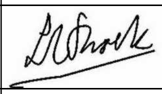
LASER REGISTRATION FORM (LS-1)

LASER REGISTRATION FORM (LS-1)	Laser Ref. No:	CRT/ICL/F-12
Policy Note: This form is to be completed and a copy sent to the Departmental Laser Supervisor, for **all** lasers ***except*** inherently safe Class 1 lasers (e.g. laser printers, CD players etc) and laser pointers below Class 3.		

1. Overview

Department:	Department of Chemistry	**Room Number/ Location:**	ICL, EPR LAB F12
Name of Research Supervisor:	Dr Chris R Timmel ICL room F10 tel. (2) 72682	**Name of Departmental Laser Supervisor:**	Lavina Snoek Denys Wilkinson 468 01865273349
Supervisor Signature:		**DLS Supervisor:**	
Date:		**Date:**	**22/04/2022**

2. Outline the project and general use or need for a laser:	Experiments in lab F12 (EPR lab) use Nd: YAG laser and GWU (to produce laser pulses between 213-2800nm). The lasers are used to excite samples in the EPR spectrometer for time resolved EPR experiments. The GWU or OPOlette laser are used with a fibre optic assembly to excite samples into the W band or X band EPR spectrometer. Two IR diode lasers are also used at 1064nm & 1047nm.

3. Detail the specifications of <u>all</u> Laser(s) involved in the system:

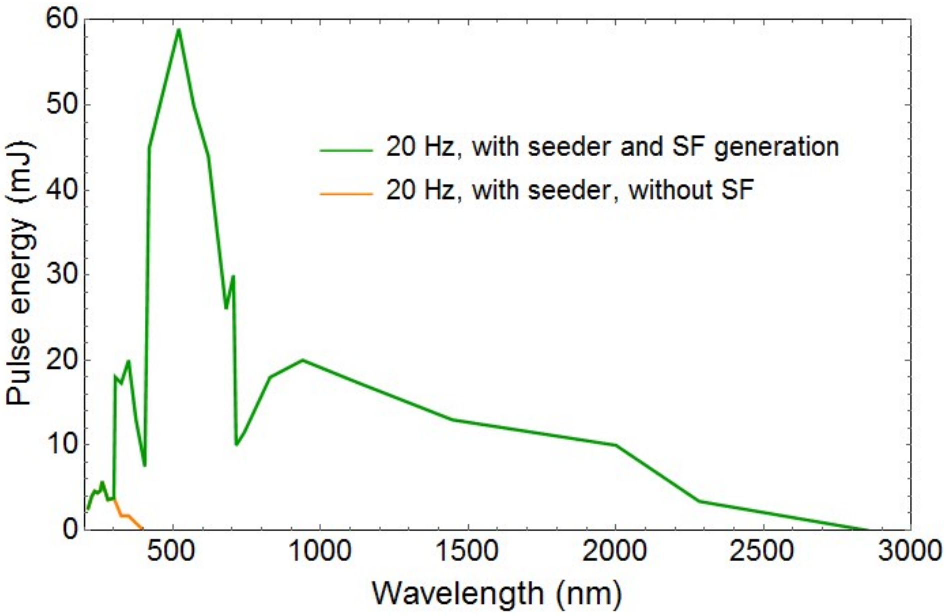
Make:	Quanta_Ray Nd_YAG laser	GWU VersaScan/UVScan (OPO)	Thor labs	CNI MLL-III-1047 500mW (CW)
Model:	Lab Pro-130-20	Versa Scan	IR diode laser	IR diode laser
Serial no:			L1060P100J	
Wavelengths/ Bands:	1064nm, 532nm 355nm	213-2800nm	1060 nm	1047 nm
Maximum output power:	800mJ @1064nm 300mJ @532nm 196mJ@ 355nm	50mJ @500nm 10mJ@400nm 4mJ@300nm	100mW @ 1064nm	560mW @ 1047nm
Beam diameter:	7.9mm	7.9mm	~1mm	2mm
Beam divergence:	0.5mrad	0.5mrad	~2 degrees	1.5mrad
CW or Pulse repetition rate:	20Hz	20Hz	CW but modulated at Hz Frequencies	CW
CW or Pulse length:	10ns @1064nm 9ns @532nm 8ns@355nm	2-3ns	-	-
Classification:	4	4	3b	4
MPE – Eye (*If known*): **Irradiance= MPE/exposure time**	At 355 nm 225 mJ 37.4 Jm^{-2} $3x10^5$ MPE	266 nm 50x10^-6J/m^2 355 nm 16.67x10^-3J/m^2 410-700 nm 2x10^-3J/m^2 At 500 nm 20 mJ 3.8mJ/m2 $40x10^3$x(MPE)	31.8Jm^{-2} 100mW= (1.55xMPE)	31.5J/m^2 560mW =116MPE 0.25 blink reflex 126W/m^2
MPE – Skin (*If known*):	Not calculated	Not calculated	Not calculated	Skin =38.4kJ/m^2

Nominal Ocular Hazard Distance (*If known*):			Not calculated	

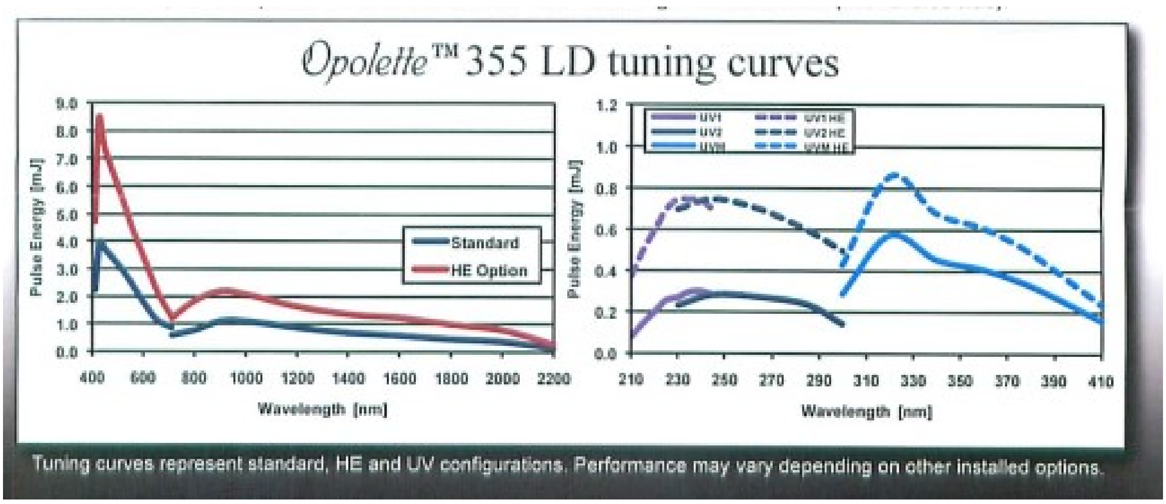
3. Detail the specifications of all Laser(s) involved in the system:				
Make:	Continuum	Continuum	NEC Corporation	Roiyhner Laser Technik GmbH
Model:	Surelite I	Minilite (Triad)	HeNe alignment laser	405nm CW diode laser
Serial no:	4453-1	14149	1055	15020243
Wavelengths/ Bands:	1064, 532, 355 nm	1064, 532 nm	632nm	405nm
Maximum output power:	100mJ @ 355 250mJ@532 400mJ@ 1064	25mJ per pulse (532 nm)	5mW	200mW
Beam diameter:	7mm	~ 3mm	~2mm	4mm
Beam divergence:	, 0.6mrads	<1mrad	~1mrad	0.5mrad
CW or Pulse repetition rate:	10Hz	Pulsed Typ. 10 Hz	CW	CW
CW or Pulse length:	7ns	~5 ns	-	-
Classification:	4	4	3b	3b
MPE – Eye (*If known*): **Irradiance=** **MPE/exposure time**	3.8 mJ/m^2 At 532nm (most limiting)	3.8 mJ/m^2 At 532nm (most limiting)	6.36Jm^{-2} (blink Response 0.25s) (0.9mWat 632nm) (5.1xMPE)	6.36Jm^{-2} Response 0.25 204x MPE (from laser safe software)
MPE – Skin (*If known*):	Not calculated	Not calculated	11 kJm^{-2} (for 1s exposure)	
Nominal Ocular Hazard Distance (*If known*):	Exceeds room dimensions	Not calculated	Not calculated	

3. Detail the specifications of <u>all</u> Laser(s) involved in the system:					
Make:	CNI MLL532/100mW	Laser Quantum	Minilite (266nm) (Faulkner Group)	Lambda Photometrics	EKSPLA 50Hz ns OPO Laser
Model:	Visible diode laser	Torus NdYAG CW laser		OPOlett Pulsed laser	NT230-50-SH/SF-SCU-FC-2H
Serial no:	III-9070430/ Oxford Physics inventory 10012	062211	4554		#PGD277
Wavelengths/ Bands:	532nm (green)	532 nm	532 nm 266 nm	410- 2200nm	210-2600nm
Maximum output power:	100mW	200mW	25mJ per pulse (532 nm) 266nm ?	4 (8.5) mJ (see tuning curve.)	18mJ at 532nm
Beam diameter:	2mm	1.7mm	~3mm	3. 4 (mm)	5mm
Beam divergence:	1.5mrad	0.5mrads	<1mrad	< 2mrad	2 mrad
CW or Pulse repetition rate:	CW to Hz pulse rate	CW	10Hz	Pulsed	50Hz
CW or Pulse length:	1 millisecond to CW		5ns	7ns	2-5ns
Classification:	3b	3b	4	4	Class 4
MPE – Eye (*If known*): **Irradiance=** **MPE/exposure time**	6.38J/m^2 25.5 Wm^{-2} (blink response 0.25s) (cf to torus laser)	6.38J/m^2 25.5 Wm^{-2} (blink response 0.25s) 204x MPE	3.8 mJ/m^2 at 532nm (most limiting)	3.3 mJm^{-2} Blink response at 0.25. For 450nm 10mJ 3.0x10^{4}xMPE	From Laser Bee At 450nm Pulse irradiance =2mJ/m^{-2} 0.25s
MPE – Skin (*If known*):	Not calculated	Not calculated	Not calculated		
Nominal Ocular Hazard Distance (*If known*):	Not calculated	Not calculated	Not calculated		

GWU Versa Scan/UV Scan (OPO) Laser output versus Wavelength



OPOlette (OPO) Laser output versus Wavelength



General Comment on using the OPO Lasers

Because of the broad band tuning capabilities of the OPO lasers used in the EPR labs special care must be taken to ensure the laser goggles protect the user at the current operating wavelength. Typically the lasers goggles used in this laboratory previously were Nd:YAG laser systems and the pair of Photonic Solutions, DBY-39 or the Glendale Spectra Physics with the G31-70111 absorbing coating was used to cover the harmonic wavelengths 355 nm, 532 nm, and 1064 nm. The alignment procedures are therefore to carry out **ALL** alignment at the green at **520 nm** wavelength where these laser goggles give greatest protection. Once the alignment is finished and beam enclosed only at this point can the laser be tuned to different wavelengths. Two separate pairs of laser goggles are available in the laboratory to cover the operating laser wavelength used and the correct pair must be worn during laser operation. The laser wavelength in operation is indicated on the laser chart outside the laboratory and must be kept up to date to ensure new laser users entering the laboratory know what laser goggles to wear.

4. Describe the laser arrangements *(or detail within the accompanying risk assessment)*

The Lasers:
There are two types of pulsed nanosecond OPO lasers available for the time resolved EPR spectroscopy experiments using the X band EPR spectrometer.

GWU OPO laser
The Lab Pro-130-20 YAG laser pumps the GWU VersaScan/UVScan (OPO) and is a Class 4 pulsed laser, capable of operating at the following wavelengths: 213 nm - 2800 nm. The harmonic wavelengths of the YAG laser are 355 nm, 532 nm, 1064 nm are only accessed and measured during maintenance visits from a laser engineer, and at all other times these laser beams are dumped within the laser in enclosed beam dumps. Typical pulse lengths are 2-3 ns, at a frequency of 10 Hz or 20 Hz, and the maximum pulse energies are 50 mJ @500 nm, 10 mJ @ 400 nm, and 4 mJ @ 300 nm.
However more typical powers required for experiments at the EPR spectrometer sample are only 1-2mJ. Hence experiments should be designed such that the minimal laser powers are used to generate good signals. With good optical alignment and optimum transmission through fibre optics, working laser powers should be of the order of a few millijoules at the sample.

OPOlette laser
The second OPO laser is the OpoTek OPOlette pulsed laser, model HE355. This is also a Class 4 pulsed laser, capable of operating at the following wavelengths: 440 nm - 2000 nm. The harmonic wavelengths of the YAG laser, 355 nm and 532 nm can also be accessed through separate ports for higher excitation energies. Maximum energy of the OPO output is at 460 nm ~8.5 mJ with a 7 ns pulse width.

Ekspla 50Hz OPO laser
2022, the new high repetition rate OPO laser installed in April 2022 is gives pulsed laser outputs from 210-2600nm. This is a class 4 laser. Installation energies for the laser are recorded at Q:_Resources\Manuals\Ekspla PGD277. At 532nm maximum energy is 18mJ pulse width is 2-5ns. The Ekspla laser is completely enclosed on an optical laser table by laser shields and alignment is as described for the existing OPO lasers

Continuum Surelite and Millilite Lasers
In addition to the tunable OPO lasers, the EPR laboratory also has the capability to excite samples with two fixed wavelengths (355nm,532nm) from the Surelite and Millilite pulsed Nd:YAG lasers (class4). An additional a Minilite laser with 266nm excitation wavelength option is also available. These pulsed lasers run at 10Hz and are typically used with energies of a few milli joules.

IR CW diode lasers
The IR diode lasers (wavelength 1060nm and 1047nm) are continuous lasers (CW) and are used to excite the samples inside the X band Spectrometer with energies up to 100-200mW. When CW diode lasers are used with the EPR spectrometers the lasers must be firmly *secured to the optical table* and aligned into the spectrometer at the lowest possible laser powers and then the beam path completely enclosed with a beam pipe and enclosed laser shields. Special care should be taken because the IR beams are invisible to the naked eye and these lasers must only be used when they are interlocked to the laboratory interlock system.

500nm and 405nm CW lasers
Two visible CW lasers are also authorised for this laboratory. Both these lasers are class 3b lasers with a maximum power of 200mW. These lasers are 200x MPE (maximum permissible exposure.) Hence great care should be used to use them safely. Use the current supply controls to reduce the power levels to below the MPE. Align at minimum laser powers, using alignment cards with laser goggles on that protect the user from the operating laser wavelength. Ensure the laser is bolted to the table securely. Alignment is with broad band laser mirrors into the spectrometer resonator directly or into the fibre optic assembly which has a beam tube that encloses the exposed fibre optic end and prevents the users from any scattered light.

HeNe CW Alignment laser
Sometimes laser alignment can be aided by “back alignment” through an array of optics using a HeNe alignment laser and for this use a HeNe laser is made available to the lab. In addition users who want to excite samples at 632nm with a ~5mW laser powers can use it as an excitation source. Although this is an alignment laser the maximum power out of the laser is 5mW which is 5x the maximum permissible exposure therefore the laser should be attenuated down to <1mW for safe use and this can be done with absorbing neutral density filters or a linear variable neutral density filter. Once the beam power is below 1mW it can be safely aligned into the X band EPR spectrometer using broadband turning mirrors. As with all portable lasers

please ensure they are firmly fixed to the laser breadboard before alignment begins. Please wear the laser goggles to cover the 632nm wavelength output of this laser and use alignment cards for the alignment process as usual.

Laser goggles must be worn ***at all times*** when all the lasers above are in use.
Beam Delivery:

OPO lasers:
he 1064nm fundamental beam of the YAG pump lasers are entirely contained within the laser units.

The output of the GWU OPO laser beam exits the laser on to an enclosed laser table space and the beam is steered by turning mirrors to a fibre optic launch (microscope objective lens and entrance aperture into the fibre optic).

The OPO laser and alignment setup is built on a new 2m x 1.6m large laser optical table, fully enclosed in a purpose-built laser enclosure of aluminium, (nonmagnetic) and anodised to absorb scattered light and fitted with internal safety covers which can be removed in sections to allow access to beam steering optics for alignment purposes. All the safety enclosures must be used to completely enclose the all laser light before experiments can be run.

Great care must be taken when aligning the opo laser into the fibre optic due to the danger of scattered light from the end of the optic fibre being scattered upwards towards the laser user. The procedure of alignment is to first remove the fibre from the fibre chuck and align the laser, at the lowest possible powers, using an alignment card to the approximate position of the end of the fibre. The laser is turned off and the fibre inserted and a beam tube and iris fixed in front of the end of the fibre to enclose any scattered light. Then the other end of the fibre is firmly secured in a mount and the exit of the fibre enclosed into a power meter head that completely encloses the beam. Only when both ends of the fibre are enclosed can the opo laser be turned on and optimisation of the throughput of the fibre carried out by fine adjustment of the X and Y movements in the fibre optic mount. Once the power throughput of the fibre is optimised the exit end of the optical fibre is coupled into the optical window of the resonator of the X band EPR spectrometer. A beam enclosure surrounding the output end of the fibre optic ensures the beam is completely enclosed. A final inspection must be carried out to ensure the laser is beam is completely enclosed from the exit shutter of OPO laser to the entrance window of the EPR spectrometer.

Alignment into the Spectrometers: Authorisation
The OPO lasers can both be used as excitation sources for the time resolved X-band, and W-band EPR experiments, only by authorised CAESR laser users. Only authorised laser users who have been *additionally authorised to align* the lasers should attempt alignment procedures. Setup of a new laser alignment into fibres, such as for the X-/Q-band and OPOlette or Surelite into W-band, requires additional demonstration and checks by CAESR laser safety officer or CAESR manager. Fibre alignment is not available to users without specific training.

Alignment of the OPO pulsed laser beams into the X-band EPR spectrometer:
With the laser(s) off, the laser beam path is inspected to check for any obstructions, moved/displaced optics, loose fittings and that the correct optics for the harmonic crystals are in the correct positions. The laser is turned on and warmed up and the laser beam power attenuated to the lowest possible laser powers, that can be viewed on a UV/VIS viewing card, (preferably below the MPE if possible) before any alignment begins.
The operating wavelength of the laser must be recorded in the laser log book at the beginning of each experiment, the users should check that the correct dichroic separators are in place if using the Surelite laser.
GWU VersaScan/UVScan (OPO) laser
The Lab Pro-130-20 YAG laser pumping the GWU VersaScan/UVScan (OPO) laser is fixed to the large laser table in F12. Alignment of any pulsed laser is carried out at the **lowest possible laser powers** using the single shot mode of the laser triggering system, if possible, while wearing completely enclosed laser goggles and using an alignment card. Ensure the laser goggles are suitable for wavelength concerned, ensuring if far IR wavelengths are used the OTG goggles are used.
The laser power is reduced most effectively by externally triggering the laser and setting the Q switch delay to a long pulse mode, or long delay times, (This means a long delay time between the flash lamp trigger pulse and the Q-switch trigger pulse).

The Q-switched delay is slowly decreased so that the laser begins to lase at powers just above its lasing threshold and the beam becomes observable as a faint dot on a UV/VIS viewing card, all alignment of the systems is carried out with the lowest possible laser powers with these conditions. The beam is aligned via laser turning mirrors, using a viewing card, and directed to the fibre optic where it is focussed into the fibre optic using the microscope objective, ***care must be taken with laser scatter coming off the end of the fibre optic upwards towards the user.*** The end of fiber must be enclosed in a beam tube.

Alignment into the fibre optic
A beam tube and iris must be in placed in front of fibre optic enclosing the tip of the fibre to ensure no laser light is scattered up towards the laser user.
Align at low powers; optimise the throughput power by measuring the output power of laser from the other end fibre using a sensitive power meter. The output of the fibre is normally highly divergent and so care must be also taken to enclose the exit beam into an enclosed power meter head. Once the throughput has been optimised the output of the fibre optic has to be aligned into the optical window entrance of the EPR spectrometer resonator. The fibre is threaded under the cable cover on the laboratory floor, around the back of the X band EPR spectrometer, and into an enclosed breadboard mounted in front of the EPR spectrometer.

Measuring laser output powers from fibres
The quality of the alignment into the fibre optic is assessed by measuring the laser power at the output of fibre directly into the digital Ophir power meter. When using the fibre optic alignment rod with sample holder to deliver the laser to the Wband, Xband or Qband spectrometers it is important to measure the output power of the laser exiting the fiber in an enclosed space. For W band the rod can be enclosed inside the laser covers for the GWU OPO laser.
For alignment into the Q-band spectrometer the rod can be enclosed inside the nearby Surelite YAG laser enclosure or if in place next to the Q-band spectrometer, the enclosed area around the OPOlette laser. For recent TR CW-EPR experiments (July 2018 onwards).
Using the OPOlette as the excitation source, transfer the fibre optic chuck and beam tube to the OPOlette enclosed laser area and align the beam into the fibre, ensuring the fiber is encased in the rod and the exit of the fibre is enclosed inside the power meter head to minimise exposure to scattered light from the exit end of the optical fibre. As always, align at lowest possible powers, wearing the appropriate goggles and with Thor labs alignment cards, use an iris and beam tube to enclose scattered light from the entrance to the fibre and use the power meter as a beam dump and maximize the power through put into the fibre with the protective beam tube in place.
Alignment into the X-band Bruker Resonator. For alignment into the X-band Bruker resonator the fibre must be secured into the fibre optic mount that is bolted to a specially made adaptor that clamps the ensemble flush with the resonator optical window and ensures that no exposed beam can escape into the laboratory. Note that fibre optics can be easily be accidently pulled or tugged so the mount and adapter must be strongly secured to the breadboard and tightly clamped on to the resonator window to ensure that in the event of the fibre being knocked it will not pull out of the mount. An additional optical enclosure cover is put in place over the fibre optical assembly for additional safety. The beam must be aligned into the window port of the EPR resonator and the laser beam path completely enclosed, such that there is no exposed section of the beam path from the laser exit port to the entrance window of the EPR resonator

Final checks
Check to ensure no back reflections or scattered light from optics, and no apparatus that impede or damage the fibre. Once all the external covers are replaced and the laser is totally enclosed the laser power can be safely increased to an operating powers by changing the Q-switch delay to a fixed known setting corresponding to the operating power. Note that maximum power into the fibre optics is 8 mJ, this is the damage threshold of the fibres and may be lower at UV wavelengths, such as 355 nm.
Even when the fibre optic assembly is completely enclosed it is important to continue to wear laser goggles throughout the experiment. If the optical fibre cracks, (for example the fibre optic could be stressed, or mechanically pinched), laser light could be opened out into to laser lab. Hence please ensure personnel protection equipment is worn by all laser users and treat the fragile fibre optic with care.
Alignment of the IR CW laser beams into the X band EPR spectrometer
IR diode lasers are dangerous to both eyes and skin and also *particularly dangerous* **because the beam is invisible to the naked eye, hence laser goggles must be used at all times when using IR diode lasers**
The IR diode lasers used Oxford Physics group are a 100mW 1064nm class 3b laser and a class 4 560mW 1047nm IR laser. The appropriate laser goggles must be worn at all times when using these lasers. The lasers must be interlocked to the lab interlock system. For alignment , the current supply to the laser must be turned to zero and then the laser switched on and the current supply increased until the laser just begins to lase, and can be viewed as a faint spot viewed on a suitable IR viewing card. The laser must be aligned into

the EPR spectrometer, via a lens and turning optics using a suitable viewing card. The laser beam path must them be completely enclosed, using a beam tube, and only then can the power of the laser increased to operating powers.

The 1047nm IR diode laser It must be securely bolted to the optical table before operation, and the laser interlocked to the laboratory interlock system, the alignment should be carried out only by users authorised to align the laser at minimum laser powers. The beam should be observed using a viewing card with laser goggles on, and the beam must enclosed before the beam powered up to full laser power. When aligned at the lowest possible powers the laser will not be harmful to skin.

The 532nm diode laser (CW) (19-09-11) At its full high power of 200mW is hazardous to both eyes and skin, hence laser goggles must be used at all times when using this laser. It must be securely bolted to the optical table before operation, and the alignment carried out at minimum laser powers to observe beam using a viewing card and the beam path should be enclosed before the beam powered up to full laser powers. The laser must be attached to the interlock at all time when in use. The laser is turned off. The green 532nm laser beam is aligned into the X band spectrometer using broadband turning mirrors into the resonator chamber through the optical Window on the external holder of the resonator. The laser system is completely enclosed inside the laser table and beam tube between the laser table and the resonator assembly. Only when the system is completely enclosed should the laser be turned on and the operating laser powers selected using the current supply of the for the Nd:YAG torus 532nm cw laser.
Alignment of the 632nm He alignment laser and the 405nm diode laser into the X band EPR spectrometer is the same as for the 532nm torus laser as described above. Ensure all lasers are aligned at powers below the MPE and then enclosed completely before the laser powers are increased to operating laser powers.

Alignment of the laser beams into the W band EPR spectrometer: (OPO lasers or IR diode laser)
When using the W band EPR spectrometer the laser should be attenuated as described for the alignment into the X band spectrometer and aligned using a viewing card, whilst wearing laser goggles at all times. The optical fibre is securely fixed in a mount to the optical table inside the enclosed laser table and the exit end of the fibre optic held in a mount to enable the laser output to be measured with the power meter or photodiode. The laser output, at minimum laser powers possible, is focused into the entrance end of the optical fibre and the alignment optimised to achieve the maximum laser power transmission.

Use of additional laser to perform TR ADMR Experiments
For most of the Time resolved EPR experiments excitation of the sample is via a pulsed nanosecond laser However for the TR-ADMR experiment the samples two lasers are used, The samples are excited with a pulsed laser and the difference in the adsorption of the sample detected via the change in the absorption of a sample measured by an additional IR a CW laser. In these experiments the pulsed excitation is aligned as described previously and the IR diode lasers are aligned into the spectrometer using IR viewing cards at the lowest possible powers and completely enclosed before the IR laser power is turned up to operating powers. Users must remember that IR laser beams are not observable to the naked eye and are therefore potentially

OPOlette *and* ***GWU OPO laser***
To excite with a pulsed laser at wavelengths other than 355nm and 532nm in time resolved EPR experiments a OPO laser is used in the CAESR EPR laser laboratory. This allows laser excitation to be used in the wavelength range from 213-2300nm. (Using the signal output with the option of infrared wavelengths if the system is adjusted to idler output setting). Currently the system is set up with only the signal output available. OPOs are lasers with considerable tuning range in this case from 213nm to 2800nm. It is therefore **extremely important** to ensure they are operated at wavelengths where the user is protected with suitable laser goggles and the beam completely enclosed. In this laboratory we use two different makes of goggles (see tables below) but only the ***Glendale goggles*** should be used when operating this OPOlette laser. These Glendale goggles are designed to protect at different wavelengths as shown below: **For IR region above 1100nm the OTG goggles should be worn to give further protection**

Wavelength /nm	190-520	520-532	533 – 709	710-750	750-850	850-1080
OD	>9	>7	No specification	>3	>5	>7

Unfortunately, it is not possible to cover all laser wavelengths with one pair of goggles therefore the protocol is to **align the OPO laser at 532nm** where the laser goggles are designed for maximum protection. The beam **must be completely enclosed before it can be tuned** to other wavelengths and then **the laser is returned**

to 532nm at the end of the experiment before being switched off at the end of an experiment. This is to ensure that the laser is not started at a wavelength that is potentially hazardous. Alignment of the OPO beam must only be carried out at 532 nm while wearing laser goggles and **using alignment cards** provided. Alignment of the laser must be carried out at the **minimum laser powers possible**. This is achieved by the usual way for pulsed YAG lasers in this laboratory which is to trigger the laser with a long delay between the flashlamp and Q-switch pulse to ensure a low energy pulse. Using single shot mode, The Q-switch delay is then carefully decreased until the beam spot begins to become visible on the viewing card. Alignment is carried out at minimum powers with this very faint laser spot observed on the alignment card with goggles on. Then the laser is completely enclosed using the safety covers. Only when the beam is completely enclosed can the power be increased to operating powers and the wavelength of the laser changed.
As with all laser experiments in this laboratory **laser goggles must be worn at all times during use,** use alignment cards to observe the beam using the fluorescence on the cards at safe energies.

Alignment of the OPOlette beam into the EPR spectrometer: (without using fibre optic coupling).
The OPOlette has three laser exits; one for the actual OPO beam, one for 532 nm and one for 355 nm (see Figure 1). The latter harmonic shutters are usually covered by screwed-on caps. The setup allows using all three exits with as little alignment as necessary. A moveable breadboard is placed in front of the laser exits on which optical elements are mounted for the OPOlette exit, the 532 nm exit (these two use the same elements) and for the 355 nm exit. The elements are placed such that the same board position works for both the 355 nm and OPOlette exit. If the 532 nm exit is wanted (in cases where the laser power at 532 nm provided by the OPOlette exit is too little), the breadboard needs to be moved such, that the elements for the OPOlette exit are now in front of the 532 nm exit. **For this, turn down the laser power by changing the Q-switch delay. After you are done, turn the Q-witch value back to optimum.** The pathways contain as first elements a λ/2 waveplate and a polarizer with which the power of the beam can be adjusted by rotating the λ/2 waveplate. This allows running the laser at optimum Q-switch delay granting better shot-shot stability. Before alignment, make sure that the proper mirrors for the intended wavelength/beam path are in the right positions, that the unused exits are blocked, and that no obstacles are in the beam path (specifically remove mirror II of the 355 nm path if using the OPOlette exit!). The mirrors are labelled with the wavelength range they are suitable for and with their position (I-III) on the board. The mirror mounts are screwed onto magnetic plates and can be pulled off and put back on easily and reproducibly (just take the mirror mount in your hand a pull slightly for them to come off). The lens used is suitable for all wavelengths usually used in the experiment and stays in place unchanged. Since the mirrors can be put back reproducibly, alignment is ONLY done using mirror III. Use the λ/2 waveplate to turn down the power to the **lowest possible powers using a viewing card with the laser user wearing Glendale goggles at all times**. The time resolved spectroscopy experiment using the OPOlette is a **completely enclosed system and the experiment should be run with no exposed beams**. Laser users should be aware that when this experiment is running and the wavelength of laser is tuned within the region 533-850nm region the laser goggles they are wearing do not give significant protection to the OPOlett output. This is why for safety in this **laser is aligned only at 532nm** where the laboratory goggles give defined OD protection levels. Laser goggles that cover the region 540-850nm do not give protection at other important YAG fundamental wavelengths such as 532nm.

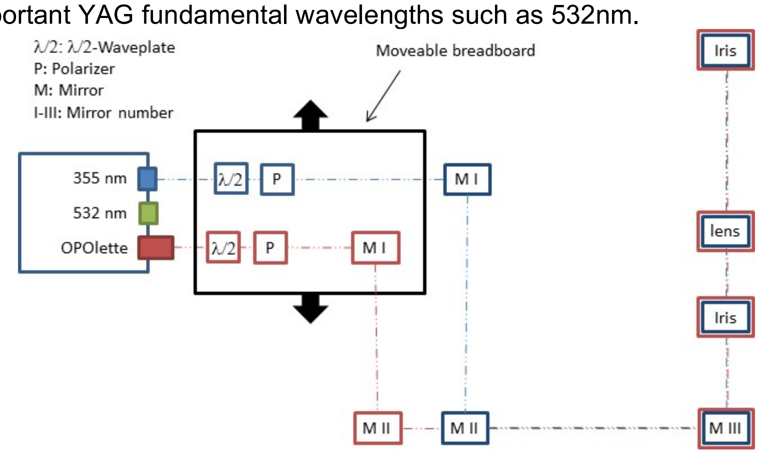


Figure 1: Beam path and optical setup for OPOlette use.

Environment: Room ICL F12 is a first floor room containing the EPR spectrometer and has been converted into a purpose built laser laboratory. Although the laboratory outside laser working hours has two entrance points, only one of them is accessible during laser operating hours. The other entrance is closed by fully fitted light-tight, black, interlocked blinds. The remaining entrance point is controlled by a key code access and linked into a LaserMet door entry system and connected to both the lasers' power supplies. A warning light is activated at the entrance point when any laser is energised. Forced entry into the laboratory results in immediate automatic laser shutdown. The laboratory is well-lit and the external windows covered with interlocked light-tight blinds.

Experiments with two laser excitation (April 2019)

Two laser experiments for pump and probe laser excitation of frozen samples inside the EPR resonator are made possible via the combination of simultaneous excitation through the optical window and from fiber optic coupled light source inserted into the quartz sample tube seated in the ERP resonator. Overlap of the excitation volume via careful alignment is required. The experiments require the use of both the GWU OPO laser and the OPOlette OPO laser. Alignment of the two lasers is as described previously but additional safety considerations are described below.

Tuning the wavelength of OPO lasers.

If laser excitation of the probe beam (OPOlett laser) is tuned to greater than 532nm we would need to be aware that the DB-39 or Glendale G31-70111do not protect the user and the LG-7 protect between only 600-700nm. Therefore the laser users should use the appropriate goggles for each of the laser wavelength they using from each OPO laser and align one laser at a time while keeping other lasers completely enclosed.

Synchronizing the two lasers

Triggering of the two laser pulsed EPR experiment requires the triggering of lasers both from the Pattern jet (pulse generator) inside the EPR spectrometer. The laser synchronisation should be set up using photodiodes to measure the weak transmittance of the laser light through 45 degree turning mirrors in the two laser optical set ups and monitoring these signals on an oscilloscope. The EPR pulse sequence is synchronised with the lasers which are locked at fixed lasers powers and fixed delays between the pump and probes lasers.

Preparation of sample

For the fiber optic excitation, the sample will be excited through a short piece of fiber optic that delivers the laser beam to the top of the frozen solution inside the X band EPR tube. This other end of this short piece of fiber optic is coupled to the main fibre optic located in a rod inserted into the resonator. The coupling is achieved by secured immobilised liquid contact. This prevents contamination of the main fiber optic with sample. Fiber optics should be cut and cleaved with the Ruby cutter used in F12.

Experiments will be run in F12 with laser laboratory Interlocks on as during normal operation.

Removal of Sample from Resonator

All fiber optic exit points should be treated an potential sources of laser light, and be either inserted into a enclosed power meter head as during optimisation of power throughput inside an enclosed laser safety cover, or inserted into the epr tube inside resonator in place for the duration of the experiment. All laser should be turned off and securely shuttered before the sample can be removed from the resonator.

Laser powers for the fibre optic experiments require 1-2mJ at most into the sample. Remember that the scattered laser light from the tip of the optical fibers can be a dangerous source of laser light and enclose both the exit and entrance fiber optics tips with beam tubes and optimise throughput of light using a sensitive power meter inside an enclosed laser safety cover .

Freespace alignment for Ekspla LASER, rooms F11 or F12

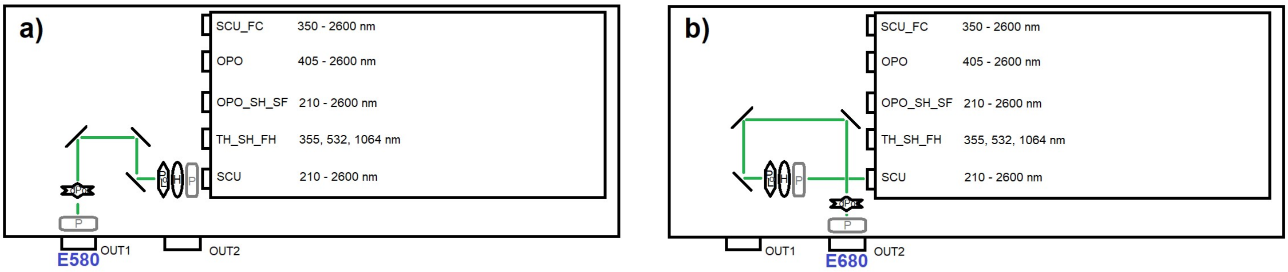


Figure. Diagram of freespace beam paths of the Ekspla NT230 for E580 (OUT1) and E680 (OUT2) spectrometers. Panel a) shows the OUT1 path, applicable to the SCU and FH_SH_TH outputs. Panel b) shows the scheme applicable to OUT2 path, except SCU_FC, for going to the E680. Panel c) shows a reconfiguration of mirrors, applicable to OPO and OPO_SH_SF. Panel d) shows the optional replacement of the beam splitter ( ) with a dichroic mirror ( ).

Freespace alignment of the NT230 must be accomplished by a trained laser user. Each of the five outputs of the NT230 have mechanical shutters and they should be used to control output during alignment processes. The choice of beam control elements is ultimately the responsibility of the trained LASER user, however the examples here should be considered as standard. Non-standard arrangements of elements, e.g. in magnetophotoselection experiments, require additional approval of trained senior LASER users, such as the Scientific Applications Manager, Dr Kevin Henbest, or group Supervisors who are trained LASER alignment users themselves.

The selection of mirrors and other components should be compatible with the wavelength(s) of interest during an experiment session. Users must be vigilant to avoid incompatible components with the wavelength range, which may lead to damaged parts.

In the above figure, there are three recommended power meter positions ( ) that may be used in sequence. The first position is used to assess the LASER performance at maximum output and to reduce outputs with Q-switch in Adjustment Mode as desired. The half-wave plate ( ) and Glan-Taylor polariser ( ) are used in combination to adjust power either from Maximum LASER output or in conjunction with Adjustment Mode reductions, as detected in subsequent power meter positions. The 90:10 (R:T) beam splitter ( ) may be used in continuous power monitoring or diode detection for shot-to-shot amplitude normalisation. When a power meter measurement device is not being used on the beam splitter transmission, it is recommended to have a beam trap in place ( ). Note that in panel b) and panel d) the proportionality of the beam splitter power measurement will be different to the final power meter position, after the depolariser ( ), but not the last mirror ( ).

Freespace alignment for LASER on table (GWU-OPO) to electromagnet, room F12

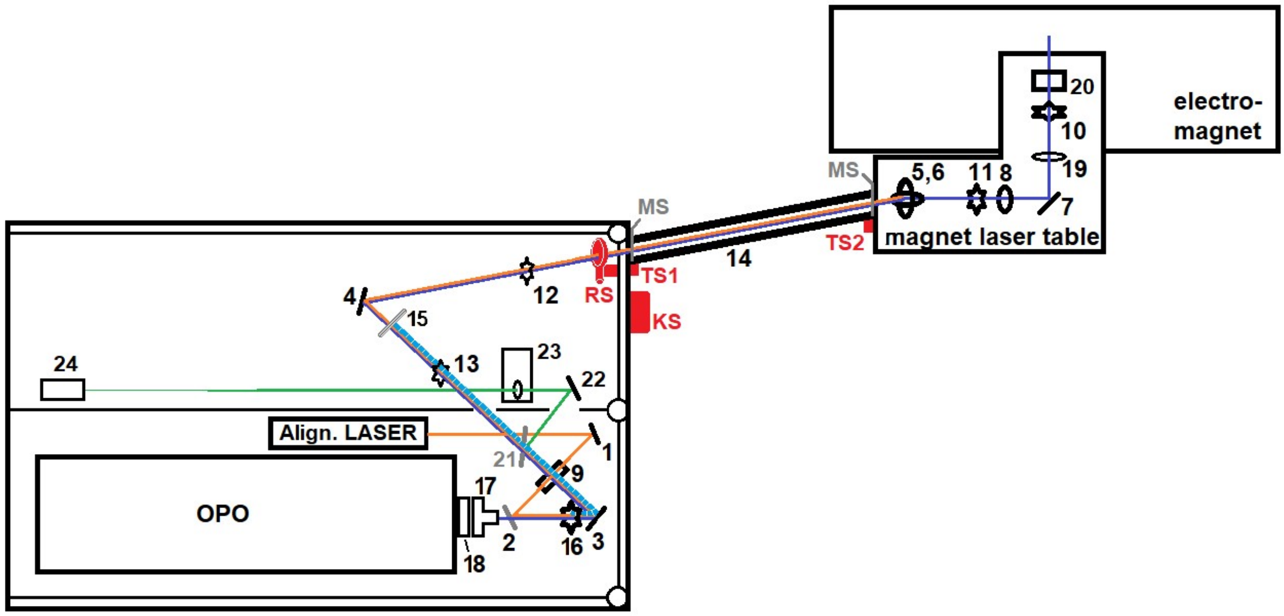


Figure 1. Diagram of freespace beam path from GWU-OPO to electromagnet in ICL room F12. The alignment laser might be class IIIR with safety glasses required. For the local HeNe source, standard amber glasses (LG6) reduce the power to class 2 (500 uW).

Numerated Component list:

1. First alignment mirror
2. Second alignment mirror, on flip mount, compact 1/2" size and compact mount.
3. First OPO turning mirror.
4. Second OPO turning mirror
5. Periscope down, third OPO turning mirror
6. Periscope across, fourth OPO turning mirror
7. Fifth and final OPO turning mirror
8. Broadband depolariser
9. Laser power sensor position

10-13,16. Irises

14. Beam tube enclosure, prepared by workshop
15. far-point alignment, for alignment LASER to be collinear with OPO
17. Glan-Taylor polariser, n.b. variation of this element may cause change beam-pointing.
18. λ/2 waveplate
19. Focusing optic, optional
20. Final power measurement position.
21. Flip-mount mirror to fibre coupling
22. Final mirror for fibre coupling
23. Focussing lens for fibre coupling
24. Fibre coupling assembly

Interlock components:

RS. Optical rotary shutter, blocks beam with < 50 ms response time.
TS1, TS2. Tube pressure/limit switch (two positions)
MS. Manual shutters on either end of the beam tube, neither card has an interlock connection.
KS. Key switch bypass

The following procedure is to be generally applied to any LASER located on same table as OPO

Alignment Procedure < wear full goggles of appropriate OD for wavelength & LASER class >:

a. With mirror 2 down, OPO at minimum power (9) gives a target indicated on alignment card (15) using the iris (16). Large wavelength changes or shifting (17) can slightly move the spot. Once a far point OPO spot on (15) is identified, put OPO pump LASER in long-pass mode and block OPO output.

b. Using mirrors 1 & 2, the alignment LASER is pointed on the indicated spot of card (15) to be collinear with the OPO.

c. The alignment LASER is passed through optimum of iris 12 to mirror 5. If sufficient alignment power is available from alignment wavelength, proceed to align through mirrors 6, 7, and into cryostat, using the irises for beam walking as necessary. A senior user must attend any KS (key switch) operation. The key will act as a momentary switch, changing the state of the optical rotary shutter (RS), and the key will not be available to general users, please ask the Scientific Applications Manager or CAESR LASER authority. General users will be able to align independently with a Class 2 alignment LASER and demonstrate alignment to a senior LASER user, currently: K Henbest or WK Myers. Prior to enclosure for Class 3b/4 operation with the OPO LASER.

Note: Alignment light might not be available for an experiment wavelength and sequential dichroic mirrors might attenuate alignment LASERs too much, such as 266 nm in the UV. In this case, ask a senior LASER user to use the OPO at minimum, Class 1 or 2 power to align the LASER from mirror 4 to 5, 6, & 7, whilst also using the key switch (see Figure 2).

d. Turn-off alignment laser and flip mirror 2 down, enclose table sides and beam tube (14).

e. Check power of OPO output (9) and minimise power using λ/2 waveplate (18).

f. Confirm beam alignment with beam card and make final adjustments if necessary.

g. Open all irises, Finish enclosing LASER tables, and select operating power (20). Note additional polarisers and optical components may be added to the magnet LASER table, after the periscope, as experiments require.

h. Fine-adjust final turning mirror (7), with separate cover, to optimise TR-EPR signal.

LOGIC	SHUTTER
0	CLOSED
1	OPEN

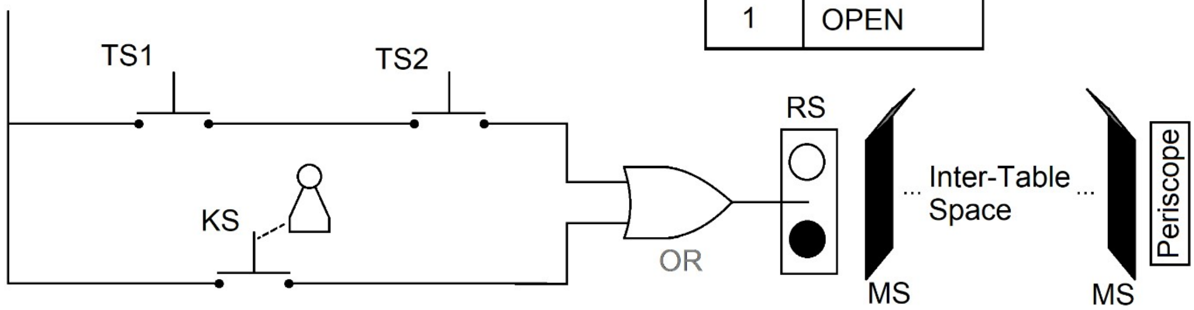


Figure 2. Diagram of beam tube interlock logic and beam path blocks.

Appendix 2

LASER RISK ASSESSMENT PROFORMA (LS-2)

LASER RISK ASSESSMENT FORM (LS-2)				Laser Ref. No:	CRT/ICL/F12	
Policy Note: A documented risk assessment is required for: • Use of any class 3R, 3B or 4 laser. • Any manipulation (e.g. use of magnifying instruments) of a lower class laser that might increase the risk under certain operating conditions. • Any lower class laser whose non-beam hazards pose a significant risk, even though the risk from the beam itself is negligible. • Embedded 'Class 1 by design' products encompassing Class 3 or 4 lasers if the beams might be exposed during routine service and maintenance. A contractor's risk assessment may be sufficient.						
A copy of this Risk Assessment must be appended to the relevant Laser Registration Form (LS-1)						
What parts of the life cycle does this risk assessment apply to?		Planning, Design, Manufacture, Testing, Transport, Installation, Commissioning, Normal Operation, Maintenance, Servicing, Modification, Decommissioning, Disposal				
Name of Assessor(s):					**Date:**	
STEP 1		**STEP 2**	**STEP 3**		**STEP 4**	
Ref. No:	**List significant hazards**	**Affected groups**	**List existing controls**	**What is the risk?**	**Actions required?**	
The laser:						
p1	OPO lasers: Electrical hazard from capacitor banks in power supply	Staff	Capacitor banks are inside power supply casing.	Low	Warn students not to touch internal high voltage electronics. Pockell cells for example.	

LASER RISK ASSESSMENT FORM (LS-2)				Laser Ref. No:	CRT/ICL/F12
P2	Trip hazard from electrical cables, water and vacuum exhaust pipe	Research staff, Students,	Electrical cables are fed from ceiling gantry. Walkways & working areas are to be kept clear of potential trip hazards	Low	Engineer Overhead storage of electric items connected to overhead power supplies to avoid trailing leads on the floor.
Beam delivery:					
P3	Class 4 Beam Hazard During operation the beams greatly exceed the MPE limits.	Researchers, Students, Visitors Contractors	Engineering controls: Laser enclosure Administrative controls: Local rules and protocols for laser operation. PPE for users.	High	Review risk assessments/ local rules / protocols noting: Access to beam required for initial alignment, signal optimisation. This to be done with highly attenuated power PPE (appropriate goggles) to be used whenever beam enclosure opened Only trained individuals, registered for these lasers to perform alignments.
P4	Open beam path from laser to various experimental arrangements.	Researchers, Students	Engineering controls: Laser enclosure Administrative controls: Local rules and protocols for laser operation. PPE for users	High	Ensure complete enclosure of the laser table to prevent beams escaping laser table, in this case a beam pipe.

LASER RISK ASSESSMENT FORM (LS-2)				Laser Ref. No:	CRT/ICL/F12
P6	Specular and diffuse reflections from multiple in-path optics	Researchers, Students	Engineering controls: Laser enclosure Administrative controls: Local rules and protocols for laser operation. PPE for users	Medium	During experimenting, the enclosure lid must be in place. Local rules to specify need to appropriately dump all reflections Terminate beams.
P7	Fire: hazard associated with Nd:YAG laser beam delivery.	Everyone in the building	Use of appropriate beam dumps and removal of any volatile substances that the laser could ignite.	Low	Fire extinguisher is required in the lab.
The laser process:					

LASER RISK ASSESSMENT FORM (LS-2)			Laser Ref. No:	CRT/ICL/F12	
P8	Beam Alignment, signal optimisation, requiring access to open beams	Researcher s, Students		high	. Engineering controls: Orientation of apparatus to ensure that all beams are aligned in the plane of the laser table, no beams to be directed out of the horizontal plane of the laser table. Review risk assessments / local rules and protocols for relevant procedure; this will depend on whether procedure is a new beam path of minor modification (tweaking or adding a new element) Operate at minimum laser power possible with as little of the laser enclosure open as possible. PPE to be worn at all times. Specify only experienced individuals to undertake major realignments. This procedure only to be undertaken with authorised personnel present. Ensure provision of appropriate PPE eyeware for during alignment, optimisation.
P9	OPO laser: Alignment of crystal and dichroics.	Researcher s, students		high	PPE (appropriate goggles) to be used whenever the laser is operated with its cover removed. Local rules to specify PPE required. Operate the laser at minimum possible power whenever the laser is operated with its cover removed.
Environment:					
p11	access to the laboratory	Unauthorise d visitors	The only access to the laboratory is fitted with a LaserMet interlock system with keycode entry.	low	Ensure only authorised personnel are informed of door entry code.
p12	Seating Provided for use during lengthy experiments when standing is impracticable.	Researcher s, Students, visitors	Lab equipped with laboratory stools positioned to ensure a seated individual has his/her head well above the plane of the laser beams During laser operation, stools must only be used by an individual when the laser table is fully covered by the safety enclosure.	low	Ensure that computer monitors at experimental station is similarly raised in height above the laser table and positioned to reduce the risk of stray out-of-plane beams encountering a computer operative (e.g. avoiding placement of the monitor along the left hand wall).

LASER RISK ASSESSMENT FORM (LS-2)			Laser Ref. No:	CRT/ICL/F12	
p13	Lighting	Researchers, Students, visitors	The laboratory is a bright well-lit room.	N/A	N/A
p14	Chemical hazards from samples under investigation	Researchers, Students, visitors	Chemical specific as detailed in the appropriate COSHH forms	med	Use minimum quantities necessary Ensure all individuals have read and signed appropriate COSHH forms and implement requirements therein.
p15	Disconnecting and re-connecting high voltage (2kV) PMT power supplies	Researchers, Students	Administrative control: Local rules	med	High voltage power supply must be turned down to 0 V then completely off at the power supply and wall socket before connecting/disconnecting any cable from the PMT or its power supply.
STEP 5					
Date for review:		**27/10/16** or earlier if any significant changes to the experiment take place.			

Appendix 3

LASER LOCAL RULES (LS-3)

LASER LOCAL RULES (LS-3)	Laser Ref. No:	CRT/ICL/F12

Policy Note: Laser Local Rules are required when engineering controls are not adequate to fully control any significant risk from a laser beam.

A copy of these Local Rules must be appended to the relevant Laser Registration Form (LS-1) and Risk Assessment (LS-2)

1. TRAINING REQUIREMENTS FOR AUTHORISED USERS

All persons present during operation of the lasers must be trained as follows:

- They will have attended a laser safety introduction by the Departmental Laser Supervisor or similar
- They will have undertaken group laser training regarding local rules, protocols and the specific laser systems to be used. This will include:
  - General operation of the laser system and accompanying experimental equipment.
  - Understanding of the hazards associated with the laser system.
  - Laser start-up and shutdown procedures.
  - The correct use and limitations of control systems (enclosures, interlocks, warning lights, curtains, ventilation)
  - Selection, use, storage and limitations of personal protective equipment.
  - Supervisory arrangements, specifically any activity that requires close supervision.
  - Entry requirements for non-authorised users into the Laser Controlled Area.
  - Emergency procedures and accident reporting arrangements.

Those persons authorised by the named supervisor are listed in the relevant Laser User Training Record”

2. LASER CONTROLLED AREA

The EPR Laboratory, F12, is a Laser Controlled Area and marked and clearly declared to all visitors as a laser laboratory at the entrance by a Laser Hazard Warning sign.

Access is restricted to authorised persons only by the use of a keycode entry system. No unauthorised person is permitted into the area, unless:

- Accompanied by an authorised user, under the controls outlined in these local rules.
- An authorised user has confirmed that ALL lasers in the Laser Controlled Area have been switched off &/or beam shutters closed.
- In an emergency, when the Lasermet entry system will automatically shut down the laser systems.

Individuals working inside the ‘Controlled Laser Area’ must:

- Follow procedures, instructions and protocols given within these local rules.
- Notify the supervisor if identified controls are not or indeed cannot be followed.
- Notify the supervisor of any significant failure or change to the system.
- Ensure all visitors to the laboratory are appropriately instructed and adhere to the local rules.
- Ensure circulation routes are kept clear of obstacles at all times.
- Ensure work area is routinely inspected and items removed &/or appropriately stored.

3. PROCEDURES

3.1 General operation

The laser table supporting the various experiments is fully enclosed in a purpose-built laser enclosure of Aluminium painted black to absorb any reflections and fitted with a lid which can be removed for alignment purposes. The enclosure must remain in place during general operation. Under circumstances in which the lid must be removed, the procedures outlined below (operating without the laser enclosure in place) must be followed.

For any procedure the appropriate Laser Safety Protocol must be followed and a note of its adherence made in the relevant lab book.

The Laser Safety Protocols cover the following aspects of laser work specifically:

1. **Setting up and Alignment**
2. **Adding new optical elements**
3. **Day to day operation**

These protocols are appended to this document and must be displayed clearly in the laboratory.

During operation of the lasers the Lasermet interlock system must be operated. However addition and removal of interlock ¼" jacks from lasers must occur only when the Lasermet system is de-energized. Reminder signs are posted as below :

INTERLOCK must be POWERED OFF when connecting / disconnecting plugs → MAINS OFF

All seating in the lab should be arranged such that eye level is high above the plane of the laser. Adjustable lab stools are provided for this purpose.

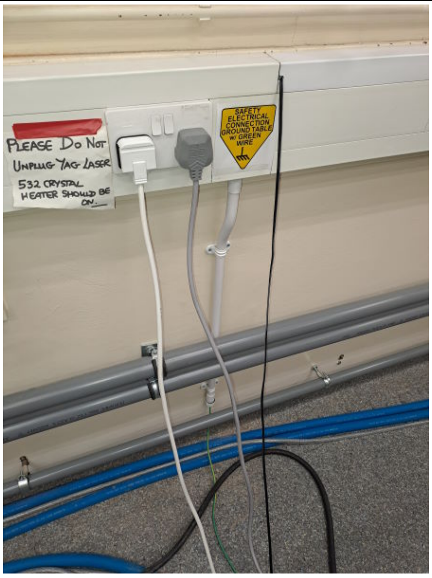
The lasers must be operated in accordance with the relevant instruction manual. Laser tables must be grounded using the green wires as shown below

3.1.1 Before turning on the laser (incorporating relevant Laser Safety Protocol)

- Review and follow the appropriate Laser safety protocol for the procedure to be performed (see Appendix and protocols on lab walls)
- The external keypad must be isolated from within the Laboratory, using the key switch on the Lasermet system, thus preventing anyone entering the laboratory. The laboratory may still be accessed in an emergency via the break glass point located next to the keypad. The keypad should only be re-activated when the laser table is completely covered by the safety enclosure.
- Before turning on the Nd:YAG laser: Be sure all covers are closed and the reservoir is filled with distilled water.
- Appropriate laser safety eyewear (see Section 4.3 below) must be worn at all times.
- The risk assessment appropriate to the specific experiment to be undertaken must be consulted.

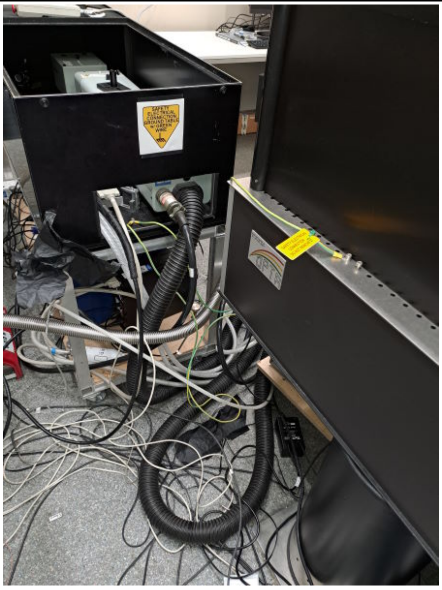
3.1.2 Turning on the laser: **Please ensure you are wearing appropriate laser goggles**.

F11 grounding wire connection at wall



F12 grounding wire connection at wall

Ekspla grounding wire



Opolette to GWU grounding wire

GWU ground wire to wall

LASER TABLES MUST BE GROUNDED TO THE WALL GREEN WIRE POINT PRIOR TO ENERGIZING LASERS AND OTHER ELECTRICAL UNITS ON TABLE

Use of the OPOlette and GWU OPO lasers
The OPO lasers must only be aligned at 532nm where the laser goggles used in this lab give significant protection to the output beam. **Laser goggles must be worn at all times when using this laser. No exceptions.** The beam **must be completely enclosed before it is tuned to any other wavelength**. The power of the laser is adjusted using the internal triggering timing between the flashlamp pulse and Q switch pulse and the alignment must be carried out **at the lowest possible laser powers using alignment cards**. Special care should be taken when the beam is tuned to the region 540-850nm where the Photonic Solutions, DBY-39 laser goggles do not give protection. At this wavelength range the goggles with 600-700nm protection with a glass LG7 should be used. The beam must be enclosed before the laser is tuned from 532nm to another wavelength.

CWV visible and IR diode lasers

Visible and IR diode lasers should be used as instructed in LS-1 section 4. The visible diode laser 405nm and CW 532nm torus laser are used as CW excitation sources into the EPR spectrometers. The IR diode laser is to be used by John Morton's group and is a 100mW 1064nm class 3b laser or the more powerful 560mW 1047nm IR laser which is a class four laser. The a**ppropriate laser goggles must be worn at all times when using these lasers.** The current supply to the laser must be turned to zero and then the laser switched on and the current supply increased until the laser just begins to lase as viewed on a viewing card. The laser must be aligned into the EPR spectrometer, via a lens and turning optics using a suitable viewing card. The laser beam path must be completely enclosed before the power of the laser increased to operating powers.

Use of the Toptica DL pro design laser This laser is an IR laser 1020-1080nm great care must be used with this laser because the beam is invisible to the naked eye yet can still cause eye damage. The laser must be completely secured to the laser table and completely enclosed during operation. The laser must be aligned using the lowest possible laser powers using and a IR alignment card and with the **aligner wearing laser goggles at all times.**

The laser power is adjust my changing the range button on the current control panel. The value of 40mW is close to the lasing threshold

The alignment is from the laser aperture of the laser to a IR turning mirror and through a focusing lens to the window of the EPR resonator. Alignment may only be carried by those authorised to carry out the procedure. The laser must be completely enclosed before operating at higher powers. Only authorised people are allowed to use this laser.

The Continuum Minilite Nd:YAG laser: Open the exit shutter on the front of the laser head. Turn the AC power on. Turn the key switch on. Push the Low Energy Mode key, its yellow LED should light. Use the up/down keys to alter firing rate. Push the start button to start flashlamp and Q-switch firing. Verify the beam is correctly aligned after leaving the laser. Full energy mode may be achieved by pressing the Low Energy Mode button again.

The **Continuum Surelite Nd:YAG laser (currently in storage in F18.)**

Before turning on the Surelite Nd:YAG laser first ensure the exit shutter is closed and place a power meter at the beam exit as an additional beam stop. Turn the laser on and warm up in mode F10 (flash lamp rep rate 10 Hz and P00 (No Q switching.) for 15minutes. Switch to external triggering, (Eon mode) and set the Q switch delay pulse to 400 microseconds delay from the flash lamp trigger using the pulse generator. This ensures a very low laser power output. Open the external shutter on the laser head and the internal shutter and measure the laser power and adjust the Q switch delay until the laser is lasing just above the lasing threshold of the laser and observable on the VRC1 viewing card. The laser is aligned into the EPR spectrometer set up at the lowest possible laser powers using a viewing card (as described is section LS-1 section 4). The laser beam must be completely enclosed by replacing all laser safety covers, before the laser power safely increased to operating powers (~15mJ).

3. 2 Common operations involving compromising the integrity of the laser enclosure

Several operations, such as signal optimisation, minor realignment require the lid of the safety enclosure to be removed. The frequency of such operations will depend on the experiments being performed but in some cases will be several times a day.

Before removal of the lid of the laser enclosure,

- The external keypad must be isolated from within the Laboratory, using the key switch on the Lasermet system, thus fully preventing anyone entering during alignment. The laboratory may still be accessed in an emergency via the break glass point located next to the keypad.
- The Nd:YAG laser should be operated in Low Power Mode
- IR and visible diode lasers should be reduced in power to the lowest powers possible using the current supply control.

Where practicable the lid should be removed, an adjustment made at low power and the lid replaced before the laser power turned up to operating power. This will be impractical for the purposes of signal optimisation, for which he following additional procedures must be followed:

- Only those individuals authorised on the Laser Training Record so to do, are permitted to remove or interfere with any of the fixed enclosures. Inform anyone present in the lab of procedure
- Wear appropriate safety glasses (see point 4.3) at all times.
- Keep as much of the enclosure as possible in place to limit the potential exposure to the beam.
- Attenuate the laser power to the lowest possible.
- Carry out the alignments in a systematic method from the laser to the experiment.
- Follow instructions in the appropriate laser manuals
- Ensure all laser lids are replaced and beams are contained before re-enabling the keypad.

3. 3 Non-routine maintenance/ major alignment

From time to time, major realignment of a beam path will be required, for example in setting up a new series of experiments with a new optical path. For such procedures Laser Safety Protocol 1 must be followed. These procedures may involve removal of a substantial fraction of the laser enclosure. In addition to the measures in Section 3.1 and 3.2 above, the named supervisor must be involved in the planning and inspect the new optical arrangement before use.

4. PROTECTION MEASURES - SUMMARY

4.1 Engineering controls:

- Lasermet door entry system, connected to the door and all laser supplies.
- Laser warning light illuminated directly by turning on lasers.
- A wooden laser enclosure, painted black is fixed in position, covering the entire beam path.
- Key code security entry systems (which may be isolated from within the lab) to ensure Authorised Users only are permitted.
- All beams should be aligned parallel to the laser table and no beams should be aligned out of the horizontal plane.

4. 2 Administrative controls:

- Only authorised users permitted to enter or operate lasers.

4. 3 Personal protective equipment (In addition to normal laboratory procedures):

The following protective eyewear to be used:

In order to reduce the output of the pulsed Nd: YAG laser used in this lab to below the MPE, an optical density of ε 6 is required. As the laser is pulsed with ~5 ns pulsewidth, they should thus be marked with RL6 for the wavelength concerned.

Make:	Continuum	Continuum	Thor labs	CNI MLL-III-1047
Model:	Surelite	Minilite	IR diode laser	IR diode laser
Serial no:	4453-1	14149	L1060P100J	
General eyewear - EN207 L scale	DL4 **RL6** (355nm) DL4 RL7 (532nm) DL5 RL8 (1064nm)	IR **L6** > 315-534nm	DL5 RL7 (1060nm)	DL5 RL7 (1047nm)
Make/Model (As per EN207 requirements)	Photonic Solutions, DBY-39  or Glendale Spectra Physics G31-70111 	Photonic Solutions, DBY-39  or Glendale Spectra Physics G31-70111 	Photonic Solutions, DBY-39  or Glendale Spectra Physics G31-70111 	Photonic Solutions, DBY-39  or Glendale Spectra Physics G31-70111 
Alignment eyewear (If different)				
- The following additional personal protective equipment is to be used:				

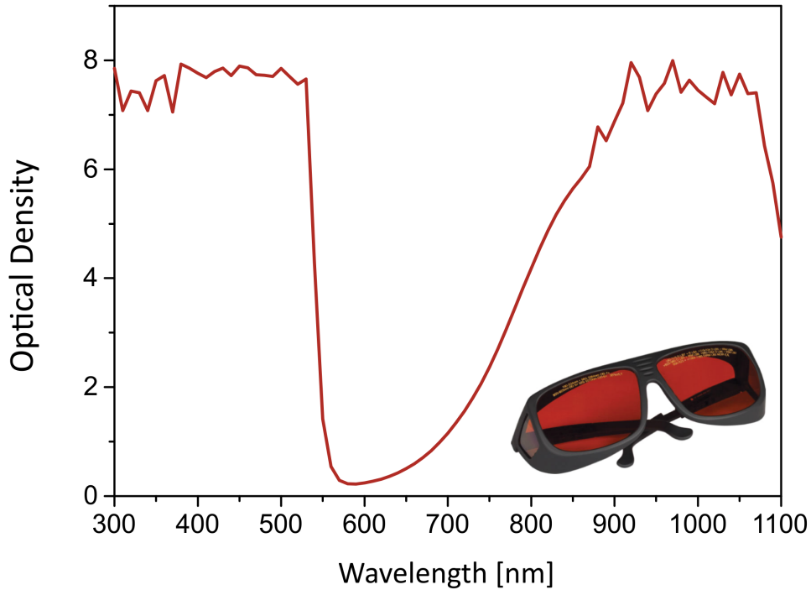
Make:	NEC Corporation	Roiyhner Laser Technik GmbH		
Model:	HeNe	405nm CW diode laser		
Serial no:	1055	5020243		
General eyewear - EN207 L scale	Optical density > 4 for 630 - 660 nm CE Marked EN 207 markings: 600 – 610 DIR L2 610 – 630 DIR L3, **630 – 660** DIR L4, 660 – 710 DIR L5 710 – 730 DIR L4, 730 – 790 DIR L5, 790 – 800 DIR L4, 800 – 820 DIR L3 Laser at 632nm	(DBy-39) **190-534nm** **+ 960-1064nm** **OD>7** + 850-925nm OD>5+ 925-1070nm OD>6+ 180-315 DL7 +RL4 >315-534nm DL4+ IRM L6 925-1064 DL5 +IRML6 980-1064 IR L7 NOIR CE	Glendale 5000-11000nm OD> 7 850-1080nm O.D.> 7. 750-850nm O.D.>5. 710-750nm OD>3. 520-532nm O.D.>7. **190-520nm** **O.D.>9**. 180-315 DL7 +IRl4. 315-532nm DIRl5. 800-1080 DIR l5.	
Make/Model (As per EN207 requirements)	LaserVision  For HeNe Alignment	Photonic Solutions, DBY-39  or Glendale Spectra Physics G31-70111 		
Alignment eyewear (If different)				
- The following additional personal protective equipment is to be used:				

4.4 Monitoring:

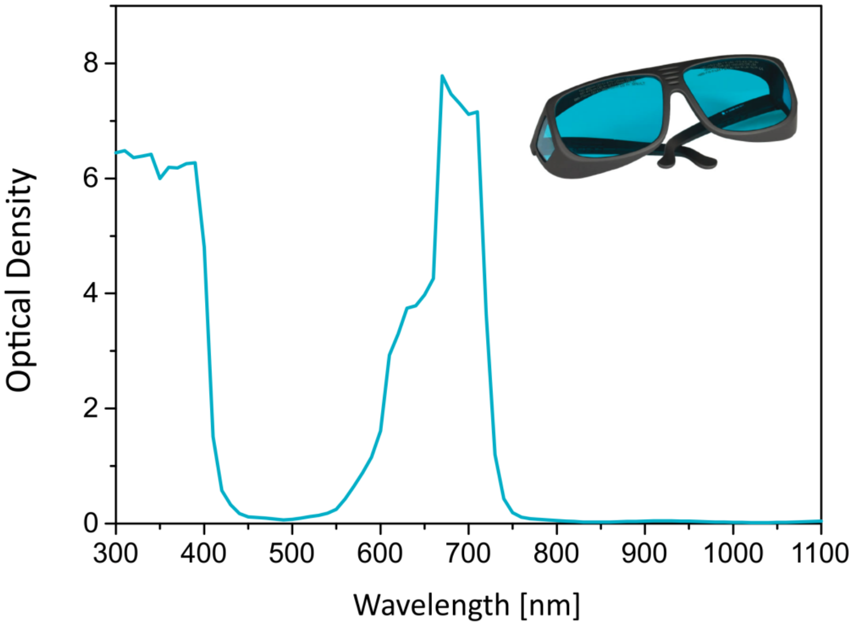
- Users to conduct a check of enclosures and PPE before use.
- Supervisors to conduct weekly checks on optics, beam stops, interlocks and emergency stops.
- Supervisors/DLS to conduct annual review of the system, risk assessment and local rules

Special Case for the GWU OPO and OPOlette Laser

The broadband nature of the OPO laser output means we have set up a system where we have two pairs of goggles that cover all the possible laser wavelengths used in our experiments. These goggles are a pair with LG10 glass, which are our most commonly used laser goggles that cover the region Nd:YAG laser wavelengths. These however have a transmitting region in the 550-800nm. See below.



Hence a second pair of goggles covers the 600-700nm with a glass LG7.



OPO laser at begining of each experiment:- Assessment of wavelengths

Before each new experiment the wavelength used by the OPO laser should be assessed in terms of the safety and suitability of laser goggles to use. All alignment of the OPO laser should be carried out at 532nm by authorised users wearing suitable Nd:YAG laser goggles using alignment cards at the lowest possible laser powers. The entire laser system should then be enclosed and laser goggles worn to protect the users at new wavelengths.

Notification of OPO laser change of wavelength

If the new opo laser wavelength requires a change of protective goggles this should be indicated on the laser warning sign posted outside the laboratory so new laser users entering the laboratory are aware of the change of wavelength.

Entering the Laser Laboratory containing the OPO Laser

Laser users should always be aware that wavelengths of the laser in experiments can change and should check before entering the laser lab that they are wearing the correct laser goggles. . If in doubt ring the bell and get the laser user to open the door and inform you what laser wavelength is currently in use.

Alignment of OPO Lasers

When lasers are being aligned the laser user should lock the interlock from the inside to prevent users coming into the lab during alignment. Once the lasers are enclosed the interlock can be set back to normal conditions so that authorised users can enter via the key code.

Always wear your laser goggles

It has been observed that some people walk through the interlocked laser doors without wearing their laser goggles relying on the laser users inside to have locked the lab when alignment is in process. They assume that if they can enter the laser lab, the lasers must therefore be enclosed. Why take that risk? Take control of your own laser safety, and **be proactive**, and wear the correct laser goggles when you enter an active laser interlocked lab and keep them on during all alignment procedures. (All alignment methods are set up to align class four lasers with alignment cards at low **powers with your laser goggles on**.

If in doubt whether it is safe to enter a laser lab, stop and ring the bell and ask the current laser user what goggles to wear.

Make:	**Lambda Photometrics**		**Spectra Physics**	
Model:	OPOlett Pulsed laser		**GWU OPO laser**	
Serial no:				

General eyewear - EN207 L scale	Physics G31-701 Glendale Specs Laser protection at wavelengths:- 5000-11000nm O.D. >7 850-1080nm O.D.>7 750-850nm O.D.>5 710-750 O.D. >3 520-532nm O.D.>7 190-520 O.D.>9 180-315**DL7** IR L4 , 315—532 DIR **L5** 800-1080 DIR L5.	Comments For the OPO Laser these goggles only cover the Wavelengths described. The Laser should only be scanned to new wavelengths after it has been completely enclosed. All alignment must be carried out at 520nm and the laser set to 520nm before enclosure is opened.	Physics G31-701 Glendale Specs Laser protection at wavelengths:- 5000-11000nm O.D. >7 850-1080nm O.D.>7 750-850nm O.D.>5 710-750 O.D. >3 520-532nm O.D.>7 190-520 O.D.>9 180-315**DL7** IR L4 , 315—532 DIR **L5** 800-1080 DIR L5.	DBY-39 goggles specs 193-315 D LB7 +IR L>315-532 DLB5+ IRM LB7 760-,760+>1075-1085 DIR LB5 800-820+ >960-1064 D LB6 + IRM LB7 770-,800 + >820-960+.1064-1075 DIRM LB6 NOIR CE Wavelength protection 190-534nm +790-850nm +>960-1070nm OD 7+ 760-1090nm OD5+ >850-960nm OD 6+ 22%VLT
(Make/Mode) (As per EN207 requirements)	Glendale Spectra Physics G31-701 	**Comments** **Glendale goggles should be used for alignment** because give better protection and are completely Enclosed. At other times the Photonic Solutions, DBY-39 or the alternative LG7 (blue region 650-730nm) Can be worn in the lab at depending on the wavelength. with beam enclosed.	Glendale Spectra Physics G31-701 Please use these goggles for alignment of OPO For wraparound protection, all alignment should be at 532nm.where goggles give maximum protection.use OTG goggles for far IR protection. (Glendale goggles below) 	DBY-39 For everyday operation. Please check wavelength OPO for which type to use. We have two sets which cover all wavelengths see page 20. **OTG goggles below for extra protection in IR region** 

Make:	**Spectra Physics**			**Laser Vision**
Model:	**GWU OPO laser**			OPO lasers
General eyewear - EN207 L scale	Frame R14, Filter T1P04, OTG	Please use the OTG goggles for the new OPO laser when using the far IR wavelengths. Where the Glendale goggles do not protect the user.		Please use R17 frame T1E03 filter goggles for region 532-578nm

Make/Model (As per EN207 requirements)	Goggles which include IR protection up to 3 microns. Frame R14, Filter T1P04, OTG goggles reinforced with soft foam cushion, VLT 4%, colour: brown		Wavelength/OD 180 – 315nm 10+ D LB9 + IR LB5 + M LB6Y >315 – 535nm 9+ DI LB7 + R LB8 + M LB9 620 - <650nm 1+ DIRM LB1 650 - <680nm 2+ DIRM LB2 680 - <690nm 7+ D LB6 + IRM LB7 690 - <750nm 8+ D LB7 - IRM LB8 750 – 1400nm 9+ D LB7 + IM LB9 + R LB8 >1400 - <3000nm 5+ DIRM LB4 3000 - 11500 nm 10+ D LB5 + I LB5Y	Wavelength/OD 180-315 DLB9 +IRLB5 + M LB6Y (OD+9) >315-515 DLB8 +IRLB8 + M LM7Y (OD+8) .515-578 DLB6 +IR LB7 + M LB7Y (OD7+)  These goggles attempt to cover the gaps between the L10 and LG7 laser goggles however there is a clear gap still between 578nm-650nm where no laser goggles completely protect O.D. >7. Hence we do not encourage people to work between 580-645nm.

Protocol 2: Adding new optical elements

Definition

Adding new elements **applies to the introduction of any new optic into the beam path of a class 3B or 4 laser such as a lens, prism, mirror, polariser or filter.**

Planning

- The placement of additional optics must be planned to minimise the possibility of stray reflections.
- Beam blocks must be devised to terminate any unavoidable stray reflections.

Initial safety checks

- Before starting the Class 3B/4 lasers, all beam paths must be inspected for any objects which should not be there and beam pipes should be replaced if necessary. Termination of each laser beam must be checked.
- Unauthorised persons must be excluded and the laboratory door closed. The external warning light should be illuminated.
- Alignment may be carried out by one or at most two authorised laser operators. No one else may be present in the room during this procedure and watches, bracelets, rings and other reflective jewellery should be removed.
- Appropriate laser safety eyewear should be worn at all times.
- All optics must be checked for damage, and stability of optics mounts verified.

Initial alignment and suppression of stray reflections

- Once a new optic is in place, initial alignment should be performed with the Nd:YAG laser at laser energies just above the lasing threshold of the lasers and can be observed on a UV/VIS viewing card it at all possible below the MPE (maximum permissible exposure) ($3.8mJ/m^2$ at 532nm). The CW IR diode lasers must be aligned at the minimum possible laser powers to observe a spot on the IR viewing cards, if it at all possible below the MPE of $32J/m^2$ at 1060nm and 1047nm.
- The new optic element in the beam path must be analysed for stray reflections. This can be done by predicting the likely path of specular (i.e., non-diffuse) reflections. The actual reflections of the highly attenuated Nd:YAG laser (below the MPE) may also be used to help identify stray reflections.
- Suitable beam blocks, opaque at the appropriate wavelengths, must then be installed to block all these stray reflections.
- Any effect ‘downstream’ of the new optic must be checked. ‘Beam pipes’ should be re-installed at this stage.
- Explicit permission of a supervisor is not deemed necessary for addition of a simple optical element. (Anything more complex must be taken as ‘setting up’ and the protocol followed accordingly.)

Laser safety protocol 3: *Day-to-day running*

Definition

Day-to-day running **applies to the operation of Class 3B/4 lasers under all circumstances except setting up or addition of a new optic element. It includes initial, minor realignment of laser beams at the beginning of an experiment and 'tweaking' of alignments.**

Initial safety checks

- Before starting the Class 3B/4 lasers, beam paths must be inspected for any objects which should not be there, and beam pipes should be replaced if necessary. Termination of each laser beam must be checked.
- Unauthorised persons must be excluded, and the laboratory door closed. The external warning light should be illuminated.
- Alignment adjustments may be carried out by one or at the most two authorised laser operators. No one else may be present in the room during this procedure.
- Watches, bracelets, rings and other reflective jewellery should be removed and appropriate laser safety eyewear should be worn at all times.
- All optics must be checked for damage, and the stability of optic mounts verified.

Check using Class 3B/4 lasers at low power

- Before turning on full power, the beam path of each laser must be verified in turn, using the lowest possible pulse energy and visualising the beam in an appropriate fashion (e.g., on fluorescent card).
- Under no circumstances must direct viewing of the laser beam be attempted even if the beam has been attenuated. There must be no exceptions to this rule.

Minor realignment ('tweaking') with lasers running at full power

- During an experimental run, it will often be necessary to re-optimise the alignment to recover diminished signal. Of necessity, this can only be carried out at full power, with all lasers on. Extra caution must therefore be exercised.
- All beam enclosures and blocks for stray reflections should remain as far as possible in place during this procedure. Enclosures should be designed to allow limited access to the beam for alignment checking without complete removal.
- It is essential to wear appropriate laser safety eyewear when visualising laser beams at full power.
- It may be possible (and indeed, preferable) to apply minor 'tweaks' to the alignment using the experimental signal as a guide. In this case it is not necessary to visualise the laser beams.
- If it is absolutely necessary to visualise the laser beams, e.g. to optimise beam overlap, this may be done by the appropriate method (fluorescent card, etc), but this should be avoided where possible e.g. by the use of iris diaphragms to define beam axes.

5. EMERGENCY PLAN
5.1 Laser Beam Incident • In case of emergency, all beams must be safely isolated or the power to the laser switched off. • If necessary, switch off the laser power by pressing the Lasermet emergency stop button. • The laboratory may be accessed in an emergency via the break glass point located next to the keypad. The laser power is automatically switched off when the break glass point is used. • In addition to the beam, all other potential hazards must be made safe, electrical supply (as necessary). • First Aid assistance must be obtained for anyone who is injured. If a Laser eye strike is suspected, the person must be sent to the John Radcliffe Eye Hospital: Note: Eye Casualty, John Radcliffe Hospital, Oxford**.** Tel: 01865 234800. • The hospital should, ideally, be notified before the person arrives • The laser registration form and these local rules must be sent with the individual, to help the hospital assess the injury. • Following any laser injury, the University Occupational Health Service and Safety Office must be contacted and/or an accident form submitted. This must be done as soon as possible or at least within 24hrs. Once the area has been made safe, the state of the room should be maintained, in case a follow-up inspection is required.
6. Hazards – Summary
Eyes: **Significant risk of eye injury from a laser eye strike. In the Visible, 400 to 780nm region, the principal risks are of photochemical and permanent thermal retinal injury.** **Skin: Visible, 400 to 780nm region, risk of skin burns, pigment darkening and photosensitive reactions.** **High Voltage: Risk of electrocution from high tension supplies**

Protocol 4: Laser Maintenance

Definition

The following maintenance checks should be carried out to ensure the integrity of the laser system and laser laboratory.

Interlocks

- Ensure the laser interlocks are in good working order by checking them on a weekly basis.

Condition of the laser

With laser off:-

- Ensure the laser is firmly bolted down to the laser table and none of the table clamps have been removed.
- The deionised water level in the YAG should be checked every two months and additional water added if necessary.
- Water filters for the YAG lasers to be changed every 12 months.
- Flashlamp changes should be recorded in the laser log book, along with the new voltage settings.

With laser on:- *<u>Laser goggles must be worn at all times when the lasers are on</u>*.

- Record of the laser power output at the beginning of each experiment and keep a record of the laser power over a weekly and monthly basis, note and decrease in laser performance.
- Regularly record the condition of the beam shape and beam profile using the specially provided laser beam burn paper. Monitor any changes to in the beam quality or shape**.**
- **Free Running in the YAG can cause considerable damage to the cavity optics and the laser should be regularly checked to ensure this does not occur to do this:- Regularly record the Free Running buffer voltage on the pulsed YAG lasers on monthly basis. This ensures that the laser not lasing without the Q switch pulse. The procedure for this measurement is described in the laser manual, and should only be carried out by users authorised to align the laser. The laser is triggered internally and in P00 mode (not Q switched) *<u>NB it is very important that the laser is not being Q-switched during this measurement</u>* The flashlamp output from the laser is observed on an IR viewing card. If an IR spot is observed, the laser is free running and needs to be realigned. If no output is observed the kV setting on the YAG is slowly increased from its operating voltage up to a maxiumum of 100 volts above its operating voltage and the free running buffer voltage recorded if any IR output is observed on the viewing card. If No IR output is observed the, free running buffer voltage is greater than 100V, this is very good. The <u>voltage must be returned to its normal operating voltage (it is important to do this!</u>) and the laser can be used safe in the knowledge it is not free running.**

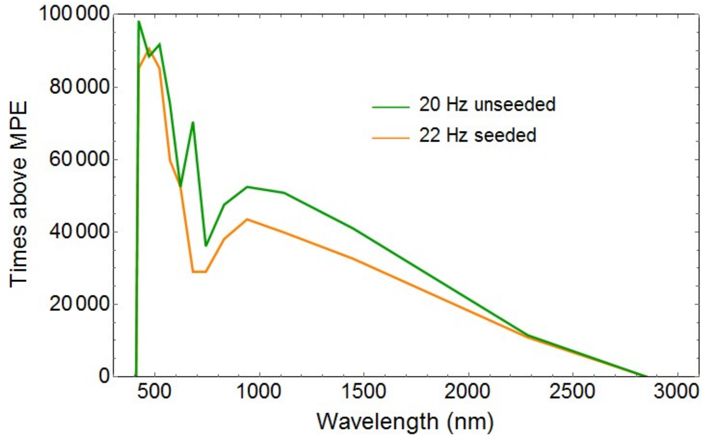
MPE determination

Make:	Continuum	Thor labs	CNI MLL-III-1047nm	OPO GWU
Model:	Minilite	IR diode laser L1060P100J	IR diode laser	
MPE – Eye (If known):	3.8 mJm^{-2} at 532 nm (most limiting) $MPE_{average}$: This is given by the MPE calculated with an exposure time of 0.25s divided by the number of pulses (N=10Hz/0.25s) : $MPE=18t^{0.75}/N = 6.4/2.5 = 2.5\ Jm^{-2}$ $MPE_{single} = 5\ mJ\ m^{-2}$ $MPE_{train} = MPE_{single} \times N^{-0.25} = 3.8\ mJm^{-2}$ The most restrictive of $MPE_{average}$, MPE_{single}, MPE_{train} is MPE_{train}, therefore the MPE is taken to be: $MPE_{train} = 3.8\ mJm^{-2}$	1060nm 0.25s blink reflex 200mW Beam diameter 2mm 2mm Divergence 2 degrees Because the beam is aligned by a lens into the spectro-meter Distance to target ~1m Gives only 1.55MPE MPE calculated from Lasersafe Software. Irradiance using p7.2 LUT/NRPB Laser safety Training manuel	1047nm 0.25s blink reflex 560mW Beam diameter 2mm x 2mm Divergence 1.5mrad Distance to target ~1m Gives 166 X MPE Comments This is a dangerous class 4 laser treat with great respect. Align at lowest possible laser powers. Be aware of possible skin damage from this laser, completely enclose beam before operating at high operating powers.	500nm Calculated with Laser Safe Software Laser beam 500nm Exposure 0.25s Energy 50mJ Beam diameter 8mm Divergence=0.5mr Distance 0.1m Rep rate 10Hz Pulse width =2ns Single pulse MPE $=5mJ/m^2$ pulse train MPE $=3.8mJ/m^2$ Average MPE $2.12J/m^2$ MPE Excess 259000 Class 4 Av Power Output =500mW. Comments This is a dangerous class 4 laser treat with great respect. Run at minimum powers, most experiments require a fraction of the OPO lasers maximum output. Align at lowest possible laser powers. Be aware of stray reflections from aligning into fibre optics, use extra laser shields, completely enclose beam before operating at high operating powers. Laser powers must be carefully reduced to alignment (lowest possible light levels seen on alignment cards with **goggles always on**. the set up must be enclosed and only then can operating conditions of ~10mJ into the fibre and maximum of 5mJ out of the end of the fibre into the W band spectrometer used.

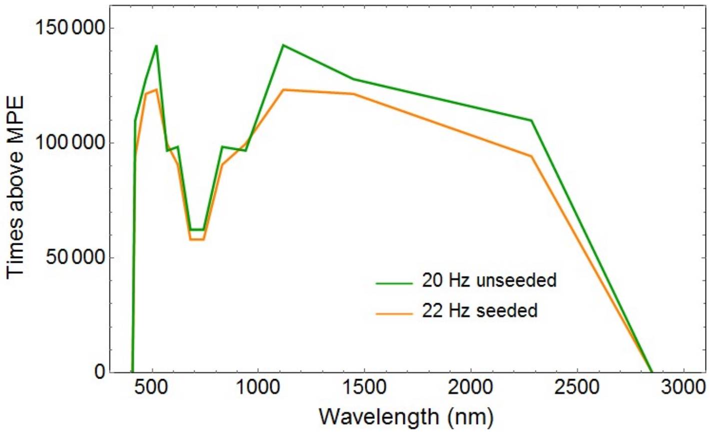
MPE measurements in detail on the New OPO laser

The pulse energy density for side output (should never be in used, but can be if necessary), is $6x10^5$ mJ/m², while for the signal behind the OPO it is $2x10^5$ mJ/m² @ 520 nm. I.e. $1.5x10^5$ x MPE and $5x10^4$xMPE for eye, respectively.

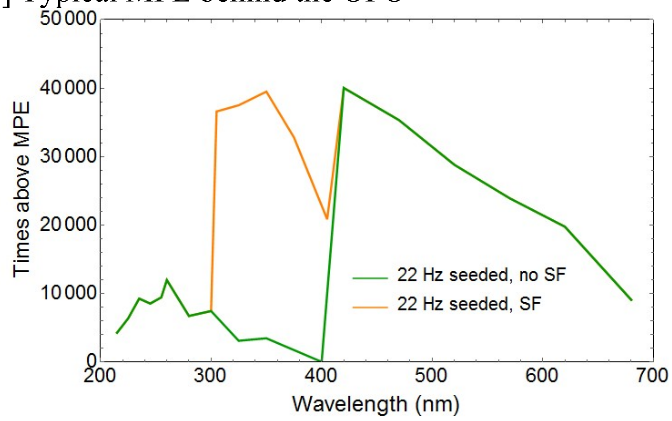
[1] Side Exit MPE with separator



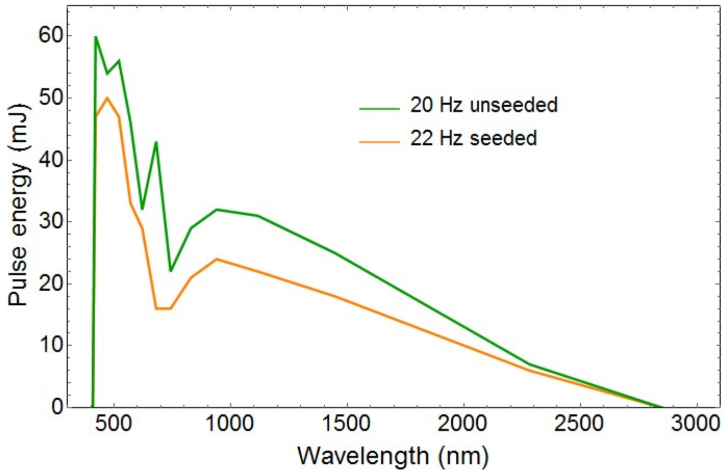
[2] Side Exit MPE without separator



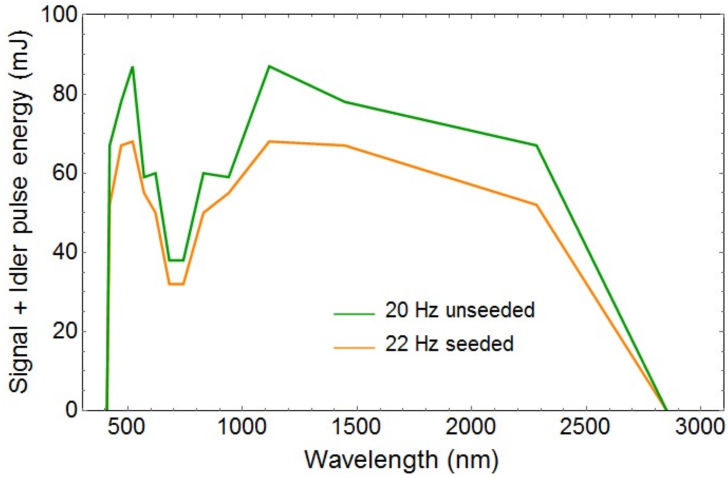
[3] Typical MPE behind the OPO



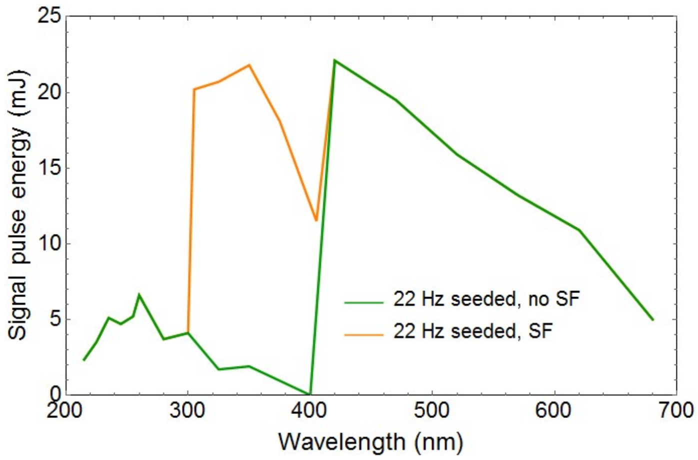
Appendix A
Pulse energies
[1] Side Exit pulse energies with separator



[2] Side Exit pulse energies without separator



[3] Typical pulse energies behind the OPO



MPE for pump beam energies

355 nm:
Unseeded: 225 mJ, 2.9*10^5 MPE
Seeded: 204 mJ, 2.5*10^5 MPE

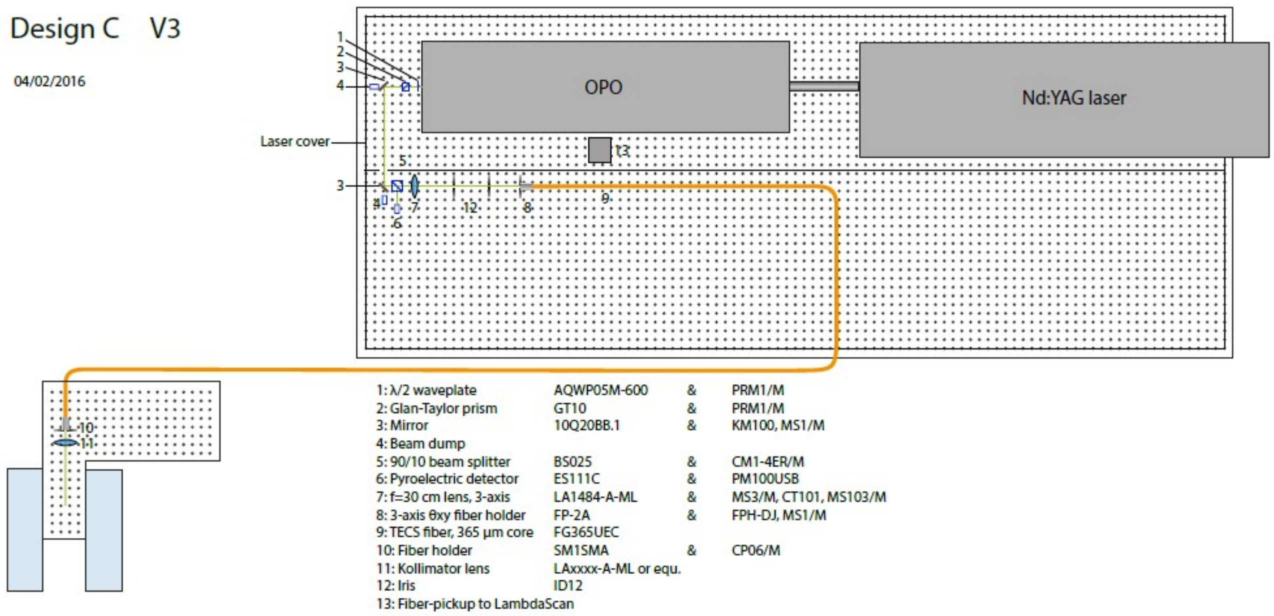
532 nm:
Unseeded: 300 mJ, 3.7*10^5 MPE
Seeded: 215 mJ, 2.7*10^5 MPE

1064 nm:

Without SHG and THG (never the case):
Unseeded: 815 mJ, ~8*10^5 MPE
Seeded: 750 mJ, ~7*10^5 MPE

With SHG and THG (always the case):
Seeded: 230 mJ, 3*10^5 MPE
Unseeded: ~~

Coupling alignment Plan



MPE determination

Make:	He Ne			
Model:	NEC Corporation			

MPE – Eye (If known):	Laser Safe calculation 632nm blink response 0.25s laser output maximum is 5mW beam diameter is 2mm beam divergence 1mrad distance to target 1m. Give an MPE equal to 5.1 xMPE this laser represents a hazard. Wear laser googles provided attenuate the beam down to 1mW which will be the MPE for this laser with neutral density filters			.