The Icarus/WA104 PMTs laser calibration system

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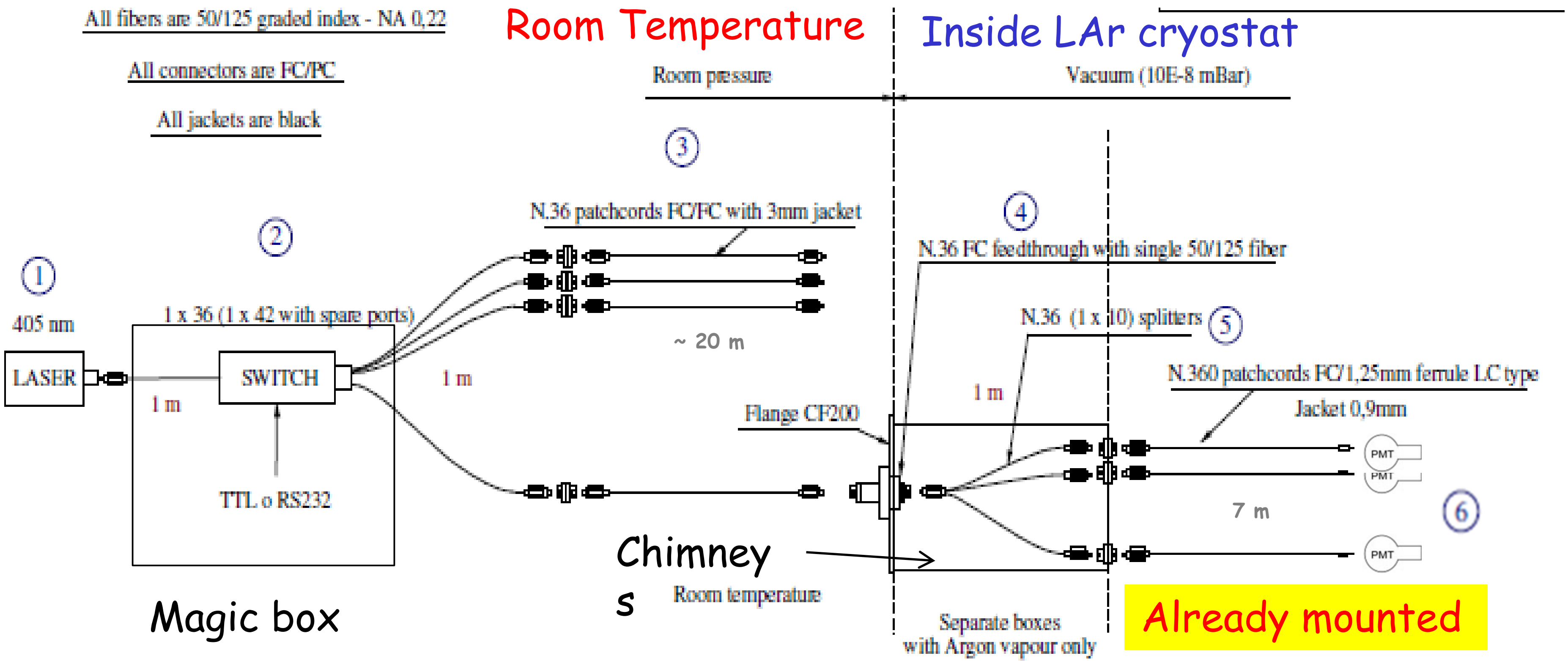
Why a laser calibration system

- Time delays Δt_i **measured by** PMTs are affected by drifts in time δi due to thermal excursion of signal cables, long-term PMT transit-time drift and other effects , that must be corrected.
- Equalization of each single channel may be obtained by analyzing crossing muons or by routinely delivering a fast laser pulse to each PMT. The equalization of all the channels can be performed splitting the signal from a fast laser diode (typical FWHM ~60 ps, peak power ~100-200W) to all the PMTs, set in common STOP, thus measuring δi
- The laser pulse delivery system may be made by an optical switch, followed by optical patchcords, optical UHV feedthroughs, fused optical splitters and injection optical patchcords and is shown in the following figure.
- Relevant points for the system are the power budget (as a laser diode has a limited peak power) and the timing dispersion properties of the system
- To calibrate a timing system with 1 ns resolution, the calibration system resolution must be around some hundreds of ps
- Preliminary studies done for MICE at RAL (M. Bonesini, R. Bertoni, A. deBari, M. Rossella JINST 11(2006) 05, P05024) have been re-used

Layout of the laser calibration system



1. 405 nm Laser [1]
2. Magic box: 1x36 optical switch [1]
3. ~20 m long armed FC/FC optical patchcords [36]
4. FC/FC UHV feedtrough [36] on CF40 flange, mounted on a CF200 flange
5. 1x10 fused fiber splitters [36]
6. 7m FC/ferrule injection patch fiber from 1x10 splitter to PMT [360]

1: some details on Hamamatsu PLP10 laser

LASER SAFETY

Conforming to international laser safety standards (USA:21 CFR 1040.10 CDRH, other areas: IEC Pub.825), which obligate manufacturers to provide preventive safety measures, Hamamatsu lasers are classified, and appropriate safety measures and labeling are provided. Duaring operation, users must also use their preventive safety measures according to laser-related regulations.

- **Labels**

Hamamatsu model PLP-10 uses lasers to be classified, Class 3B.

Description Label (Sample)

Caution Label

- **M8903 Laser diode head**
  - Output form type: window: PLP10-xxx / FC connector (for multi-mode optical fiber) : PLP10-xxxC

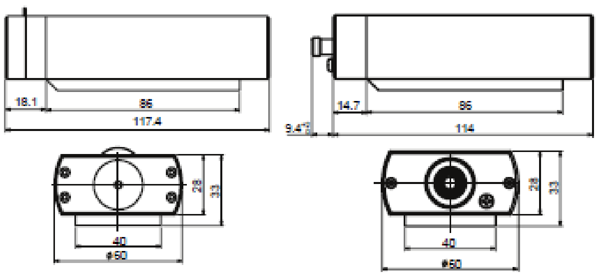
Parameter			Unit	PLP10-038 ******	PLP10-041 PLP10-041C	PLP10-044 PLP10-044C	PLP10-063 PLP10-063C	PLP10-065 PLP10-065C	PLP10-067 PLP10-067C	PLP10-078 PLP10-078C	PLP10-085 PLP10-085C	PLP10-130 PLP10-130C	PLP10-155 PLP10-155C
Emission wavelength			nm	375	405	440	635	650	670	780	850	1300	1550
Wavelength tolerance			nm	<±10	<±10	<±10	<±10	<±10	<±10	<±20	<±10	<±30	<±30
Spectral half-width			nm	<10	<10	<10	<5	<5	<5	<5	<5	<10	<20
Pulse width		max.	ps	100	100	100	110	100	100	100	100	100	100
		typ.		80	70	80	90	70	70	70	70	70	70
Beam divergence angle*		$\theta_{//}$	deg.	15	16	13	10	11	10	15	12	25	25
		$\theta_{\perp}$		30	34	28	35	35	40	30	32	30	30
Peak power	Window output	typ	mW	70	100	80	70	70	70	70	100	20	10
		min.		30	50	40	30	30	30	30	50	10	5
	FC connector output	typ		***	50	20	30	30	30	30	50	10	5
		min.		***	25	10	10	10	10	10	25	5	2

*Measured using a window output type.

Note: Measured with 100MHz. The values can be changed depending on the frequency. The PLP head should be selected according to wavelength and output form and can be exchangeable with the controller C8898.

Class III-B laser, power output in fiber

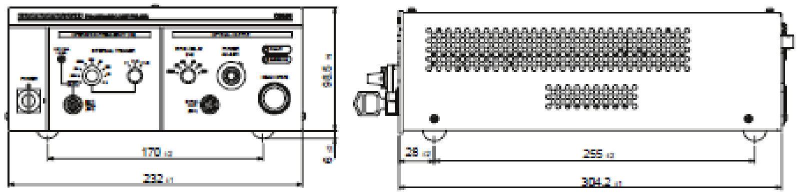
- **M8903 Laser diode head (approx. 0.5 kg)**



- Window output type -

- FC connector output type -

- **C8898 Controller (approx. 5.1 kg)**

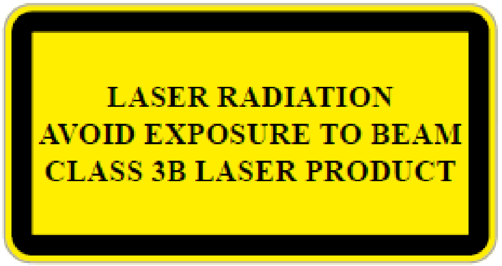


Laser safety

<table>
<tr><th>CLASS</th><th>US: FDA/CDRH</th><th>IEC 60825
(AMENDMENT 2)</th></tr>
<tr><td>Class 1</td><td colspan="2">• No known hazards during to eye or skin during normal operation
• Note: Service Operation may require access to hazardous embedded lasers</td></tr>
<tr><td>Class 1M</td><td>N/A</td><td>• No known hazards to eye or skin, unless collecting optics are used</td></tr>
<tr><td>Class 2a</td><td>• Visible lasers not intended for viewing.
• No known hazards up to maximum exposure time of 1000 seconds</td><td>N/A</td></tr>
<tr><td>Class 2</td><td colspan="2">• Visible lasers
• No known hazard with 0.25 seconds (aversion response)</td></tr>
<tr><td>Class 2M</td><td>N/A</td><td>• No known hazard with 0.25 seconds (aversion response) unless collecting optics are used</td></tr>
<tr><td>Class 3a</td><td>• Similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam
• Visible only</td><td>N/A</td></tr>
<tr><td>Class 3R</td><td>N/A</td><td>• Replaces Class 3a (with different limits)
• 5 x Class 2 limit for visible
• 5 x Class 1 limit for some invisible</td></tr>
<tr><td>Class 3B</td><td colspan="2">• Medium-powered (visible or invisible)
• Intrabeam and specular eye hazard
• Generally not a diffuse or scatter hazard
• Generally not a skin hazard</td></tr>
<tr><td>Class 4</td><td colspan="2">• High powered lasers (visible or invisible)
• Acute eye and skin hazard intrabeam, specular and scatter conditions
• Non-beam hazard (fire, toxic fumes, etc.)</td></tr>
</table>

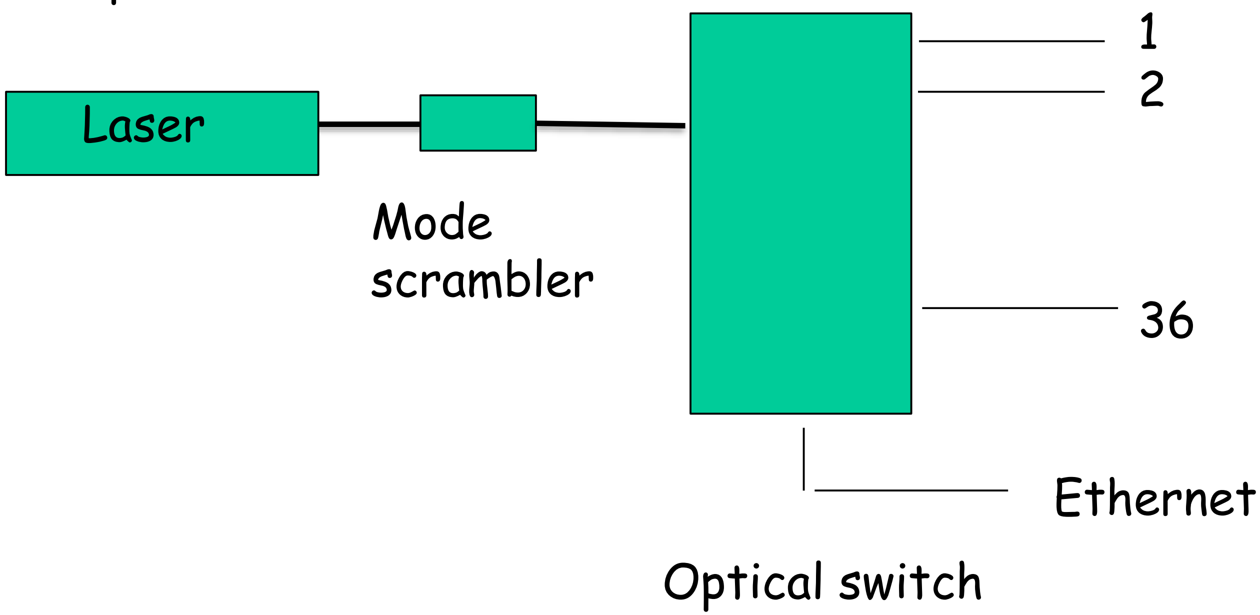
Class 3B

A Class 3B laser is hazardous if the eye is exposed directly, but diffuse reflections such as those from paper or other matte surfaces are not harmful. The AEL for continuous lasers in the wavelength range from 315 nm to far infrared is 0.5 W. For pulsed lasers between 400 and 700 nm, the limit is 30 mJ. Other limits apply to other wavelengths and to ultrashort pulsed lasers. Protective eyewear is typically required where direct viewing of a class 3B laser beam may occur. Class-3B lasers must be equipped with a key switch and a safety interlock. Class 3B lasers are used inside CD and DVD writers, although the writer unit itself is class 1 because the laser light cannot leave the unit.



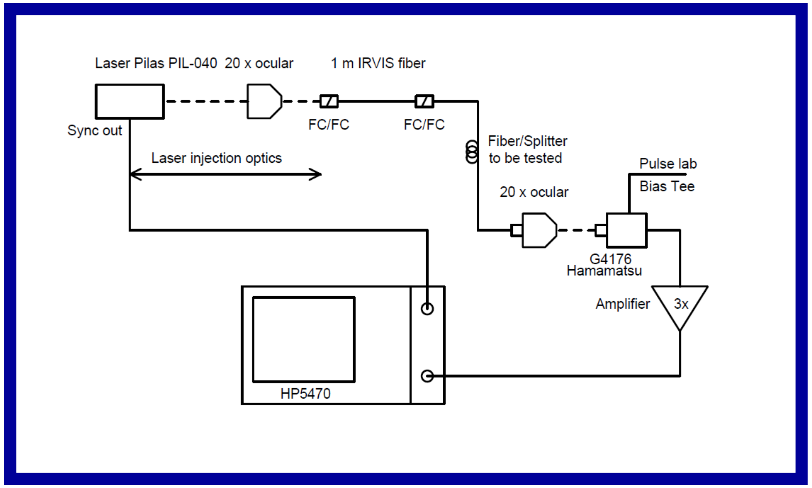
2) the optical switch

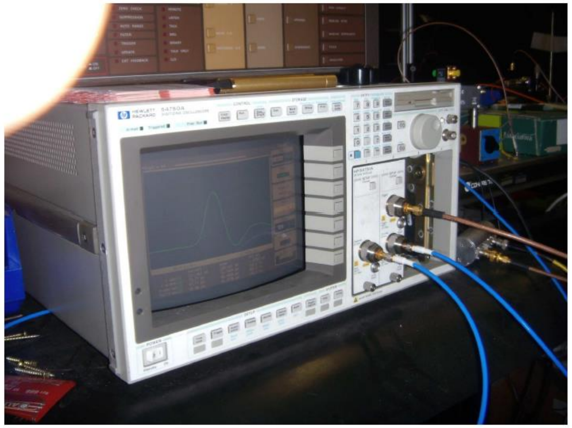
- Must go from 1 input to 36 lines to the 1x10 splitters, one after the other with minimal insertion loss (IL) and pigtail to pigtail output spread
- Stability over a months/years time span is also a concern
- Preliminary studies done with a PiezoJena 1x9 switch and a Leoni 1x4 switch gave a good response for Leoni
- Ordered and received at CERN a Leoni 1x36 switch with big IL at 405 nm and channel to channel spread
- Probably it will be replaced by an Agiltron switch (1x46: some spare channels) or use variable attenuators for single channels to equalize response



3) 20 m long patchcords (x36)

- To reduce injection problem (tight power budget with a laser diode) : use MM fibers instead of SM fibers -> full characterization at 405 nm, including timing (dispersion) and attenuation properties of MM fibers.





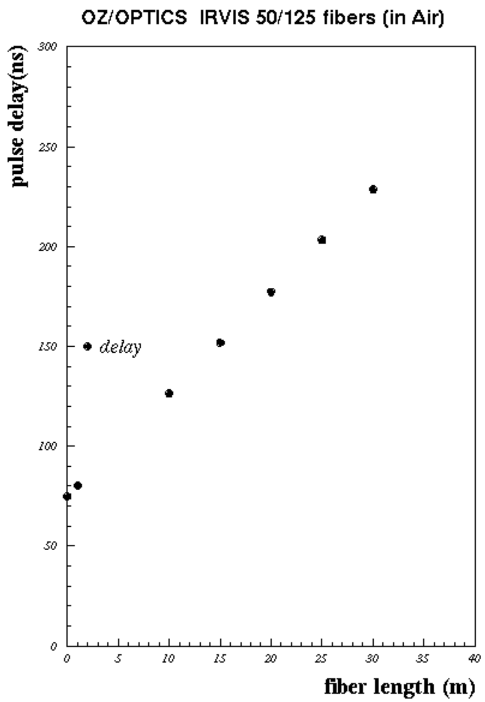
- Attenuation studies with an OPHIR NOVA powermeter
- Dispersion studies with an HP 54750A sampling scope with a 20 GHz head after an Hamamatsu G4176 photodetector powered by a 10 GHz bias tee (Model 5550B from Picosecond Pulse Lab) or a Picometrix D30 photodetector

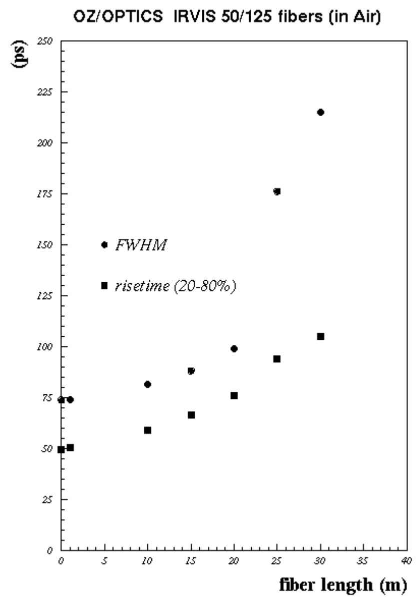
Results on attenuation

MM fiber	type	Attenuation (dB/m) no scrambler	Attenuation (dB/m) with mode scrambler
Thorlabs AFS 50/125 Y (step index: 400-2400 nm)	50 μm core	0.169 +- 0.007	0.193+- 0.011
Thorlabs AFS 105/125Y (step index: 400-2400 nm)	100μm core	0.0796+- 0.0026	0.0808+- 0.0046
Corning 50/125 (graded index)	50 μm core	0.0794+- 0.0029	0.0894+-0.0051
OZ/OPTICS IRVIS 50/125 (graded index: 400-1800 nm)	50 μm core	0.0696+-0.0026	0.0569+-0.0063
OZ/OPTICS UVVIS 50/125 (step index: 200-900 nm)	50 μm core	0.118+-0.009	0.114+0.007
Thorlabs SFS 50/125 Y (step index: 250-1200 nm)	50 μm core	0.0657+-0.0052	0.0744+-0.0097

Our choice: OZ/Optics IRVIS 50/125

Fiber characterization



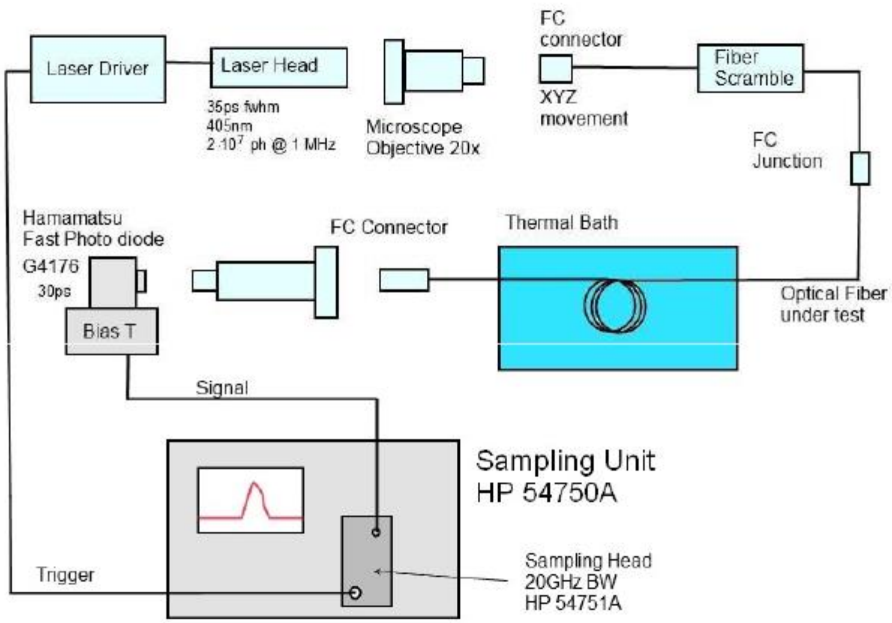


Pulse delay

Pulse degradation

(measurement with an Arden Photonics mode scrambler before the fiber patch to be tested)

A detour on temperature effects



Test system includes a precision LAUDA thermal machine (precision of 0.1C) where part of the fiber may be kept at fixed temperature

Fiber under test: 15 m patches
Thorlabs AFS 50/125Y or 105/125Y
(14 m in thermal bath, 1m in air) ;
30 m patch OZ/OPTICS IRVIS 50/125
(28 m in thermal bath, 2m in air)

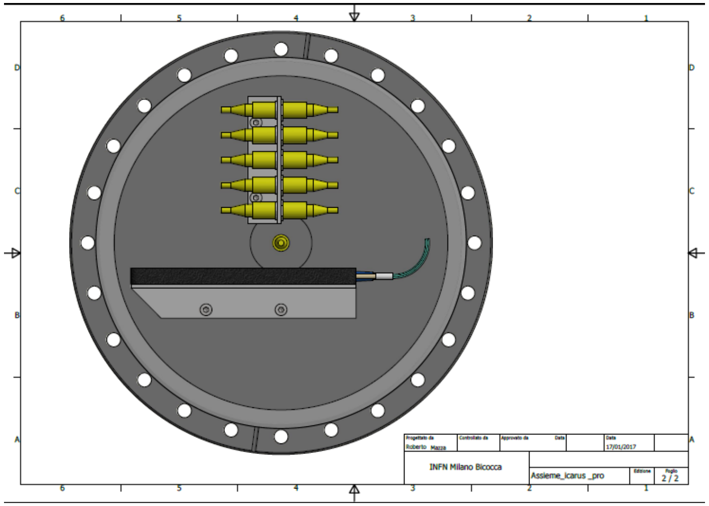
Conclusions on 50 μm core fibers test

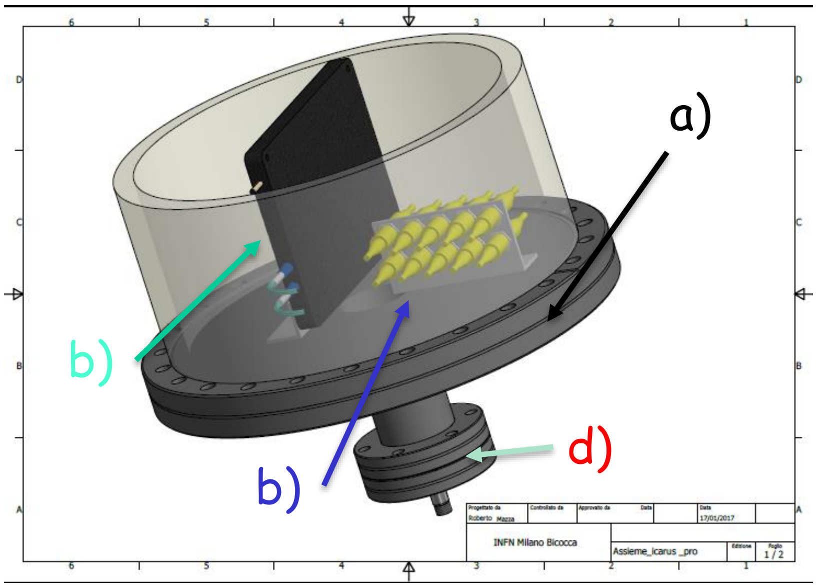
	OZ Optics Irvis 50/125	OZ OPTICS UVVIS 50/125	Thorlabs AFS 50/125	Thorlabs SFS 50/125 (*)	Corning 50/125(*)
Delay (fs/m ^0C)	106	40.6	52.2	—	—
Delay (ns/m)	5.11	5.05	5.11	—	6.4
Attenuation (dB/m)	0.06	0.12	0.08	0.07	0.08
Pulse risetime dispersion (ps/m)	1.12	1.22	1.21	0.70	0.90
Pulse width dispersion (ps/m)	0.99	2.21	2.71	0.63	1.63

(*) measure without mode scrambler

4) optical feedthroughs

- Each DN200CF to DN35CF nibble (36 in total) (a) will host a 1x10 splitter (b), a support for the fibers FC/FC fiber connectors (c) and a optical feed-through (DN35CF) (d)

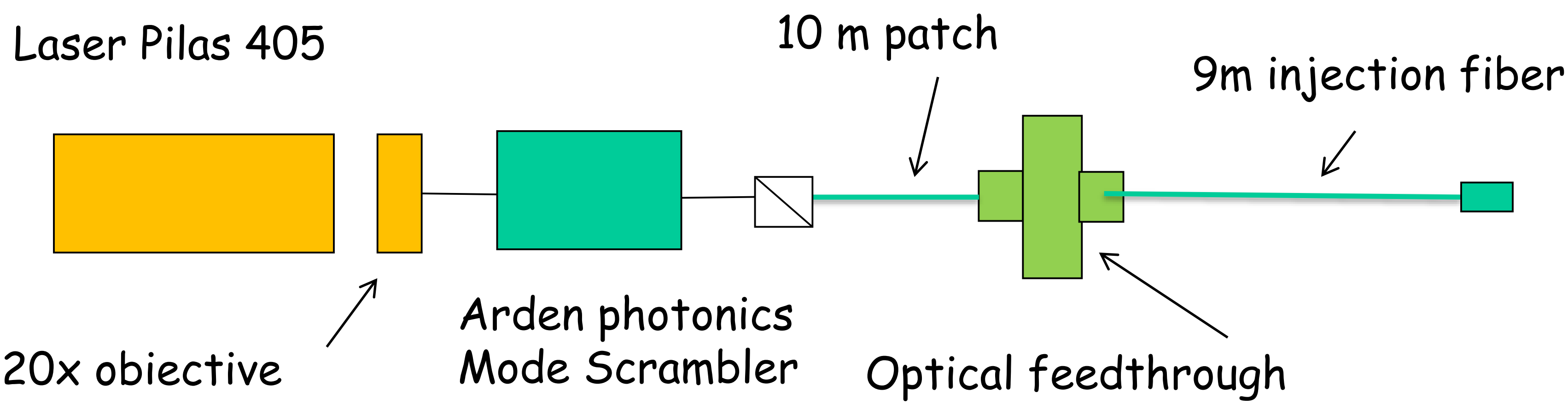




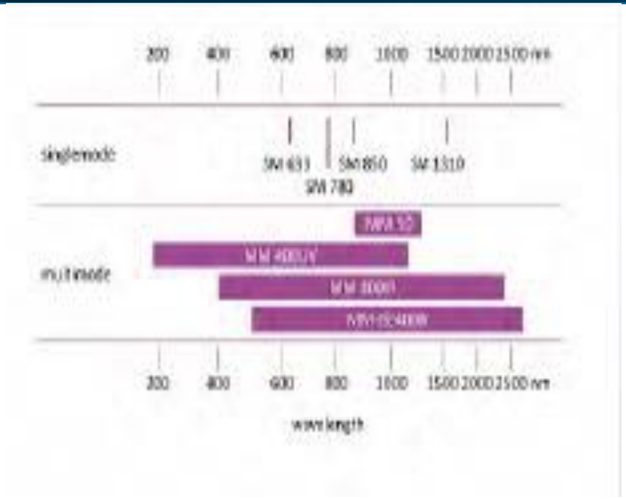
- All materials ordered/in hand and tested after a long R&D: splitters from Lightel (US), optical feedthroughs from Vacom (DE), nibbles CF200 - CF40 from Lesker

Tests of optical feedthroughs

- Use FC connectors (better than SMA, but more difficult to find)
- Optical feedthrough from VACOM Gmbh, Alectra Ltd and OZ/Optics
- Tests on KF 40 flanges



Measurements on VACOM graded index FF



- Measurements with Ophir NOVA powermeter
- Transmission is fine : up to 66% at the end of all the system, 70-80% through the feedthrough

	Laser 10 KHz	transmission	Laser 1 MHz	transmission
MS only	89.5 nW		6.96 mW	
MS+ 9m fiber	90.7 nW (*)	100 %	6.79 mW (*)	98%
MS+feedthrough+9m fiber	64.2 nW	72%	5.95 mW	85%
MS+10m fiber + feedthrough+ 9m fiber	58 nW	65%	4.50 mW	66% (*) correction applied for laser power fluctuations

Additional measurements

	Vmax (mV)	Risetime(ps)	FWHM (ps)	Pulse delay (ns)
MS only	74.8 +- 0.4	53.2 +- 1.3	78.0 +- 0.8	78.932
MS+9m fiber	51.40 +- 0.2	71.6+-13.7 (*)	89.4+-1.1	124.930
MS+feedthrough+ 9m fiber	46.80 +- 0.1	66.5 +- 0.7	88.8 +- 0.6	125.054
MS + 10 m fiber+ feedthrough + 9m fiber	33.8 +- 0.3	86.0 +- 1.5	112.8 +- 0.6	176.488 (*) problems: laser instabilities

- Measurements with HP5750 20 GHz sampling scope + Hamamatsu G4176 fast MSSM photodetector
- **VACOM feedthrough is fine**

5) Tests on 1x10 splitters

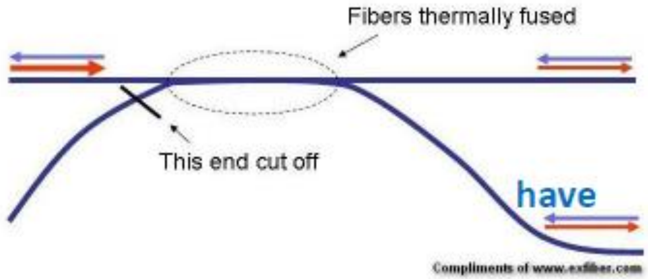
A fused fiber 1xN splitter divides the input pulse into N output channels. Technology well-known for Telecom (> 1200 nm) not so common for visible light and MM fibers

Main concerns are:

- Equality of transmission ratios over the N pigtails
- Loss in dB over the pigtails
- Minimal deterioration of timing characteristics of the transmitted pulses (FWHM, risetime)

Tested splitters (with 50/125 μm graded index fiber) :

- Even ratio 1X8, 1x10, 1x16 OZ/OPTICS
- Even ratio 1x8, 1x10 Lightel
- Even ratio 1x10 Comcore
- Even ratio 1x10 Unifibre (CH producer)



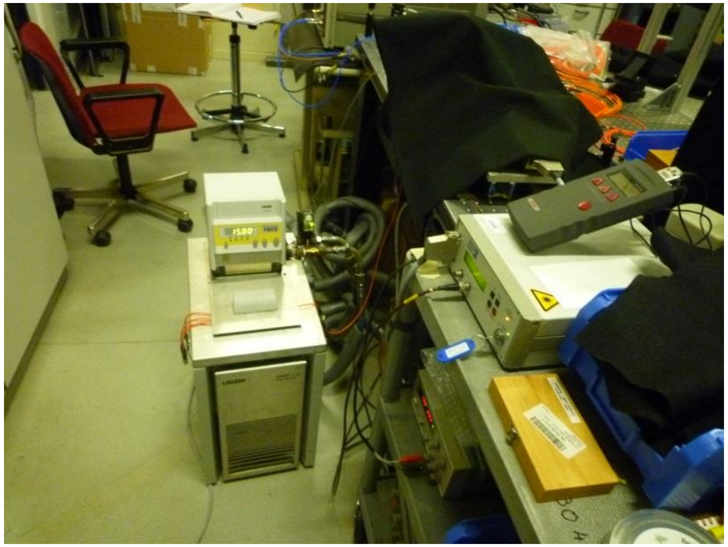
Conclusions on 1x10 splitters

	Trans (%)	Delay	$FWHM/FWHM_0$
Comcore # 1	2.74 +- 0.69	98.9942+-0.5520	1.07+-0.03
Comcore # 2	3.95 +-0.40	96.6338+-0.1207	-
Lightel # 1	5.47 +- 1.16	96.597+-0.004	1.04+-0.01
Lightel # 2	4.46 +- 0.90	92.990+-0.019	1.03+-0.01
OZ/Optics # 1	4.06 +- 1.34	107.70+-5.16 *	1.04+-0.01
OZ/Optics # 2	4.16 +- 1.23	107.56+-4.99 *	1.02+-0.02

* 2 pigtails out of 10 are out of ~13 ns !!

- **Best choice: Lightel 1x10 splitters**
  - Better transmission ~ 5% (with a 20% dispersion)
  - Similar delays on all pigtails (within 10-20 ps)

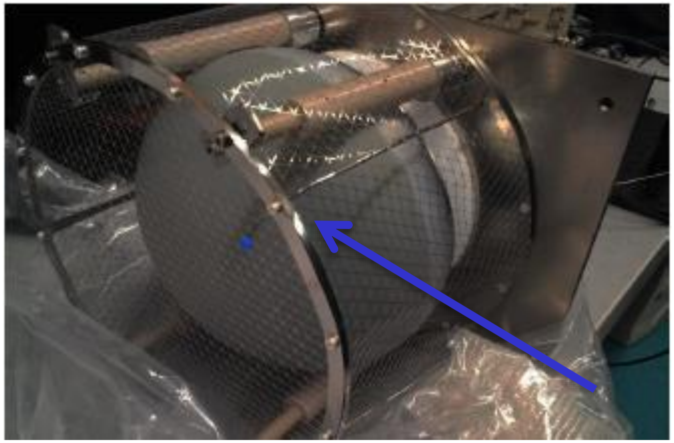
Temperature effects on fused splitters

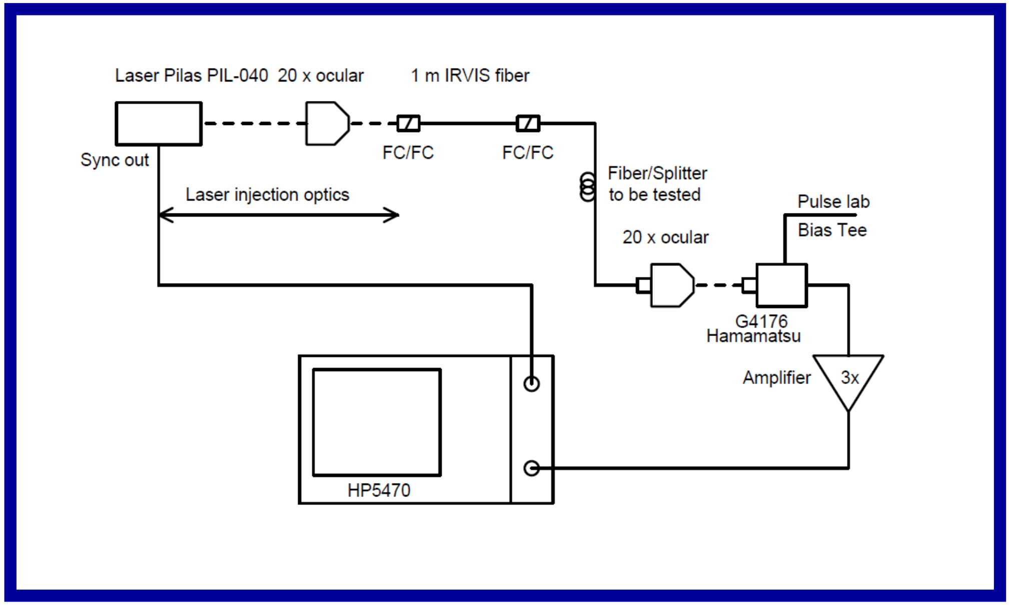


- Splitter in the Lauda thermal bath at various T
- Tests with 1x4 OZ/Optics splitter
- No evidence of effects between -10 C and +15 C
- Results for a typical output channel (ch # 1)
- good for chymney's zone

T	+15 C	+5 C	0 C	-5 C	-10 C
V max (mV)	10.76+-.06	10.79+-.02	10.71+-.07	10.56+-.04	10.72+-.08
Risetime (ps)	58.85+-3.47	59.57+-.85	59.09+3.45	59.38+-5.52	58.93+-5.85
Width (ps)	81.95+-1.07	81.53+1.00	81.92+1.34	81.67+-0.96	81.91+-1.53
Pulse delay	105.015	105.011	105.009	105.001	105.008

6) tests on the 7m injection patches

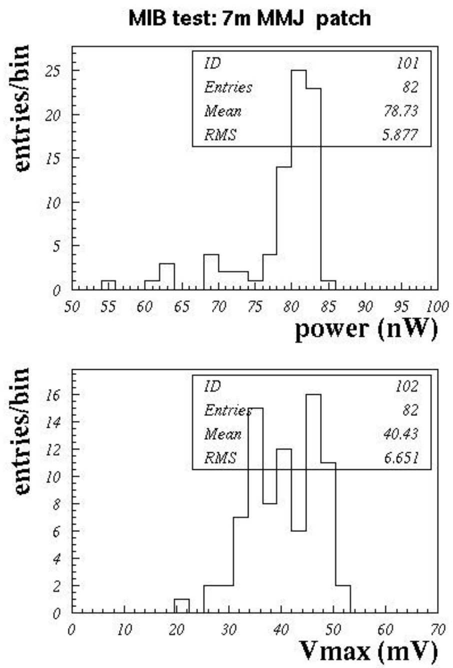


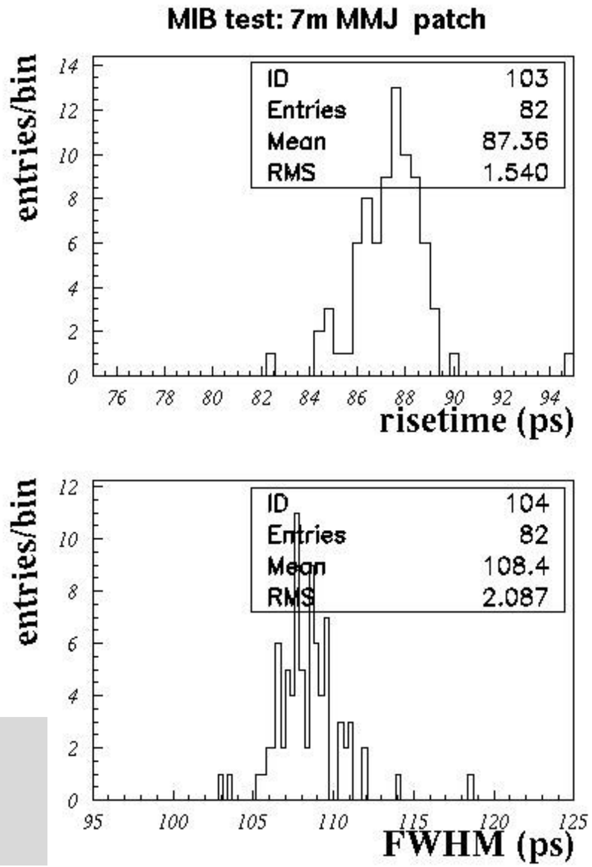


Measure of optical components: risetime, falltime, width, delay with ps precision + power transmission …

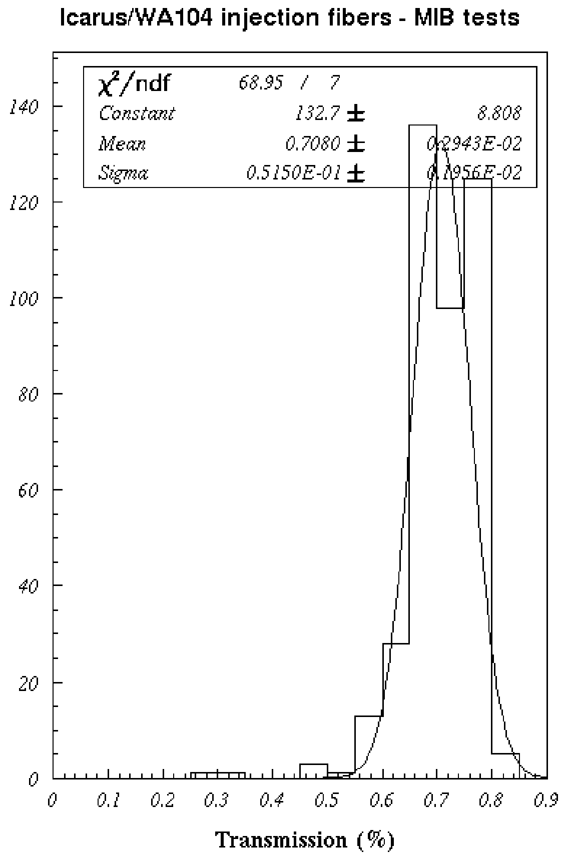
Test setup at MIB based on HP54750 sampling scope (20 GHz), fast diode laser (FWHM~30 ps) …

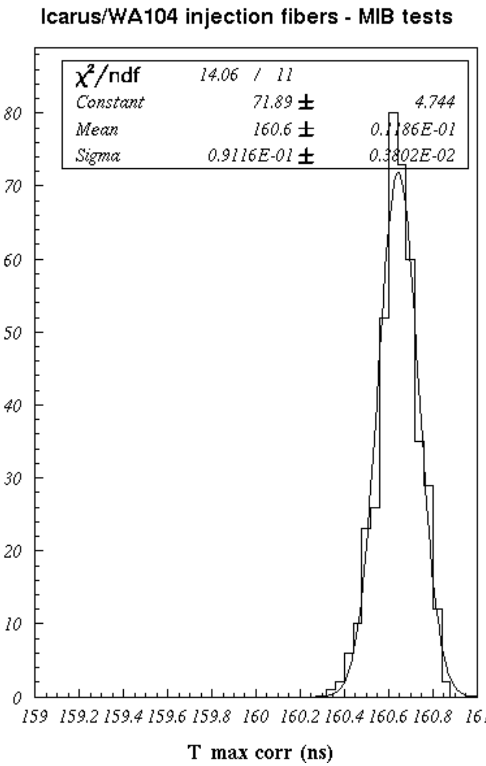
Measure of 7m injection patches





- Measure at CERN of transmission
- Measure at MIB of fiber parameters

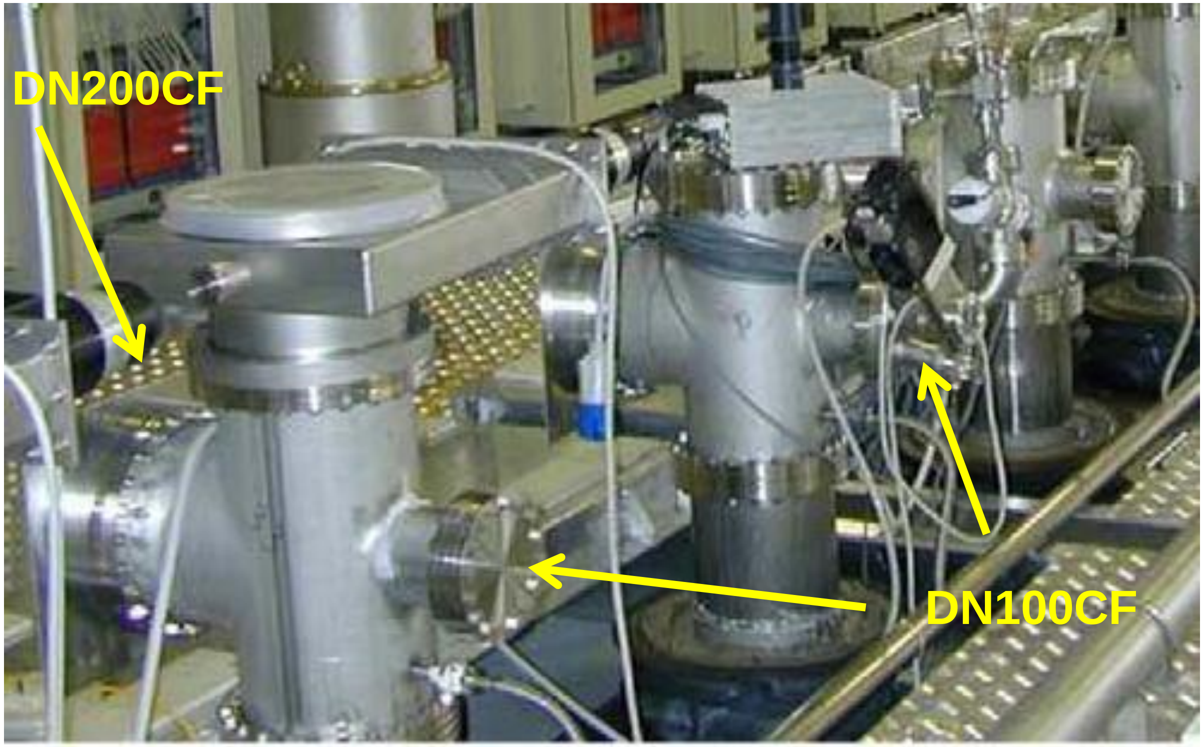




All 360 patches measured. ~10-15 bad with transmission + delay criteria

Cabling layout for laser system

- option for cabling: LASER + optical switch in the middle.
- From optical switch 36 fiber patches 20 m long going to the UHV optical feedthroughs (one CF200 every two cimmeys)
- 20 m long fiber patches in a special conduit next to the ones of signal cables
- Installation foreseen at beginning of November



Tests at CERN

- Tests at CERN with the LAr prototype, equipped with 10 PMTS
- Study calibration procedures with a reduced system based on one PLP10 laser diode, one 20 m patch cable an optical feedthrough with a 1x10 splitter and ten 7m meters injection patches
- Only missing item: the optical switch

Conclusions

- Laser calibration system components available and tested (minor problems with optical switch)
- Ready for installation at beginning of November
- Test bench for calibration system at CERN with 10 PMTs setup in a LAr chamber