g-2 laser calibration system

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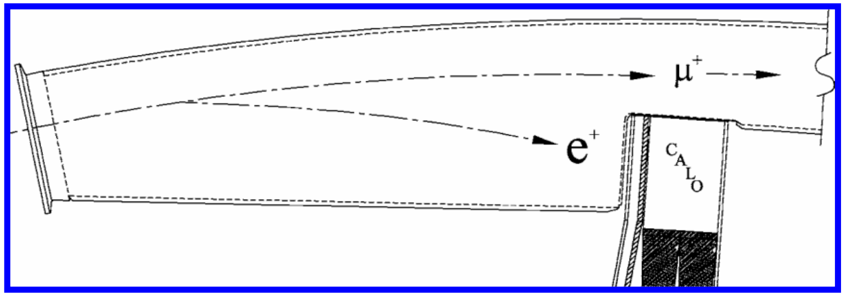
LNF, INFN Frascati

MUSE General Meeting

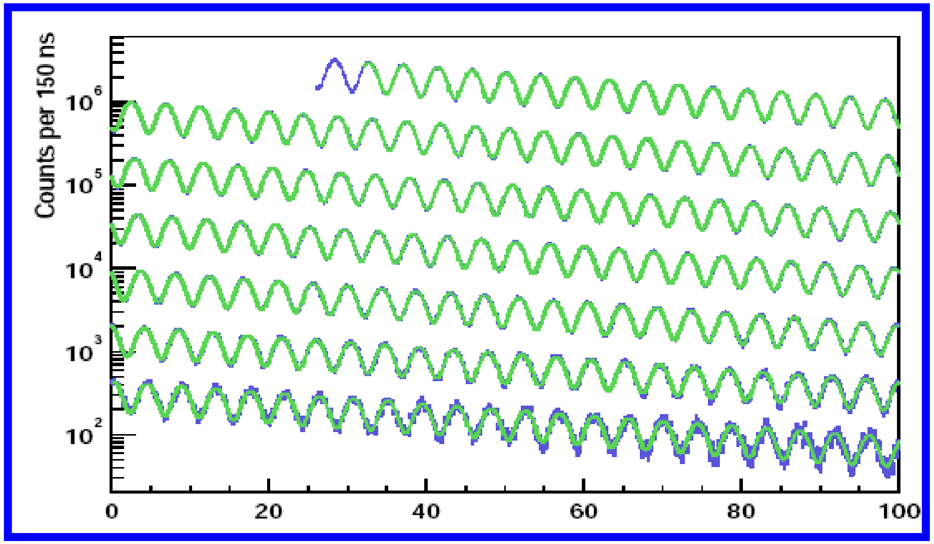
Outline

- Motivations
- Laser distribution system
- Source and local monitors
- First results on calibration
- Schedule
- Conclusions

Muon spin precession frequency



e+ with E > 1.8 GeV



$$\omega_a = \omega_S - \omega_c = \frac{eB}{m} a_\mu$$

- Decay self-analyzing:
  - Higher energy positrons emitted preferentially in direction of muon spin

$$N(t) = N_0 e^{-t/\tau} \left(1 + A cos(\omega_a t + \phi)\right)$$

- **Spectrum distortions from**
  - **Pileup, gain stability**
  - **Beam Effects, Losses**

ω_a systematic

Category	E821 [ppb]	E989 Improvement Plans	Goal [ppb]
Gain changes	120	Better laser calibration	
		low-energy threshold	20
Pileup	80	Low-energy samples recorded	
		calorimeter segmentation	40
Lost muons	90	Better collimation in ring	20
CBO	70	Higher n value (frequency)	
		Better match of beamline to ring	< 30
E and pitch	50	Improved tracker	
		Precise storage ring simulations	30
Total	180	Quadrature sum	70

- Tackling each of the major systematic errors with knowledge gained from BNL E821

Gain stability: short term fluctuations

- A rule of thumb: **$\Delta G/G$ ~0.2% → $\Delta\omega_a/\omega_a$~0.1 ppm** **[F. Gray, PhD Thesis]**
  → For E989: $\Delta\omega_a/\omega_a$~0.02 ppm → $\Delta G/G$ ~0.04%

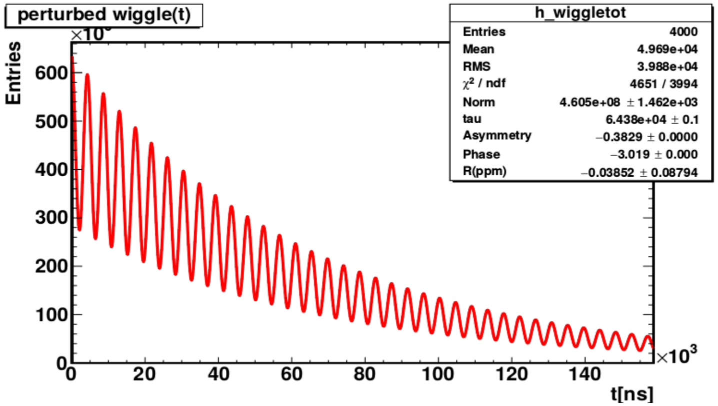
G(t) Function	ε (10^{-3})	χ^2/Ndf	R (ppm)
1	0	0.98	-0.02±0.08
Linear (1)	1	1.16	-0.03±0.08
Linear (1)	5	5.05	-0.08±0.08
Exp (2)	1	9.1	0.36±0.08
Cos (3) φ=π	1	1.6	-0.02±0.08
Cos (3) φ=π/2	1	1.6	-0.04±0.08
Cos (3) φ=π	1	15.5	-0.02±0.08
Cos (3) φ=π/2	5	15.5	-0.13±0.09

1 $G(t)= 1+\varepsilon\bullet(700-t)/700\mu s$

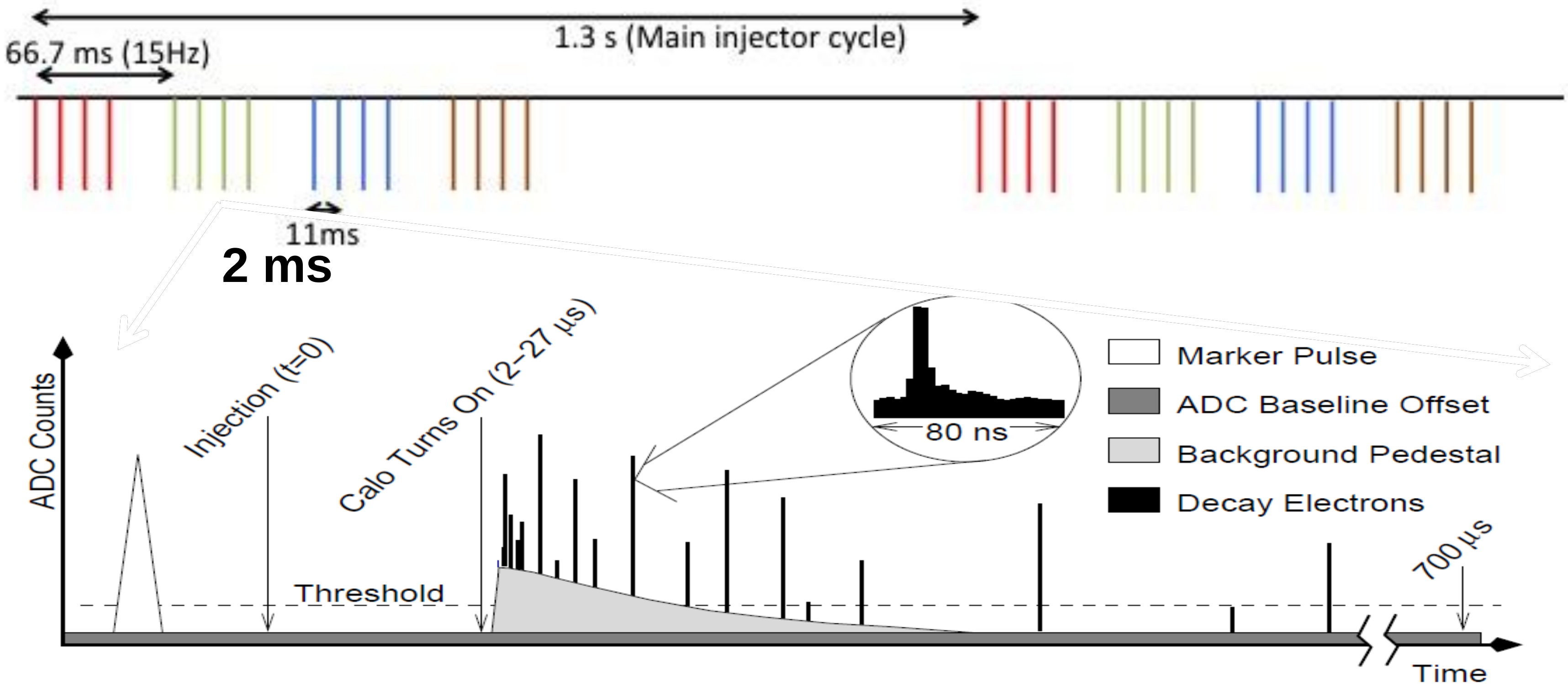
2 $G(t)= 1+\varepsilon\bullet\exp(-t/\tau)$

3 $G(t)=1+\varepsilon\bullet\cos(\omega t + \varphi)$

(Sub)per mill fluctuations are important!



Laser calibration mode: 10kHz within fill

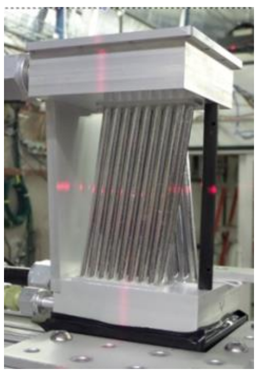


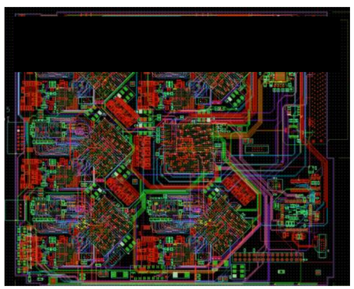
To reach 0.04% statistical uncertainty per point (2000 events/point)

- 7 points per fill (1 every 100 μs, 10 kHz laser repetition rate)
- By moving the offset by 5 μs after a fill → 16 fills to have a single event calibration cycle (i.e. one point every 5 μs), i.e. 1.3 s (1/2 hour to have full calibration cycle (1600 events every 5 μs).

30' calibration runs with ~10 kHz laser frequency → sampling of G(t) in 140 points between 0 and 700μs. Required Stability at 10^{-4} in 1-2 hours

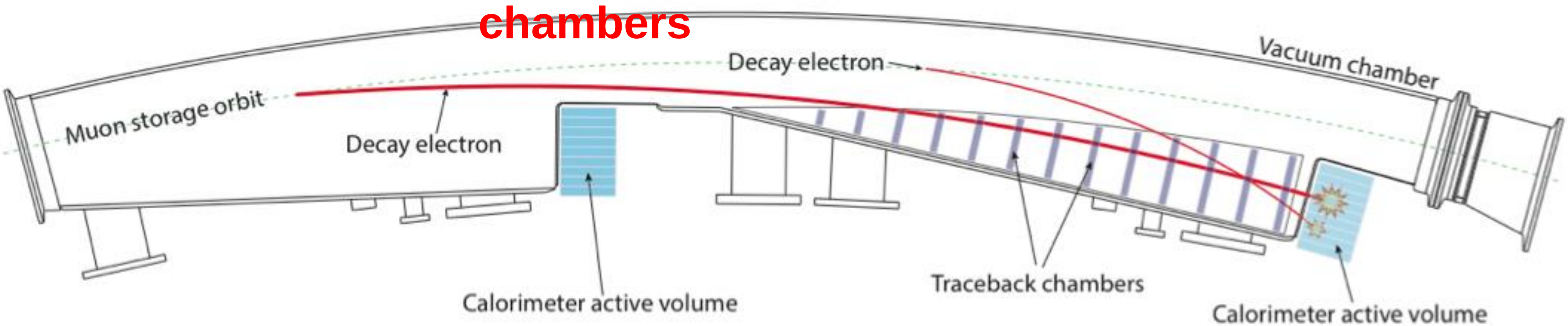
New detector systems





- Calorimeters 24 6x9 PbF2 crystal arrays with SiPM readout, segmentation to reduce pileup
- New electronics and DAQ, 800MHz WFDs and a greatly reduced threshold
- Three 1500 channel straw trackers to precisely monitor properties of stored muon beam via tracking of decay positrons
- New laser calibration system from INFN crucial for untangling gain from other systematics

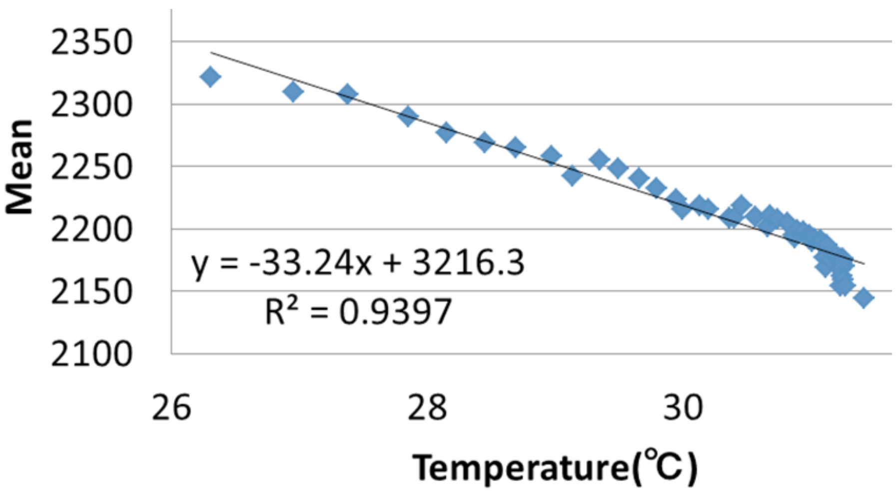
Top view of 1 of 12 vacuum chambers



SiPM Photo Detection Efficiency

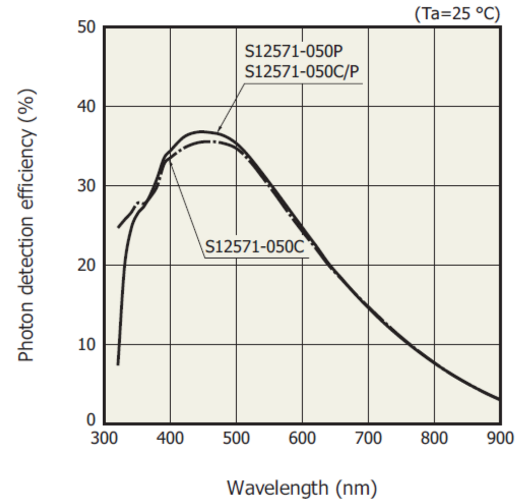
PDE = QE * Fill Factor * Avalanche Probability

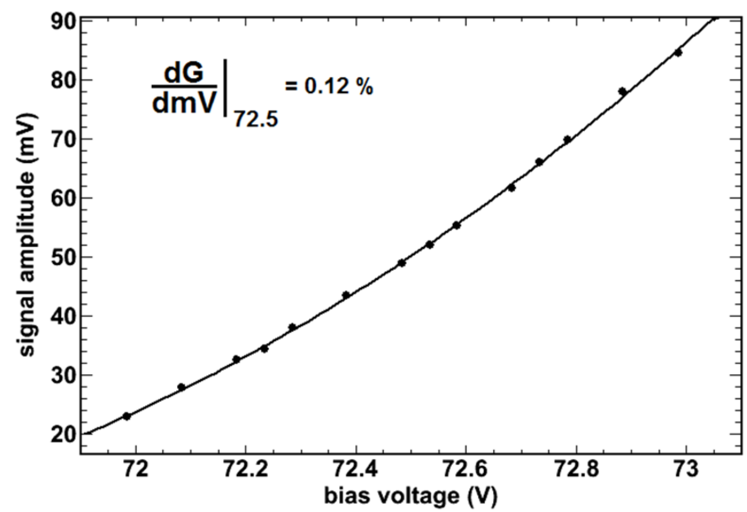
- Small footprint
- Works in high magnetic field
- Cost effective
- Requires temperature and bias stability



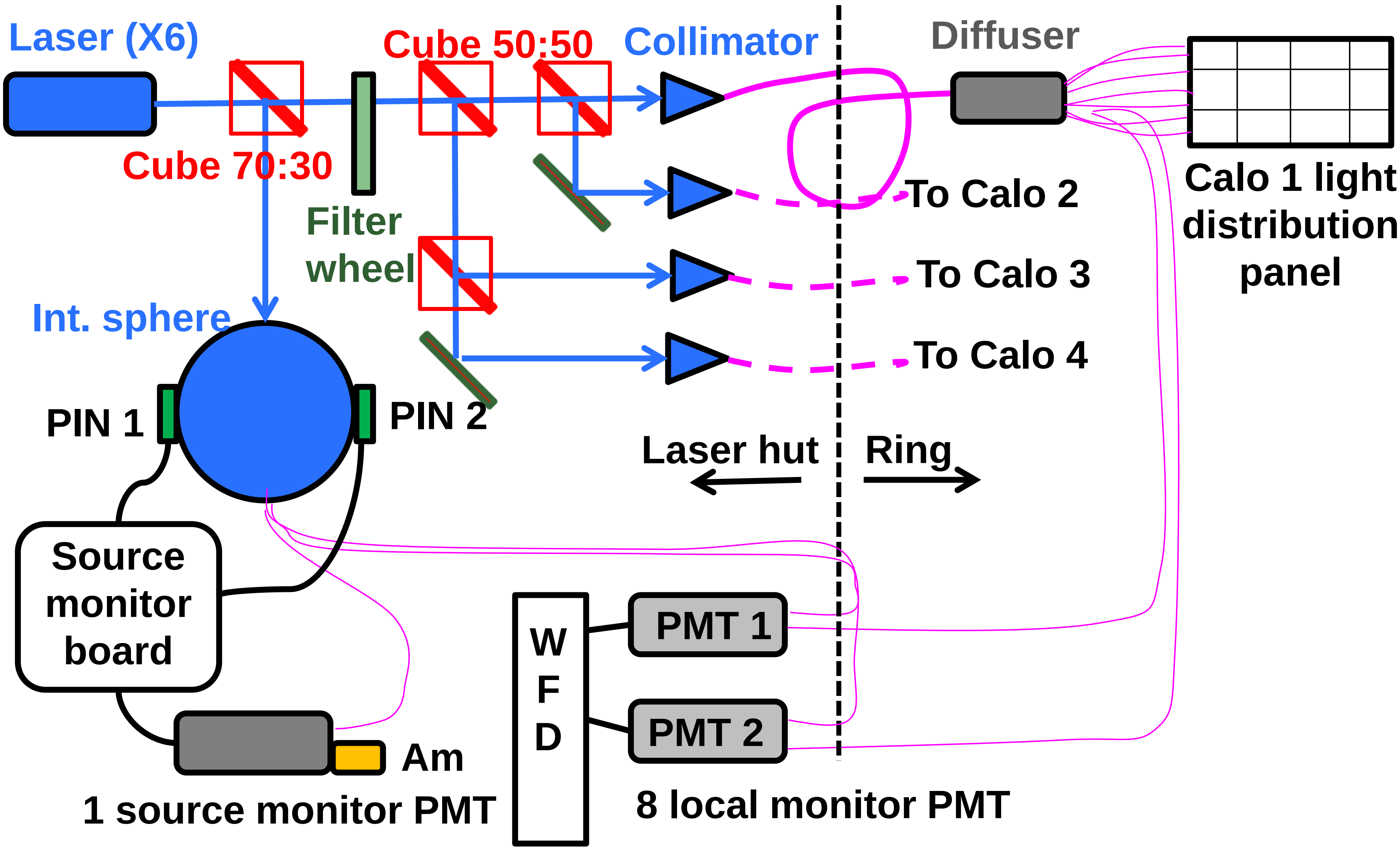
Long term and short term effect

Hamamatsu 50 μm pitch Devices

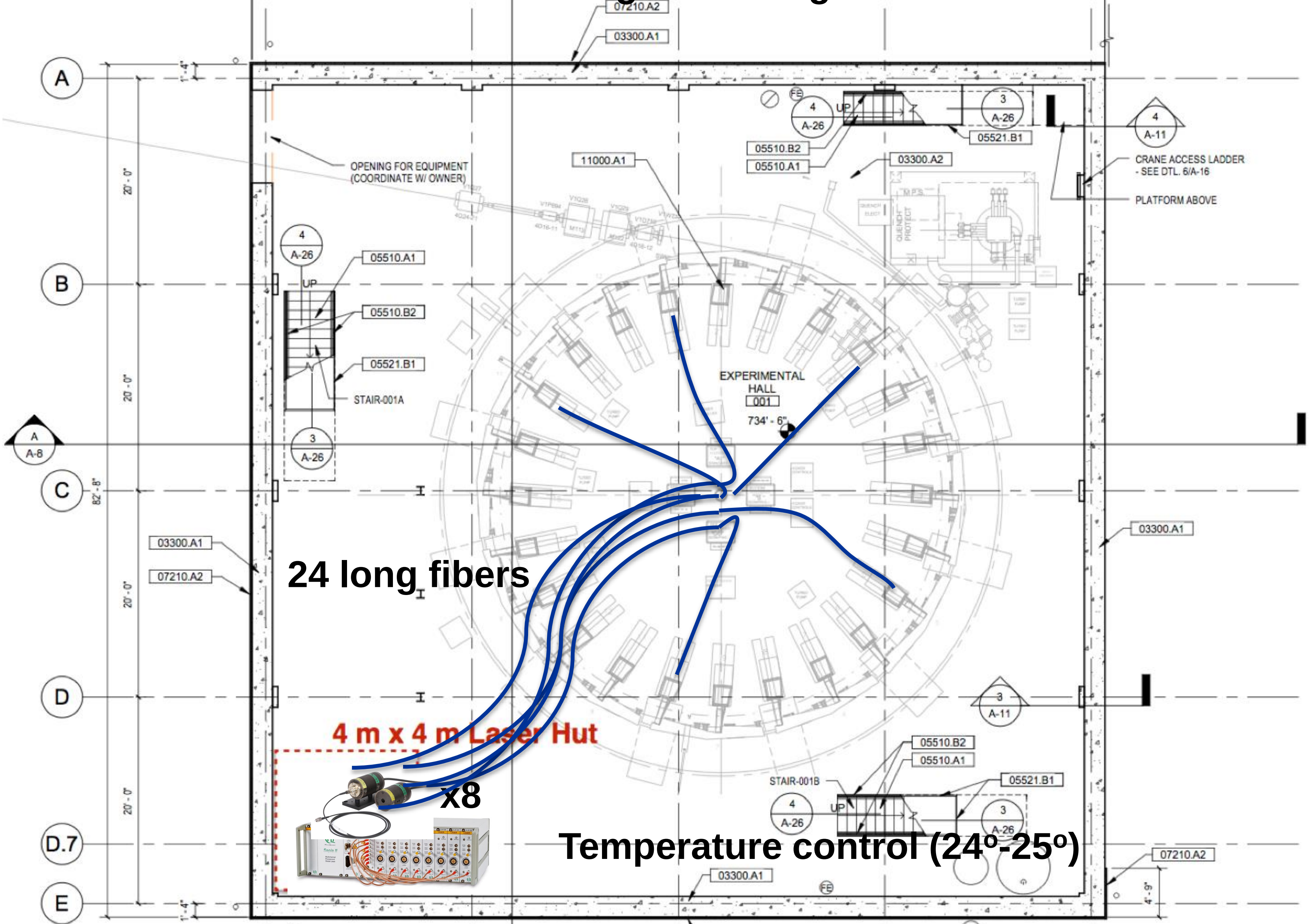




Laser calibration system

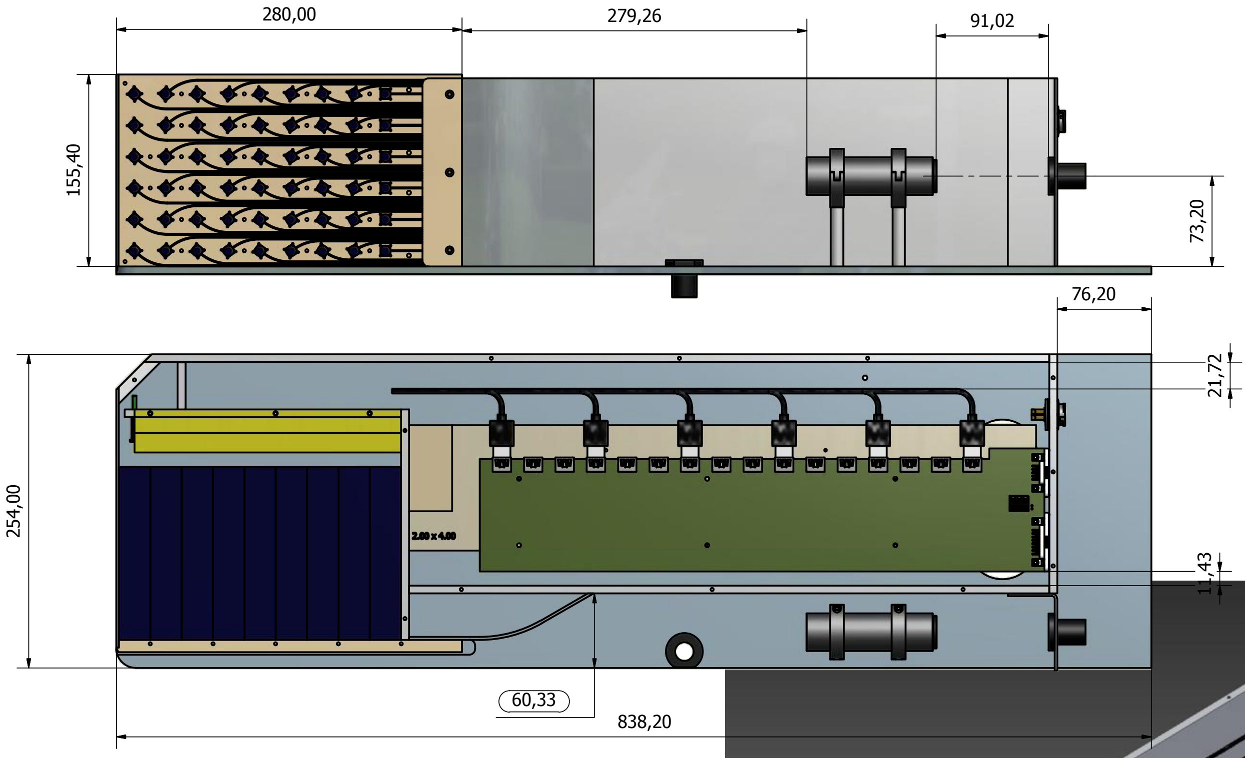


Hall g-2 Building



Optical table

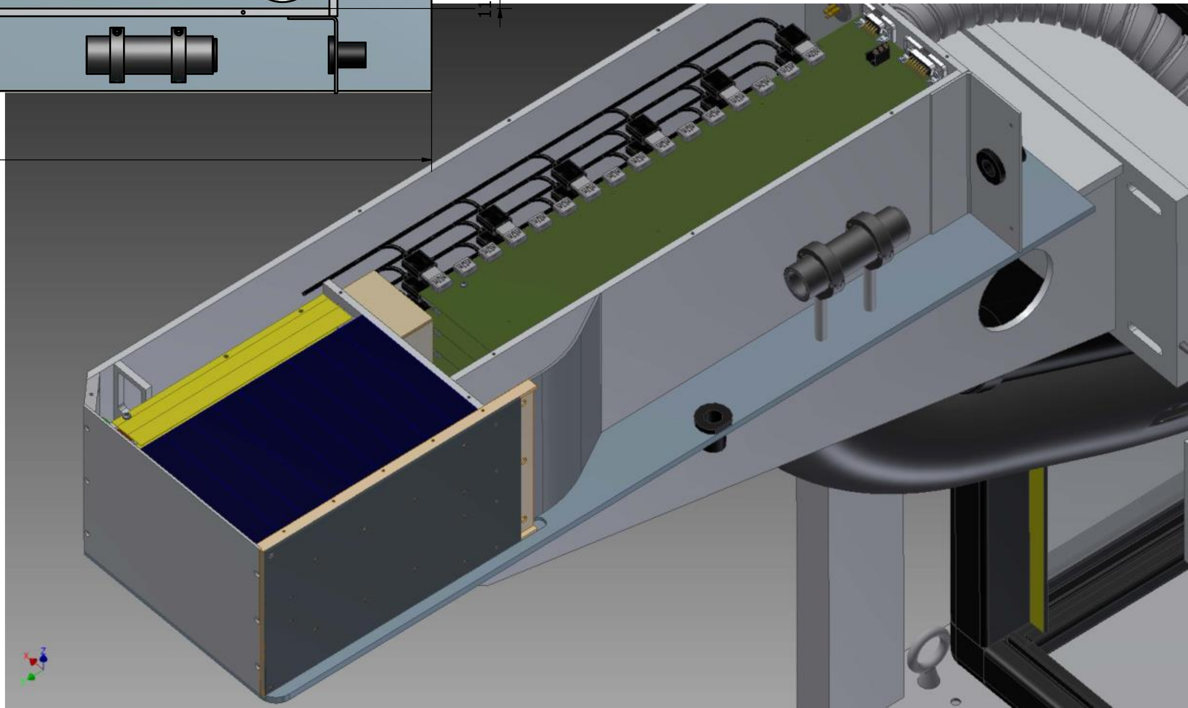
Calorimeter assembly

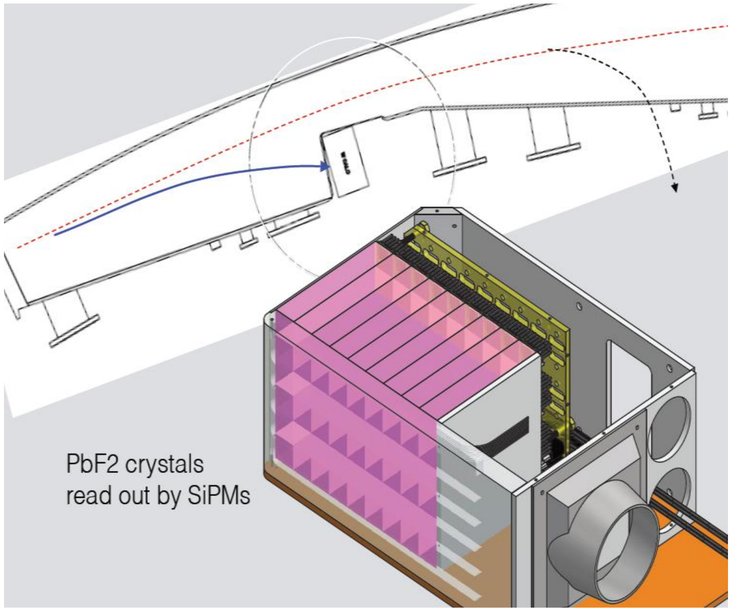


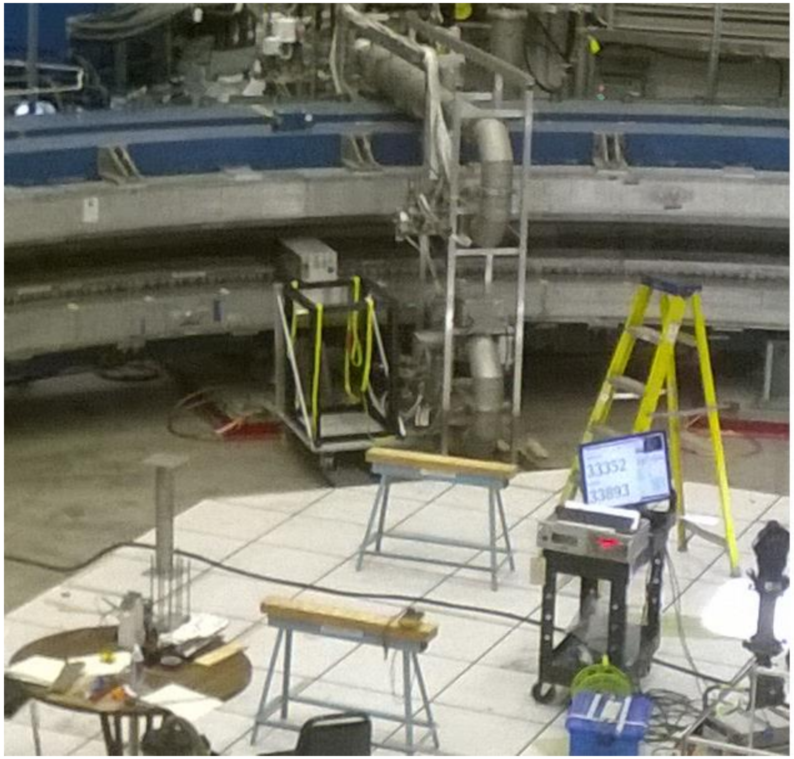
Diffuser +

Fiber bundle +

panel




PbF2 crystals
read out by SiPMs


33352
33893

Diode laser from PicoQuant

LDH-P-C-405M (transversal multimode)

Wavelength: 405 nm ± 10nm

Pulse FWHM: < 600 ps

Average Power (@ 40 MHz): 20 mW

PDL 828 'Sepia II'

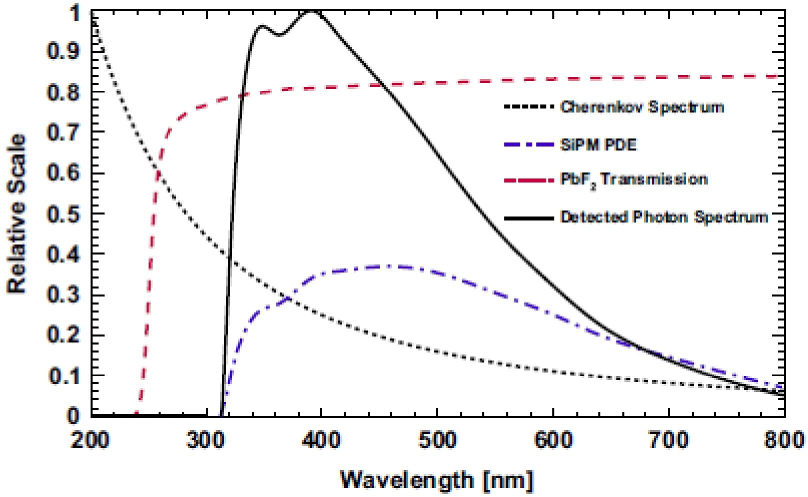
drives up to 8 laser heads

Driven by custom laser board (NA)

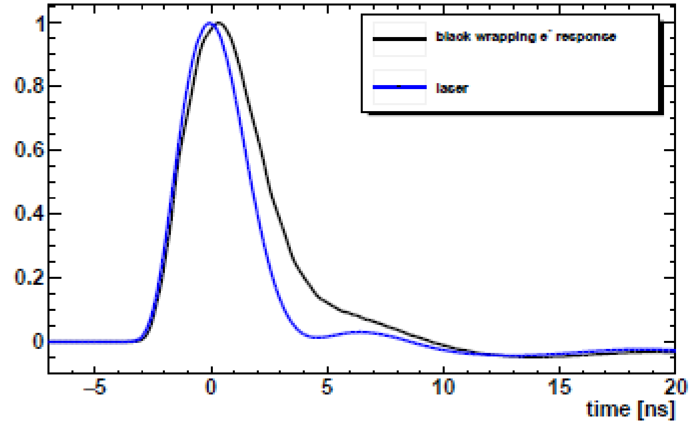
also in flight simulator mode

Laser matches

both spectral region



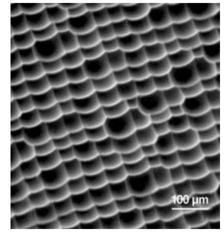
and pulse shape

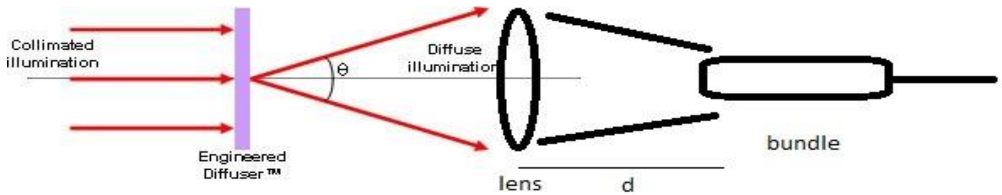


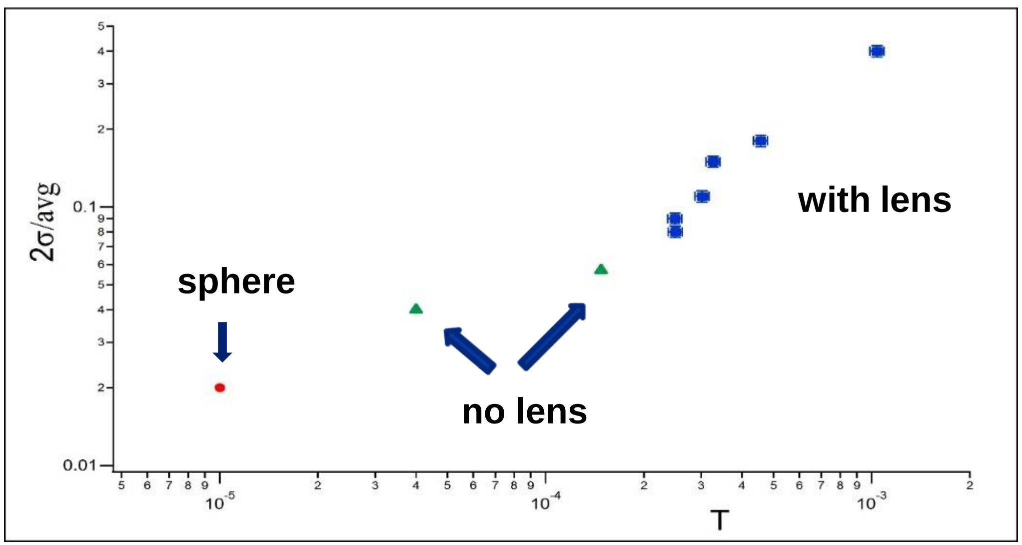
Diffuser

Engineered diffuser ED1-S20

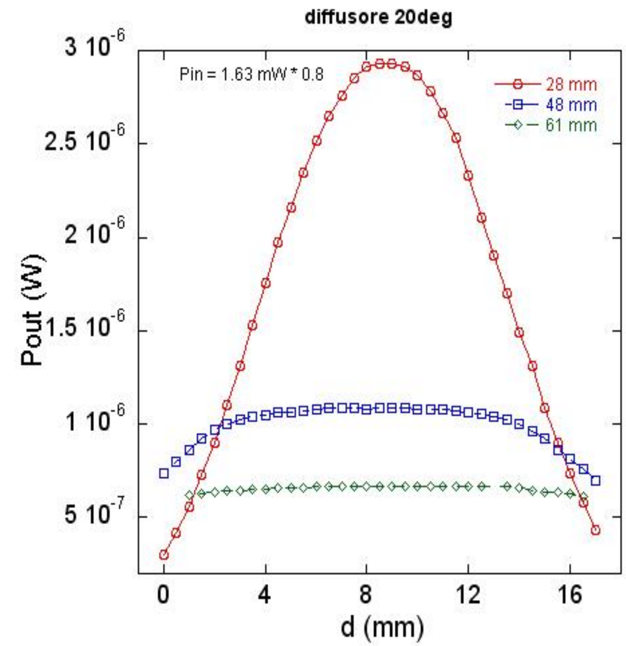
by RPC Photonics – Thorlabs



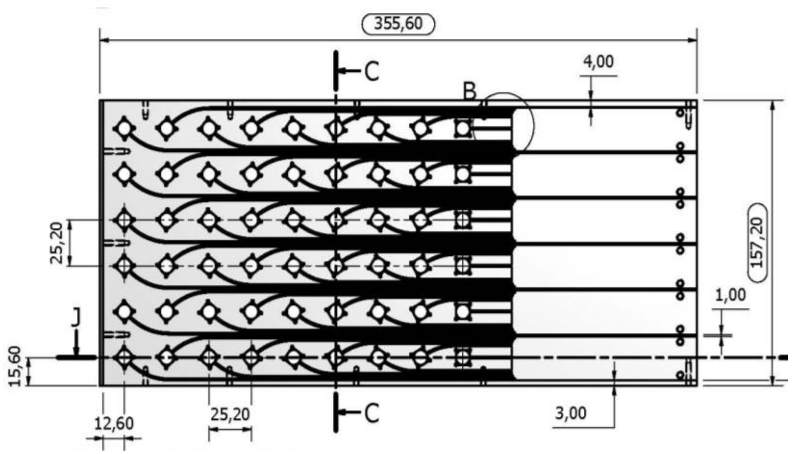


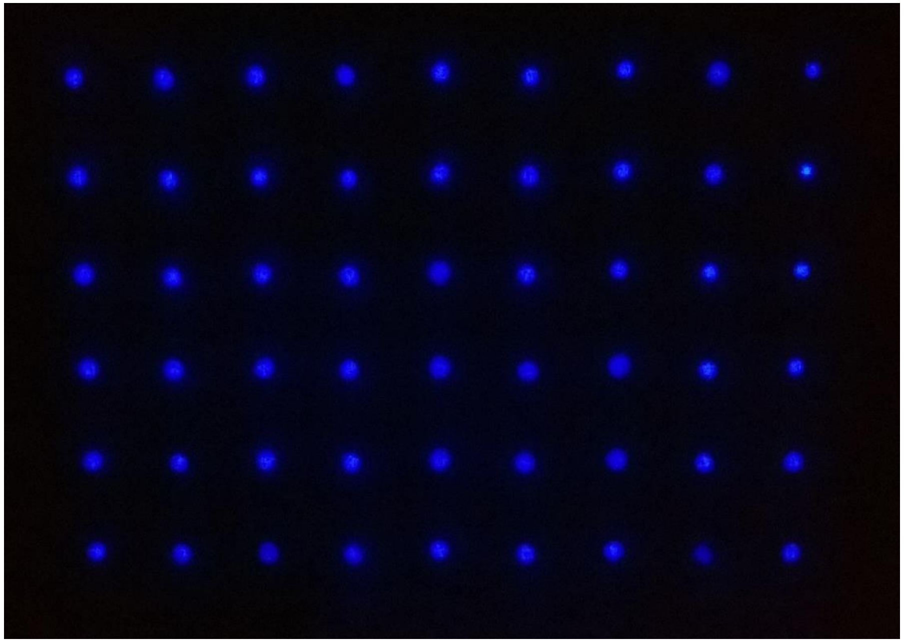


no lens



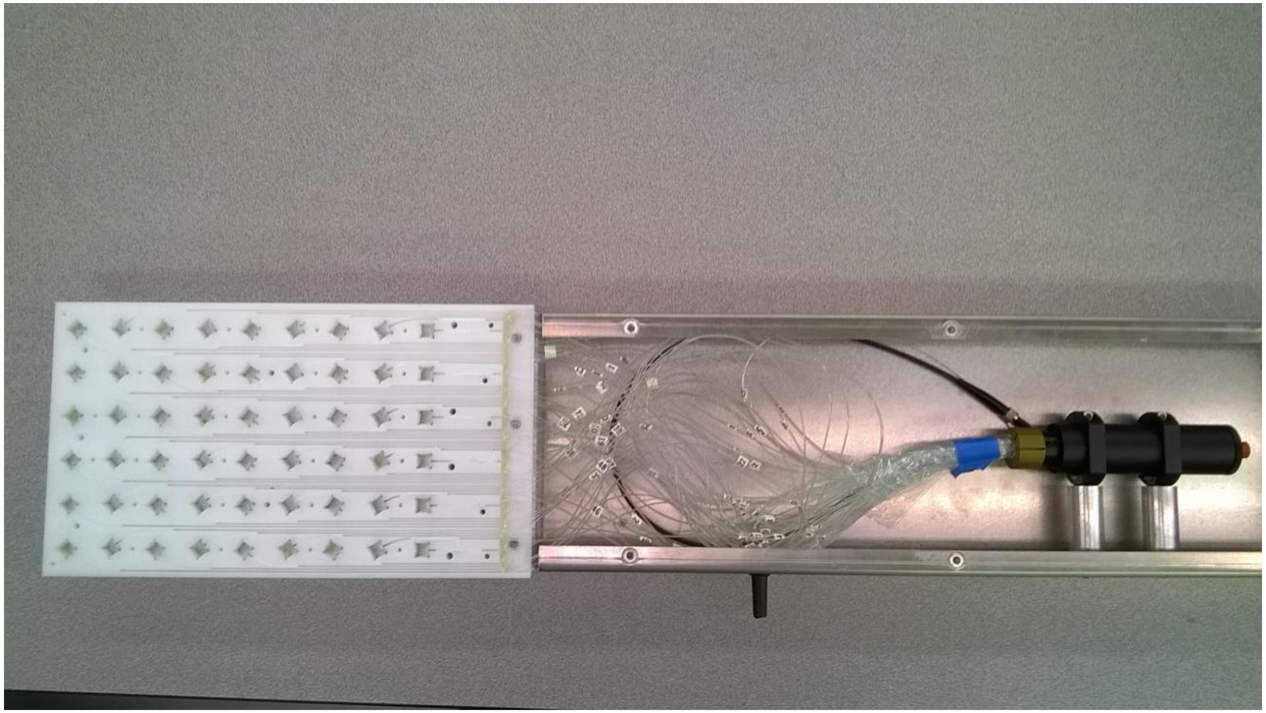
Light from panel





Fnal

last week

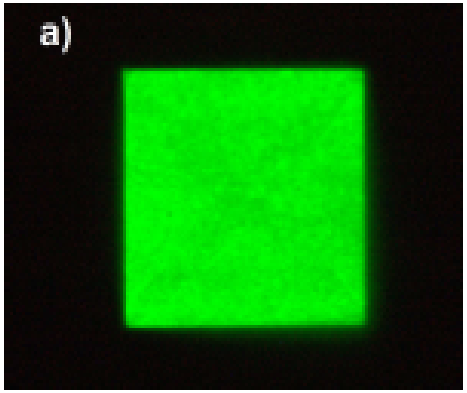


Inhomogeneity

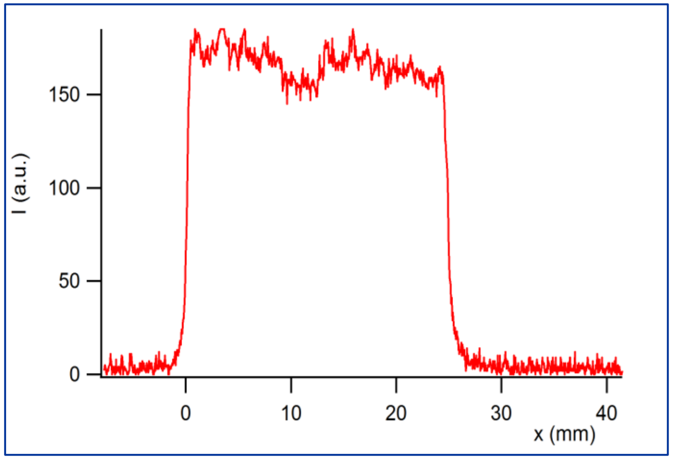
< 20% over all

54 crystals

Light out of crystal



Fiber 1mm PMMA
NA=0.49



Inhomogeneity 3% on 12 mm 1D

Distribution system transmission:
6 lasers/ 24 diffusers

Required value of the output of each crystal: 0.01 pJ/pulse (el. 2 GeV); for each calorimeter: 0.6 pJ/pulse

Not included:

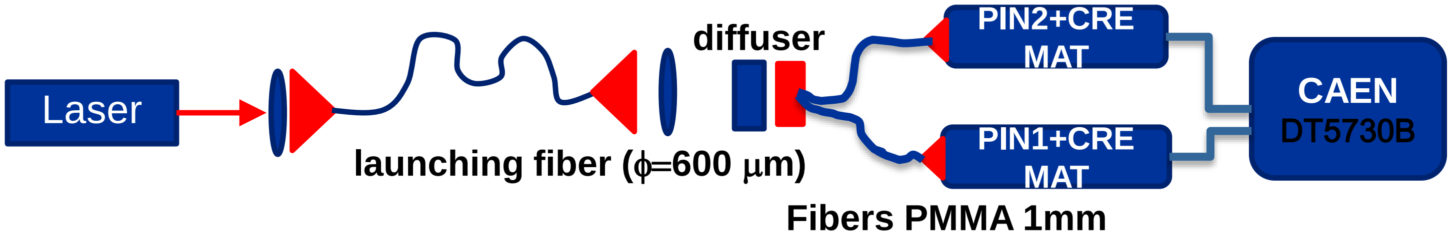
Beam splitting losses (mirrors, b.s.)

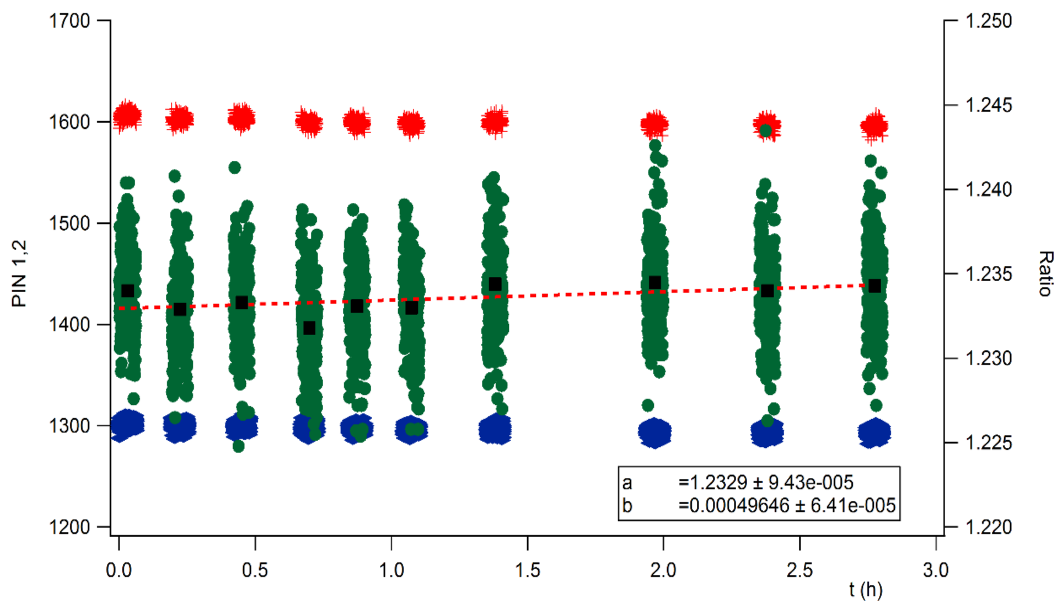
Values confirmed by test beam @ BTF

Calibration up to 10 GeV will be available @ Fnal

Element	Transmission	Energy (pJ)	Notes
Laser Picoquant output		750	100% current intensity
Source monitor sampling	80%	600	150 pJ/pulse for the source monitor (2 PD and 1 PMT)
Filter wheel	100%	600	
Division into four fibers	25%	150	
Fiber coupling + 25 mt quartz fiber	70%	105	
Diffuser with bundle (54 fibers) + 3 local monitors	10%	10.5	It can increased by reducing uniformity
0.6 mt bundle POF (200 dB/km)	90%	9.5	
Prism coupling	65%	6.1	Prism with anti-reflection coating and with metallized reflecting face
PbF_2 crystal reflection + absorption (20%)	65%	4.0	
Total per calorimeter		**4.0**	**Required: 0.6 pJ /pulse /calorimeter**

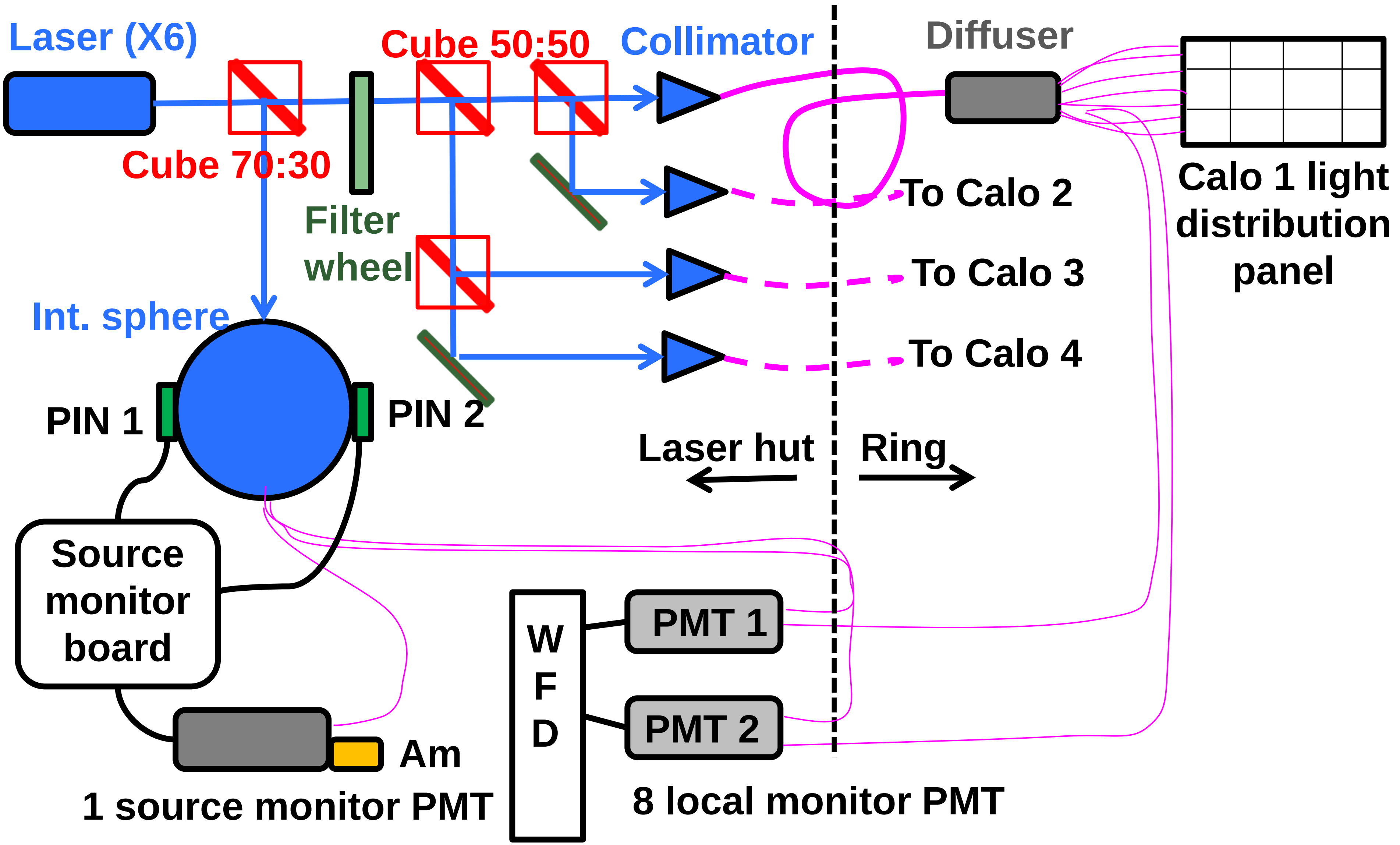
Stability of distribution system (a few pJ/pulse at the PINs)



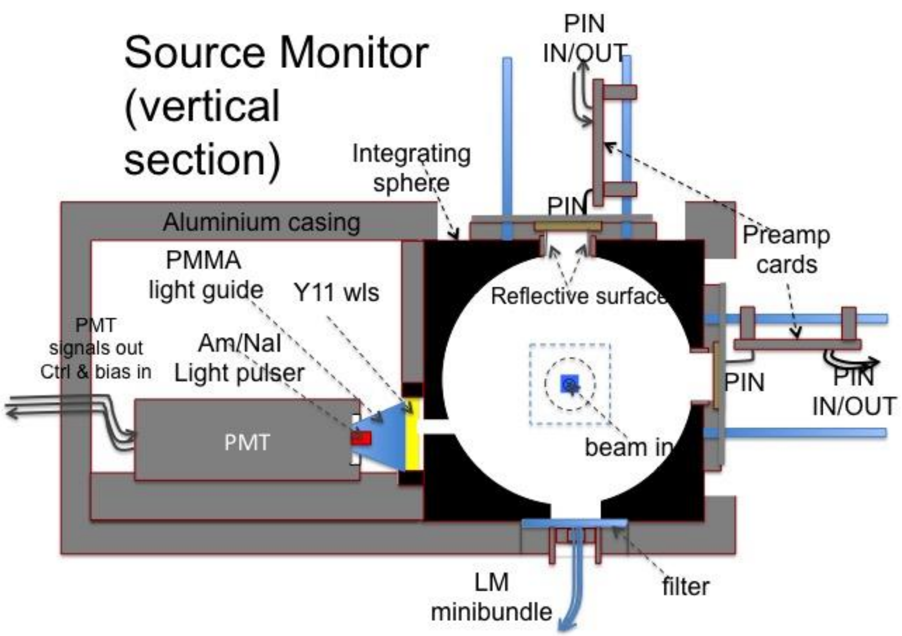


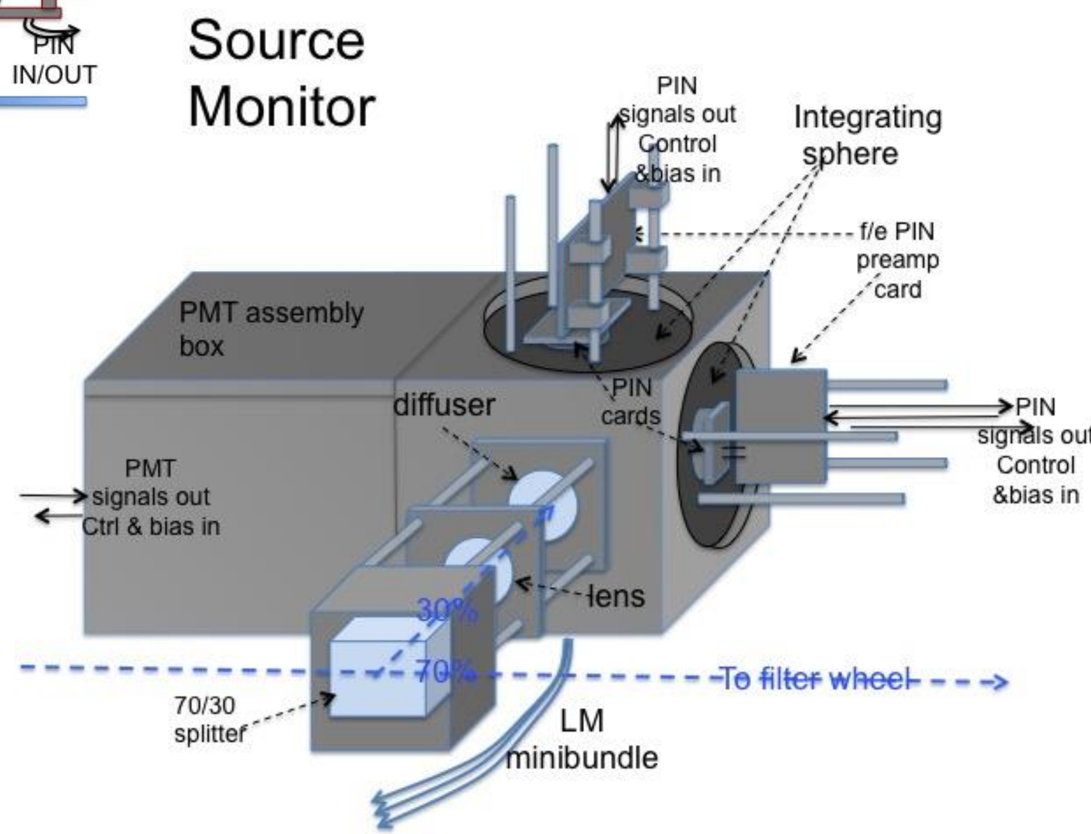
systematics ~ 4 10^{-4}/h

Laser calibration system

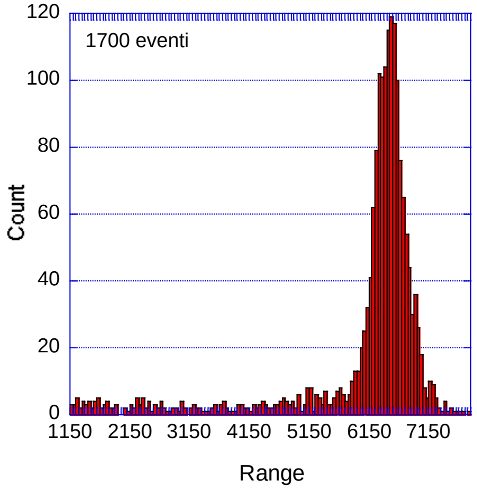


Details of the Source Monitor (UD)



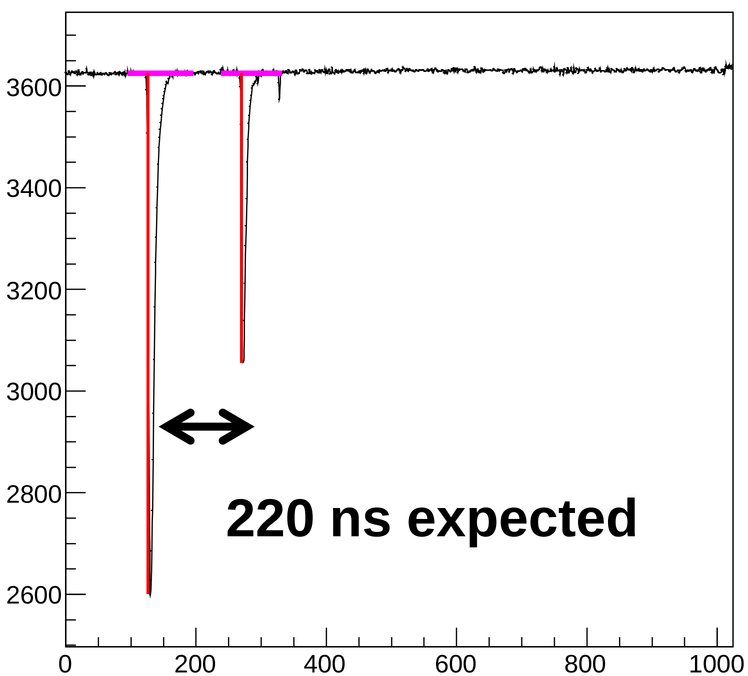


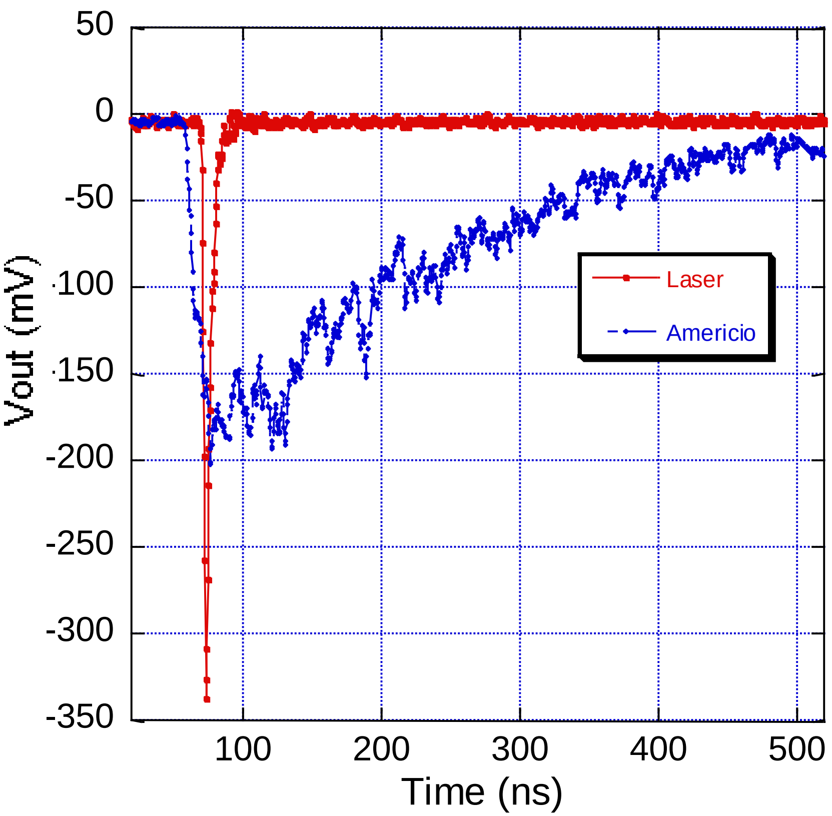
Monitors



The source monitor provides the absolute value of the laser pulse energy.

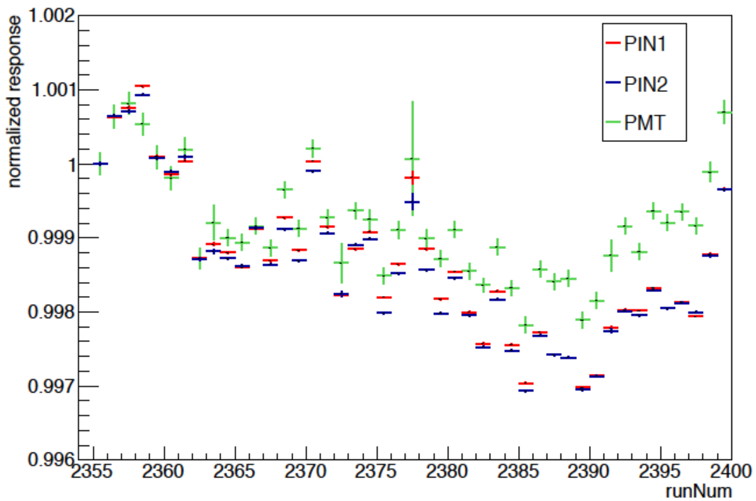
Waveform display ch.6 - Event 3.





The local monitor provides the stability of the distribution system (ratio of the two laser pulses at the PMT). The ratio is independent on the PMT gain fluctuations.

Results from SLAC test beam



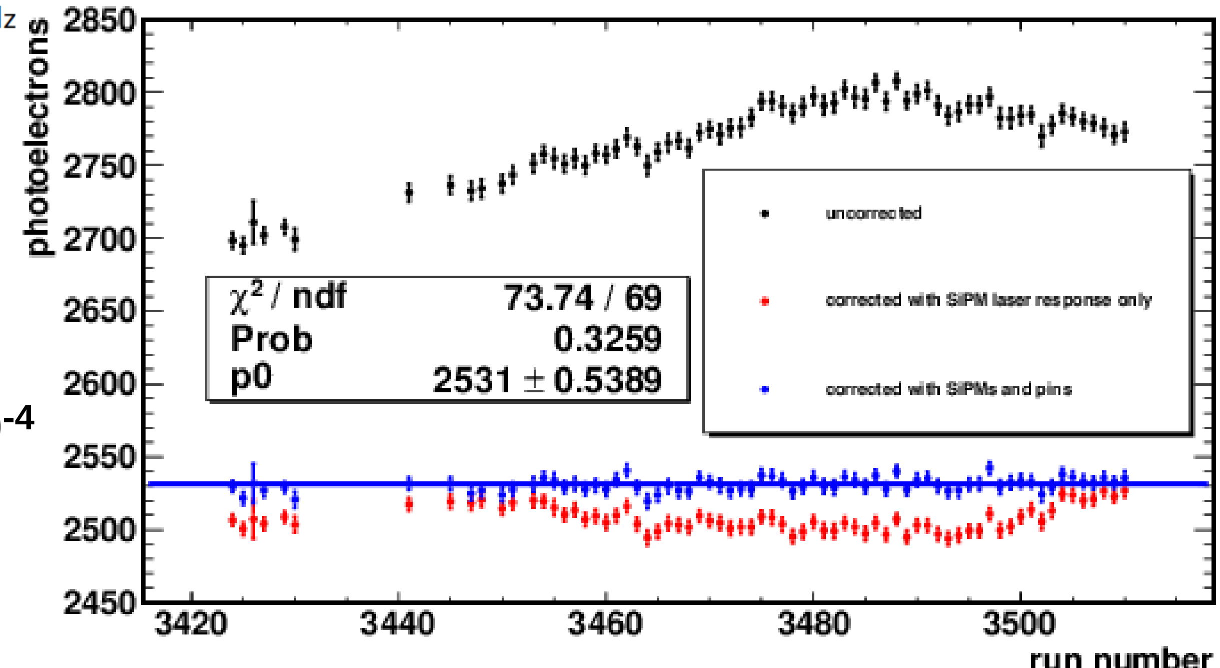
Long term laser stability

Analysis is in progress

- 2.5 hours of data
- Laser fill ~350μs and pulses at 100 kHz
- max. fluctuation ~0.3%

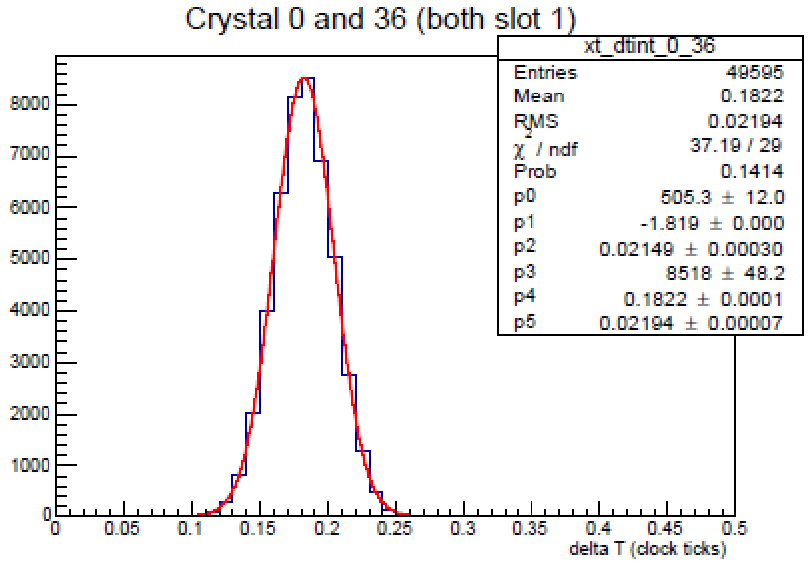
Correction with laser system

Stat error~2x10^{-4}



Results from SLAC test beam

Timing resolution 25 ps



Schedule

	June	July	Aug	Sep	Oct	Nov
Optical comp. in laser hut						
6 lasers / electronic						
Light distribution panels Construction+bundles						
Light distribution panels Prisms+bundles/test						
Calorimeter assembly and test						
Fibers installation						
Fire lasers						

Conclusions

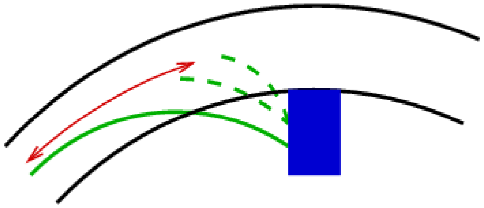
- ❖ **The design is definite**
- ❖ **Lab tests and test beams (@ BTF and SLAC) demonstrated accuracy goals are close by**
- ❖ **Instrumentation (optical and electronics) almost complete**
- ❖ **Construction @ Fnal is underway**
- ❖ **Flight simulator and Pileup studies are forecast**


Thank You!

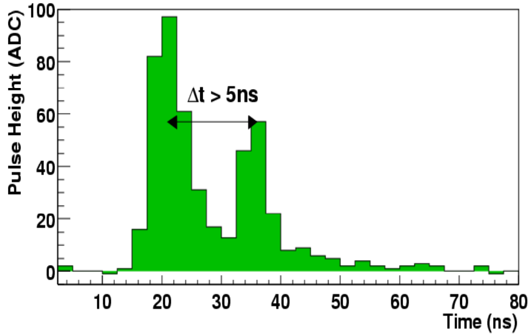
SPARES

Pileup

2 “below-threshold” events conspire to make one “above-threshold” event → with a **different average phase**

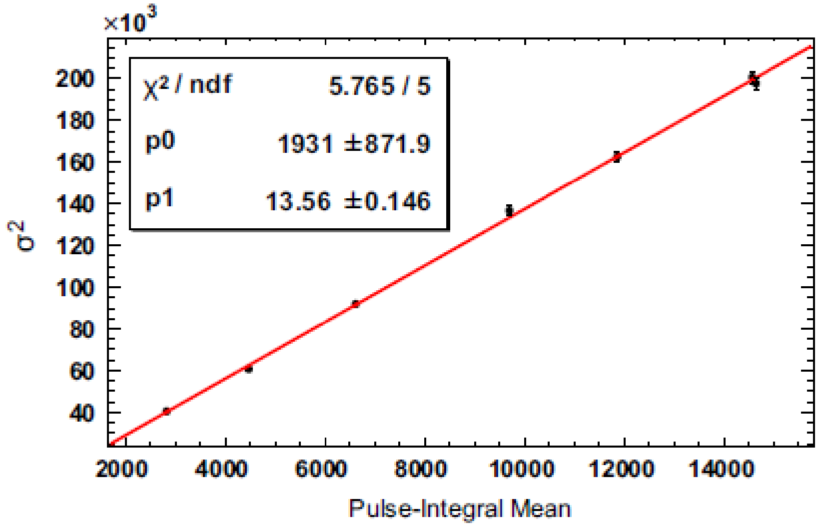


Separate by good timing



$$dN/dt = N_0(t)e^{-\frac{t}{\tau}}\left[1 + A(t)\cos(\omega_a t + \phi_a(t))\right]$$

Calibration method



Laser calibration system