

NPS Calorimeter

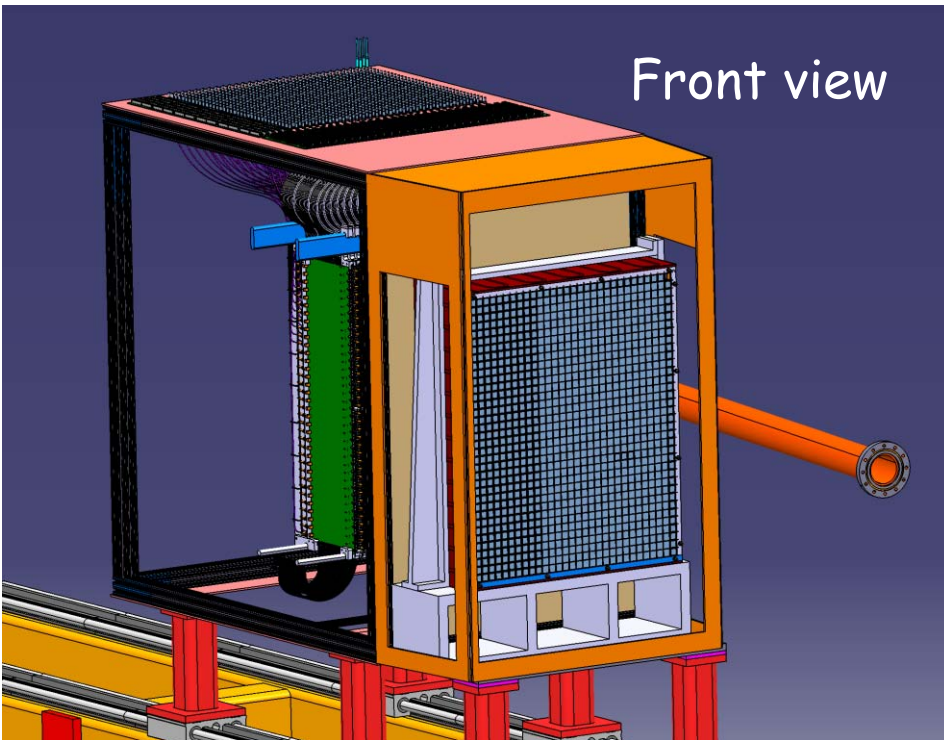
ERR, May 15 (2019)

Carlos Munoz Camacho, IPN-Orsay
for the NPS Collaboration

IPN-Orsay NPS group:

- E. Rindel, T. Nguyen Trung, G. Hull, J. Bettane
- C. Domingues, M. Imre, B. Mathon, L. Seminor, L. Vatrinet, B. Geoffroy
- H. S. Ko, C. Munoz

Overview: conceptual design



- 30x36 (1080) PbWO_4 crystals ($2 \times 2 \times 20 \text{ cm}^3$)
- Hamamatsu R4125 PMTs
- Custom-made active bases

JLAB,
CUA

JLAB, YEREVAN

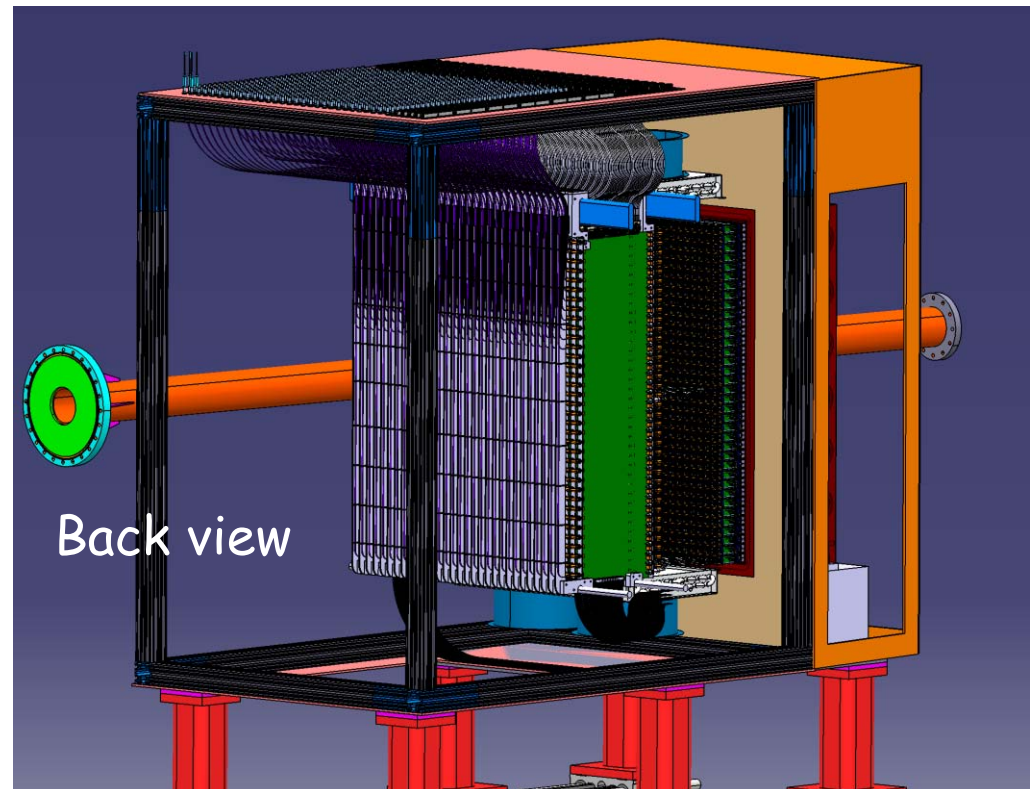
OHIO, YEREVAN

Survey & alignment requirements: $\sim 1\text{mm}$

Calorimeter frame:

ORSAY

- Crystals placed in a 0.5 mm-thick carbon frame to ensure good positioning
- PMTs accessible from the back side to allow maintenance
- Calibration and radiation curing with blue LED light though quartz optical fiber

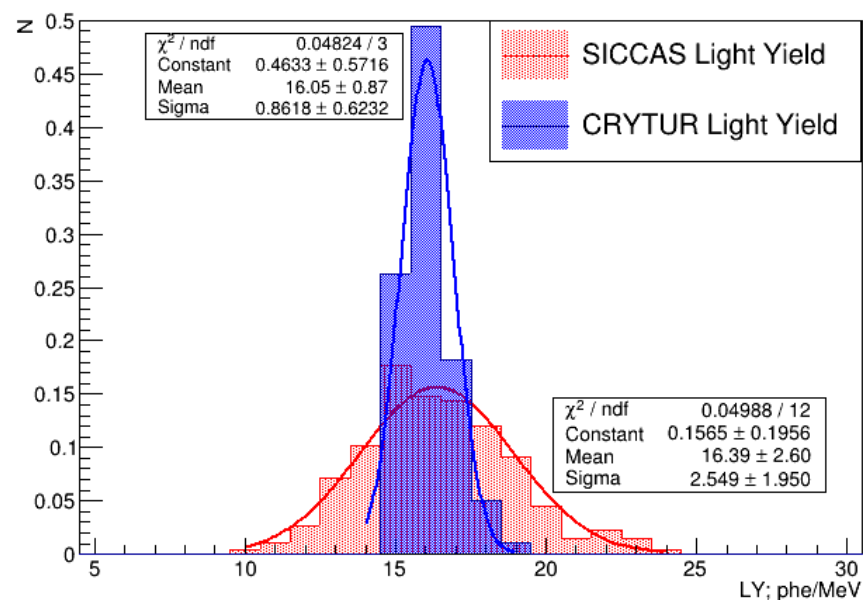
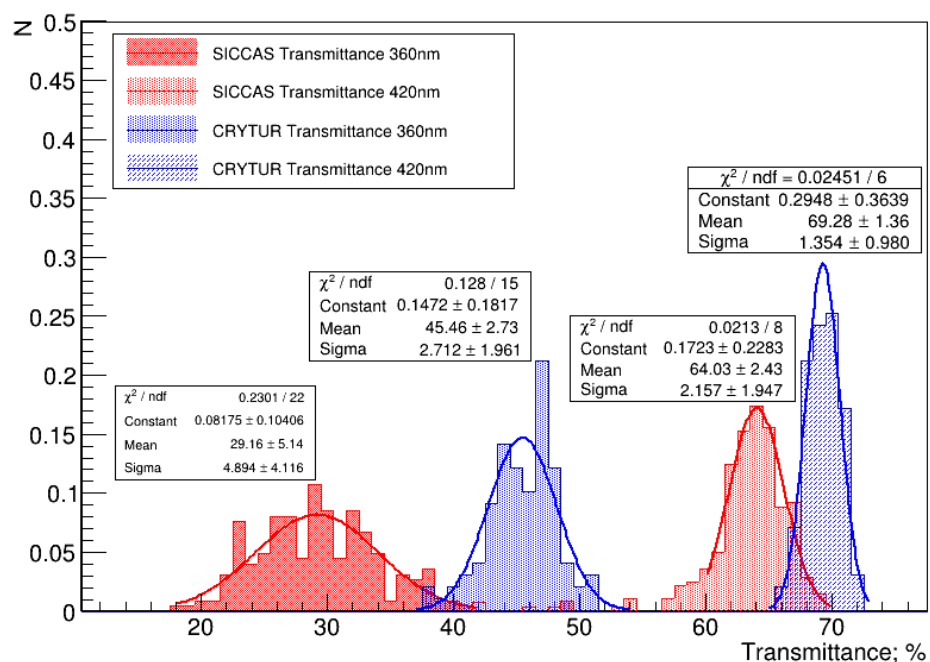


Design 100% completed

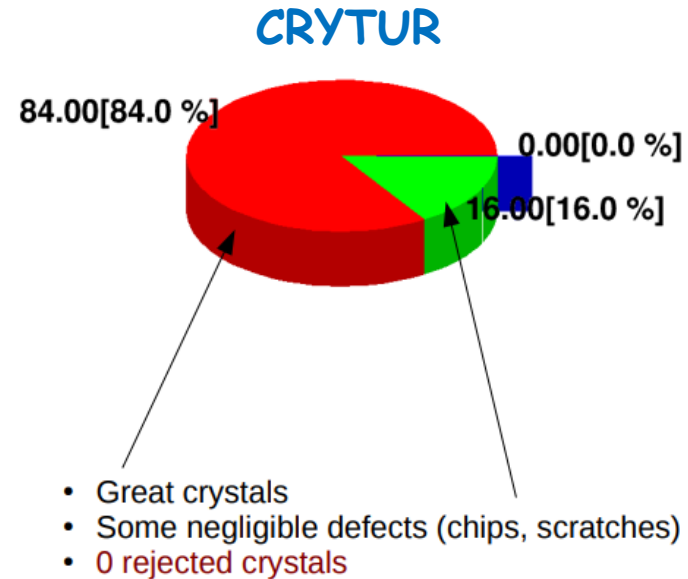
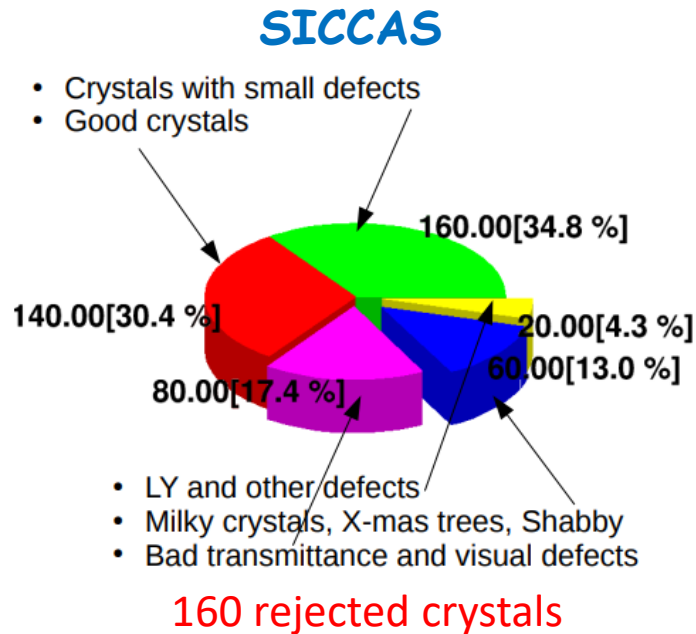
Crystals status

Vendor	Samples	Delivered	Experimental investigation	CRYTUR	SICCAS
SICCAS	460	FY 2017	Visual inspections including 5mW green laser	100%	100%
			Dimension measurements	100%	100%
CRYTUR	100	FY 2018	Transmittance measurements	100%	100%
			Light yield measurements	100%	70%
			Radiation resistance, sample of 10 pieces	to be done	done
			Beam tests (additional)	to be discussed	done; data analysis ongoing
			Chemical and surface analysis few samples (optional)	done	done

Quality analysis:



Crystals status



4

Crystal procurement:

SICCAS:

460 (2017-18) onsite

CRYTUR:

100 (2018) onsite

250 (ordered 2019)

300 (ordered 2019 - replacing an order to SICCAS)

=====

650

All crystals will be onsite by Summer 2020

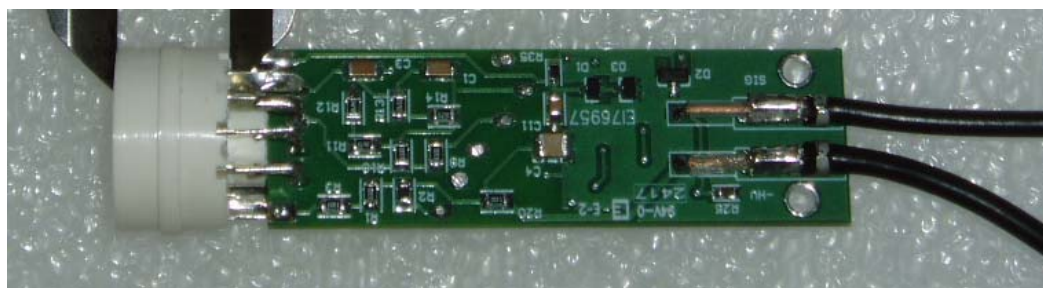
PMT and voltage dividers

➤ PMT (Hamamatsu R4125):

340 onsite, 1000 more ordered (delivery by Summer 2019)

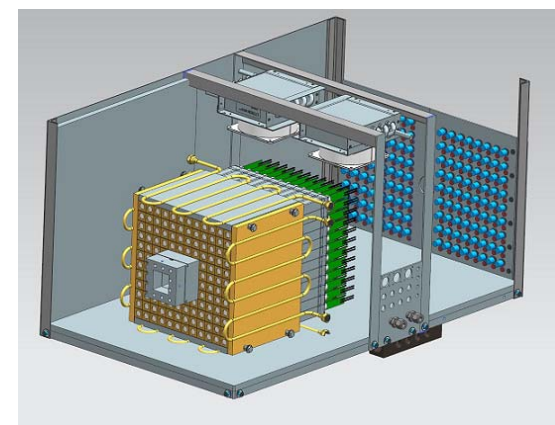
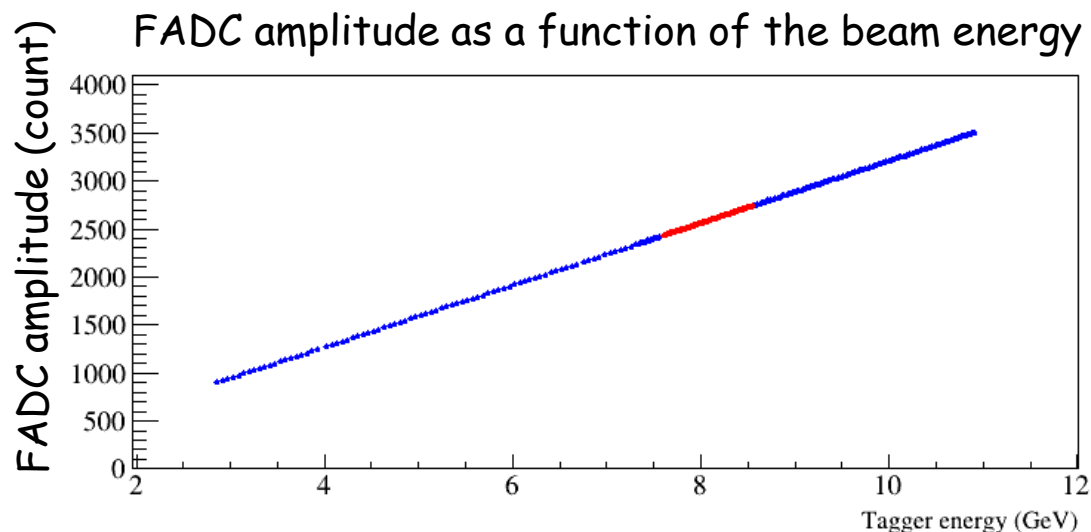
➤ Voltage dividers:

80% of them (865) assembled. Completion expected by Summer 2019



Array of 12x12 PbWO₄ crystals

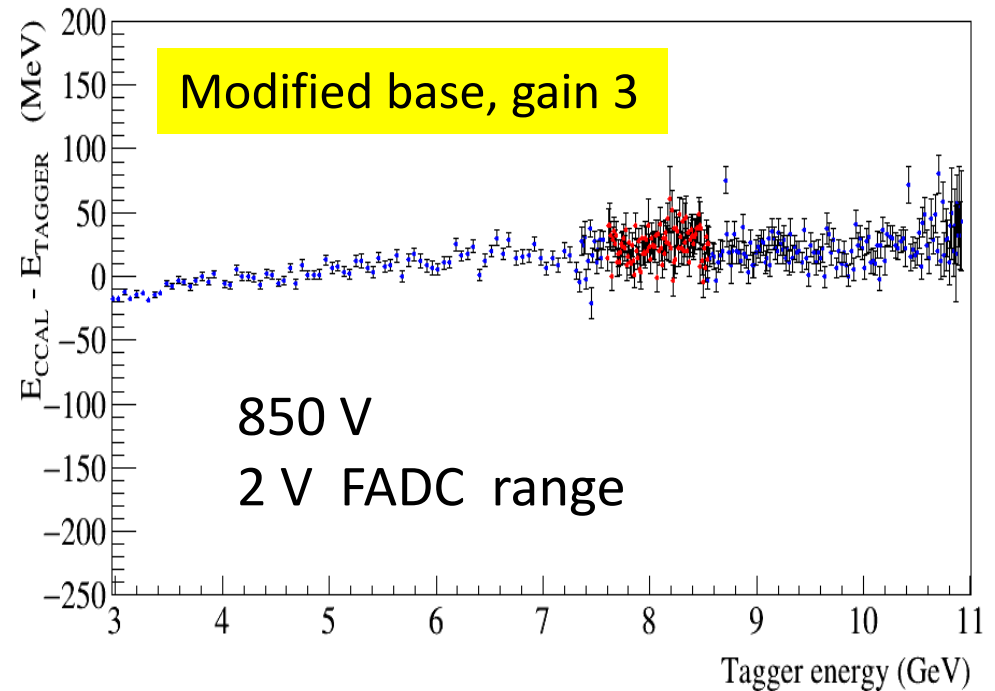
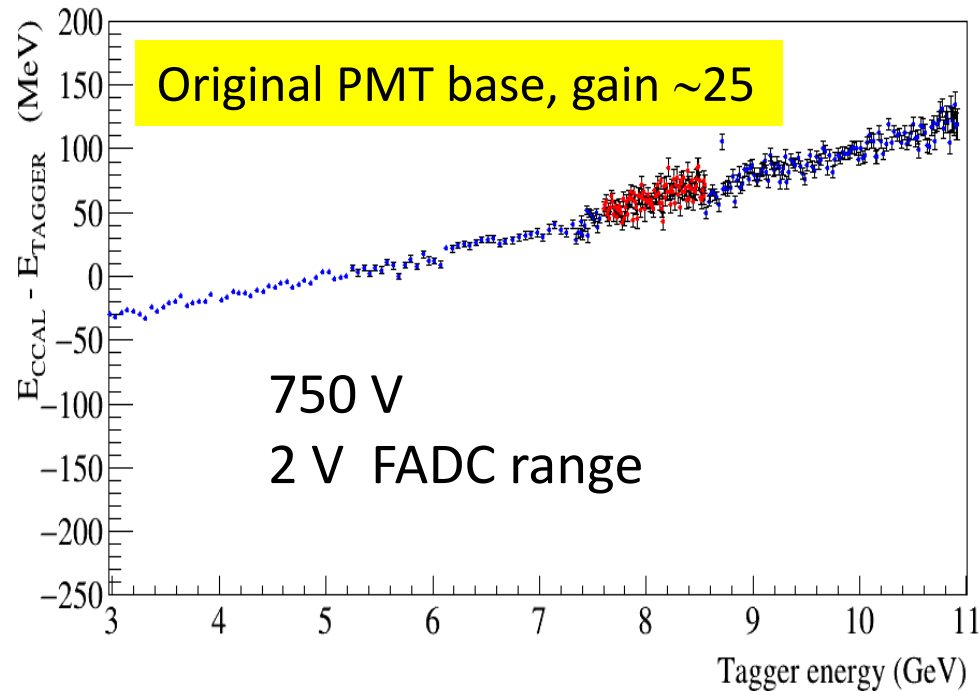
Voltage dividers tested in the Hall D ComCal prototype:



10 GeV :
FADC range:
Typical HV:

3200 FADC channels
2 V (maximum range)
700 - 750 V

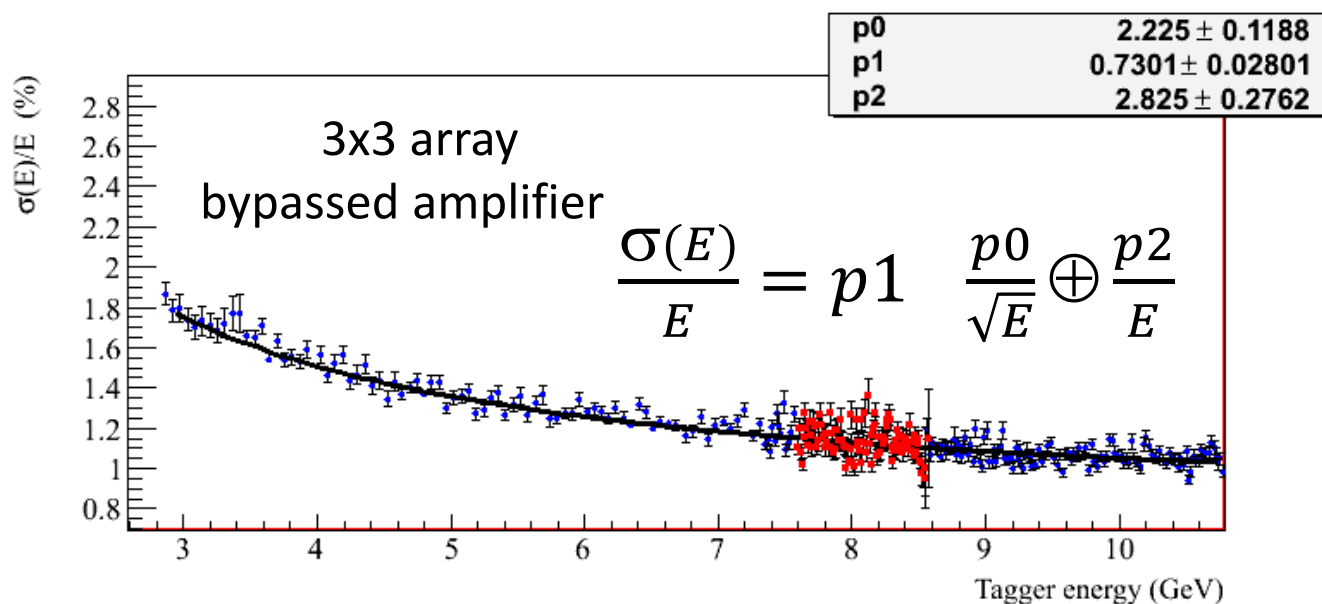
Linearity of the FADC peak amplitude



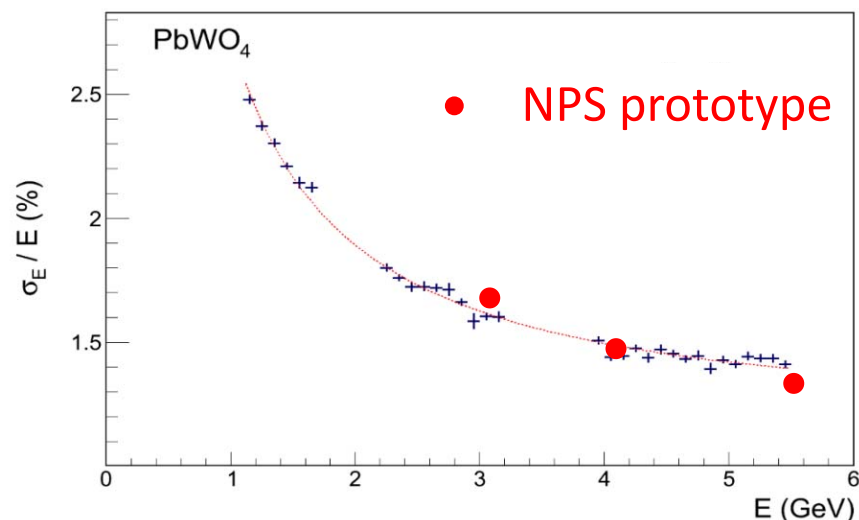
- Some non-linearities on the level of 2 - 3 % were observed for the original PMT base
(PMT was operated at relatively small HV, recommended HV is about 1 kV)
- The linearity can be improved by reducing the amplifier gain and increasing HV:
change of 1 resistor in the base needed
- Anode current will be evaluated and gain adjusted as needed

Energy resolution of prototype

NPS Prototype

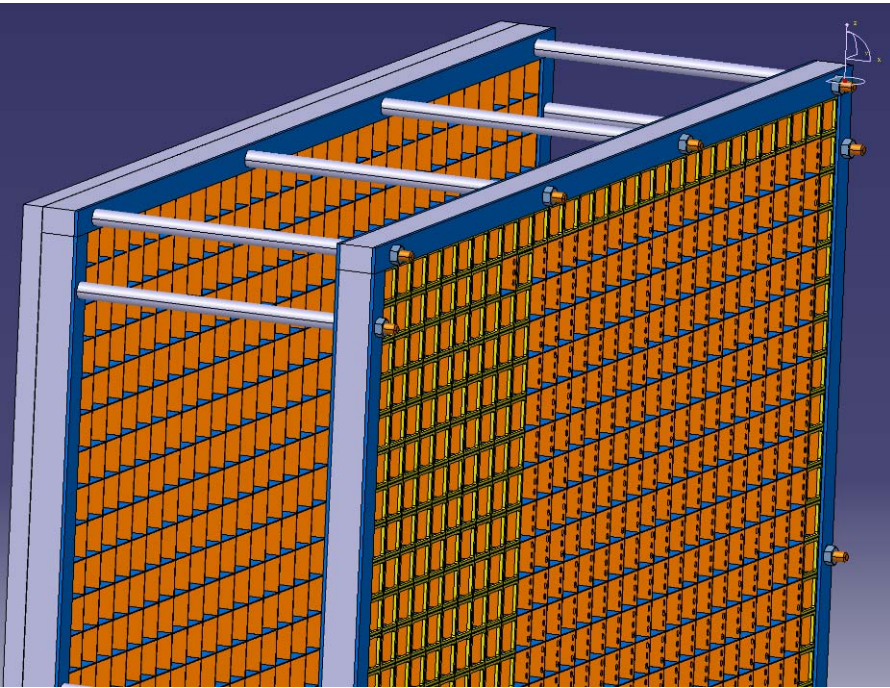


HyCal

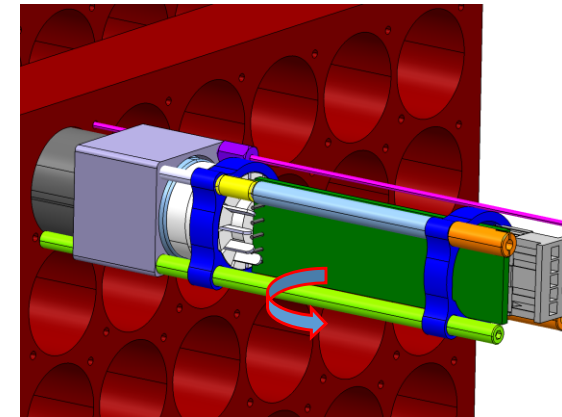
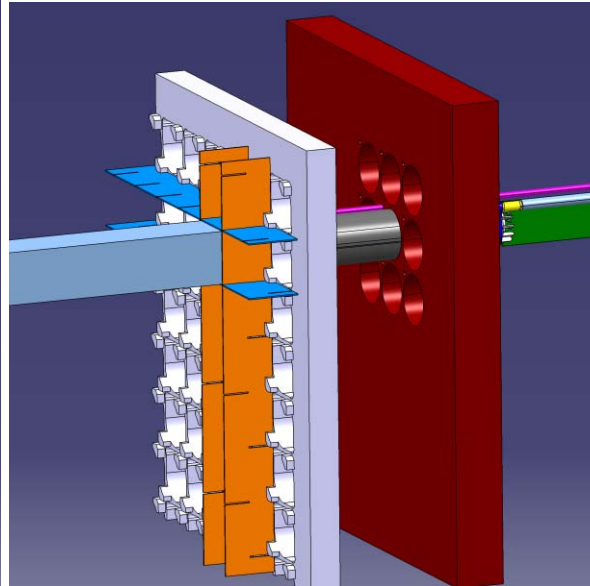


- Relatively good energy resolution.
- Consistent with Hall B HyCal, constructed with SICCAS crystals

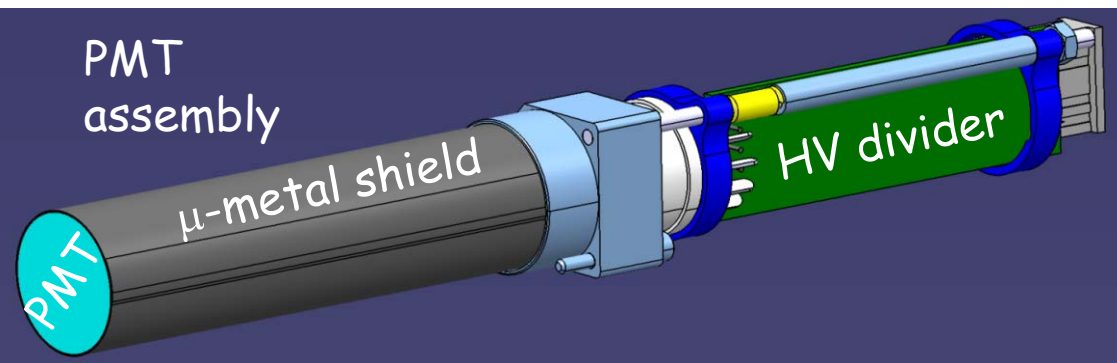
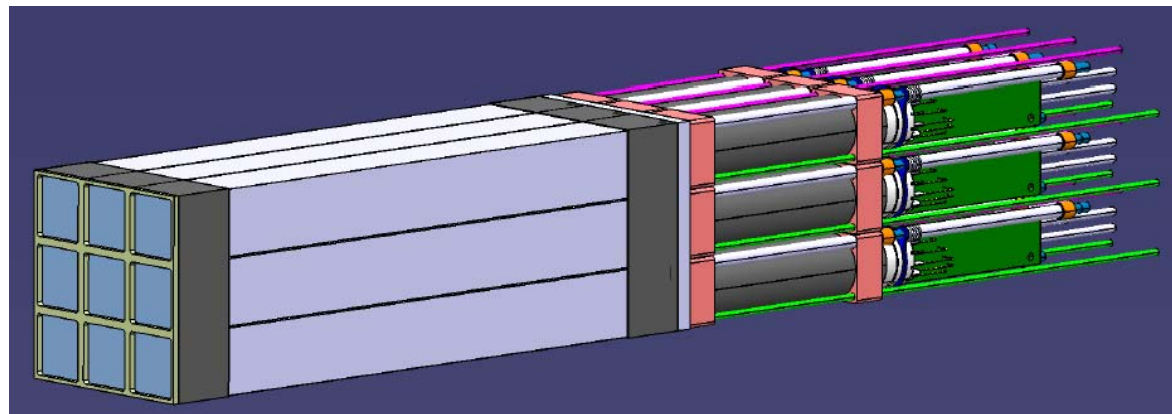
Calorimeter carbon frame



2-cm of C (0.5 mm thick) at the front and back of the crystals



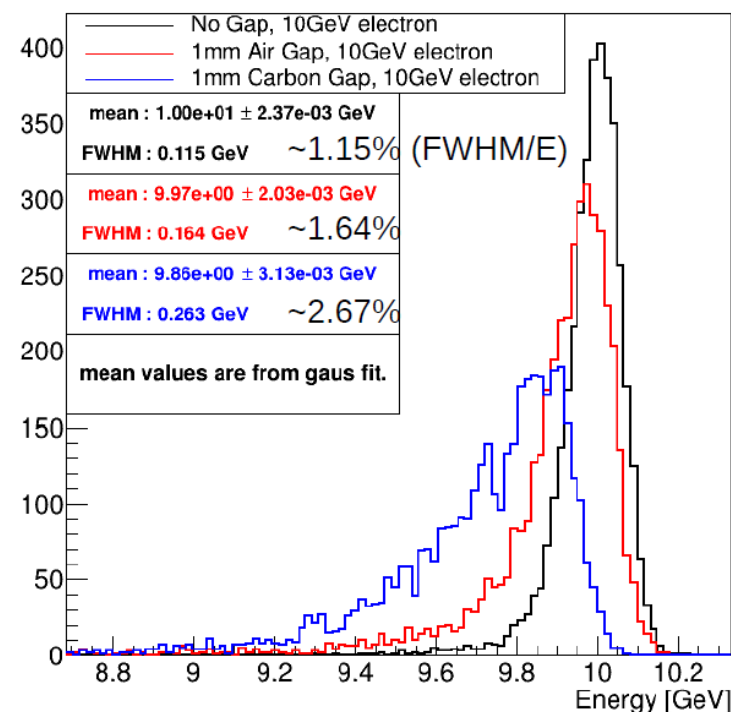
Easy disassembly of PMT block with one long single captive screw



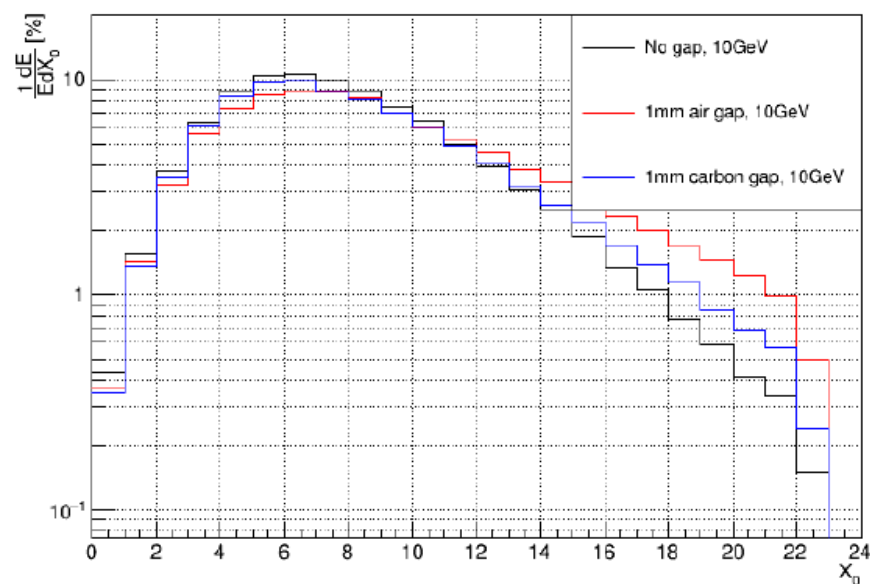
Carbon frame: impact on energy resolution & efficiency

- 1.2% (ideal case) to 1.6% at 10 GeV with 1mm of air between crystals
- More than 97% of energy collected after 22 X_0

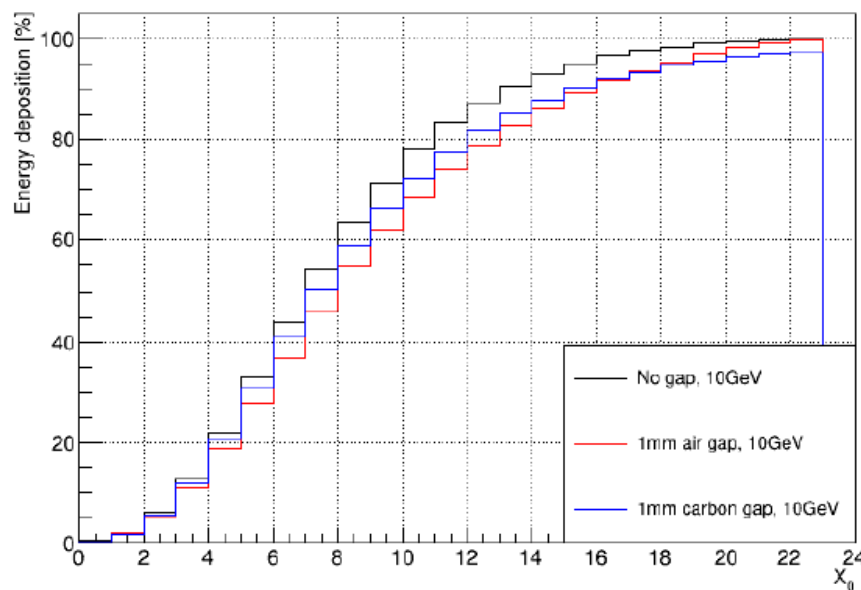
Energy resolution in PbWO₄ calorimeter



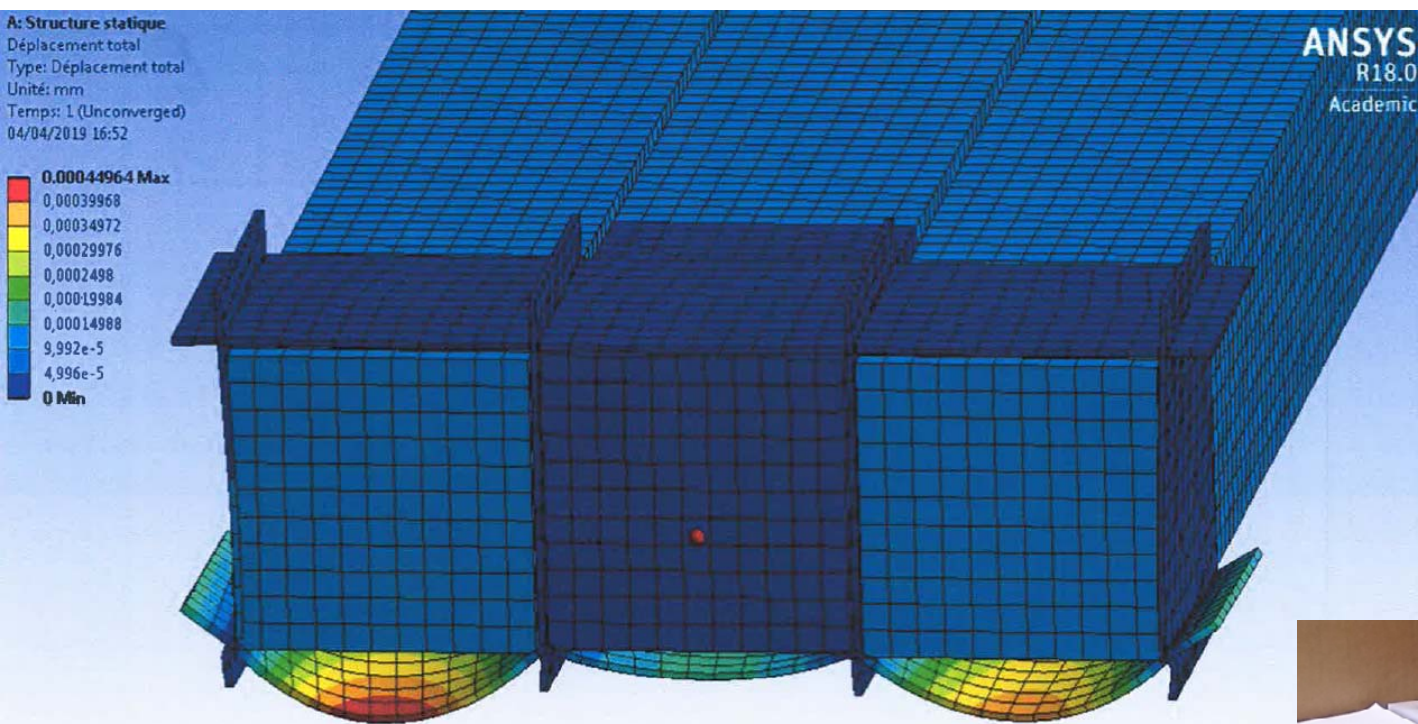
Longitudinal energy deposition in PbWO₄ calorimeter



Cumulated energy deposition in PbWO₄ Calorimeter



Carbon frame: mechanical simulations and tests



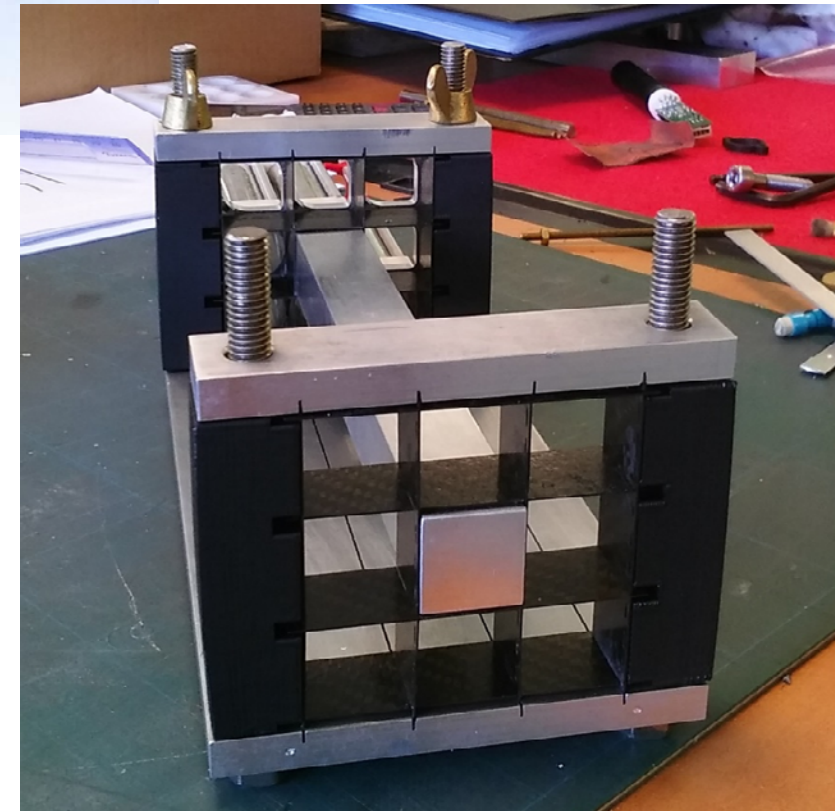
Very resistant structure

Simulations:

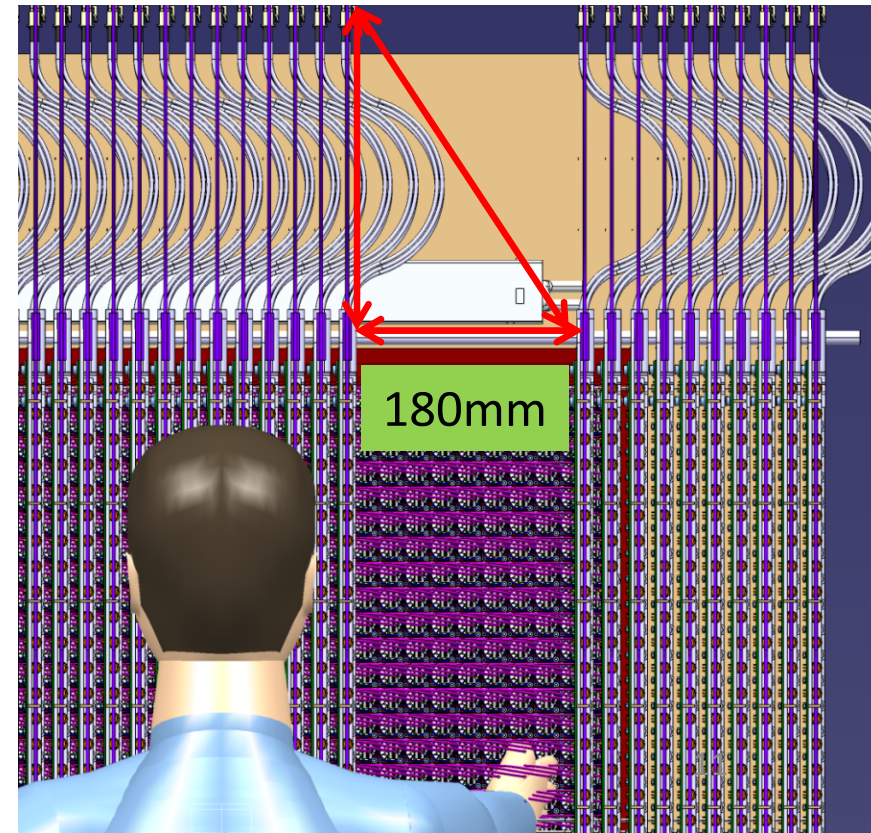
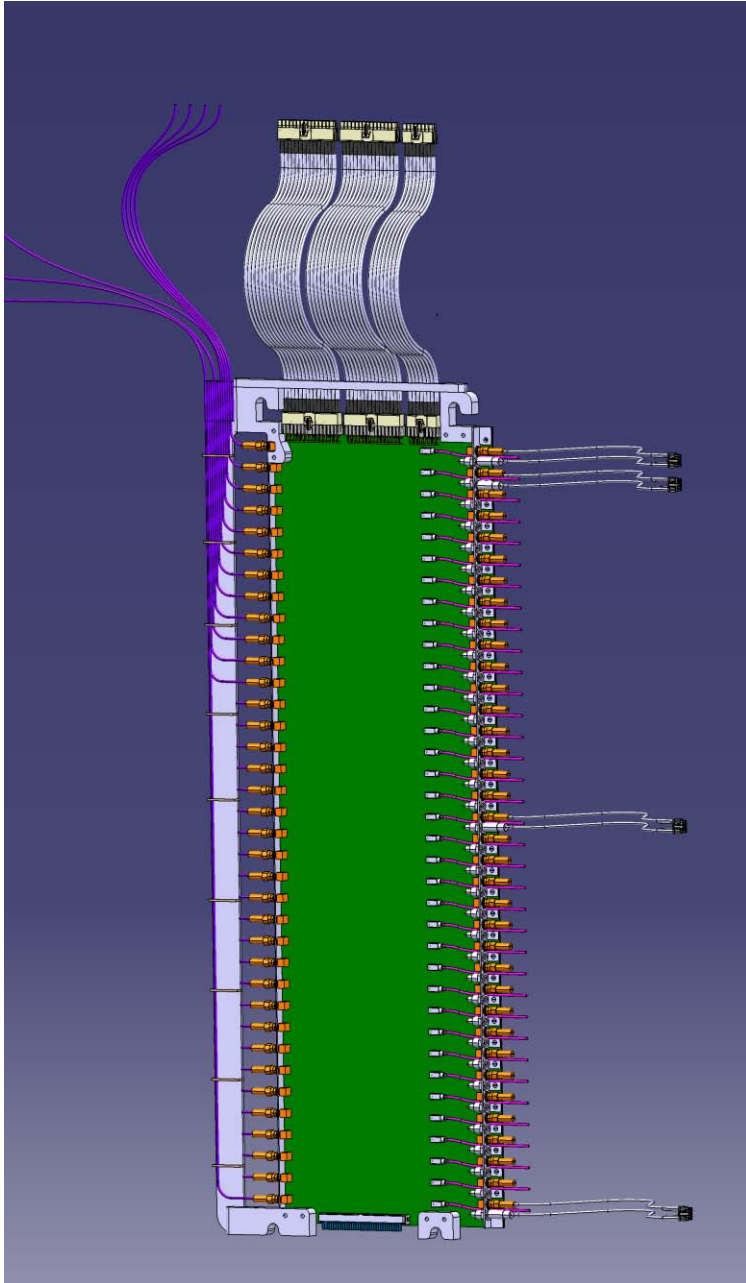
Effect of 1 crystal in each cell

- Less than $0.2 \mu\text{m}$ deformation at the center
- $0.4 \mu\text{m}$ deformation on external layer

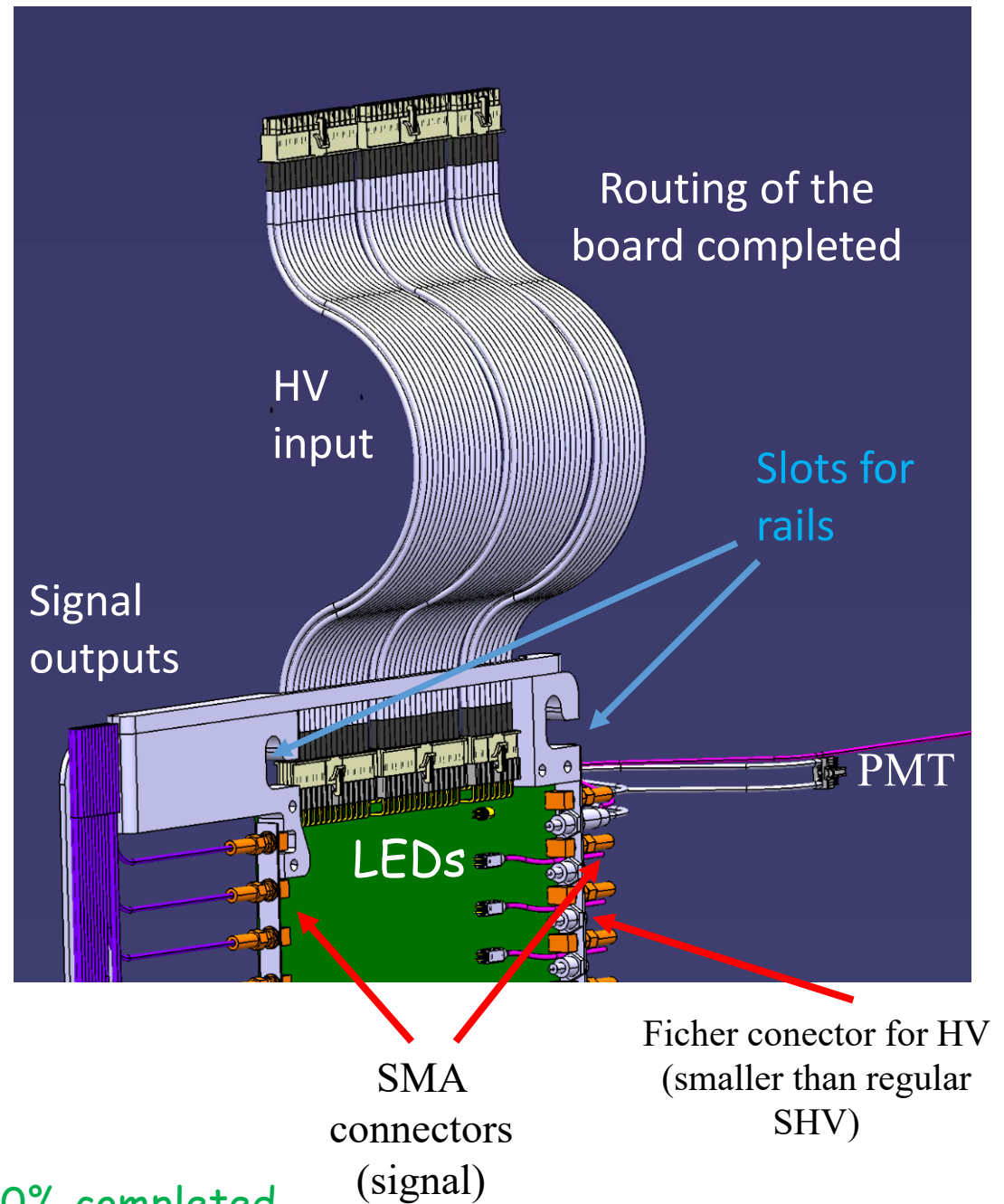
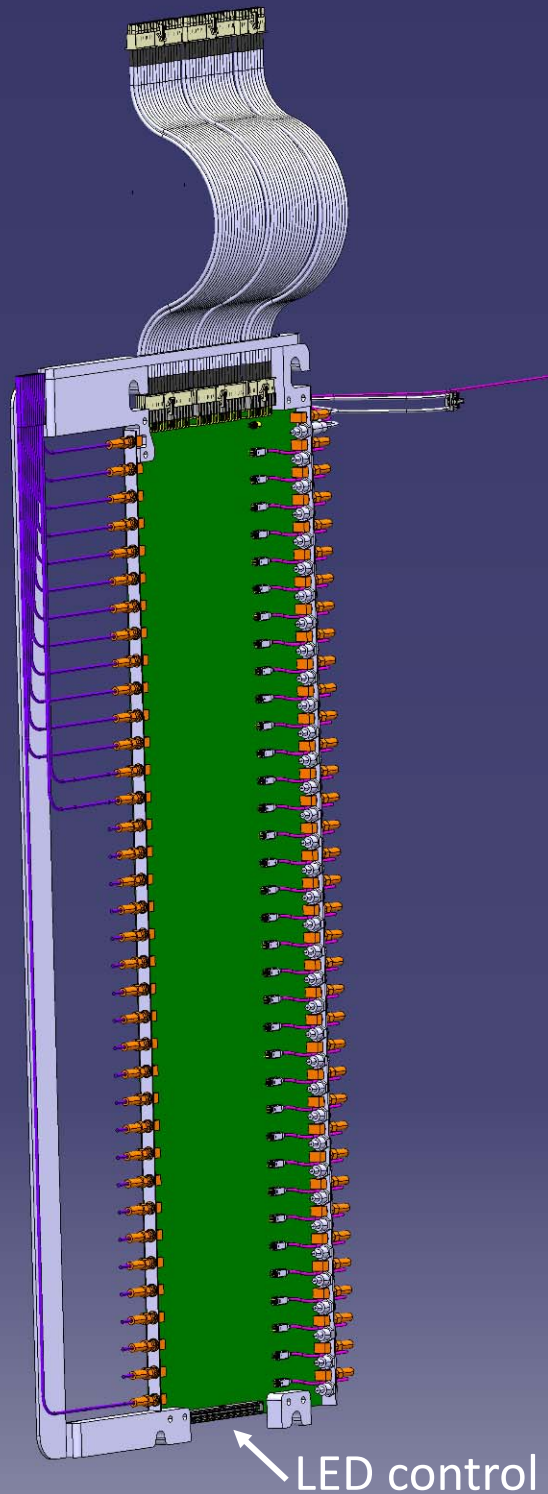
Real tests on the bench ongoing:



Cables and fibers



PCB design (HV, signal, LED)



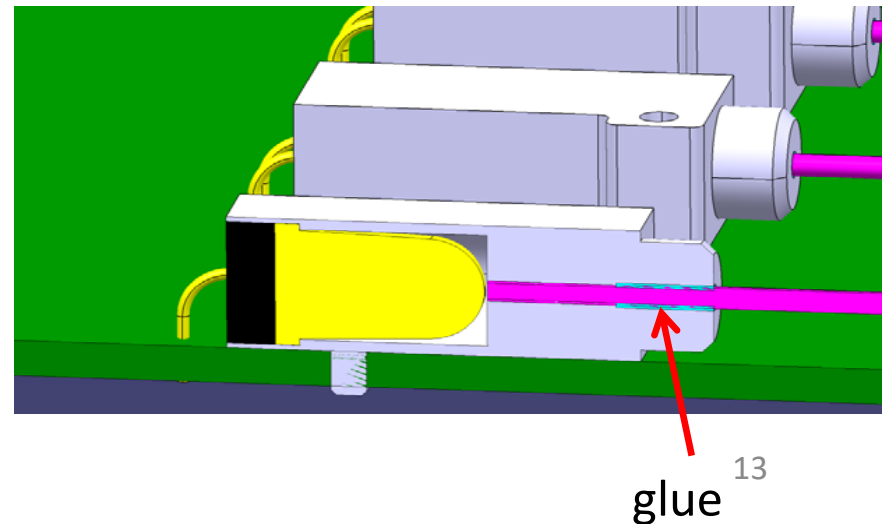
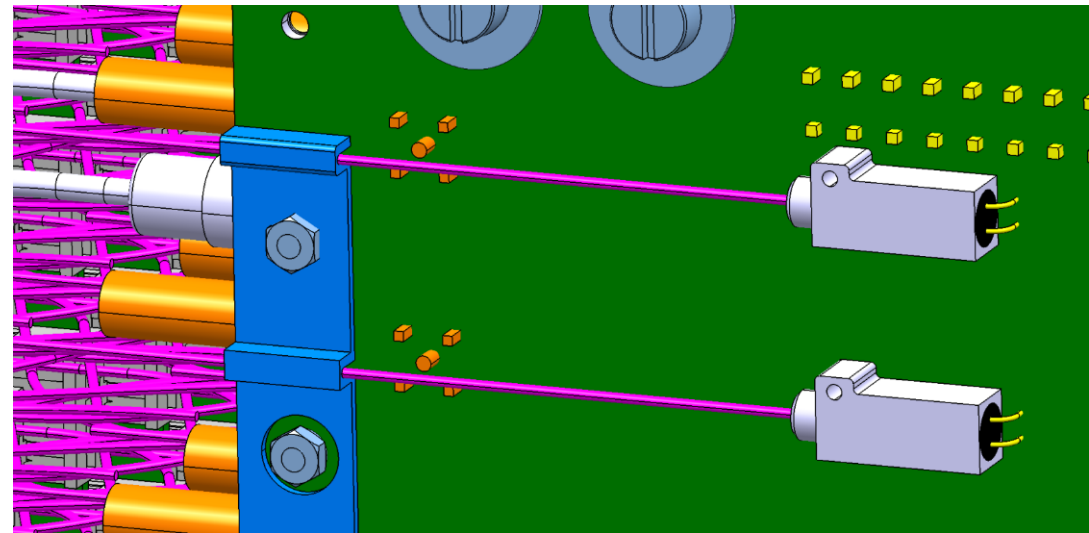
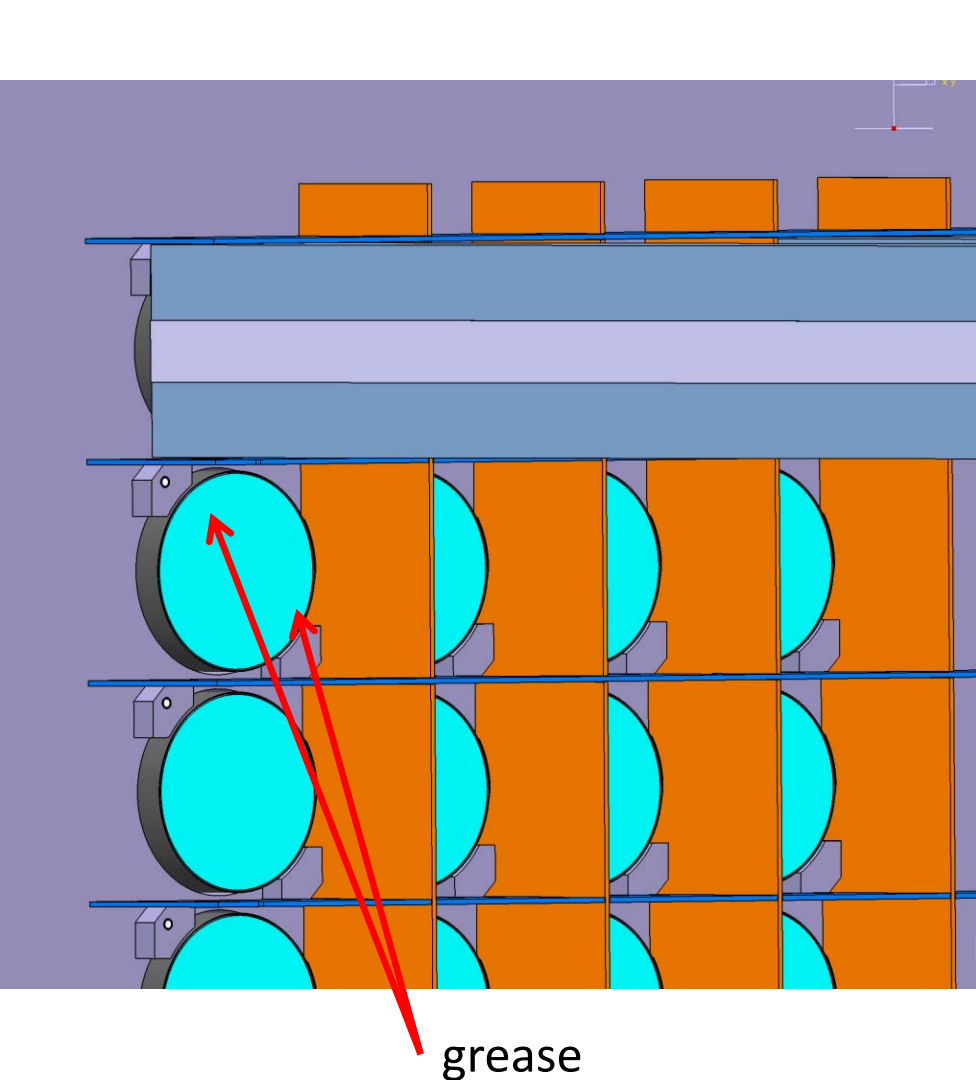
Design 100% completed
1st board being manufactured (delivery by end of May)

Calibration and curing

1 blue LED per channel (onto the PCB board)

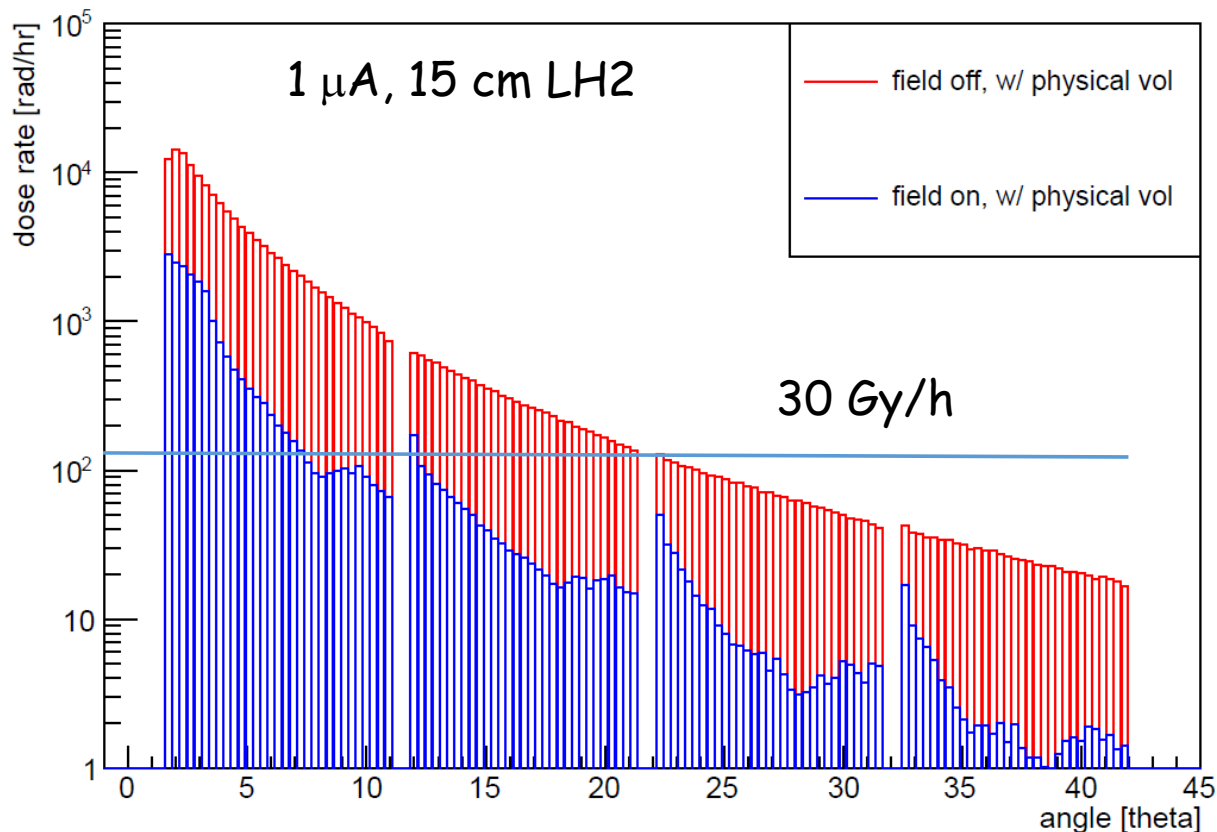
- Pulsed mode for calibration
- Continuous mode for curing
- Light through 800 μm diameter silicate fiber (radiation hard)

TO DO:
LED control board (JLAB)



Radiation environment

Dose rate on NPS with field on|off



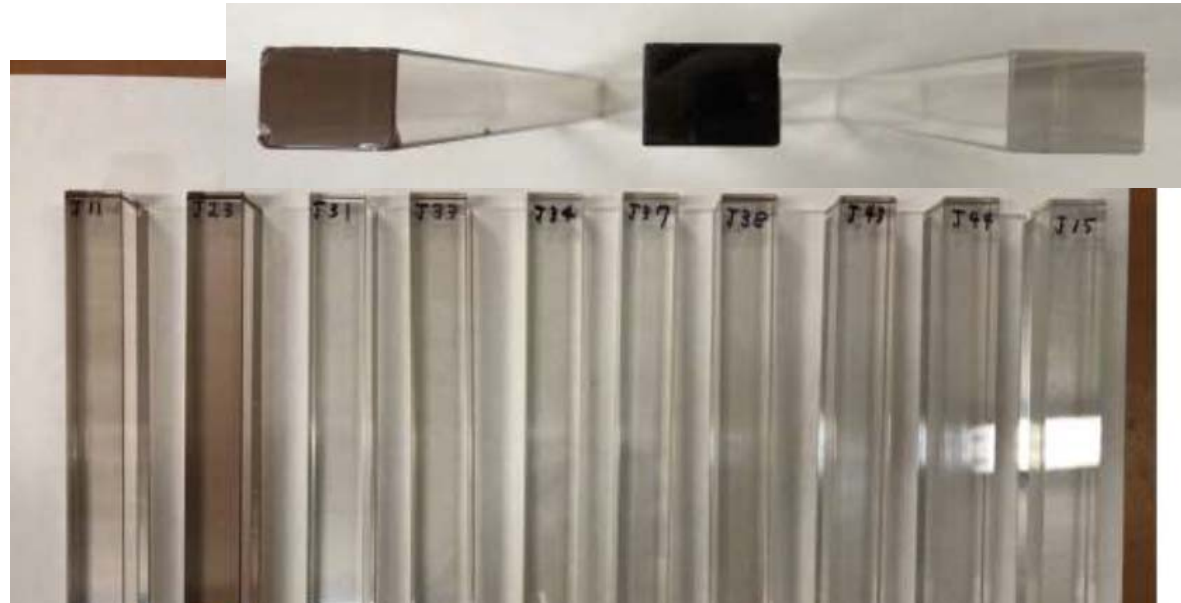
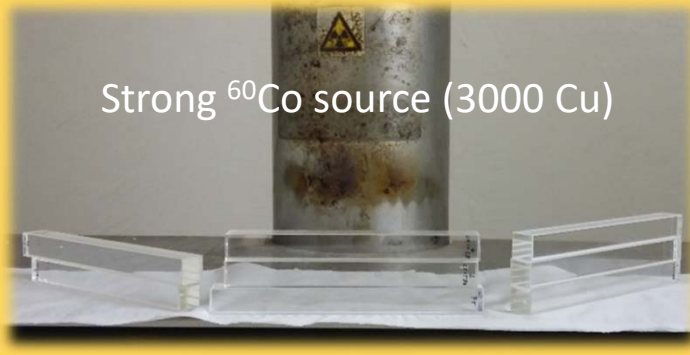
Curing expected to be needed
every few days or few weeks,
depending on the kinematics setting

Irradiation and curing tests made
with 30 Gy at 1Gy/min rate

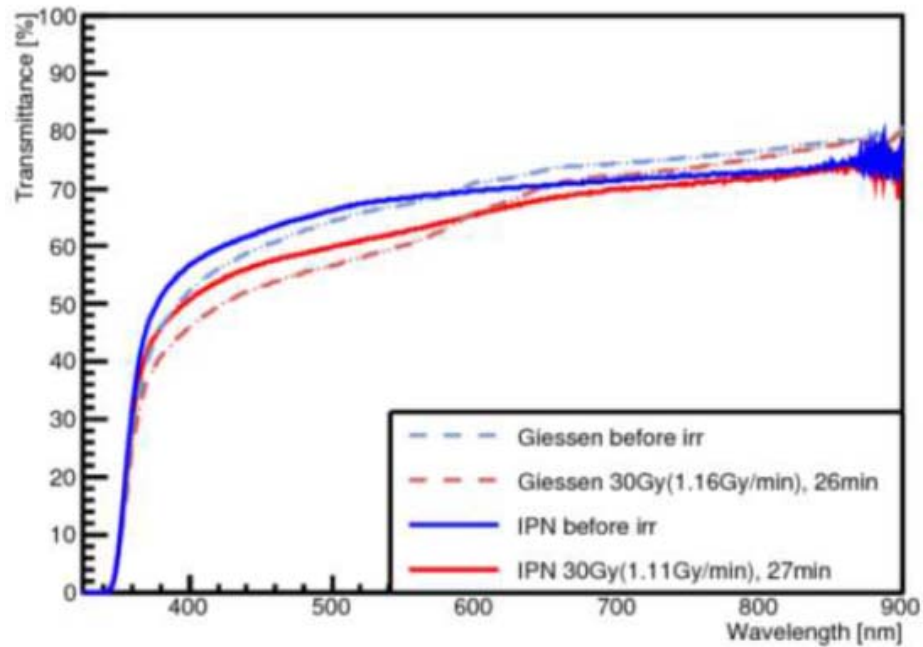
Geant4 simulation, cross-checked with RadCon estimates

Irradiation and curing tests

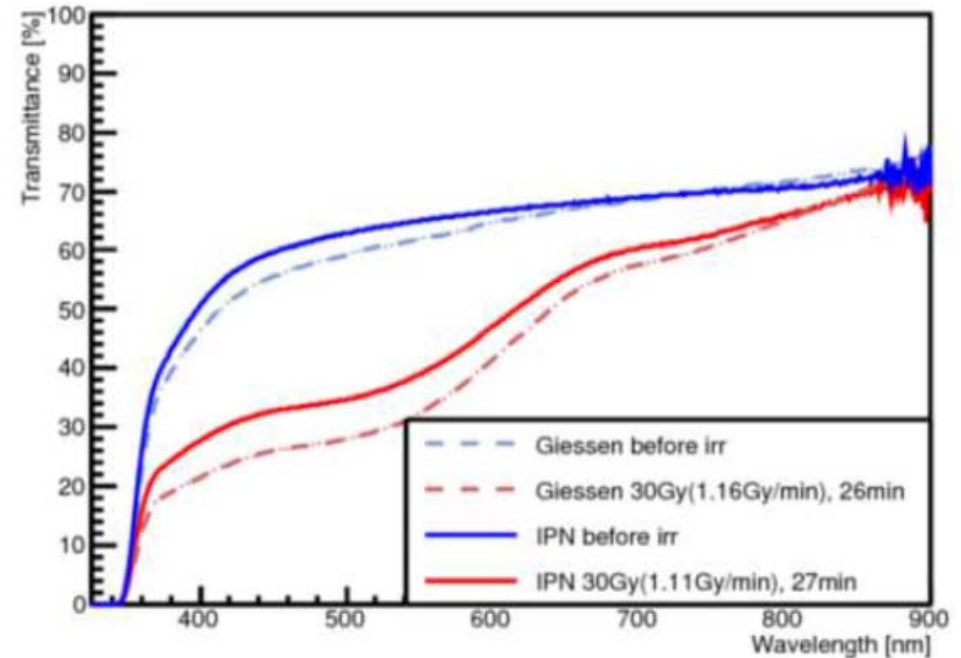
Radiation hardness measurements



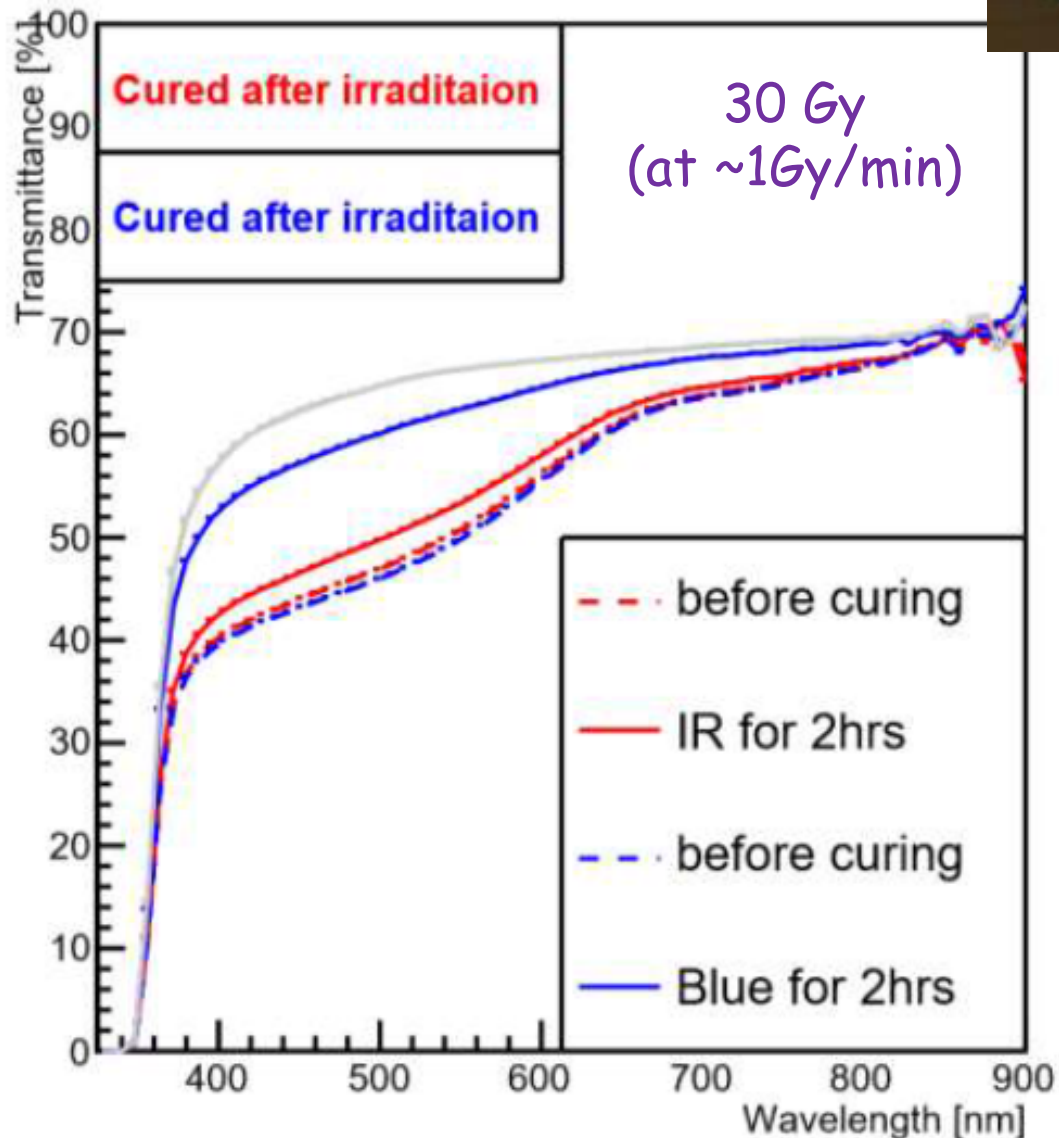
J43



J23



Irradiation and curing tests



Radiation damage recovered with a few hours of blue light curing

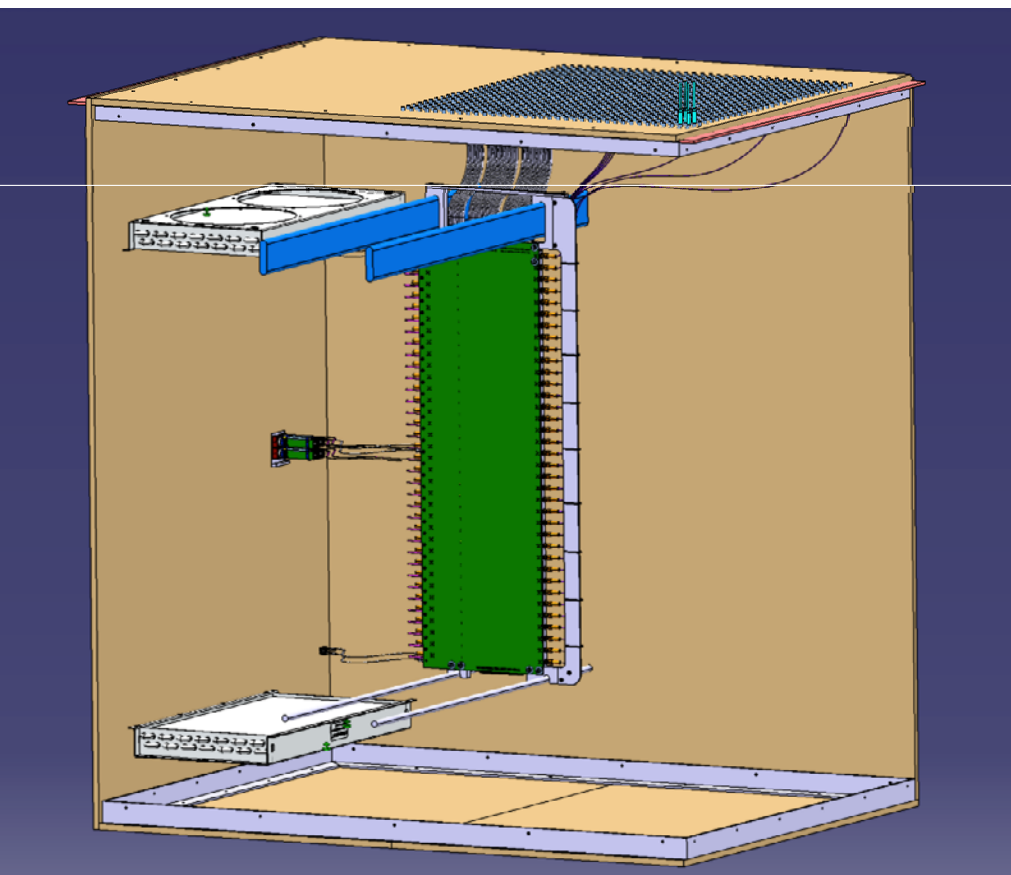
Blue LED optical bleaching



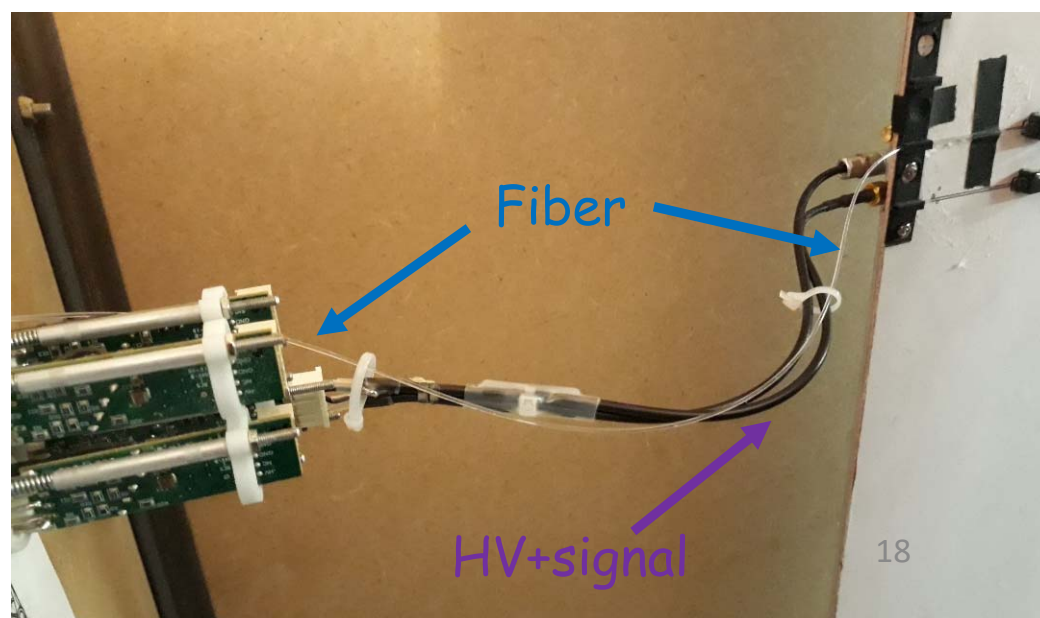
Full scale mock-up of NPS frame

Cable lengths defined:

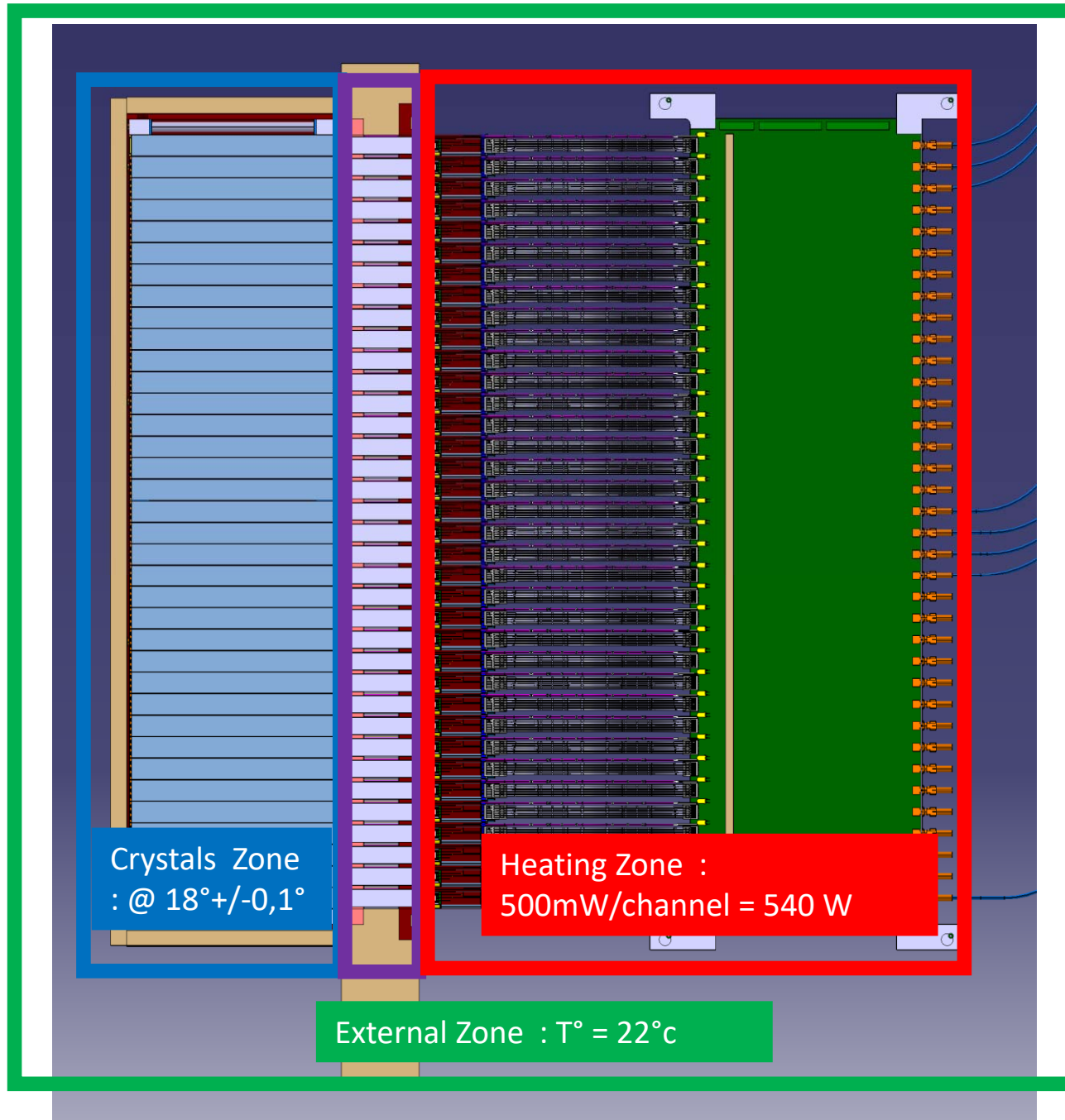
- 32 cm PMT→PCB (HV+signal)
- Signal PCB→ top of box: 0.5-1.5 m



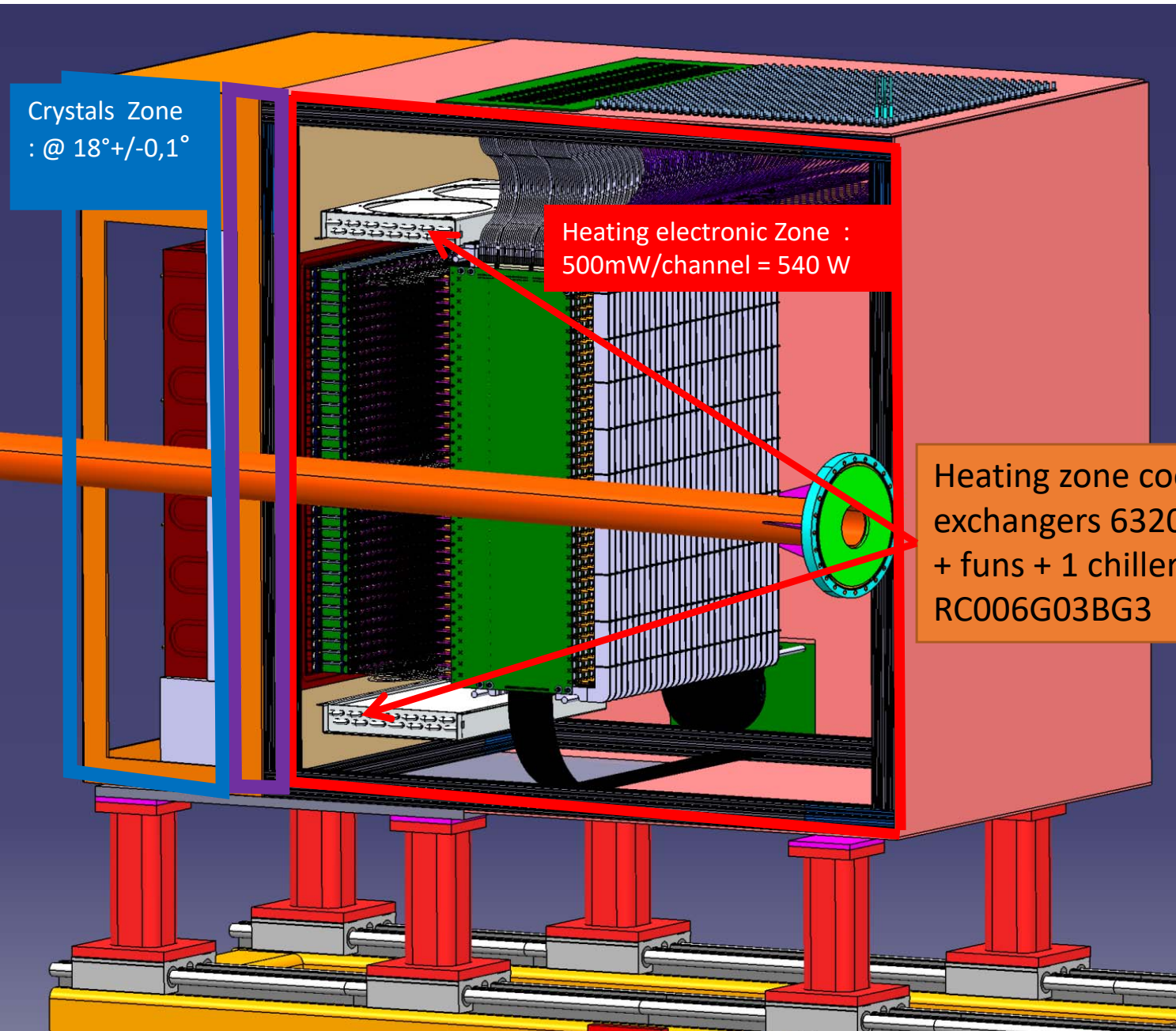
Full scale mock-up of NPS frame



Temperature zones



Temperature control: back side



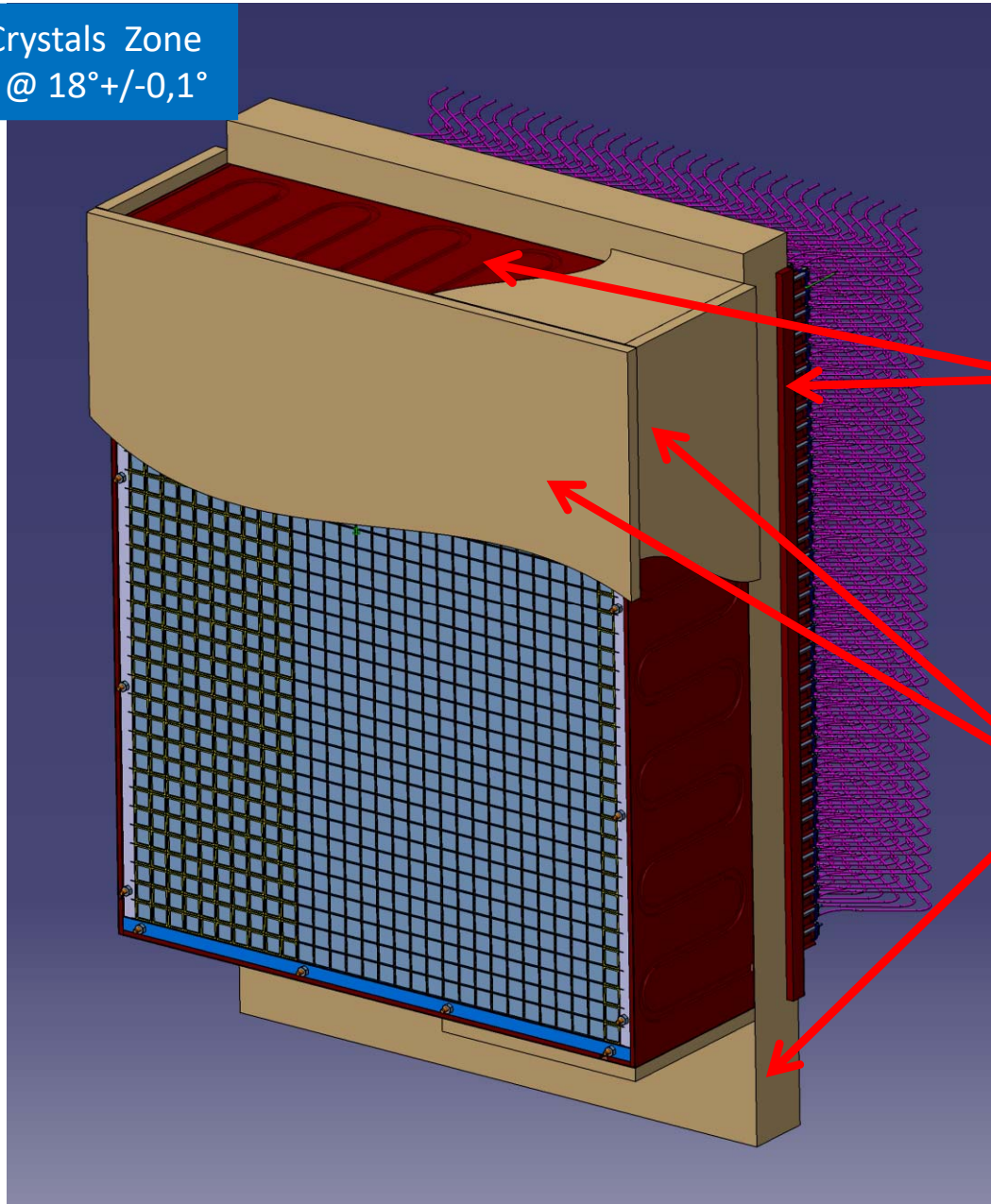
Heat exchangers & chiller procured

Heating zone cooled with 2 heat exchangers 6320G3SB (Lytron) + fans + 1 chiller Kodiak RC006G03BG3

- Same manufacturer than the ones used for HyCal
- Higher heat load specification

Temperature control: crystals

Crystals Zone
: @ $18^{\circ} \pm 0,1^{\circ}$



4 copper plates around + 1
intermediate copper plate + 1
other chiller (cooling separated
from backward zone)

Foam : thermal insulator

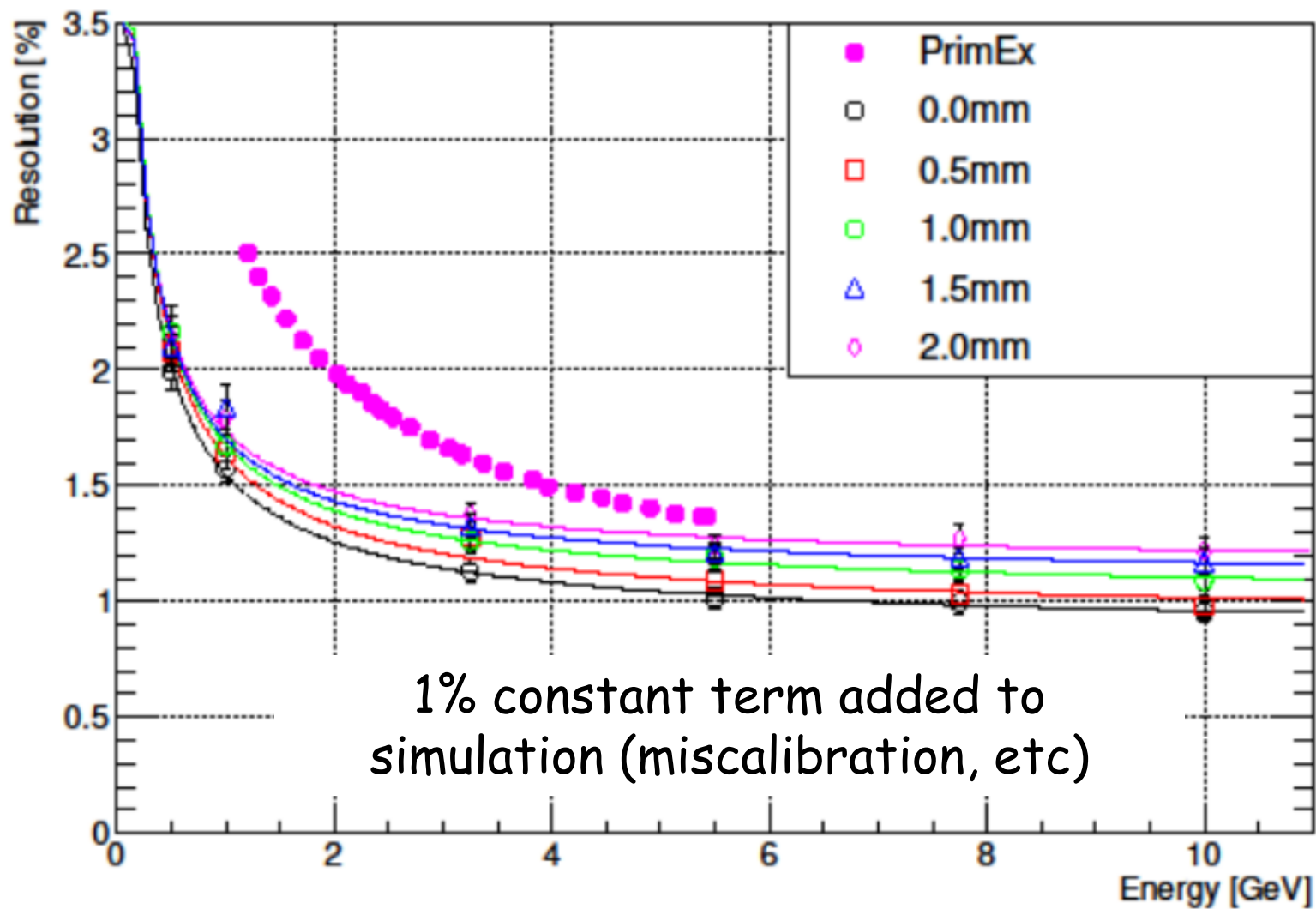
Summary

- ✓ NPS calorimeter **construction in progress**:
 - o All crystals and PMT/bases will be onsite by **Summer 2020**
 - o Calorimeter frame components will be shipped (from Orsay) **early 2020**
 - o **Assembly** (+tests) at JLab can start from **September 2020**

- ✓ No show-stoppers anticipated

Back-up

Gap between the crystal : Air

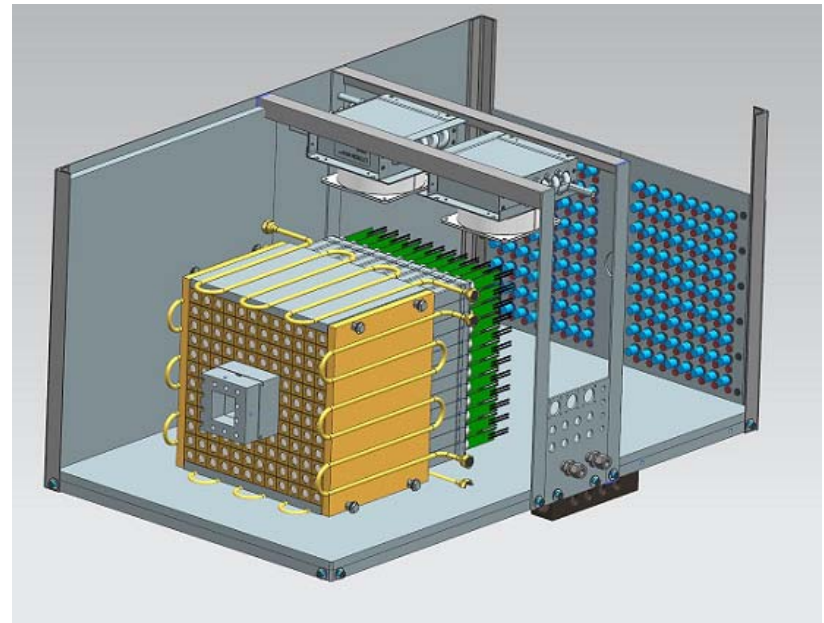


Beam Test of the Calorimeter Prototype

Installed in the experimental Hall D. Used to detect Compton events in the PrimEx D experiment

- successfully operated during PrimEx D production run in the Spring of 2019

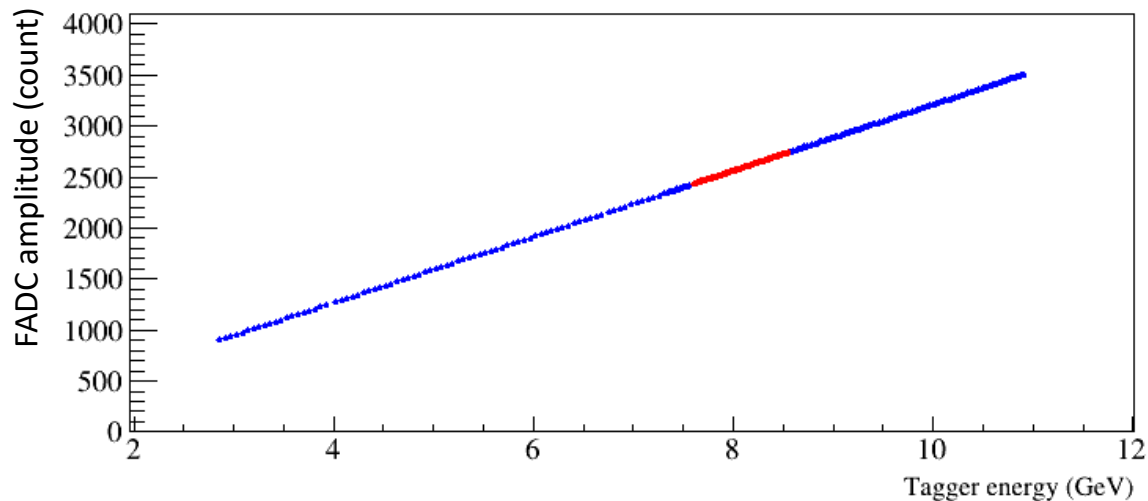
- Array of 12x12 PbWO_4 crystals
- Beam hole: 2 x 2 crystals
- Tungsten absorber covers the inner most layer (taken from HyCal)
- Water cooling (minimum 5° C), nitrogen purge
- LED-based gain monitoring system
- Positioned on X-Y movable platform



Calibration

- Move each calorimeter module to the photon beam
 - Calibration runs at small luminosity (rate in the module 30 kHz at 30 MeV threshold)
- Use beam energy provided by the Hall D tagger counters to equalize gains

FADC amplitude as a function of the beam energy



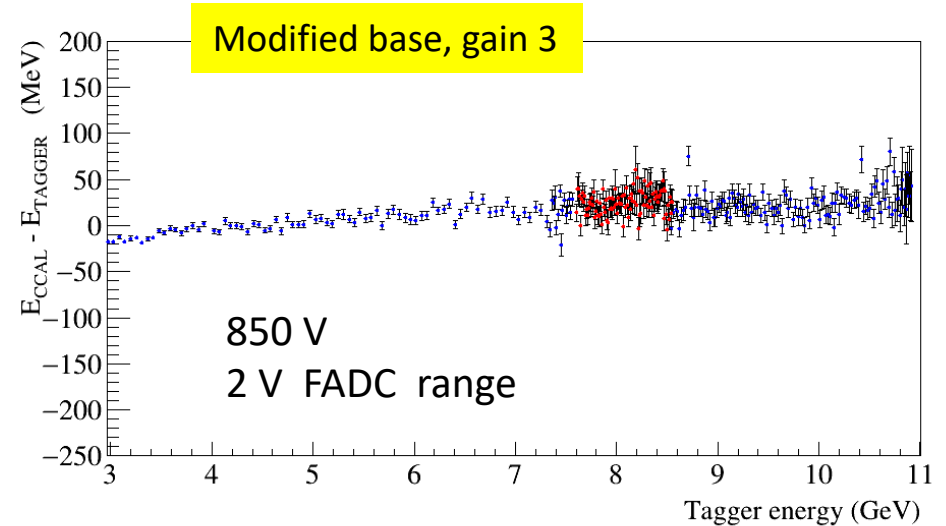
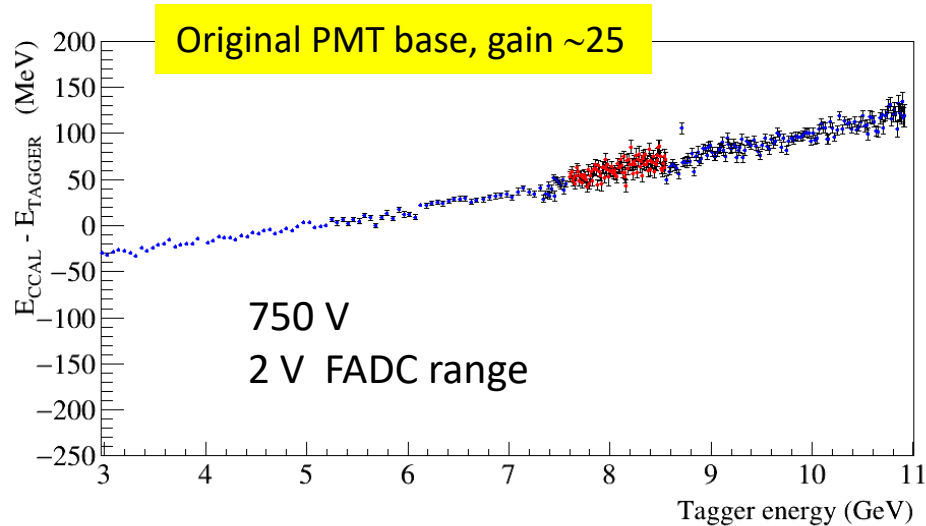
10 GeV : 3200 FADC channels

FADC range: 2 V (maximum range)

Typical HV: 700 – 750 V

Linearity

Linearity of the FADC peak amplitude

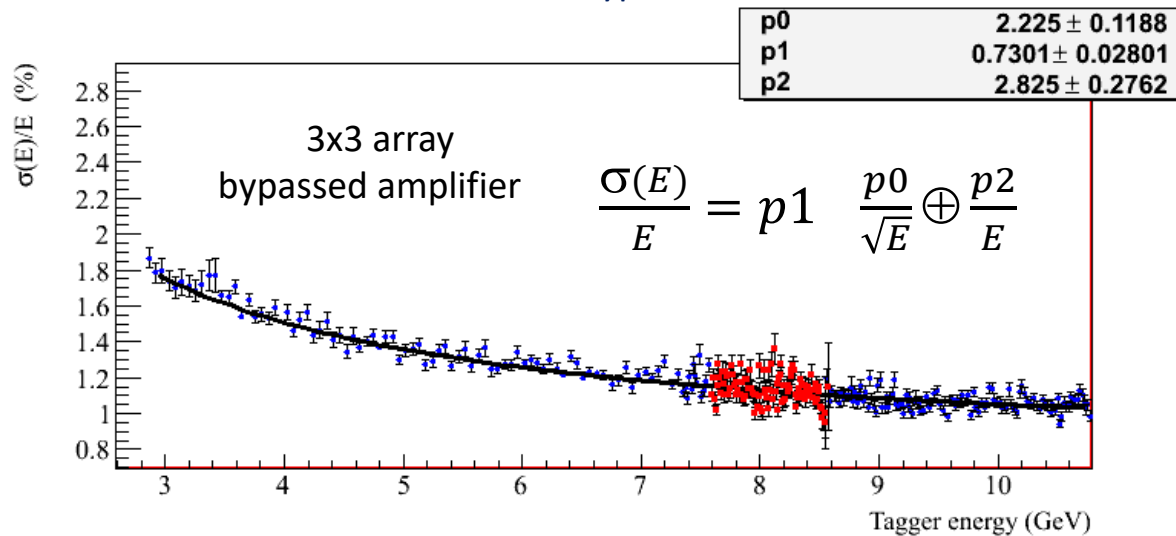


- Some non-linearities on the level of 2 – 3 % in the calorimeter response were observed for the original PMT base for both the peak amplitude and pulse integral
 - PMT was operated at relatively small HV, recommended HV is about 1 kV
- The linearity can be improved by reducing the amplifier gain and increasing HV. Some tuning of the PMT base may be required

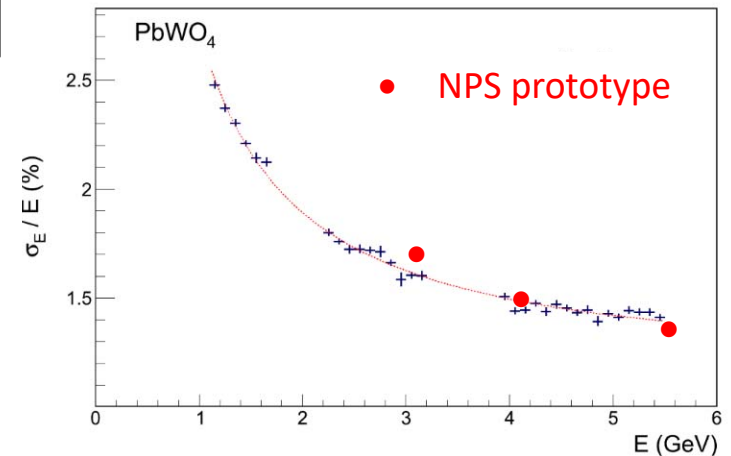
Energy Resolution

This plot will be updated

NPS Prototype



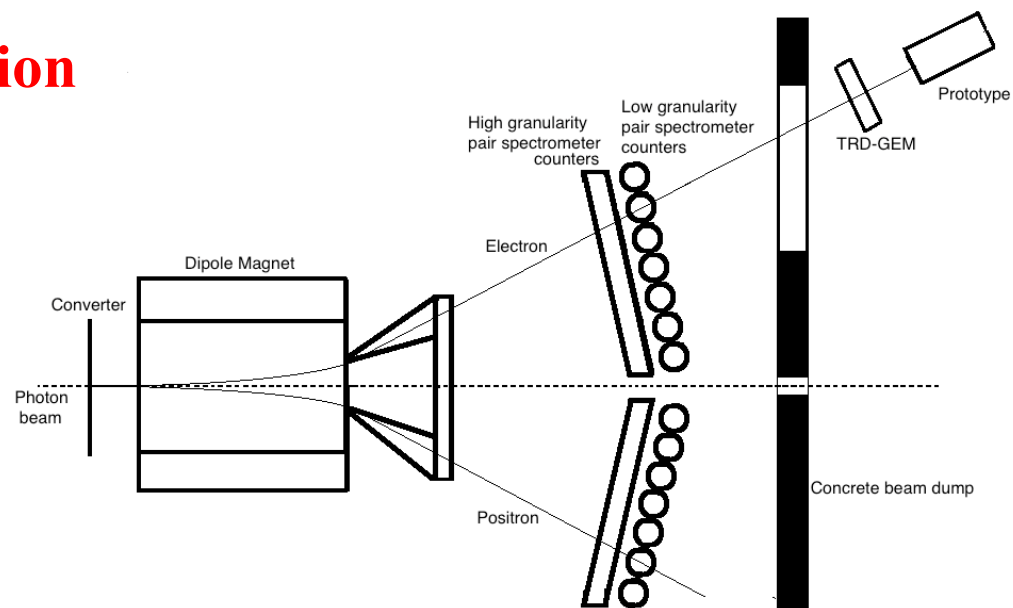
HyCal (Hall B)



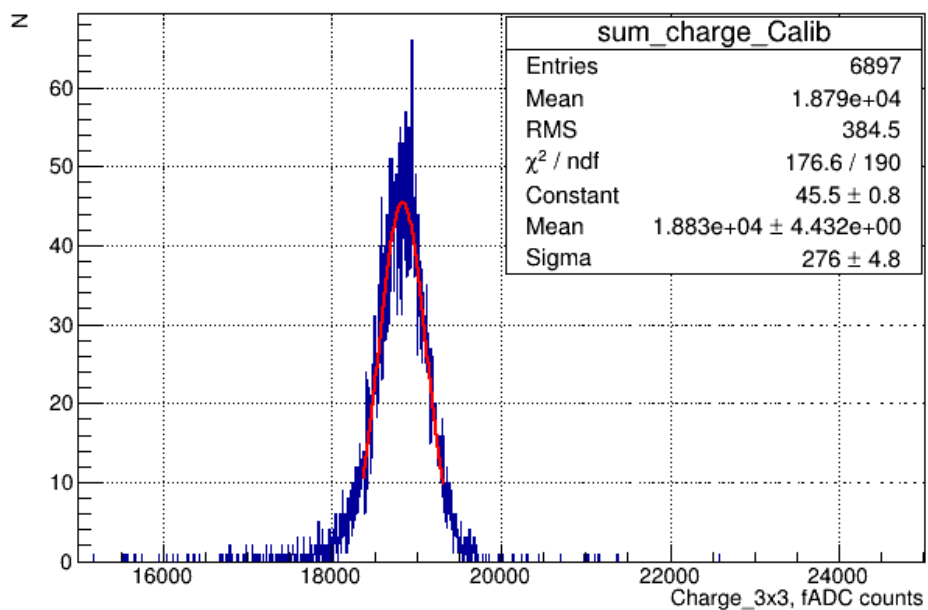
Relatively good energy resolution, which is consistent with the resolution of the Hall B HyCal calorimeter (which was constructed using SICCAS crystals)

More details can be found in
GlueX-doc-3590, GlueX-doc-3998, V. Berdnikov, A.Somov, J. Crafts

Energy Resolution

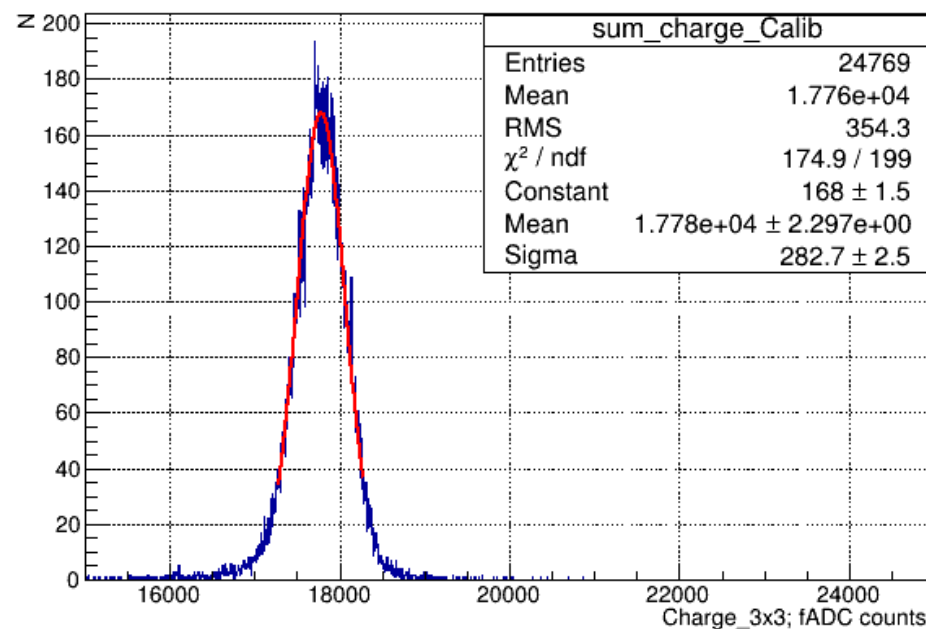


Total Charge Calib



3x3 SICCAS crystals

Total Charge Calib



3x3 CRYTUR crystals