JEF Experiment and FCAL-II Upgrade

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- Jlab Eta Factory (JEF) experiment was approved by PAC in 2017 to test fundamental symmetries and search for dark matter via rare η decays. It requires an upgraded FCAL-II with a PWO crystal insert.

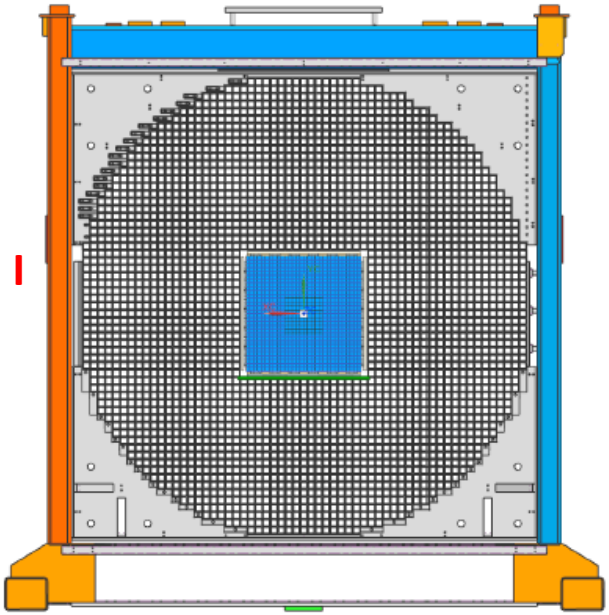
- Crystal specifications for FCAL-II will be mostly based on the HyCal specifications.

- Potential modification for the radiation hardness requirement may apply to FCAL-II depending on the future R&D and the performance of CompCal.

- Crystal specifications and performance of HyCal.

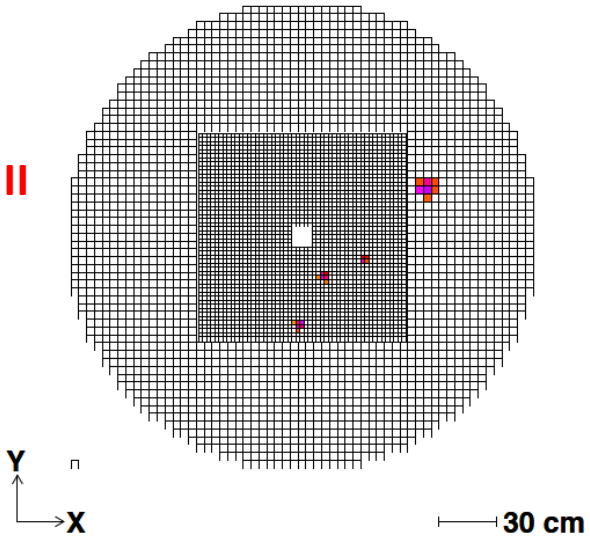
Proposal for FCAL-II Upgrade

Option I



- **Option I upgrade will be a 30x30 matrix of PWO insert (60x60 cm^2 in size, a total of ~900 PWO detector modules) .**

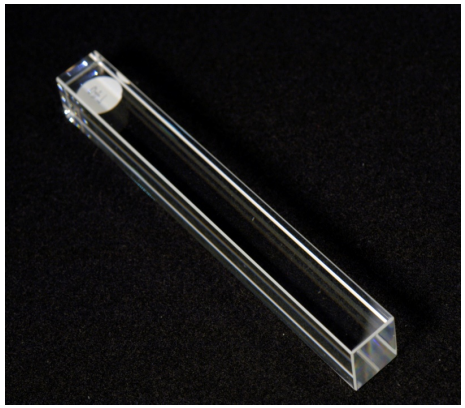
Option II

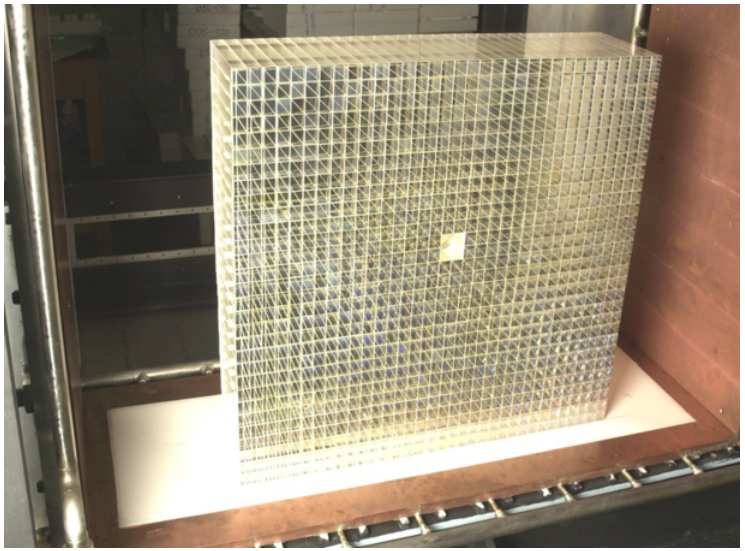


- **Option II upgrade will be a 44x44 matrix of PWO insert (88x88 cm^2 in size, a total of ~1932 PWO detector modules).**

$PbWO_4$ Crystal Dimensions

Geometrical size:
20.5 x 20.5 x 180.0 mm^3

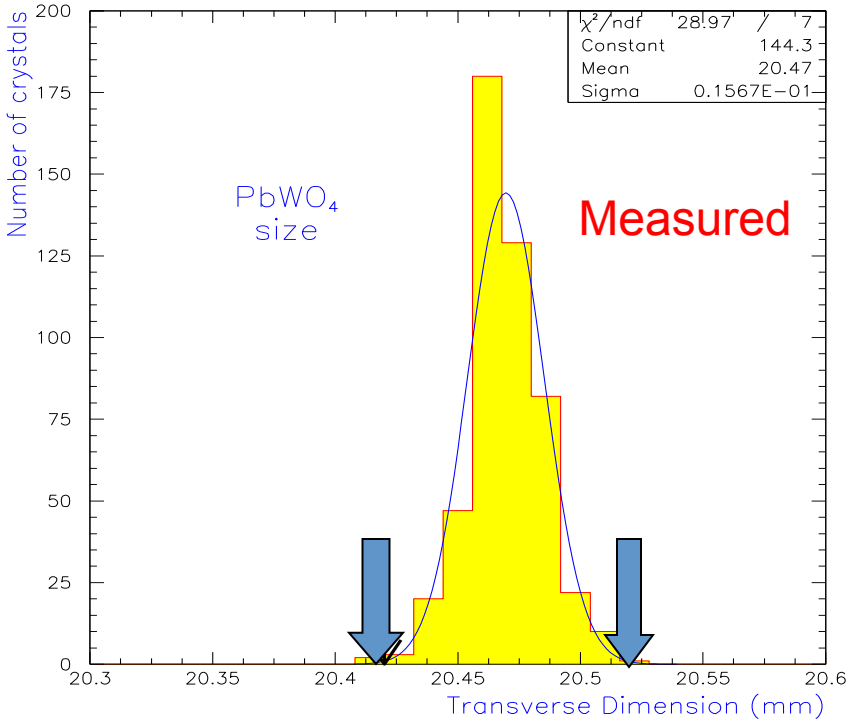




Tolerances (mm):

20.5 + 0.0 - 0.1
180.0 + 0.3 -0.0

Specified



$PbWO_4$ Crystal Optical Properties

. **Longitudinal transmission (absolute values)**

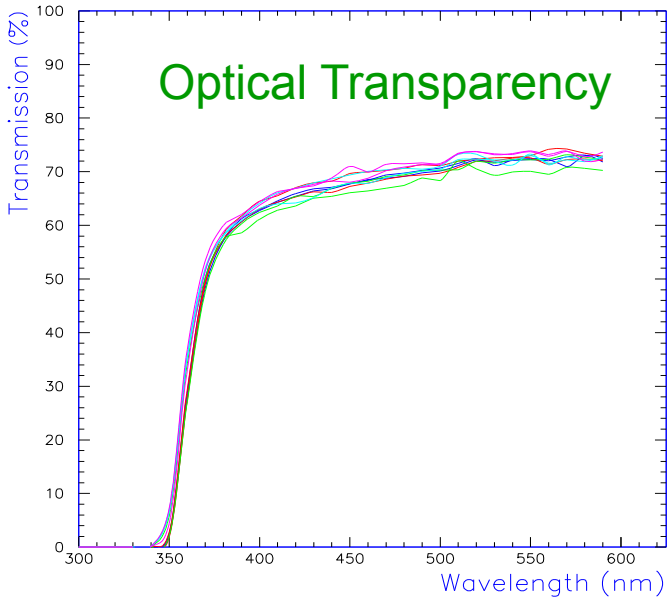
≥ 10 % at 360 nm;

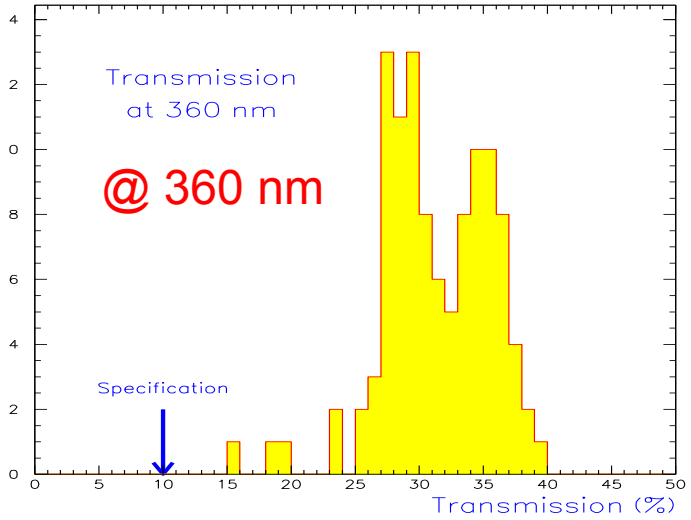
≥ 55 %at 420 nm;

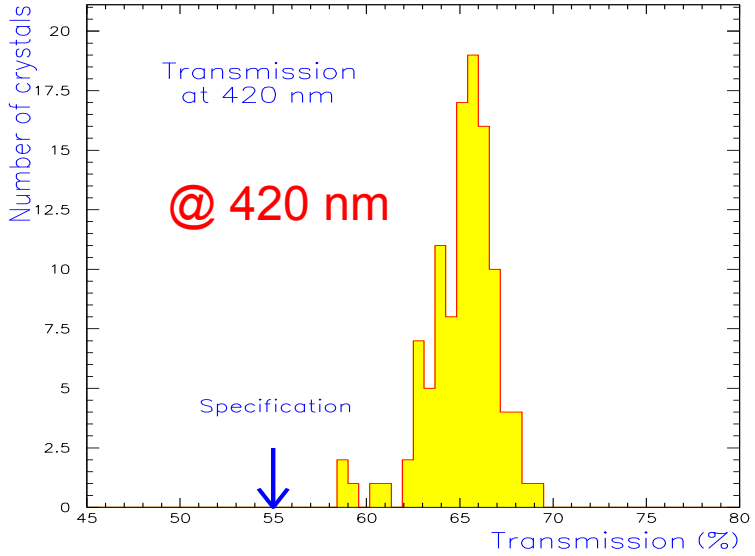
≥ 65 % at 620 nm

. **Transversal transmission**

At a transmission of 50%, $\delta\lambda \leq$ 6nm for a 5 measurements every 3 cm, starting at 1.5 cm from front face.







Scintillation Light Requirement

. Scintillation Light

Light Yield ≥ 9.5 photoelectrons/MeV, measured at 18 ^{o}C and in a 100 ns gate, with ^{60}Co source at 3 cm from PWO front face, with a Phillips XP2262B photomultiplier covering all rear face, with a n = 1.5 silicon coupling grease, wrapped on 4 sides and face in 1 layer of Tyvek.

. Decay Time

LY(100 ns)/LY(1μs) >90%

Afterglow ≤ 0.5 % of peak amplitude with a ^{60}Co counting rate of 1 MHz.

Radiation Hardness

Requirement:

. Induced absorption for full crystal saturation:
$\mu \leq 1.5$ m^{-1} at 420 nm for lateral ^{60}Co irradiation, >3 krad, rate of 5-15 krad/h at 18 ^{o}C.

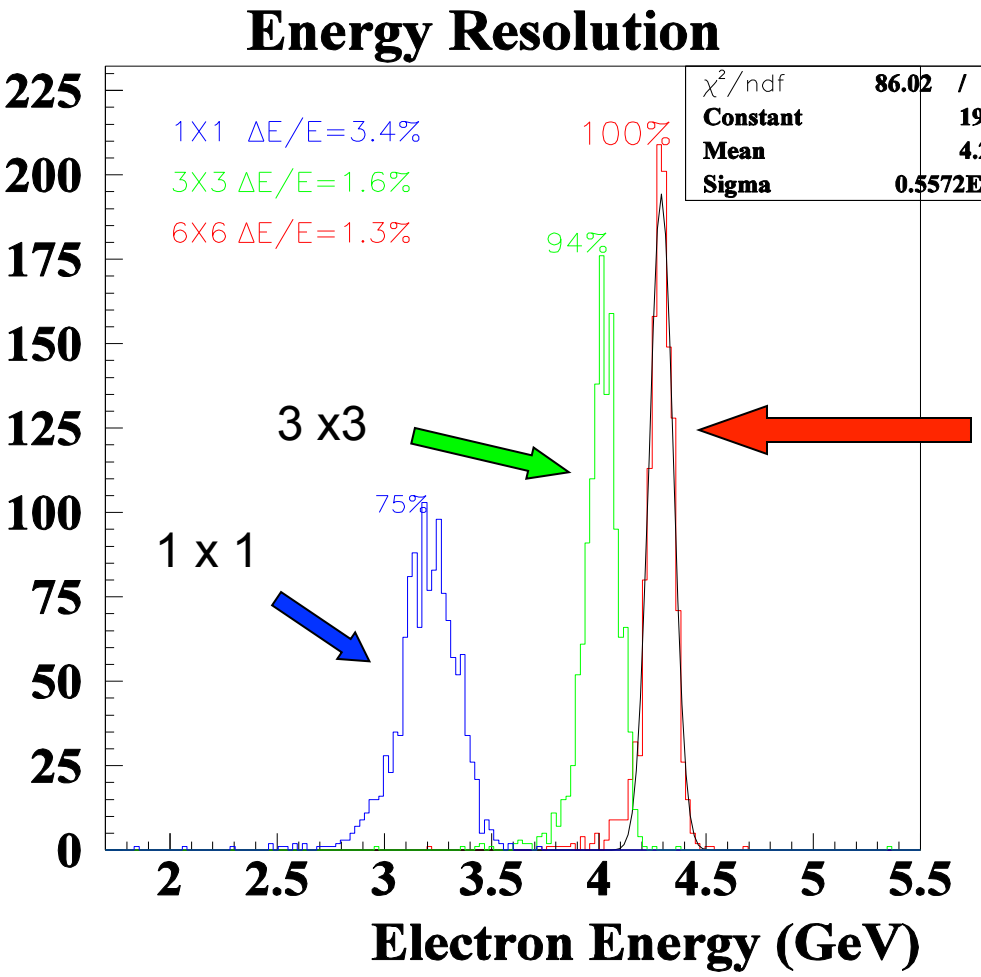
. Light yield loss < 6% for front ^{60}Co irradiation, 200 rad, 15 rad/h

. No recovery time constant shorter than 1 hour.

$PbWO_4$ Prototype Calorimeter and Beam Test Results

- A 6x6 matrix of crystals (18 SIC and 18 Bogoroditsk crystals)
- The calorimeter was located behind one of the PrimEx pair spectrometer detector arrays in Hall B
- A scintillating fiber (width of fiber is 2mm) detector was installed in front of the calorimeter

Energy Resolution

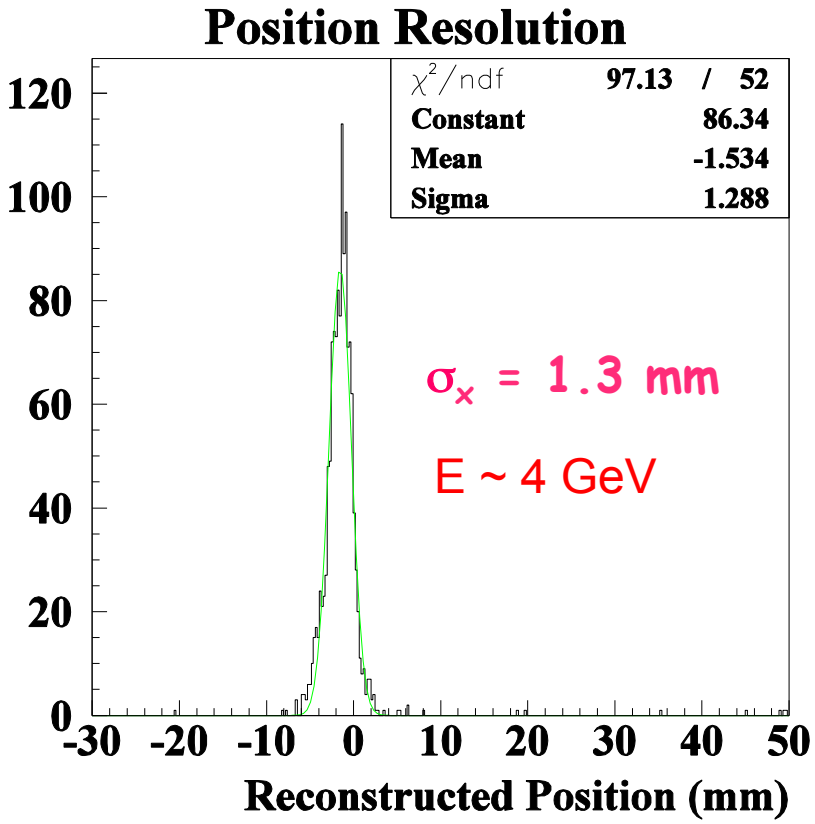


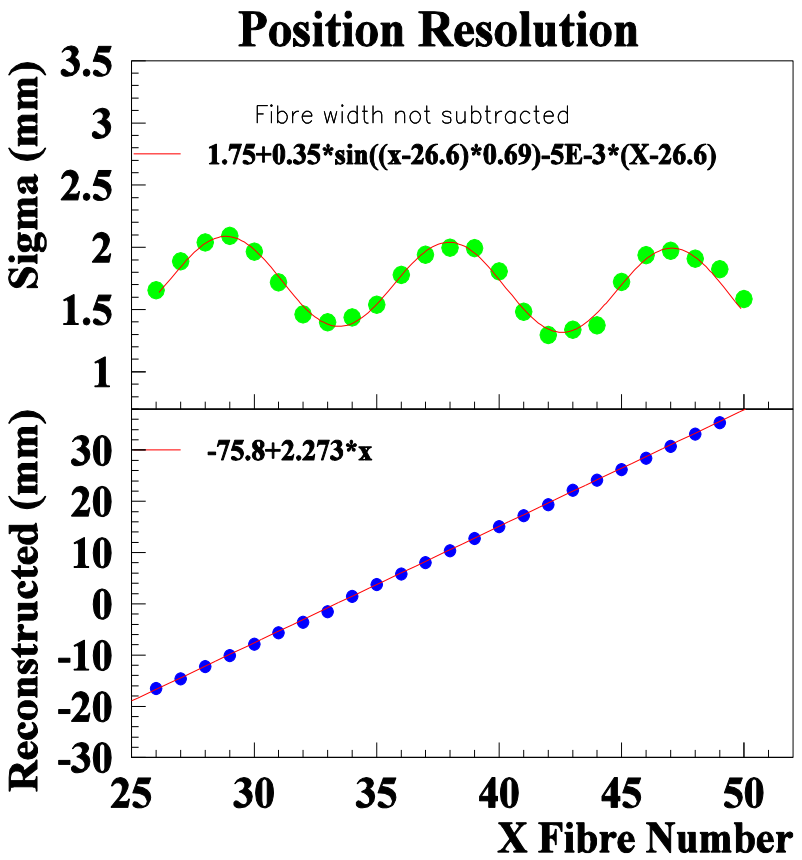
6 x 6 crystals

σ_E/E = 1.3 %

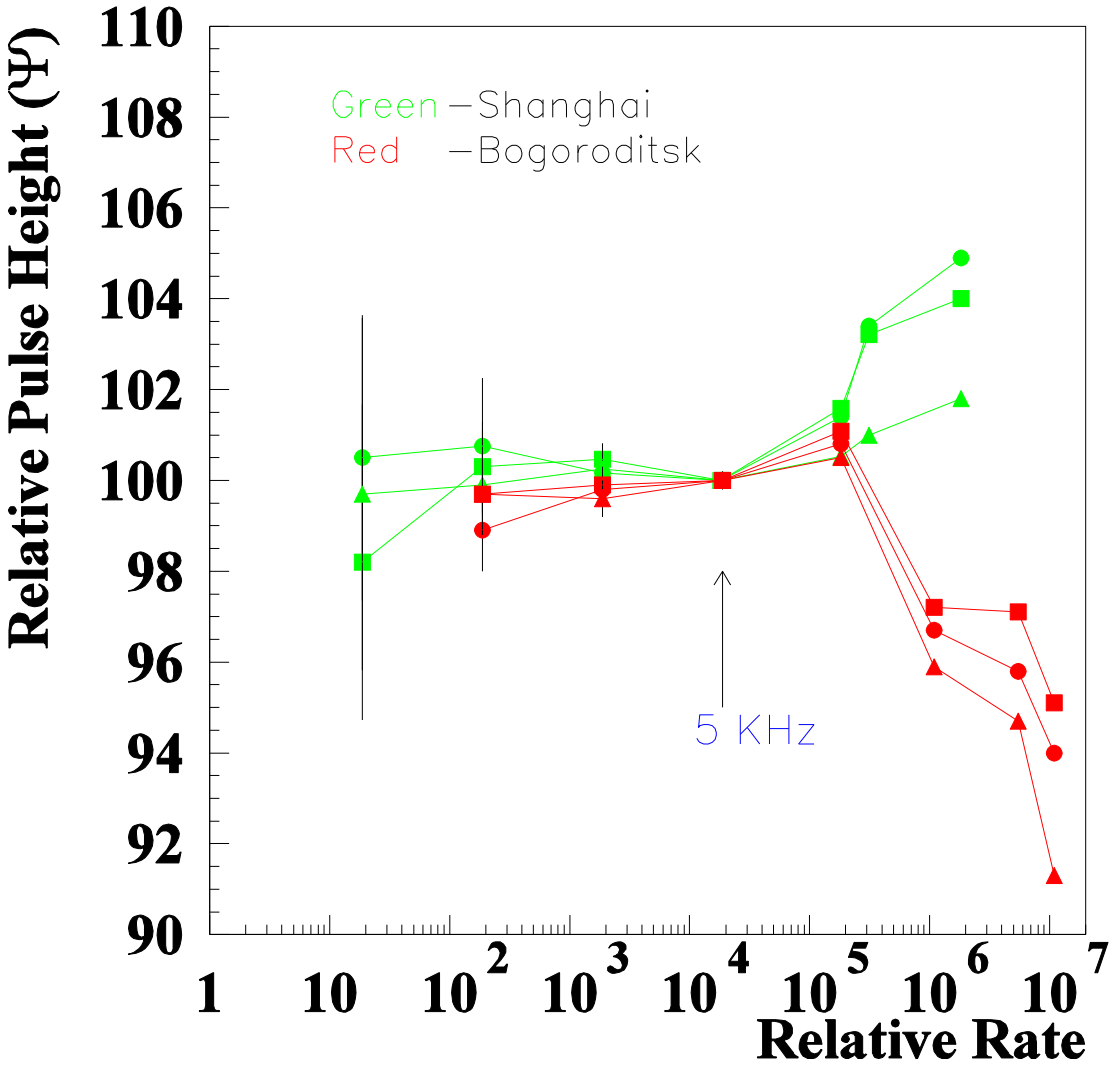
E = 4 GeV

$PbWO_4$ Position Resolution

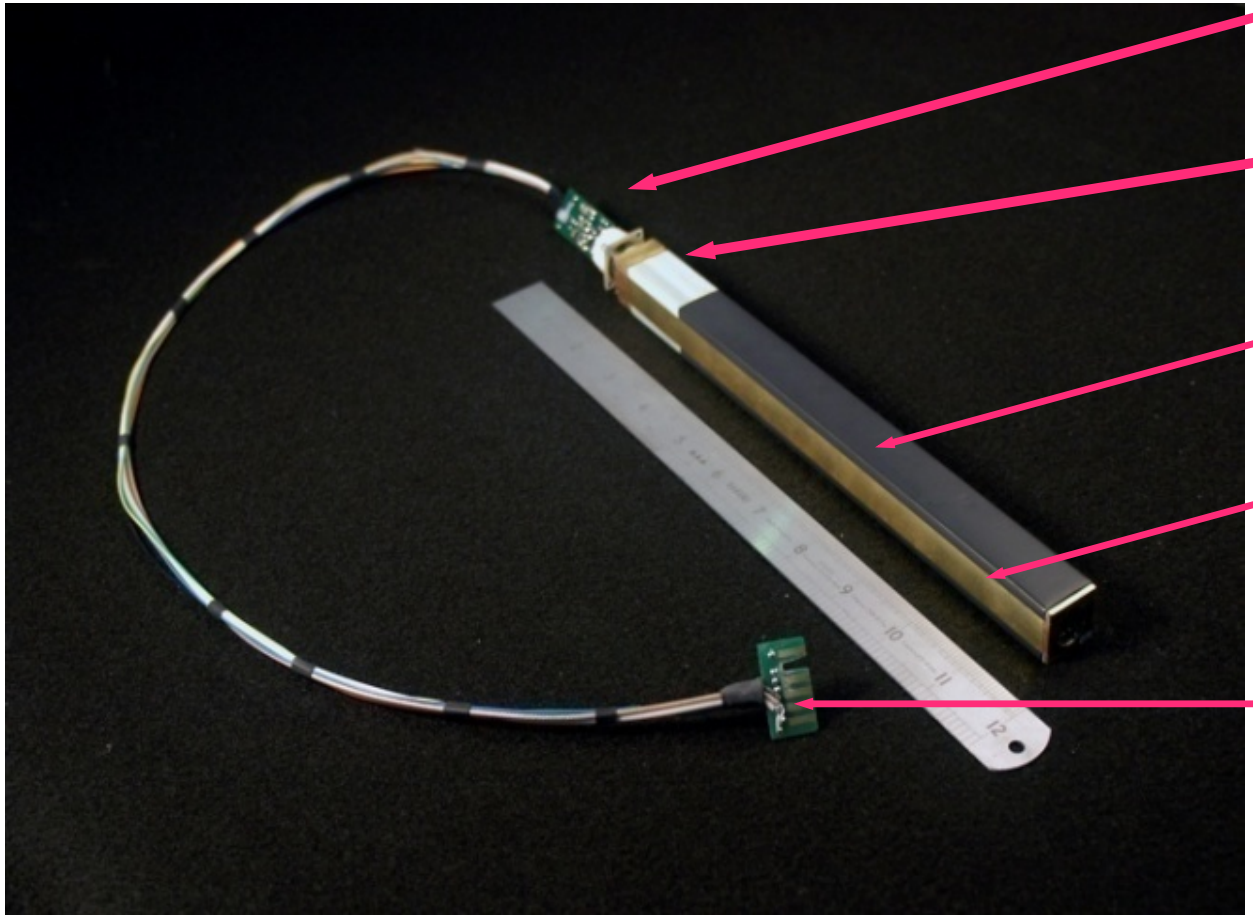




Rate dependence



$PbWO_4$ Module Development



HVD

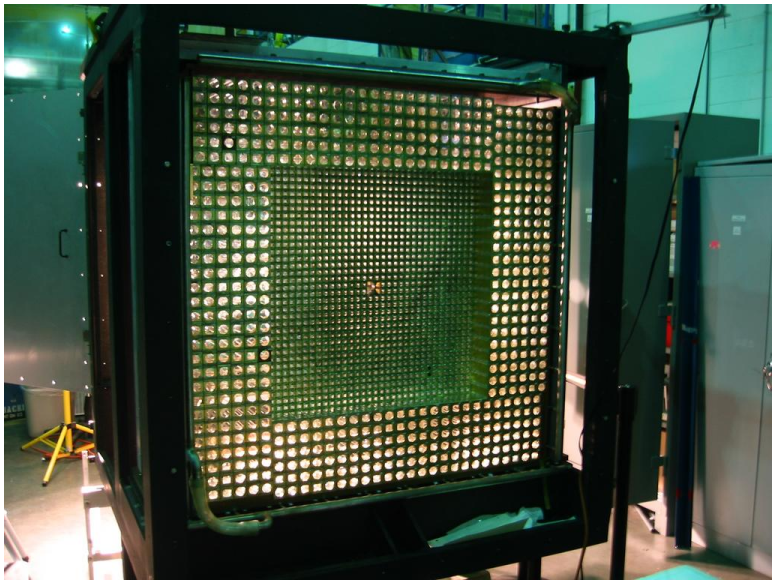
G10 PMT housing
with R4125HA tube

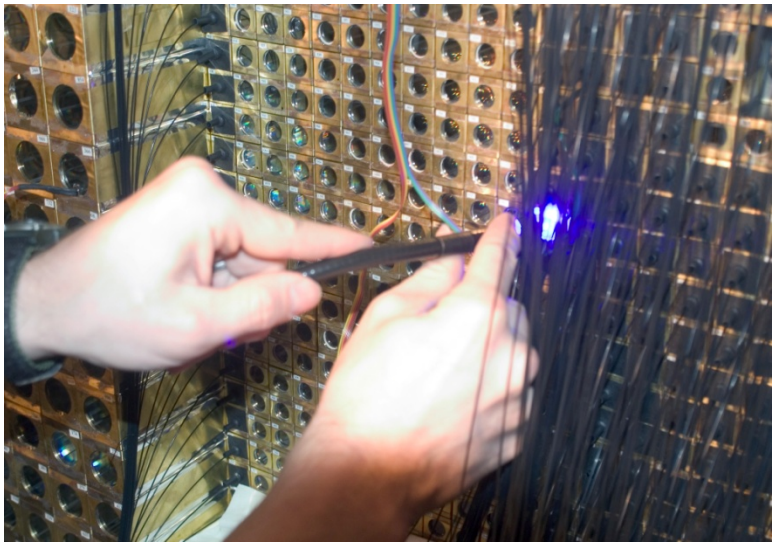
VM-2000 and Tedlar
wrapping (38.1 microm)

25 microm brass strips

Readout cable

HyCal Calorimeter





Size: 118x118 cm^2

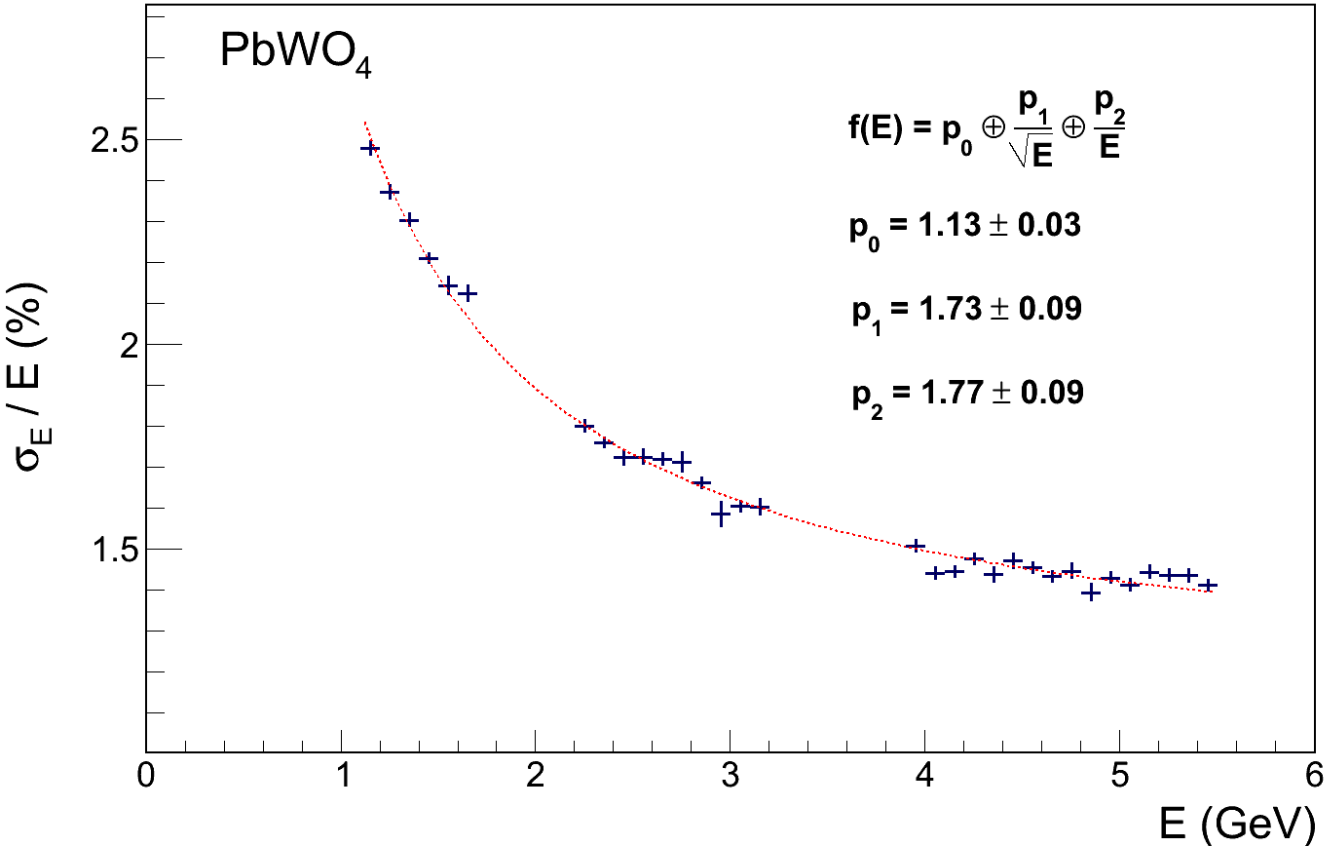
Composition:

$PbWO_4$ modules: 1152

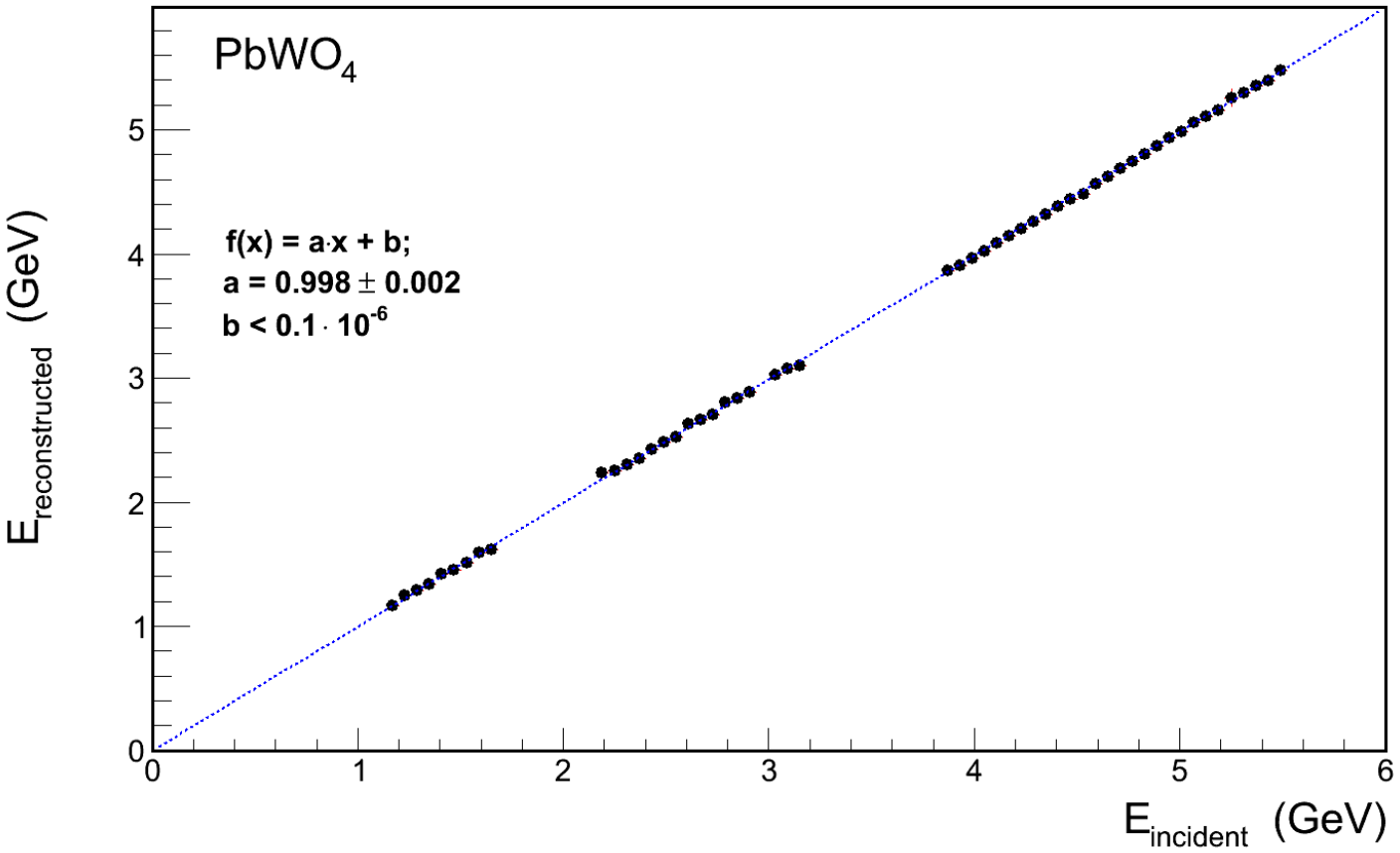
Lead Glass modules: 576

Central beam hole: 4x4 cm^2

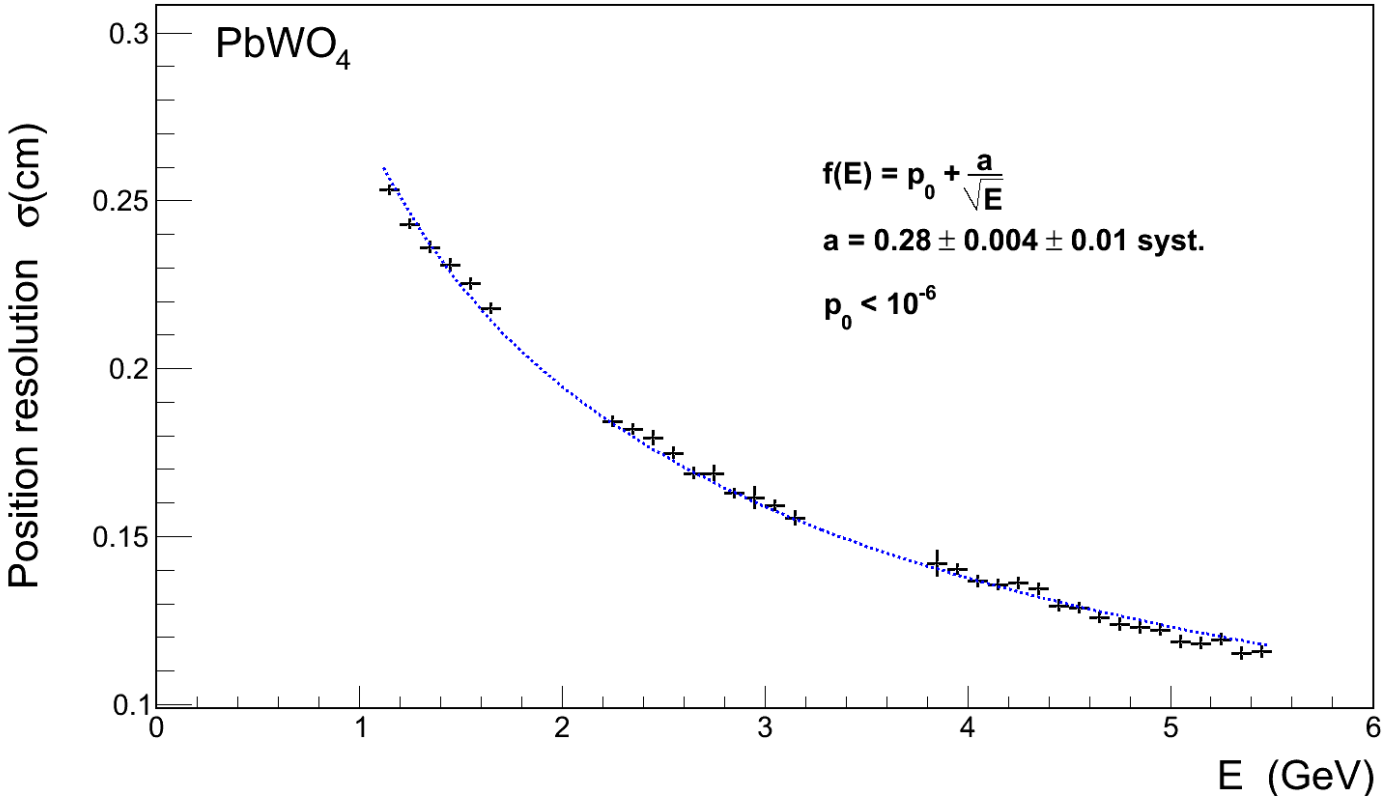
Energy Resolution



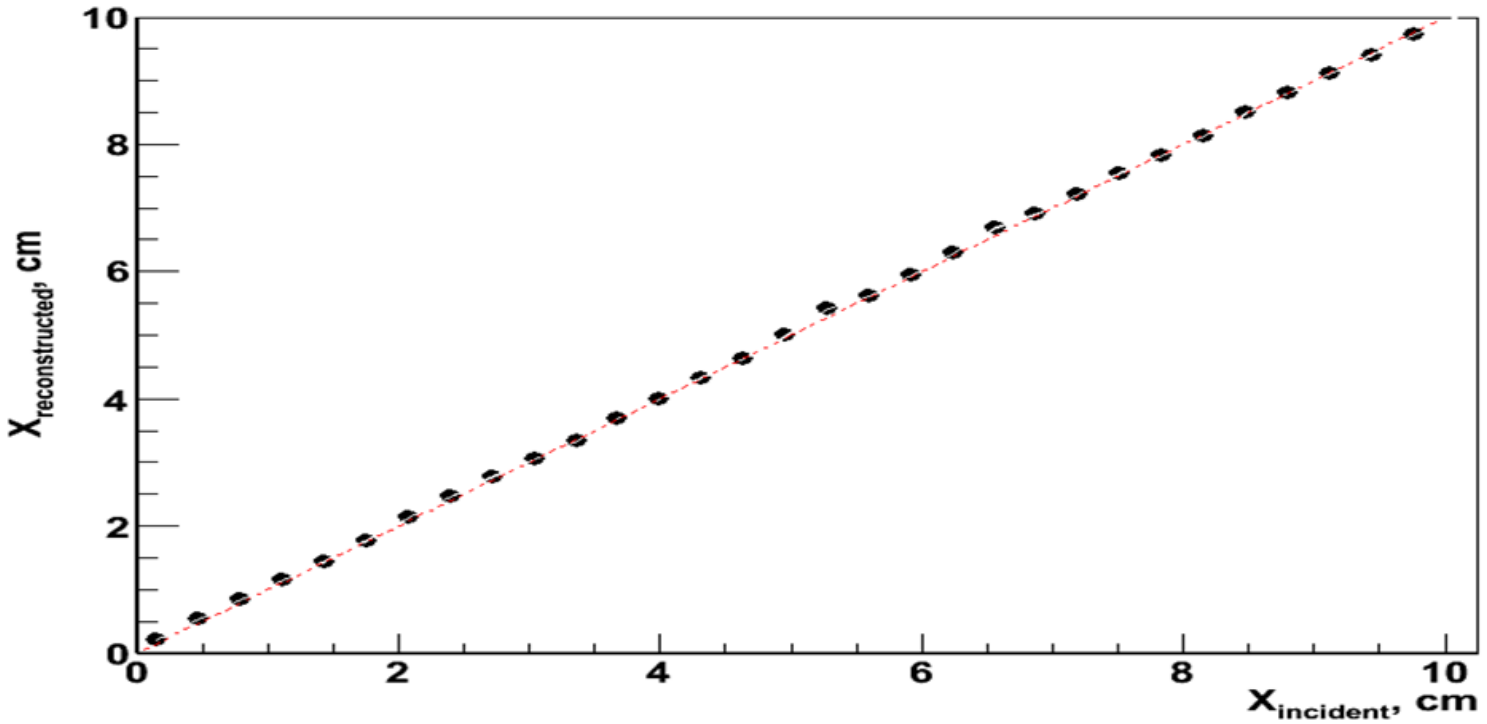
Energy Reconstruction: Linearity



Position Resolution



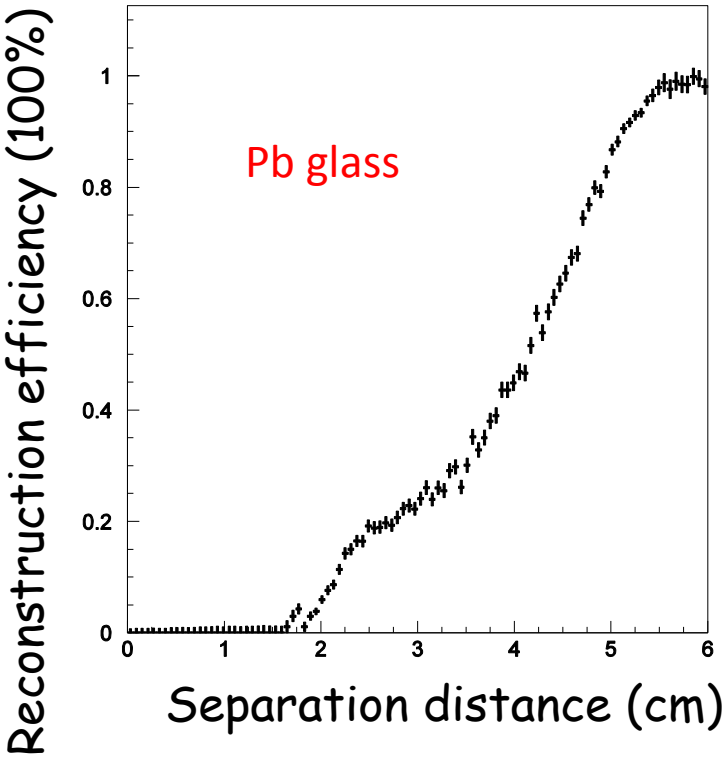
Position Reconstruction: $PbWO_4$ Crystal Part

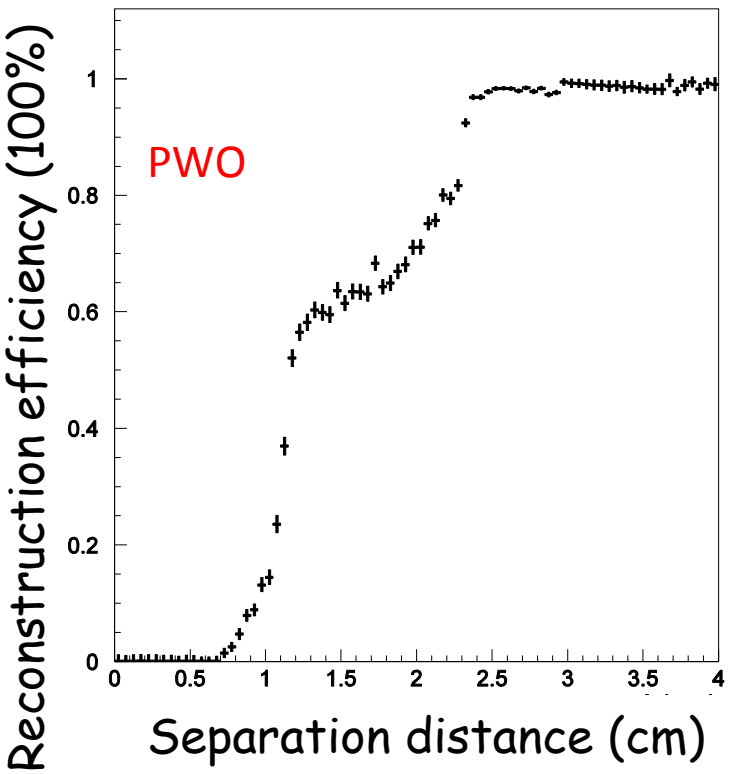


Probability of two-cluster separation vs. distance between hits

Study done by using PrimEx-II snake scan data

- First cluster: "permanent" with energy 5 GeV
- Second cluster: "changing" in energy 1-5 GeV

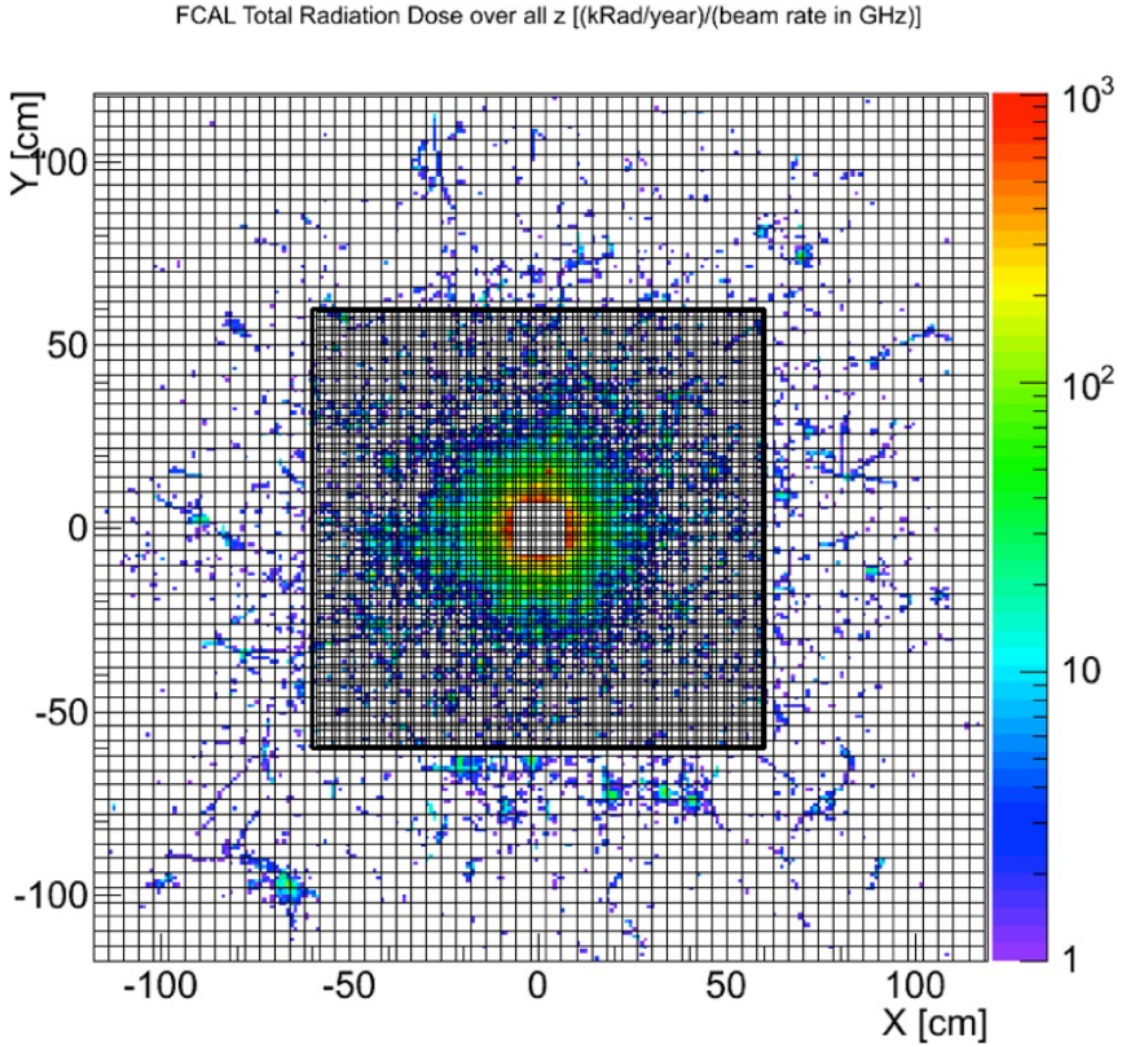




Expected Dose Rate for FCAL-II

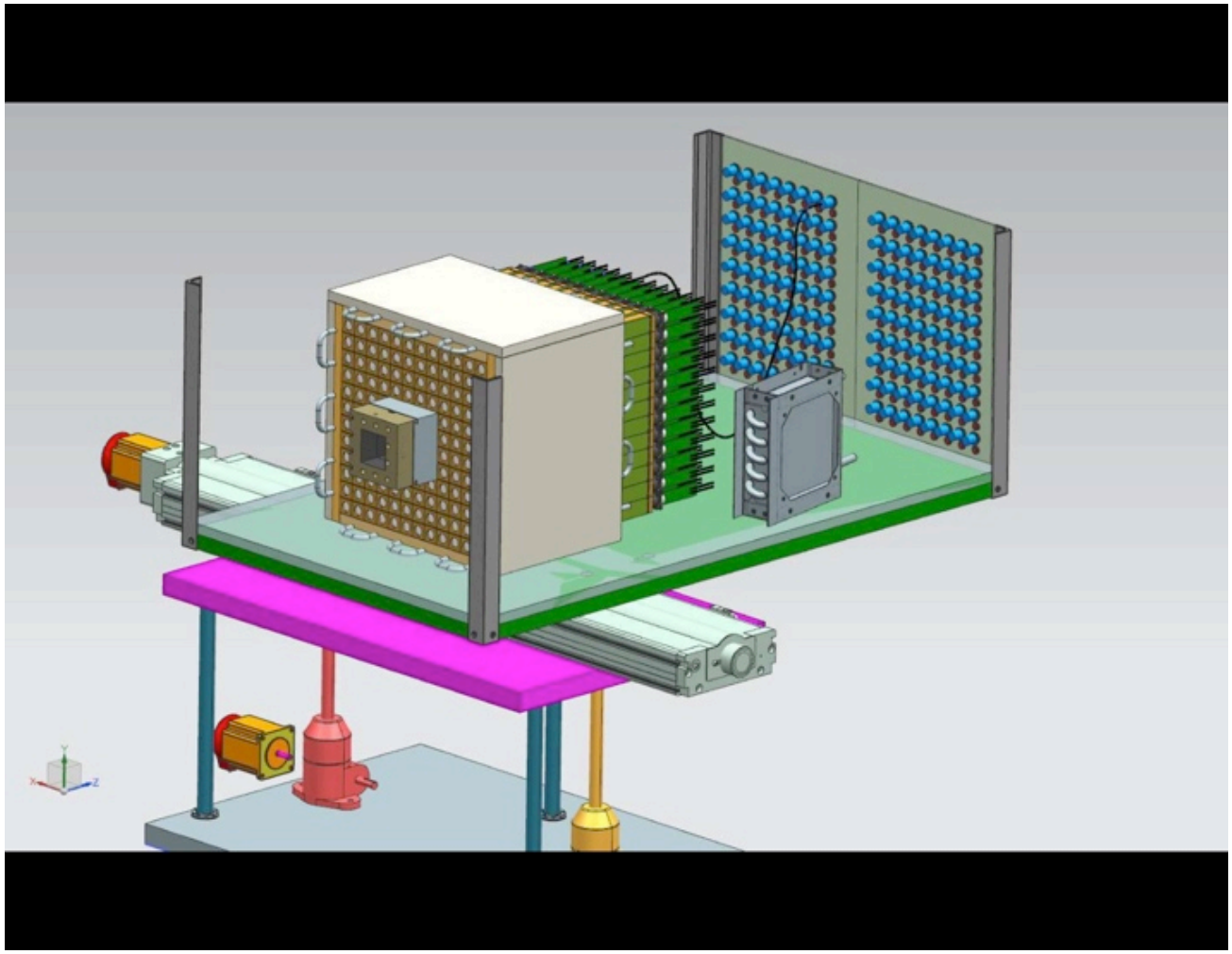
(by Dipangkar)

Conditions: luminosity = 1.1×10^8 tagged photons per second
EM background simulations only



- For the first crystal layer closest to the beam hole: ~100 krad/year (~12 rad/h)
- The 2-3 crystal layers to the beam hole: ~25 krad/ year (~3 rad/h)

Prototype calorimeter: CompCal



Summary

- FCAL-II requires about 900-2000 PWO crystals depending on available funds
- The most of the HyCal specifications are sufficient for FCAL-II
- More work will be needed in order to finalize the radiation hardness requirement for FCAL-II

Radiation Hardness: Protvino beam test result

Nucl.Instrum.Meth.A512:488-505,2003

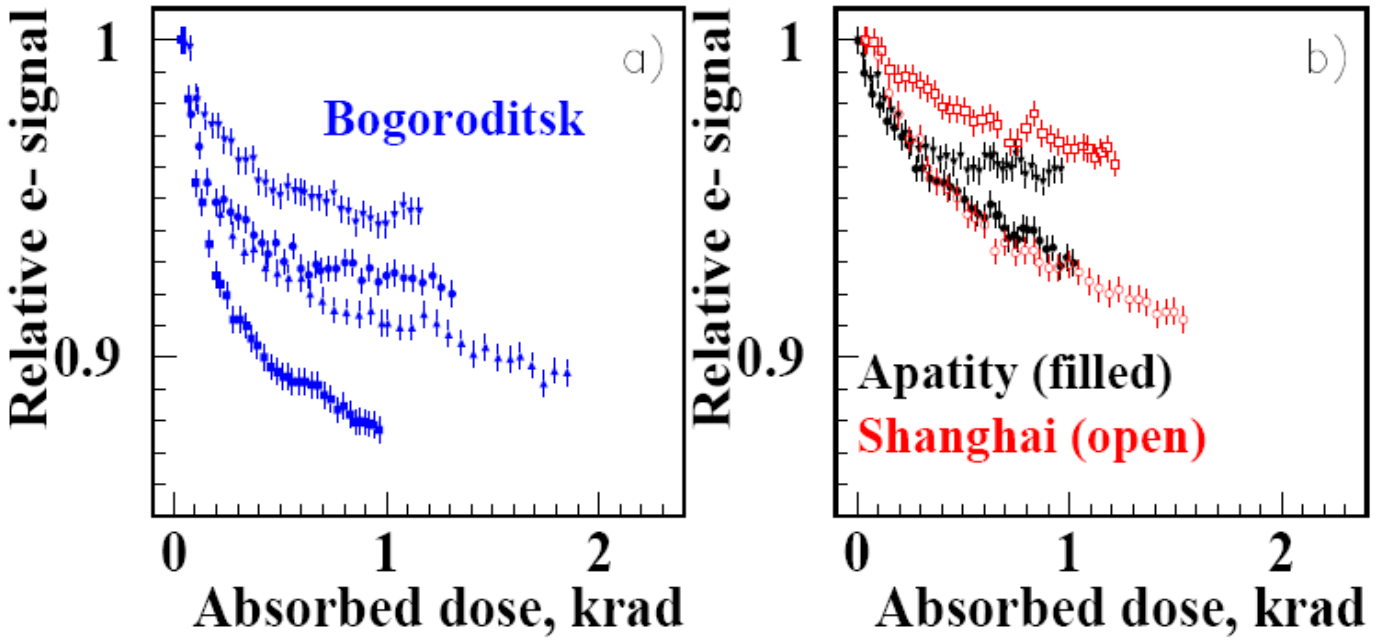


FIG. 13. The dependence of the electron signal on the absorbed dose (a) for the Bogoroditsk crystal (b) for the Shanghai (open points) and Apatity (filled points) crystals. Each crystal was irradiated by 27-GeV electrons for 85 hours.

- Dose rate: 10-25 rad/hour 27-GeV electron beam
- Average saturated light loss of ~8% after 1-2 Krad
- Recovery study shows that 85% damage can be recovered in 2 months after irradiation
- The energy resolution was not noticeably degraded after 2.5 Mrad dose at 60 rad/hour rate, so that radiation damage can be regarded as a gain calibration issue