THE CATHOLIC UNIVERSITY of AMERICA

Jefferson Lab

The EEEMCAL prototype beam tests with Pair Spectrometer in HallD

Vladimir V. Berdnikov (CUA)
for EEEmCal consortia

Jlab EIC meeting; August 20 2021

Yellow Report Calorimetry Requirements

η	Nomenclature			Tracking				Electrons and Photons			π/K/p PID		HCAL		Muons
				Min p_T	Resolution	Allowed X/X_0	Si-Vertex	Min E	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Min E	Resolution σ_E/E	
-6.9 — -5.8			low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
…															
-4.5 — -4.0	↓ p/A	Auxiliary Detectors													
-4.0 — -3.5			Instrumentation to separate charged particles from γ											~50%/√E+6%	
-3.5 — -3.0									2%/√E+ (1-3)%						
-3.0 — -2.5					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30μm/p_T+ 40μm								
-2.5 — -2.0			Backwards Detectors											~45%/√E+6%	
-2.0 — -1.5					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm				≤ 7 GeV/c				
-1.5 — -1.0									7%/√E+ (1-3)%	π suppression up to 1:10^4					
-1.0 — -0.5															
-0.5 — 0.0				100 MeV π											
0.0 — 0.5		Central Detector	Barrel		σ_p/p ~ 0.05%×p+0.5%	~5% or less	σ_{xyz} ~ 20 μm $d_0(z)$ ~ $d_0(r\varphi)$ ~ 20/p_T GeV μm + 5 μm	50 MeV			≤ 10 GeV/c	≥ 3σ	~500 MeV	~85%/√E+7%	Useful for bkg, improve resolution
0.5 — 1.0				135 MeV K							≤ 15 GeV/c				
1.0 — 1.5									(10-12)%/ √E+(1-3)%		≤ 30 GeV/c				
1.5 — 2.0					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm								
2.0 — 2.5			Forward Detectors							3σ e/π	≤ 50 GeV/c			~35%/√E	
2.5 — 3.0							σ_{xy}~30μm/p_T+ 40μm				≤ 30 GeV/c				
3.0 — 3.5					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30μm/p_T+ 60μm				≤ 45 GeV/c				
3.5 — 4.0															
4.0 — 4.5			Instrumentation to separate charged particles from γ												
…	↑e	Auxiliary Detectors													
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: 0.2< p_T <1.2 GeV/c										

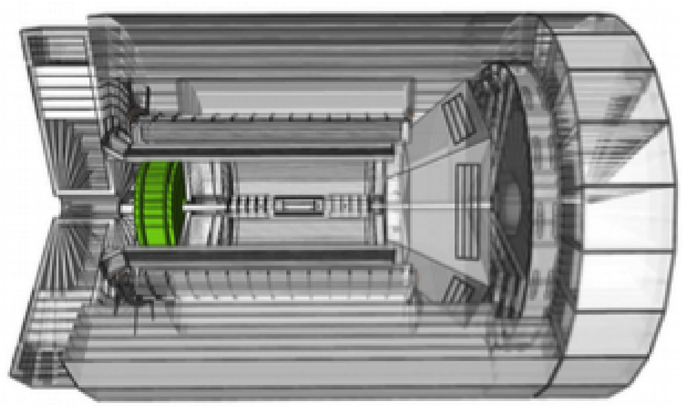
ECAL

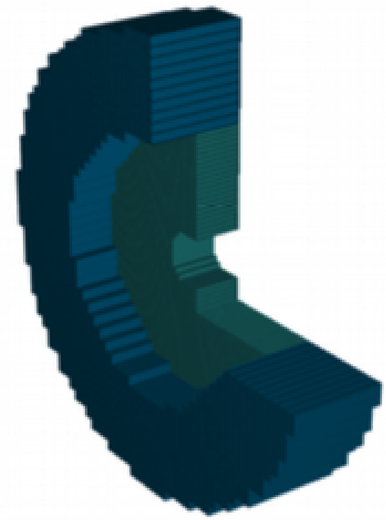
HCAL

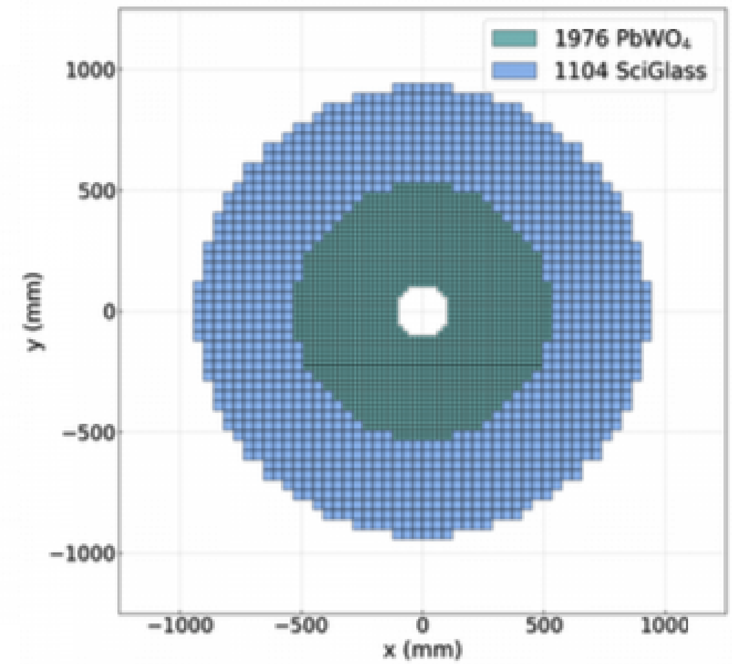
Figure 8.126: Summary of the Physics Working Group detector requirements

EEEMCAL

EEEMCAL consortia institutions:
CUA, LehighU., MIT and MIT-Bates Research and Engineering Center, U. Kentucky, AANL, FIU, Charles U.-Prague, IJCLab-Orsay







Dimensions/Location

Overall Length	60 cm
Bore	16 cm
Radius	82 cm
Support Sides	17
Support Radius	100 cm
Offset	199 cm in Lepton Direction
Total Volume	1.27 m^3

Geometry:
- z=-195cm
- R_in=11 cm (eta ~ -3.5) = R_min_PWO
- R_max_PWO=53 cm (eta ~2)=R_min_Glass
- R_max_total=100cm (eta ~ 1.4)=R_max_Glass

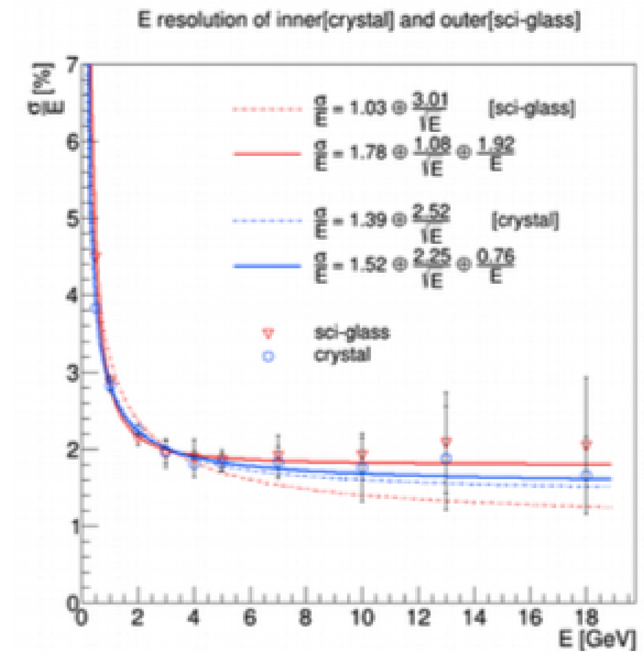
Modules **PWO 1976** (2x2x20 cm^3)
Modules **Glass 1104** (4x4x40 cm^3)
All PWO for this volume: ~7600 PWO modules
Weight: 5-6 tons

PWO: compact, radiation hard, luminescence yield to achieve high energy resolution, including the lowest photon energies
Sensor: SiPMs
SciGlass: EIC eRD1
radiation hard, luminescence yield similar or better than crystals depending on longitudinal length
Sensor: SiPMs

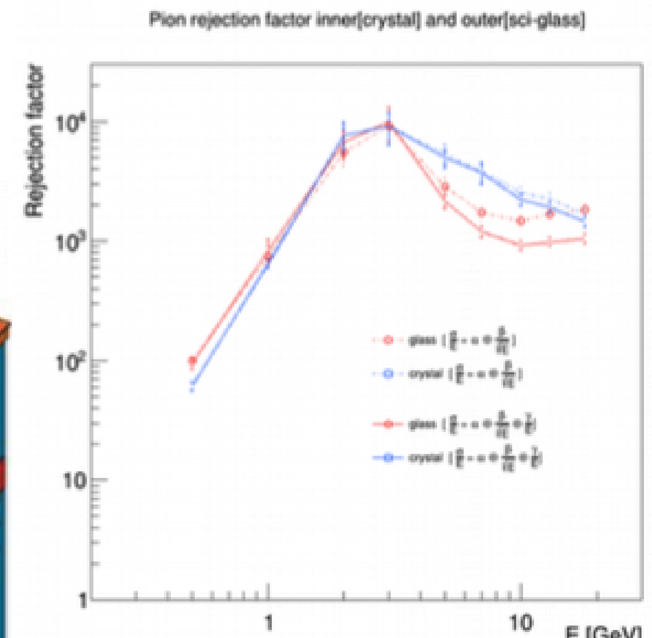
EEMCAL

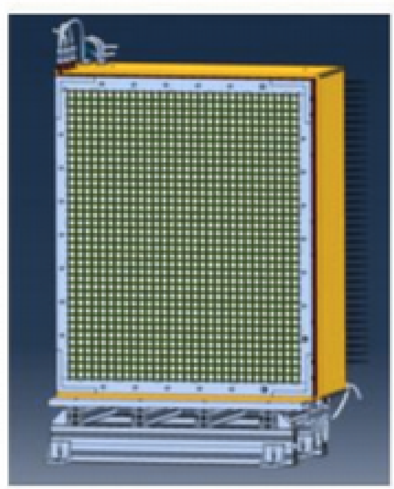
EEEmCal consortia items of interest and ongoing activities:

- Radiator: crystal/glass fabrication and characterization
- Frame design/construction – to hold the crystal/glass bars
- Prototype construction/commissioning and beam tests
- Monte Carlo simulations and comparison with test beam results
- Readout, electronics, detector cabling and infrastructure
- Slow controls and online software
- Calibration and monitoring of performance

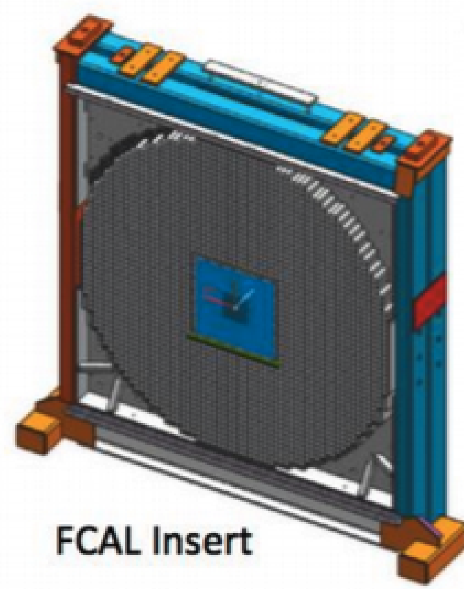


Questions:
- Cost vs Resolution
- Monolithic vs Hybrid



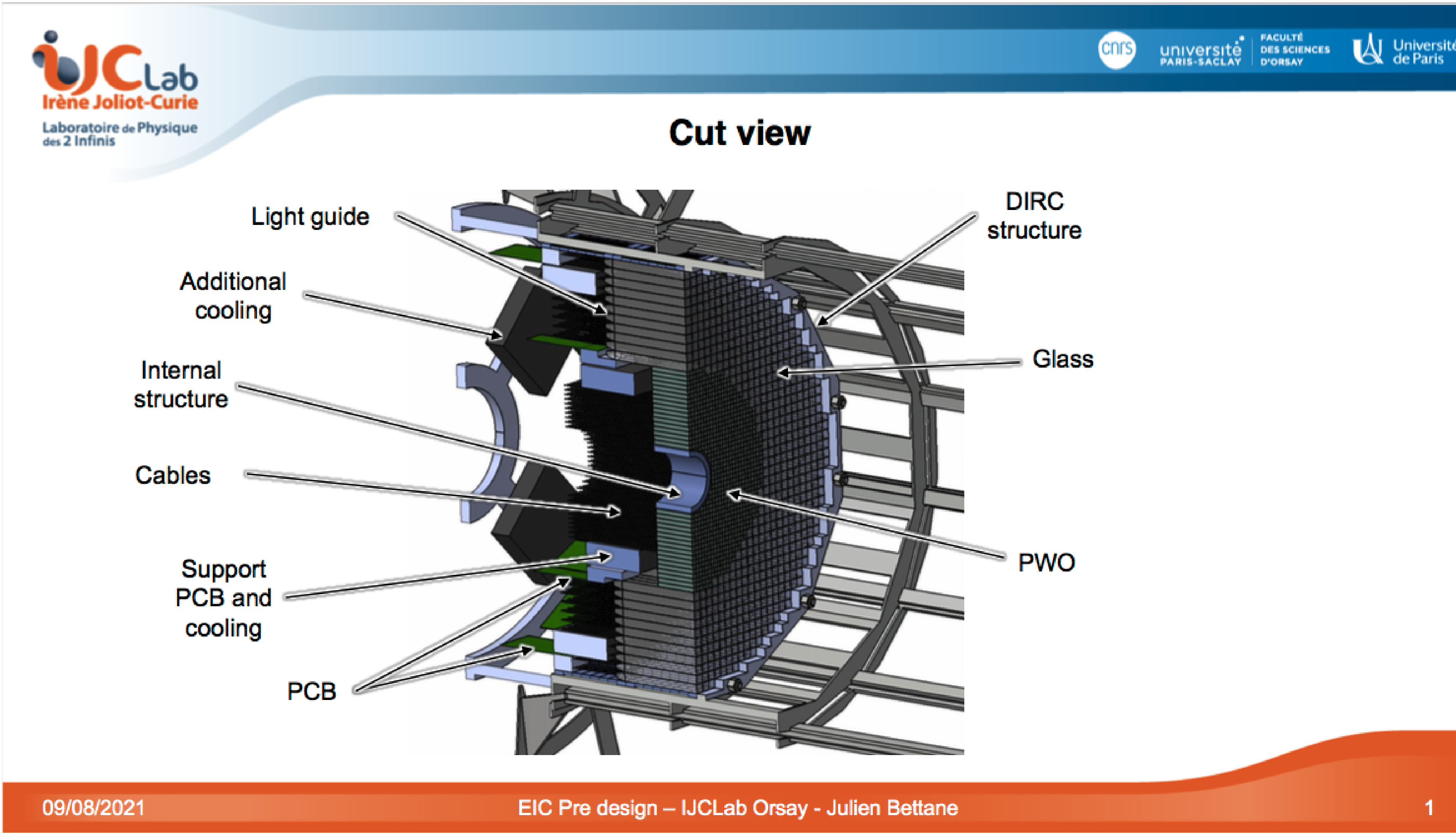


NPS



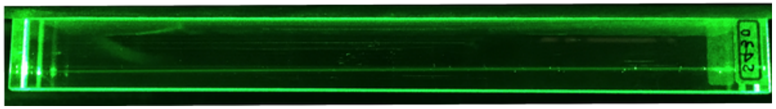
FCAL Insert

EEEMCAL mechanical predesign

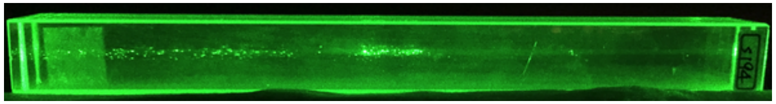


EEEMCAL PWO crystals

- Much effort has gone into crystal evaluation over the last decade
- Benefits from synergies with other projects: Neutral Particle Spectrometer (NPS) and FCAL at JLab, PANDA
  - Resources, prototypes, software development
- Crystal dimensions 20.5x20.5x200 mm3
- Vendors exist, but only two vendors of $PbWO_4$ crystals available worldwide
- Still some R&D related to raw crystal material powder
- SICCAS/China: failure rate ~30% of crystals produced in 2014-19 due to major mechanical defects
- CRYTUR/Czech Republic: Strict quality control procedures – so far 100% of crystals accepted

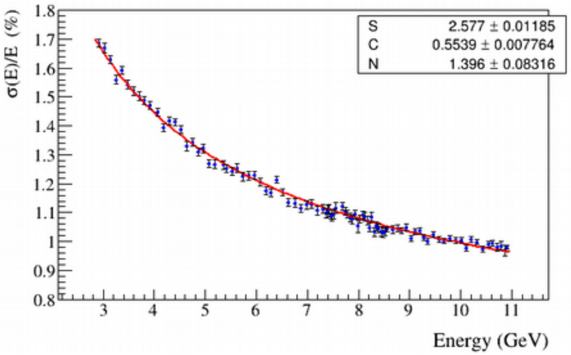


Good crystal



Bad crystal: bubbles in bulk, old labels ...

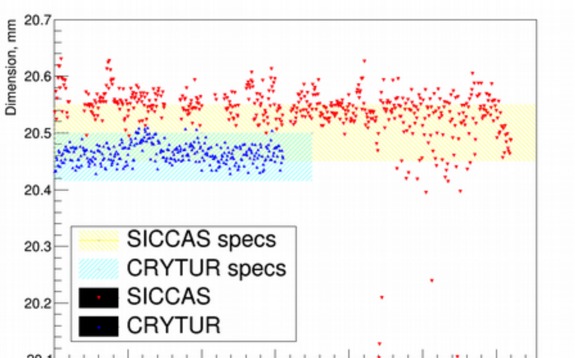
Electromagnetic calorimeters based on scintillating lead tungstate crystals for experiments at Jefferson Lab, 2021



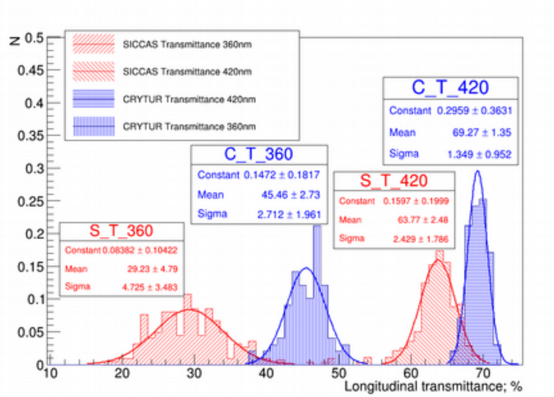
2x2x20 cm^3 , cluster 3x3

1.396%/E+2.577%/sqrt(E)+0.5539%

https://inspirehep.net/literature/1896934



Quality check: dimension uniformity



Longitudinal transmittance

EEEMCAL SciGlass

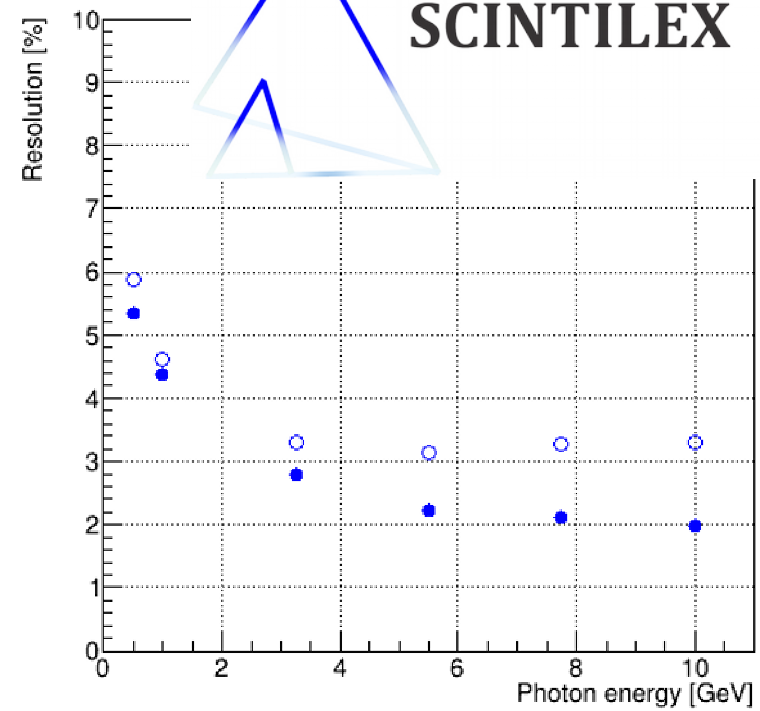
- **Ongoing EIC R&D program (eRD1)**
- **Simulation suggests a resolution comparable to PbWO4**

$$\frac{\sigma_E}{E} = \frac{2.5\%}{\sqrt{E}} \oplus \frac{2.7\%}{E} \oplus 1.5\%$$

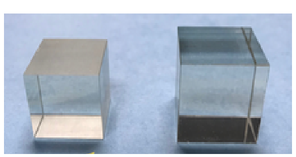
Assumes that 40cm long glass bars with these properties will be available for mass production

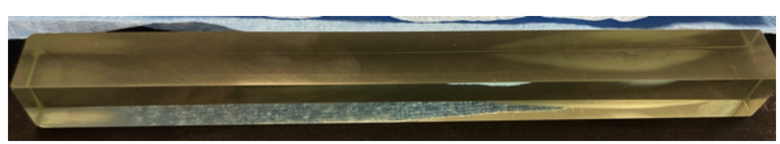
- **Scintilex has developed the scale-up and can now fabricate 20cm and 40cm long glass bars – optimization ongoing.**
- **Ongoing preparation for beam tests: bars need to be polished (flatness, rectangularity etc.), quality assurance, testing with gamma sources, cosmic**

SCINTILEX



MC results for 40 and 50 cm long bars





1cm x 1cm x 0.5cm

2cm x 2cm x (2-4)cm

2.0cm x 2.0cm x 20.0cm

4.0cm x 4.0cm x 40.0 cm

2019

2020

2021

Scintillating Glass beam performance in the past

Performance of a scintillating glass calorimeter for electromagnetic showers, 1988

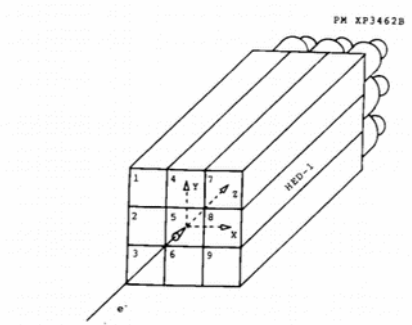


Fig. 3. Layout of the calorimeter setup in the test bea

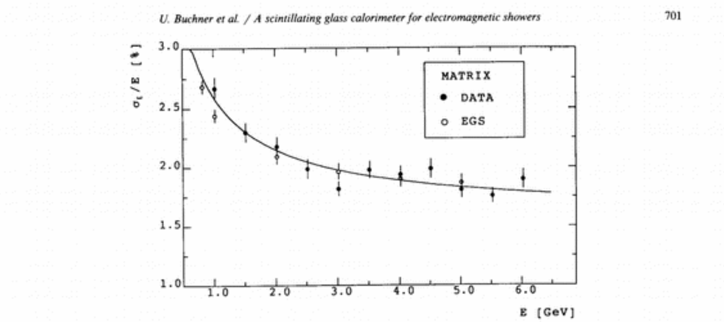


Fig. 12. Energy resolution as a function of the electron energy (black circles) and the EGS prediction (open circles). The line shows the parametrization (4) described in the text.

8x8x66 cm^3

ER=1.46%/E+2.4%/sqrt(E)+1.63%

https://inspirehep.net/literature/261664

The Experiment 705 Electromagnetic Shower Calorimeter, 1993

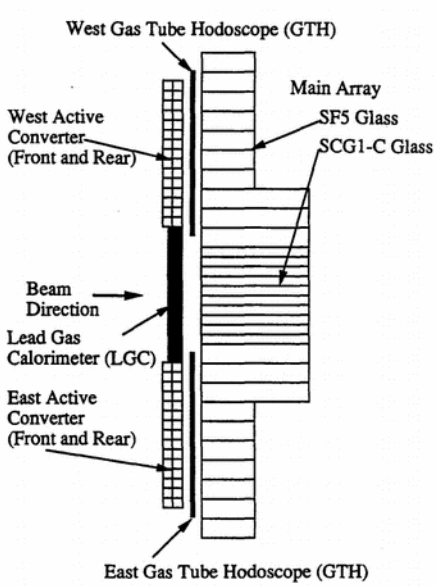


Figure 1. Plan view of the major components of the Experiment 705 calorimeter

	SCG1-C	SF5
Composition (by weight)	BaO 43.4% SiO2 42.5% Li2O 4.0% MgO 3.3% K2O 3.3% Al2O3 2.0% Ce2O3 1.5%	PbO 55% SiO2 38% K2O 5% Na2O 1%
Density	3.36 g/cm3	4.08 g/cm3
Radiation Length	4.25 cm	2.47 cm
Absorption Length (30-200GeV/c^2 pions)	45.6 cm	42.0 cm

Table 1. Properties of SCG1-C Scintillating and SF5 Lead Glass

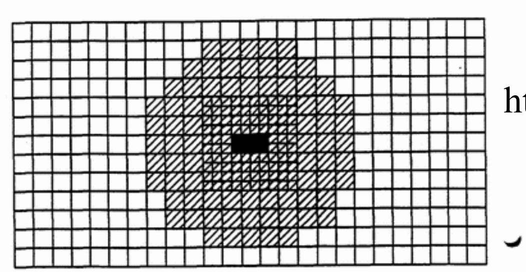


Figure 2. Beam view of the Main Array (SCG1-C scintillating glass is cross-hatched)

15.x15.x89 cm^3

7.5x7.5x89 cm^3

Rad. Length 20.9 X0

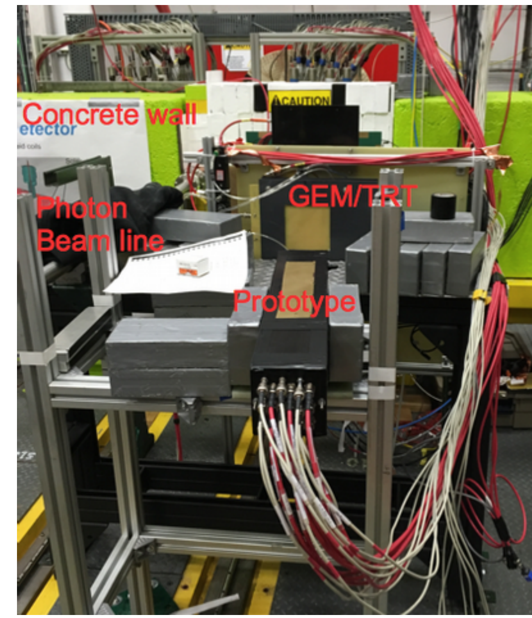
ER=0.99%+4.58%/sqrt(E)

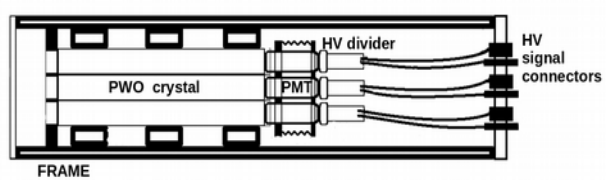
https://inspirehep.net/files/1299a6aa1e200e01f9d7f208800a81f6

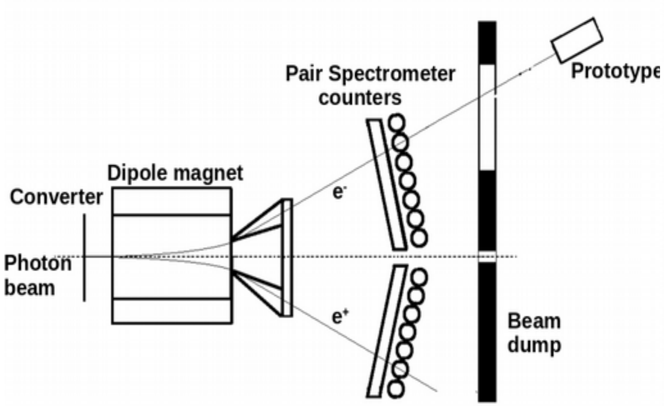
Beam tests with Configuration #1 prototype

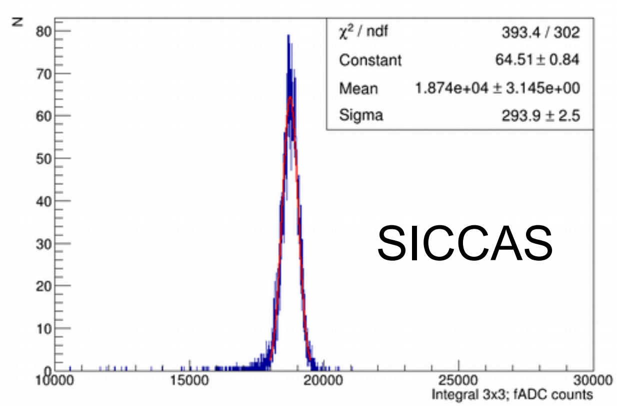
Goal of the tests: PWO crystal quality check and vendor comparison for NPS, FCAL insert projects and eRD1 consortium

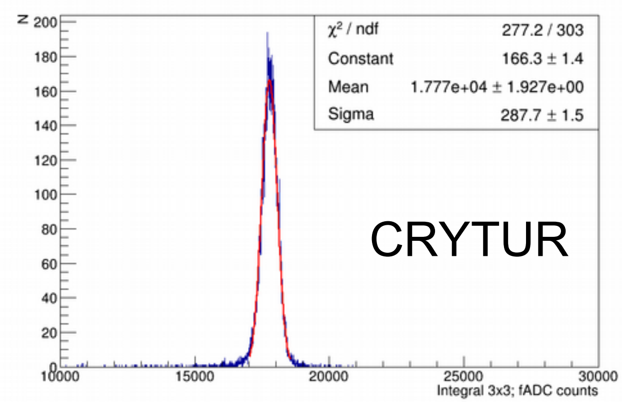
- **Installed 3x3 prototype behind the PS with SICCAS or CRYTUR crystals**
- **Readout electronic chain optimized**
- **Energy resolution at 4.7 GeV is about 1.5 % for bypassed bases**
- **Light yield of SICCAS crystals is about 6 % larger than CRYTUR**
  - ✯ **True for selected SICCAS crystals, but large variation in SICCAS crystal properties while CRYTUR is very uniform**
- **Details: Nucl.Instrum.Meth.A 956 (2020) 163375**



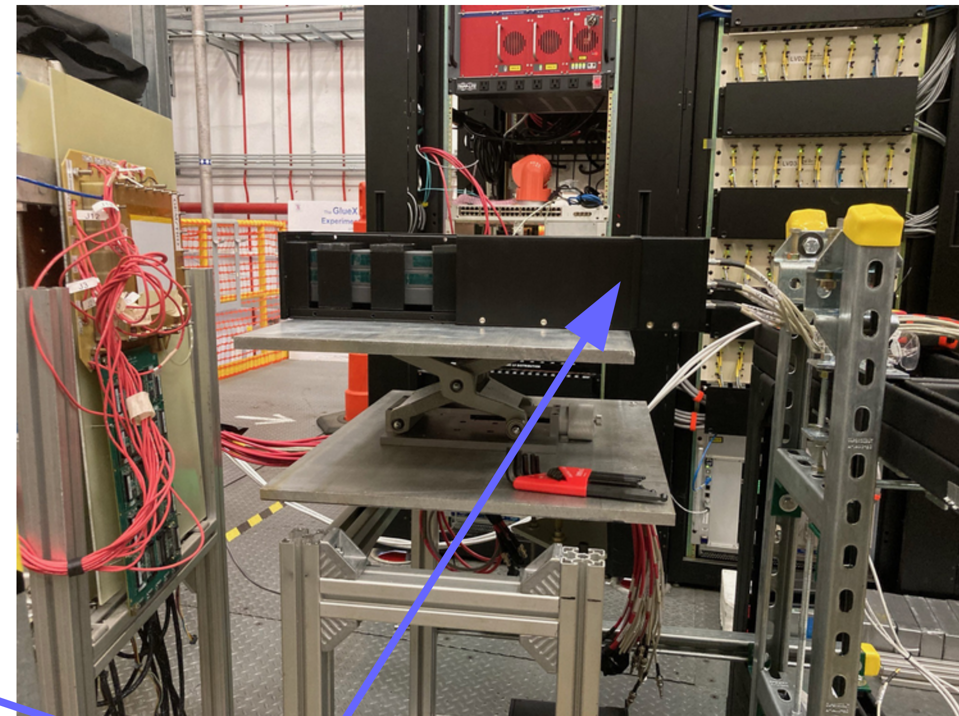








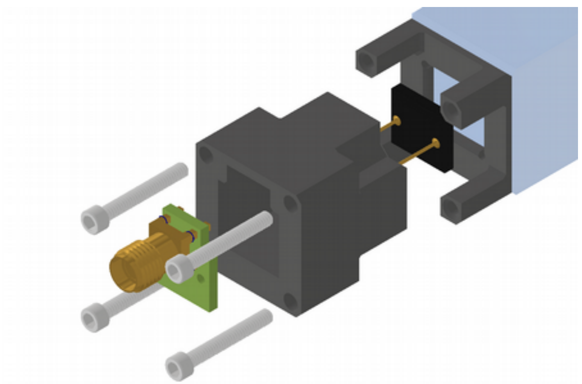
Beam test preparations



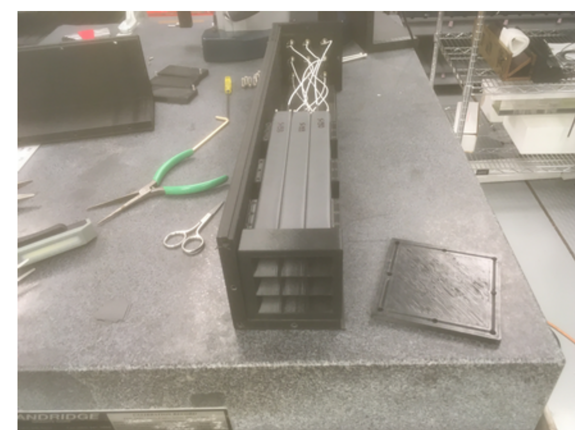
EEEMCAL prototype

Configuration #2: SiPM based 3x3 PWO prototype

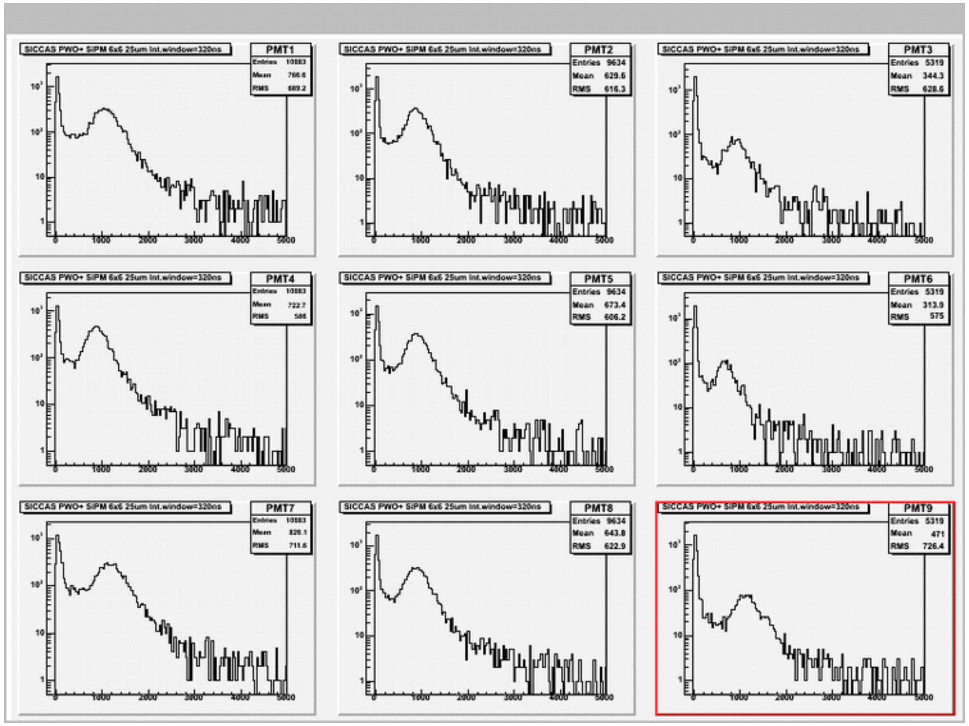
Goal of the tests: Optimize and test SiPM readout chain with new generation PWO crystals



- **Improved prototype with new SiPM based assembly**
- **Same size 3D printed frame as PMT based version**
- **Two piece SiPM holder concept developed**
- **Holders are 3D printed (PLA plastic)**
- **PEEK plastic will be used in real detector**
- **Silicon based glue for frame, no SiPM glueing to crystal**
- **SiPM soldered to circuit board with SMA connector**
- **25um cell SiPM for beam tests installed (75um second option)**
- **LEMO output at the detector patch panel (BIAS/Preamp or Waveboard application)**



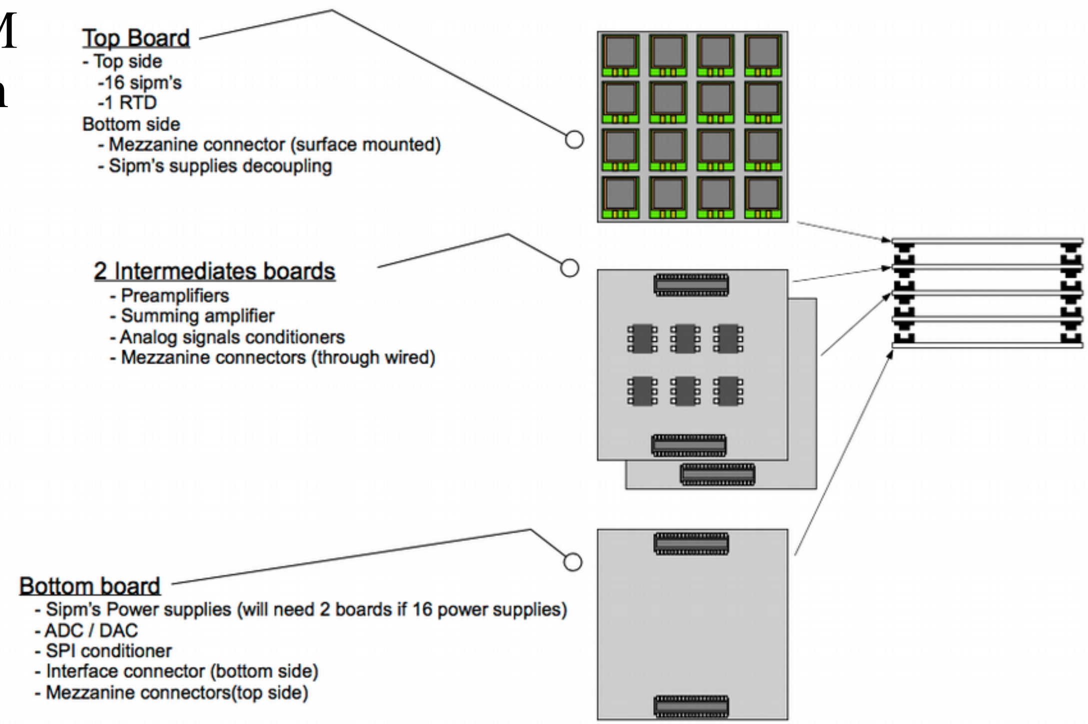
Configuration #2: SiPM based 3x3 PWO prototype

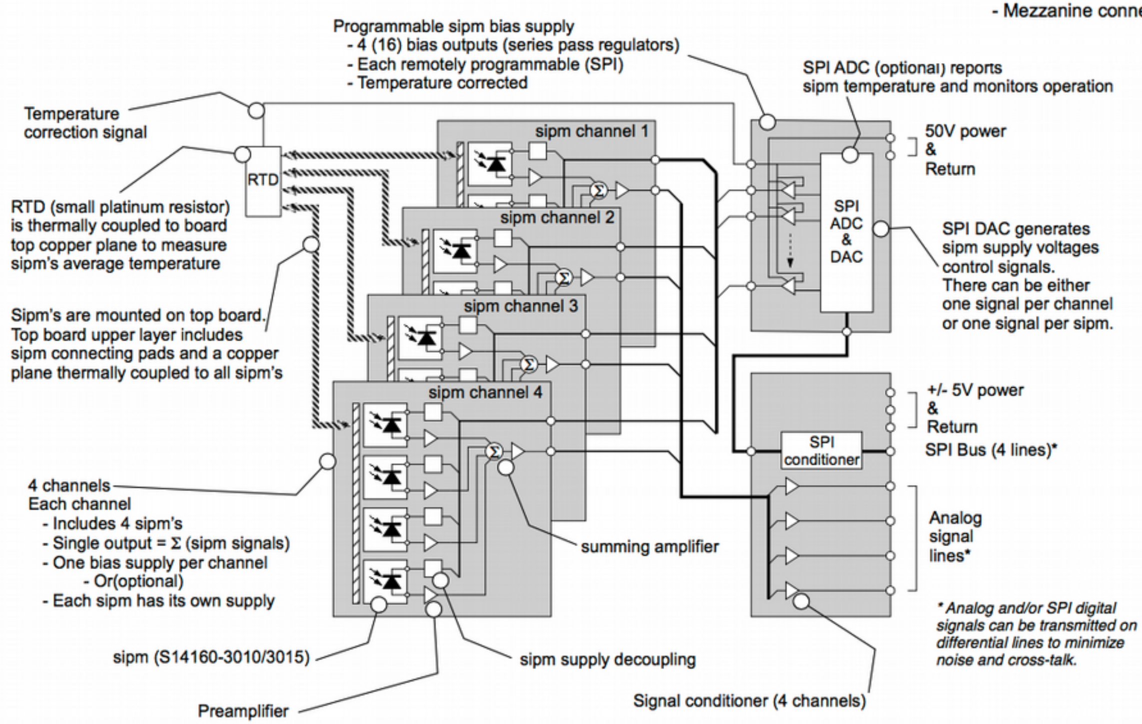


Configuration #3: SiPM matrix based 3x3 CRYTUR PWO prototype

Goal of the tests: Optimize and test SiPM matrix readout chain with new generation PWO crystals

- CRYTUR USA concept
- 9 CRYTUR crystals
- 16 SiPMs per crystal
- 3x3 mm^2 SiPMs
- ~90k cells per SiPM
- Plug-n-play prototype
- First working RO version for EIC





- Expect delivery: October 2021
- Direct performance comparison with 3x3 PMT version, INFN SiPM version
- Energy resolution studies
- Noise studies
- Light collection studies
- Linearity studies
- Threshold studies

Outlook

- **The method for calorimetry tests behind PS in hallD established with series of successful measurements since 2018**
- **Beam performance comparison between CRYTUR PWO crystals produced from powder purchased from old and new vendor**
- **Different electronics readout chains PMT`s and SiPM`s , preparations ongoing**
- **Readout using SiPM matrix, development ongoing**
- **Trigger and trigger-less (SRO) DAQ options**
- **New generation Scintilex SciGlass measurements with the beam**
- **Expecting ~ 10 new different configurations during 2021 run including PWO crystals and new generation SciGlass bars, different photosensor readout and DAQ options**