Lead Tungstate Calorimetry

CORE Workshop
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IJCLab – Orsay, CNRS/IN2P3

(in collaboration with the eRD1 consortium)

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Introduction

- Lead tungstate (PWO) is the preferred material for high resolution EM calorimetry
- Excellent resolution (~1-2%/√E) due to its high LY (wrt to eg. Cerenkov materials)
- Very dense: allows for compact detectors
- Good radiation hardness

Typical PWO specs for different experiments

Parameter	Unit	NPS	Hy(F)CAL	EIC	CMS	PANDA
Light Yield (LY) at RT	pe/MeV	≥15	≥9.5	≥15	≥8	≥16
LY (100ms)/LY(1μs)	%	≥90	≥90	≥90	≥90	≥90
Longitudinal Transmission						
at λ=360 nm	%	≥35	≥10	≥35	≥25	≥35
at λ=420 nm	%	≥60	≥55	≥60	≥55	≥60
at λ=620 nm	%	≥70	≥65	≥70	≥65	≥70
Inhomogeneity of Transverse Transmission $\Delta\lambda$ at T=50%	nm	≤5	≤6	≤5	≤3	≤3
Induced radiation absorption coefficient dk at λ=420 nm and RT, for integral dose ≥100 Gy	m^{-1}	≤1.1	≤1.5	≤1.1	≤1.6	≤1.1
Mean value of dk	m^{-1}	≤0.75		≤0.75		≤0.75
Tolerance in Length	μm	≤ ±150	-100/+300	≤ ±150	≤ ±100	≤ ±50
Tolerance in sides	μm	≤ ±50	±0	≤ ±50	≤ ±50	≤ ±50
Surface polished, roughness Ra	μm	≤0.02		≤0.02	≤0.02	
Tolerance in Rectangularity (90°)	degree	≤0.1		≤0.1	≤0.12	≤0.01
Purity specific. (raw material)						
Mo contamination	ppm	≤1		≤1	≤10	≤1
La, Y, Nb, Lu contamination	ppm	≤40		≤40	≤100	≤40

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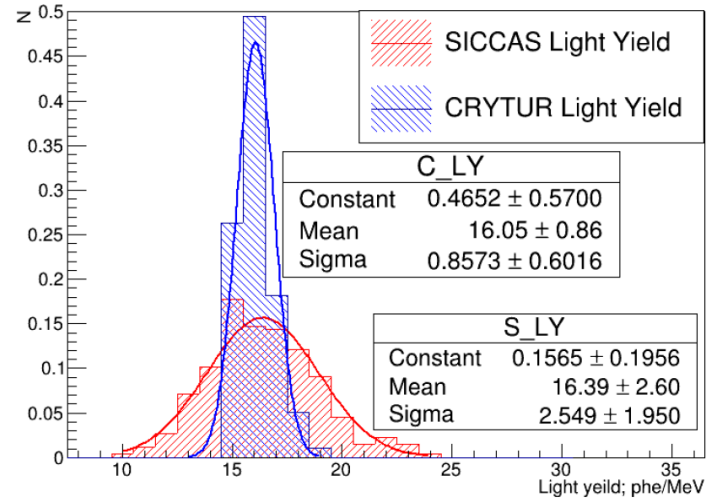
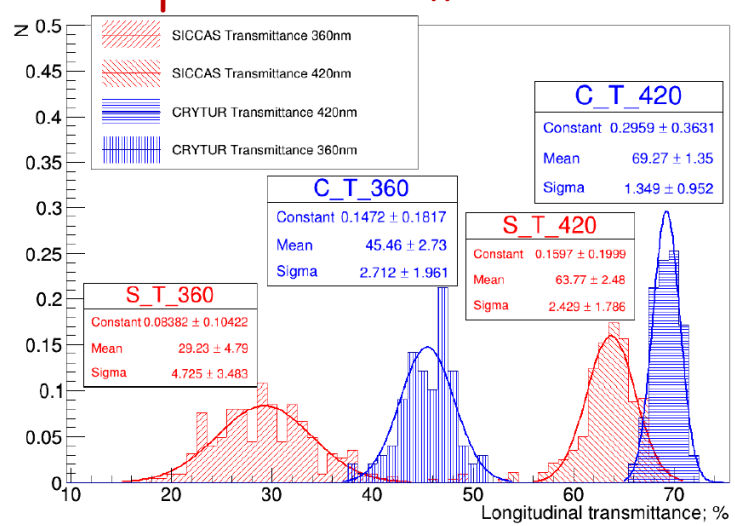
PWO Manufacturers

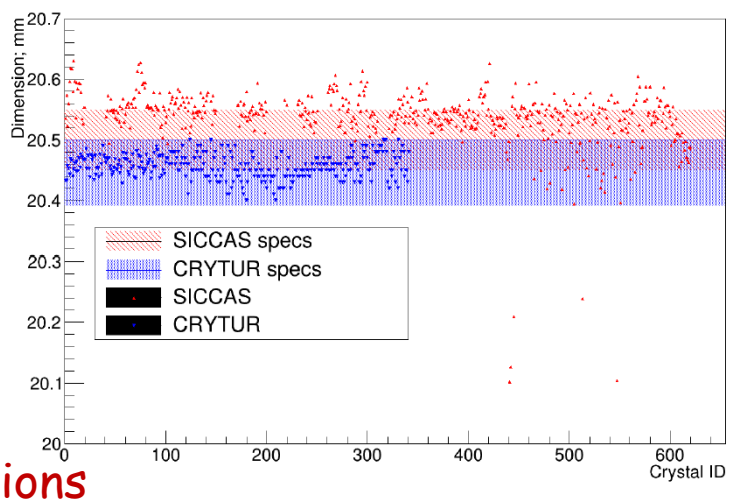
- Up to 2010 – PWO-II production at BTCP, Russia
  - Missing funding -> bankruptcy of BTCO
- Limited availability of reliable producer
  - SICCAS (China): significant QA concerns
- 2014: Restart of high-quality PWO-II production at CRYTUR (Czech Republic)
  - 900 crystal produced for JLab since 2018 at 20-30 crystals/month
- Cost of PWO: $15-25/cm^3

Light yield



Optical transmittance





Dimensions

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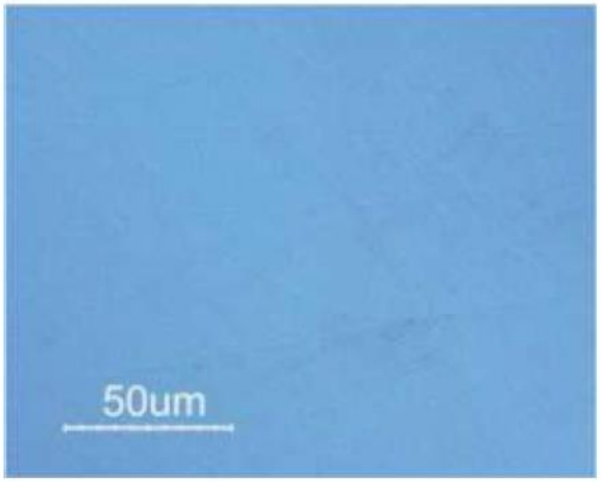
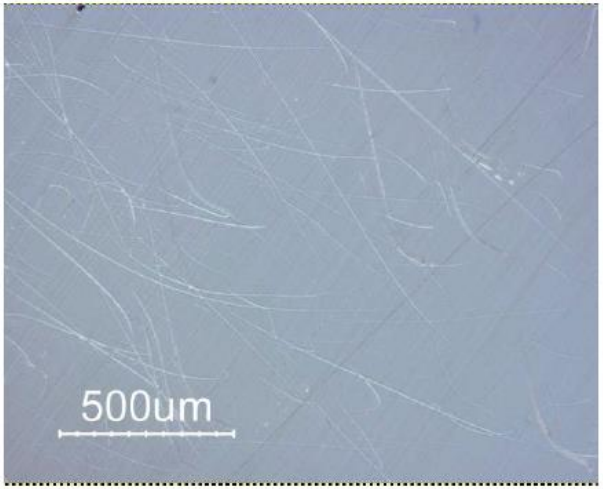
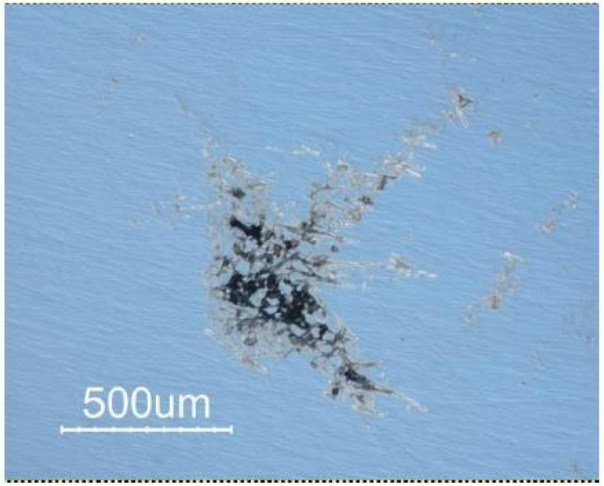
Surface properties



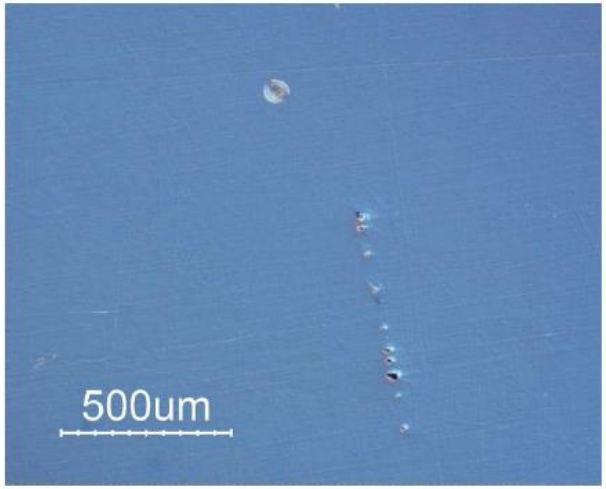
(a) Crytur



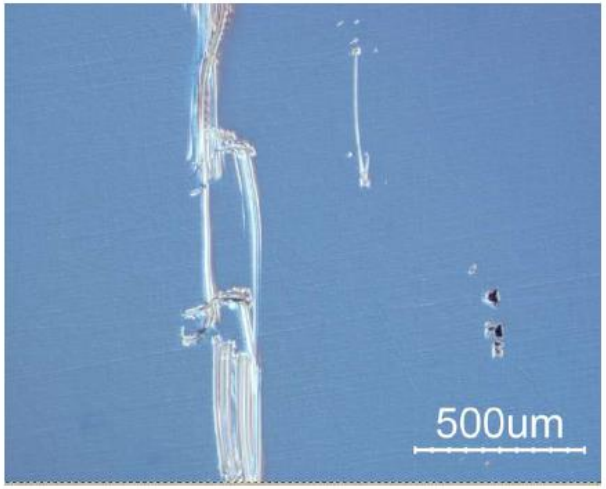
(b) BTCP



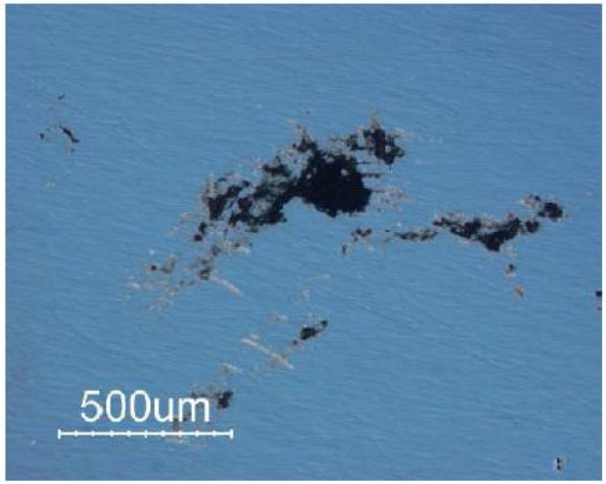
(c) SICCAS



(a) SICCAS crystals bubbles



(b) SICCAS crystals scratches



(c) SICCAS crystals pits

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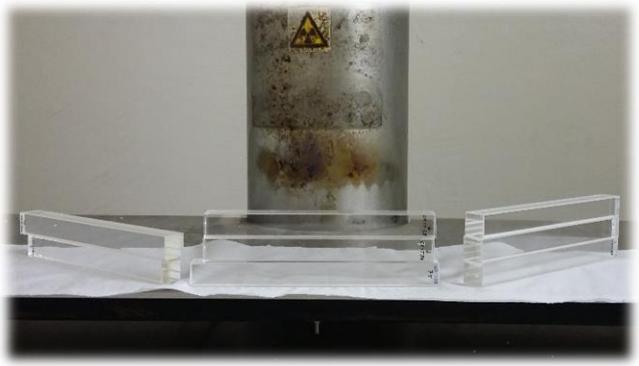
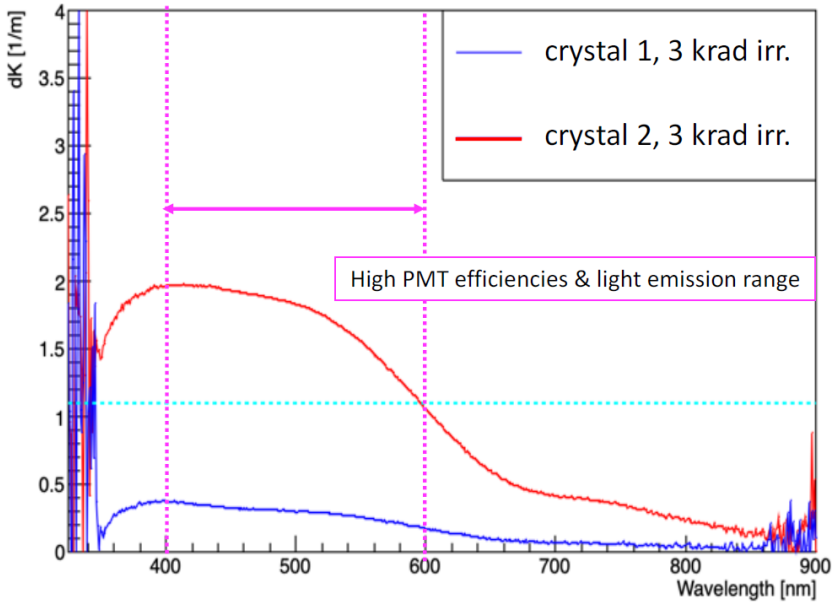
Irradiation measurements

Panoramic irradiation facility in Orsay

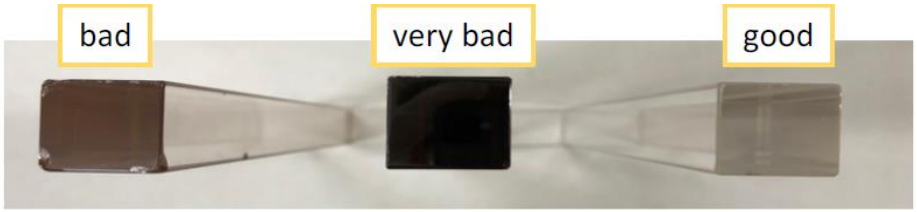


Dose rates:
0.01 to 100 Gy/min



$$dk = ln(T_b/T_a)/l$$

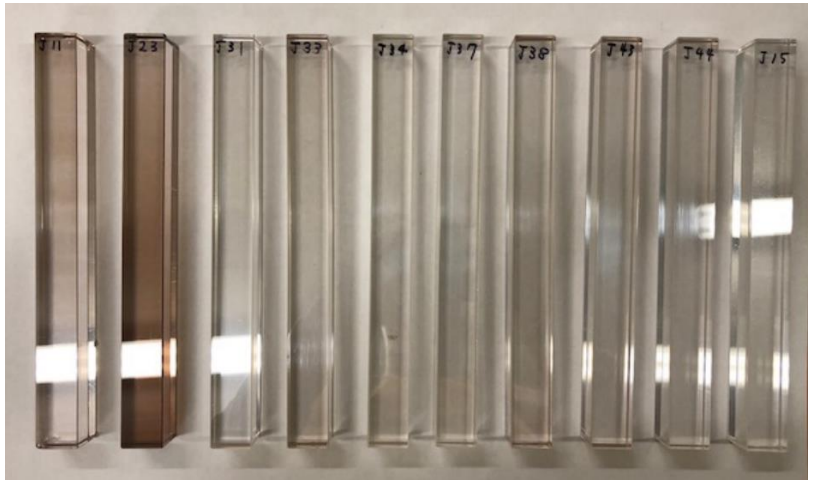
T_b : transmittance measured before the irradiation
T_a : transmittance measured after the irradiation
l : length of the crystal



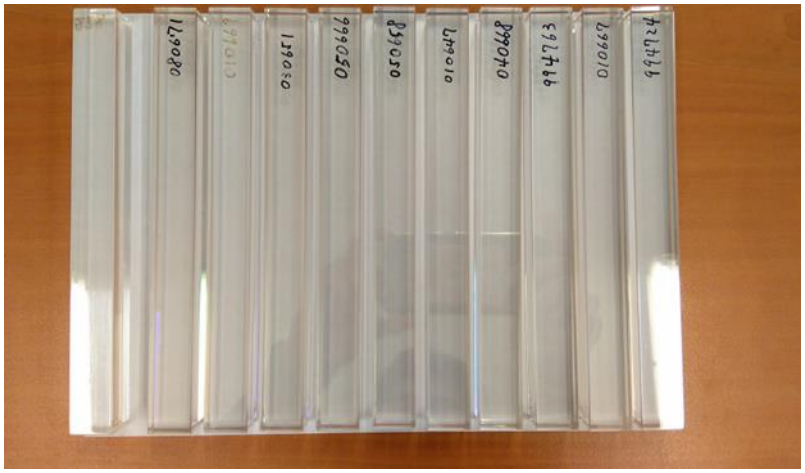
After 500 krad dose (SICCAS)

Radiation hardness

^{60}Co source irradiation



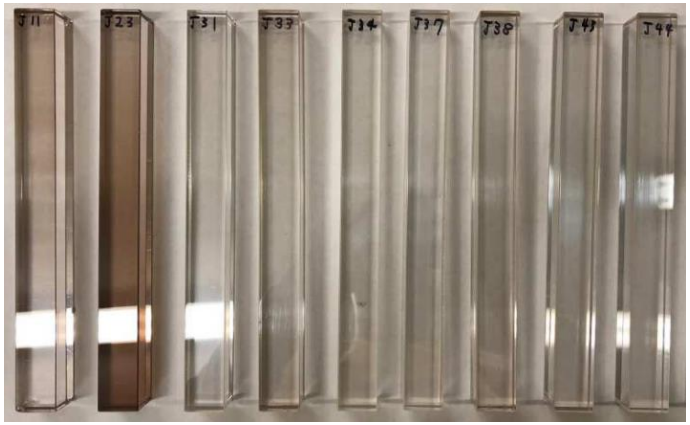
SICASS: 0.5 MRad

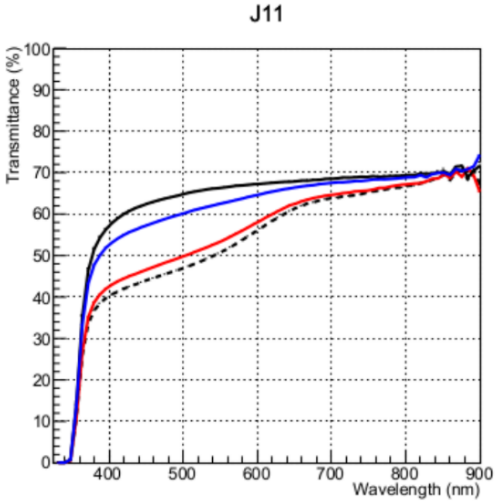


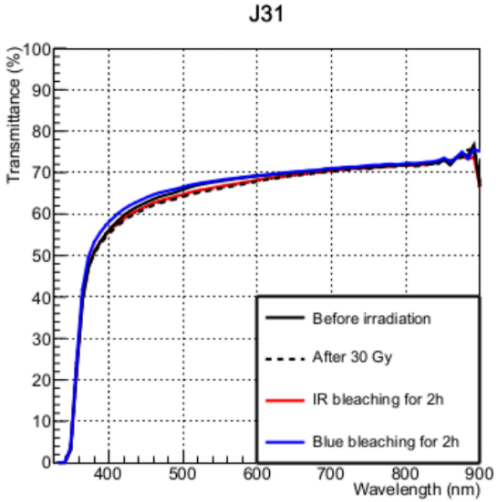
Crytur: 1 MRad

Optical bleaching

- Optical bleaching with blue light validated
- Tests with infrared light also: less efficient







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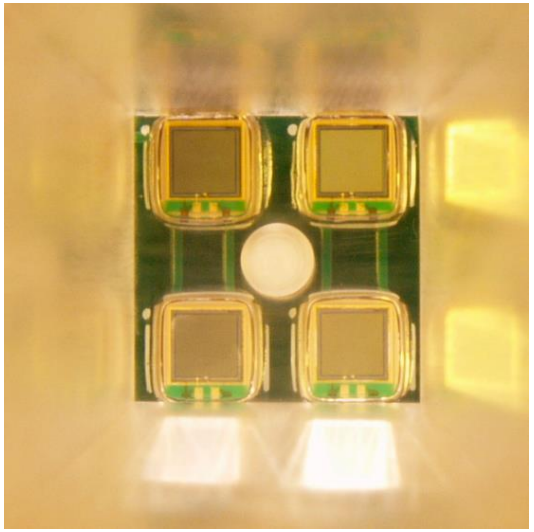
Readout

Interest in investigating the combination of PWO and SiPM as a readout

- ✓ Fast response
- ✓ Insensitive to magnetic field
- ✓ Higher gain (than eg. APDs)

- Small size
- Significant dark noise
- Not very radiation hard



Challenge:

Large dynamic range → high pixel density required

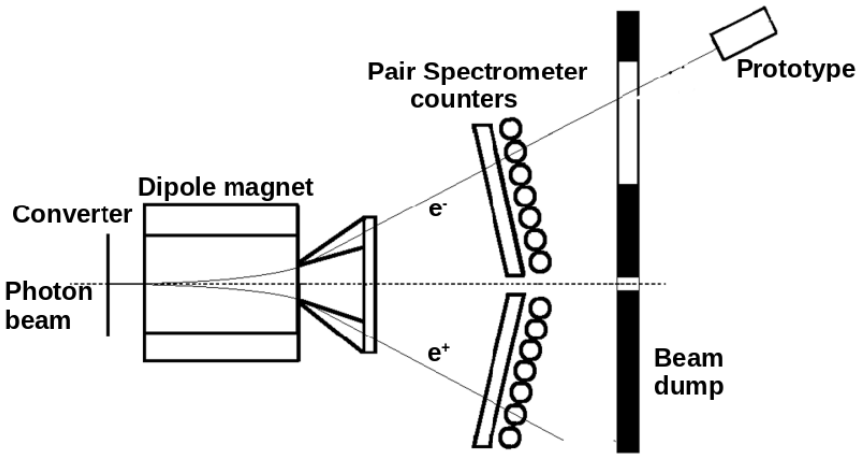
(usually also means small size)

Fallback solution:
APDs (lower gain → better frontend electronics required)

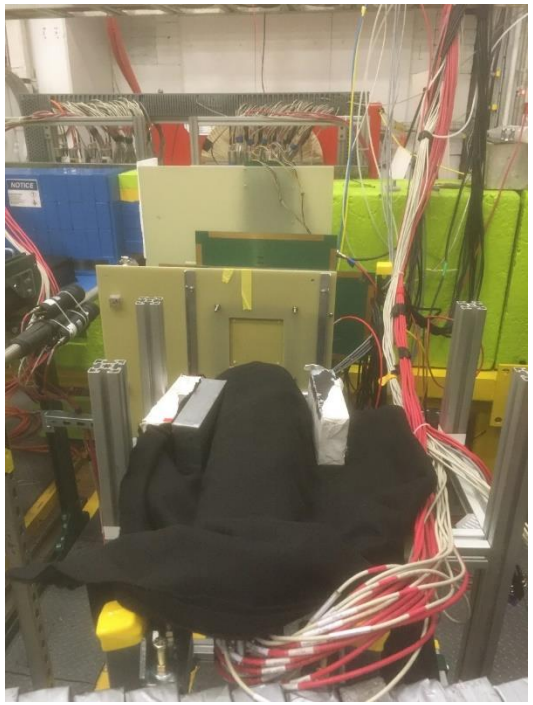
Electronics:

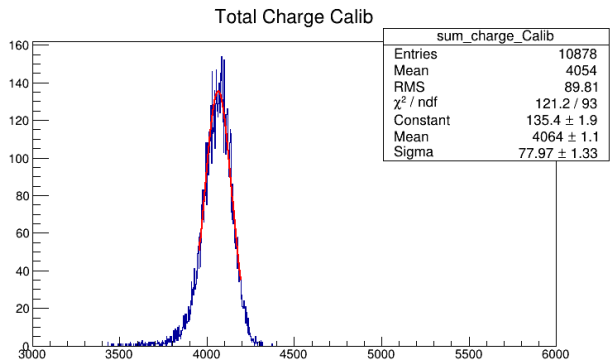
SiPM & ~10k channels → ASIC readout (commercial or to be developed)

Beam test



- Instrument two 3x3 SiPM and PMT based prototypes to test scintillator materials and test/optimize the entire readout: preamps, fADC and streaming DAQ system
- Establish baseline performance with PMT based PWO prototype and standard RO – performed a few test runs
- Tests in Hall D with 8 production configurations





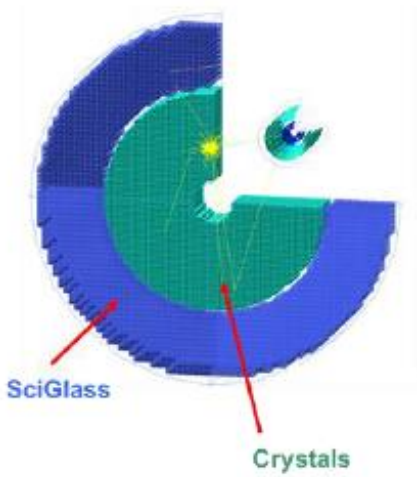
Energy resolution:

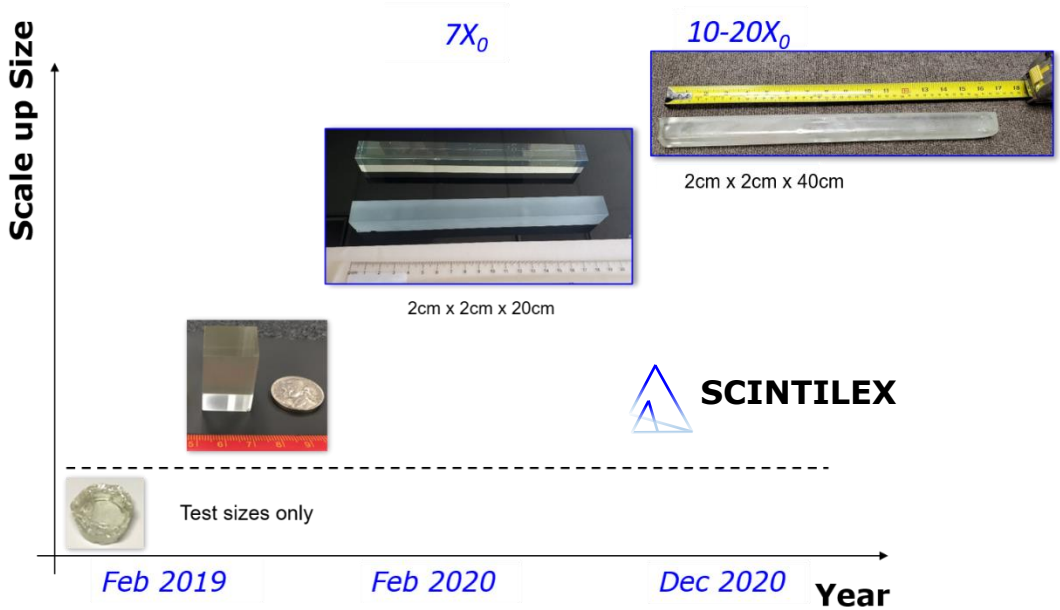
~1.9% for ~4 GeV lepton

EEEMCal EoI

Collaboration (open to new institutions):

CUA (contact: Tanja Horn), Lehigh U. (contact: Rosi Reed), MIT and MIT-Bates Research and Engineering Center (contact: Richard Milner), U. Kentucky (contact: Renee Fatemi), AANL (contact: Ani Aprahamian), FIU (contact: Lei Guo), Charles U.-Prague (contact: Miroslav Finger), IJCLab-Orsay (contact: Carlos Munoz-Camacho)





Expected cost: $2/cm2 (10 x less than PWO)

- SciGlass is a radiation hard material optimized to provide characteristics similar to or better than PbWO4
  - Fabrication is expected to be cheaper, faster, and more flexible than PbWO4 crystals.
- SciGlass is being developed by Scintilex, LLC in collaboration with the Vitreous State Laboratory at CUA

Overview of EEEMCal specs

- Coverage: -3.5 < eta < -1
  - Inner: Rin=15cm, Rout=49cm
  - Outer: Rin=49cm, Rout=133cm
- Egamma:
  - Inner: 20 MeV – 20 GeV
  - Outer: 50 MeV – 20 GeV
- Energy Resolution:
  - Inner: 1%+2.5%/sqrtE+1%/E
  - Outer: 2%+4%/sqrtE+2%/E
- Spatial Resolution:
  - 1mm+3mm/sqrtE
- Maximum Annual Dose at top luminosity:
  - EM: ~3krad/year (30 Gy/year)
  - Hadron: 10^10 n/cm2
- Signal dynamics
  - 2 V dynamic range
  - ADC 12 bits
- Signal Rate: =<1 MHz/channel
- Digitization Gate: ~(100-200) ns
- Sampling Rate: 250 MHz
- Peaking Time: ~4ns
- Data sparsification/feature extraction
  - Peak
  - Integral
  - Time
  - Pedestal
  - Number samples
  - Pulse quality
  - Pileup detection and recovery

Conclusion

- PWO can provide excellent resolution EM calorimetry with a very compact design
- A major drawback is its current cost that prevents to cover large areas with a reasonable budget
  - CORE design: 0.78 m^2 electron endcap + 4.2 m^2 barrel $\rightarrow$ ~$20-25M
- A more cost-effective alternative could be SciGlass (in final R&D stage)
- CRYTUR is by far the best currently available producer of PWO
- SICCAS can still produce PWO crystals (cheaper than CRYTUR) but quality control remains an issue

Back up