A Generic Crystal Calorimeter R&D Proposal

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Outline:

- ✧ Introduction and our goals
- ✧ BSO Crystal Characteristics
- ✧ Doped PWO Characteristics and R&D Plan
- ✧ Summary

Introduction

1) Crystal detectors have been widely used for their excellent energy resolution and e-γ/hadron separations.

2) In an EIC detector along the electron forward direction, excellent electron energy resolution is needed (low x region) – crystal detector is a viable option, especially if a solenoid magnet is used for the tracking.

3) BSO crystals show very promising features as a detector

Our goals:

1) Characterize BSO crystals from SICCAS and define the requirements for a crystal detector at EIC

2) work with SICCAS to improve the PWO crystal performance

3) establish detector performance and reliable crystal vendor for EIC

Requirements for Crystals

BGO and PWO Crystal detectors have been widely used in high energy experiments.
- Identify electron and photon
- Measure energy/position(angle)
- Electron/photon trigger

Requirements:

1) **High light yield output for high energy resolution (~ a few percent).**
2) **Resistance to irradiated damage must be high. (e.g. $\eta < -2$, L~ 10^{34}).**
3) **Fast timing for trigger.**
4) **Cost/performance optimized.**

Properties of crystals[1]:

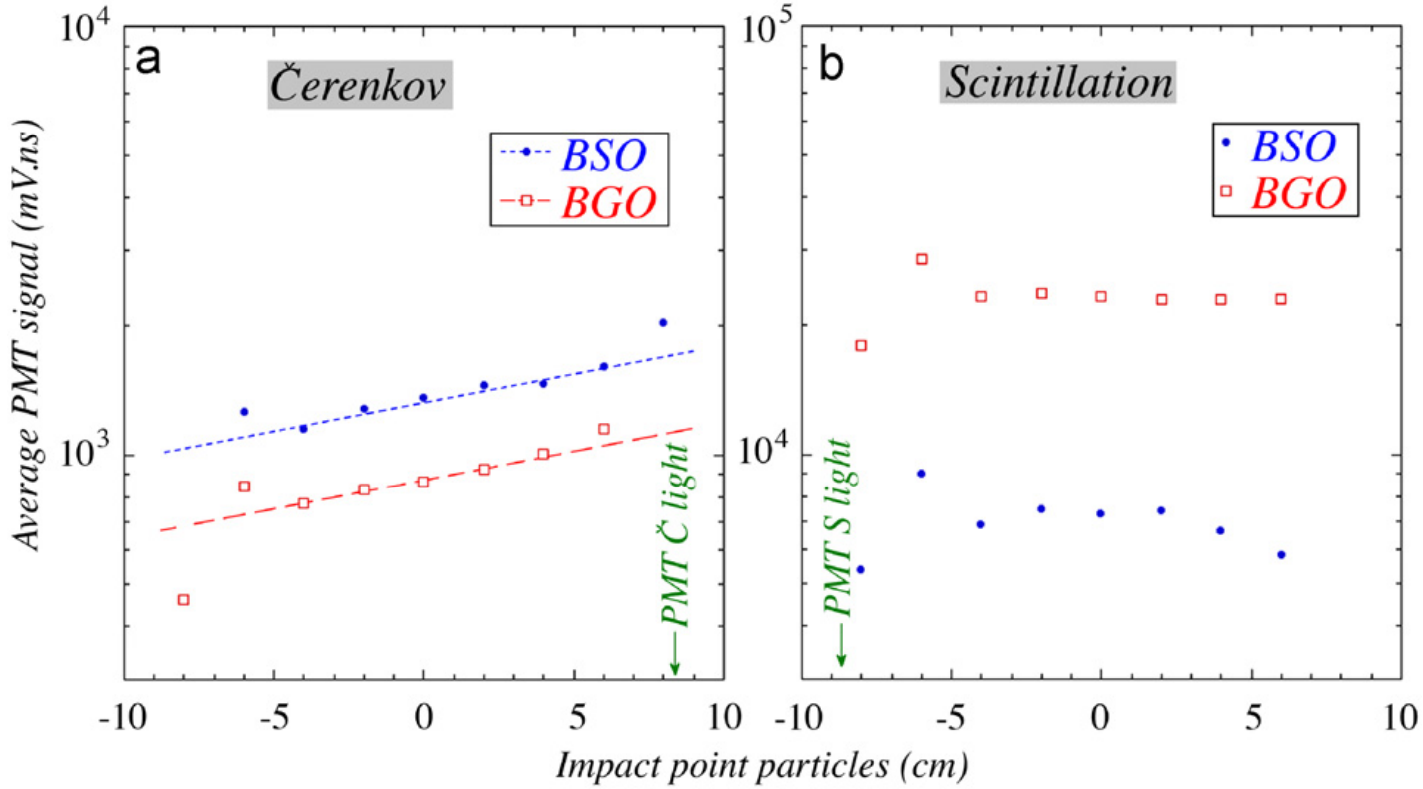
Crystal	Density (g cm^{-3})	Rad. length (mm)	Decay time (ns)	Peak emission (nm)	Relative light output	Price ($/cc)
BSO	6.80	11.5	~ 100	480	0.04	13-18
BGO	7.13	11.2	~ 300	480	0.10 – 0.21	> 40
PWO	8.28	8.9	~ 10-30	410 - 450	0.003	10-13

Price is provided by SICCAS[2]. CMS PWO price is ~7 $/cc. Light yield relative to that of NaI.

[1] H. Shimizu, et al., Nucl. Instrum. Meth. A**550** (2005) 258; C. Amsler et al., Phy. Lett. B**667** (2008) 1.
[2] http://www.siccas.com

BSO light yield compared with BGO

- **Using Si to replace Ge in the BGO. Cost reduced by x3-4.**
- **Scintillation light yield output is less than BGO, but x10 of PWO.**
- **Cherenkov signal is larger than BGO.**

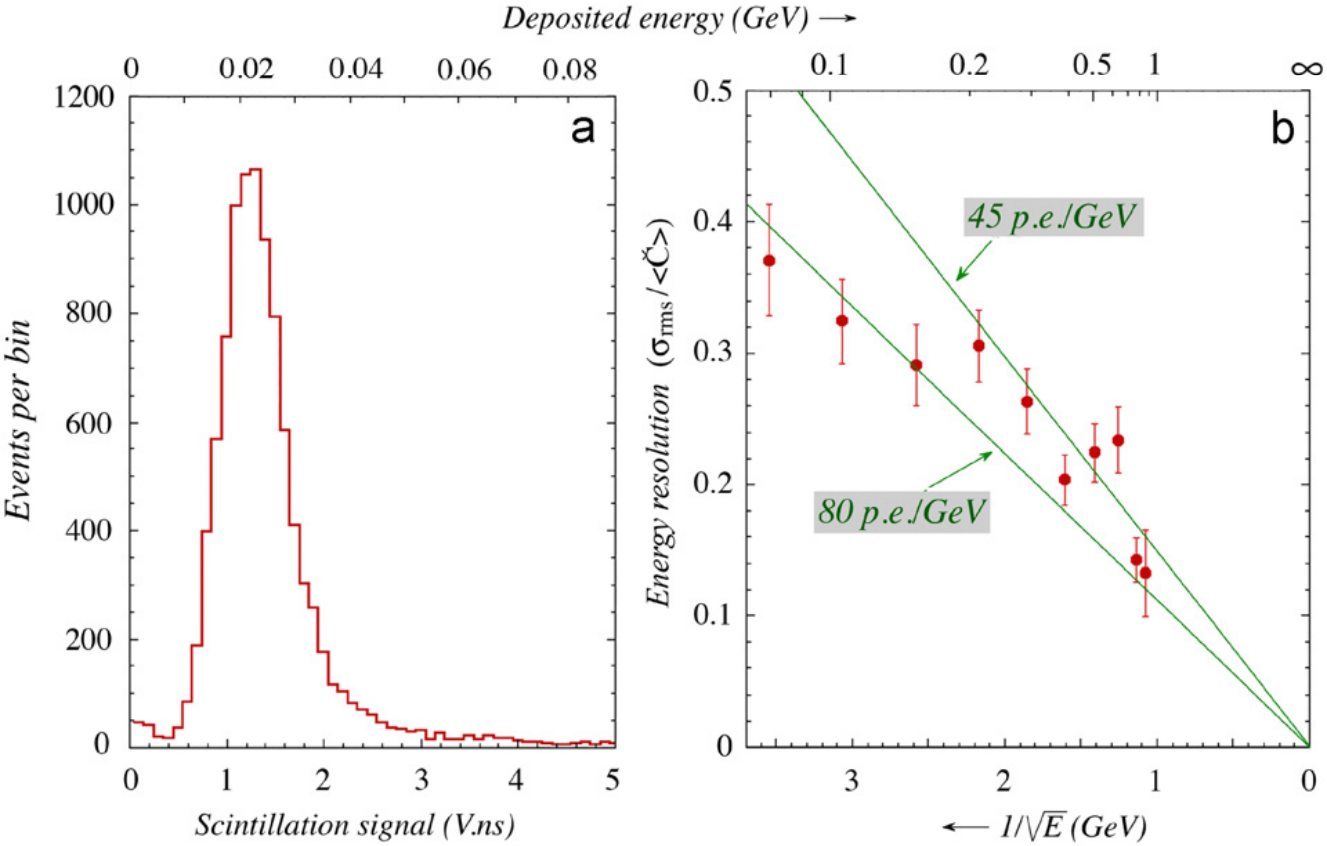


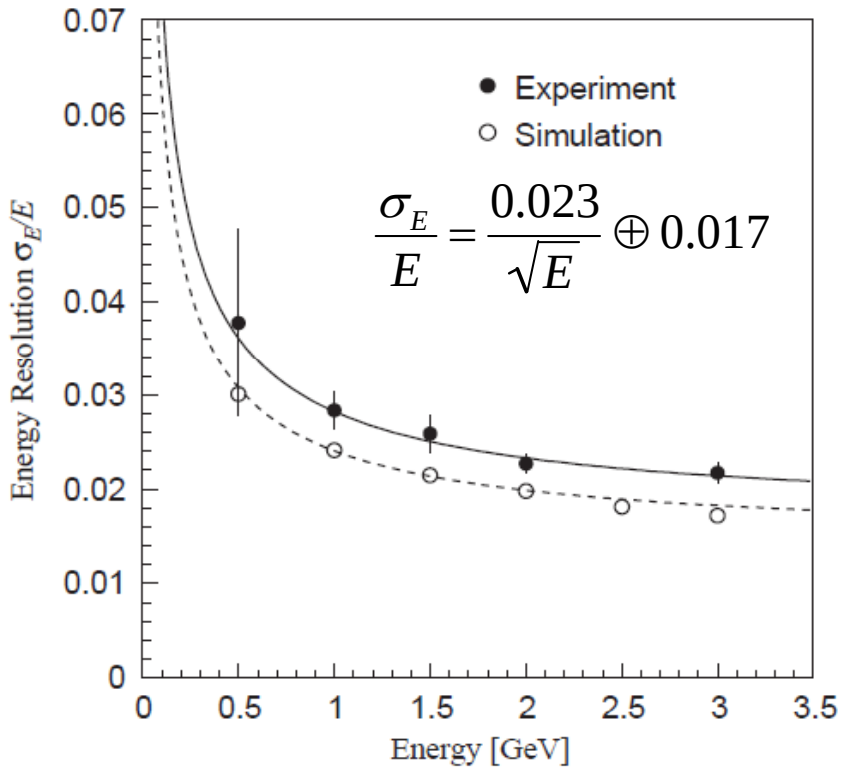
180 GeV pions traverse the crystals at $\theta = 30^{o}$,
Impact point particles: the distance the light had to travel to the PMT.

N. Akchurin, et al., NIM A**640** (2011) 91.

BSO resolution performance

High light yield output results in very good energy resolution.





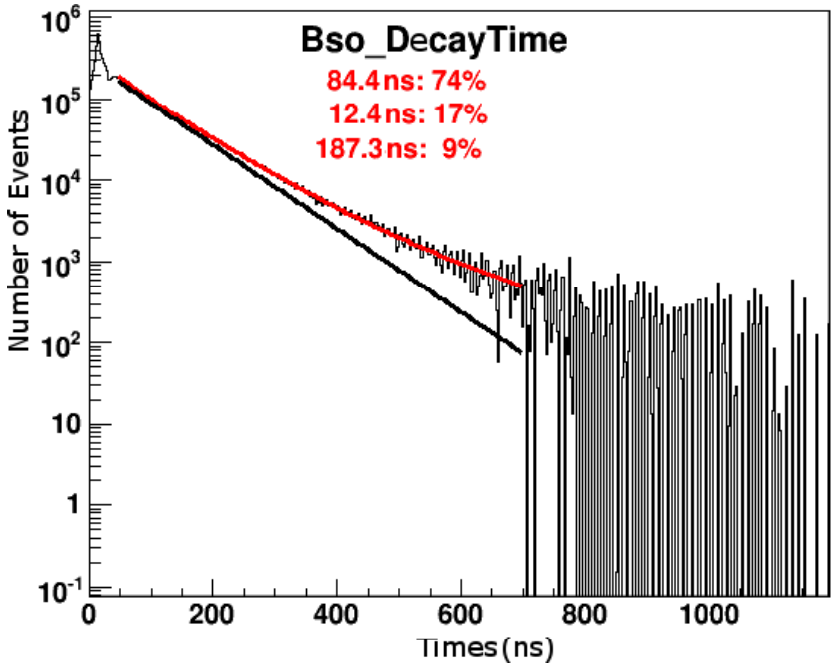
Left: Scintillation Signal and energy resolution for 180 GeV pions traverse the BSO at $\theta = 30^o$.

N. Akchurin, et al., NIM A**640** (2011) 91.

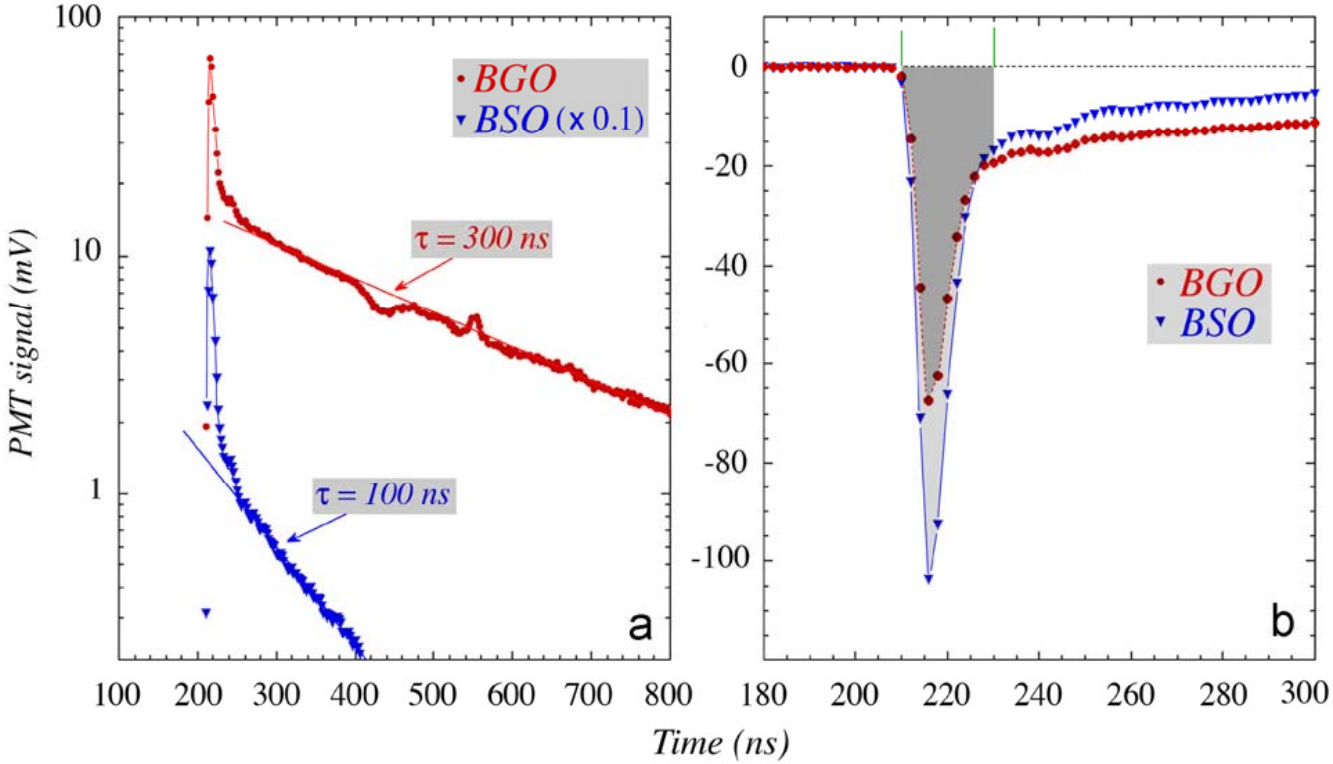
Right: Energy resolution vs electron beam energy. 2-3 GeV electron -> 2-3% energy resolution.

H. Shimizu, et al., NIM A**550** (2005) 258.

Timing structure



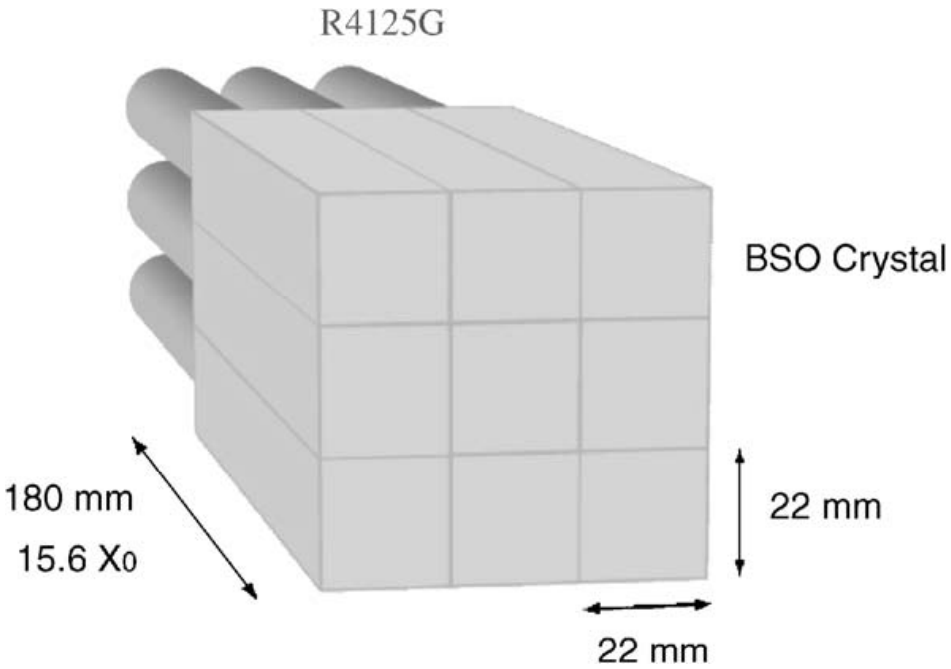
H. J. Kim, et al., JKPS59 (2011) 686.



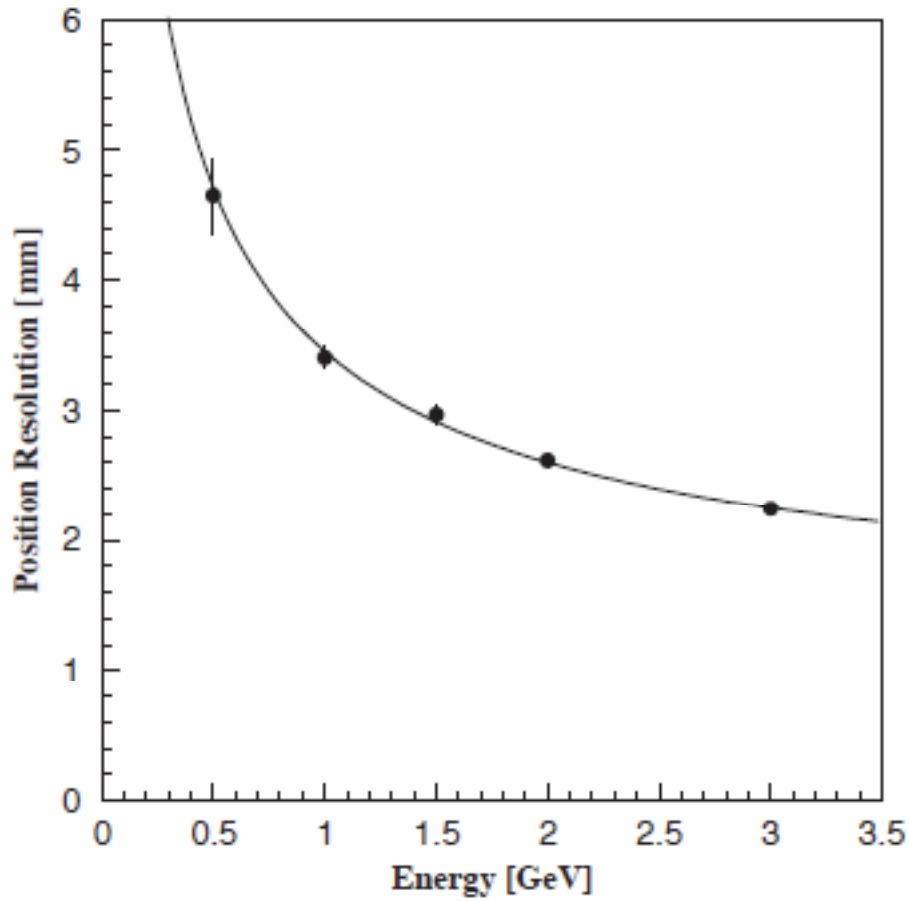
N. Akchurin, et al., NIM A**640** (2011) 91.

Average decay time ~ 100 ns.
Not as fast as PWO but a factor of 3 better than BGO.

Position resolution



H. Shimizu, et al., NIM A**550** (2005) 258.

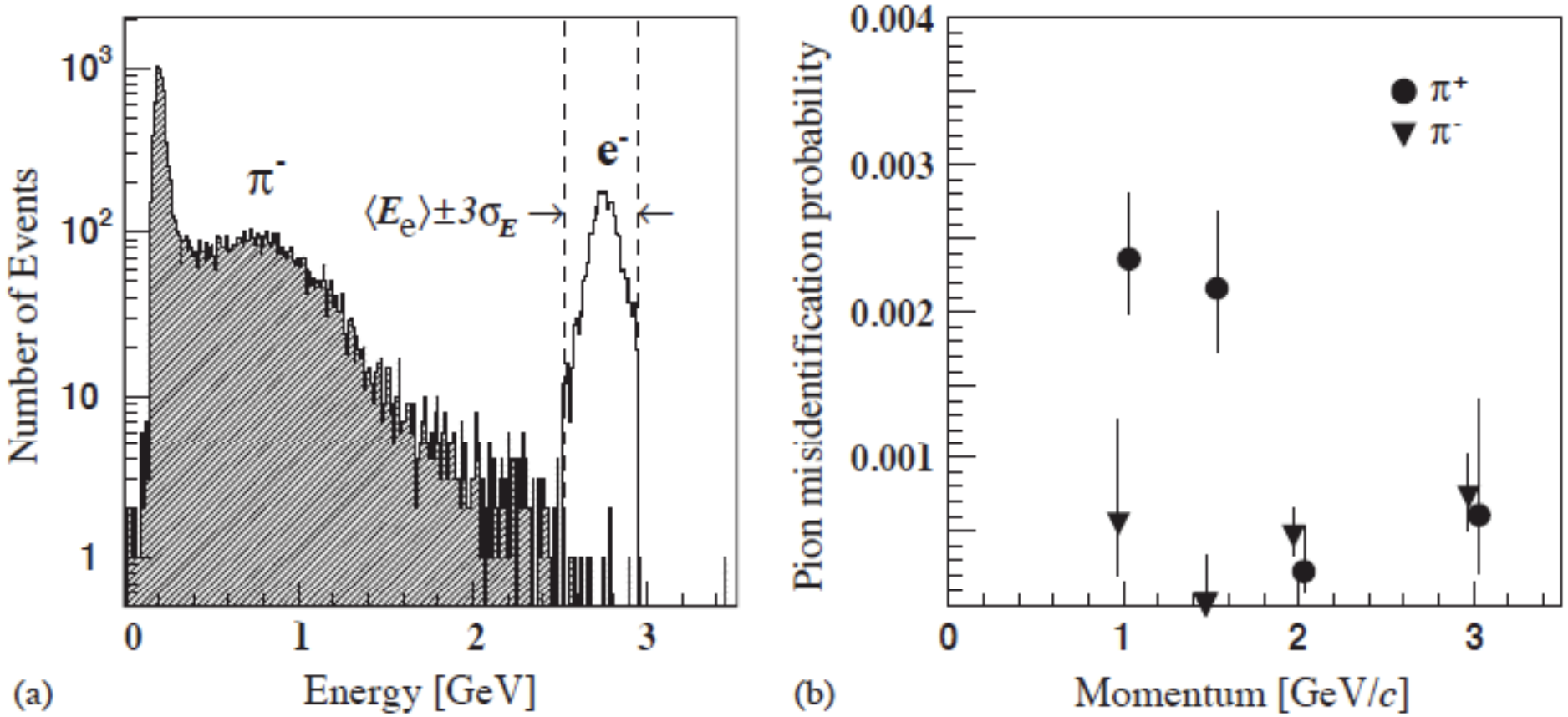


3x3 example: $X_{CG} = \frac{\sum_{i=1}^{9} E_i x_i}{\sum_{i=1}^{9} E_i}$

$$\sigma_x = [\frac{3.2 \pm 0.1}{\sqrt{E}} \oplus (1.3 \pm 0.1)] \quad mm$$

For incident electron energy > 0.5 GeV, the position resolution is better than 5 mm.

Electron identification capability

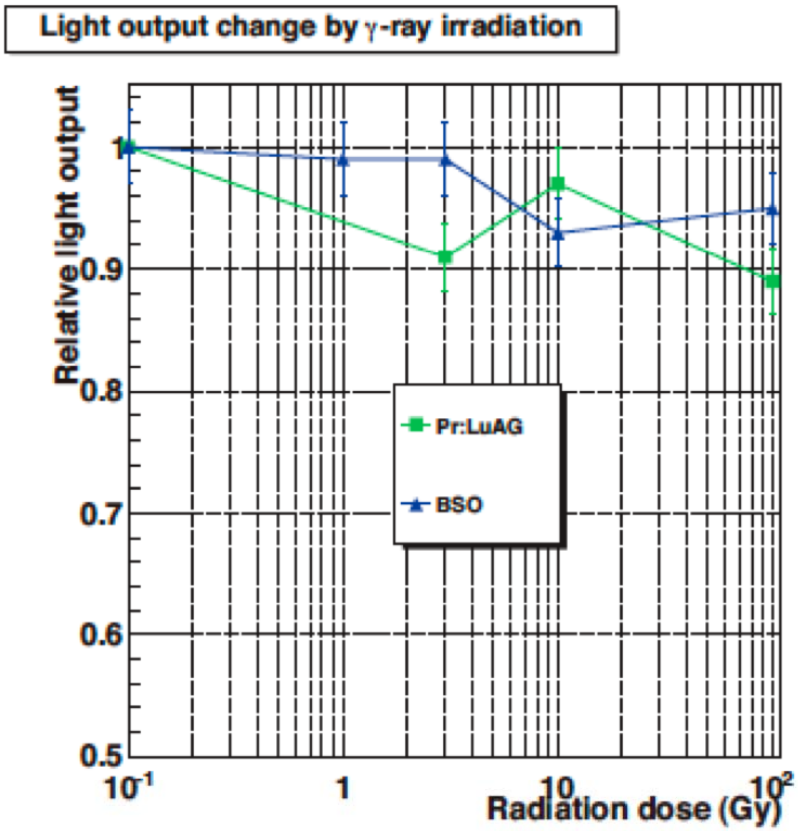


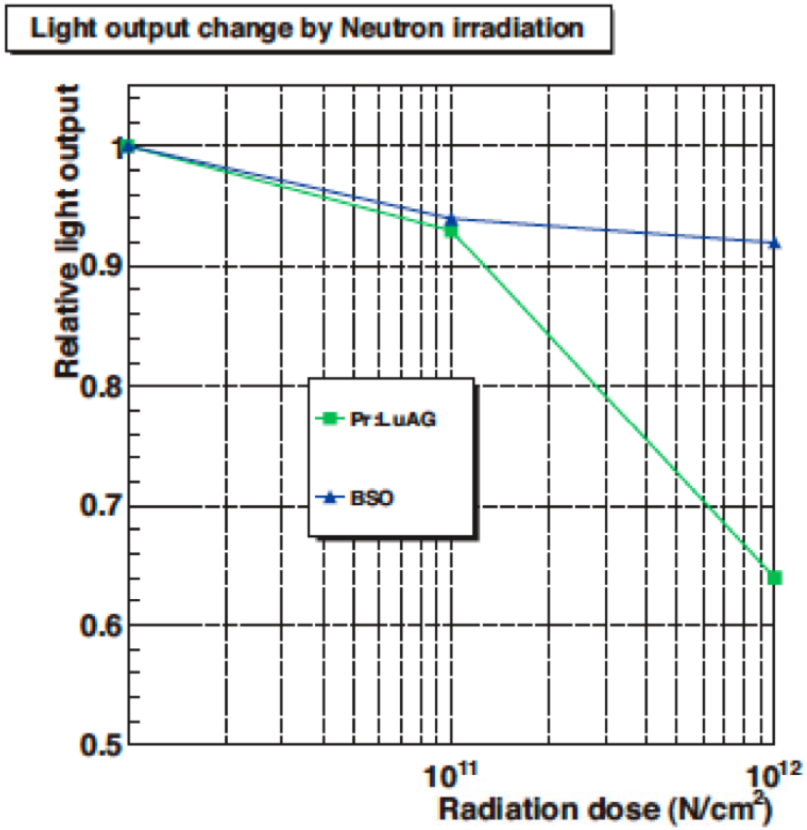
H. Shimizu, et al., NIM A**550** (2005) 258.

Test with 3 GeV pion and 3 GeV electron beam.
Misidentification probability is below 0.3%.

Irradiation test

Good resistance to irradiation damage.





Irradiation test in SuperKEKB/Belle-II with γ-ray and neutron sources.

Reduction of the light yield output is < 10%.
Very good performance particularly at radiation dose < 3 Gy.

PWO crystal is also an option

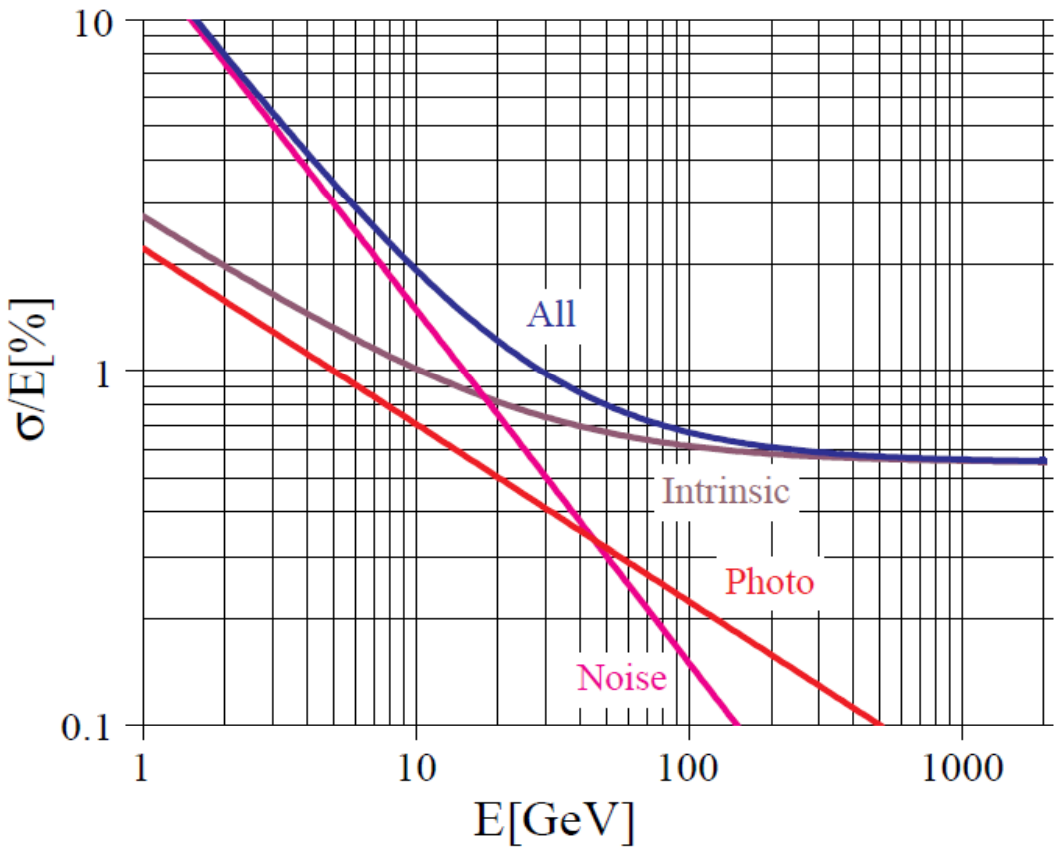
CMS and ALICE all used PWO crystals with excellent performance

Our goals:

- **Work with SICCAS to test a doped PWO for enhanced light yields**
- **Characterize the doped PWO crystals**

PWO energy resolution

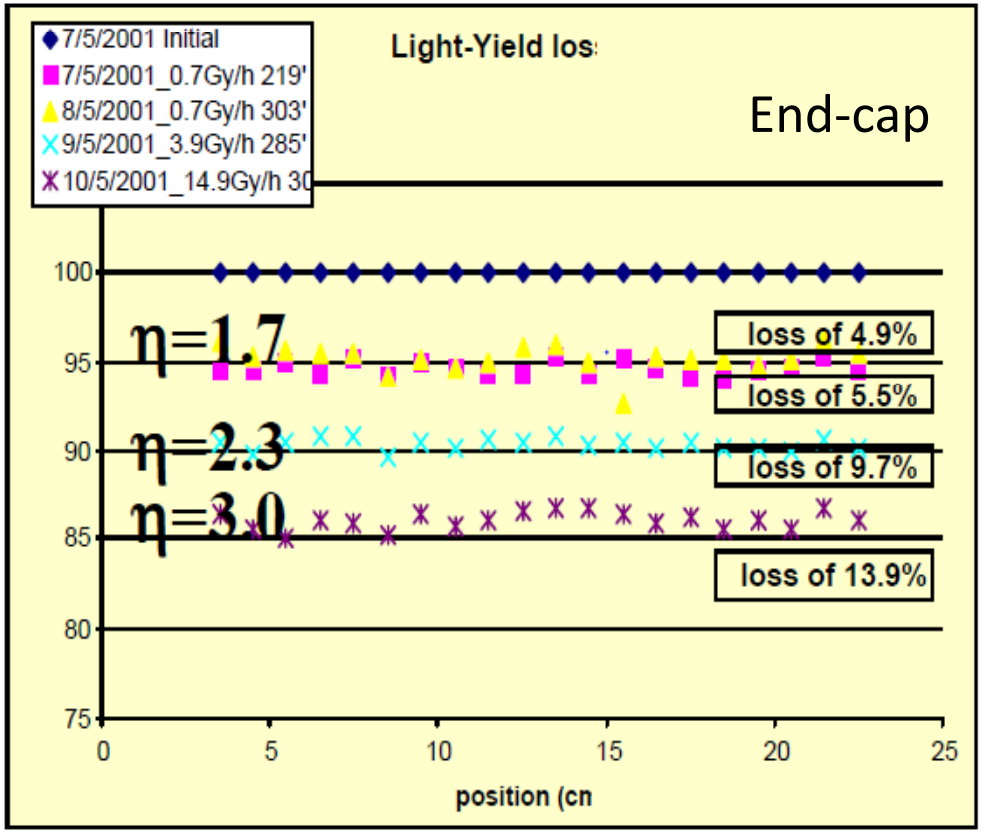
- Not expensive, easy to produce.
- Disadvantage: low light yield output, resolution affected by electronic noise.

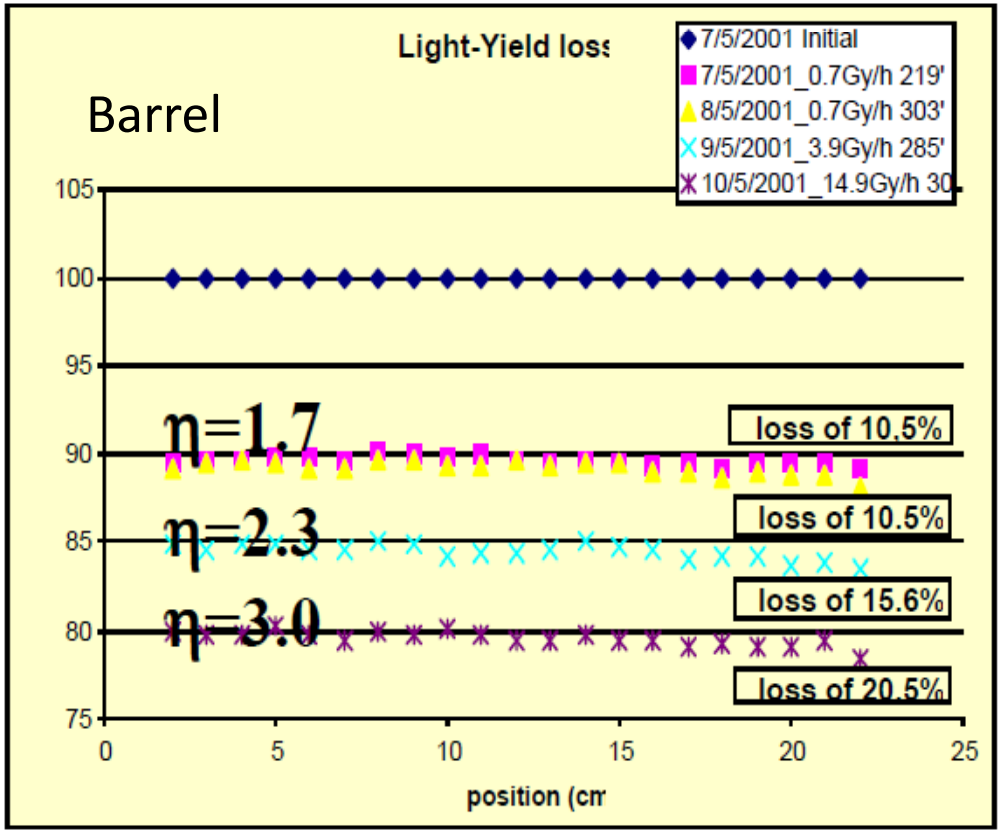


Good energy resolution for high energy electron but not for low energy.
Need study doped PWO to improve its light yield output.
Reduce noise from electronics.

CMS PWO Irradiation Test Results

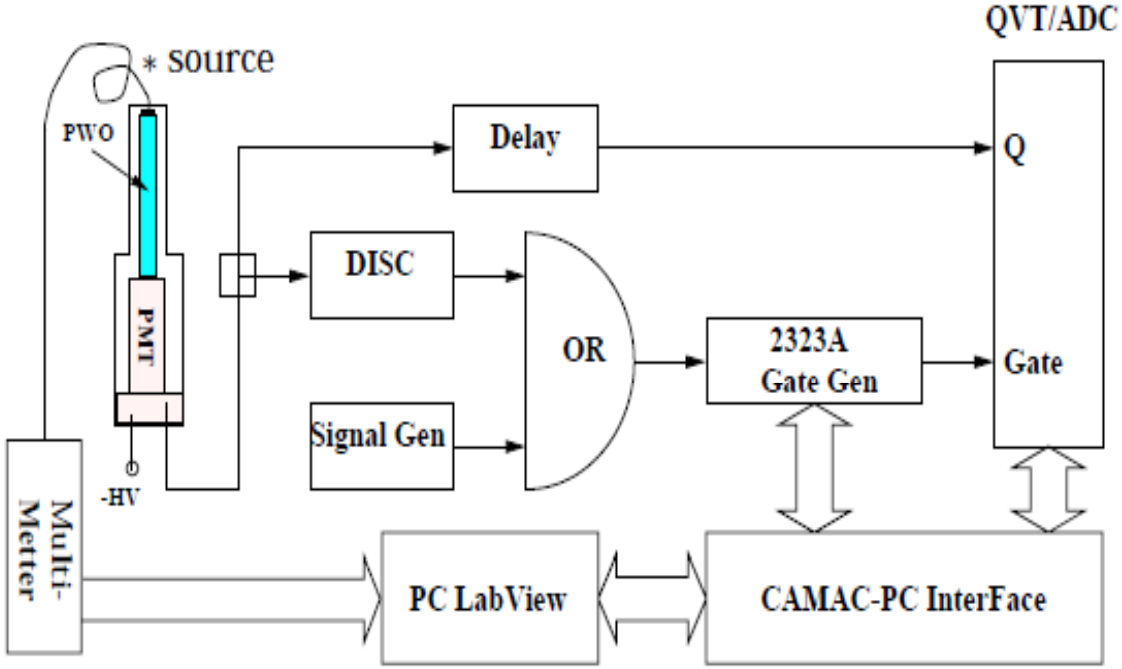
CMS Irradiation Test: Good resistance to radiation damage.

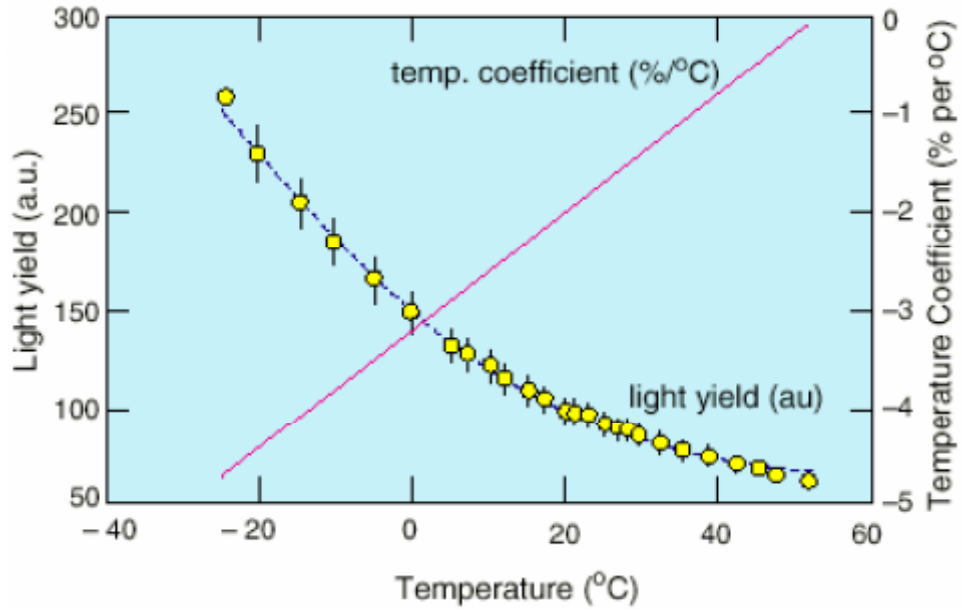


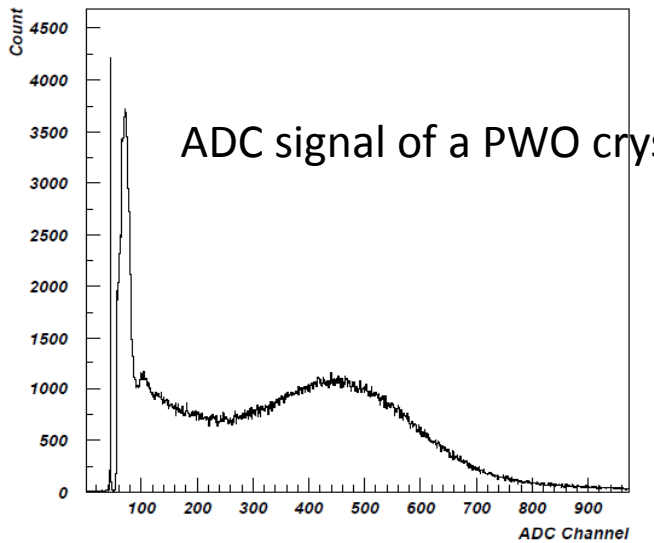


At eta = 2.3, dose = 3.9 Gy/h 285', the light-yield loss is at a level of 15% for the barrel PWO and 10% for the end-cap.

Light Yield Testing System @USTC







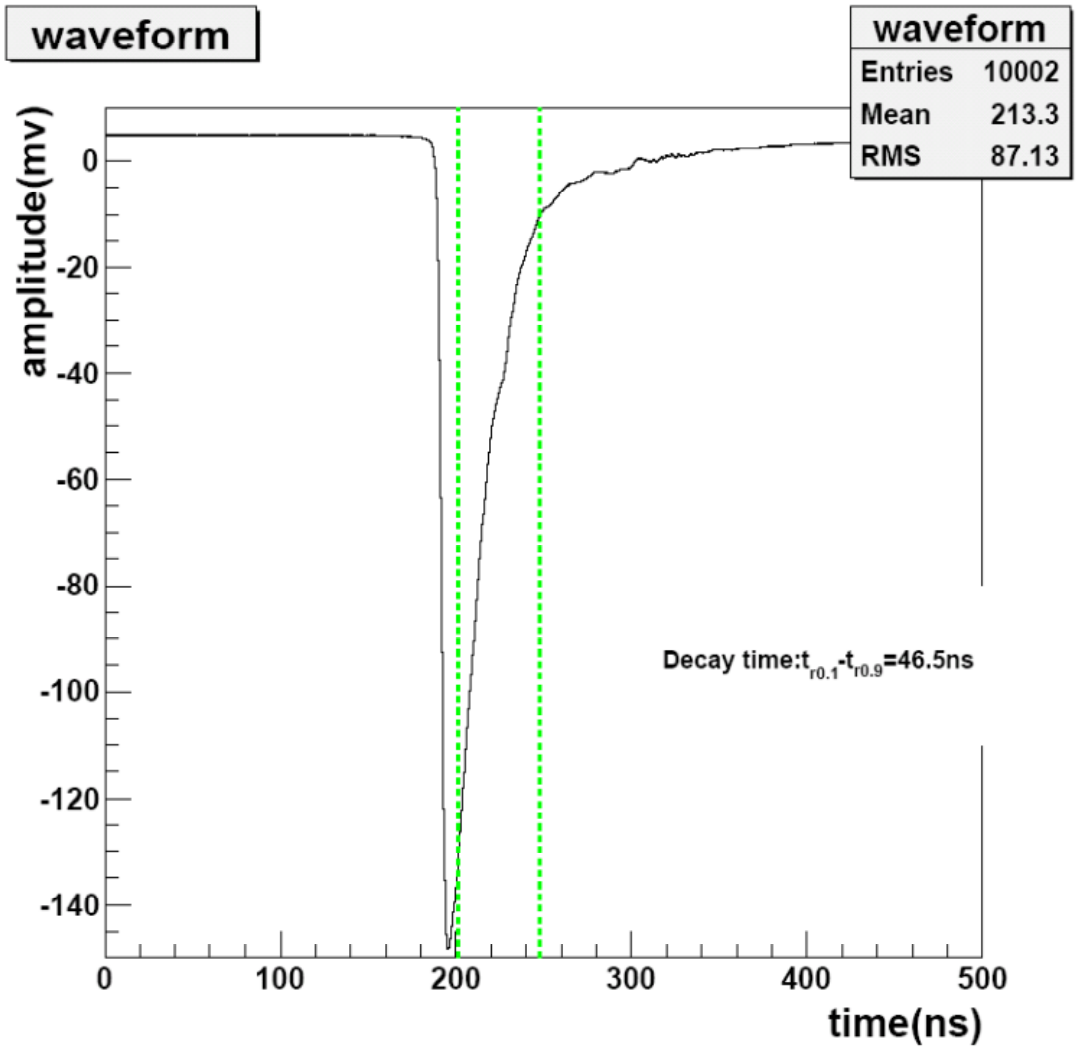
ADC signal of a PWO crystal

High light yield output but a good temperature stabilization is required.

New doped PWO testing at USTC

New doped PWO crystals provided by SICCAS.

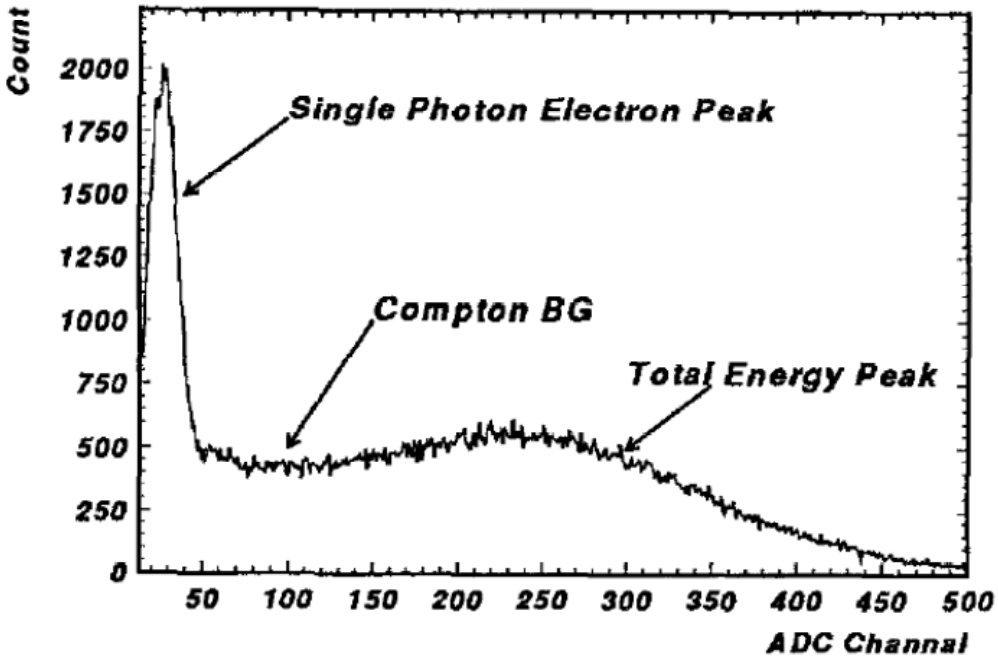
PMT signal as a function of time.
Very good decay time ~ 47 ns.



Lailin Xu, Cheng Li, Hongfang Cheng, Zebo Tang et al

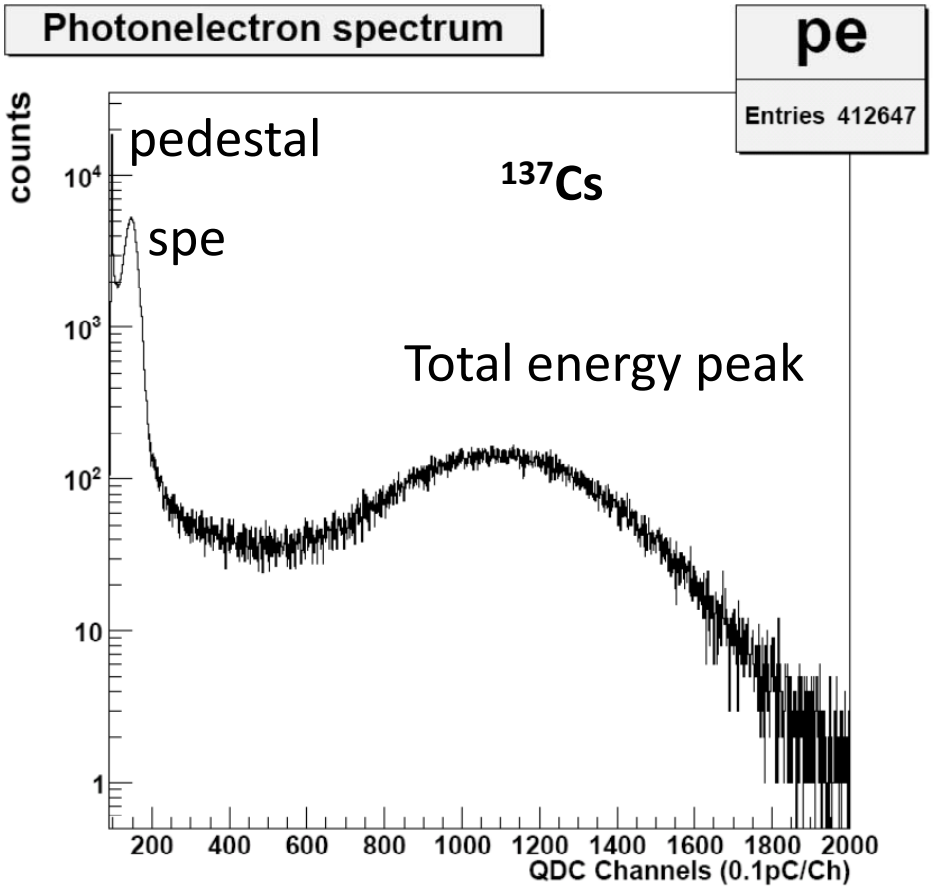
New doped PWO testing at USTC

Lailin Xu, Cheng Li, Hongfang Cheng, Zebo Tang et al



Jian Wu et al, NIMA 404 (1998) 311

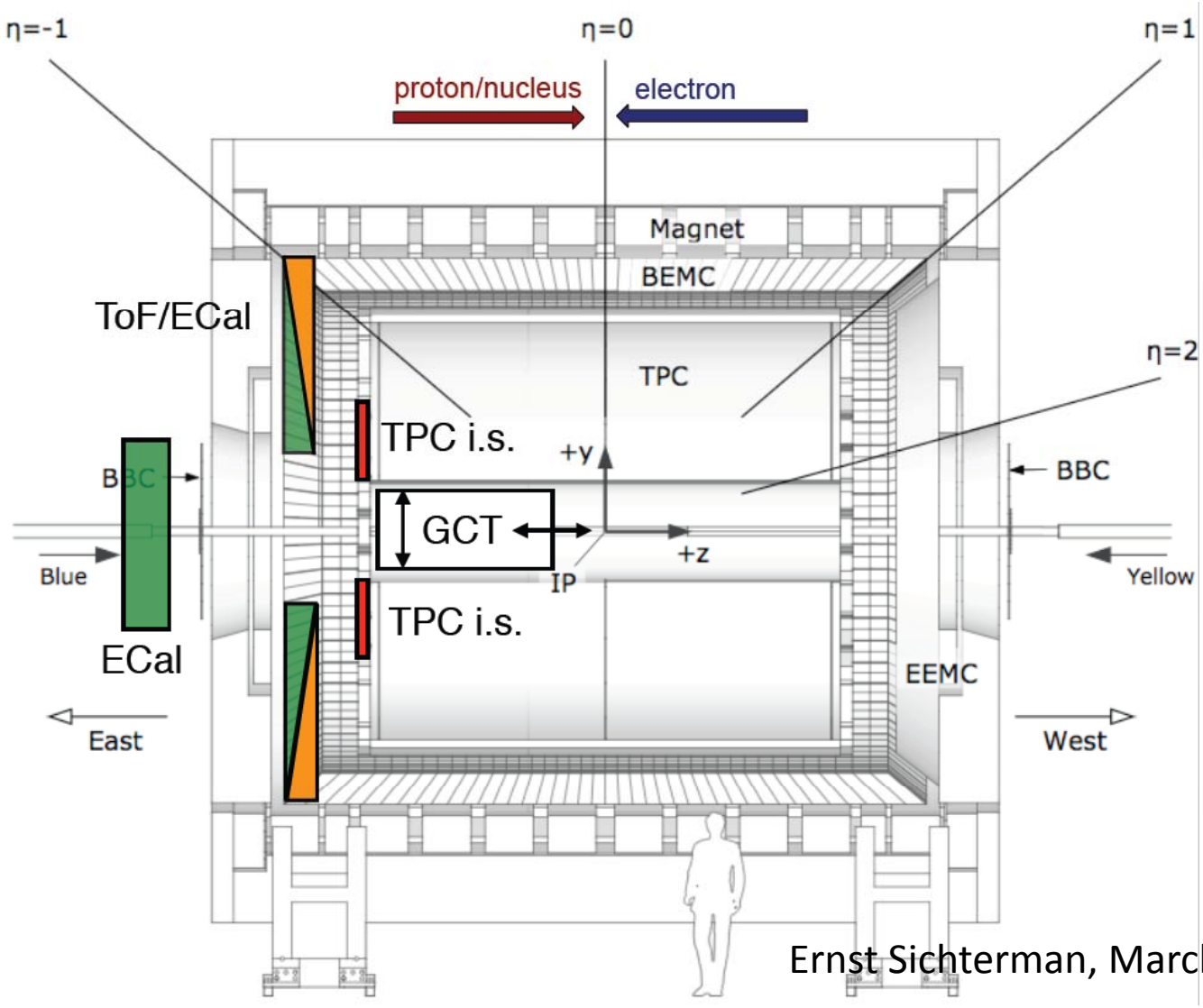
CMS PWO: ~18 phe/MeV for ^{137}Cs



About a factor of 2 achieved with new doped technique.

Doped PWO from SICCAS:
^{60}Co: 29.8 phe/MeV
^{137}Cs: 30.4 phe/MeV

Concept of the very forward calorimeter in eSTAR



Ernst Sichterman, March 10, eRHICworkshop

Crystal detector (BSO, doped PWO) is good option for the very forward calorimeter (η < -2).

R&D Plan

Chinese crystal manufacture: A reliable crystal vendor – SICCAS.
http://www.siccas.com/

✧ **We order small samples of PWO and BSO crystals from SICCAS for performance test.**

✧ **We will carry out simulations for the detector design and for understanding the performance of the crystal detectors.**

✧ **We need to purchase 5x5 crystals array each with suitable size and length (e.g. 22mmx22mmx180mm) for prototype. That will be a significant cost of the project.**

✧ **For the first step we will use PMT read-out. We will test APD read-out also.**

✧ **We plan to have a beam testing either at CERN or at FNAL or at SLAC.**

Summary

Crystal detector is an viable detector for electron identification with high energy resolution in EIC.

BSO and PWO are promising candidates for the crystal detector at forward electron direction.

Very good energy resolution for BSO crystal. 2-3% for 3 GeV electron beam.

The light yield of new doped PWO tested at USTC is a factor of 2 higher than CMS PWO. Comparable with Panda PWO.

Both BSO and PWO will undergo irradiation tests.

BSO also provided good position resolution. For a 3x3 design, the position resolution is better than 5mm for electron energy > 0.5 GeV.

We are ready to carry out the R&D project on the crystals

Update for W/ScFi Calorimeter R&D

J. Dunkelberger, H.Z. Huang, G. Igo, S. Trentalange, O. Tsai
University of California at Los Angeles

C. Gagliardi
Texas A&M University

S. Heppelmann
Pennsylvania State University

Toward Proof of Principle.
Test Run: Jan.18-31 2012 @FNAL

Three Prototypes are now ready for shipping to FNAL.

Three prototypes:

- 2004 old SPACORDION type
- 2011 Summer new SPACORDION
- 2011 November, SPACAL

Differences are: fibers, W powder type, light collection, construction technique, readout.

The most promising technique as it seems now is the latest one (SPACAL).

Details of Three Prototypes

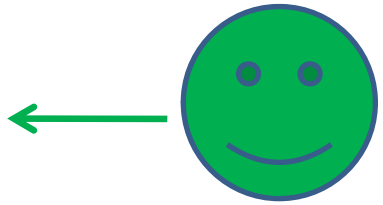
W/ScFi

SPACORDION

Wiggled fibers
Tower made from few sub–assemblies
Bundled fibers

SPACAL

Straight Fibers
Two towers made at once.
Non–bundled fibers.



Ver. 2004	Ver. 2011	Ver. 2011
Two sub–assemblies	Four sub–assemblies	Four towers readout by a single PMT
Light guide to match	No Light guide	Long light guide with mirror pipe.
APD (4.9 mm x 4.9 mm)	14 mm x 14 mm	Mirror will be sputteredby FNAL
W powder ("PLUS")	W powder ("ULTRA")	
Mirror glued with BC600	Mirror glued (Silgard 184	Optical coupling BC–630
Optical coupling GE silicone	Optical coupling BC–630	W powder ("ULTRA")
Perforated meshes 0.88 mm center to center, BCF 12 fibers, 0.33 mm diameter.		Precision meshes by PHOTOFAB 1mm center to center. KURARAY SCFS –78, 0.47 mm diameter.

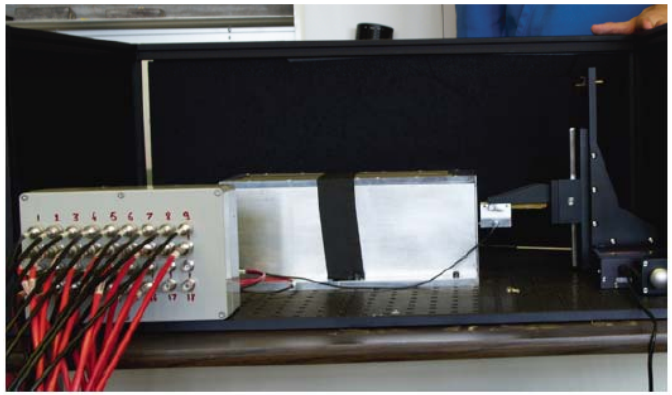
Building a tower from multiple sub-assemblies turn out to be labor extensive !

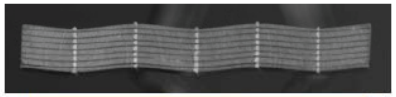
Bundled fibers at the end are OK for the "proof of principle" (skip optimization for light collection in year 1).

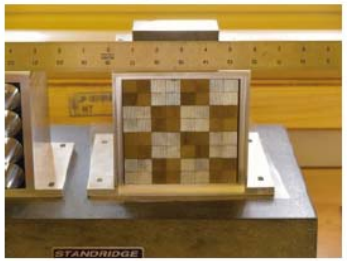
For SPACAL we have already developed techniques which may further improve the construction and performance assuming promising beam testing result.

Both 2011 prototypes were scanned with UV LED from the front face of the matrix to assure uniform response

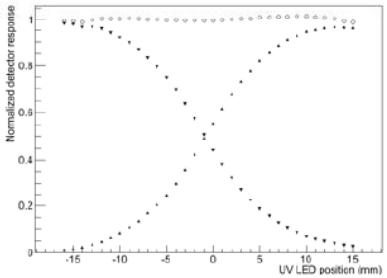
Spacordion Prototype Setup and Testing

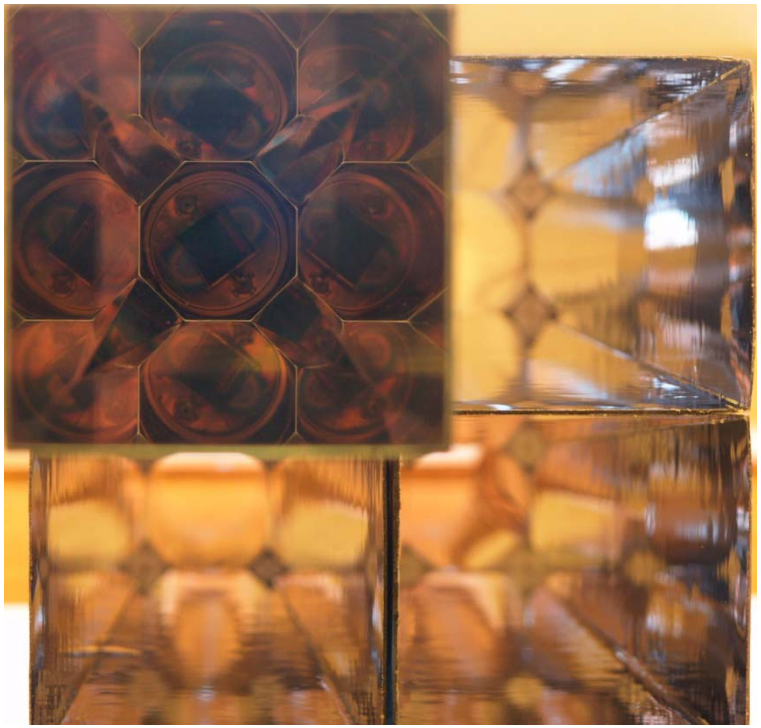






Setup with UV LED mounted to test for non-uniformities in light collection by the fibers at the boundaries between cells. Construction of spacordion towers is labor intensive and complicated



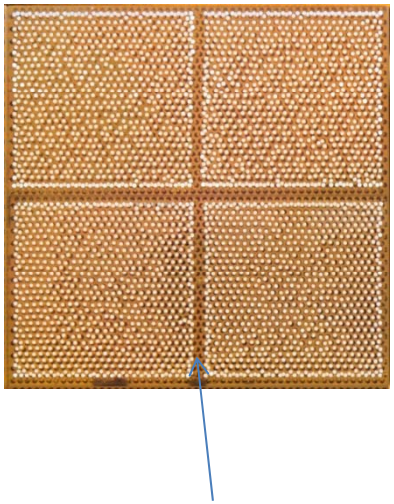


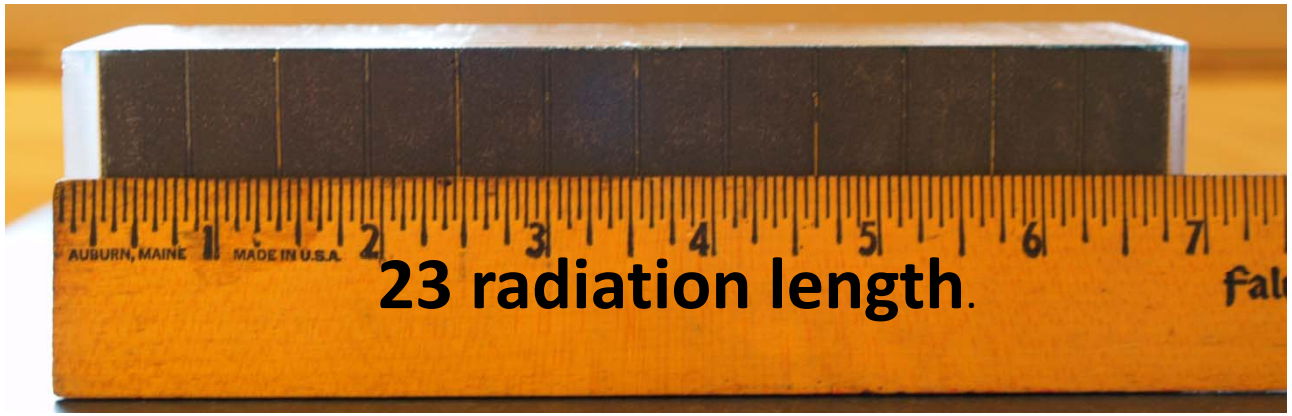
SPACAL Readout for the test Run. Conservative 8" long acrylic light guide with mirror pipe collecting light from four towers.

Some Details of SPACAL Type.

Photodetector side.

Mirror sputtered here





Clearances ~1.5 mm wide (fibers squeezed toward center of assembly at photodetector end) to provide towers separations and future compact readout integration.

All mechanical stability aspects left for future R&D (the scope of such measurements will depend on the results of the test run).

Goals for the Test Run and Future Plan

a) **Energy Resolution**

b) **Light Yields**

And all other things: linearity, uniformity across and along the towers, etc.

Results (a) and (b) will provide:

direction for future developments (technology)

We plan to submit a joint R&D proposal in spring 2012 with several other groups:

1) new or improvement on construction techniques, light collection and address mechanical issues

2) readout options – APD, SiPM

3) electronics