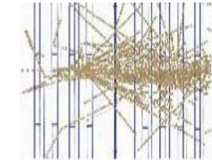

A Crystal Shashlik Electromagnetic Calorimeter for Future HEP Experiments

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May 17, 2016

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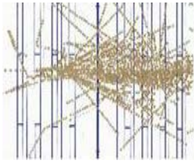
Why Crystal Calorimetry in HEP?



- Photons and electrons are fundamental particles. Precision e/γ measurements enhance physics discovery potential for HEP experiments.
- Performance of crystal calorimeter in e/γ measurements is well understood:
  - The best possible energy resolution;
  - Good position resolution;
  - Good e/γ identification and reconstruction efficiency.
- A crystal Shashlik ECAL concept was developed to preserve precision e/γ measurements and face the challenge of the severe radiation environment expected by the future HEP experiments at the energy frontier.

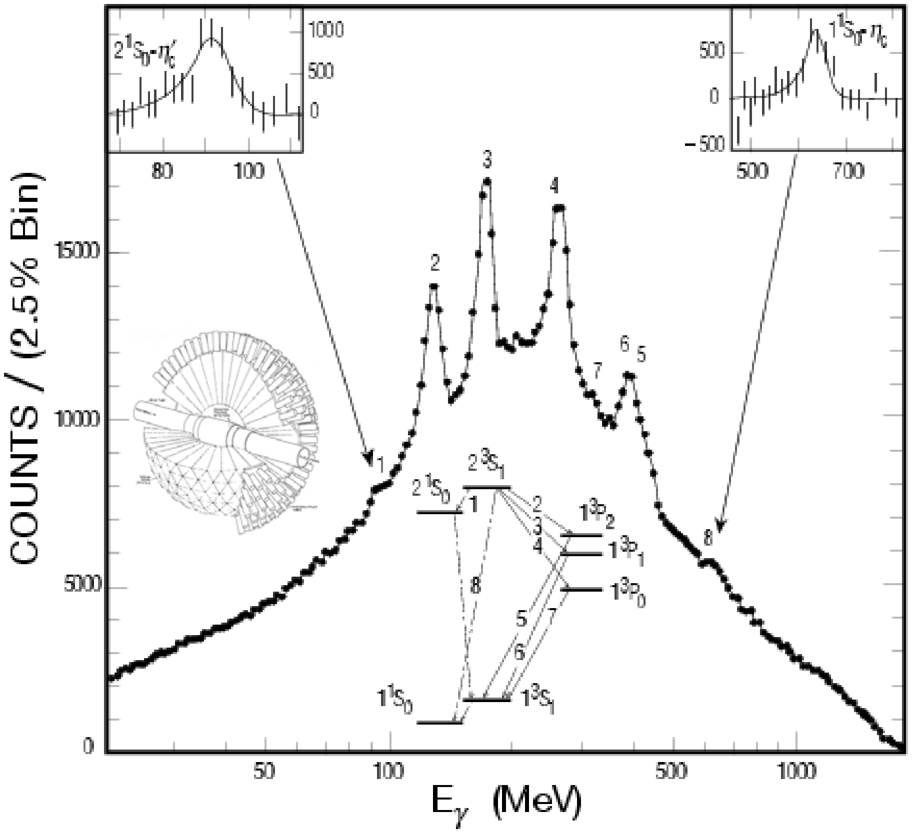
Physics with Crystal Calorimetry

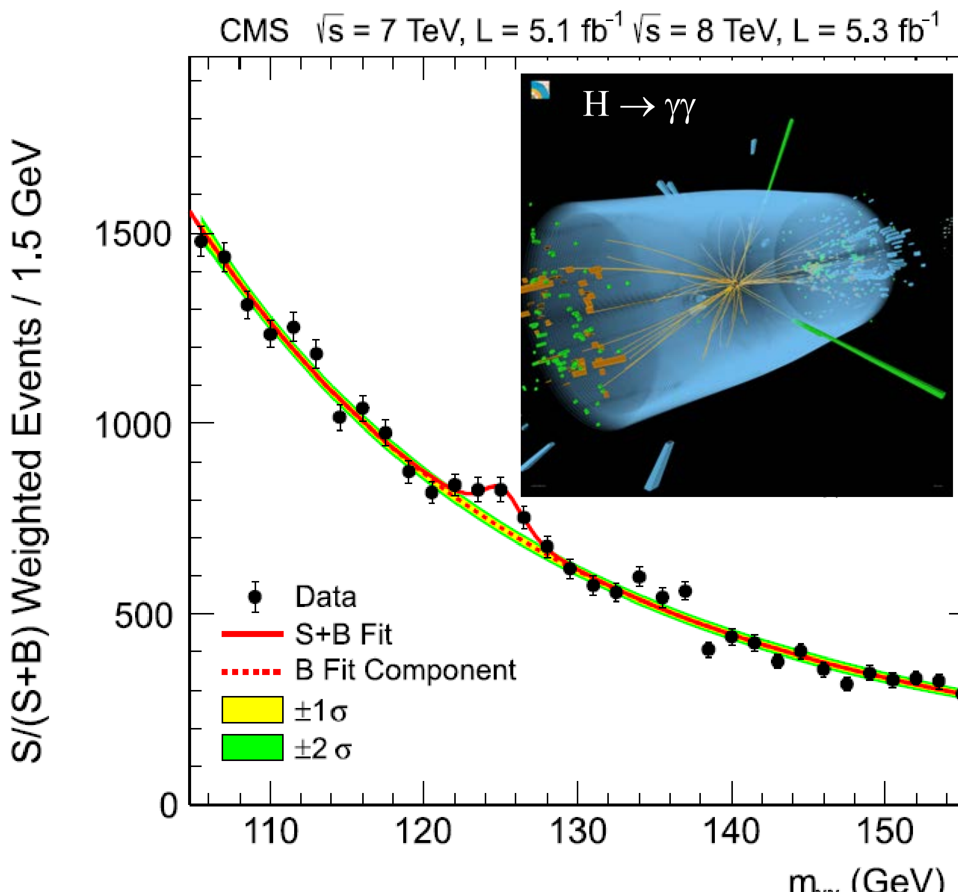
Charmonium system observed by CB through Inclusive photons

Higgs -> $\gamma\gamma$ by CMS through reconstructing photon pairs

CB NaI(Tl)

CMS PWO

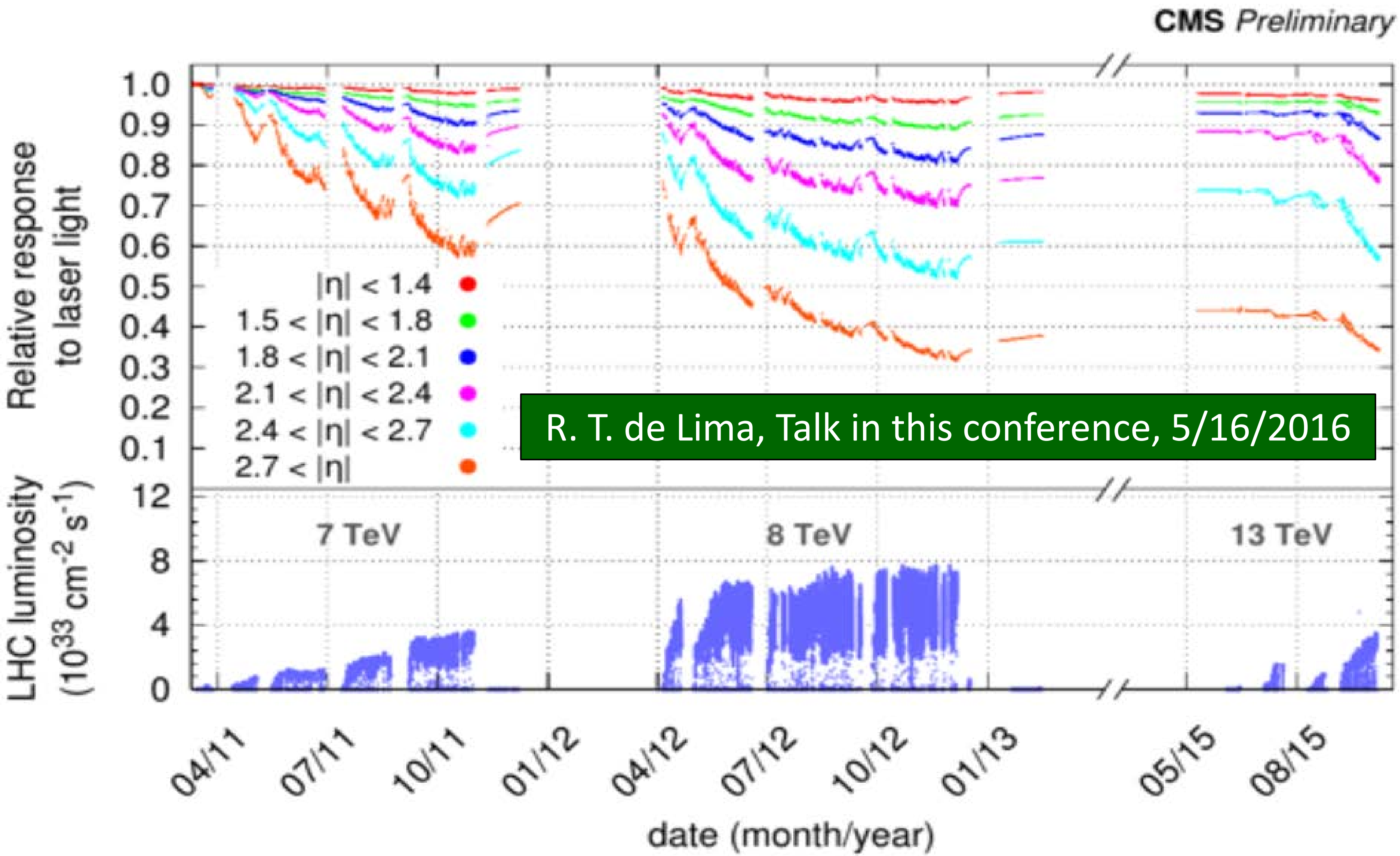




$\gamma\gamma$ bumps at 750 GeV reported in this conference hint the importance of the EM resolution at HL-LHC

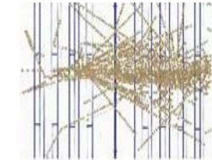
Degradation of CMS PWO of 25 X_0

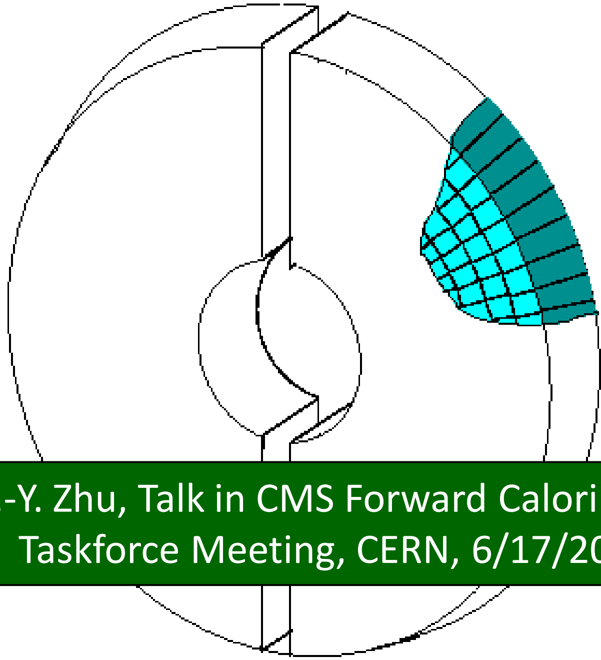
Ionization dose induced dose rate dependent damage in PWO is well understood



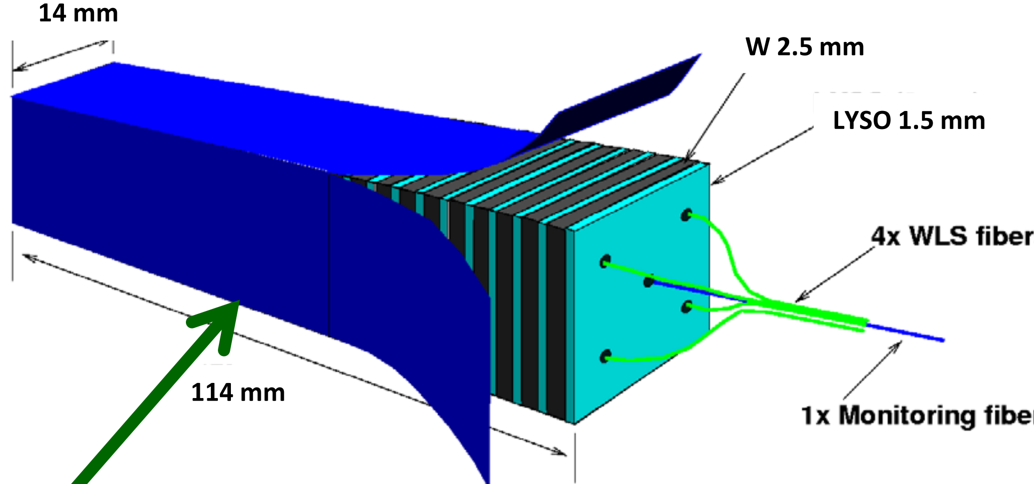
R. T. de Lima, Talk in this conference, 5/16/2016

Reduce Light Path Length



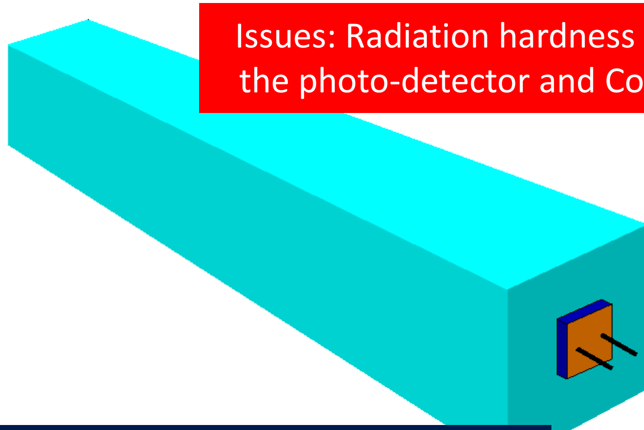


R.-Y. Zhu, Talk in CMS Forward Calorimeter Taskforce Meeting, CERN, 6/17/2010



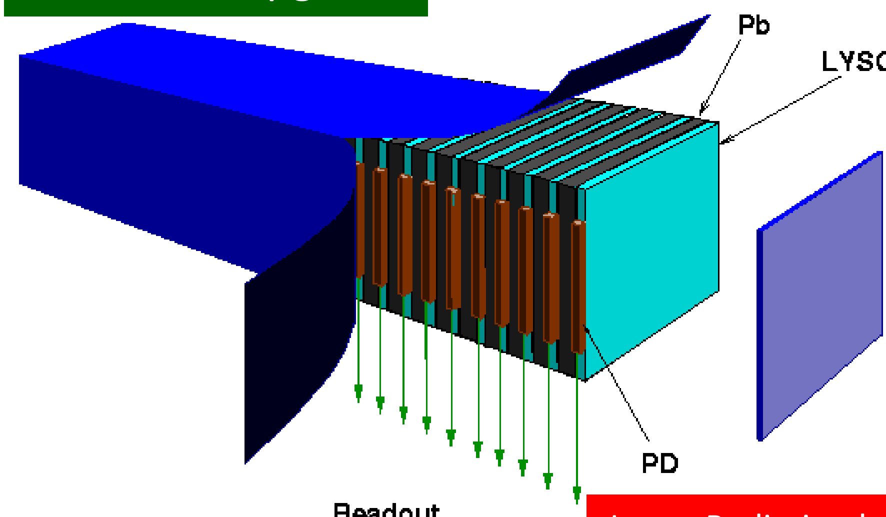
One option for CMS FCAL Upgrade

Issues: Radiation hardness of WLS fibers & photo-detector



Issues: Radiation hardness of the photo-detector and Cost

CMS ECAL endcap: Single Crystal: 160 cm^3
Total number: 16,000 Total Volume: 3 m^3

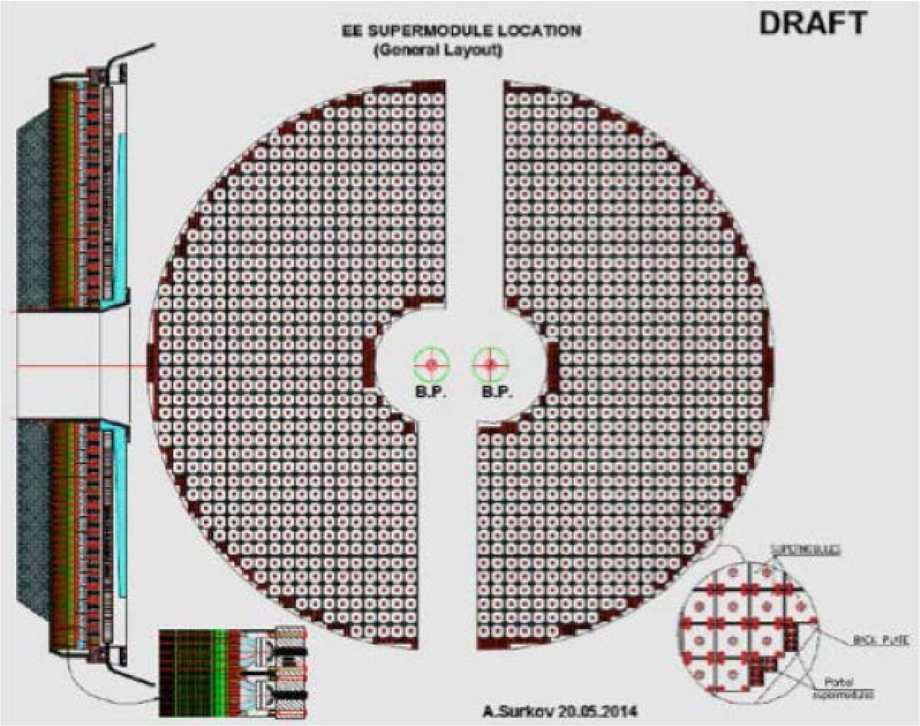


Reduced Crystal Cost & Damage

Issue: Radiation hardness of the photo-detector

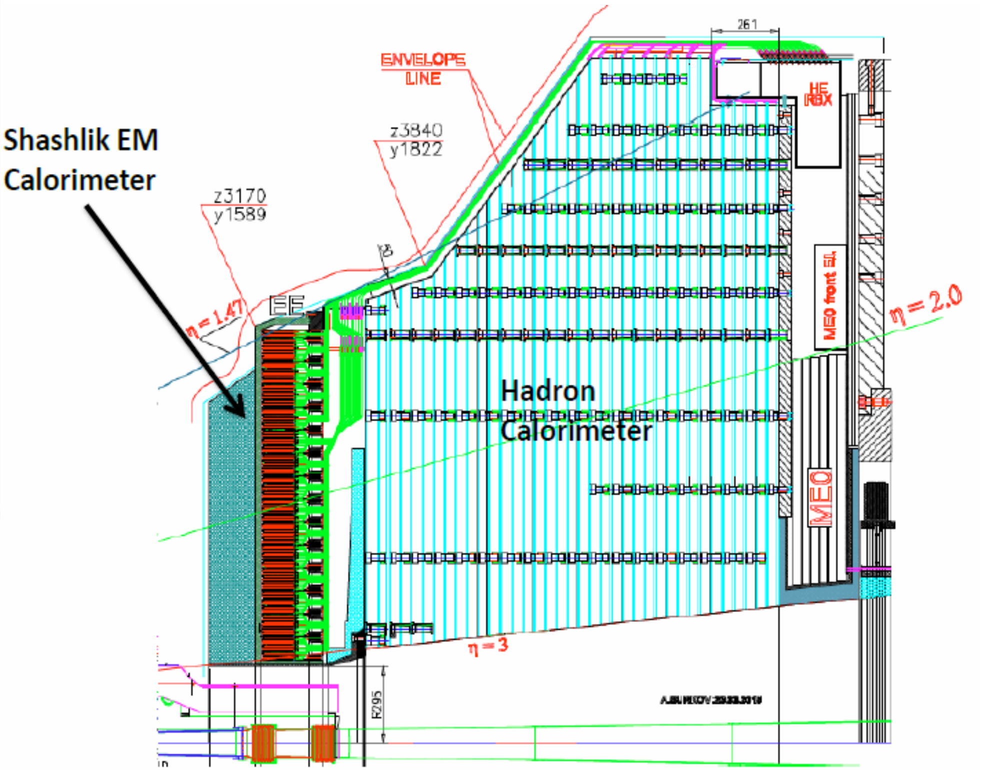
An Option for CMS FCAL Upgrade

Typical Shashlik resolution: 10%/√E + 1%

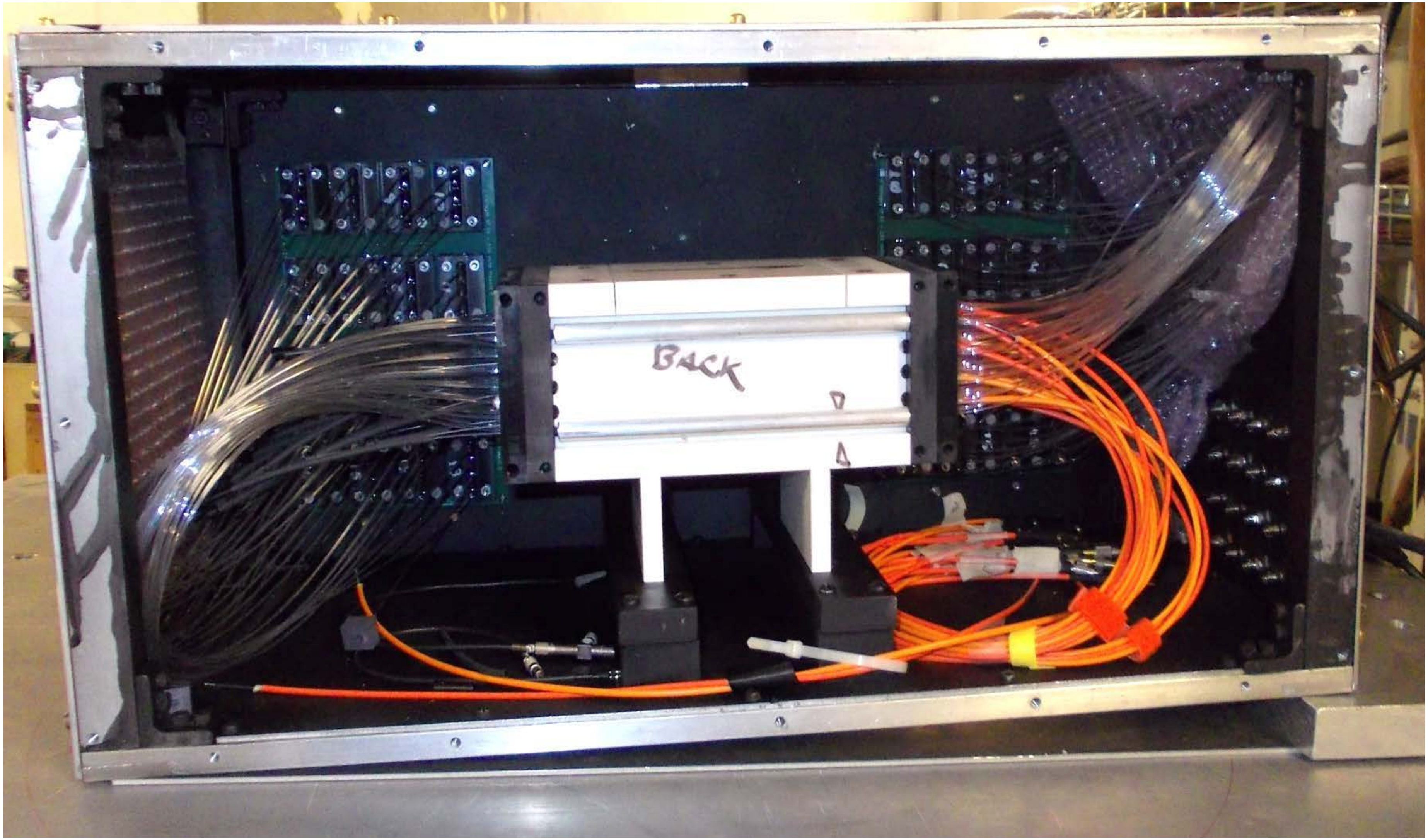


A Front View

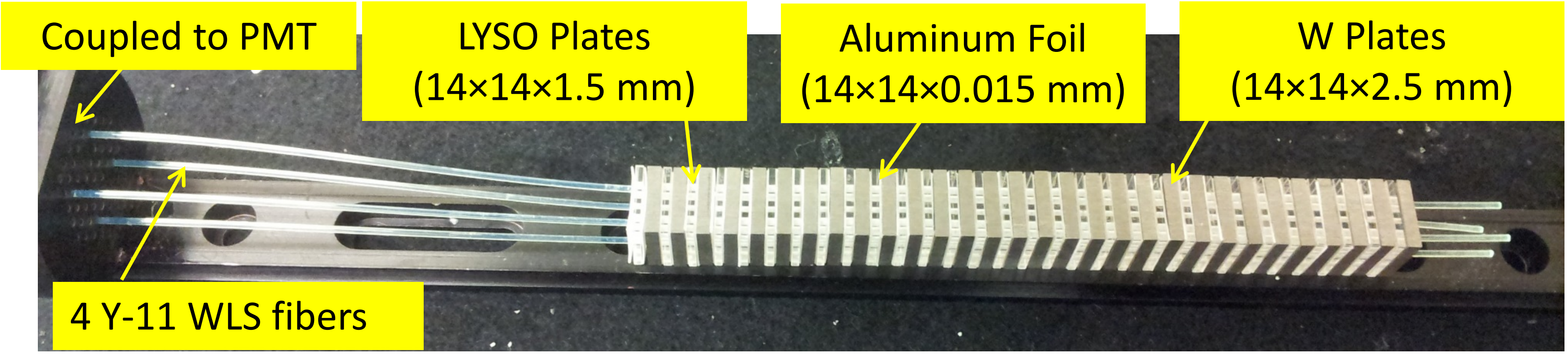
A Side Cut View

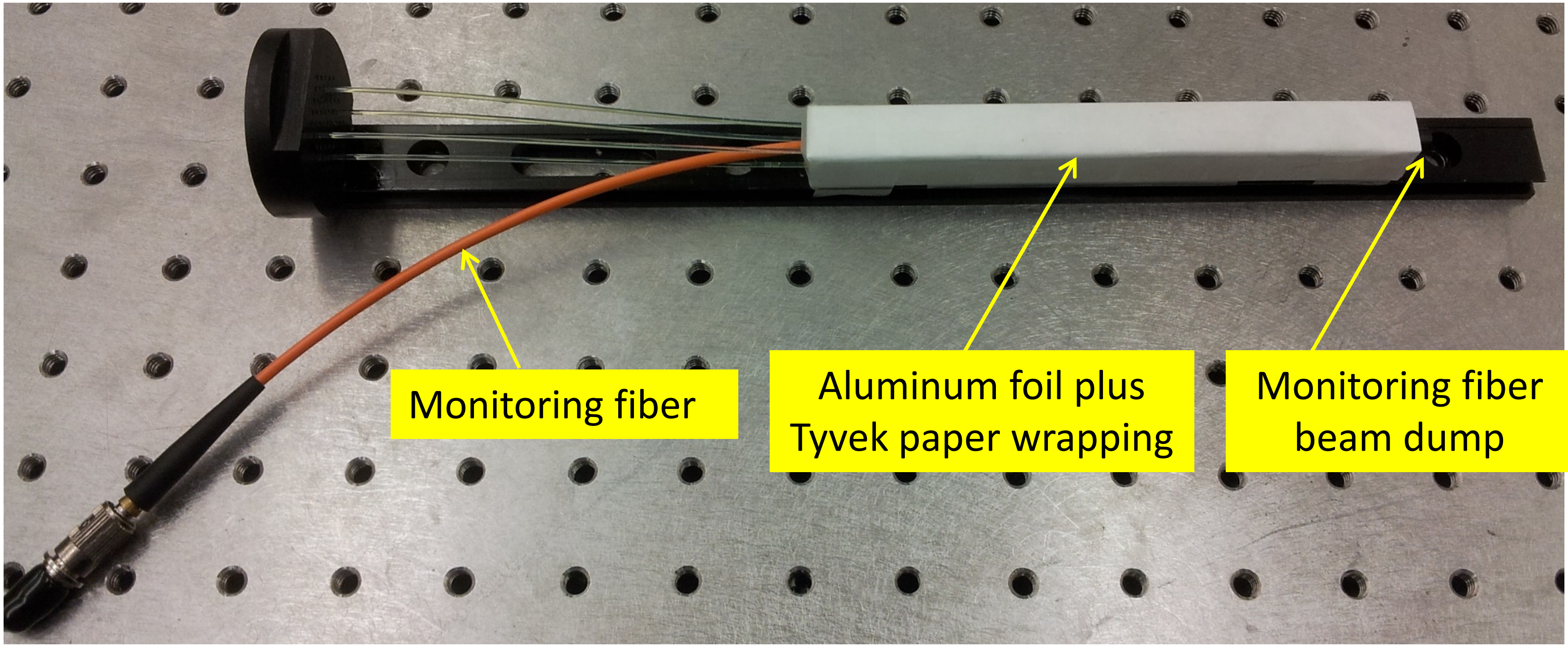


A 4 x 4 LYSO/W/Y-11 Array for 2014 BT



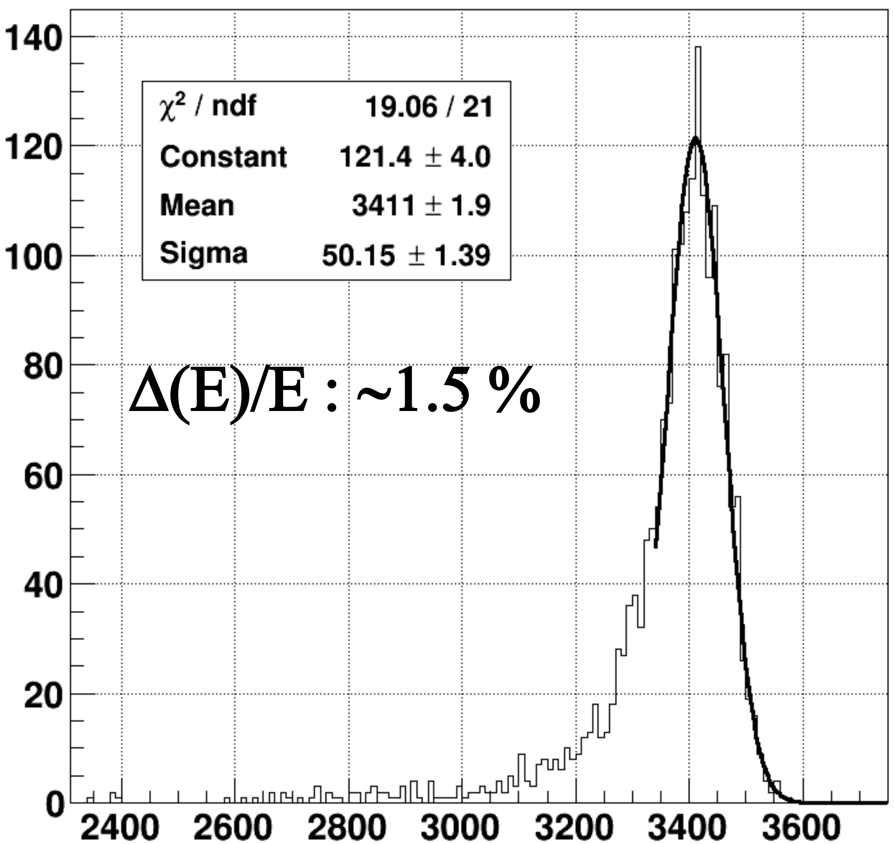
A LYSO/W/Y-11 Tower for 2014 BT

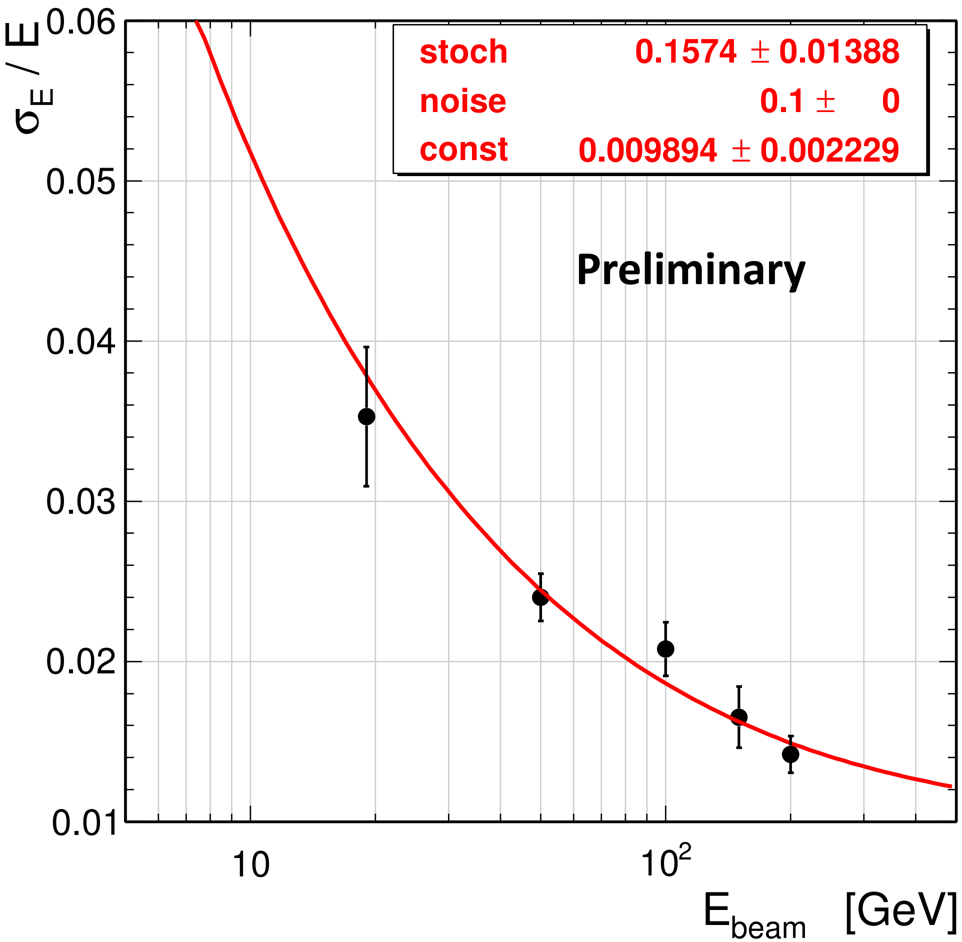




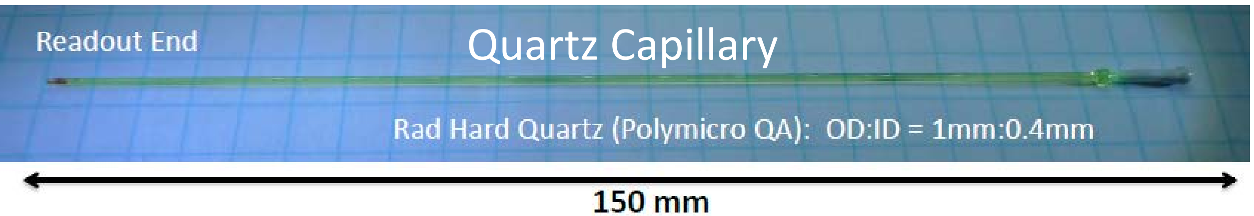
Resolution in CERN H4 Beam

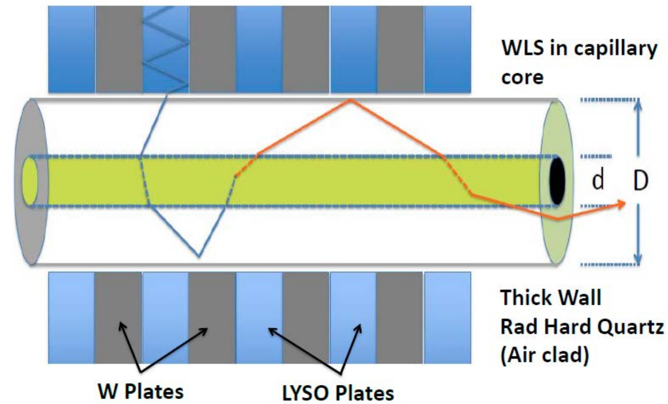
Good resolution achieved at high energies

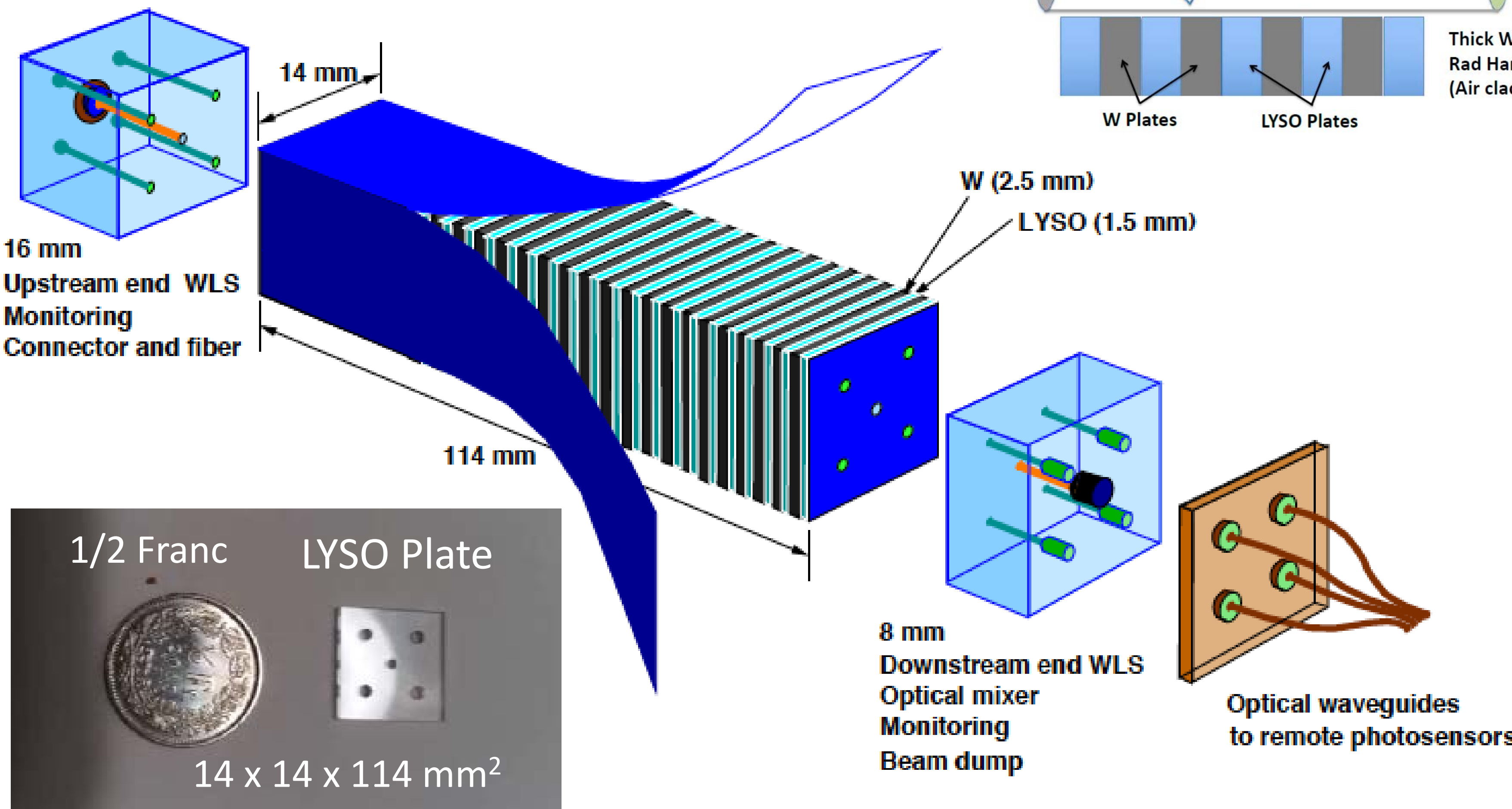




LYSO/W/Quartz Capillary Shashlik

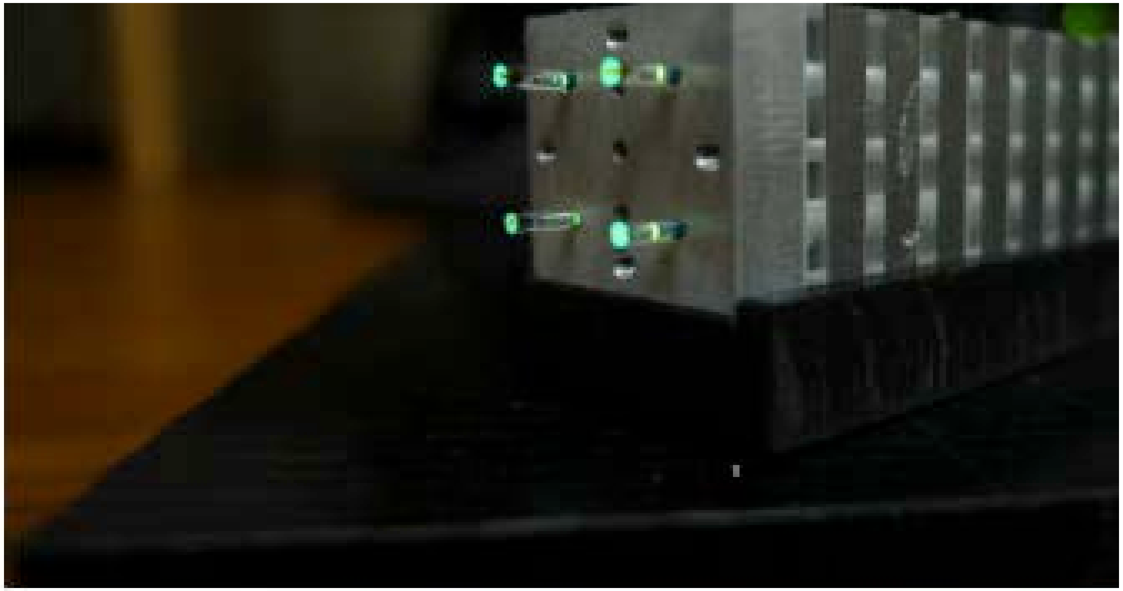


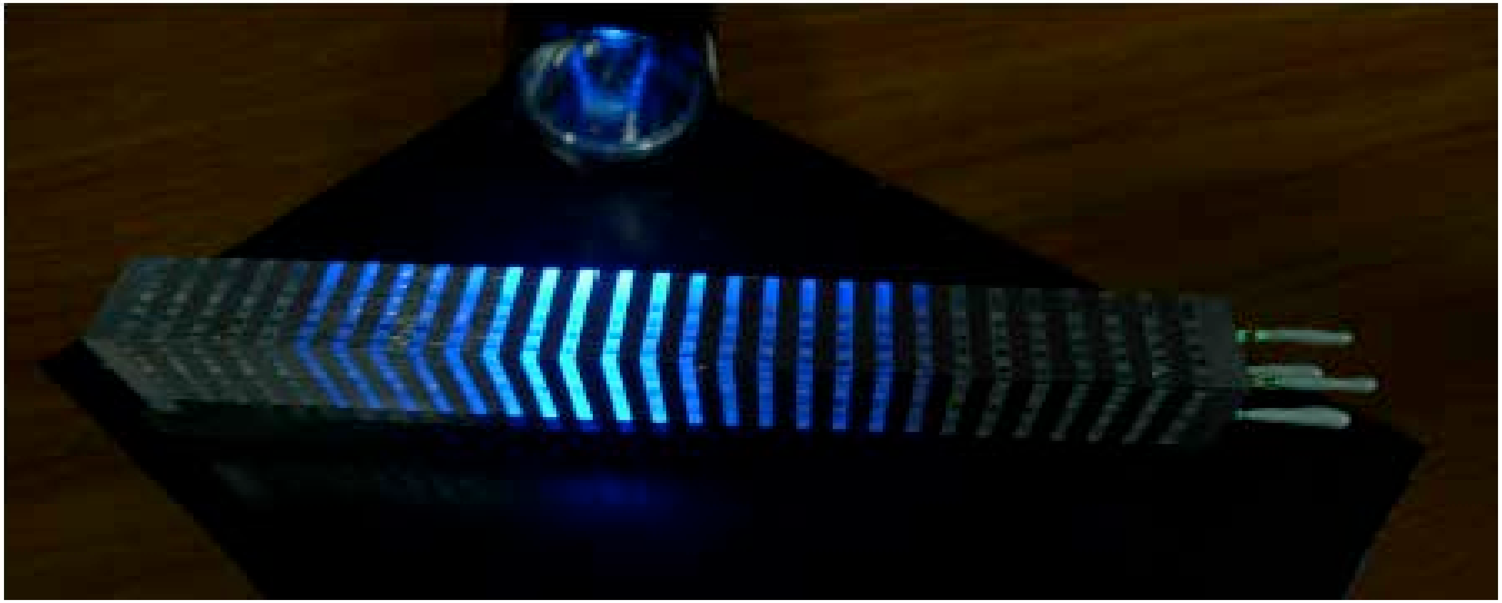




A LYSO/W/Capillary Tower for 2015 BT

A 4 x 4 matrix will be tested at CERN in 2016





Bright, Fast Scintillator: LSO/LYSO

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	LYSO(Ce)	PWO	PbF_2
Density (g/cm³)	3.67	4.51	4.51	4.89	7.13	7.40	8.3	7.77
Melting Point (ºC)	651	621	621	1280	1050	2050	1123	824
Radiation Length (cm)	2.59	1.86	1.86	2.03	1.12	1.14	0.89	0.93
Molière Radius (cm)	4.13	3.57	3.57	3.10	2.23	2.07	2.00	2.21
Interaction Length (cm)	42.9	39.3	39.3	30.7	22.8	20.9	20.7	21.0
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	1.82	2.20	1.82
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	310	300 220	480	402	425 420	?
Decay Time [b] (ns)	245	1220	26	650 0.9	300	40	30 10	?
Light Yield [b,c] (%)	100	165	4.7	36 4.1	21	85	0.3 0.1	?
d(LY)/dT [b] (%/ ºC)	-0.2	0.4	-1.4	-1.9 0.1	-0.9	-0.2	-2.5	?
Experiment	Crystal Ball	BaBar BELLE BES III	KTeV S. BELLE Mu2e	(GEM) TAPS Mu2e-II	L3 BELLE EIC?	COMET {Mu2e,SuperB) CMS?	CMS ALICE PANDA	A4 g-2 HHCAL?

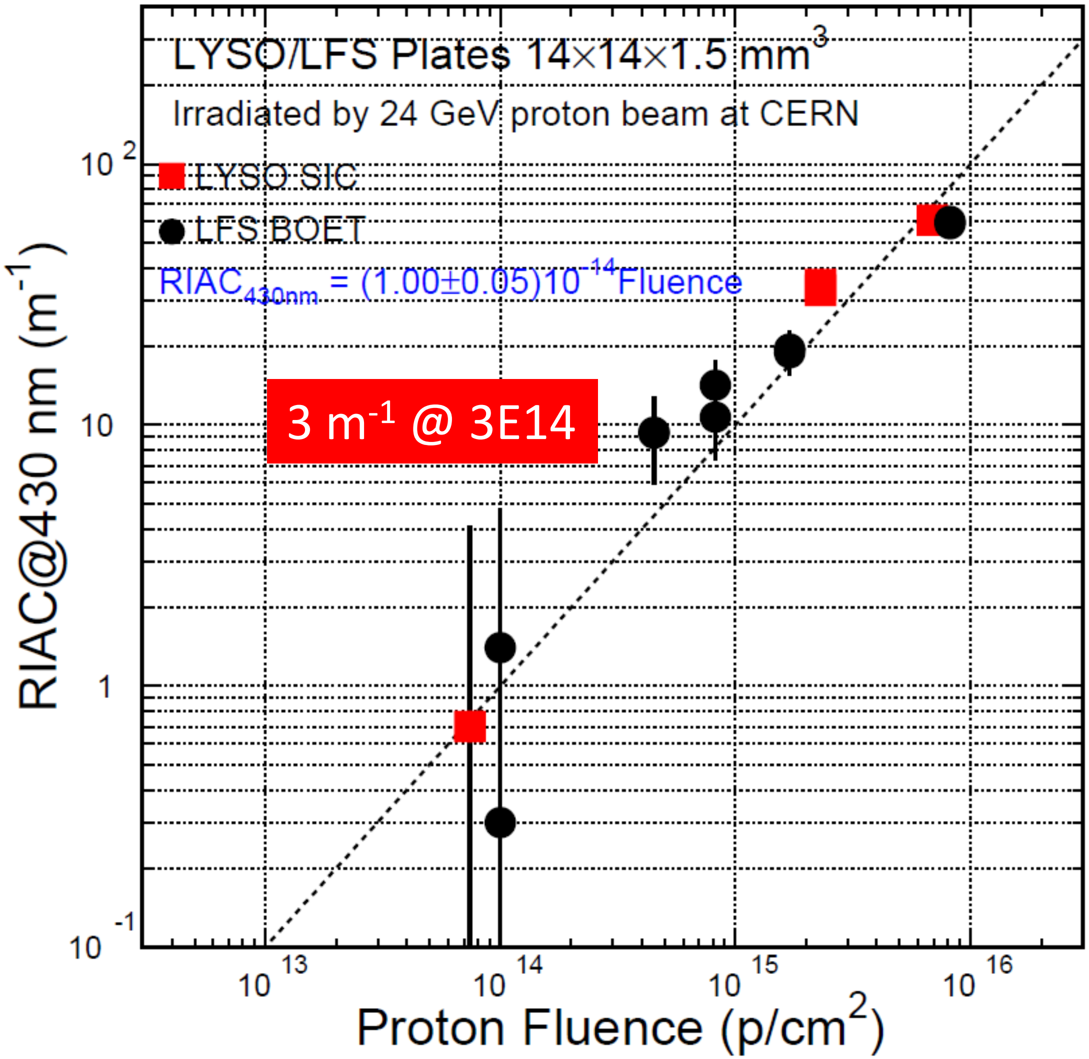
a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

Bright, Fast & Rad Hard LYSO

- LYSO is a bright (200 times of PWO), fast (40 ns) crystal scintillator widely used in the medical industry with mass production capability. It is also the most radiation hard crystal.
- Damage in LYSO does not recover, leading to a stable calorimeter.
- γ-ray and proton induced absorption coefficient is about 3 m^{-1} for 150 Mrad or 3 x 10^{14} p/cm^2, leading to a robust calorimeter with few percent light output loss at the HL-LHC.

See two talks on May 19, 2016, in this conference for the details

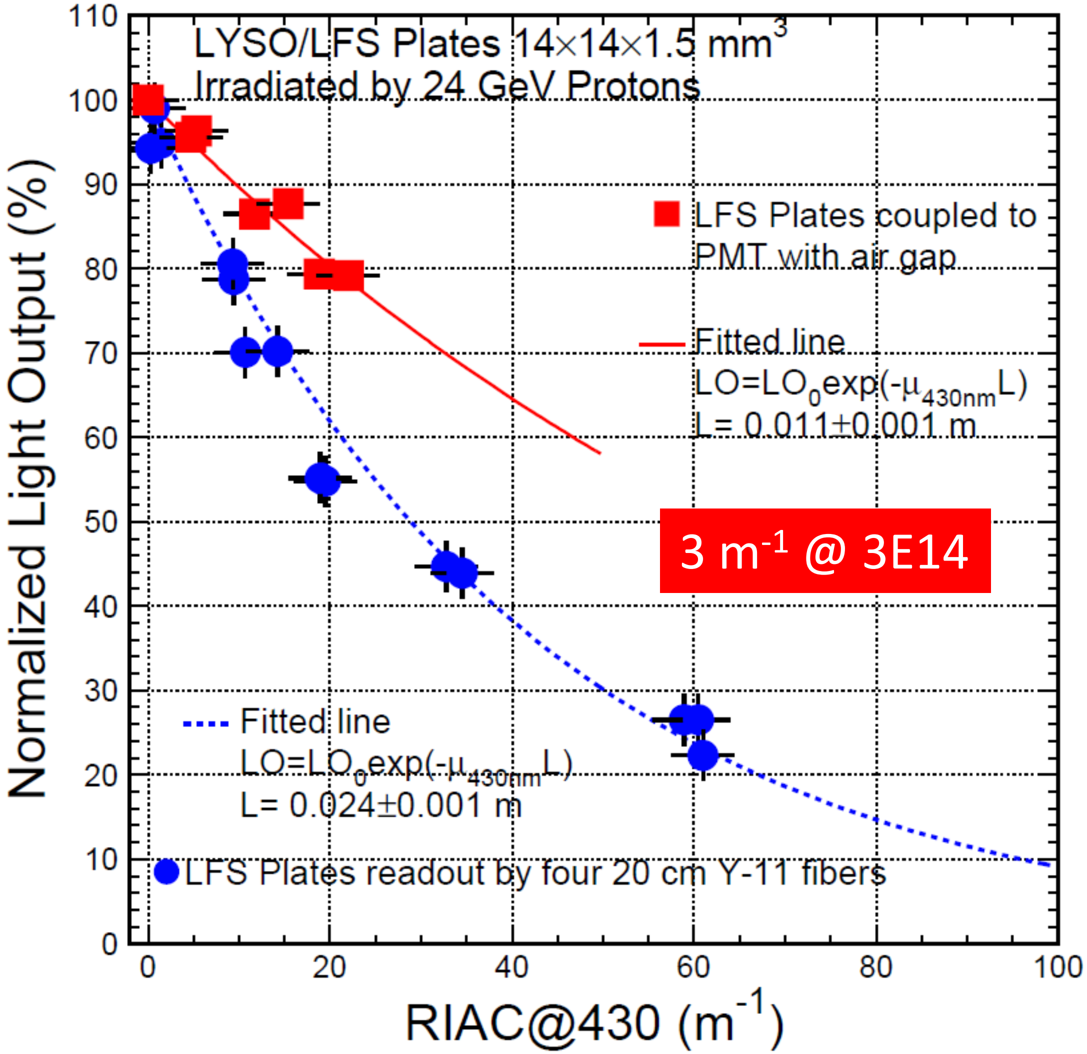
RIAC at 430 nm in LYSO



Consistent RIAC at 430 nm is observed in LYSO and LFS plates irradiated by 24 GeV protons up to 8.19×10^{15} p/cm^2 at CERN in 2014 and 2015.

LO: Direct & Y-11 Couplings

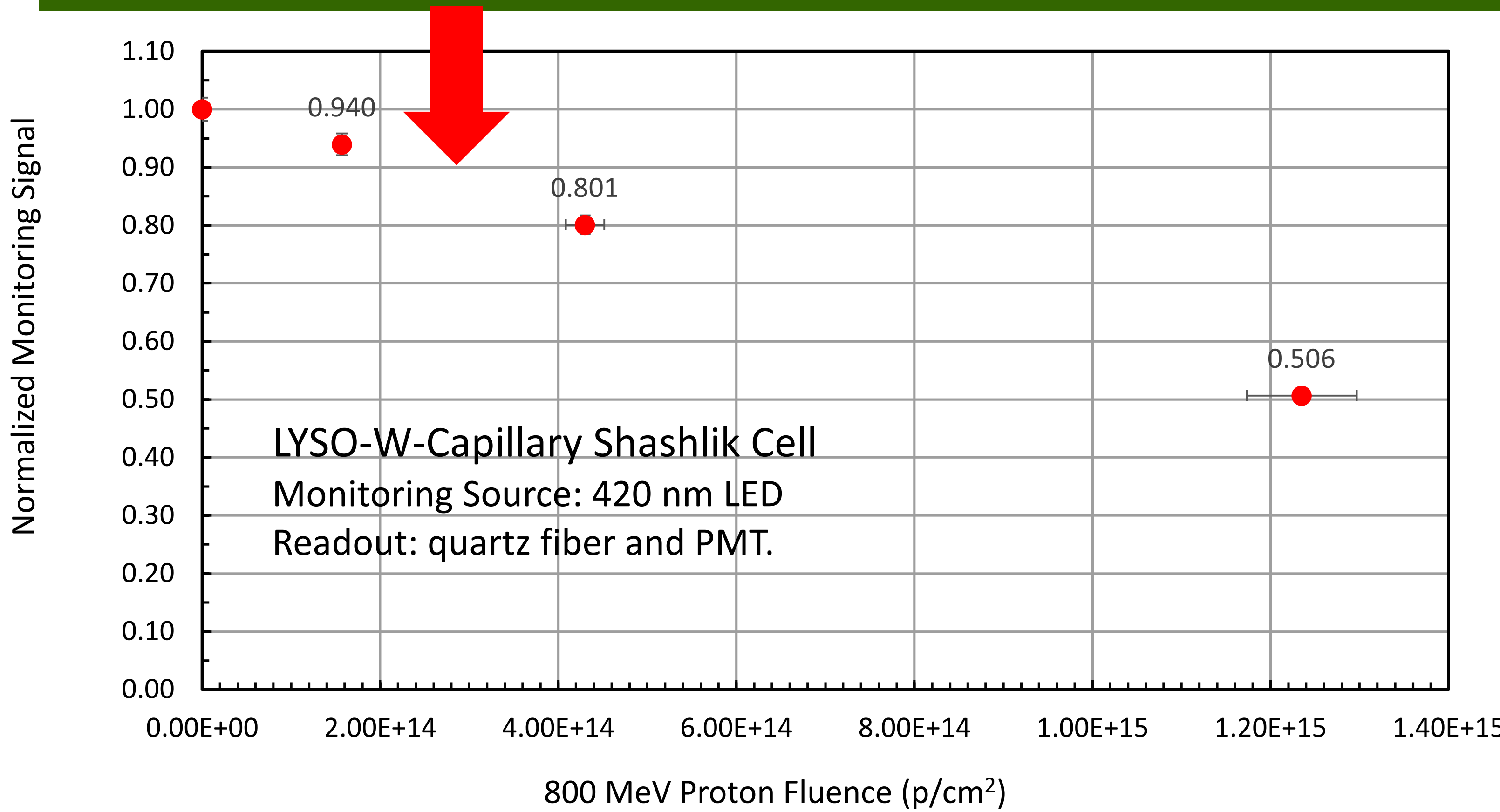
Data consistent with average light path length of 1.1 and 2.4 cm at 430 nm for direct and Y-11 readout respectively.



6% light output loss in LYSO plates @ 3E14 with Y-11 readout

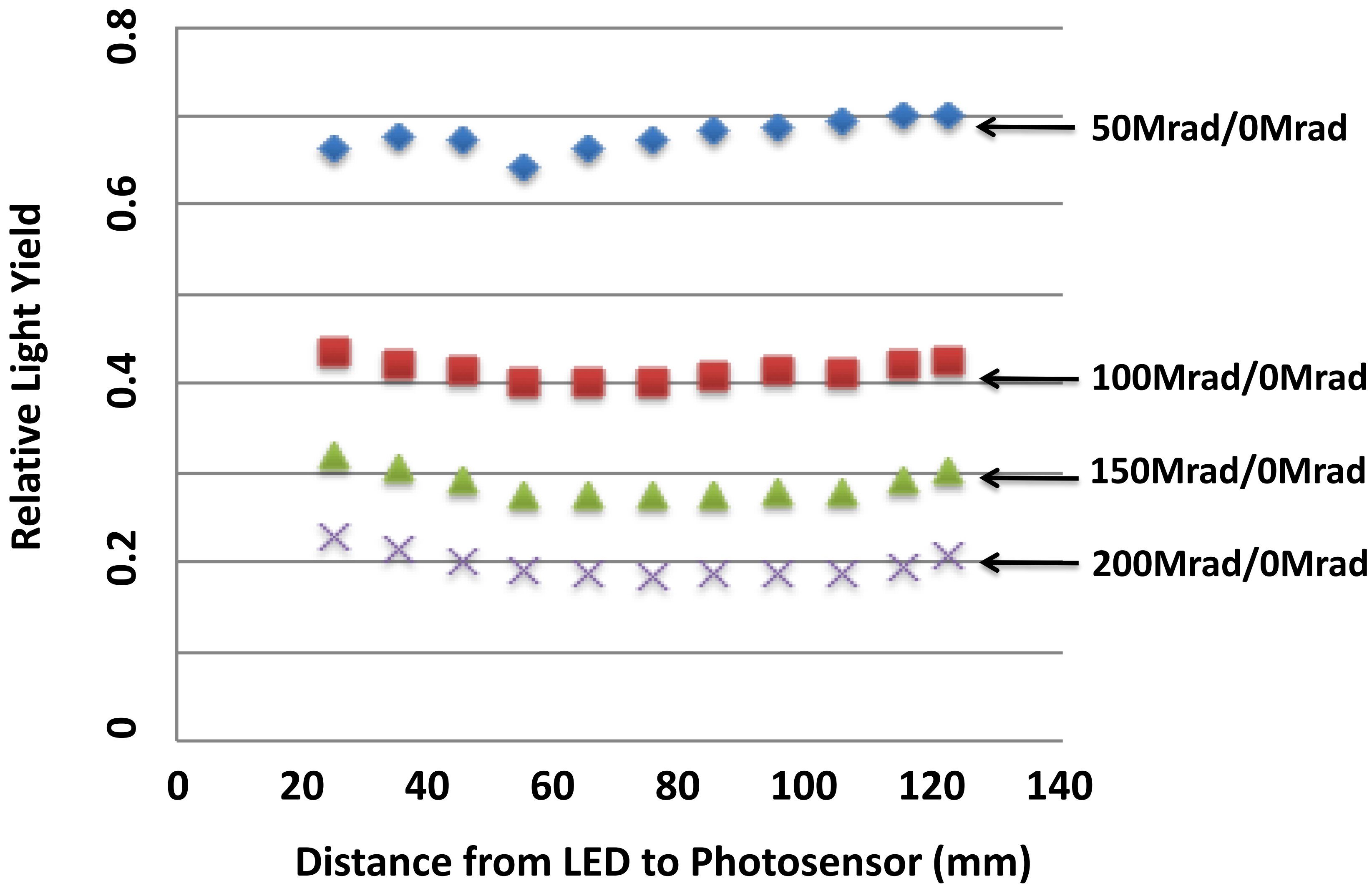
LFS/W/Capillary: 800 MeV Protons

A Shashlik tower irradiated to 1.2×10^{15} p/cm^2 in 3 steps with degradation of 20%/50% after 4.3×10^{14}/1.24×10^{15} p/cm^2



~10% light output loss in a LYSO/capillary based Shashlik tower @ 3E14

Radiation Hardness: Quartz Capillary



Radiation Hardness: SiPM

Irradiation to 1.3 x 10^{14} p/cm^2

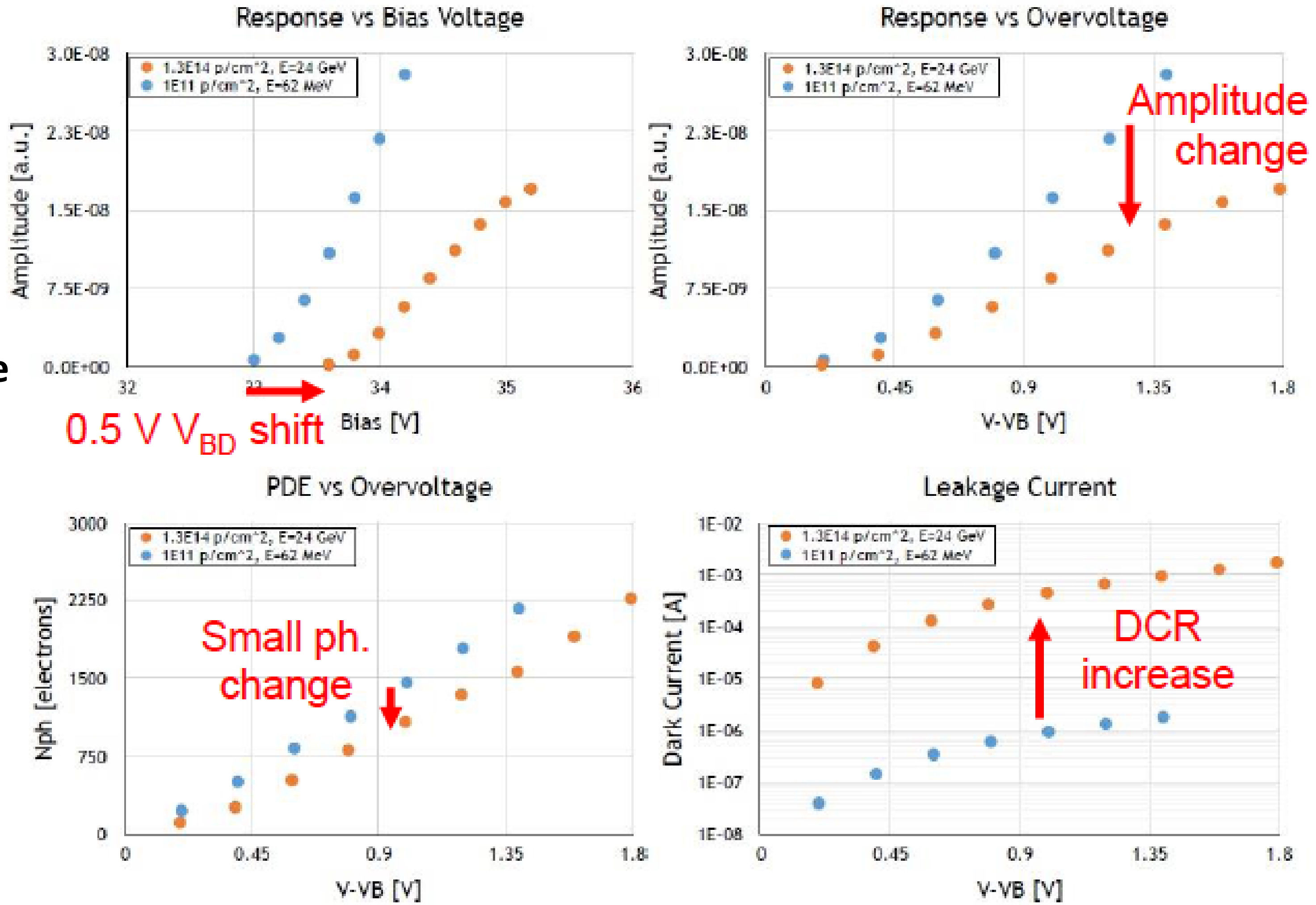
Temp = 23c

Small Bias Shift of 0.5V

Low PDE change

Dark Current 1mA/mm^2

Gain reduction due to heating of the device

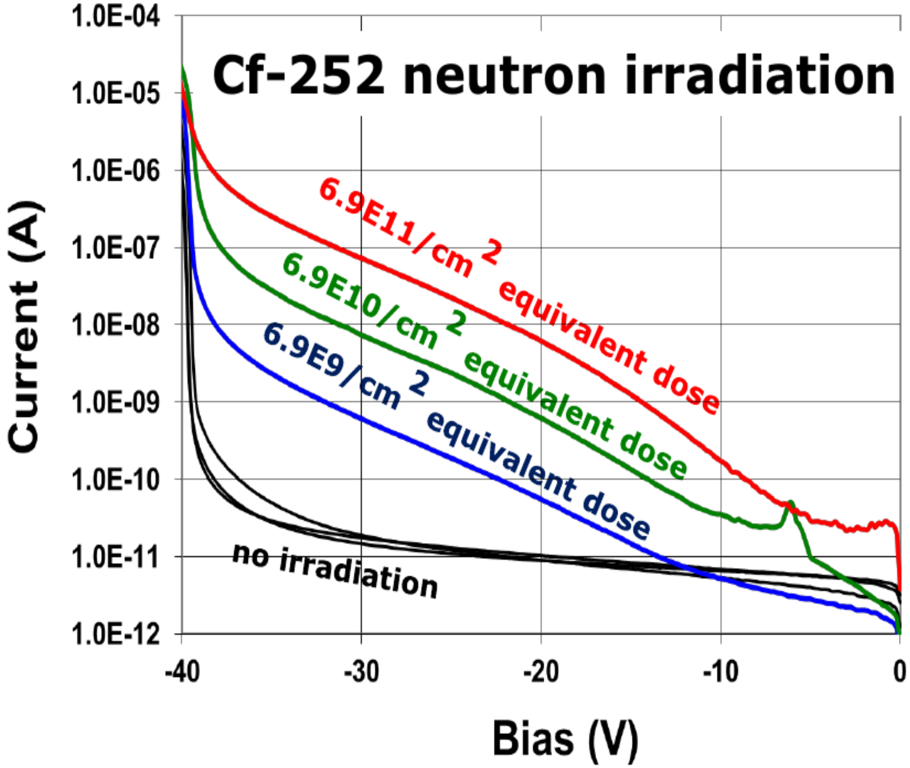


FBK 1mm^2 device with 12 micron pixels

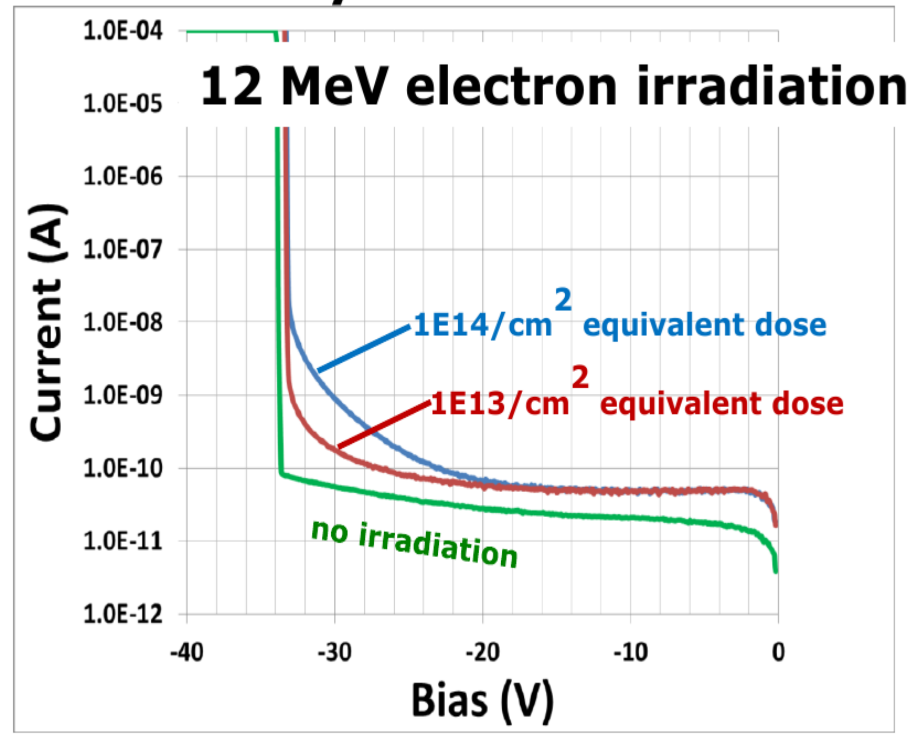
Radiation hardness: GaInP

Generation 3" first GaInP devices compared to GaAs

Previous GaAs SPAD results

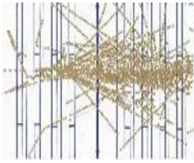


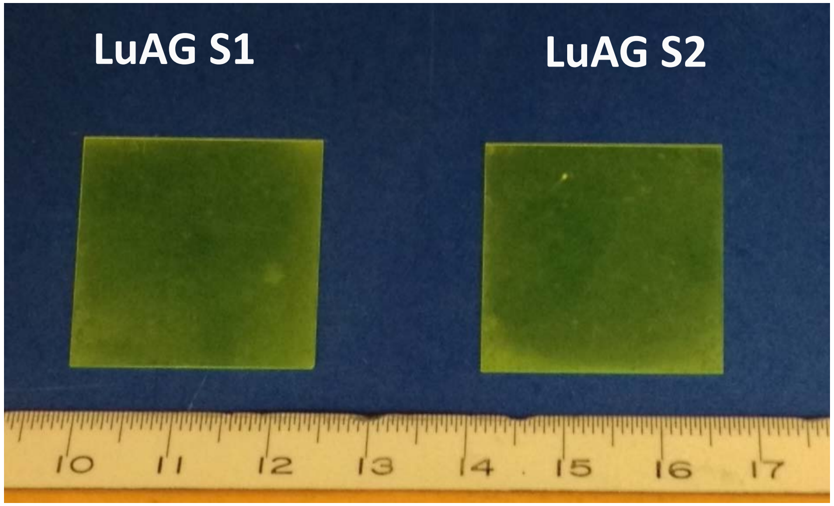
Preliminary GaInP SPAD results



Generation 5 followed these with device structure further optimized for increased radiation tolerance

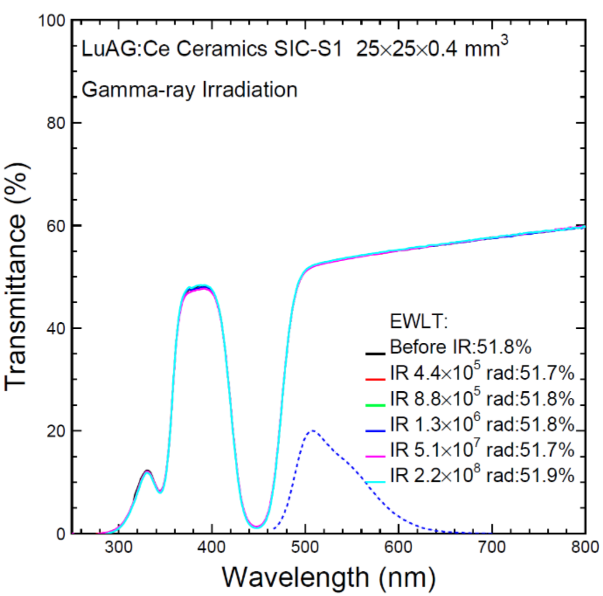
Alternative: LuAG:Ce Ceramics

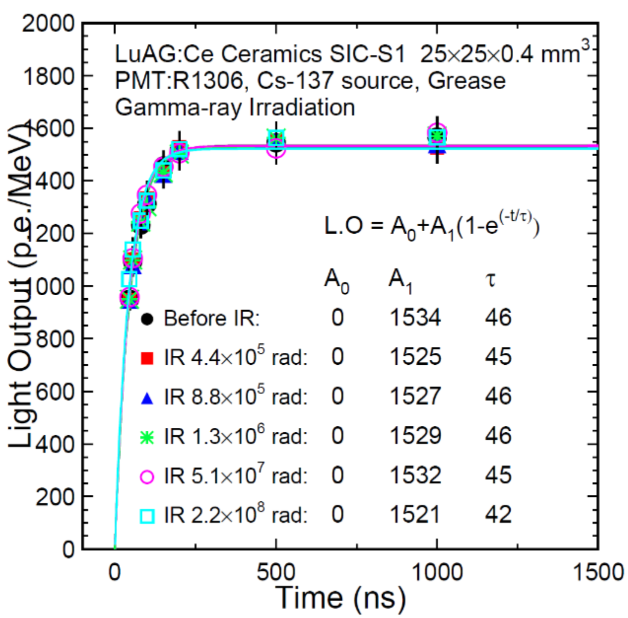


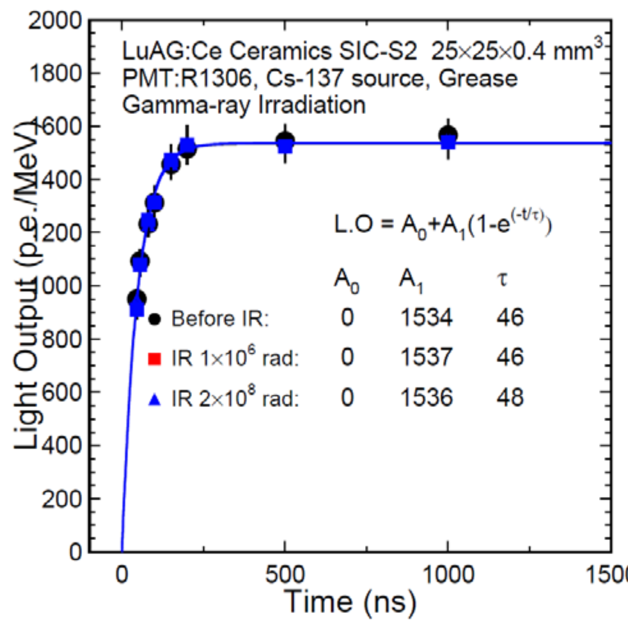


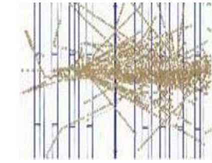
Sample ID	Dimension (mm3)
LuAG S1	25×25×0.4
LuAG S2	25×25×0.4

Rad hard up to 220 Mrad









Summary

- Precision e/γ by total absorption crystal calorimeters provide excellent physics discovery potential.
- To preserve precision e/γ and face the challenge of the radiation environment expected by future HEP experiments at the energy frontier, a crystal based Shashlik calorimeter reduces the light path length in crystals and thus enhances the radiation hardness.
- Bright, fast and radiation hard LSO/LYSO crystals provide a solid foundation for a stable and robust Shashlik calorimeter. Developments on quartz capillary based WLS and photo-detectors are very encouraging.
- Scintillating ceramics and glasses, such as LuAG:Ce ceramics, may play an important role for a cost-effective Shashlik calorimeter concept.