Calorimetery for EIC detector

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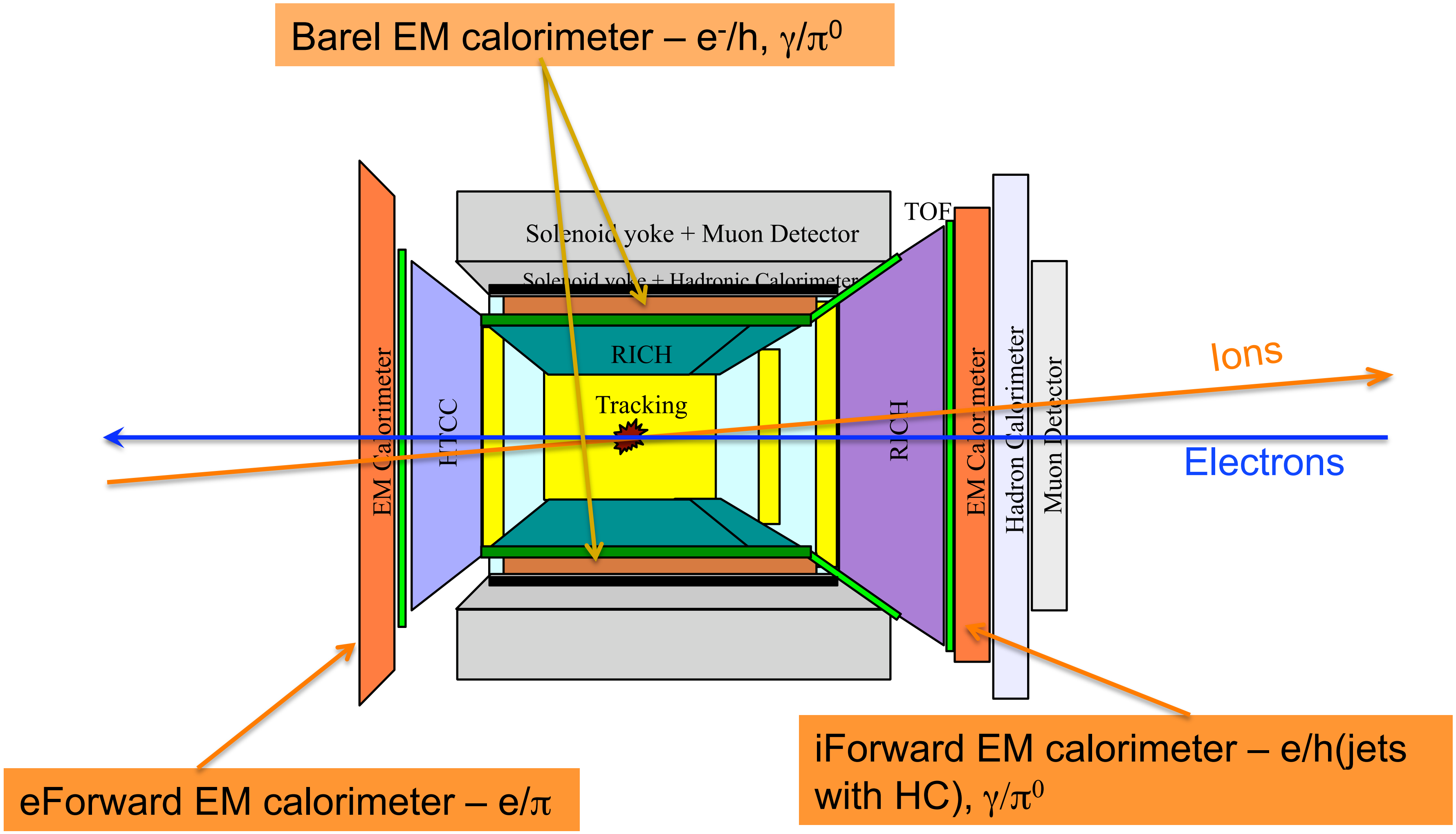
EIC detector Workshop, June 4 & 5, JLAB

EIC detector

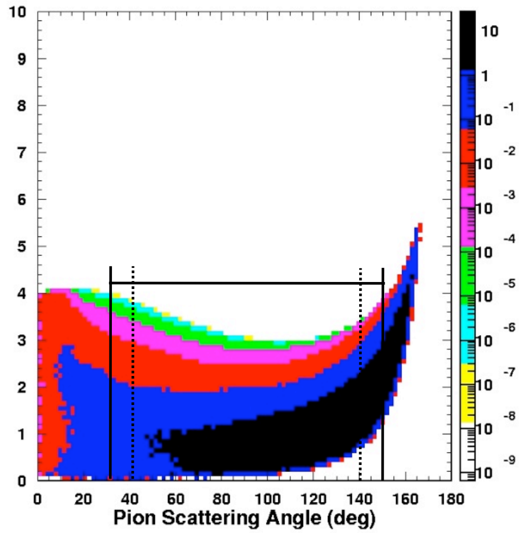


Physics requirements to EM calorimeters

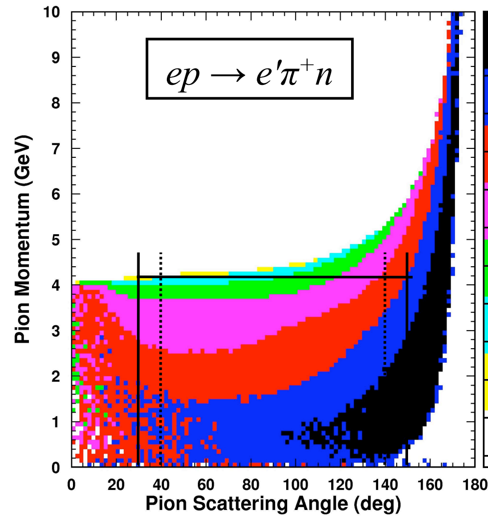
- Electron-forward Electromagnetic Calorimeter (EFEC) –
  - electron identification, should have enough radiation length to absorb up 10 GeV EM showers
  - fine granularity close to the beam
- Central Barel Electromagnetic Calorimeter (BEC)
  - electron identification, p < 6 GeV
  - $\pi^0 \rightarrow \gamma\gamma$ identification, p < 5 GeV
  - should be compact (tight space) and insensitive to high magnetic field
  - should have fine granularity (distance from IP ~3 m) and high resolution (~4 %)
- Ion-forward Electromagnetic Calorimeter (IFEC) –
  - electron-hadron (jet) separation (together with HC), p < 5 GeV
  - $\pi^0 \rightarrow \gamma\gamma$ identification, p ~10 GeV
  - should have fine granularity (distance from IP ~4 m) and high resolution (~4 %)

Kinematics of exclusive final states

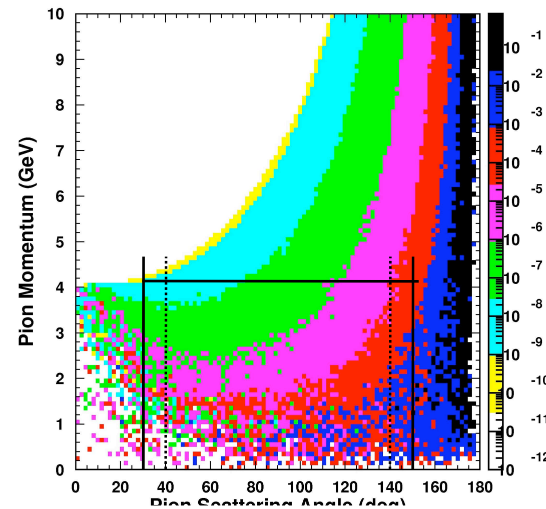
4 on 12 GeV

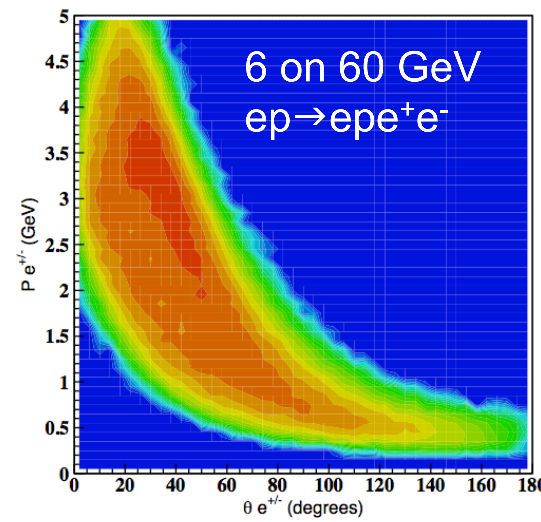


4 on 30 GeV



4 on 250 GeV





Challenges –

- π^0/γ separation in IFEC
- high radiation near beam regions
- high rates near beam regions

Choices for calorimeters

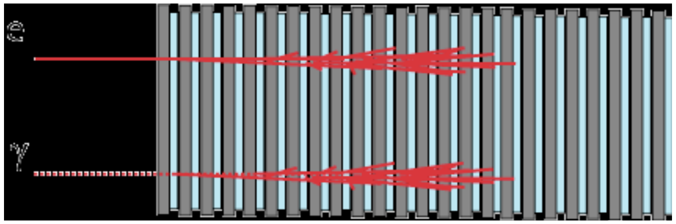
Homogenous calorimeters

- Based on dense materials that are also active in generating the signal
- Archetype is the crystal calorimeter
  - Scintillating crystals (BaF2, $PbWO_4$, CsI, LYSO)
  - Cherenkov radiators (Pb-glass)

- Almost without exception used for EM calorimetry

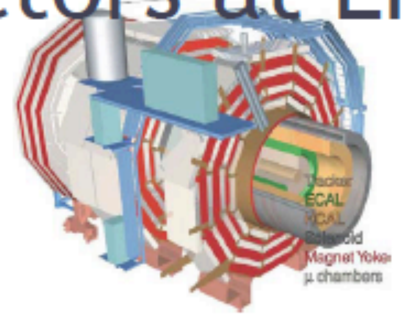
Sampling calorimeter

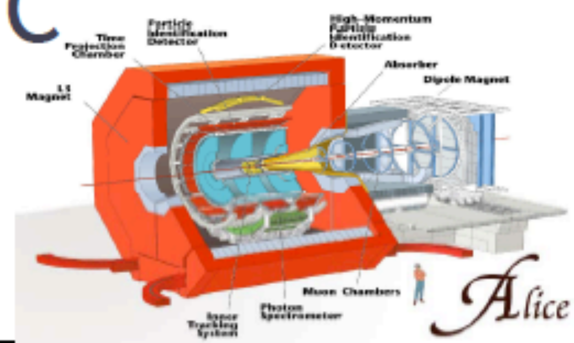
- Layers of inactive, dense material (e.g. Pb, W, U) mixed with active layers
- Active layers can be
  - Scintillators (plates or fibers) or Cherenkov in SiO_2 fibers
  - Silicon strips
  - Cryogenic noble liquids (Ar, Kr)
  - Gaseous detectors



- The technology for HCAL, but also used in ECAL

Photon Detectors at LHC





Exp.	ATLAS		CMS		ALICE	
Name	LAr Barrel	LAr Endcap	ECAL(EB)	ECAL(EE)	PHOS	EMCal
Structure	Liquid Ar		PWO + APD		PWO + APD	Pb + APD
Coverage	0<|η|<1.4, 2π	1.4<|η|<3.2, 2π	0<|η|<1.5, 2π	1.5<|η|<3.0, 2π	0<|η|<0.12, 0.6π	0<|η|<0.7, 0.6π
Granularity ΔηxΔφ	0.003x0.100 0.025x0.025 0.025x0.050	0.025x0.100 0.025x0.025 0.025x0.050	0.0174x0.0174	0.0174x0.0174 to 0.05x0.05	0.004x0.004	0.0143x0.0143
Res.	10%/√E⊕ 0.5%	10%/√E⊕ 0.5%	2.7%/√E⊕ 0.55%	5.7%/√E⊕ 0.55%	3.3%/√E⊕ 1.1%	7%/√E⊕1.5%

Calorimeters at JLAB

Homogenous calorimeters

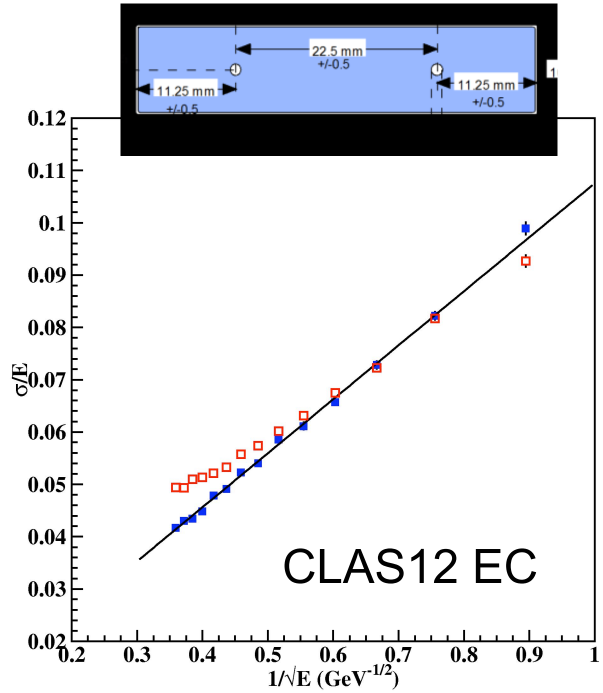
- Pb-glass – Hall A and C, Primex (Hall B) $\sigma/E=6\%/\sqrt{E}$
- PbF_2 – Hall A DVCS, $\sigma/E=4\%/\sqrt{E}$
- $PbWO_4$ – Hall B, DVCS (APD readout, high magnetic field), $\sigma/E=4.5\%/\sqrt{E}$ and Primex (PMT readout), $\sigma/E=2.5\%/\sqrt{E}$

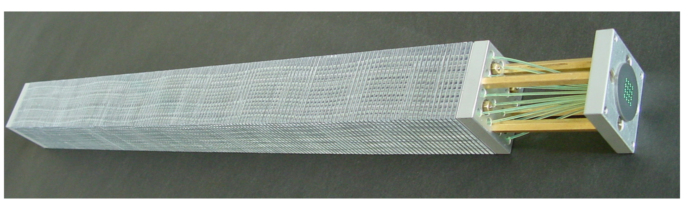
Sampling calorimeter

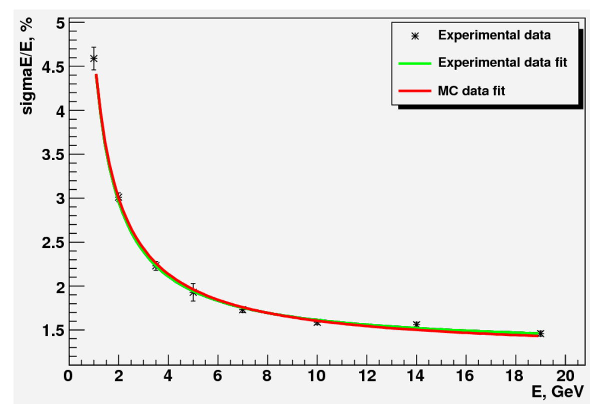
- Pb-scintillator plate sandwich – Hall B, $\sigma/E=10\%/\sqrt{E}$
- Pb-scintillating fibers – Hall D (SiPM readout, high magnetic field), $\sigma/E=7\%/\sqrt{E}$

EFEC

- Area to cover - ~40 m^2 (similar to CLAS)
- The most economical solution - lead-scintillator sandwich
  - Extruded scintillators with WS fiber readout (CLAS12 PCAL)
  - Will provide required hermeticity and needed granularity
  - Expected energy resolution $\sigma/E=10\%/\sqrt{E}$
- Somewhat better resolution can be achieved with “shashlyk” type configuration, used in ALICE, LHCb (LHC), HERA-B (DESY), PHENIX (RHIC), PANDA (GSI)

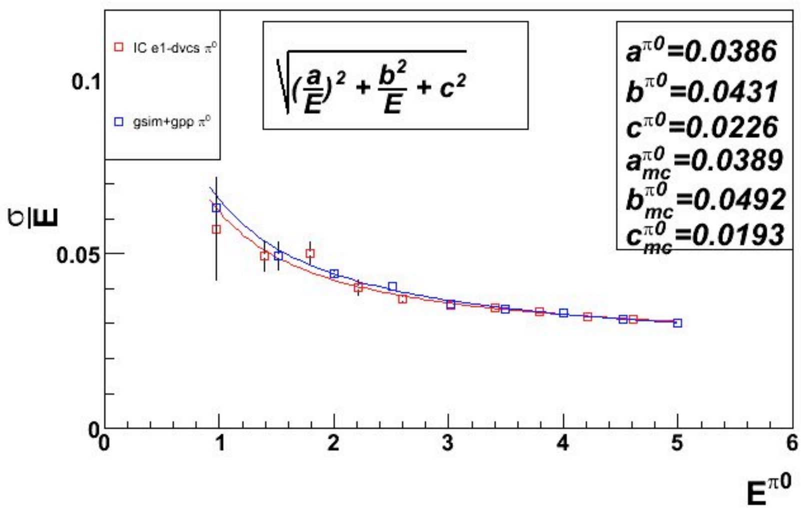


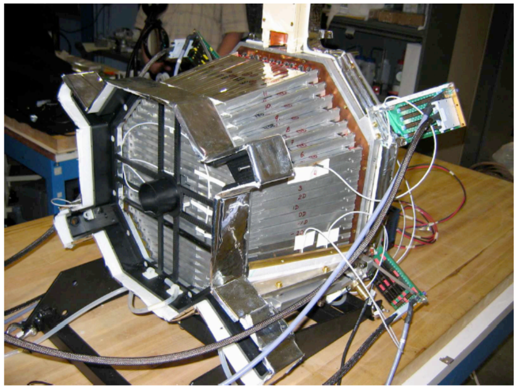


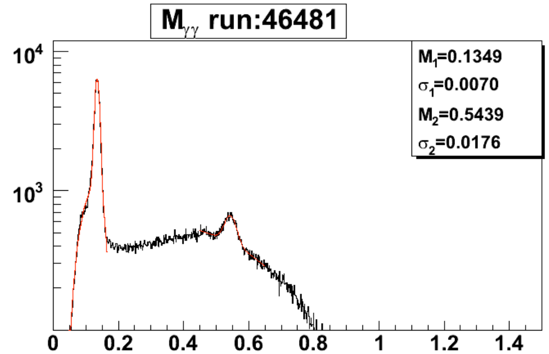


BEC

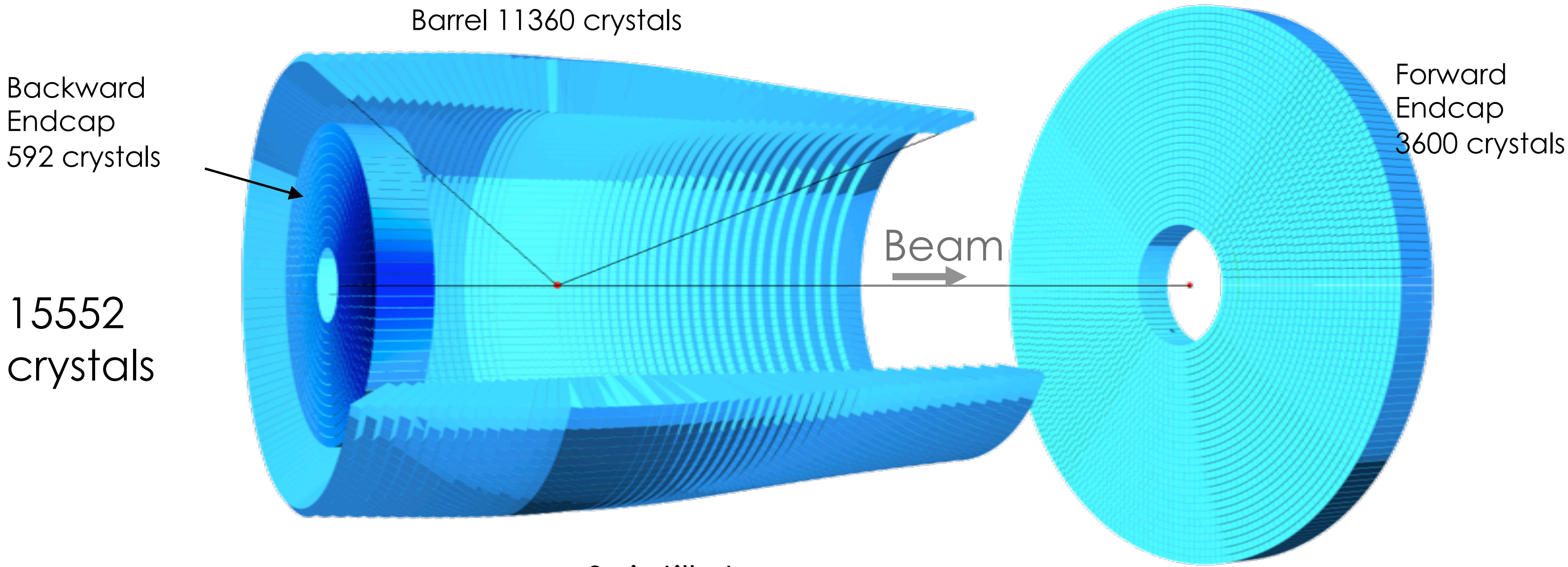
- Area to cover - ~30 m^2
- Should be compact (tight space) with a photodetector insensitive to magnetic field
- Logical choice – crystal calorimeter, such as PbWO4, with APD (CLAS, CMS, PANDA) or SiPM readout







2-The electromagnetic calorimeter in the target spectrometer



Compact geometry
Nearly 4π coverage
High rate capabilities

→

<u>Scintillator</u>
Small Radiation length
Small Moliere radius
Fast response

→

Lead tungstate ($PbWO_4$)

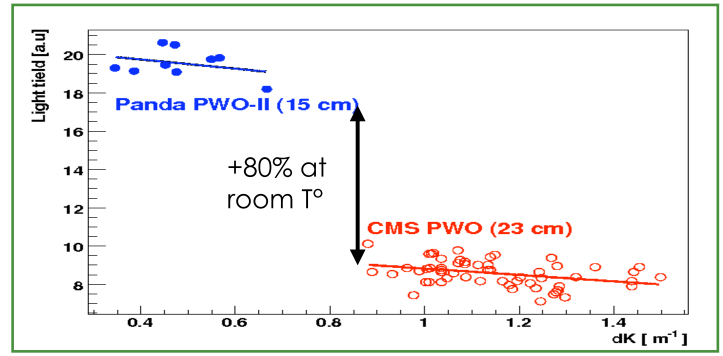
Magnetic field 2T → Photo sensors APD (Barrel)
VPT (Endcap)

Energy from 10 MeV to 15 GeV

Optimization of the PbWO4 and increase of the light output

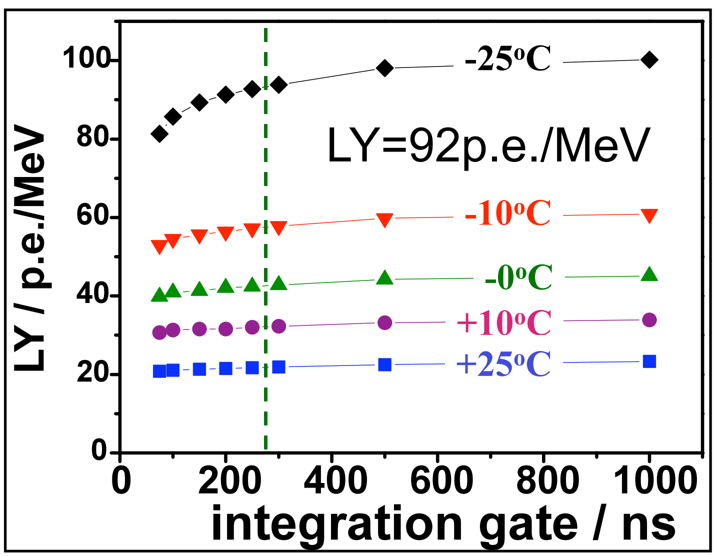
Optimization of the $PbWO_4$ (collaboration RINP, Minsk and the manufacturer BTCP at Bogoroditsk, Russia)

- –reduction of defects (oxygen vacancies)
- –reduced concentration of La-, Y-Doping
- –better selection of raw material
- –optimization of production technology

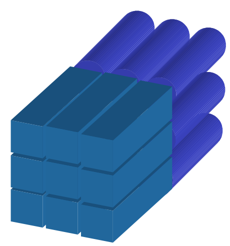


Development of the PWO-II : Light yield increased

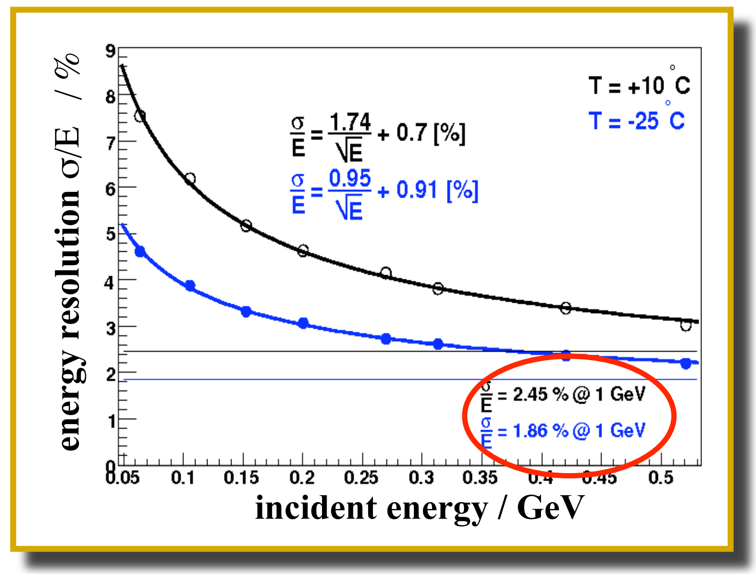
4x lighter if cooled down



3x3 matrix
20x20x200mm^3
PM-readout



Response to high energy photons @MAMI, Mainz



Crystals for HEP calorimeters

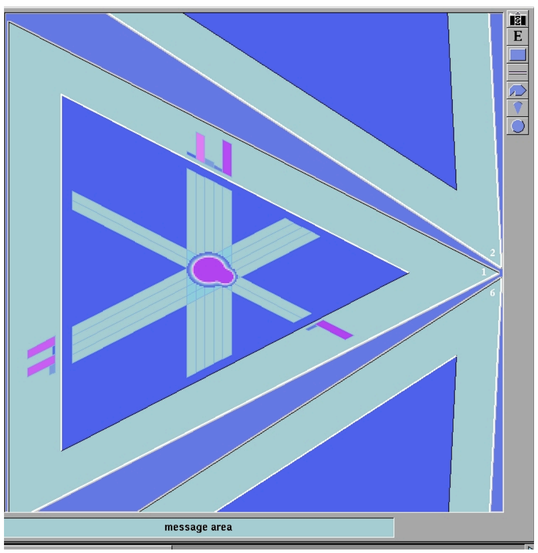
Crystal	NaI(Tl)	CsI(Tl)	CsI(Na)	CsI	BaF_2	CeF_3	BGO	PWO(Y)	LSO(Ce)
Density (g/cm^3)	3.67	4.51	4.51	4.51	4.89	6.16	7.13	8.3	7.40
Melting Point (^oC)	651	621	621	621	1280	1460	1050	1123	2050
Radiation Length (cm)	2.59	1.86	1.86	1.86	2.03	1.70	1.12	0.89	1.14
Molière Radius (cm)	4.13	3.57	3.57	3.57	3.10	2.41	2.23	2.00	2.07
Interaction Length (cm)	42.9	39.3	39.3	39.3	30.7	23.2	22.8	20.7	20.9
Refractive Index [a]	1.85	1.79	1.95	1.95	1.50	1.62	2.15	2.20	1.82
Hygroscopicity	Yes	Slight	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420	420 310	300 220	340 300	480	425 420	402
Decay Time [b] (ns)	245	1220	690	30 6	650 0.9	30	300	30 10	40
Light Yield [b,c] (%)	100	165	88	3.6 1.1	36 4.1	7.3	21	0.3 0.1	85
d(LY)/dT [b] (%/ °C)	-0.2	0.4	0.4	-1.4	-1.9 0.1	0	-0.9	-2.5	-0.2
Experiment	Crystal Ball	BaBar BELLE BES III	-	KTeV	(L*) (GEM) TAPS	-	L3 BELLE	CMS ALICE PANDA	SuperB

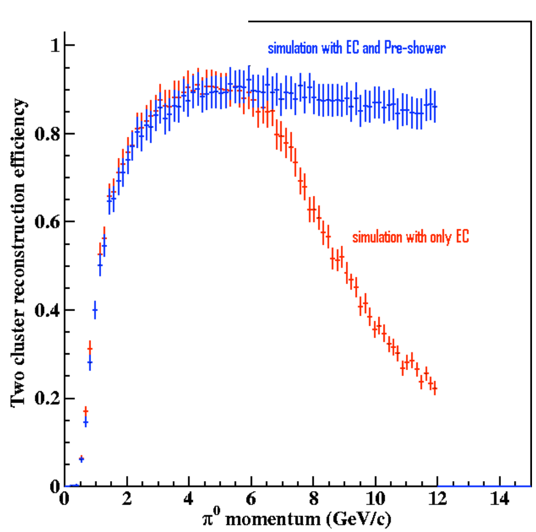
a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

IFEC

- Area to cover - ~40 m^2
- The most demanding in terms performance – wide energy range of particles and requires high resolution
- Challenge -π^0/γ separation, important DVCS/DVMP

Example from CLAS EC





Efficiency of two photon reconstruction from high energy $\pi^0 \rightarrow \gamma\gamma$ decays

- Crystal calorimeter – continue BEC coverage
- Must find solution for near beam coverage

Near-beam calorimetry

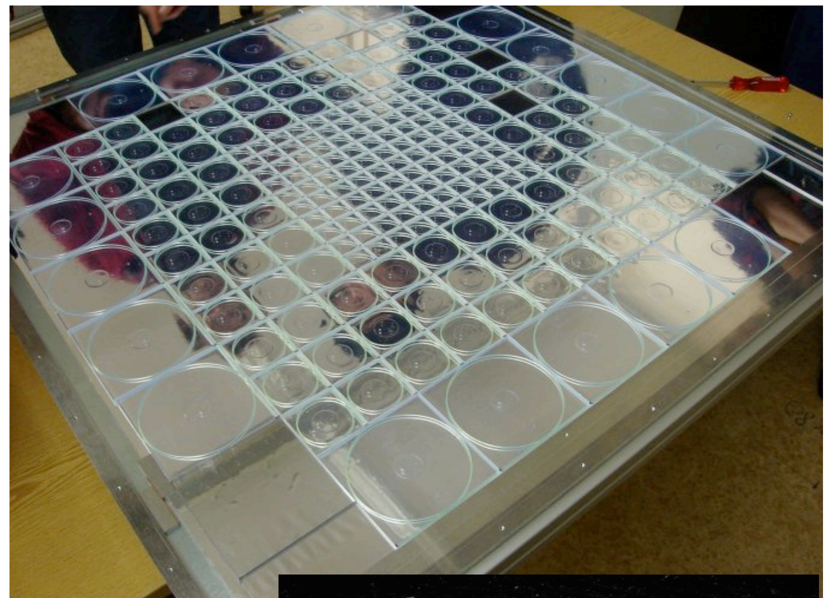
- Challenges – high density and high rate of outgoing particles (especially in ion beam direction) and high radiation
- 1 or 2 bit digital sampling calorimeter (IFEC/HC), e.g. W (absorber) with silicon readout
  - One can increase detector granularity and hence PFA performance while reducing cost.
  - Cheap, robust detectors suitable for the digital version exist and are very attractive: GRPC, μMEGAS, GEM…
- Quartz fiber calorimeter (IFEC/HC)
- Scintillating fiber tungsten powder calorimeter (EFEC)

Summary

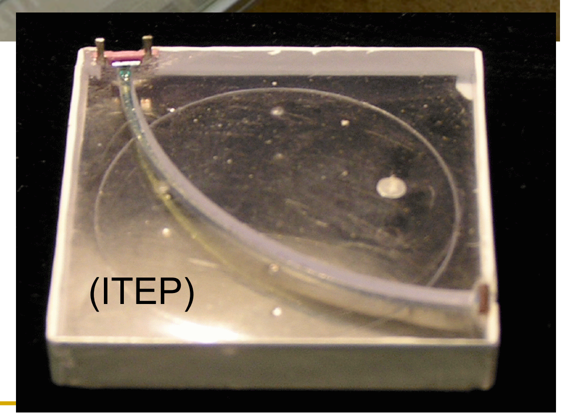
- Challenges to EM calorimeters are not to demanding
- Many collider detectors solve bigger issues
- Solutions exist with today's technologies
- Future technologies might gave better handle on rates, coverage, triggering, resolution, integration with HCAL
- Some of challenges in PID can be solved combining ECAL and HCAL solutions (in particular IF detector)

Other options (HCAL)

- Novel multi-pixel Geiger mode photo-diodes (SiPMs)
  - B-field proof, small, affordable
- High granularity with scintillator at reasonable cost
  - photo-sensors integrated
- Opens revolutionary design options:
  - embedded electronics and calibration system for minimal dead zones
  - thin readout gap
- Granular, compact, hermetic



(DESY)



(ITEP)