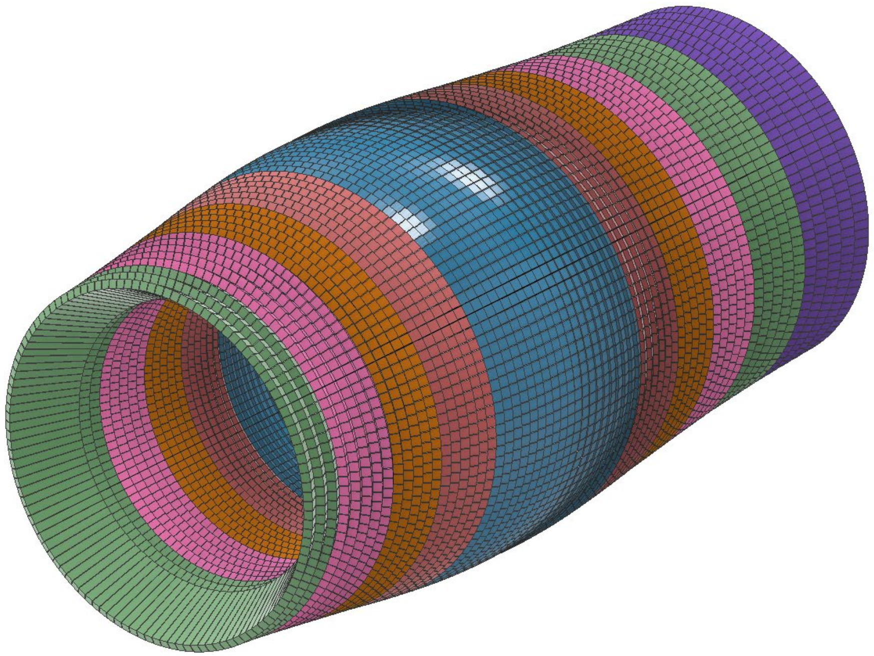
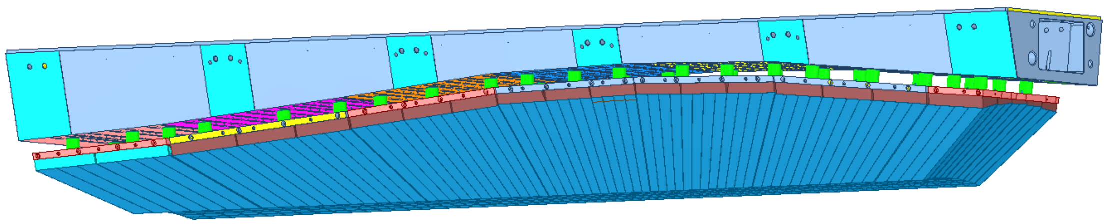
Electromagnetic Barrel Calorimetry



Tanja Horn

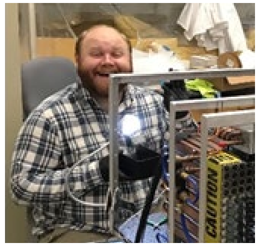
The Catholic University of America / Jefferson Lab



Detector-1 Barrel EMCal Reference Design


- Homogeneous EM calorimeter – typical materials in lepton induced hadron scattering: crystals and glass, a **well-established detector technology**
- Barrel EMCal readout electronics can be identical with the backward EM calorimeter → **no additional technology required**
- Experienced team of institutions (AANL, CUA, FIU, JMU, UK, MIT..) including **many early-career researchers** working on design, simulation, prototypes
- Opportunities for many early-career **in-kind contributions** for radiator, design/construction, simulation, readout
- **No long-lead items**



Report from the EIC Detector Proposal Advisory Panel

Conclusions for Detector Concept and Feasibility

Based on the careful study by the DAC and the information provided by the three proto-collaborations, the panel finds that ATHENA and ECCE satisfy the requirements to fulfil EIC's "mission need" statement based on the EIC community White Paper and the National Academies of Science (NAS) 2018 report. The more limited range of new technologies and the reuse of the BABAR Magnet and the sPHENIX HCAL make ECCE less expensive and more likely to be ready for data taking on time for Critical Decision 4A (CD-4A), the start of EIC accelerator operations, and therefore suitable as Detector 1. Core has provided a more conceptual, less fully developed design.

A. ALIKHANYAN National Laboratory

THE CATHOLIC UNIVERSITY OF AMERICA

University of Kentucky

FIU FLORIDA INTERNATIONAL UNIVERSITY

Massachusetts Institute of Technology

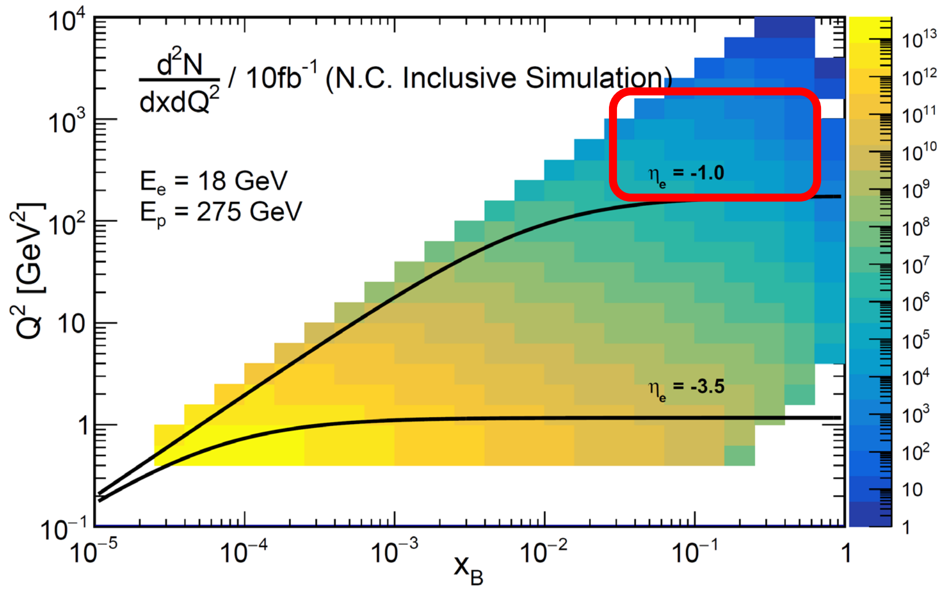
JMU JAMES MADISON UNIVERSITY

+ additional institutional interest

Introduction

Scattered electron kinematics measurement is essential at the EIC

- ❑ High precision, hermetic detection of the scattered electron is required over a broad range in η and over energy range from 0.1 to tens of GeV
  - ○ In the very backward direction high precision is required for electron kinematics measurement
  - ○ In backward and barrel region it is required for clean electron identification. In the barrel region, driven by high-x and high-Q^2 science drivers
- ❑ In ECCE we chose SciGlass in the barrel as this provides excellent e/h separation due to its good energy resolution, matched to the backward region need, and its cost effectiveness



η	[-4 .. -1.75]	[-1.75 .. 1.3]	[1.3 .. 4]
Material	$PbWO_4$	SciGlass	Pb/Sc
X_0 (mm)	8.9	24-28	16.4
R_M (mm)	19.6	35	35
Cell (mm)	20	40	40
X/X_0	22.5	17.5	19
Δz (mm)	60	56	48

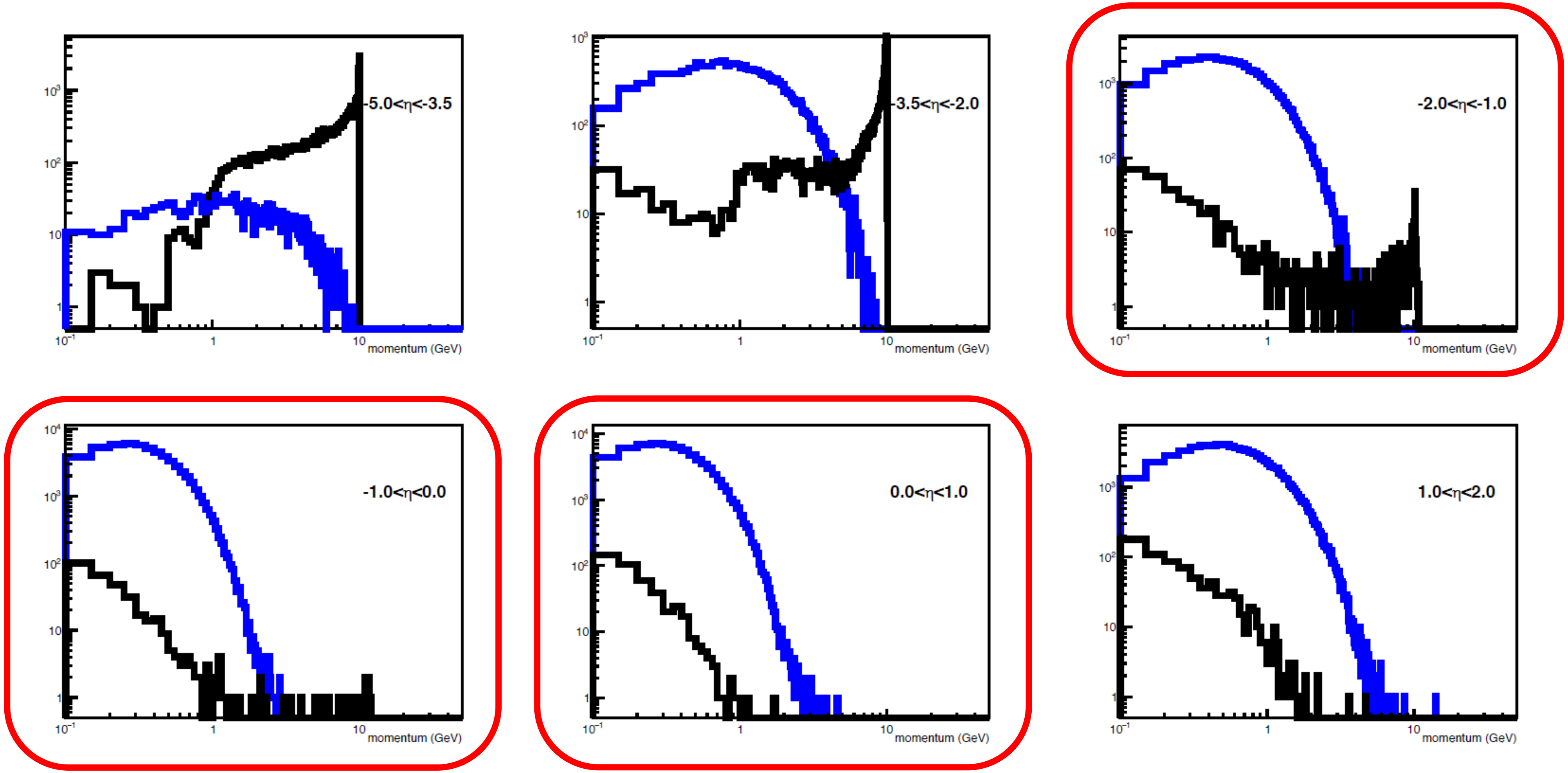
Requirements

- ❑ Good energy resolution
  - ○ e.g., region $-2 < \eta < -1$ requires ~7%/√E
- ❑ e/h separation up to 10^{-4}

e/π SEPARATION

NEEDS

ΔG needs pi/e 10^{-3} , A_{PV} needs pi/e 10^{-4} in η bins -2 to 1



10 x 100 GeV Pion/e- Ratio (Work by **Hanjie Liu**)

Homogeneous Design based on PANDA

PANDA

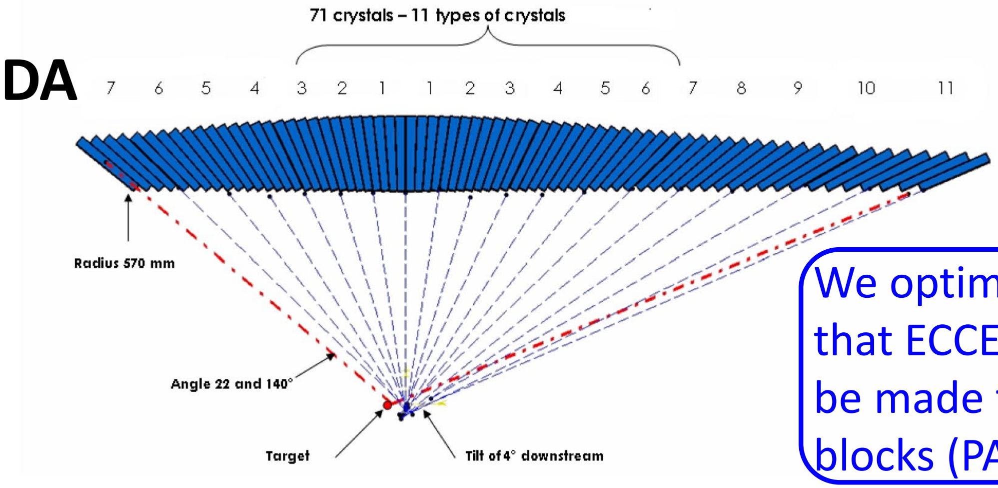
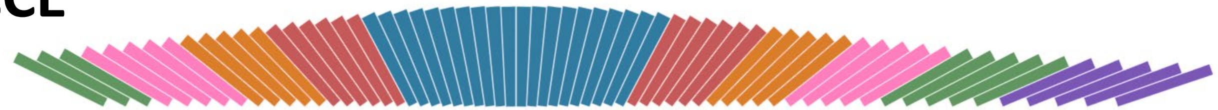
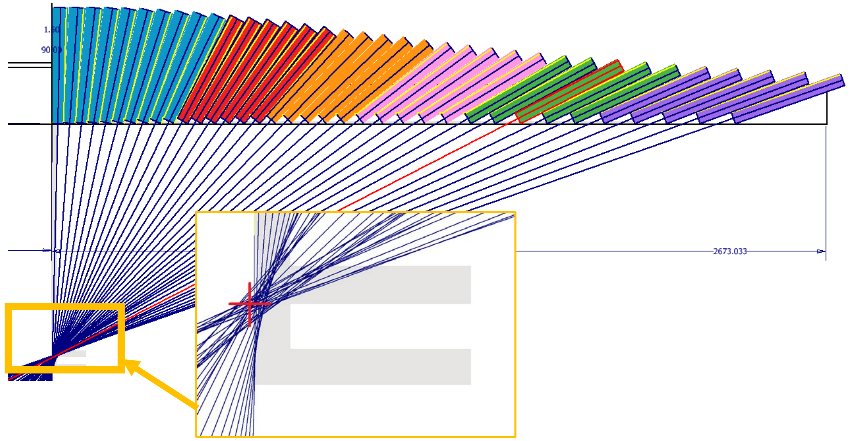


Figure 5.4: Crystal arrangement of the barrel along the beam axis. Positions of the different crystal types are indicated. Due to the mirror symmetry, 11 types are sufficient instead of 18.

ECCE

Based on realistic CAD design (CUA)





We optimized the geometry so that ECCE barrel calorimeter can be made from 6 families of blocks (PANDA has 11 families)

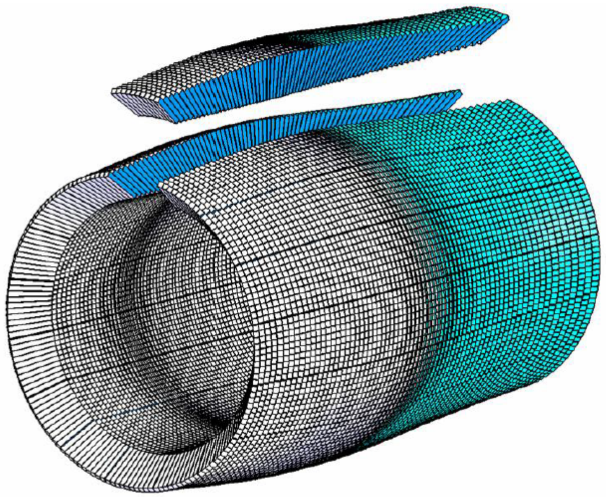
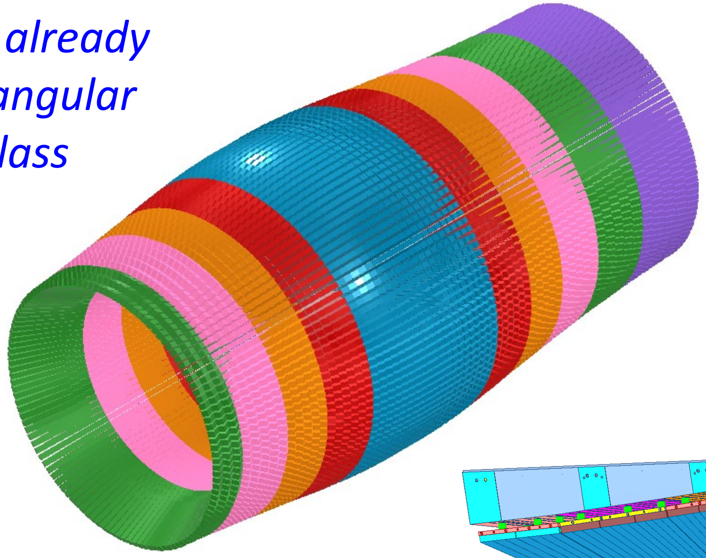
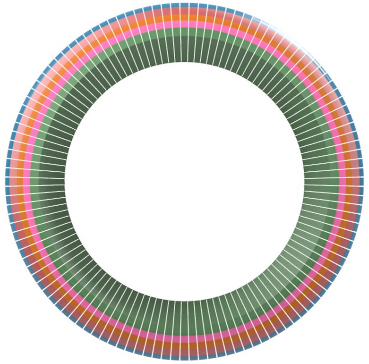
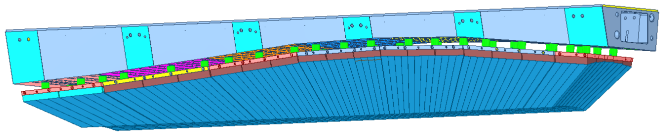


Figure 5.5: View of the total barrel volume with a separated single slice of 710 crystals. A slice covering 1/16 of the barrel volume.

With these families we already reduced any gap both angular and radially between glass blocks to <5mm

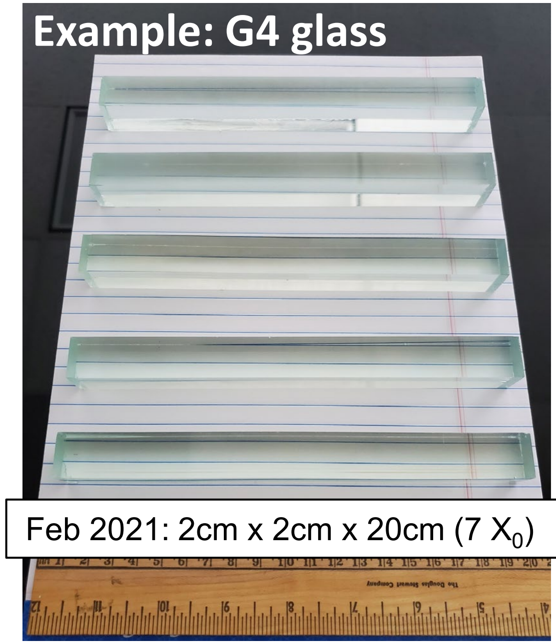




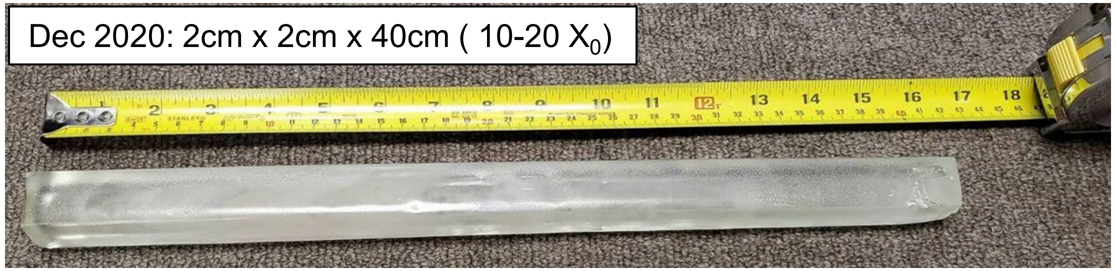


Homogeneous materials: Crystals and Glass

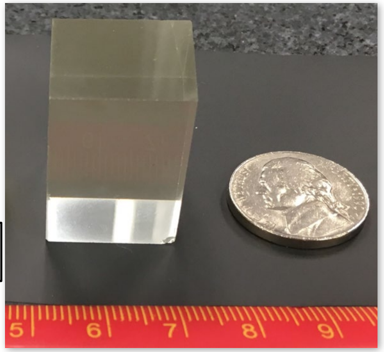
- High-resolution $PbWO_4$ (PWO) crystals are available from two vendors
- SciGlass 20cm has been produced reliably; We tested a 3x3 20 cm SciGlass prototype detector in beam and measured its performance (ongoing R&D EEEMCAL consortium, eRD105)
- **Measured performance for 20cm SciGlass ($7X_0$) as per GEANT simulation**
- We have an SBIR phase-II to start large-scale production or larger blocks (40+ cm, rectangular and projective shapes)
- Received the first polished 40 cm SciGlass ($15X_0$) late 2021, more on the way



Feb 2021: 2cm x 2cm x 20cm (7 X_0)



Dec 2020: 2cm x 2cm x 40cm (10-20 X_0)



2019: 2cm x 2cm x 4cm

2018: 1cm x 1cm x 1cm

Previous Scintillating Glass Calorimeters

Scintillating Glass of different formulation has been used for beam tests and as EMCal in the 1980s

https://inspirehep.net/literature/261664

Performance of a scintillating glass calorimeter for electromagnetic showers, 1988

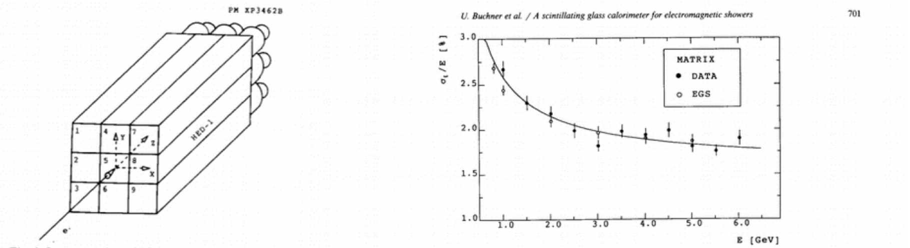


Fig. 3. Layout of the calorimeter setup in the test beam.

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

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

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

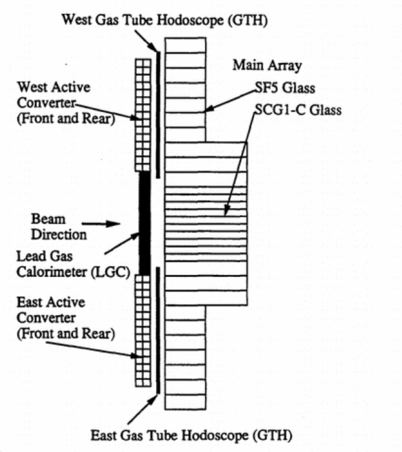


Figure 1. Plan view of the major components of the Experiment 705 calorimeter

	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

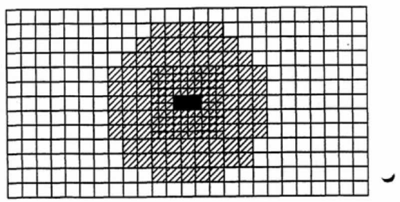


Figure 2. Beam view of the Main Array (SCG1-C scintillating glass is cross-hatched)

The Experiment 705 Electromagnetic Shower Calorimeter, 1993

15.x15.x89 cm^3
7.5x7.5x89 cm^3

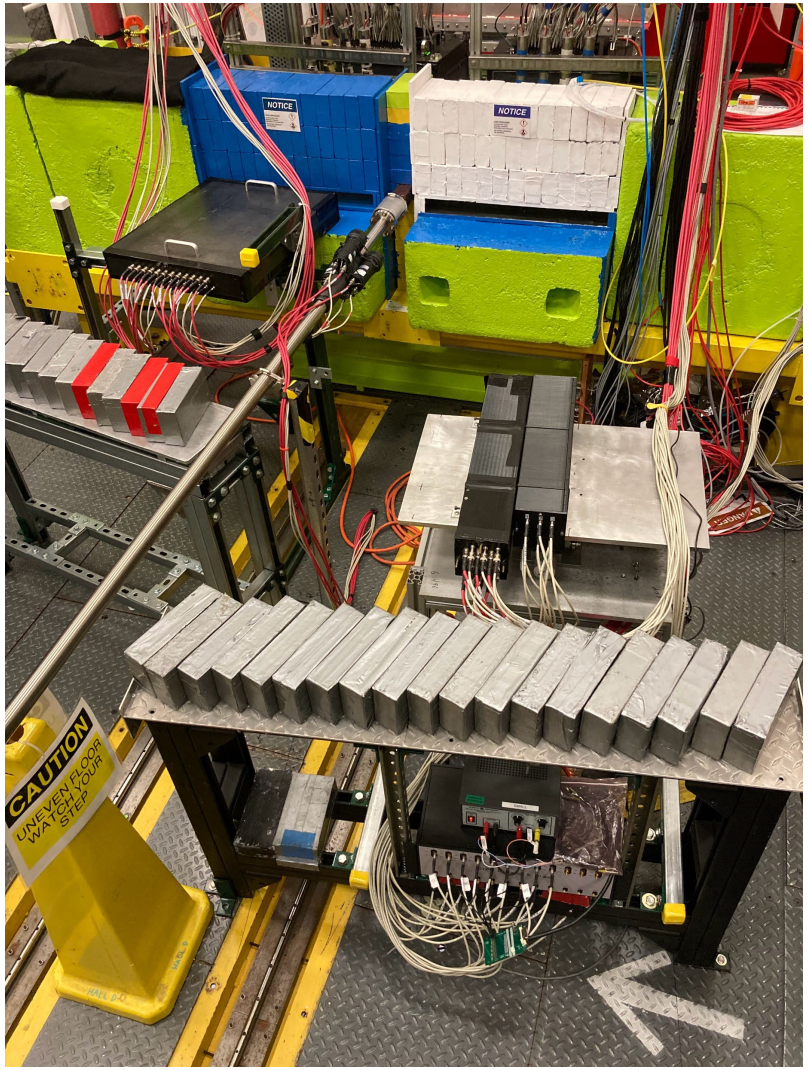
Rad. Length 20.9 X0

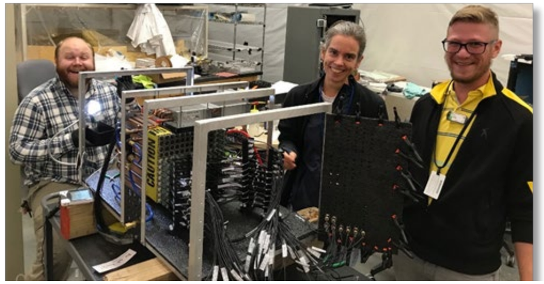
0.99%+4.58%/sqrt(E)

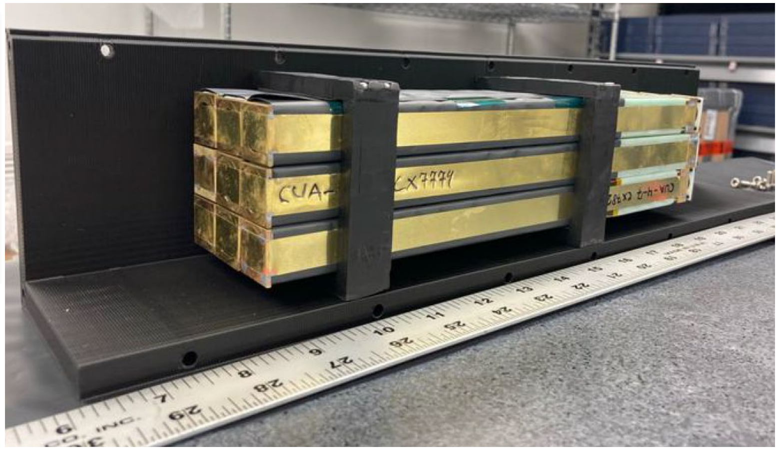
Resolution for mixed calorimeter (lead glass and SCG1-Glass)

Results from 1980s scintillating glass calorimeters encouraging → Need to establish performance for SciGlass (different formulation)

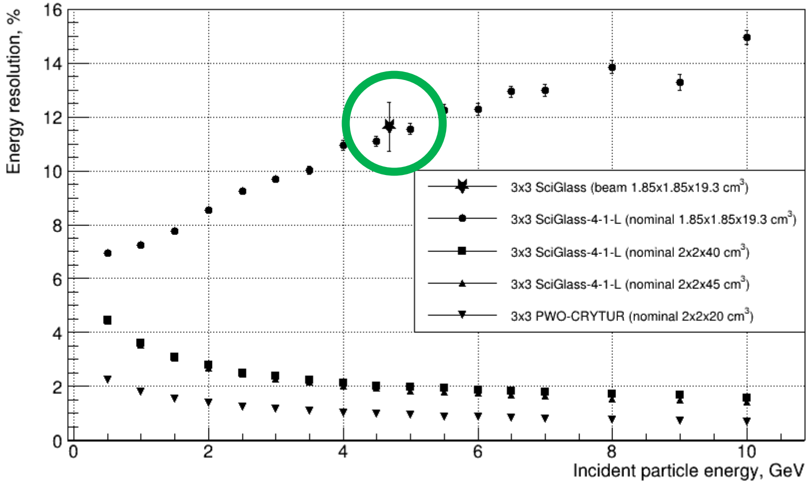
Ongoing Beam Tests



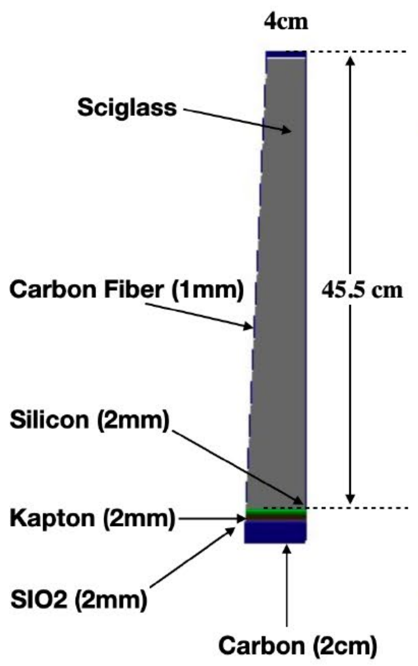


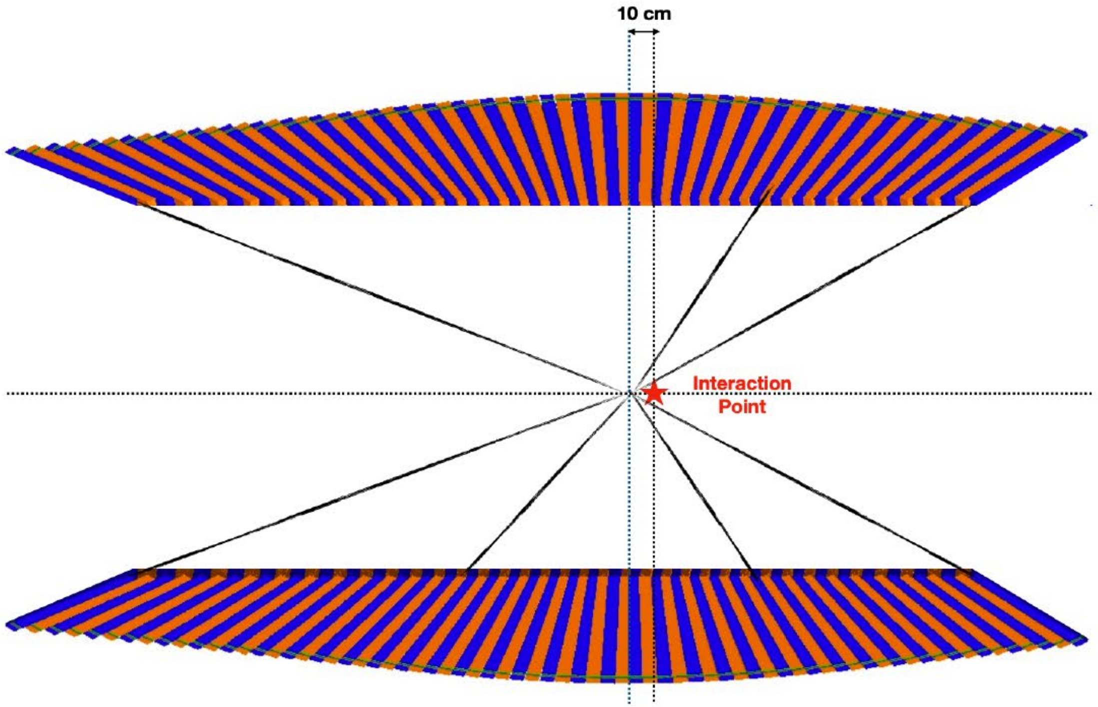


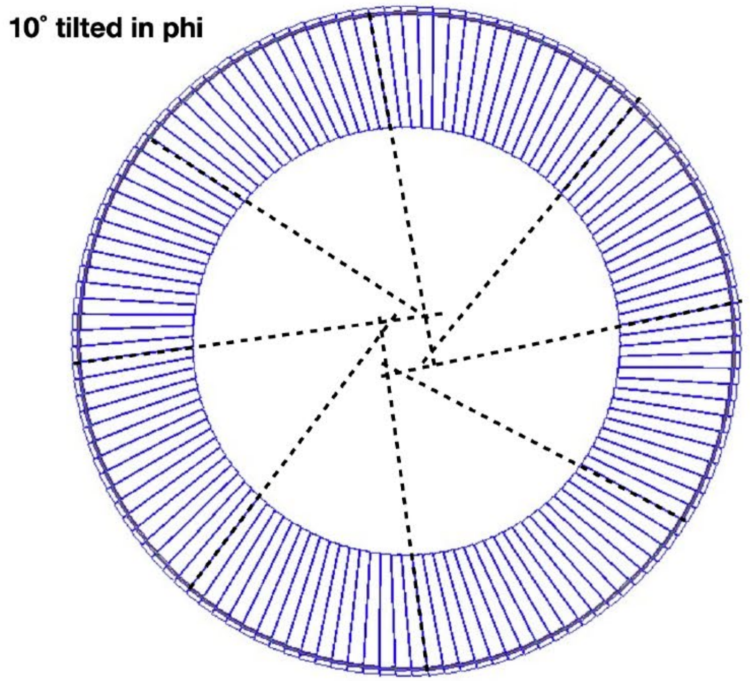
- Prototype 3x3 array installed and tested – energy resolution measured for three different beam energies
- **Results for ~7 X_0 blocks – matches with Geant4**
- **Plans for 2022: Test with ~15X_0 (40cm) long blocks**



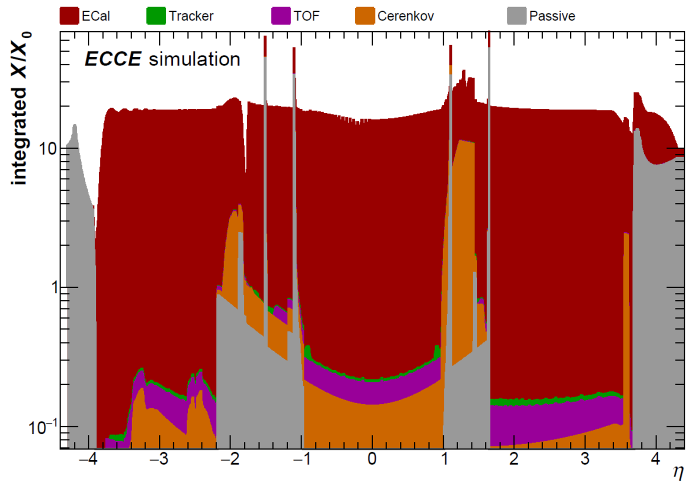
Barrel EMCal in Simulations





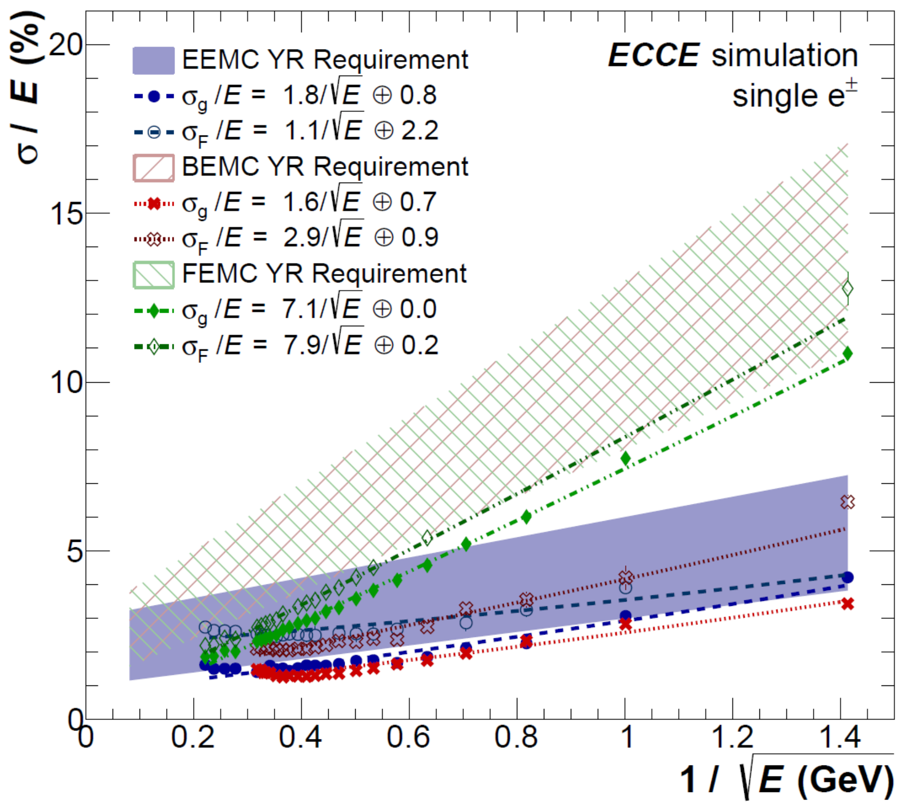


- ❑ Assumes 45.5cm long blocks ($17X_0$) – close to 40cm prototype
- ❑ Implemented with the active components and support structures
- ❑ Also important to consider materials in front of the EM calorimeter as it impacts performance (resolution, rejection, etc.)

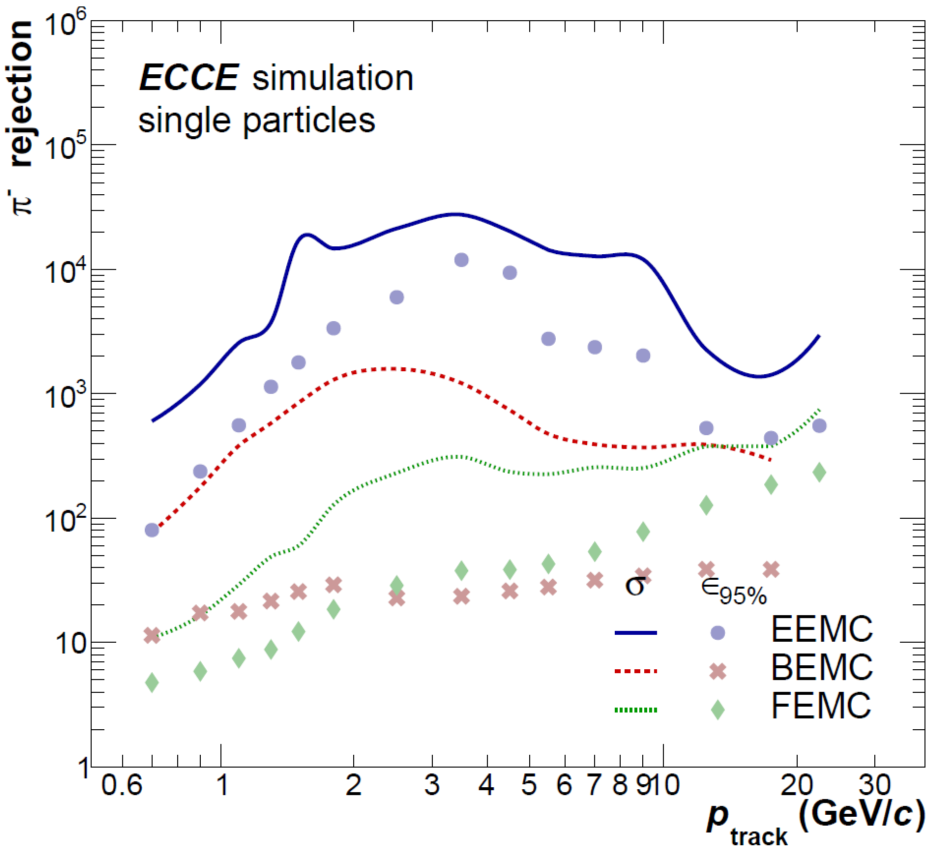


Barrel EMCal Performance

Energy resolution



Pion Rejection



Exceeds requirements from Yellow Report

Mechanical Design based on PANDA

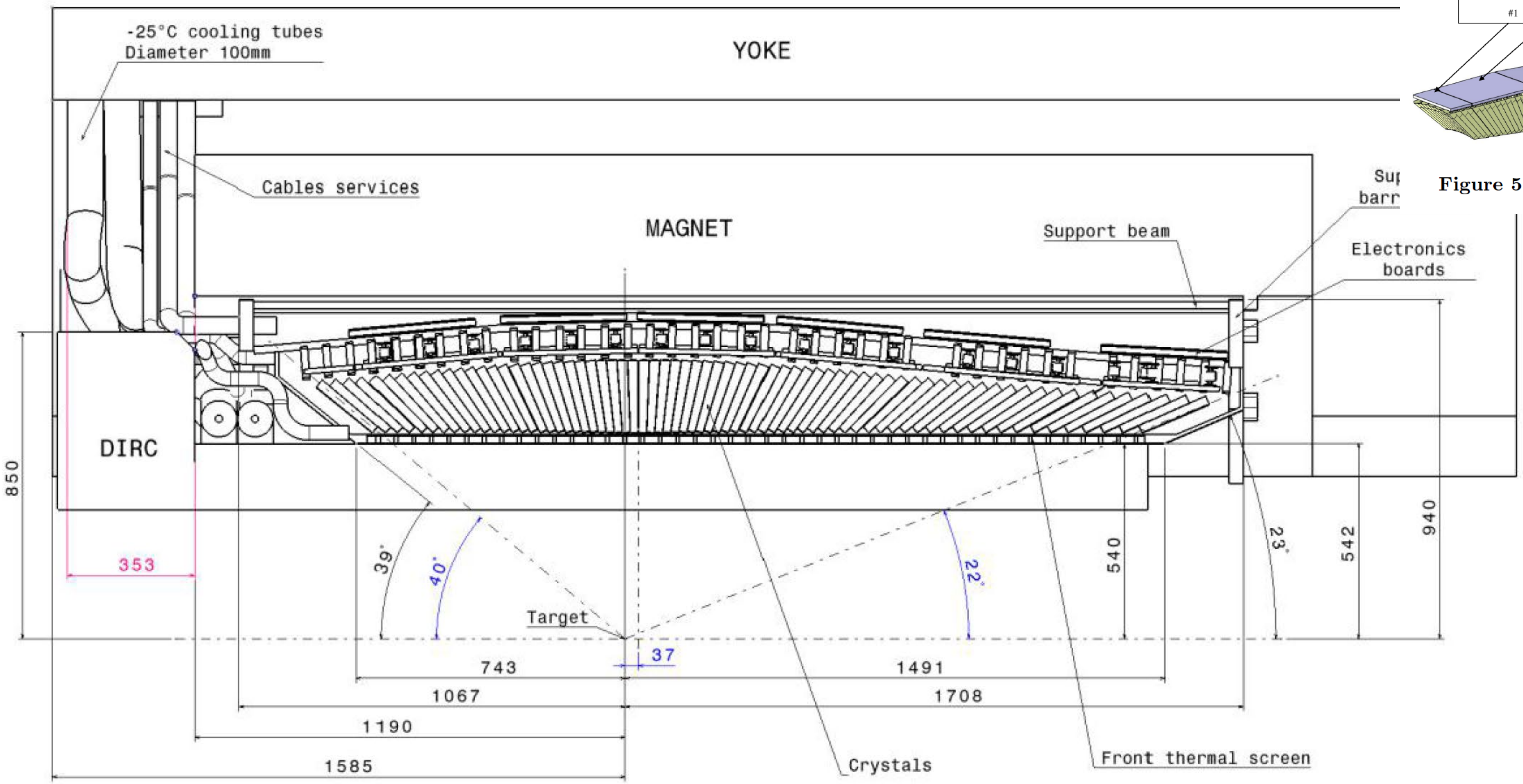


Figure 5.26: Dimensions of one slice.

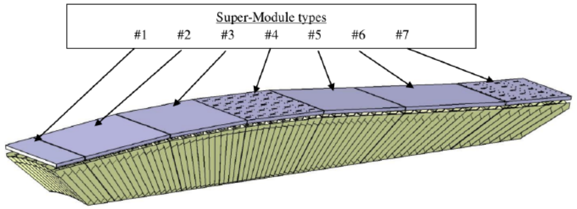
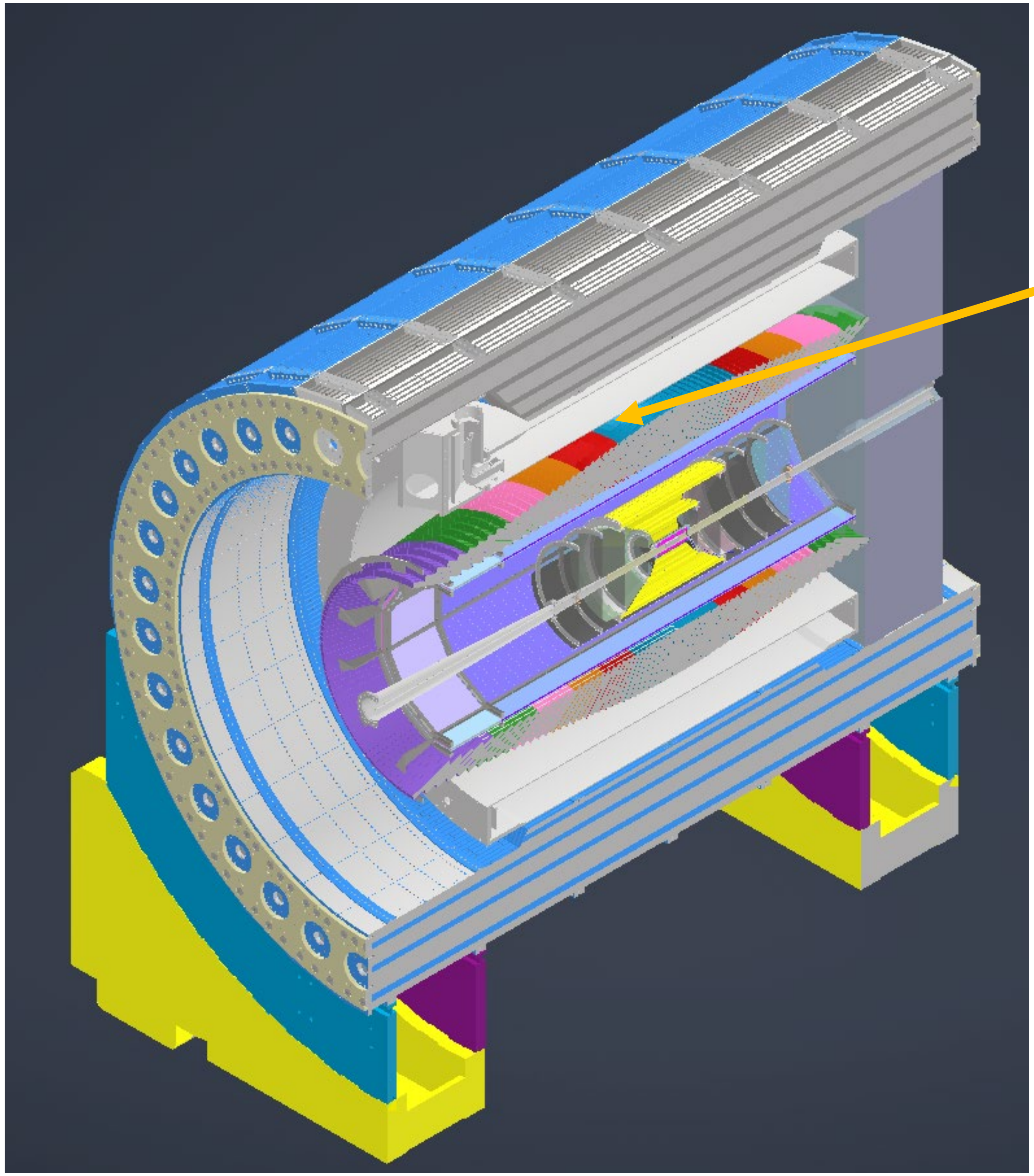


Figure 5.9: Modular structure of a slice.

PANDA

The barrel EMCal in the ECCE Reference Detector

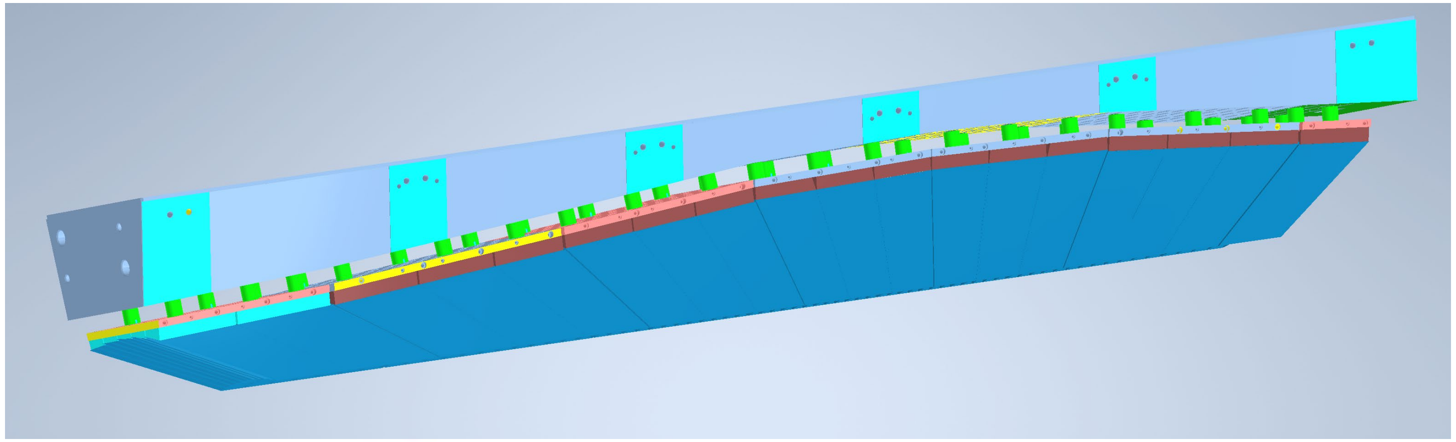


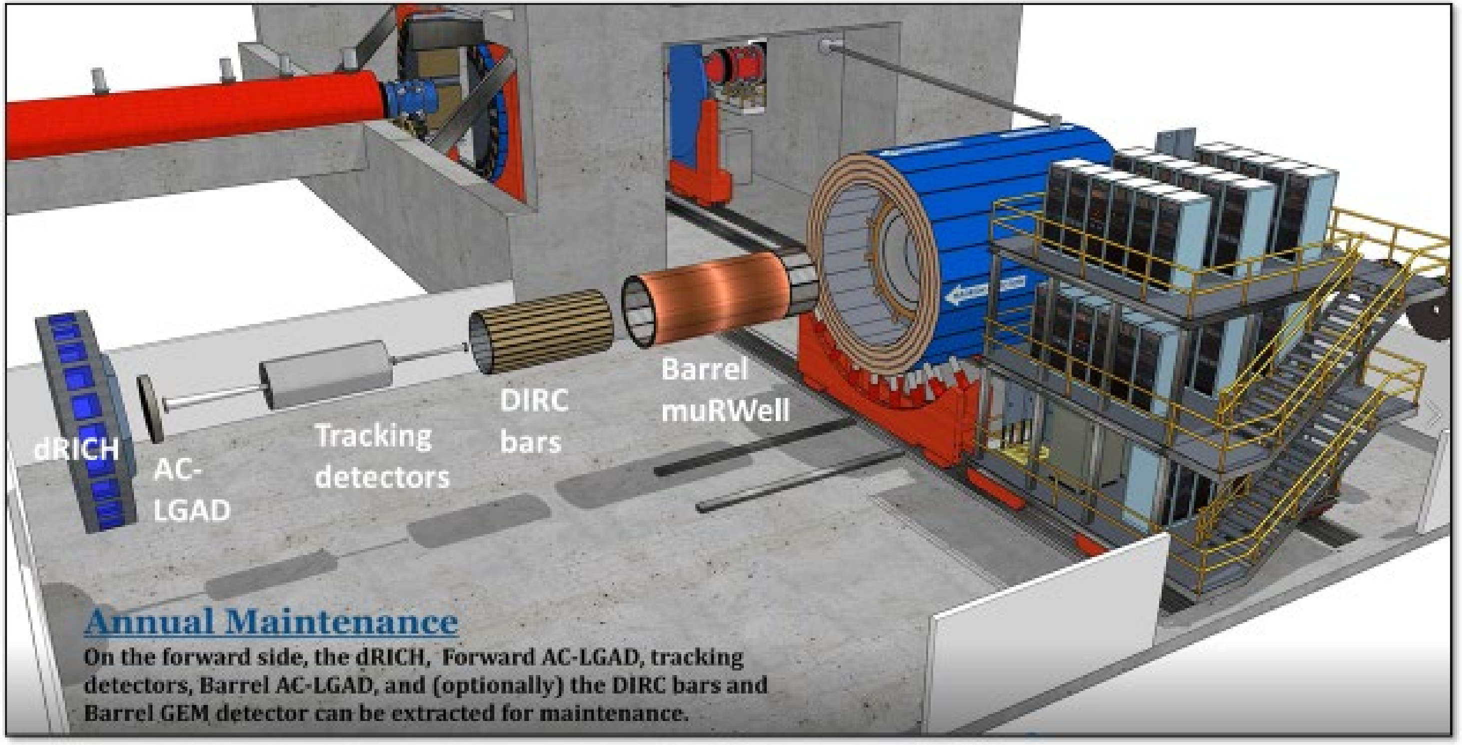
Barrel ECAL(BEMC)

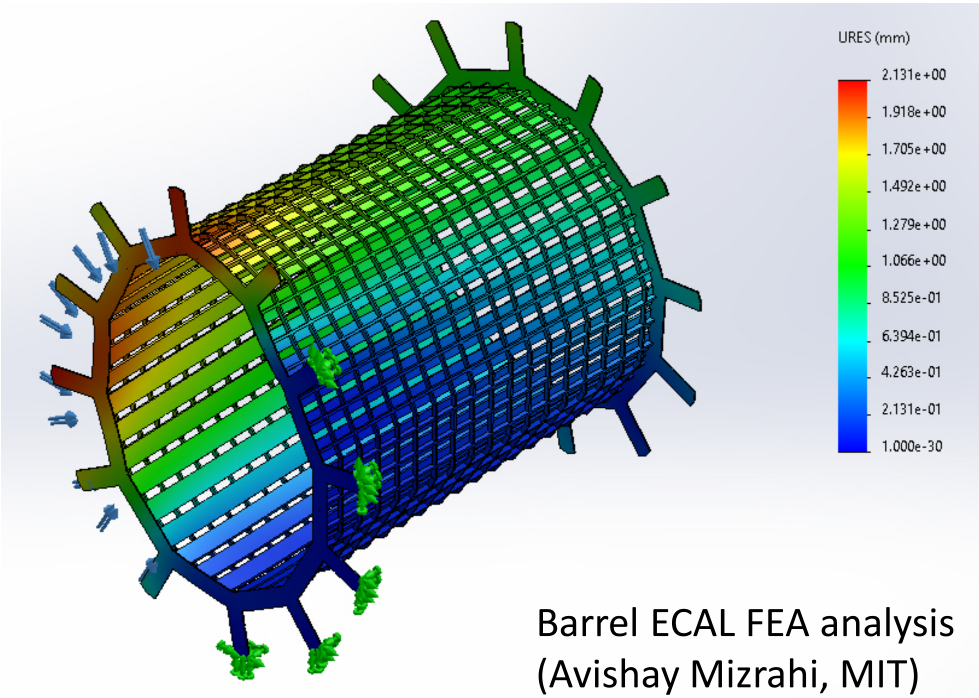
Homogeneous, projective calorimeter based on SciGlass, cost-effective alternative to crystals

- The barrel is one of the largest sub-detectors with 8000 homogeneous scintillator blocks of 45.5cm length (and ~10cm radial readout space)
- It is extended in the negative rapidity direction (with η coverage from -1.75 to +1.3) to provide hermeticity with the backward ECal.
- In the backward direction hermeticity is provided by the combination of barrel, backward ECals, and mRICH complements (3σ e/h up to 2 GeV) . Readout and supply lines are included.
- In the forward direction the barrel EMCal faces much higher range of particle rates across the acceptance of the forward endcap

Advancing the Design (making use of work already done at PANDA)





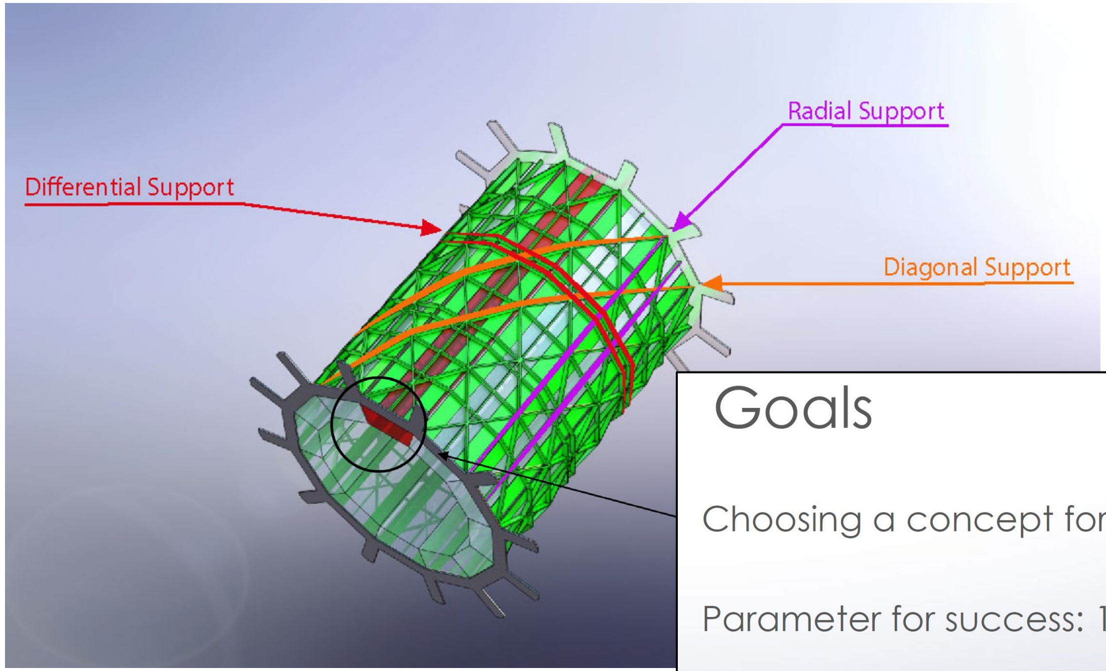


Barrel ECAL FEA analysis (Avishay Mizrahi, MIT)

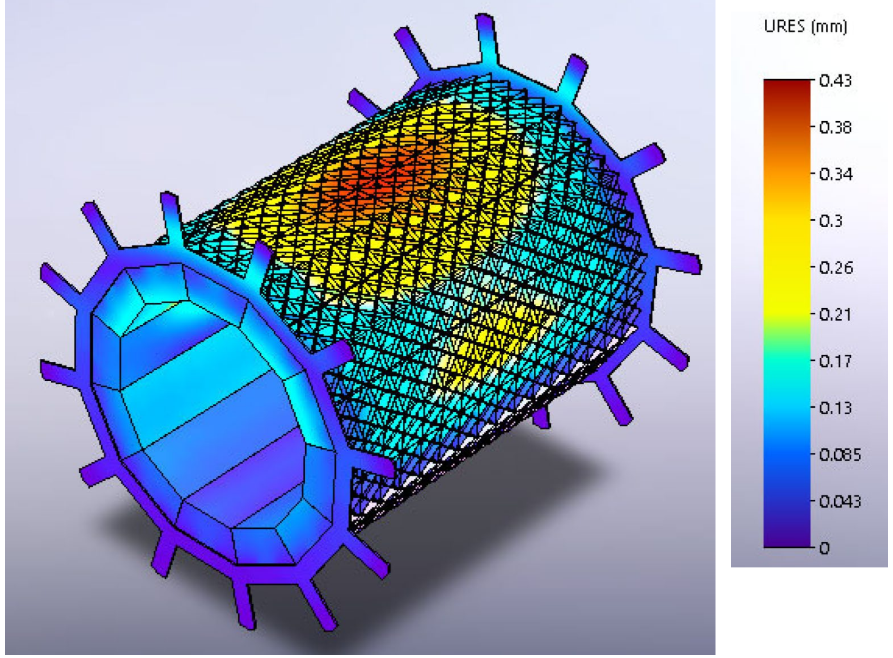
- ❑ Slice/supermodule details – also cooling, cabling, etc.
  - Ongoing studies (CUA/MIT)
- ❑ Support structure optimization
  - Ongoing studies (MIT)
- ❑ Access and maintenance
  - Add thin Teflon layer to avoid friction when removing wedge

Advancing the Design – barrel support structure

Barrel ECAL support FEA analysis (Avishay Mizrahi, MIT)



One promising option



Goals

Choosing a concept for mesh design

Parameter for success: 1mm max Deflection.

Constraints:
- Paramagnetic material.
- 19mm max thickness for each beam.

Nice to have:
- Lightweight
- Symmetric shape (easier to manufacture)

- Volume: 0.571 m³.
- Works with Aluminum, Titanium and stainless-steel alloys.
- Uniform width to all beams (6.5mm).

Detector-1 Barrel EMCal Reference Design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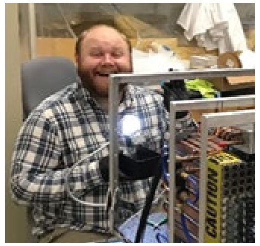
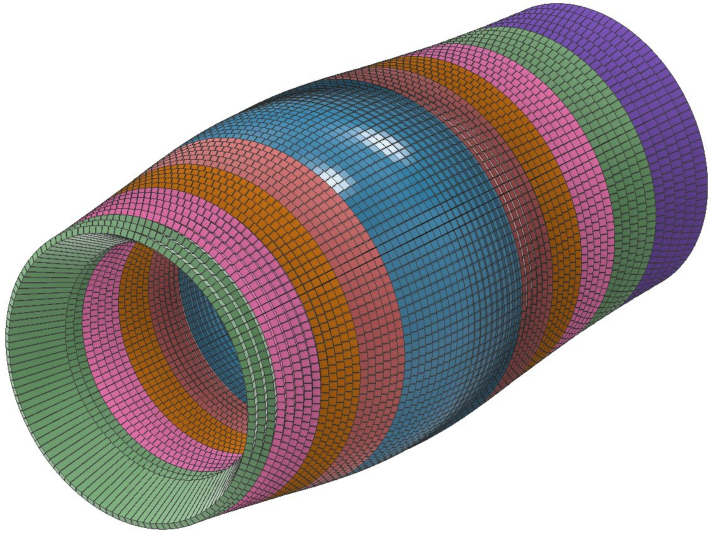
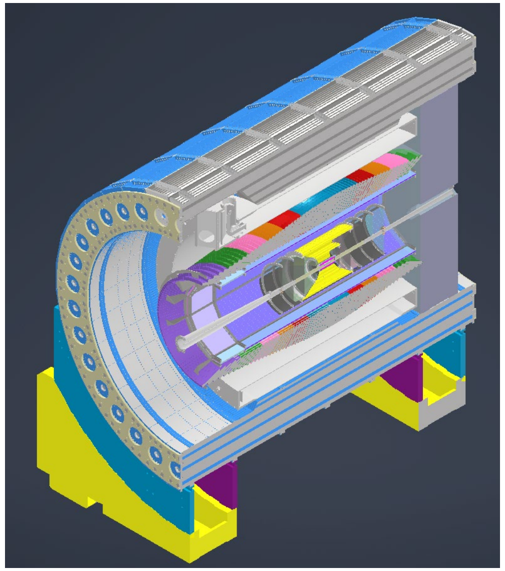
- Barrel EMCal readout electronics can be identical with the backward EM calorimeter → **no additional technology required**
- Experienced team of institutions (AANL, CUA, FIU, JMU, UK, MIT..) including **many early-career researchers** working on design, simulation, prototypes
- Opportunities for many early-career **in-kind contributions** for radiator, design/construction, simulation, readout
- **No long-lead items**







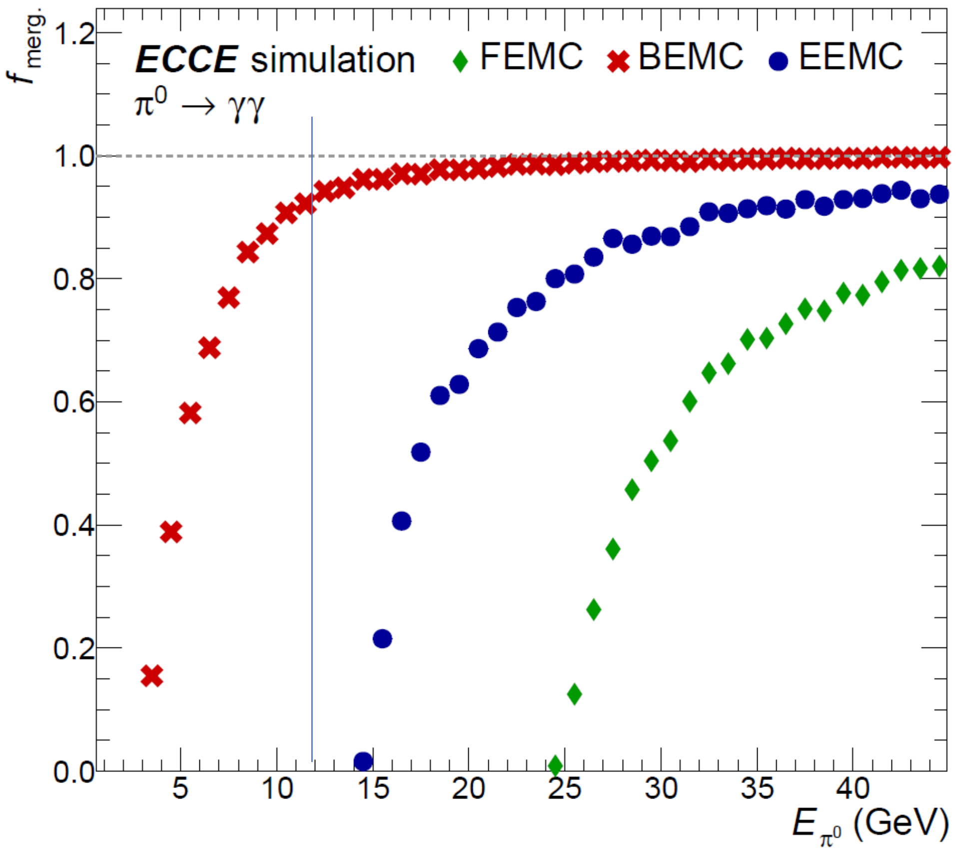
+ additional institutional interest

University of Regina
Augustana University
University of Illinois Urbana-Champaign
University of Colorado Boulder
Ohio University 1804

A. Alikhanyan National Laboratory
The Catholic University of America
University of Kentucky
FIU Florida International University
Massachusetts Institute of Technology
JMU James Madison University

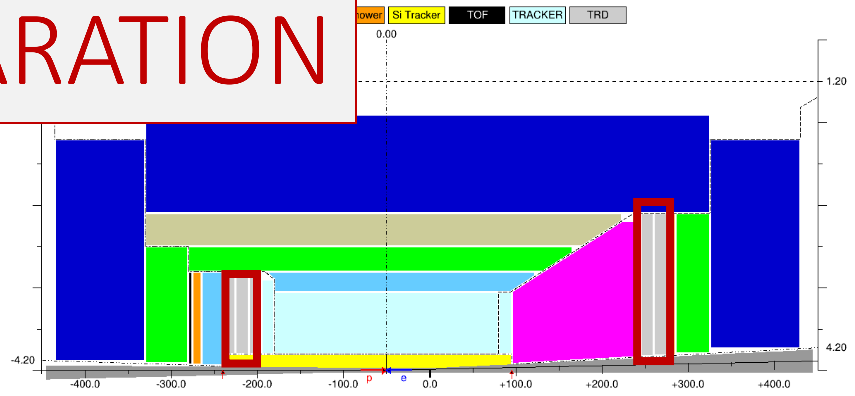
Barrel EMCal Complementarity

Pi0 merging fraction



- ECCE emphasized electron detection from YR requirements
- Jet measurements might benefit from good 1photon/pi0 separation
- A good reason for 2 complementary EIC detectors

e/π SEPARATION

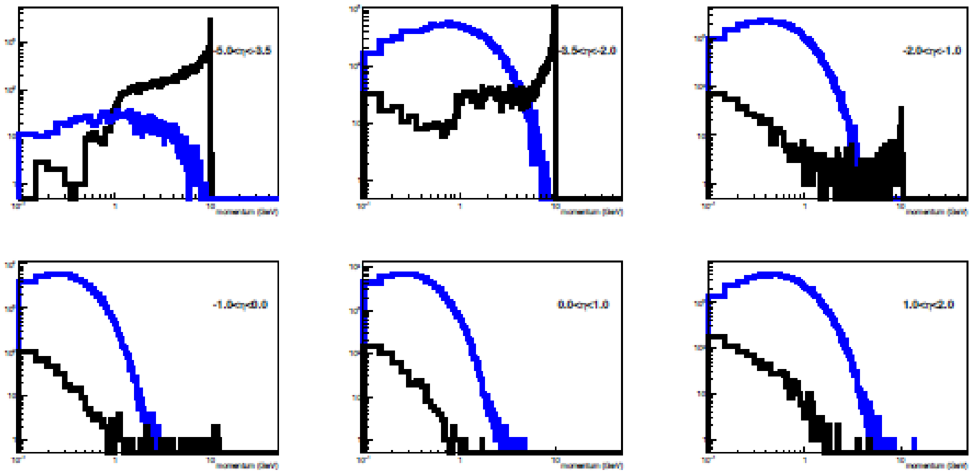


REFERENCE

- ECal as main actor
- Complemented by Cherenkov detectors
  - Backward, mRICH : e/π separation 3 σ up to 2 GeV/c
  - Forward, dRICH: e/π separation 3 σ up to 15 GeV/c
  - Barrel: no support from reference detector (DIRC)

NEEDS

ΔG needs pi/e 10^{-3} , A_{PV} needs pi/e 10^{-4}.

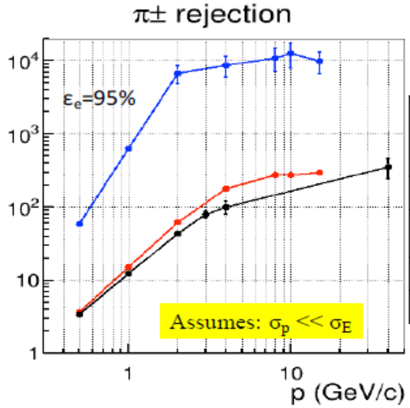


10 x 100 GeV Pion/e- Ratio

Renee Fatemi, Nobuo Sato and Barak Schmookler

3rd EIC Yellow Report Workshop
Catholic University of America
Sept 17, 2020

π± rejection with E/p cut



Ideal case:
- No material on the way to EMCal
- Perfect EMCal (no gaps/cracks)
- Gaussian response to electron

	$PbWO_4$ Crystal	W/SciFi	PbSc
Depth, X_0	20	~20	18
$\frac{\sigma_E}{E}$	$\frac{2.5\%}{\sqrt{E}} \oplus 1\%$	$\frac{13\%}{\sqrt{E}} \oplus 3\%$	$\frac{8\%}{\sqrt{E}} \oplus 2\%$
Depth, λ_I	0.87	~0.83	0.85
e/h	>2		<1.3

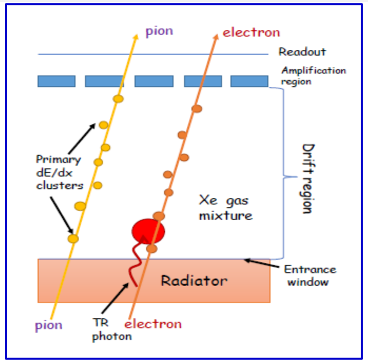
E/p > 1 - 1.6 · σ_{EMC} to keep ε_e=95%

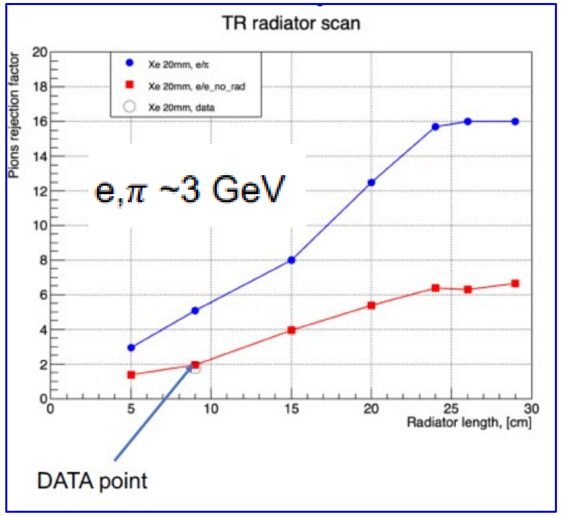
6

ECal studies

GEM-TDR as specific detector to complement e/π SEPARATION

- Also precise tracker





ABOUT π SUPPRESSION REQUIREMENTS

Here a π suppression at the 10^{-4} level is applied

Estimated π/e ratios

$E^{e^-}_{beam}$ (GeV)	η bin	$p^{e^-}_{min}$ (GeV)	Max π^-/e^-	final π^-/e^- ratio
18	(-3.5,-2)	0.9	200	0.02
18	(-2,-1)	0.9	800	0.08
18	(-1, 0)	1.0	1000	0.1
18	(0, 1)	1.8	100	0.01
10	(-3.5,-2)	1.4	10	0.001
10	(-2,-1)	0.5	400	0.04
10	(-1, 0)	0.6	800	0.08
10	(0, 1)	1.0	1000	0.1
5	(-3.5,-2)	2.8	0.1	0.00001
5	(-2,-1)	0.4	100	0.01
5	(-1, 0)	0.3	500	0.05
5	(0, 1)	0.5	1000	0.1

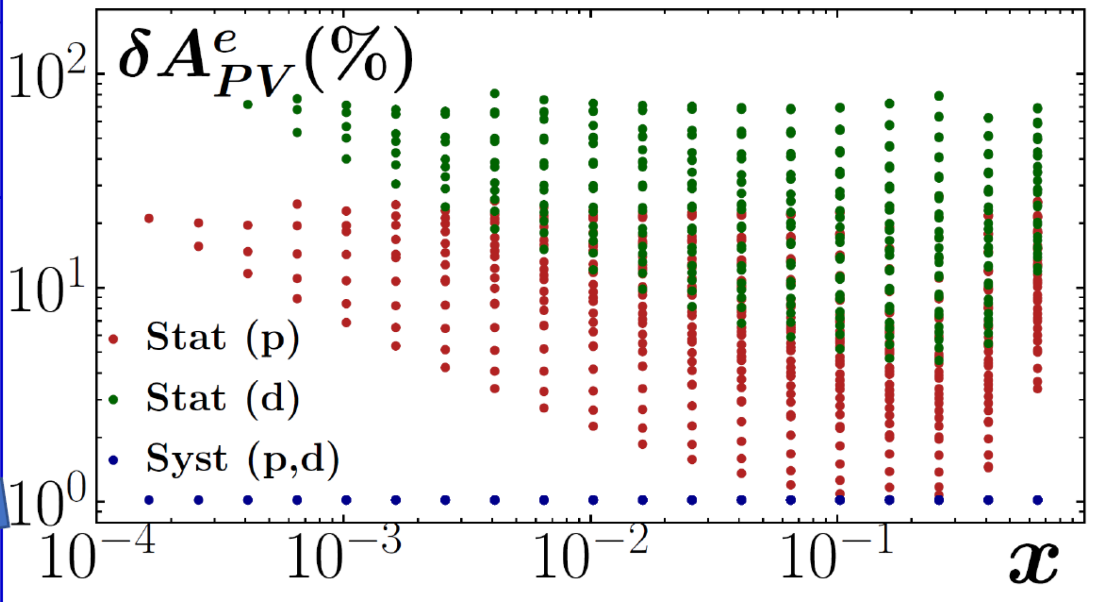
Pion contamination

1) Inflates statistical errors because it is typically treated as a dilution
2) Incurs ~1% systematic error

Tightest constraints come electron parity violating asymmetries A_{PV}^{e-}

Despite, the sever π rejection applied, the condition: "π/e at the 10^{-3} level" is satisfied only here

2 slides by Renee Fatemi, 12 Nov. 2020



the impact study of the detector performance is being repeated (Chris Concuzza)

BEMC Institutional Interest

Region	System	Technology	Institutions	Experience / Comments
Forward Endcap (Hadron direction)	Tracking	ITS-3 Si Disks	LANL, LBL, ORNL, MIT/BATES, EIC-China, EIC-Taiwan, EIC-Korea, Brunel (UK), Regina (Canada), Czech. Tech. Univ., BNL	Experience constructing previous Si trackers, most recently for sPhenix.
	PID	AC-LGAD	RICE, ORNL, BNL, UTSM	Experience in CMS
		dRICH	UConn, Duquesne, Duke, JLab, Tsinghua/China	E&D (strong engineering) Simulations (Hall B RICH, Hall A/SBS RICH), HERMES RICH refurbishment
	EM Calorimetry	Longitudinally segmented, scintillating tile	ORNL, ISU, Ohio U., EIC-Japan, EIC-Korea, EIC-China, BNL	Experience with calorimeters in sPHENIX and ALICE
	Hadron Calorimetry			
Barrel	Tracking	ITS-3 Si (vertex & sagitta)	LANL, LBL, ORNL, MIT/BATES, EIC-China, EIC-Taiwan, EIC-Korea, Brunel (UK), Regina (Canada), Czech. Tech. Univ., BNL	Experience constructing previous Si trackers, most recently for sPhenix.
		µRWell	UVA, GWU, MIT, EIC-China, EIC-Korea, BNL	GEM construction for SBS; µRWell prototyping and testing at Fermilab
	PID	AC-LGAD	RICE, ORNL, BNL, UTSM	Experience in CMS
		hpDIRC	CUA, GSI, ODU, W&M, MIT/BATES	Design and construction (PANDA, GlueX), simulations

Region	System	Technology	Institutions	Experience / Comments
Backward Endcap (e⁻ direction)	Tracking	ITS-3 Si Disks	LANL, LBL, ORNL, MIT/BATES, EIC-China, EIC-Taiwan, EIC-Korea, Brunel (UK), Regina (Canada), Czech. Tech. Univ., BNL	Experience constructing previous Si trackers, most recently for sPhenix.
	PID	AC-LGAD	RICE, ORNL, BNL, UTSM	Experience in CMS
		mRICH	GSU, JLab	GSU originated mRICH concept and led its design
	EM Calorimetry	PbWO4	AANL/Armenia, CUA, Charles U./Prague, FIU, IJCLab-Orsay/France, JLab, JMU, MIT, Lehigh U., UKY, Ohio U.	Experience with crystal fabrication and characterization, detector design and construction, technical support and infrastructure, readout electronics, simulations (Hall C EMCal & NPS, STAR ECAL)
Far-Forward	B0	AC-LGAD Tracking	UH, U. Kansas	ZDC at LHC, Roman Pots, fast timing
		PWO4 Calorimeter	EIC-Israel	EM calorimetry, ZDC at LHC
	Off-momentum Detectors	AC-LGAD Tracking	UH, U. Kansas	Fast timing, tracking experience at RHIC, LHC
	Roman Pots	AC-LGAD Tracking	IJCLab-Orsay/France, BNL, UH, U. Kansas, BNL	ASIC readout of AC-LGAD (OMEGA, ATLAS)
	ZDC	PWO, W/Si, Pb/Si, Pb/Sci	EIC-Japan, KU	Experience with LHCf, RHICf development of FOCAL
	Low-Q^2	AC-LGAD Tracking	York U. Glasgow U.	Experience from CLAS12 tagger
DAQ / Computing	Streaming DAQ, Online Event Filter		Morehead state, ORNL, PNNL, SBU, UC Boulder, UConn	Experience with sPHENIX streaming DAQ; CMS and GlueX computing

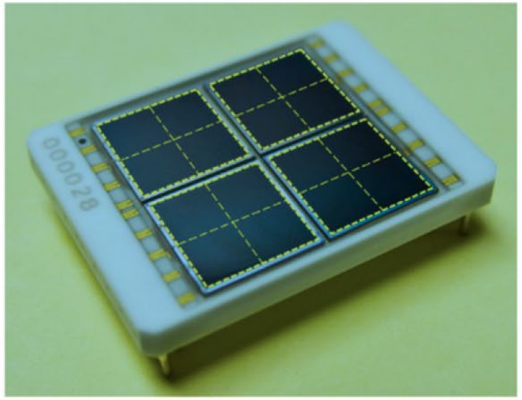
	System	Technology	Institutions	Experience / Comments
	EM Calorimetry	SciGlass	CUA, MIT, KU, Augustana, Ohio U., UC Boulder, UIUC, U. Regina	Glass fabrication and characterization, detector design and construction, technical support, simulations

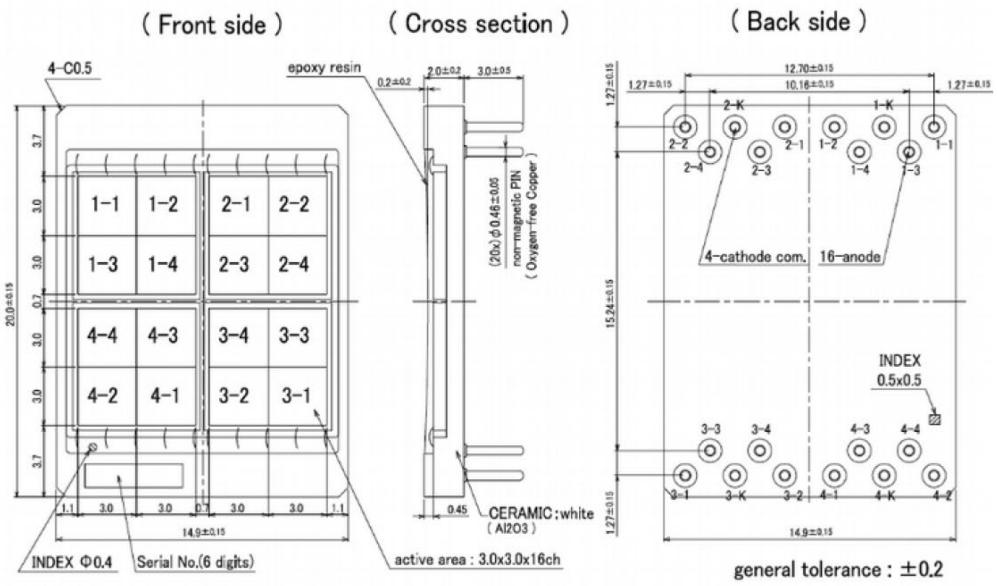
Figure 4.2: Planed responsibilities of the ECCE institutions for the production of different detector sub-systems.

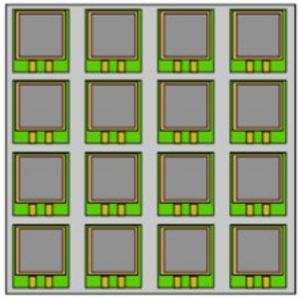
Overview of Barrel EMCal Specifications

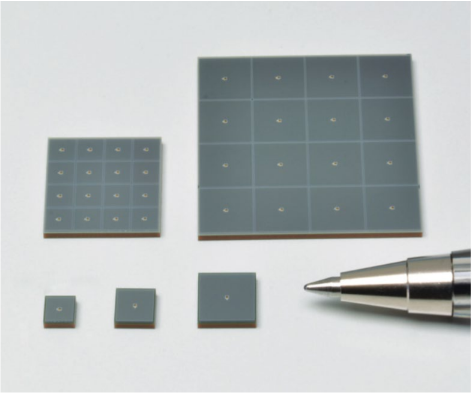
- Coverage: $-1.75 < \eta < 1.3$
  - R_{min}=80cm
  - R_{max}=125.5cm (i.e., glass blocks are 45 cm long → 17 X0)
  - Electronics:125.5cm < R < 134cm
  - Outer support: 134cm < R < 140cm
  - Length along z= 445m (192.5cm(start) < z < 252.5cm (end))
- Egamma: 0.1 – 35 GeV
- Energy resolution (based on simulation): 2.5%/SqrtE + 2.7%/E + 1.5%
- Maximum Annual dose at top luminosity
  - EM: ~3 krad/year (30 Gy/year)
  - Hadron: 10^10 n/cm2
- Signal dynamics: 2 V dynamic range

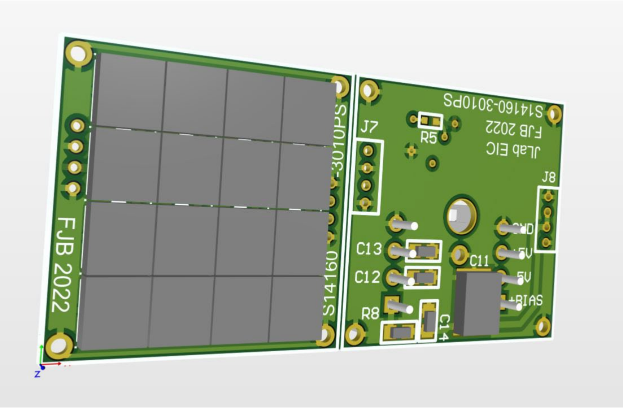
SiPM Readout Option

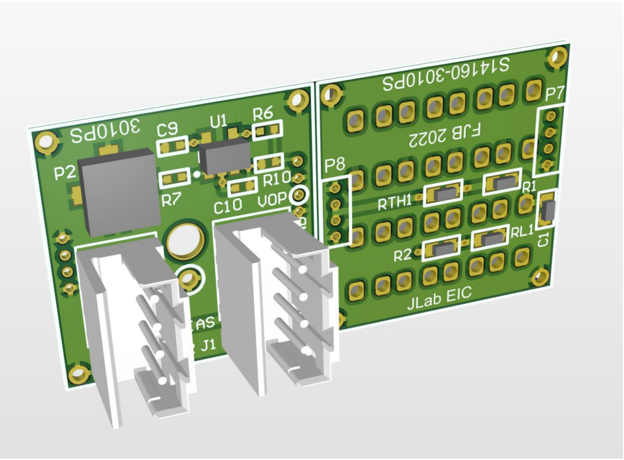












Considerations:

- ❑ SiPMs with (15-50)um pixel pitch and good PDE
- ❑ Use of light guides (potential light loss) versus big sensitive surface matrix of SiPMs.