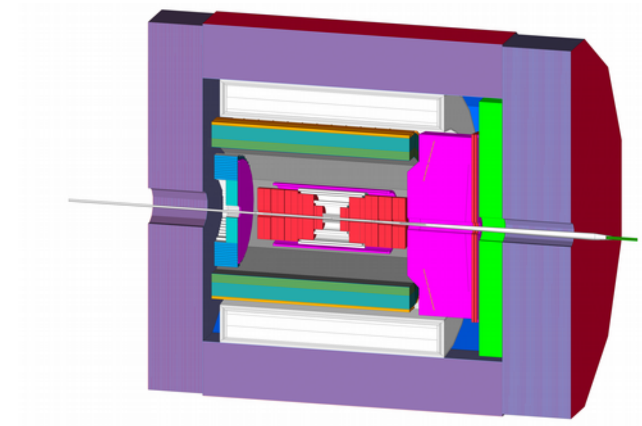


ATHENA Calorimetry

Vladimir V. Berdnikov
for Calorimetry WG

ATHENA calorimetry working group conveners:

Oleg Tsai (UCLA), Paul P. Reimer (ANL) and Vladimir V. Berdnikov (CUA)

EICUG Summer 2021 Meeting
08/04/21

Yellow Report requirements for calorimetry

η	Nomenclature			Tracking: Min p_T	Tracking: Resolution	Tracking: Allowed X/X_0	Tracking: Si-Vertex	Electrons and Photons: Min E	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	π/K/p PID: p-Range (GeV/c)	π/K/p PID: Separation	HCAL: Min E	HCAL: Resolution σ_E/E	Muons
-6.9 — -5.8			low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
...	↓ p/A	Auxiliary Detectors													
-4.5 — -4.0			Instrumentation to separate charged particles from γ												
-4.0 — -3.5														~50%/$\sqrt{E}$+6%	
-3.5 — -3.0					$\sigma_p/p \sim 0.1\%\times p+2.0\%$				2%/$\sqrt{E}$+(1-3)%						
-3.0 — -2.5							σ_{xy}~30μm/p_T+40μm								
-2.5 — -2.0			Backwards Detectors		$\sigma_p/p \sim 0.05\%\times p+1.0\%$									~45%/$\sqrt{E}$+6%	
-2.0 — -1.5							σ_{xy}~30μm/p_T+20μm		7%/$\sqrt{E}$+(1-3)%		≤ 7 GeV/c				
-1.5 — -1.0										π suppression up to 1:10^4					
-1.0 — -0.5															
-0.5 — 0.0				100 MeV π											
0.0 — 0.5		Central Detector	Barrel		$\sigma_p/p \sim 0.05\%\times p+0.5\%$	~5% or less	σ_{xyz} ~ 20 μm, $d_0(z) \sim d_0(r\varphi)$ ~ 20/p_T GeV μm + 5 μm	50 MeV			≤ 10 GeV/c	≥ 3σ	~500 MeV	~85%/$\sqrt{E}$+7%	Useful for bkg, improve resolution
0.5 — 1.0				135 MeV K							≤ 15 GeV/c				
1.0 — 1.5									(10-12)%/$\sqrt{E}$+(1-3)%		≤ 30 GeV/c				
1.5 — 2.0					$\sigma_p/p \sim 0.05\%\times p+1.0\%$		σ_{xy}~30μm/p_T+20μm								
2.0 — 2.5			Forward Detectors							3σ e/π	≤ 50 GeV/c			~35%/$\sqrt{E}$	
2.5 — 3.0							σ_{xy}~30μm/p_T+40μm				≤ 30 GeV/c				
3.0 — 3.5					$\sigma_p/p \sim 0.1\%\times p+2.0\%$		σ_{xy}~30μm/p_T+60μm				≤ 45 GeV/c				
3.5 — 4.0			Instrumentation to separate charged particles from γ												
4.0 — 4.5															
...	↑e	Auxiliary Detectors													
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: 0.2< p_T <1.2 GeV/c										

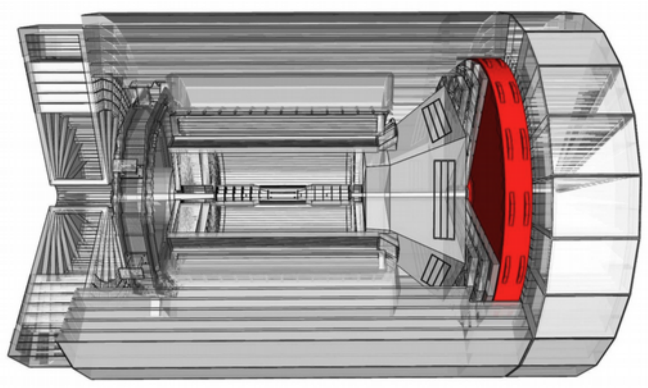
ECAL **HCAL**

Figure 8.126: Summary of the Physics Working Group detector requirements

ATHENA Positive (Forward) EndCap calorimetry

Forward EndCap institutions:
UCLA, UCR, Fudan U., Shandong U.,Tsinghua U., South China Normal U.

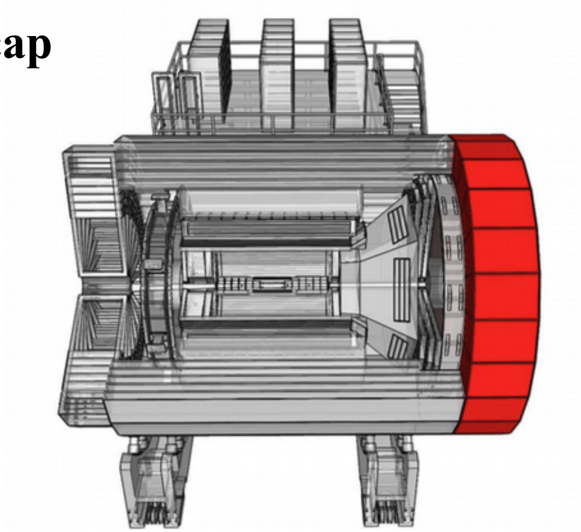
Compensated system of W/SciFi+Fe/Sc for hadron endcap



Dimensions/Location

Overall Length	40 cm
Bore	30 cm
Radius	250 cm
Offset	335 cm in Hadron Direction
Total Volume	7.74 m³

- W/SciFi ECAL
- Technology pioneered at UCLA
- Very compact with good EM resolution
- Similar technology now used in construction of sPHENIX EmCal
- Forward EmCal with good resolution is critical for jet-related measurements



Dimensions/Location

Overall Length	120 cm
Bore	30 cm
Radius	320 cm
Offset	375 cm in Hadron Direction
Total Volume	38.26 m³

- Fe/Scintillator HCAL
- Similar to STAR Forward calorimetry system. Constructed in 2020 with new, very efficient method.
- Hadron resolution to a single particle is about 30%/sqrt(E) with a small constant term

ATHENA Positive (Forward) EndCap calorimetry

Hadron endcap in Geant4:

- EM part (pECAL) is W/SciFi of 23 X_0
- Hadron part (pHCAL) is Fe/Sc of 20 mm Fe and 3 mm plastic
- The Fe/Sc part has 51 layers for 6 interaction lengths
  Note: for ATHENA: Fe/Sc will be 7 interaction length

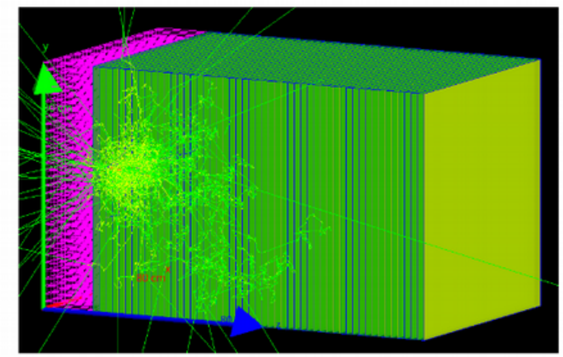
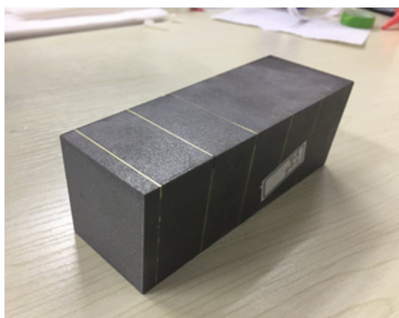
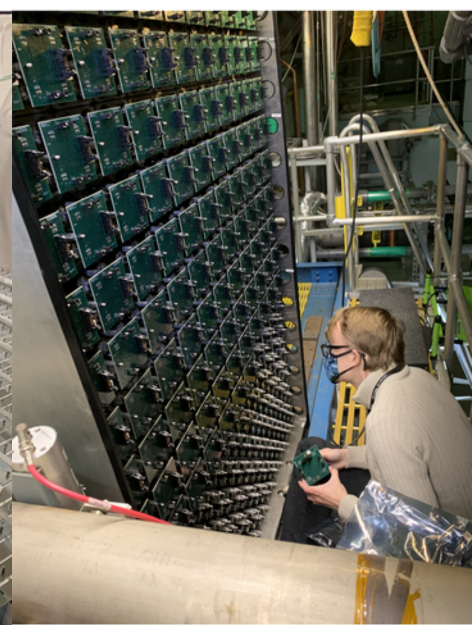
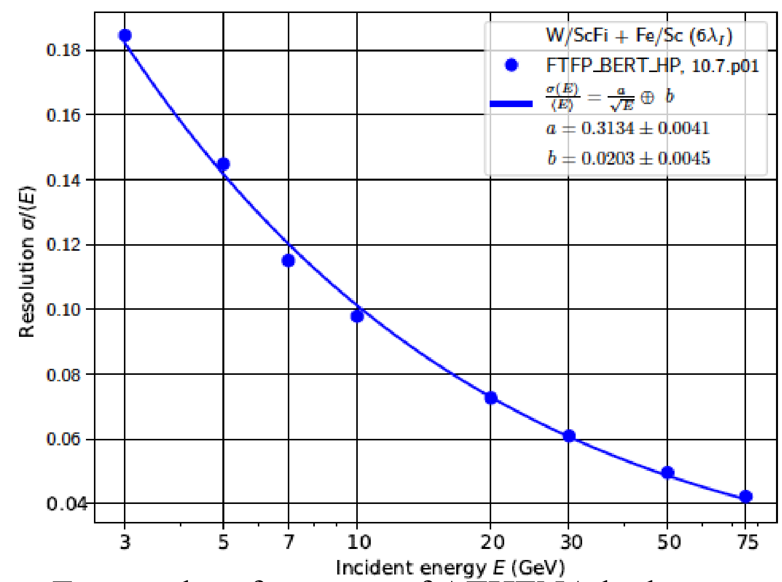


Figure: Event of π^+ at 20 GeV in EM (magenta) and HAD (green and yellow) parts



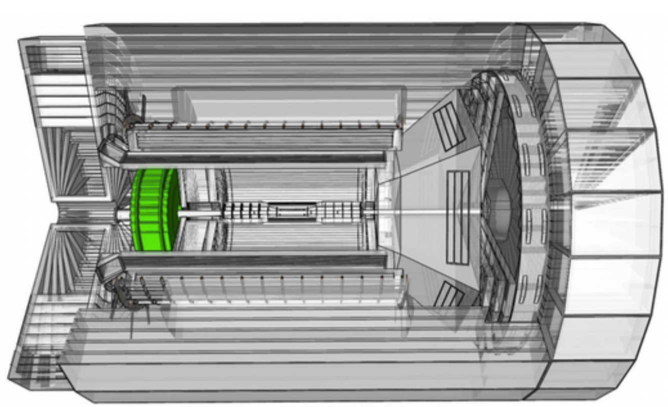


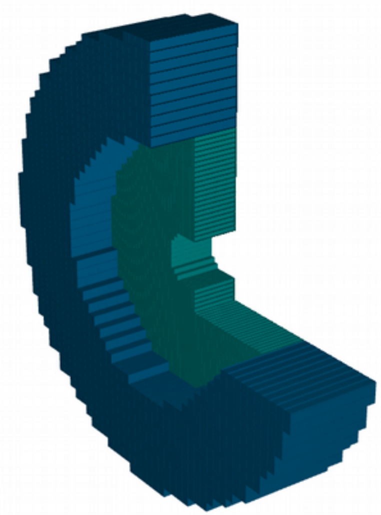


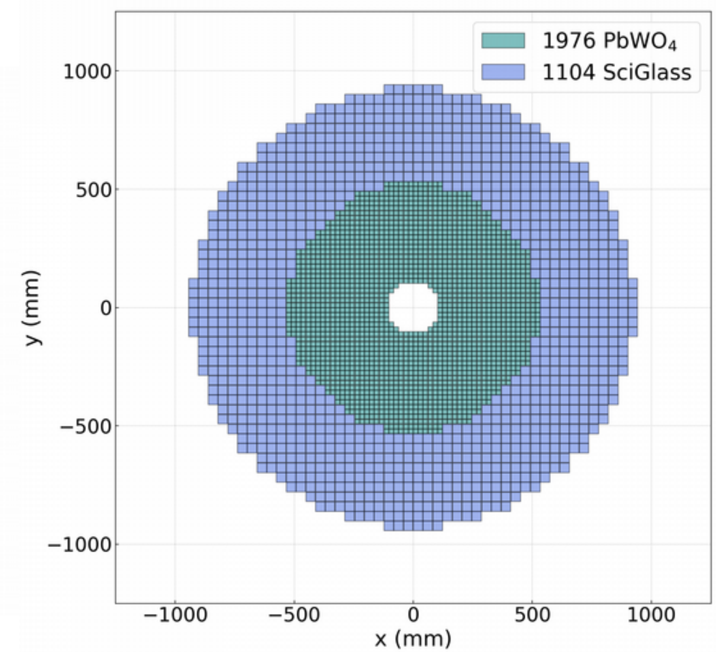
Expected performance of ATHENA hadron endcap (improved version of STAR FCS)

ATHENA Negative (Backward) EndCap EM calorimetry

EEEMCAL consortia institutions:
CUA, LehighU., MIT and MIT-Bates Research and Engineering Center,
U. Kentucky, AANL, FIU, Charles U.-Prague, IJCLab-Orsay







Dimensions/Location

Overall Length	60 cm
Bore	16 cm
Radius	82 cm
Support Sides	17
Support Radius	100 cm
Offset	199 cm in Lepton Direction
Total Volume	1.27 m³

Geometry:
- z=-195cm
- R_in=11 cm (eta ~ -3.5) = R_min_PWO
- R_max_PWO=53 cm (eta ~2)=R_min_Glass
- R_max_total=100cm (eta ~ 1.4)=R_max_Glass

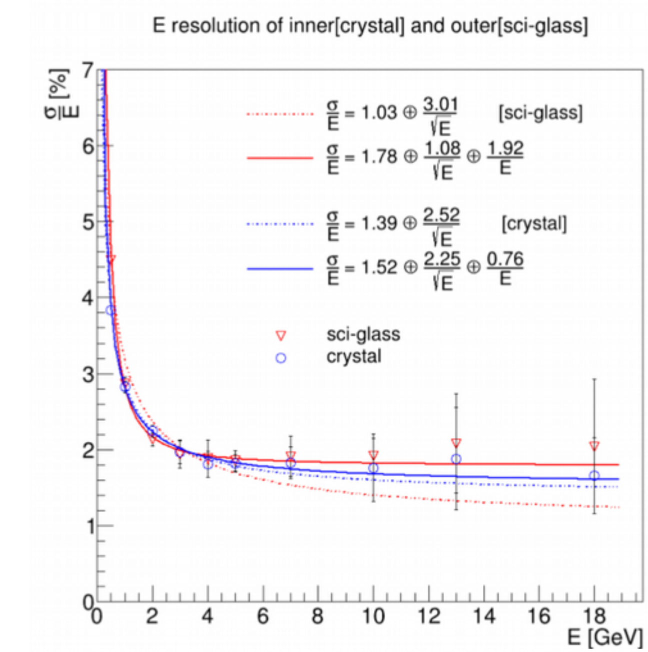
Modules **PWO 1976** (2x2x20 cm^3)
Modules **Glass 1104** (4x4x40 cm^3)
All PWO for this volume: ~7600 PWO modules
Weight: 5-6 tons

PWO: compact, radiation hard, luminescence yield to achieve high energy resolution, including the lowest photon energies
Sensor: SiPMs
SciGlass: EIC eRD1
radiation hard, luminescence yield similar or better than crystals depending on longitudinal length
Sensor: SiPMs

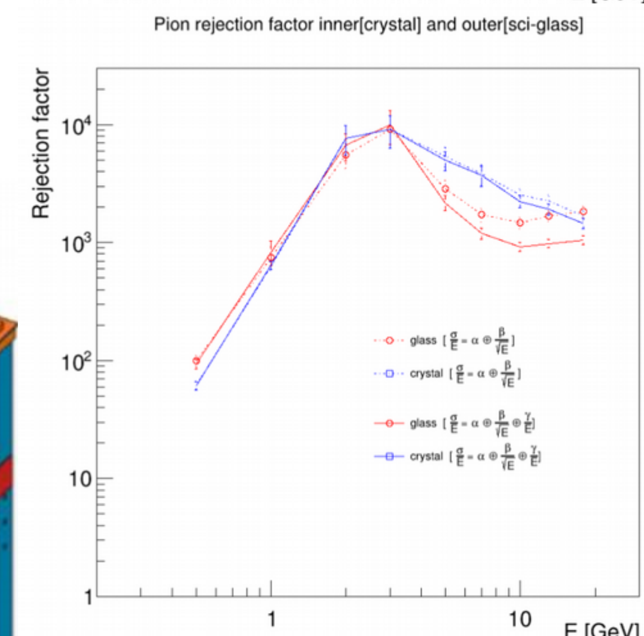
ATHENA Negative (Backward) EndCap EM calorimetry

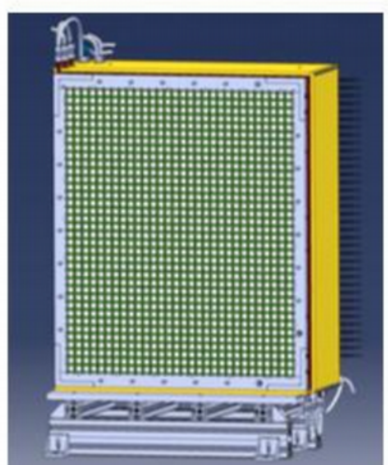
EEEmCal consortia items of interest and ongoing activities:

- Radiator: crystal/glass fabrication and characterization
- Frame design/construction – to hold the crystal/glass bars
- Prototype construction/commissioning and beam tests
- Monte Carlo simulations and comparison with test beam results
- Readout, electronics, detector cabling and infrastructure
- Slow controls and online software
- Calibration and monitoring of performance

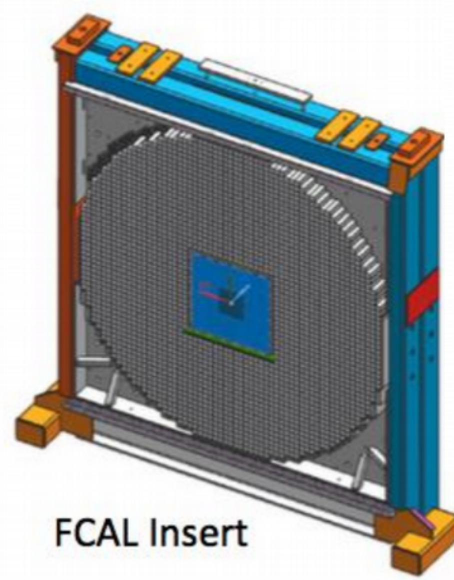


Questions:
- Cost vs Resolution
- Monolithic vs Hybrid





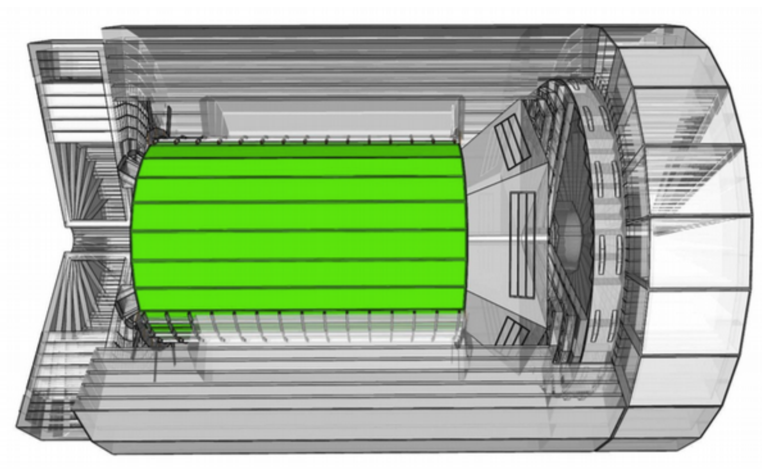
NPS

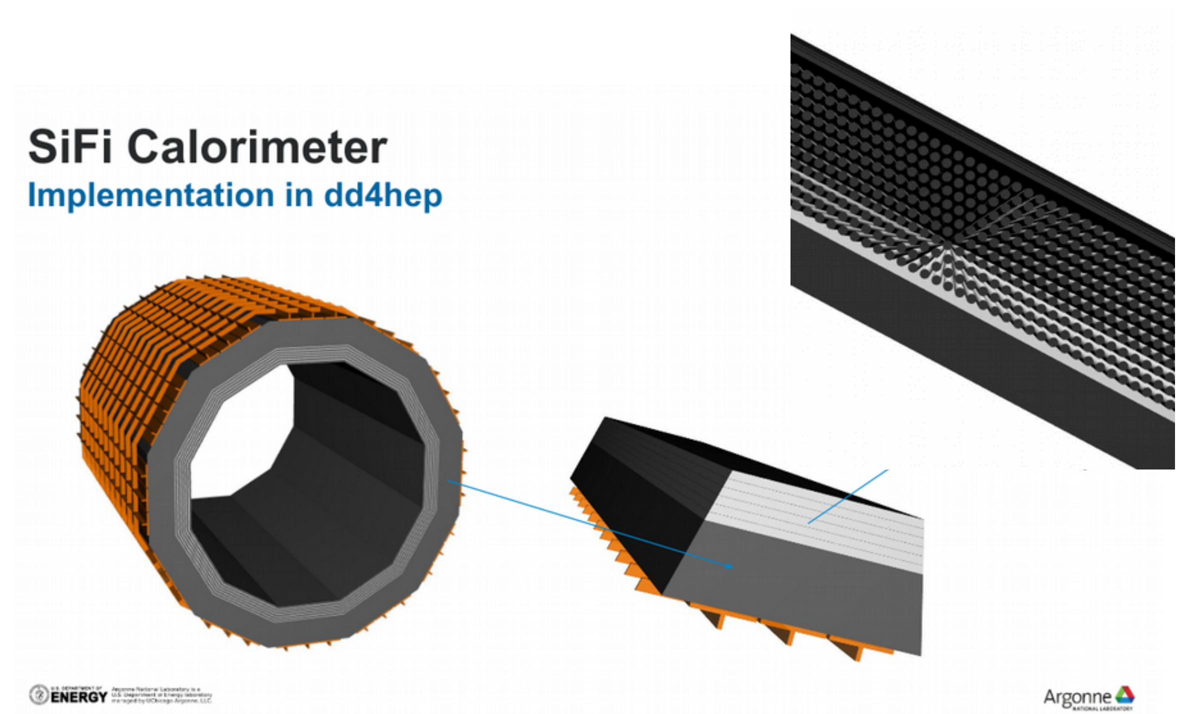


FCAL Insert

ATHENA Barrel EM calorimetry

Barrel EMCAL institutions:
Argonne National Laboratory





Dimensions/Location

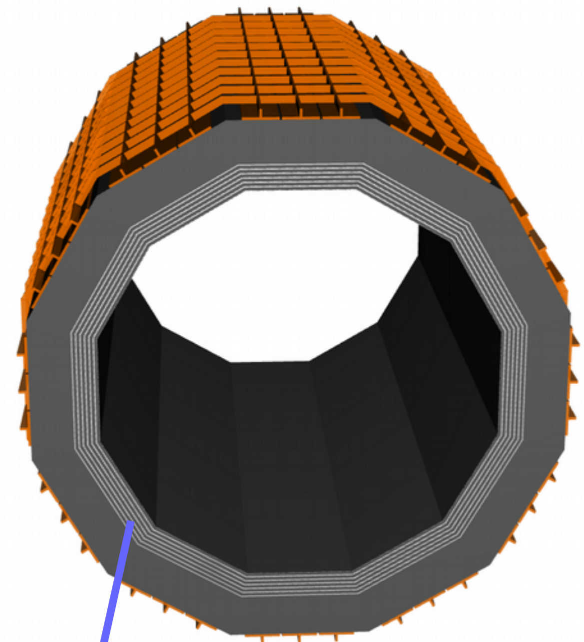
Overall Length	460 cm
Bore	115 cm
Radius	152 cm
Offset	42 cm in Lepton Direction
Total Volume	14.28 m^3

- Absorber/Fiber calorimeter in combination with a Si-based tracking calorimeter
- Provide better e/π separation at low energy
- LGAD timing layer to help PID

Currently working on optimization. The goal is to find the optimal separation between imaging layers (thickness of the ScFi layer in between) assuming use of only 6/7 layers for the e/pi benchmark.

ATHENA Barrel EM calorimetry

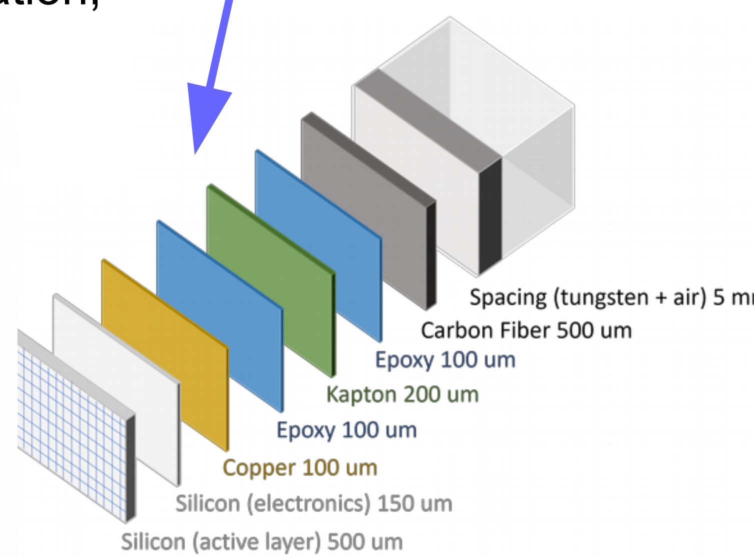
Imaging calorimeter based on monolithic silicon sensors

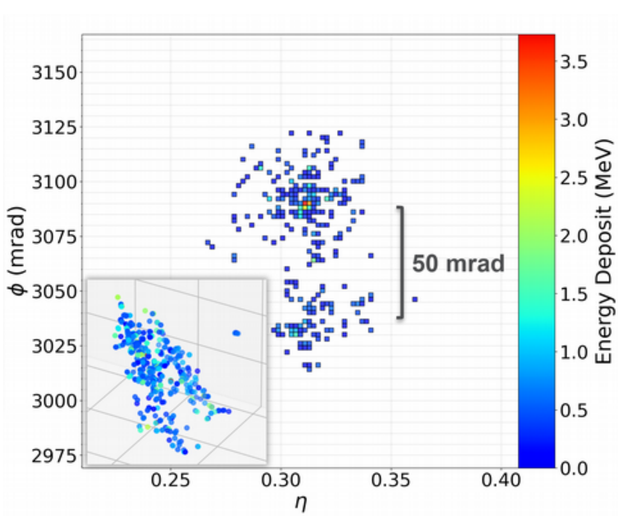


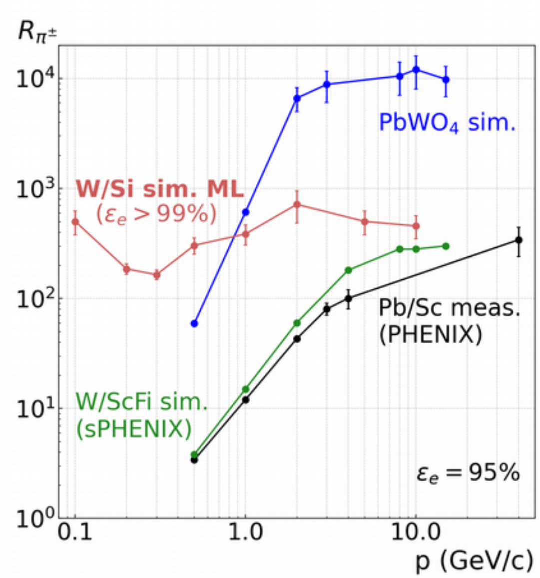
AstroPix (developed for NASA, off-the shelf)

- Have no stringent power and cooling requirements (used in space)
- Energy resolution:~2% within dynamic range (20keV to ~a few MeV)
- Time resolution: 50ns

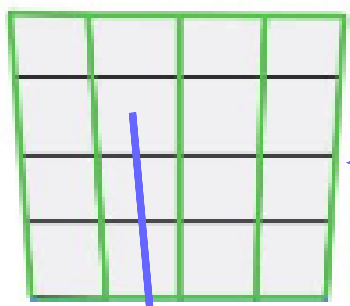
Ongoing design optimization using the simulation with ATHENA software framework with AstroPix digitization, 3D clustering, ML algorithms,…
Test against YR benchmarks: separation, shower separation, spatial and energy resolutions

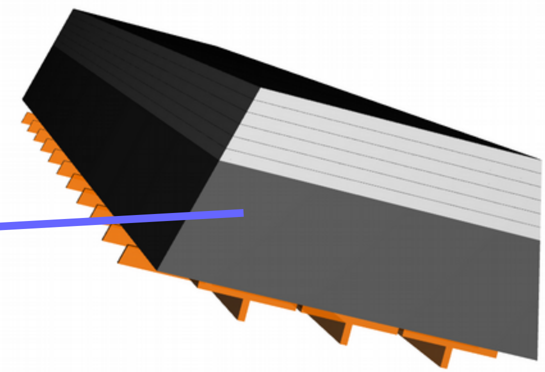


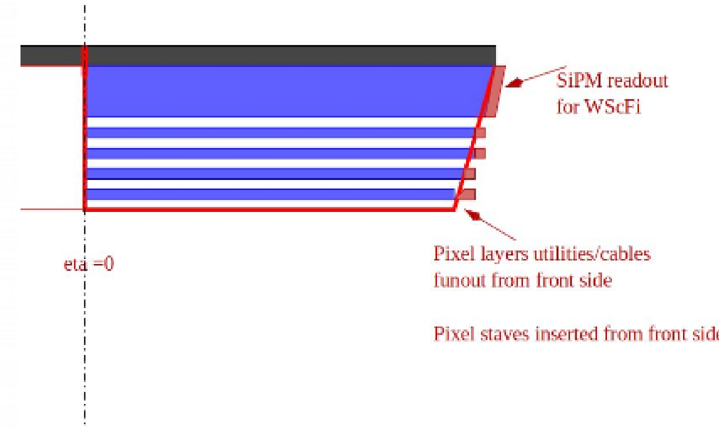


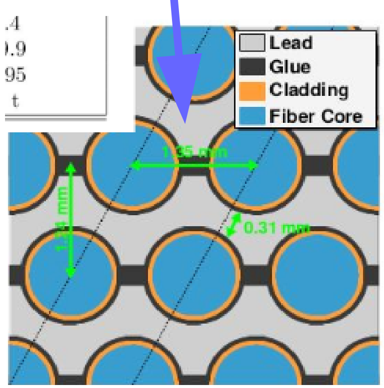


ATHENA Barrel EM calorimetry





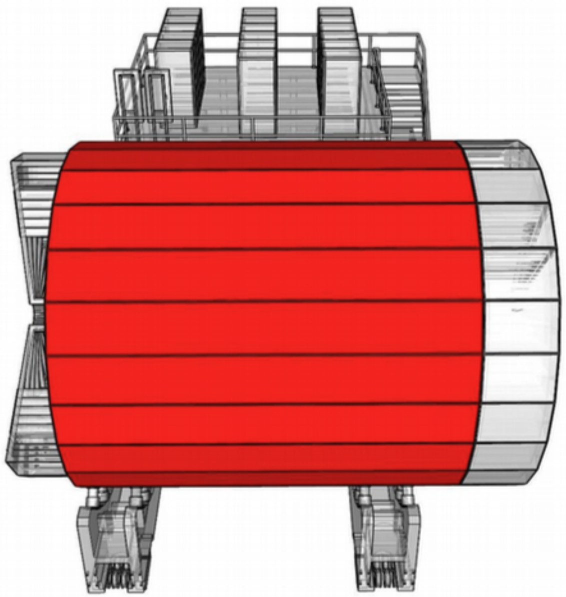


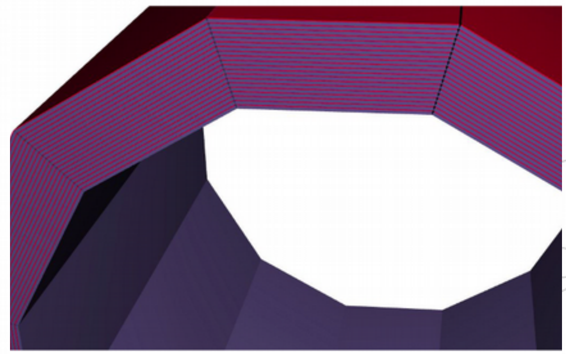


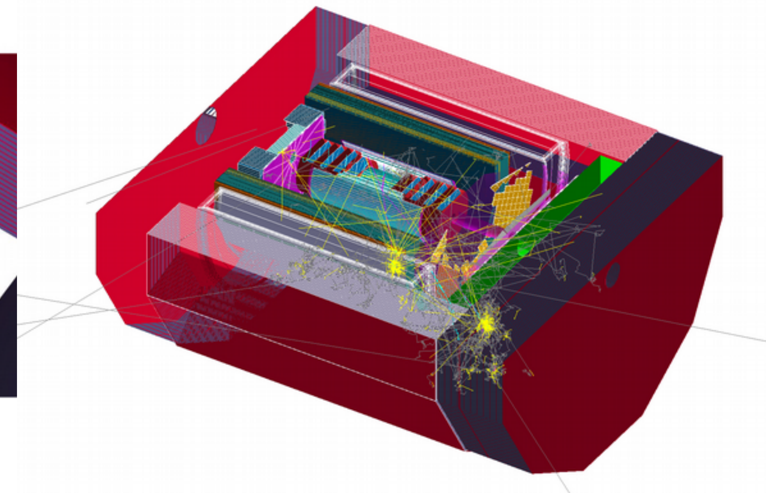
SiFi/Pb with GlueX parameters

- Layers of scintillating fibers embedded in absorber can be added to the current barrel calorimeter with choice of absorber, fiber spacing, radius, etc.
- Sampling fraction will be in between original SPACAL and GlueX, currently optimizing
- Only fibers in absorber (no epoxy now), fibers 1mm diameter
- Polygonal segmentation on the side of the calorimeter staves (similar to GlueX)
- Currently 12 staves
- Digitization implementation in progress

ATHENA Barrel Hadron calorimetry







Dimensions/Location

Overall Length	690 cm
Lepton Direction Section Length	610 cm
Hadron Direction Section Length	80 cm
Lepton Direction Bore	220 cm
Hadron Direction Bore	250 cm
Radius	320 cm
Offset	30 cm in Hadron Direction
Total Volume	113.51 m^3

KLM type calorimeter:

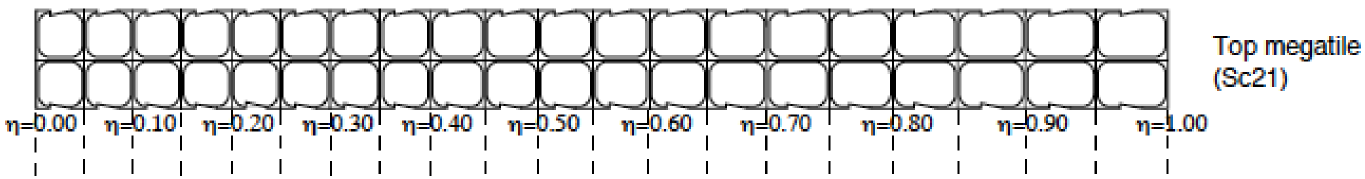
- 20mm Fe and 5 mm plastic scintillator layers
- 10x10 cm^2 cell

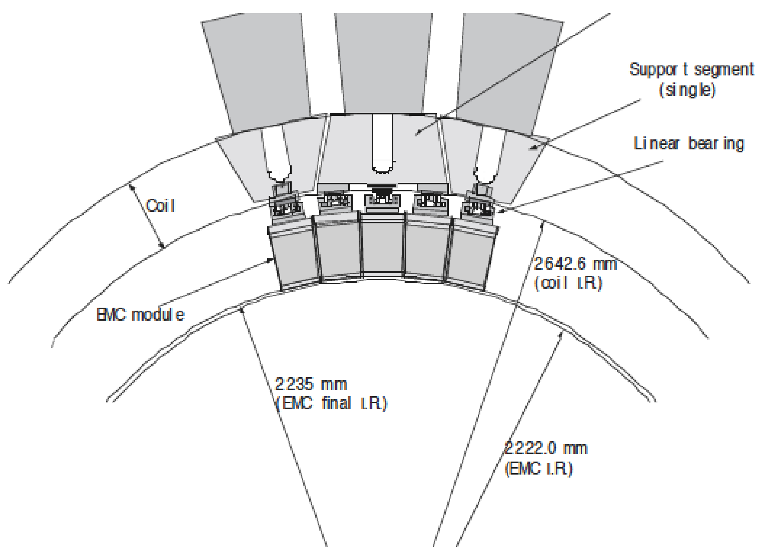
- Sampling layers as shown put in place for optimization only
- Due to thick magnet coils most likely number of layers will be small
- Calorimeter is being optimized

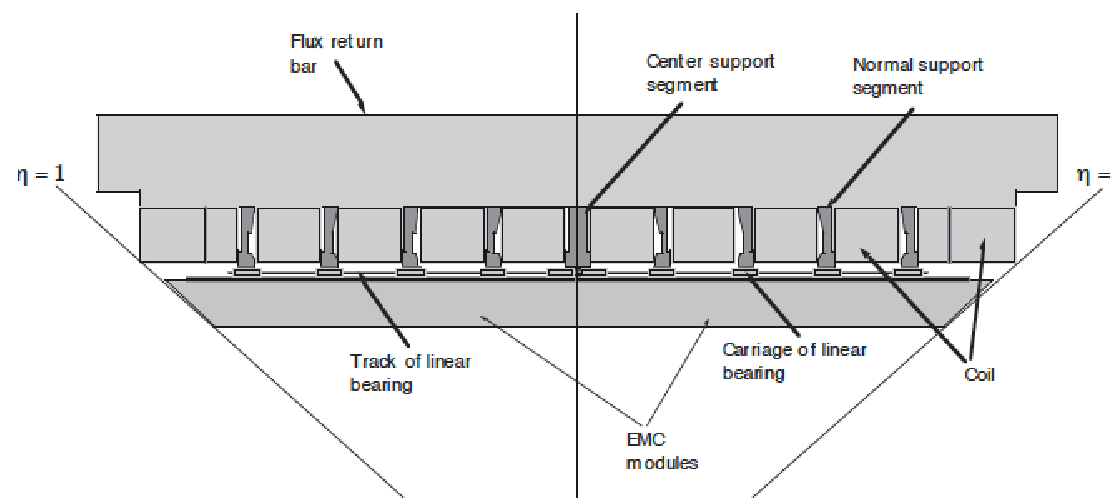
ATHENA Barrel Hadron calorimetry

- ATHENA ***considering*** to reuse STAR BEMC Scintillator megatiles for "KLM" type

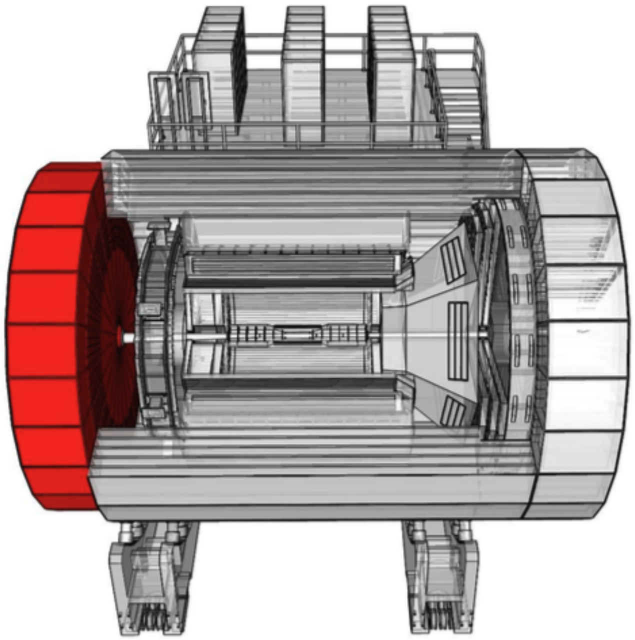
- One layer – 80 tiles each readout by a single SiPM
- Final number of layers TBD- need full simulations

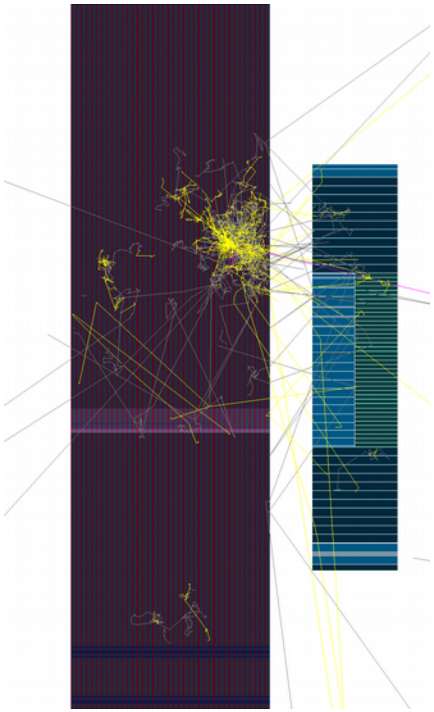


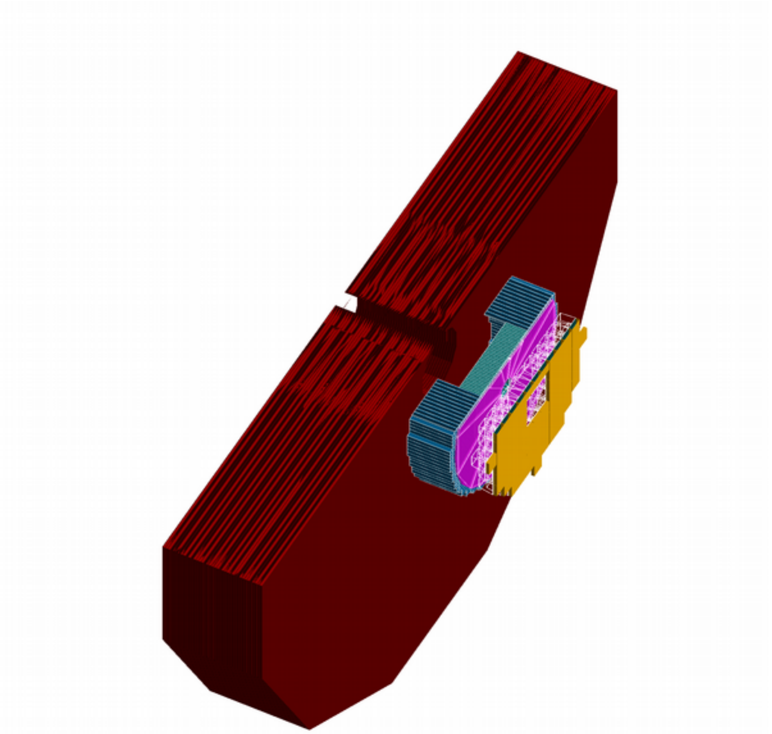




ATHENA negative (backward) Hadron calorimetry







Dimensions/Location

Overall Length	105 cm
Bore	22 cm
Radius	300 cm
Offset	315 cm in Lepton Direction
Total Volume	29.53 m^3

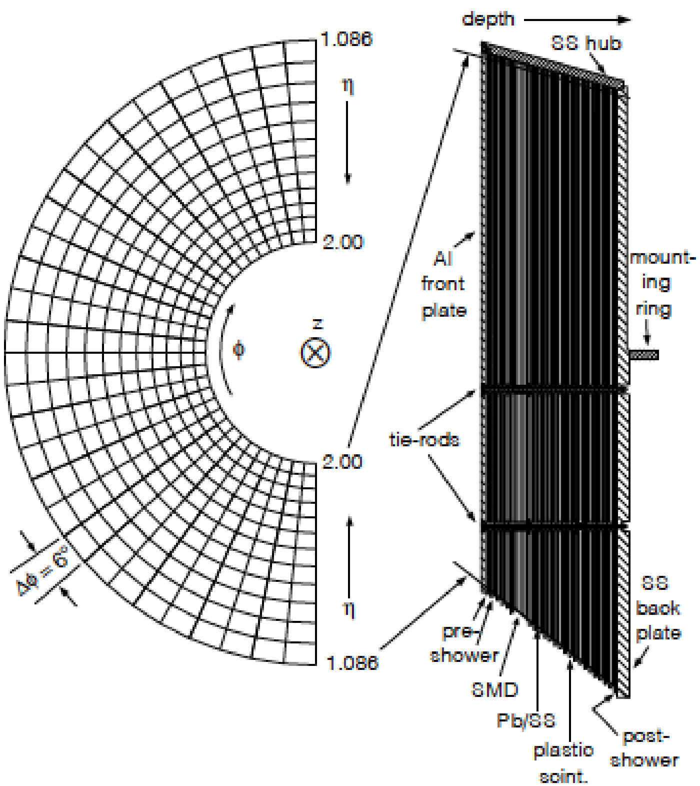
KLM type calorimeter:

- 20mm Fe and 5 mm plastic scintillator layers
- 10x10 cm^2 cell

- Calorimeter is being optimized

ATHENA negative (backward) Hadron calorimetry

C.E. Allgower et al. / Nuclear Instruments and Methods in Physics Research A 499 (2003) 740–750 743



The STAR endcap electromagnetic calorimeter

C.E. Allgower[a,1], B.D. Anderson[b,1], A.R. Baldwin[b,1], J. Balewski[a,1], M. Belt-Tonjes[c], L.C. Bland[a,1], R.L. Brown[d,2], R.V. Cadman[e,1], W. Christie[d,2], I. Cyliax[a,1], V. Dunin[f], L. Efimov[f], G. Eppley[g], C.A. Gagliardi[h,2], N. Gagunashvili[f], T. Hallman[d,2], W. Hunt[a,1], W.W. Jacobs[a,1], A. Klyachko[a,1], K. Krueger[e,2], A. Kulikov[f], A. Ogawa[i], Y. Panebratsev[f], M. Planinic[a,1], J. Puskar-Pasewicz[a,1], G. Rakness[a,1], S. Razin[f], O. Rogachevski[f], S. Shimansky[f], K.A. Solberg[a,1], J. Sowinski[a,1], H. Spinka[e,2], E.J. Stephenson[a,1], V. Tikhomirov[f], M. Tokarev[f], R.E. Tribble[h,2], D. Underwood[e,2], A.M. Vander Molen[c], S.E. Vigdor[a,*,1], J.W. Watson[b,1], G. Westfall[c], S.W. Wissink[a,1], A. Yokosawa[e,2], V. Yurevich[f], W.-M. Zhang[b,1], A. Zubarev[f]

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[b] Department of Physics, Kent State University, Kent, OH 44242, USA
[c] Department of Physics, Michigan State University, East Lansing, MI 48824, USA
[d] Physics Division, Brookhaven National Laboratory, Upton, NY 11973, USA
[e] High Energy Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA
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[g] Department of Physics, Rice University, Houston, TX 77251, USA
[h] Cyclotron Institute, Texas A&M University, College Station, TX 77843, USA
[i] Department of Physics, Pennsylvania State University, University Park, PA 16802, USA

Same idea as for bHCAL:

- ATHENA ***considering*** to reuse megatiles from STAR EndCap
- STAR EndCap have 20 layers, nHCAL need ~(5-7)

Summary

WG weekly meetings: Monday 7pm ET, https://indico.bnl.gov/category/364/

- ECAL and HCAL subsystems and reconstruction implemented in DD4HEP
- Ongoing discussions:
  - Barrel tracking ECAL hybrid
  - Default option
  - Optimize pi^0 identification
  - LGAD timing layers to help PID
  - Barrel HCAL & effect of materials from the magnet coils
  - nECAL hybrid PWO/Glass vs full PWO
  - bECAL as “inner HCAL”, neutrons performance
  - Integration issues and cost estimates

- Validation of subsystems performance in DD4HEP is the next step