Barrel Hadronic Calorimetry

J. Lajoie

Iowa State University

Introduction

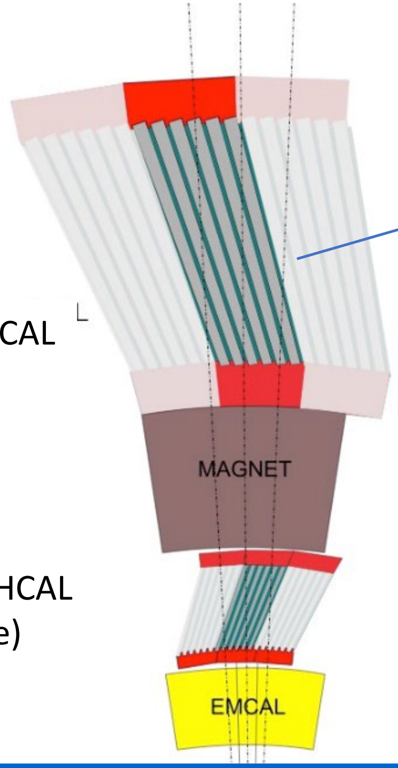
- Two main goals for barrel HCAL @ EIC:
  - Precise reconstruction of jet energy
    - Jets at the EIC are relatively soft
    - Tracks will provide a better determination of momentum than hadronic calorimetry over most of the kinematic coverage.
    - HCAL provides a measurement of neutral hadrons.
      - Sufficient resolution to resolve overlaps
  - Secondary determination of scattered electron kinematics from hadronic remnants

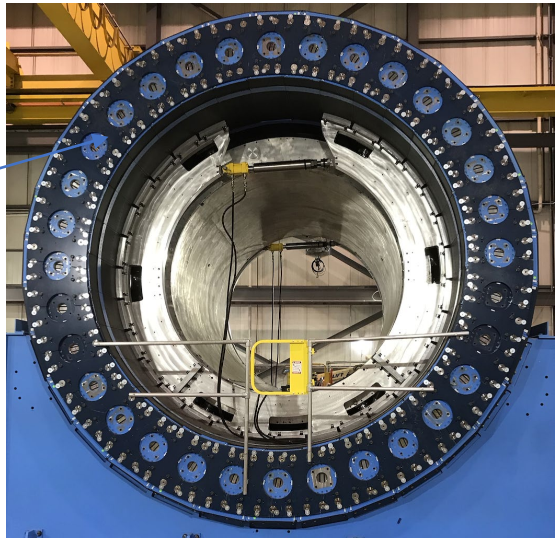
EIC Yellow Report

η	EIC Specifications		Conservative option	
	σ_E/E, %	E_{min}, MeV	σ_E/E, %	E_{min}, MeV
-3.5 to -1.0	$45/\sqrt{E}+7$	500	$50/\sqrt{E}+10$	500
-1.0 to +1.0	$85/\sqrt{E}+7$	500	$100/\sqrt{E}+10$	500
+1.0 to +3.5	$35/\sqrt{E}$	500	$50/\sqrt{E}+10$	500

Table 11.35: HCAL parameters from the EIC specifications (Table 10.6) and for a technically conservative option. Several ways to improve the energy resolution are described in the text.

Outer Hadronic Calorimeter (sPHENIX)





- HCAL steel and scintillating tiles with wavelength shifting fiber
  - **Outer HCal (outside the solenoid)**
  - **$\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$**
  - **1,536 readout channels**
- SiPM Readout

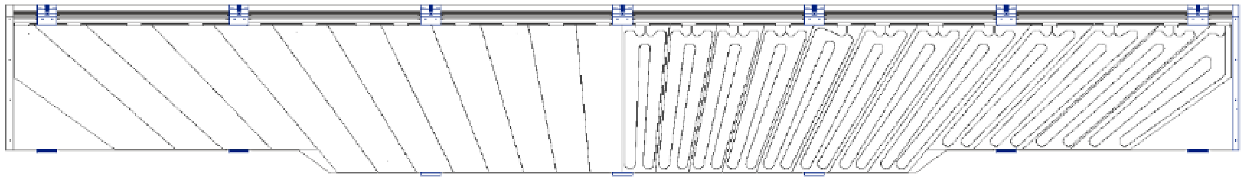
- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- (Frame $\approx 0.25\lambda_I$) (sPHENIX)
- (EMCAL $\approx 18X_0 \approx 0.7\lambda_I$) (sPHENIX)

HCAL performance requirements driven by jet physics in HI collisions

- Uniform fiducial acceptance $-1<\eta<1$ and $0<\phi<2\pi$
  - Extended coverage $-1.1<\eta<1.1$ to account for jet cone
- **(sPHENIX)** Absorb >95% of energy from a 30 GeV jet
  - Requires ~4.9 nuclear interaction length depth
- **(sPHENIX)** Hadronic energy resolution of *combined* calorimetry:
  - UPP: $\frac{\sigma}{E} < \frac{150\%}{\sqrt{E}}$ (in central Au+Au collisions)
  - Gaussian response (limited tails)
- HCAL created by instrumenting barrel magnetic flux return

Outer HCAL Design

tiles in sector gap:



Assembly Detail:
5 scintillators/tower
48 towers per sector
32 sectors;
1536 channels (7680 SiPMs)

32 assembled and tested sectors - 1.9m inner radius, 2.6m outer radius

10 rows of 8mm scint. tiles (24 tiles per row), 12^{o} tilt angle

Tapered 1020 steel plates ~26.1mm - ~42.4mm

Completed sector is 6.3m long, 13.5 tons

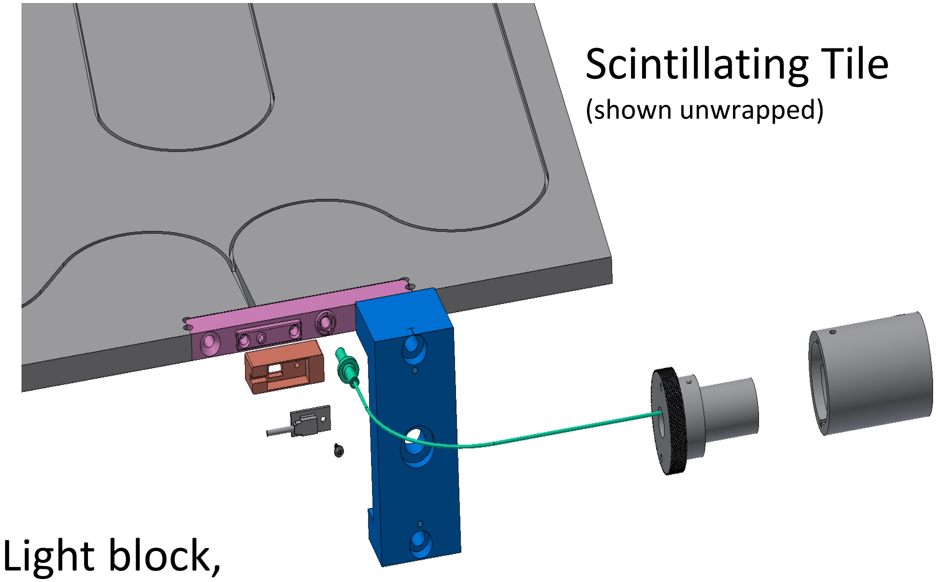
Tower preamplifiers

LV/Bias and slow controls.

Tower signals cabled out to digitizers

Scintillating Tiles

Scintillating tiles are integrated units manufactured by Uniplast.
Detailed cosmic ray response maps from MEPHI (Urugan), integrated into simulations.



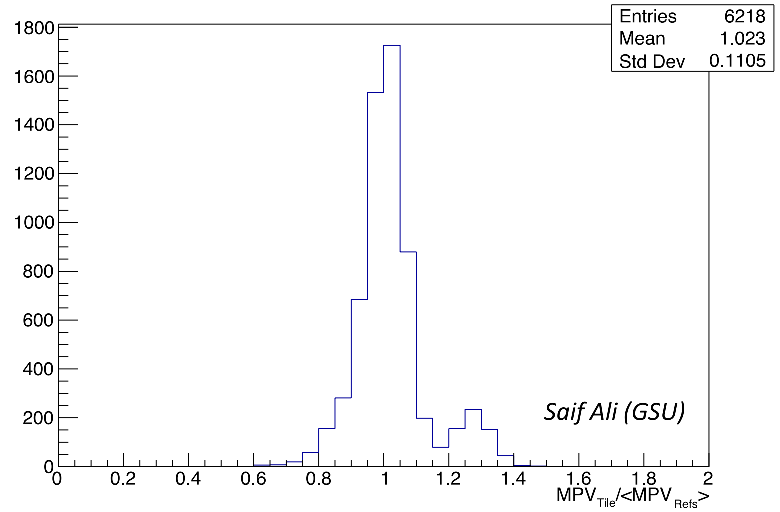
Scintillating Tile
(shown unwrapped)

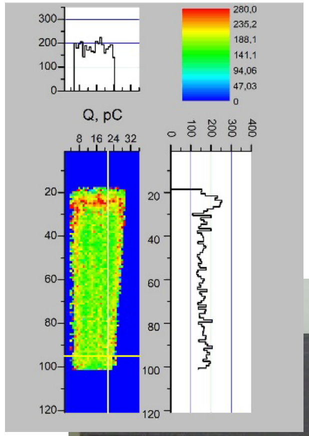
Light block, SiPM mount and SiPM

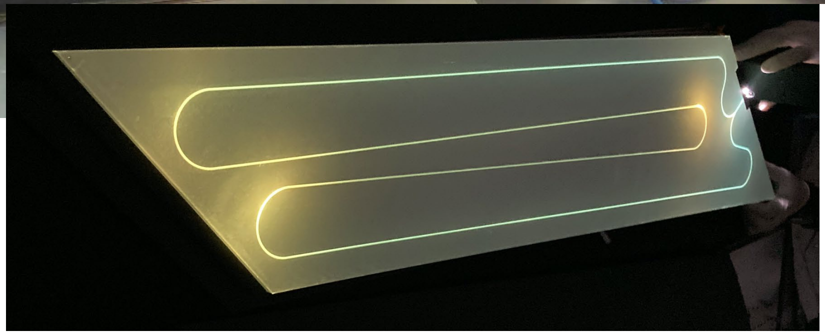
Tile Retainer Clip

Calibration Fiber

Extensive testing of produced tiles for unform response, results used to sort tiles into a tower with variation <5%







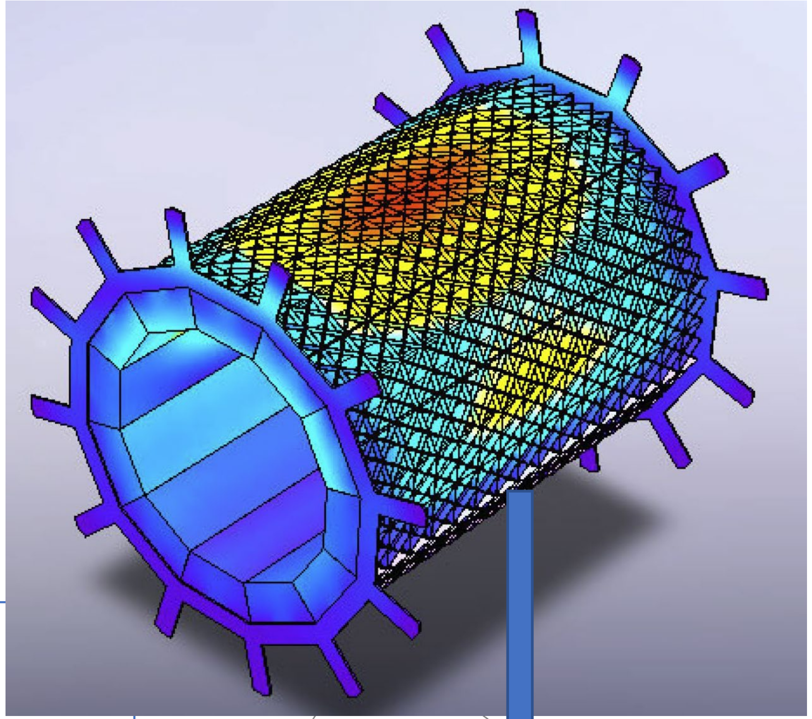
Inner Hadronic Calorimeter

The “inner HCAL” in ECCE was a conceptual design based on the design of the sPHENIX inner HCAL, although it is much thinner. It is not a calorimeter by itself, but a tool to measure energy flow out of the EMCal, prior to the cryostat.
The support frame may not support an iHCAL design of this type. Needs to be evaluated if we need some measure of energy flow to optimally calibrate the oHCAL.

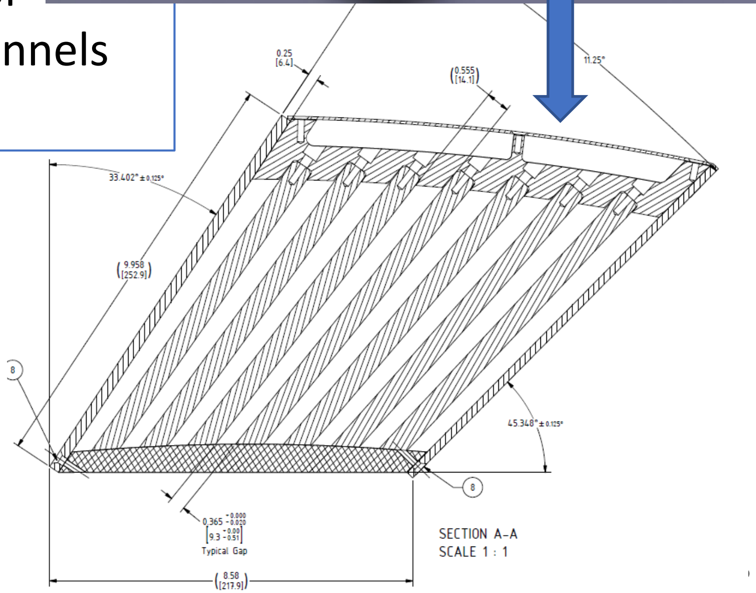
Parameter	Value
Inner radius (envelope)	1350 mm
Outer radius (envelope)	1385 mm
Material	310 stainless steel
# towers in azimuth ($\Delta\varphi$)	64
# towers per module	$2 \times (12 + 15) = 56$
# tiles per tower	4
# towers in pseudorapidity ($\eta > 0$)	24
# towers in pseudorapidity ($\eta < 0$)	30
# electronic channels (towers)	$64 \times 27 = 1728$
# optical devices (SiPMs)	$4 \times 1728 = 6912$
Tilt angle (relative to radius)	32 °
Absorber plate thickness	13 mm
Gap thickness	8.5 mm
Scintillator thickness	7 mm
# modules (azimuthal slices)	32
Sampling fraction	0.059
Calorimeter depth	$0.17\lambda/\lambda_0$

Table 3: Design parameters for the Inner Hadronic Calorimeter (instrumented frame) for ECCE.

A lot of effort to instrument a very small region.



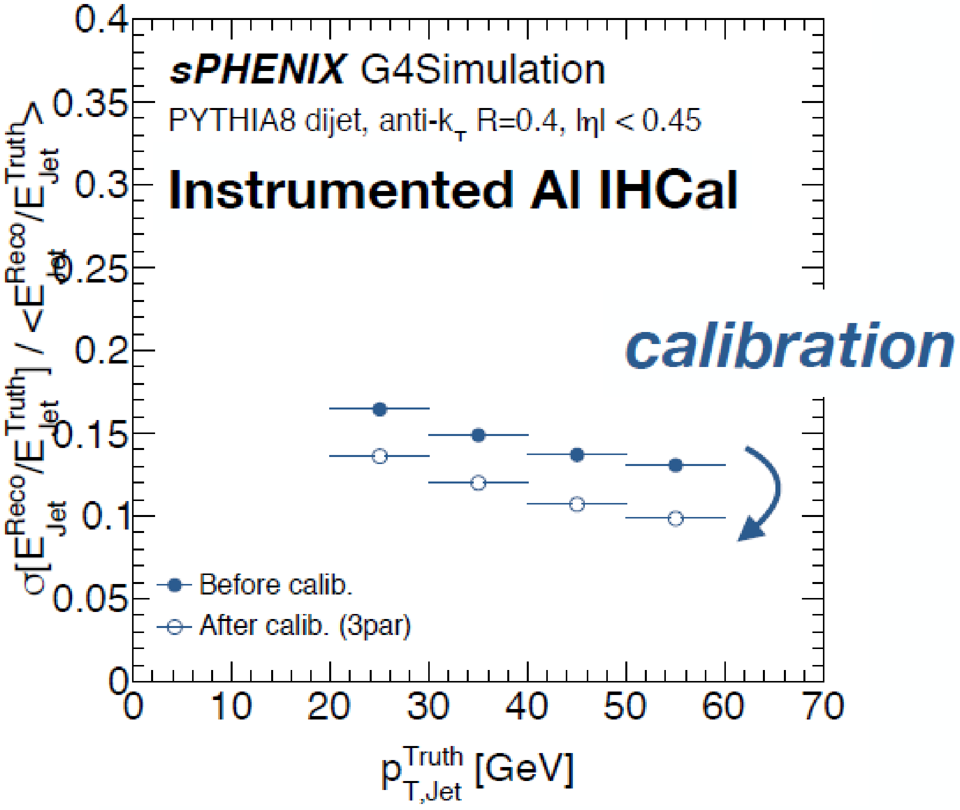
4 scintillators/tower
56 towers per sector
32 sector; 1728 channels
(7168 SiPMs)

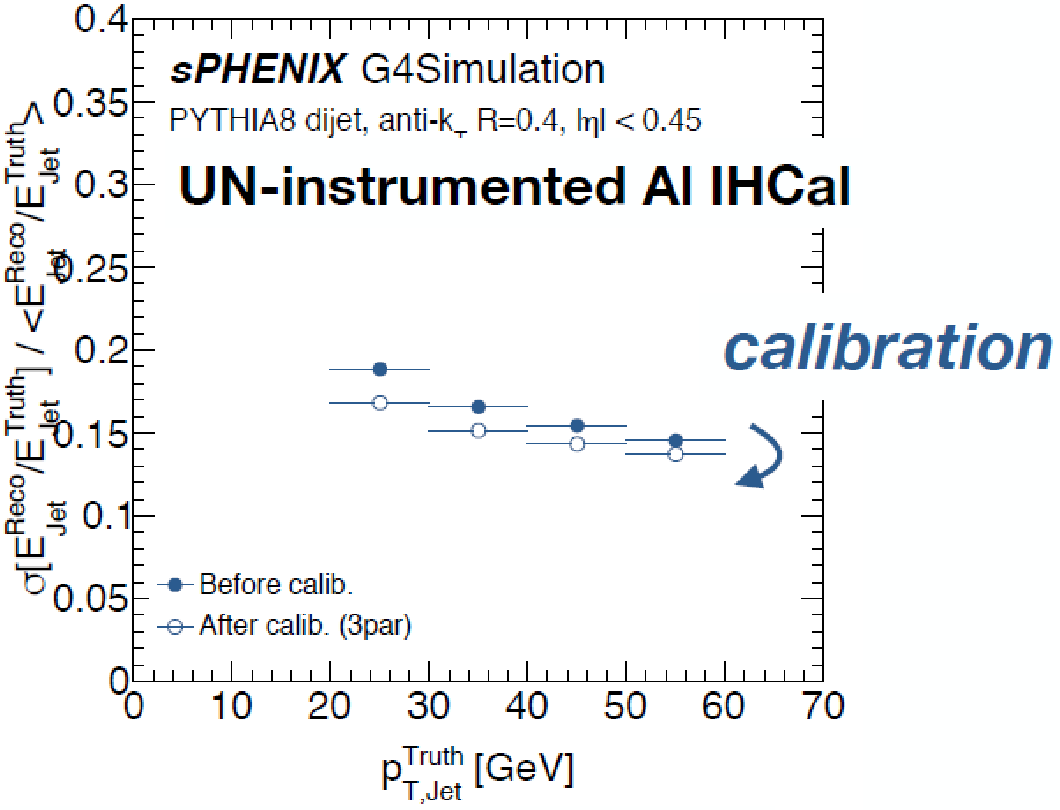


Inner HCAL Motivation

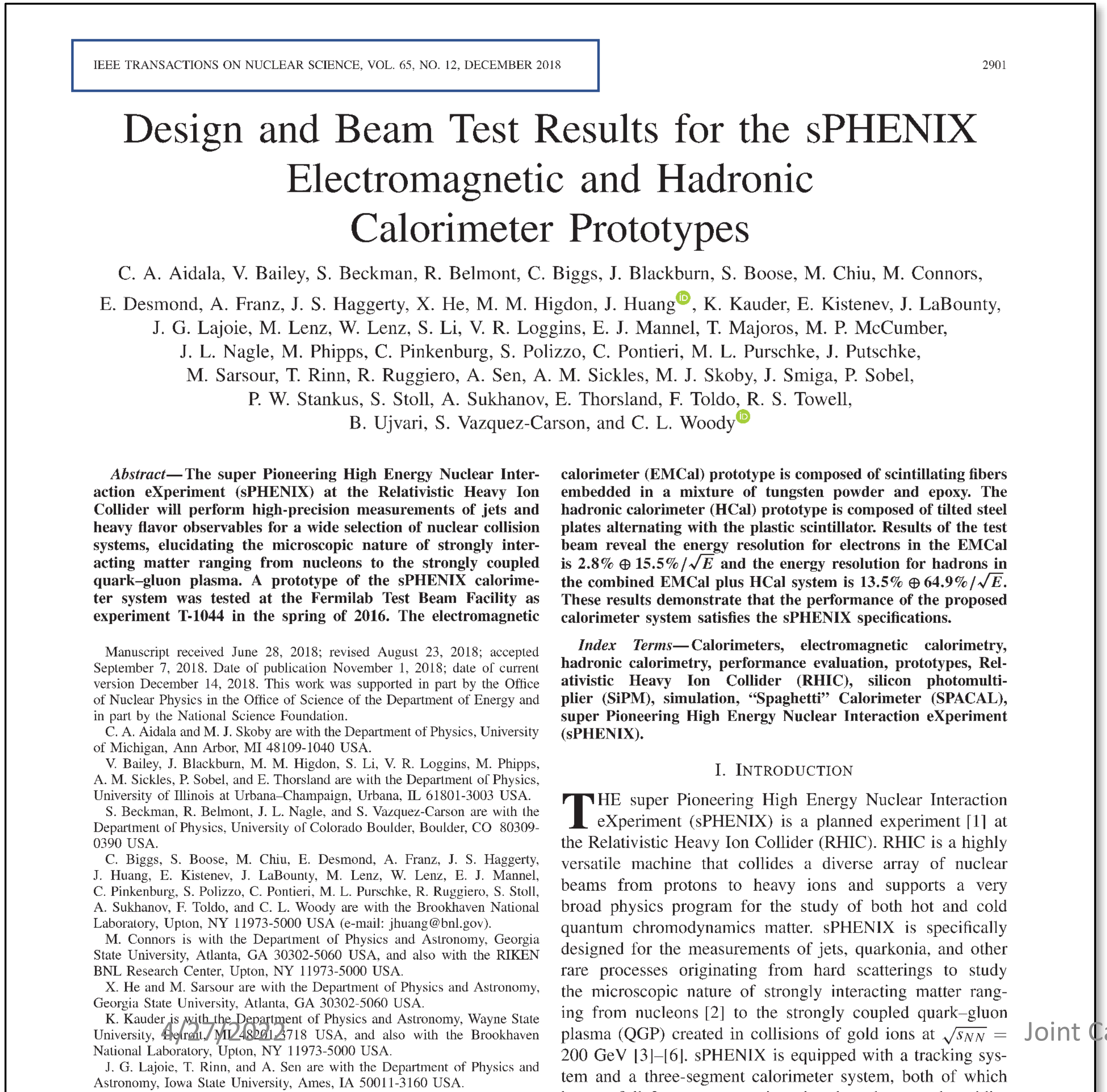
Studies in sPHENIX showed the iHCAL allowed you to do a better job of calibrating the jet energy (essentially it provides longitudinal information. Can it potentially help in the EIC detector?

Is it useful to understand leakage from the EMCal?





Performance



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Design and Beam Test Results for the sPHENIX Electromagnetic and Hadronic Calorimeter Prototypes

C. A. Aidala, V. Bailey, S. Beckman, R. Belmont, C. Biggs, J. Blackburn, S. Boose, M. Chiu, M. Connors, E. Desmond, A. Franz, J. S. Haggerty, X. He, M. M. Higdon, J. Huang, K. Kauder, E. Kistenev, J. LaBounty, J. G. Lajoie, M. Lenz, W. Lenz, S. Li, V. R. Loggins, E. J. Mannel, T. Majoros, M. P. McCumber, J. L. Nagle, M. Phipps, C. Pinkenburg, S. Polizzo, C. Pontieri, M. L. Purschke, J. Putschke, M. Sarsour, T. Rinn, R. Ruggiero, A. Sen, A. M. Sickles, M. J. Skoby, J. Smiga, P. Sobel, P. W. Stankus, S. Stoll, A. Sukhanov, E. Thorsland, F. Toldo, R. S. Towell, B. Ujvari, S. Vazquez-Carson, and C. L. Woody

Abstract—**The super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) at the Relativistic Heavy Ion Collider will perform high-precision measurements of jets and heavy flavor observables for a wide selection of nuclear collision systems, elucidating the microscopic nature of strongly interacting matter ranging from nucleons to the strongly coupled quark–gluon plasma. A prototype of the sPHENIX calorimeter system was tested at the Fermilab Test Beam Facility as experiment T-1044 in the spring of 2016. The electromagnetic calorimeter (EMCal) prototype is composed of scintillating fibers embedded in a mixture of tungsten powder and epoxy. The hadronic calorimeter (HCal) prototype is composed of tilted steel plates alternating with the plastic scintillator. Results of the test beam reveal the energy resolution for electrons in the EMCal is 2.8% $\oplus$ 15.5%/$\sqrt{E}$ and the energy resolution for hadrons in the combined EMCal plus HCal system is 13.5% $\oplus$ 64.9%/$\sqrt{E}$. These results demonstrate that the performance of the proposed calorimeter system satisfies the sPHENIX specifications.**

Index Terms—**Calorimeters, electromagnetic calorimetry, hadronic calorimetry, performance evaluation, prototypes, Relativistic Heavy Ion Collider (RHIC), silicon photomultiplier (SiPM), simulation, "Spaghetti" Calorimeter (SPACAL), super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX).**

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C. A. Aidala and M. J. Skoby are with the Department of Physics, University of Michigan, Ann Arbor, MI 48109-1040 USA.

V. Bailey, J. Blackburn, M. M. Higdon, S. Li, V. R. Loggins, M. Phipps, A. M. Sickles, P. Sobel, and E. Thorsland are with the Department of Physics, University of Illinois at Urbana–Champaign, Urbana, IL 61801-3003 USA.

S. Beckman, R. Belmont, J. L. Nagle, and S. Vazquez-Carson are with the Department of Physics, University of Colorado Boulder, Boulder, CO 80309-0390 USA.

C. Biggs, S. Boose, M. Chiu, E. Desmond, A. Franz, J. S. Haggerty, J. Huang, E. Kistenev, J. LaBounty, M. Lenz, W. Lenz, E. J. Mannel, C. Pinkenburg, S. Polizzo, C. Pontieri, M. L. Purschke, R. Ruggiero, S. Stoll, A. Sukhanov, F. Toldo, and C. L. Woody are with the Brookhaven National Laboratory, Upton, NY 11973-5000 USA (e-mail: jhuang@bnl.gov).

M. Connors is with the Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30302-5060 USA, and also with the RIKEN BNL Research Center, Upton, NY 11973-5000 USA.

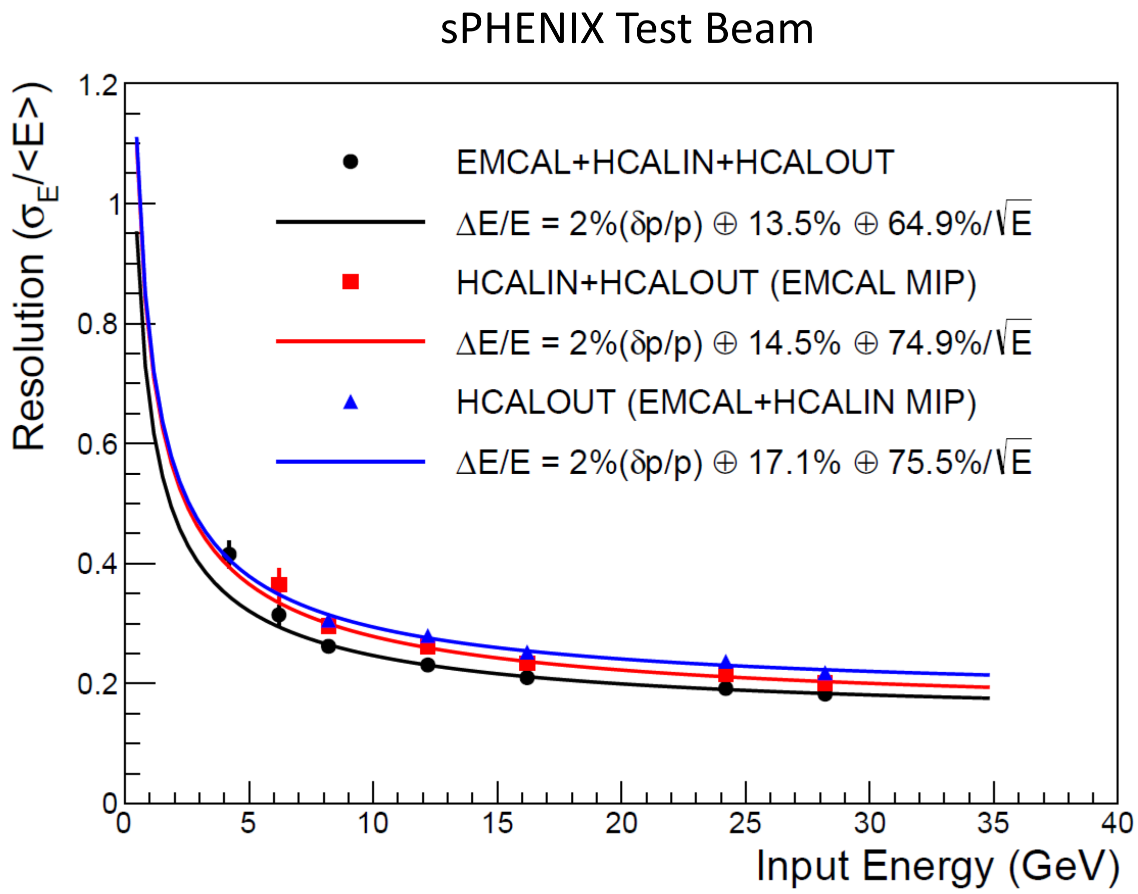
X. He and M. Sarsour are with the Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30302-5060 USA.

K. Kauder is with the Department of Physics and Astronomy, Wayne State University, Detroit, MI 48201-3718 USA, and also with the Brookhaven National Laboratory, Upton, NY 11973-5000 USA.

J. G. Lajoie, T. Rinn, and A. Sen are with the Department of Physics and Astronomy, Iowa State University, Ames, IA 50011-3160 USA.

I. INTRODUCTION

THE super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) is a planned experiment [1] at the Relativistic Heavy Ion Collider (RHIC). RHIC is a highly versatile machine that collides a diverse array of nuclear beams from protons to heavy ions and supports a very broad physics program for the study of both hot and cold quantum chromodynamics matter. sPHENIX is specifically designed for the measurements of jets, quarkonia, and other rare processes originating from hard scatterings to study the microscopic nature of strongly interacting matter ranging from nucleons [2] to the strongly coupled quark–gluon plasma (QGP) created in collisions of gold ions at $\sqrt{s_{NN}}$ = 200 GeV [3]–[6]. sPHENIX is equipped with a tracking system and a three-segment calorimeter system, both of which



Performance of full device will be measured in sPHENIX. We should achieve a reduced constant term due to tighter control on the scintillator variation in a tower for production sectors.

oHCAL Refurbishment Plans

- SPHENIX will be disassembled, including the barrel HCAL and pedestal.
  - BaBar solenoid to be removed for refurbishment
  - Everything moves to 1006
- Refurbish outer HCAL sectors:
  - Do not anticipate significant radiation damage to scintillator
  - Plan is to replace SiPMs
  - Potential to replace/repair scintillating tiles, electronics as necessary
  - Opportunity to perform cosmics calibration
- Reassemble in 1006

HCAL 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
	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
	Hadron Calorimetry	Scintillating tiles (sPHENIX Reuse)	ISU, GSU	sPHENIX Construction

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,	
		PWO4 Calorimeter	EIC-	
	Off-momentum Detectors	AC-LGAD Tracking	UH,	
	Roman Pots	AC-LGAD Tracking	UCL BNL	(OMEGA, ATLAS)
	ZDC	PWO, W/Si, Pb/Si, Pb/Sci	EIC-Japan, KU	Experience with LHCf, RHICf development of FOCAL
Far-Backward	Low-Q^2 Detector	AC-LGAD Tracking	York U. Glasgow U.	Experience from CLAS12 tagger
		PWO4 Calorimeter	EIC-Israel	EM calorimetry, ZDC at LHC
	Luminosity Monitor	AC-LGAD Tracking	York U. Glasgow U.	Experience from CLAS12 tagger
		PWO4 Calorimeter	EIC-Israel	EM calorimetry, ZDC at LHC
Electronics	Streaming readout electronics, Data Aggregation Modules		Columbia, ISU, UC Boulder, OU, ORNL, LLNL, UNH	Electronics expertise at RHIC, JLab
DAQ / Computing	Streaming DAQ, Online Event Filter		CNU, ISU, MIT, LLNL, Morehead state, ORNL, PNNL, SBU, UC Boulder, UConn	Experience with sPHENIX streaming DAQ; CMS and GlueX computing

	Hadron Calorimetry	Scintillating tiles (sPHENIX Reuse)	ISU, GSU	sPHENIX Construction

OK … so it's not as exciting as a shiny new detector, but there will be lots of opportunities for students, etc., to get some practical hands-on experience.