Calorimetry in the sPHENIX Experiment at RHIC

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For the sPHENIX Collaboration

sPHENIX in a nutshell

The sPHENIX experiment at Brookhaven is a second-generation RHIC experiment designed to measure jets and the upsilon states in heavy ion collisions in order to characterize the transport coefficients of the quark-gluon plasma

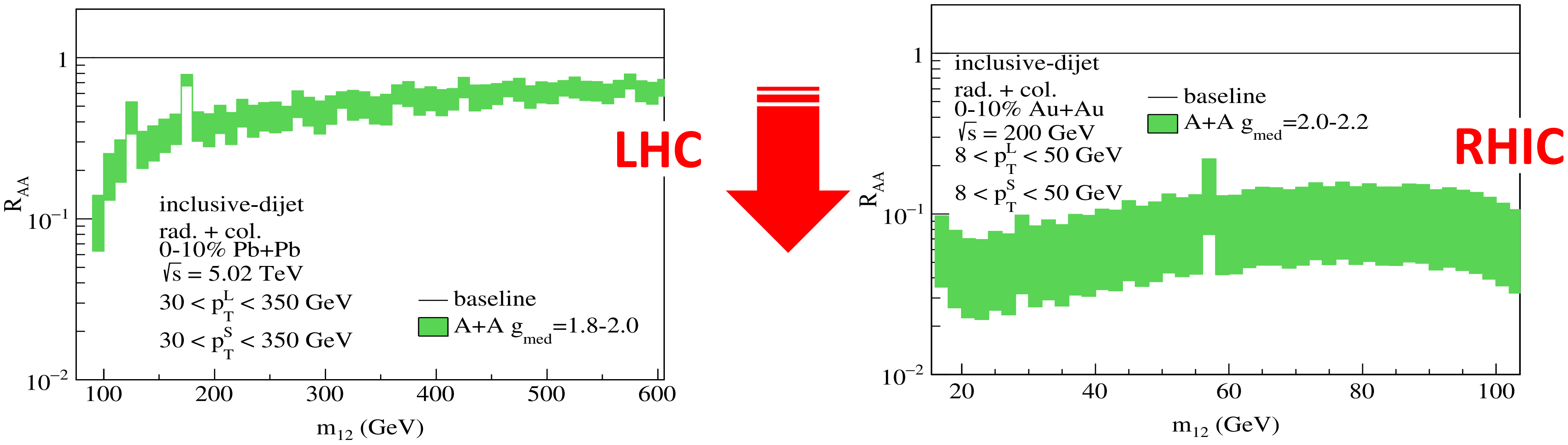
- 2012 Initial proposal
- 2015 BaBar magnet acquired from SLAC
- 2016 CD-0 (mission need), begin PHENIX removal
- 2018 CD-1/3a (begin final design, place long lead time procurements)
- 2019 PD-2/3 (begin construction–in process, review complete), complete PHENIX removal
- 2021-2022 Planned installation
- 2023 Planned first RHIC run of sPHENIX

sPHENIX detector concepts

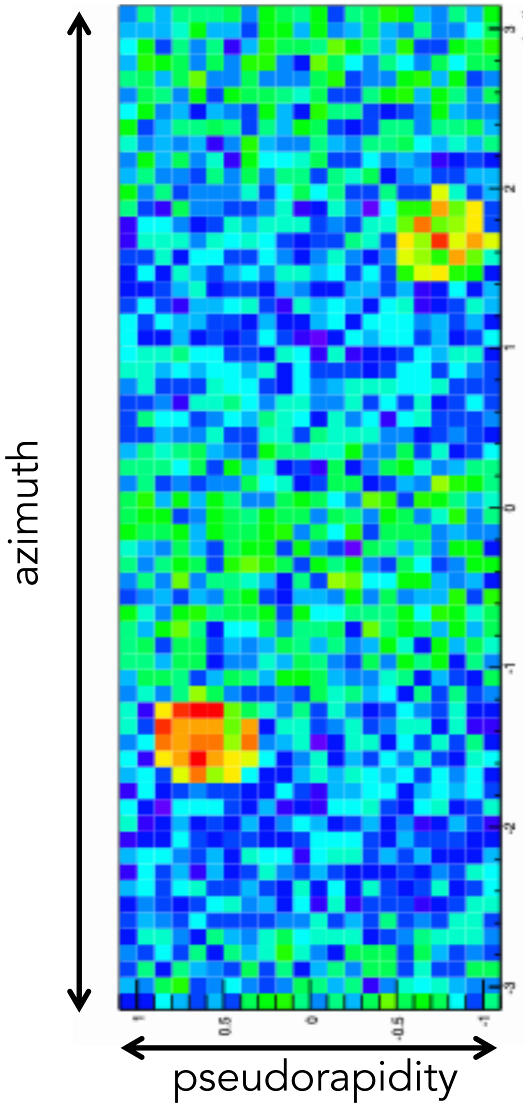
- High rate data acquisition (record 15 kHz)
- 100 MeV/c^2 mass resolution on the ϒ states
  - 1.4T superconducting magnet
  - High resolution tracking system (TPC+silicon vertex detectors)
- Uniform electromagnetic and hadronic calorimetry covering $0<\varphi<2\pi$ and $|\eta|<1$
  - Electron triggering for $\Upsilon \rightarrow e^+e^-$
- Silicon vertex detectors for heavy flavor tagging

Why continue at RHIC?

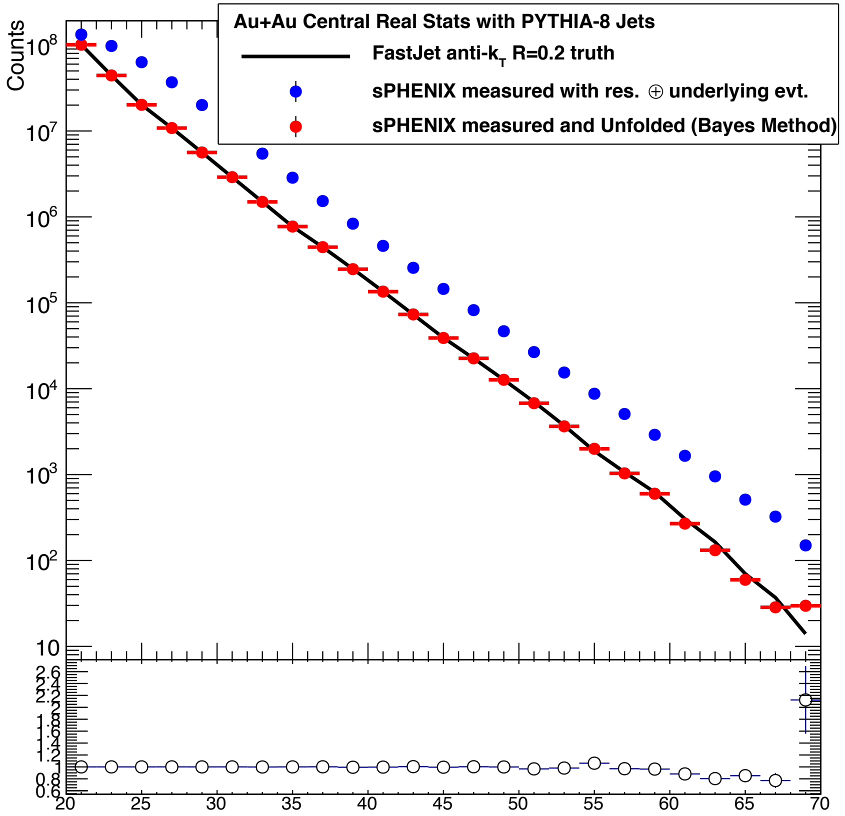
- Increased coupling to the medium near T_c ⇔ stronger dijet suppression at RHIC
  - For example, Z-B Kang, J Reiten, I Vitev, B Yoon, “Light and heavy flavor dijet production and dijet mass modification in heavy ion collisions”, Phys. Rev. D99 034006 (2019), but there are many other examples



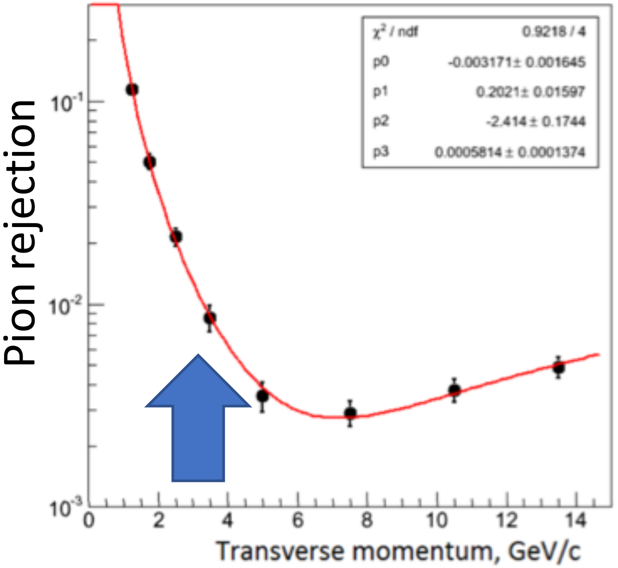
Physics challenge #1: Jets



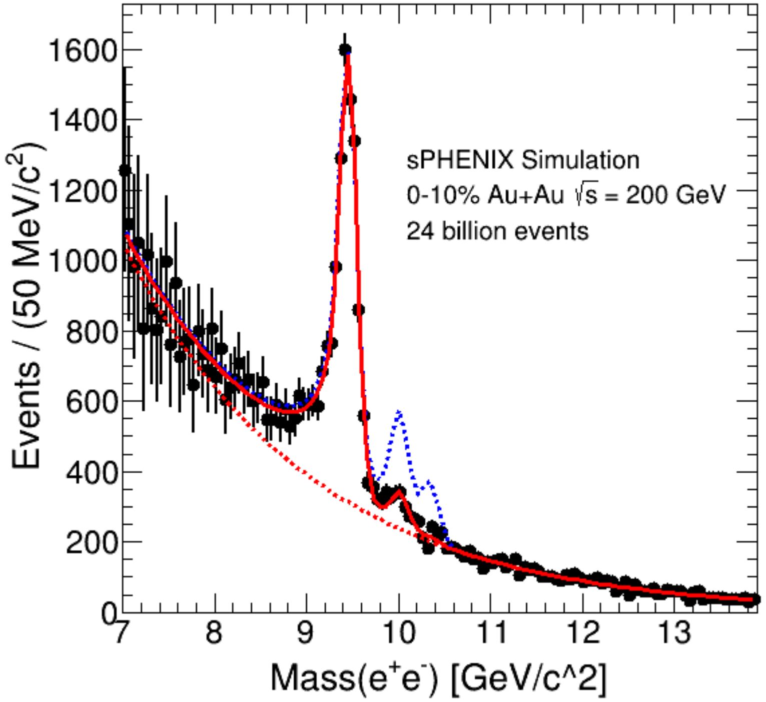
- Central Au+Au event illuminates full HCAL
- $dE_T/d\eta$ ~ 500 GeV, with significant azimuthal modulation
- Underlying event (UE): 40±3.5 GeV in the area of a R = 0.2 jet
- Inclusive PYTHIA8 jets smeared by p+p jet resolution determined from full GEANT4 and by the underlying central Au+Au event fluctuations – unfolded back to truth distribution

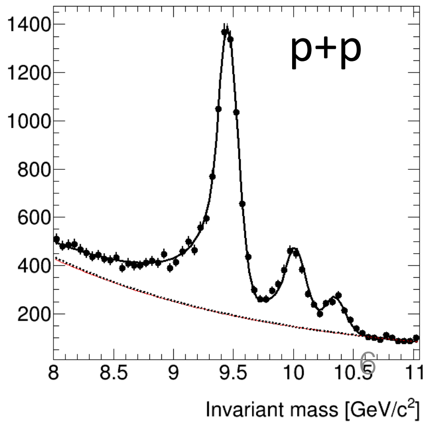


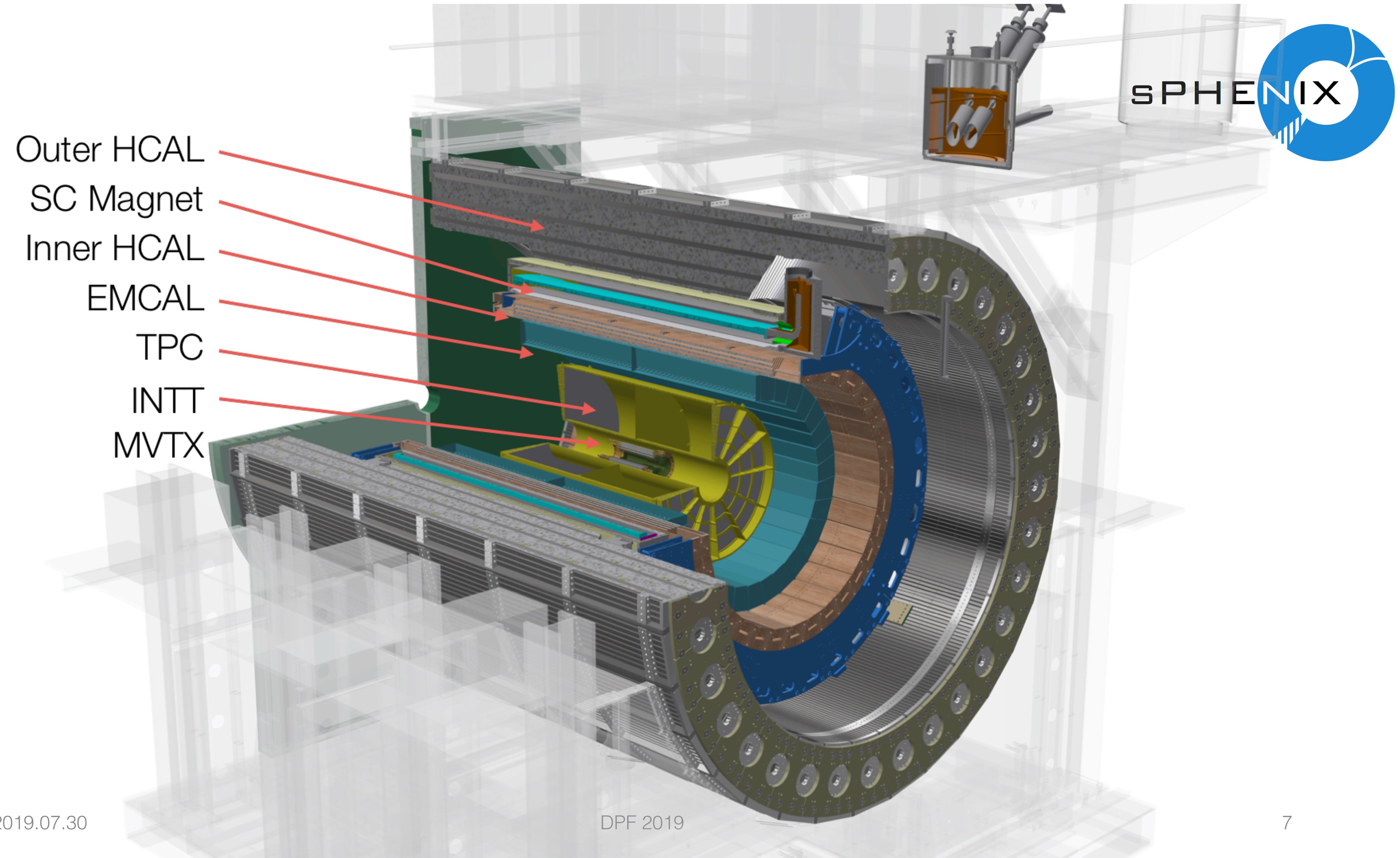
Physics challenge #2: ϒ(1S,2S,3S)



- Although the ϒ states will be reconstructed with tracks in the TPC, the e^+e^- will be identified with the EMCAL
- In p+p collisions, it is necessary to trigger on events with e^+e^- candidates

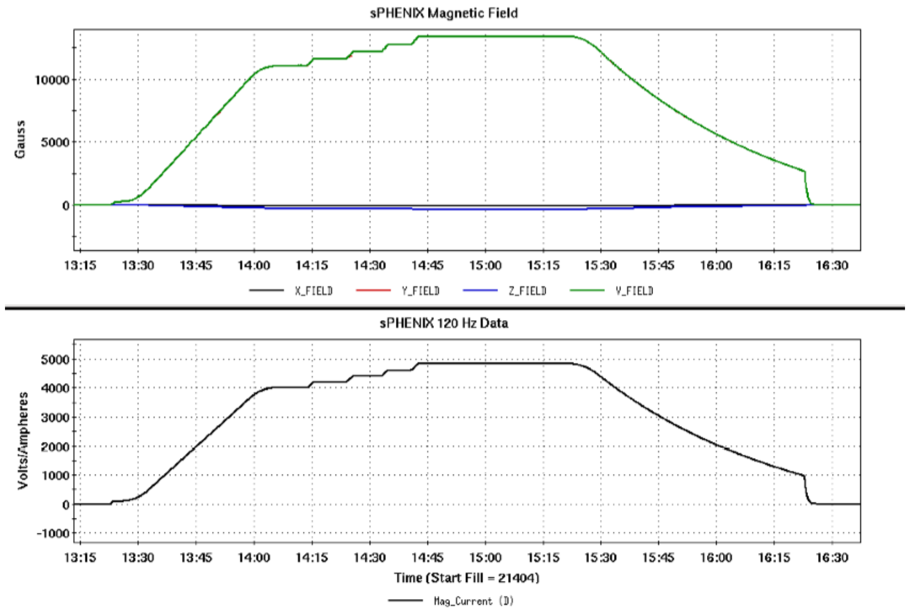





Outer HCAL
SC Magnet
Inner HCAL
EMCAL
TPC
INTT
MVTX
sPHENIX

Solenoid

Solenoid leaving SLAC January 2015

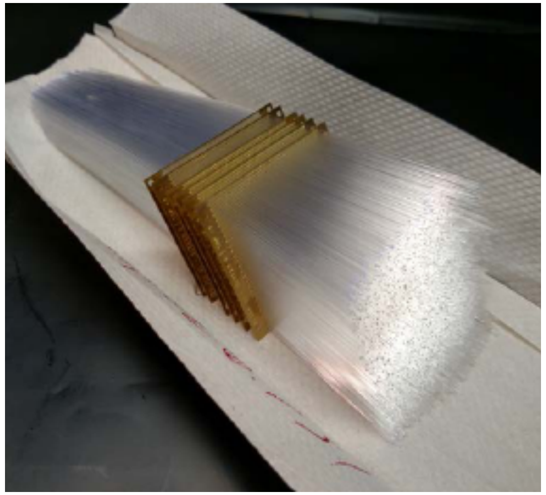


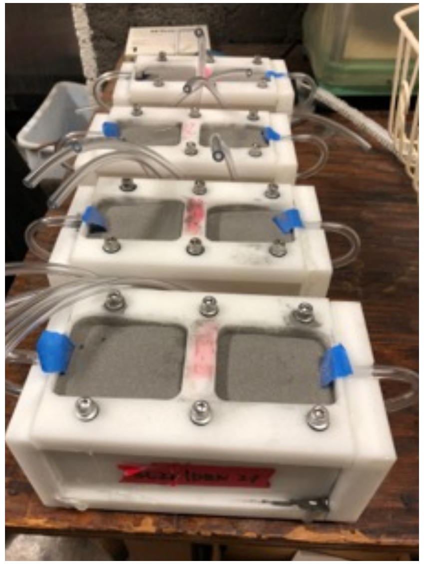
Full current test February 2018

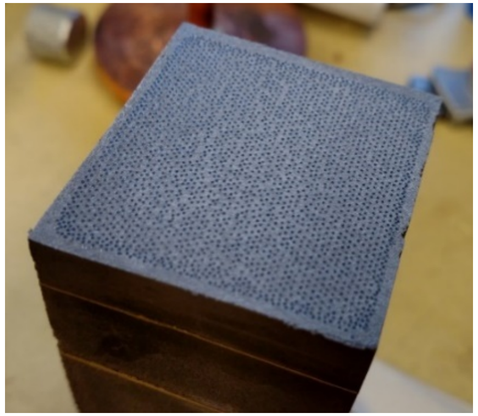
EMCAL properties

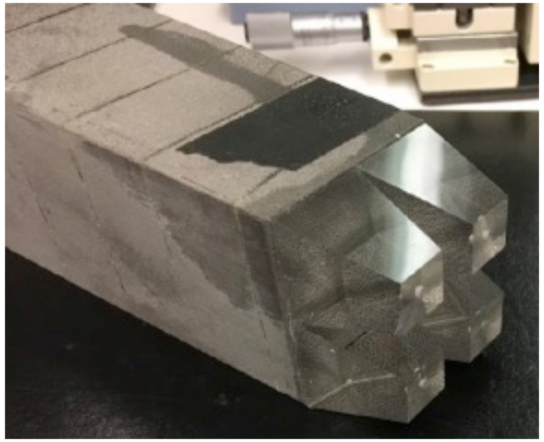
Property	Value	Units
Segmentation	0.025x0.025 256x96 = 24576	$\Delta\varphi$x$\Delta\eta$ towers or channels
SiPM's/tower	4	
Radiation length	0.7	cm
Moliere radius	2.3	cm
Sampling fraction	2.3%	
Tower length	14.4	cm
Density	> 9	g/cm^3
Fiber	0.47 St. Gobain BCF12 SC	mm
Fiber spacing	1	mm
Shaping time	30	ns
Energy resolution	$< 16\%/\sqrt{E} \oplus 5\%$	$\Delta E/E$

EMCAL block fabrication (UIUC)

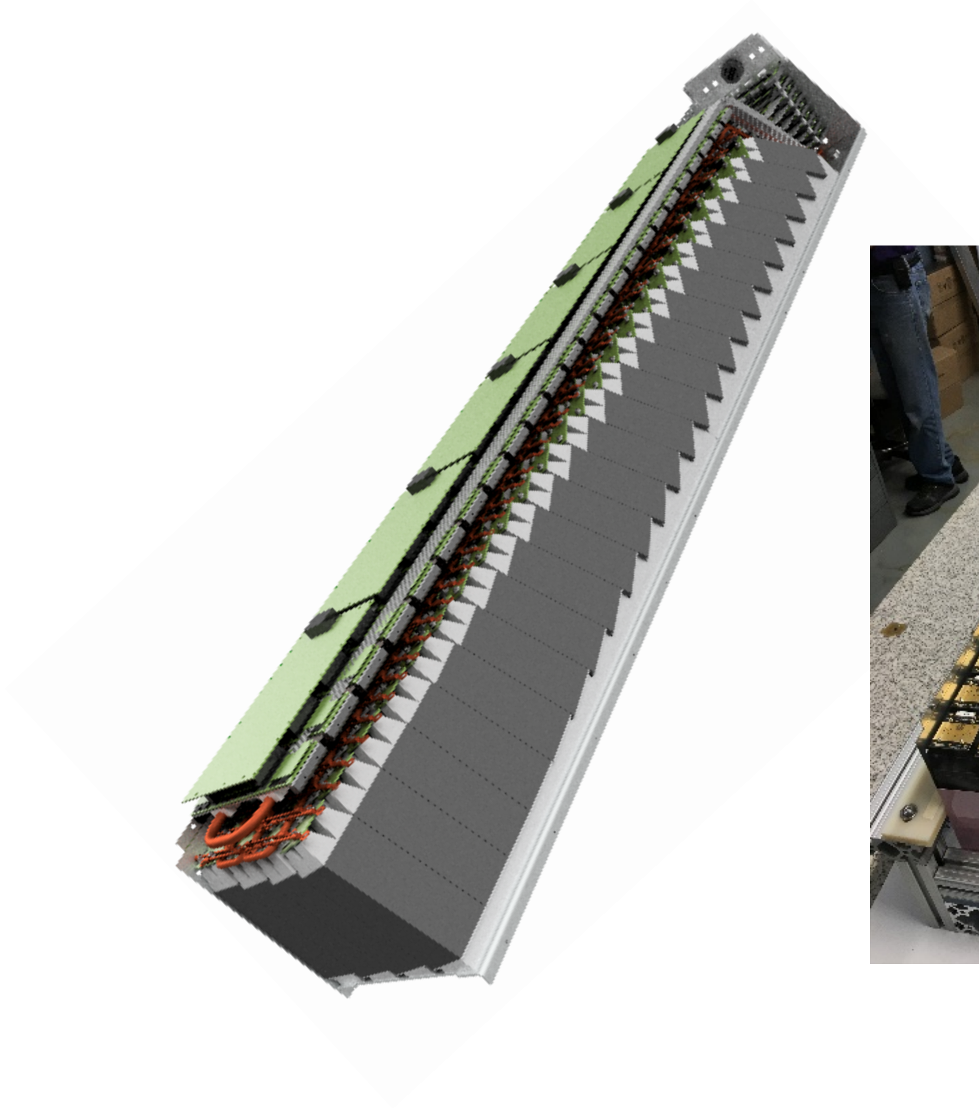








EMCAL half sector

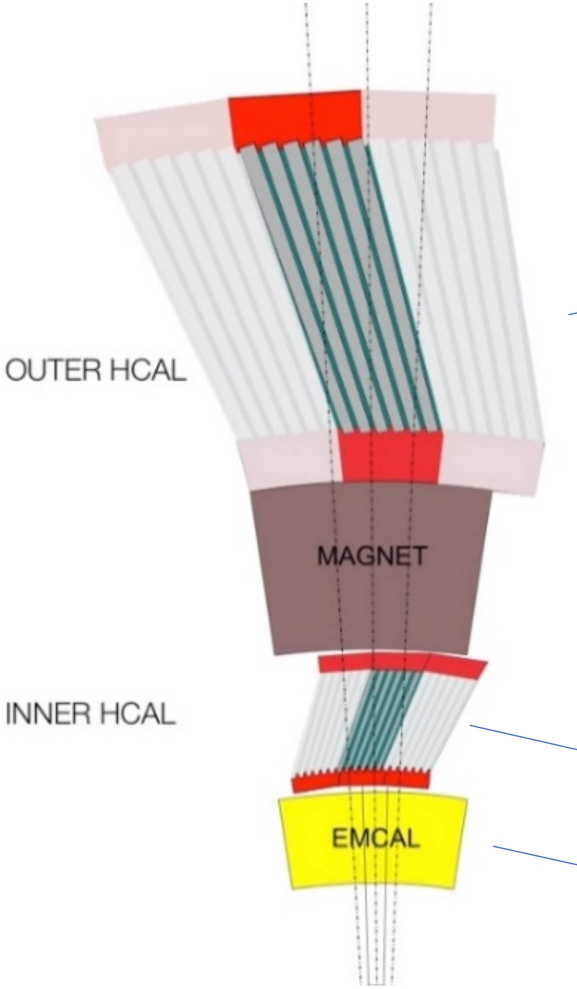


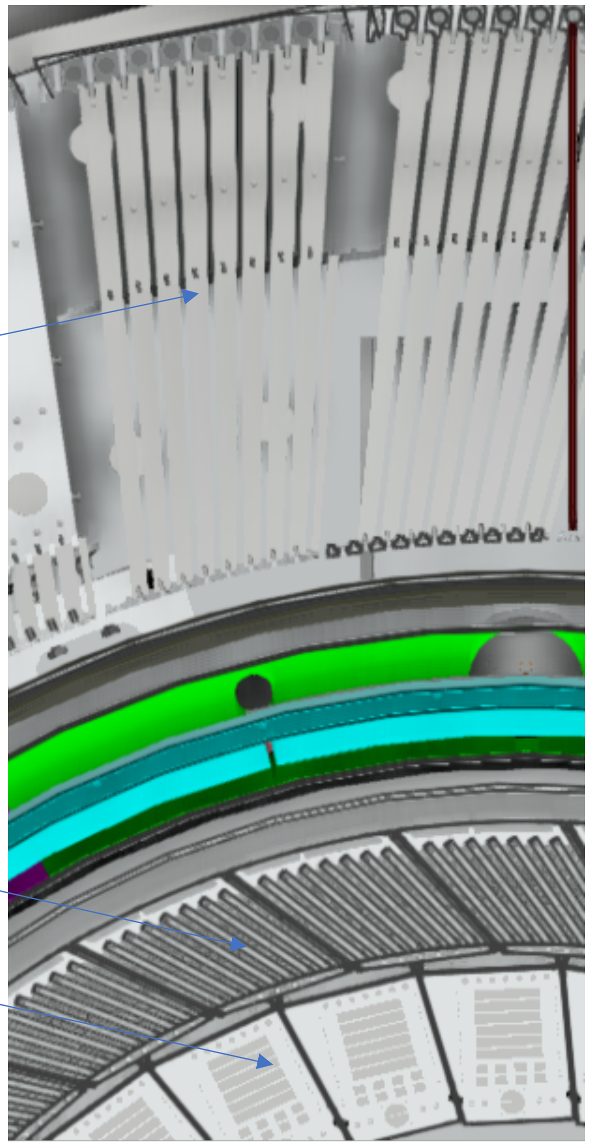
- $\Delta\eta \mathrm{x} \Delta\varphi \sim 0.025$ towers
- 4 3x3 mm SiPM's per tower
- Shaped analog signal transmitted off-detector
- Cooling as low as 0°C

HCAL properties

Property	Value	Unit
Segmentation	0.1x0.1 64x24 = 1536	$\Delta\varphi x \Delta\eta$ towers or channels
SiPM's or tiles per tower	5	
Sampling fraction	2.8-3.7% (varies in depth)	
Scintillator	7 mm Extruded polystyrene with 1.5% PTP and 0.01% POPOP	
Fiber	1 mm Kuraray Y-11 (200)	
Tilt angle	12	°
Total depth	> 5	λ_I
Energy resolution	< 150%/√E	ΔE/E

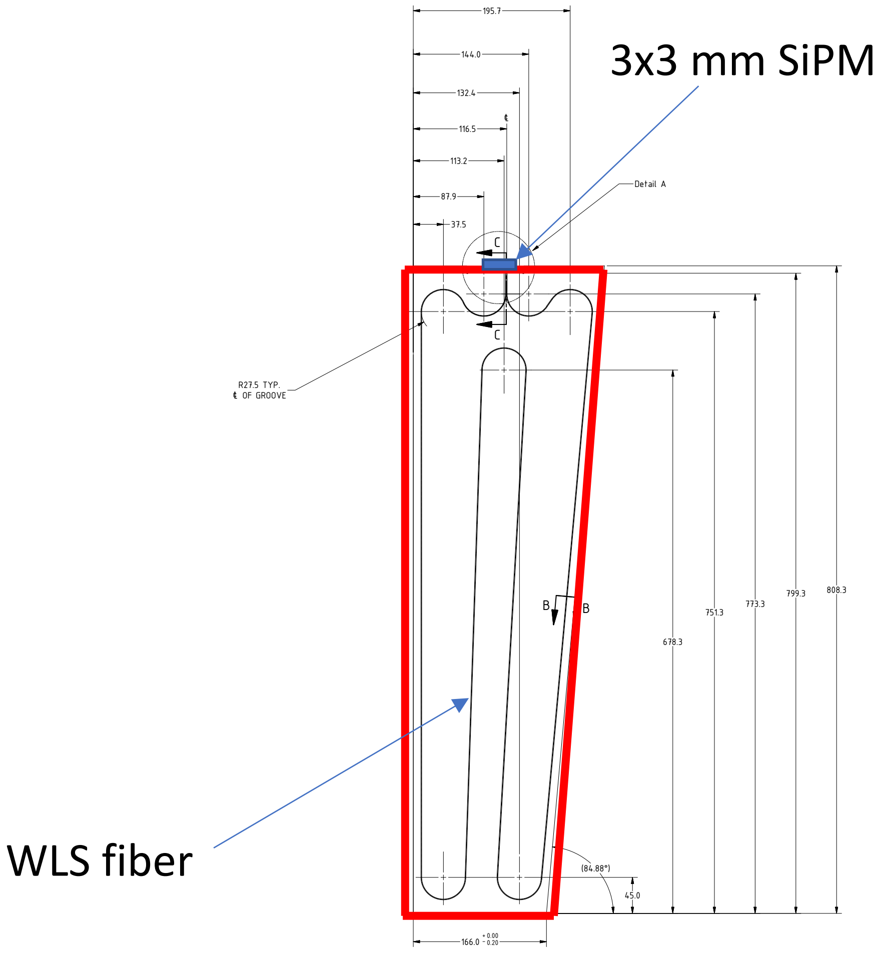
HCAL





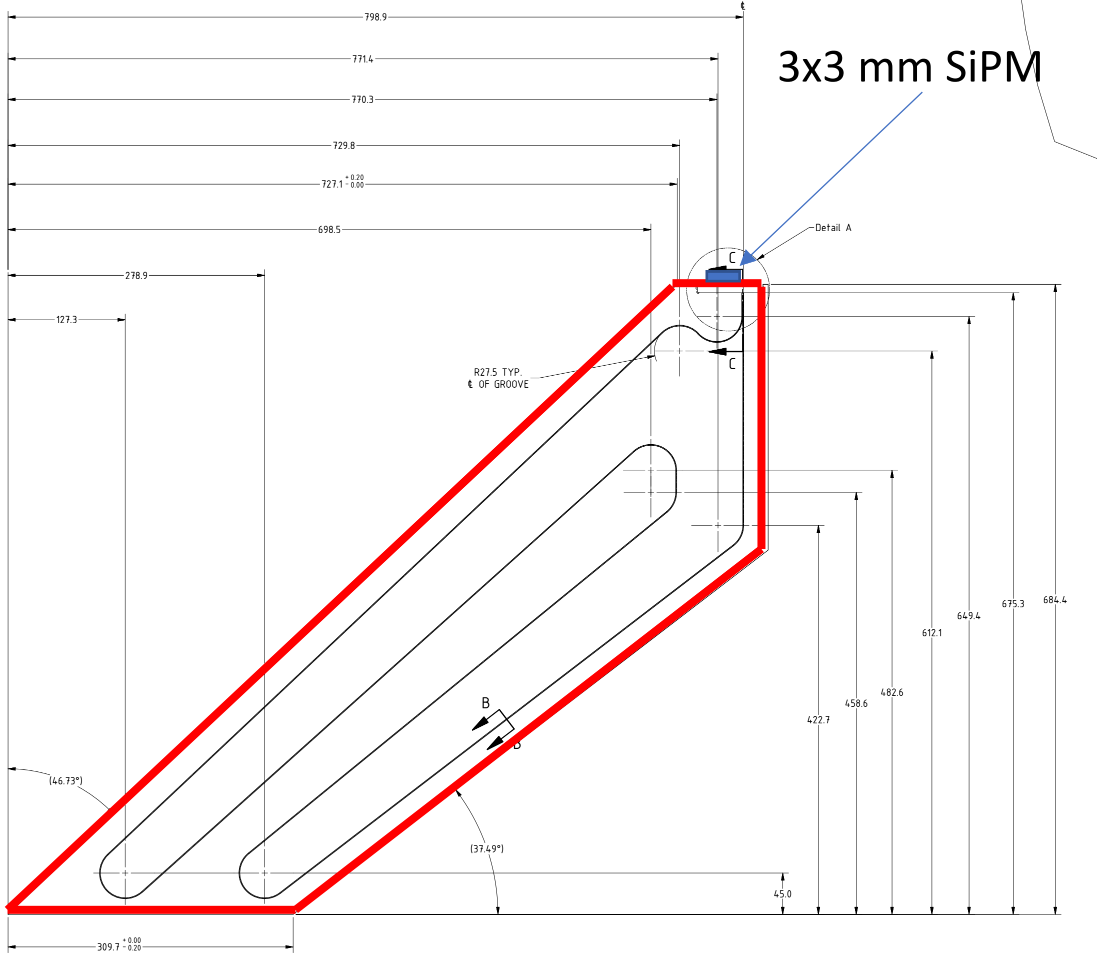
- Tilted and tapered steel plates with scintillator tiles between them
- Extruded polystyrene scintillator with wavelength shifting fiber in grooves
- Each tile read out by a 3x3 mm SiPM
- Five tiles analog summed to a $\Delta\eta x \Delta\varphi \sim 0.1$ tower

HCAL scintillator tiles



$\eta\sim0$

…10 others…

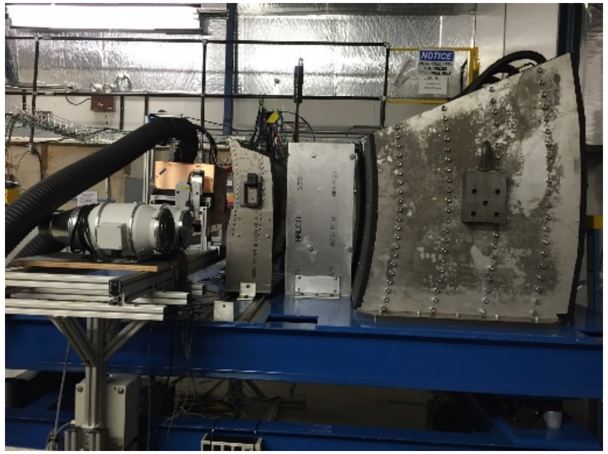


$\eta\sim1$

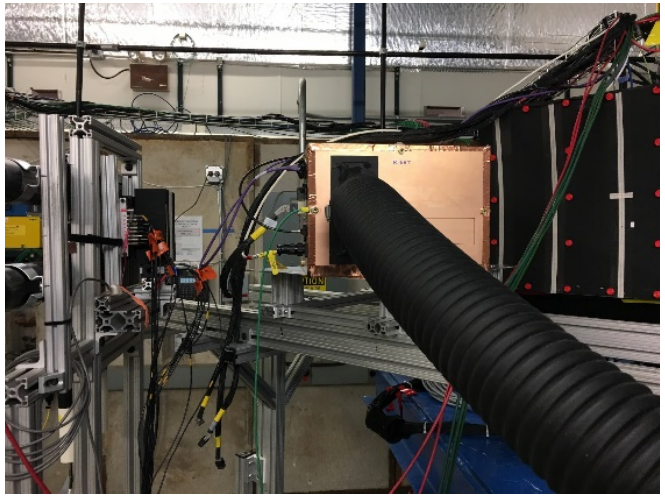
2 of the 12 tile designs

Calorimeter beam tests at Fermilab TBF

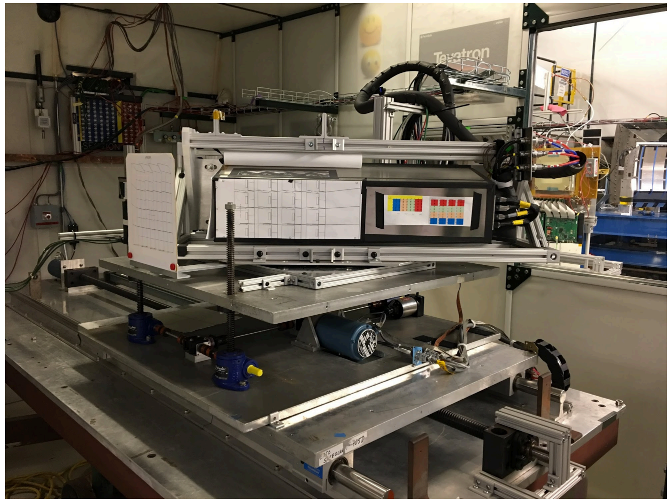
February 2014
Proof of principle



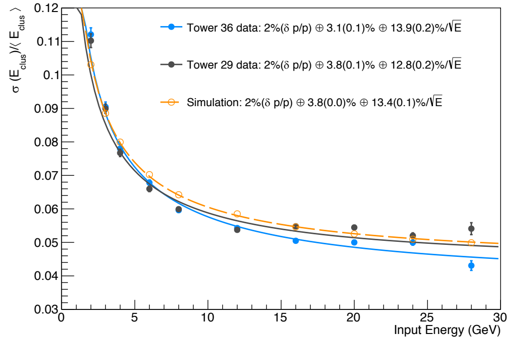
February 2016
η~0
sPHENIX geometry
https://arxiv.org/abs/1704.01461
(published IEEE TNS)



February 2017
η~0.9



February 2018

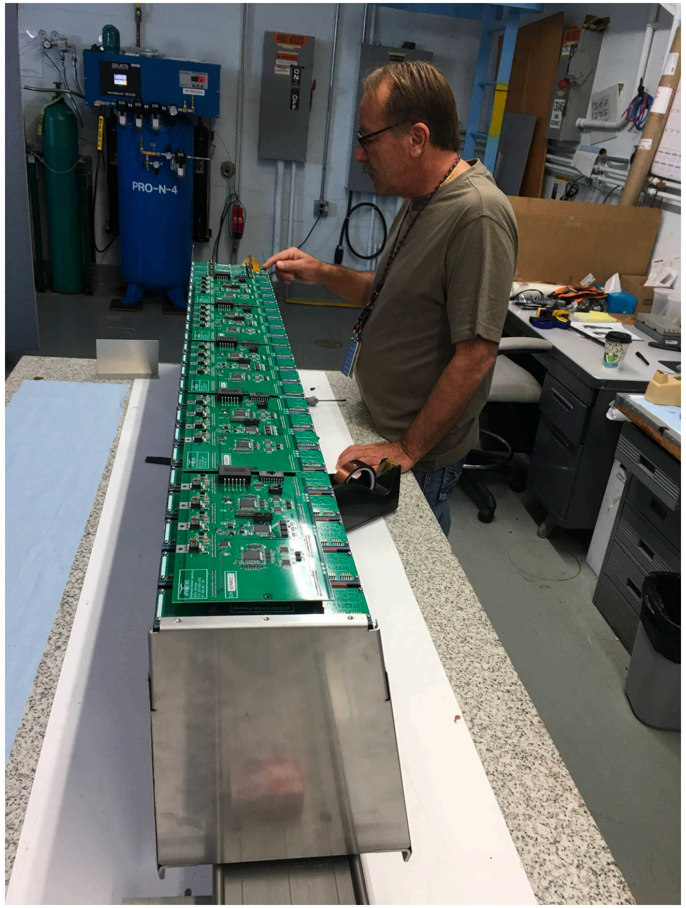


EMCAL meets energy resolution requirement

Calorimeter full size prototypes

First HCAL sector with scintillator tiles

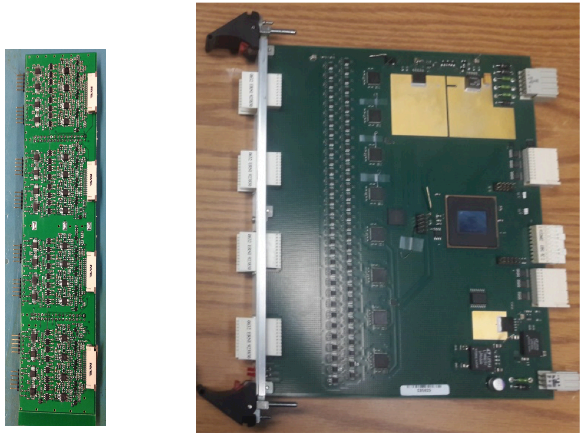
Final HCAL sector delivered



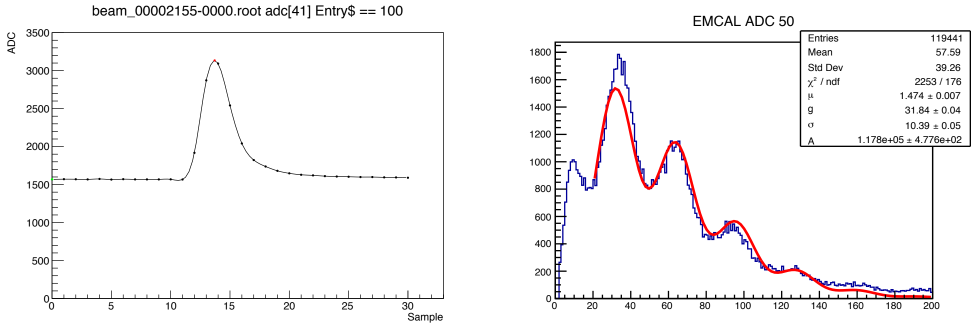
EMCAL sector 0 instrumented

Calorimeter Electronics

- We chose common sensors (Hamamatsu 12572-015P) and electronics for EMCAL and HCAL
- We chose to drive the analog signals to digitizers outside the magnet to avoid designing new ASIC's

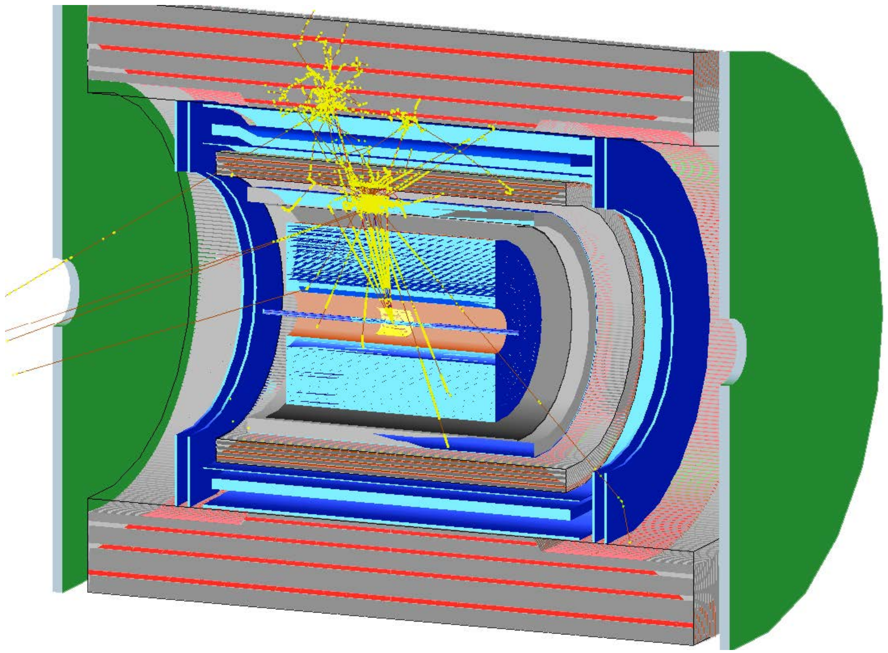


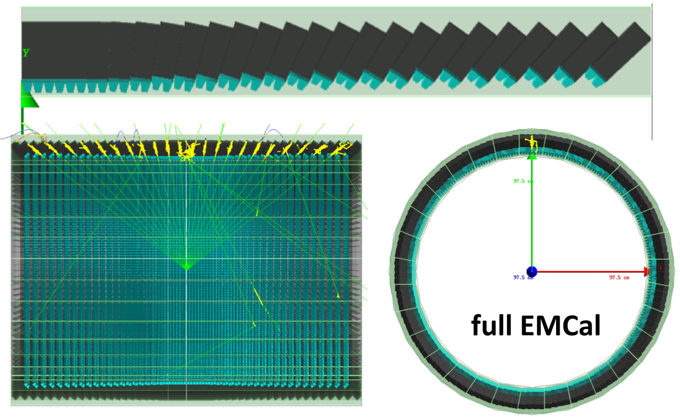
EMCAL preamp and 60 MHz waveform digitizer



Typical digitized pulse and single pixel peaks from production grade electronics

Simulation



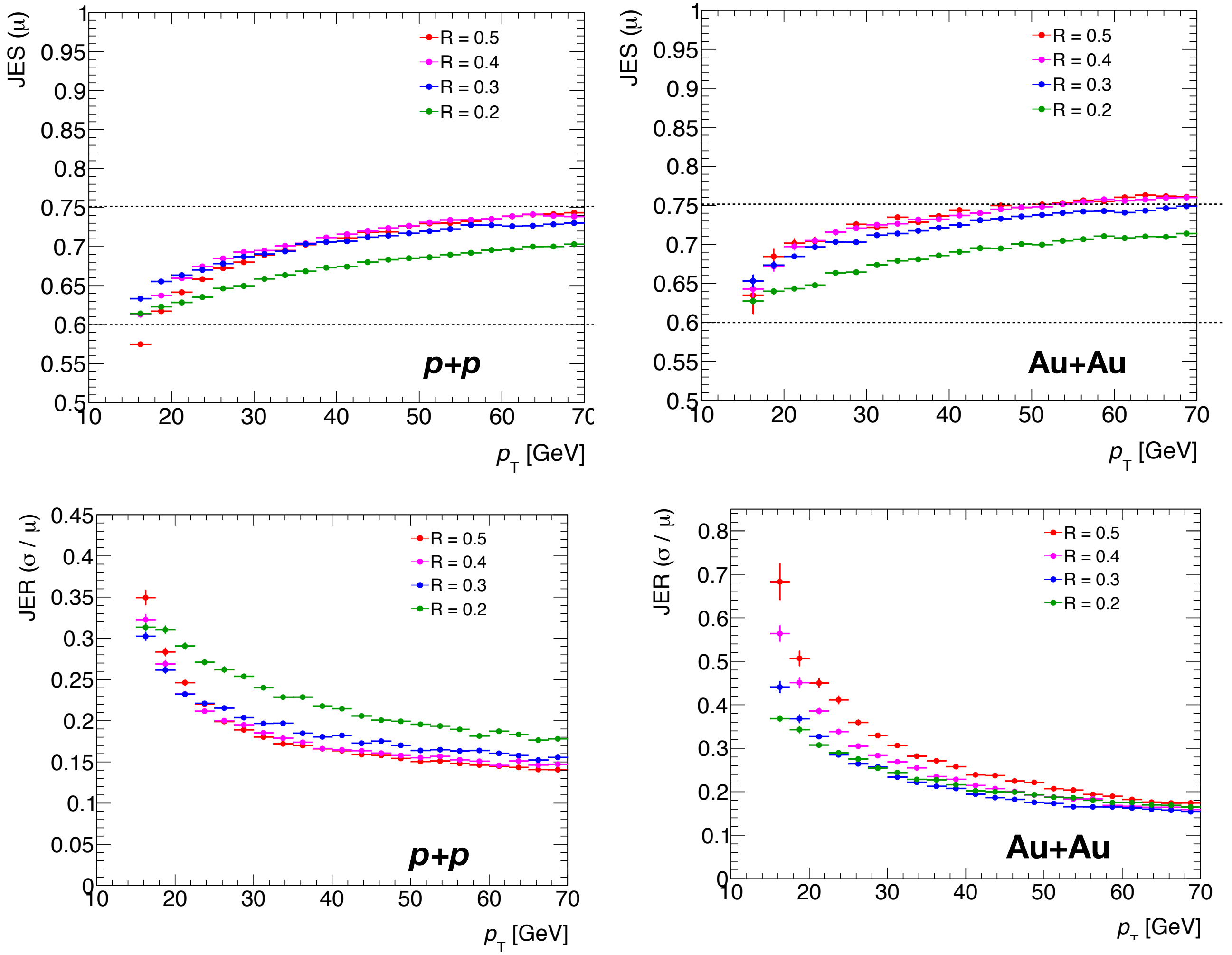


- GEANT4 from the initial design
- Most of the physics plots we show are from full G4 simulation
- Calorimeter simulations have been carefully compared with beam tests

Basic jet performance

sPHENIX

- Jet Energy Scale (JES) and Jet Energy Resolution (JER) in simulation
- Tests Underlying Event (UE) subtraction and calorimeter response



Summary

- A new detector is being designed for a second generation of experiments at RHIC
- Full electromagnetic and hadronic calorimetry combined with a superconducting magnet and TPC tracker will provide a new window into the physics of the QGP
- Testing and simulation show that the calorimeters achieve required energy resolution and e/h rejection
- Likely on the eve of construction start to be ready for first collisions in early 2023
- Preliminary three year run plan has been developed, discussion of operating conditions (luminosity, crossing angle) commenced
- More details in TDR
- Studies show that the calorimeters would be suitable for an EIC experiment