New Developments in Calorimetry for RHIC and EIC

Craig Woody

Brookhaven National Lab

Instrumentation Frontier Meeting

Boulder, Colorado
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PHENIX

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN
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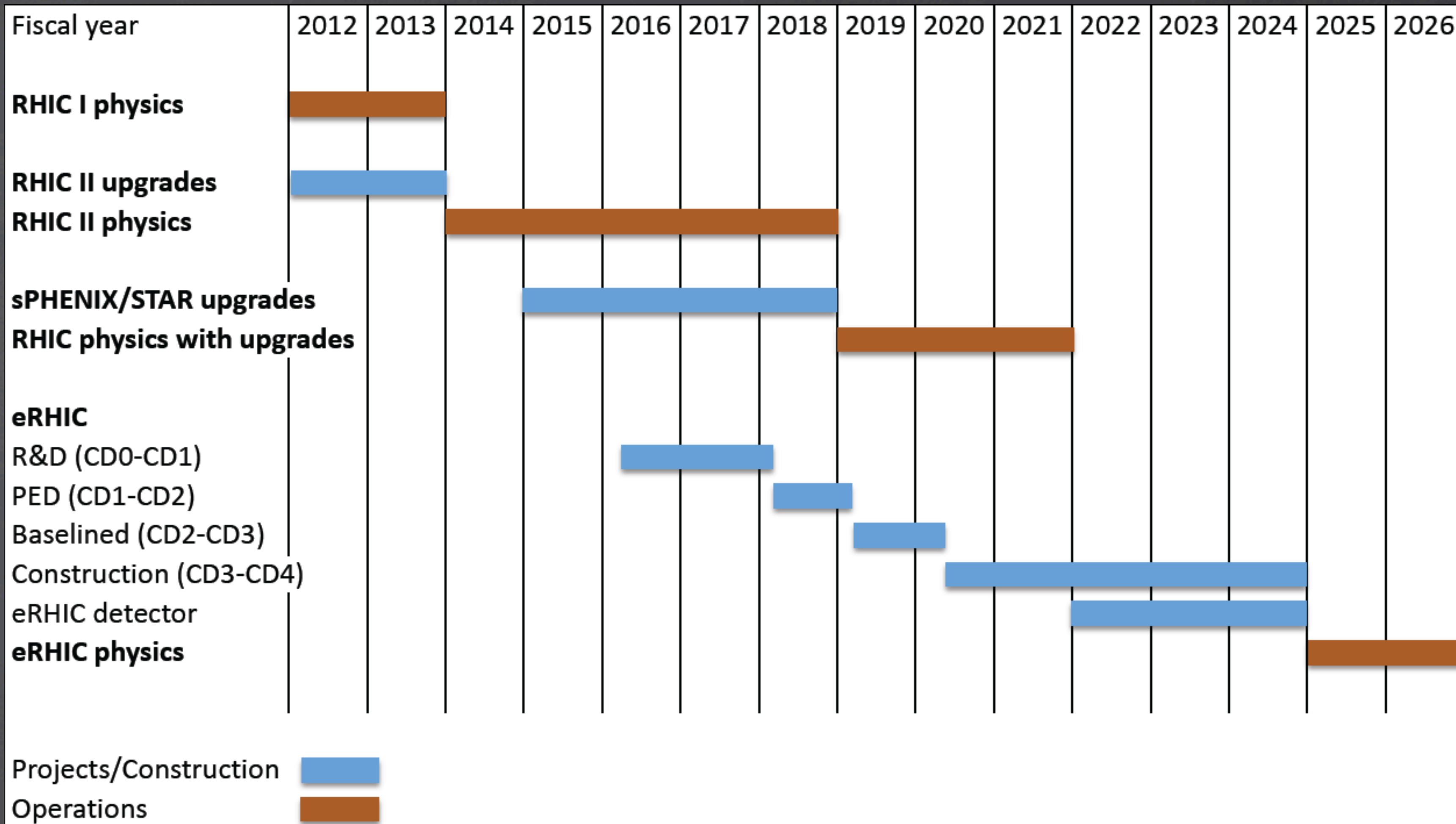
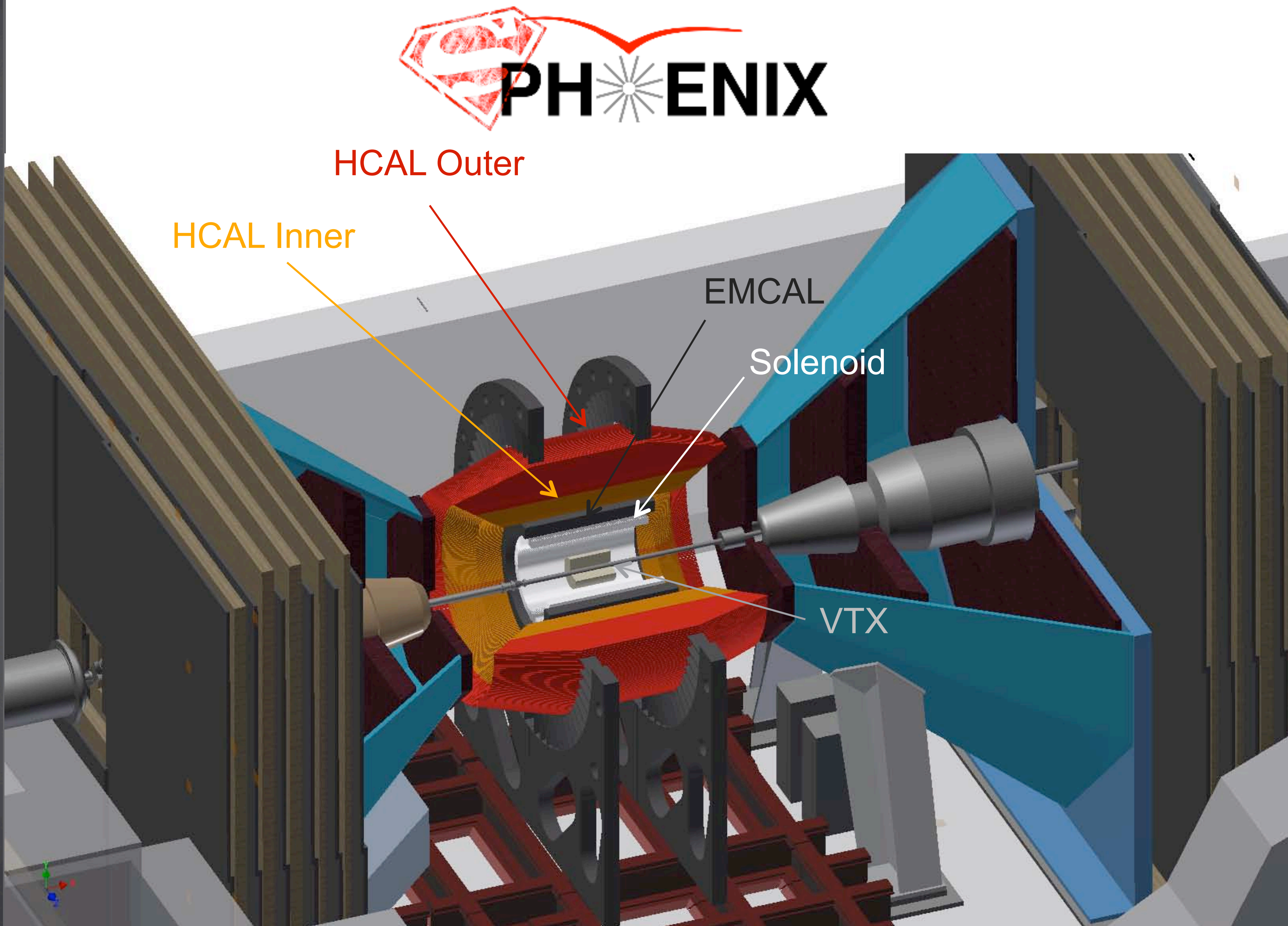
RHIC Long Range Plan

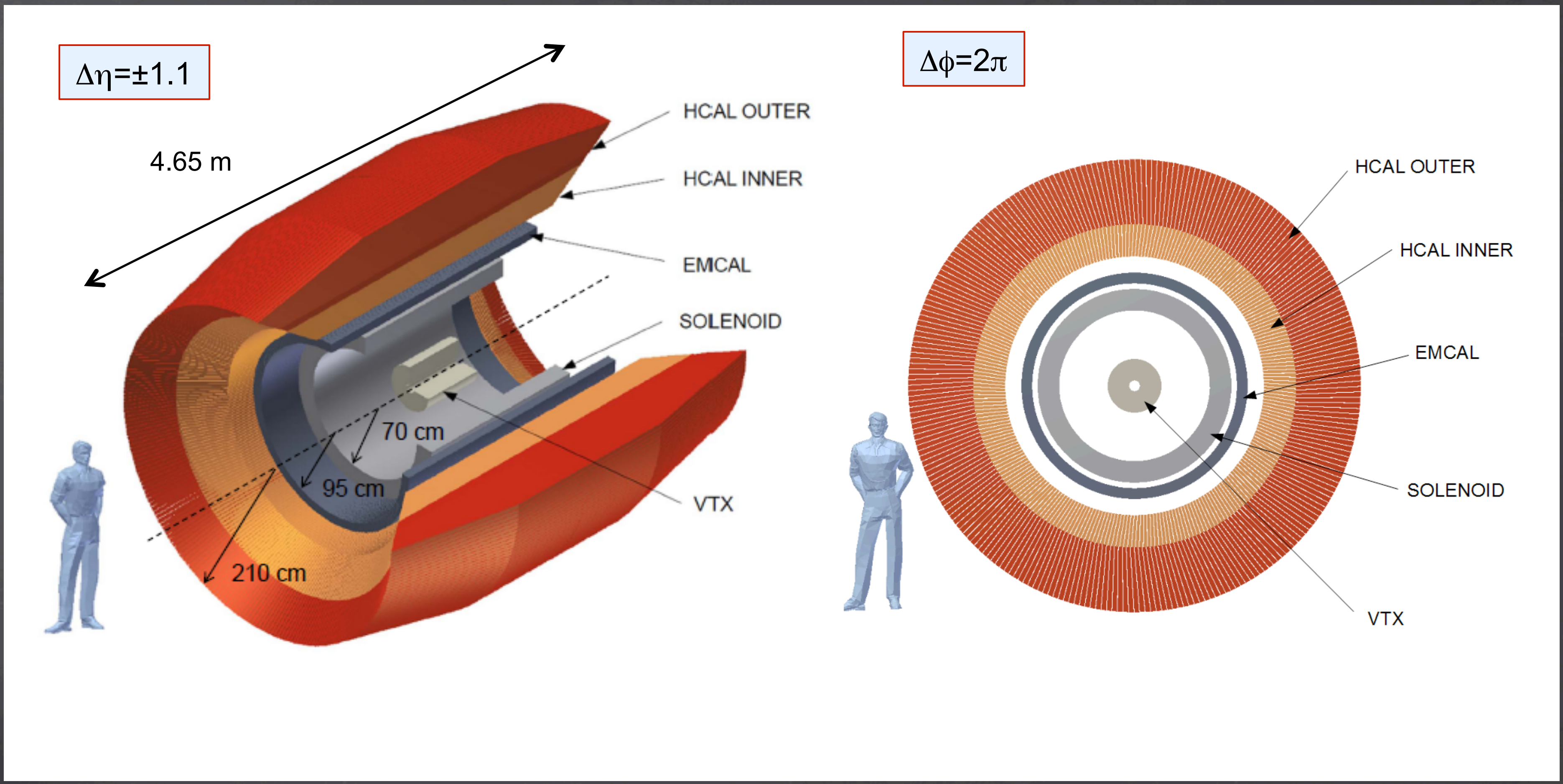


Upgraded PHENIX and STAR detectors operating by 2019
These detectors are also being designed for initial eRHIC operations
New dedicated eRHIC detector ready by 2025

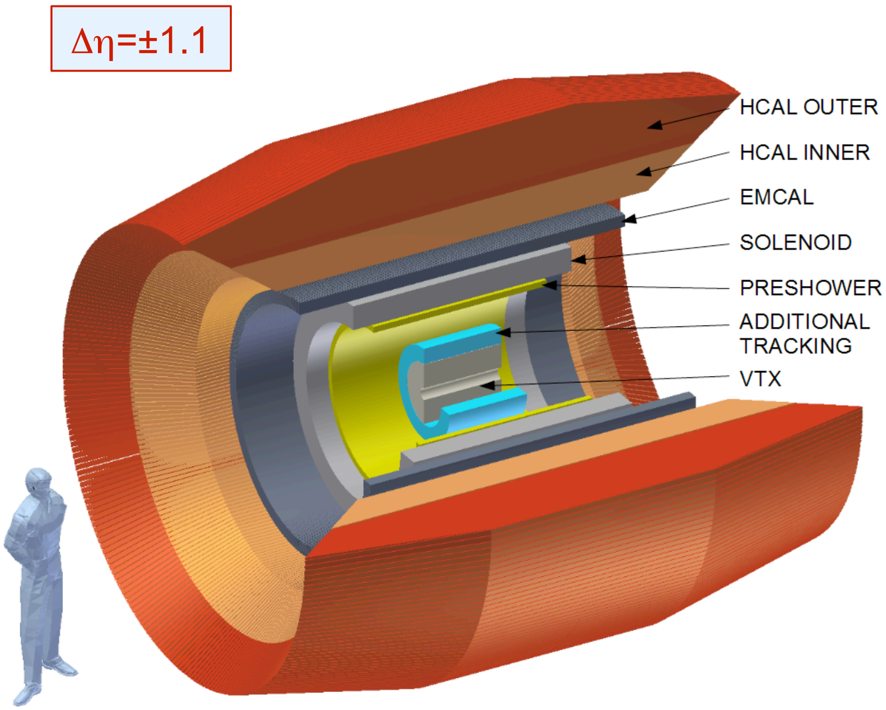
The sPHENIX Experiment

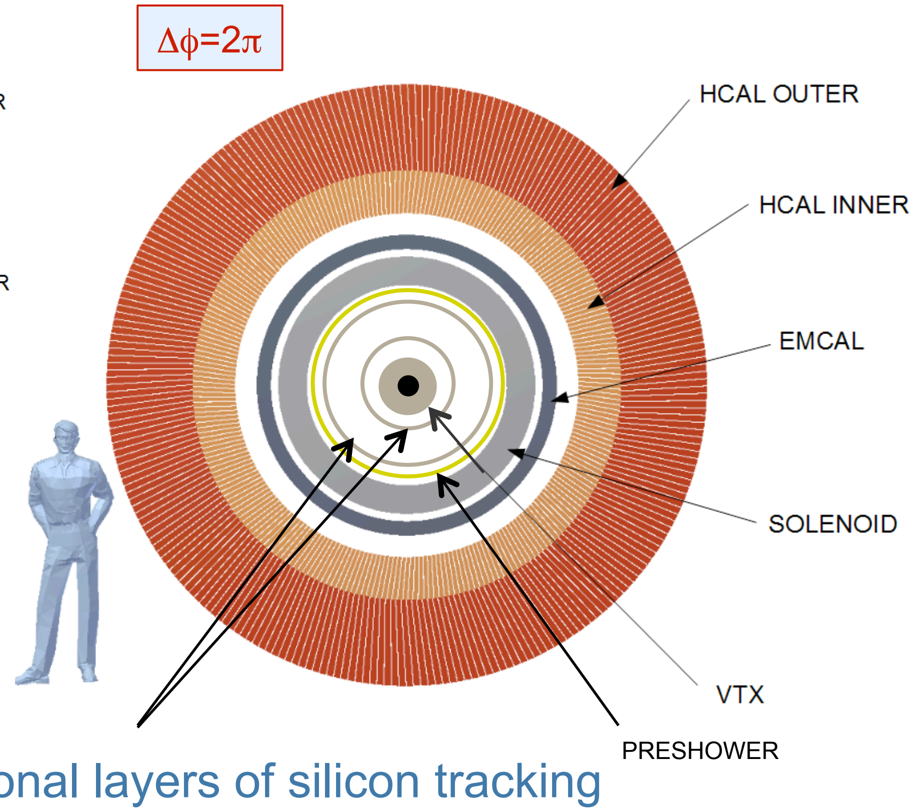
- Major upgrade to the PHENIX Experiment at RHIC
- Primary purpose is to measure jets in heavy ion collisions
  - Measure total energy using calorimetry (including hadron)
  - Good solid angle coverage ($|\eta| < 1$, $\Delta\phi = 2\pi$)
- Provide a basis for expanded physics capabilities in the future
  - Forward spectrometer
    - Study Cold Nuclear Matter and Spin Physics (ΔG) using polarized pp and dA collisions
  - eRHIC (Electron Ion Collider)
    - Study nucleon structure and QCD in nuclei over a broad range of x and Q^2 using deep inelastic polarized ep and eA collisions
- Driving force behind the design – Low Cost
  - ~ $30M from DOE
  - Additional funds from other funding sources


PHENIX
HCAL Outer
HCAL Inner
EMCAL
Solenoid
VTX


sPHENIX
Δη=±1.1
4.65 m
HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
VTX
70 cm
95 cm
210 cm
Δϕ=2π
HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
VTX

sPHENIX


Δη=±1.1
HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
PRESHOWER
ADDITIONAL TRACKING
VTX


Δφ=2π
HCAL OUTER
HCAL INNER
EMCAL
SOLENOID
VTX
PRESHOWER
Two additional layers of silicon tracking

Detector Requirements

- Large solid angle coverage (± 1.1 in η, 2π in ϕ)
- Moderate energy resolution
  - EMCAL ~ 15%/$\sqrt{E}$
  - HCAL ~ 75 %/$\sqrt{E}$ (single particle), ~100 %/$\sqrt{E}$ (jet)
- Compact (for EMCAL ⇒ small R_M, short X_0)
  - Physically small (dense) – occupies minimal space
  - High segmentation for heavy ion collisions
- Hermetic
- Projective (approximately)
- Readout works in a magnetic field
- Low cost

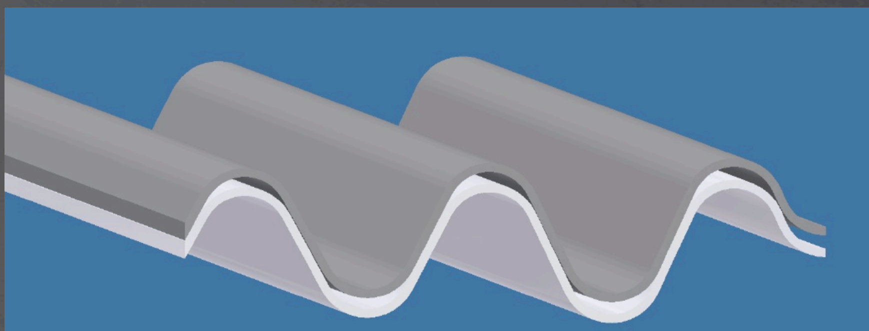
Technology Choices:

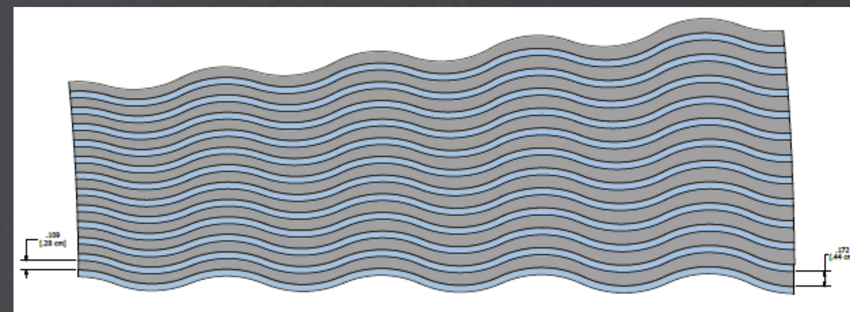
- EMCAL → Tungsten Scintillating Fiber
- HCAL → Iron Scintillating Tile with WLS Fiber
- Readout → SiPMs

EMCAL - Optical Accordion

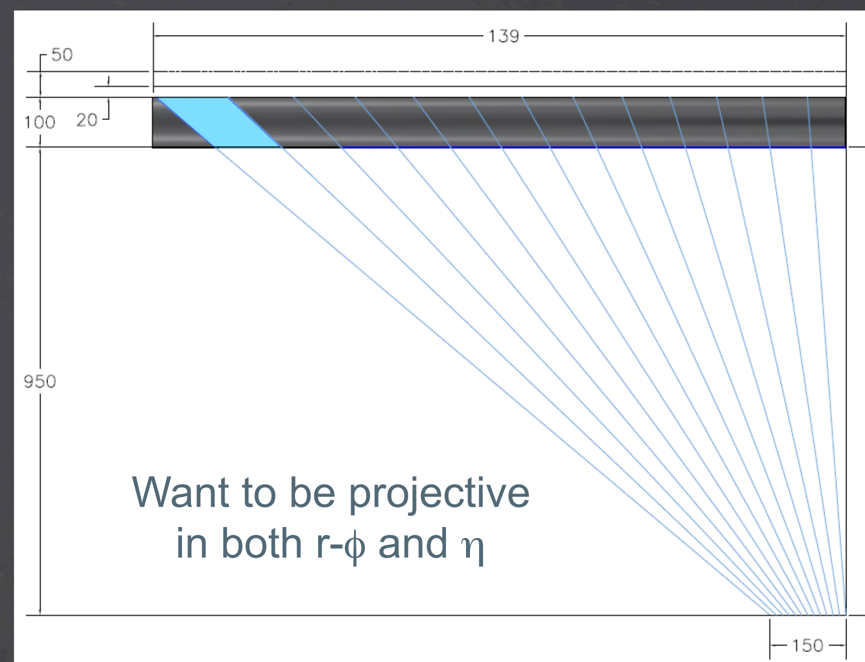
Accordion design similar to ATLAS Liquid Argon Calorimeter

Layered accordion of tungsten plates and scintillating fibers



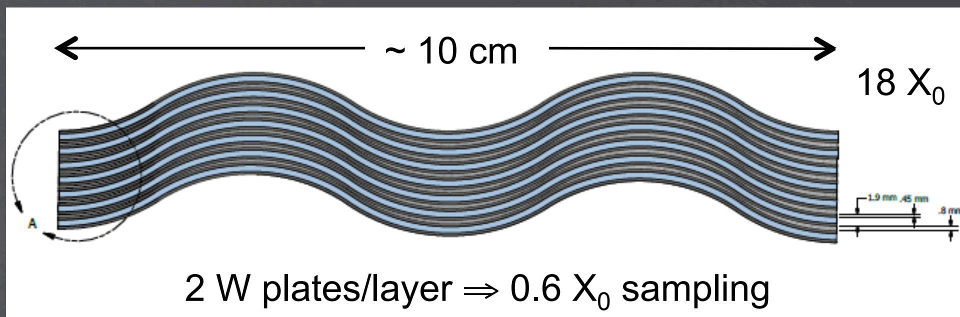


- Undulations produce gaps between scintillator and absorber
- Volume increases with radius
- Scintillator thickness doesn't increase with radius, so either tungsten thickness must increase or the amplitude of the oscillation must increase, or both



Tungsten-SciFi Epoxy Sandwich

Uniform thickness, thin pure tungsten metal sheets with wedge shaped SciFi + tungsten powder epoxy layer in between

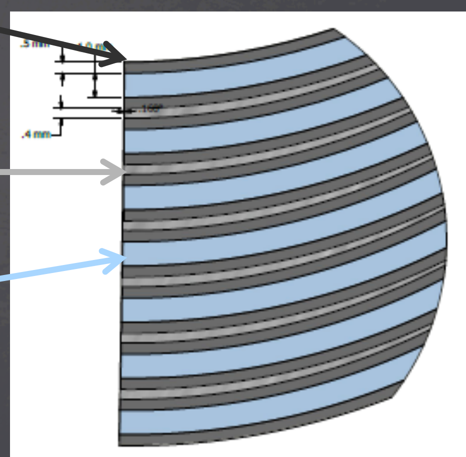


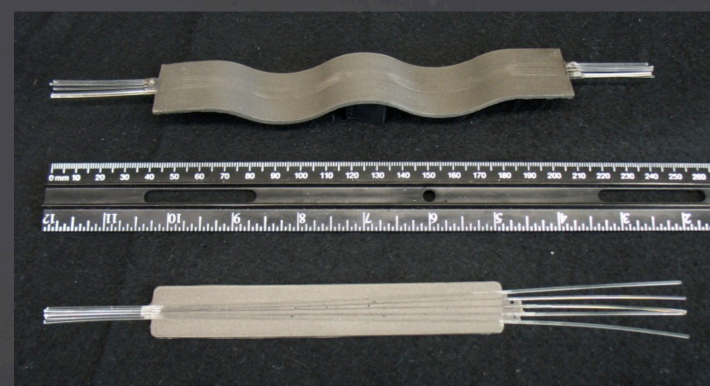
Pure tungsten metal sheet ($\rho \sim 19.3$ g/cm^3)
Thickness: 2x1.0 mm

Tungsten powder epoxy
($\rho \sim 10$-11 g/cm^3)
0.08-0.2 mm

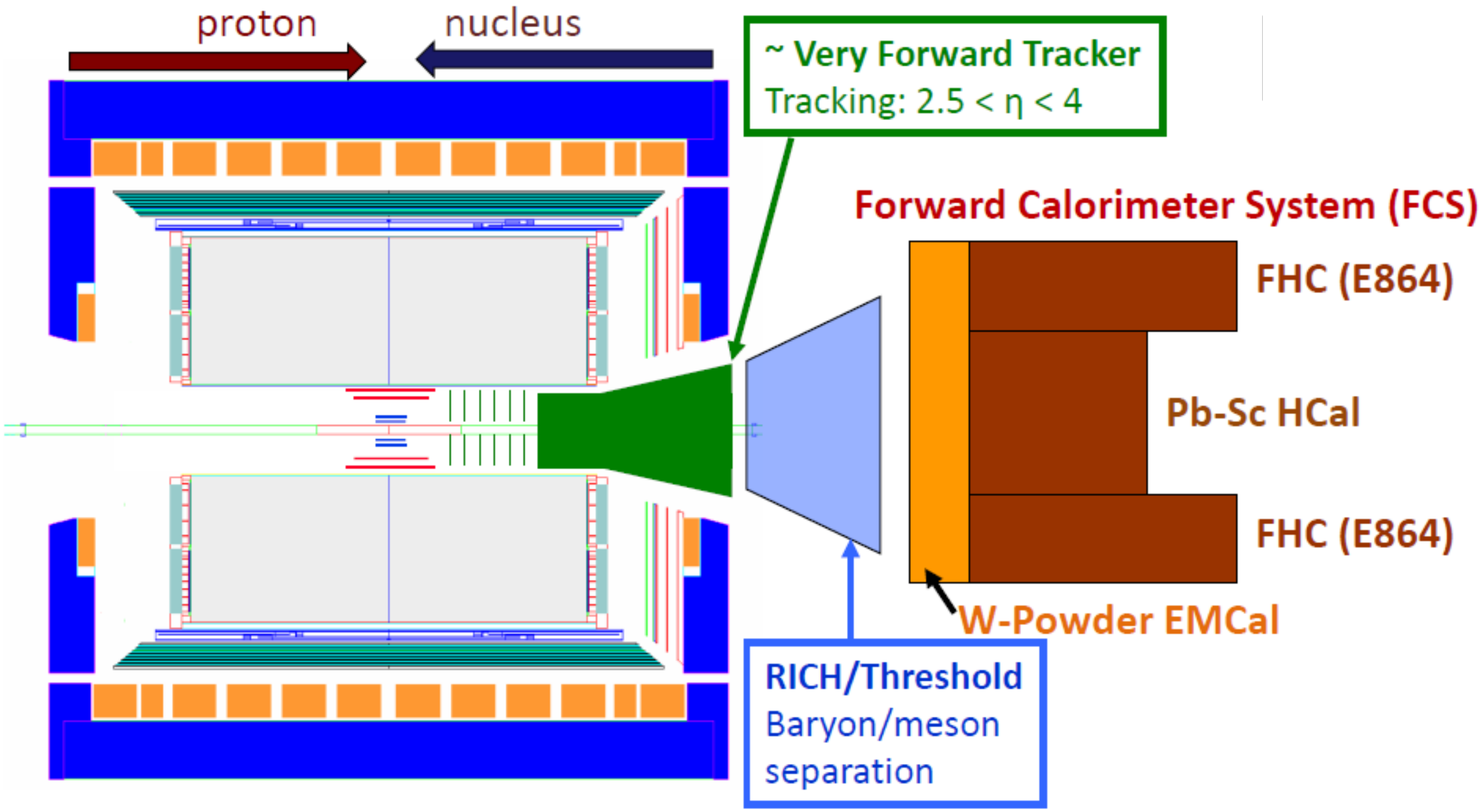
Scintillating fibers
1.0 mm

X_0 = 5.3 mm
R_M = 15.4 mm





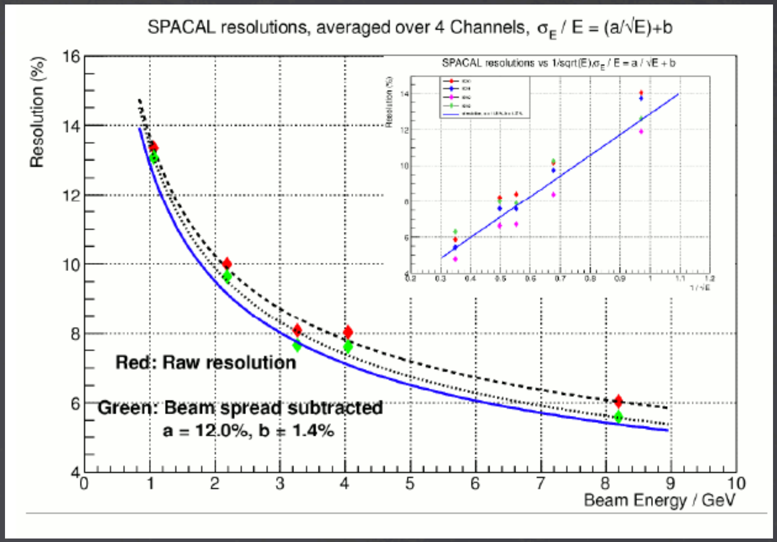
STAR Forward Instrumentation upgrade



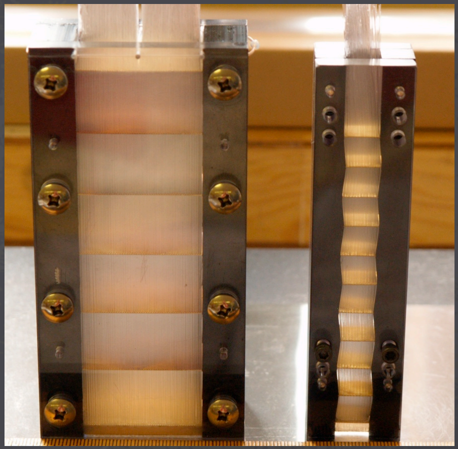
- Forward instrumentation optimized for **p+A** and **transverse spin** physics
  - Charged-particle tracking
  - *e*/*h* and γ/π^0 discrimination
  - Possibly Baryon/meson separation

Tungsten SPACAL

Tungsten Powder/Epoxy/SciFi



Inexpensive, easy to assemble



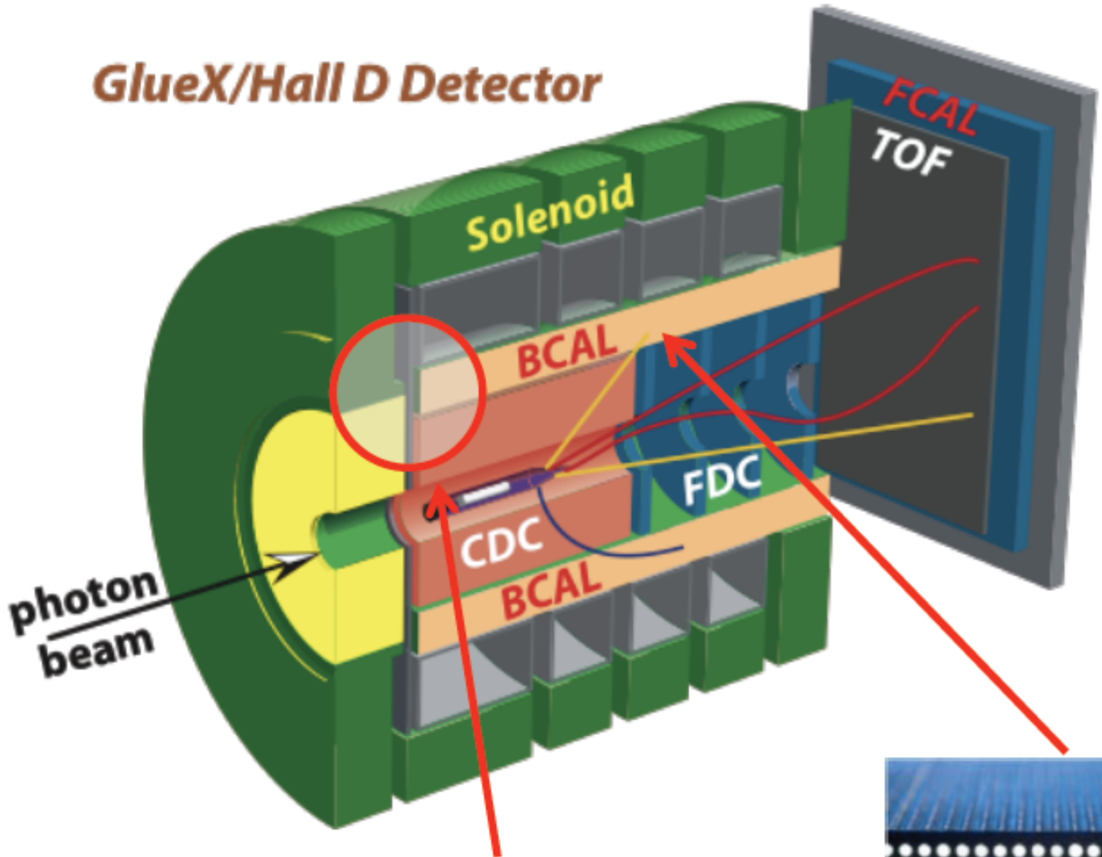
Results from beam test at Fermilab (Jan 2012)

$\sigma_E/E = 12\%/\sqrt{E} + 1.4\%$

$\rho \sim 10.2\ g/cm^3$
$X_0 \sim 7$ mm
$R_M \sim 2.3$ cm

O.Tsai, CALOR 2012

GlueX Experiment at JLAB



BCAL - barrel calorimeter
FCAL - forward calorimeter

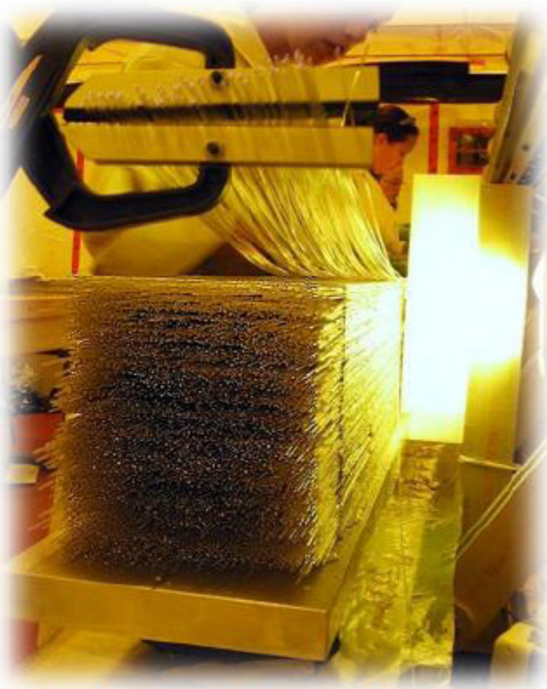
CDC - central drift chamber
FDC - forward drift chambers

TOF - time-of-flight

2.2 Tesla

SciFi•Lead
Calorimeter
4 meter length
48 sectors

GlueX Barrel Calorimeter

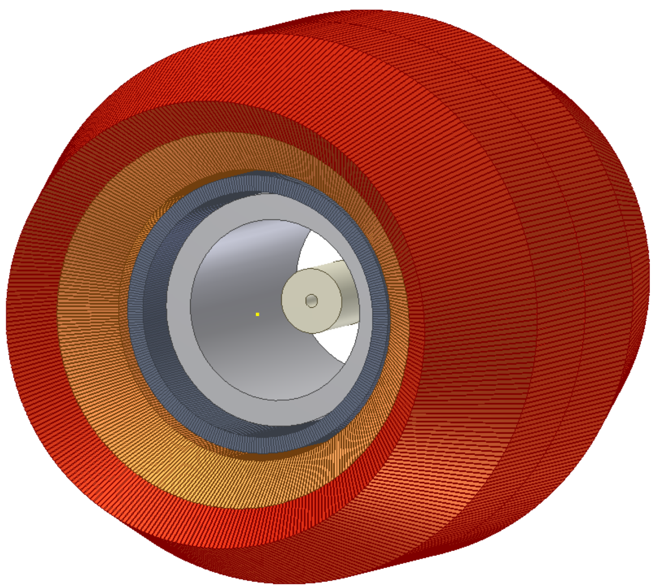


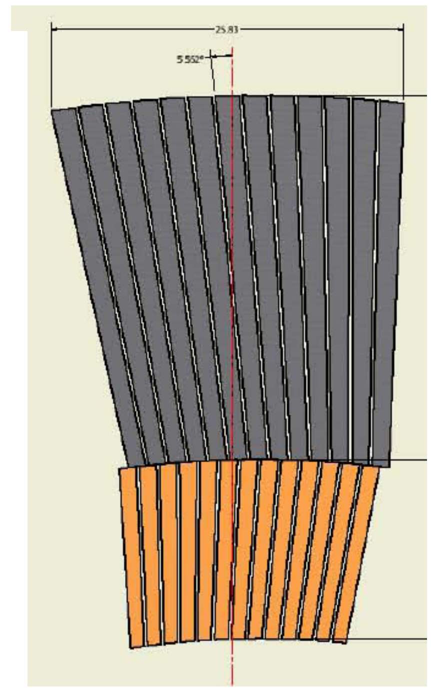
BCAL module being assembled from layers of fibers and Pb

- 48 modules arranged into cylinder
- Scintillating fiber + Pb   1 mm fibers
- 12.5% sampling fraction
- $\sigma_E/E = \frac{5.5\%}{\sqrt{E}} \oplus 1.6\%$ X_0 = 14.5 mm, R_M ~ 3.8 cm
- $\sigma_z = \frac{5mm}{\sqrt{E}}$
- $\sigma_t = \frac{75ps}{\sqrt{E}} \oplus 33ps$
- 11° < α < 120°
- Double-ended readout (SiPMs)
- 300 km of fiber

Polished BCAL module demonstrating optical clarity with cell phone held to opposite end

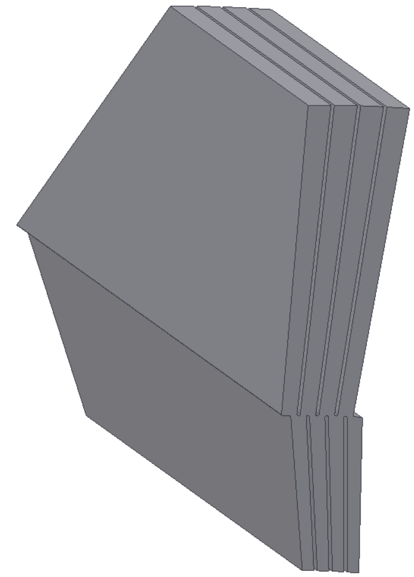
sPHENIX Hadron Calorimeter





60 cm
3.5 λ_{abs}

30 cm
1.5 λ_{abs}

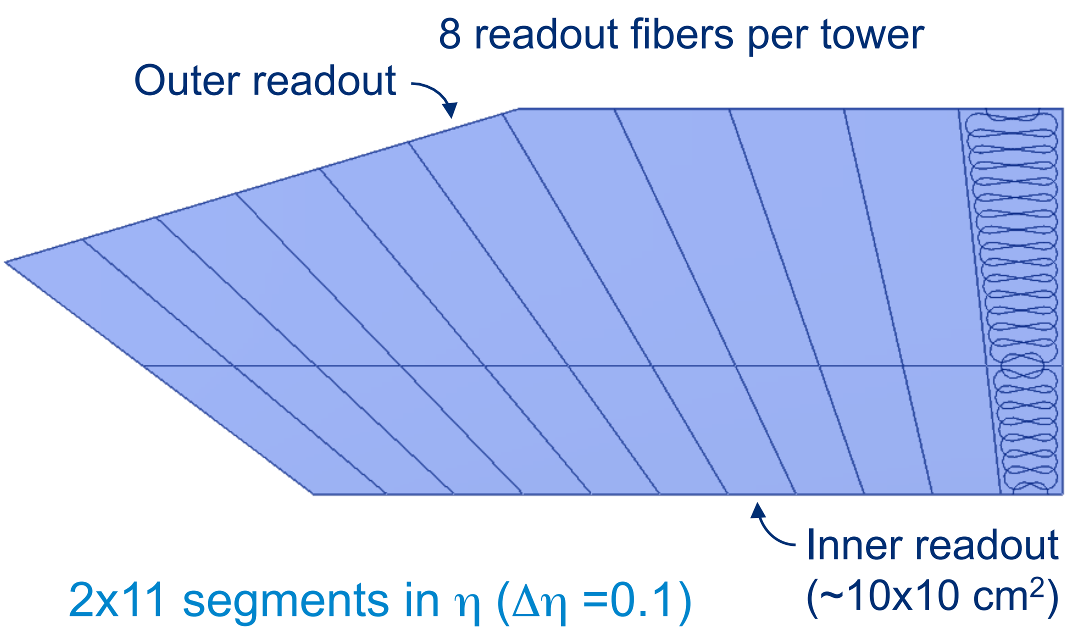


4 inner and 4 outer plates joined together to form one section

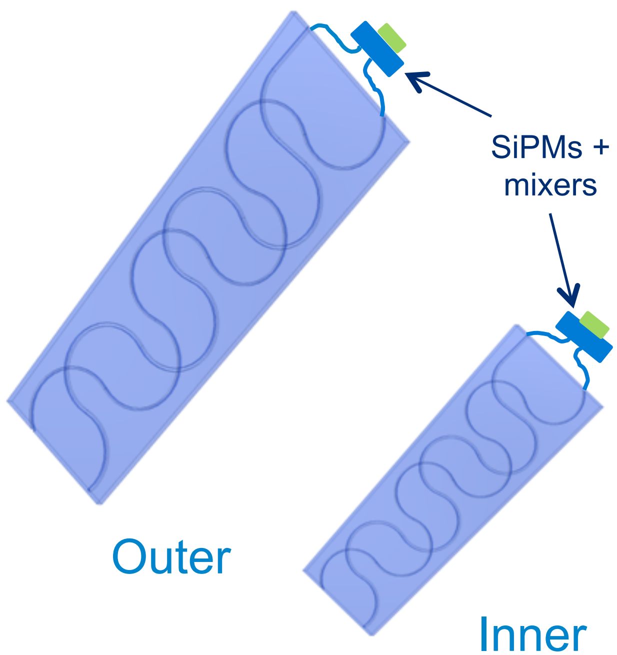
- Steel plates with scintillating tiles parallel to beam direction
- Iron in steel serves as flux return
- Steel plates are tapered
  - ⇒ Sampling fraction changes with depth
- Divided into two longitudinal sections
  - Measure longitudinal center of gravity to correct for longitudinal fluctuations
- Plates tilted in opposite directions to avoid channeling

HCAL Readout

Scintillating tiles with WLS fibers embedded in grooves
Read out with SiPMs (similar to T2K)



2x11 scintillator tile shapes



2x11 segments in η ($\Delta\eta$ =0.1)
64 segments in ϕ ($\Delta\phi$ =0.1)
1408 x 2(inner,outer) = 2816 towers

SiPM Readout

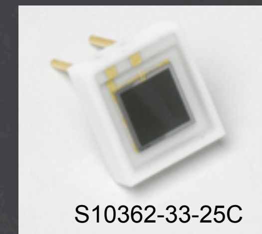
All calorimeters described plan to use SiPMs for their readout

sPHENIX

EMCAL segmentation ~ .024 x .024 (η x ϕ) $\Rightarrow$ ~ 25K channels
HCAL segmentation ~ 0.1 x 0.1 $\Rightarrow$ ~ 3K channels

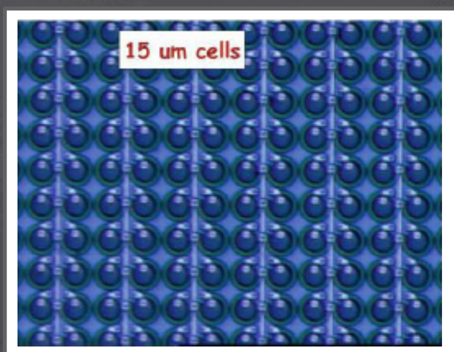
Considering various devices:

- SiPMs: Hamamatsu, AdvanSiD, SensL,…



3x3 mm^2,14.4K pixels (25 μm)
G ~ 2 x 10^5, peak PDE ~ 25% @ 440 nm

New, highly pixellated SiPMs are becoming available



Hamamatsu MPPC-15 μm being developed for CMS

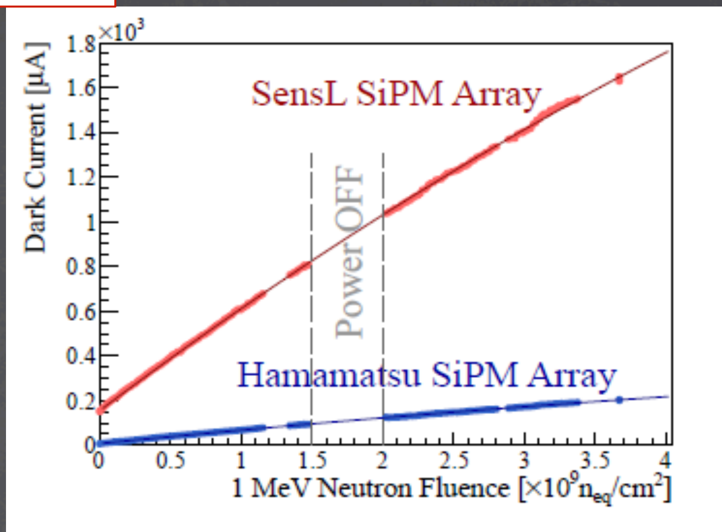
- Requires bias stabilization with temperature compensation and control

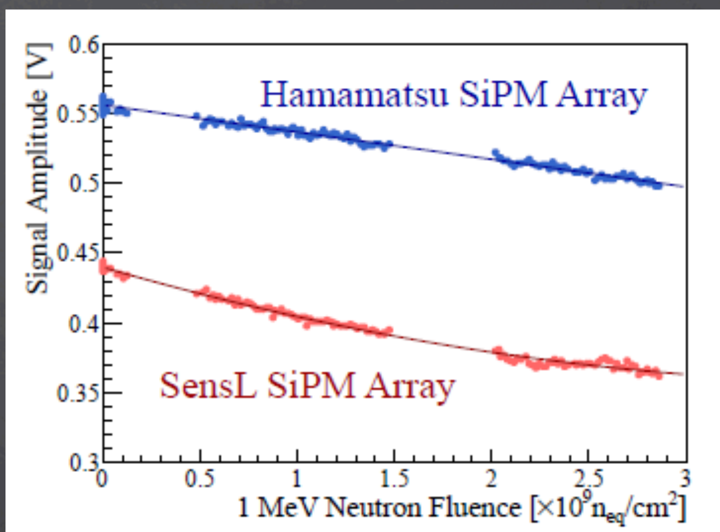
  dV_{br}/dT ~50 mV/°C $\Rightarrow$ dG/dT ~ 10% /°C

- Want dynamic range ~ few x 10^3
- Due to saturation, must tune light levels to stay within correctable linear range.
- Avoid noise at 1 p.e. level

Radiation Damage in SiPMs

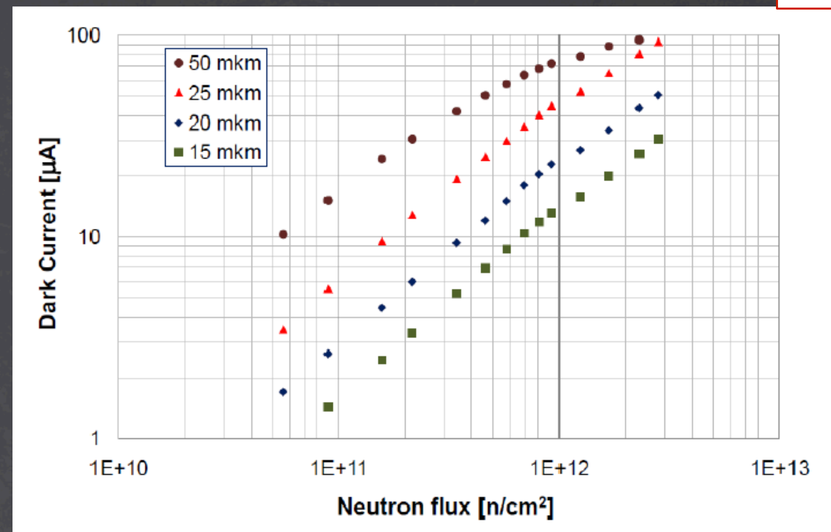
GlueX

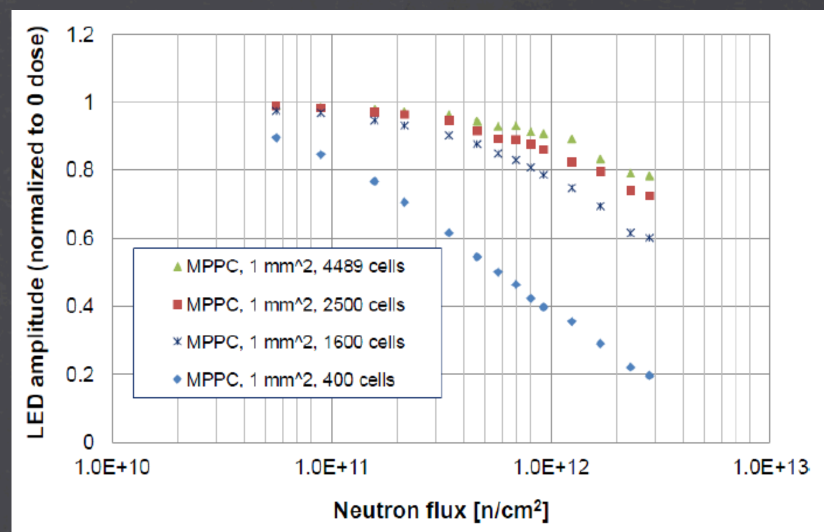




Radiation Hardness Tests of SiPMs for the JLab Hall D Barrel Calorimeter, Yi Qiang et.al., arXiv:1207.3743

CMS

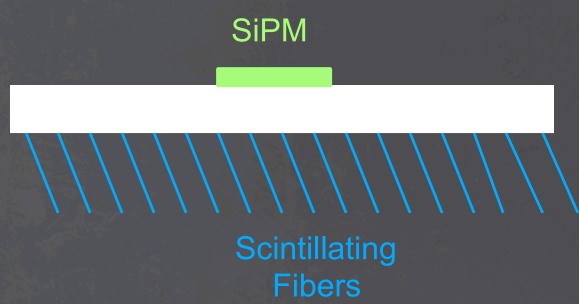


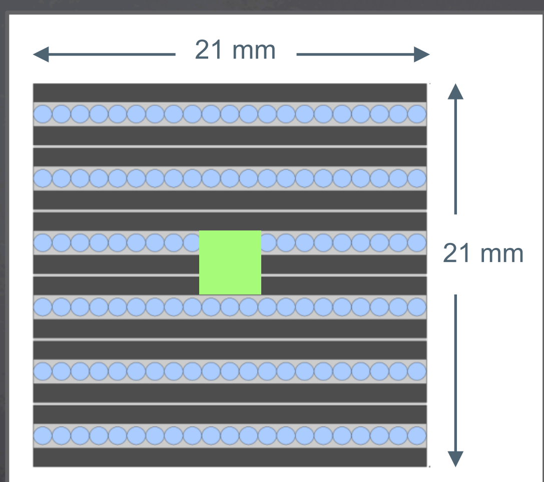


Upgrade of the CMS Calorimeter for an Upgraded LHC, J. Anderson, CALOR12 Proceedings

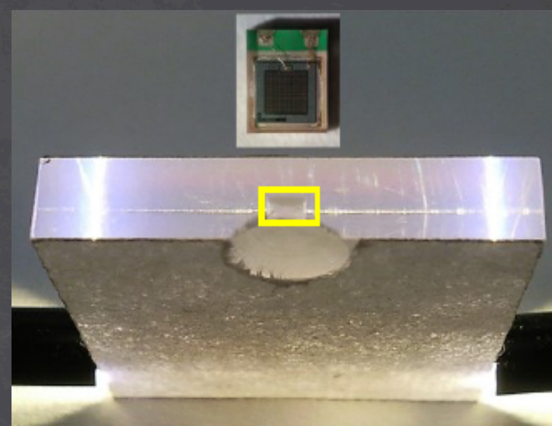
Light Collection and SiPMs

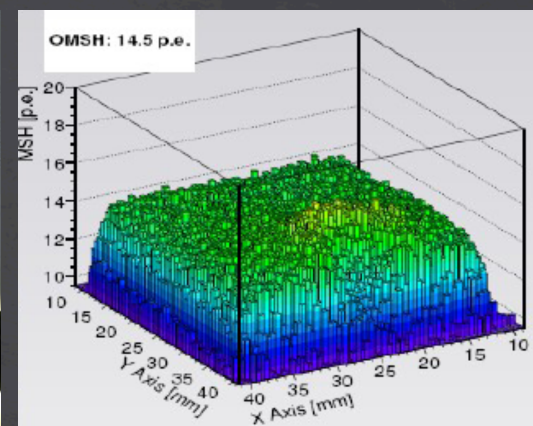
Need to collect and randomize the light from many scintillating fibers onto a small number of small readout devices





In the sPHENIX EMCAL, need to match ~150 1 mm diameter fibers onto a single 3x3 mm^2 SiPM with good efficiency and uniformity (ε_{area} ~ 2%)

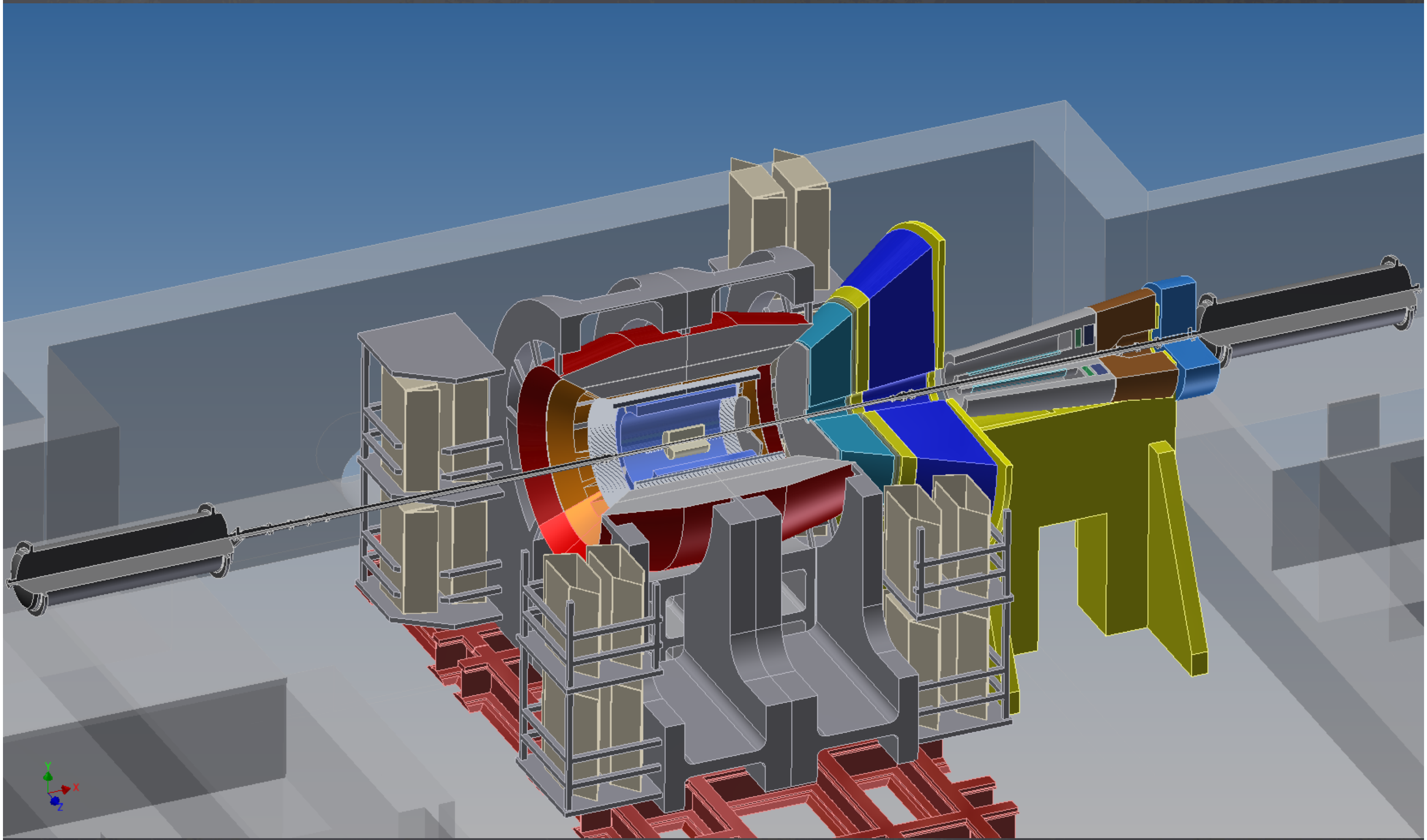




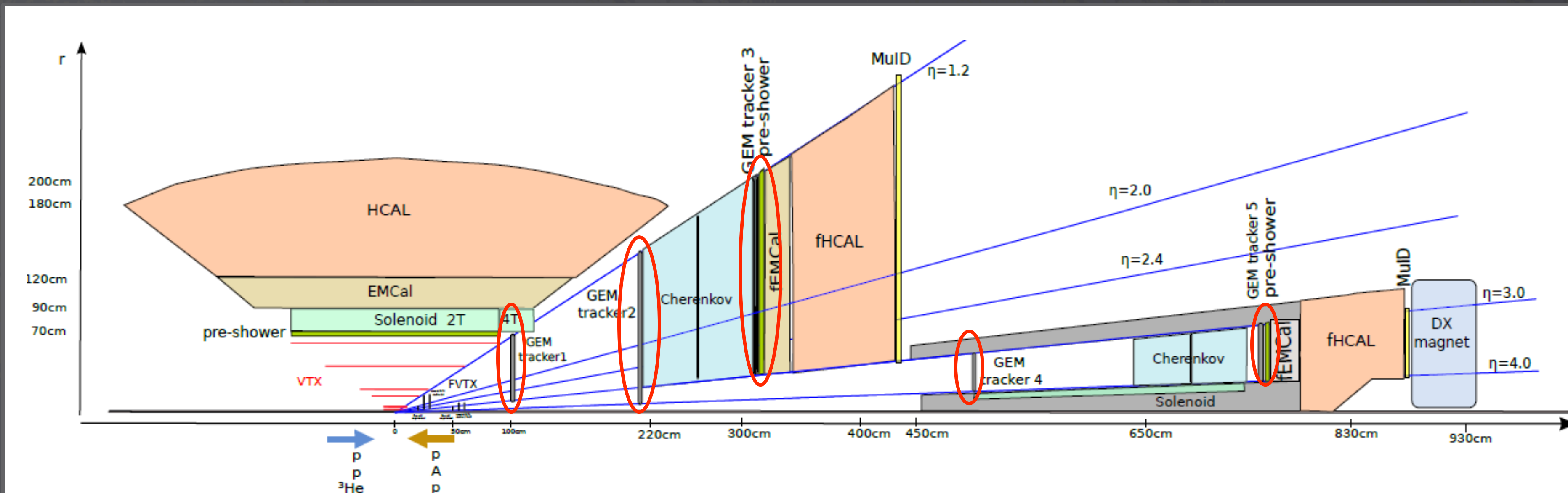
CALICE calorimeter achieved good uniformity and efficiency with direct coupling to scintillator

F.Simon and C.Soldner, NIM A620 (2010) 196-201

The fsPHENIX Detector

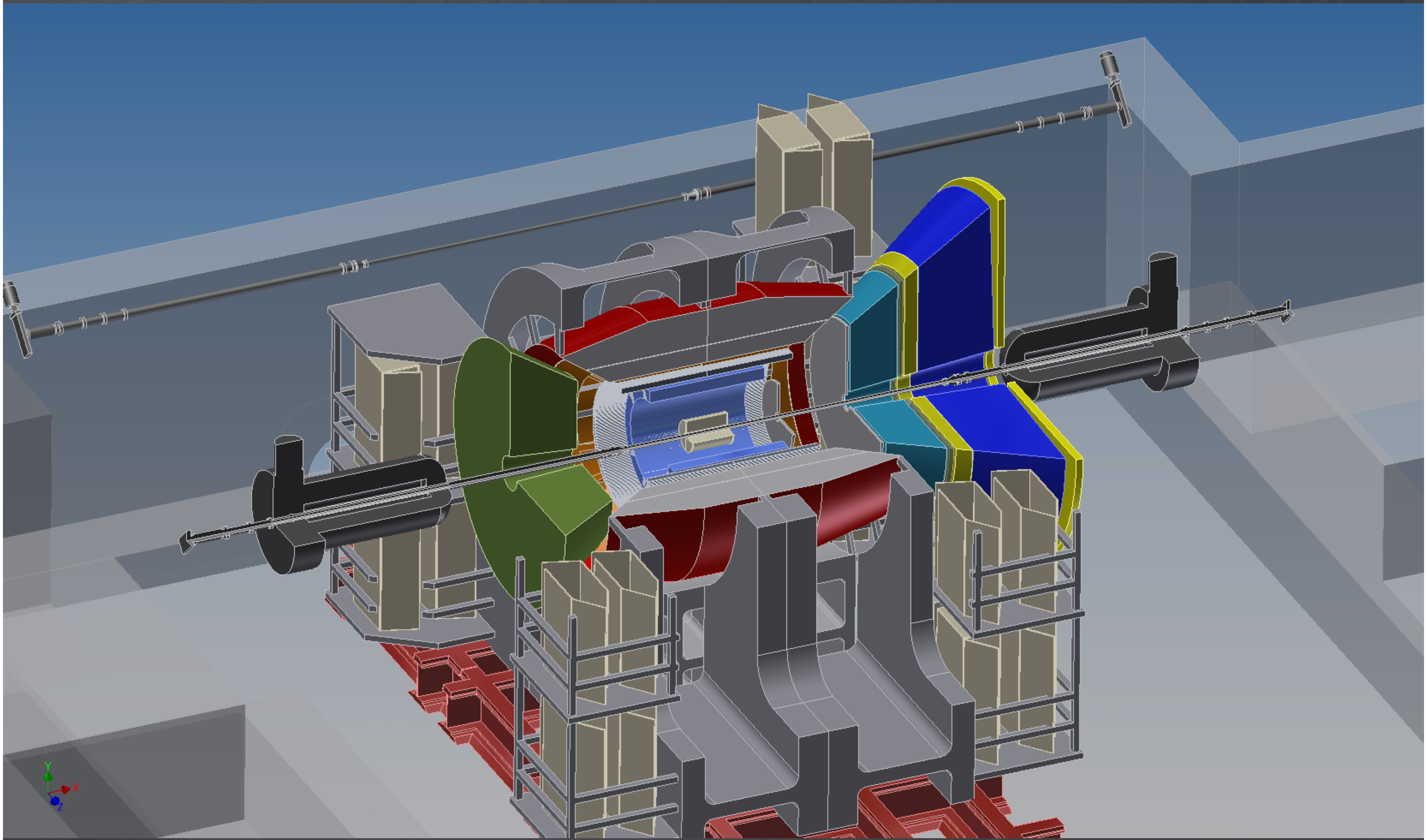


Forward PHENIX

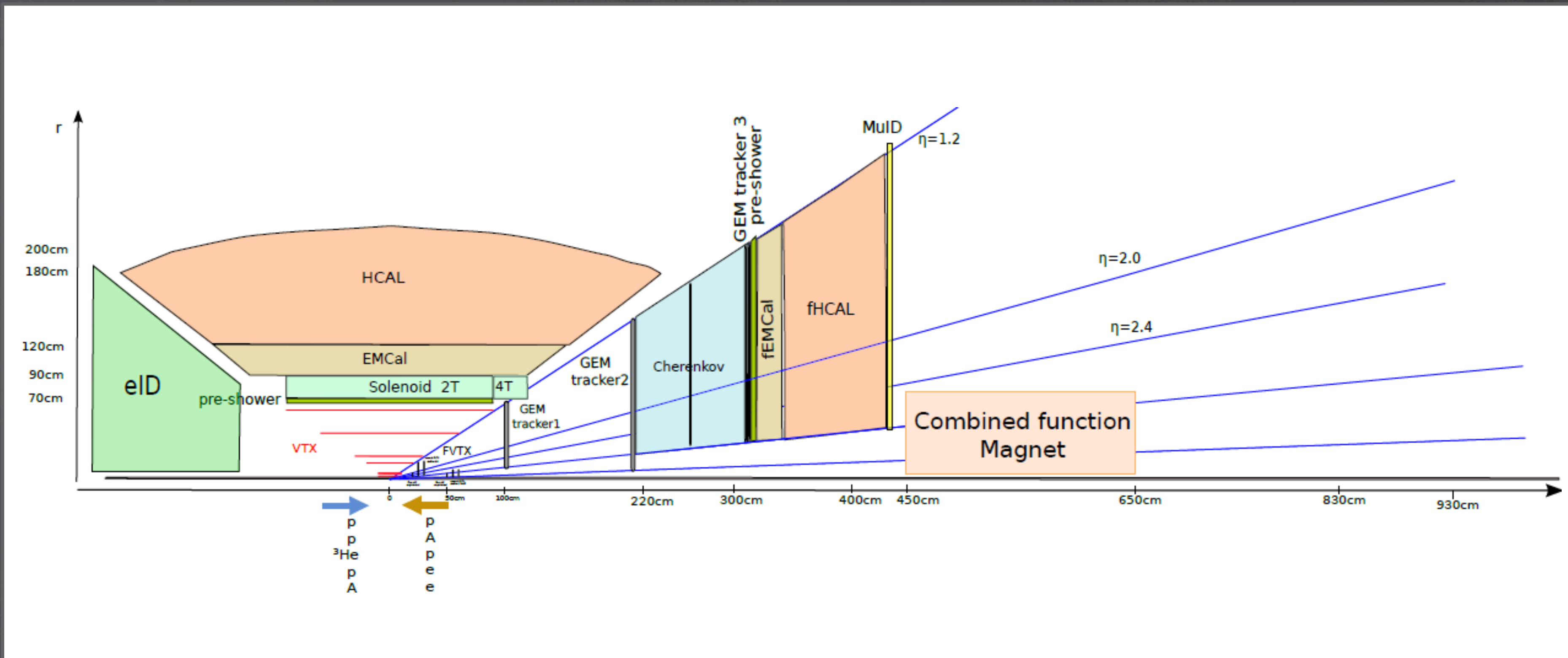


- Designed to study Cold Nuclear Matter and Spin Physics
- New forward magnet for better momentum resolution in the forward direction
- Mid rapidity calorimeter might be a re-stacking of current PHENIX EMCAL modules
- Forward rapidity calorimeters would be new
- GEM tracking detectors

The ePHENIX Detector



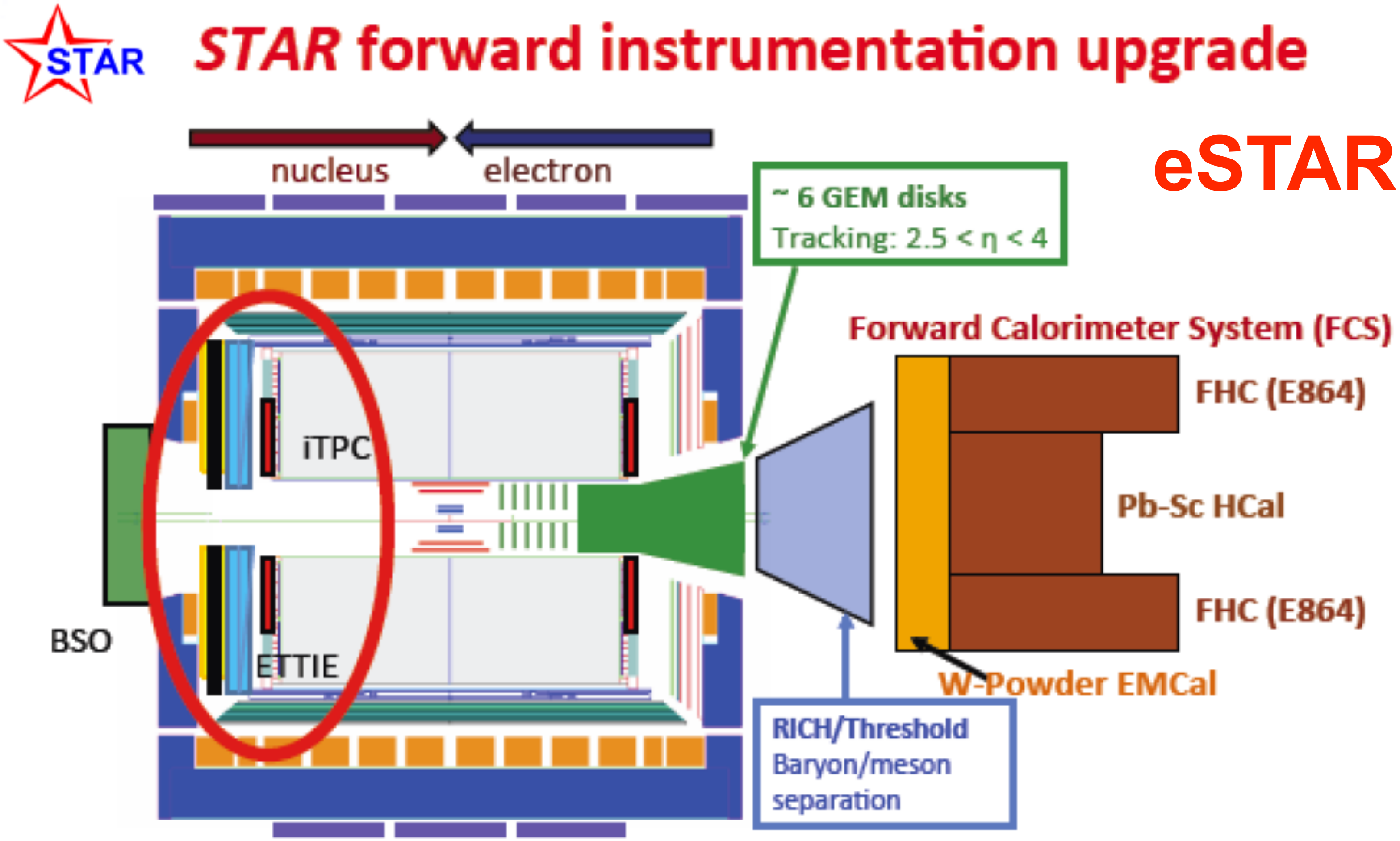
e sPHENIX



- Similar detector configuration to fsPHENIX, but forward spectrometer must be removed to make room for one of the eRHIC magnets
- New backward rapidity spectrometer added for electron id

STAR forward instrumentation upgrade

eSTAR

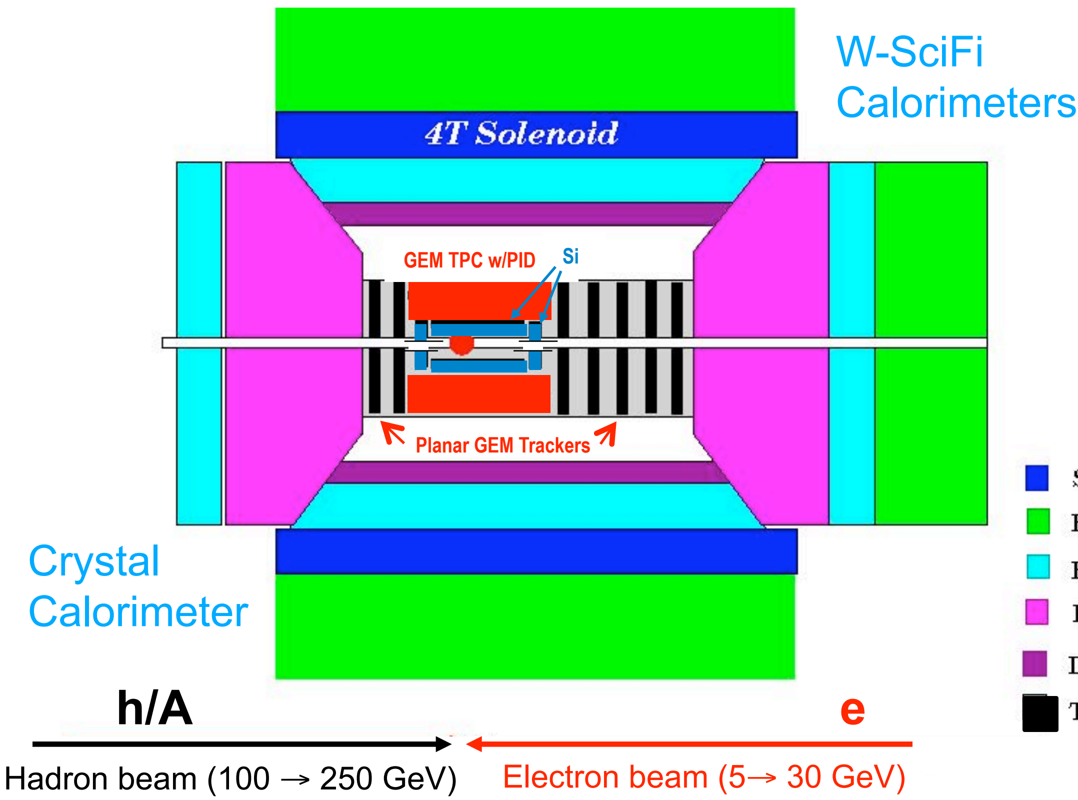


eSTAR specific upgrades:
EToF: e, π, K identification,
ETRD: electron ID and hadron tracking
BSO: 5 GeV, 10 GeV, ...
electron beams
Re-instrument HFT

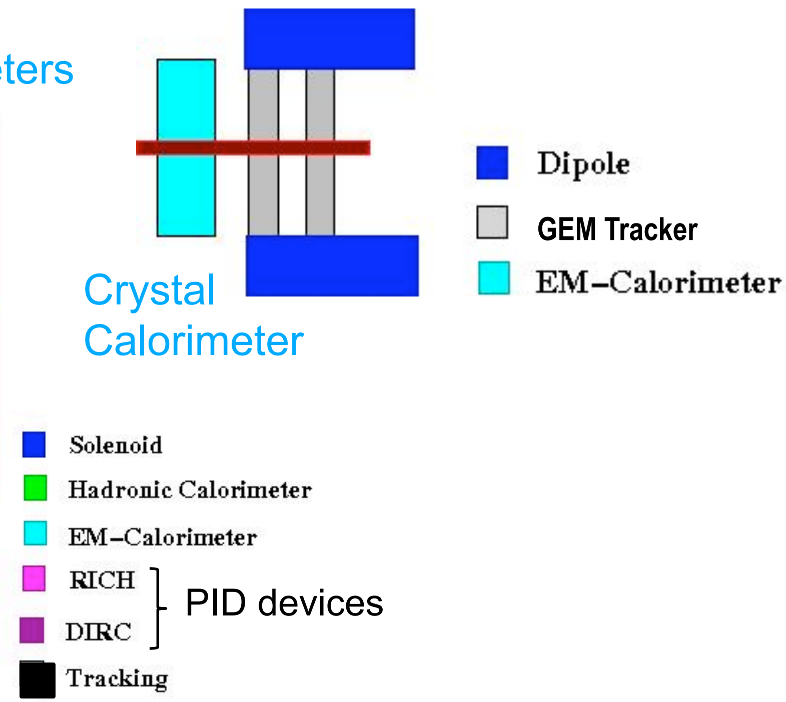
- **Forward instrumentation optimized for p+A and transverse spin physics**
  - Charged-particle tracking
  - e/h and γ/π^0 discrimination
  - Baryon/meson separation

EIC Detector – Conceptual Design

Central Detector



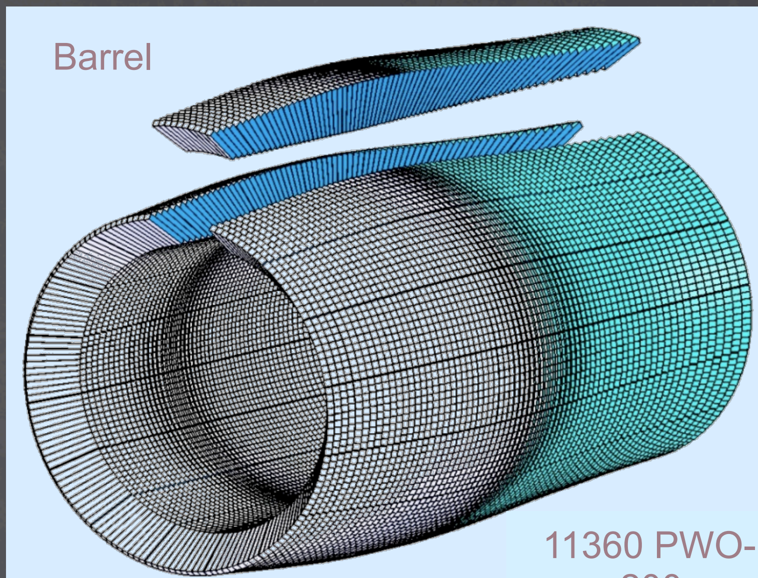
Forward/Backward Detectors



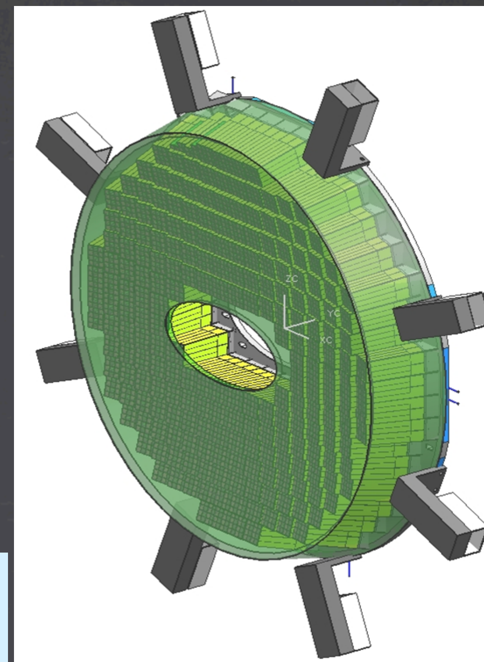
- Large acceptance: $-5 < \eta < 5$
- Asymmetric
- Nearly 4π tracking and EMCAL coverage
- HCAL coverage in central region and hadron direction
- Good PID
- Vertex resolution (< 5 μm)

- Electron is scatted over large range of angles (up to 165˚)
- Low $Q^2 \Rightarrow$ low momentum electrons (~ few GeV) for $\eta < 0$
- Tradeoff between calorimeter resolution and tracking resolution for $|\eta| < 1$

PWO Crystal Calorimeter for PANDA



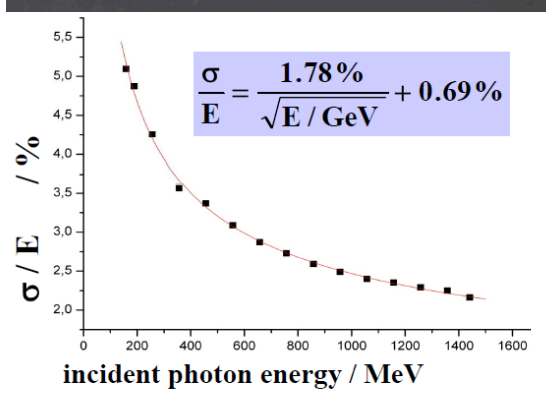
11360 PWO-II crystals
200 mm long



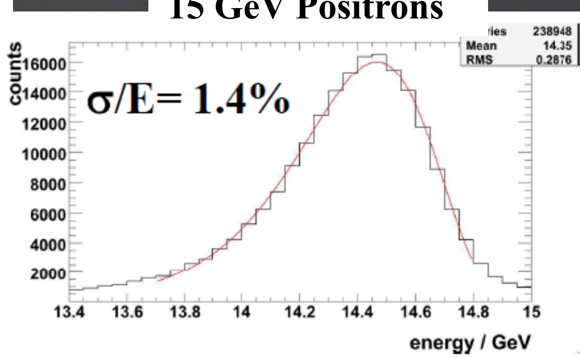
Endcap
3864 crystals

- physical goals of PANDA require further development

	PWO-I (CMS)	PWO-II (PANDA)
luminescence maximum, nm	420	420
La, Y concentration level, ppm	100	40
expected energy range of EMC	150MeV - 1TeV	10MeV - 10GeV
light yield, phe/MeV at room temperature	8-12	17-22
EMC operating temperature, °C	+18	-25
energy resolution of EMC at 1GeV, %	3,4	2,0



15 GeV Positrons



R. Novotny, CALOR12

Areas in calorimetry development where NP and HEP could collaborate

- Dense, compact EM calorimetry (tungsten/SciFi)
- New techniques for compensating hadronic calorimeters
- New crystal calorimeters and their applications
- Development of new light collection schemes for fiber calorimeters
- Development of new and improved SiPMs (particularly extending their dynamic range and improving their PDE and radiation hardness)
- Development of new readout systems for large numbers of SiPMs, including temperature stabilization, compensation and calibration