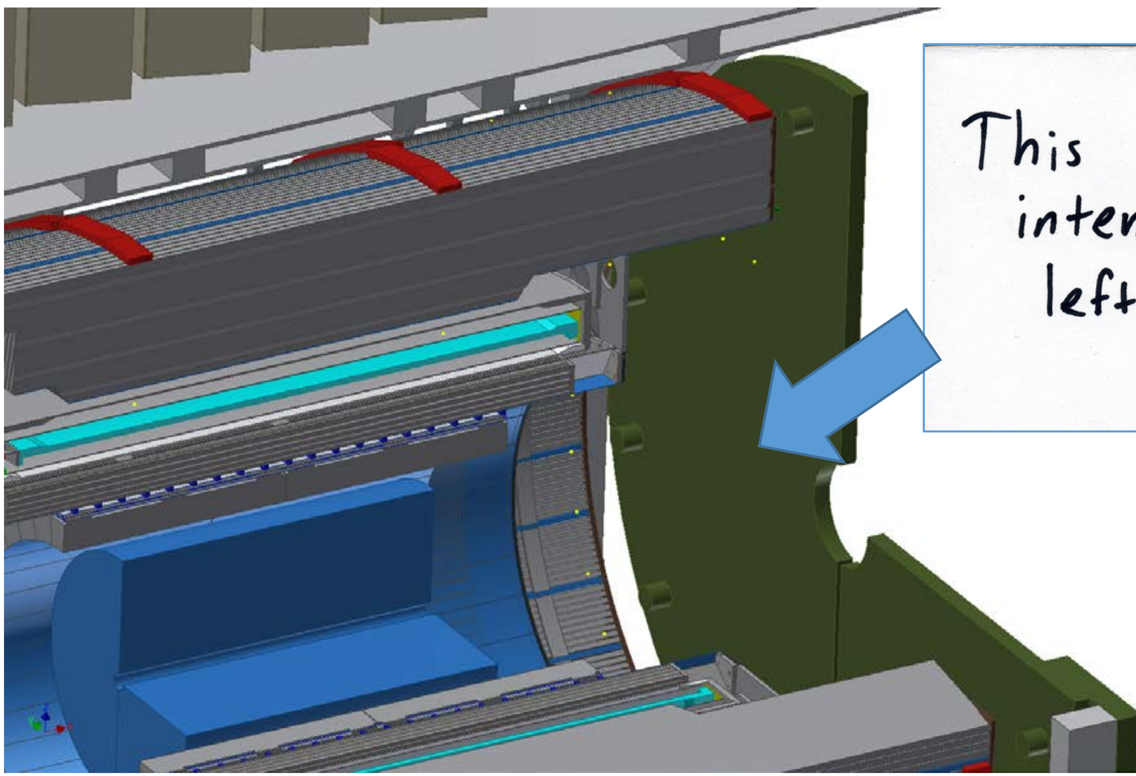
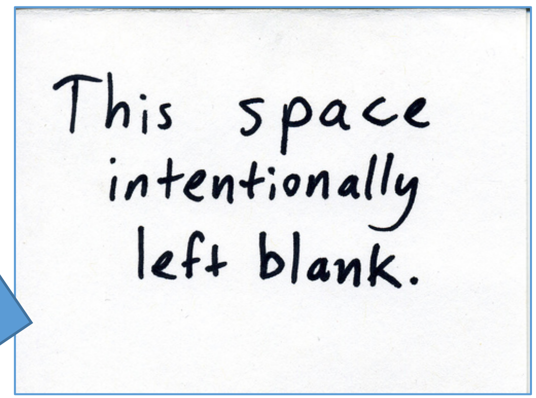
# Physics Opportunities with Forward Instrumentation (in sPHENIX )






*J. Lajoie*

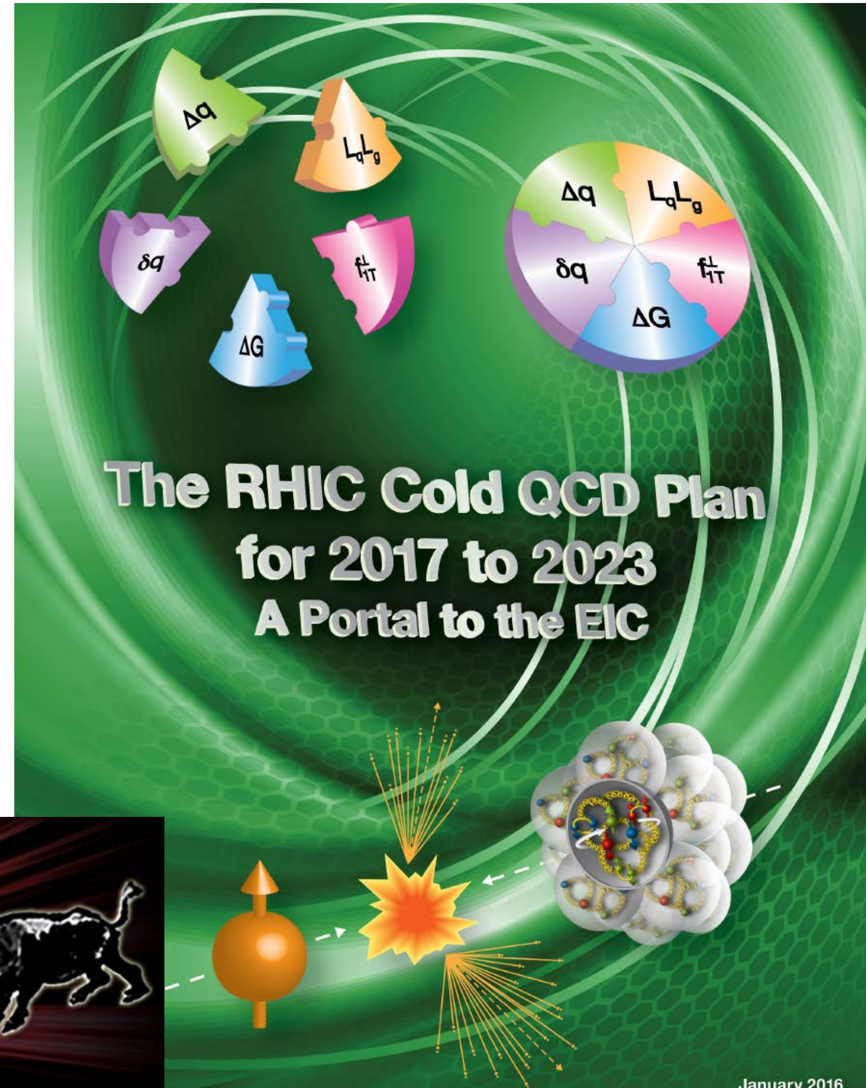
Iowa State University

# Outline

- The RHIC Cold QCD Plan
  - Physics opportunities in spin and CNM
- sPHENIX and the fsPHENIX concept
- Forward Physics with STAR
- Conclusions

# RHIC Cold QCD Plan

- Requested by DOE, submitted Feb 2016
  - Subject of RBRC workshop
- Lays out a comprehensive set of important measurements to be made on the road to an EIC





http://arxiv.org/abs/1602.03922

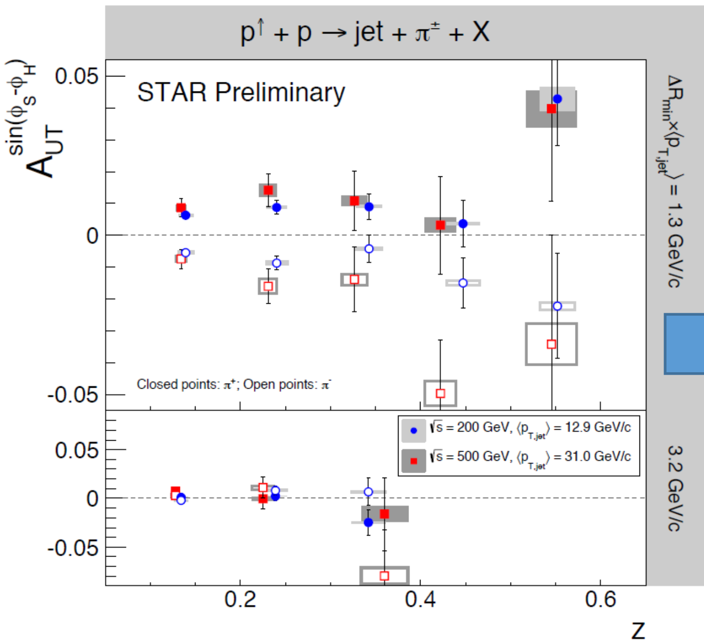
# Physics Goals From Cold QCD Plan

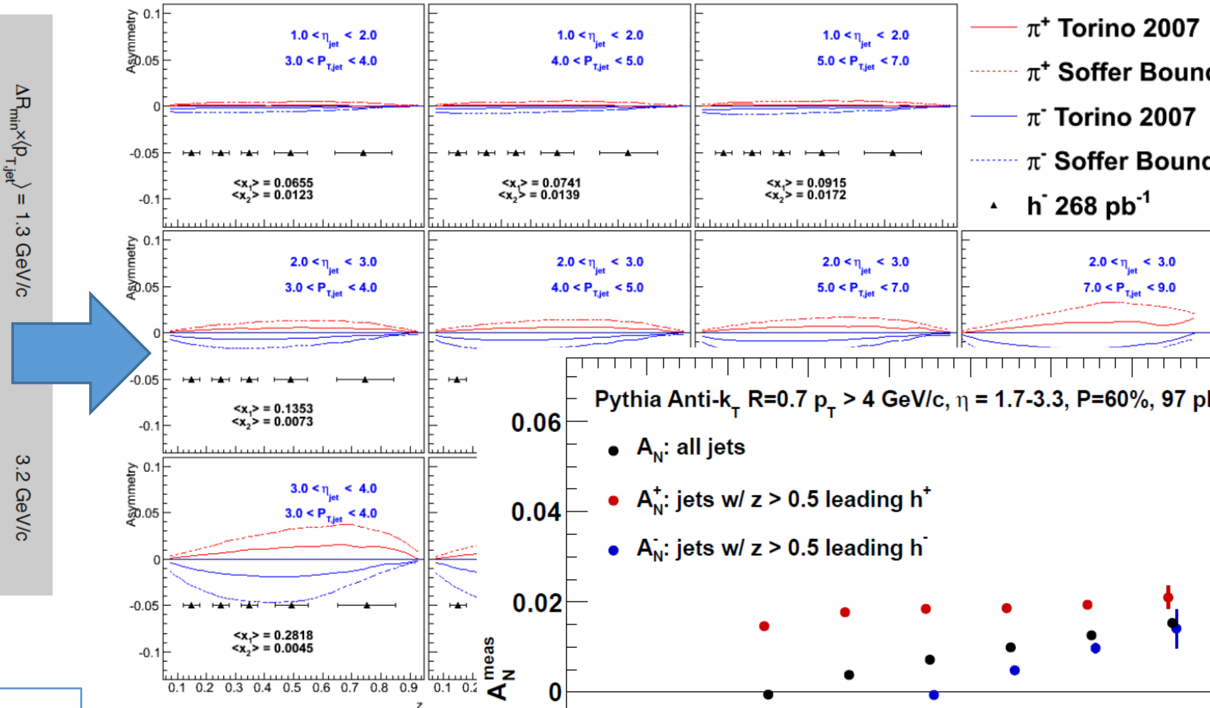
- **Key Physics Measurements**:
  - **Jets in polarized p+p (510 GeV):**
    - Kinematics limited in p+p 200 (transverse), better kinematic reach at 510 GeV
    - Jet $A_N$, Collins in jets ($h^-$ good proxy for $\pi^-$ if PID not an option)

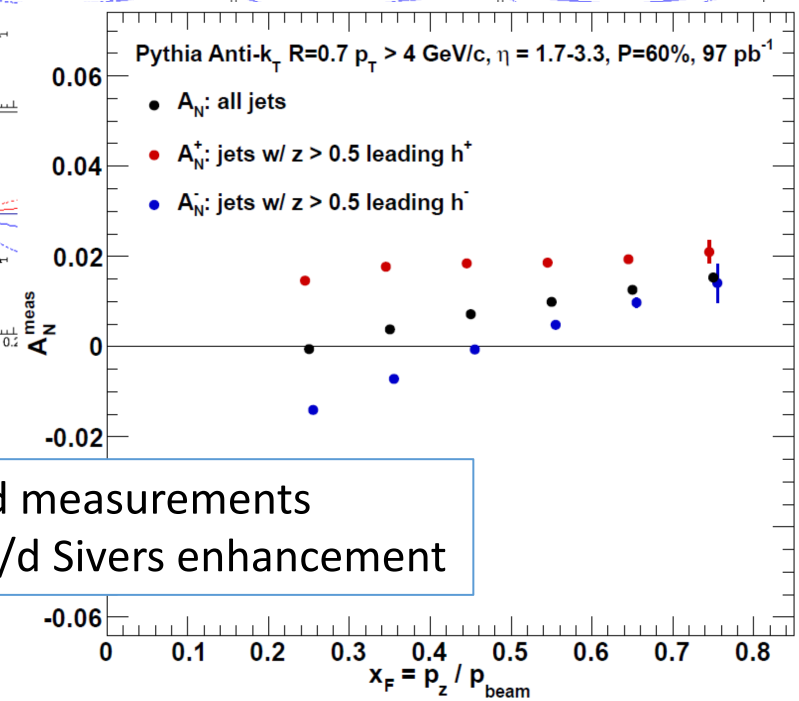
**For many of these measurements RHIC offers *unique* capabilities**

  - **DY and Direct Photons in p+A:**
    - Measurements of saturation, A-scan required
  - **Diffraction in polarized p+p (200 GeV):**
    - $A_{UT}$ from single-diffractive events (pol. proton breaks up).
  - **Ultraperipheral Collisions in p+Au:**
    - p-shine (unpolarized): gluon impact parameter distribution via $J/\Psi$
    - Au-shine (polarized): access GPD $E_g$ via $J/\Psi$ production ($A_{UT}$)
      - set the scale for a program to measure GPD $E_g$ at the EIC

# Jets and Polarized Jet Structure



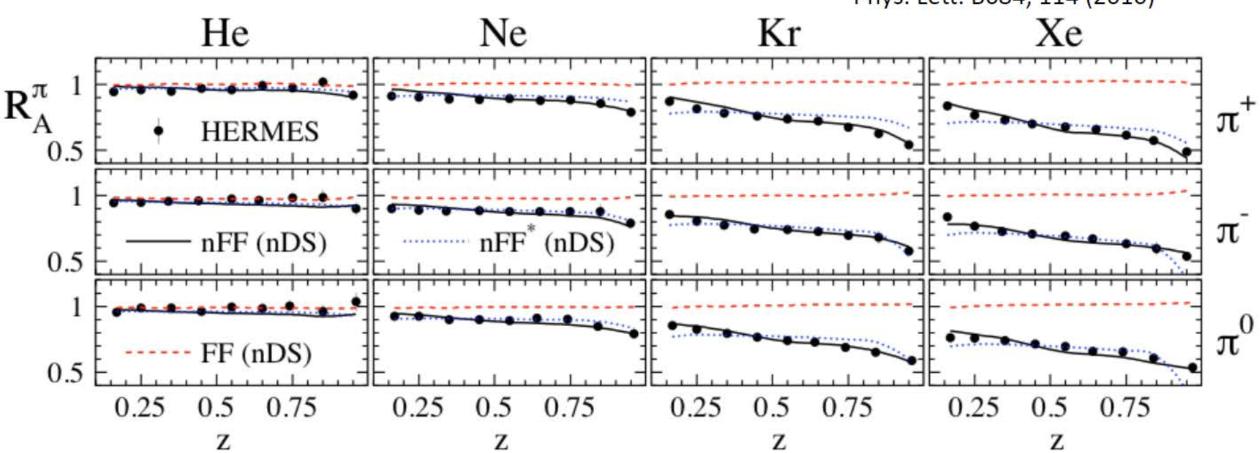




Future high luminosity measurements will allow detailed differential study of spin-dependent fragmentation

Charge-tagged measurements would allow u/d Sivers enhancement

# Nuclear Fragmentation Functions

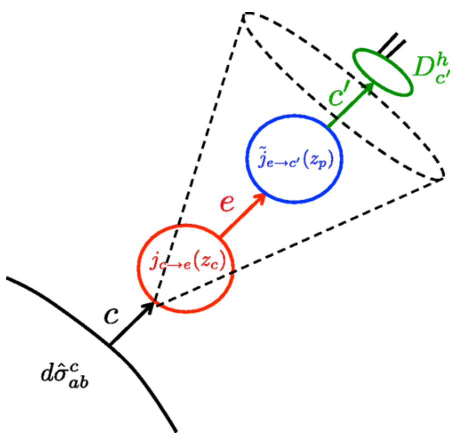
Phys. Lett. B577, 37 (2003)
Phys. Lett. B684, 114 (2010)

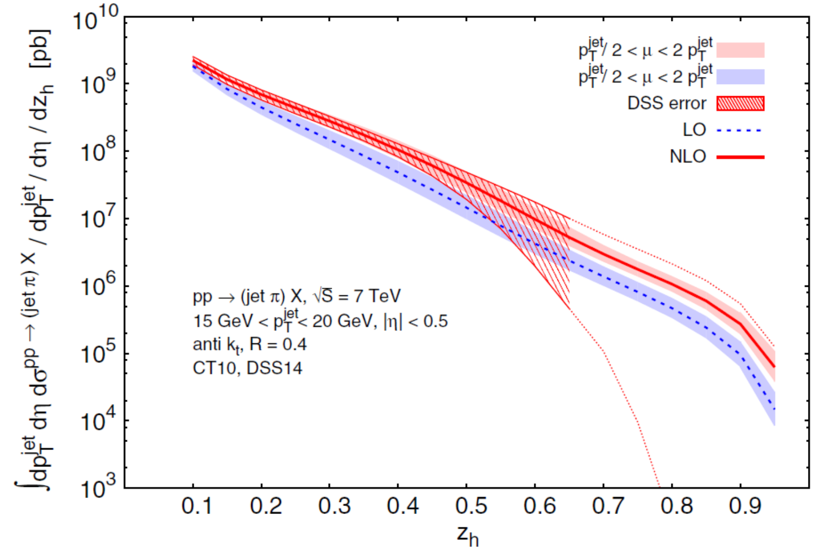



Hadron production in e+A suppressed compared to e+p

Kaufmann, Mukherjee and Vogelsang
Phys.Rev.D 92 5, 054015

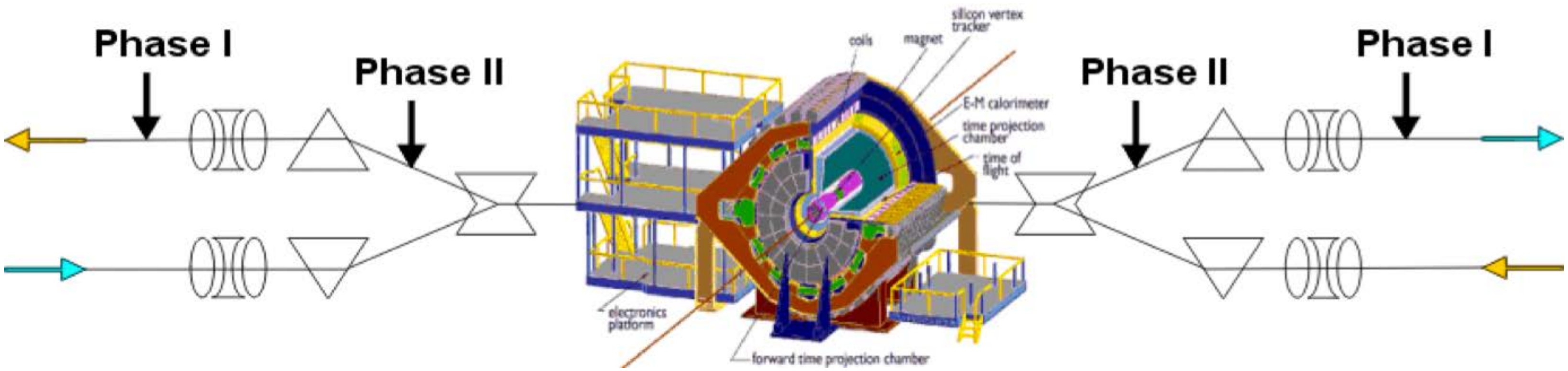
Access fragmentation functions (FF) through p+p(A) -> (jet *h*) X

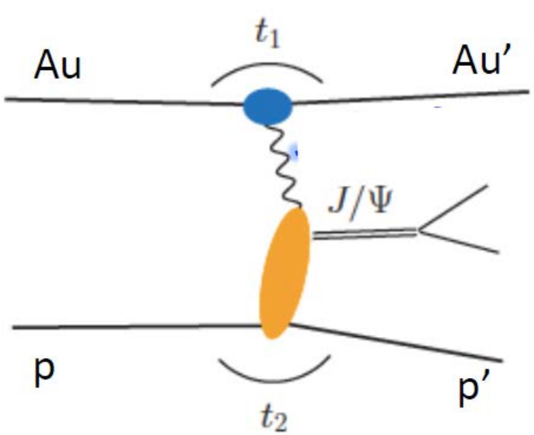


# Diffraction/UPC

Data taken in 2015 by STAR will elucidate the diffractive contribution to $A_N$ a RHIC.




$$A_{UT}(\tau,t) \sim \frac{\sqrt{t_0 - t}}{m_p} \frac{\mathrm{Im}(E * H)}{|H|}$$

$$t = \frac{M^2_{J/\Psi}}{s}$$

UPC collisions in p+A will allow study of:

- The gluon spatial distribution in nuclei ("proton shine")
- The gluon helicity flip Generalized Parton Distribution (GPD) $E_g$ ("A-shine")

Requires Roman Pots, good t-acceptance and high luminosity

# A Timeline for the LHC and RHIC

Future ion running at LHC to be split between p+Pb and Pb+Pb…

**ATLAS:**
- ❑ Trigger Upgrades
- ❑ Inner Tracker

**CMS:**
- ❑ L1 Trigger
- ❑ HCAL Upgrade

**ALICE:**
- ❑ ITS Upgrade
- ❑ Trigger and DAQ

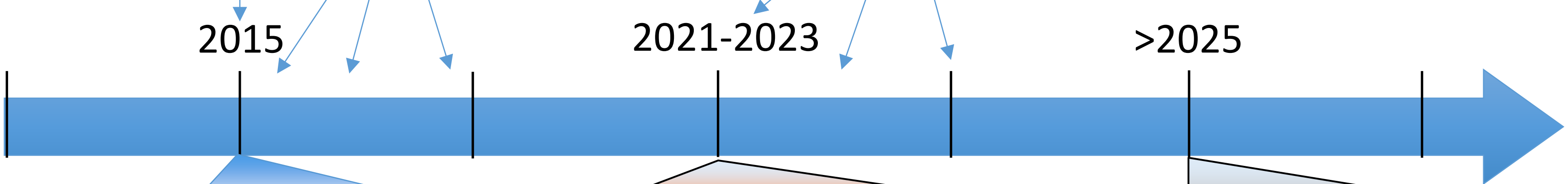
1 Month Ion Running 11/2015, 11/2016, 6/2018

1 Month Ion Running 11/2020, 11/2021, 12/2022

## LHC

End of LS1

LS2 7/18-12/19




## RHIC

**STAR Upgrades:**
- ❑ FMS-Preshower, Roman Pots-II*

**PHENIX Upgrade:**
- ❑ MPC-EX Preshower

**Run:**
- ❑ p+p 200 GeV
- ❑ p↑+Au 200 GeV transverse

**Goals:**
- ❑ nPDF: $g(x,Q^2)$
- ❑ Saturation
- ❑ Energy loss in CNM

**STAR Upgrades:**
- ❑ Roman Pots-II

**New Detector:**
- ❑ sPHENIX barrel + forward

**Run:**
- ❑ p+p 200 GeV
- ❑ p↑+A (Au, Cu, C…) 200 GeV transverse

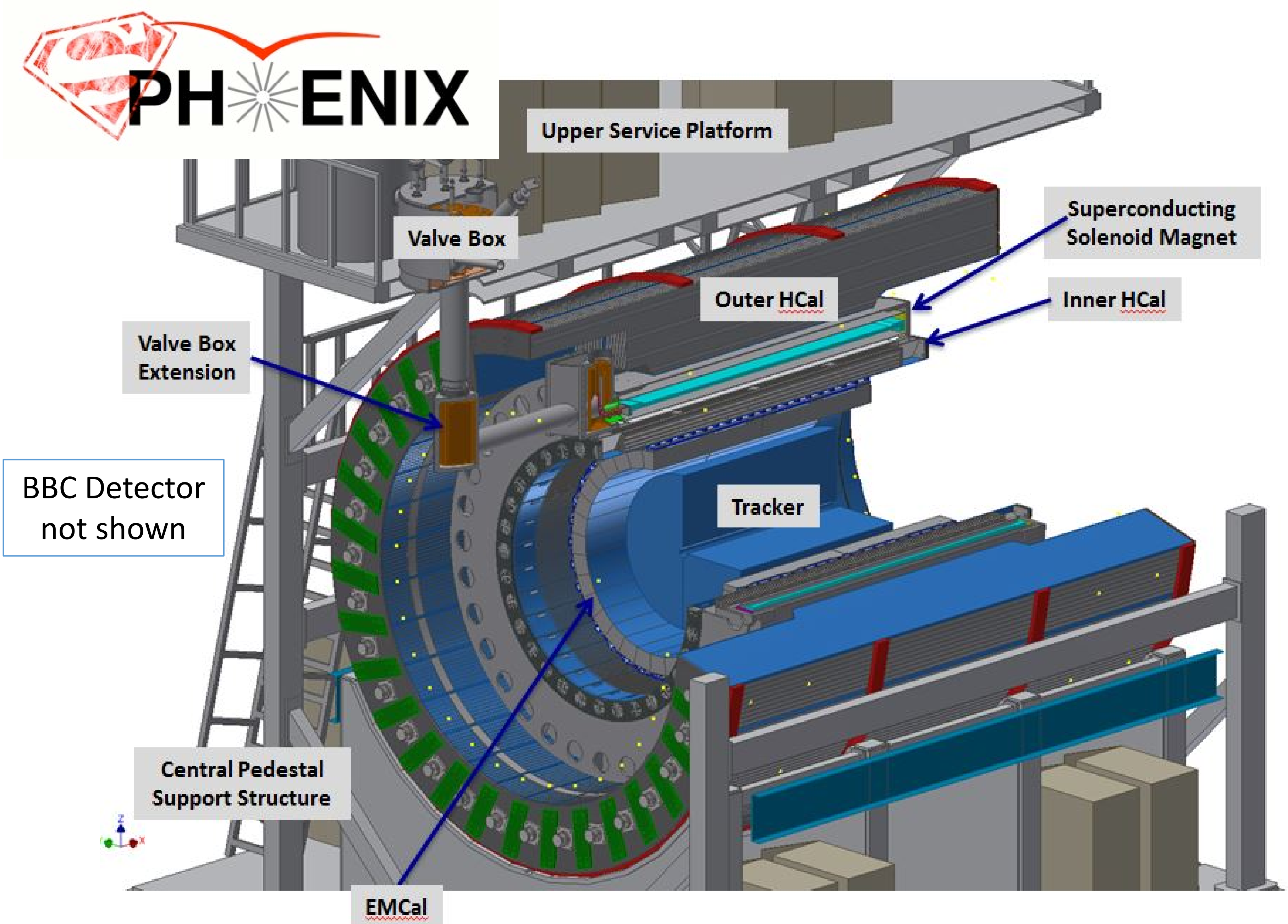
**Goals:**
- ❑ nPDF: $g(x,Q^2)$, $q(x,Q^2)$
- ❑ Saturation
- ❑ Energy loss in CNM

Electron-Ion Collider

Is there an opportunity for a comprehensive forward polarized p+p/p+A program?

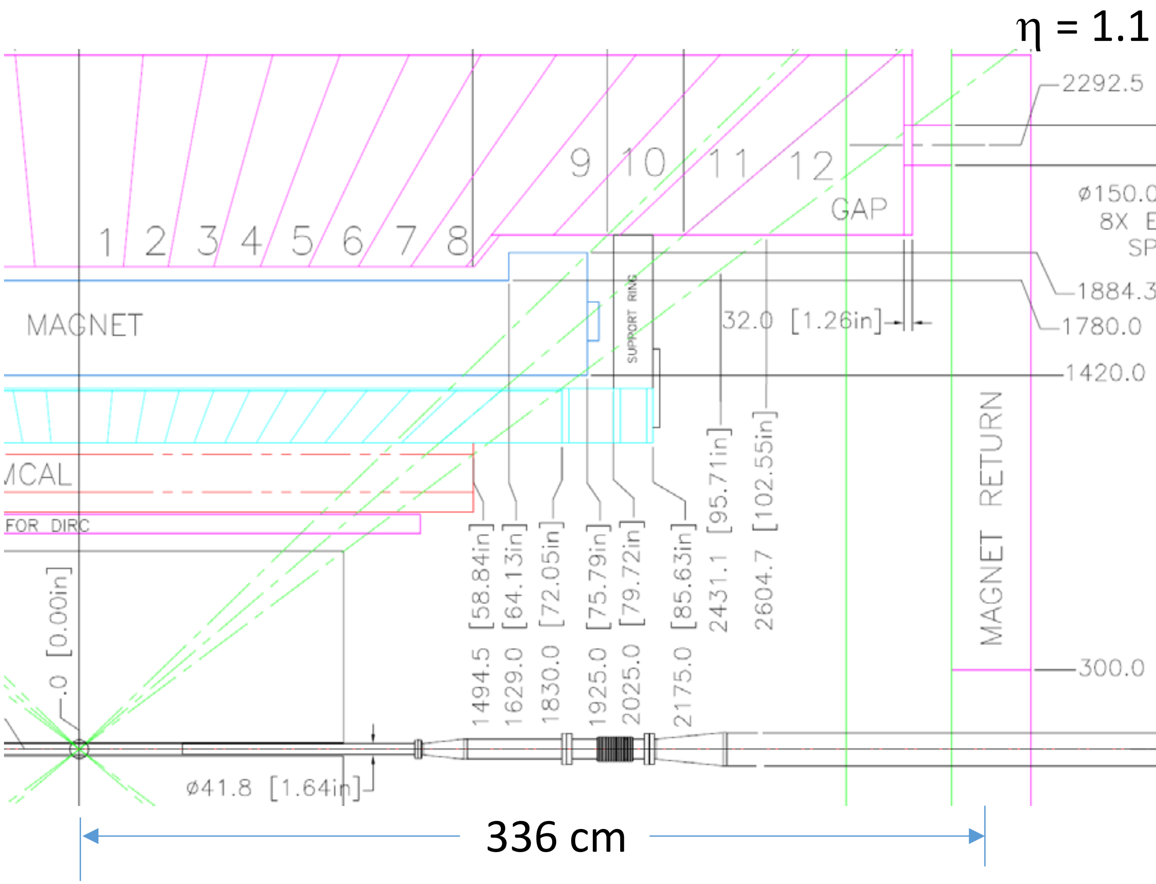
# The sPHENIX Detector Design

- **Uniform acceptance** $|\eta|<1.1$ and $0<\phi<2\pi$
- **Superconducting solenoid -** high resolution tracking
  - Acquired the BaBar solenoid!
- Compact **electromagnetic calorimeter** allowing fine segmentation at a small radius
- **Hadronic calorimeter** doubling as flux return
- **Solid state photodetectors** that work in a magnetic field, low cost, do not require high voltage, are physically small
- **Common readout electronics** in the calorimeters
- **15 kHz recorded** in A+A allows for large unbiased data sample
- **High resolution tracking** within an 80 cm radius
- Utilization of infrastructure in an **existing experimental hall** (cranes, rails, beam pipe, power, network…)

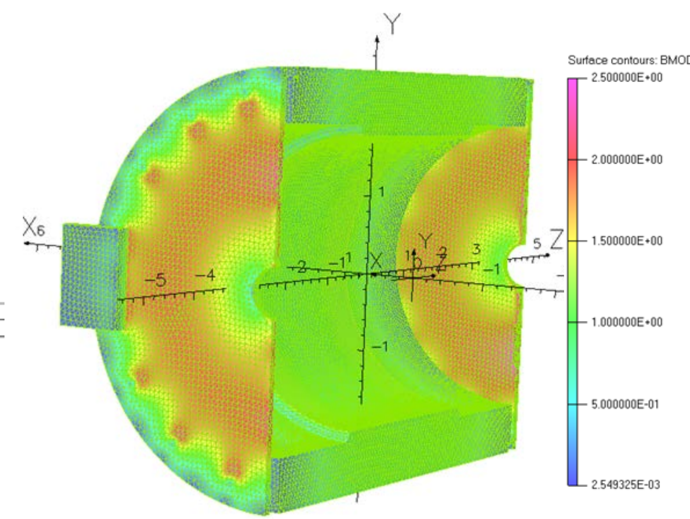



BBC Detector not shown

# Current sPHENIX Design



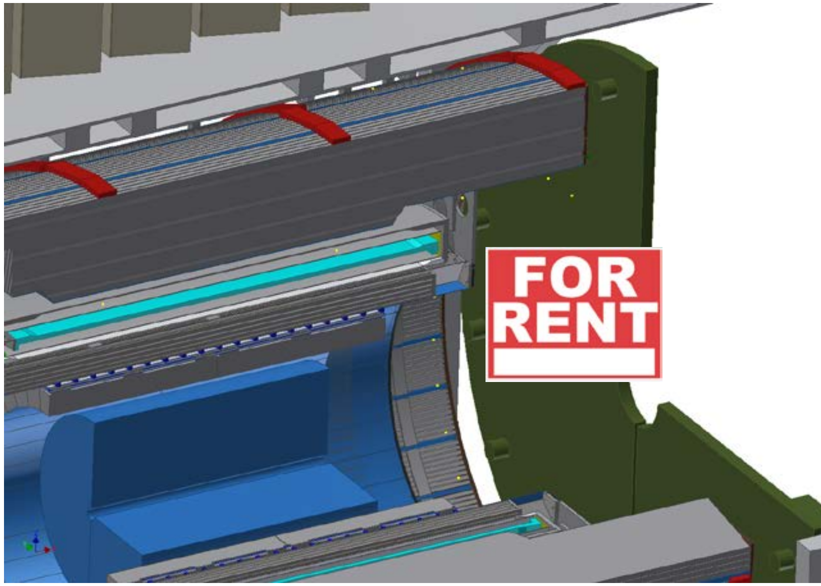

OPERA calculations show that a flux return only 10cm thick should be OK.




Current sPHENIX design well-suited to forward instrumentation!

# A New Possibility – fsPHENIX!

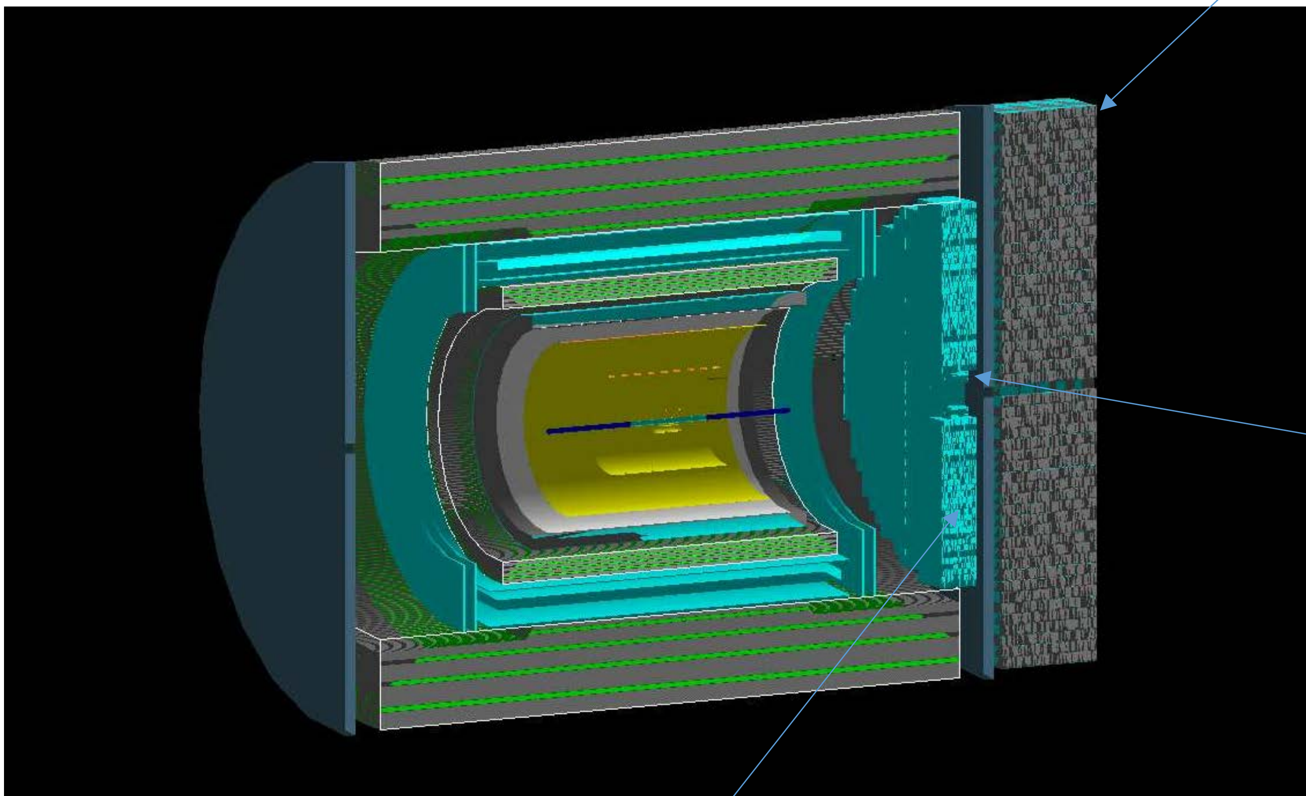
- The sPHENIX plug door is compatible with a forward detector suite!
- Implement "forward sPHENIX":
  - GEM trackers and FEMC in magnetic field volume
    - PHENIX EMCal (PbSc) -> FEMC
  - FHCAL outside plug door
    - Plug door could be as thin as ~10cm
  - Magnetic field shaper piston
  - Roman Pots in beamline
  - Fits in 4.5m eRHIC IR constraint




fsPHENIX

# Forward Calorimeters

Pb/Sc sandwich hadronic calorimeter (NEW)
10 x 10 x 100 $cm^3$ towers
($1.2 < \eta < 4.0$)



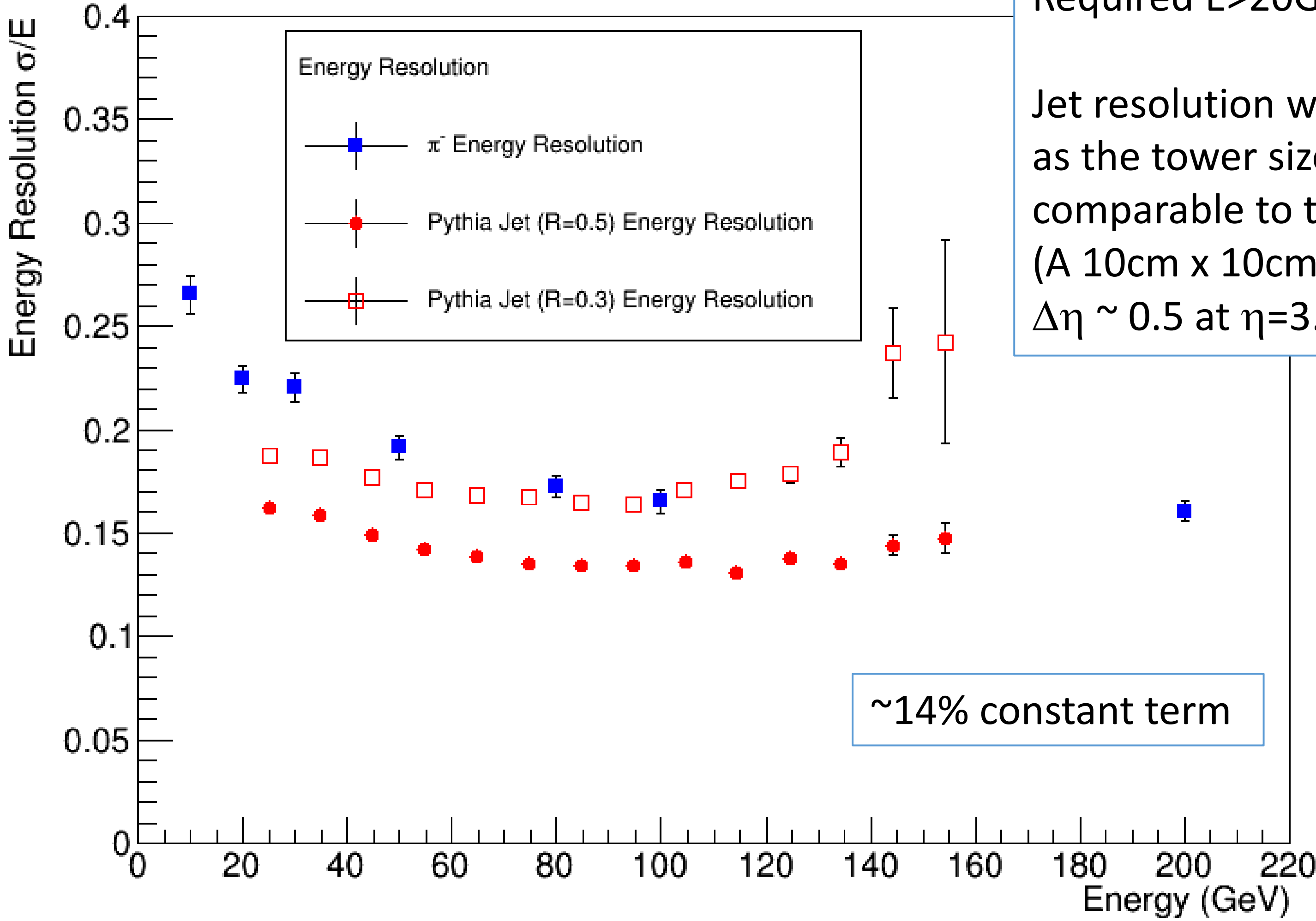
20x20 array of 2.2 x 2.2 x 18 $cm^3$ PbW (PHENIX MPC) crystals with 10x10 square hole (300 crystals total)
$3.0\text{-}3.3 < \eta < 4.0$

PHENIX PbSc modules (5.5 x 5.5 x 33 $cm^3$) organized in groups of four modules (3152 modules or 788 groups of 4)
($1.4 < \eta < 3.0\text{-}3.3$)

# Jet Energy Resolution

Jets from 510 GeV Pythia8, using jet trigger, jet energy is correlated with pseudorapidity. Required E>20GeV, $p_T$>5GeV.

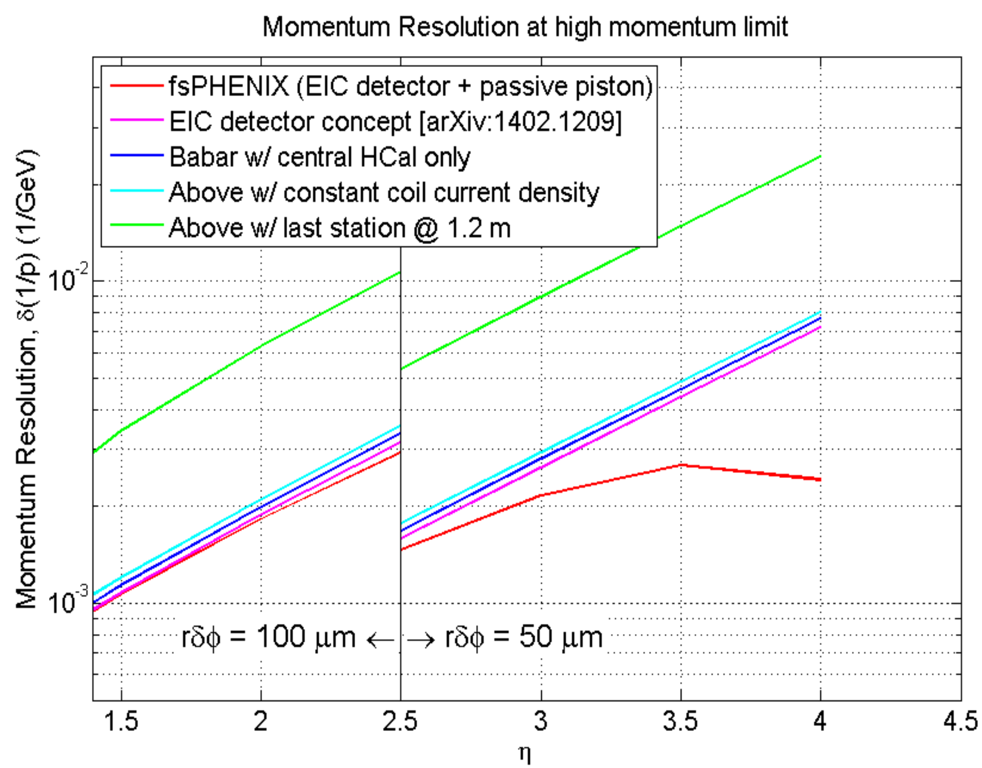
Jet resolution worsens at high $\eta$ as the tower size gets comparable to the cone size. (A 10cm x 10cm FHCAL tower is $\Delta\eta$ ~ 0.5 at $\eta$=3.5.)

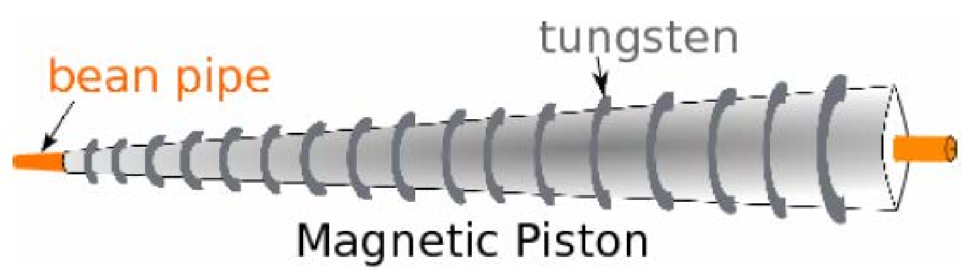



~14% constant term

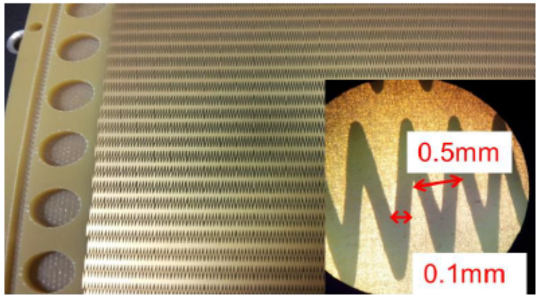
# Forward Tracking

- Large area GEM tracking stations at z=120, 150, 275cm ($1.45 < \eta < 4.0$)
  - Space left between ST1 and 2 for future PID
- Additional passive field shaper piston to enhance field shape for improved momentum resolution at high $\eta$.



# Forward GEM Trackers



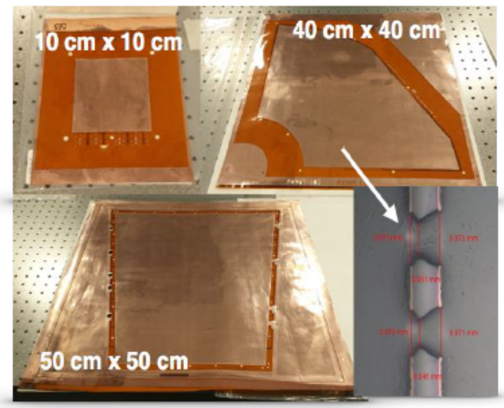

NIM A 811 (2016) 30-41

Florida Institute of Technology (FIT)

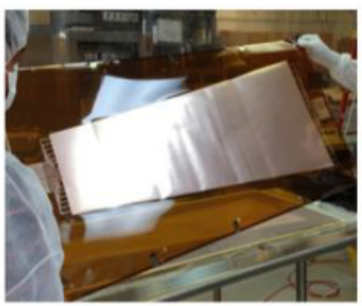
- Recently submitted a results of their large area (~1 m) triple-GEM detector to NIM A for publication.
- Successfully used zig-zag readout as a means to maintain good sp atial resolution while reducing number of readout channels needed
- $\sigma_\varphi$ = 193 µrad

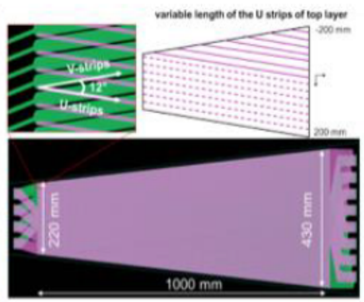
Temple University (TU)

- Have been working with US company Tech-Etch towards commercializing la rge-area GEM foils.
- Recently published results of electrical and geometrical foil quality




NIM A 802 (2015) 10-15






NIM A 808 (2016) 83-92

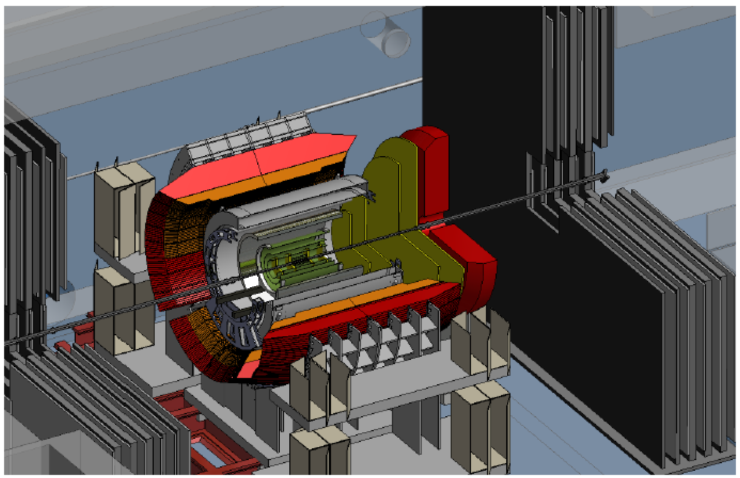
University of Virgina (UVa)

- Recently published results on their large-area (~1 - m)/ light weight triple GEM detector
- The detector successfully implemented 2D stereo -angle (U-V strips) readout
- $\sigma_r$ = 550 µm, $\sigma_\varphi$ = 60 µrad

***Strong tie-ins with existing EIC R&D efforts!***

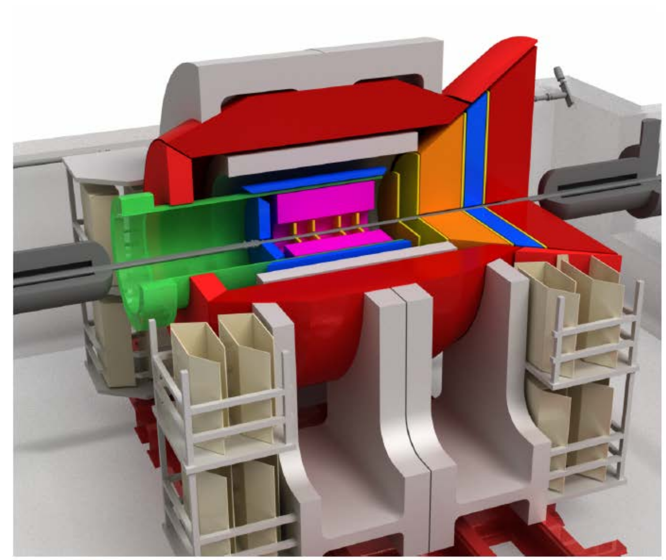
# On to the EIC…

Future Opportunities in $p+p$ and $p+$A Collisions at RHIC with the Forward sPHENIX Detector



The PHENIX Collaboration
April 29, 2014

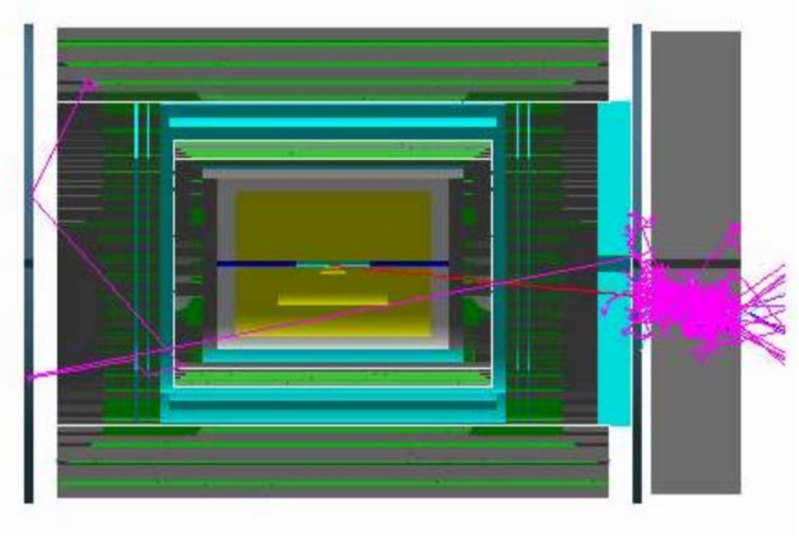
Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid



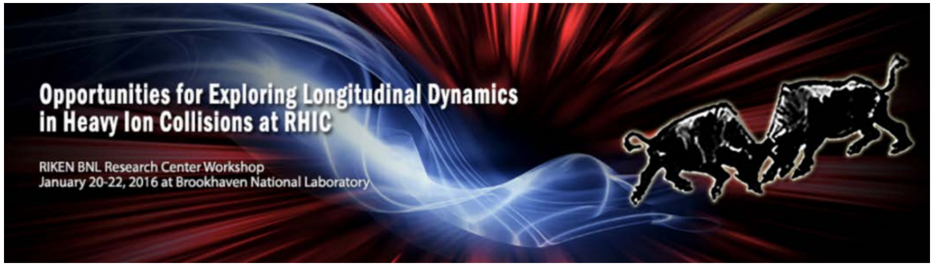
The PHENIX Collaboration
February 3, 2014

*The forward detectors for fsPHENIX could potentially be re-used for an EIC detector!*

# What About Heavy Ions?

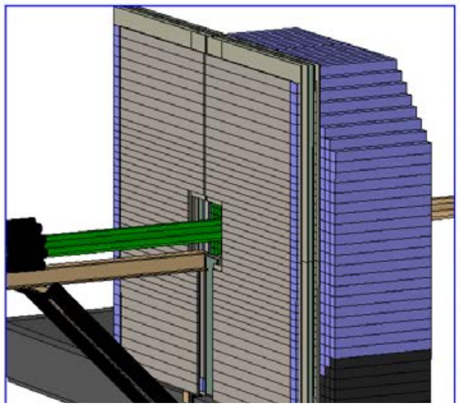


- Extended coverage for both calorimetry and tracking.
  - $-1.1 < \eta < 4.0$
- Opportunity to extend the study of longitudinal dynamics in HI collisions:
  - No new data since PHOBOS/BRAHMS
  - State-of-the-art hydro fails to explain PHOBOS high rapidity – hydro needs to know longitudinal dynamics!
  - Particle correlations over a wide rapidity range could shed light on the *very initial* stages of a HI collision



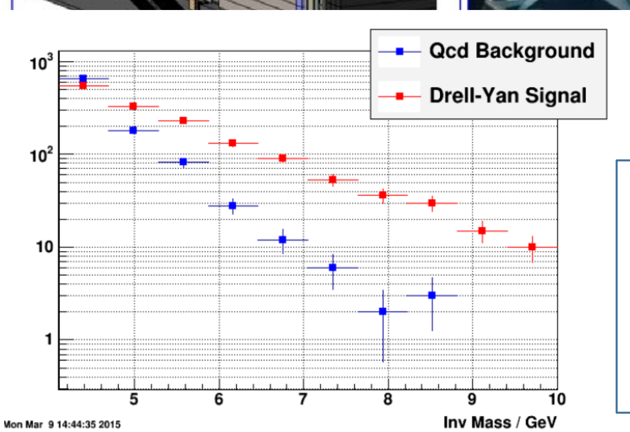
# Forward Physics with STAR

- The existing (or soon to exist) STAR detector already has significant forward capabilities:

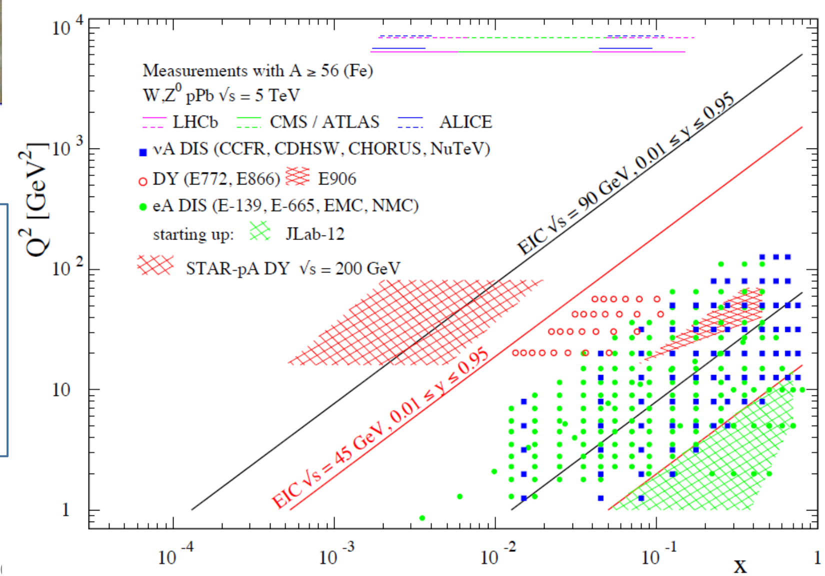


FMS (EMCal) and preshower in place

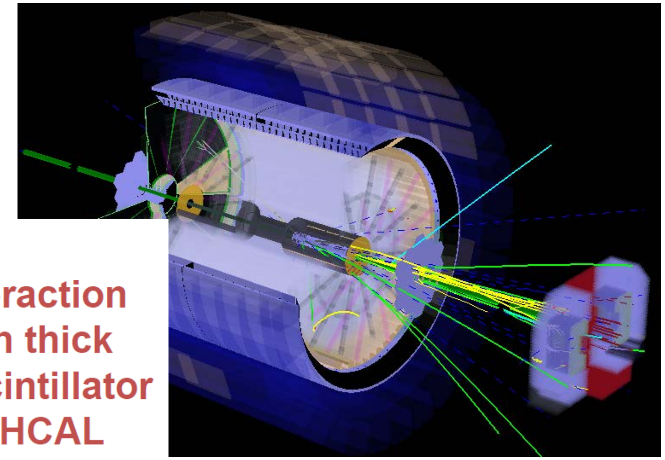
Additional post-shower planned for Run-17; enables DY -> $e^+e^-$ measurements



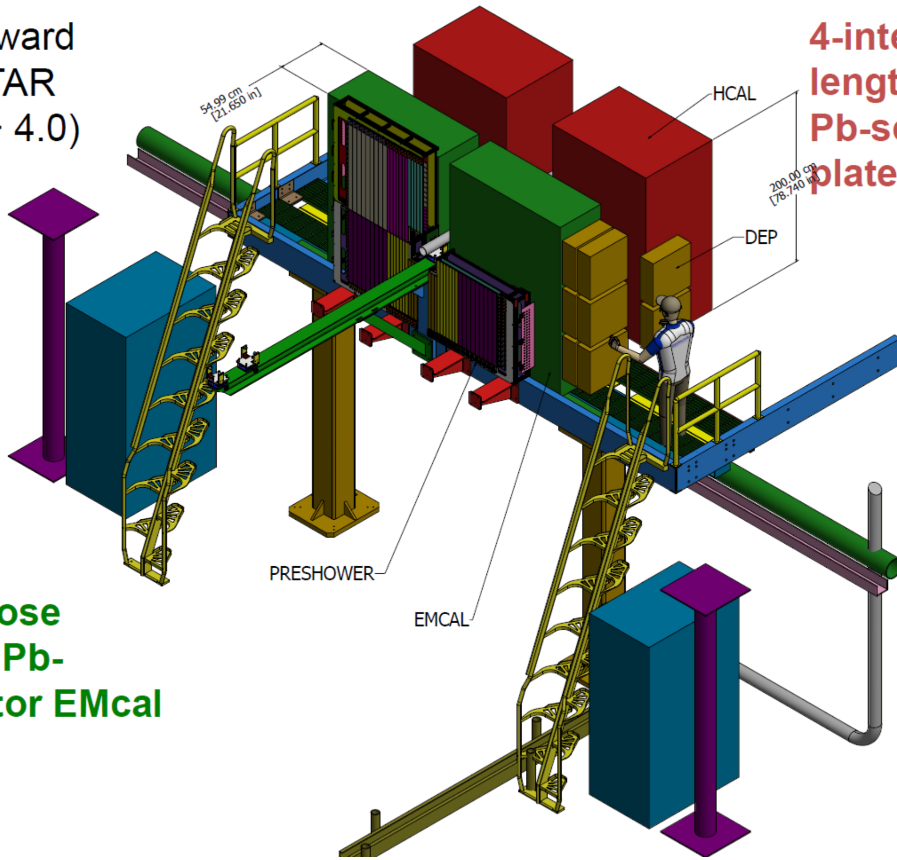

Coverage for nPDFs extended even compared to EIC!



# STAR 2020+



Install in forward region at STAR ( 2.3 > eta > 4.0)




**4-interaction length thick Pb-scintillator plate HCAL**

**Re-purpose PHENIX Pb-scintillator EMcal**

Similar physics calls for similar instrumentation….

Lots of opportunities for collaboration between STAR and fsPHENIX!

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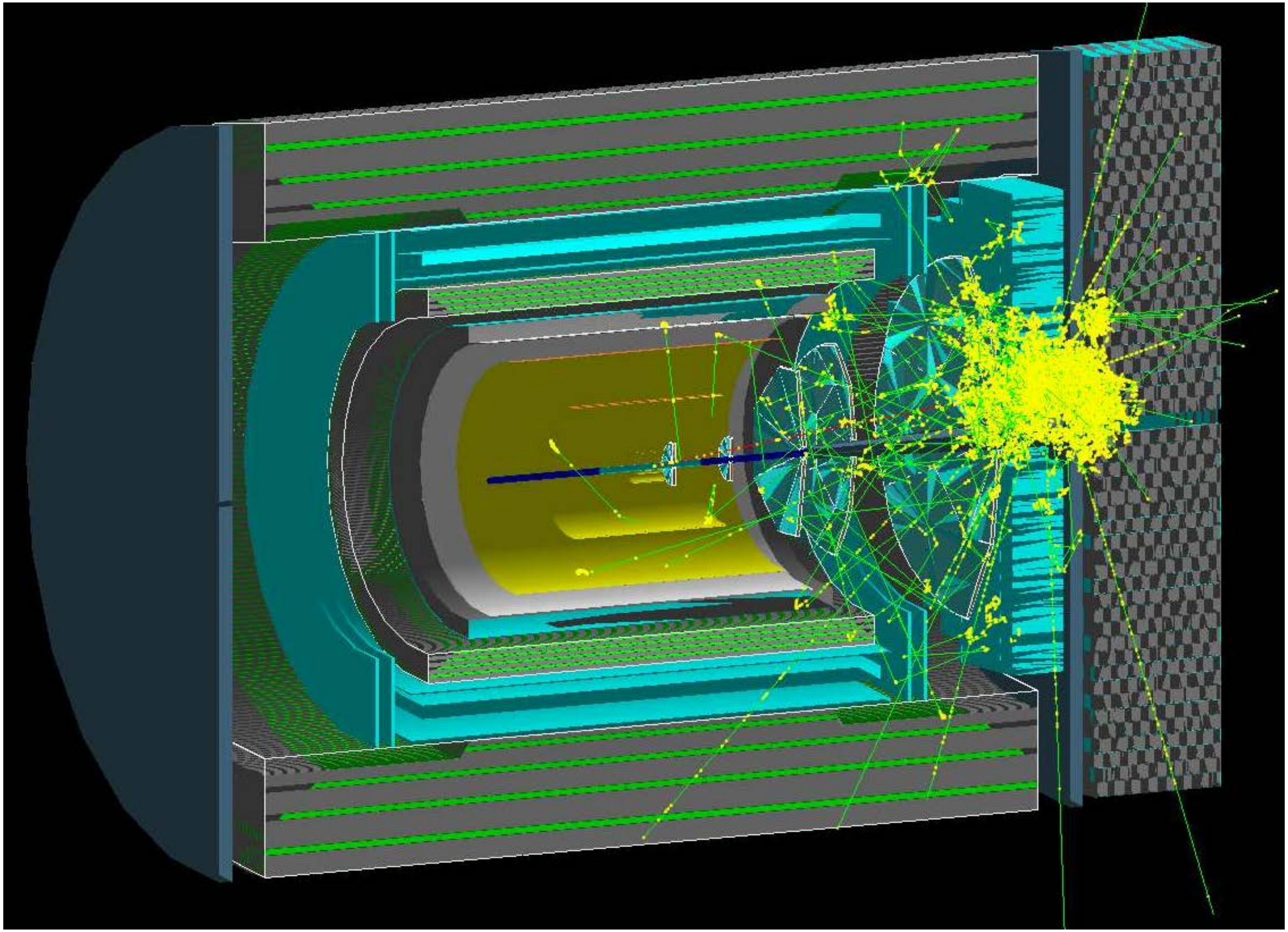
## Tracking:

Silicon mini-strip detector 3-4 disks at z ~70 to 140 cm
Each disk has wedges covering full 2π range in $\phi$
and 2.5-4 in η (other options still under study)

# Conclusions

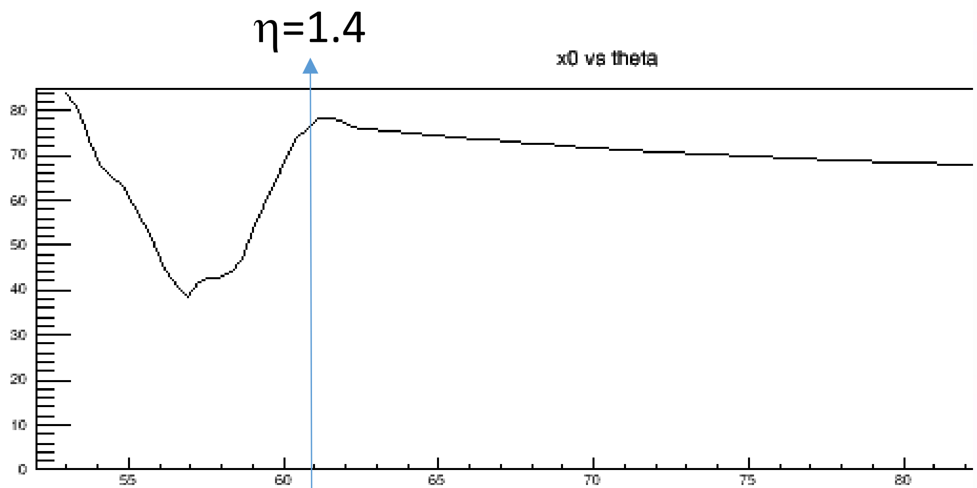
- There is a wealth of unexplored physics in the forward region at RHIC!
- sPHENIX is a major new project that will make available probes of the Quark Gluon Plasma with unprecedented precision.
- An option for additional forward instrumentation added to sPHENIX (fsPHENIX) is being actively explored.
  - Extend the sPHENIX physics program to include p+p/p+A as well as longitudinal dynamics in HI collisions
  - Substantial re-use of existing detector systems for calorimetry
  - Tie-ins with EIC R&D as well as re-use of equipment for future EIC detector
  - Pushing towards a new fsPHENIX LOI end of 2016
- The existing STAR detector also has significant forward capabilities, more with upgrades

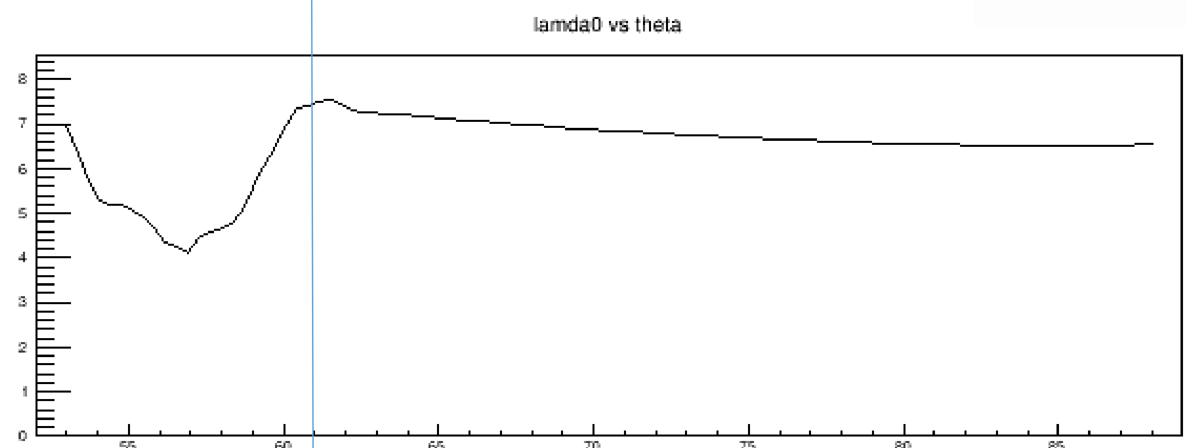
# No longer left blank…

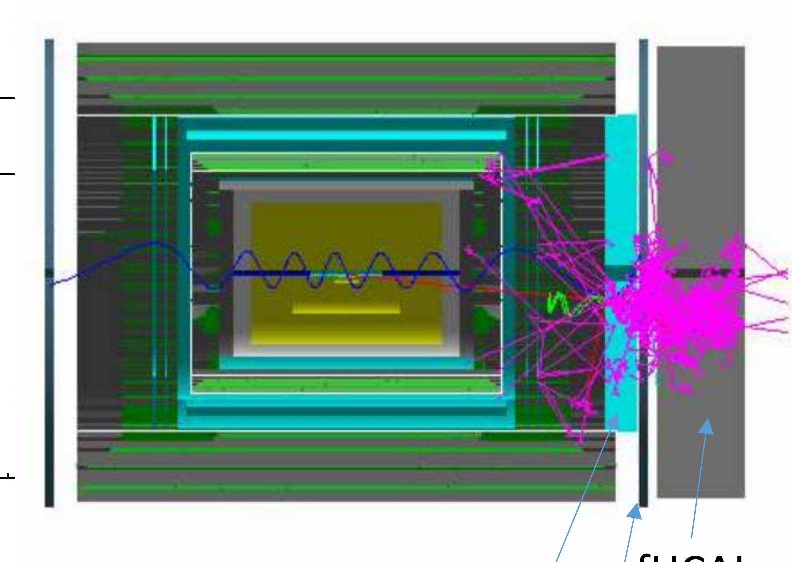


# BACKUP

# fsPHENIX G4 Forward Calorimeters




The theta angle in G4 is calculated opposite how we normally calculate pseudorapidity.

The fEMC is modeled on the PHENIX EMCal, covers as much as it can without interfering with the barrel to get complete jet coverage.

Are there nuclear effects at very high $Q^2$?

Does gluon saturation really exist?

**Era I:** Perturbative

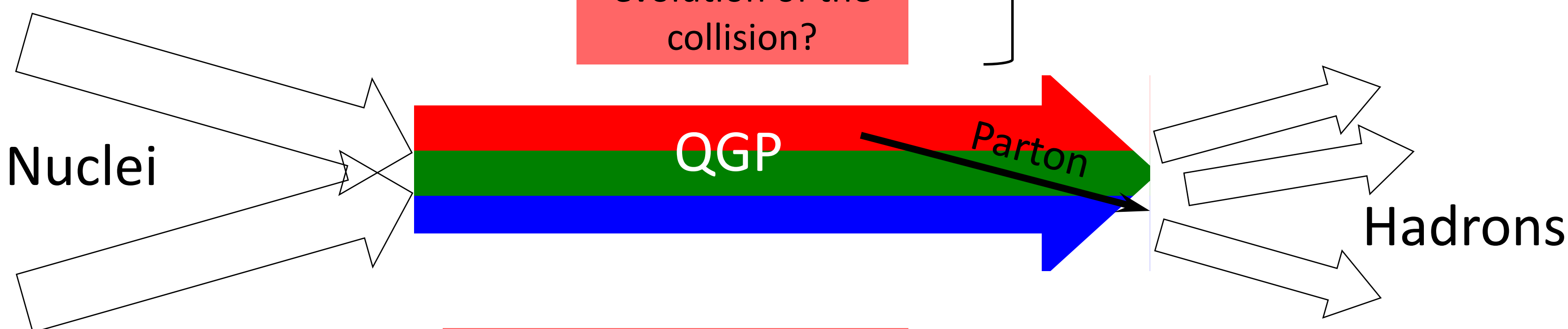
How well-thermalized is the QGP state?

What happens at higher baryon density?

What is the 3+1D evolution of the collision?

**Era II:** Thermal

Paul Stankus




What are the transport/ non-equilibrium properties of the QGP?

How does the QGP decay? Ie hadronization

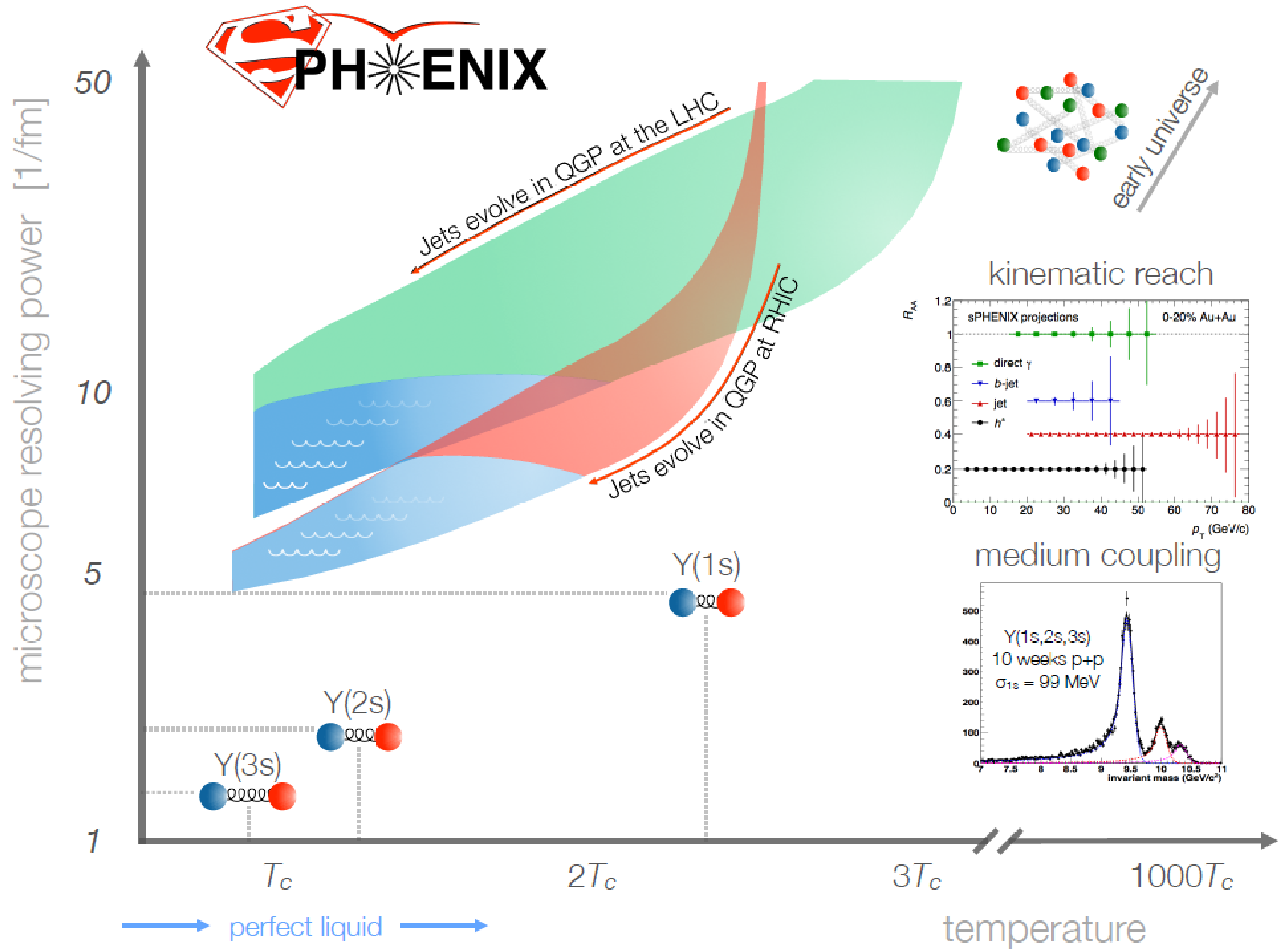
How/when is initial equilibration/entropy generation achieved?

How are conserved quantum numbers transported?

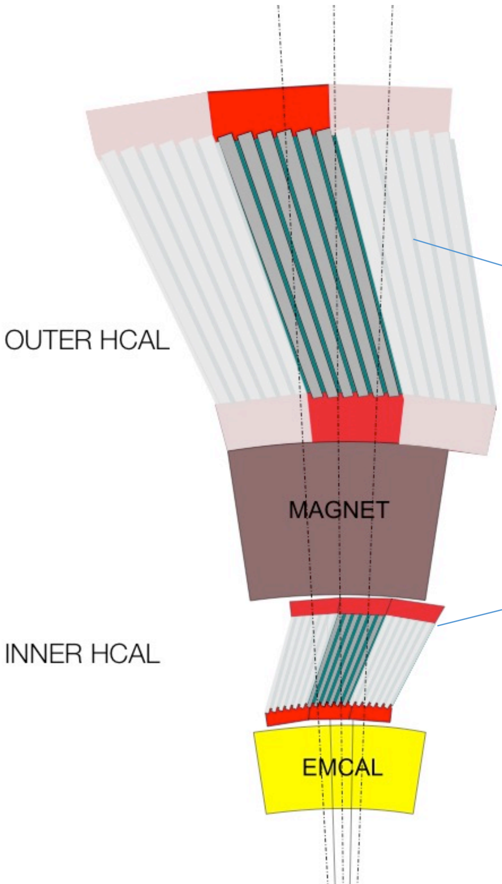
What is the parton-medium interaction?

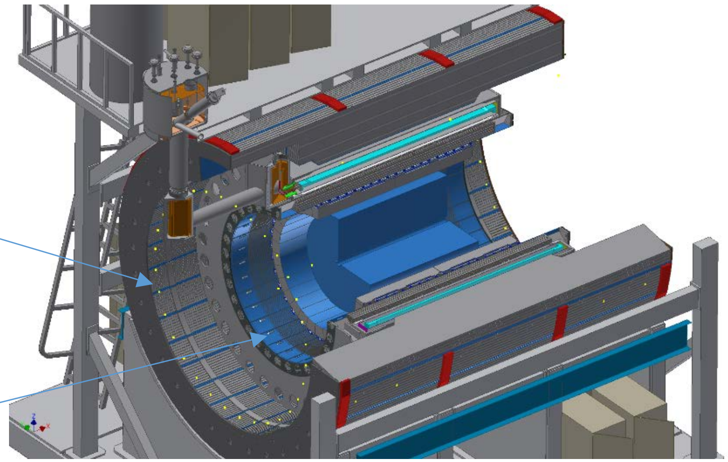
**Era III:** Non-Perturbative and Non-Thermal

# Jets as a Probe of the QGP



# HCAL Reference Design

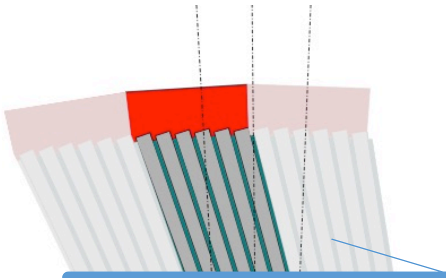


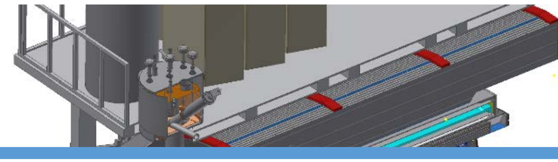



- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

- HCAL steel and scintillating tiles with wavelength shifting fiber
  - 2 longitudinal segments.
  - An Inner HCal inside the solenoid.
  - An Outer HCal outside the solenoid.
  - $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$
  - 2 x 24 x 64 readout channels
  - $\sigma_E/E < 100\%/\sqrt{E}$ (single particle)
- SiPM Readout

# sPHENIX HCAL Description





OUTER HCA

INNER HCA

## Why a "tilted plate" design?

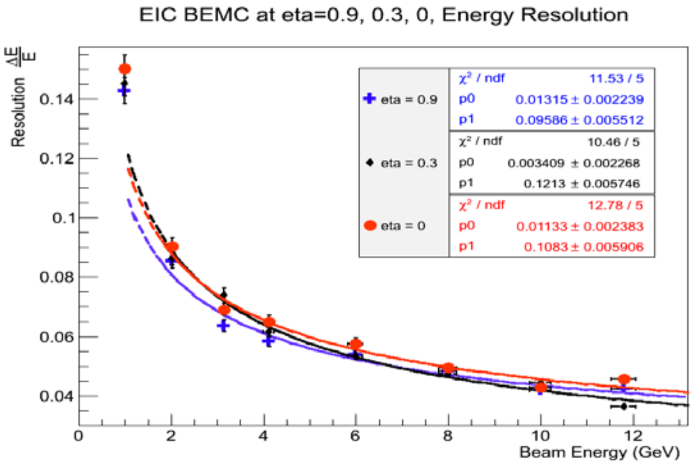
- Size limitations set by existing 1008 interaction hall lead us to integrate the flux return and the outer HCAL.
  - Requires longitudinally contiguous steel sections
  - Design consistent with requirements for a hermetic detector
    - Variation of a tile calorimeter design
  - Minimizes engineering challenges
- Adequate performance for the sPHENIX physics goals.

- 
- Magnet ≈1.4$X_0$
- Inner HCAL ≈1$\lambda_I$
- EMCAL ≈18$X_0$≈1$\lambda_I$

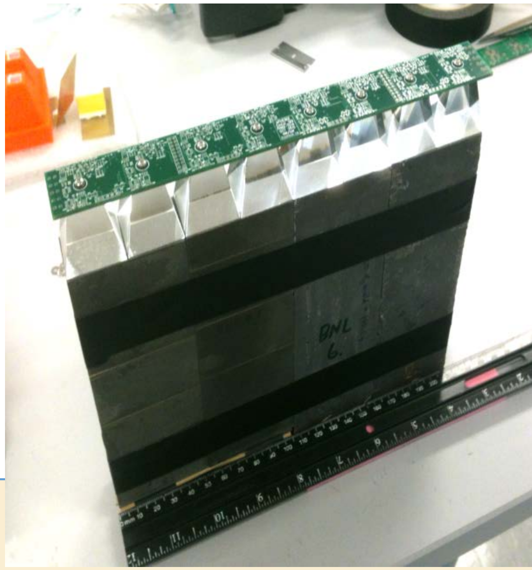
  - $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$
  - 2 x 24 x 64 readout channels
  - HCal $\sigma_E/E < 100\%/\sqrt{E}$ (single particle)
- SiPM Readout

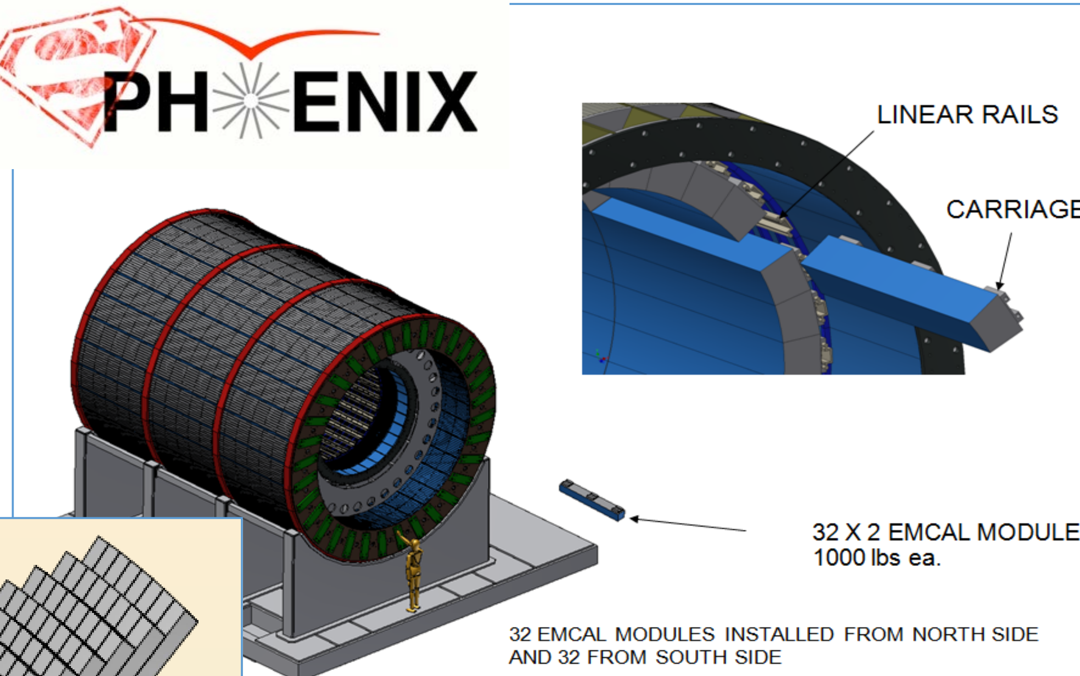
# Electromagnetic Calorimeter

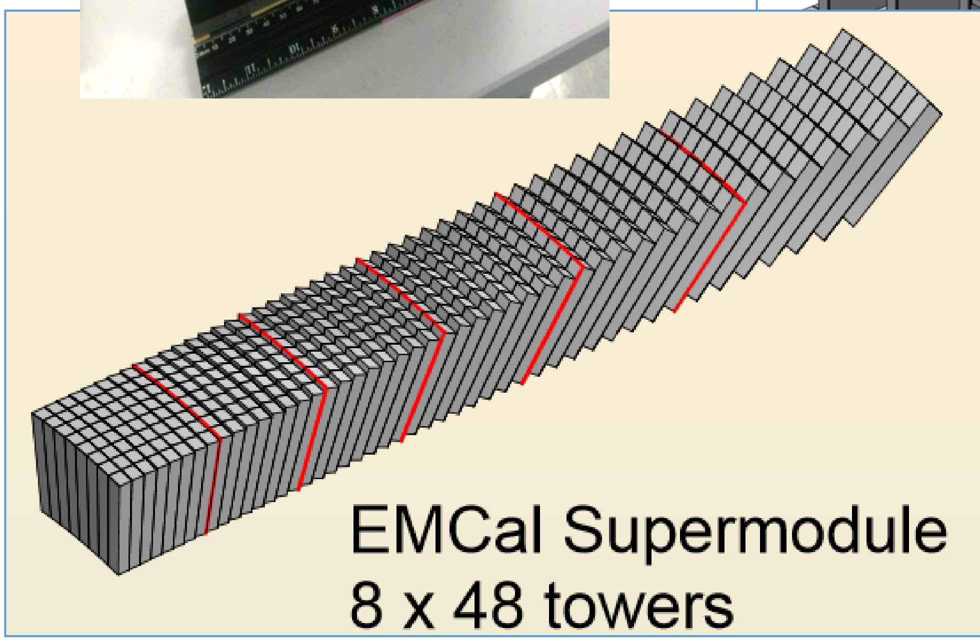
- Tungsten-scintillating fiber SPACAL
- Radiation length of ≈7 mm allows it to be inside the solenoid where only the material of the tracker is in front of it
- Beam tested by UCLA group
- Development of projective geometry which could improve e/π separation needed for the Upsilon measurements
- Readout on inner radius of EMCAL with 4 3x3 mm SiPM's
- On-detector electronics limited to preamps, bias control and temperature monitoring



# 1D Projective Reference Design






- Efforts to produce towers of spacal modules using UCLA-developed design is ongoing at UCLA, UIUC and Tungsten Heavy Powder
- Work supported in part by RHIC and EIC R&D

Ultimately need to build ~25k towers

# Putting it all together