A new detector at RHIC, sPHENIX goals and status

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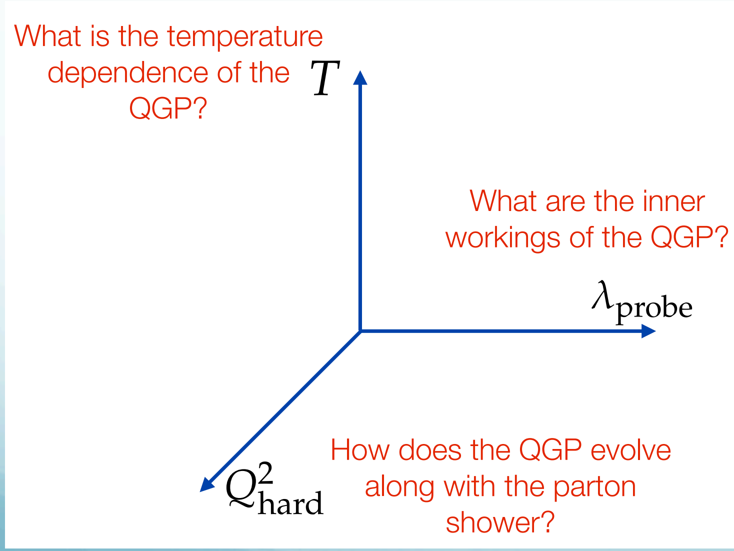
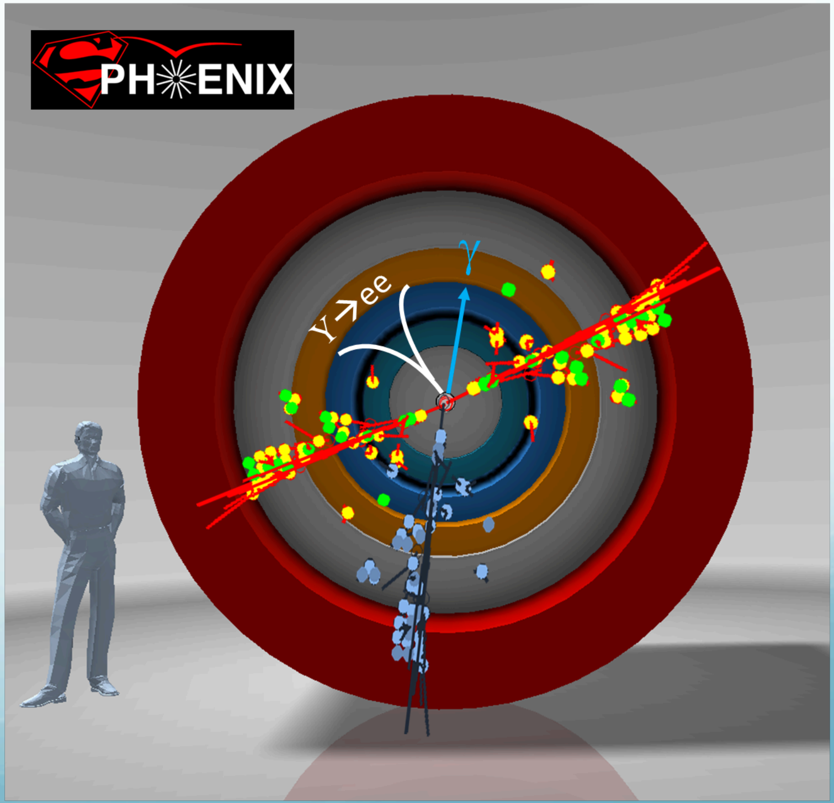
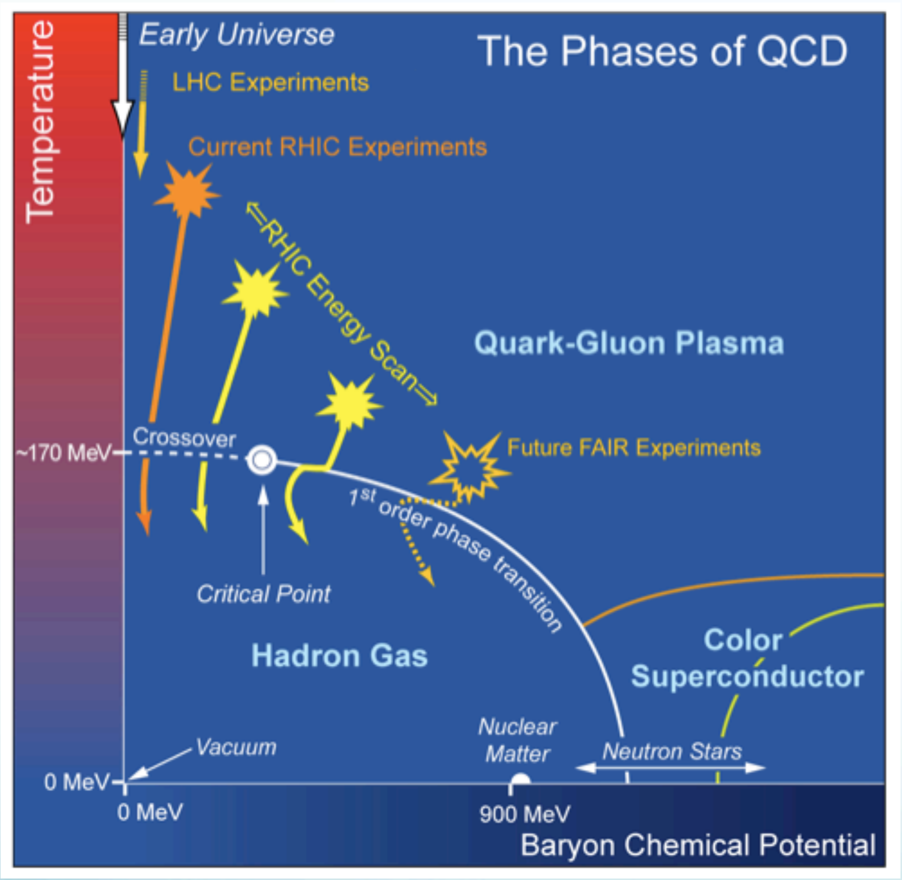
Outline

- Introduction to the QGP and RHIC
- Physics case for sPHENIX
- Detector Design and Performance
- Timeline





Quark Gluon Plasma (QGP)
QCD Phase Diagram

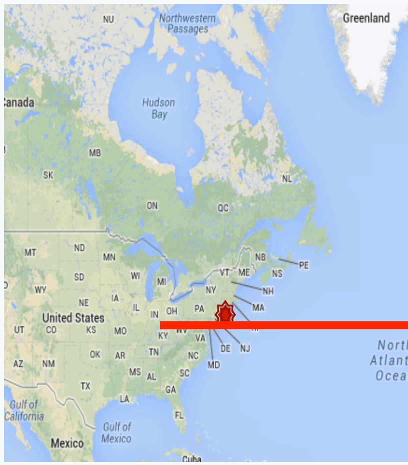


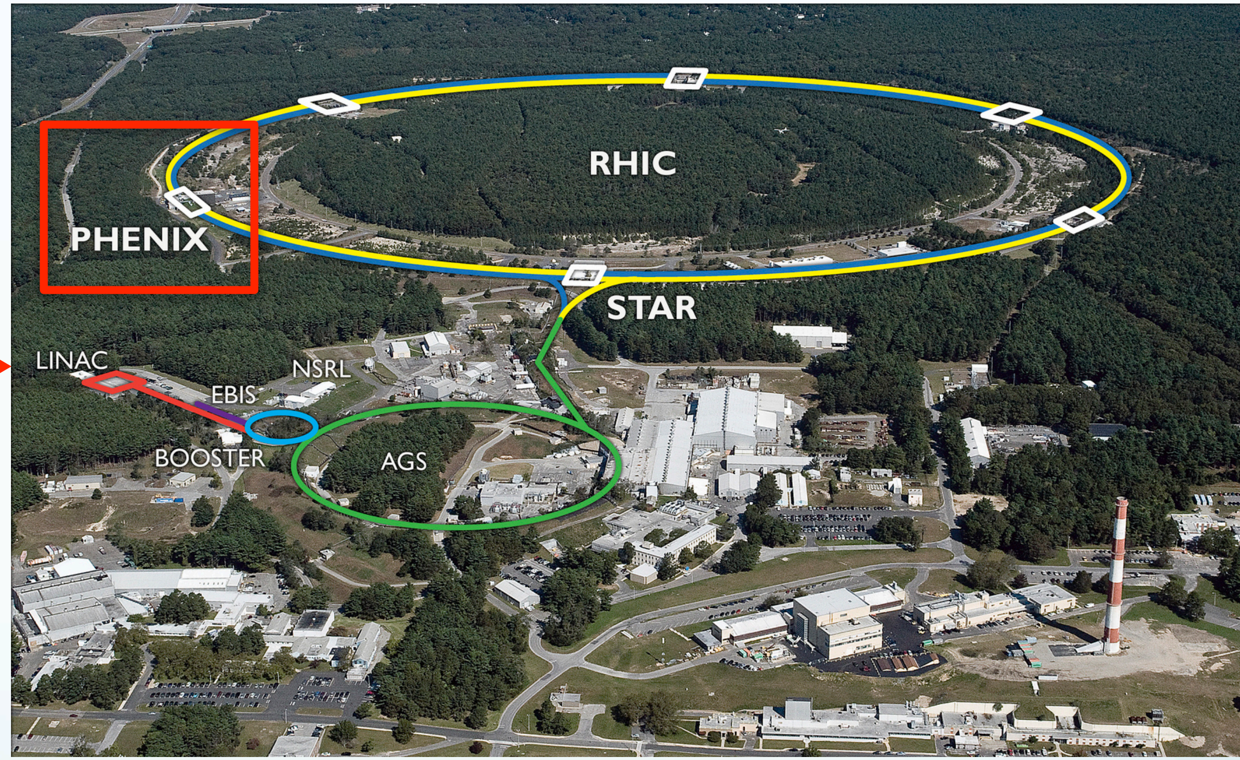
- Ultra-relativistic heavy ion collisions create a hot, dense liquid of quarks and gluons
  - **Partonic degrees of freedom**
- The goal is to map out the many-body properties of QCD at extreme temperatures and densities

QGP properties depend on temperature/density ➔ Probe different collisional energies and systems

Relativistic Heavy Ion Collider (RHIC)

BROOKHAVEN NATIONAL LABORATORY





Long Island, NY
1.2 km diameter
pp, p+Au, d+Au,
p+Al, p+^{3}He, Cu+Cu, Cu+Au, Au+Au, U+U

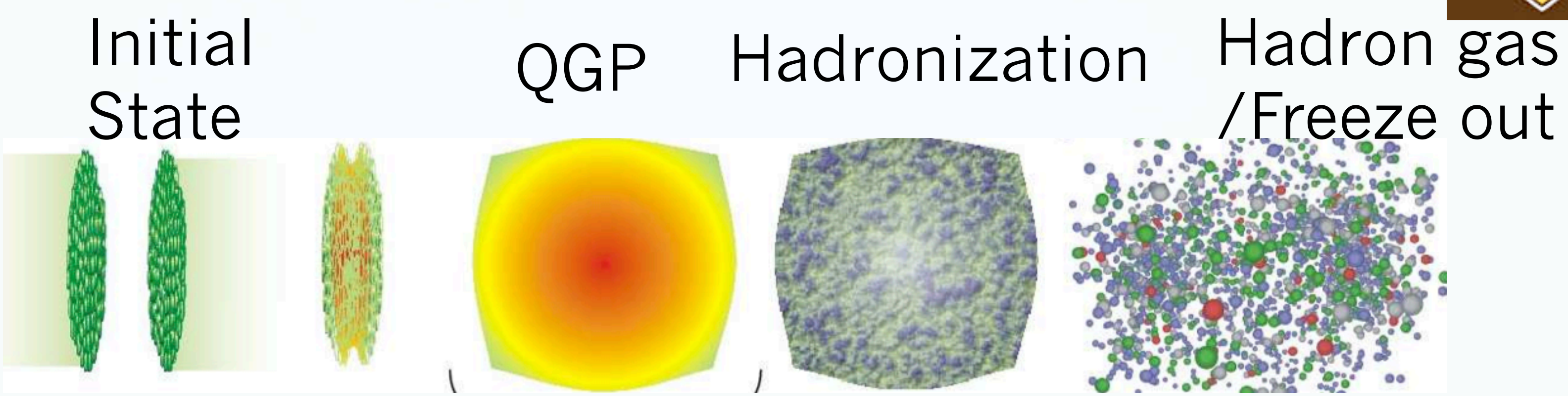
$\sqrt{s_{NN}}$ = 7.7 – 510 GeV
Operating since 2000!

Extremely versatile machine!
Only high energy collider with polarized proton beams.

The sPHENIX Project

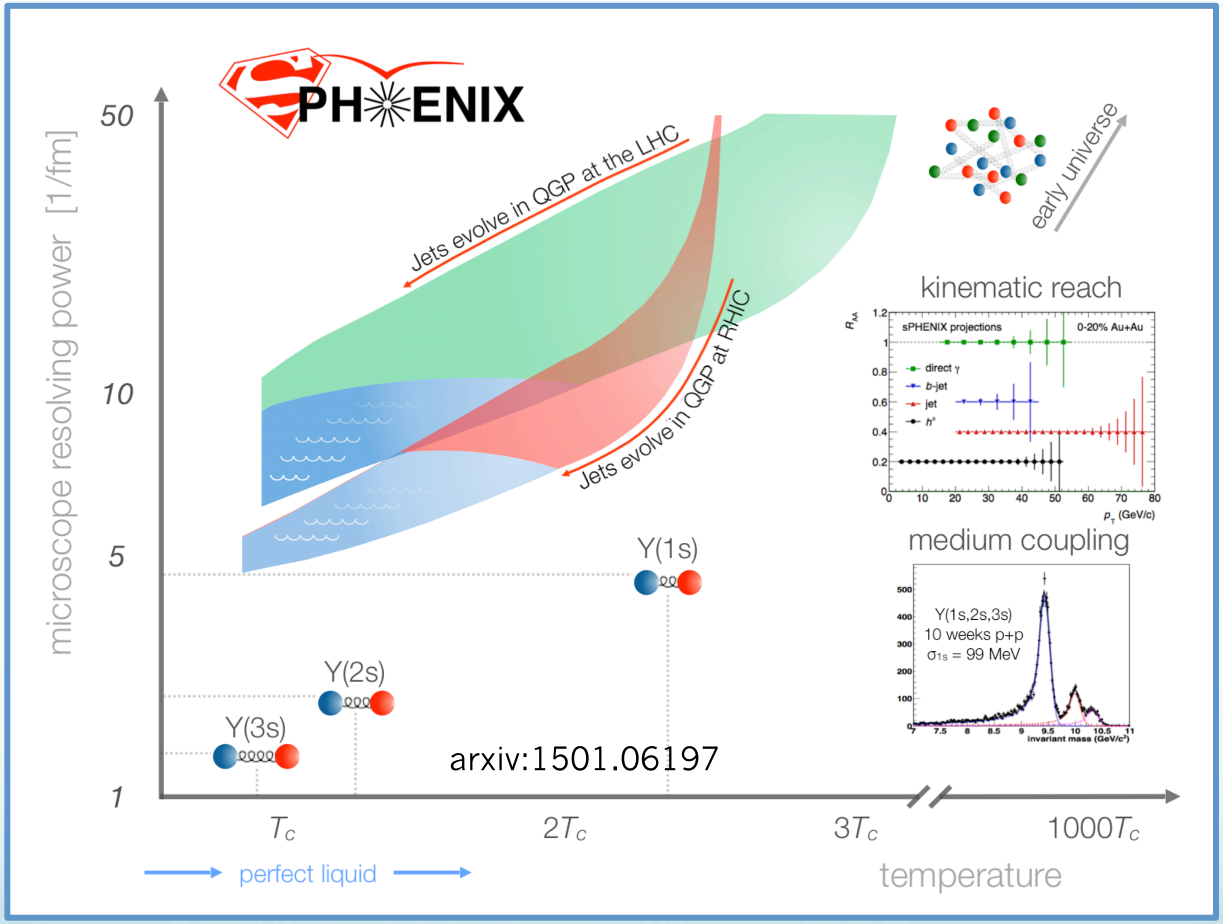
- It's the 16th and final year of PHENIX Operations
  - Extending LHC/RHIC results require measurement capabilities beyond either PHENIX/ STAR
  - A proposal has been submitted to DOE for a mid-size detector
- The new detector will have:
  - High rate, **minimum biased trigger**
  - Strong magnetic field
  - **2π calorimetry coverage** (EMCal + HCal)
  - Reuse much of the PHENIX infrastructure
  - Build schedule will allow the 1st sPHENIX run in **early 2022**
  - Potential future application as a foundation for an Electron Ion Collider (EIC) detector

Heavy-ion Collision Evolution



- Study of HI collisions is broken into 2 categories:
  - **Hard probes**
    - High p_T (jets) or high mass makes perturbative treatment of initial production possible (pQCD)
    - Evolution reflects presence of medium
  - The bulk
    - Many-body QCD system, collectivity
    - Nonperturbative

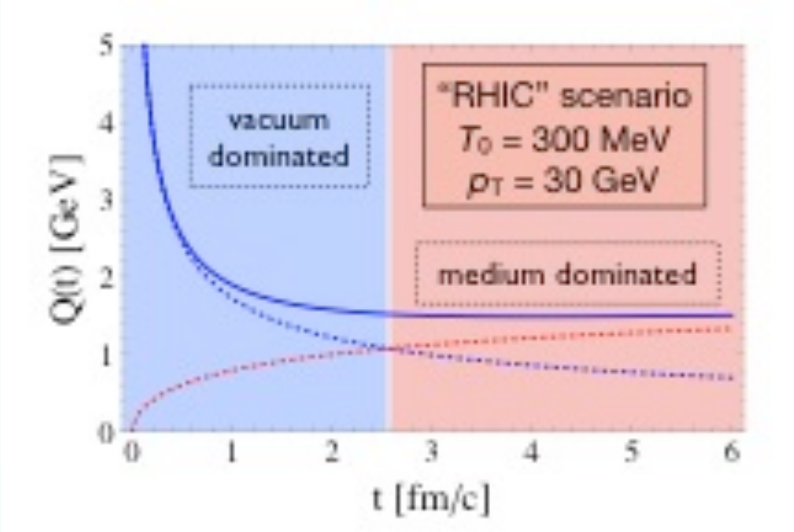
New Detector at RHIC "sPHENIX" proposal

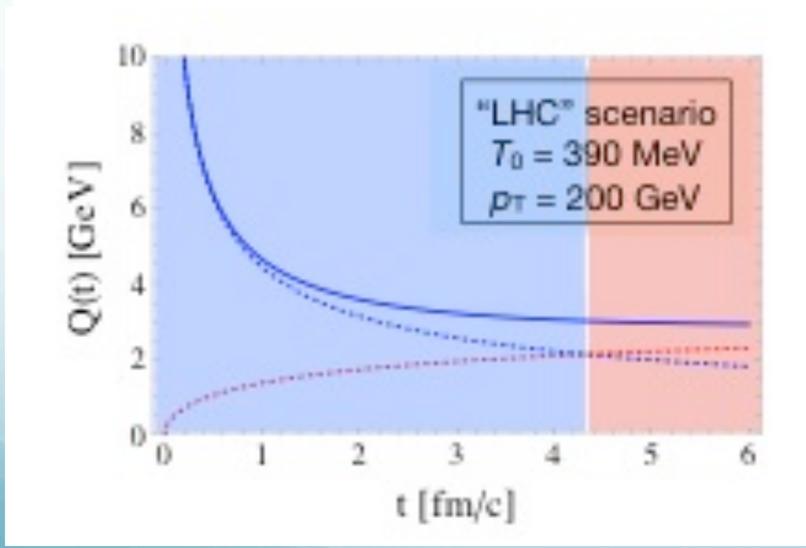


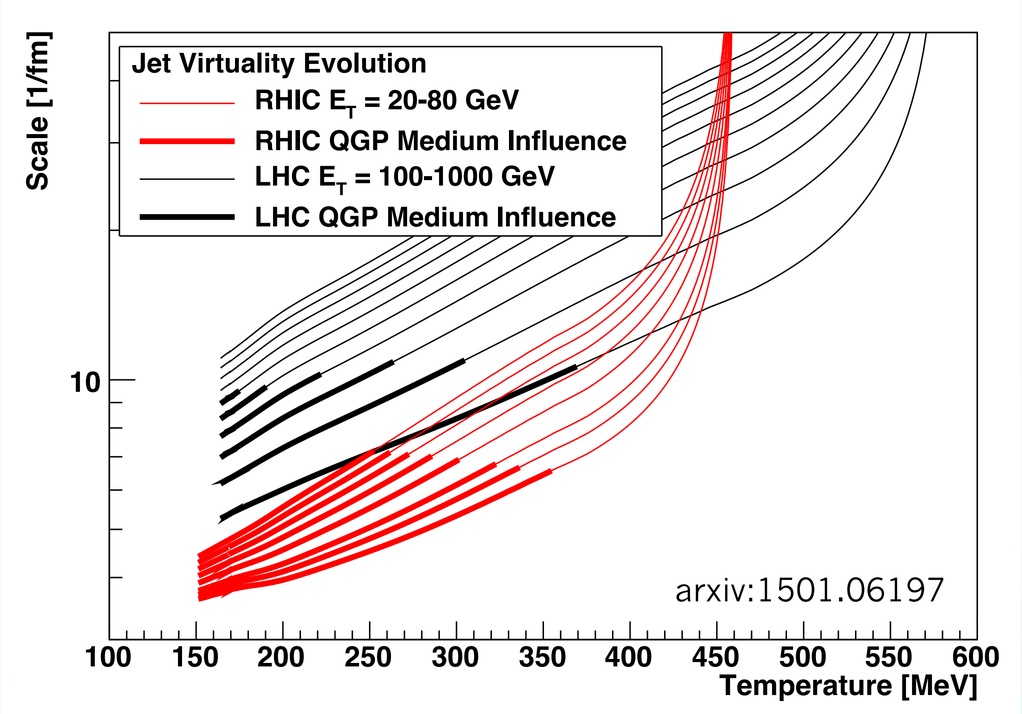
Jets and Υ mesons are ideal hard probes of the QGP!

Jet Evolution in the QGP

Virtuality and Scale



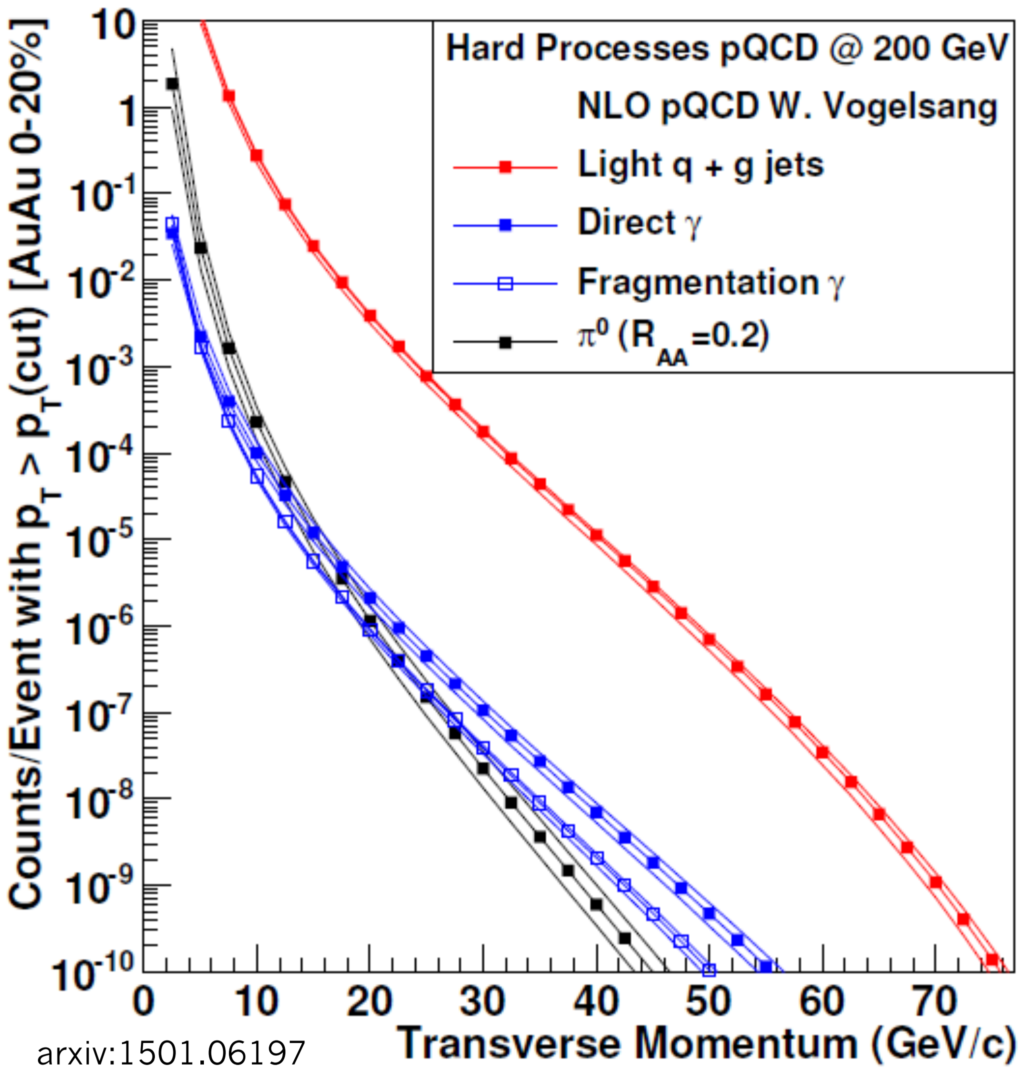




Jets interact minimally until their virtuality ~ medium virtuality

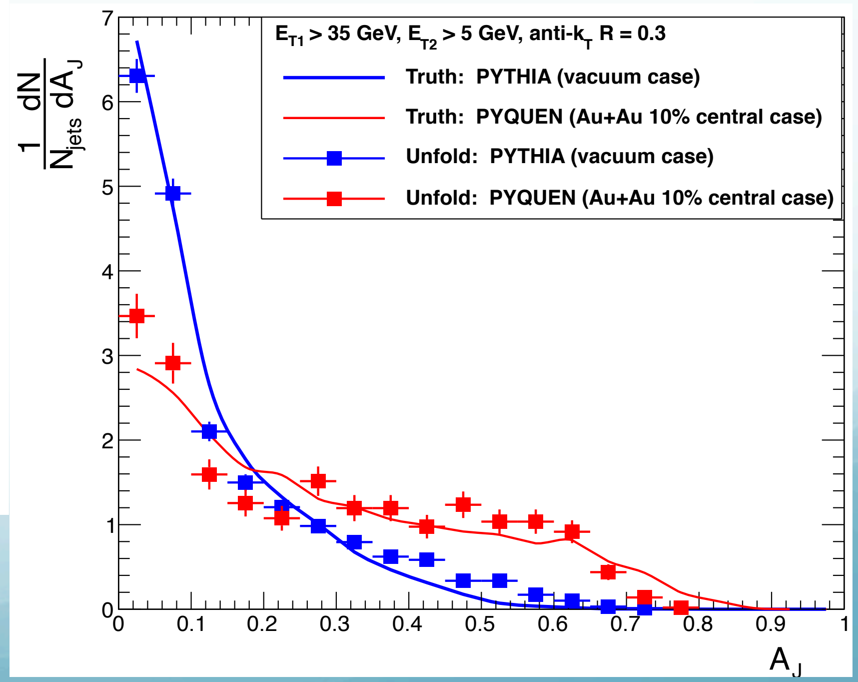
- Jets from the highest collision energies are mostly vacuum (pQCD) dominated

RHIC Jet Rates

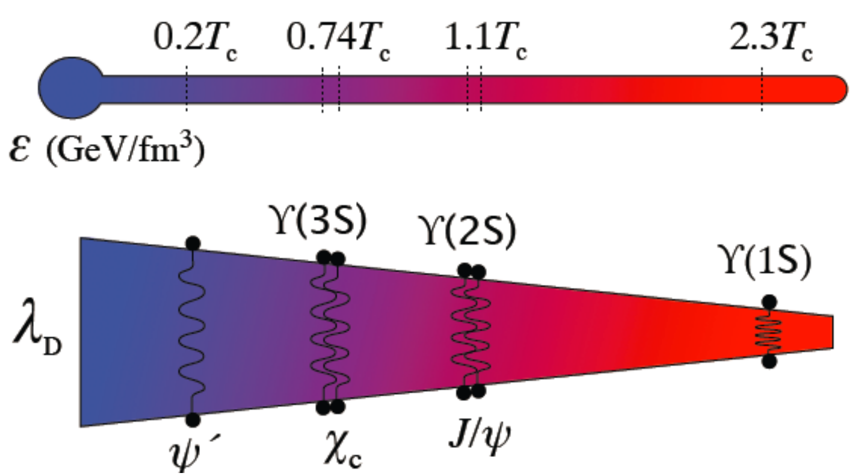


arxiv:1501.06197

- Sampling 50 billion Au +Au events in 1 year
  - 10^7 jets > 20 GeV
  - 10^6 jets > 30 GeV
  - 80% are dijet events
  - 10^4 direct γ > 20 GeV



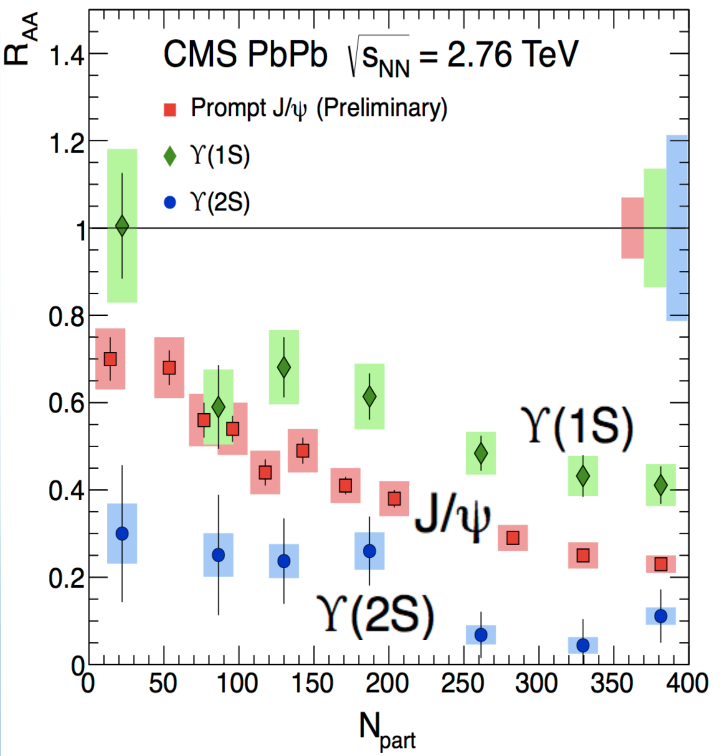
Quarkonia in the QGP

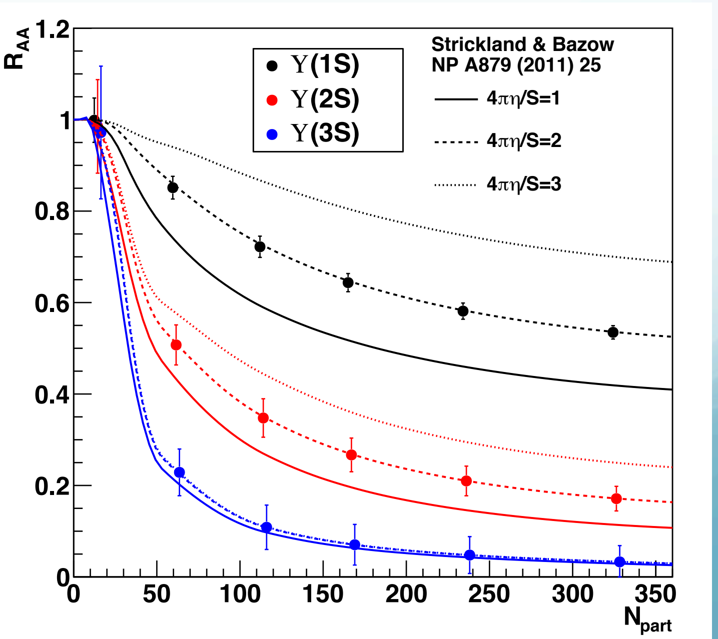


Heavy Quarkonia states will be sequentially suppressed in the QGP

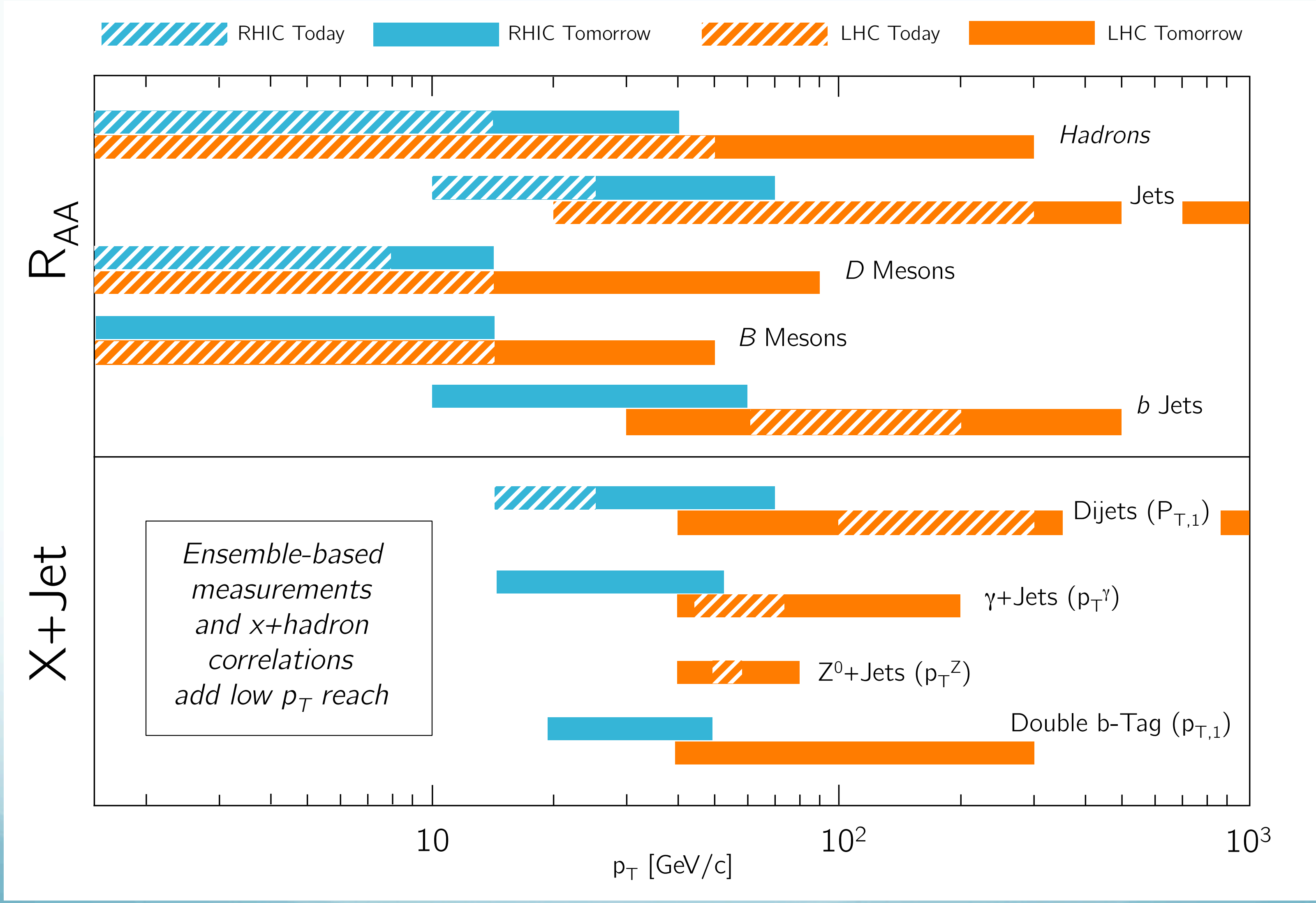
- Different Binding energies = Different sizes T. Matsui, H. Satz, Phys. Lett. B 178 , 416 (1986).+ others
- Due to color screening

PHENIX, STAR, and CMS data consistent with melting of ϒ(2S,3S) states

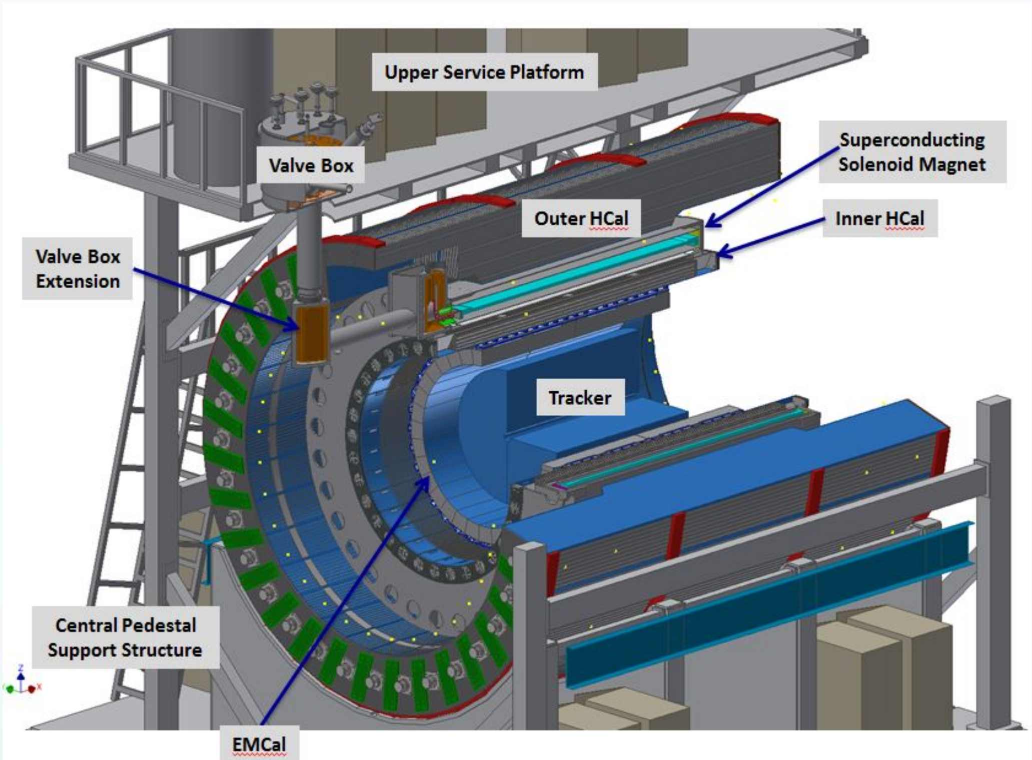




RHIC and LHC
Today vs the Future



sPHENIX Reference Design

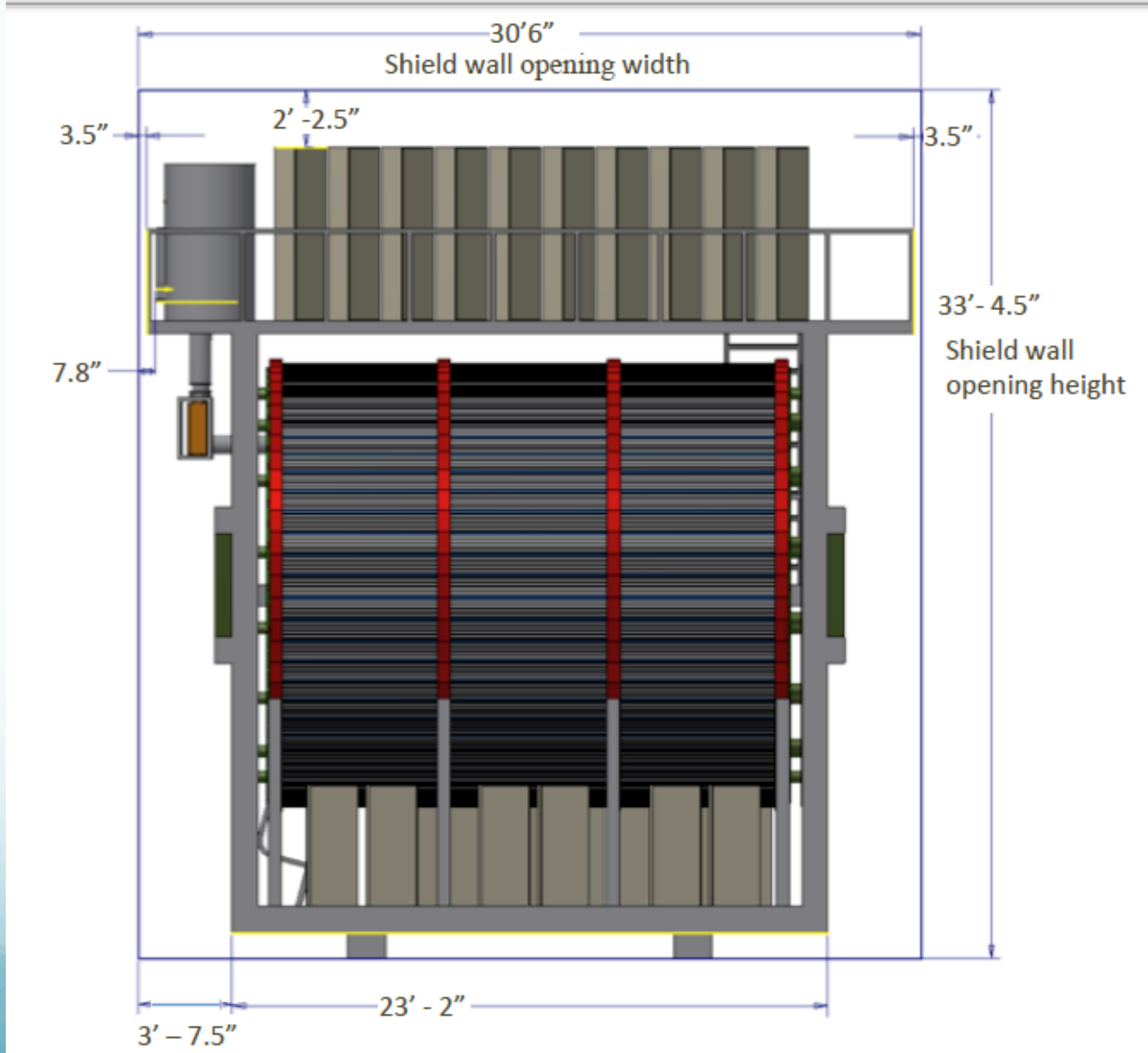


- Uniform acceptance
  - $|\eta| < 1.1$ and $\phi = 2\pi$
- Use of BaBar solenoid
- Hadronic calorimeter doubles as flux return
- Compact electromagnetic calorimeter to allowing fine segmentation at a small radius
- Solid state photodetectors which work in a magnetic field, have low cost, do not require high voltage
- Common readout electronics for all calorimeters
- High rate 14 kHz in AA will yield large unbiased MB data samples

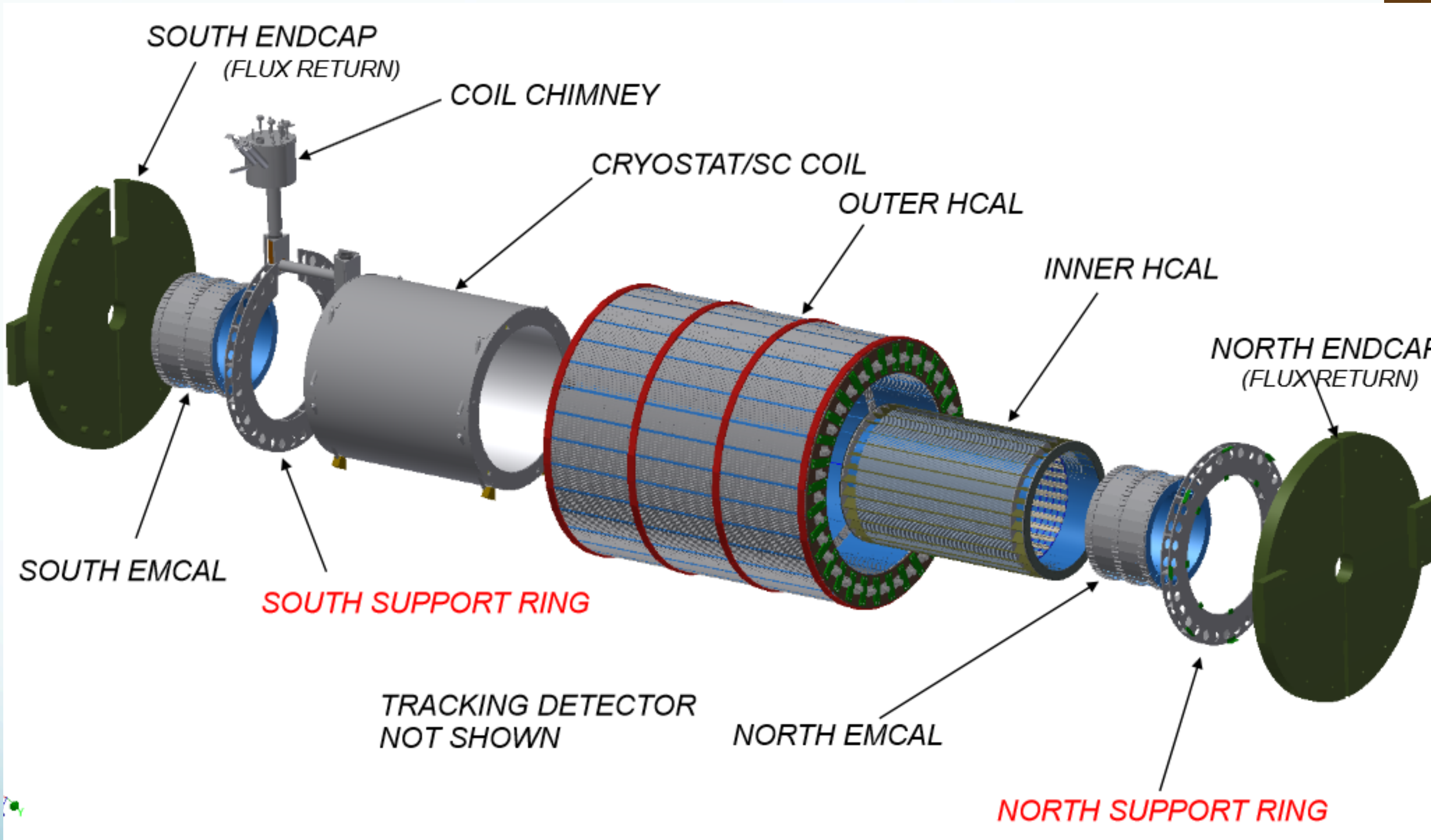
BaBar solenoid

- BaBar magnet secured from SLAC after SuperB canceled, arrived at BNL in February 2015
- Considerable additional equipment also acquired (power supplies, dump resistor, quench protection, cryogenic equipment)
- Preparing it for low power cold test
- Well suited to our needs without compromises
  - 1.5 T central field
  - 2.8 m diameter bore
  - 3.8 m long
  - $1.4X_0$ coil+cryostat

Overall Detector Size

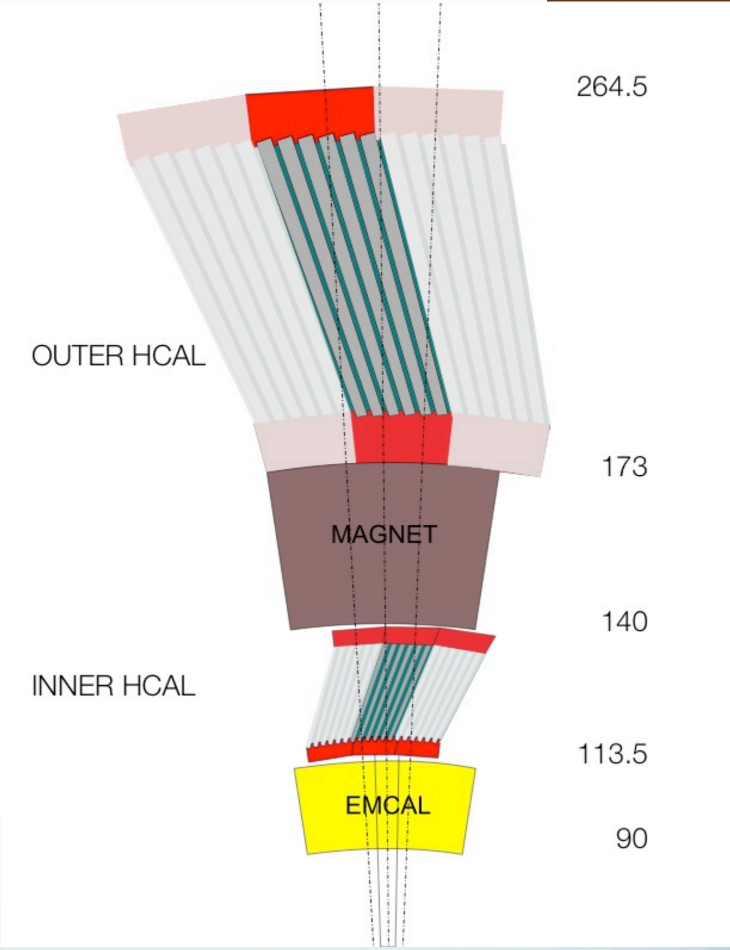


sPHENIX Design – Exploded View



Calorimeter reference design

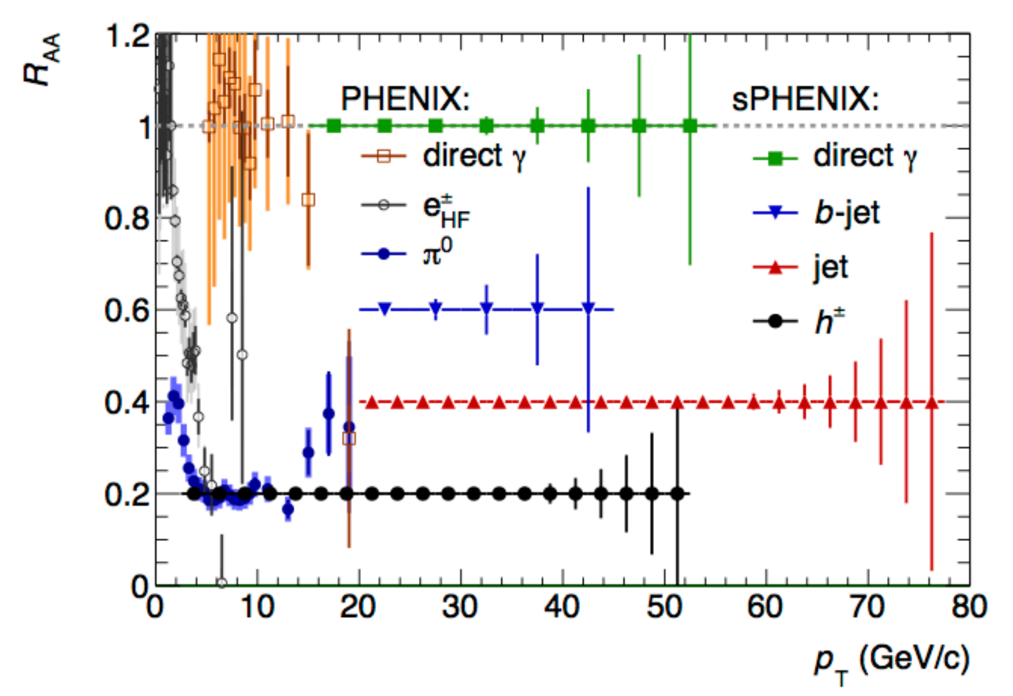
- **EMCal:** Tungsten-scintillating fiber
  - $\Delta \eta \times \Delta \phi \approx 0.025 \times 0.025$
  - 96 x 256 readout channels
  - EMCal $\Delta E/E < 15\%/\sqrt{E}$ (single particle)
- **HCAL:** Steel and scintillating tiles with wavelength shifting fiber
  - 2 Longitudinal segments.
  - An 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
  - HCal $\Delta E/E < 100\%/\sqrt{E}$ (single particle)
- Readout Solid state photodetectors (silicon photomultipliers (SiPMs), avalanche photodiodes)

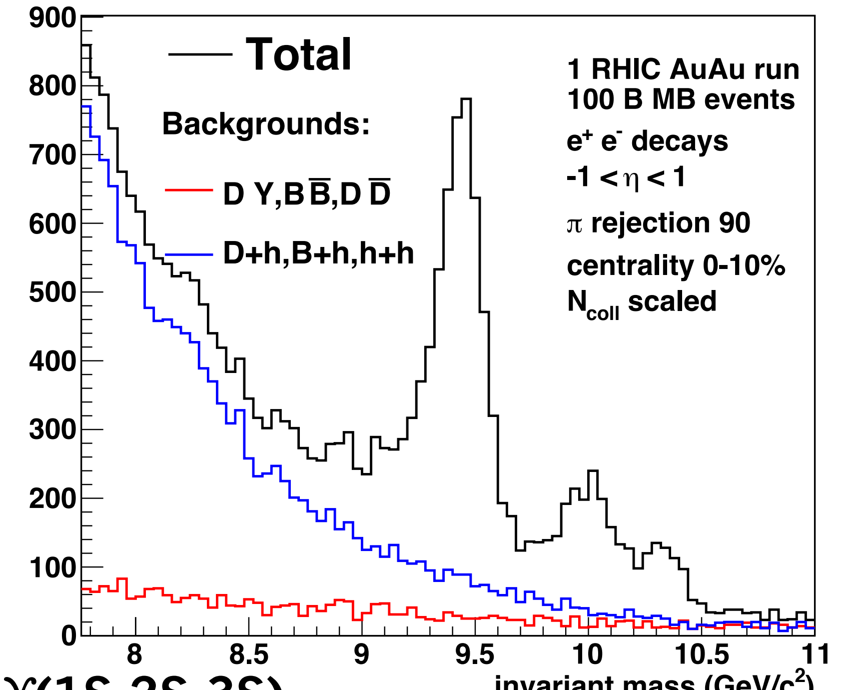


Calorimeter Observables

- Observables that drive the Calorimeter Design:
  - Photons
  - $\Upsilon \rightarrow e^+e^-$
    - Electron id: E/p matching necessary to suppress combinatoric background under ϒ states
  - Jets
    - EMCal & HCal with full, uniform acceptance over $|\eta| < 1$
      - Essential — jets are large objects in the calorimeter

~5.5 $\lambda \rightarrow$ 95% E containment

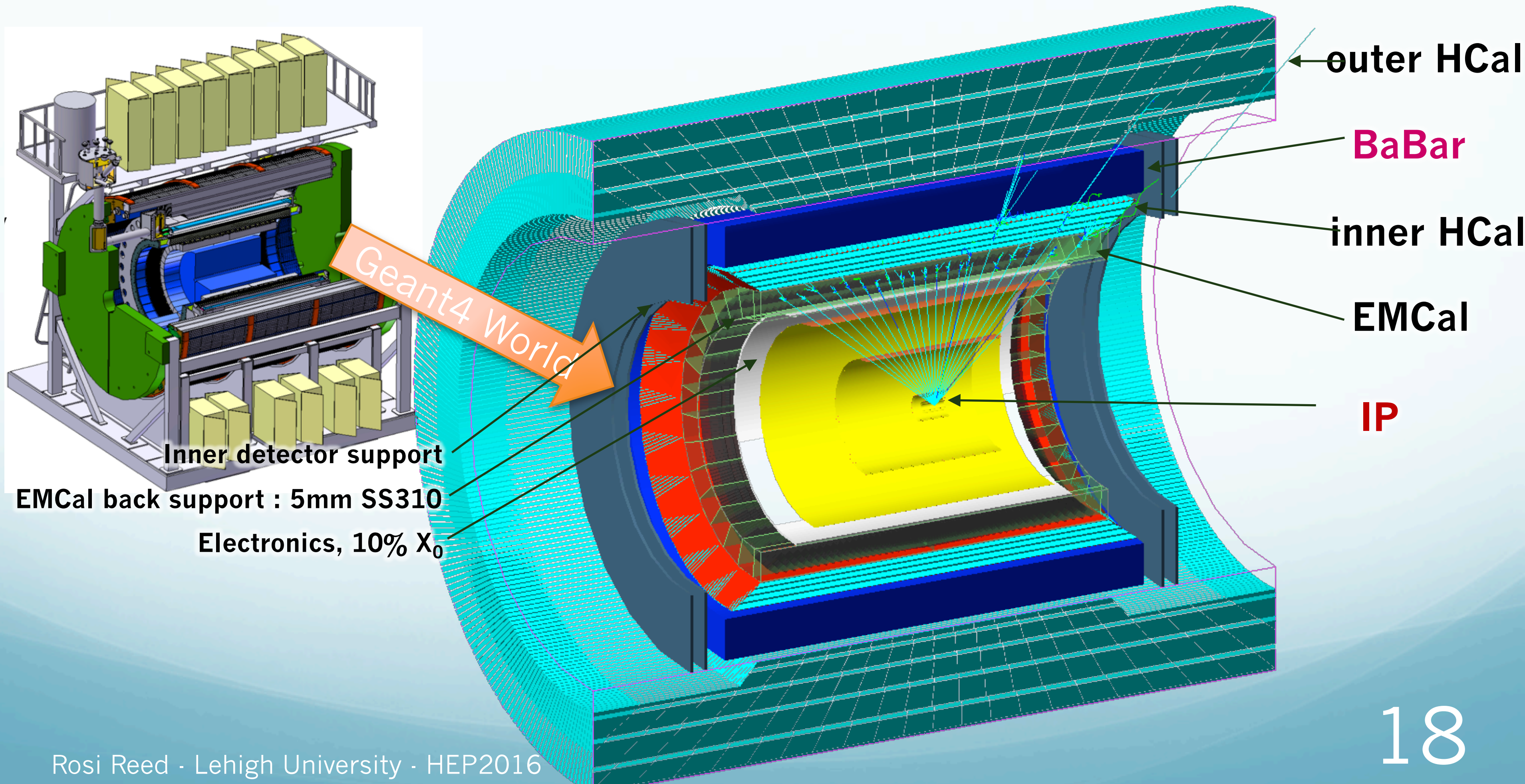




ϒ(1S,2S,3S)

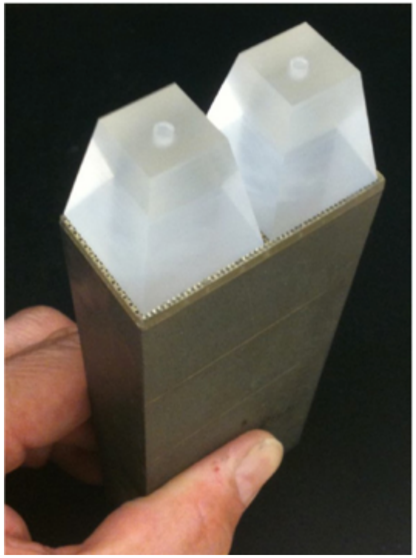
sPHENIX Calorimeter in GEANT4

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 SS-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1.4 X_0 Coil & Cryostat
- Outer hadron calorimeter (outer HCal) : 4 λ_0 SS-Scint. sampling



EMCal Plan

- Tungsten powder / scintillating fiber EMCal
  - 2.3 cm Moliere radius suitable for high mult. at a detector R of 90cm
- $\Delta\eta x \Delta\phi$ = 0.024x0.024 = ~25k towers
  - X_0 = 7mm, $18X_0$ = 12cm thick absorber
- Provides the necessary 15%/√E energy resolution

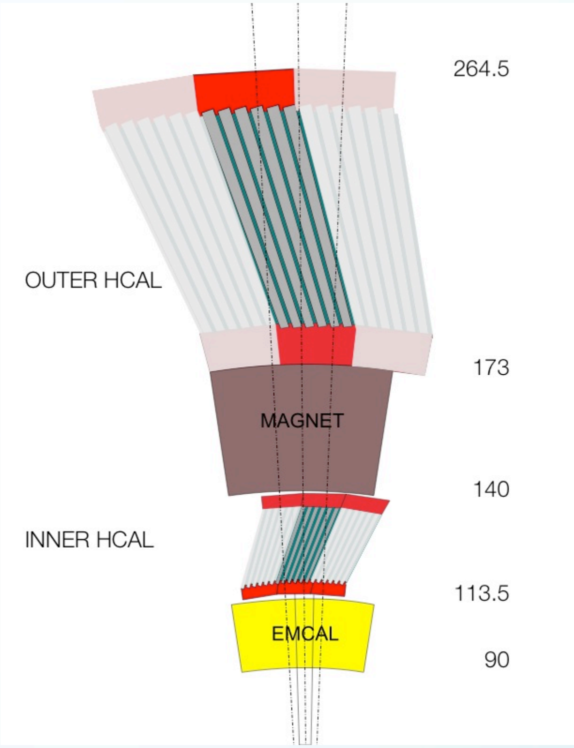


two towers

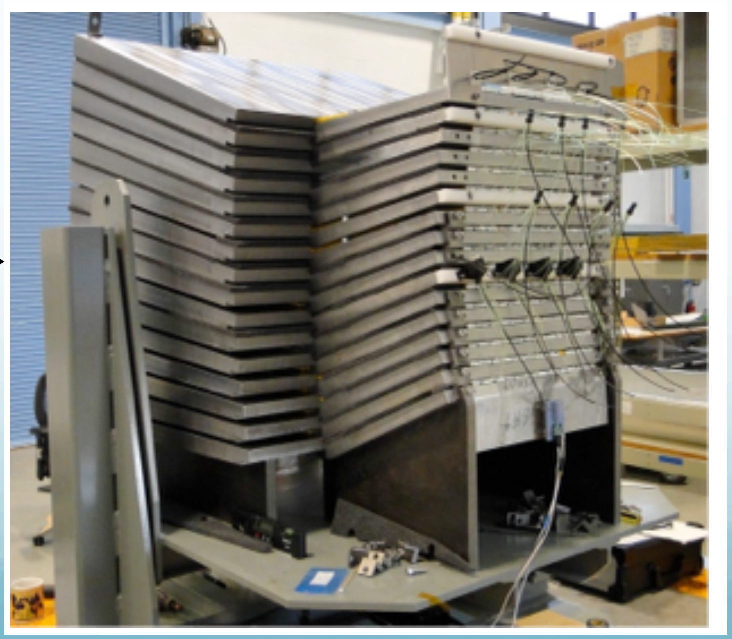
- 1D/2D projectivity is a major decision point in the EMCal design
  - fibers point back to the IP in ϕ & η or just in ϕ
  - 1D projective production under control
  - 2D projective production process needs development
  - 2D will always have better performance, but production process still under development

HCal Concept

- 2 sections
  - 1 λ between the EMCal and magnet
- 3.5 λ after magnet
- $\Delta\eta x \Delta\phi$ = 0.1x0.1
  - hadronic showers are large
- Steel absorber plates with scintillating tiles

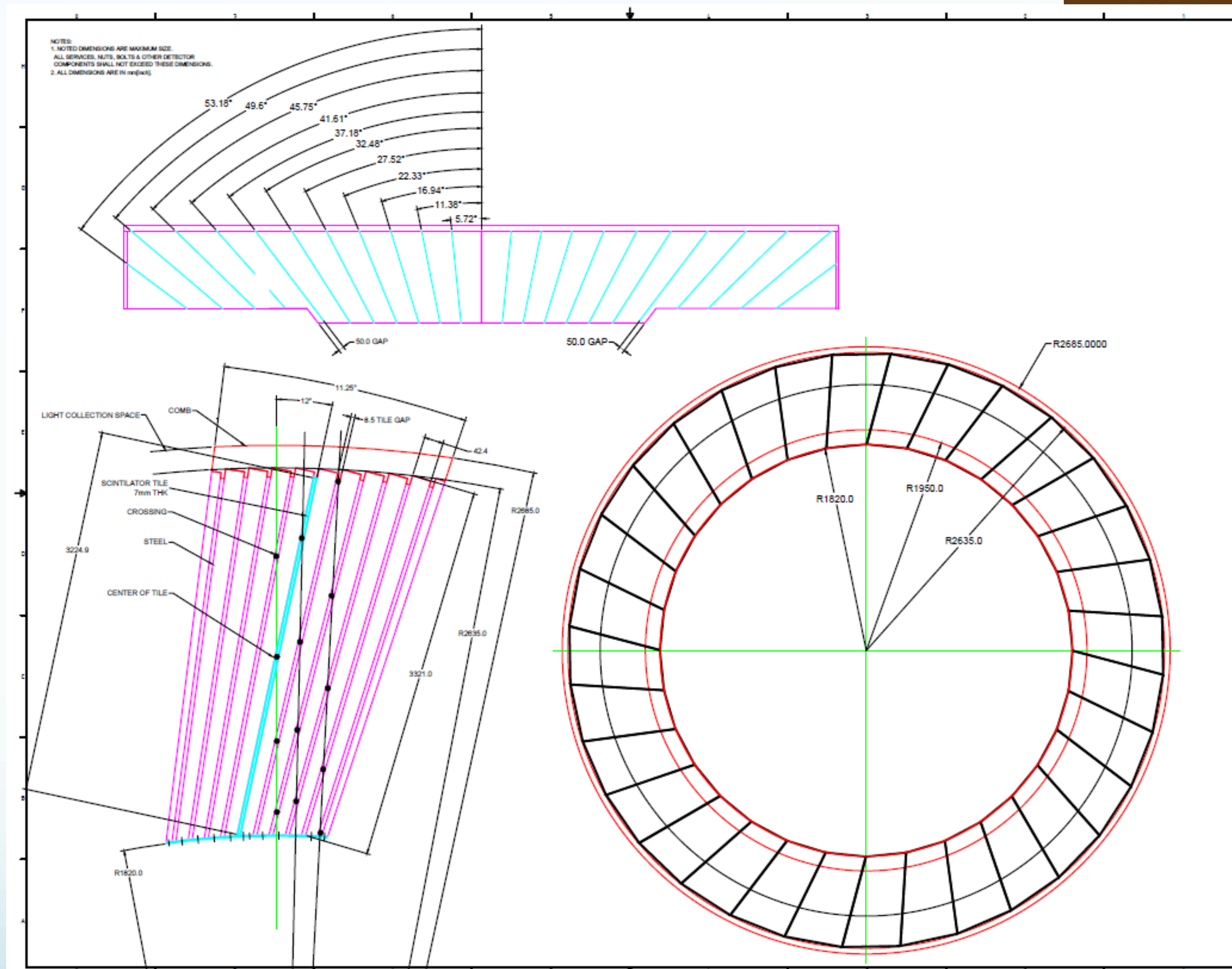


2014 Prototype →



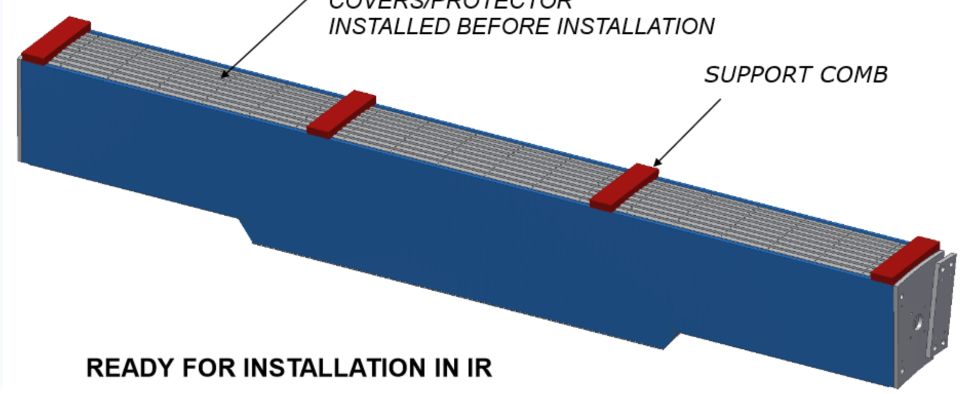
Outer HCal Reference Design

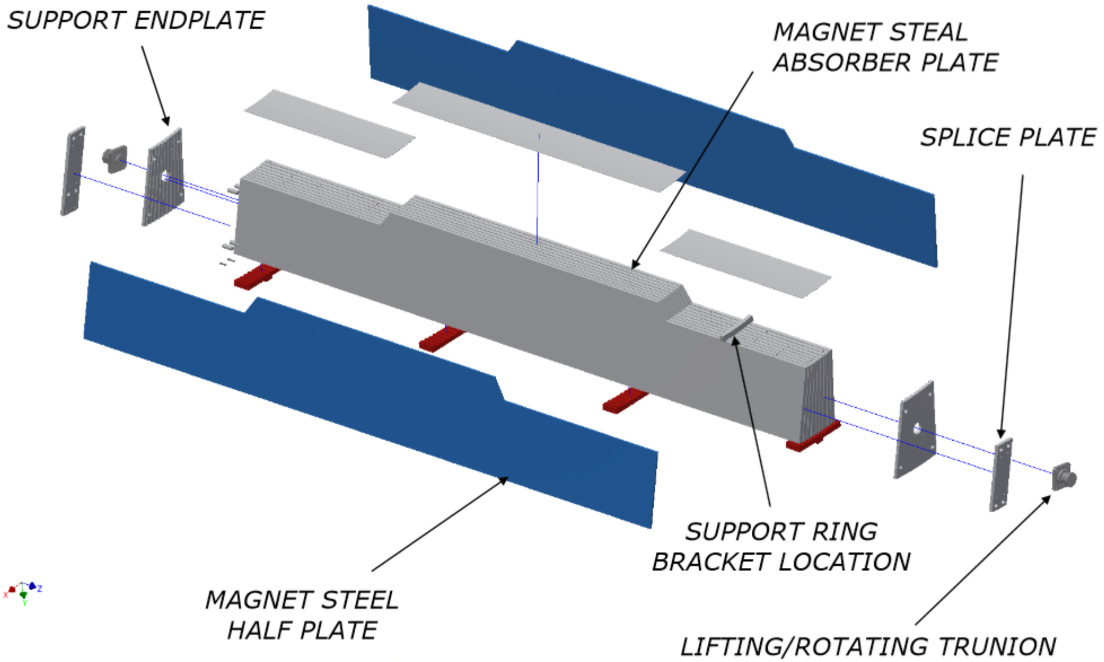
- 32 Modules
  - Inner R = 1.9m
  - Outer R = 2.6m
- 10 Rows:
  - 7mm Scintillator Tiles
- 22 Tiles/ row
- Absorber:
- Tapered 1006 Steel Plates w/thickness
  - R_{in}= 26.1mm
  - R_{out}= 42.4mm



Outer HCal Reference Design

Detailing near complete for full scale HCal Prototype. Plan is to build one in the next 12 months.



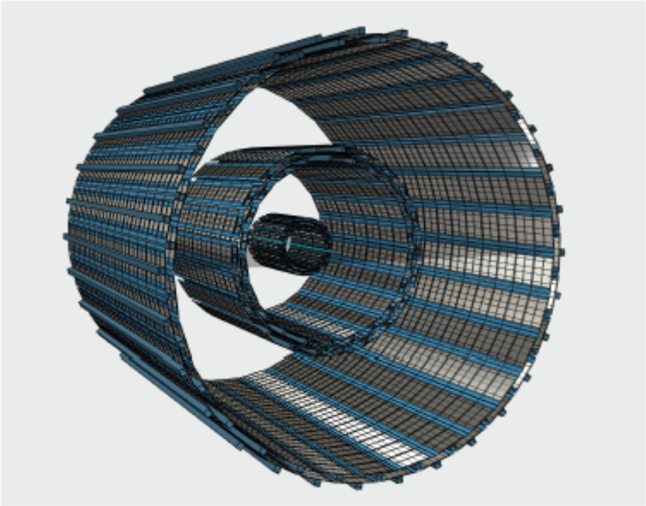


Tracker Options

Open question which tracking design gives us the Υ program at a reasonable cost

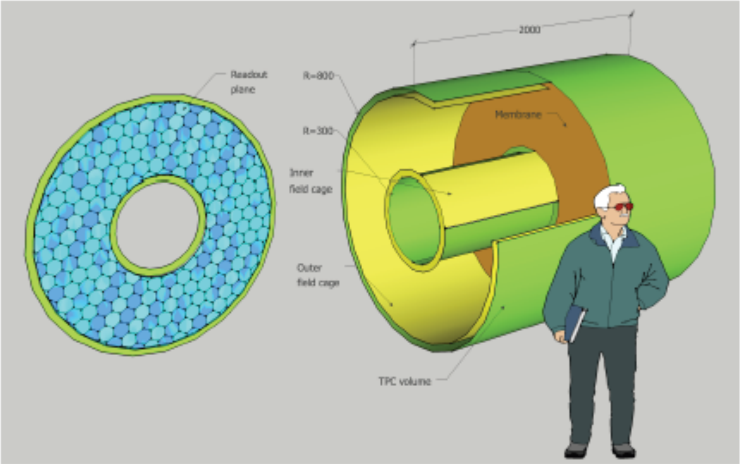
Si tracker

- 7 layers strips and pixels
- Achieves design goals of pattern recognition and 100 MeV mass resolution on Upsilon states
- Total thickness ≈$0.1X_0$



TPC + inner Si layers

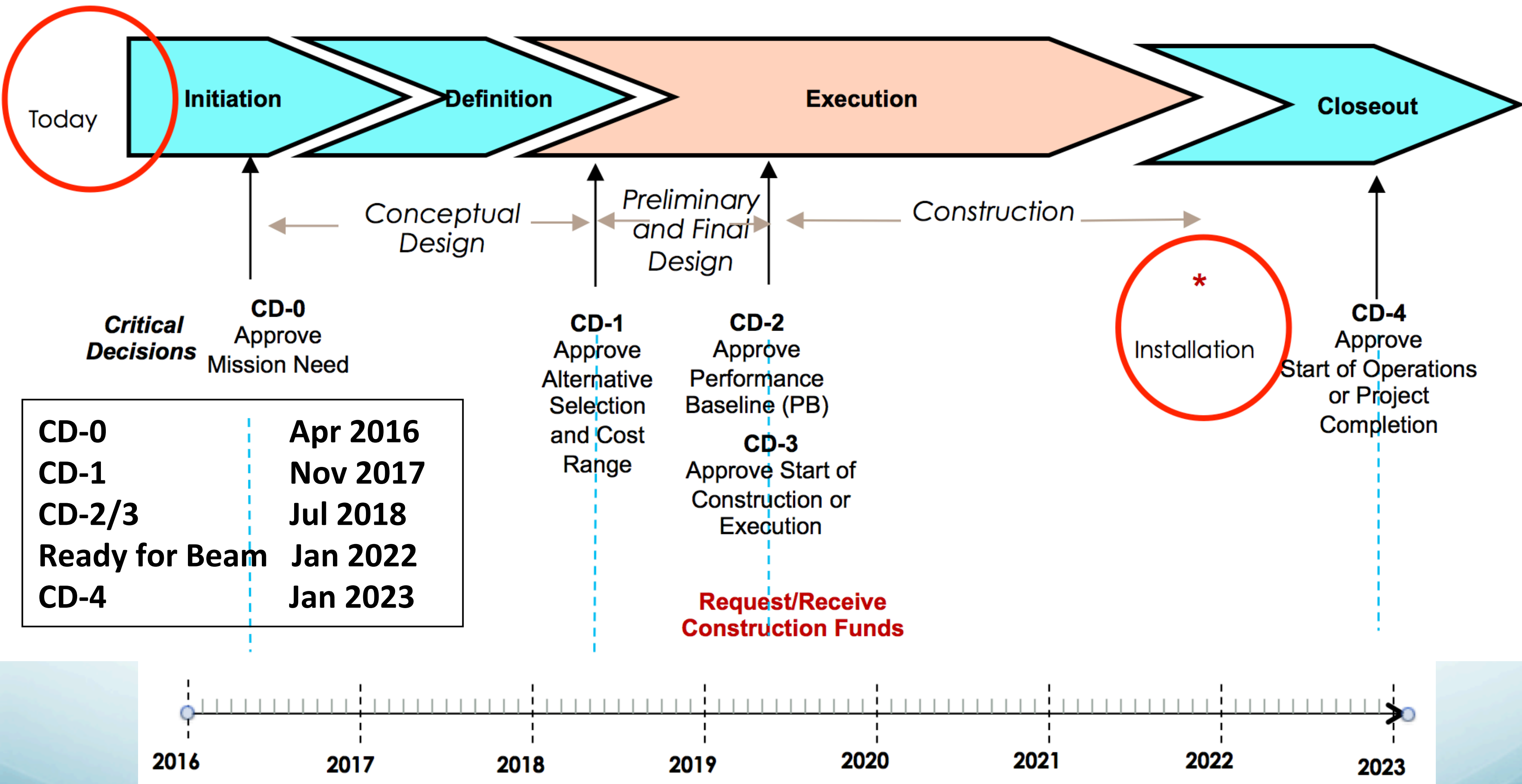
- 80 cm outer radius TPC
- Inner Si detector
- TPC electronics following from ALICE upgrade



R&D

- Workfests leading up to the July 1, 2014 DOE Science Review were used to develop concepts, simulation, and plan prototypes
- First beam test of concepts for HCAL and EMCAL Feb 5-26, 2014 in T-1044 at Fermilab Test Beam Facility
- **Second prototypes** of HCAL and EMCAL under construction now for beam test **April 4-May 3, 2016**
  - Central Rapidity Prototype (Spring 2016)
    - 5x5 tower HCAL
    - 8x8 tower EMCAL (1D projective)
  - Large Rapidity Prototype (~ Fall 2016)
    - 5x5 tower HCAL
    - 8x8 tower EMCAL (2D projective)
- Pre-Production Prototype EMCAL (~ 2017) Test
  - 1 EMCAL Sector (384 towers)
- Radiation damage tests of SiPM's, cosmic ray testing of HCAL tiles and EMCAL towers, manufacturing trials

DOE Critical Decision Scenario



CD-0	Apr 2016
CD-1	Nov 2017
CD-2/3	Jul 2018
Ready for Beam	Jan 2022
CD-4	Jan 2023

Conclusions

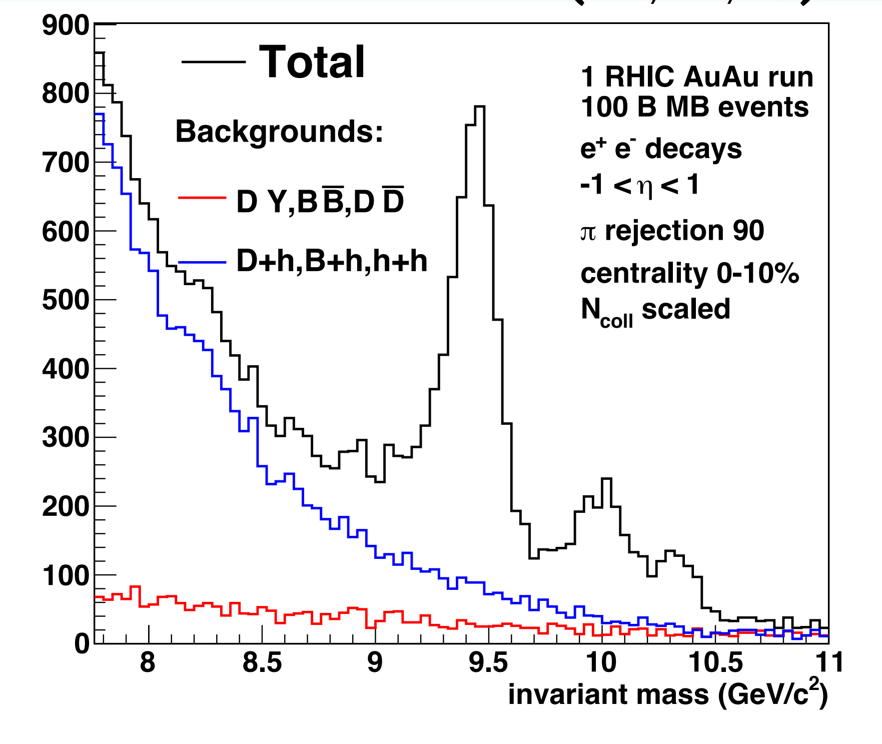
- In order to fully understand the properties of QCP at extreme temperature and density we need to extend LHC/RHIC results
  - Beyond either PHENIX/ STAR
- The sPHENIX upgrade addresses specific questions whose answers are necessary to advance our understanding of the QGP such as:
  - How does a partonic shower develop and propagate in the quark-gluon plasma?
- The detector design for the magnet, calorimeters and electronics is largely complete
  - A decision will be made on the tracking technology shortly
- First Collaboration Meeting held in December 2015
- The plan is to be **ready for beam January 2022**

Back-Up

Calorimeter Observables

- Observables that drive the Calorimeter Design:
  - Photons
    - γ/π^0 ratio > 15 GeV exceeds 1 in Au+Au
    - γ rates out to ~50 GeV
    - segmentation of EMCal needs to be < size of γ clusters
  - $\Upsilon \rightarrow e^+e^-$
    - Electron id: E/p matching necessary to suppress combinatoric background under Υ states
  - Jets
    - Reconstruction of jets from ~20 – 70 GeV
    - EMCal & HCal with full, uniform acceptance over $|\eta| < 1$
      - Essential — jets are large objects in the calorimeter
    - Good jet performance, in pp, pA, and AA
- ~5.5 $\lambda \rightarrow$ 95% E containment

Υ(1S,2S,3S)

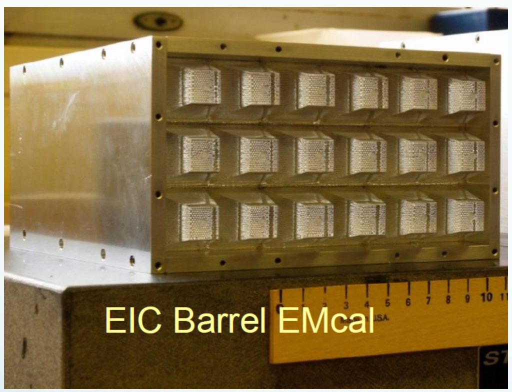


Verification of Simulation: EMCal

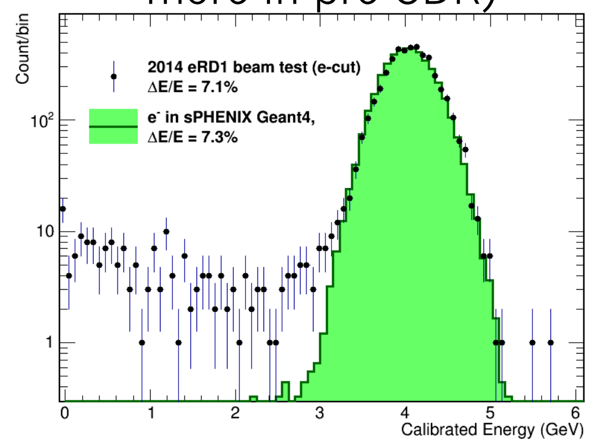
- Verification of EMCal simulation using eRD1 2014 data VS sim using sPHENIX Geant4
- Need this excessive with sPHENIX config, better quantification of hadron tail/tunnel effect

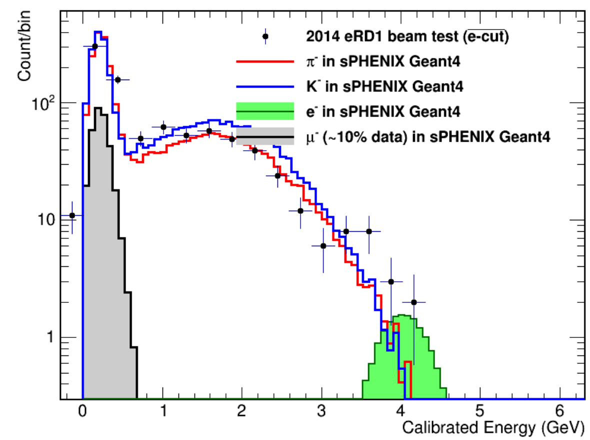
eRD1 2014 test beam (UCLA)

- 1D projective tower in 3x6 block
- slightly different fiber with double cladding

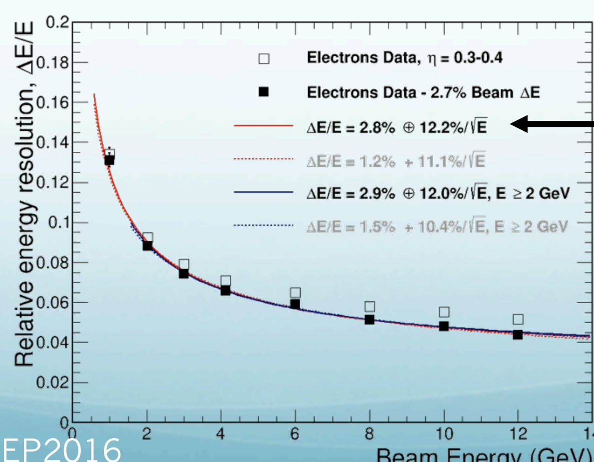


Beam test data reproduced in simulation (4GeV shown, more in pre-CDR)

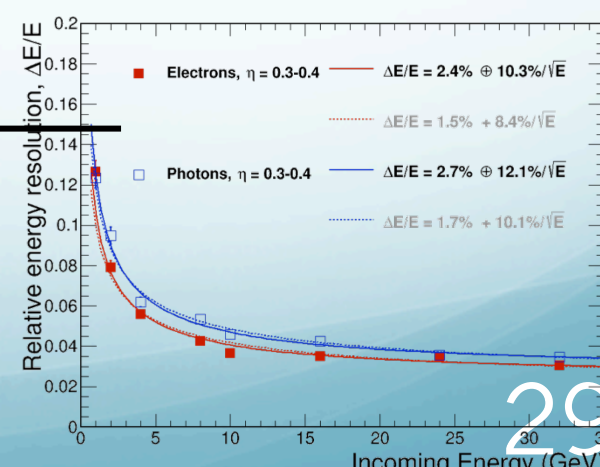




Energy resolution: eRD1 test beam

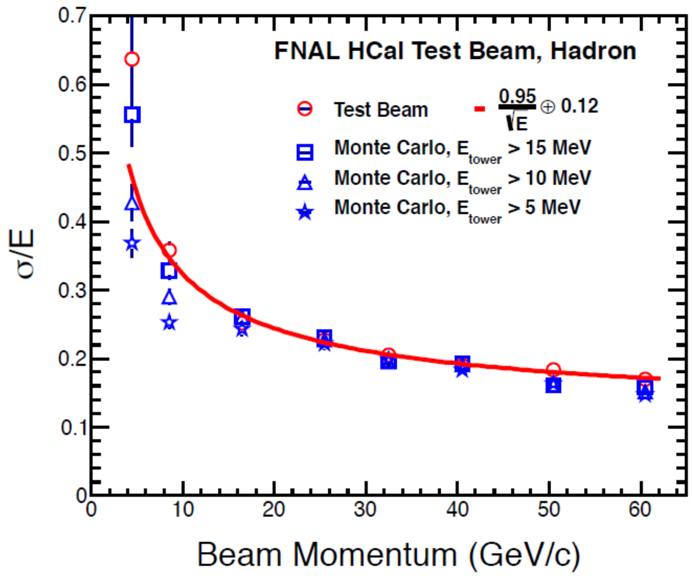


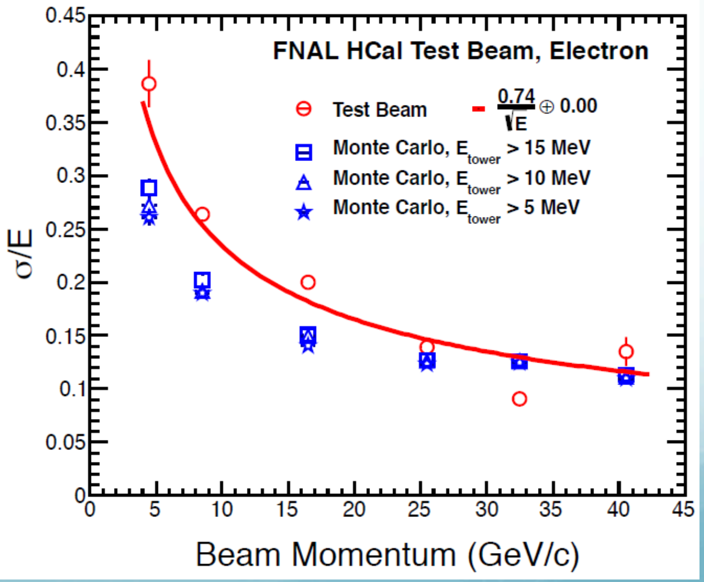
sPHENIX full SPACAL



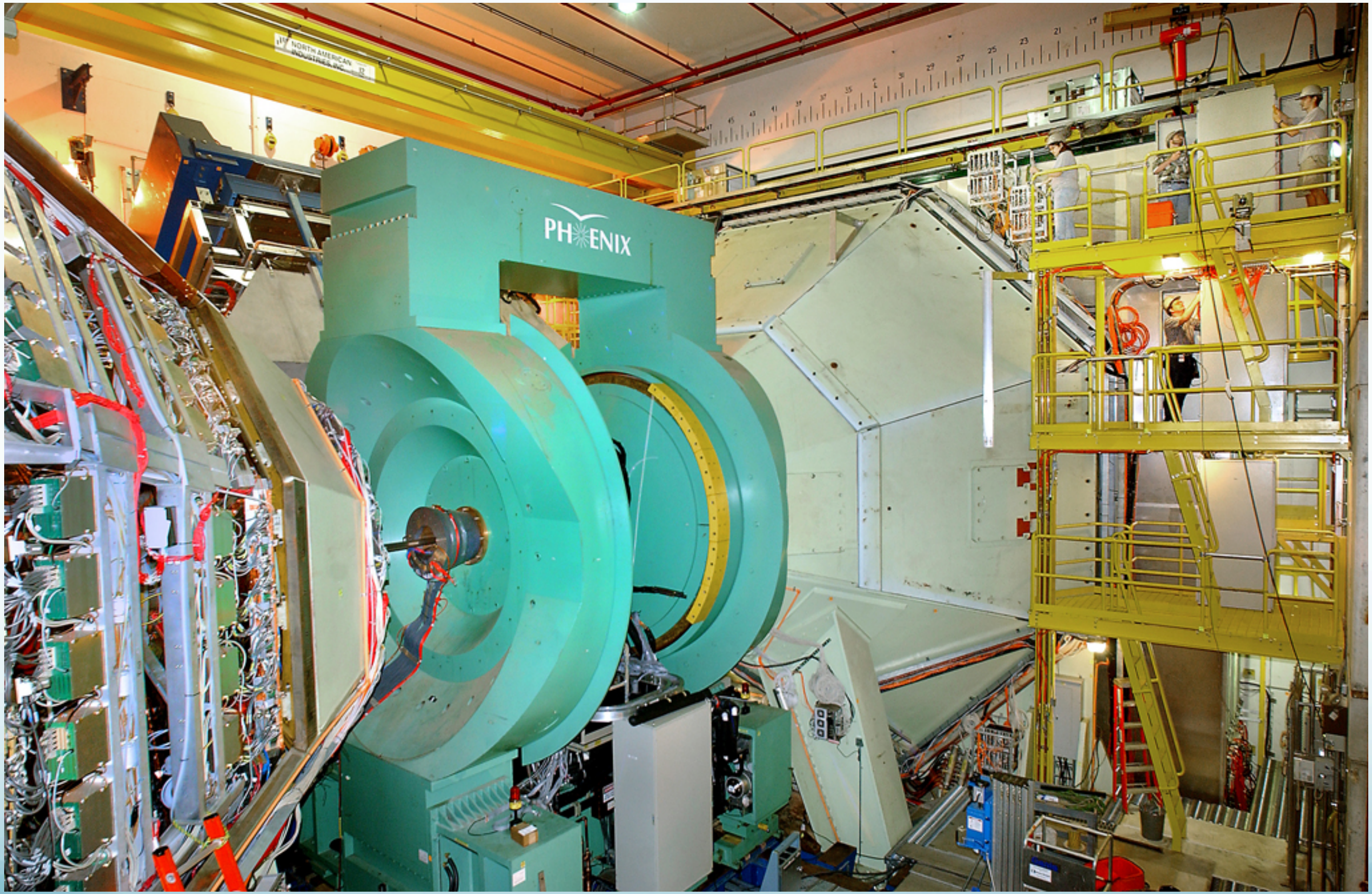
Verification of Simulation: HCal

- HCal Simulation tested against Apr 2014 sPHENIX Fermi-lab test beam (HCals alone, v1-design)
- Reasonably reproduced resolution
- New test beam Apr 2016 with full calorimeter system planned (EMCal + Inner Hcal + magnet gap + Outer HCal). Effort on-going with GSU group

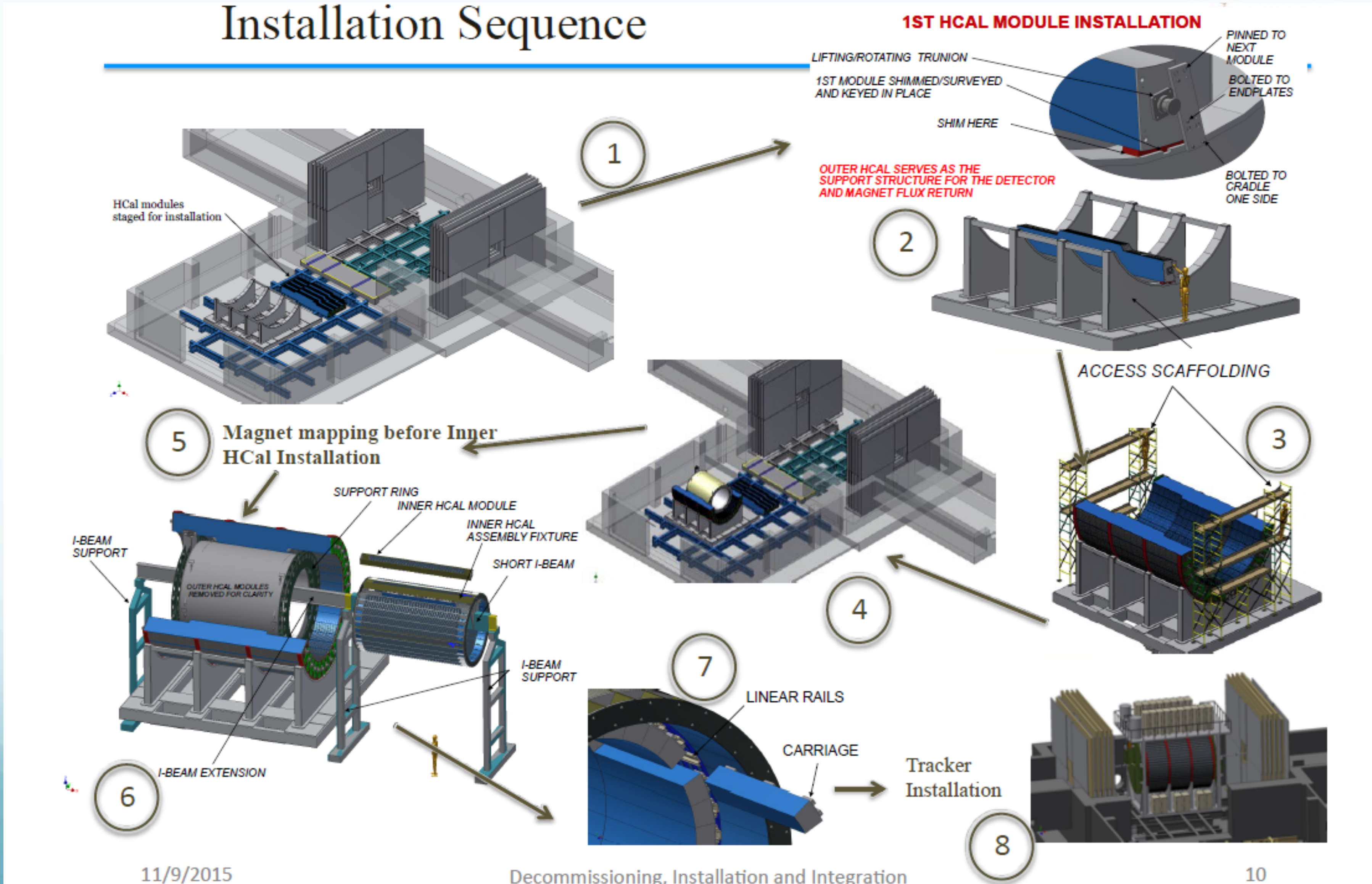




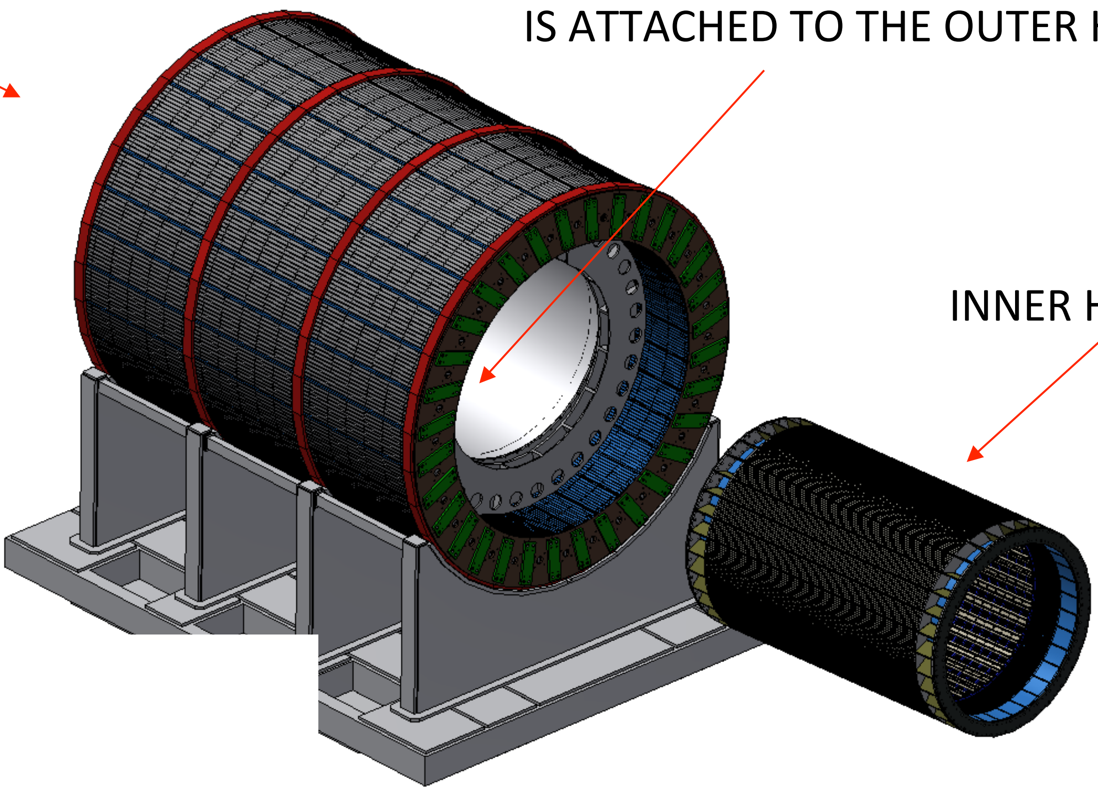
Phenix Today

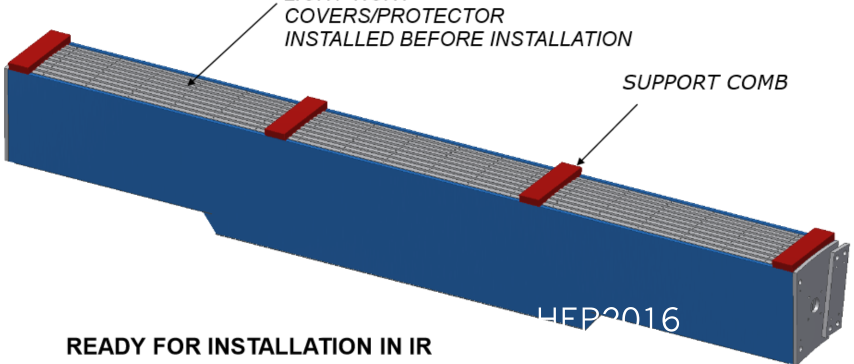


Mechanical Design

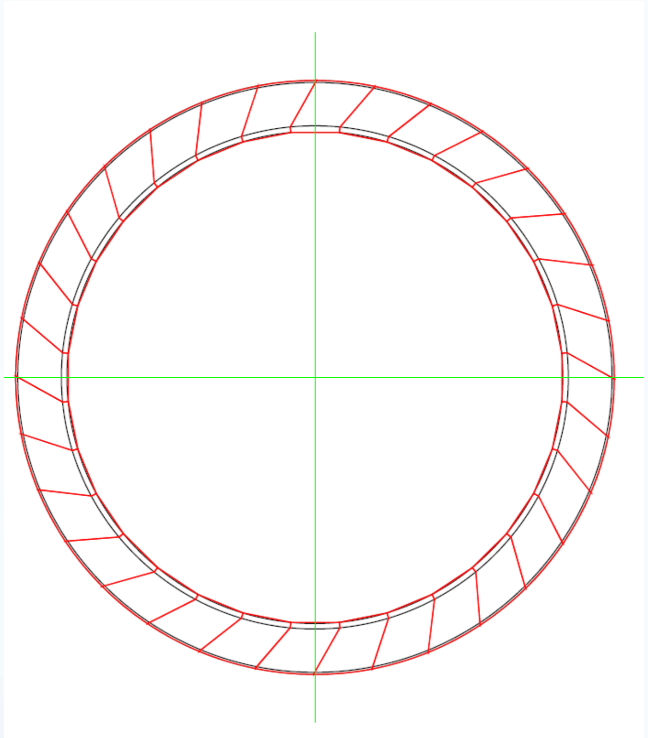


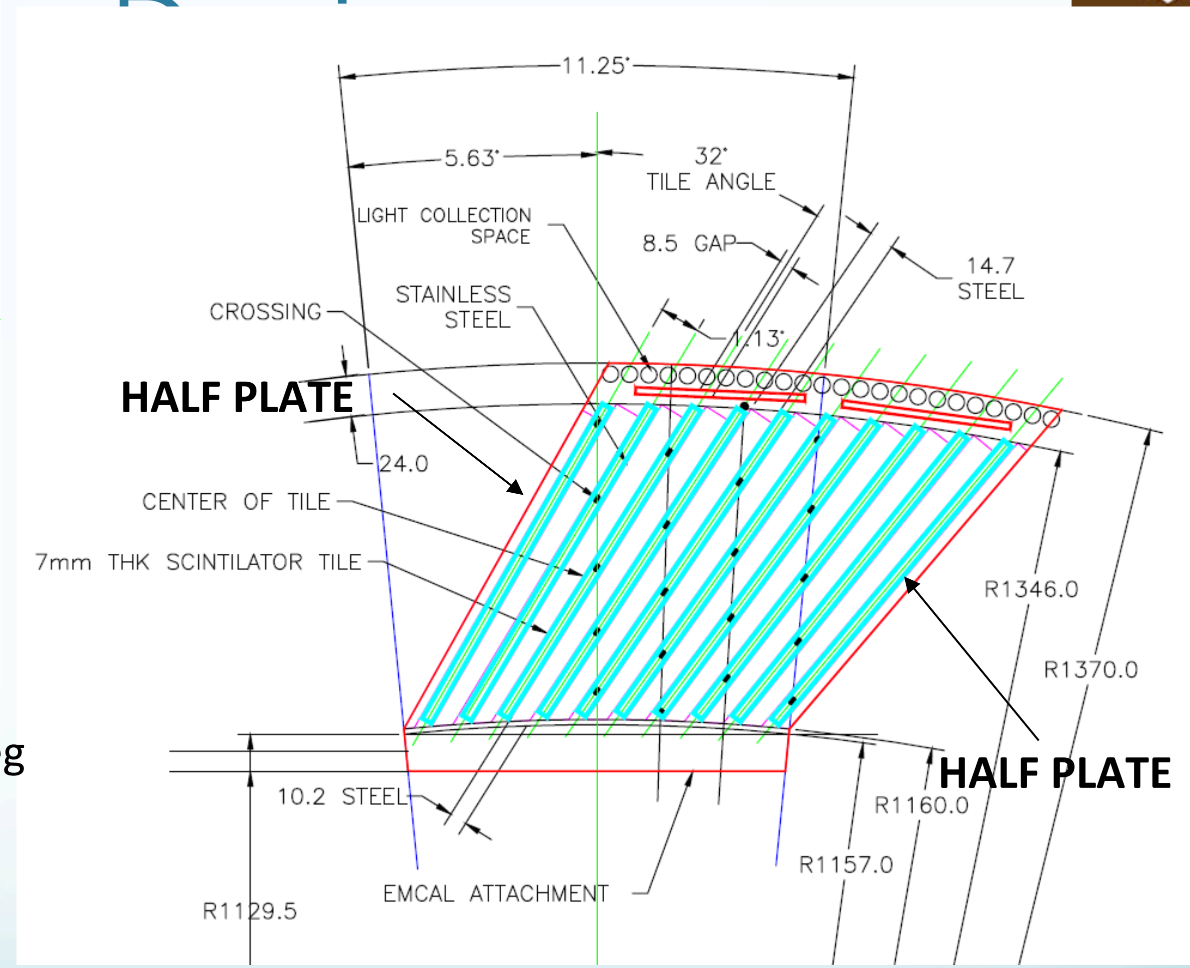
Structure + Integration of HCal





Inner HCal Reference



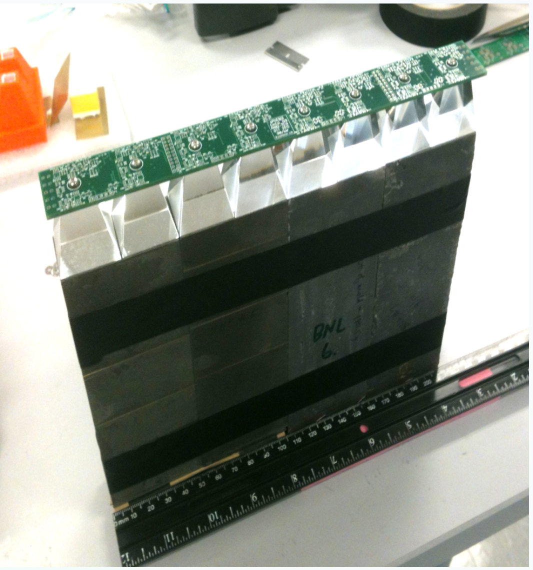


32 MODULES COVERING 360deg

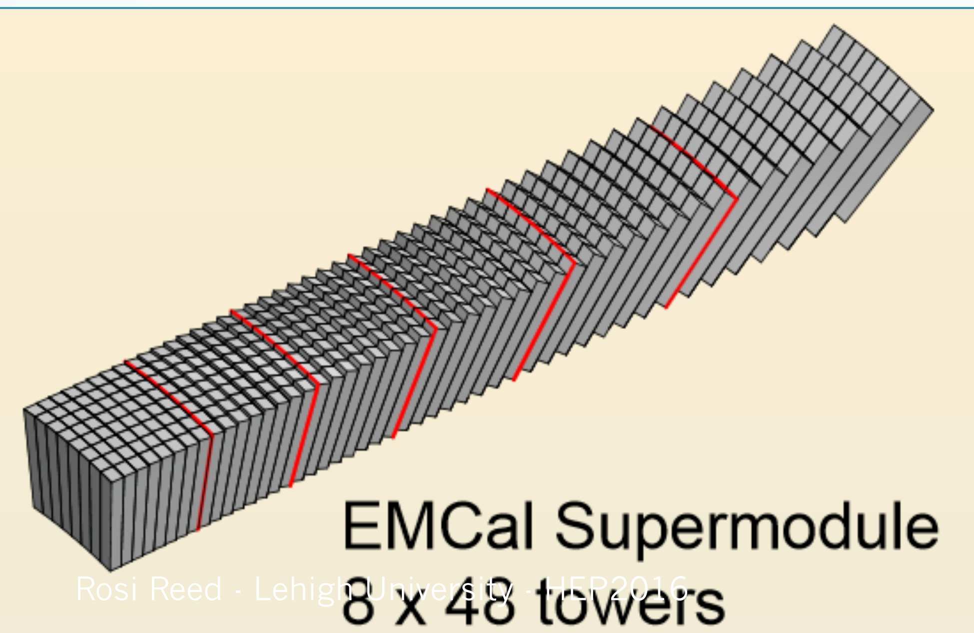
INNER RADIUS ENVELOPE -1.16m
OUTER RADIUS ENVELOPE - 1.37m

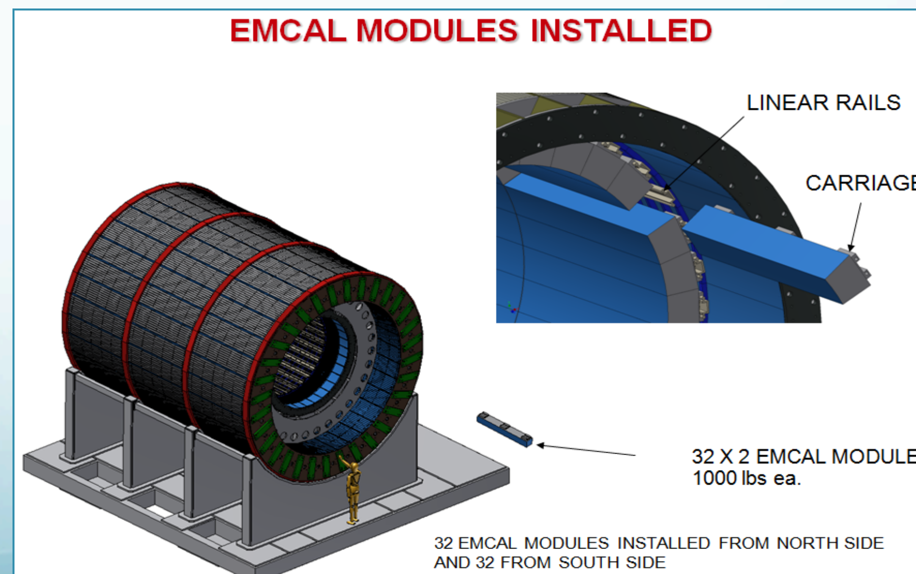
10 ROWS of 7mm Scint Tiles
22 Tiles in each row.
32deg Tilt Angle
~10.2mm – ~14.7mm Tapered SST 304 Plates

EMCal Reference Design

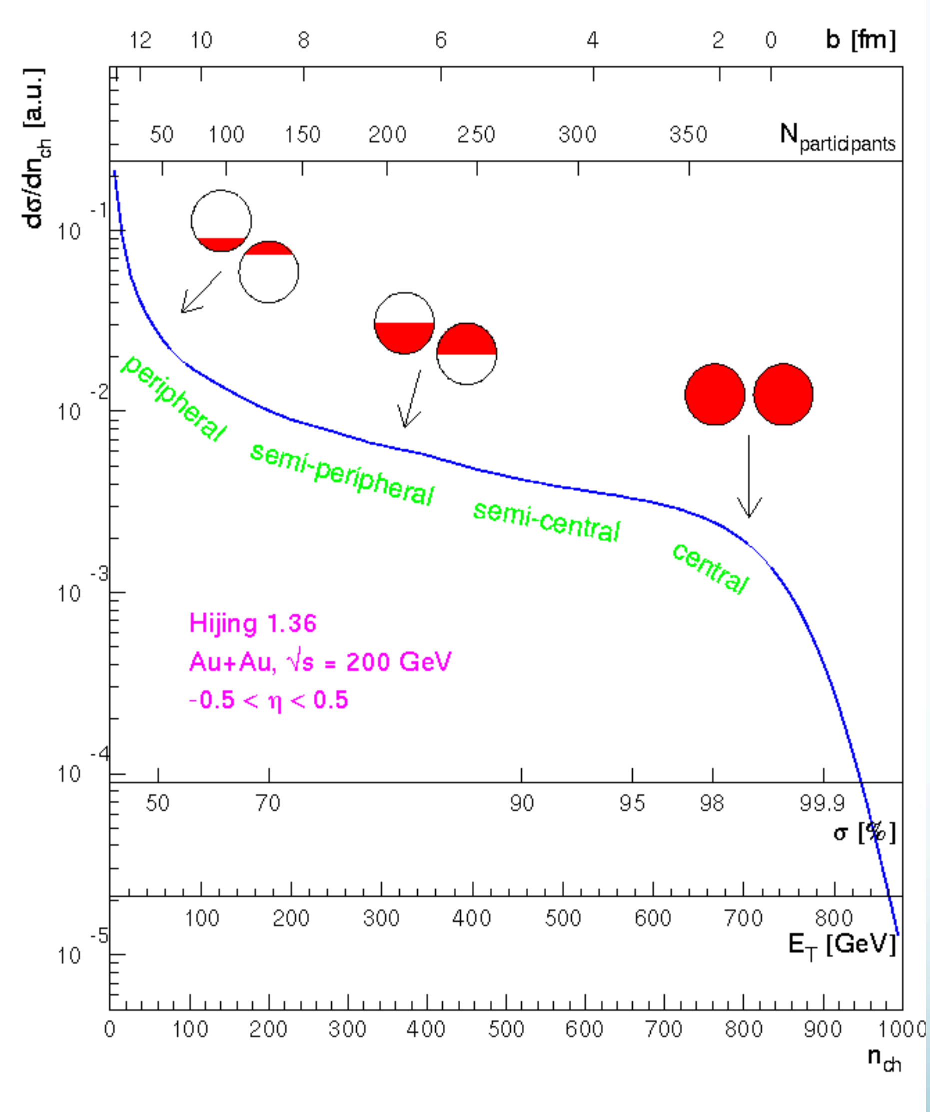


- CAD engineers working with Physics Dept personnel and university collaborators
- Efforts to produce towers of spacal modules using UCLA-developed design is ongoing at UCLA, UIUC and Tungsten Heavy Powder
- Work supported in part RHIC and EIC R&D
- Ultimately want to build ~25k towers





Centrality in Heavy-ion Collisions



Collision centrality defined by **impact parameter** between colliding nuclei

b = impact parameter

$N_{participants}$ = # of nucleons that collide

$N_{collisions}$ = # of total collisions

% central = % of total cross-section at that impact parameter