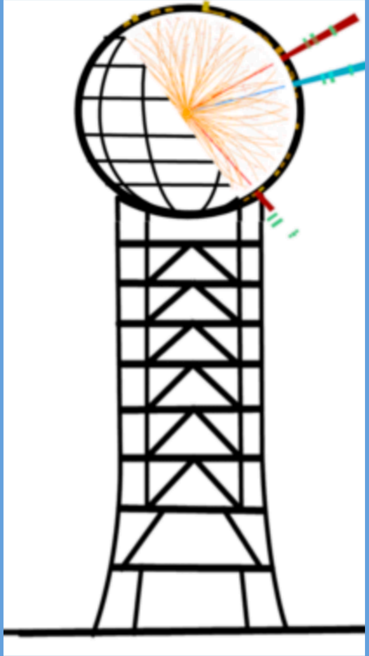
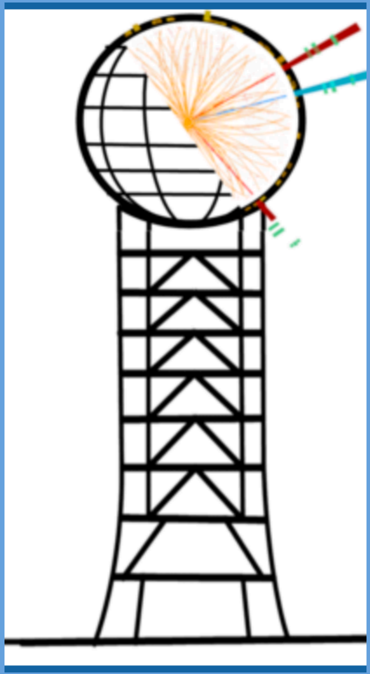
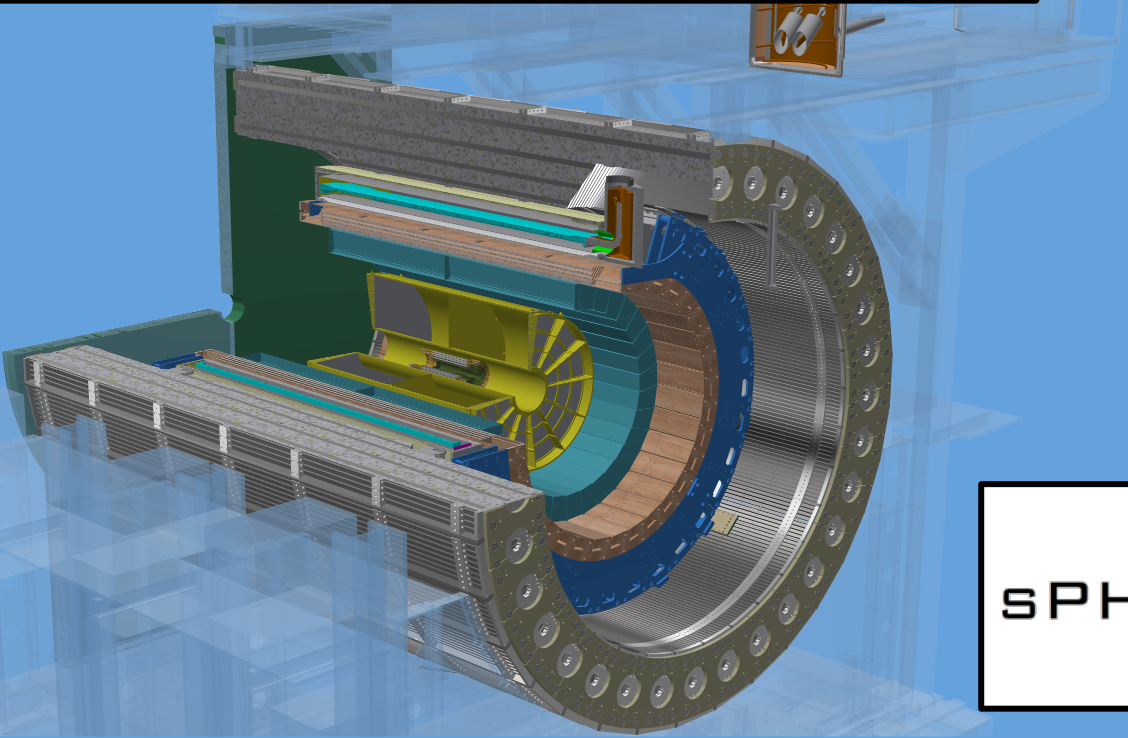


High p_T measurement opportunities with sPHENIX



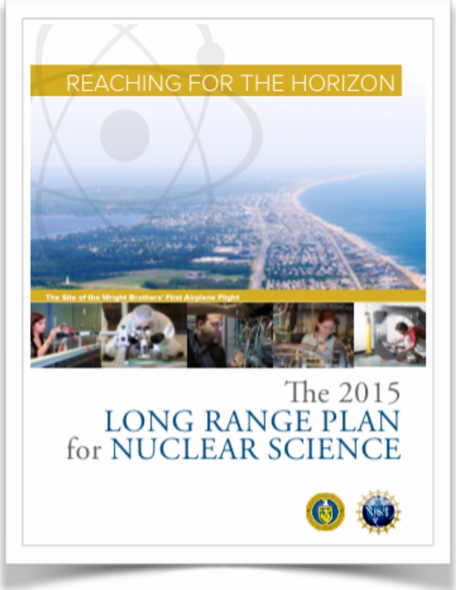
13th international workshop on High-p_T Physics in the RHIC/LHC era

Rosi Reed



Complementarity

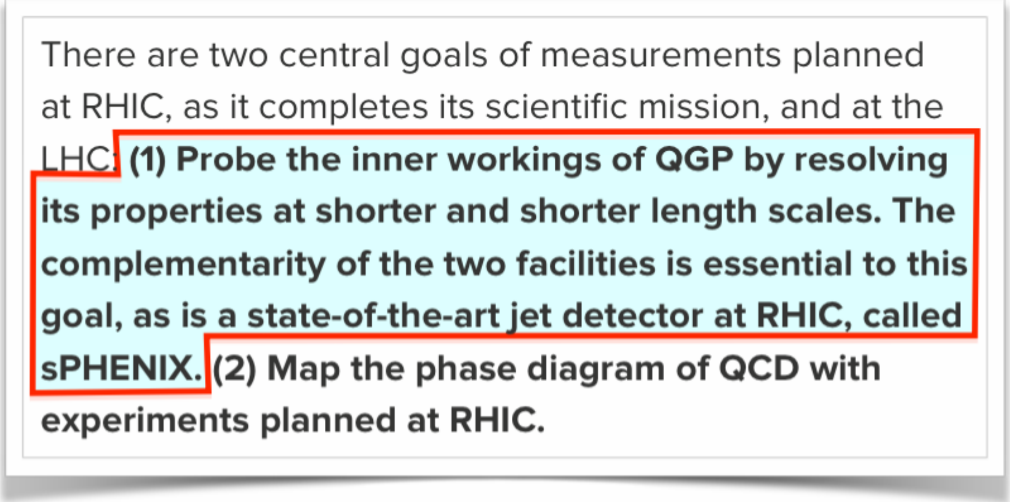
13^{th} international workshop on High-p_T Physics in the RHIC/LHC era



REACHING FOR THE HORIZON

The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

Section 2.2, page 22 →

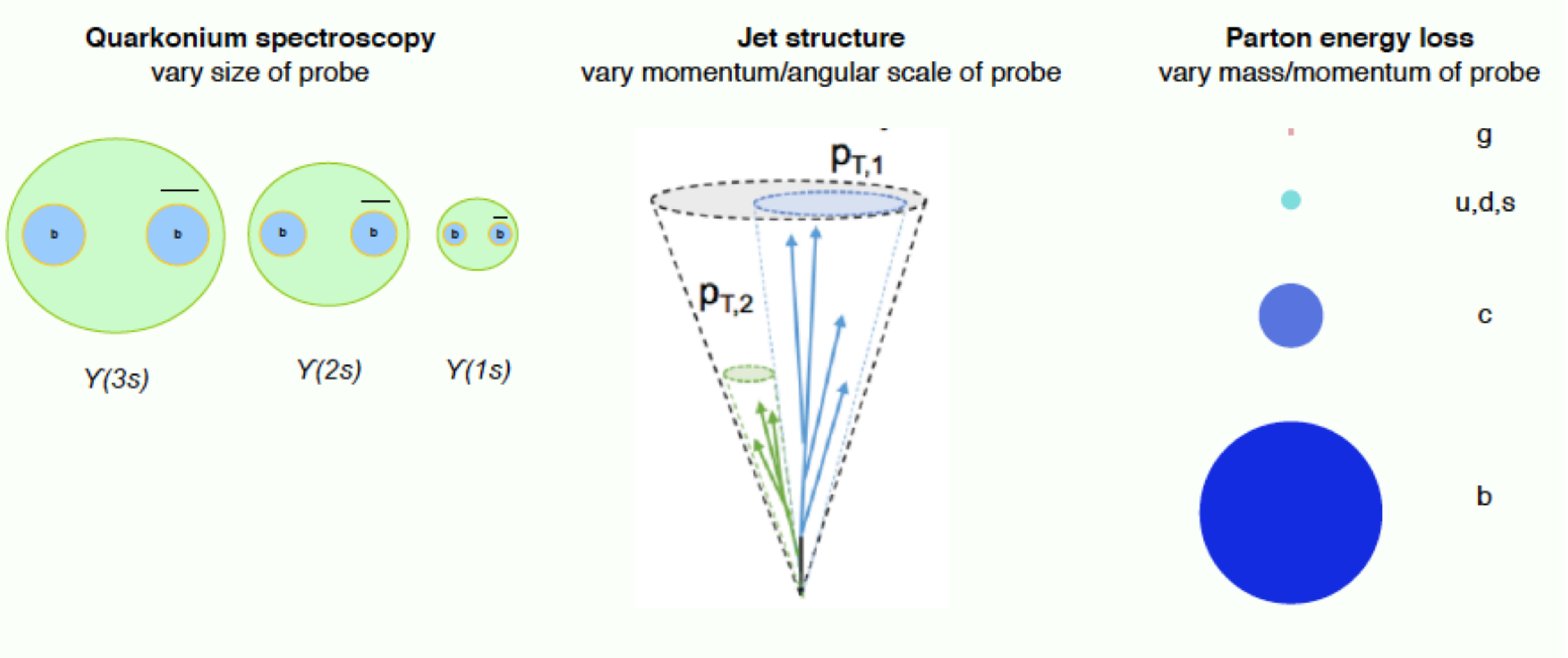


There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

Apples-to-apples RHIC/LHC comparisons necessary to fully understand the QGP → Same probes at different energies!

Core sPHENIX science program

Key approach → Study the structure of the QGP at multiple scales!



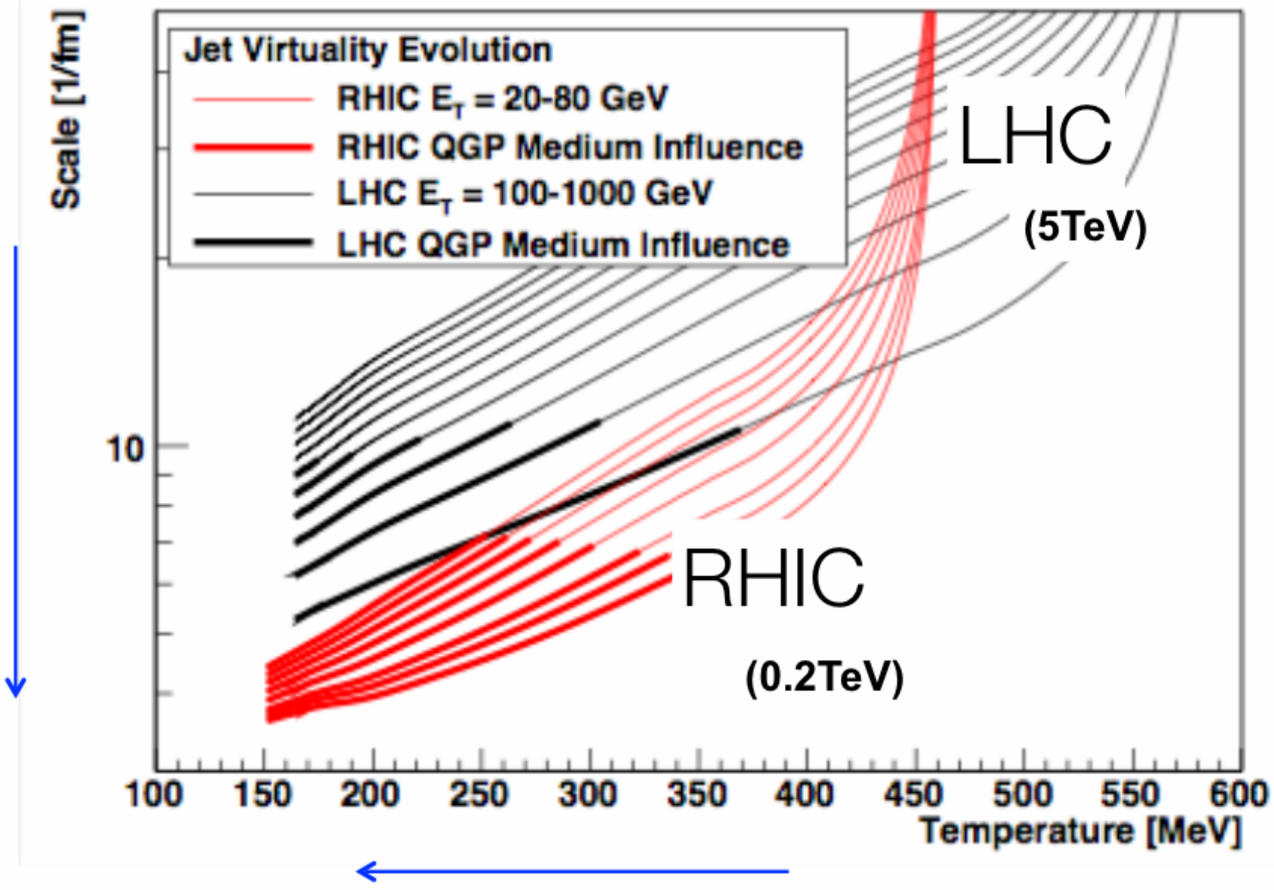
Quarkonium spectroscopy
vary size of probe

Jet structure
vary momentum/angular scale of probe

Parton energy loss
vary mass/momentum of probe

Jet Evolution @ RHIC

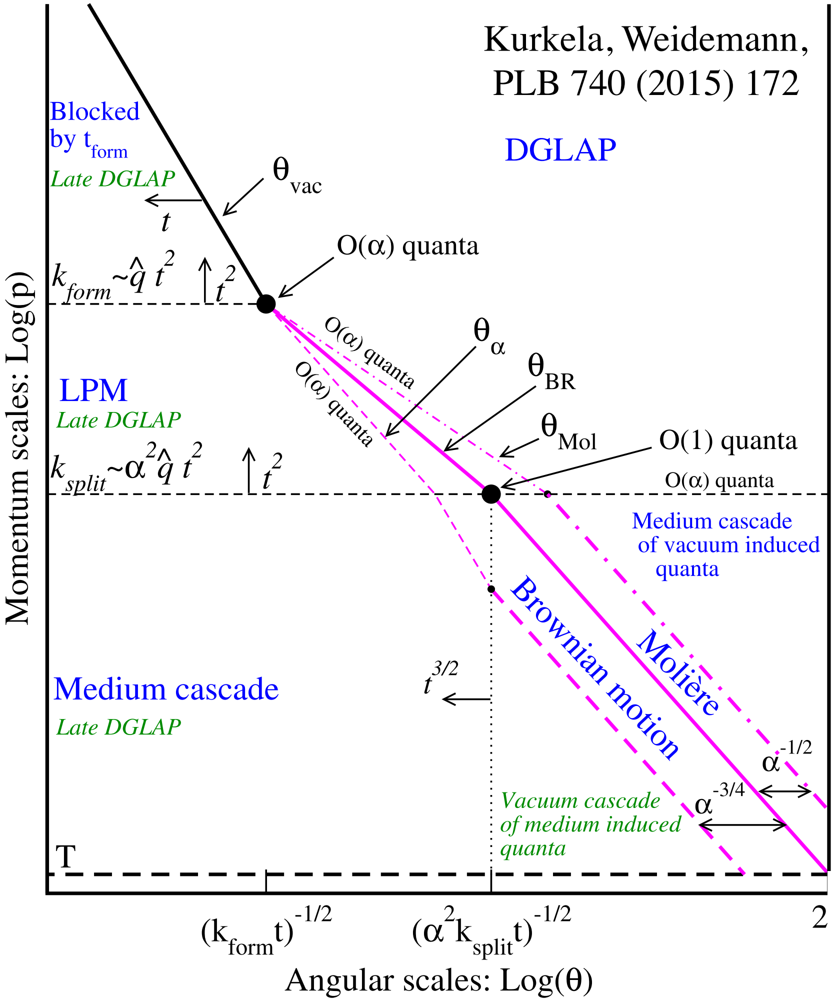
M. Habich, J. Nagle, and P. Romatschke, EPJC, 75:15 (2015)



QGP@RHIC →
Closer to transition temperature

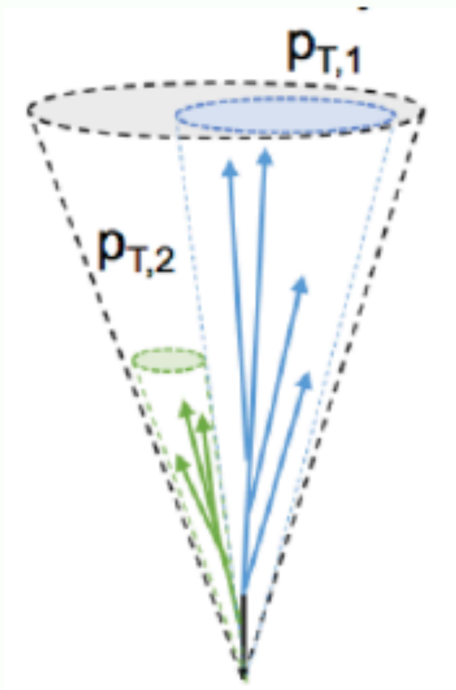
- Better access to strong coupling regime
- Larger fraction of jet evolution dominated by QGP medium @RHIC

Core sPHENIX science program

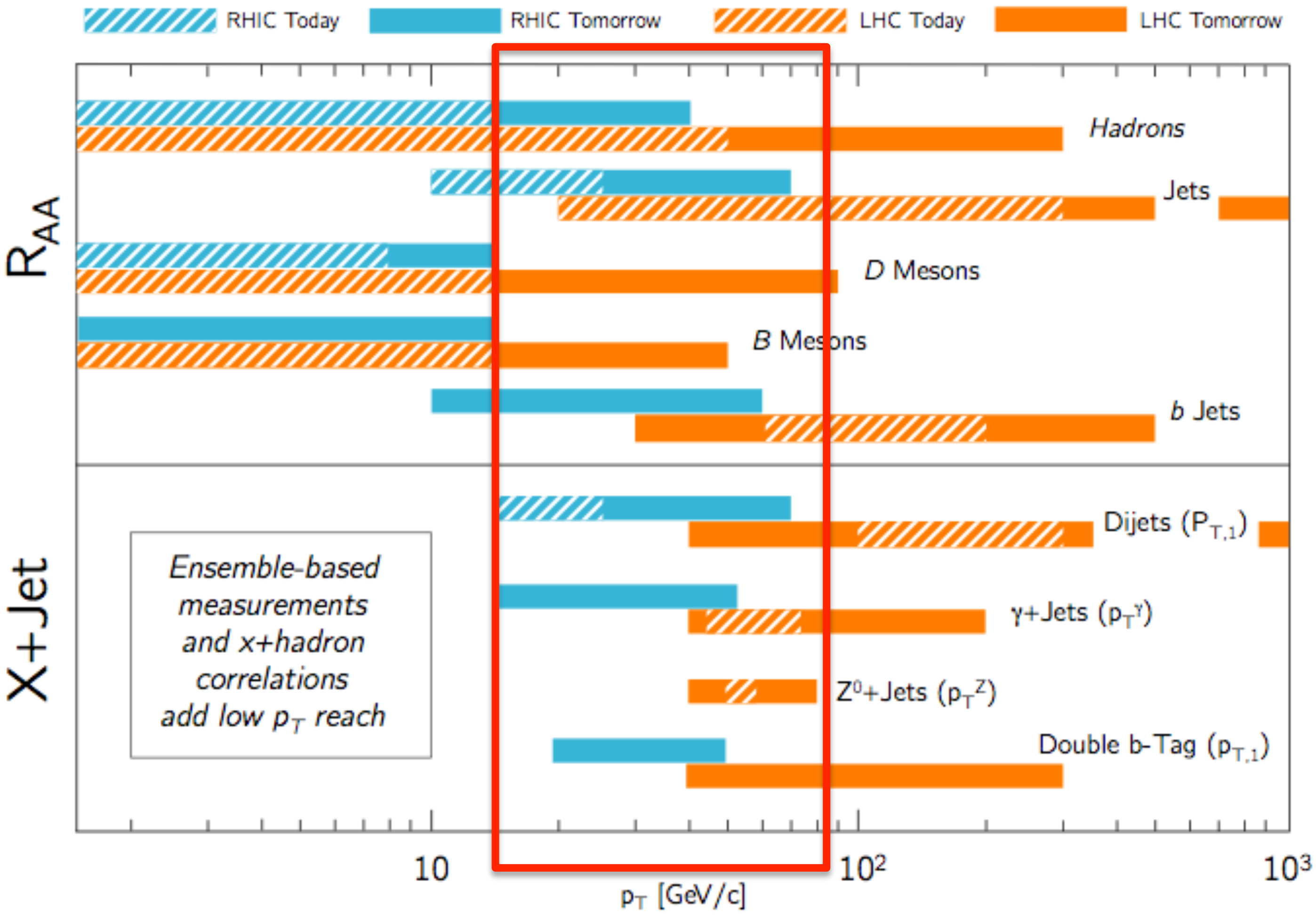


Jet structure

vary momentum/angular scale of probe

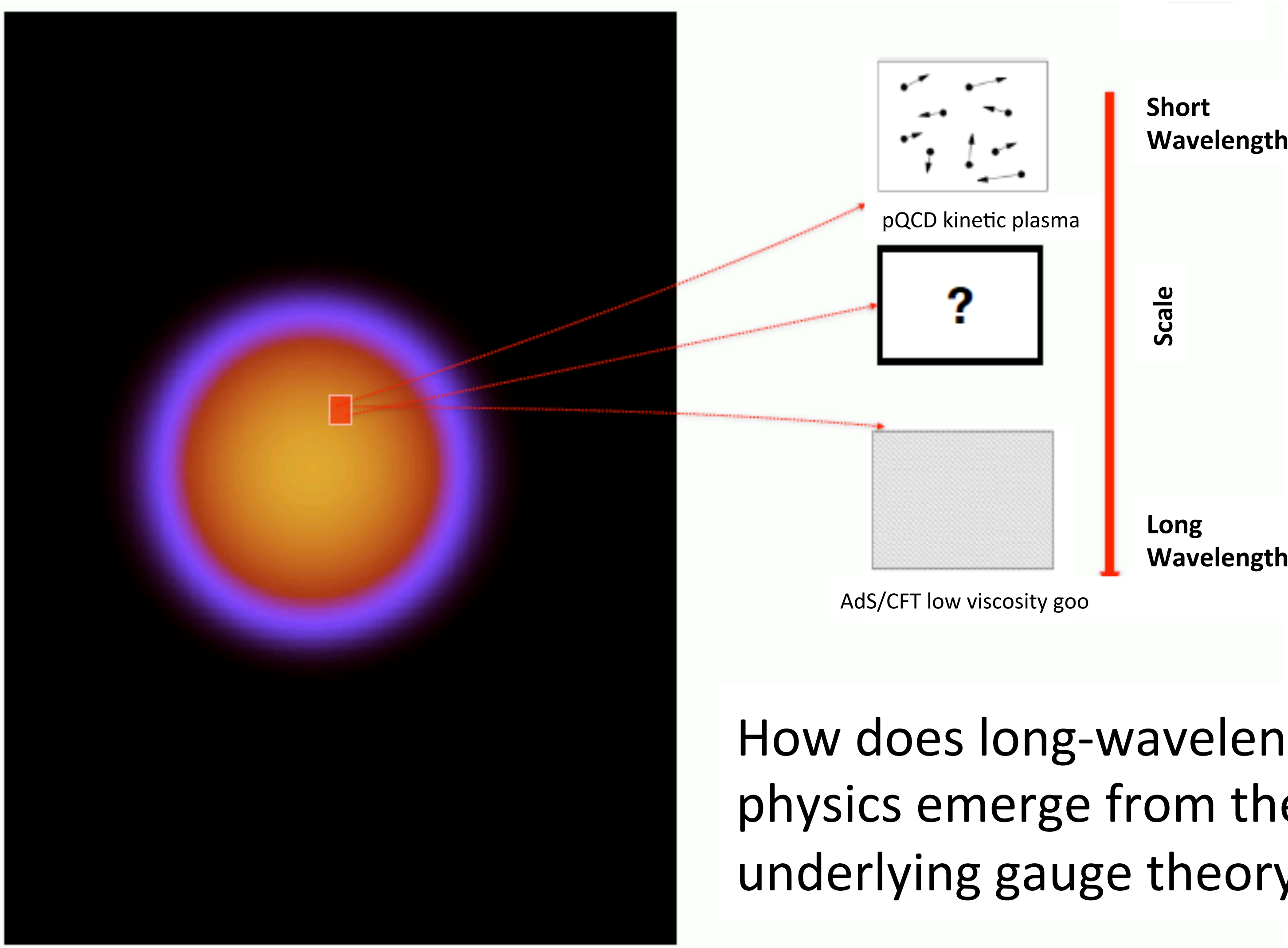


RHIC/LHC Complementarity



Study same probe @ different QGP evolution

Experimental Approach



pQCD kinetic plasma

?

AdS/CFT low viscosity goo

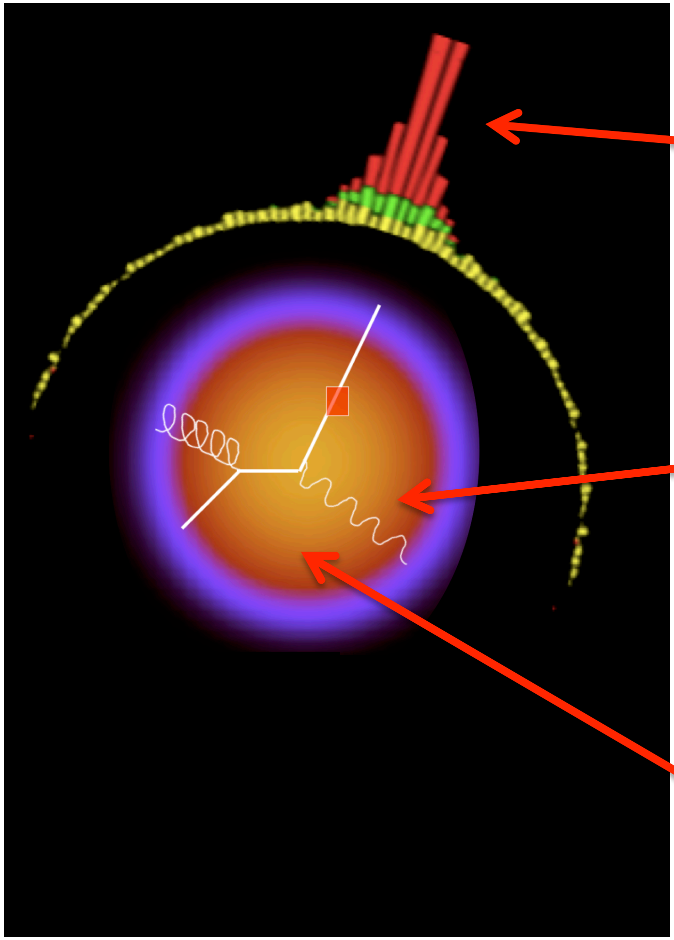
Short Wavelength

Scale

Long Wavelength

How does long-wavelength physics emerge from the underlying gauge theory?

Experimental Approach



Full characterization of final state

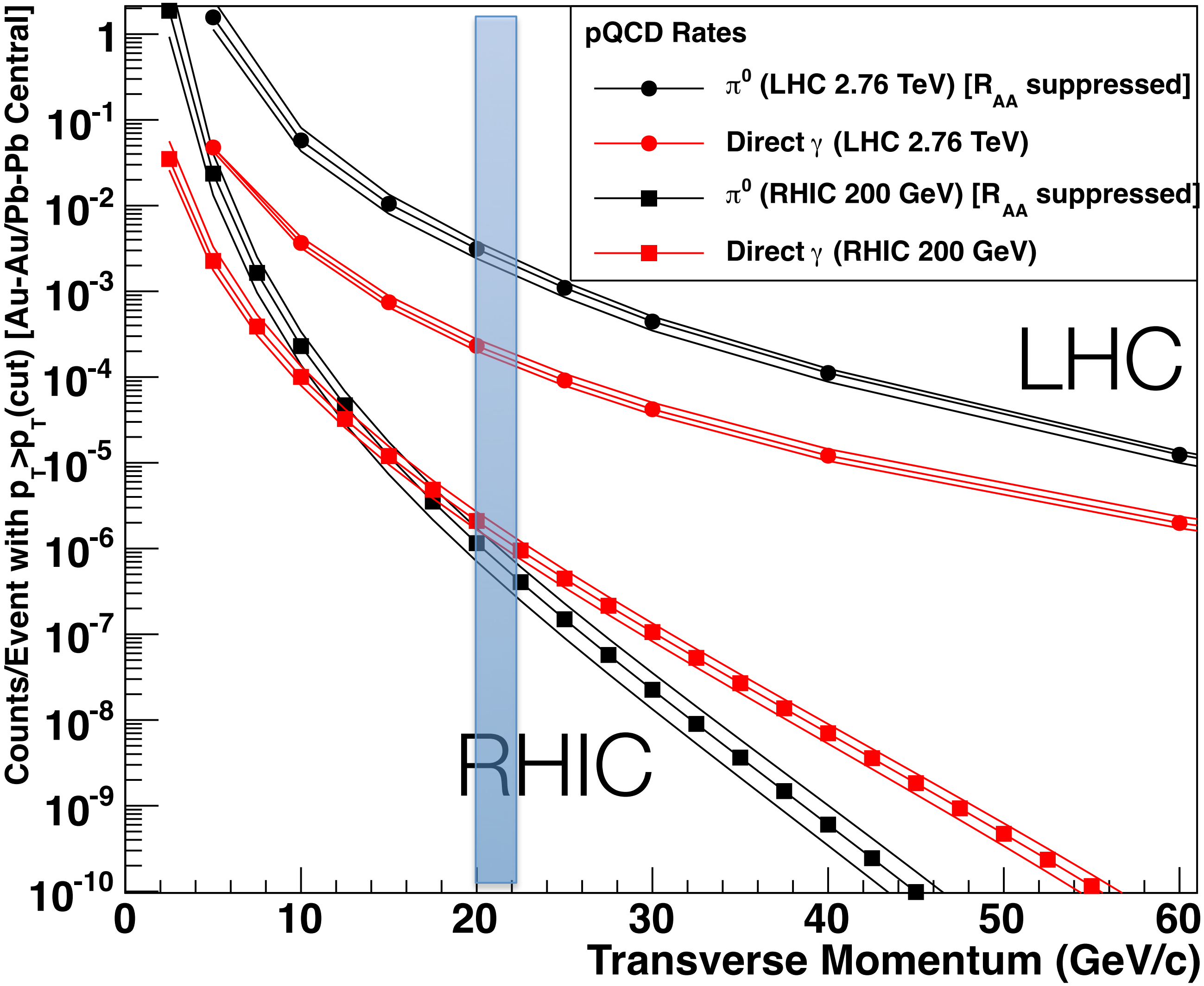
- HCAL, EMCal, Tracking

Same hard process

Initial Conditions

- RHIC vs LHC

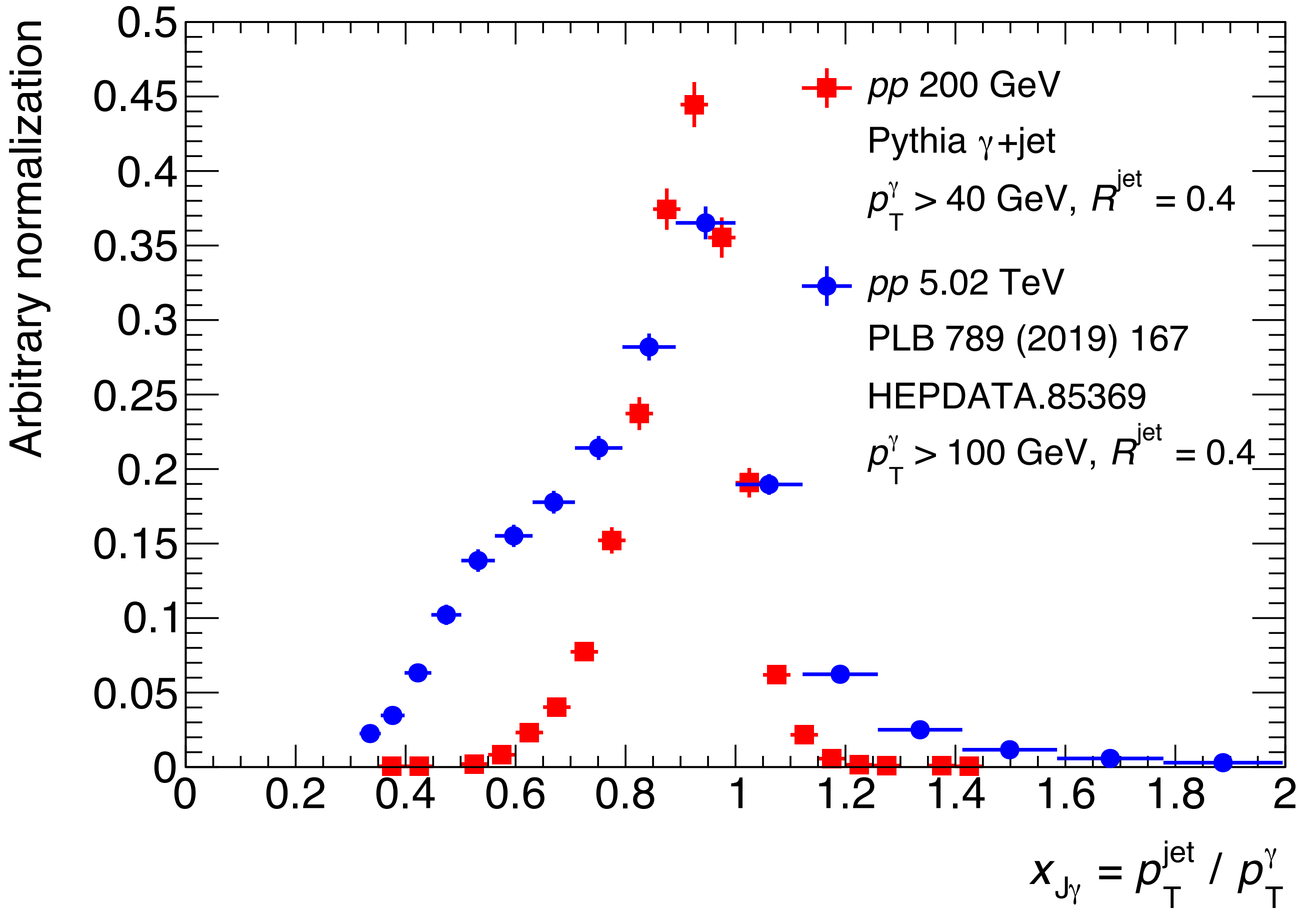
γ – Jet Correlations



For 20 GeV γ, S/B is 20x larger at RHIC than LHC

- UE 2.5x smaller

LHC/RHIC Comparison



Major physics goal for the HI community

- compare "similar" jets at RHIC & LHC

γ-jet!

- **γ+inclusive-jet** @ RHIC-sPHENIX
- **unfolded γ +leading-jet** @ LHC-ATLAS

Physics Goals

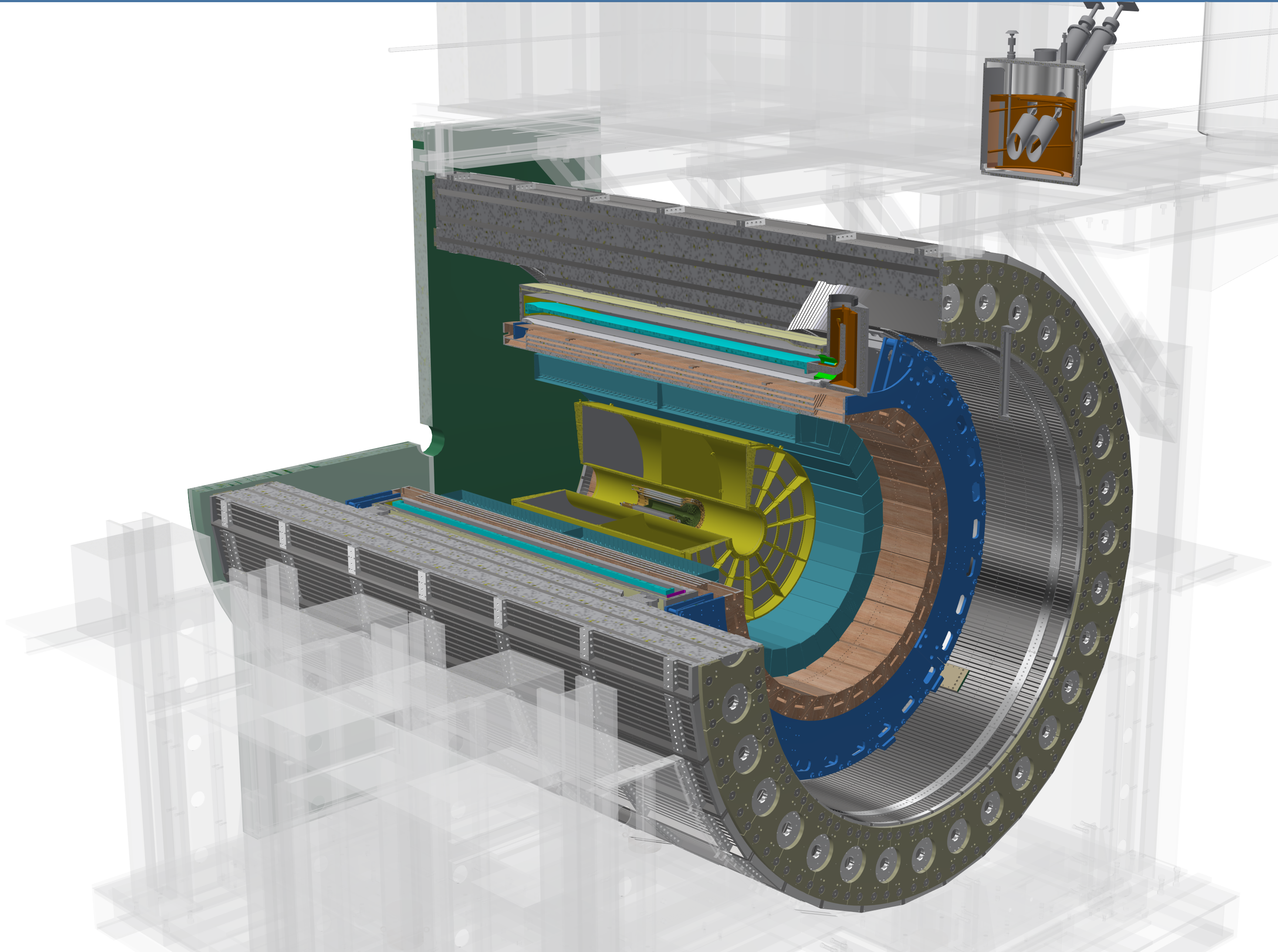
Physics goal	Analysis requirement	UPP
Maximize statistics for rare probes	**Accept/sample full delivered luminosity**	**Data taking rate of 15kHz for Au+Au**
Precision Upsilon spectroscopy	**Resolve Y(1s), Y(2s), (Y3s) states**	**Upsilon(1s) mass resolution ≤ 125MeV in central Au+Au**
High jet efficiency and resolution	**Full hadron and EM calorimetry** **Jet resolution dominated by irreducible background fluctuations**	**$\sigma/\mu \leq 150\%/\sqrt{pT_{jet}}$ in central Au+Au for R=0.2 jets****
Full characterization of jet final state	**High efficiency tracking for $0.2 < p_T < 40$GeV**	**Tracking efficiency ≥ 90% in central Au+Au**** **Momentum resolution $\lesssim$ 10% for p_T = 40 GeV****
Control over initial parton p_T	**Photon tagging with energy resolution dominated by irreducible higher order processes**	**Single photon resolution ≤ 8% for p_T = 15 GeV in central Au+Au****

(**) to be extracted using Au+Au, p+p data + simulations → LHC example

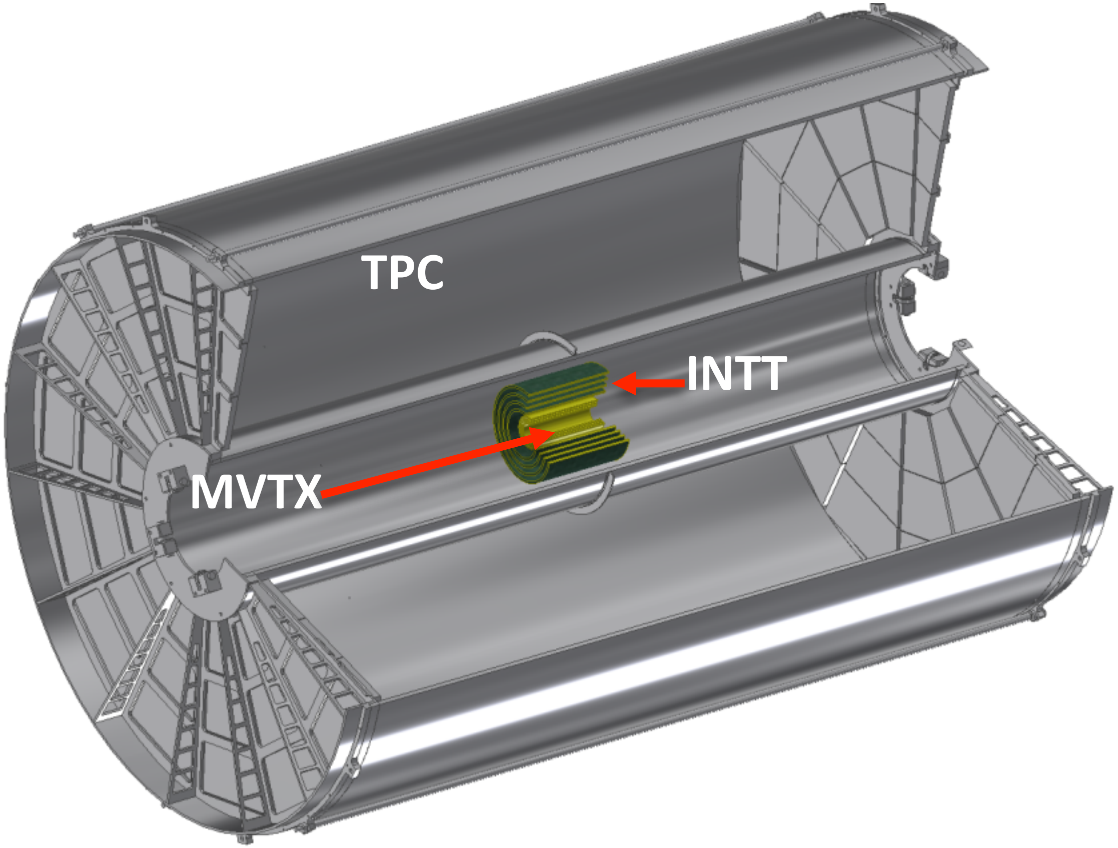
sPHENIX Design

Lets get down to the nuts and bolts

sPHENIX Design



Tracking



1/30th volume
ALICE TPC

MVTX (based on ALICE ITS):

- 3-layer MAPS vertex tracker
- Excellent 2-D DCA resolution, < 25 µm $p_T > 1$ GeV/c

INTT:

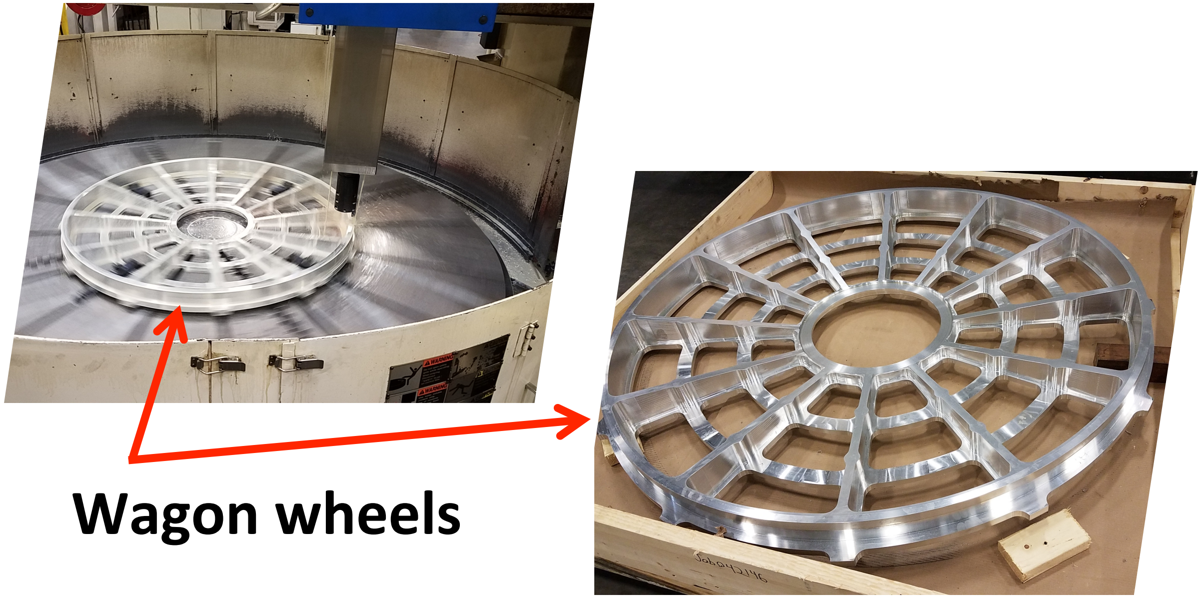
- 2-layer Si strip

TPC:

- 48 layer, continuous readout, $R = 20\text{-}78$ cm
- Good momentum resolution $p_T = 0.2\text{-}40$ GeV/c

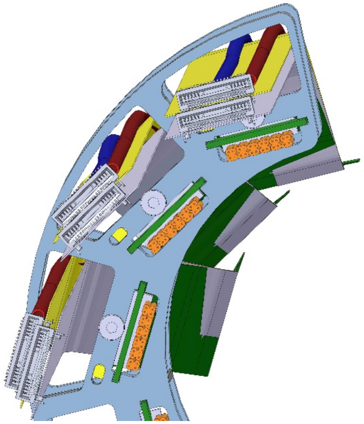
TPC

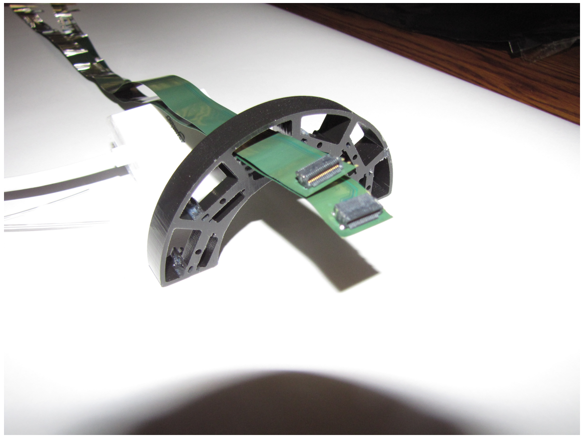
Initial analysis of small prototype test beam data shows resolution as good predicted resolution

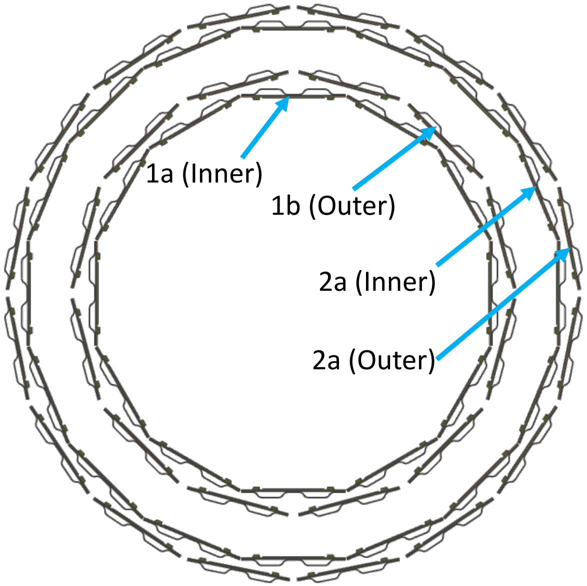


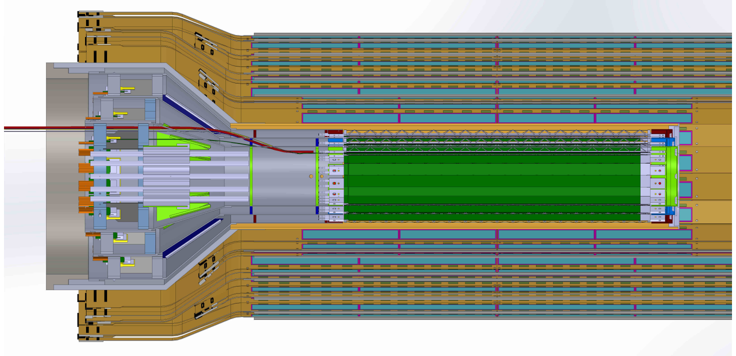
Wagon wheels

MTVX + INTT



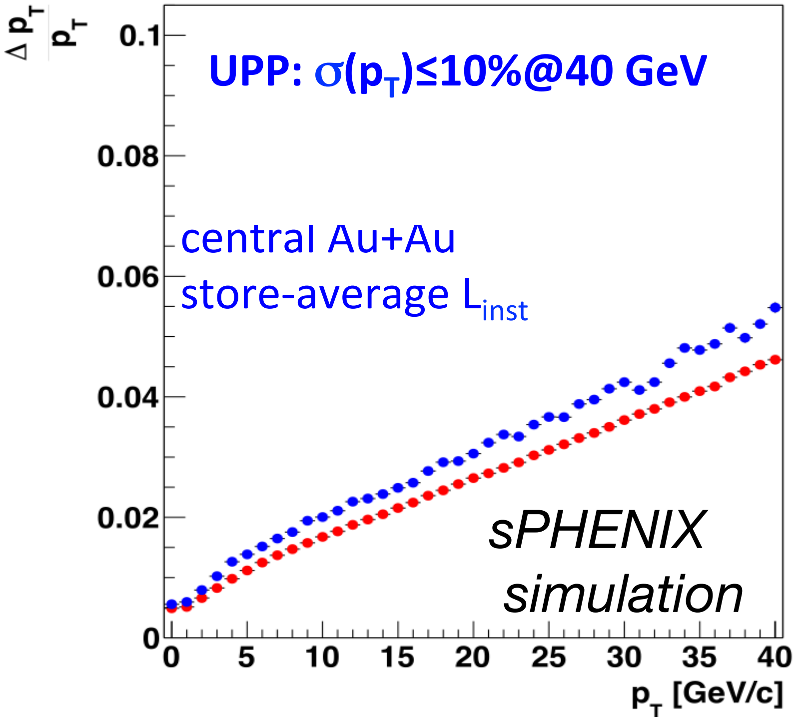




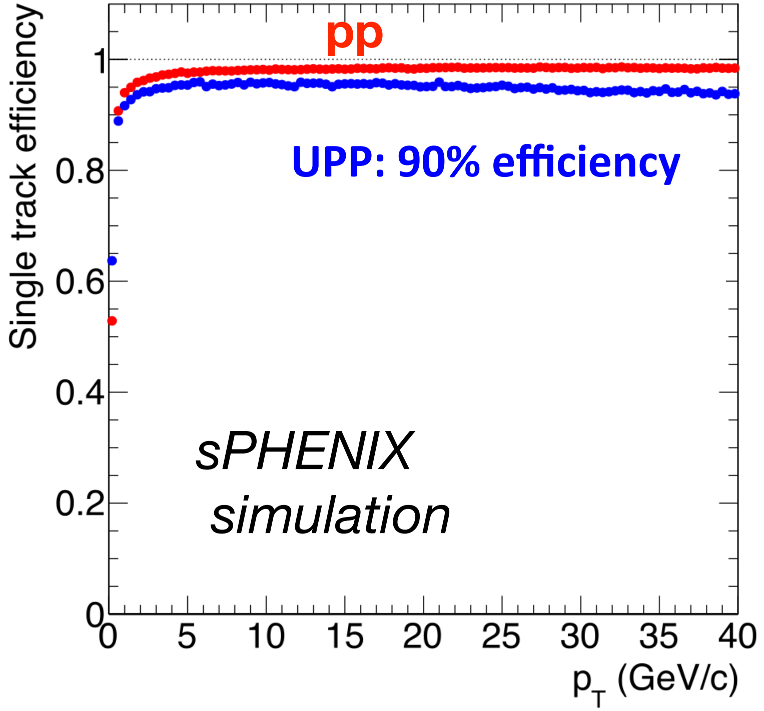


Tracking Performance

Track p_T resolution (central Au+Au)



Tracking efficiency (central Au+Au)

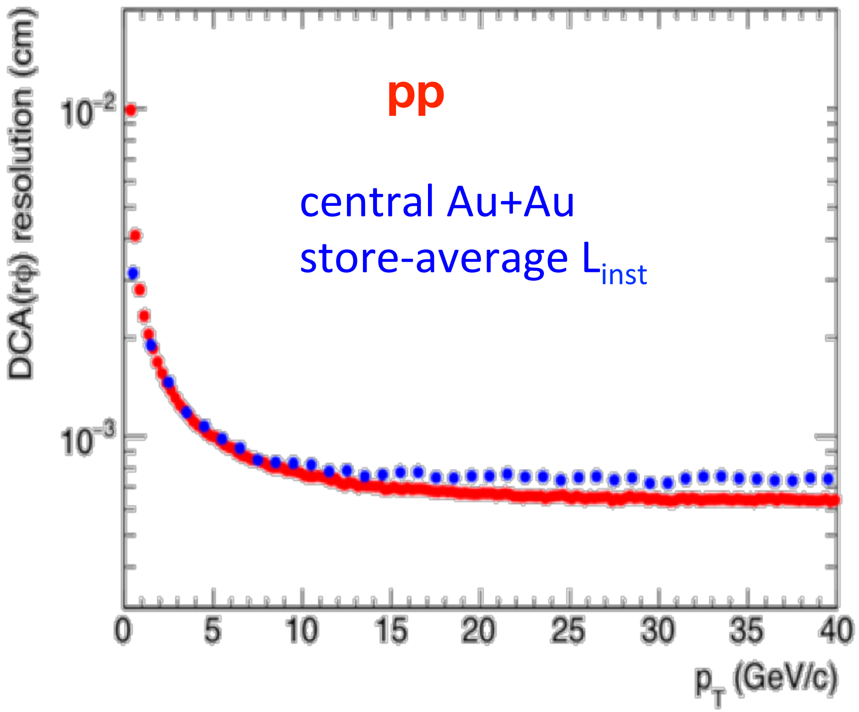


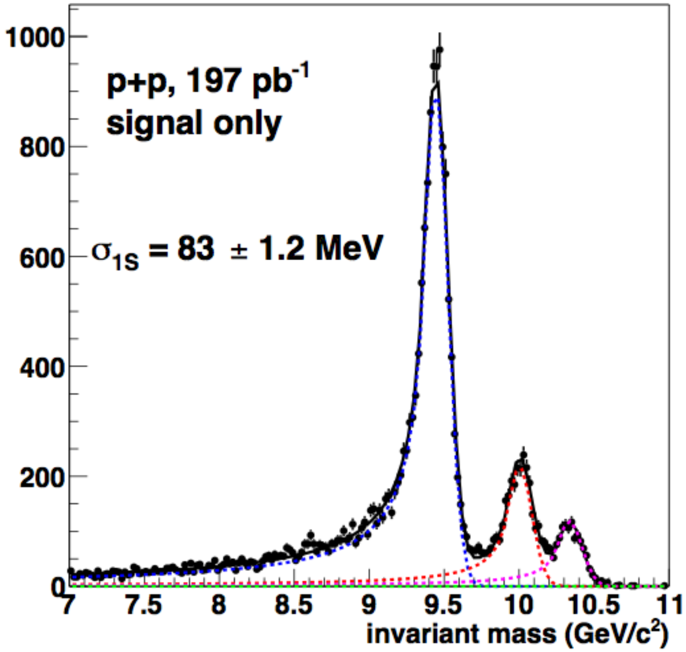
High momentum resolution

Tracking efficiency > 90% in high pileup Au+Au environment

Tracking Performance

MVTX DCA Resolution





Key for b-tagging and open HF measurements

Resolve Upsilon 2S and 3S mass states

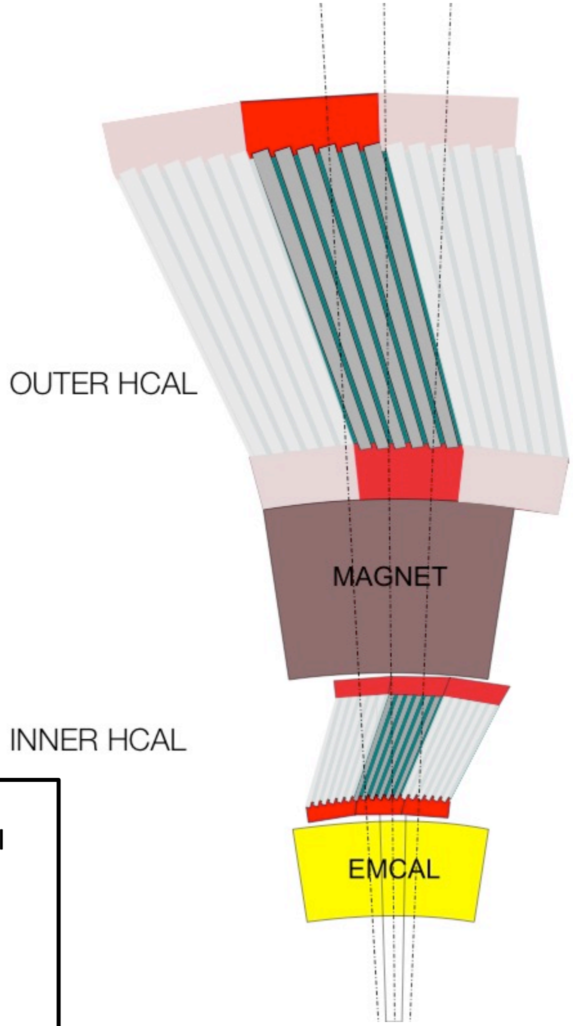
Calorimetery

EMCal: Scintillating fibers embedded in W powder

- $\Delta\eta\times\Delta\phi = 0.024\times0.024$
- $\sigma_E/E = 15\%/\sqrt{E}$

HCal: Plastic scintillating tiles + tilted Steel/Al plates

- $\Delta\eta\times\Delta\phi = 0.1\times0.1$
- $\sigma_E/E = 100\%/\sqrt{E}$



- 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

Slots for scintillating tiles, read-out by SiPMs

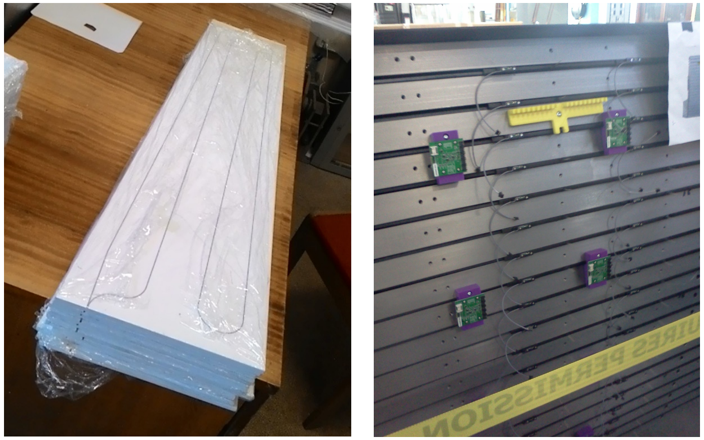
6.4 meters long

|η| < 1.1

32 modules form flux return

instrumented to be outer Hcal

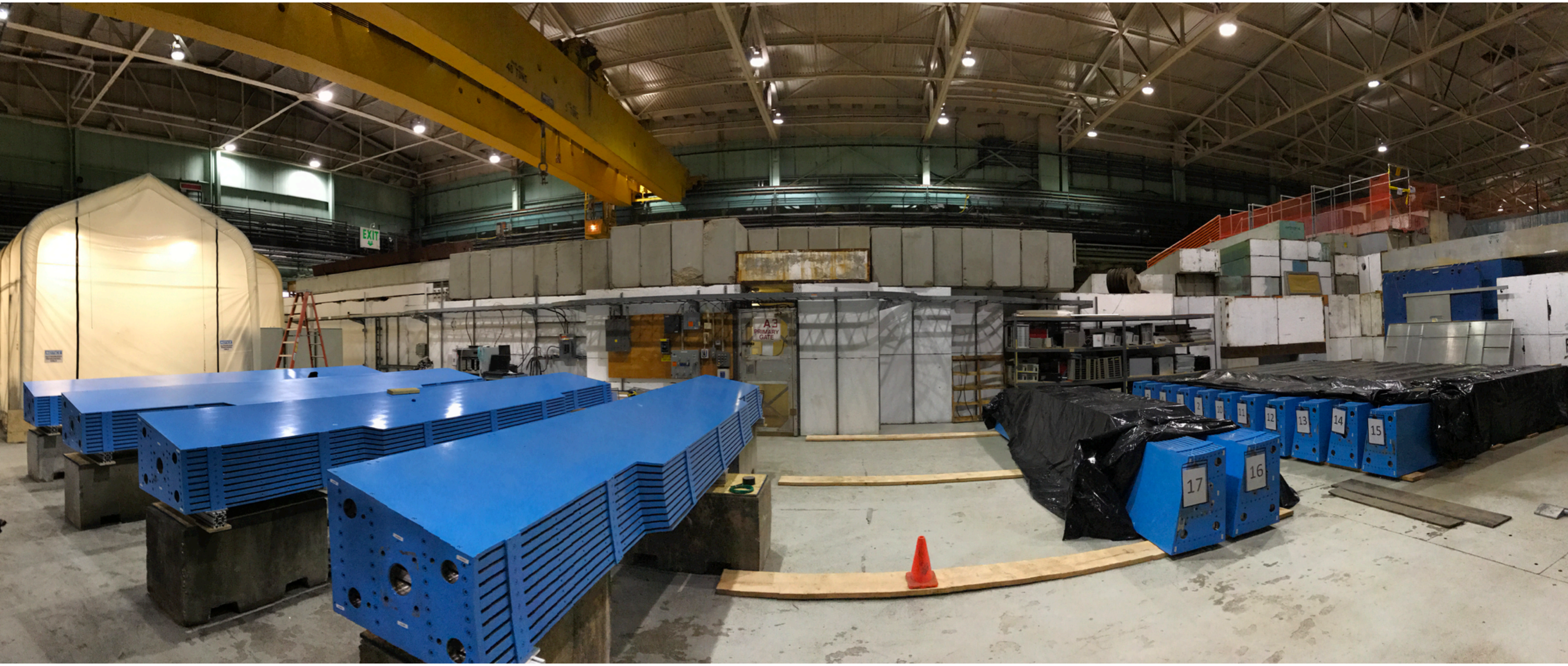
Started arriving at BNL late 2018



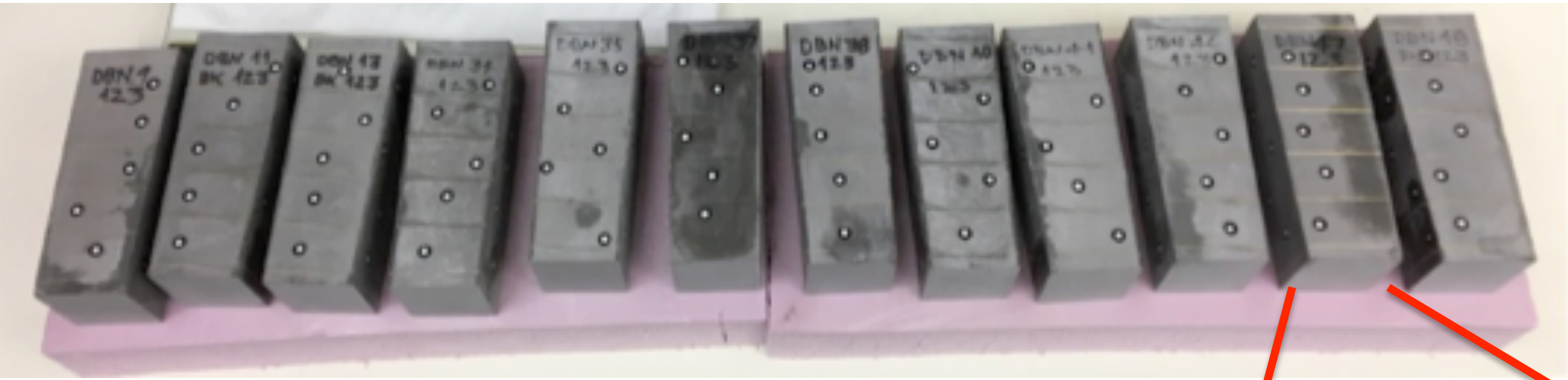
- 7 mm polystyrene with embedded 1 mm WLS fiber ala T2K
- Five tiles each with an SiPM ganged together in Φ to create a tower readout

HCAL

18 of 32 HCal/Barrel Magnet Steel Sectors now at BNL

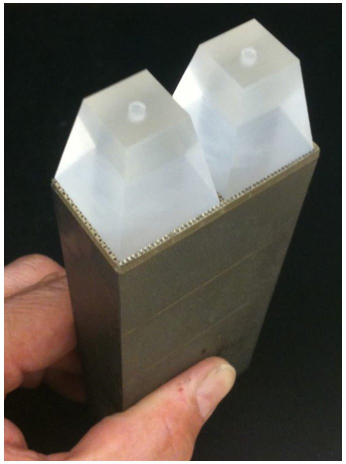


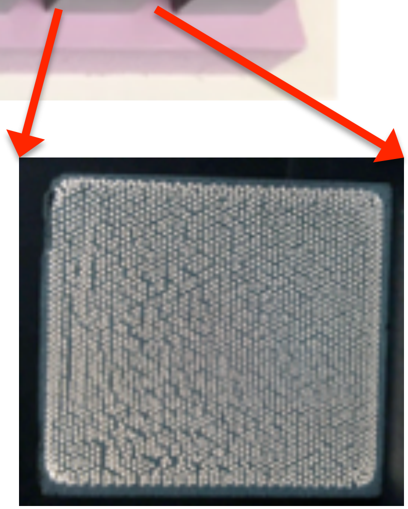
EMCal



Technology pioneered by UCLA group

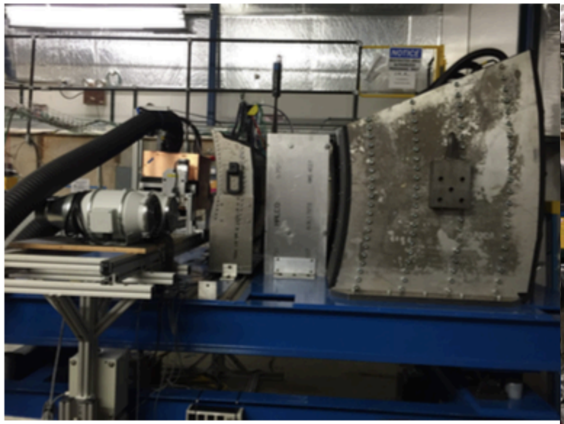
- 2D projective, read out by SiPMs
- Same electronics as HCal
- Production techniques advanced by UIUC group





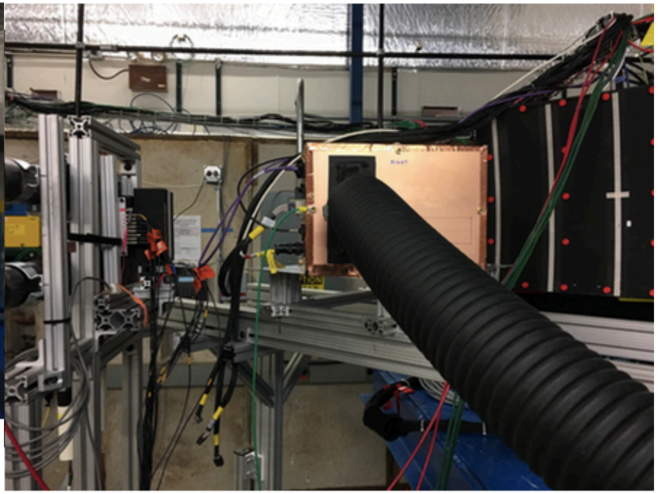
Calorimeter Beam Test

Proof of principle, Feb 2014



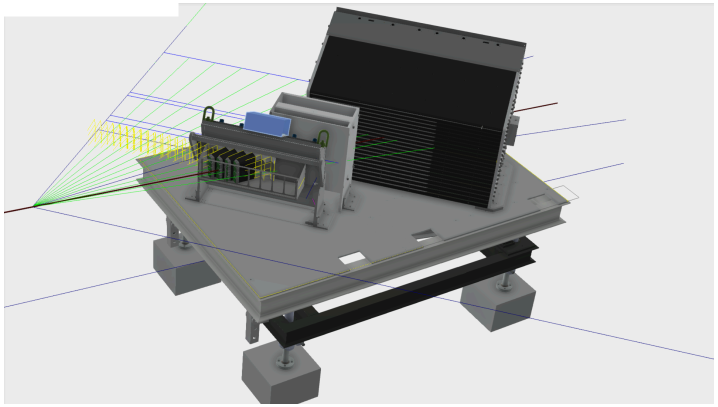
η~0 Geometry, Feb 2016

EEE Transactions on Nuclear Science, Volume 65, Issue 12, pp. 2901-2919, December 2018



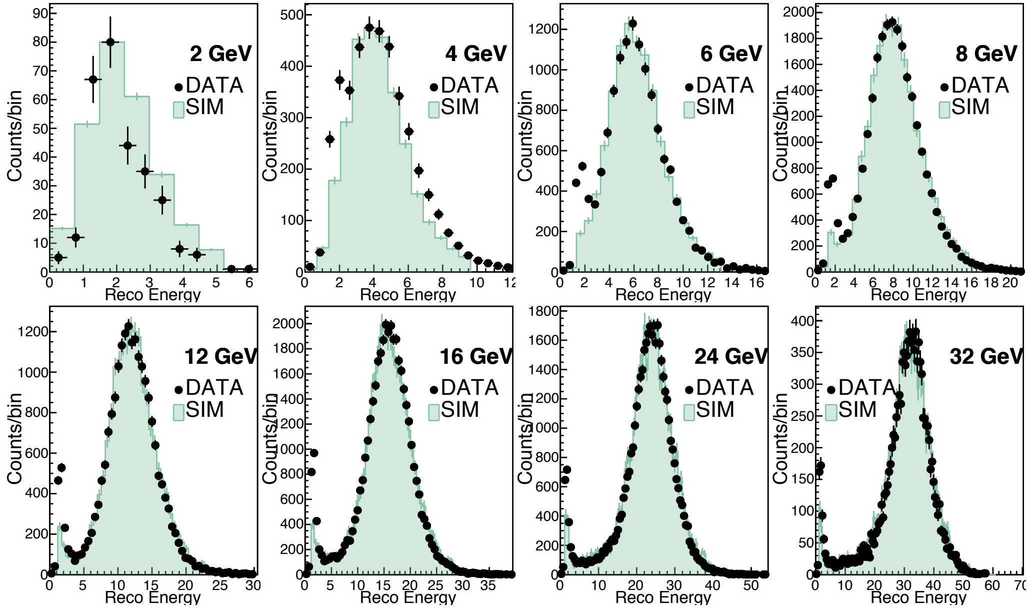
η~0.9 Geometry, Feb 2017

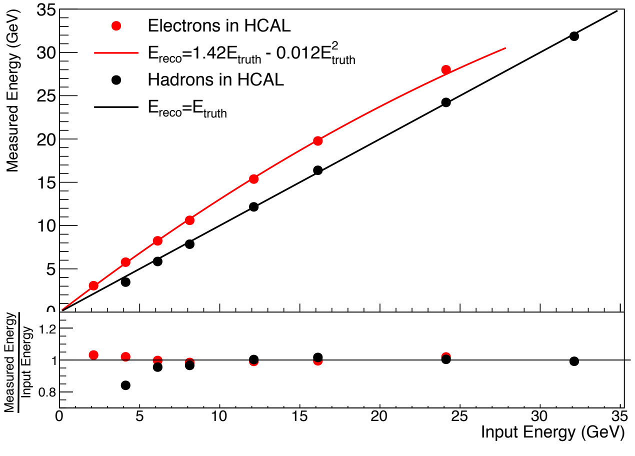
Combined test of improved large η calorimetery design, Feb-March 2018 @ FermiLab →



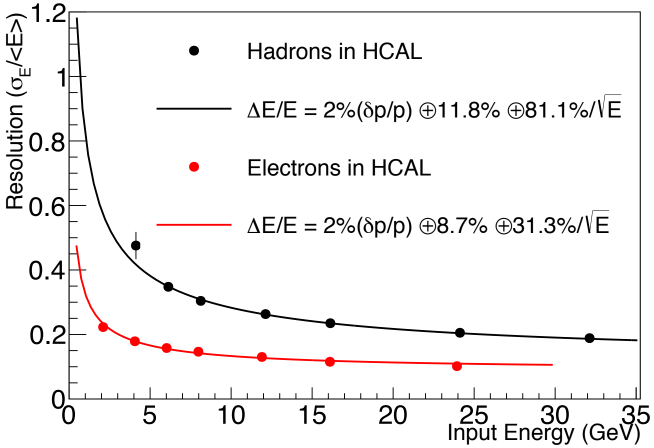
HCal Test Beam

Good agreement between data and simulation validates simulation





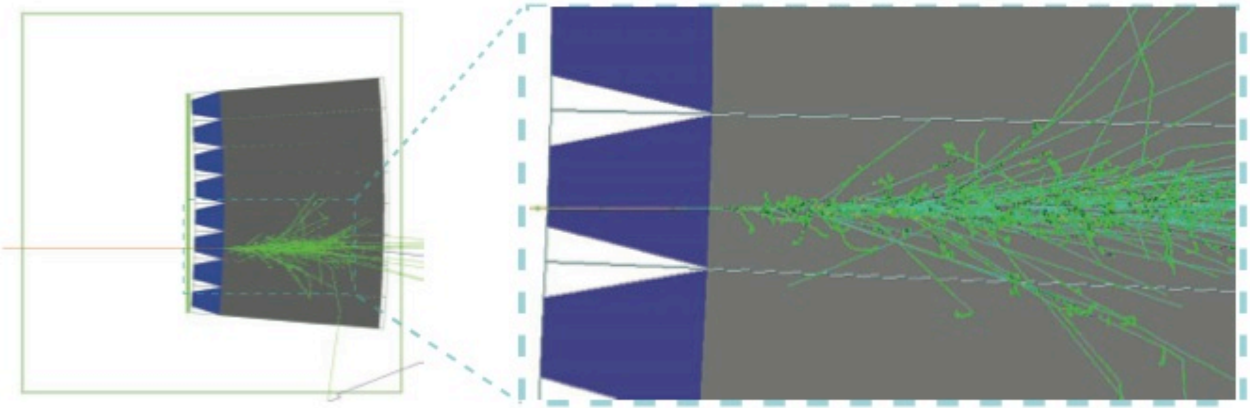
(a)



(b)

Linearity and resolution for electrons and hadrons in the HCal

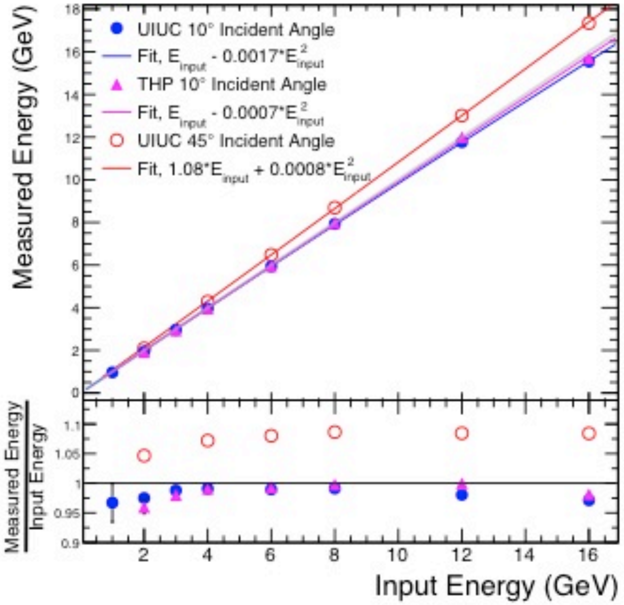
EMCal Beam Test

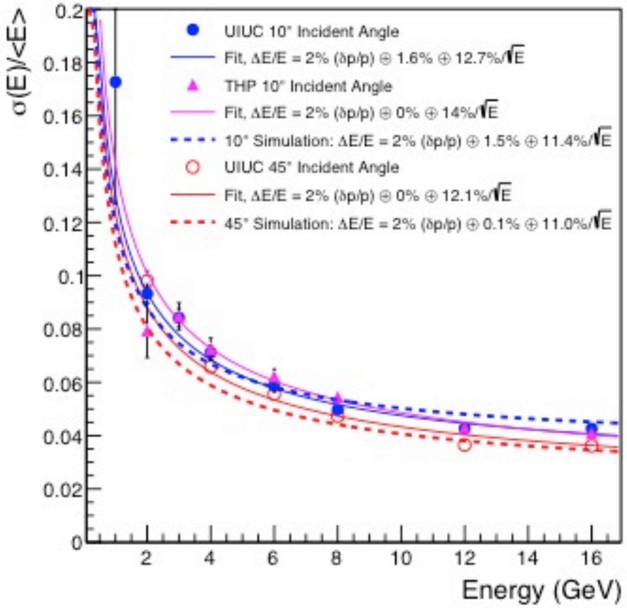


GEANT4 simulation of 8 GeV electron incident on EMCal (in test beam configuration)

Linearity and resolution vs. Electron Energy

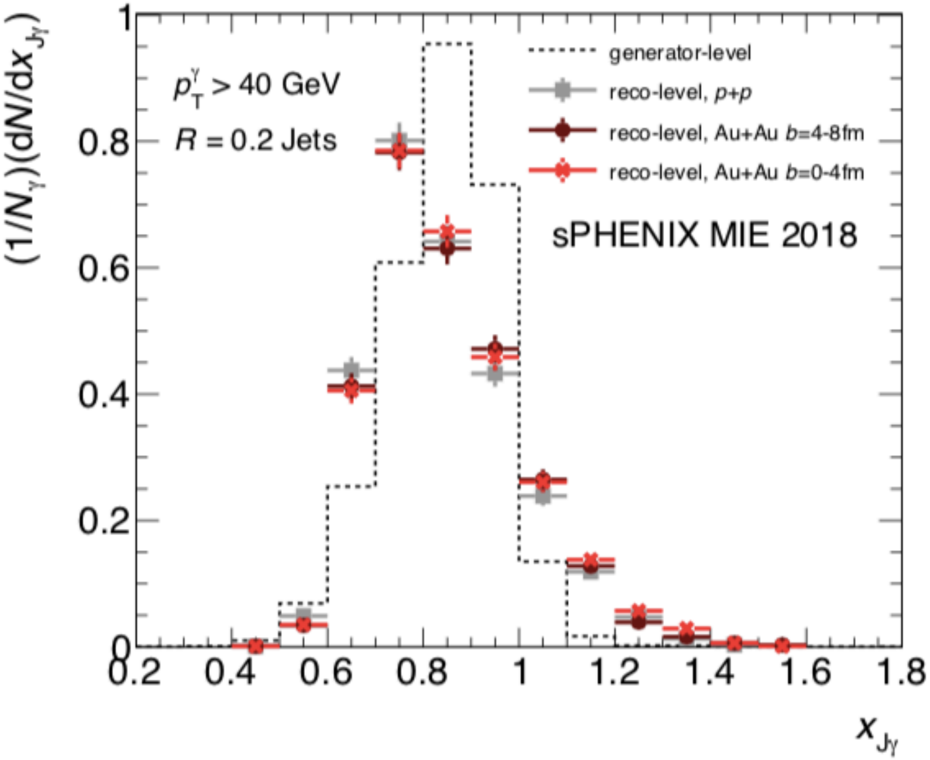
(different tower designs & incidence angles)



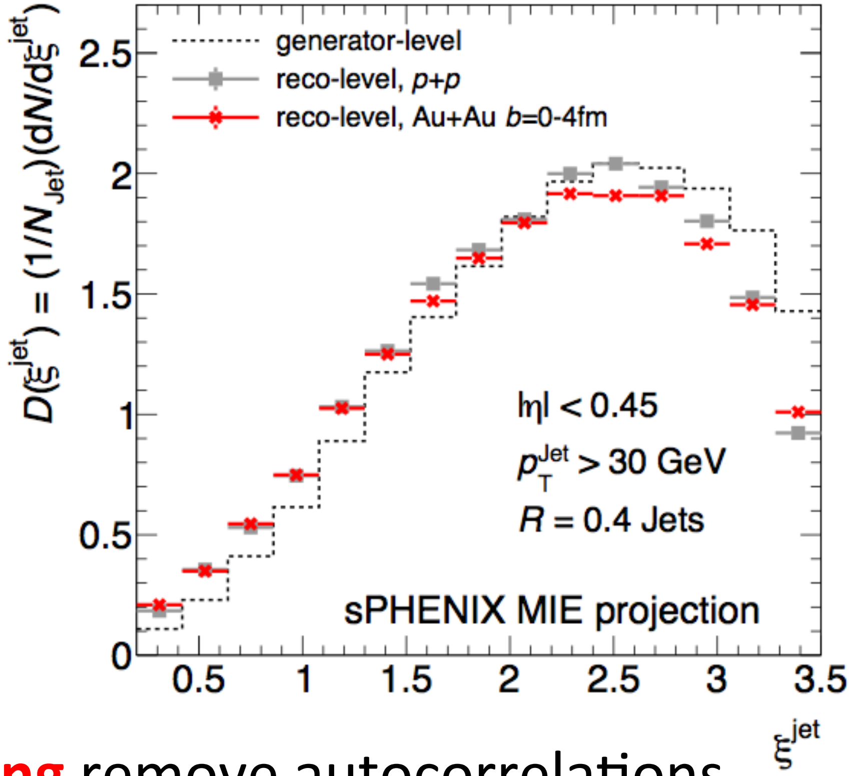


Jets in sPHENIX

γ+jet momentum balance



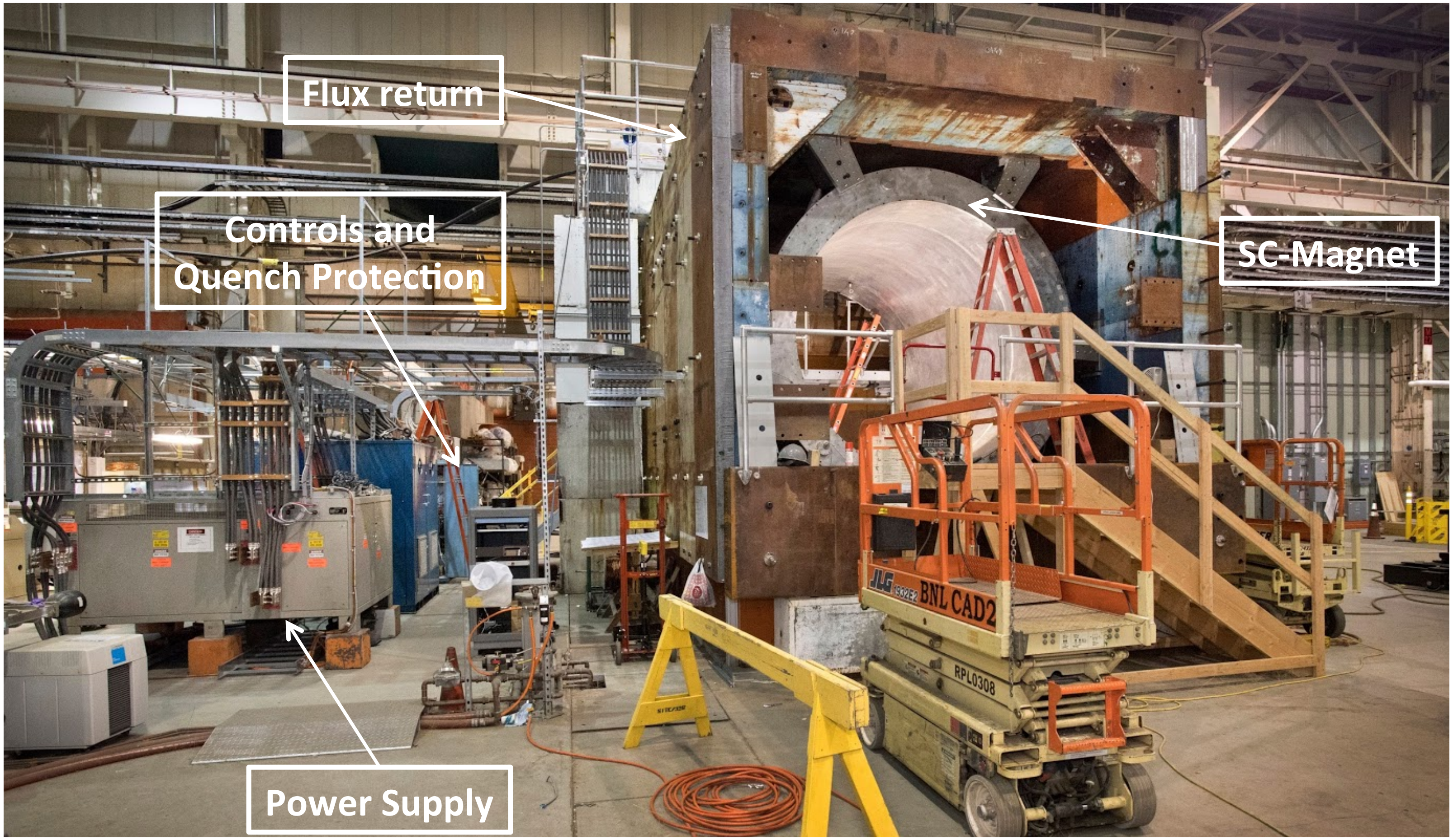
γ+jet fragmentation function



Calorimeter jets + **precision tracking** remove autocorrelations between jet reconstruction and jet structure

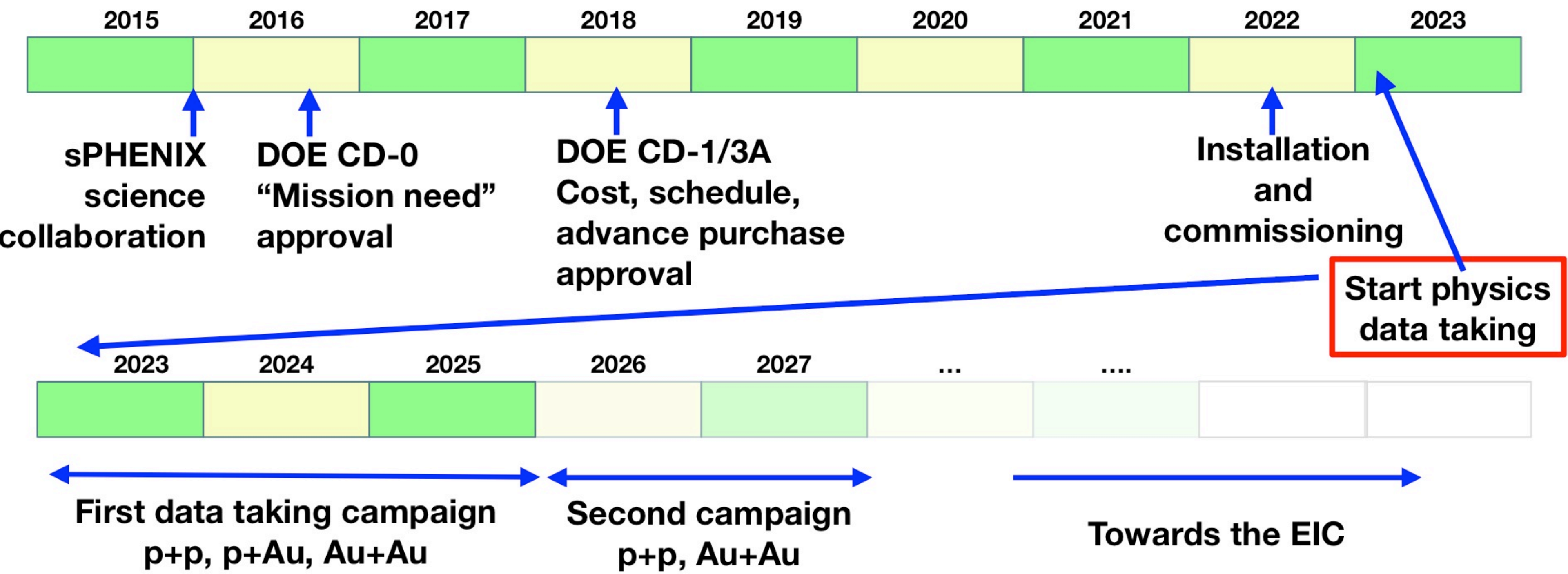
- New era in RHIC jet physics!

sPHENIX Magnet



- Formerly Babar magnet, 1.4 T solenoid

Timeline



sPHENIX science collaboration

DOE CD-0 "Mission need" approval

DOE CD-1/3A Cost, schedule, advance purchase approval

Installation and commissioning

Start physics data taking

First data taking campaign
p+p, p+Au, Au+Au

Second campaign
p+p, Au+Au

Towards the EIC

record 240B minimum bias Au+Au events
record 35/nb, sample 83/nb

sPHENIX and HI Strategy

- Hot QCD w/different $T_{initial}$ (RHIC vs LHC) → T dependence of transport properties
  - Mid-rapidity HCal at RHIC → HEP-style jet measurements
- LHC approaches PbPb refined in RHIC AuAu w/steeper spectra, lower UE multiplicities, $\gamma/\pi^0 > 1$ for $p_T > 20$ GeV/c
- Use of ALICE MAPS and RUs, and the ATLAS FELIX card strengthen justification for future development efforts
- Good alignment between sPHENIX and LHC HI run plans provides options for bridging efforts and collaboration.
- Good data at RHIC improves argument for extending calculations to lower energy and building frameworks
  - DOE JET collaboration, LANL LDRD, NSF JETSCAPE

Summary

- Greatly extended capabilities at RHIC, motivated by HEP experience and LHC HI successes
  - mid-rapidity hadronic calorimetry
  - Excellent momentum resolution
  - High rate DAQ → exploit full RHIC luminosity
- Continued extremely productive exchanges with LHC detector and electronic efforts – ALICE MAPS, TPC, SAMPA; ATLAS FELIX
- sPHENIX collaboration continues to grow – adding relevant physics and technological expertise
  - On track for 2023 start of sPHENIX data taking
  - Now have CD-3A funds!