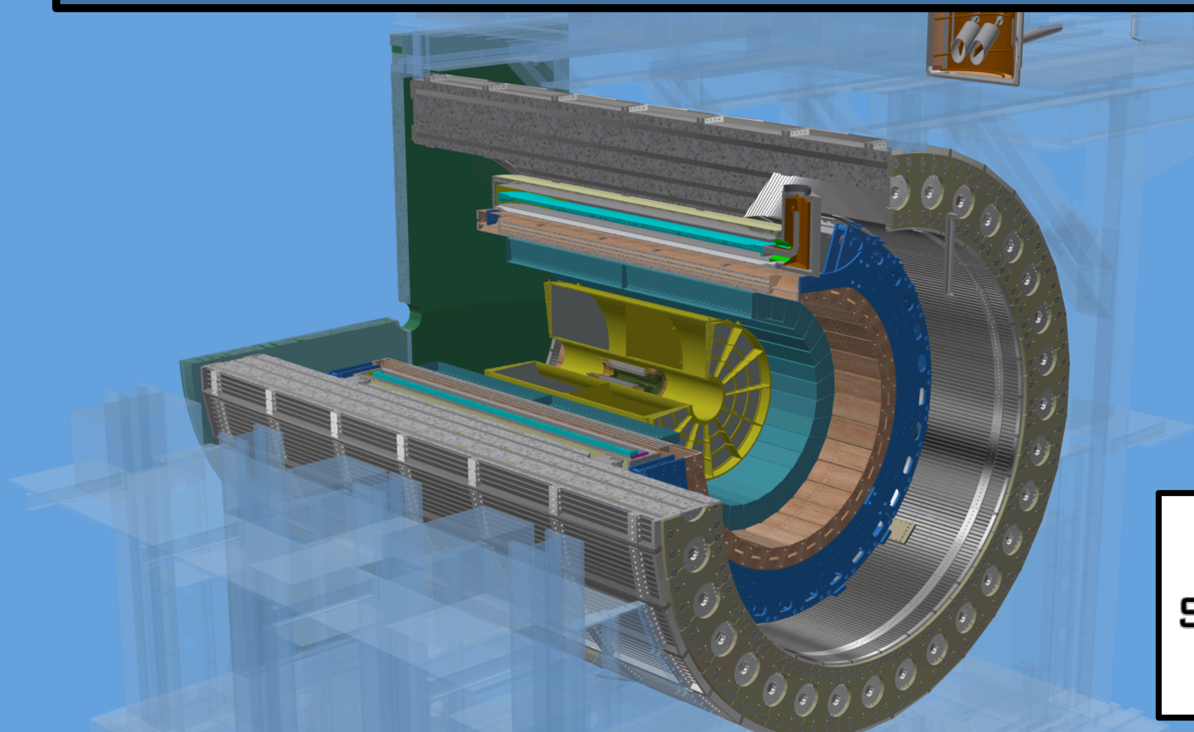
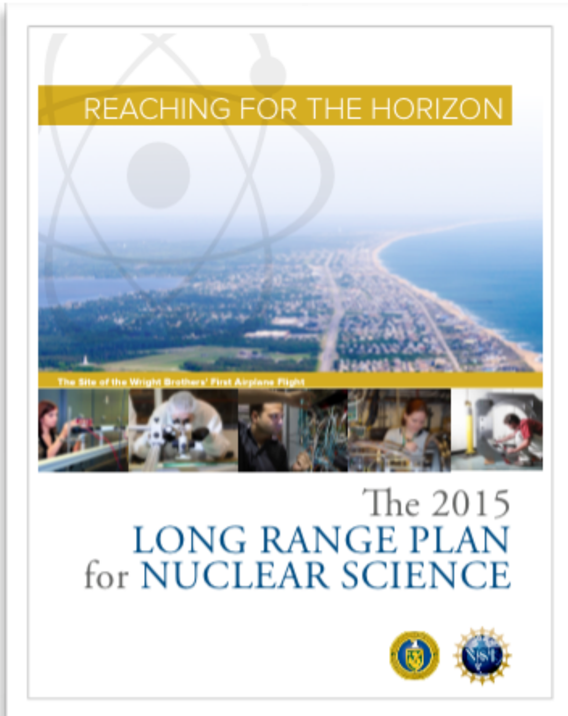
Probing initial stages with scale dependent observables of the QGP in sPHENIX

5th International Conference on the Initial Stages in High-Energy Nuclear Collisions

Rosi Reed



RHIC/LHC Complementarity

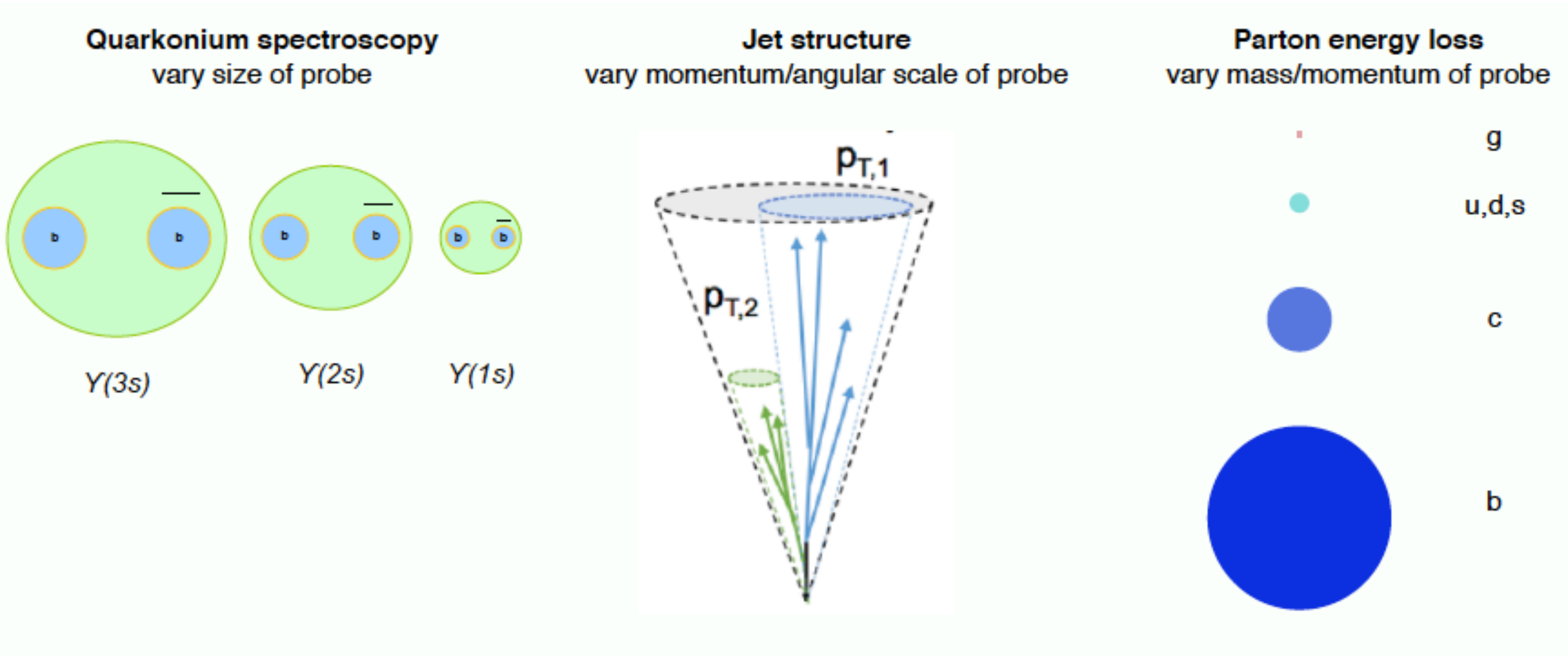


There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art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

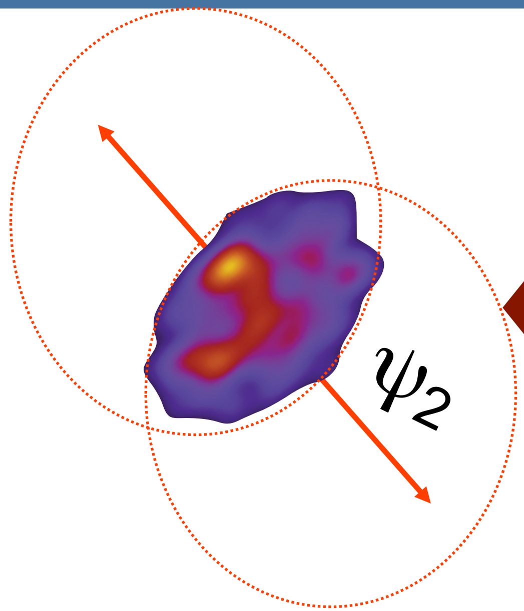
Success of LHC experiments in HI physics demonstrates importance of large acceptance, high resolution tracking, high collision rates and full EM+Hadronic calorimetry

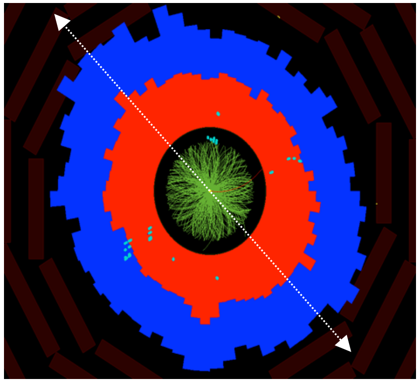
Core sPHENIX science program

Key approach → Study QGP structure at multiple scales!



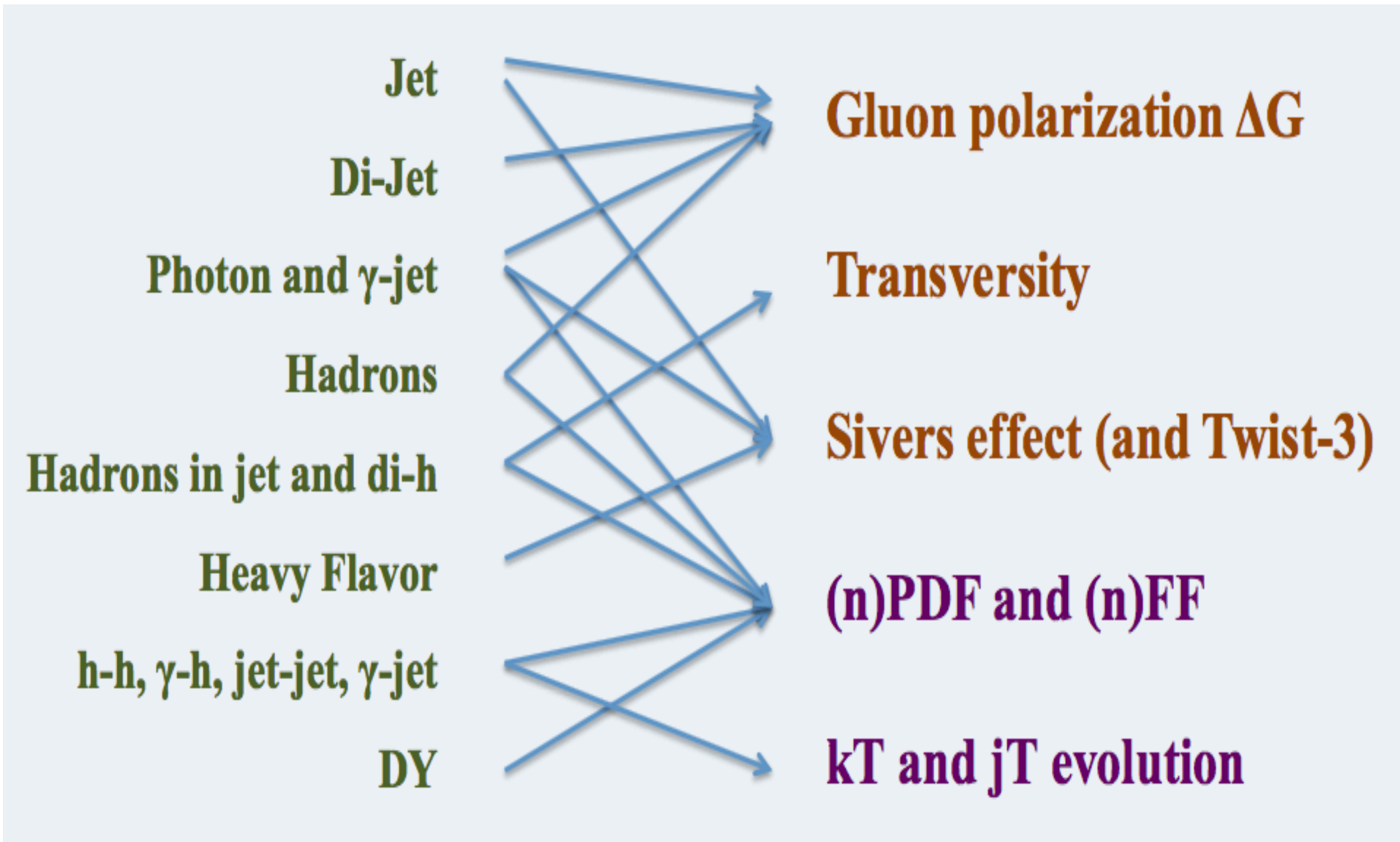
Hot QCD





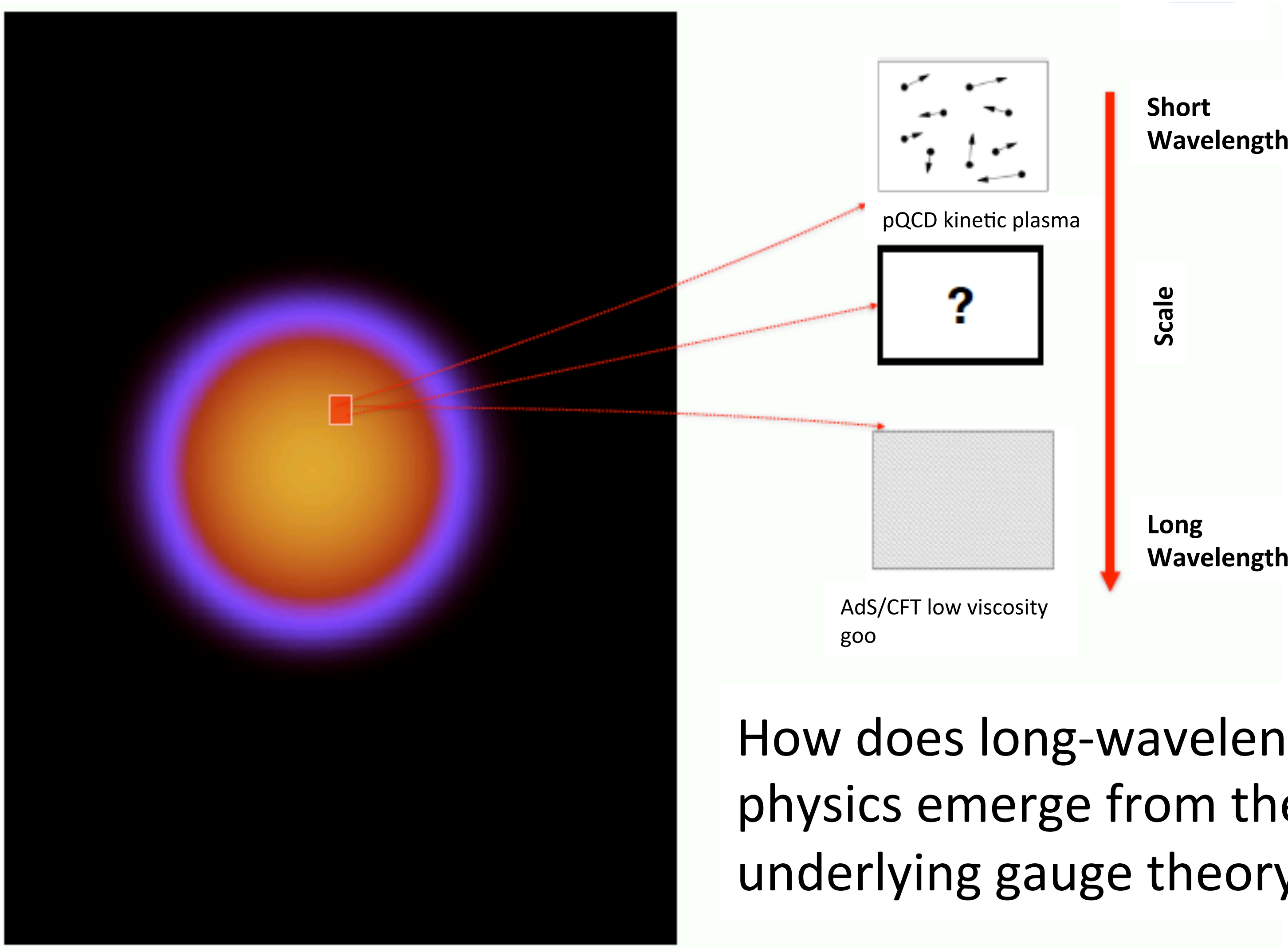
- RHIC: QGP has near perfect fluidity and extreme opacity
- Precision studies @ RHIC/LHC → aspects of final state structure understood as relativistic viscous hydrodynamics applied to QGP evolution
  - Understanding the initial state is of key importance
- Improved instrumentation key to understanding how QGP properties emerge

Cold QCD



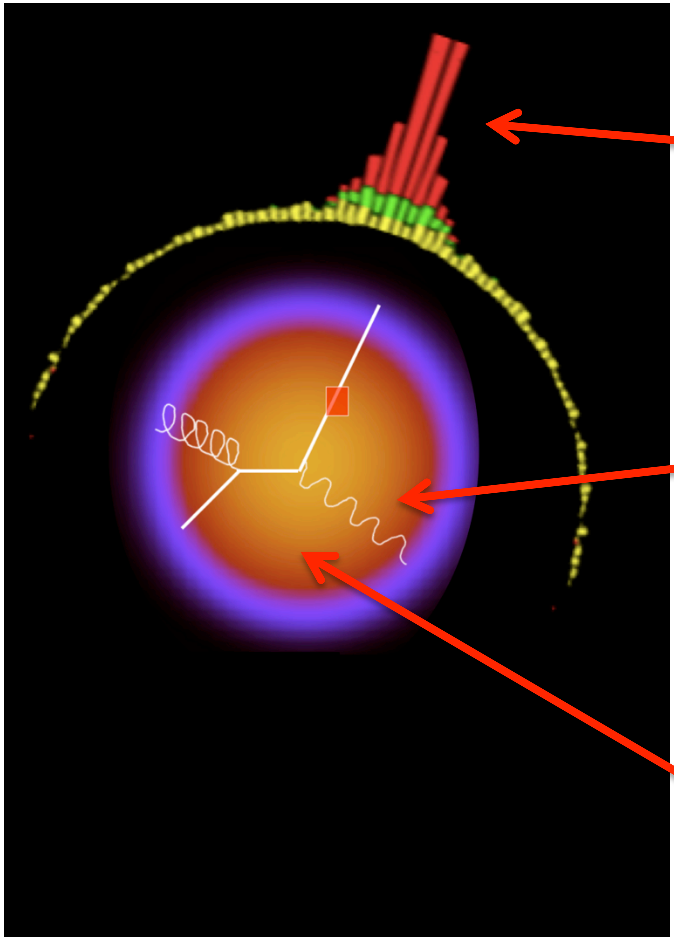
sPHENIX also has robust cold QCD program!

Experimental Approach



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

Experimental Approach



Full characterization of final state

- HCAL, EMCal, Tracking

Same hard process

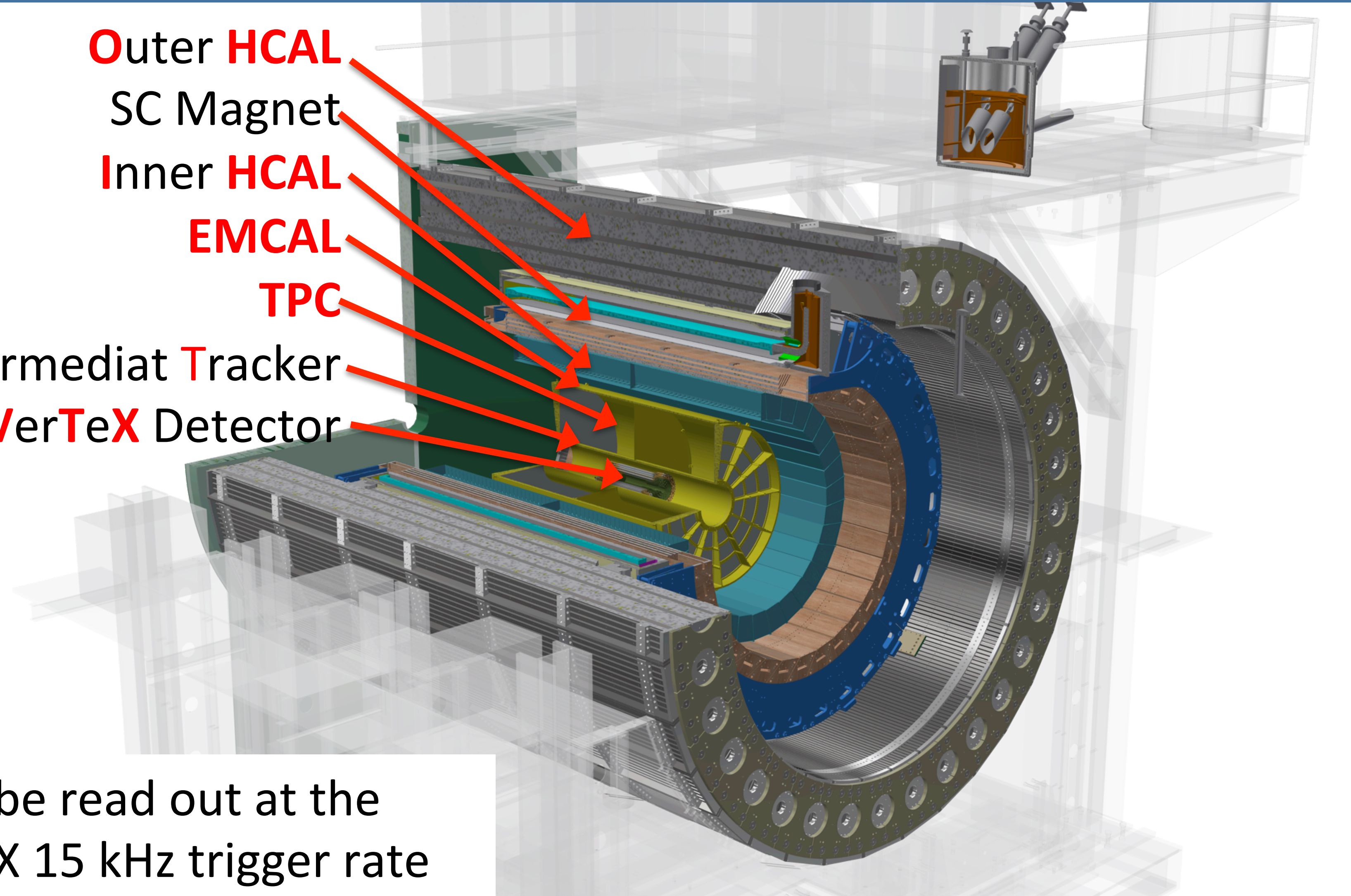
Initial Conditions

- RHIC vs LHC

sPHENIX Design

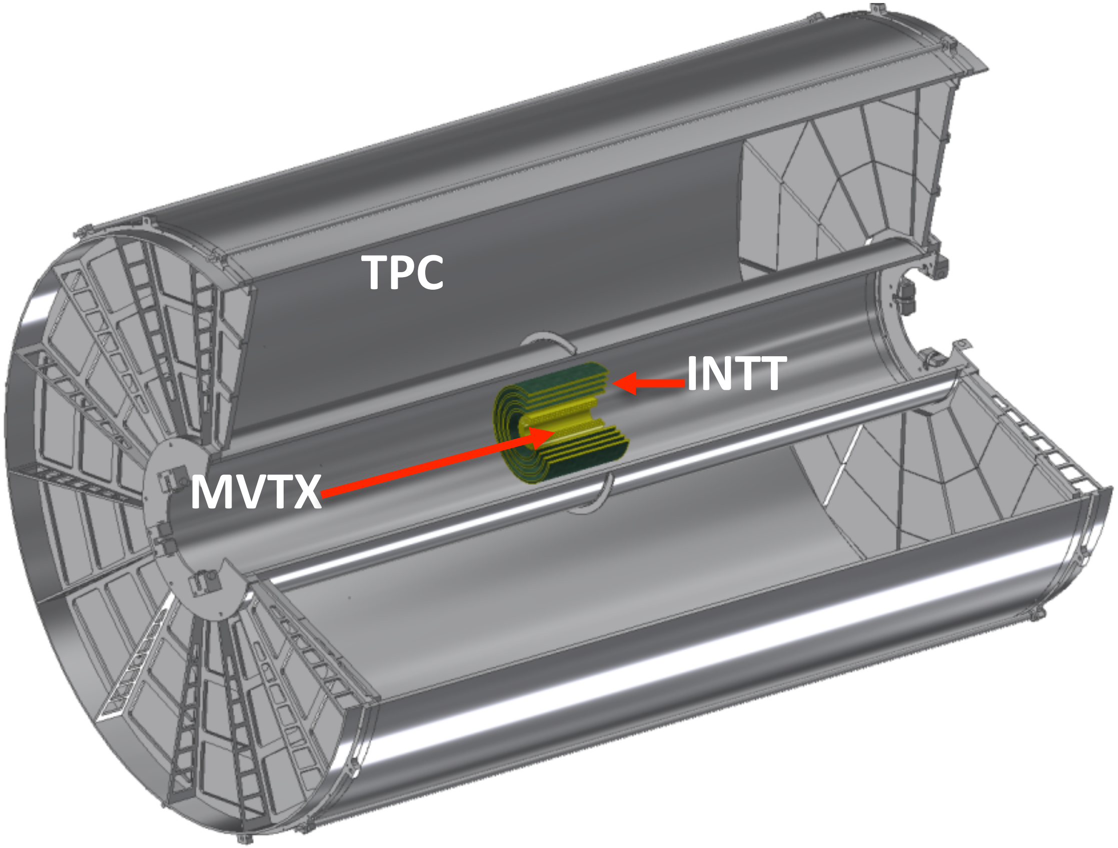
Lets get down to the nuts and bolts

sPHENIX Design



All can be read out at the sPHENIX 15 kHz trigger rate

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

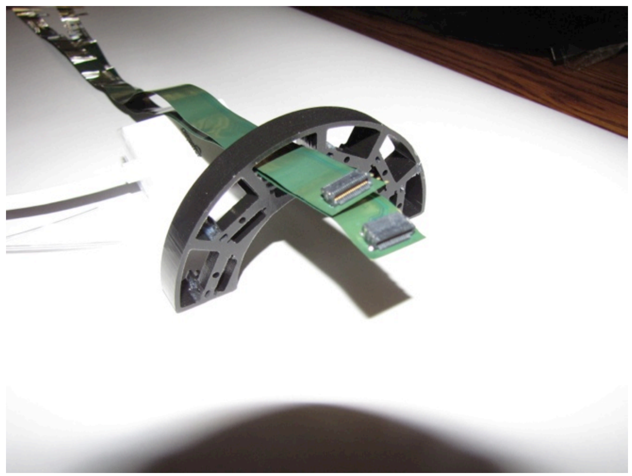
TPC:

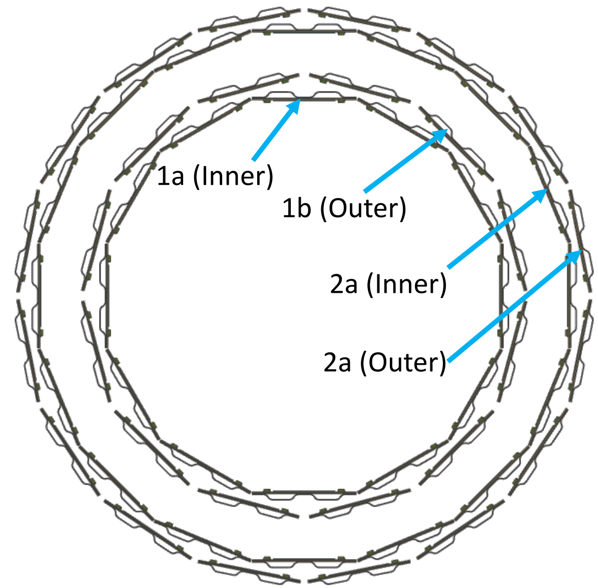
- 48 layer, continuous readout, R = 20-78 cm
- Good momentum resolution p_T = 0.2-40 GeV/c

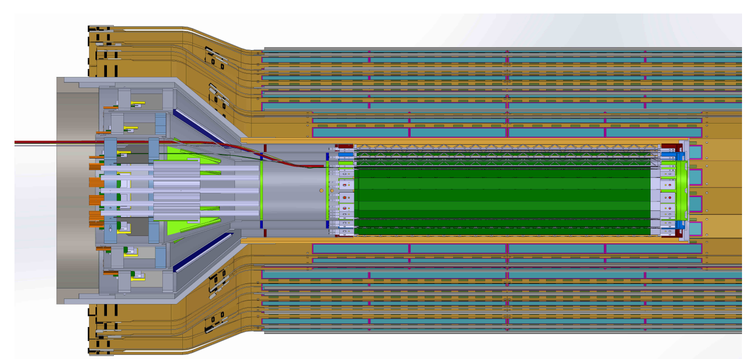
MTVX + INTT

Inner Tracking System adds:

- Out-of-time track rejection
- Outward pointing resolution for TPC calibration
- Inward pointing resolution for displaced vertices

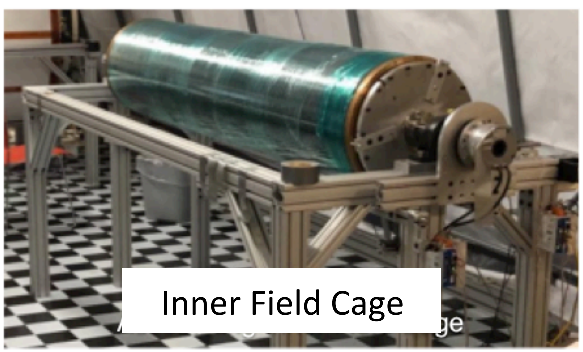




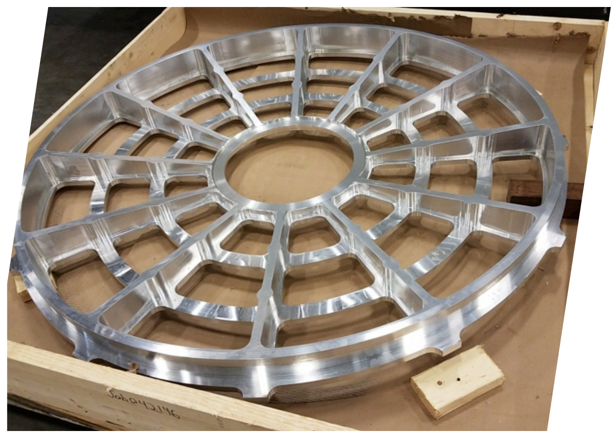


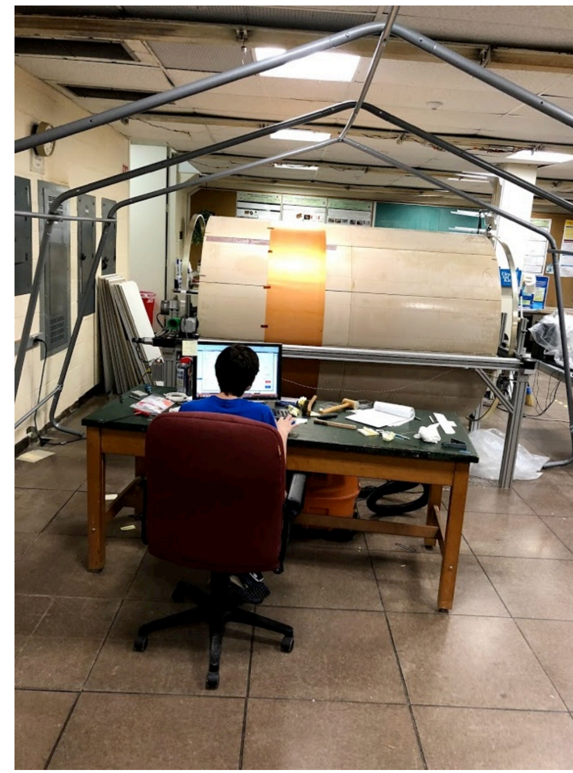
TPC

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



Wagon wheel

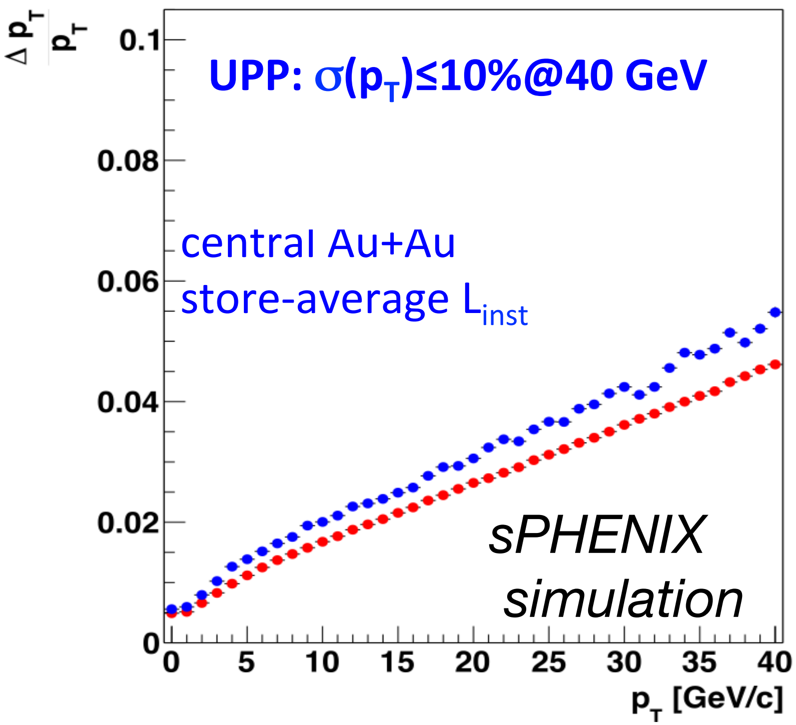




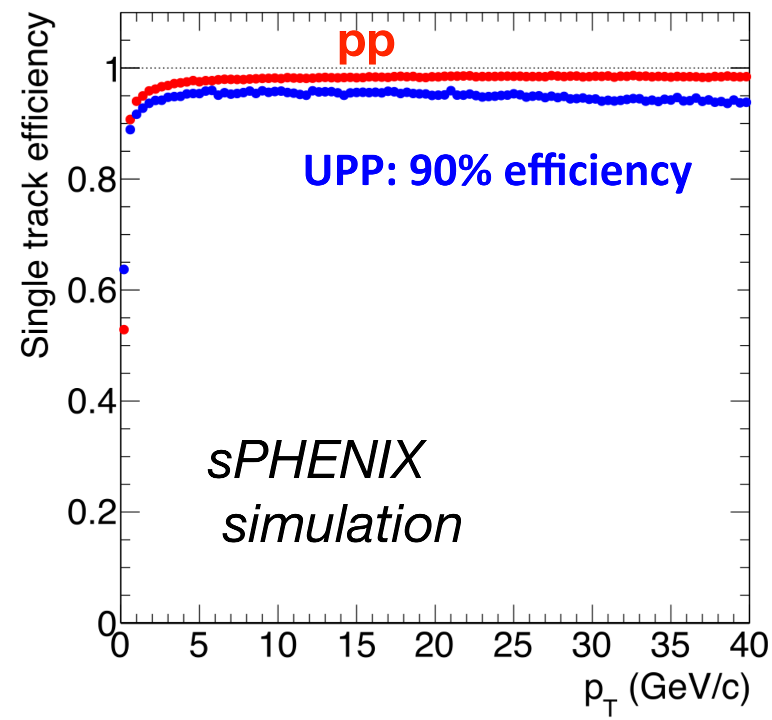
The TPC position resolution in the r-ϕ (bend) direction measured to be 114 μm averaged over the full drift length

Tracking Performance

Track p_T resolution (central Au+Au)



Tracking efficiency (central Au+Au)

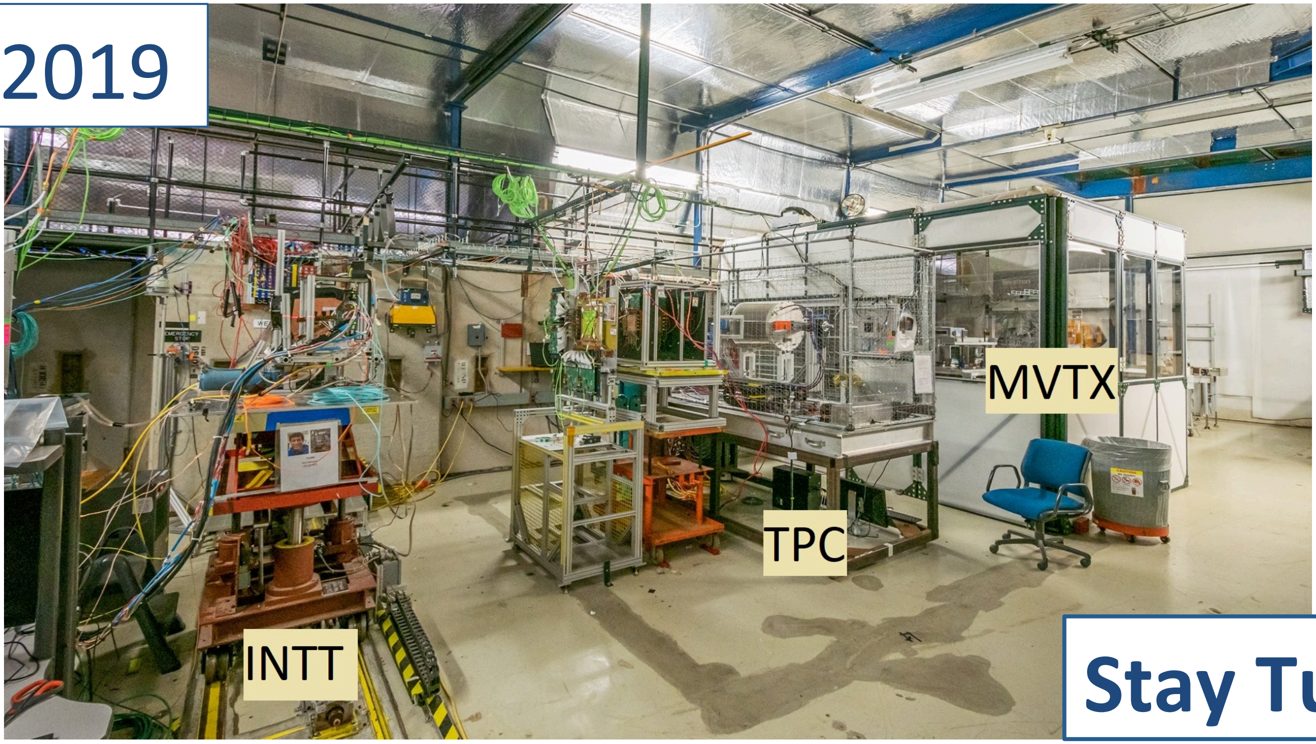


High momentum resolution

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

Tracking Beam Test

2018/2019



Stay Tuned!

- Test of telescope w/full readout + cables completed
- Readout tested up to 300 kHz with p beam and p-on-Pb sprays (sPHENIX requirement 15kHz)

- Si Modules tested
- Track resolution measurements + full readout chain test just completed

- Beam tests of TPC prototype with sPHENIX R2 quad-GEM module
- Successful data taking with near final TPC electronics

Calorimetery

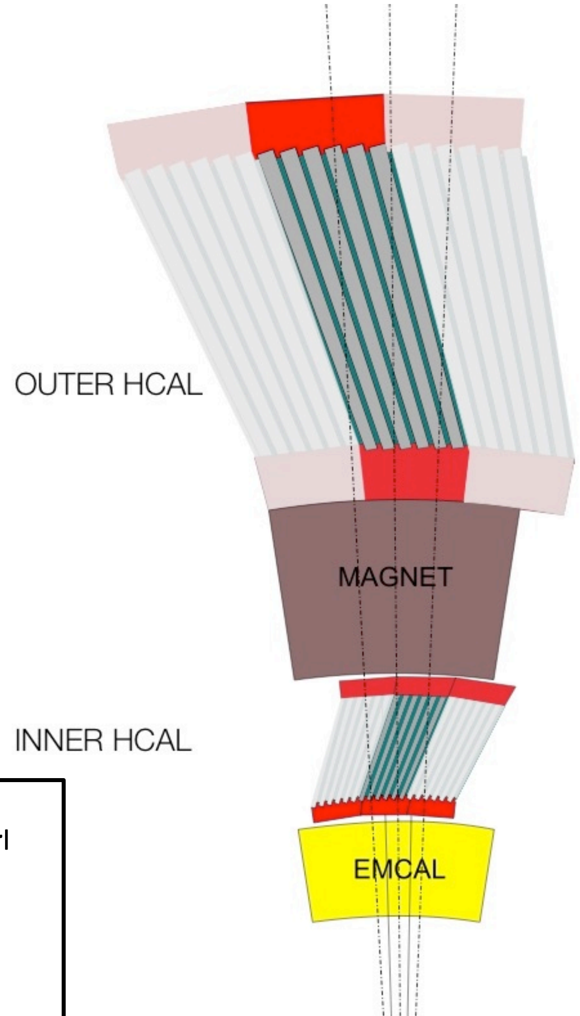
EMCal: Scintillating fibers embedded in W powder

- $\Delta\eta\times\Delta\phi = 0.024\times0.024$
- $\sigma_E/E < : < 16\%/\sqrt{E} \oplus 5\%$

HCal: Plastic scintillating tiles + tilted Steel/Al plates

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

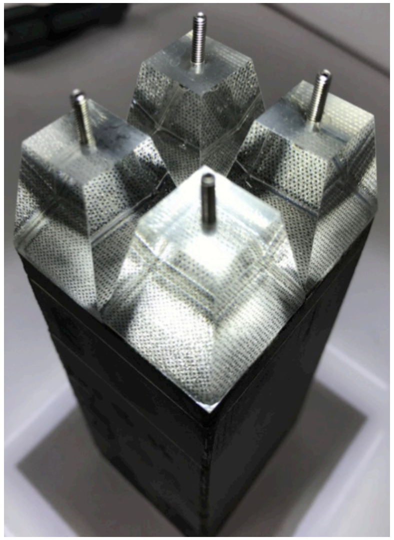
- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

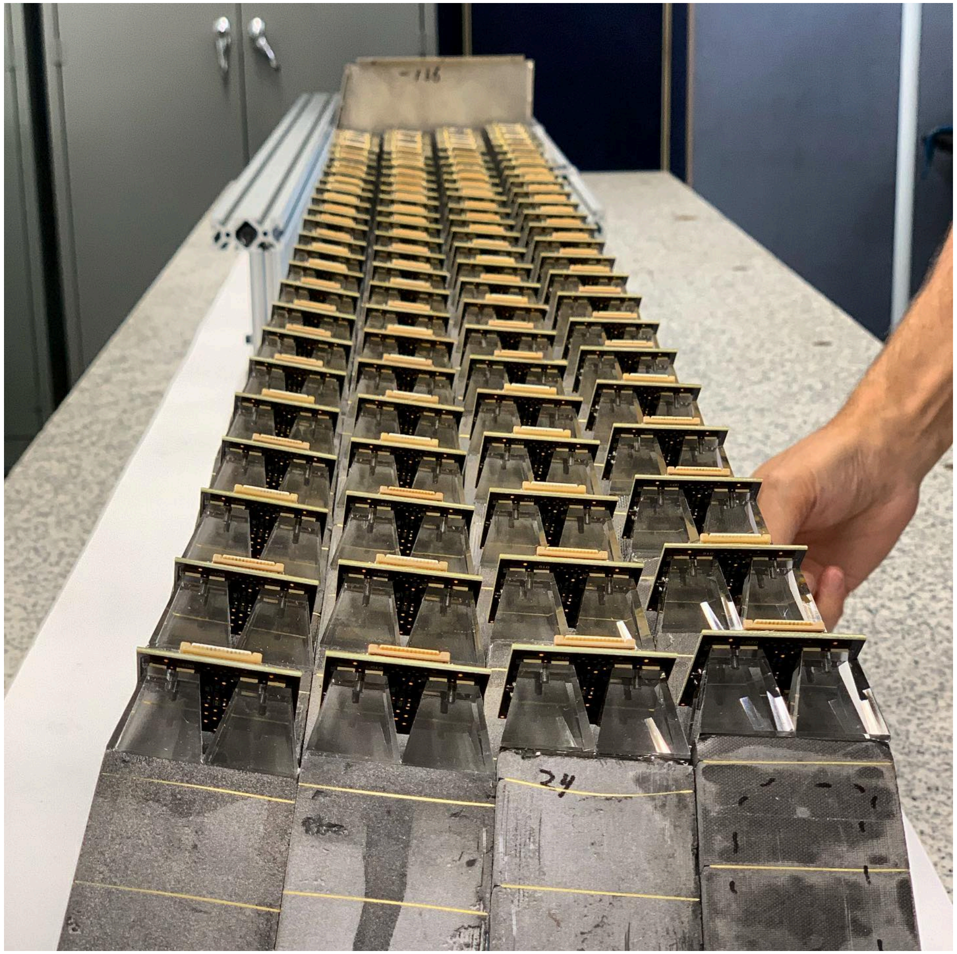


EMCal

Technology pioneered by UCLA group

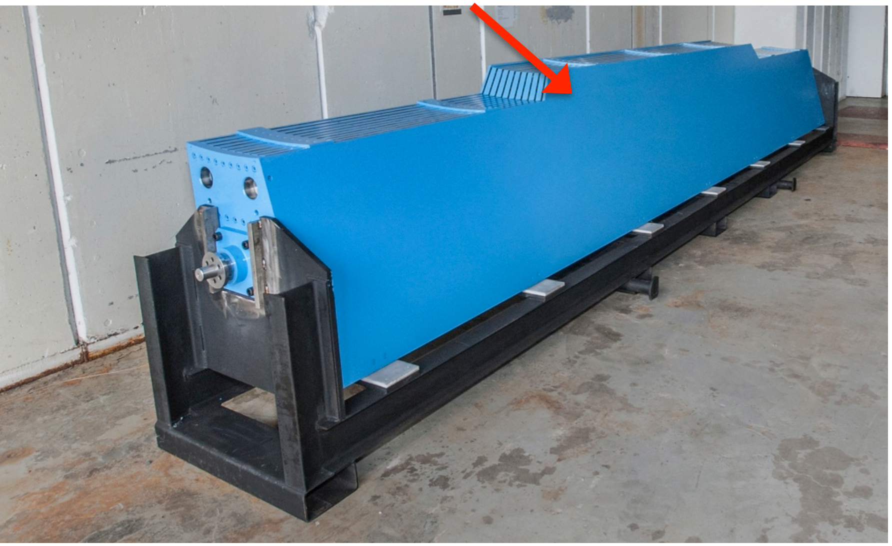
- 2D projective, read out by SiPMs
- Same electronics as HCal
- Production techniques advanced by UIUC group



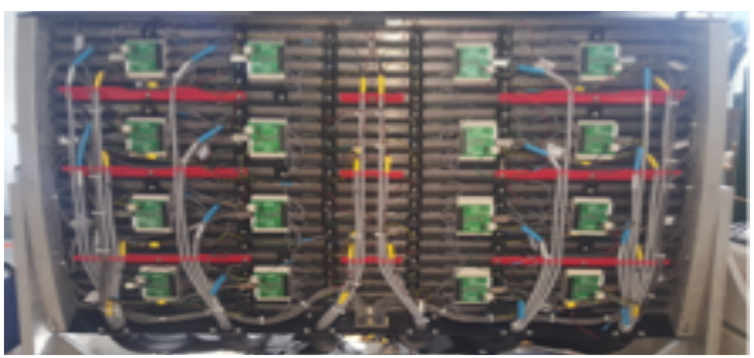


HCAL

Slots for scintillating tiles, read-out by SiPMs



6.4 meters long
|η| < 1.1
32 modules form flux return



Cosmic ray testing tiles

- 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

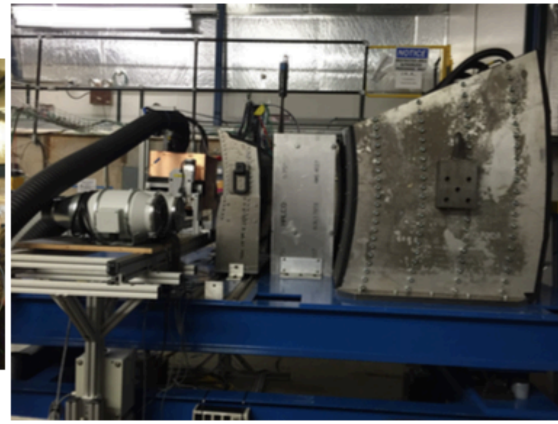
30 of 32 HCal/Barrel Magnet Steel Sectors now at BNL

13.5 tons each!

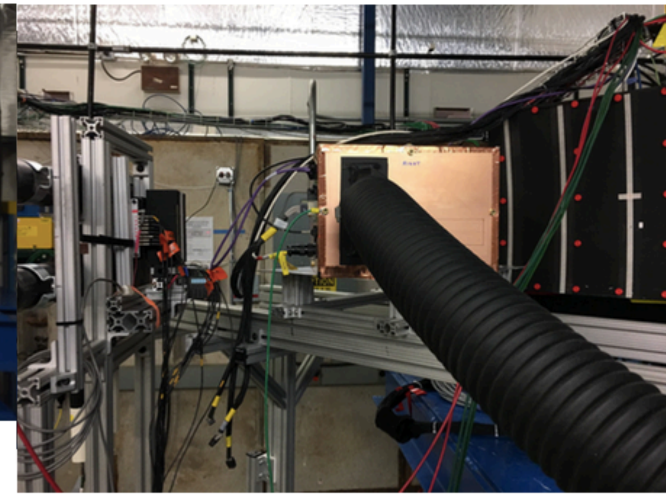
Testing support assembly

Calorimeter Beam Test

Proof of principle, Feb 2014



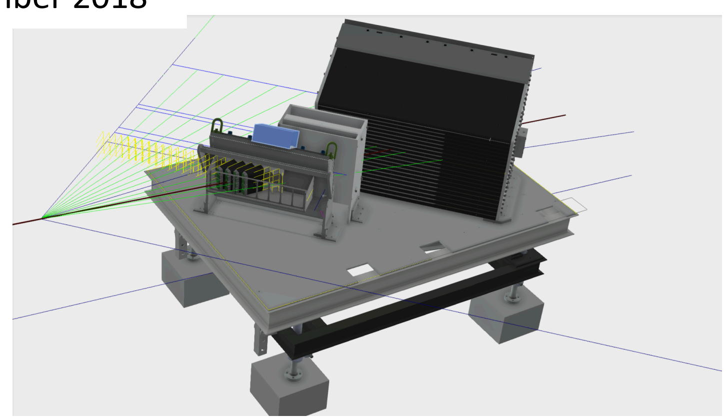
η~0 Geometry, Feb 2016



η~0.9 Geometry, Feb 2017

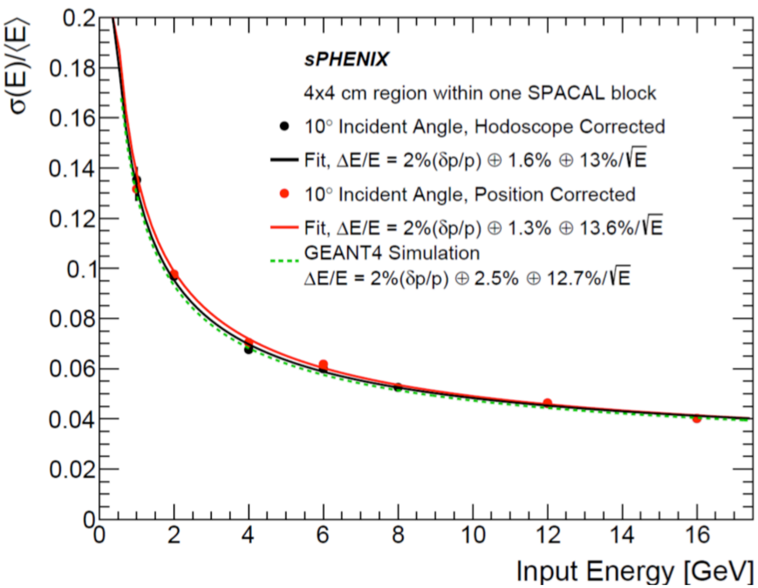
EEE Transactions on Nuclear Science, Volume 65, Issue 12, pp. 2901-2919, December 2018

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

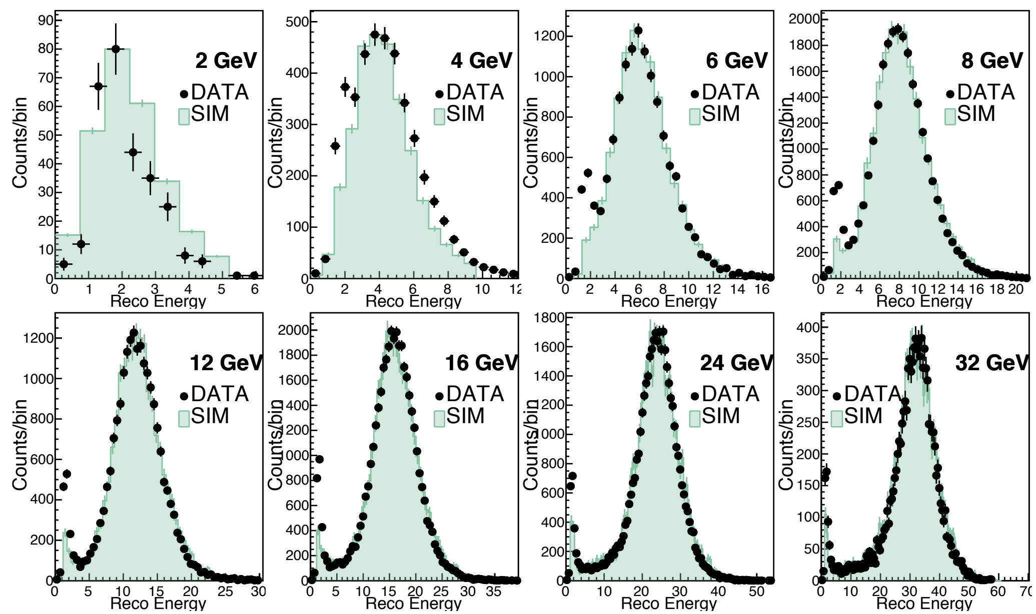


Calorimeter Performance

EMCal energy resolution for EM shower in tower center

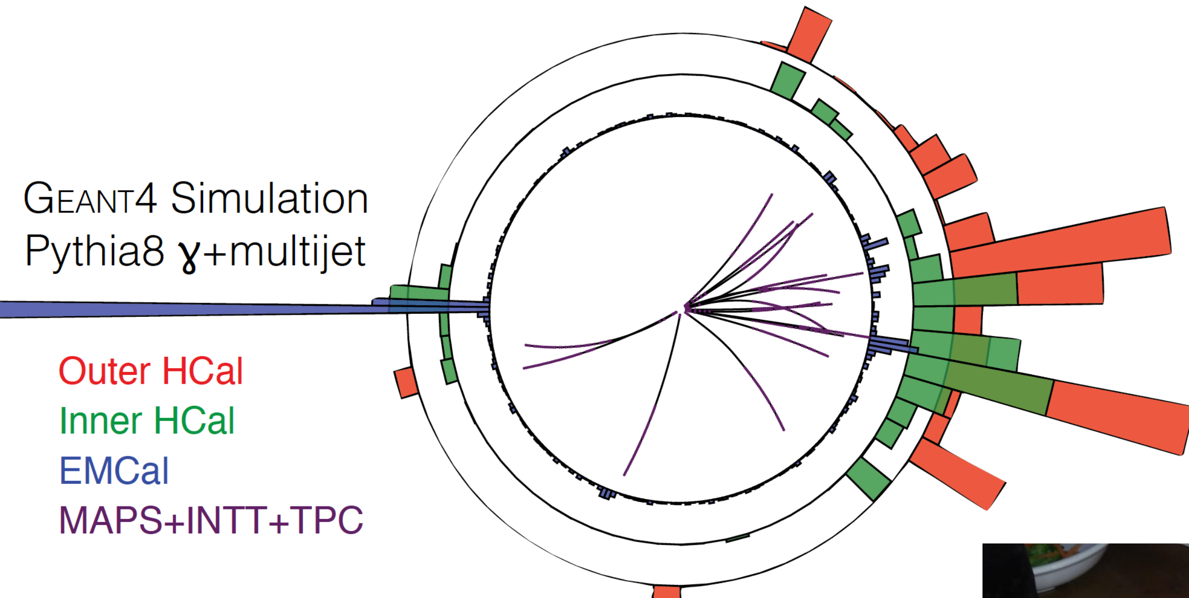


HCal energy response to π^{-}



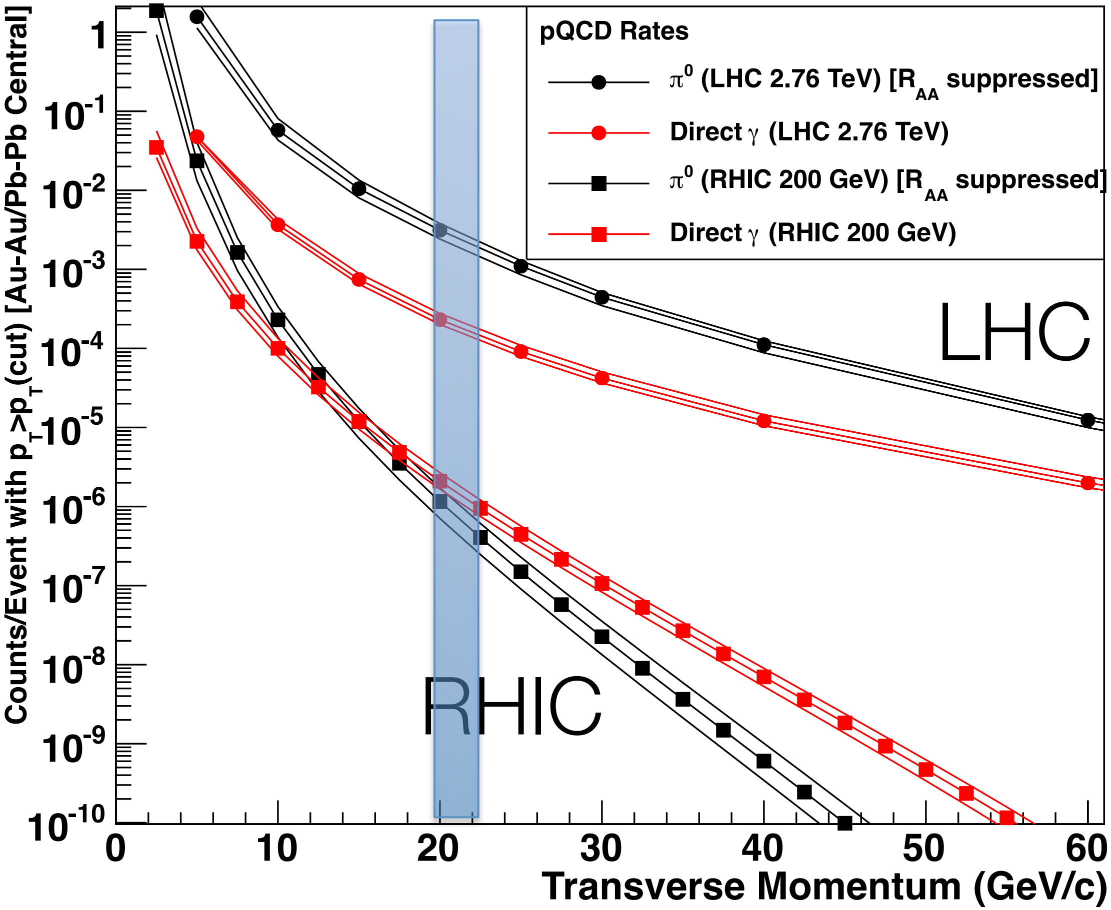
IEEE Trans. Nucl. Analysis of 2018 data underway Sci. 65 (2018) 2901

A Taste of Physics



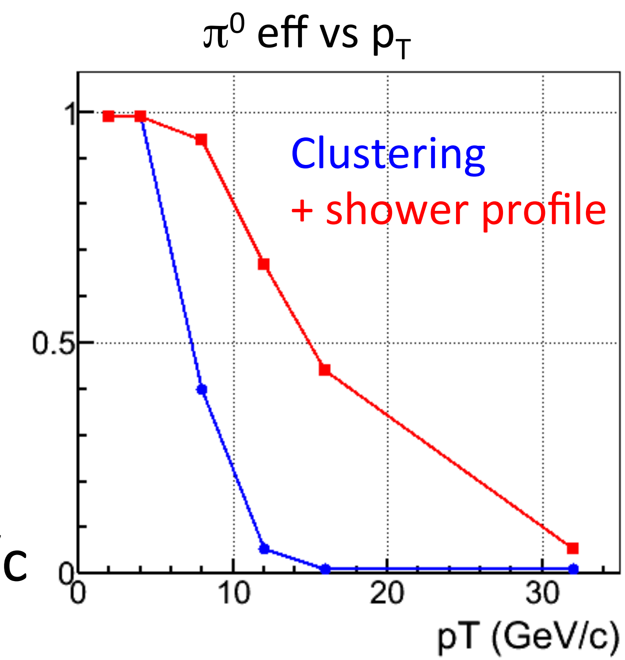
What will our detector performance give us in terms of physics observables?

γ – Jet Correlations



For 20 GeV γ

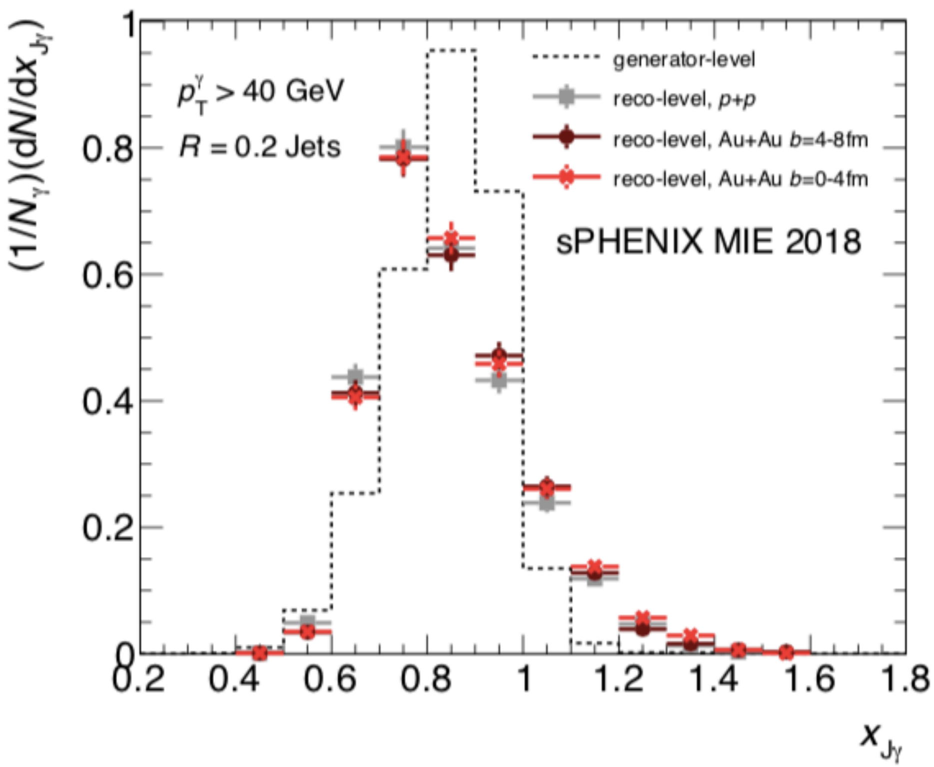
- S/B is 20x larger at RHIC than LHC
- UE 2.5x smaller



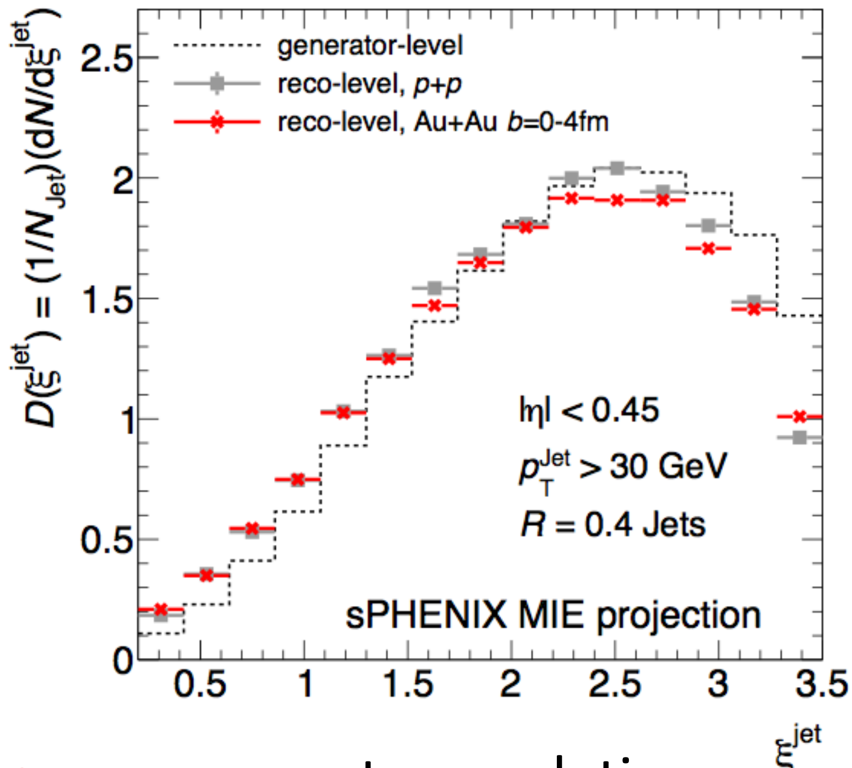
Allows for γ/π^0 discrimination up to ~20 GeV/c

Jets in sPHENIX

γ+jet momentum balance



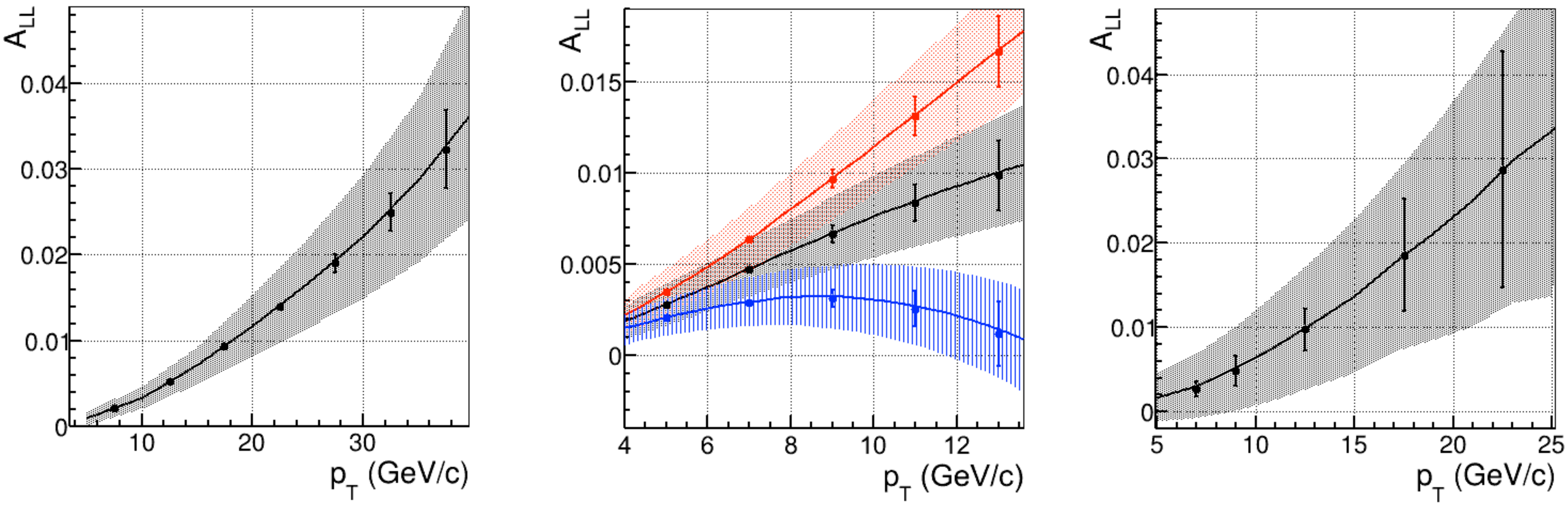
γ+jet fragmentation function



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

- New era in RHIC jet physics!

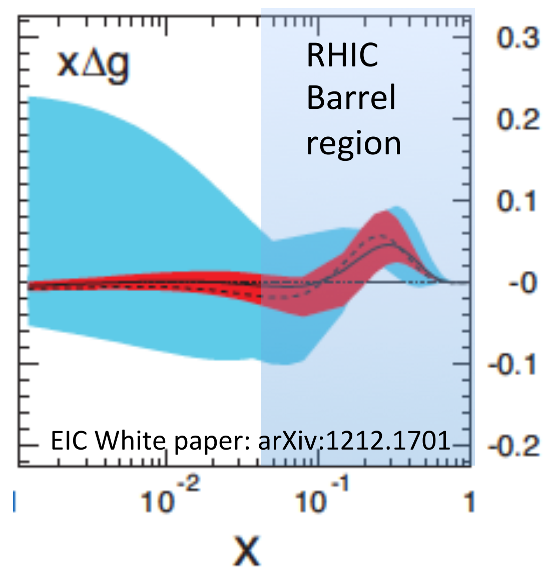
ΔG Projection



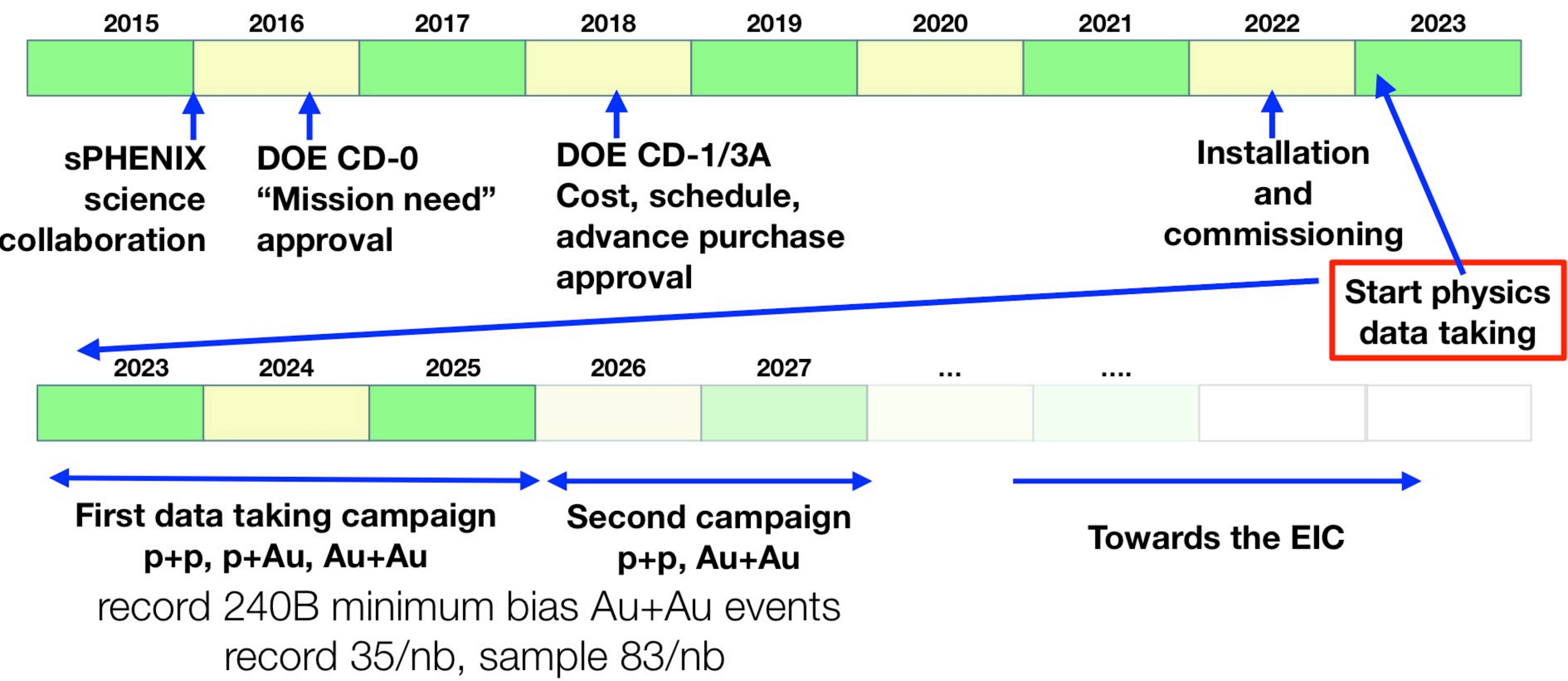
Era of high precision ΔG measurements:

- Will crucially improve ΔG constraint at x>0.05
- Complementary to the future EIC
- Crucial universality test in the overlapping x-range

With EIC data the dominant uncertainty to ΔG-integral will be coming from the "RHIC region"



Timeline



2015
2016
2017
2018
2019
2020
2021
2022
2023
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
2023
2024
2025
2026
2027
...
....
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

Run Plan

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

1st Campaign **2nd Campaign**

- Minimum bias Au+Au at 15kHz, vertex |z| < 10 cm (in acceptance of Si tracking):
  - 47 billion (Year-1) +
  - 96 billion (Year-3) +
  - 96 billion (Year-5) = Total 239 billion events
- Topics with Level-1 selective trigger (e.g. high pT photons), |z|<10cm, can **sample 0.5 trillion Au+Au events**

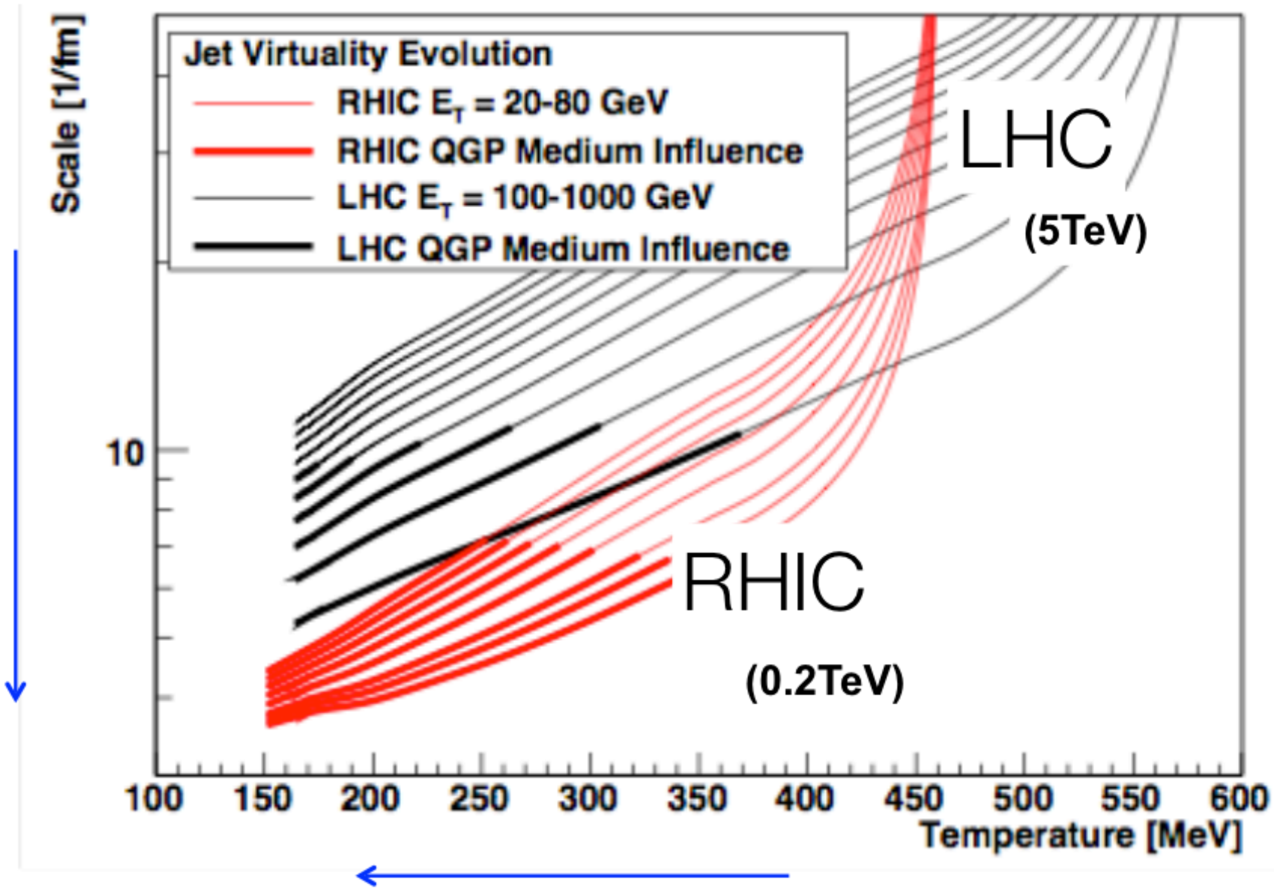
Summary

- 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!

Back Up

Jet Evolution @ RHIC

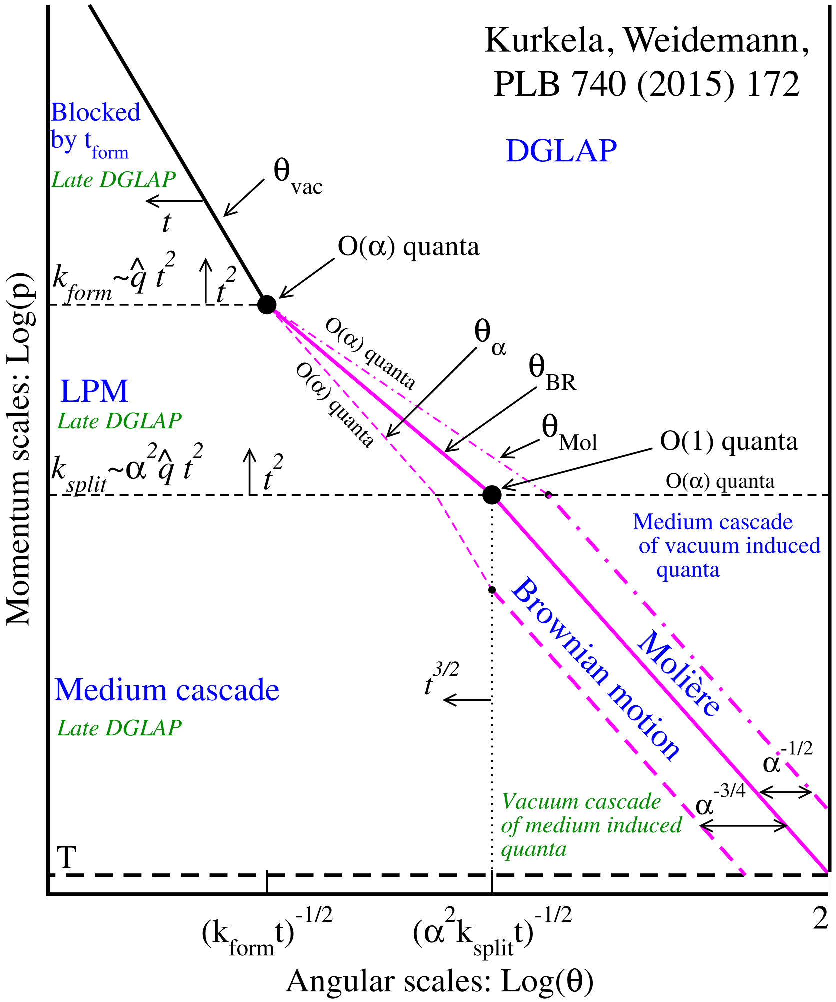
M. Habich, J. Nagle, and P. Romatschke, EPJC, 75:15 (2015)

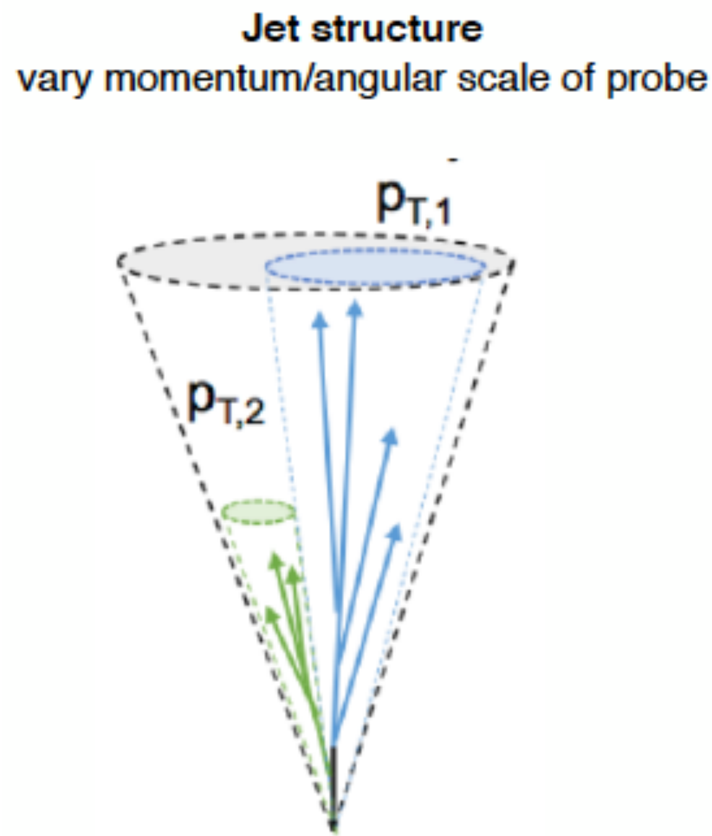


QGP@RHIC → Closer to transition temperature

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

Core sPHENIX science program



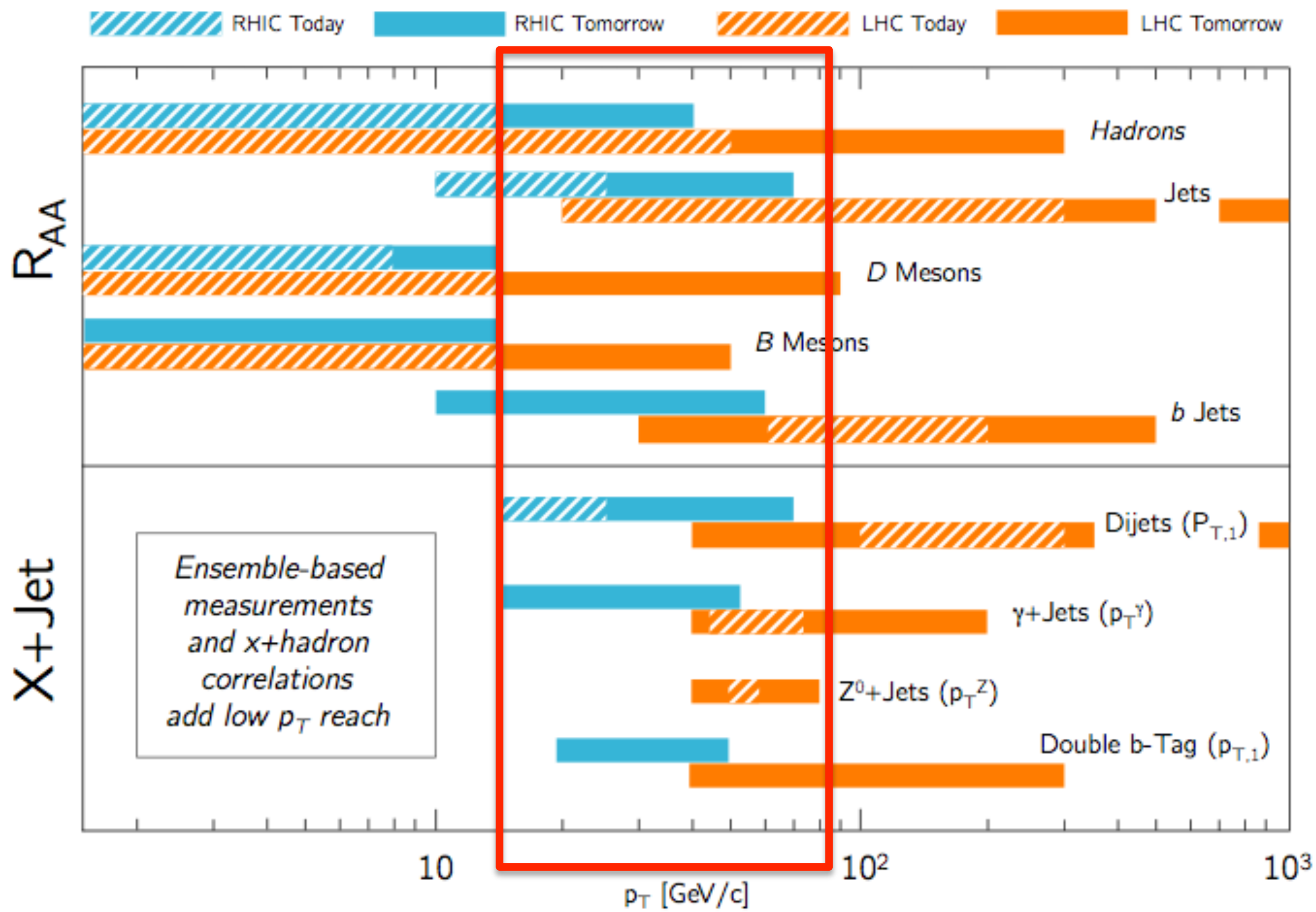


Physics Goals

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 Υ(1s), Υ(2s), (Υ3s) 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 ≲ 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**

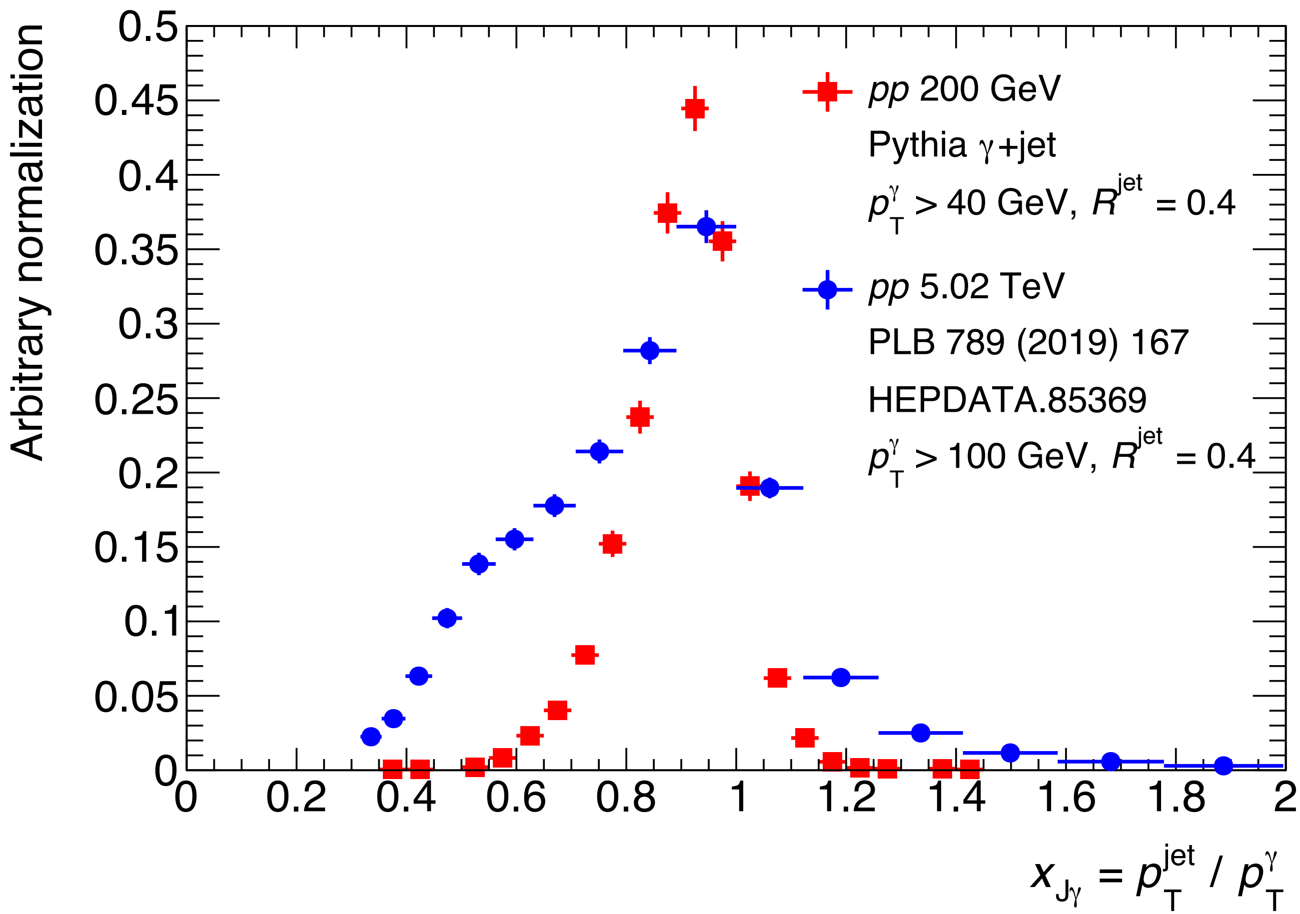
(**) to be extracted using Au+Au, p+p data + simulations → LHC example

RHIC/LHC Complementarity



Study same probe @ different QGP evolution

LHC/RHIC Comparison



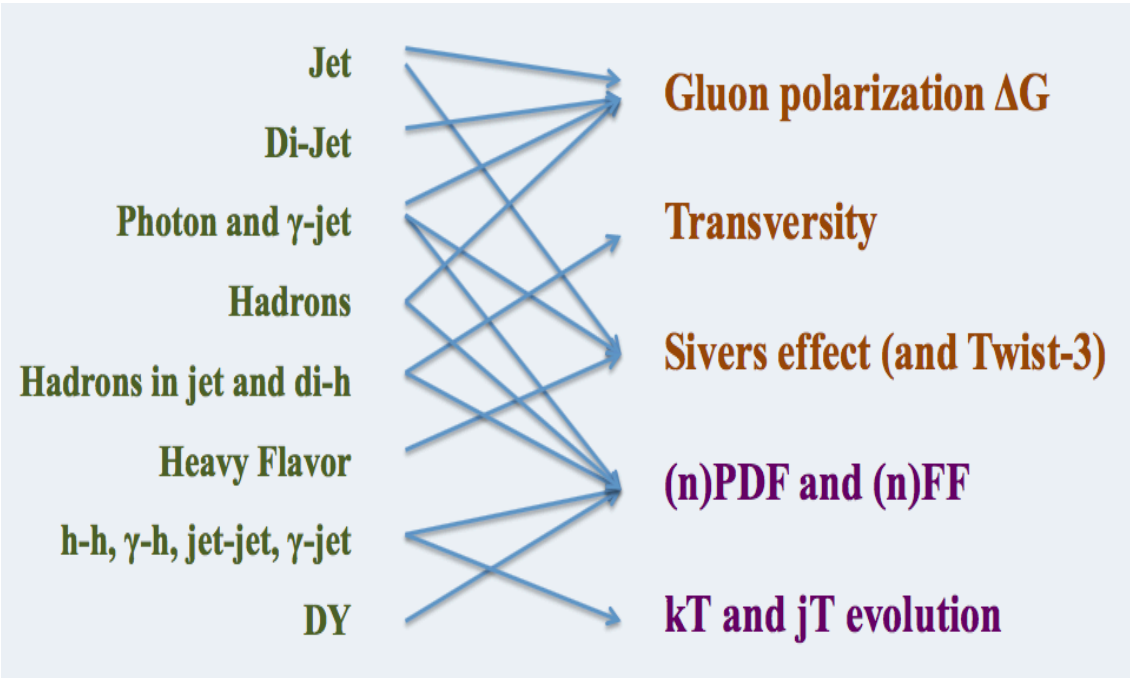
Major physics goal for the HI community

- compare "similar" jets at RHIC & LHC

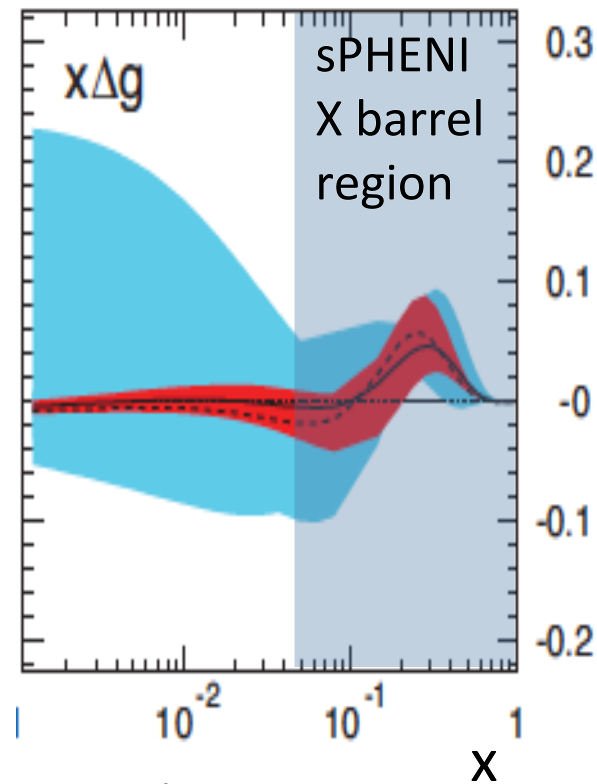
γ-jet!

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

Cold QCD



Gluon Polarization

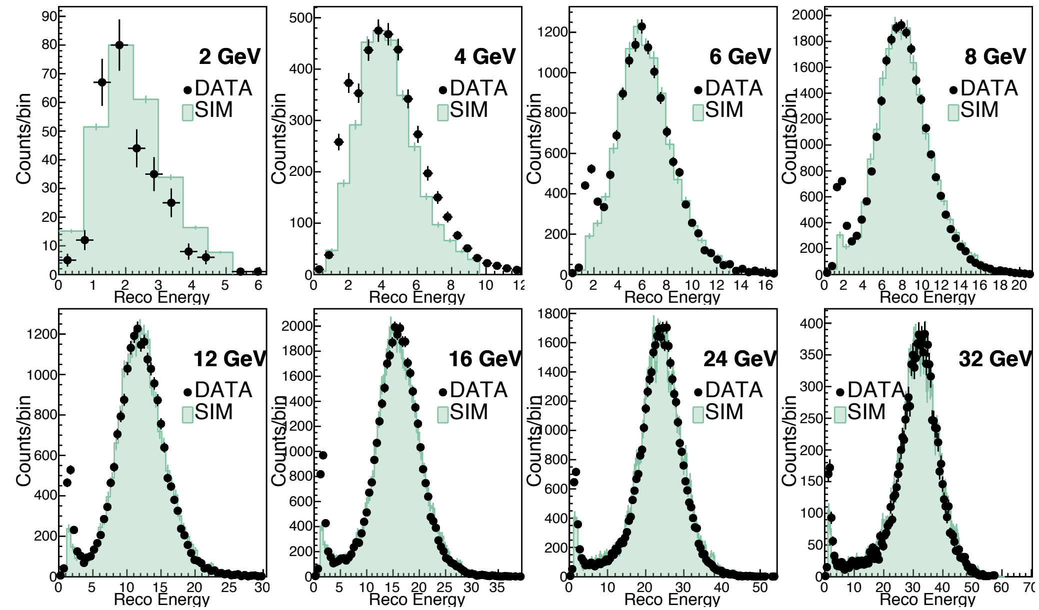


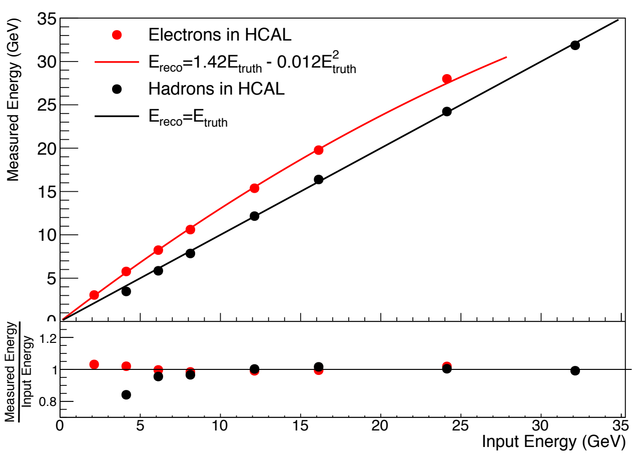
EIC White paper:
arXiv:1212.1701

Jet and hadron asymmetries in polarized pp are sensitive to gluon polarization in high-x region compared to EIC reach

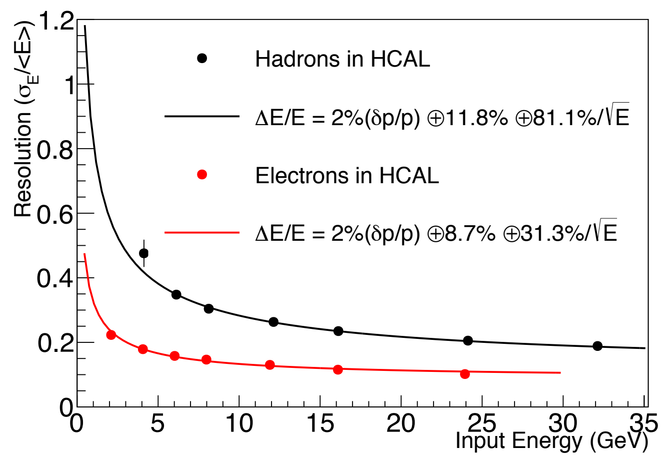
HCal Test Beam

Good agreement between data and simulation validates simulation





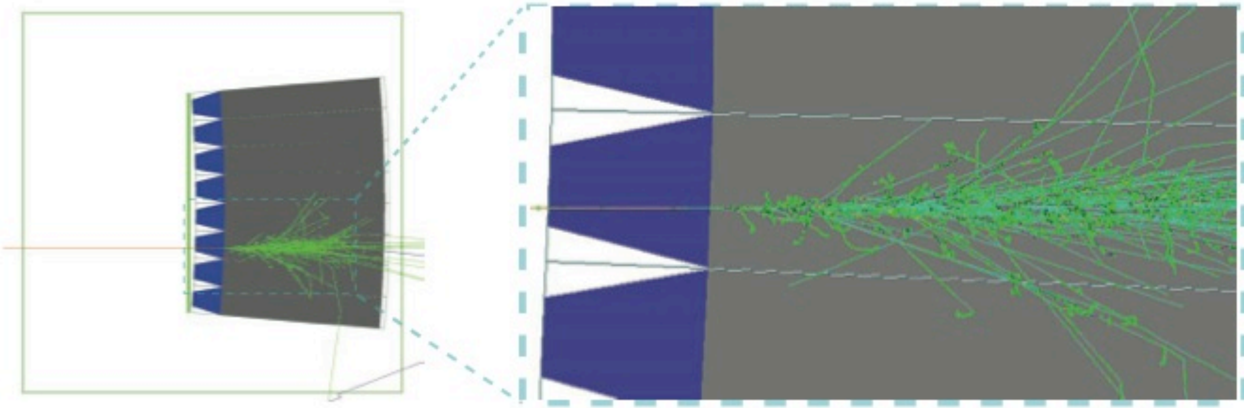
(a)



(b)

Linearity and resolution for electrons and hadrons in the HCal

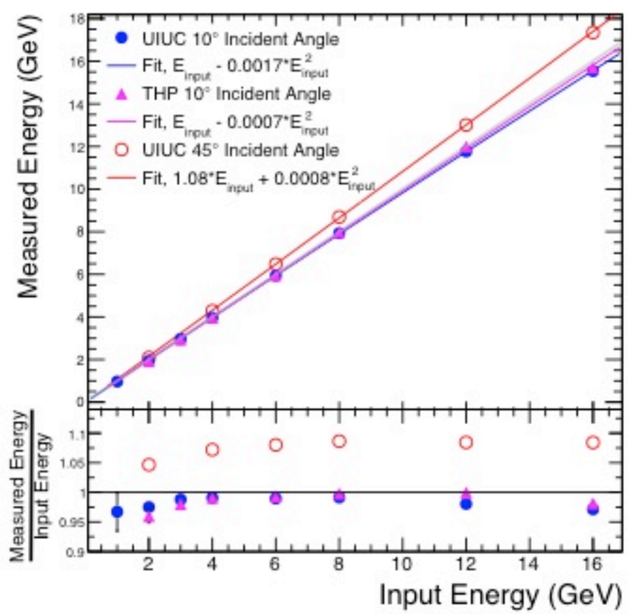
EMCal Beam Test

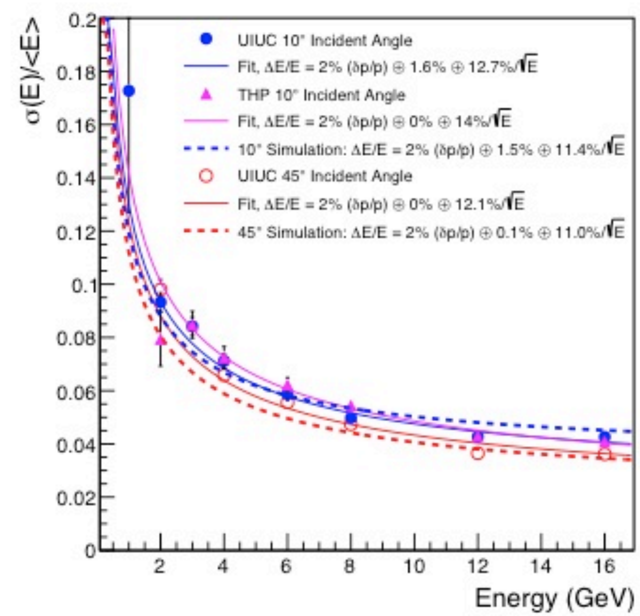


GEANT4 simulation of 8 GeV electron incident on EMCal (in test beam configuration)

Linearity and resolution vs. Electron Energy

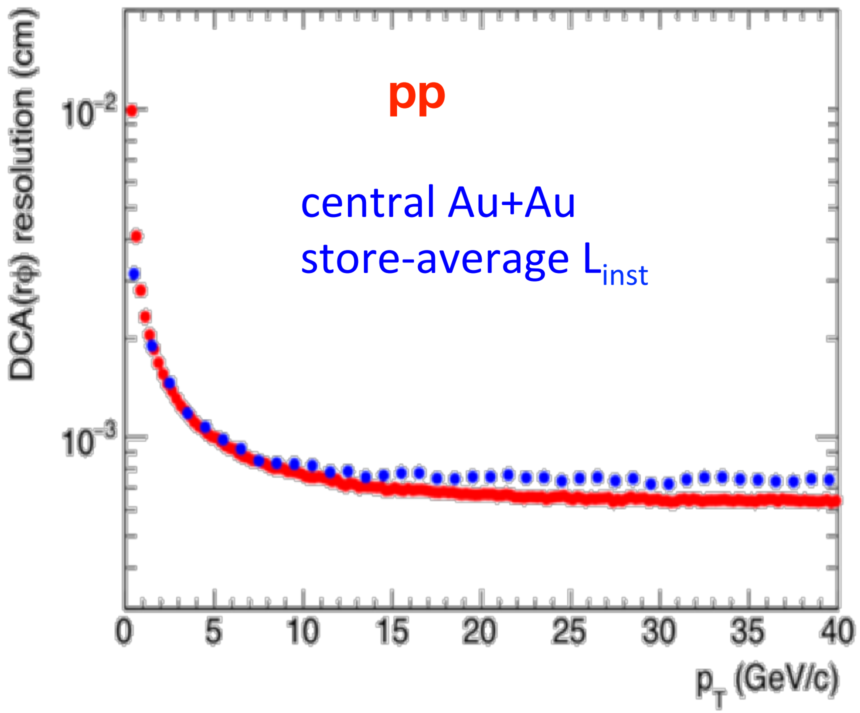
(different tower designs & incidence angles)

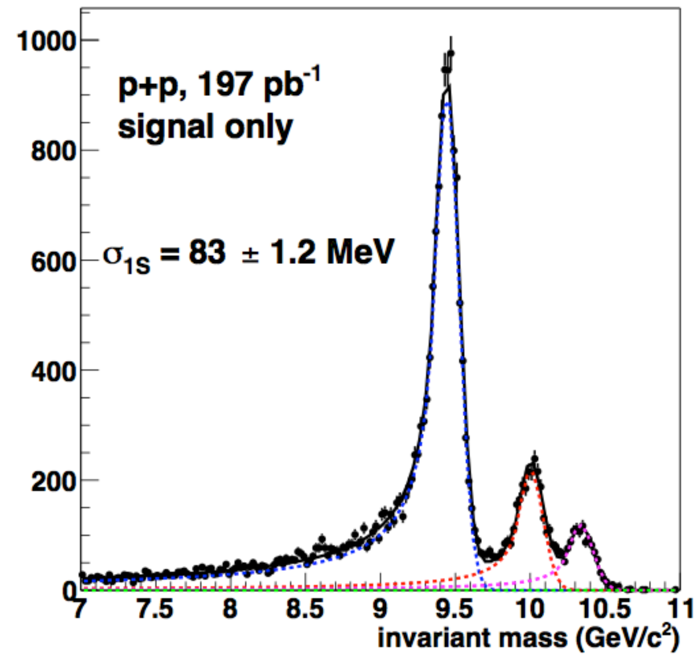




Tracking Performance

MVTX DCA Resolution

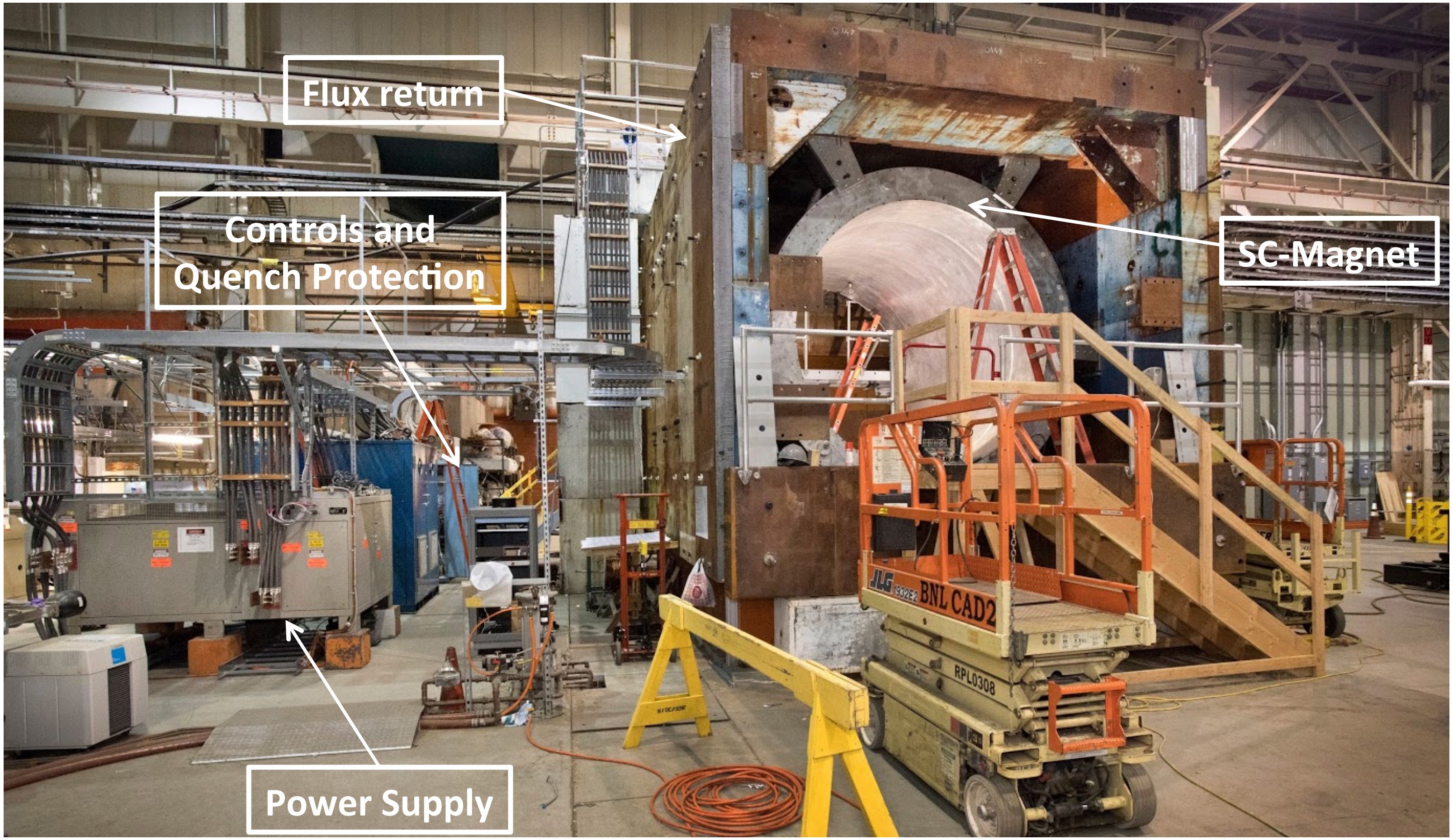




Key for b-tagging and open HF measurements

Resolve Upsilon 2S and 3S mass states

sPHENIX Magnet

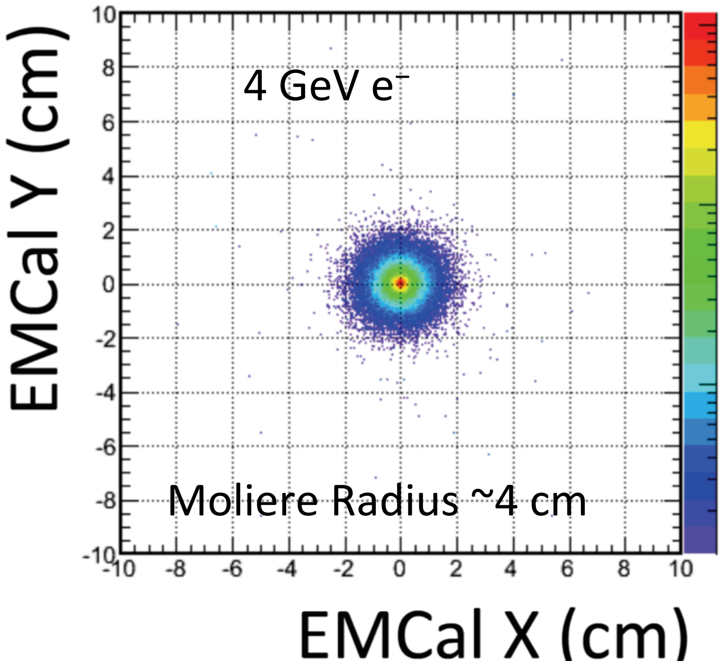


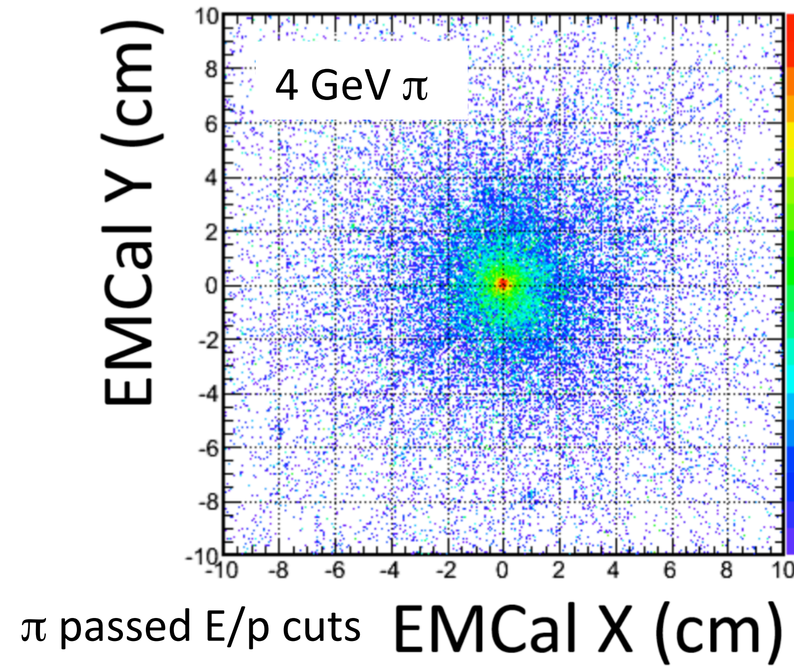
- Formerly Babar magnet, 1.4 T solenoid

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

Calorimeter Performance





95% containment in 3x3 tower square

50% containment in 3x3 tower square