sPHENIX: the Next Heavy Ion Detector at RHIC

Sarah Campbell

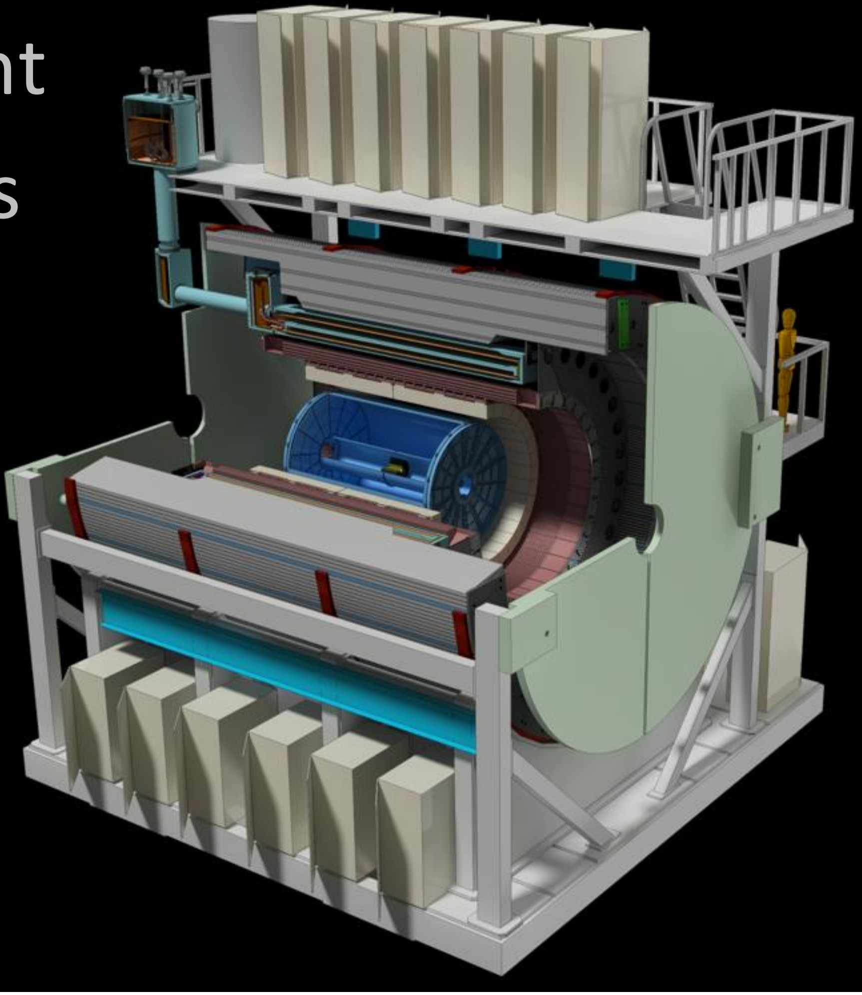
Hot Quarks

South Padre Island, TX

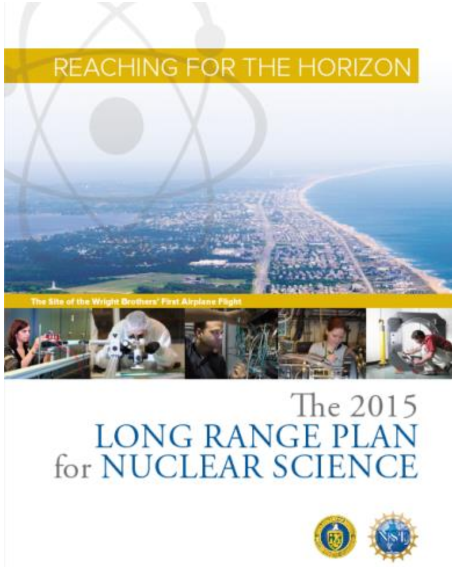
Sept 16, 2016

Outline

- Goals of the new RHIC detector
- Detector development
- Simulated capabilities



Goals of the new RHIC detector



RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

… other facilities …

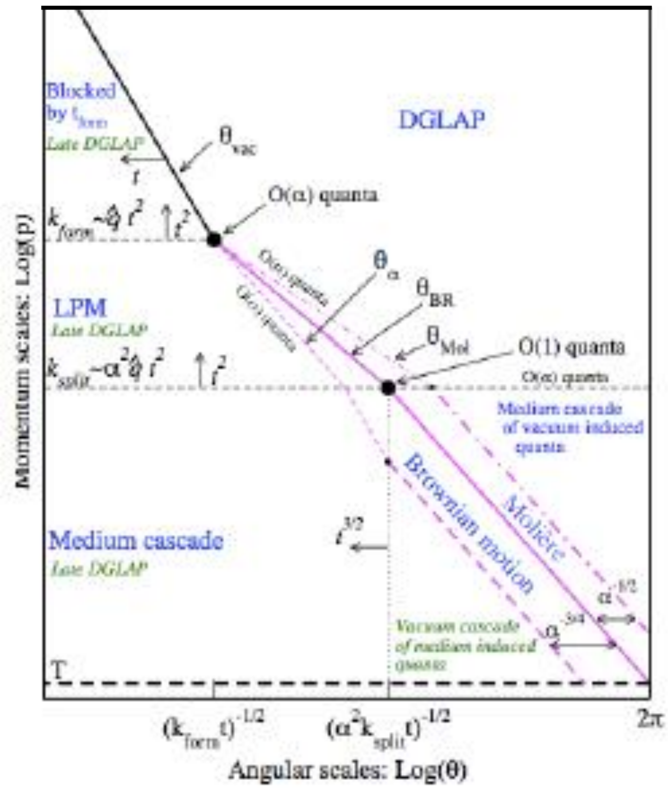
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

From sPHENIX Cost and Schedule Review:

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.**

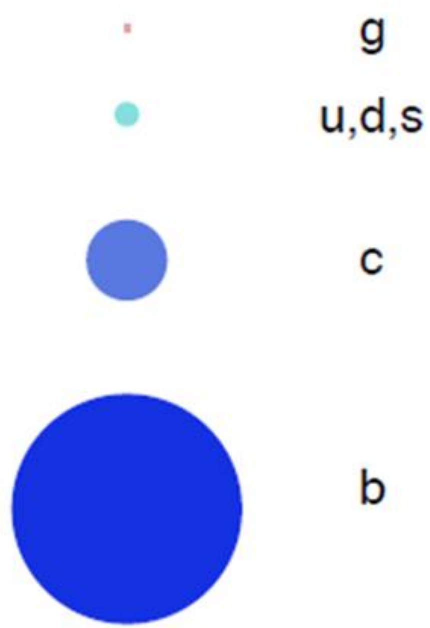
Length-scale probes of QGP

Jet evolution and structure

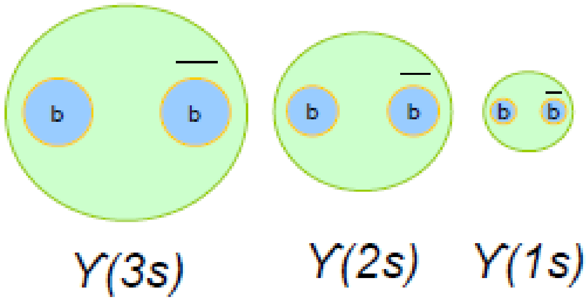


Phys. Lett. B 740 172 (2015)

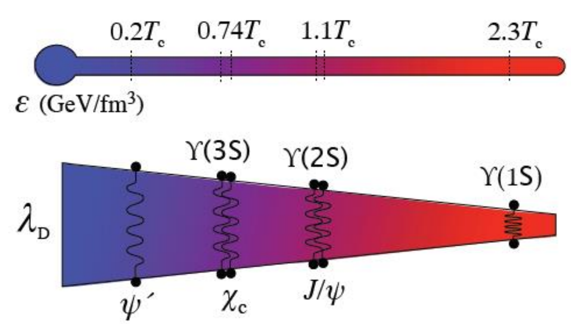
Partonic probes



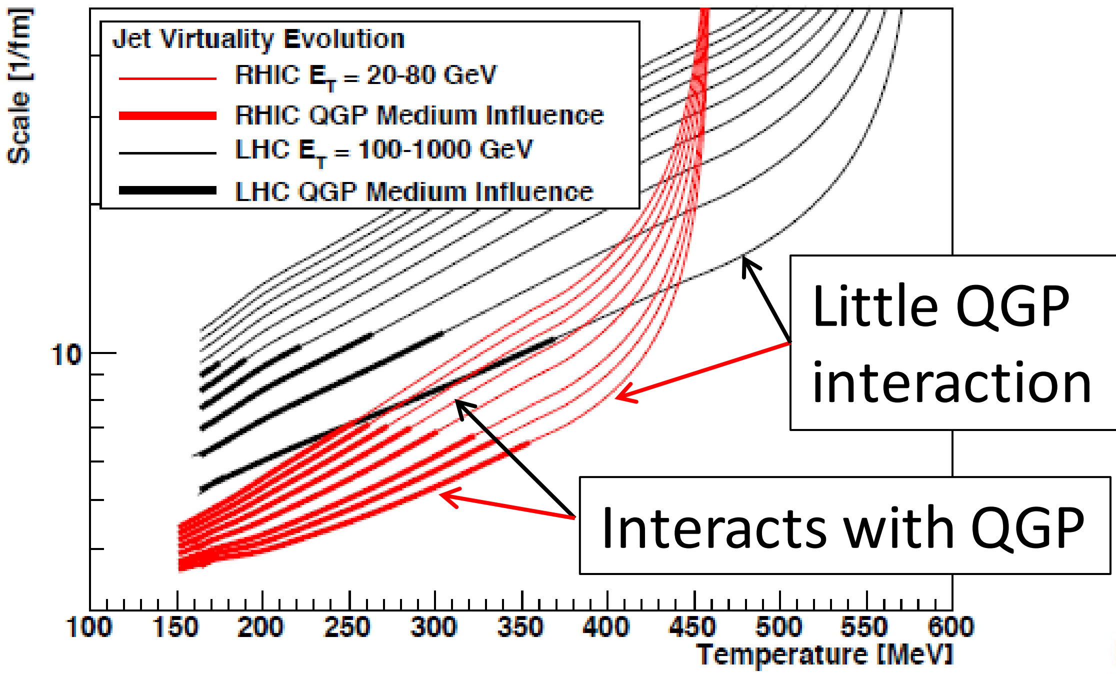
Upsilon states

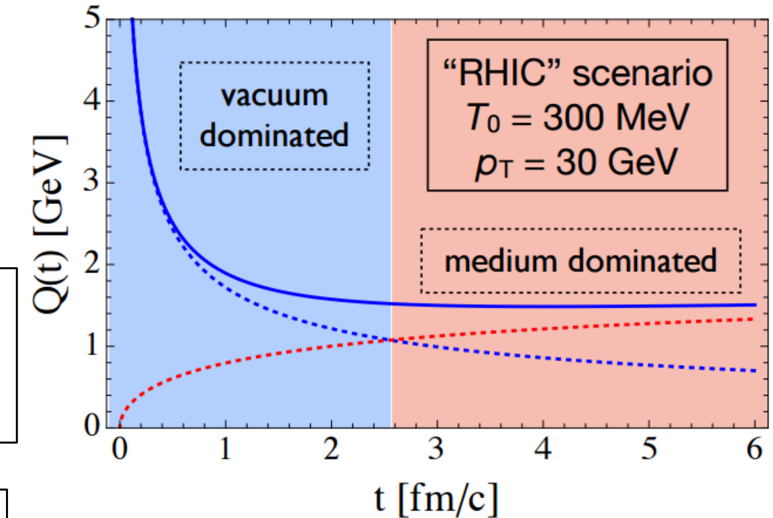


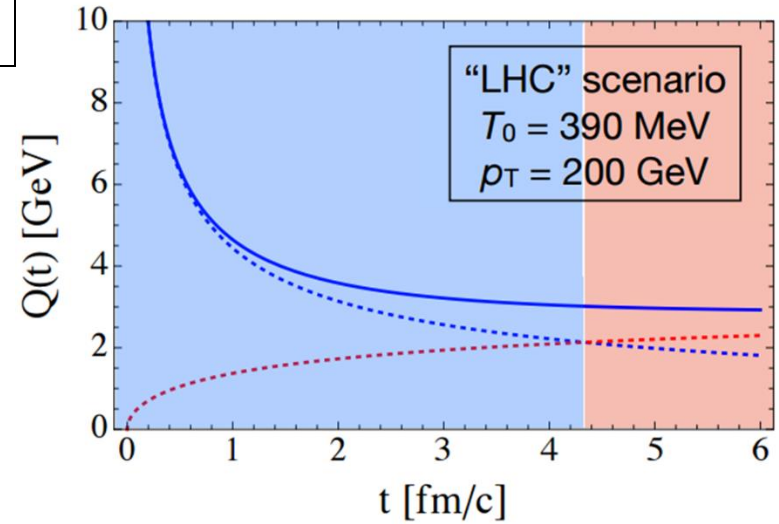
Sequential melting



Jet Evolution and Virtuality







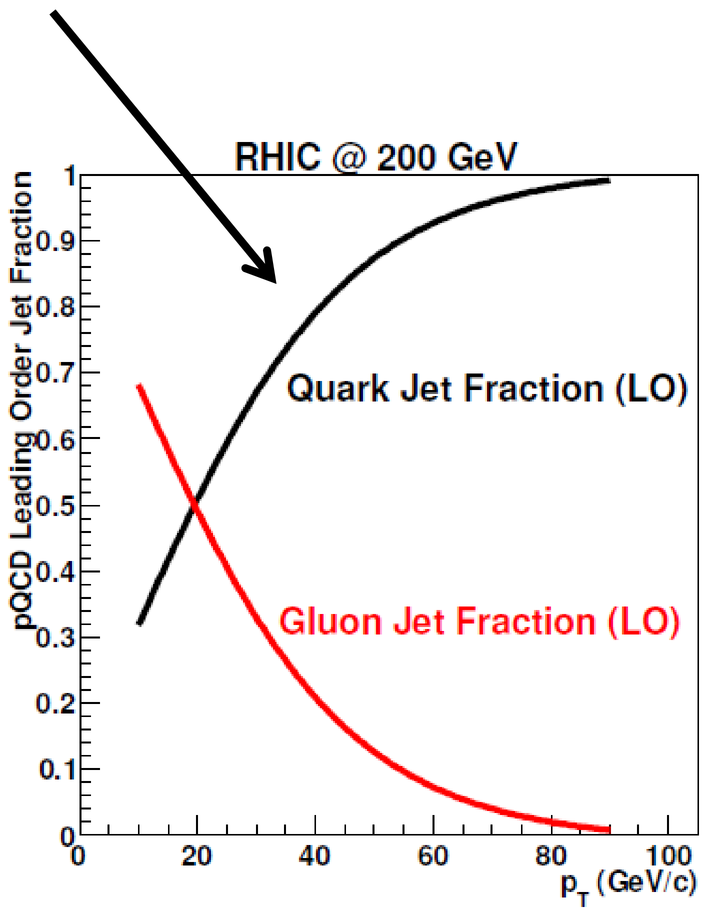
Lower energy jets, jets at RHIC have increased sensitivity to QGP interactions

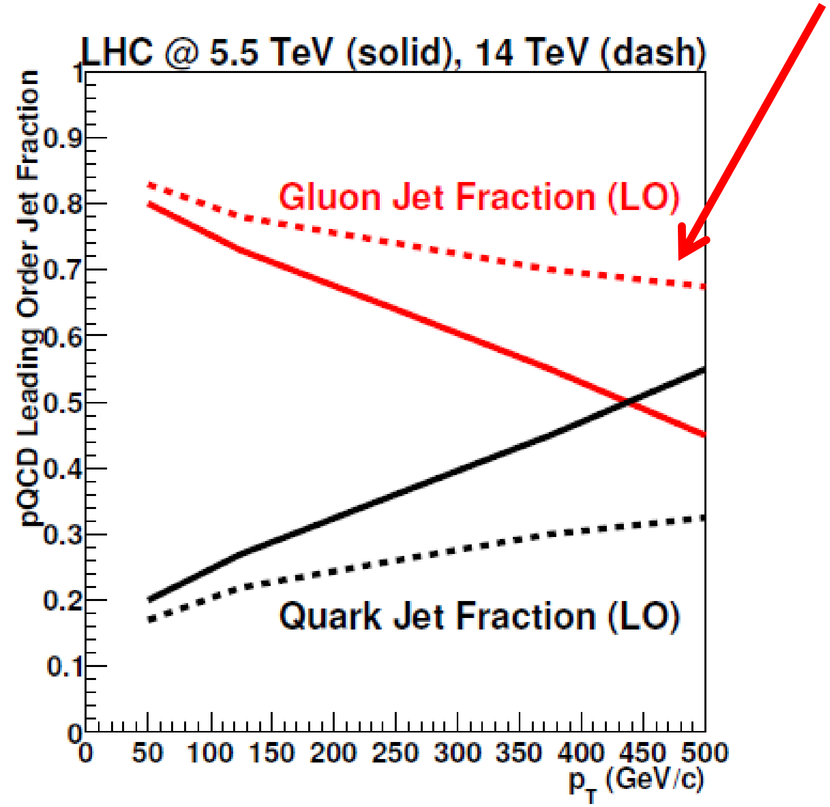
Complementary measurements at RHIC & LHC

Partonic Composition of Jets

Higher quark-jet fraction at RHIC

LHC gluon-jet dominated until significantly higher jet energies



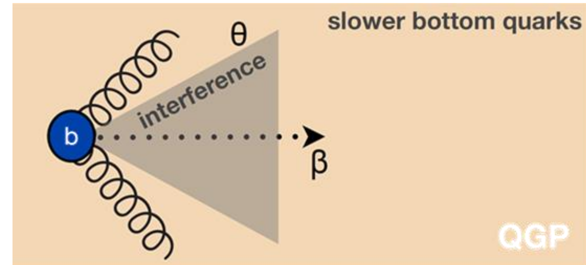


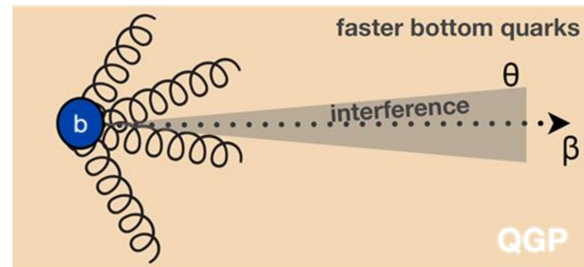
Complementary measurements at RHIC & LHC

Heavy quark–medium interactions

Heavy Flavor jets

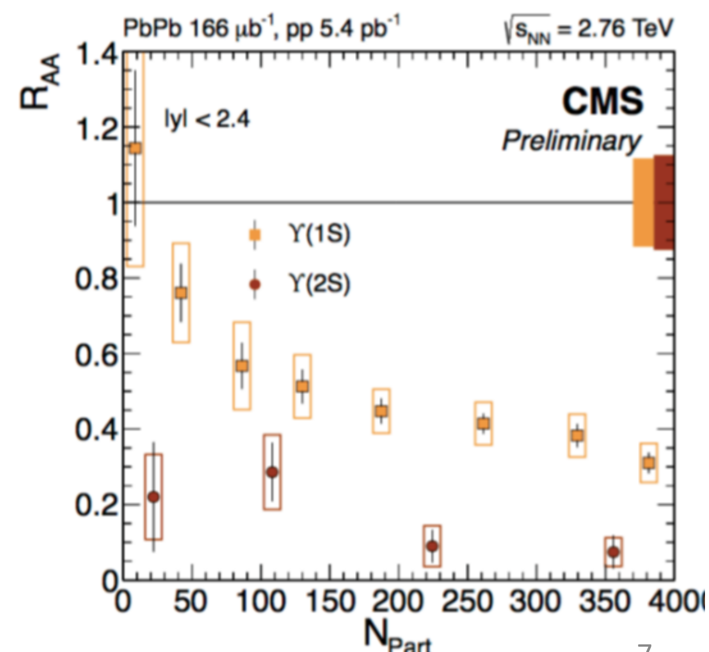
- Collisional vs radiative energy loss
  - Separate $\hat{q}$ and $\hat{e}$
- Dead cone effect





Upsilons

- Sequential melting & color screening → T_{LHC} ~30% higher T_{RHIC}
- Reduced coalescence at RHIC
  - Lower Υ rates, compensated by RHIC luminosities
  - Compare J/ψ and Υ(2S) similar size and binding energies



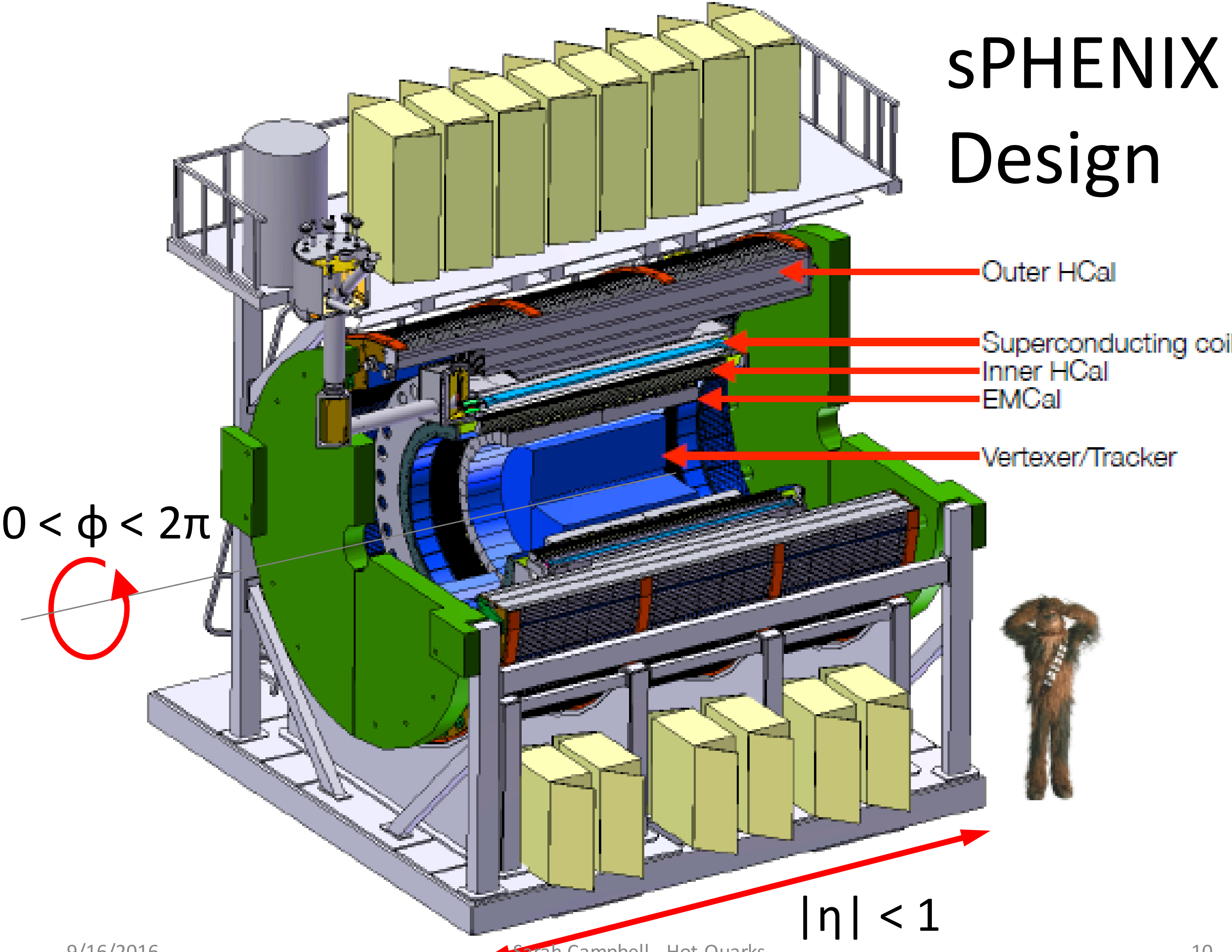
The 3 Pillars of sPHENIX

Three-legged Buddha by Zhang Huan at Storm King Art Center, NY

Physics driven detector requirements

Physics goal	Detector requirement
High statistics for rare probes	Accept/sample full delivered luminosity (15kHz rate) Full azimuthal and large rapidity acceptance
Precision Upsilon spectroscopy	Hadron rejection > 99% with good $e^{+/-}$ acceptance Mass resolution 1% @ m_{Υ}
High jet efficiency and resolution	Full hadron and EM calorimetry Tracking from low to high pT
Control over parton mass	Precision vertexing for heavy flavor ID DCA_{vtx} < 70μm
Control over initial parton p_T	Large acceptance, high resolution photon ID
Full characterization of jet final state	High efficiency tracking for $0.2 < p_T < 40$GeV Uniform, constant tracking efficiency

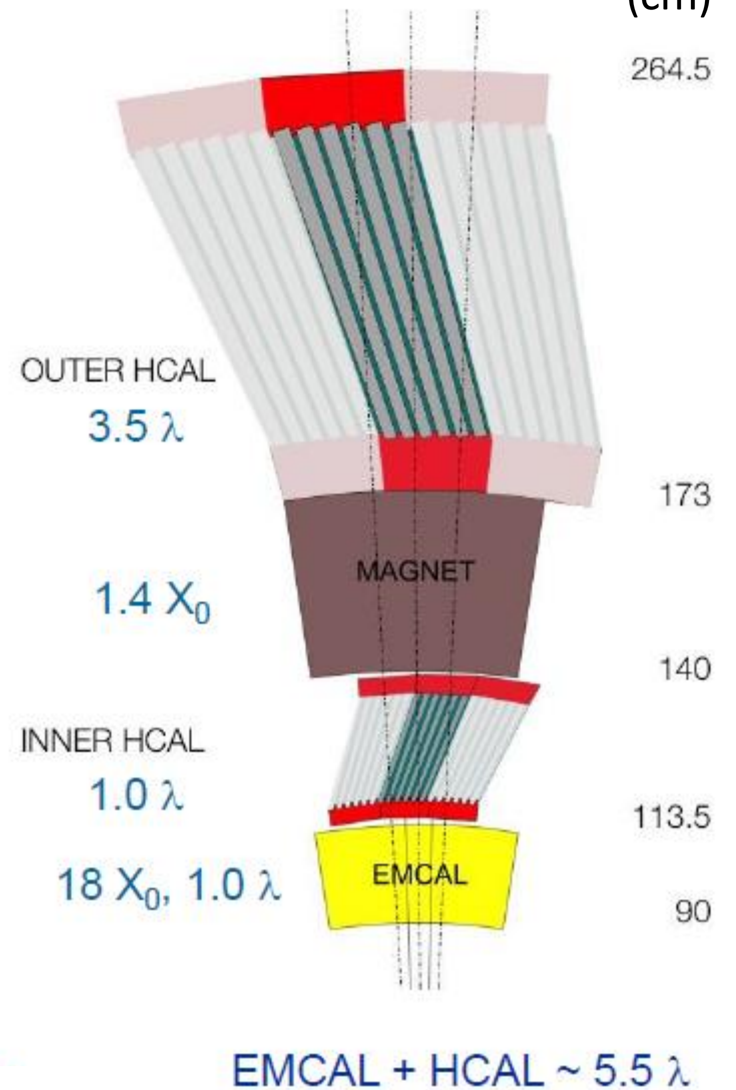
sPHENIX Design



Outer Subsystems

- HCal: Tilted Steel-Si plates
  - Inner and Outer HCal
  - $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$
  - Single particle: $\sigma/E < 100\%/\sqrt{E}$
- 1.5T Superconducting magnet
  - From BaBar, cold tested at BNL
- EMCal: W powder-Si fiber
  - $\Delta\phi \times \Delta\eta = 0.025 \times 0.025$
  - $\sigma/E < 15\%/\sqrt{E}$
  - R&D on 1D or 2D projective modules

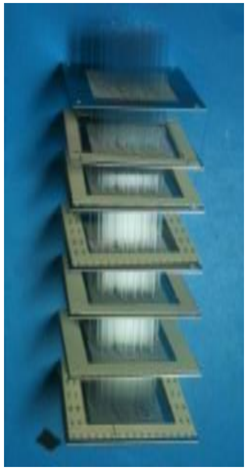
Radii (cm)



Calorimeter R&D

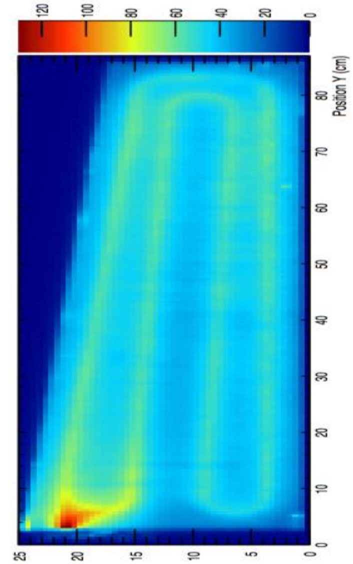
EMCal

2D projective (η, ϕ) modules



HCal

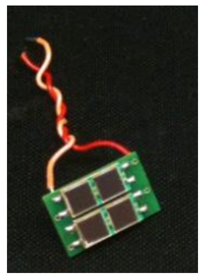
Polystyrene panels embedded with 1mm wavelength shifting fiber



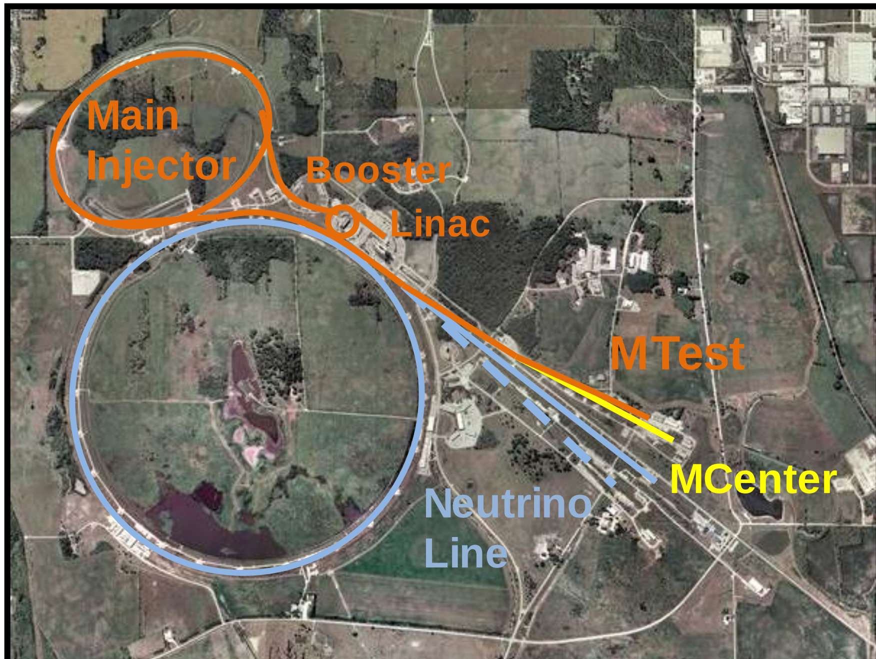
1D projective (ϕ) modules

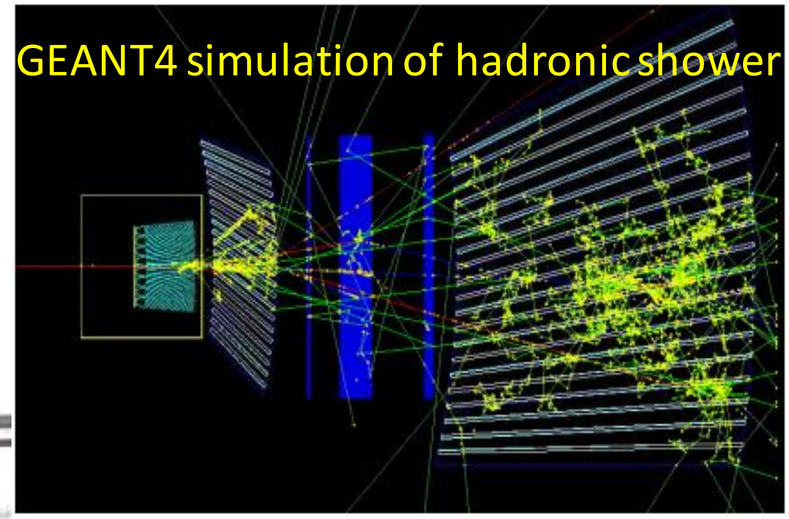
Lightguide and Si-photomultiplier readout

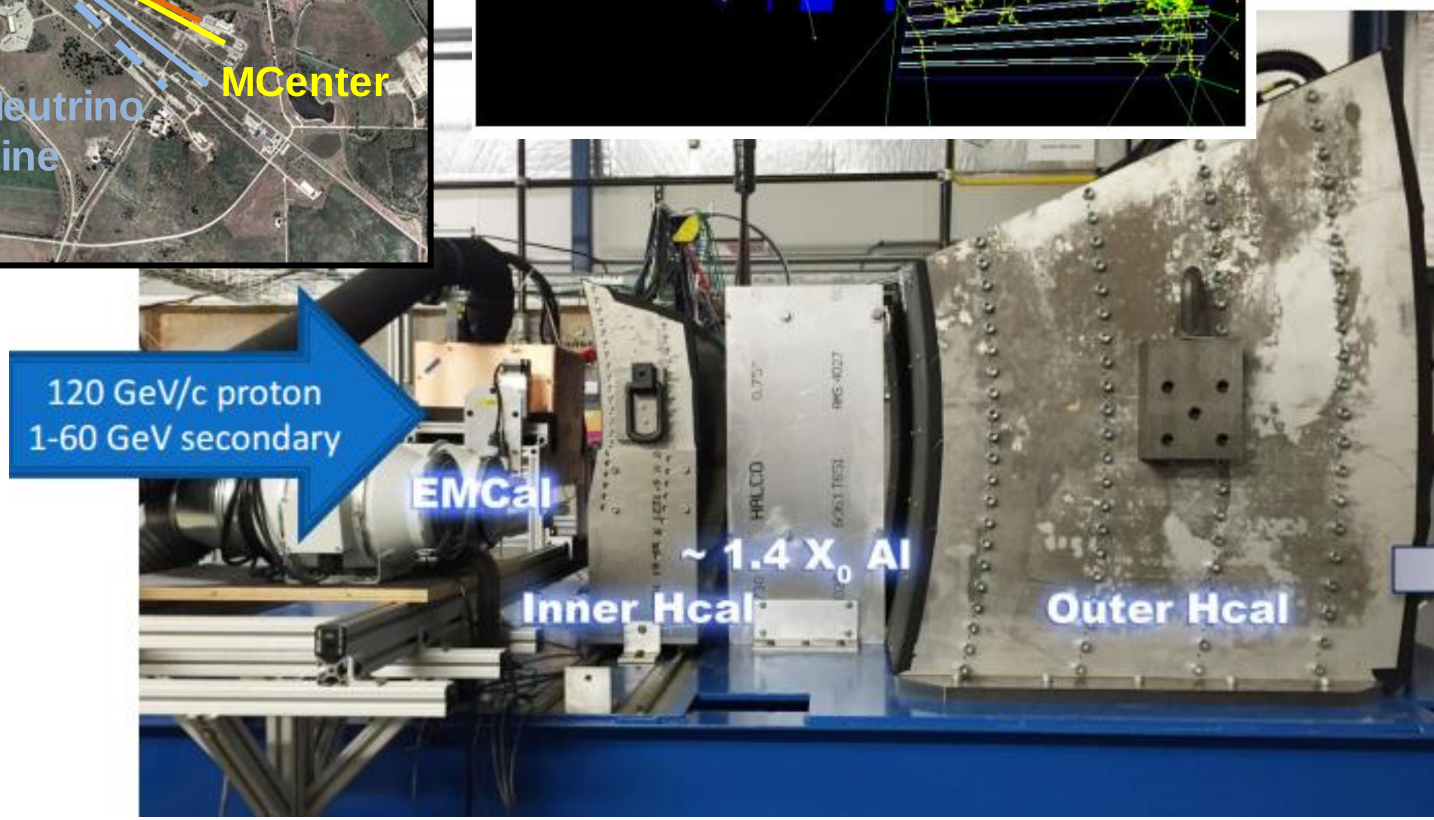
5 HCal tiles readout by 1 Si-photomultiplier



Test Beam at FermiLab

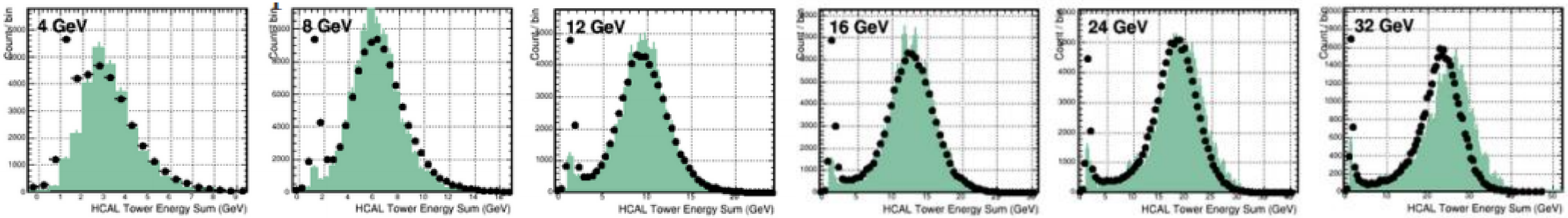


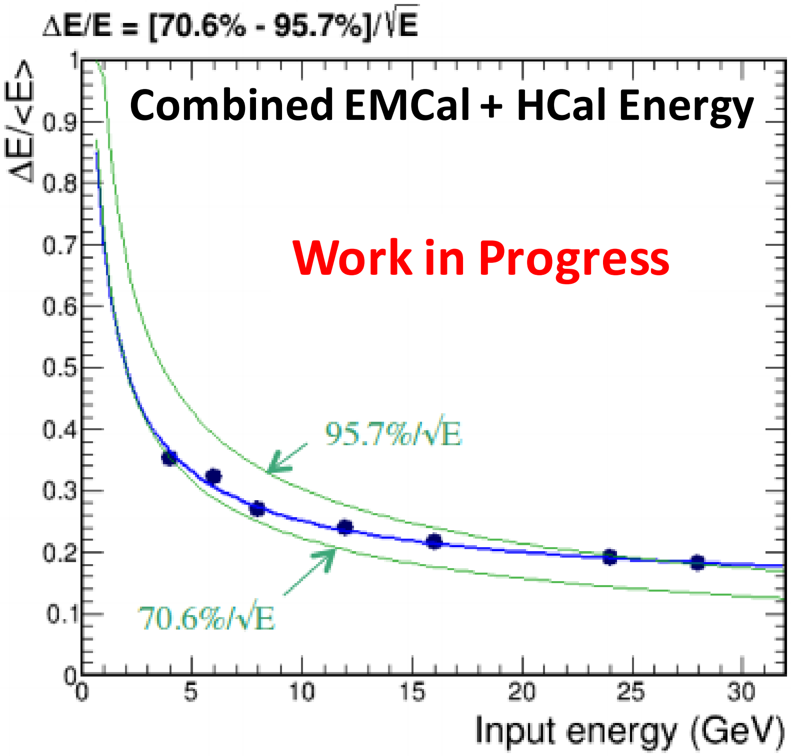


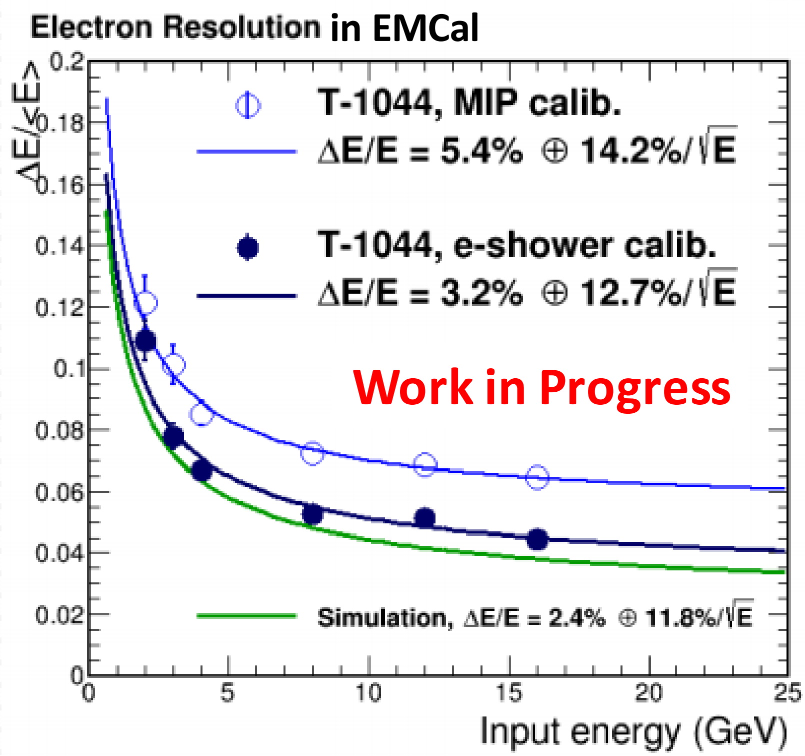


Early Test Beam Results

HCal energy distributions well described by simulation





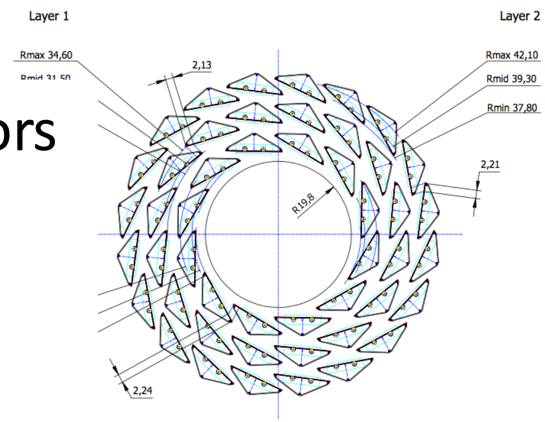


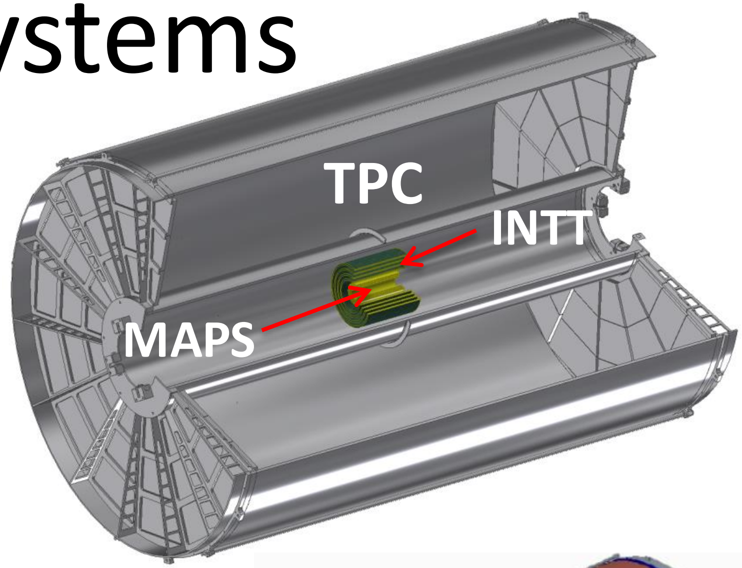
Meets design goals of <100%/√E and <15%/√E for EMCal

Tracking Subsystems

MAPS

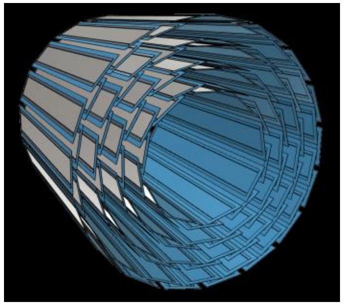
- 3 layers Si sensors
- Based on ALICE ITS upgrade
- DCA_{xy} < 70 µm
- |zvtx|< 10 cm





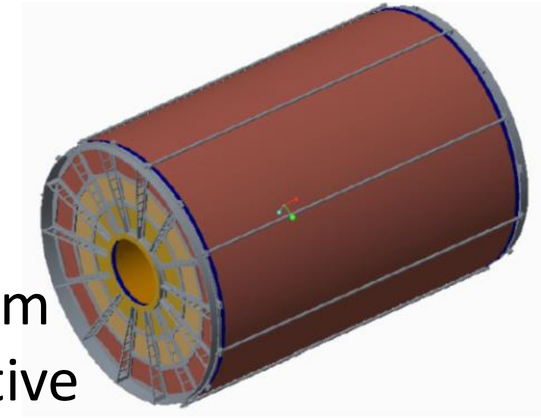
INTT

- 4 layers Si strips
- Reuse PHENIX FVTX electronics
- Pattern recognition, DCA, connect tracking systems, reject pile-up



TPC

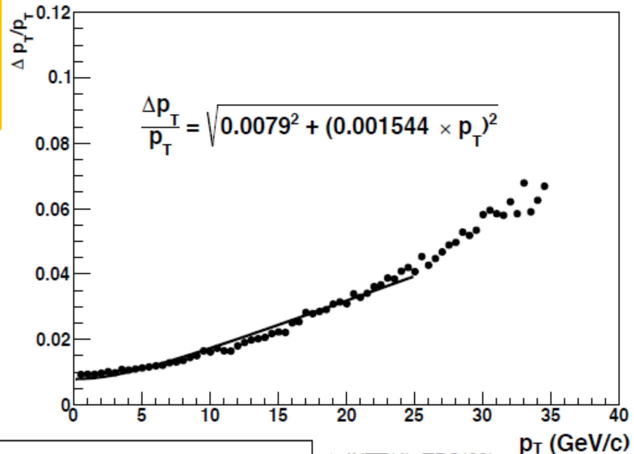
- Radius 20–78 cm
- ~250 µm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

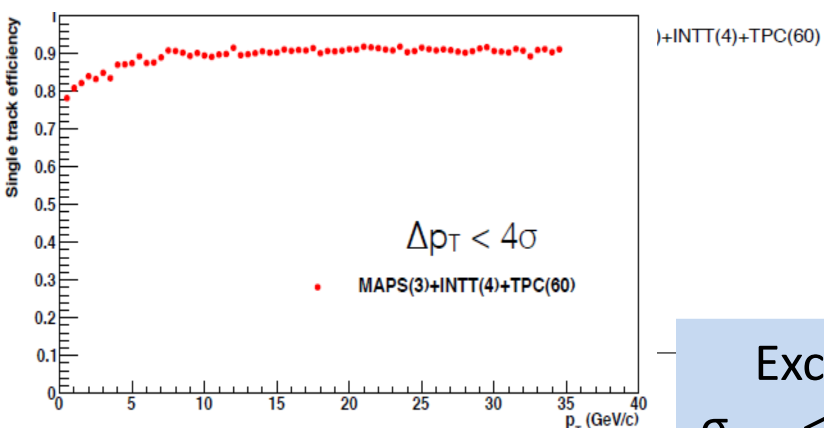


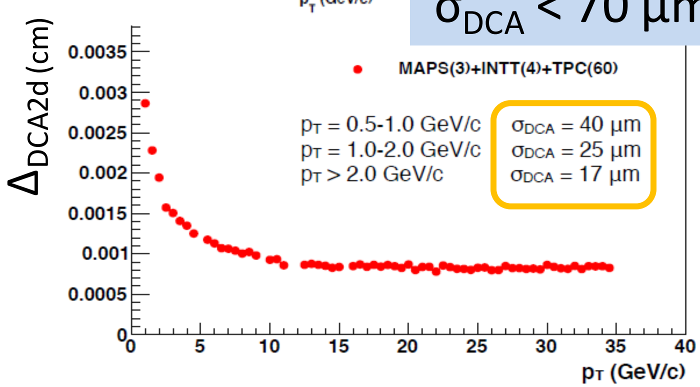
Detector capabilities

Tracking

Embedded π's in central HIJING events

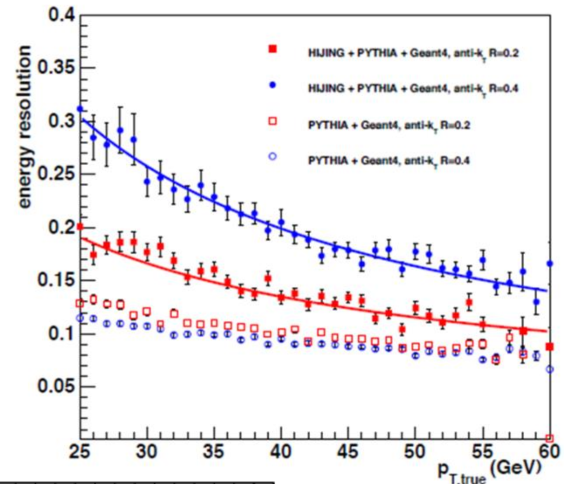


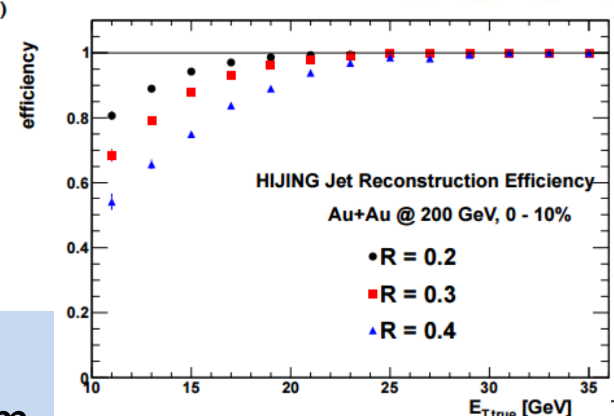


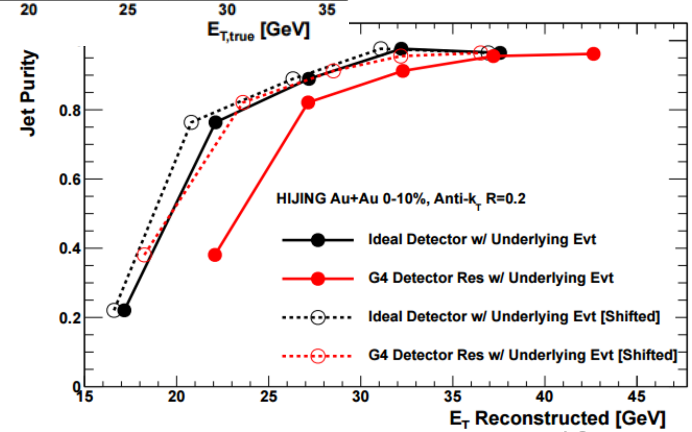


Exceeds $\sigma_{DCA} < 70\ \mu m$

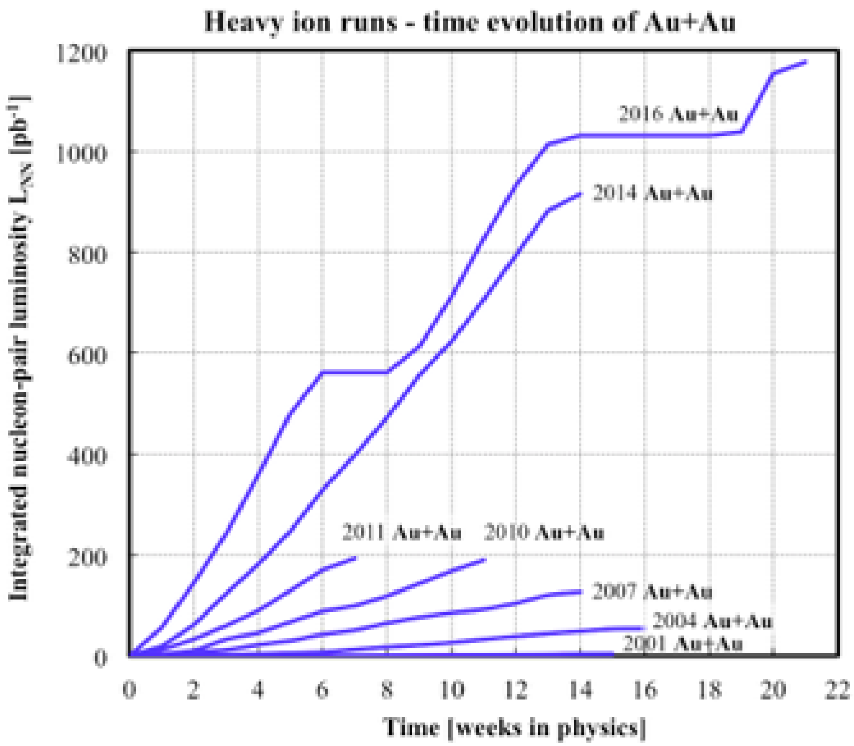
Jets



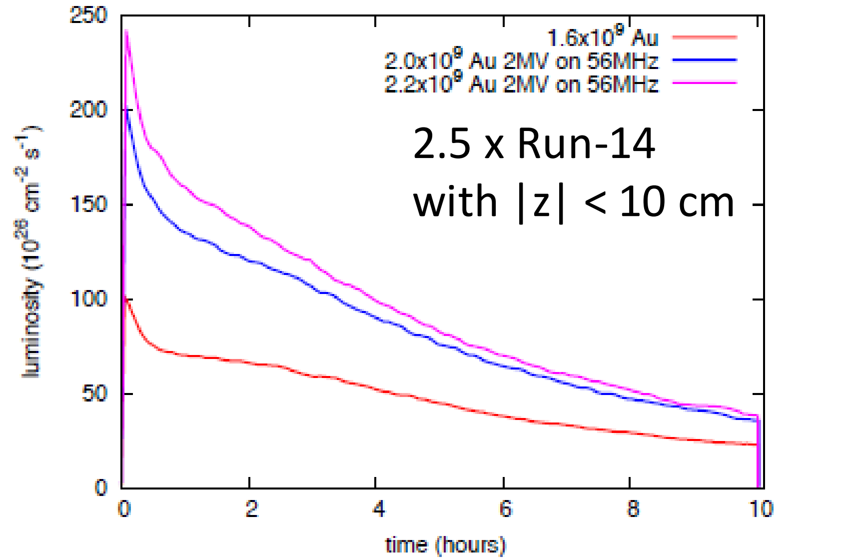


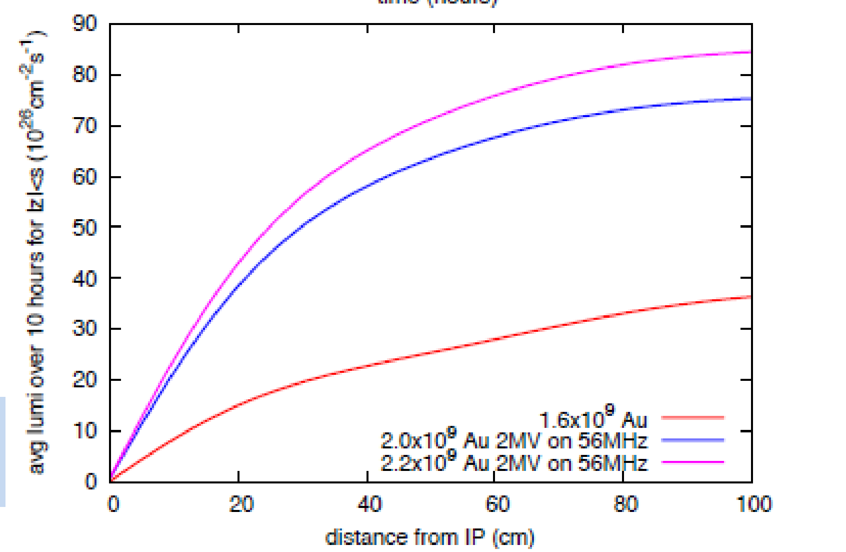


Increased luminosity at RHIC



Luminosity projections from C-AD

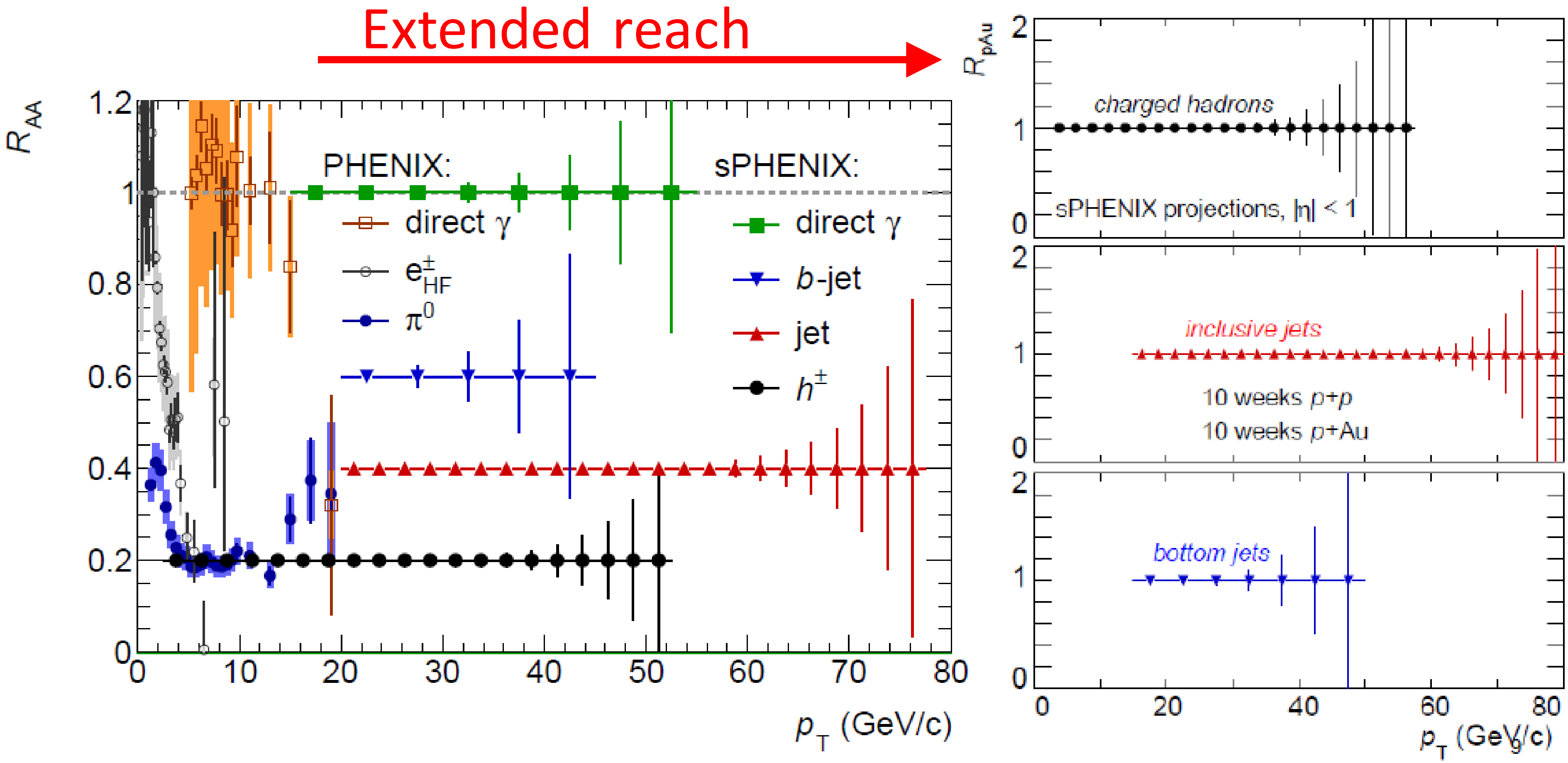




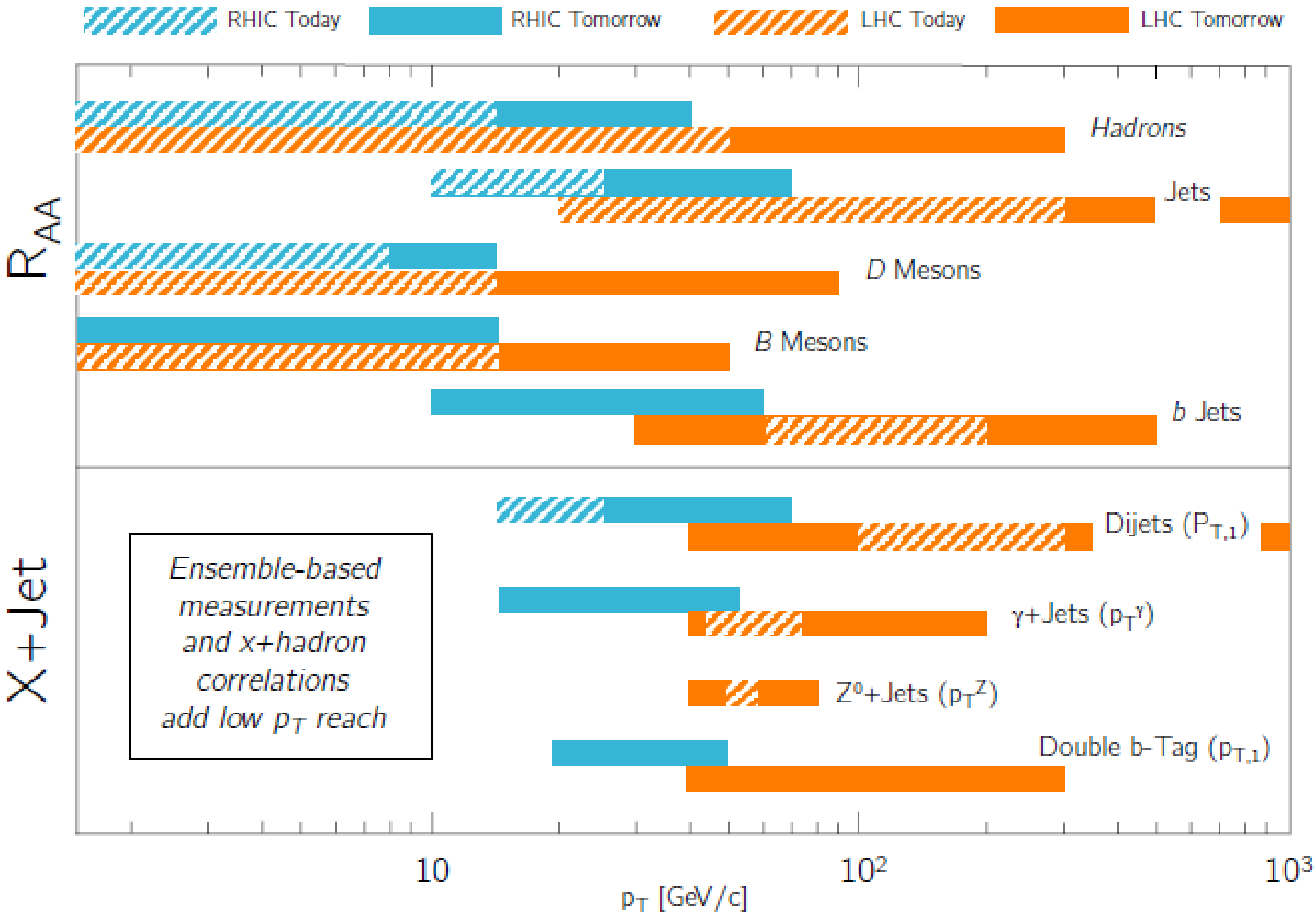
22-weeks 200 GeV Au+Au
→ 100B Min Bias events

High statistics requirement met

Increased Kinematic Range



Overlap with LHC



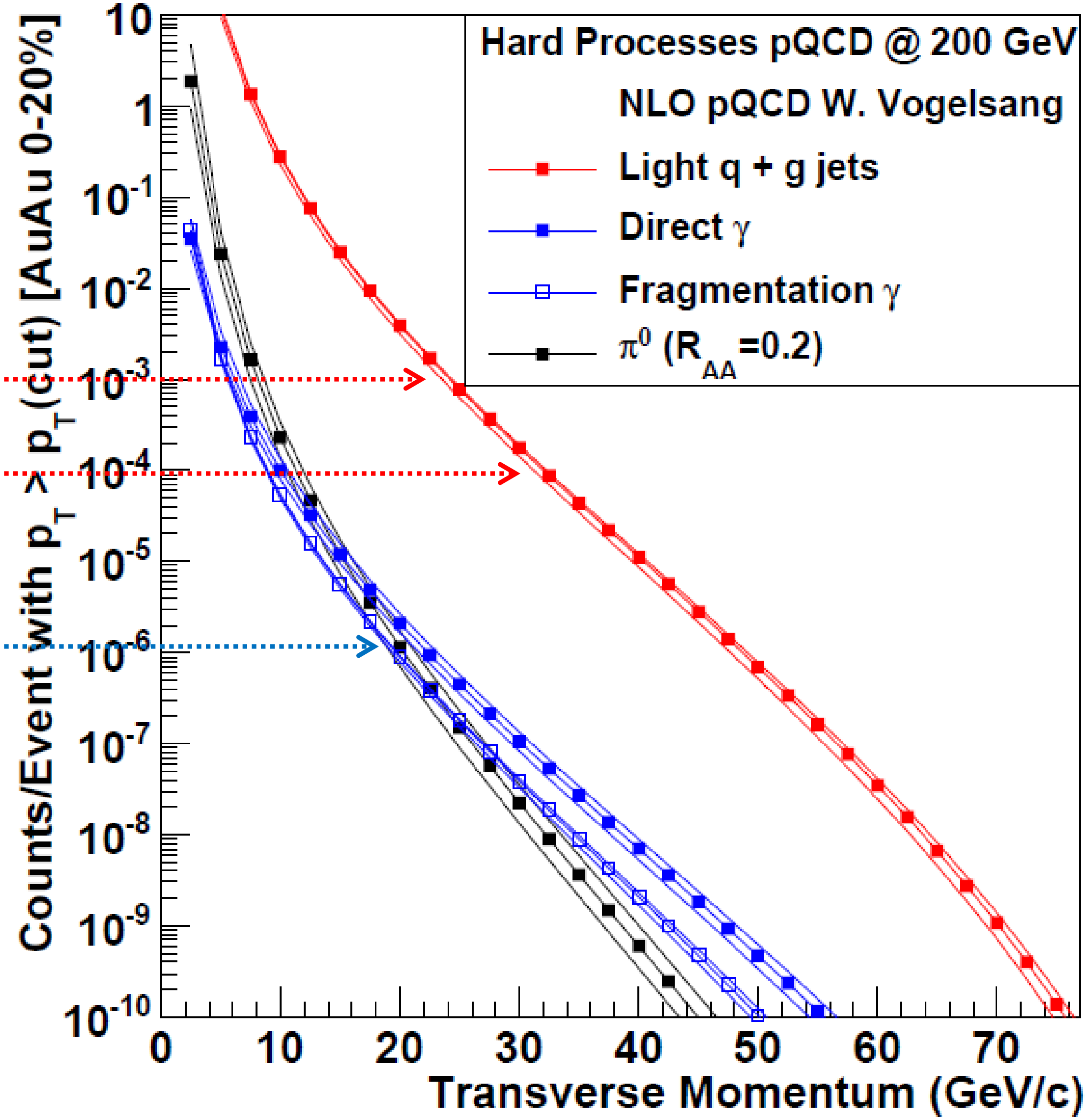
pQCD Jet Rates

22 weeks Au+Au
→ 20B 0-20% events

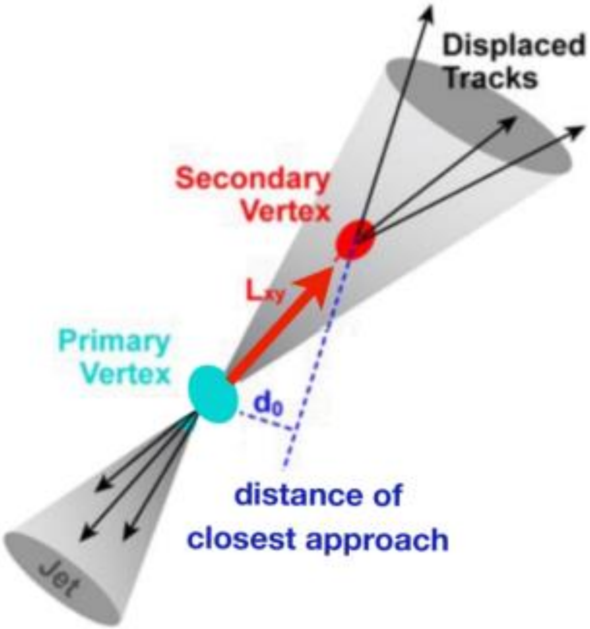
10^7 jets $p_T > 20$ GeV/c

10^6 jets $p_T > 30$ GeV/c

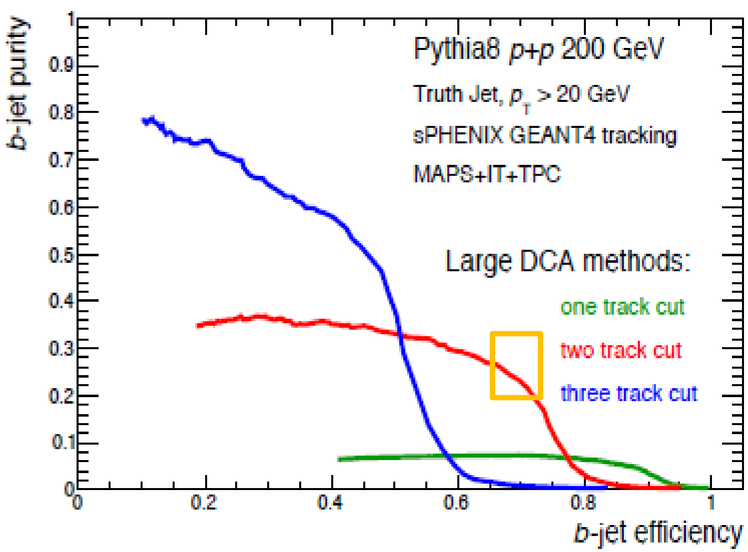
10^4 γ_{dir} $p_T > 20$ GeV/c

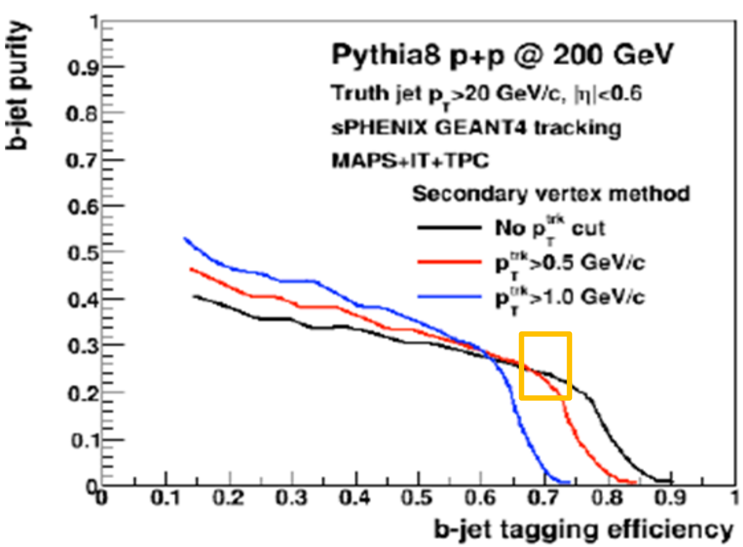


b-Jet Tagging

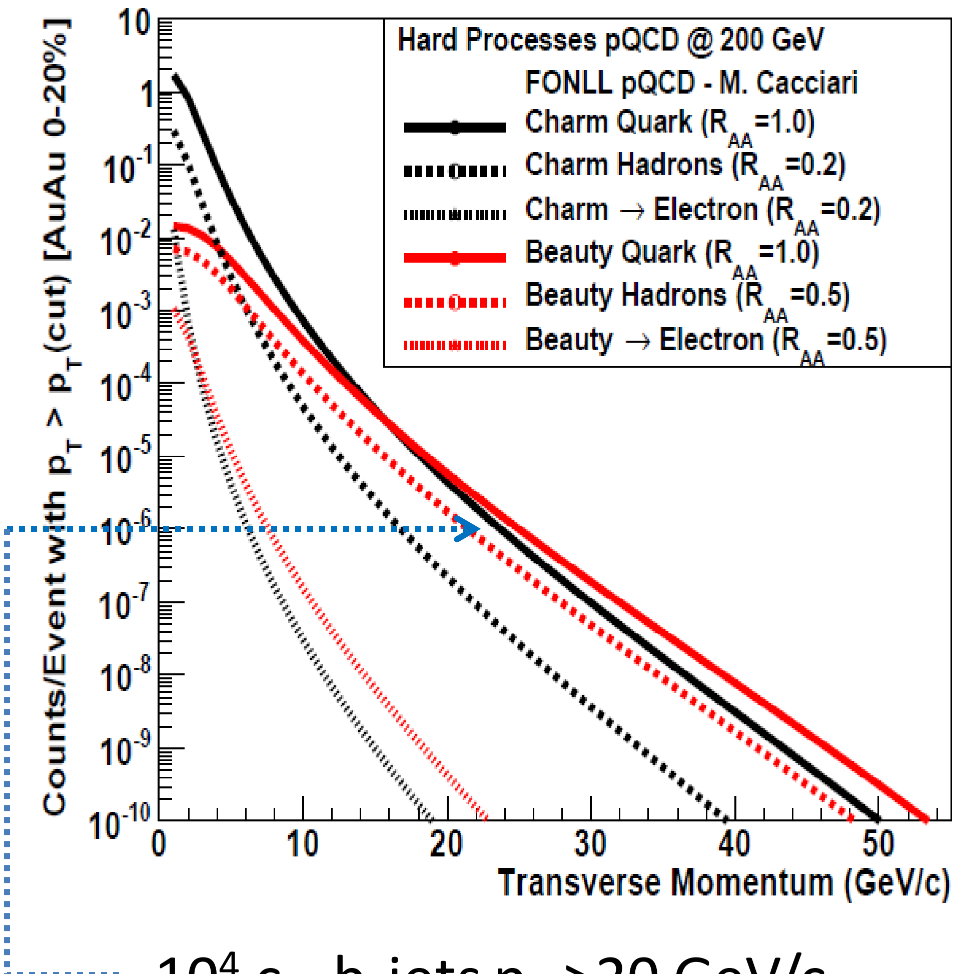


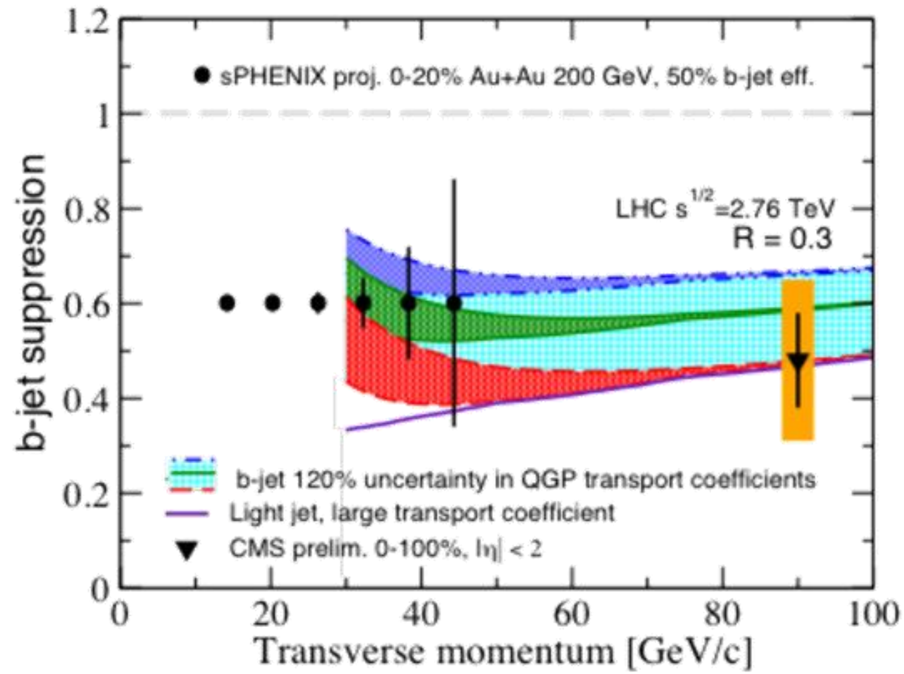
- Require 30% purity, 70% efficiency
- 3 Methods
  - Multiple large DCA tracks
  - Secondary vertex mass
  - B-meson tagging by semi-leptonic decay or by $m_{Inv\ B}$ → in progress





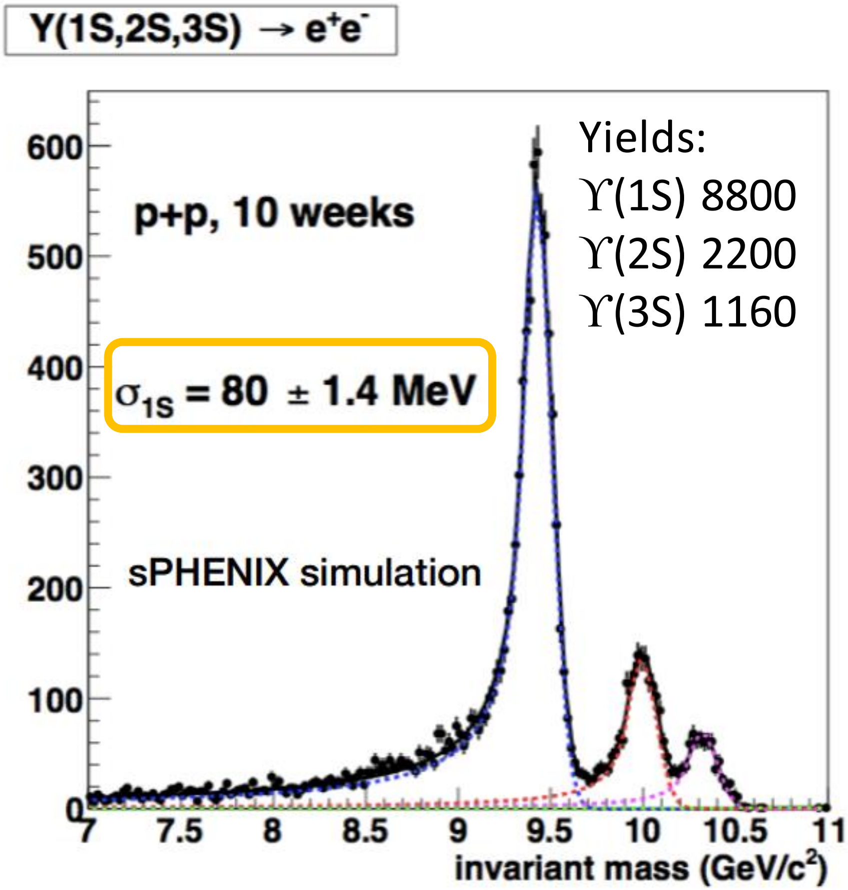
b-Jets

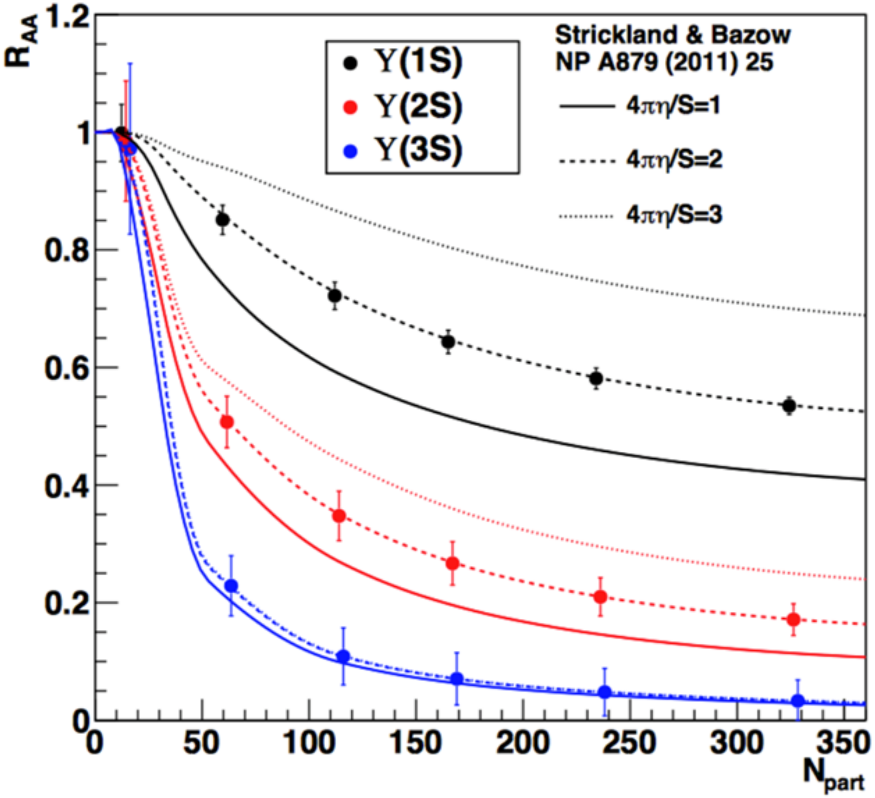




10^4 c-, b-jets p_T >20 GeV/c

Upsilon states



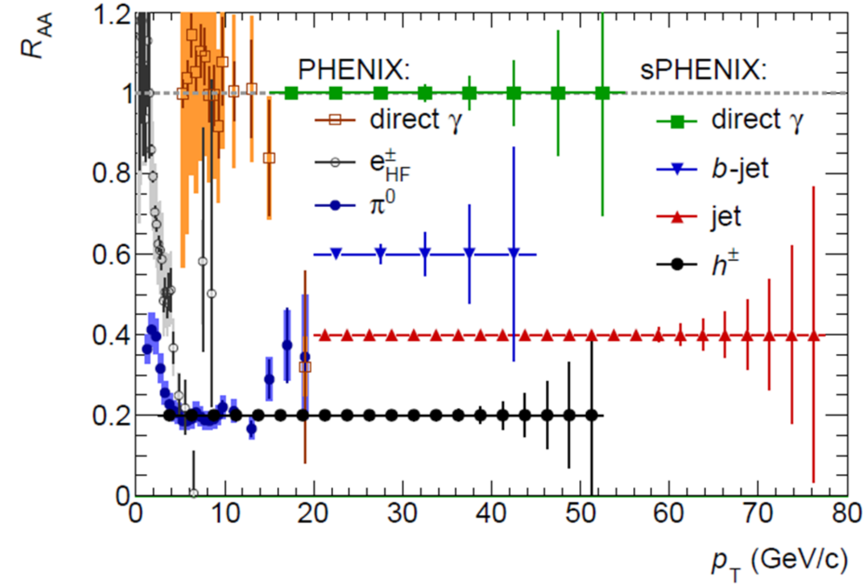


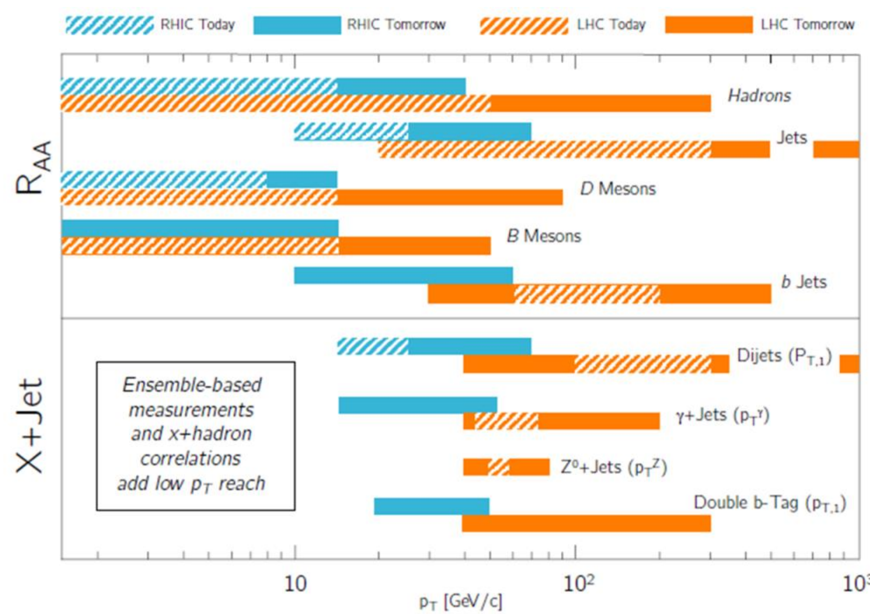
First time Υ(1S), Υ(2S), Υ(3S) separation achievable at RHIC!

Conclusions

- New RHIC experiment needed to understand QGP
  - Complement LHC results
  - Extend RHIC results beyond PHENIX and STAR capabilites
- sPHENIX design tailored to jet, Υ's, b+jet physics
- Preparing for beam in 2022
- Rich future at RHIC with sPHENIX

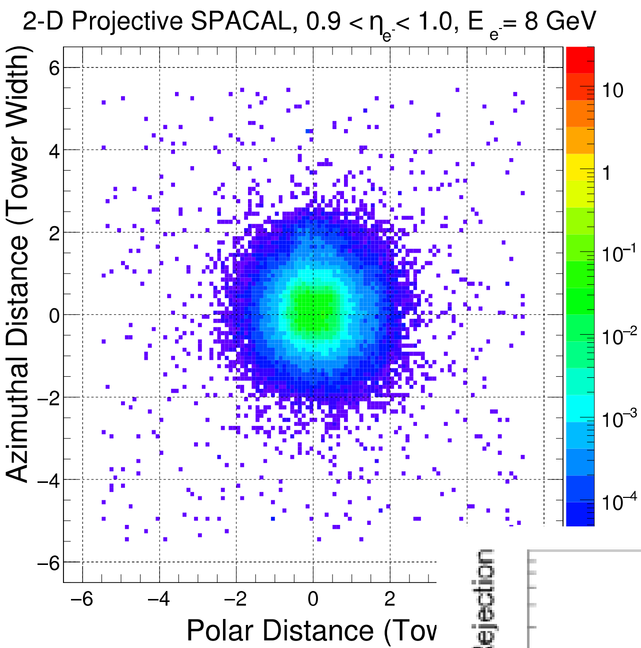
  http://www.phenix.bnl.gov/phenix/WWW/publish/documents/sPHENIX_proposal_19112014.pdf



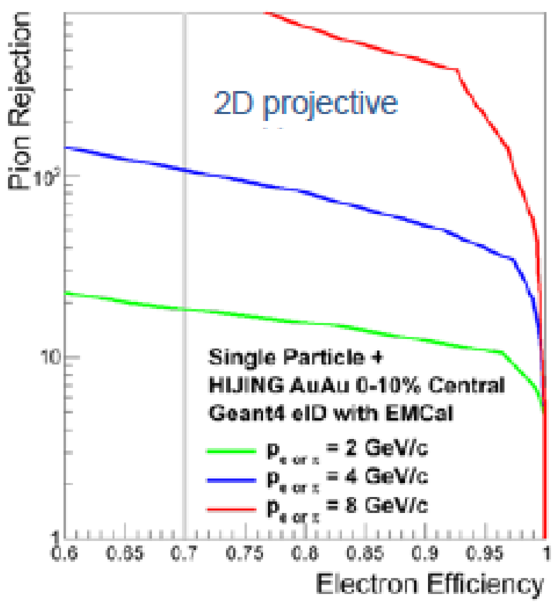


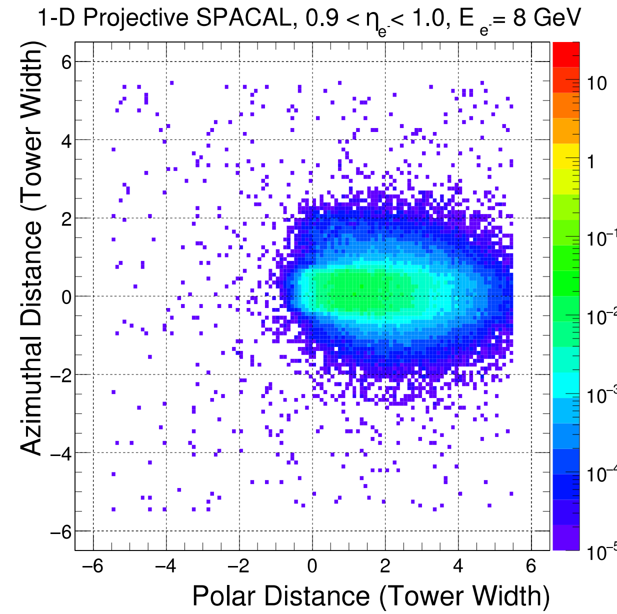
Backup

1D vs 2D projective EMCal modules



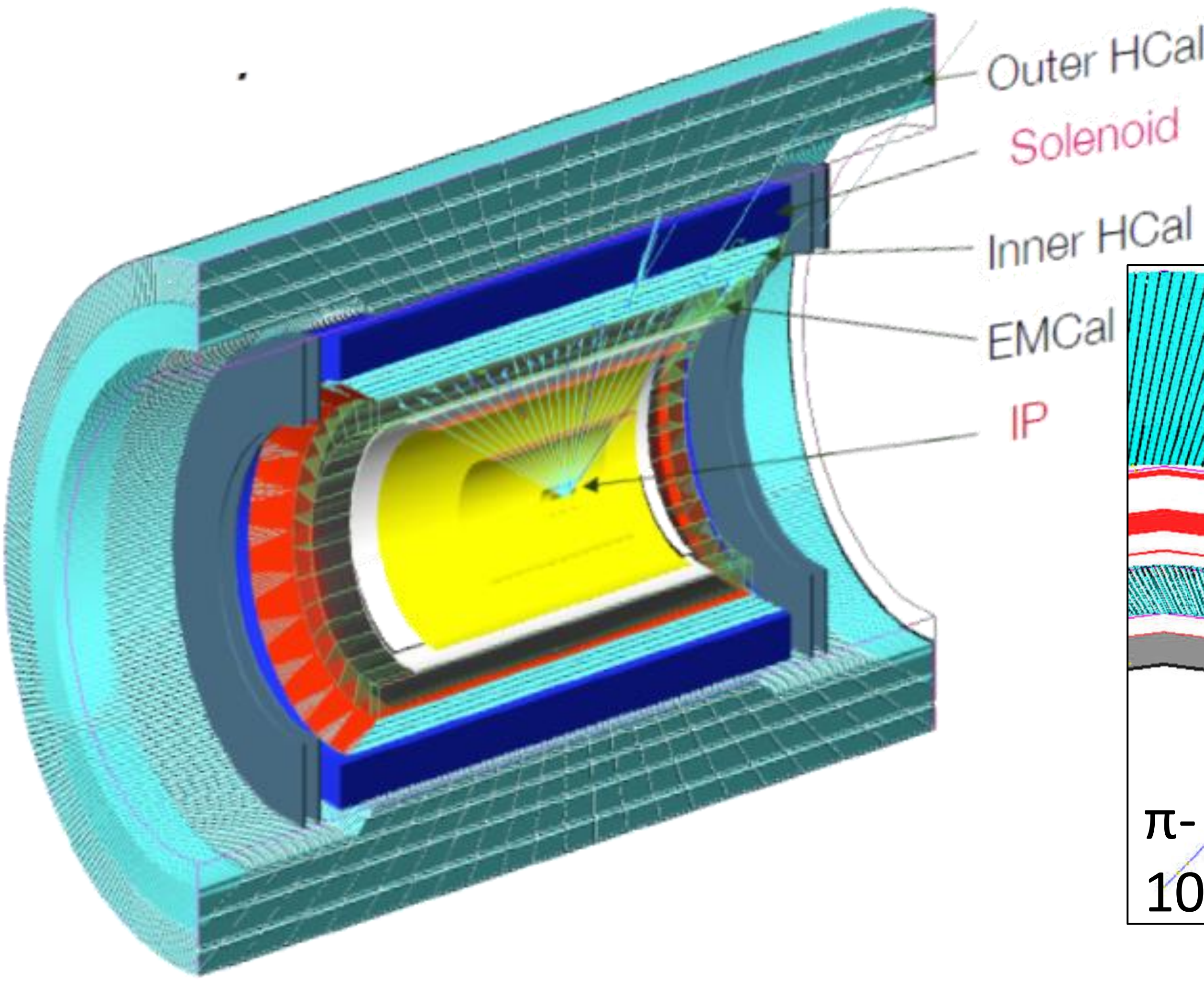
2D projective improves e/π separation

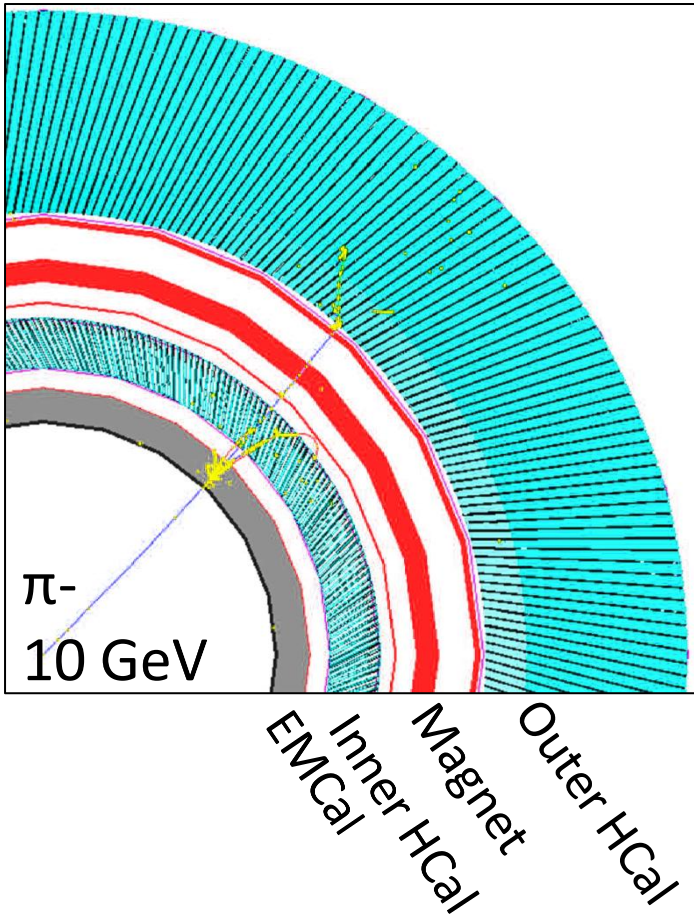




1D Production process more established

GEANT4 Simulations

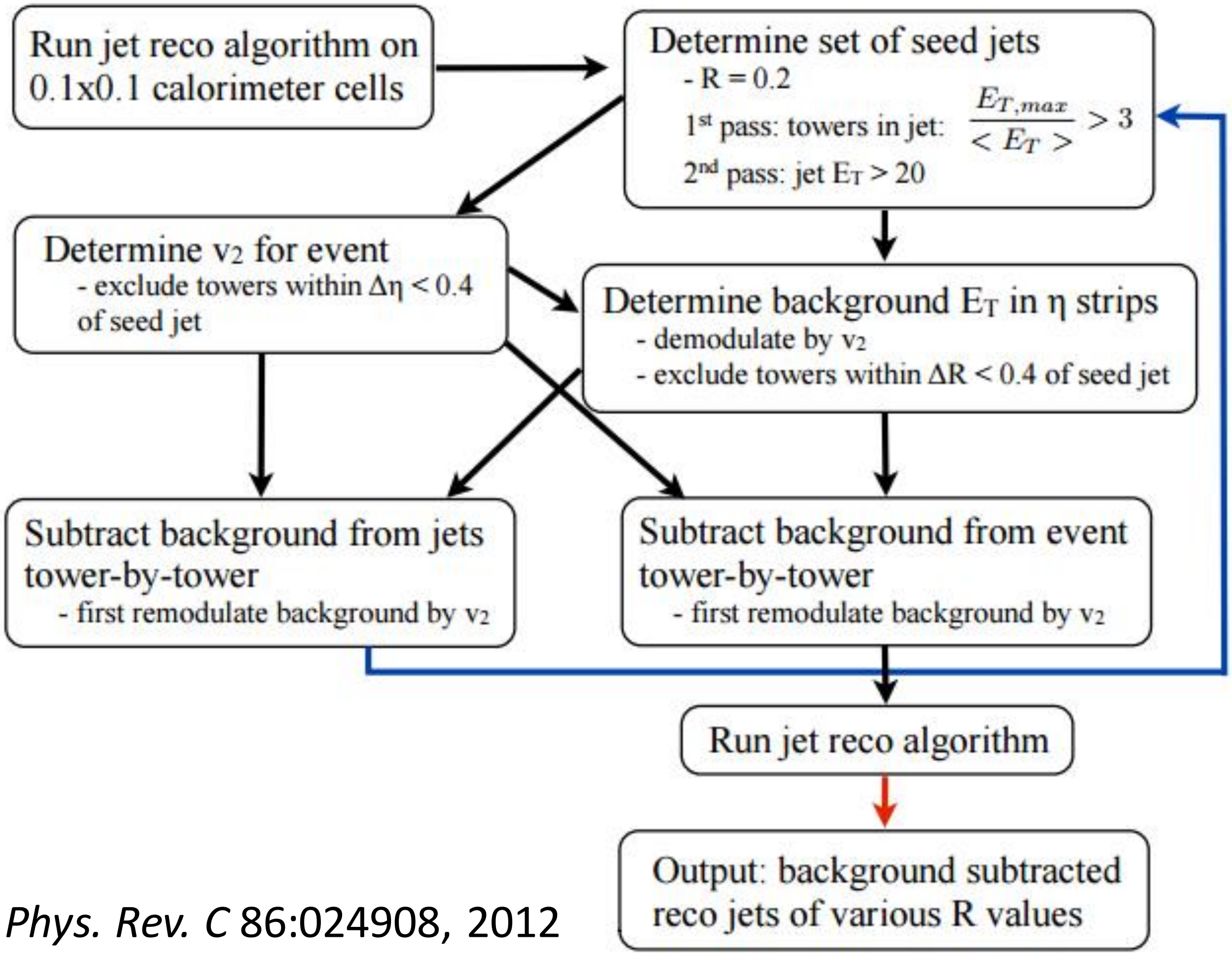




https://github.com/sPHENIX-Collaboration

Jet Reconstruction

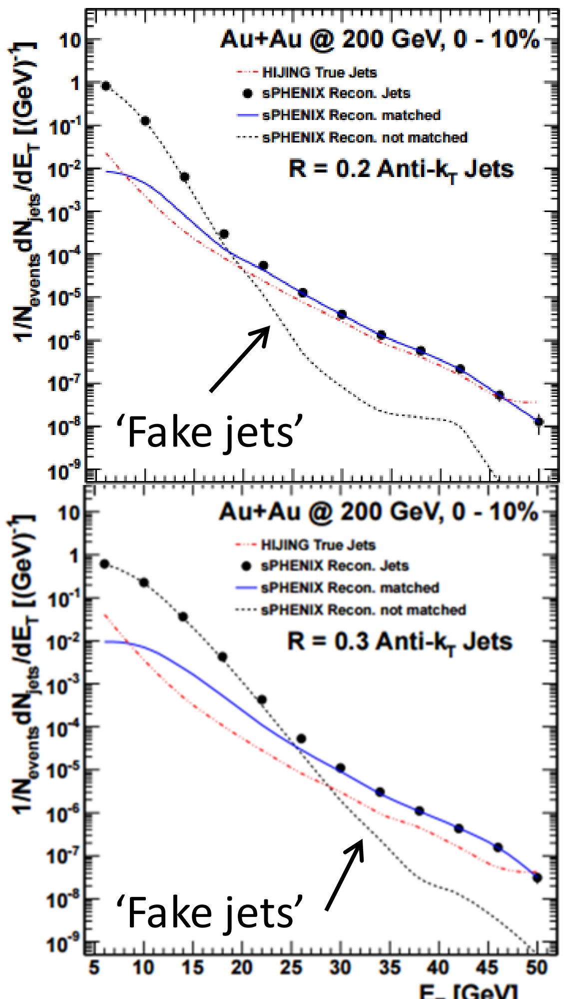
Inspired by ATLAS' heavy ion jet reconstruction:

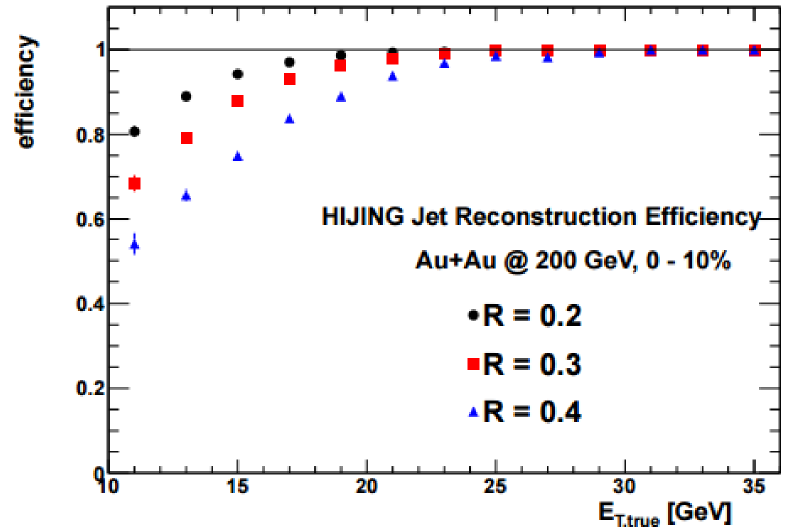


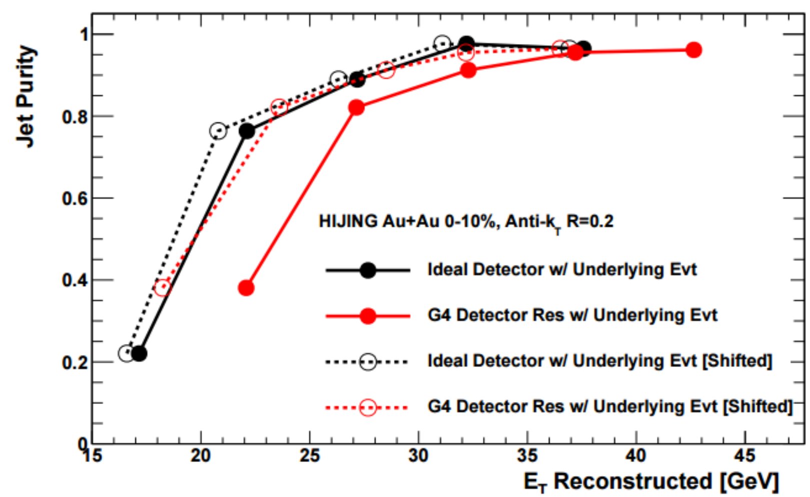
Hanks et al. *Phys. Rev. C* 86:024908, 2012

Jet Reconstruction

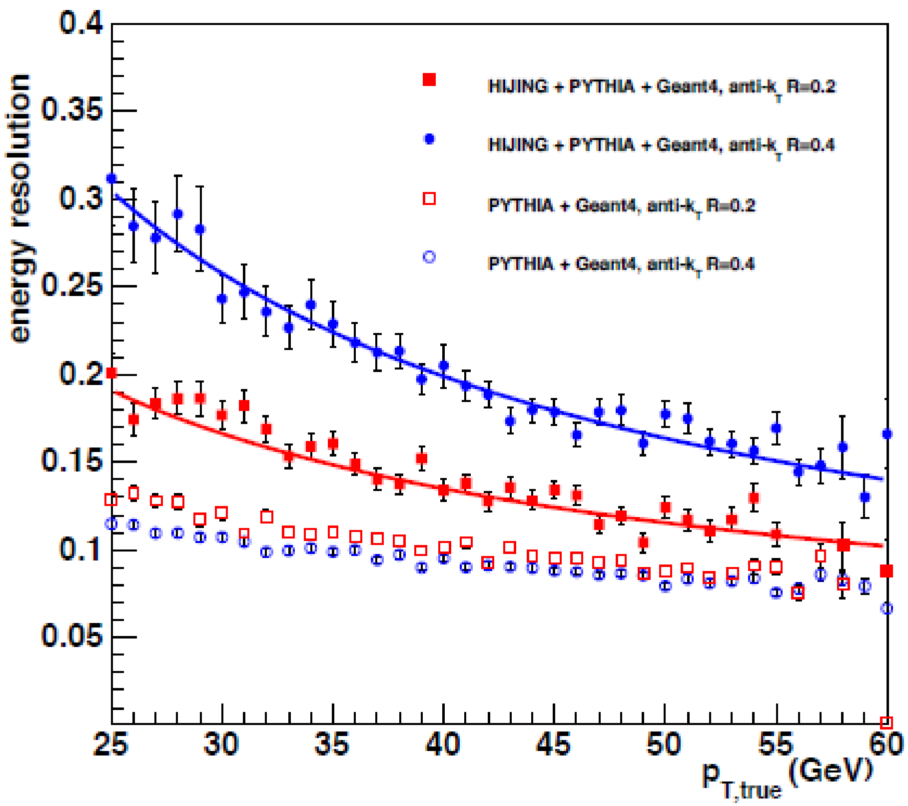
Fluctuations in the underlying event create ‘fake jets’

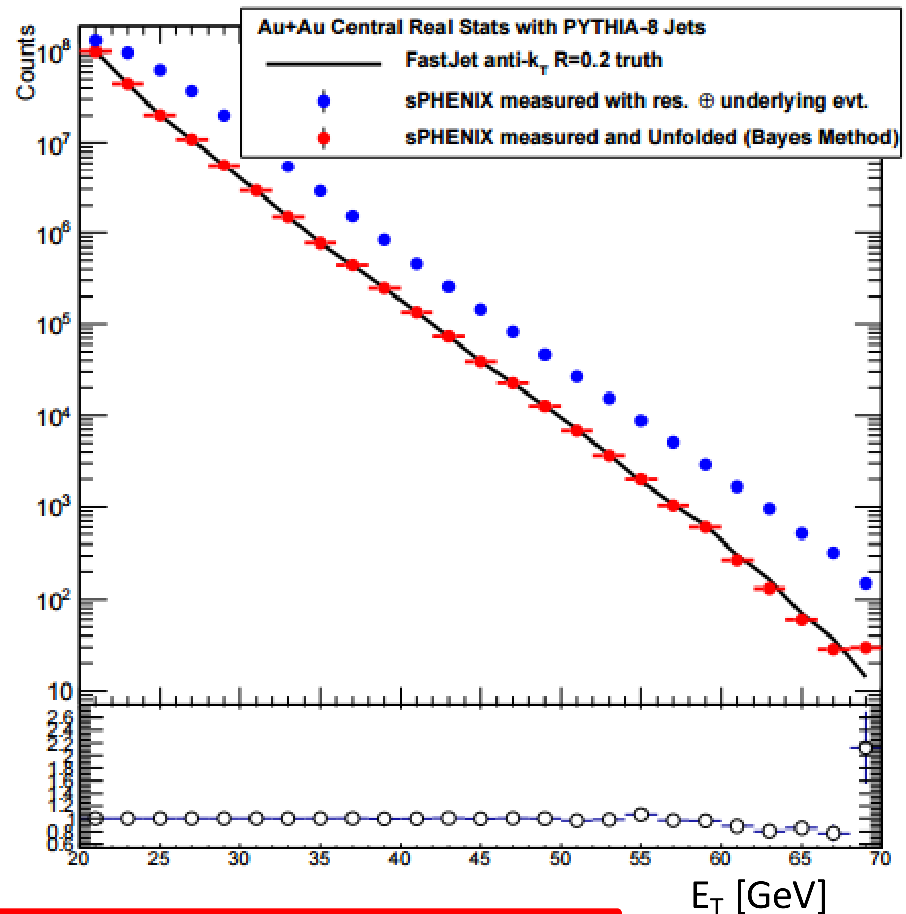






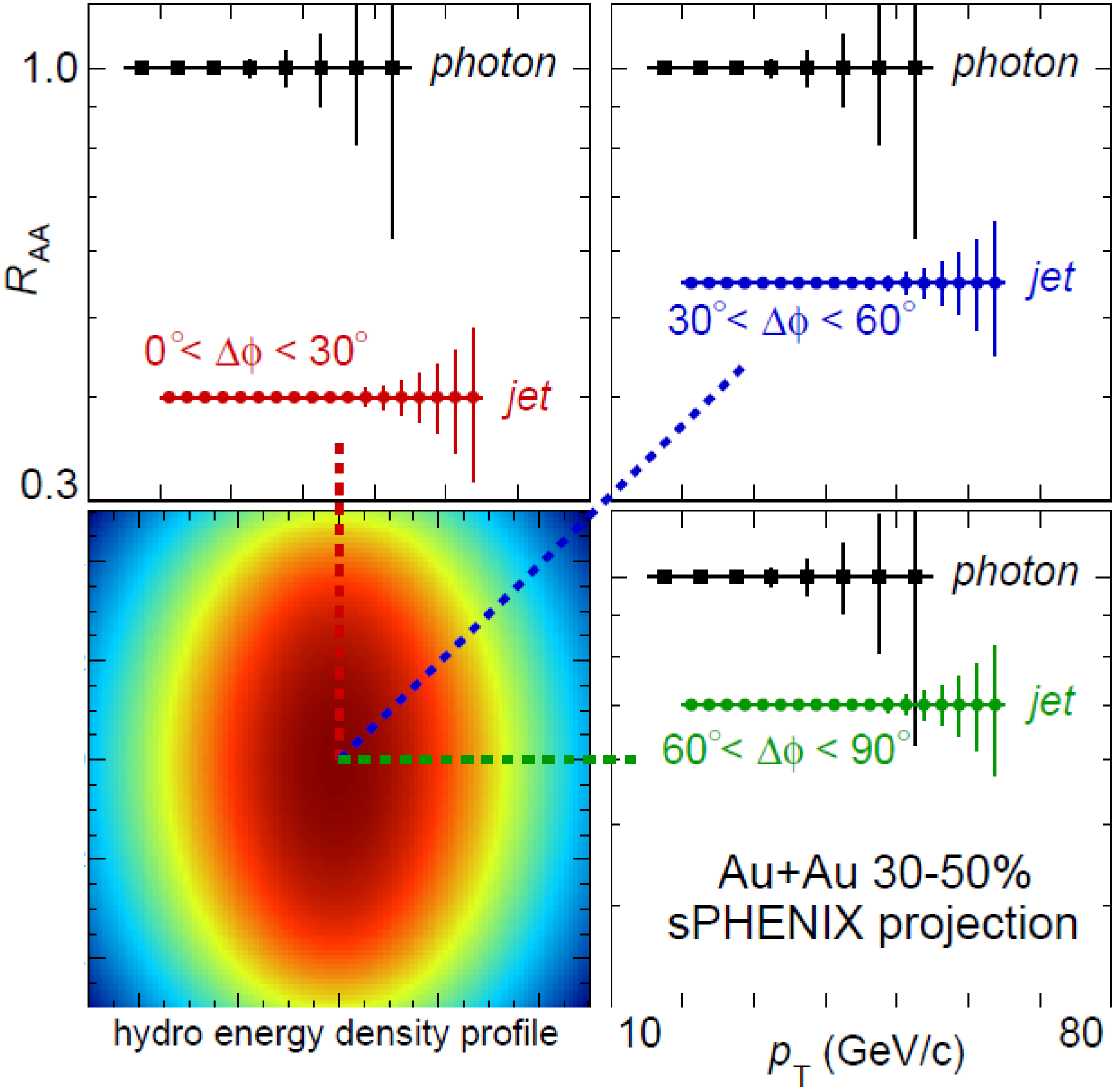
Jet Energy Resolution and Unfolding



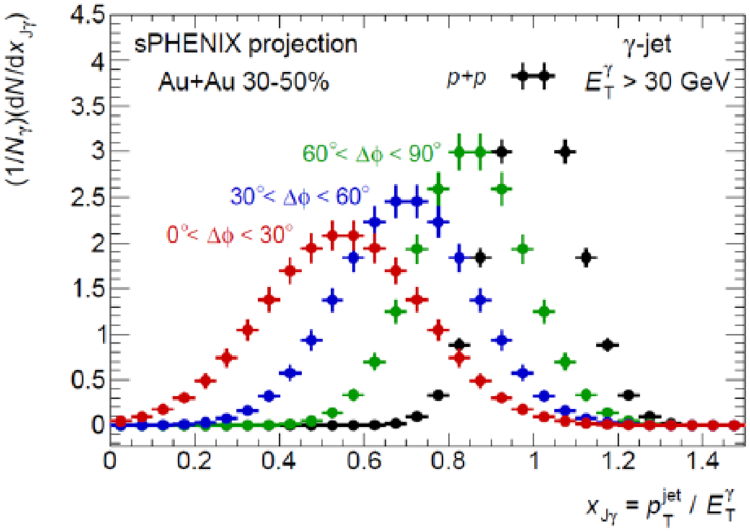


Unfolding corrects for the resolution and underlying event fluctuation effects

Path Length Dependence

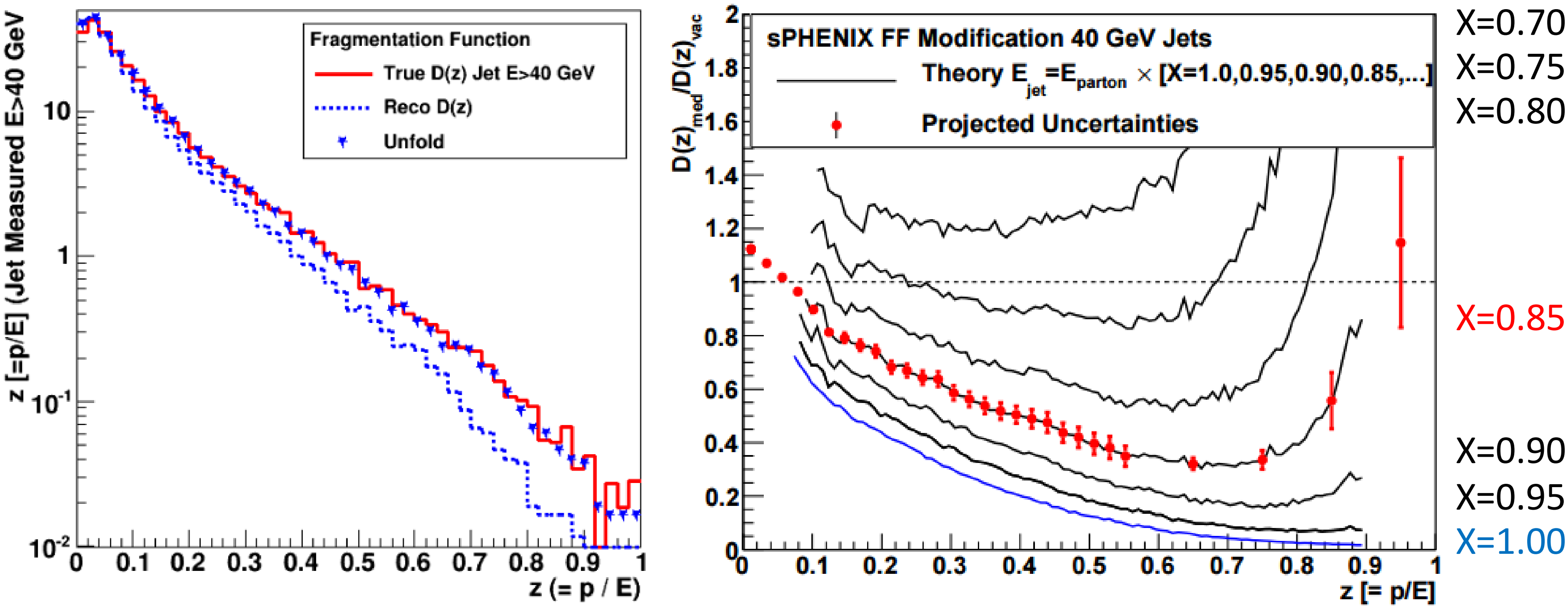


Important constraint to energy loss models



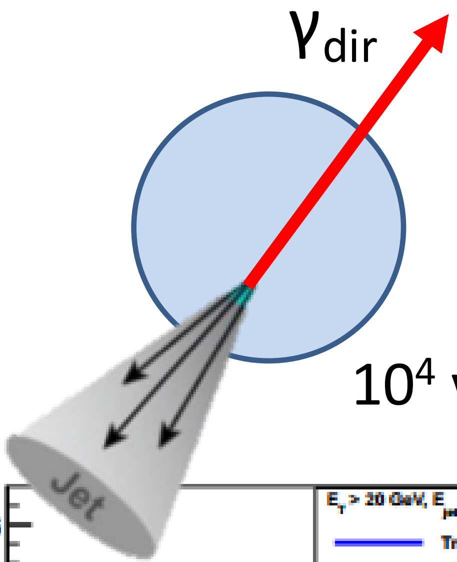
Fragmentation Functions, D(z)

Energy distribution within the jet → Dynamics of jet quenching

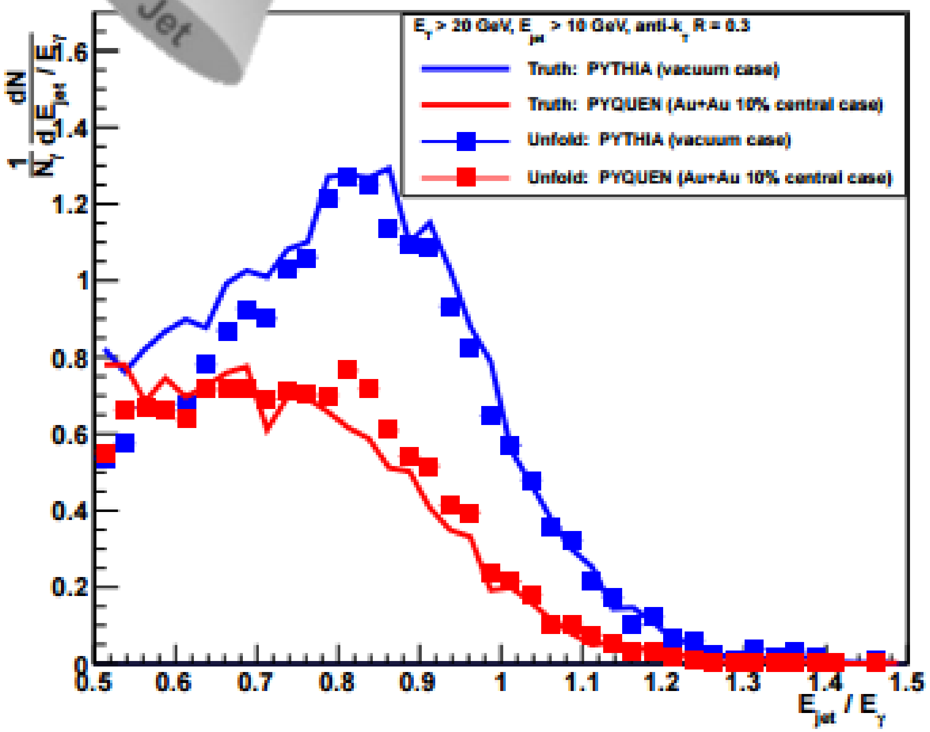


X ≡ fraction of parton energy retained in jet cone

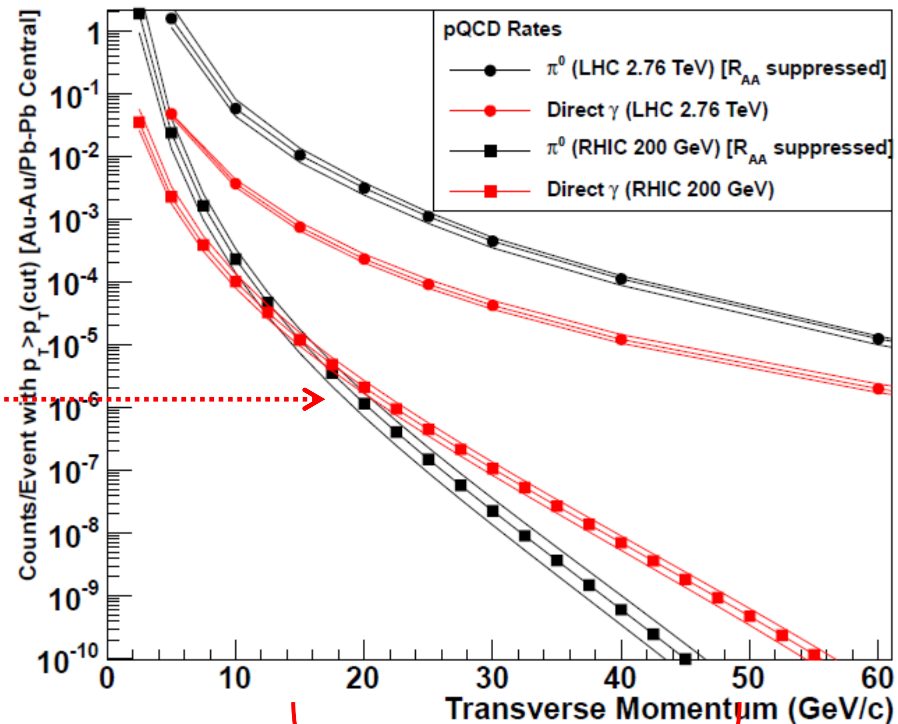
Gamma-Jet



10^4 γ_{dir} p_T > 20 GeV/c

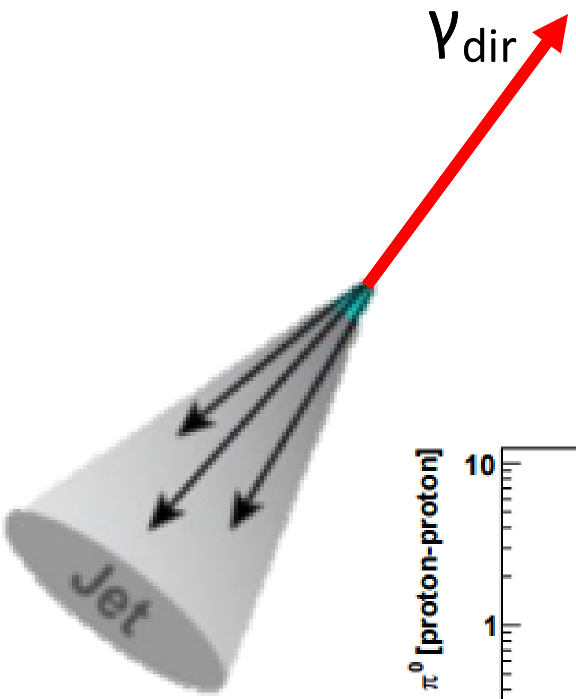


Advantageous γ_{dir}-to-π^0 ratio at RHIC

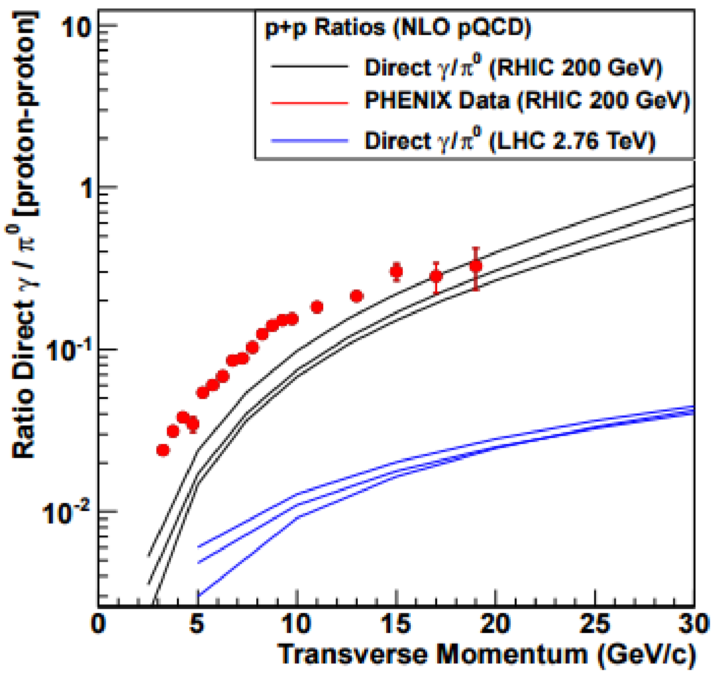


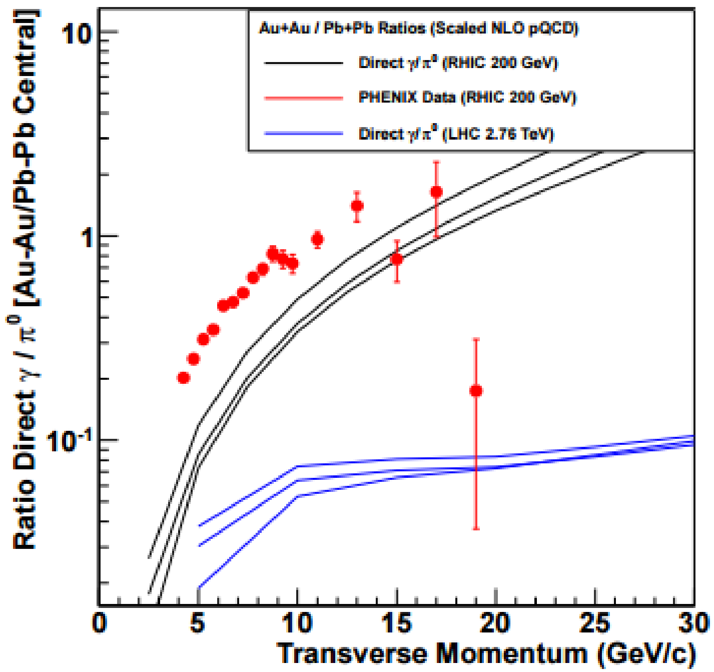
Range of direct photon ID

Photon provides unmodified reference for jet energy loss

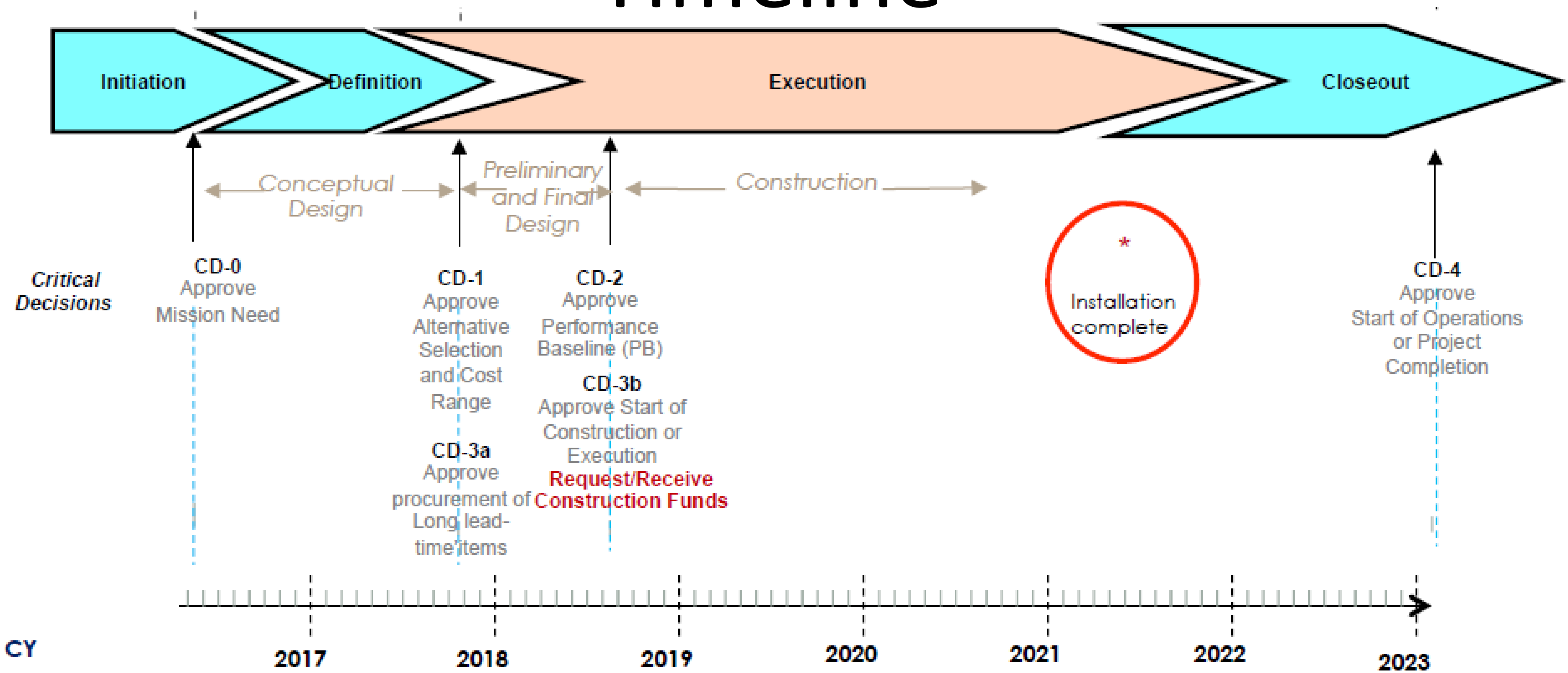

γdir
Jet

Gamma-Jet


p+p Ratios (NLO pQCD)
Direct γ/π0 (RHIC 200 GeV)
PHENIX Data (RHIC 200 GeV)
Direct γ/π0 (LHC 2.76 TeV)
Ratio Direct γ / π0 [proton-proton]
Transverse Momentum (GeV/c)
10
1
10-1
10-2
0
5
10
15
20
25
30


Au+Au / Pb+Pb Ratios (Scaled NLO pQCD)
Direct γ/π0 (RHIC 200 GeV)
PHENIX Data (RHIC 200 GeV)
Direct γ/π0 (LHC 2.76 TeV)
Ratio Direct γ / π0 [Au-Au/Pb-Pb Central]
Transverse Momentum (GeV/c)
10
1
10-1
0
5
10
15
20
25
30

Timeline



CD-0	**2016**
CD-1/CD-3a	**Nov 2017**
CD-2/3b	**Jul 2018**
Installation complete	**Jun 2021**
Ready for Beam	**Jan 2022**
CD-4	**Jan 2023**

Recent reviews:

- Tracker review — Sept. 2016
- Scientific review — May 2016
- pre-Conceptual Design Report — Nov. 2015