sPHENIX: the New Heavy Ion Detector at RHIC

Sarah Campbell

Hot Quarks

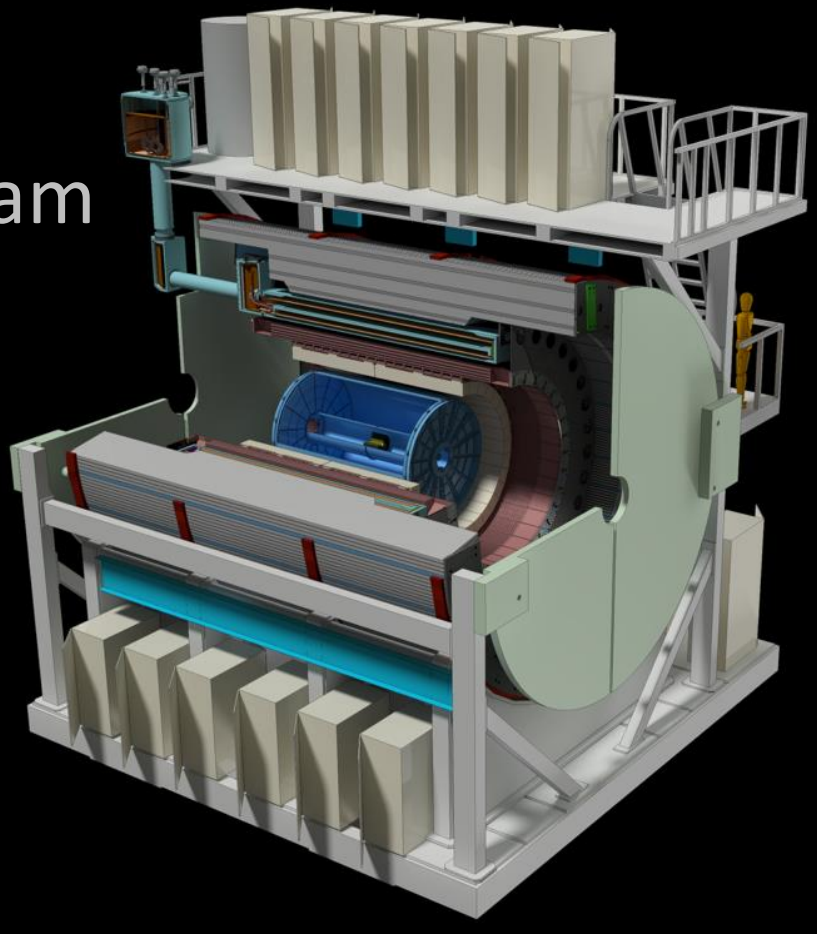
South Padre Island, TX

Sept 16, 2016

COLUMBIA UNIVERSITY

Outline

- Goals of the new RHIC detector
- Detector development
- Simulation and test beam results

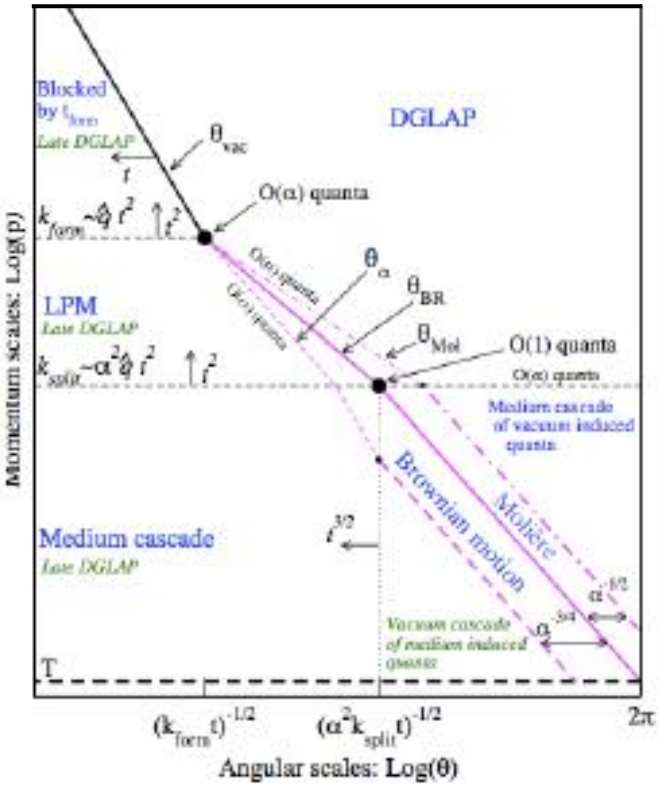


Probe QGP at multiple length-scales

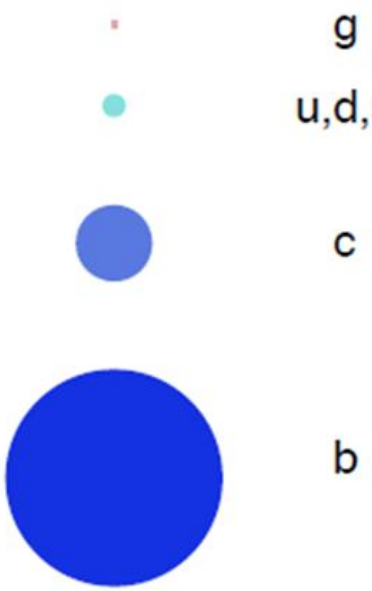
Jet evolution and structure

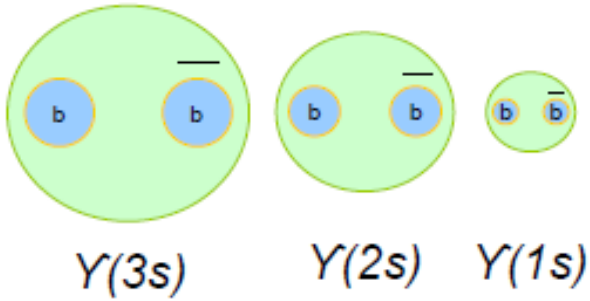
Partonic probes

Upsilon states

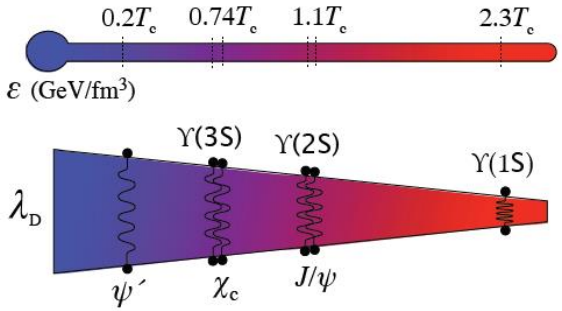


Phys. Lett. B 740 172 (2015)

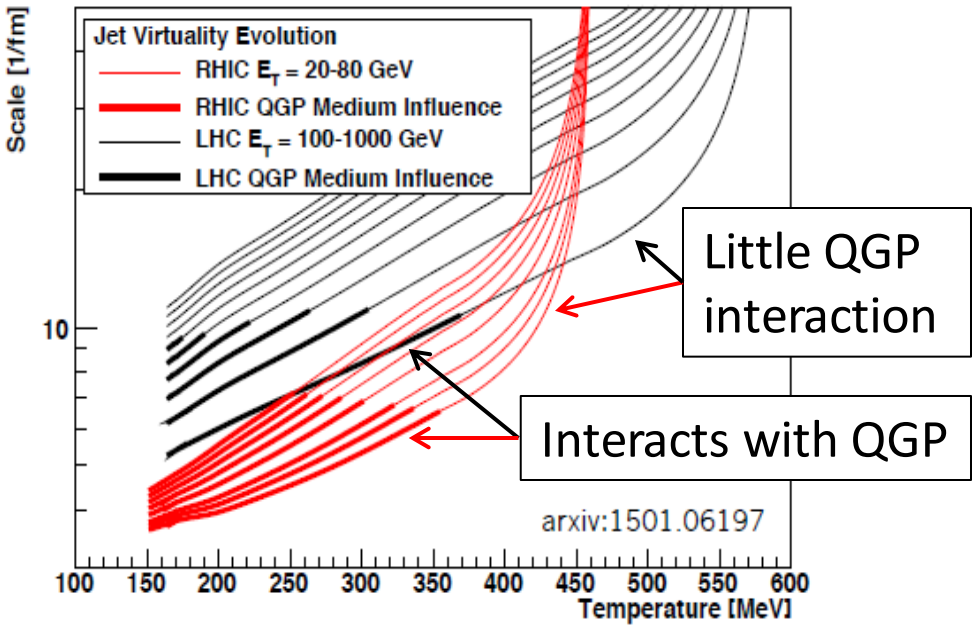




Sequential melting

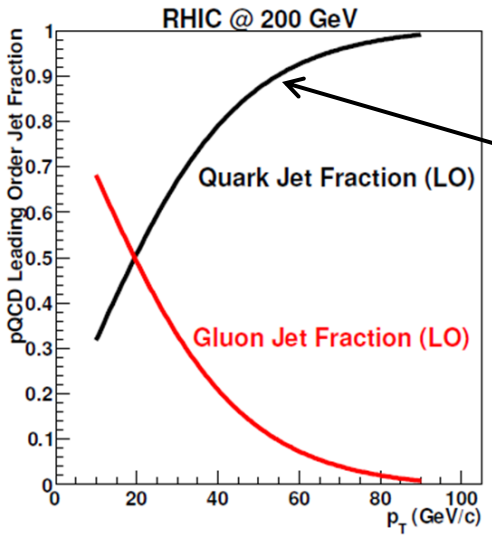


Jets as QGP probes

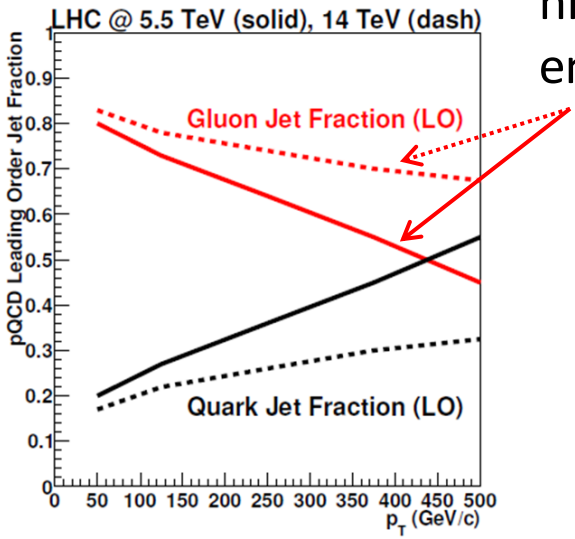


Little QGP interaction

Interacts with QGP



Higher quark-jet fraction at RHIC



LHC gluon-jet dominated until significantly higher jet energies

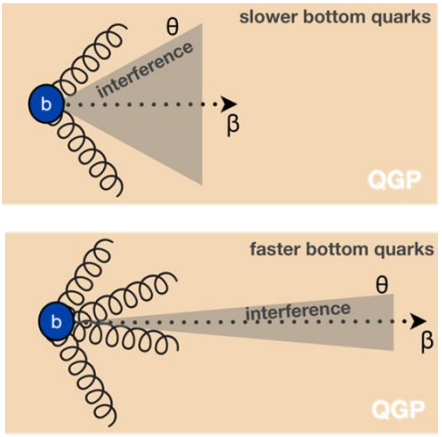
Lower energy jets, jets at RHIC have increased sensitivity to QGP interactions

Complementary measurements at RHIC & LHC

Heavy quark–medium interactions

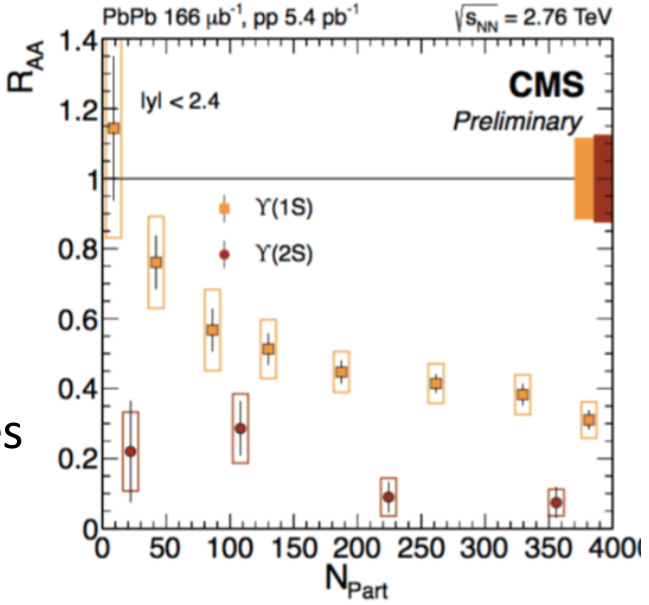
Heavy-Flavor Jets

- Collisional vs radiative energy loss
  - Separate $\hat{q}$ and $\hat{e}$
- Dead cone effect: $\theta_{min} < m_Q/E$



Upsilon States

- 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) where size and binding energies are similar



Complementary measurements at RHIC & LHC

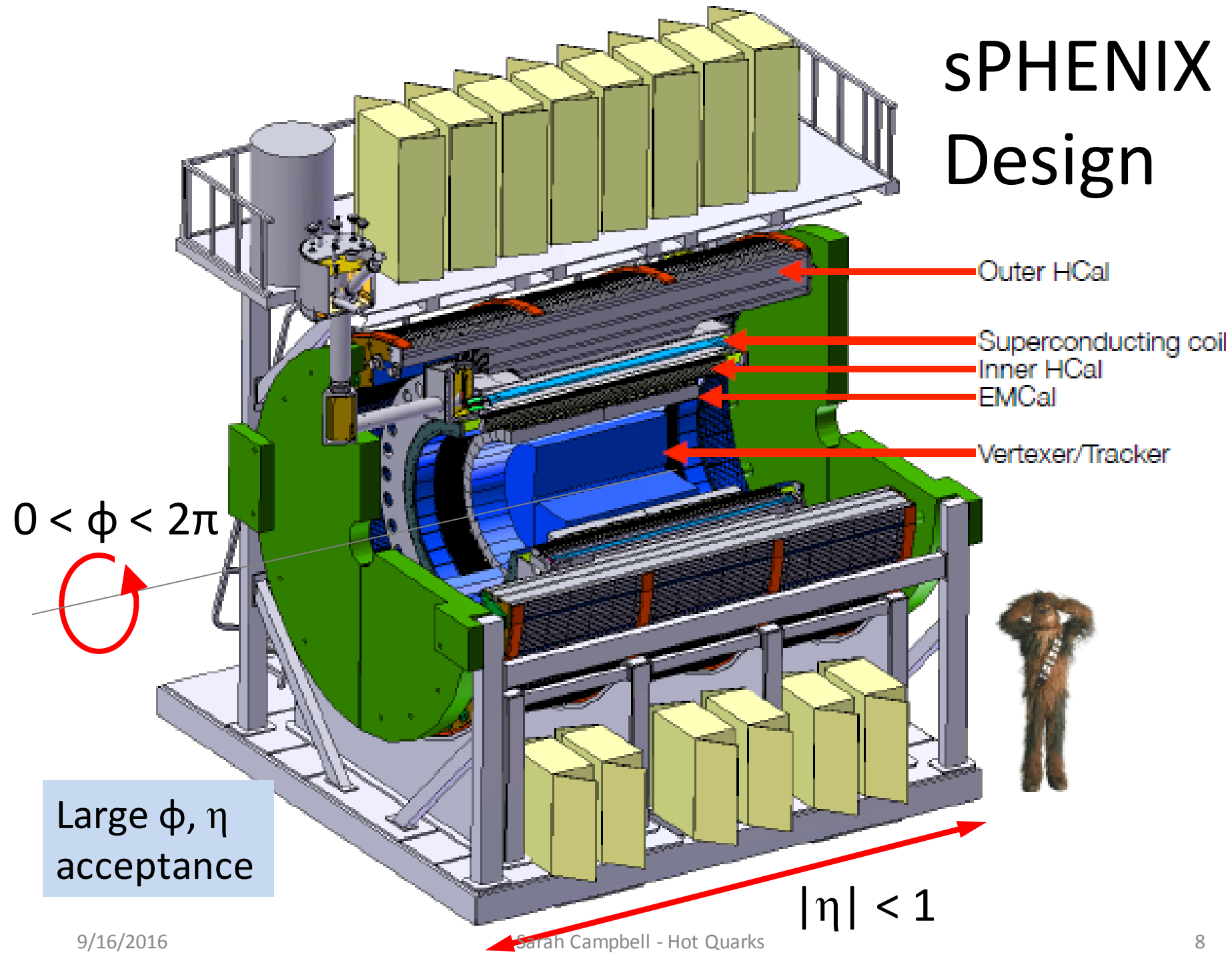
The 3 Pillars of sPHENIX

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

Physics driven detector requirements

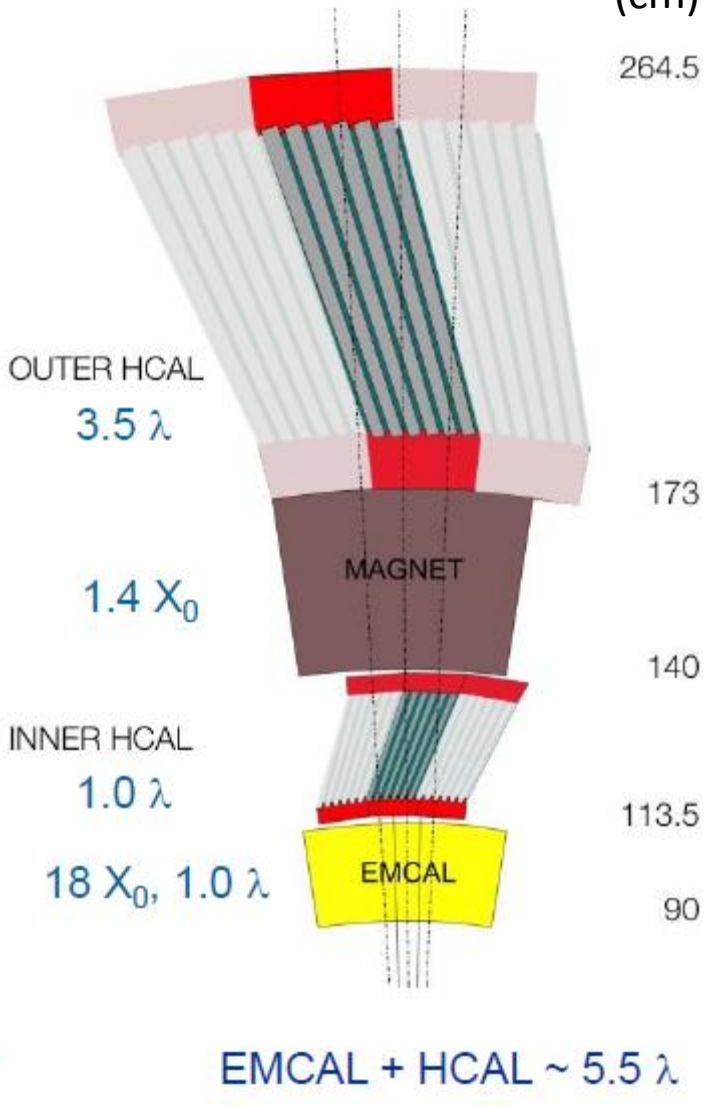
Physics goal	Detector requirement
High statistics for rare probes	Accept/sample full delivered luminosity (15kHz rate) Full azimuthal and large rapidity acceptance
Precision Upsilon spectroscopy	Hadron rejection > 99% with good $e^{+/-}$ acceptance Mass resolution 1% @ m_Υ
High jet efficiency and resolution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

sPHENIX Design



Outer Subsystems

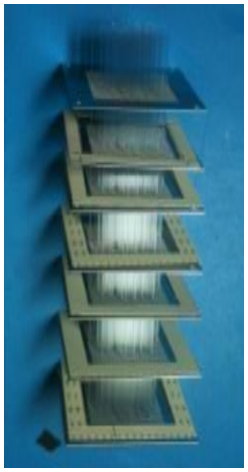
- HCal: Tilted Steel-Si plates
  - Inner and Outer HCal
  - $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$
  - Single particle: $\sigma/E < 100\%/\sqrt{E}$
- 1.5T Superconducting magnet
  - From BaBar, cold tested at BNL
- EMCal: W powder-Si fiber
  - $\Delta\phi \times \Delta\eta = 0.025 \times 0.025$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



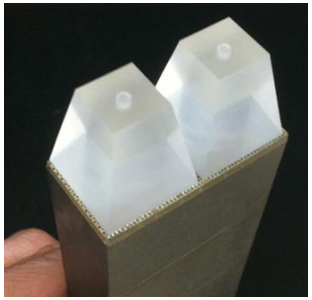
Calorimeter R&D

EMCal

2D projective (η, ϕ) modules



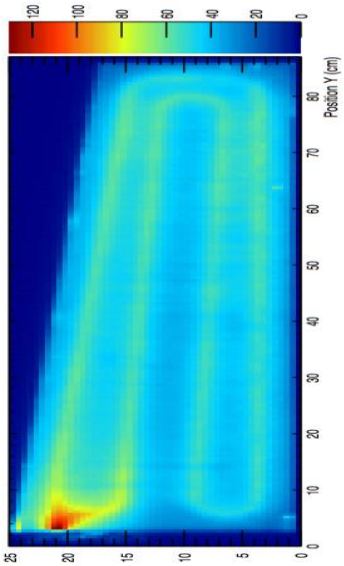
1D projective (ϕ) modules



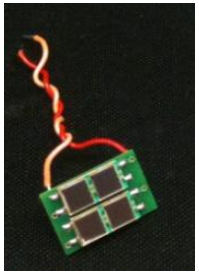
Lightguide and Si-photomultiplier readout

HCal

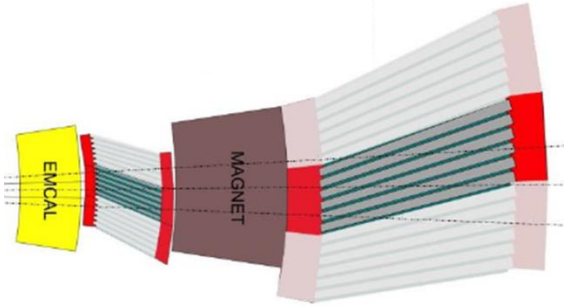
Polystyrene panels embedded with 1mm wavelength shifting fiber



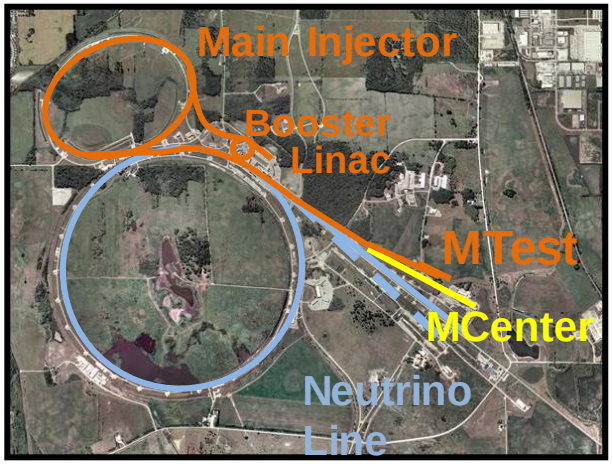
5 HCal tiles readout by 1 Si-photomultiplier

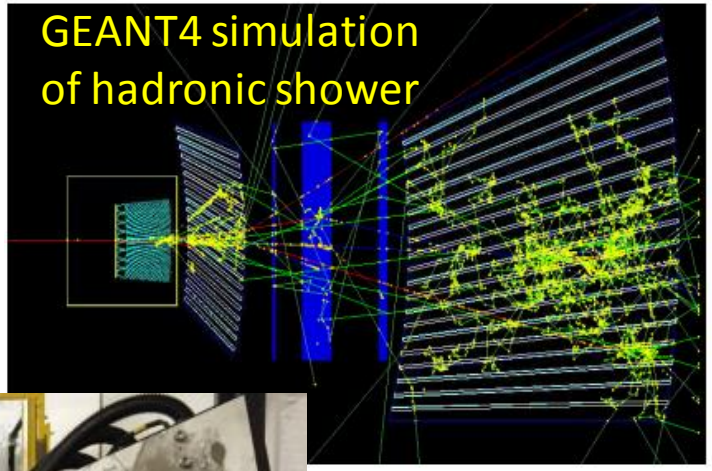


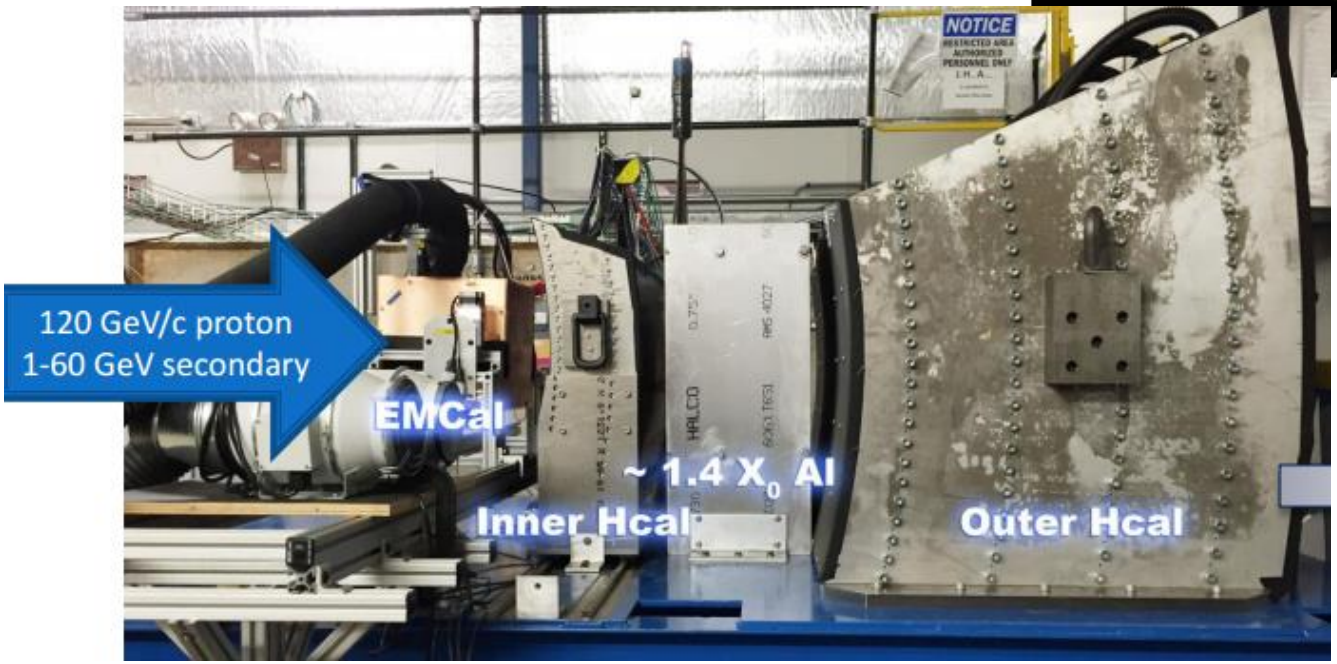
Calorimeter Test Beam



FermiLab's MTest Facility

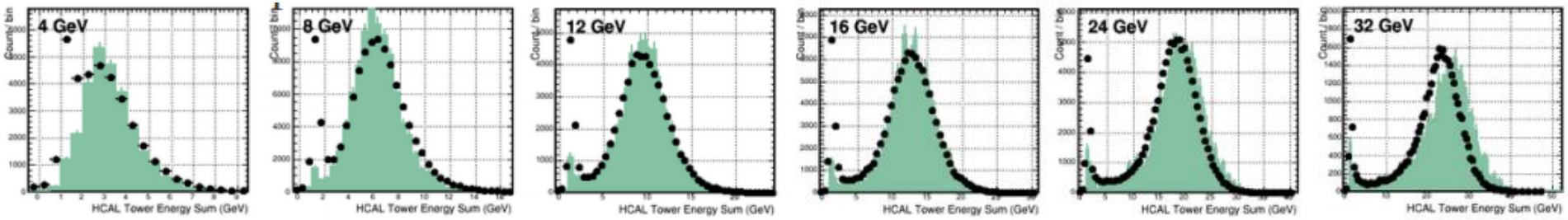


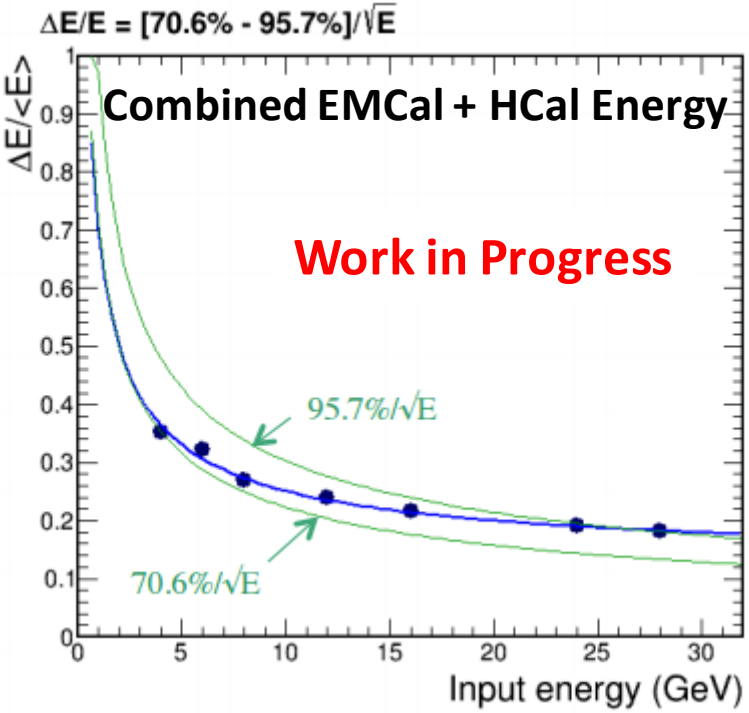


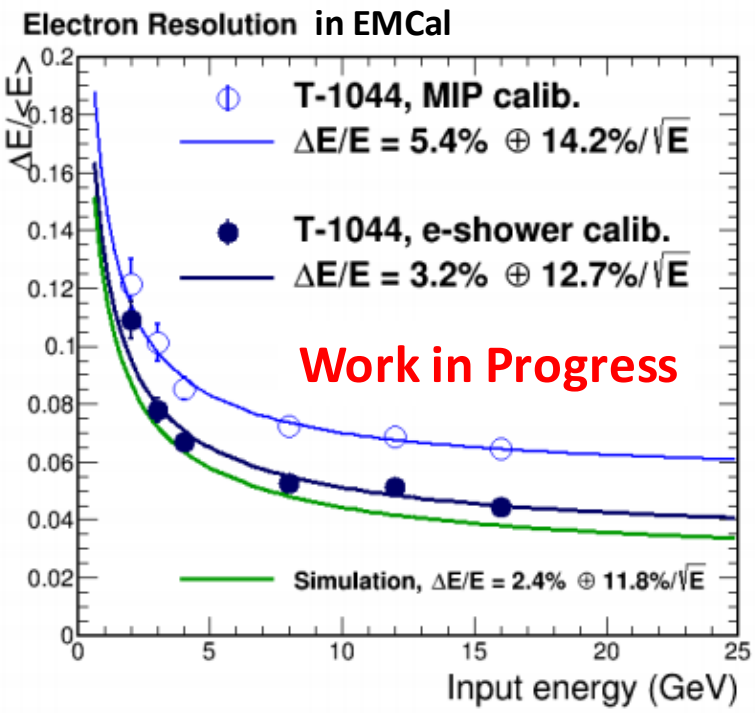


Early Test Beam Results

HCal energy distributions well described by simulation





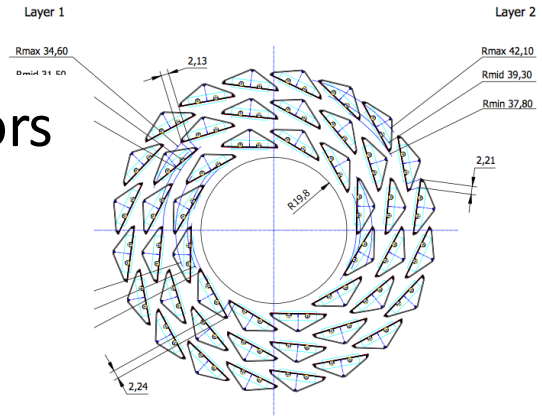


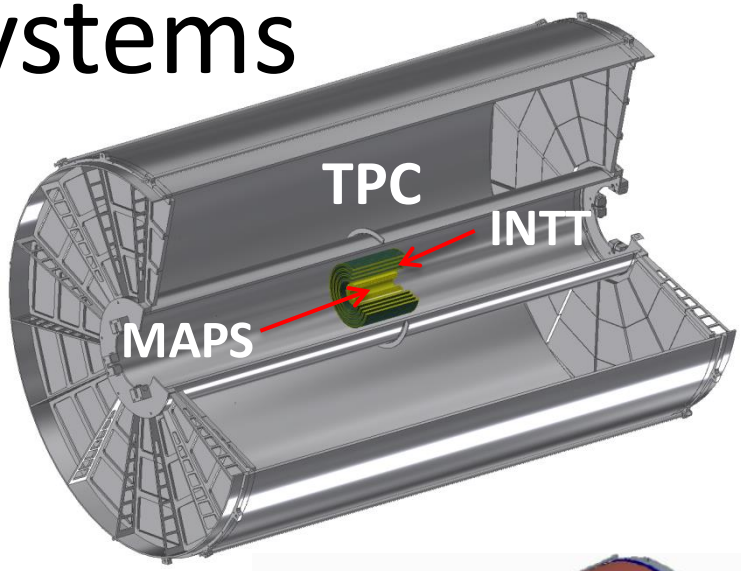
Meets design goals of <100%/√E and <15%/√E for EMCal

Tracking Subsystems

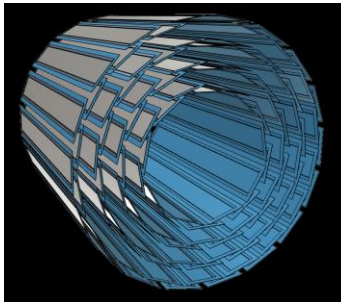
MAPS

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



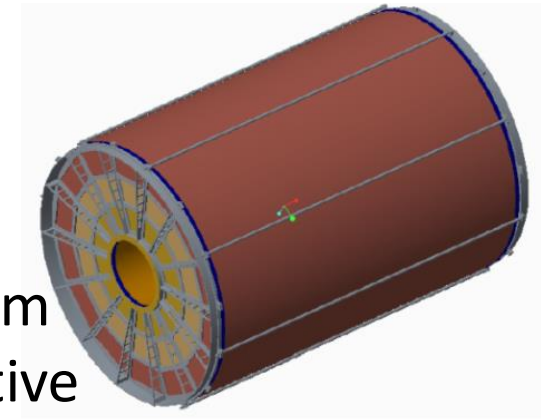


INTT



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

TPC

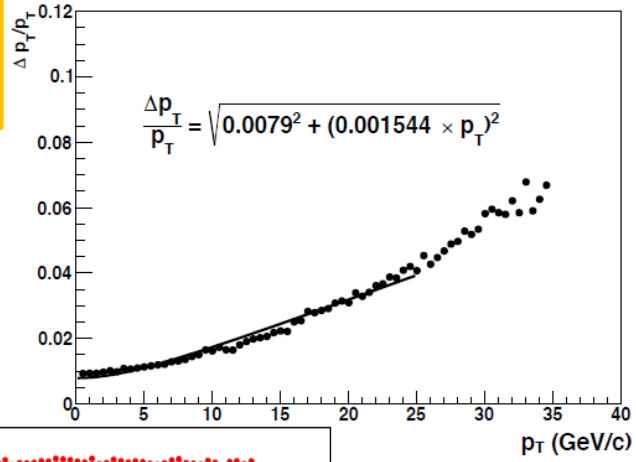


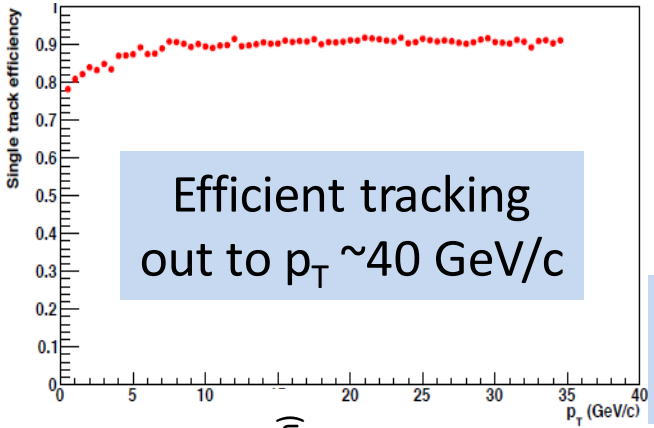
- Radius 20–78 cm
- ~250 µm effective hit resolution
- Continuous (non-gated) readout
- Pattern recognition, momentum resolution, p_T 0.2-40 GeV/c

Detector capabilities

Tracking

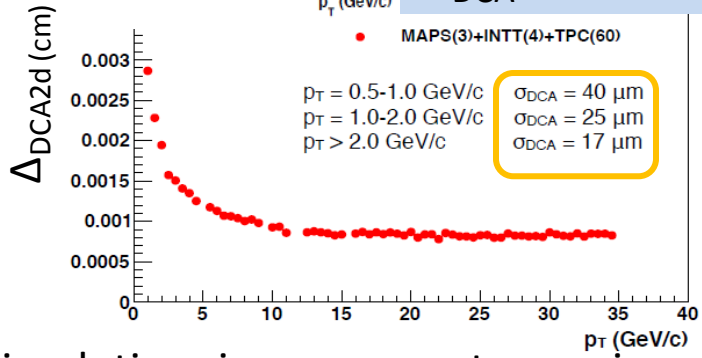
Embedded π's in central HIJING events





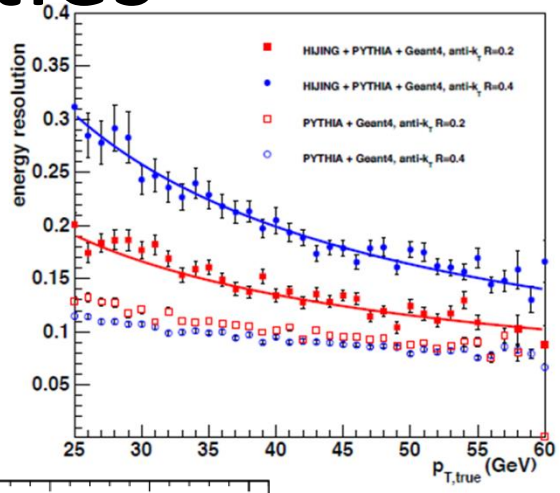
Efficient tracking out to p_T ~40 GeV/c

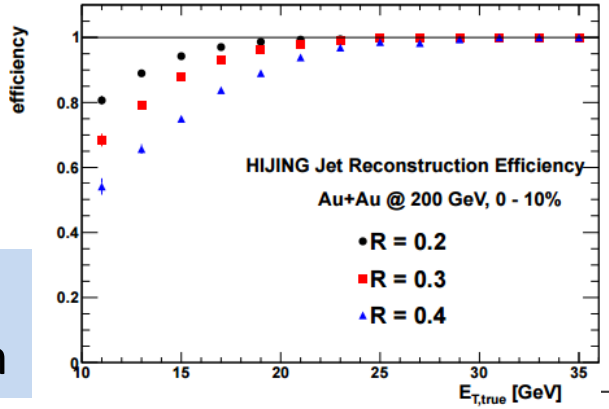
Better than $\sigma_{DCA} < 70$ μm

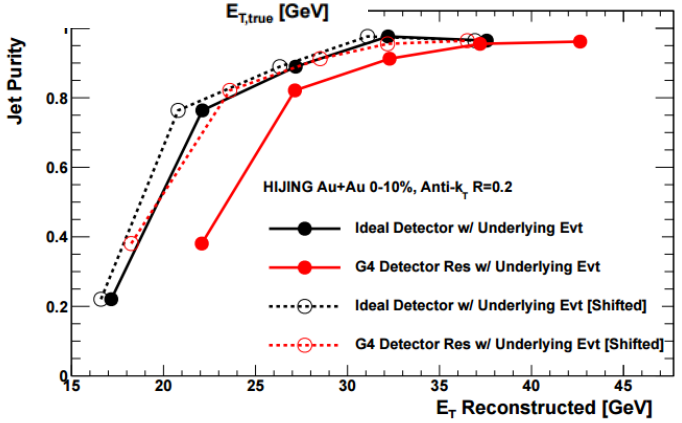


Tracking simulations improvements ongoing

Jets







pQCD Rates

22 weeks of Au+Au at RHIC
→ 100B MB events
→ 20B 0-20% events

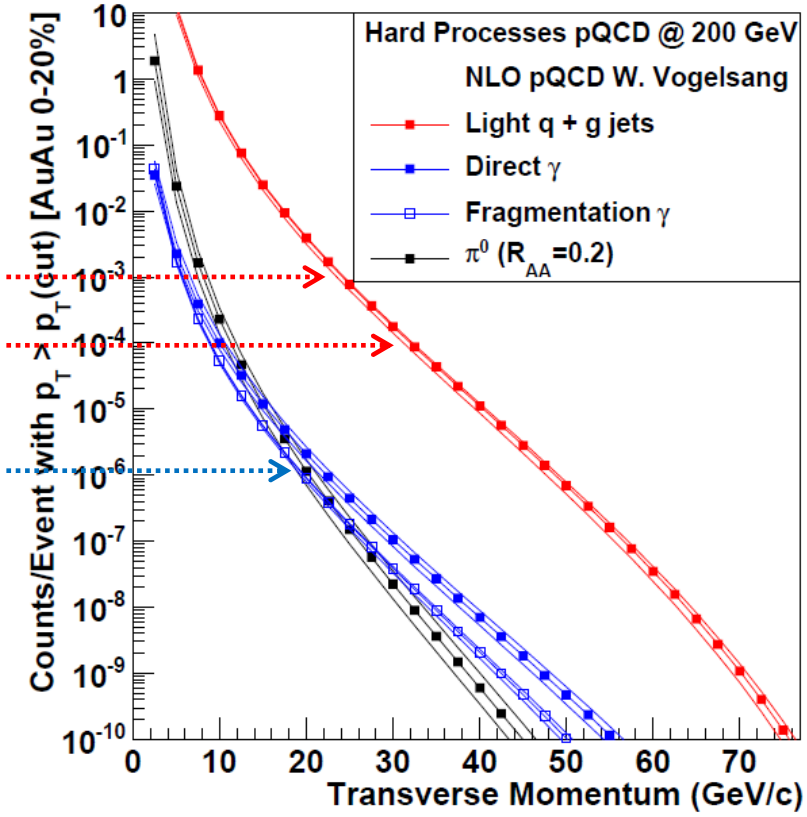
Yields in 0-20% centrality:

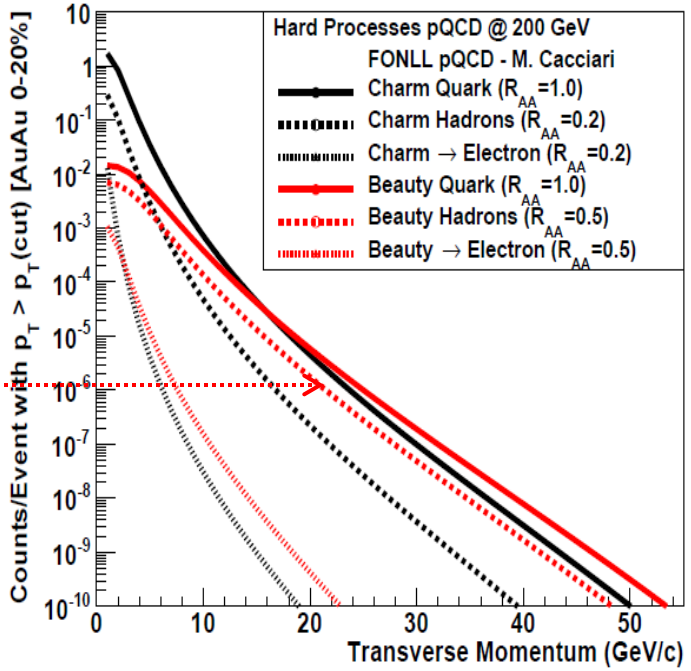
10^7 jets $p_T > 20$ GeV/c

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

10^4 γ_{dir} $p_T > 20$ GeV/c

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

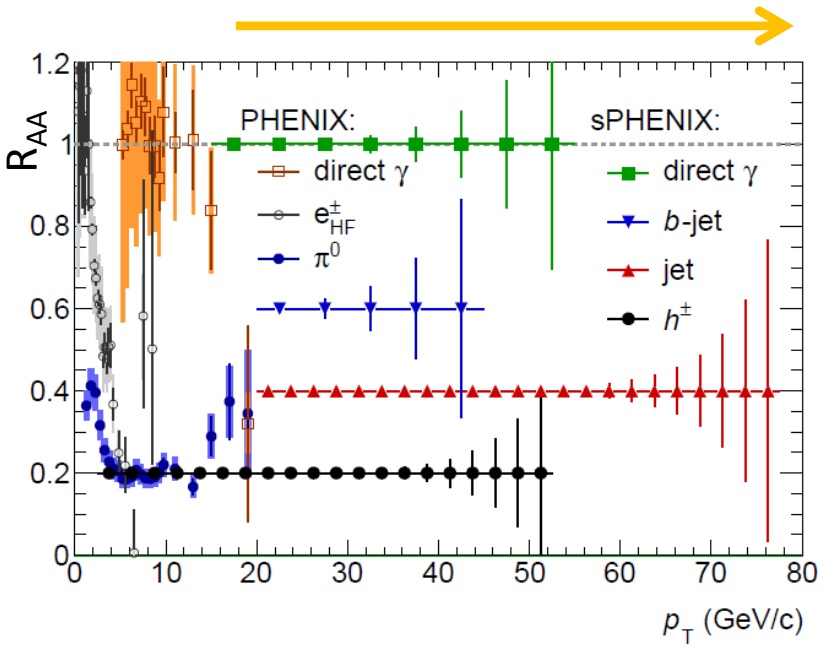




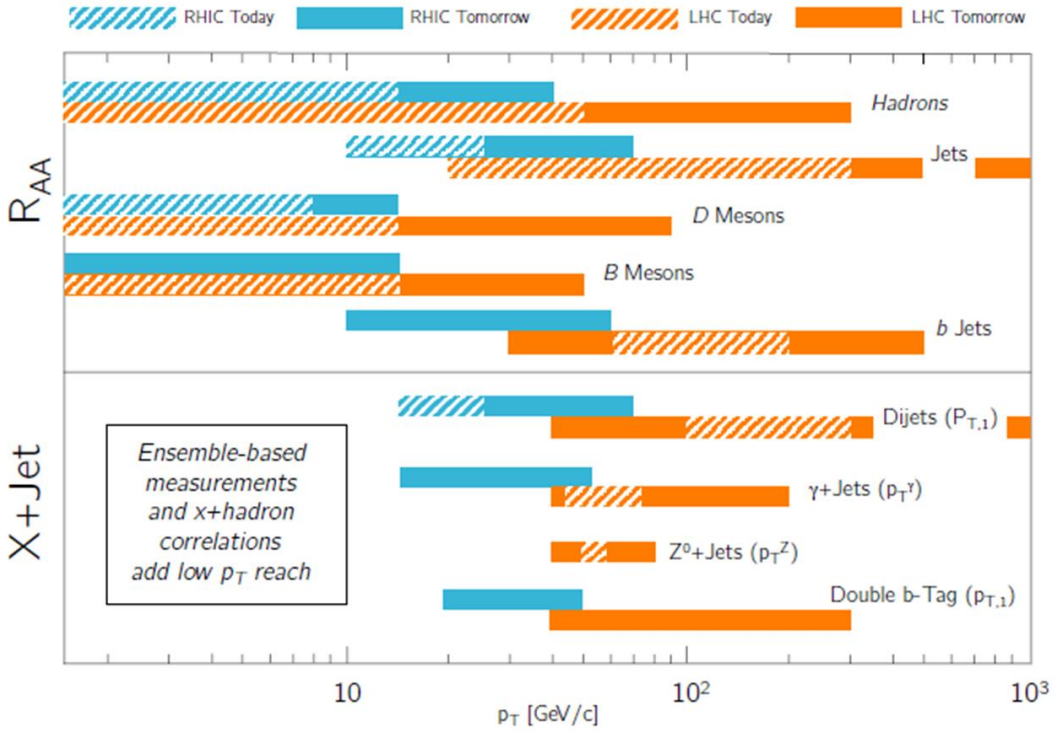
High statistics requirement met

Kinematic Reach

Extends range at RHIC

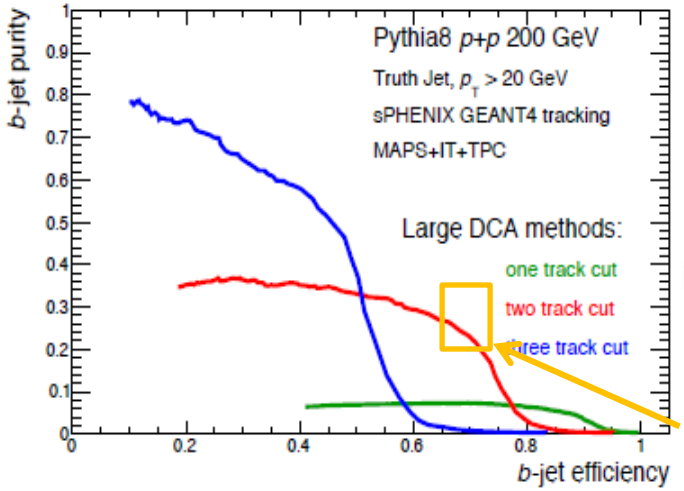


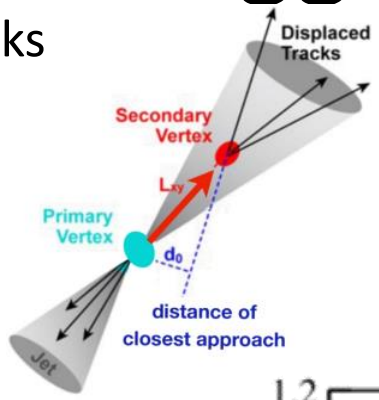
Overlaps with LHC



b-Jet Tagging

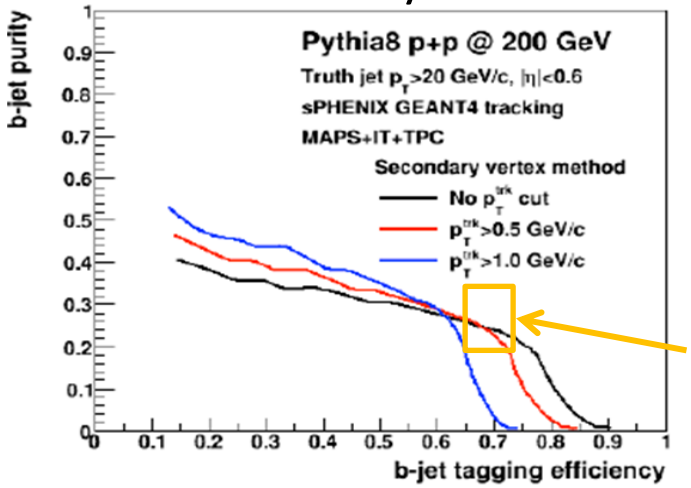
Method 1: Multiple large DCA tracks





30% purity
70% eff.

Method 2: Secondary vertex



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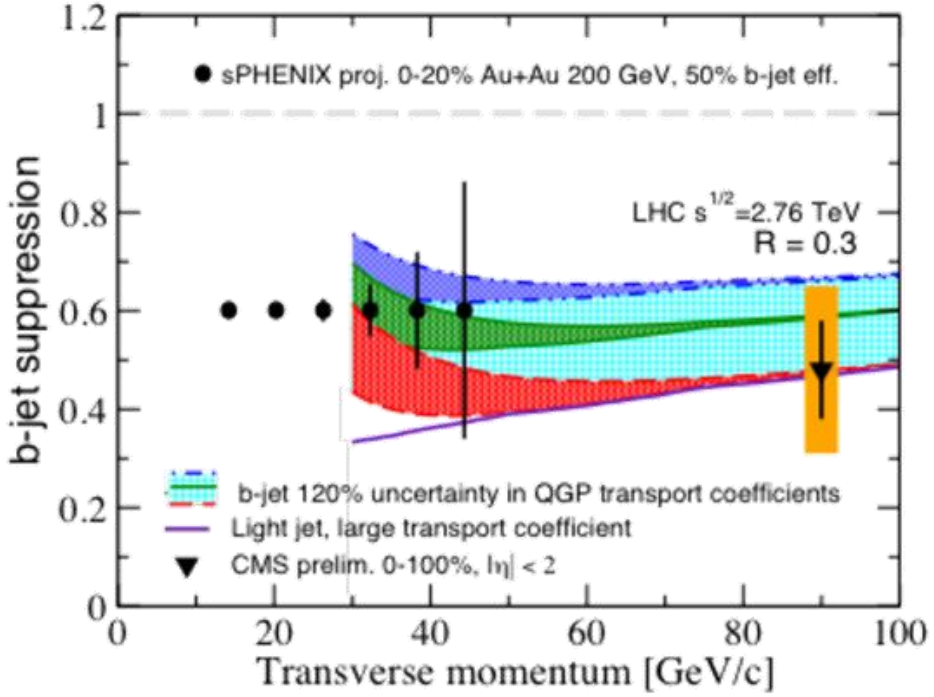
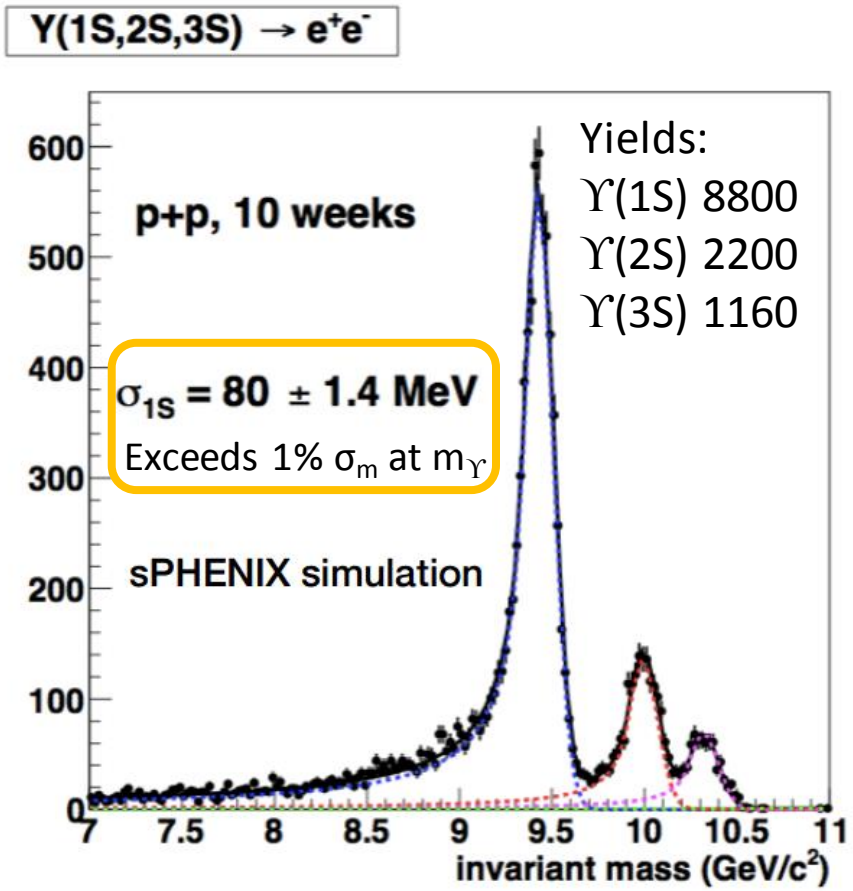
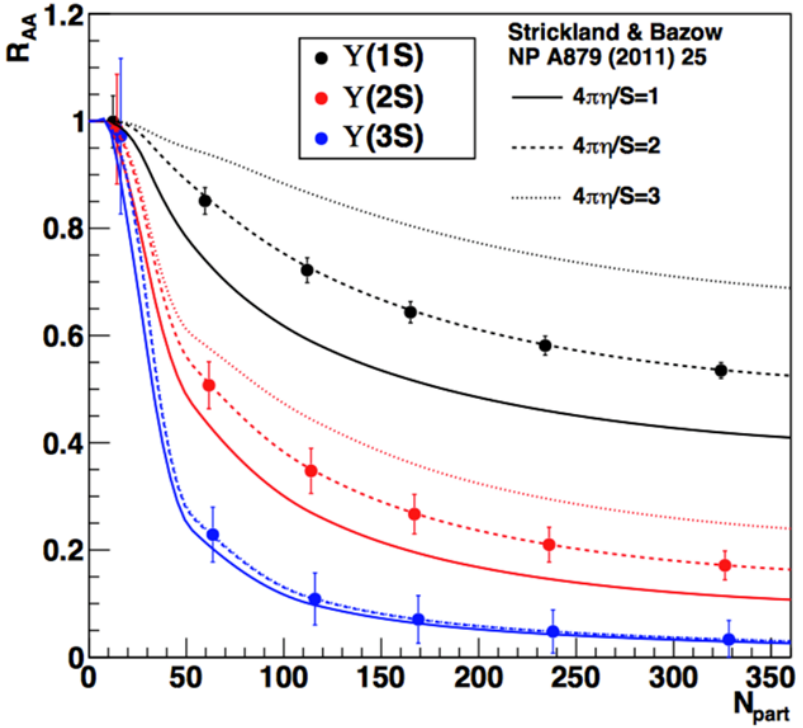


Method 3: B-meson tagging by semi-leptonic decay or by m_B → in progress

Upsilon states

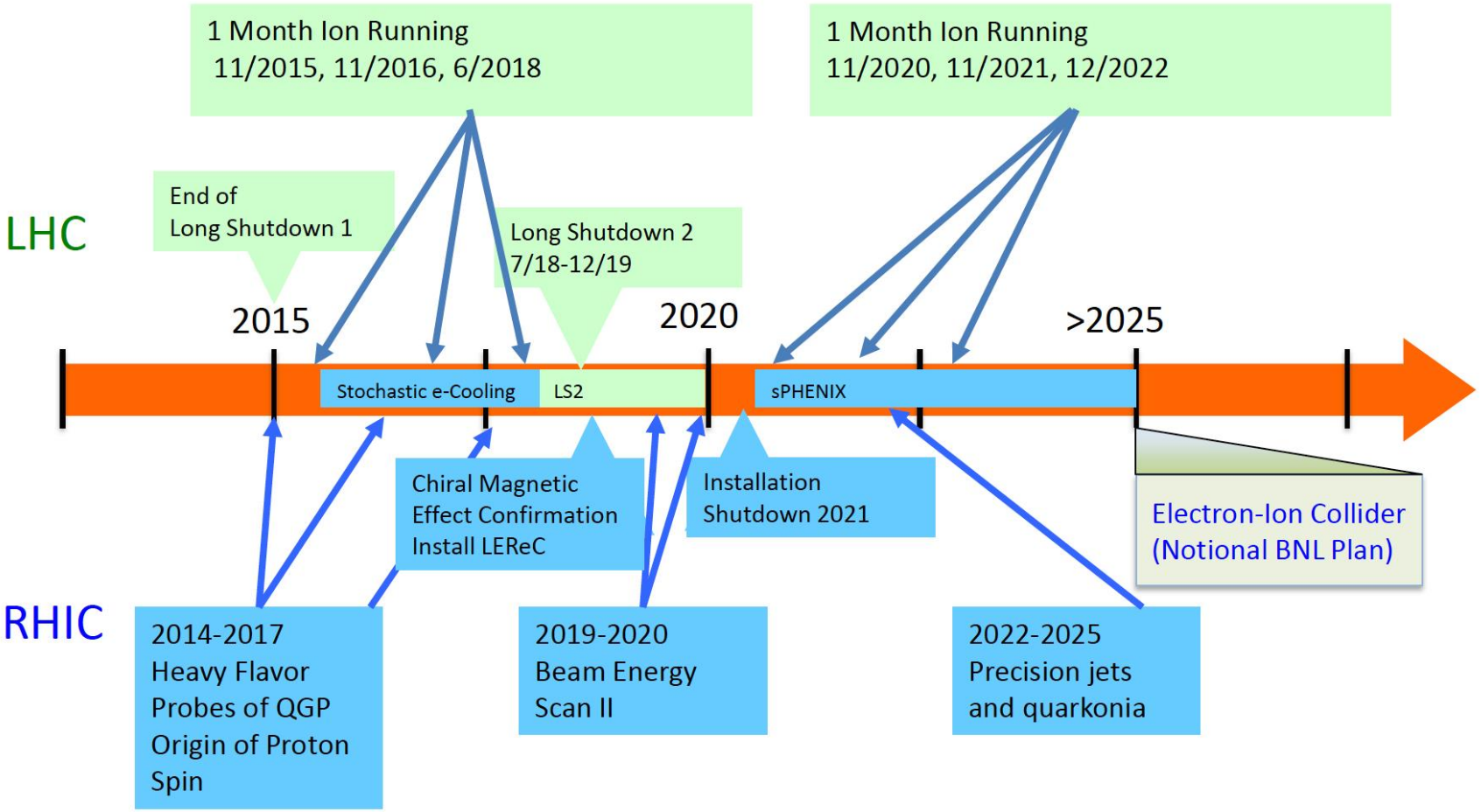




First time Υ(1S), Υ(2S), Υ(3S) separation achievable at RHIC!

Timeline

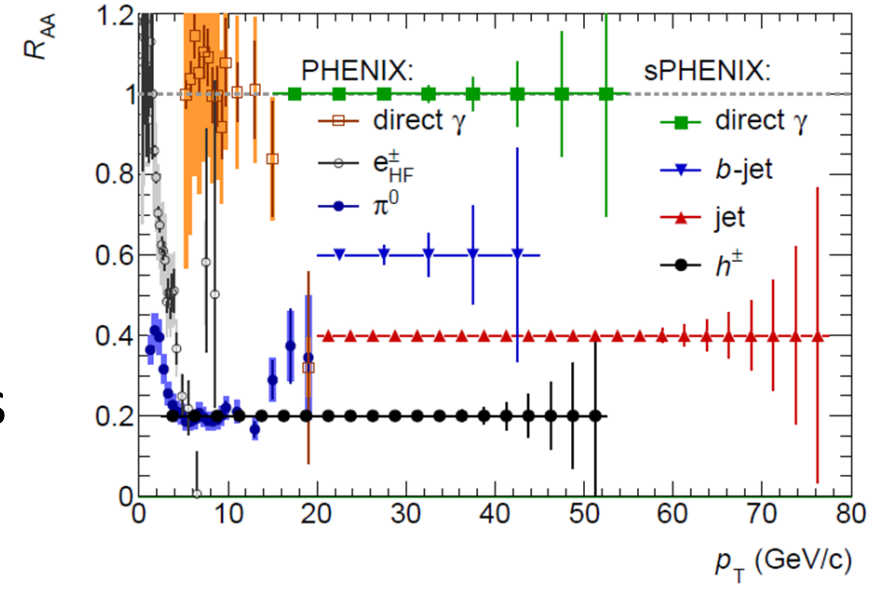
From Tim Hallman at 2016 RHIC/AGS Users meeting:

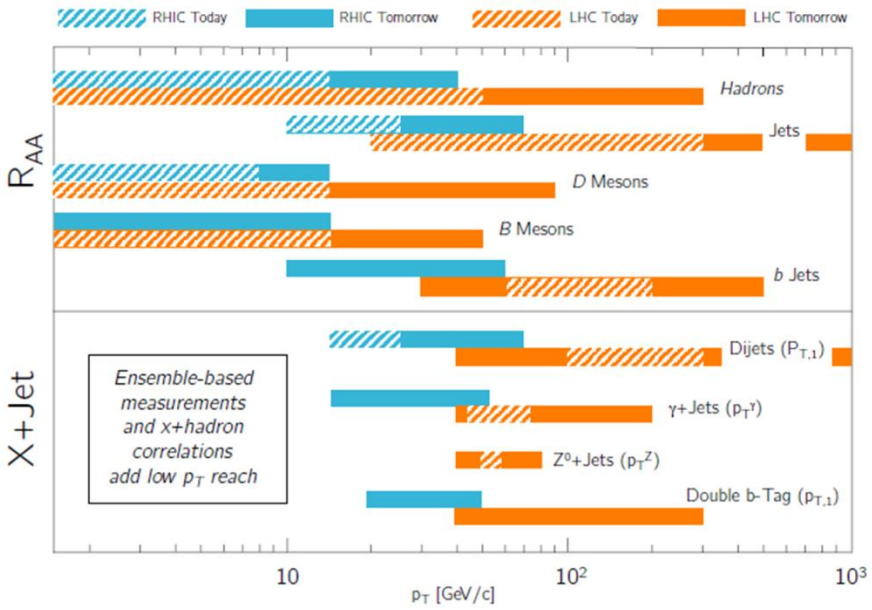


Conclusions

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

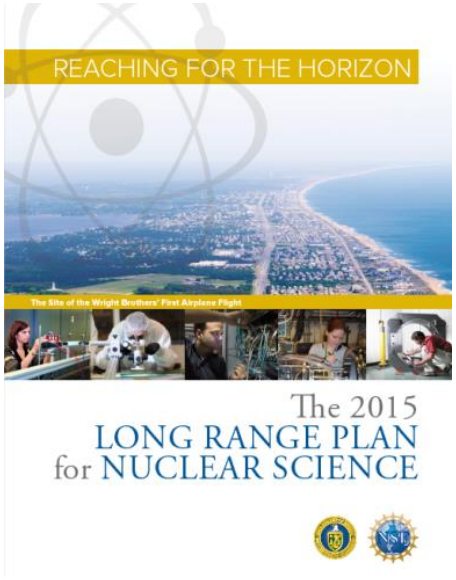
http://www.phenix.bnl.gov/phenix/WWW/publish/documents/sPHENIX_proposal_19112014.pdf





Backup

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.

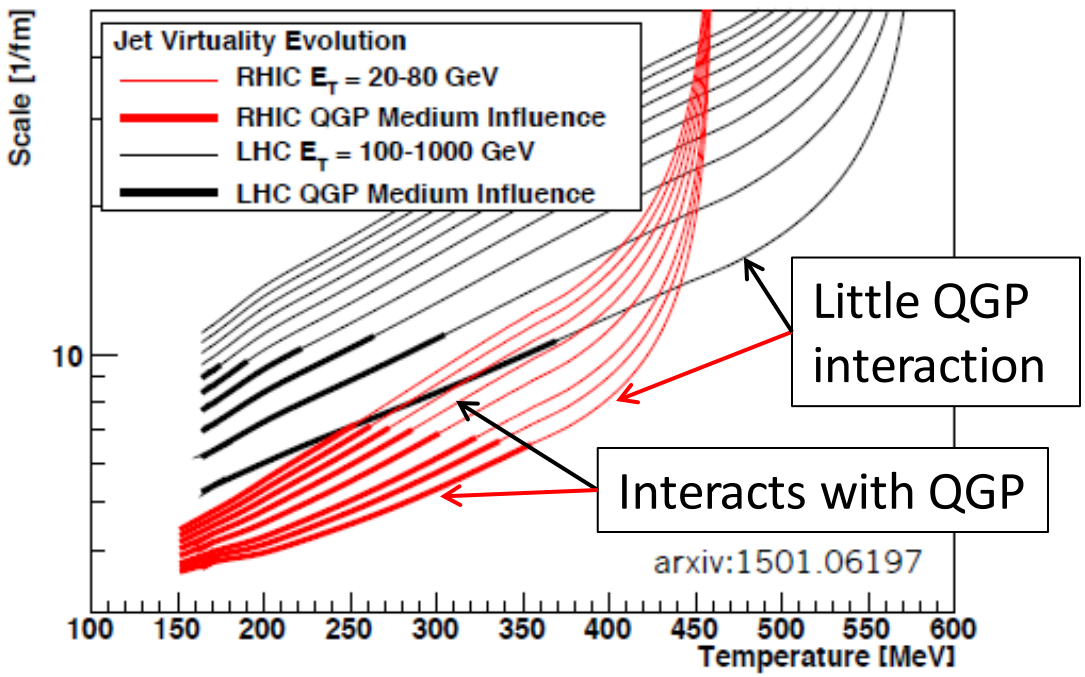
… other facilities …

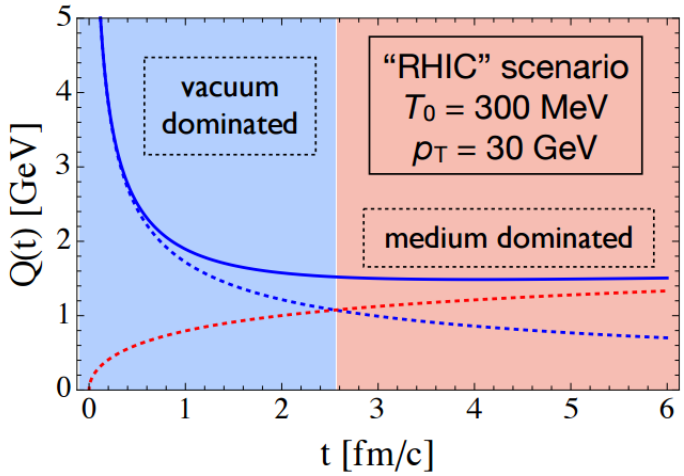
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

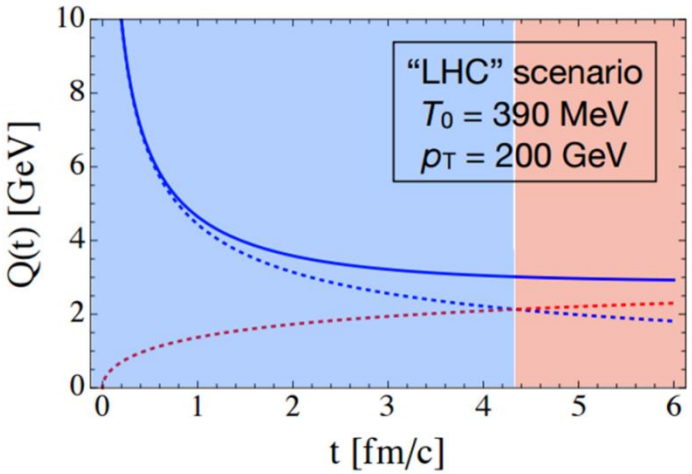
From sPHENIX Cost and Schedule Review:

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.**

Jet Evolution and Virtuality







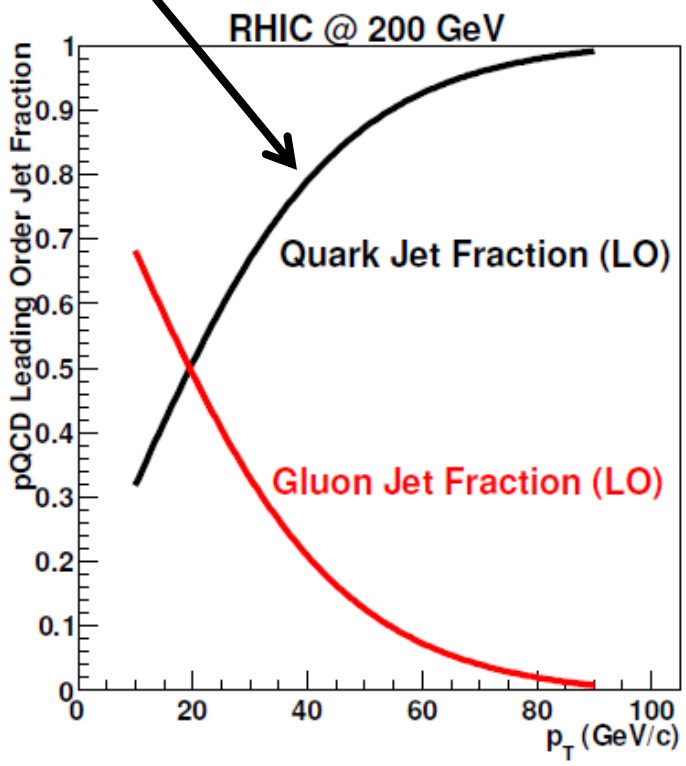
Lower energy jets, jets at RHIC have increased sensitivity to QGP interactions

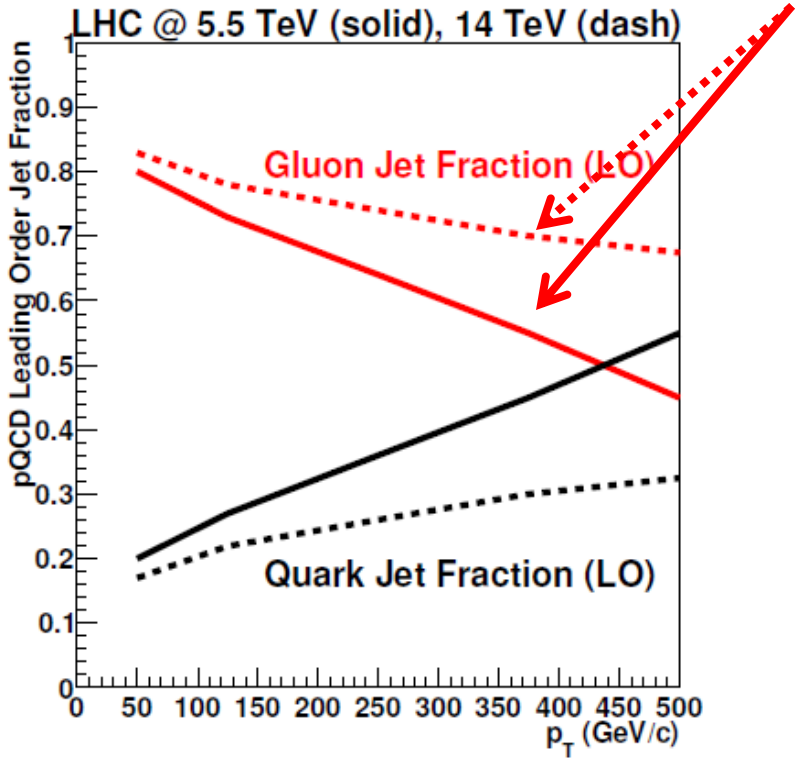
Complementary measurements at RHIC & LHC

Partonic Composition of Jets

Higher quark-jet fraction at RHIC

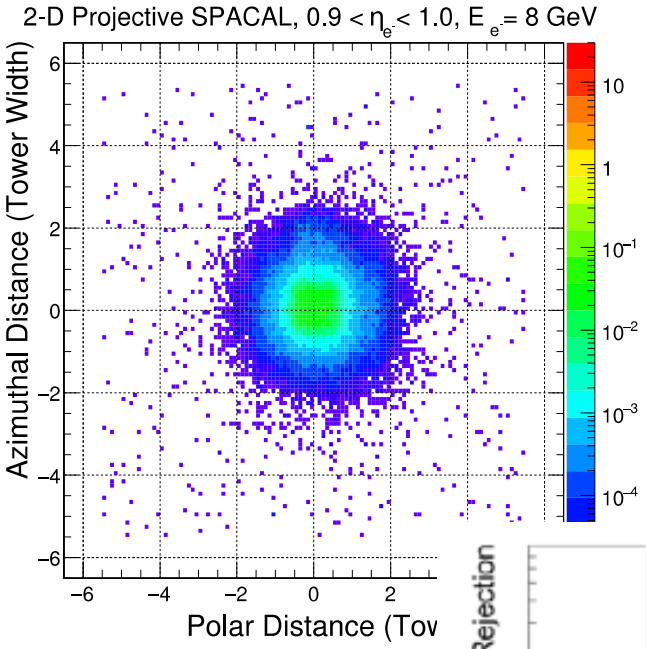
LHC gluon-jet dominated until significantly higher jet energies

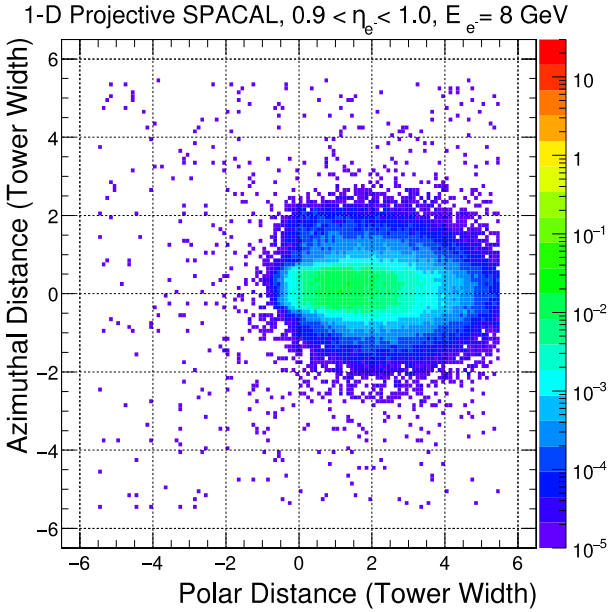




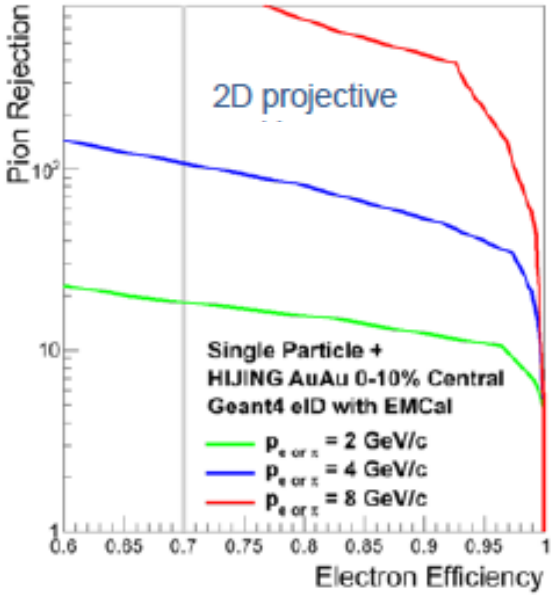
Complementary measurements at RHIC & LHC

1D vs 2D projective EMCal modules



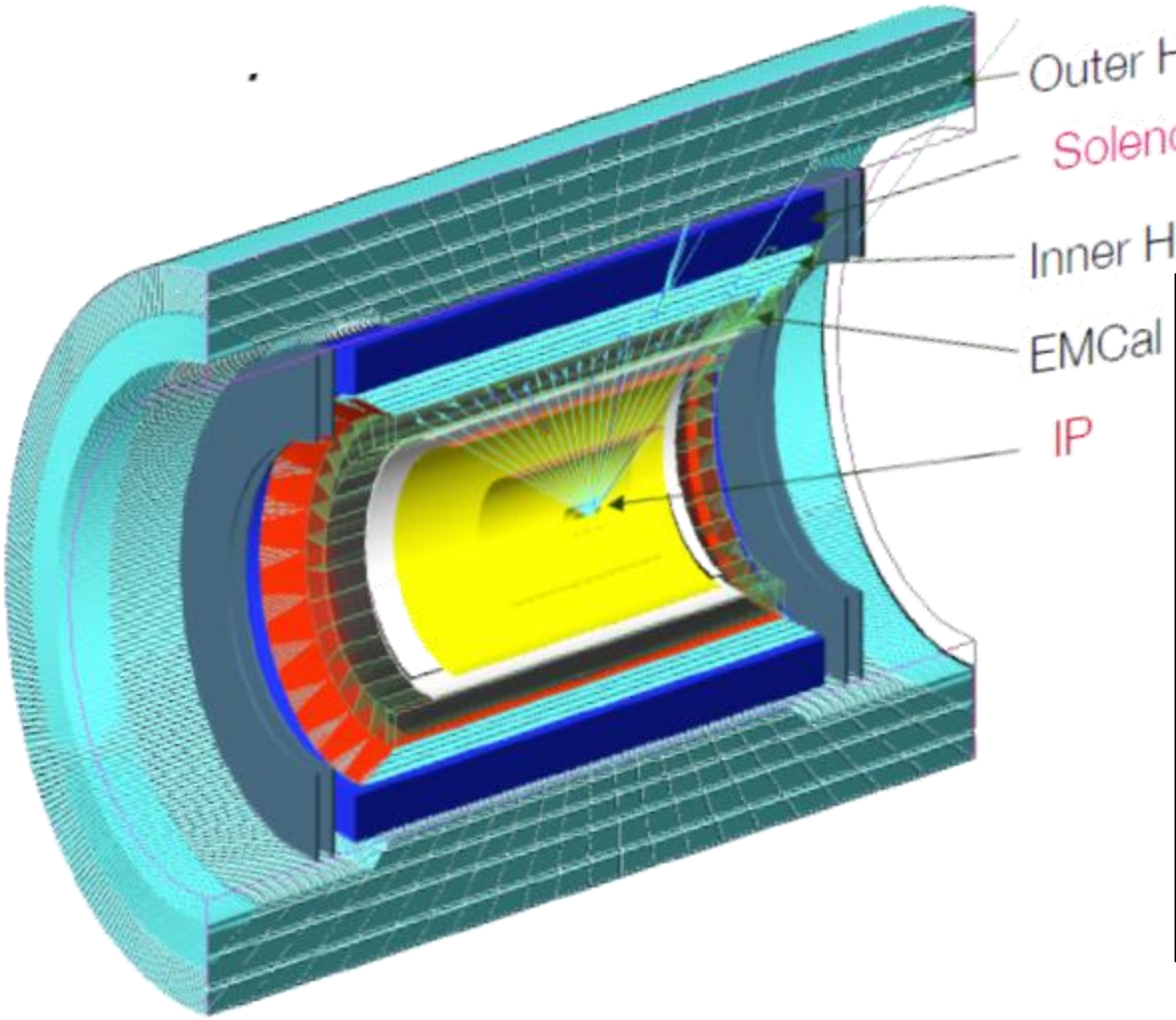


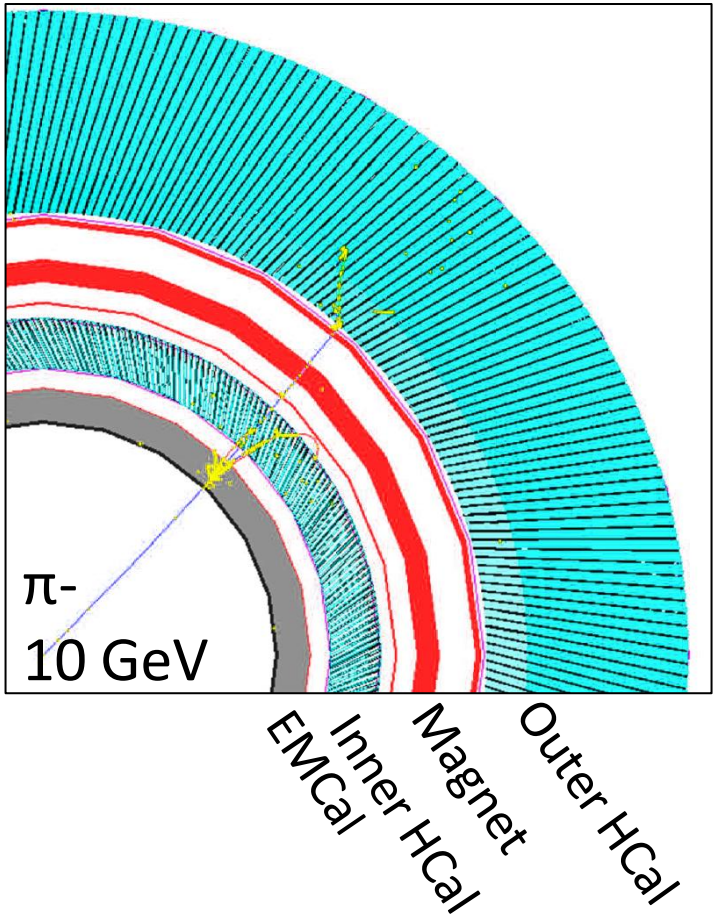
2D projective improves e/π separation



1D Production process more established

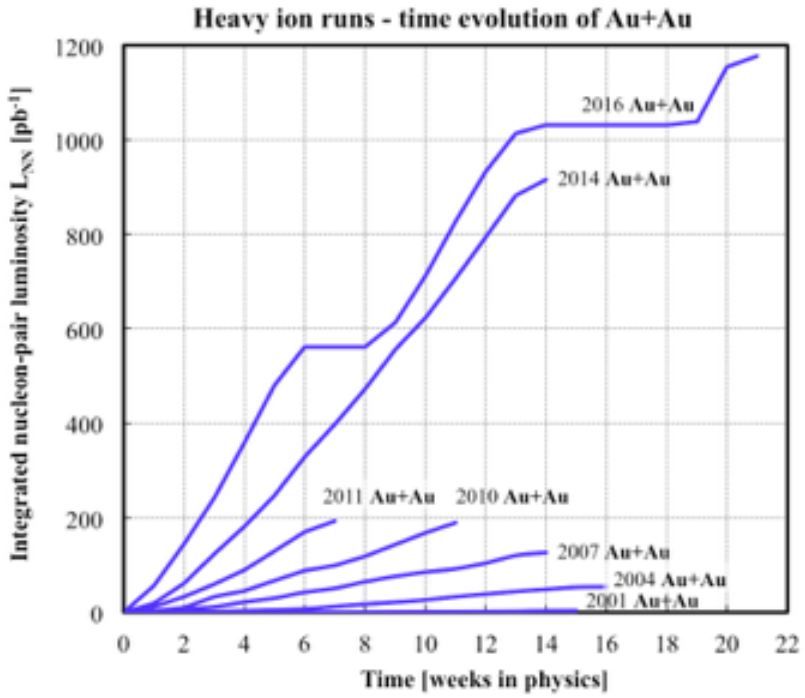
GEANT4 Simulations



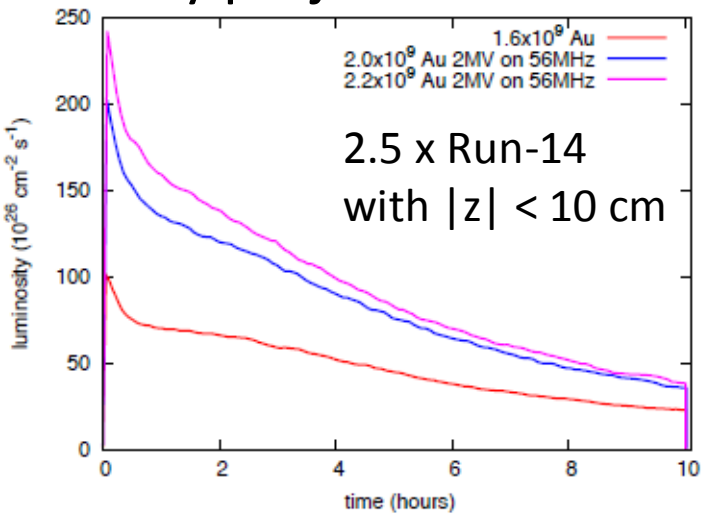


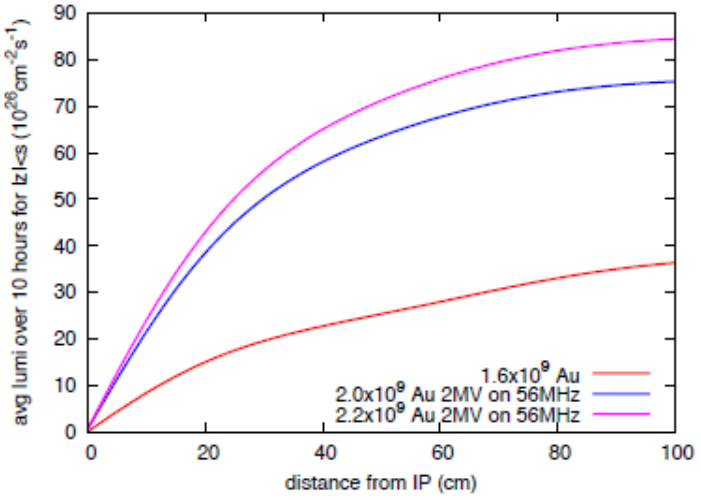
https://github.com/sPHENIX-Collaboration

Increased luminosity at RHIC



Luminosity projections from C-AD

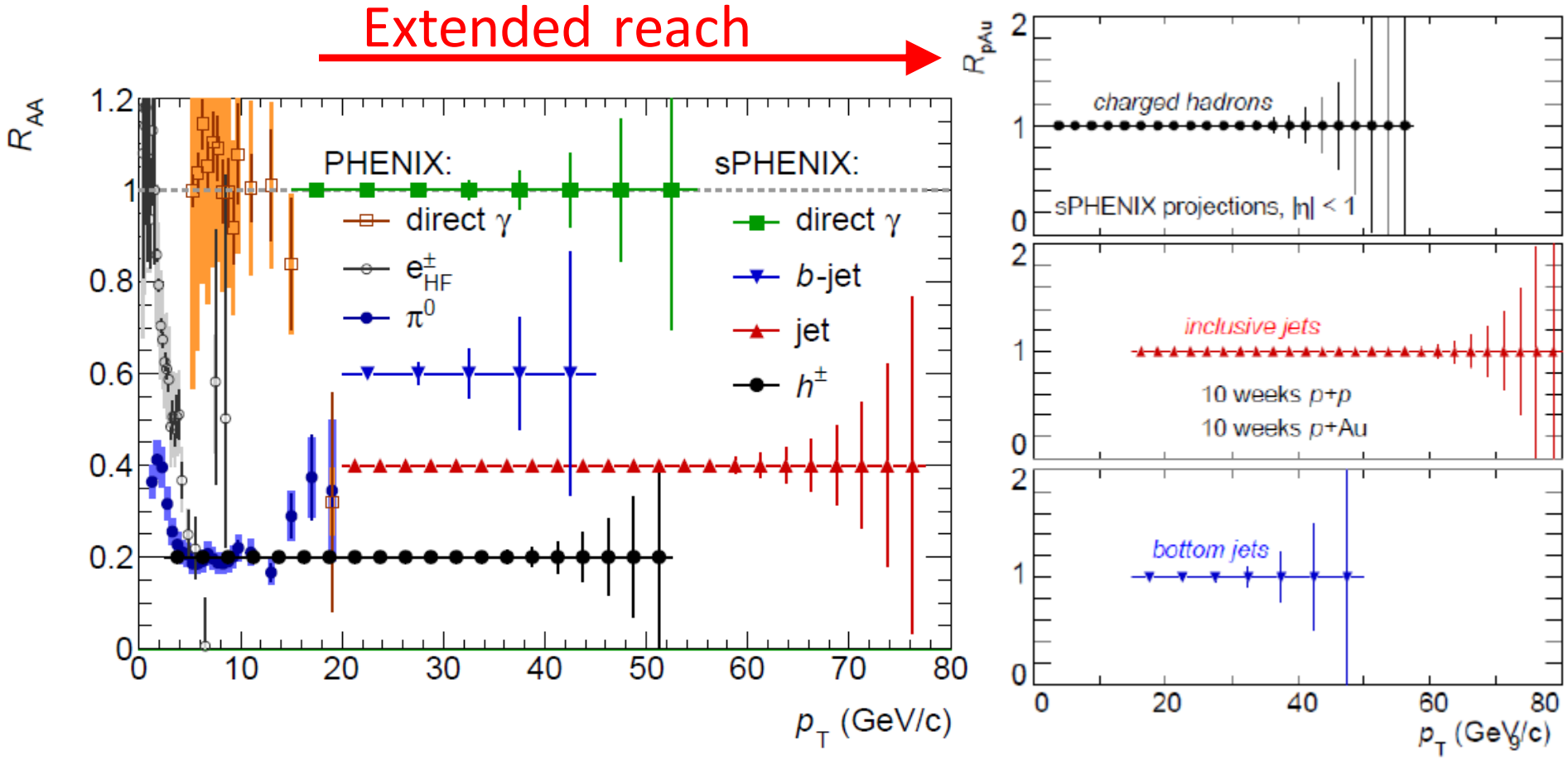




22-weeks 200 GeV Au+Au
→ 100B Min Bias events

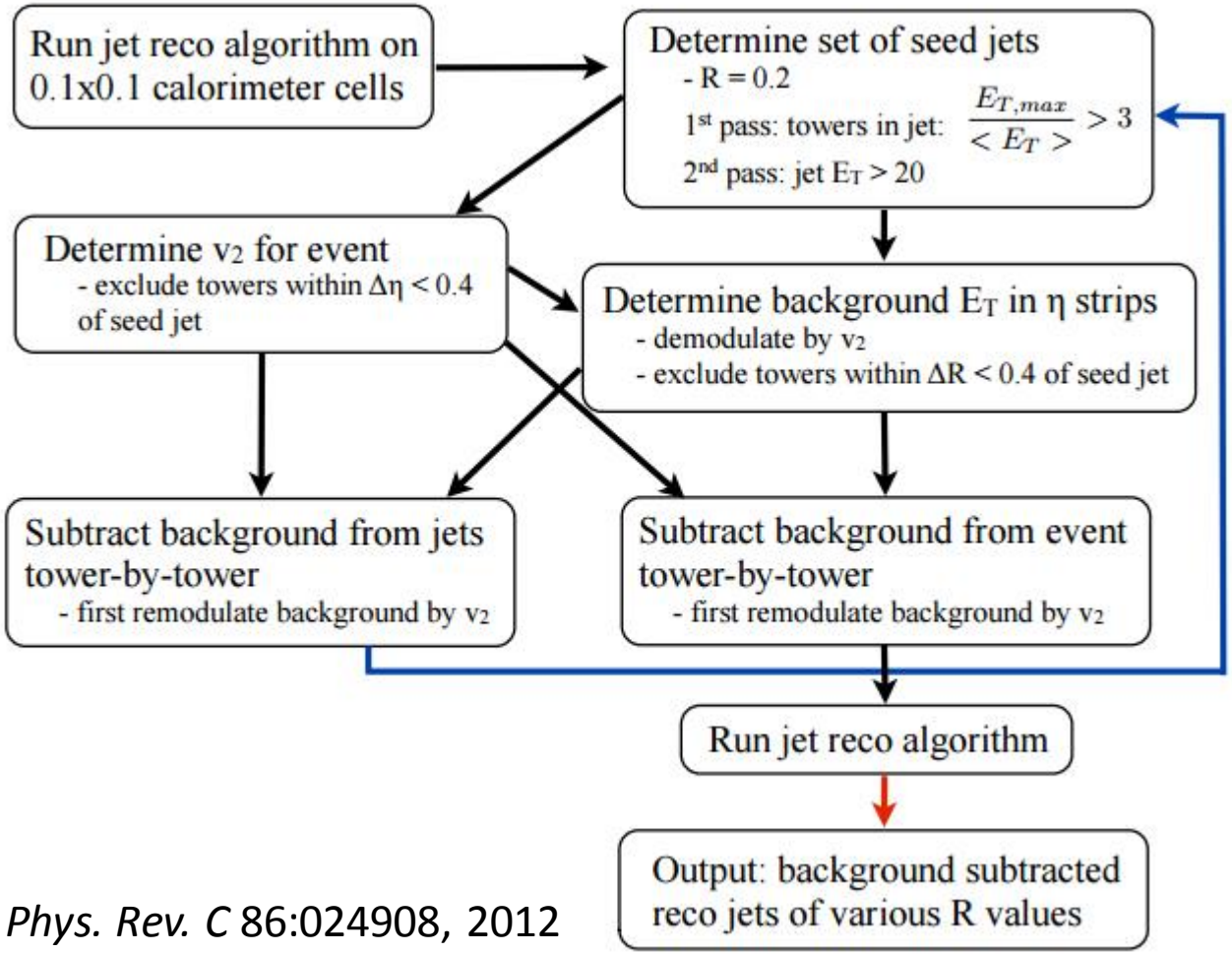
High statistics requirement met

Increased Kinematic Range



Jet Reconstruction

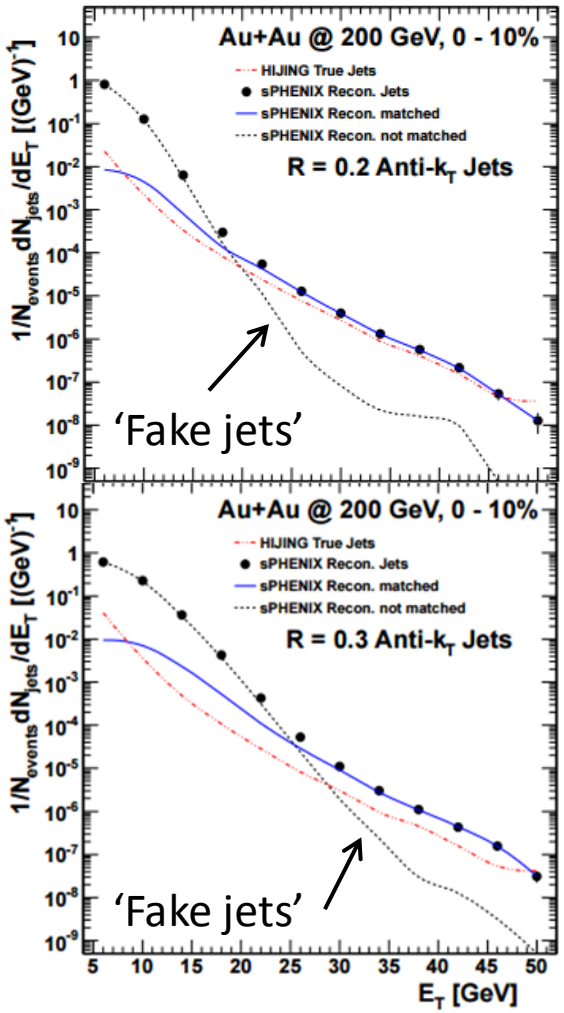
Inspired by ATLAS' heavy ion jet reconstruction:

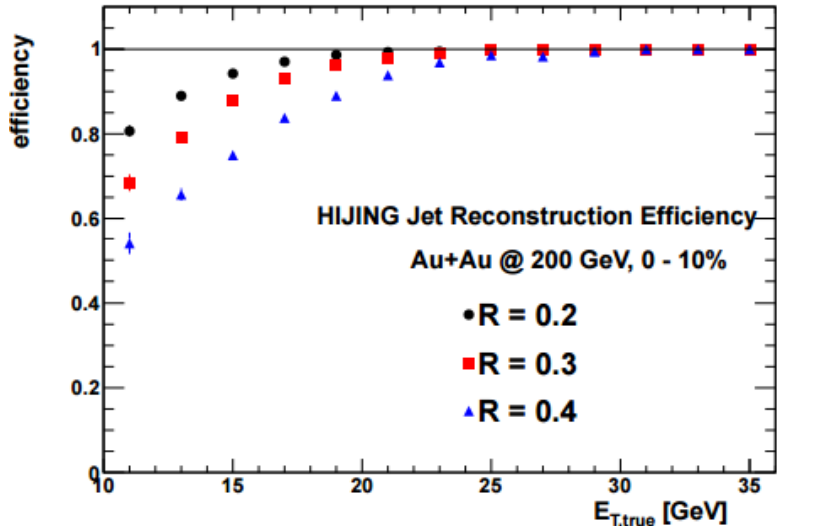


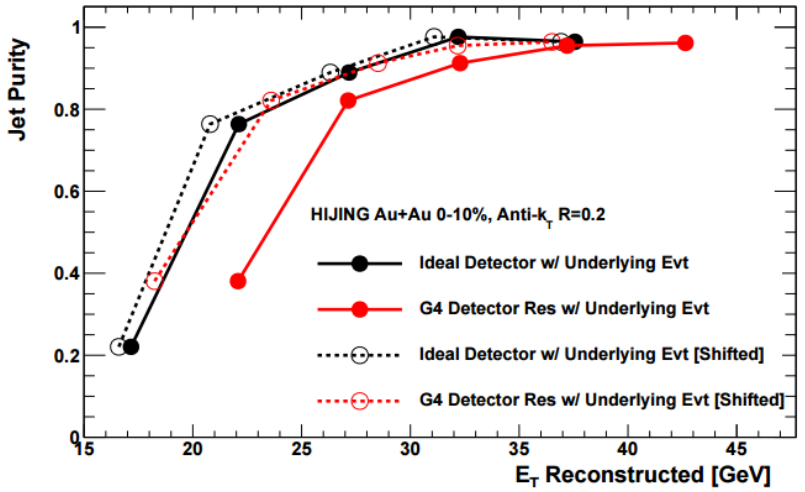
Hanks et al. *Phys. Rev. C* 86:024908, 2012

Jet Reconstruction

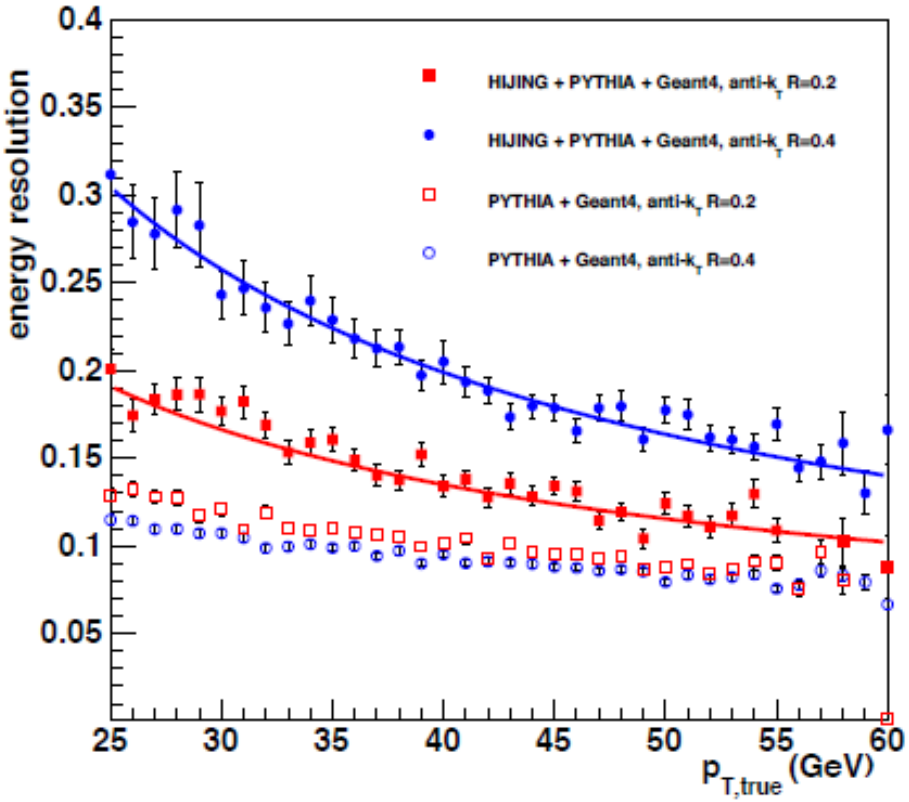
Fluctuations in the underlying event create 'fake jets'

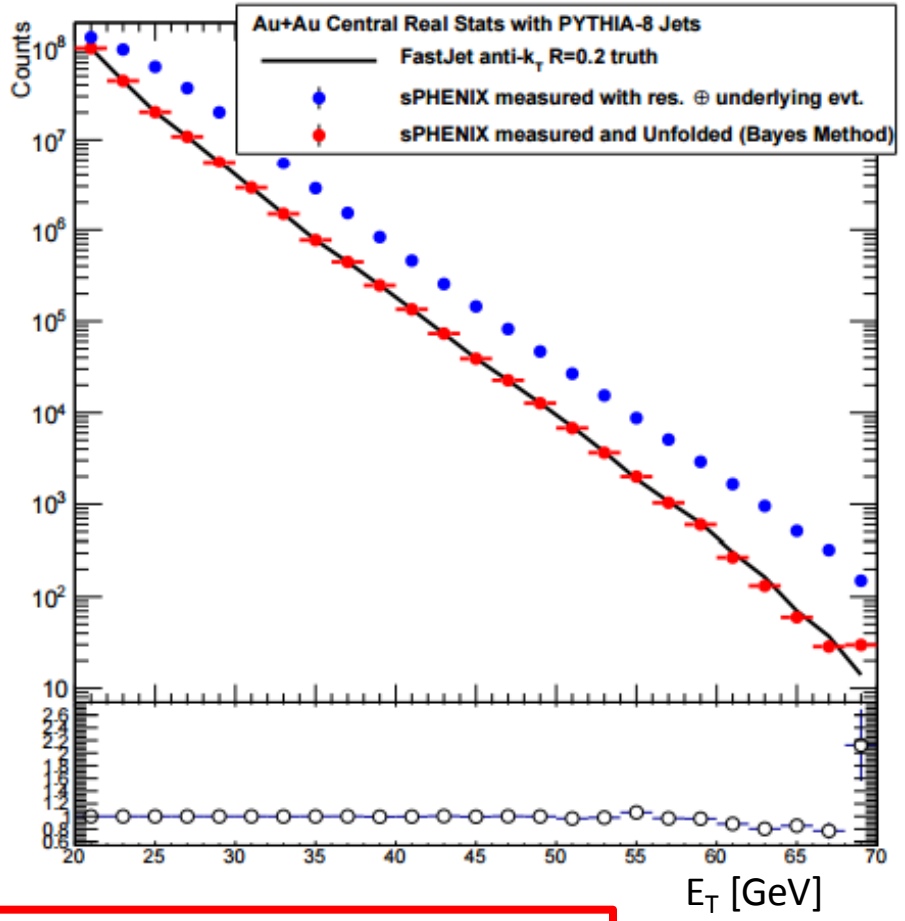






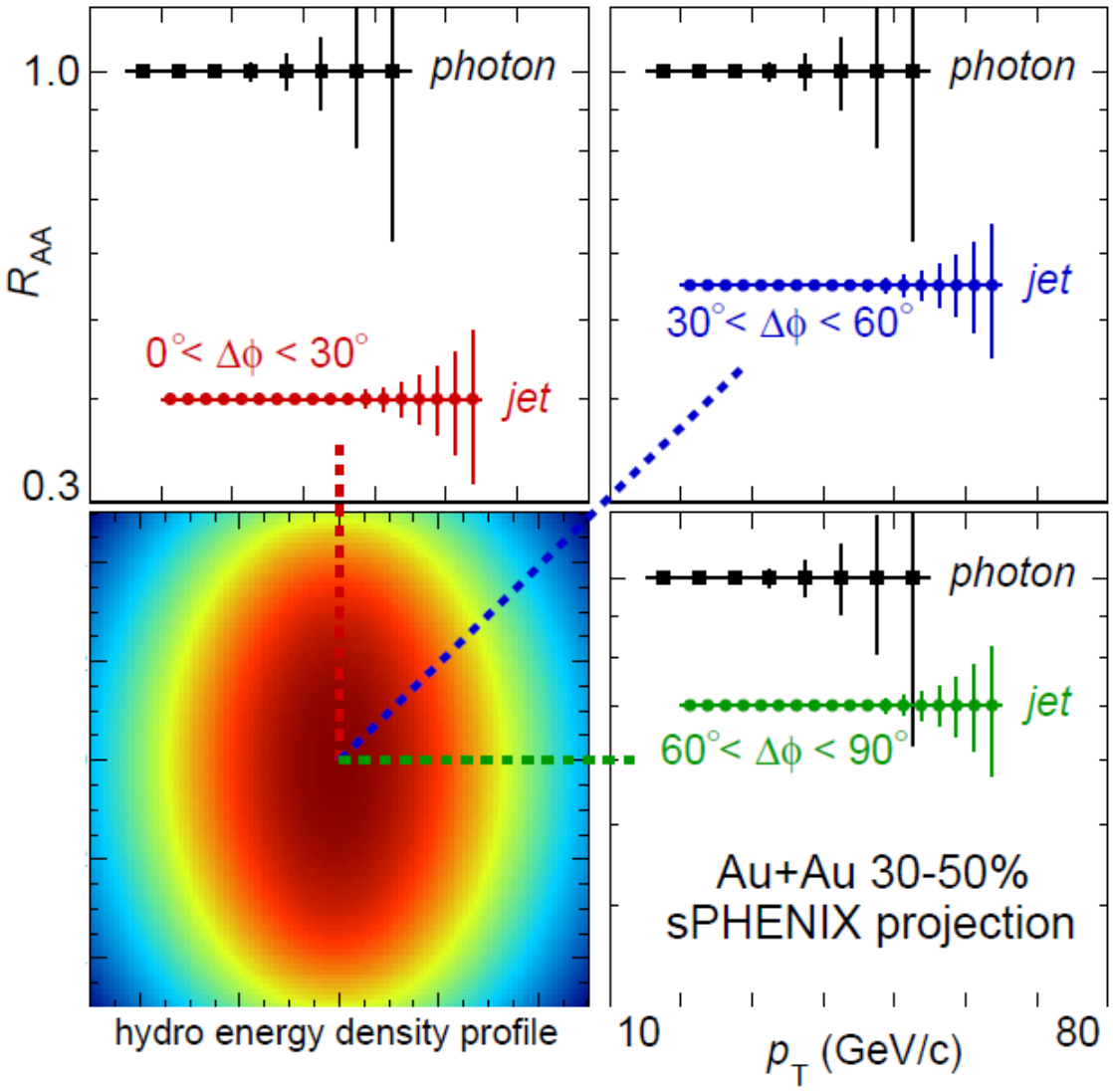
Jet Energy Resolution and Unfolding



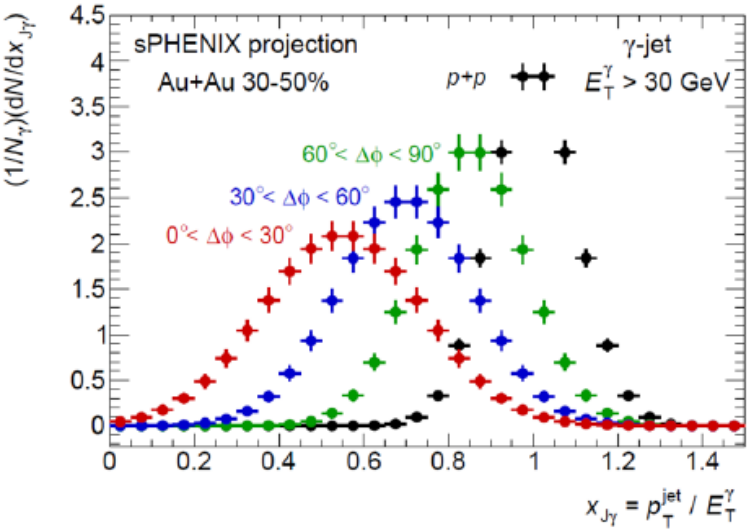


Unfolding corrects for the resolution and underlying event fluctuation effects

Path Length Dependence

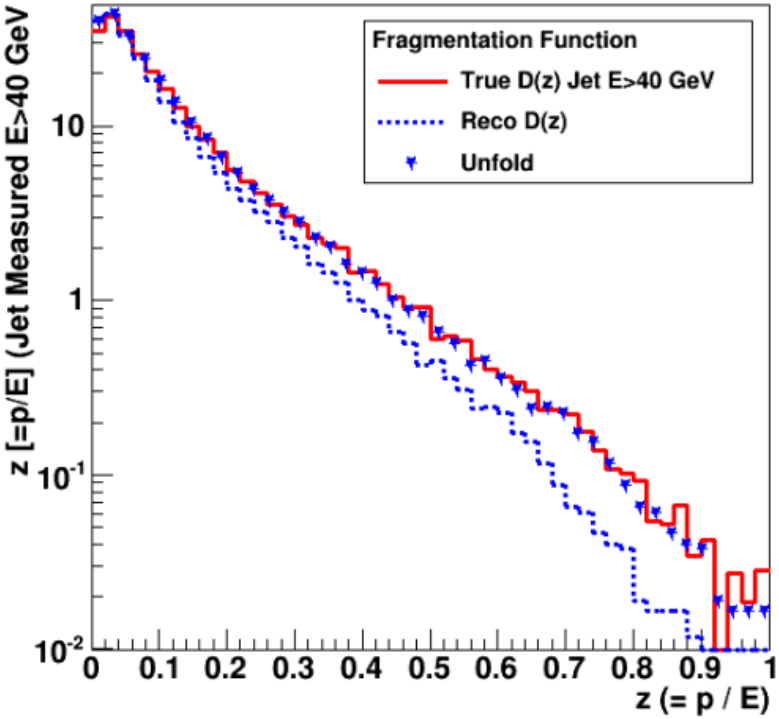


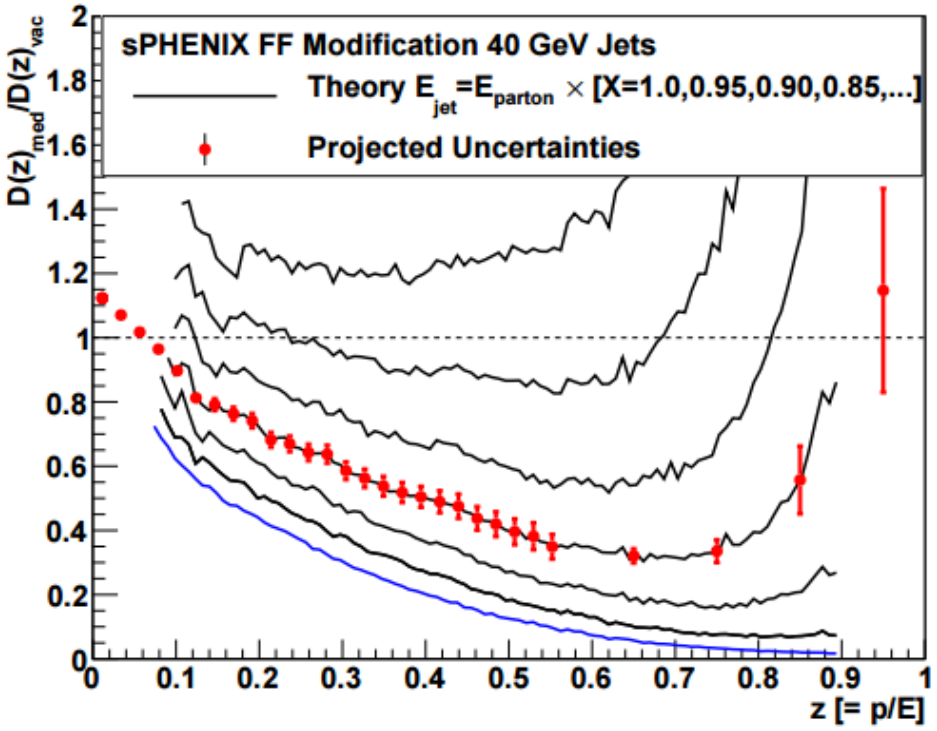
Important constraint to energy loss models



Fragmentation Functions, D(z)

Energy distribution within the jet → Dynamics of jet quenching





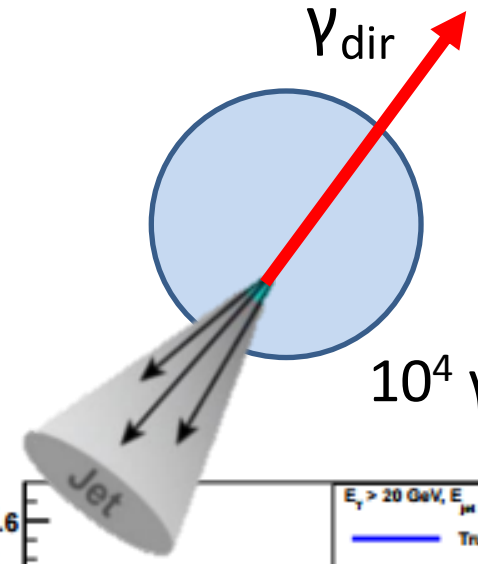
X=0.70
X=0.75
X=0.80

X=0.85

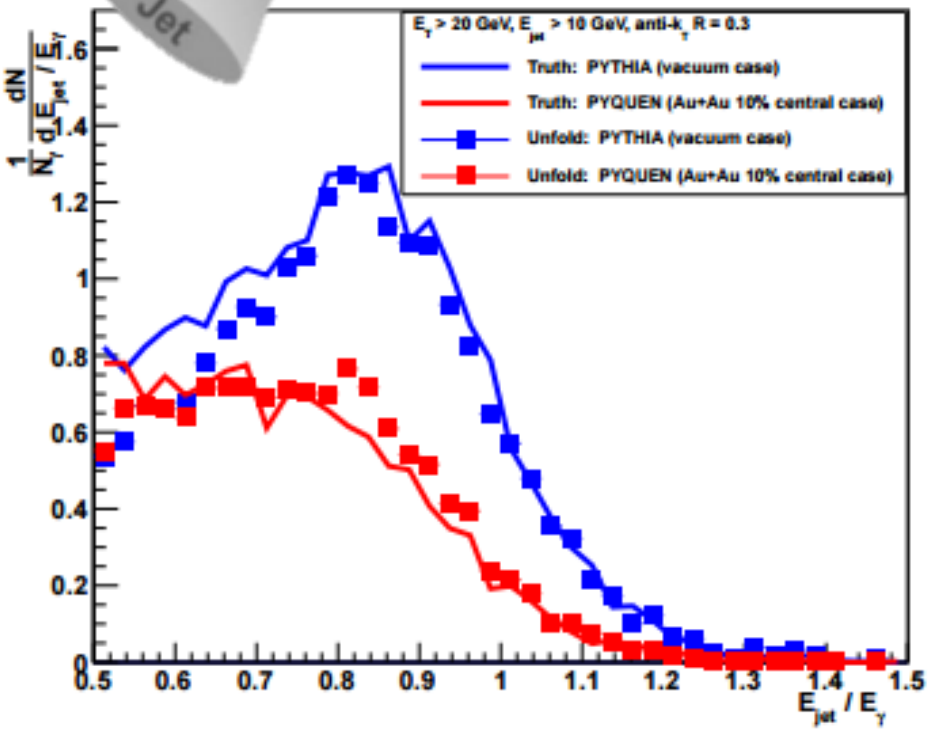
X=0.90
X=0.95
X=1.00

X ≡ fraction of parton energy retained in jet cone

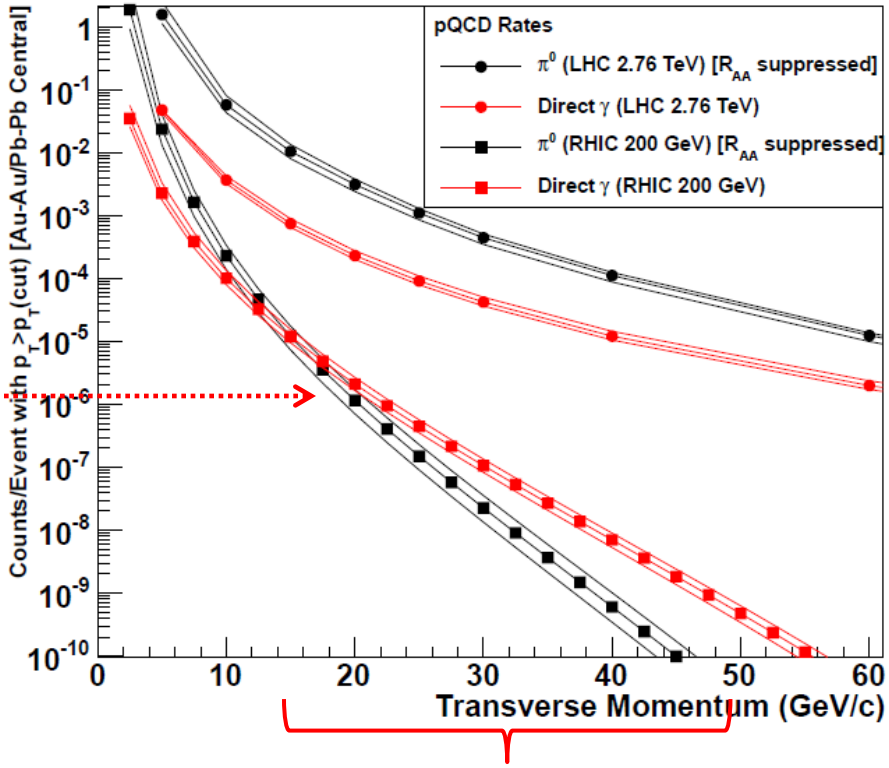
Gamma-Jet



10^4 γ_{dir} p_T > 20 GeV/c



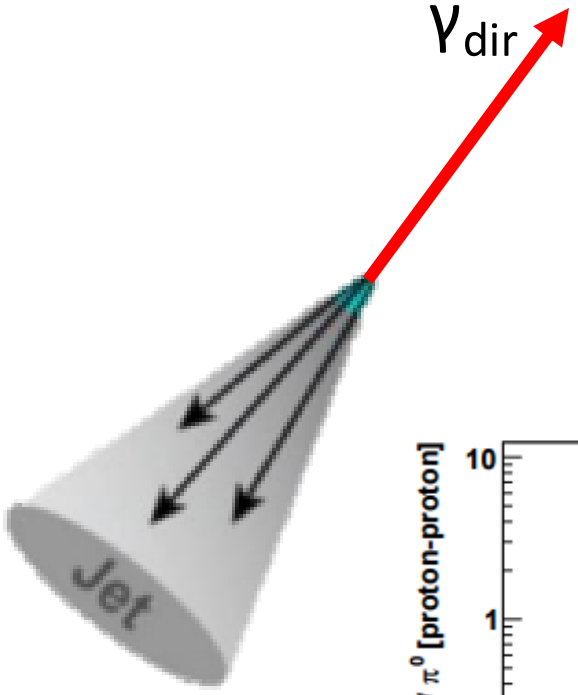
Advantageous γ_{dir}-to-π^0 ratio at RHIC

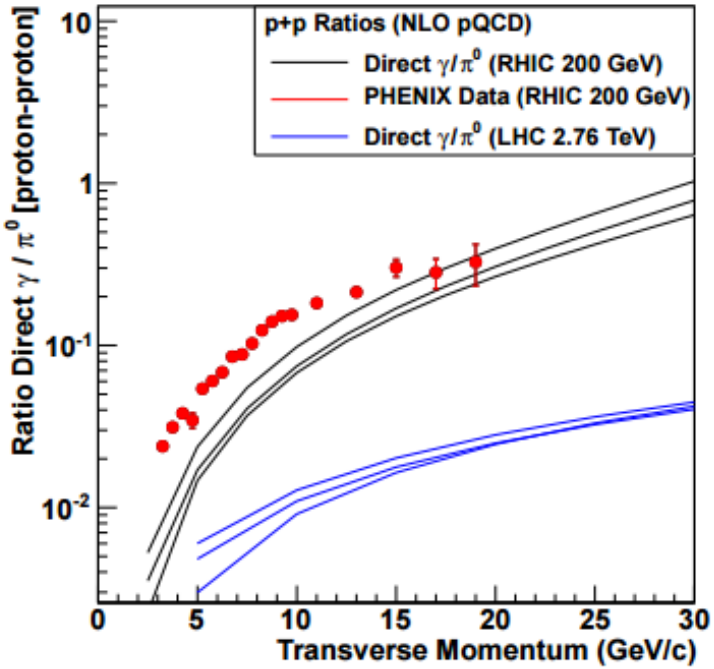


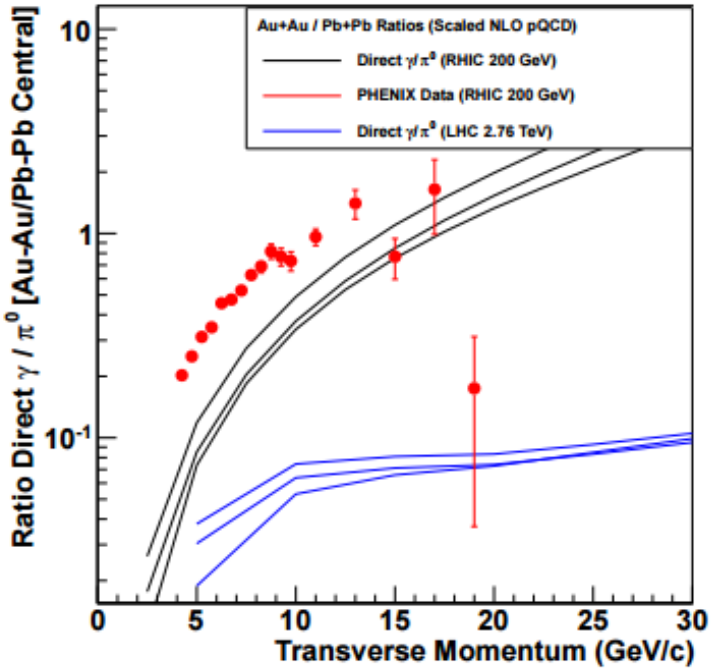
Range of direct photon ID

Photon provides unmodified reference for jet energy loss

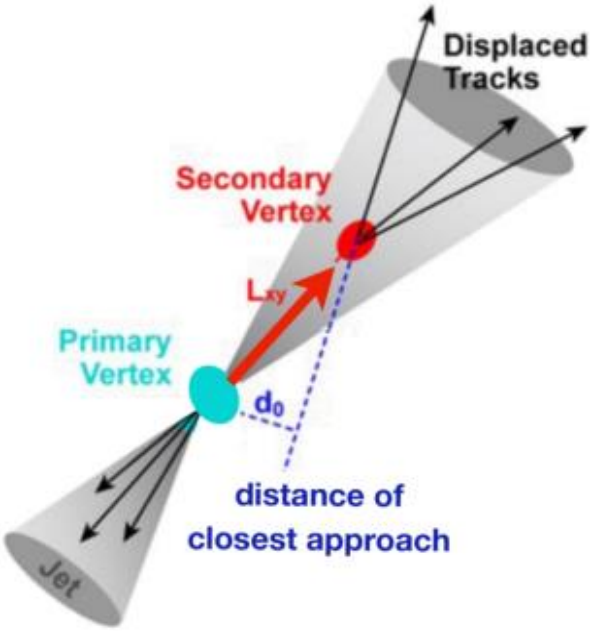
Gamma-Jet


γ_{dir}
Jet

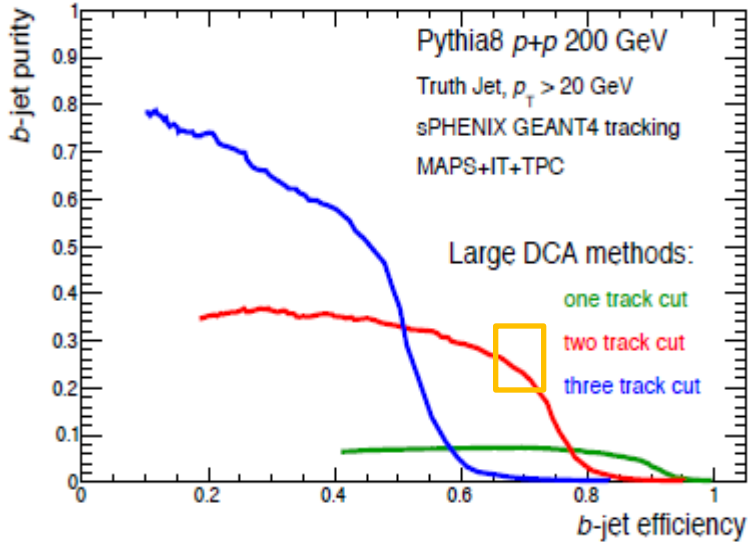

p+p Ratios (NLO pQCD)
Direct γ/π⁰ (RHIC 200 GeV)
PHENIX Data (RHIC 200 GeV)
Direct γ/π⁰ (LHC 2.76 TeV)
Ratio Direct γ / π⁰ [proton-proton]
Transverse Momentum (GeV/c)

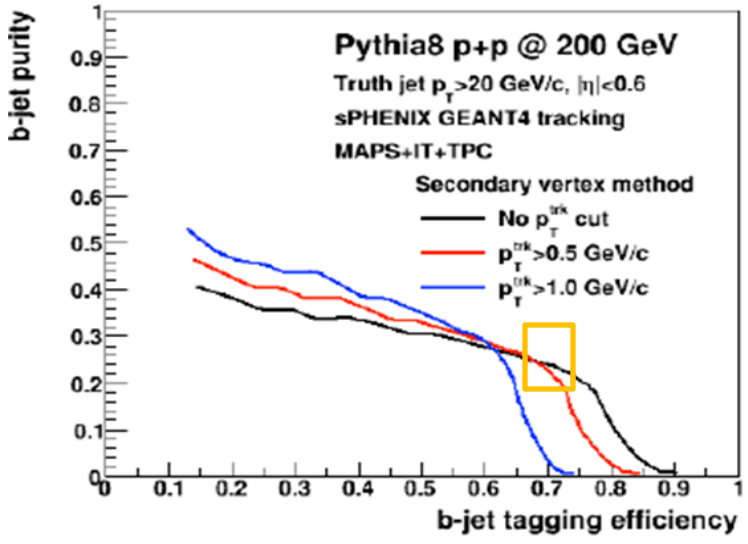

Au+Au / Pb+Pb Ratios (Scaled NLO pQCD)
Direct γ/π⁰ (RHIC 200 GeV)
PHENIX Data (RHIC 200 GeV)
Direct γ/π⁰ (LHC 2.76 TeV)
Ratio Direct γ / π⁰ [Au-Au/Pb-Pb Central]
Transverse Momentum (GeV/c)

b-Jet Tagging

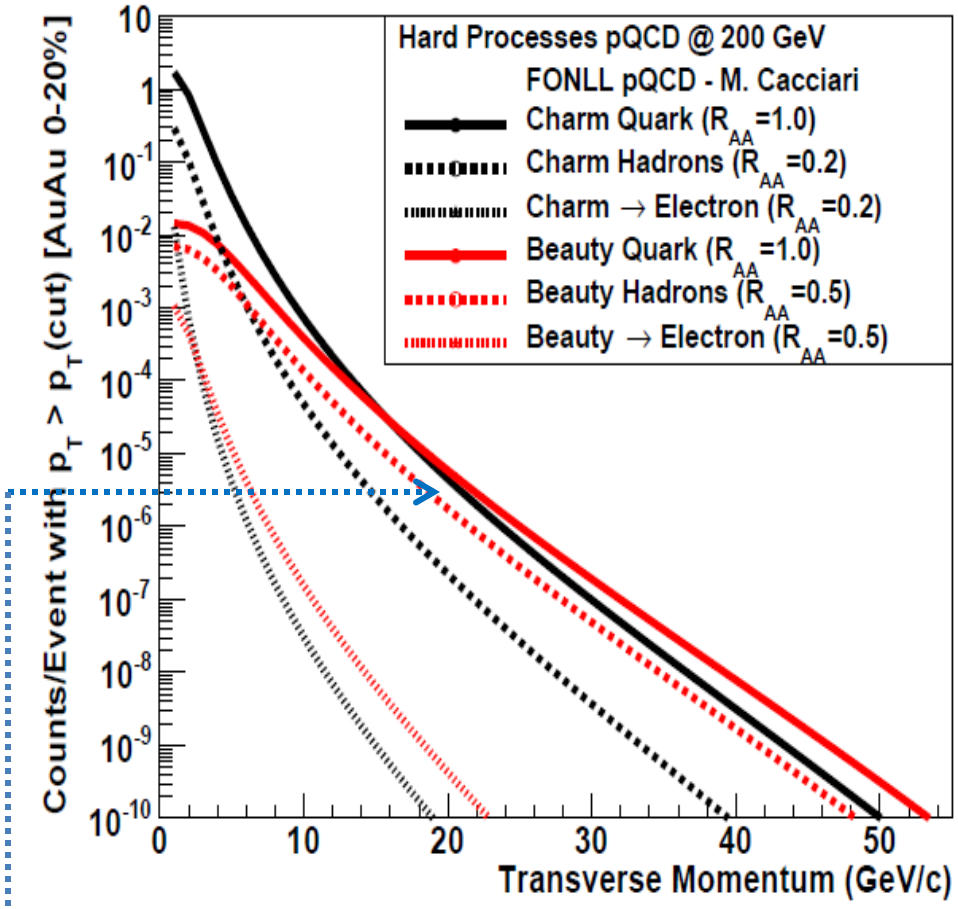


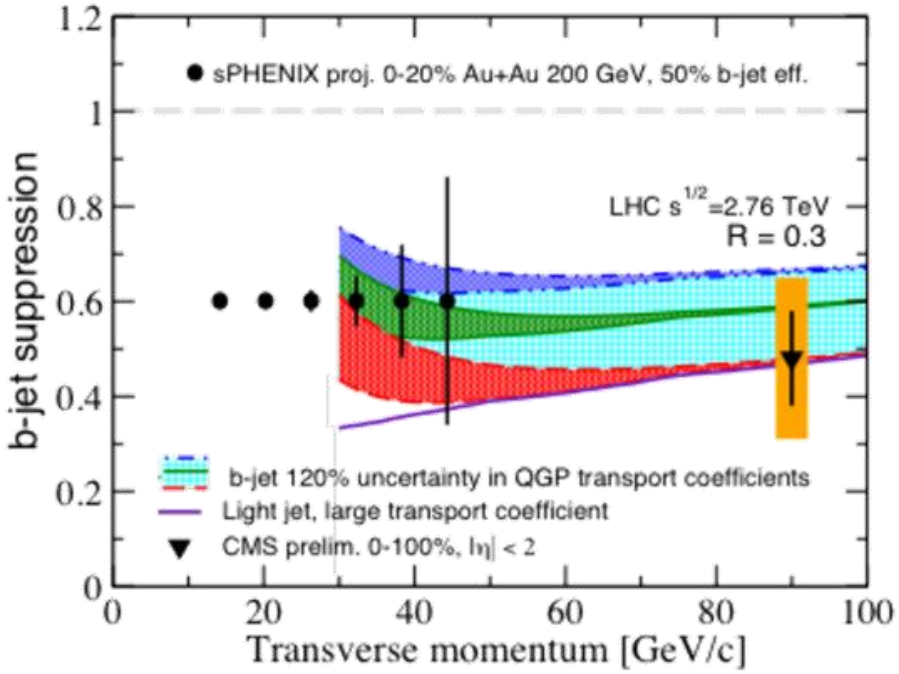
- Require 30% purity, 70% efficiency
- 3 Methods:
  - Multiple large DCA tracks
  - Secondary vertex mass
  - B-meson tagging by semi-leptonic decay or by $m_{Inv\ B}$ → in progress





b-Jets





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