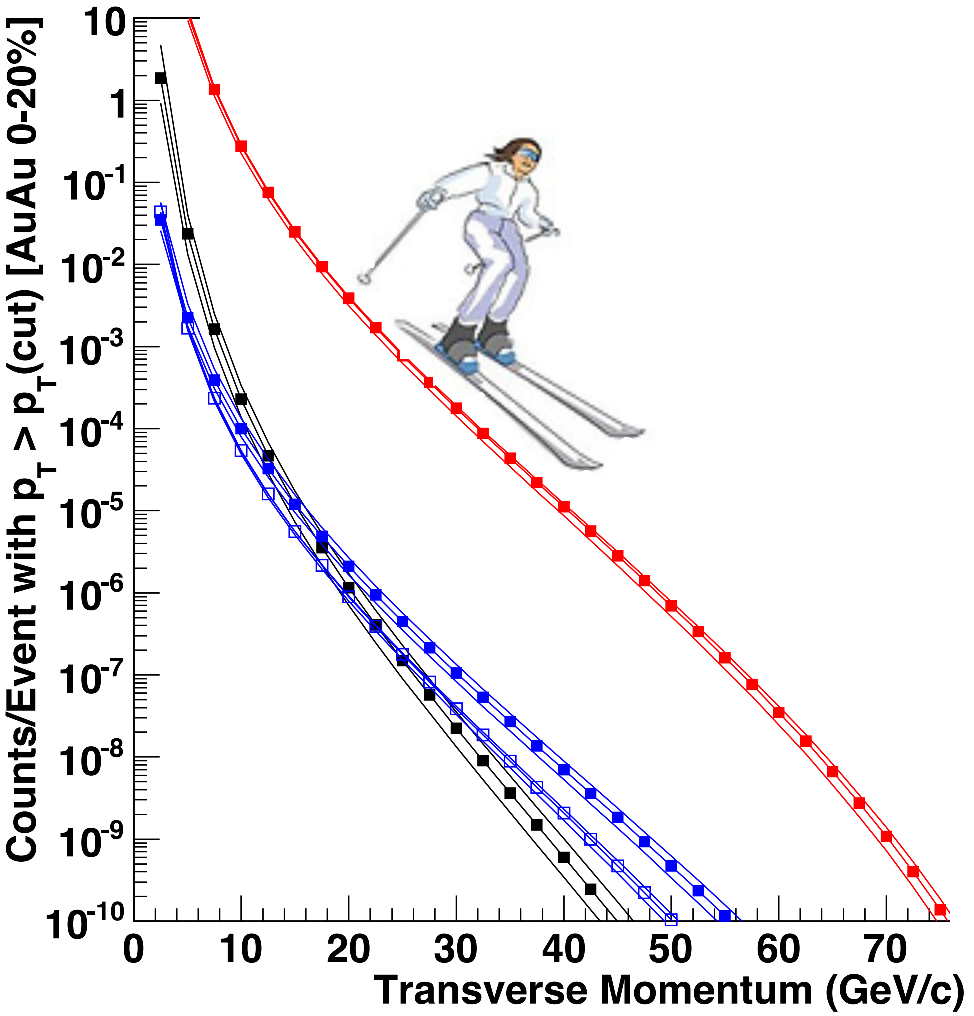
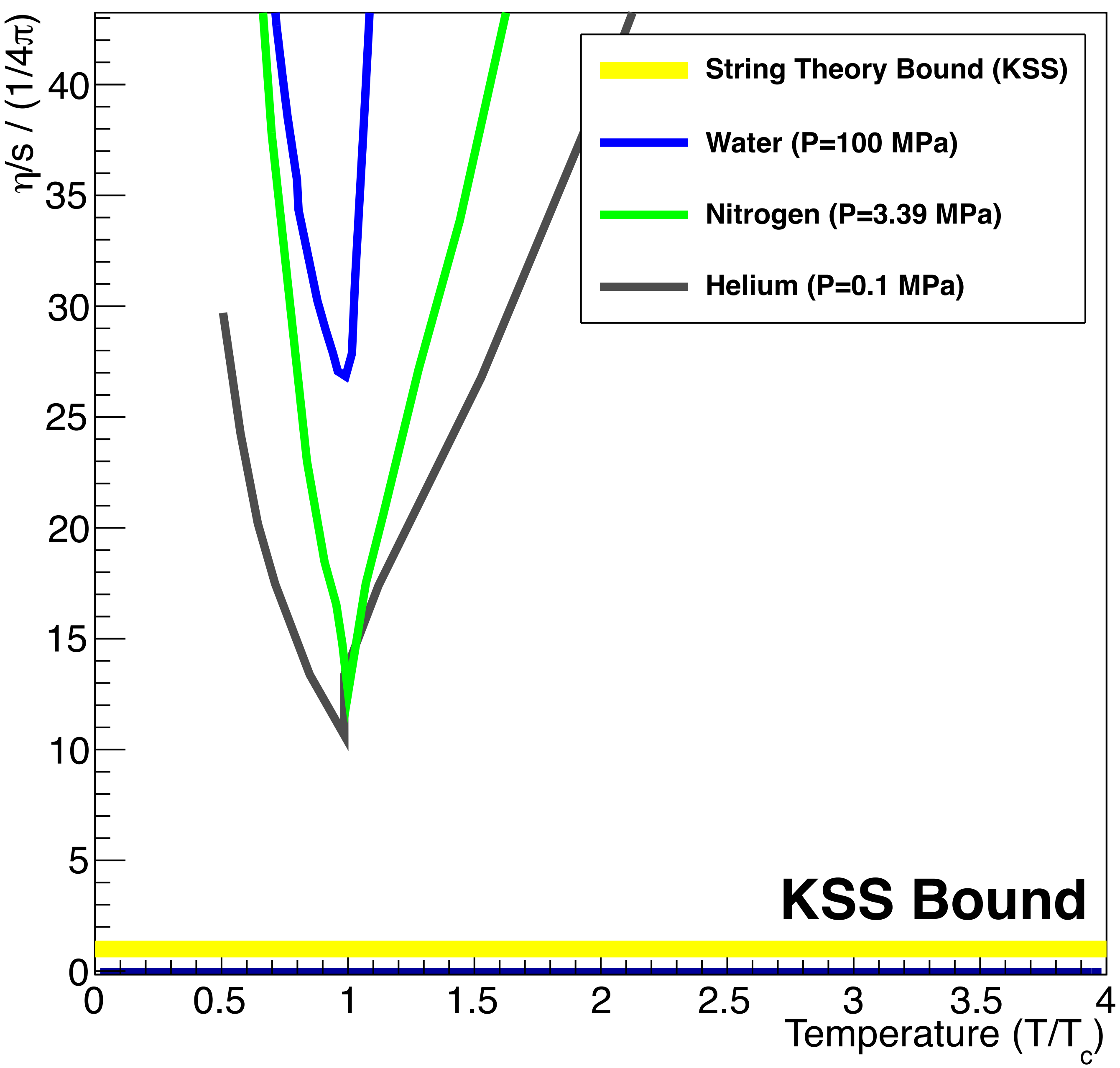
Jets and quarkonia with sPHENIX

Dave Morrison (Brookhaven National Laboratory)
for the PHENIX Collaboration
Winter Workshop on Nuclear Dynamics 2013



sPHENIX in a couple of slides



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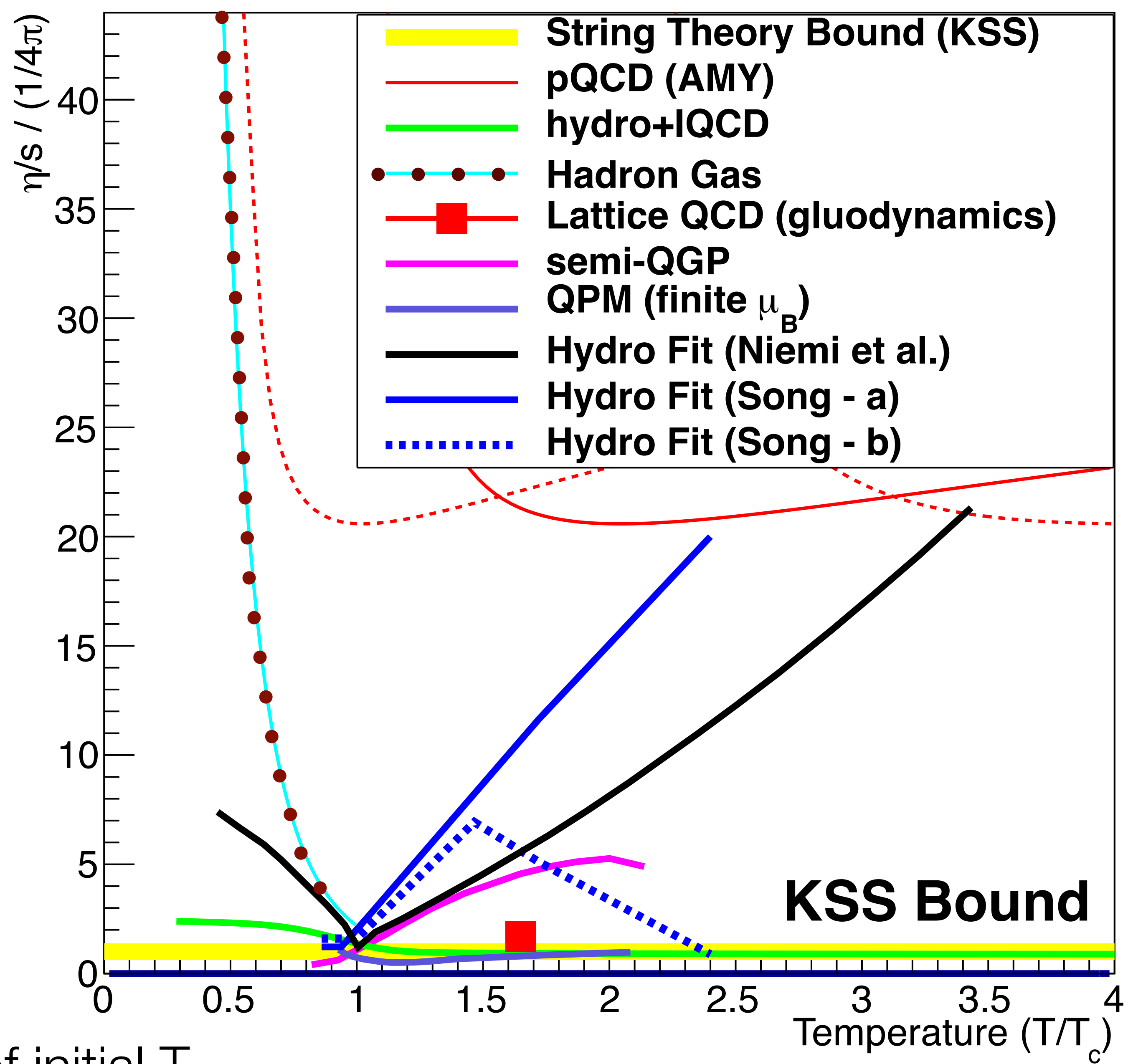
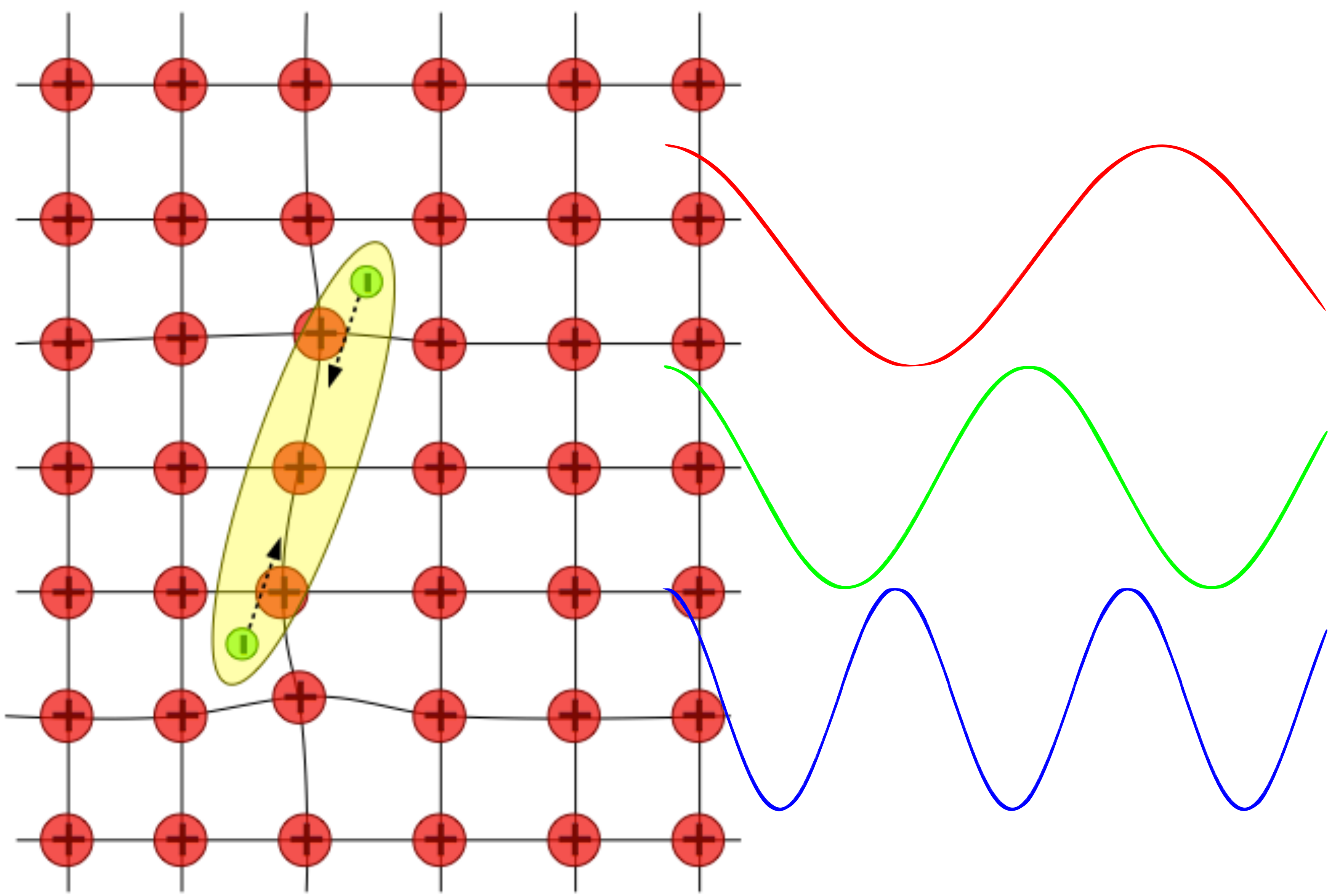


range of initial T
accessible at RHIC

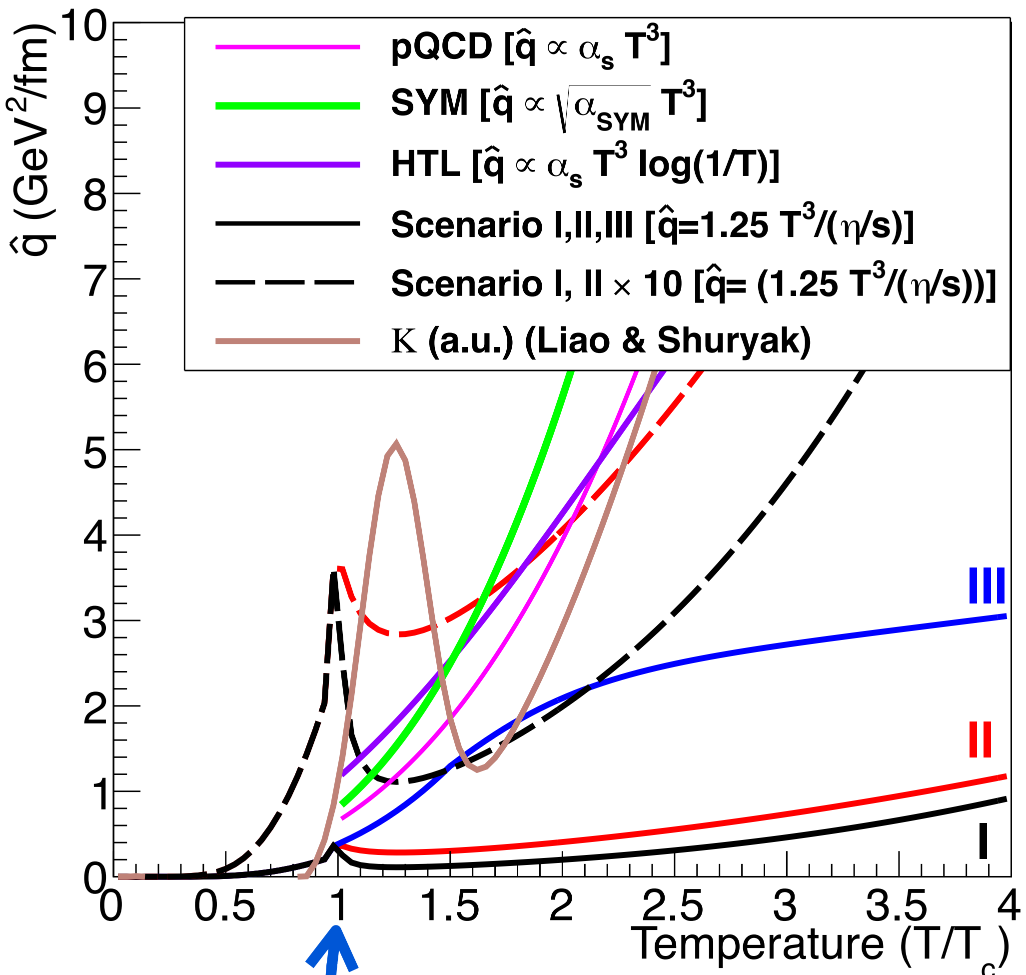
sPHENIX in a couple of slides

superconductor   scale of probe

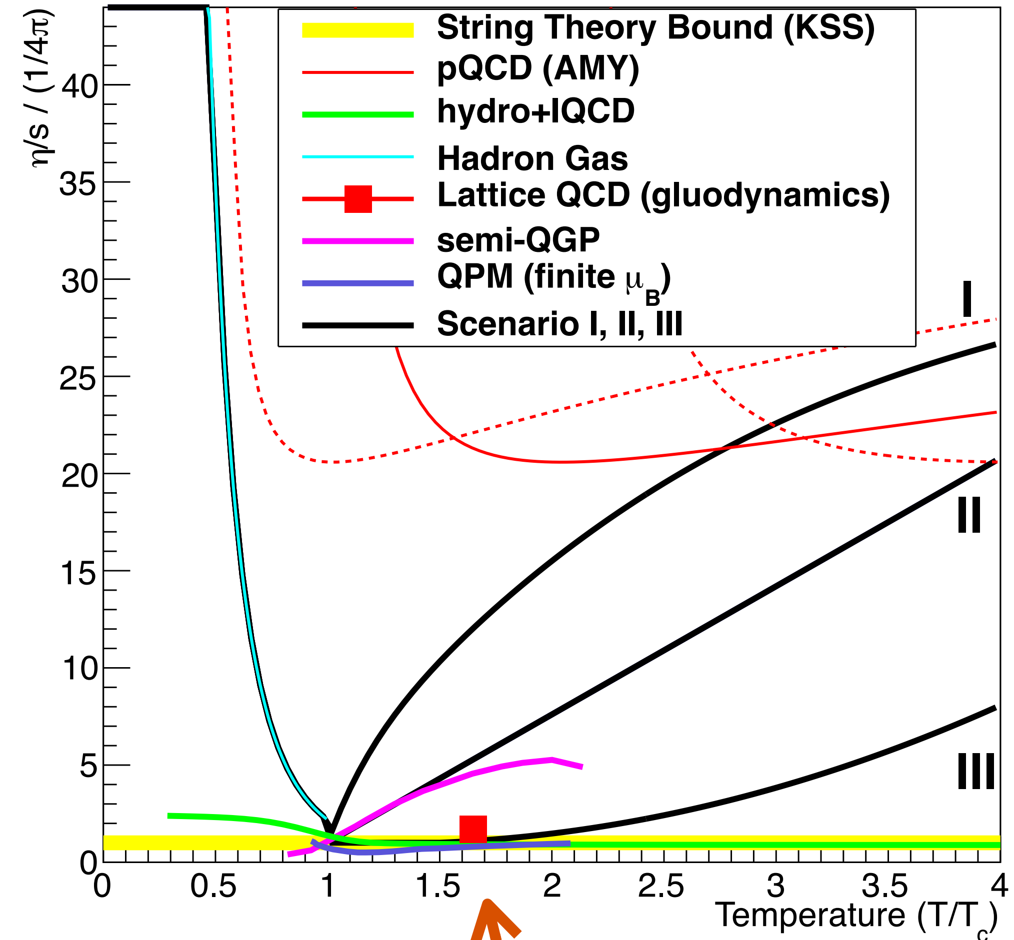


Cooper pairs
quasiparticles

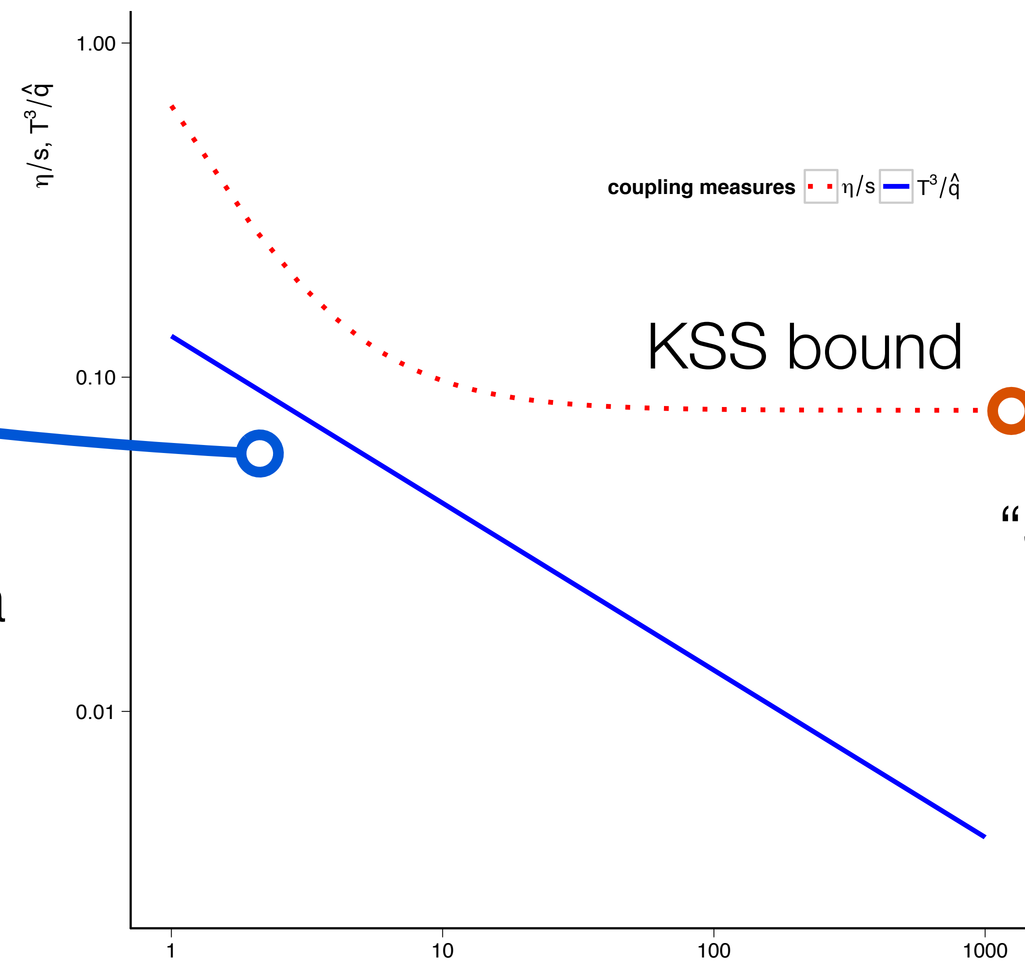
electrons
elementary
constituents



$$\hat{q} \stackrel{?}{=} \frac{1.25T^3}{\eta/s}$$



q̂ retains sensitivity even when coupling is strong



η/s saturates when coupling is strong

't Hooft coupling

"[We find] the jet quenching is a few times stronger near T_C relative to the QGP at $T > T_C$."
Liao, Shuryak, PRL (2009)

"Small shear viscosity implies strong jet quenching"
Majumder, Mueller, Wang, PRL (2007)

What *is* the nature of the strongly coupled QGP?

- What are the inner workings of the sQGP?
- Are the key degrees of freedom quasi-particles? excitations? other?
- How do these degrees of freedom depend on the scale of the probe?
- How does the sQGP itself evolve along with the parton shower?
- What are the dynamical and other underlying changes to the medium as one crosses this temperature expanse?

Theoretical guidance on observables/sensitivity

The theoretical bridgework needed to connect measurement to the interesting and unknown medium properties of deconfined color charges is under active construction by many theorists

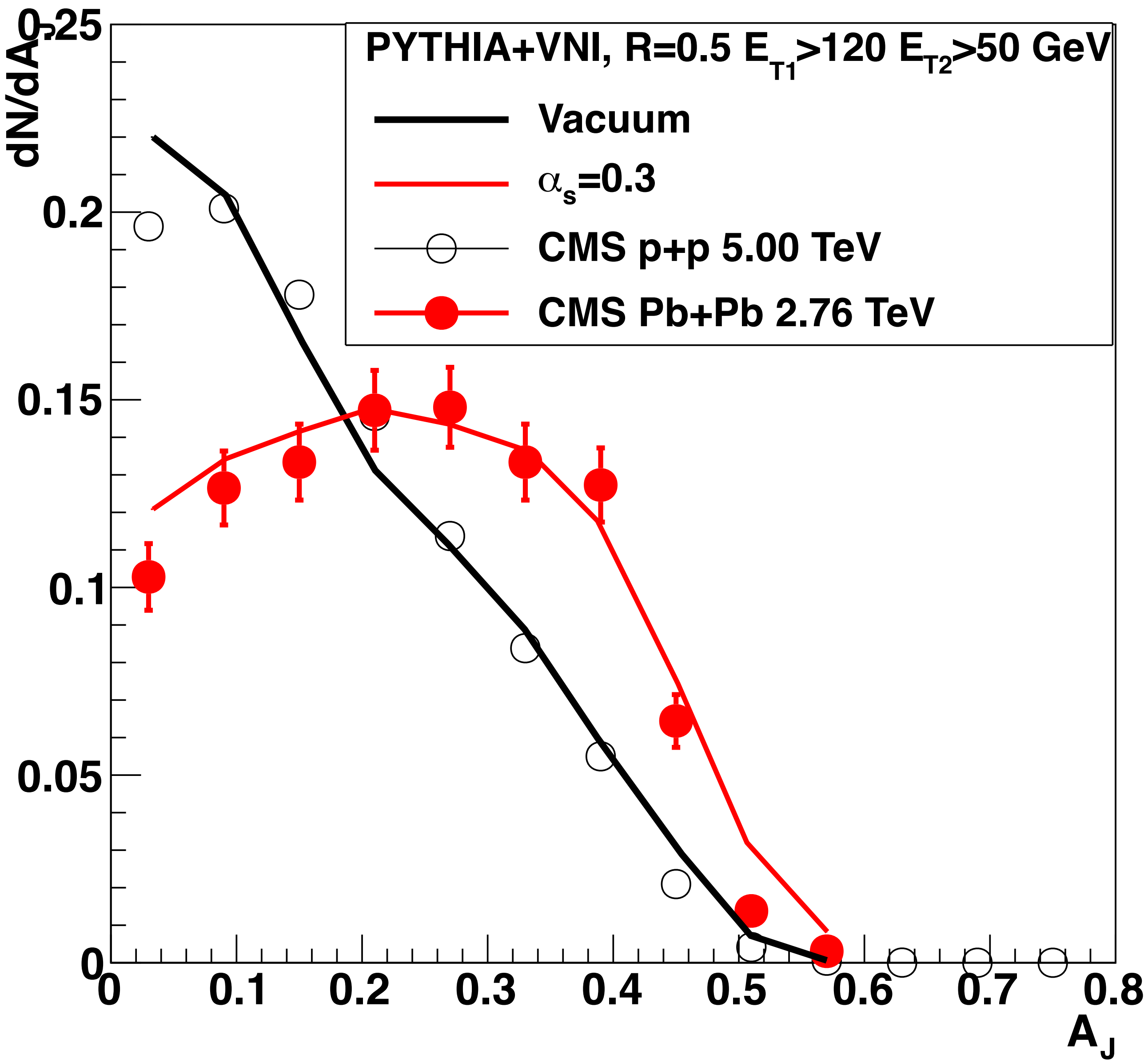
JET Collaboration

Just one example: March 3-4, 2012 Jet Collaboration meeting at Duke University
Lots of interest from theory community

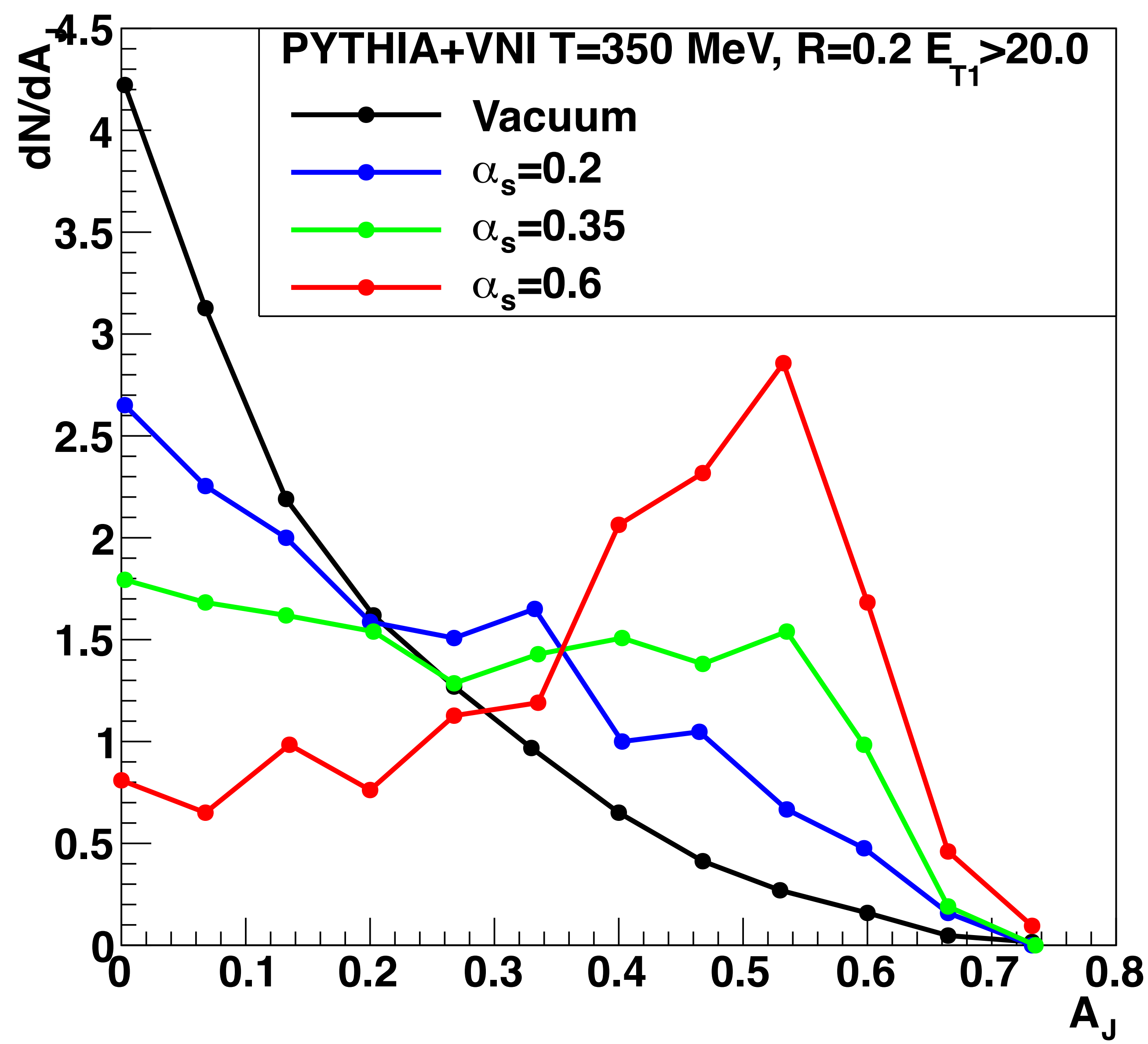
Follow up EVO meetings.

Sensitivity to coupling strength

Comparison to LHC data



Sensitivity to α_s at RHIC energies

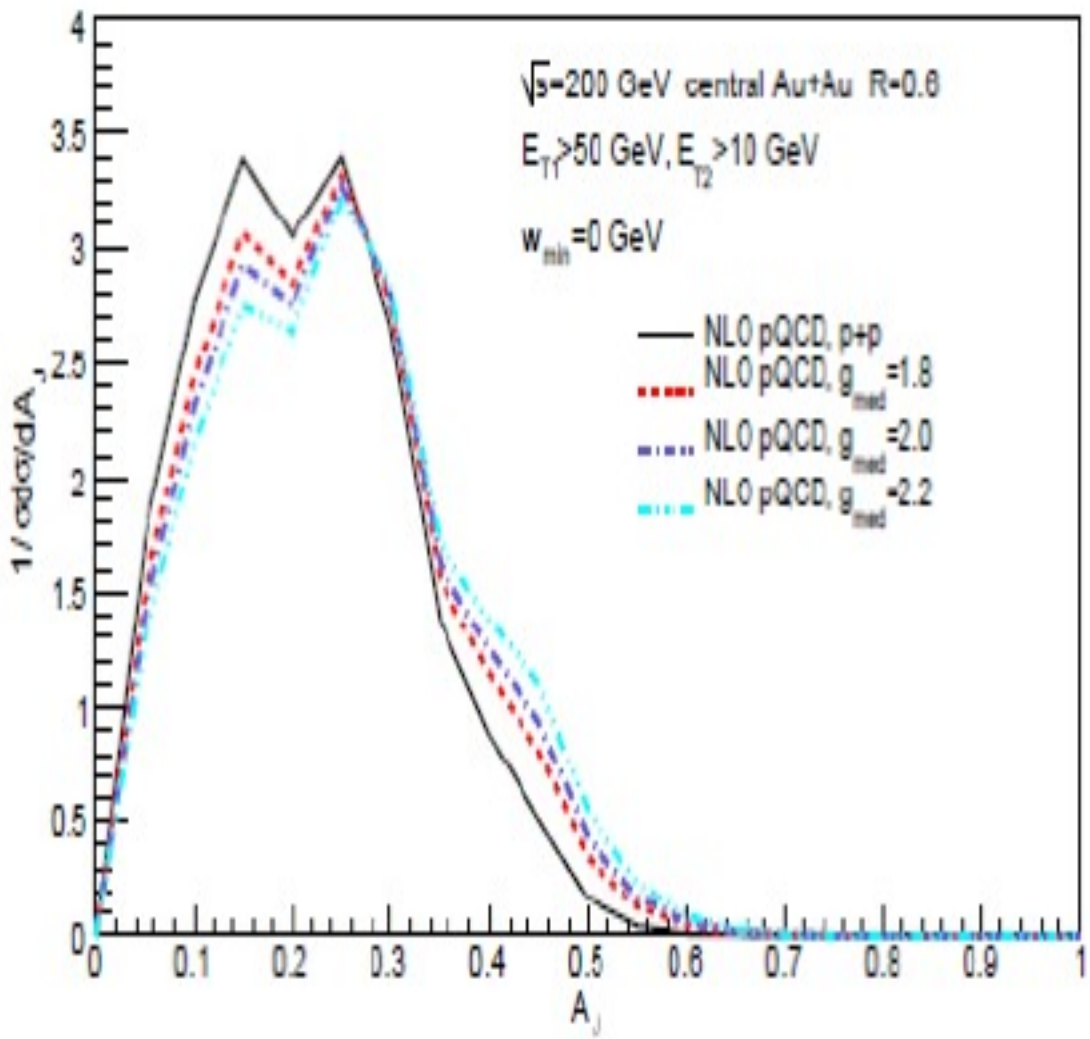


symmetric ⟷ asymmetric

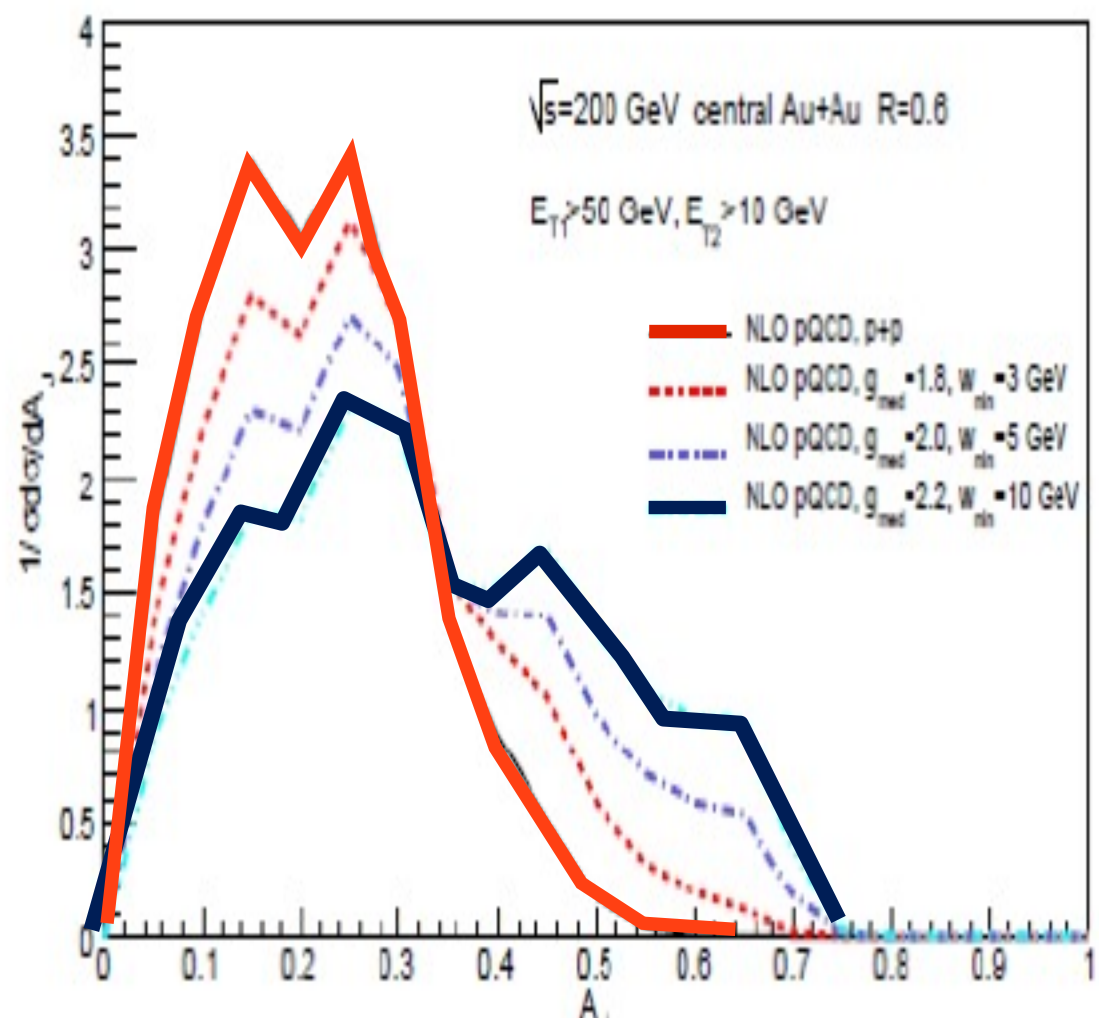
Chris Coleman-Smith (Duke)

Radiative and collisional energy loss

What are the effective constituents of the QGP?



Radiative energy loss only

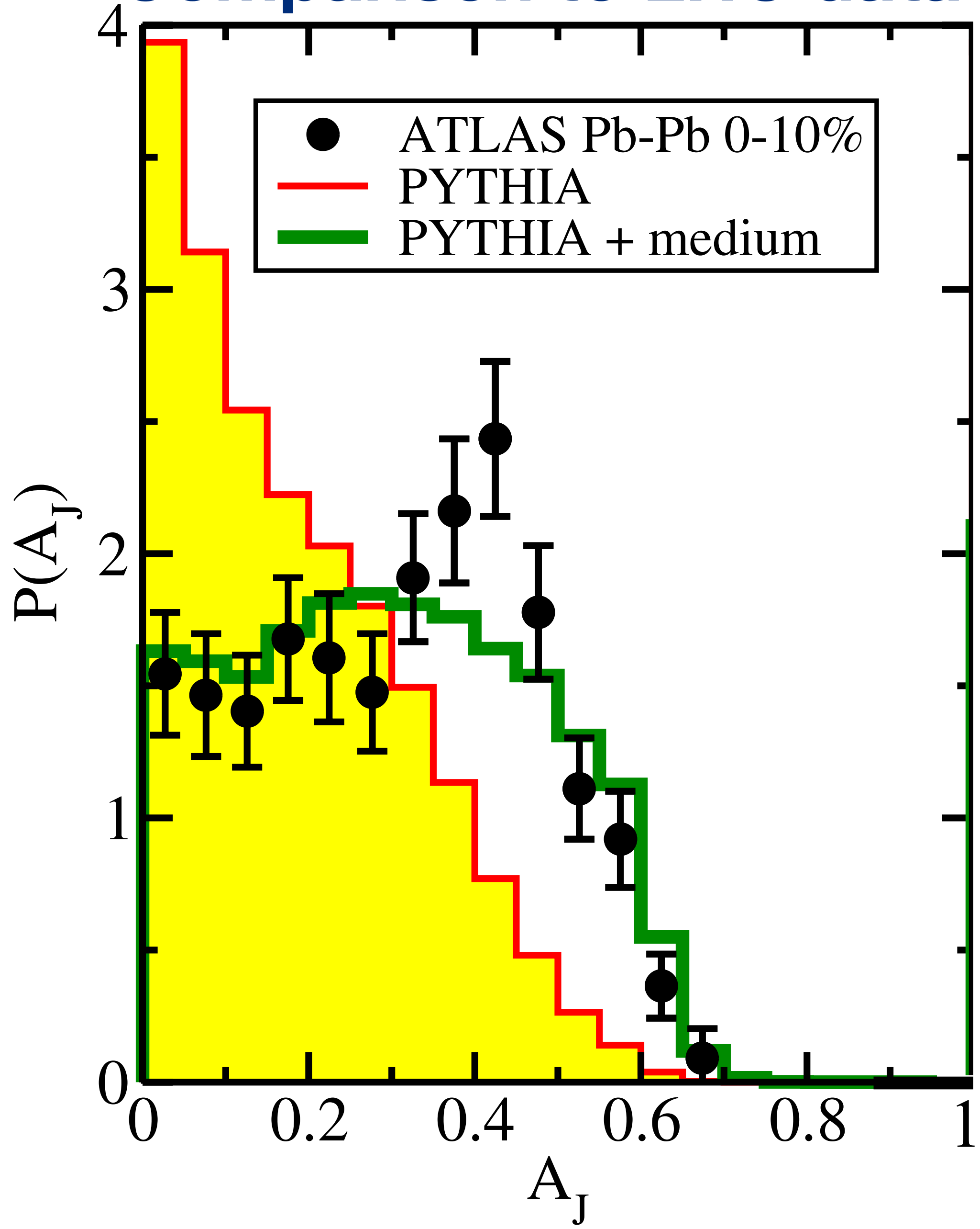


Radiative + Collisional energy loss
±10% changes in coupling strength

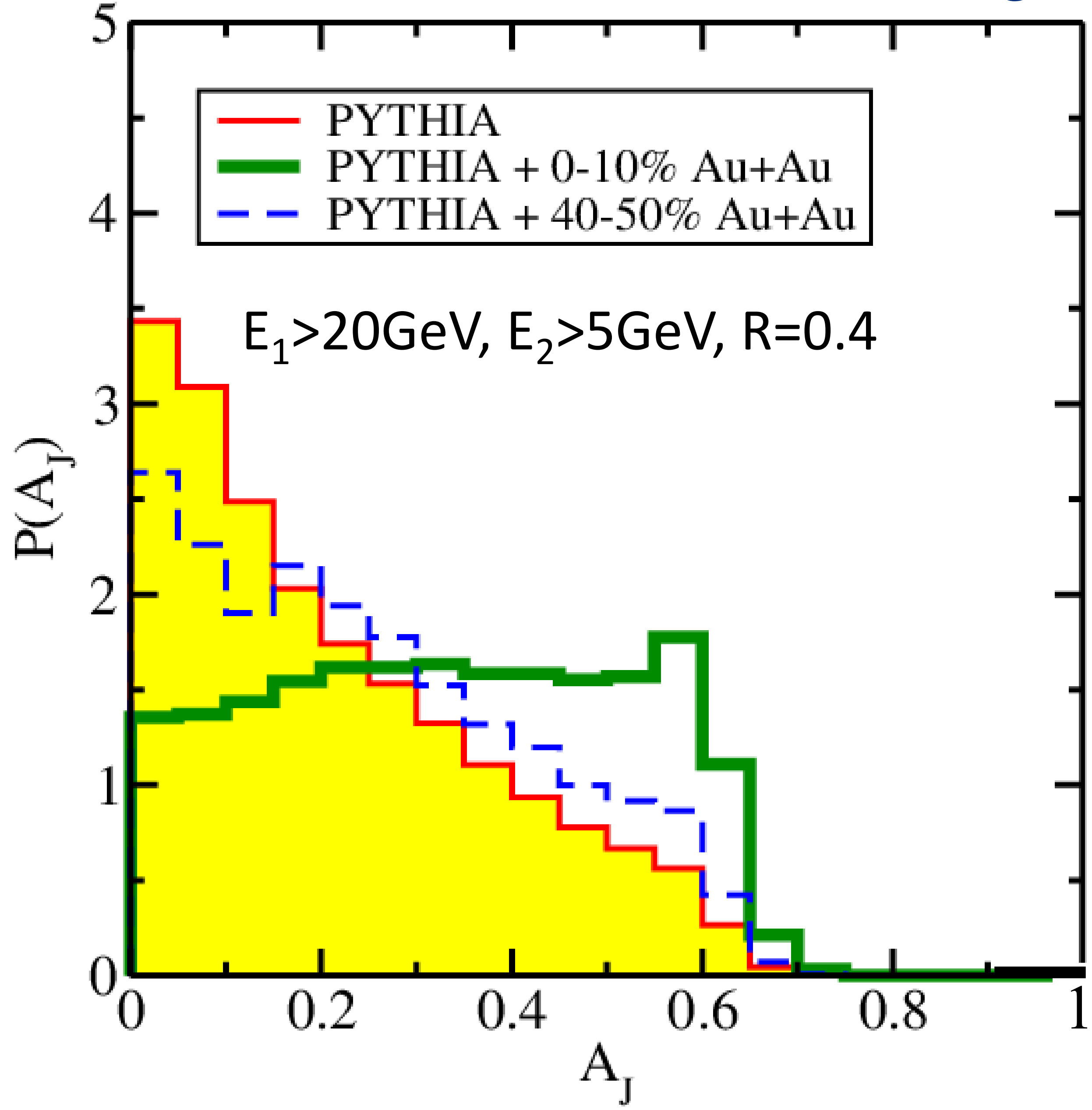
Ivan Vitev

Interaction of jet with medium

Comparison to LHC data

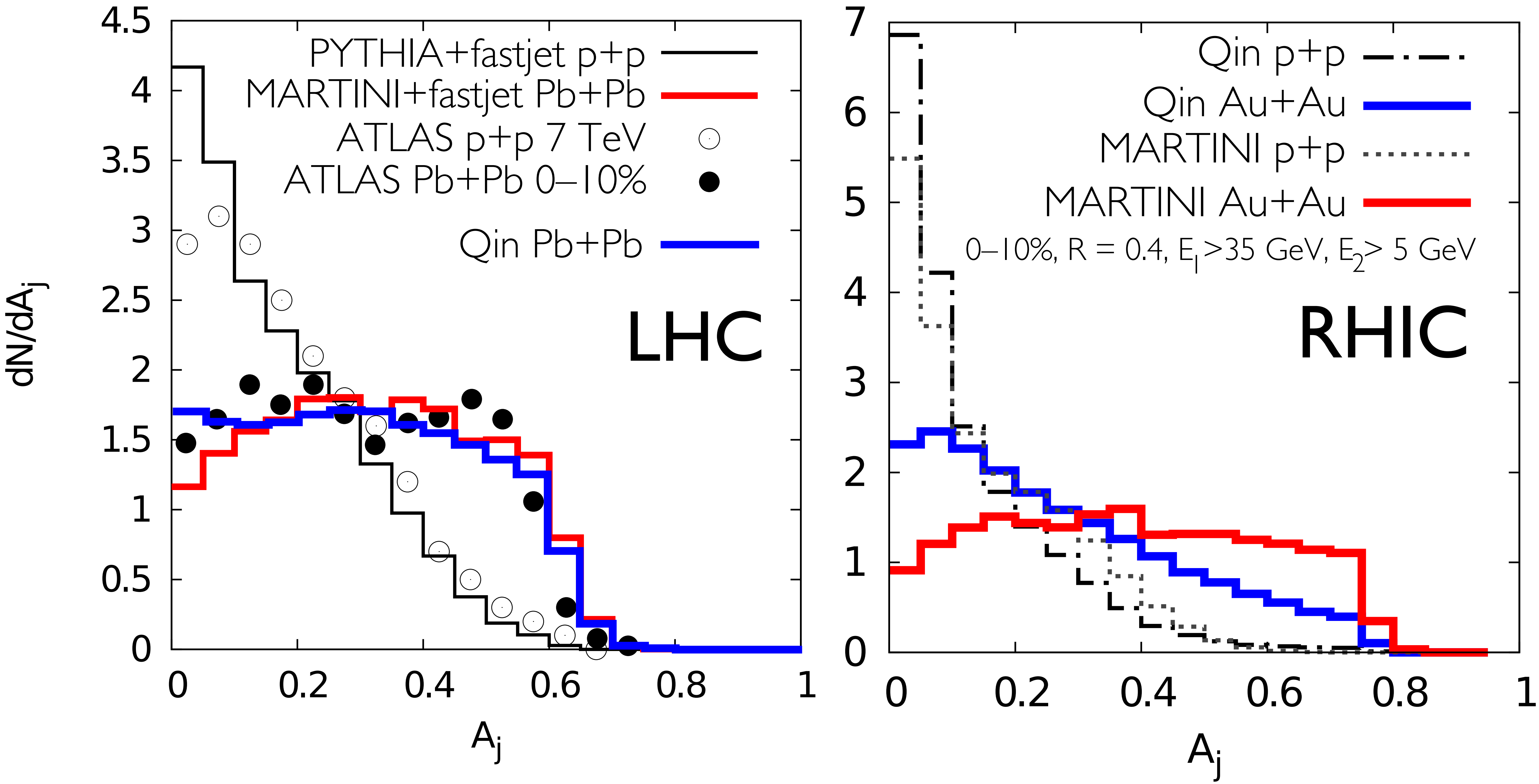


Distribution of A_J at RHIC energies



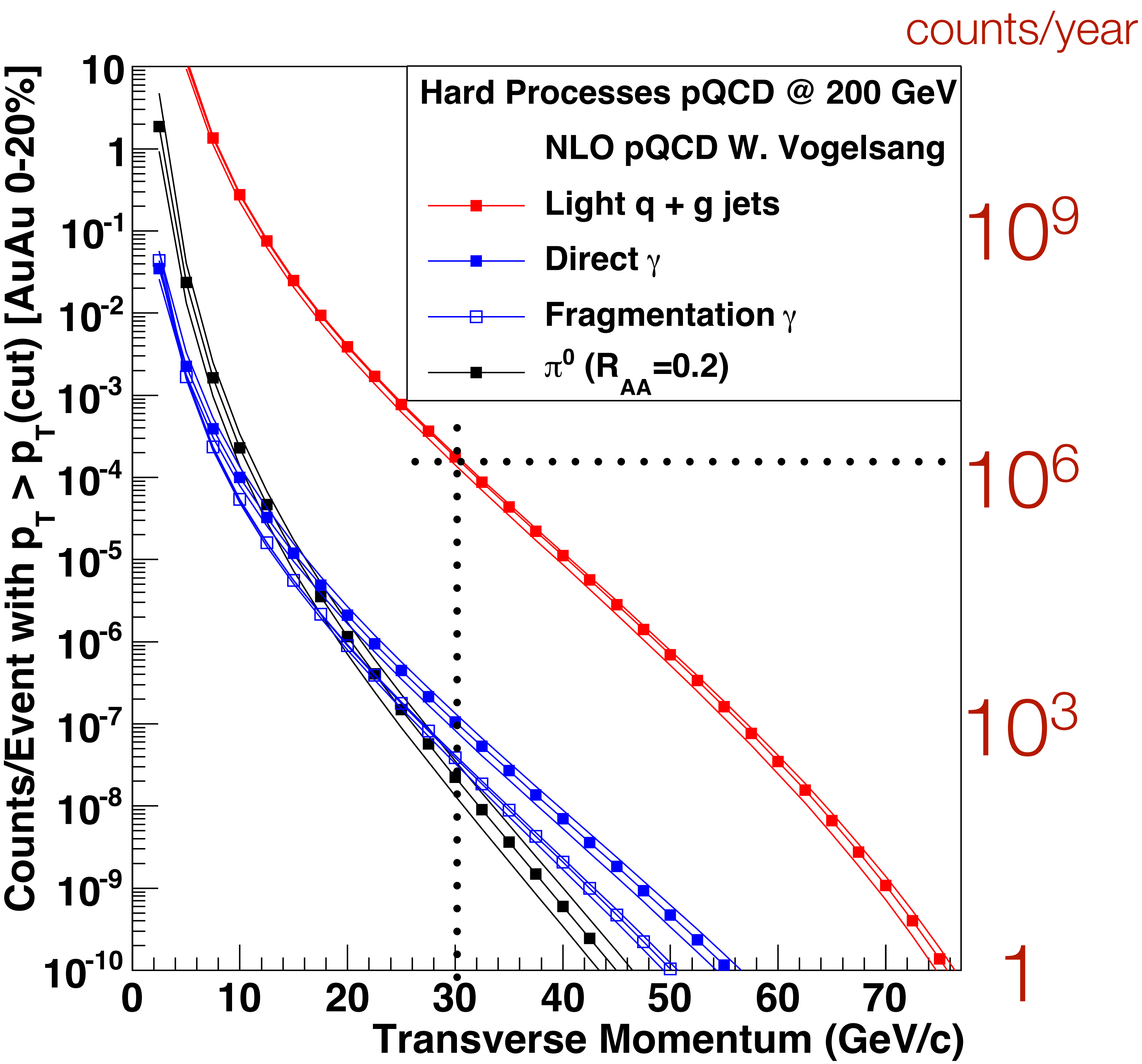
Guang-You Qin, Berndt Müller
PRL 106, 162302 (2011)

Same at LHC, different at RHIC



C. Young, B. Schenke; G-Y Qin, Berndt Mueller

Jet rates in Au+Au at 200 GeV



There are *lots* of jets!

Only stochastic cooling of Au beams assumed

Greater rate and p_T reach than singles

1 RHIC year = 50 billion min. bias Au+Au events = 10 billion central

Expected counts in a 20 week run at 200 GeV

	Au+Au central 20%	p+p	d+Au
>20 GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30 GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40 GeV	10^5 jets	10^4 jets	10^5 jets
>50 GeV	10^4 jets	10^3 jets	10^4 jets

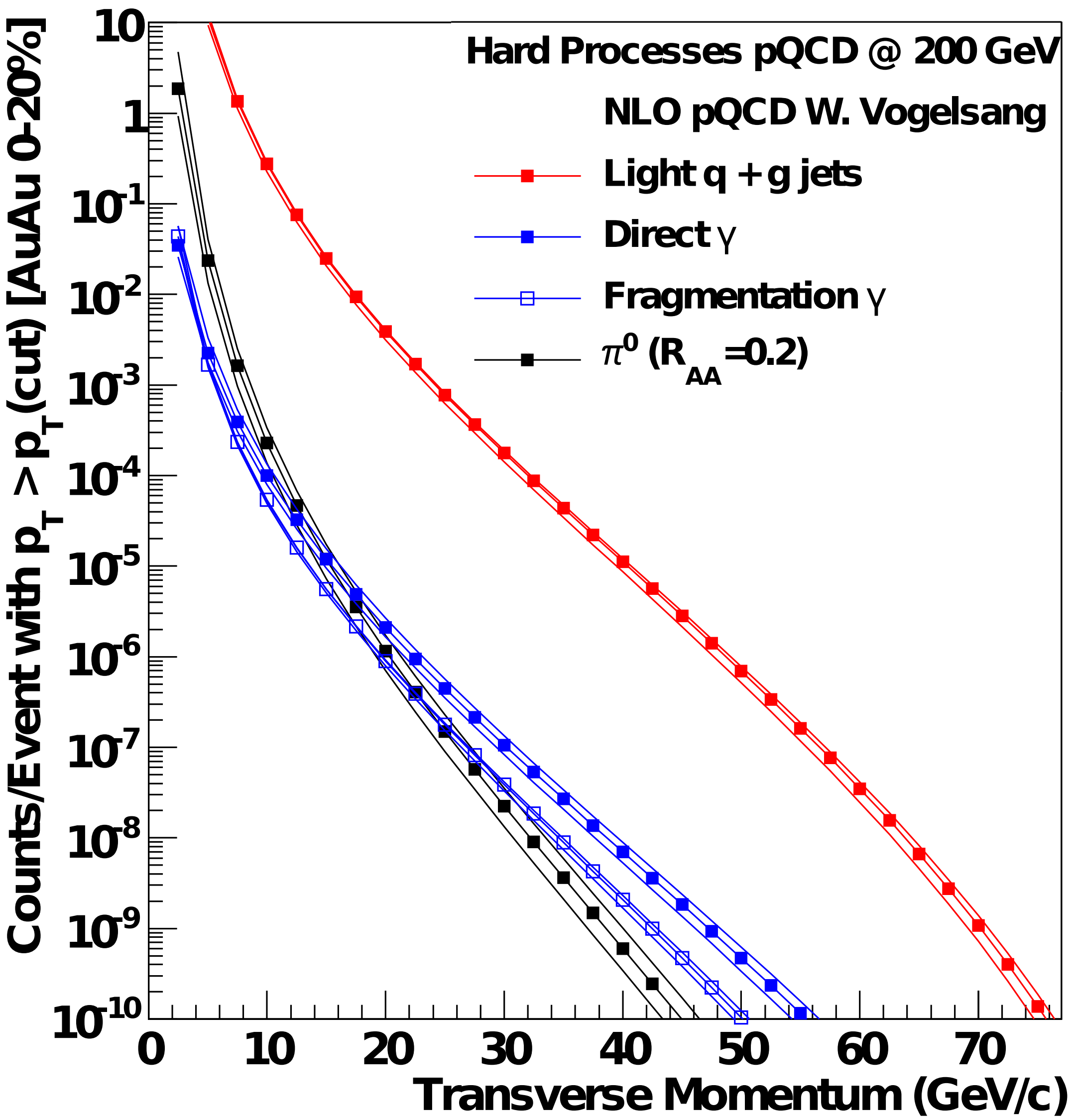
Huge rates allow differential measurements with geometry (v_2, v_3, A+B)

Precise control measurements (d+Au & p+p)

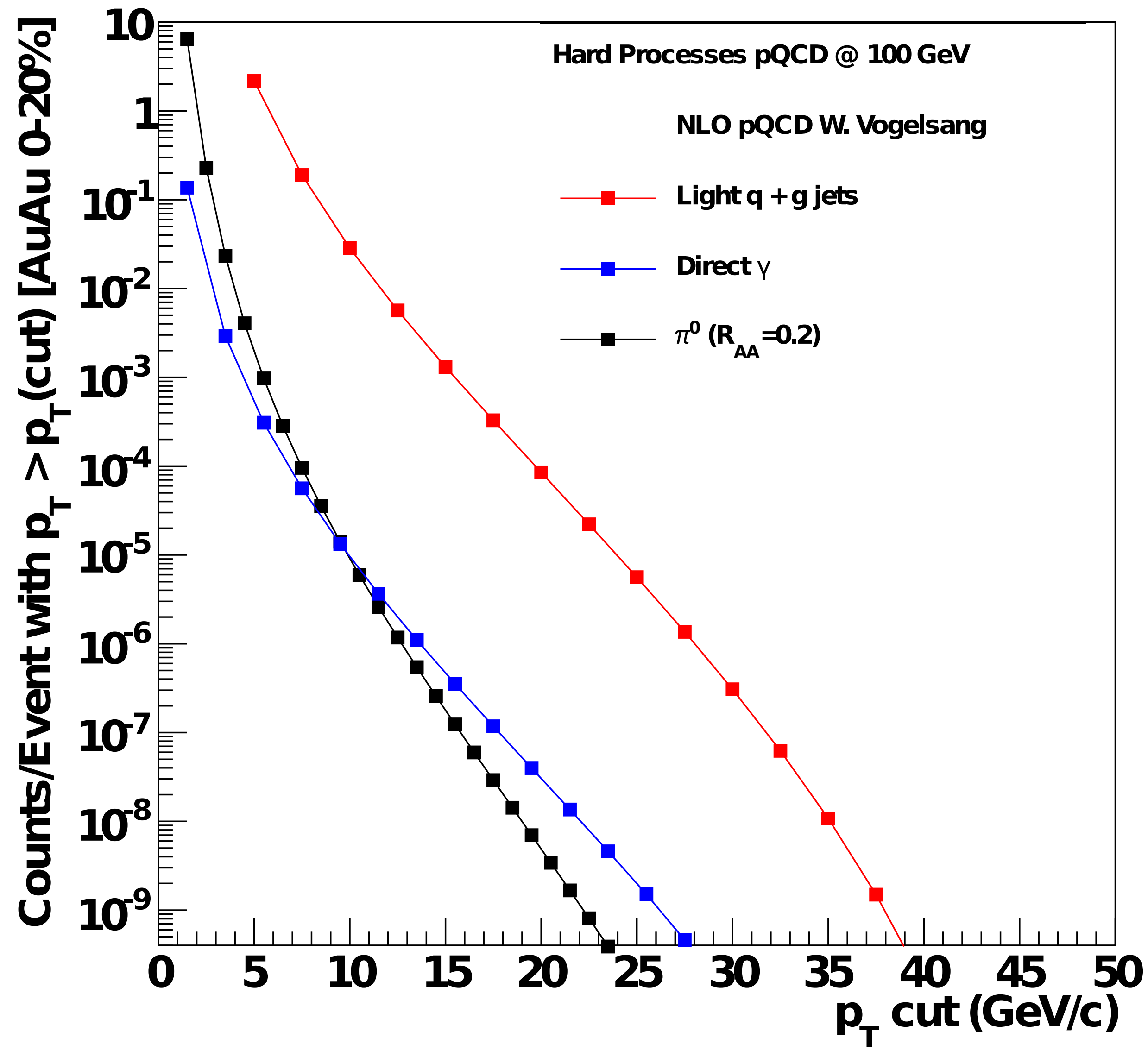
Over 80% as dijets into $|\eta| < 1$

A different kind of beam energy scan!

200 GeV



100 GeV



L(100 GeV) ~ L(200 GeV)/6

PHYSICAL REVIEW C **86**, 024908 (2012)

Method for separating jets and the underlying event in heavy ion collisions at the BNL Relativistic Heavy Ion Collider

J. A. Hanks,[1] A. M. Sickles,[2] B. A. Cole,[3] A. Franz,[2] M. P. McCumber,[4] D. P. Morrison,[2] J. L. Nagle,[4] C. H. Pinkenburg,[2] B. Sahlmueller,[1] P. Steinberg,[2] M. von Steinkirch,[1] and M. Stone[4]
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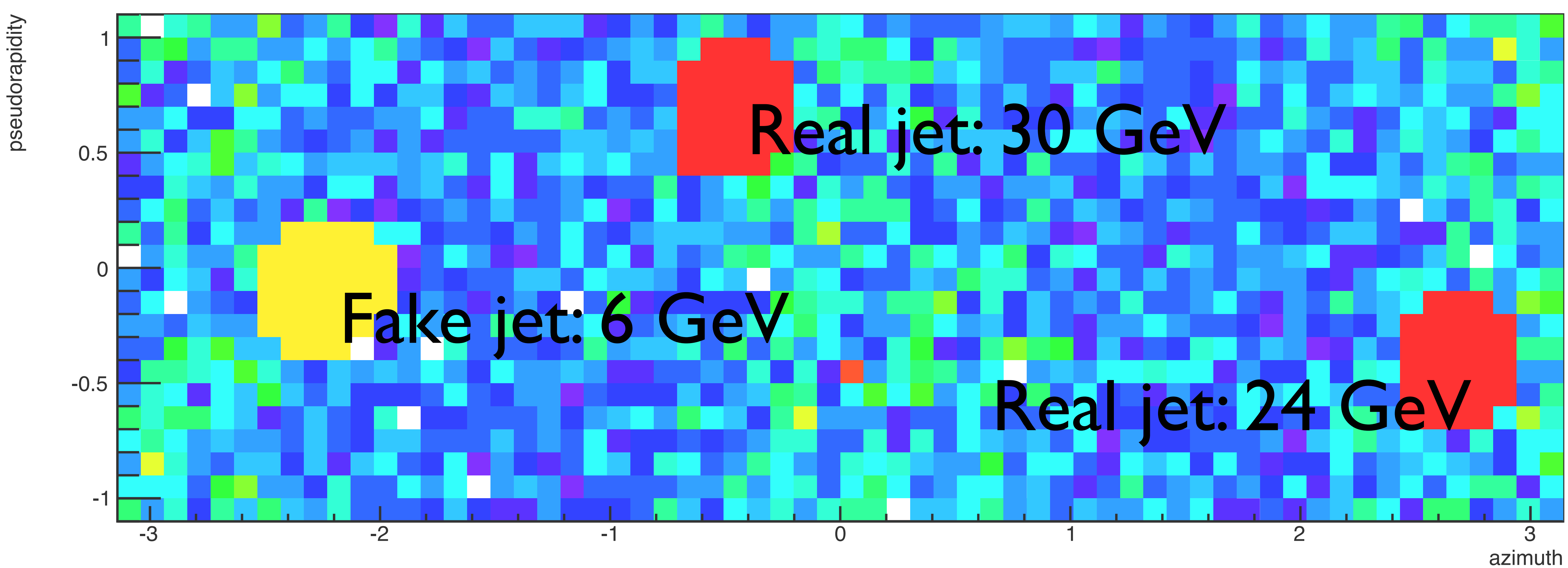
(Received 6 April 2012; published 10 August 2012)

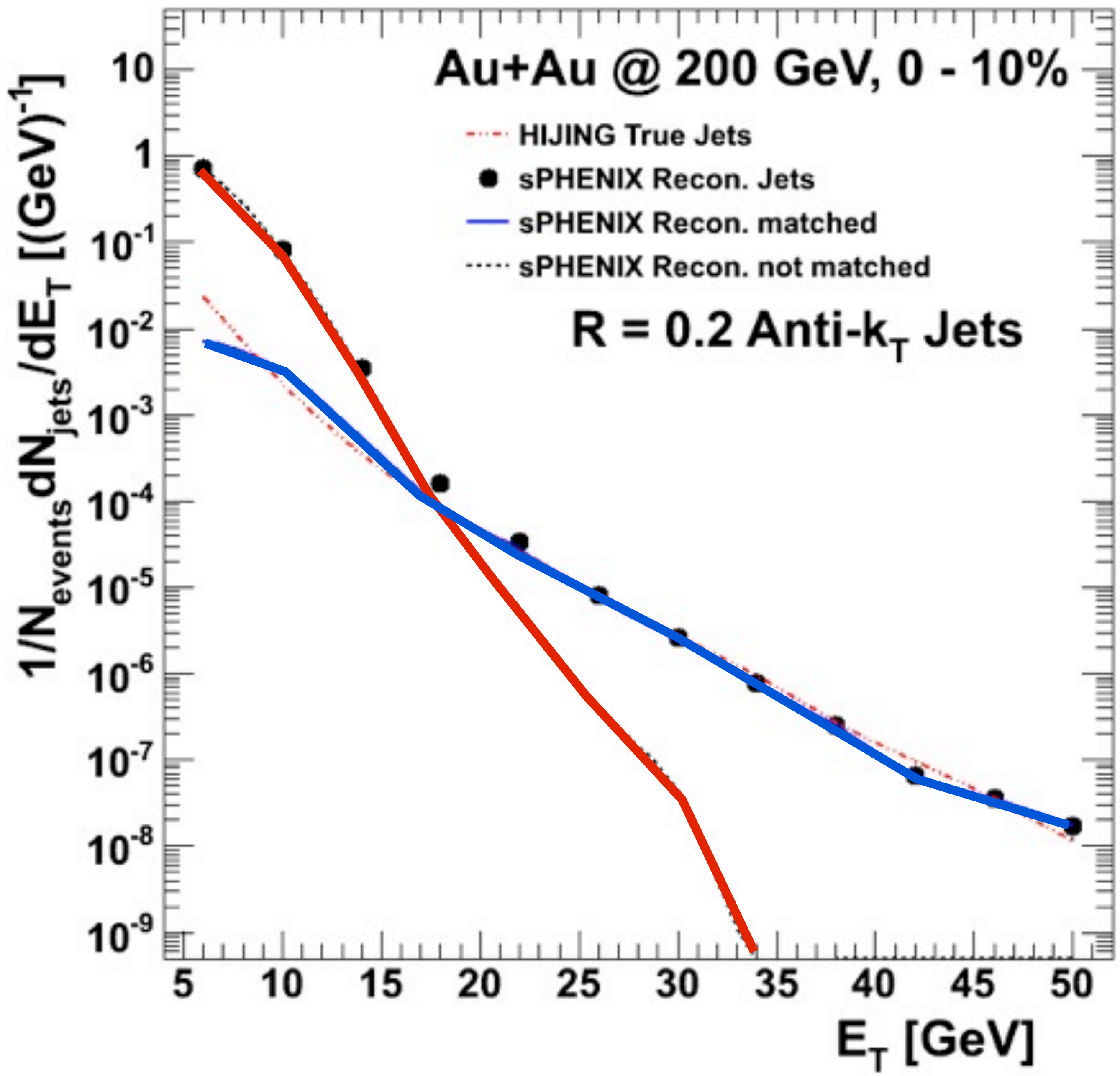
employs ATLAS-style jet finding (as described by Aaron Angerami yesterday)



reconstructed jets

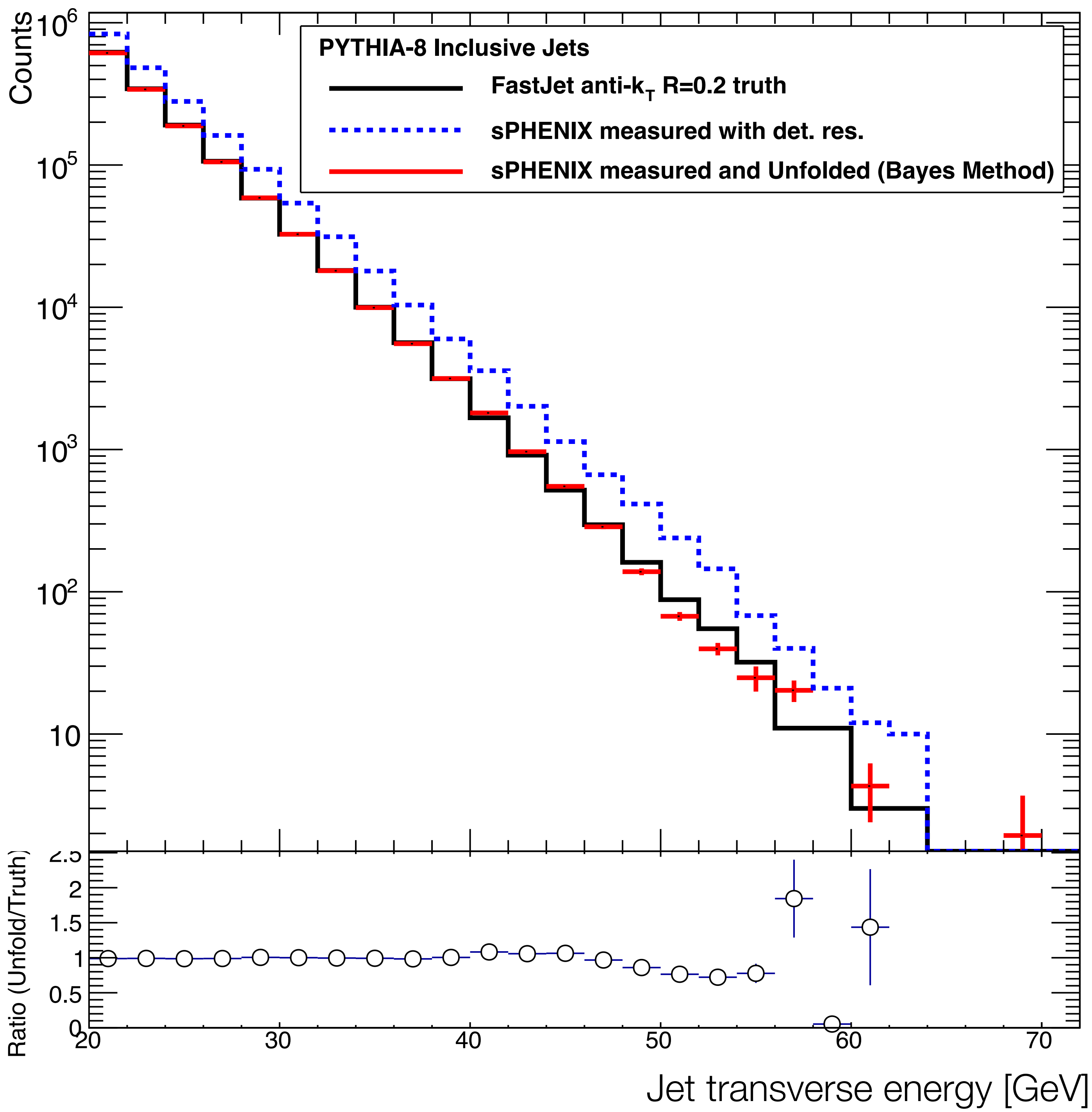
not matched jets:
no nearby HIJING jets
"fakes"

matched jets:
within ΔR< 0.25 of a HIJING
truth jet (>5GeV)



for a given R, there is an E_T above which jet signal is clean

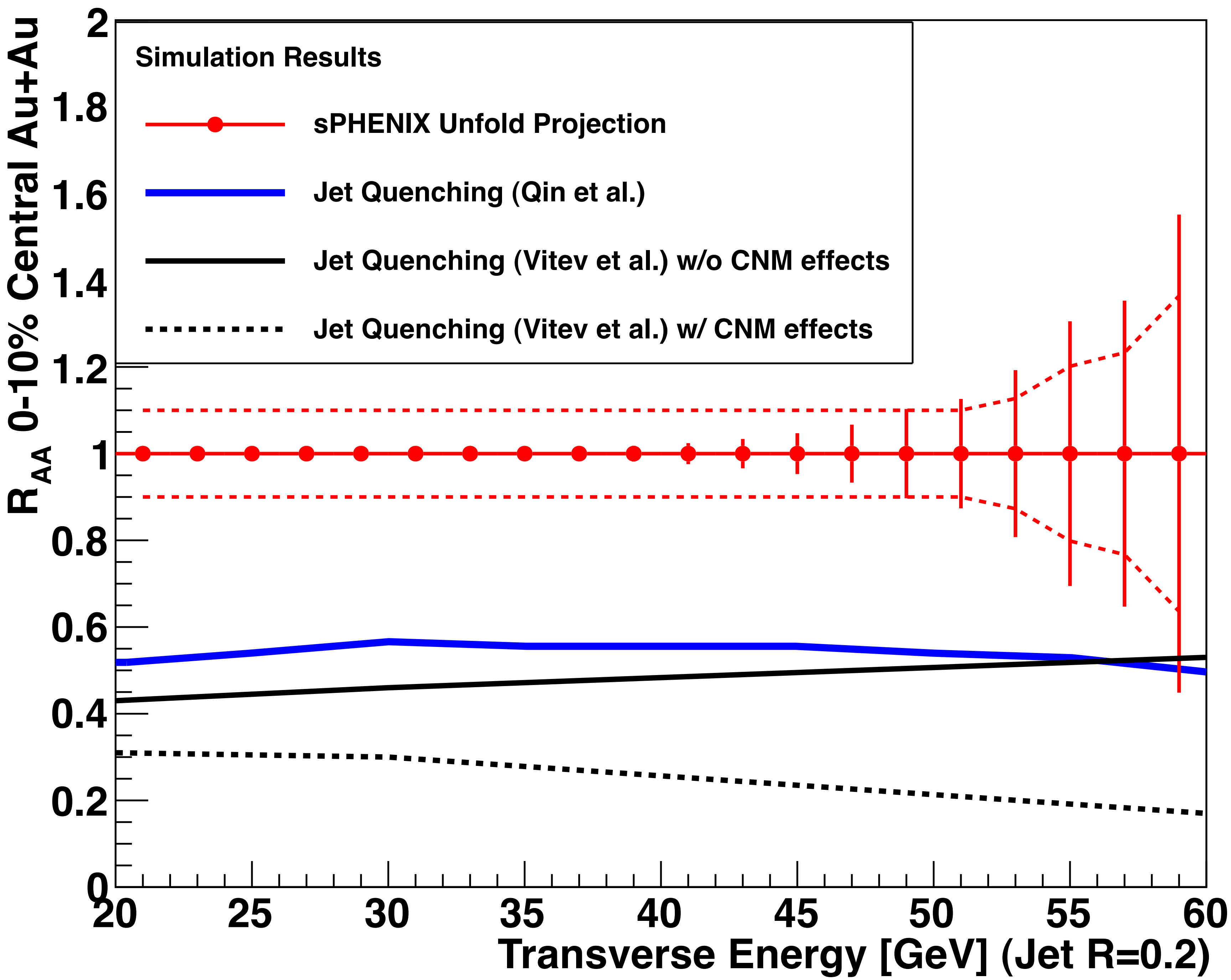
unfolding the inclusive jet spectrum in p+p



- measurement is convolution of underlying truth with experimental resolution
- iterative Bayes' method of the ROOUNFOLD package (arXiv: 1105.1160) used to "unfold" measurement
- convolution of ~exponential truth with ~Gaussian detector response ⇒ E_T independent

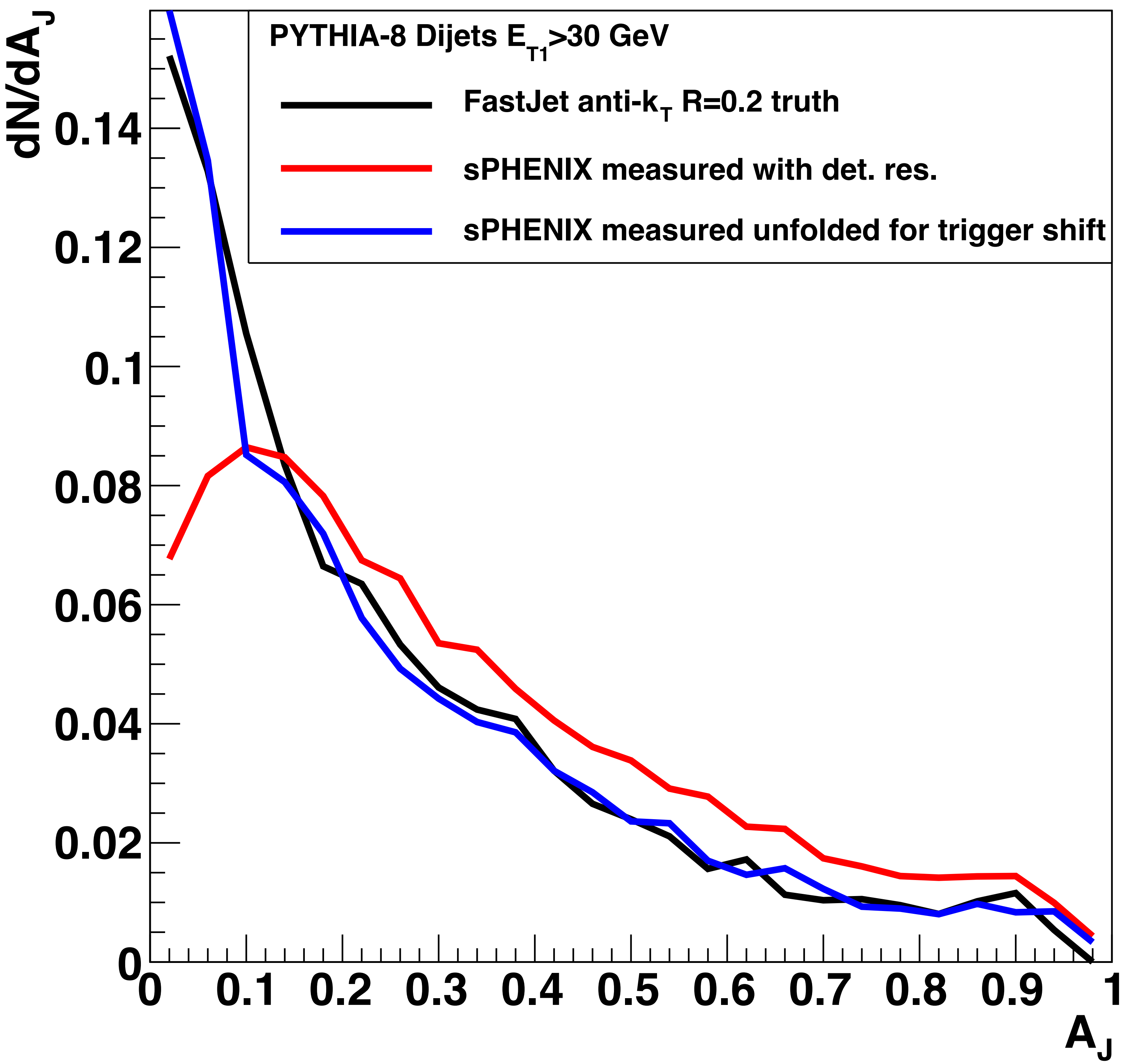
  shift upward in measured E_T

jet R_{AA} for 200 GeV collisions with inclusive jets



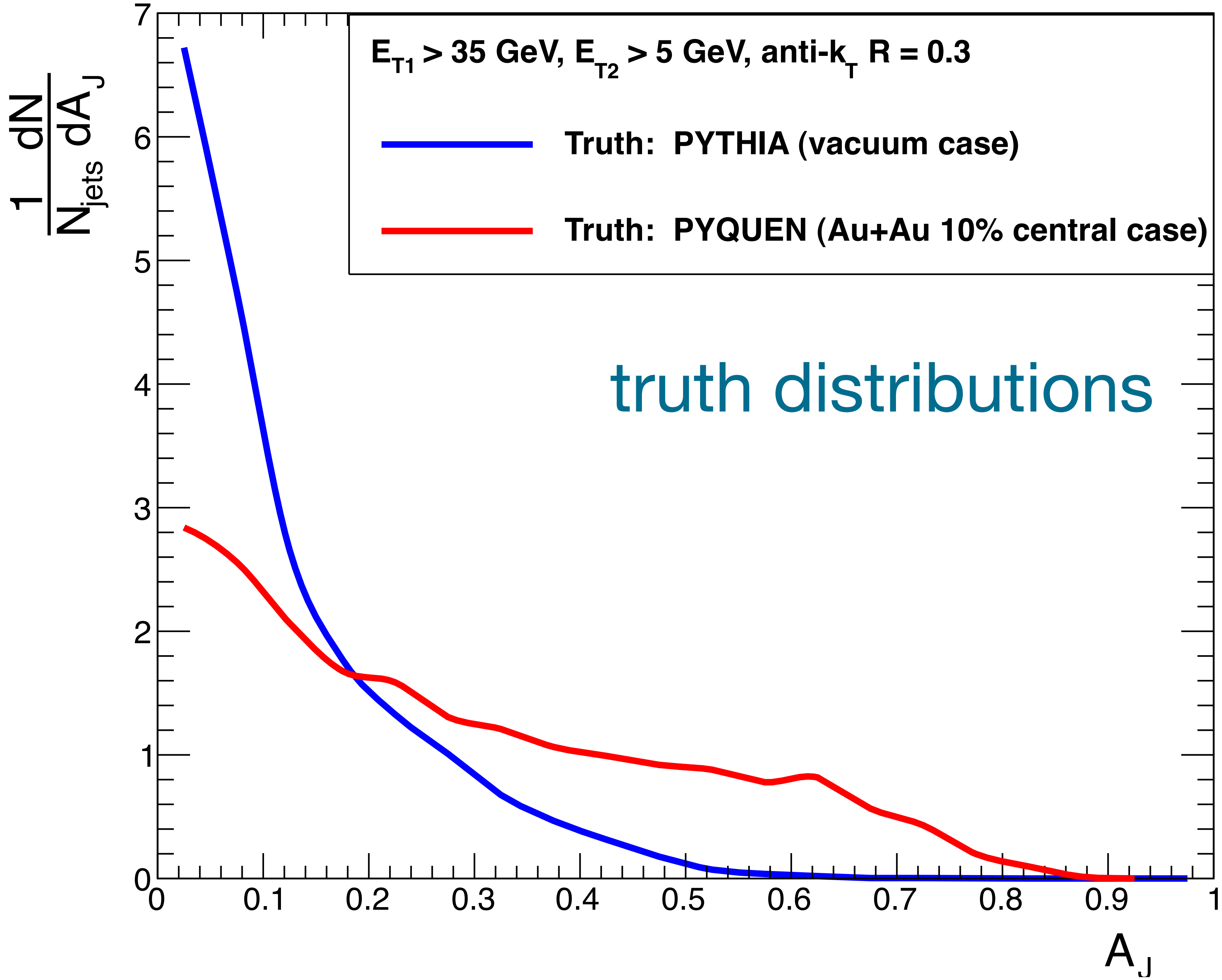
- calculation by Guang-You Qin includes radiative and collisional energy loss
- calculations by Ivan Vitev with and without cold nuclear matter effects
- simulation shows statistical and 10% systematic uncertainties

di-jet asymmetry in p+p with approximate unfolding



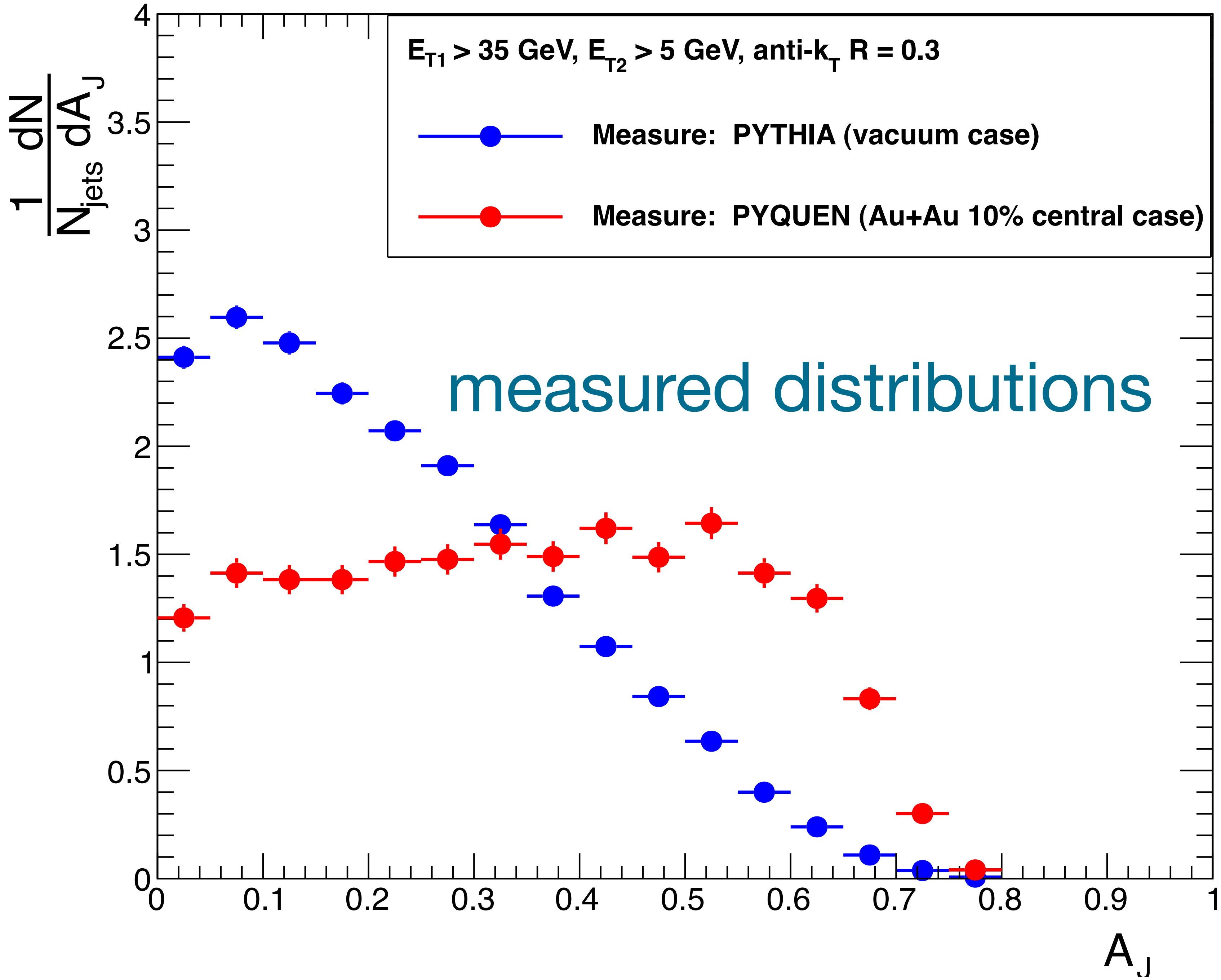
- truth A_J smeared by detector resolution shows reduction of symmetric jets
- shift of trigger by average E_T bias largely recovers truth A_J
- eventually would use full 2D unfolding–something that LHC expt's are also working on

measuring A_J in central Au+Au



- clean trigger jet allows clean away-side jet to much lower E_T
- shift in trigger jet as proxy for full 2D unfolding; largely recovers truth distribution
- for even lower away-side E_T employ jet-hadron correlations

measuring A_J in central Au+Au



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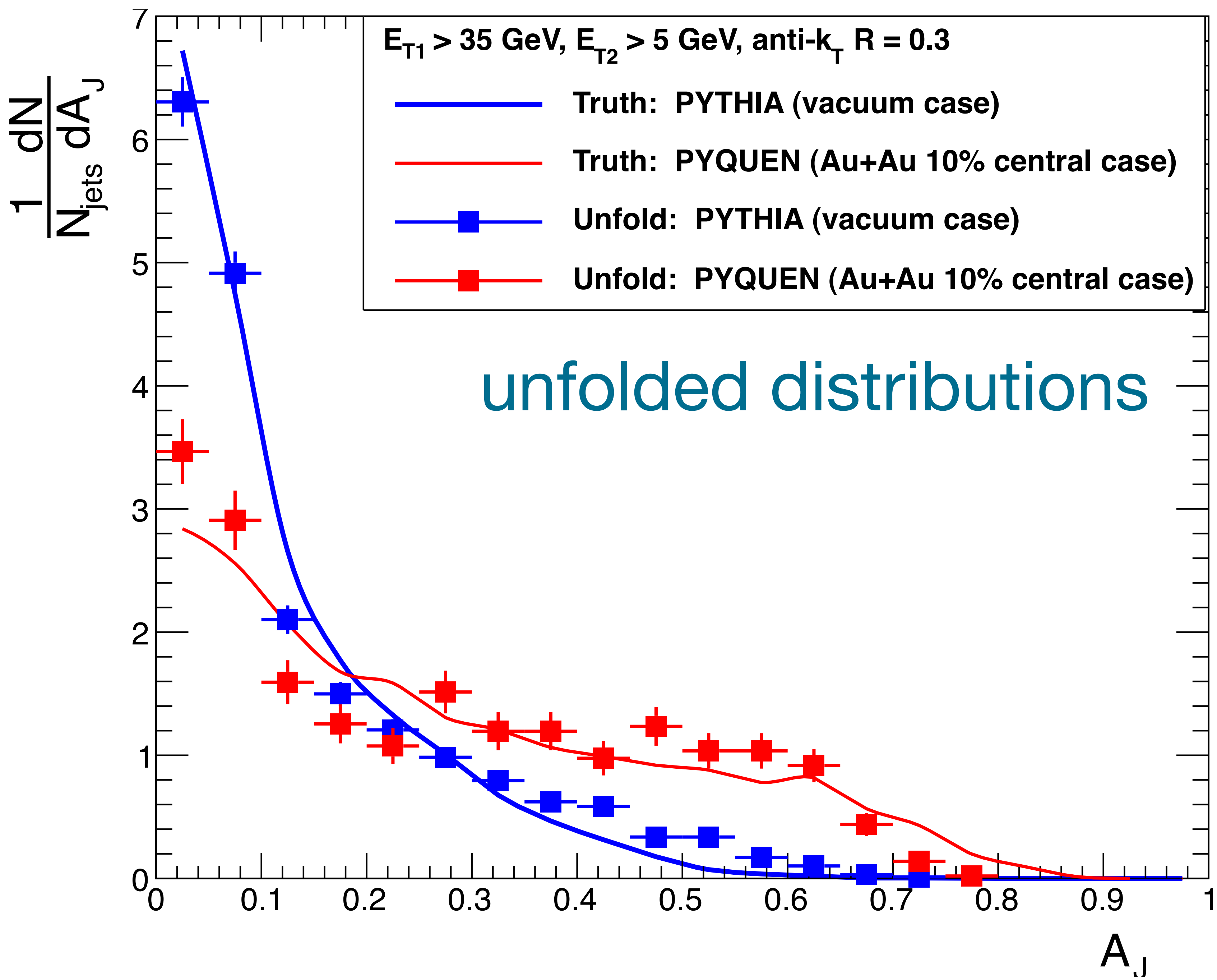

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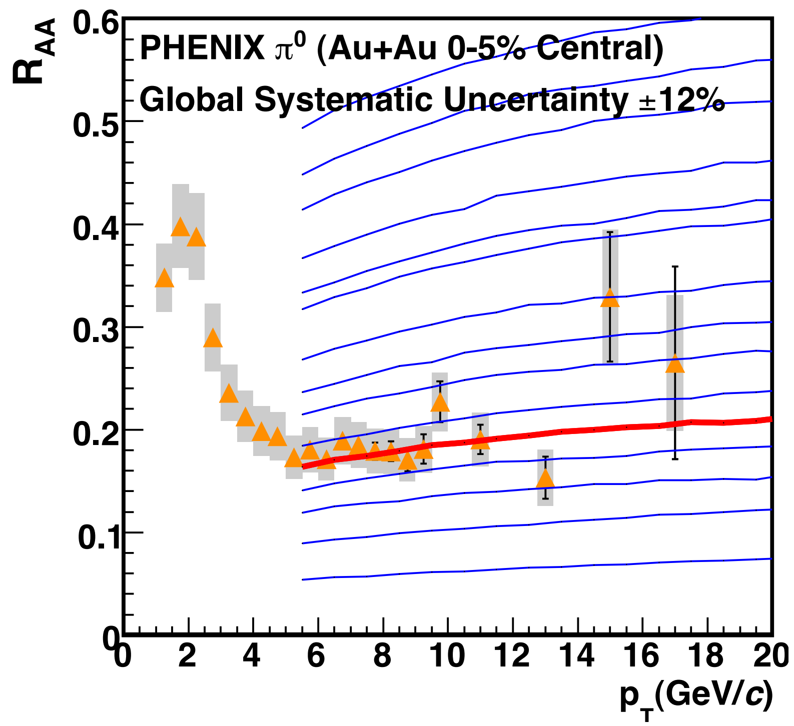
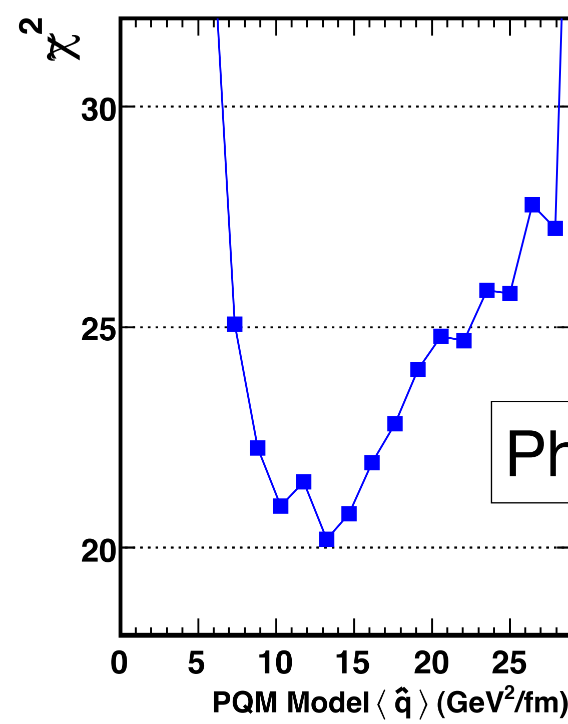
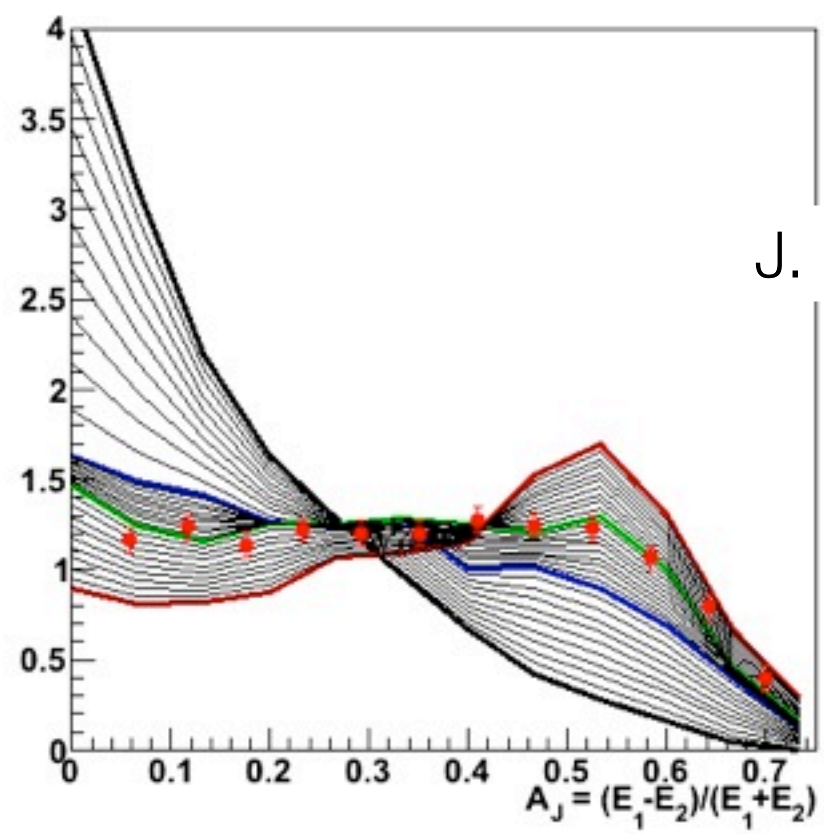
How would we extract physics quantities?



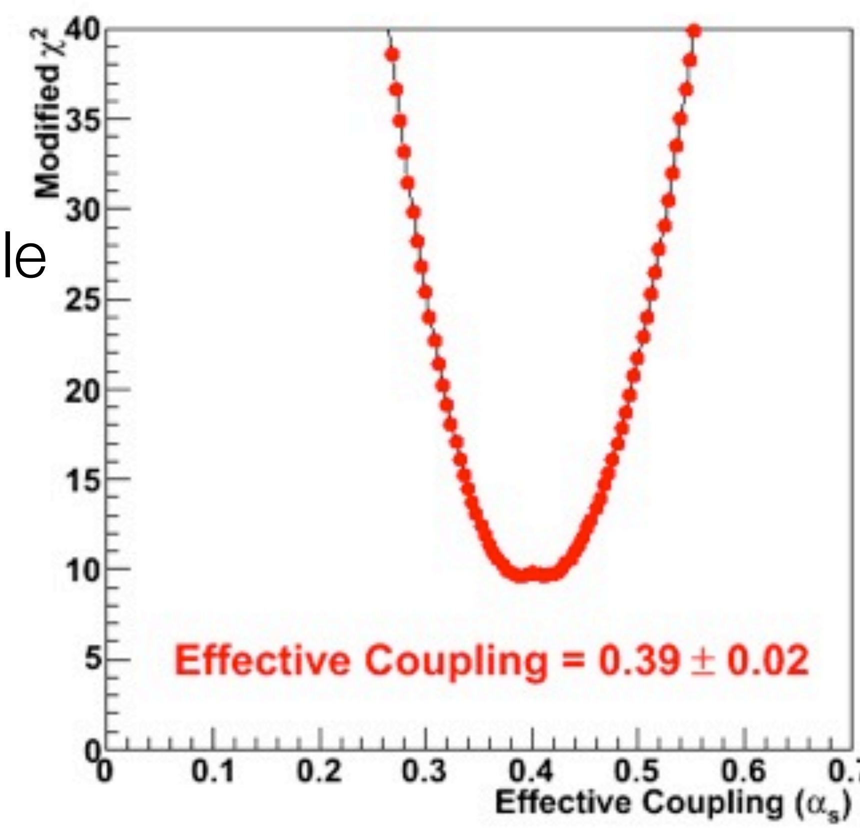


Phys. Rev. Lett. 101:232301,2008

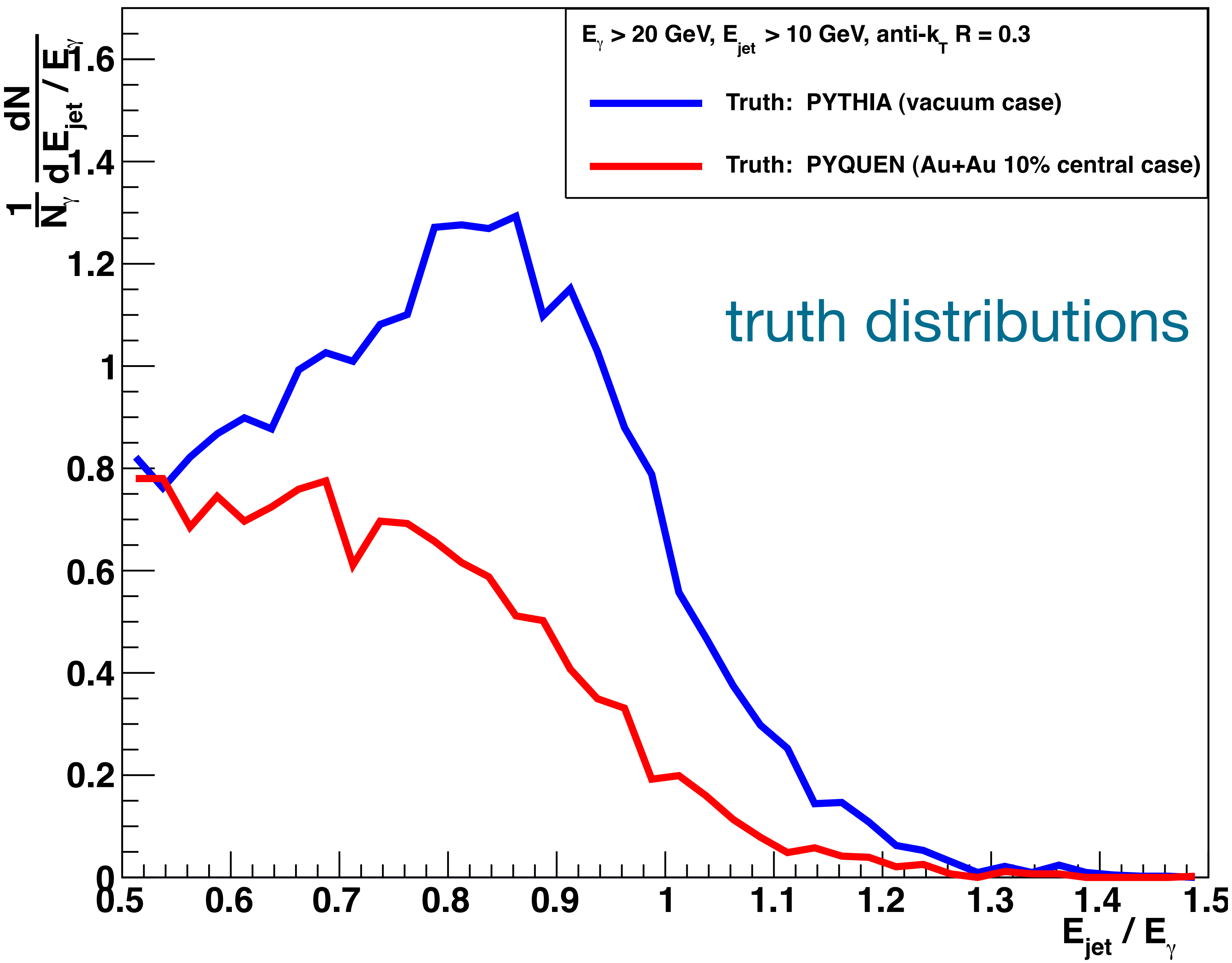
varying and comparing to model predictions, taking into account experimental correlated and uncorrelated experimental uncertainties



J. Nagle

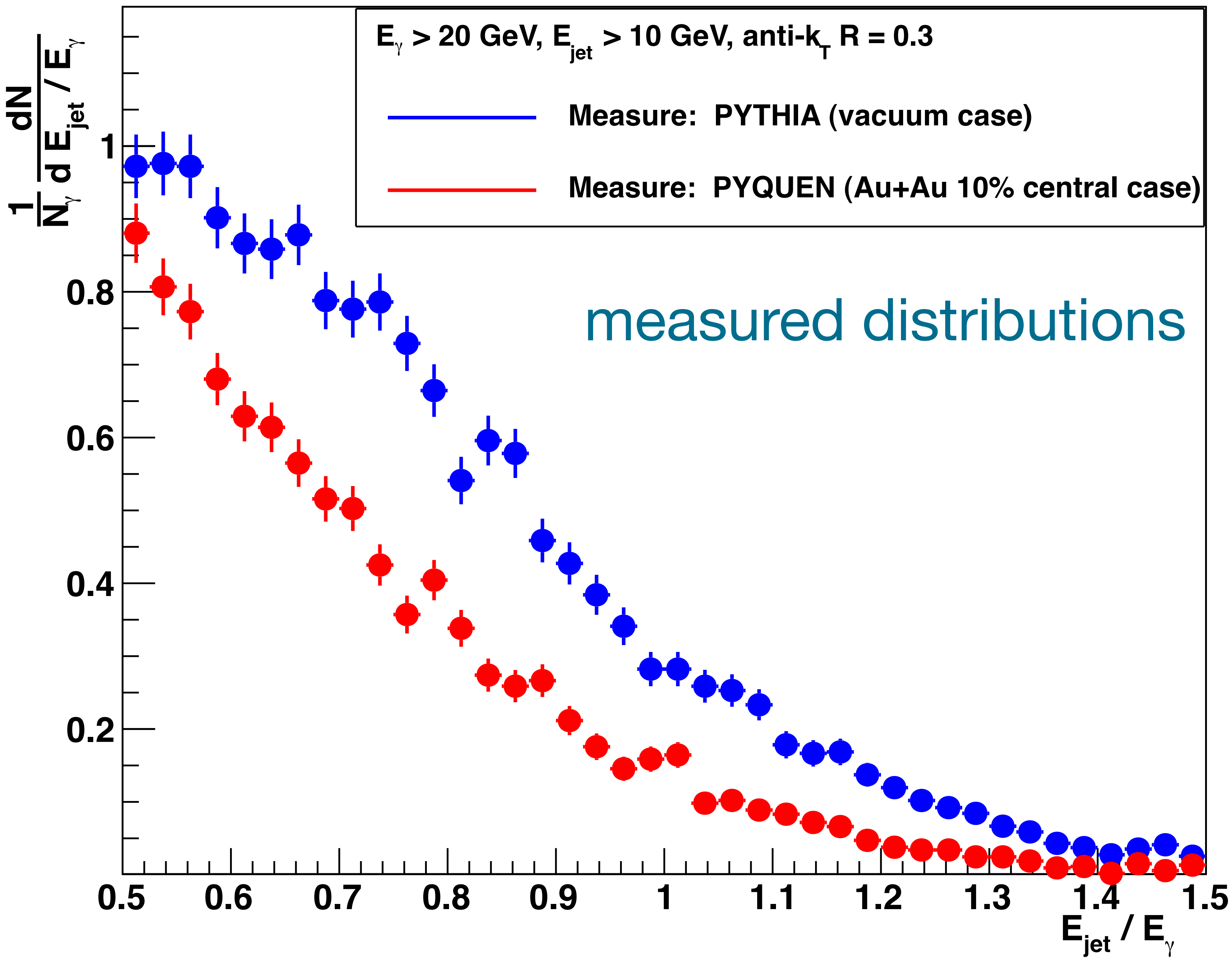


photon+jet correlations



- trigger on clean photon signal E_γ > 20 GeV
- measure ratio (rather than asymmetry) to away-side jet energy
- EMCal measures photon energy precisely, no need for unfolding
- real 1D unfolding of jet energy

photon+jet correlations



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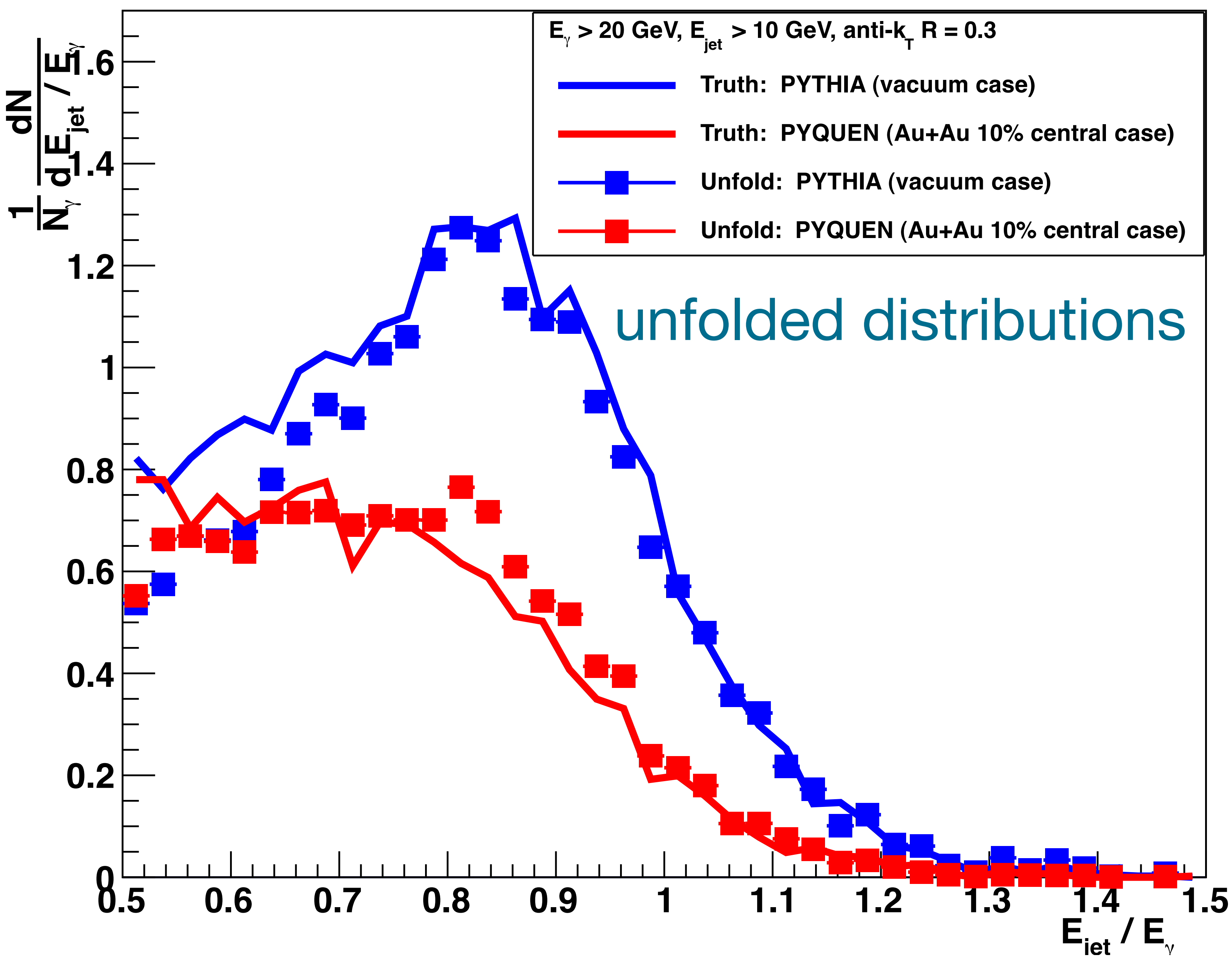

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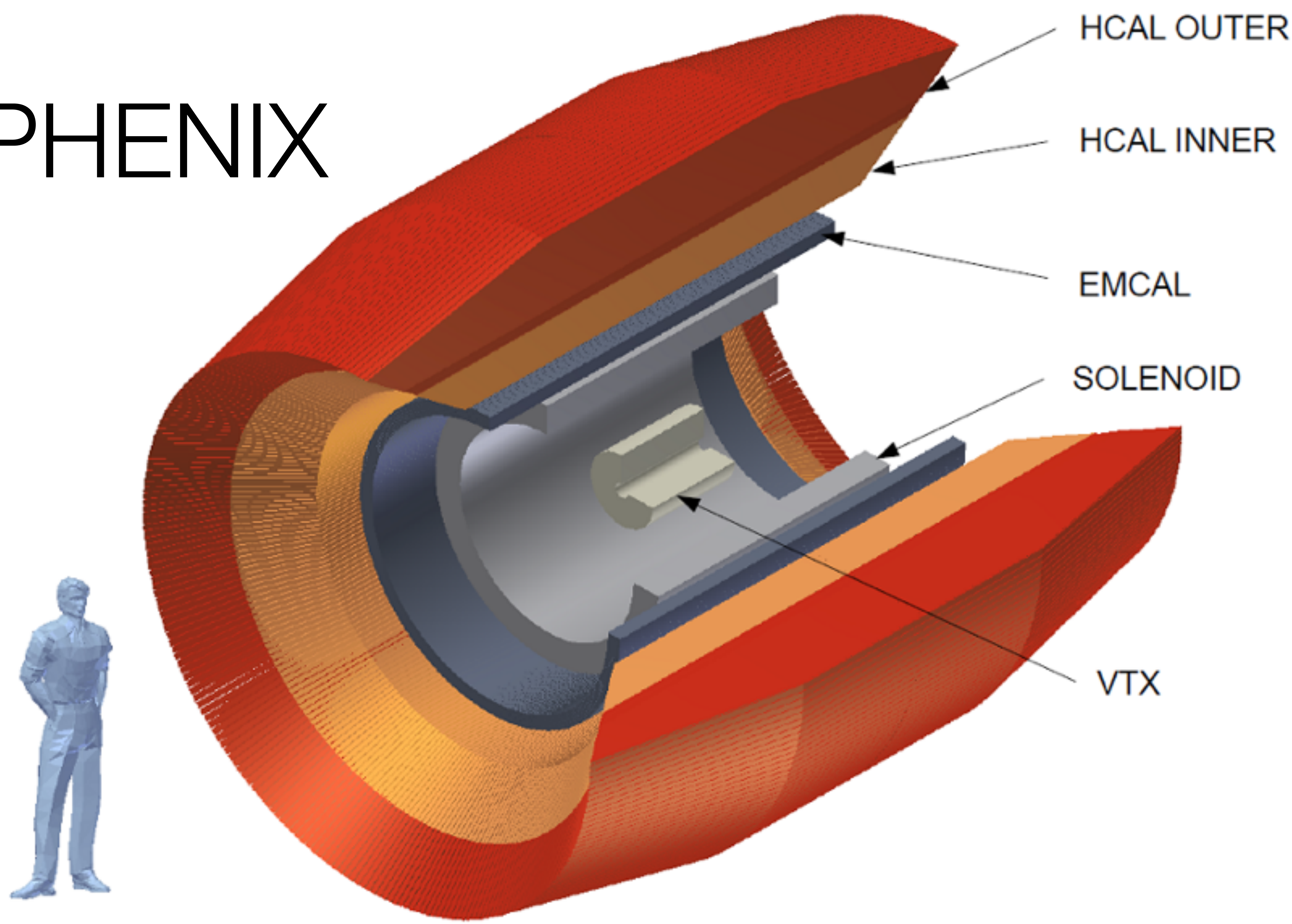
sPHENIX



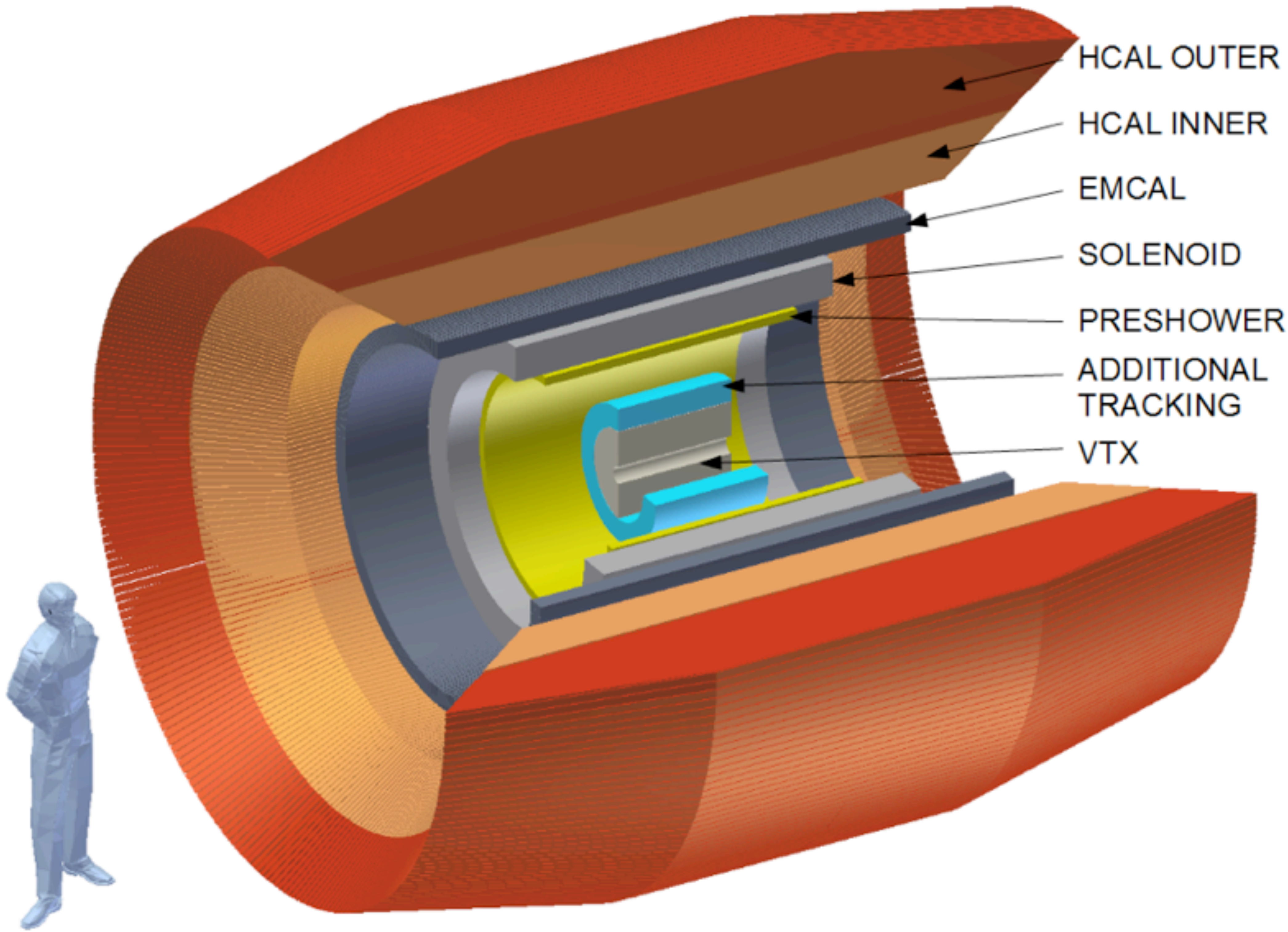
MIE proposal: **arXiv:1207.6378**. BNL review October 5–6, 2012
Committee "strongly endorsed the science case"
Aiming for submission to DOE in 2013

Mid-rapidity quarkonia with sPHENIX

- heavy flavor statistics in A+A per year at RHIC – small production cross sections (e.g., $\Gamma(\Upsilon_{LHC}) \sim 100\ \Gamma(\Upsilon_{RHIC})$), but high A+A luminosity and long running periods

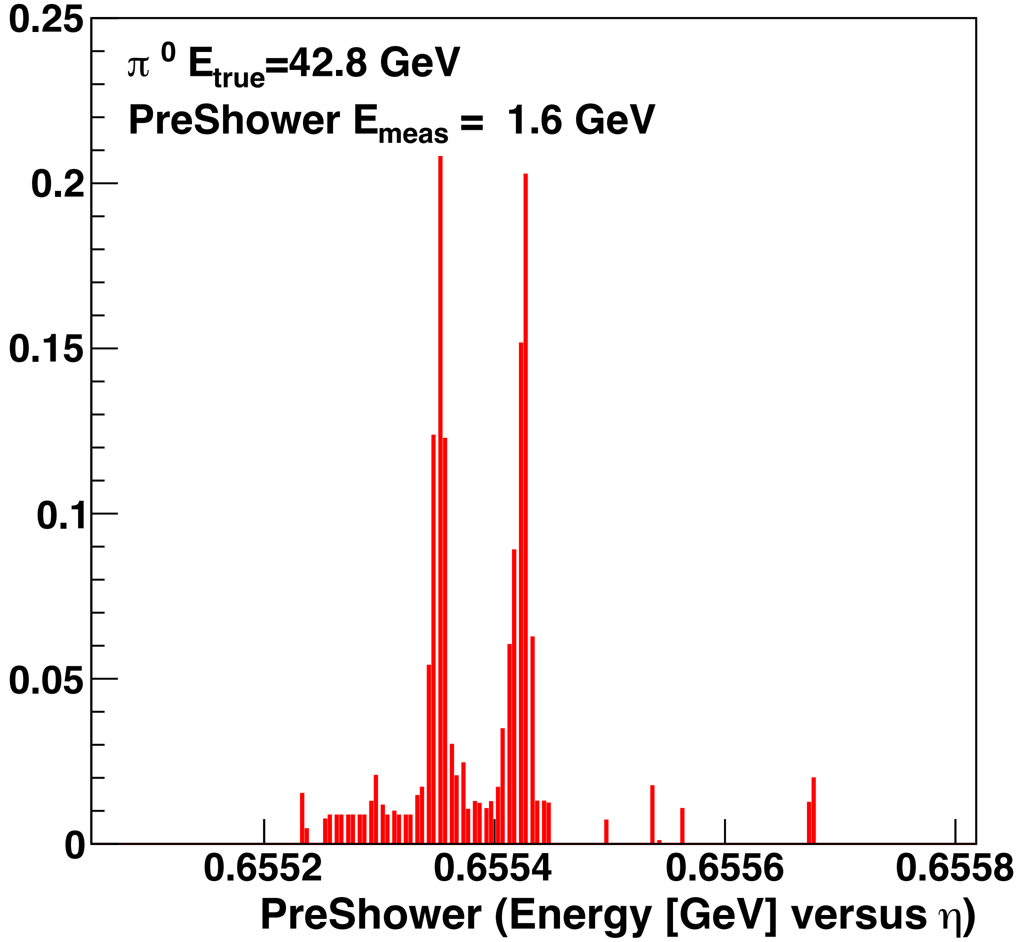
Species	$\int$ L dt	Events	$\langle N_{coll} \rangle$	Υ(1S)	Υ(2S)	Υ(3S)	Υ(1S+2S+3S)
$p+p$	$18\ pb^{-1}$	756 B	1	805	202	106	1113
Au+Au (MB)		50 B	240.4	12794	3217	1687	17698
Au+Au (0–10%)		5 B	962	5121	1288	675	7084

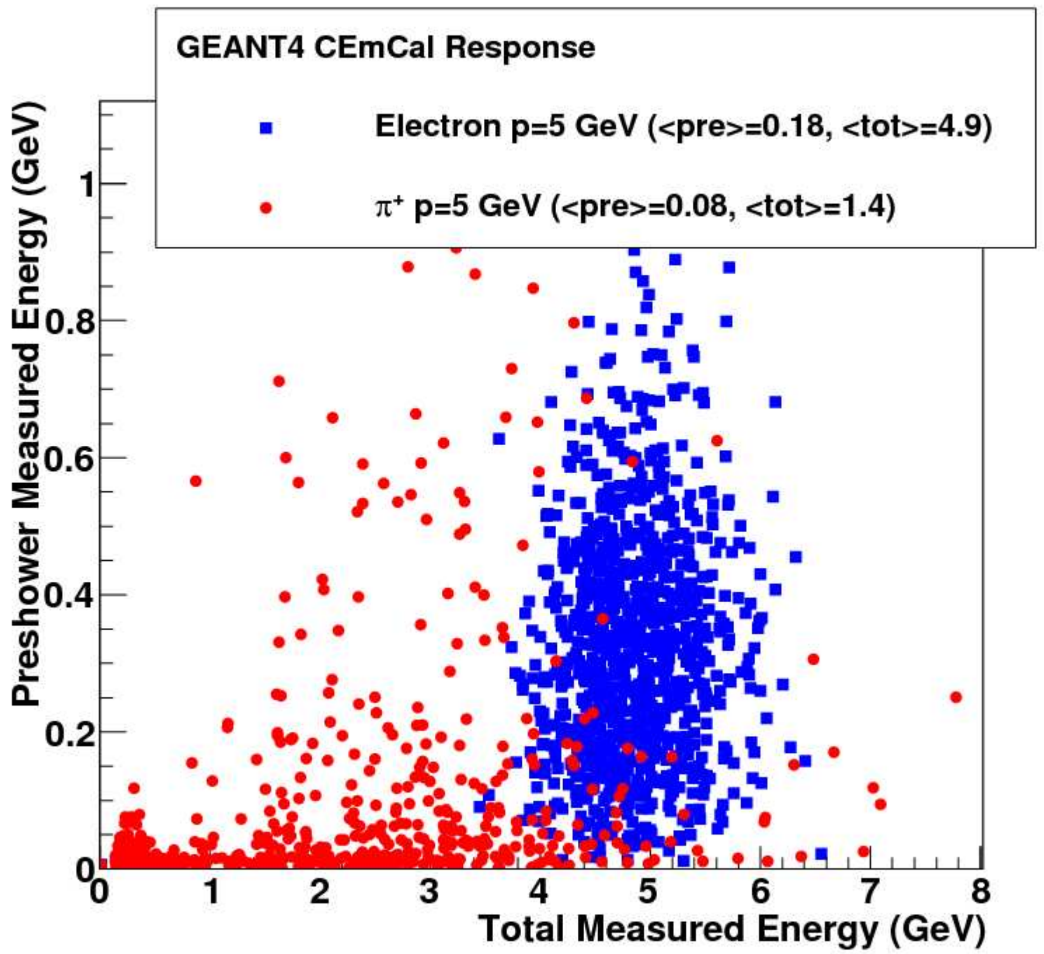
sPHENIX (DOE MIE) + add'l tracking + EMCal pre-shower



actively pursuing non-DOE funding, aiming to install on day-1

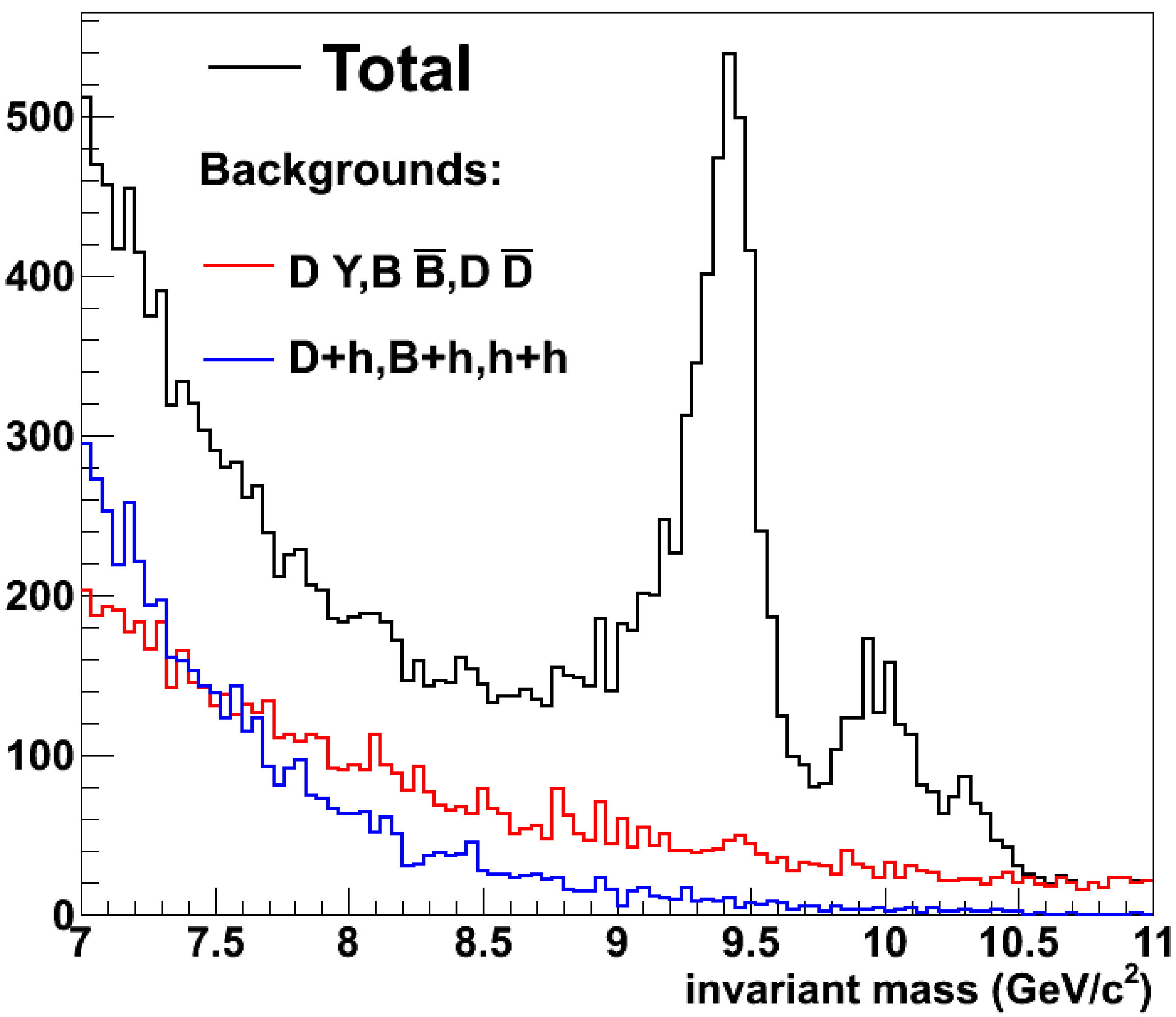
Pion rejection





charged pion rejection ~200 using pre-shower and p/E matching

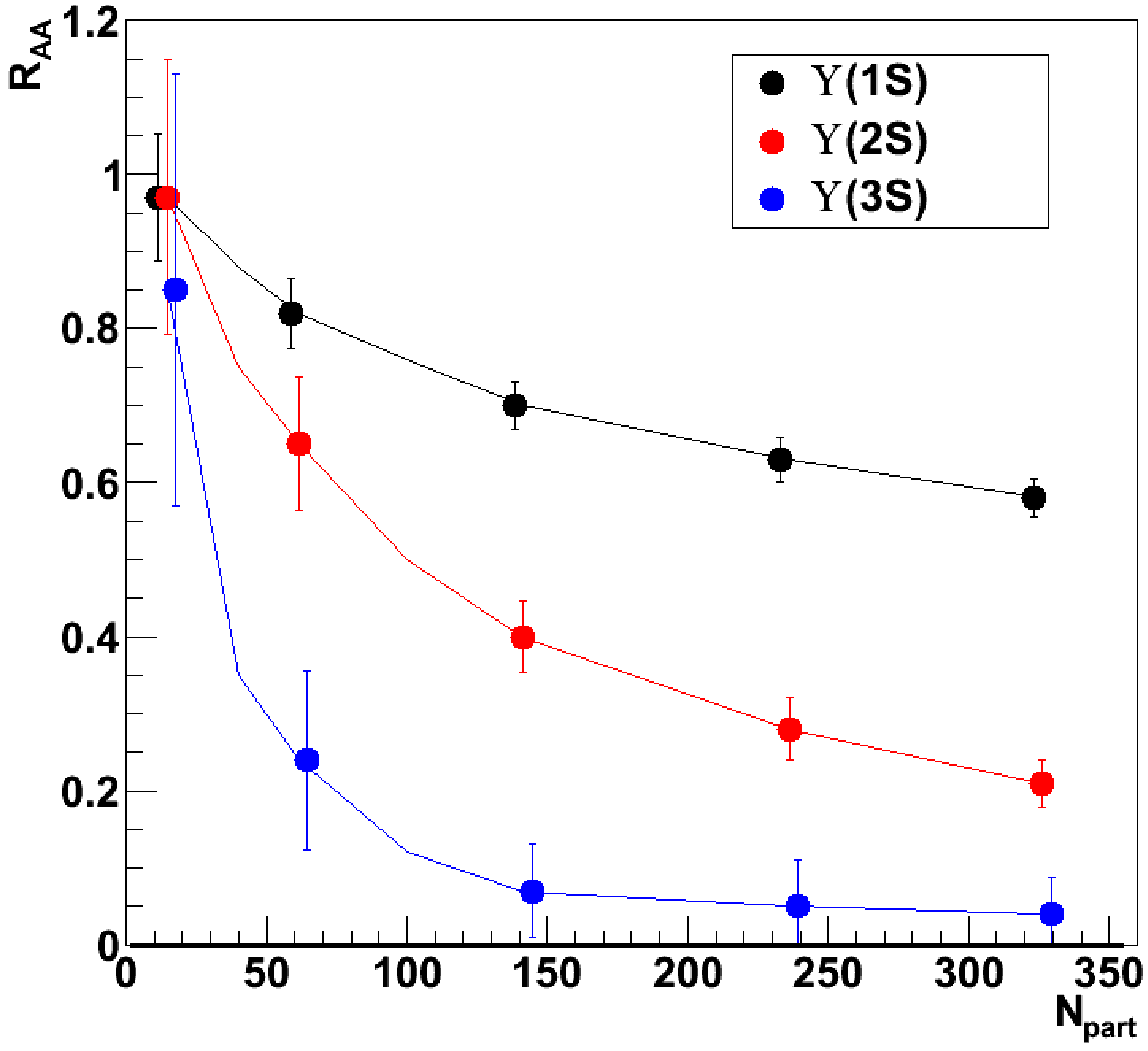
$\Upsilon \rightarrow e^+e^-$ embedded in central Au+Au events



e^+e^- from real upsilons, correlated charm, correlated bottom, DY and mis-ID'ed pions of 5 billion central Au+Au at 200 GeV (1 RHIC year)

- assumes pion rejection of 200
- good separation of Υ states: momentum resolution < 0.2%
- 2T field improves momentum resolution over existing PHENIX tracking
- the exact design and technology of the additional tracking is under active investigation

Uncertainty on Upsilon yields



Statistical precision of Upsilon yields, assuming R_{AA} values from Strickland and Bazow (Nucl. Phys., A879:25–58, 2012)

Jets and quarkonia as probes of sQGP at RHIC

- jet measurements at RHIC complement jet measurements at LHC and investigate temperature and coupling dependence of sQGP properties
- jet observables sensitive to dynamics even when coupling is strongest
- extensive (and published) study shows that one can extract a clean jet signal, even against central Au+Au background
- unfolded inclusive jet, di-jet and gamma-jet observables show marked sensitivity to underlying physics
- initial stage sPHENIX detector optimized for jet physics studies – positively reviewed and aiming for submission to DOE as MIE in 2013
- additional tracking layers and EMCal pre-shower provide mass resolution and pion rejection to enable quarkonia program to augment STAR's and complement LHC
- extensive suite of *forward* instrumentation also being developed

Coda as prologue

- sPHENIX is a significant reworking of PHENIX – exciting new capabilities
    - enabled because of recent technological developments
    - interesting because of medium properties near T_C and because of complementarity with jet and quarkonia measurements from LHC
    - possible due to work by Collaboration and by community on a plan
- not “out of the blue” – guidance from both BNL and from DOE
- PHENIX is planning for, and anticipating, a super future of QGP physics

unfolding (or deconvolution)

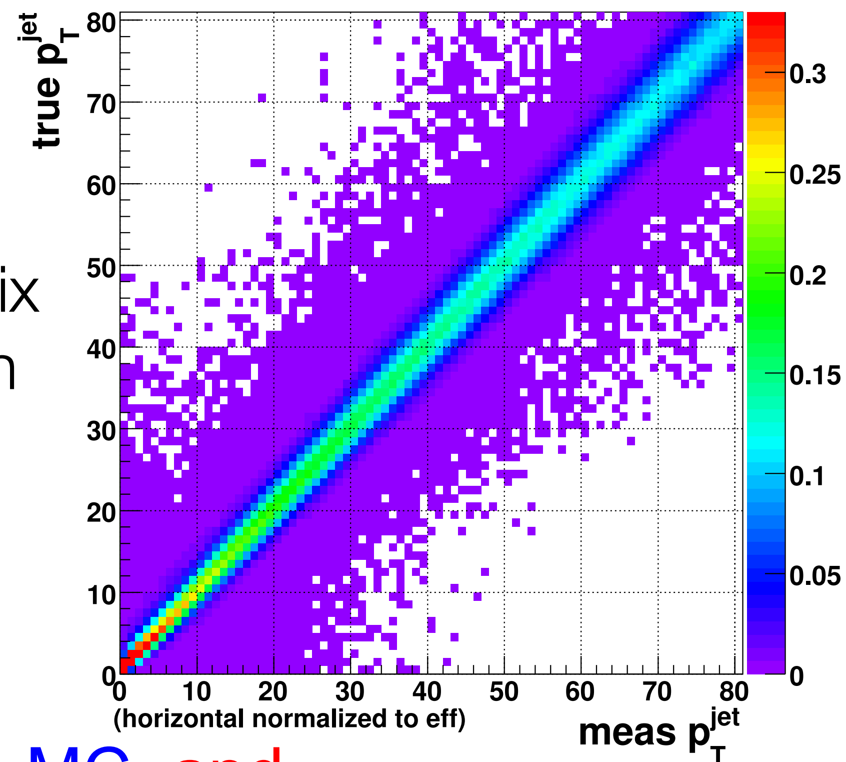
- Given a “true” PDF in $\boldsymbol{\mu}$ that is corrupted by detector effects, described by a response function, $\mathbf{R}$, we measure a distribution in $\boldsymbol{\nu}$. For a binned distribution:

$$\nu_i = \sum_{j=1}^{M} R_{ij}\mu_j \qquad i = 1..N$$

- With infinite statistics, it would be possible to recover the original PDF by inverting the response matrix

$$\boldsymbol{\mu} = \mathbf{R}^{-1}\boldsymbol{\nu}$$

an example response matrix from PHENIX decadal plan



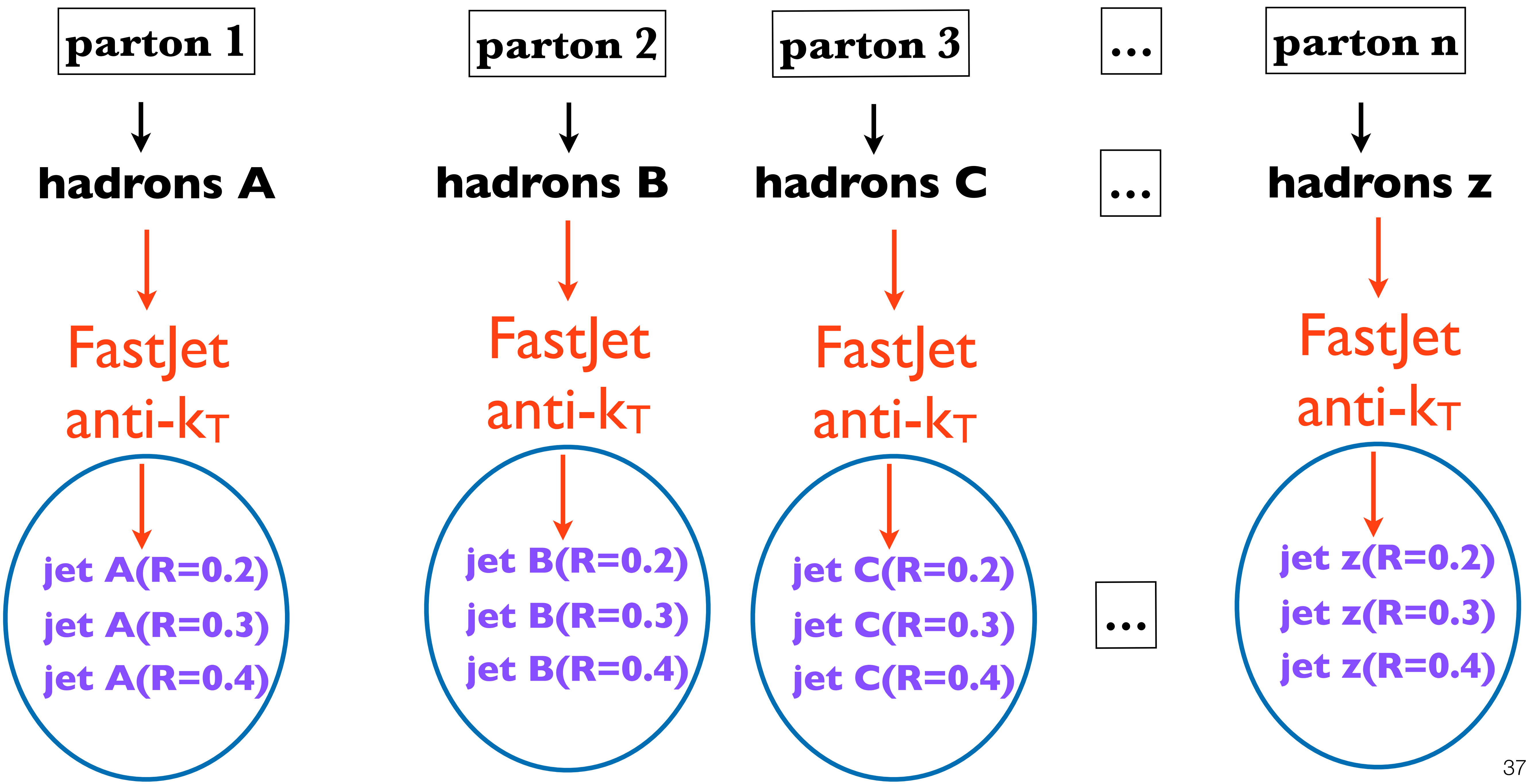
- Use unfolding to recover theoretical distribution where
  - there is no a-priori parameterisation, and
  - it is needed for the result and not just comparison with MC, and
  - there is significant bin-to-bin migration of events

bullets taken verbatim from “http://hepunx.rl.ac.uk/~adye/talks/080520-unfold.pdf”

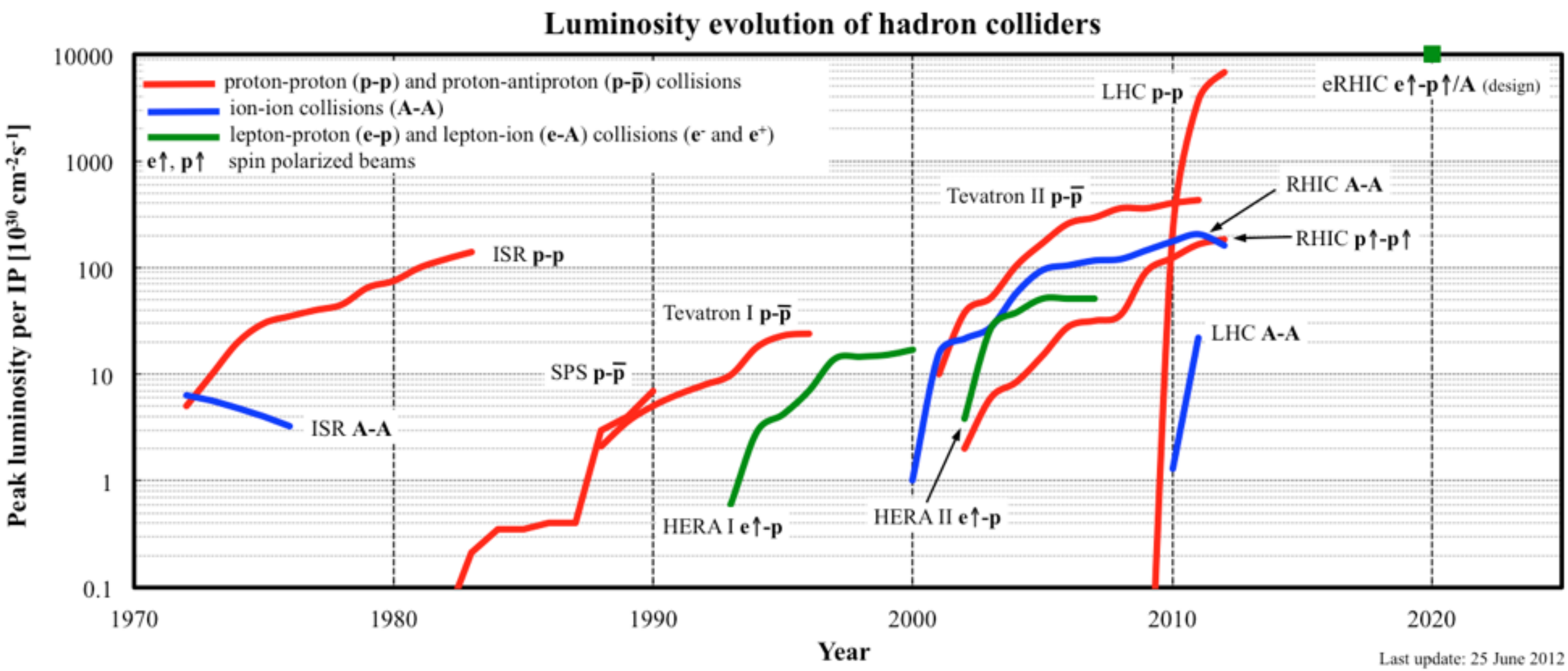
identifying truth jets

Y-S Lai (MIT)
B. Cole (Columbia)
DPM (BNL)

deep within the HIJING Event Generation...



Collider luminosity history

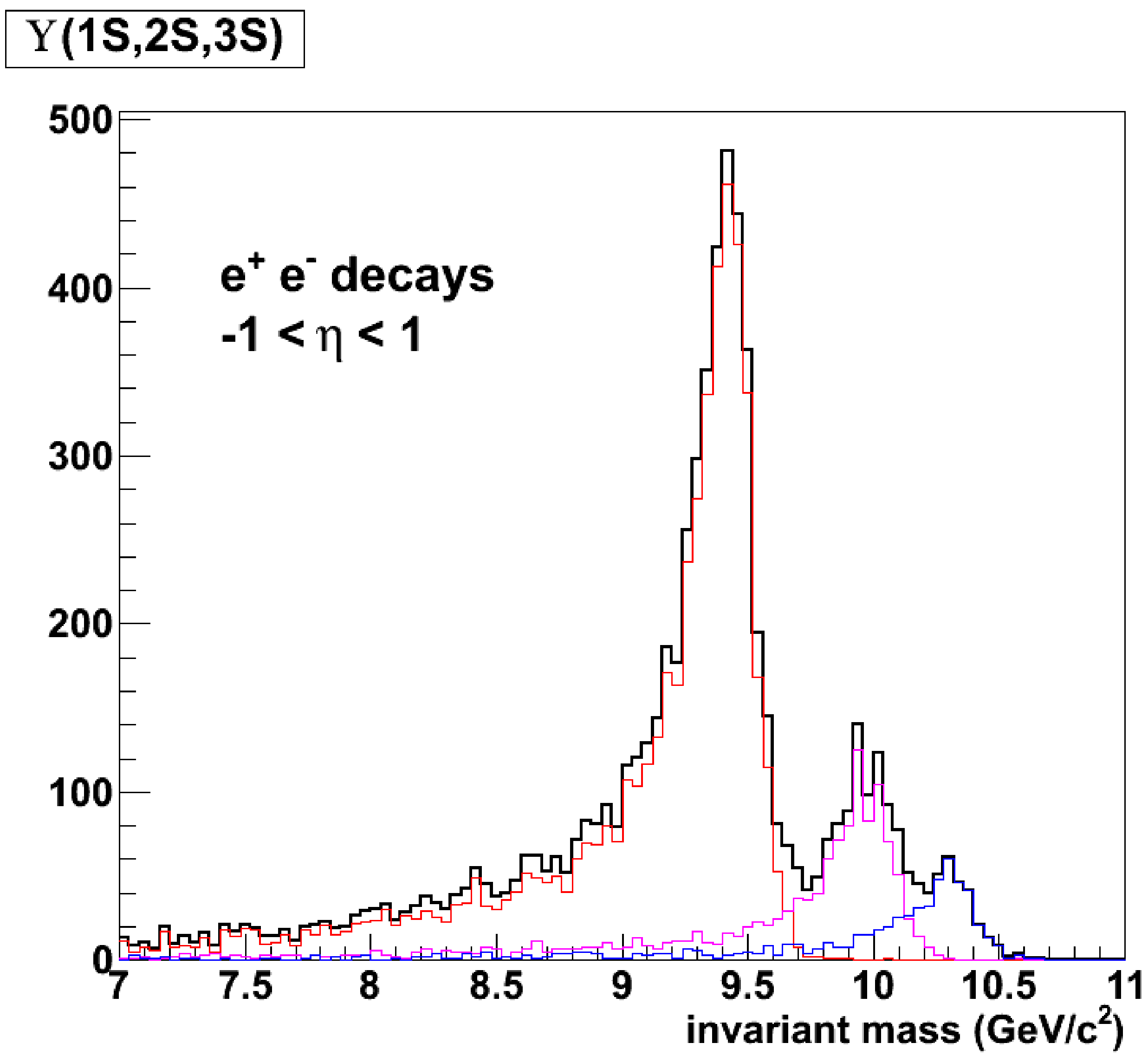


Why quarkonia at RHIC?

- no coalescence role in upsilon production at RHIC (Emerick, Zhao, Rapp, arXiv:1111.6537)

- lower initial temperature at RHIC (~30% lower) means medium in which upsilons are produced is quite different

Mass resolution of Υ→e⁺e⁻



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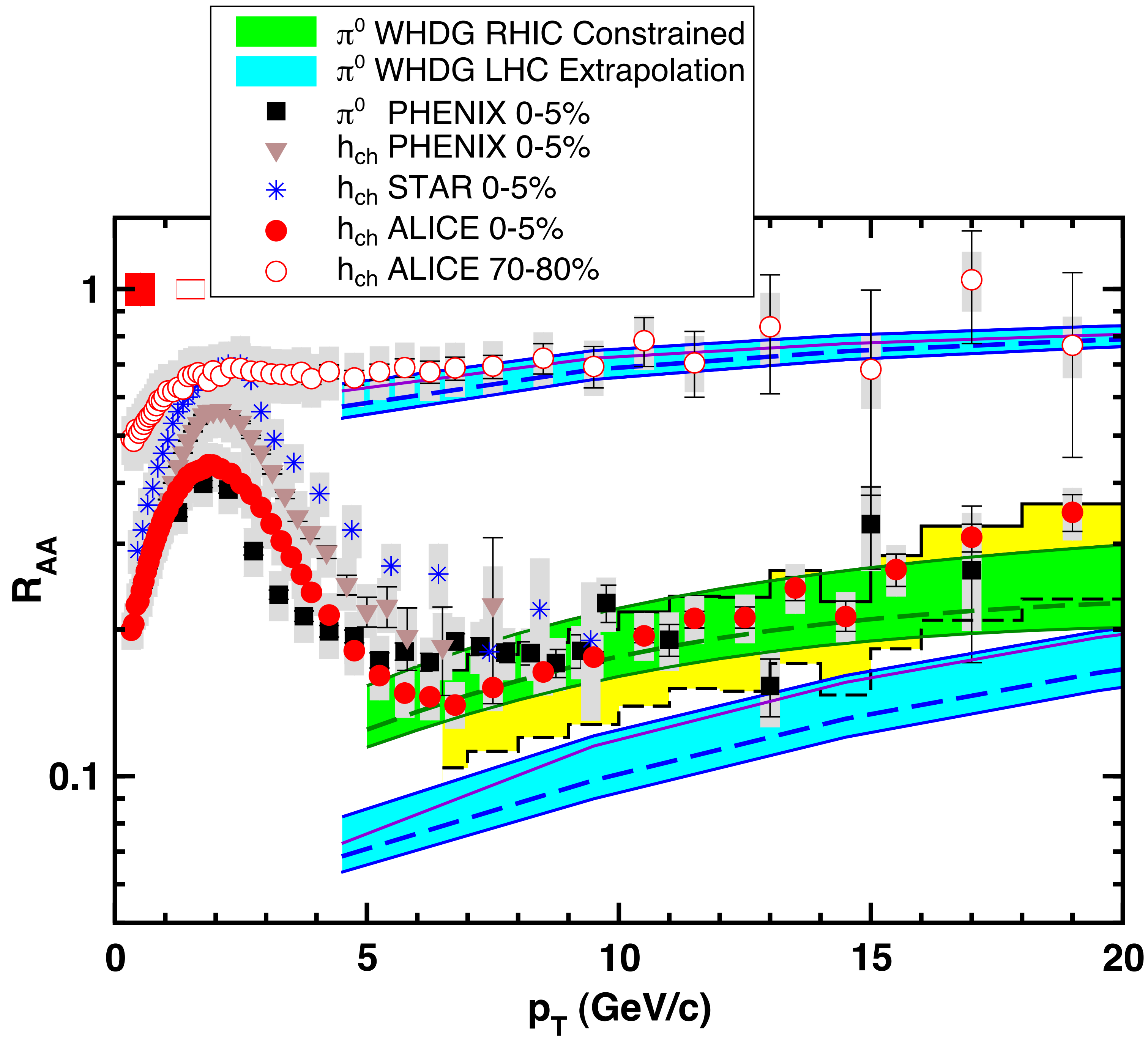

Figure 1.11: R_{AA} measurements from RHIC and the LHC compared to WHDG calculations. The parameters are constrained by the RHIC data and extrapolated to 2.76 TeV. The prediction for the LHC is shown (blue band) and lies below the ALICE data for central collisions (red circles). From Ref. [56].