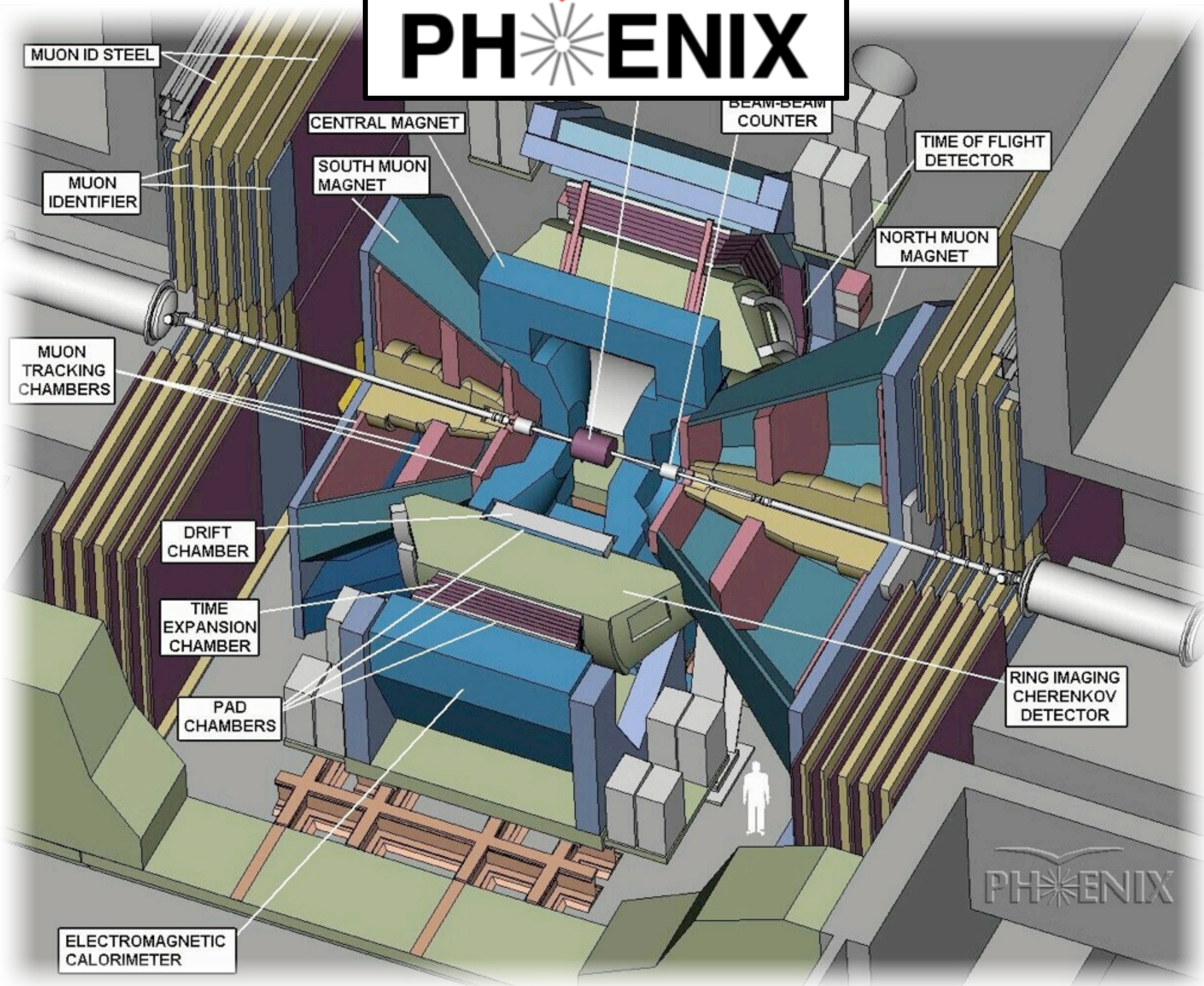
Stage 1:
The Future of Jet Physics at RHIC

Michael P. McCumber
University of Colorado

LANL Nuclear Physics Seminar
16 April 2012

What is sPHENIX?



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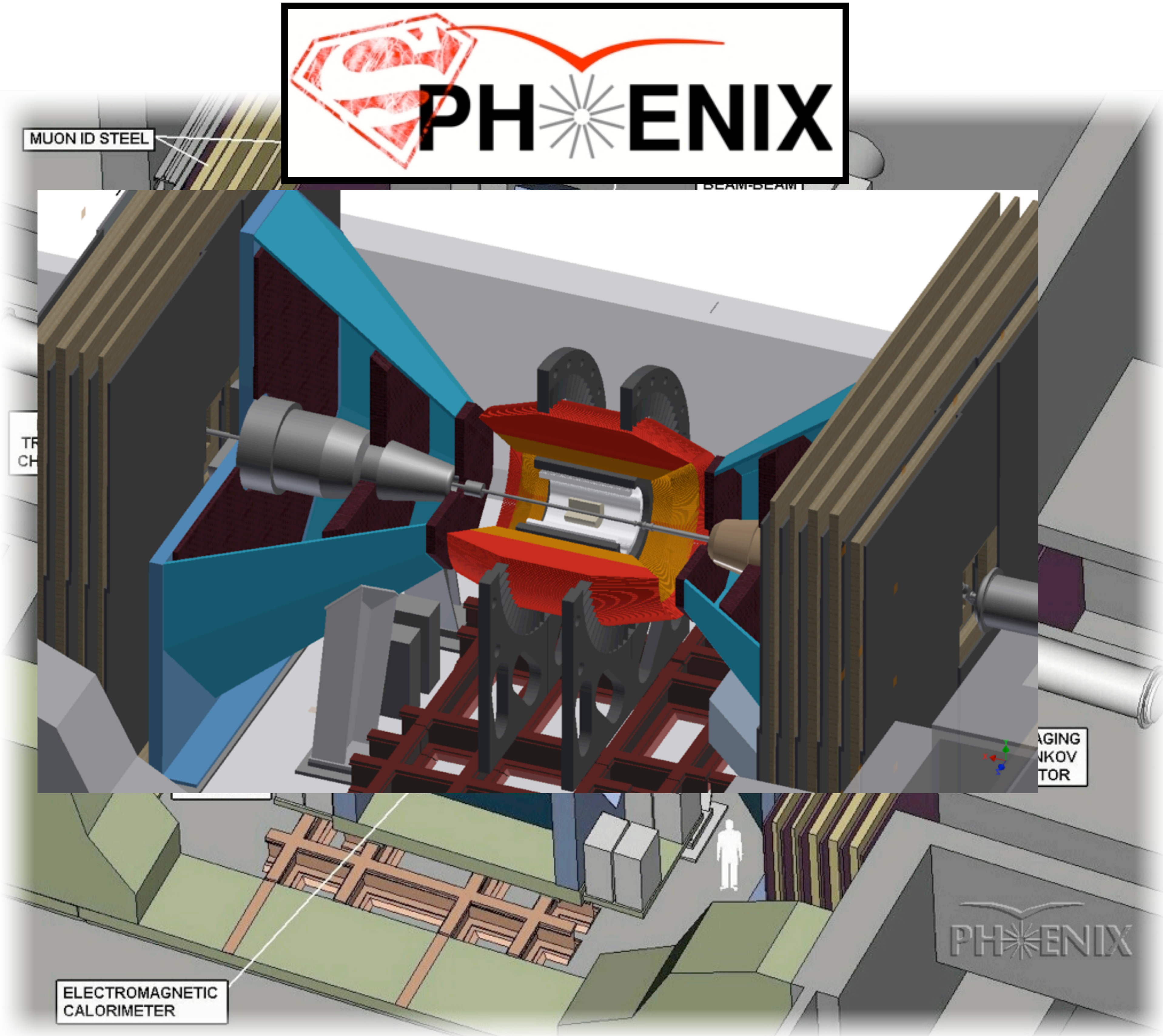
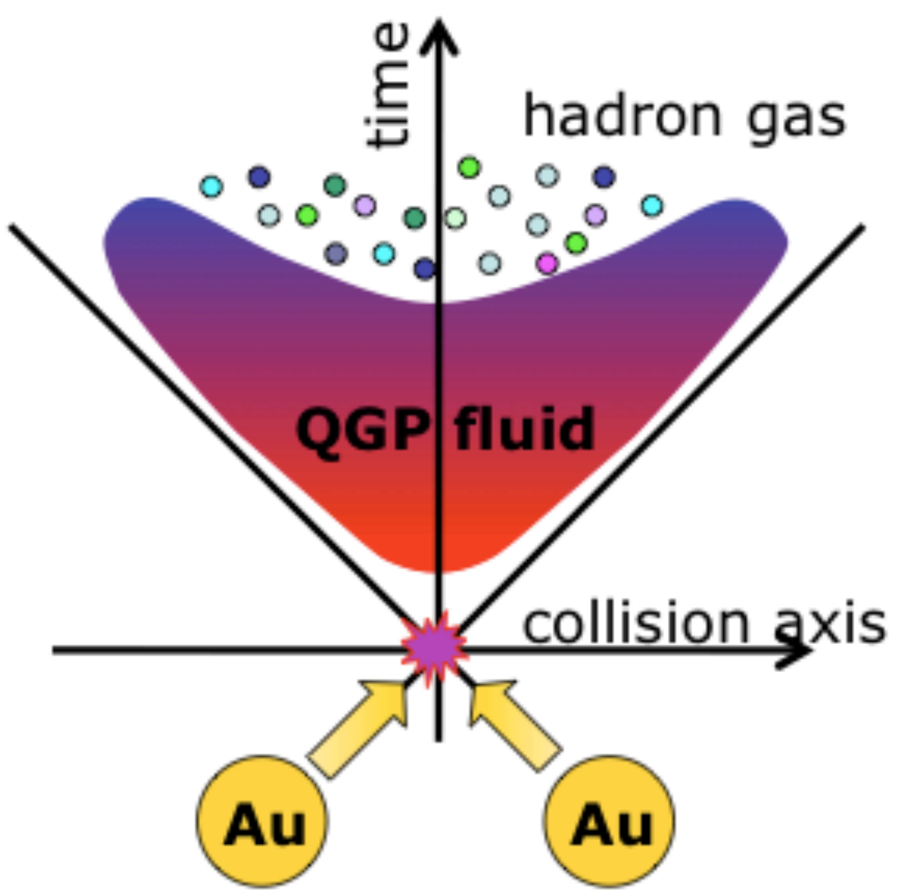
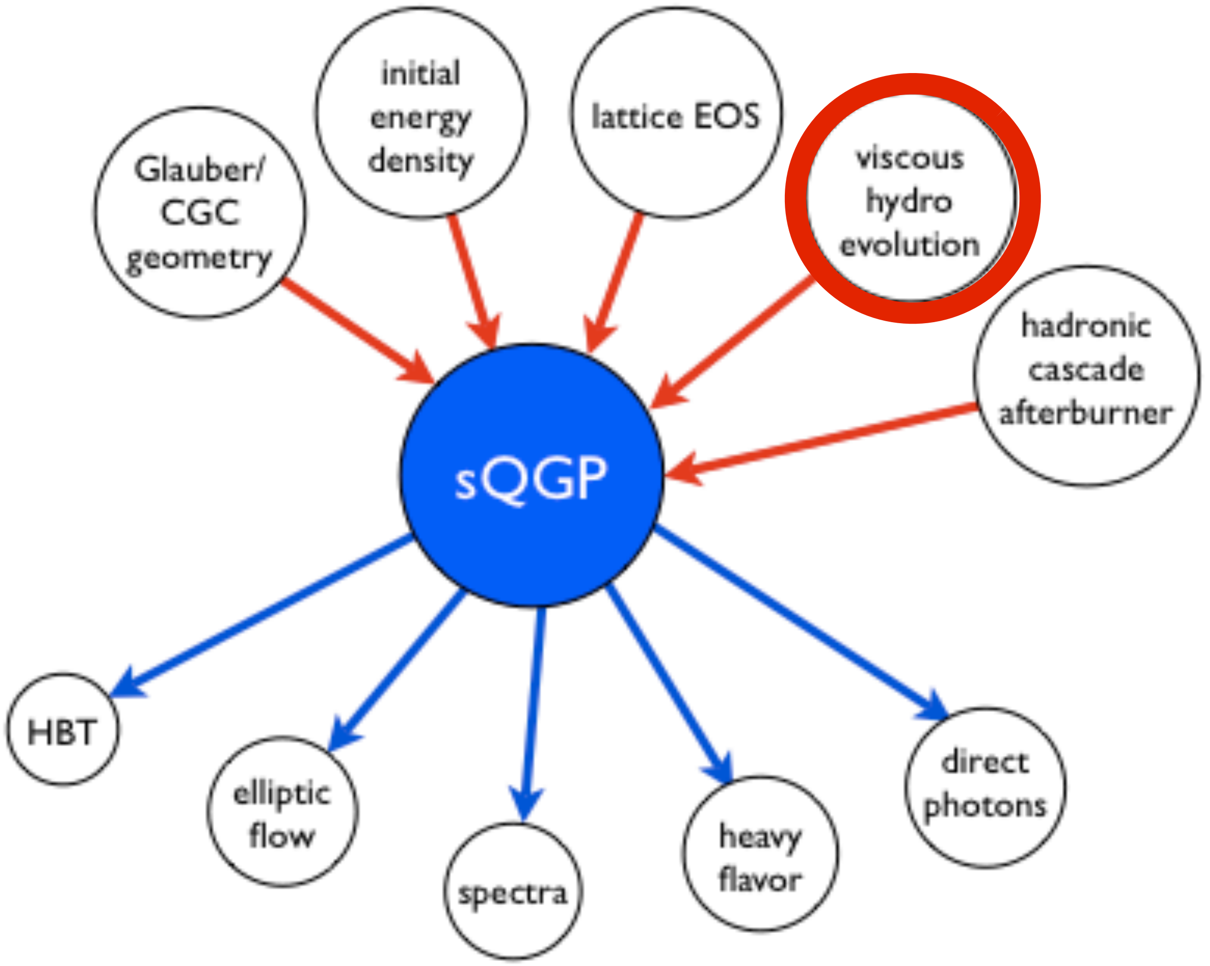


Strongly Coupled (s)QGP Paradigm





the core of a *standard model* for heavy ion collisions

but missing a comprehensive description of the hard sector:
parton energy loss and *quarkonia suppression*

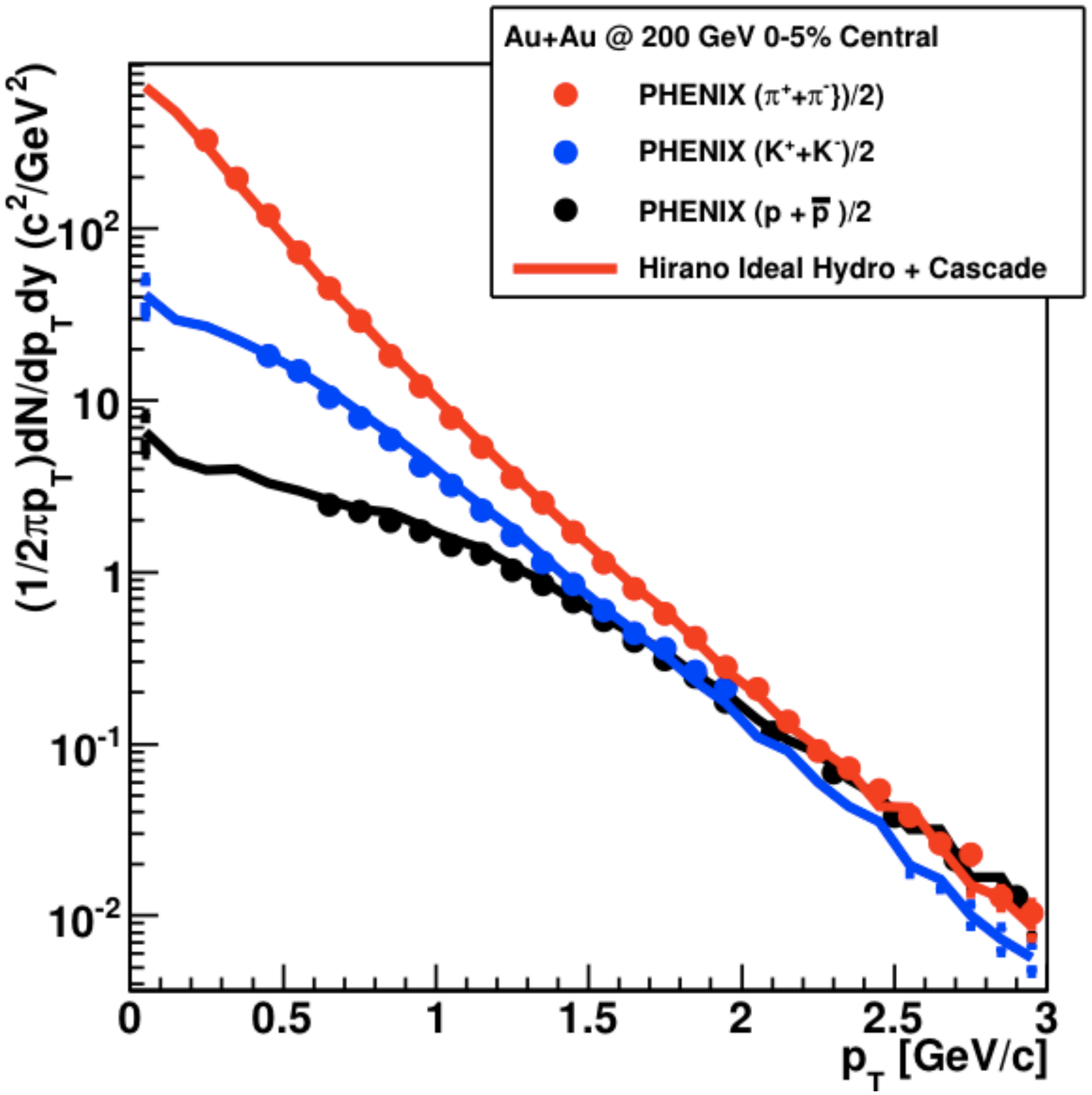
+ bulk medium properties and microscopic state

Jet Physics

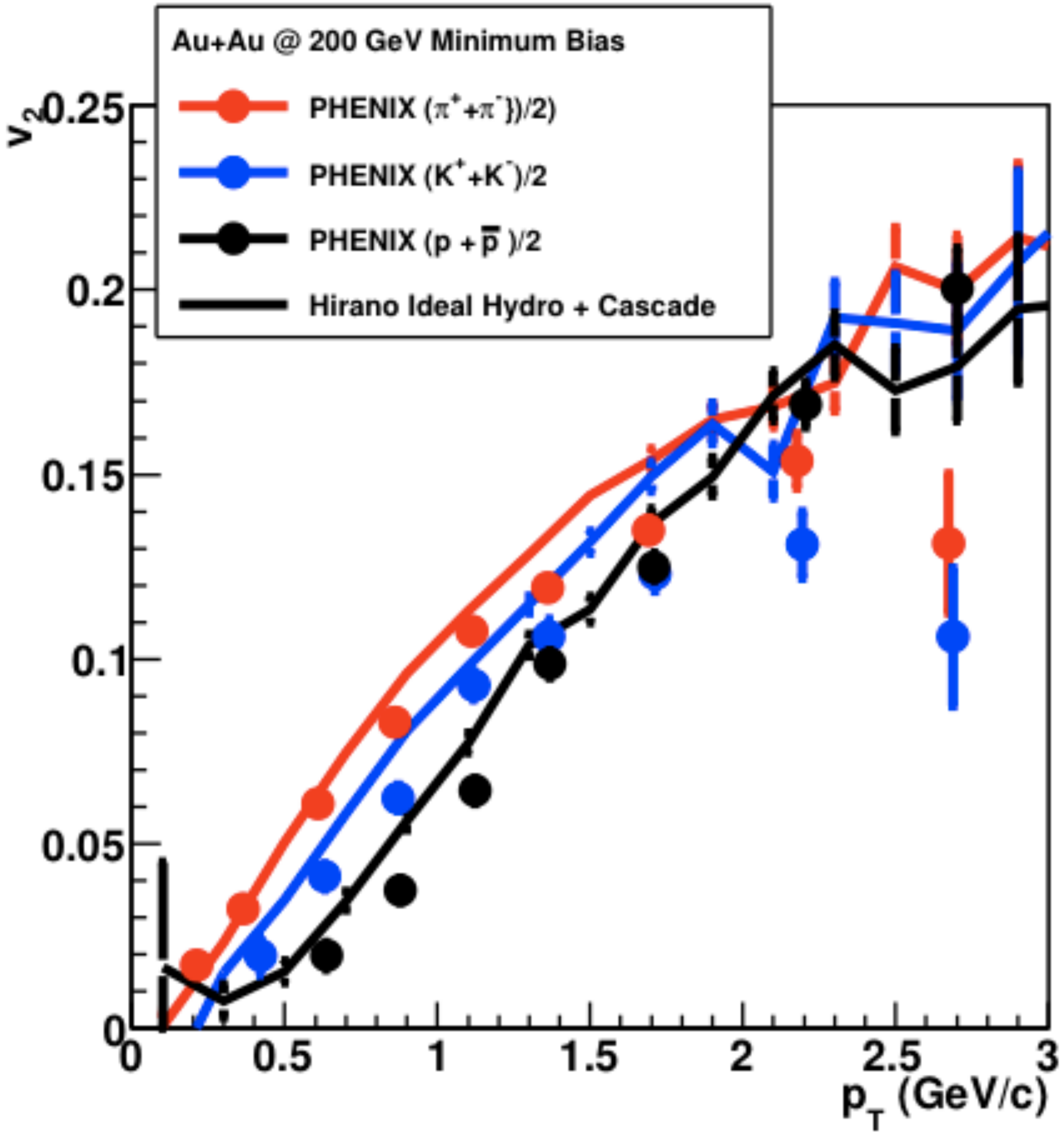
Can jet measurements be integrated into this *standard model* of heavy ion collisions in a meaningful way?

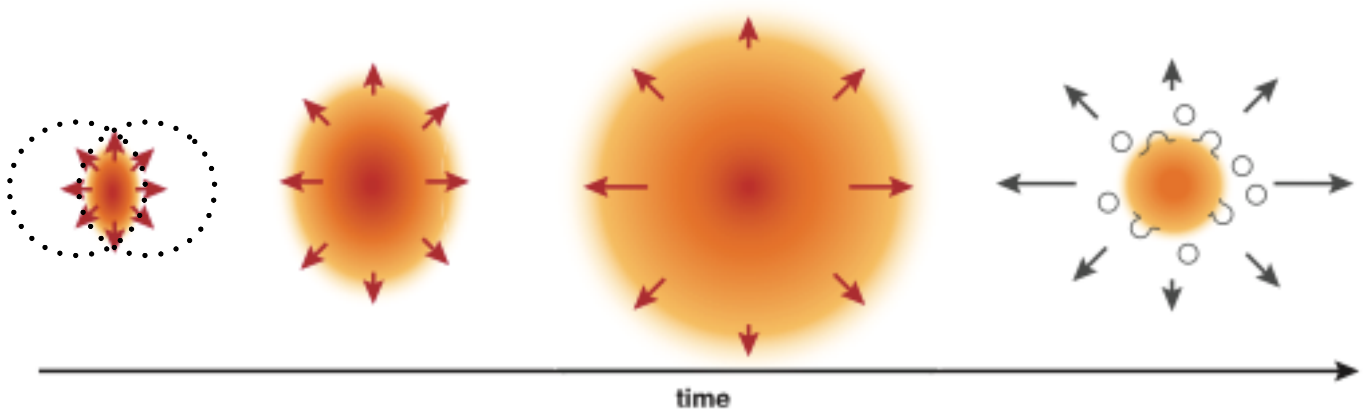
Hydro's Home Turf

spectra



elliptic flow





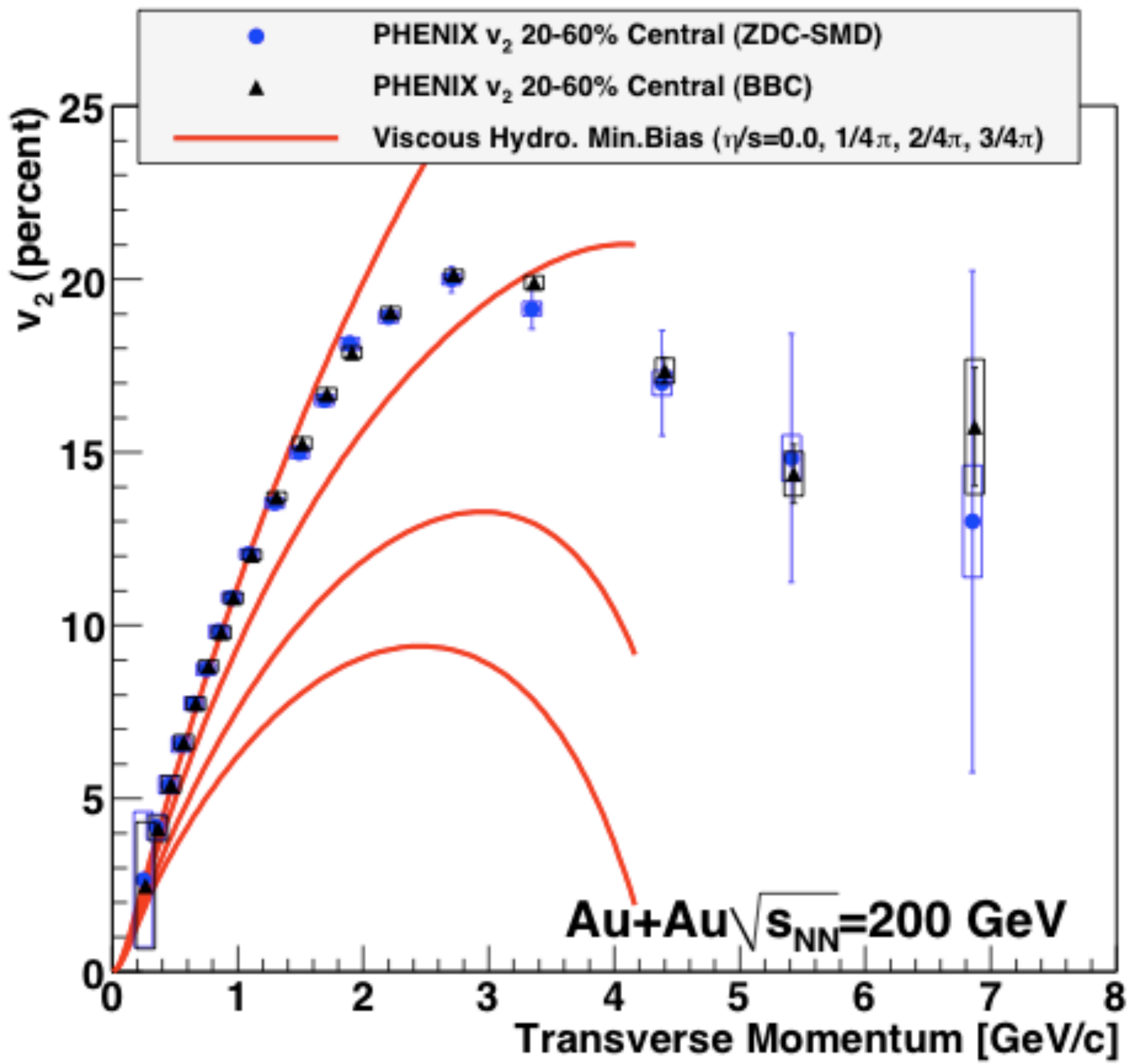
An Assonishingly *Perfect Fluid*

Different descriptions of the initial state yield different best fit values for the viscosity term...

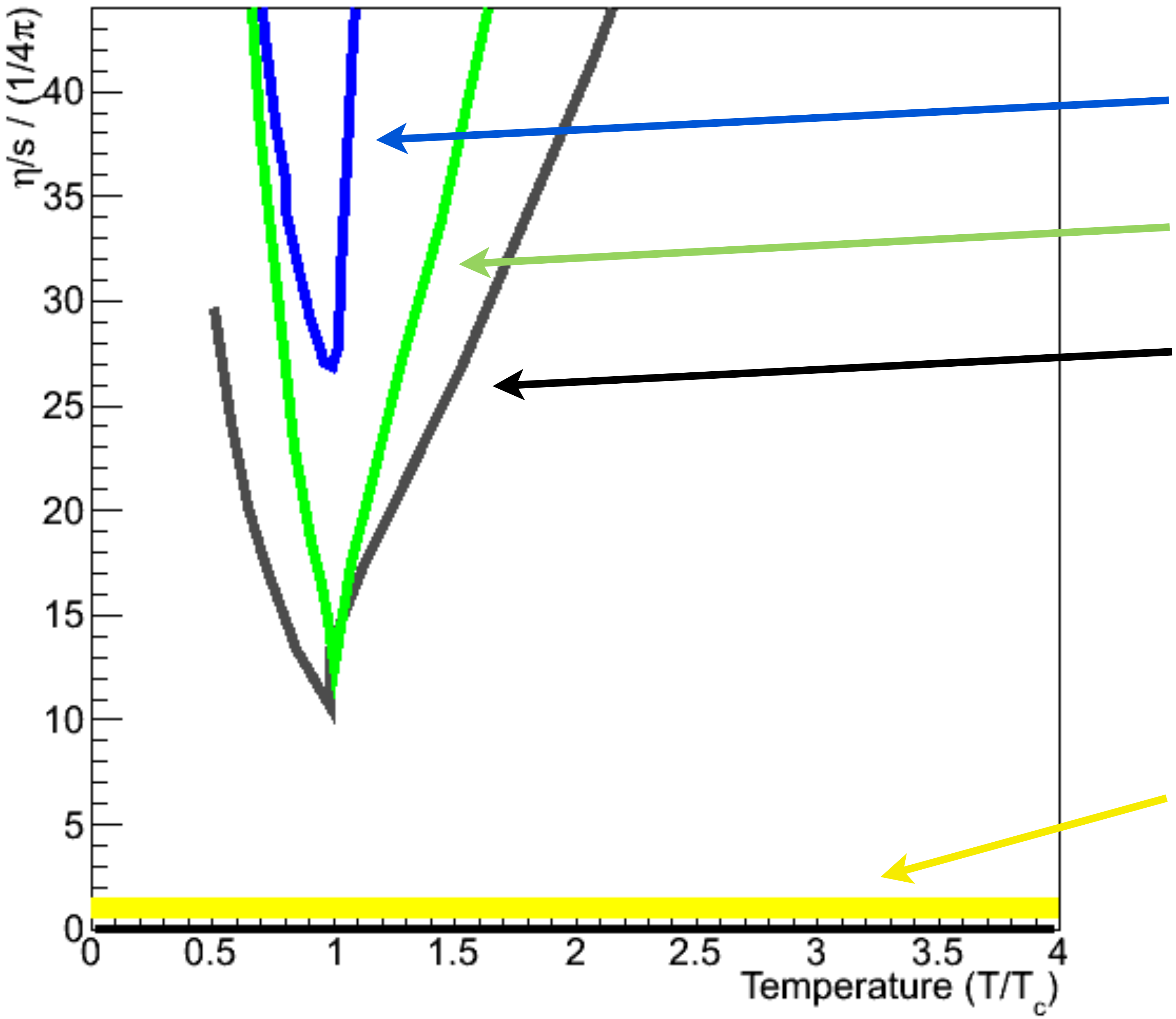
But the different descriptions are all incompatible with large values of viscosity

However, these values are near the conjectured lower bound for quantum fluids

$\eta/s = 1/4\pi$



Low Viscous Fluids



Water at 100 MPa

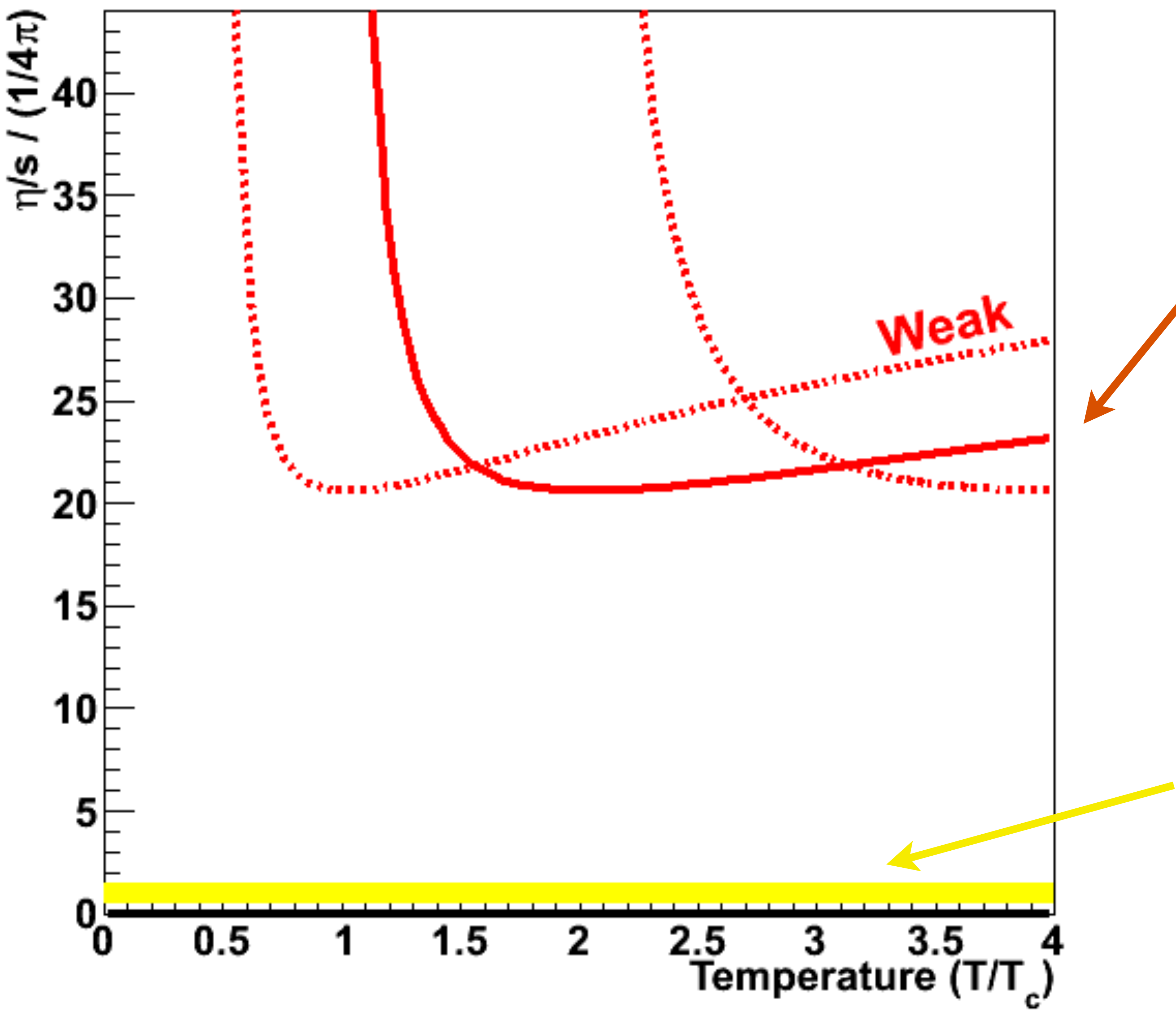
Nitrogen at 3.4 MPa

Helium at 0.1 MPa

Quantum bound

KSS PRL 94, 111601 (2005)

pQGP Calculations



Perturbative QCD

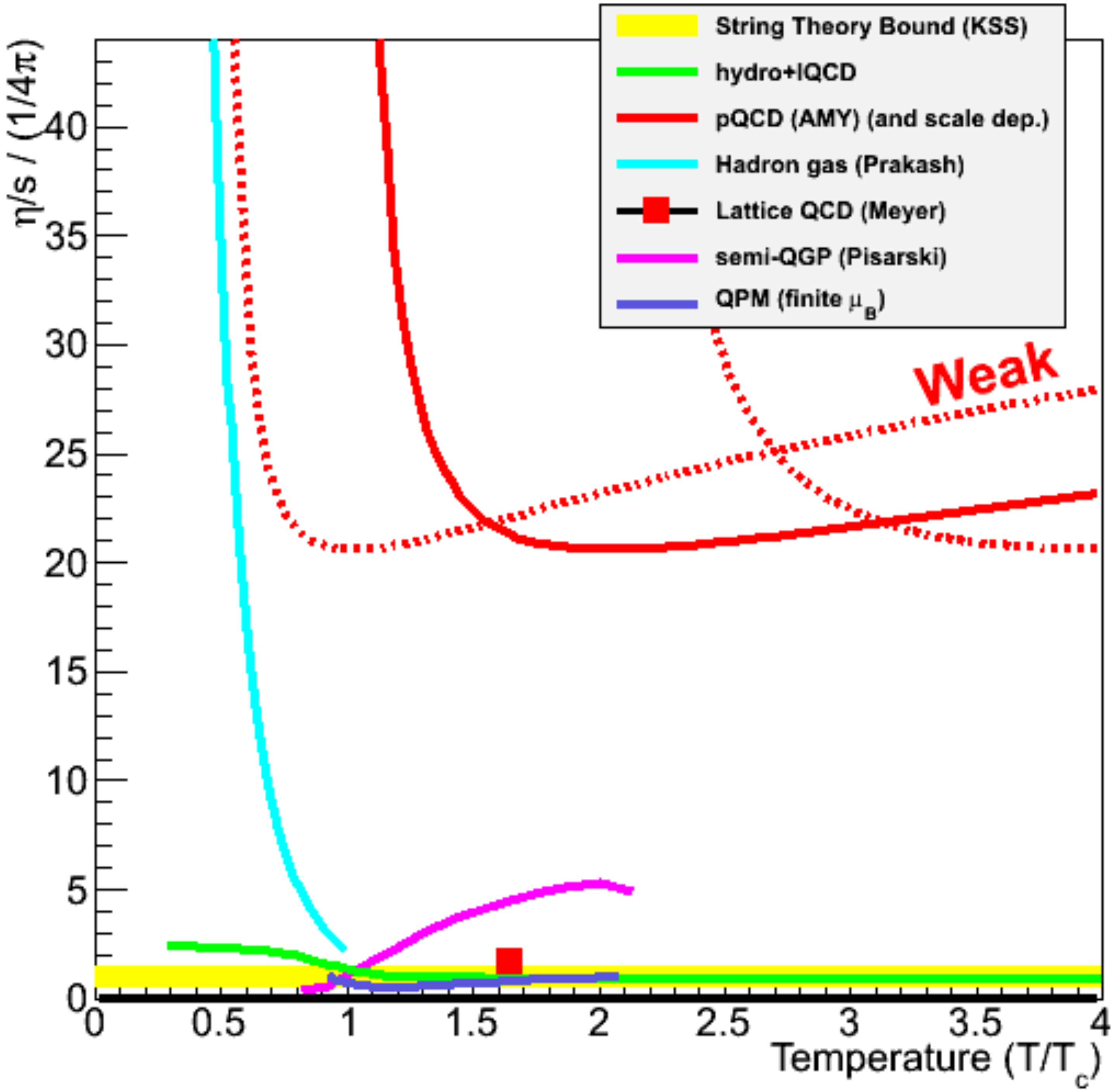
Weakly-coupled description of the QGP imply a much larger viscosity and a very large scale dependence

AYM JHEP 0305:051,2003

Quantum bound

KSS PRL 94, 111601 (2005)

sQGP Calculations



sQGP calculations all yield much lower values
Internally very different…

Hydro + lQCD calculation
Kovtun, Moore, and Romatschke
http://arxiv.org/abs/arXiv:1104.1586

Hadron gas calculation
Prakash (almost 20 years ago) 1/T^4)
http://www.sciencedirect.com/science/article/pii/037015739390092R

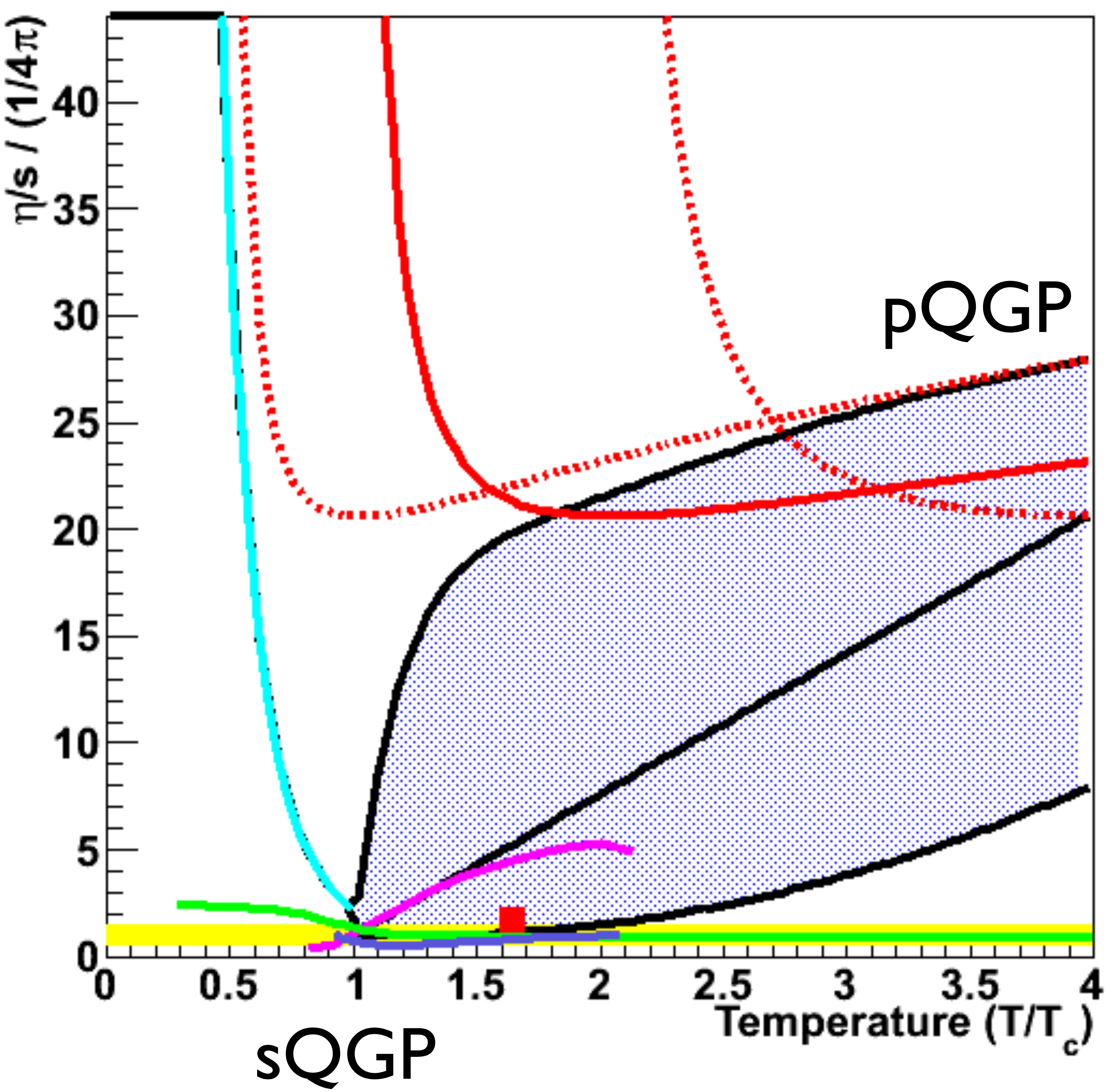
Lattice QCD result
Harvey Meyer (gluodynamics)
http://arxiv.org/abs/0704.1801

QPM, finite mu_B calculation
Shrivistava and Singh
http://arxiv.org/abs/1201.0445

Semi-QGP calculation
Rob Pisarski with kappa = 8
http://arxiv.org/abs/arXiv:0912.0940

sQGP-pQGP Evolution

If we accept: (I) the viscosity is low near Tc as implied by the hydro fits...
(II) at large T, the pQCD description is correct...



Some transition between the two must exist. Illustrative scenarios:

(I) Rapid evolution

(II) Intermediate evolution

(III) Slow evolution

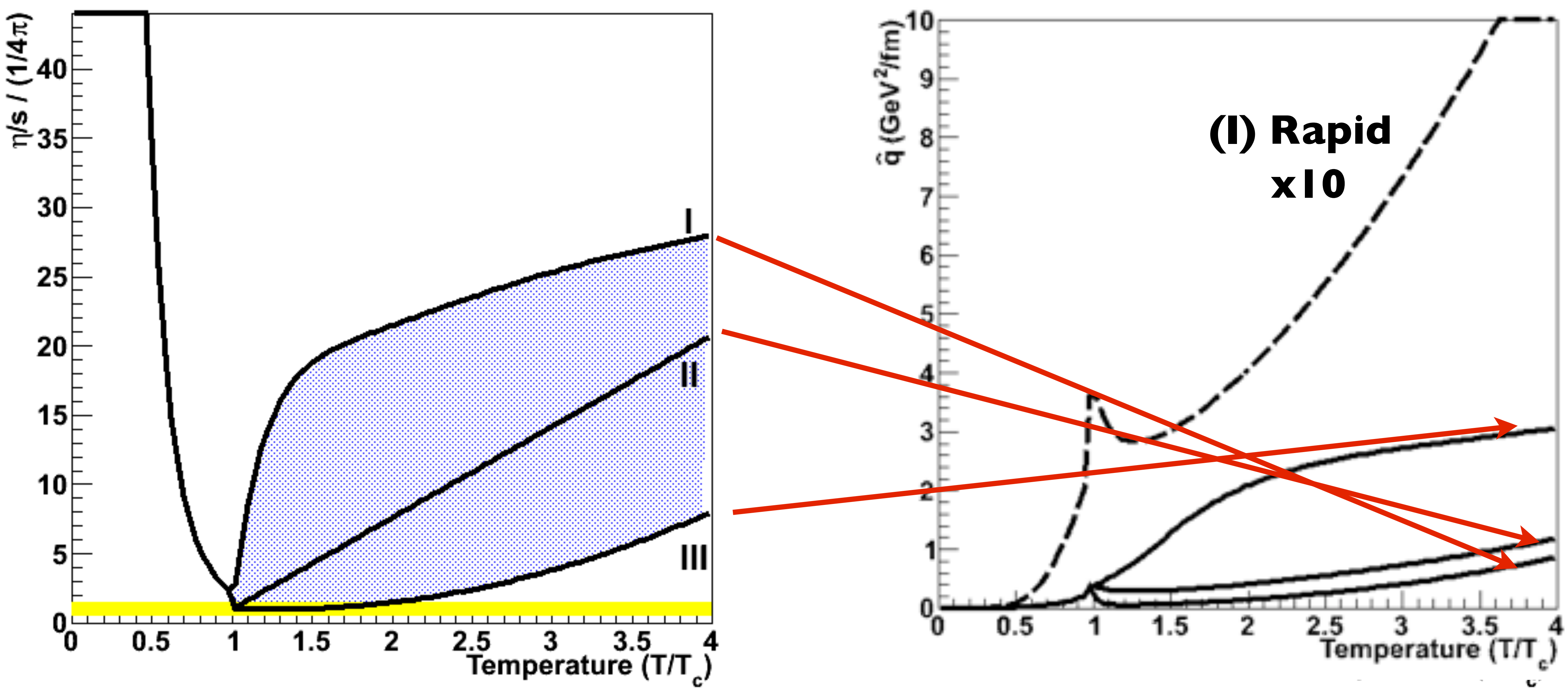
Jet Quenching Implications

PRL **99,** 192301 (2007) PHYSICAL REVIEW LETTERS week ending 9 NOVEMBER 2007

Small Shear Viscosity of a Quark-Gluon Plasma Implies Strong Jet Quenching

Abhijit Majumder,[1] Berndt Müller,[1] and Xin-Nian Wang[2]
[1]*Department of Physics, Duke University, Durham, North Carolina 27708, USA*
[2]*Nuclear Science Division, MS 70R0319, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
(Received 10 March 2007; revised manuscript received 13 June 2007; published 7 November 2007)

in the pQGP limit: $\hat{q} = 1.25T^3/(\eta/s)$



Quenching near T_c

PRL **102,** 202302 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

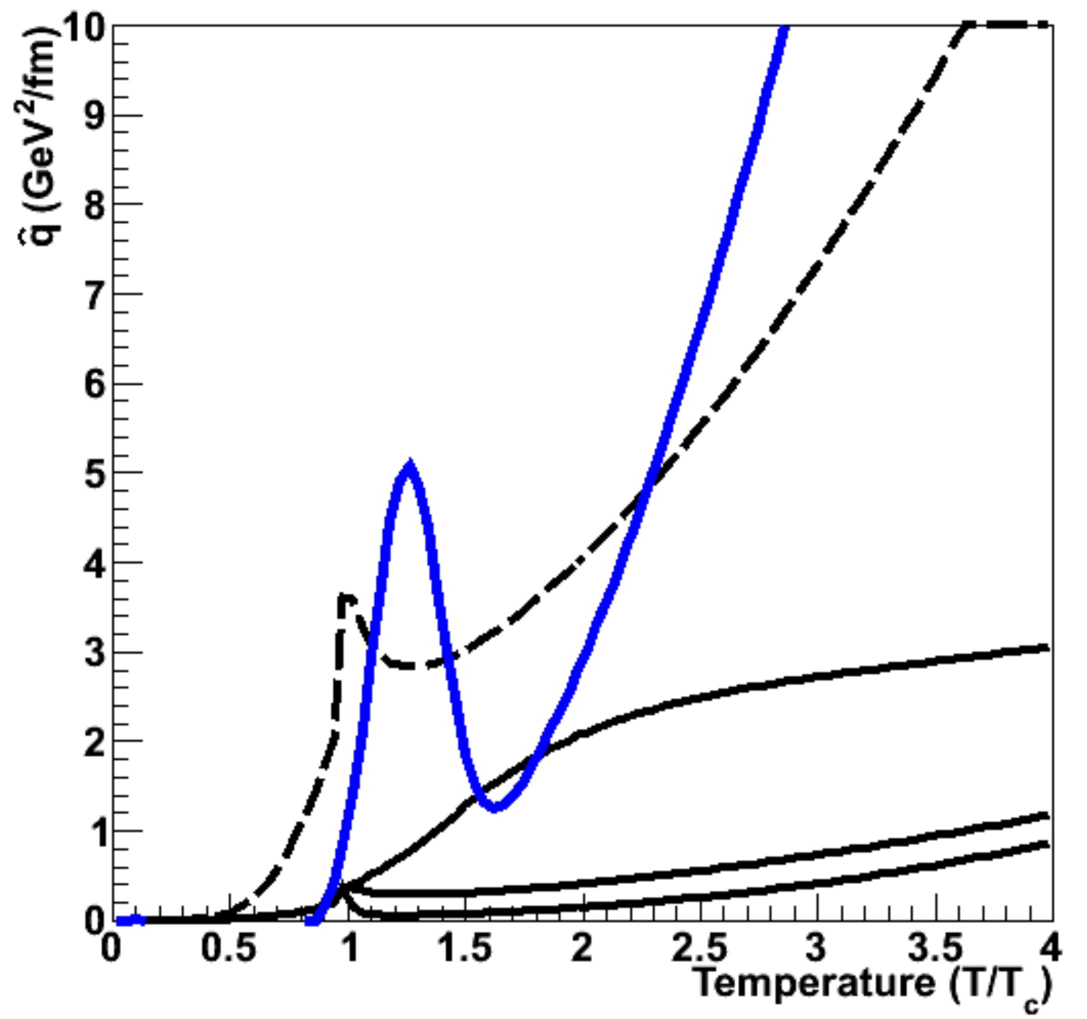
Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

Jinfeng Liao[1,2,*] and Edward Shuryak[1,†]
[1]*Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794, USA*
[2]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
(Received 22 October 2008; revised manuscript received 19 February 2009; published 22 May 2009)

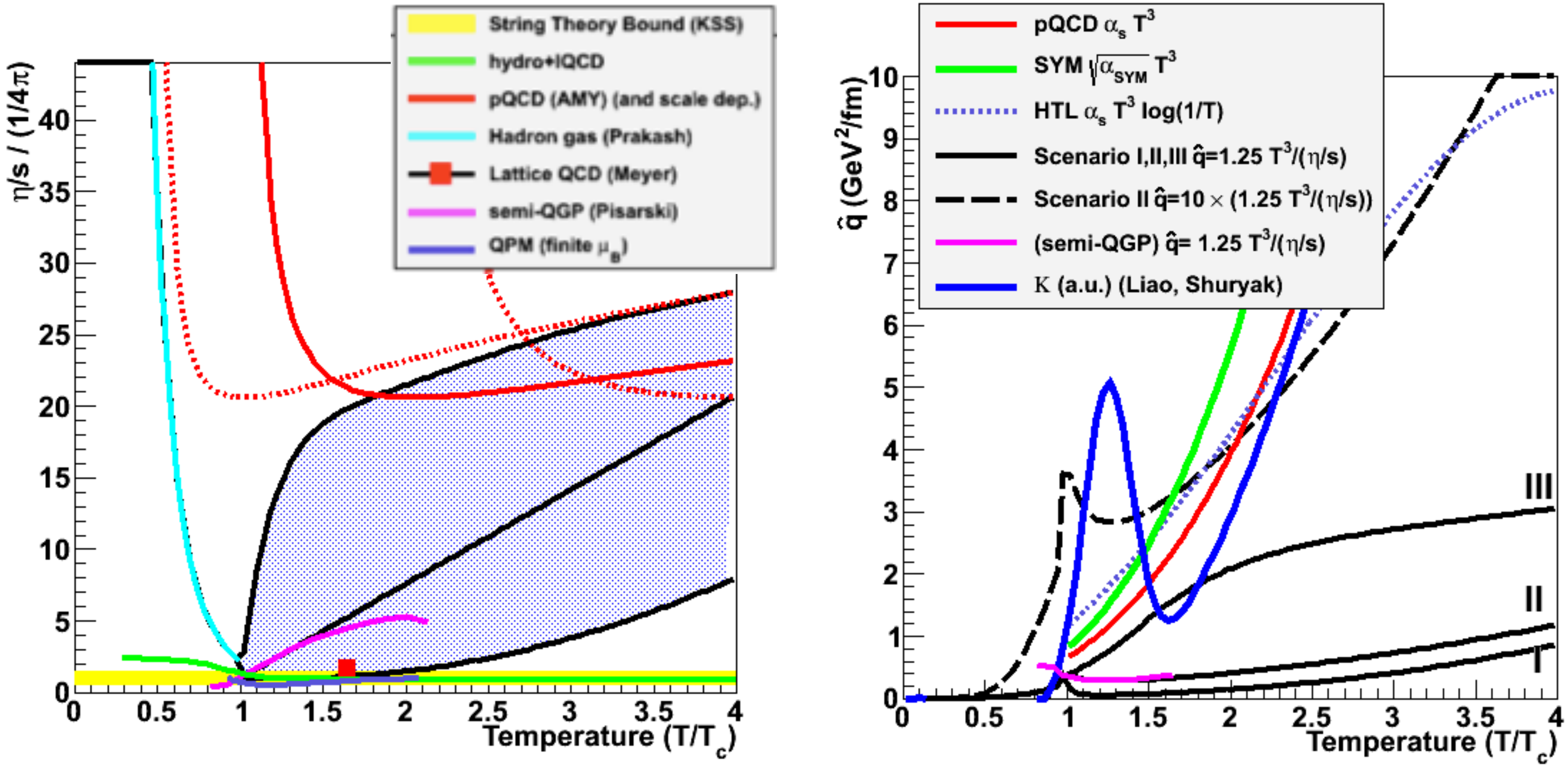
"[We find] the jet quenching is a few times stronger near T_c relative to the QGP at $T > T_c$"

Completely different physical source, here the creation of magnetic monopoles

Thus the evolution of η/s likely has implications on the characteristics of jet quenching



The η/s and q-hat Dualism

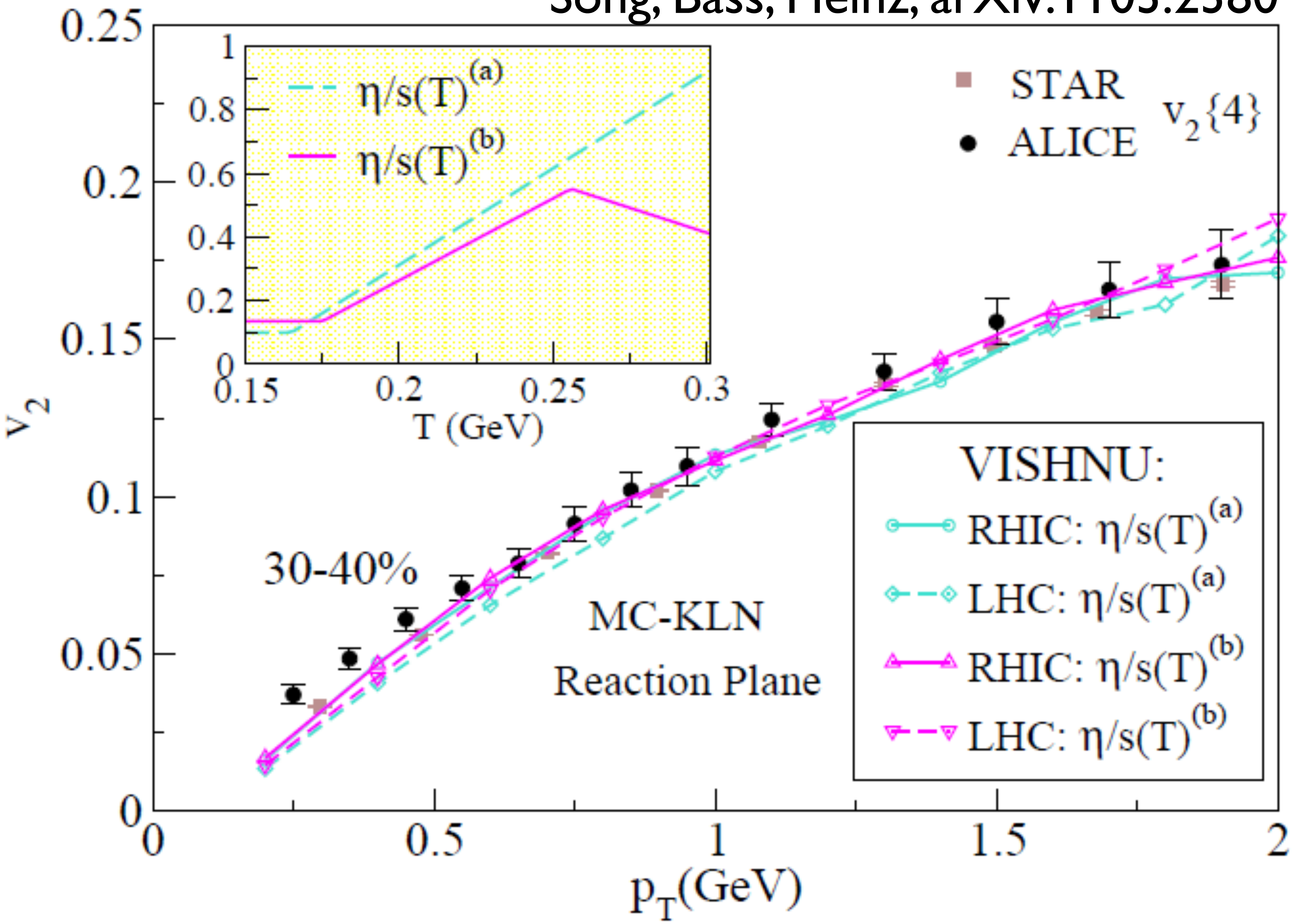


Of course a better theoretical translation between the medium properties and energy loss characteristics is needed

But an opportunity exists to **integrate the jet observables** into our wider understanding of heavy ion collisions

Hydro-only Attempts

Song, Bass, Heinz, arXiv:1103.2380



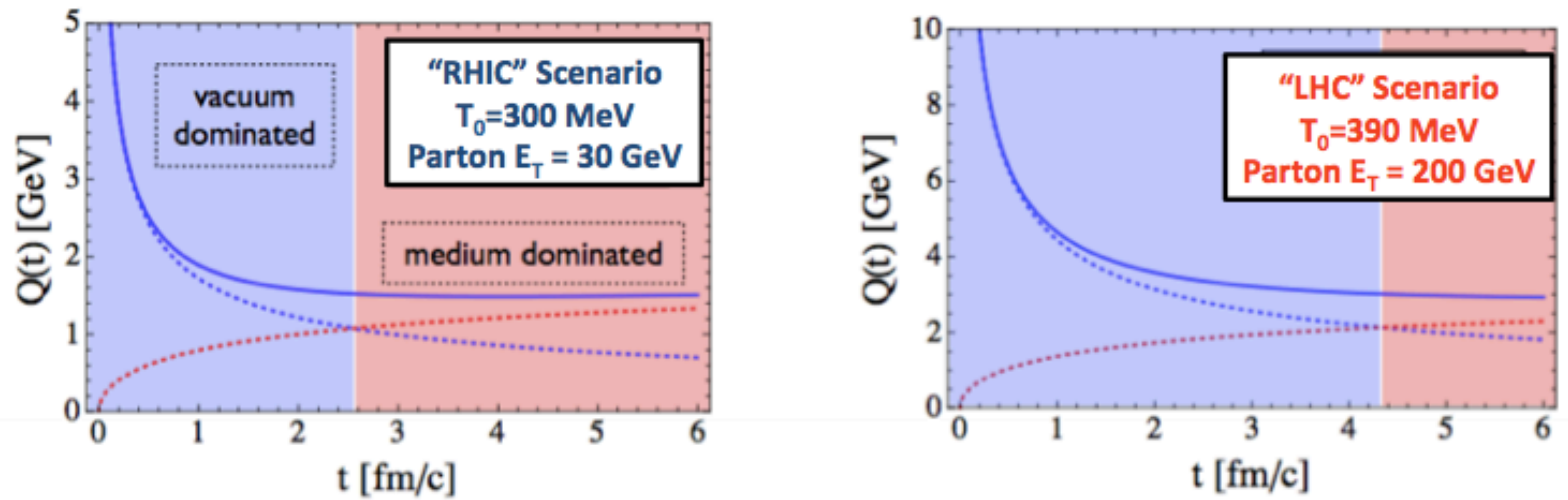
It isn't clear hydro can solve this on its own...

LHC Collaborative or Competitive?

Hard Parton Virtuality

$$Q^2_{vac}(t) = \frac{E}{2t} \qquad Q^2_{med}(t) = \int \hat{q}(t)\,dt$$

$$Q^2(t) = Q^2_{vac}(t) + Q^2_{med}(t)$$



LHC Scenario

the vacuum contribution to the parton virtuality to fall below the in-medium contribution in the pQCD scenario. This effect is due to the collinear splitting in pQCD, which reduces the parton energy only gradually and thus leads to an increase in time dilation as the virtuality drops. This means that the very energetic parton hardly notices the medium for the first 3 – 4 fm of its path length. On the other hand, in the AdS/CFT scenario, parton energy and virtuality

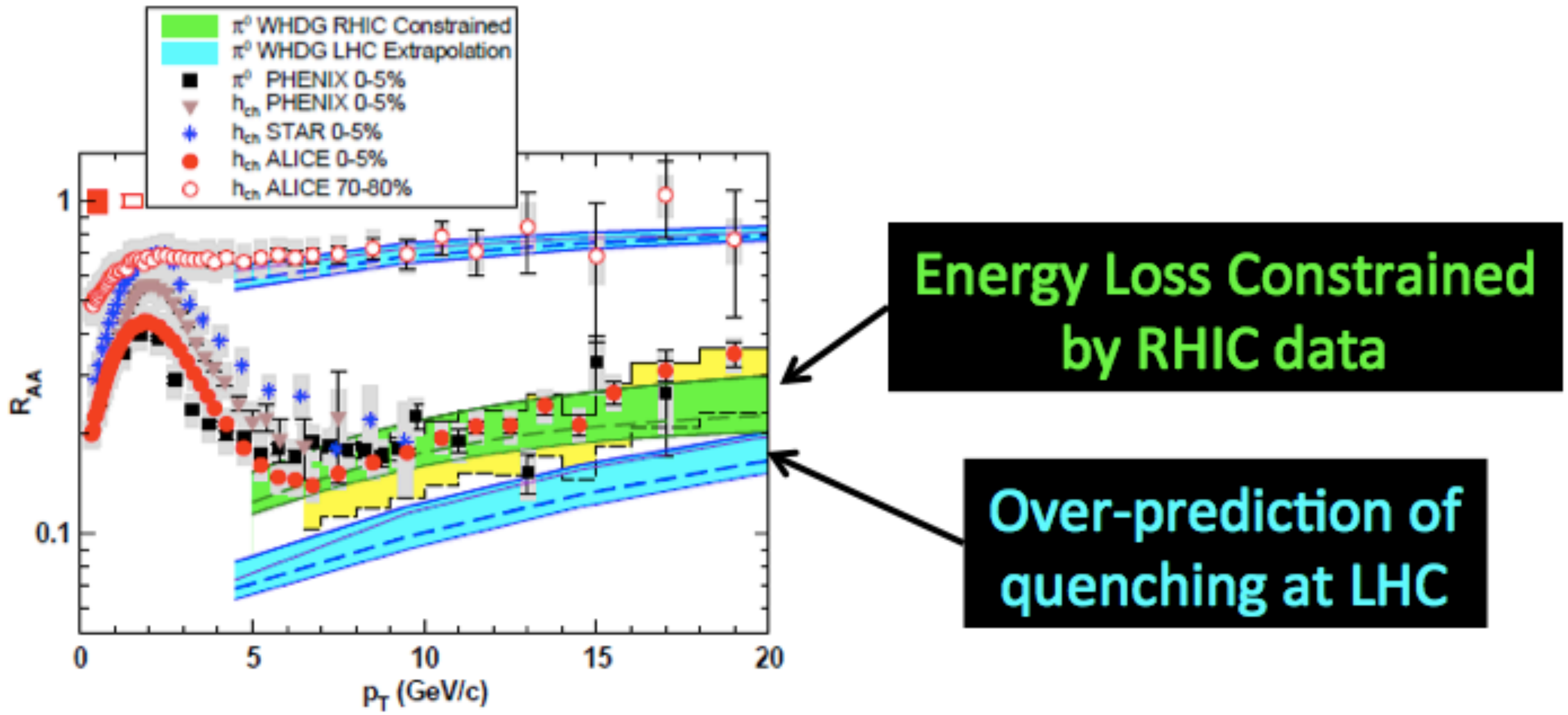
B. Muller. Nucl.Phys., A855:74–82, 2011, RHIC/AGS Users Meeting 2011

LHC Collaborative or Competitive?

The surprisingly transparent sQGP at LHC

W.A. Horowitz [a,*], Miklos Gyulassy [b]

Nuclear Physics A 872 (2011) 265–285



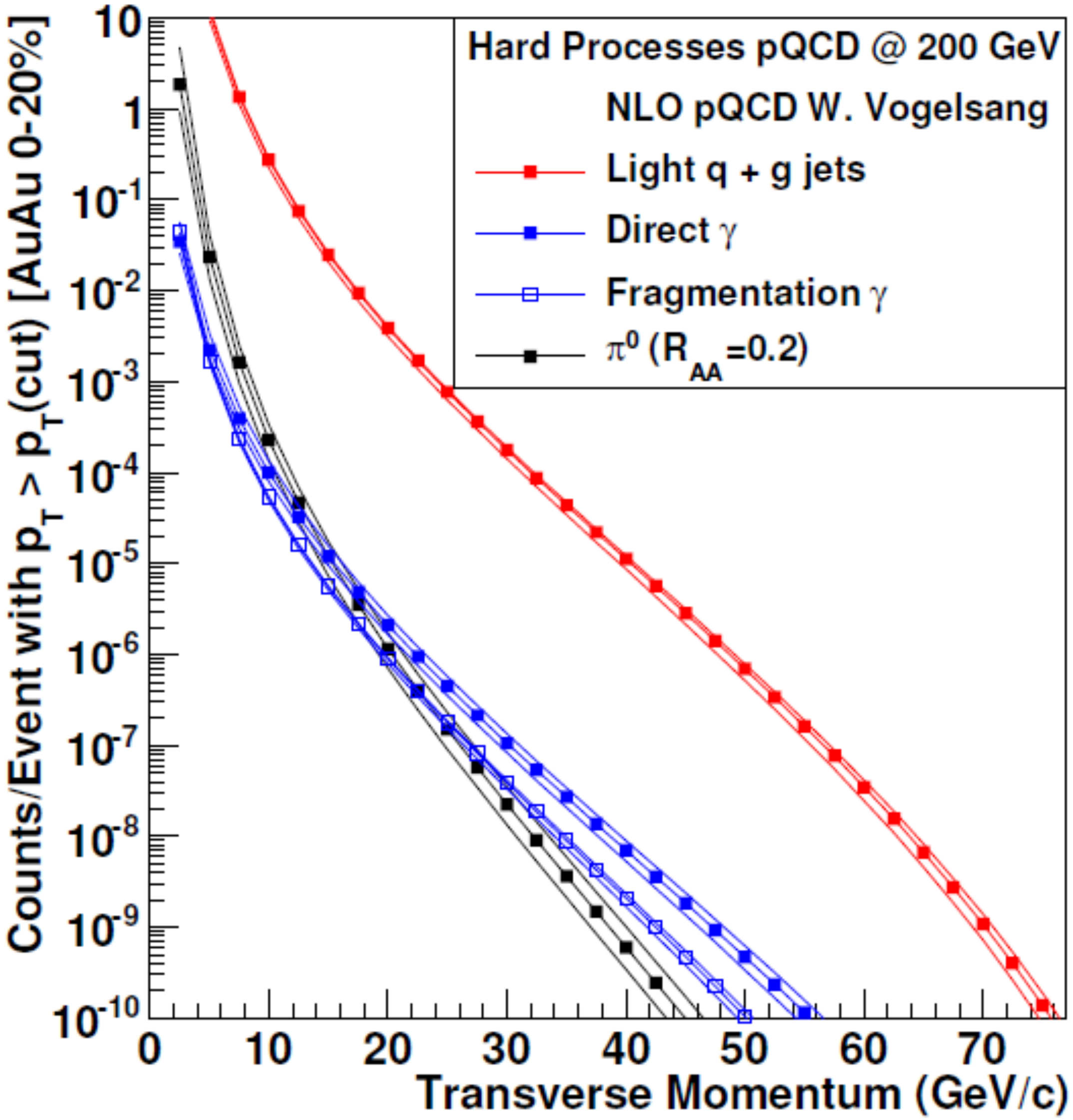
Since there are no adjustable parameters for us, the significant tension between our results and the ALICE data is a failure to *simultaneously* describe the normalizations of both the RHIC and LHC $R_{AA}(p_T)$. One possibility is the sQGP produced at LHC is in fact more transparent than predicted by perturbative QCD tomographic models with medium densities that scale with observed particle rapidity densities.

Beam energy variation will likely be an asset

Jet Capabilities

Can we measure these jet observables at RHIC?

RHIC Jet Rates

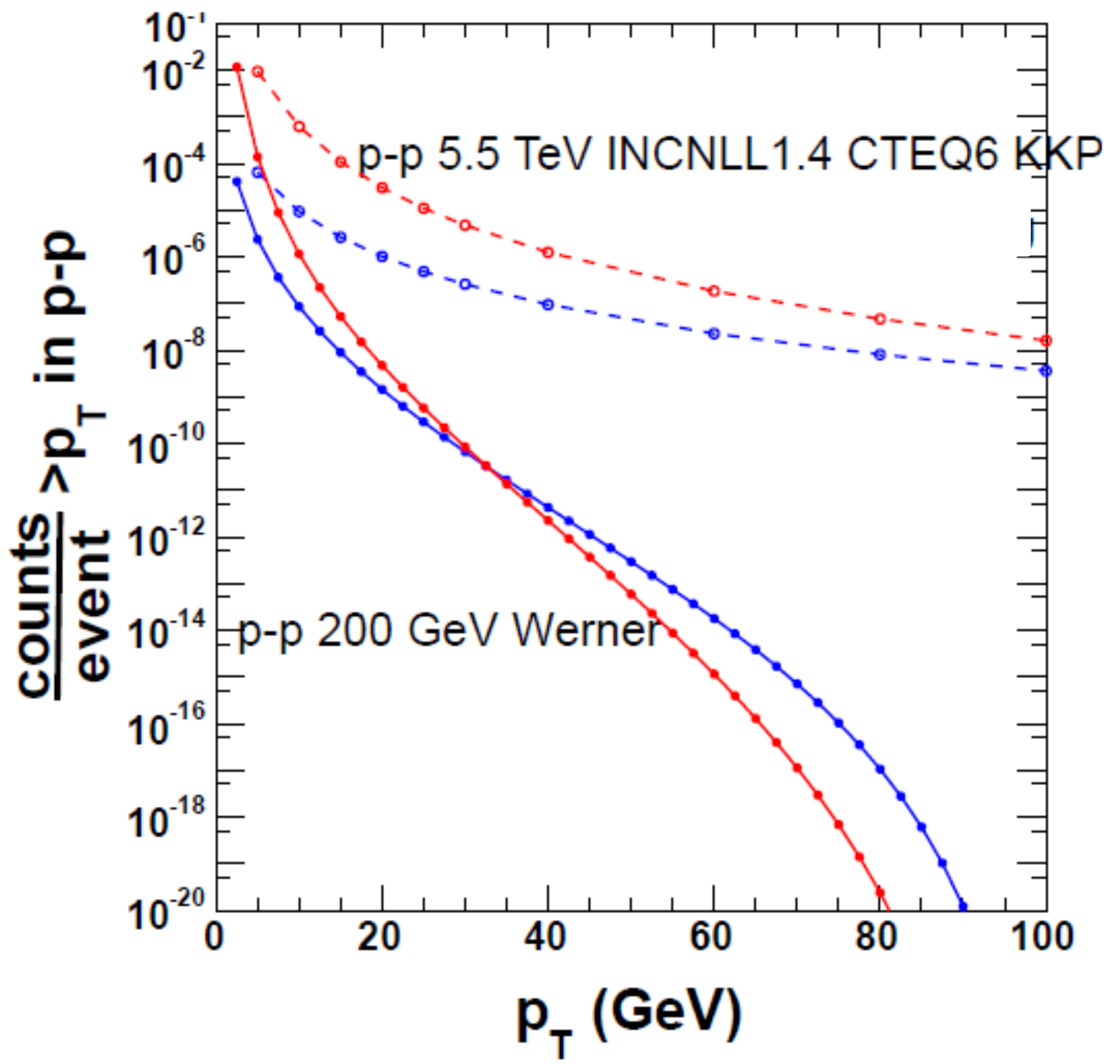


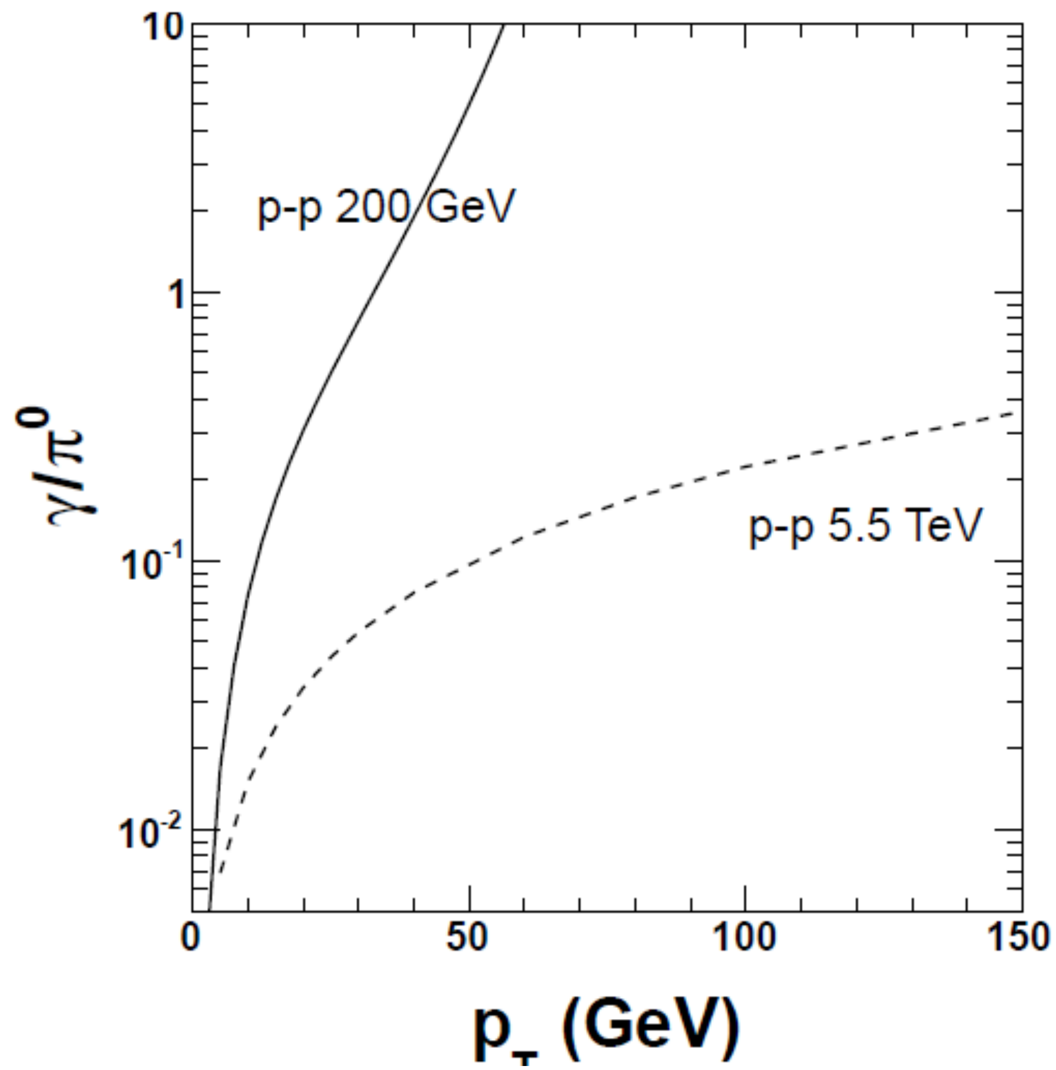
	Au+Au (central 20%)	p+p	d+Au
>20GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40GeV	10^5 jets	10^4 jets	10^5 jets
>50GeV	10^4 jets	10^3 jets	10^4 jets

Huge rates allow differential measurements with geometry (v_2, v_3, A+B, U+U, …) & precise control measurements (d+Au & p+p).
Over 60% as dijets!

Rates based on full stochastic cooling, but no additional accelerator upgrades

Direct Photons





γ/π^0 very large at RHIC

good S/B >20GeV

substantial rate even >30GeV

RHIC a very good place for γ-jet correlations

How Well Can Jets Be Measured at RHIC?

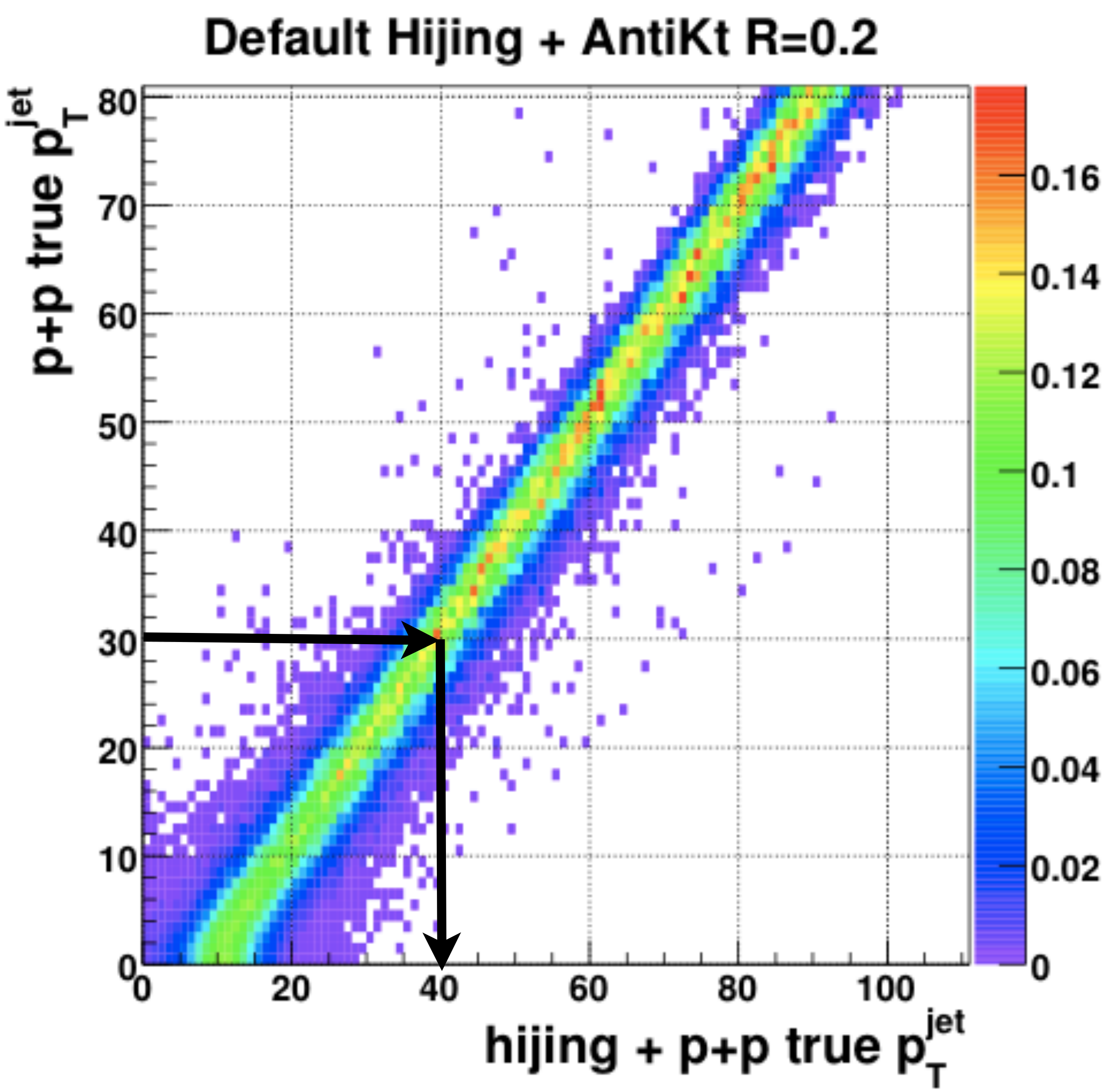
(I) Irresolution: How well can we measure real jets?

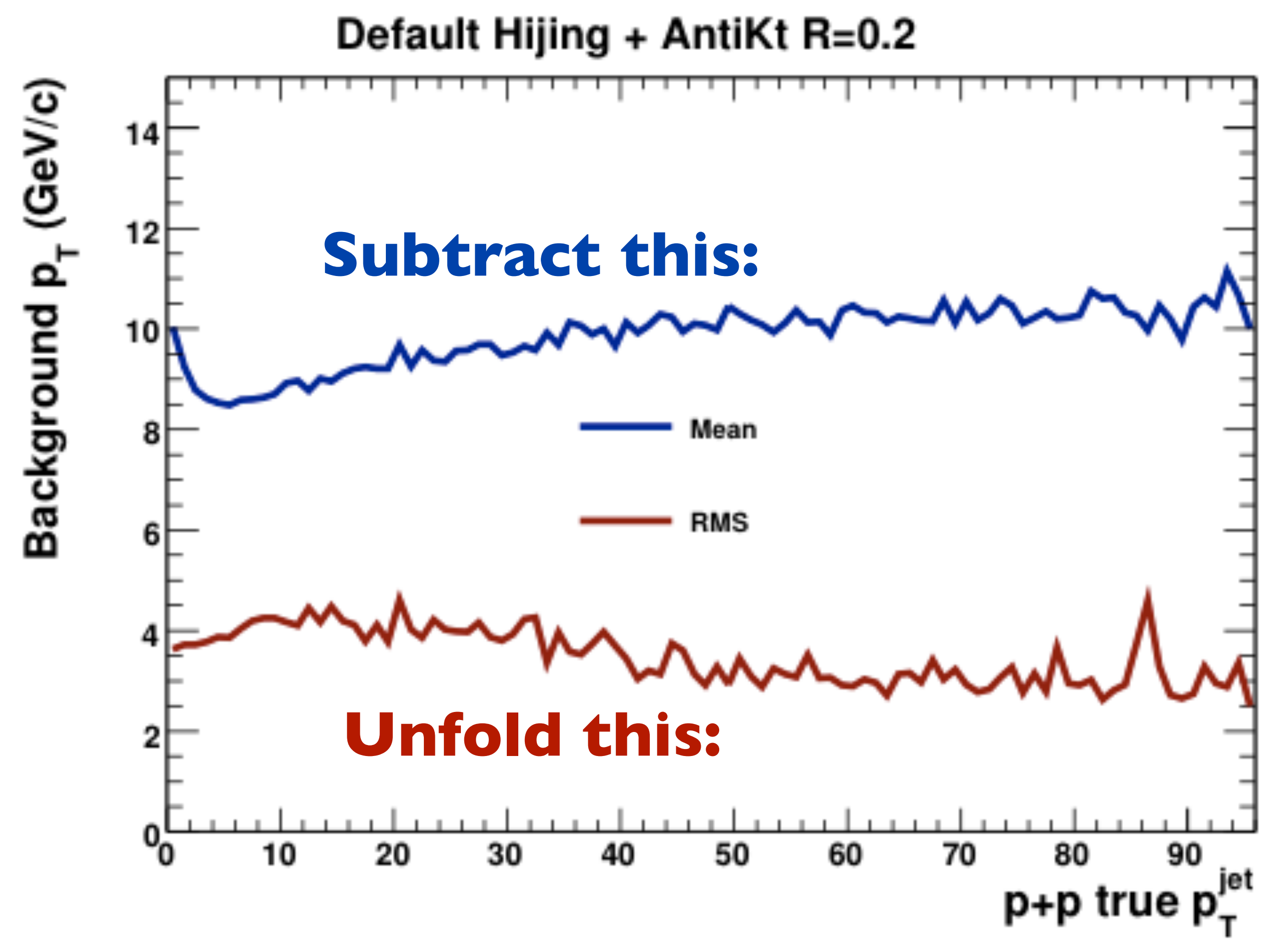
metrics: jet energy scale, jet energy resolution
method: embed PYTHIA jets in HIJING events

(II) Contamination: How are the jet measurements impacted by background fluctuations masquerading as jets--fakes?

metric: relative rate of fake jets and true jets
method: 500M minimum bias HIJING events to determine relative rates of fake and real jets

Embedding





A 30 GeV embedded jet picks up ~10 GeV from the background to become a 40 GeV reconstructed jet

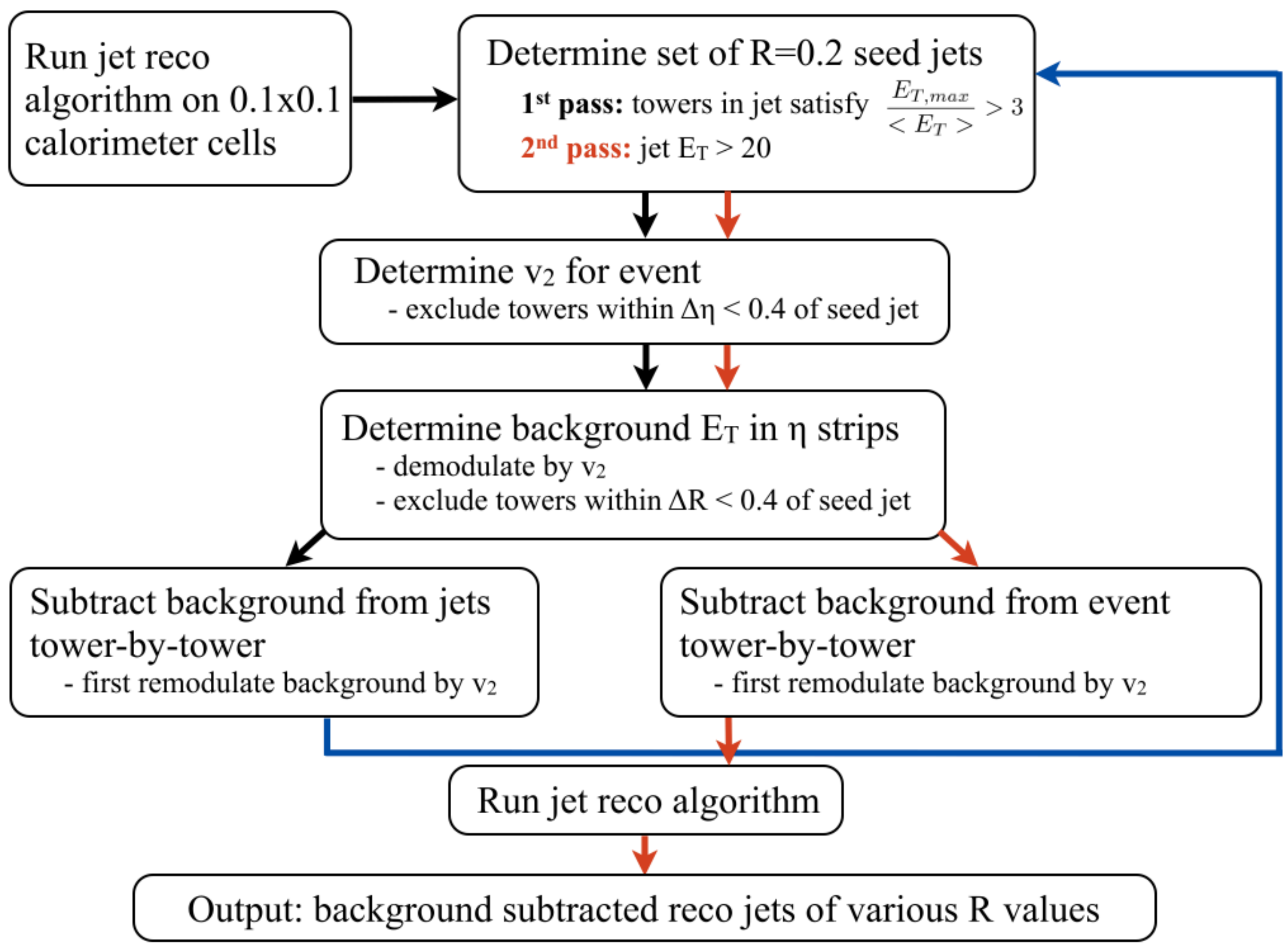
These tools are underdevelopment...

Background Subtraction

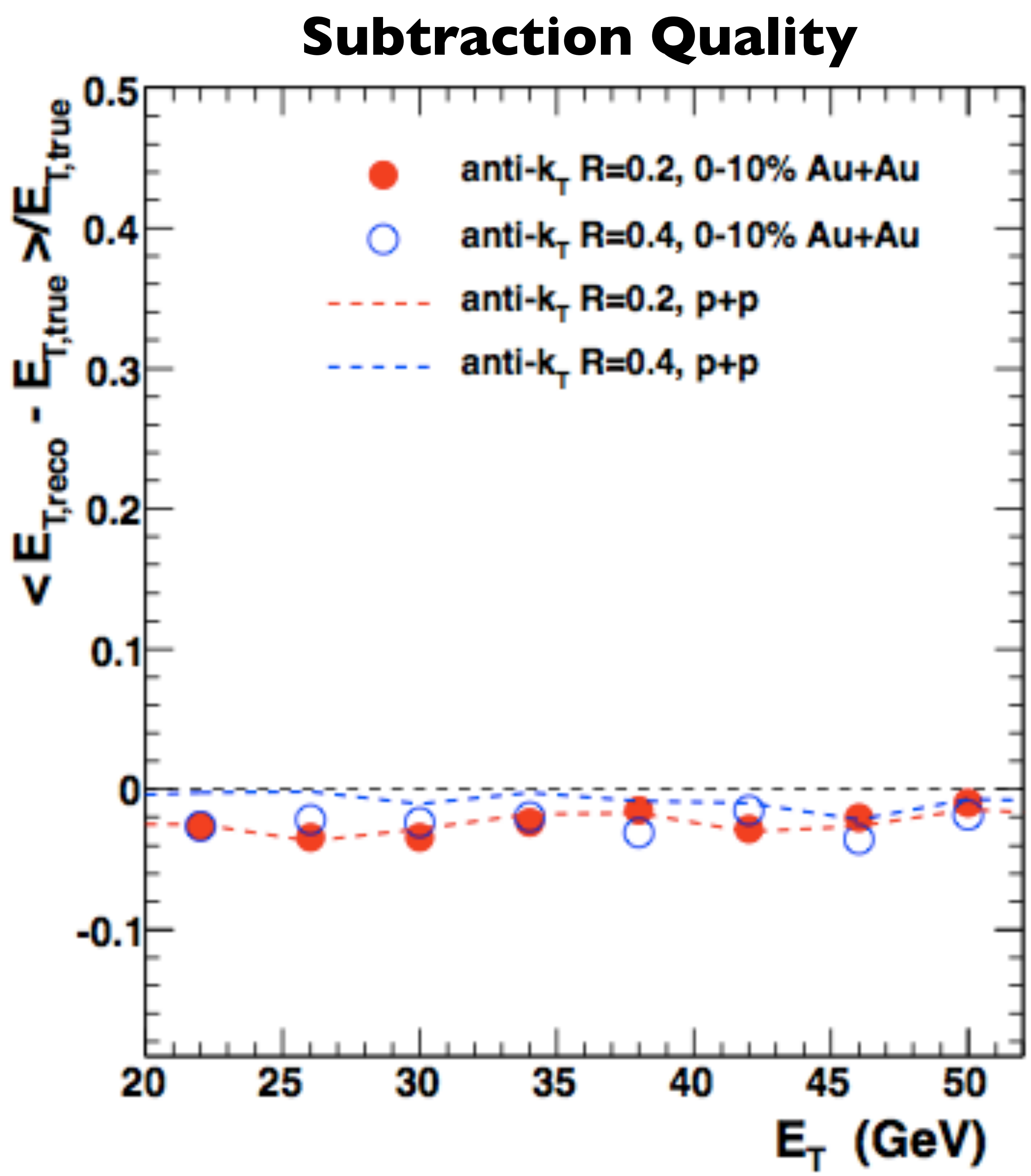
Jet - Underlying Event Separation Method for Heavy Ion Collisions at the Relativistic Heavy Ion Collider

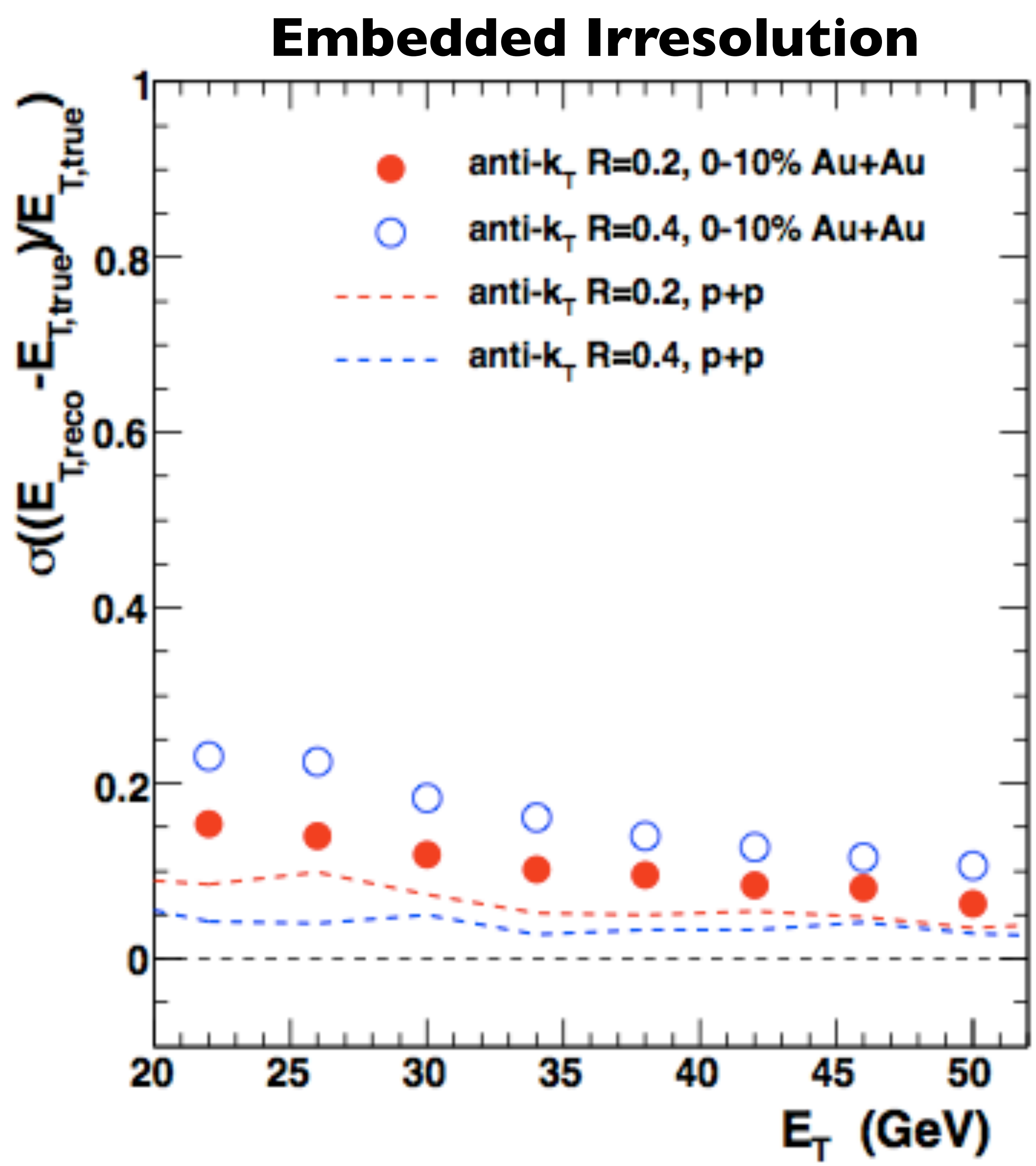
J. A. Hanks[1], A. M. Sickles[2], B. A. Cole[3], A. Franz[2], M. P. McCumber[4], D. P. Morrison[2], J. L. Nagle[4], C. H. Pinkenburg[2], B. Sahlmueller[1], P. Steinberg[2], M. von Steinkirch[1], M. Stone[4]
[1] *Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, New York 11794-3400, USA*
[2] *Physics Department, Brookhaven National Laboratory, Upton, New York, 11973-5000*
[3] *Columbia University, New York, New York 10027 and Nevis Laboratories, Irvington, New York 10533, USA and*
[4] *University of Colorado, Boulder, Colorado 80309, USA*
(Dated: March 8, 2012)

arXiv:1203.1353



Irresolution Performance



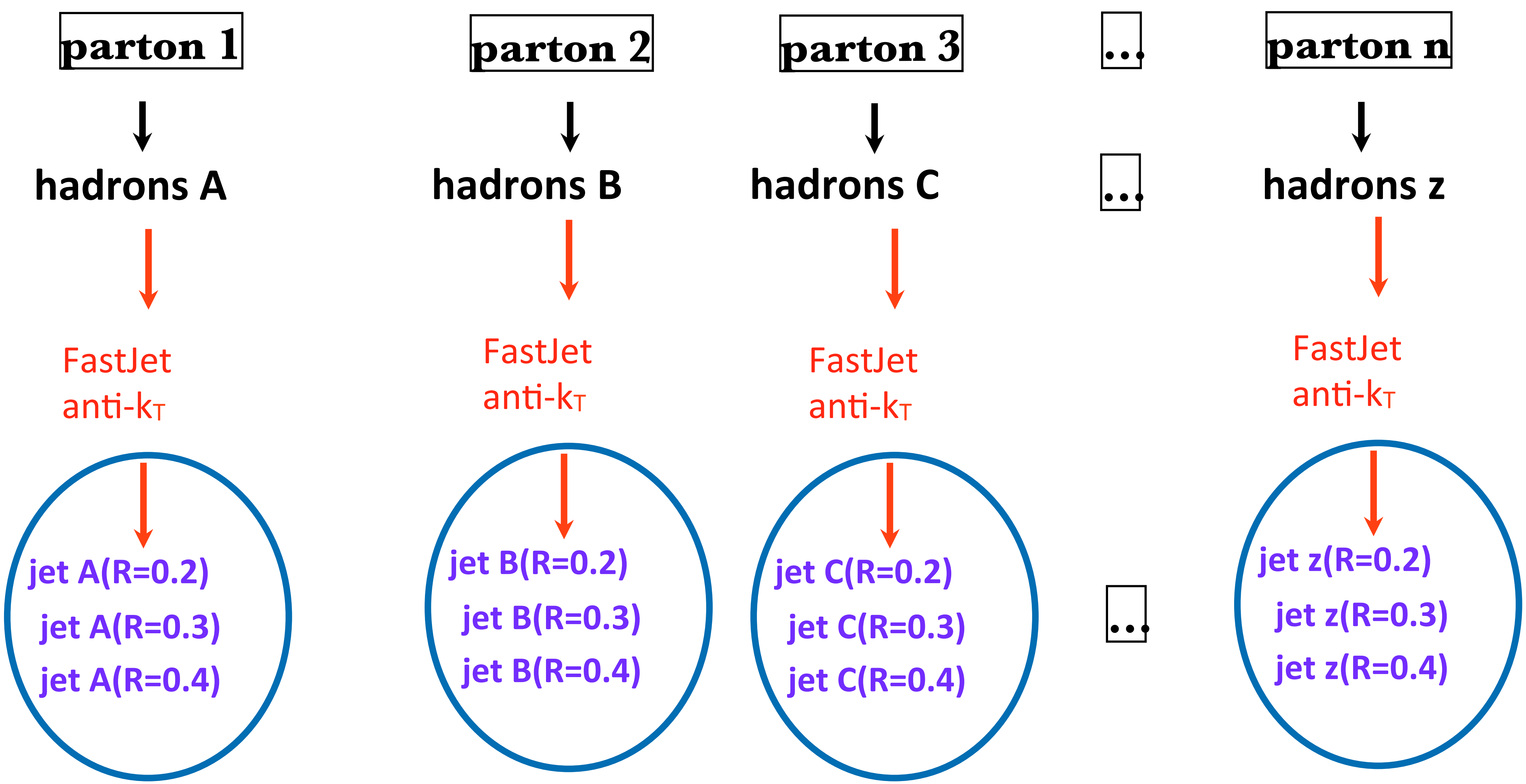


good performance in heavy ion background, small over-subtraction of few%

resolution only from the underlying event, no detector resolution included

Truth Jets

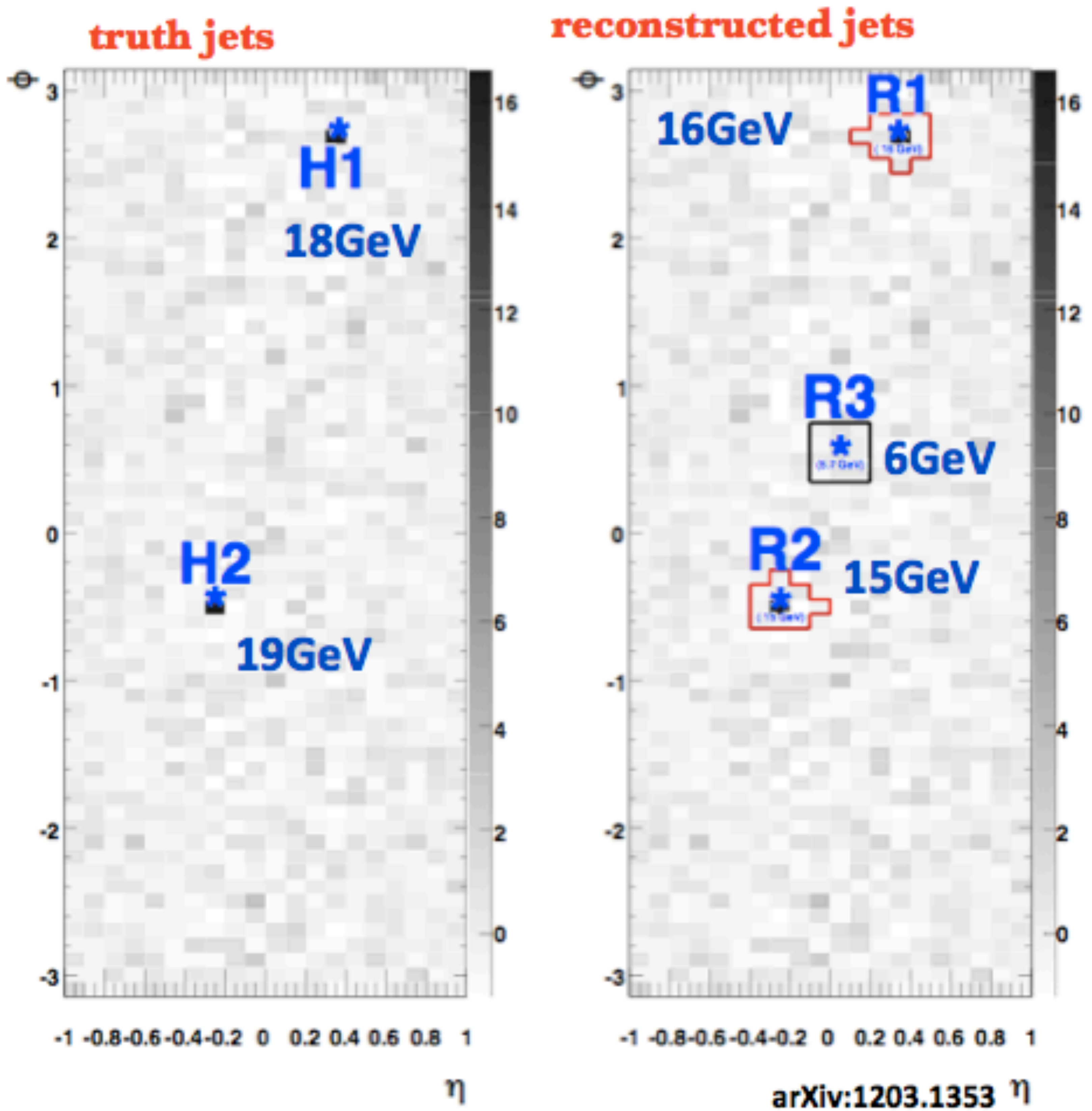
Implemented a modified HIJING simulation to report instances of jet production whenever those processes are called.



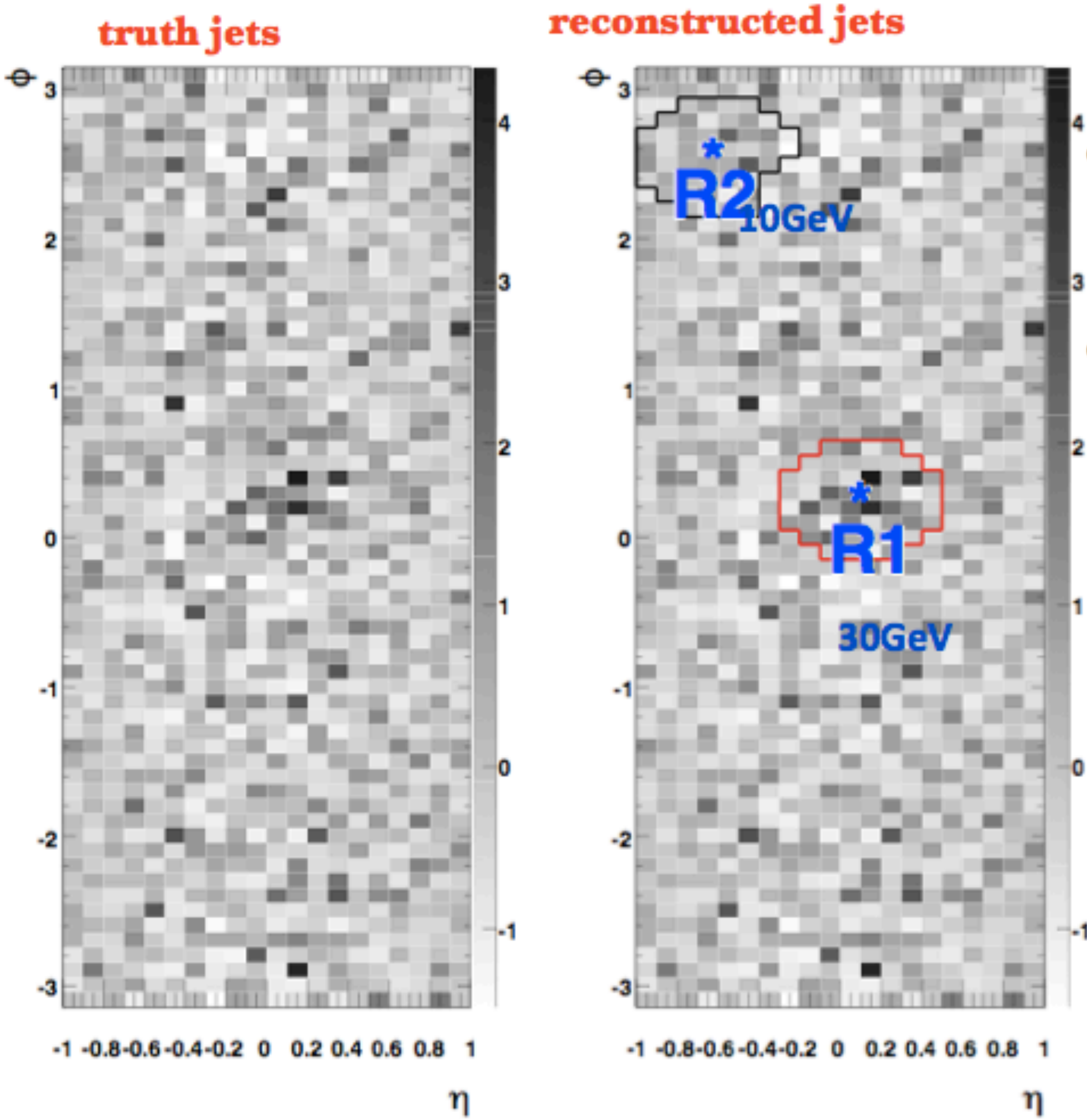
Working Jet Reconstruction Example

- b = 1.8fm HIJING dijet event
- well reconstructed with anti-k_T R=0.2

Calorimetric Event Displays



Fake Jet Example

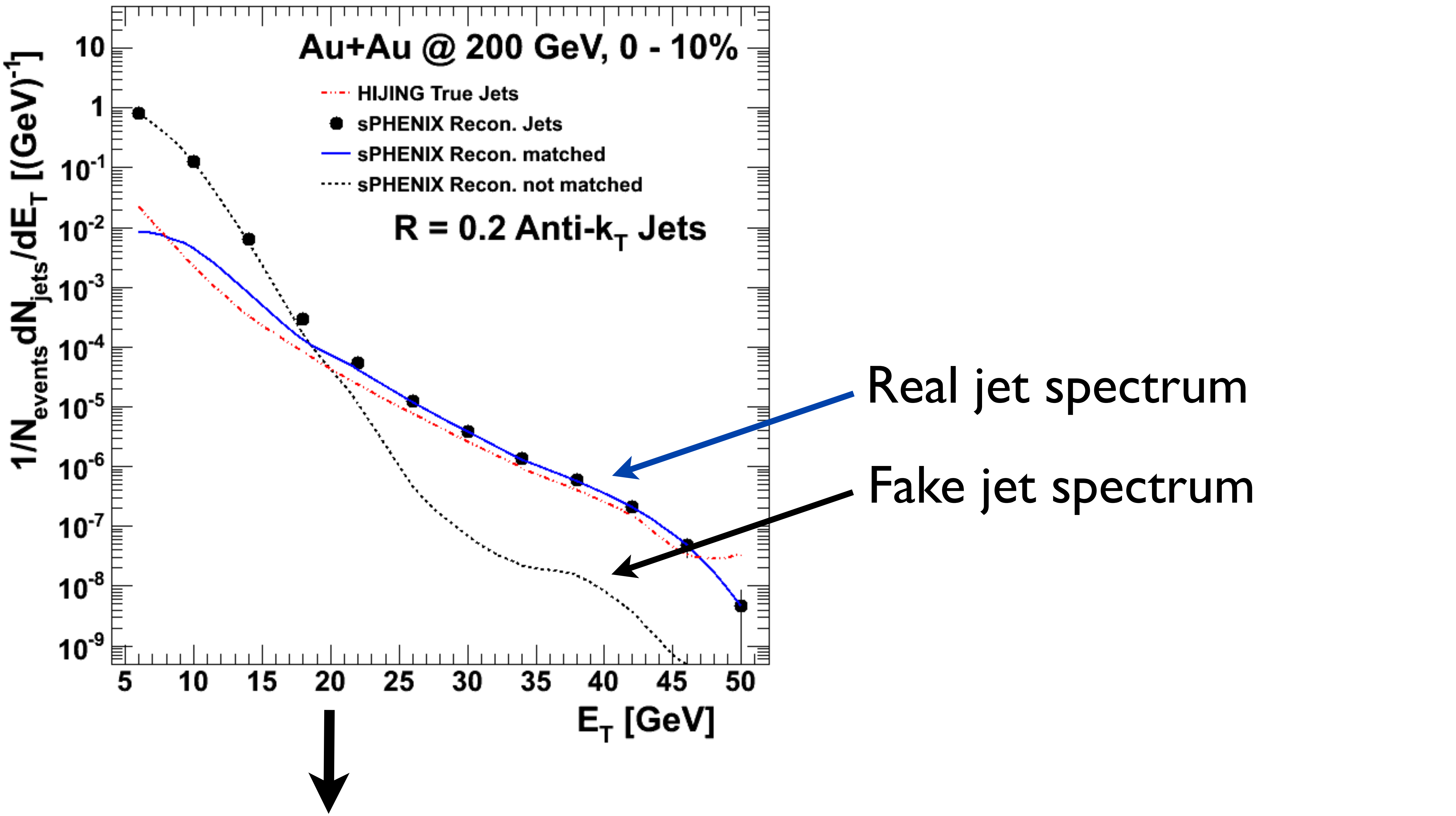


- b=2.4 HIJING event, no true jets
- 30 & 10GeV fake jets with anti-k_T R=0.4

however, we looked at 500M events! need quantitative rate assessment

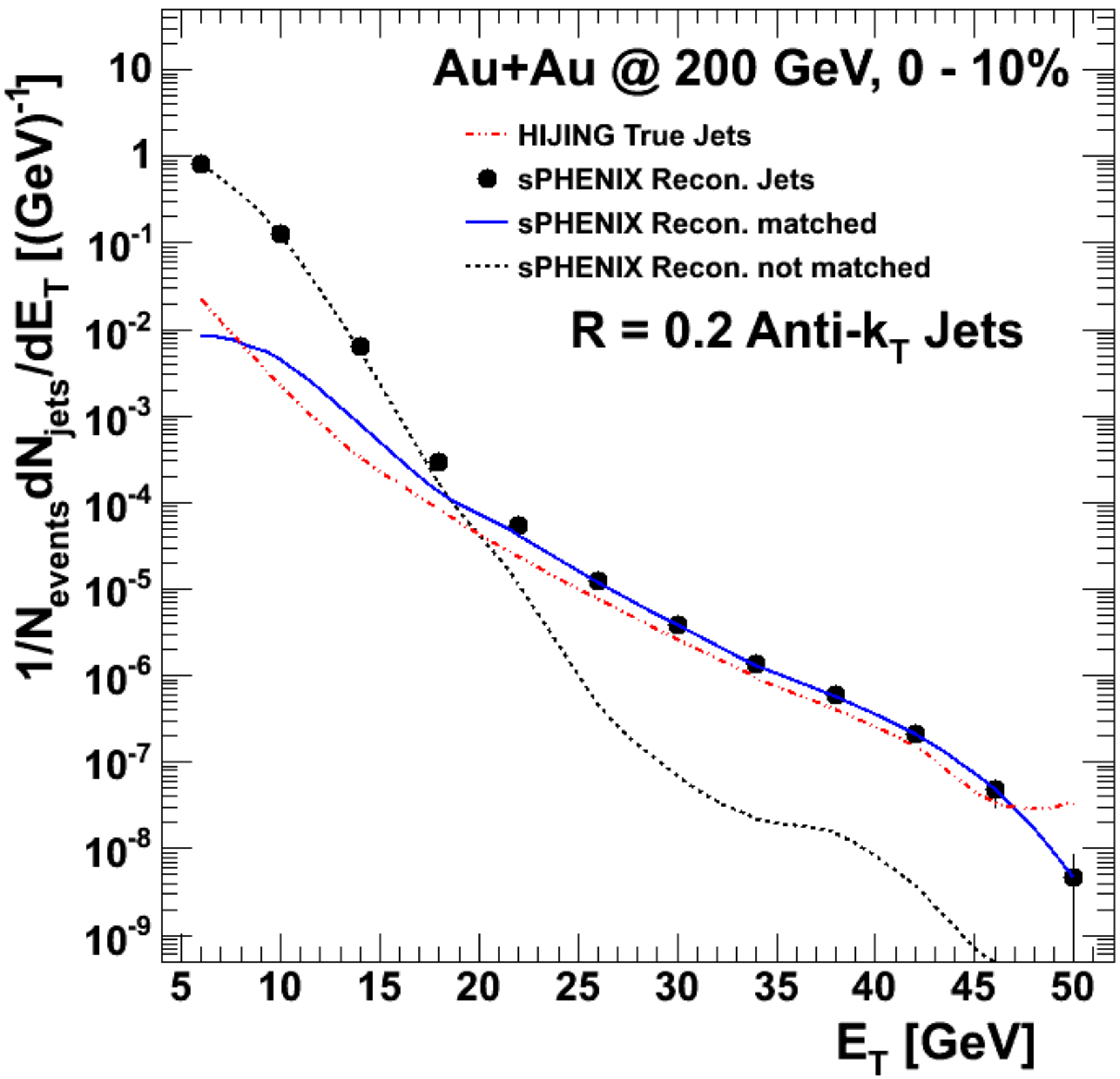
arXiv:1203.1353

Reconstructed Jets and Fakes



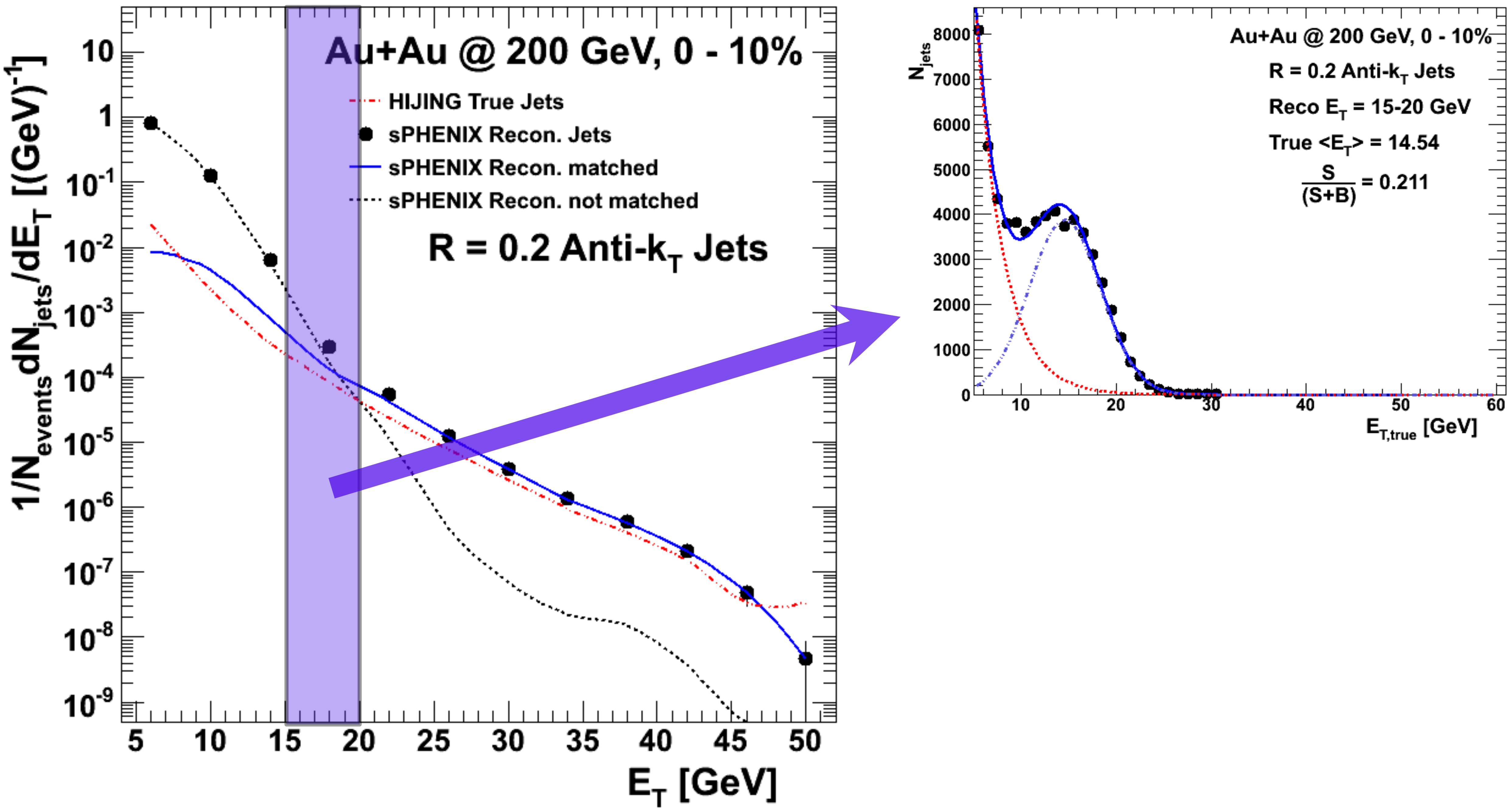
Real jets dominant above 20 GeV for R = 0.2

Fake Rate



Conservative: no additional fake jet rejection or selective cuts.

Fake Rate



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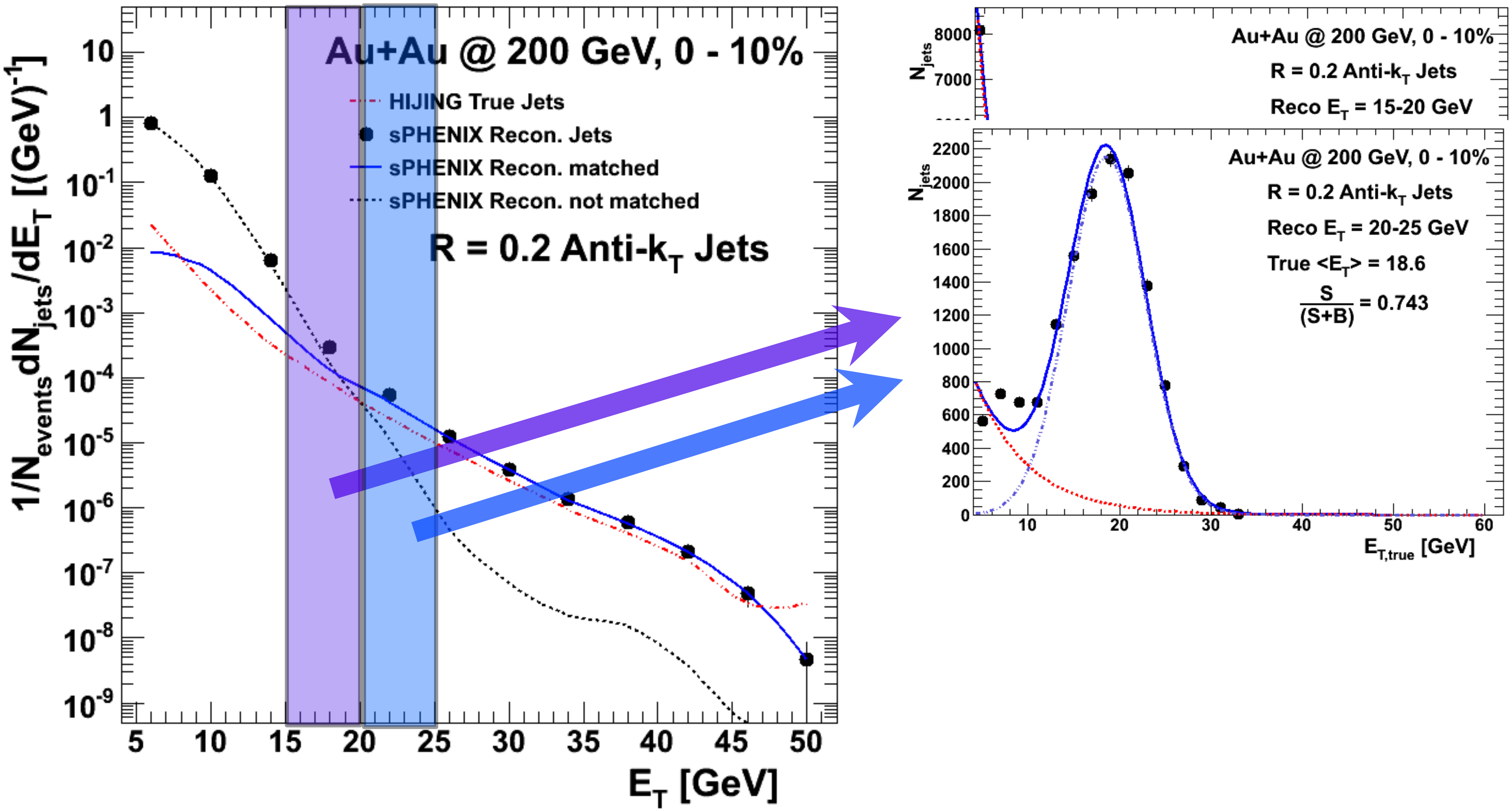

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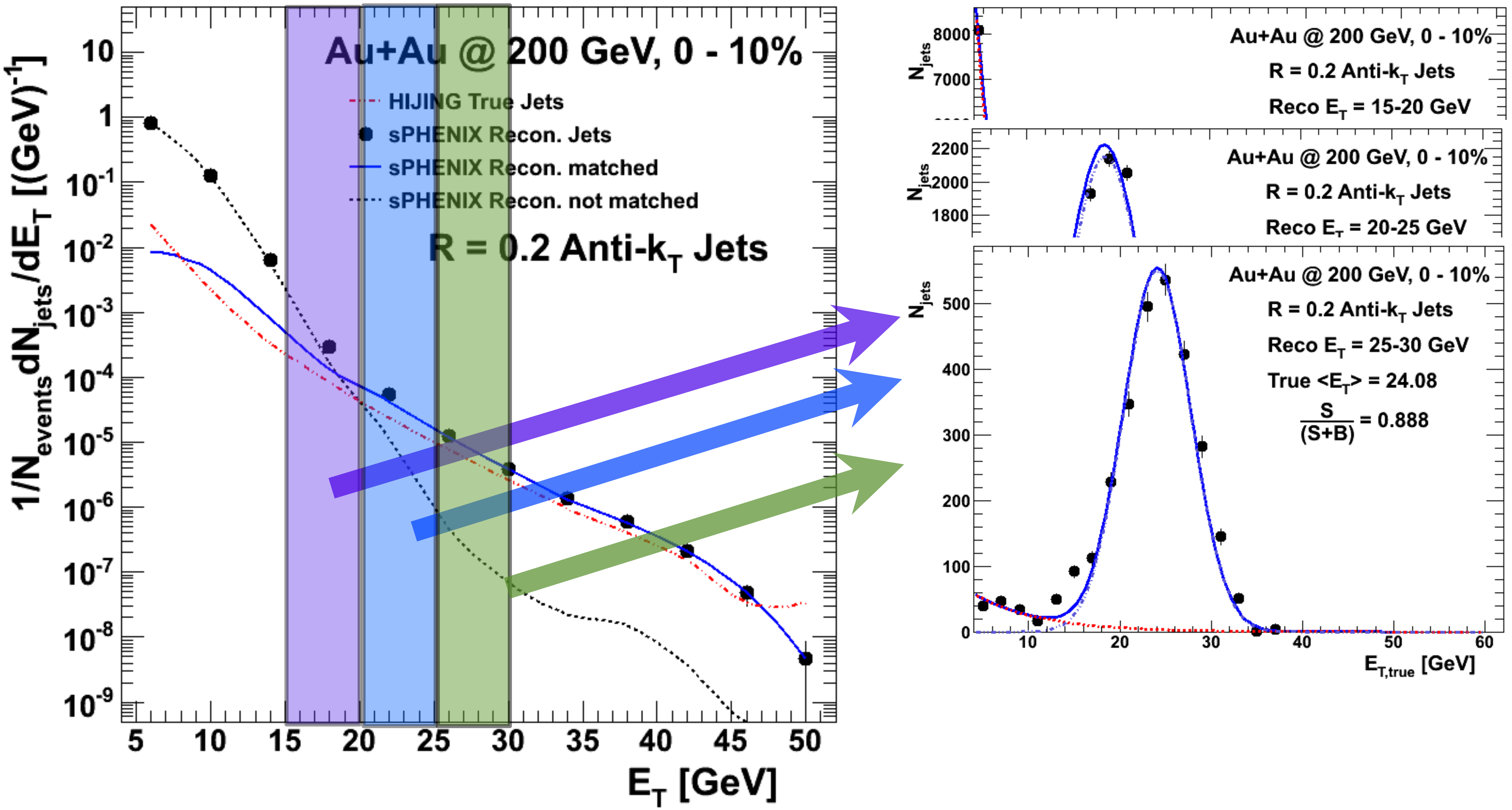

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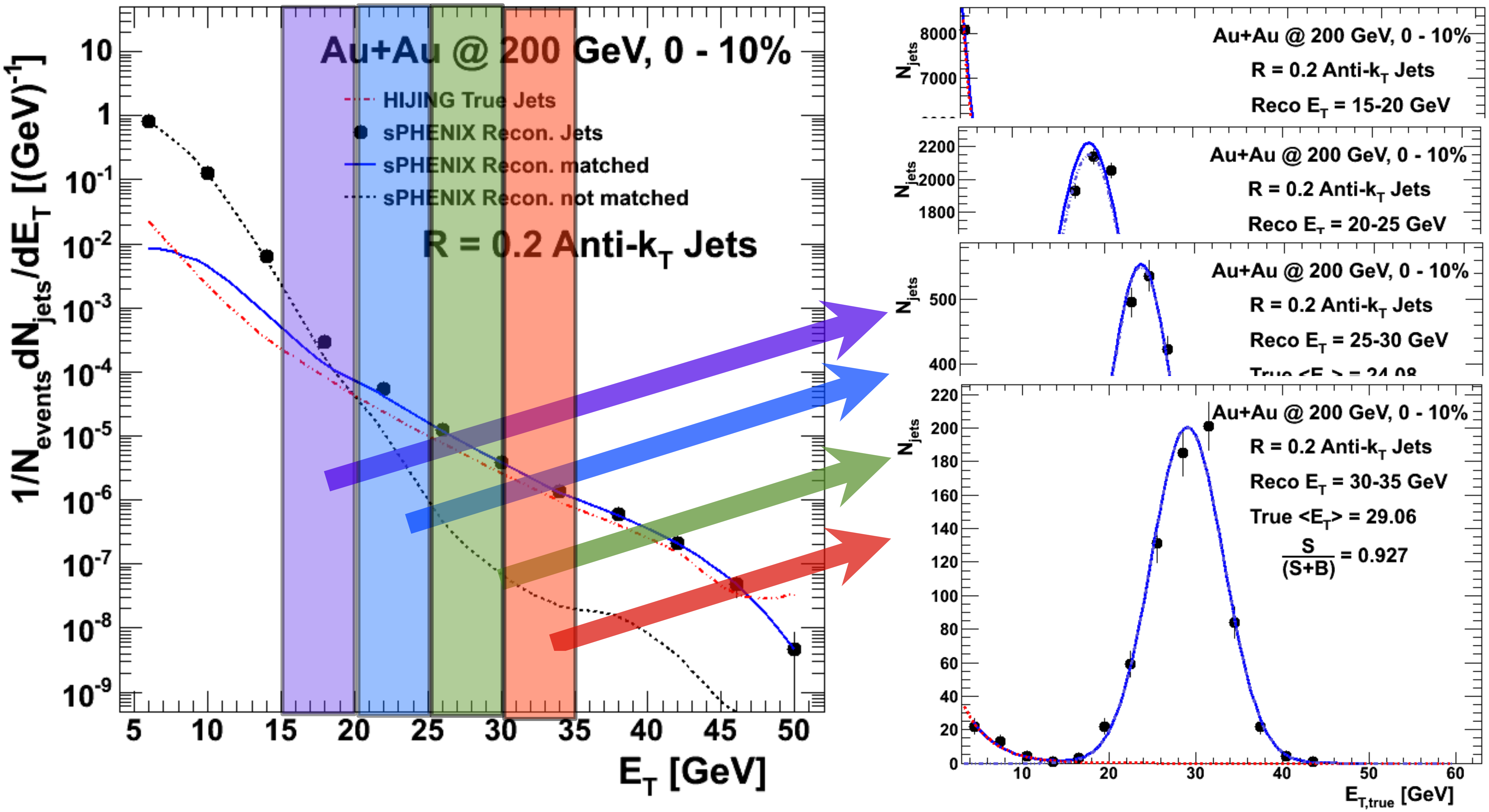

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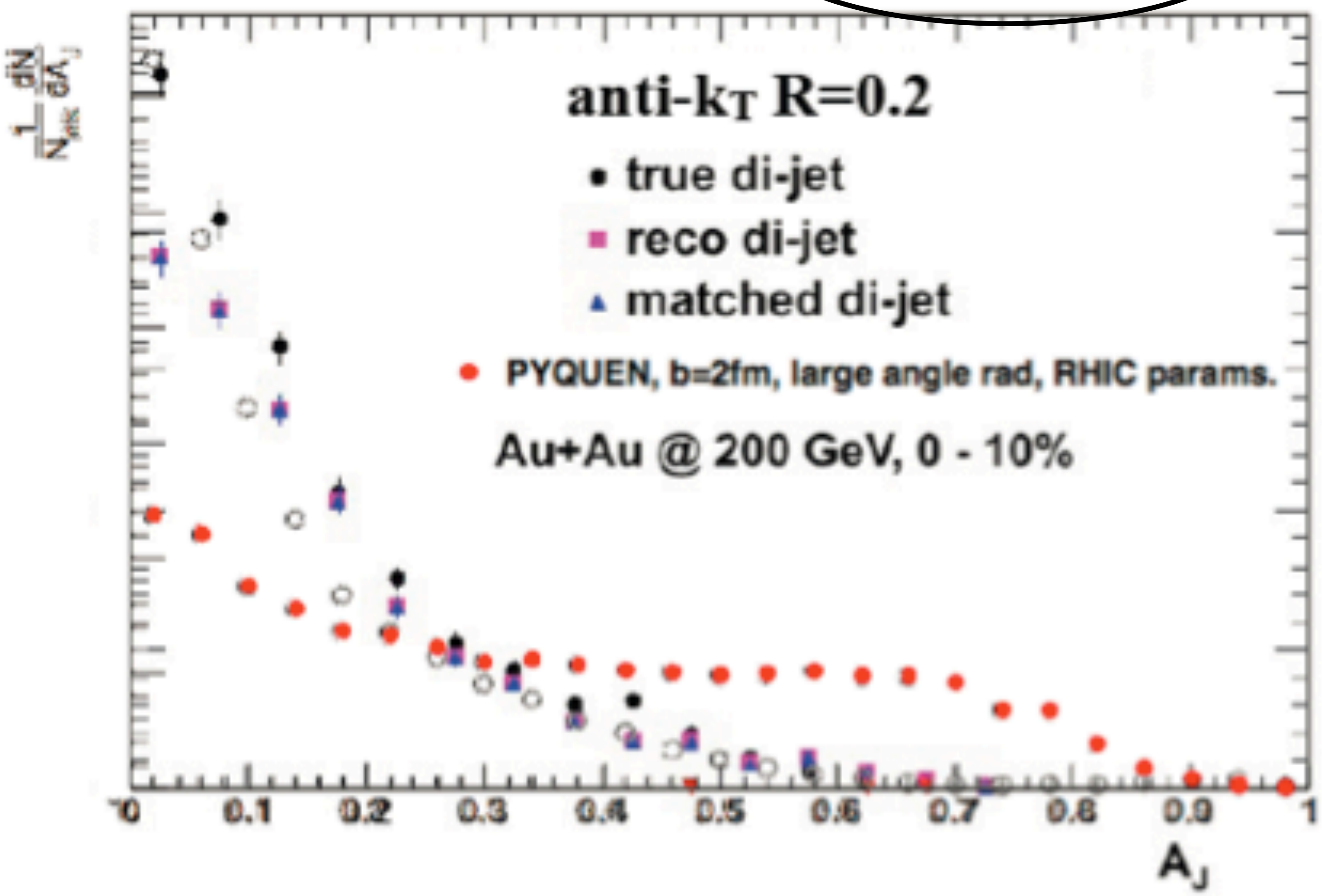
Impact on Dijet Measurements

NB: second jet can go much lower...

PYQUEN parameters from
Lokhtin et al.
hep-ph/0506189

$E_{T1} > 35$ GeV , $E_{T2} > 5$ GeV



Expected modification to A_J from quenching models clearly measurable

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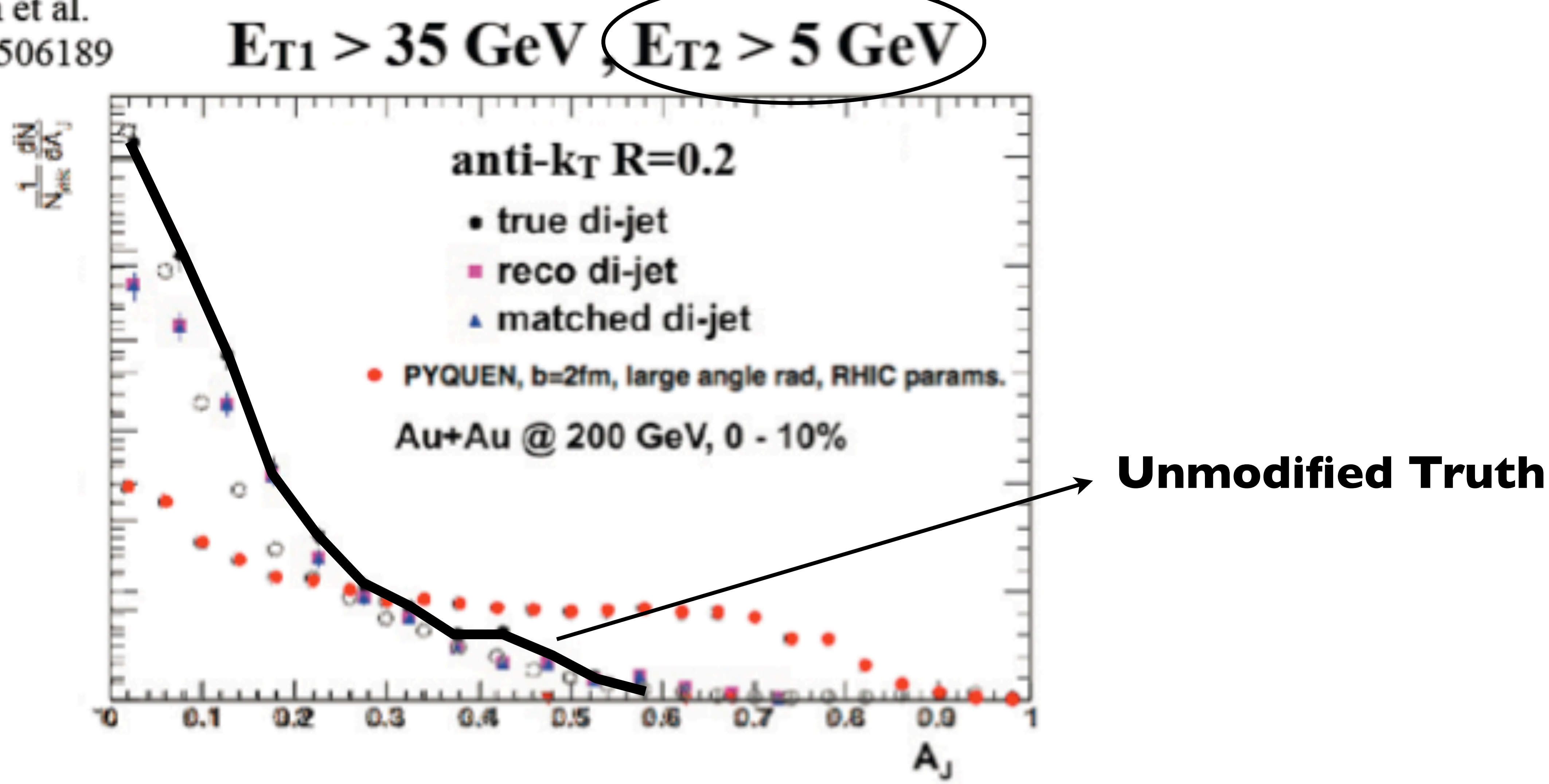

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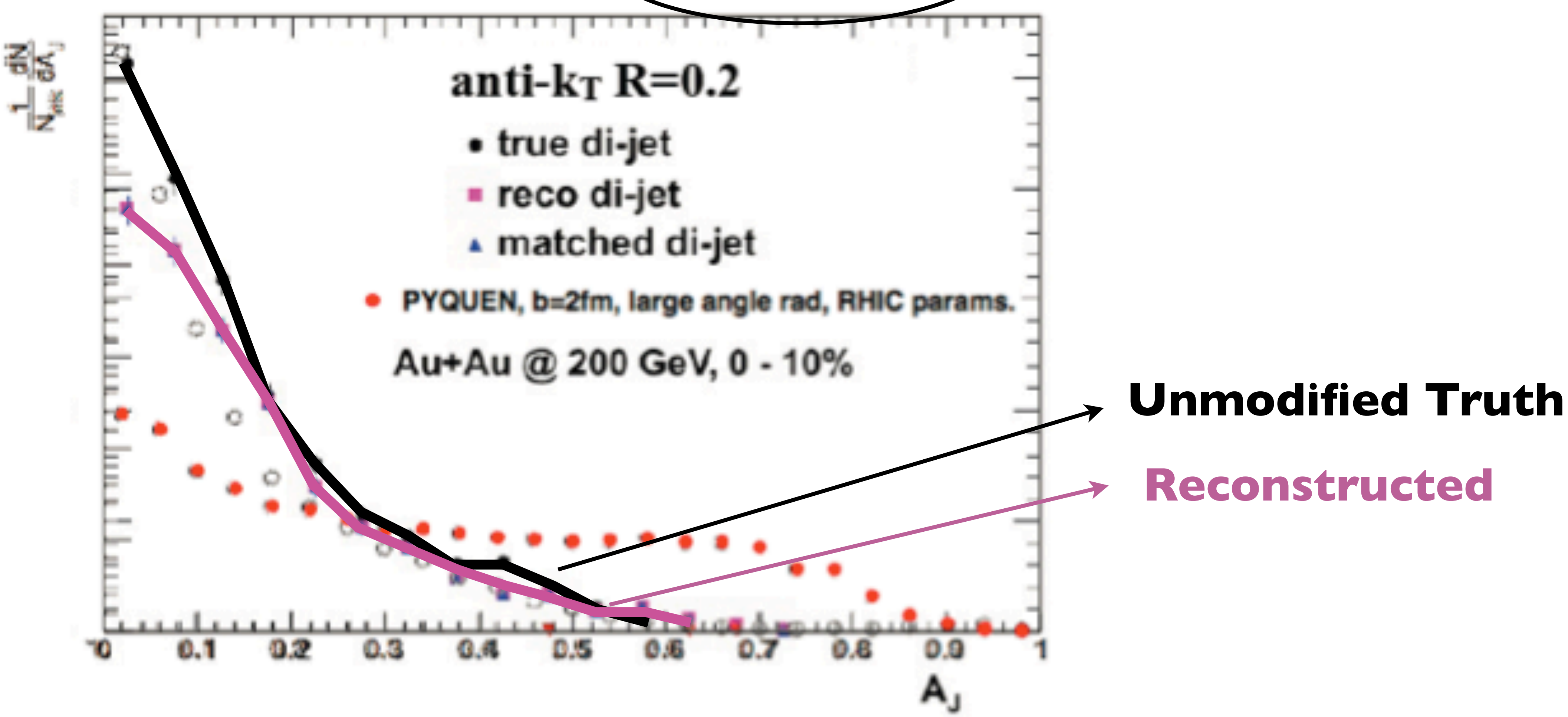

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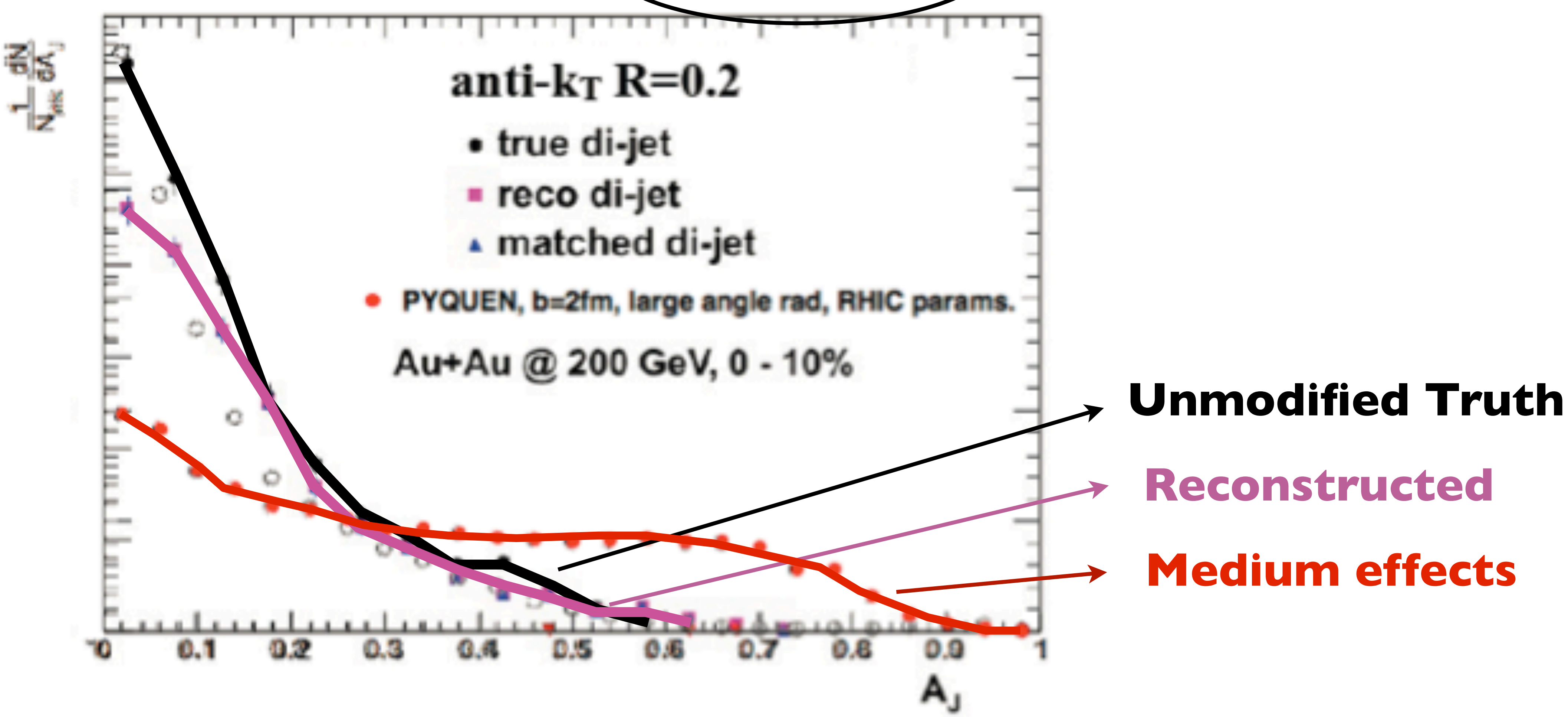


Expected modification to A_J from quenching models clearly measurable

Doable!

Upgraded sPHENIX detector will measure jets out to 70 GeV, R=0.2 (0.4) above 20 (35) GeV in central collisions

Direct photons out to 50 GeV

π^0 R_{AA} out to 40 GeV
(with additional pre-shower detector)

Jet longitudinal and transverse profiles are key in disentangling radiative and collisional

Jets substantially extend transverse energy reach!

Jets allow for full correlation and fragmentation function measurements

All put together allows one to over-constrain theory (best of all worlds)

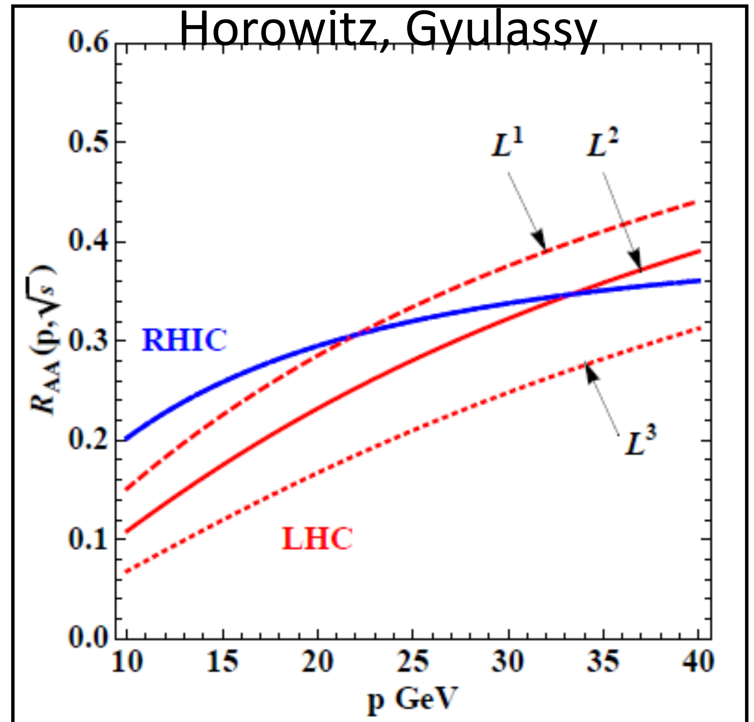


FIG. 2. Schematic nuclear modification factor model Eq. (8) for a “Bjorken plasma brick” normalized to $R_{AA}(p_T = 10) = 0.2$ for central RHIC (blue) assuming $a = 1/3$. The momentum dependence at RHIC is independent of b once the reference normalization at $p_T = 10$ GeV/c is fixed. The red curves for LHC are evaluated with initial rapidity density scaled up by a factor 2.0 relative to RHIC. The $b = 0, 1, 2$ dependent extrapolations to LHC (red dashed, solid, dotted) are labeled by the equivalent L^b path length dependence of the total energy loss in the static plasma limit.

Detector Design

What will sPHENIX need to look like to make these measurements?

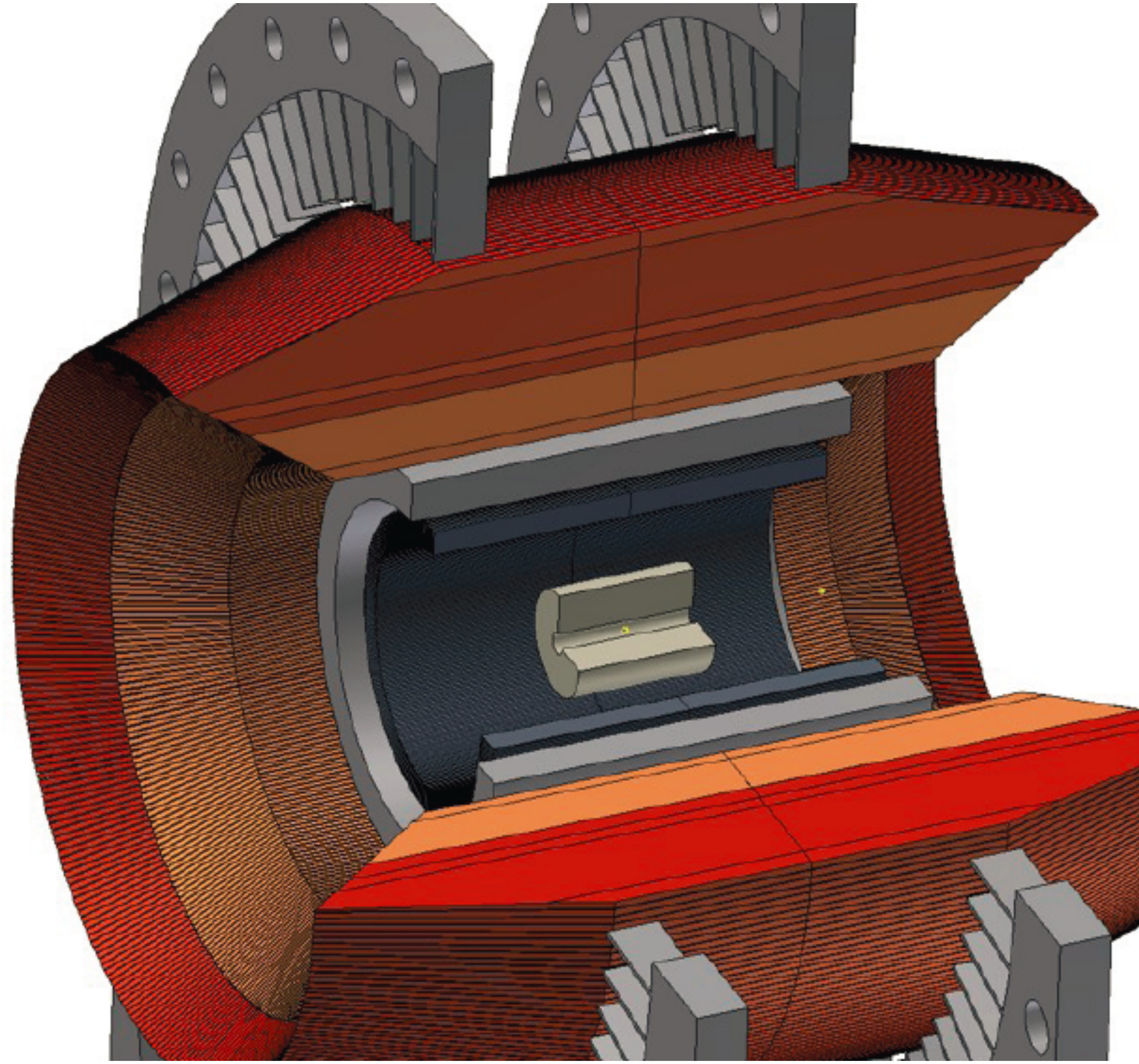
Staging

Requirements

- large acceptance
- high rate

sPHENIX detector concept

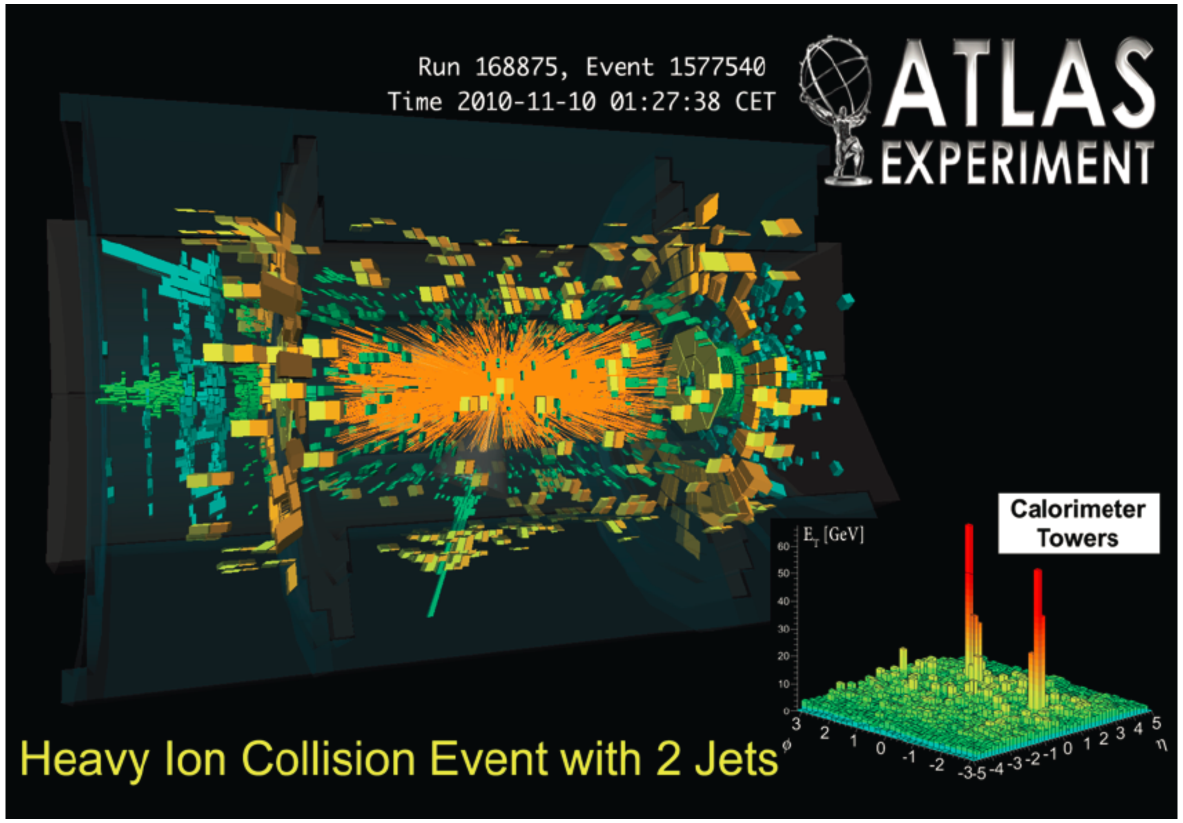
- **Stage 1**
  - compact 2T solenoid
  - tungsten-scintillator EMCal
  - steel-scintillator HCal and flux return
- **Additional**
  - tracking layers
  - preshower EMCal



Why Hadronic Calorimetry?

<u>All</u> heavy ion jet publications to date (i.e. ATLAS and CMS) come from hermetic calorimeter measurements !

Ability to try different methods (supplementing with tracking) is also a big advantage.

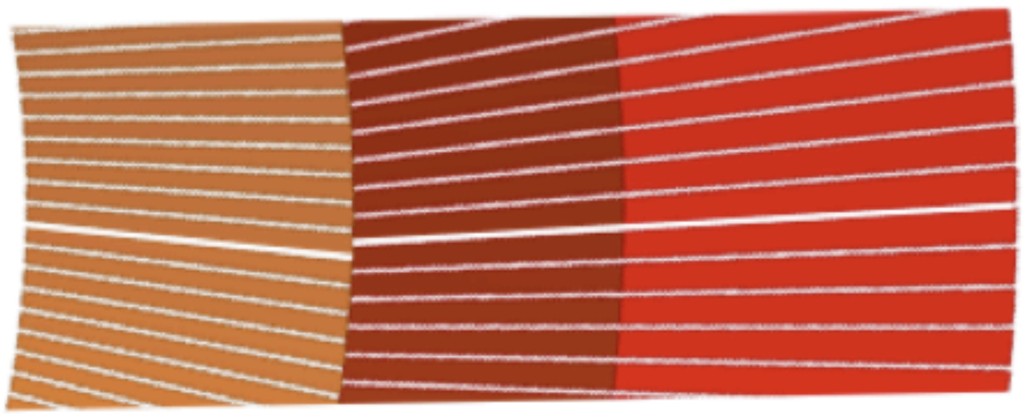


Critical to have EMCal + HCAL with hermetic coverage (no gaps, spokes, holes) with large coverage to see both jets and γ-jet and at very high rate. Then add in tracking information as key additional handle for systematic studies.

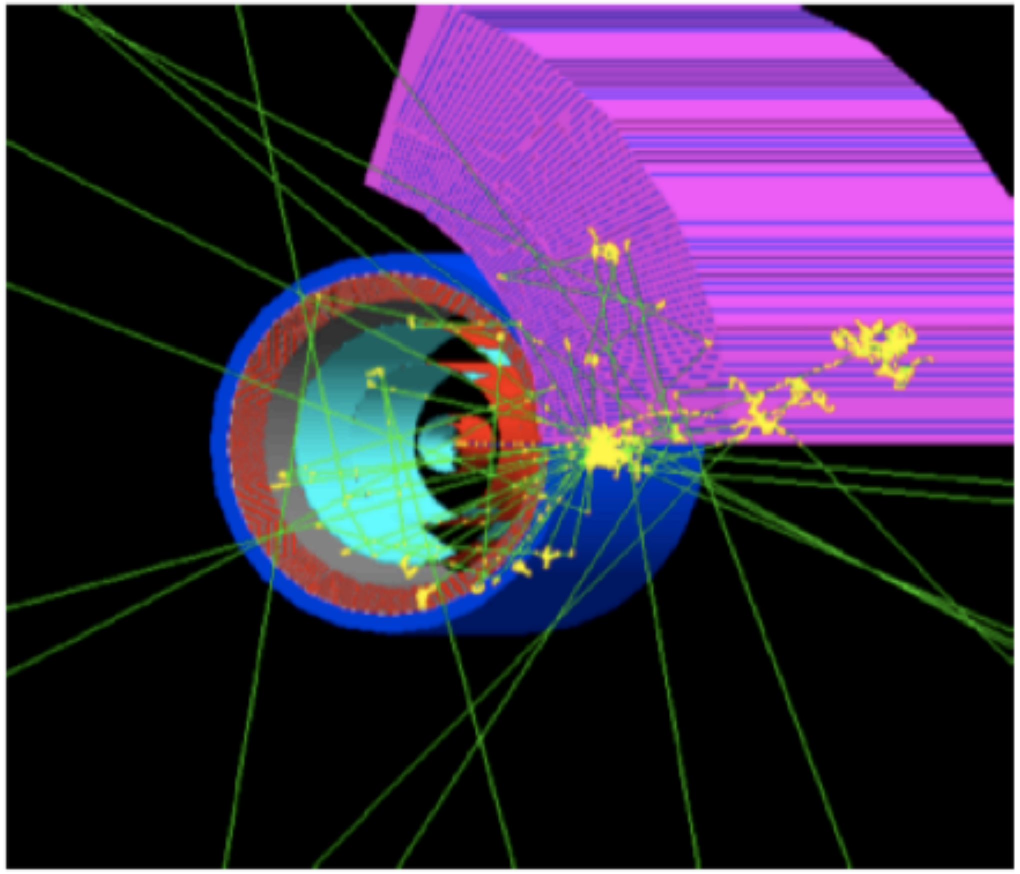
Also, when measuring fragmentation functions, hadron p_T and jet energy measures are independent.

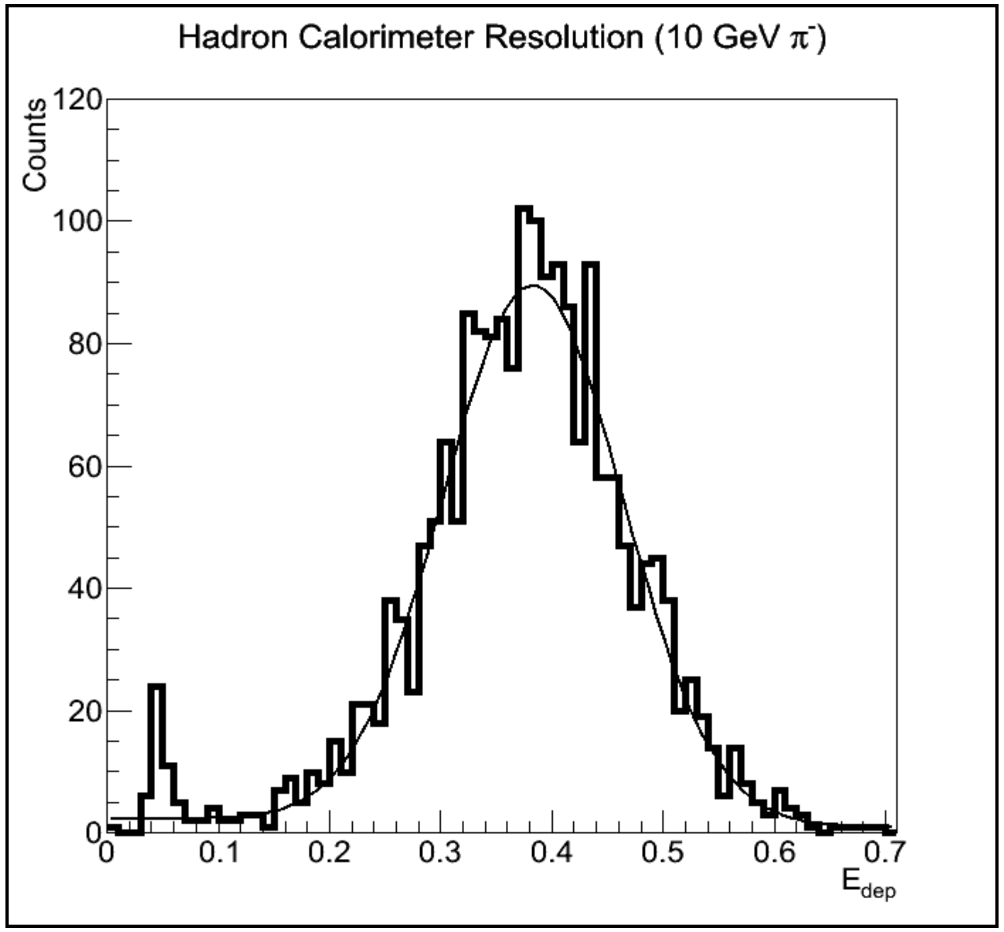
Stage 1: HCal

HCal Design & GEANT-4 Response



Steel-Scintillator Design
Flux Return for Magnet
Fiber Coupled to SiPM Readout
Common Electronics with EMCal



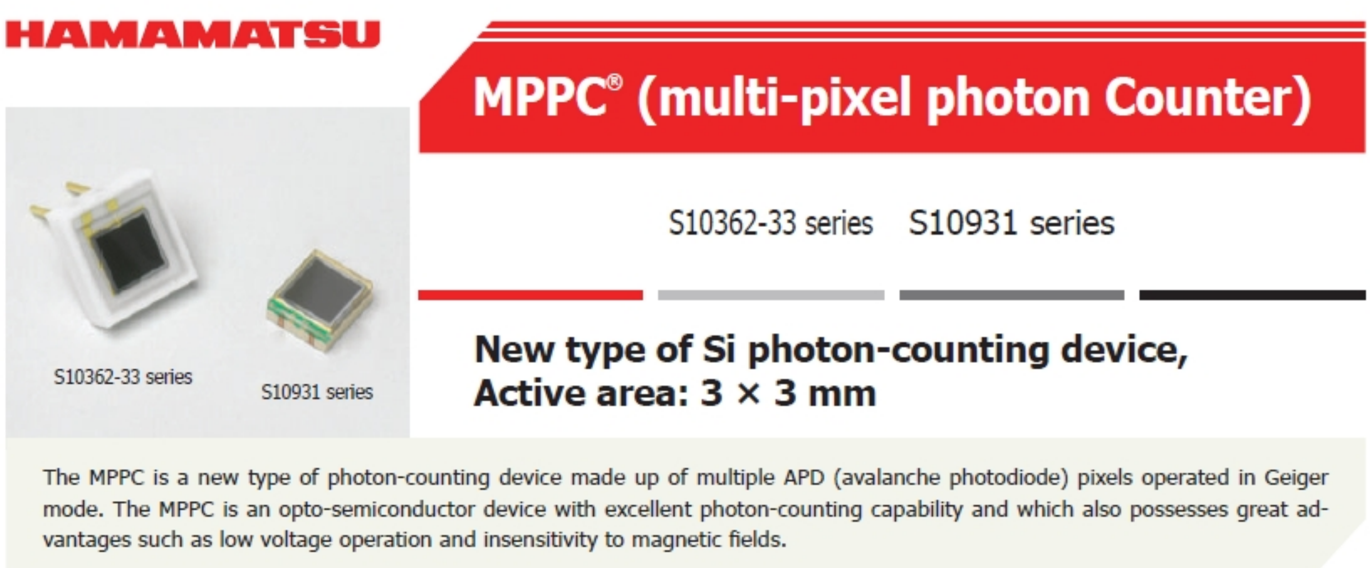


Corresponds to 75%/√E

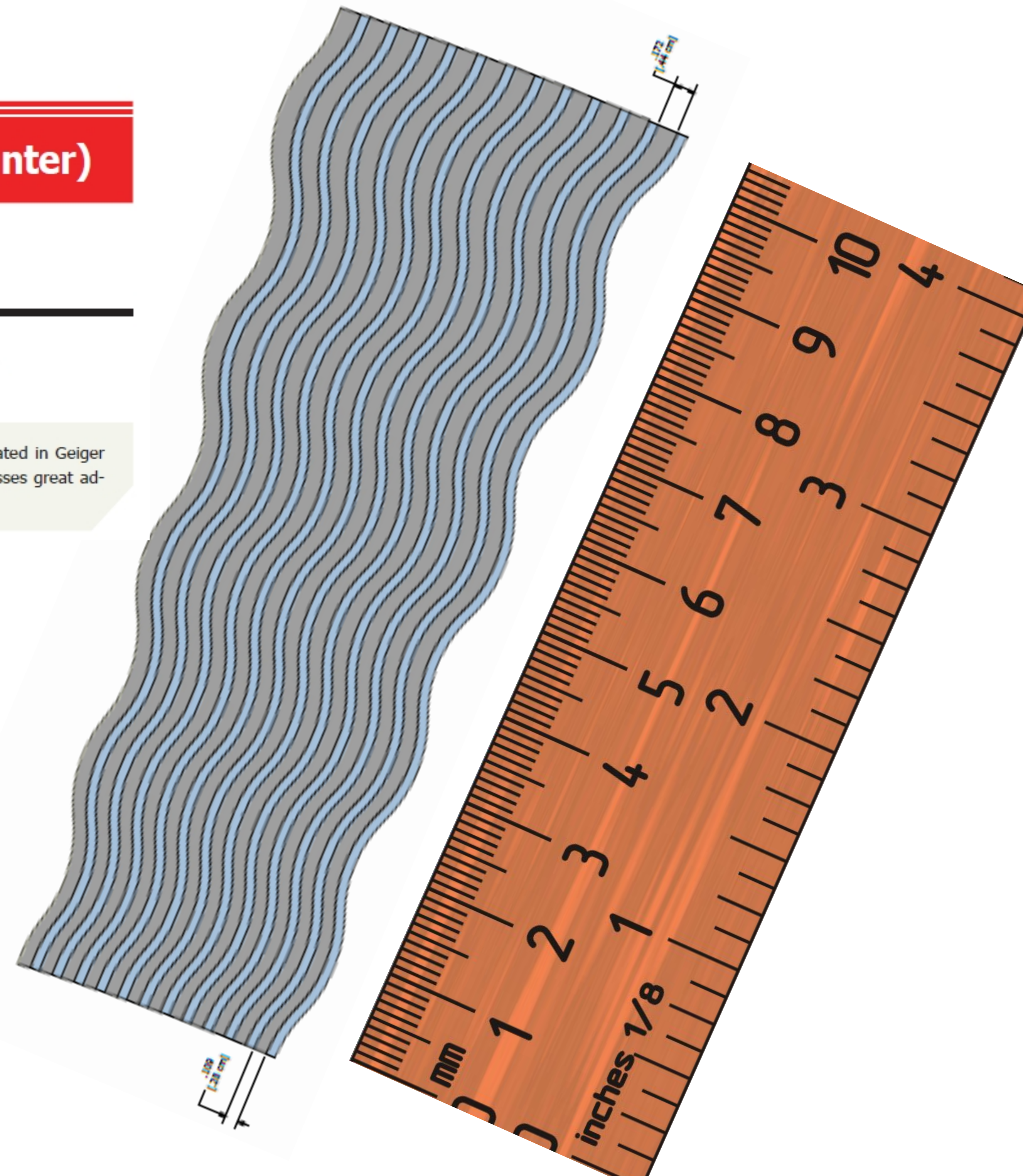
Stage I: Compact EMCal

Innovative EMCal design

SiPMs or APDs



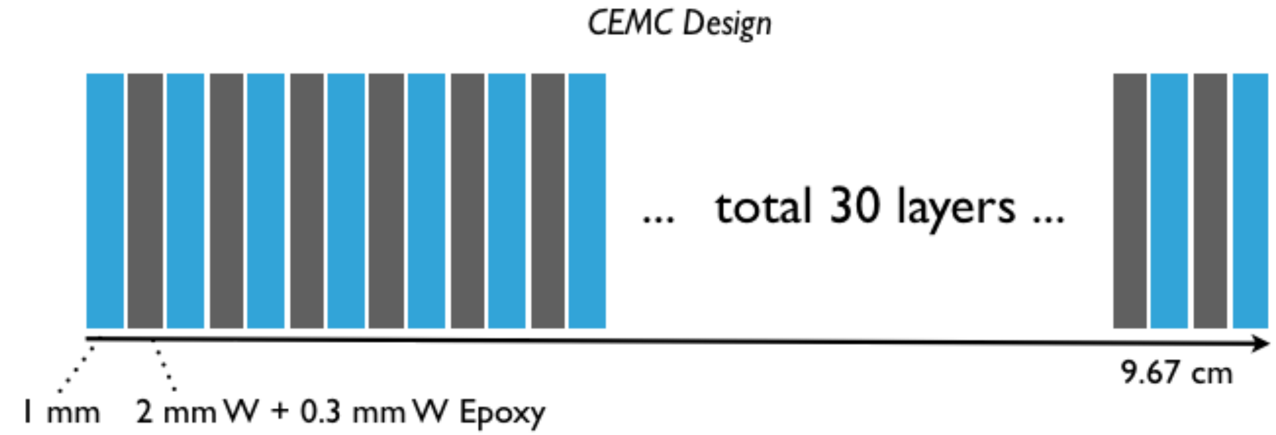
ρ(sintered W) ~ 0.9ρ(pure W)
formed in arbitrary shapes
& SiPMs
↓
compact EMCal

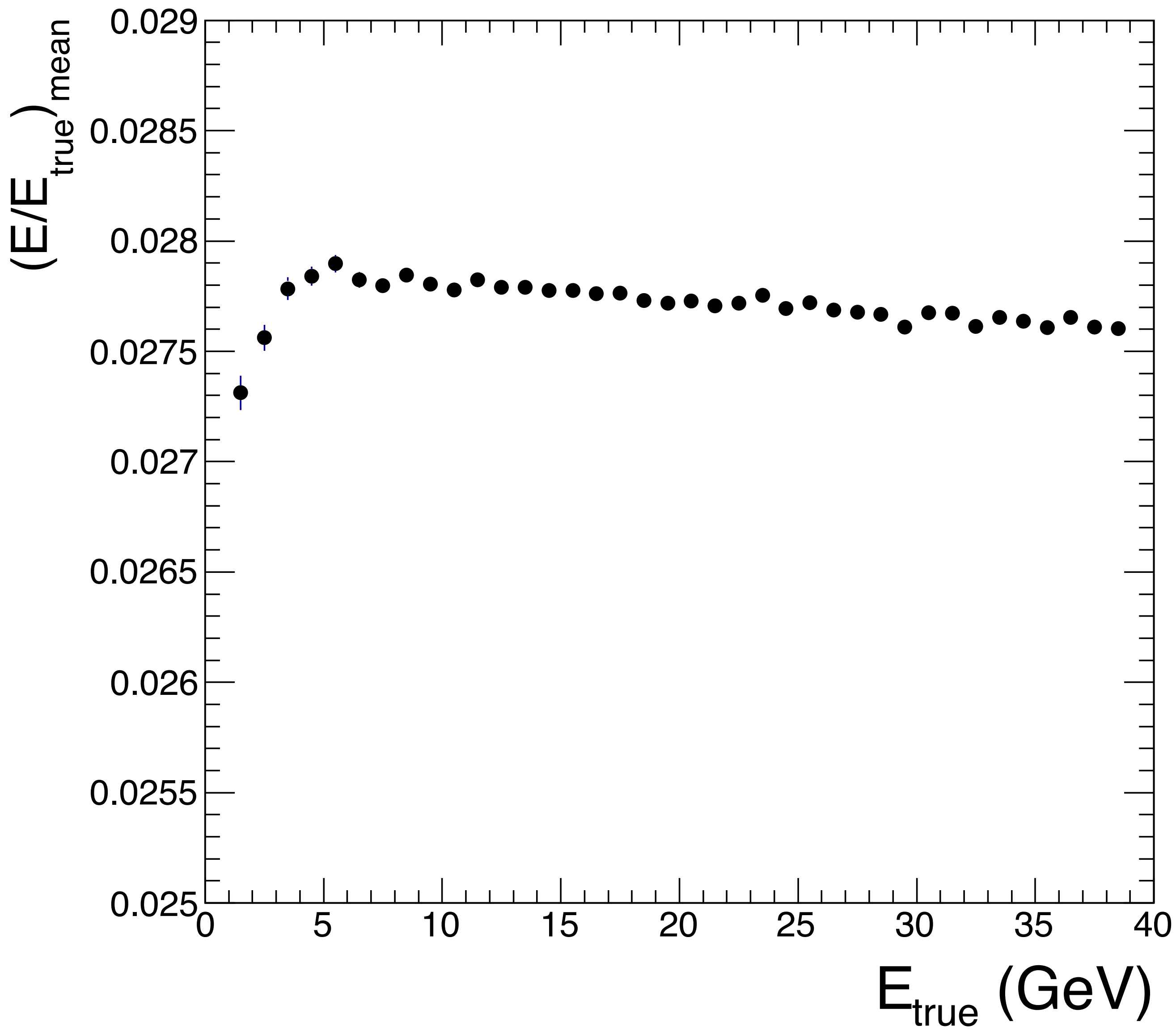


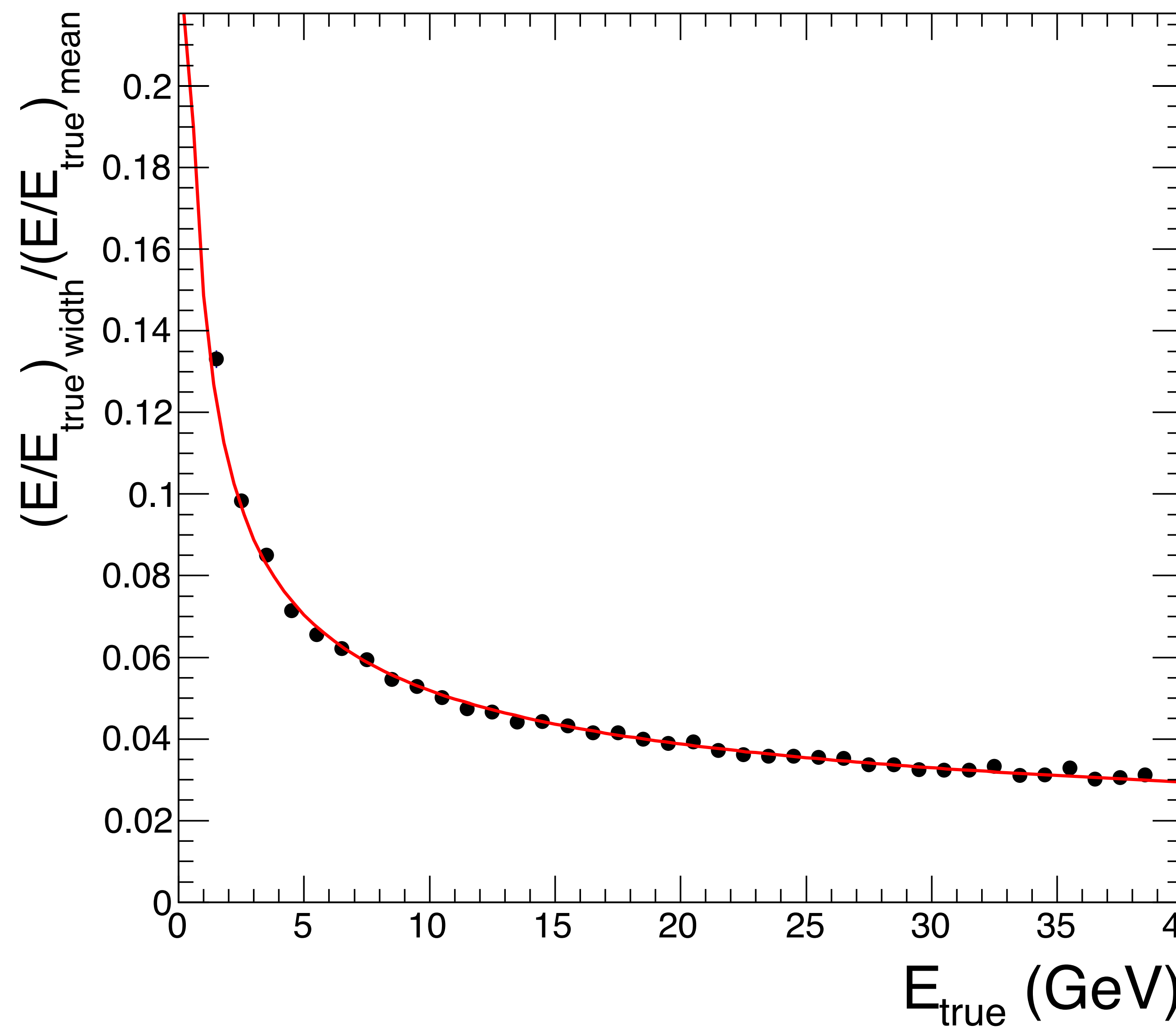
Stage 1: Compact EMCal II

Magnet + CEMC Response

Al
(8.879 cm)

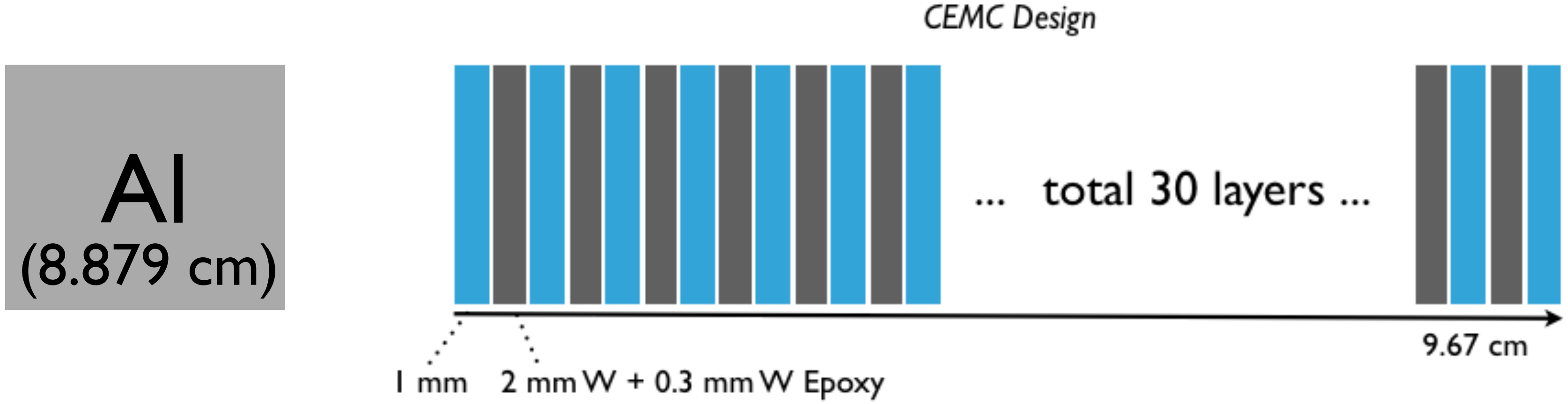


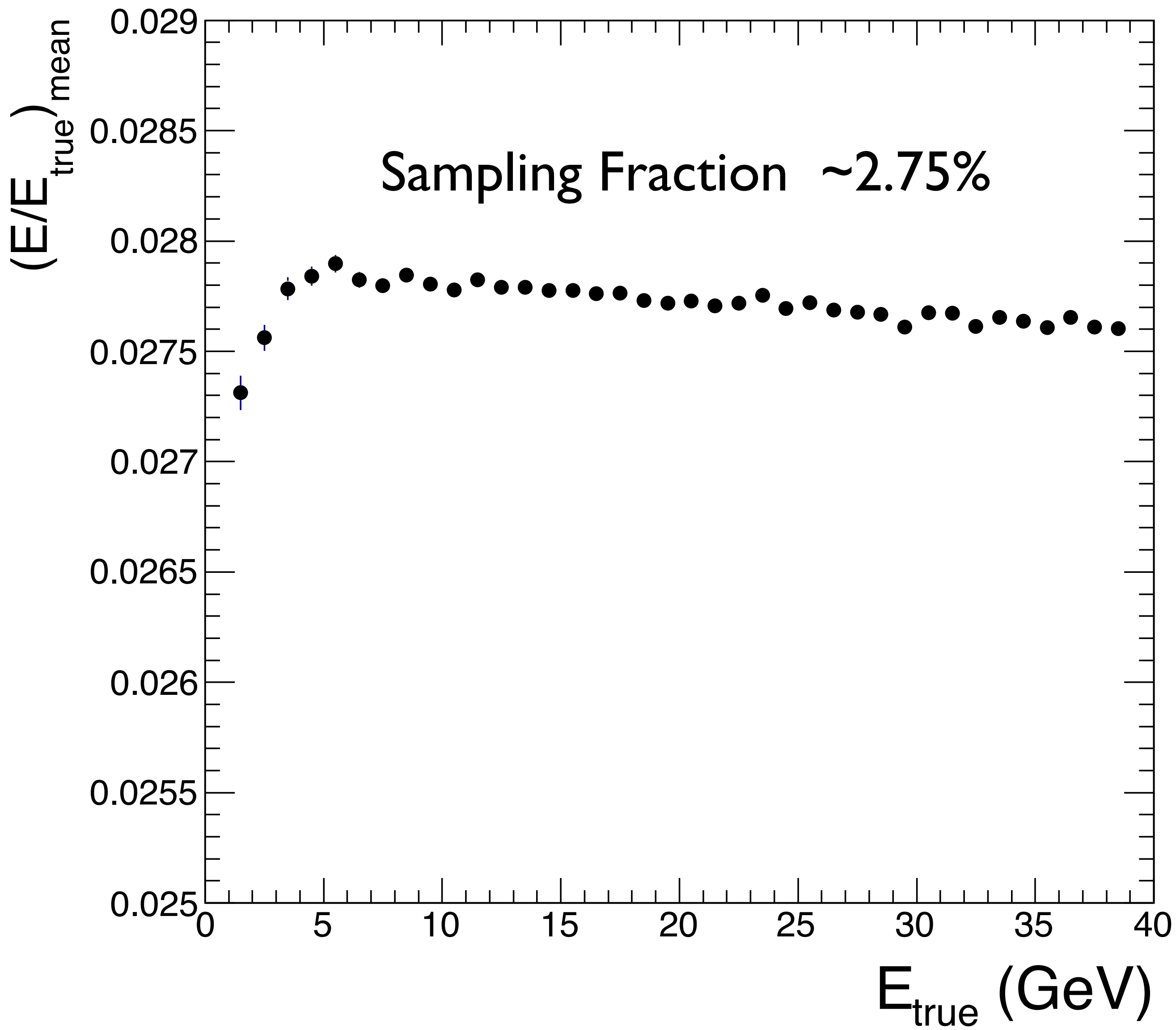


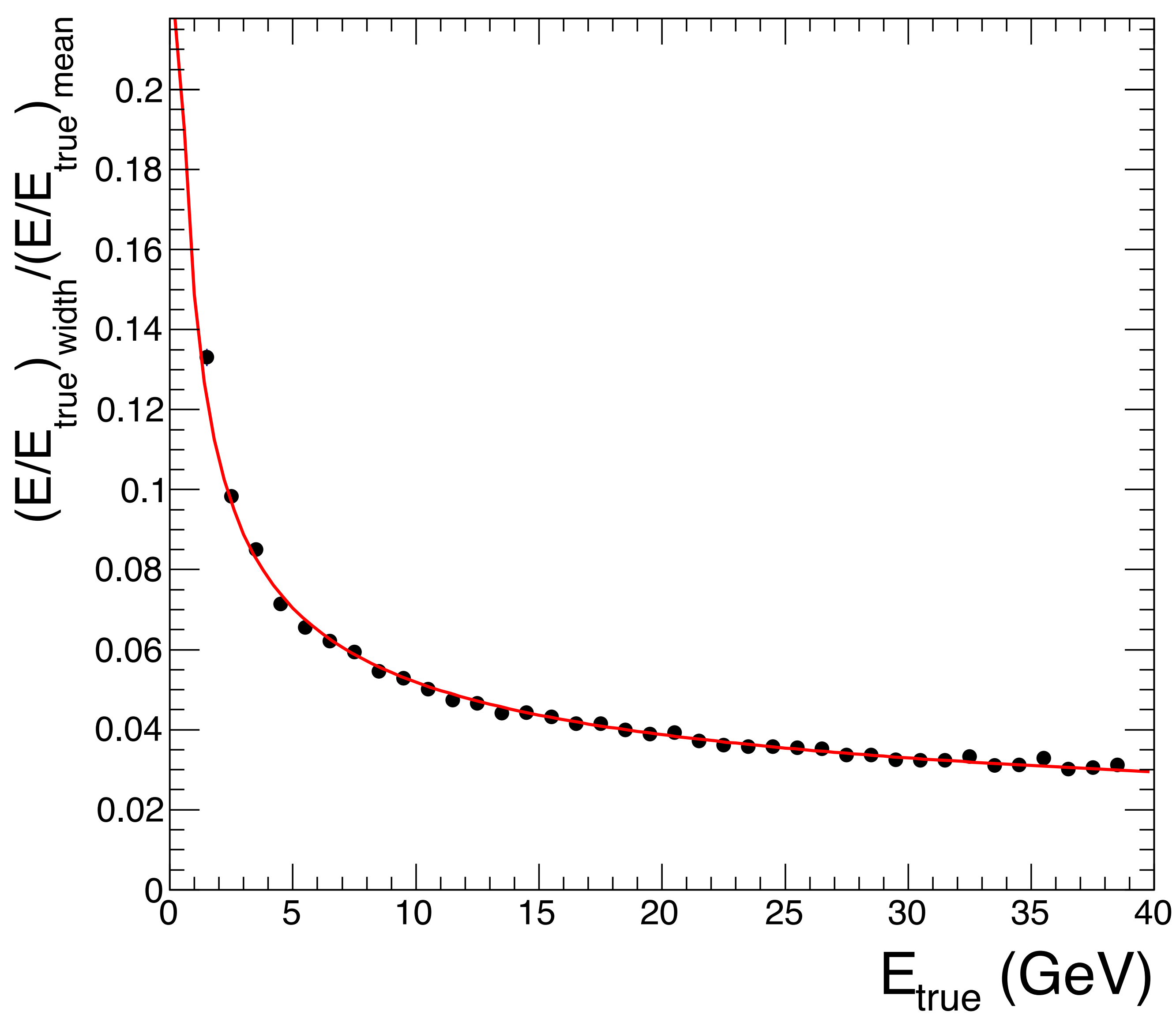


Stage 1: Compact EMCal II

Magnet + CEMC Response

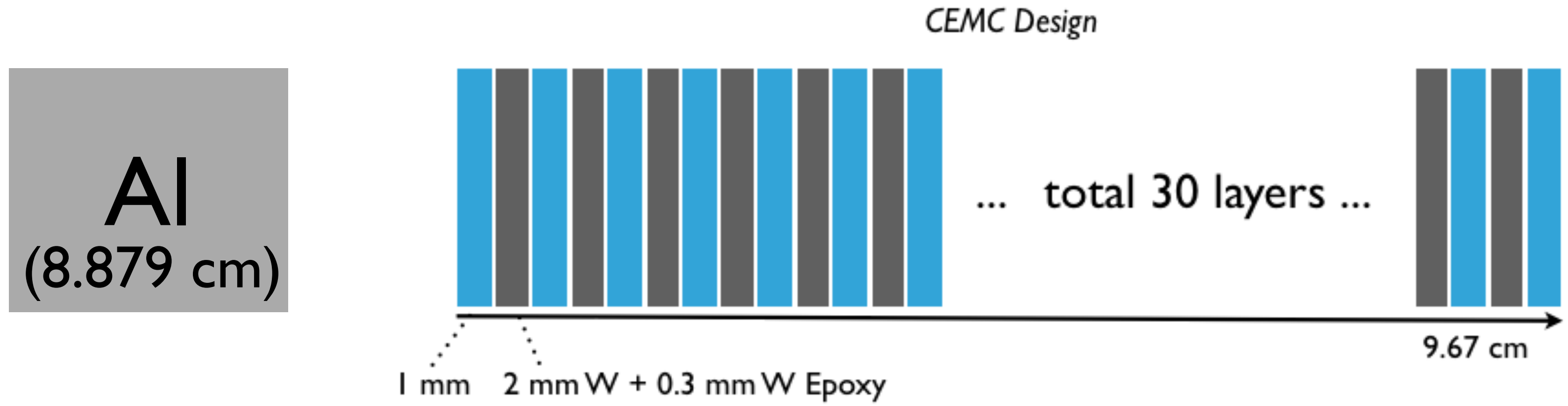


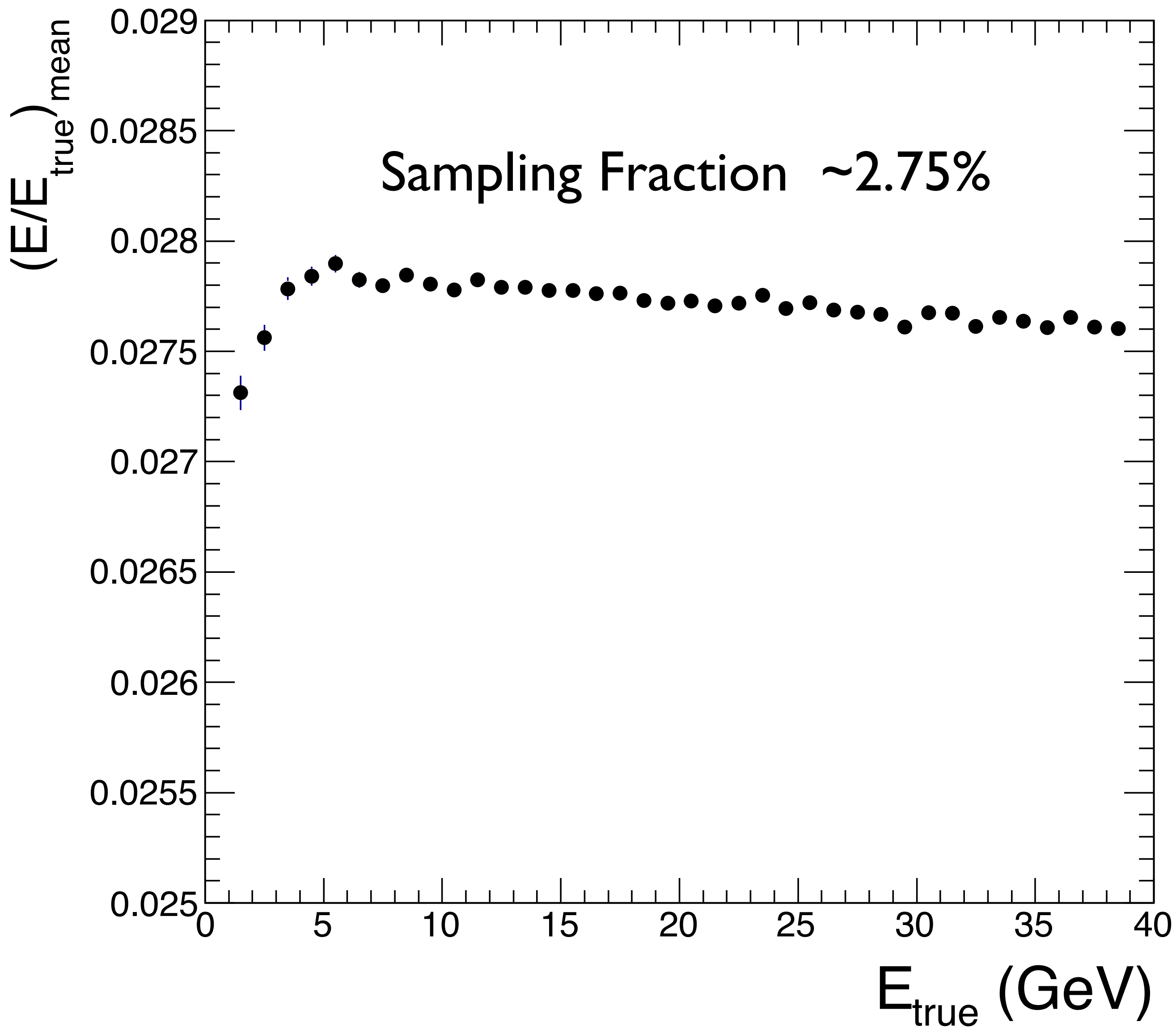


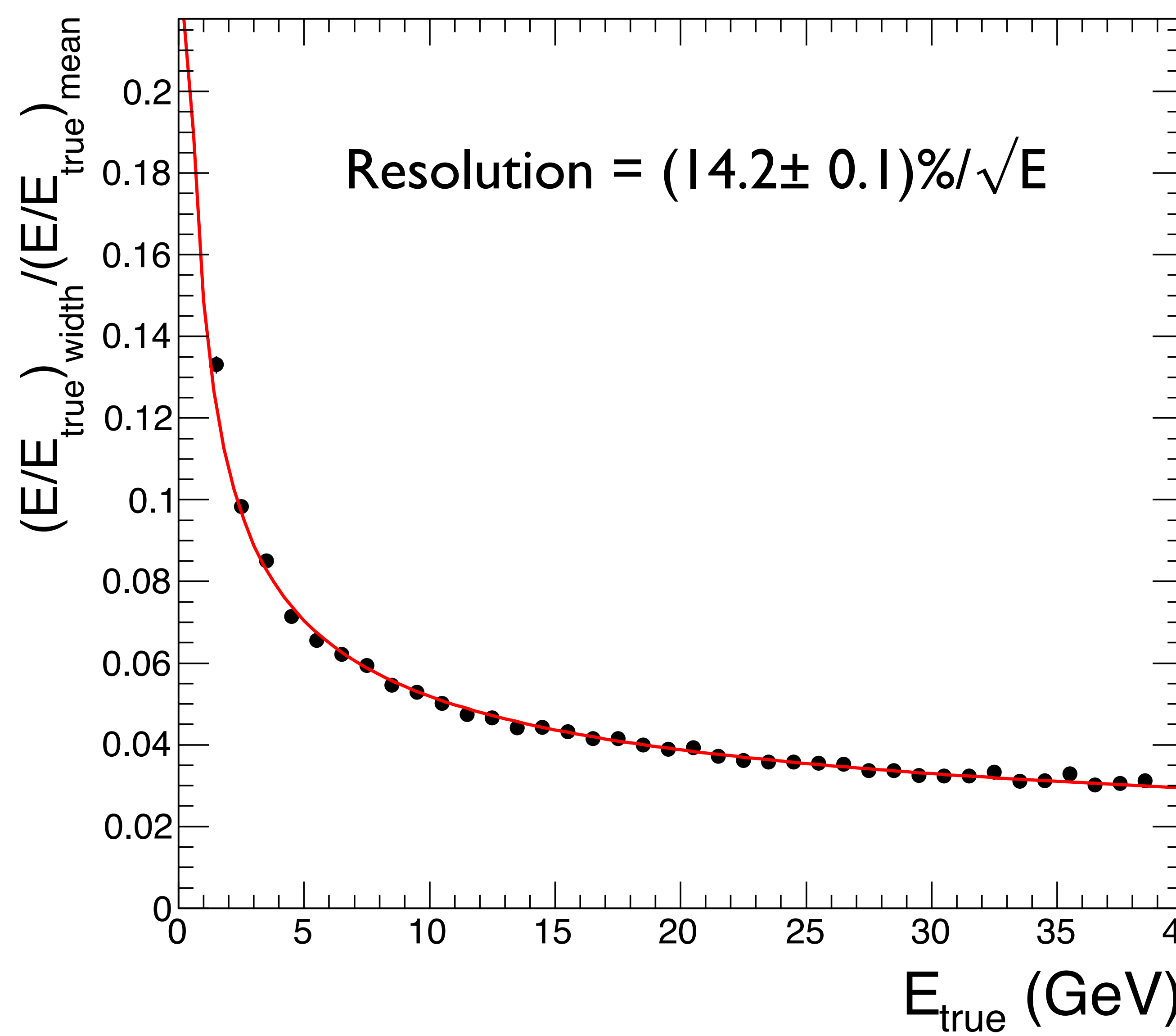


Stage 1: Compact EMCal II

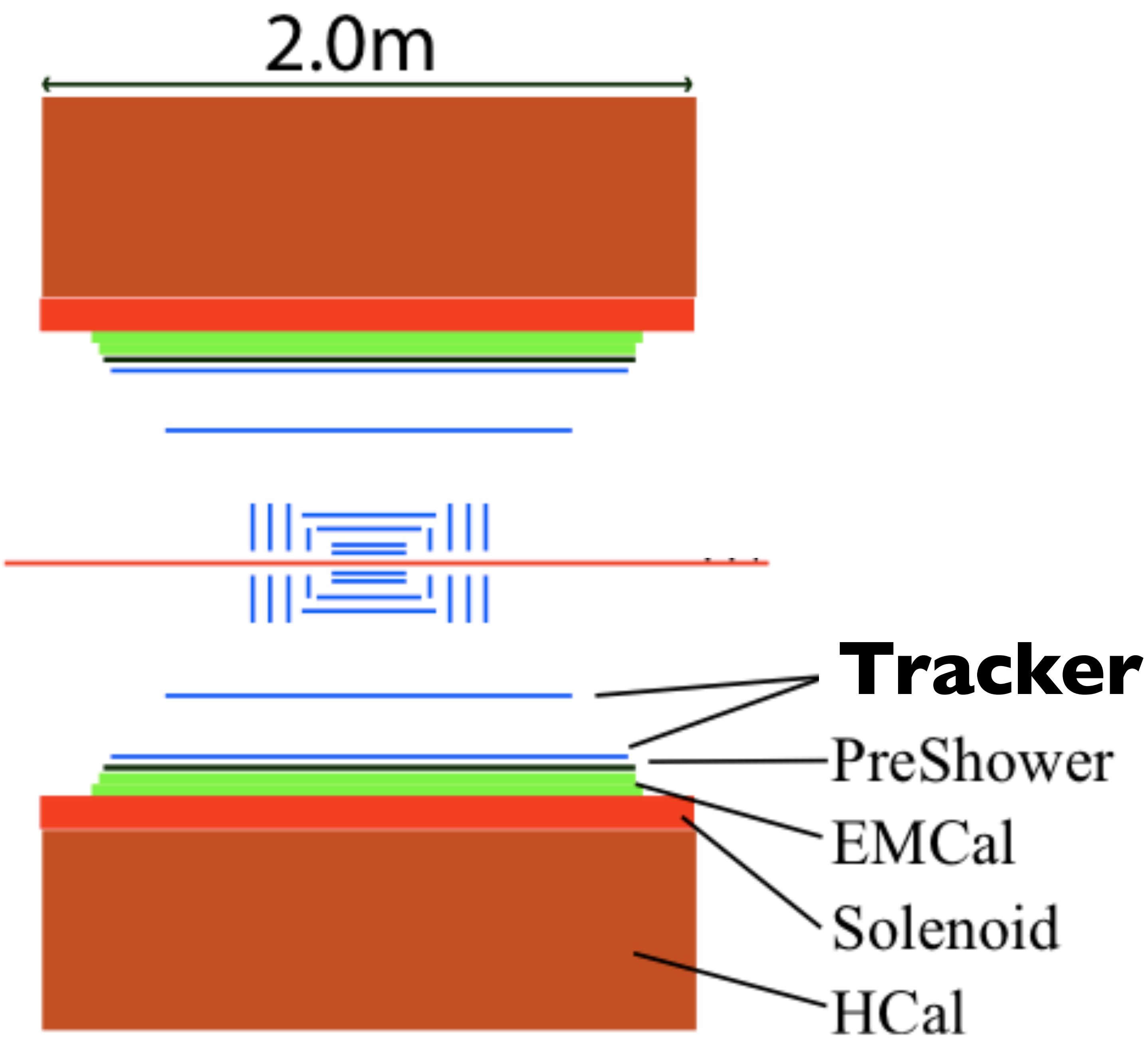
Magnet + CEMC Response







Further Staged Upgrades

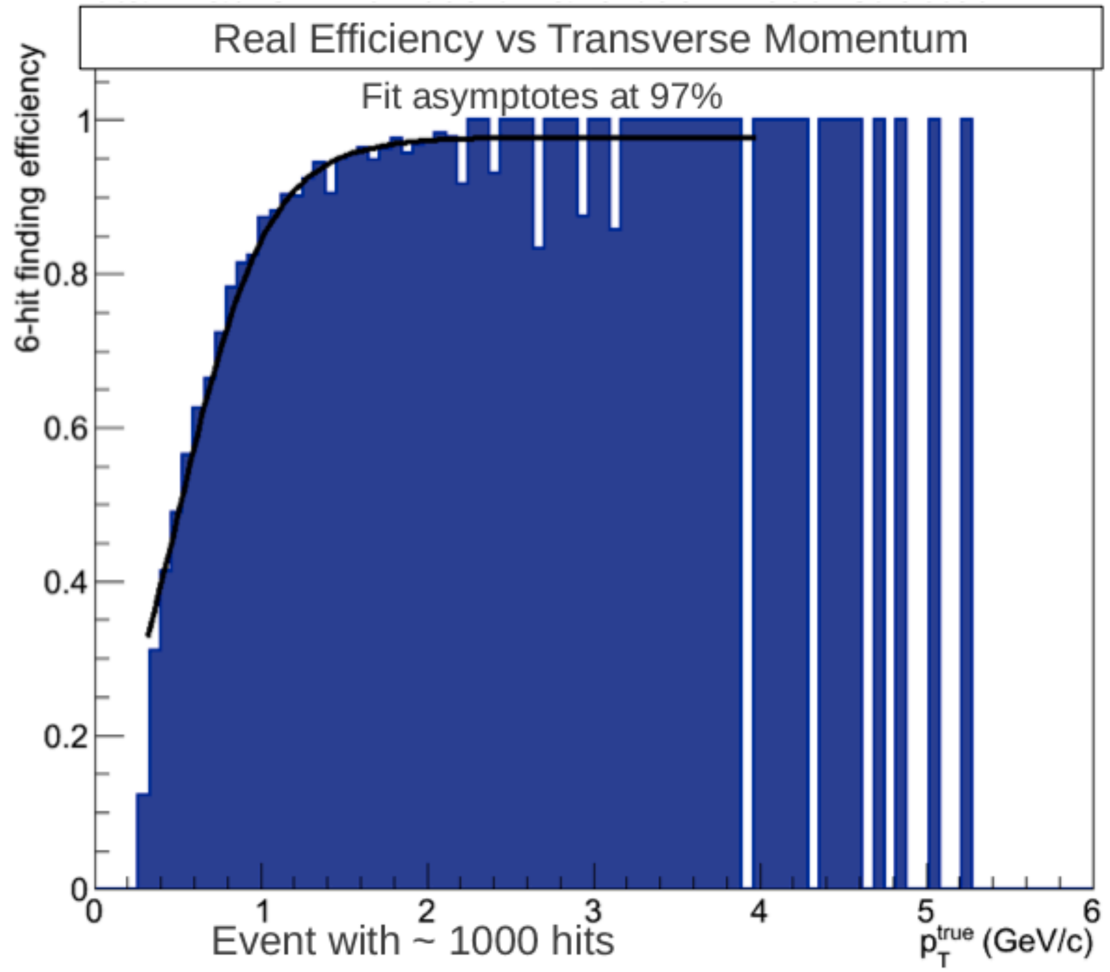


Charged Particle Tracking:

Add spare ladders to the VTX to fill out 2π acceptance

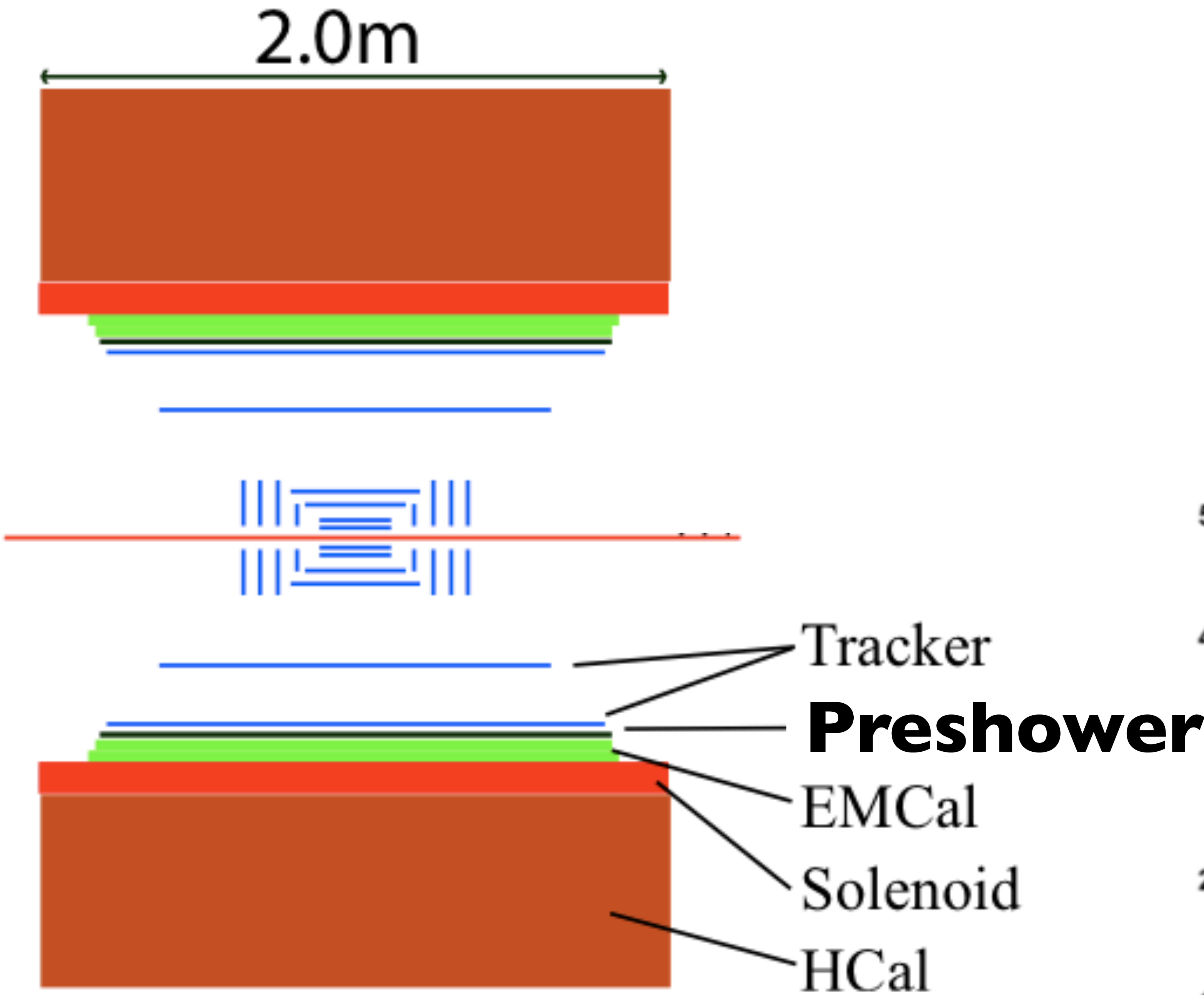
Add 2 or more tracking layers needed to recover tracking capability

Get intra-jet measurements (FF, jT)



Theo Koblesky (Colorado), APS 2012

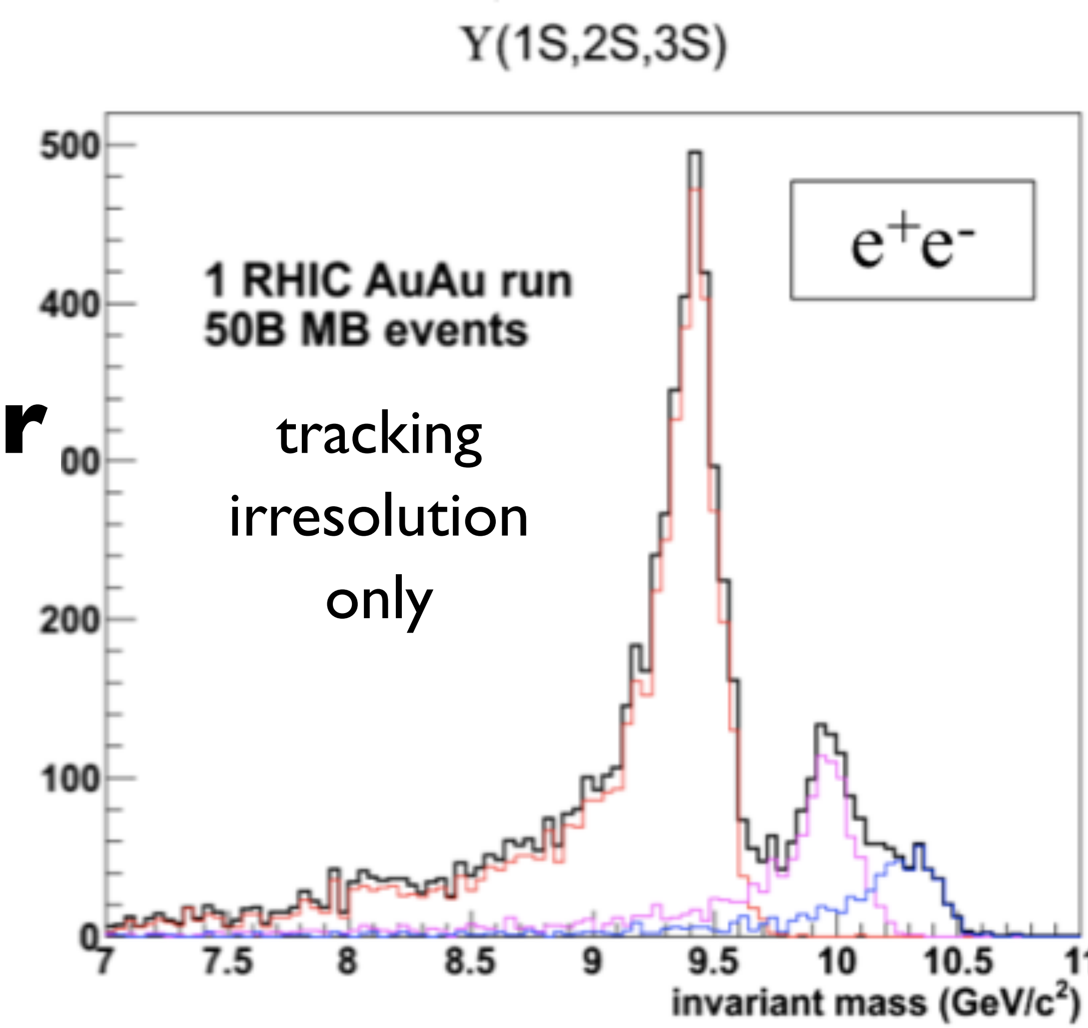
Further Staged Upgrades



Electron (pi0) Identification

Add a Preshower EMCal
Together need ~x1000 rejection

Get pi0 spectra to 40 GeV
Get Heavy flavor jets
Get quarkonia decay channels



sPHENIX

Jet measurements at RHIC can inform our understanding of the bulk behavior of the QGP.

Discussed the viscosity quenching dualism
Differences in behavior at RHIC vs LHC
Eventually narrow in on a microscopic picture

Jet measurements at RHIC are feasible against the backgrounds

Background subtraction is working
Embedded irresolution can be handled
Fake rates are small for a wide range of interesting kinematics

sPHENIX is being designed to meet the needs of the jet program

Impact of detector irresolution on key physics being studied

sPHENIX => ePHENIX