Jet physics opportunities and *b*-jet tagging in sPHENIX

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for the PHENIX Collaboration
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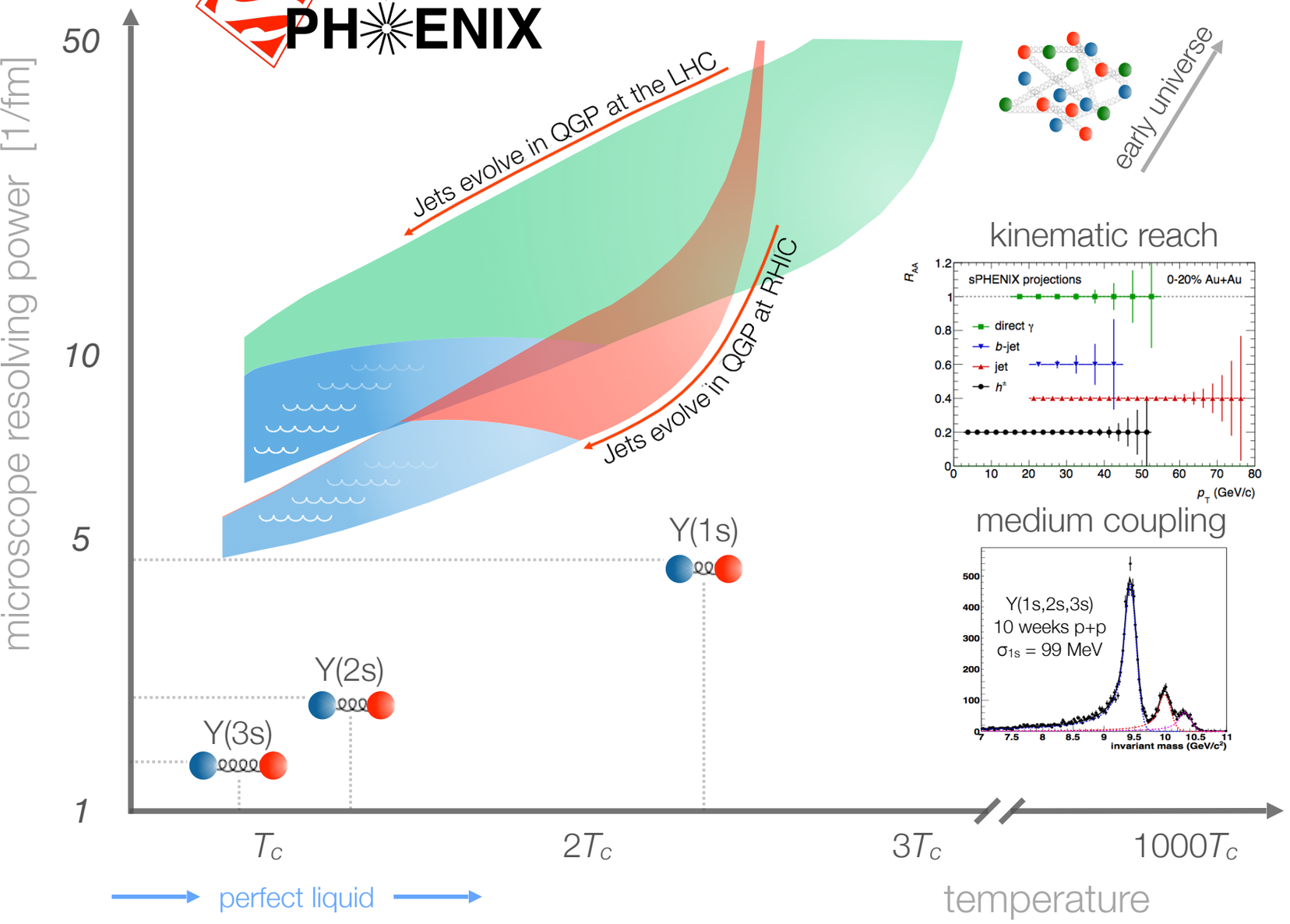
29 January 2015
The 31st Winter Workshop
on Nuclear Dynamics
Keystone, Colorado USA

The science case for sPHENIX



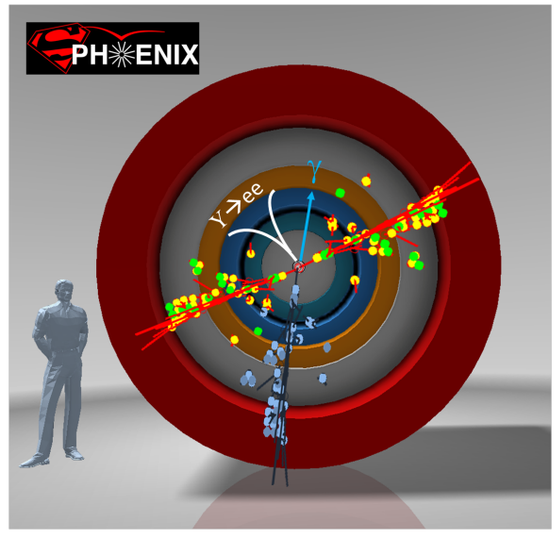
kinematic reach

medium coupling

Goal: quantitative understanding of the QCD medium over a range of length scales and temperatures

An Upgrade Proposal from the PHENIX Collaboration

November 19, 2014

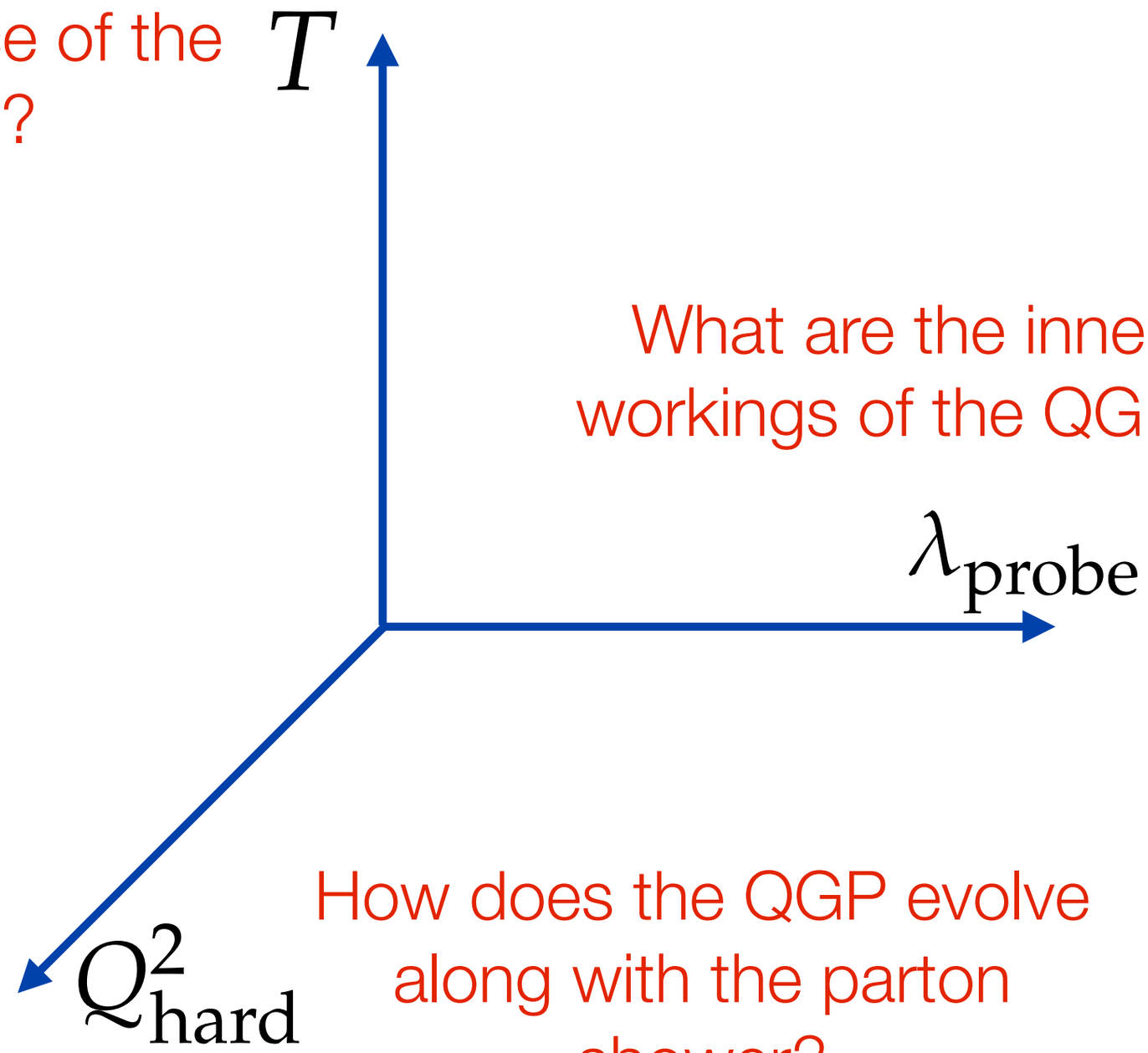


nucl-ex/1501.06197

Revised proposal:

- jet triggering,
- *b*-tagged jets,
- kinematic reach
- jet+X observables
- tracking performance
- projections, etc.

What is the temperature dependence of the QGP?

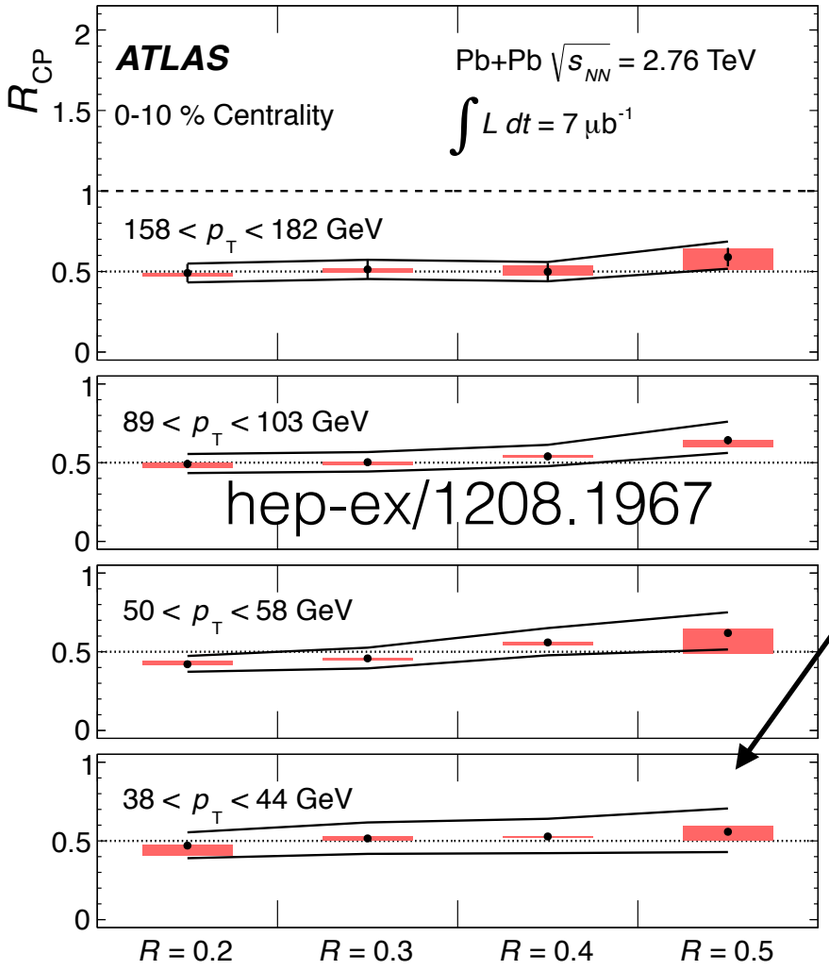


What are the inner workings of the QGP?

How does the QGP evolve along with the parton shower?

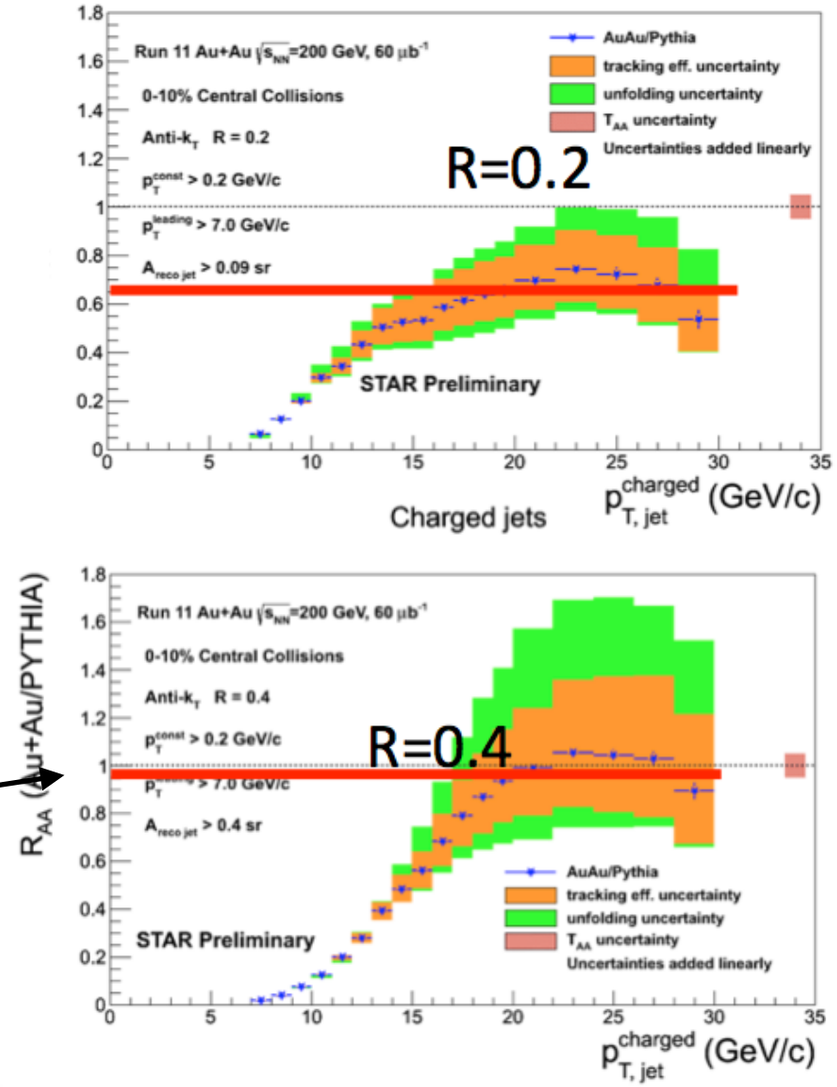
“Push” and “Probe” the QGP along three axes

What is the temperature dependence of the QGP?



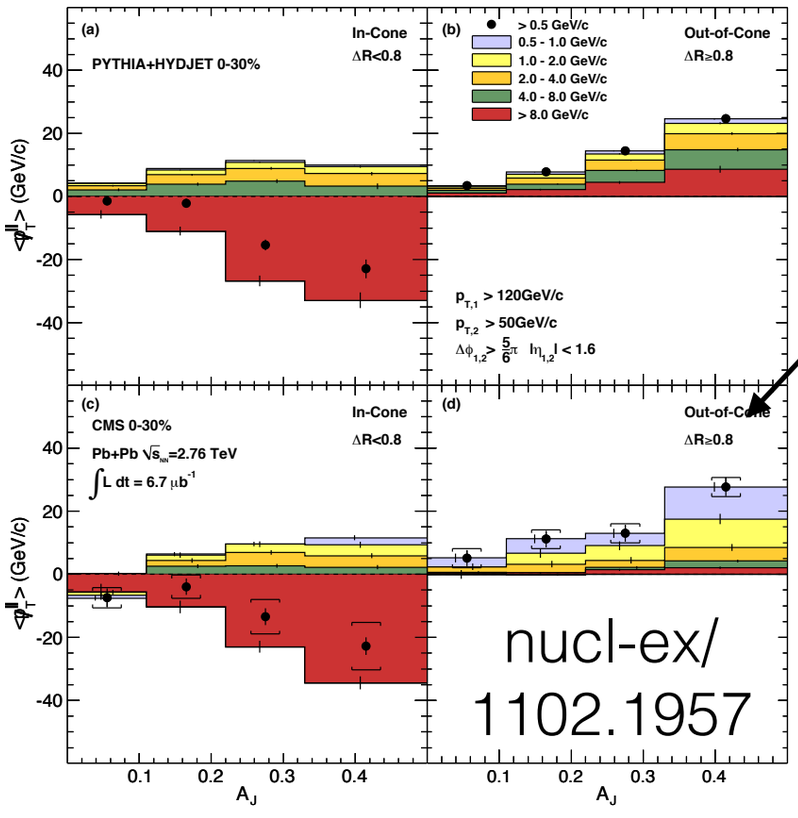
ATLAS: ***modest*** cone size dependence

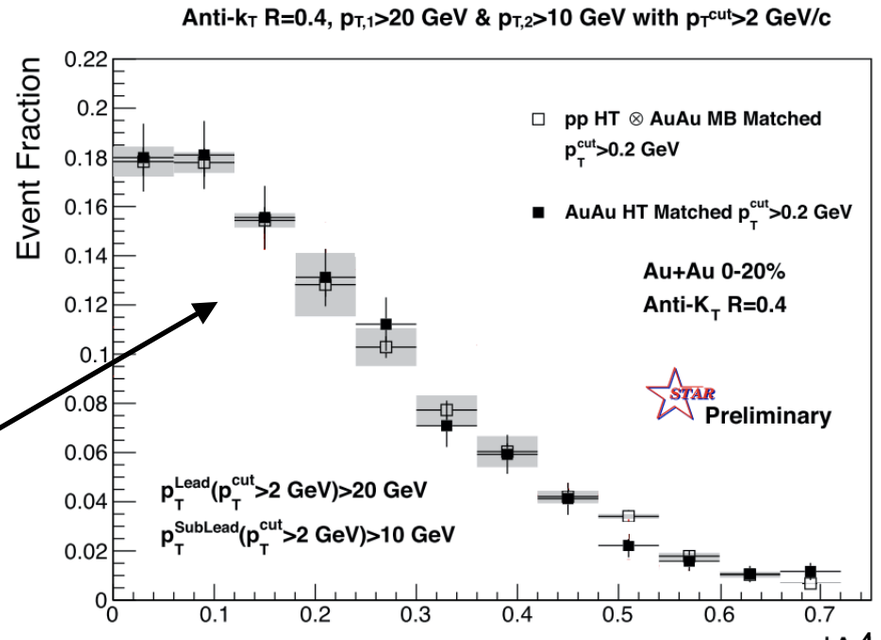
STAR: ***strong*** cone size dependence



CMS: lost energy ***transported*** to ΔR>0.8

STAR: lost energy ***recovered*** near jet





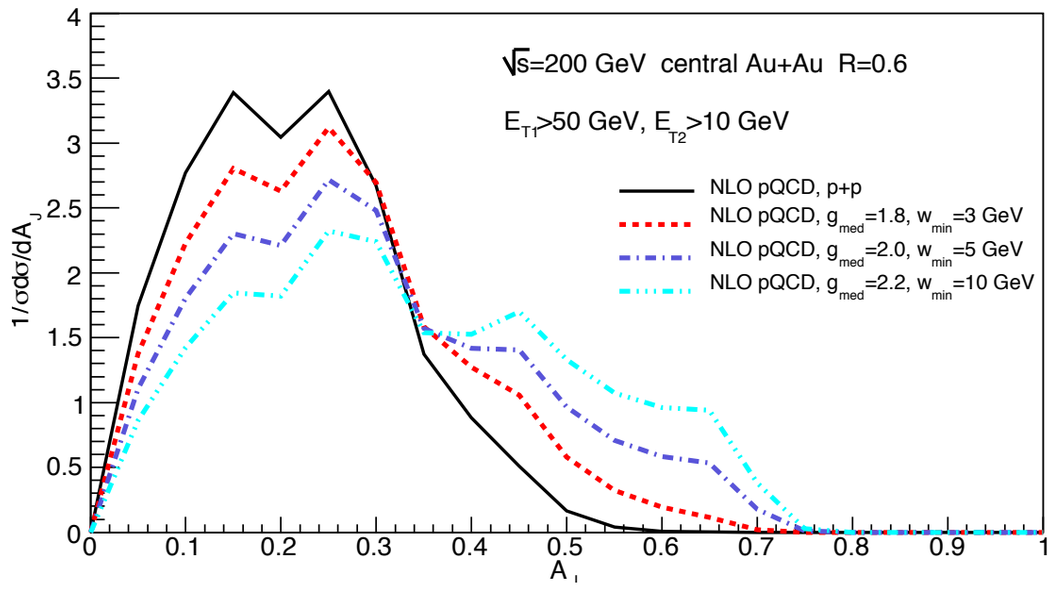
What are the inner workings of the QGP?

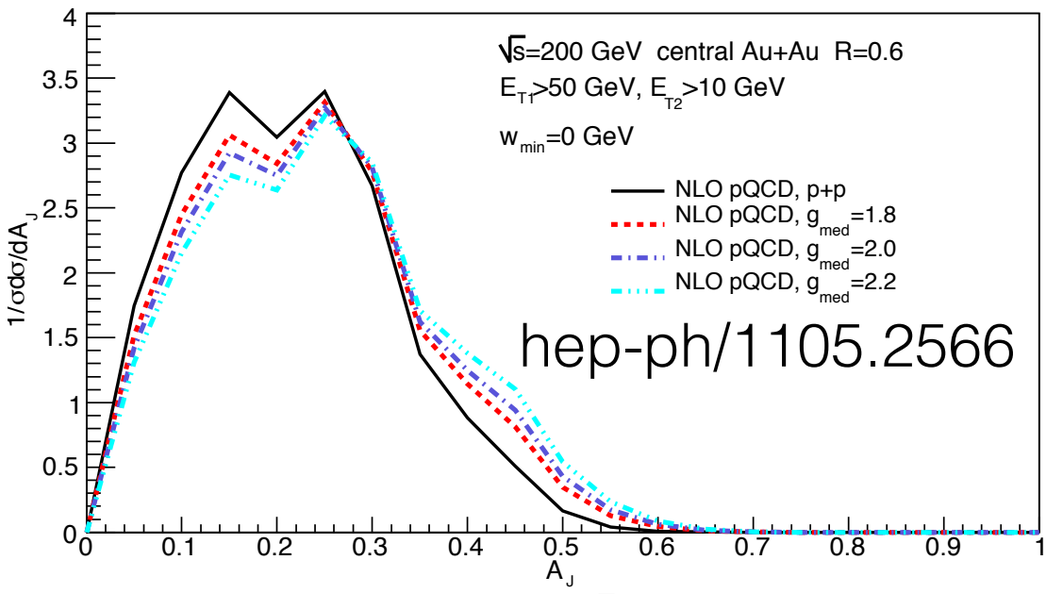
What are fast partons in the medium scattering from?

Elastic
+
Radiative

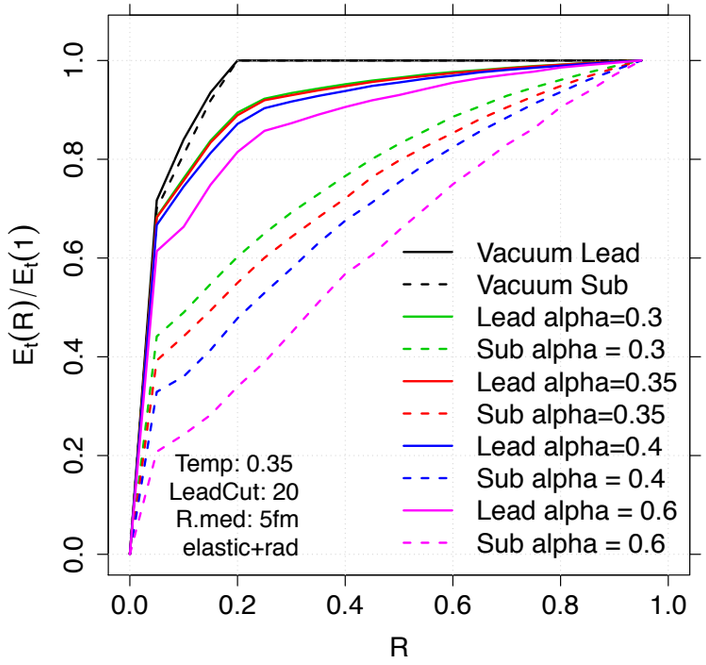
Elastic
Only

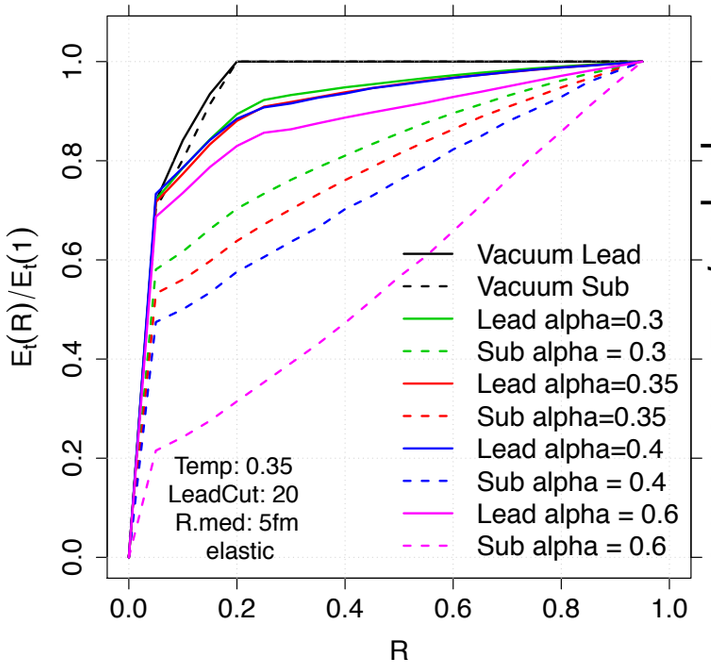
Dijet asymmetry





Jet shape

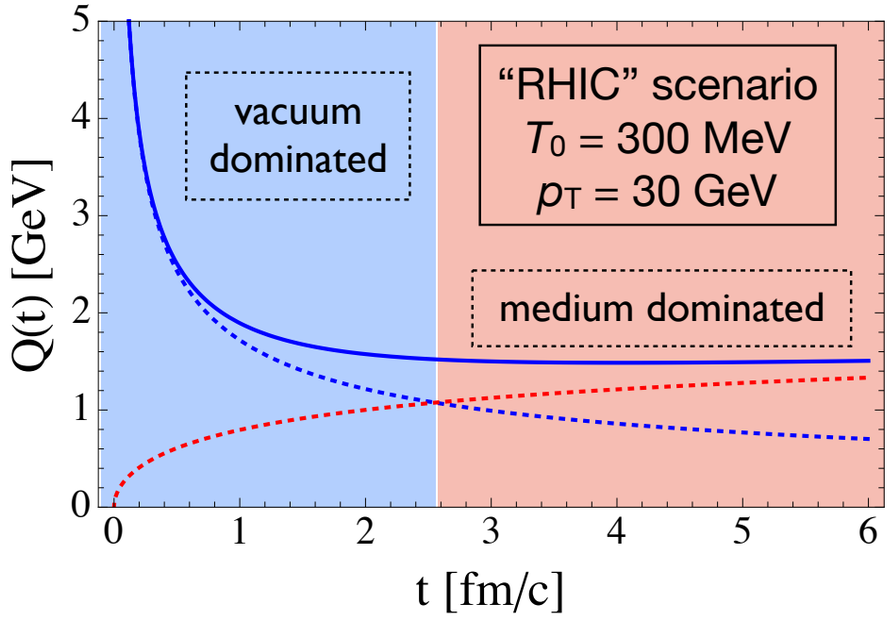


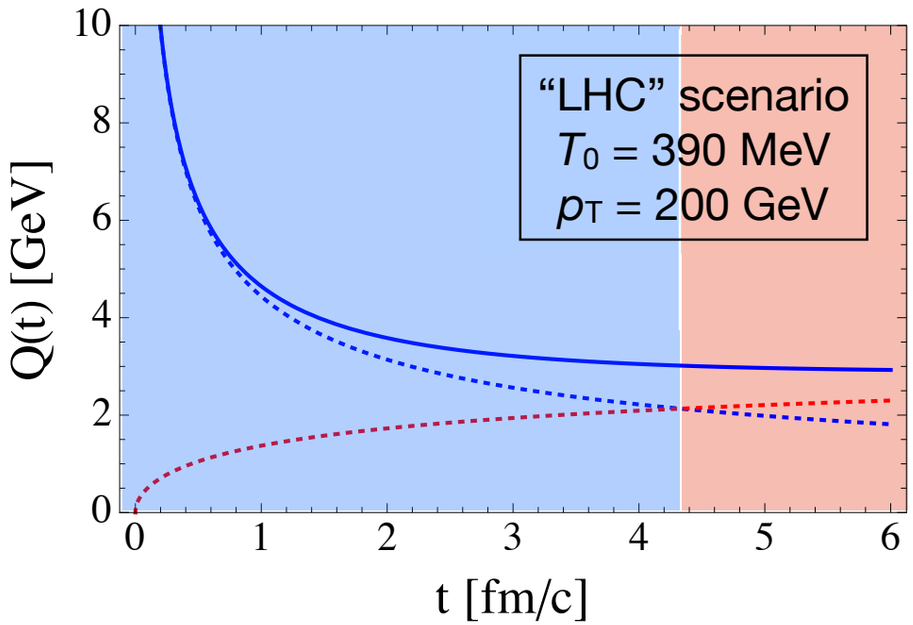


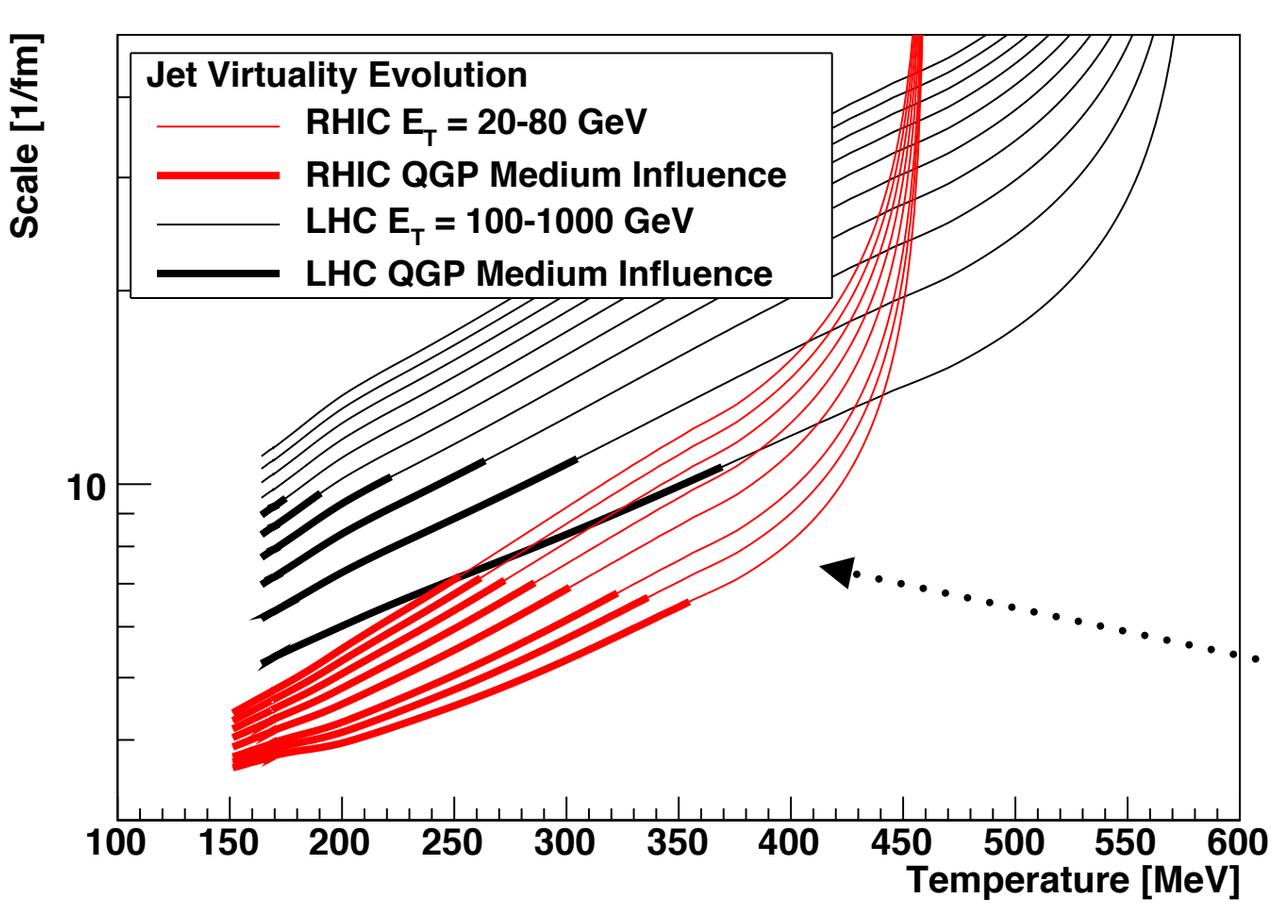
hep-ph/1205.6781

How does the QGP evolve along with the parton shower?

(plots from B. Mueller, RHIC/AGS Users Meeting '11 talk)



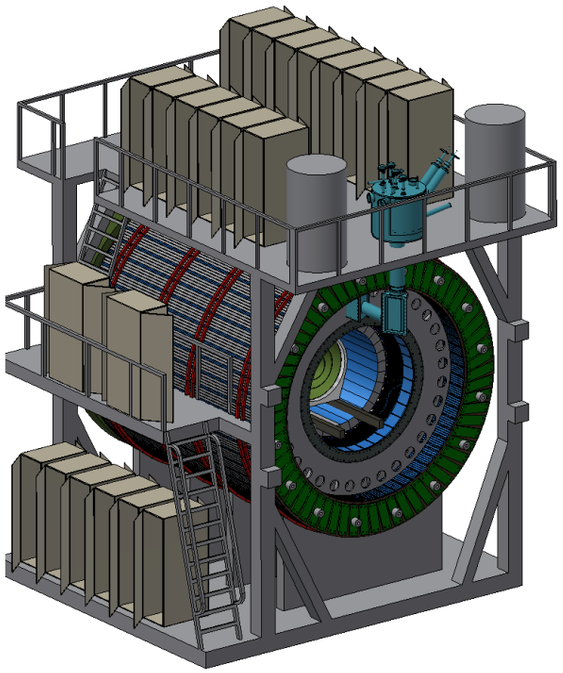




In some pictures, parton splitting is modified only when the ***medium-induced*** contribution to the virtuality dominates the **total**.

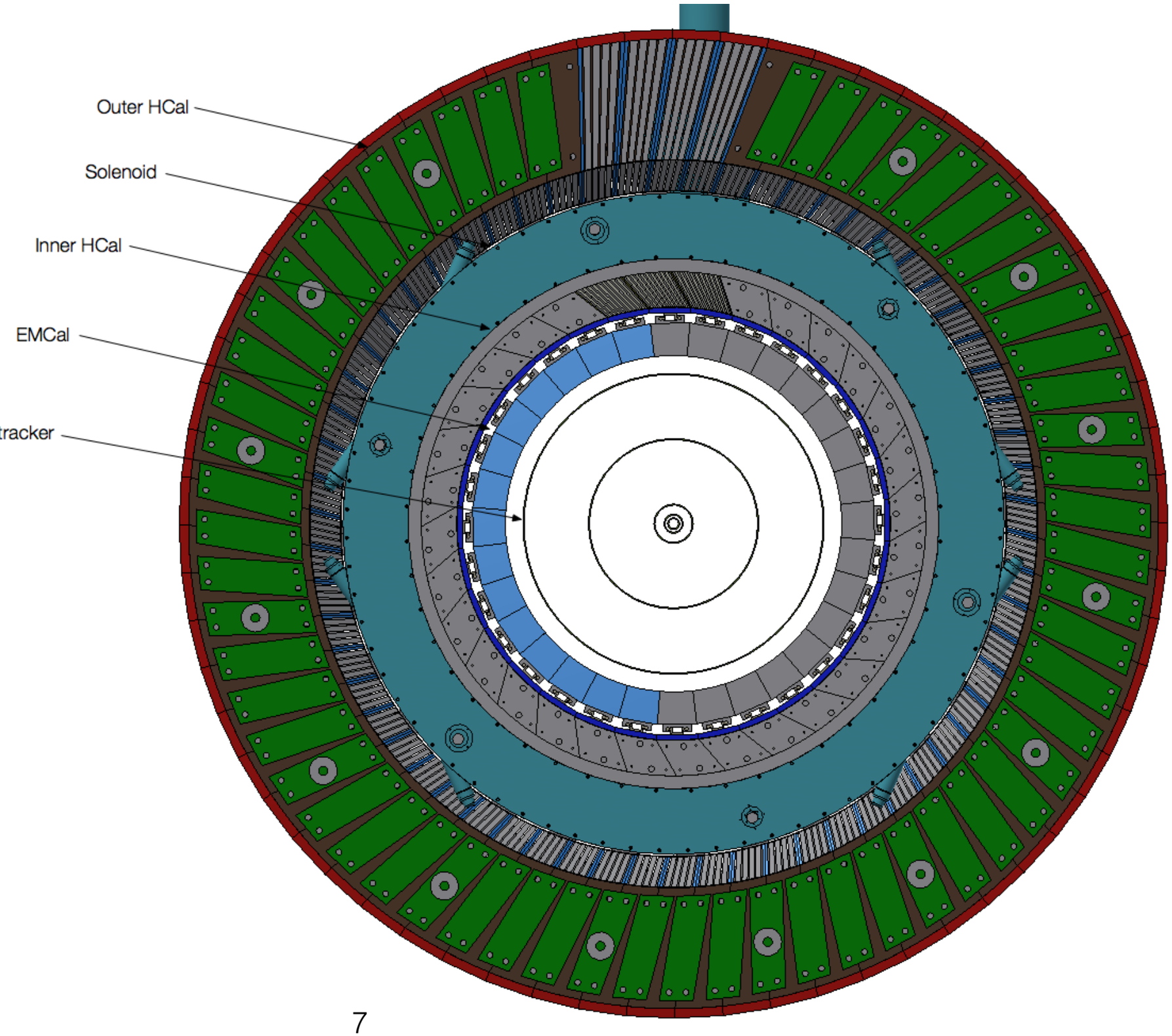
Jets spend *more time* in this regime at **RHIC** than the **LHC**

PHENIX Detector design

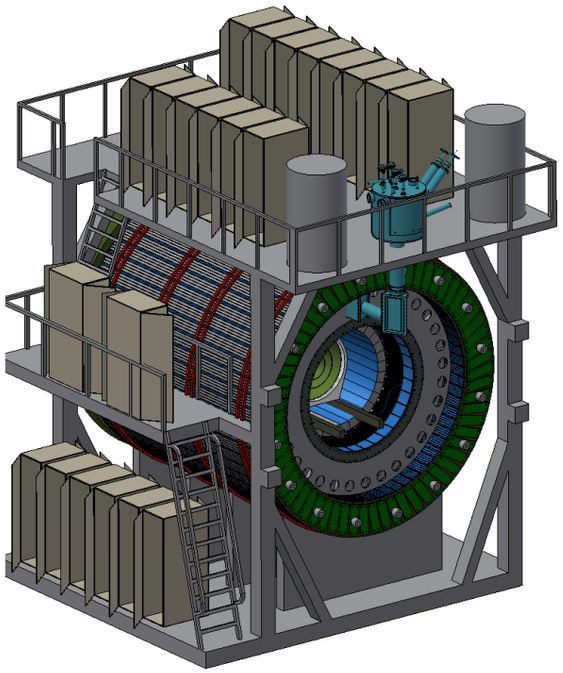


Reference design

- $|\eta|<1$, $\Delta\phi=2\pi$

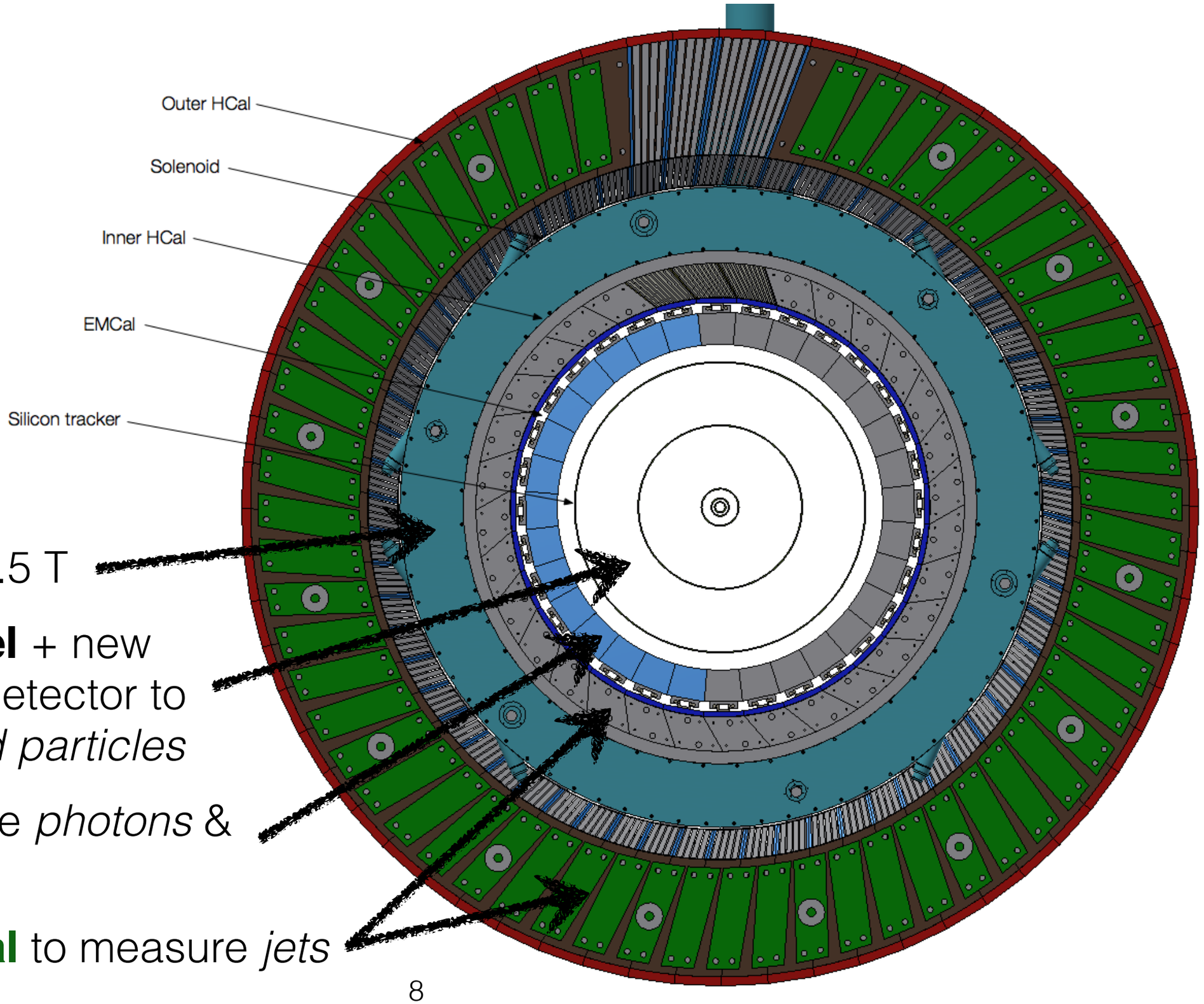


PHENIX Detector design

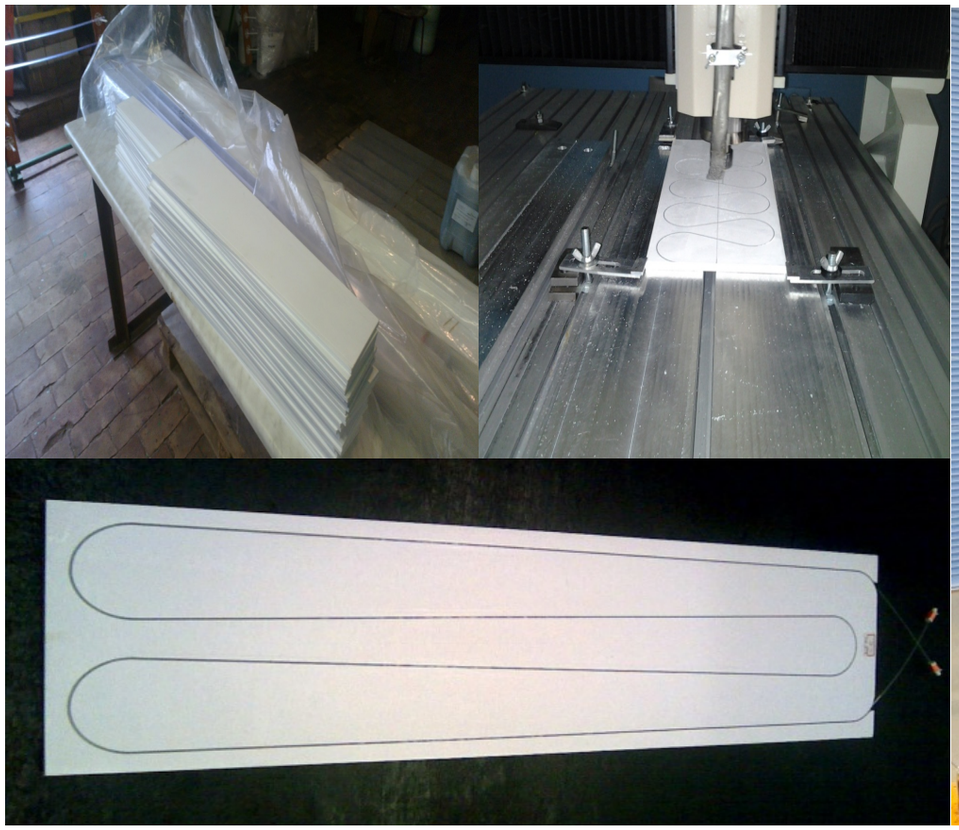


Reference design

- $|\eta|<1$, $\Delta\phi=2\pi$
- BaBar **magnet**, 1.5 T
- reconfigured **pixel** + new large area **strip** detector to measure *charged particles*
- **EMCal** to measure *photons* & *electrons*
- **Inner+Outer HCal** to measure *jets*

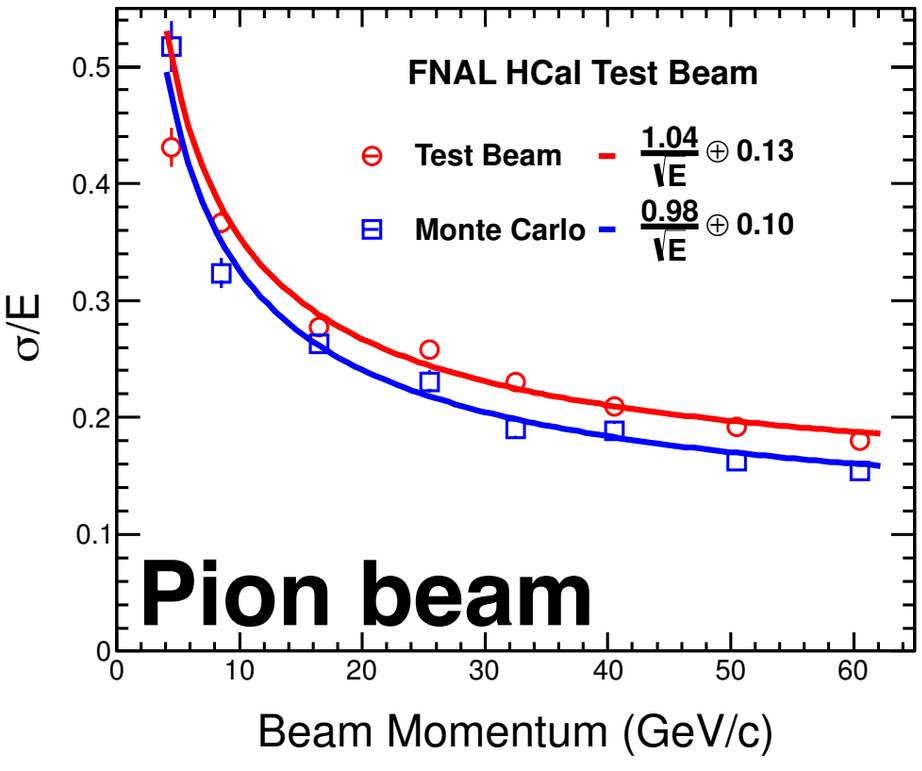


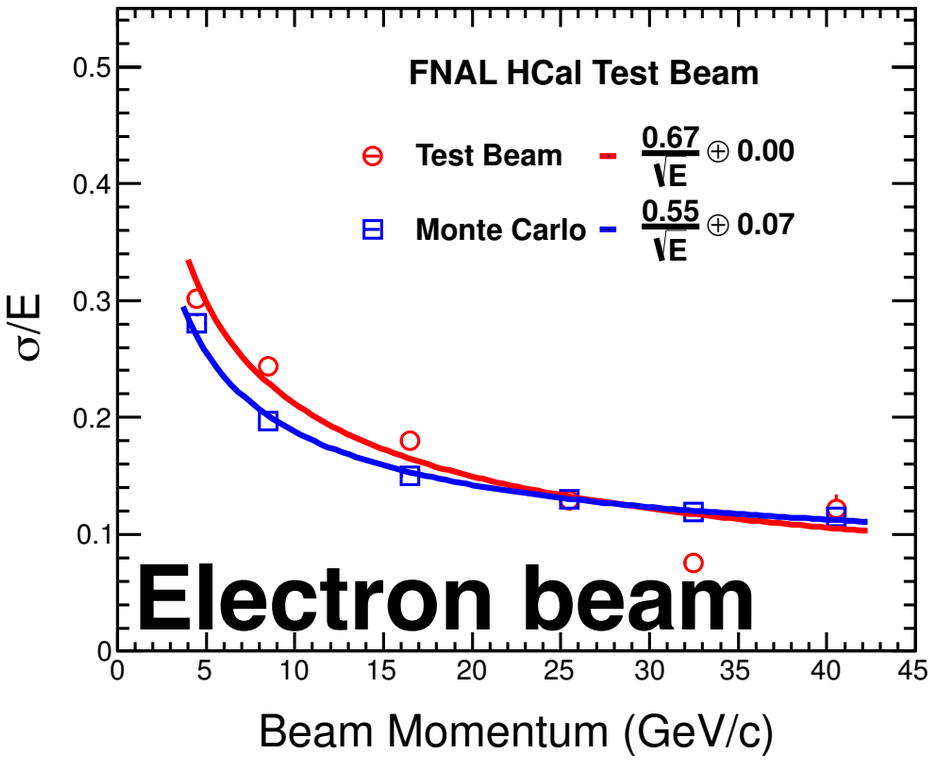
HCal prototype beam tests



Test beam
@ Fermilab
Feb. 2014

"tilted plate"
HCal
prototype





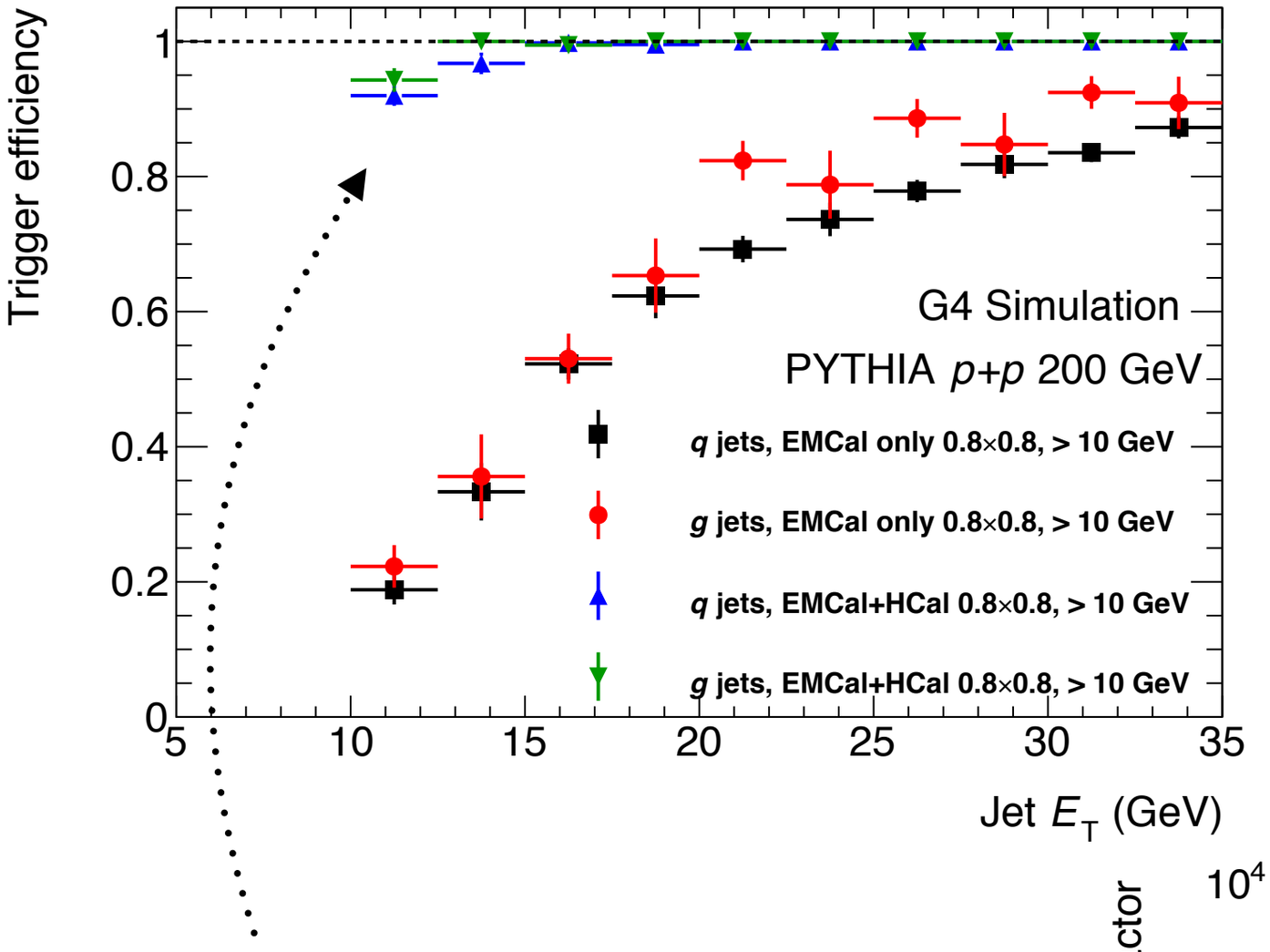
The BaBar magnet is en route!

16 January 2015, SLAC

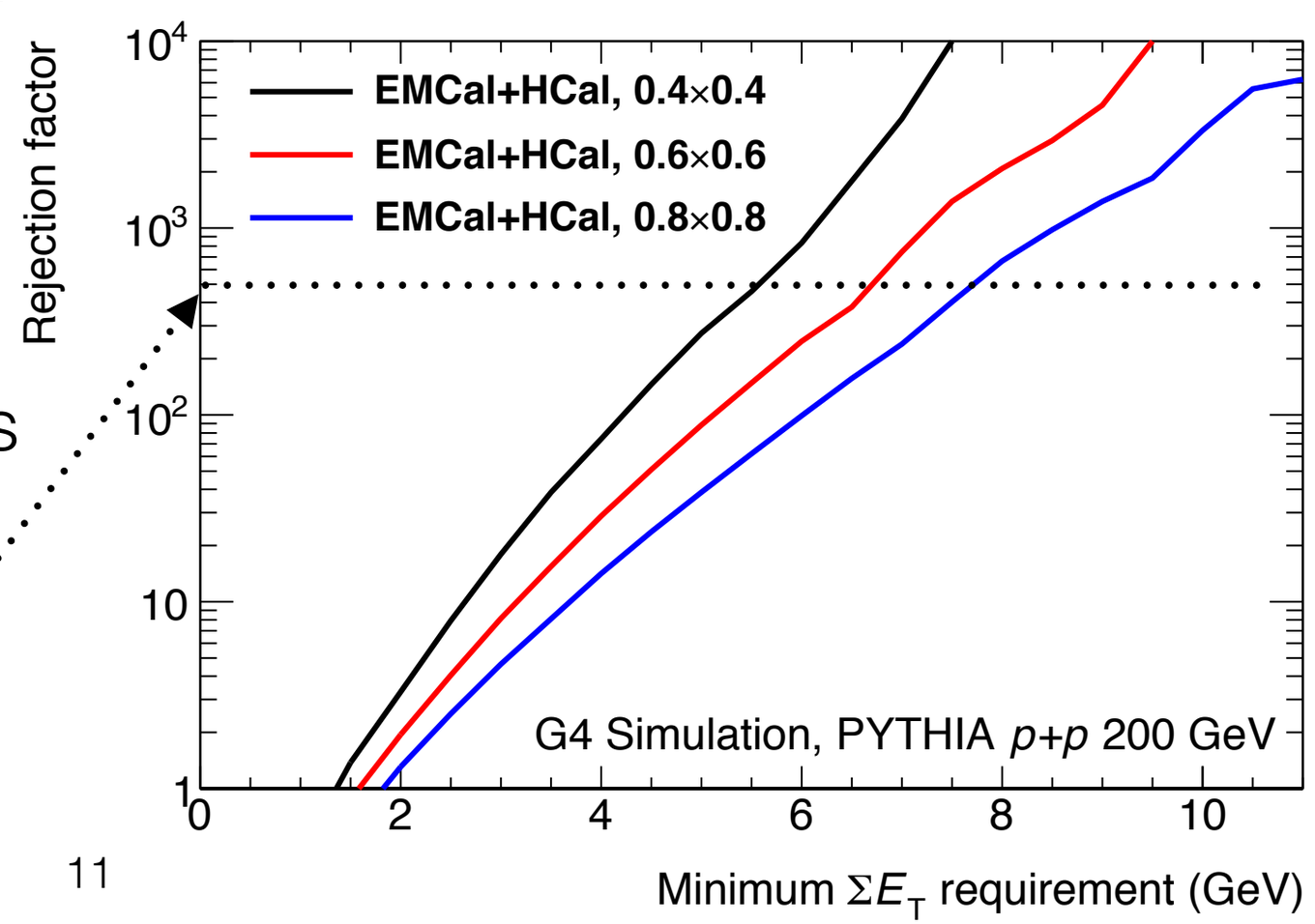
www.symmetrymagazine.org/article/january-2015/20-ton-magnet-heads-to-new-york

Jet triggering

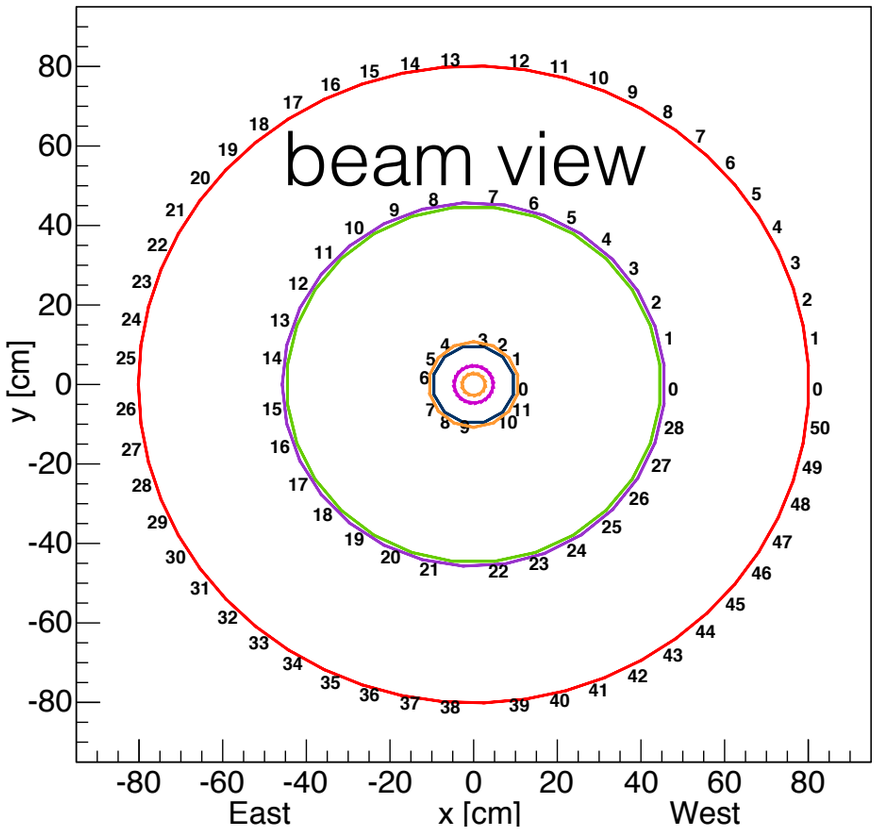
- Large PHENIX DAQ rate can record (almost) all Au+Au data minimum bias
- Triggering needed in *p*+*p* running to sample the equivalent *NN* luminosity



- Wide-area EMCal+HCal "**jet patch**" triggers
  - 100% efficiency for low-p_T jets with no flavor dependence
- Rejection factors for MB *p*+*p* events are sufficiently high

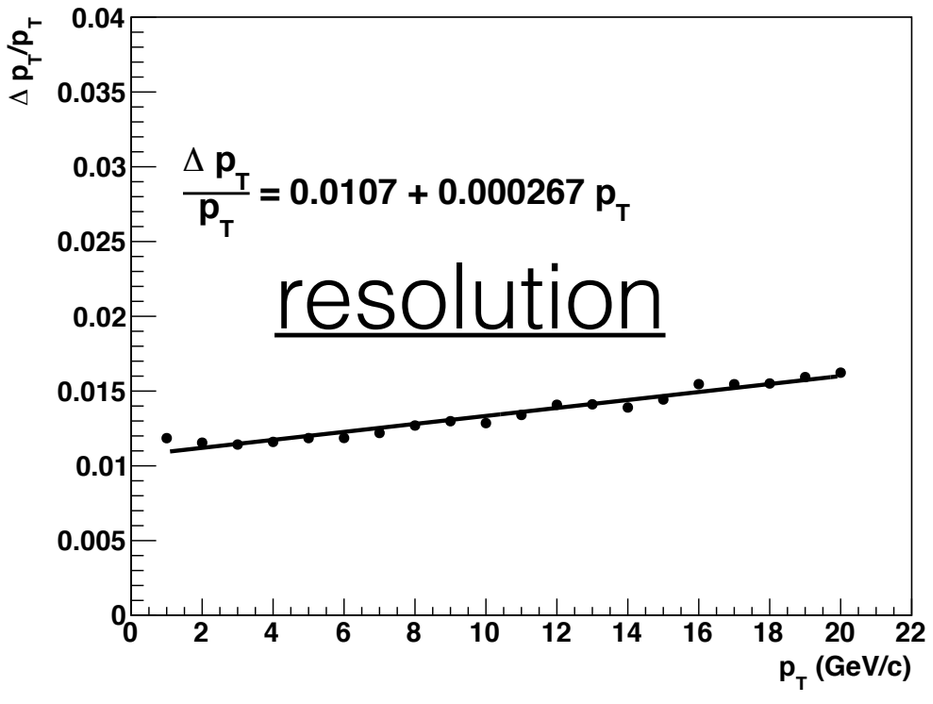


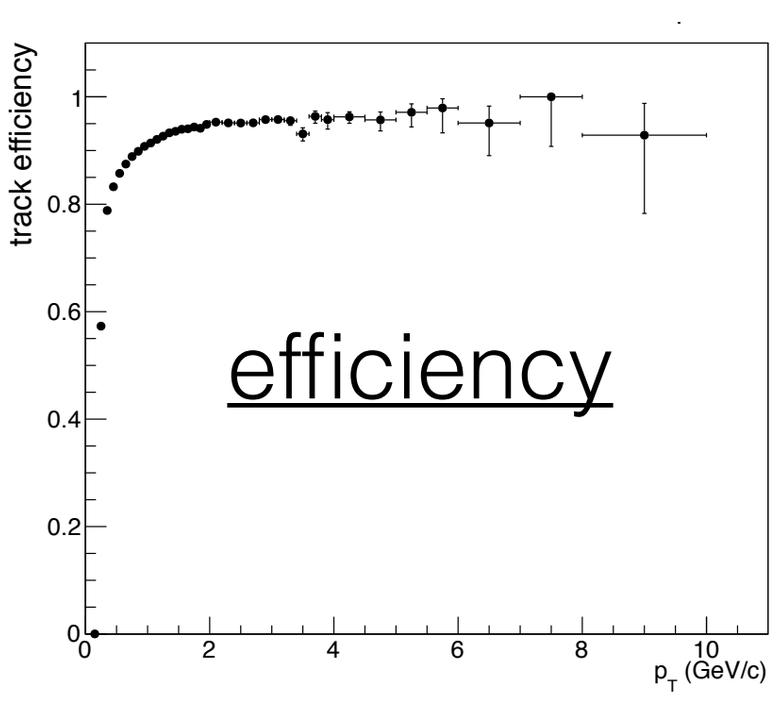
Charged hadron capability

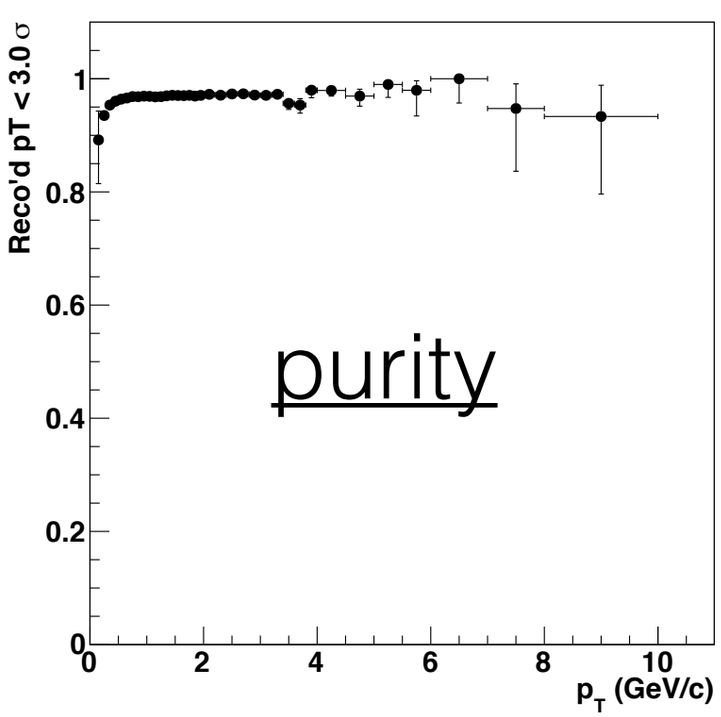


Reconfigured silicon tracking configuration

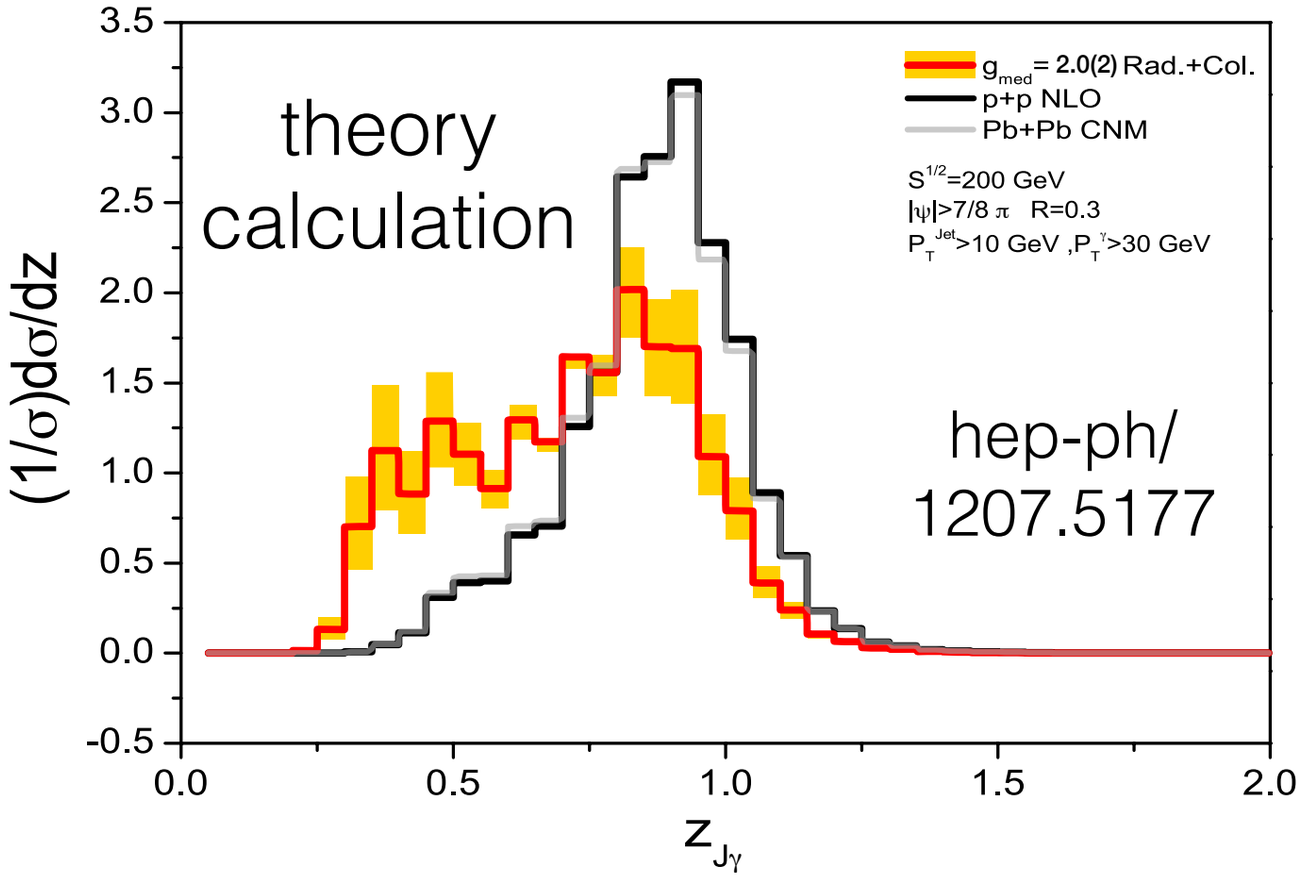
- performance benchmarked with full GEANT4-based simulations
- one physics-driven target: Υ mass resolution < 100 MeV/c^2 (see Jin Huang's talk)
- robust behavior even in high-multiplicity environments (HIJING Au+Au)



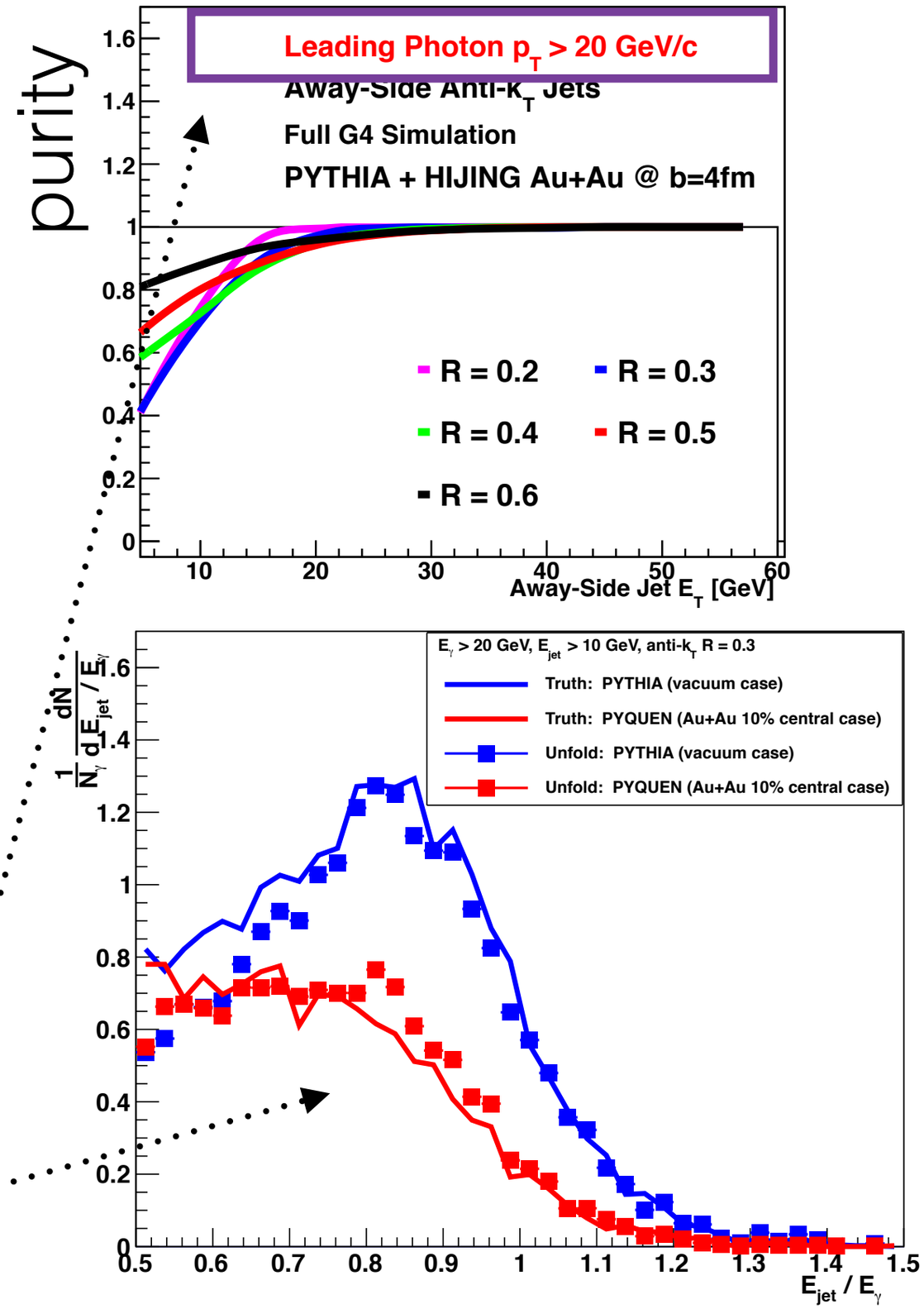




Photon-jet observables

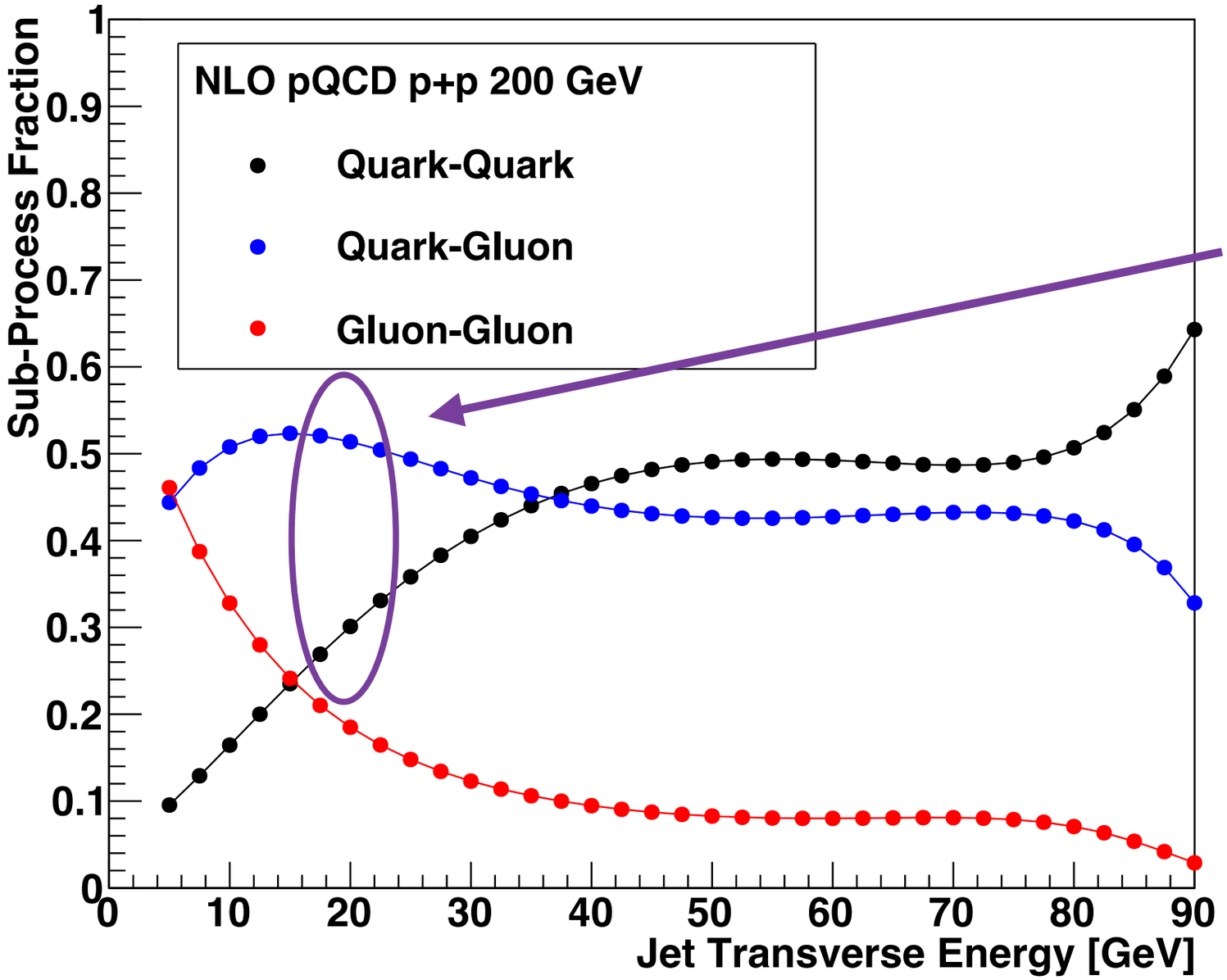


- Steeply falling cross-section at RHIC results in narrower initial $z_{J\gamma} = E_T^{jet} / E_T^{\gamma}$ distribution
  - *and* a larger **modification** than at the LHC
- Purity for jets on the away-side of a **trigger photon** is high
- Detector effects in $z_{J\gamma}$ distribution can be corrected to a high degree



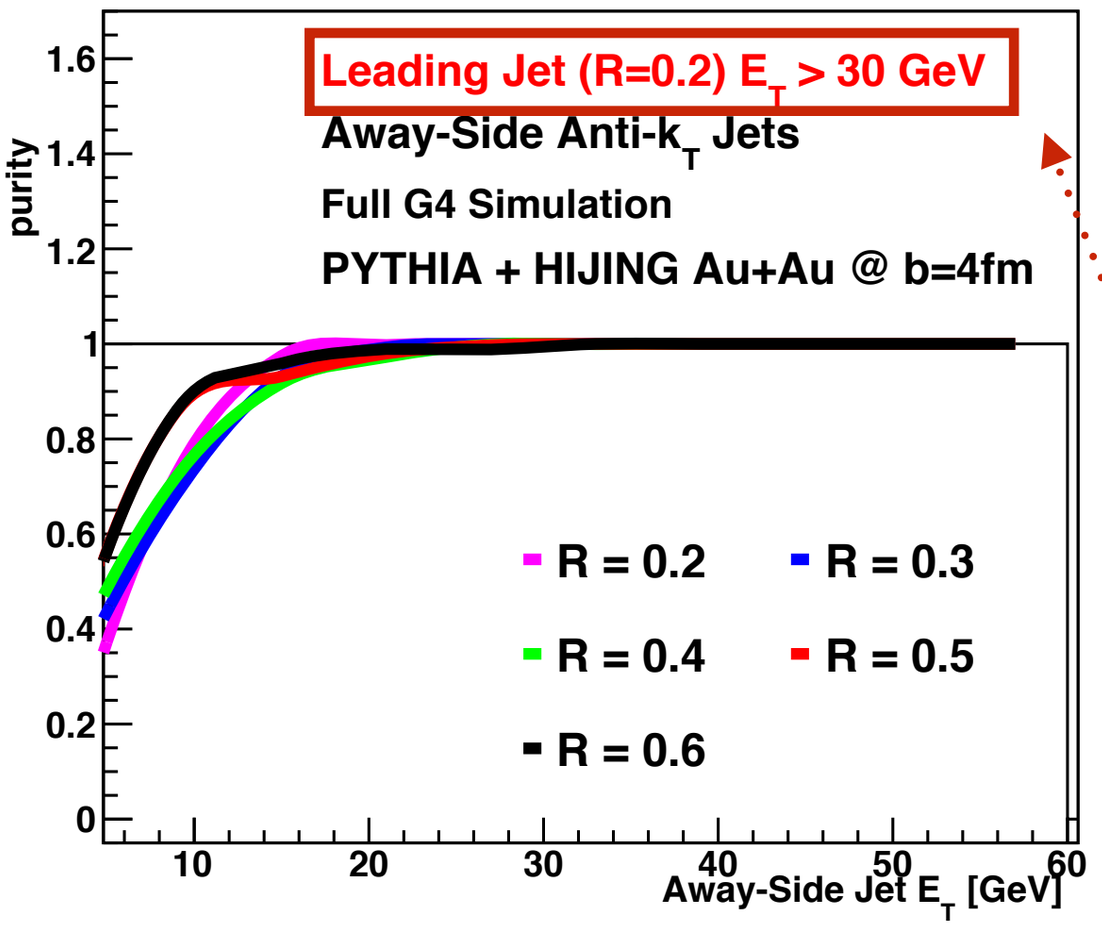
Selecting gluon jets

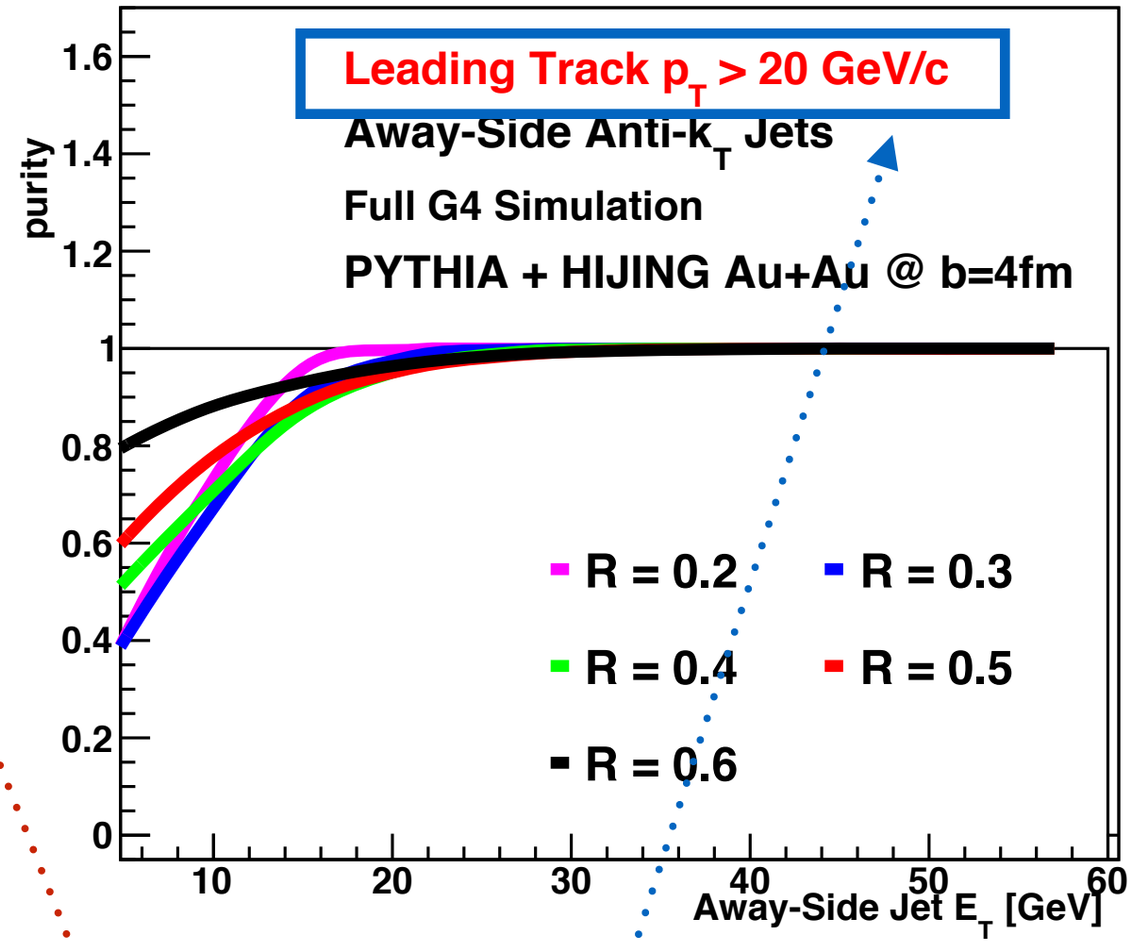
- Photons are an excellent way to select a quark-enhanced jet sample
- Can we experimentally tag gluon jets?



In a given **kinematic regime**, a near-side ***quark*** jet is preferentially accompanied by an away-side ***gluon*** jet

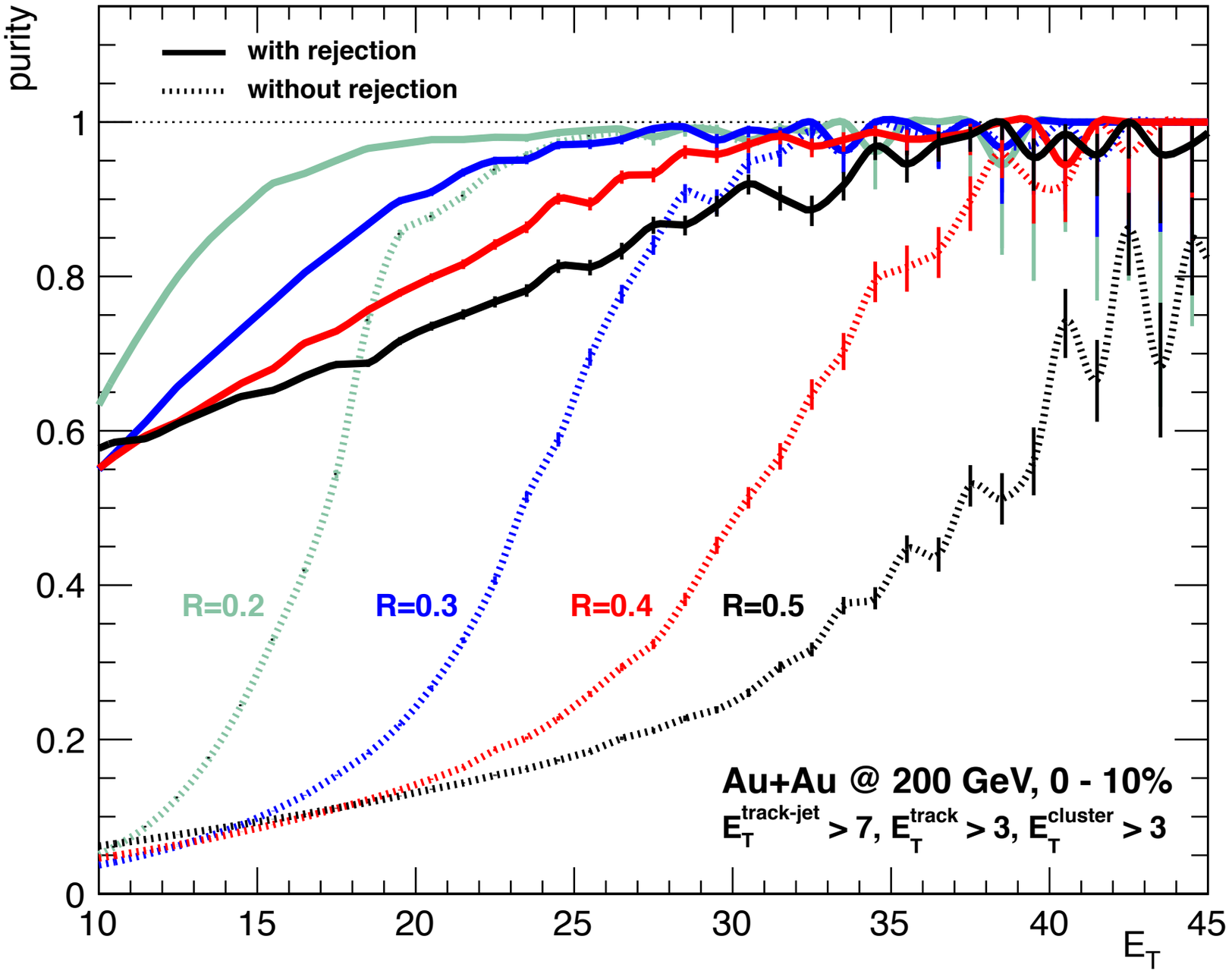
Selecting gluon jets





- We can select quark jets a high-p_T **narrow-*R* jet** or **track**
  - the purity for away-side jets is high down to low p_T and large R
- sPHENIX can explore the modification of jets in a flavor-dependent way

Extending the kinematic reach



Purity of hard-scattered jets (vs. background fluctuations) in inclusive spectrum

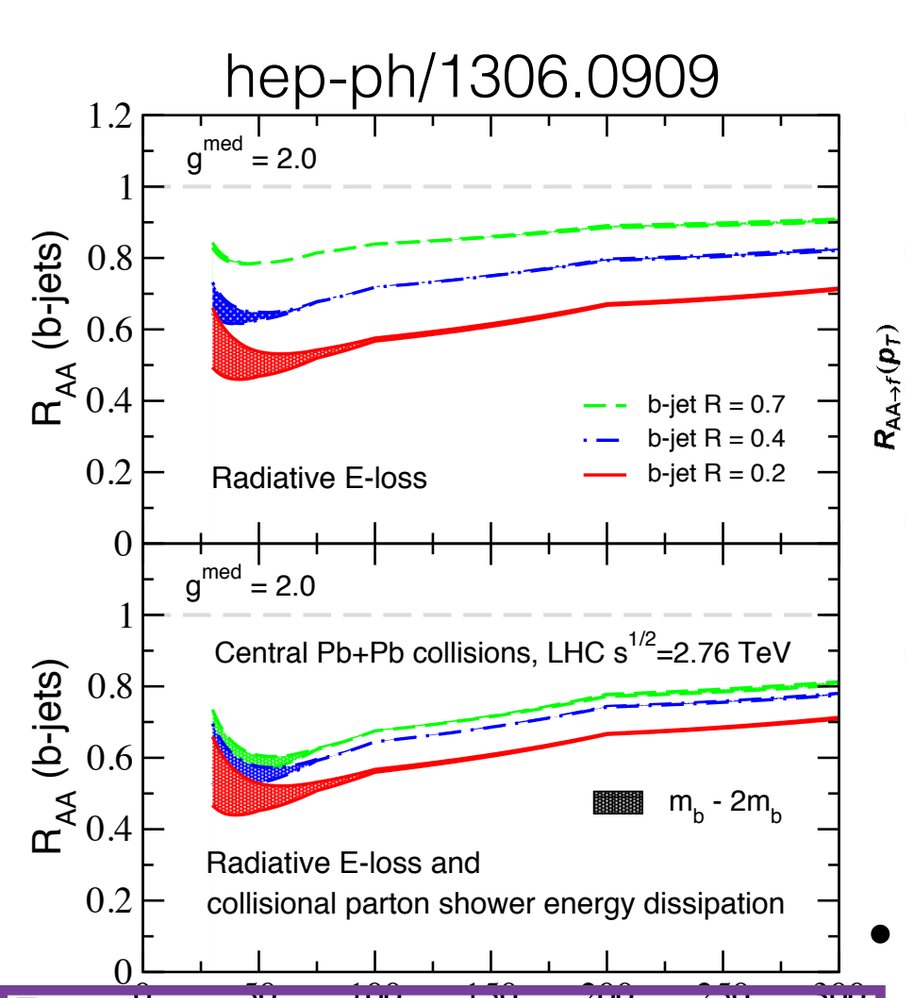
Application of ATLAS-style "fake jet rejection" requirement

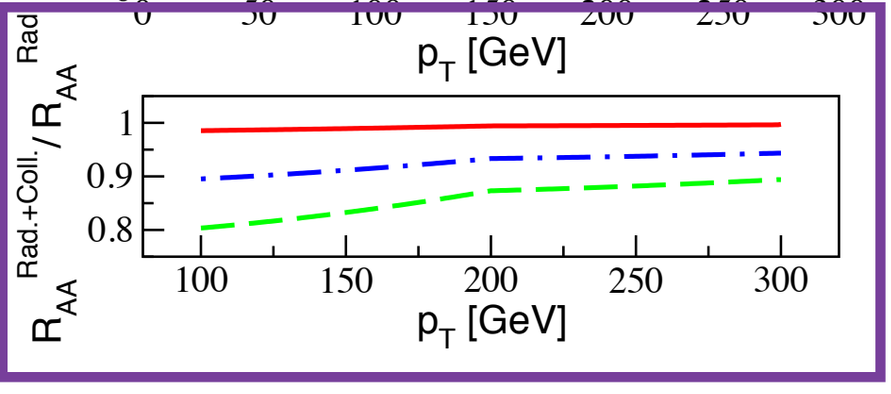
- relies on presence of high-p_T track-jet, track or cluster

Such techniques certainly bias the surviving population of low-p_T jets

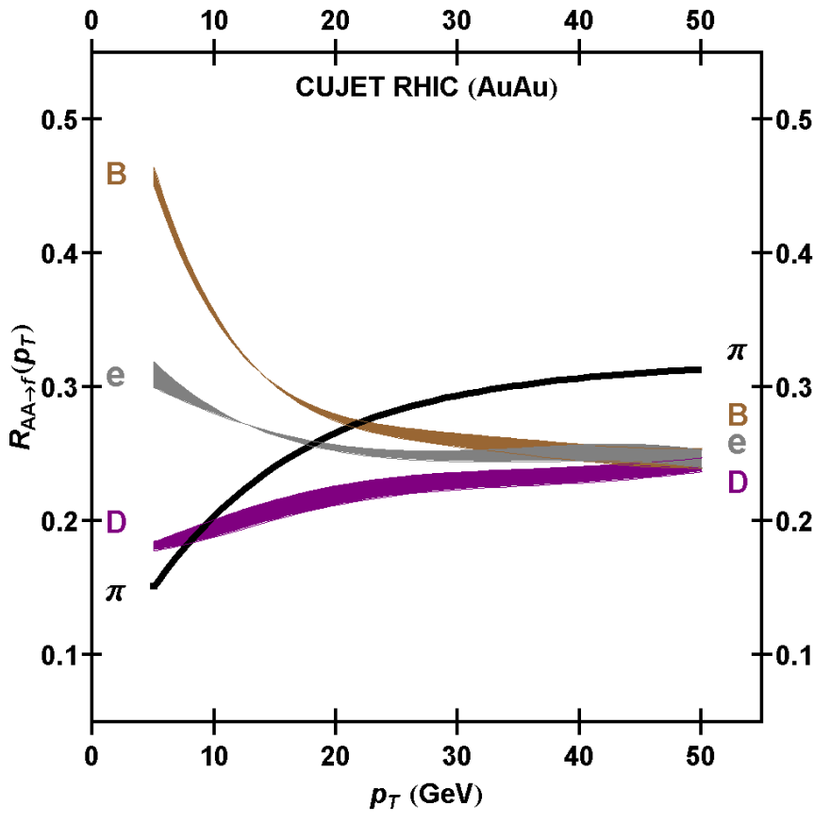
- however, this can be exploited to perform "event shape engineering"

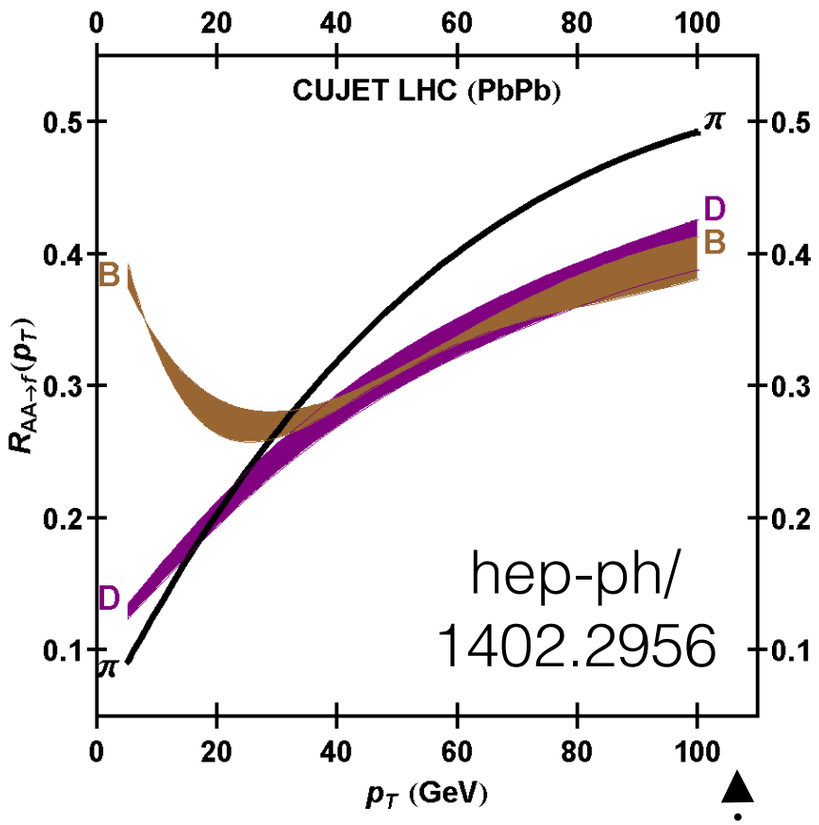
b-jet physics in HI collisions





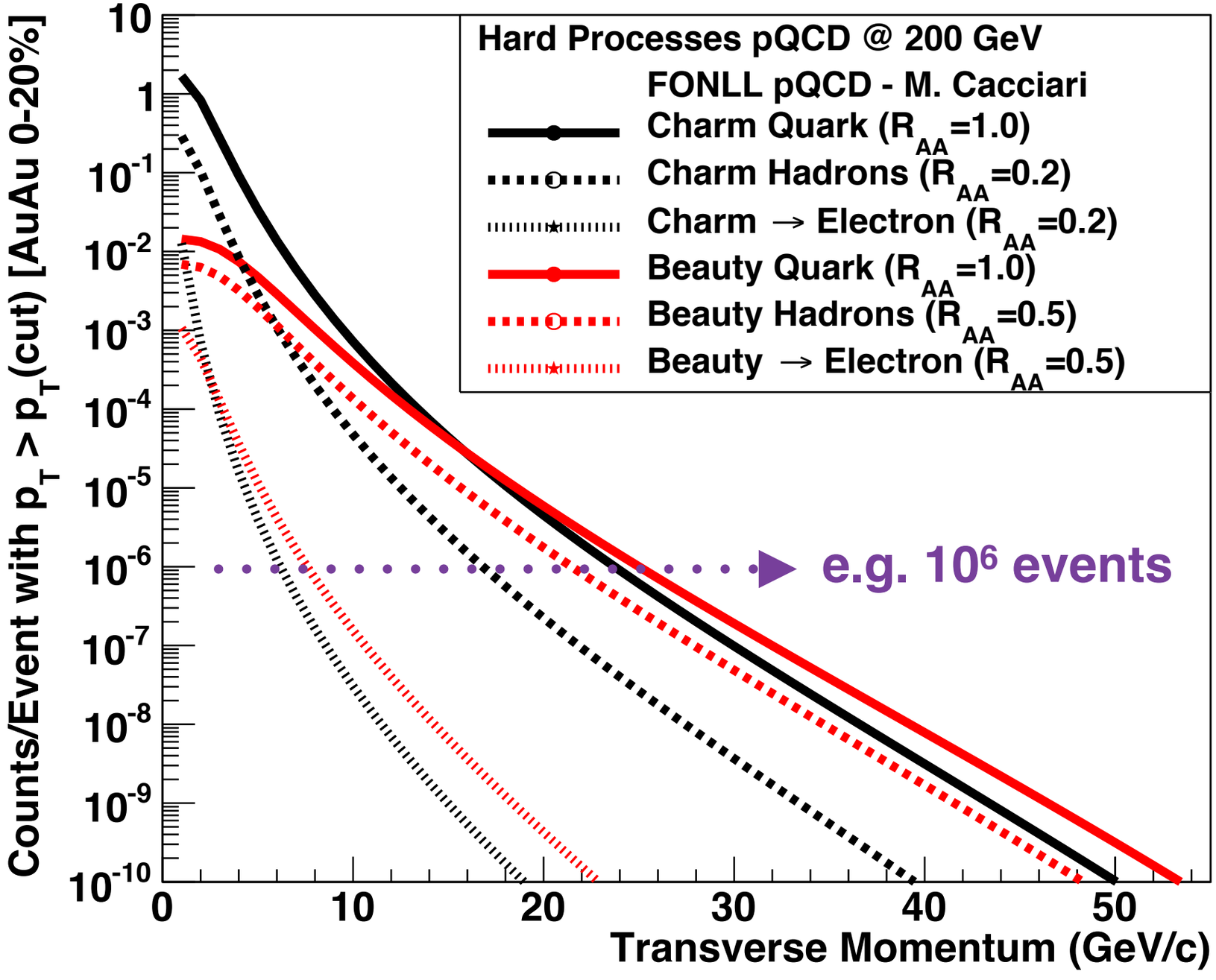
Ratio of R_{AA} with/without collisional E-loss





- The quenching of heavy quark jets may differ in a number of ways from light quarks / gluons:
  - suppression of radiation at small angles
  - different sensitivity to <u>radiative</u> vs. <u>collisional</u> energy loss
- Important dimension for a full picture of the physics!

b-jet production rates

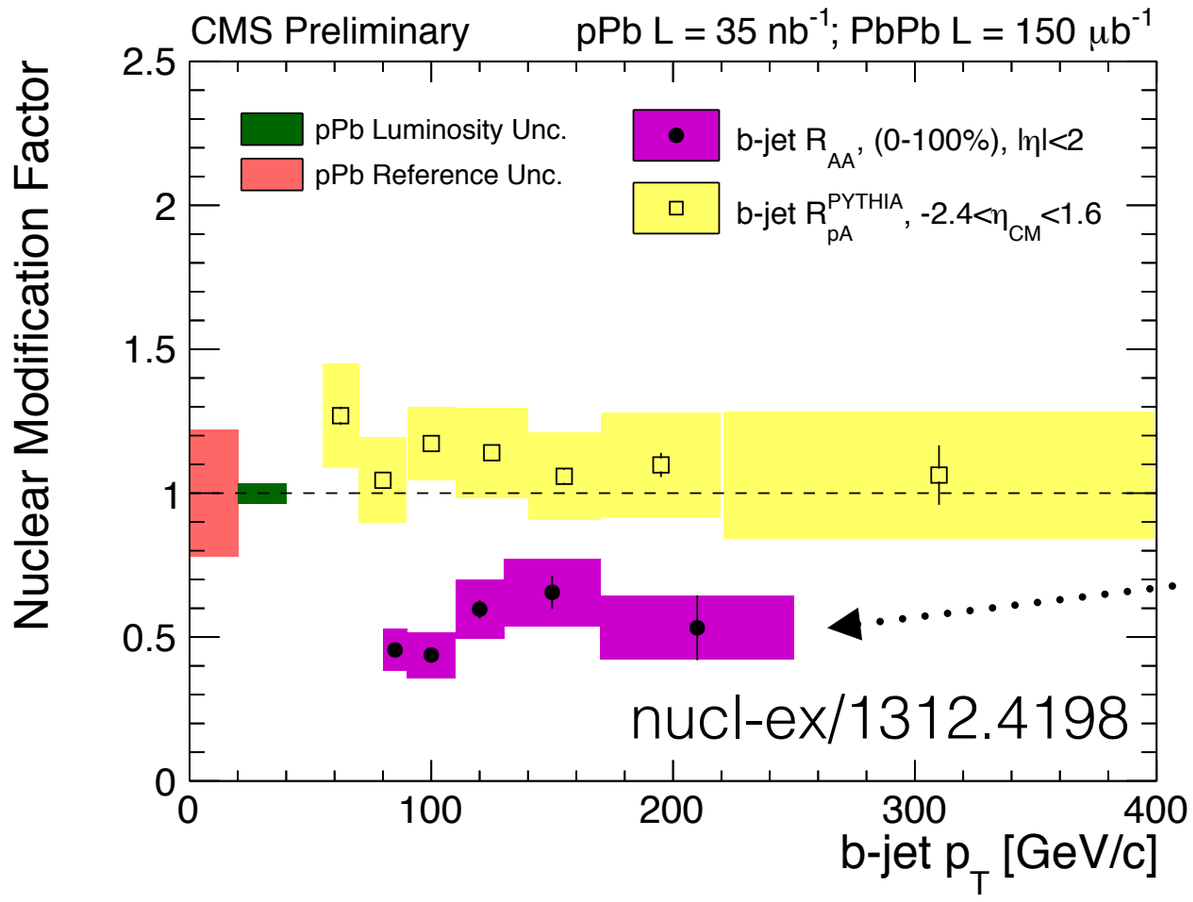


RHIC luminosity projections for sPHENIX:

- nominal 22 week run
- Au+Au events within the vertex *z*-range needed to perform *b*-tagging
- **0.1 trillion** (10^{+11}) minimum bias Au+Au

◀..... y-axis doesn't go low enough to show the p_T reach!

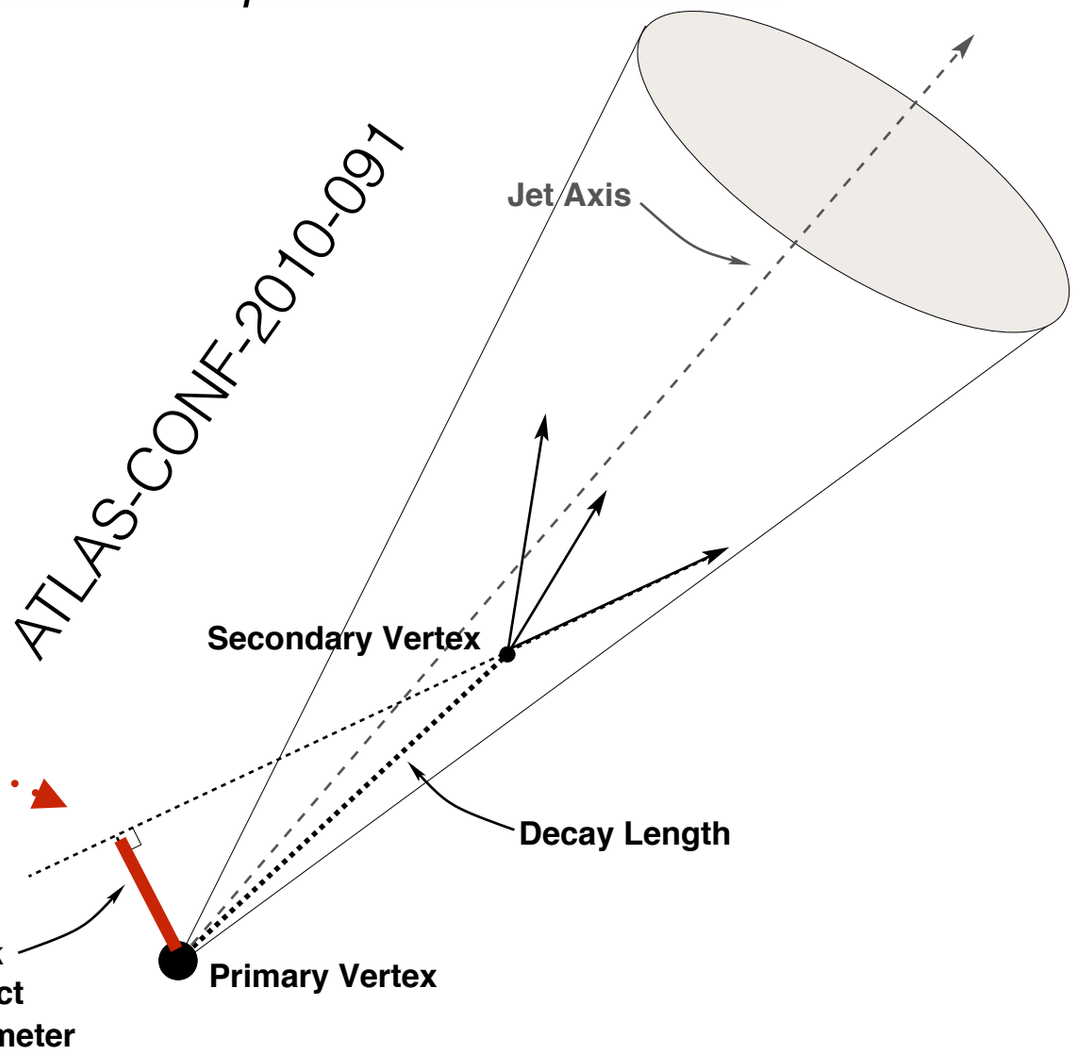
b-jet tagging



Experimental selection of an enriched sample of bottom quark initiated jets

Cottage industry at the LHC, new to HI

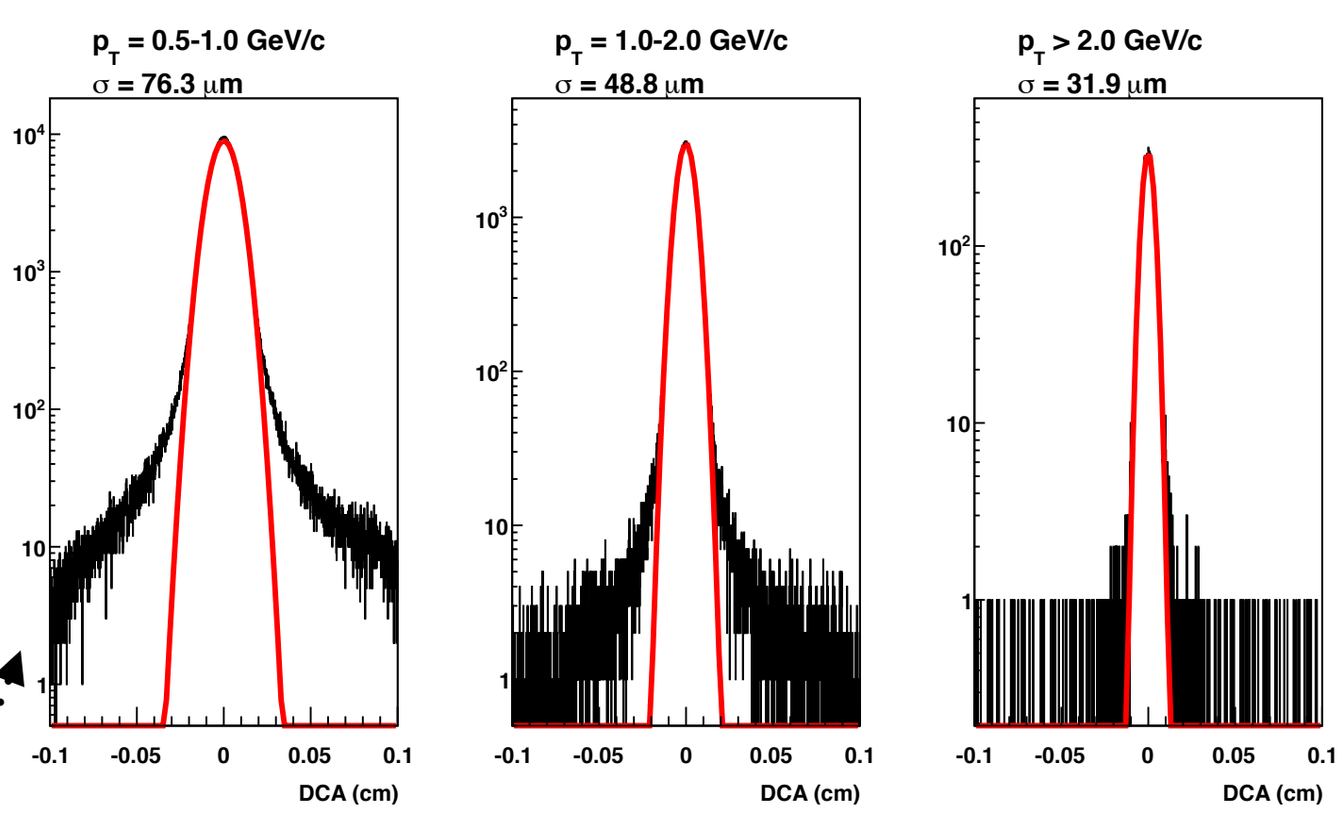
CMS *b*-jet R_{AA}, via reconstructing *large-mass displaced vertices*



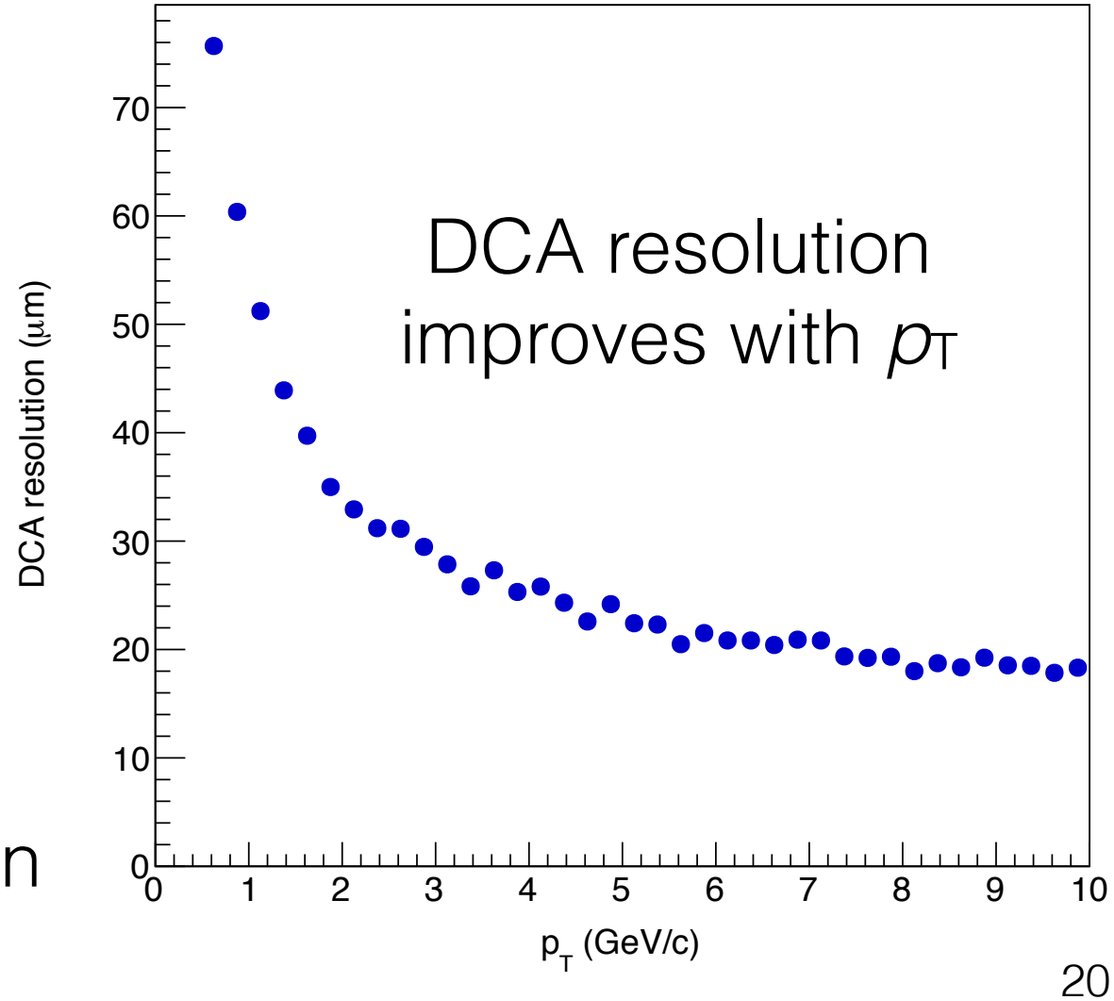
- In sPHENIX, we have explored the "Track Counting" algorithm
  - *requires one or more tracks with a* ***non-zero PV impact parameter***
  - must balance high rejection of light jets with high efficiency for *b*-jets

Distance of closest approach (DCA) reconstruction

- 2-d (transverse) distance of closest approach reconstruction is *<u>the</u>* major driver of this *b*-jet tagging method
- GEANT4-based simulations of the DCA resolution within the reference tracking configuration

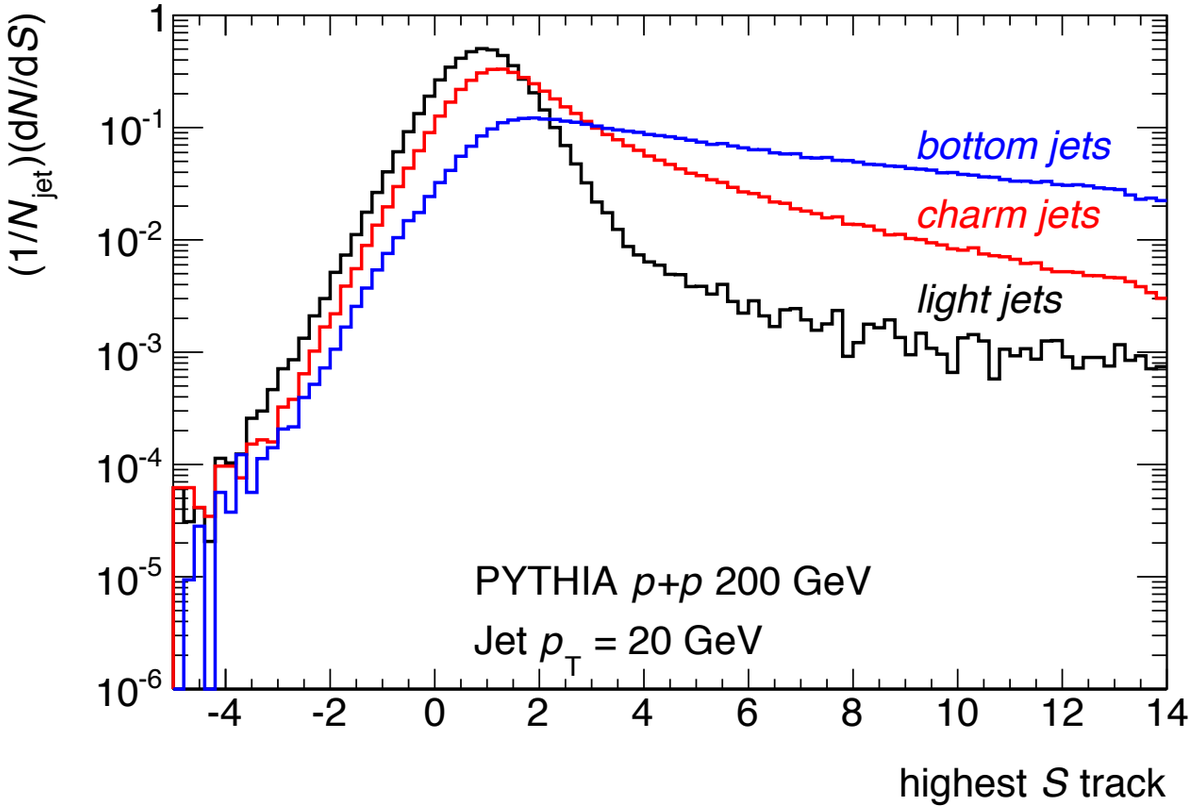


Note: large-DCA tails will be present even for hadrons born at the primary vertex



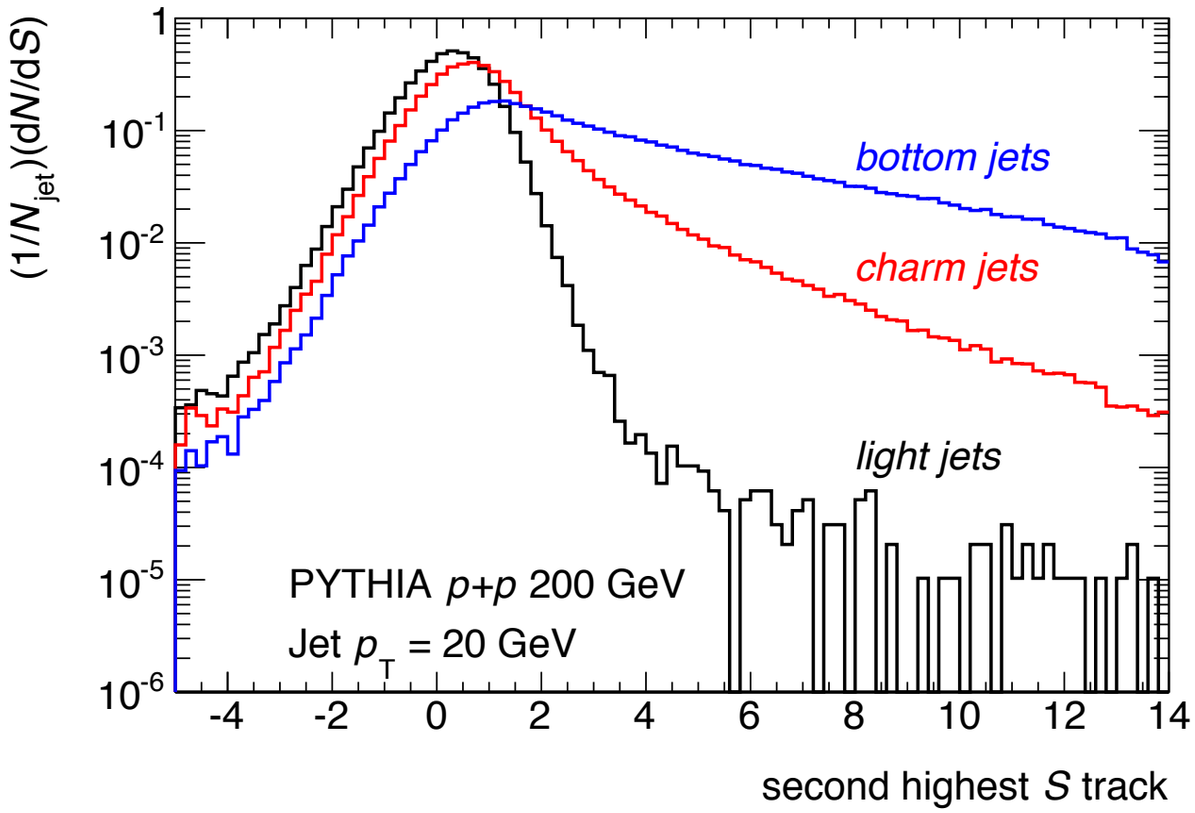
Reconstructed DCA of hadrons in jets

- Generate p_T = 20 GeV truth jets from **light**, **charm** and **bottom** quarks
  - smear the DCA of their tracks according to the G4 simulation results
  - sort all tracks in jet cone by their *significance* S_{DCA} = DCA / σ_{DCA}



High-DCA in **charm**/**bottom** jets from displaced vertices

High-DCA tail in **light** jets from tails in DCA resolution + Σ/Ξ decays



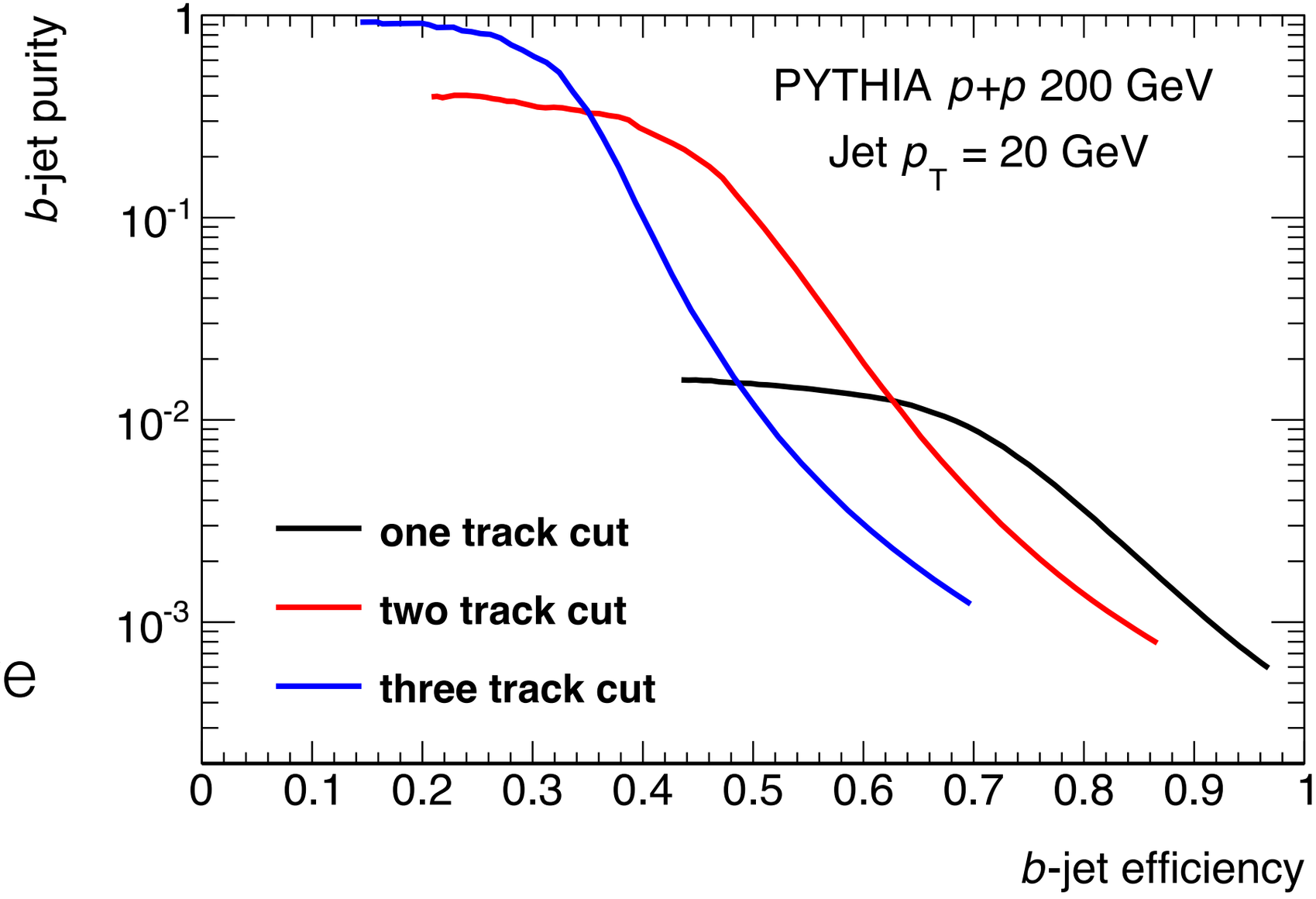
Asking for a high DCA in >1 track cuts down on the **light** jet background

b-jet performance in *p*+*p*

Purity of *b*-jets after Track Counting cut

(note: purity <10^{-3} before any cuts)

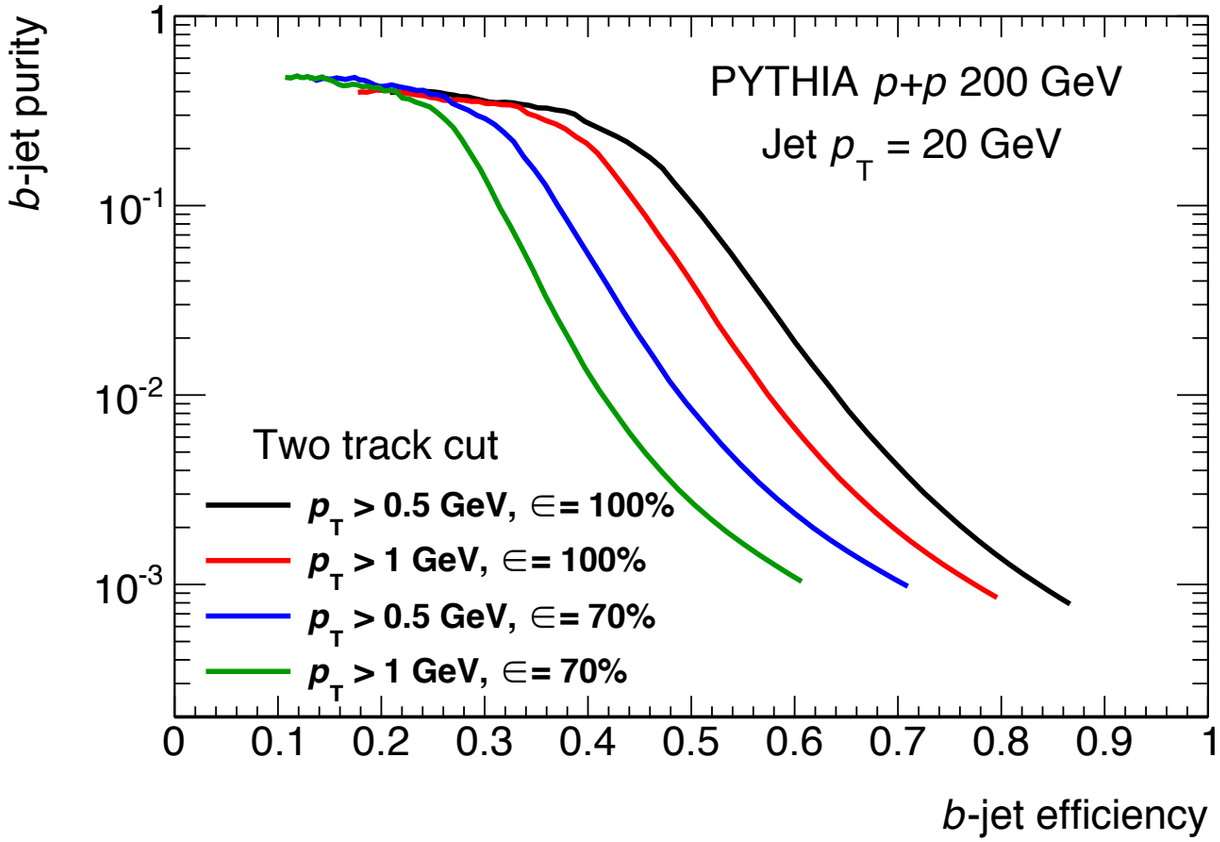
P vs. **E** curves for requiring **1**, **2** or **3** tracks with S_{DCA} above some minimum value



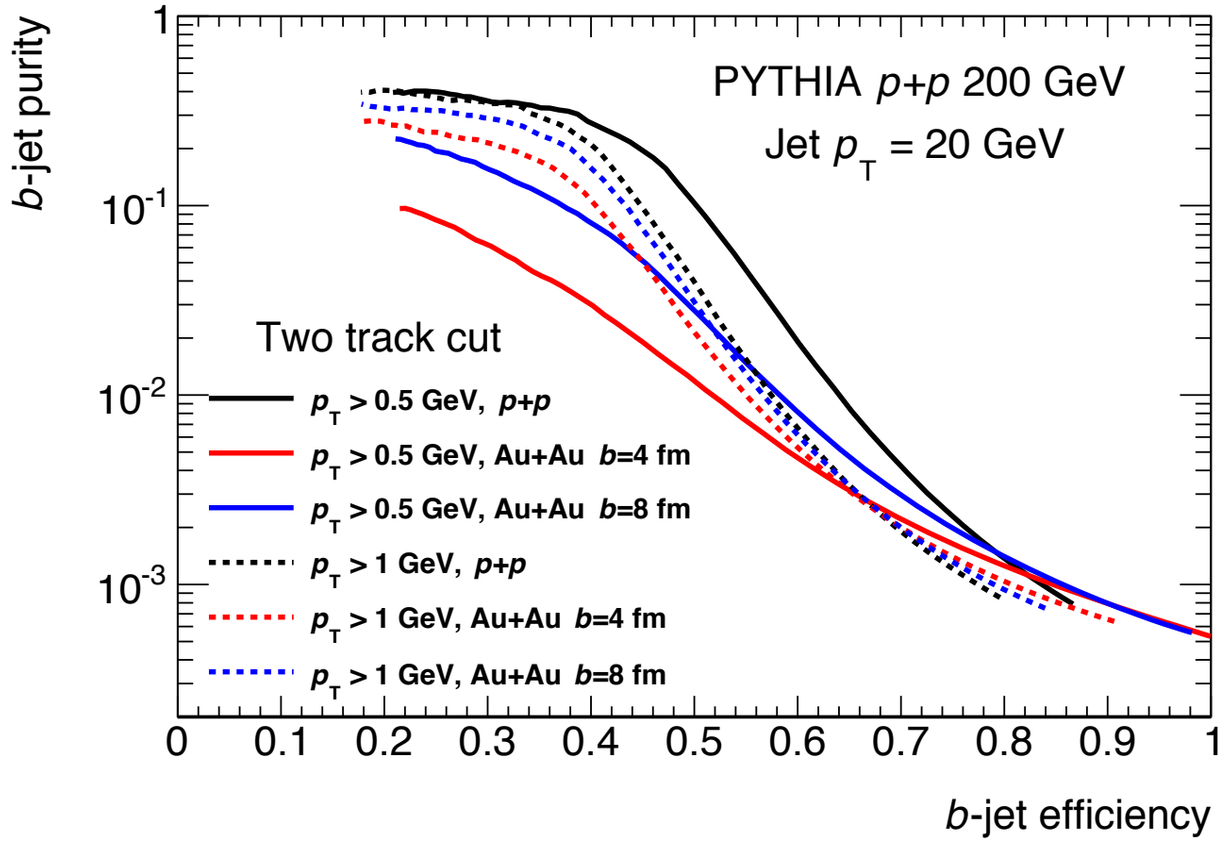
Curves are generated by varying the minimum S_{DCA} that those tracks must have

Efficiency for real *b*-jet to pass the Track Counting cut

Incoporating more realistic effects



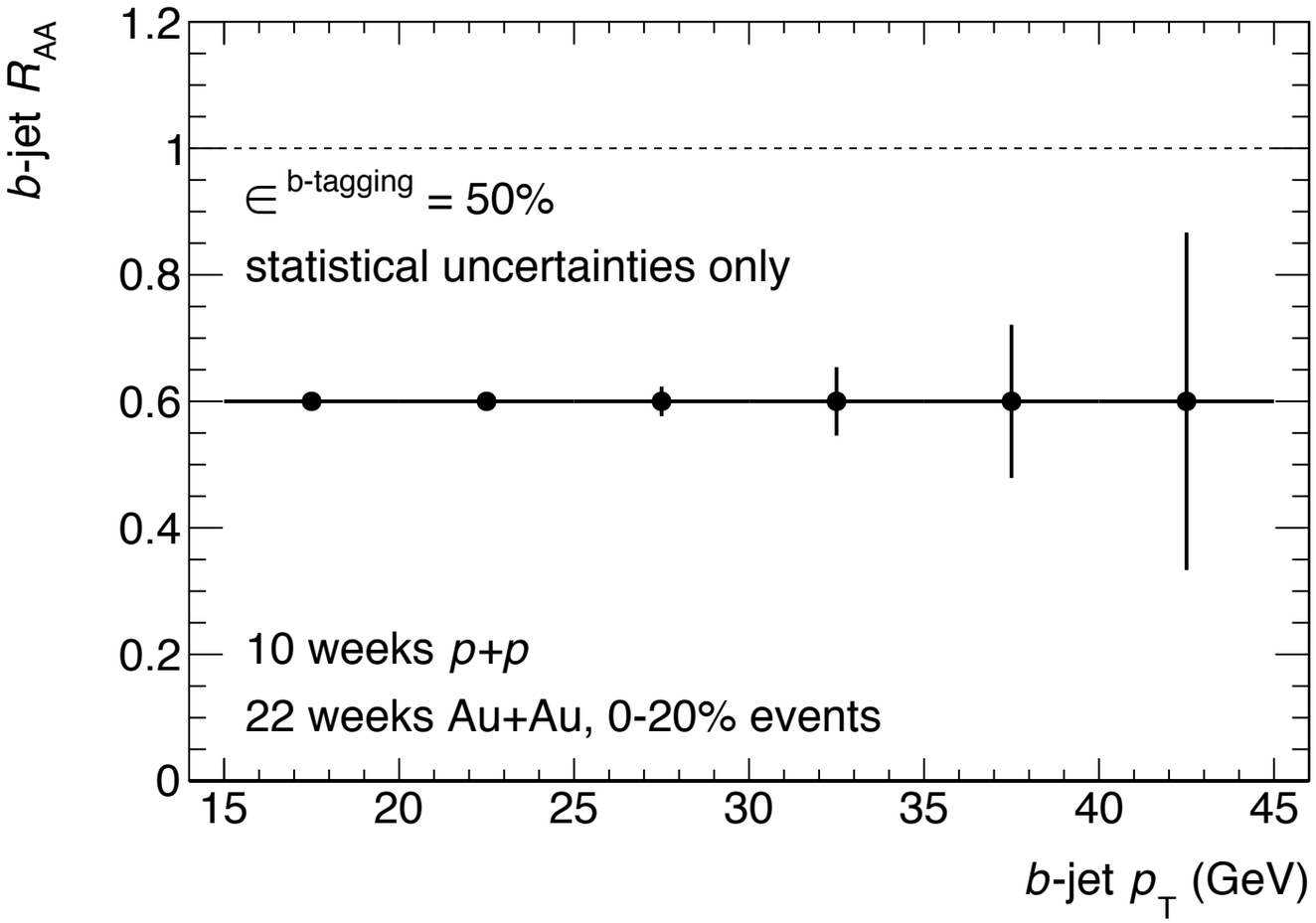
Different assumptions of the tracking efficiency and minimum p_T

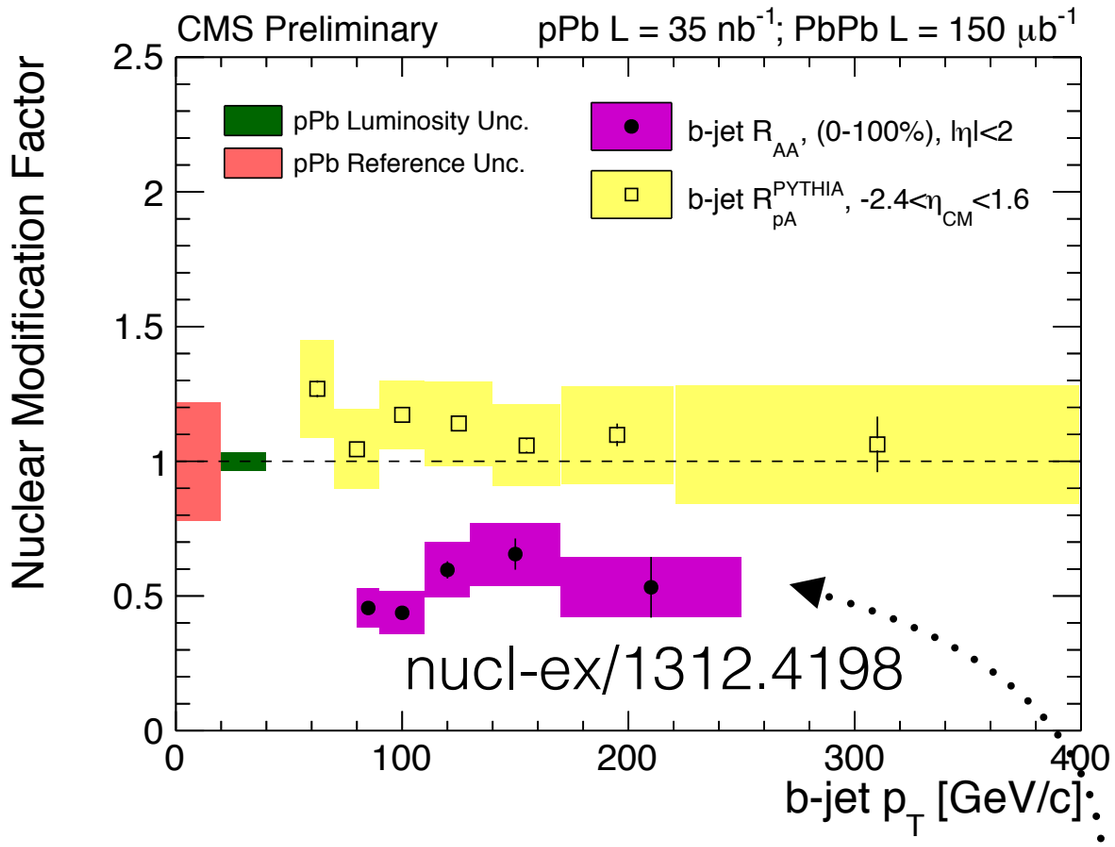


Embedding into Au +Au HIJING events

First indications are positive:
≈50% purity with ≈30-40% efficiency

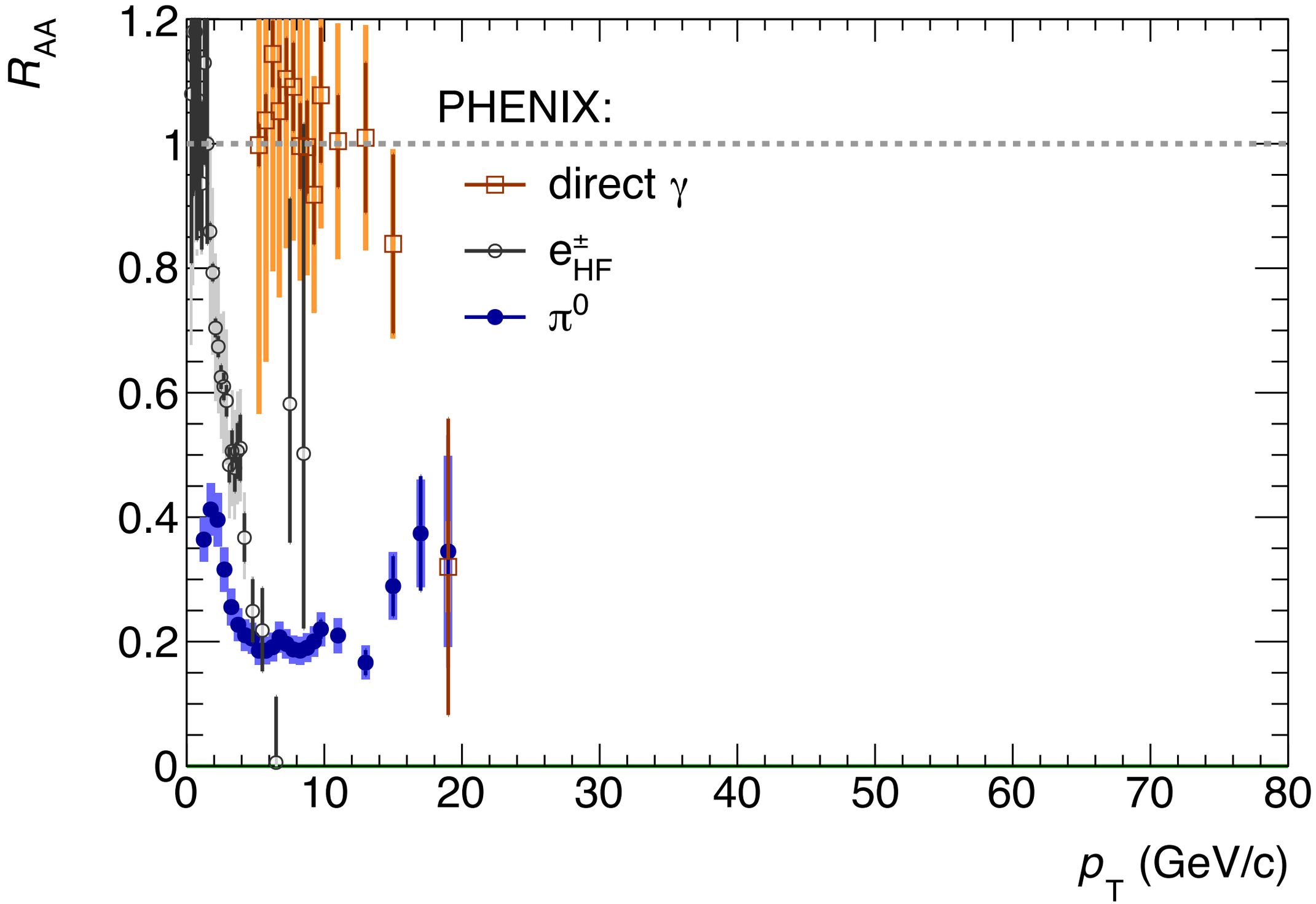
b-jet projections



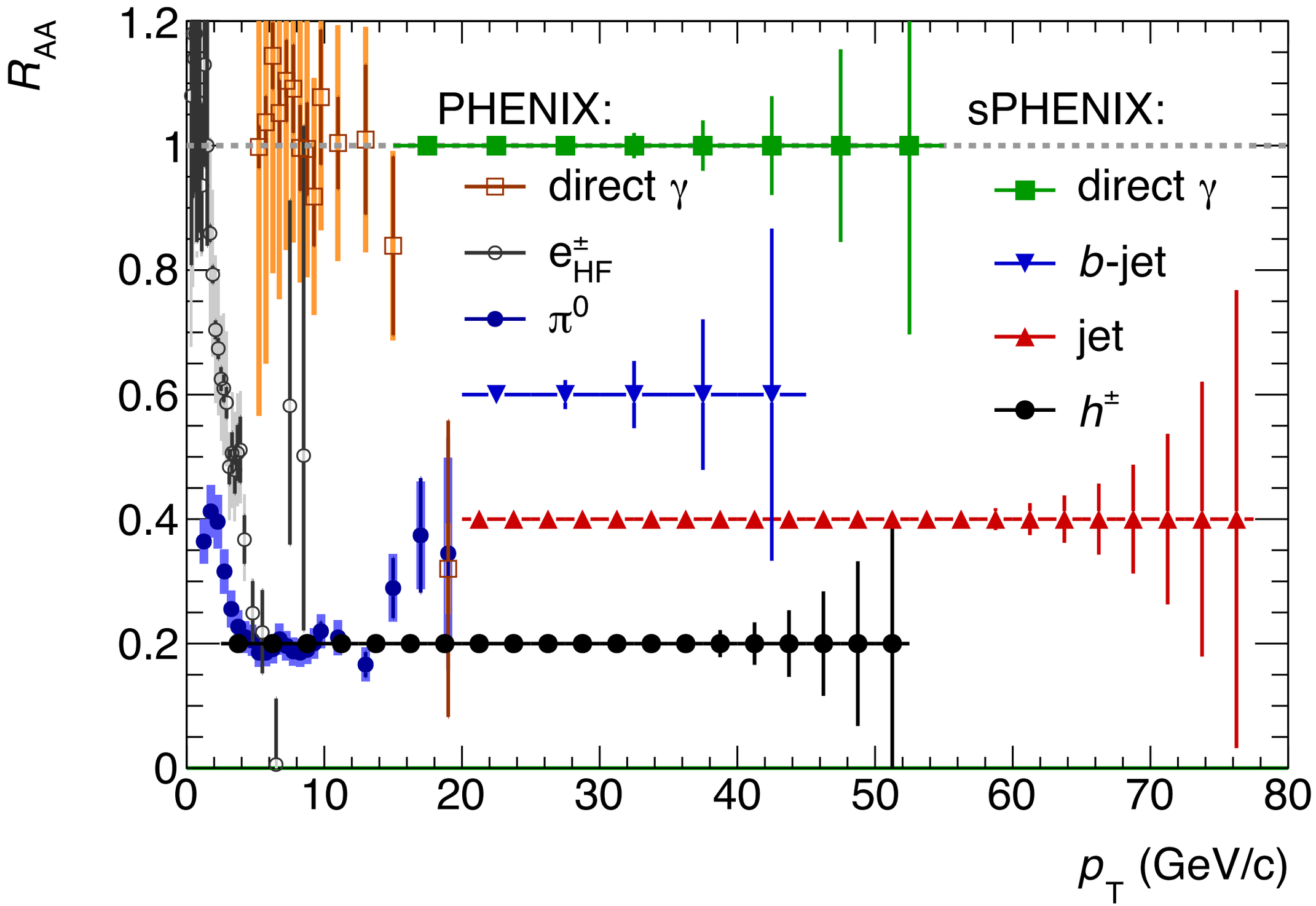


- Projected statistical reach for the inclusive *b*-jet R_{AA}
  - 0-20% Au+Au events: R_{AA} = 0.6 with 50% *b*-jet tagging efficiency
  - high *b*-jet purity needed to keep systematics under control
- Compare to CMS proof of principle ***b*-jet R_{AA}** in 0-100% Pb+Pb

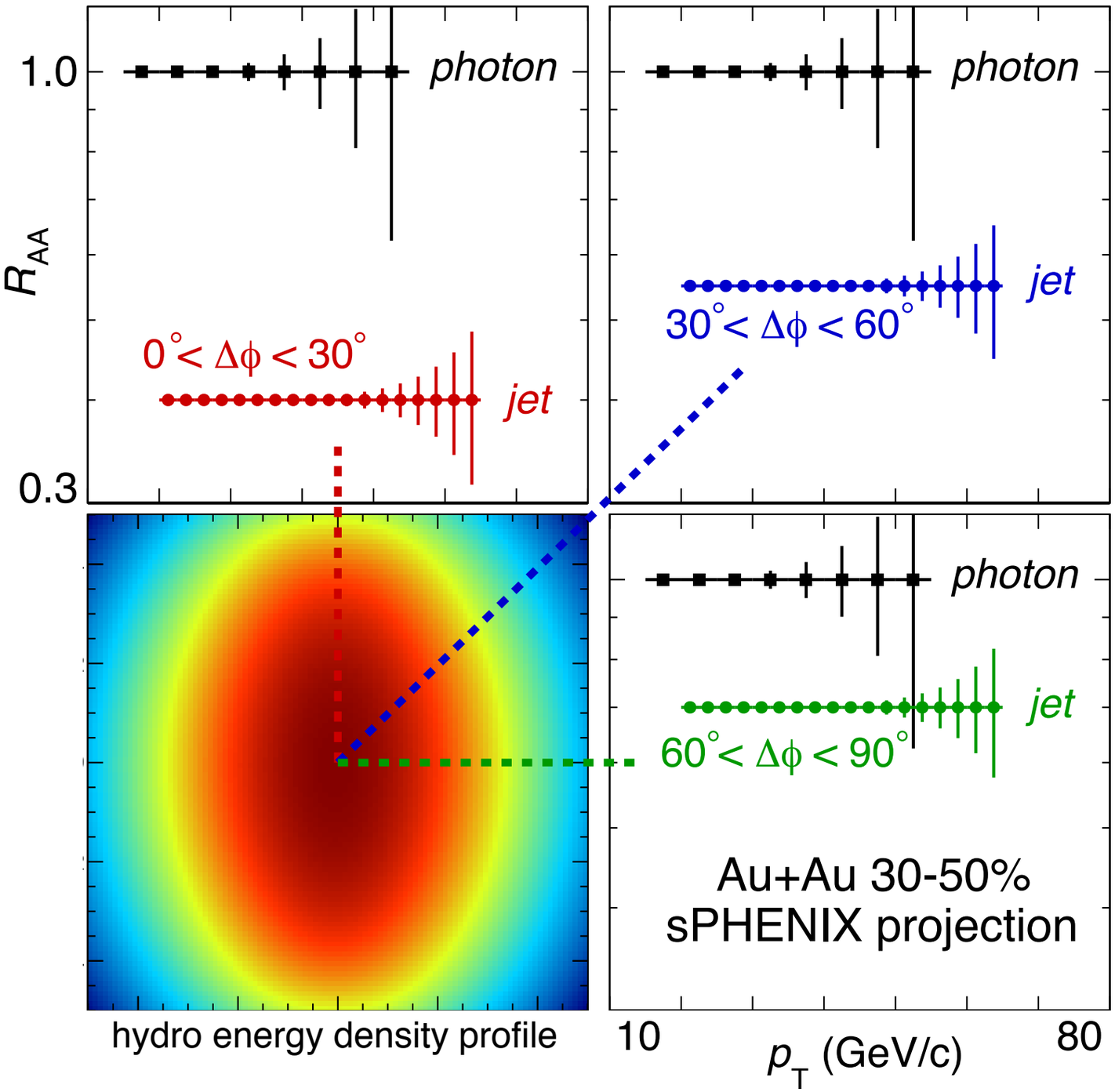
Hard probe projections



Hard probe projections

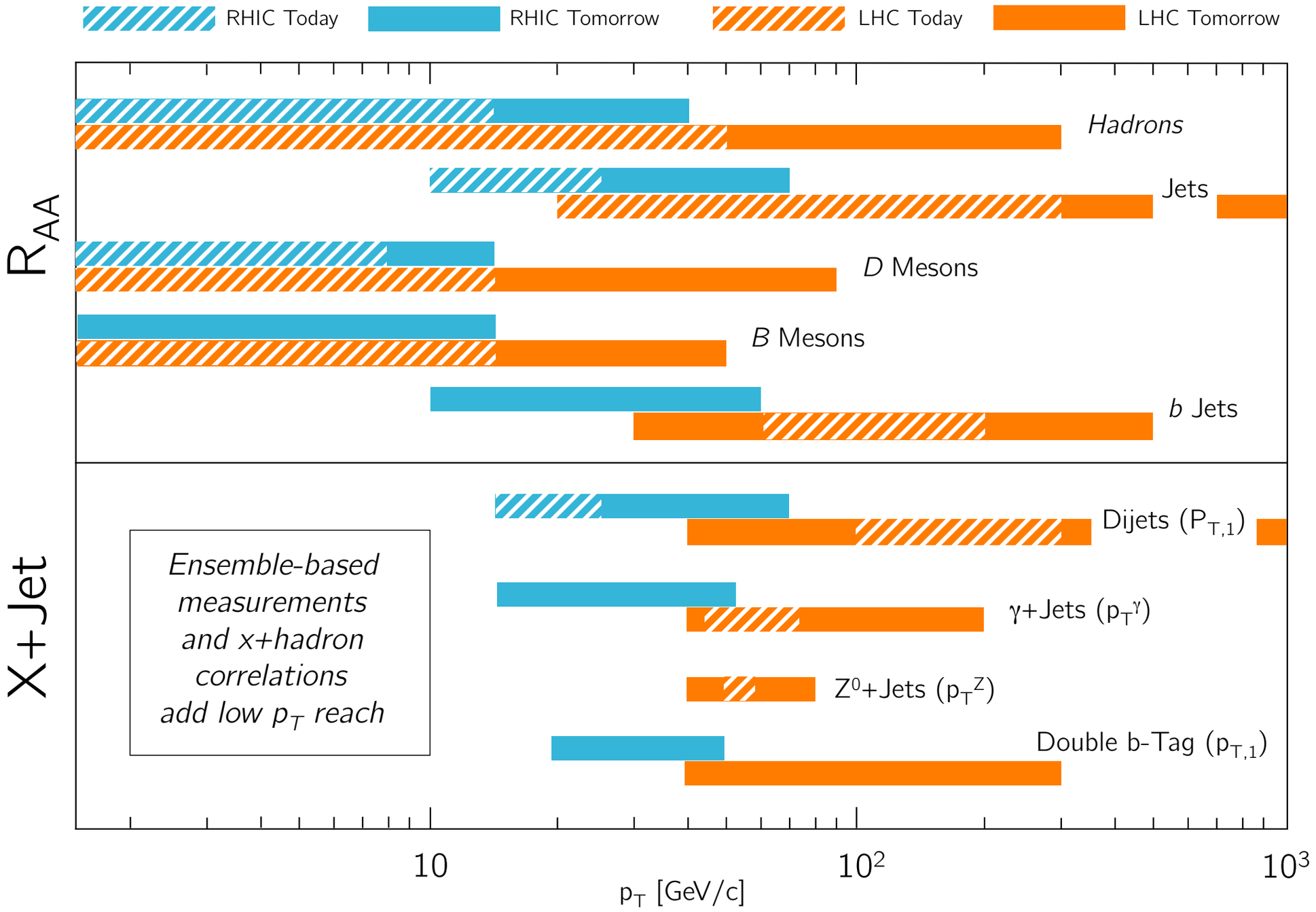


Example: R_{AA} vs. ϕ-Ψ_2



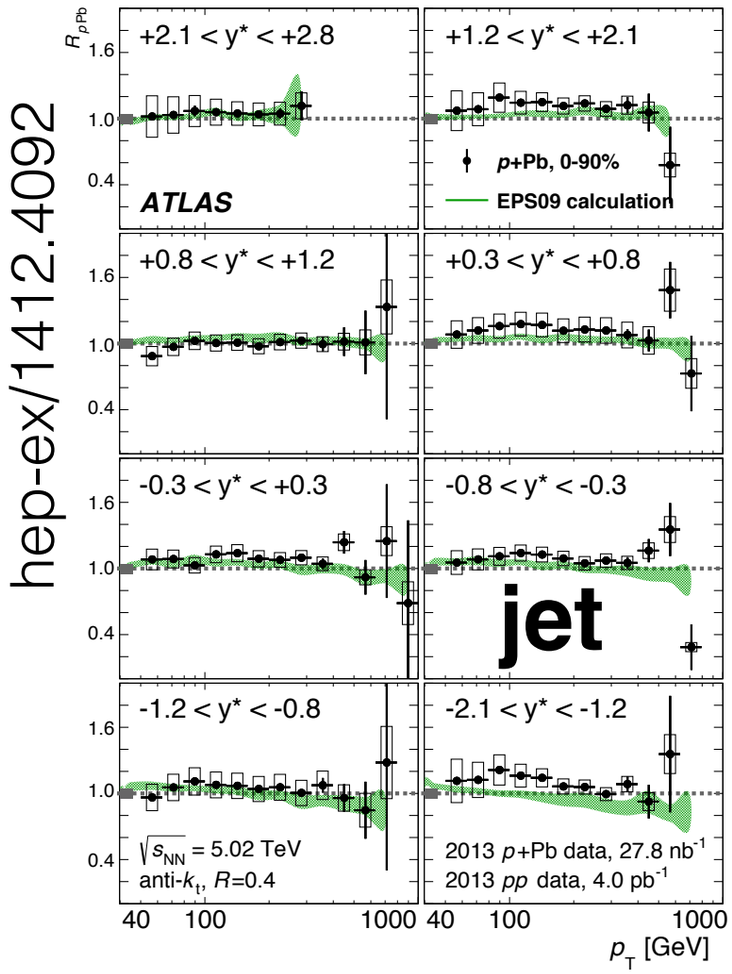
- Projected γ and inclusive jet R_{AA} in mid-centrality collisions
  - vs. angle with respect to reaction plane
- Sufficient statistics to measure observables in a differential fashion

RHIC/LHC complementarity



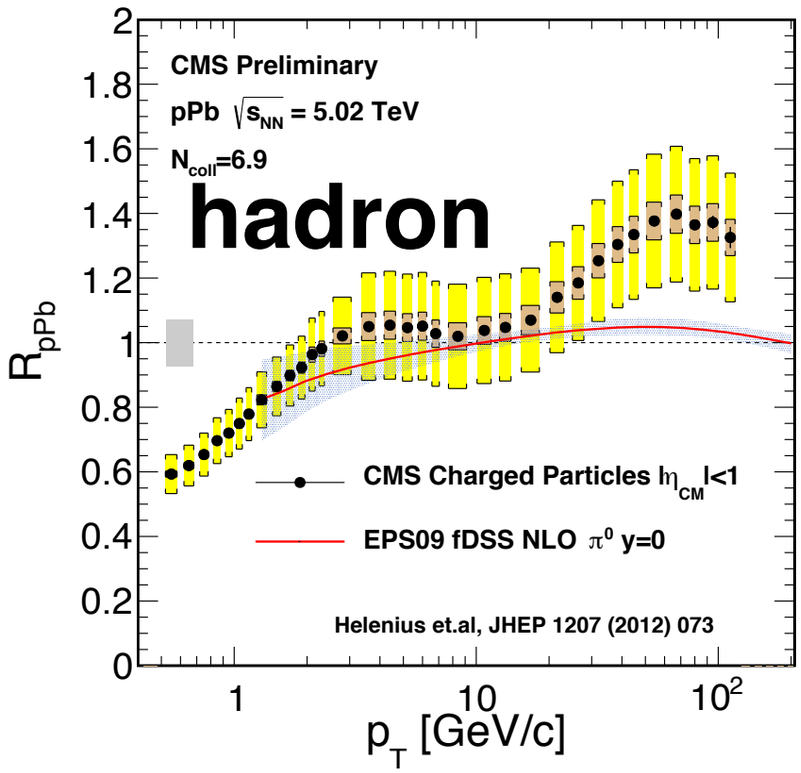
talk at QCD town hall meeting at Temple U. by G. Roland

p+Au physics motivation



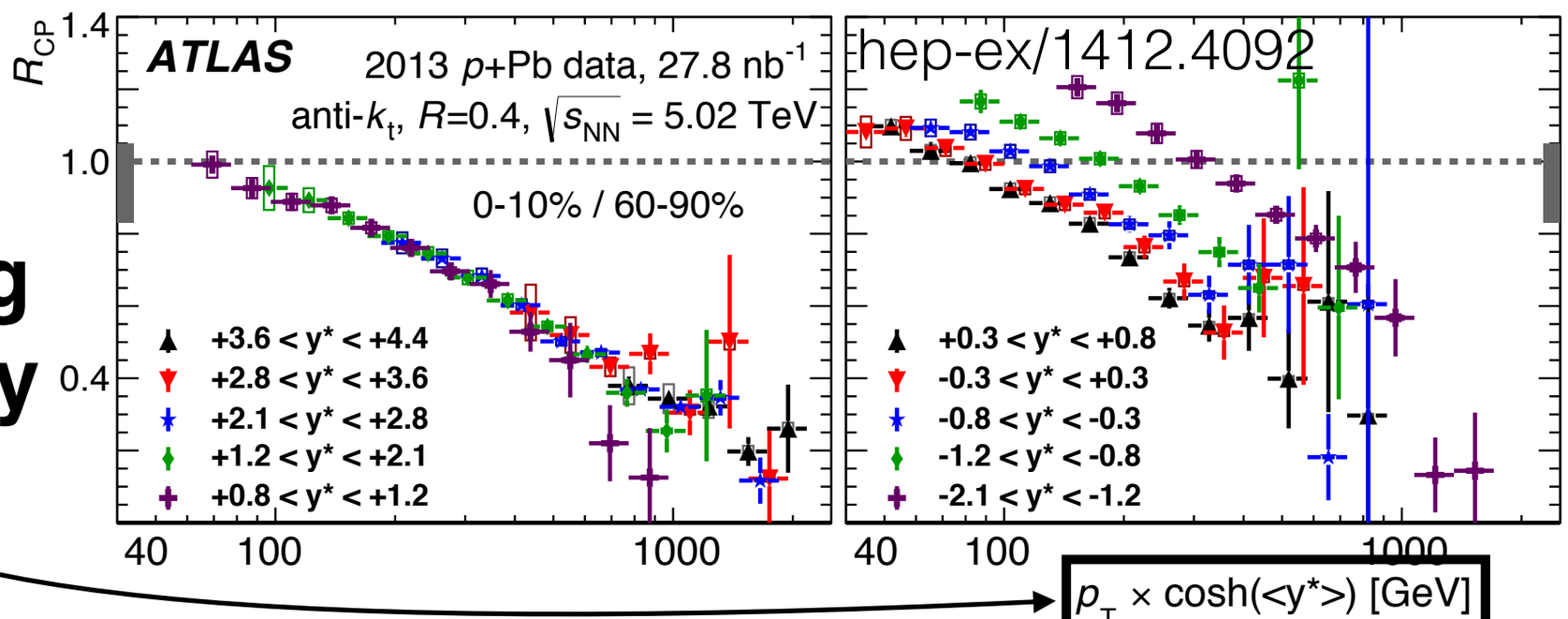
vs.

CMS PAS HIN-14-001

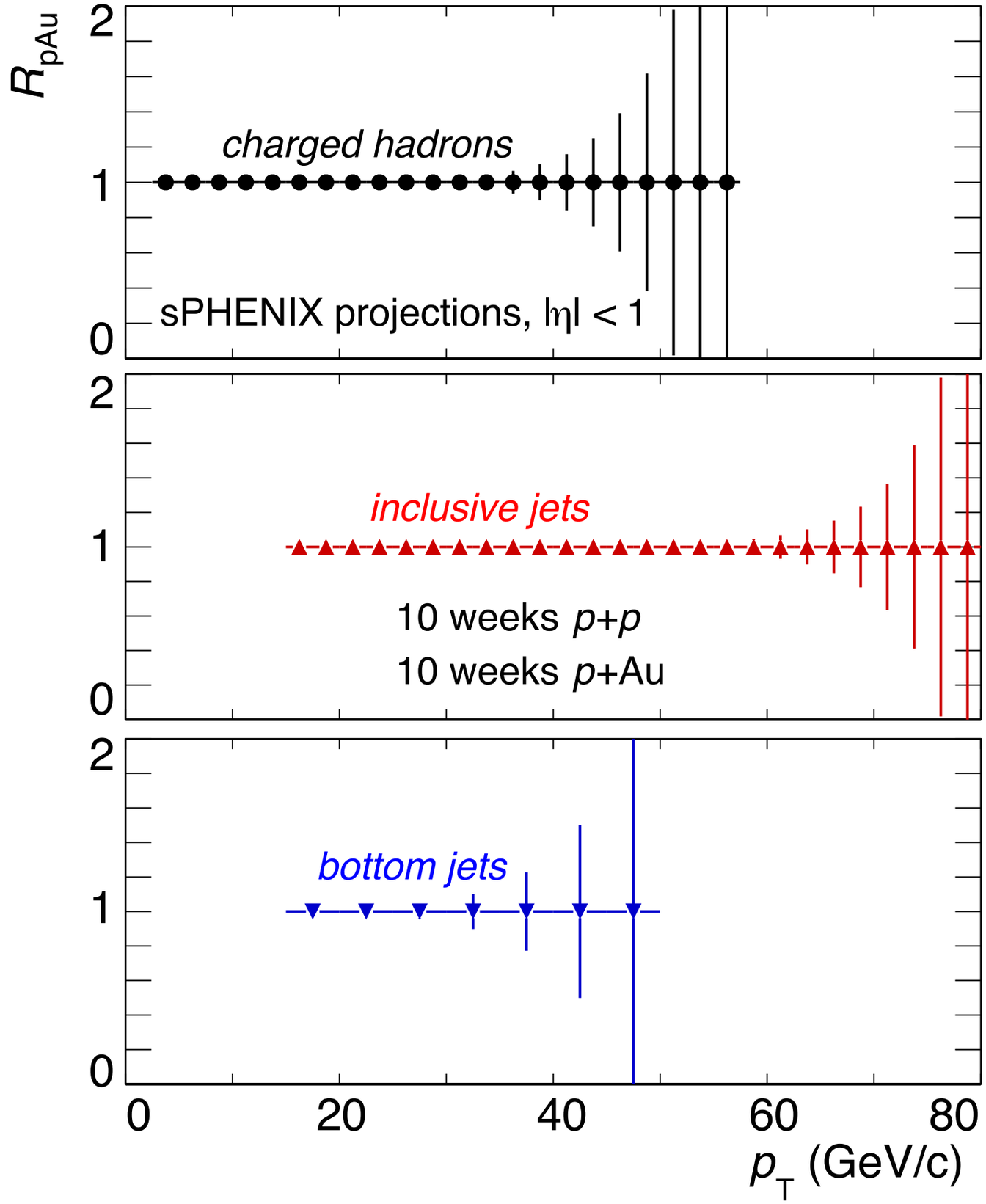


Unexpected discrepancy in **jet** vs. **hadron** R_{pPb}

Anomalous centrality dependence: **scaling** in the **total jet energy**



- Projected statistical reach for R_{pAu}
  - 10 weeks of *p*+Au running
    - minimum bias *p*+Au collisions
    - (photons not shown)



PHENIX Summary

The sPHENIX detector will crucially expand the range of *length scales* and *temperatures* over which QGP dynamics are known

- we envision a comprehensive and precise program of jet physics measurements
- which overlap with, and expand on, the kinematic ranges explored at the LHC

Enormous work in the updated MIE proposal since summer 2014:

- optimization of the tracking configuration, rate and trigger considerations, *b*-jet tagging, detailed simulations of jet-correlated observables, *p*+Au physics, statistical projections, etc.

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