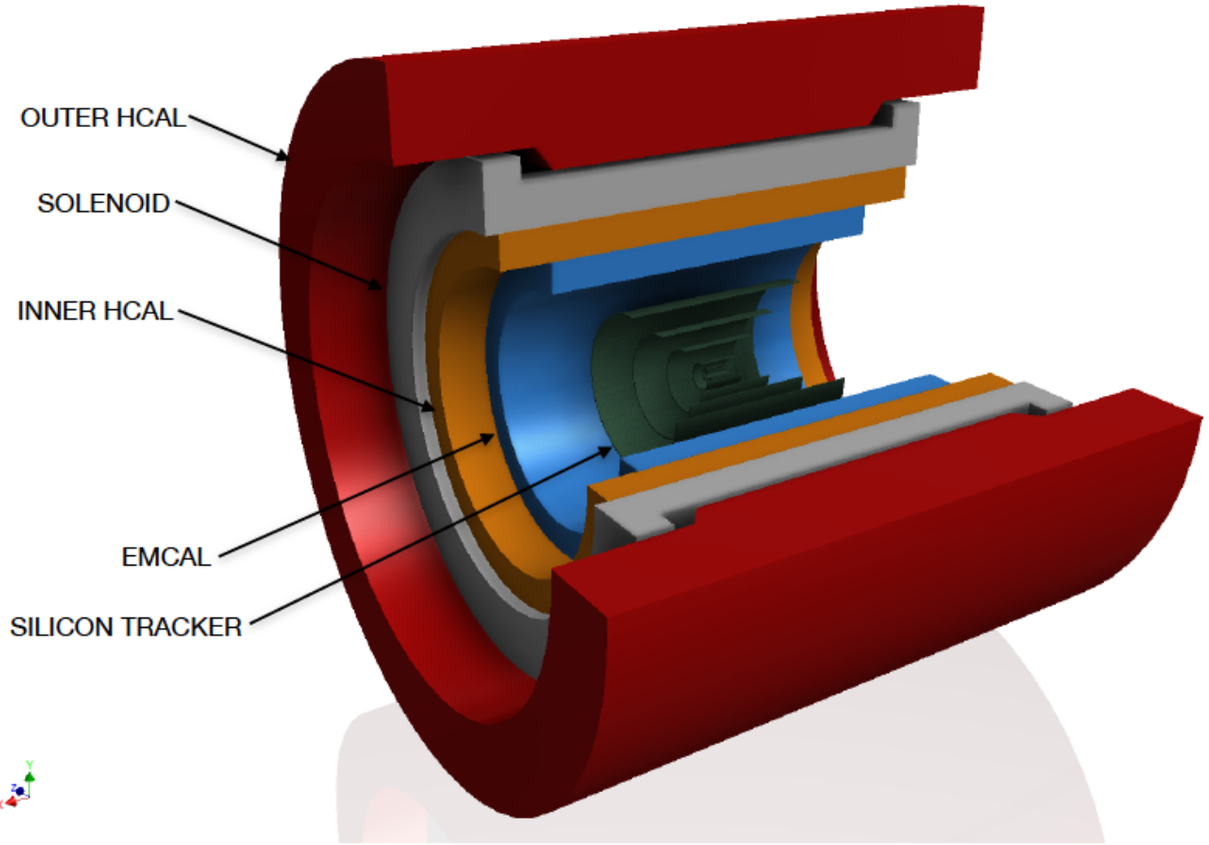
# Measuring jets with sPHENIX




Ali Hanks

*for the (s)PHENIX collaboration*

**CIPANP 2015**

*May 24th, 2015*

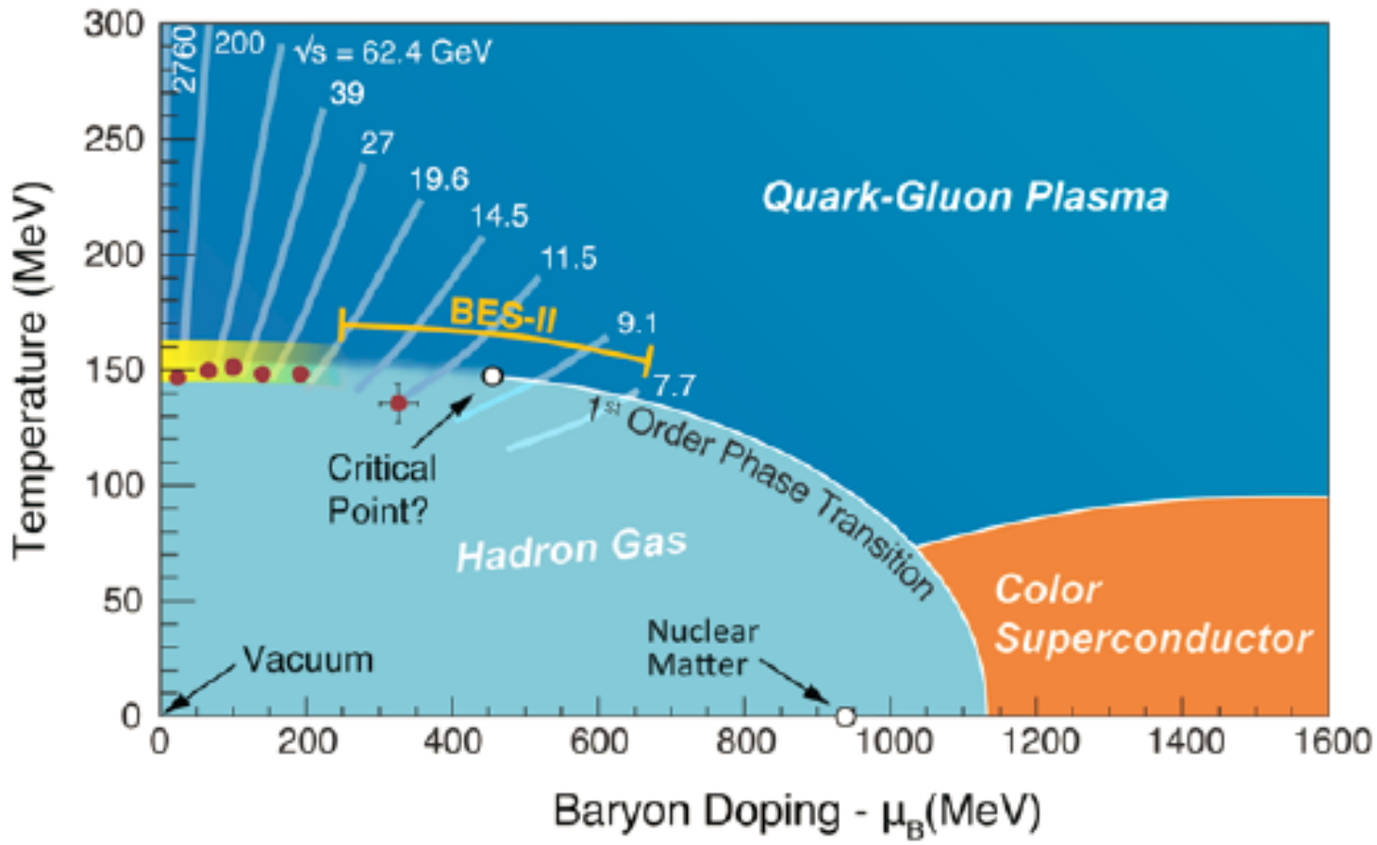
sPHENIX

Stony Brook University | The State University of New York

# WHY sPHENIX?

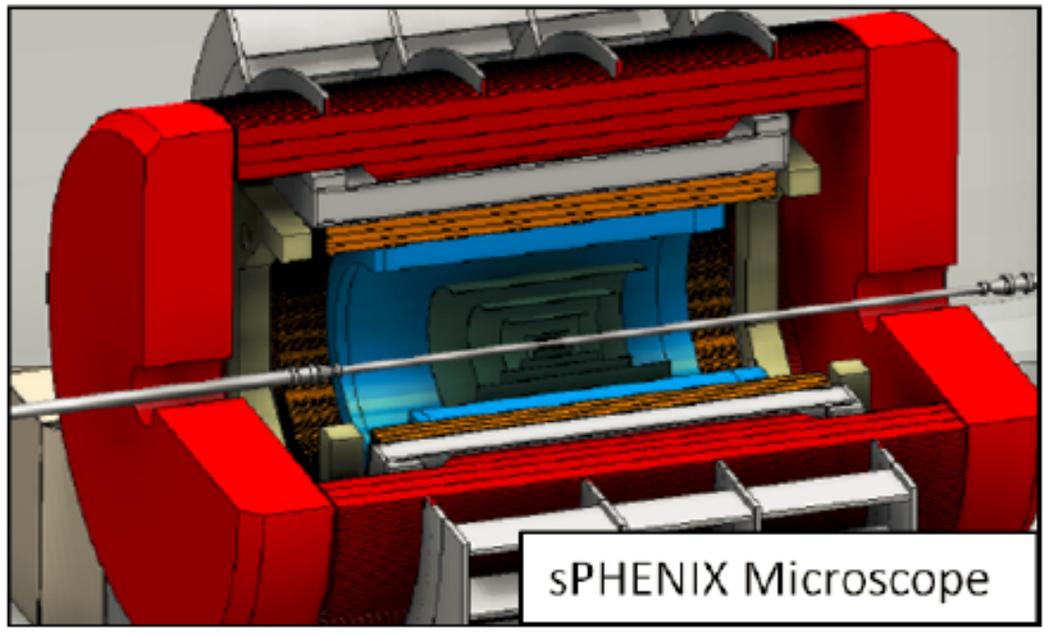
DISCOVERY OF QGP AS PERFECT FLUID WAS HUGE!

WE KNOW A LOT ABOUT HOW QGP BEHAVES, BUT NOT SO MUCH ABOUT HOW IT REALLY WORKS.



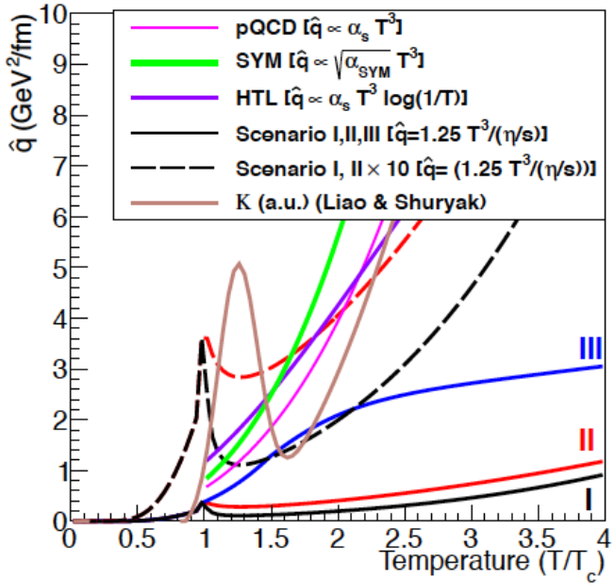

sPHENIX DESIGNED FOR PRECISION JET, JET CORRELATION AND UPSILON MEASUREMENTS

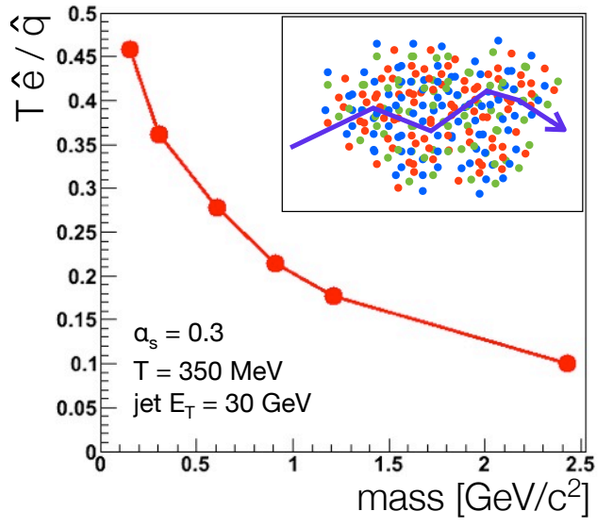
MICROSCOPE FOR TRANSPORT PROPERTIES AND COLOR SCREENING LENGTH OF THE QGP



# Pushing and probing the medium

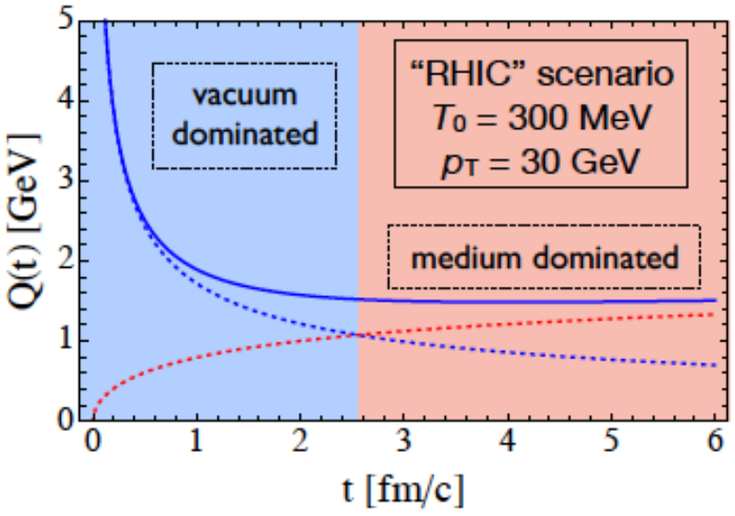
What is the temperature dependence of the QGP?




What are the inner workings of the QGP?

How does the QGP evolve along with the parton shower?



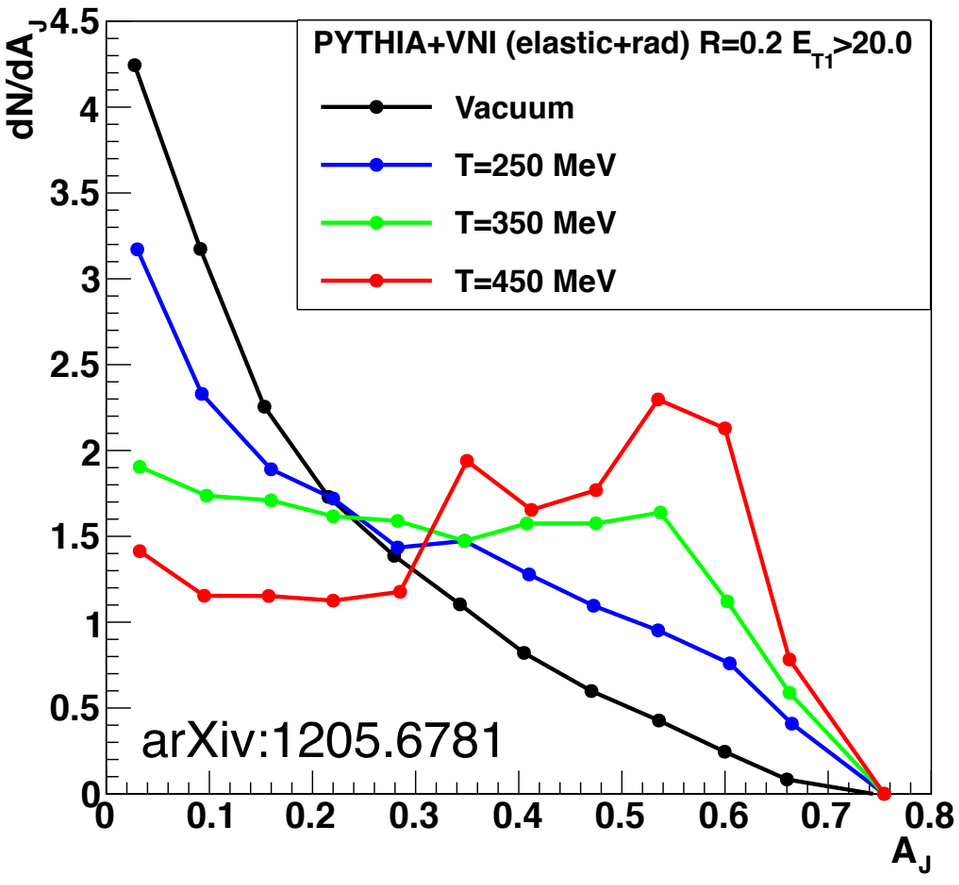

$T$

$\lambda_{\text{probe}}$

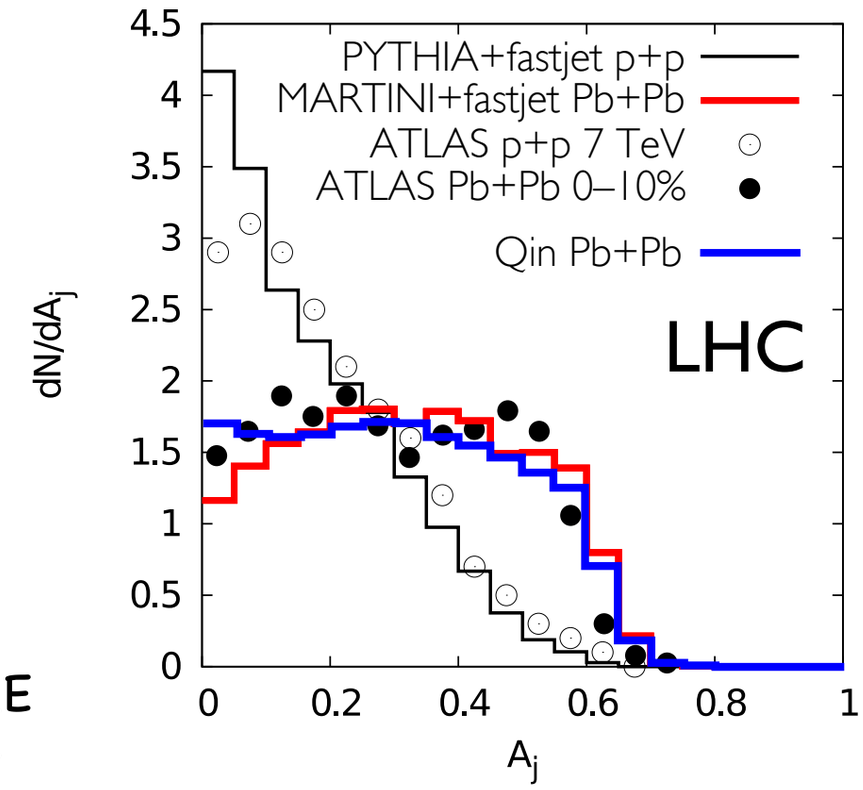
$Q^2_{\text{hard}}$

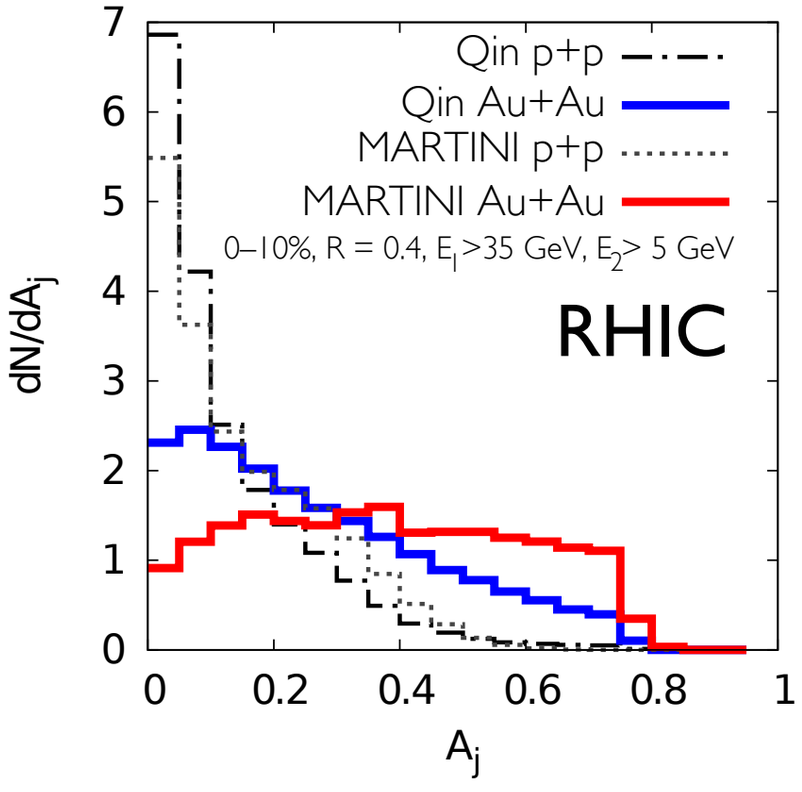
# The effect of temperature

## What is the temperature dependence of the QGP?




Strong temperature dependence on key observables

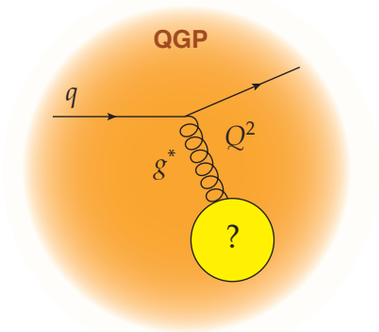



Comparisons of LHC and RHIC will help to distinguish between models

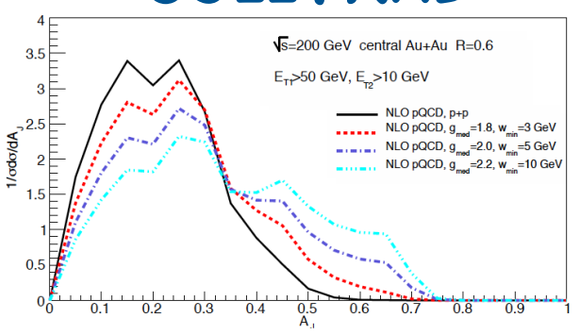
# Probing the length scale

## What are the inner workings of the QGP?

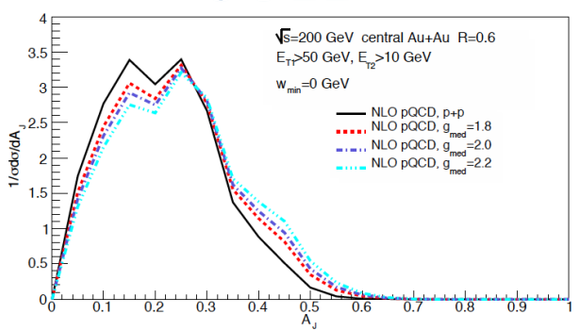


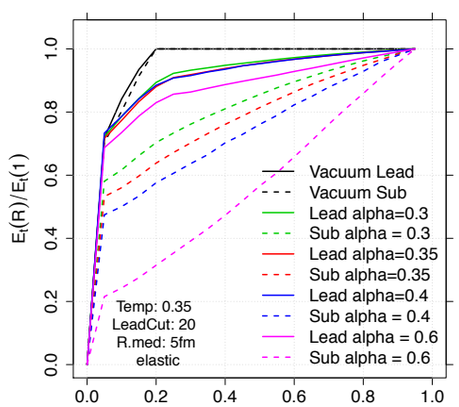

## Radiative vs Collisional energy loss

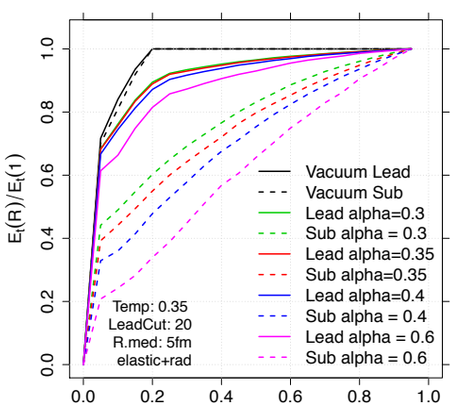
### Coll+Rad

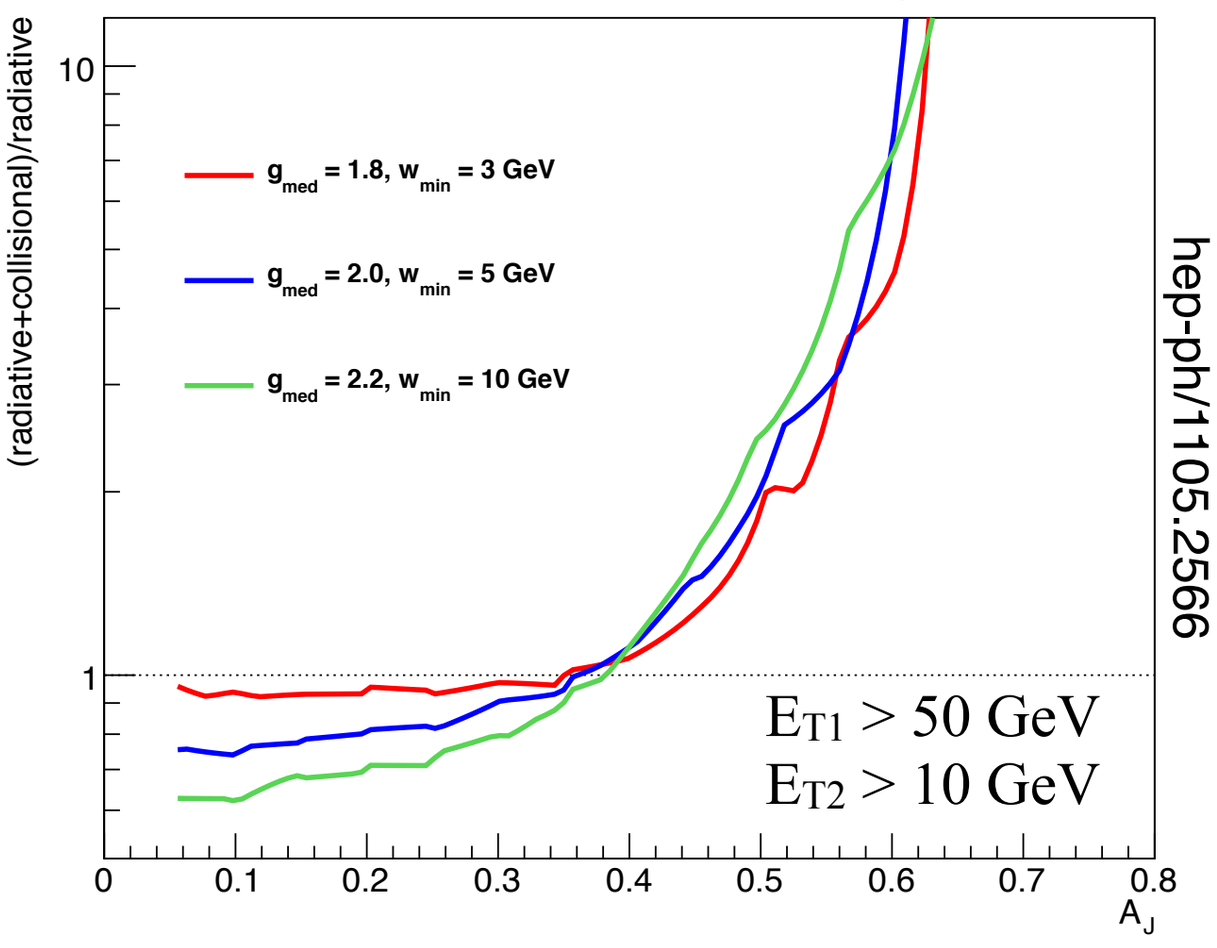


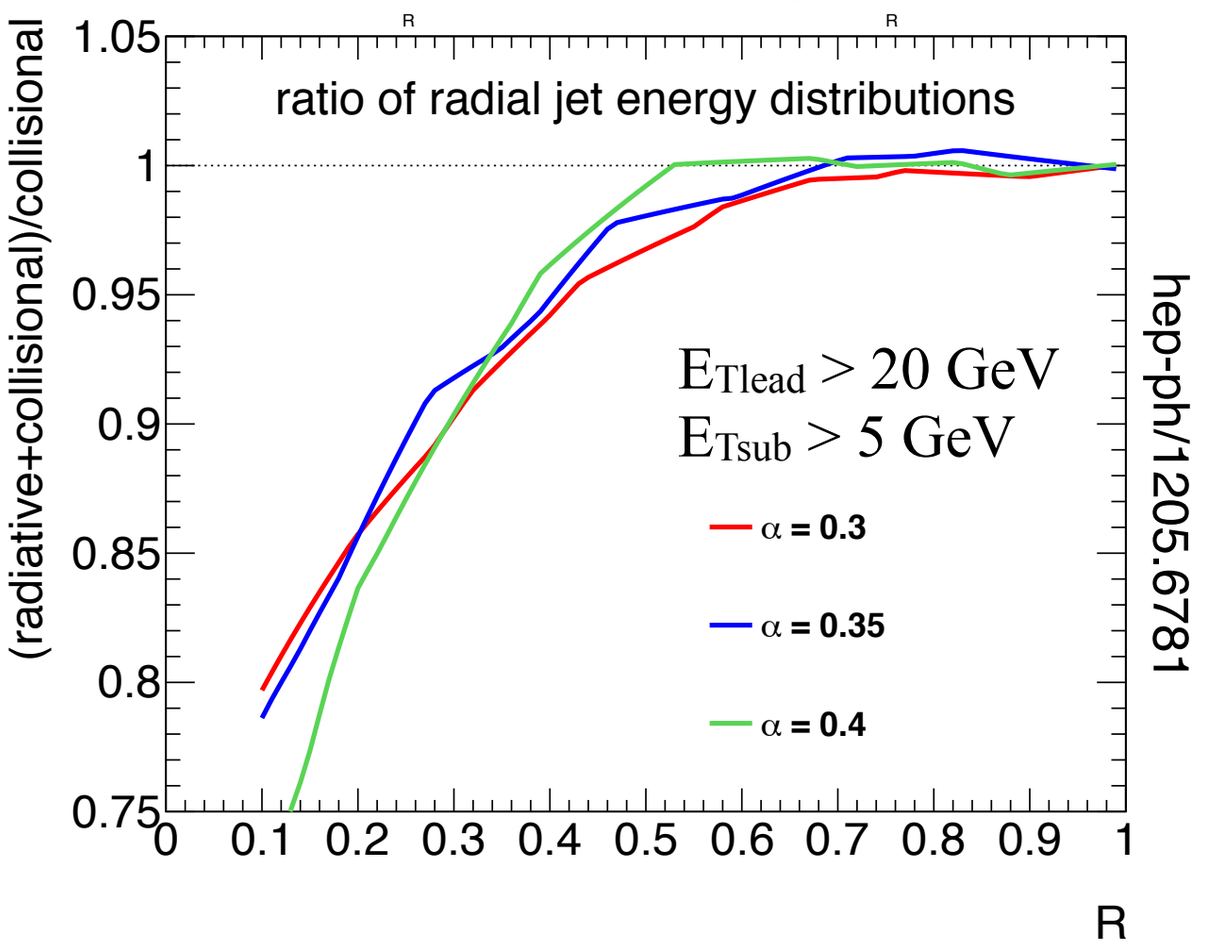

### Coll



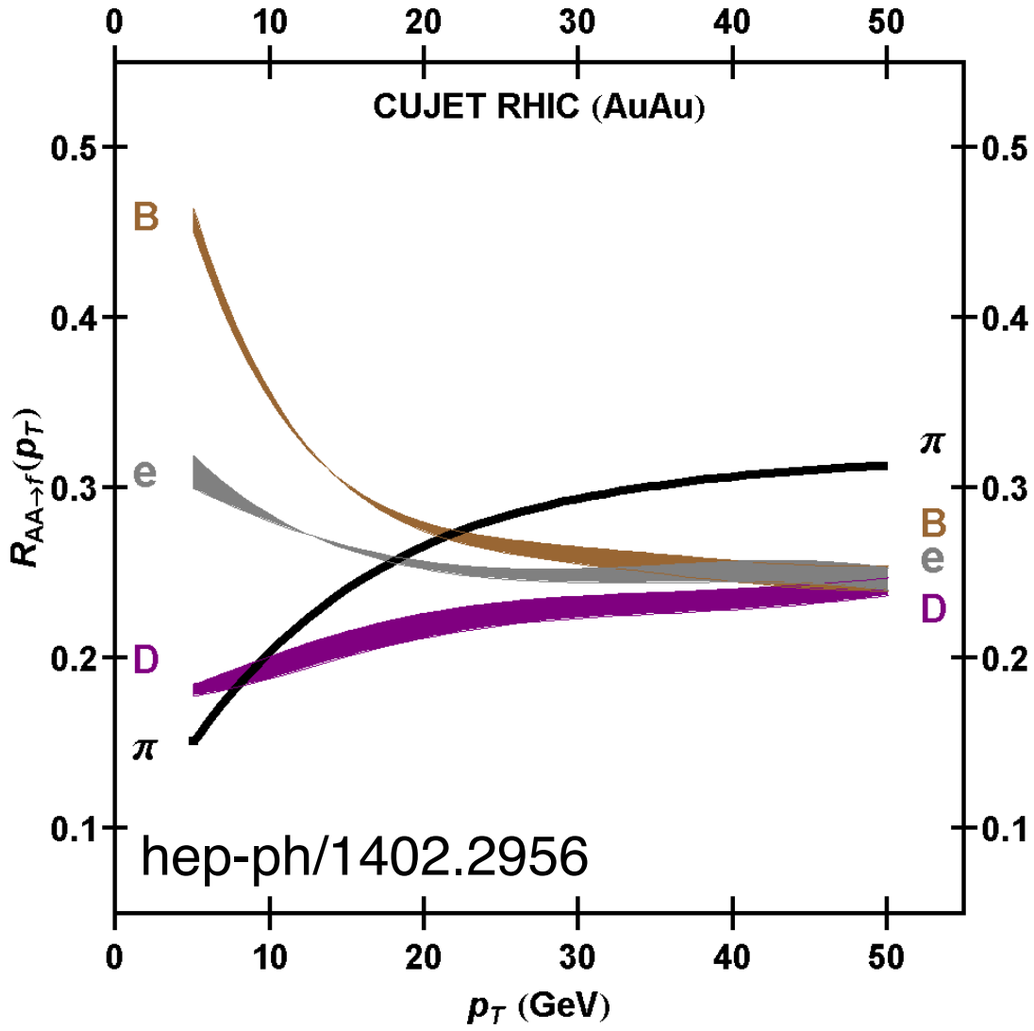



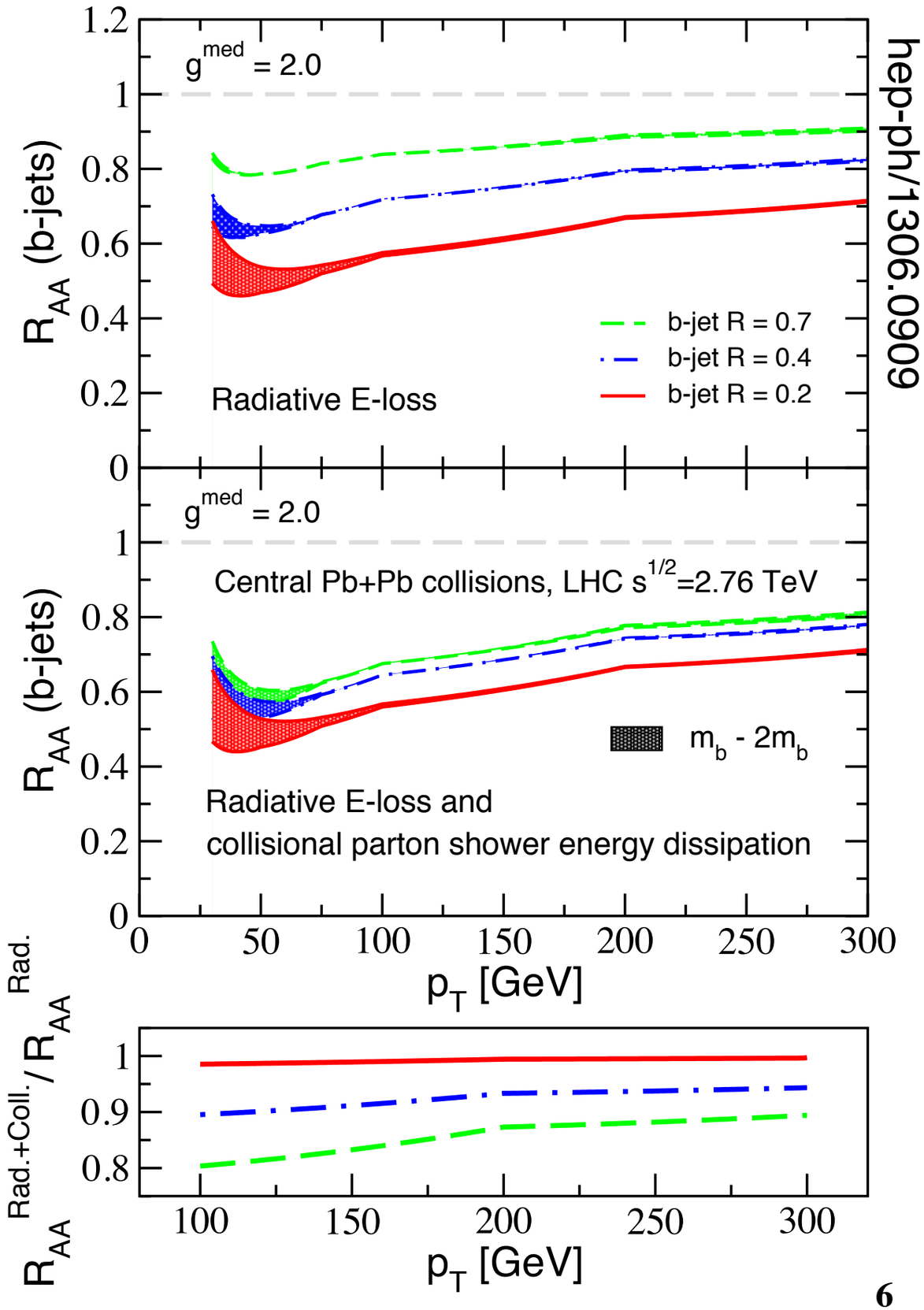



# Probing the length scale

## What are the inner workings of the QGP?

### Heavy flavor more sensitive to collisional effects



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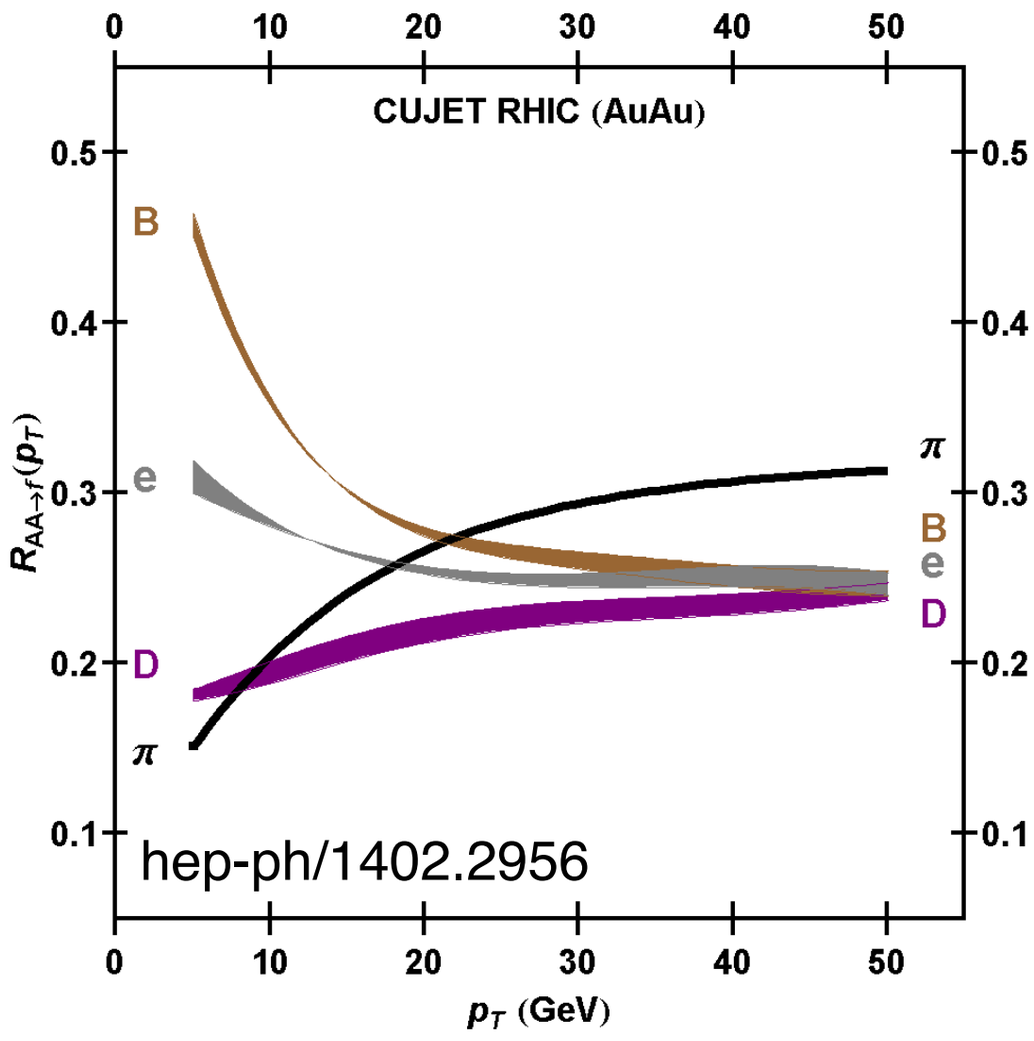
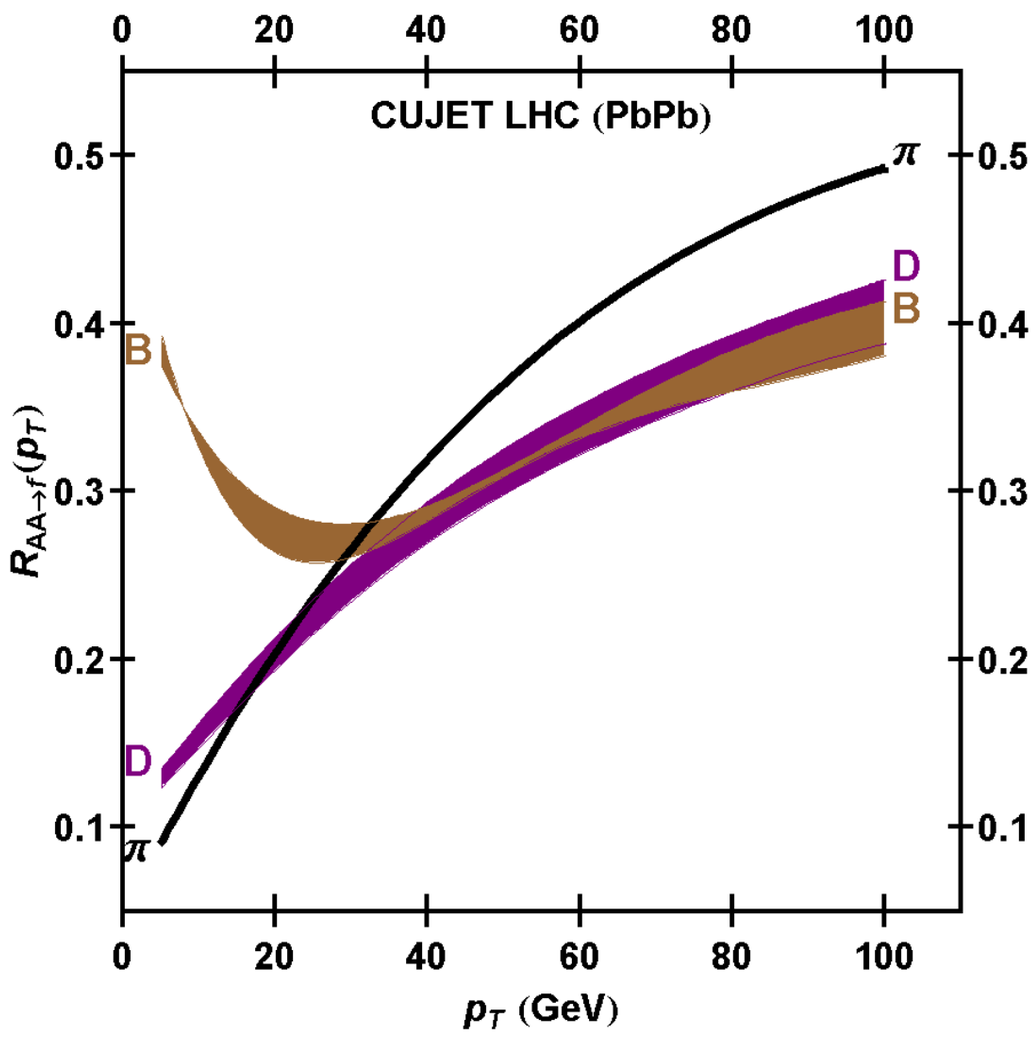
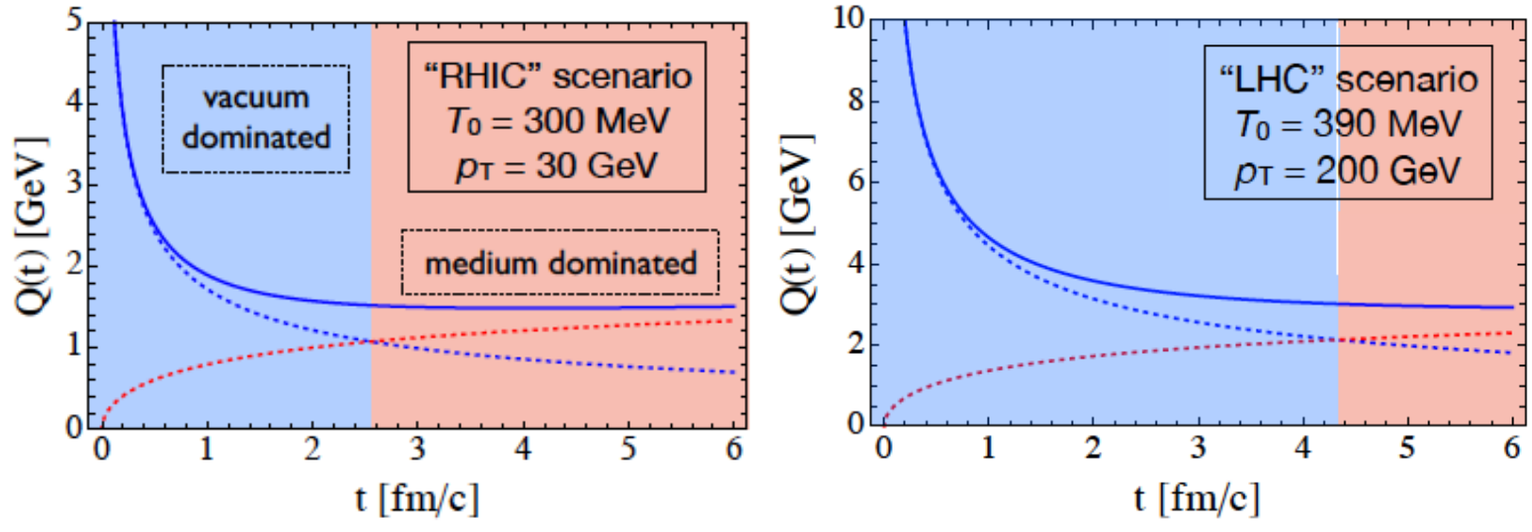


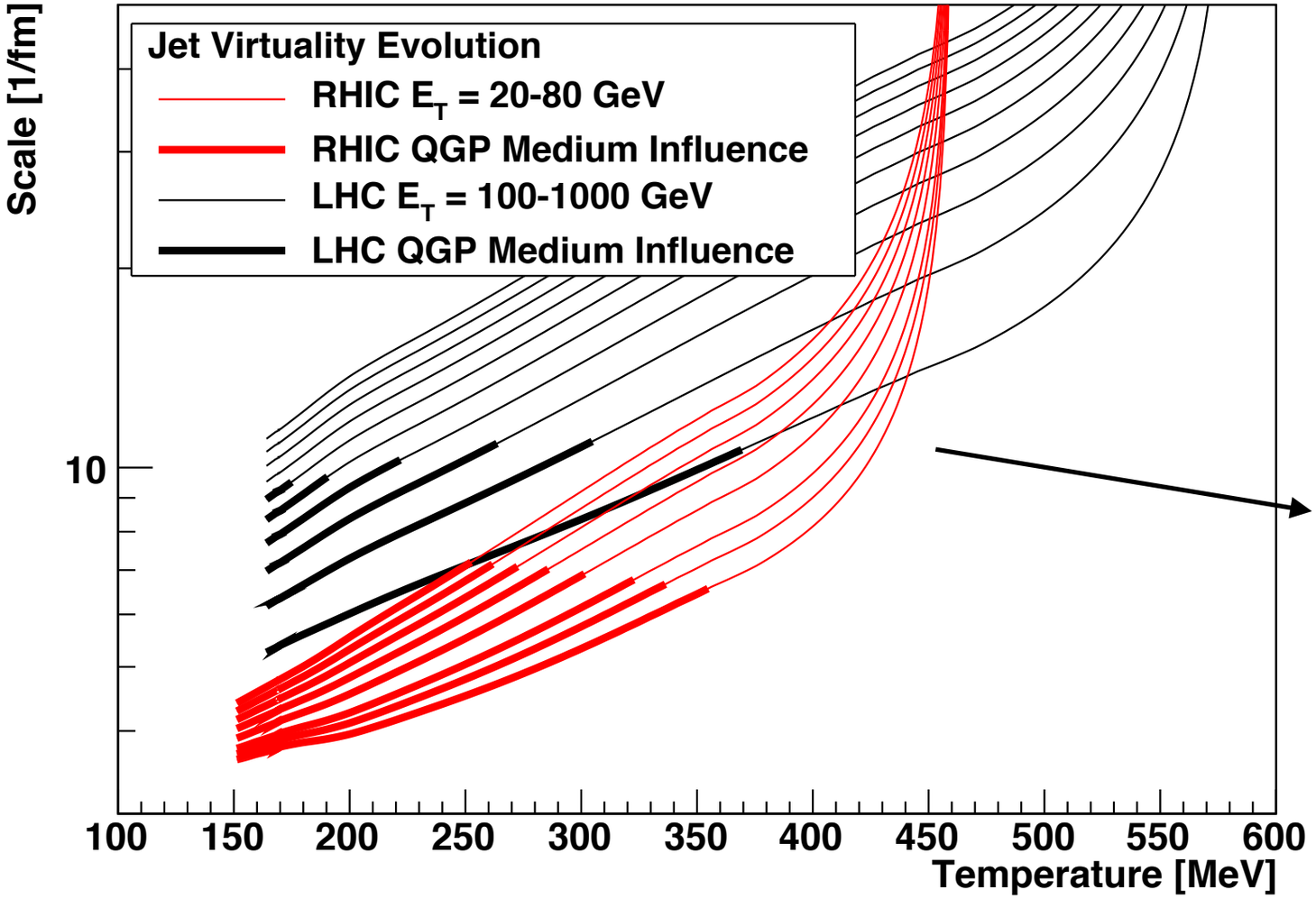



# Evolution of Jet Virtuality

## How does the QGP evolve along with the parton shower?

B. Muller talk given at RHIC/AGS Users Meeting '11



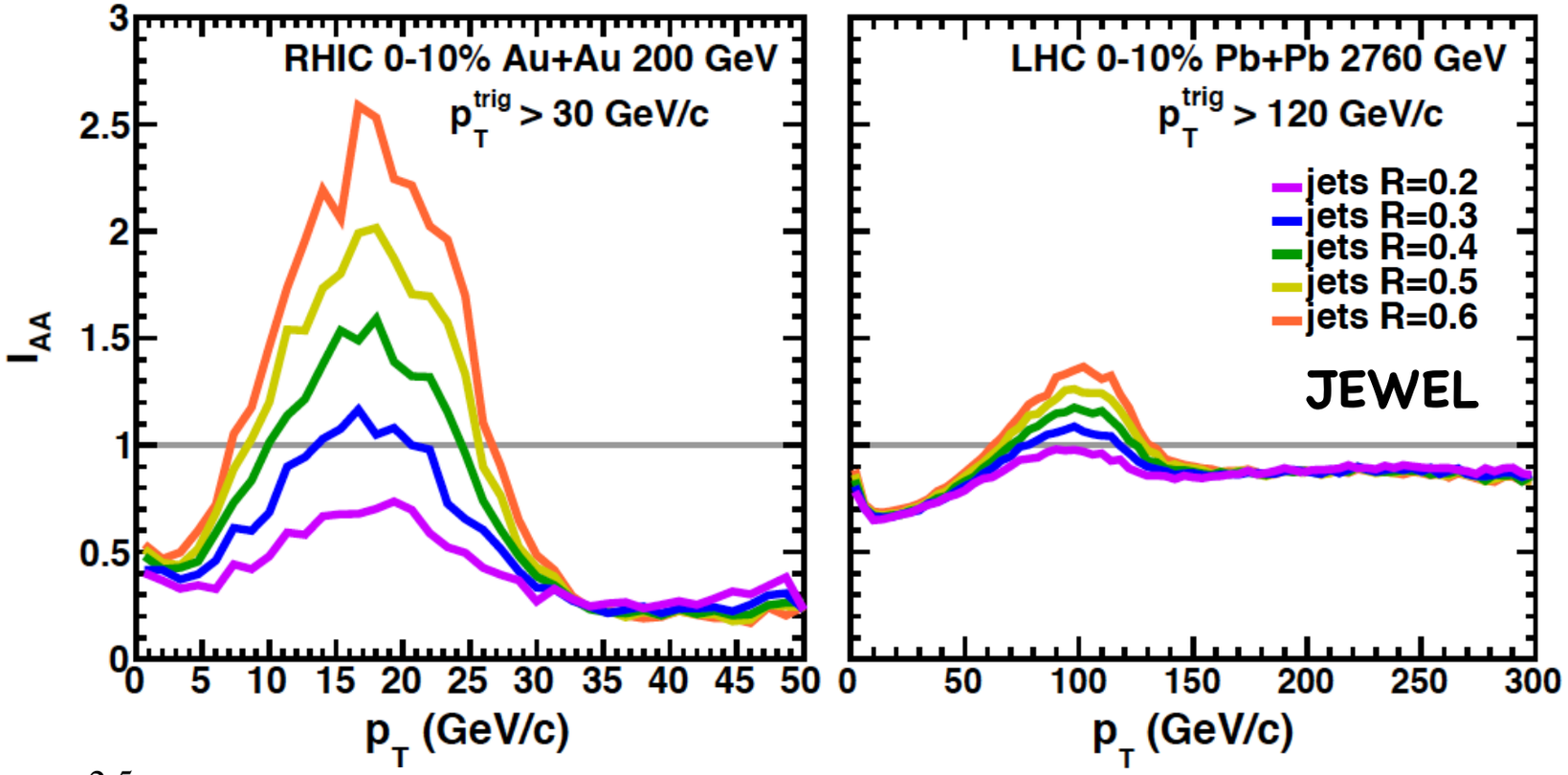

Parton splitting modified while **medium influence** dominates

RHIC and LHC have different sensitivity to medium

Overlapping jet energies will provide important constraints

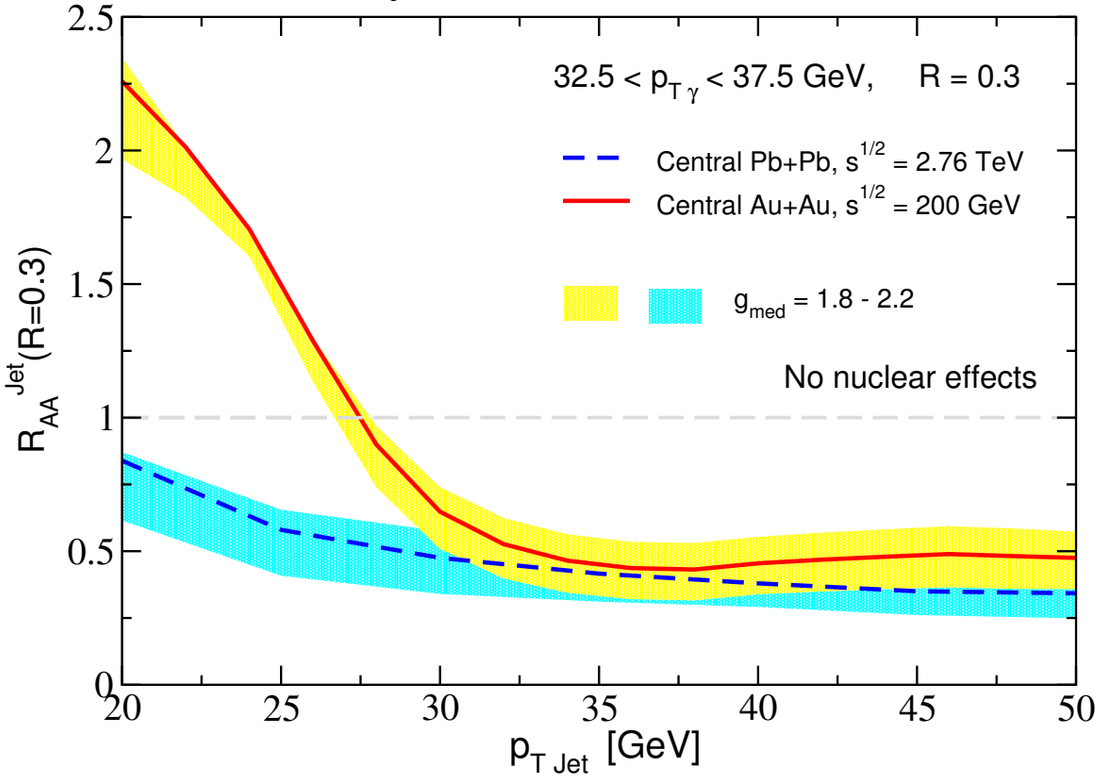
# Predicted RHIC vs LHC

## Many observables where greater sensitivity expected at RHIC



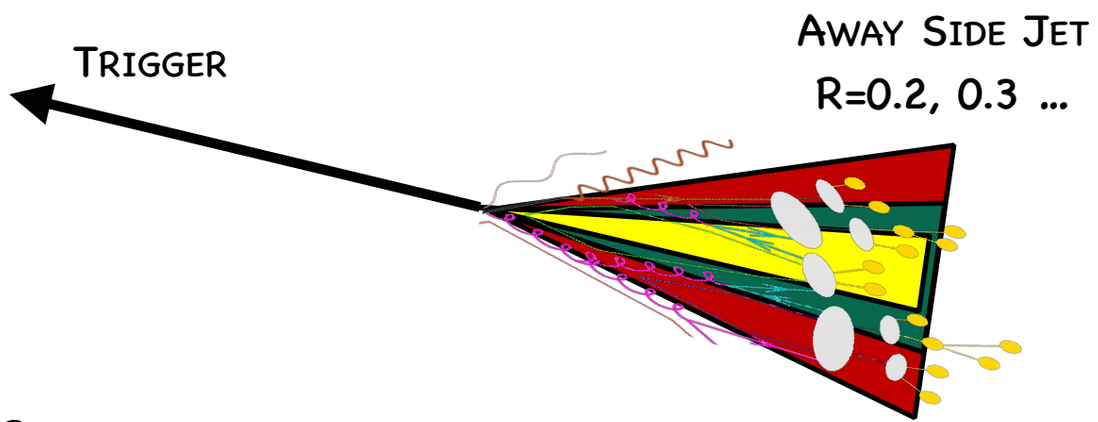

Trigger:

High $p_T$ track

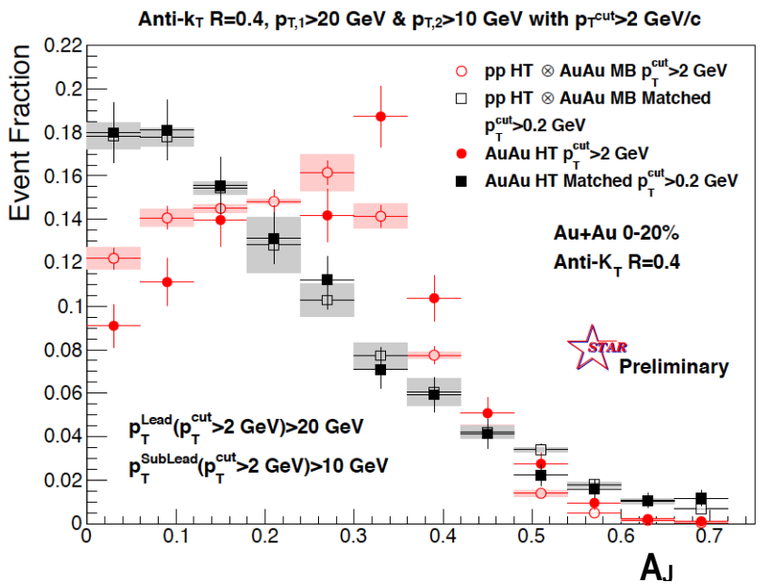



Trigger:

High $p_T$ photon



# RHIC vs LHC now



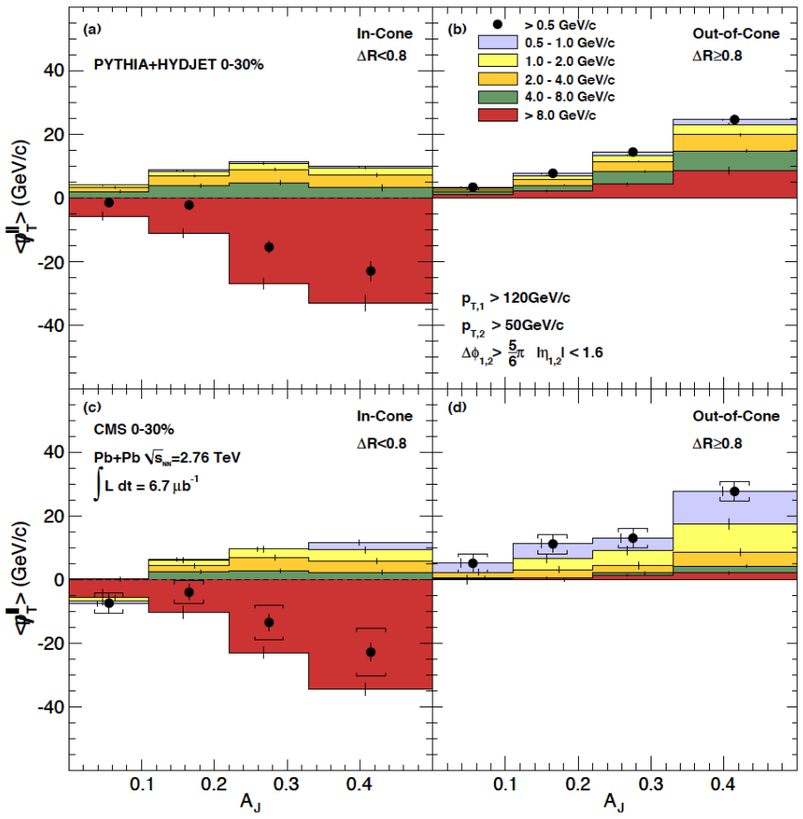

ENERGY RECOVERED:

**INSIDE** THE JET CONE

AT **RHIC**

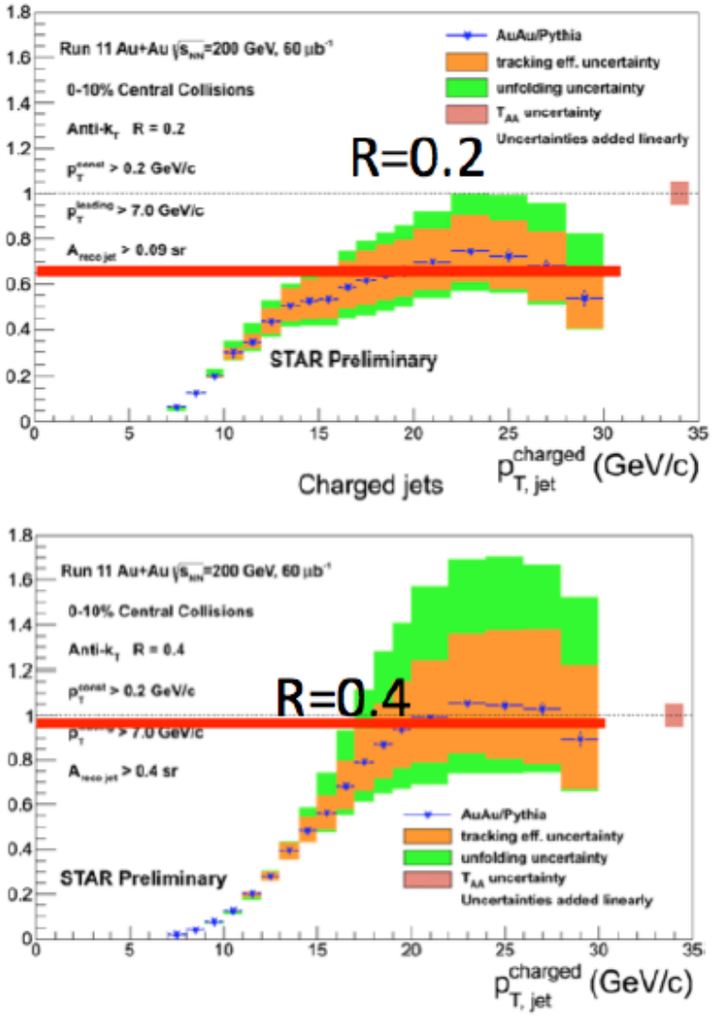
**OUTSIDE** THE JET CONE

AT **LHC**

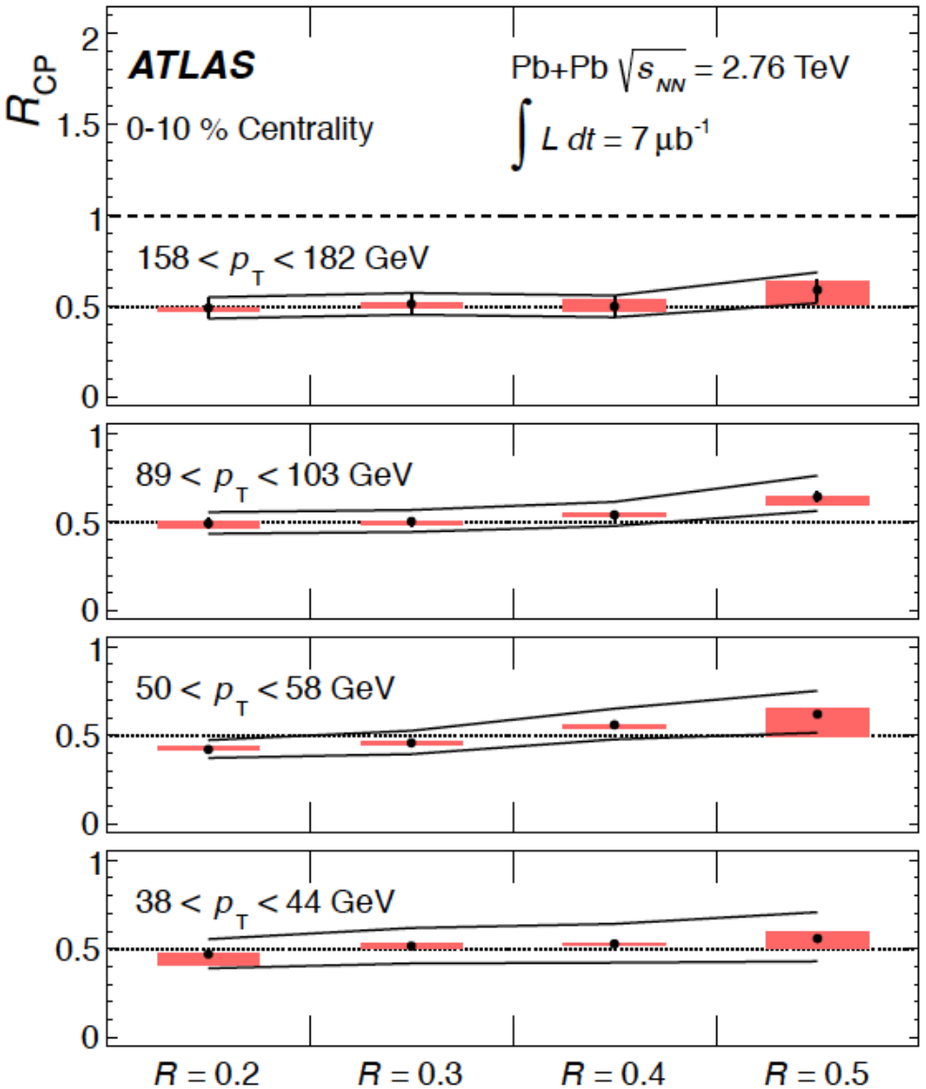



nucl-ex/1102.1957

# RHIC vs LHC now

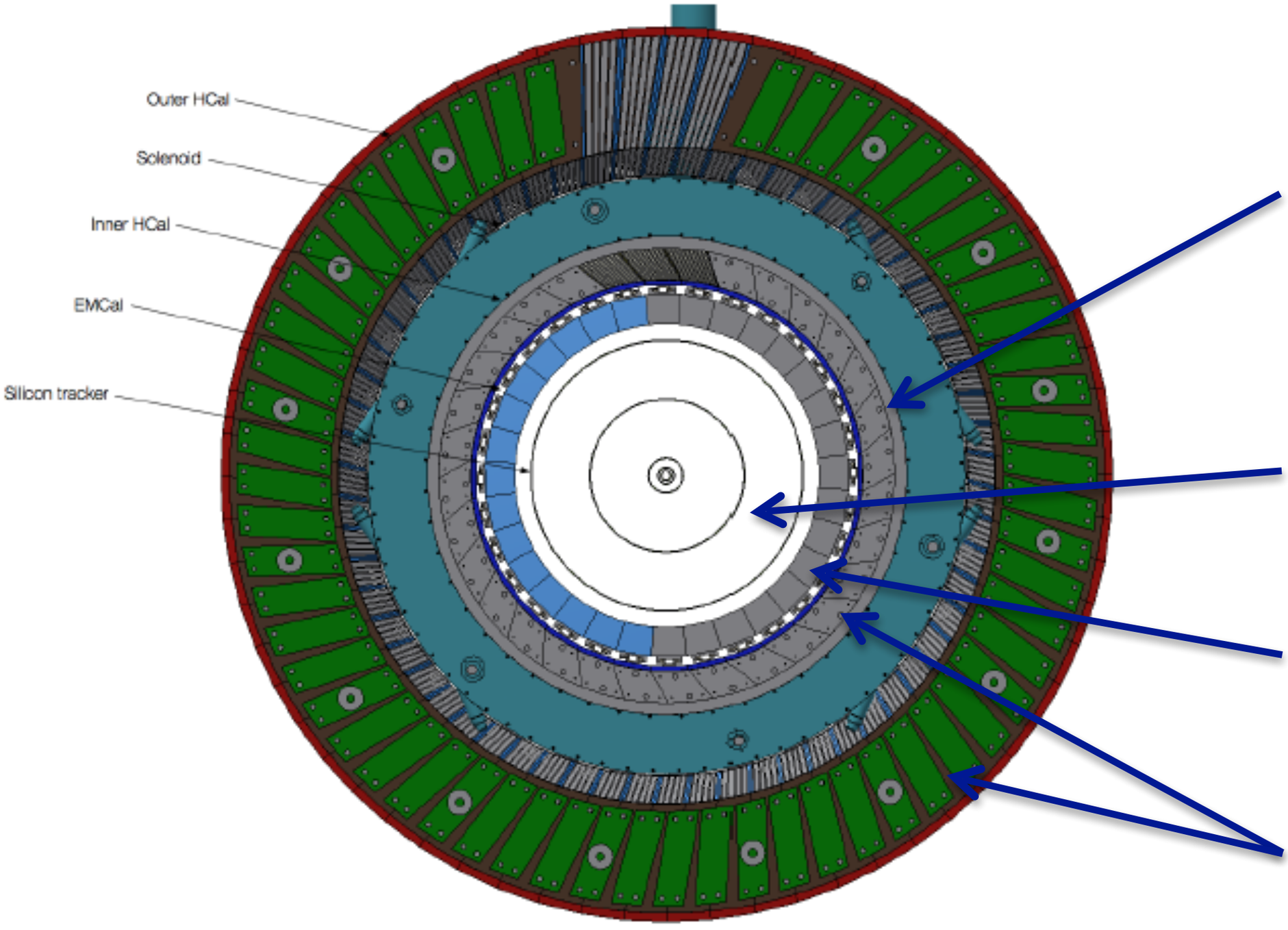



## Stronger R dependence at RHIC




hep-ex/1208.1967

# Detector Design




BaBar Magnet 1.5 T (at BNL!)

Coverage $|\eta| < 1.1$

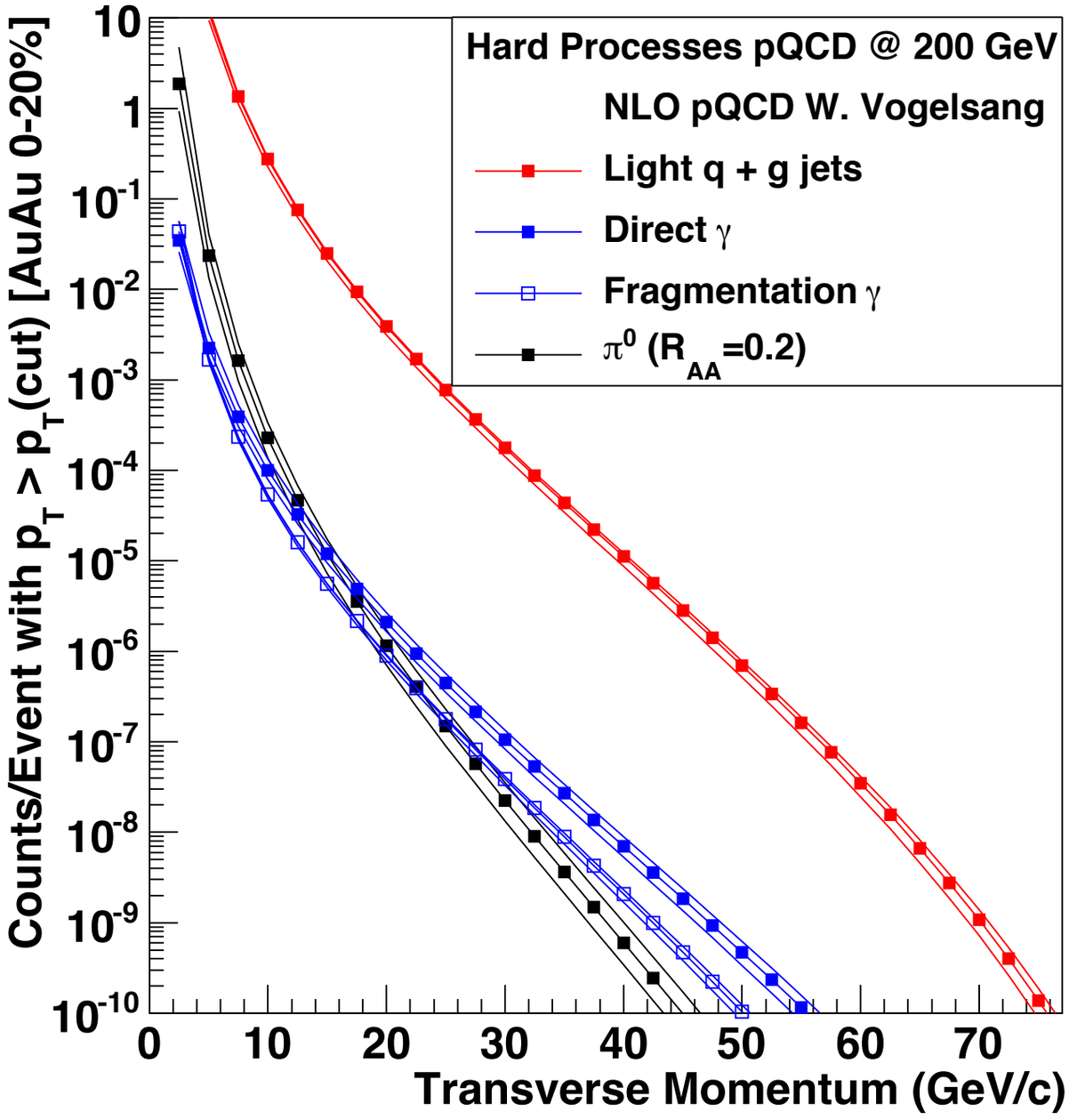
Silicon tracking for Heavy flavor tagging

Electromagnetic Calorimeter

Two longitudinal Segment Hadronic Calorimeter

High data acquisition rate capability ~ 15 kHz

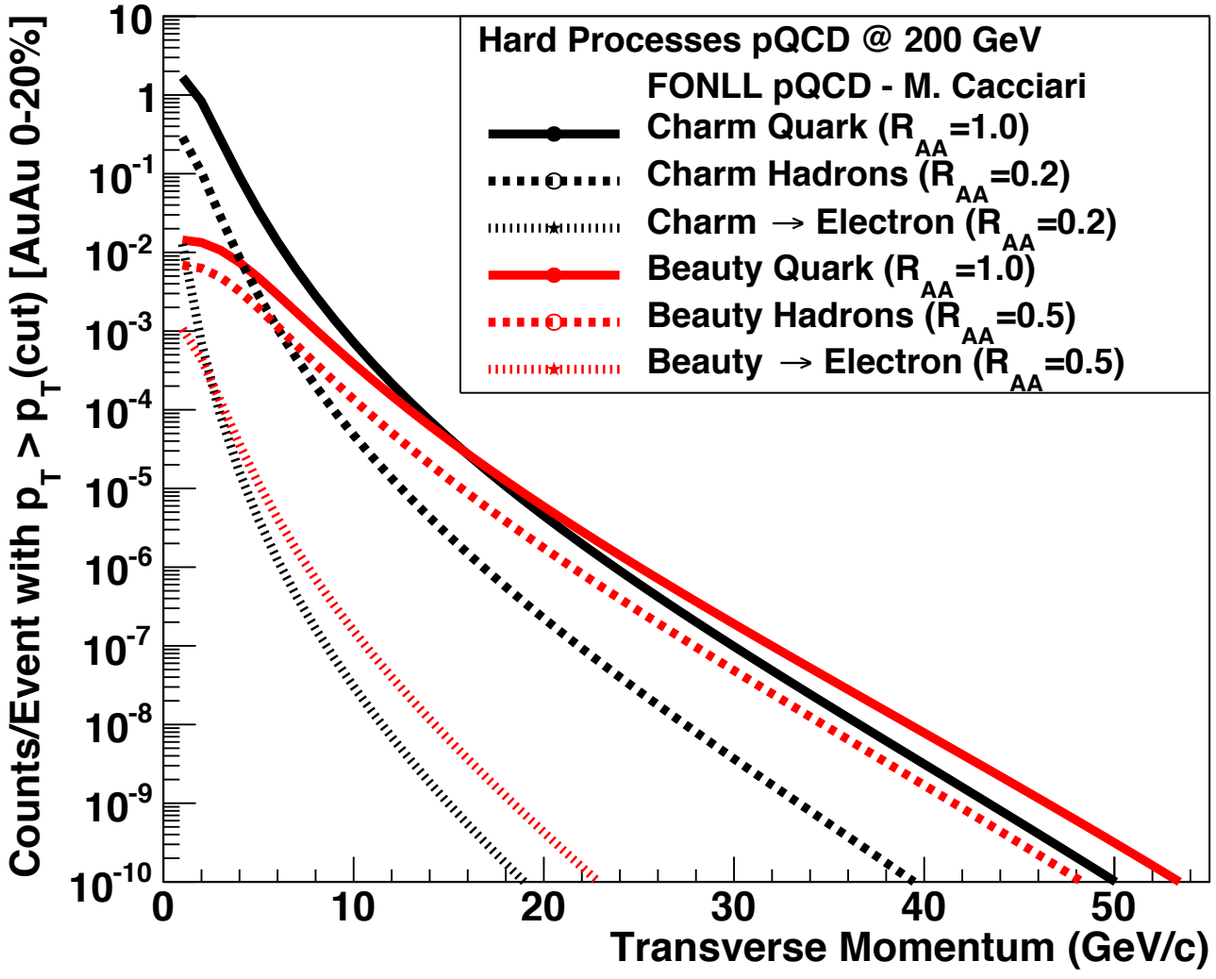
# EXPECTED RATES




RHIC II + sPHENIX CAN RECORD

**50 BILLION EVENTS**

WITHIN |z|<10CM IN 20-WEEKS

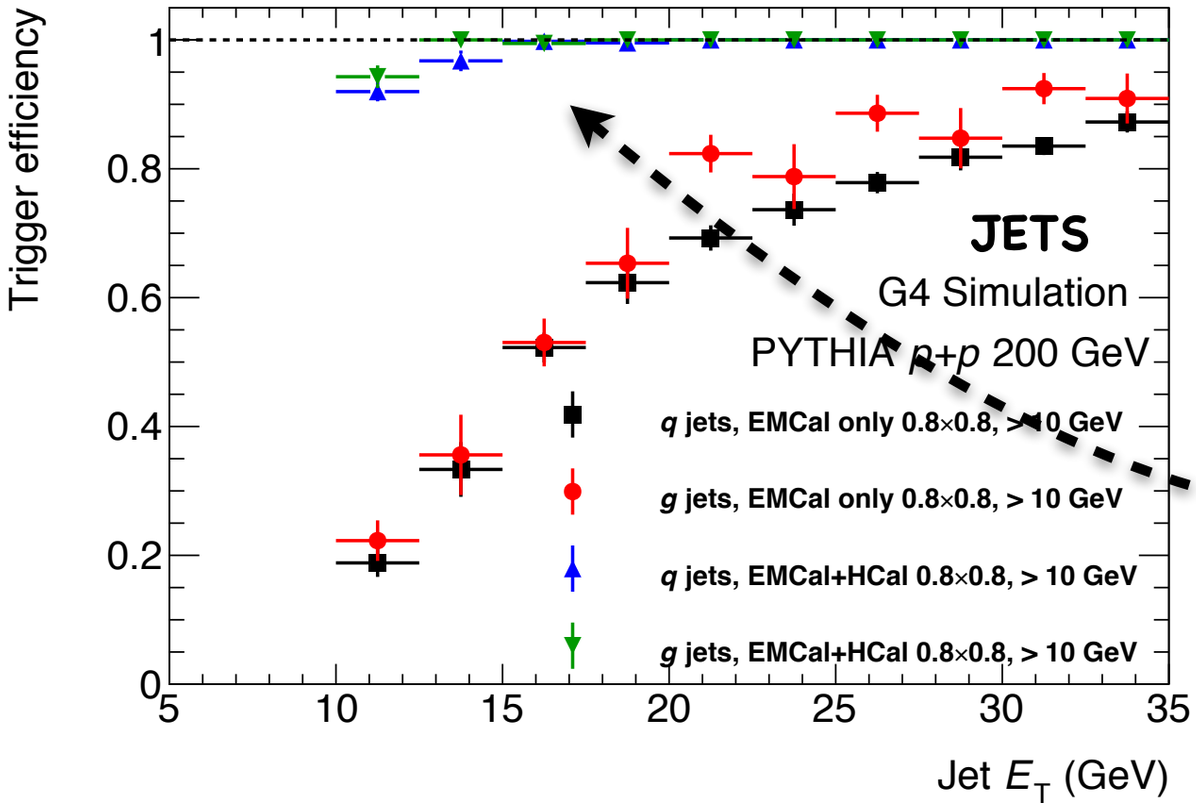


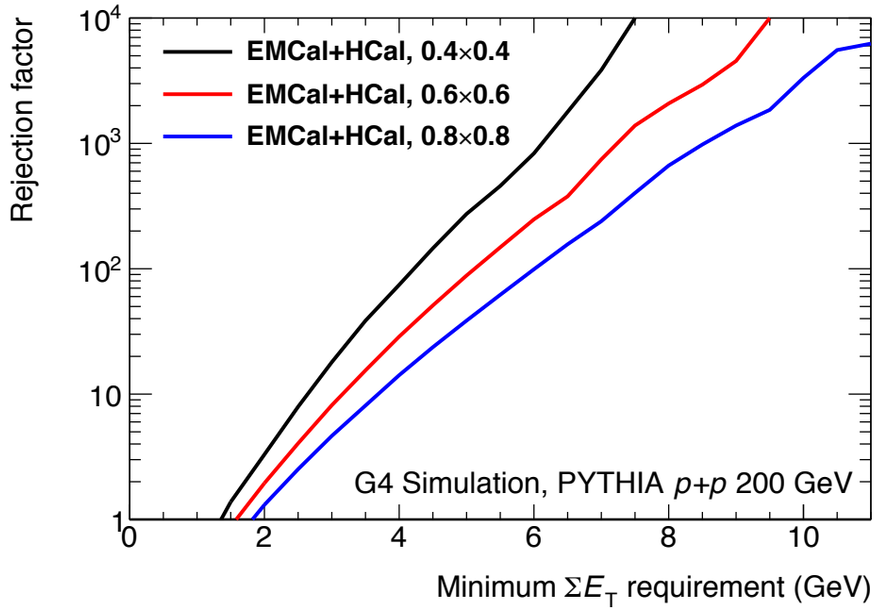

MIN. BIAS ~ **9,000 JETS > 50 GEV** IN CENTRAL EVENTS

**$10^5$ PHOTONS/B-JETS > 20 GEV**

CRITICAL SIMILAR STATISTICS IN P+P AND P+A

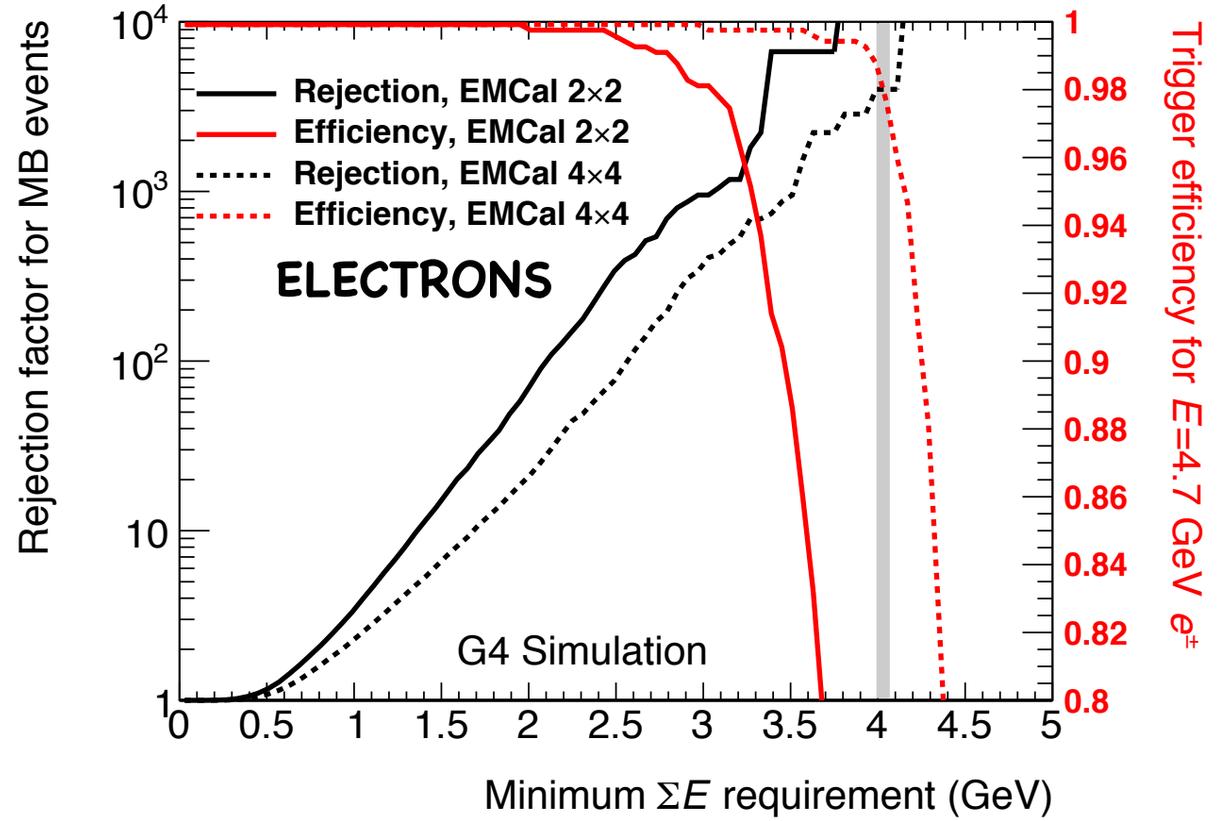
# TRIGGERING



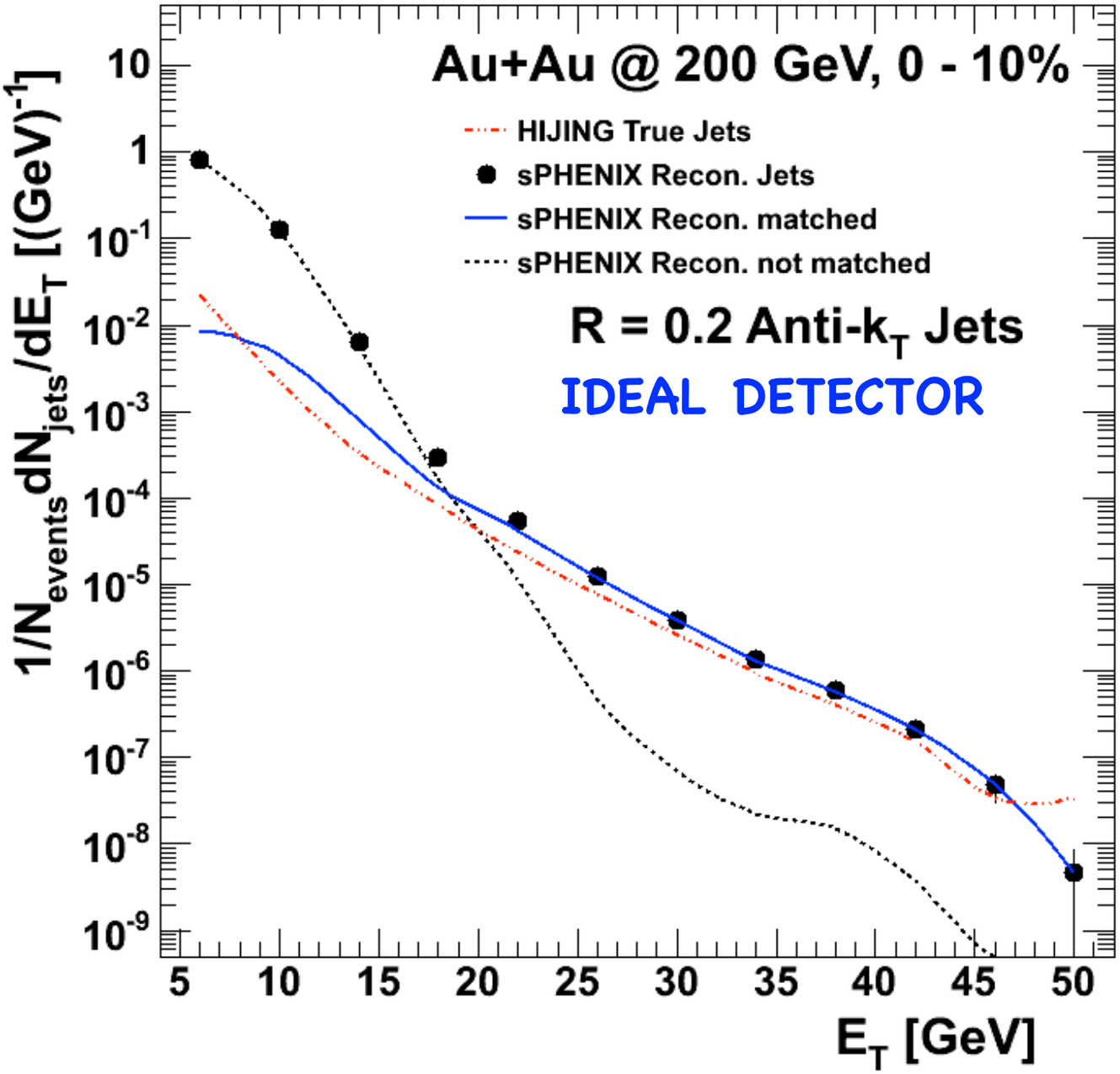

NEW C-AD PROJECTION WILL ALLOW AU+AU SAMPLING OF 0.5 TRILLION EVENTS

FULL CALORIMETER TRIGGER IMPROVES EFFICIENCY AND REMOVES POTENTIAL FLAVOR BIASES




sPHENIX FULL CALORIMETER TRIGGER ~ 50,000 JETS > 50 GeV IN CENTRAL EVENTS

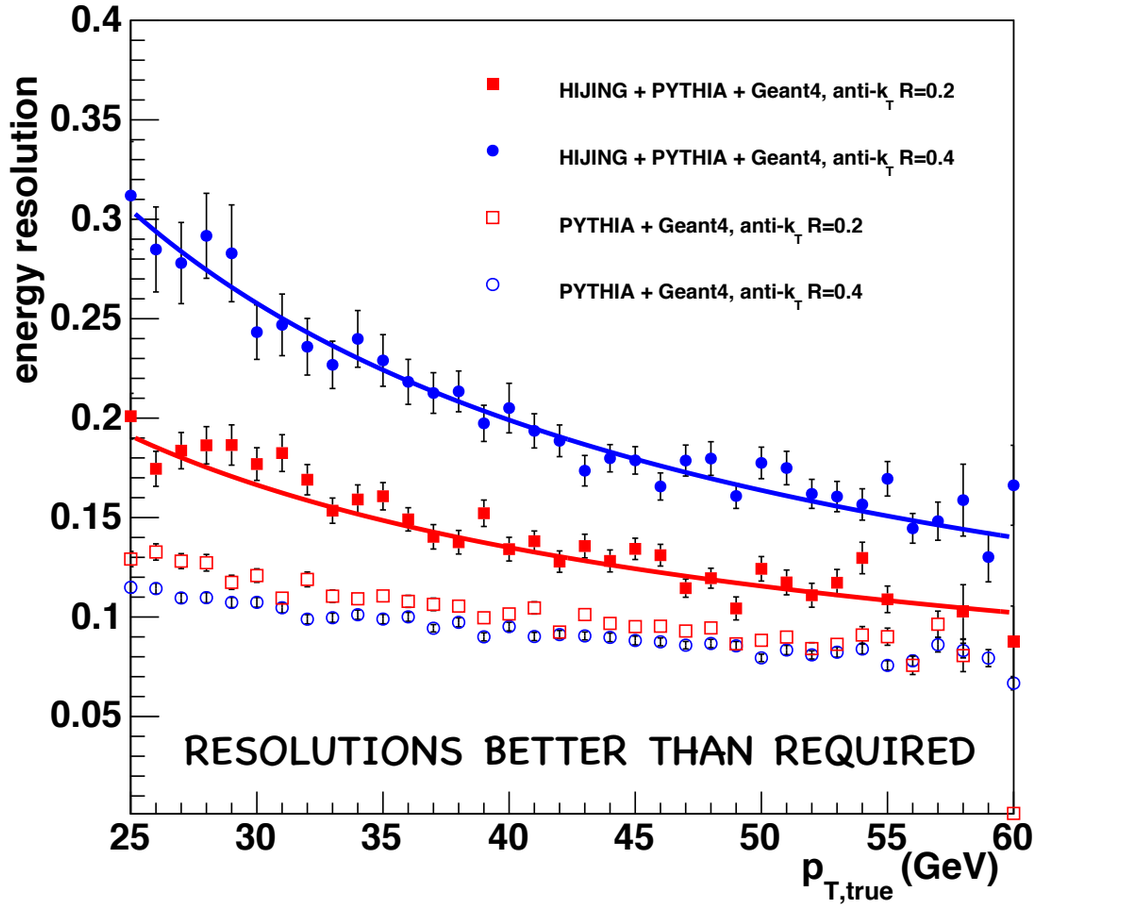
# JET CAPABILITIES

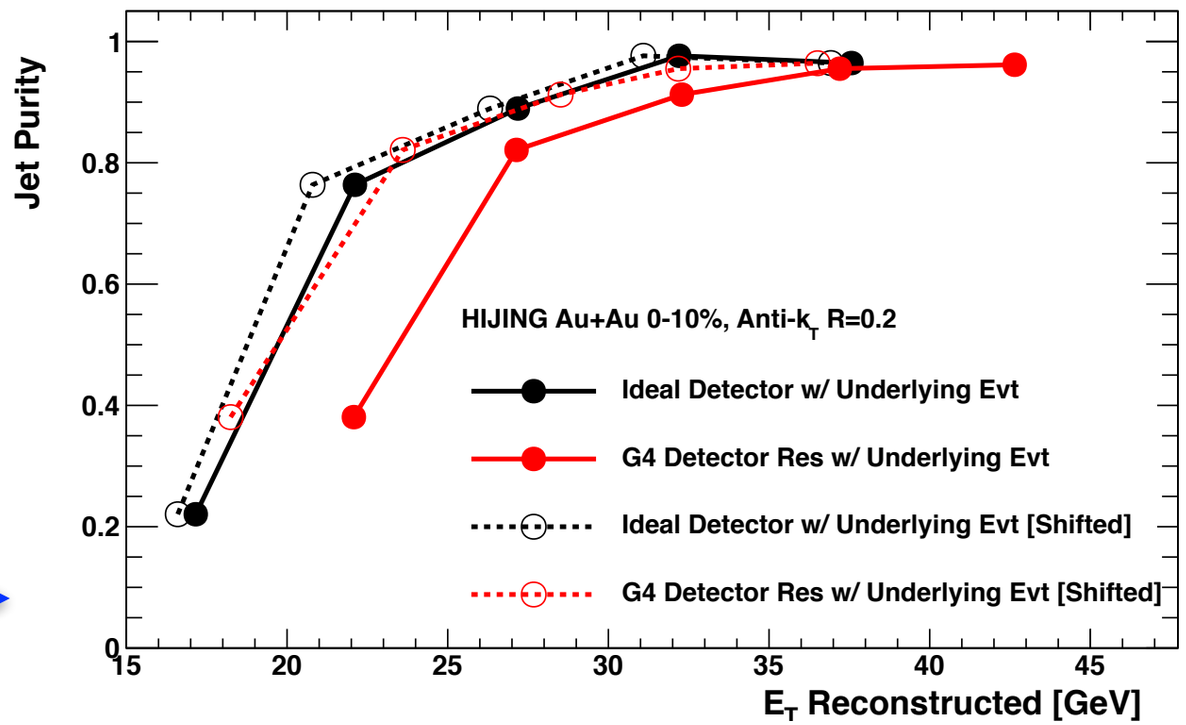



FAKES

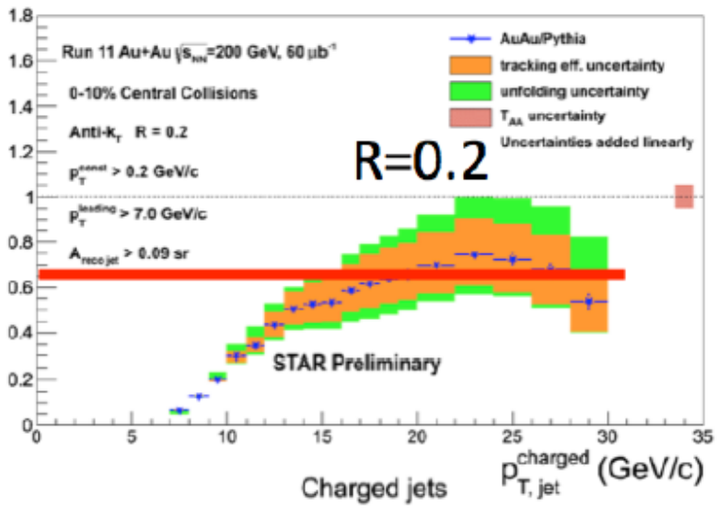
REAL

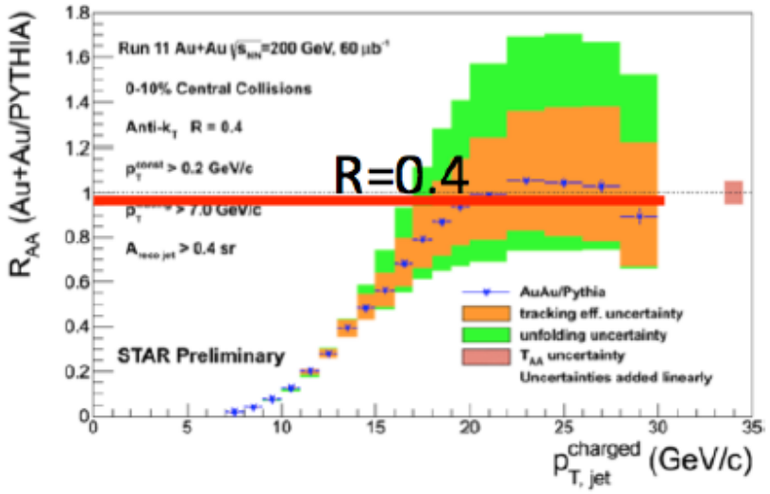
ADDING DETECTOR EFFECTS

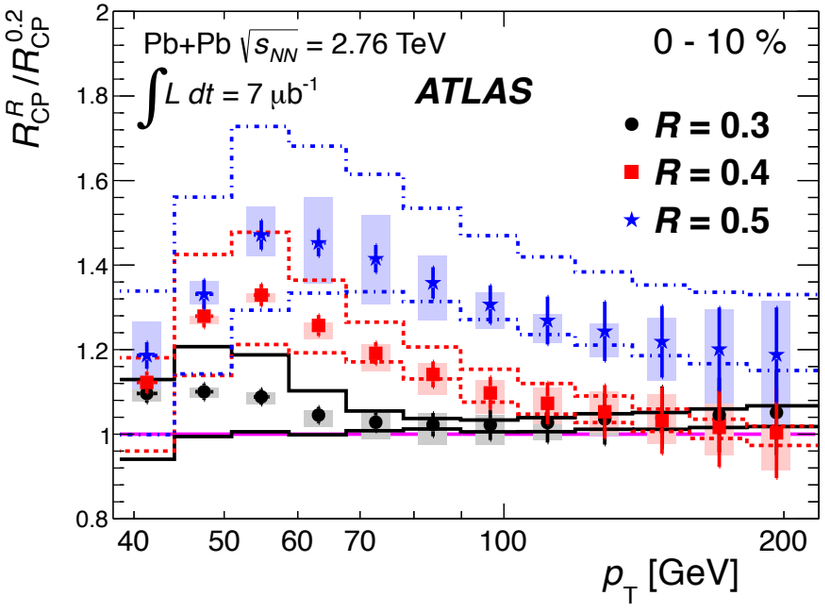


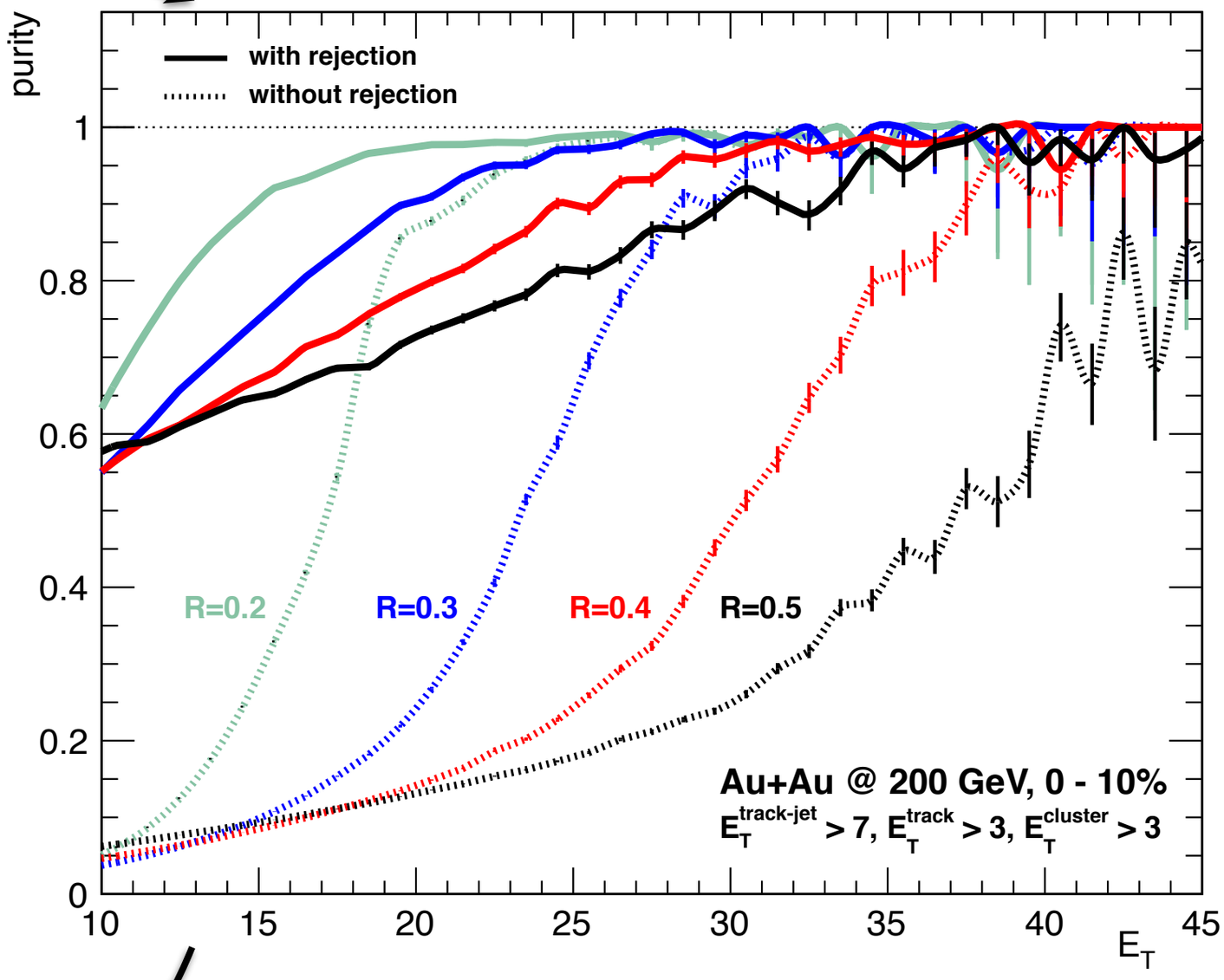



# EXTENDING KINEMATIC REACH



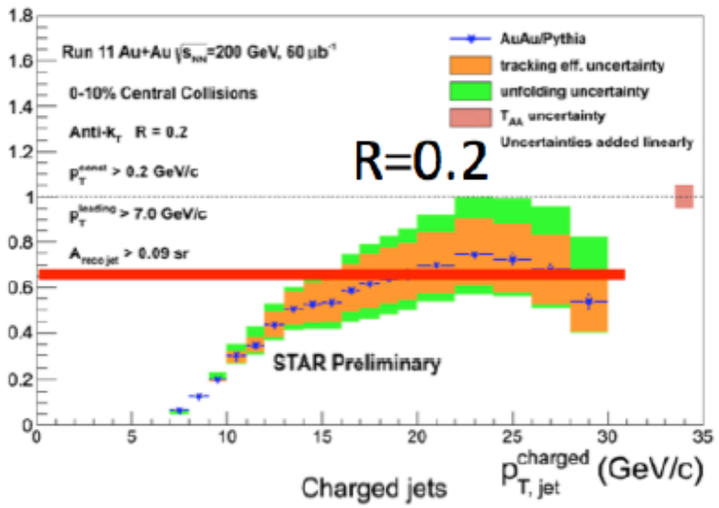



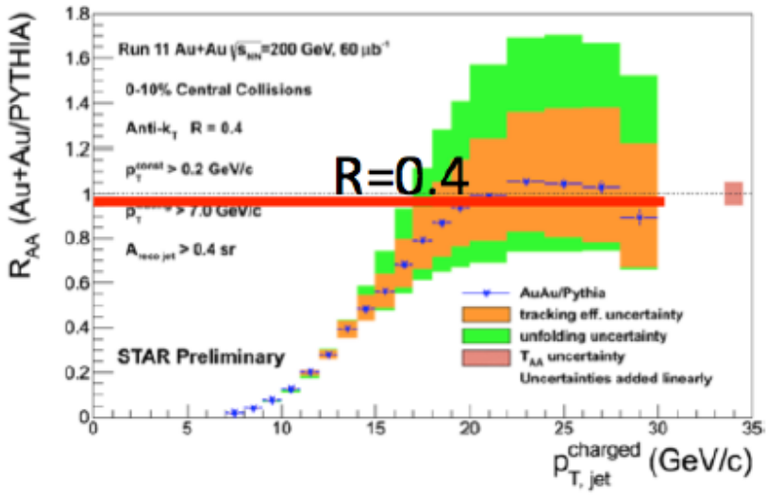



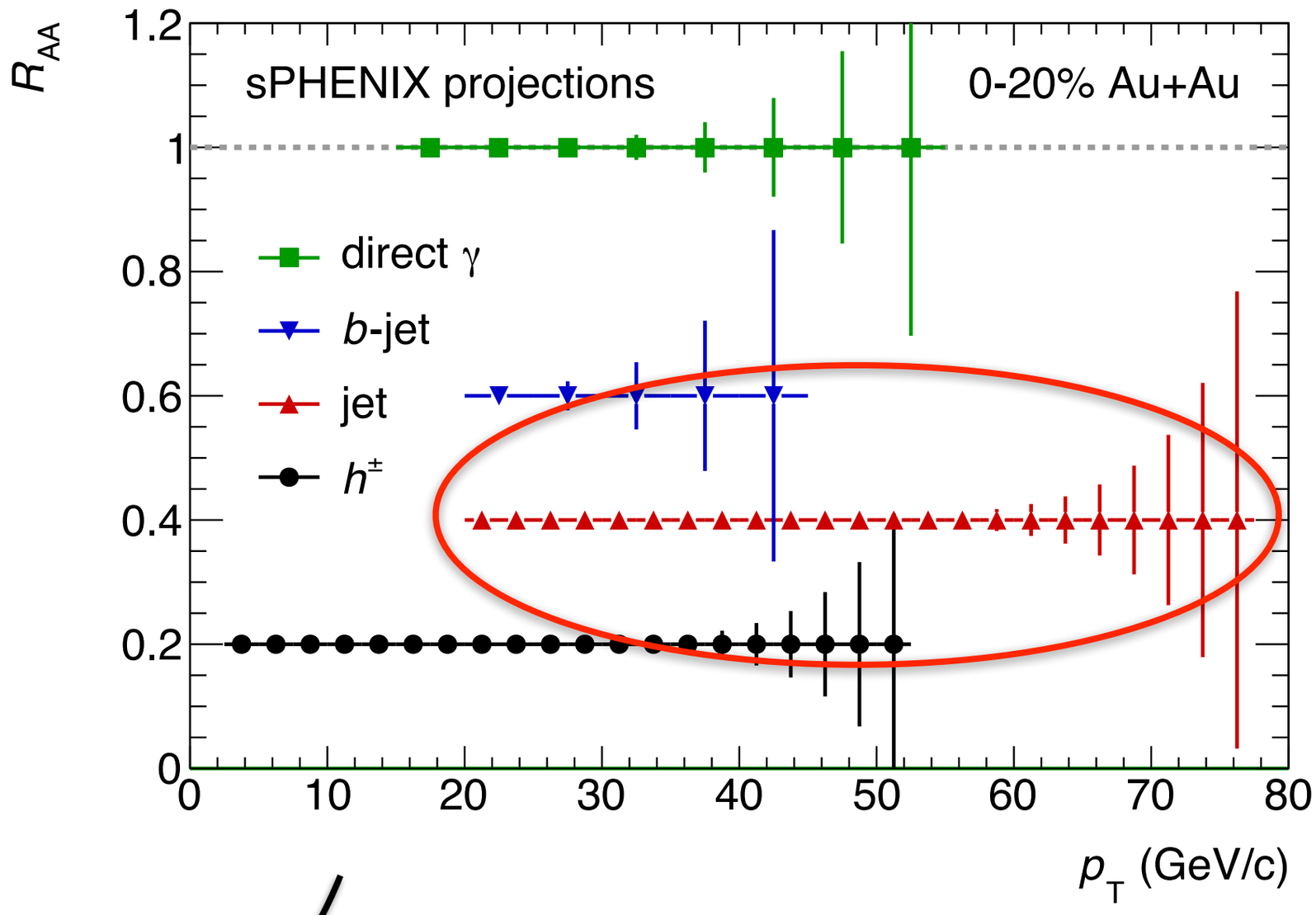



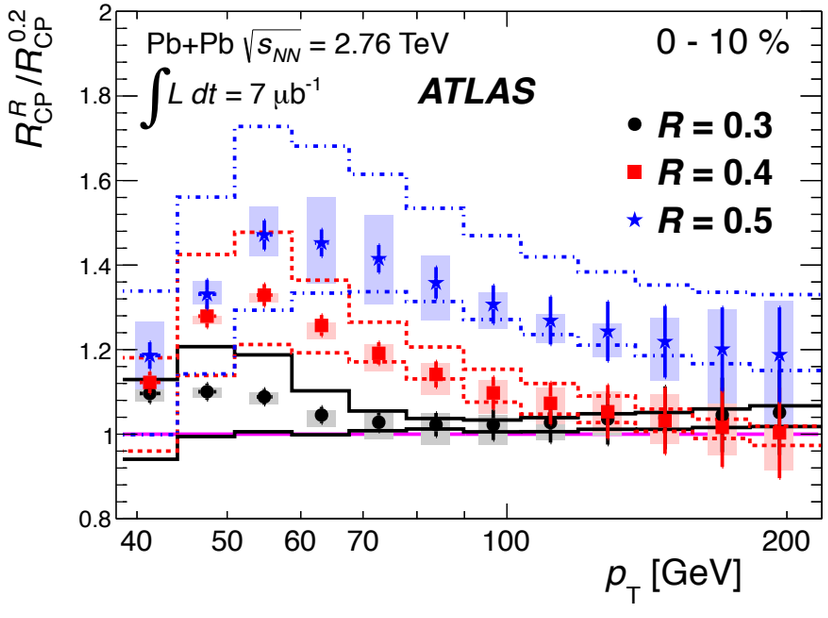

PURITY OF JETS RELATIVE TO BACKGROUND FLUCTUATIONS IMPROVED USING ATLAS-LIKE REJECTION (HIGH-$P_T$ TRACK-JET OR CLUSTER)

# EXTENDING KINEMATIC REACH



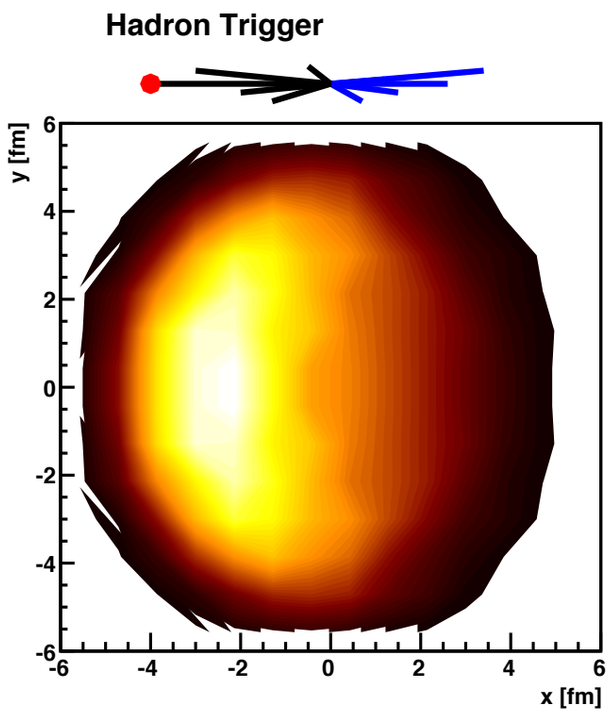



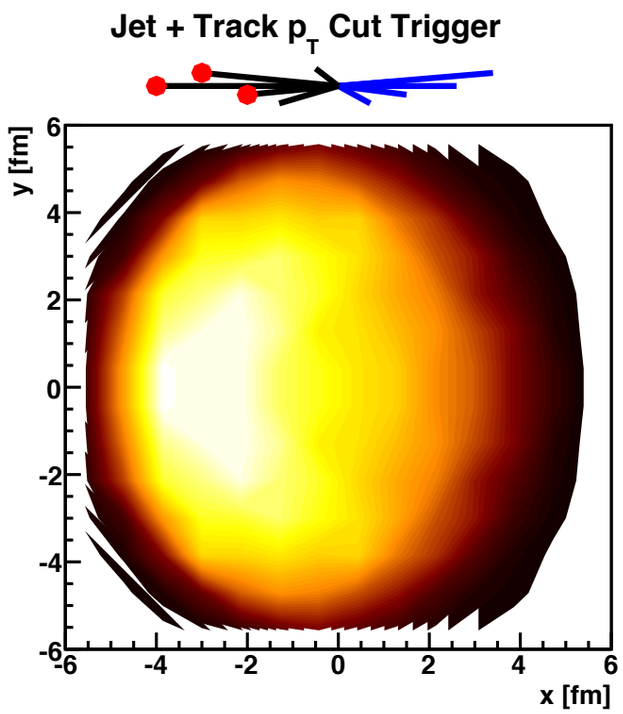



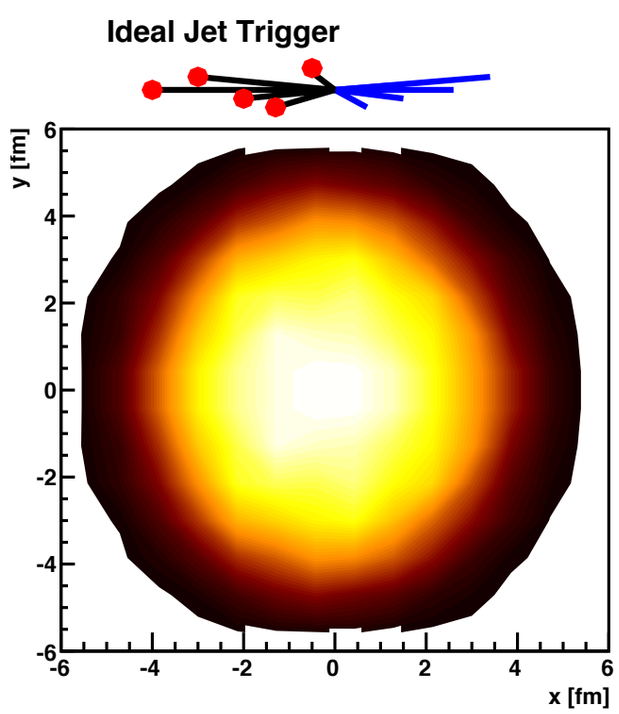

GOOD STATISTICS OUT TO 60 GEV

# Learning from Surface Bias

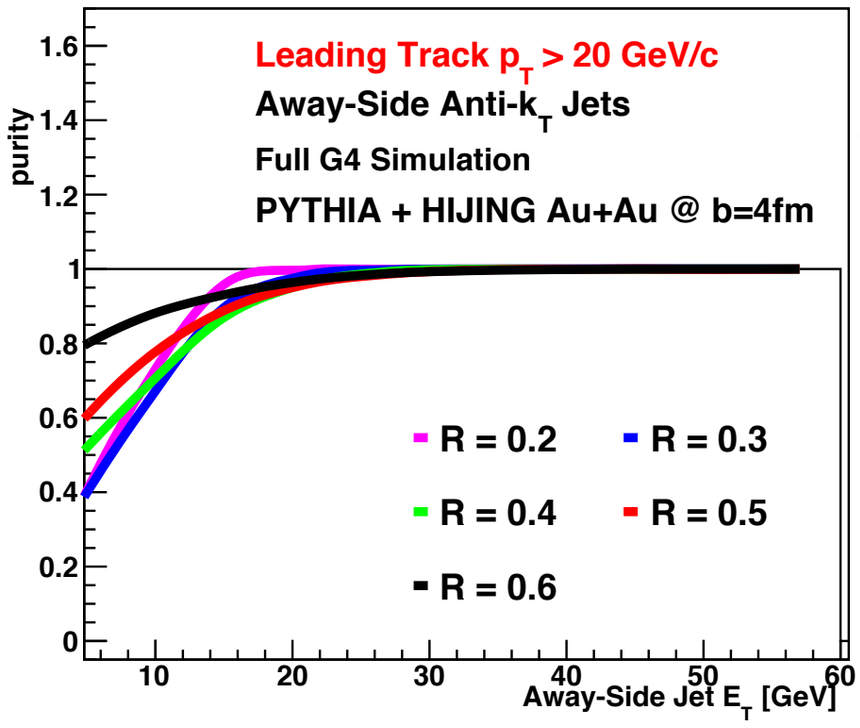
## Jet Surface Emission Engineering

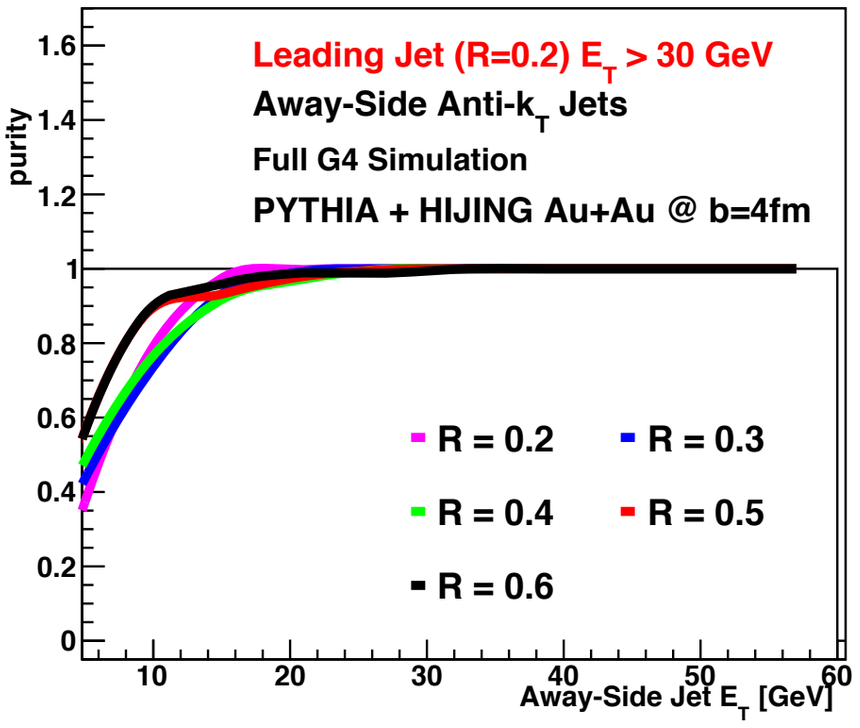


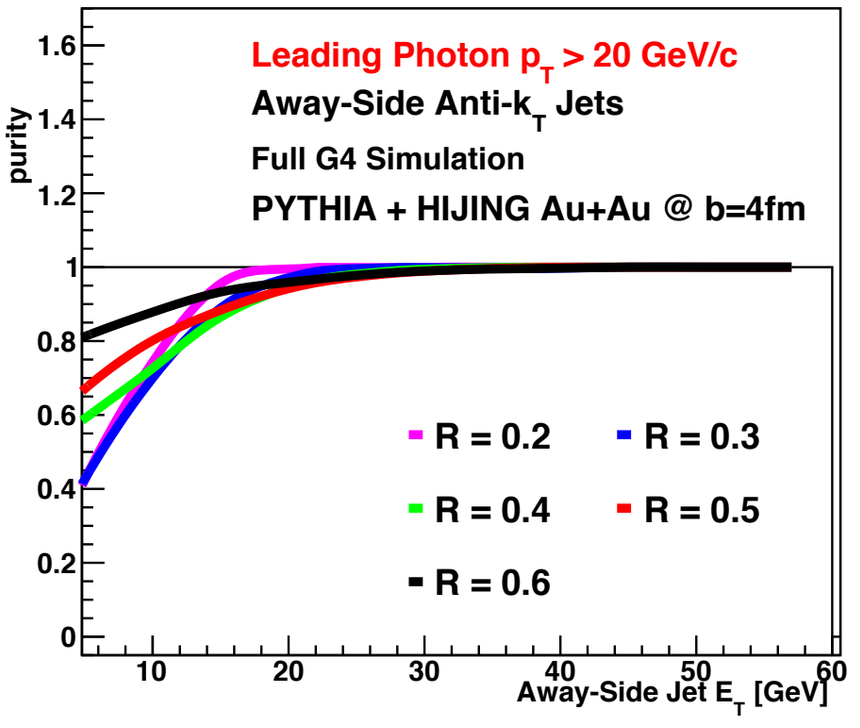




arXiv:1212.0646

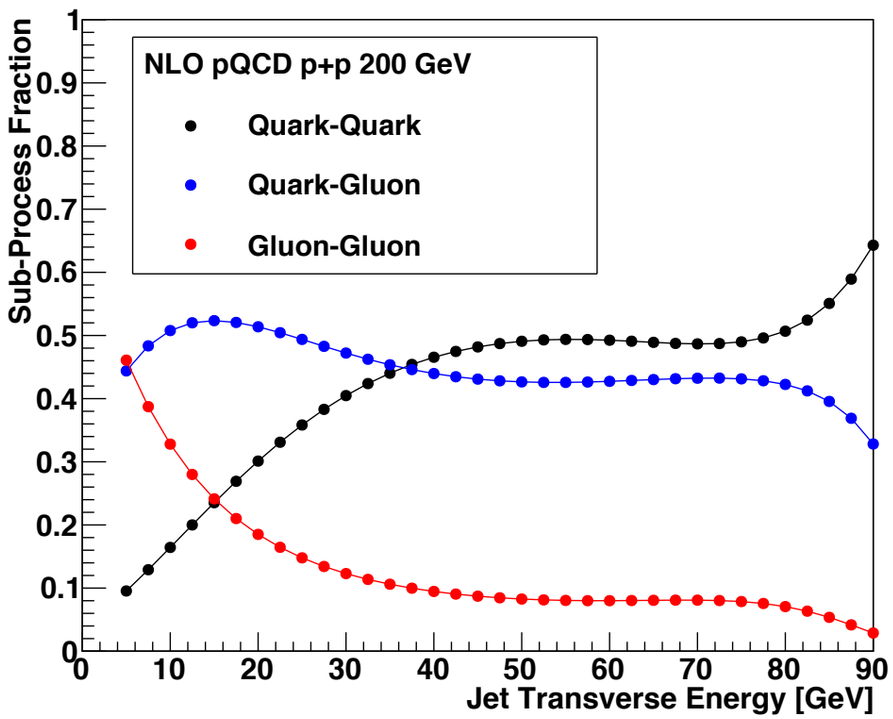


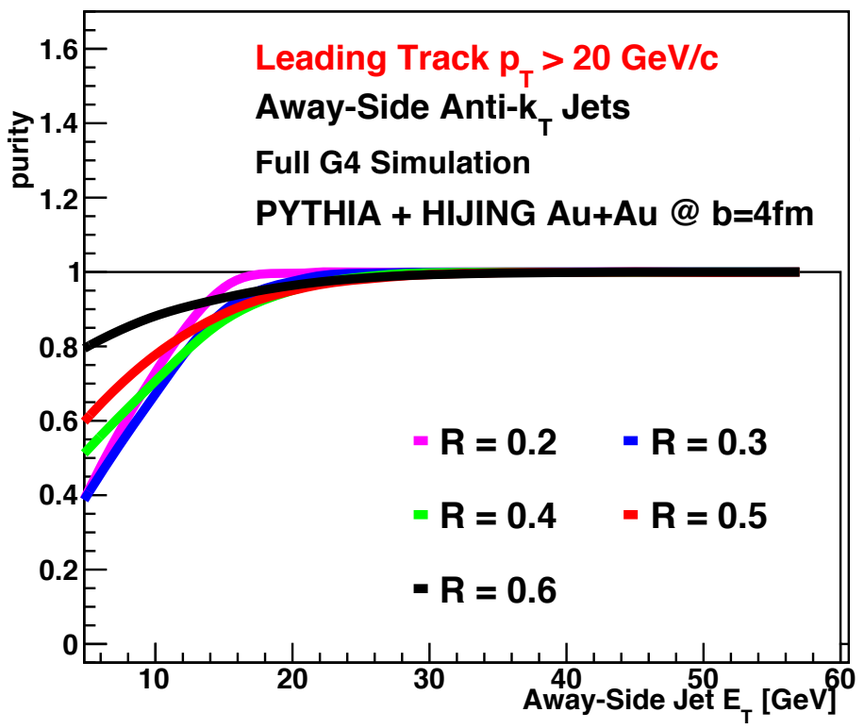



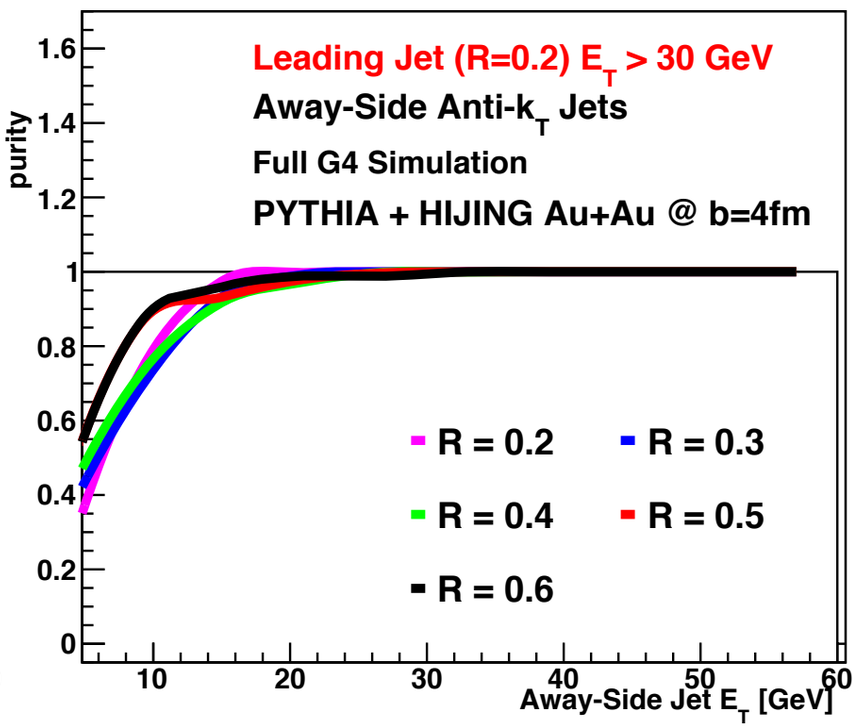
# Flavor dependence

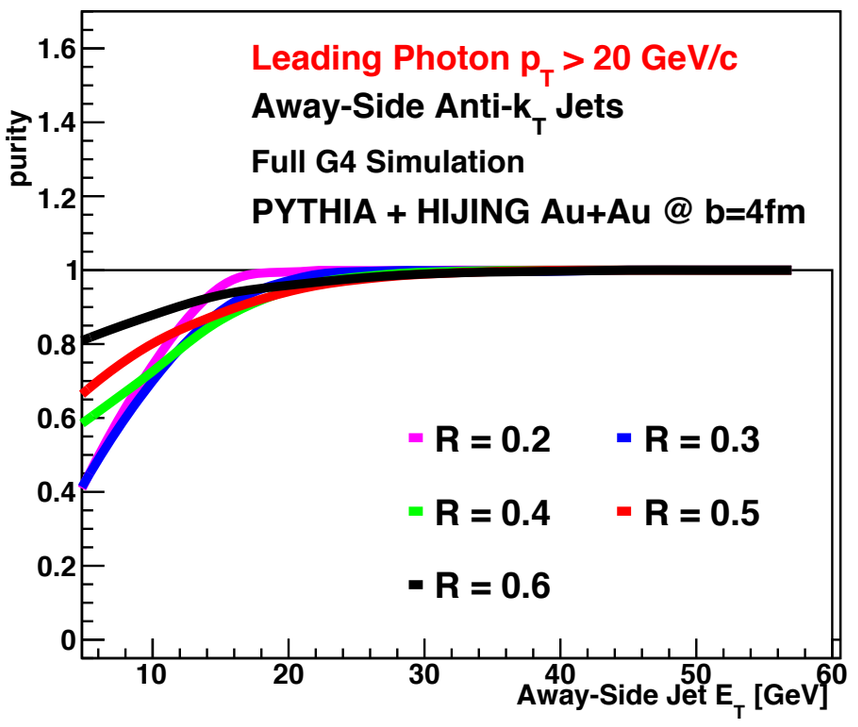
Gluon enhanced jets



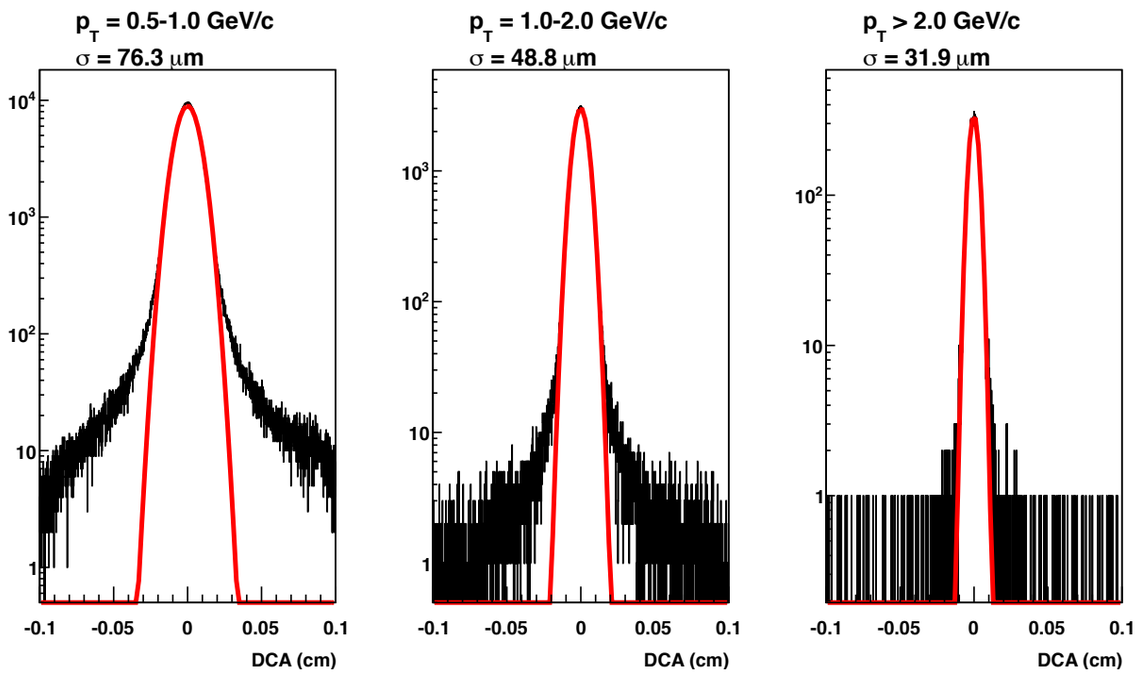

Quark enhanced jets

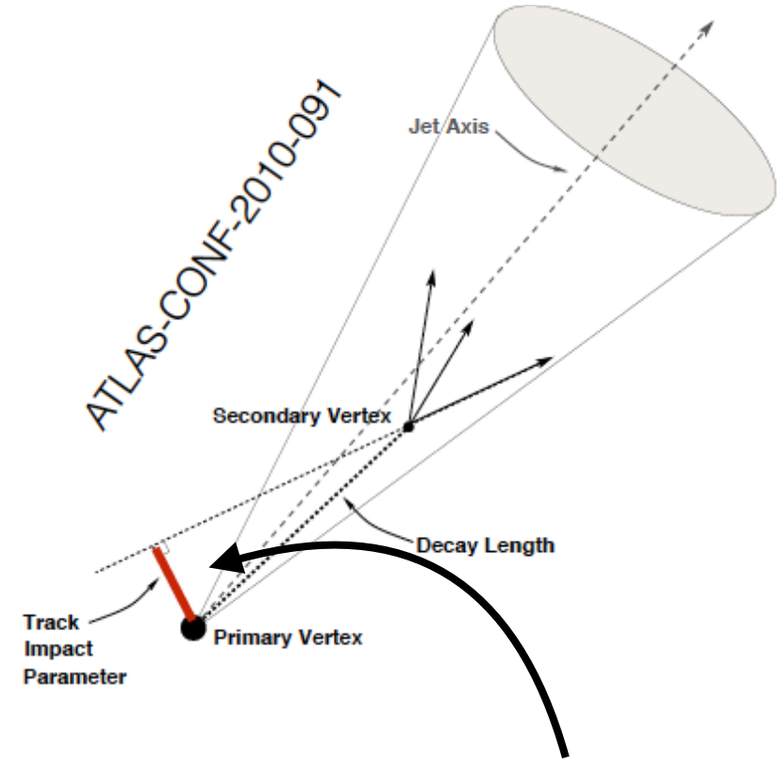


# HEAVY FLAVOR TAGGED JETS

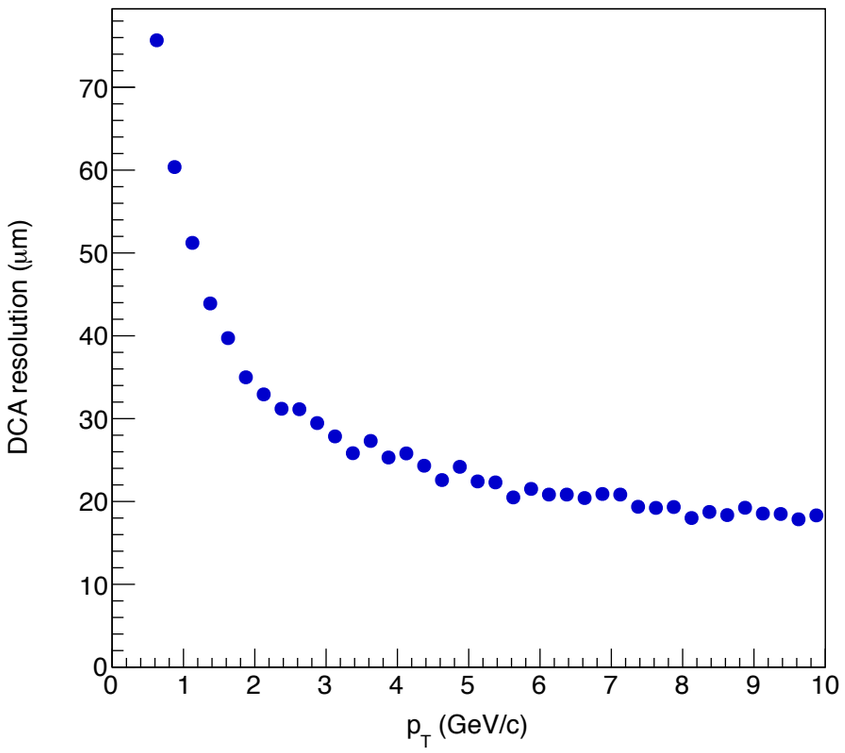



REQUIRE ONE OR MORE TRACKS WITH NON-ZERO IMPACT PARAMETER

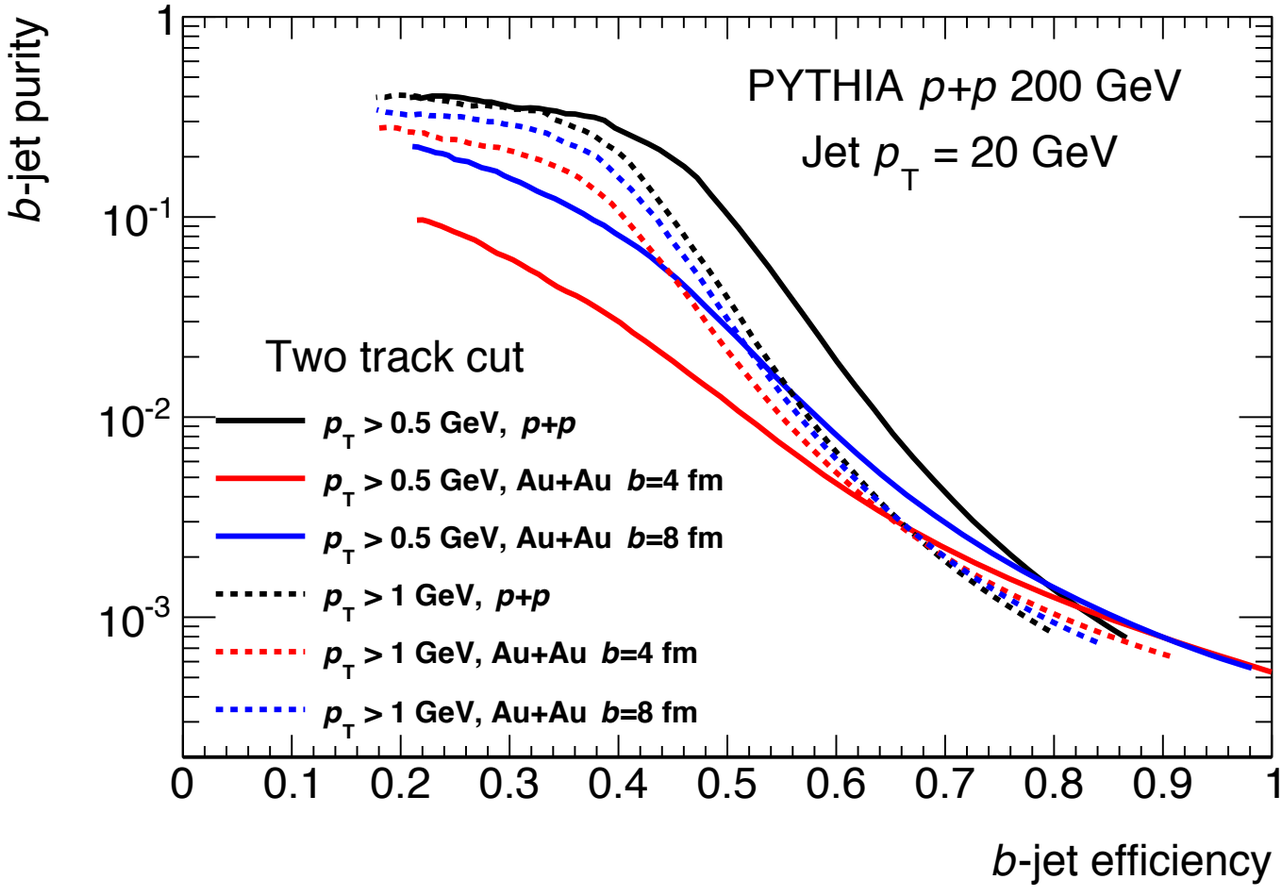
DETERMINED USING 2D DISTANCE OF CLOSEST APPROACH:

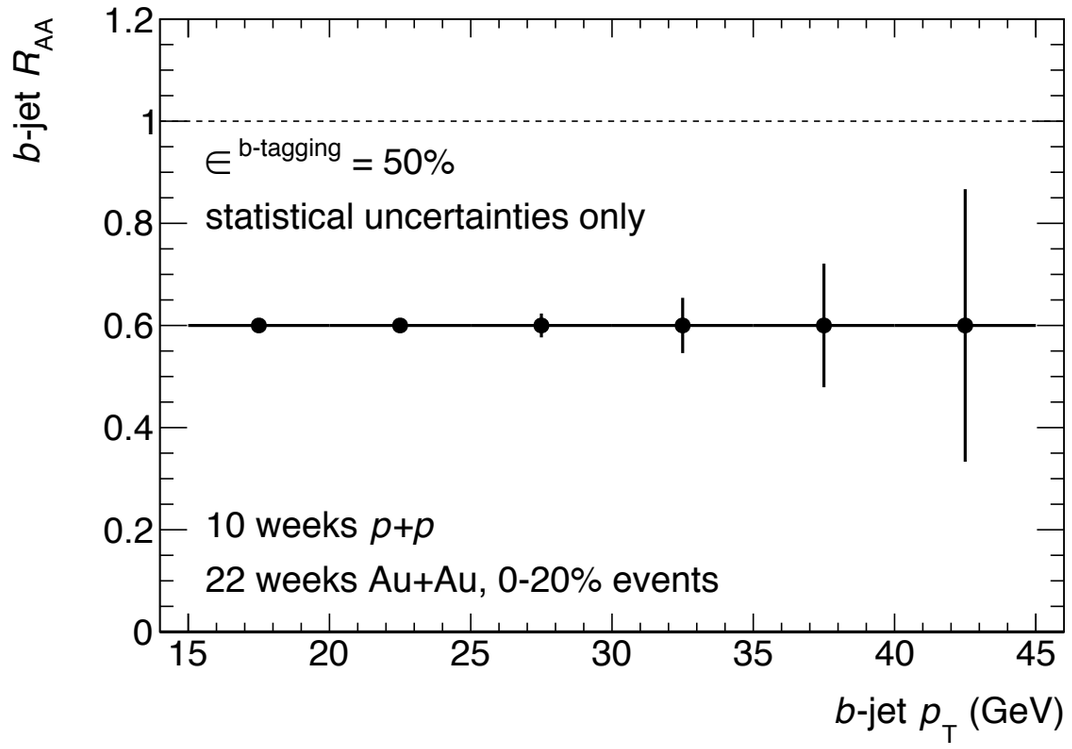
$S_{DCA} = DCA / \sigma_{DCA}$




REQUIRES GOOD DCA RESOLUTION + TRACKING EFFICIENCY

# HEAVY FLAVOR TAGGED JETS

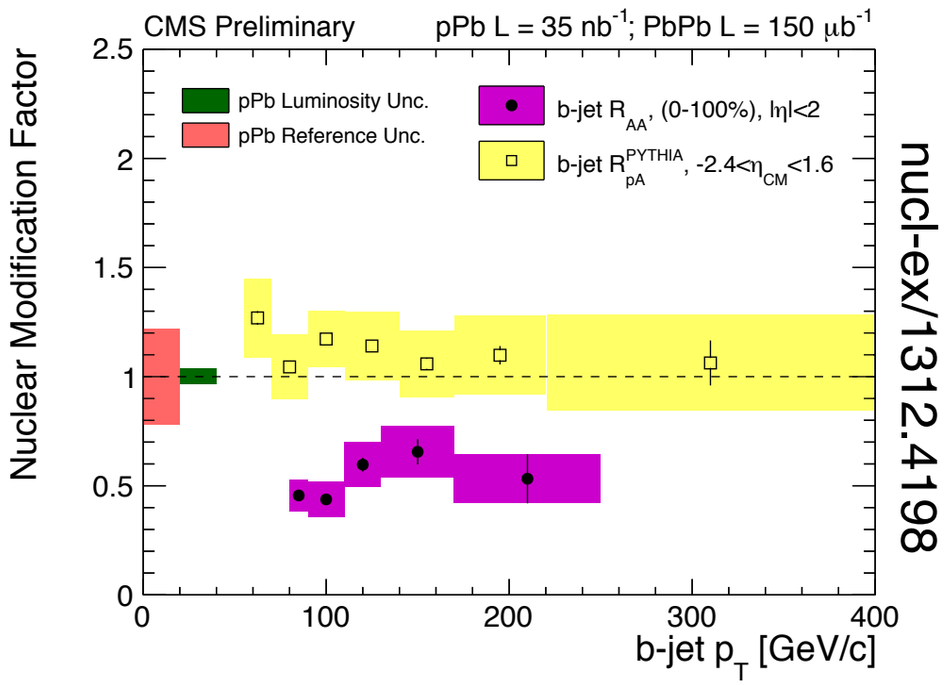



PROJECTED UNCERTAINTIES AT 50% TAGGING EFFICIENCY

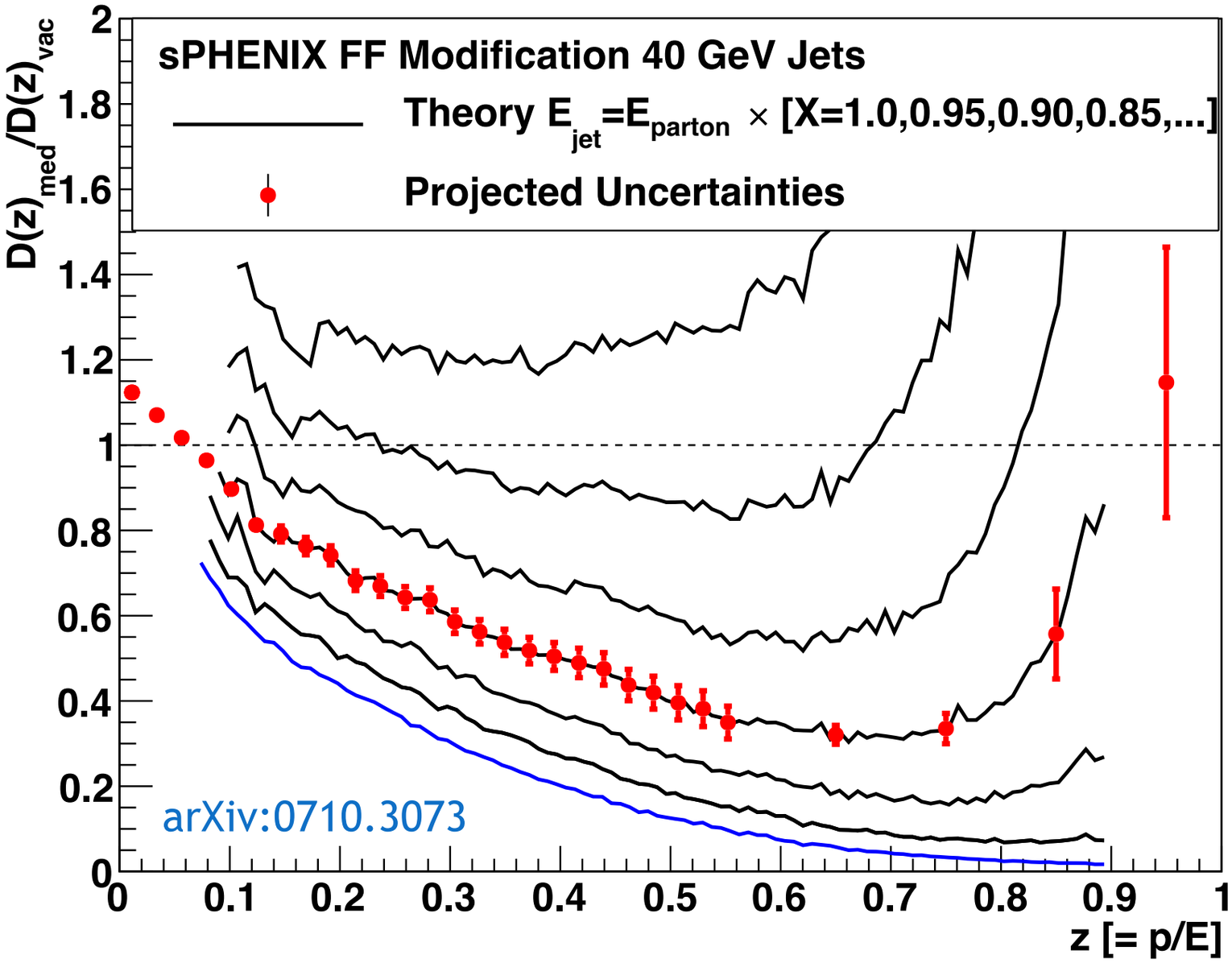
PURITY VS EFFICIENCY →

SYSTEMATIC VS STATISTICAL UNCERTAINTIES



# JET FRAGMENTATION

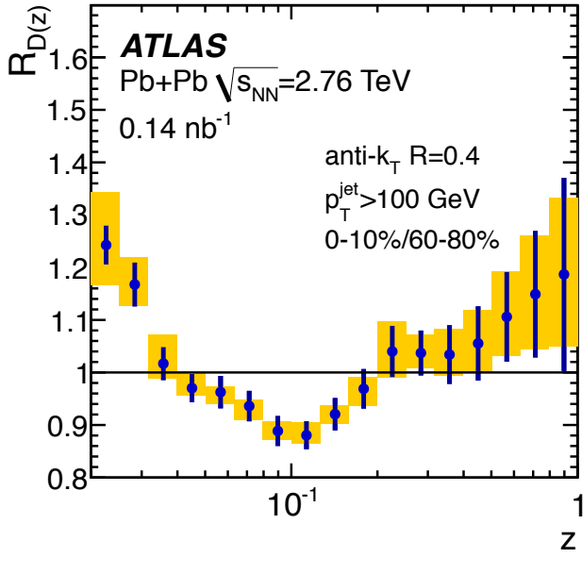
## PREDICTIONS THAT FF D(z) = p / $E_{JET}$ WILL HAVE DRAMATIC HIGH-z SUPPRESSION




MODIFICATION SENSITIVE TO ENERGY CONTAINED IN JET CONE

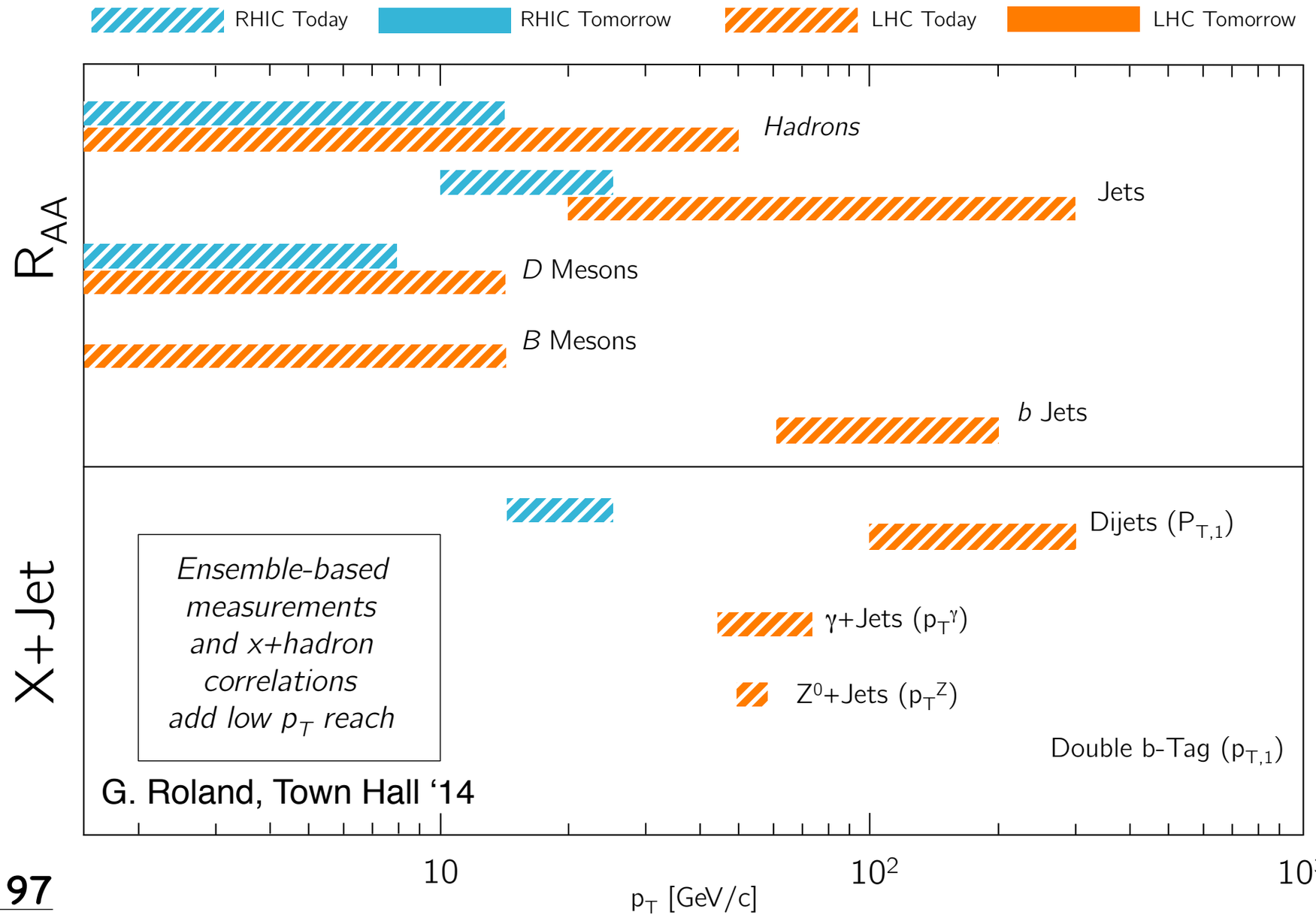
REQUIRES MEASUREMENT OF **FULL JET ENERGY** (CALORIMETRIC JETS)

REQUIRES PRECISION TRACKING



# SUMMARY

- NO SINGLE OBSERVABLE ALONE CAN ANSWER FUNDAMENTAL "HOW" AND "WHY" QUESTIONS FOR QGP FORMATION
  - THEORY POORLY CONSTRAINED WITH WIDE RANGE OF PARAMETERS TO PLAY WITH
- NEED A RANGE OF JET OBSERVABLES ACROSS LARGE ENERGY RANGE AND DIFFERENT COLLISION PARAMETERS (TEMP, SPECIES, SIZE, ETC)




FULL TEXT:
HTTP://ARXIV.ORG/ABS/1501.06197

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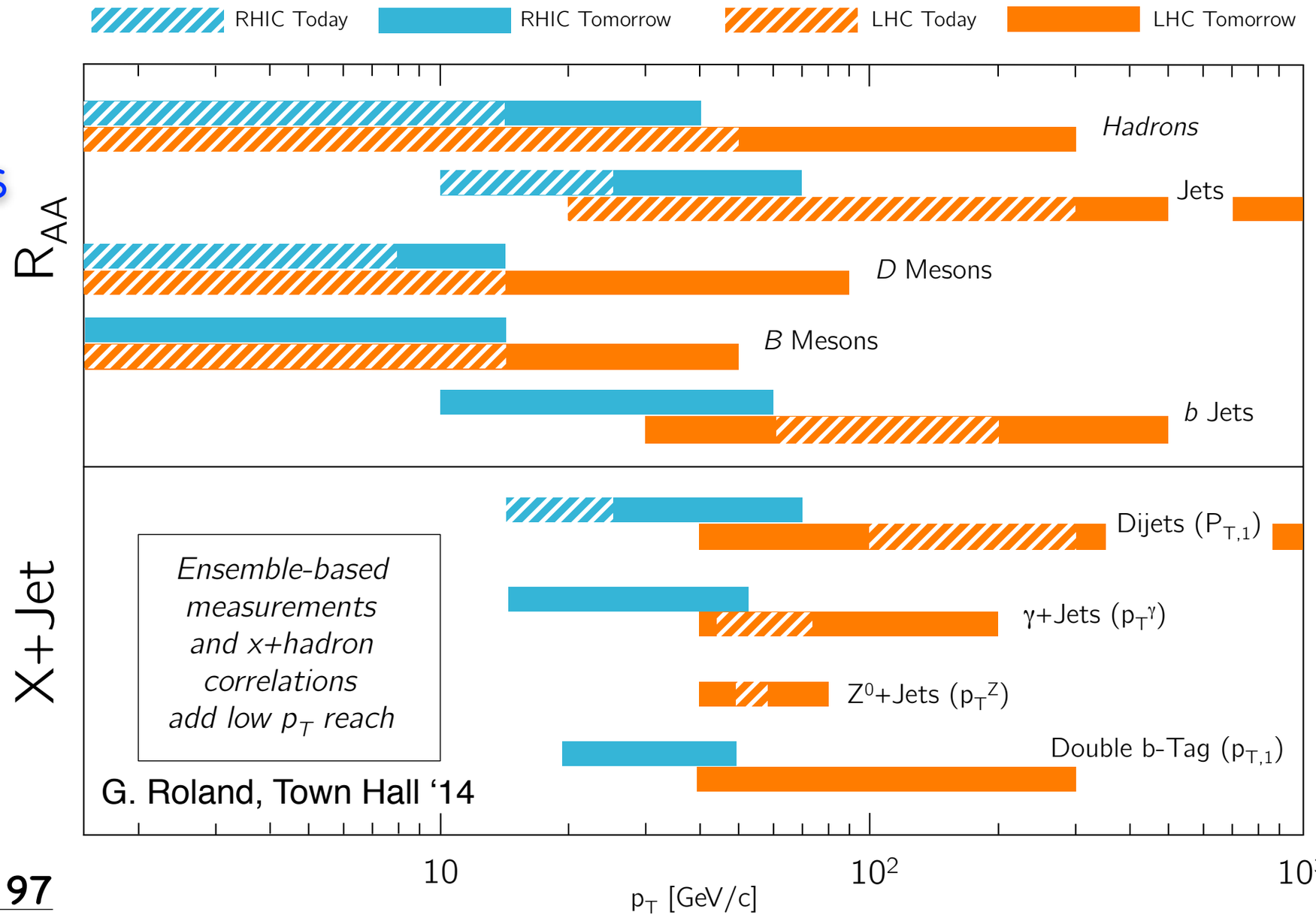
VERSATILITY OF
RHIC + sPHENIX MAKES
THAT ALL POSSIBLE!

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VERSATILITY OF
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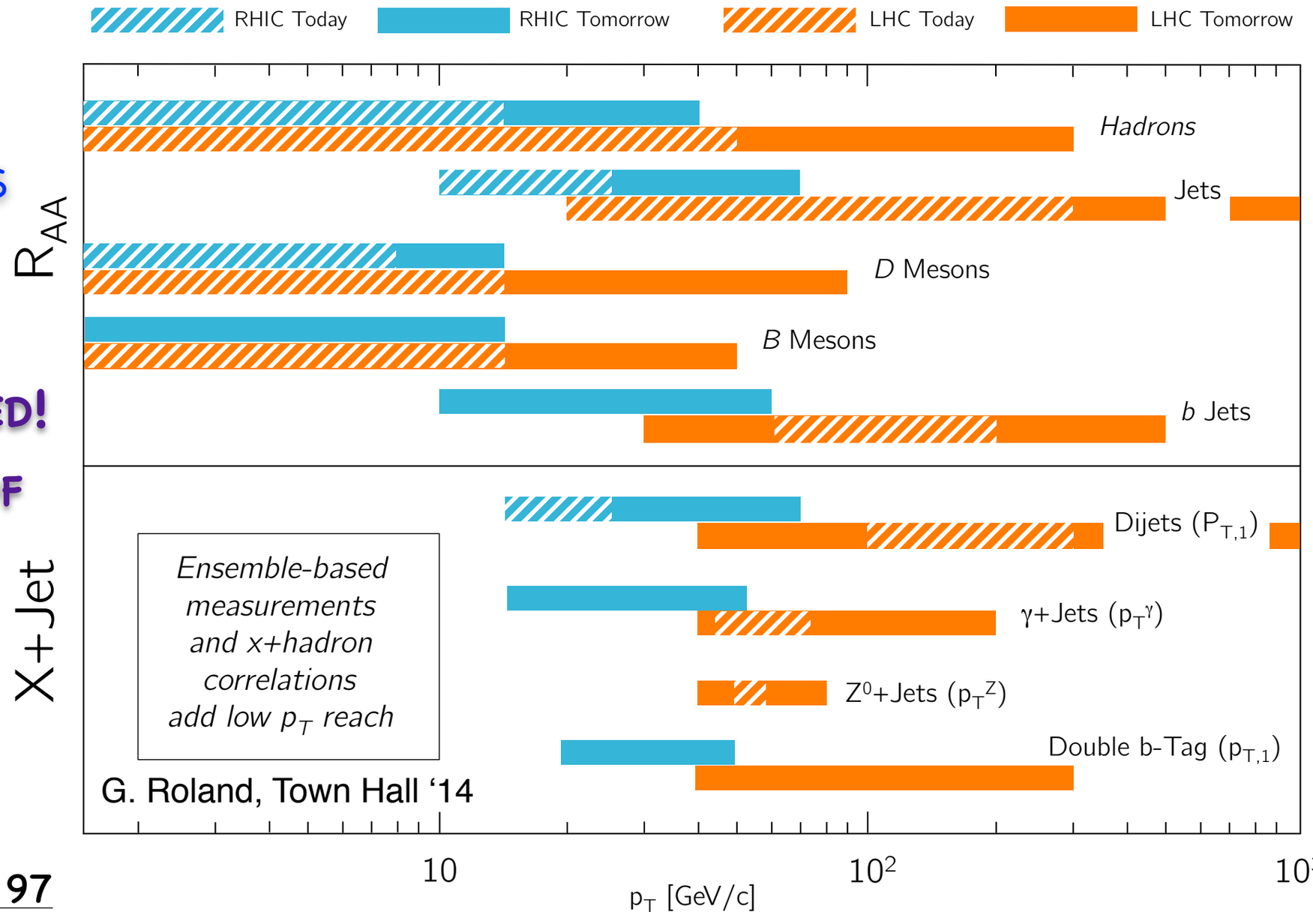
**MAJOR MILLSTONE PASSED!**
**DOE SCIENCE REVIEW OF sPHENIX CHAIRED BY DR. TIM HALLMAN**

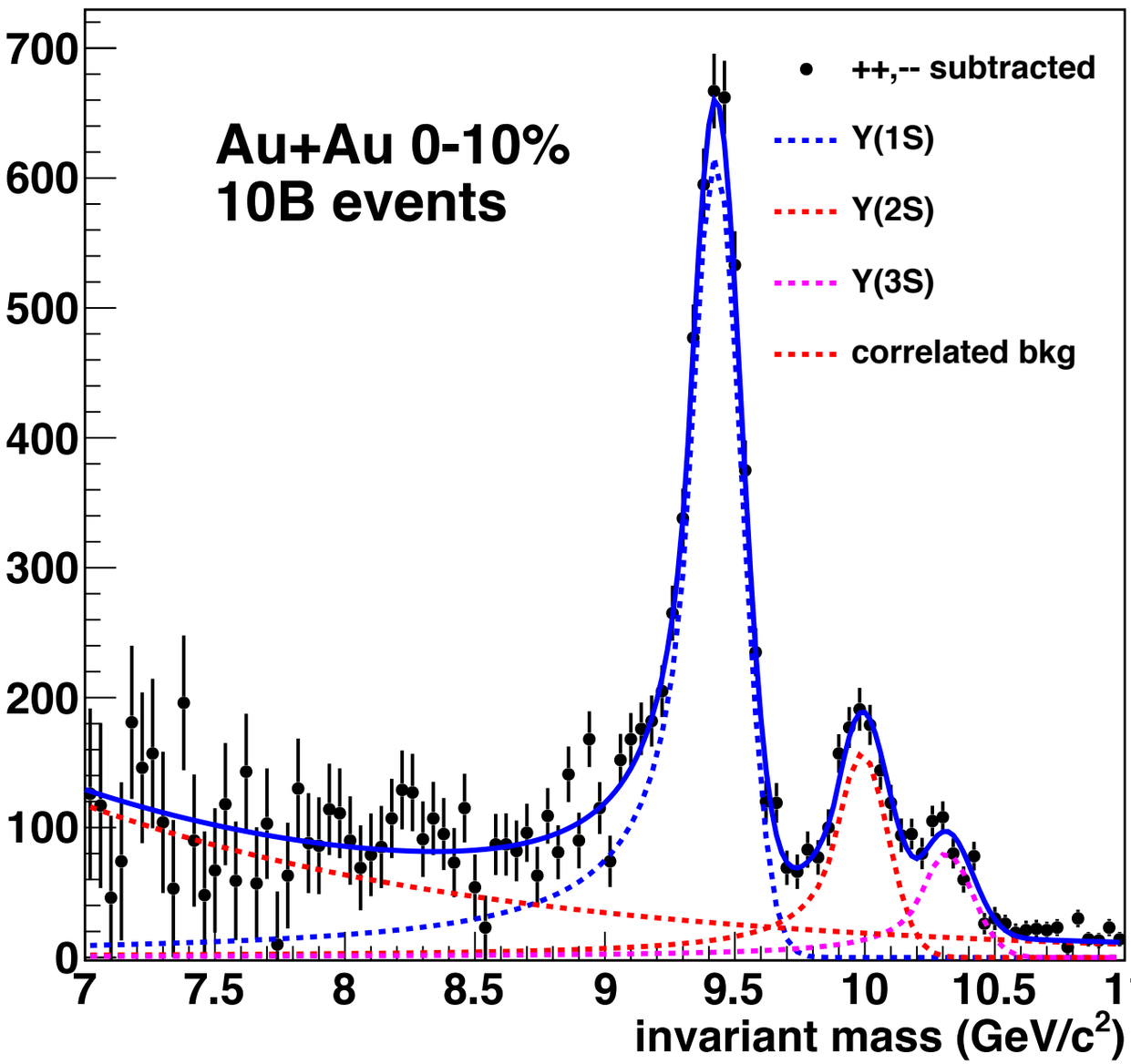
FULL TEXT:
HTTP://ARXIV.ORG/ABS/1501.06197

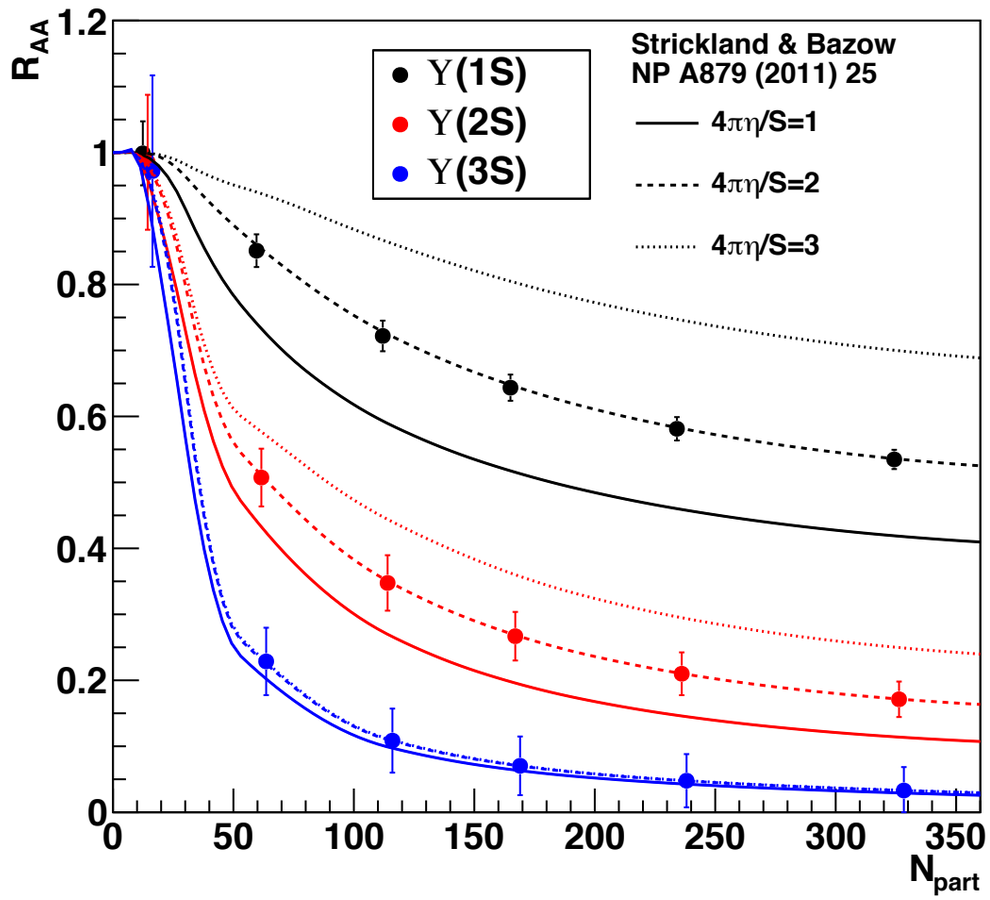


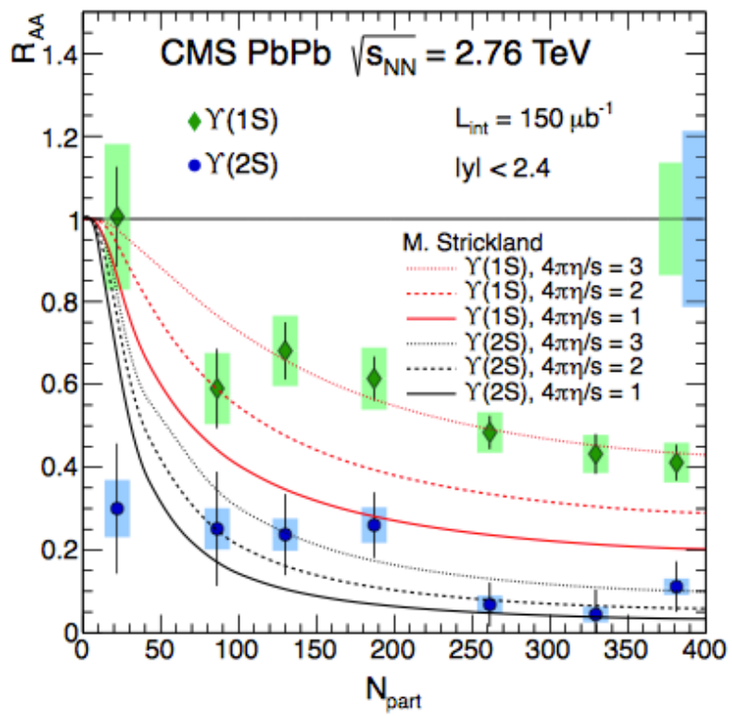
# Backup Slides

# Resolvable Upsilon states

Υ(1S,2S,3S)



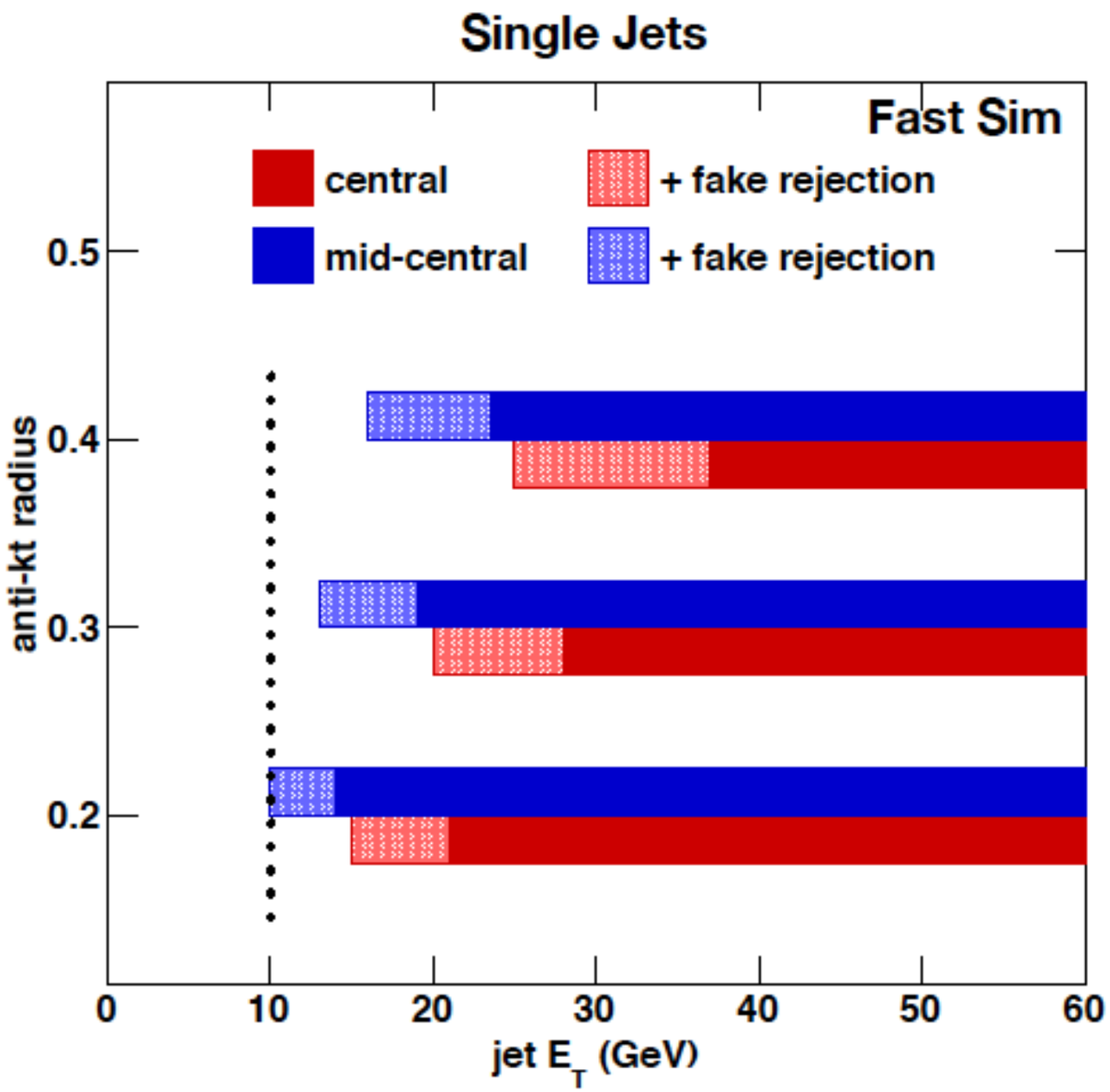



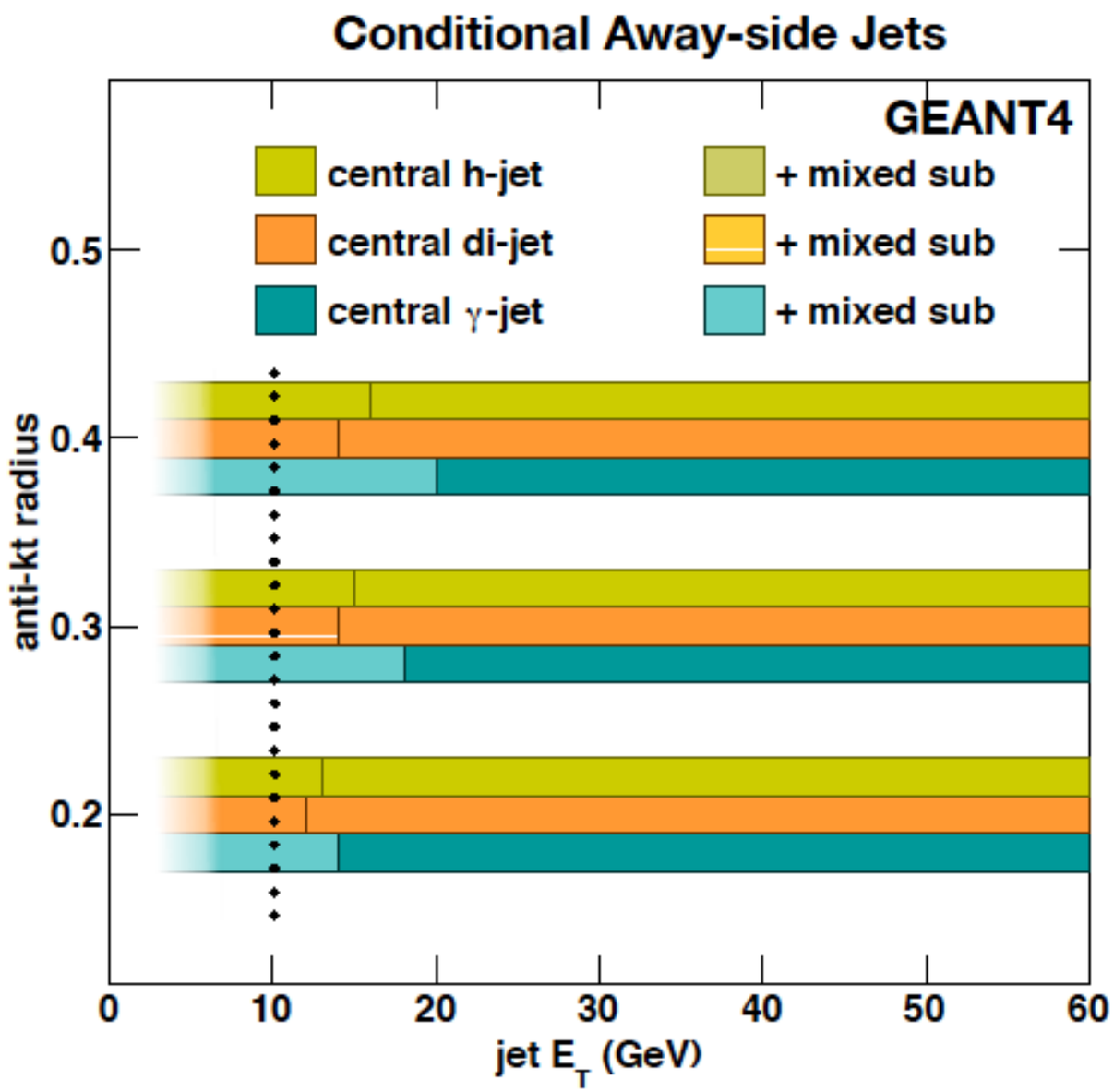

Tracking gives mass resolution of <100 MeV/$c^2$

Separation of all three states with "LHC" precision

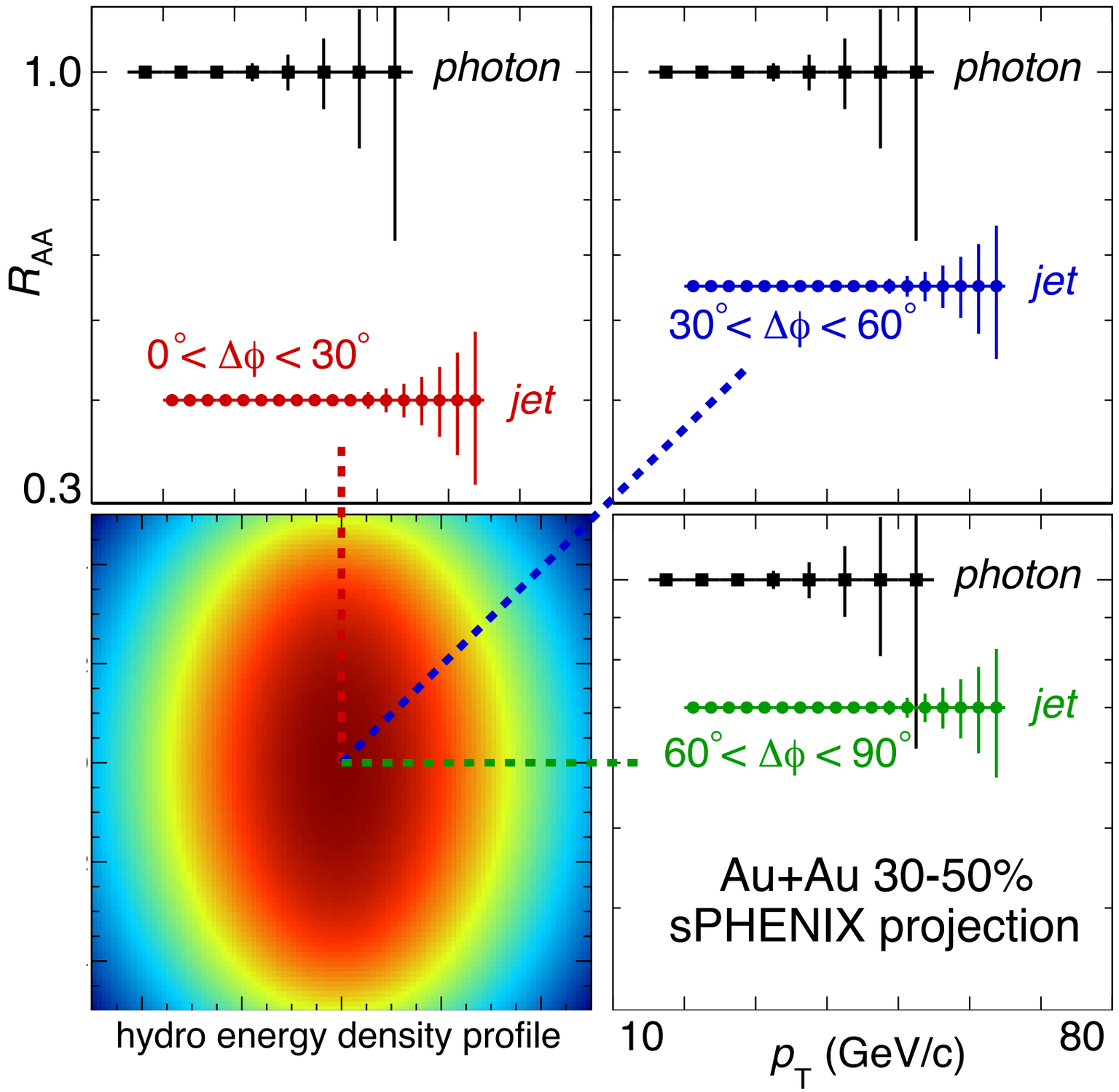
# Pushing down in $E_T$

## >90% Purity Limit Summary



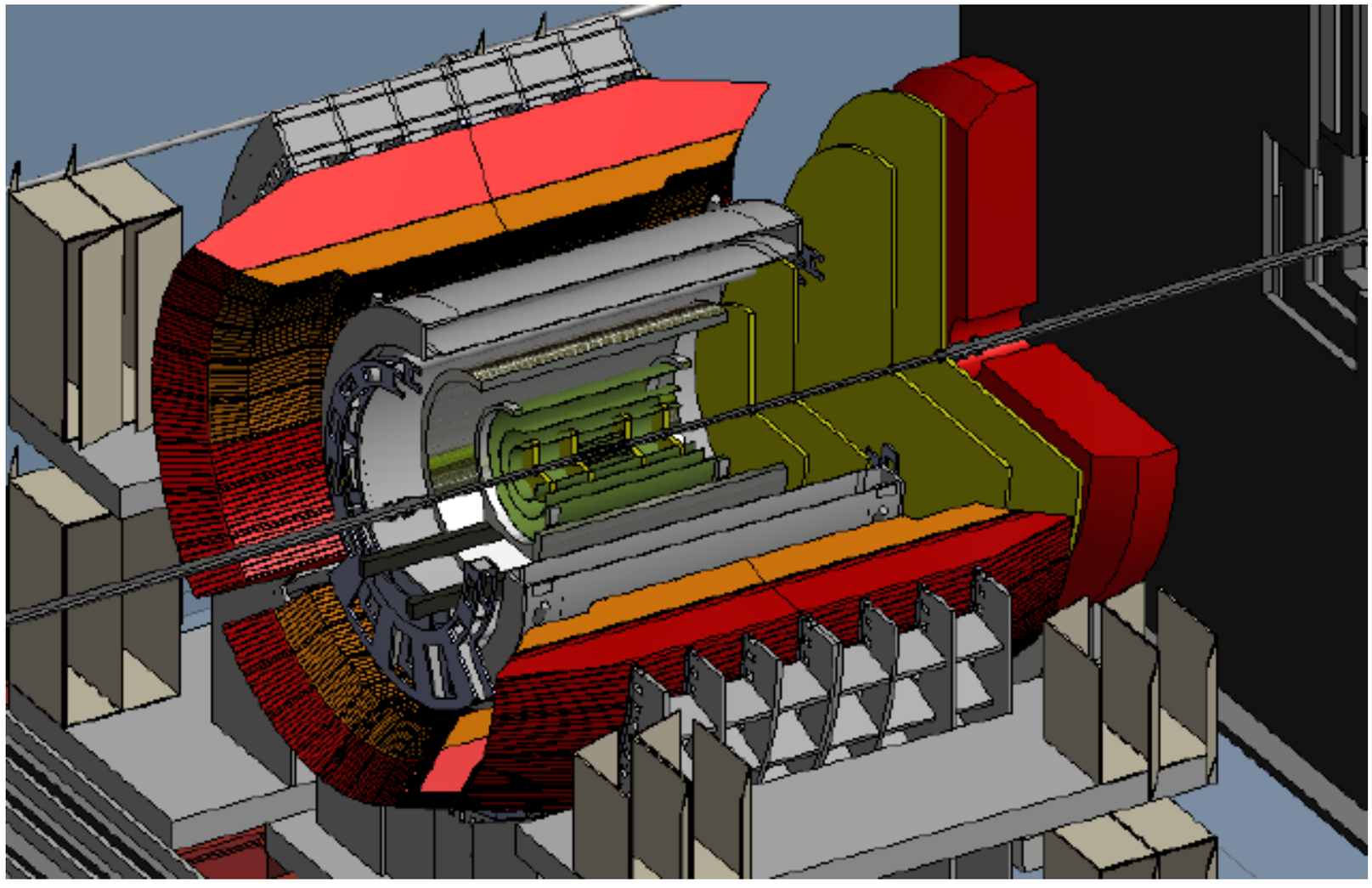



# Path length dependence



# FORWARD sPHENIX

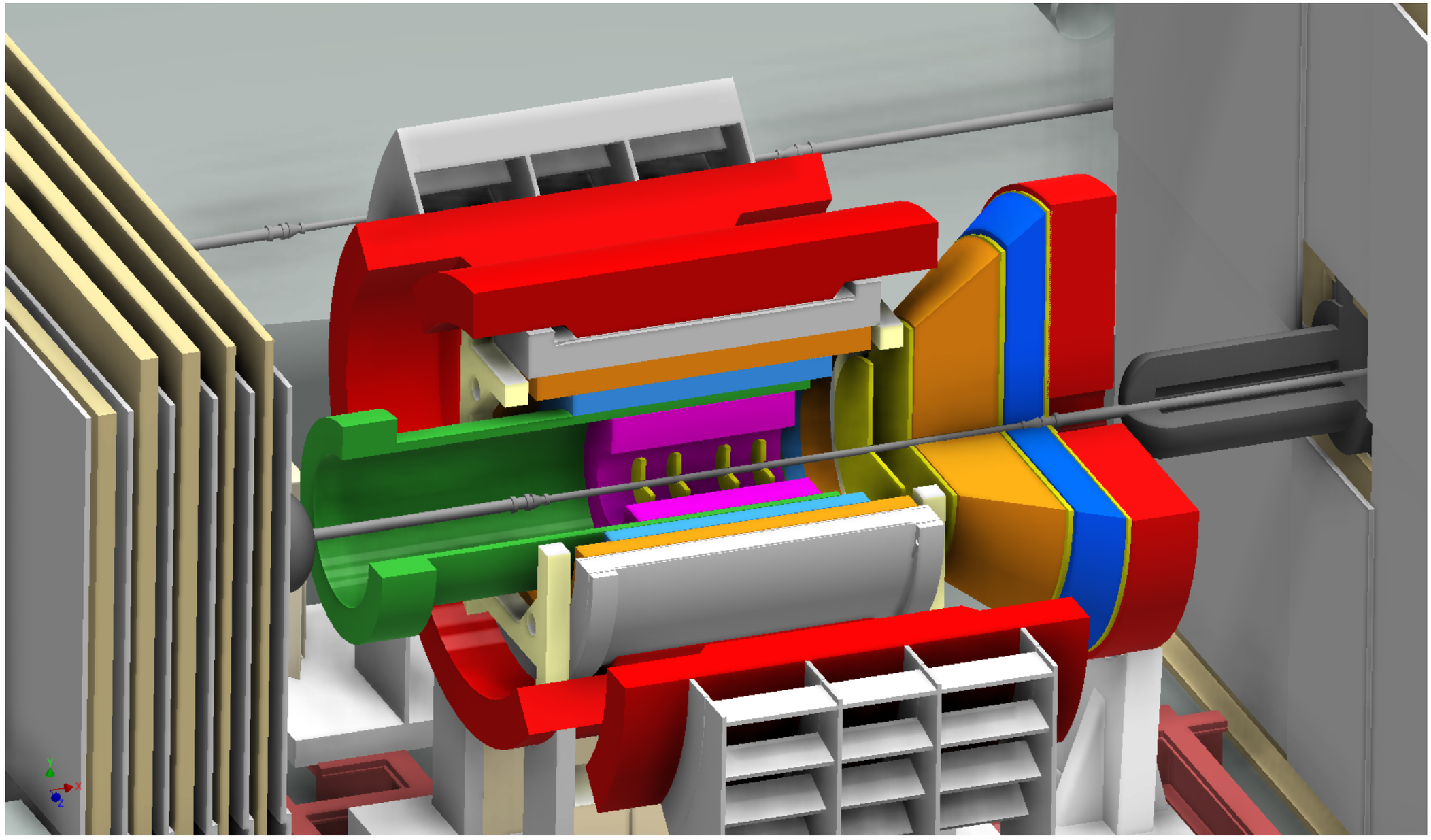
## EXPANDED SPIN-POLARIZED P+P AND P+A MEASUREMENTS WITH ADDITION OF FORWARD CALORIMETRY - IMPROVED JET ACCEPTANCE FOR HI



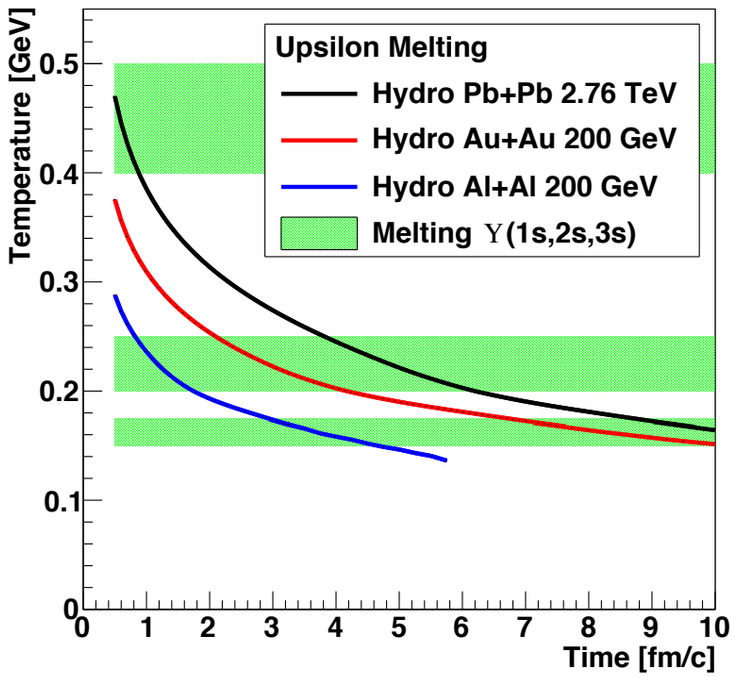
http://www.phenix.bnl.gov/phenix/WWW/publish/dave/sPHENIX/pp_pA_whitepaper.pdf

# An EIC detector

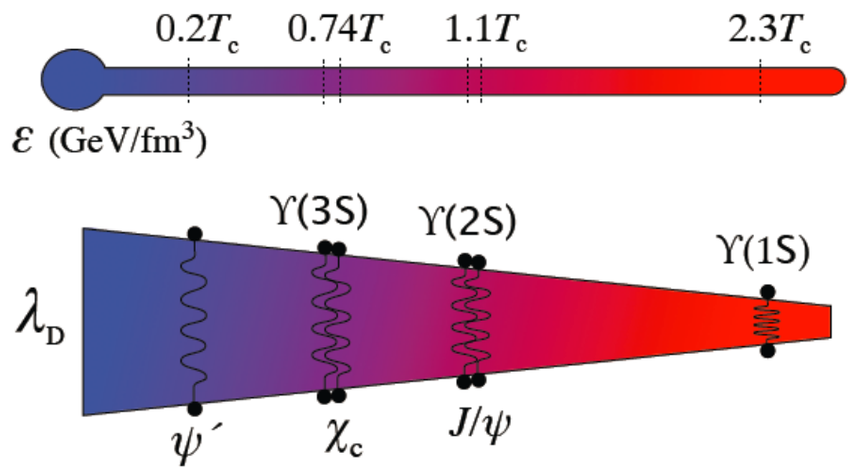
Make use of BaBar magnet and sPHENIX calorimetry
as first part of full EIC capable detector
w/added tracking/PID capabilities

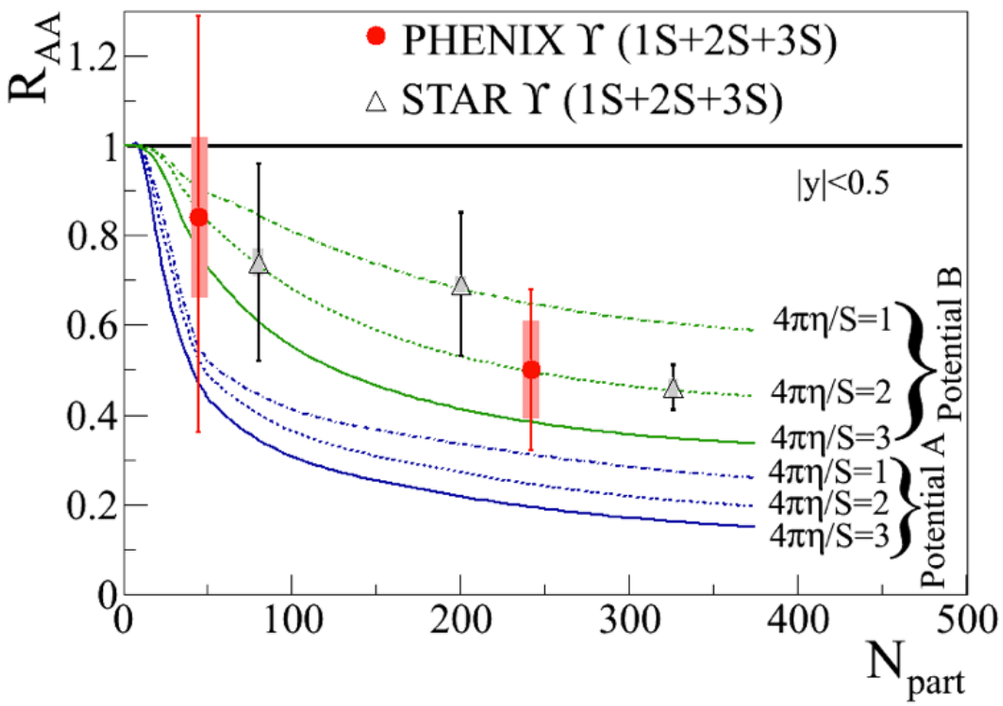


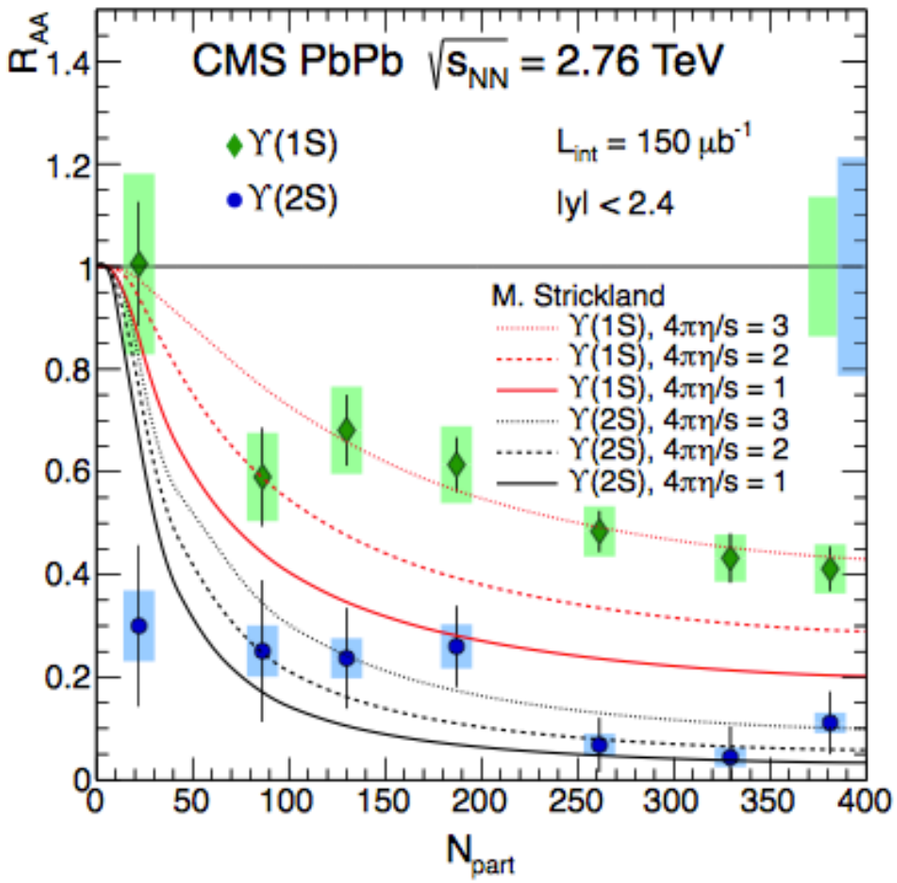
# Color screening



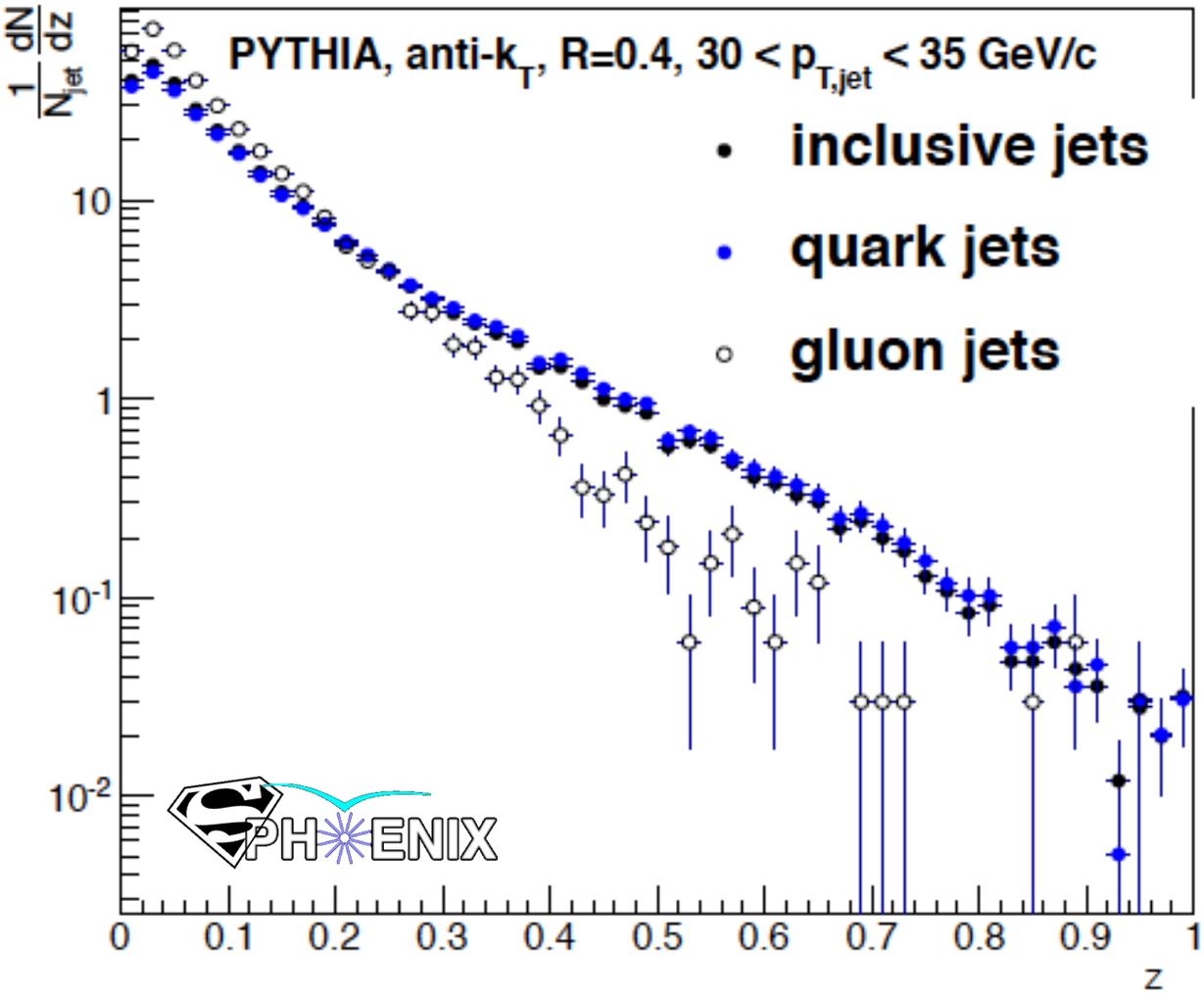

Differences in Temperature and rate -> differences in screening environment and coalescence effects

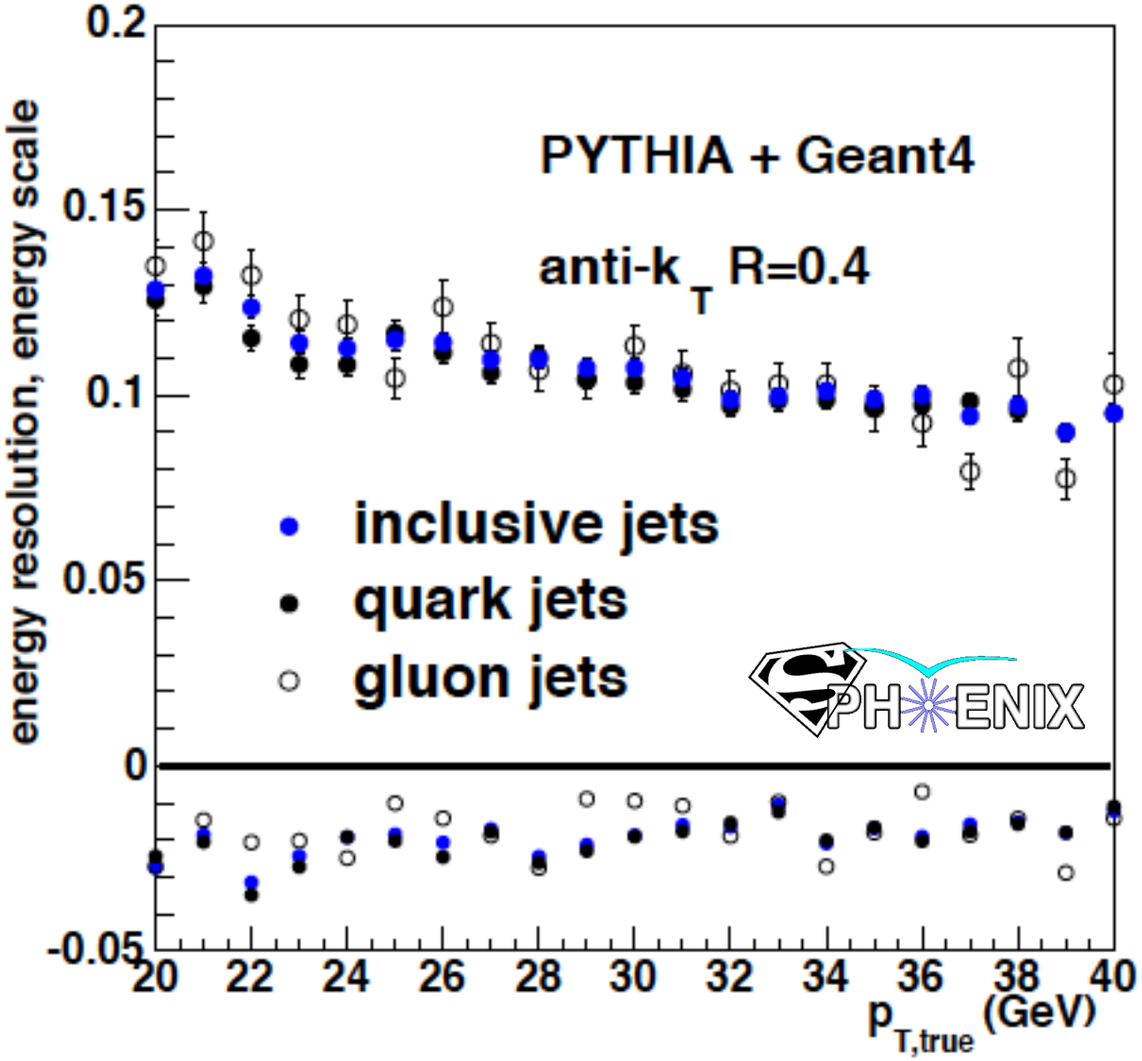


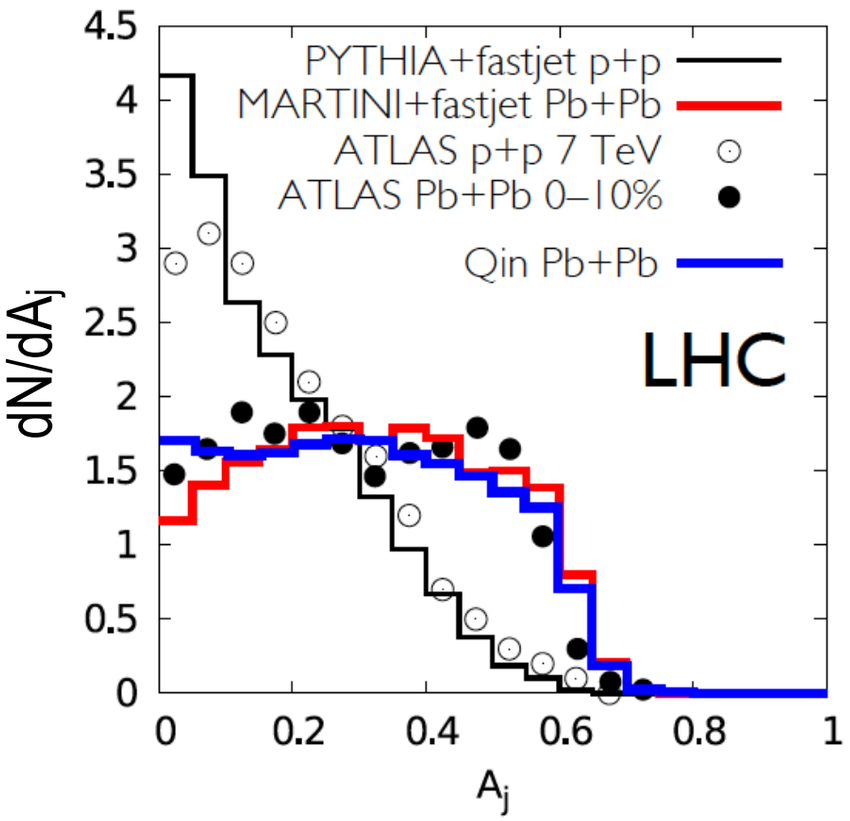
# Quark vs Gluon



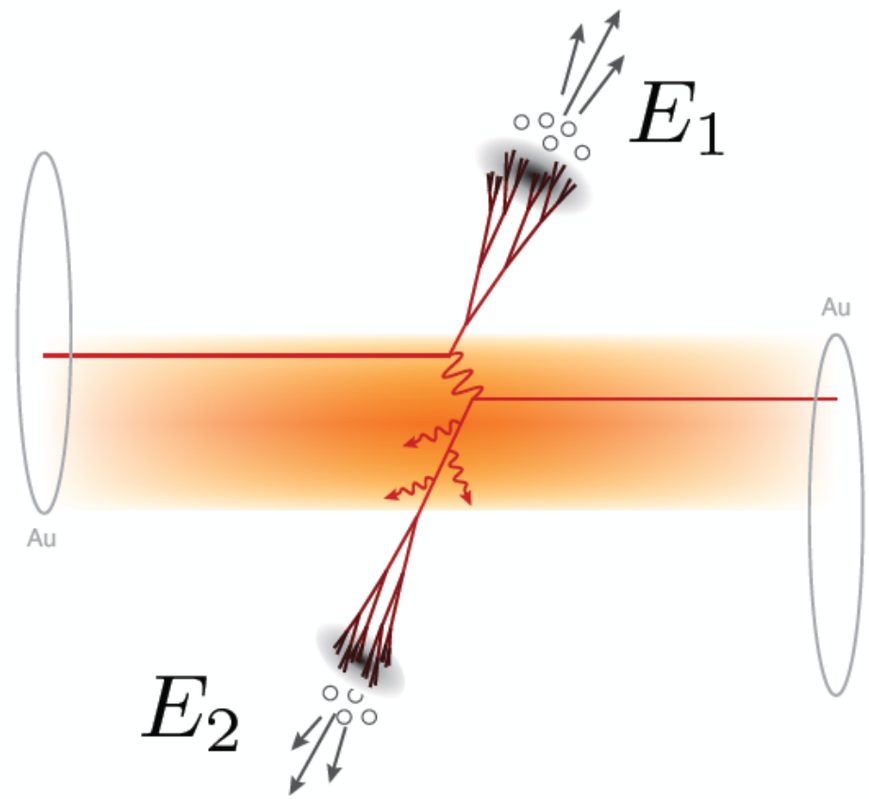




jet resolution similar for quark & gluon jets
gluon jets have softer FF (like a quenched jet)

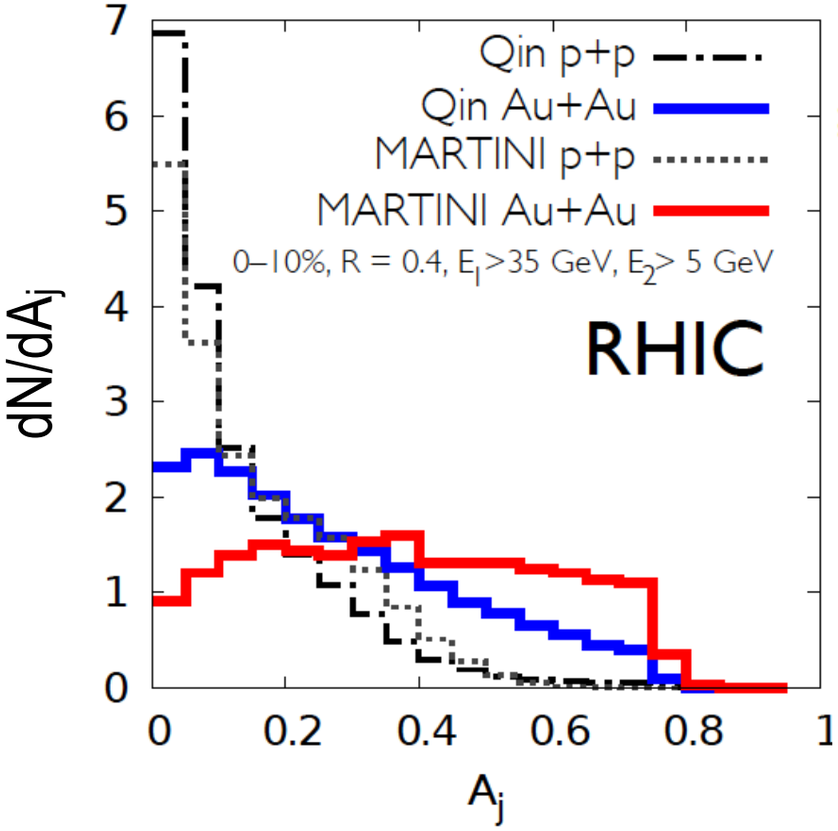
# Model Sensitivity

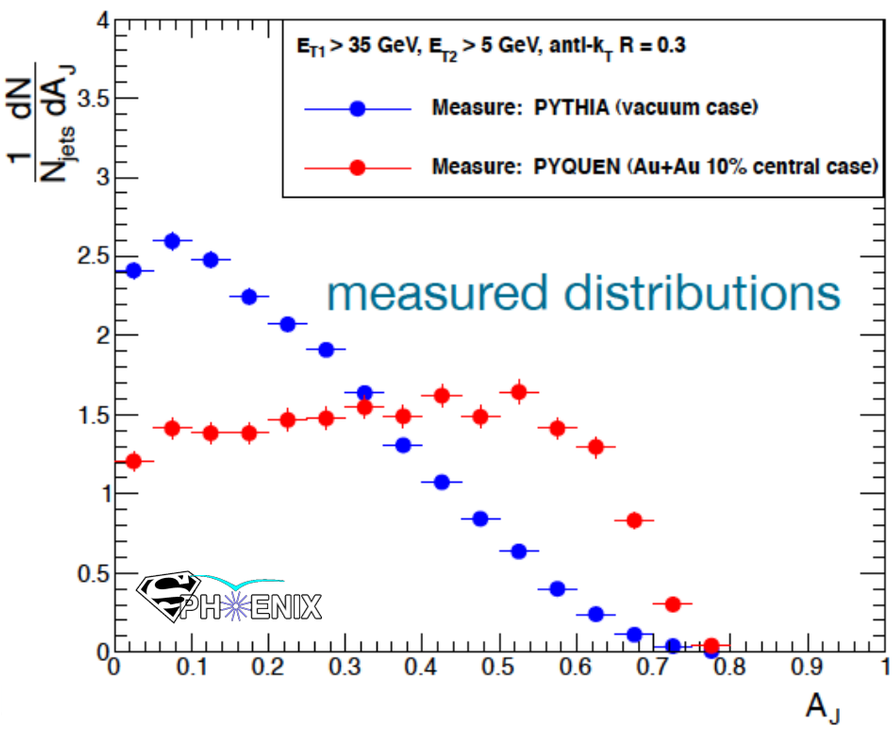


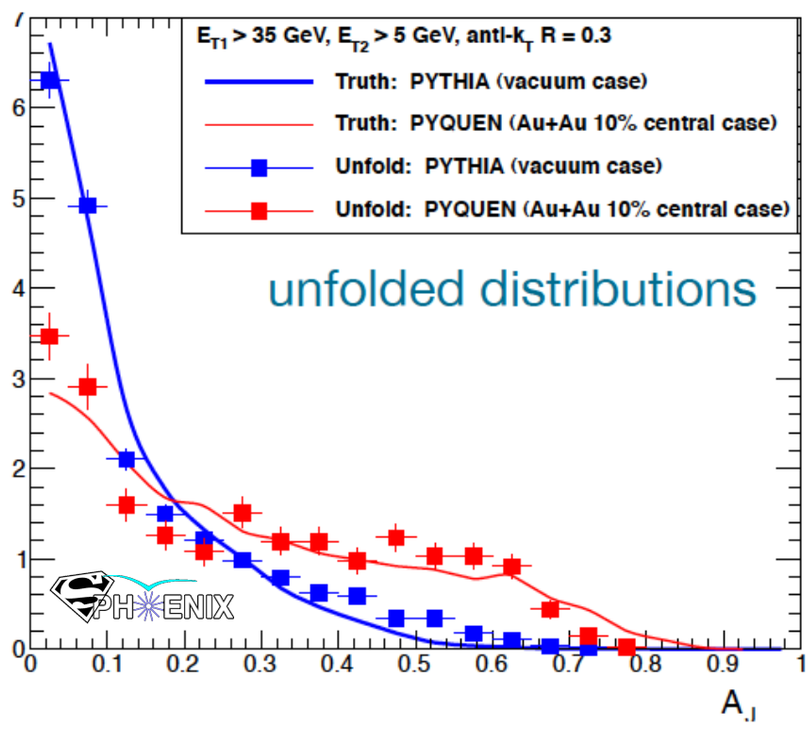

$$A_J = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$




## RESOLVABLE PYTHIA/PYQUEN DIFFERENCES

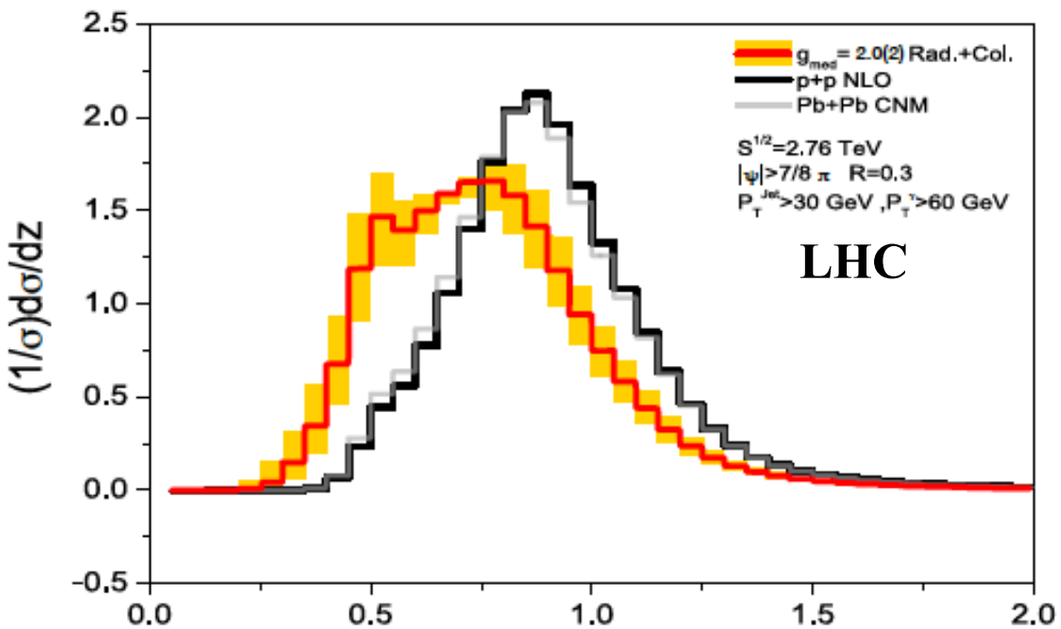


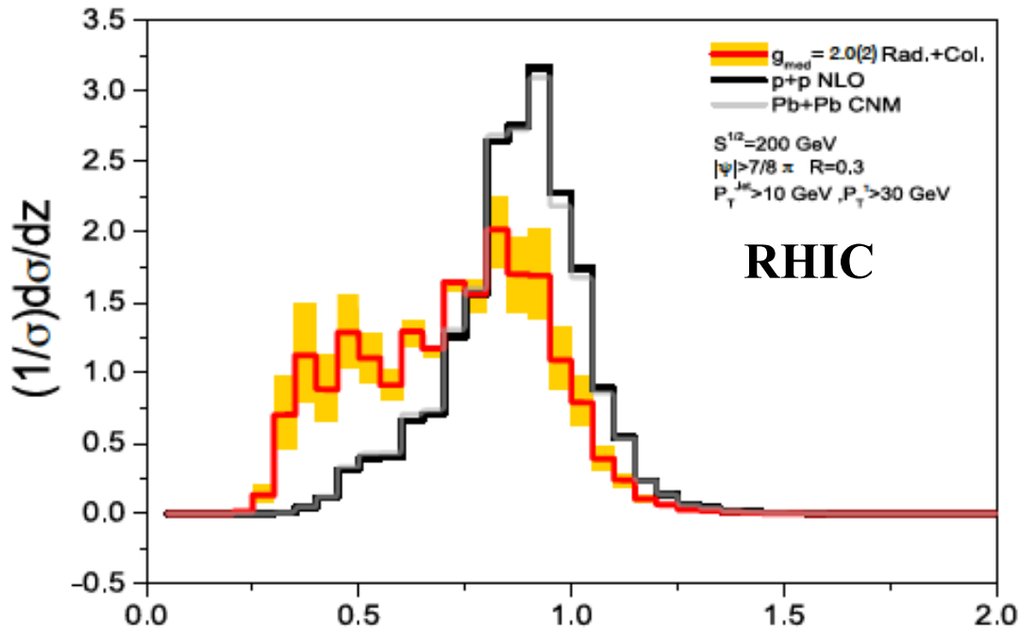



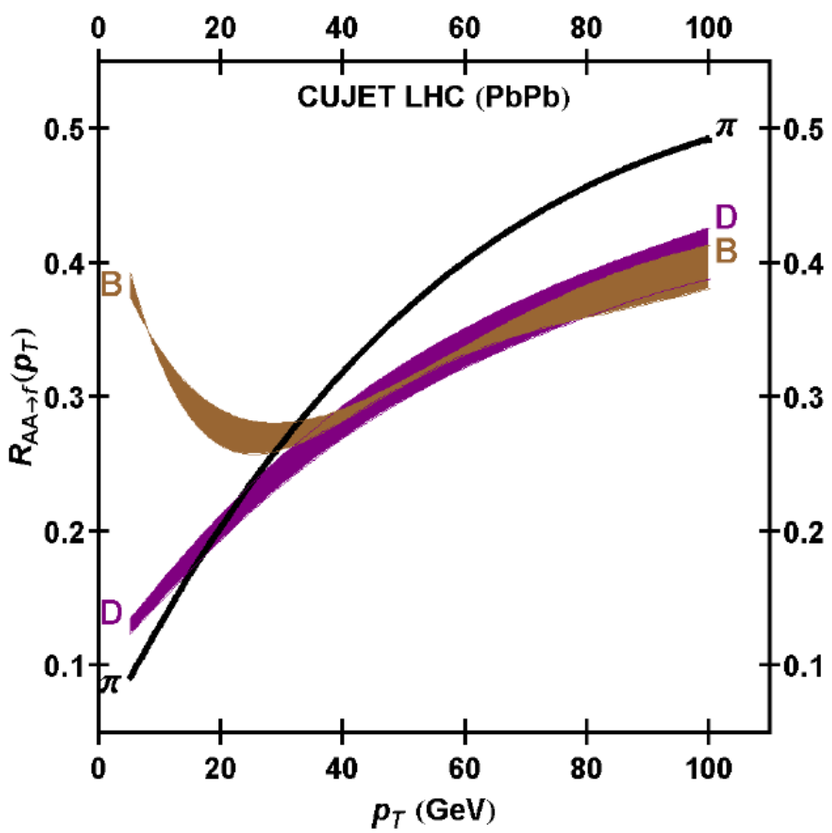



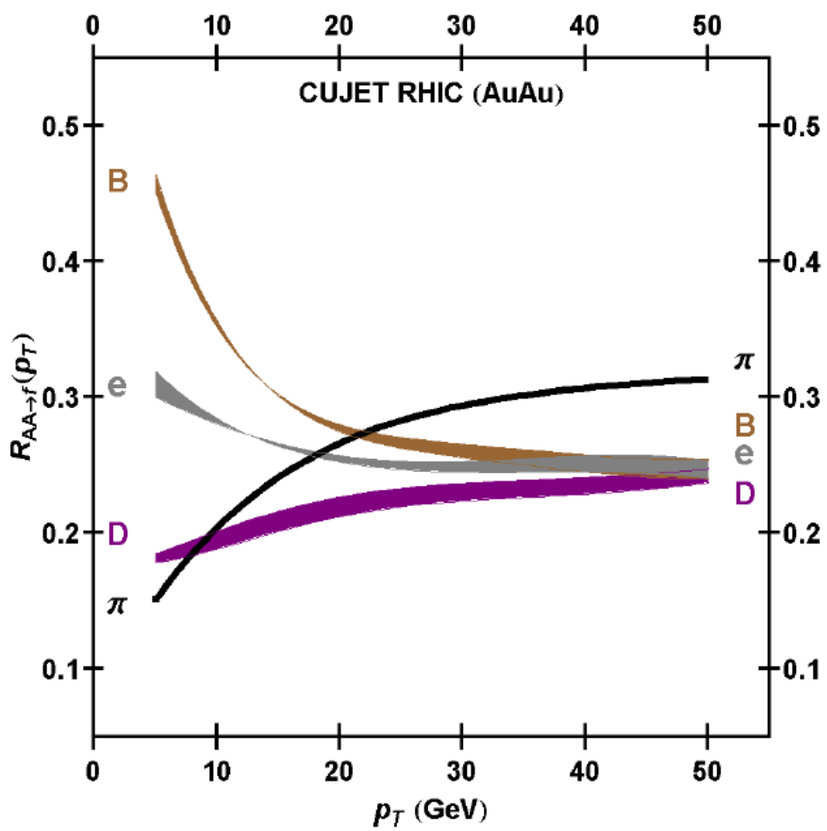
# Predicted RHIC vs LHC

## Many observables where greater sensitivity expected at RHIC

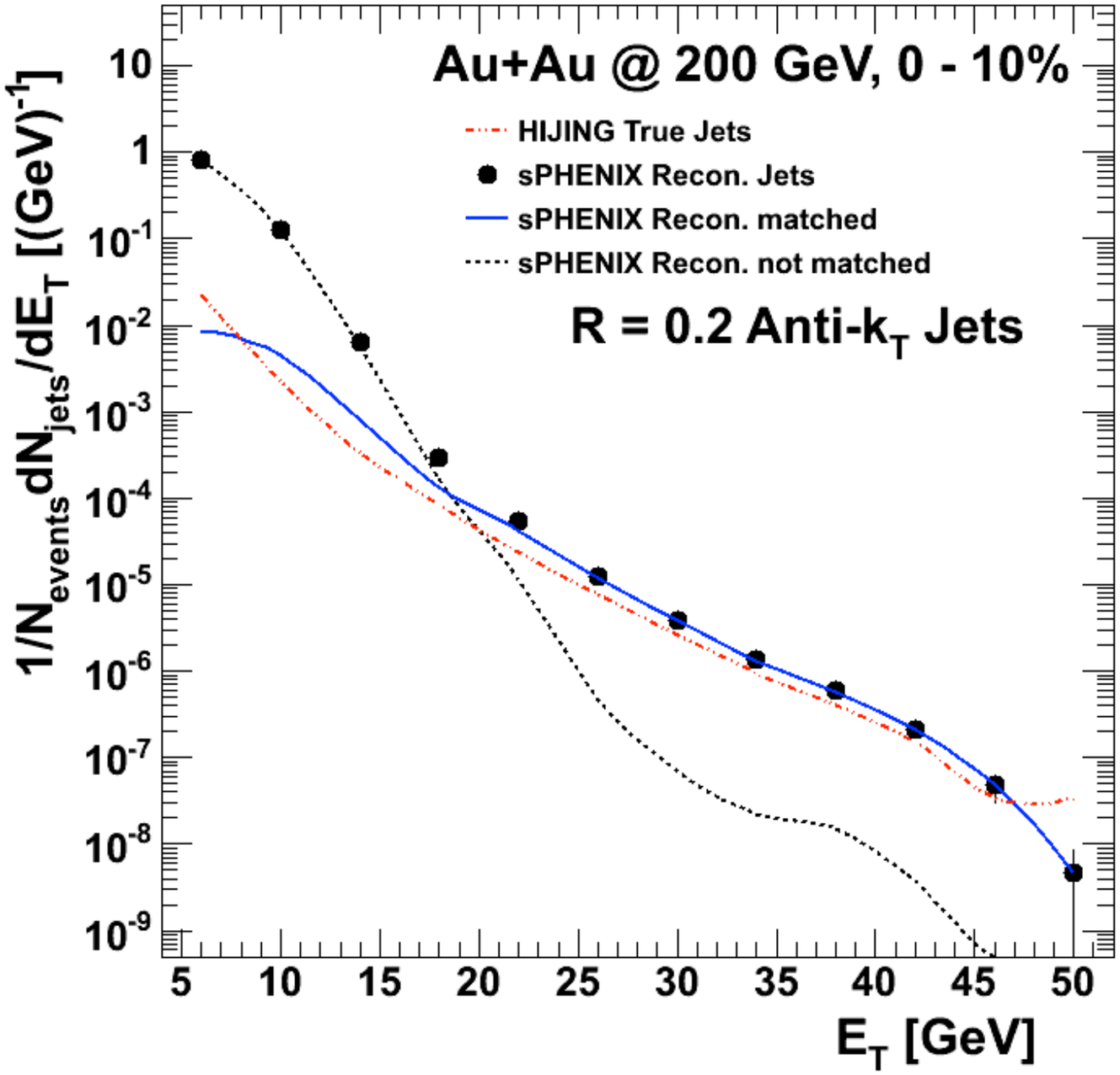


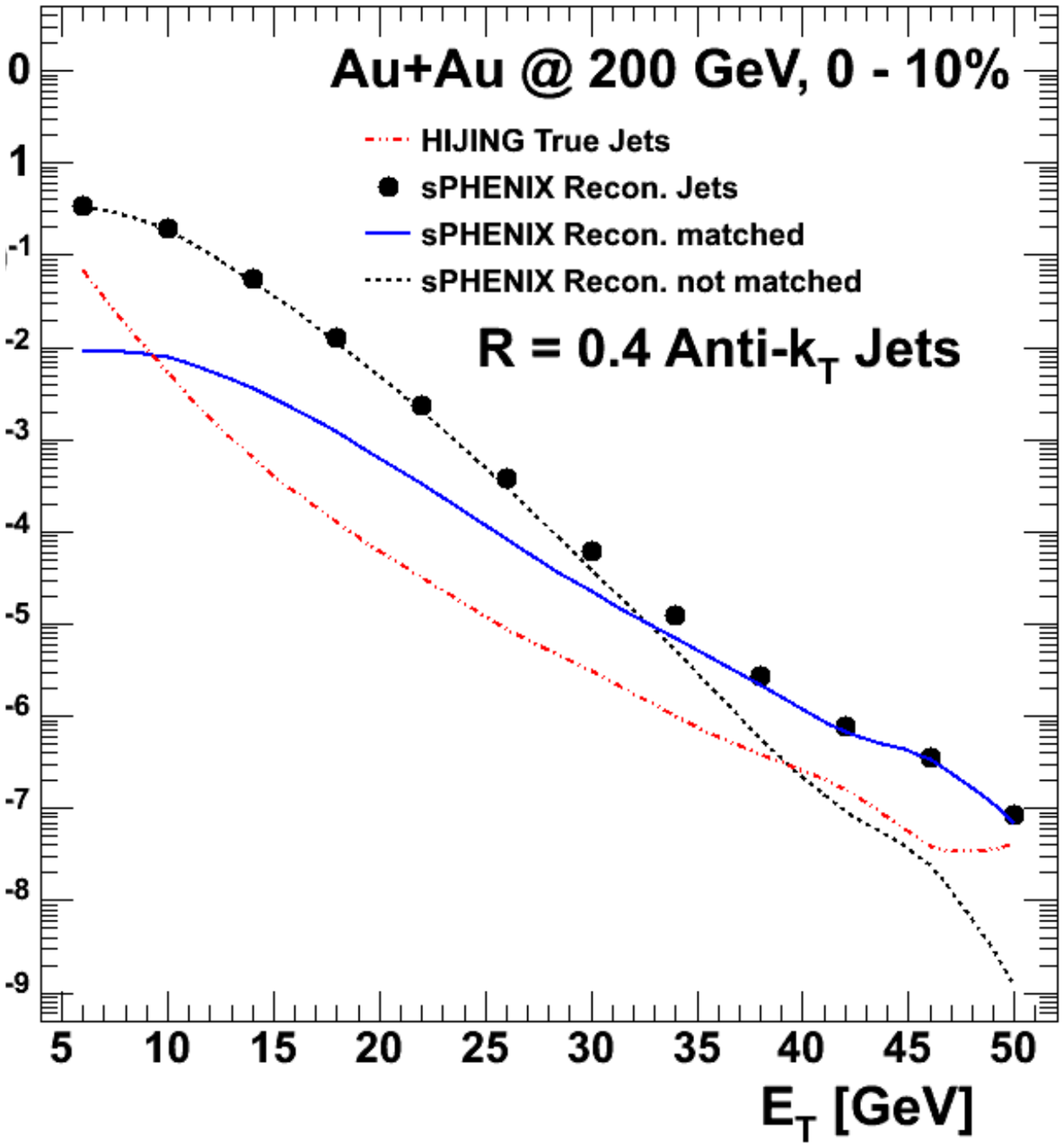
# MEASURING JETS IN HI EVENTS




SUBTRACT <UE>

RMS SMEARS JET – REQUIRE UNFOLDING

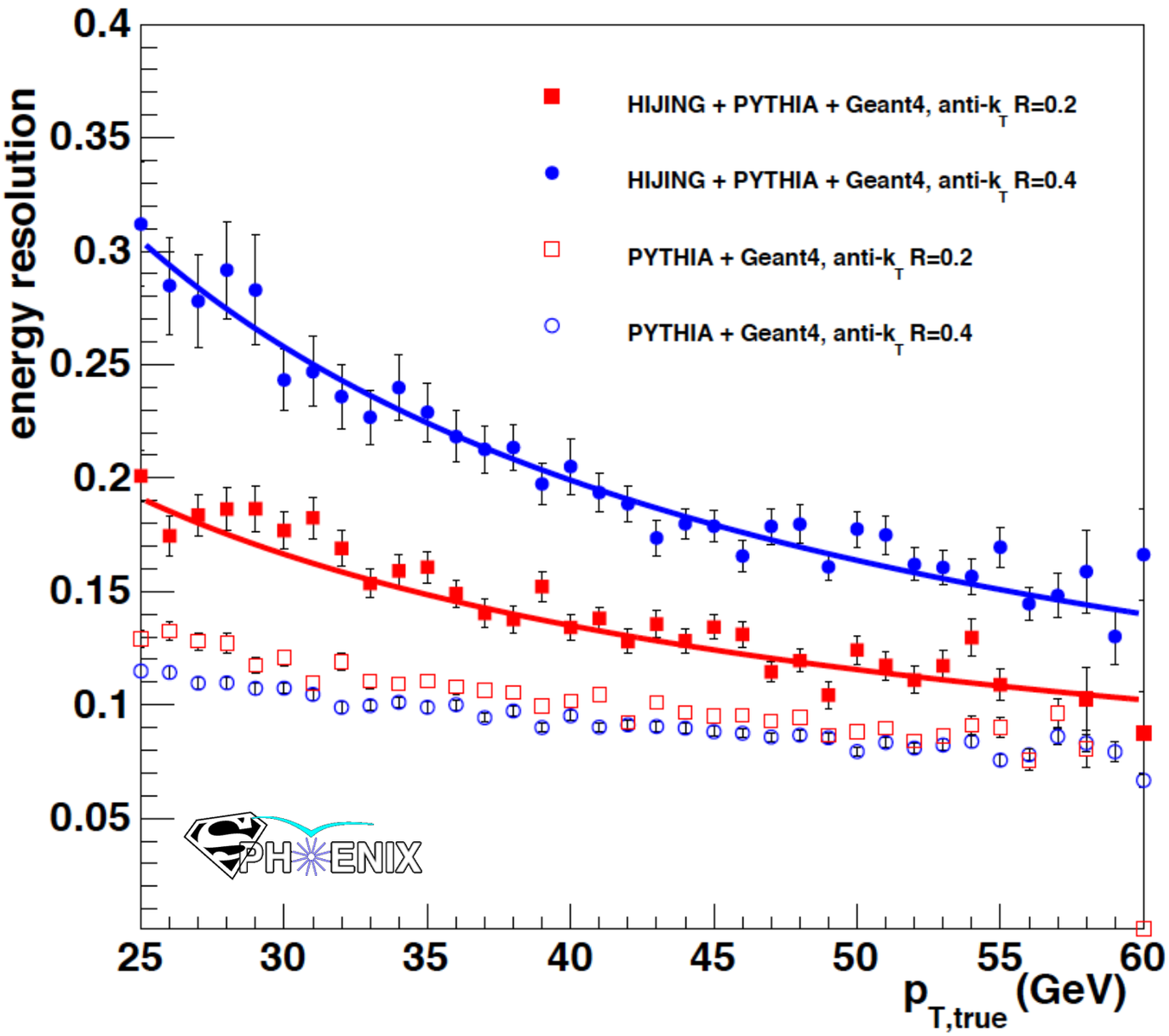
FLUCTUATIONS CAN LOOK LIKE JETS – FAKES

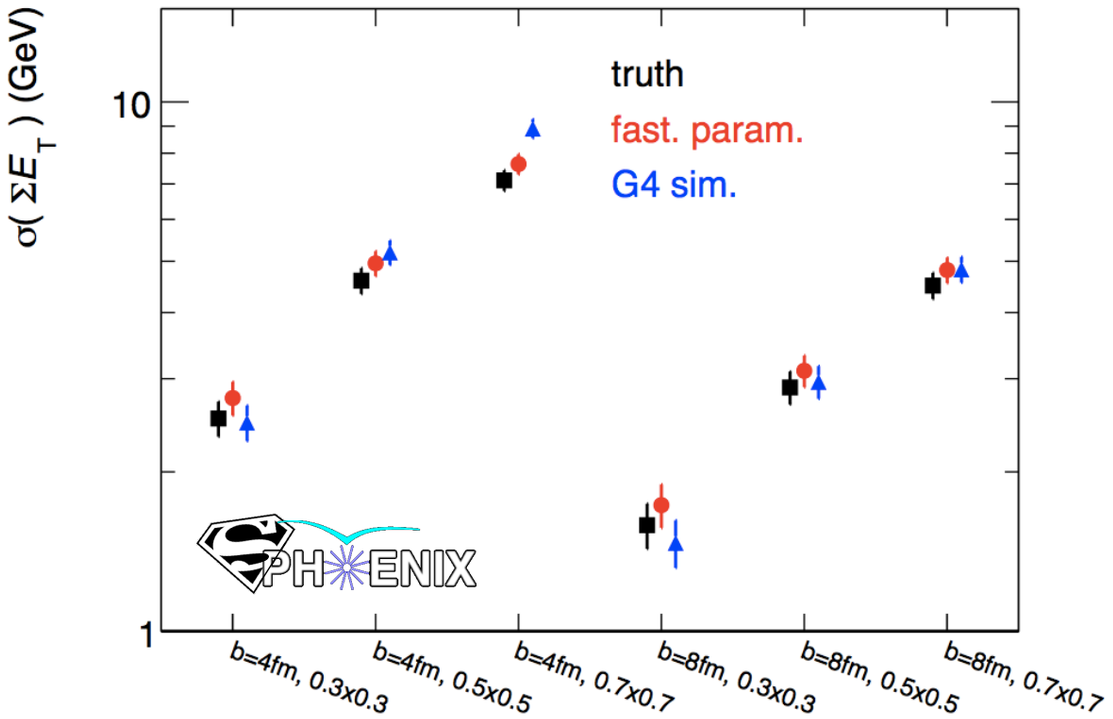


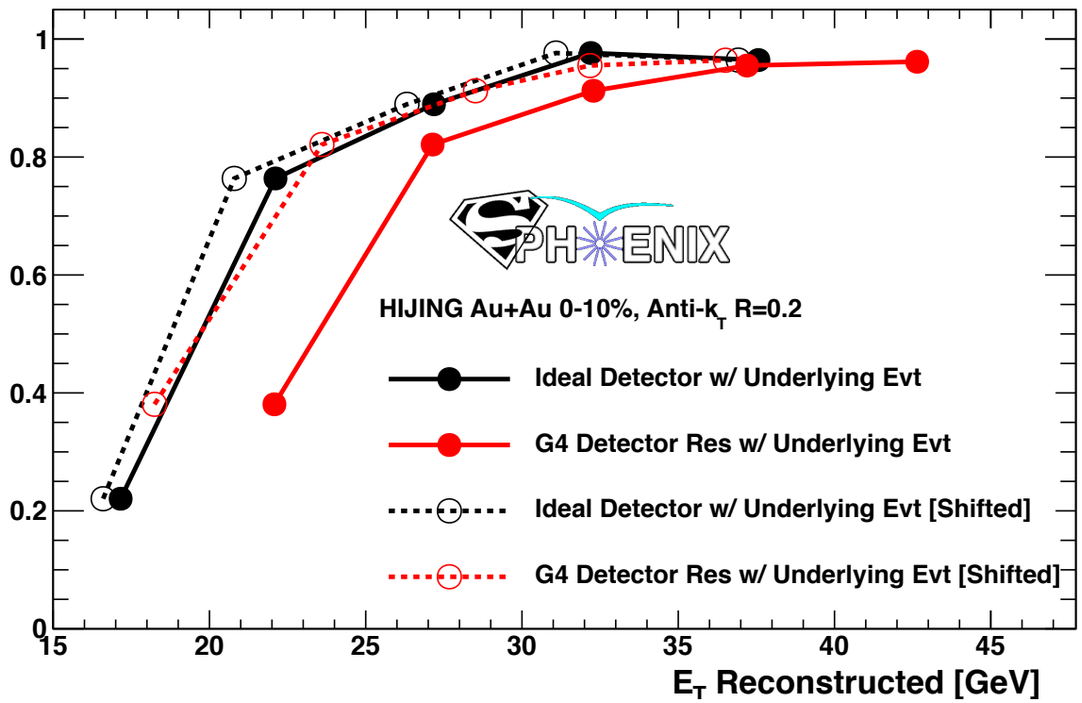

REAL JETS START TO DOMINATE ABOVE

~20 GEV (R=0.2) AND ~35 GEV (R=0.4)

# ADDING DETECTOR EFFECTS




RESOLUTIONS SUBSTANTIALLY BETTER THAN REQUIRED

LARGELY RECOVER INITIAL PURITY AFTER UNFOLDING

Run jet reco (anti-$k_T$) algorithm on 0.1x0.1 calorimeter cells

Determine set of R=0.2 seed jets

**1st pass:** towers in jet satisfy $\frac{E_{T,max}}{< E_T >} > 3$

**2nd pass:** jet $E_T > 20$

inspired by ATLAS

Determine $v_2$ for event

- exclude towers within $\Delta\eta < 0.4$ of seed jet

Determine background $E_T$ in $\eta$ strips

- demodulate by $v_2$
- exclude towers within $\Delta R < 0.4$ of seed jet

Subtract background from jets tower-by-tower

- first remodulate background by $v_2$

Subtract background from event tower-by-tower

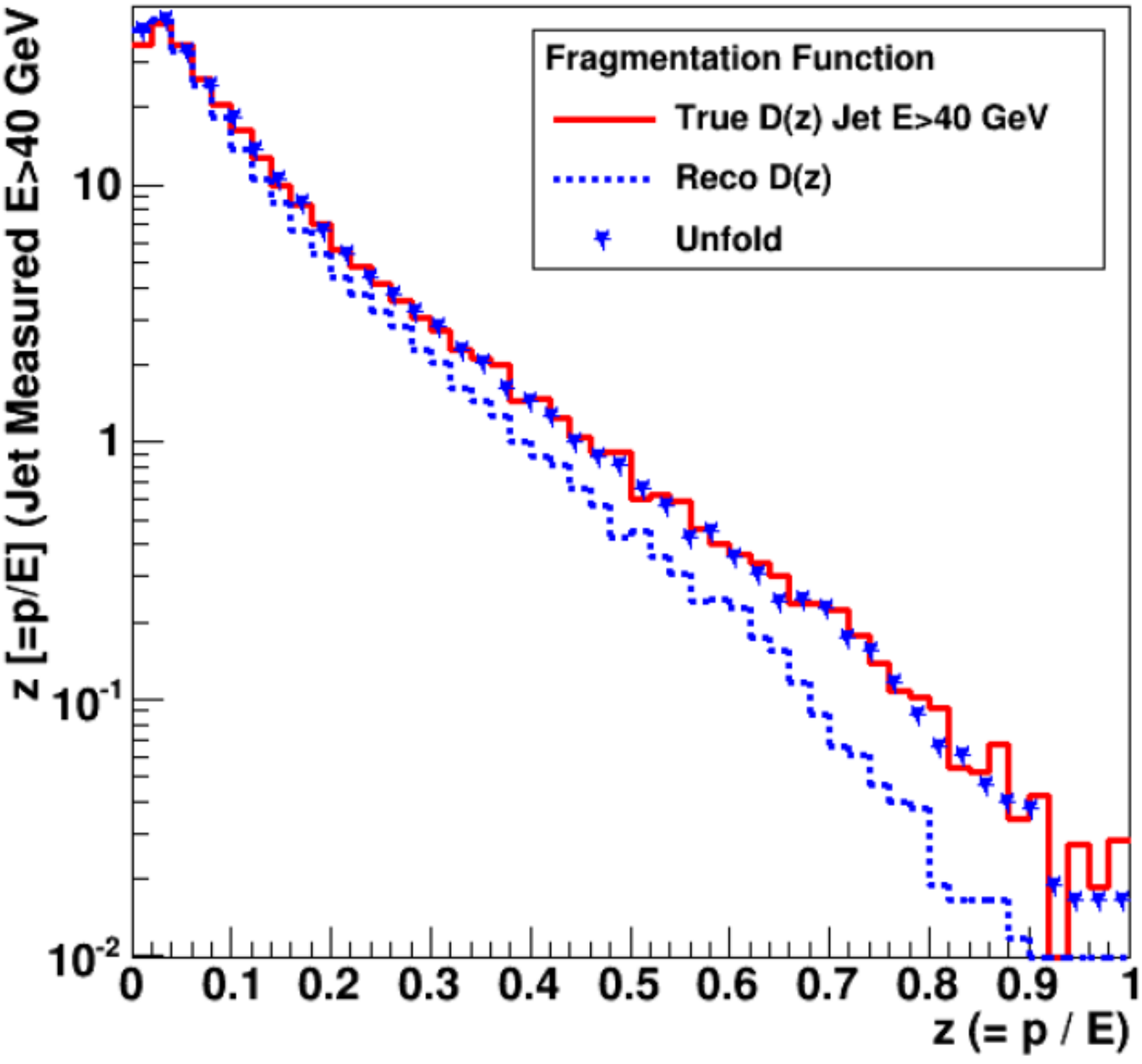
- first remodulate background by $v_2$

Run jet reco algorithm

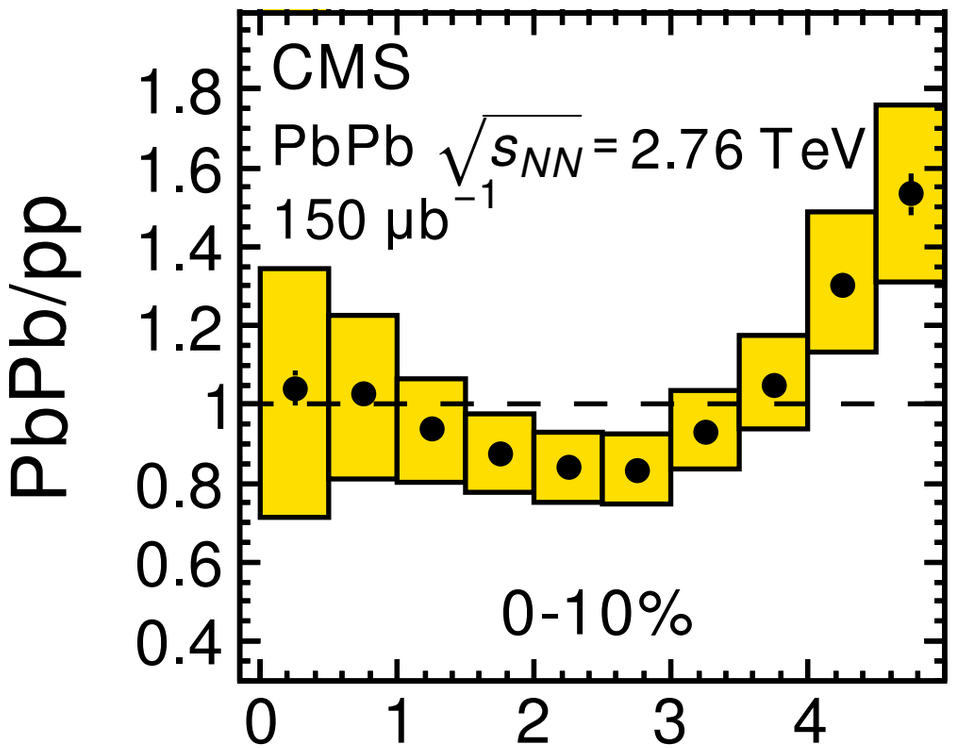
Output: background subtracted reco jets of various R values

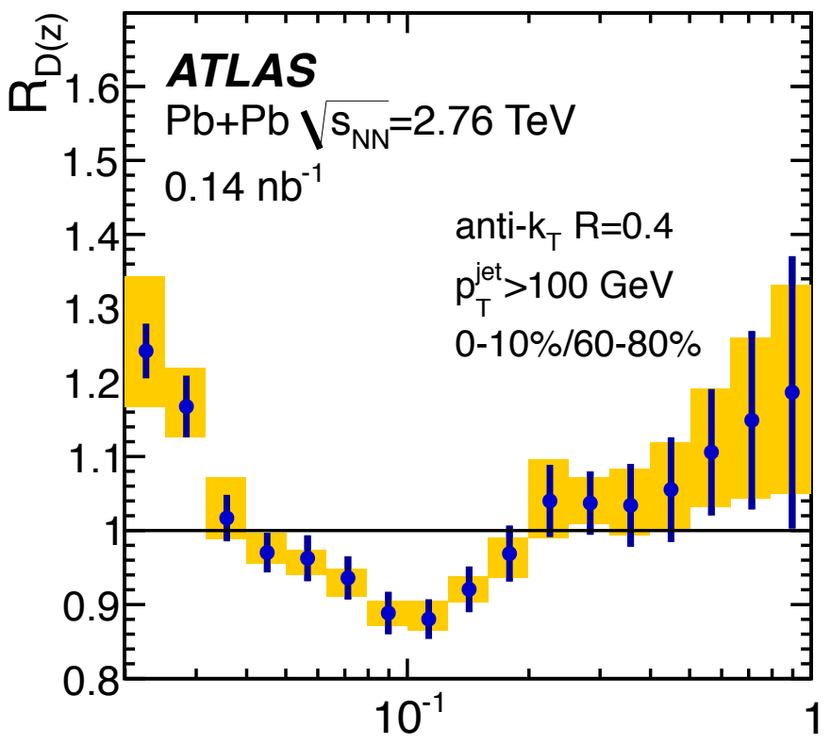
$V_2$ MODULATION ADDED TO **HIJING** EVENTS AND REMOVED BY ALGORITHM

# Fragmentation Function Details

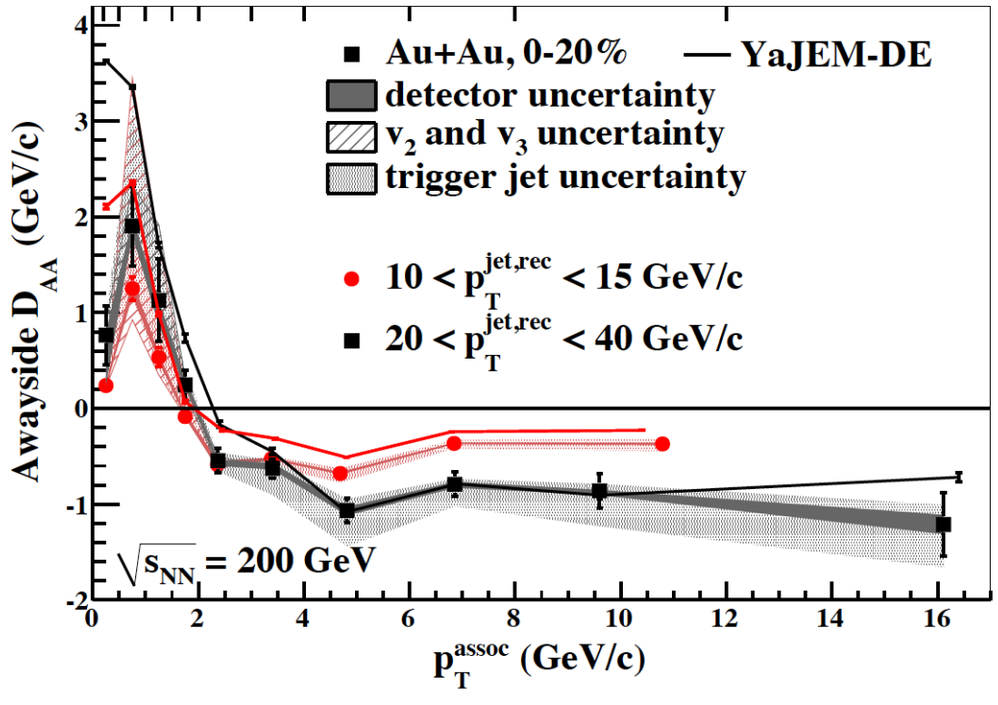


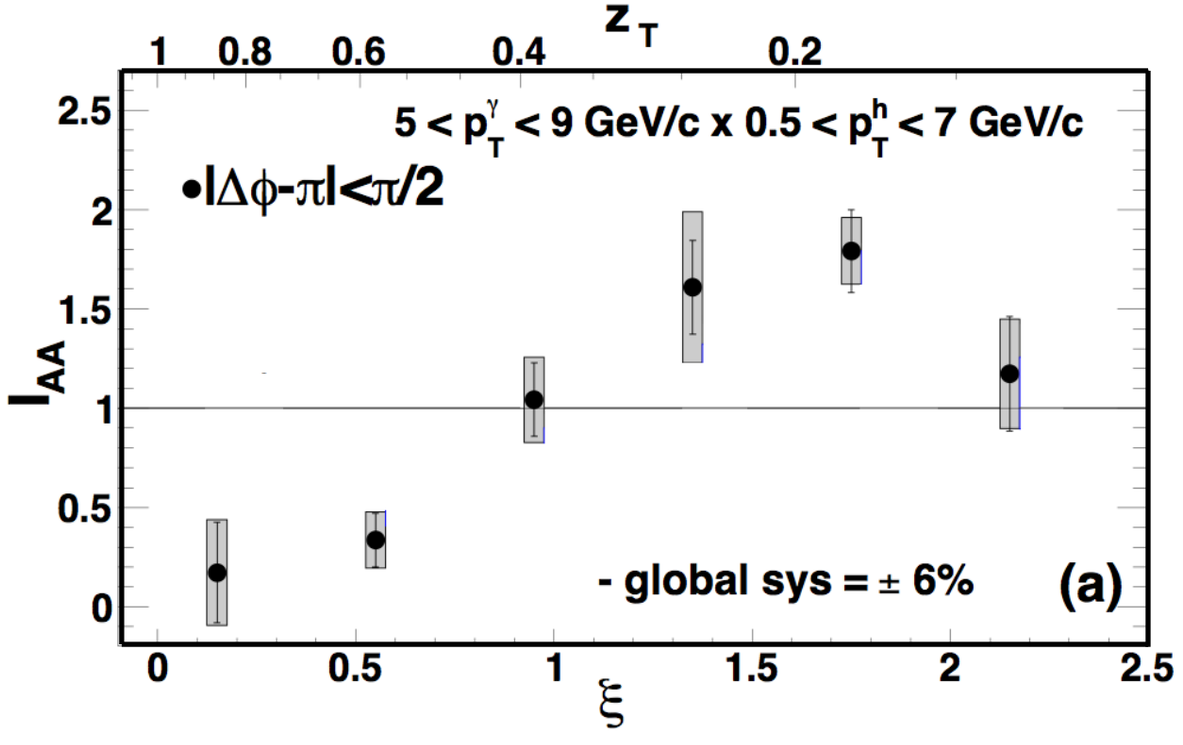
# Jet fragmentation




$\xi = \ln(1/z)$

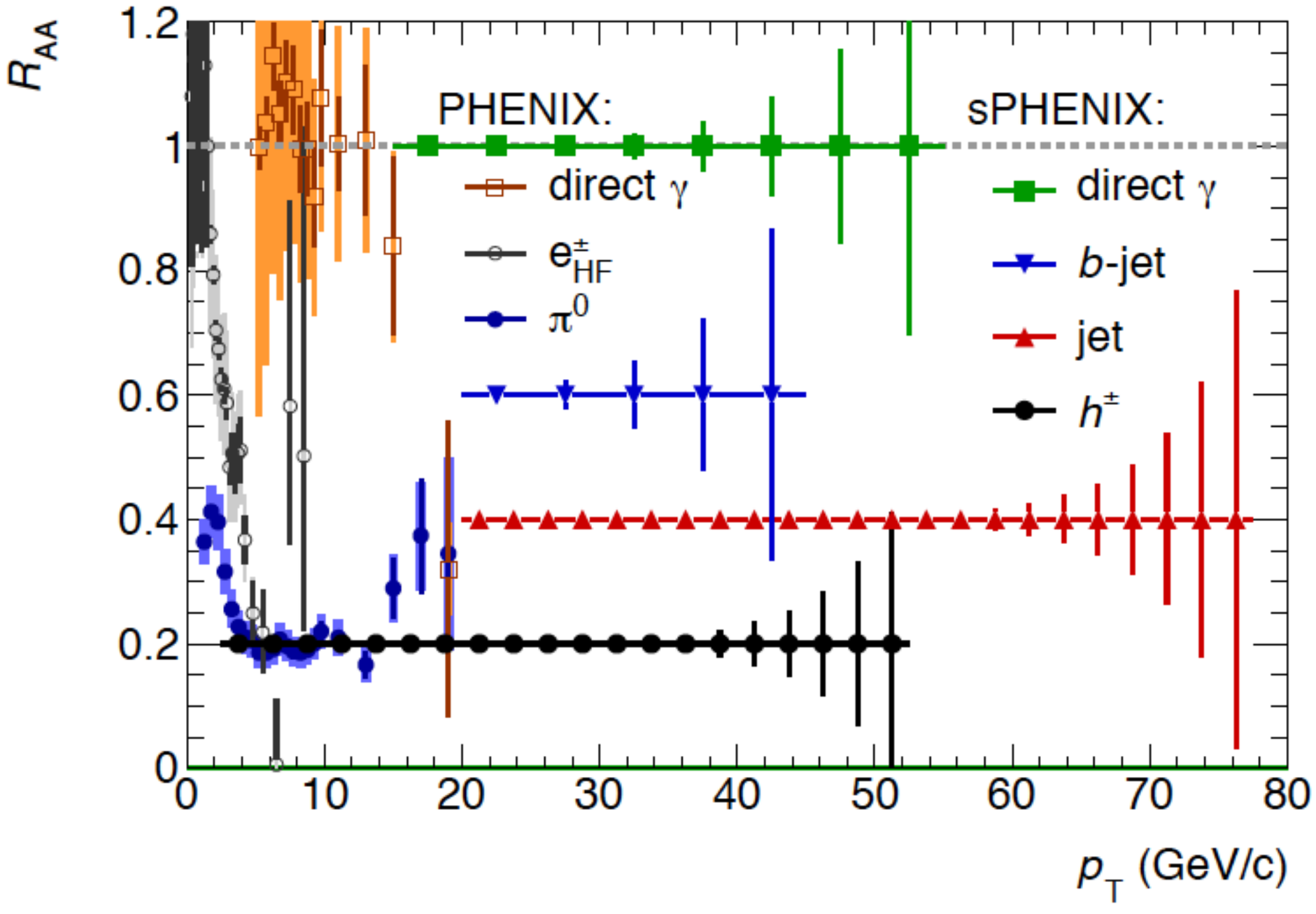



Qualitatively similar effects

Not directly comparable measurements

# KINEMATIC REACH



# The BaBar magnet has arrived!


Left SLAC Jan. 16th

Arrived at BNL Feb. 4th

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