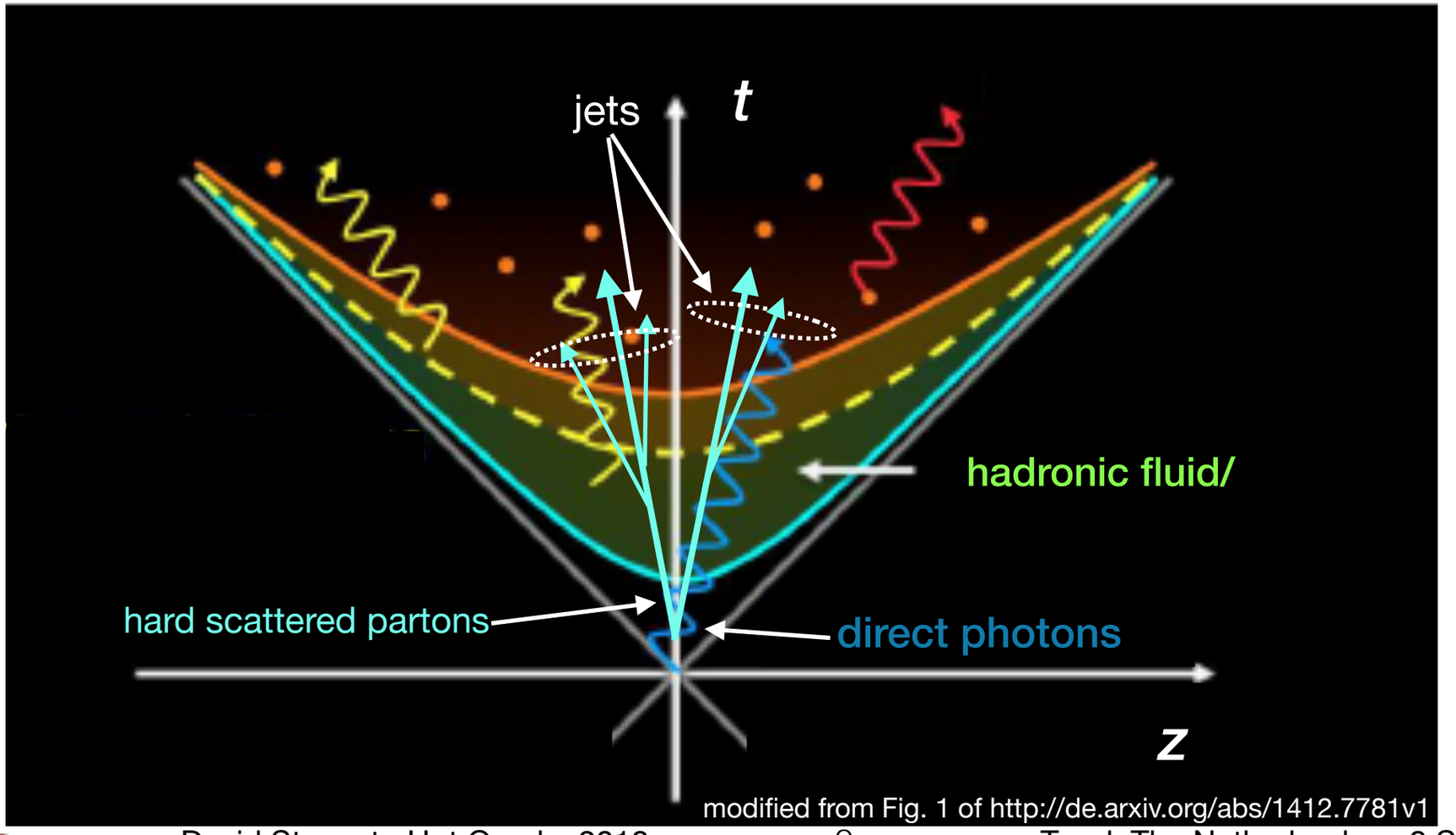
Event activity measurements and mid-rapidity correlations in 200 GeV *p*+Au collisions at STAR

David Stewart for the STAR Collaboration

Hot Quarks 2018

intro: jets

- Jets: algorithmically clustered final constituents of a collision
- Hard scattering of partons occur early in collision and subsequently may interact with the medium.
  ⇒ final state particles are algorithmically combined into jets
  ⇒ anti-k_T algorithm is common because of (a) infrared and (b) collinear safety; i.e. stability in shape and p_T in the face of (a) soft particles and (b) splitting of hard tracks
- Used to probe existence and properties of QGP



modified from Fig. 1 of http://de.arxiv.org/abs/1412.7781v1

intro: jet yield as an observable

$$\mathrm{d}^2N_{jet}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta$$

inclusive:

A + A → *jet* + …

semi-inclusive:

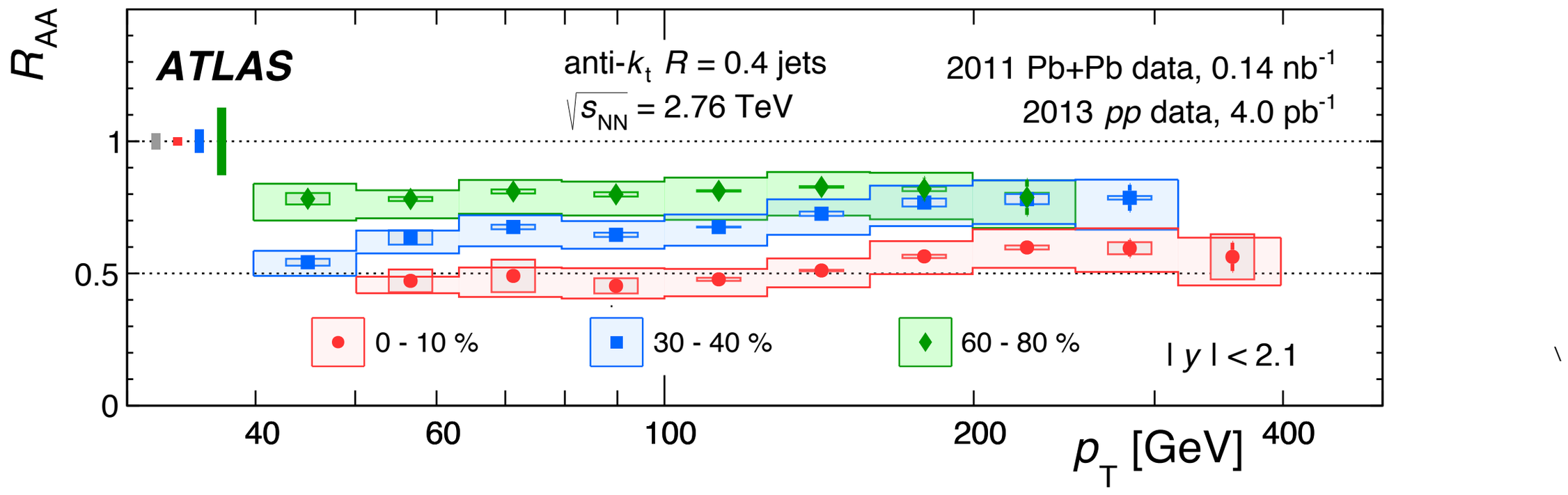
(trigger + jet correlations)

A + A → *trigger* + *jet* + …

Suppression of both inclusive and semi-inclusive jet yields are primary signatures of a QGP

"Wait! Jet yields suppressed compared to what?"

- "p+p collisions"
- Glauber models generate scaling factors N_{coll} by which p+p jet spectra can be scaled to "equivalent" A+A collisions
- (A+A spectra) / (scaled p+p spectra) ≡ R_{AA}
- If $R_{\text{AA}} = 1$ then A+A is equivalent to a superposition of p+p collisions (i.e. "no nuclear modification")

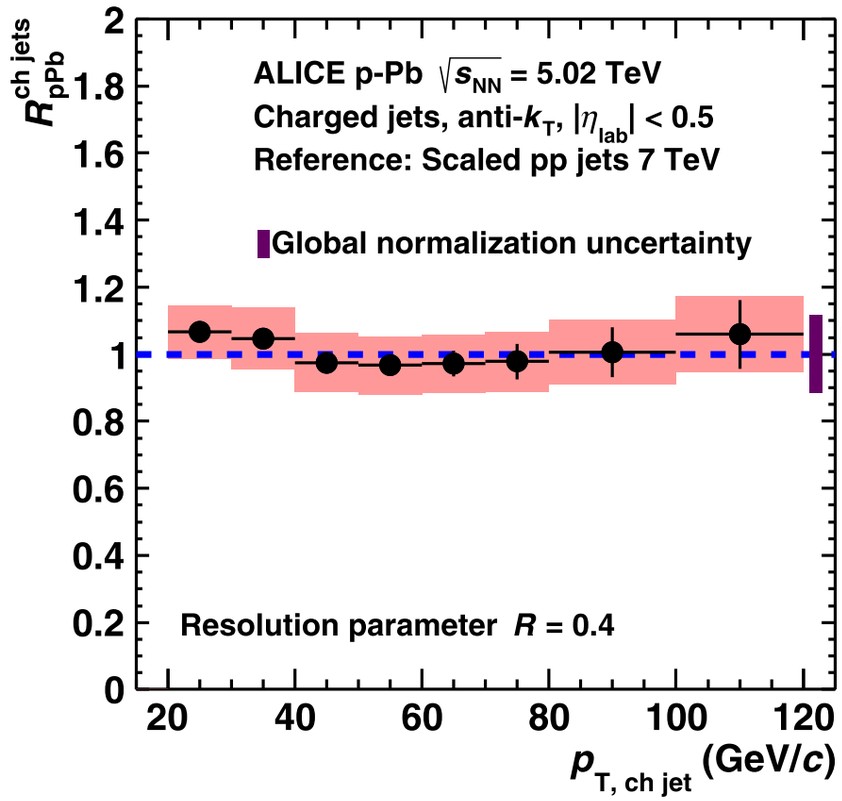


ATLAS *Physics Letters B* **748,** 392–413 (2015)

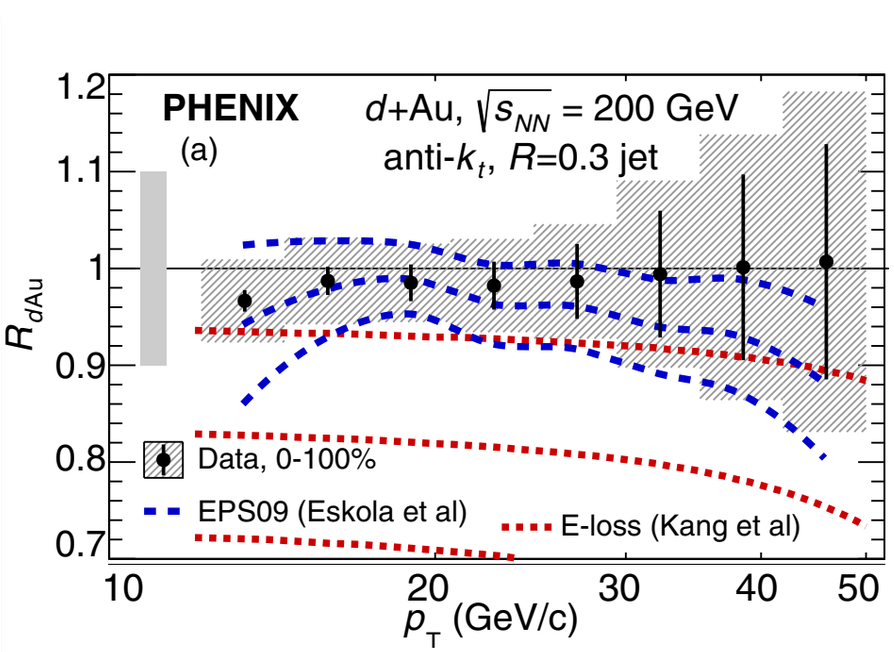
intro: "expectations" kept

- Small systems (this talk): *p*+Pb, *p*+Au, *d*+Au
- If you don't anticipate medium formation in small systems, expect that $R^{jet}_{(p/d)\mathrm{A}} \approx 1$

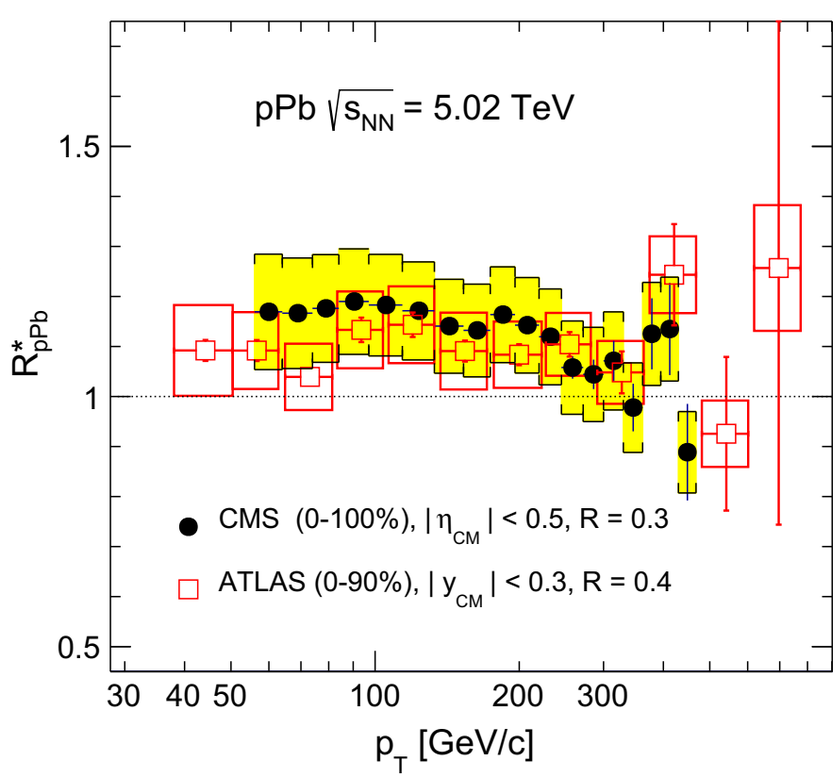
ALICE



PHENIX



ATLAS & CMS

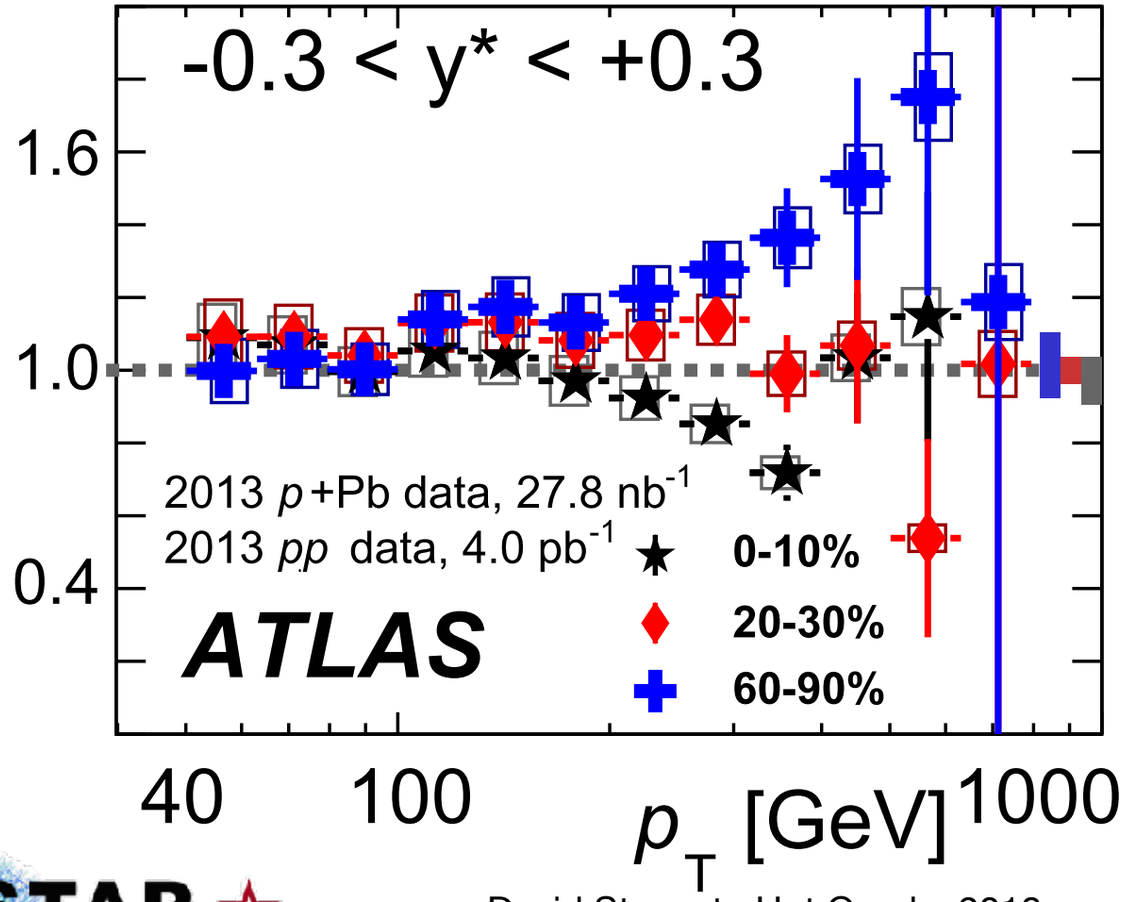


ALICE *Phys. Lett. B749 (2015) 68-81*
PHENIX *Phys. Rev. Lett.* **116,** 122301 (2016)
CMS Eur. Phys. J. C **76**, 372 (2016)

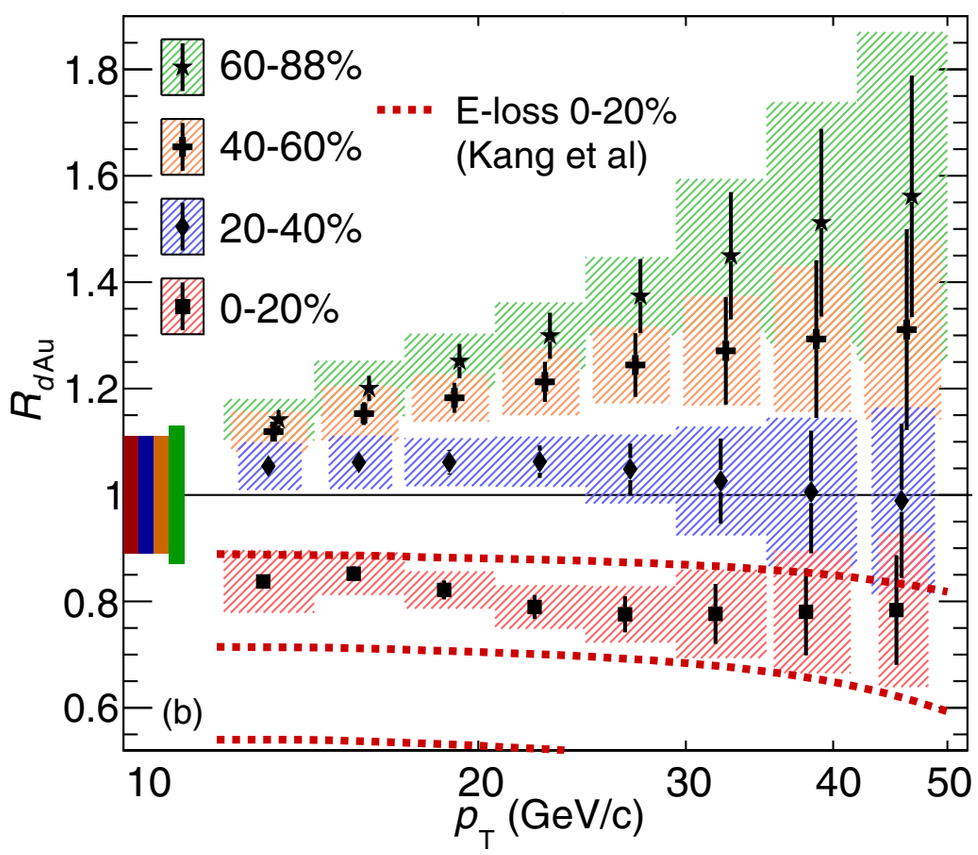
intrigue: "expectations" broken

- Undeniably flow-like signals are observed in small systems
- There is much growth and activity in studying flow (or flow-like) effects in small systems
- It is perhaps no longer obvious what "expectations" should be
- Looking at event activity (EA) binned data in small systems,

$$R_{(p/d)\mathrm{A}}^{jet\ \mathrm{High\ EA}} < 1 \quad \& \quad R_{(p/d)\mathrm{A}}^{jet\ \mathrm{Low\ EA}} > 1$$



PHENIX d+Au, $\sqrt{s_{NN}}$ = 200 GeV
anti-k_t, R=0.3 jet



PHENIX *Phys. Rev. Lett.* **116**, 122301 (2016)
ATLAS *Physics Letters B* **748**, 392–413 (2015)

motivation: what happened?

a few possibilities

1. Traditional Glauber calculation and N_{coll} are ok, and either Jet quenching or other new physics is present

2. Traditional N_{coll} calculation and/or application cannot be applied as in A+A due to new physics

a few current results*

(1) Correlation between suppression and total p-going jet momentum (p_{tot} vs p_T) at ATLAS

(2) Theory conserving p(/d) p_{tot} suggests anti-correlation between multiplicity & hard scattering (ergo modify Glauber) (e.g.: Kordell II & Majumder, 2018)

(3) Semi inclusive measurements circumvent N_{coll} entirely at ALICE (with current null result on jet quenching at mid rapidity)

* some details are given in “extra slides” at end of presentation

what can STAR do from here?

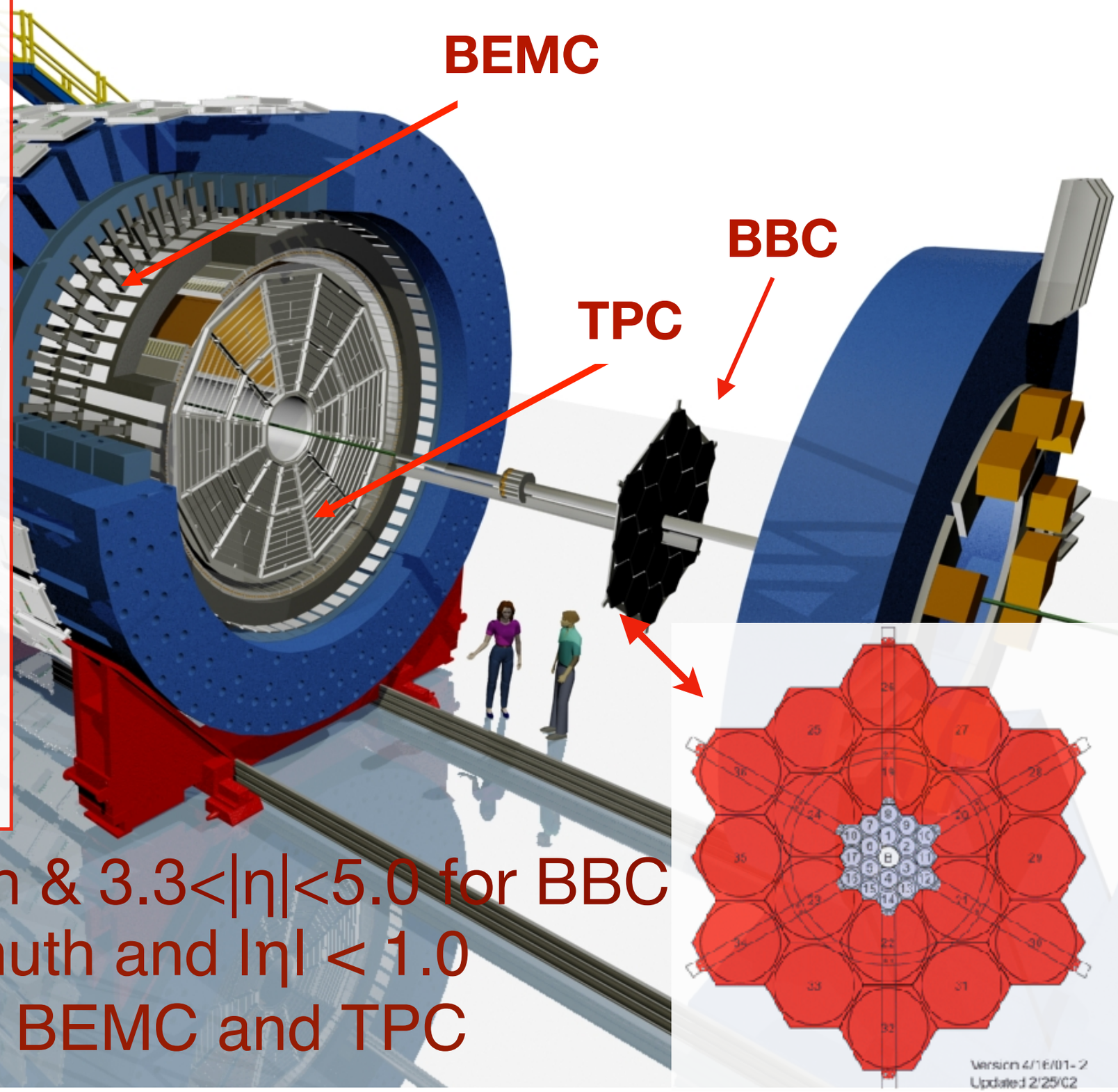
Current	STAR
Intriguing jet spectra in ✦ *d*+Au @ 200GeV (PHENIX) ✦ *p*+Pb @ 5.2 TeV (LHC)	Has large *p*+Au 200 GeV dataset from 2015
ALICE p+Pb→h+jet+X ✦ Circumvent Glauber dependence ✦ Suggests no jet quenching at mid-rapidity	Large dataset triggered on BEMC Calorimeter hits ⇒ p+Au→$BEMC_{hit}$+jet+X
EA determined by high |η| activity	Beam Beam Counter (BBC) ADC signal measured at |η|∈(3.3,5.0)
ATLAS ✦ Hint of new physics in x_p (~p_T cosh(η)/($\sqrt{s_{NN}}$/2)) correlation in jet enhancement/suppression	Due to lower $\sqrt{s_{NN}}$, have statistics to report jet spectra at matching x_p
Theory ✦ Suggested correlations between EA at high |η| and observables at mid rapidity not seen in A+A	Before generating jet spectra, and taking ratios of EA, look at EA in the data and its correlation to mid rapidity observables

STAR detector system

sub systems of interest

- Time Projection Chamber (TPC)
  Measures charged tracks with p_T
- Barrel Electromagnetic Calorimeter (BEMC) measures energy deposition, primarily neutral particles
- Beam Beam Counter (BBC)
  plastic scintillators

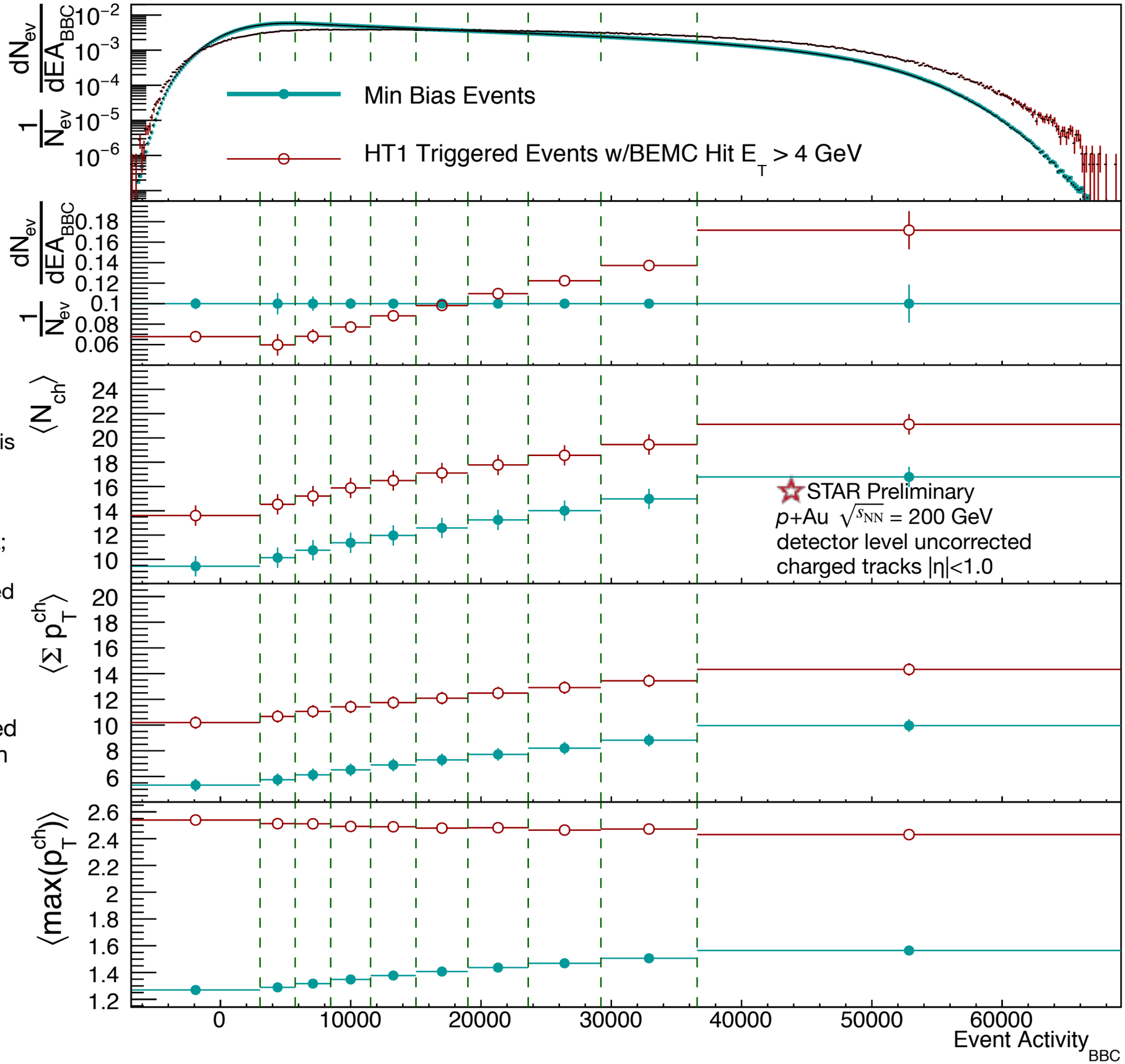
The sum of the grey (inner) tiles in the BBC in the Au going direction, corrected for z-vertex and luminosity, is the EA estimator (EA_{BBC})



2π-azimuth & 3.3<|η|<5.0 for BBC
2π-azimuth and |η| < 1.0
both for BEMC and TPC

correlations at |η|<1.0 for deciles of EA

take away



Although the data is uncorrected, the corrections are expected to be independent of EA; therefore these trends are expected to persist

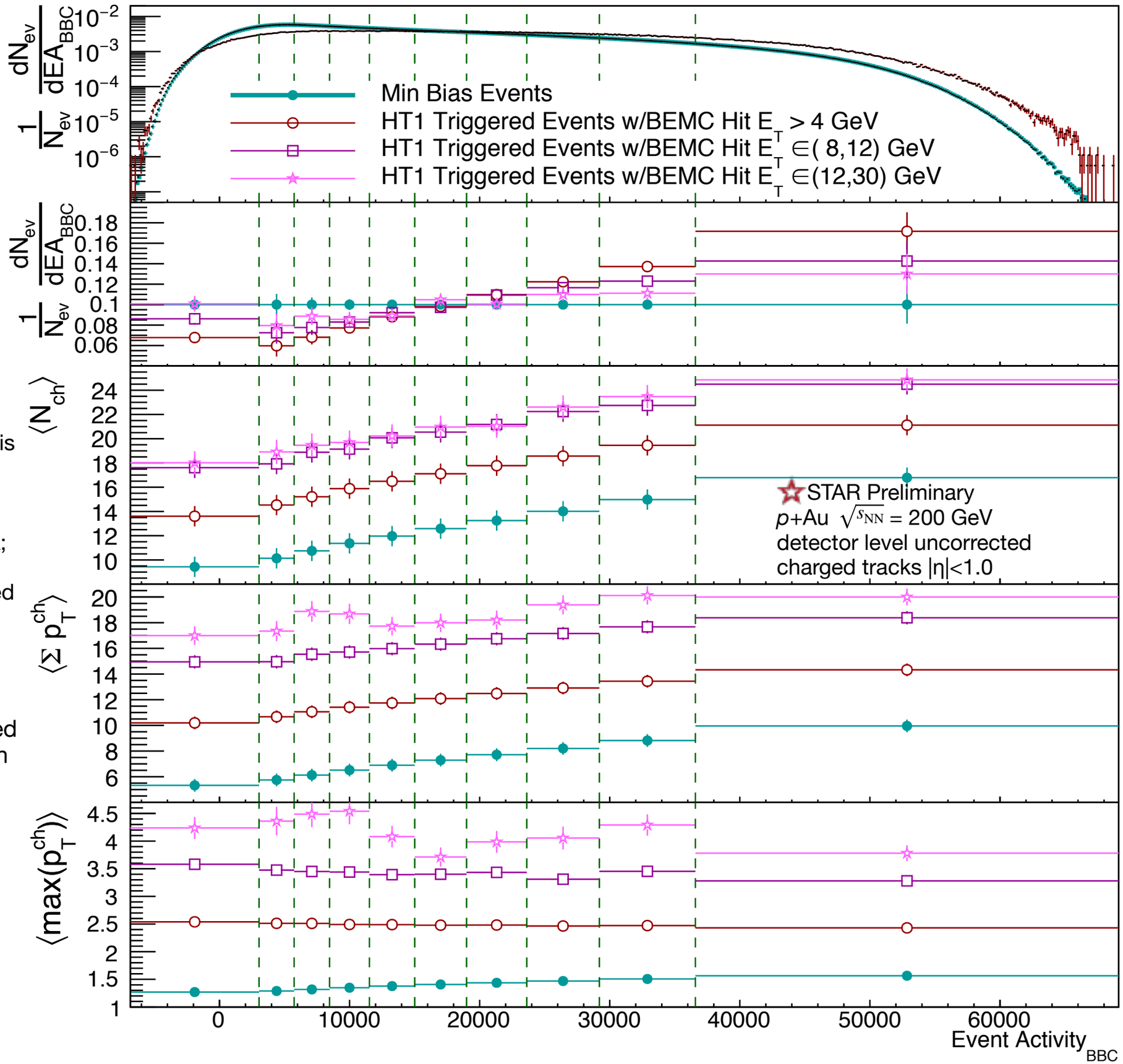
Trigger bias systematics added in quadrature with statistical errors

As expected — positive correlation between EA and probability of finding a trigger tower in BEMC & $\langle N_{ch} \rangle$ & $\langle \Sigma p_T^{ch} \rangle$

Contrary to typical Glauber calculation:

Chance of finding a high p_T track at central |η| not monotonically increasing with EA

correlations at |η|<1.0 for deciles of EA: w/higher E_T triggers



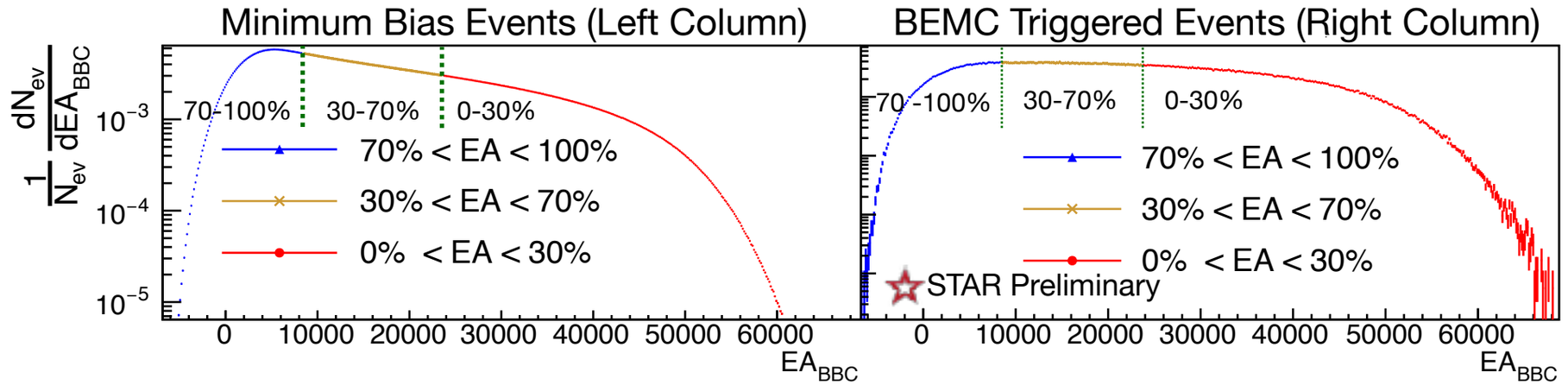
Although the data is uncorrected, the corrections are expected to be independent of EA; therefore these trends are expected to persist

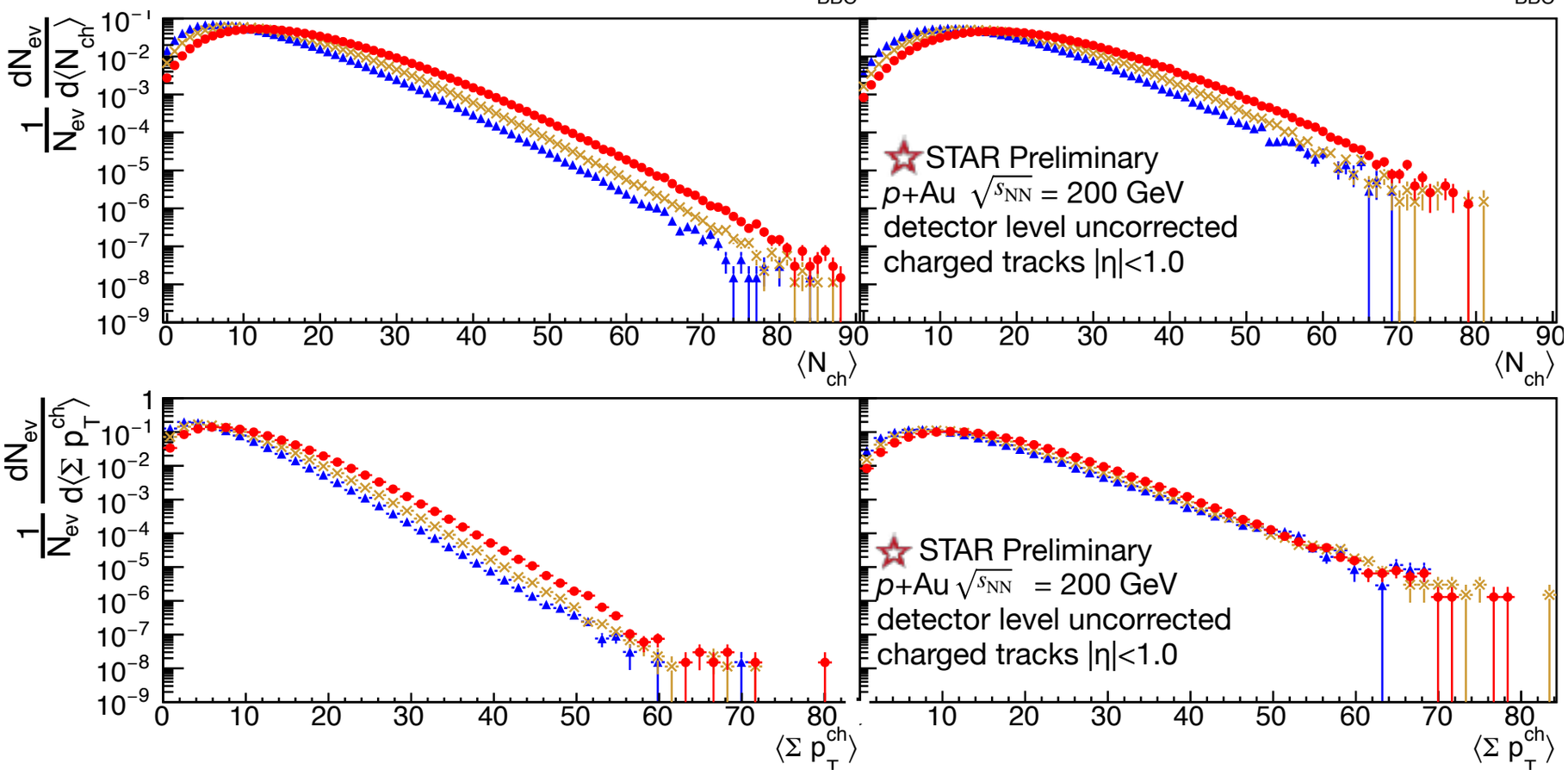
Trigger bias systematics added in quadrature with statistical errors

The positive correlation between EA and chance of finding a mid-rapidity event weaken at harder trigger requirements

The statistics are limiting; however it is hinted that with a harder trigger, the anti-correlation is increased

distributions behind these tightly defined means





Note that the EA percentage definition follows the convention from centrality: 0% is maximum EA, and 100% is minimum EA

Although the means of these distributions are well defined and distinct in EA bins, the distributions are broad with a large amount of overlap between the highest and lowest EA sets

Note: although the data is uncorrected, the corrections are expected to be independent of EA; therefore these trends are expected to persist

conclusions

Event Activity to mid rapidity correlations in 200 GeV *p*+Au collisions indicate:

- EA_{BBC} is broadly correlated with multiplicity and mid rapidity indications of total EA
- In contrast with the traditional Glauber model, the chance of finding a mid rapidity high p_T hard scattering does not monotonically increase with EA

There are, however, theory models against which to adapt the Glauber; these may ultimately provide better insight in how to measure EA*

Noting the above, it is still meaningful to obtain the trigger-hadron jet spectra to:

- Compare to theory
- Compare against existing measurements (next slide)
- Check ratios in x_p

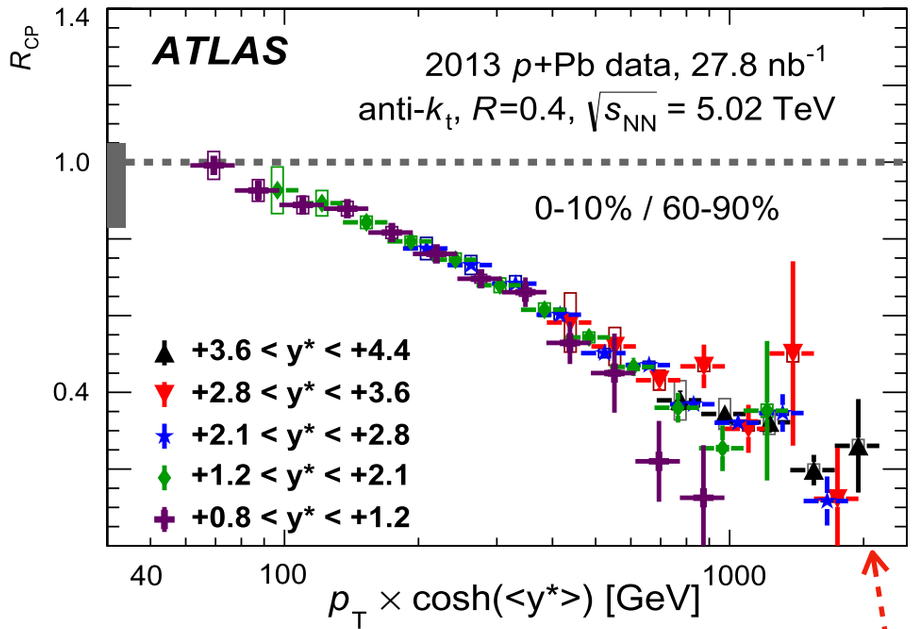
* Kordell II & Majumder *Physical Review C* **97,** (2018)
Armesto, Gulhan, Milhano, *Physics Letters B* **747,** 441–445 (2015).

next to do

release semi-inclusive jet spectra

p + Au → $BEMC_{Hit}$ + jet + X

- Compare against PHENIX inclusive jets at same $\sqrt{s_{NN}}$ (200 GeV)
- Compare against ATLAS over same x_p (~0-0.44)
- Compare against ALICE semi-inclusive spectra (does enhancement/suppression drop out)?
- Compare against theory



- At 5.02 TeV, 1100 GeV ⇒ ~0.44 x_p
- At 200 GeV, 0.44 x_B ⇒ 22 GeV charged jets (~50% of full jets) or 44 GeV full jets.

ATLAS *Physics Letters B* **748,** 392–413 (2015)

fin

(the end)

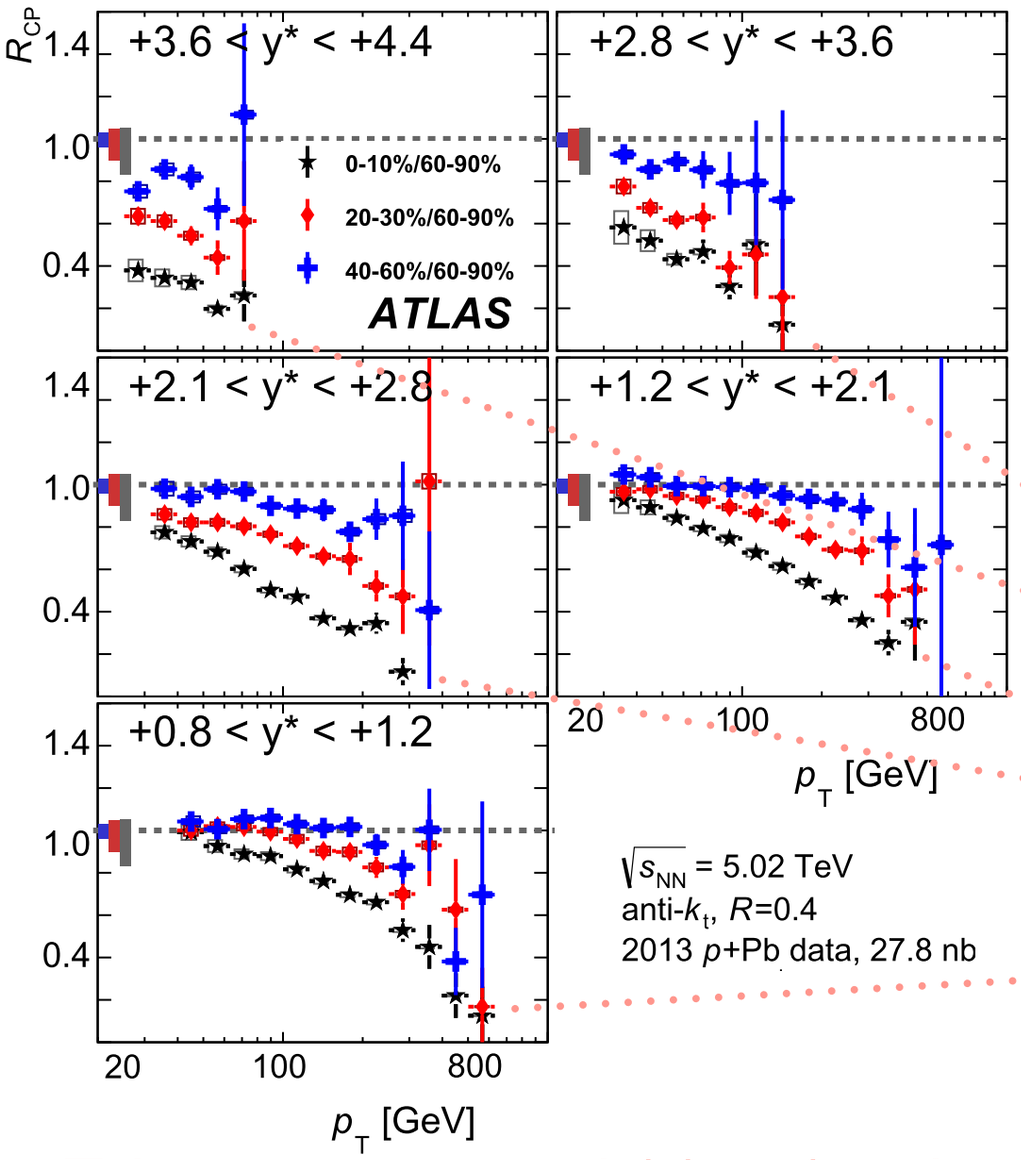
extra slides

note: The next four slides present some detail on current results (1), (2), & (3) listed on slide 7

from **(1)** (slide 7)

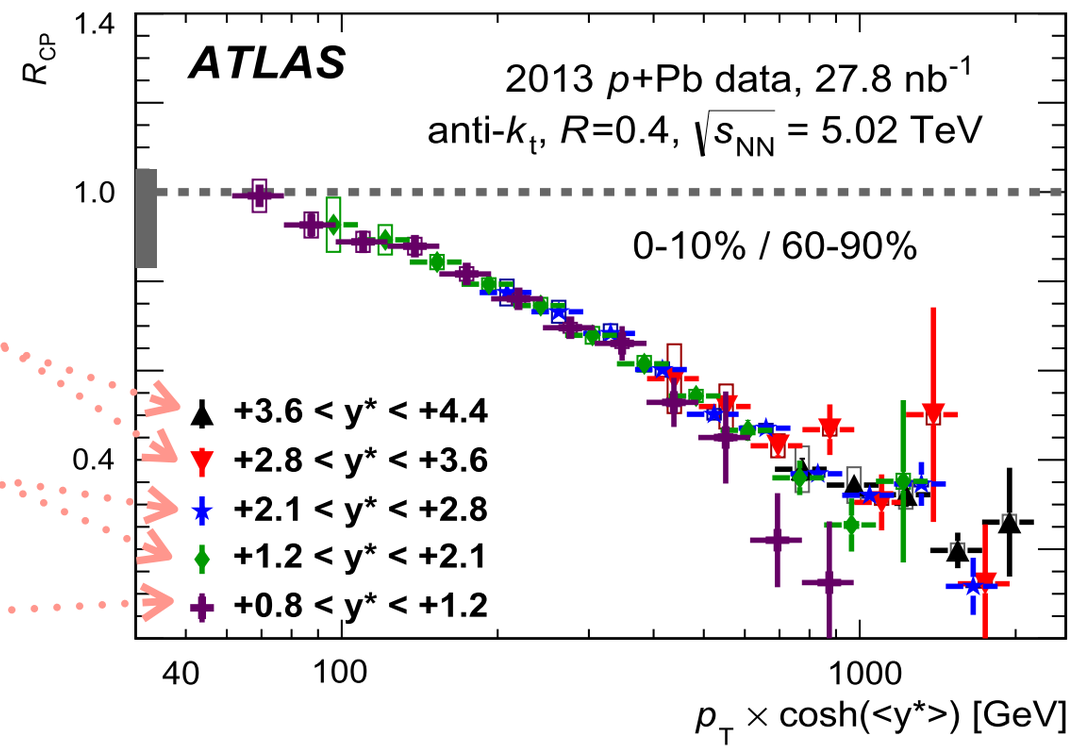
correlation between x_p & $R_{CP} \equiv \dfrac{R_{AA}^{jet\ \text{High EA}}}{R_{AA}^{jet\ \text{Low EA}}}$

$R_{CP}(p_T)$ in p-going η



$R_{cp}(p_T \times \cosh(\langle y^* \rangle))$ in p-going η

black stars from left figure replotted below with new x-axis scaling



Takeaway: $p_T \times \cosh(\eta) \equiv p$ (total momentum) ⇒ p-going R_{CP} appears to relate to x_p

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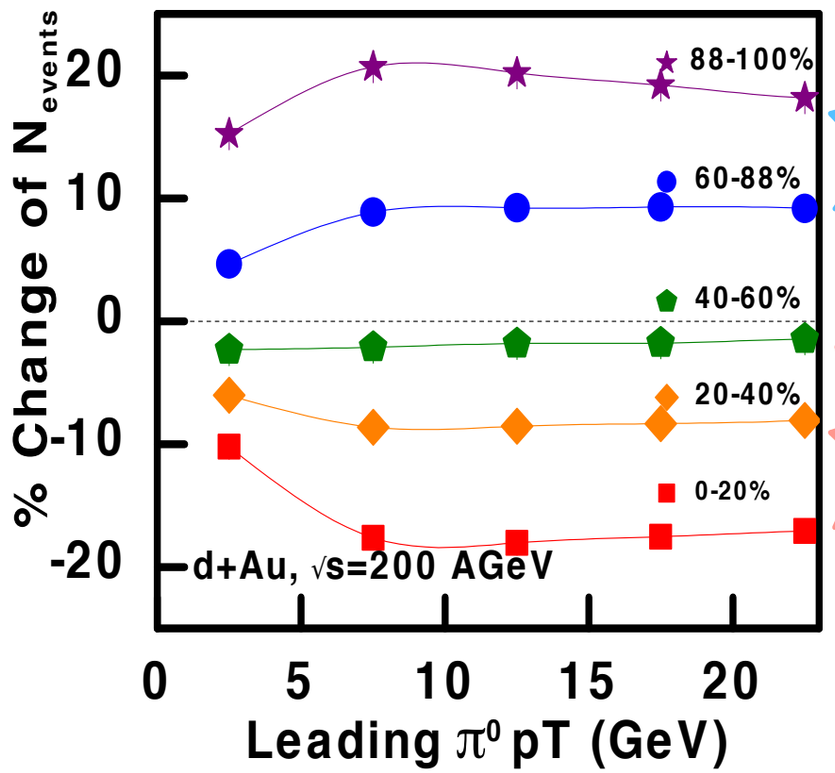
from **(2)** (slide 7)

modify Glauber to conserve p_{tot} of d/p and get

$$R^{jet\ \mathrm{High\ EA}}_{(p/d)\mathrm{A}} < 1 \quad \& \quad R^{jet\ \mathrm{Low\ EA}}_{(p/d)\mathrm{A}} > 1$$

- Traditional Glauber treats all N_{coll} collisions as equal
- Modify Glauber for depletion of energy (p_{total}) of the proton/deuteron
- Primary result: more high energy jets (from N_{coll}) are correlated with lower overall multiplicity (by energy conservation)
- Takeaway: high & low EA events are mis-binned causing R_{CP} to drop



Low EA events getting extra counts

High EA events getting less counts

Kordell II & Majumder *Physical Review C* **97,** (2018)

from **(3)** (slide 7)

method:

circumvent N_{coll} w/ semi-inclusive measurement

$$A + p \rightarrow t + jet + X$$

Measure jet spectra vs number of triggers;
N_{coll} dependence cancels in ratio:

a

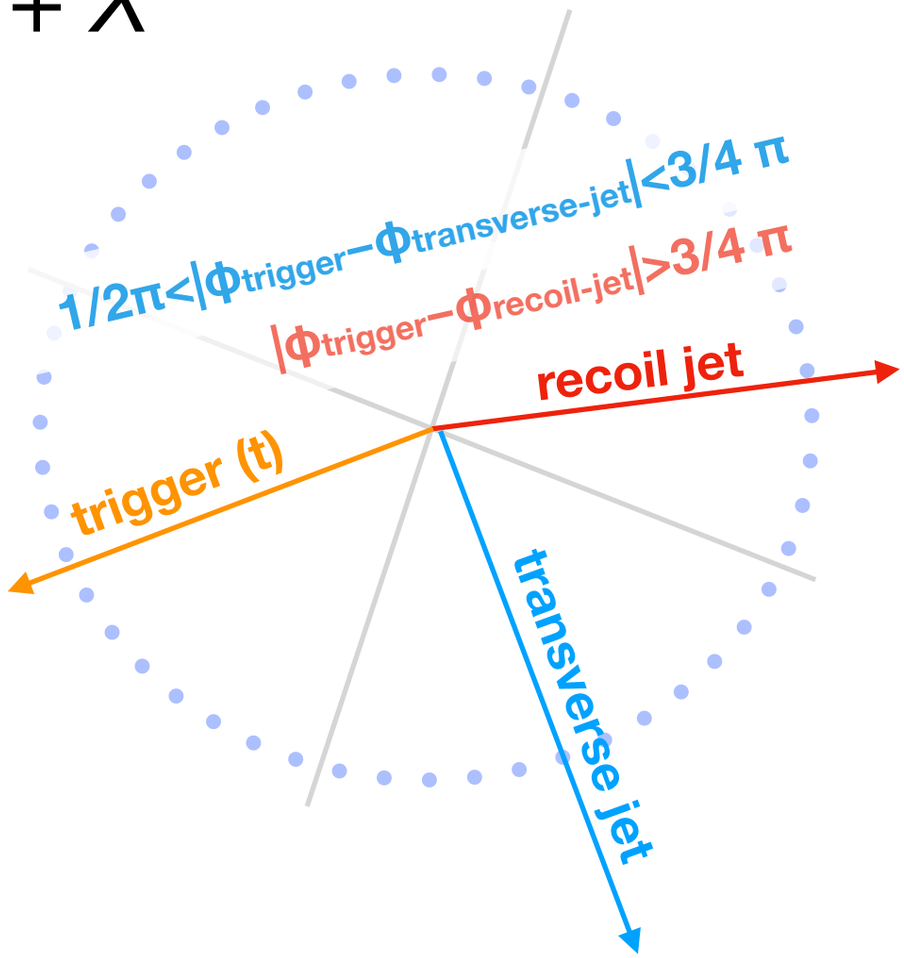
$$\frac{1}{N_{trig}^{t,p+A}} \frac{dN_{jet}^{p+A}}{dp_{T,jet}^{p+A}} = \frac{1}{\sigma^{p+A \rightarrow t+X}} \frac{d\sigma^{p+A \rightarrow t+jet+X}}{dp_{T,jet}^{p+A}}$$

If no nuclear modification for product "*Y*":

$$\sigma^{p+A \rightarrow Y} = N_{coll}\, \sigma^{p+p \rightarrow Y}$$

Sub into a and cancel N_{coll}:

$$\left(\frac{1}{\sigma^{p+p \rightarrow t+X}} \frac{d\sigma^{p+p \rightarrow t+jet+X}}{dp_{T,jet}^{p+p}} \right) \frac{N_{coll}}{N_{coll}} = \frac{1}{N_{trig}^{t,p+p}} \frac{dN_{jet}^{p+p}}{p_{T,jet}}$$



N_{coll} calculation is no longer required to compare spectra to p+p

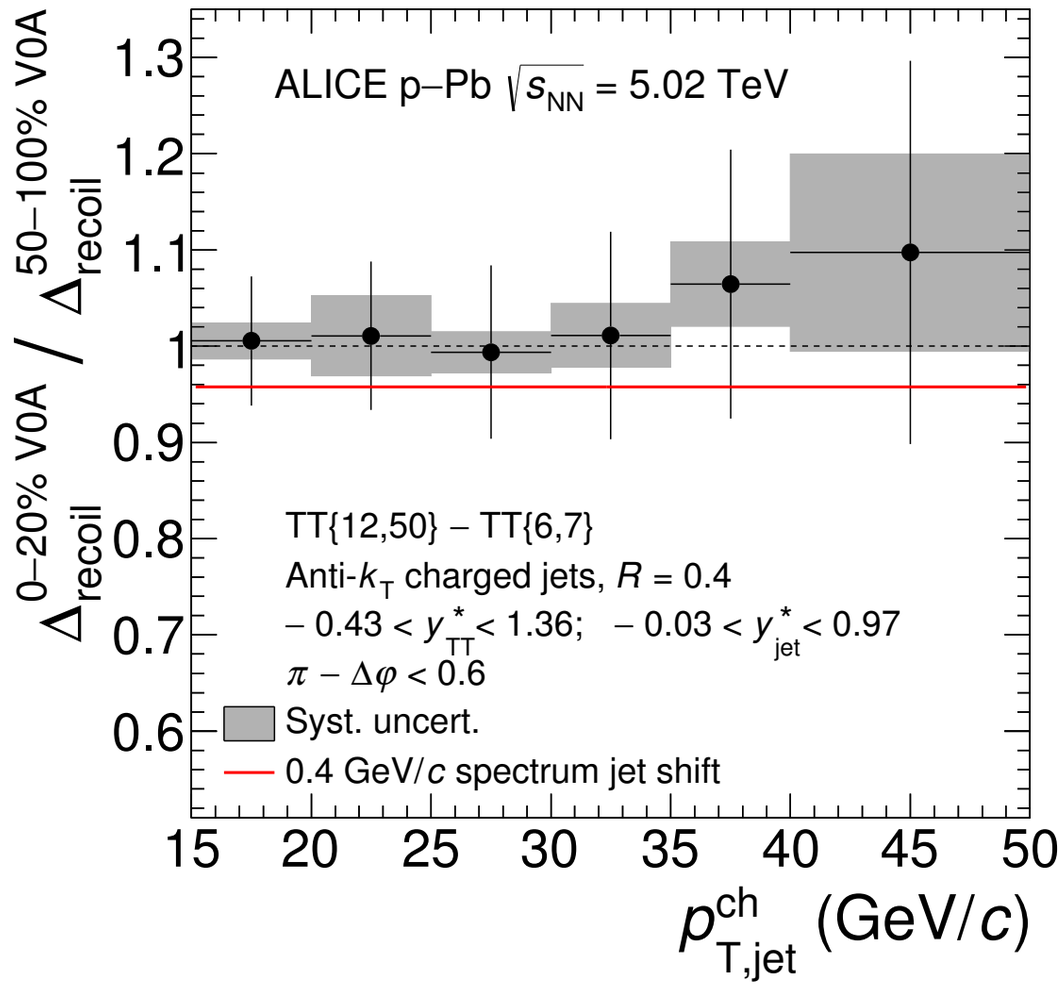
from **(3)** (slide 7)

application and results

application

- Use high |η| multiplicity to define EA (to isolate from jet region phase space)
- Compare high EA to low EA h+jet spectra

result (ALICE)



Takeaway: no jet quenching signal for both (a) semi-inclusive (non-Glauber) and (b) inclusive (Glauber) (see second reference) jet spectra *within this p_T (and p_{tot}) range*

ALICE *arXiv:1712.05603v1* (2017).
ALICE The European Physical Journal C. 76 (2016) 271