Dependence of semi-inclusive jet and high-p_T charged particle production on event activity at high backward-rapidity in $\sqrt{s_{NN}}$ = 200 GeV p+Au collisions at STAR

10th International Conference on Hard & Electromagnetic Probes of High-Energy Nuclear Collisions

June 2nd, 2020

Austin, TX (remote)

David Stewart (Yale University) for the STAR Collaboration

Wright Laboratory

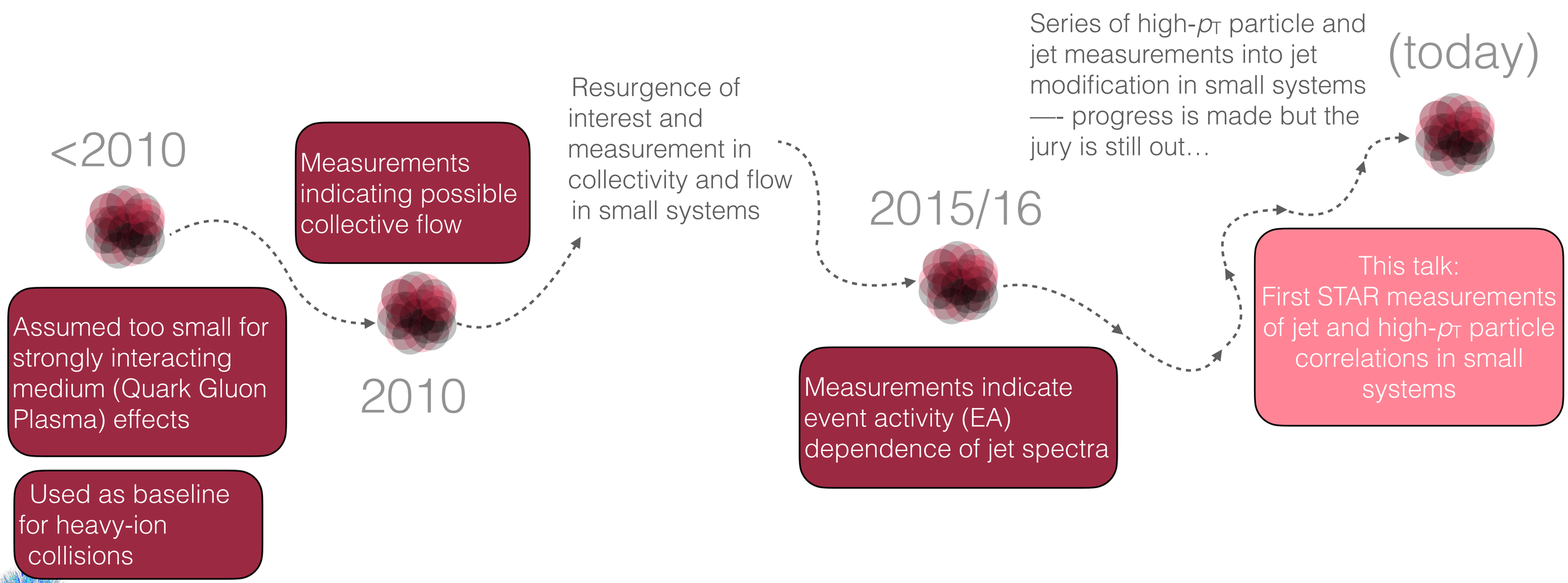
STAR

Funded in part by U.S. DEPARTMENT OF ENERGY Office of Science

Yale

Small system (pp, p+Au, d+Au, p+Pb, ^{3}He+Au) collisions

(timeline from point of view of experimental heavy ion physics)



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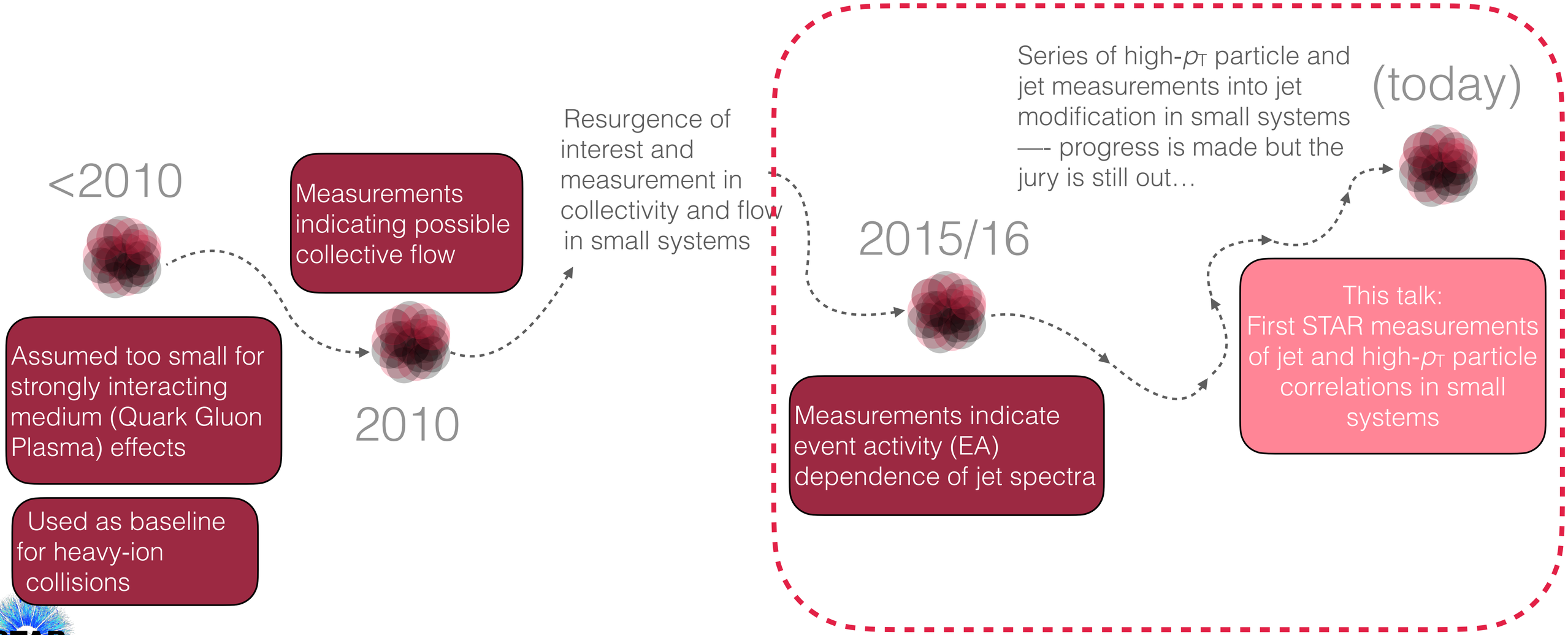
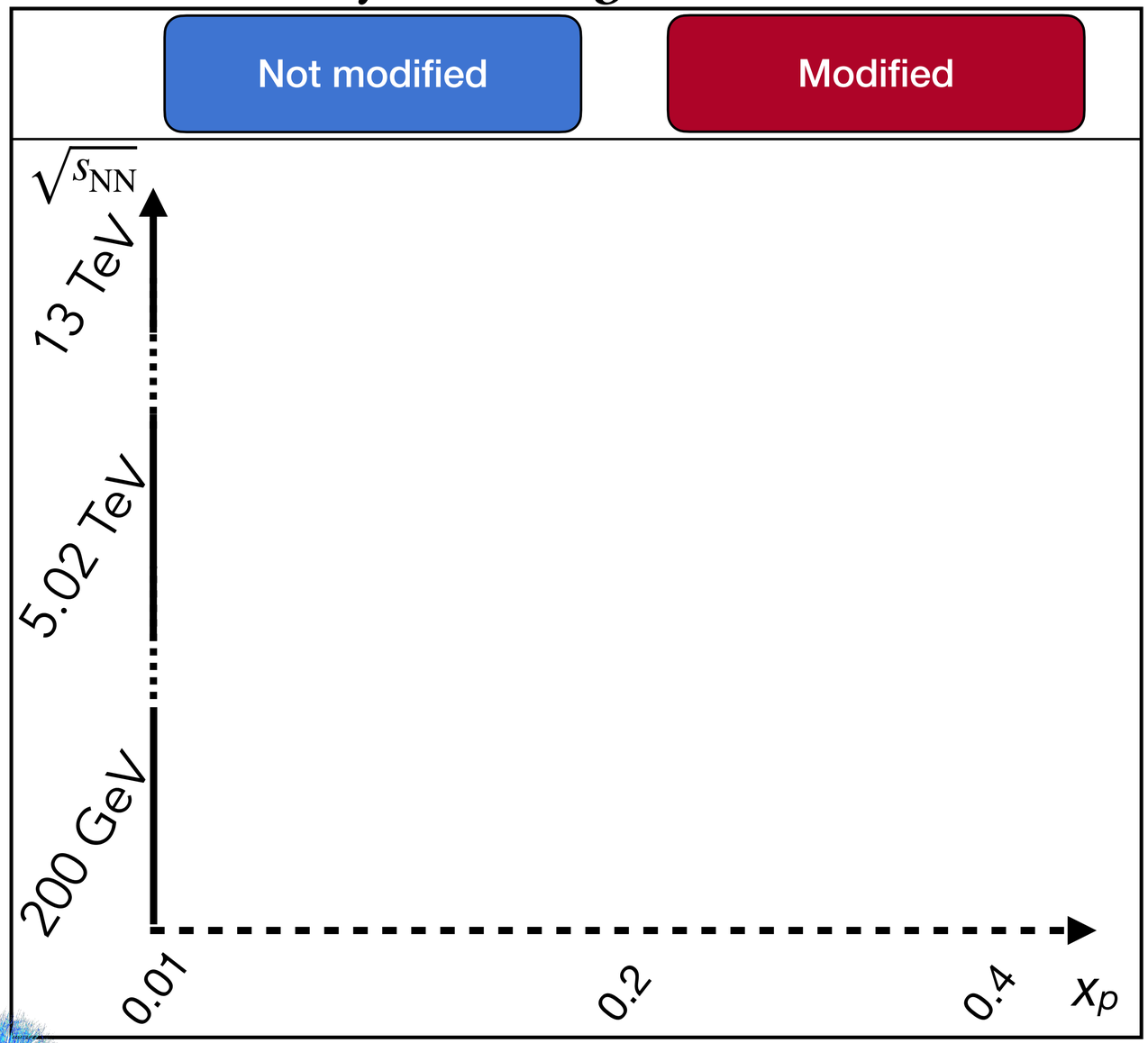
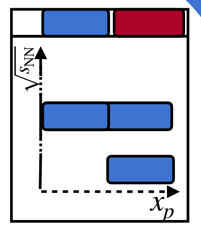


Small system jet modification score card

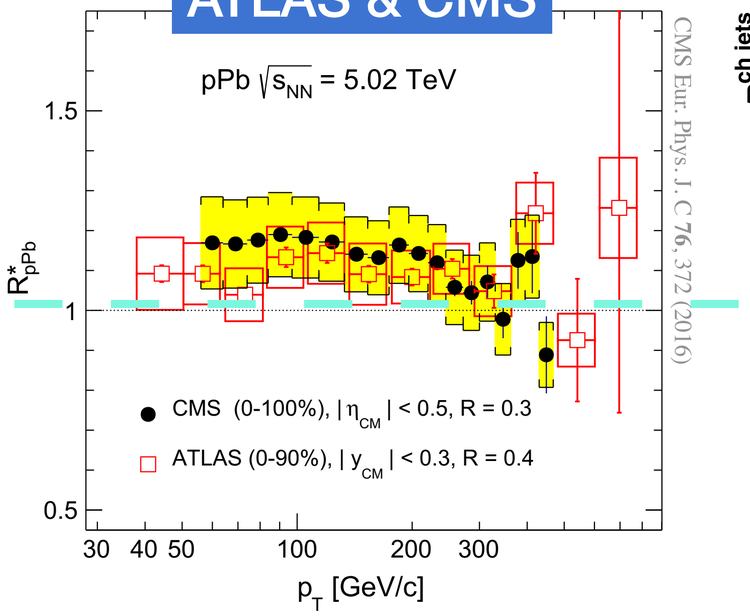


Jet inclusive $R_{p/d+A}$:

2015 & 2016: $R_{p/d+A}$ consistent with unity

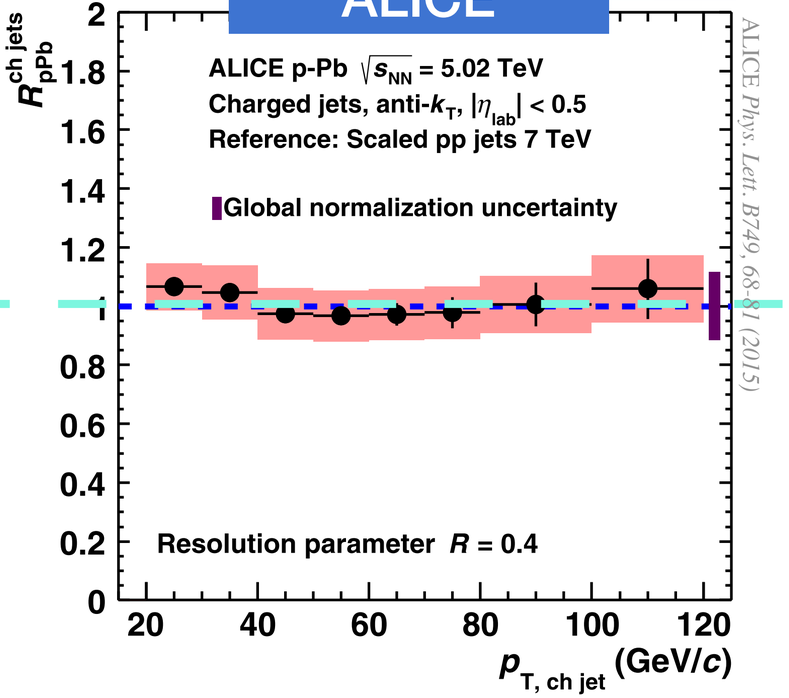


ATLAS & CMS



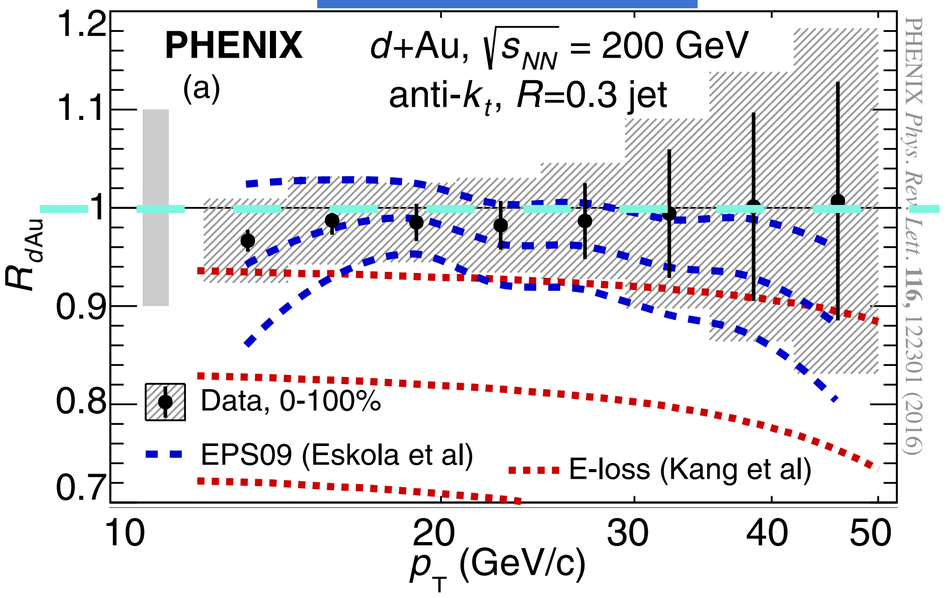
CMS Eur. Phys. J. C **76**, 372 (2016)

ALICE



ALICE *Phys. Lett. B*749, 68-81 (2015)

PHENIX



PHENIX *Phys. Rev. Lett.* **116**, 122301 (2016)

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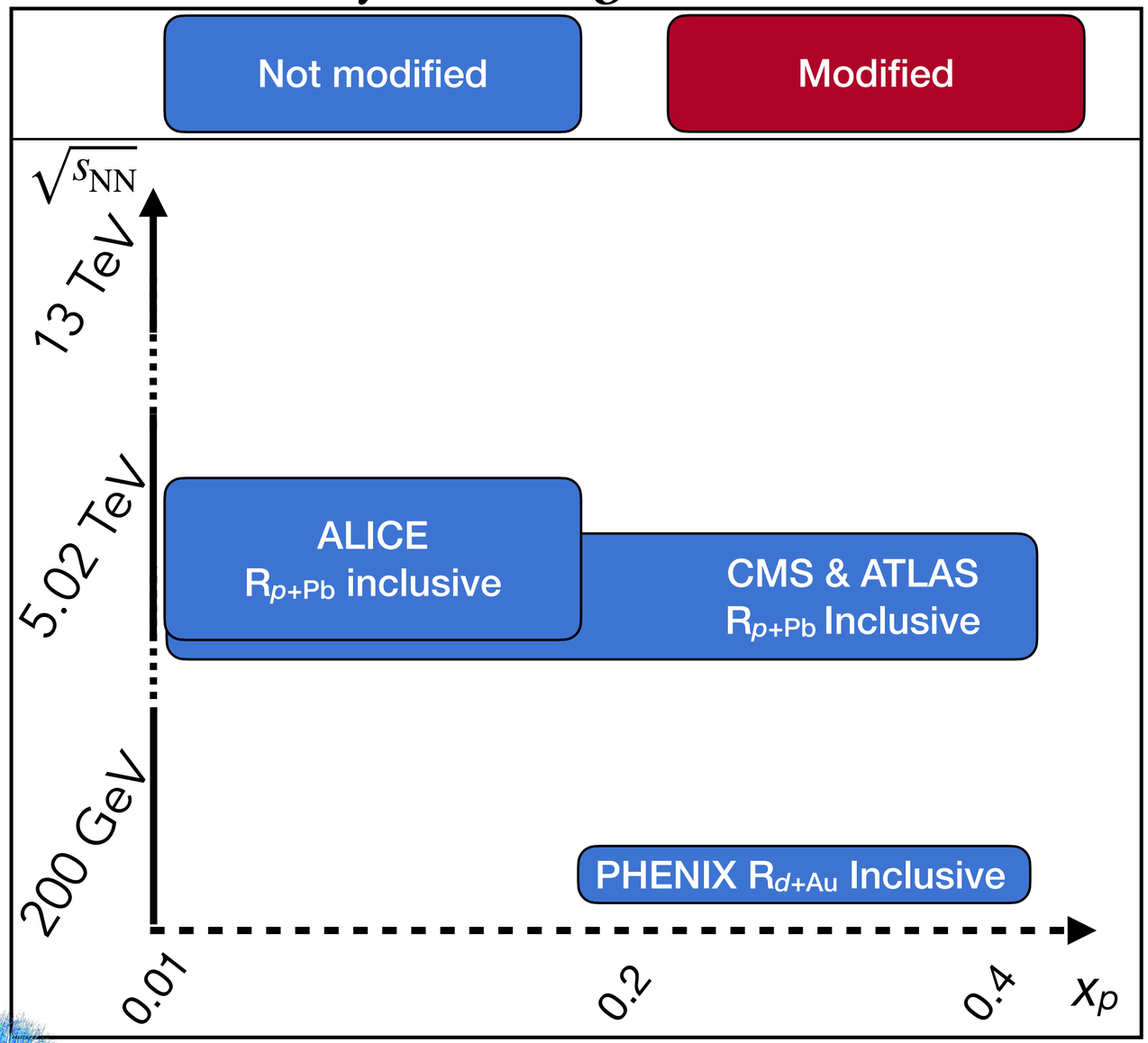
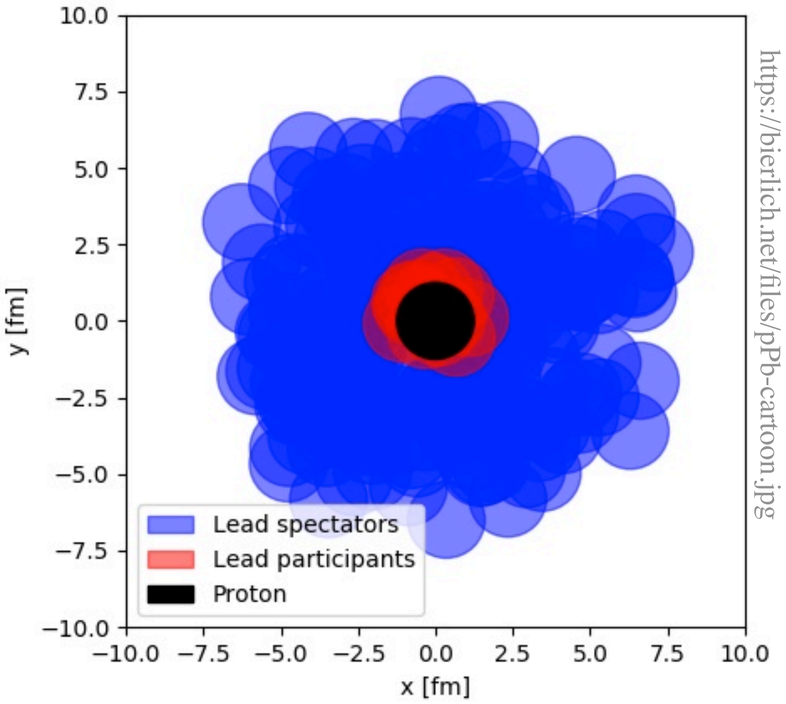


- Inclusive yields scale with *pp* collisions

Jet inclusive $R_{p/d+A}$ binned by EA



https://bierlich.net/files/pPb-cartoon.jpg

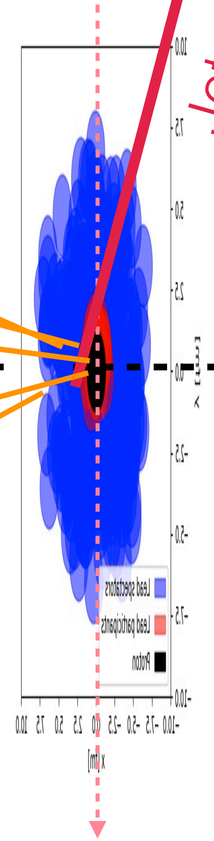
Jet at mid-η

Event Activity (EA):
signal @ high backward-η

Beam Line Axis

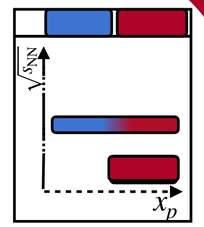
A-going direction

p-going direction

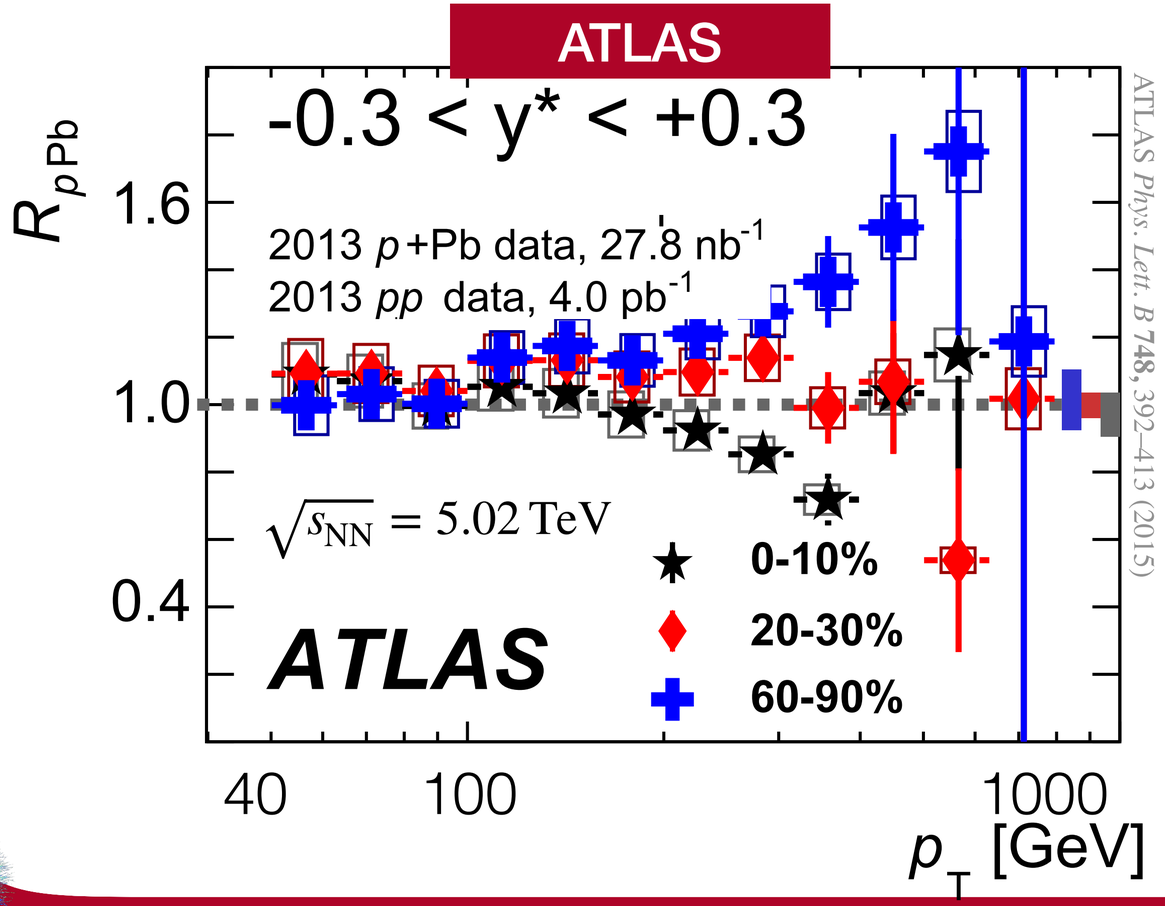


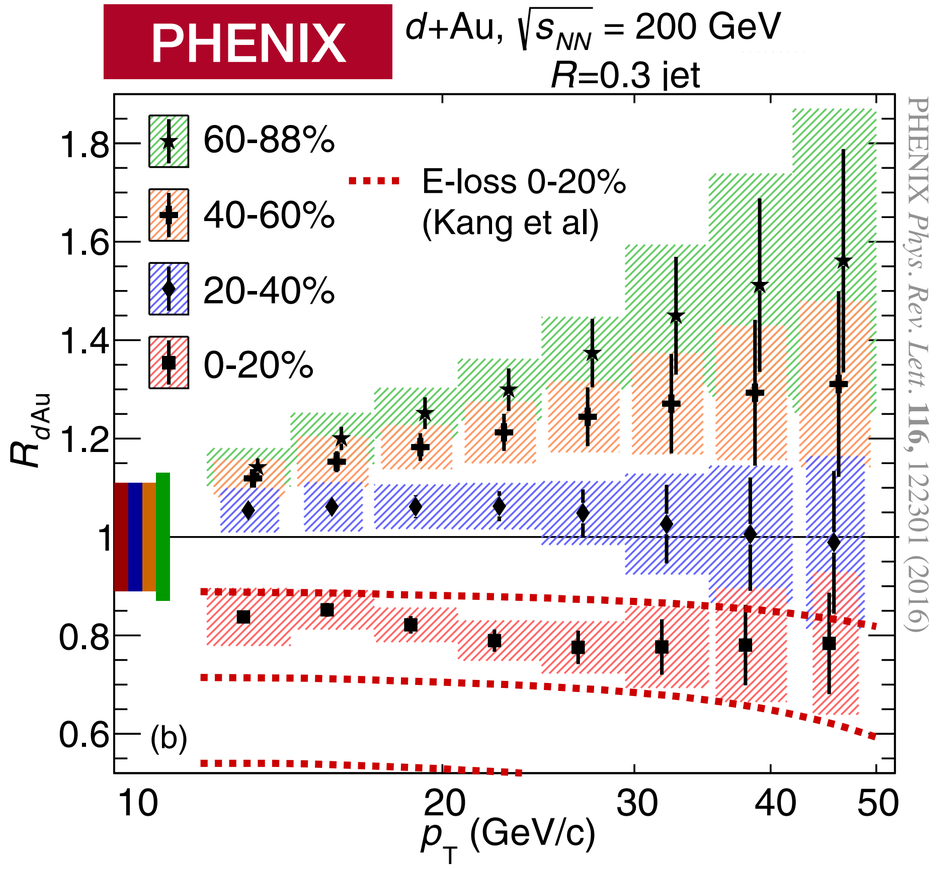
Select geometry from EA

Jet inclusive $R_{p/d+A}$ binned by EA



2015 & 2016: $R_{p/d+A}\Big|_{\text{High EA}} < 1$ & $R_{p/d+A}\Big|_{\text{Low EA}} > 1$





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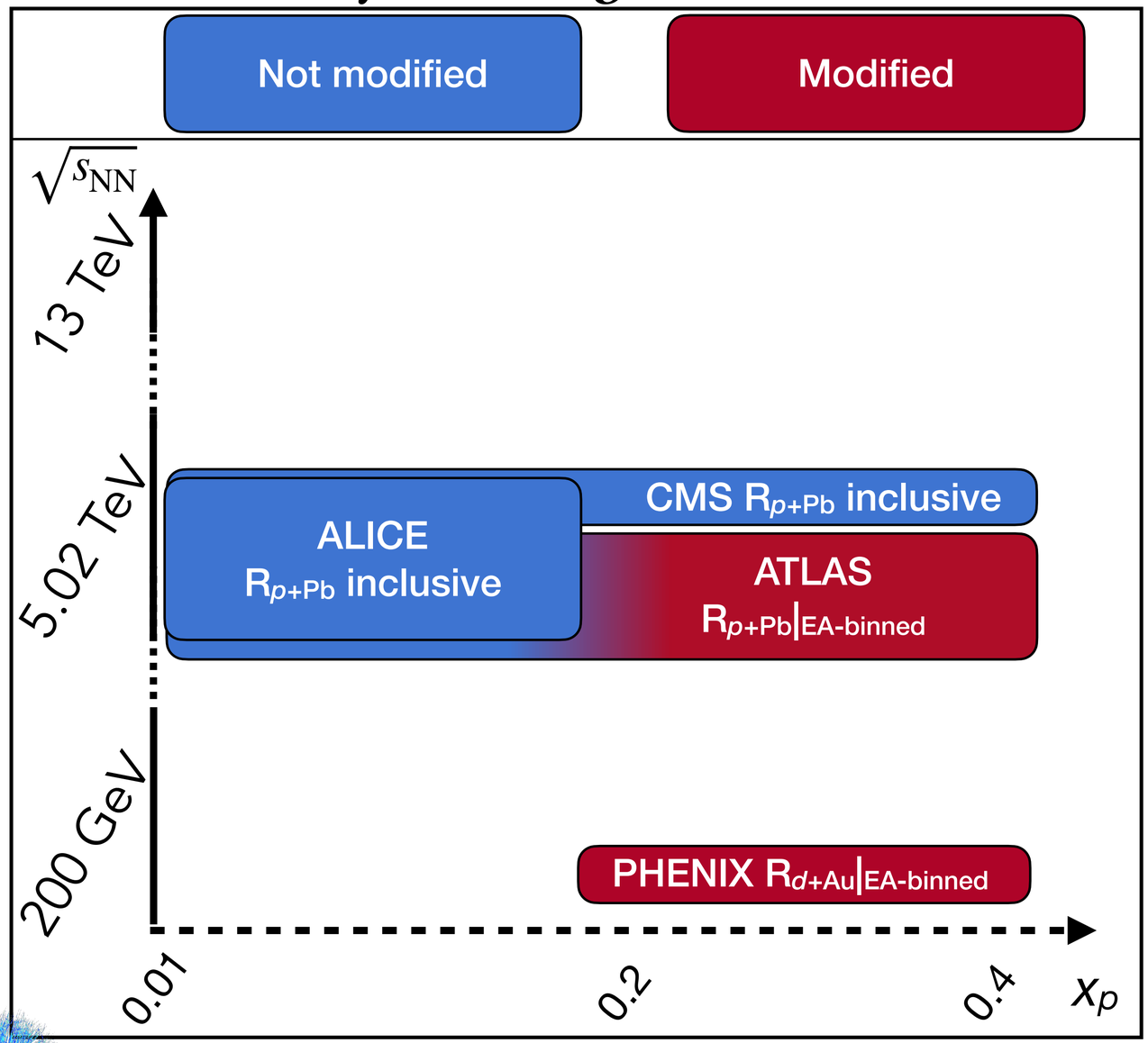
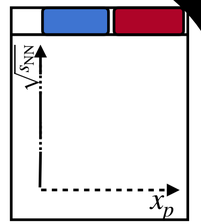


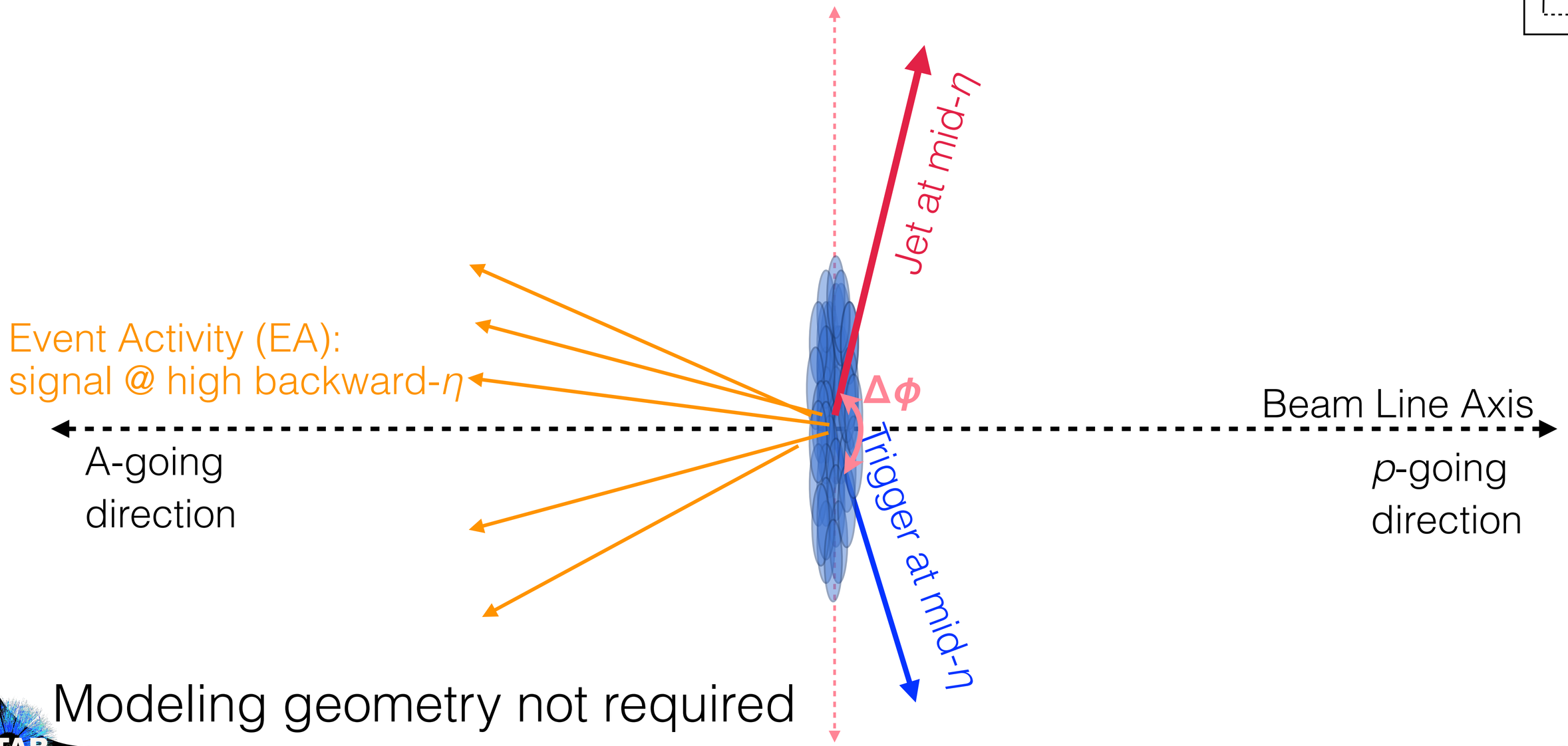
- Inclusive yields scale with pp collisions
- Determining geometry via EA non-trivial†
- Modification at high, but not low, x_p‡

†ALICE measured an EA-binned inclusive jet spectra with a modified EA definition which found jet spectra modification consistent with unity. See ALICE European Physical Journal C. 76 (2016). Plot in backup.

‡The ATLAS results include a ratio plot of $R_{CP}=(R_{p+Pb|high\text{-}EA})/(R_{p+Pb|low\text{-}EA})$ which scale nicely for different EA bins when plotted against x_p in place of p_T

Semi-inclusive: jet spectra per trigger (S)

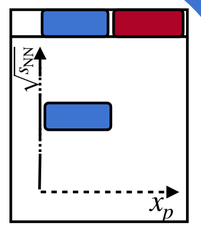




Modeling geometry not required

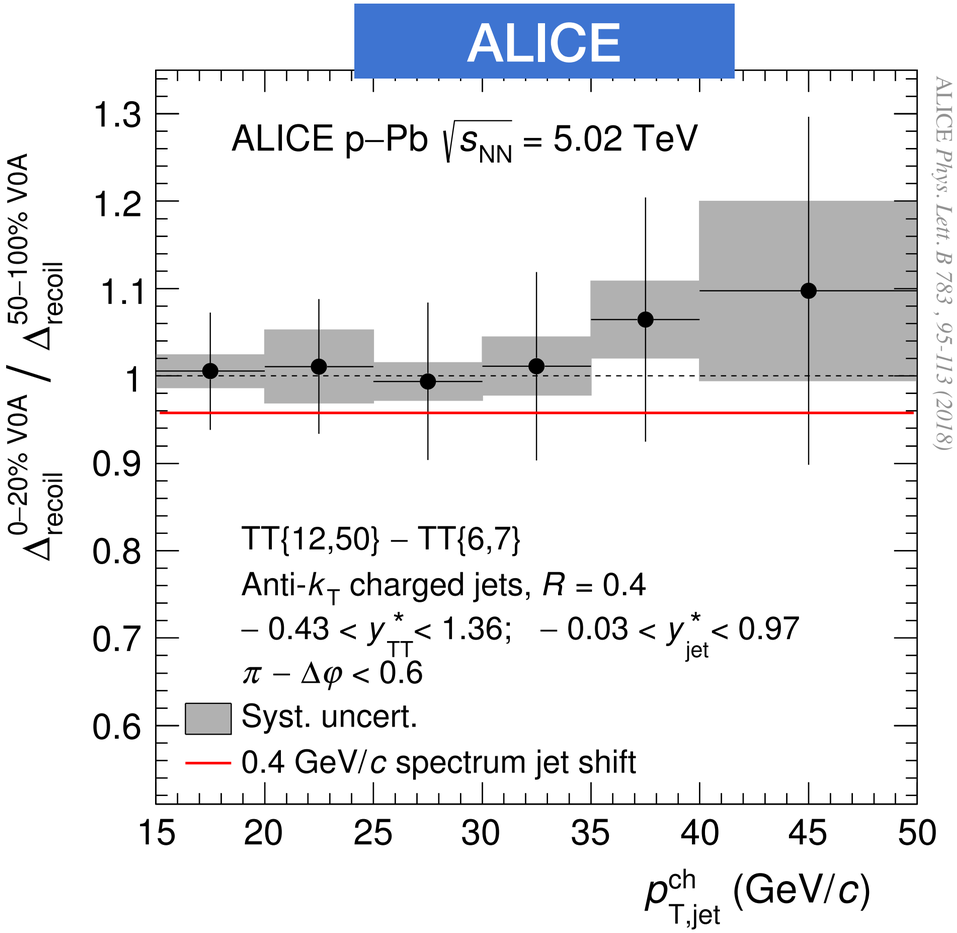
Semi-inclusive: jet spectra per trigger (S)

2018: Recoil jet spectra not EA dependent



- Upper limit set on out-of-cone energy transport (jet quenching), using jets up to x_p~0.02

- Not consistent with ATLAS and PHENIX measurements — applicable at all x_p?



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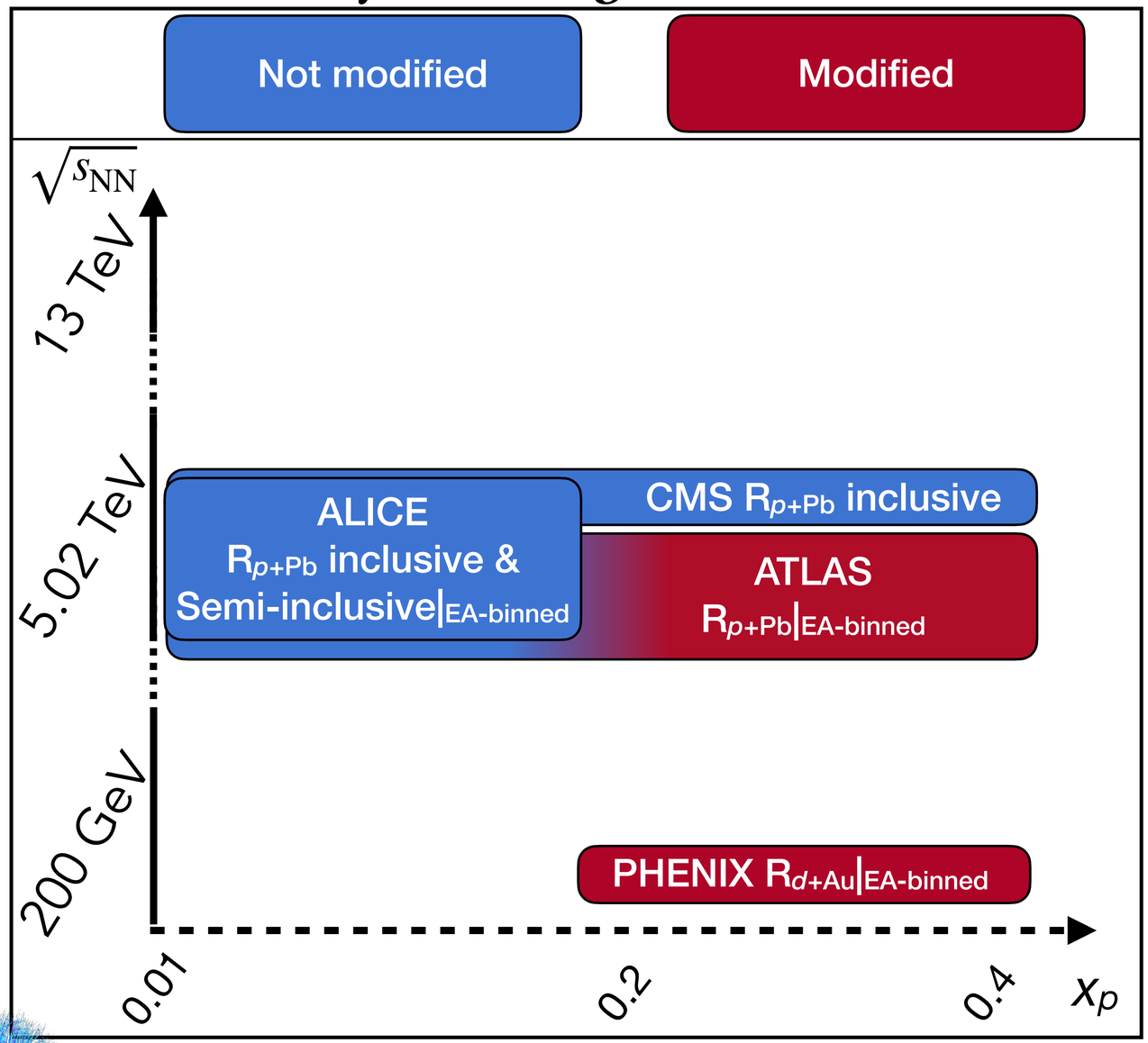

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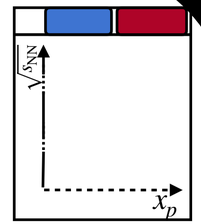
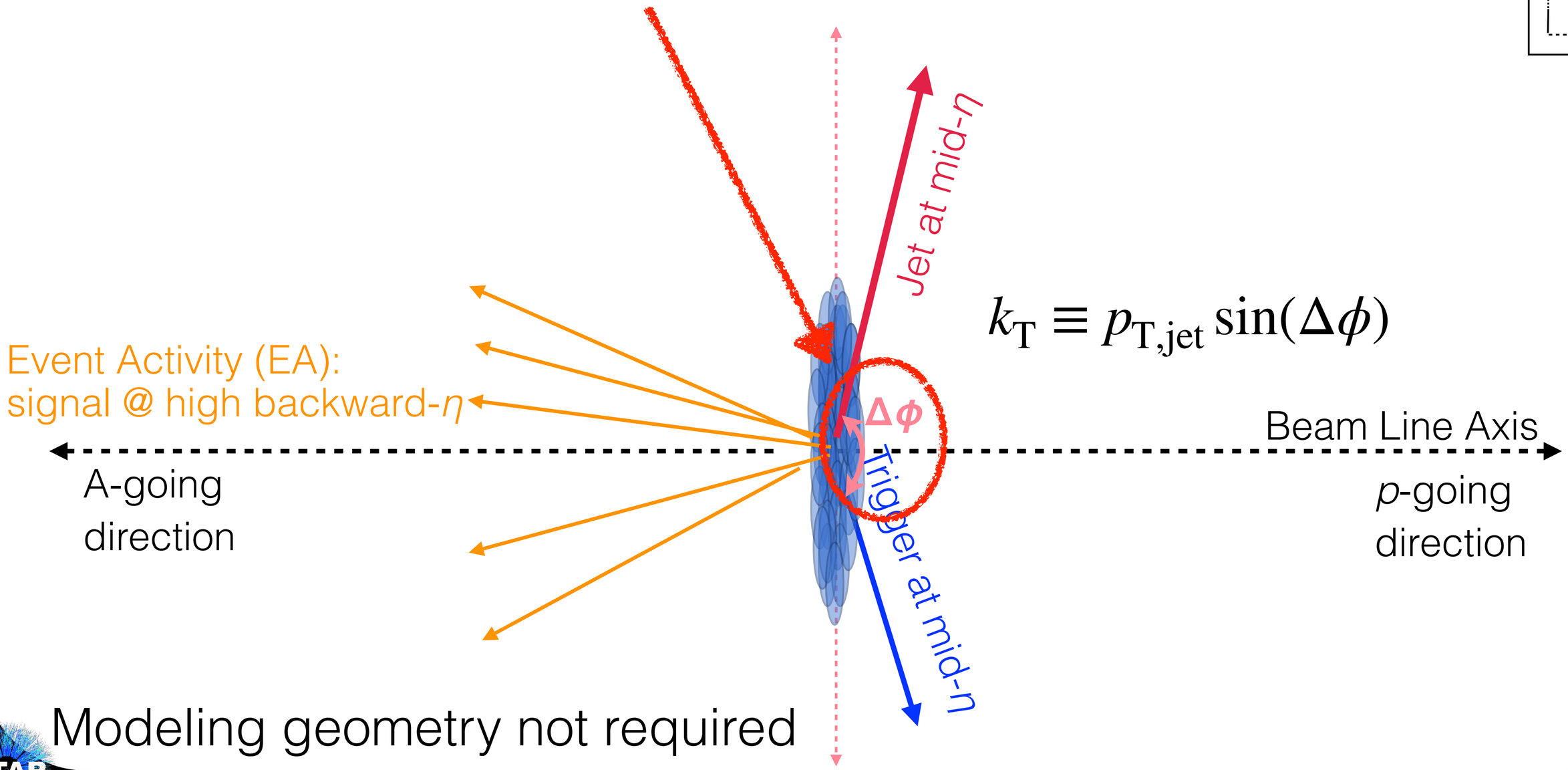
Semi-inclusive: Acoplanarity & dijet k_{T}

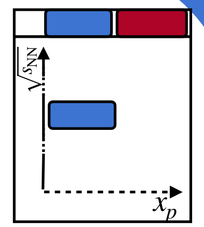




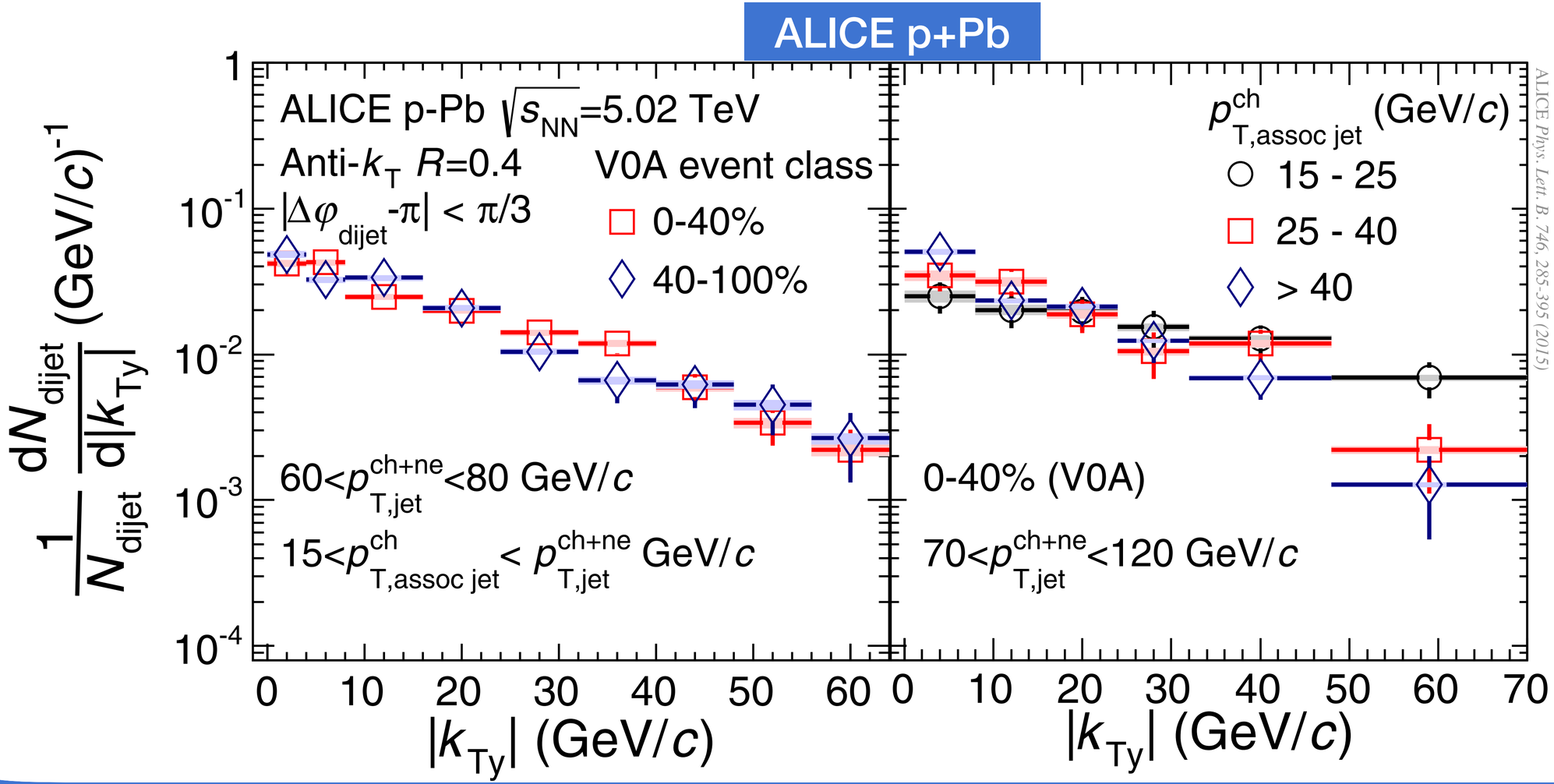
$$k_{\mathrm{T}} \equiv p_{\mathrm{T,jet}} \sin(\Delta\phi)$$

Modeling geometry not required

Dijet momentum balance $k_{T,}$ normalized per dijet

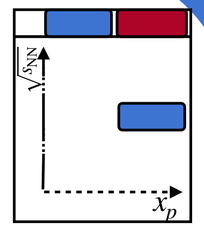


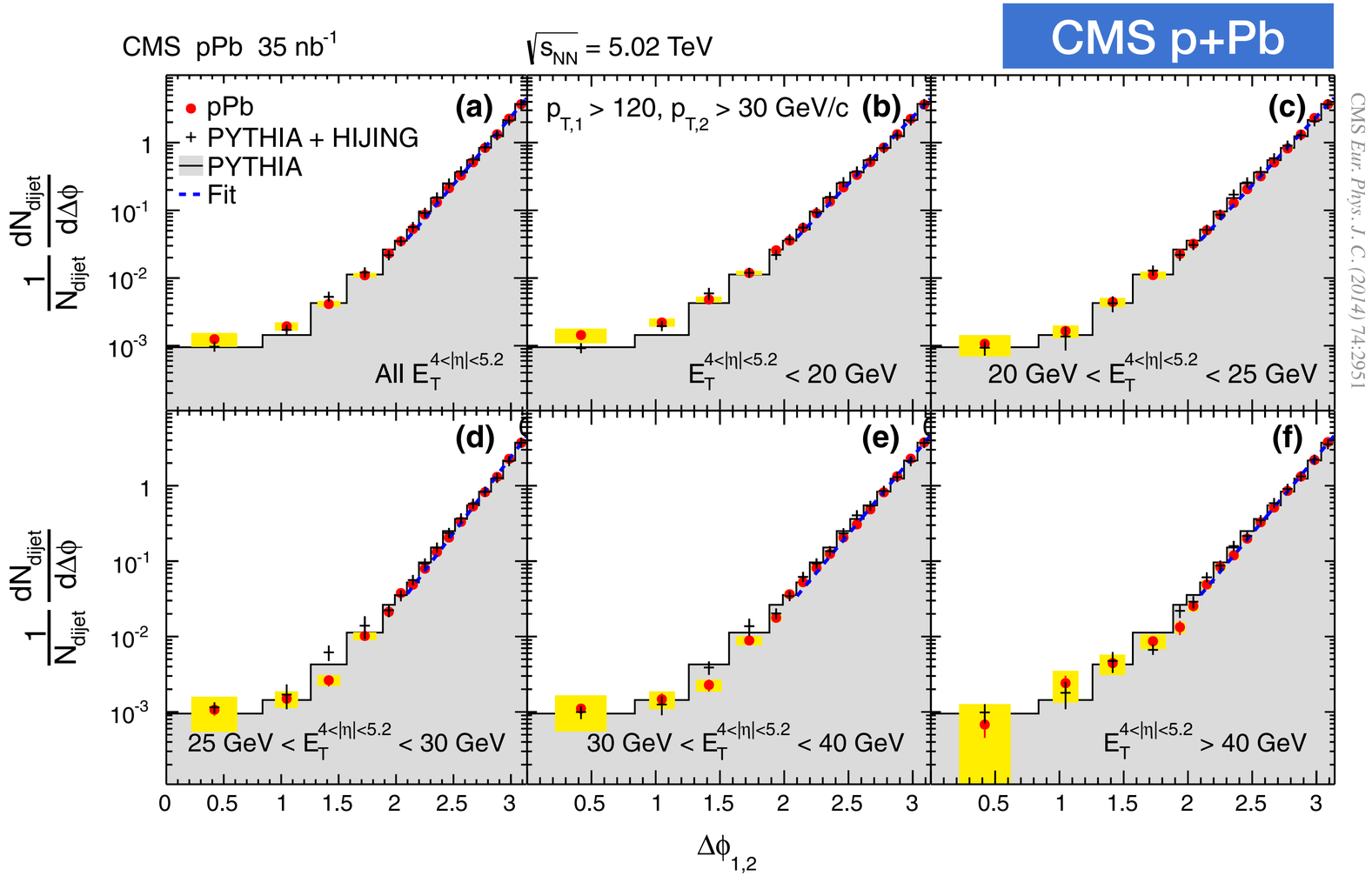
2015: EA binned *p*+Pb dijet k_T not modified



Inclusive dijet acoplanarity

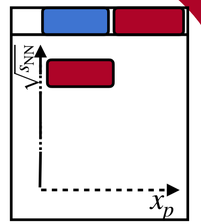
2014: *p*+Pb dijet acoplanarity no modification



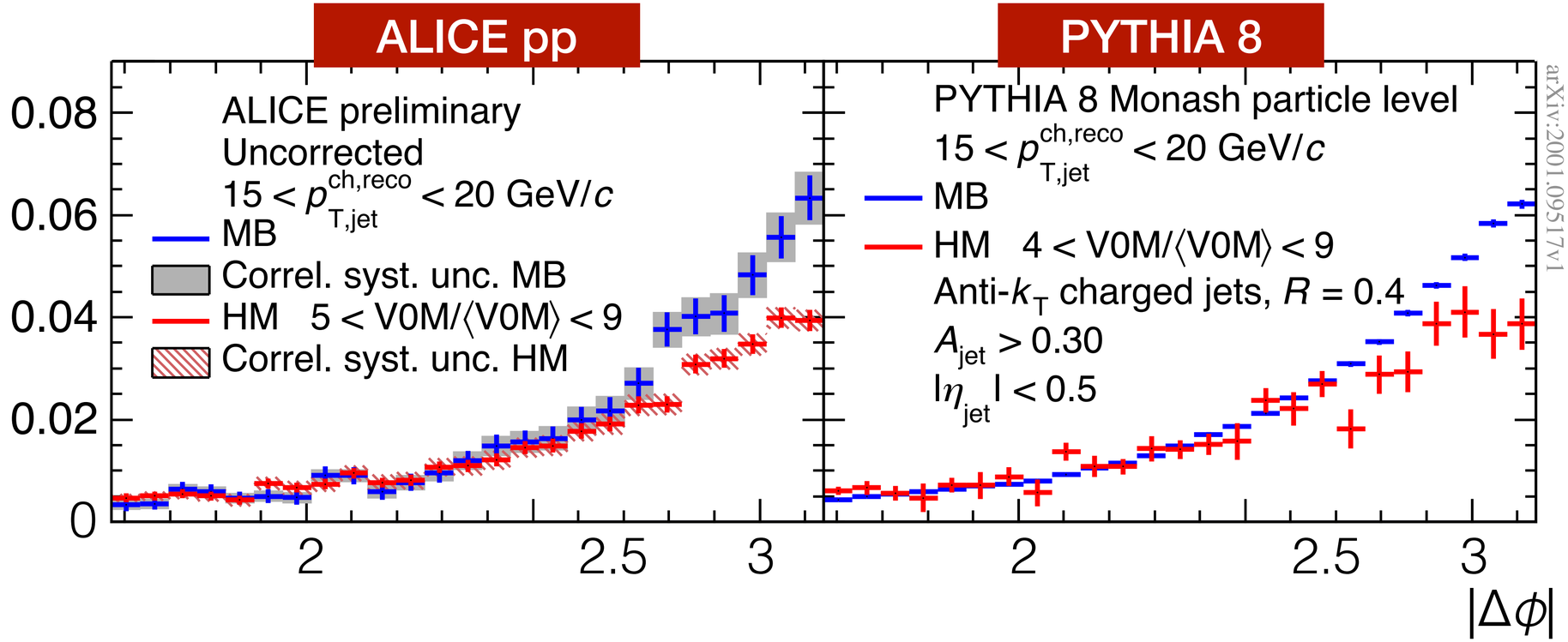


CMS *Eur. Phys. J. C.* (2014) 74:2951

Semi-inclusive Acoplanarity

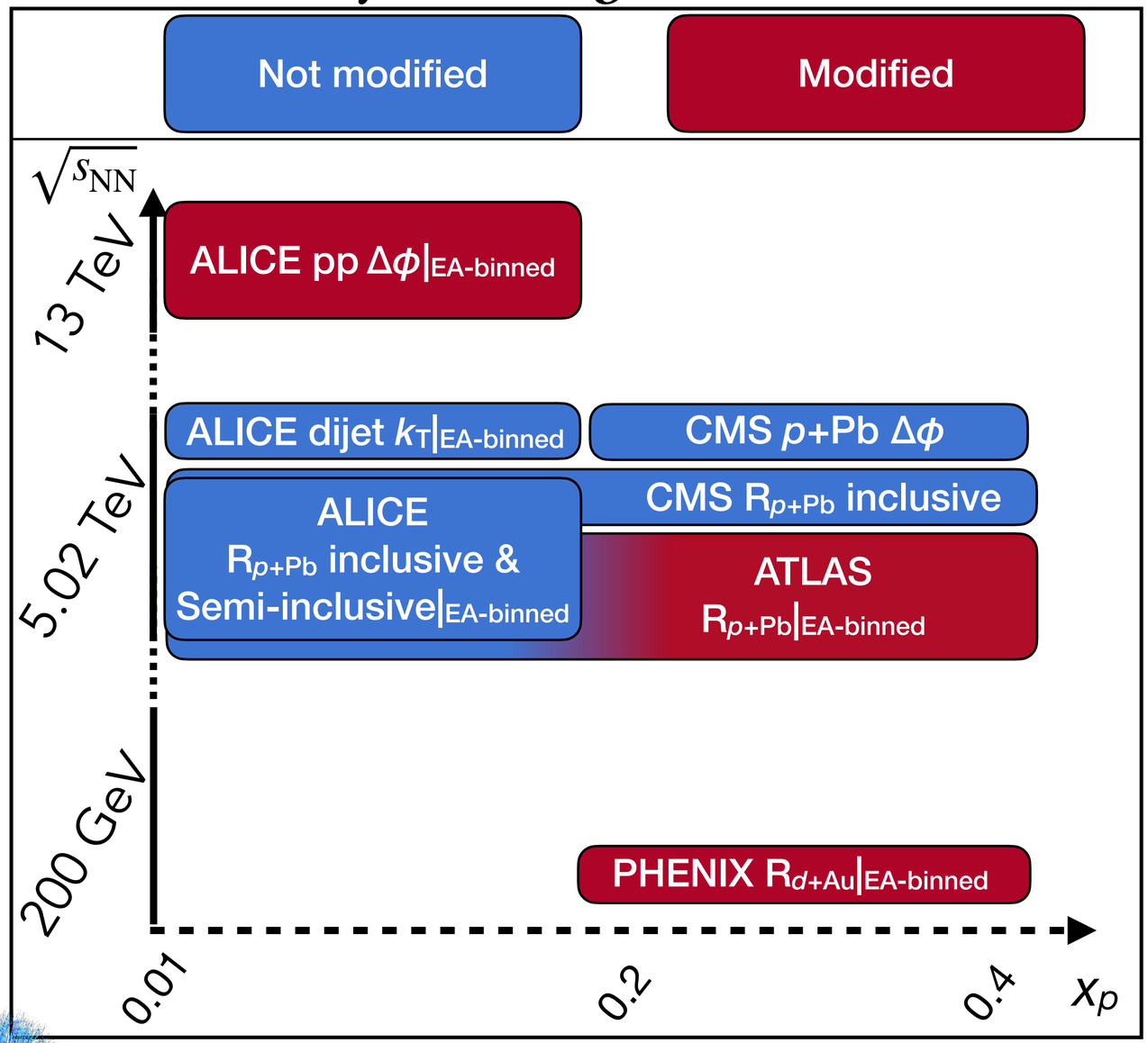


2019: High-EA *pp* acoplanarity broadening of recoil peak



PYTHIA simulation in qualitative agreement with data

Small system jet modification score card



- Inclusive yields scale with *pp* collisions
- Determining geometry via EA non-trivial†
- Modification at high, but not low, x_p‡
- Low-x_p semi-inclusive measurement sets jet energy loss limit which is violated by high-x_p measurements
- k_T inclusive and EA-binned not modified
- Low-x_p acoplanarity (Δφ) shows EA dependence

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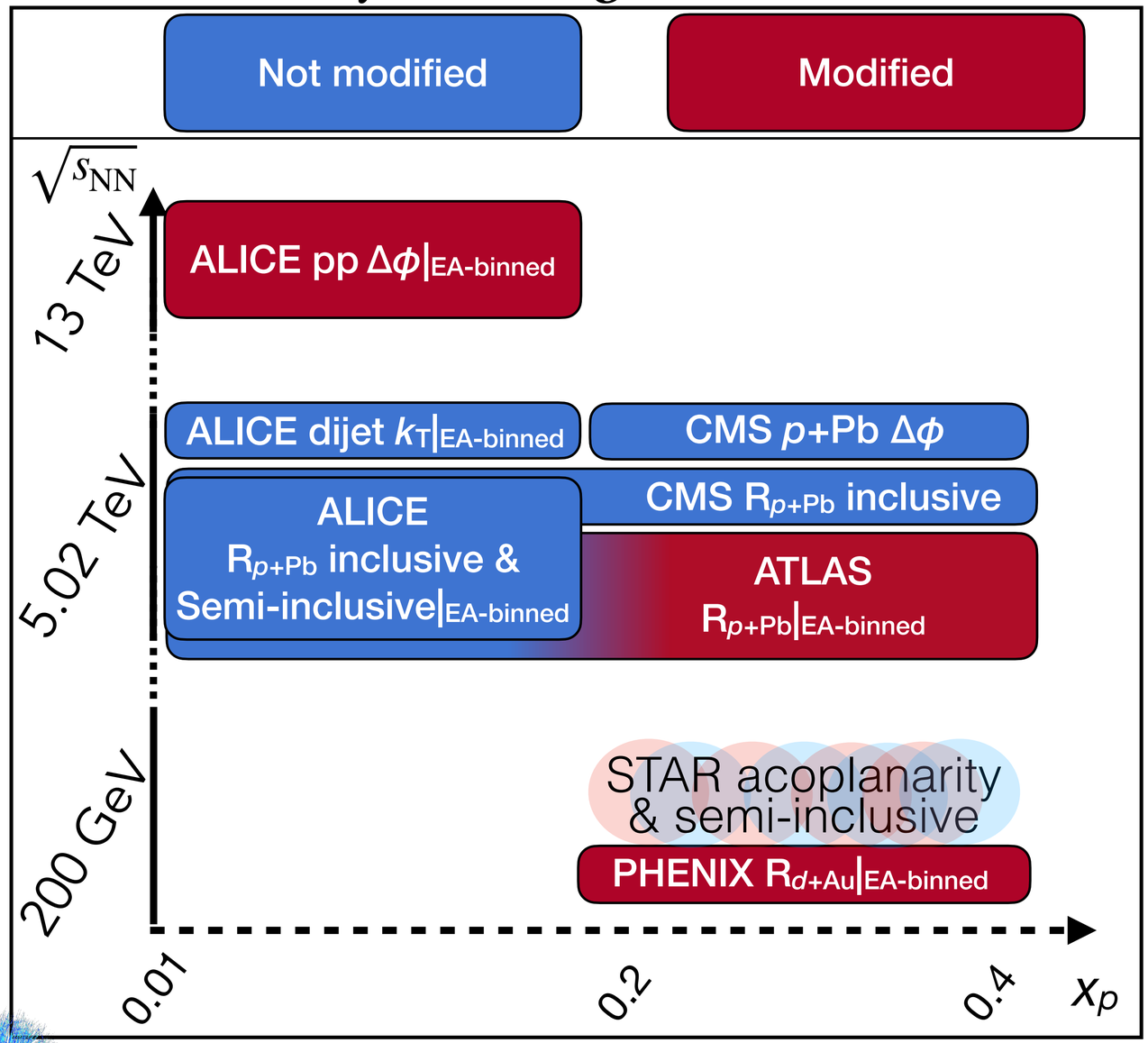

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- k_T inclusive and EA-binned not modified
- Low-x_p acoplanarity ($\Delta\phi$) shows EA dependence
- EA-binned results at high x_p, RHIC energy? (This talk)

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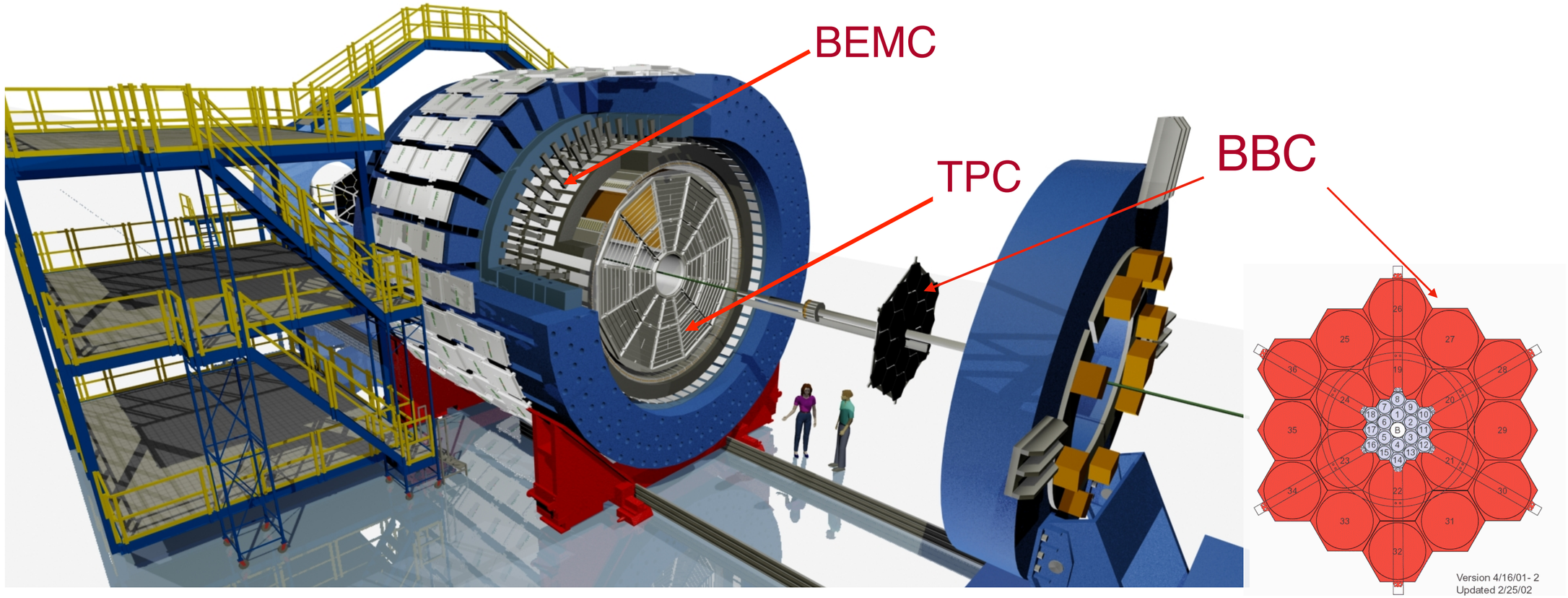
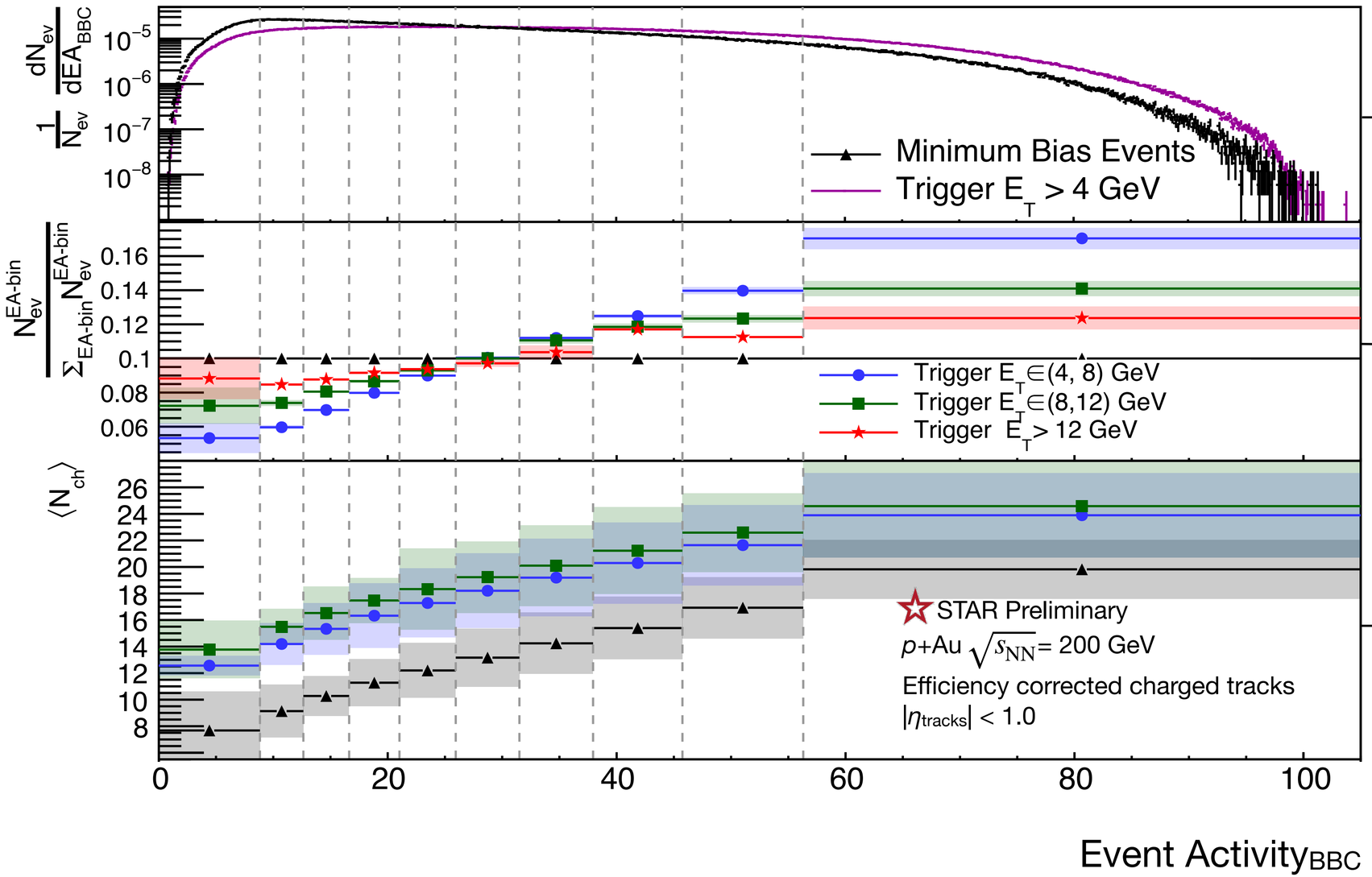
Jet and EA measurement at STAR



- Time Projection Chamber (TPC): charged tracks with η, ϕ, & p_T at $|\eta|<1.0$
- Barrel Electromagnetic Calorimeter (BEMC): energy deposition, primarily neutral particles at $|\eta|<1.0$
- Beam Beam Counter (BBC): plastic scintillators in two rings: $2<|\eta|<3.4$ and $3.4<|\eta|<5.0$
- BBC, in Au-going direction, corrected for vertex position along the beam direction and luminosity, is EA estimator

Au-going BBC at STAR works as EA estimator



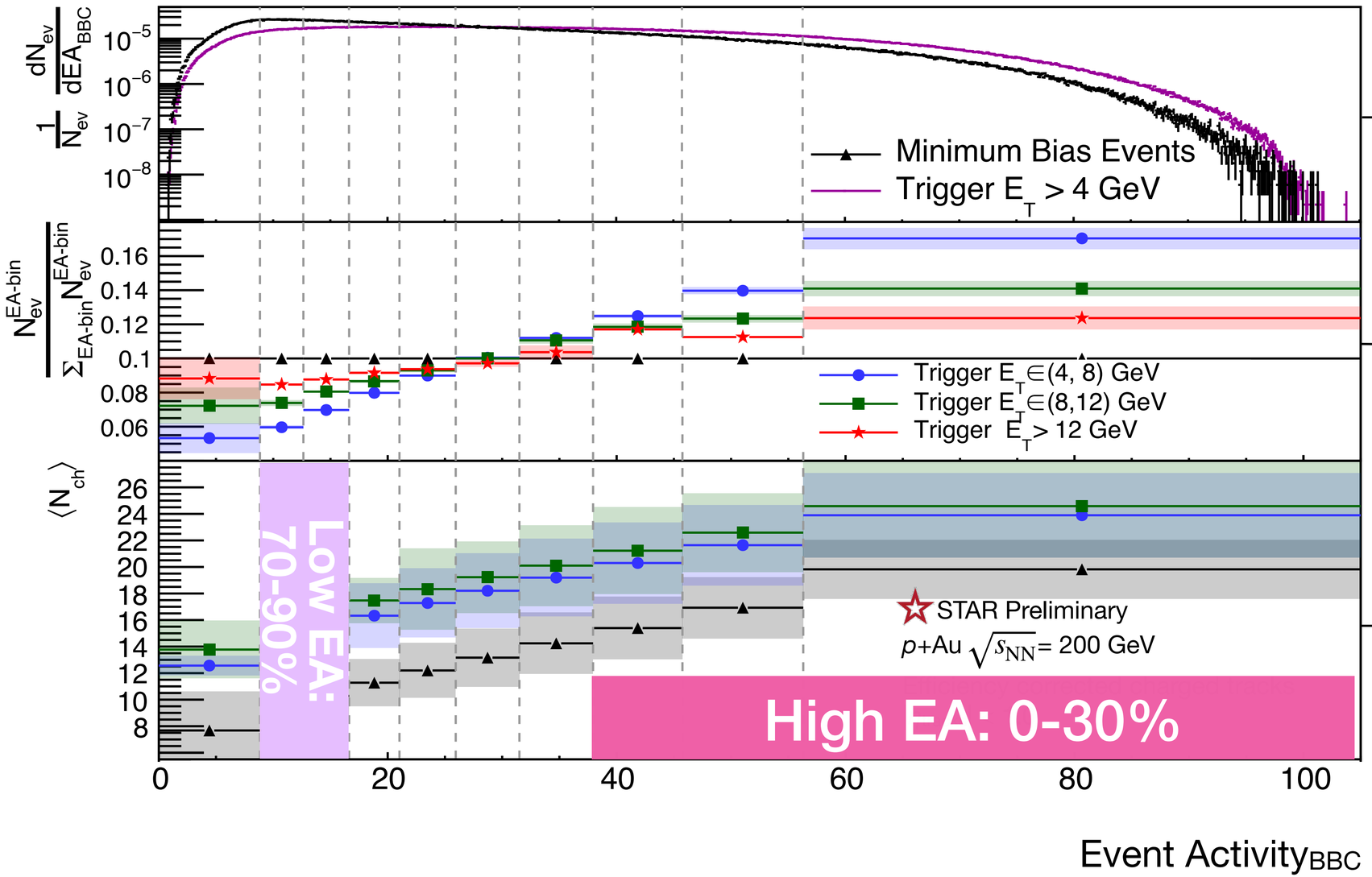
- Trigger from BEMC
- Charged tracks in the TPC

- More activity at BBC → more likely to find a trigger in TPC
- Trend decreases towards turnover for harder triggers†

- More activity in BBC → more charged tracks in TPC → BBC good EA-estimator for mid-η

†See CMS corollary result in extra slides

Au-going BBC at STAR works as EA estimator



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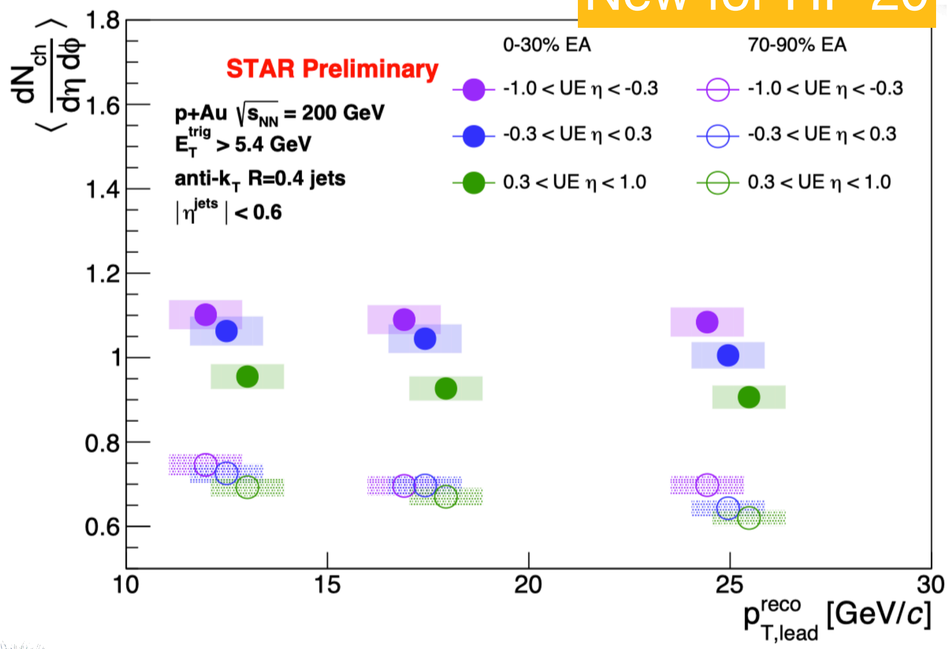
Charged Tracks to Jets

- Jets:
  - anti-k_T
  - R=0.4
  - $|\eta|<1$
- Binned in $\Delta\phi$ in $\pi/8$ slices from the trigger
- Jet spectra *(S)* presented in this talk are raw uncorrected, detector level
- Tracking efficiency is EA-independent & **negligible underlying event**
  - $S_{0-30\%\mathrm{EA}} / S_{70-90\%\mathrm{EA}}$ expected to be insensitive to corrections

New for HP'20



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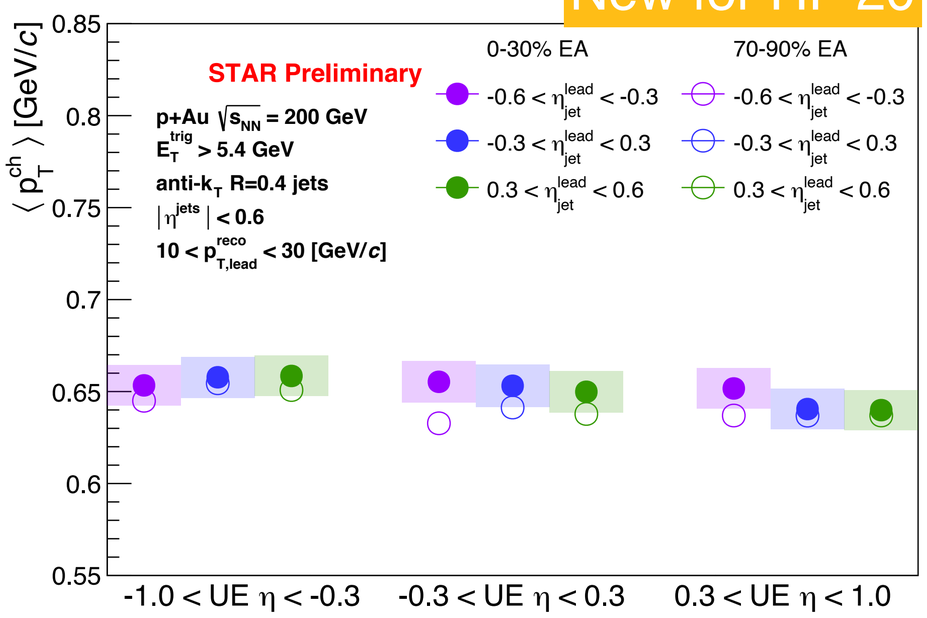
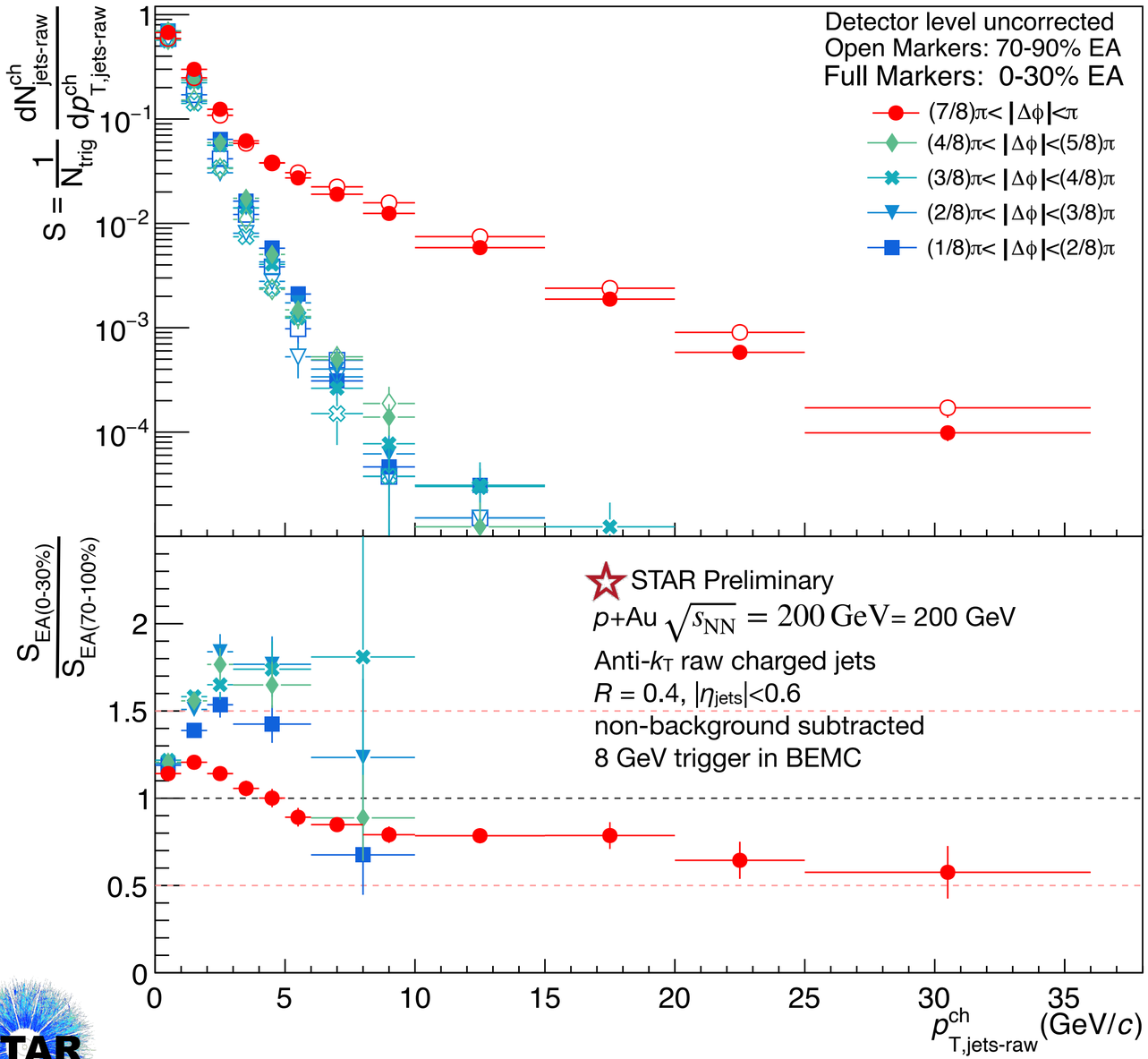


NEW FOR HP'20
Poster Session:
Poster 249
By: Veronica Verkest

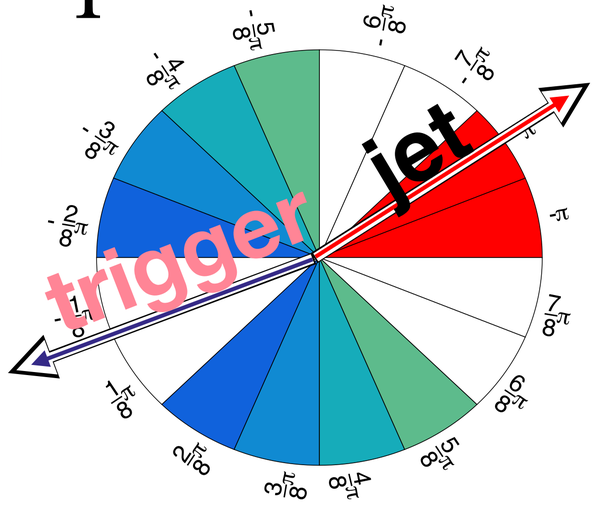
- Mean underlying event (EA) of about 1 particle at about 650 MeV/c per unit $\eta\phi$
- Refer to poster for:
  - EA and UE correlations to mid-η hard scatterings
  - High p_T events vs. dijet events

Suppressed recoil & negligible transverse spectra



Open Markers: Low EA: 70-90%

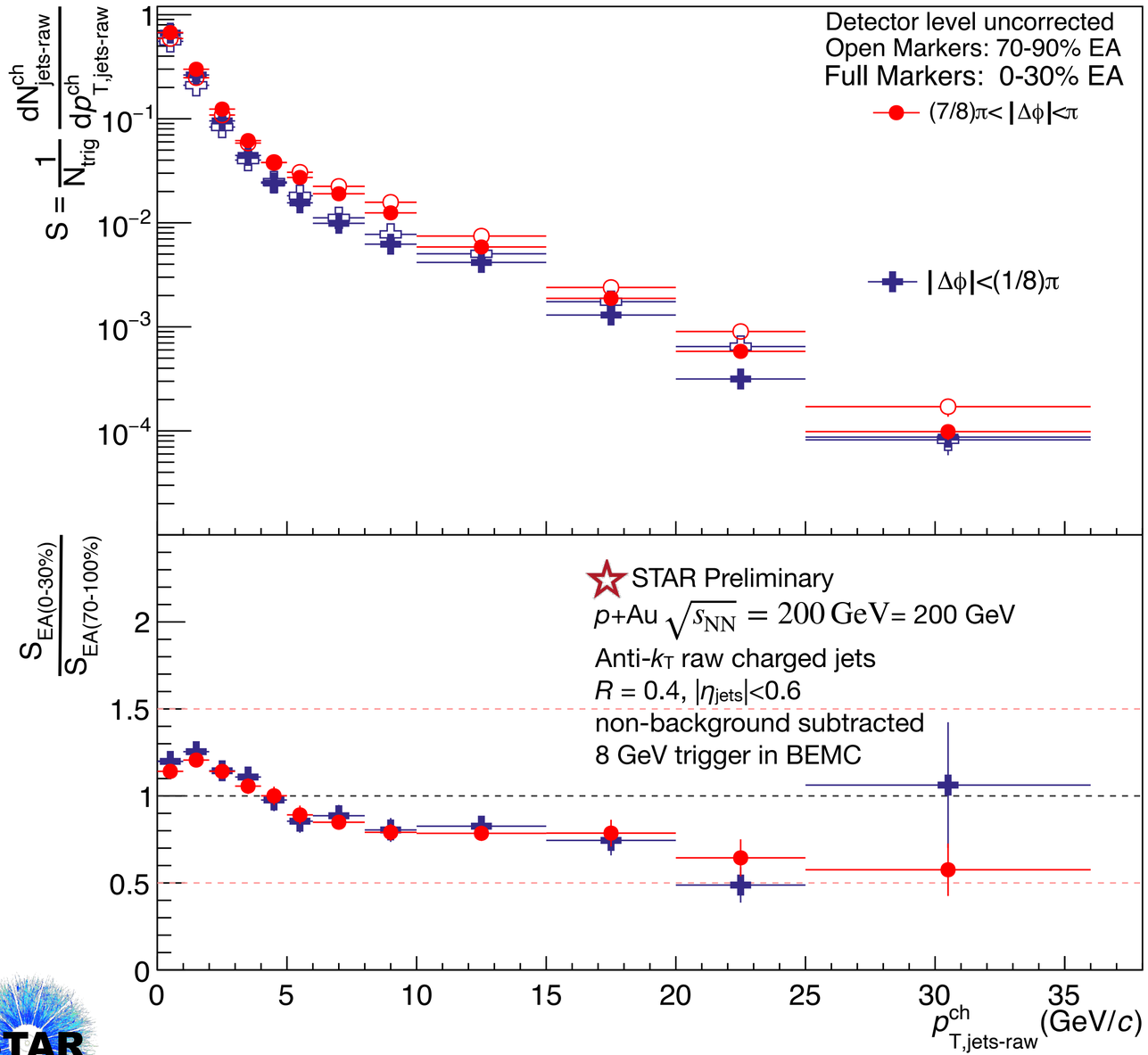
Full Markers: High EA: 0-30%



- At "jet-like" p_T (>~8 GeV/c) transverse $\Delta\phi$ (background) negligible compared to recoil spectra

  ➡ background correction negligible for $S_{0-30\%\mathrm{EA}}$ & $S_{70-90\%\mathrm{EA}}$

Both same-side and recoil spectra suppressed



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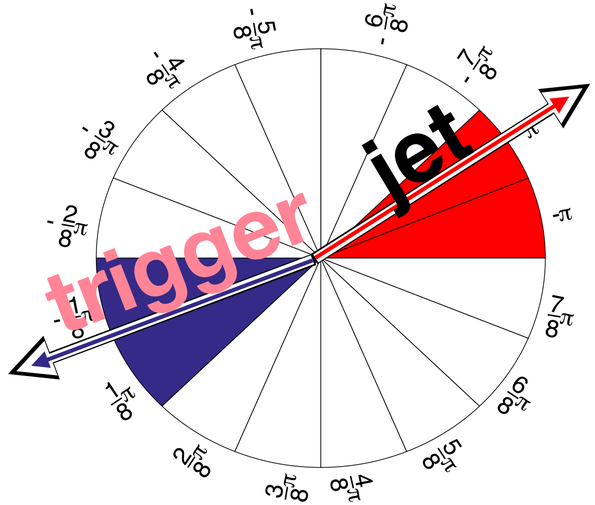
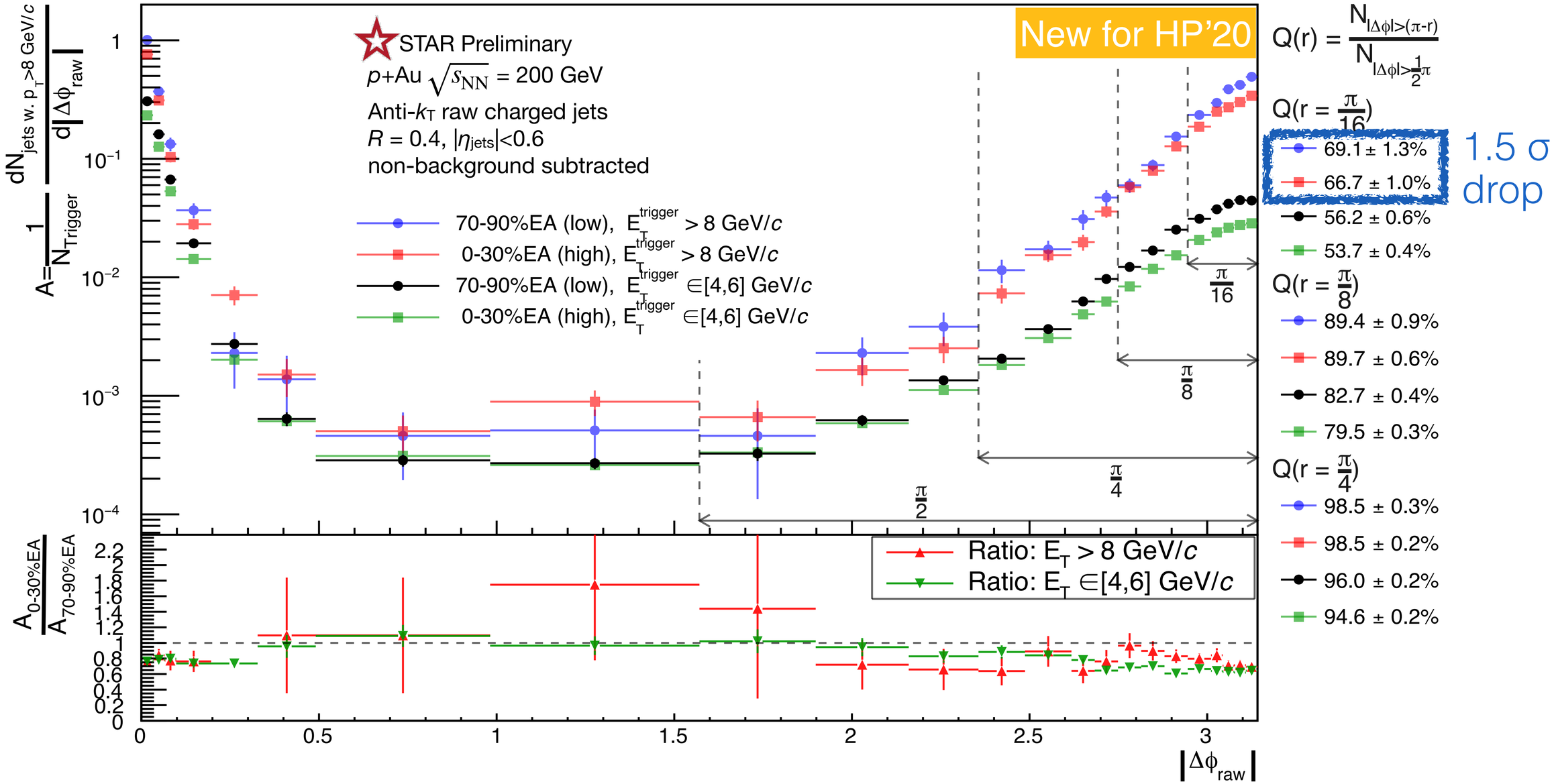
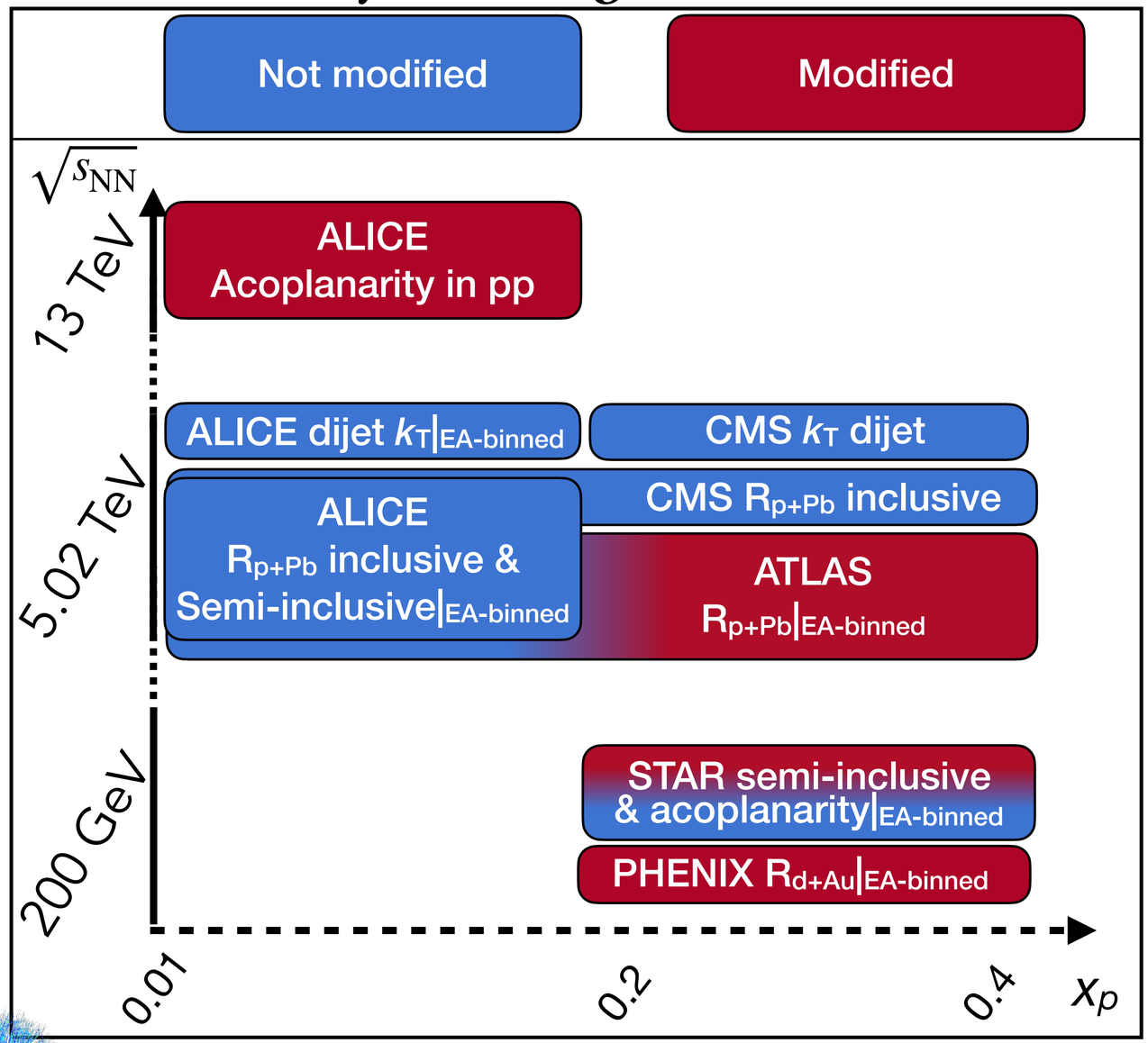


- Both near and recoil jets suppressed in high EA relative to low EA
- Qualitatively different from quenching in QGP in A+A collisions
  - In A+A collisions, away-side jets are preferentially more quenched due to trigger surface bias

Acoplanarity minimally modified by EA



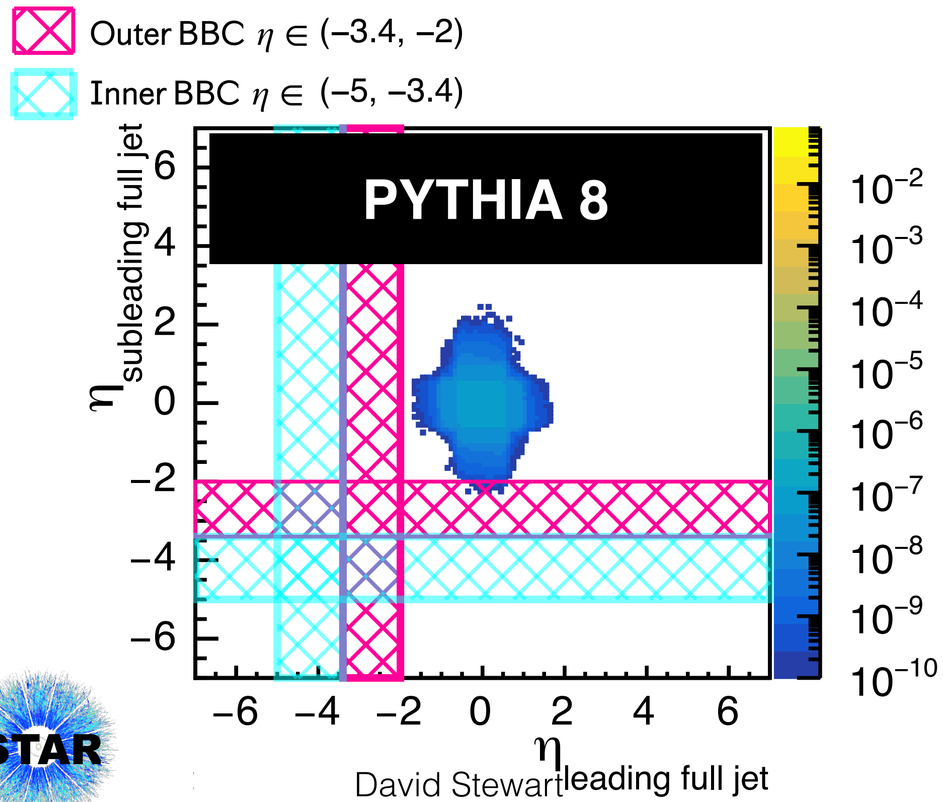
Small system jet modification score card



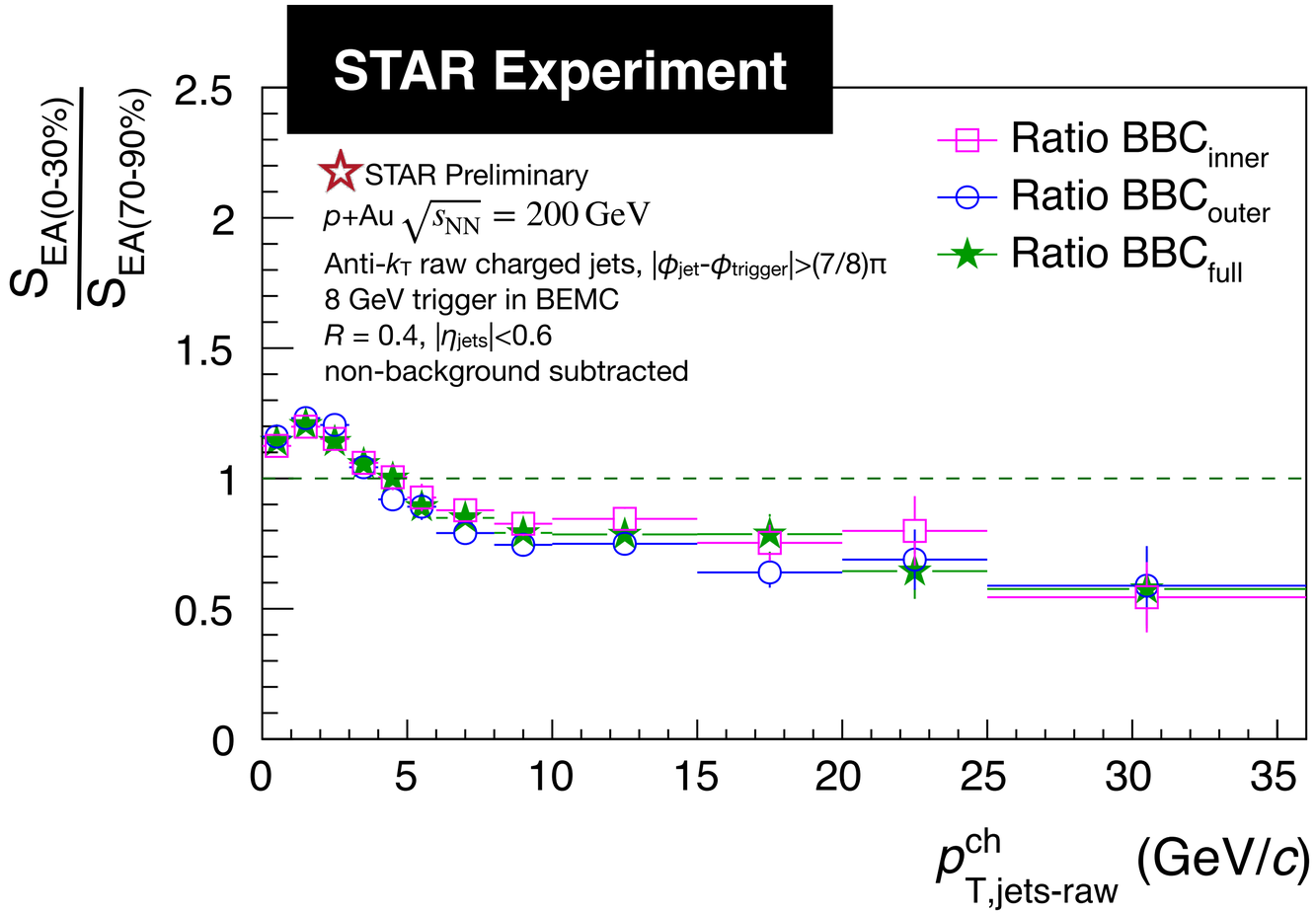
- 200 GeV *p*+Au collisions at STAR:
  - Marked suppression of high-EA recoil jet p_T spectra relative to low-EA spectra
  - Indication of broadening of recoil peak in acoplanarity
- Both STAR and ALICE results in qualitative agreement with PYTHIA
- Why does PYTHIA (which has no jet quenching) agree with the STAR results?

Spectra modification *not* due to dijets hitting BBC

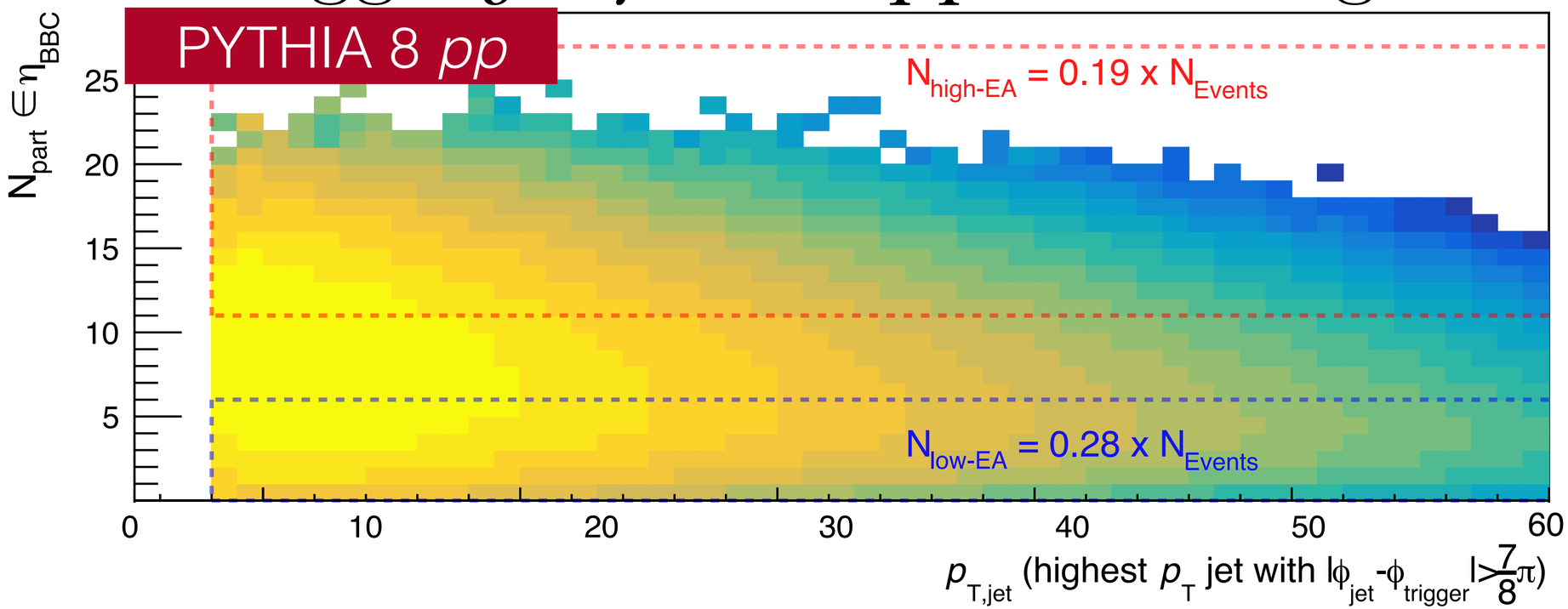
- In PYTHIA 8 (with 200 GeV *pp* collisions)
  - When an event has the required trigger particle and an 8 GeV/*c* jet, the outer BBC is rarely hit and, within the precision of the study, the BBC inner is *never* hit



- In experimental data, sorting EA by outer vs inner BBC did not change the jet spectra suppression



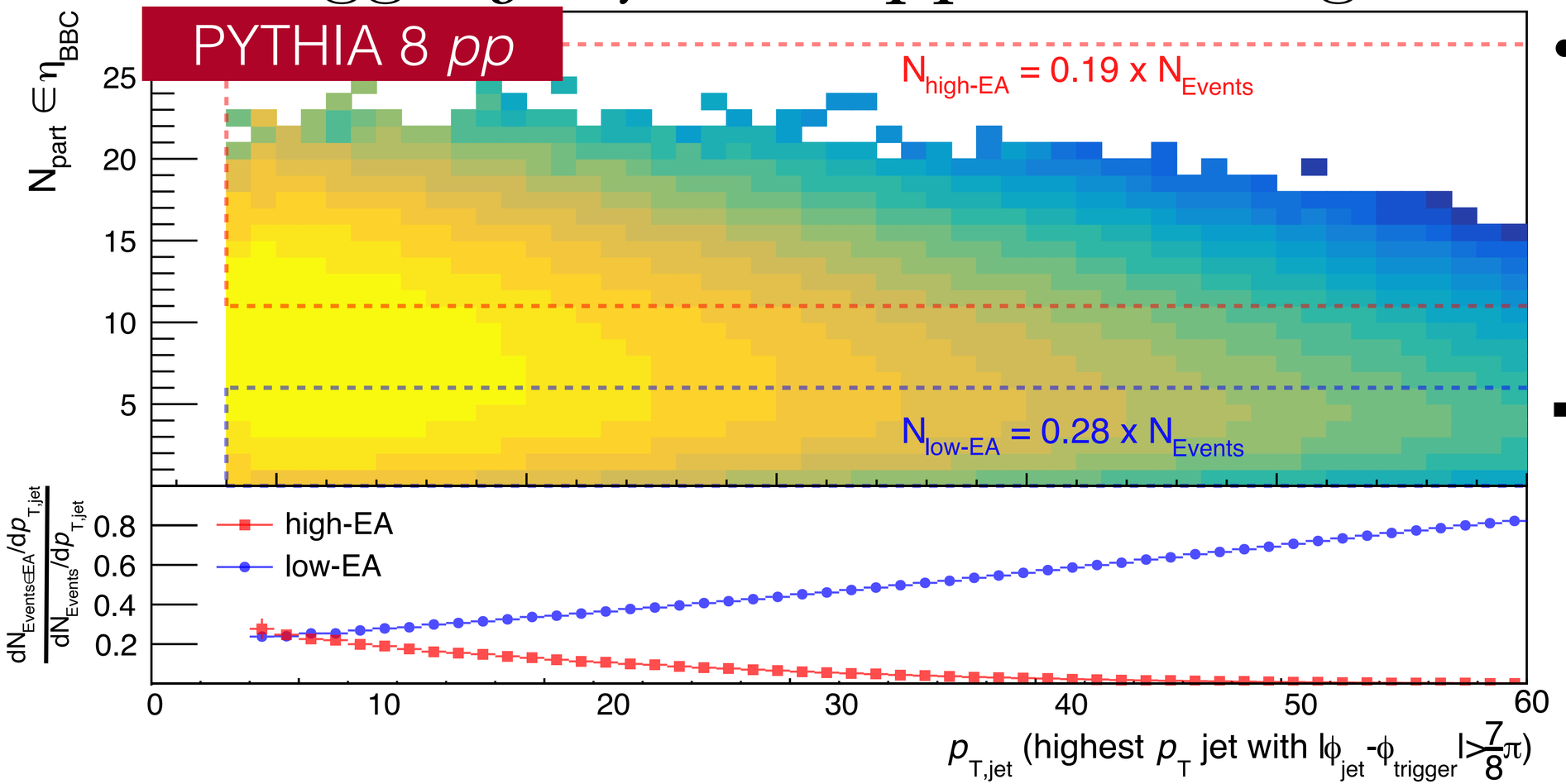
Per trigger jet yield suppressed: high-EA vs. low-EA



- PYTHIA 8 strongly correlates the p_T of the initial parton scattering (and therefore leading jet p_T)†

†Refer to backup

Per trigger jet yield suppressed: high-EA vs. low-EA



- PYTHIA 8 strongly correlates the p_T of the initial parton scattering (and therefore leading jet p_T)†

➡ Ratios of events in the high (low) EA bin drop (rise) dramatically with increasing leading $p_{T,jet}$

†Refer to backup

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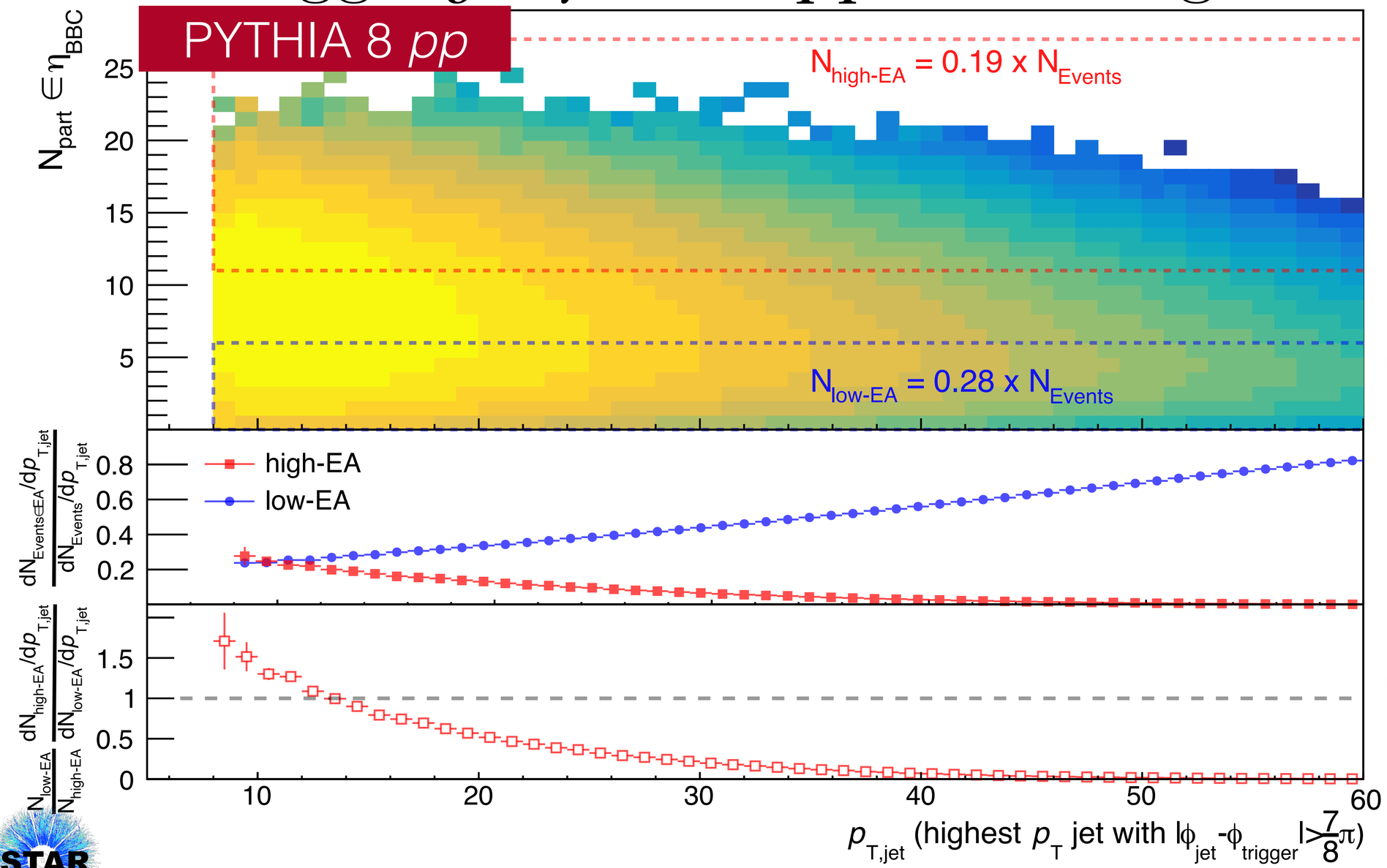


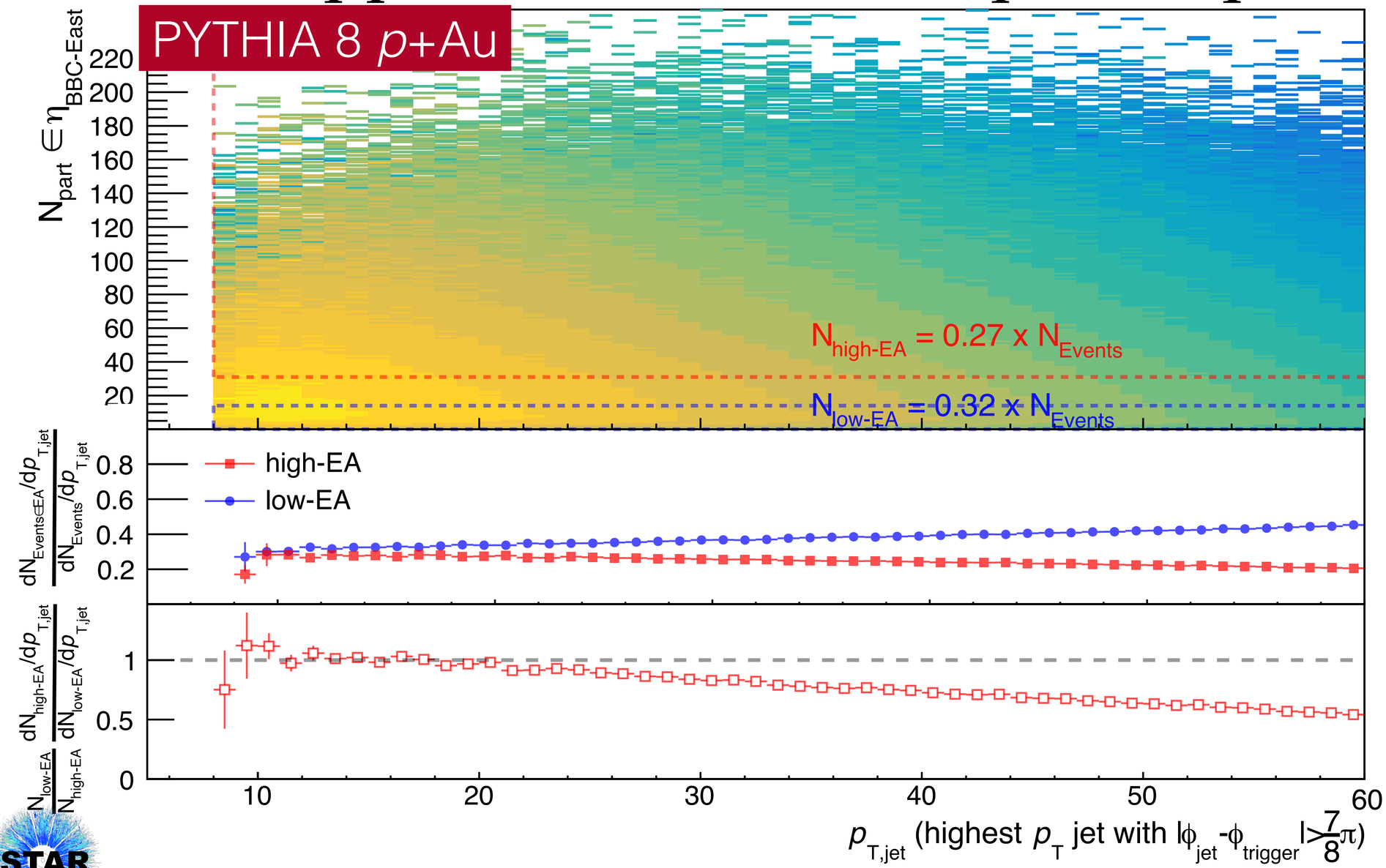
- PYTHIA 8 strongly correlates the p_T of the initial parton scattering (and therefore leading jet p_T)†

➡ Ratios of events in the high (low) EA bin drop (rise) dramatically with increasing leading $p_{T,jet}$

➡ Per trigger yield strongly suppressed in high-EA relative to low-EA

†Refer to backup

Less suppression: increased phase space in *p*+Au

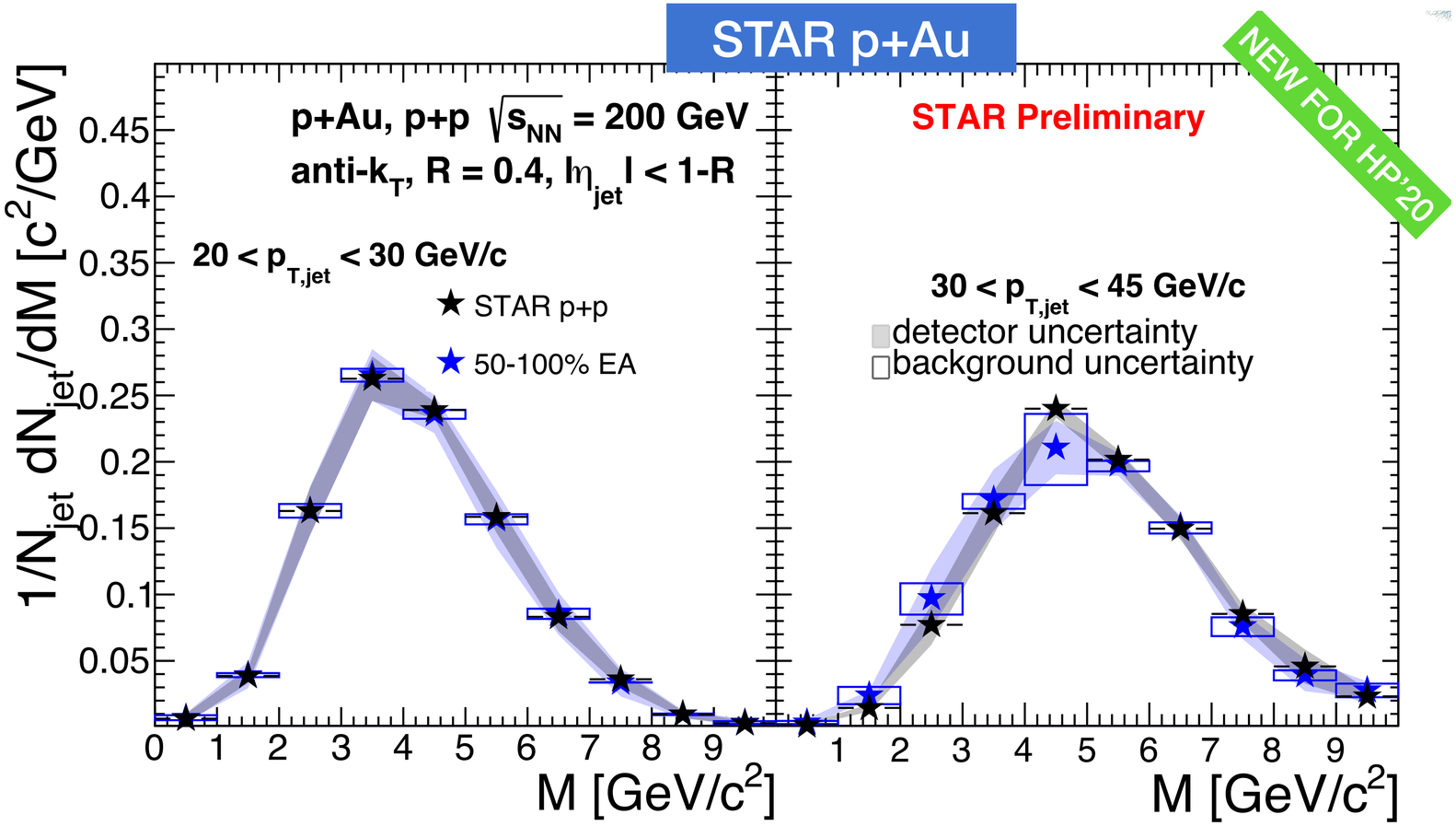


- PYTHIA 8 Angantyr heavy ion model predicts a smaller, but still significant suppression for *p*+Au collisions
- PYTHIA 8 acoplanarity results also less modified in *p*+Au than in *pp* collisions
- Are per-jet normalized observables modified?

†Refer to backup

Jet mass: Inclusive and EA-binned

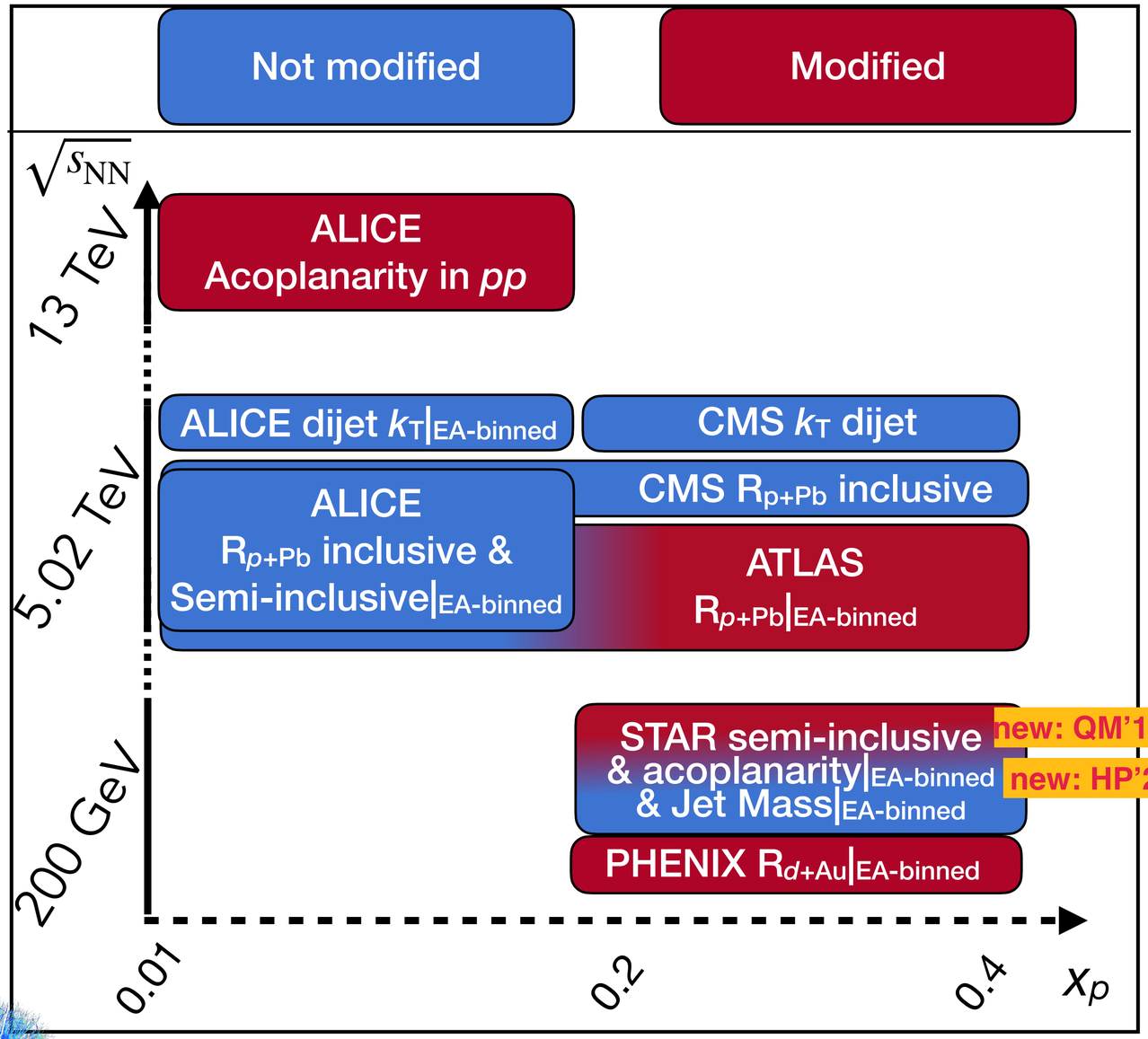
HP'2020: Jet mass distribution not modified



NEW FOR HP'20
3 June, 11:50 CDT (tomorrow)
Parallel: Jets and High Momentum Hadrons
Given by: Isaac Mooney

*see also ALICE inclusive p+Pb result from 2018; also not modified

Small system jet modification score card

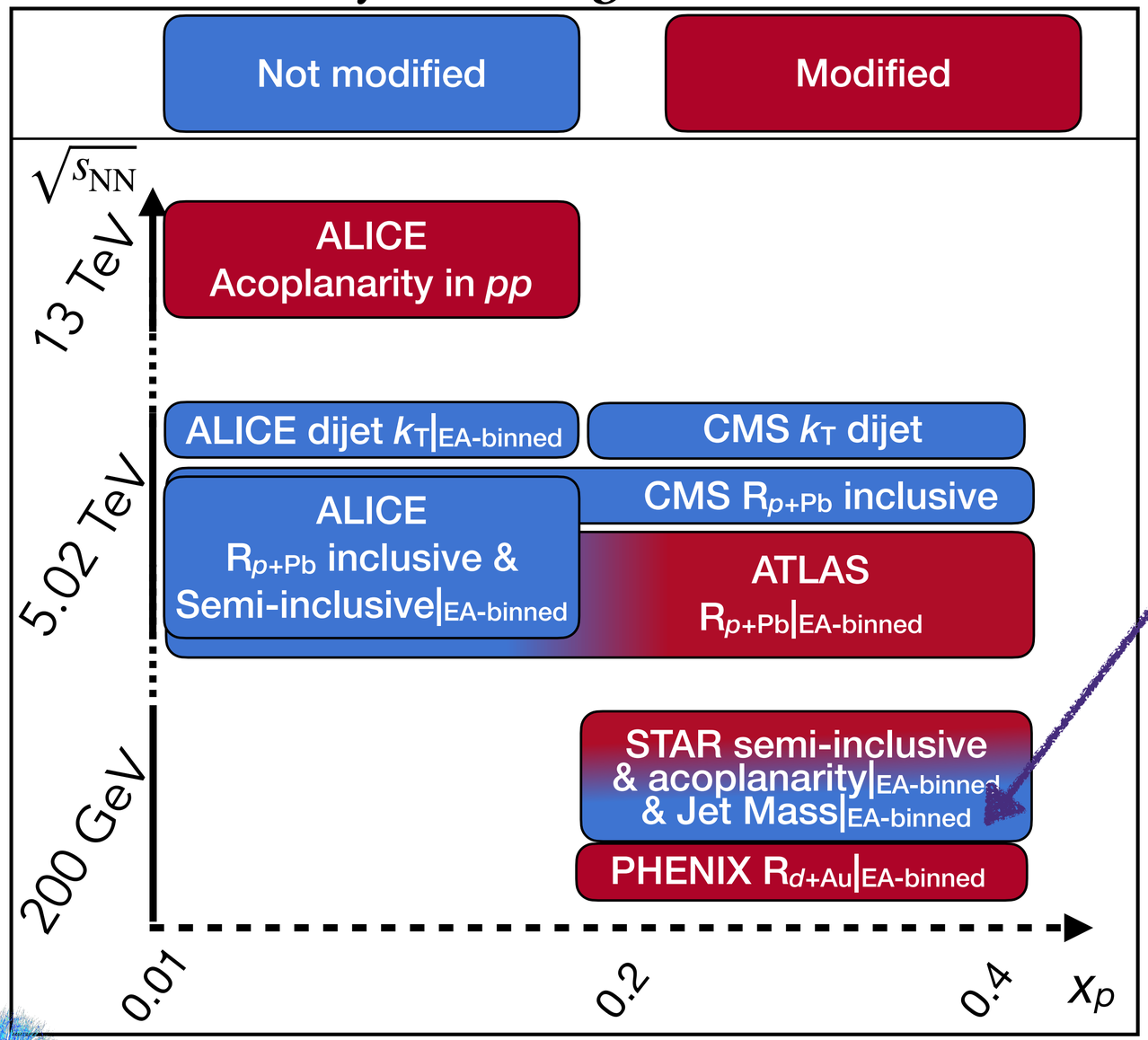


New STAR data in this presentation:

$\sqrt{s_{NN}}$ = 200 GeV, *p*+Au collisions

- Track correlations at $|\eta| \leq 1$ w/ EA at $\eta \in [-5,-2]$
  - Track multiplicity positively correlated
  - Trigger multiplicity positively, but increasingly weakly, correlated for 4, 8, and 12 GeV triggers
- Charged jet p_T spectra per trigger binned by high and low EA
  - High EA spectra strongly suppressed relative to low EA spectra
- Charged jet acoplanarity in high and low EA for 4-6 GeV and 8-30 GeV triggers
  - Acoplanarity minimally modified

Small system jet modification score card



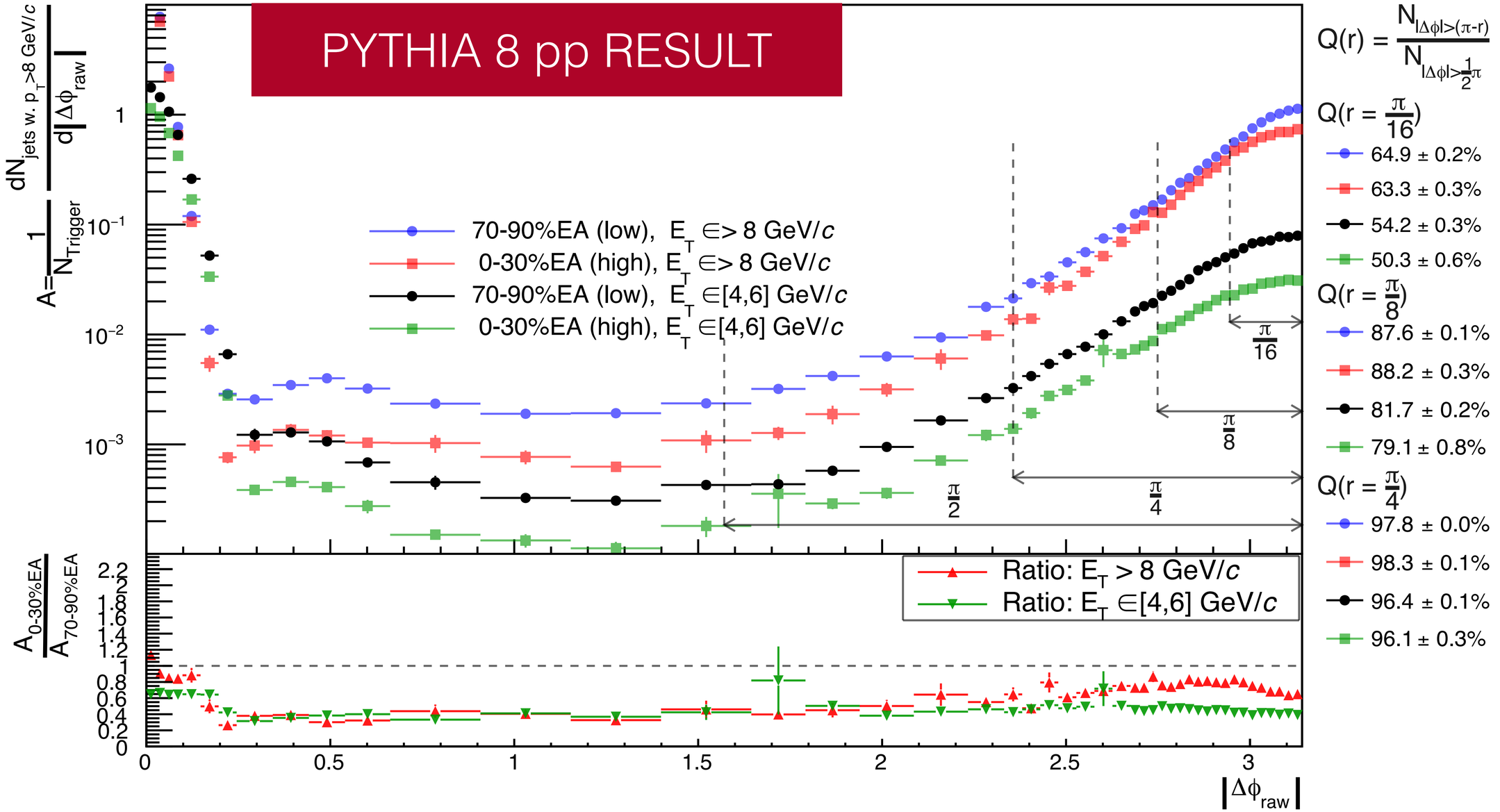
At $\sqrt{s_{NN}}$ = 200 GeV

- PYTHIA 8 suggests that phase space restrictions anti-correlate mid-η jet p_T with high-η EA
- Explains semi-inclusive p+Au results?
- No jet mass modification
- Predict dijet momentum balance and other jet substructure observables EA independent
- More studies to come

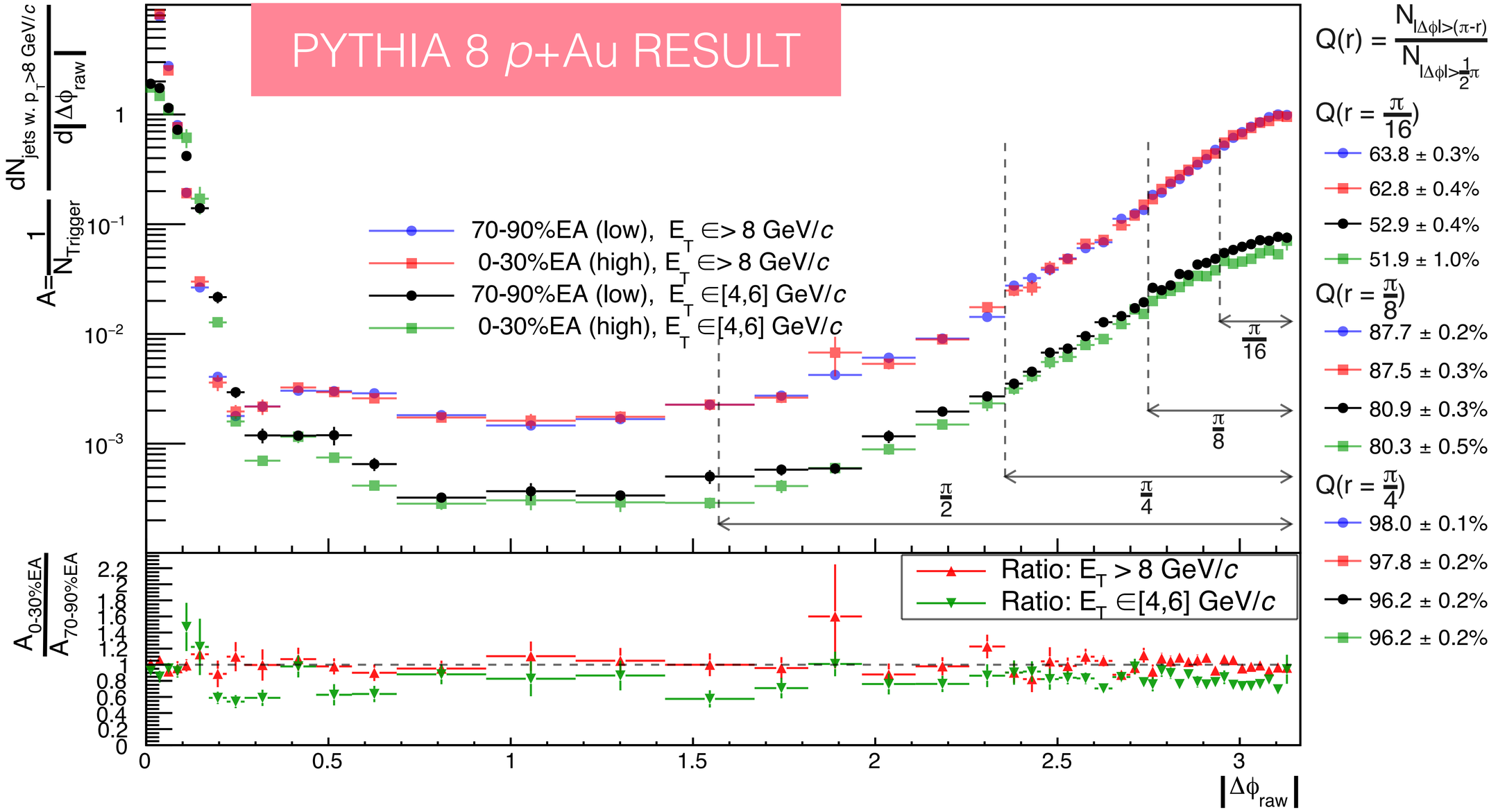
Thank you!

Extra Slides

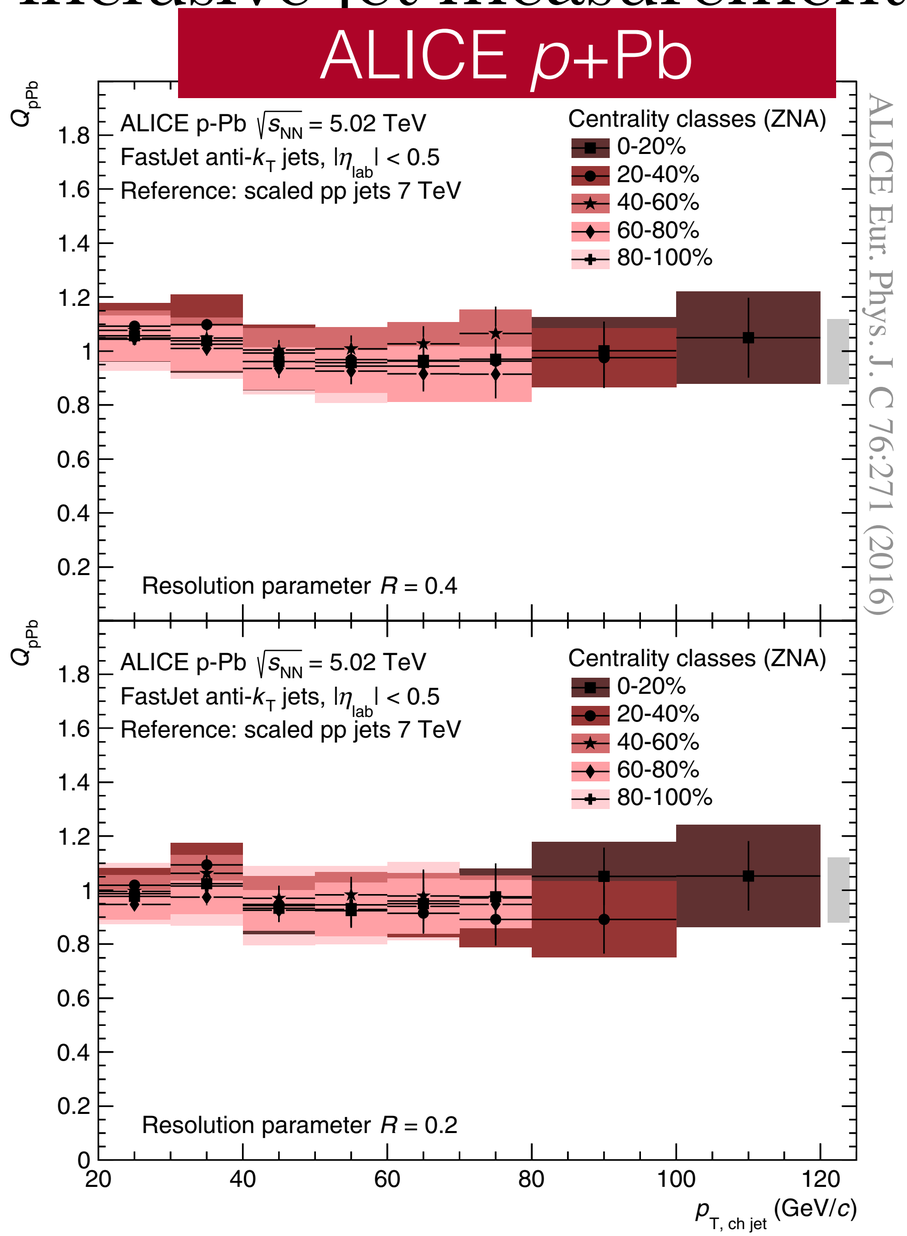
PYTHIA 8 acoplanarity away-side suppression more significant



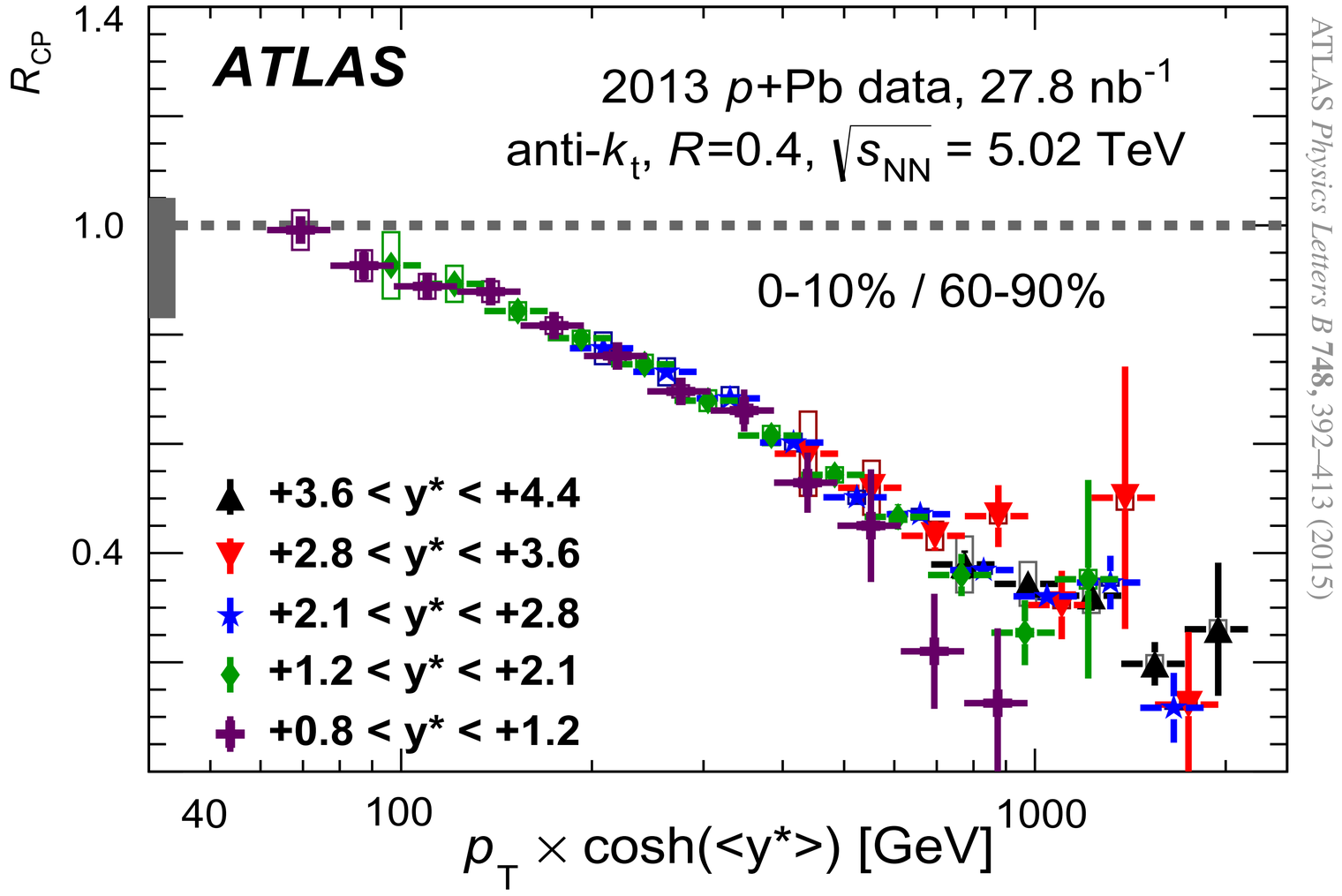
PYTHIA 8 p+Au acoplanarity away-side suppression similar to data



ALICE EA-binned inclusive jet measurement consistent with unity



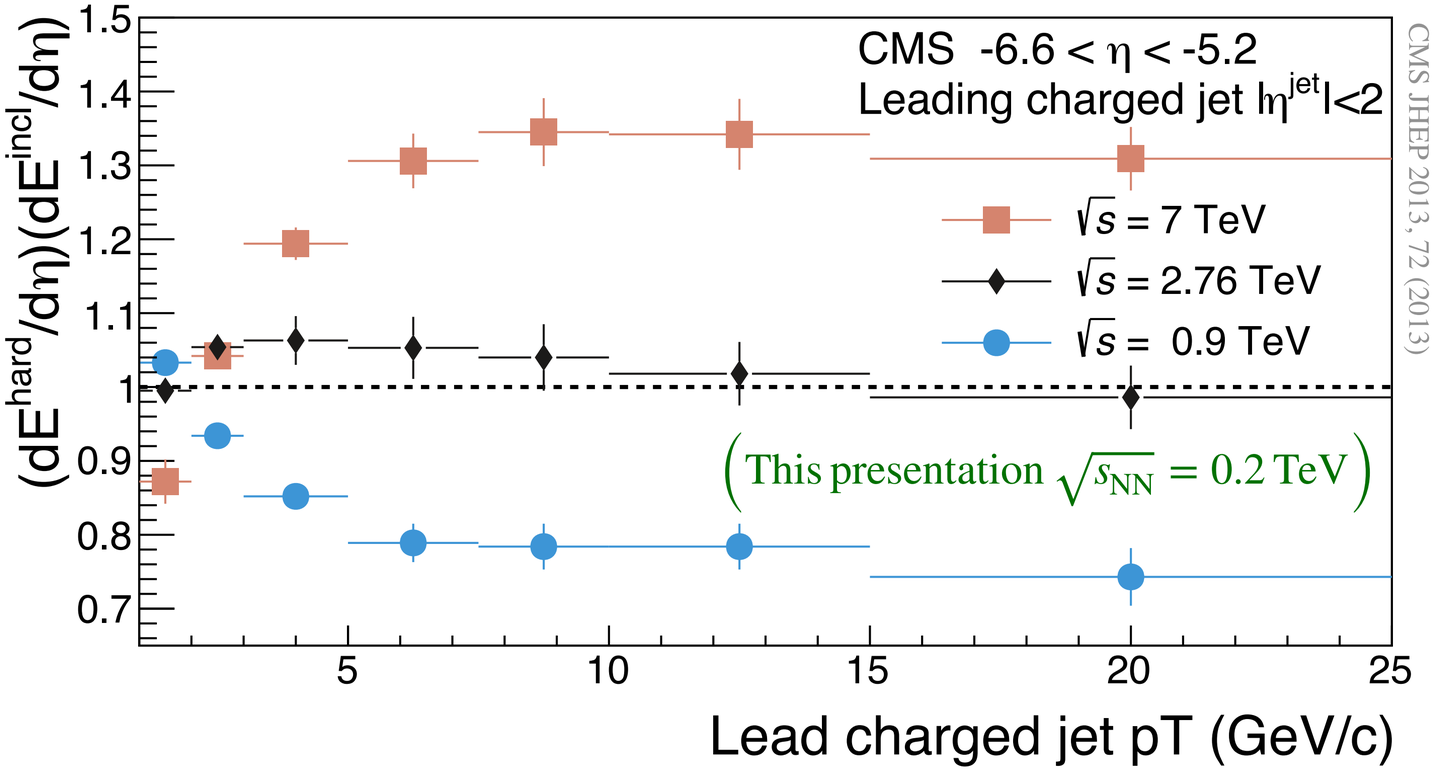
ATLAS Pb-going R_{CP} indicate x_p scaling physics



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

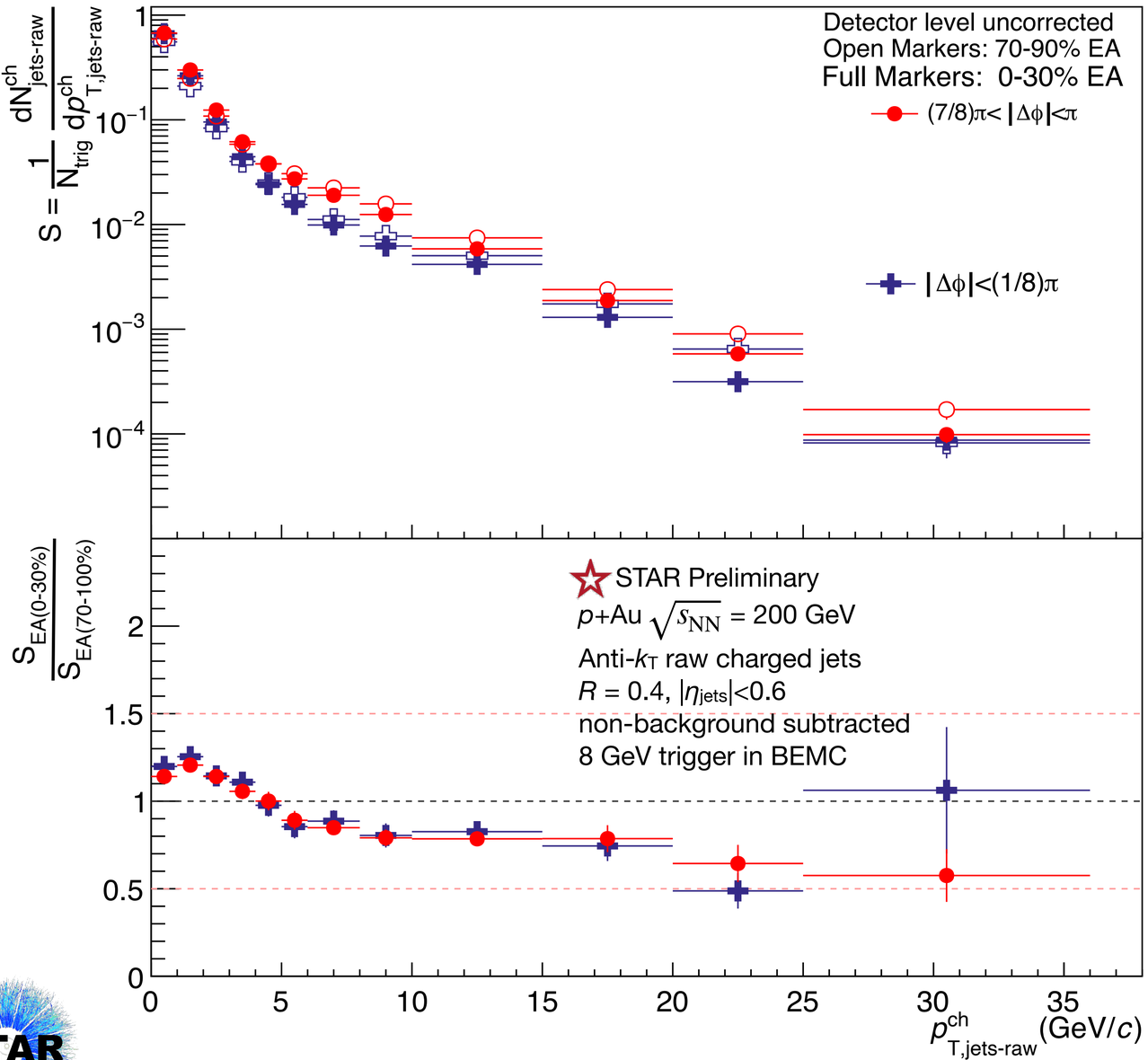
CMS lead $p_{T,jet}$ correlation to high backward-η EA

- CMS measured energy deposition at $\eta \in$ [-6.6,-5.2] as a function of leading charged jet p_T at $|\eta| < 2$
- Found for increasing mid-η jets:
  - Enhancement in 7 TeV collisions
  - Slight enhancements that turn over in 2.76 TeV collisions
- Suggested in study of possible cause of energy conservation
- Naively, would artificially suppress EA classification of events with hard mid-η jets



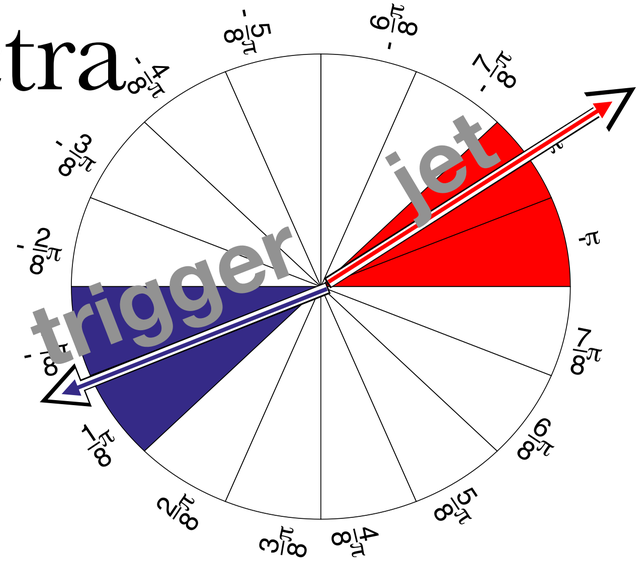
CMS JHEP 2013, 72 (2013)

NEF modifies near-side vs awayside spectra



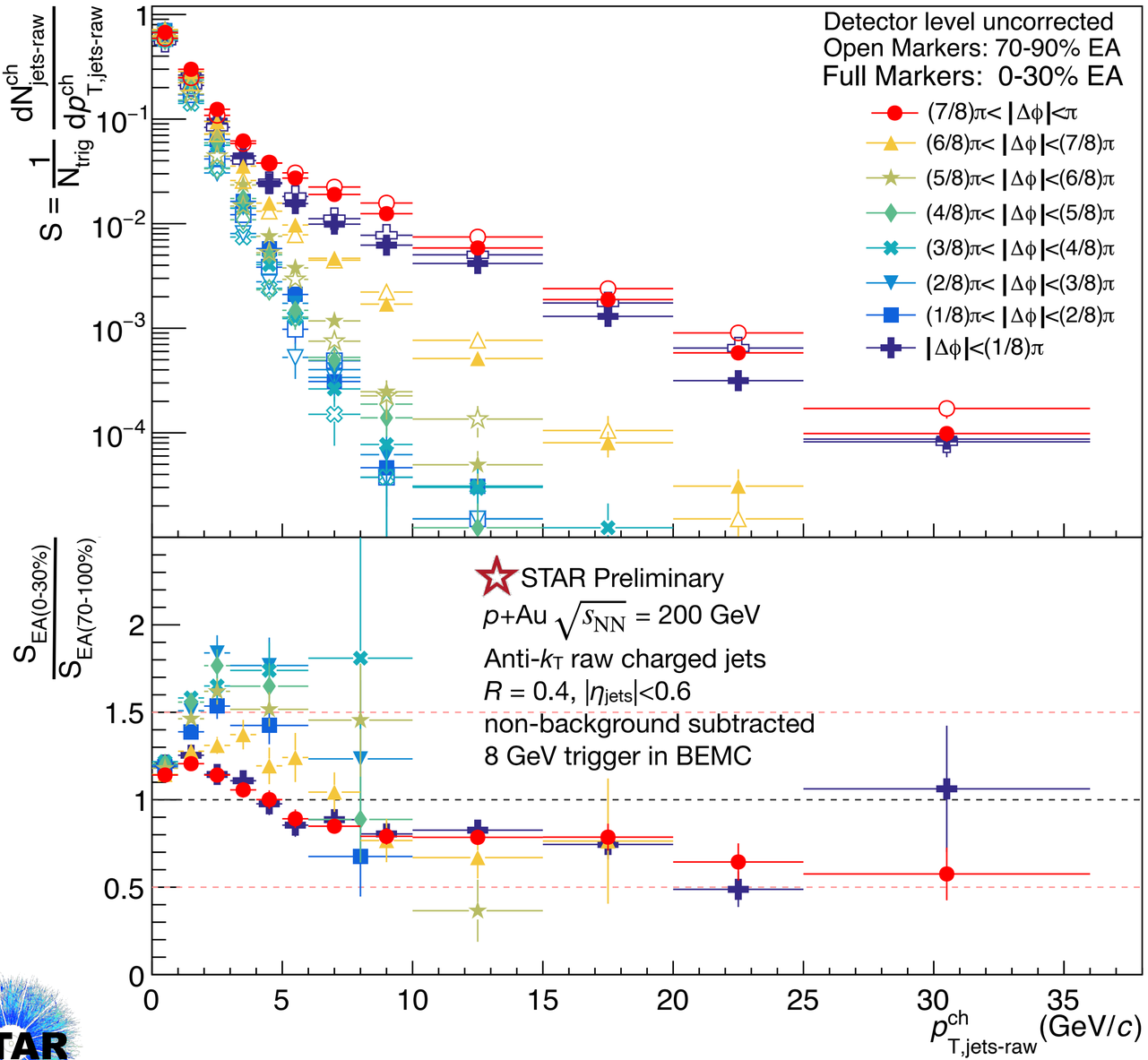
Open Markers: Low EA: 70-90%

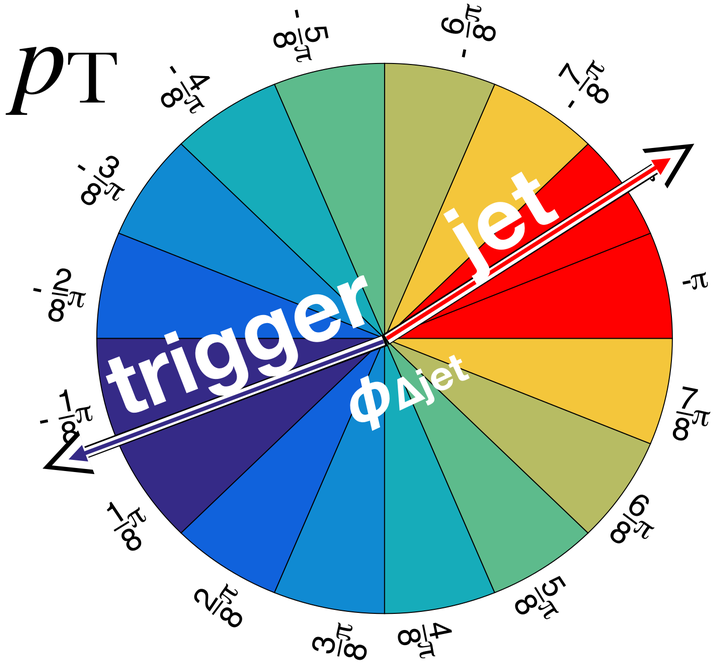
Full Markers: High EA: 0-30%



- Both near and recoil jets suppressed in high EA relative to low EA
- n.b.: These are charged jet spectra; the near-side jets have a neutral energy fraction (NEF) bias because near side must also always contain the neutral trigger
  - This NEF bias is not present in the recoil jets
  - This NEF bias on the near-side is expected to decrease at higher $p_{T,jet}$

Peripheral $|\Delta\phi|$ bins enhanced at low p_T

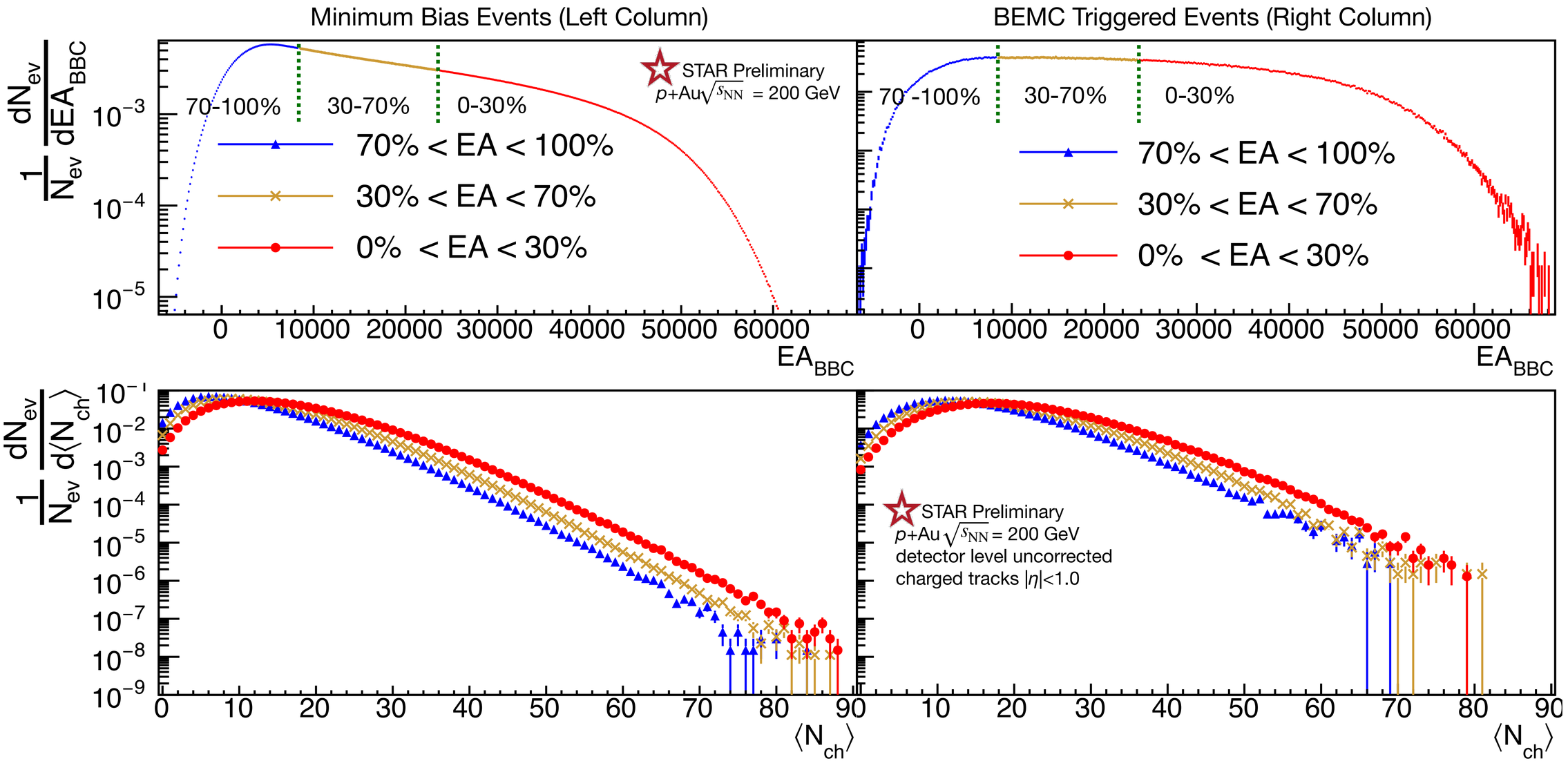




- Transverse bins contains little (no) dijet components but rather the underlying event (UE)
- At high-EA there is more UA making more combinatoric jets, as evidenced in a stronger relative enhancement for low p_T "jets" in peripheral bins

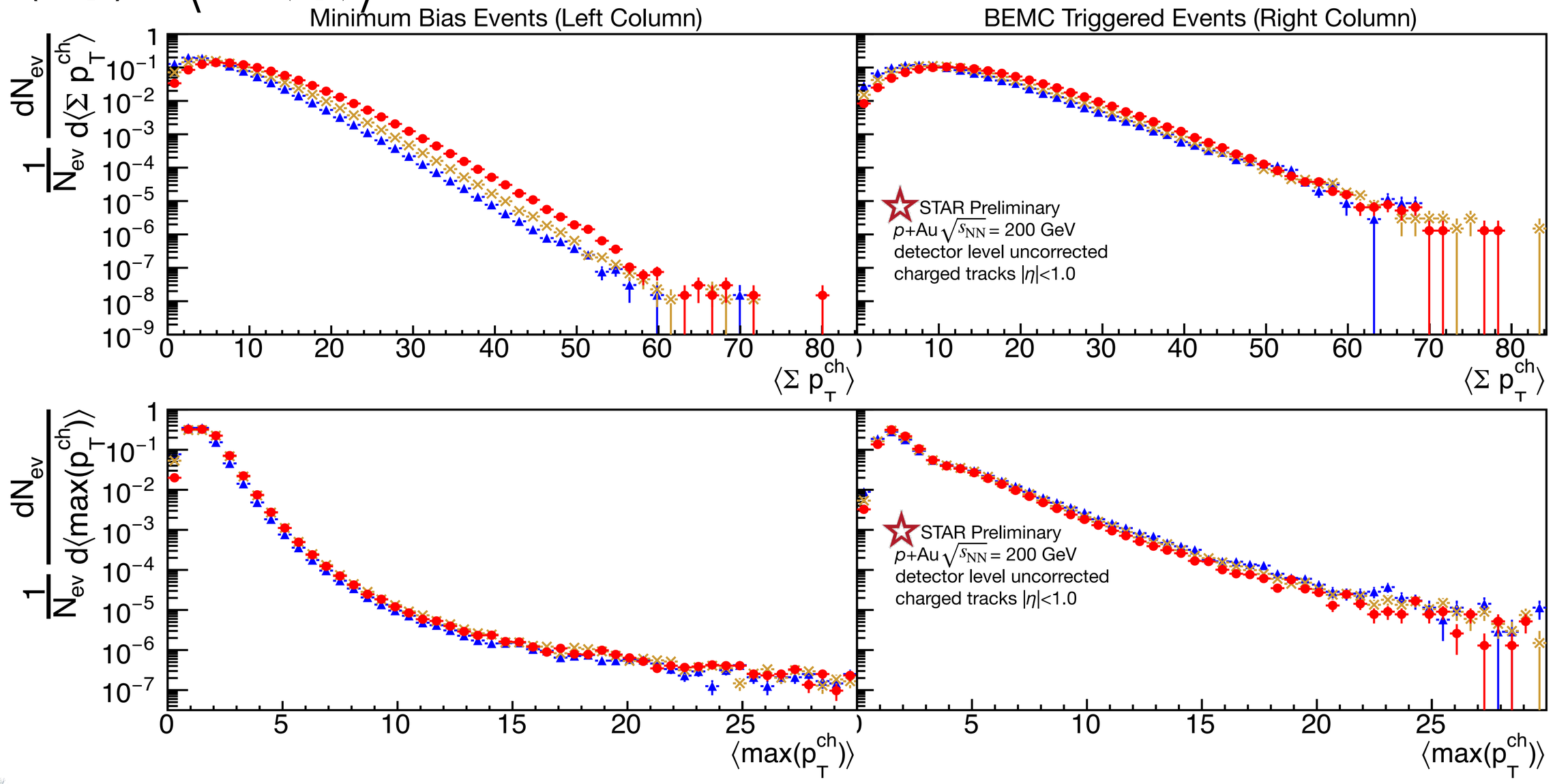
EA track activity: change in means w/ broad overlapping distributions

BBC-East & $\langle N_{ch} \rangle$ distributions



EA track activity: change in means w/ broad overlapping distributions

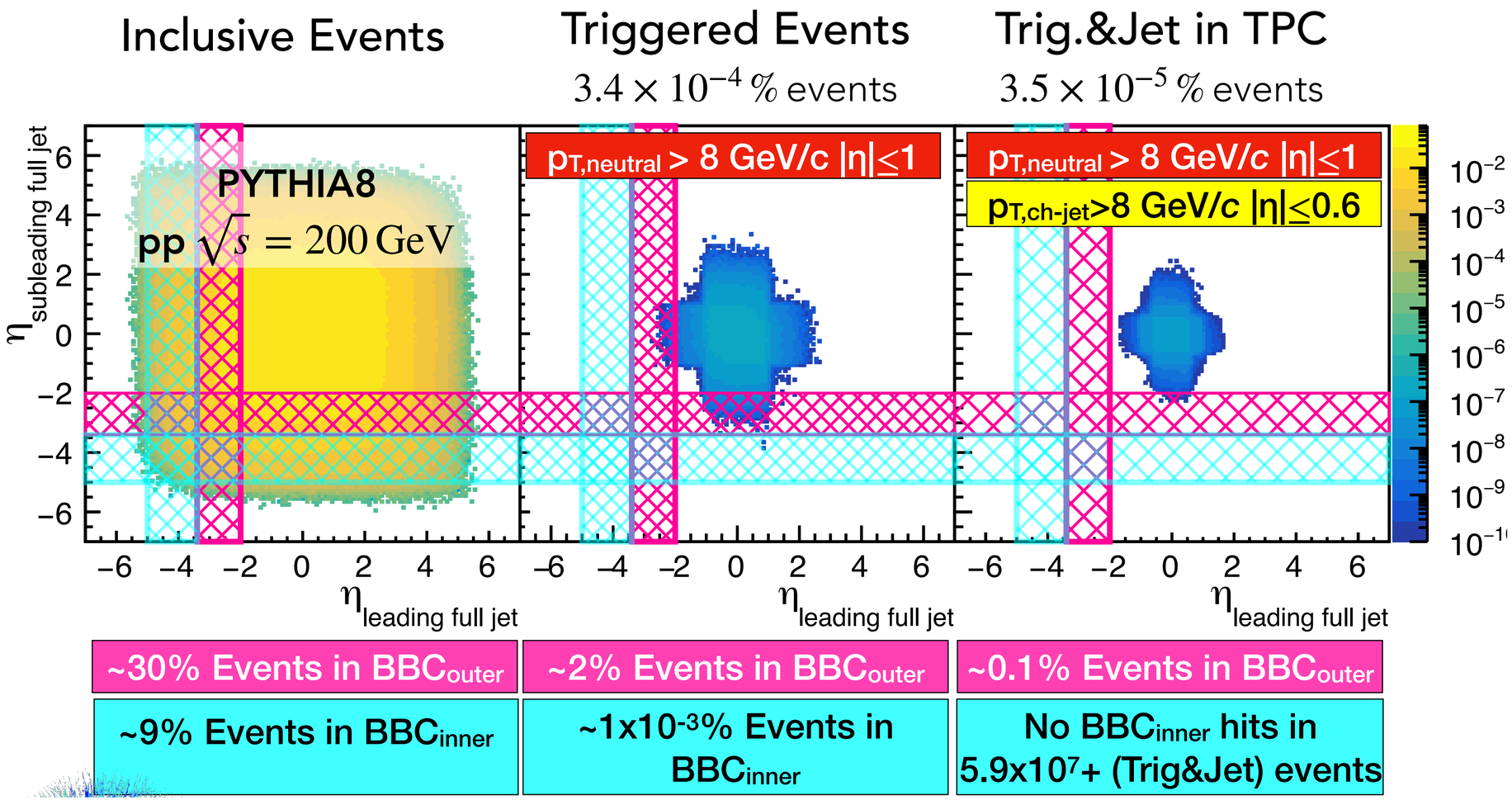
$\langle \Sigma p_{\mathrm{T}}^{\mathrm{ch}} \rangle$ & $\left\langle \max\left(p_{\mathrm{T}}^{\mathrm{ch}}\right) \right\rangle$ distributions



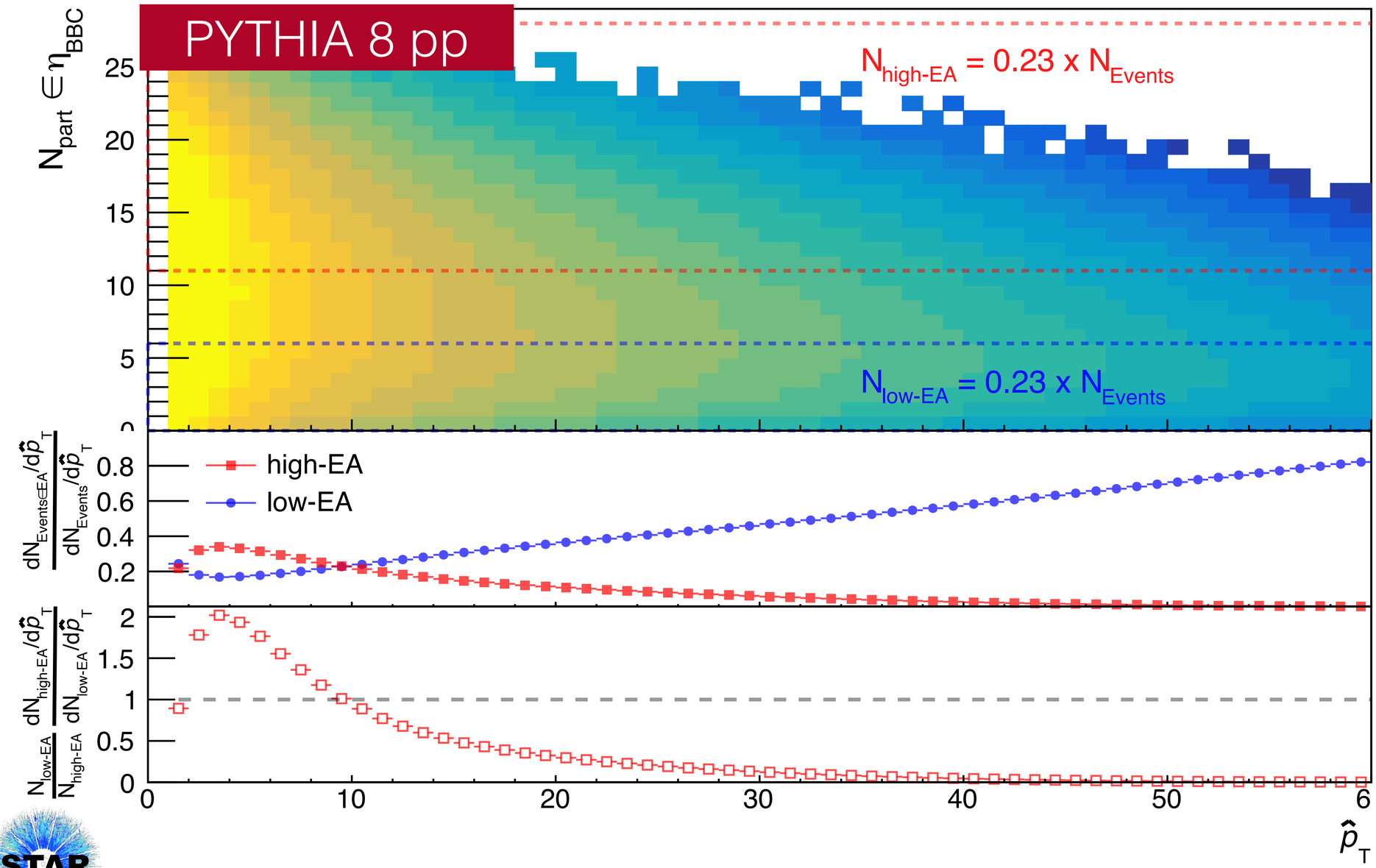
STAR spectra modification *not* due to dijets hitting BBC

Outer BBC $\eta \in (-2, -3.4)$

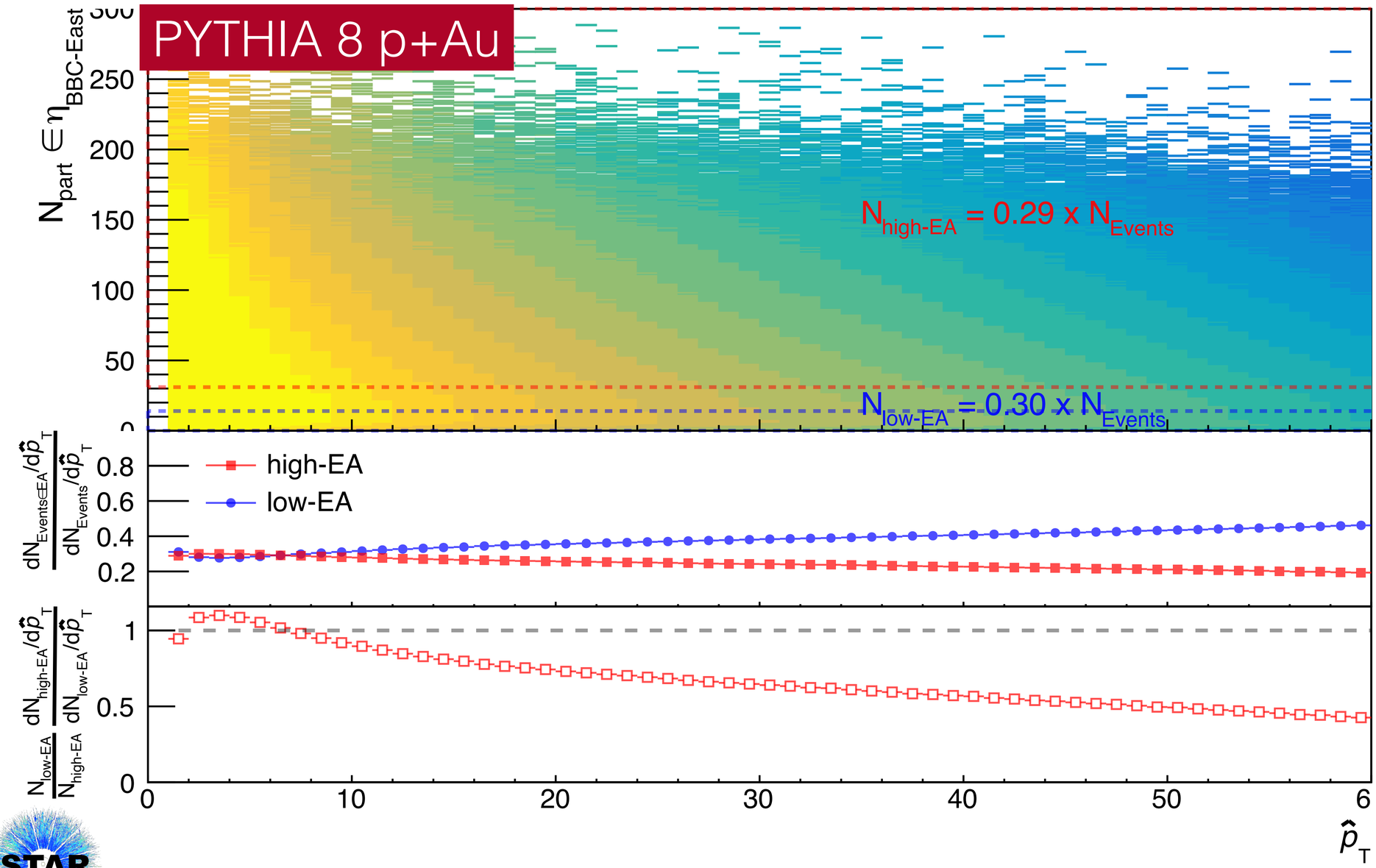
Inner BBC $\eta \in (-3.4, -5)$



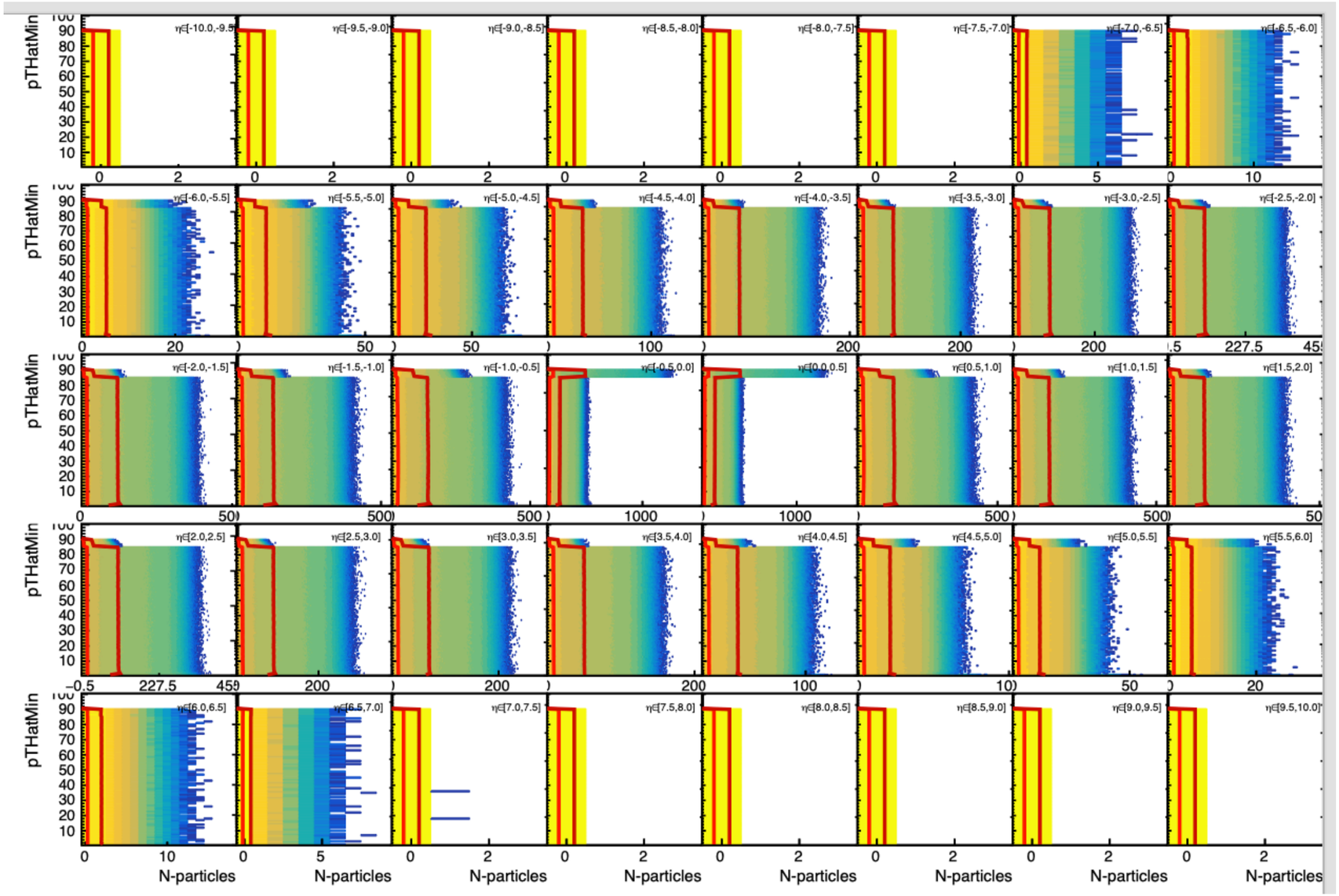
PYTHIA 8 strong correlation from $\hat{p}_T$ to high negative-η EA



PYTHIA 8 strong correlation from $\hat{p}_T$ to high negative-η EA



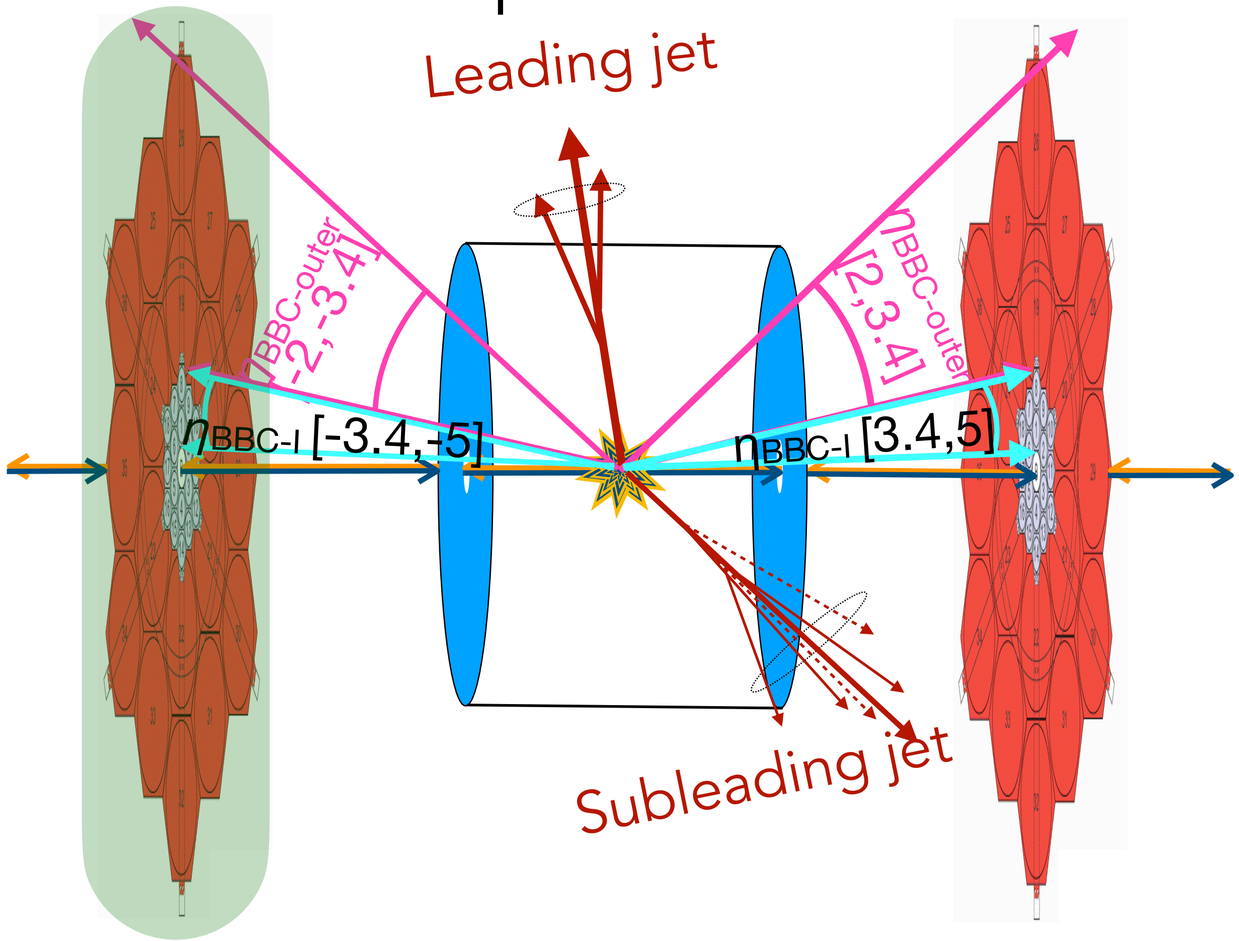
PYTHIA 8 Au+Au EA ratios largely independent of $\hat{p}_{\mathrm{T}}$



Red lines in each sub plot give the 30% and 70% locations

Use “opposite” TPC to avoid “dijet contamination of EA”

Example event

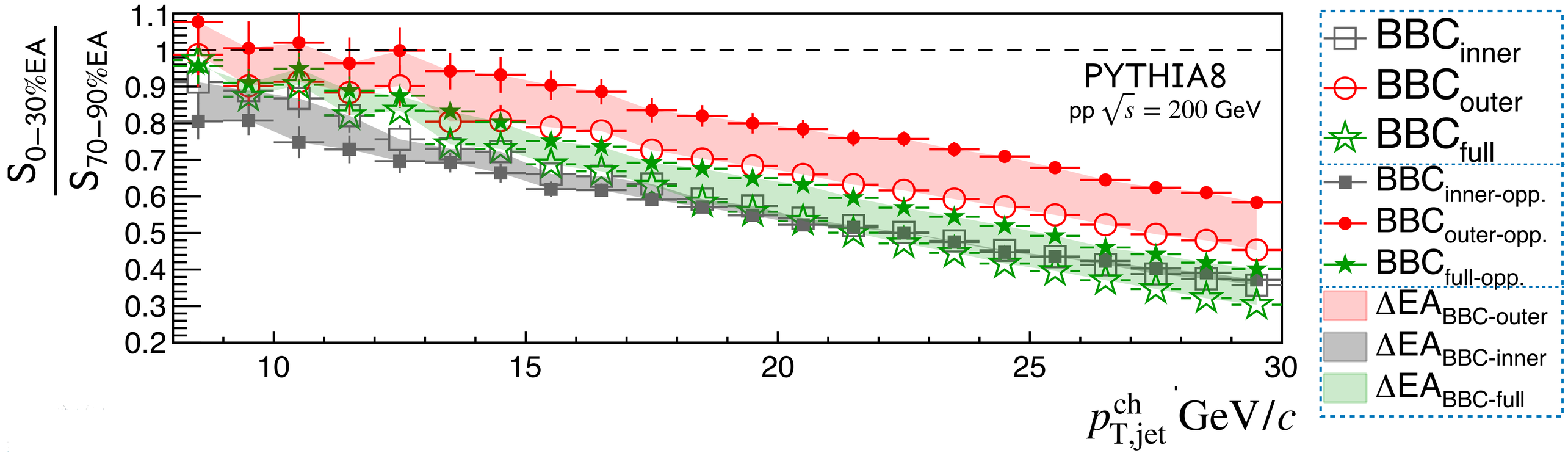


Method

- In each event, read EA signal from the BBC opposite of leading/subleading jet with max(|η|)
- Remove all dijet constituents from BBC
- Remove suppression of due to dijets in BBC_{outer}
- PYTHIA results on next slide

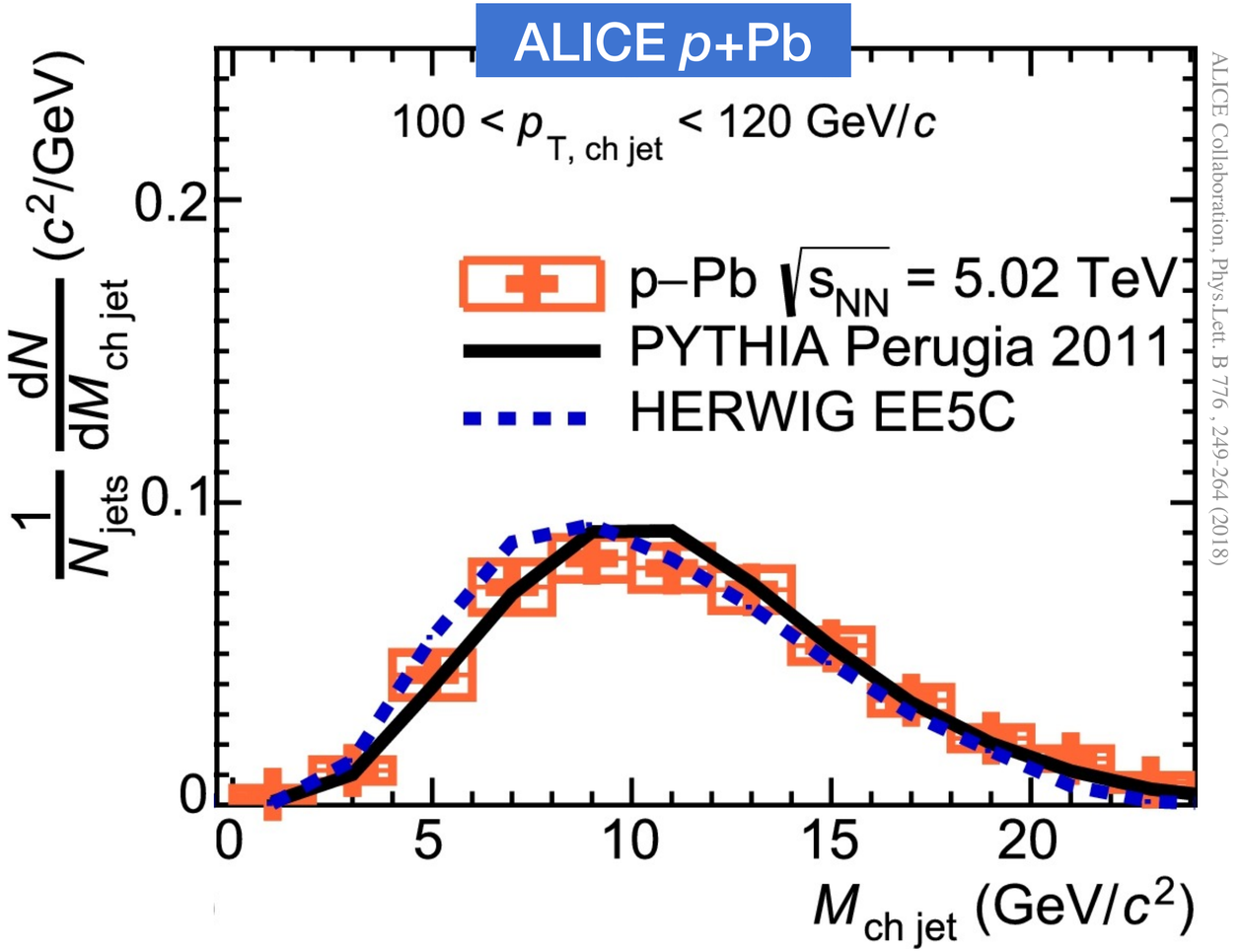
PYTHIA 8 TPC charged jet per trigger suppression

PYTHIA 8 predicts jet spectra suppression when using either the inner or the outer BBC, or even when always using the BBC “opposite” in η from the highest p_T jets of the generated pp event



Inclusive jet mass

2018: Jet mass distribution not modified



ALICE Collaboration, Phys.Lett. B 776 , 249-264 (2018)