Modification of semi-inclusive jet spectra in high event activity $\sqrt{s_{\mathrm{NN}}} = 200$ GeV p+Au collisions at STAR

2020 Fall Meeting of the Division of Nuclear Physics of the American Physical Society DNP 2020

New Orleans, LA (→ virtual conference hosted by FRIB) 2020: 10/29-11/1

David Stewart (Yale University) for the STAR collaboration

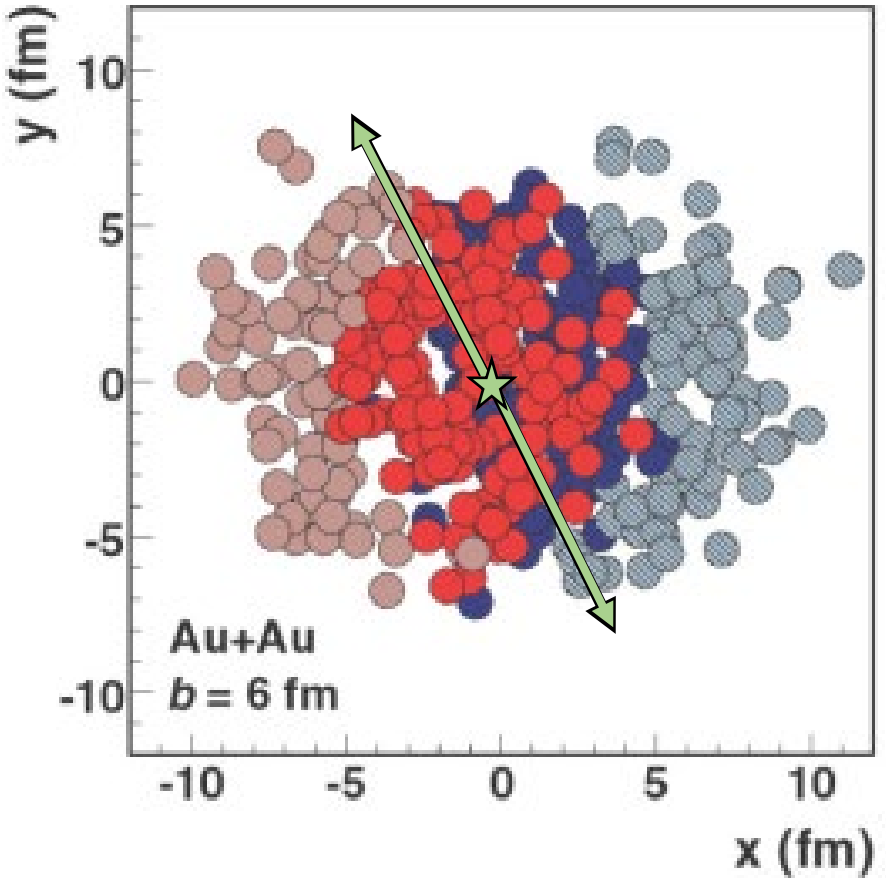
Funded in part by U.S. DEPARTMENT OF ENERGY | Office of Science

Yale

APS physics

Ingredients of measurement: A+A

- **Jet/Trigger**:
  - rare high-Q^2 process
- **Event Activity (EA)**:
  - aggregate result of all nucleon-nucleon (N_{coll}) collisions
  - more or less independent from jet production
- **Measurement**
  - use **EA** to compare jets in A+A to $N_{coll}\times$ *pp* collisions



Ann.Rev.Nucl.Part.Sci. 57 (2007), 205-243 (modified)

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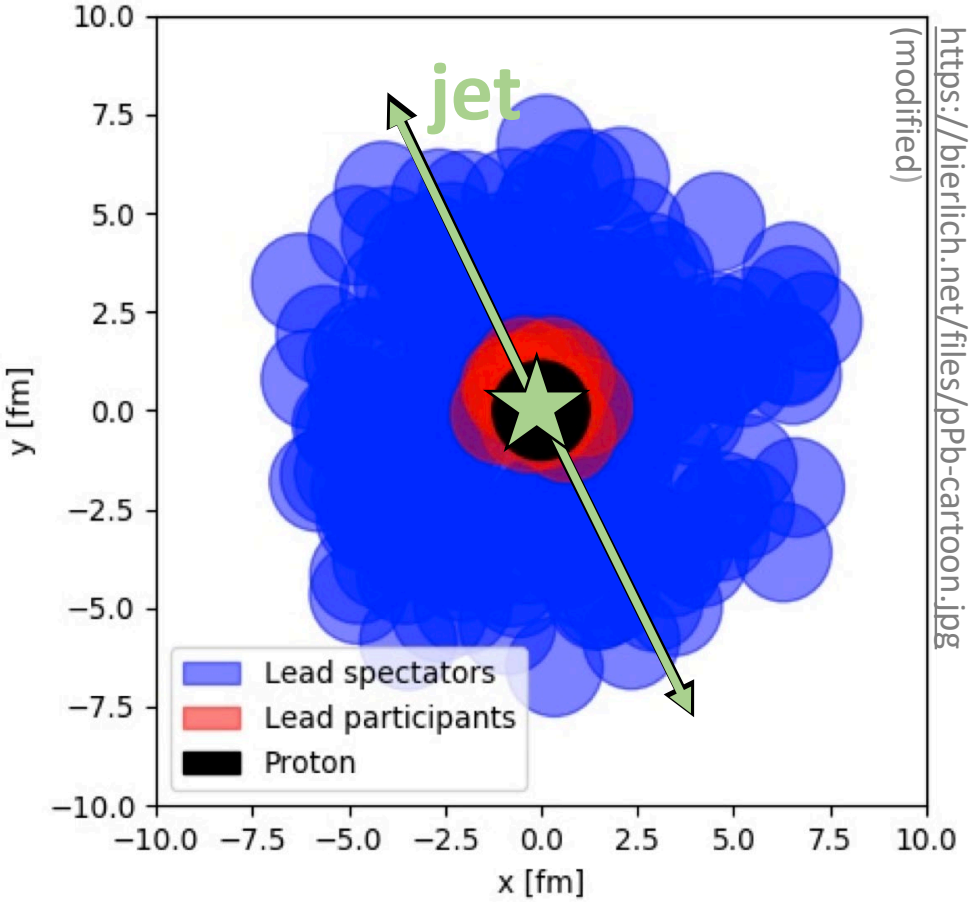

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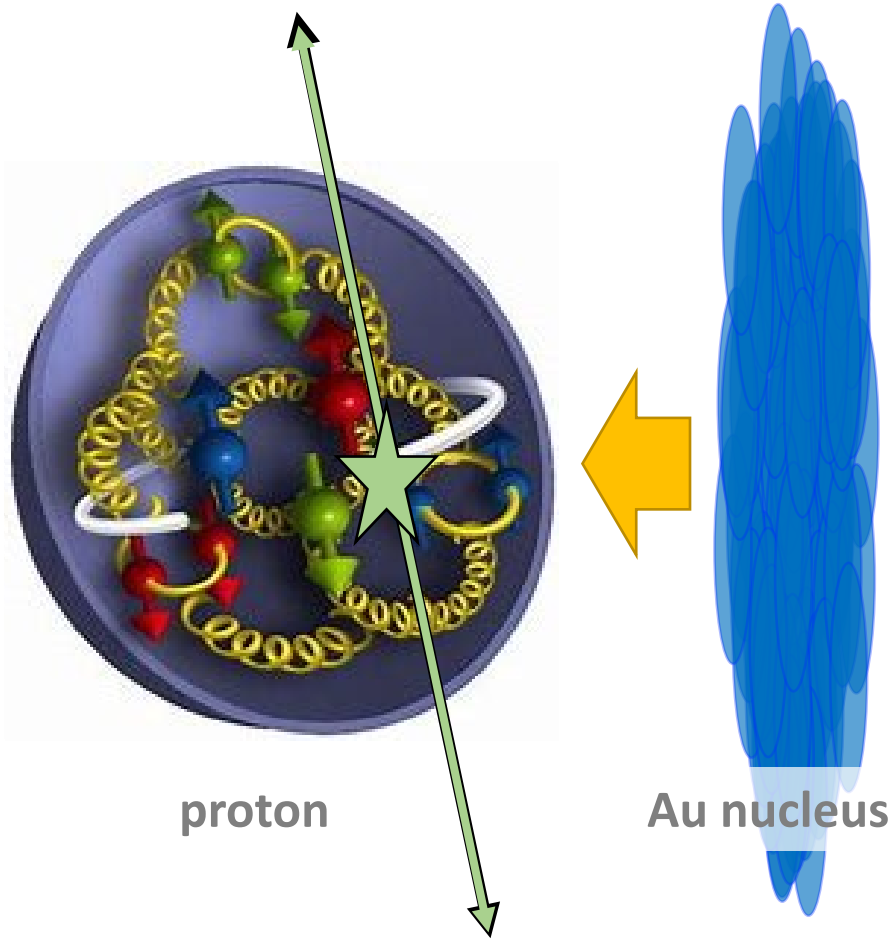

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(high-*x* *p*)

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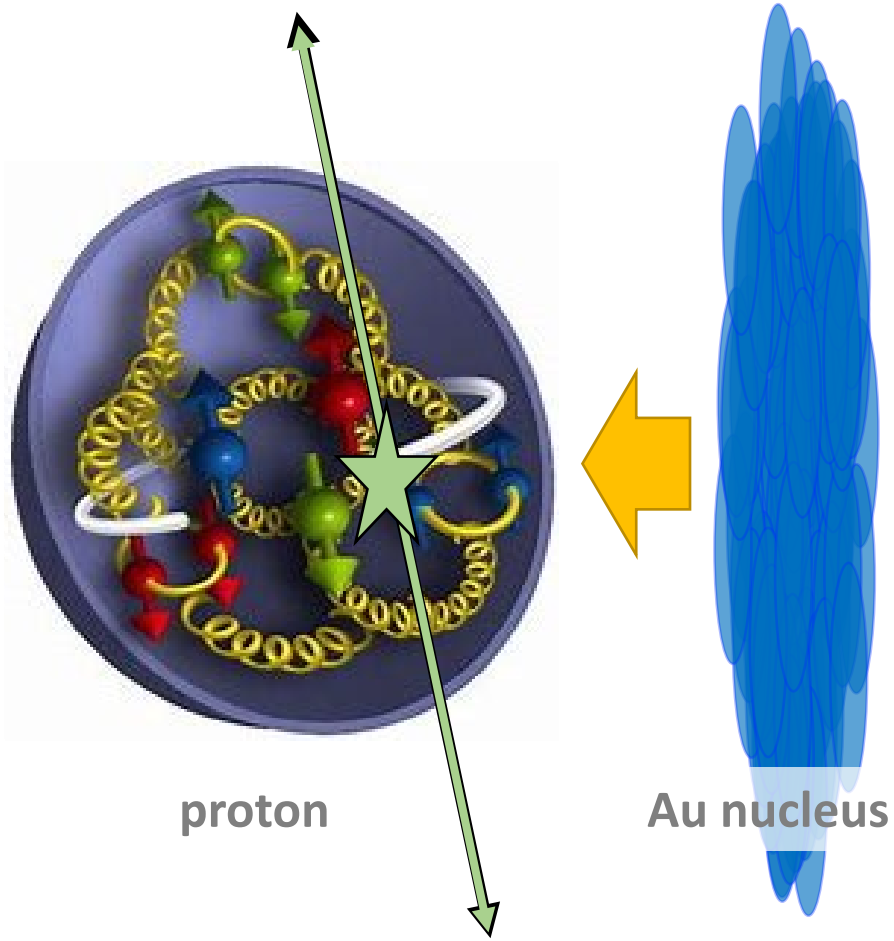

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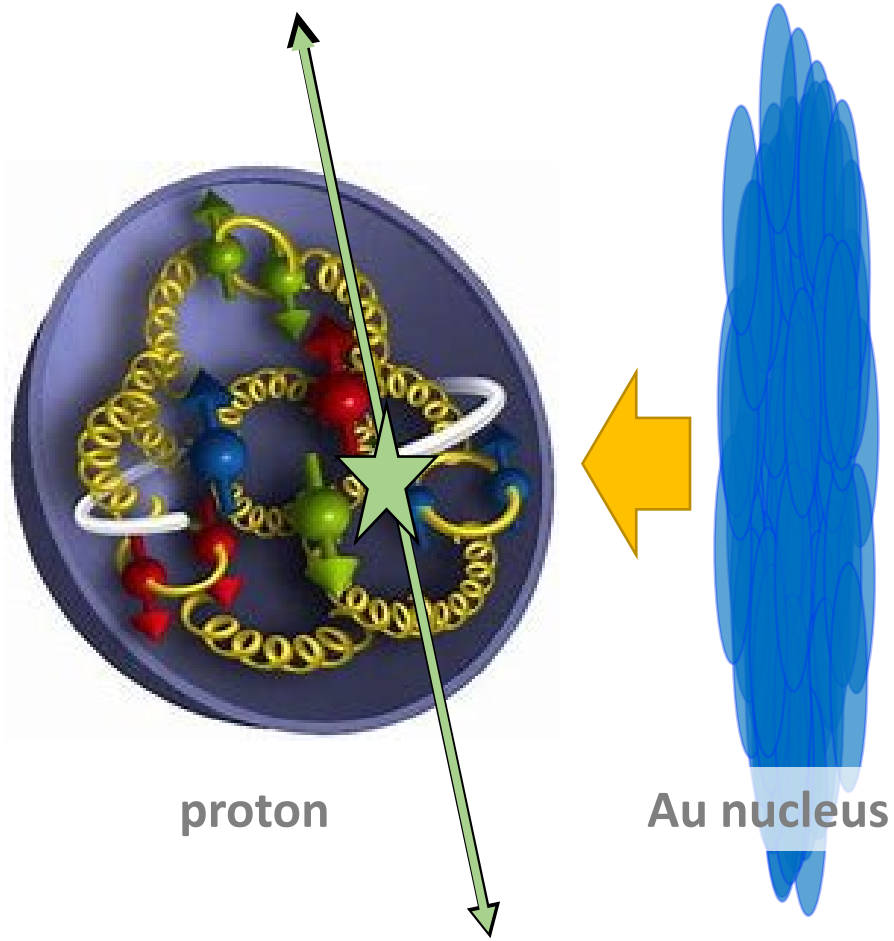

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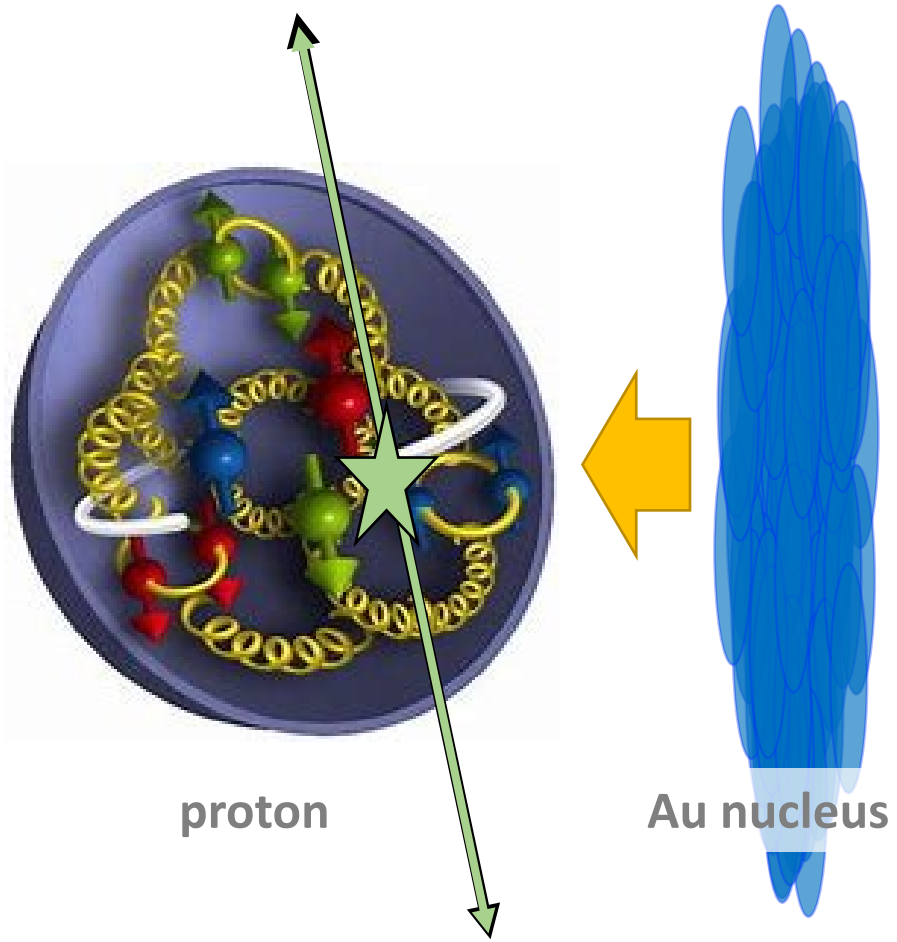
  - use EA to compare jets in ~~A+A~~ *p*+A to $N_{coll}\times$ *pp* collisions
  - use EA generically as "violence of the collision" → can compare high-EA to low-EA results without N_{coll} (jets per trigger, dijet momentum balance, etc…)



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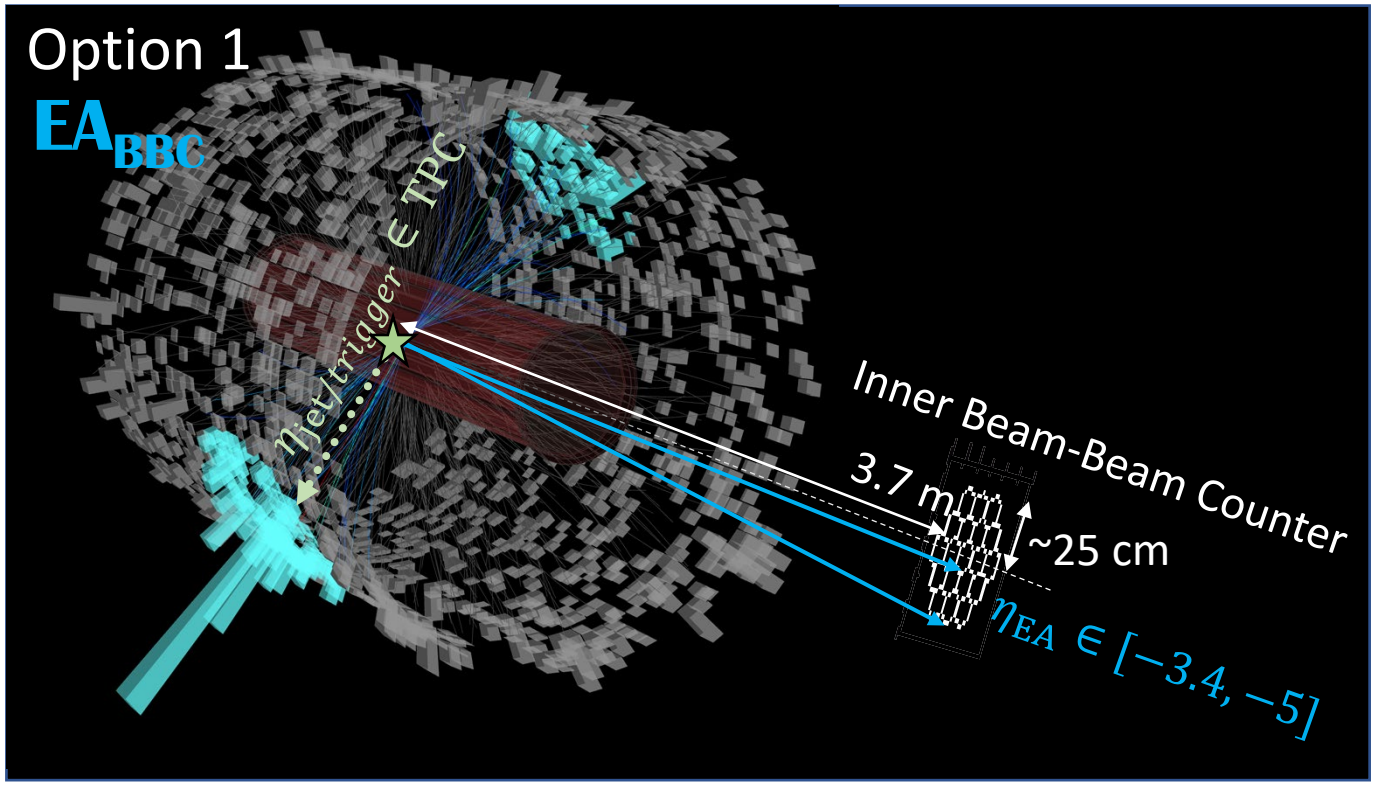
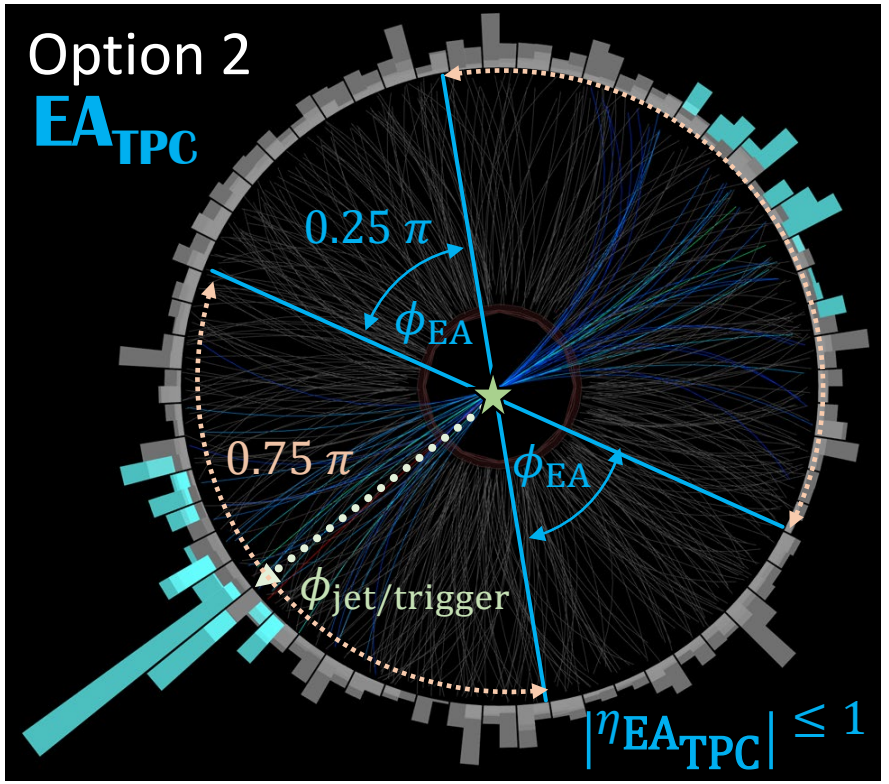
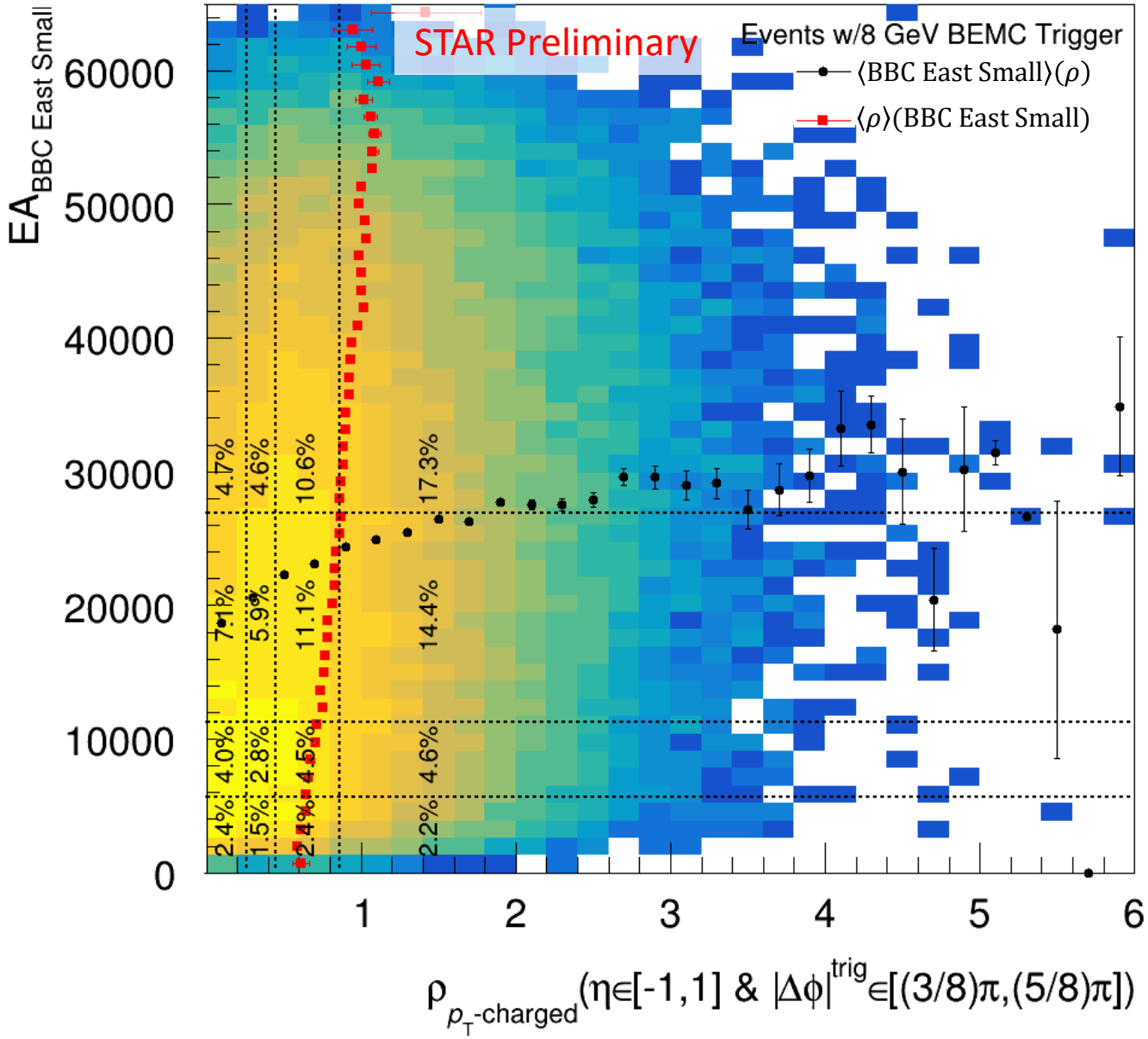
Measuring **Event Activity (EA)** at STAR

- Measure the jet (& possibly triggers)
- Measure **event activity (EA)** elsewhere, separated in η-ϕ phasespace



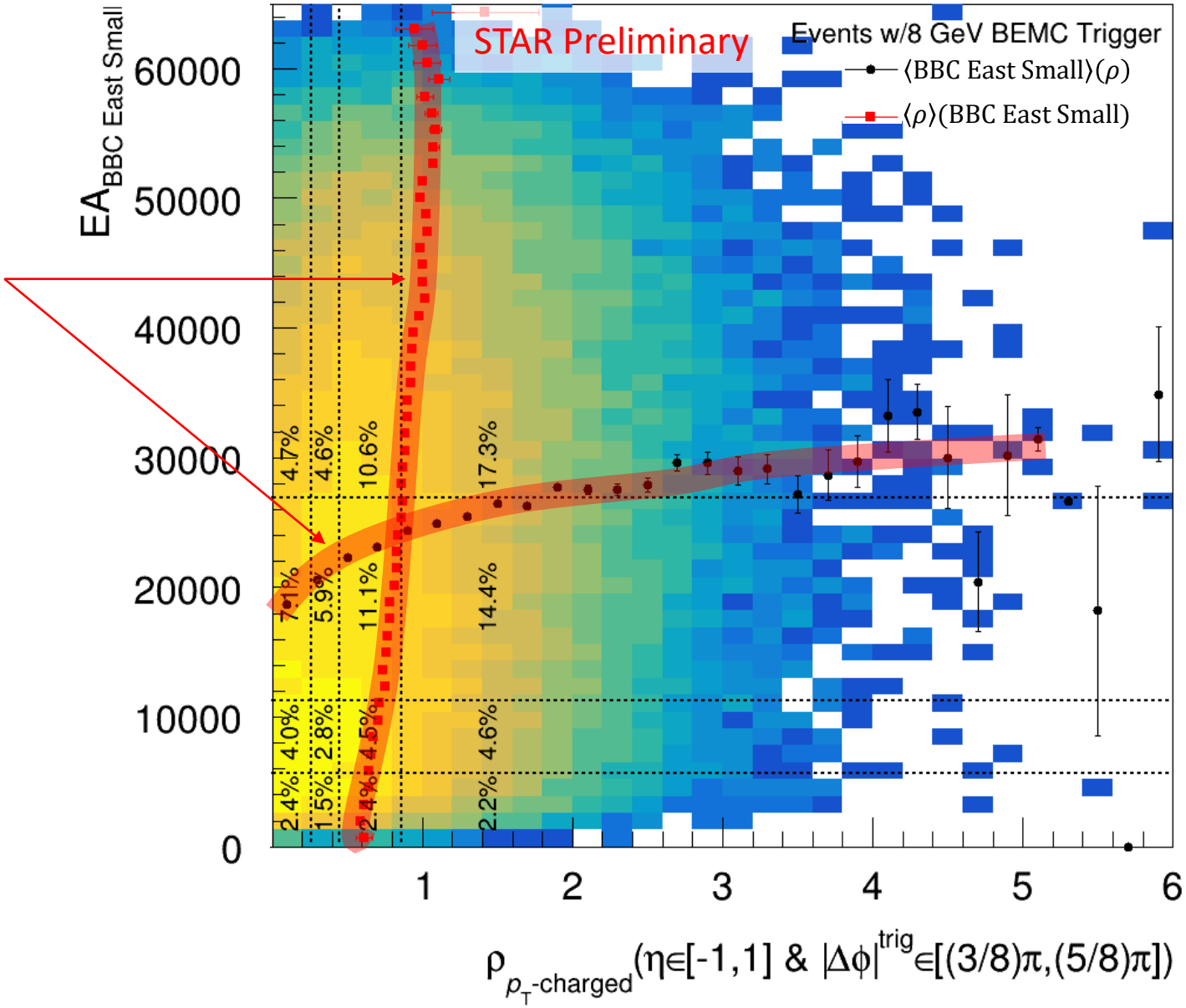


STAR data: EA


STAR Preliminary
Events w/8 GeV BEMC Trigger
⟨BBC East Small⟩(ρ)
⟨ρ⟩(BBC East Small)
EA_BBC East Small
60000
50000
40000
30000
20000
10000
0
1
2
3
4
5
6
4.7%
4.6%
10.6%
17.3%
7.1%
5.9%
11.1%
14.4%
2.4%
4.0%
2.8%
4.5%
4.6%
1.5%
2.4%
2.2%
ρ_pT-charged(η∈[-1,1] & |Δφ|^trig∈[(3/8)π,(5/8)π])

STAR data: EA

- EA_{BBC} & EA_{TPC} positively correlated



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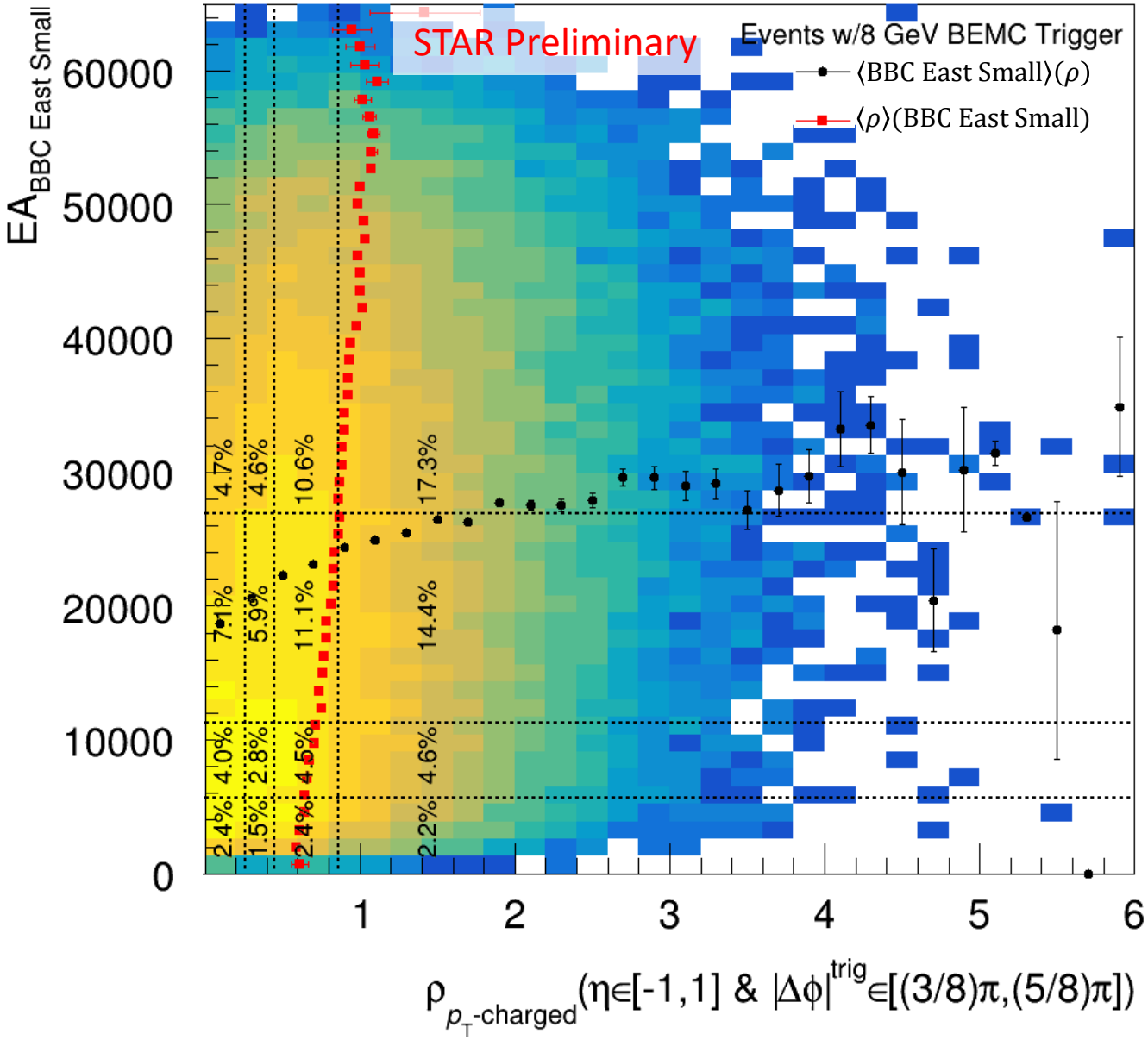
- Can compare **high-EA** events to **low-EA** events using:



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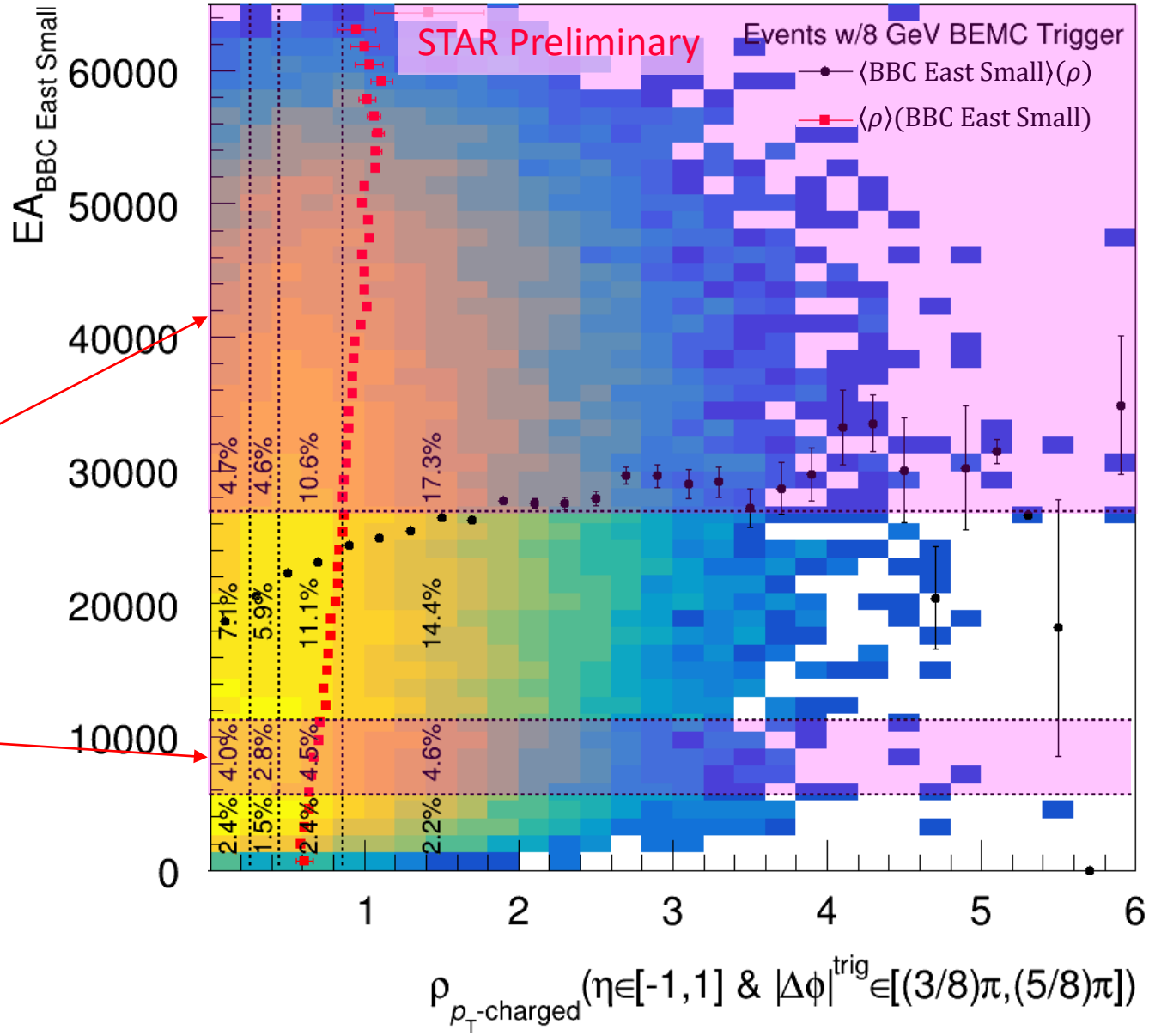

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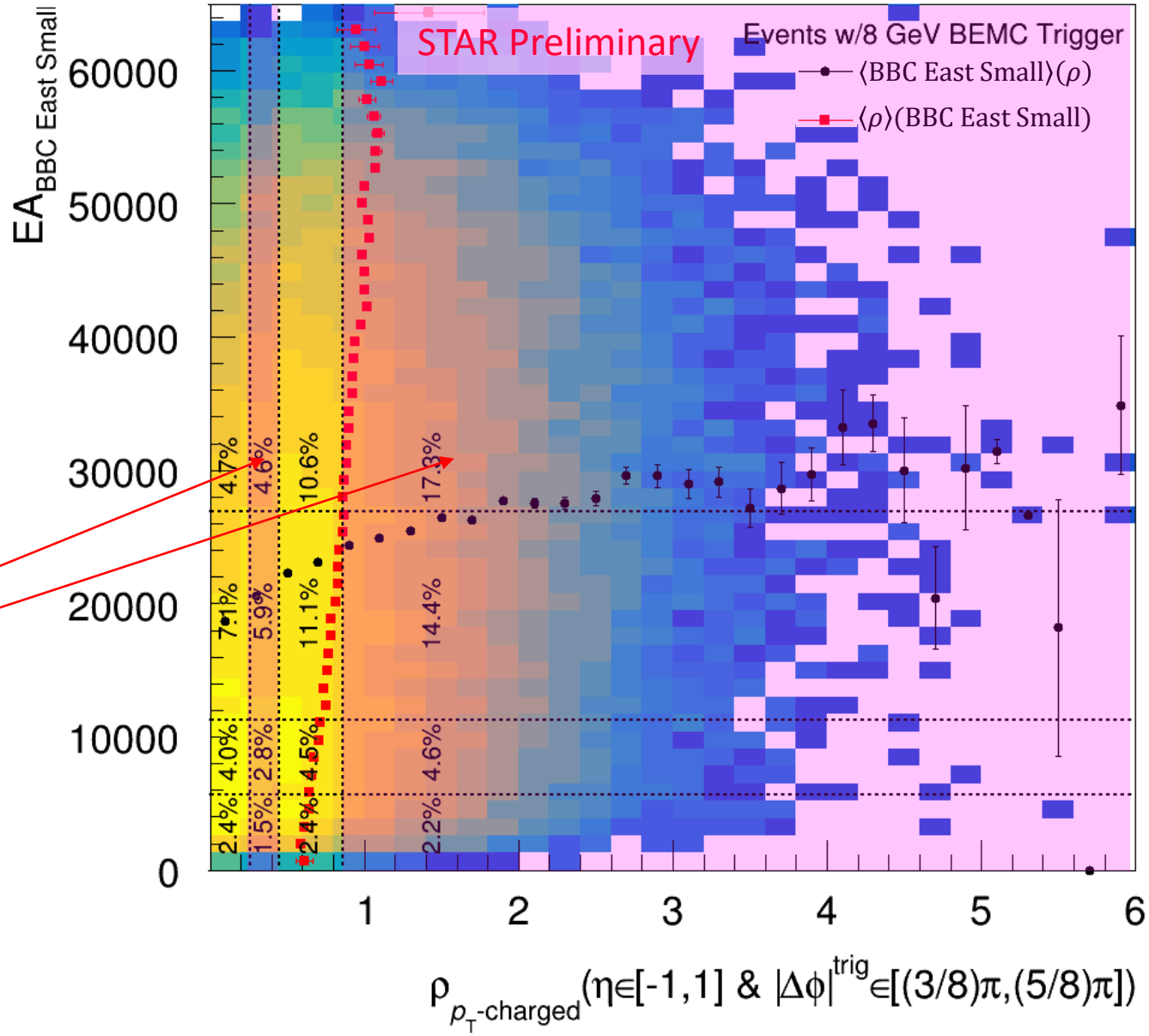
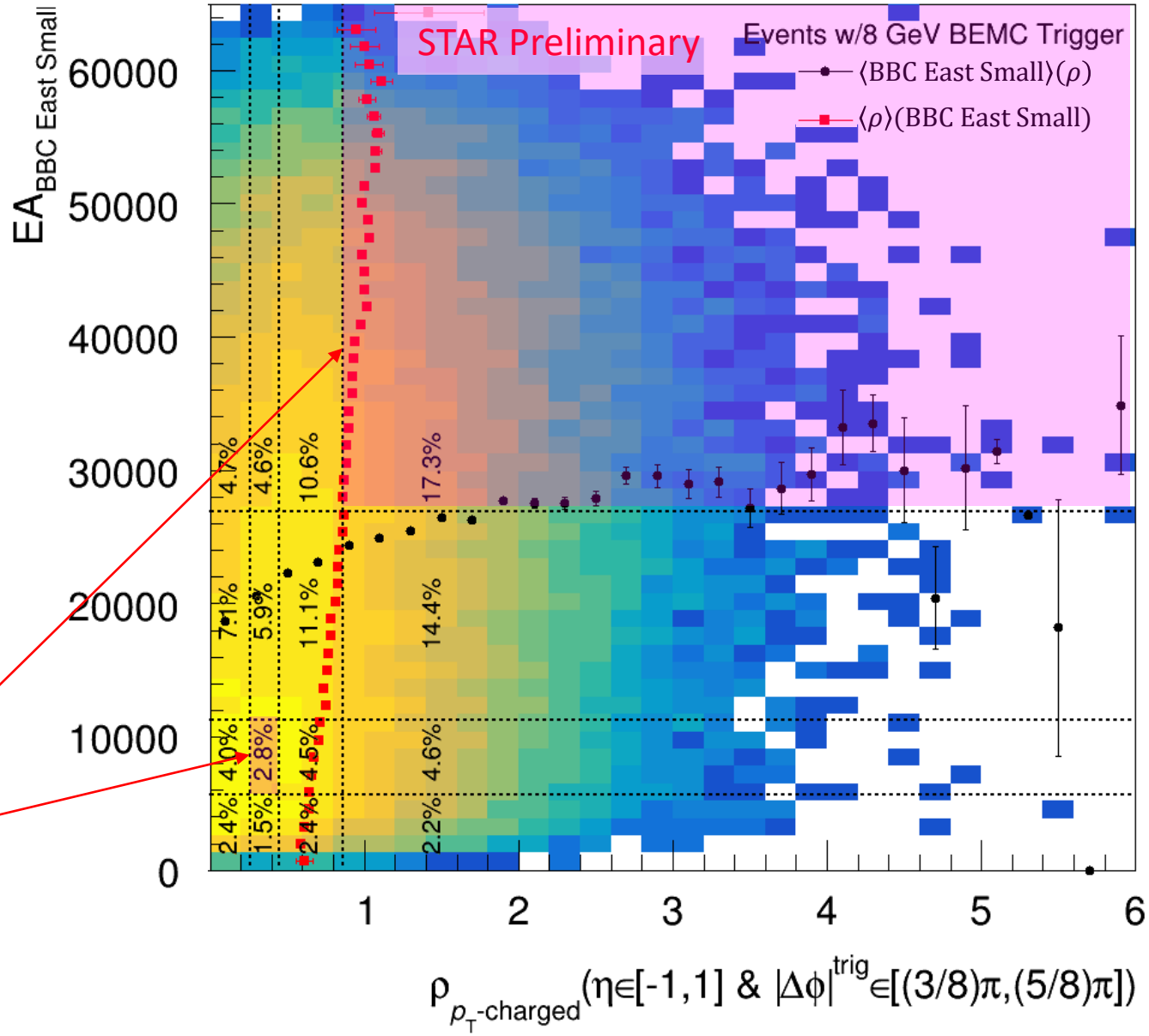


STAR data: EA

- EA_{BBC} & EA_{TPC} positively correlated
- Can compare **high-EA** events to **low-EA** events using:
  - EA_{BBC}
  - EA_{TPC}
  - Both: $EA_{BBC} \cap EA_{TPC}$

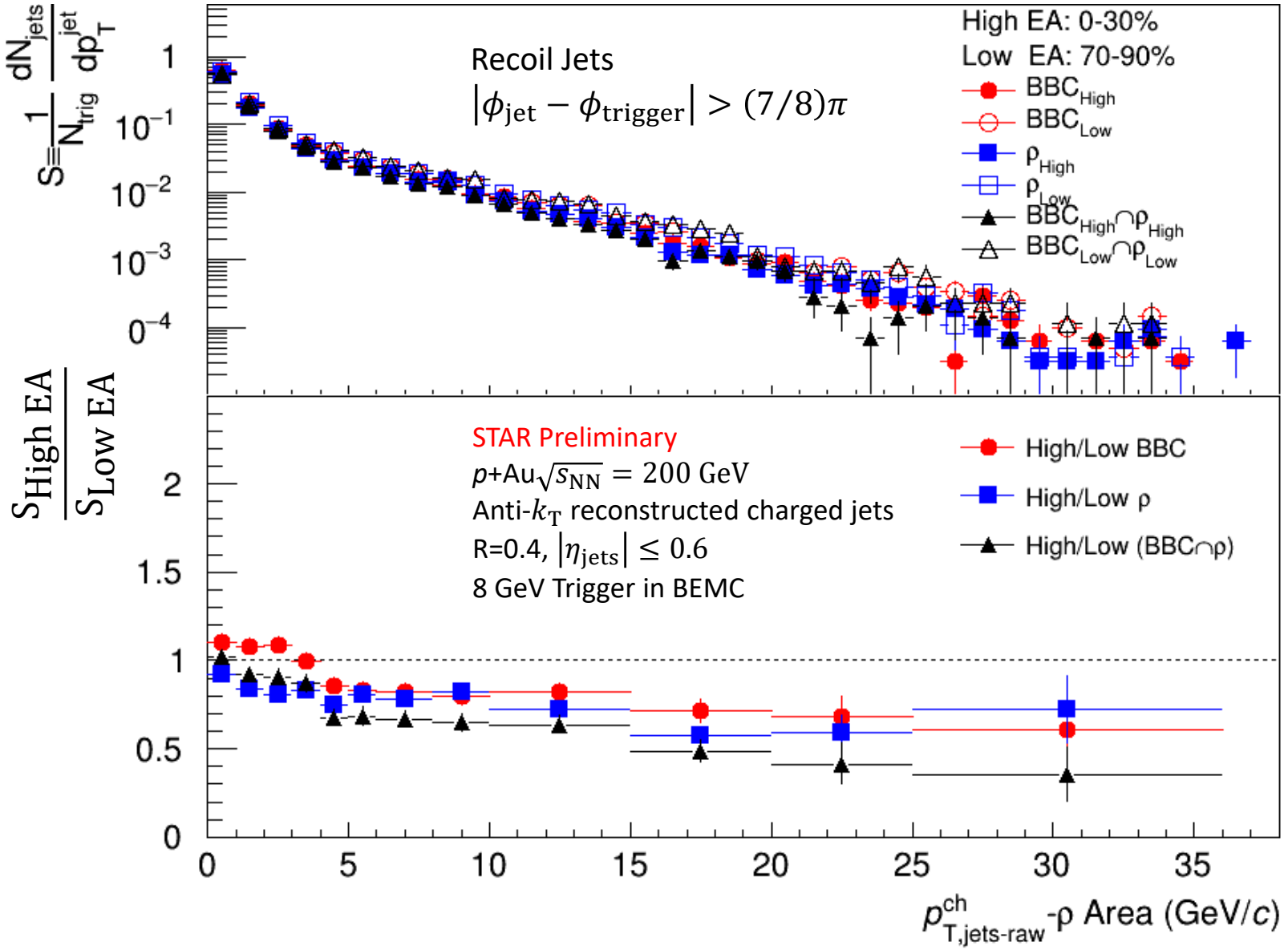


Results:

Using:

- **EA (high-η)** (**EA_{BBC}**)
- **EA (transverse-ρ)** (**EA_{ρ}**)
- or both (**$EA_{BBC} \cap EA_{\rho}$**)

→ charged jet spectra per trigger are suppressed in **high-EA** events relative to **low-EA** events

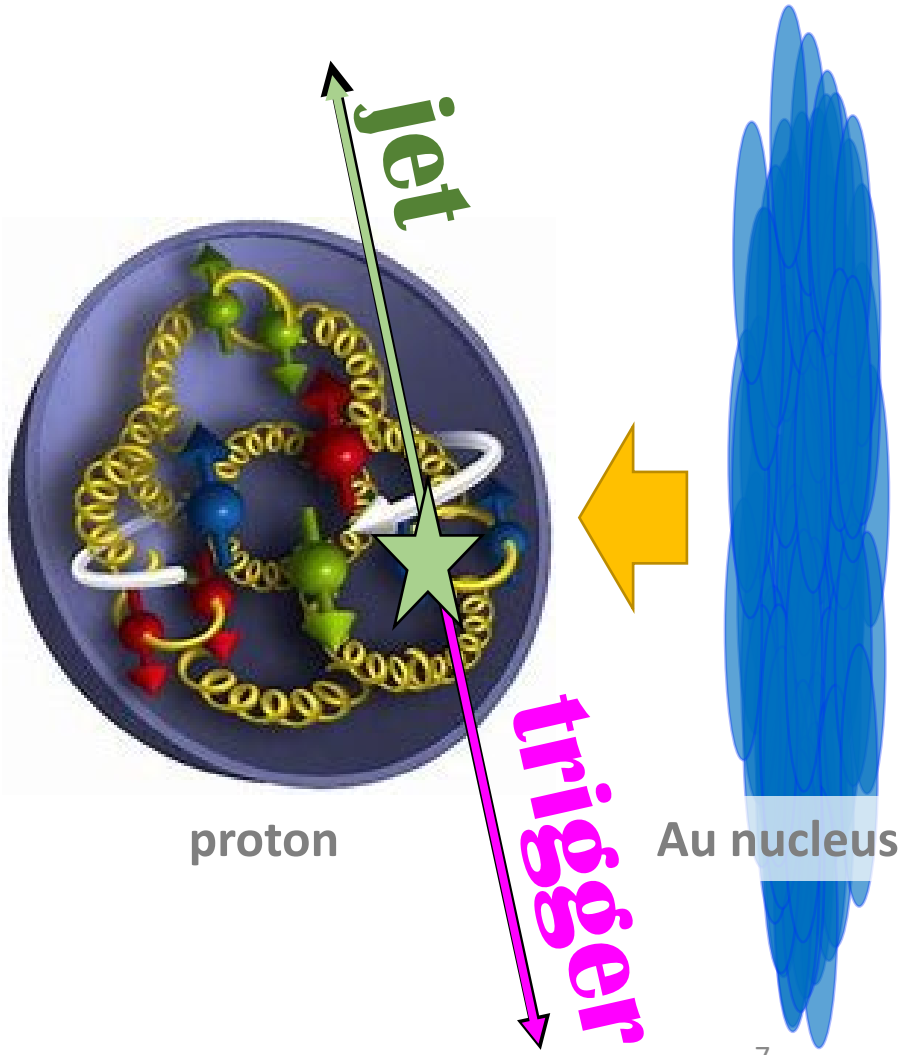


How can charged jet spectra (per trigger) be suppressed at **high-EA**?

- Trivial autocorrelation

  Jets selectively contaminate **EA** signal at **high/low-EA**?

- Quenching of jets & triggers at **high-EA**
- Phase space correlates (constrains) **EA** and jet formation



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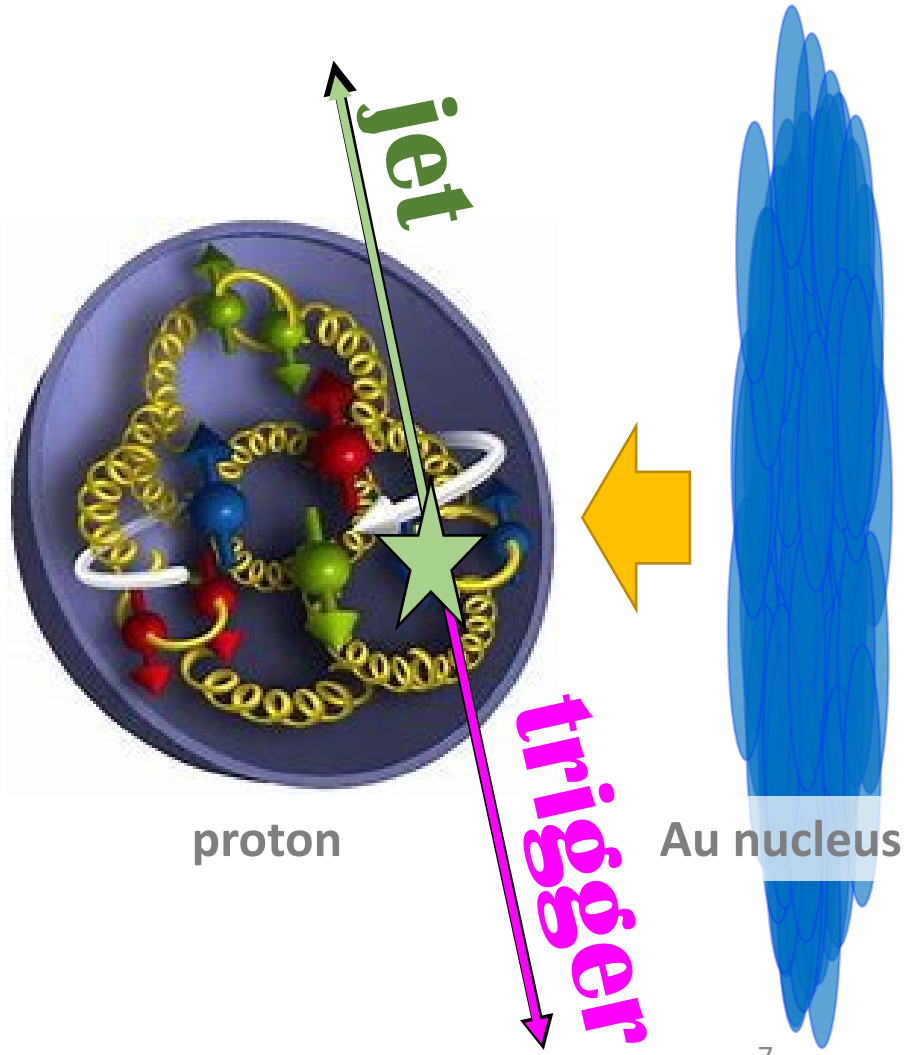

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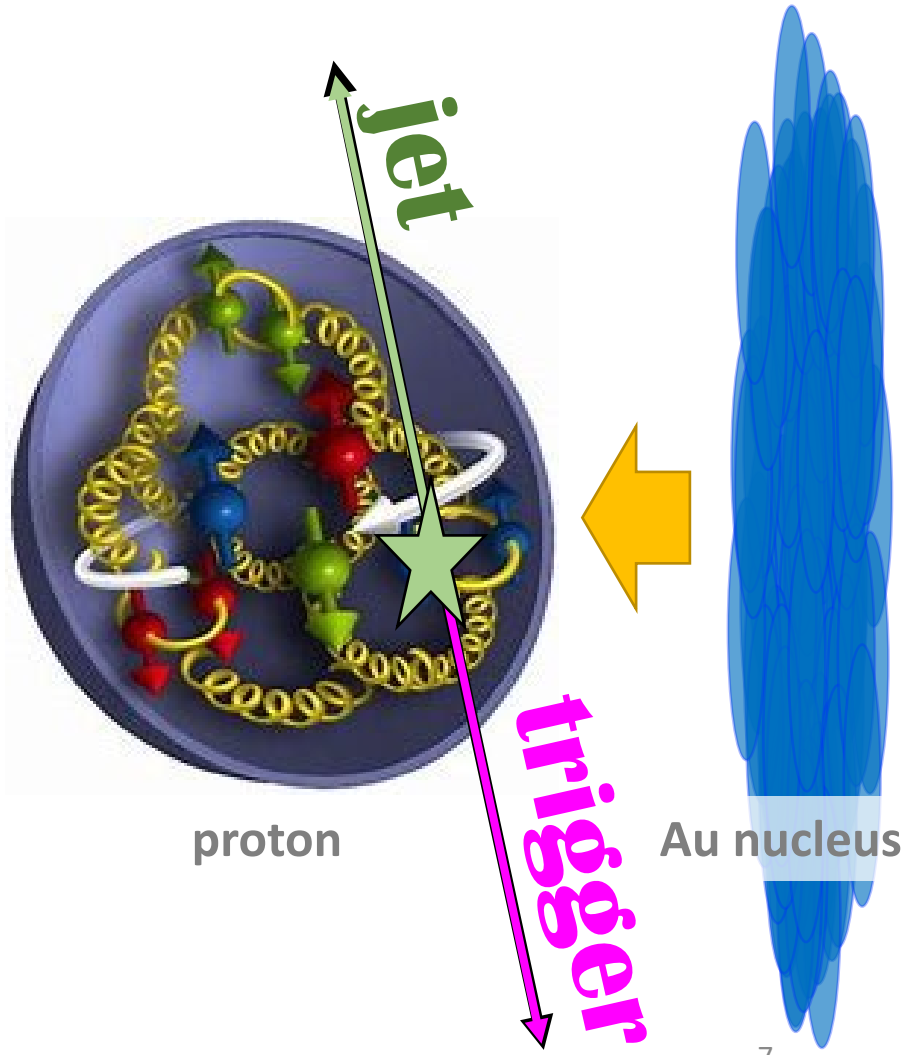

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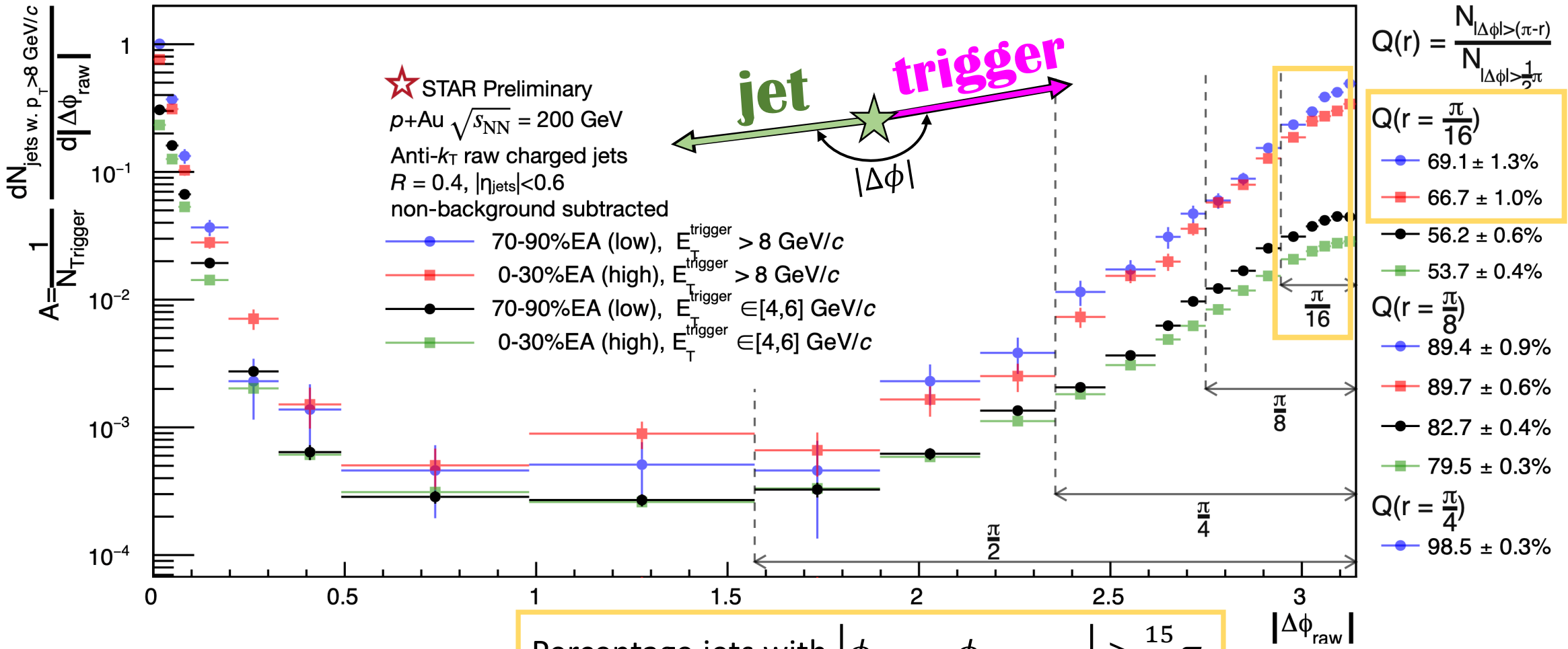
Not indicative of jet quenching

Results: No broadening of acoplanarity with EA_{BBC}



$$Q(r) = \frac{N_{|\Delta\phi|>(\pi-r)}}{N_{|\Delta\phi|>\frac{1}{2}\pi}}$$

$Q(r = \frac{\pi}{16})$
- 69.1 ± 1.3%
- 66.7 ± 1.0%
- 56.2 ± 0.6%
- 53.7 ± 0.4%

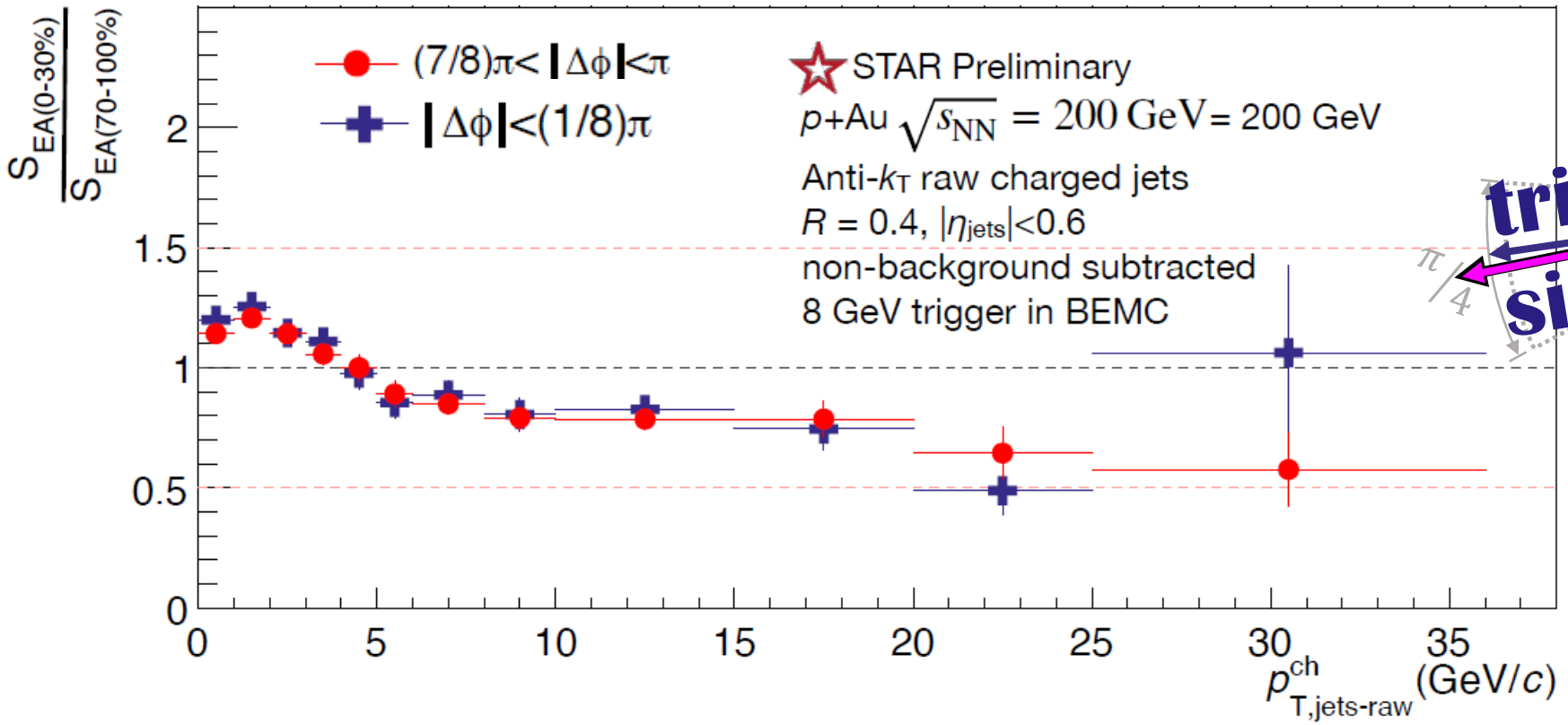
$Q(r = \frac{\pi}{8})$
- 89.4 ± 0.9%
- 89.7 ± 0.6%
- 82.7 ± 0.4%
- 79.5 ± 0.3%

$Q(r = \frac{\pi}{4})$
- 98.5 ± 0.3%

Percentage jets with $\left|\phi_{\text{jet}} - \phi_{\text{trigger}}\right| > \frac{15}{16}\pi$ decreases by 1.5 σ from **low-EA** to **high-EA**

Not indicative of jet quenching

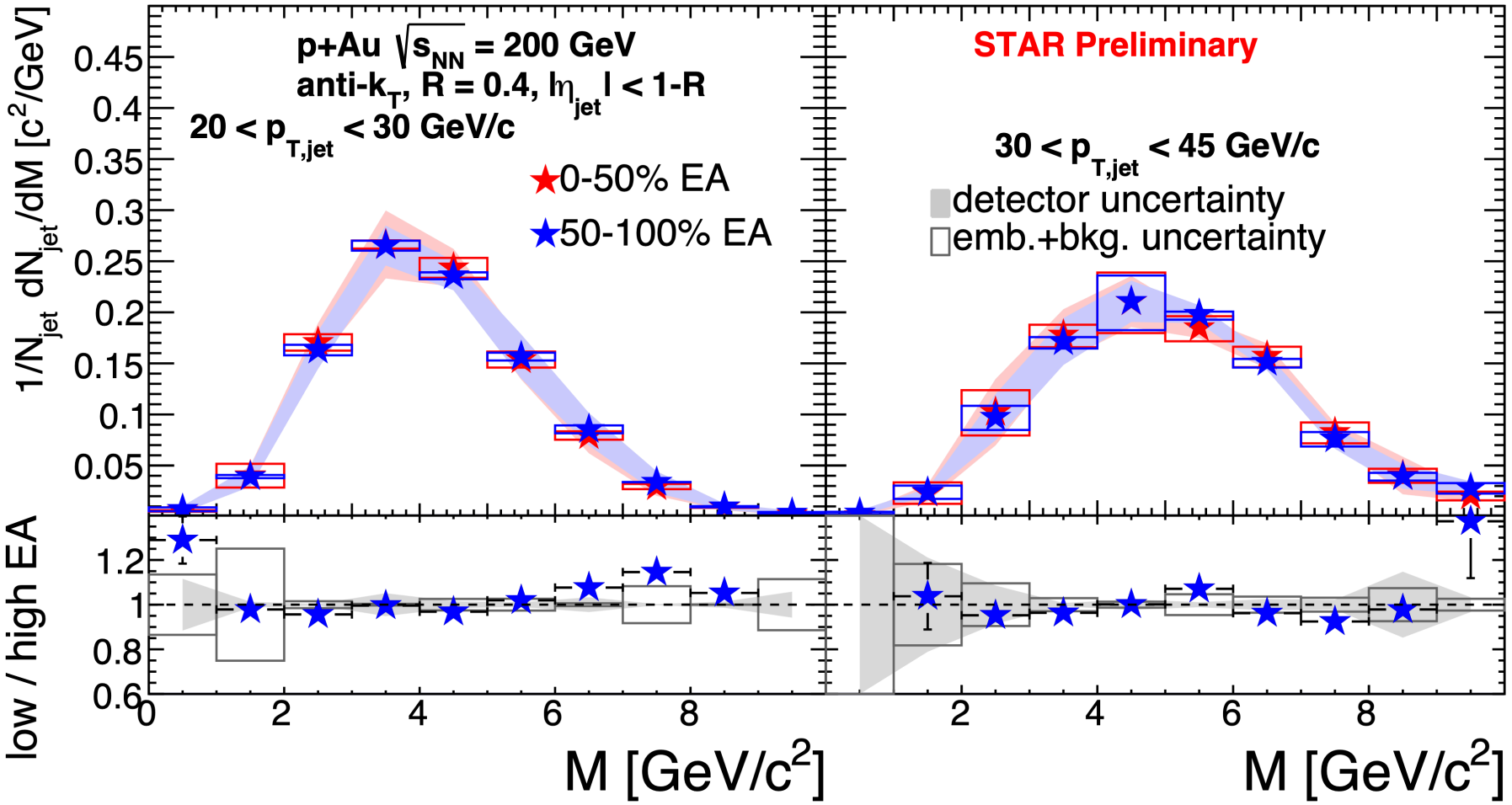
Results: No recoil-side bias in jet quenching (EA_{BBC})



- Both trigger-side and recoil-side jets comparably quenched:
  - Not indicative of pathlength-dependent quenching of dijet in QGP
  - Not indicative of statistical bias in always picking “less quenched” trigger

Not indicative of jet quenching

Results: jet mass distribution not EA_{BBC} modified



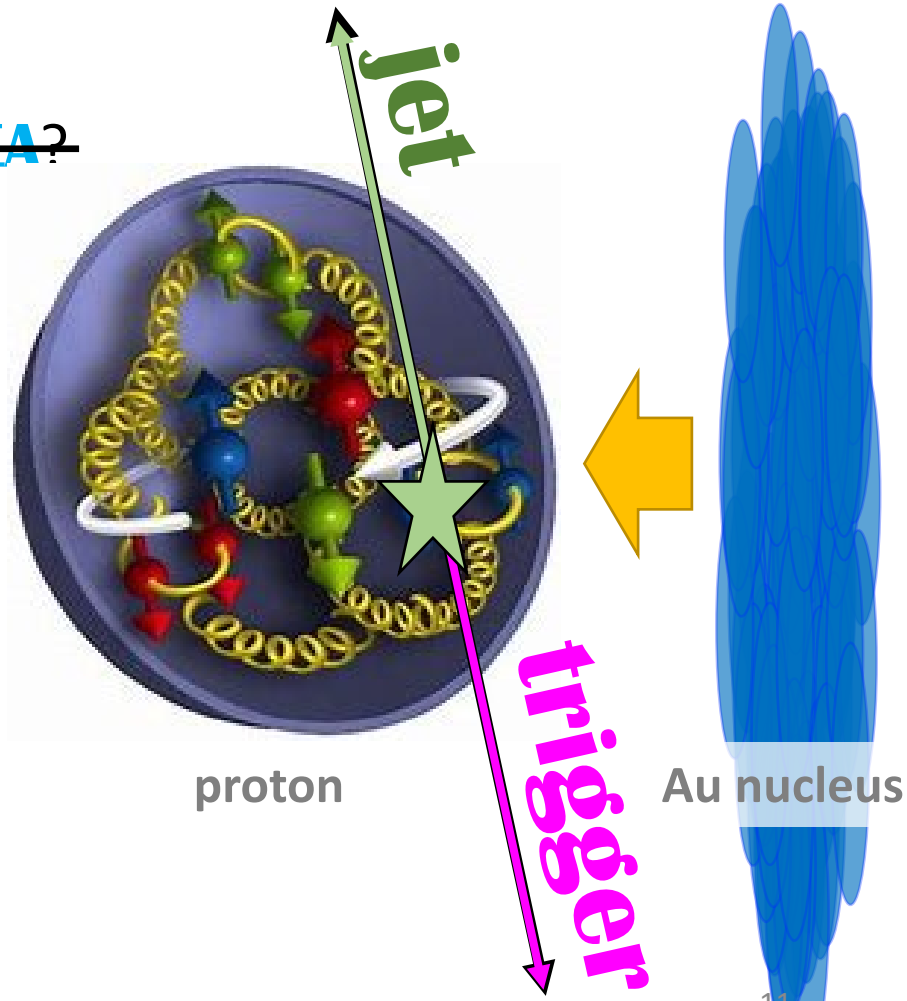
See talk FB.00003
By Isaac Mooney

How can charged jet spectra (per trigger) be suppressed at **high-EA**?

- ~~Trivial autocorrelation~~
  ~~Jets selectively contaminate **EA** signal at **high/low-EA**?~~
- ~~Quenching of jets & triggers at **high-EA**~~
- Phase space correlates (constrains) **EA** and jet formation?

How is it possible to suppress jets per trigger without actual quenching?

Aren't all triggers made alike?



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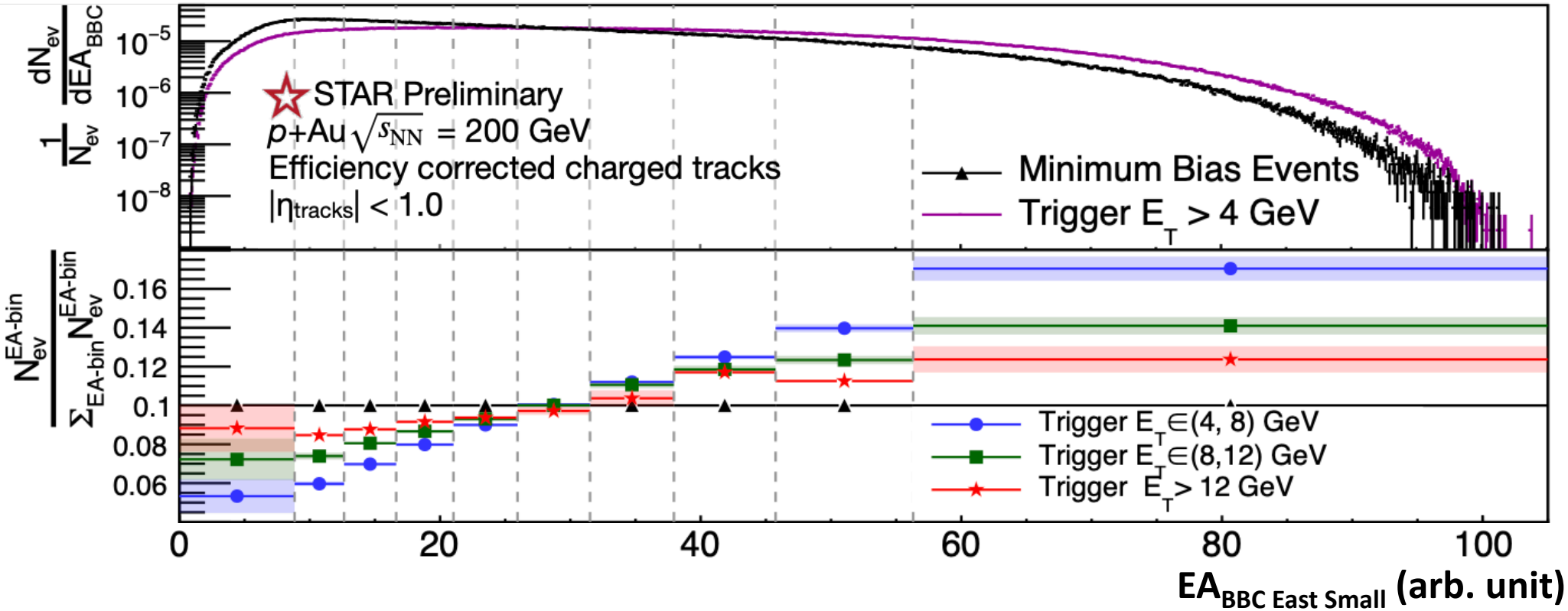
“Hard” trigger suppression in EA_{BBC} deciles



Note: $\langle E_T \rangle$ scales mono-tonically with Q^2

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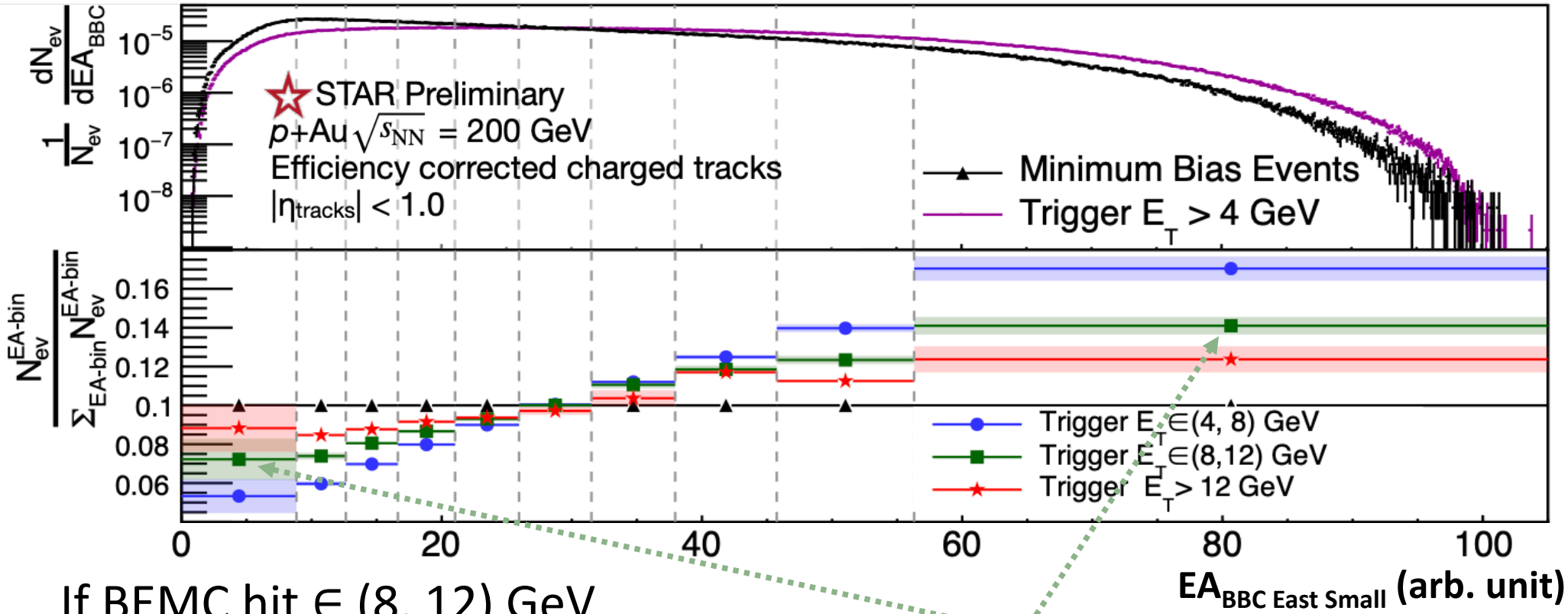

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⇒ ratio of shape **lowest-EA** : **highest-EA** ≈ 1:2

If BEMC hit > 12 GeV
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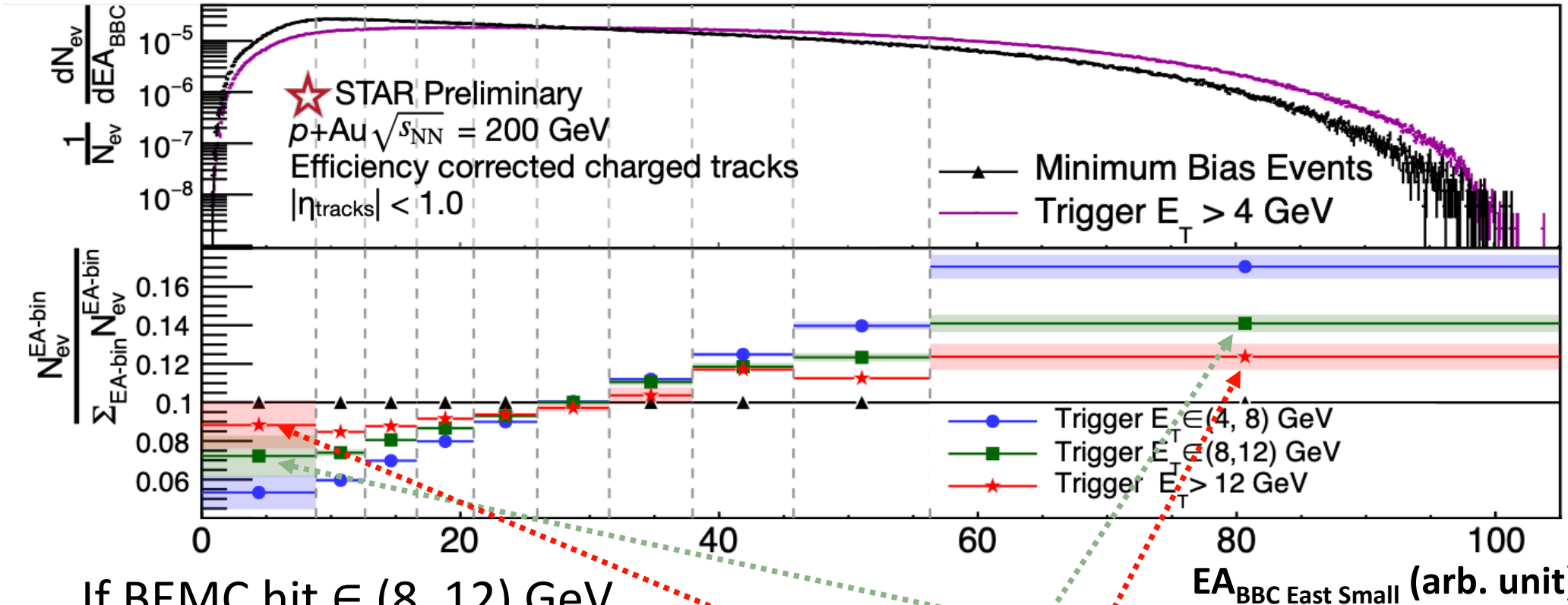

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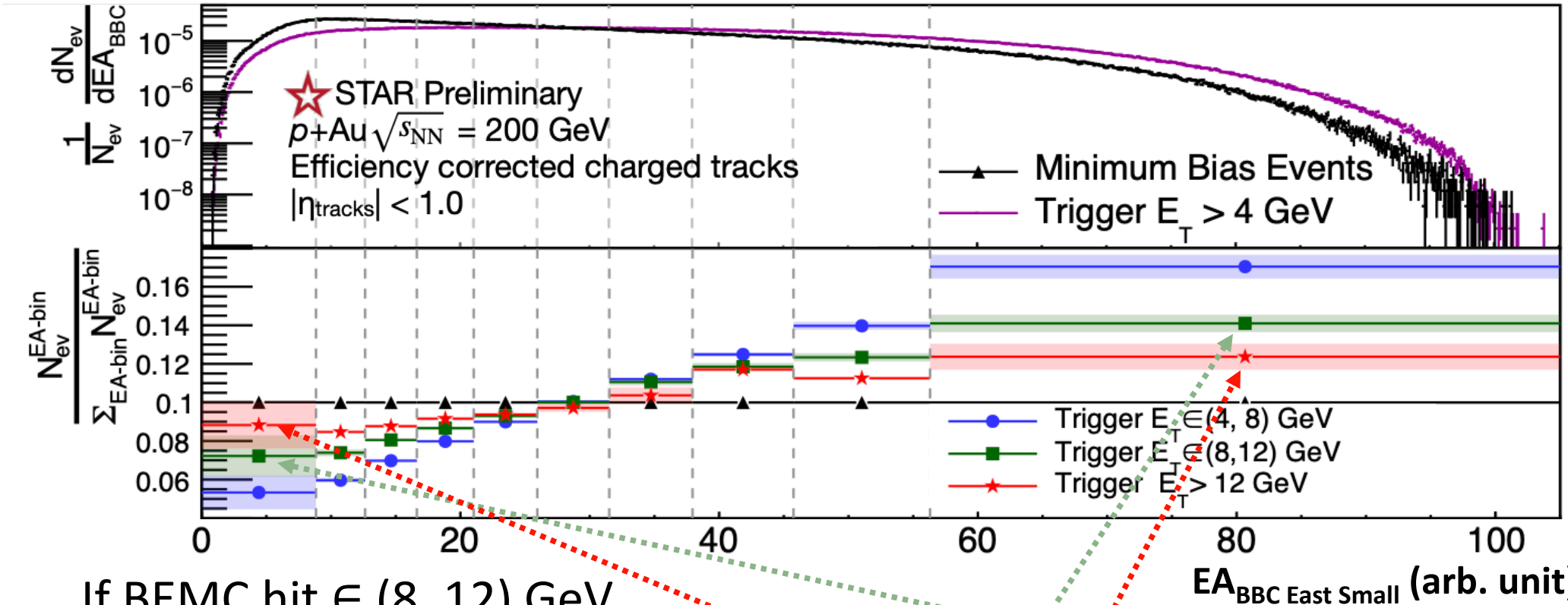

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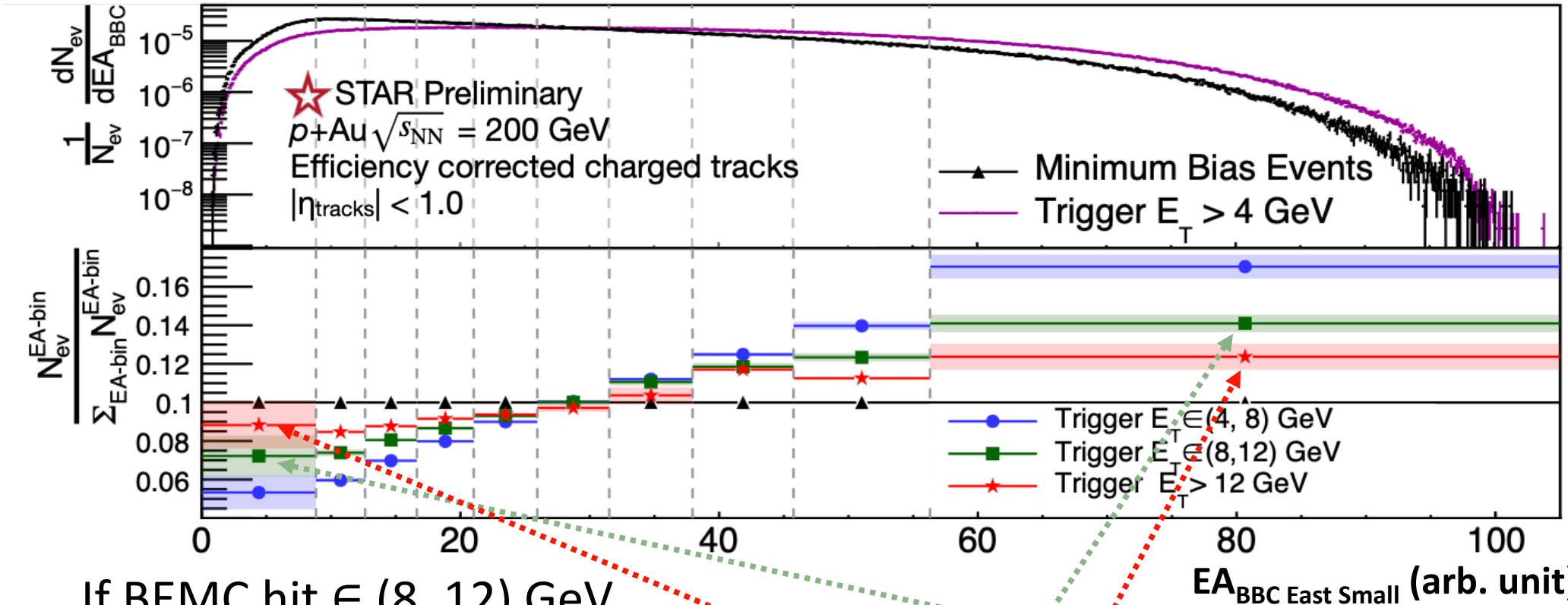

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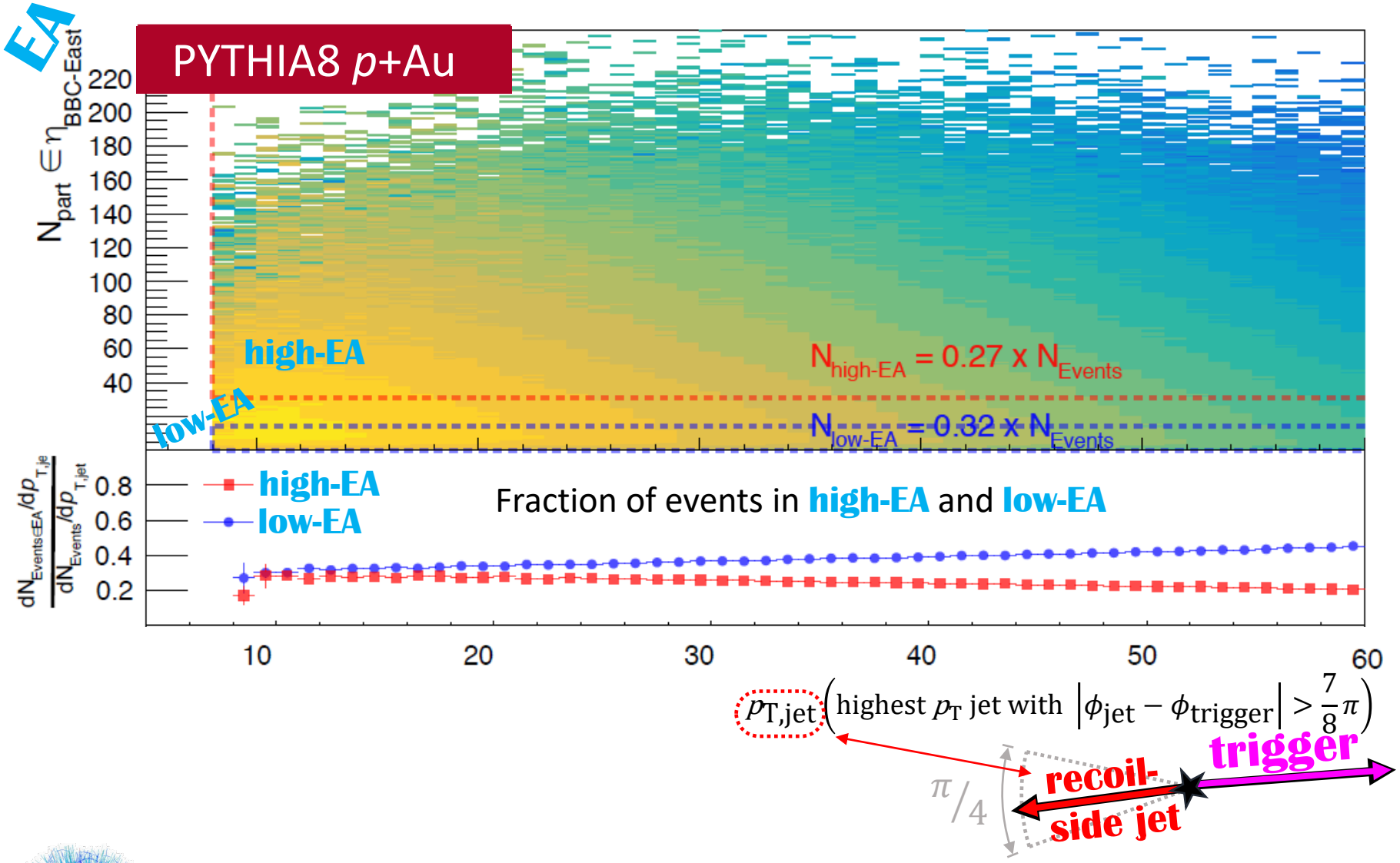
See talk: Veronica Verkest
LB: 00005

Simulated phase-space caused semi-inclusive suppression



- Events sorted by **EA** and leading recoil jet p_T (goes as Q^2)
- Ratio of events in **high-EA** inversely correlated to Q^2

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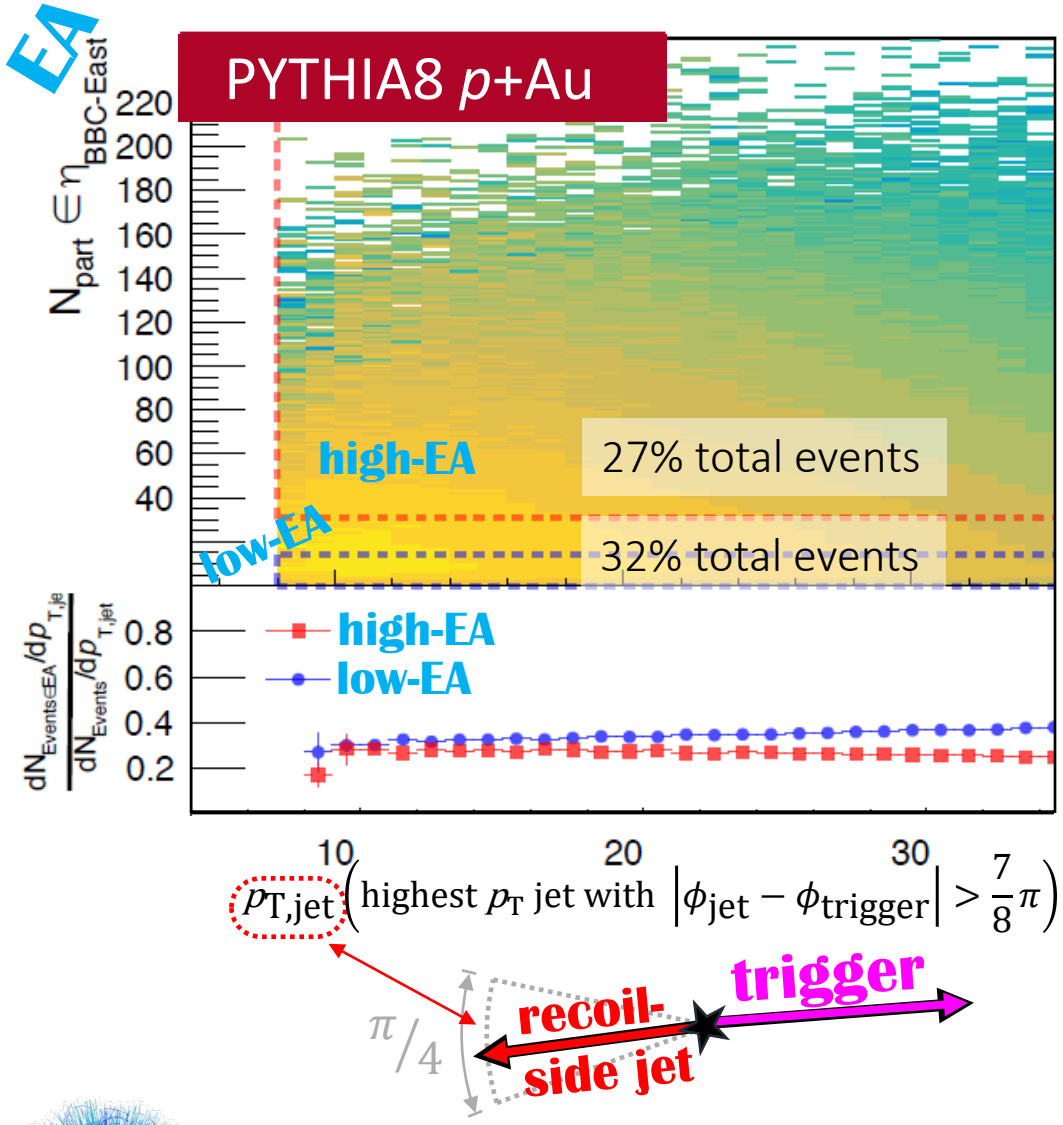

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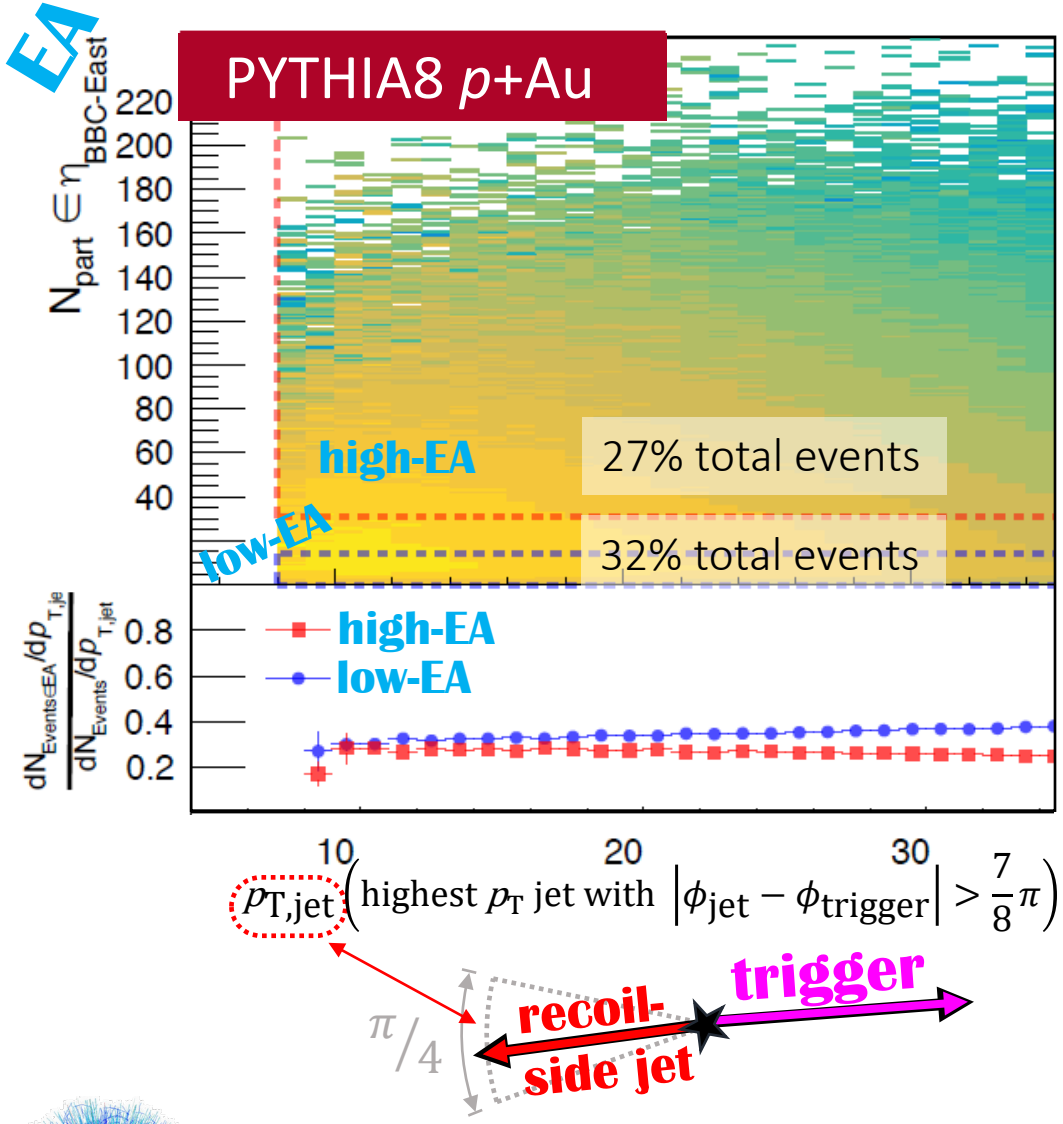

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- For jets ~30 GeV/*c*:

$$S = \frac{N_{jets}^{high-EA}}{N_{jets}^{low-EA}}\Bigg|_{p_{T,jet}\approx 30GeV} \frac{N_{triggers}^{low-EA}}{N_{triggers}^{high-EA}}\Bigg|_{p_{T,jet}\approx 30GeV} =$$

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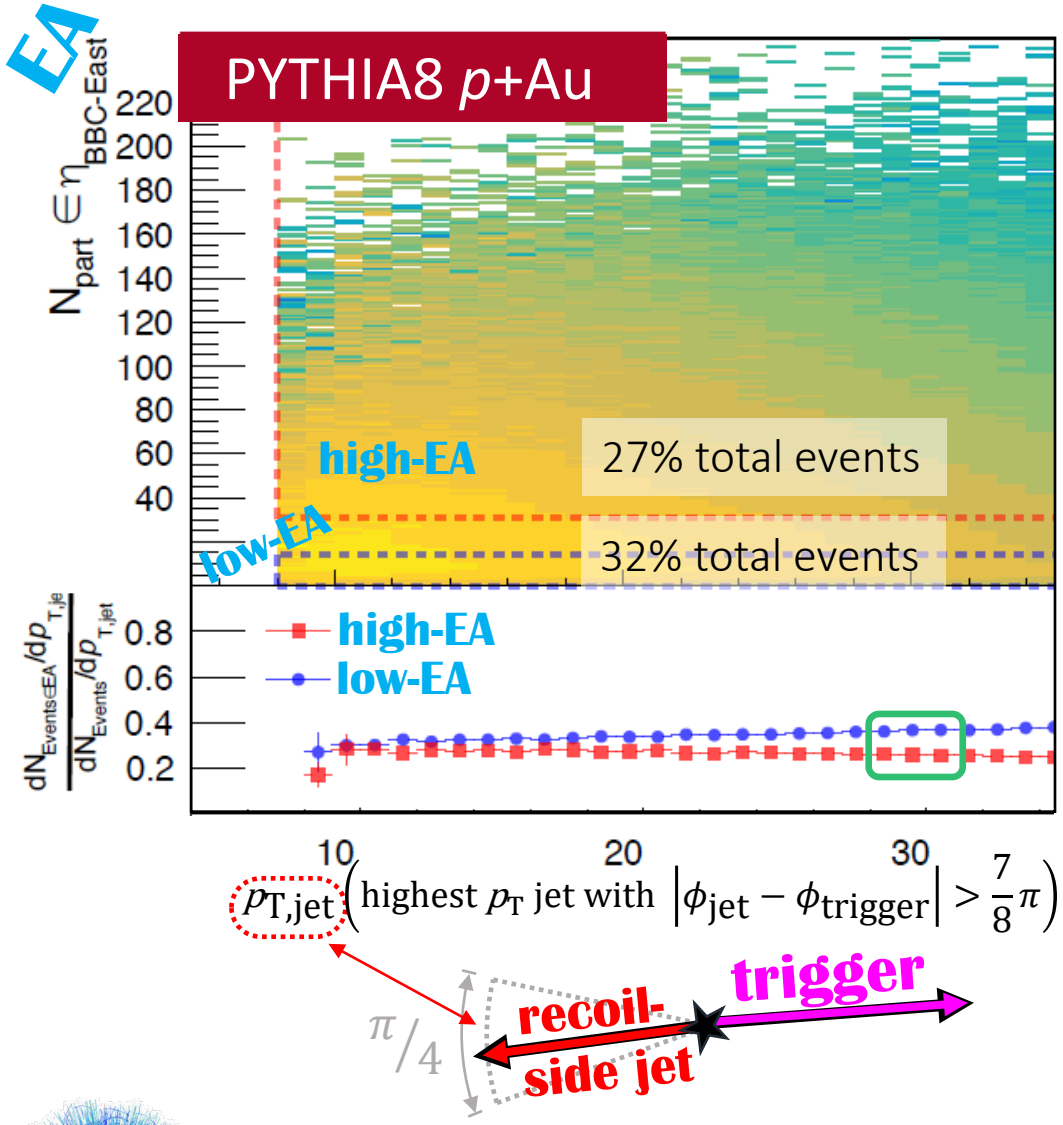

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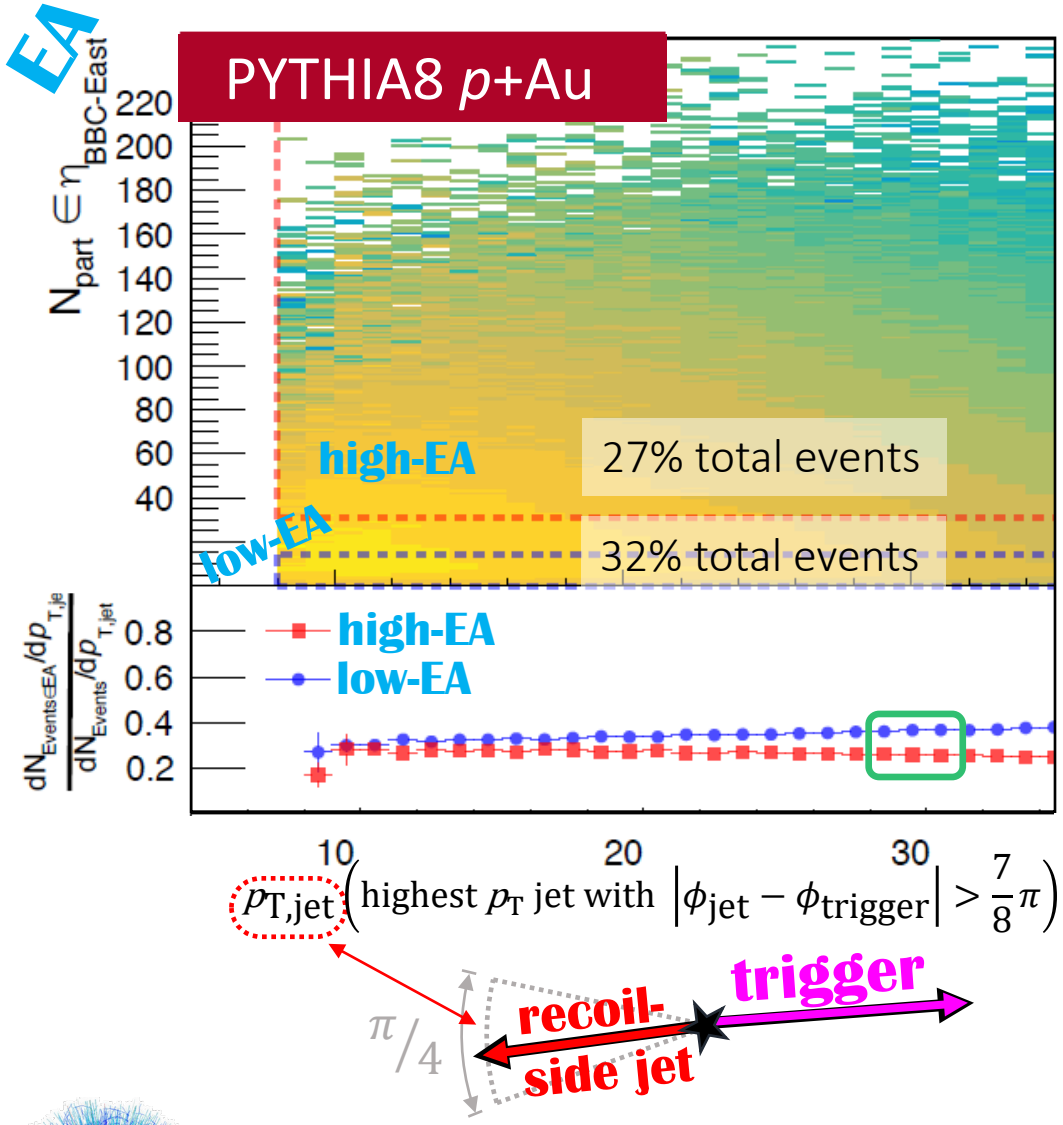

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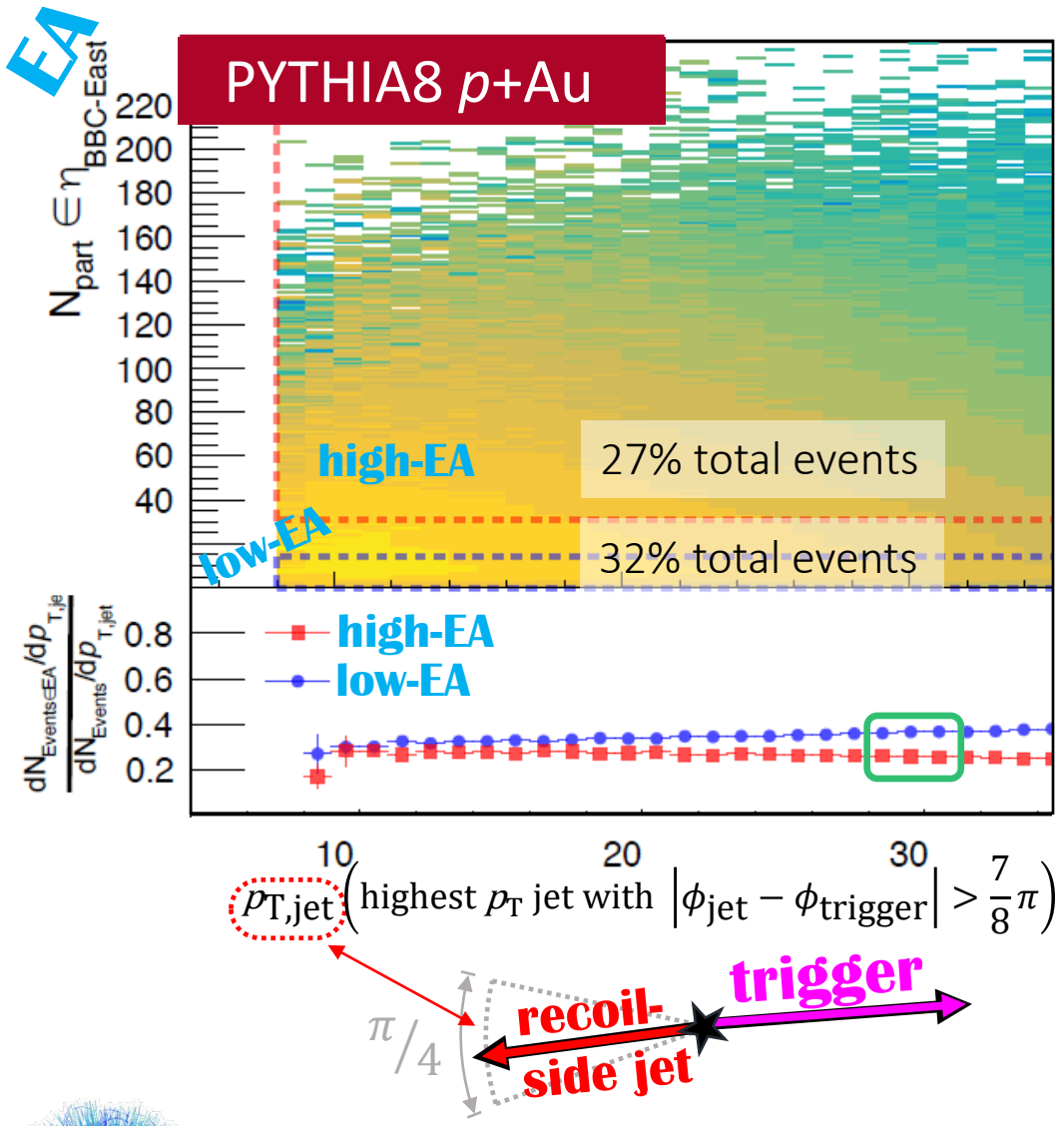

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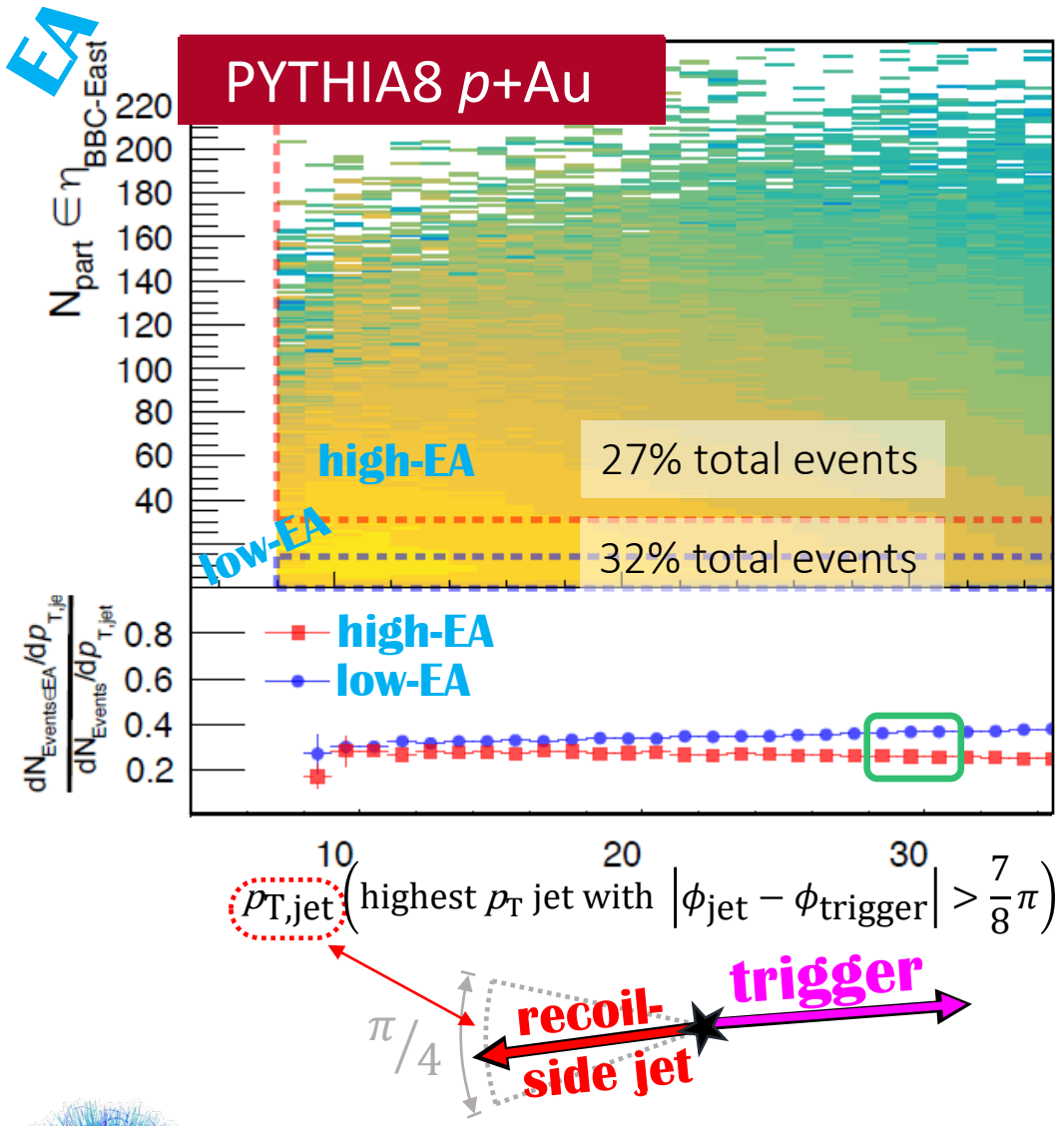
- In experiment, normalization is set by all **high-EA** and **low-EA** triggers:

Simulated phase-space caused semi-inclusive suppression



- Each entry includes the single leading jet
  - $N_{jets}:N_{triggers}:N_{events}$ = 1:1:1
- For jets ~30 GeV/*c*:

$$S = \left.\frac{N_{jets}^{high-EA}}{N_{jets}^{low-EA}}\right|_{p_{T,jet}\approx 30GeV} \left.\frac{N_{triggers}^{low-EA}}{N_{triggers}^{high-EA}}\right|_{p_{T,jet}\approx 30GeV} = 1.0$$

~0.7 ~1.4

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~0.7

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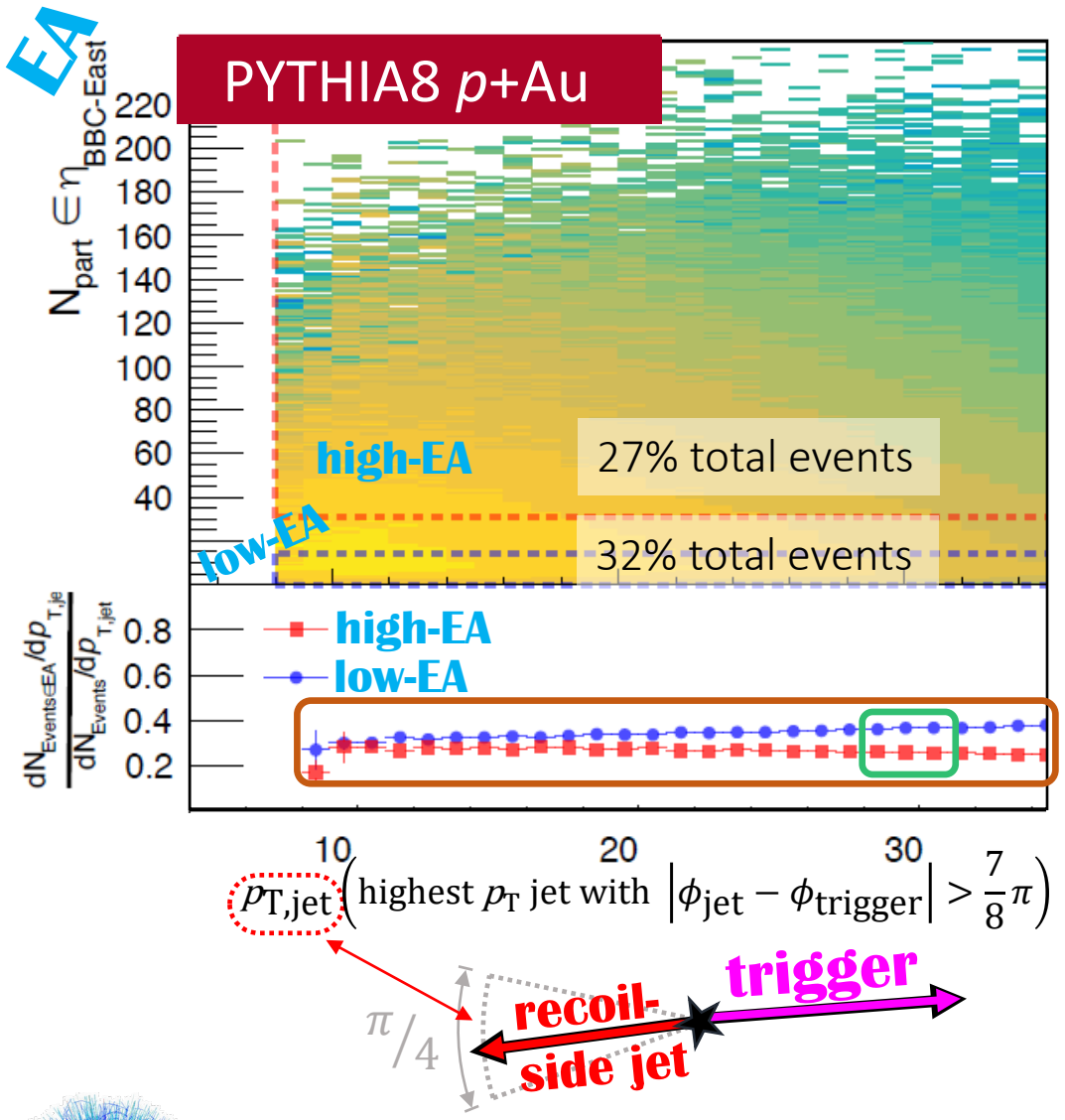

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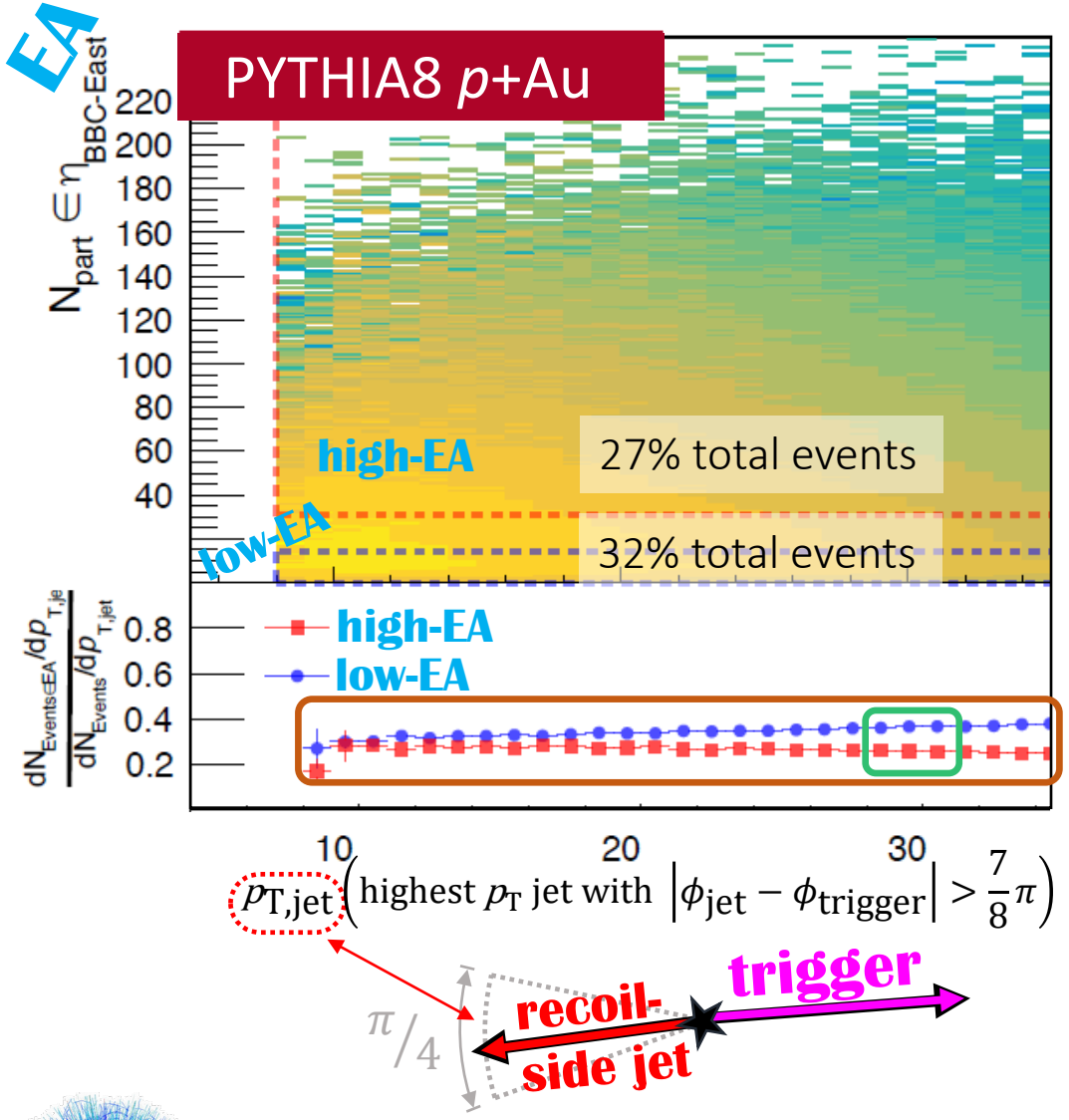
~0.7 ~1.2

Simulated phase-space caused semi-inclusive suppression



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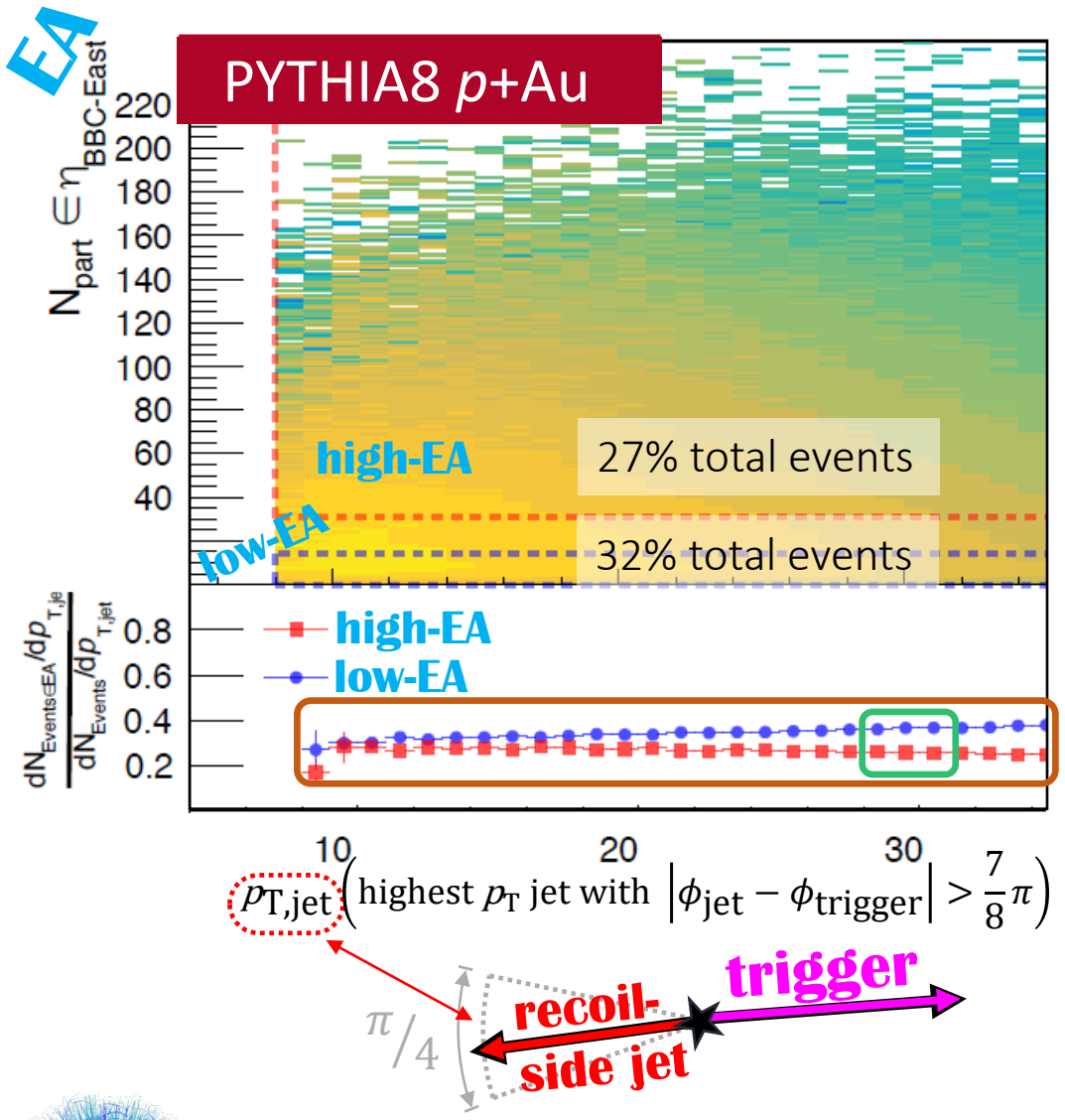
Simulated phase-space caused semi-inclusive suppression



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- In experiment, normalization is set by all **high-EA** and **low-EA** triggers:

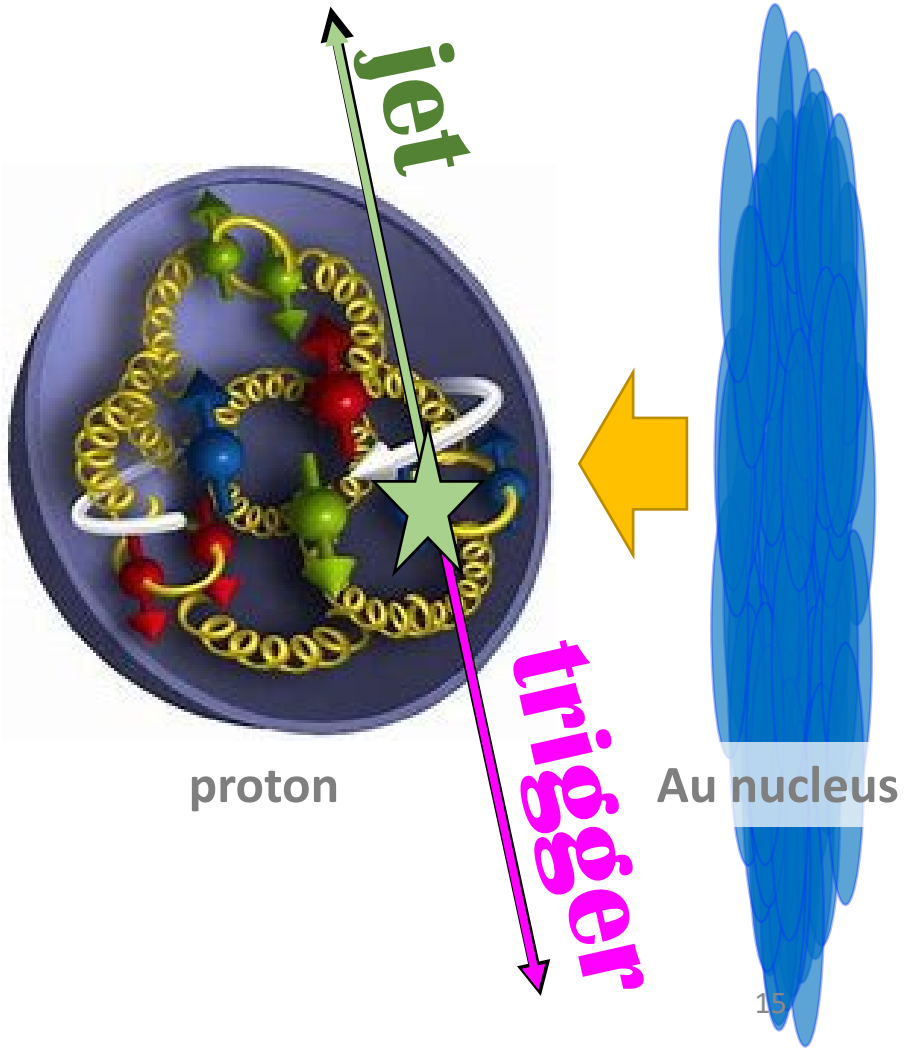
$$S = \left.\frac{N_{jets}^{high-EA}}{N_{jets}^{low-EA}}\right|_{p_{T,jet}\approx 30GeV} \sim 0.7 \qquad \left.\frac{N_{triggers}^{low-EA}}{N_{triggers}^{high-EA}}\right|_{\text{all events}} \sim 1.2 \qquad \approx 0.84$$

~16% suppression of 30 GeV/*c* jets from **EA** to Q^2 correlation

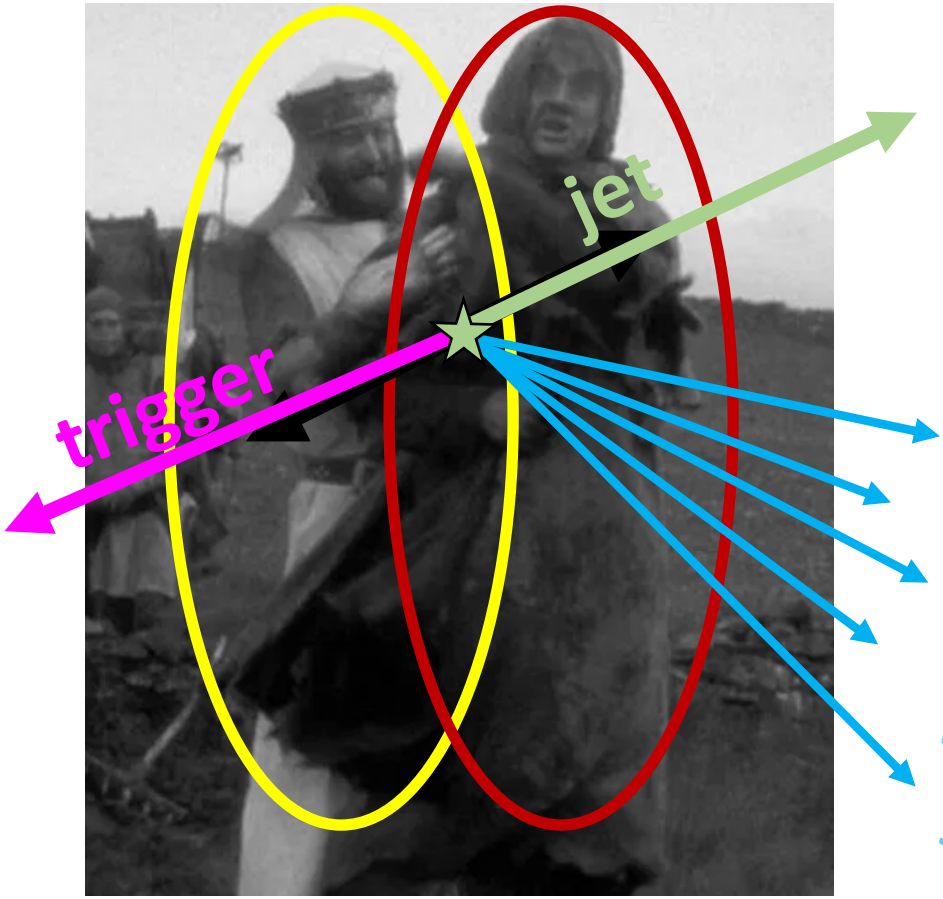
See talk EB.00004
By Tong Liu

STAR *p*+A **jet** + **EA** conclusion

- **EA** jet spectra suppression in *p*+Au 200 GeV collisions results from phase space constraints
- Higher Q^2 scatterings more negatively correlated with **EA** as measured everywhere outside the dijet
  - Result of simple energy conservation ?
  - Result of high-Q^2 proton configuration? (e.g. "shrunk proton" with fewer N_{coll}) ?
  - Relates how to inclusive **EA**-dependent jet spectra measured at ATLAS and PHENIX?
- Predict dijet momentum imbalance and other jet substructure observables **EA** independent
- More studies to come!



The End

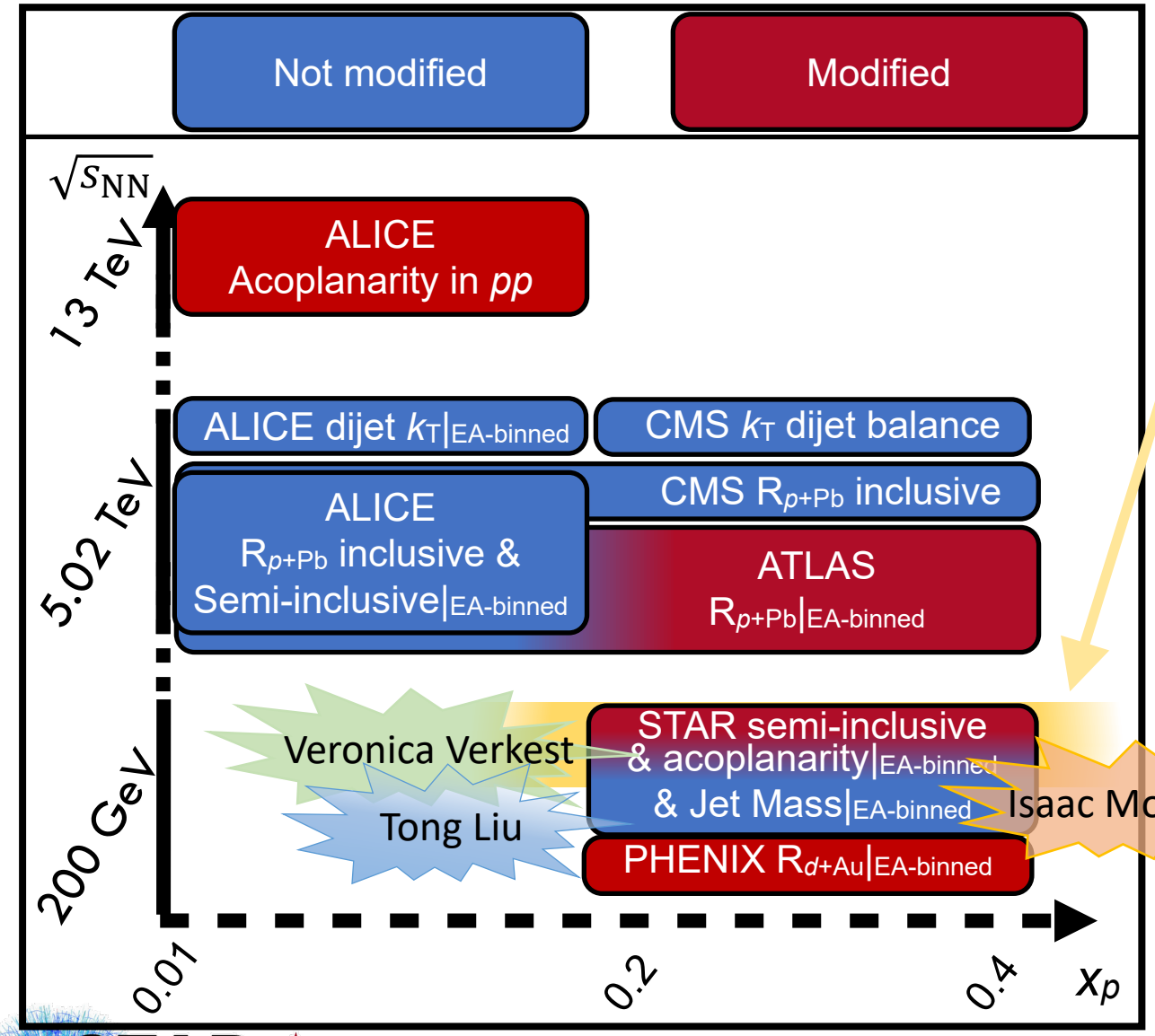


EA: *"the violence inherent in the system"**

Thank You!

*Monty Python and the Holy Grail

Where these fit in small system measurements

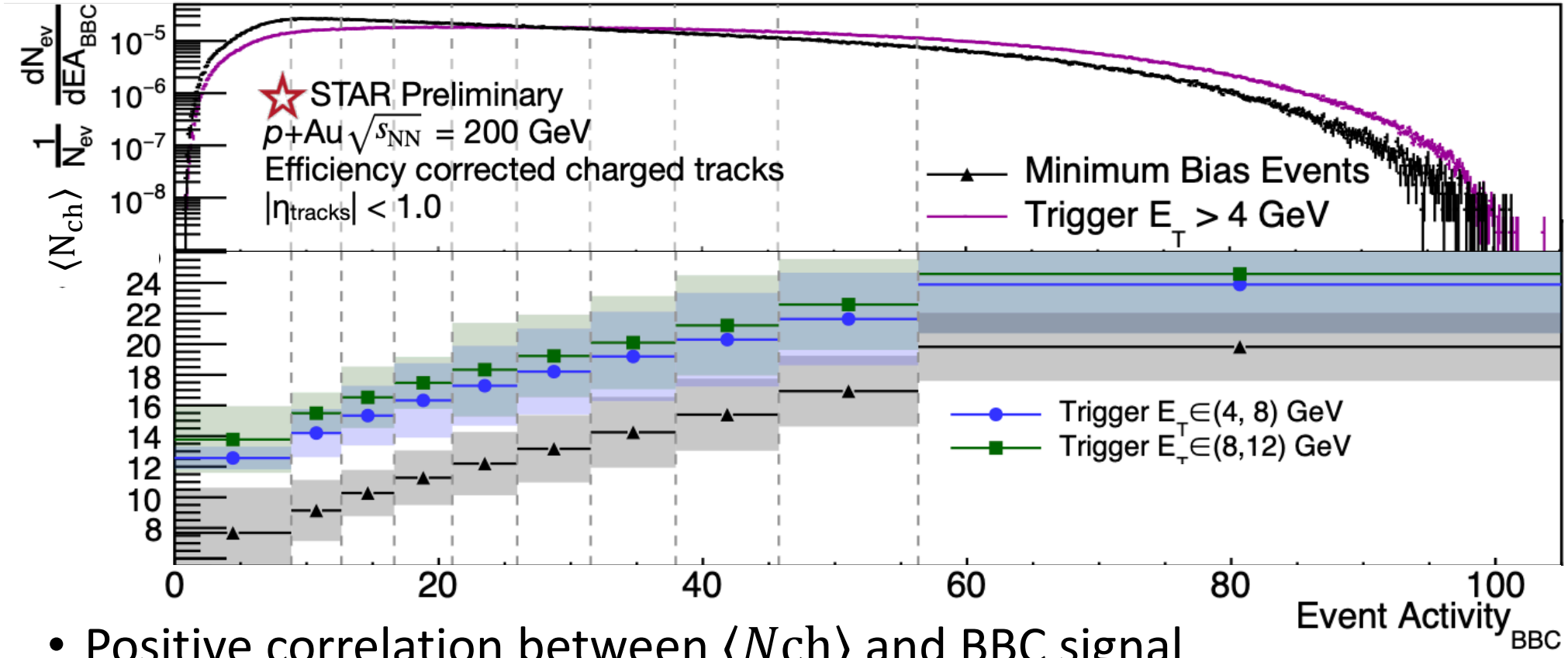


Semi-inclusive small system jet measurements:

- First at high x_p
- First at high RHIC energies

- Jet spectra per trigger suppression results at least partially from correlation:
  - Higher Q^2 scattering:
    ⇒ Higher p_T jets
    ⇒ Lower activity everywhere outside of dijet (both in η and ϕ)
- No jet mass modification
- Predict dijet momentum balance and other jet substructure observables EA independent

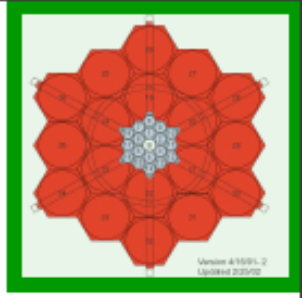
TPC charge track activity in deciles of EA_{BBC}



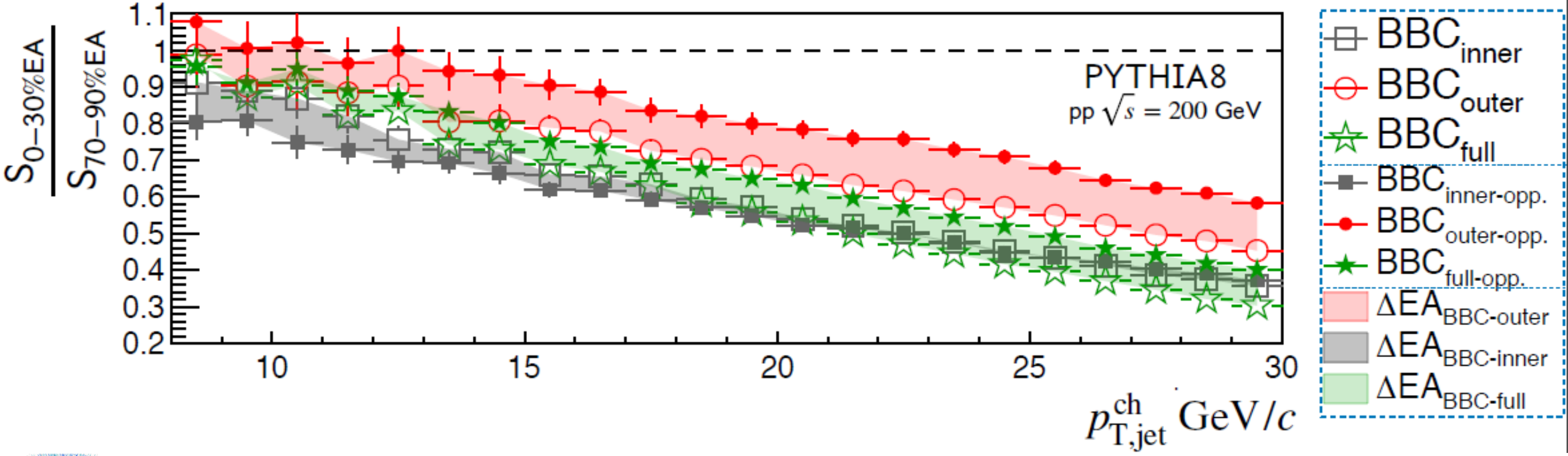
Note: $\langle E_{\mathrm{T}} \rangle$ scales mono-tonically with Q^2

- Positive correlation between $\langle Nch \rangle$ and BBC signal
- Separated in phase space
  ⇒ BBC signal taken as good EA estimator

PYTHIA $S_{0-30\%EA}/S_{70-90\%EA}$ with and without dijet bias

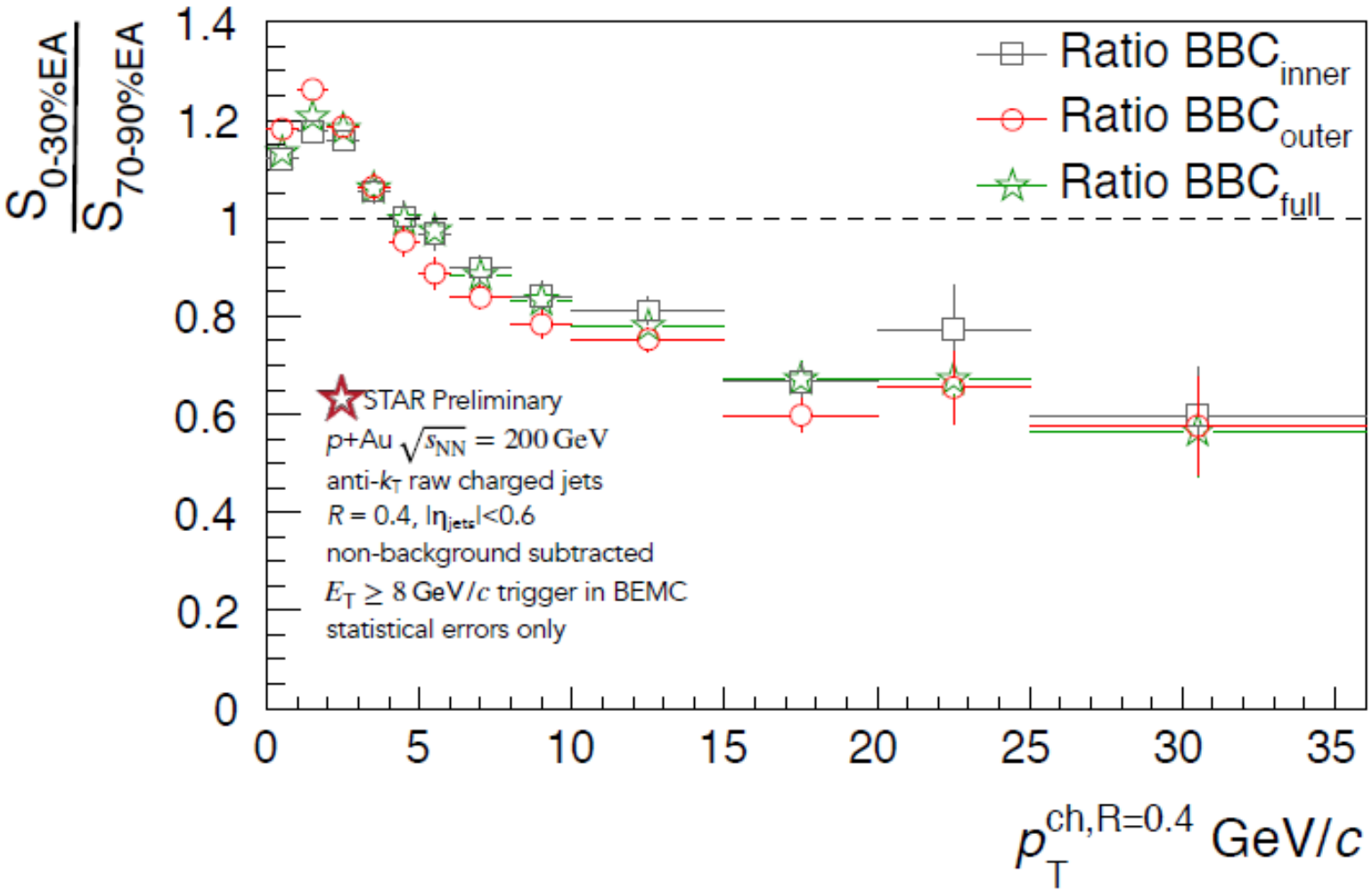


- Using "opposite-side" BBC for EA sorting reduces suppression by ~constant factor for outer and full, but not inner, BBC



Suppression persists with BBC_{inner} EA selection

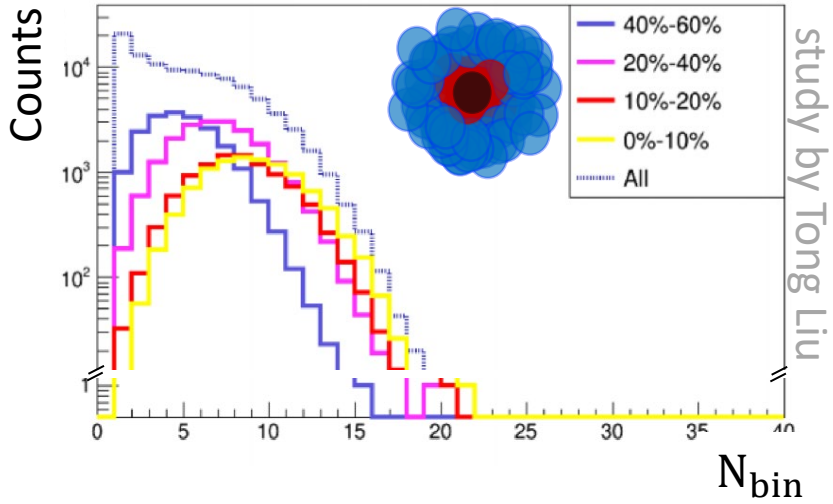
Recoil jets ($|\varphi_{jet}-\varphi_{trigger}|>(7/8)\pi$)



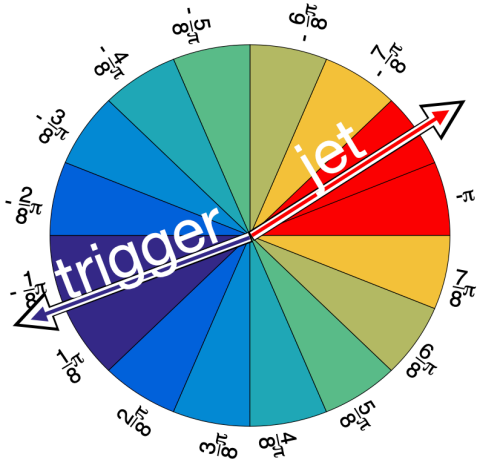
- Smaller expected dijet kinematic effects in p+Au collisions than pp collisions, due to multiple soft collisions measured with hard collisions
- Suppression of $S_{0-30\%}/S_{70-90\%}$ persists with EA selection by BBC_{inner} or BBC_{outer} instead of BBC_{full}

How to compare jet spectra

a. Per N_{bin} (inclusive):
- Measure all jet spectra
- Sort by EA into centrality bins
- Compare to *pp* jet spectra scaled by N_{bin} from Glauber model

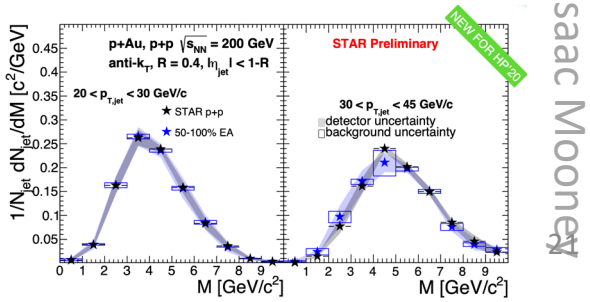


b. Per-trigger (semi-inclusive)
- Measure $p + \mathrm{Au} \rightarrow \mathrm{trigger} + \mathrm{jet} + X$
- Separate into EA bins
- Measure jet per trigger spectra (S_{EA})
- Compare spectra in high to low EA ($S_{\mathrm{EA-high}}/S_{\mathrm{EA-low}}$)

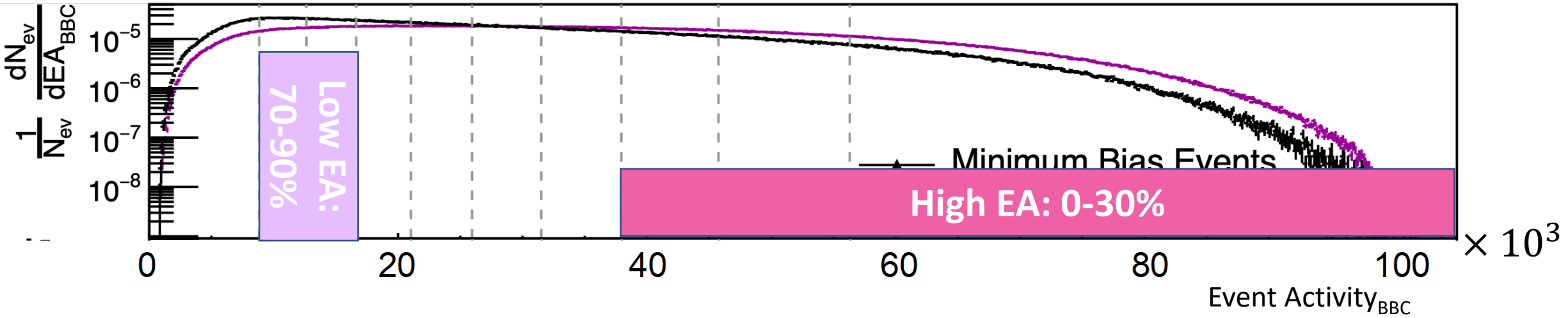


c. Per-jet (shape)
- Compare shapes in different EA bins

Example: jet mass distribution

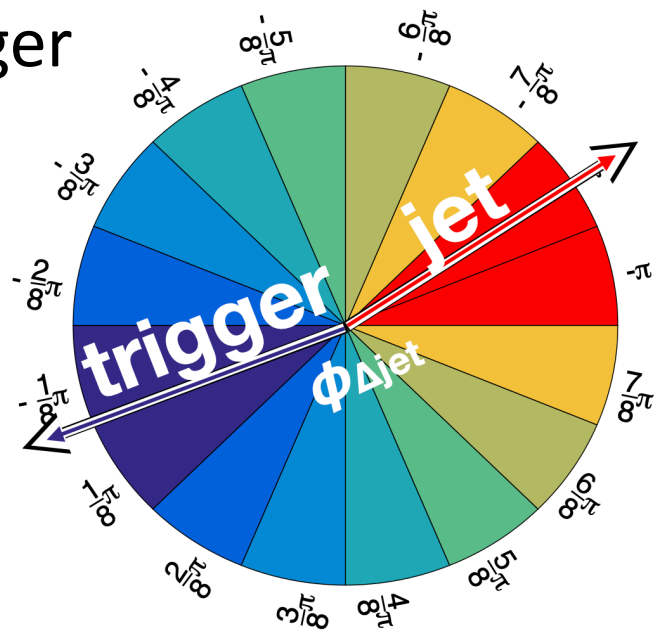


Data: BBC Event Activity Selection and Jet ϕ binning

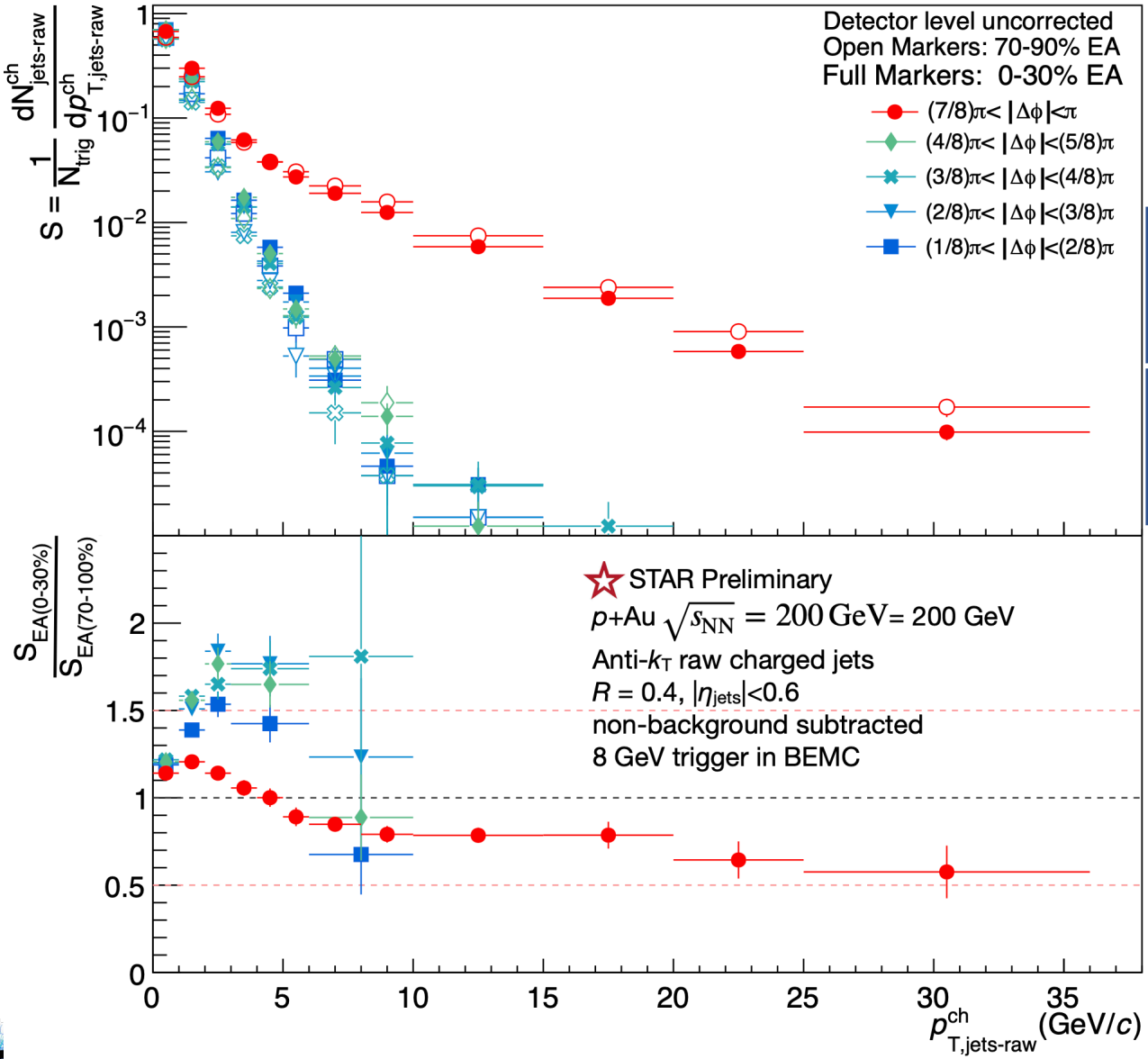


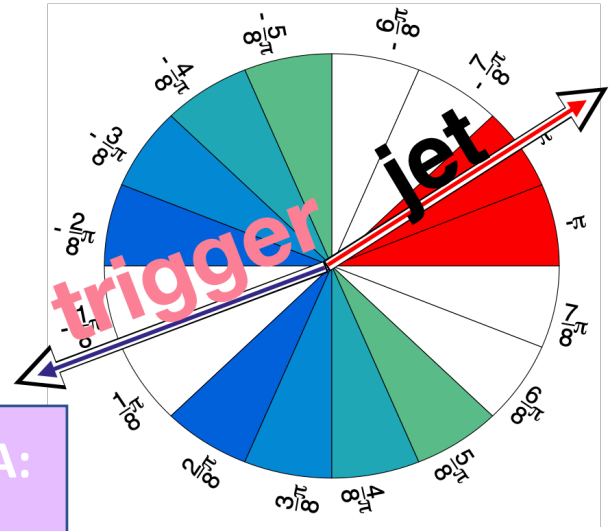
- Jets:
  - anti-kT
  - R=0.4
  - $|\eta|<0.6$

- Binned in Δϕ in π/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
  - $S_{0\text{-}30\%EA}/S_{70\text{-}90\%EA}$ expected to be insensitive to corrections



Suppressed recoil & negligible transverse spectra



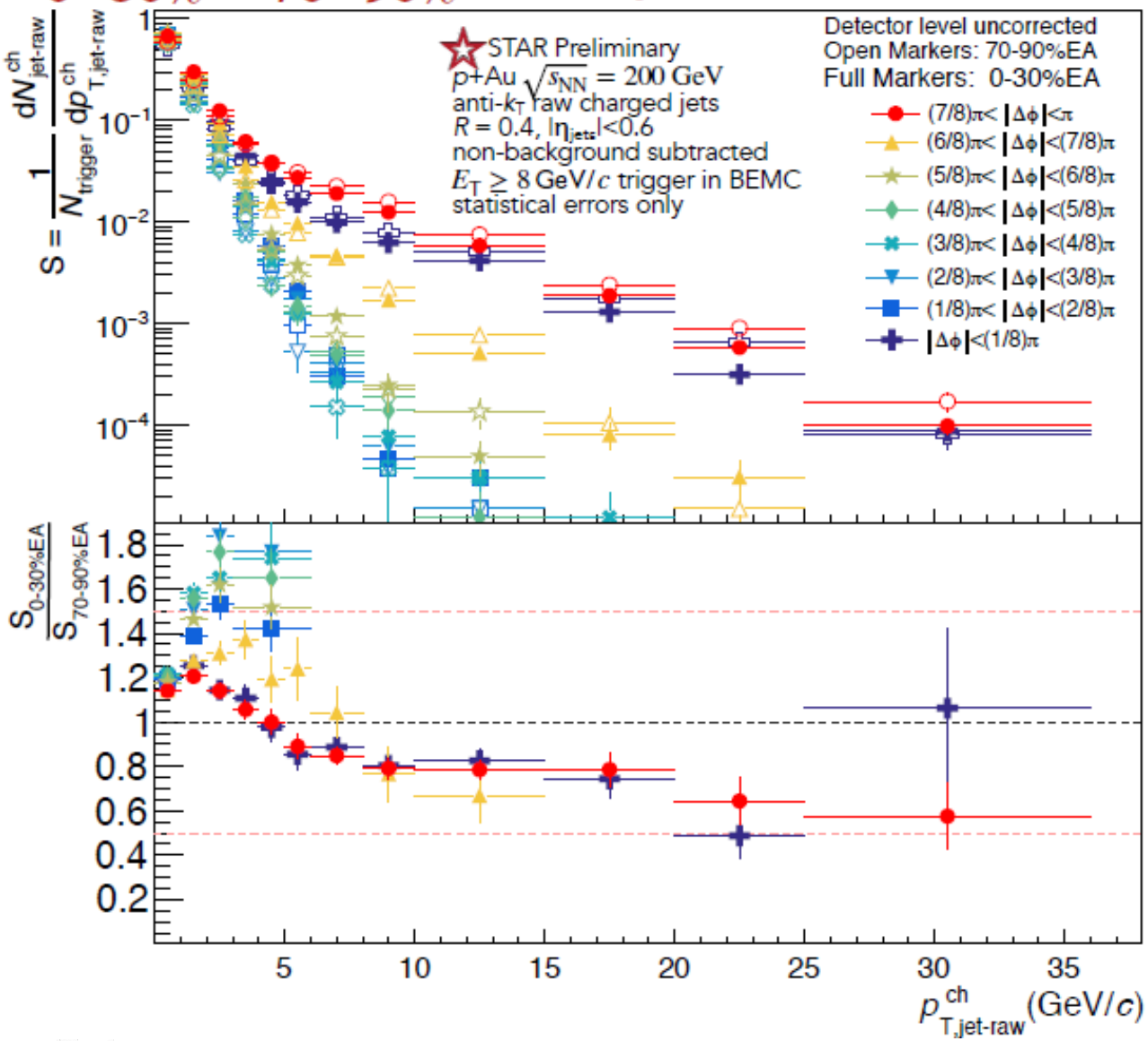


Open Markers: Low EA: 70-90%

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 $S_{0\text{-}30\%EA}$ & $S_{70\text{-}90\%EA}$

$S_{0-30\%}/S_{70-90\%}$ all $\Delta\phi$ bins



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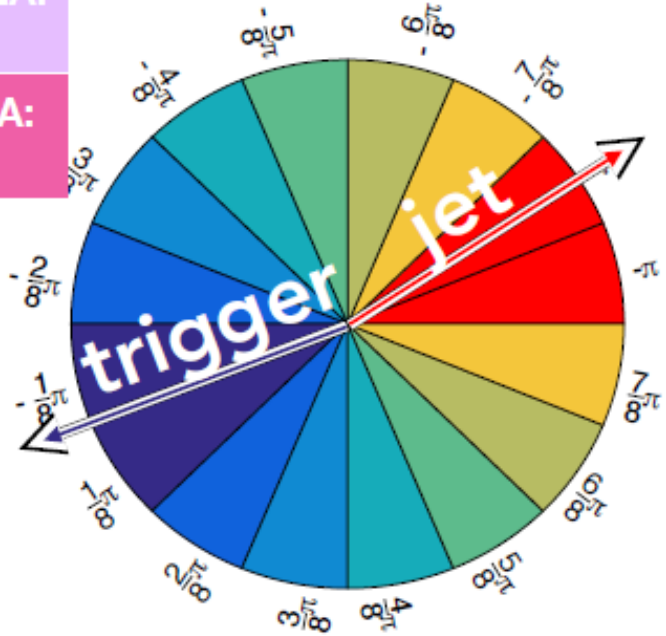
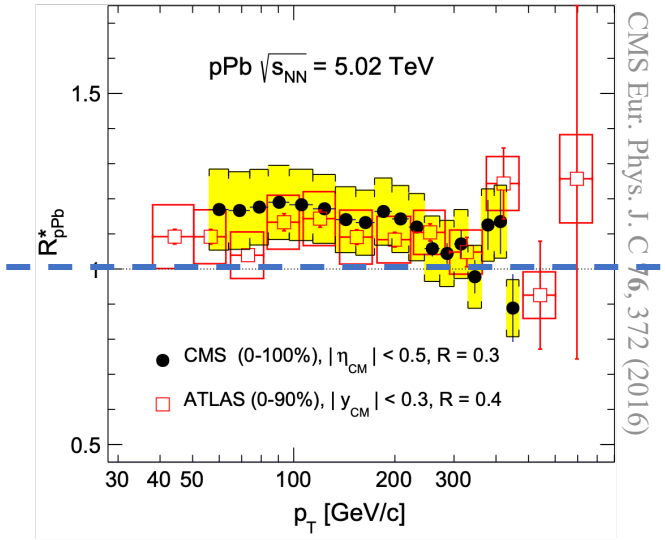


- Both near and recoil jets suppressed in high EA relative to low EA
- n.b.: These are charged jet spectra; the near-side jets have a neutral energy fraction (NEF) bias because near side must also always contain the neutral trigger
  - This NEF bias is not present in the recoil jets
  - This NEF bias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

Geometry: Jets/N_{coll} over all b are as expected

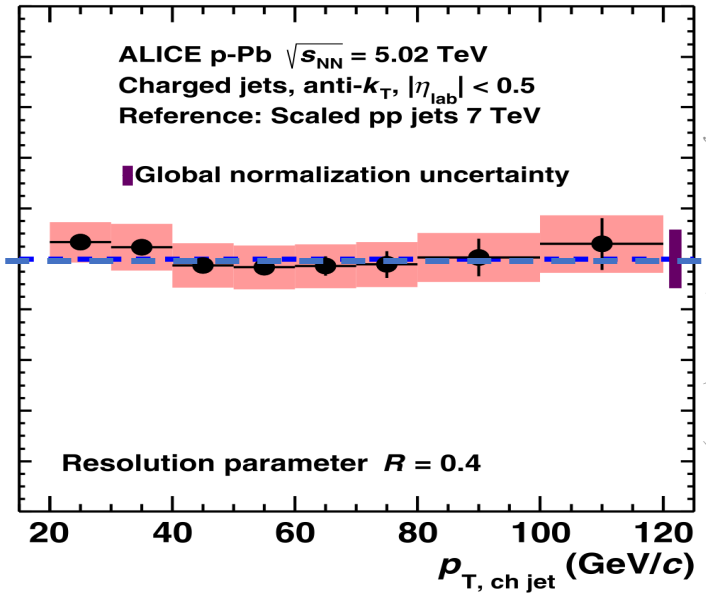
2015 & 2016: $R_{p/d}$+A consistent with unity

ATLAS & CMS



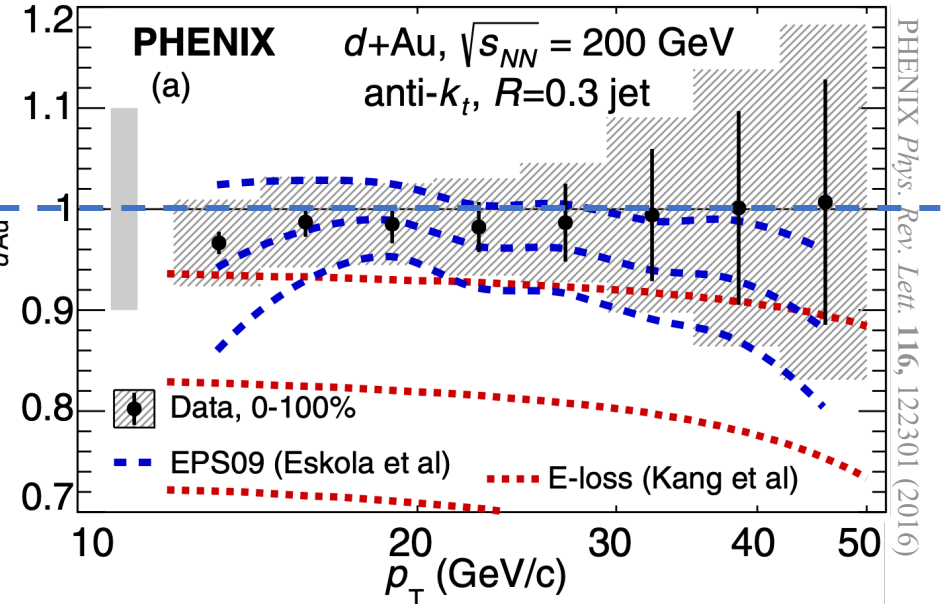
CMS Eur. Phys. J. C 76, 372 (2016)

ALICE



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

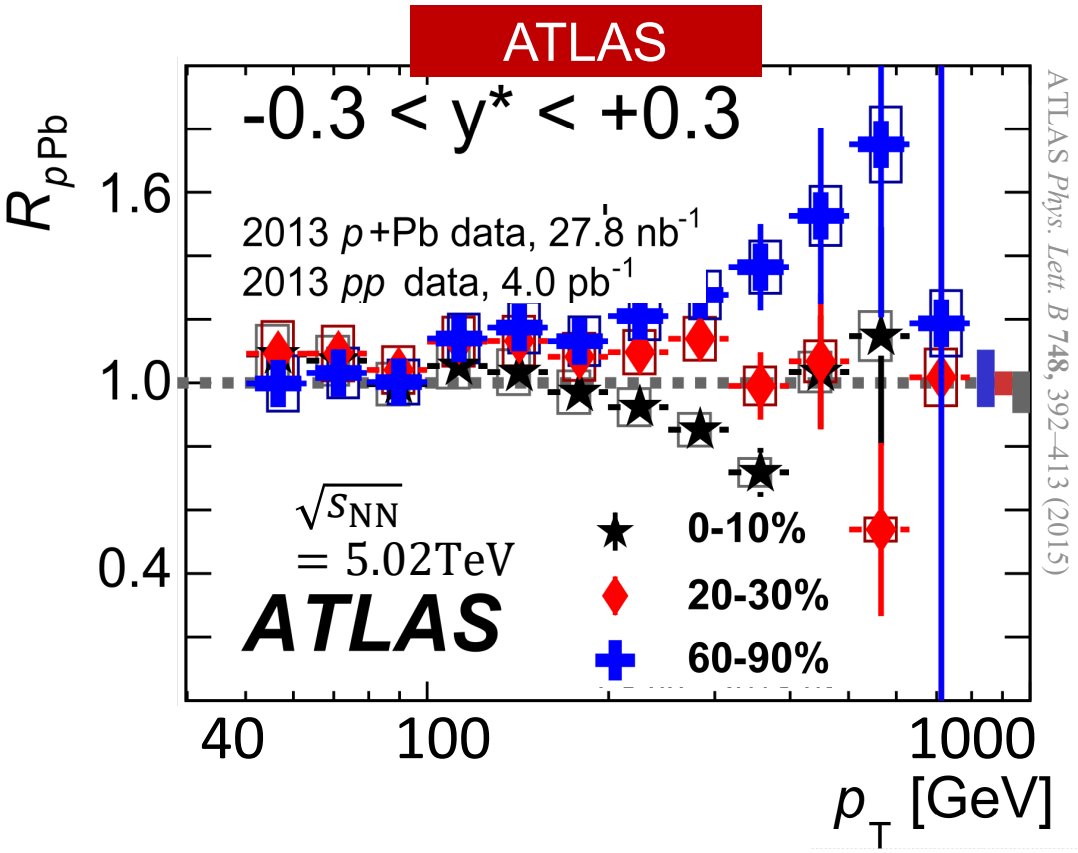
PHENIX

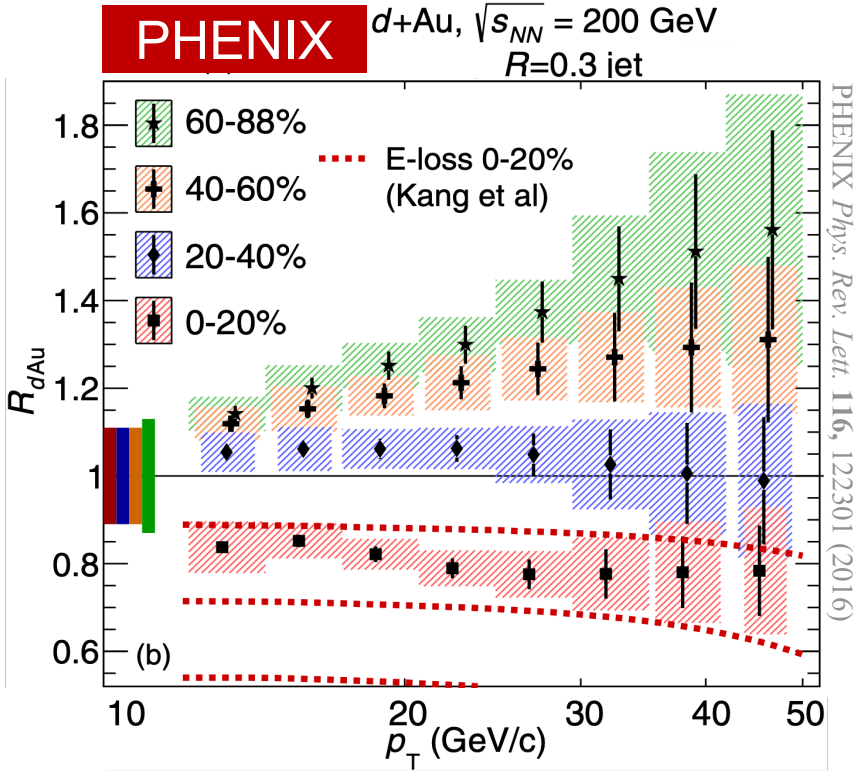


PHENIX Phys. Rev. Lett. 116, 122301 (2016)

- The average number of jets per N_{coll} (integrated over all b) is identical for p/d+A collisions as in pp collisions (values of R≈1)

Geometry-binned $R_{p/d+A}$ were surprising





- EA activity converted to N_{coll} via geometry, central $R_{p/d+A}$ suppressed, peripheral $R_{p/d+A}$ enhanced
- Naïve A+A interpretation: Central events form QGP in which jets are quenched

Tantalizing hint from ATLAS

- Suppression ratios between central and peripheral R_{p+Pb} for jets at p-going η's scale with total jet $|\vec{p}|$ (i.e. $p_T \times \cosh\eta$)
- Related to Bjorken-x of the proton (x_p)