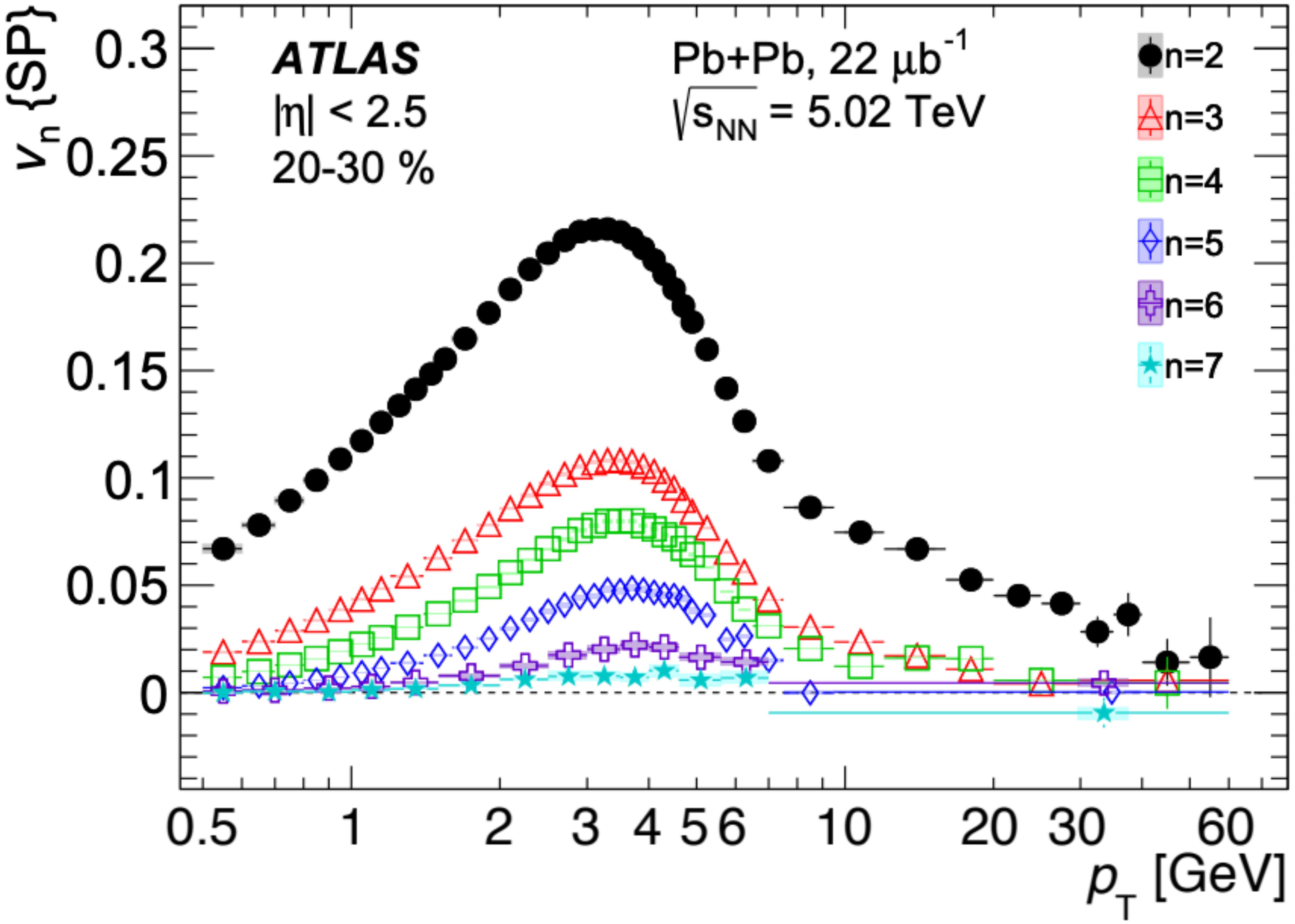
Collective behavior of high-p_T particles in 8.16 TeV p+Pb collisions with ATLAS

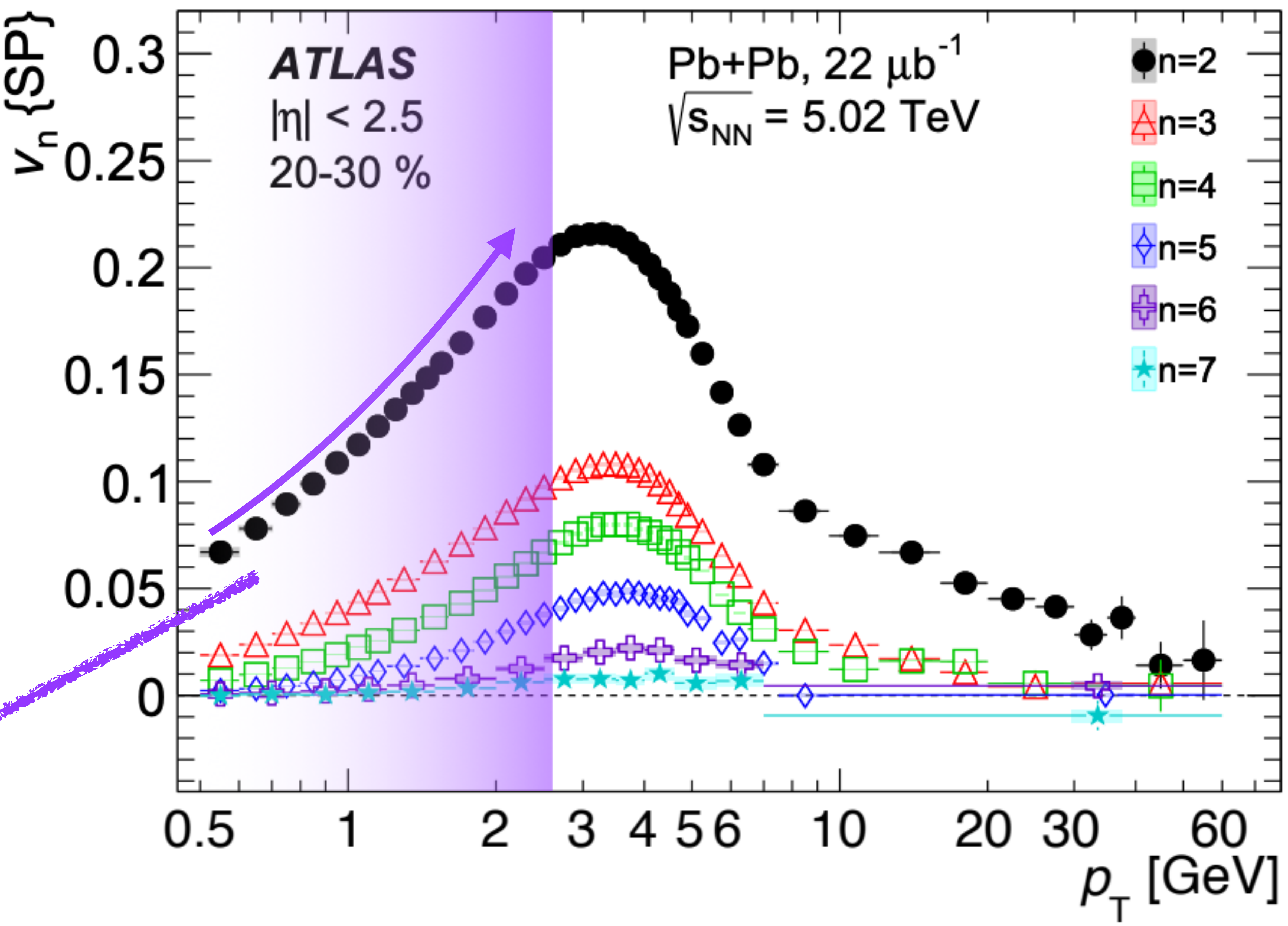
Kurt Hill
University of Colorado, Boulder
for the ATLAS collaboration

v_n in Pb+Pb



Eur. Phys. J. C 78 (2018) 997

v_n in Pb+Pb



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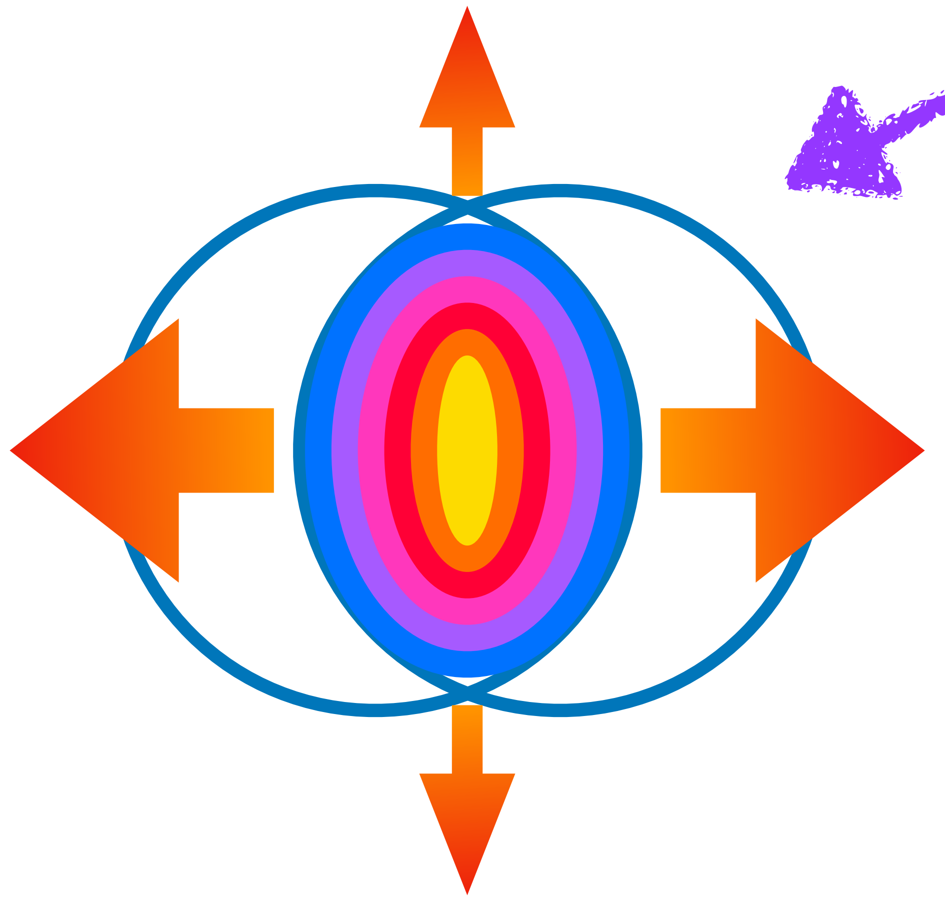
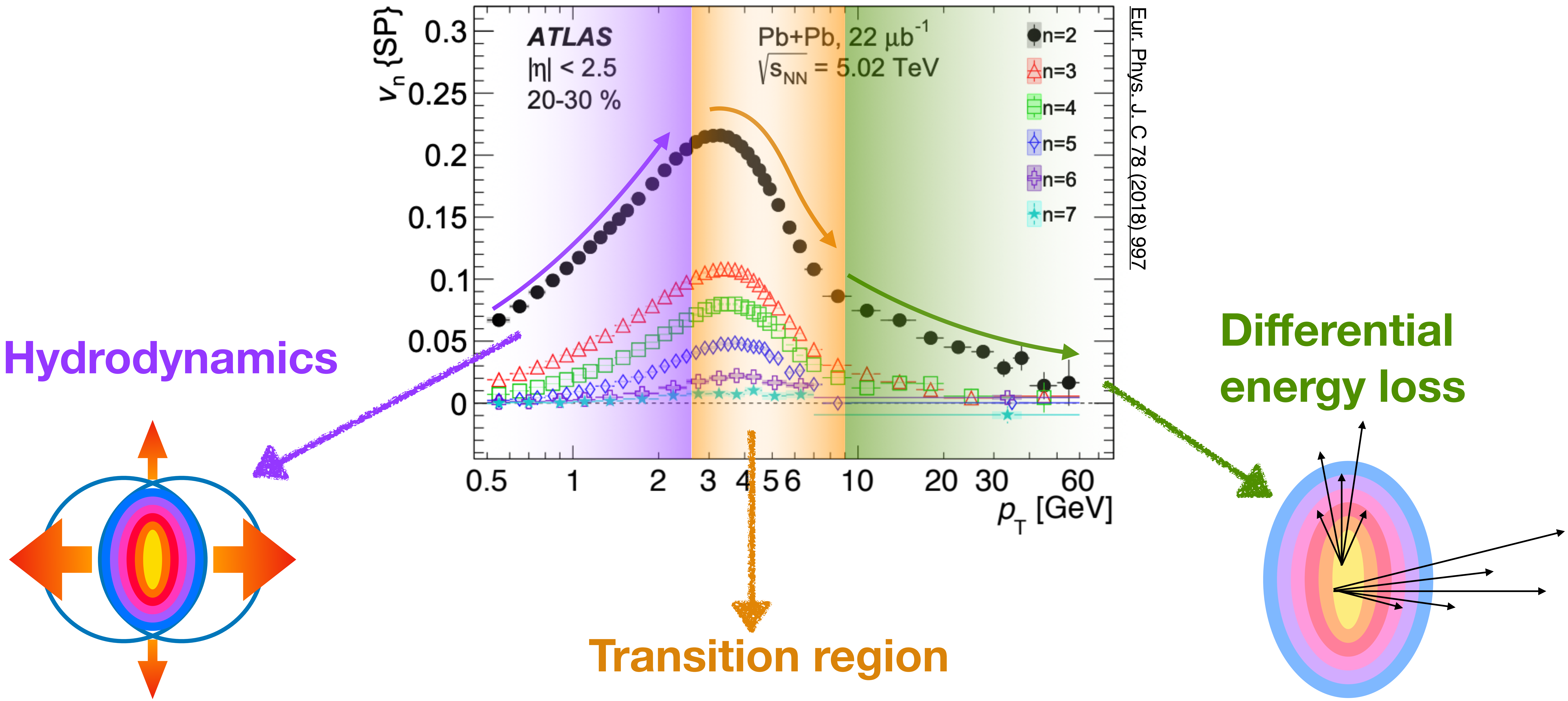
Hydrodynamics



v_n in Pb+Pb


Hydrodynamics
ATLAS
|η| < 2.5
20-30 %
Pb+Pb, 22 μb⁻¹
√sNN = 5.02 TeV
n=2
n=3
n=4
n=5
n=6
n=7
vn{SP}
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5 1 2 3 4 5 6 10 20 30 60
pT [GeV]
Eur. Phys. J. C 78 (2018) 997
Differential
energy loss

v_n in Pb+Pb


ATLAS
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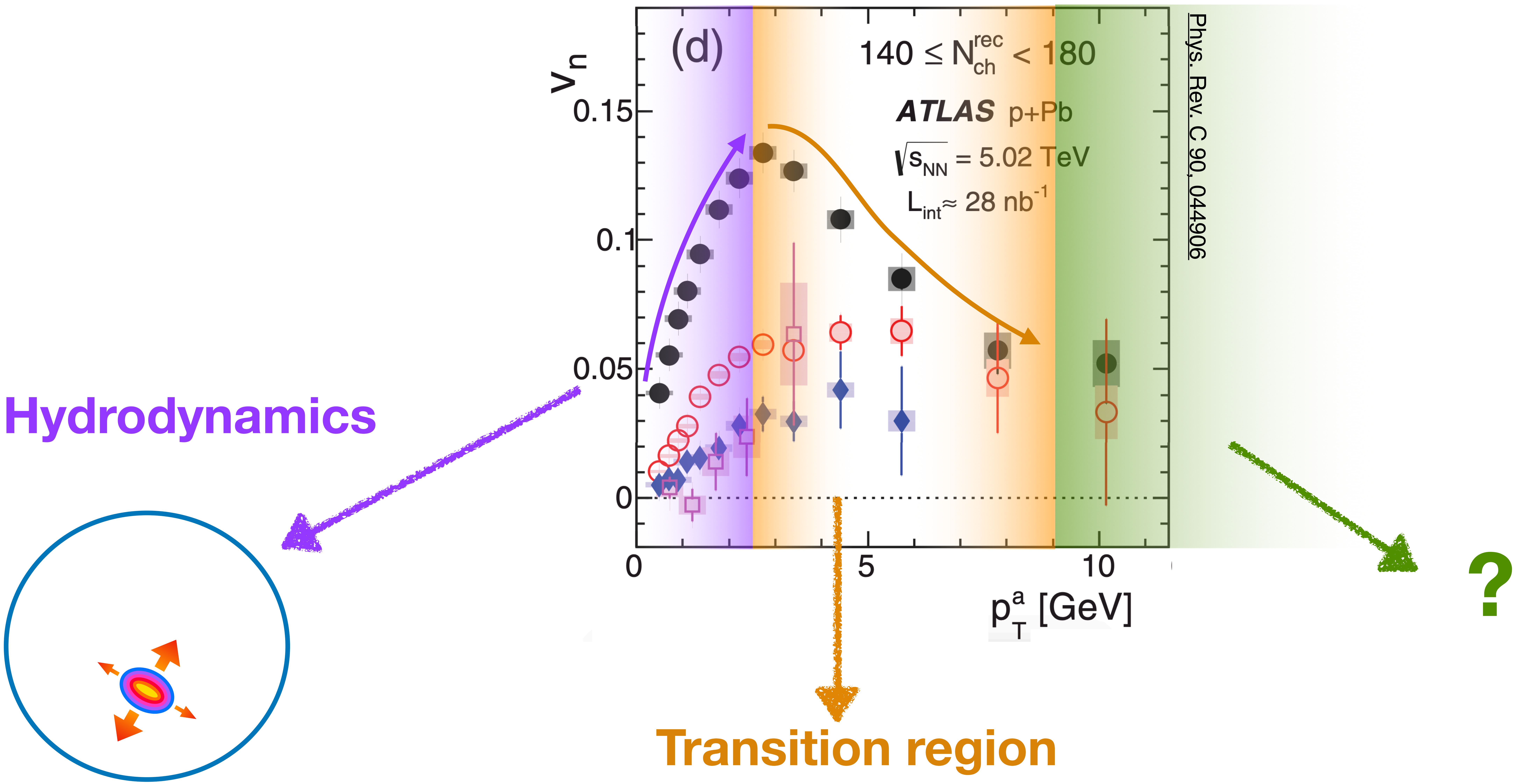
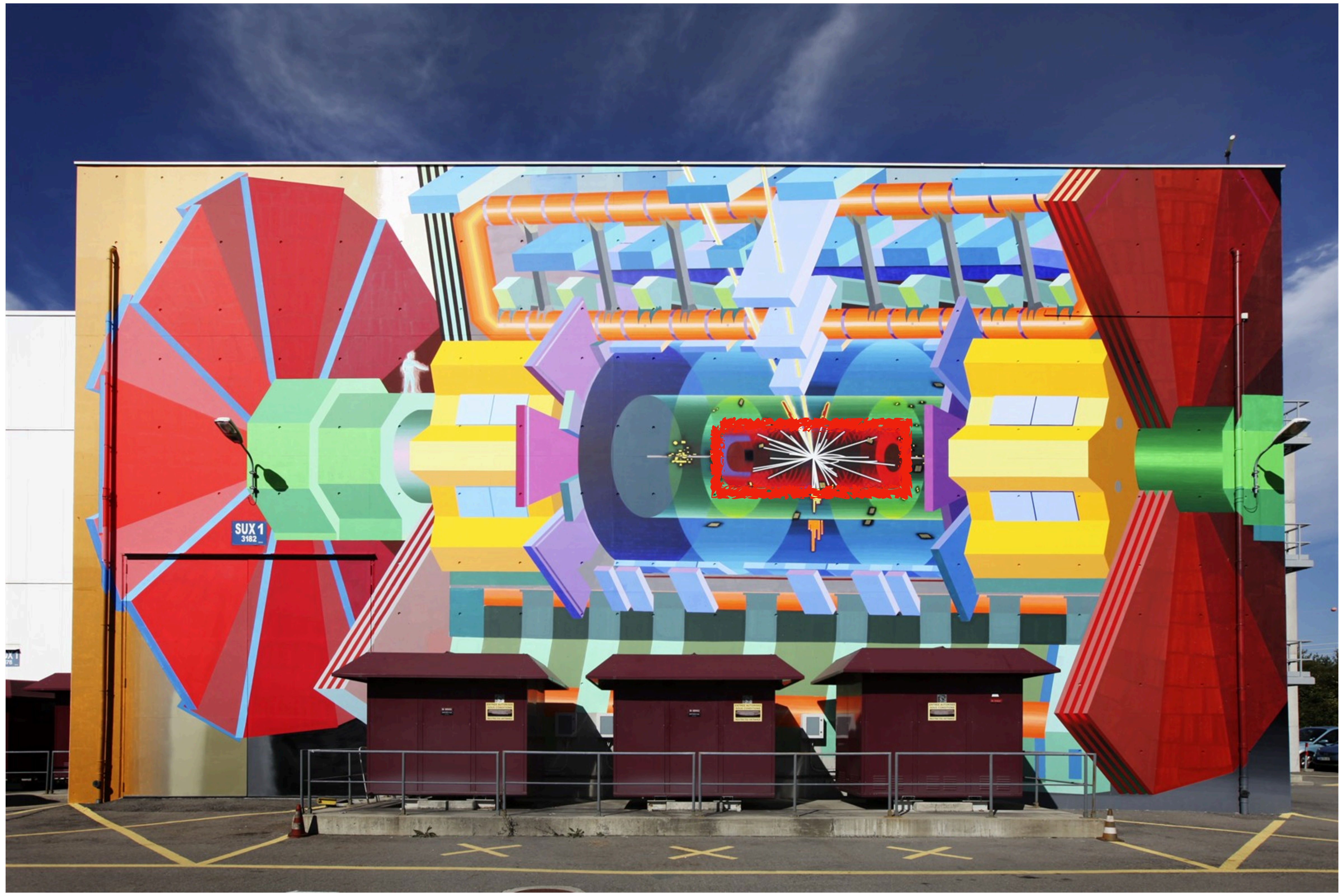
Hydrodynamics
Differential energy loss
Transition region

v_n in p+Pb


(d)
$140 \le N_{ch}^{rec} < 180$
ATLAS p+Pb
$\sqrt{s_{NN}}$ = 5.02 TeV
$L_{int} \approx 28$ nb^{-1}
v_n
0.15
0.1
0.05
0
0
5
10
p_T^a [GeV]
Phys. Rev. C 90, 044906
Hydrodynamics
Transition region
?

Event selection

- 165 nb^{-1} of 8.16 TeV *p*+Pb data taken in 2016
- Select events with three different triggers
  - Minbias
  - Jet p_T > 75 GeV
  - Jet p_T > 100 GeV



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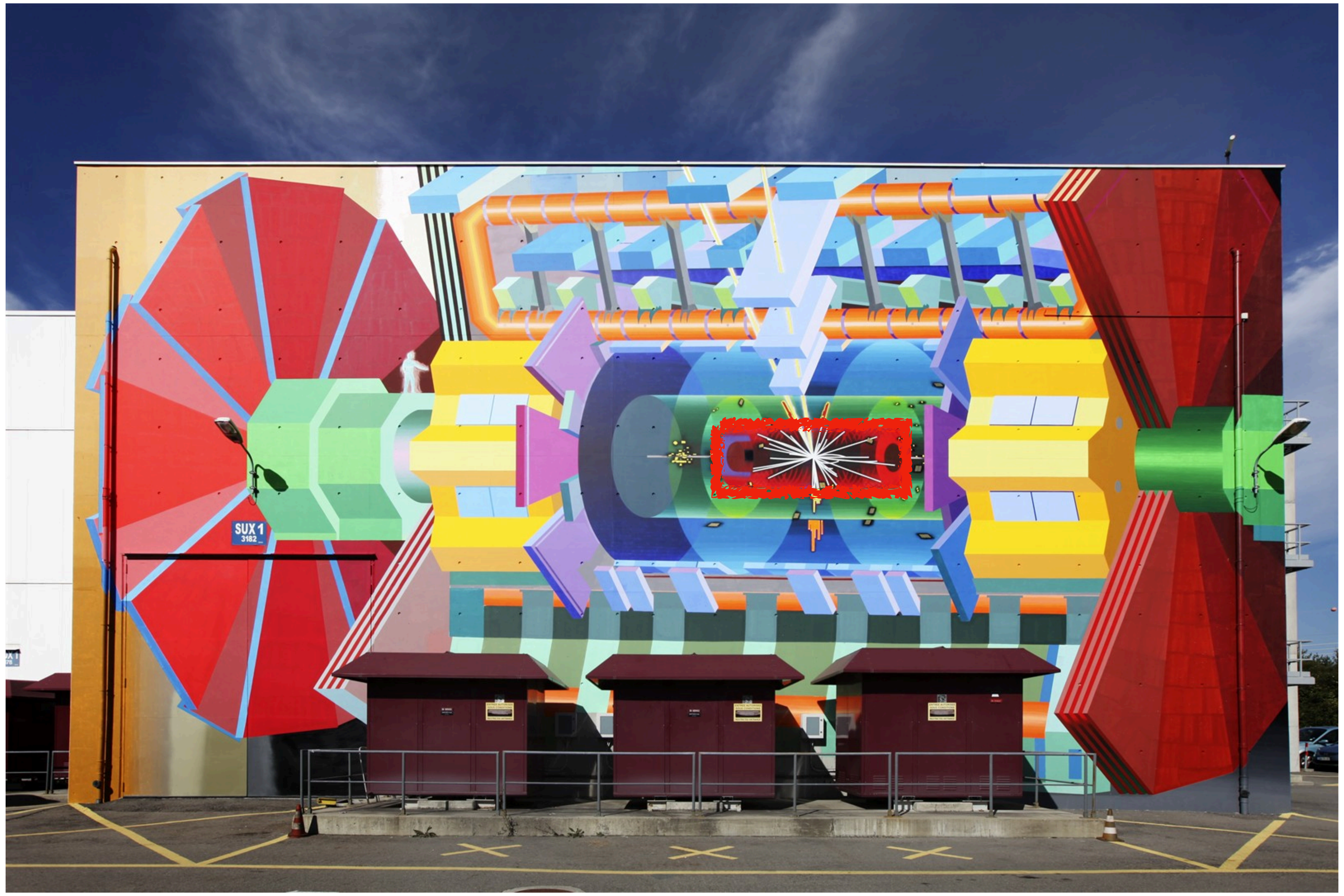
ATLAS EXPERIMENT



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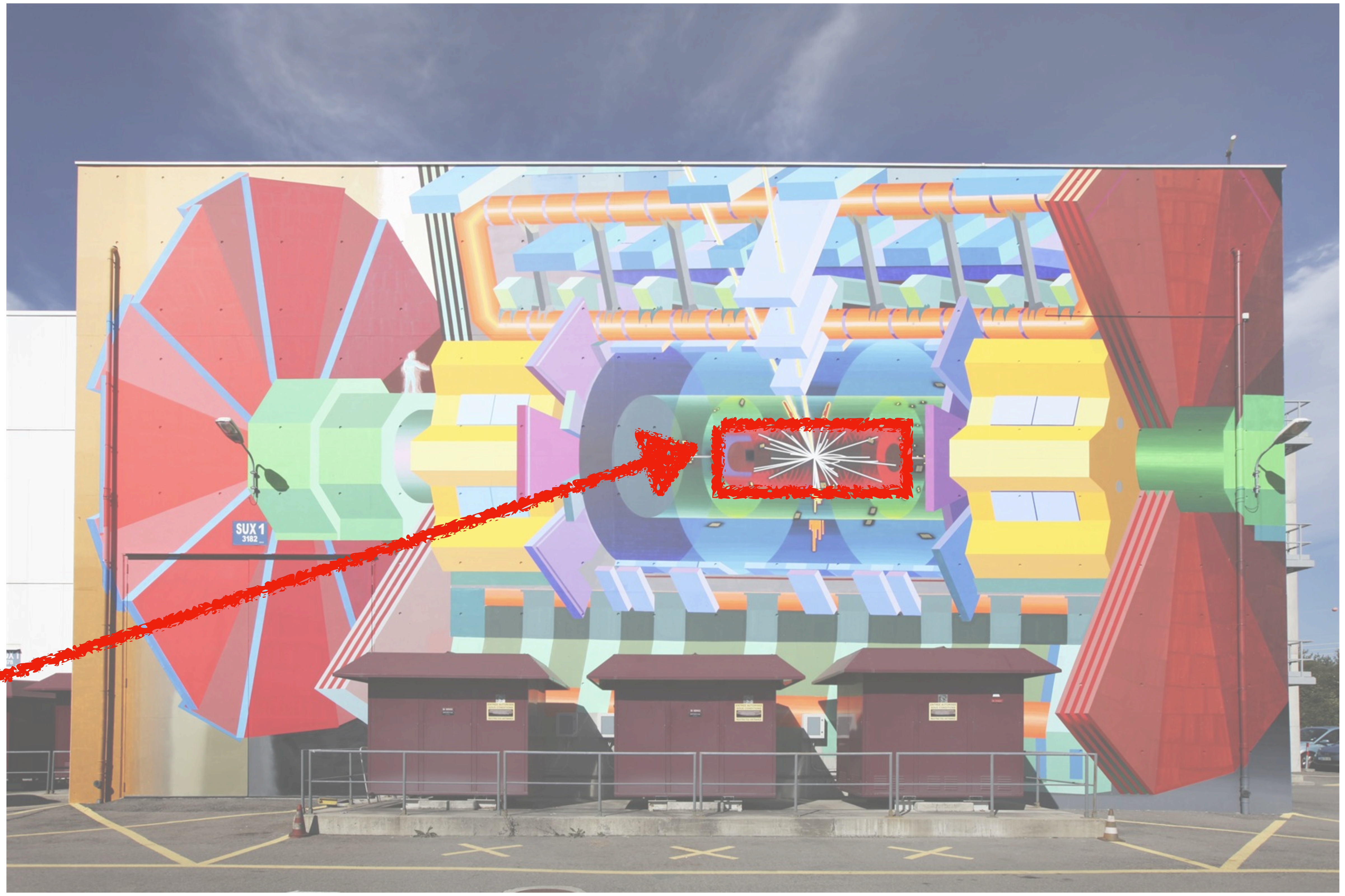

- Charged particles in tracker $|\eta| < 2.5$

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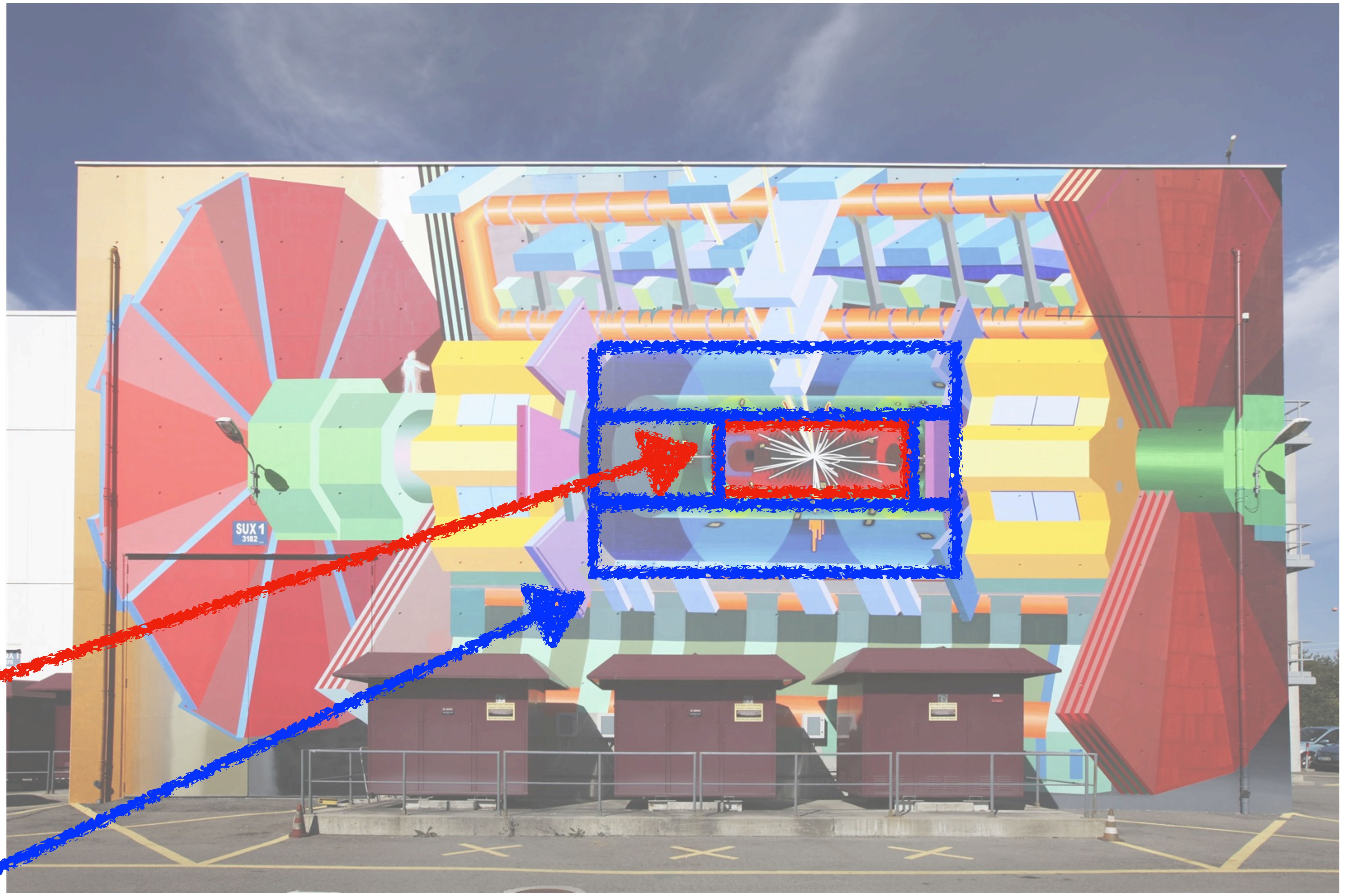

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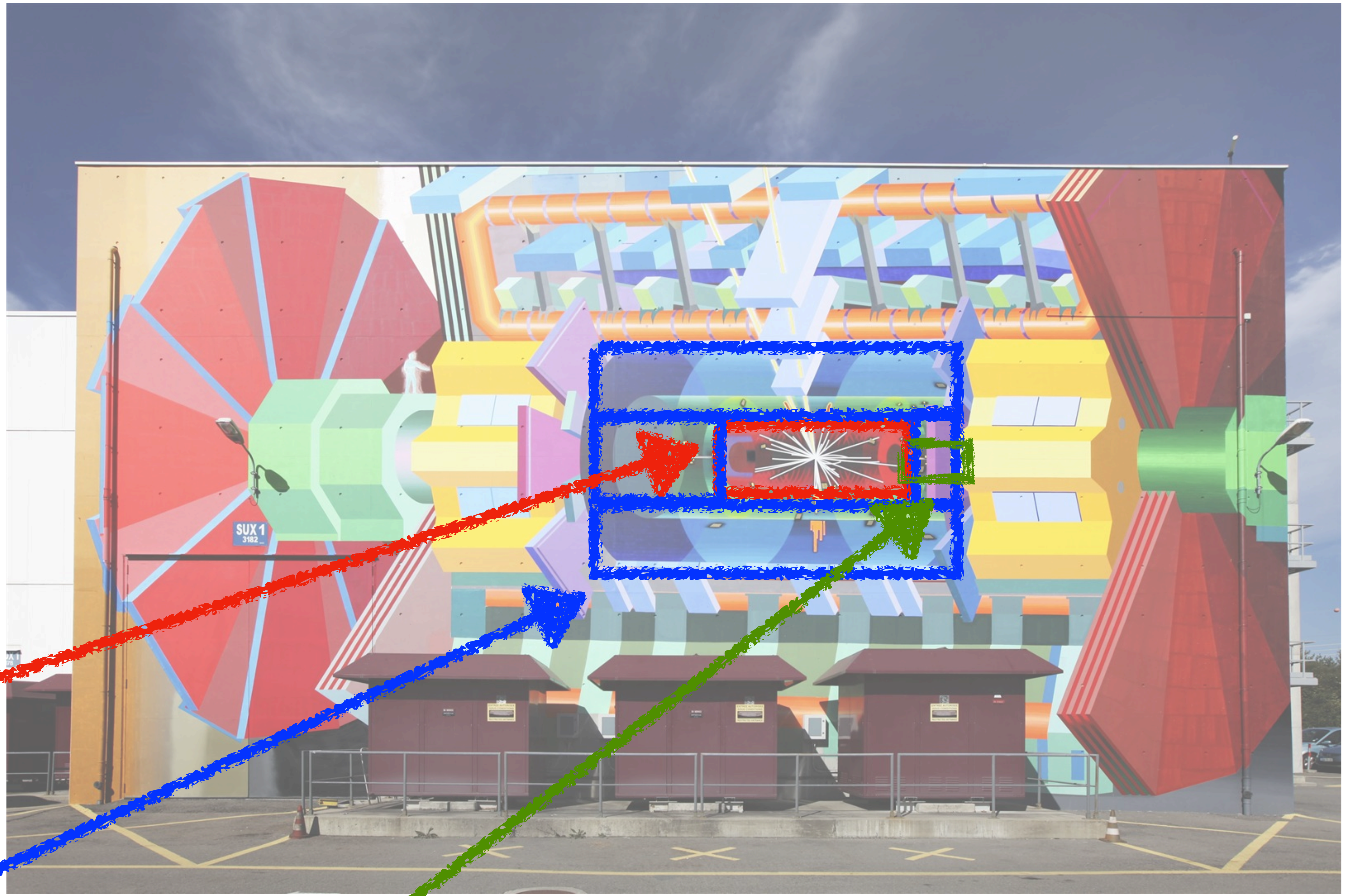
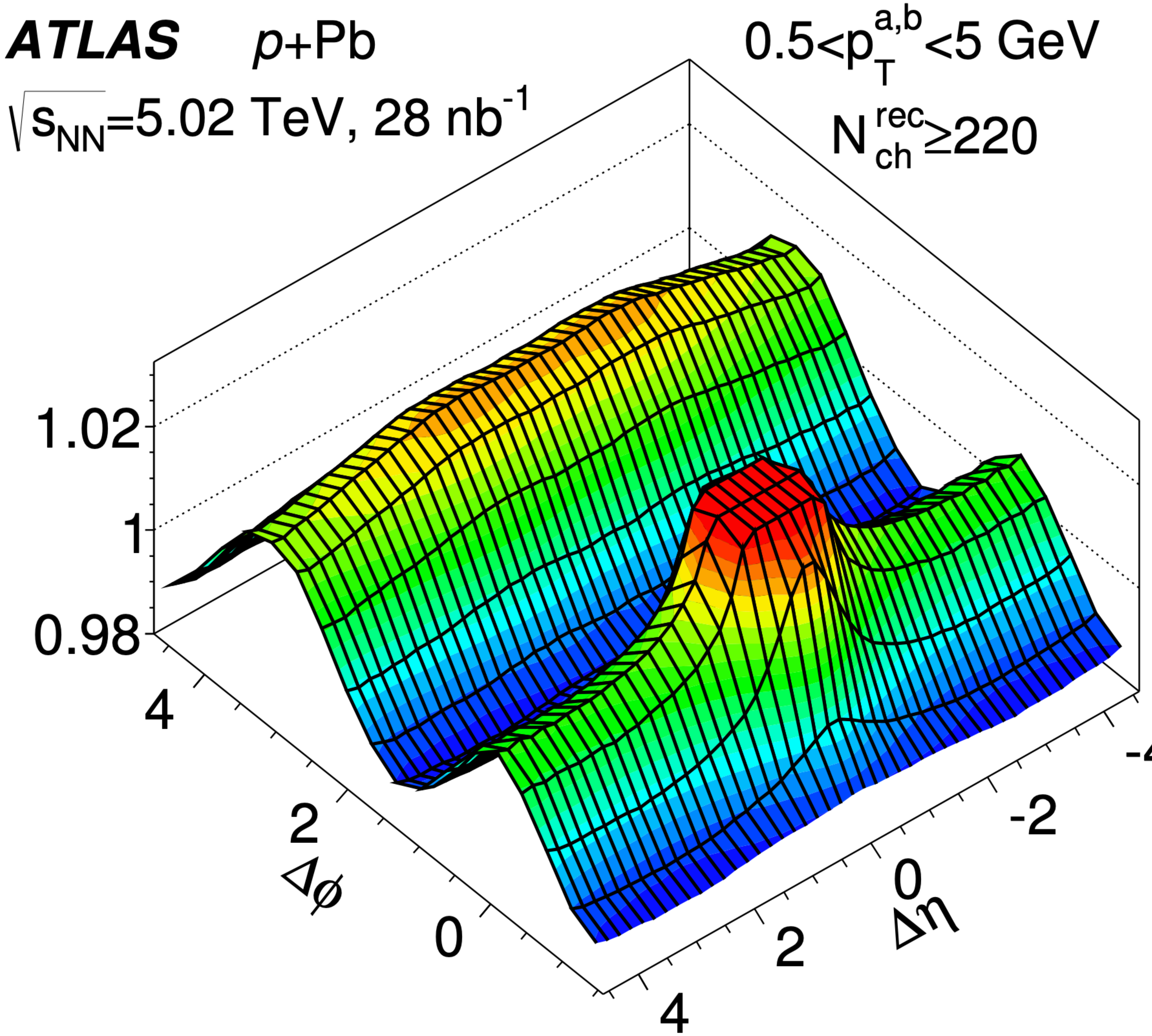


- Charged particles in tracker $|\eta| < 2.5$
- Jets in calorimeter: $|\eta| < 4.9$
- Centrality measured via ΣE_T in Pb-going FCal: $3.1 < \eta < 4.9$

2-particle correlations

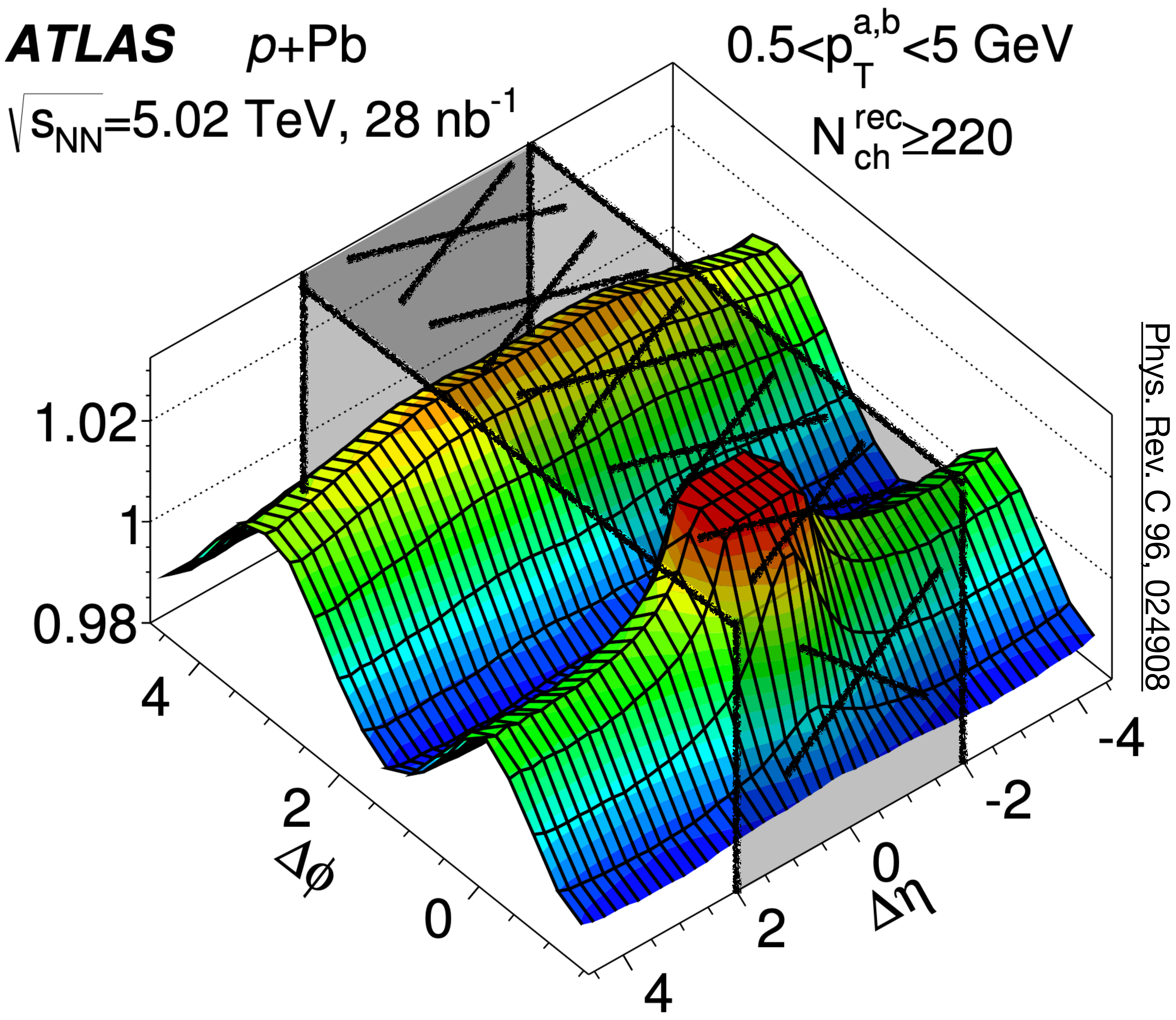
- Make standard 2-particle $\Delta\phi$ correlations



Phys. Rev. C 96, 024908

2-particle correlations

- Make standard 2-particle $\Delta\phi$ correlations
- Require $|\Delta\eta| > 2$



2-particle correlations

- Make standard 2-particle $\Delta\phi$ correlations
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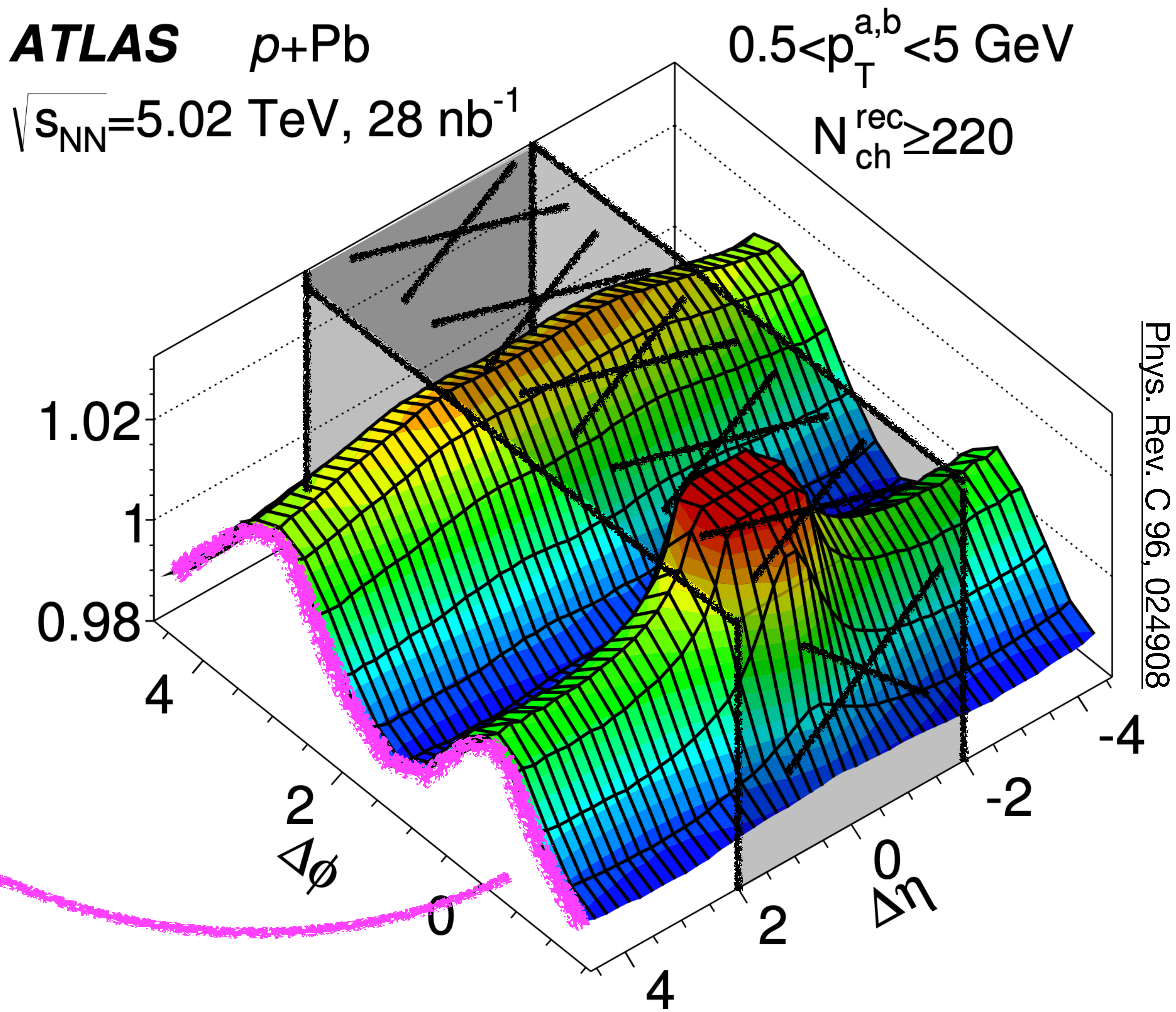
$$Y(\Delta\phi) = G\left\{1 + 2\sum_{n=1}^{\infty} v_{n,n}\cos(n\Delta\phi)\right\}$$



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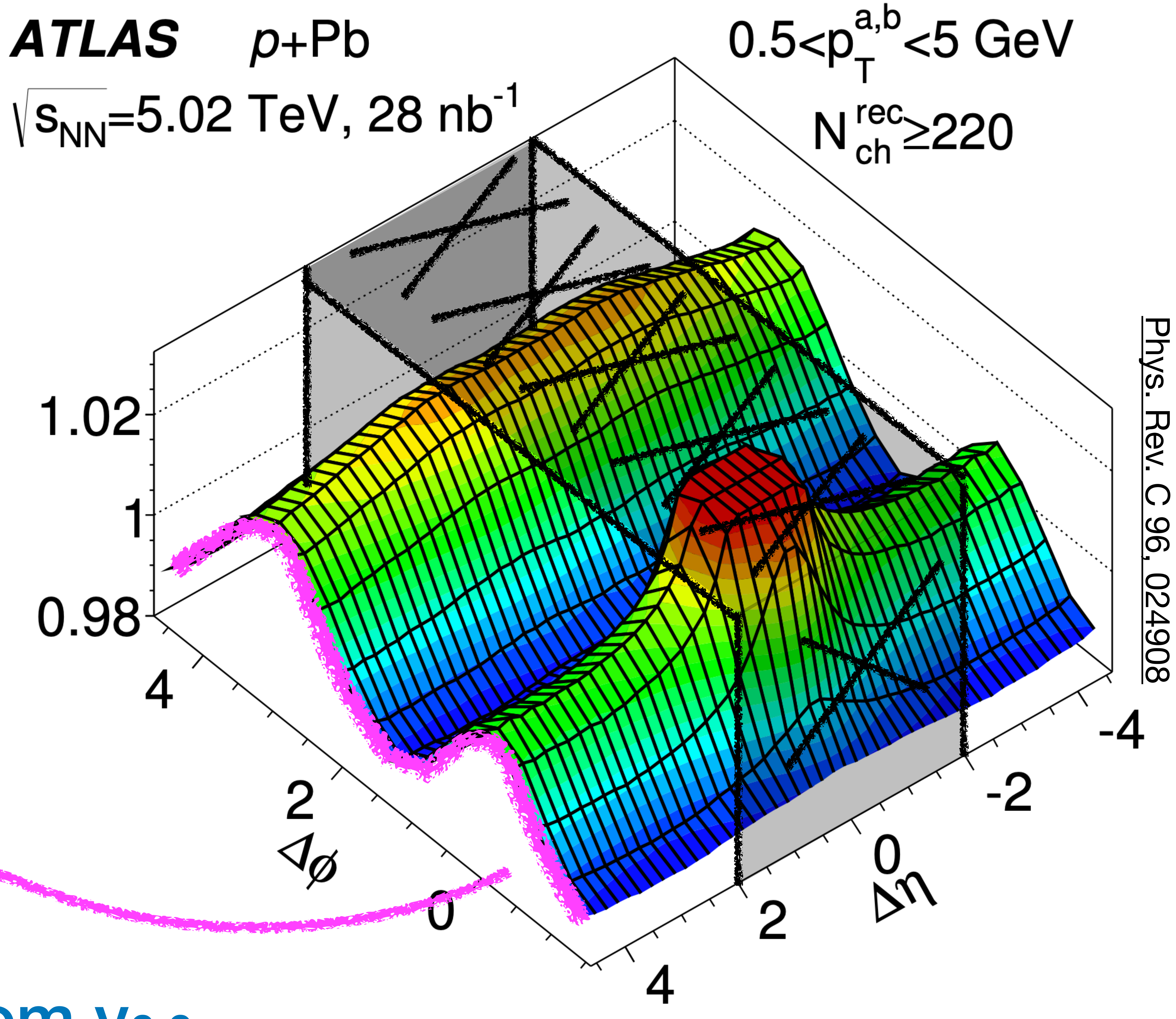
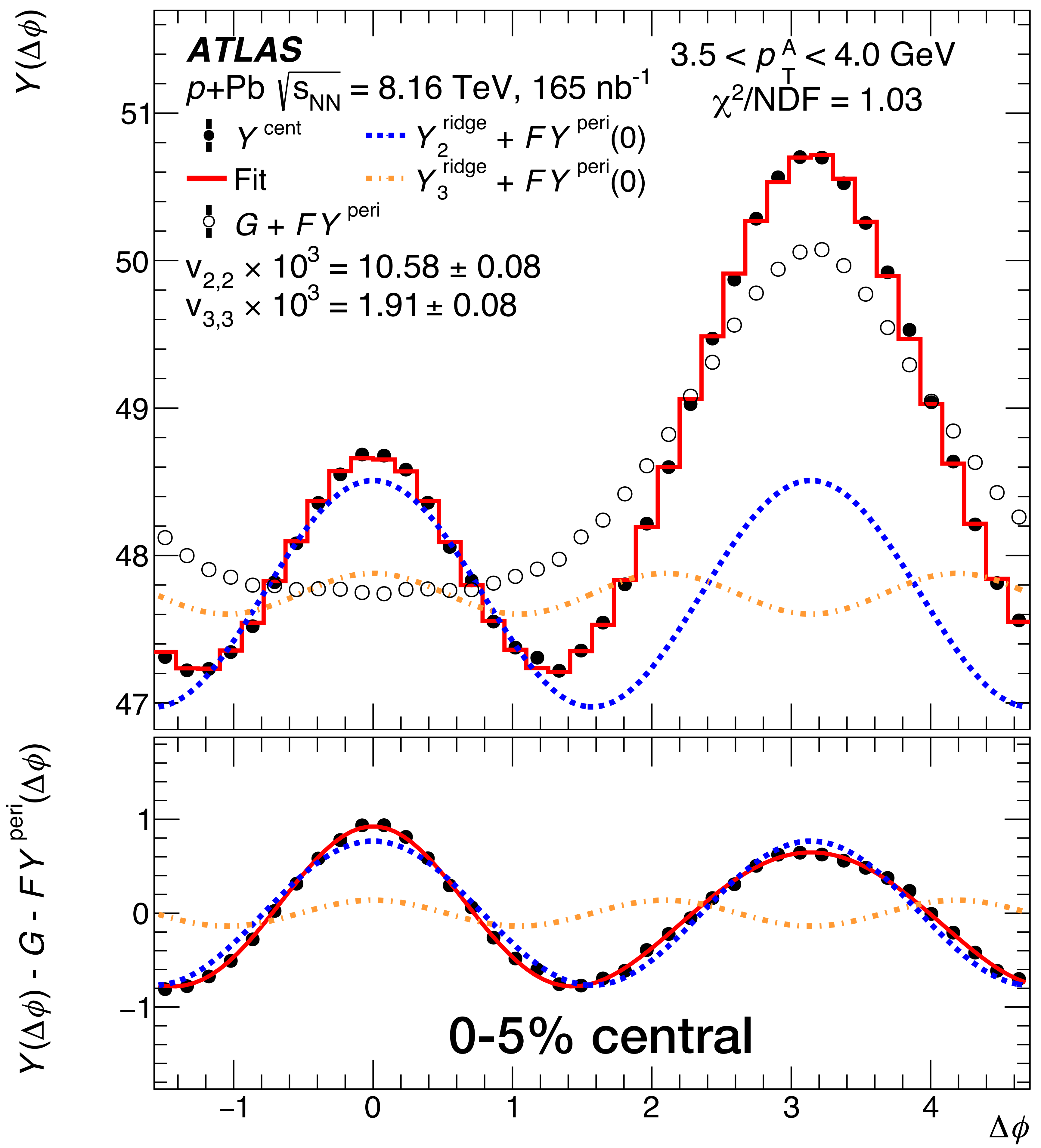


Assume factorization to extract v_2 from $v_{2,2}$

Template fit non-flow subtraction

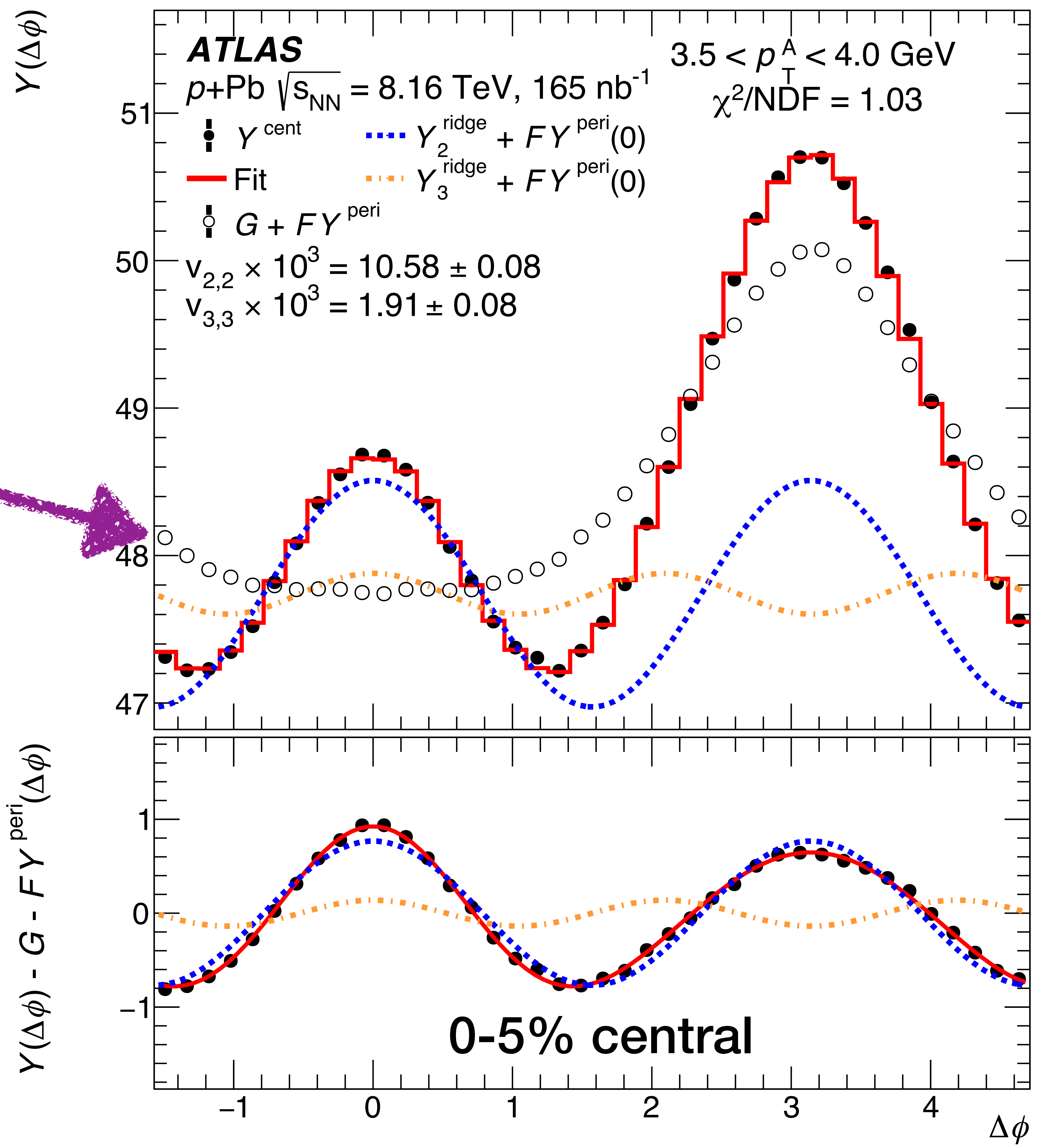
Minimum bias (0-5% central)



Template fit non-flow subtraction

Minimum bias (0-5% central)

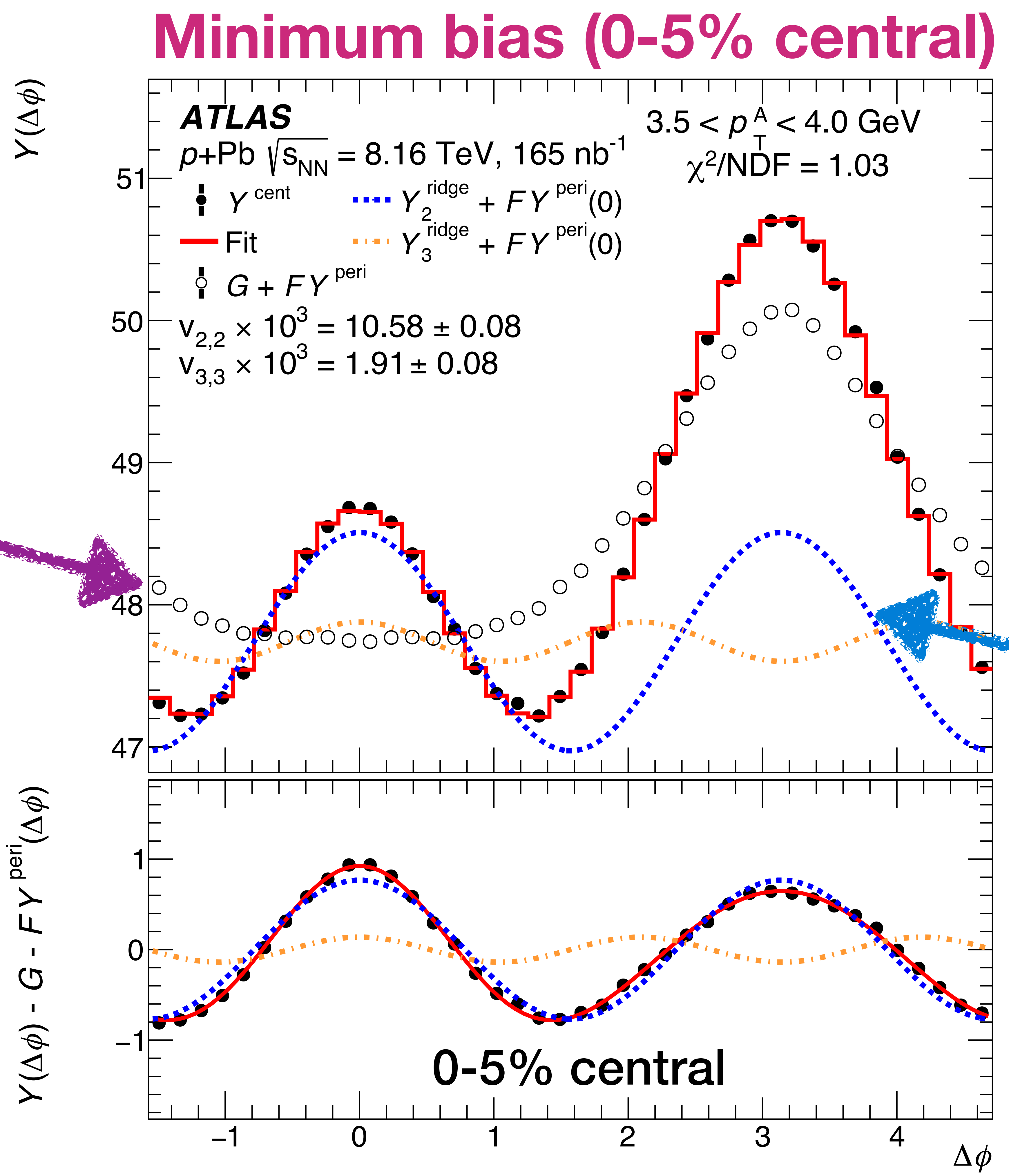
Peripheral data used to form template



$$Y^{\text{Central}}(\Delta\phi) = F^{\text{temp}} \cdot Y^{\text{Peripheral}}(\Delta\phi) + Y^{\text{Flow}}(\Delta\phi)$$

Template fit non-flow subtraction

Peripheral data used to form template

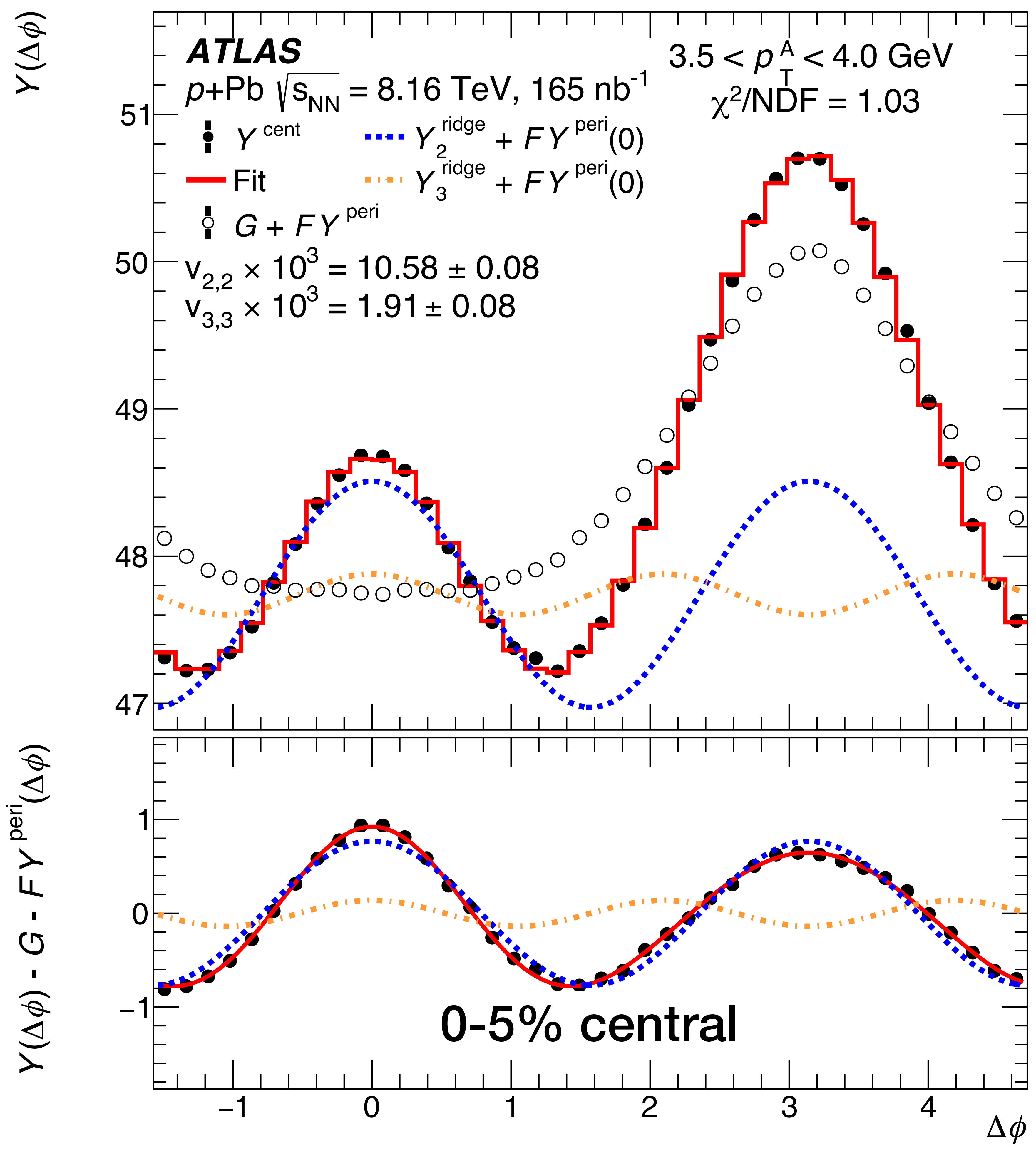


Fit scaled template with added harmonics to central data

$$Y^{\text{Central}}(\Delta\phi) = F^{\text{temp}} \cdot Y^{\text{Peripheral}}(\Delta\phi) + Y^{\text{Flow}}(\Delta\phi)$$

Template fit non-flow subtraction

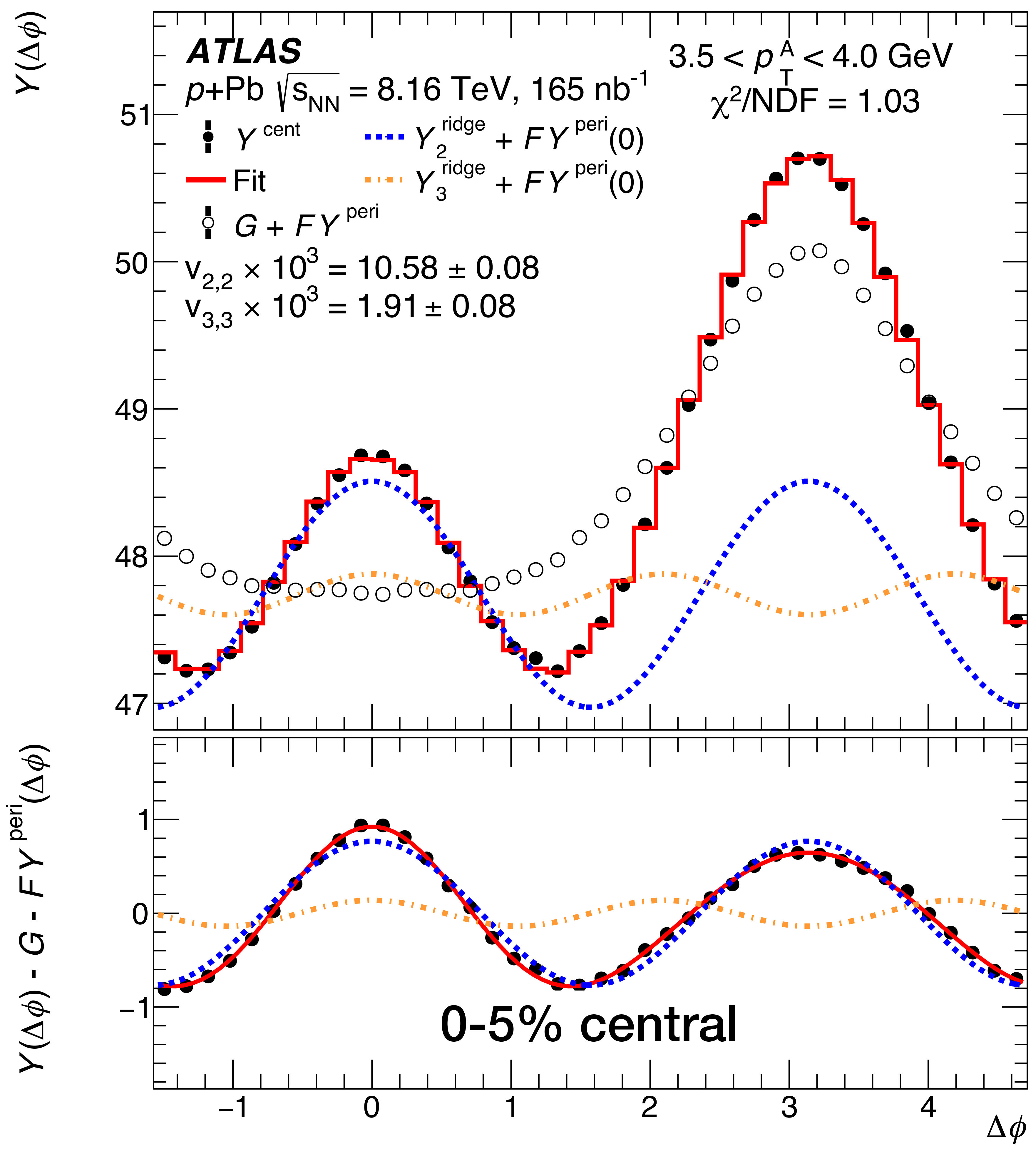
Minimum bias

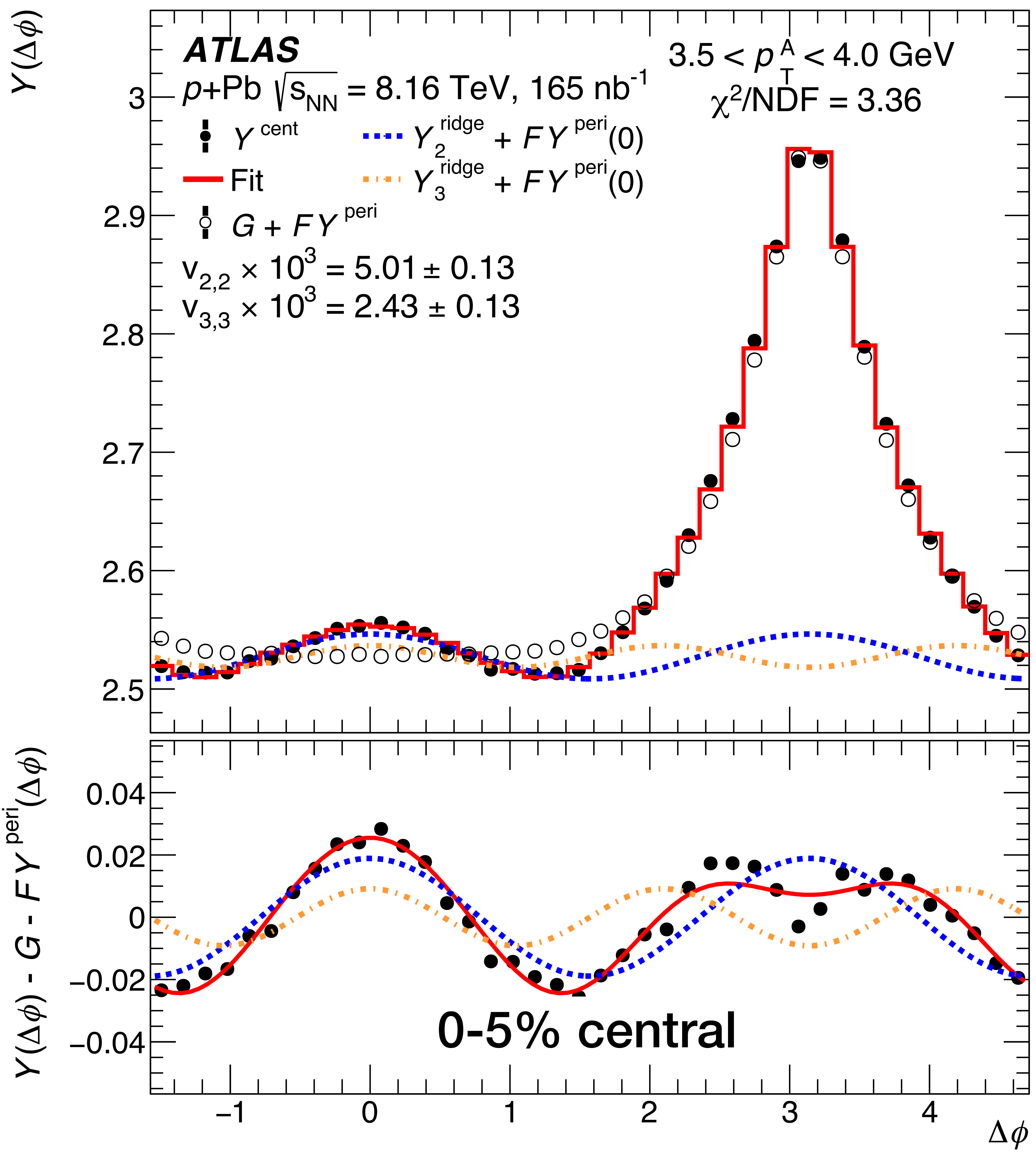


Template fit non-flow subtraction

Minimum bias

Jet p_T > 100 GeV



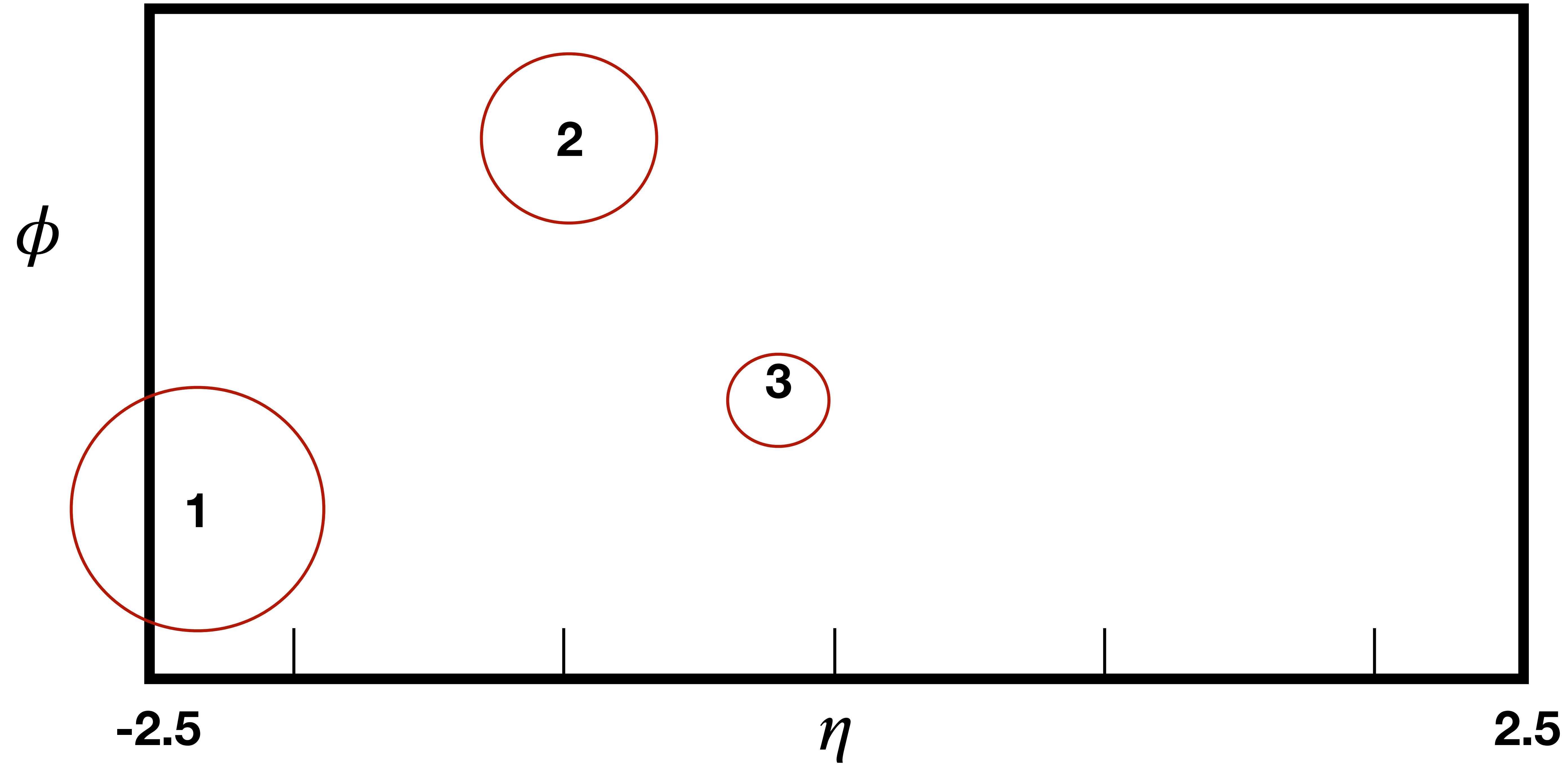


Jet events have significantly stronger away-side peak from non-flow

Restricting associated particles in jet events

Associated particles are required to have $|\Delta\eta| > 1$ w.r.t. jets in event with $p_T > 15$ GeV

$p_T^{Jet} > 15$ GeV



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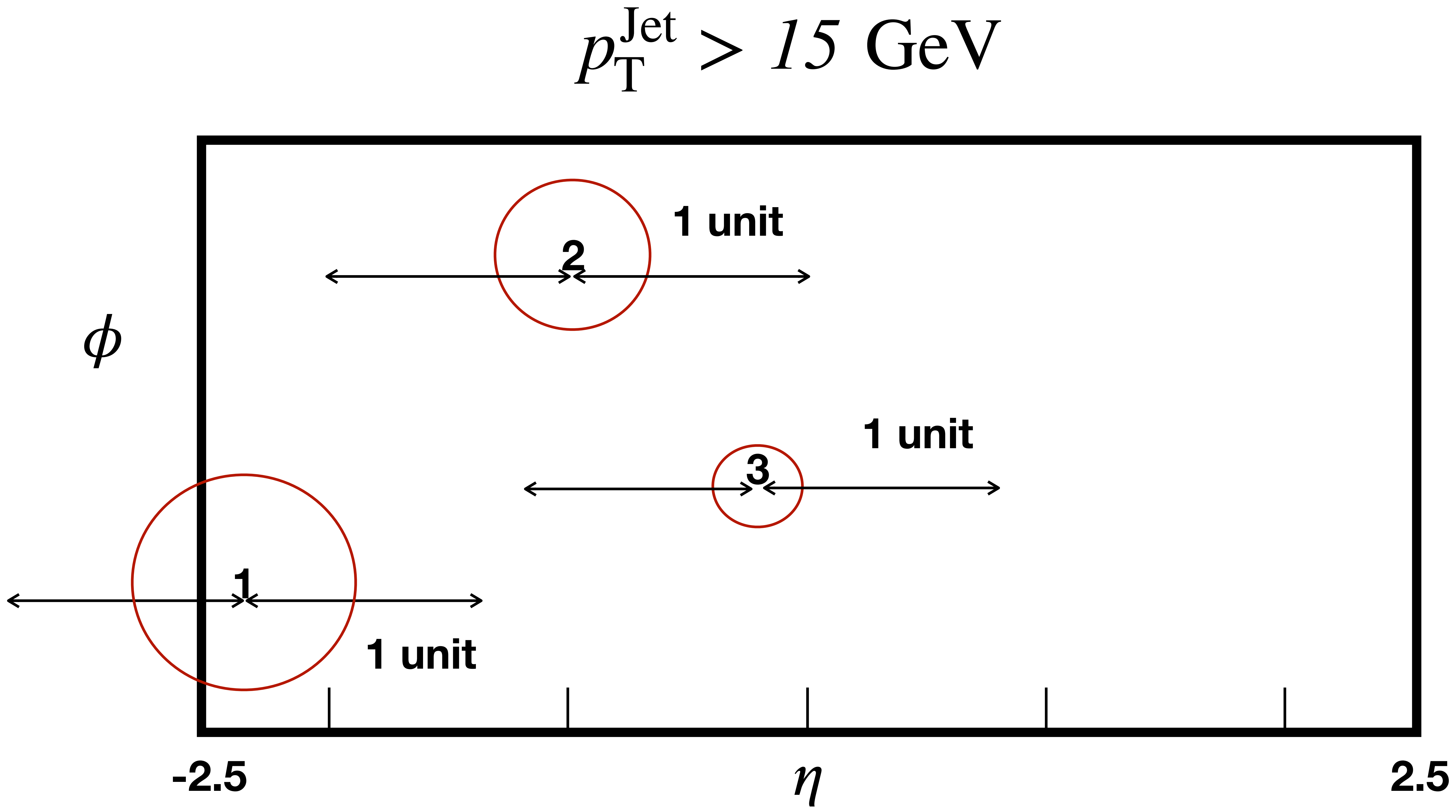

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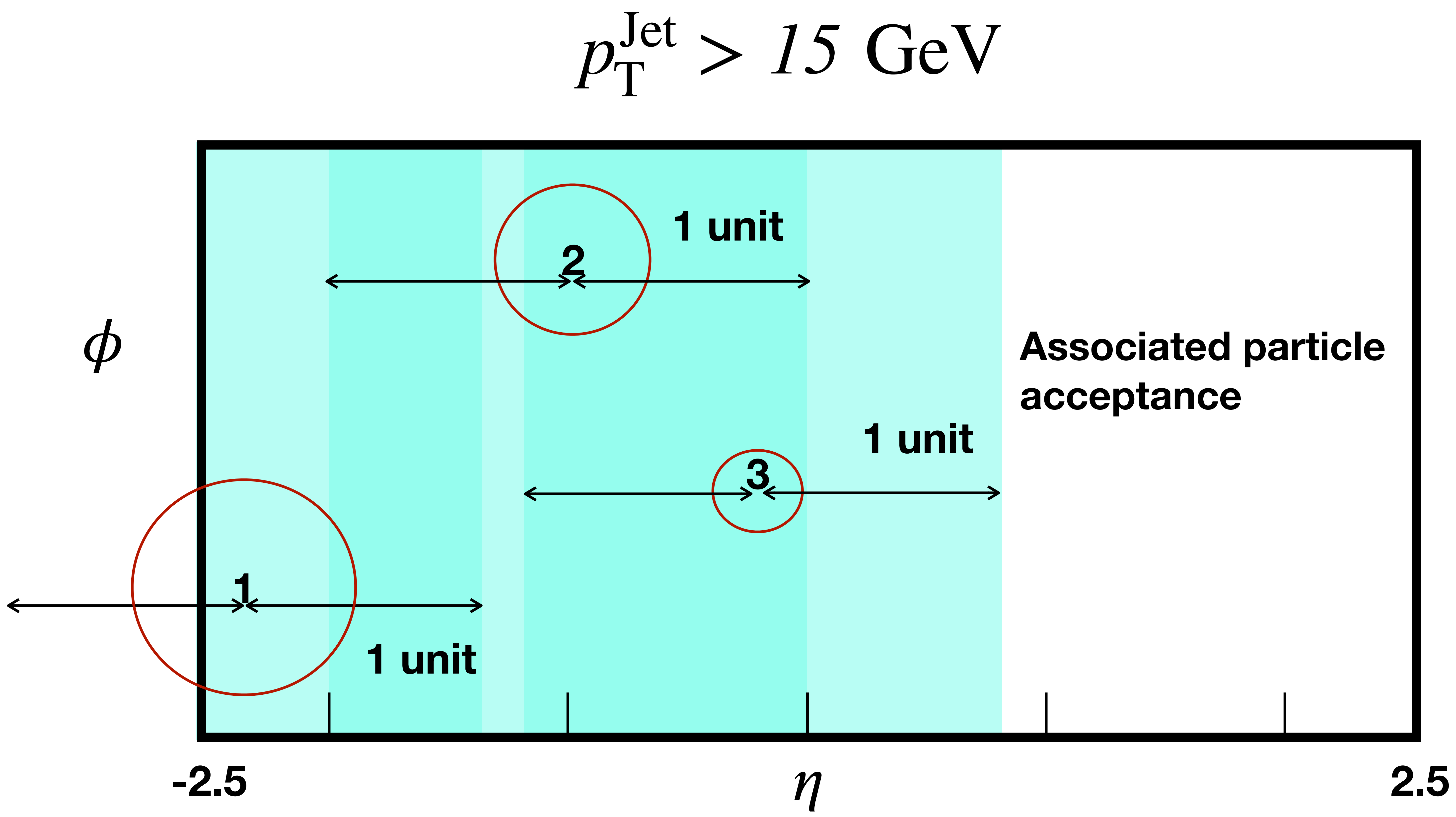

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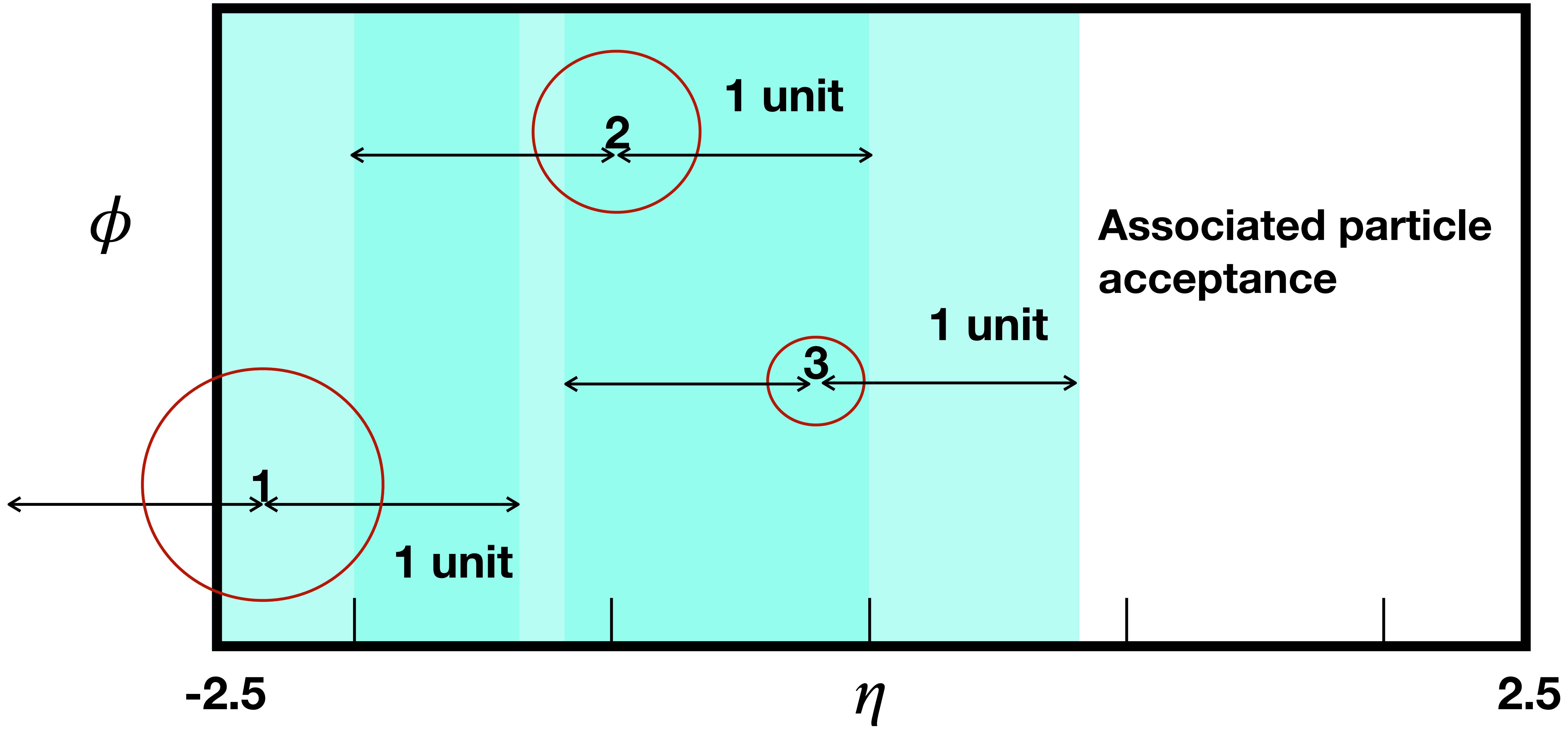
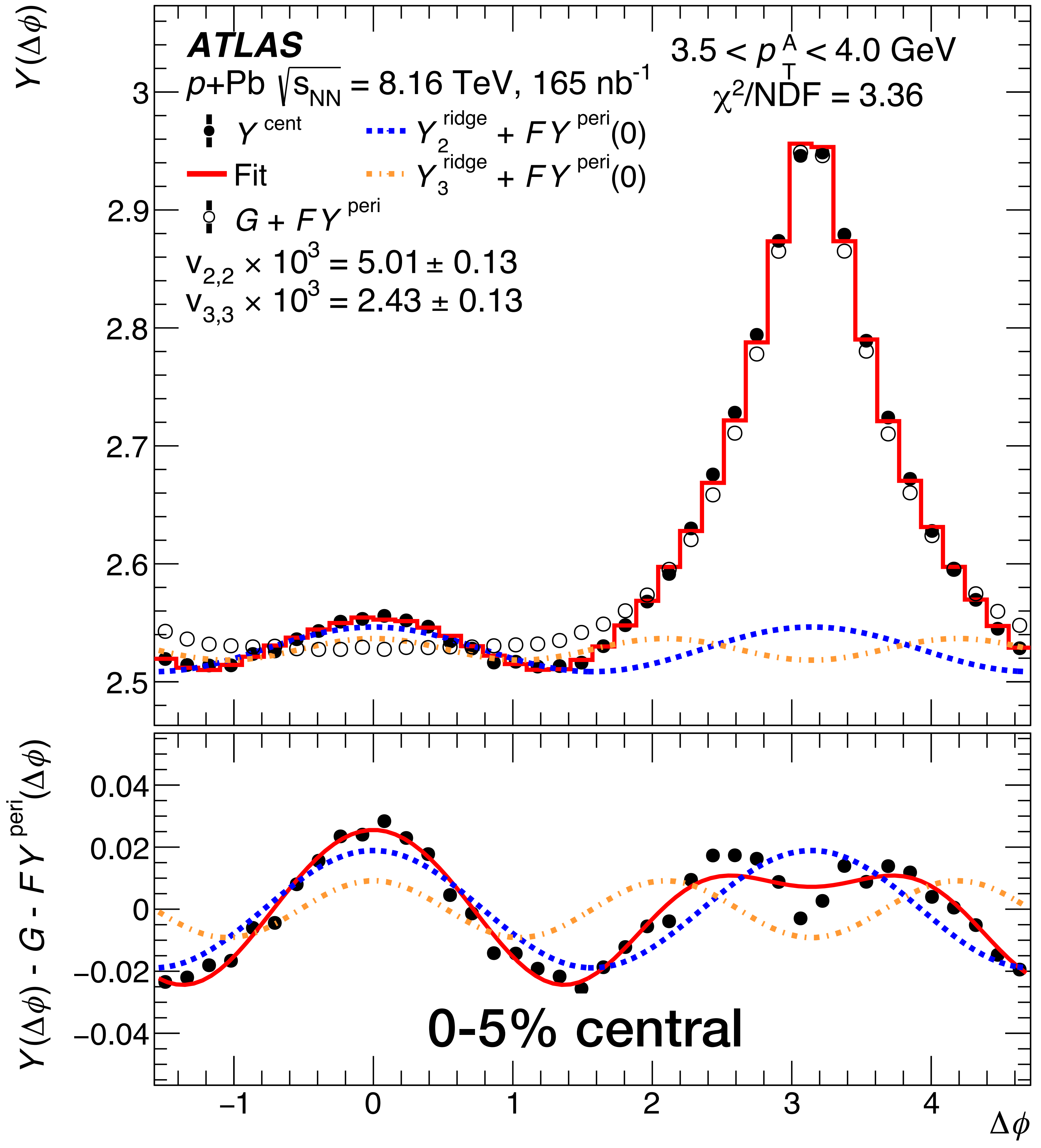


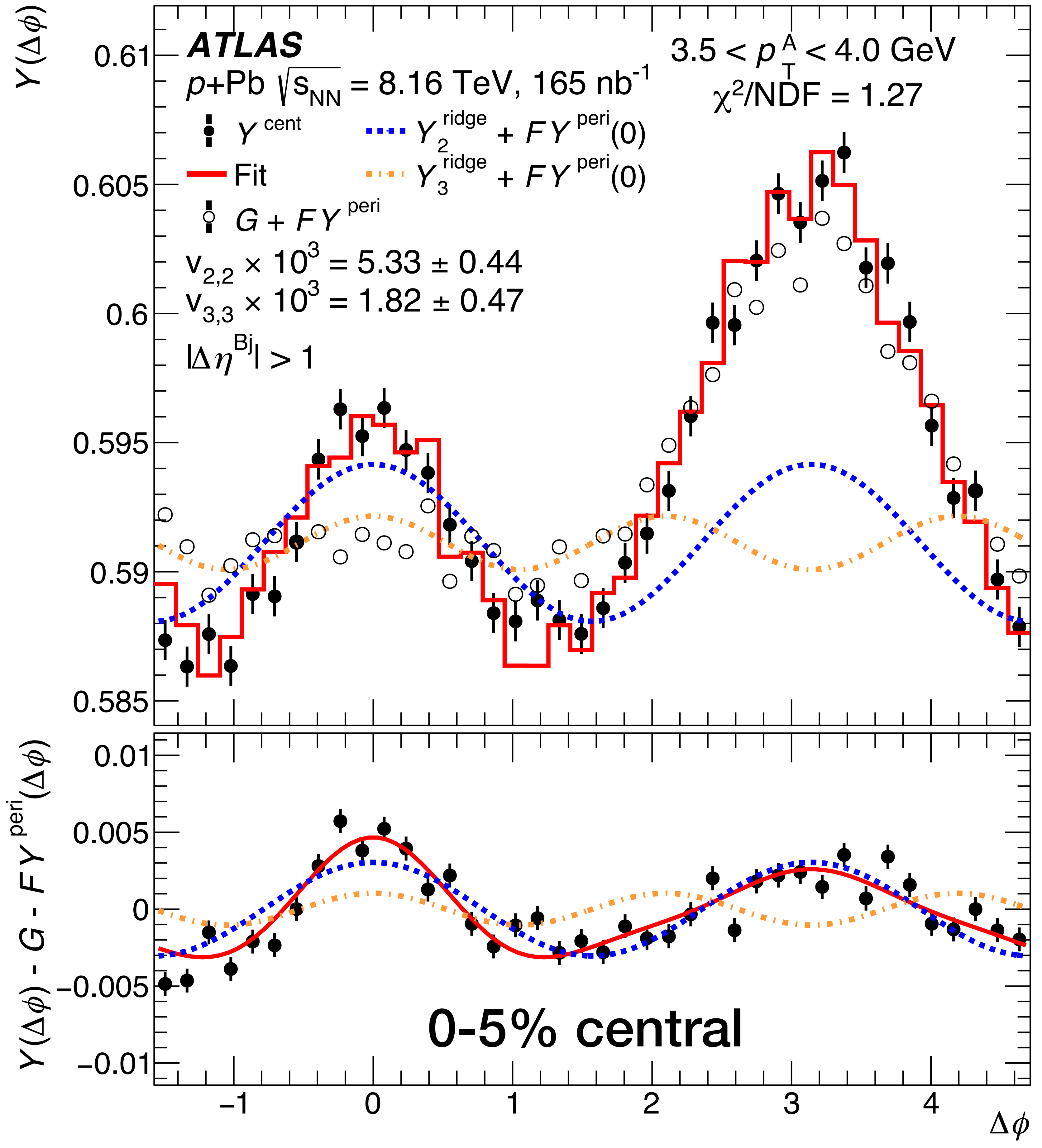
Not done in Minbias events

Restricting associated particles in *100 GeV jet events*

Before jet restriction



After jet restriction

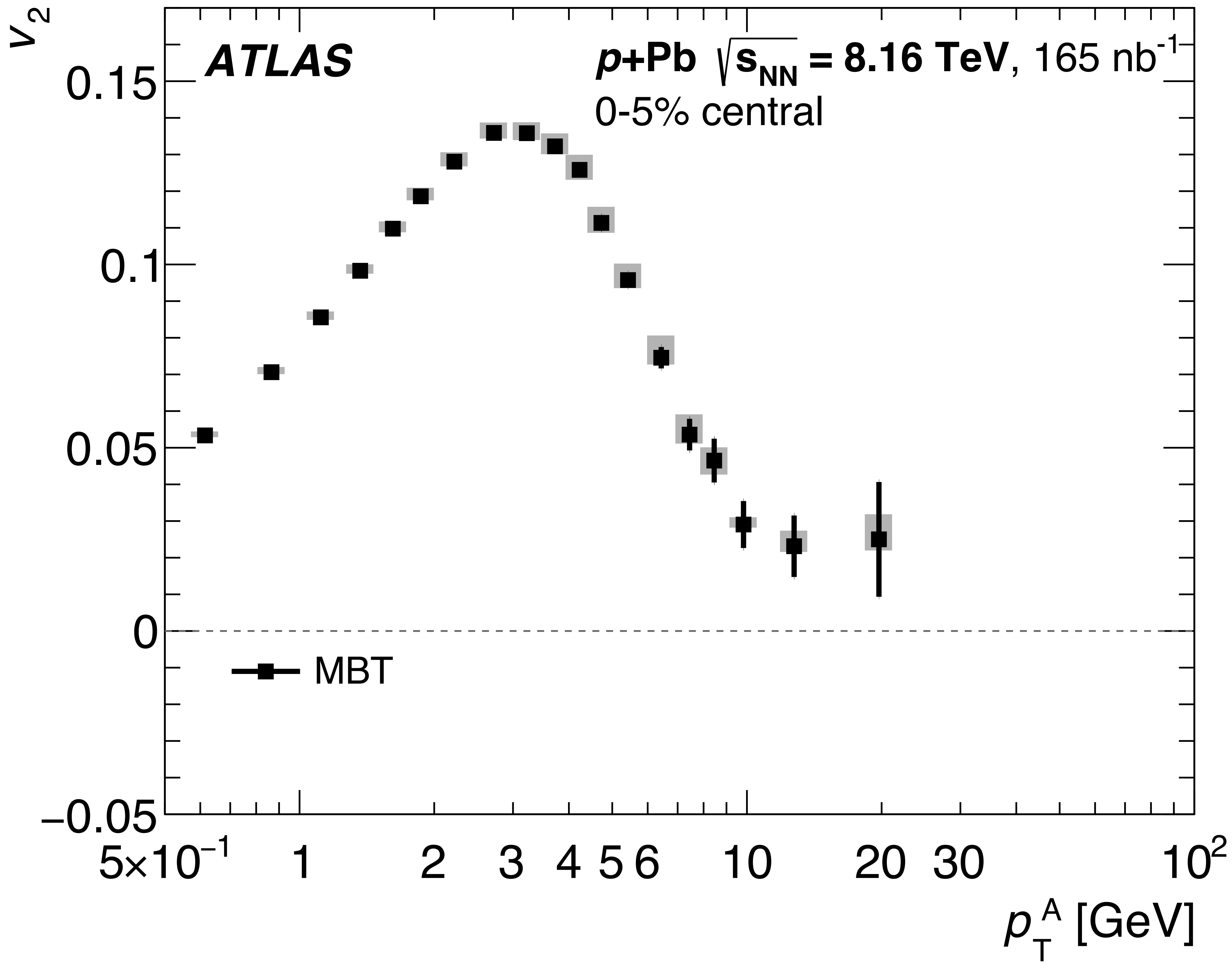


Jet rejection drastically improves ‘signal-to-noise’

- Reduces sensitivity to template method assumptions

p_T dependent v_2 results

- MB p_T reach extended to ~20 GeV



p_T dependent v_2 results

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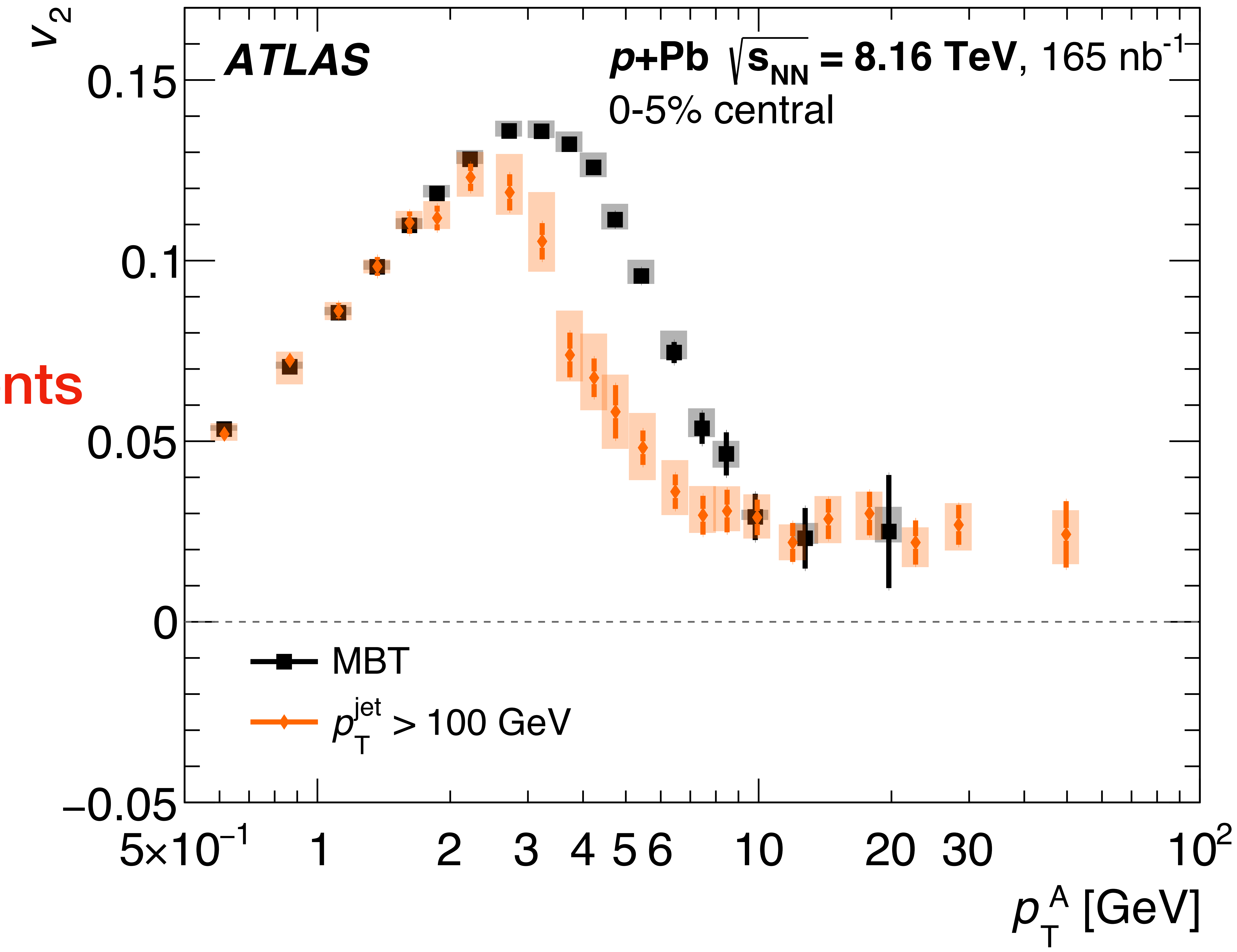
- **Clear non-zero v_2 out to ~50 GeV in jet events**



p_T dependent v_2 results

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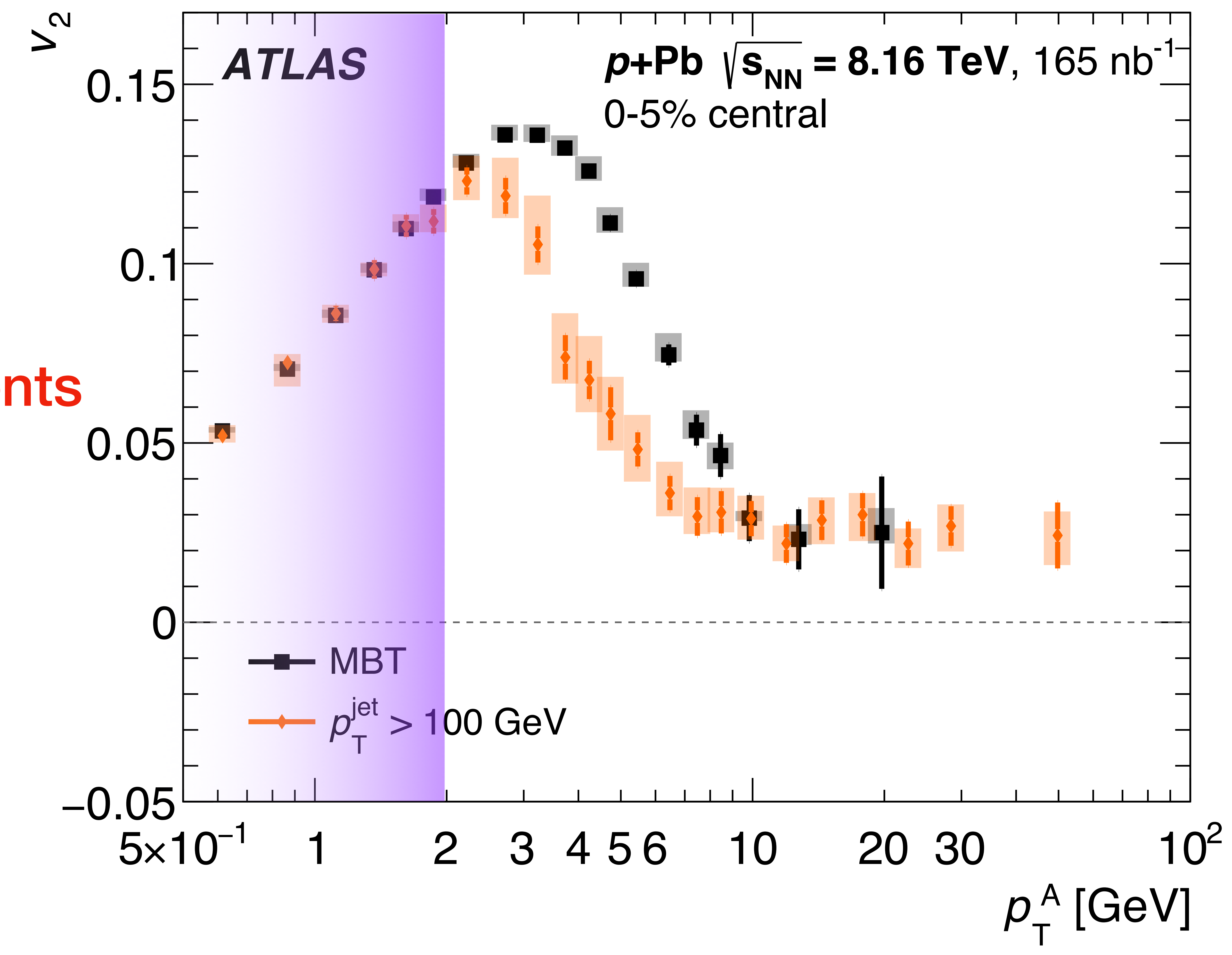
- Consistency at *low*



p_T dependent v_2 results

- MB p_T reach extended to ~20 GeV
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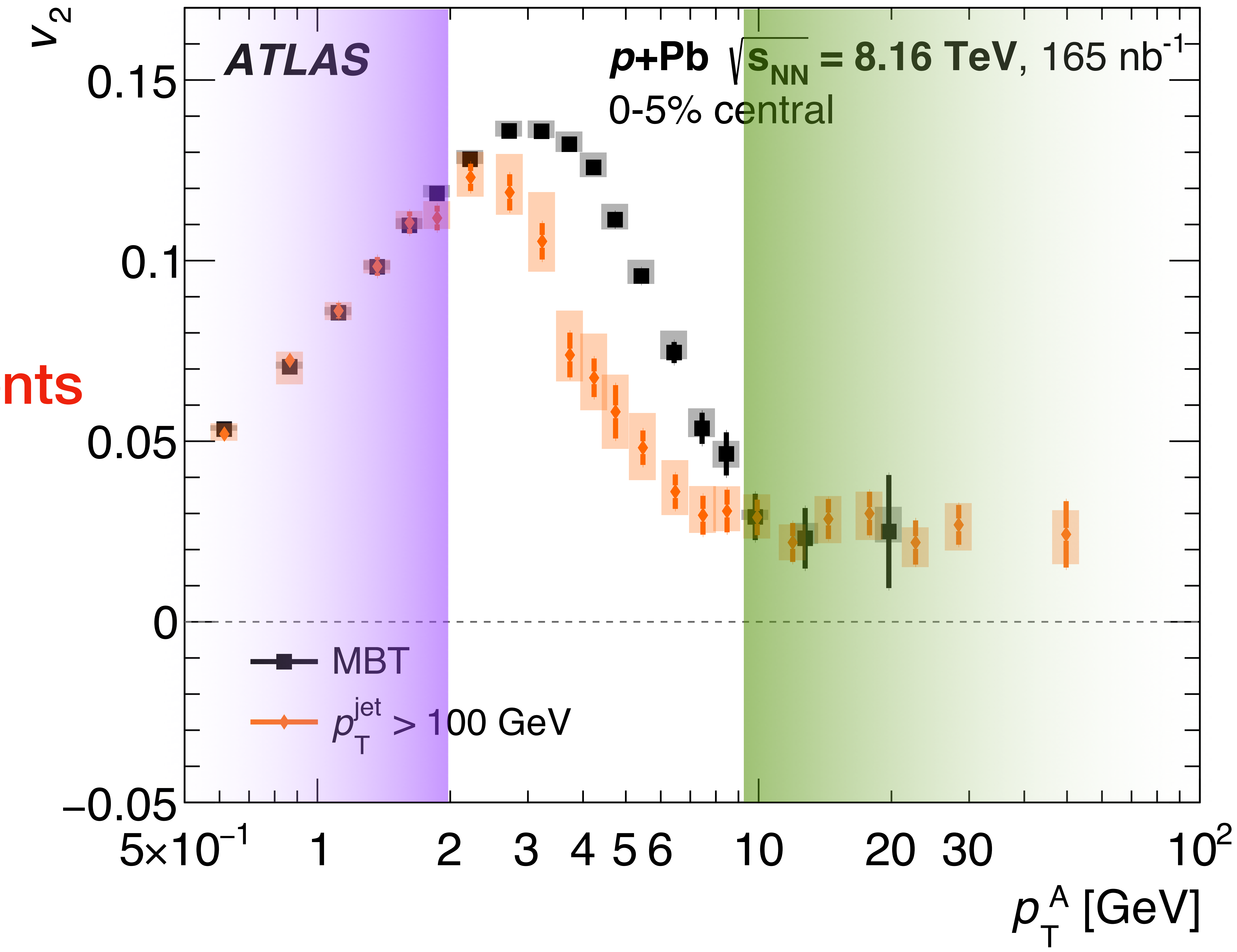
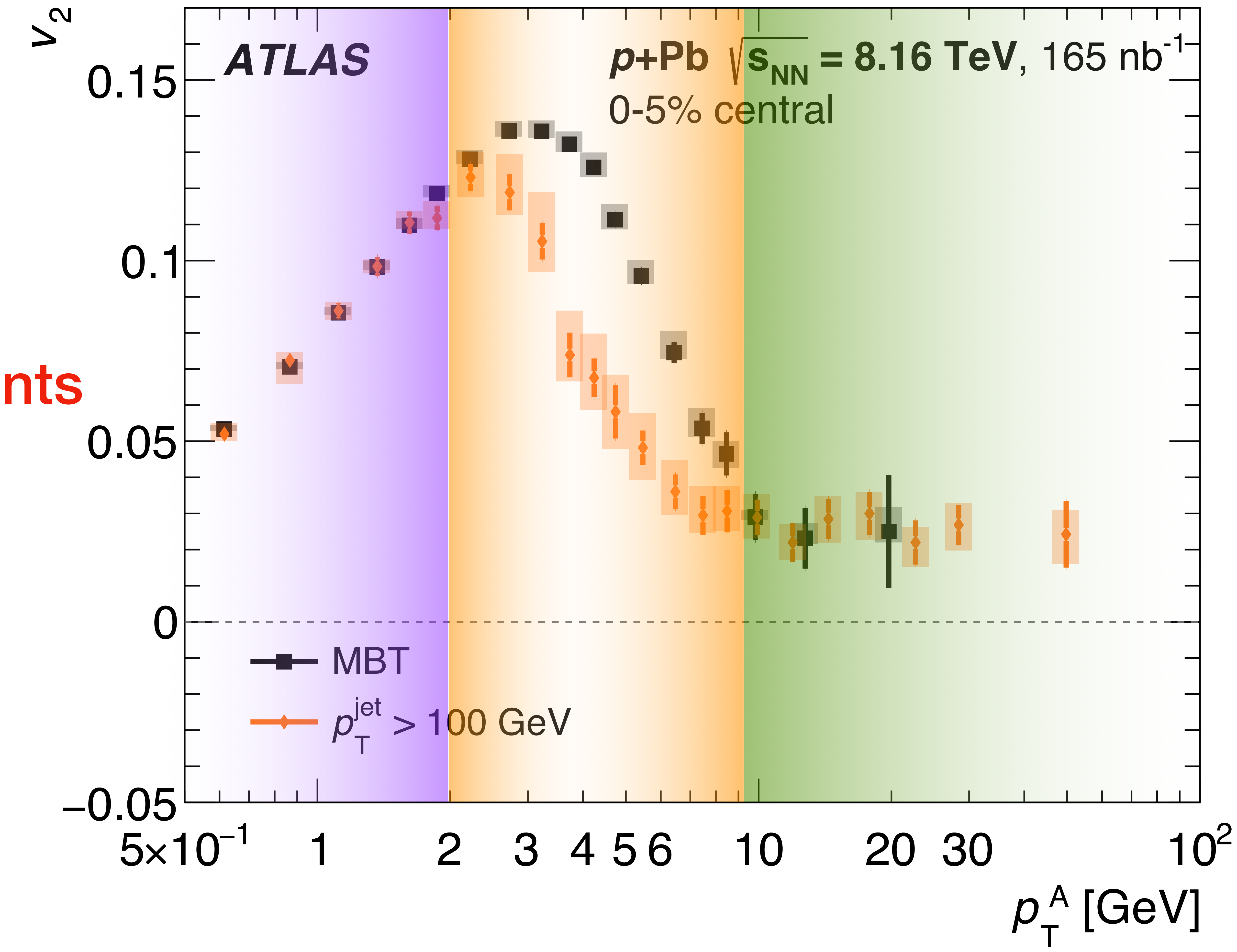
- Consistency at *low* and *high* p_T

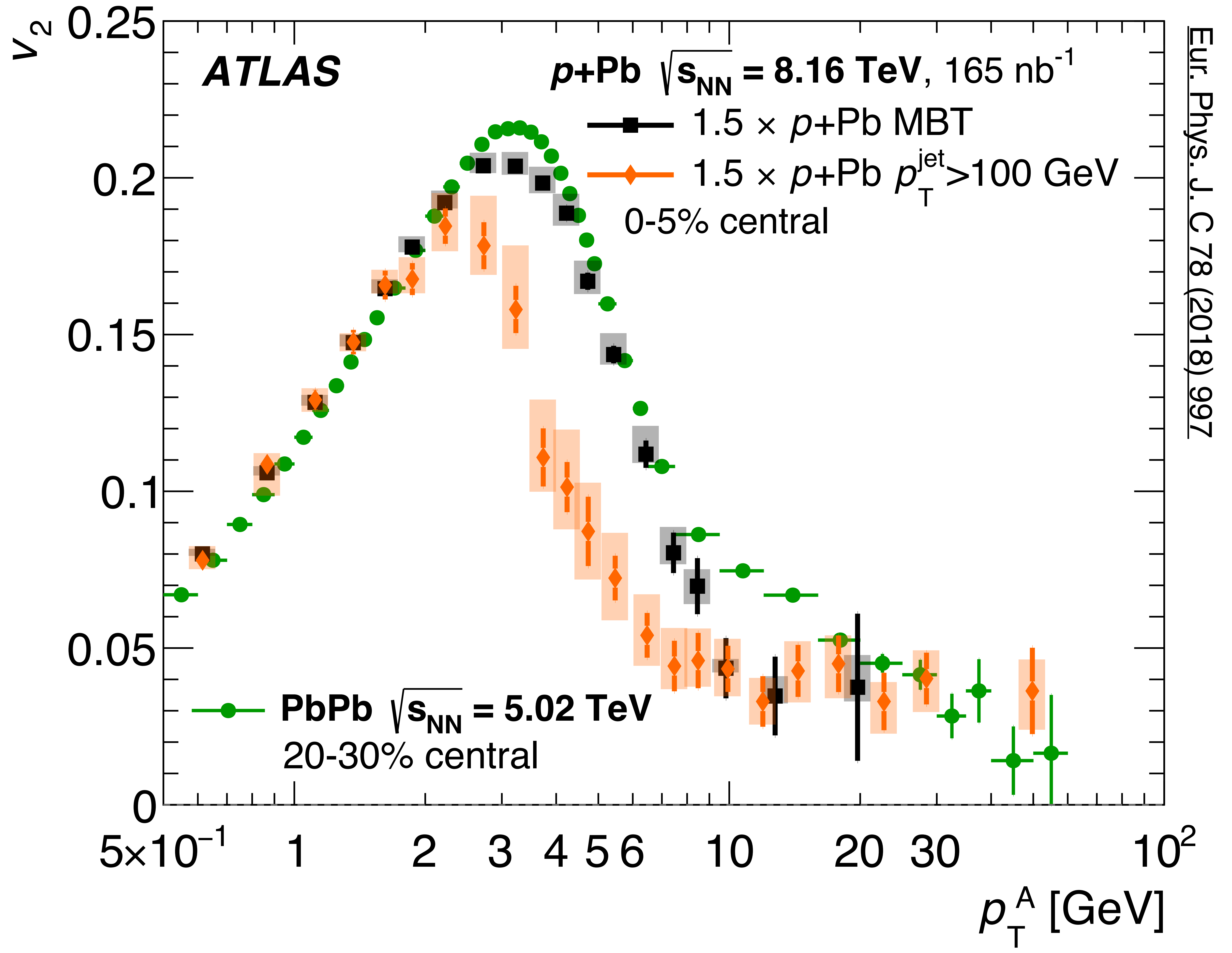


p_T dependent v_2 results

- MB p_T reach extended to ~20 GeV
- **Clear non-zero v_2 out to ~50 GeV in jet events**
- Consistency at *low* and ***high*** p_T
- *Transition* to high p_T behavior happens at *lower* p_T for jet events



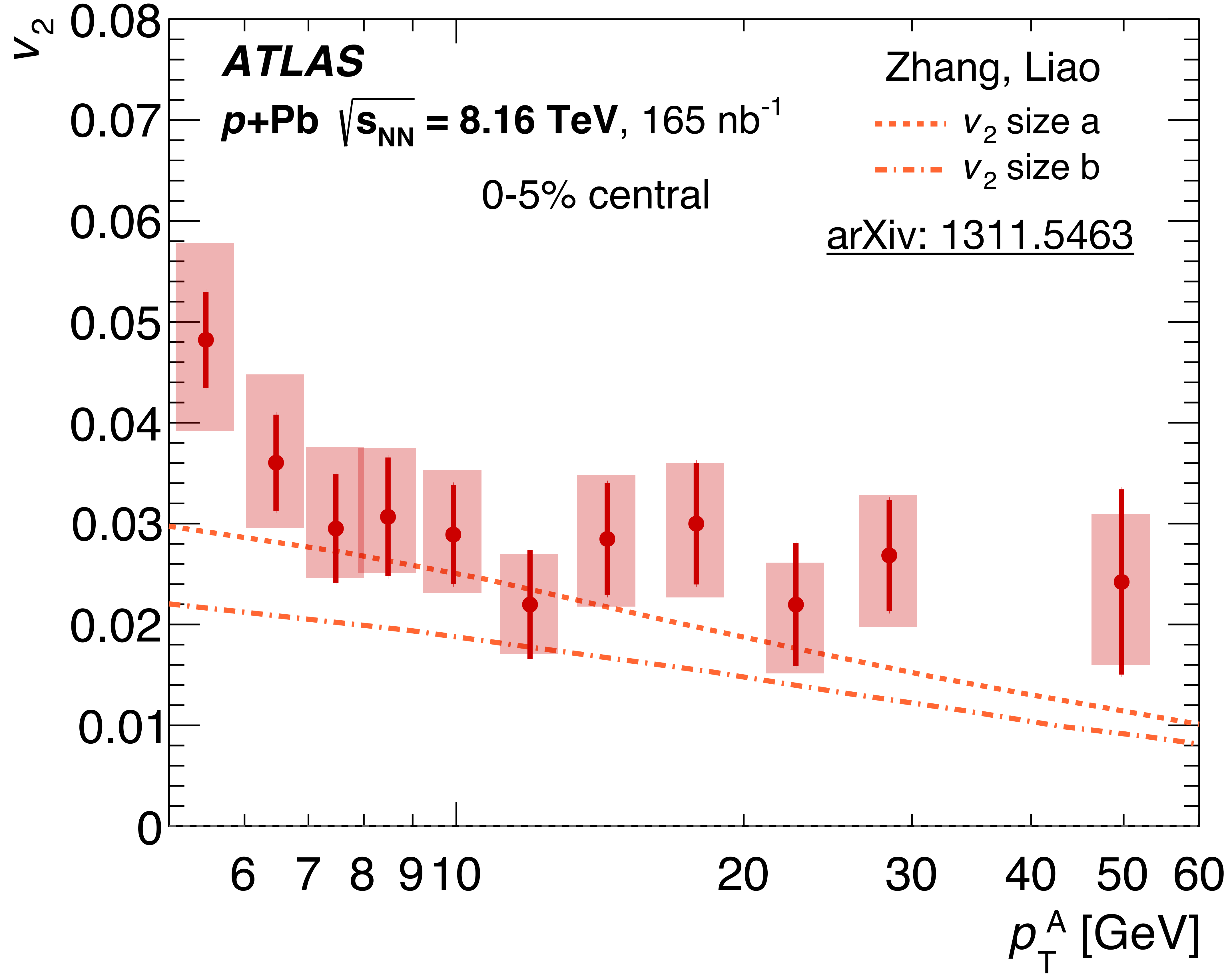
p+Pb / Pb+Pb comparison



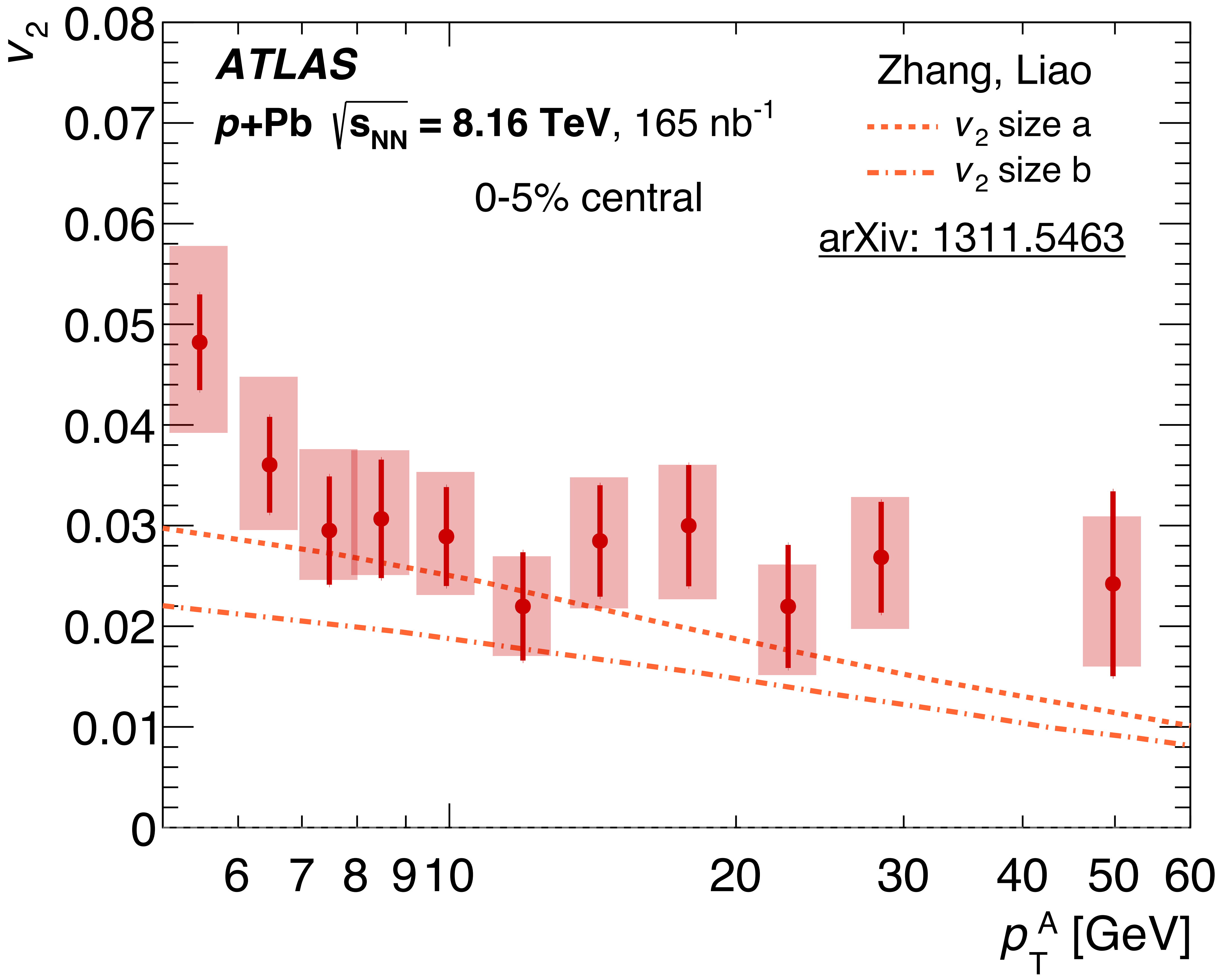
- Very similar behavior when p+Pb scaled up, though high-p_T seems to have less p_T dependence for p+Pb

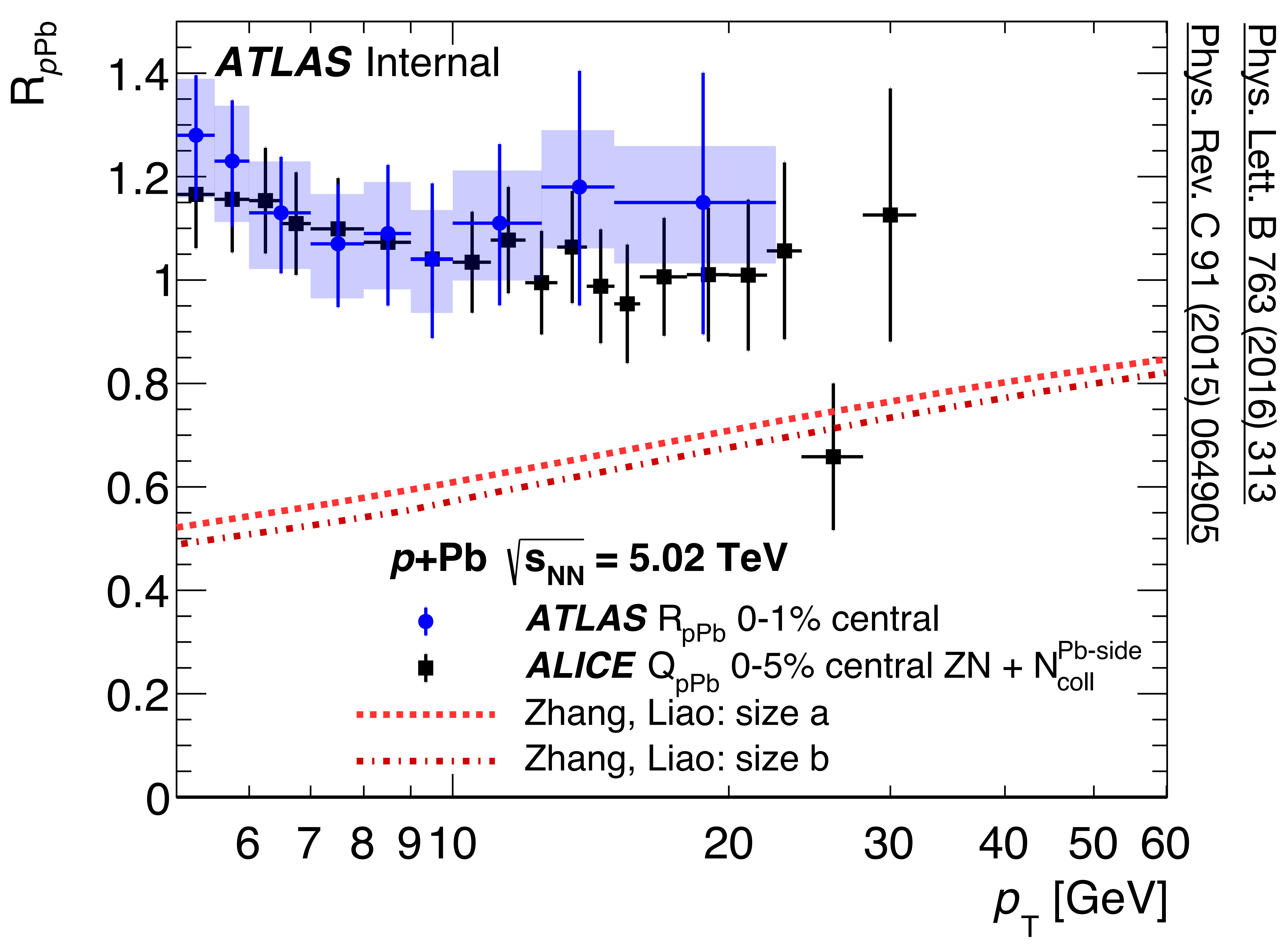
Comparison to jet quenching calculation

v_2



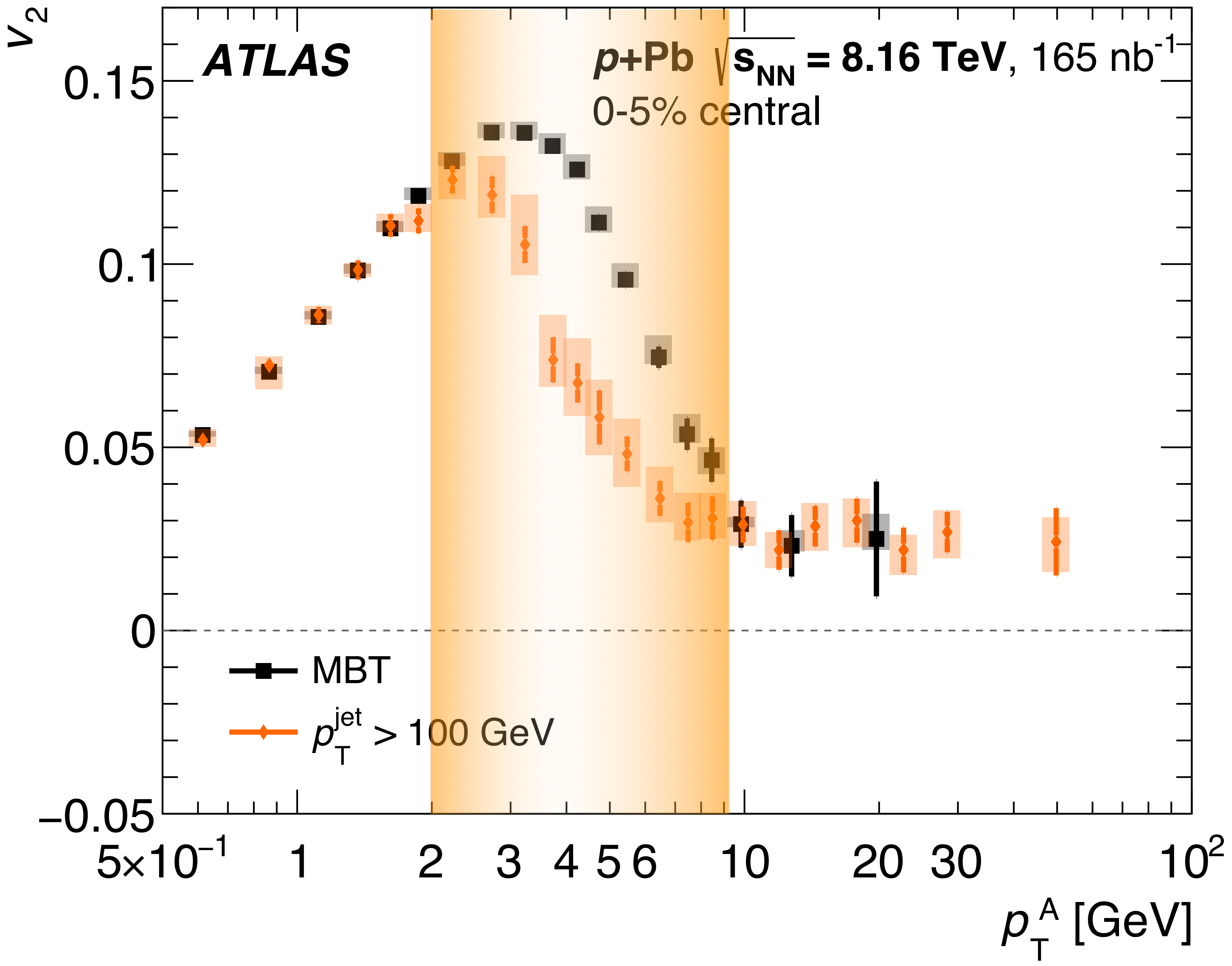
Comparison to jet quenching calculation





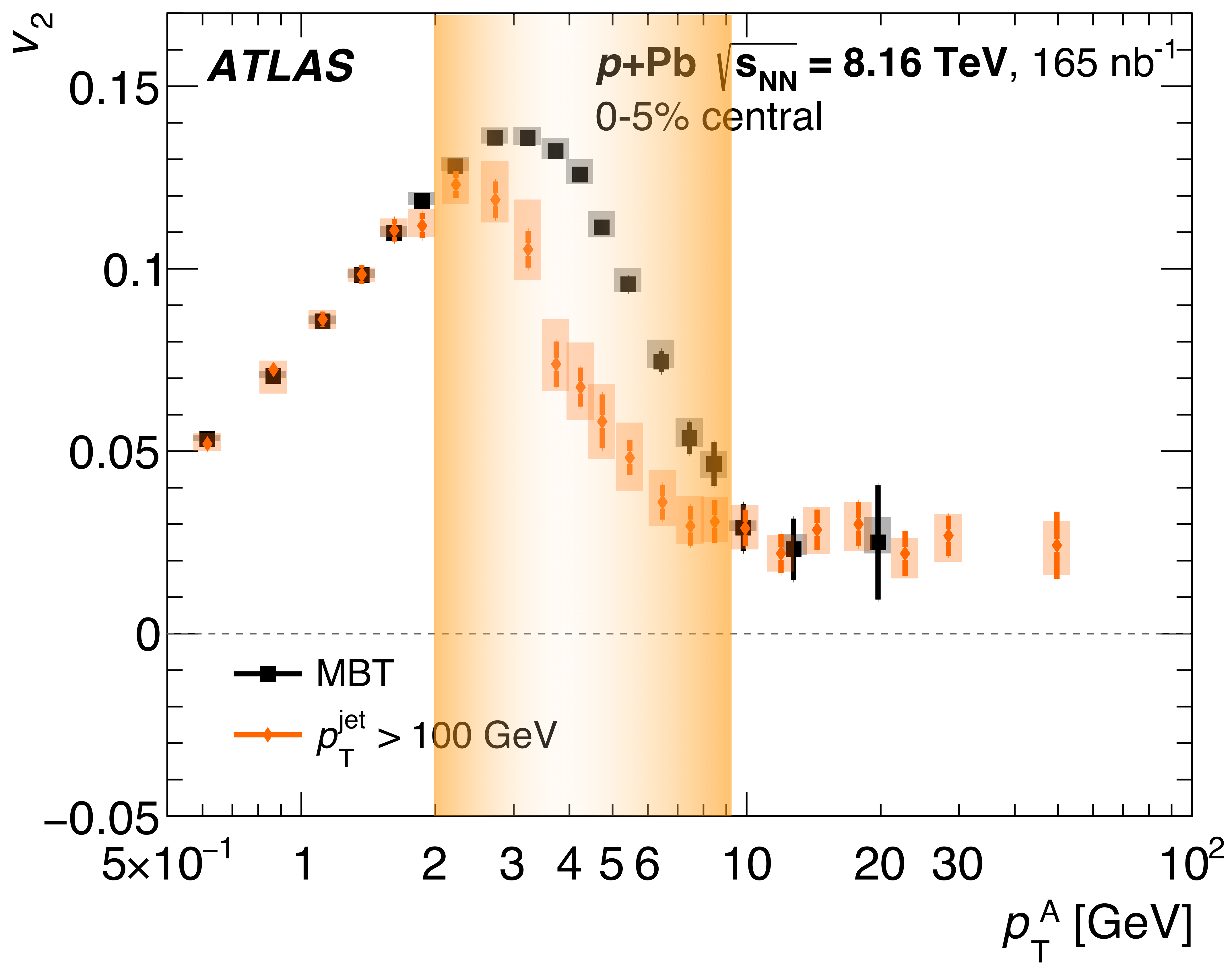
Jet quenching calculation cannot simultaneously describe flow and spectra modification

What about the transition region?



Transition behavior could be driven by admixture of particles from hard scattering **(jet)** and from the underlying event **(bulk)**

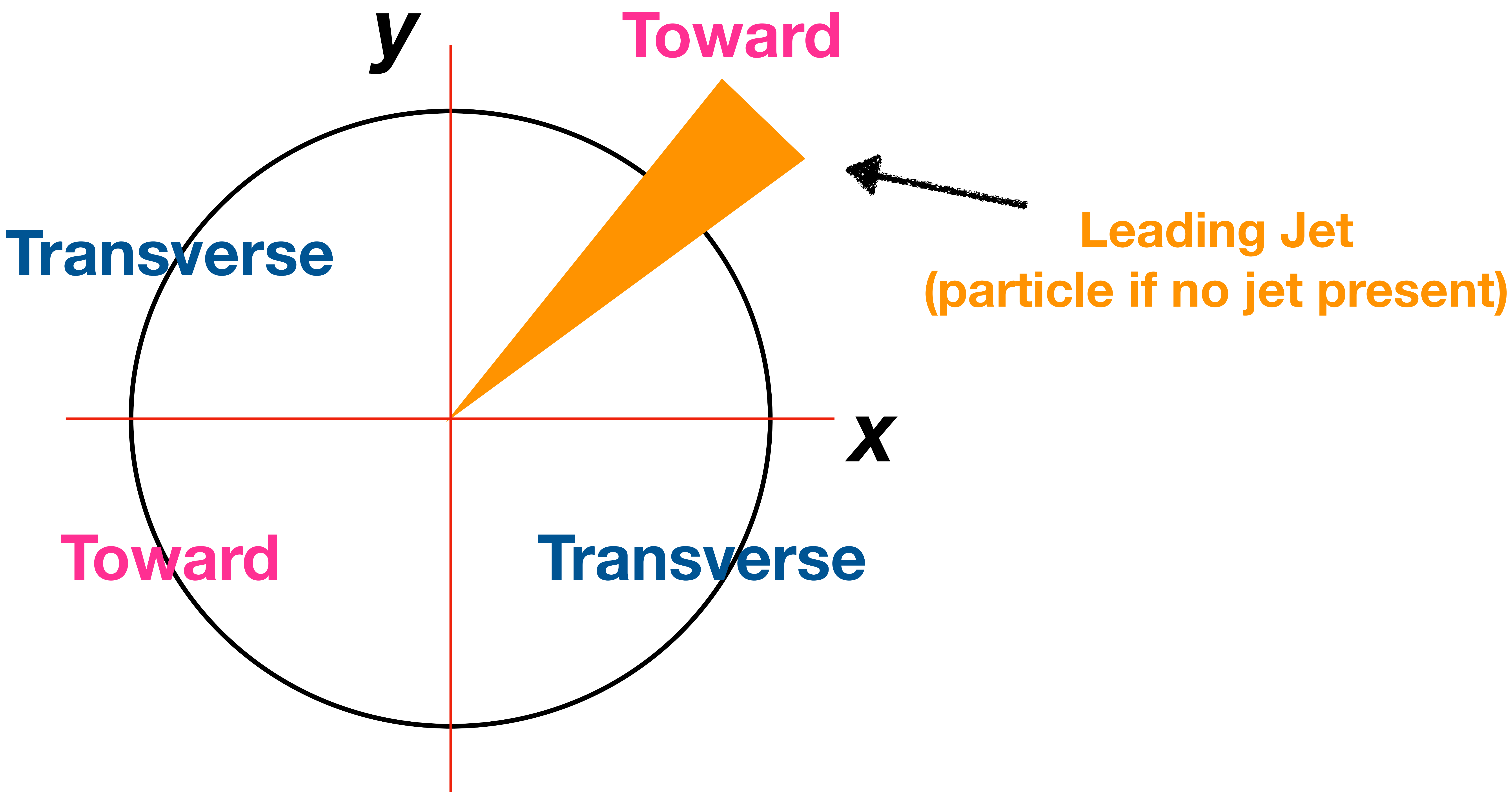
What about the transition region?



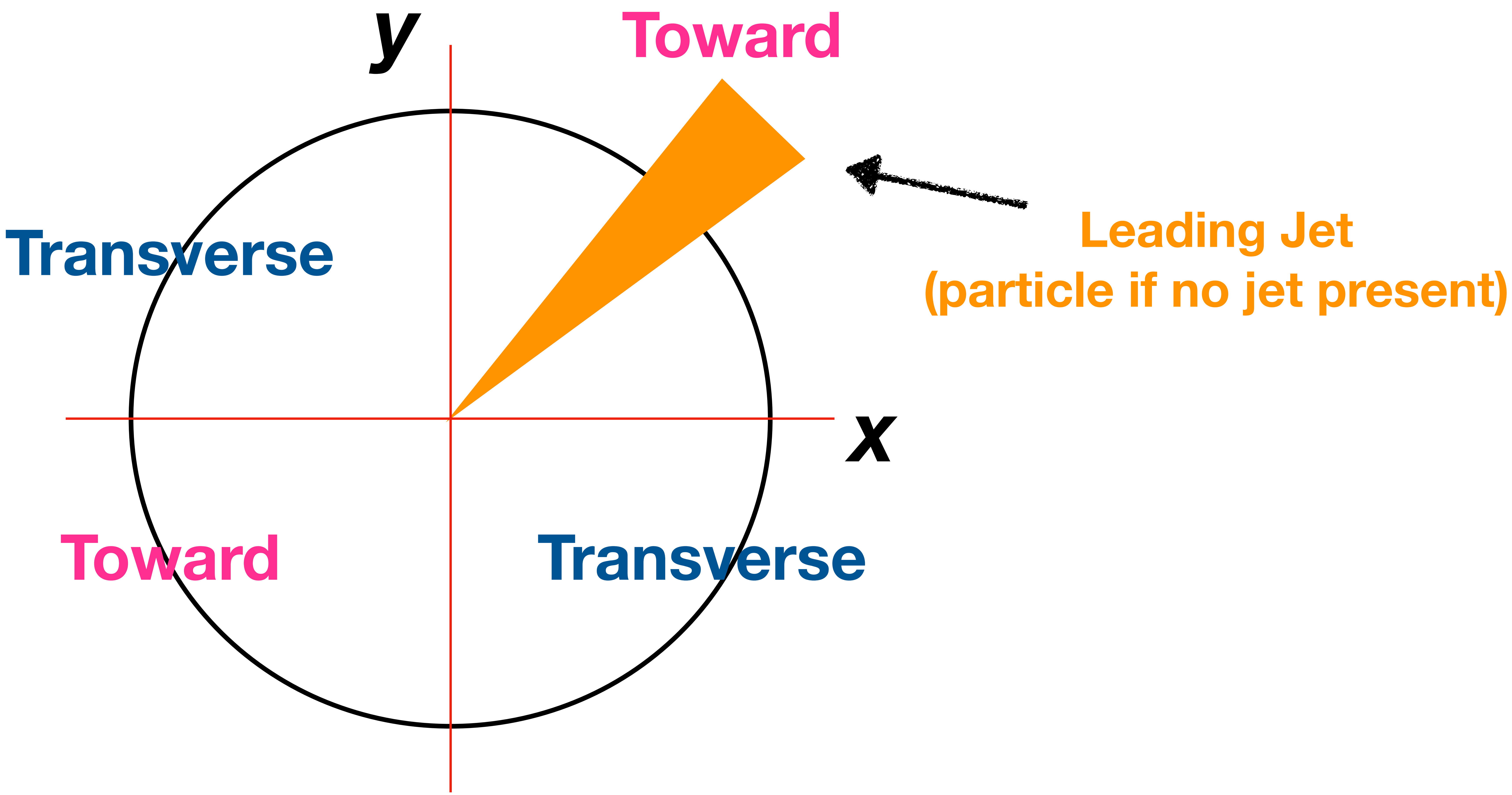
Transition behavior could be driven by admixture of particles from hard scattering **(jet)** and from the underlying event **(bulk)**

- Measure the relative contribution of each type

Jet and bulk particle yield



Jet and bulk particle yield

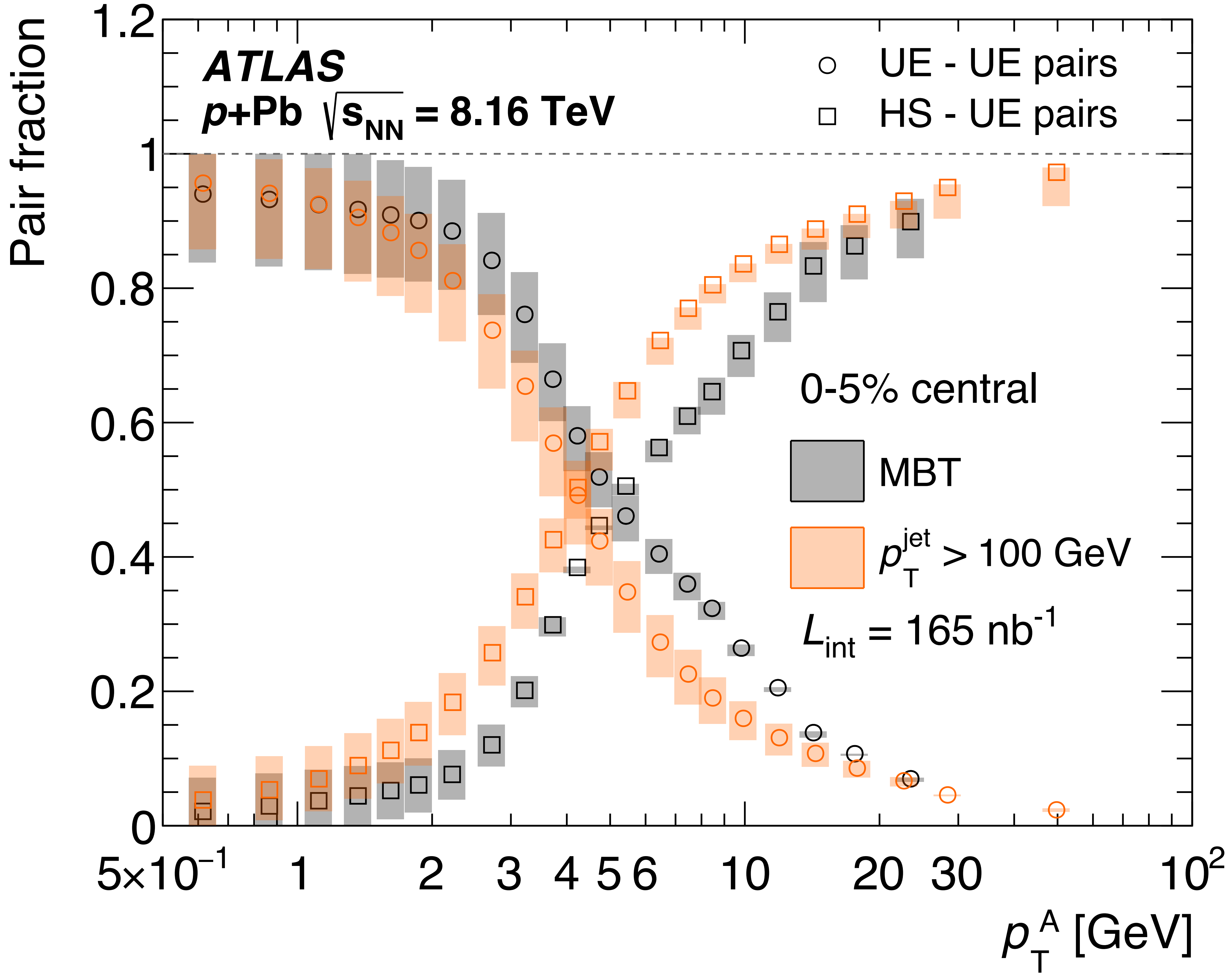


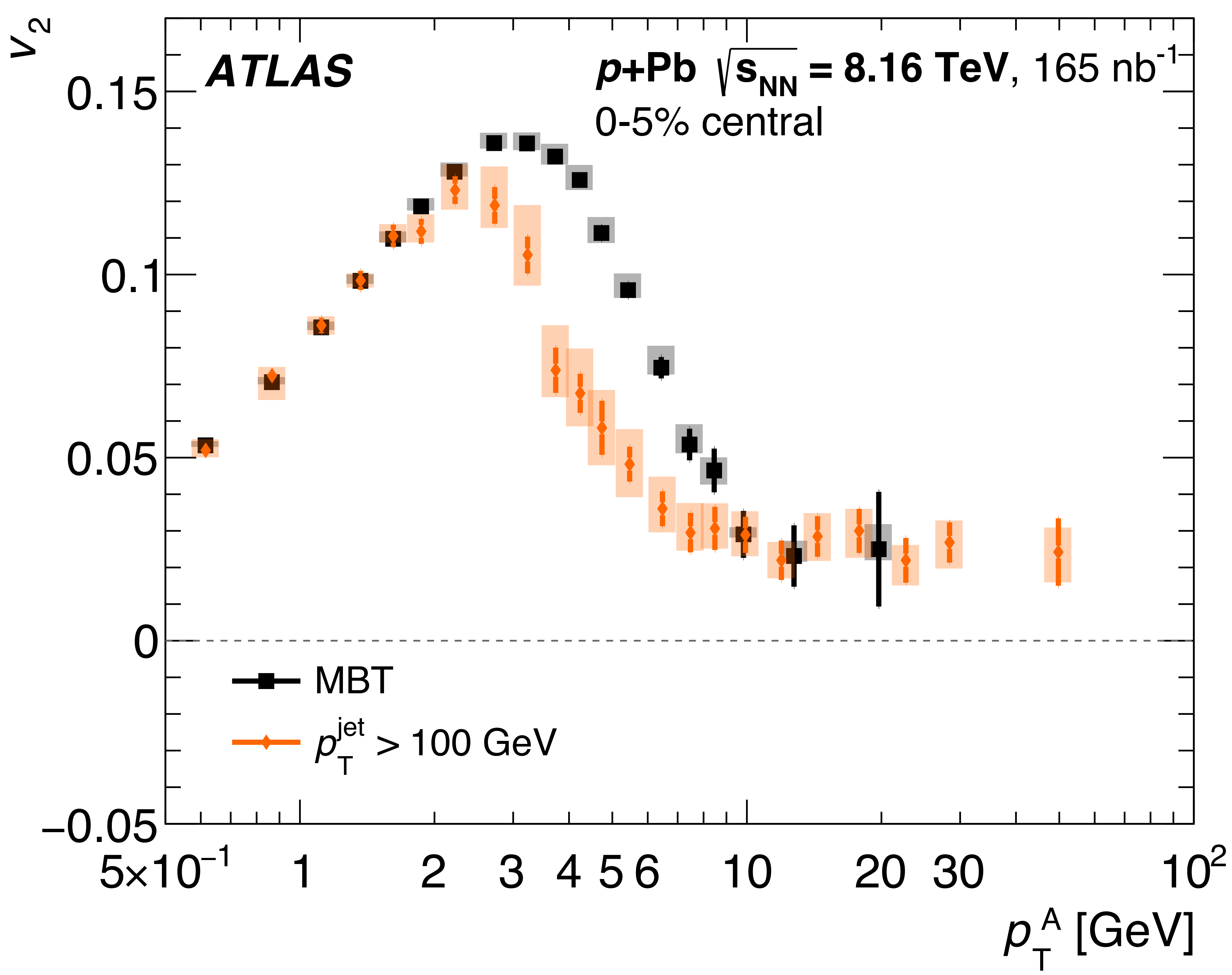
Assume:

1. **Transverse** has only **bulk** particles
2. **Toward** has both **bulk** *and* **jet** particles

→ Solve for yield of **bulk** and **jet**

Particle pair composition





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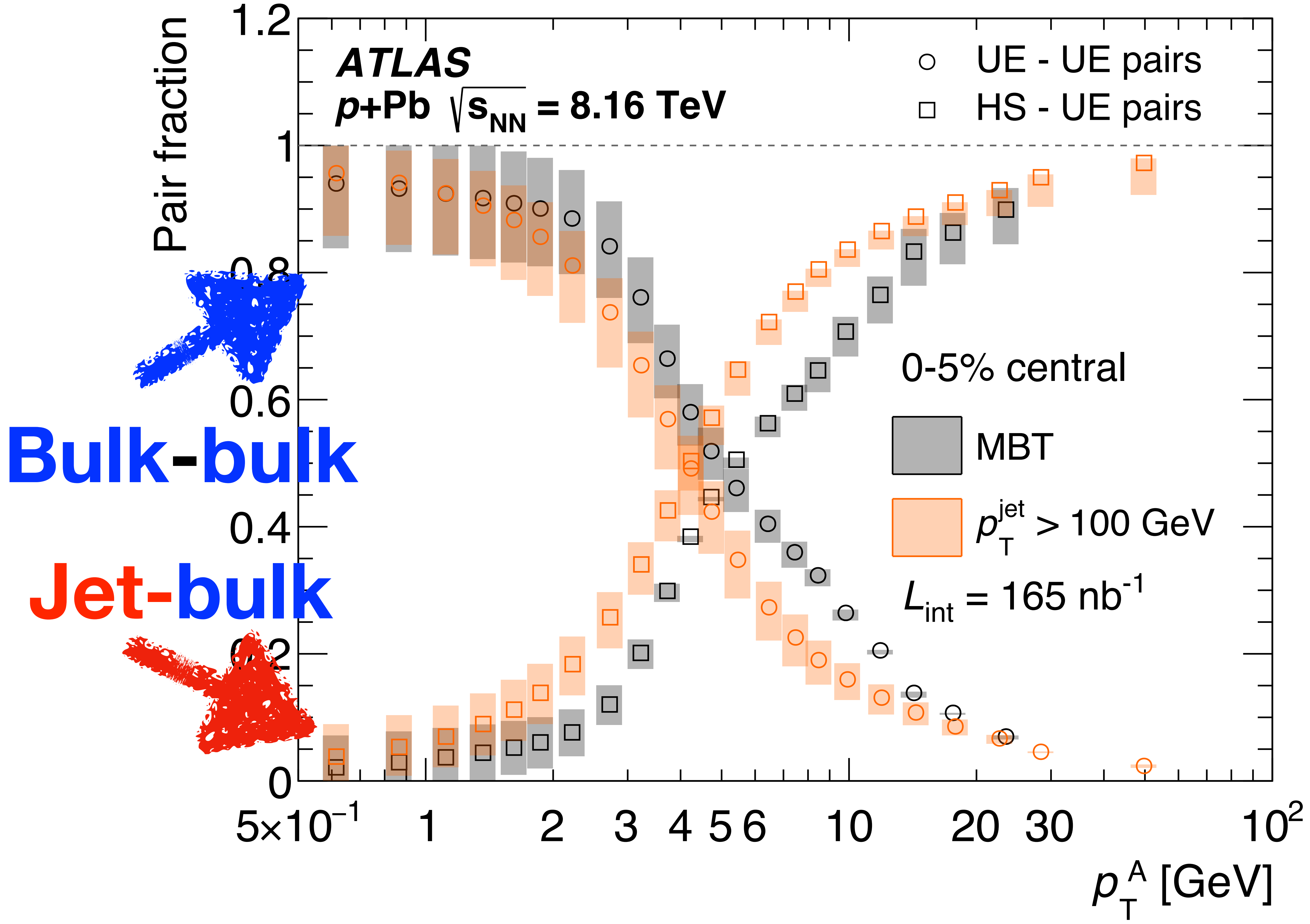
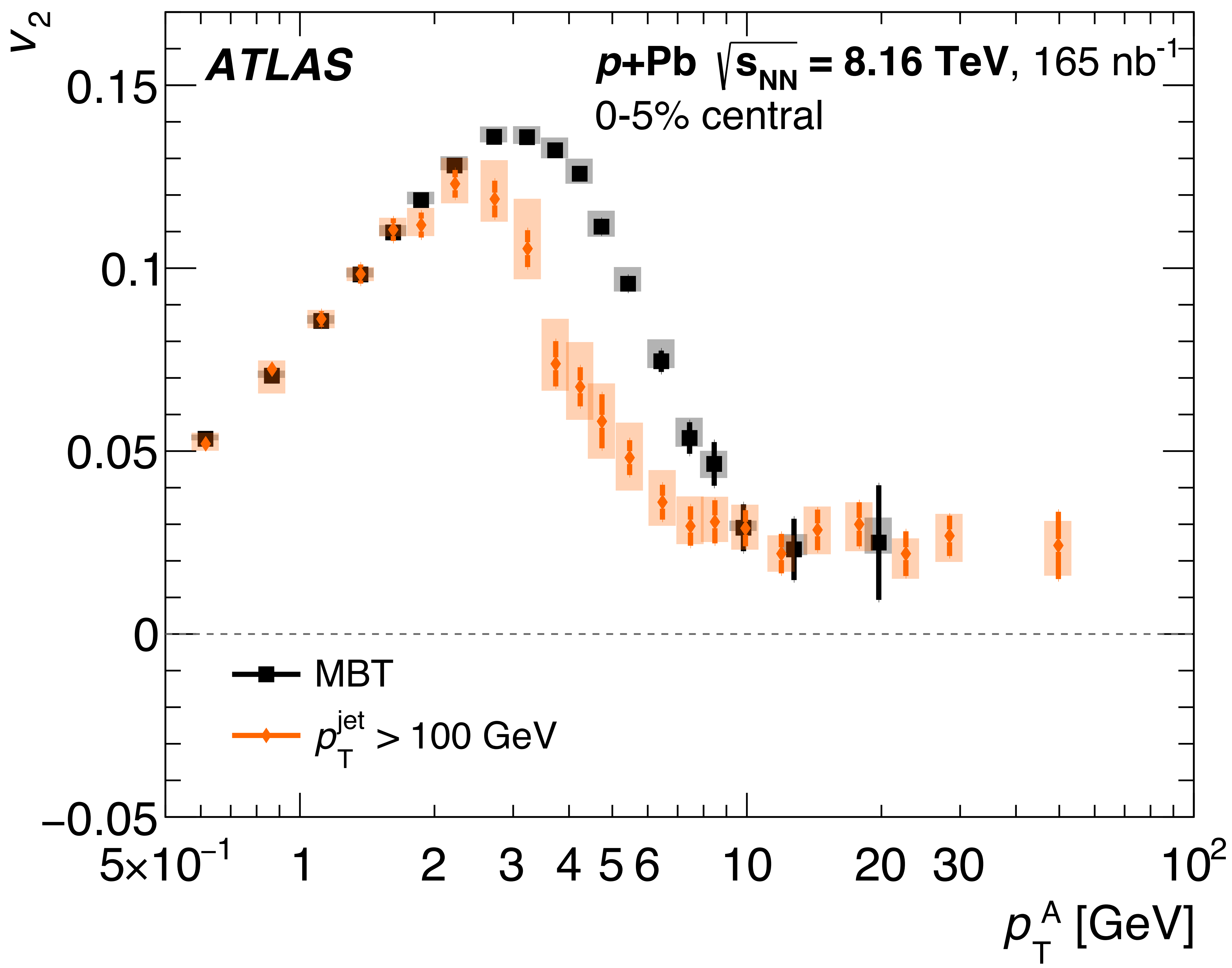
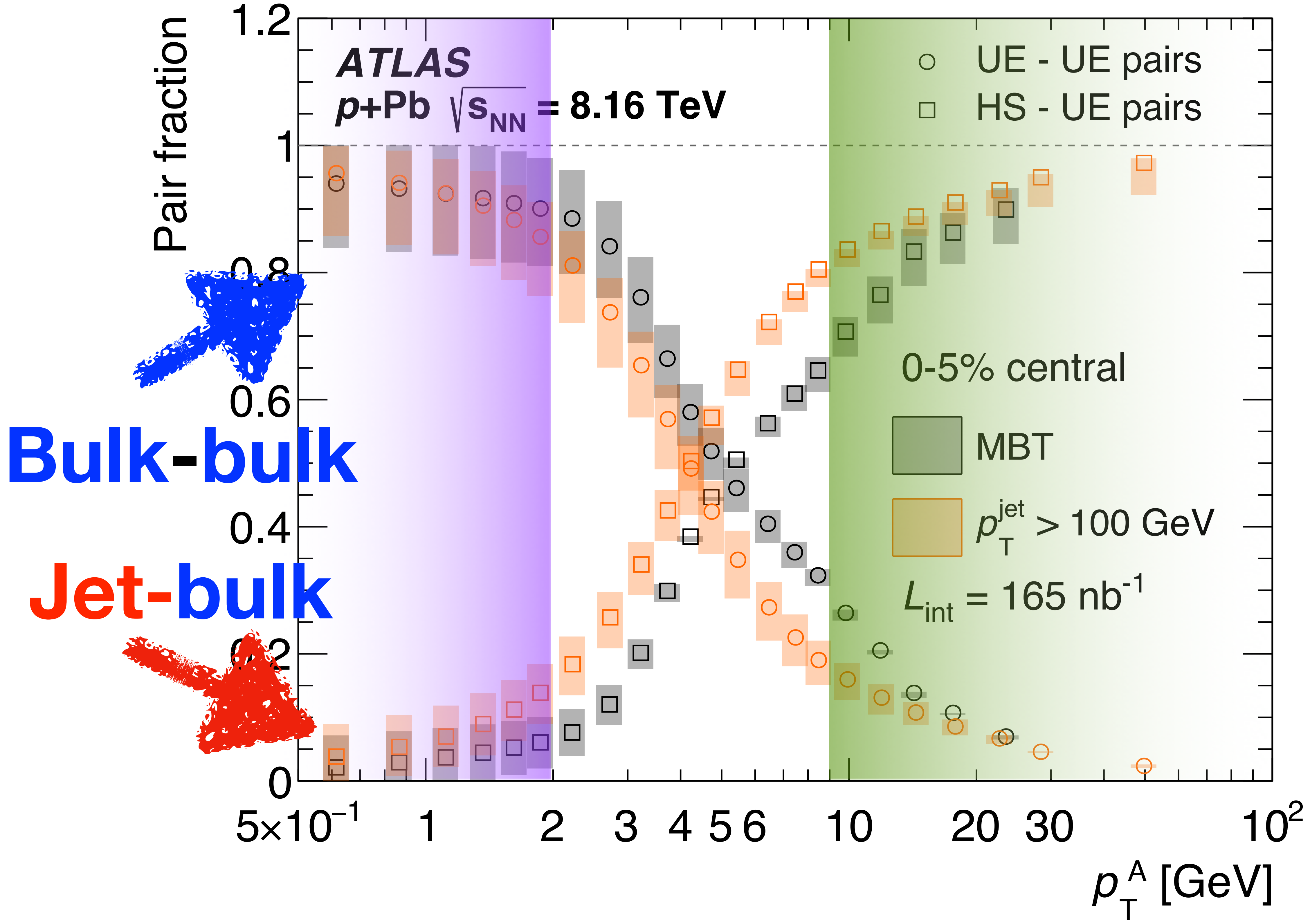
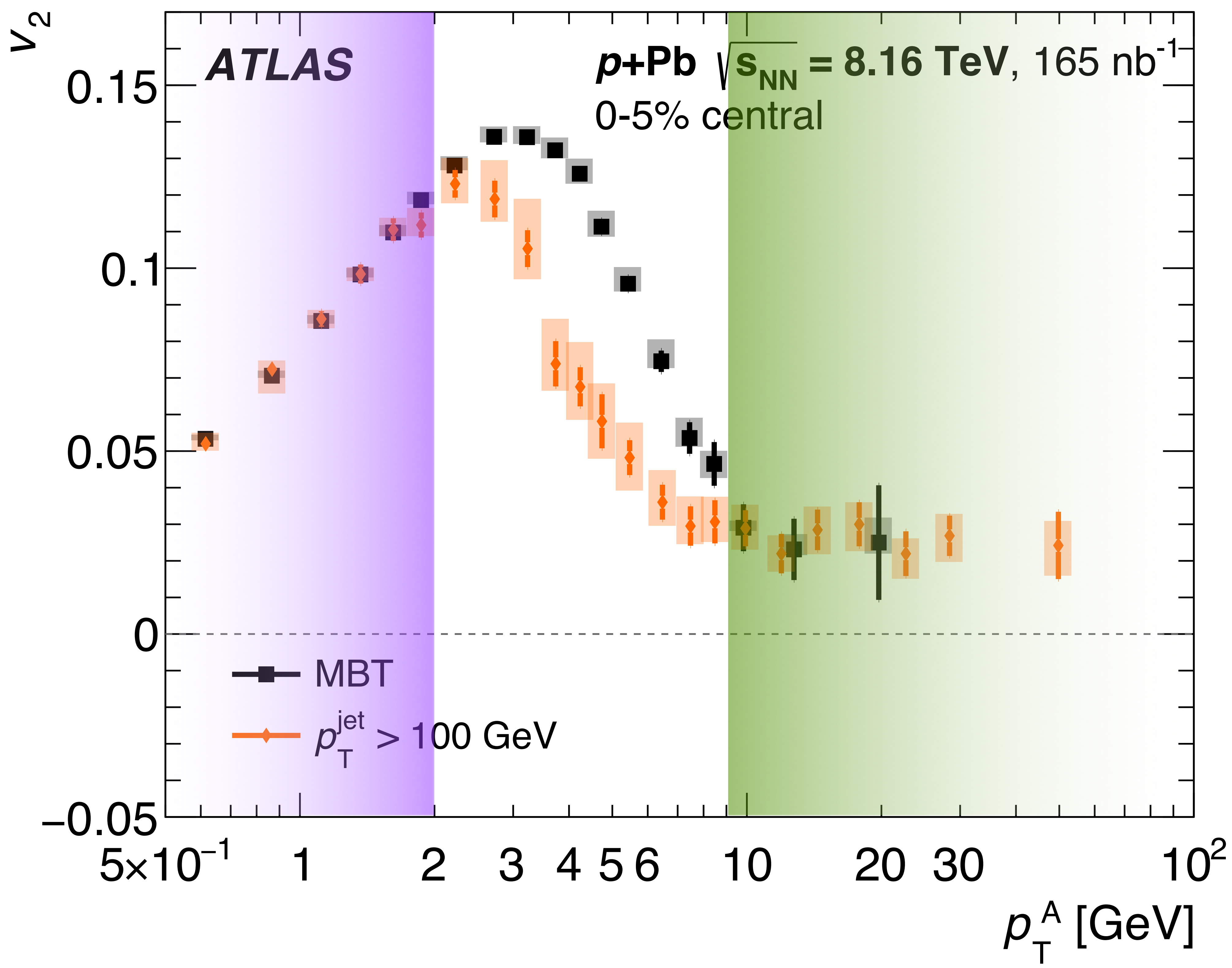




- Associated particles highly likely to be from **bulk**

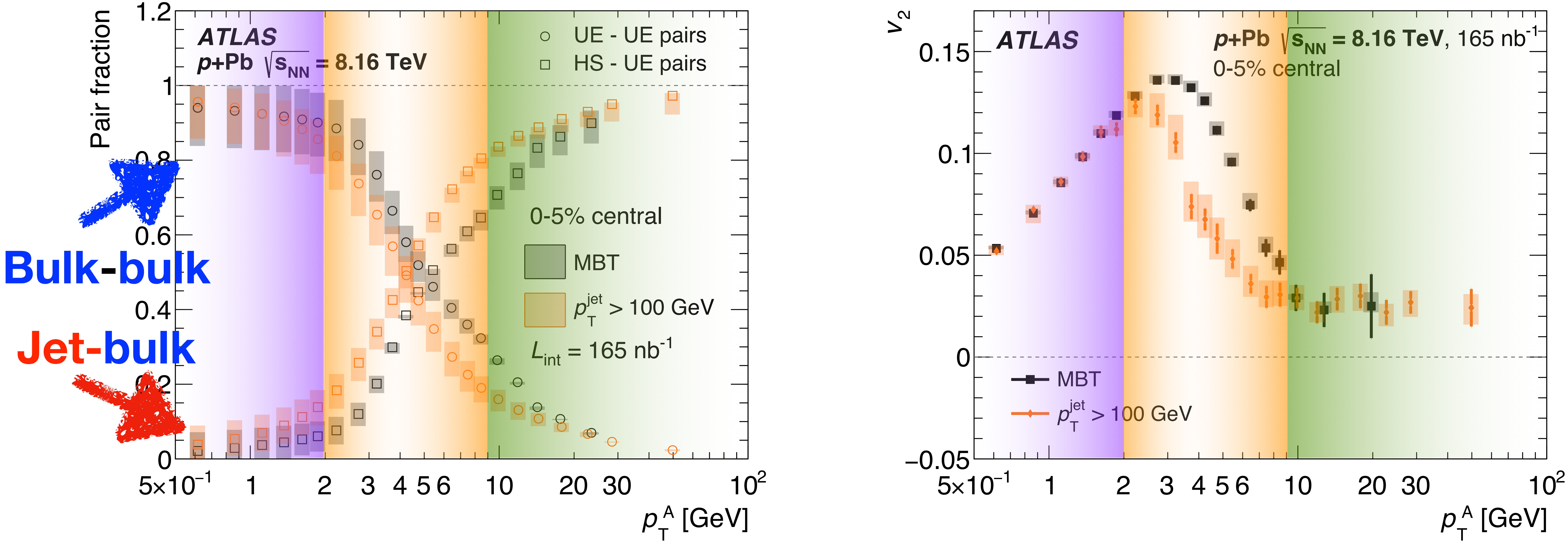
Particle pair composition





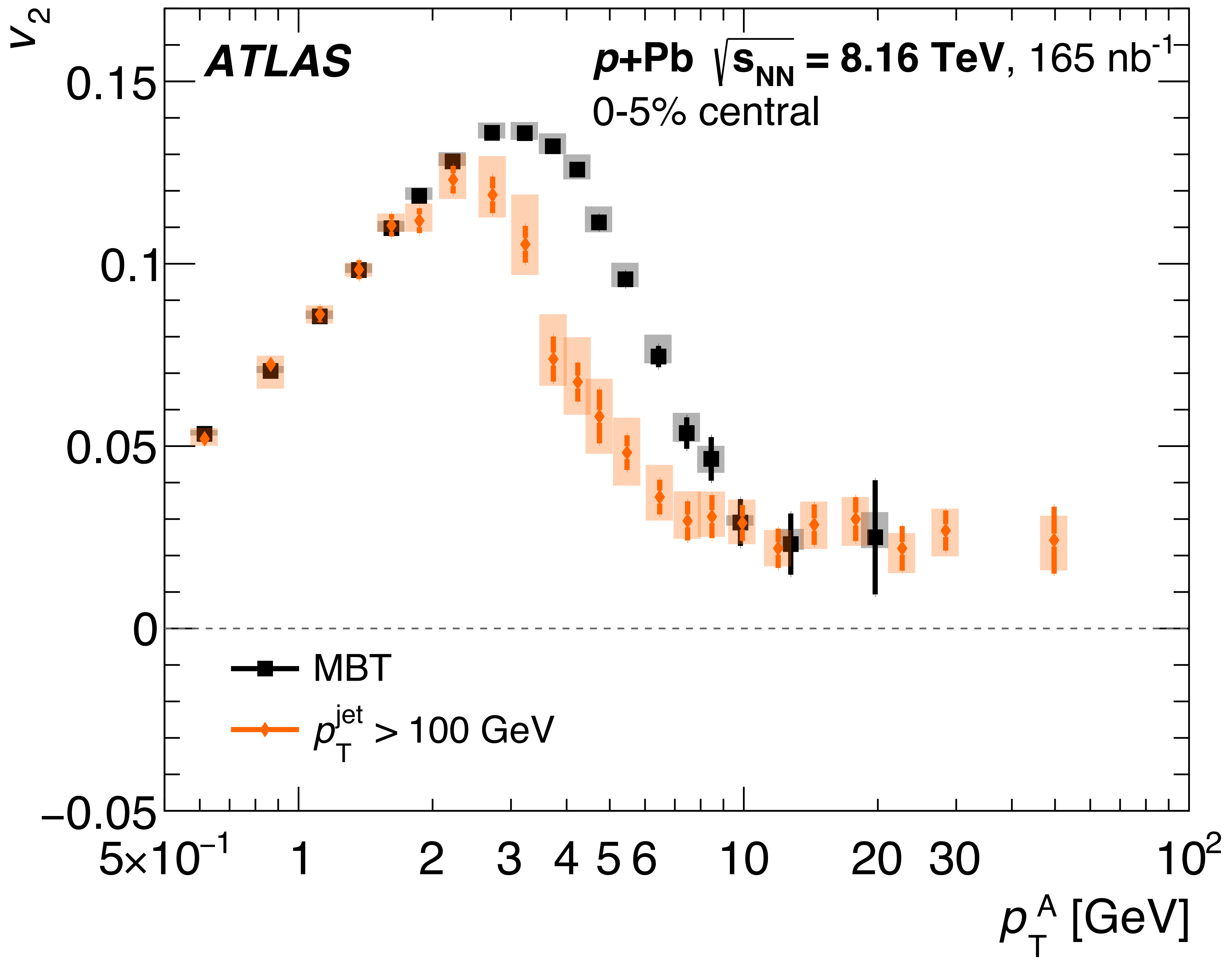
- Associated particles highly likely to be from **bulk**
- *Low* and *high* p_T dominated by **bulk** and **jet** particles respectively

Particle pair composition



- Associated particles highly likely to be from **bulk**
- *Low* and *high* p_T dominated by **bulk** and **jet** particles respectively
- *Transition* region sensitive to relative mixture of **bulk** and **jet**
  - e.g. ~4 GeV particle more likely to be from a jet if it's in a jet triggered event

Conclusions



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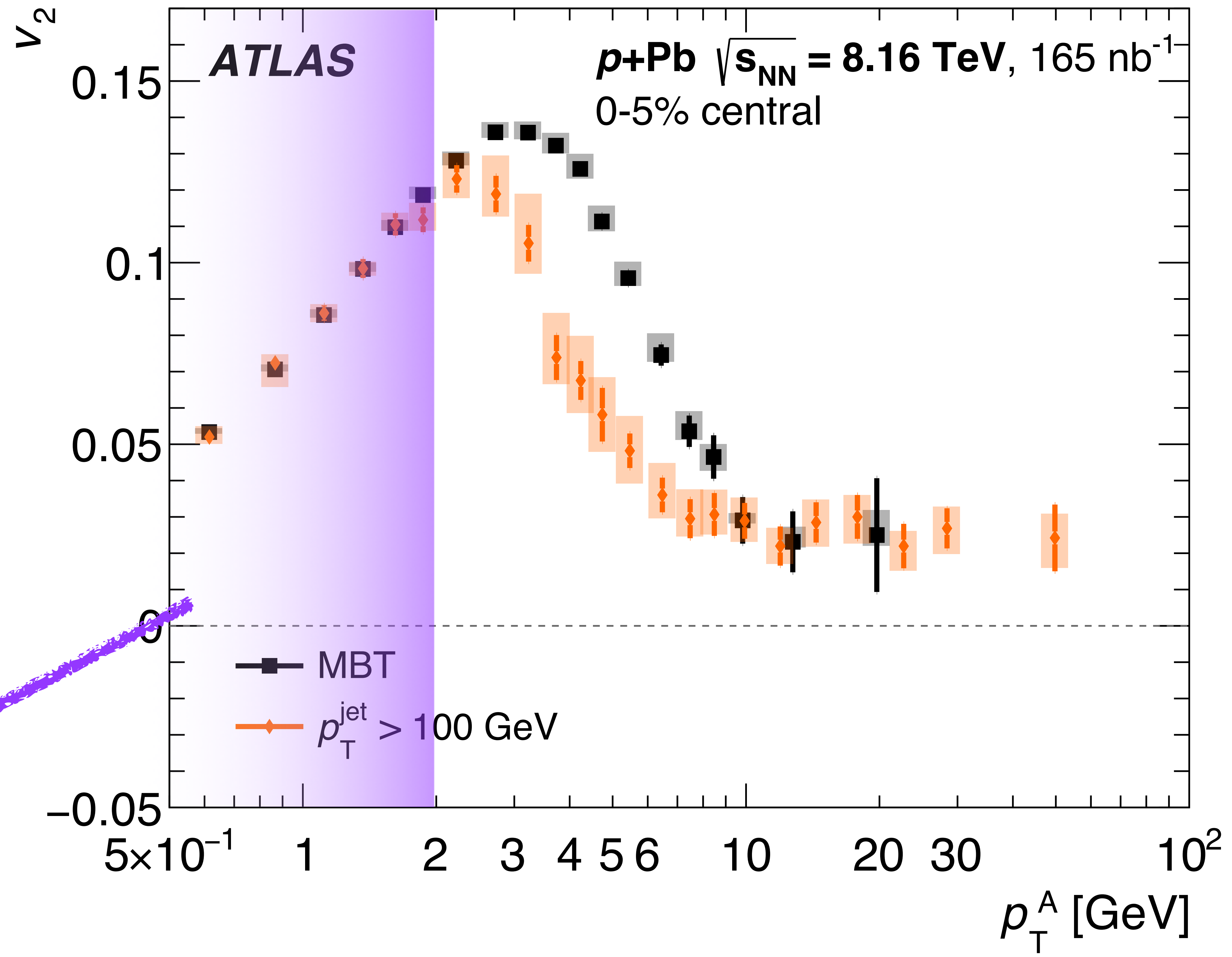
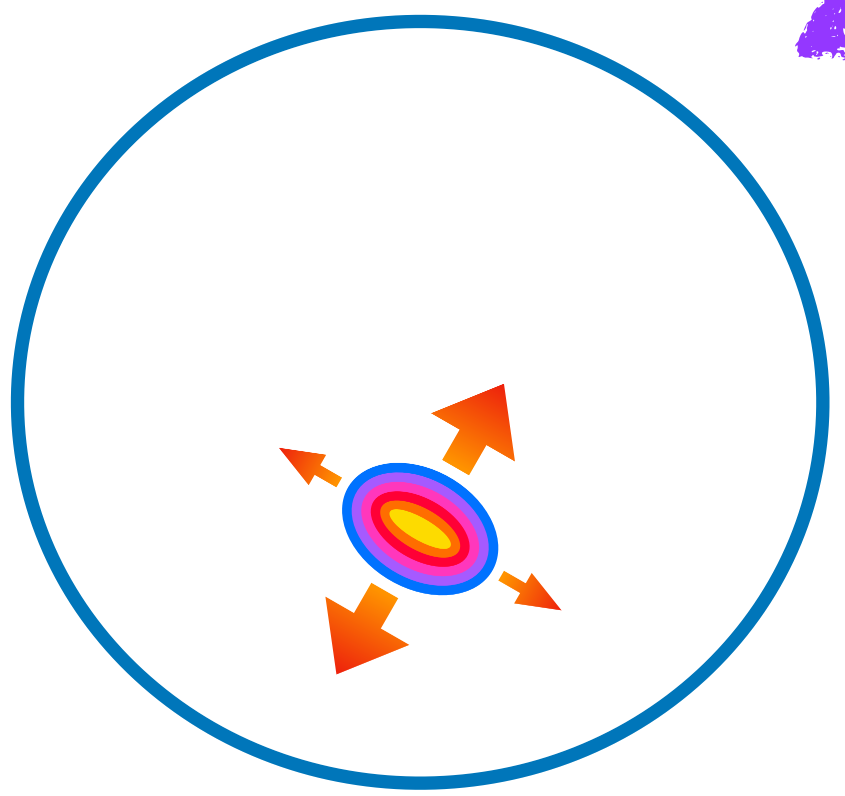
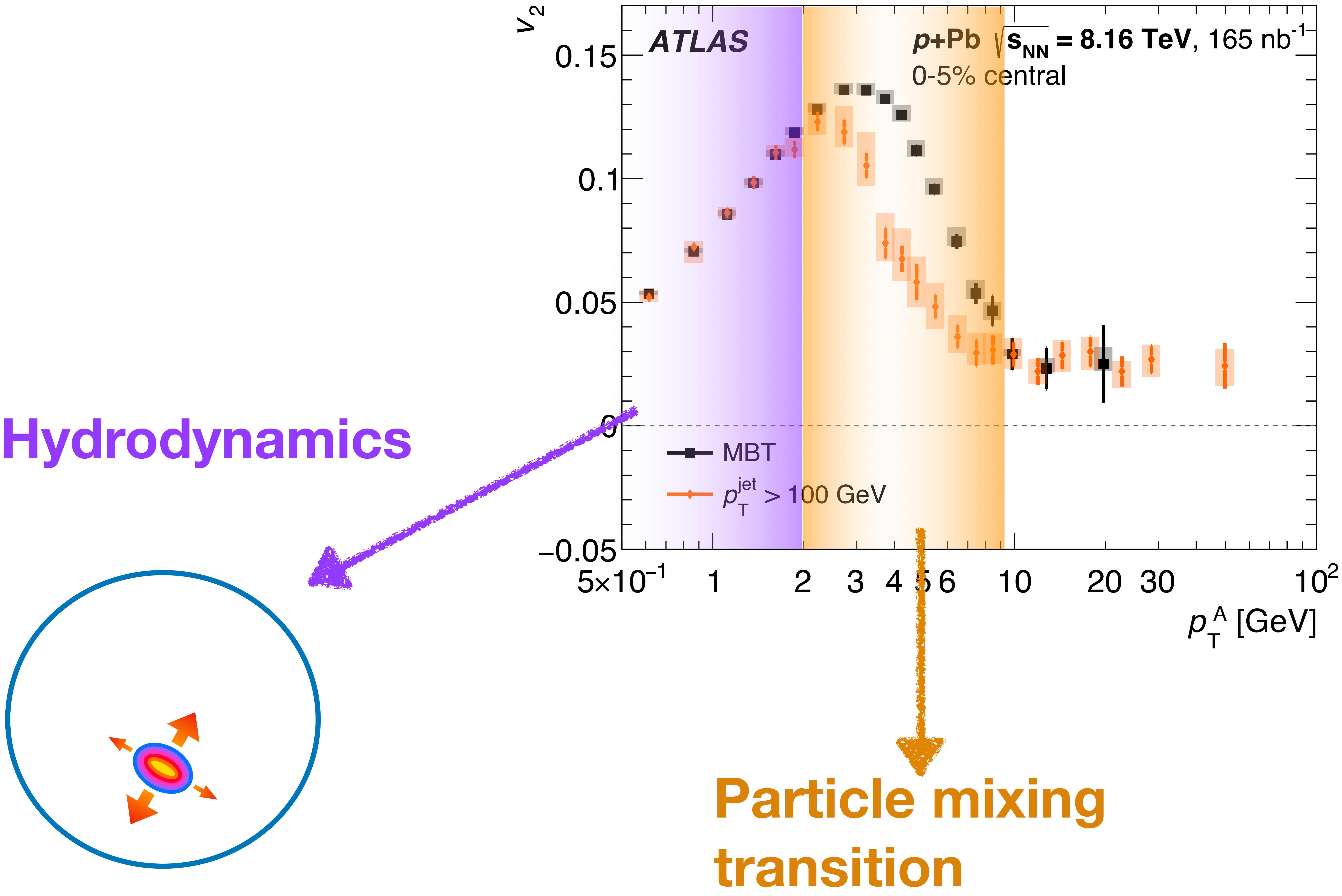


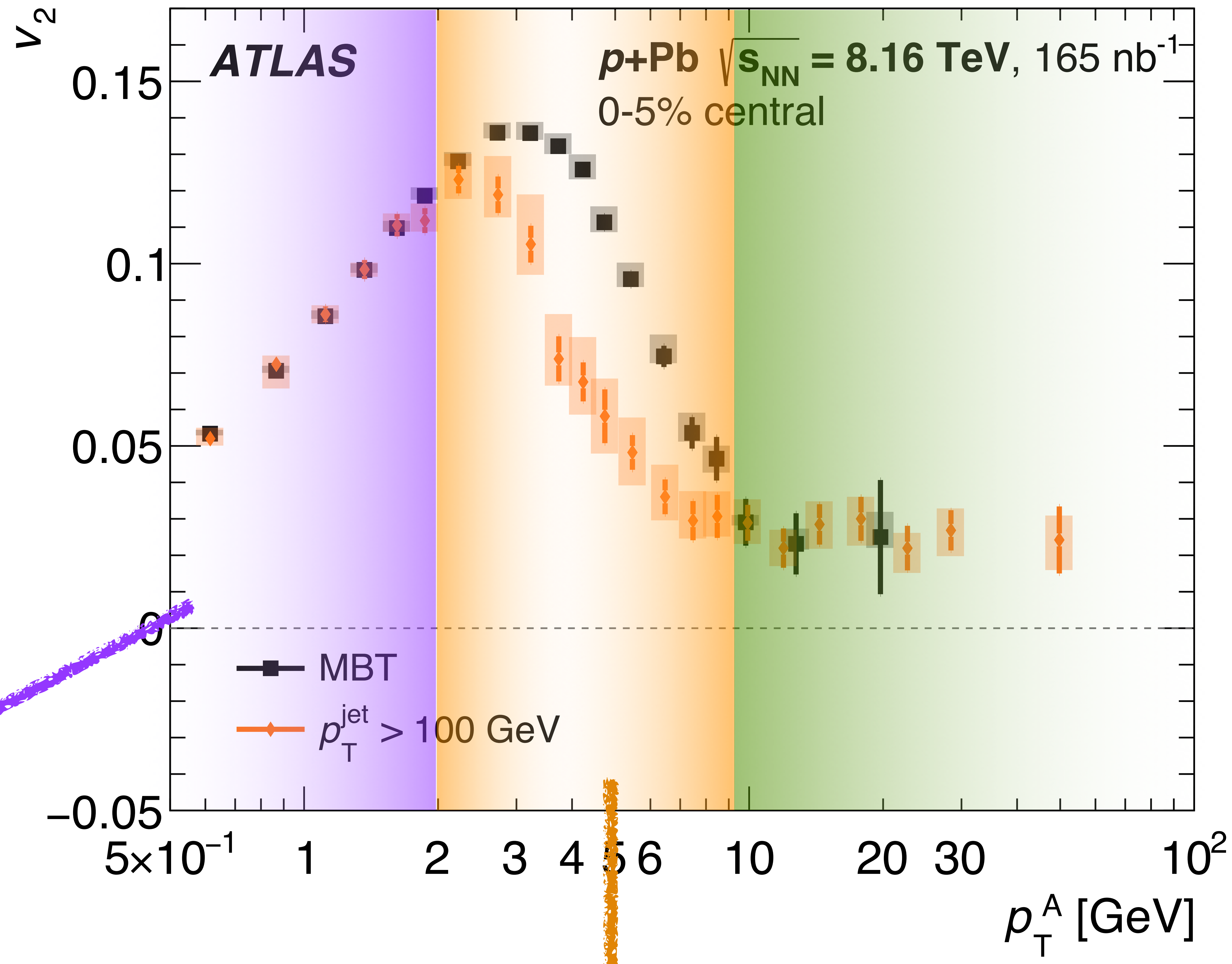
Hydrodynamics



Conclusions



Conclusions



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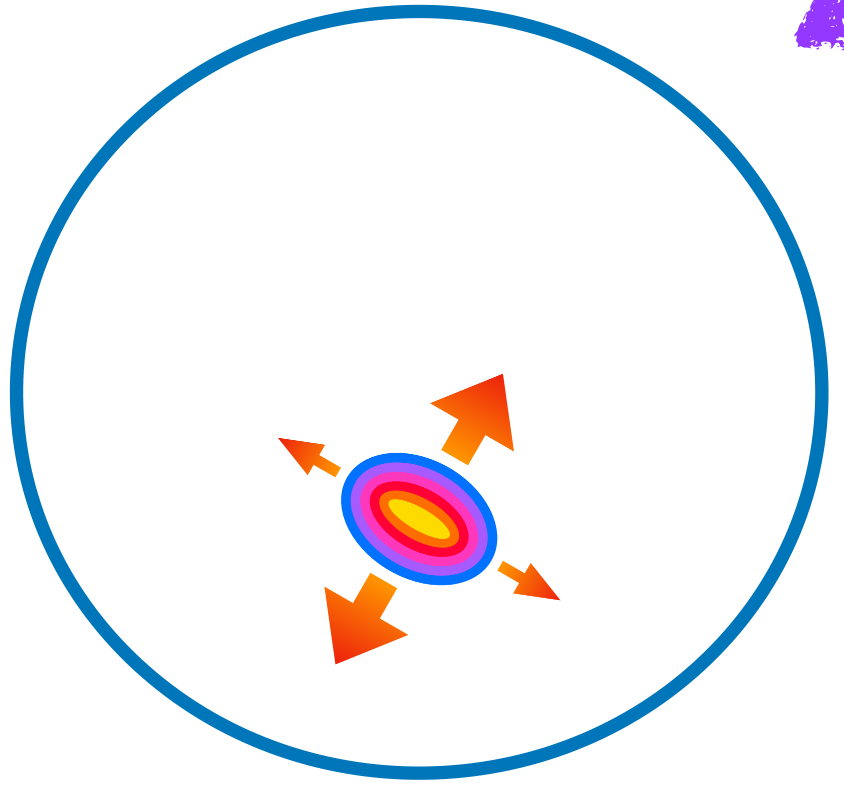
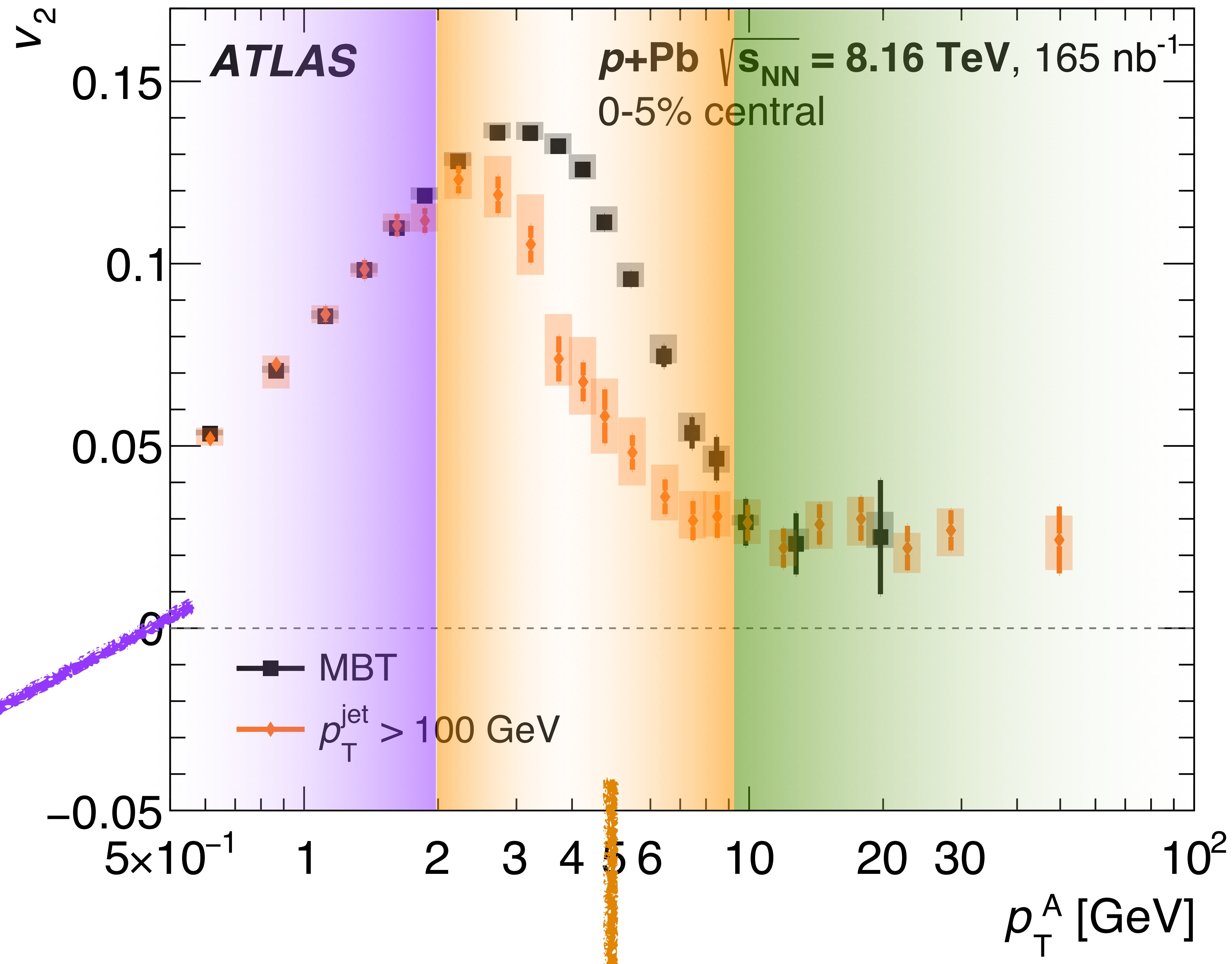


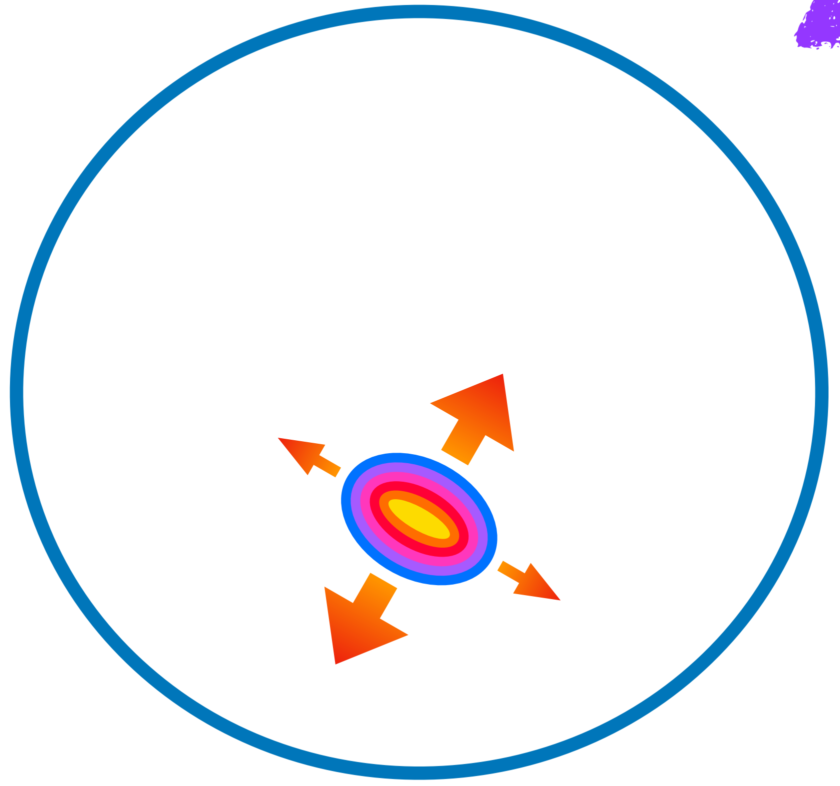
Particle mixing transition

?

These results and more are detailed in new paper arXiv:1910.13978



Hydrodynamics



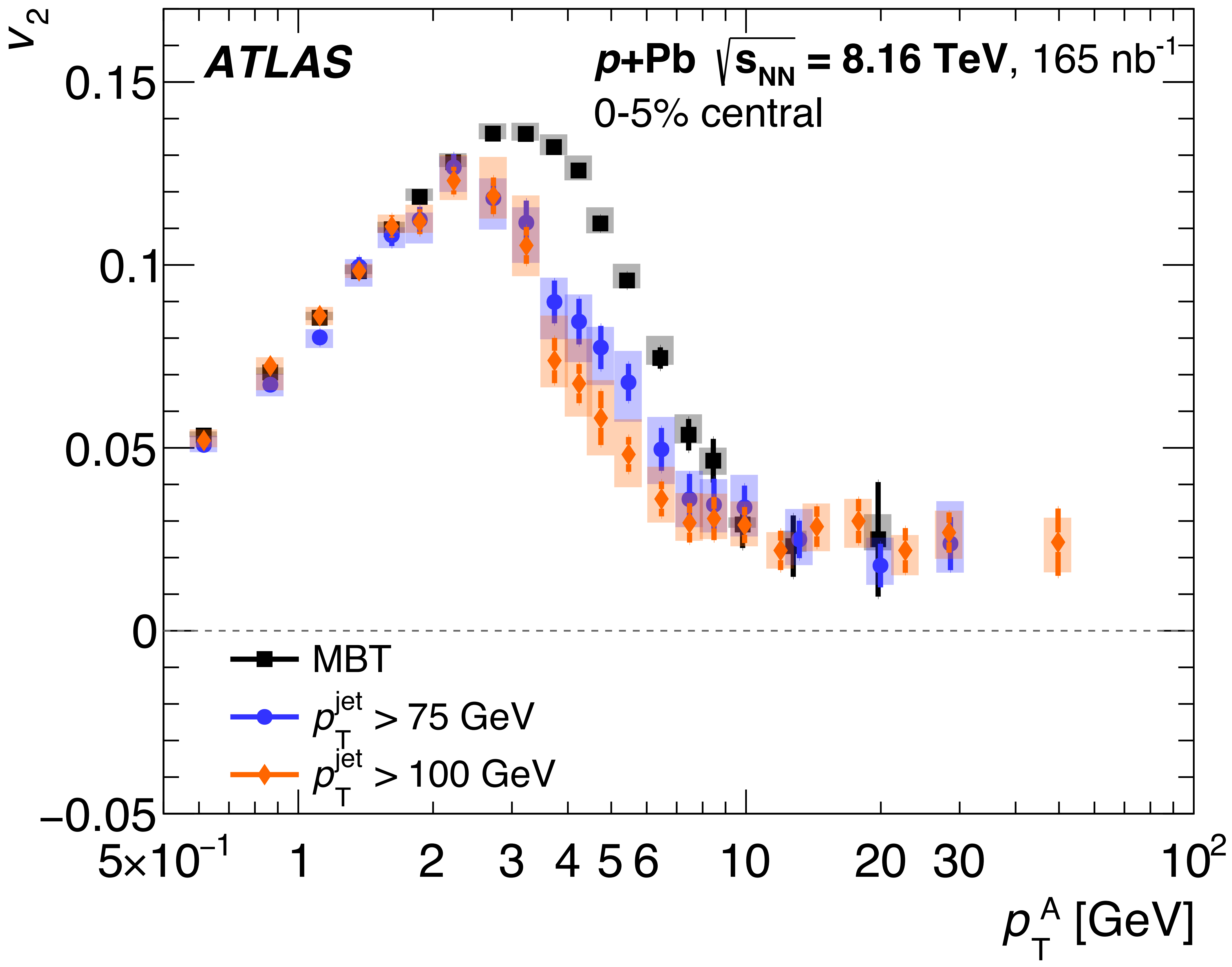
Particle mixing transition

?

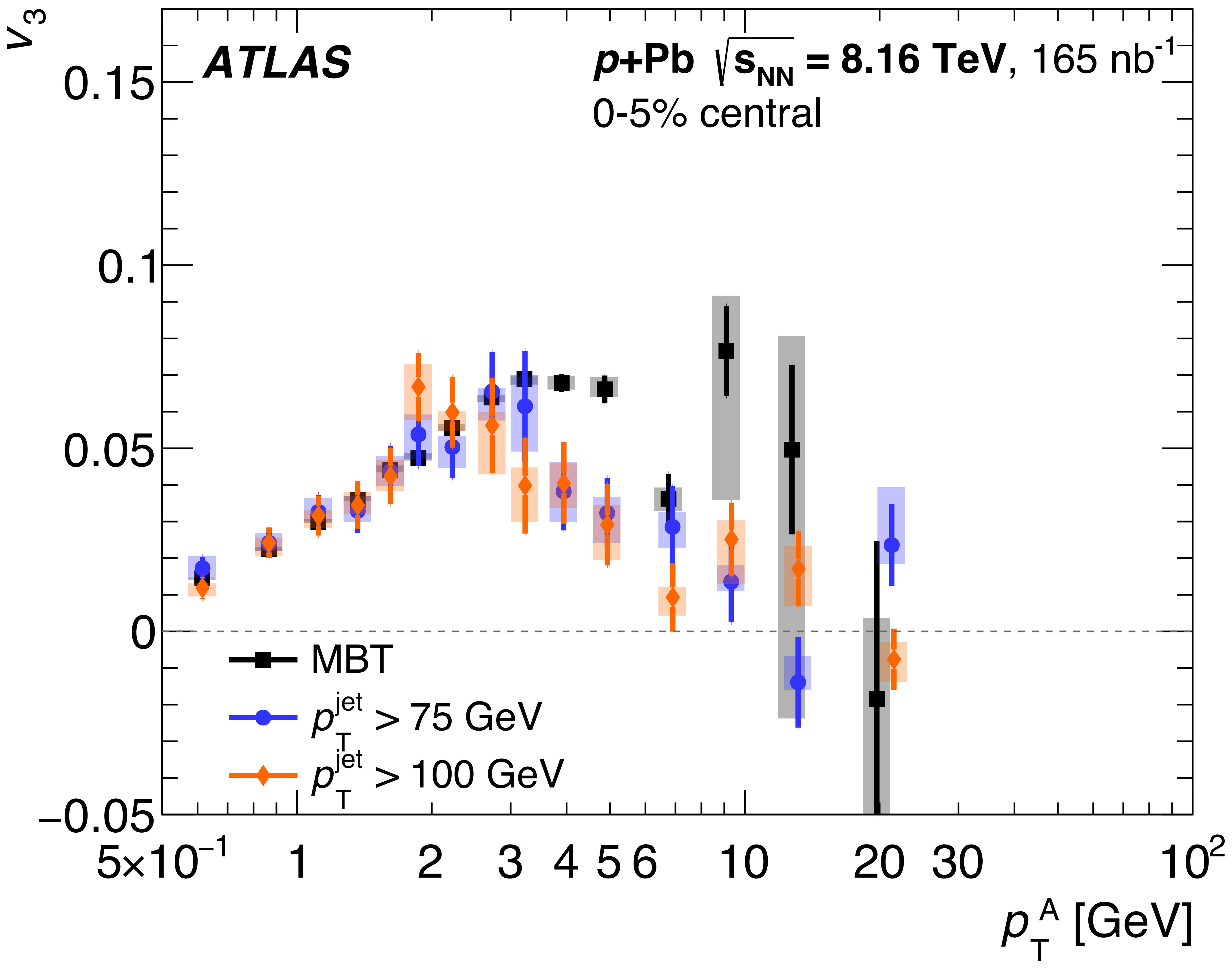
Backup

p_T dependent v_n results

v_2



v_3



- Both v_2 and v_3 show similar behavior between MB and jet events
  - Consistency at *low* and *high* p_T
  - *Transition* to high p_T behavior happens at *lower* p_T for jet events

Factorization test

Centrality dependent v_2 results

- At *low* and *high* p_T, v_2 roughly independent of centrality and event type
- At *mid* p_T, v_2 decreases with centrality and is *lower* for *high* p_T jet events

Particle *pair* yields

Total pairs

$$P_{\text{total}} = N^{\text{A}} \cdot N^{\text{B}}$$

$$= (N^{\text{A}}_{\text{HS}} + N^{\text{A}}_{\text{UE}}) \cdot (N^{\text{B}}_{\text{HS}} + N^{\text{B}}_{\text{UE}})$$

$$= N^{\text{A}}_{\text{HS}} \cdot N^{\text{B}}_{\text{HS}} + N^{\text{A}}_{\text{HS}} \cdot N^{\text{B}}_{\text{UE}} + N^{\text{A}}_{\text{UE}} \cdot N^{\text{B}}_{\text{HS}} + N^{\text{A}}_{\text{UE}} \cdot N^{\text{B}}_{\text{UE}}$$

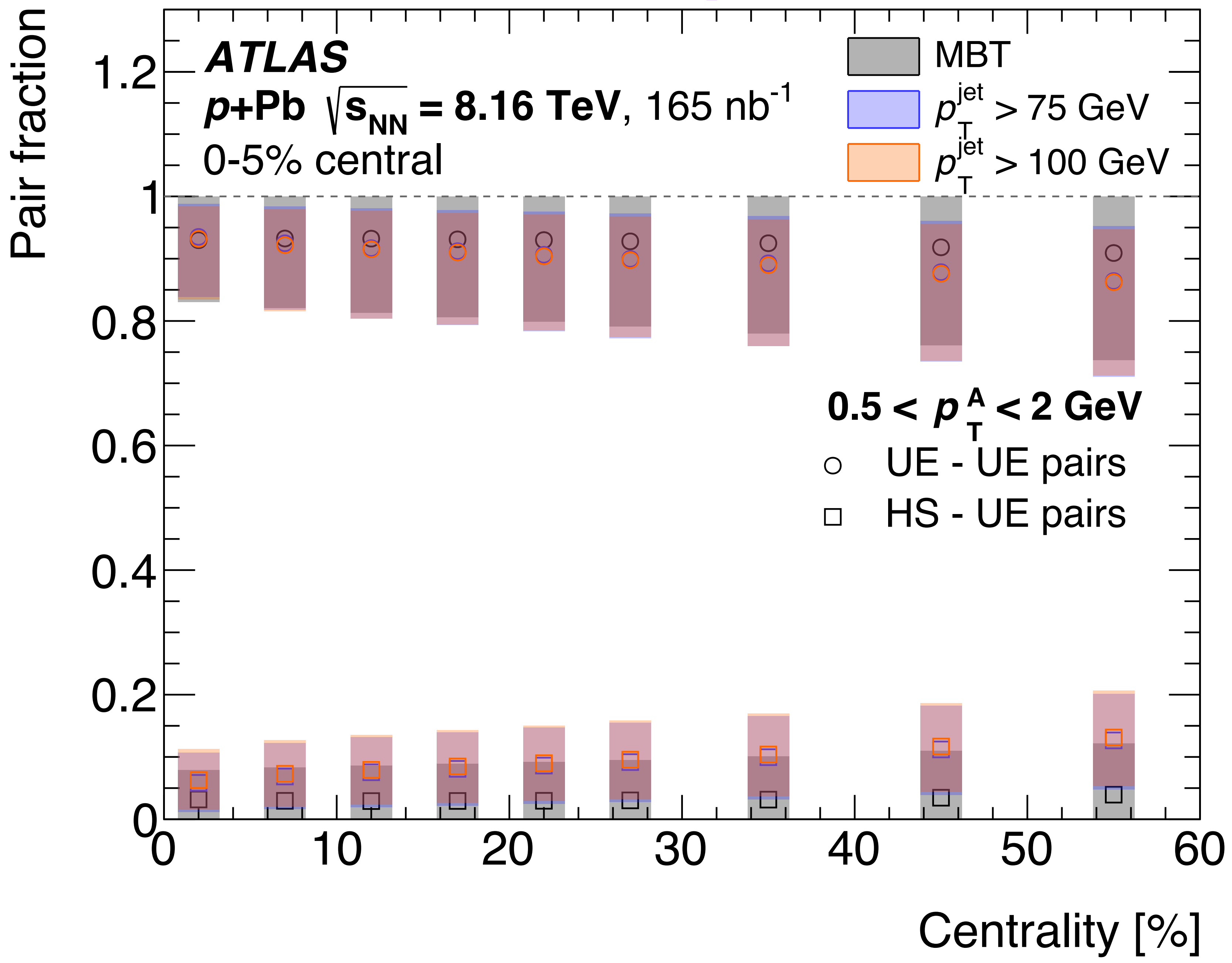
HS correlations **Cross correlations** **UE correlations**

Associated particles are required to be separated by 2 units in $\Delta\eta$, so these are not simple products

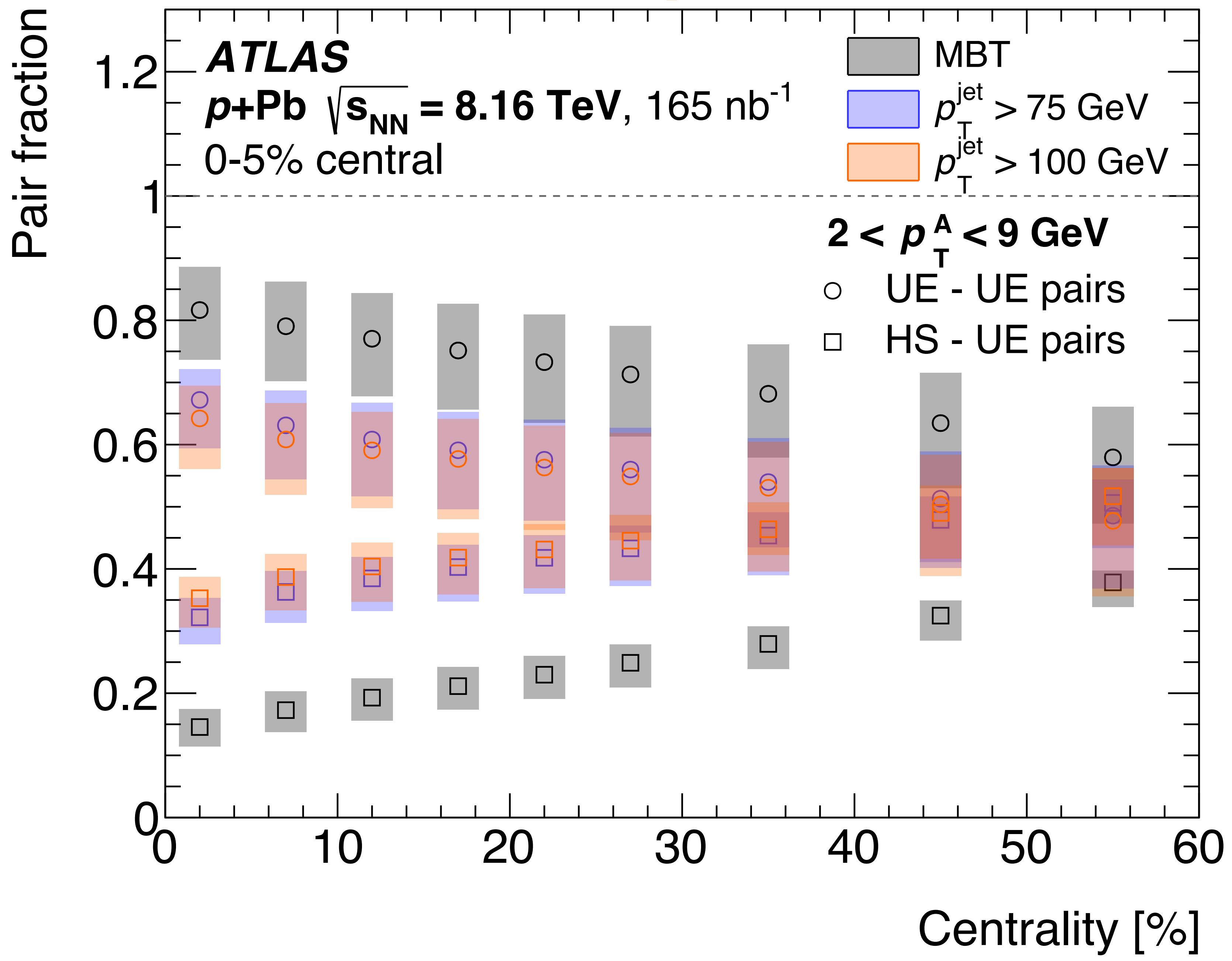
$$N^{\text{A}}_{\text{X}} \cdot N^{\text{B}}_{\text{Y}} = \int_{-2.5}^{2.5} \frac{\mathrm{d}N^{\text{A}}_{\text{X}}(\eta^{\text{A}})}{\mathrm{d}\eta^{\text{A}}} \left[\int_{2}^{5} \frac{\mathrm{d}^2 N^{\text{B}}_{\text{Y}}(\eta^{\text{A}}, |\Delta\eta|)}{\mathrm{d}\eta^{\text{A}}\mathrm{d}|\Delta\eta|} \mathrm{d}|\Delta\eta| \right] \mathrm{d}\eta^{\text{A}}$$

Centrality dependent pair fractions

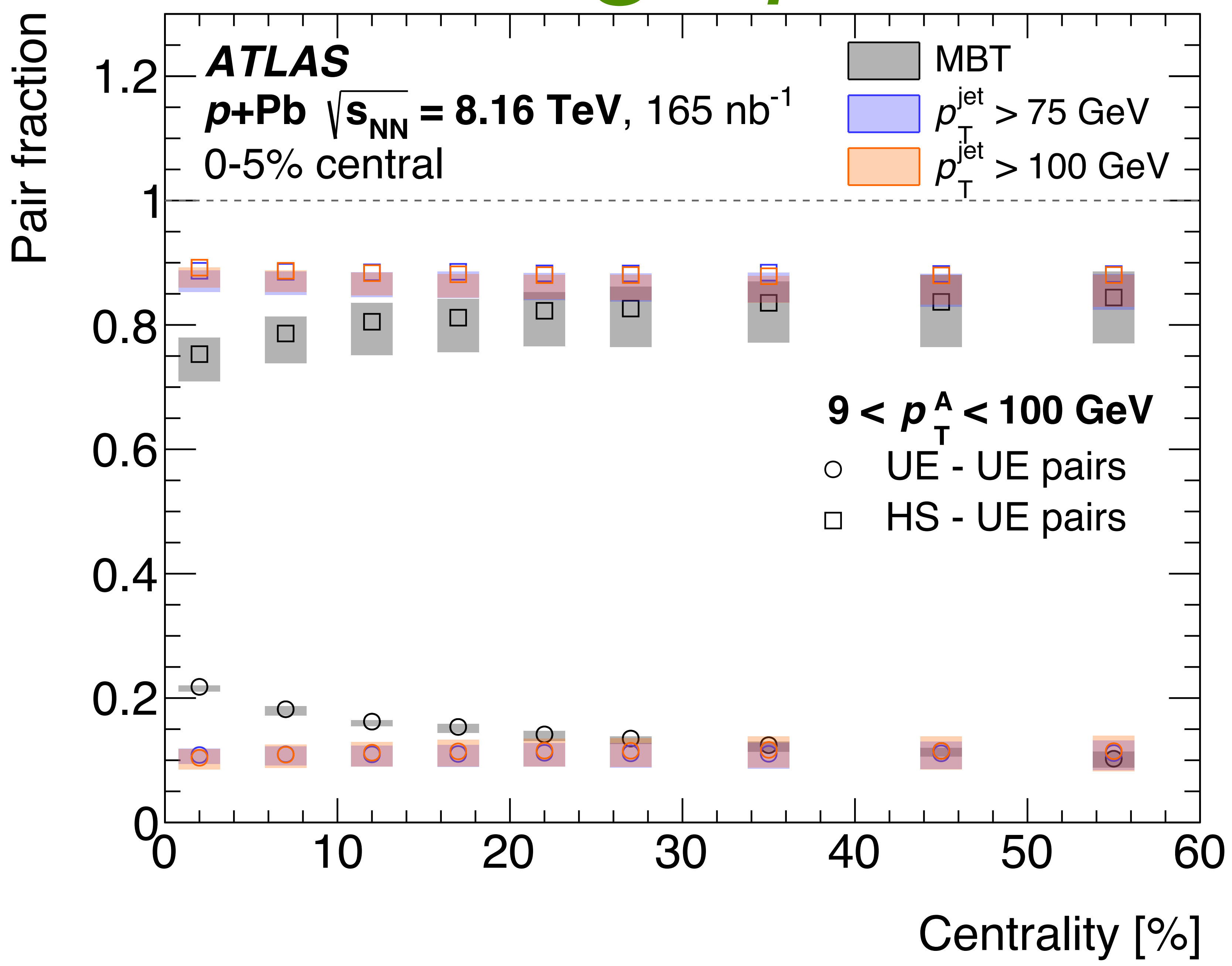
Low p_T



Mid p_T

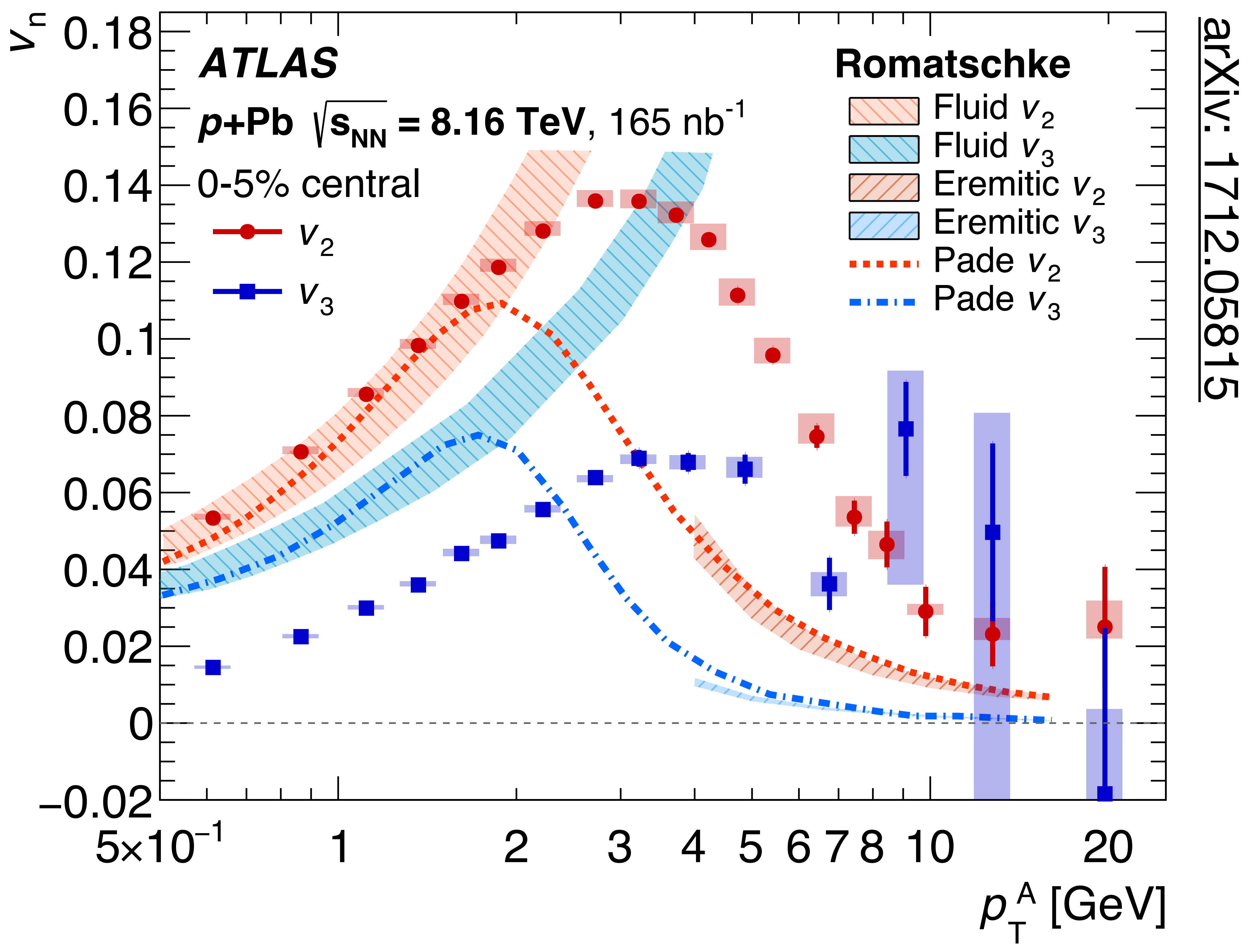


High p_T



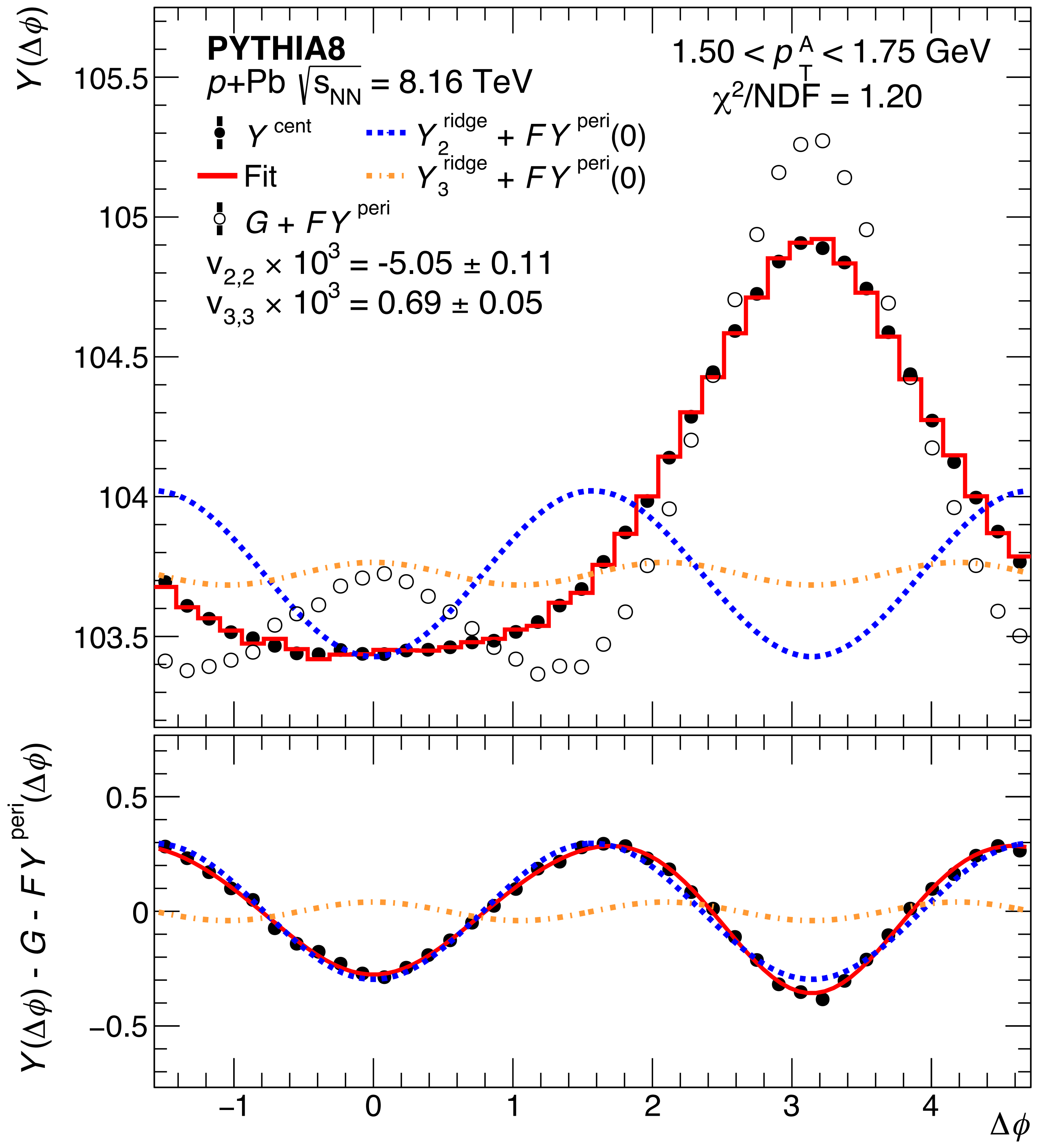
- Again, *low* and *high* p_T roughly independent of centrality and event type
- Centrality changes pair fractions most in *mid* p_T region

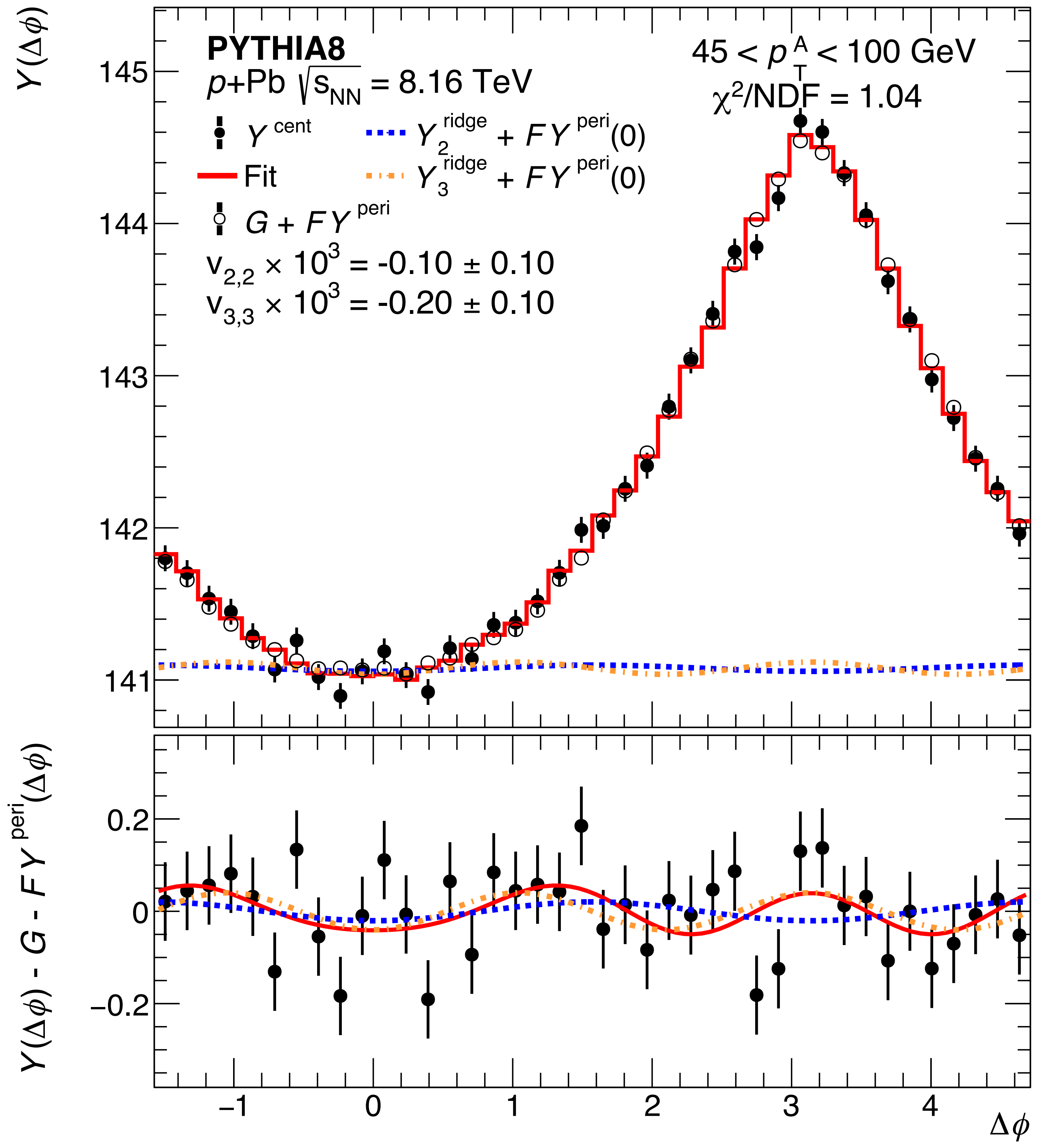
Eremitic calculation comparison

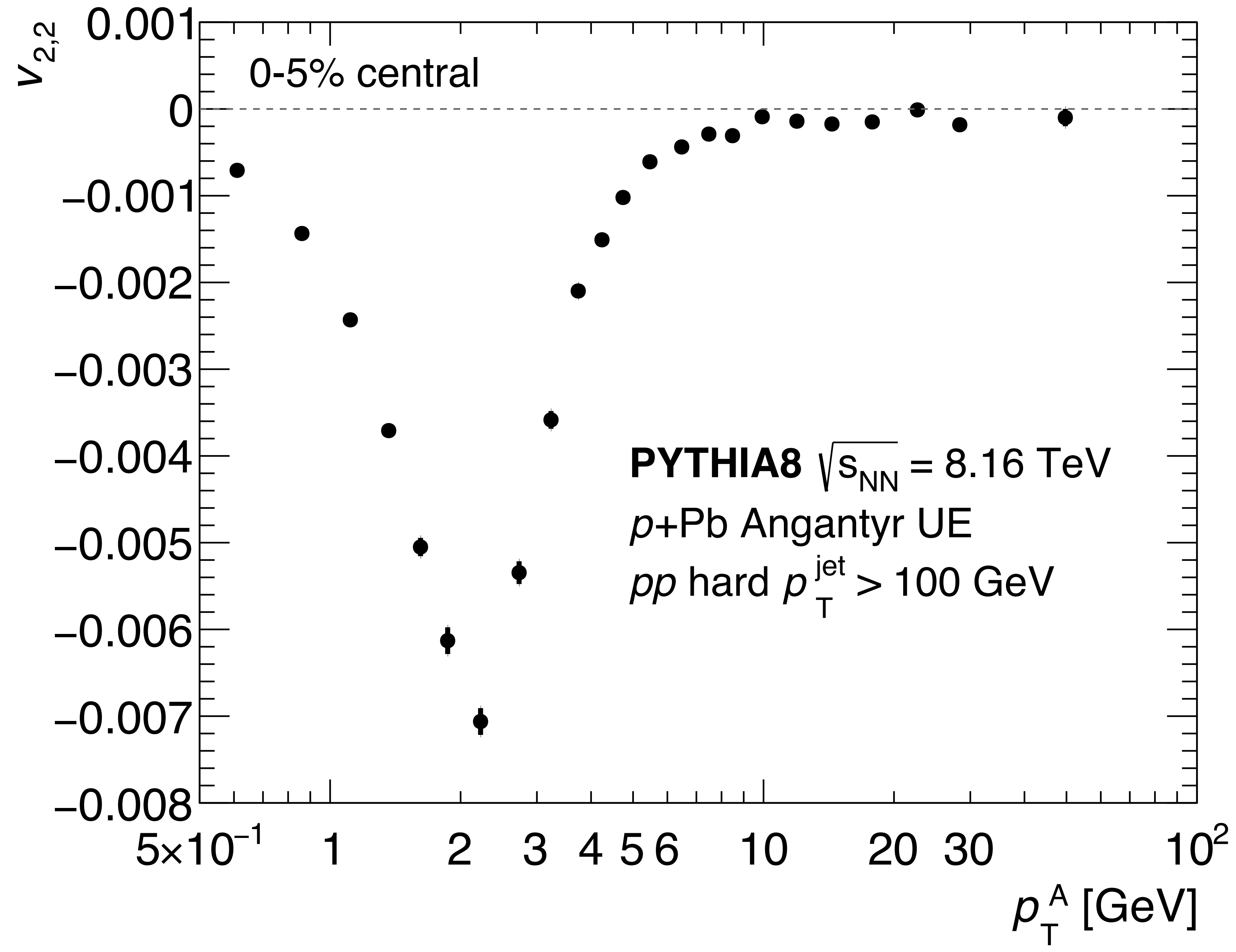


- Ideal hydro limit at low p_T (short mean free path) and eremitic limit at high p_T (large mean free path)

Pythia8 correlations







- Run Pythia8 with HardQCD:all=on and PartonLevel:MPI=off
  - Select events with truth jet p_T > 100 GeV
- Embed Pythia jet events into MB *p*+Pb using Angantyr model

- Pythia jet events have long range nearside ridge from implementation of ISR
  - Correlation washed out by UE and thus gets smaller in more central events
- Opposite behavior as what is seen in data