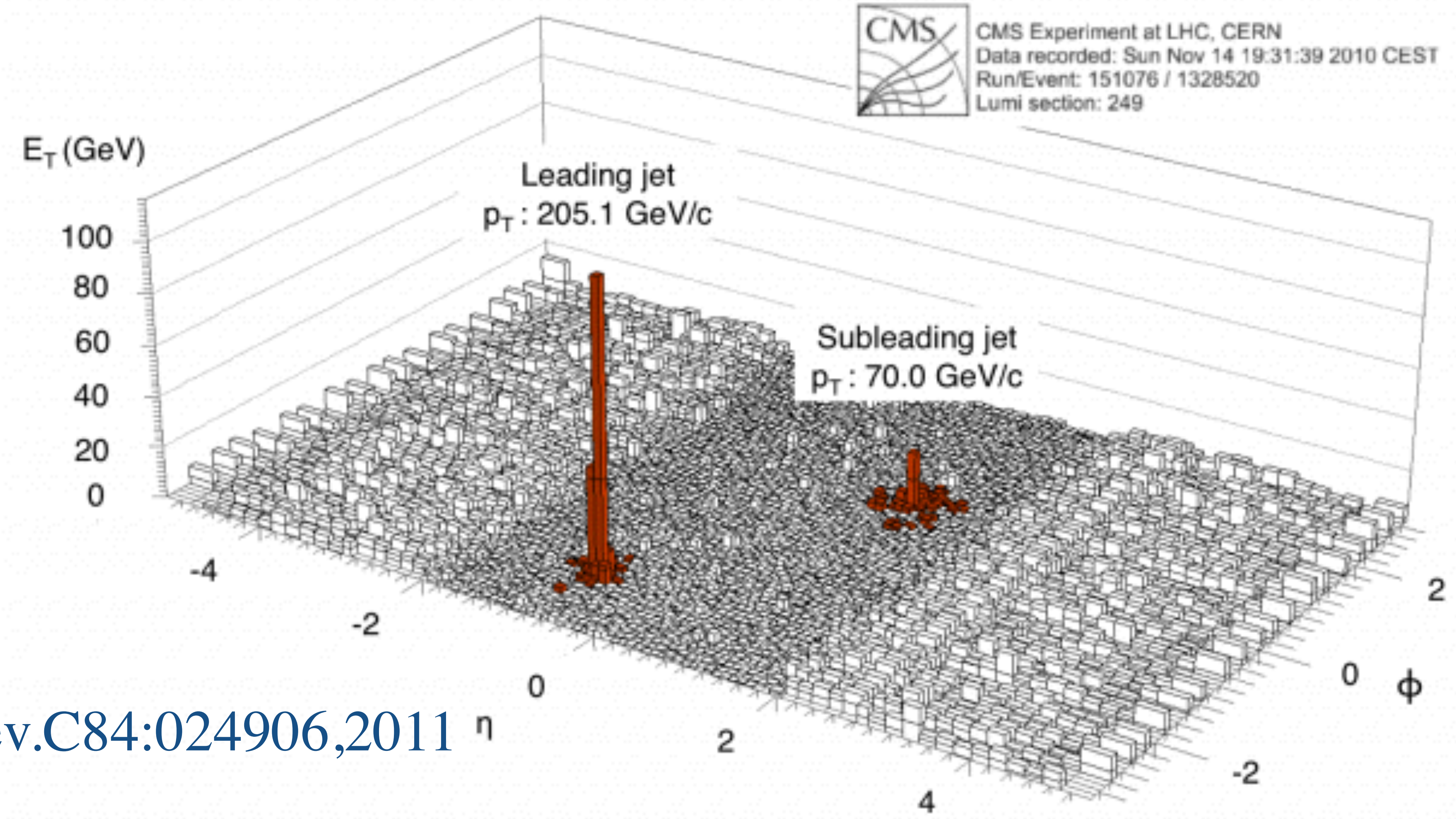

Phys.Rev.C84:024906,2011

The Fate of Missing p_T in PbPb Collisions

Lisbon Jet Workshop, 2014

On Behalf of CMS Collaboration

Overview

- Motivation
- Event Selection
- Jet Reconstruction
- Tracking Corrections
- Observables/Results
  - Hemisphere Multiplicity Difference
  - Missing p_T v. A_J
  - Missing p_T v. ΔR
- Summary and Plans

Motivation (I)

- Dijet imbalance observed in PbPb collisions as part of first LHC heavy ions run
  - Enhanced relative to pp, marked centrality dependance
- Can ask:
  - Can we recover missing momentum by looking at ΔR outside of the jet cone?
  - What is the momentum characterizing particles in leading and subleading jet hemispheres? Relative to pp?

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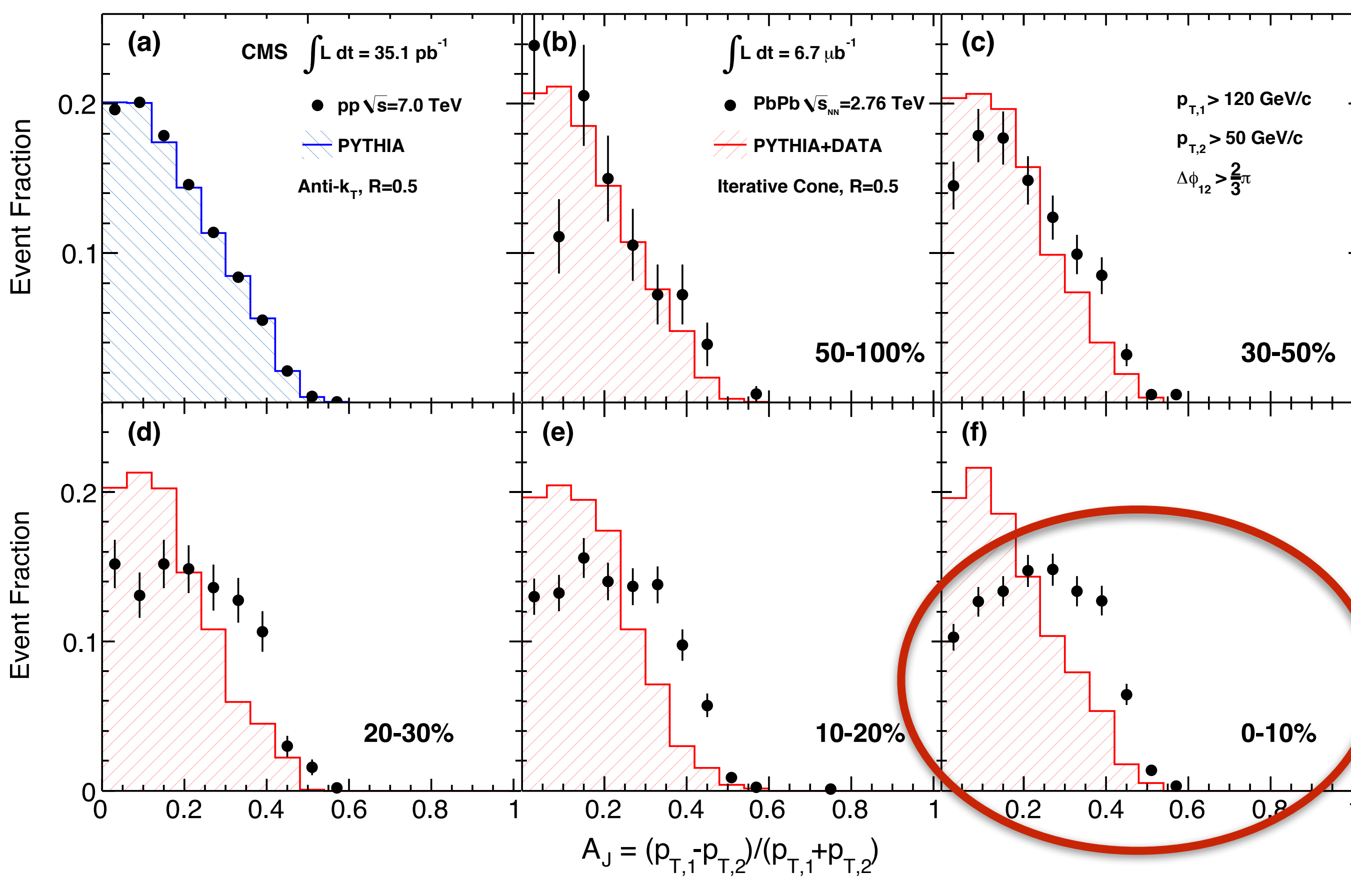

Motivation (II)

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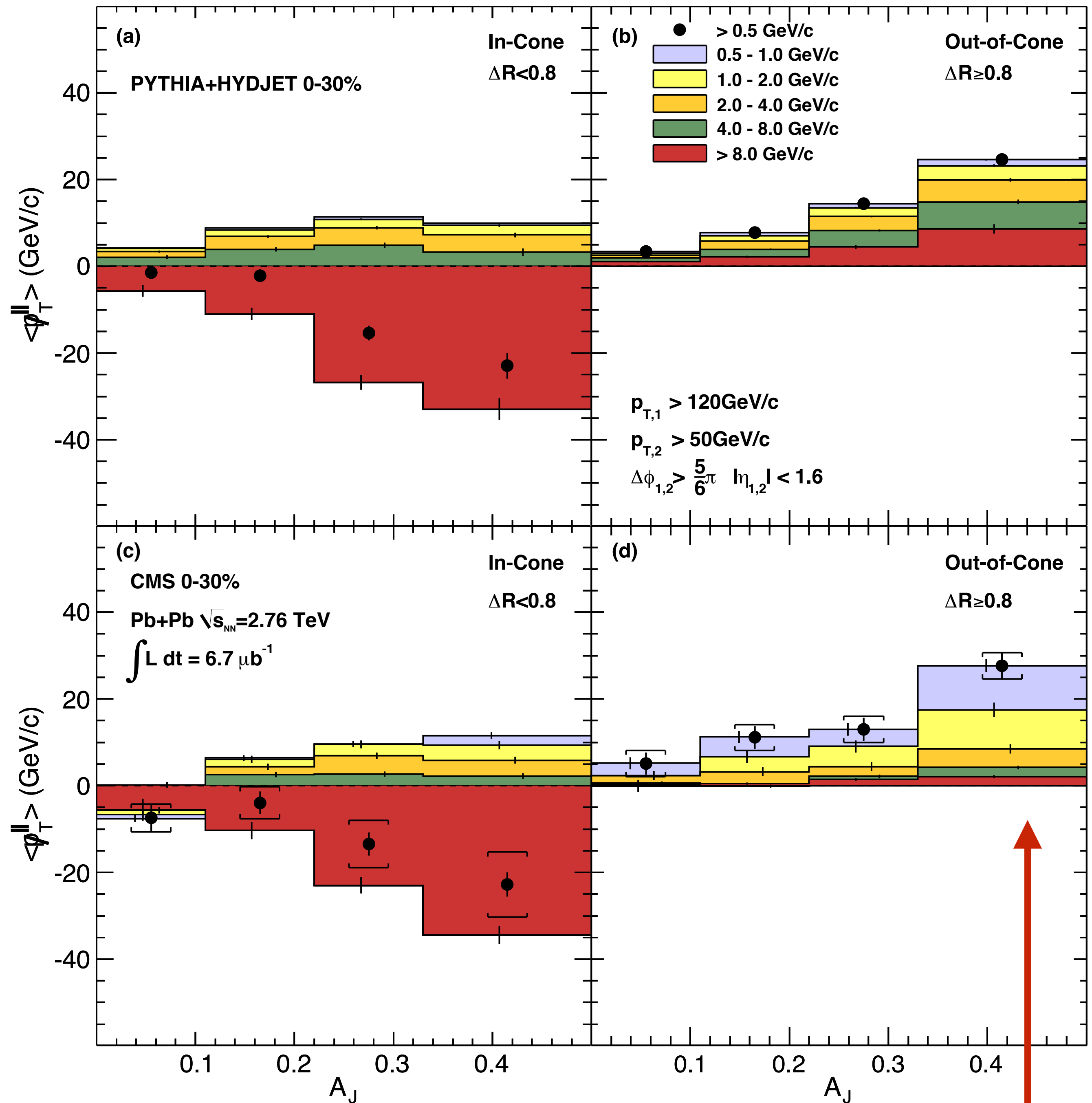
- Momentum not fully recovered out to ΔR = 0.8
- Out-of-cone momentum preferentially towards subleading hemisphere
- Can still ask (and to be presented):
  - What is the distribution as a function of ΔR?
  - How does this compare to pp?

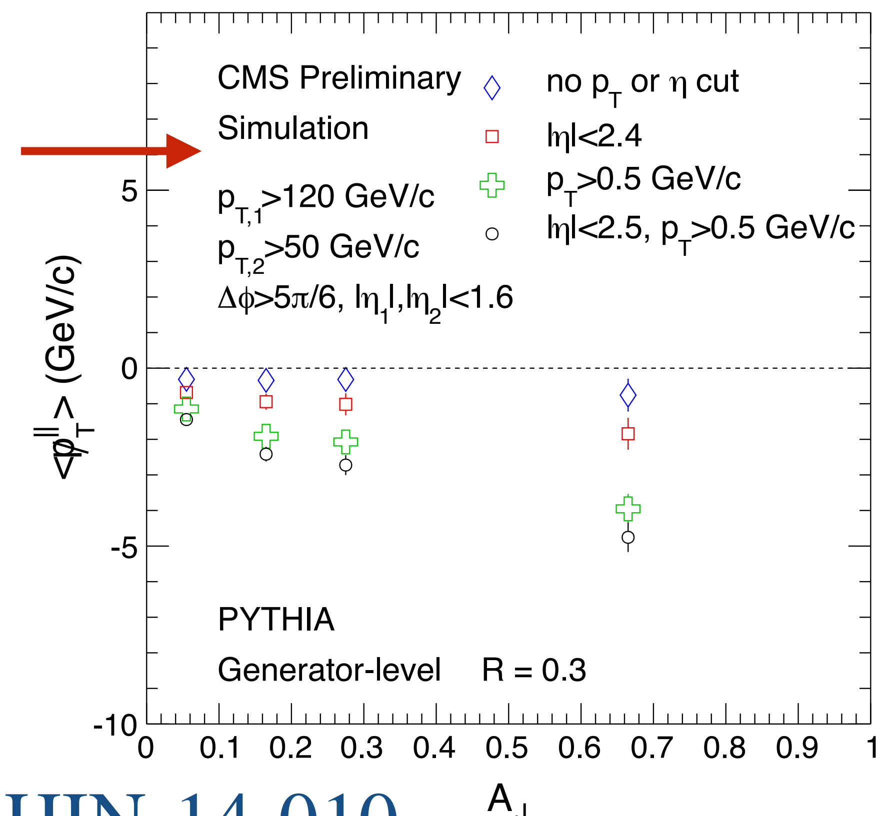


Subleading recovered out-of-cone

Samples and Selection

- PbPb data at 2.76 TeV with integrated luminosity of 150 μb^{-1}
  - Tracks reconstructed over 3 iterations
  - Calo jets, reconstructed with anti-k_T R = 0.3, Voronoi subtraction
- pp data at 2.76 TeV with integrated luminosity of 5.3 pb^{-1}
  - Tracks reconstructed over 7 iterations
  - Calo jets, reconstructed with anti-k_T R = 0.3
- High p_T trigger in PbPb and pp, require jet with $p_T > 80$ Gev/c
- Dijet Selection
  - $p_{T,1} > 120$ GeV/c
  - $p_{T,2} > 50$ GeV/c
  - $|\eta_1|,|\eta_2| < 1.6$ (0.5)
  - $\Delta\phi > 5\pi/6$
- Track Selection
  - $p_T > 0.5$ GeV/c
  - $|\eta| < 2.4$

Impact of cuts →



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Jet Reconstruction w/ Voronoi Algorithm

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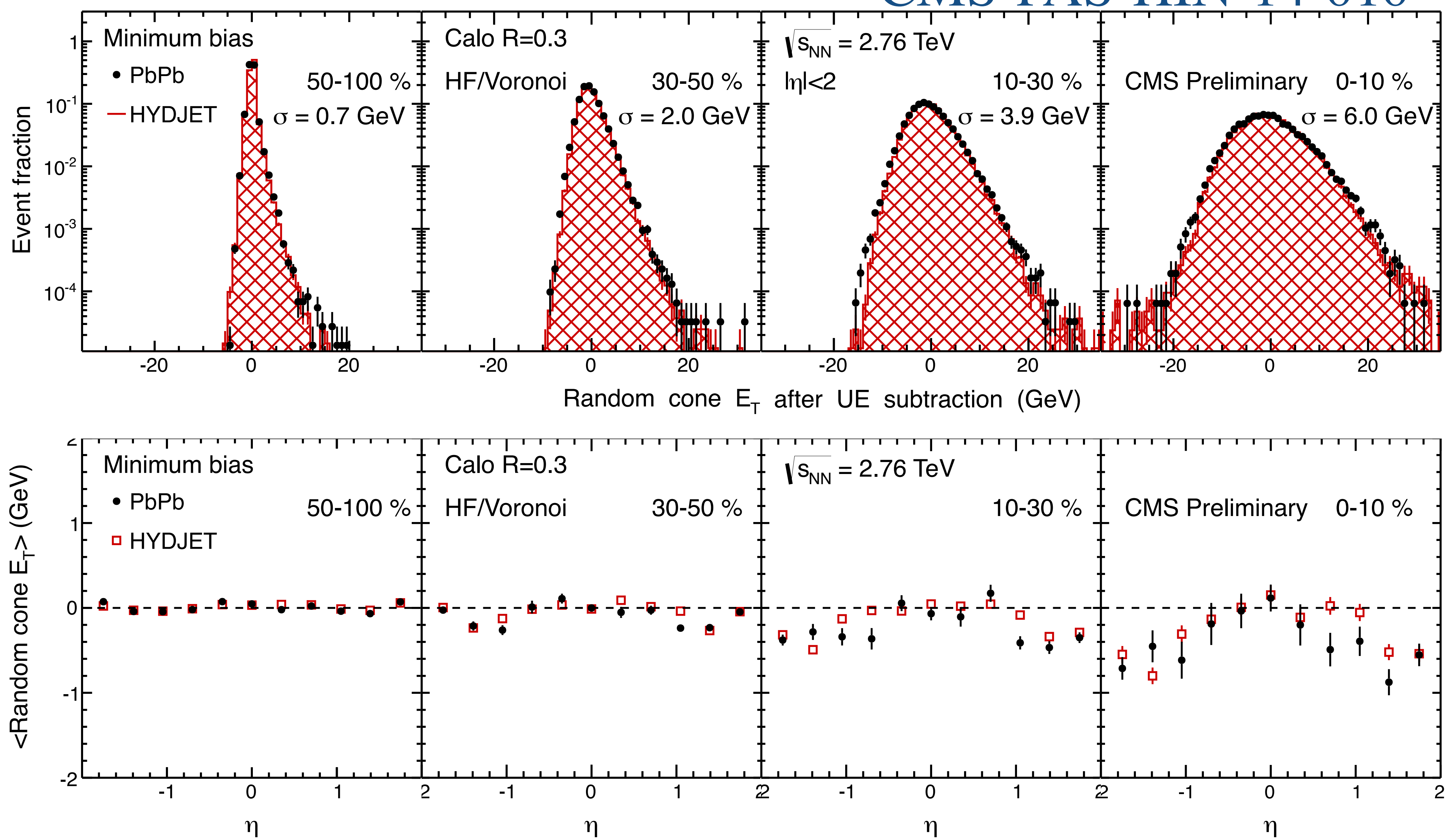

- Performed random cone study in minimum bias data
- Deviations as a function of η are less than 1 GeV through all bins

Tracking Corrections

- Correct for efficiency and fake rate in both pp and PbPb
  - Additional secondary rate correction applied to pp
- Correction parameters are:
  - Centrality
  - p_T
  - ϕ
  - η
  - Minimum ΔR_{jet}
- Good agreement with truth after correction in all parameters
  - Left: example in p_T

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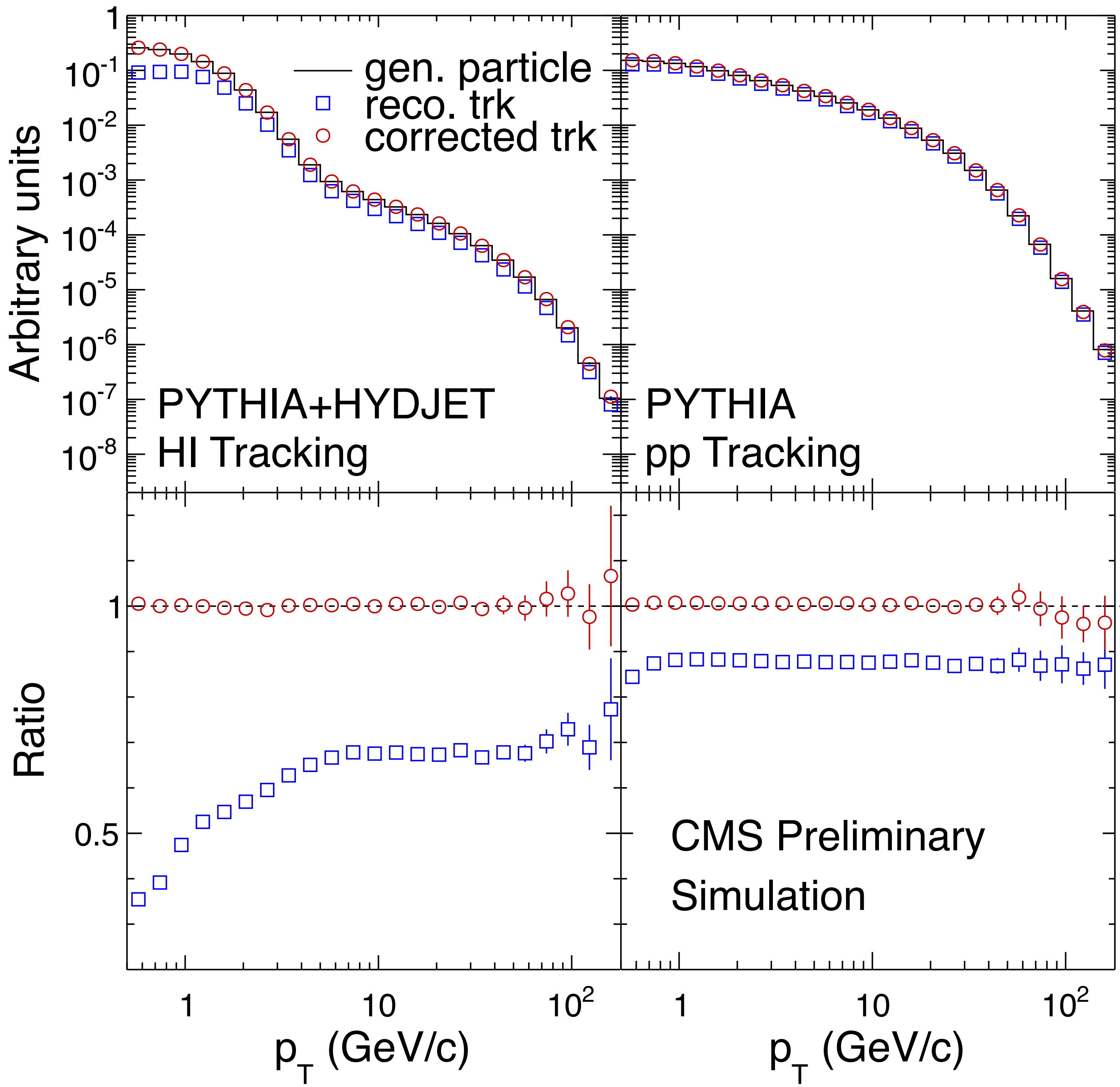
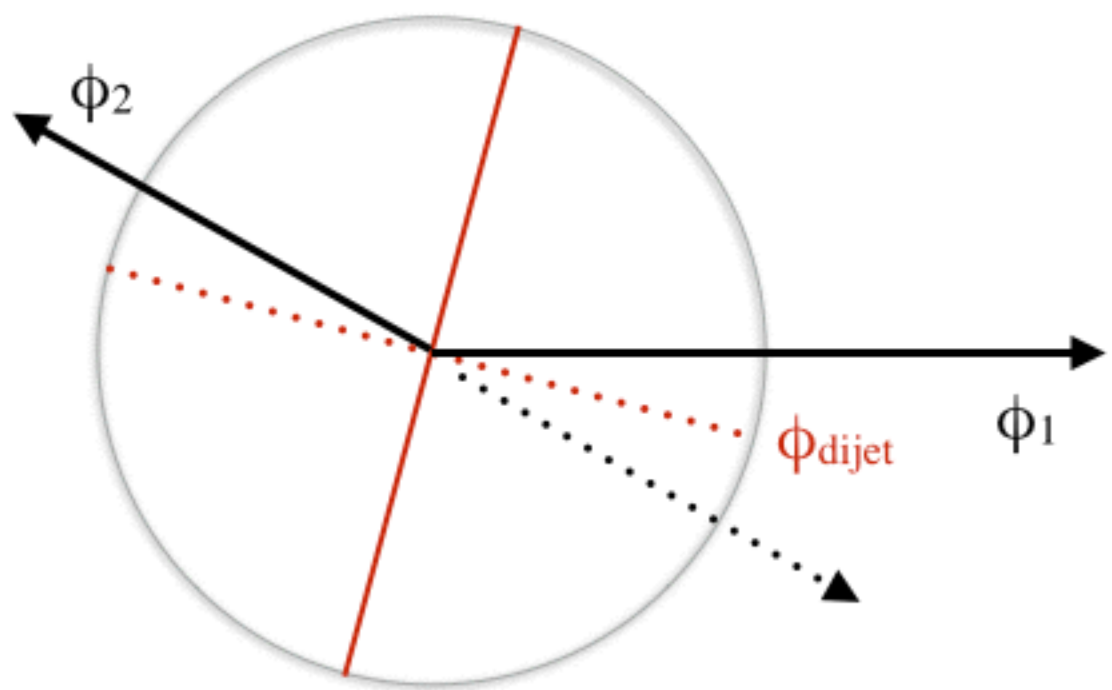
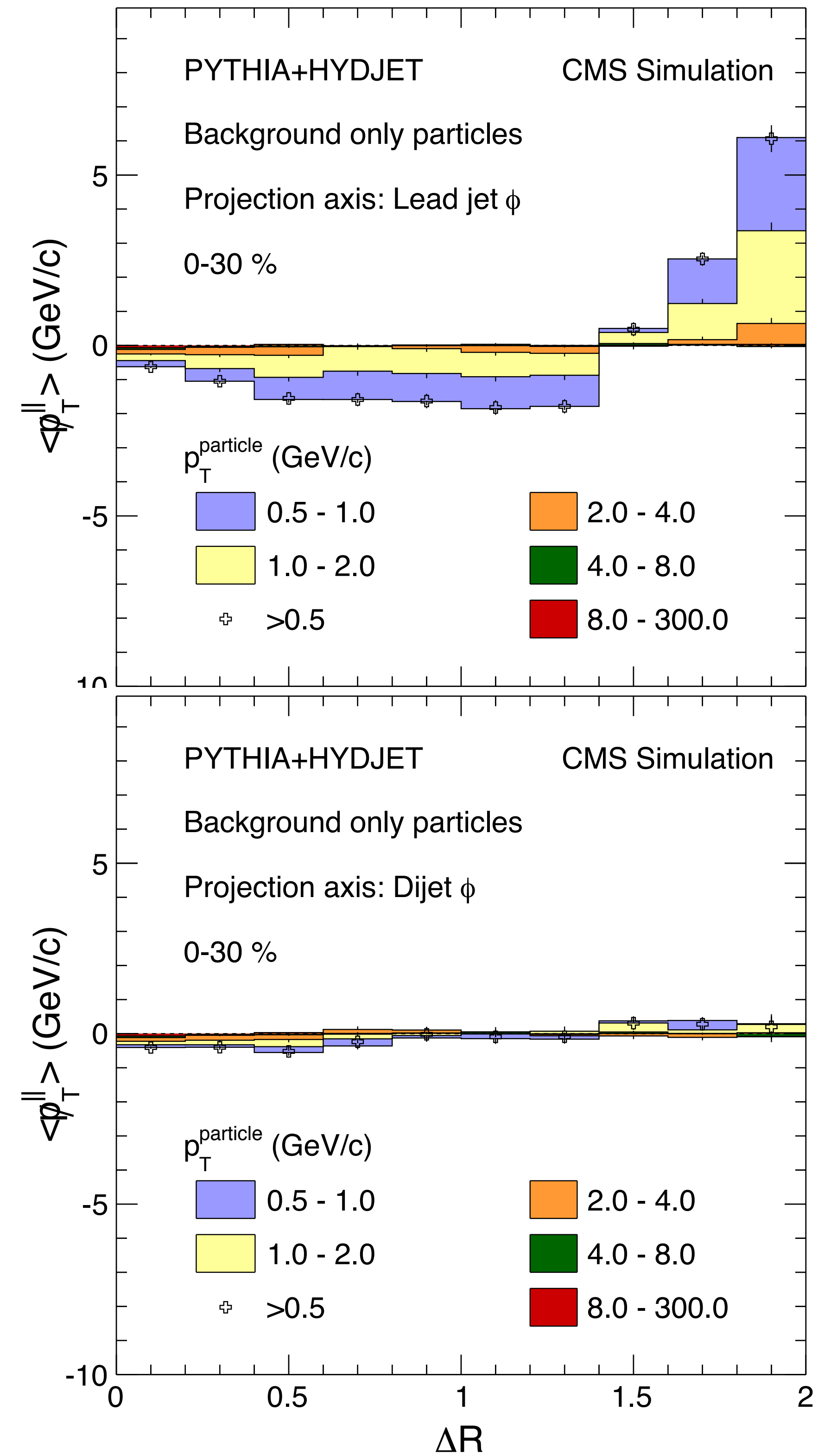


Observables: Dijet Axis

Define new axis for projection of track momentum: **Dijet Axis**

- $\phi_{dijet} = (\phi_1 + (\pi - \phi_2))/2$
- CMS-HIN-10-004 used leading jet axis
  - This choice results in non-cancellation of background in ΔR
  - Dijet Axis symmetric w.r.t. dijet system, background cancels





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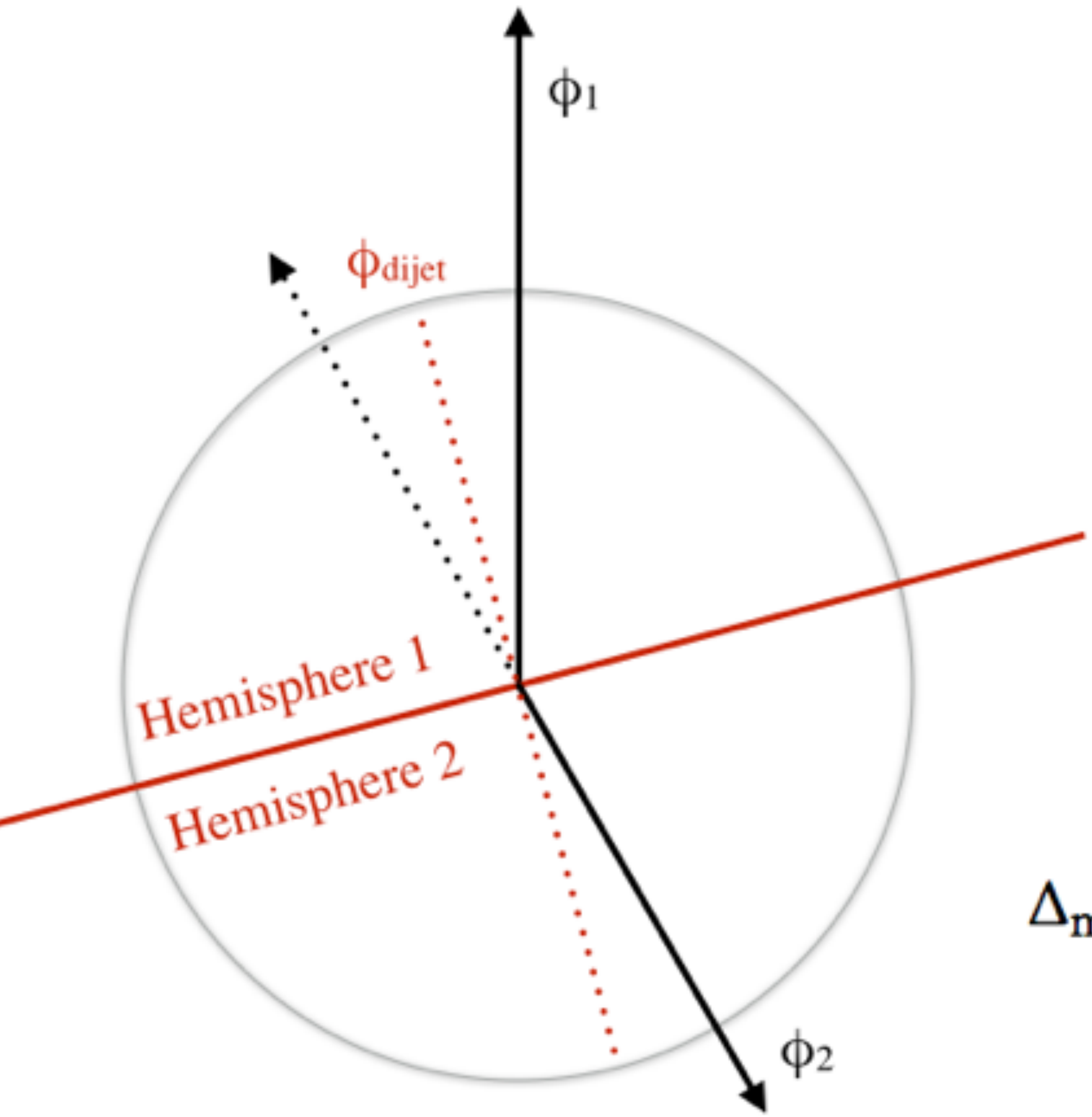
Observables: Multiplicity Difference



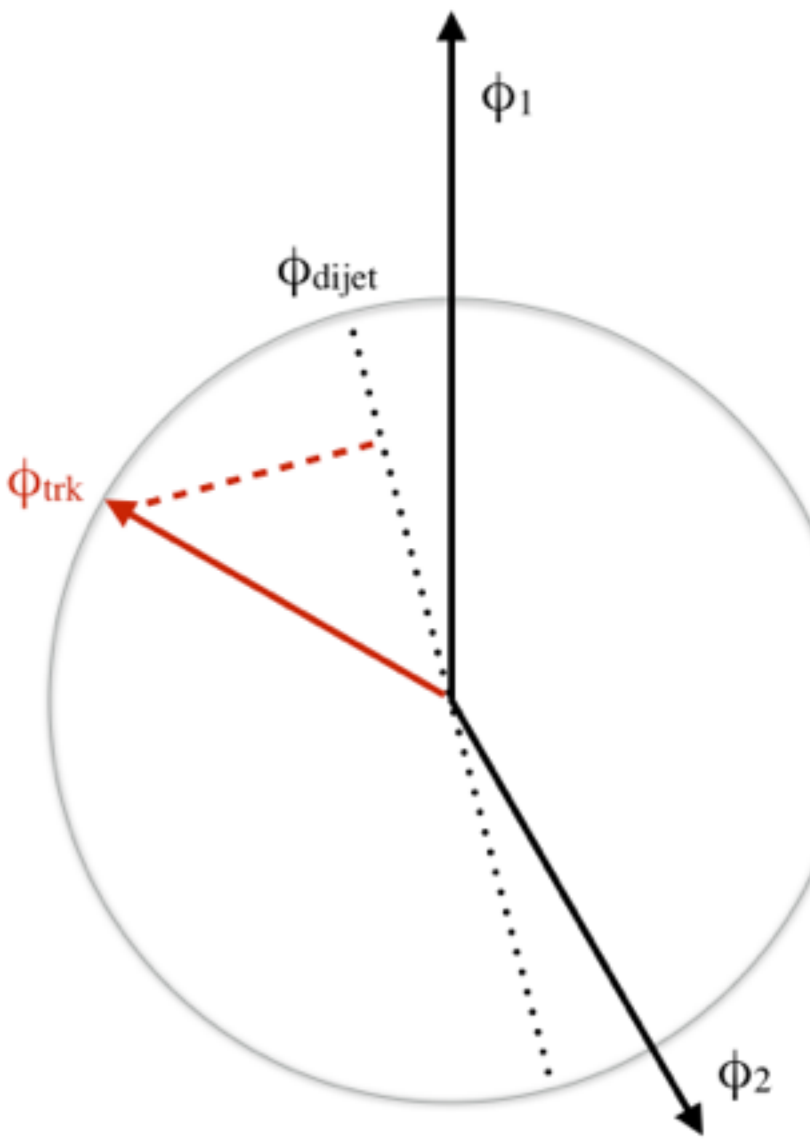
- CMS-HIN-10-004, observed tracks in subleading hemisphere of lower p_T than leading
- Can re-examine observation with a hemisphere multiplicity difference measurement

Define:

$$\Delta_{\text{mult}} = N_{\text{Trk}}^{\text{Corrected}}|_{\Delta\phi_{\text{Trk,average}} > \pi/2} - N_{\text{Trk}}^{\text{Corrected}}|_{\Delta\phi_{\text{Trk,average}} < \pi/2}$$

Hemisphere 2 — Hemisphere 1

Observables: Missing p_T v. A_J



- Return to missing p_T measurement
  - More differential in centrality
  - Examine relative to pp
- Define sum of track momentum projected onto dijet axis:

$$\not{p}_T^{||} = \sum_i -p_T^i \cos(\phi_i - \phi_{Dijet})$$

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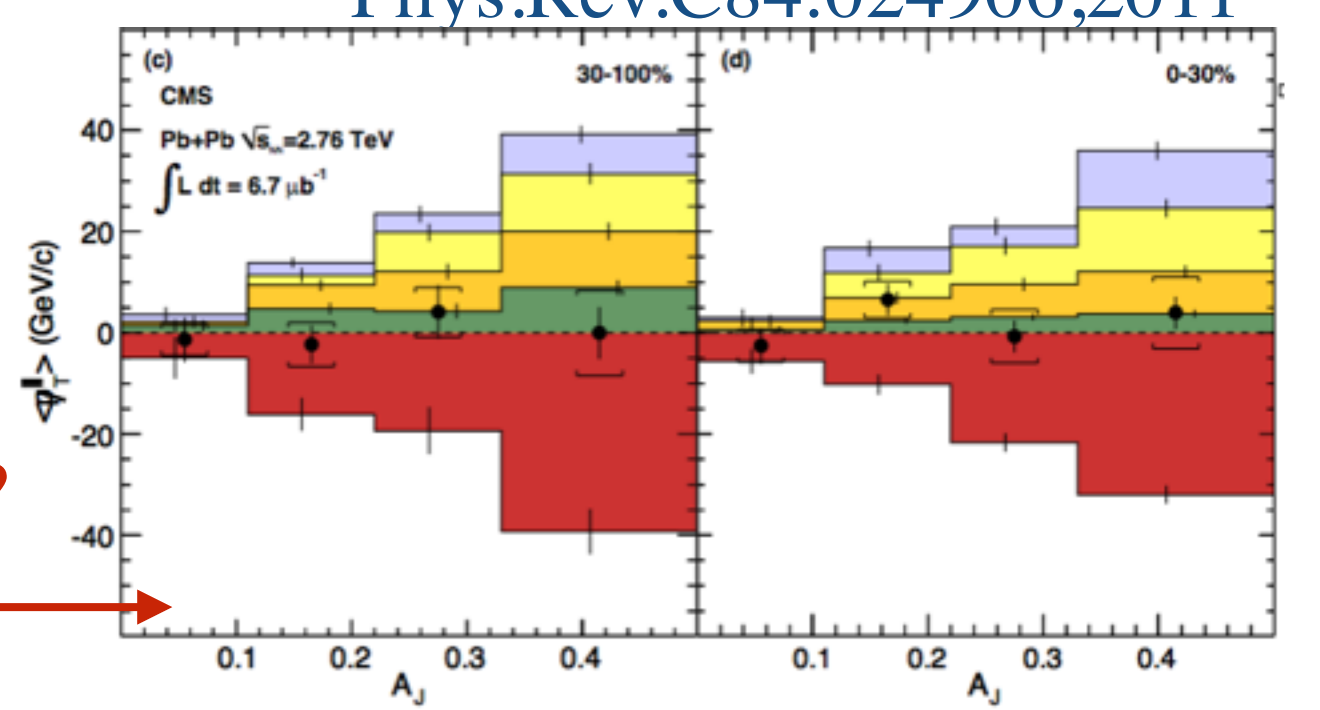
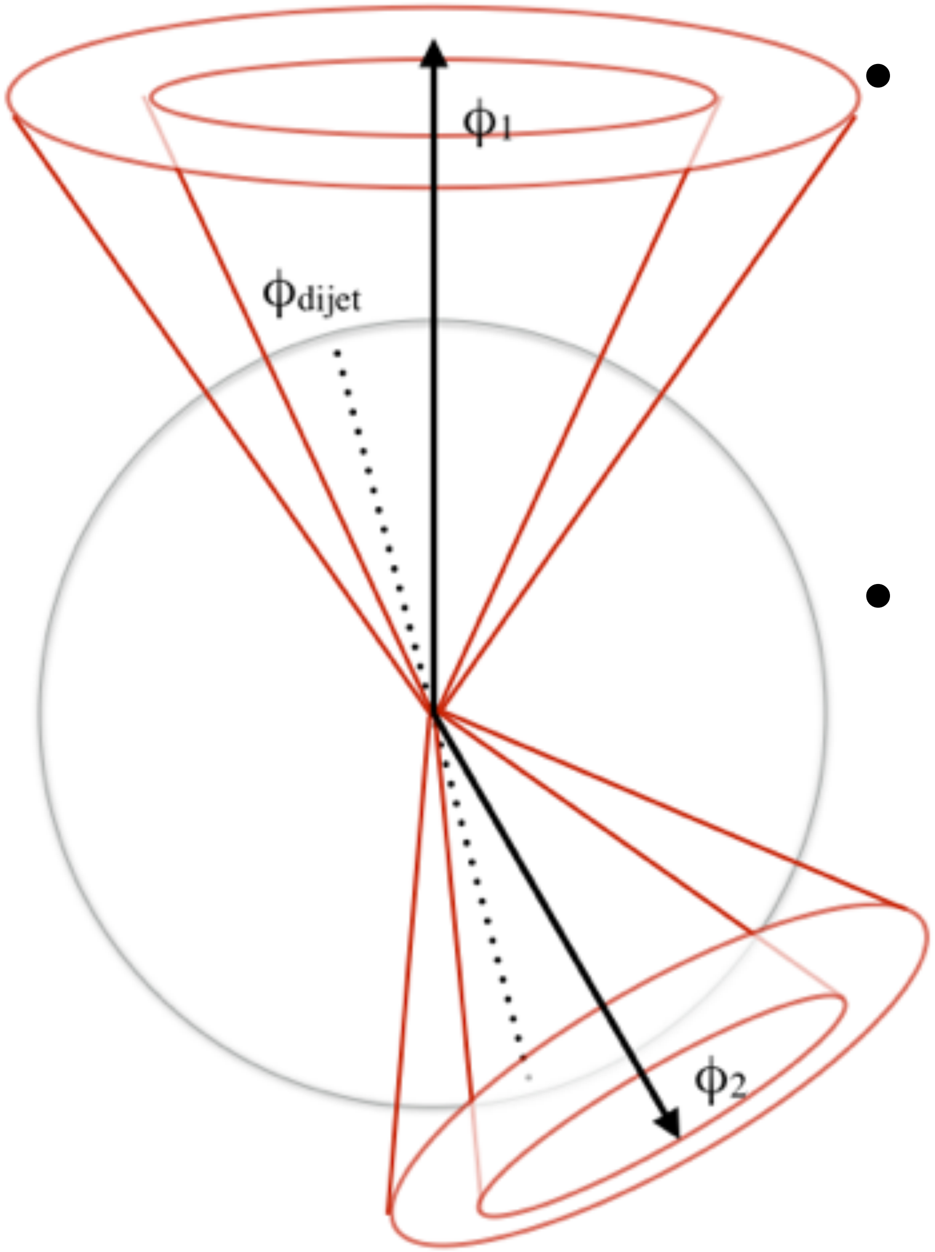


What do we expect after subtracting pp?

Observables: Missing p_T v. ΔR



- What is the missing p_T distribution through large ΔR?
  - Do we recover full imbalance?
  - How does this compare to pp?
- Define binning:

$$\Delta R = \sqrt{\Delta\phi^2_{\mathrm{Trk,jet}} + \Delta\eta^2_{\mathrm{Trk,jet}}}$$

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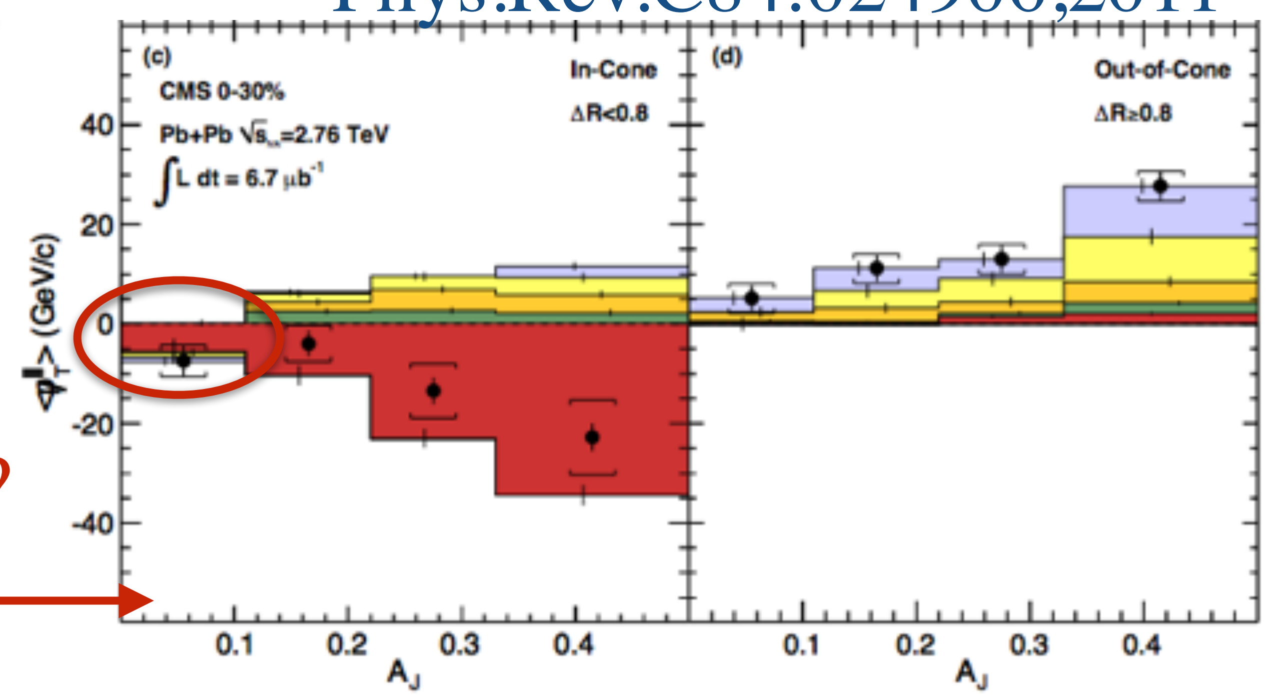

What is the full distribution this samples?

Results: Multiplicity (I)

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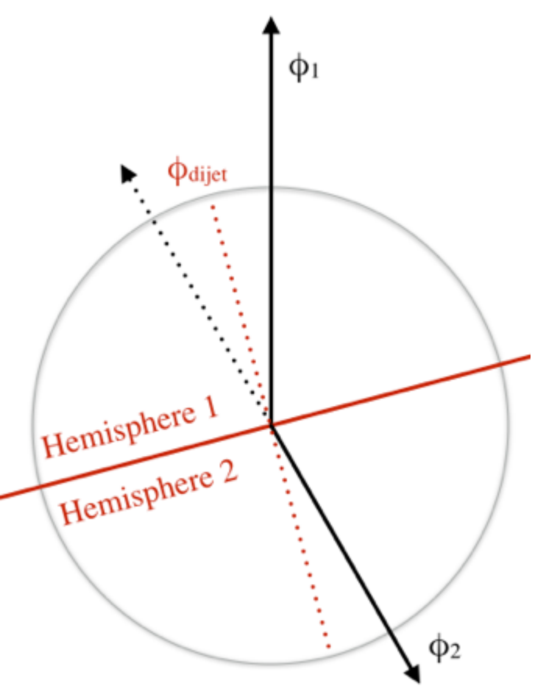

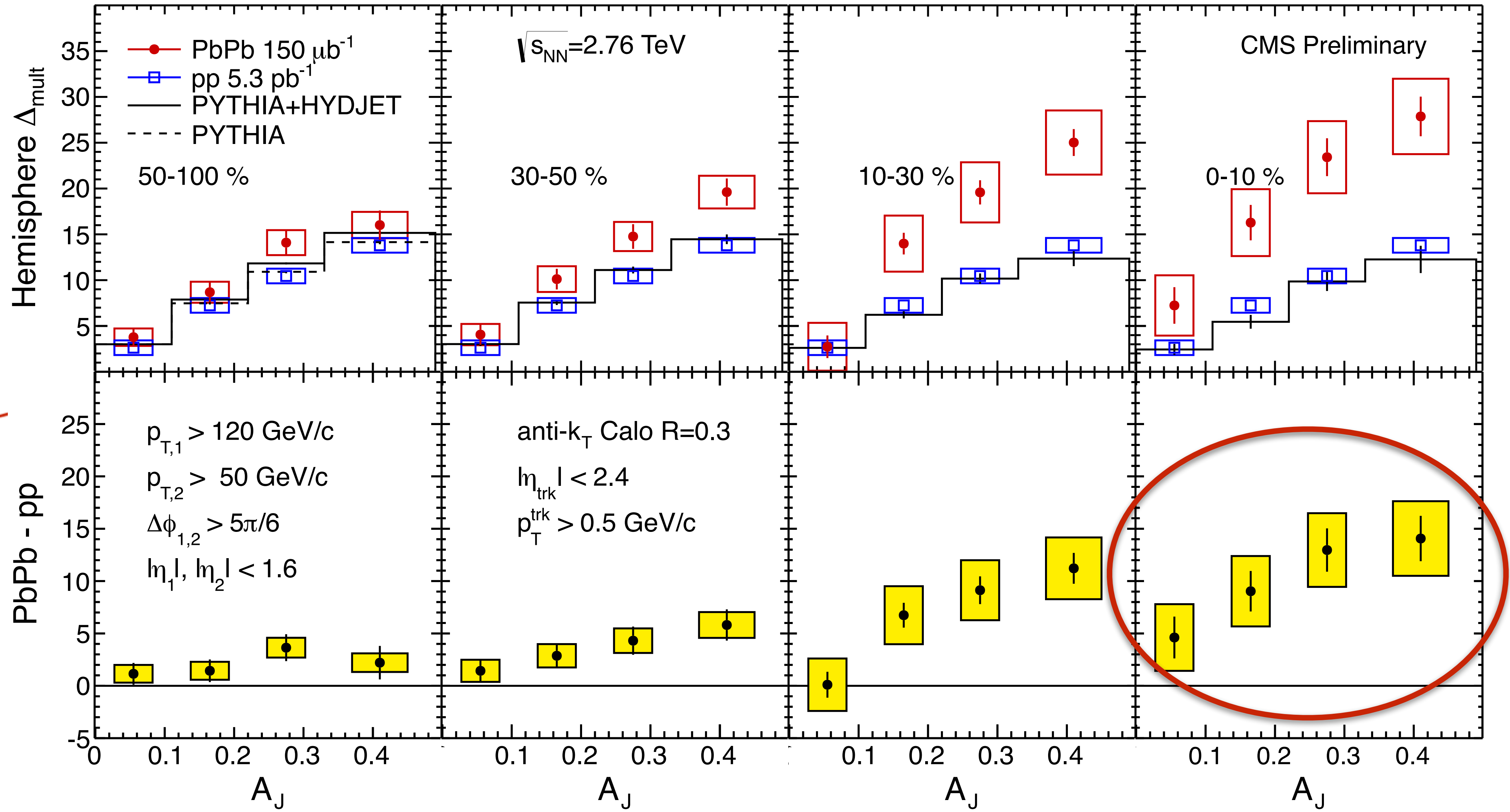

- As function of $A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$, increasing multiplicity towards subleading hemisphere
  - excess approaches 15 particles in most central PbPb relative to pp

Results: Multiplicity (II)

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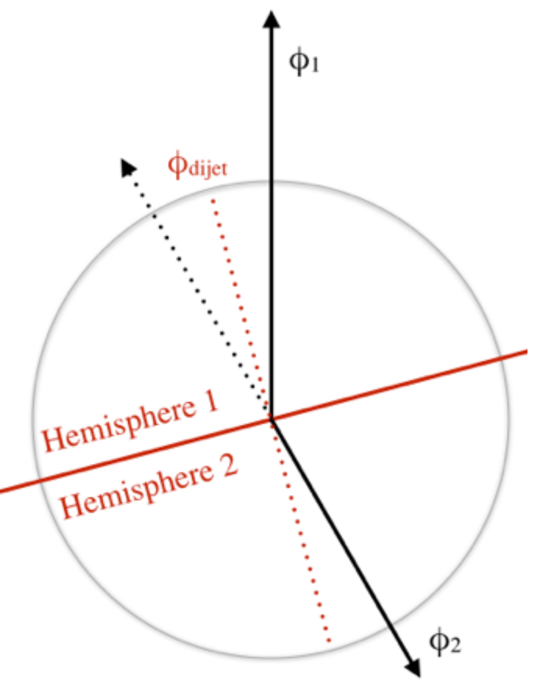

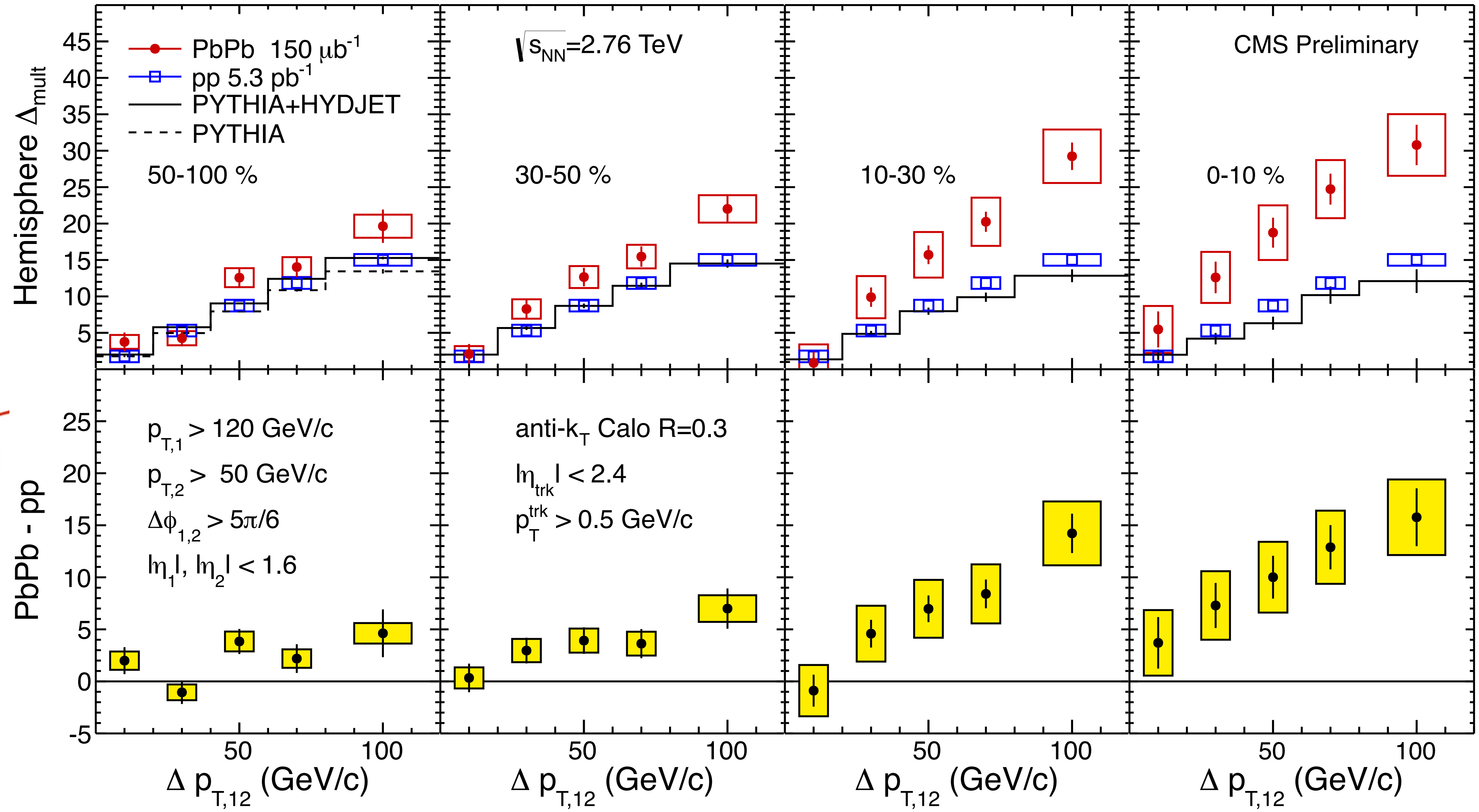

- As function of $\Delta p_{T,12} = (p_{T,1} - p_{T,2})$, similar picture
  - excess approaches same rough numbers in PbPb central collisions towards subleading hemisphere

Results: Missing p_T v. A_J

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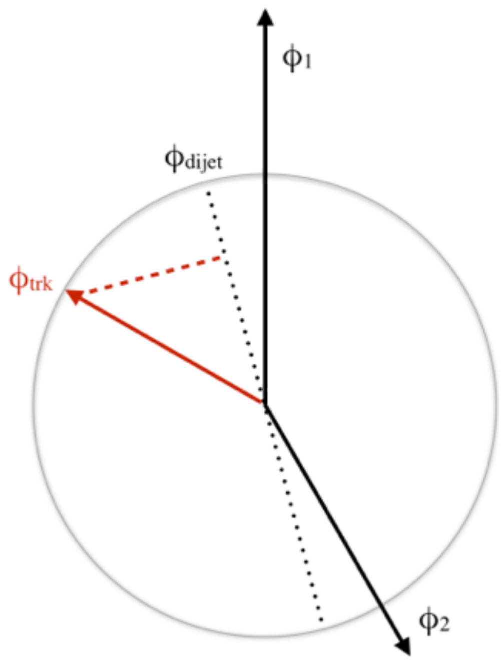

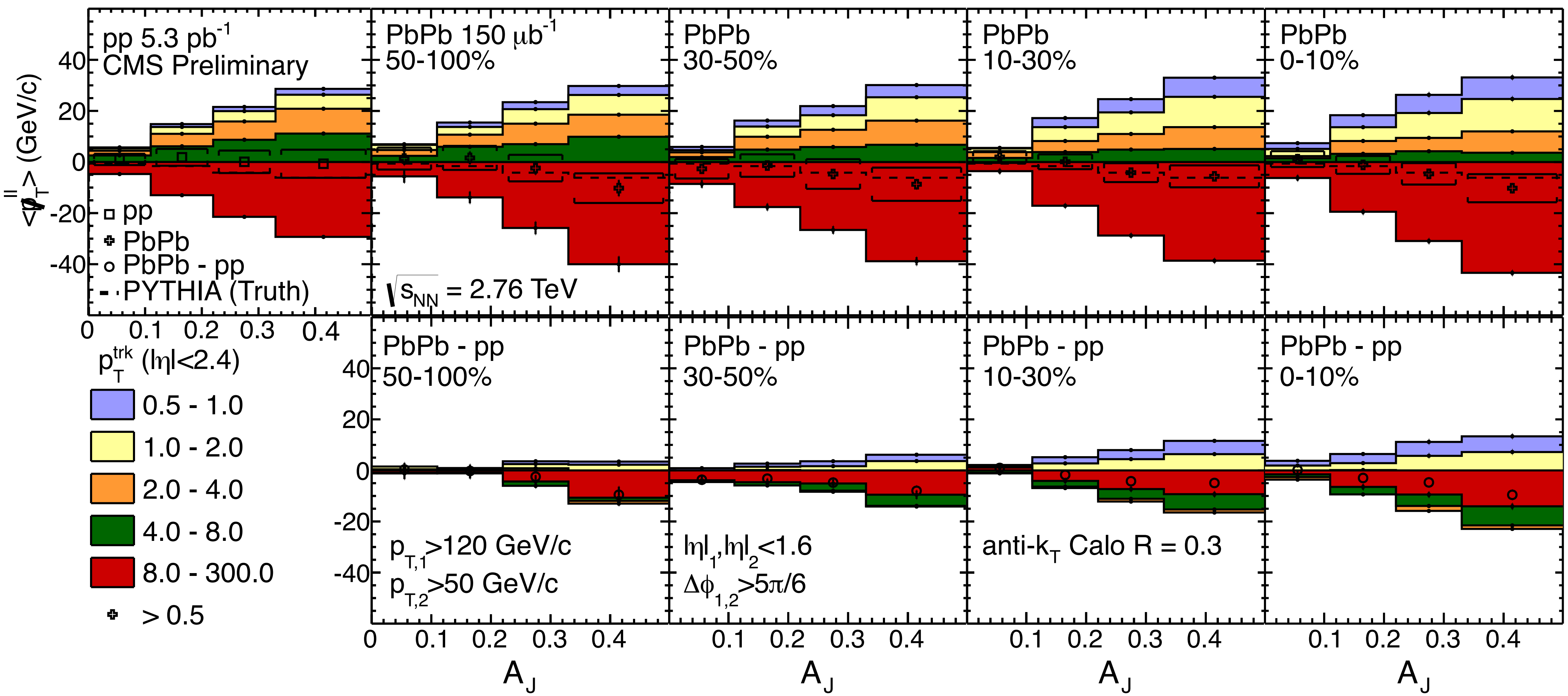

- Compared to pp, see a centrality dependent excess of 0.5 - 2.0 p_T particles towards subleading hemisphere
  - Replace 2.0 - 8.0 p_T particles in pp

Results: Missing p_T v. ΔR (I)

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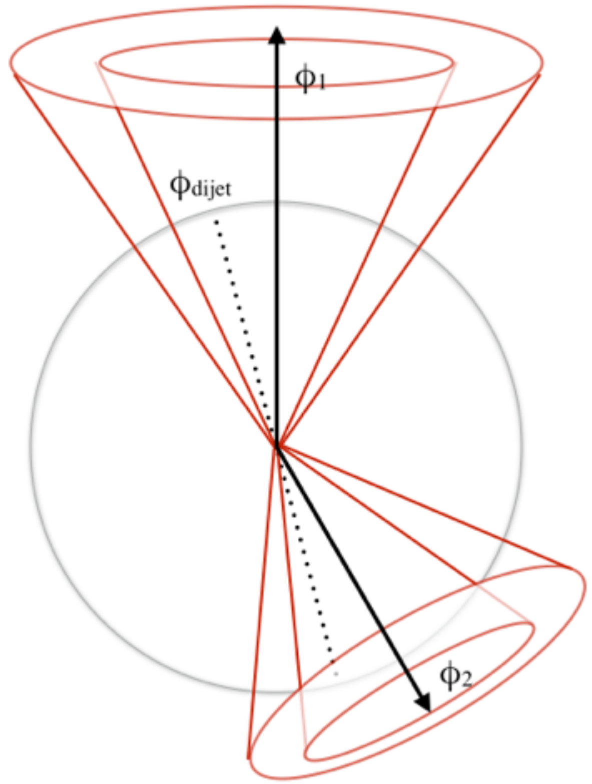
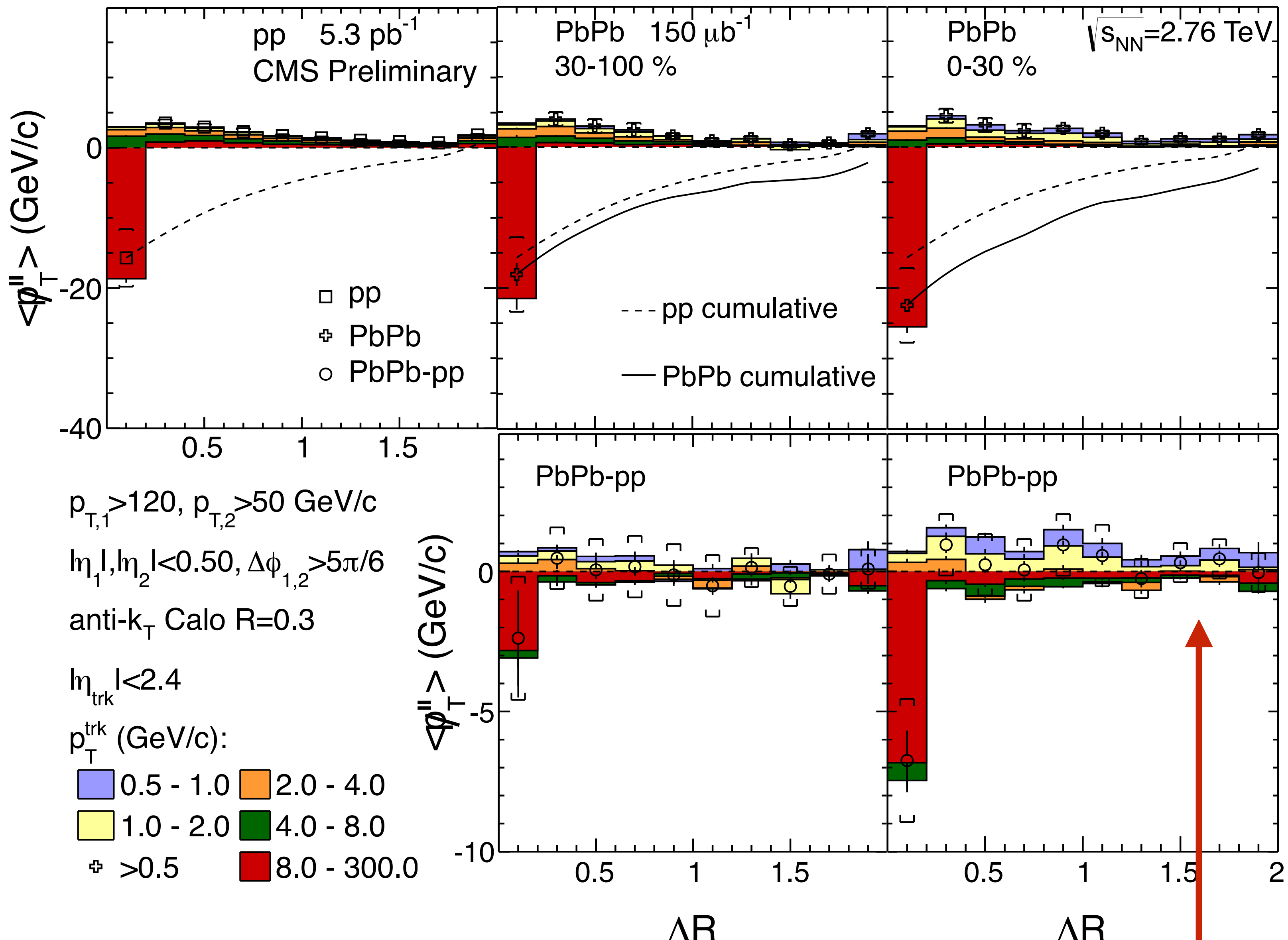
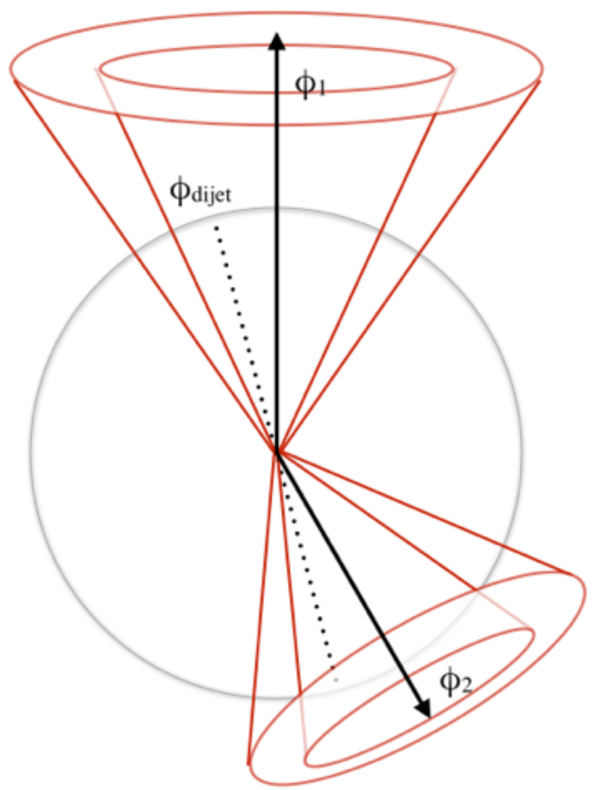




Excess through large ΔR

- Inclusive A_J selection
- See a centrality dependent enhancement of low p_T particles in PbPb relative to pp

Results: Missing p_T v. ΔR (II)



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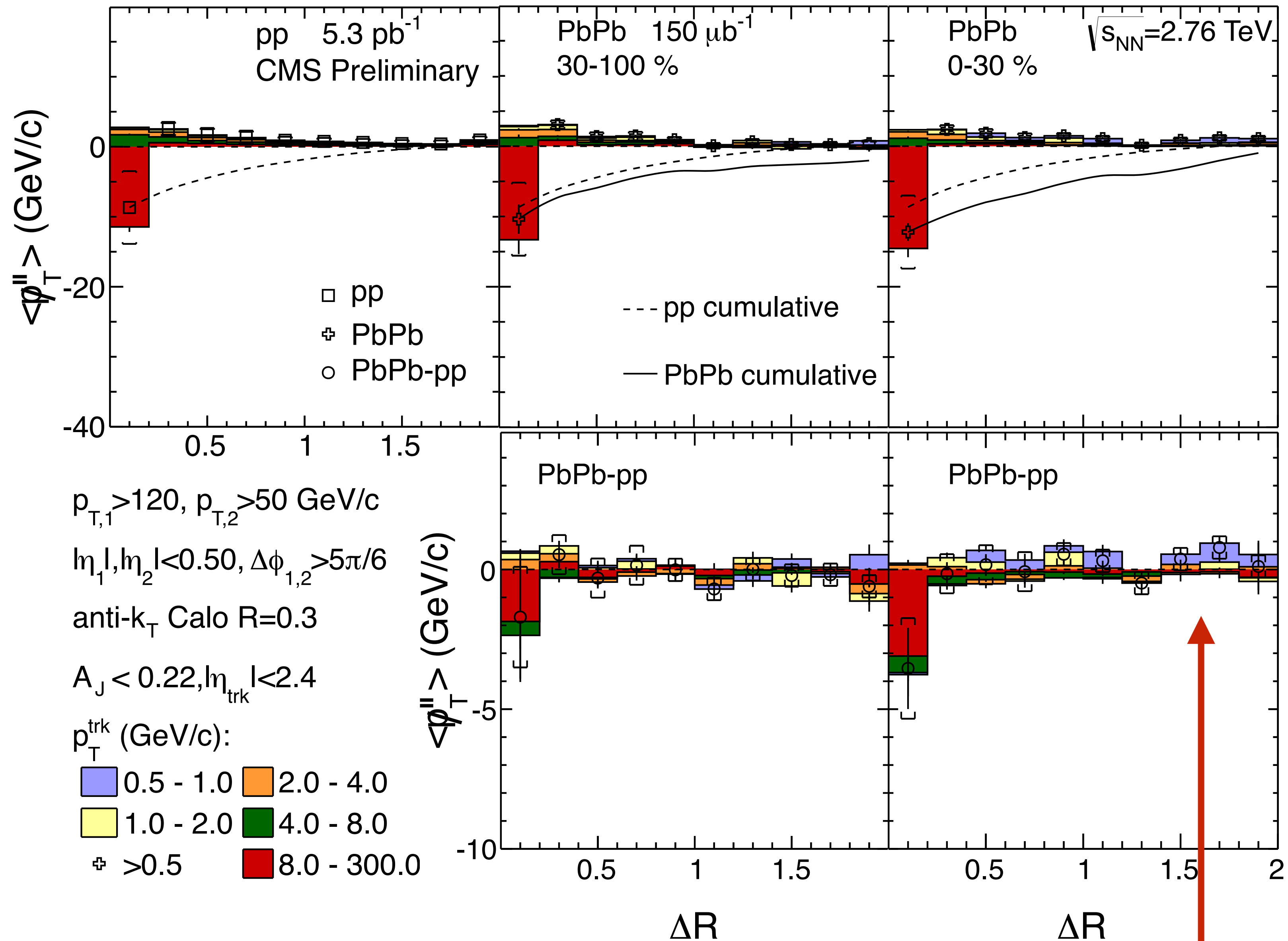

0.5 - 1.0 p_T excess through large ΔR

- $A_J < 0.22$ selection
- Some enhancement of 0.5-1.0 GeV/c particles in PbPb relative to the same selection in pp

Results: Missing p_T v. ΔR (III)

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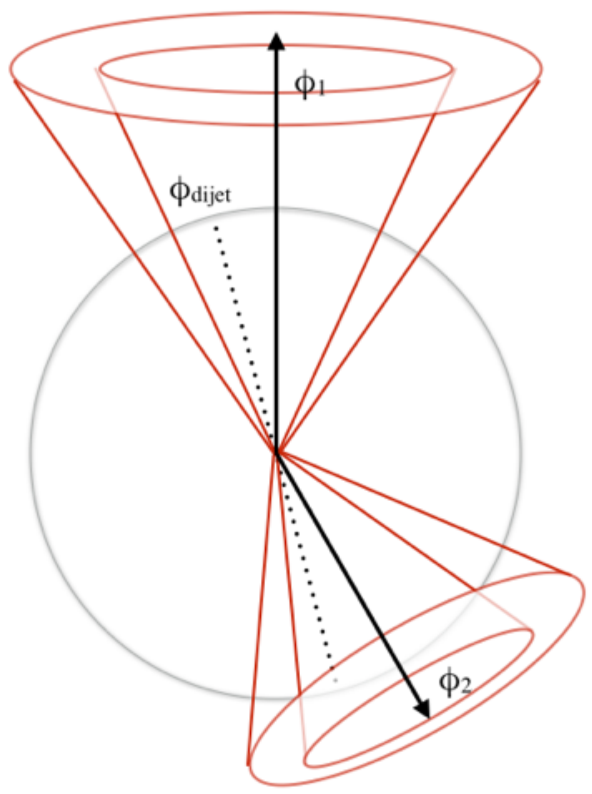

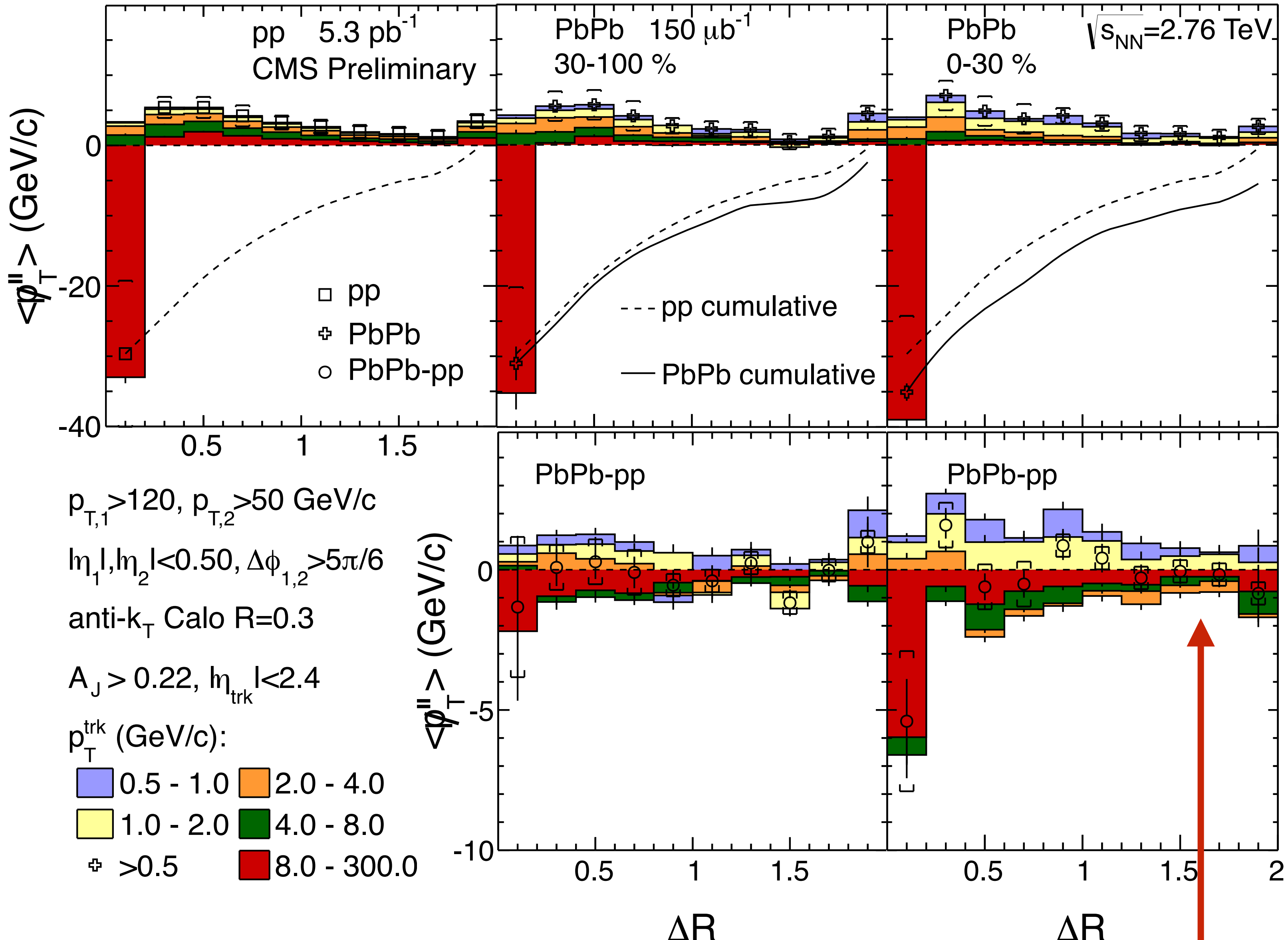

1.0 - 2.0 p_T excess through large ΔR

- $A_J > 0.22$ selection
- See a greater enhancement of low p_T particles in PbPb relative to the same selection in pp, particularly 1.0-2.0 GeV/c

Results: Missing p_T v. ΔR (IV)

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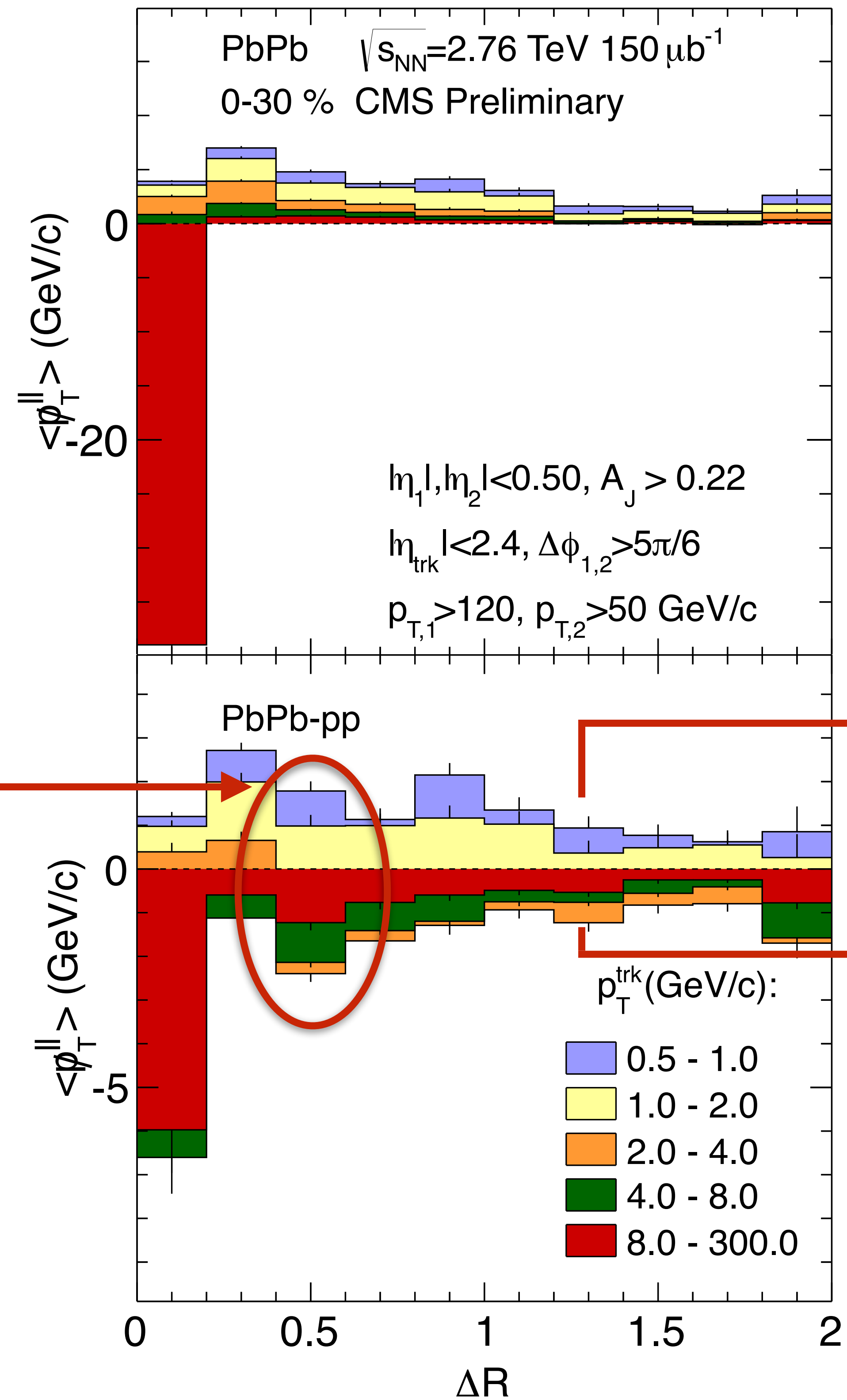

In pp, out-of-cone radiation for $A_J > 0.22$ selection carried by third jets

0.5 - 2.0 GeV/c p_T balances in PbPb

2.0 - 8.0 GeV/c p_T balances in pp

Results: Missing p_T v. ΔR (V)

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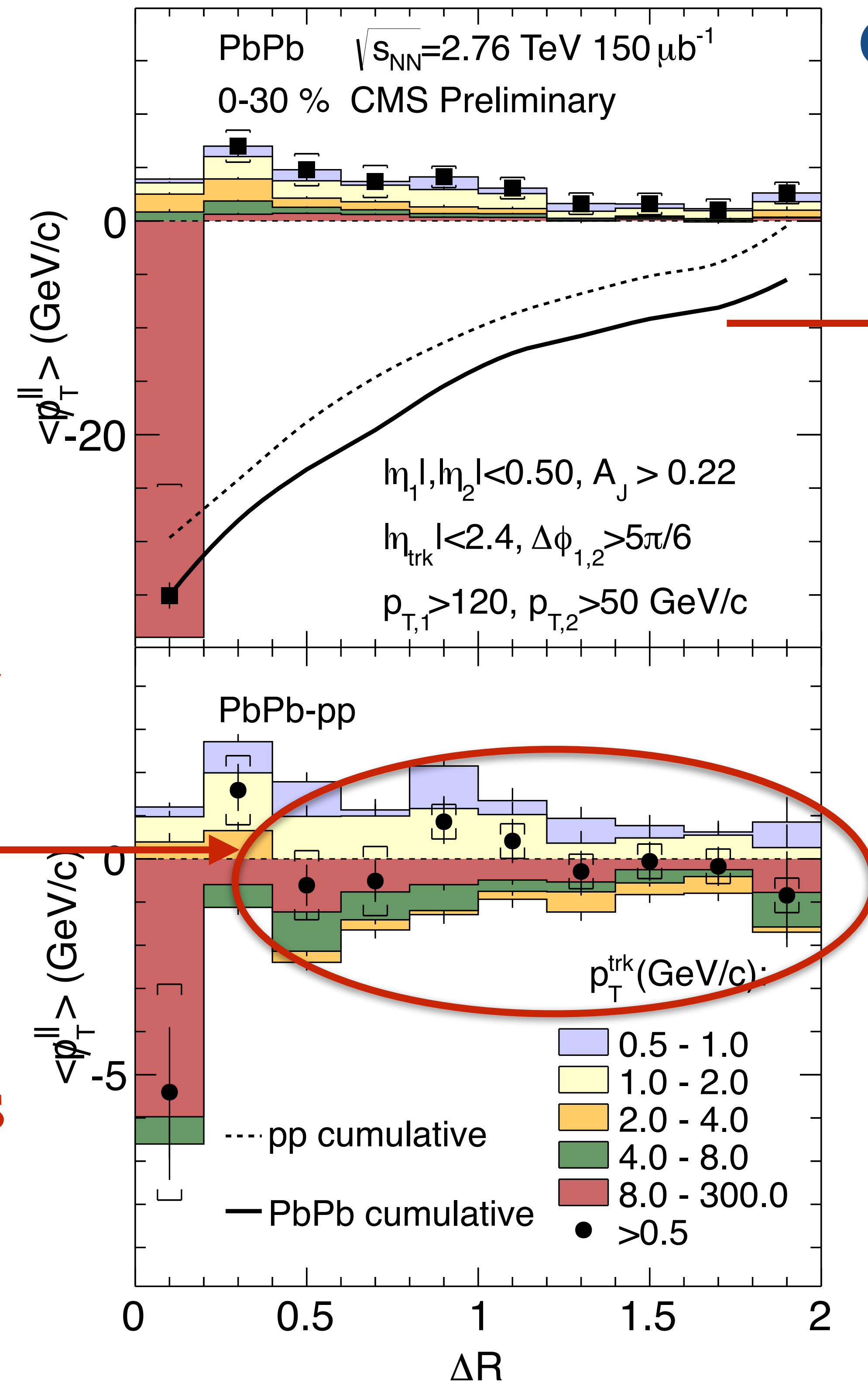
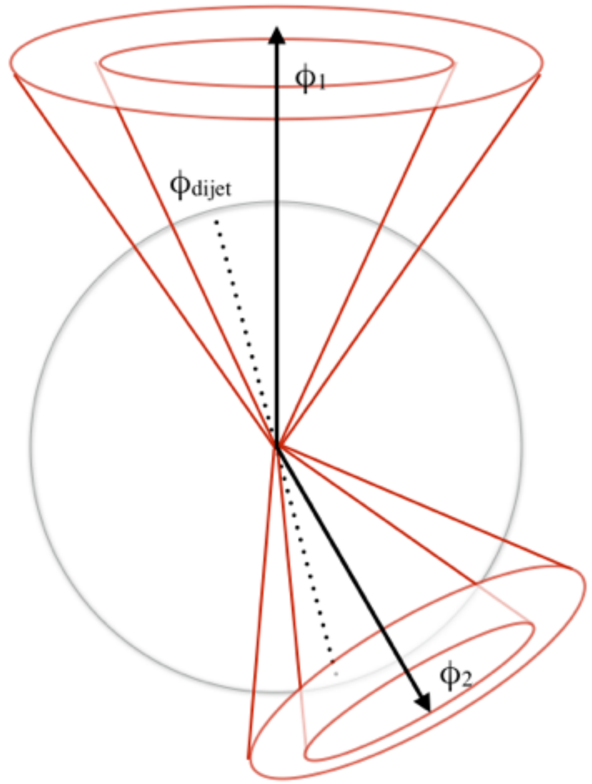


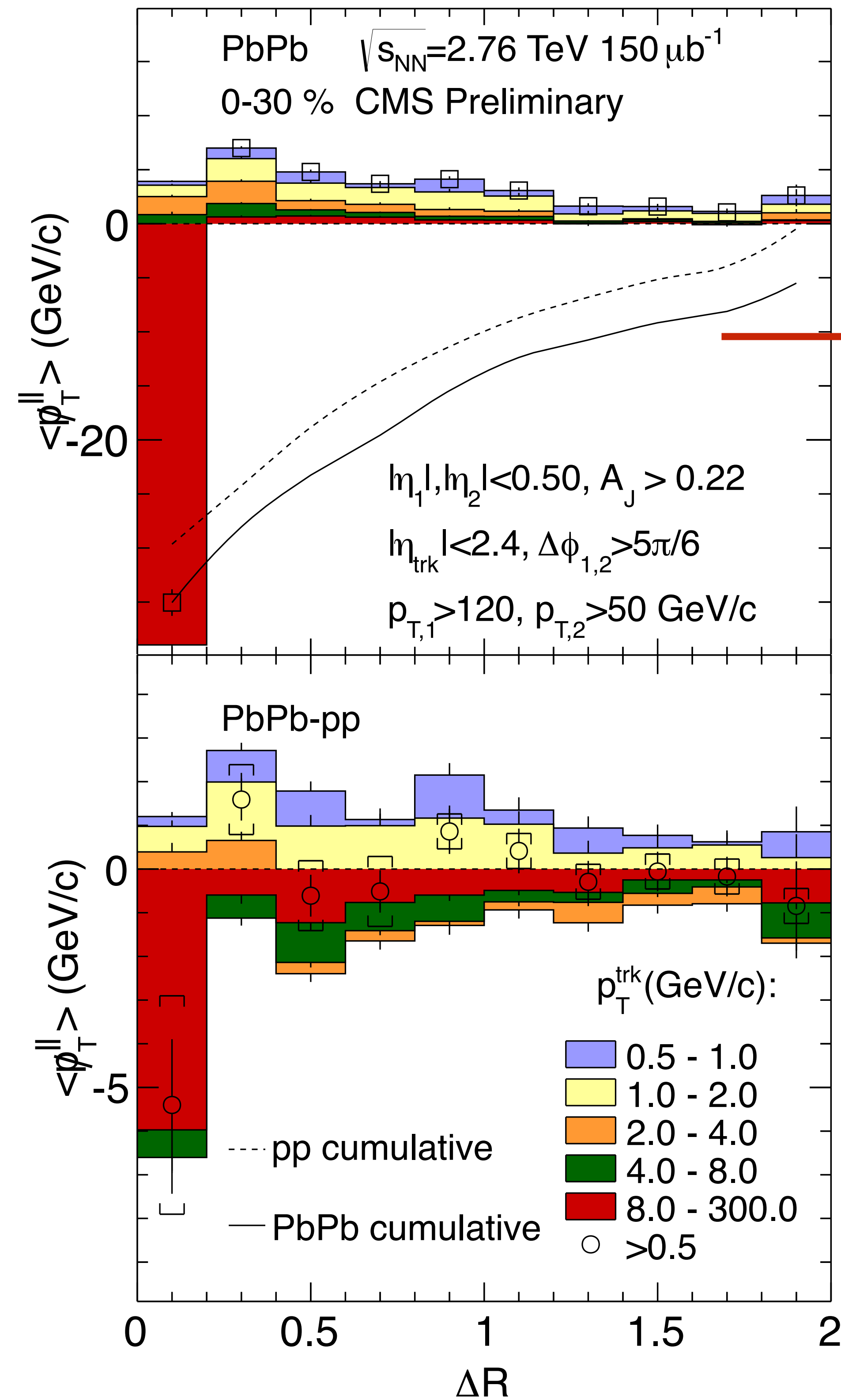
Curves of integrated missing p_T similar shape, adjust starting point?

Totals within 1 GeV/c of zero outside of cone of R = 0.4.

Difference between PbPb and pp in momentum of particles making up imbalance.

Results: Missing p_T v. ΔR (VI)





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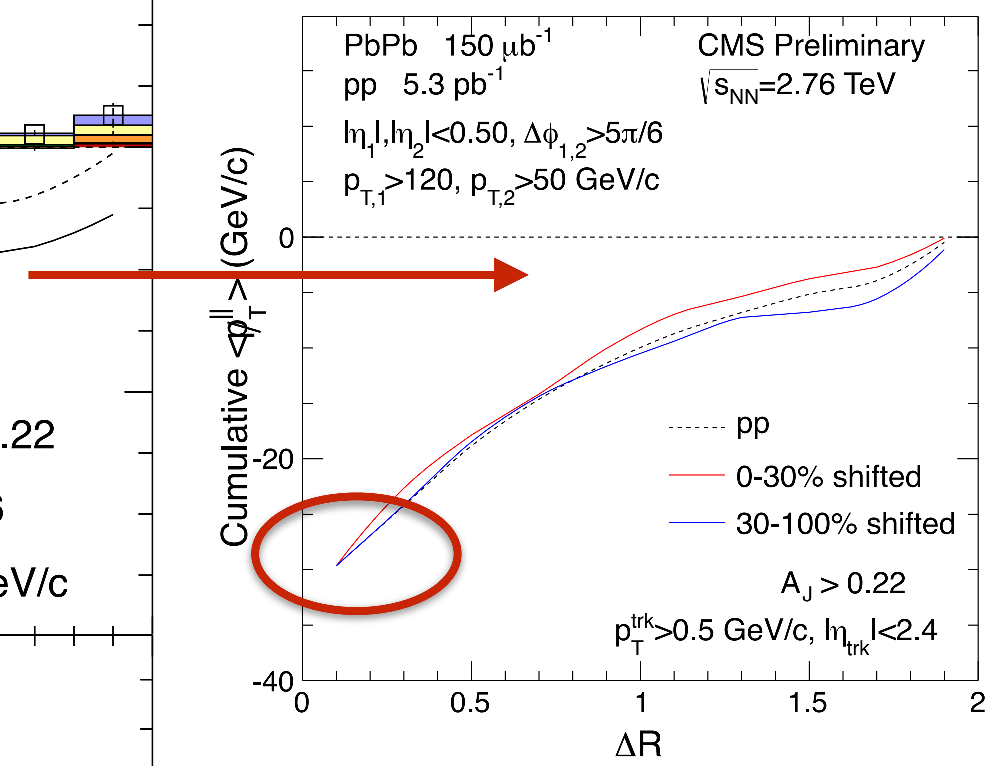

Adjusting for starting point, curves in PbPb and pp approximately the same

Summary and Plans

- Dijet momentum imbalance can be recovered by summing over large angles
  - Subleading jet particles are characterized by higher multiplicities at a lower momentum
  - Relative to pp, observe lower momenta and higher multiplicities
    - 2.0 - 8.0 GeV in pp -> 0.5 - 2.0 in PbPb
    - Differences centrality dependent
- Currently interested in doing generator comparisons with results
  - Particularly for ΔR distribution, look for low p_T enhancement through large angles

Backup

Backup: In-Cone

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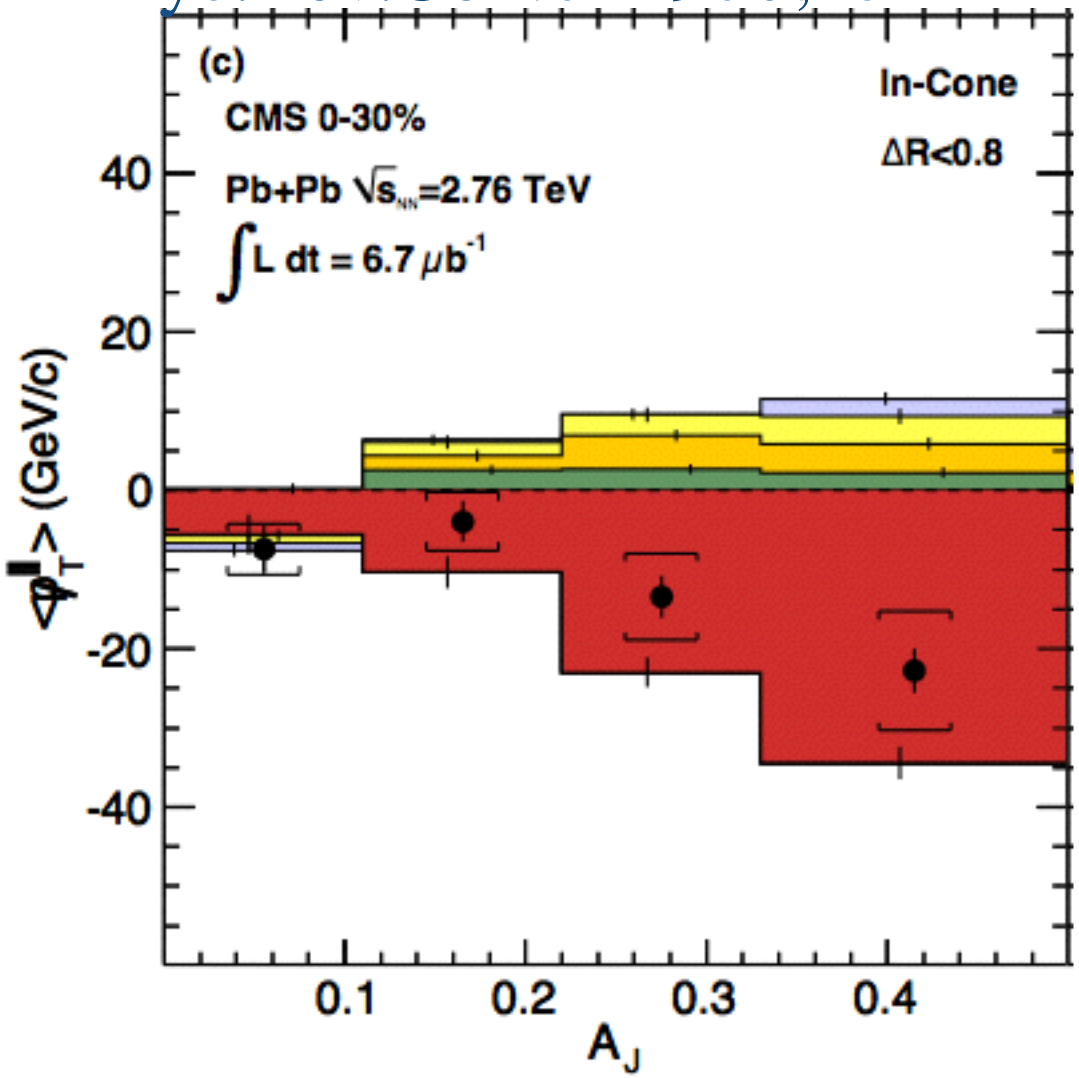

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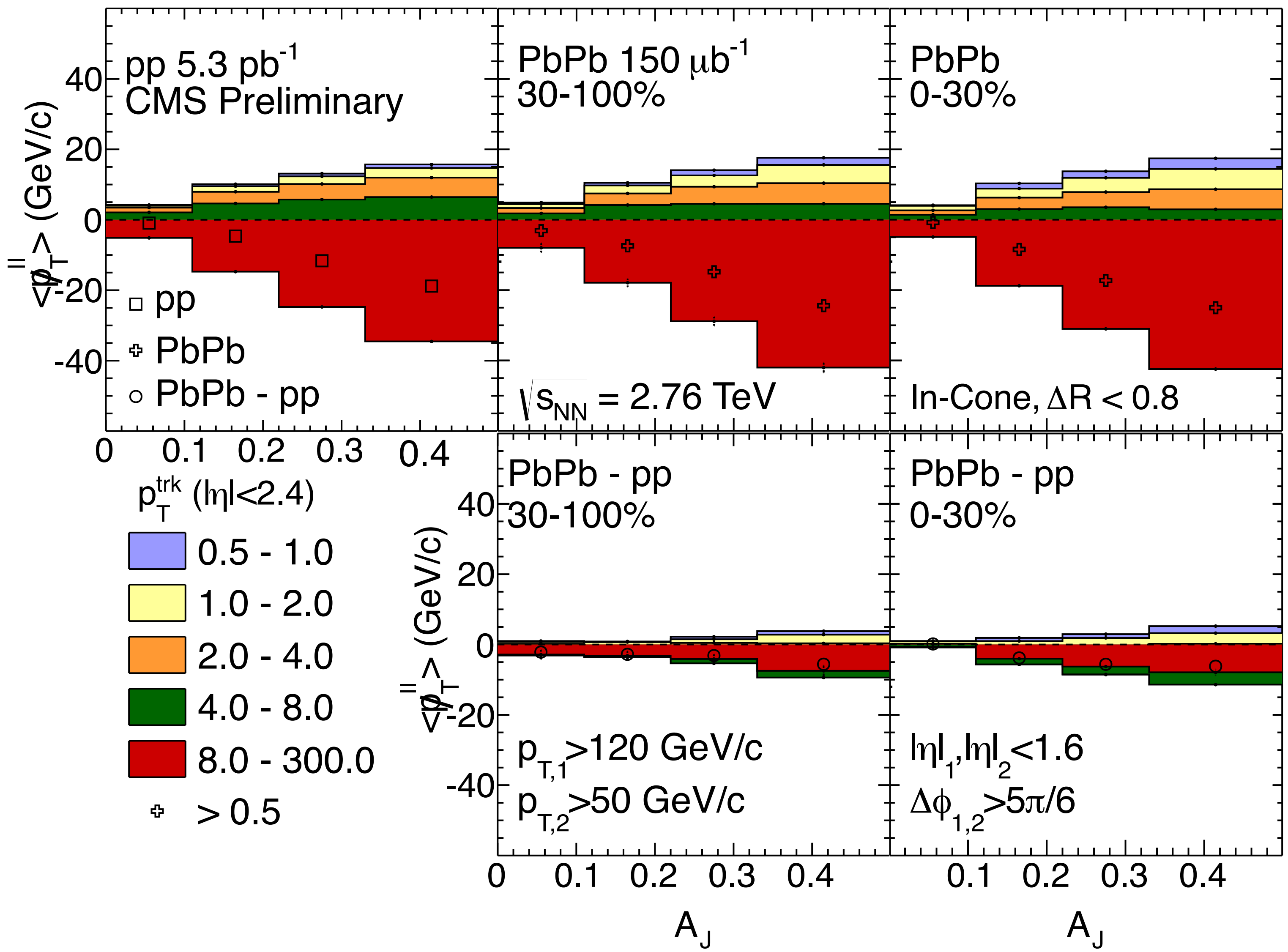

Backup: Out-Cone

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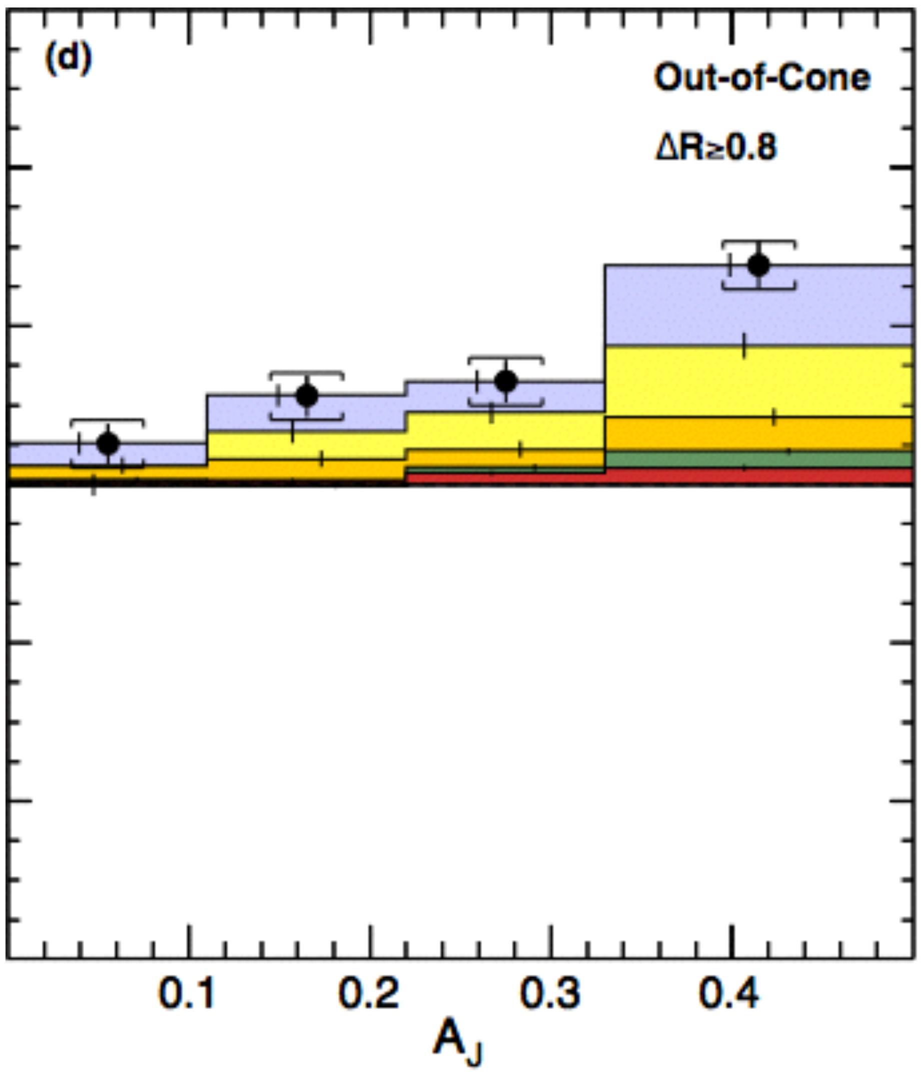

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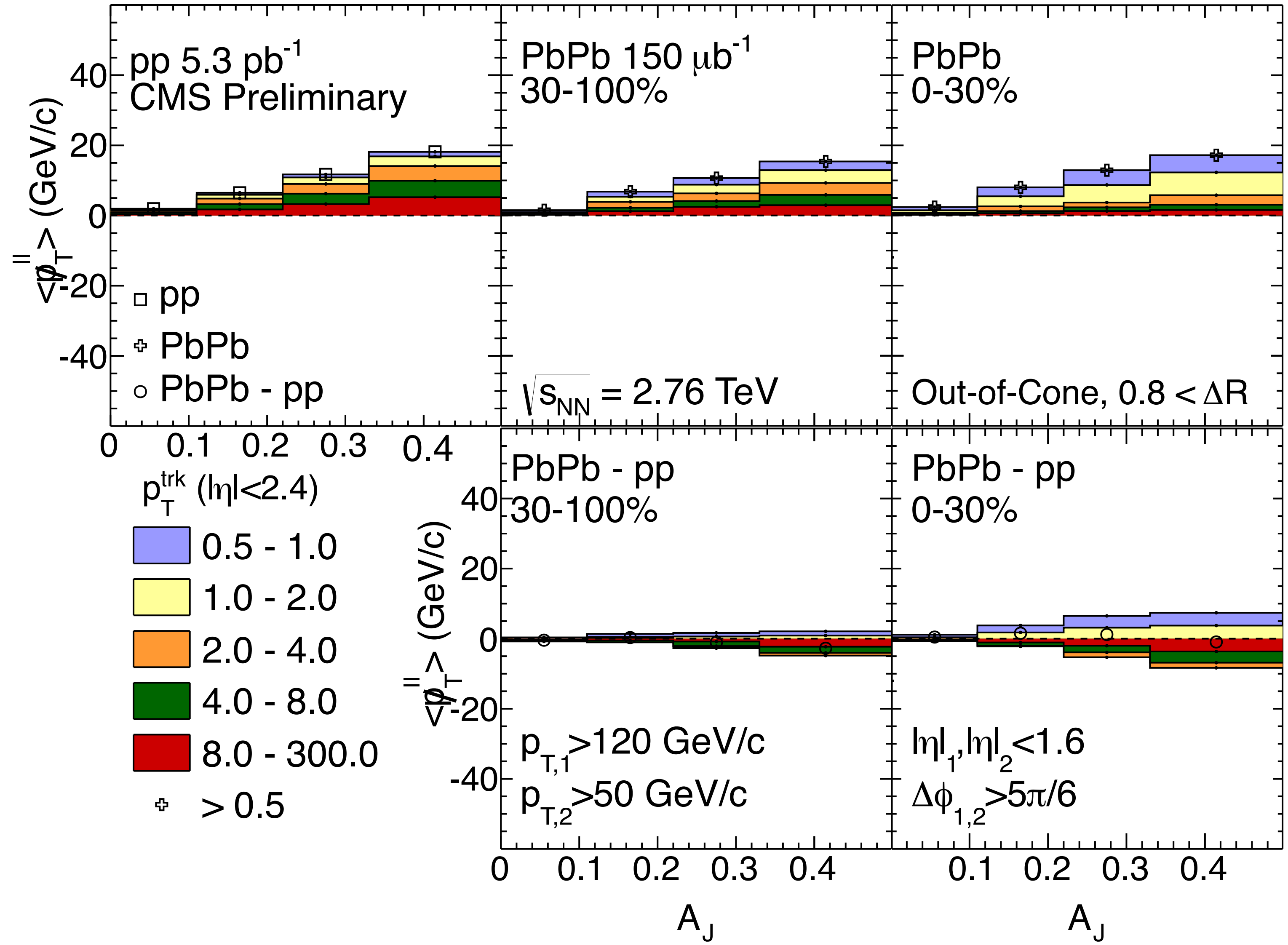

Backup: Gen. Pythia w/ Cuts

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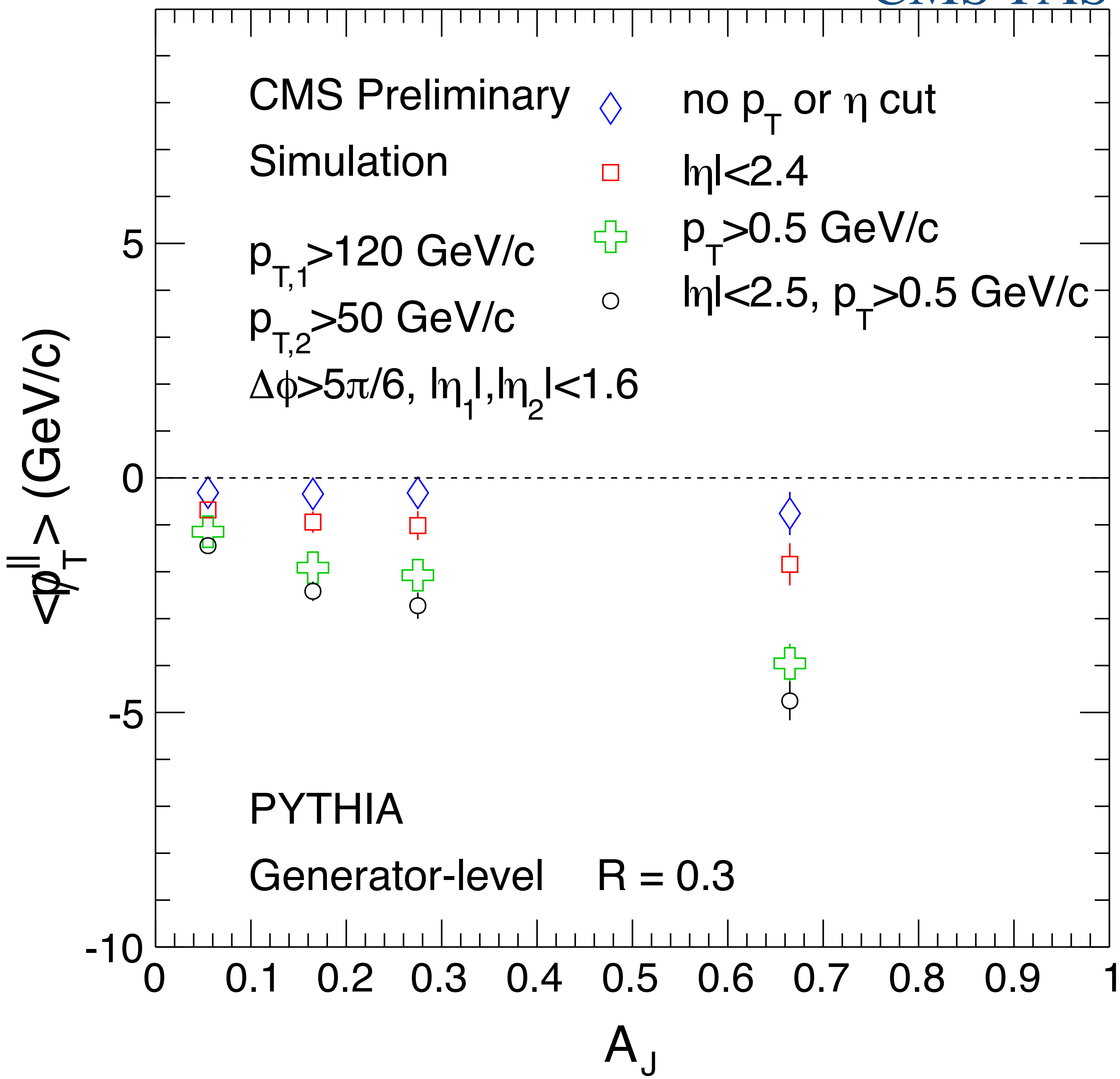

Backup: Jet p_T scale and resolution

CMS-PAS-HIN-14-010