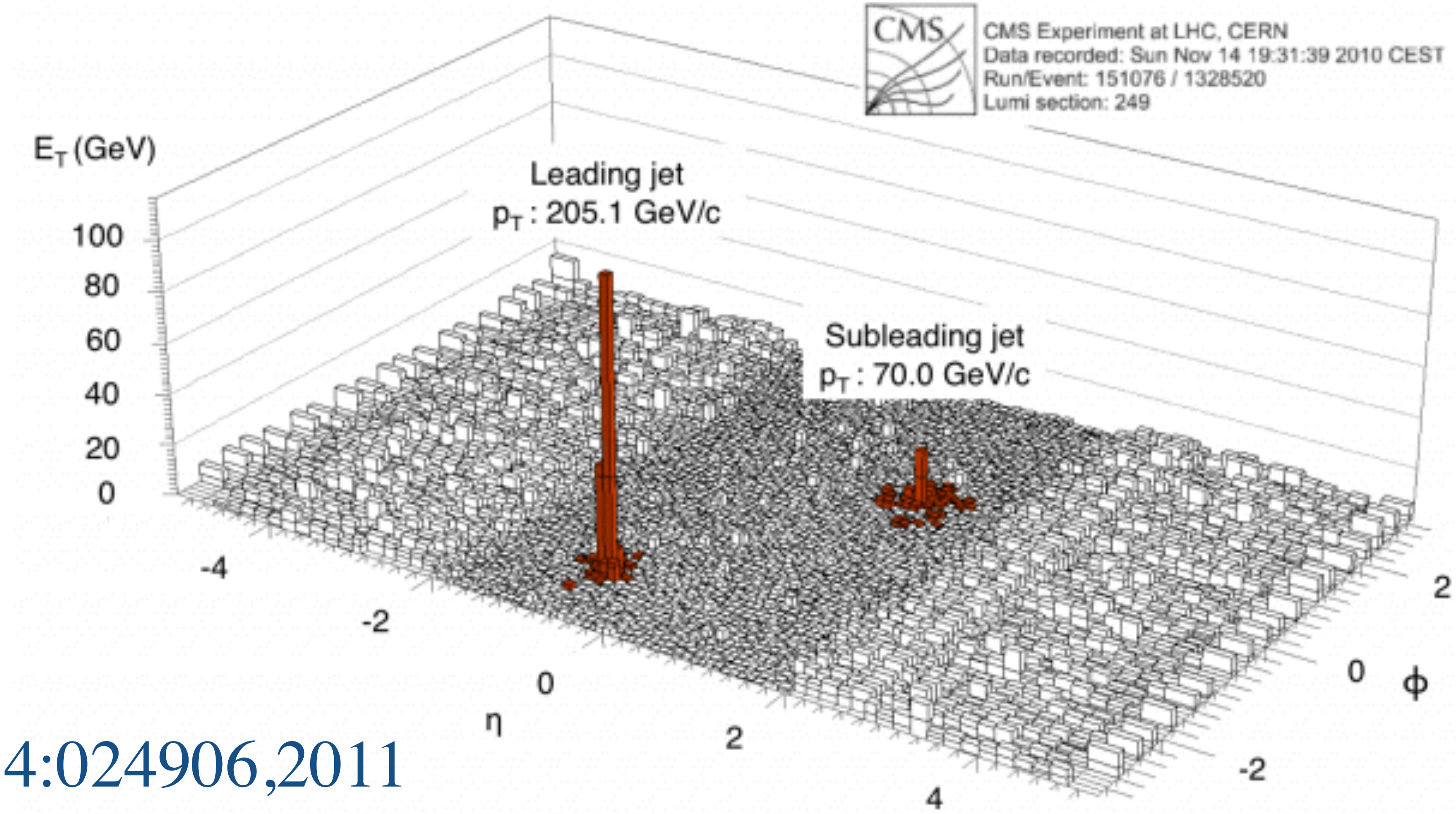

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Missing p_T measurements in CMS

3rd Workshop on Jet Modification in the RHIC and LHC Era

Wayne State University, Detroit, USA (2014)

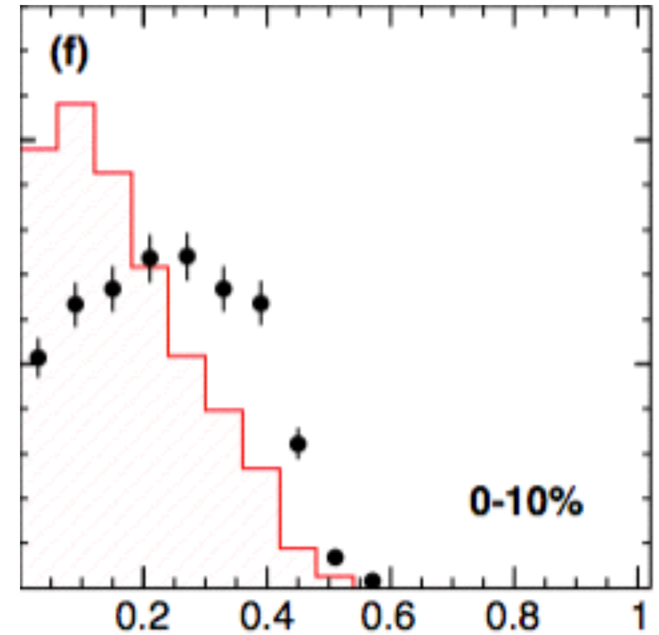
On Behalf of CMS Collaboration

Overview

- Motivation and Previous Results
- Samples and Event Selection
- Jet Reconstruction with New HF/Voronoi Method
- Track Reconstruction and Corrections
- Observables and 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



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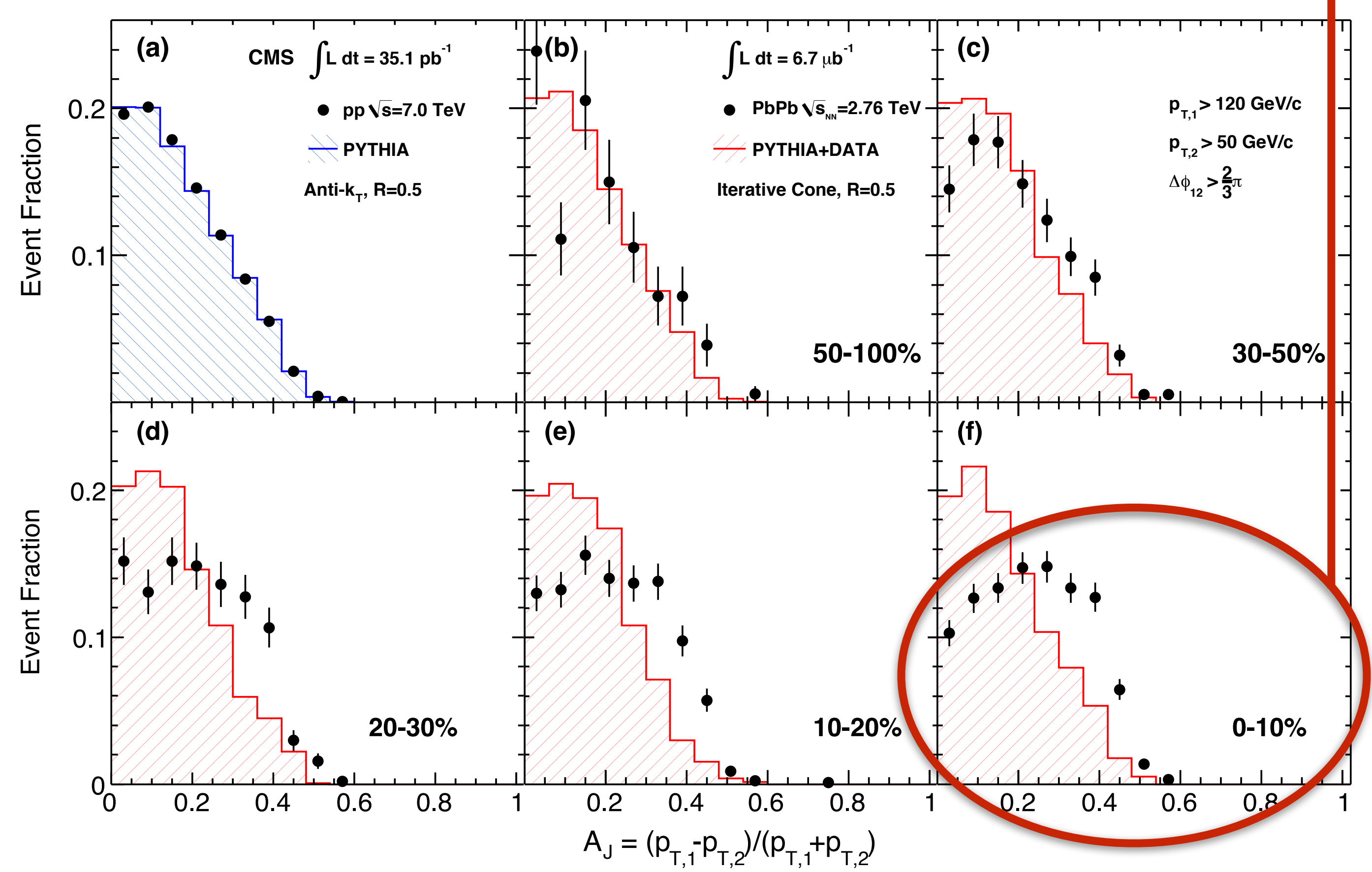
- Can ask:
  - Where does the missing momentum go? (Outside the jet cone?)
  - How is the total momentum distributed amongst particles in different p_T ranges?



Motivation (II)

$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

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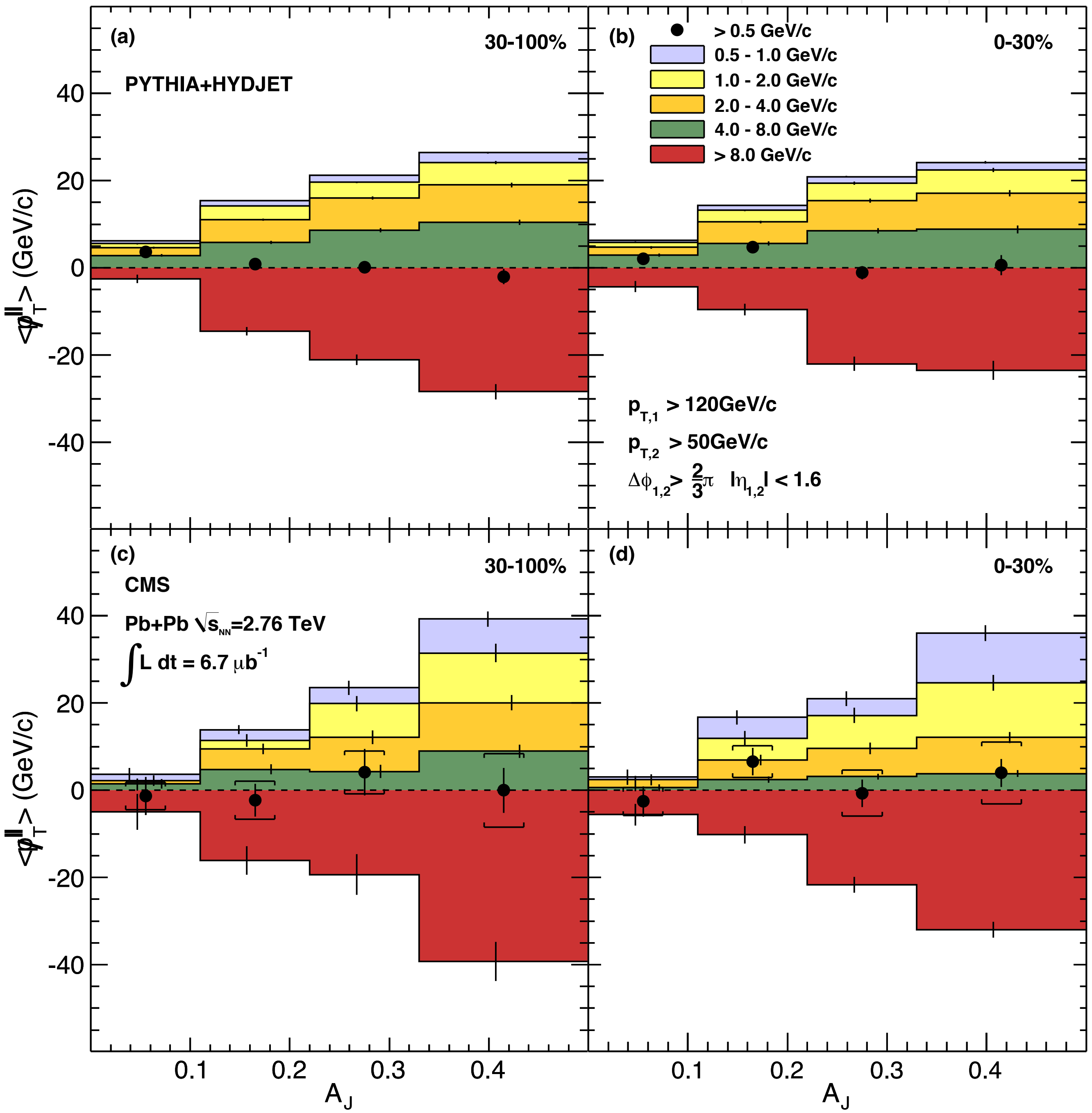
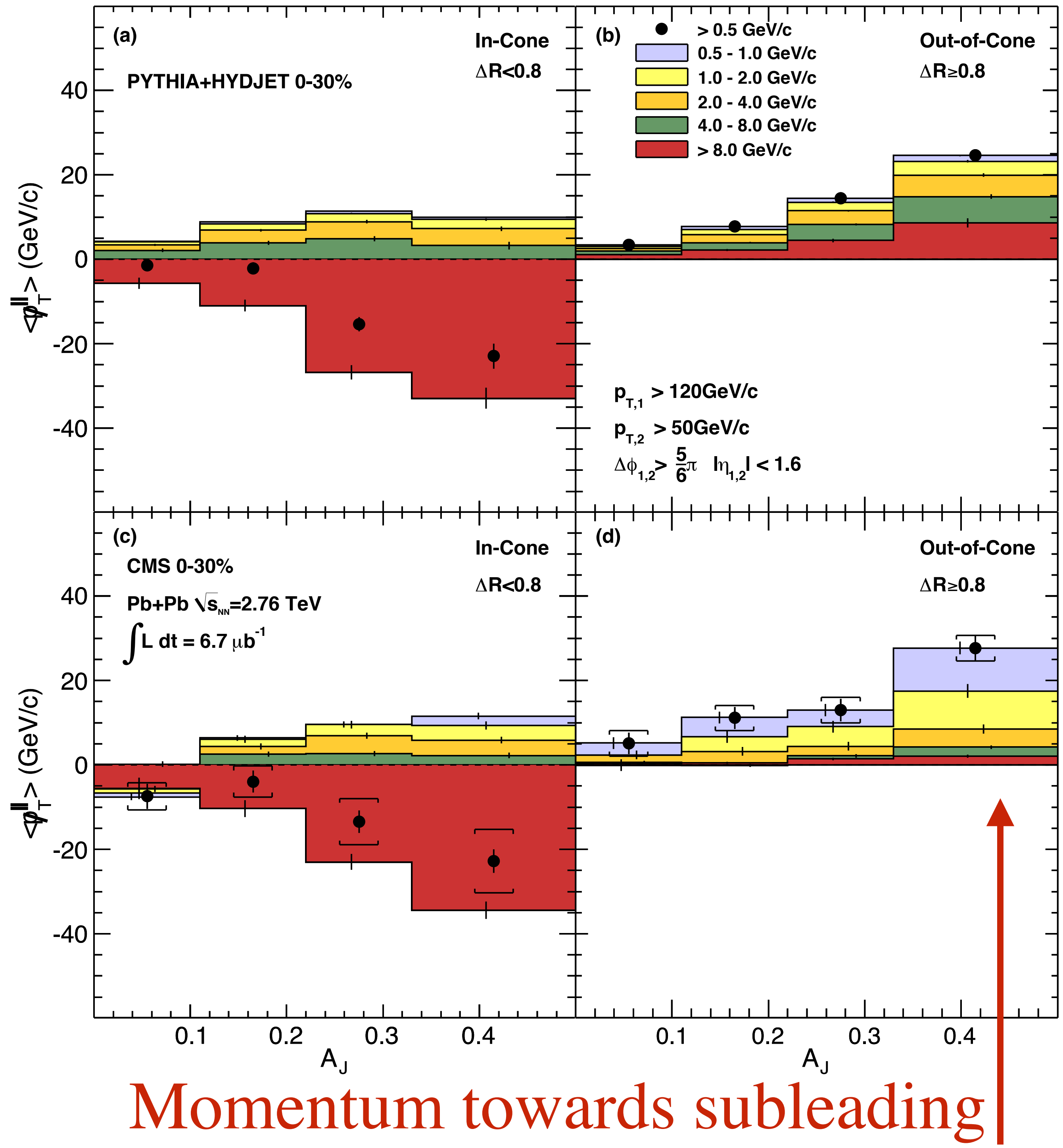




Enhancement of low momentum contribution by centrality

Momentum towards subleading recovered out of cone

Motivation (III)

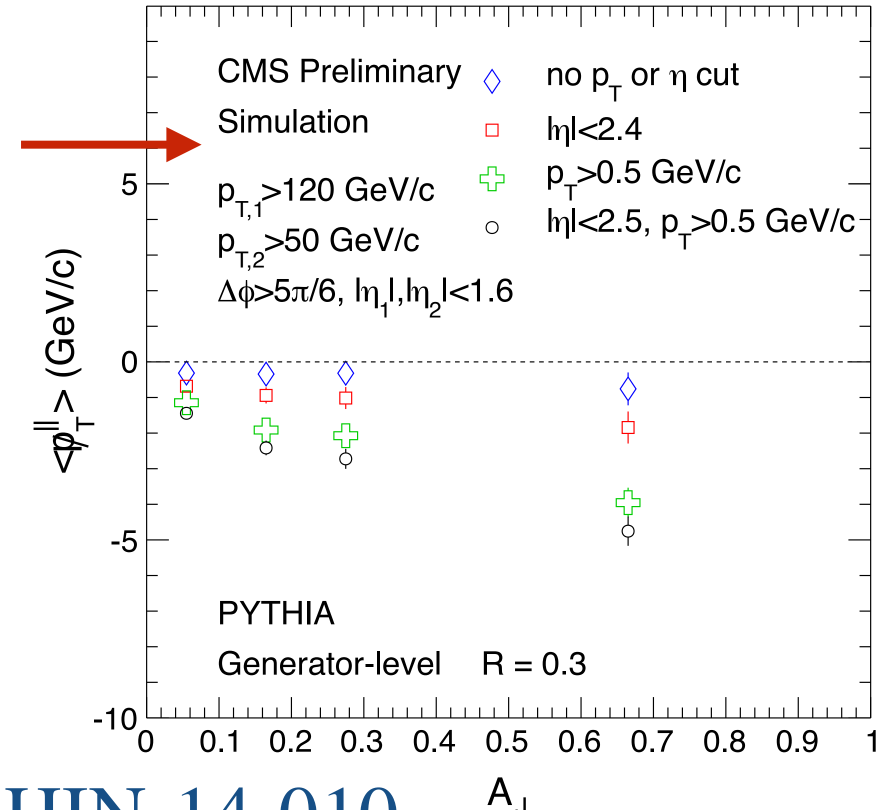
- Dijet imbalance observed in cone (A_J) is not fully recovered until large ΔR
  - Lower momentum contribution preferentially towards the subleading jet axis
  - Large ΔR momentum contribution also preferentially towards the subleading jet axis

- Can still ask (and to be presented):
  - What is the distribution of this momentum imbalance as a function of ΔR?
  - How does this compare to pp?
    - In contrast with previous comparisons to PYTHIA+HYDJET

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 Reco. w/ Voronoi Algorithm (I)

- New CMS underlying event subtraction algorithm
- Model the underlying event at mid-rapidities by the transverse energy eta dependence and Fourier harmonics at forward rapidity
- Subtraction of the underlying event performed on constituent basis
  - energy subtracted from individual towers
  - results in negative towers
- Equalization to remove negative towers
  - Energy is redistributed
  - Smear jets by transferring energy locally to negative towers

Jet Reco. w/ Voronoi Algorithm (II)

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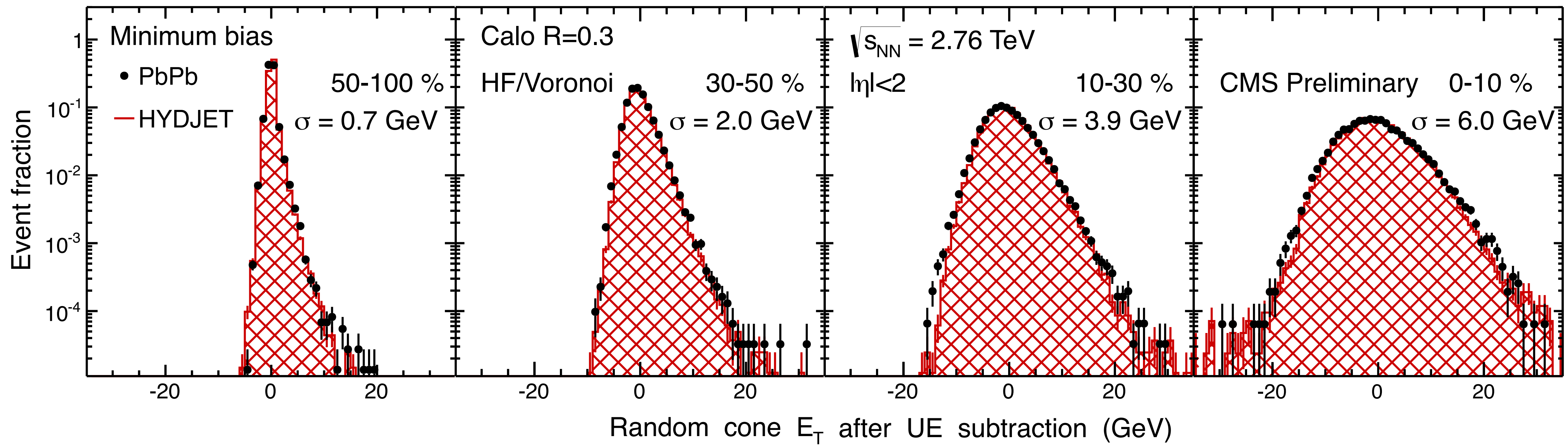
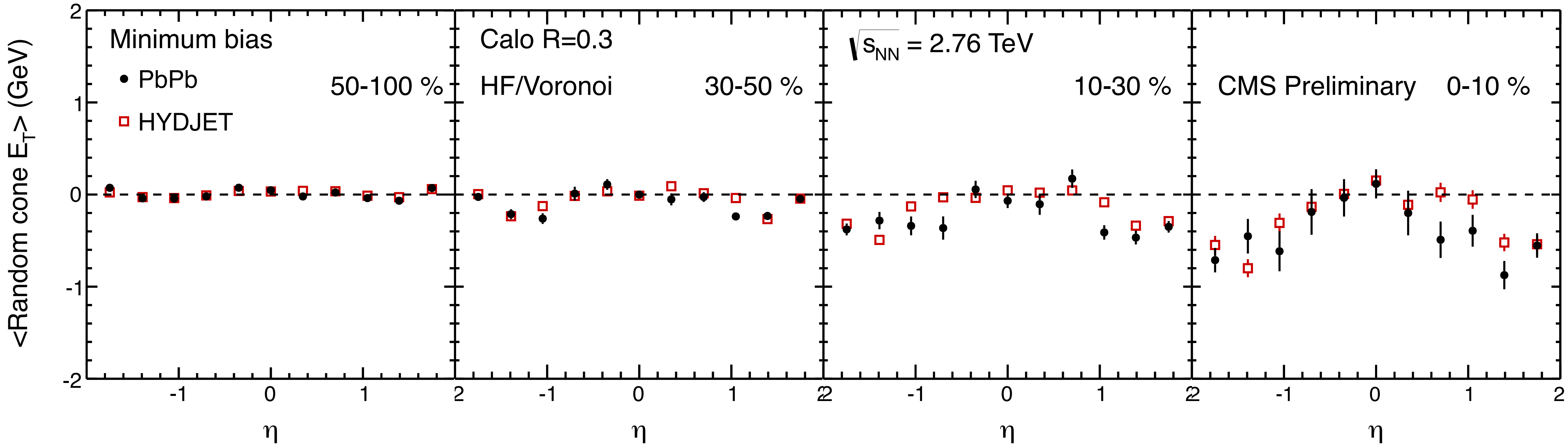


- Random cone study in minimum bias data shows result consistent with zero through centrality and deviation of less than 1 GeV/c as function of η



Track Reco. and Corrections

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

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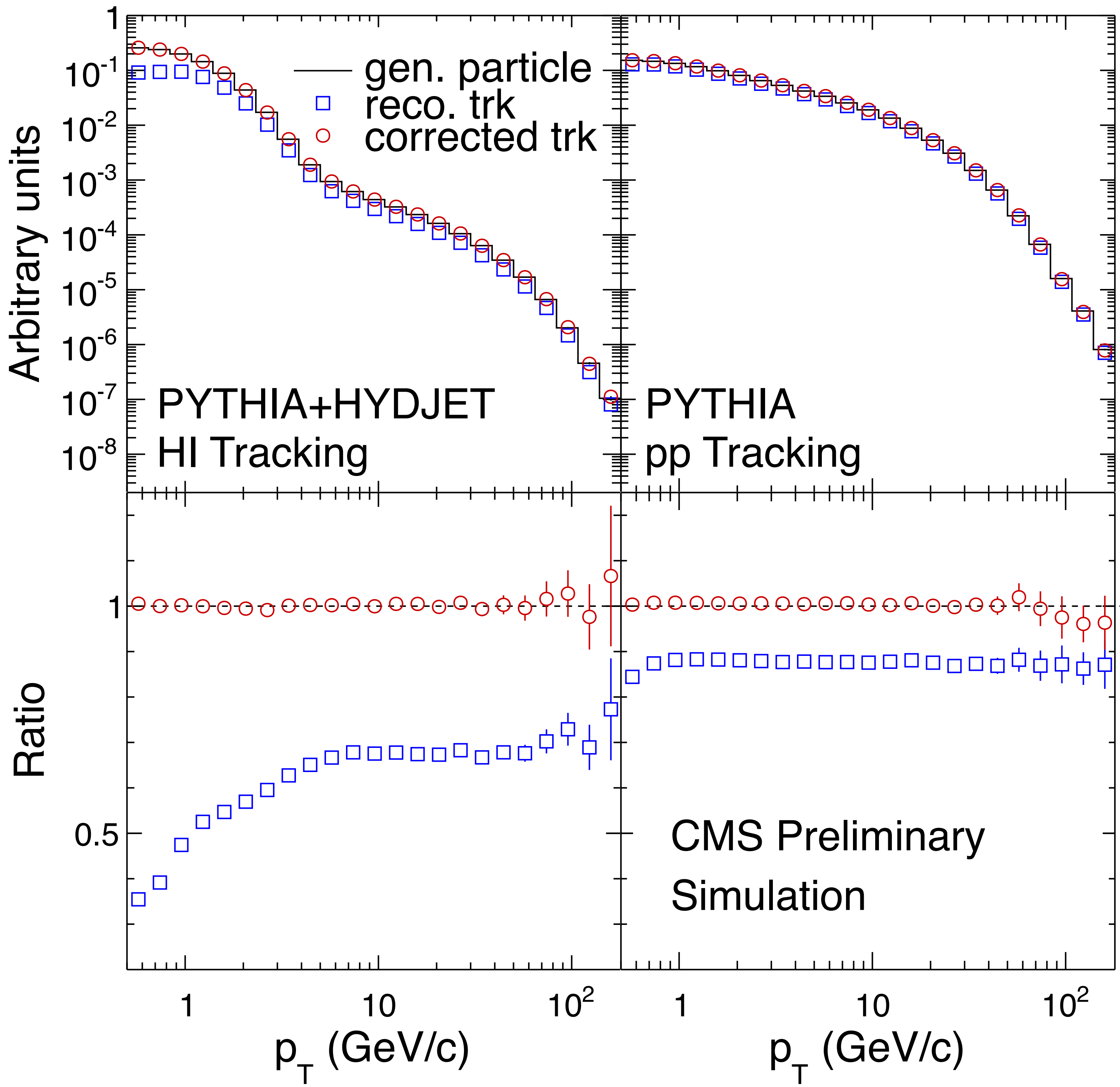
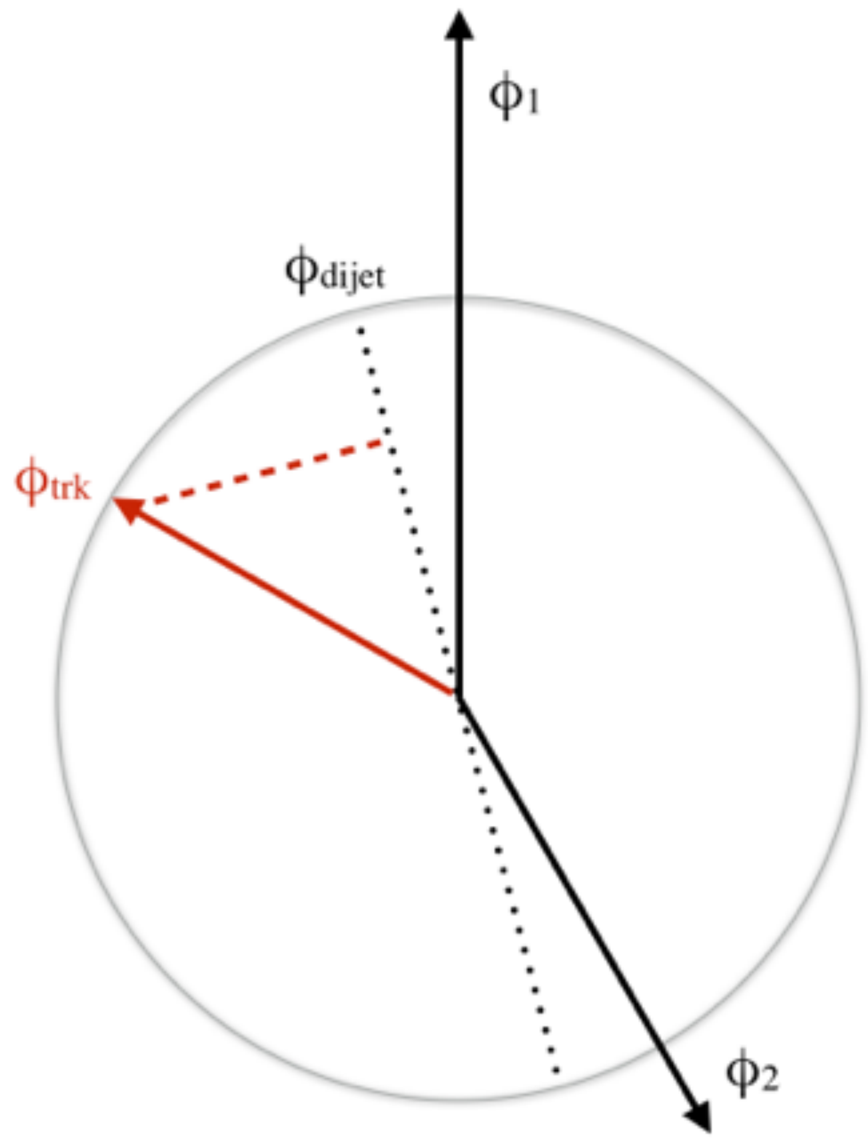
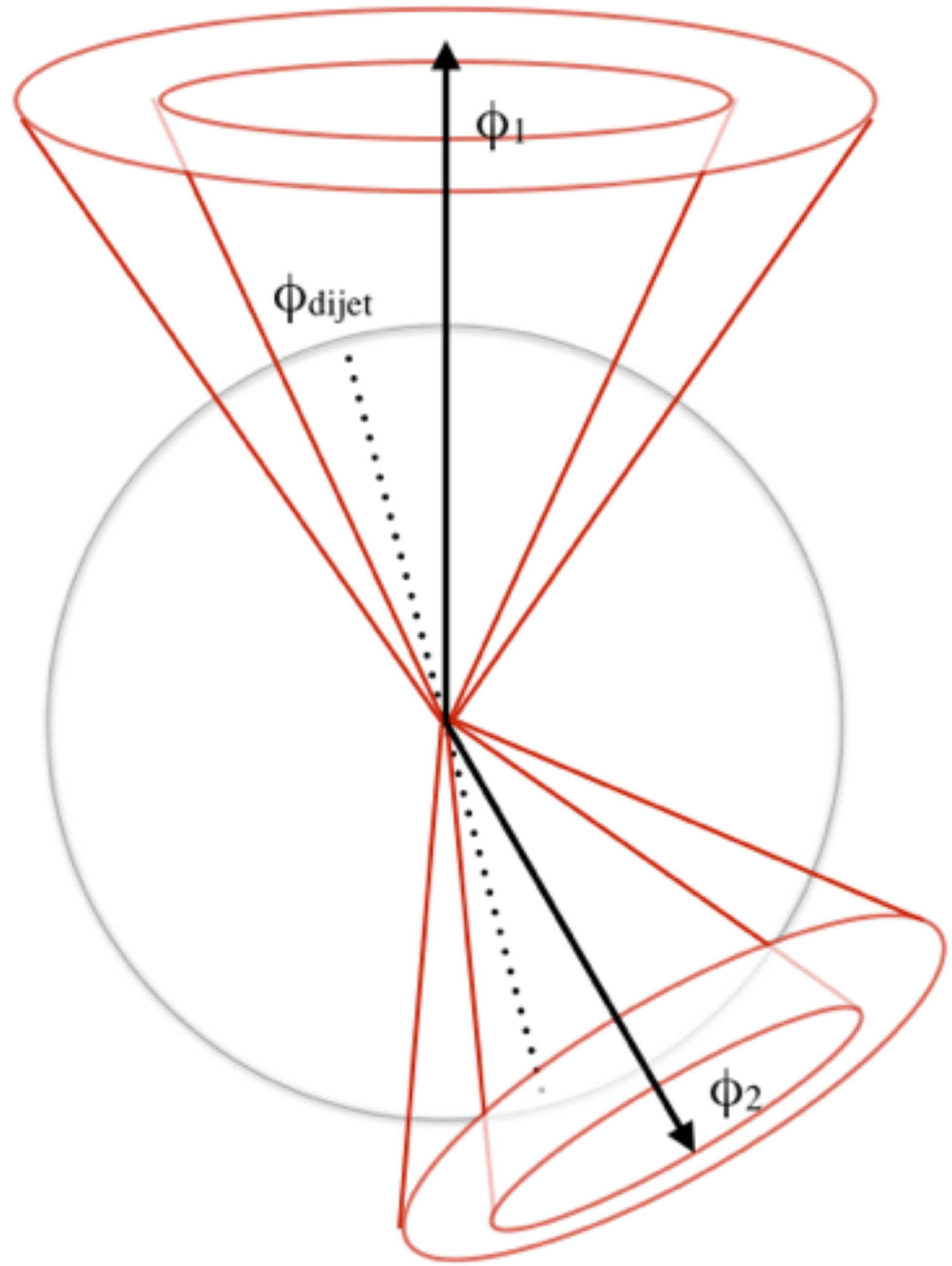


Observables: A Cartoon Picture



Project onto diet axis

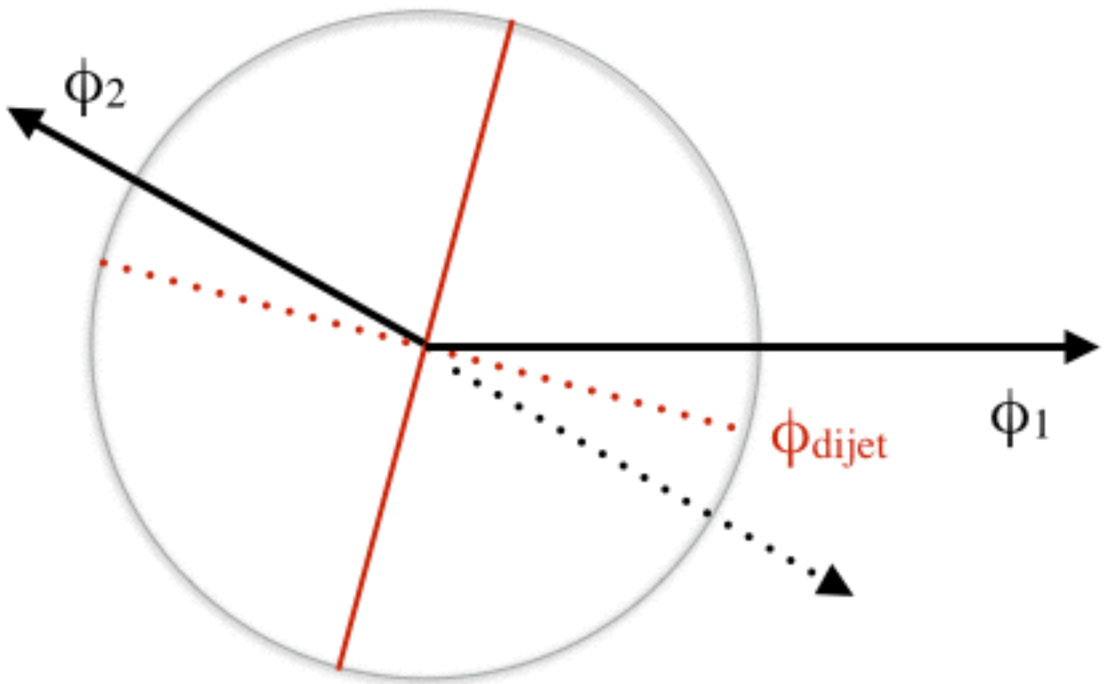


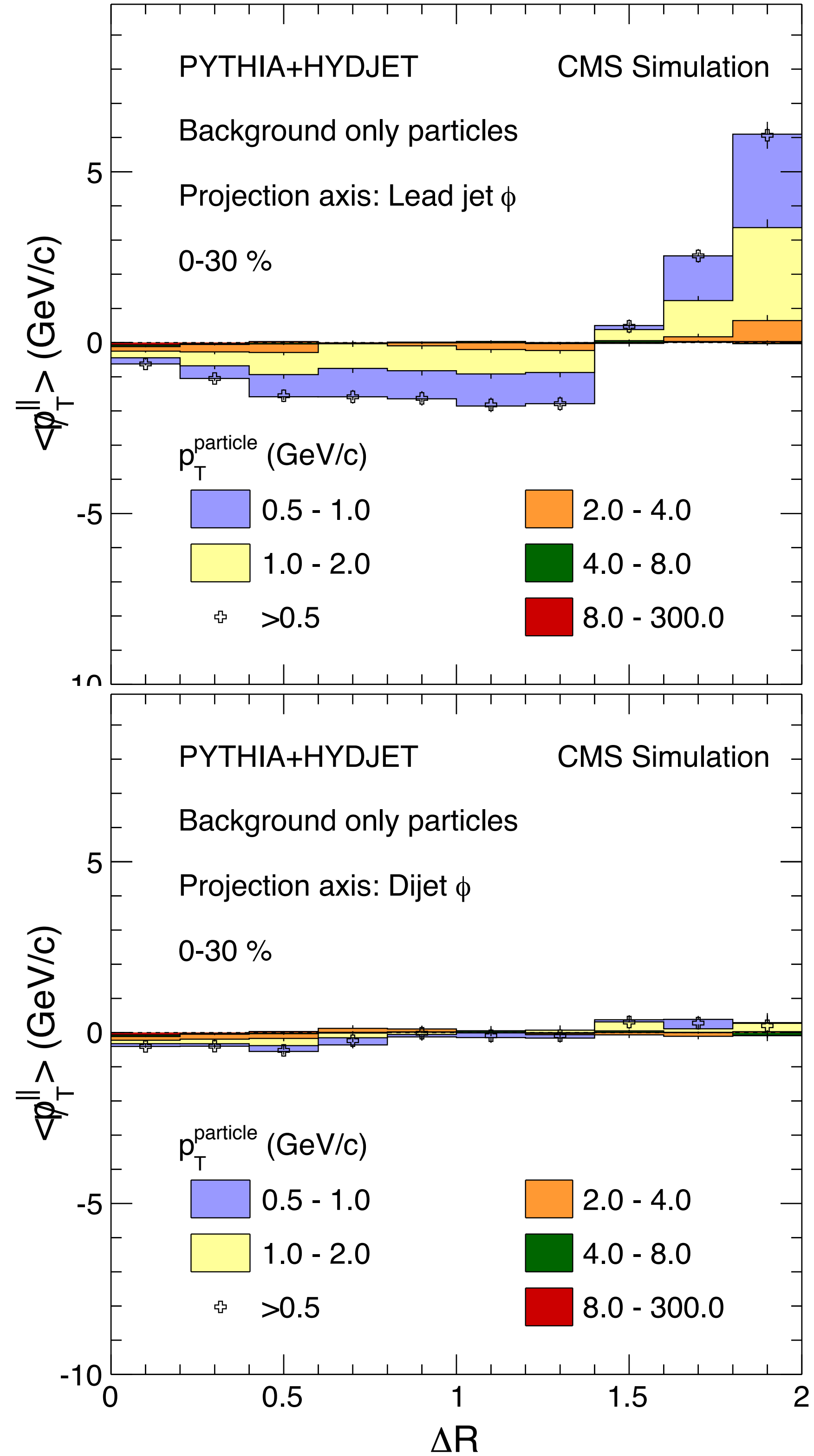
Define cones w.r.t. individual jet axes

Observables: Dijet Axis

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

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





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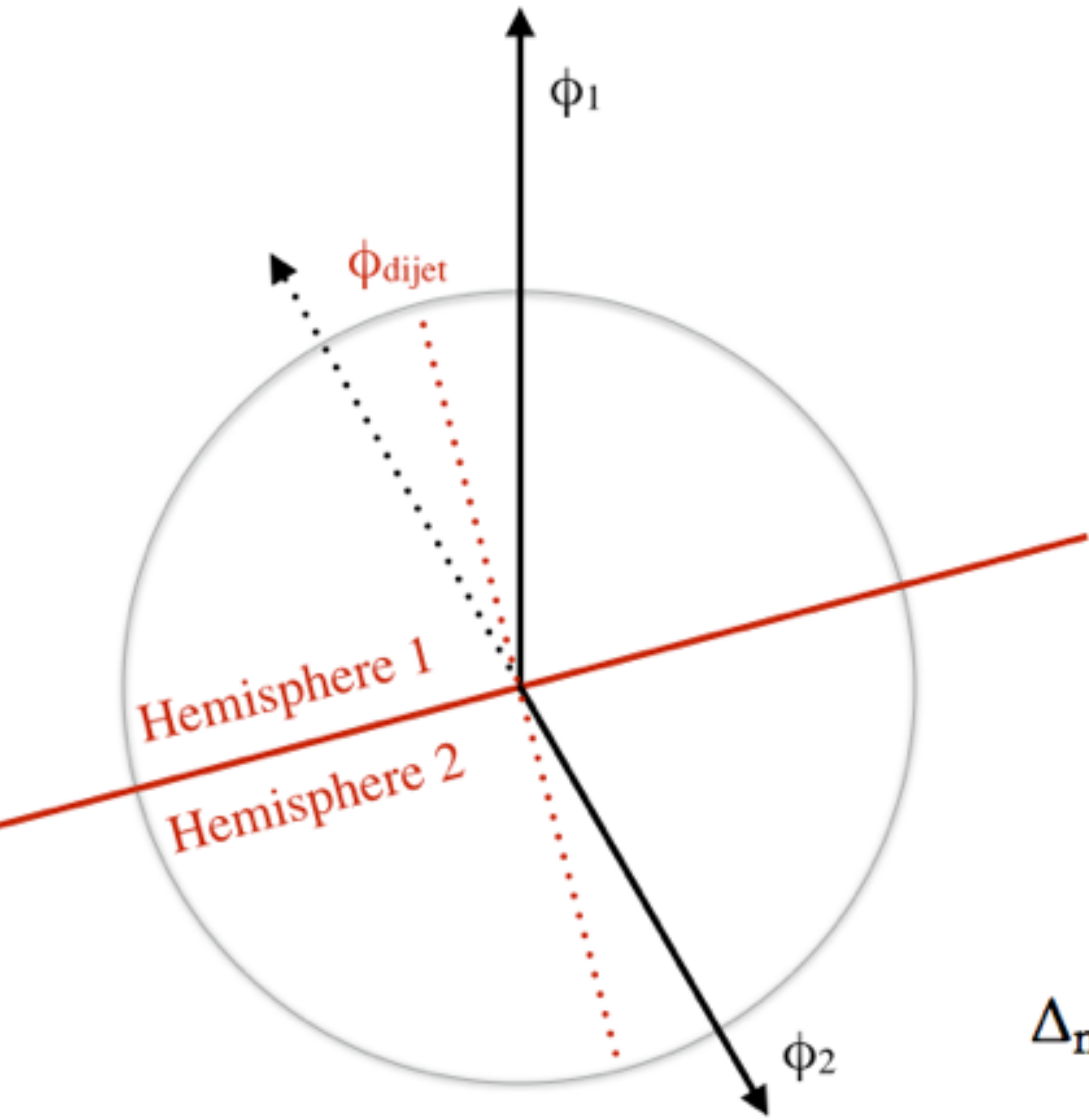
Observables: Multiplicity Difference



- CMS-HIN-10-004, observed tracks in subleading hemisphere of lower p_T than leading

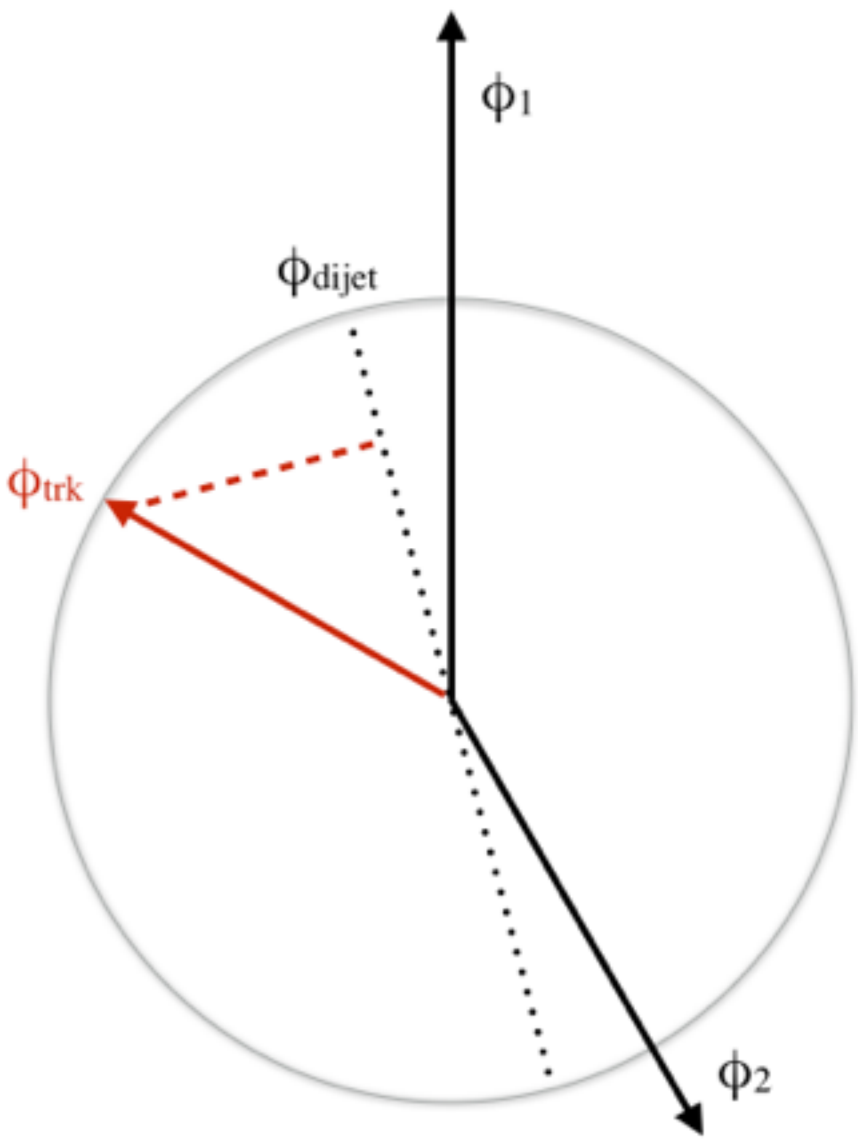
- Can revisit observation with a multiplicity difference measurement

Define:

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

Hemisphere 2 Hemisphere 1

Observables: Missing p_T v. A_J



- Revisit 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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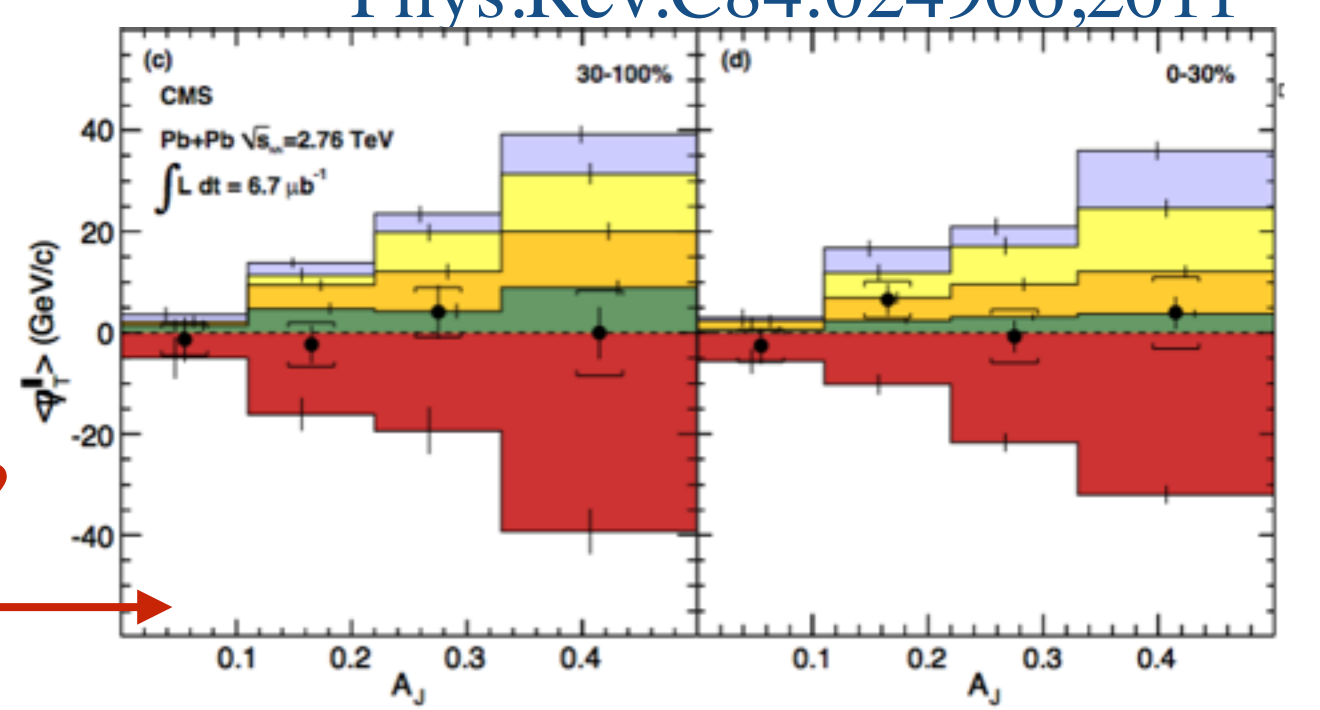
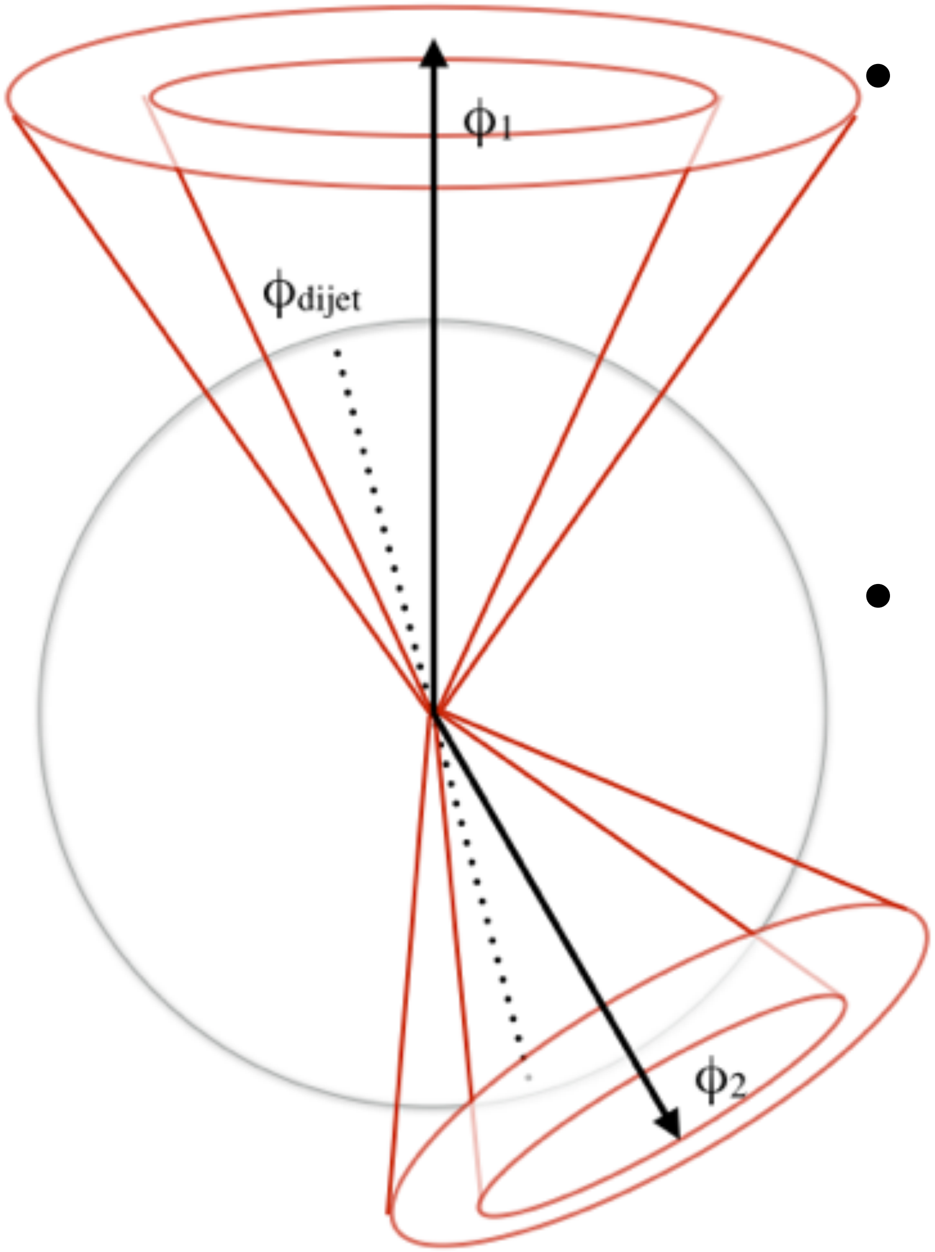


What do we expect after subtracting pp?

Observables: Missing p_T v. ΔR (I)



- 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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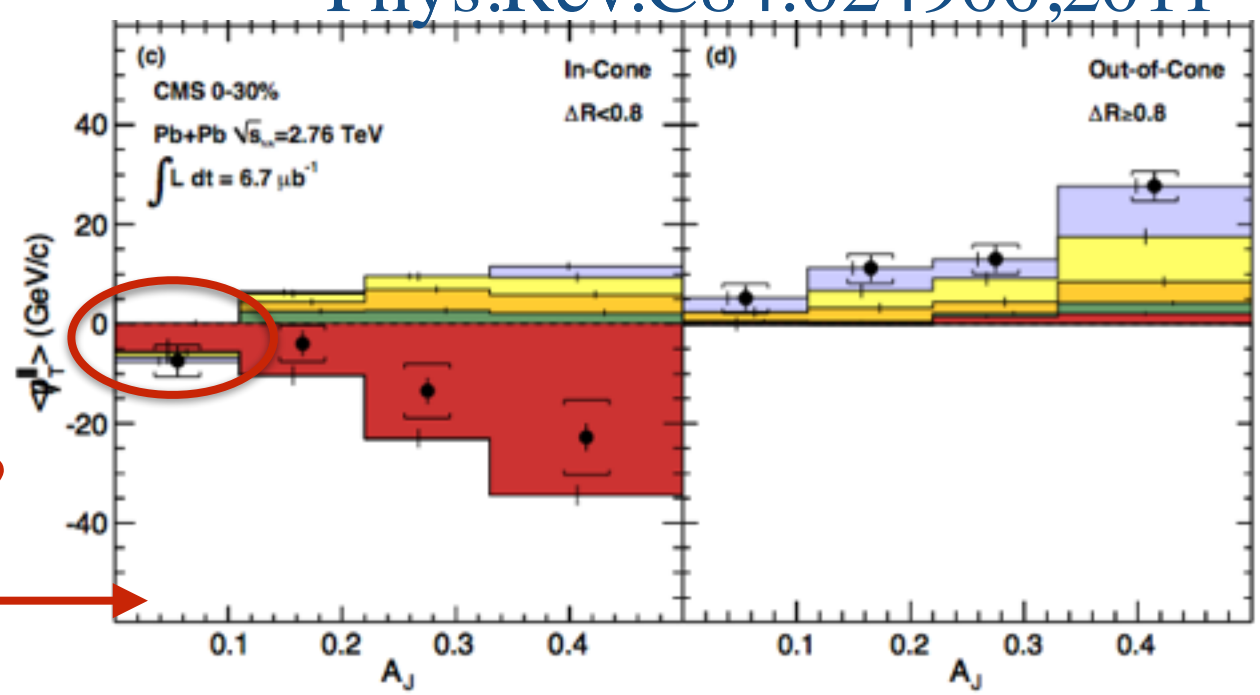
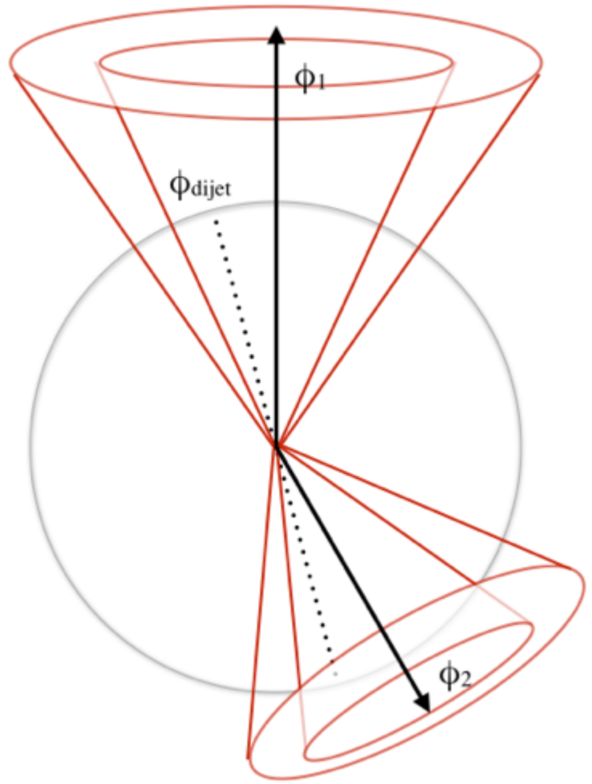
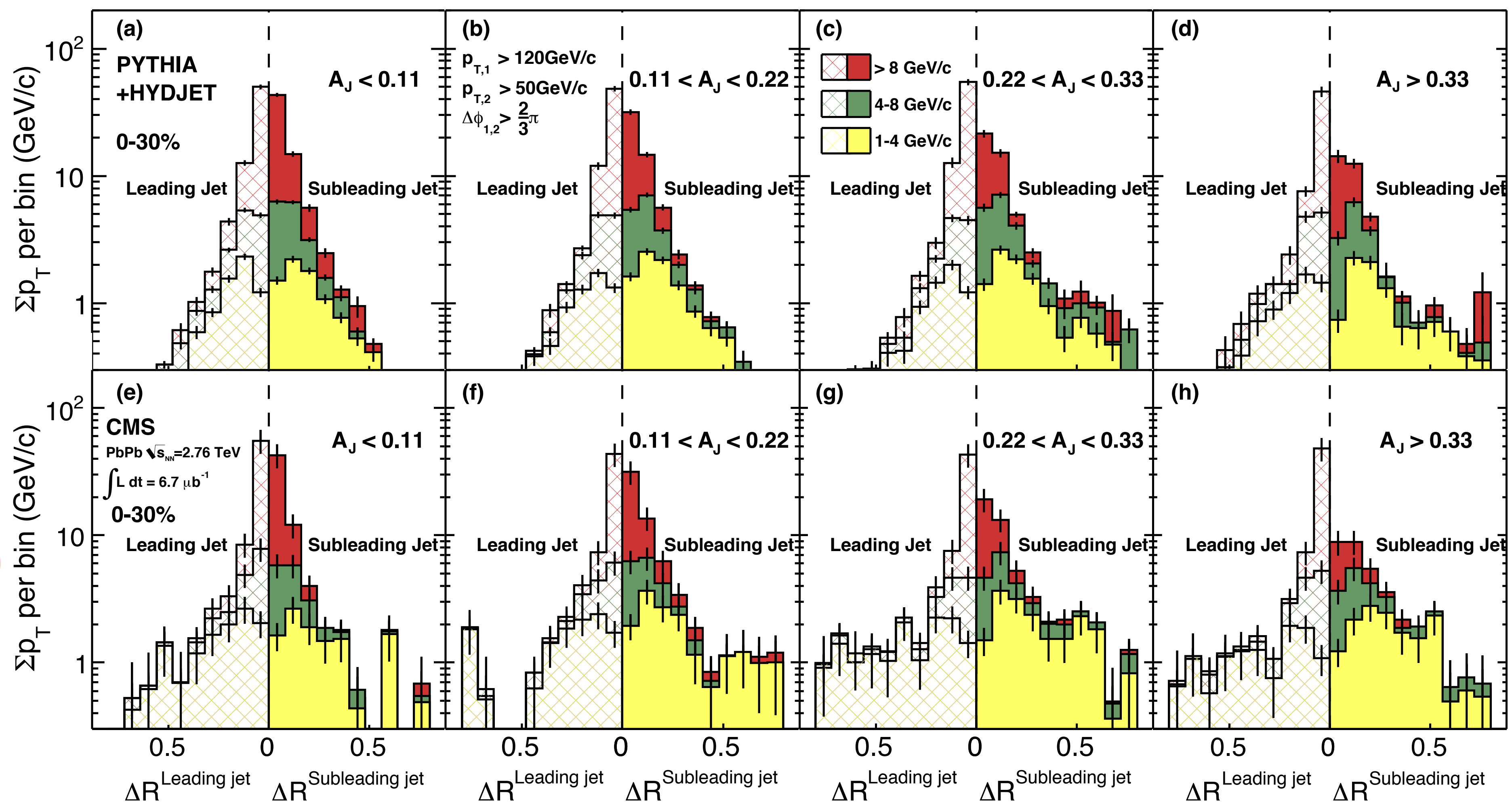


What is the full distribution this samples?

Observables: Missing p_T v. ΔR (II)





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

- Limited here in ΔR due to statistics and acceptance
  - Need mid-rapidity jets

Results: Multiplicity (I)

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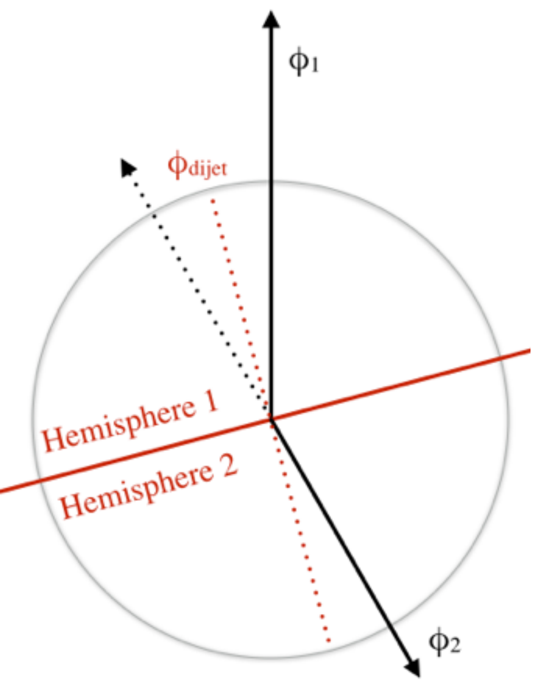

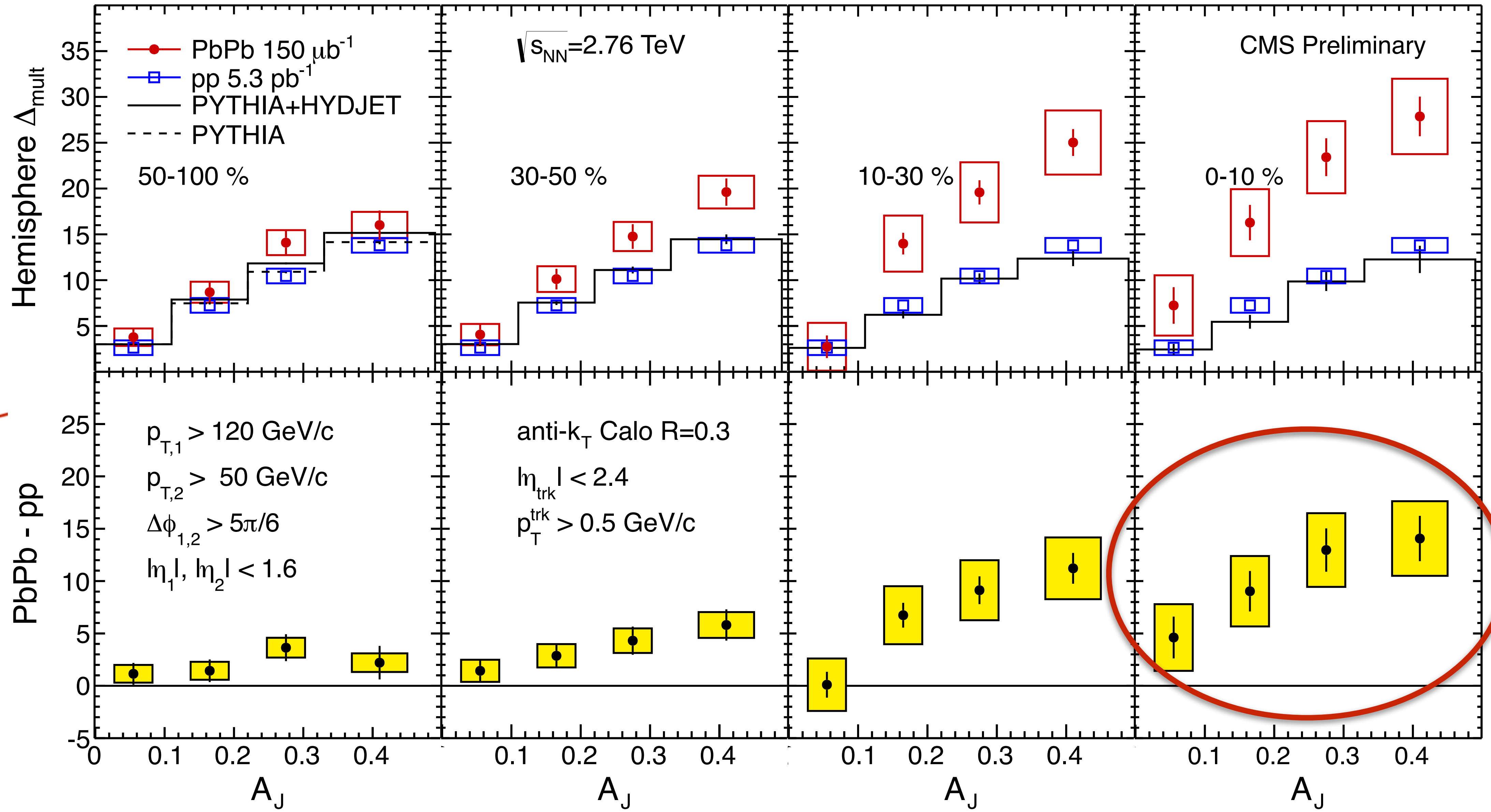

- As function of $A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$, increasing multiplicity towards subleading hemisphere
  - excess approaches 15 particles in most central PbPb relative to pp

Results: Multiplicity (II)

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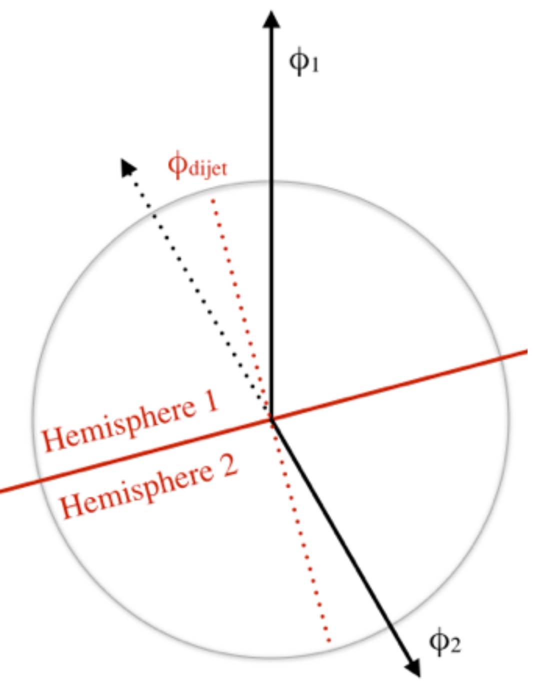

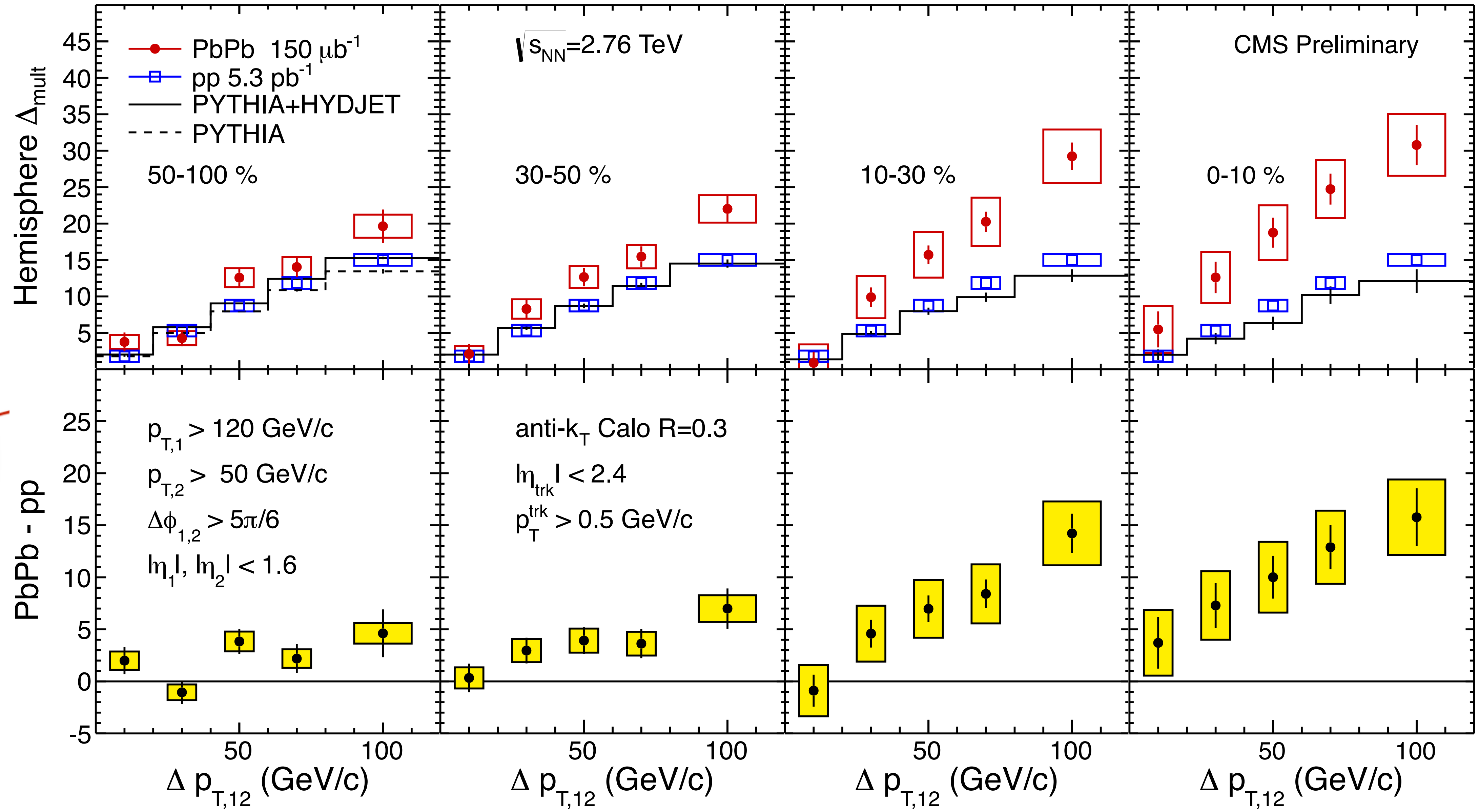

- As function of $\Delta p_{T,12} = (p_{T,1} - p_{T,2})$, similar picture
  - excess approaches same rough numbers in PbPb central collisions towards subleading hemisphere

Results: Missing p_T v. A_J

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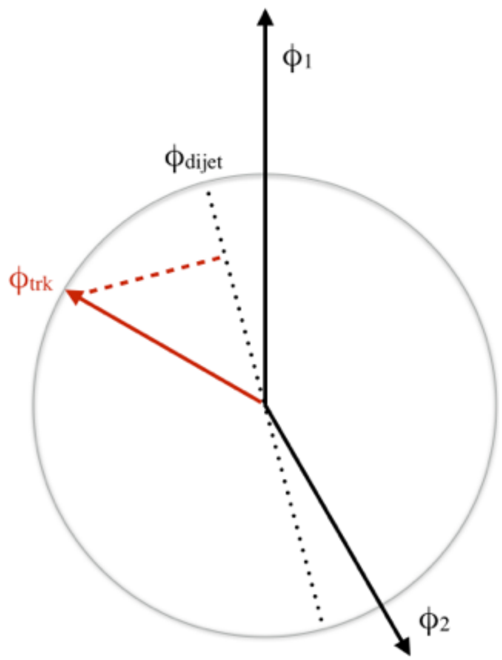

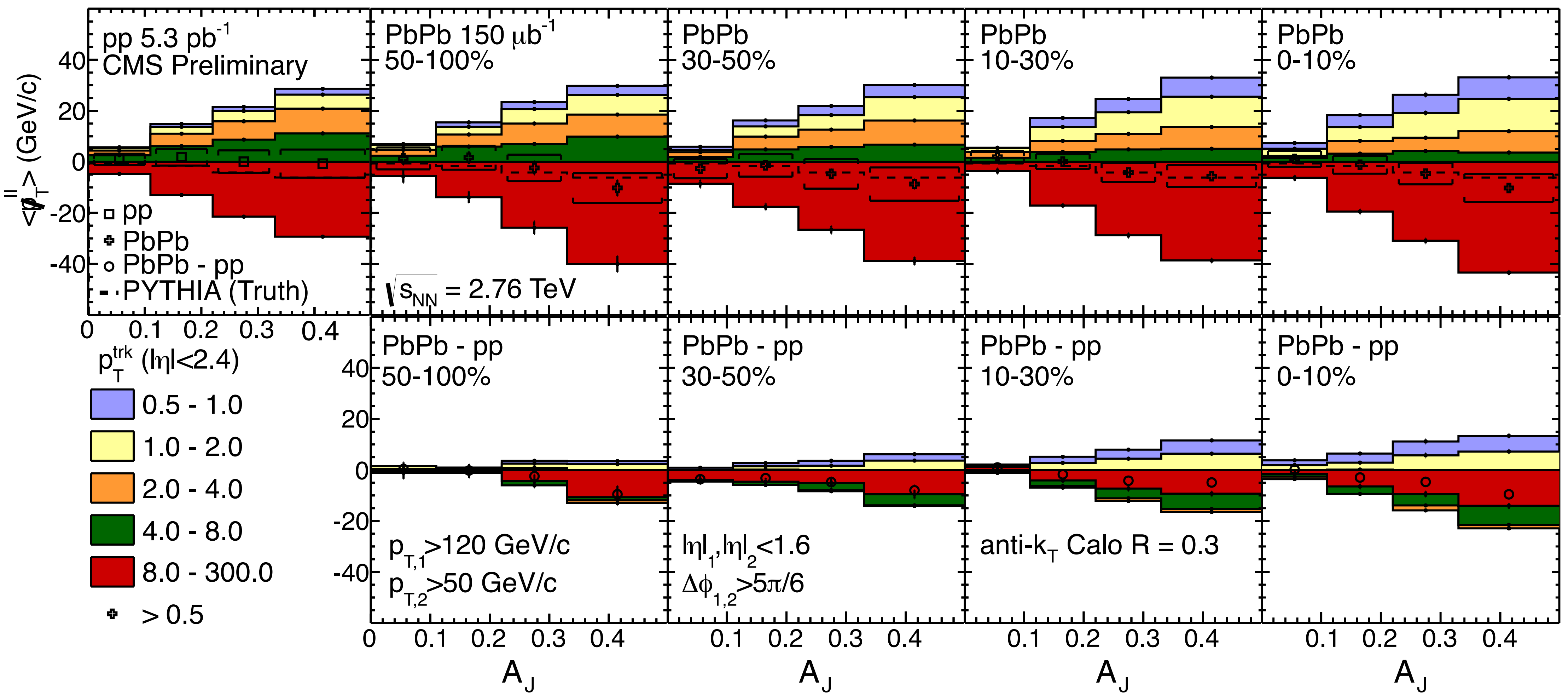

- Compared to pp, see a centrality dependent excess of 0.5 - 2.0 p_T particles towards subleading hemisphere
  - Replace 2.0 - 8.0 p_T particles in pp

Results: Missing p_T v. ΔR (I)

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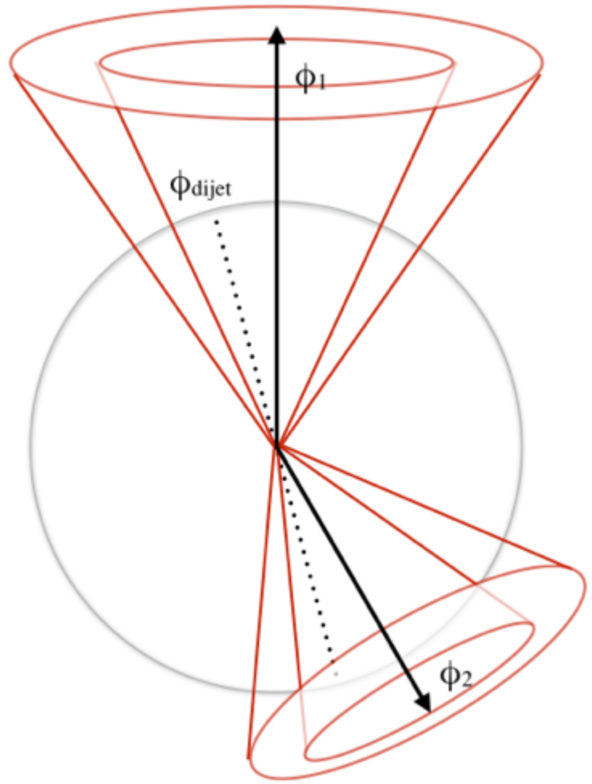

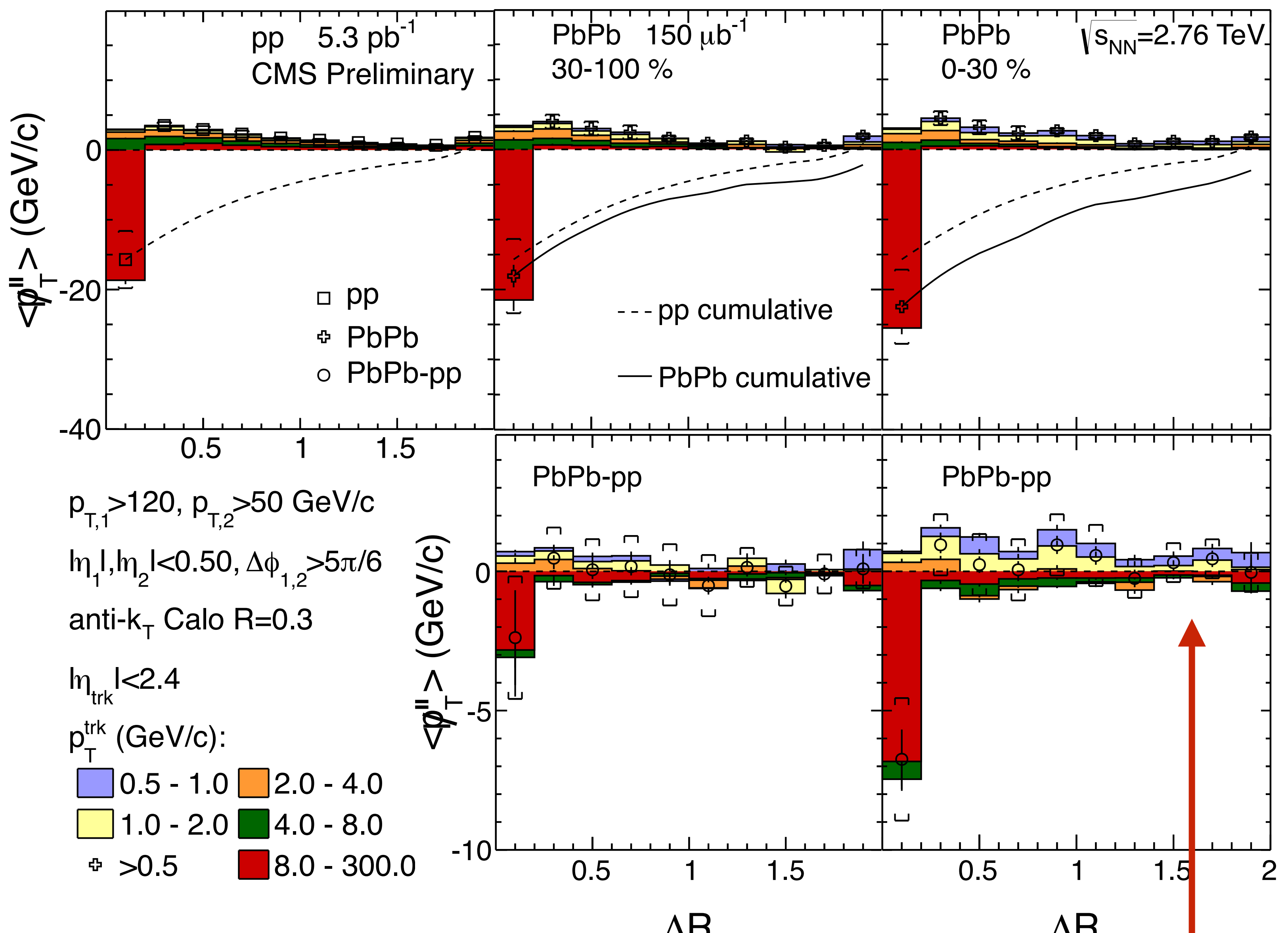

- Inclusive A_J selection
- See a centrality dependent enhancement of low p_T particles in PbPb relative to pp

Results: Missing p_T v. ΔR (II)

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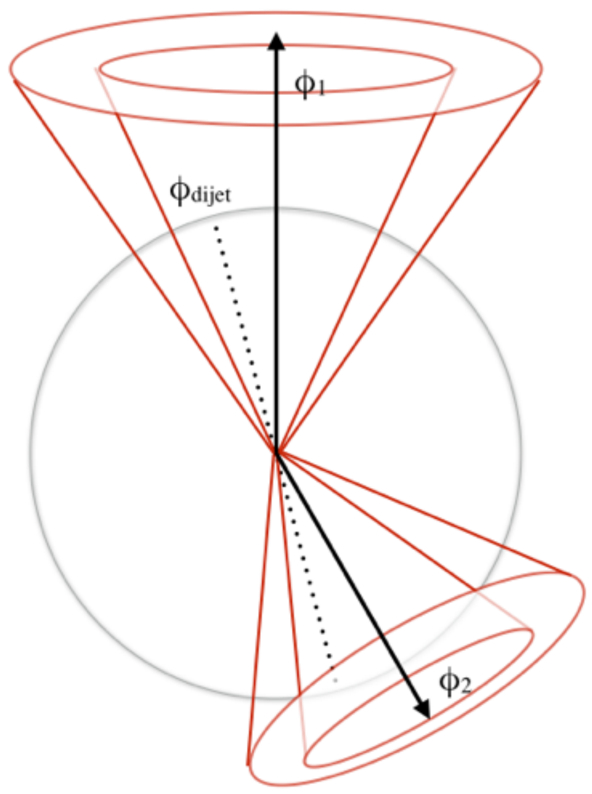

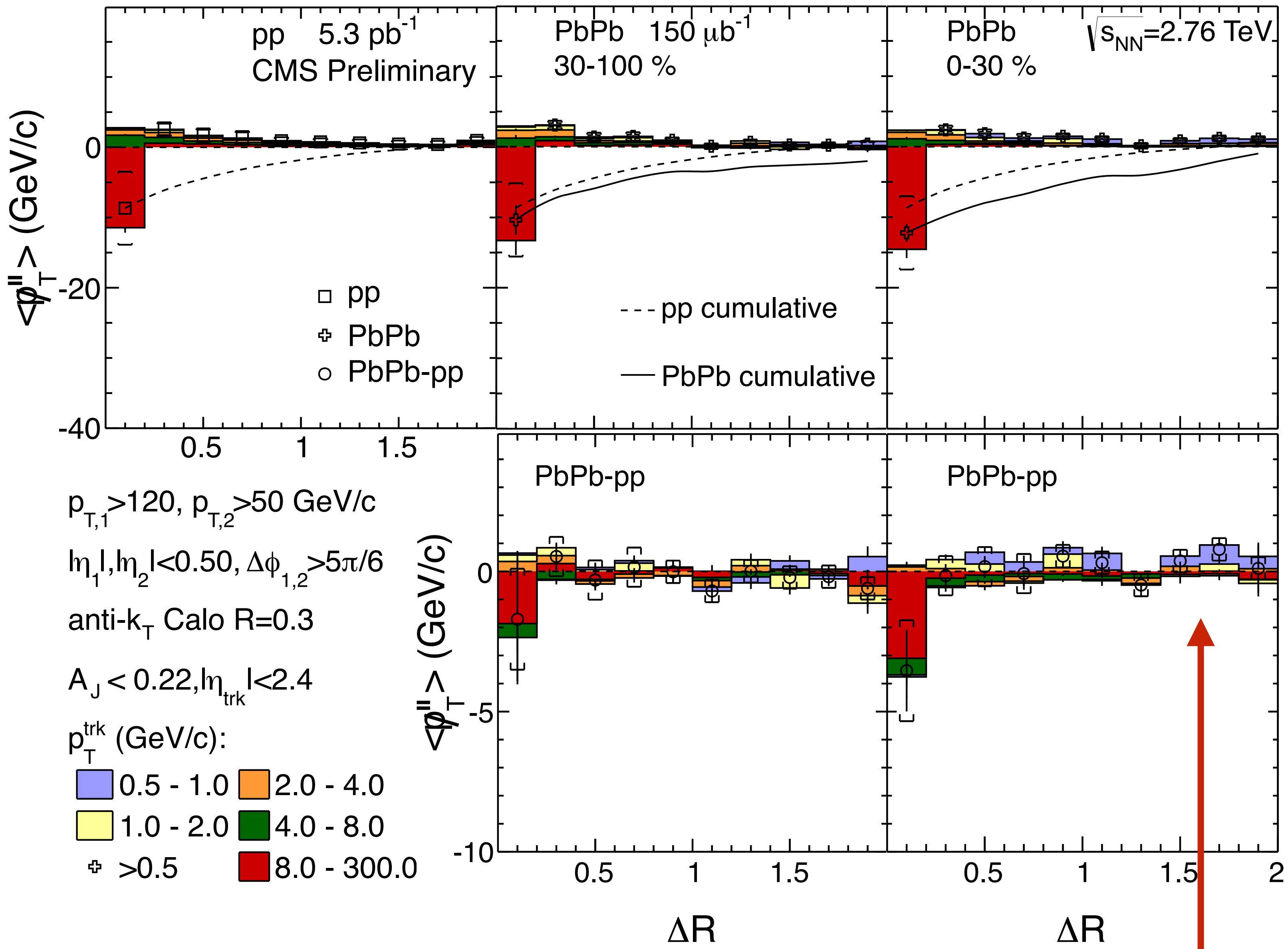

0.5 - 1.0 p_T excess through large ΔR

- $A_J < 0.22$ 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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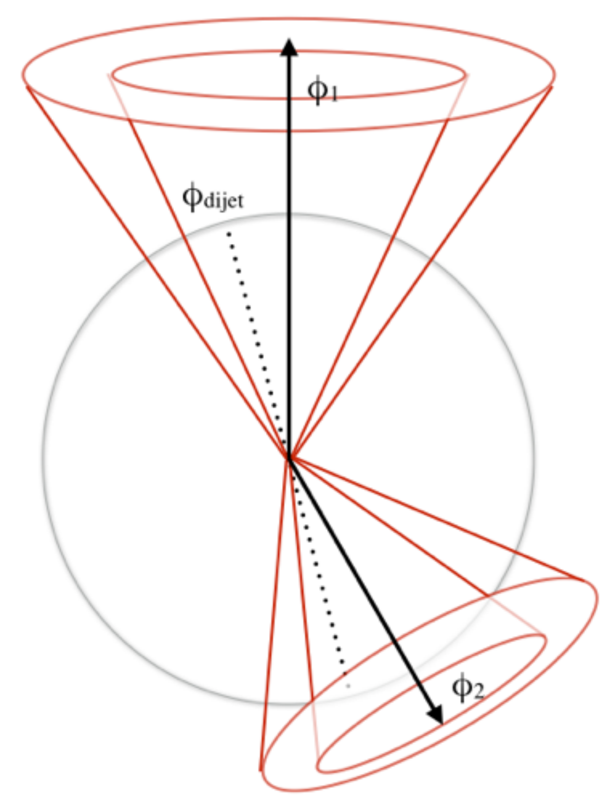

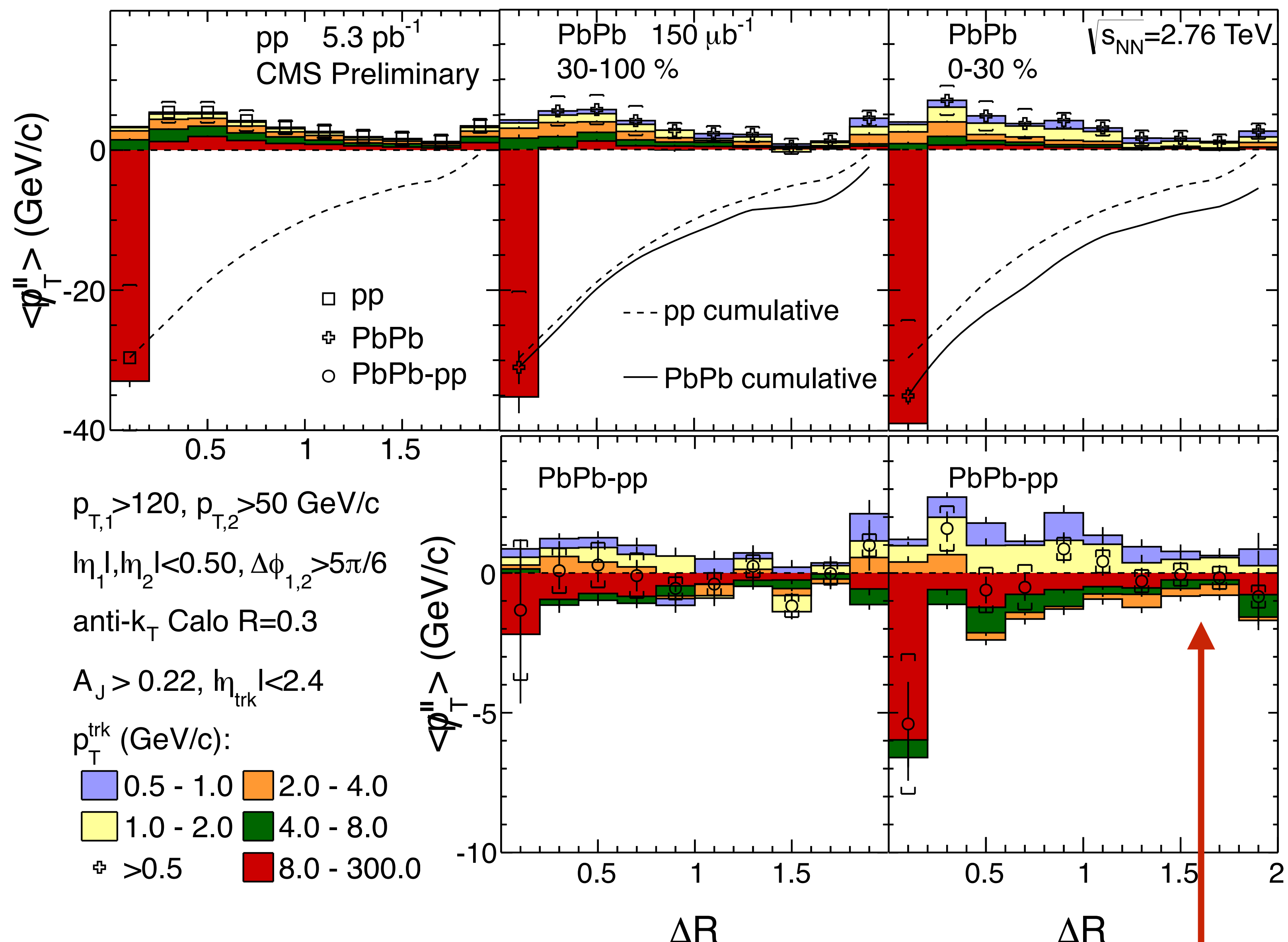

1.0 - 2.0 p_T excess through large ΔR

- $A_J > 0.22$ 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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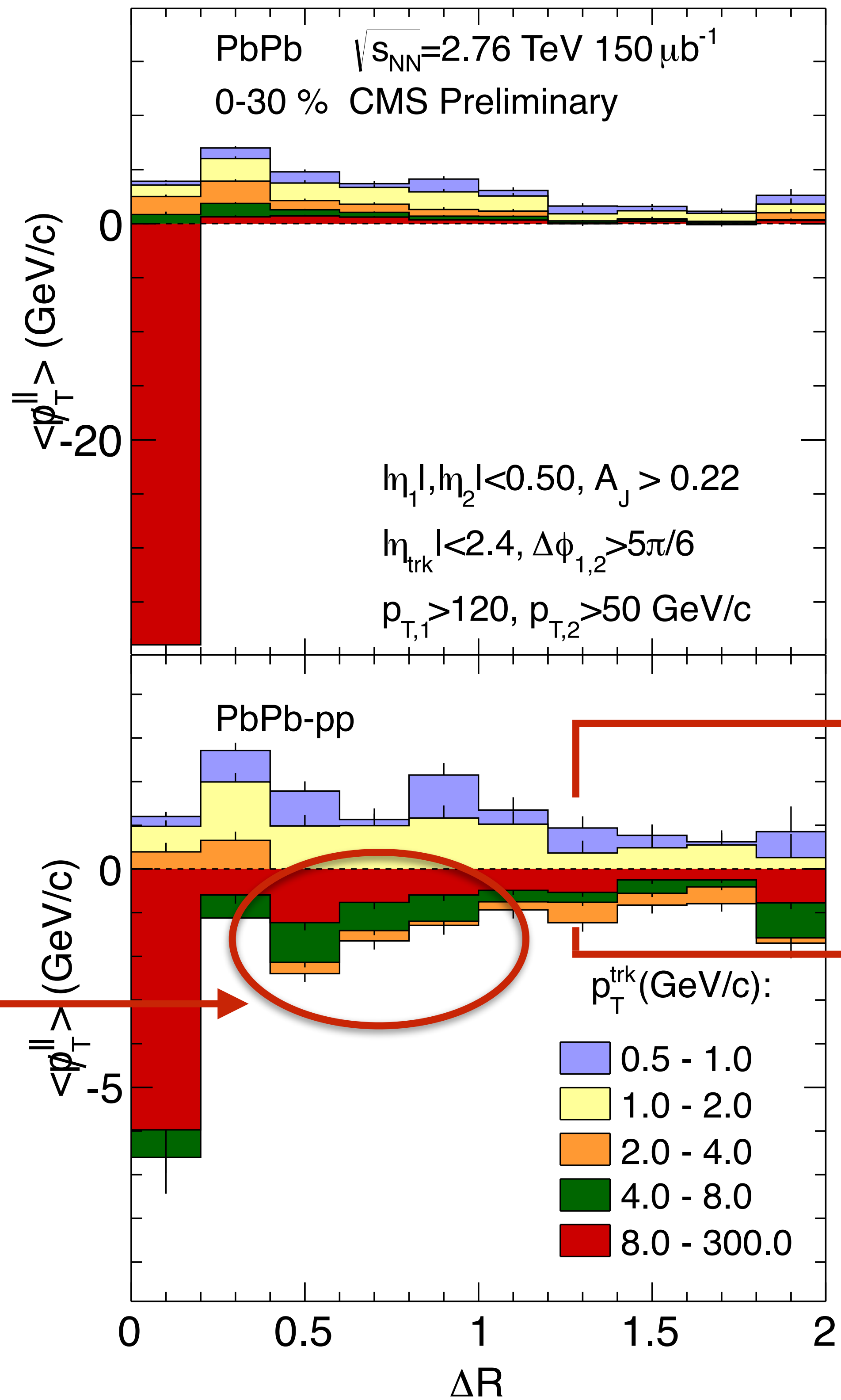

0.5 - 2.0 GeV/c p_T balances in PbPb

2.0 - 8.0 GeV/c p_T balances in pp

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

Results: Missing p_T v. ΔR (V)

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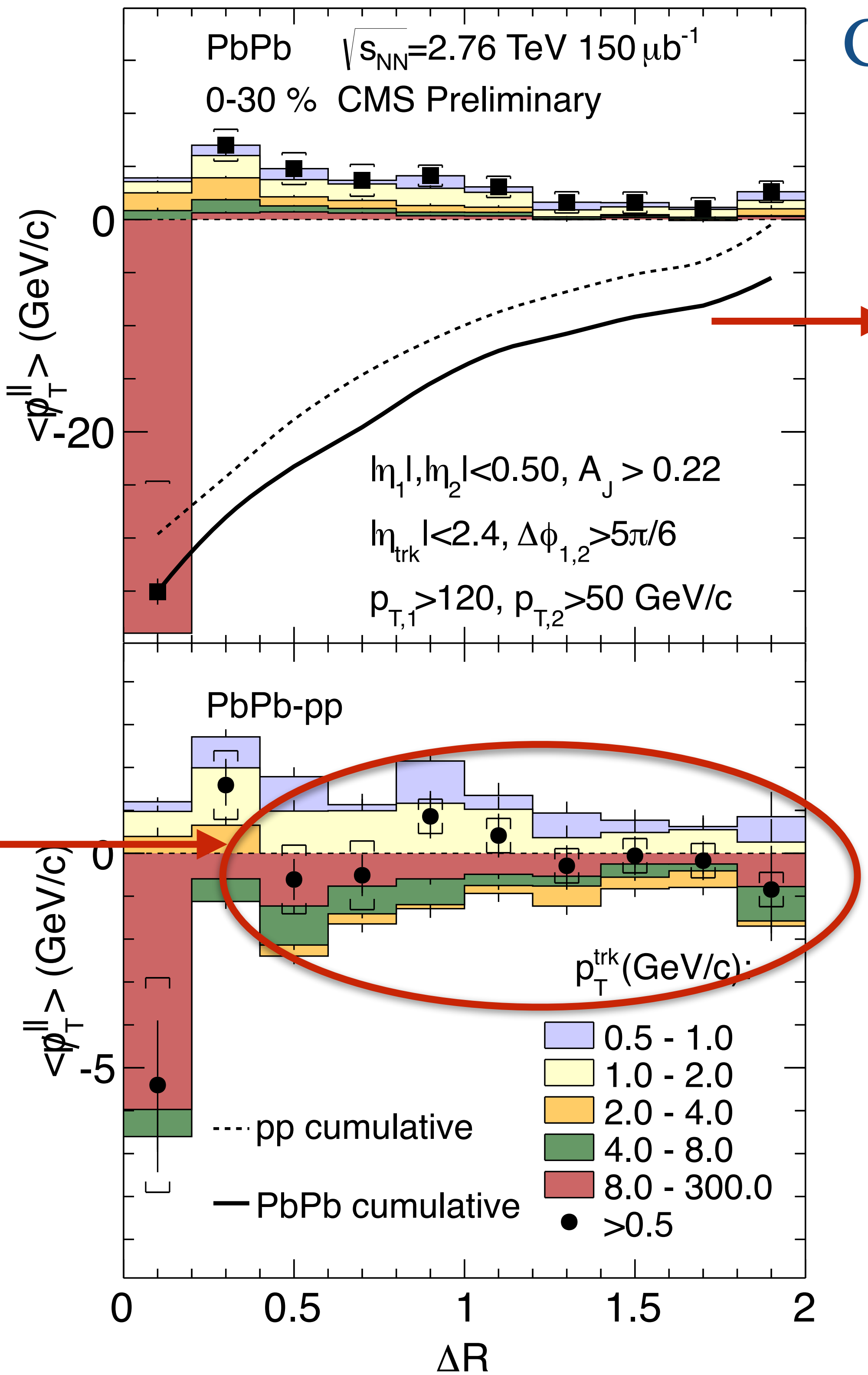
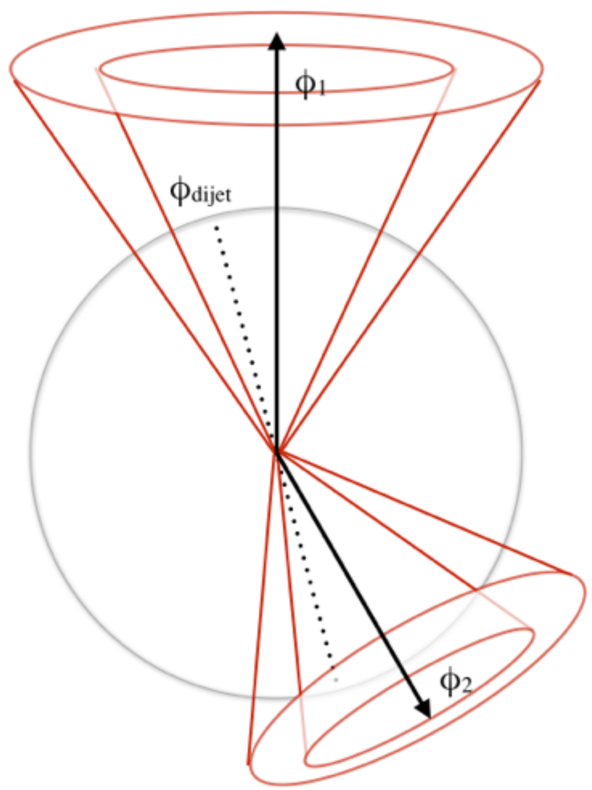


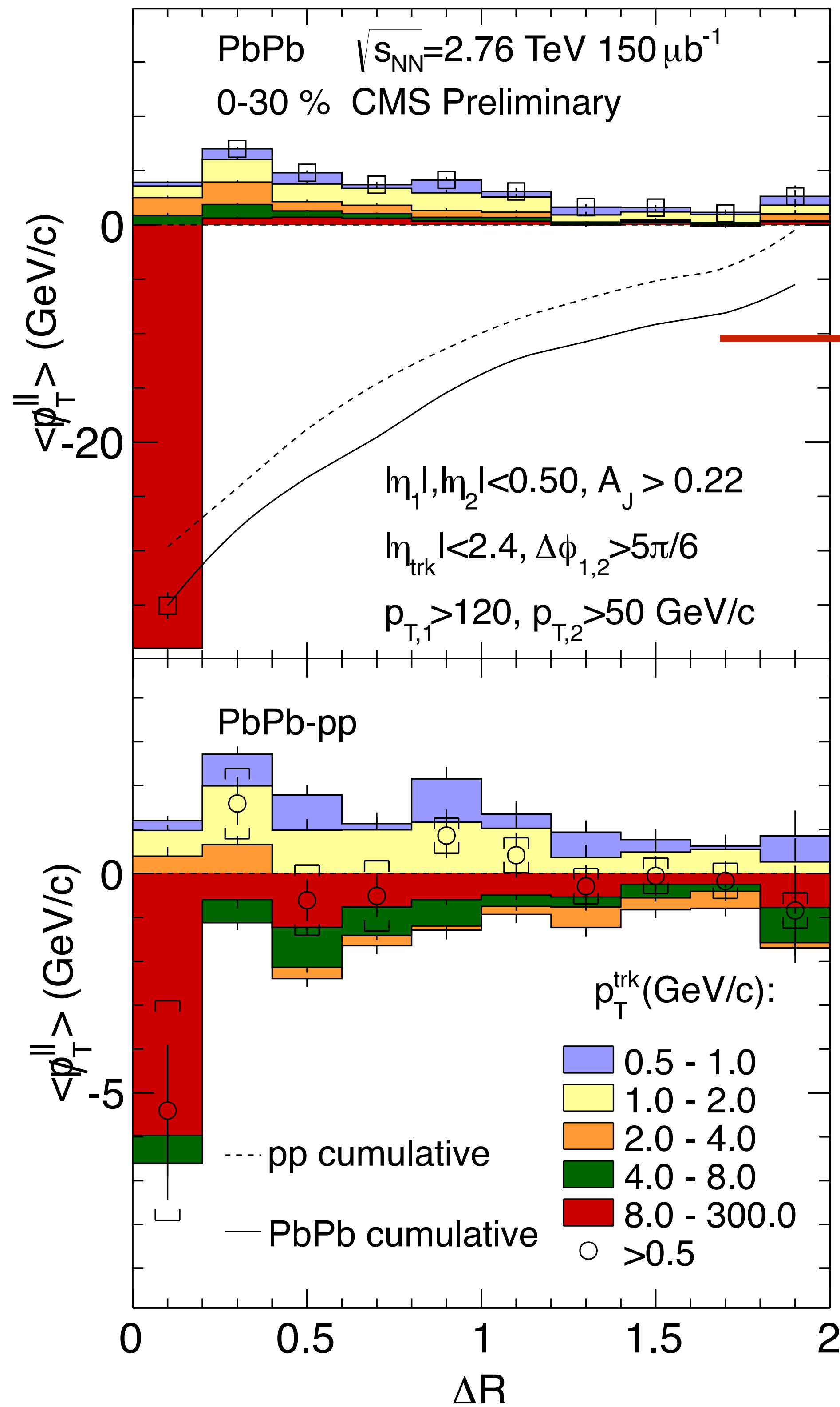
Curves of integrated missing p_T similar shape, adjust starting point?

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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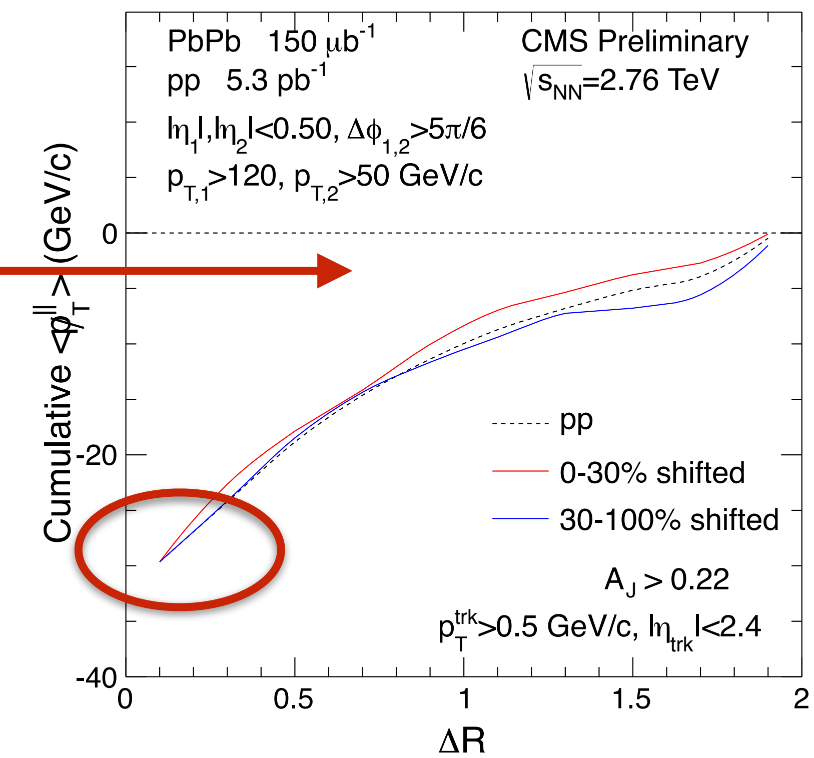

Adjusting for starting point, curves in PbPb and pp approximately the same

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
    - Integrated curve very similar after adjusting first bin
- Currently pursuing generator comparisons:
  - Particularly for ΔR distribution, look for low p_T enhancement through large angles and integrated curves
  - Working with generator authors to integrate into framework useable by CMS collaboration in spirit of Lisbon Accord (I believe our next topic?)

Backup

Backup: Gen. Pythia w/ Cuts

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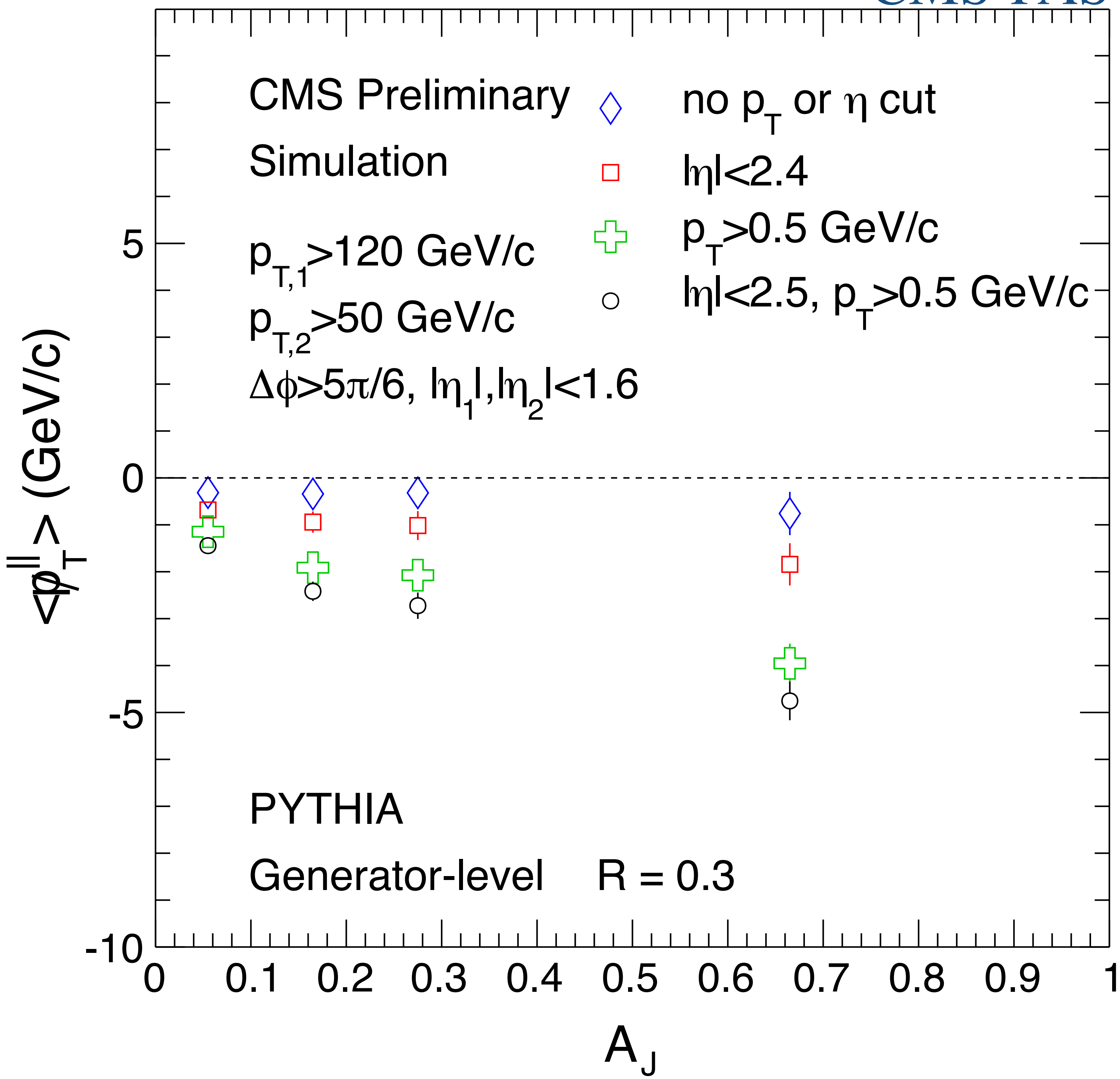

Backup: Jet p_T scale and resolution

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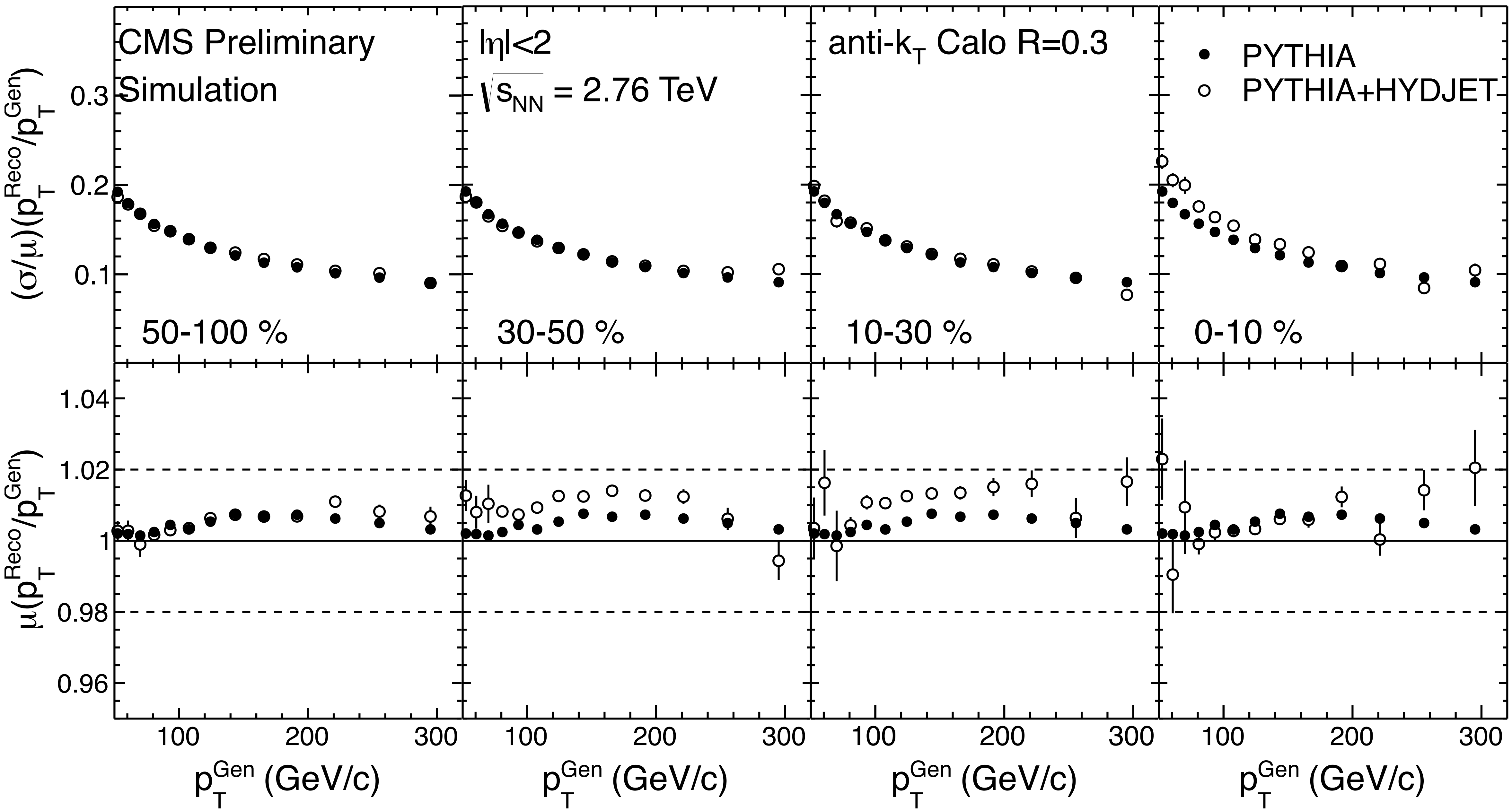
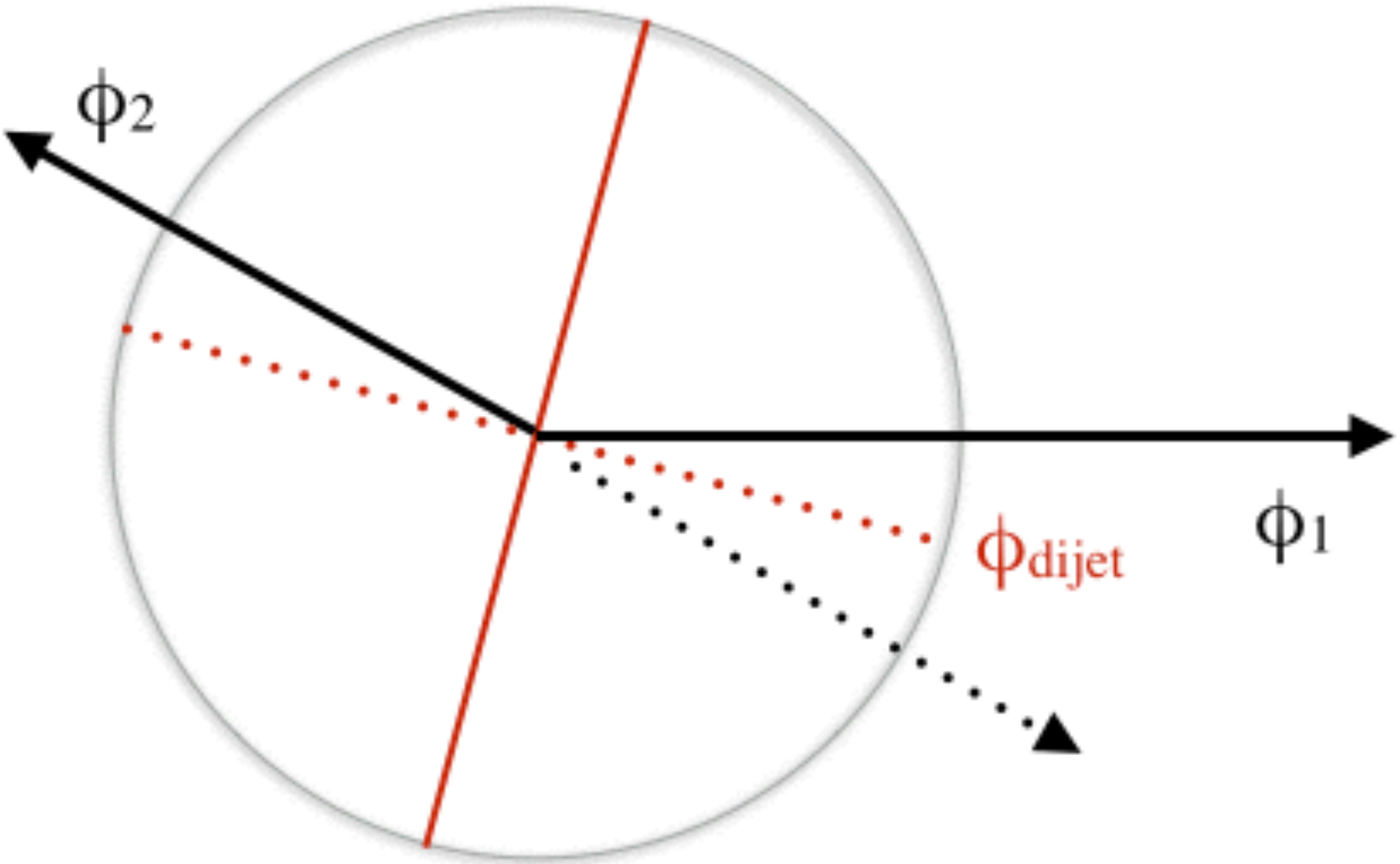
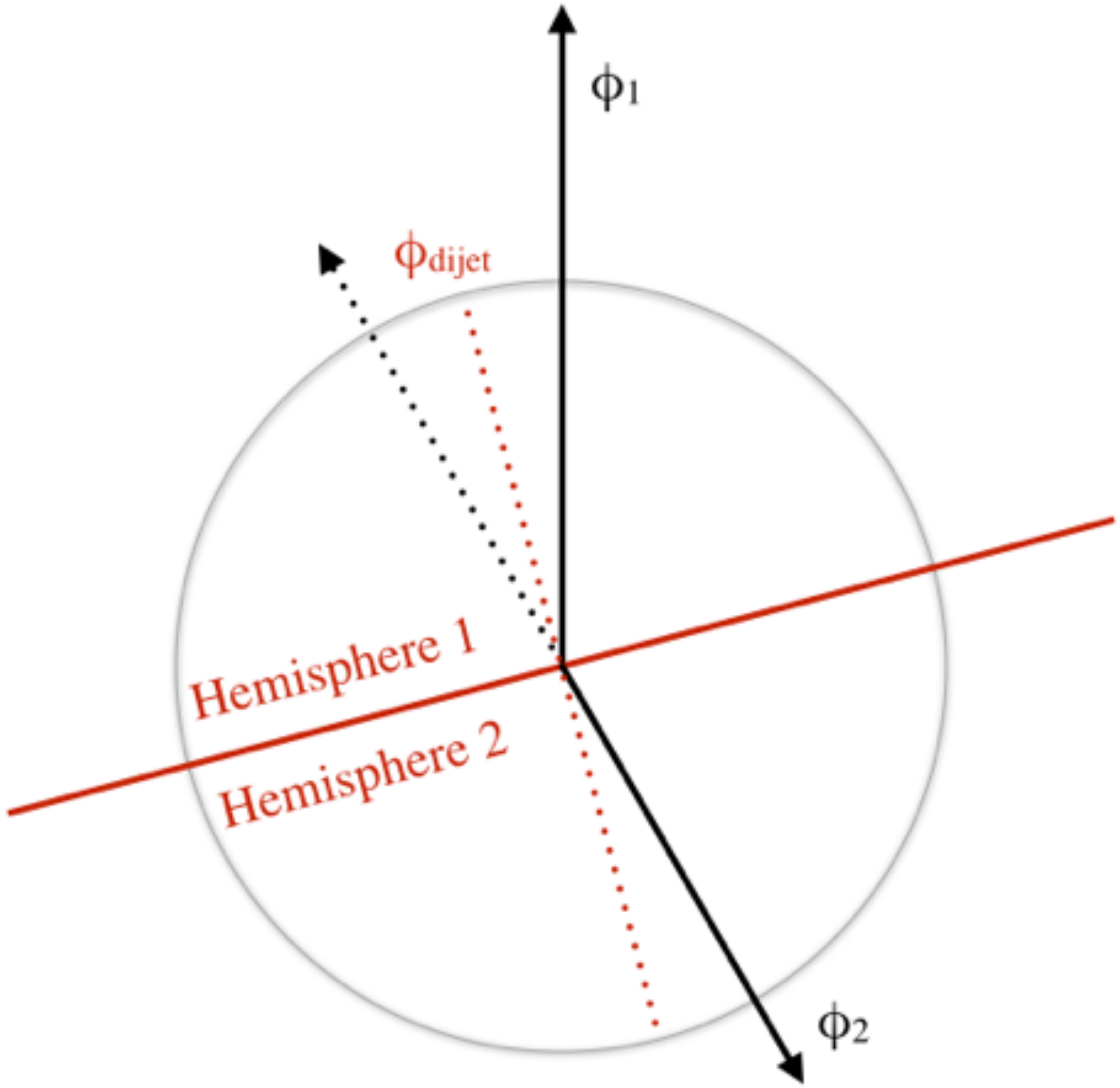


Observables: A cartoon picture (II)

Define dijet axis as bisecting axis between leading and flipped subleadi





Hemispheres defined w.r.t. axis perpendicular to dijet

Backup: In-Cone

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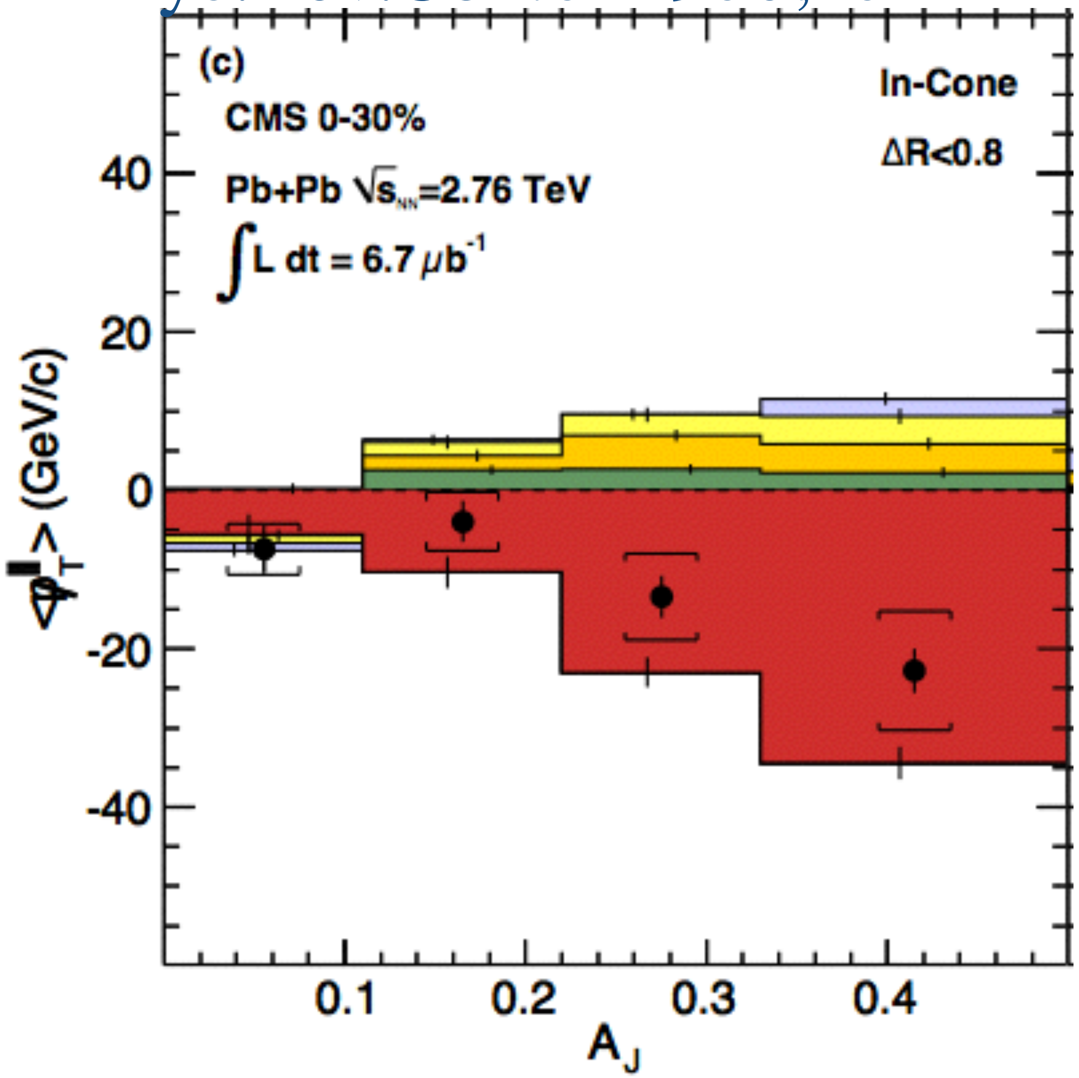

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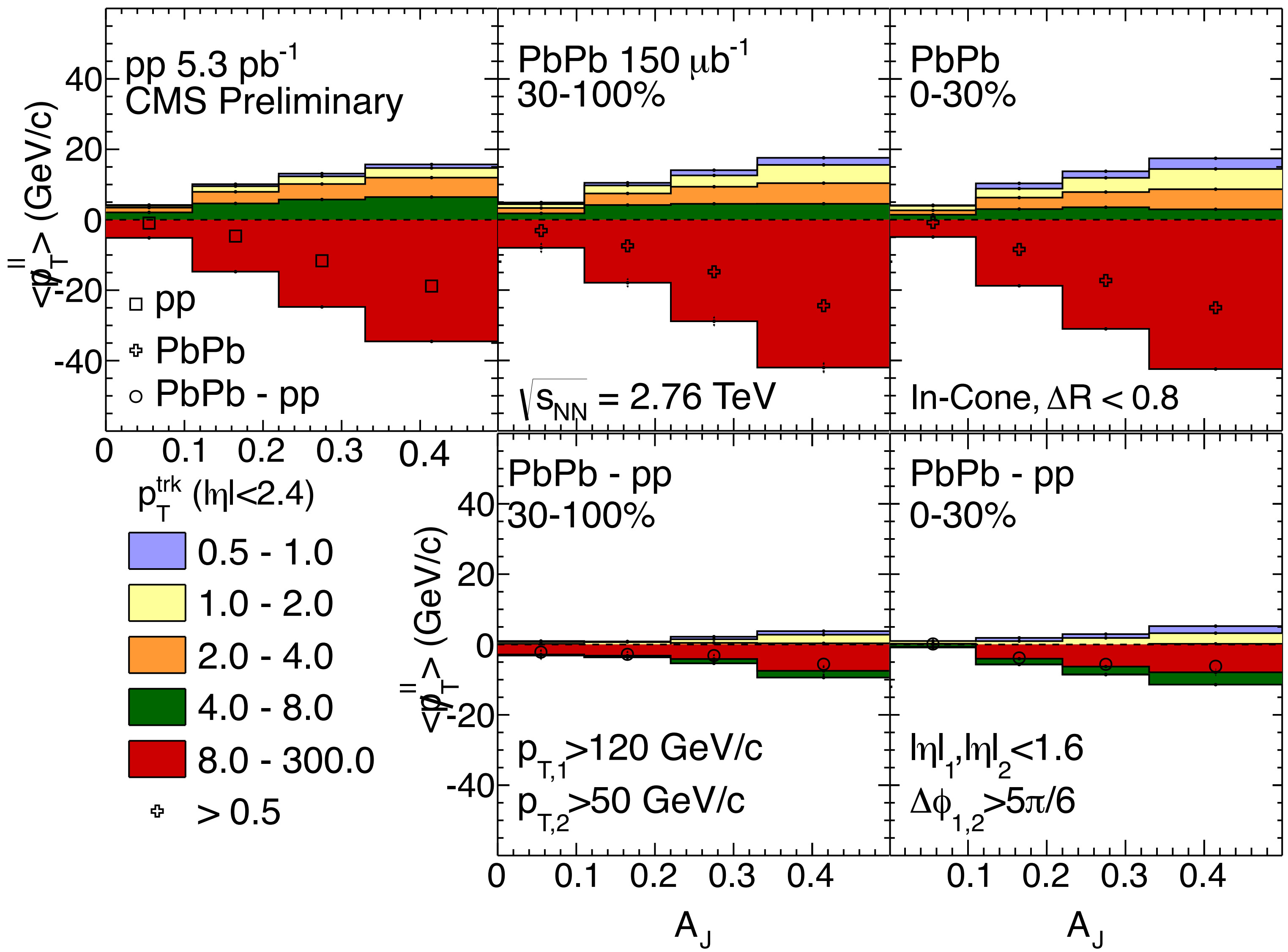

Backup: Out-Cone

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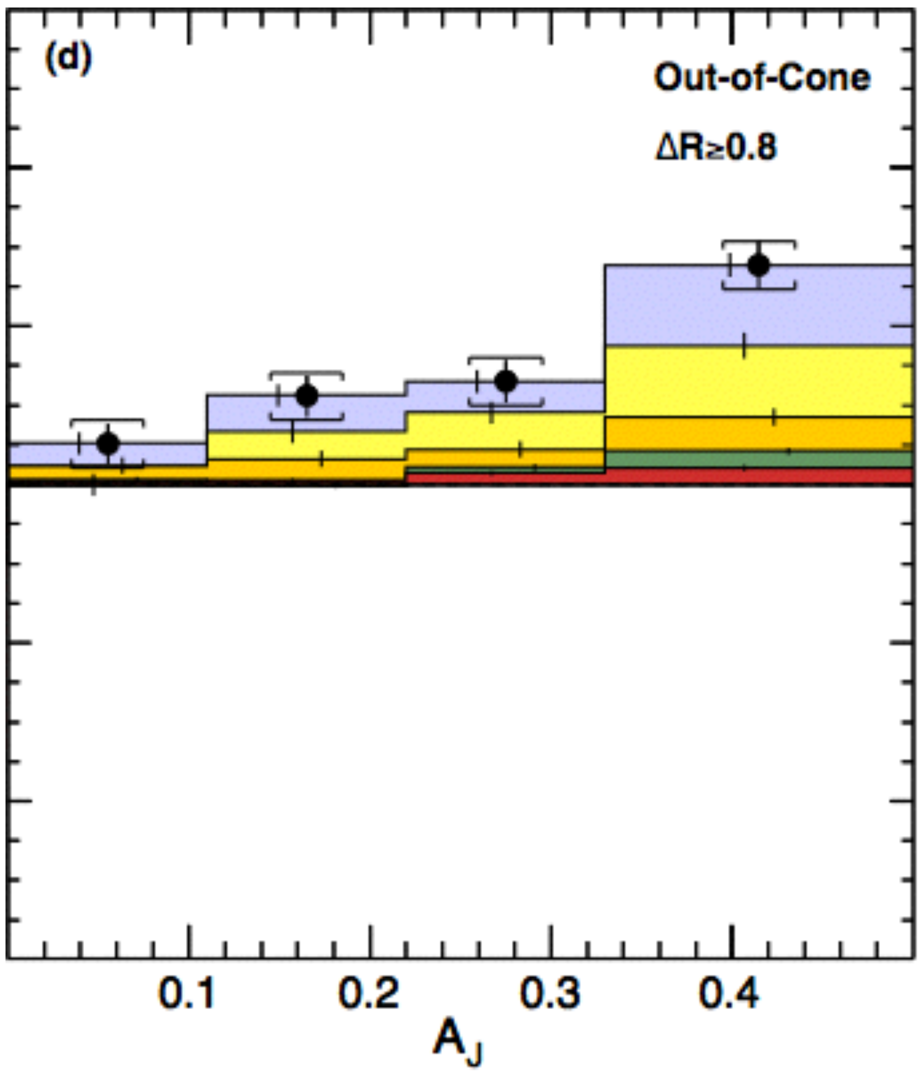

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