Study of medium response and electroweak probes with the CMS collaboration

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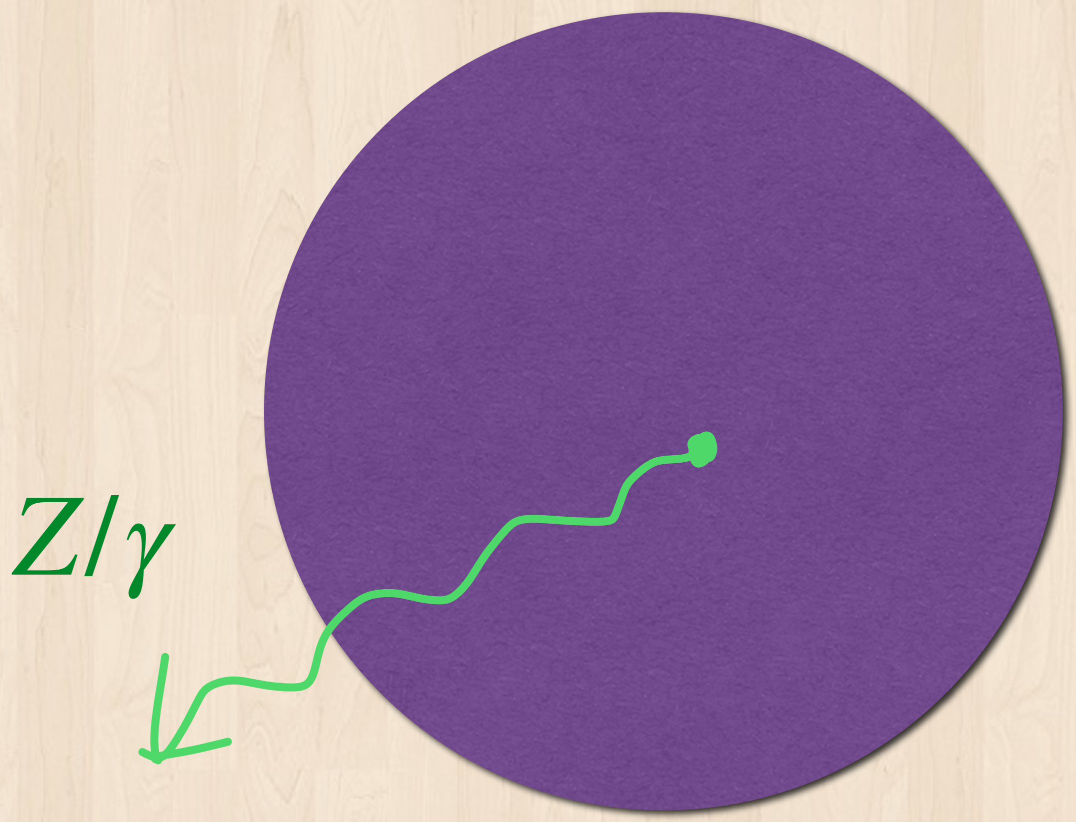
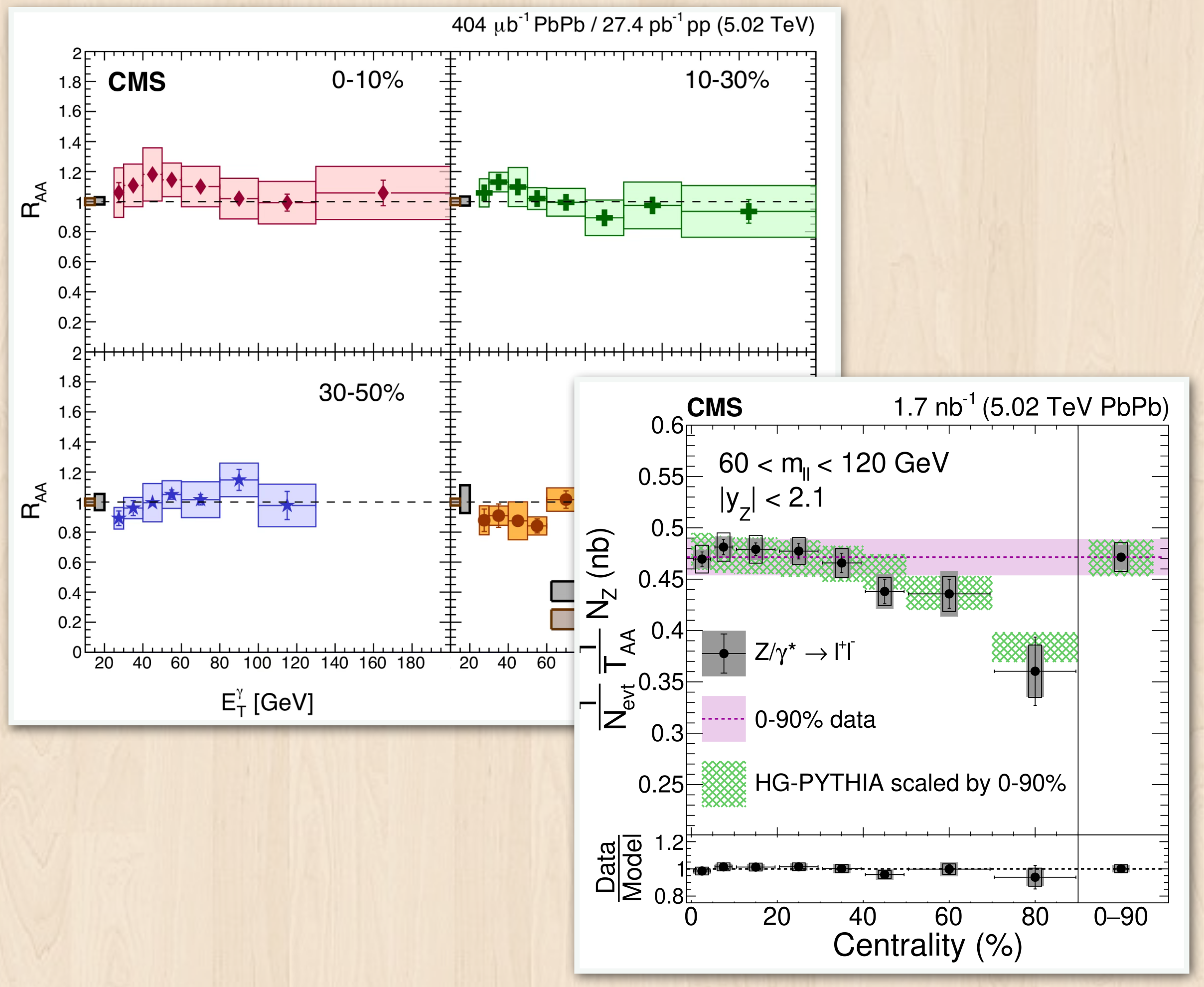
The Vanderbilt HENP group's work is supported by US DOE-NP

Electroweak probes

Unique probe of QGP





Electroweak probes do not interact strongly with QGP

when we go to high energy, QGP effects are minimal

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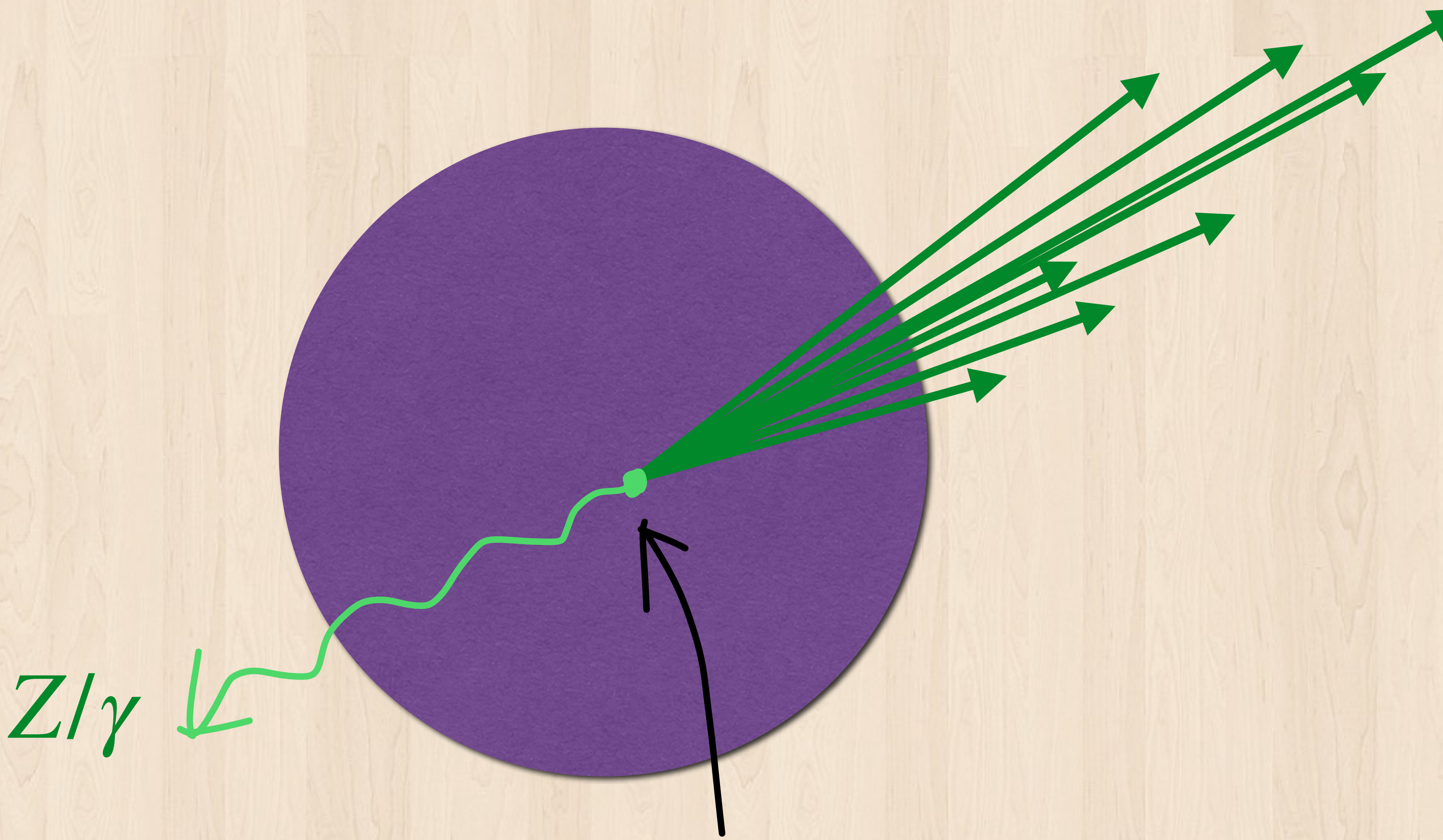
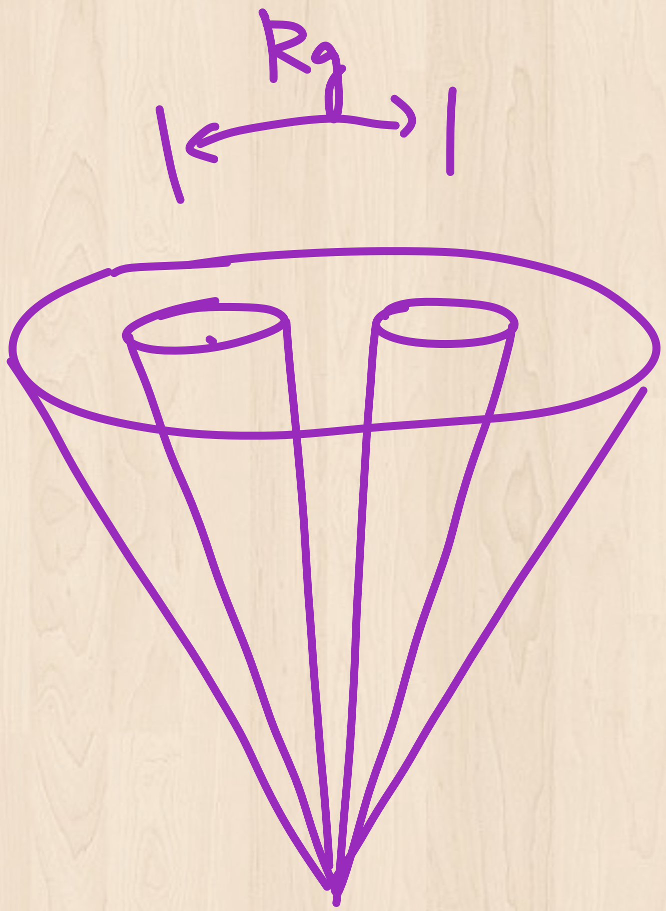
Tagging initial collision



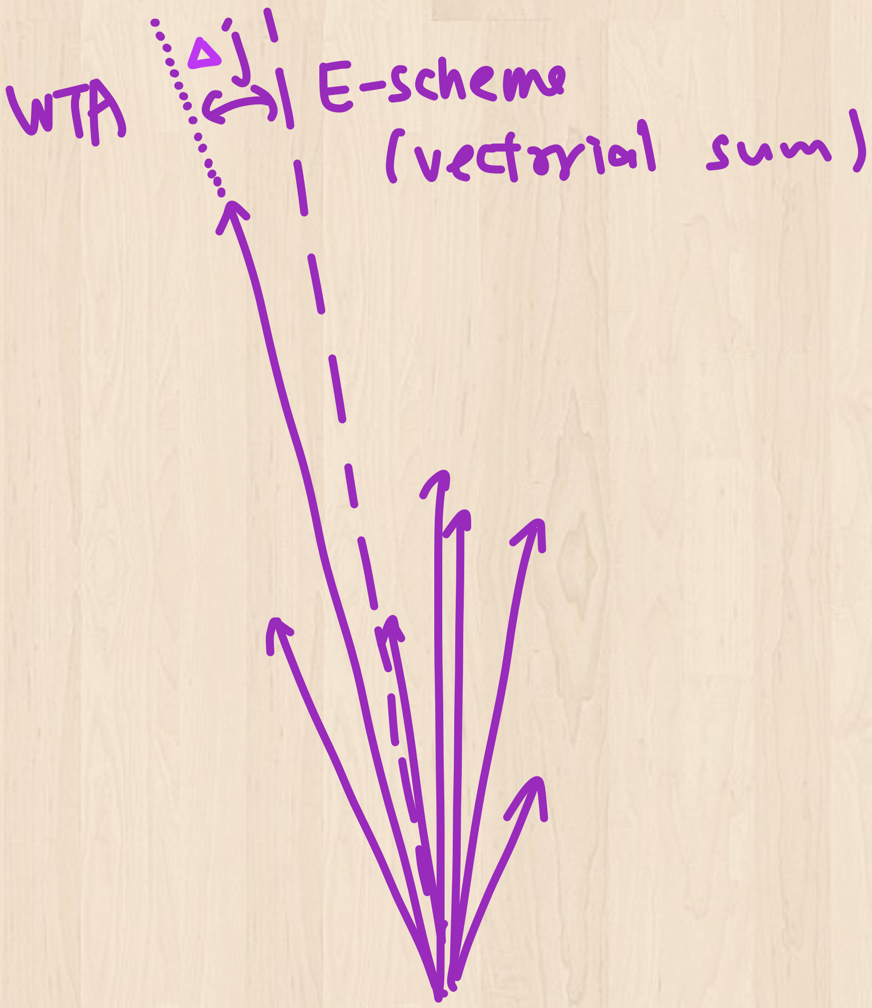
They can serve as excellent tag to tell us something about this hard process vertex

e.g. Z/γ+jet, or even Z/γ+X

Observable: examples



Groomed angle



Axis difference
WTA/E-scheme

Observable: examples

Remove wide angle soft energy

opening **angle** of identified **hard core**

Groomed angle

WTA: insensitive to random soft energy

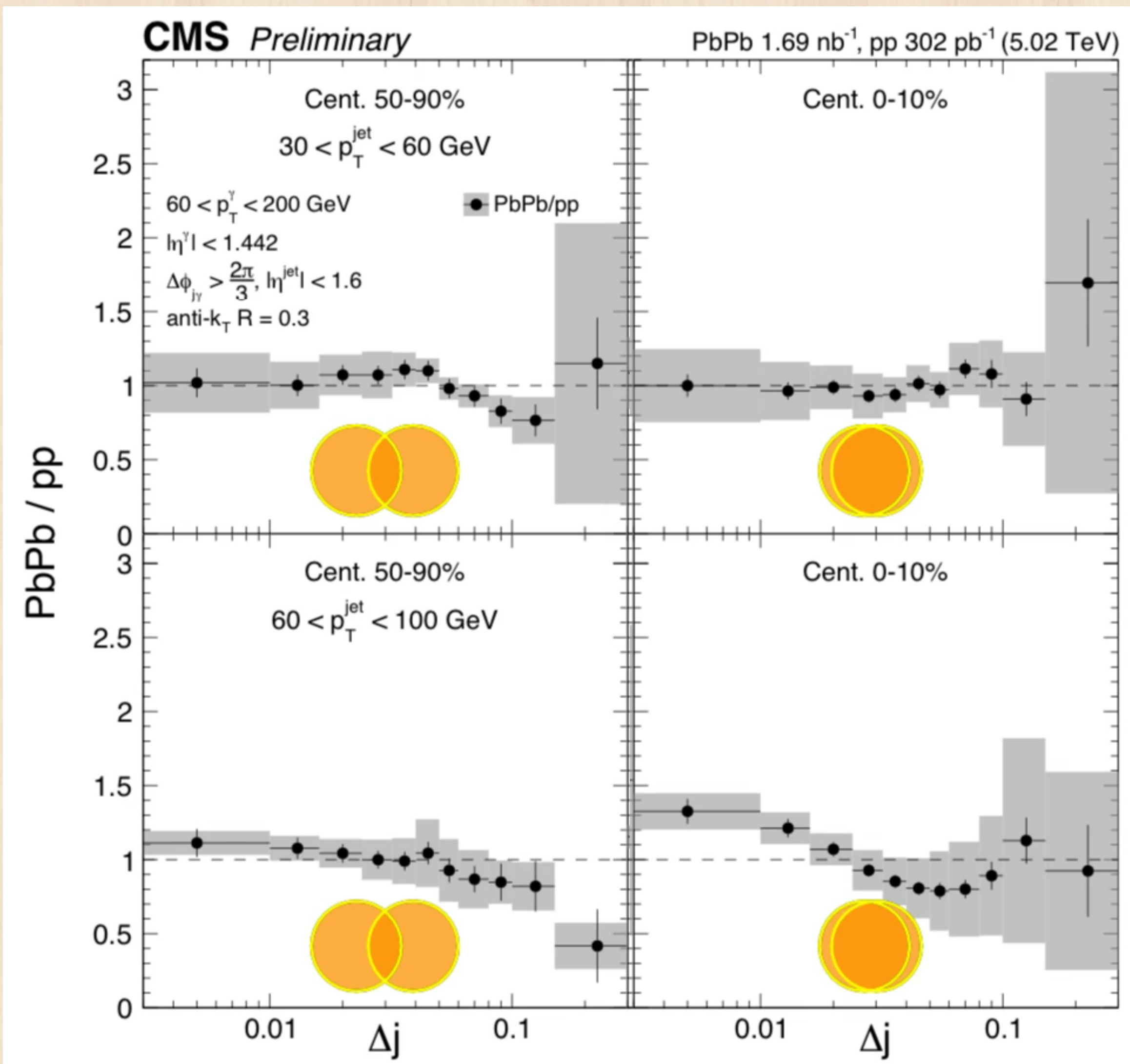
E-scheme: can be smeared around by soft particles

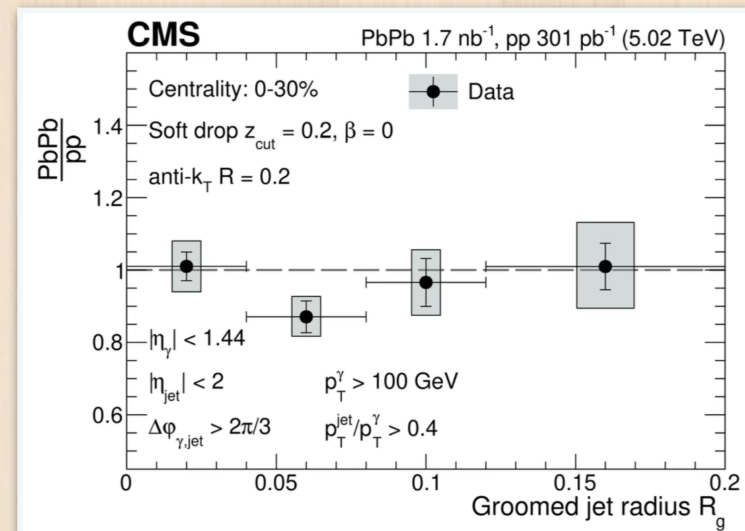
Difference = how much (E-scheme) axis gets **smeared** around

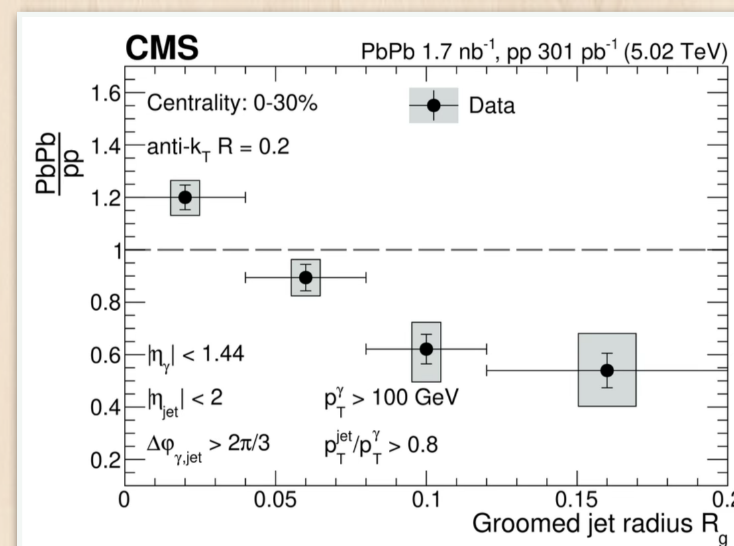
Axis difference WTA/E-scheme

Results

Looser selection on jets = different trend







More similar to inclusive jets

Tighter selection on jet = larger selection effect
= narrowing effect reproduced

Electroweak probe as tags

- Electroweak probes can be used as tags
  - They provide a **new experimental dial** where we can study the jet quenching effects in more details
- See Molly's talk for further information on R_G and Δj

Wake effect search

HP 2024

RIDING THE WAKE

Wake effect

- Analyses isolating the effect with different methods

- Before going to the results I will go through some of them and compare the differences among the analyses

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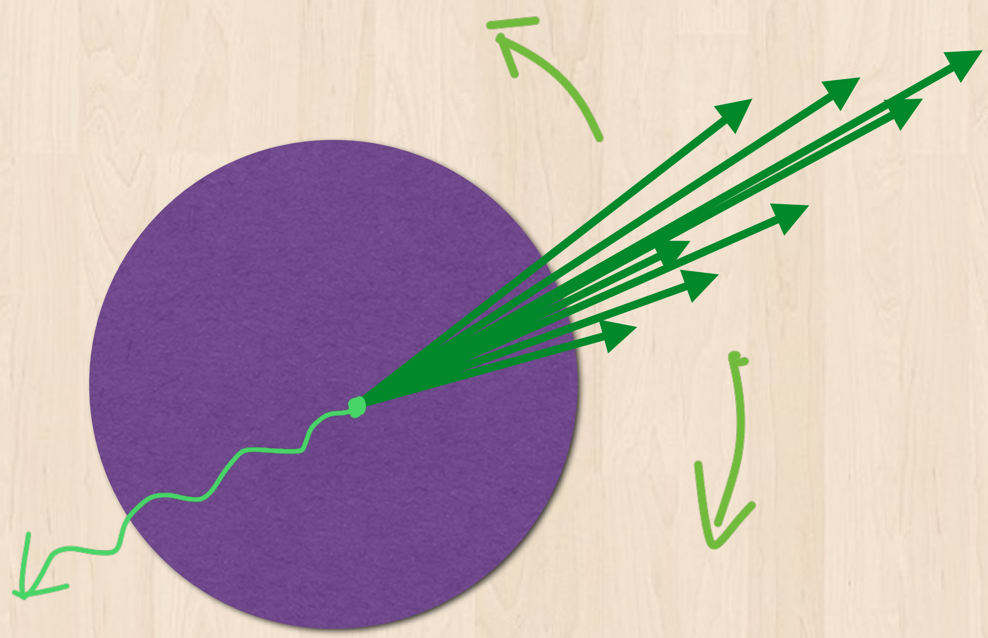
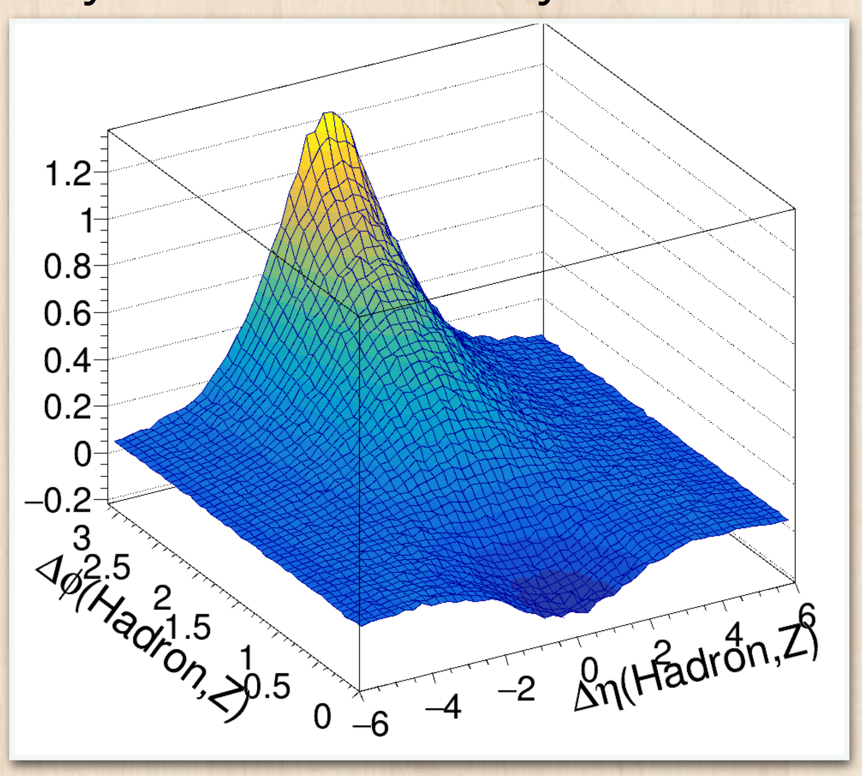
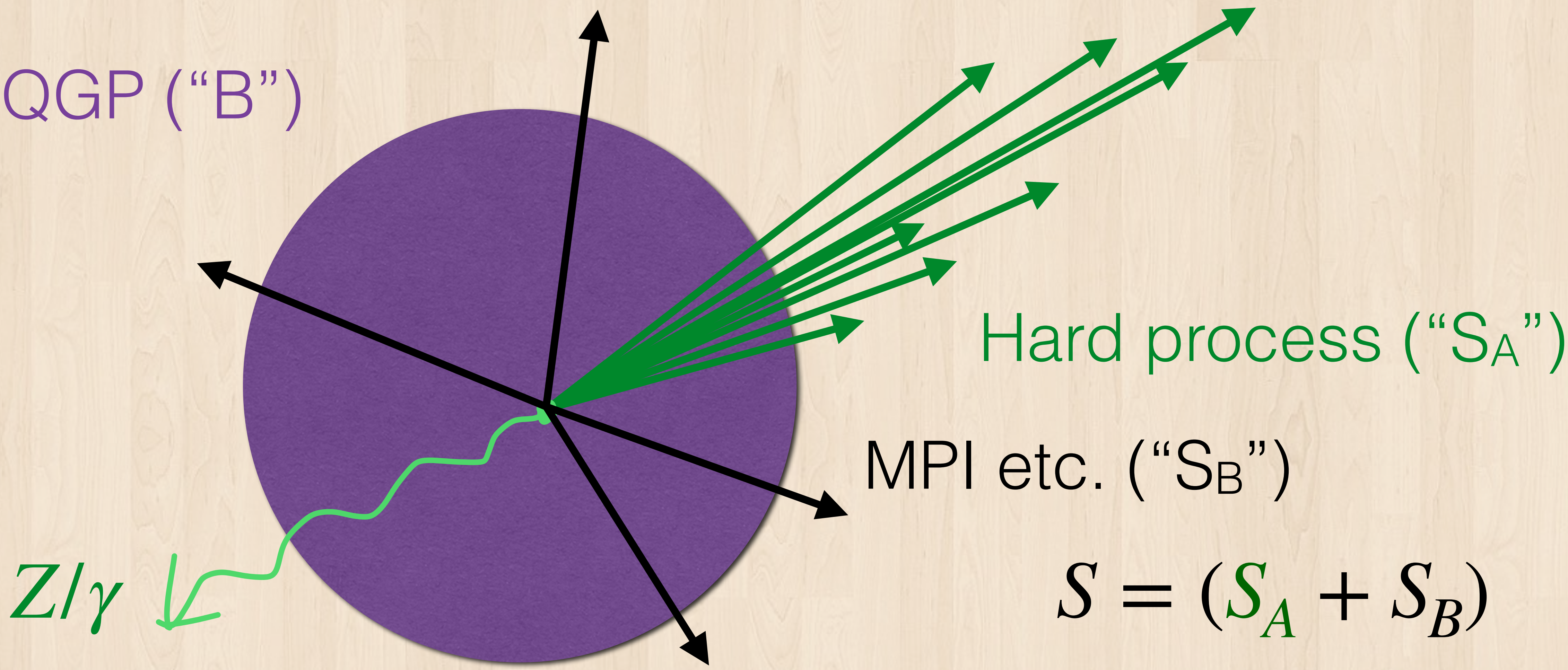


Hybrid wake-only



Pablos, Rajagopal, Lee

Different components



$$S = (S_A + S_B)$$

S: everything that arises because of the existence of the high-Q^2 collision

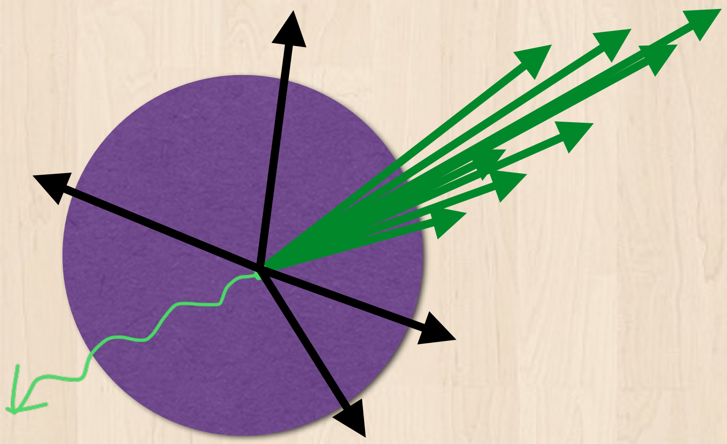
S_A: things directly linked to the hard process

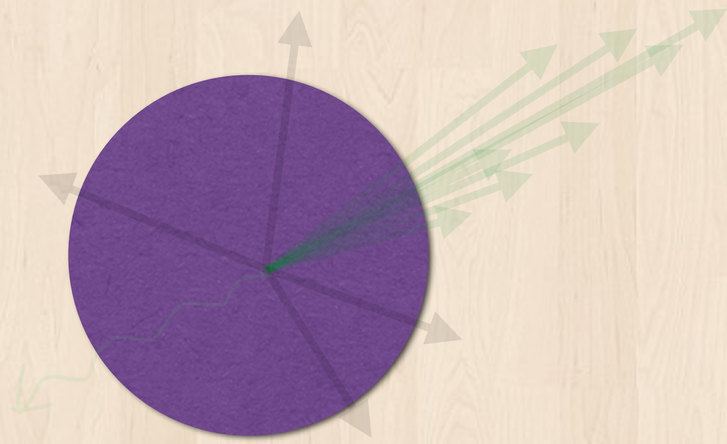
Z-hadron (CMS, 2021)

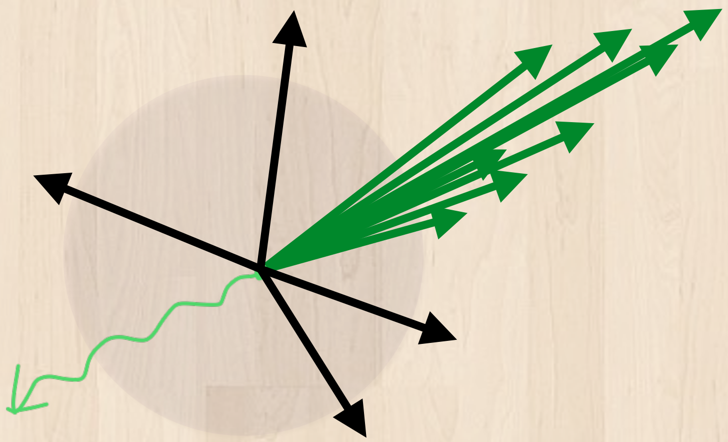
Find Z events (S+B)

Find B event compatible to signal sample (B)

Subtract and study the “pure-S” contribution



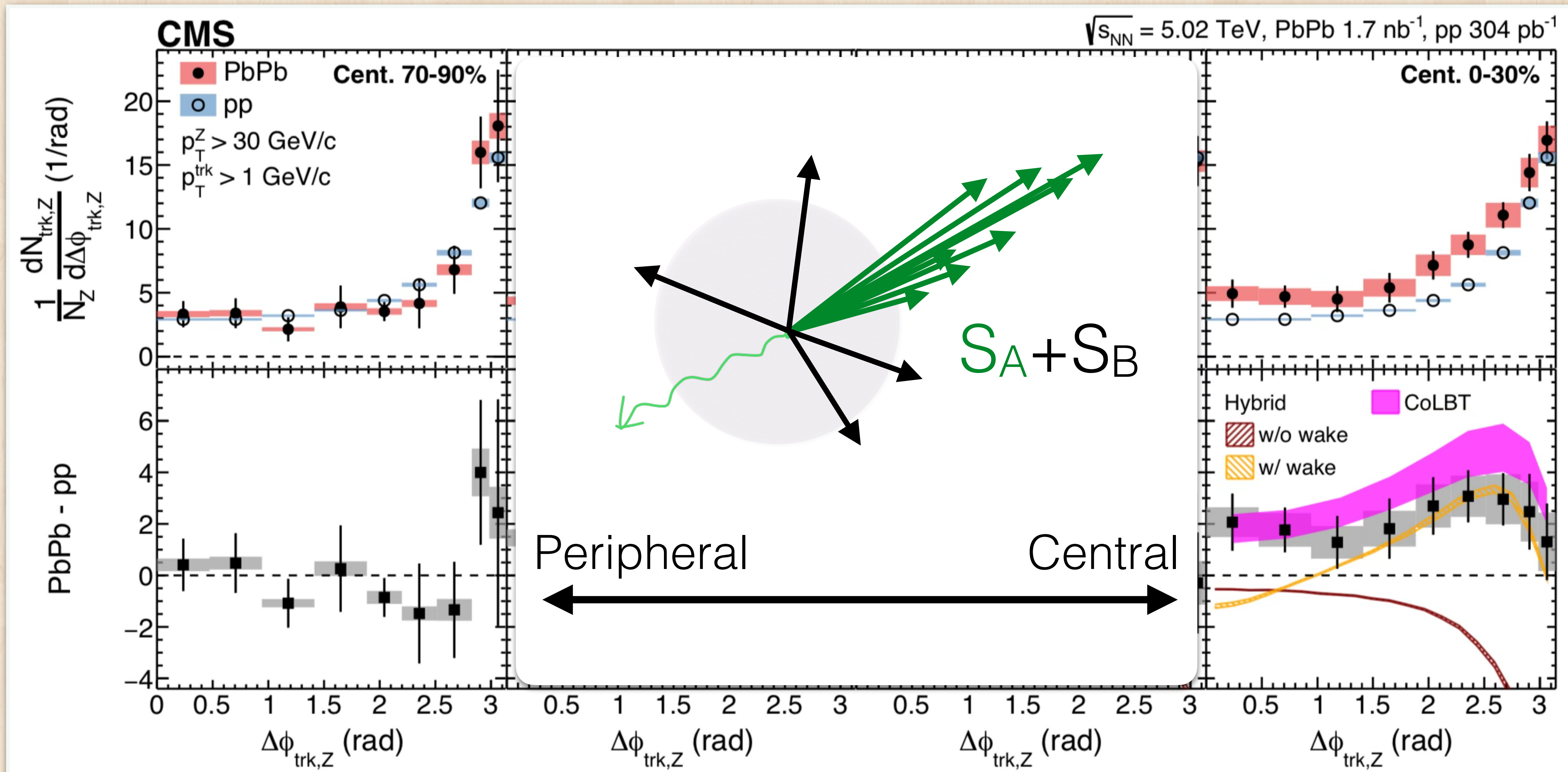




Do not require jets

PRL 128 (2022) 122301

Z-hadron (CMS, 2021)



MPI energy (SB) thermalized and increase particle count

Shape of SA drowned by SB

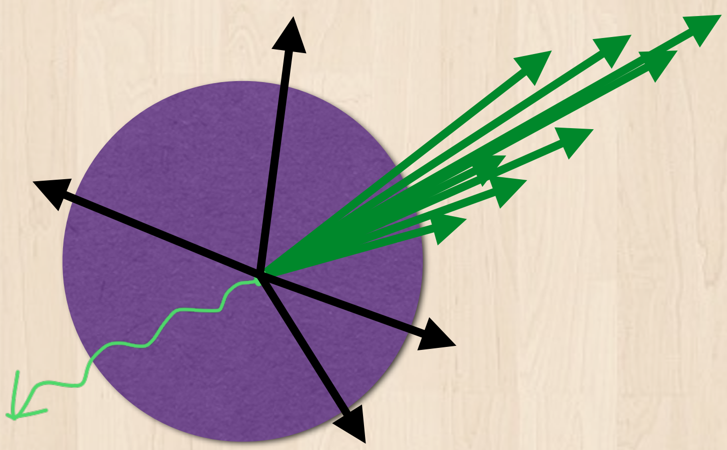
PRL 128 (2022) 122301

Photon-jet (ATLAS, 2023)

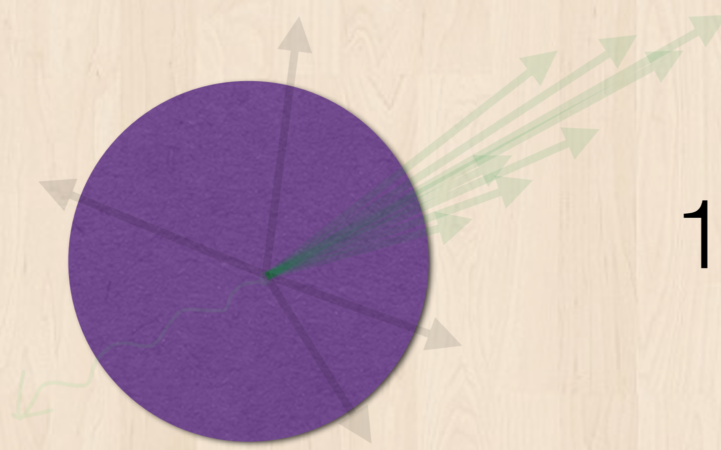
Find γ events (S+B)

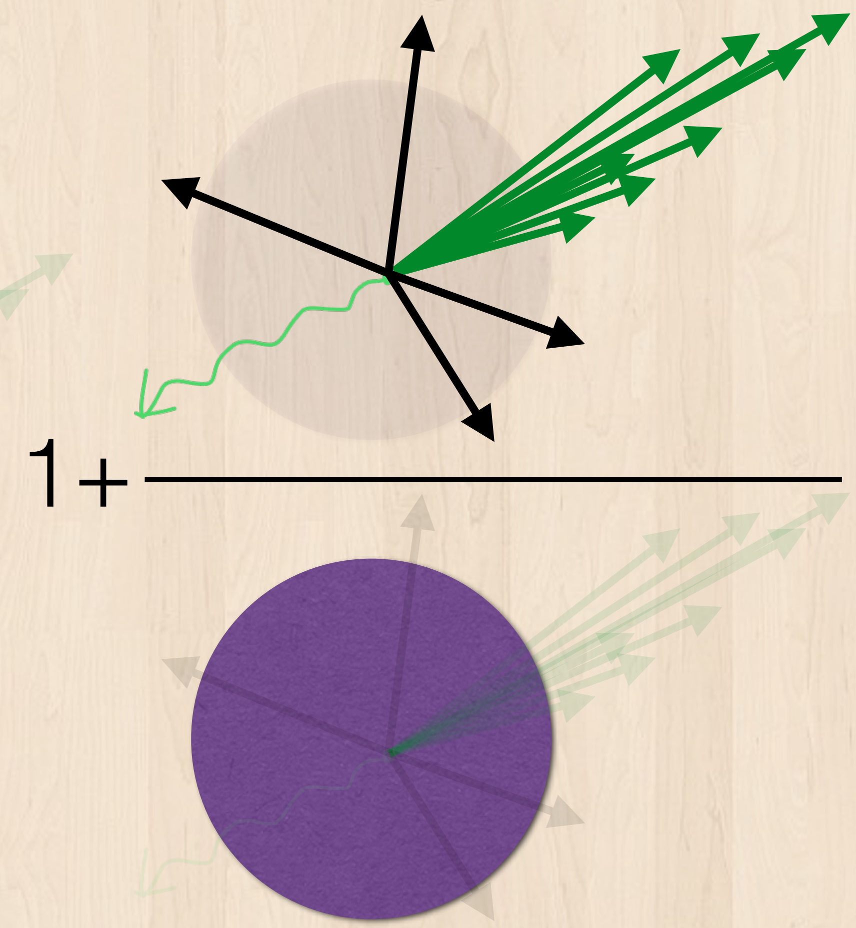
Build pure-B contribution through event mixing

Divide and search for effects



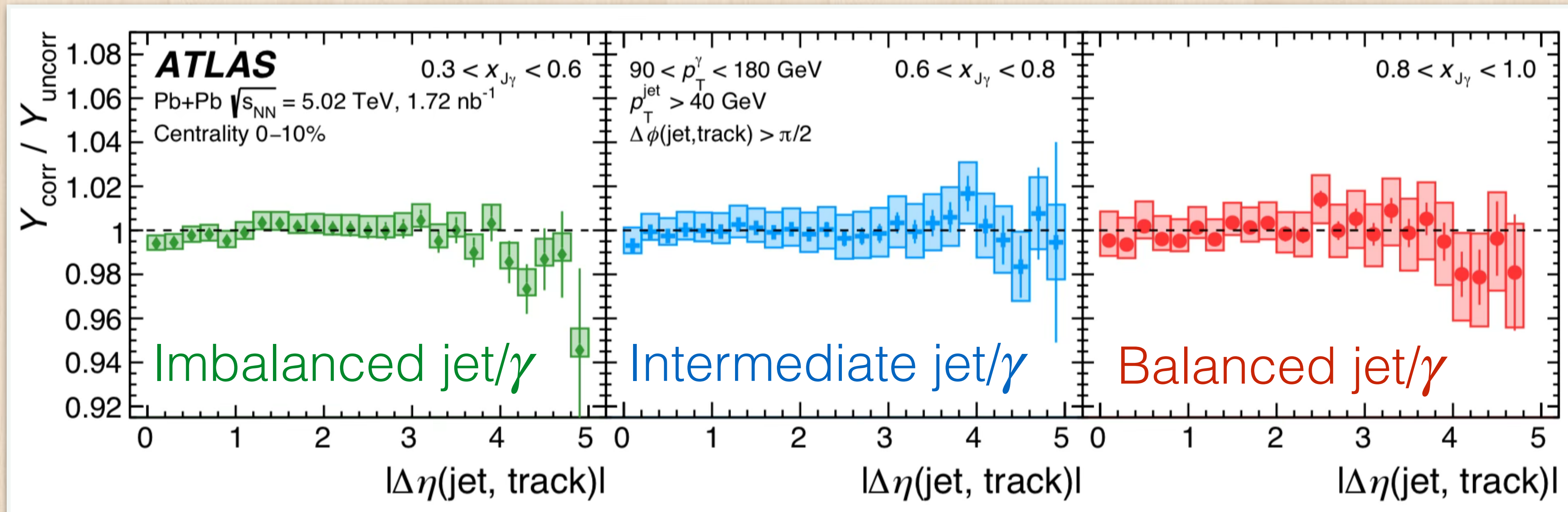
Require jets

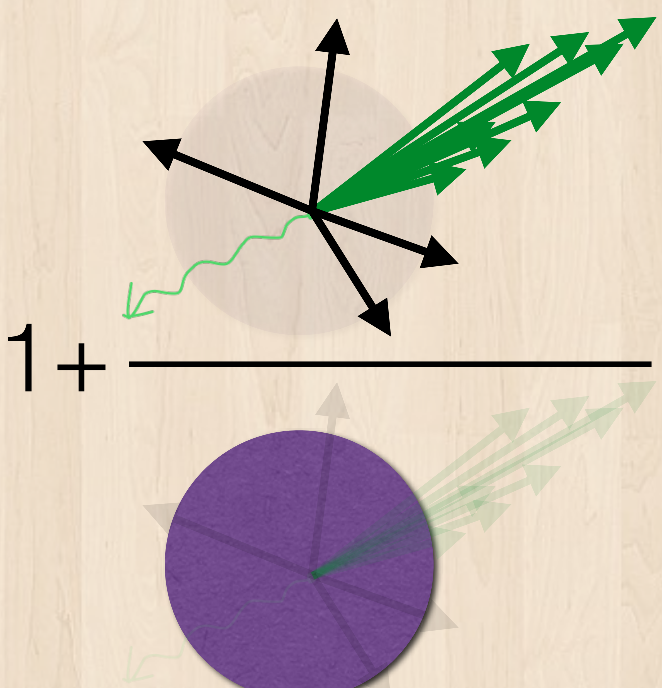




2408.08599

Photon-jet (ATLAS, 2023)





Size of signal w.r.t. background

"1.005" means "S is 0.5% of B"

Some hint but not very significant with further analysis with fits

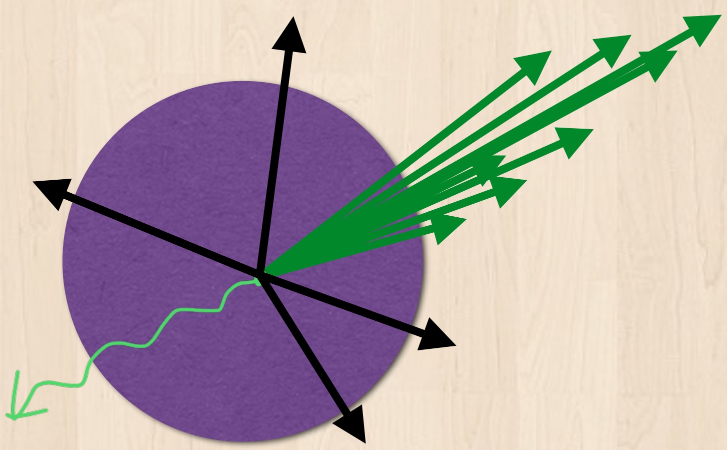
2408.08599

Z-hadron (CMS, 2024)

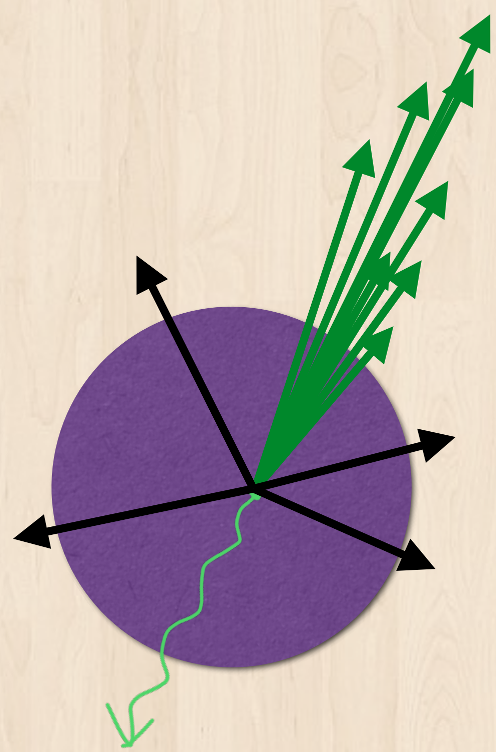
Find Z events (S+B)

Match with another Z event (S’+B’)

Subtract and observe difference



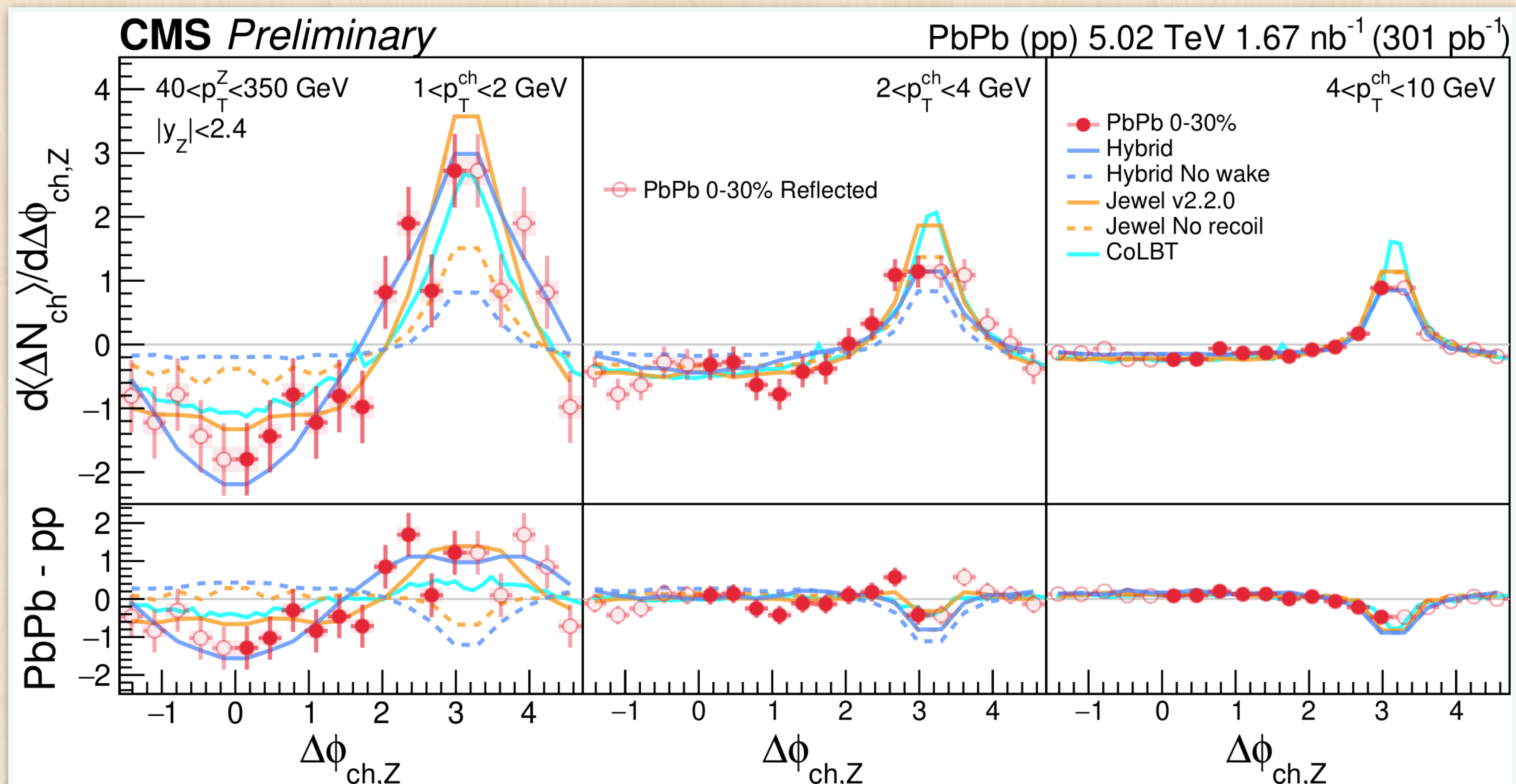
Do not require jets

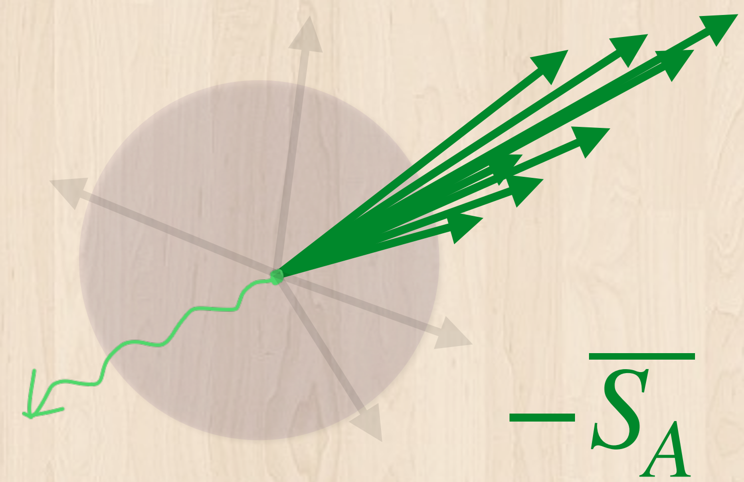


$-\overline{S_A}$

CMS-PAS-HIN-23-006

Z-hadron (CMS, 2024)





Subtraction of average S_A: area by definition 0

We report the relative modification in different angles

…can always shift back to absolute yield

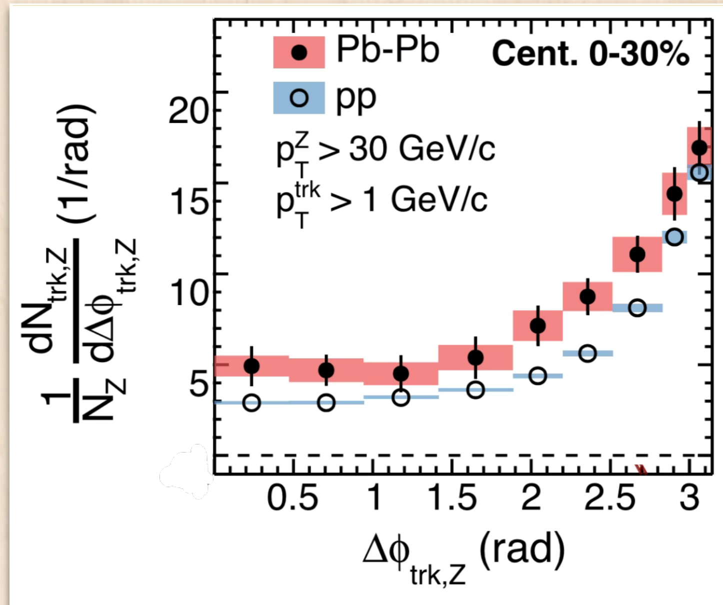
Background (B) and MPI (S_B) do not contribute

CMS-PAS-HIN-23-006

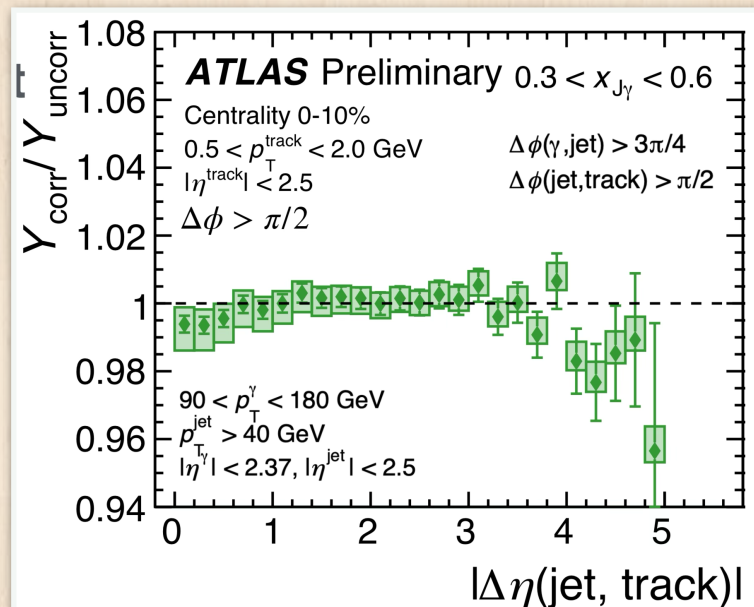
Some additional discussions

- Why $Z \to \mu^+\mu^-$ channel?
  - There is nothing special in the Z direction in the detector
  - We are looking for small effects: ATLAS sees $|S/B| < 1\,\%$
- How to interpret this $\langle \Delta N_{ch} \rangle$?
  - It's the **shape**: relative enhancement/depletion
  - We can measure the shape and normalization separately. They contain different information

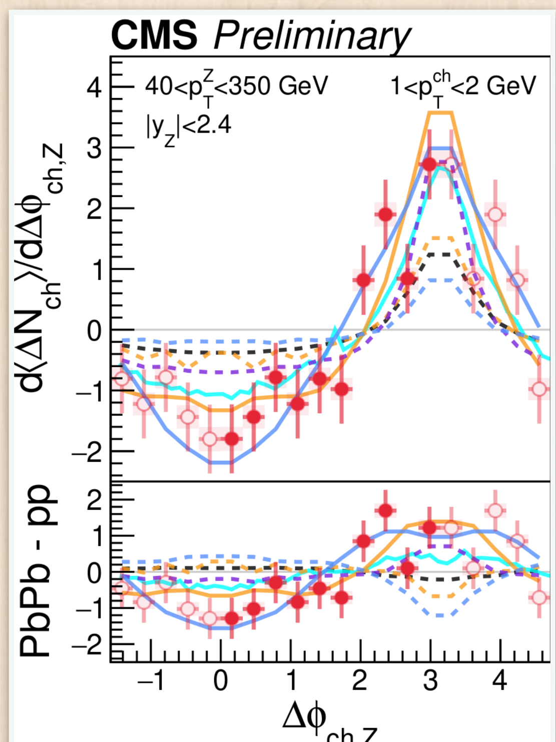
What’s measured: overview



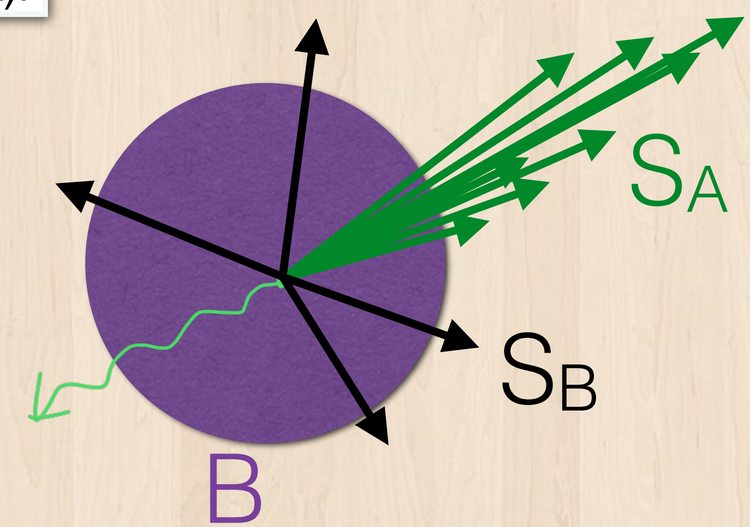
$$(S+B)-B = S = S_A+S_B$$



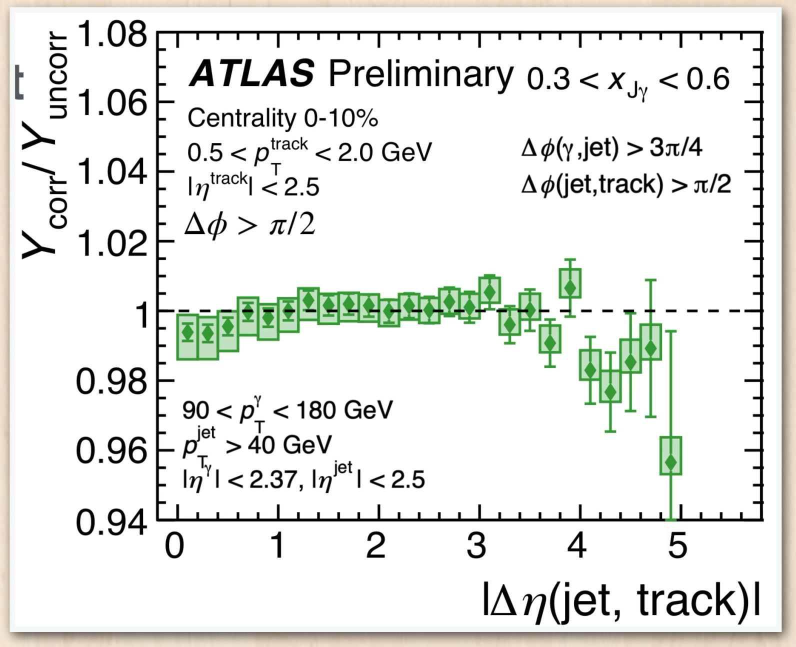
$$(S+B)/B$$



$$(S+B) - (S'+B')$$
$$= S - S' = S_A - \overline{S_A}$$

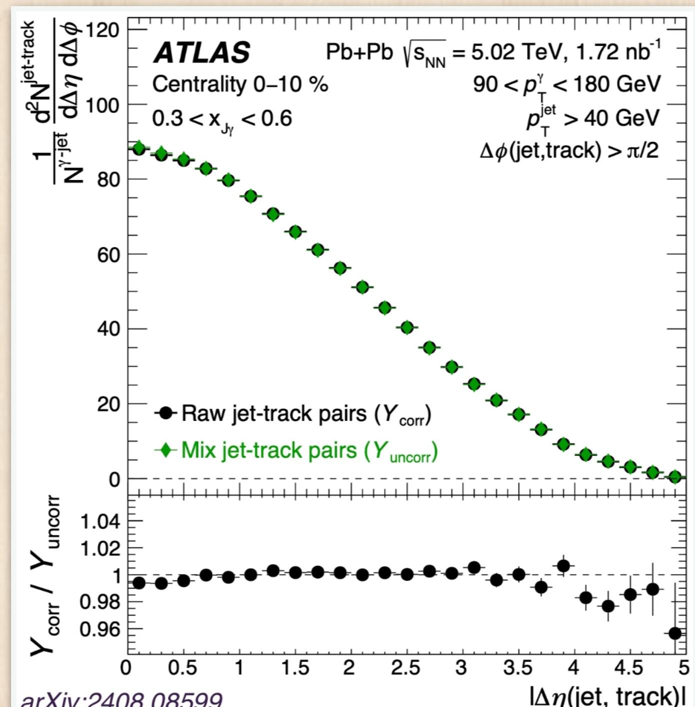


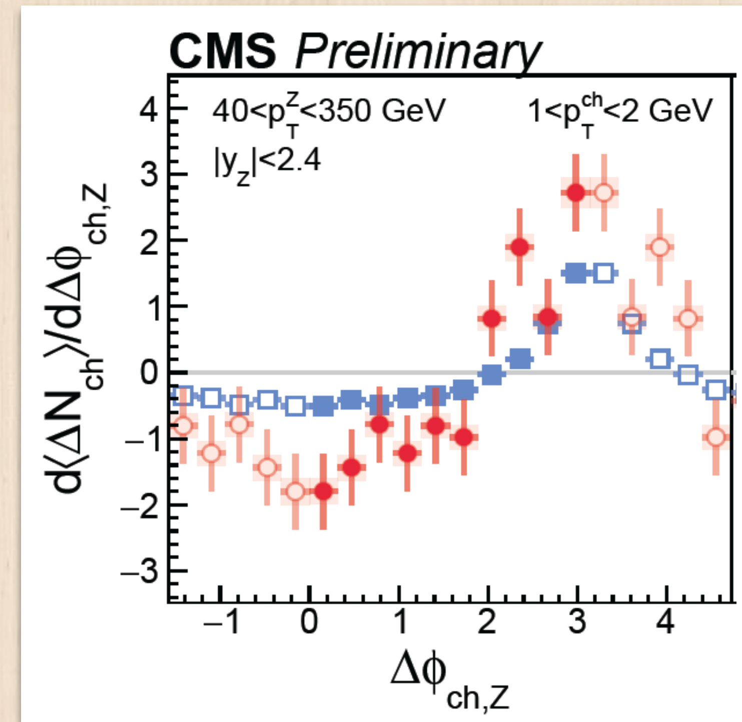
Compatibility ATLAS vs CMS?



$$|S/B| \lesssim 1\,\%$$

(check PbPb vs pp)





$$B \simeq 90$$

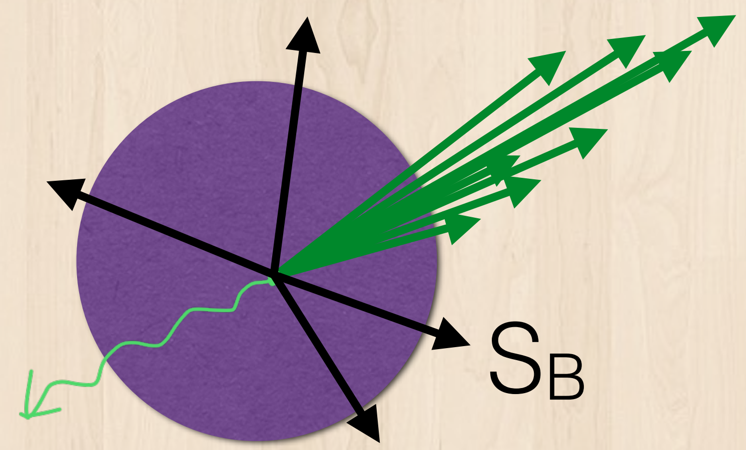
$$S - \bar{S} \simeq O(1-2)$$

Caveat: selections not the same

Need more careful look to conclude
but don't see obvious signs of inconsistency

Note on building "B" contribution

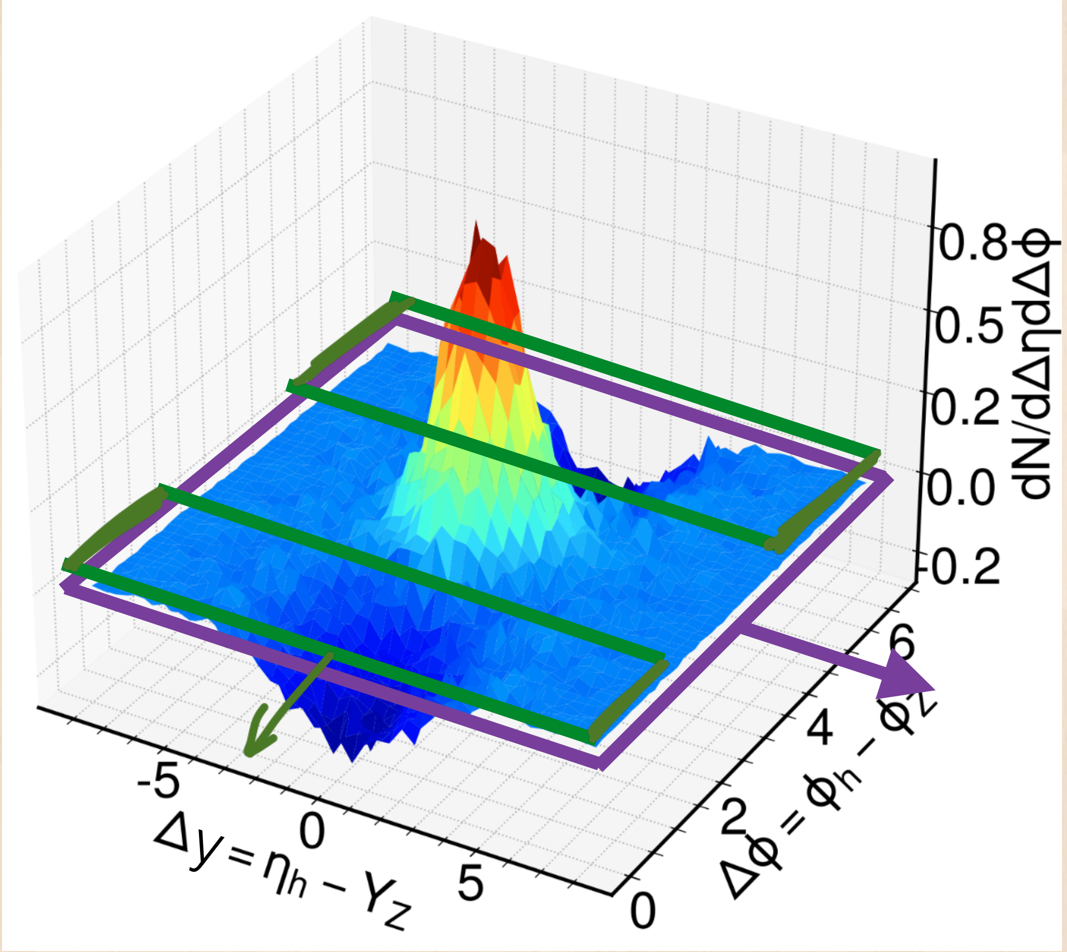
- Typically we use some detector region as "event activity measure" and we match it (in addition to event plane & vertex position)
- Some difference between ATLAS 2023 and CMS 2021 treatment
  - CMS 2021: HF ($3 < |\eta| < 5$)
    - Corrects for S that enters HF
  - ATLAS 2023: FCal ($3.1 < |\eta| < 4.9$)
  - Not applicable for CMS 2024



Looking closer at latest CMS Z-hadron result

Projection to 1D

CoLBT



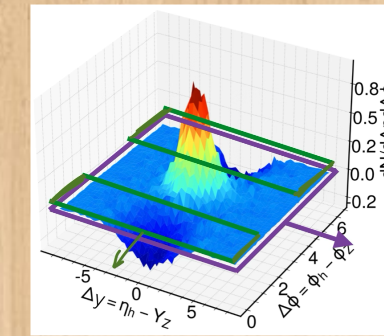
Project to $\Delta\phi$

- **Full phase space**
- **Jet-side peak**
- **Z-side dip**

Project to Δy

- **Select only Z side**
- **Focus on the dip structure**

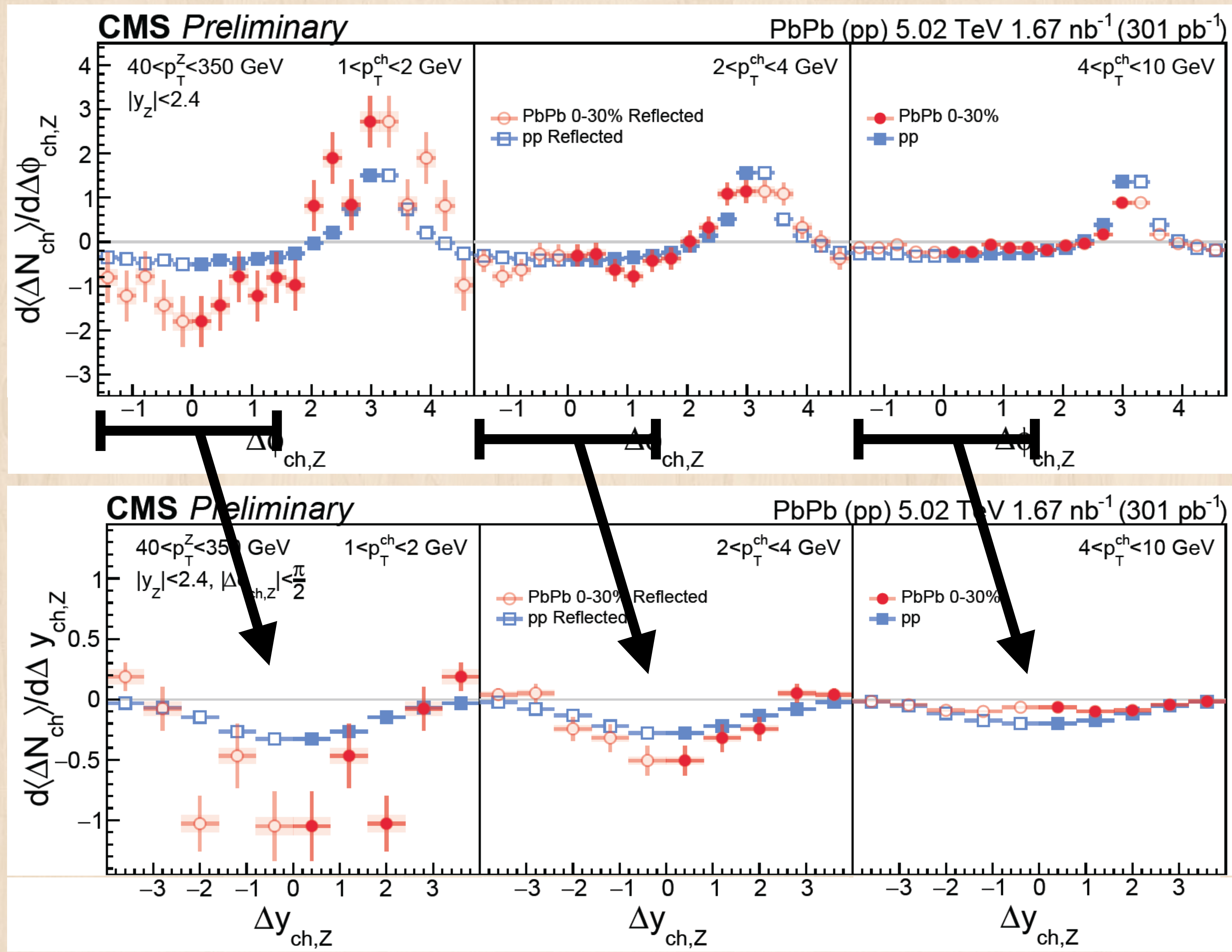
p_T dependence



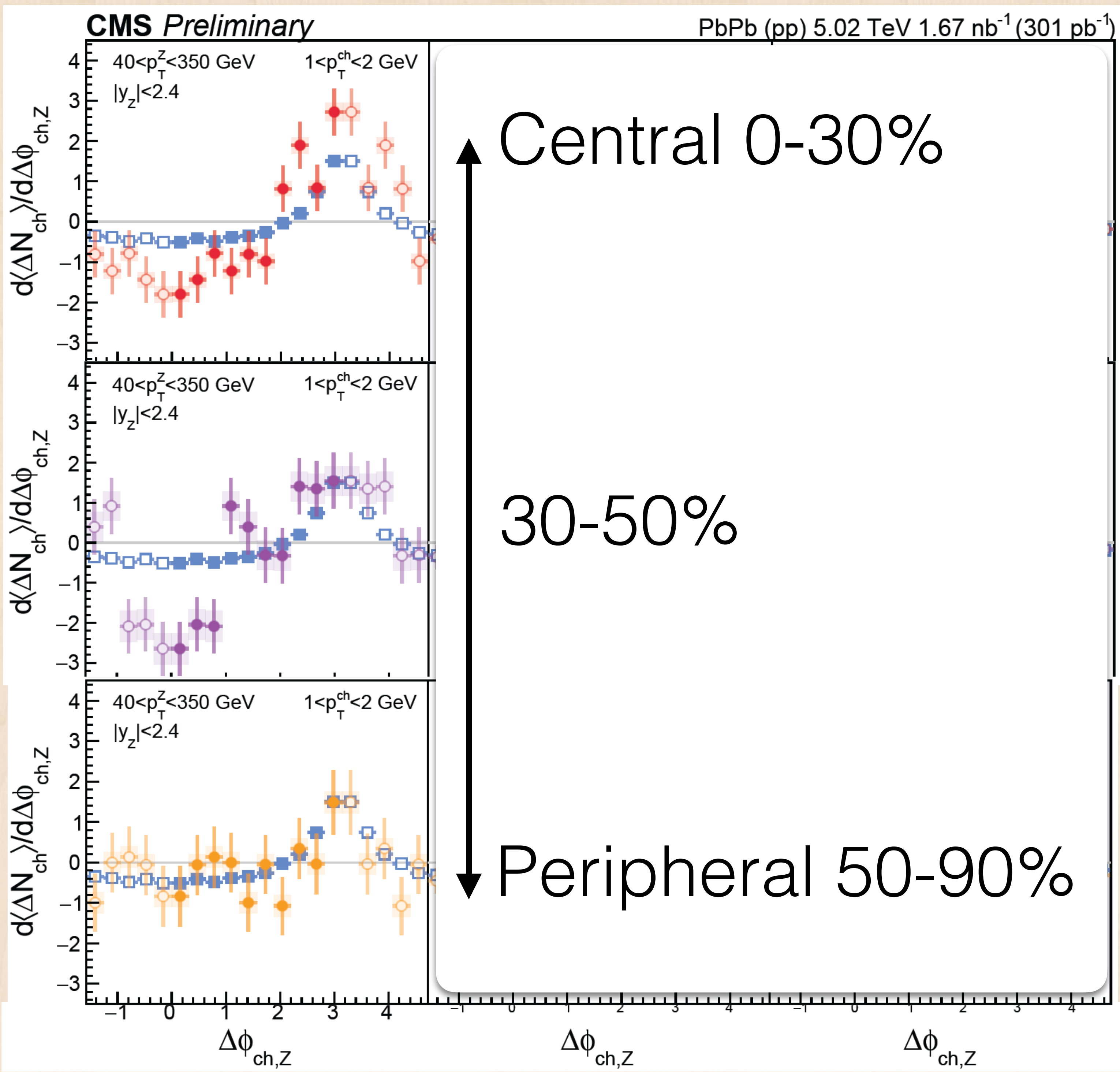
Larger modulation at lower track p_T

Reverse trend at higher $p_T \rightarrow$ jet quenching

Dip structure also in Δy



Centrality dependence (low p_T)

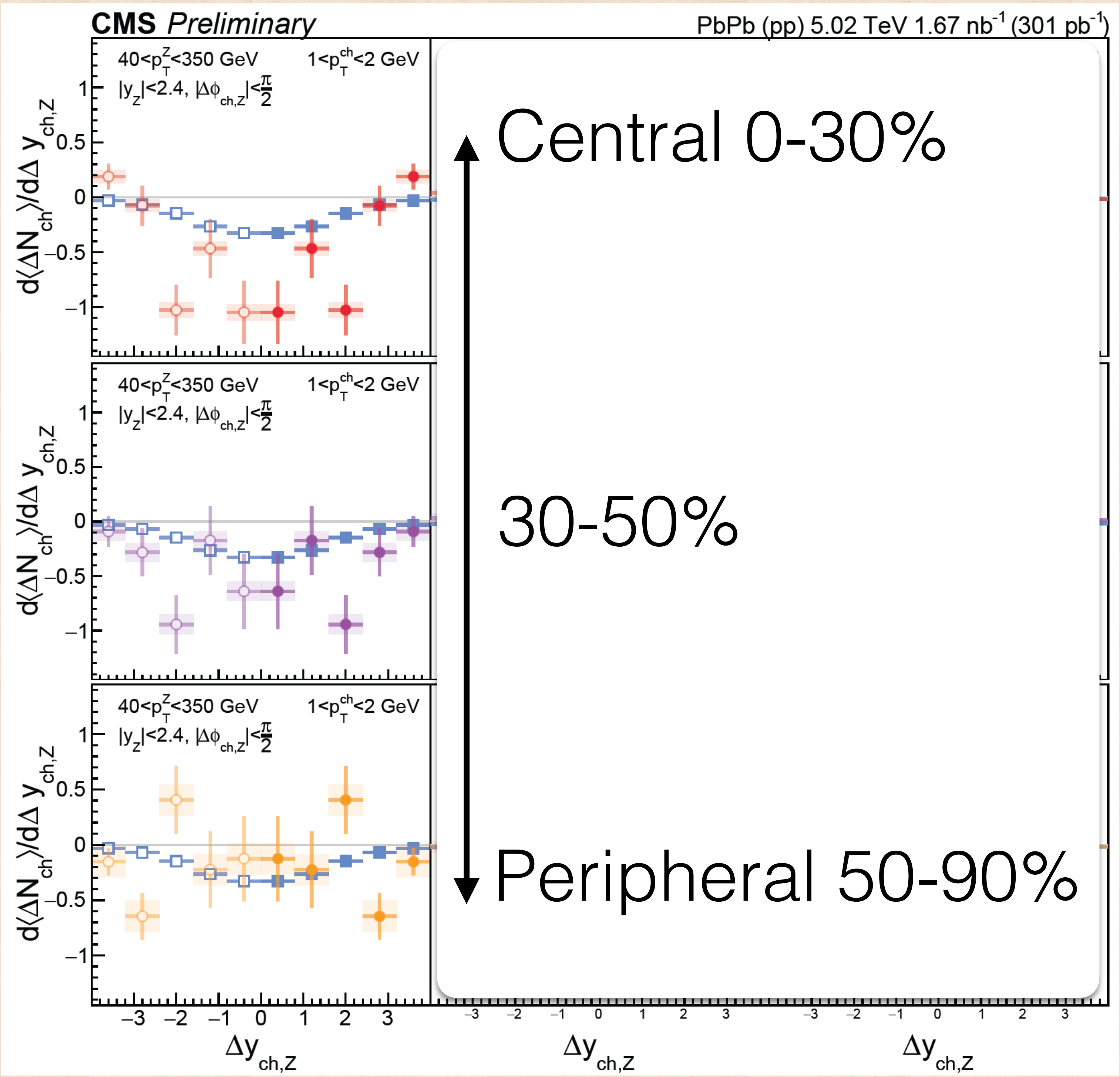


Effect seen in 0-30% and 30-50%

Larger fluctuation 30-50%: smaller range

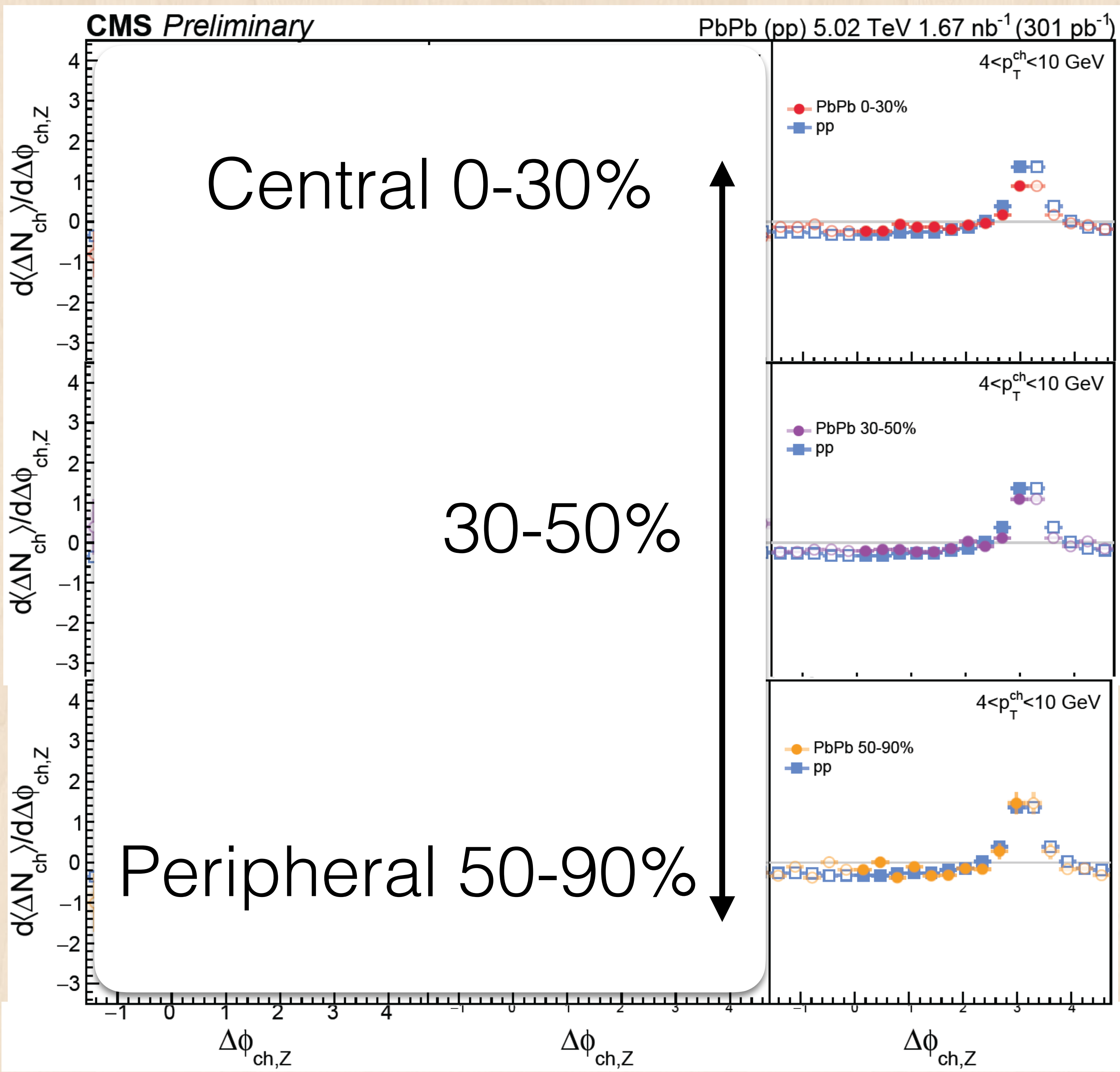
Nothing 50-90%

Centrality dependence (low p_T)



More easily see the centrality evolution in this projection

Centrality dependence (high p_T)



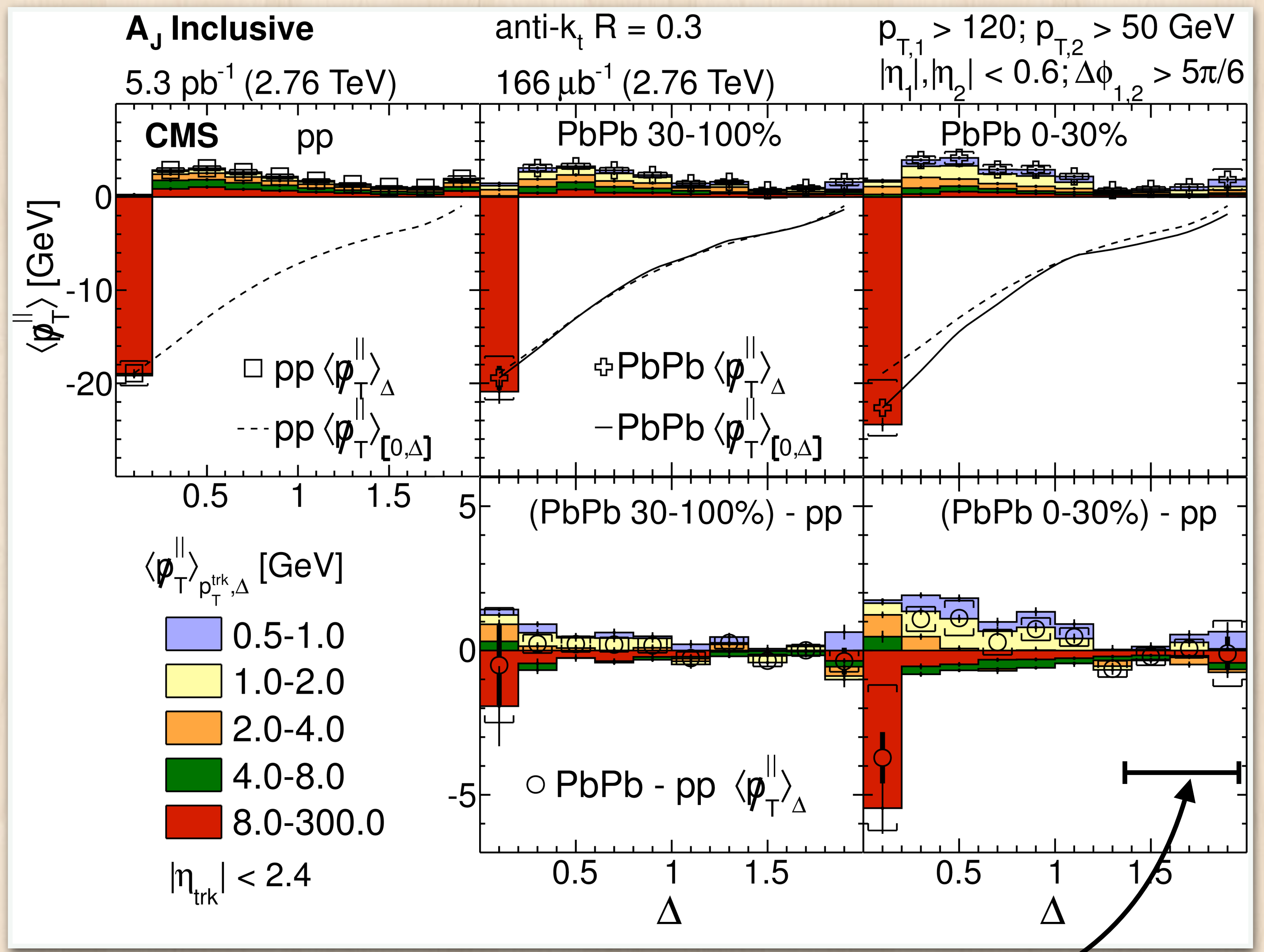
Jet-side peak gets lower for more central

Consistent with intuition on jet quenching

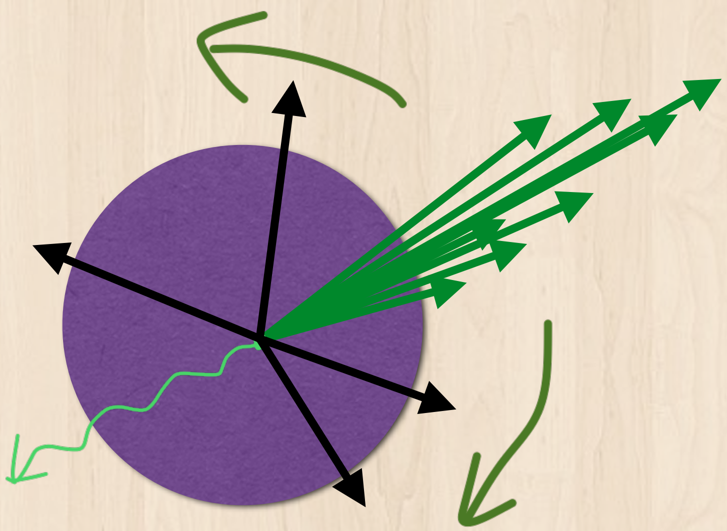
Nothing 50-90%

One possible next step

Energy propagation

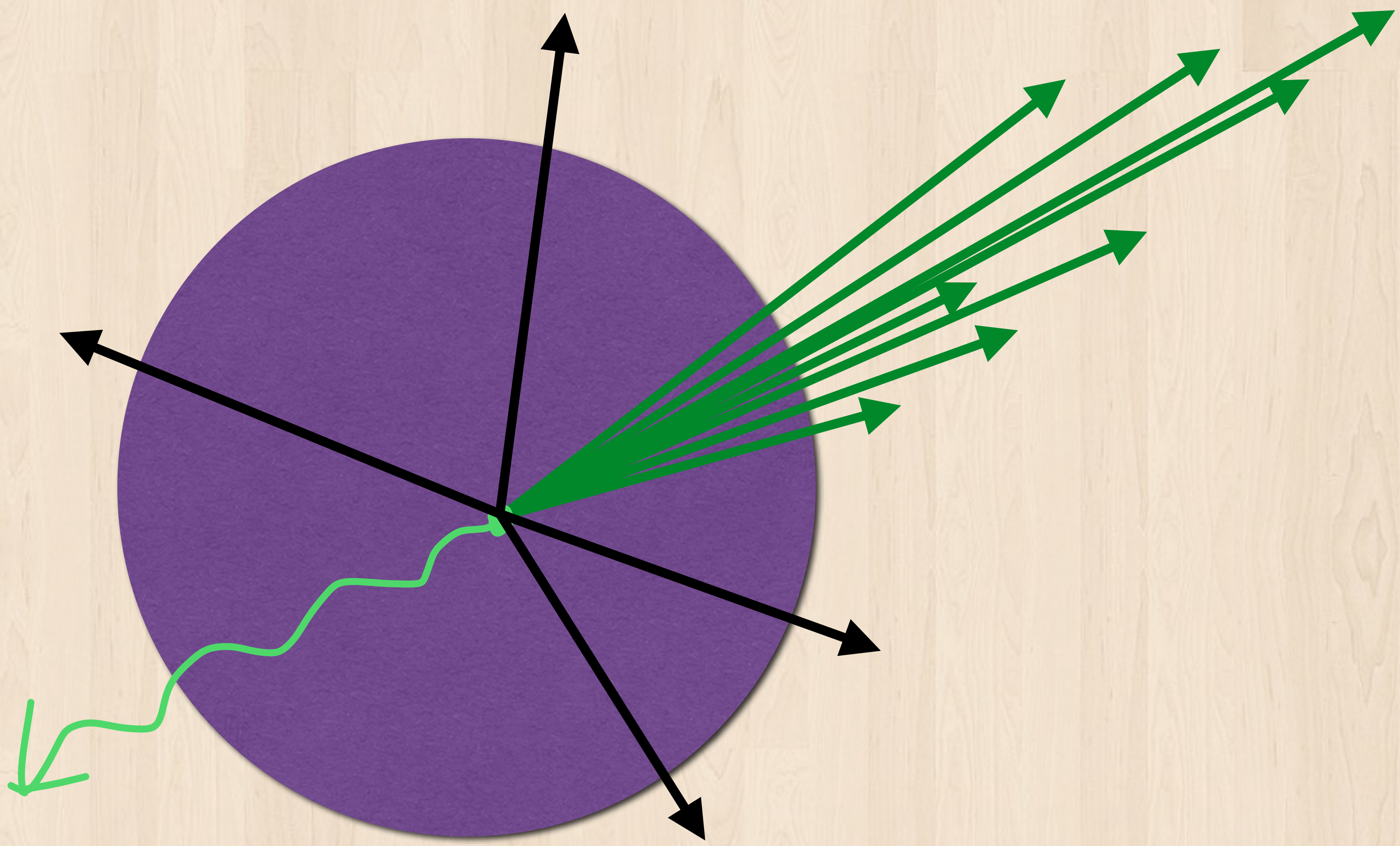


Effect can go beyond $\pi/2$



Z-tag allows looking at the full phase space

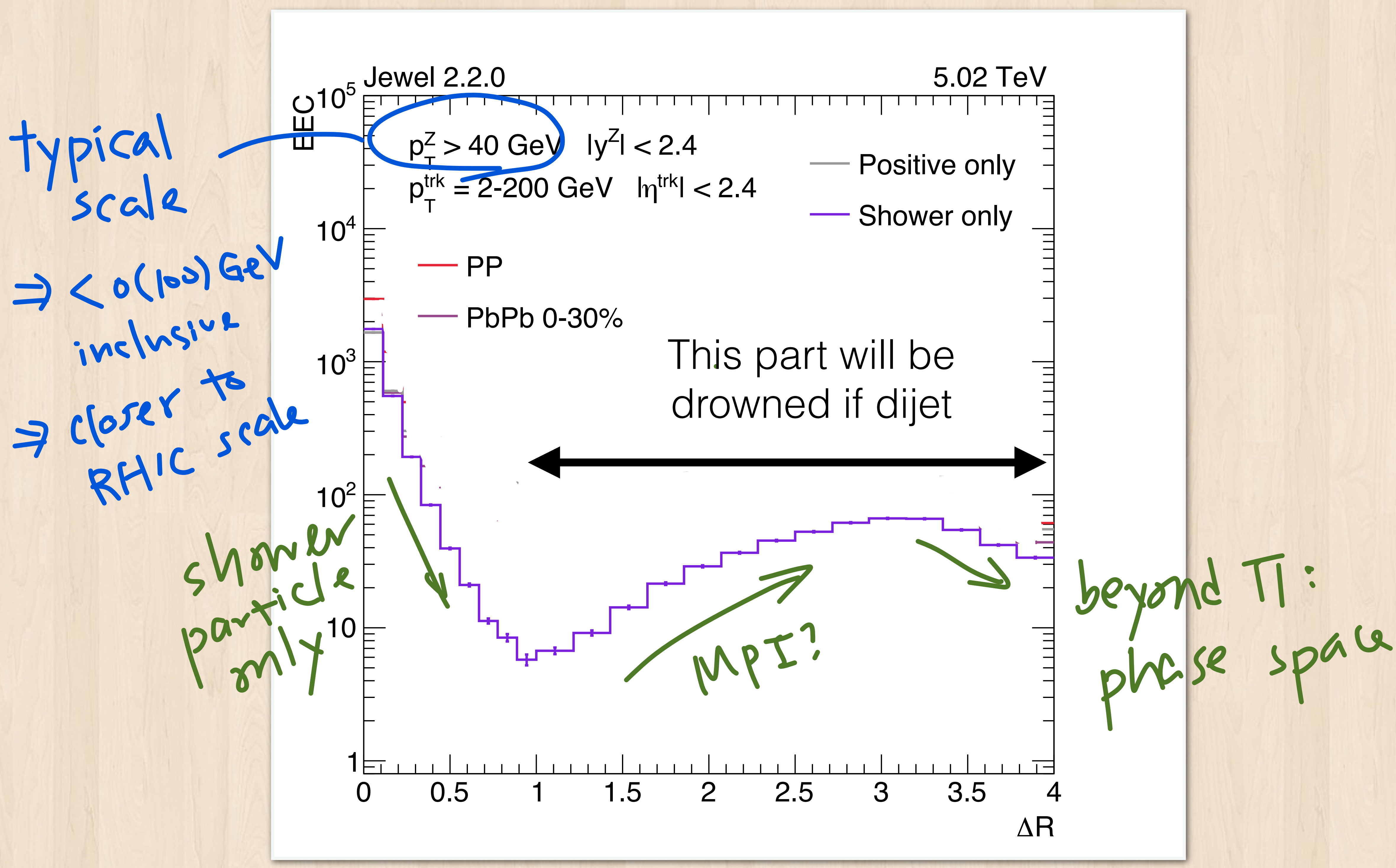
Mapping out energy propagation



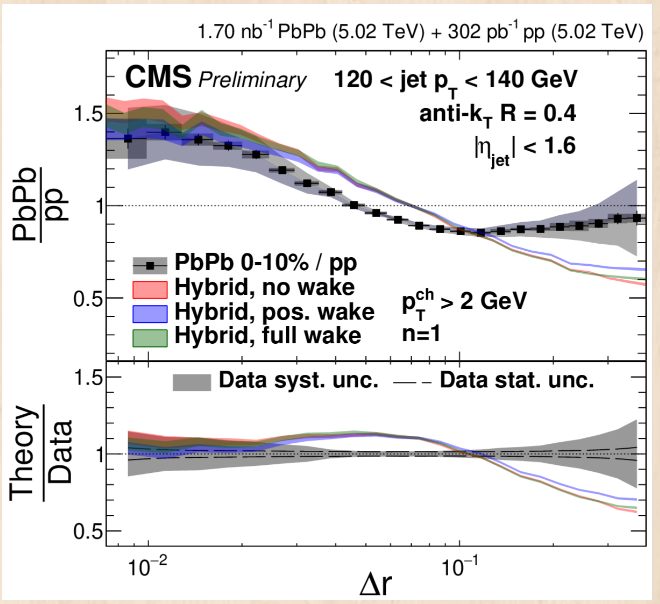
Z-hadron: correlation hadrons vs. Z

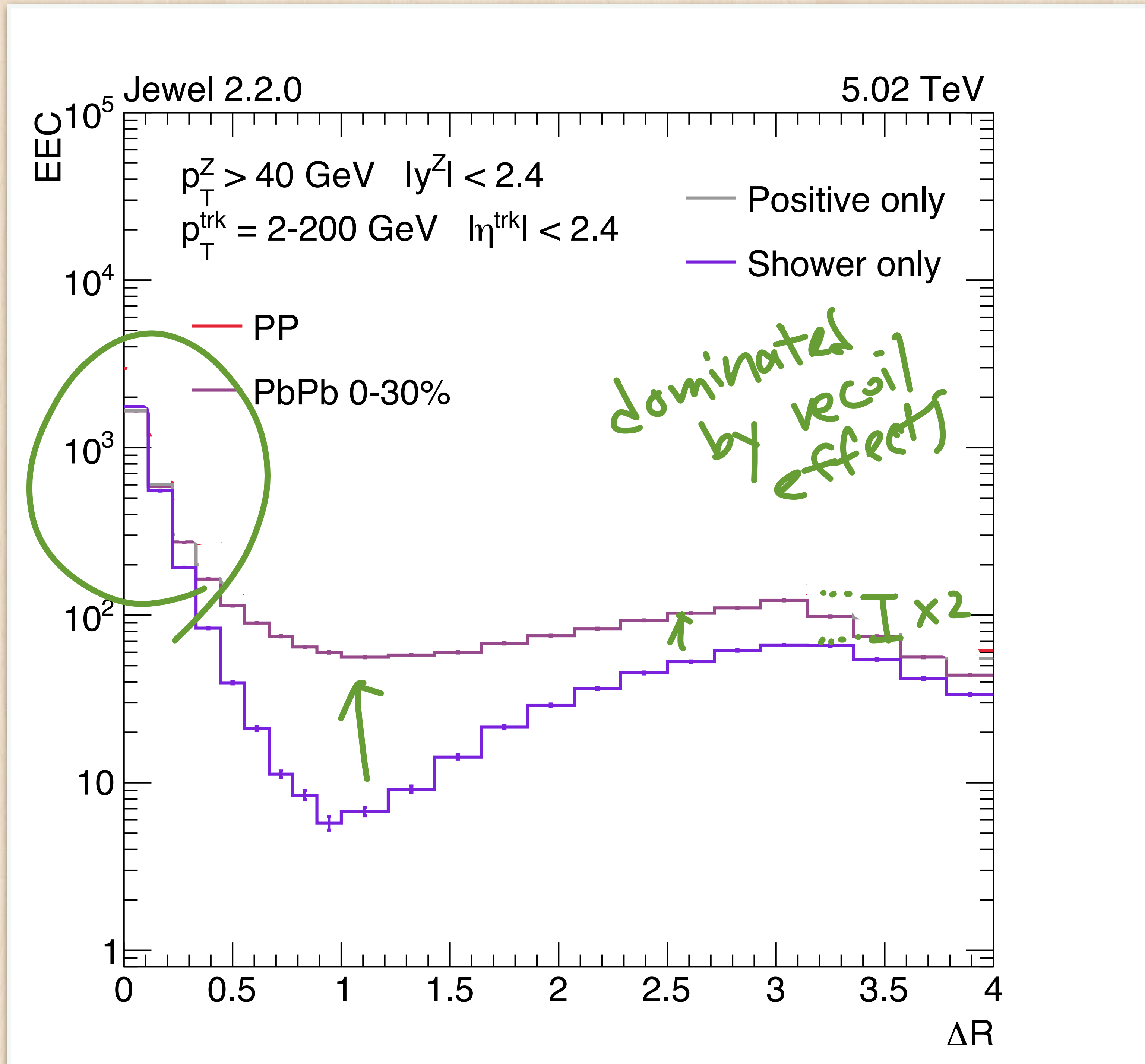
Next step: correlation between hadrons
→ tag event with Z then look at hadron EEC

No-recoil JEWEL



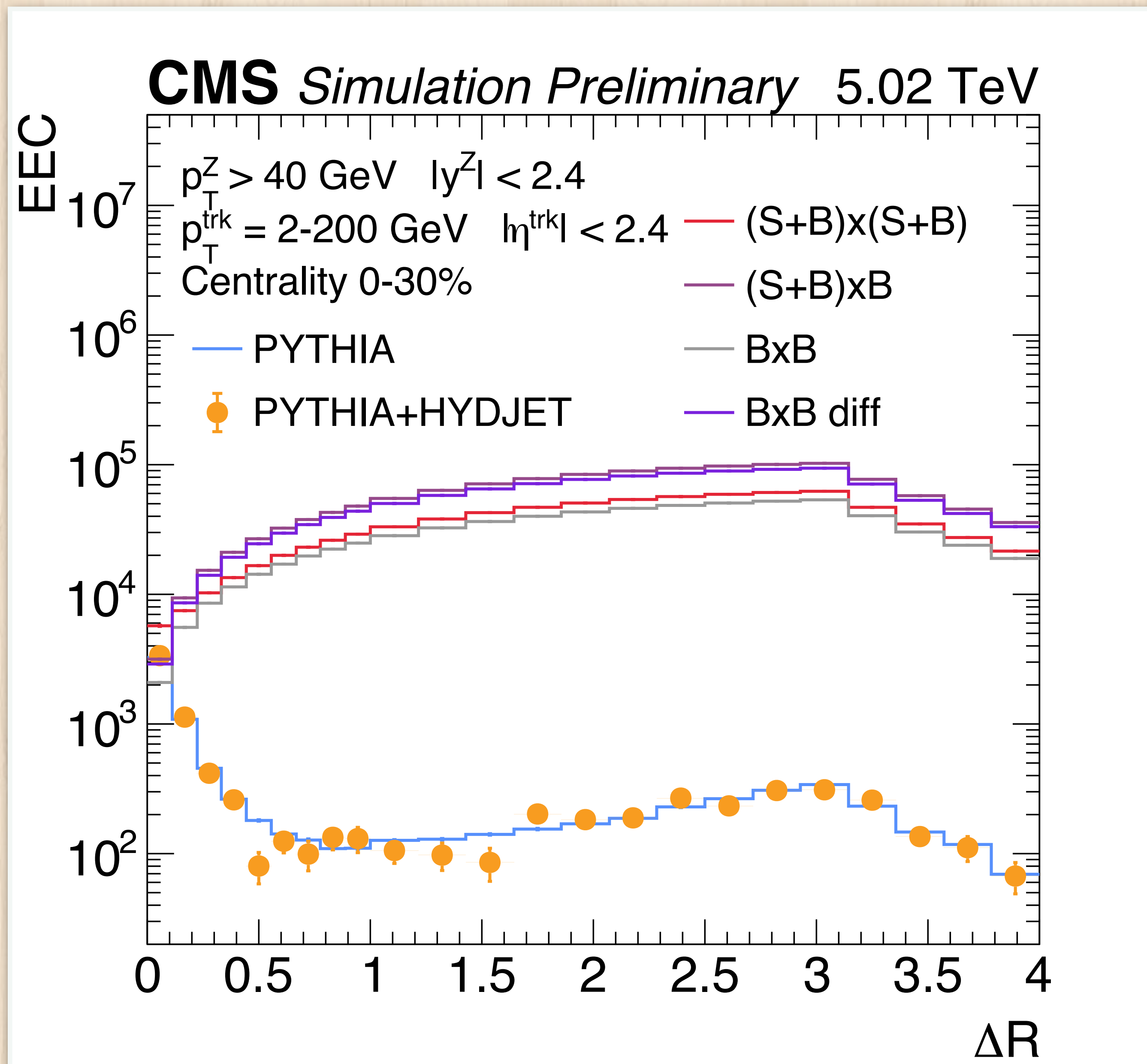
Full JEWEL





recoil not too big at jet core

S/B expectations



Mixed-event background subtraction

Separately derive normalization

Not simple analysis but doable

Concluding Remarks

Electroweak objects for hard probes

- High energy electroweak objects do not interact strongly with the QGP
  - Can be used to tag initial collision
  - A number of recent measurements with jets
- Wake search: recent analyses with different methods
  - We start to see some signals
- Next efforts ongoing from experiments

Backup Slides Ahead

JEWEL pp vs PbPb