NATIONAL SCIENCE FOUNDATION
U.S. DEPARTMENT OF ENERGY | Office of Science
VANDERBILT UNIVERSITY

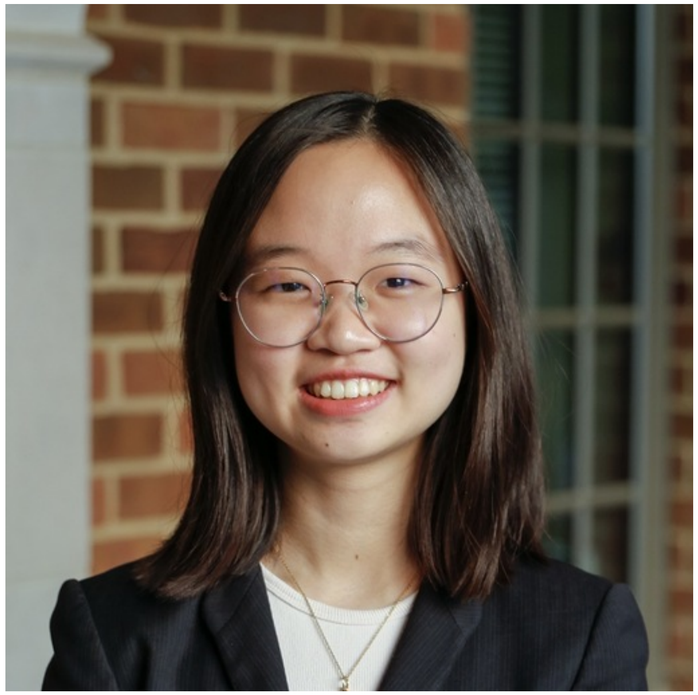
Energy-Energy-Energy Correlators

What they show in JEWEL and how to measure it

Rachel Koh Huiqi [she/her], Junxing (Leo) Sheng [he/him], Yilun Wu [she/her]
Jussi Viinikainen [he/him], Raghav (Rithya) Kunnawalkam Elayavalli [they/them]
Vanderbilt University

Jet Modifications and Soft-Hard Correlations
SoftJet Tokyo, Japan
Sept 29th 2024

Power to the people!



Junxing (Leo) Sheng [he/him]
junxing.sheng@vanderbilt.edu

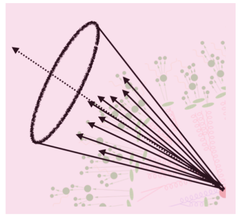
Rachel Koh Huiqi [she/her]
rachel.koh@vanderbilt.edu

What are the physics we measure with the E3C observables

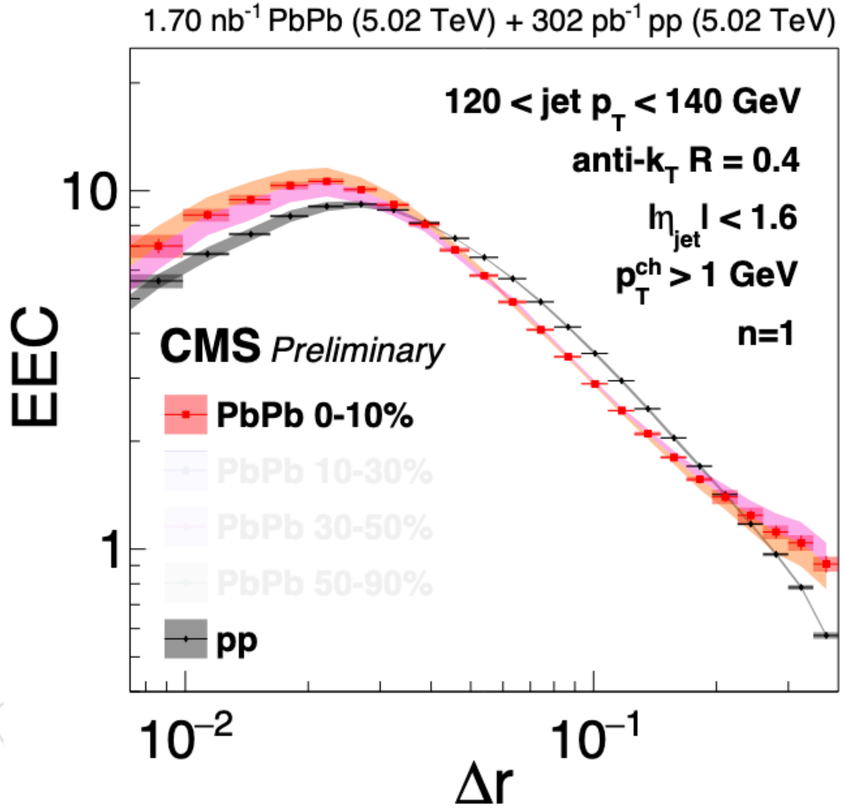
- Compare JEWEL w/ and w/o recoils for inclusive jets at fixed energy
- Insights into the nature of jet modification and energy loss from different combinations of E3C observables
- Invariant in jet structure!

Realistic impact of the background on E3Cs and how we remove it

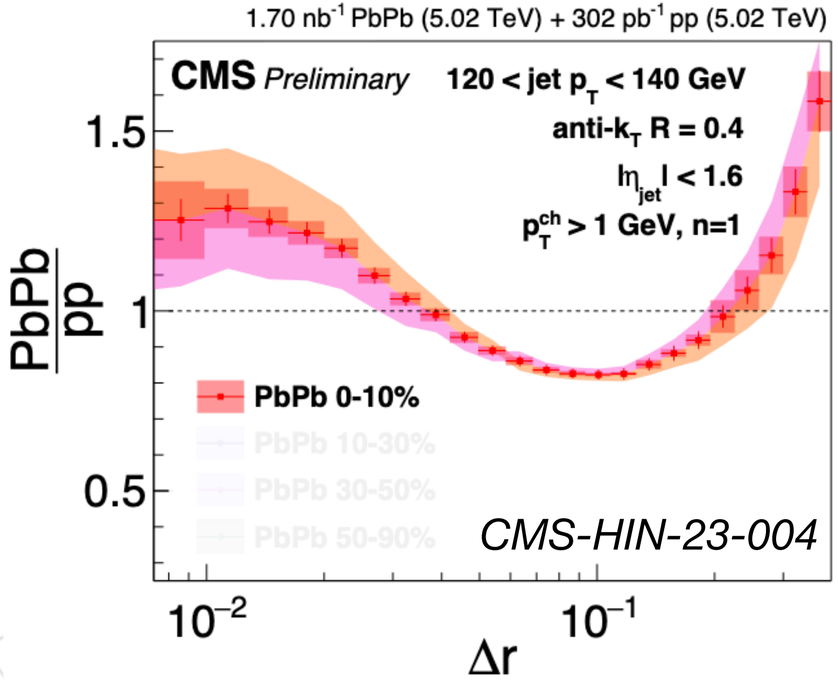
- Embed PYTHIA di-jet events into multiple PYTHIA minbias events
- How does this uncorrelated background contribute to the observables related to E3Cs
- How can one remove this background and at what precision?

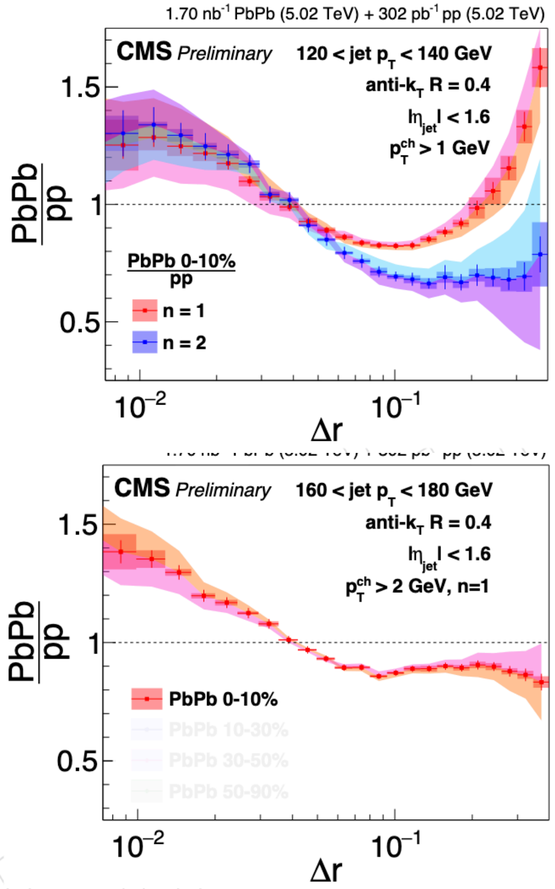


Recap - what we learned from E2C



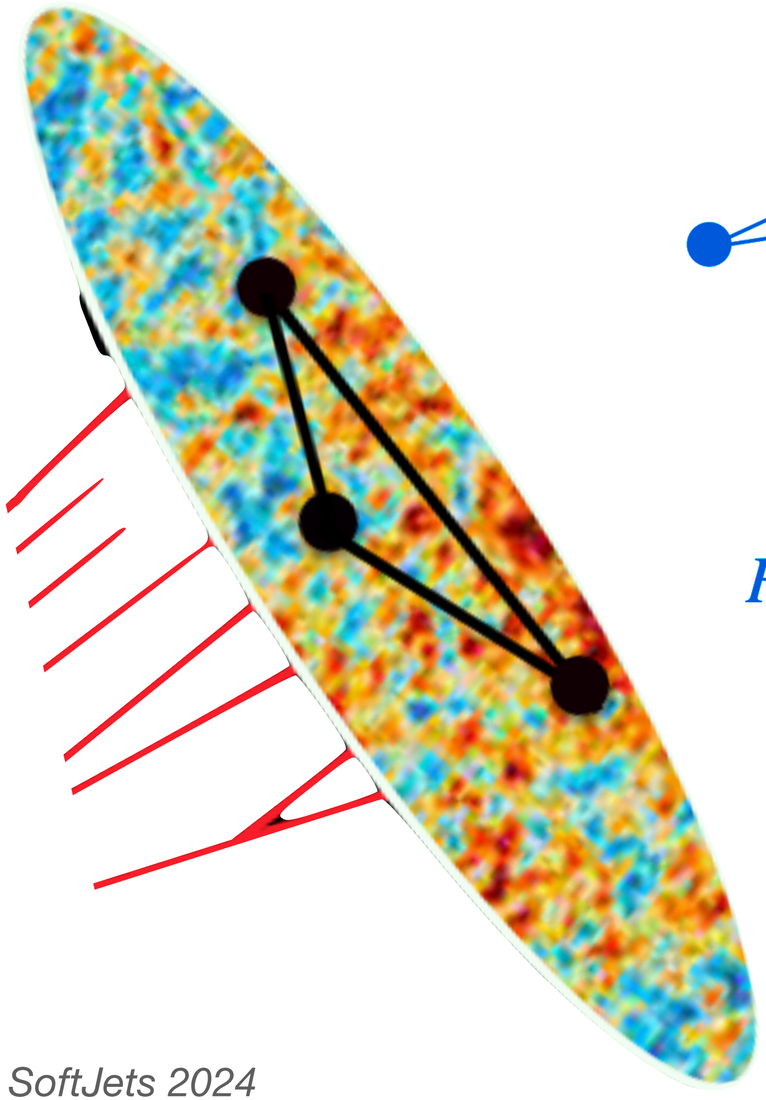
See talk by Jussi Viinikainen

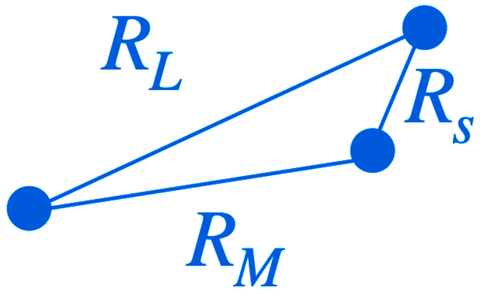




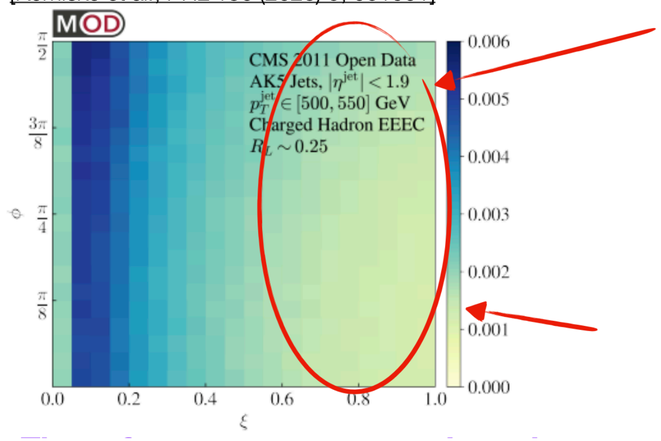
- We now have evidence of PbPb jets starting at higher virtuality
- Impact of **medium response/wake, elastic 2-2 scatterings/recoils/Moliere/Rutherford and coherence-decoherence transition**

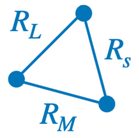
What are 3-point correlators?



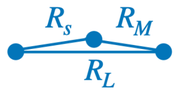


[Komiske et al., PRL 130 (2023) 5, 051901]





Upper right corner is populated with equilateral triangles



Bottom right corner is populated with “flat” triangles

Compilation by Hannah Bossi and Ananya Rai

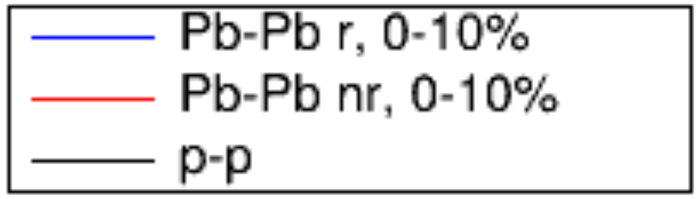
R_L

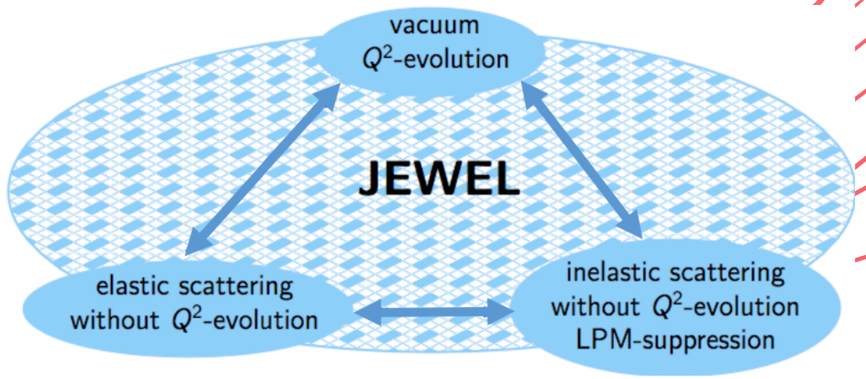
$$\xi = \frac{R_S}{R_M}$$

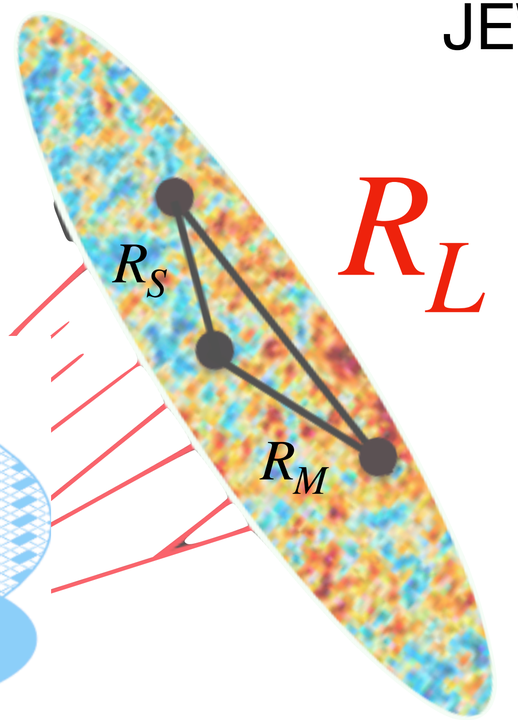
$$\phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$$

- Projected 3-point correlators onto the larger angle side RL can asymptote to 2-point
- ϕ and ξ are sensitive to different shapes of particle fragmentation within jets

R_L, R_S, R_M



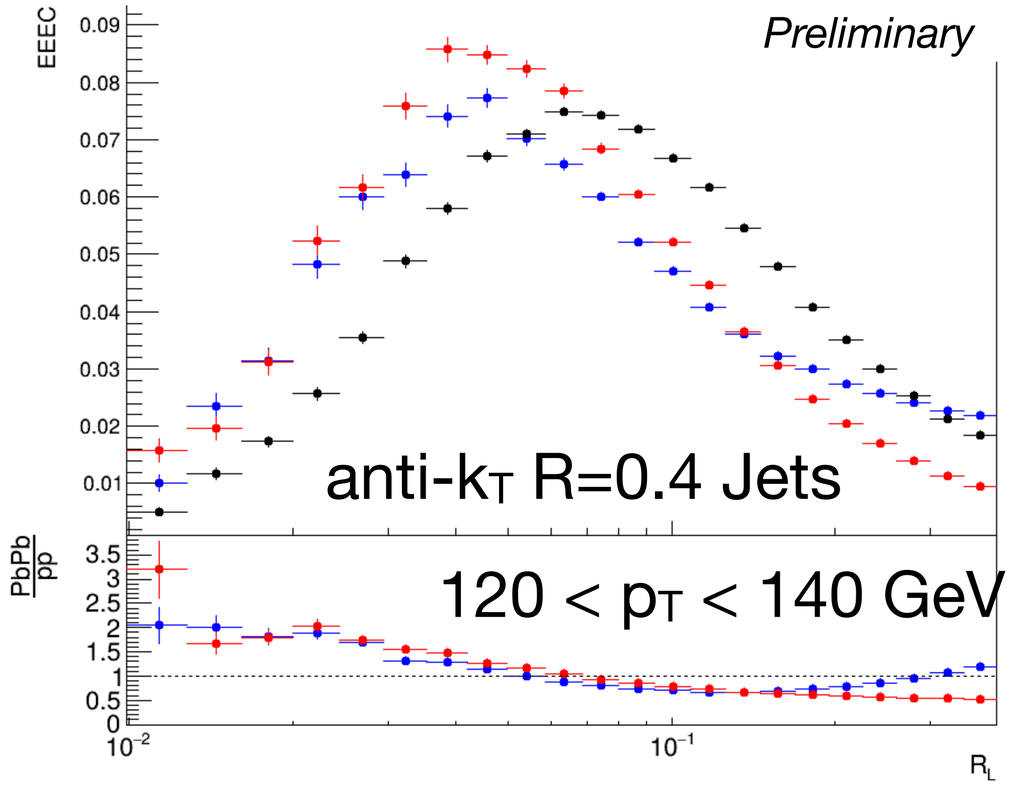




w/ recoils + thermal subtraction

w/o recoils

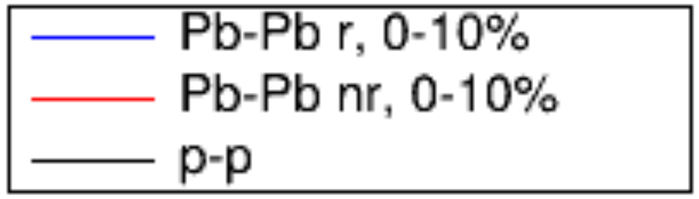
JEWEL 2.4.0 + PYTHIA $\sqrt{s} = 5.02$ TeV

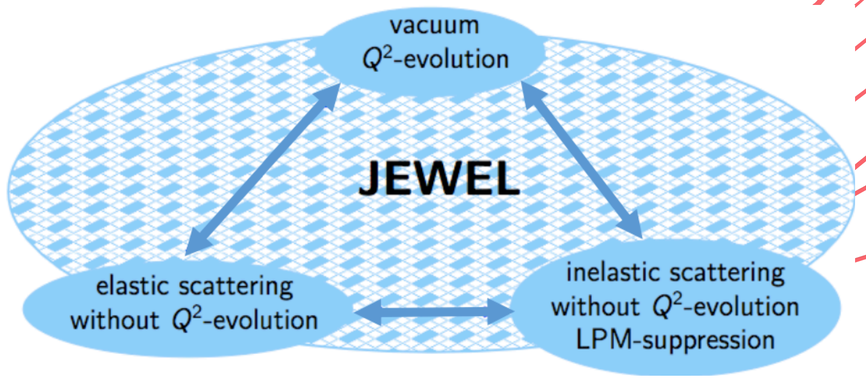


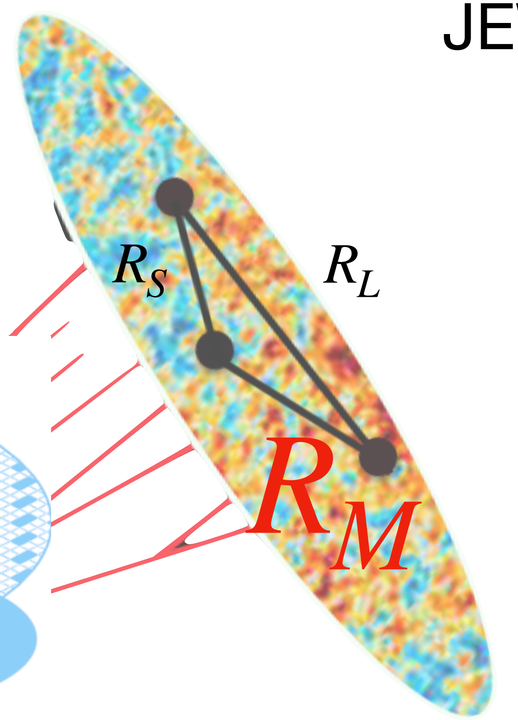
- Similar behavior to 2-point correlators with slight difference at the larger angles - enhancement seems to be smaller with 3-particles!

Note: these are from unique triplets!

R_L, R_S, R_M



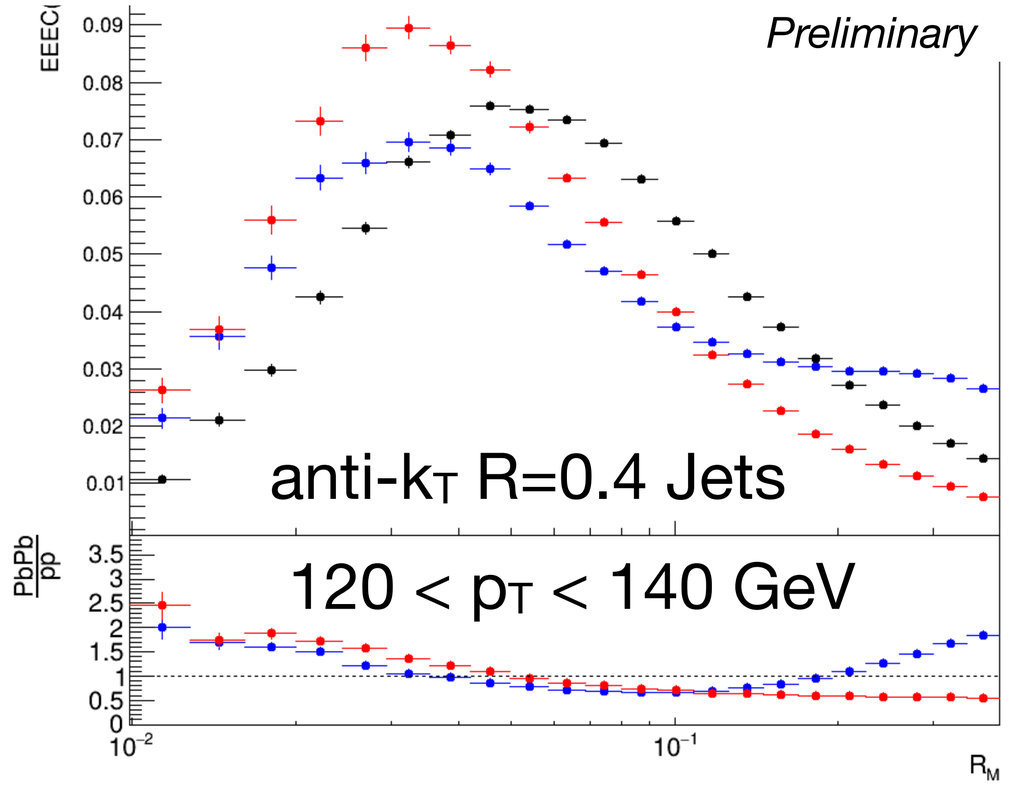




w/ recoils + thermal subtraction

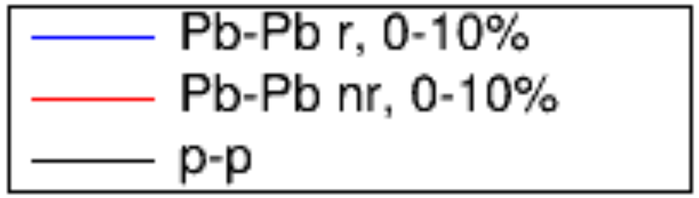
w/o recoils

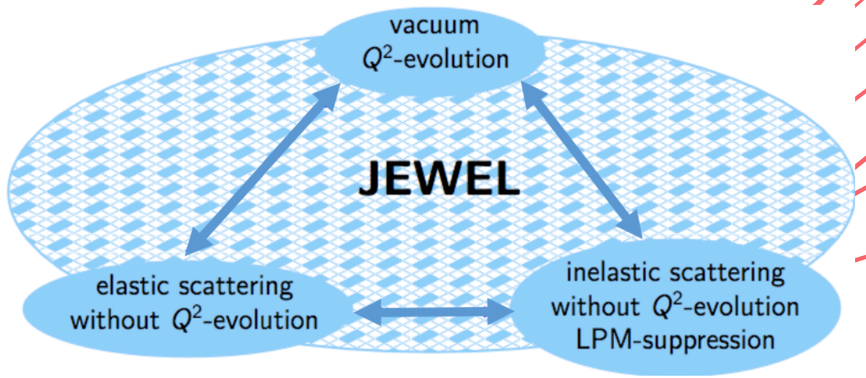
JEWEL 2.4.0 + PYTHIA $\sqrt{s} = 5.02$ TeV

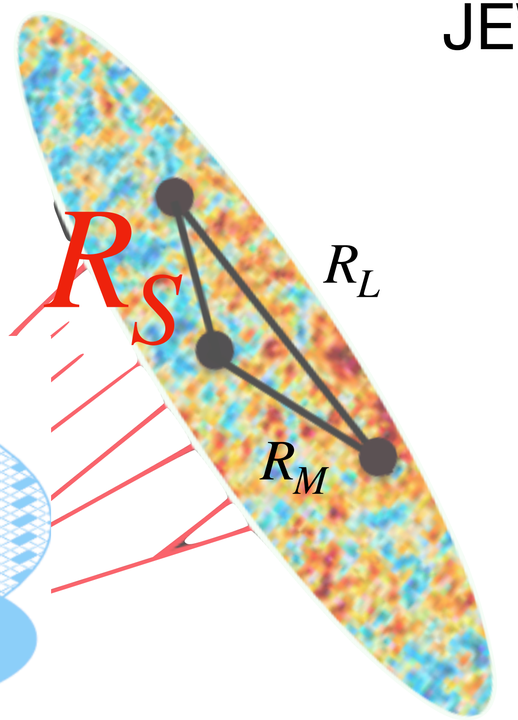


- As we go to smaller distances - R_M - we see enhancement start to creep up again! Deviation from w/o recoils happens at larger angles…

R_L, R_S, R_M



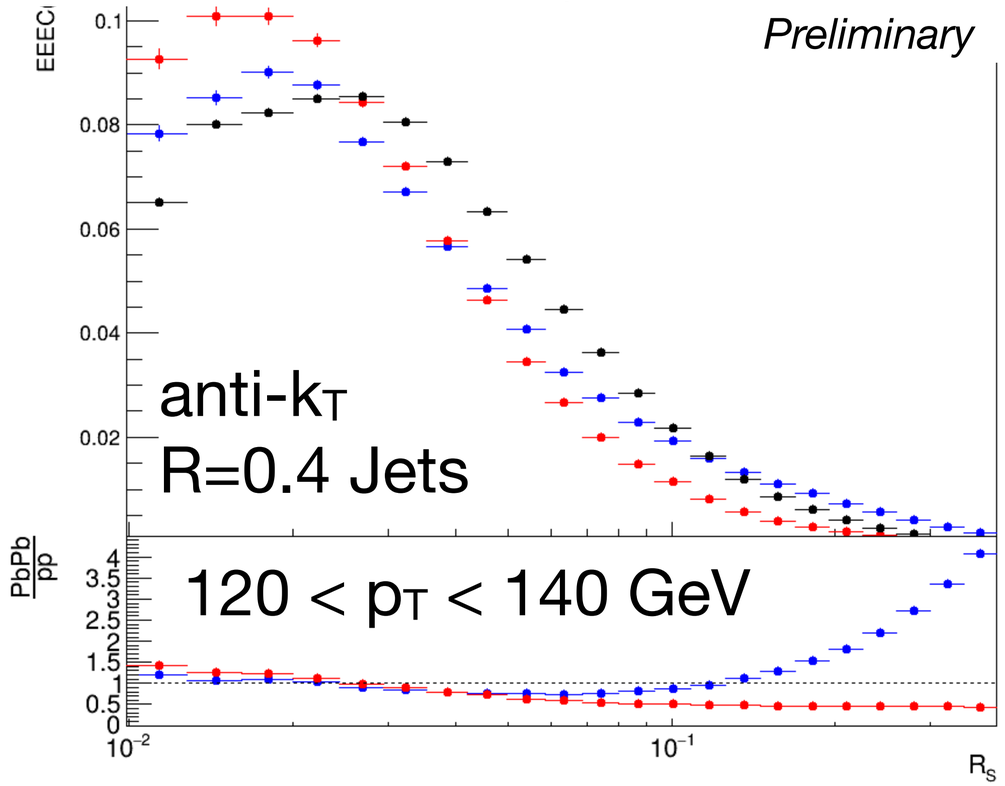




w/ recoils + thermal subtraction

w/o recoils

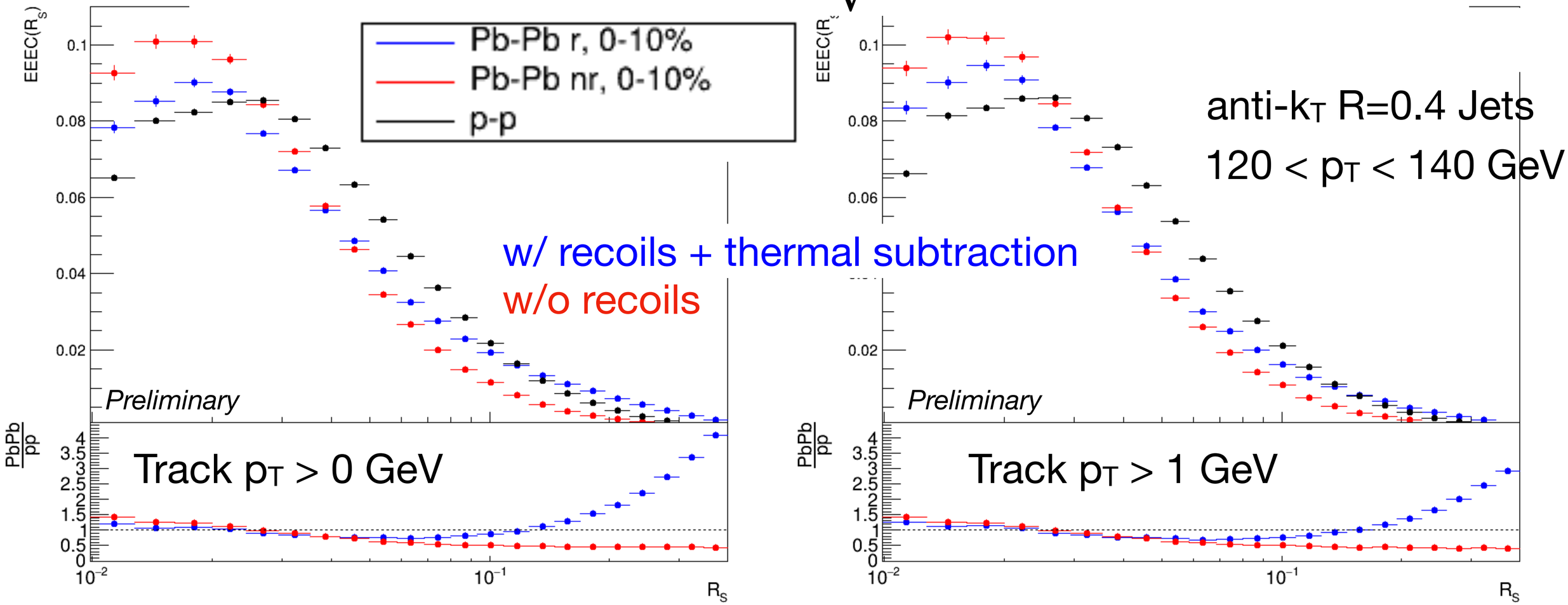
JEWEL 2.4.0 + PYTHIA $\sqrt{s} = 5.02$ TeV



- Largest enhancement reserved for the smallest side of the triangle! And also showcases the deviation goes to smaller angles!!

Sensitive to particle p_T?

JEWEL 2.4.0 + PYTHIA $\sqrt{s} = 5.02$ TeV



anti-k_T R=0.4 Jets

$120 < p_T < 140$ GeV

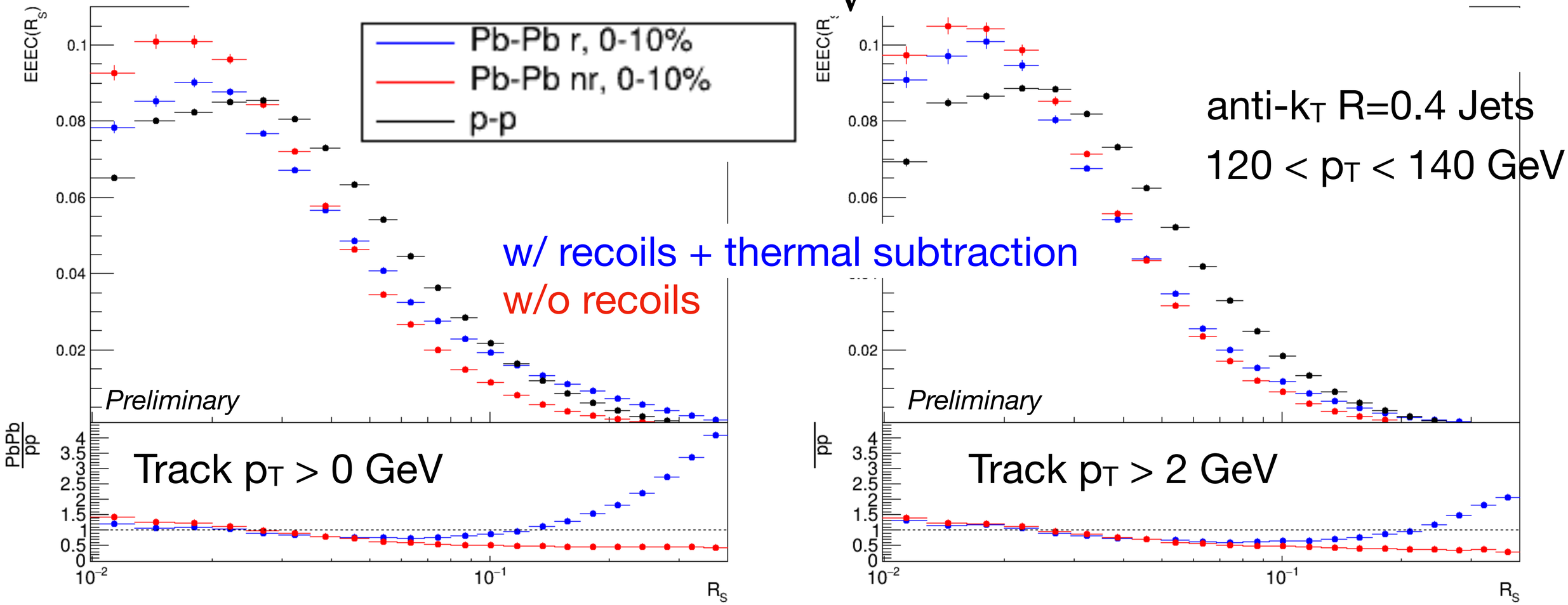
w/ recoils + thermal subtraction

w/o recoils

- Increasing the track p_T results in reduced enhancement at large R_S

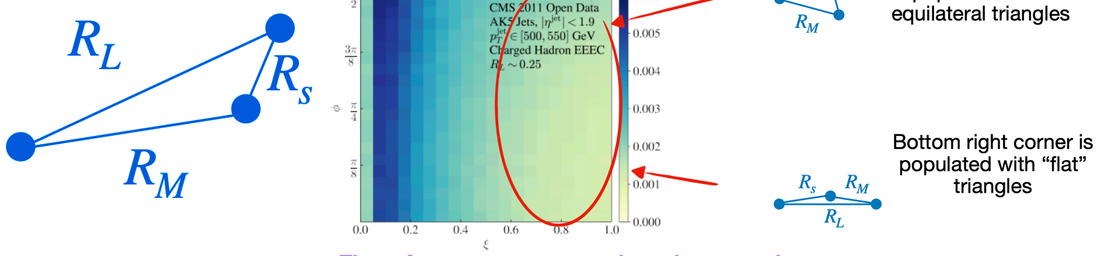
Sensitive to particle p_T?

JEWEL 2.4.0 + PYTHIA $\sqrt{s} = 5.02$ TeV



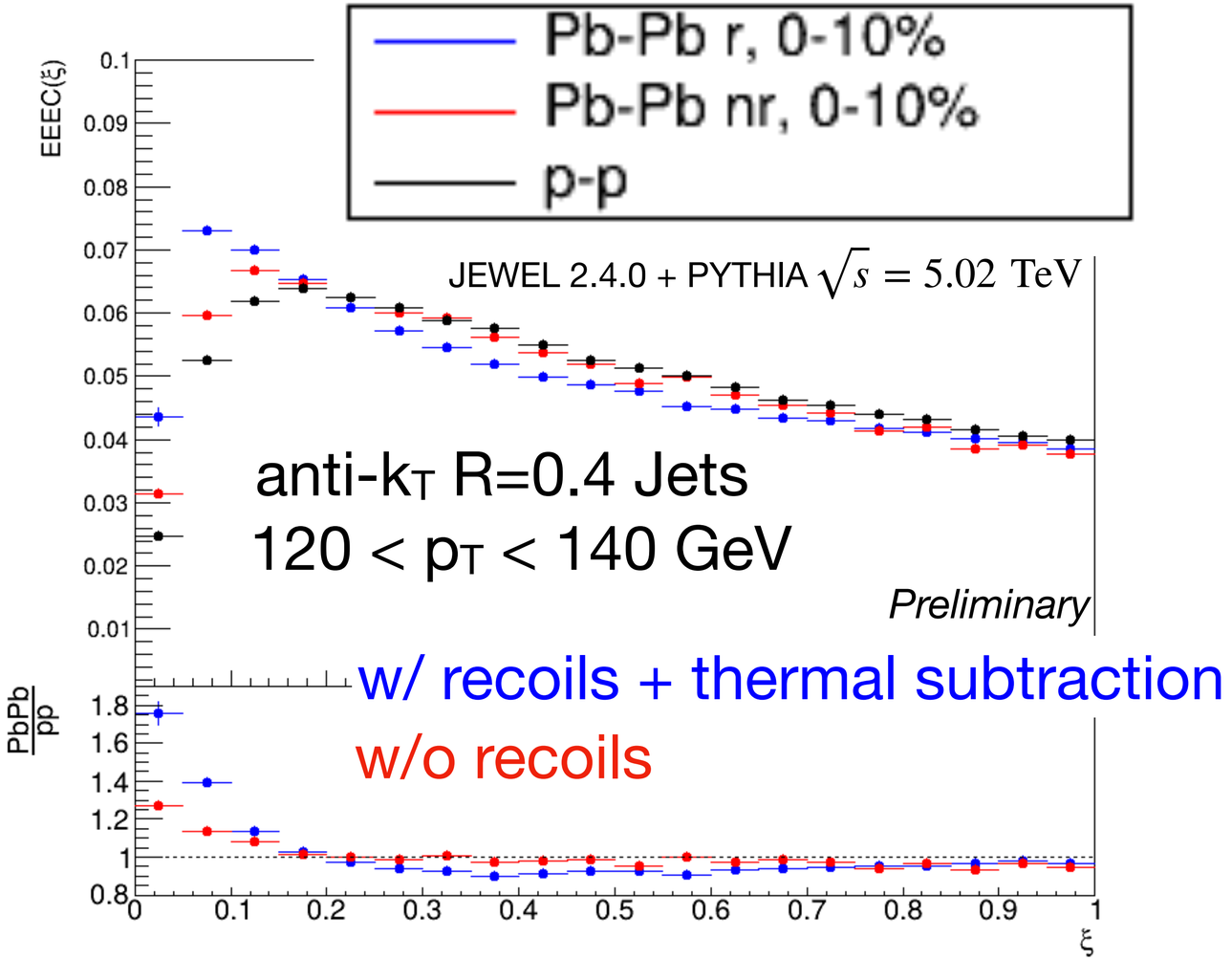
- Even going to $p_T > 2$ GeV we still see modification - which we did not see in E2C!

How about the ratios of lengths? ξ

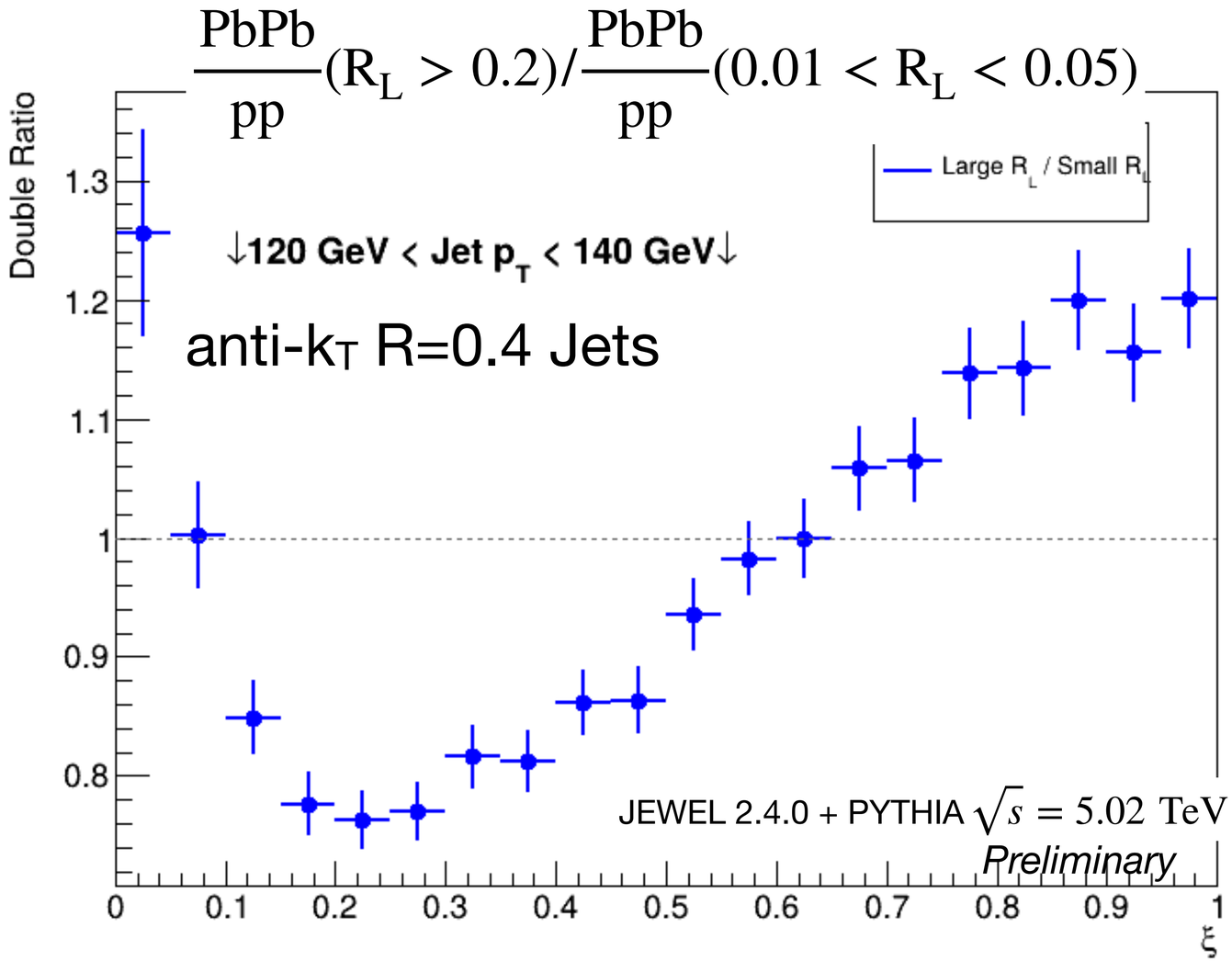


R_L $\quad \xi = \frac{R_S}{R_M} \quad \phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$

- Shows an enhancement at smaller ξ - we see larger smaller RS in heavy ions compared to pp - expected from having more lower p_T particles in the pbpb jet!
- What about ϕ?



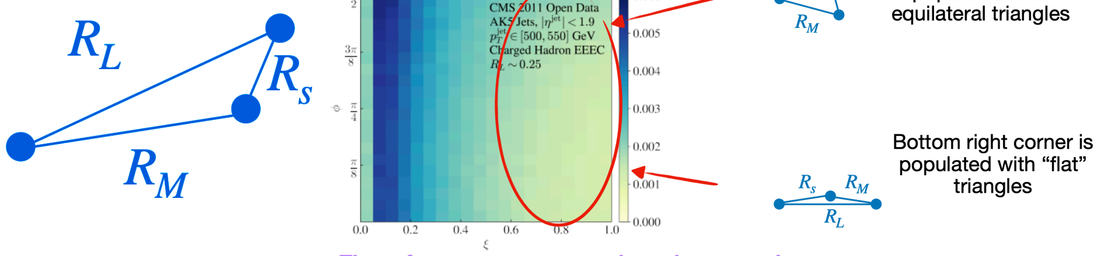
Double ratios!



$$\xi = \frac{R_S}{R_M}$$

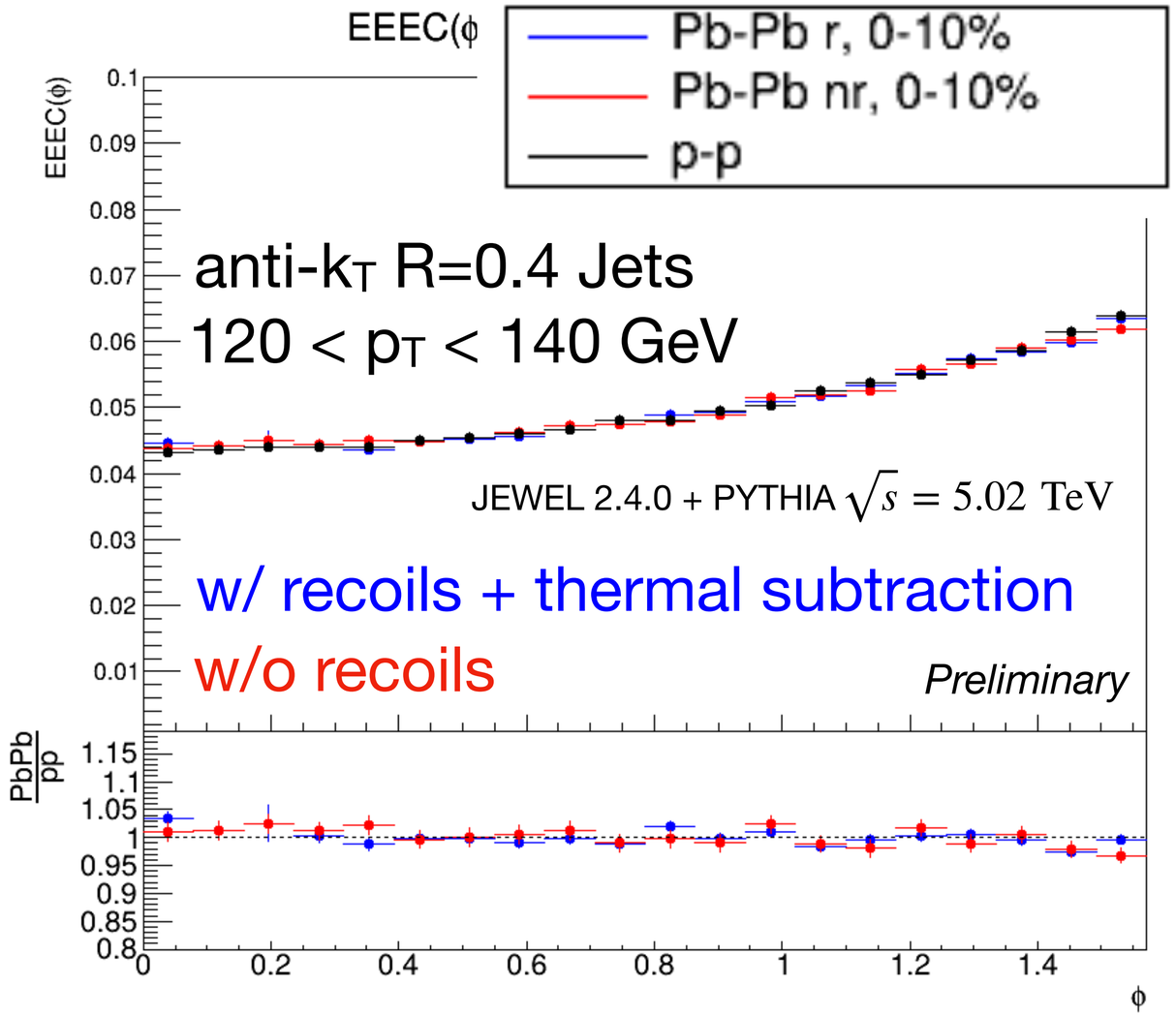
- Selection on RL seems to indicate a shape we are familiar with!
- These are ofcourse normalized so the integral is consistent

Controlling the shape of our triangles

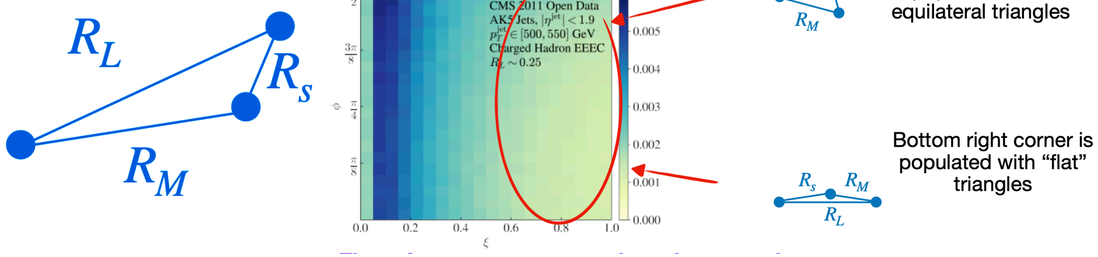


$R_L \qquad \xi = \frac{R_S}{R_M} \qquad \phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$

- Very surprising! Potential invariant under JEWEL's energy loss
- Why does this happen so? Is it a cancellation effect with change in jet p_T and possible quenching?

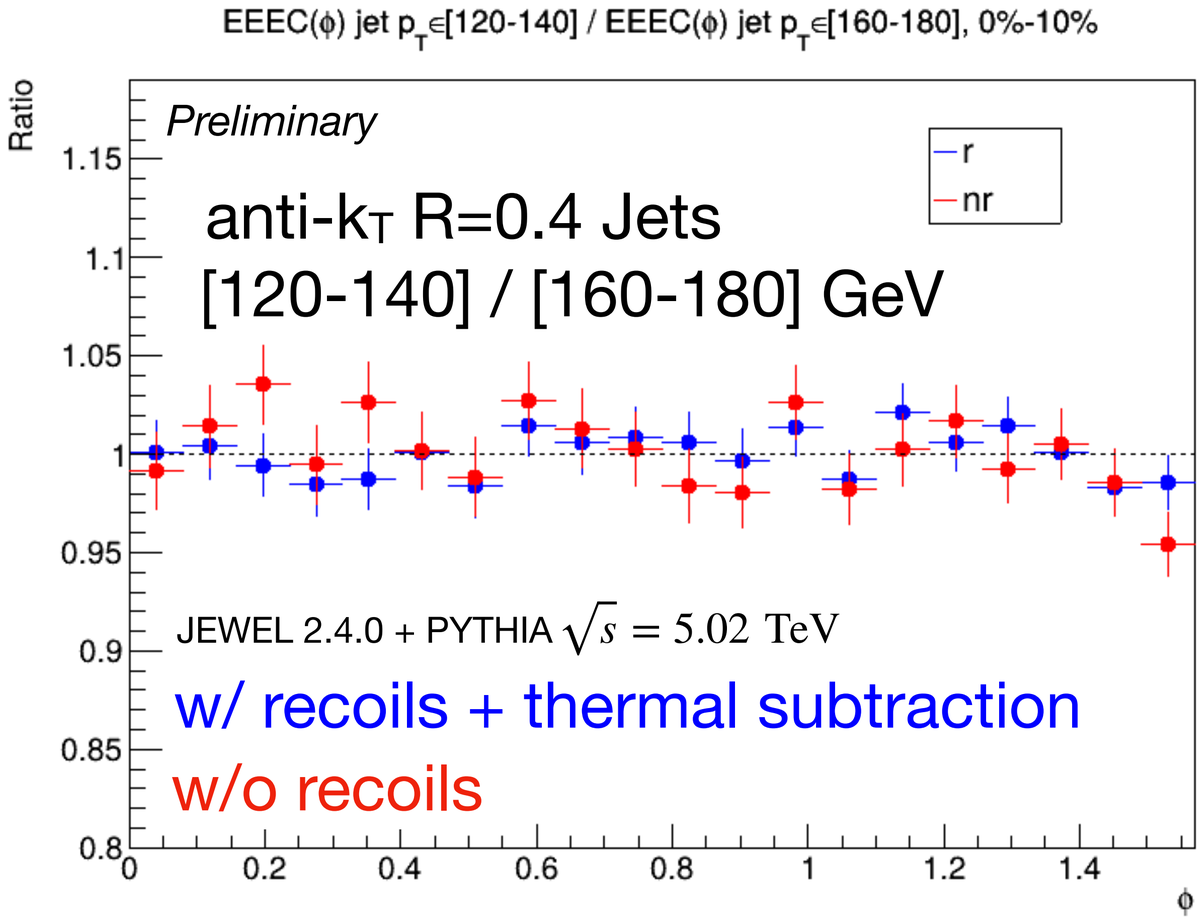


Controlling the shape of our triangles



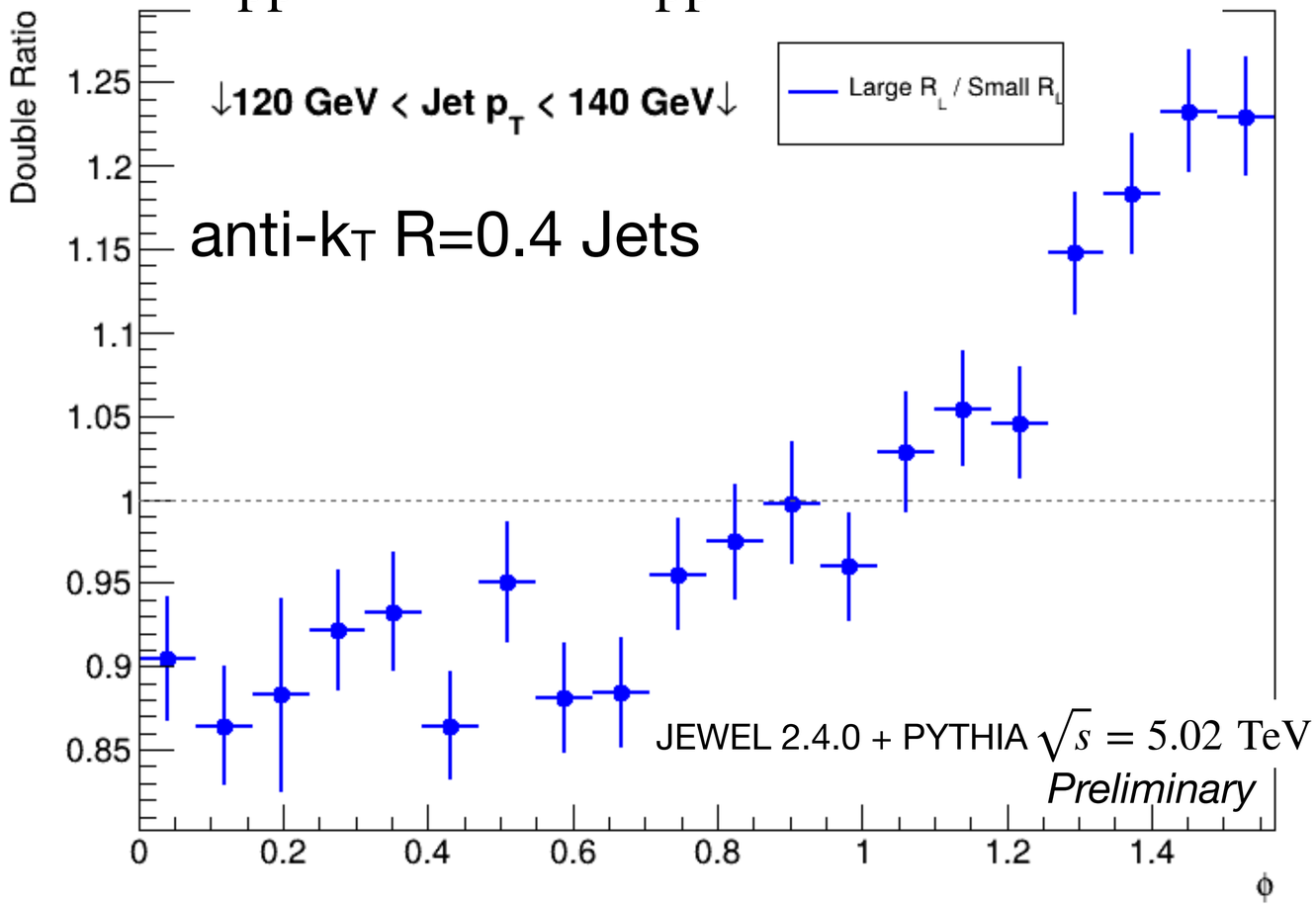
R_L $\quad \xi = \frac{R_S}{R_M} \quad \phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$

- Very surprising! Potential invariant under JEWEL's energy loss
- Why does this happen so? Is it a cancellation effect with change in jet p_T and possible quenching?



How to see modifications in phi?

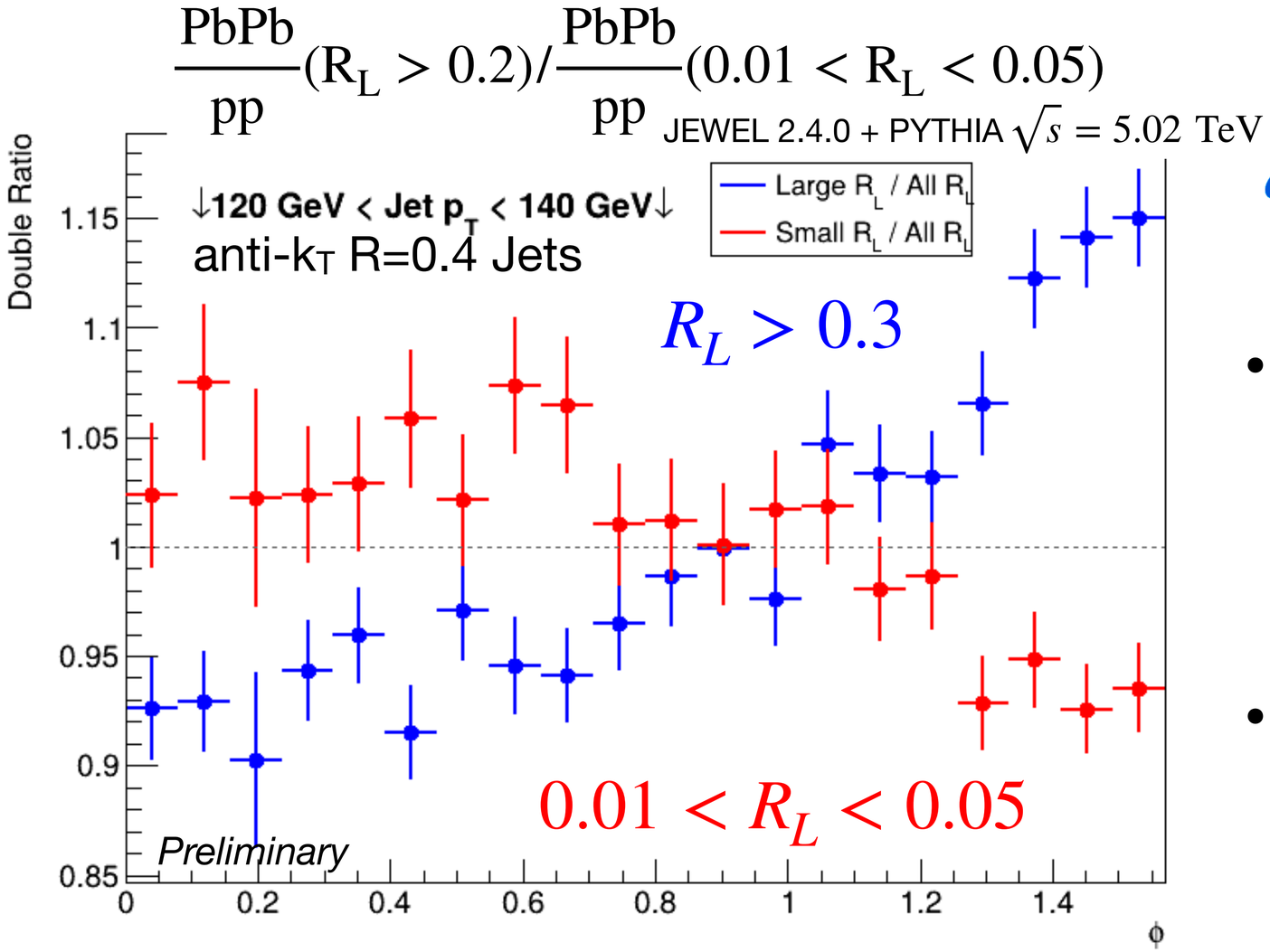
$$\frac{\text{PbPb}}{\text{pp}}(R_L > 0.2)/\frac{\text{PbPb}}{\text{pp}}(0.01 < R_L < 0.05)$$



$$\phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$$

- Selection on RL seems to indicate an enhancement of larger ϕ
- Relatively small effect - if you have larger RL, you end up with larger ‘equilateral’-like triangles…
- These are ofcourse normalized so the integral is consistent

How to see modifications in phi?



$$\phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_s^2}}$$

- Example of a cancellation effect that results in an RL integrated ϕ showing up as unmodified…
- Would be very interesting if different methods of energy loss show up differently in such obserables!

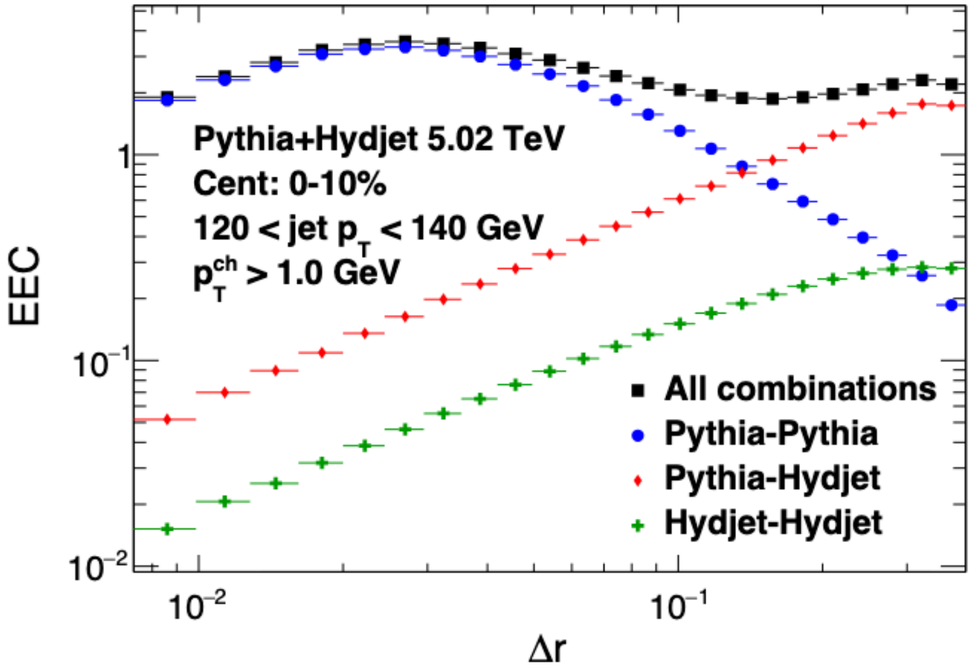
What are the physics we measure with the E3C observables

- Compare JEWEL w/ and w/o recoils for inclusive jets at fixed energy
- Insights into the nature of jet modification and energy loss from different combinations of E3C observables
- Invariant in jet structure!

Realistic impact of the background on E3Cs and how we remove it

- Embed PYTHIA di-jet events into multiple PYTHIA minbias events
- How does this uncorrelated background contribute to the observables related to E3Cs
- How can one remove this background and at what precision?

Expected background in PbPb collisions



- Different pairings in the simulation
  - All pairs
  - Signal+signal pairs
  - Signal+background pairs
  - Background+background pairs
- Background contributions dominant at large Δr
- Background subtraction needed

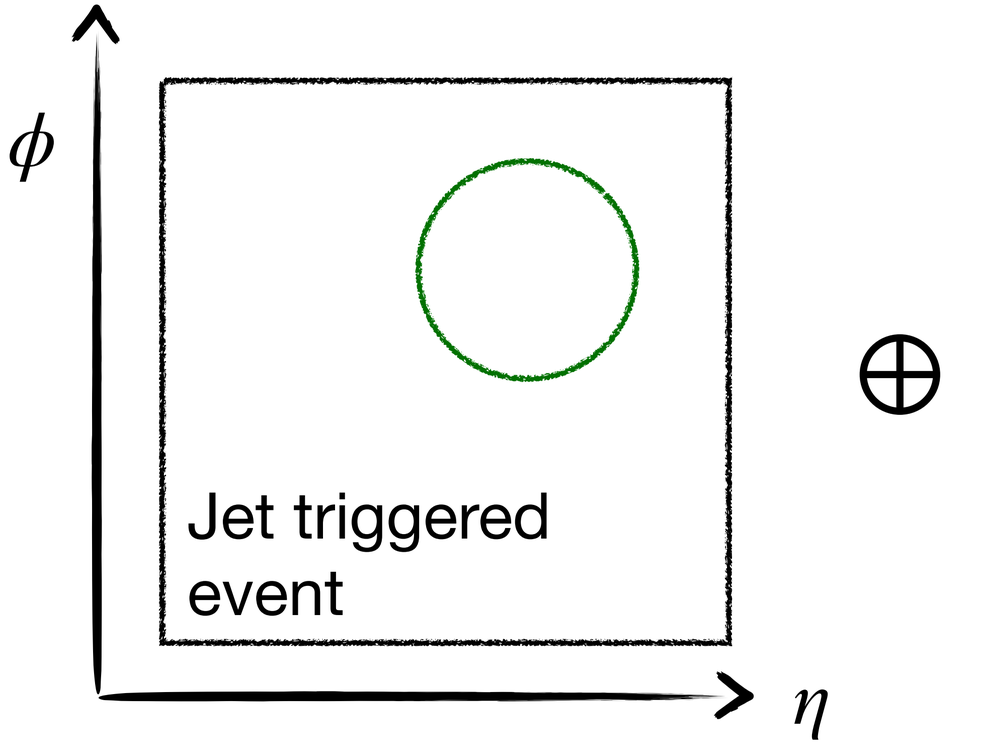
The good 

The bad 

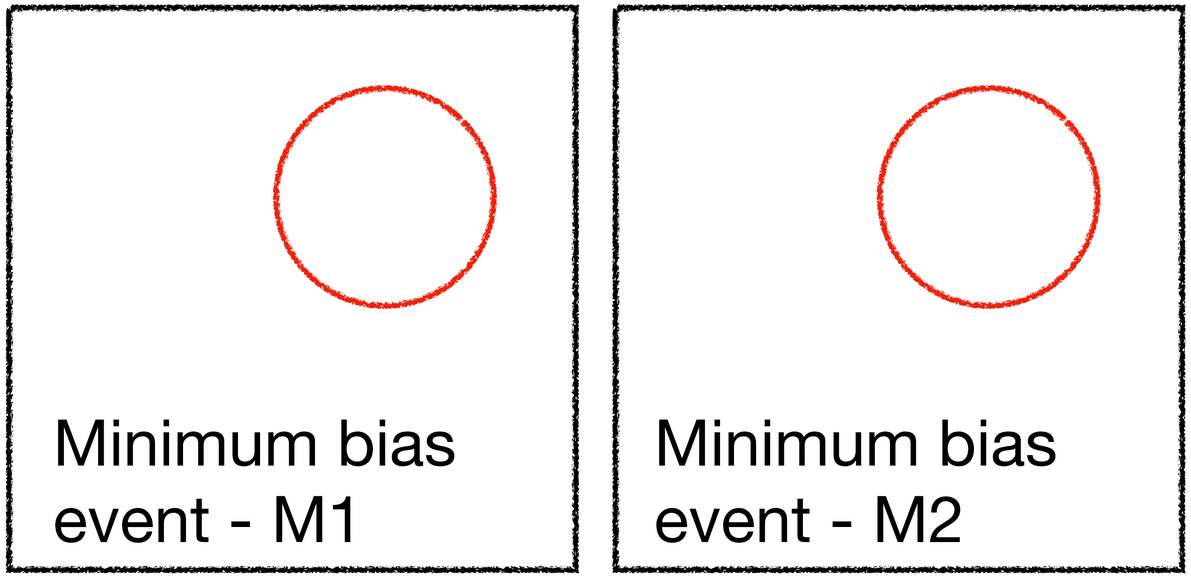
The ugly 

Background subtraction method

Reminder of the 2-point method



$\oplus$

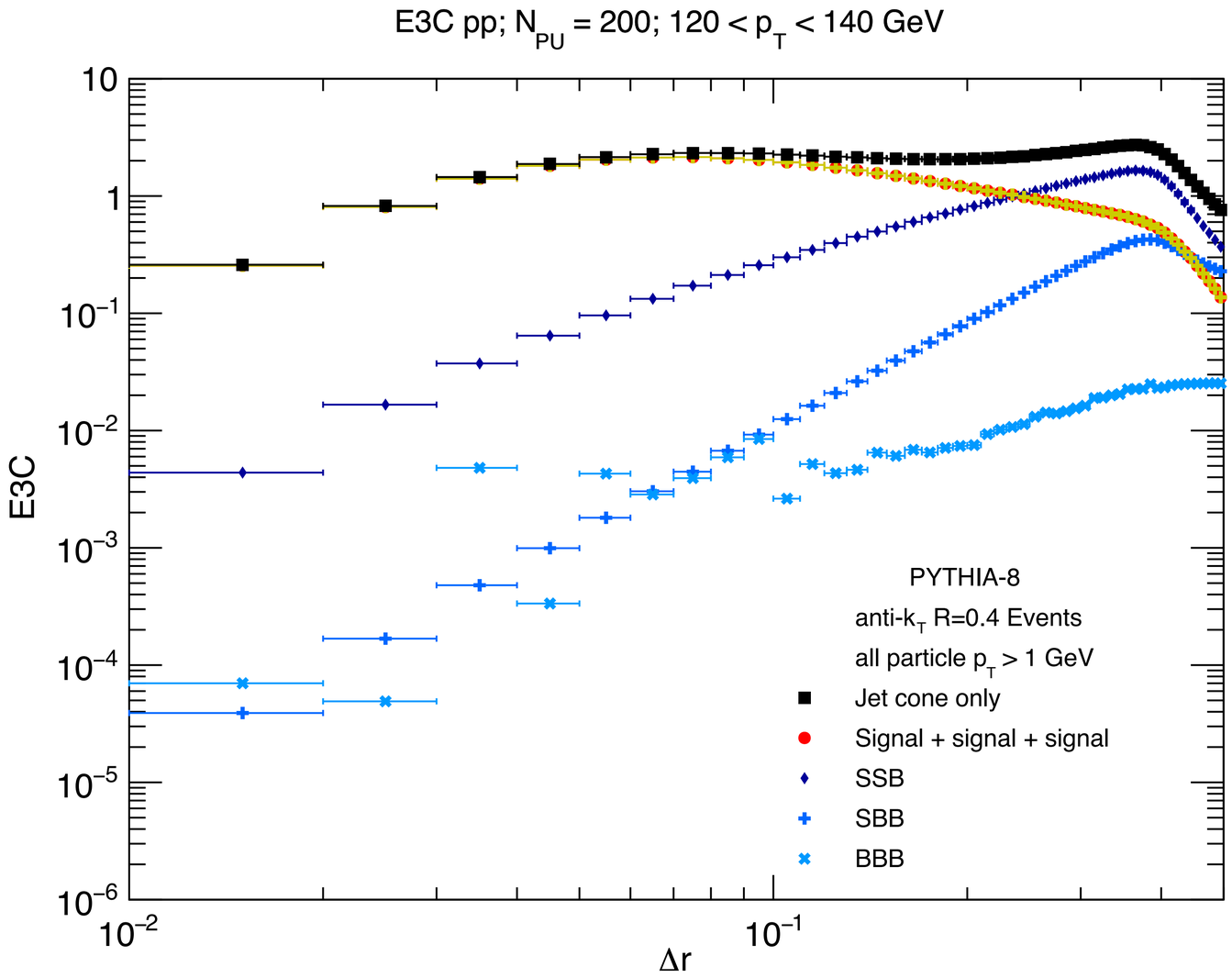


- SS + SB + BB - thats what we start with in Data
- SM1 + M1M1 – M1M2 - gives us the background we need the subtract!

- S + M1: signal+fake together with mismodeled fake+fake
- M1+ M1: properly modeled fake+fake
- M1+ M2: mismodeled fake+fake

Note: these are from unique triplets!

Dealing with triplets!



SSS — Good

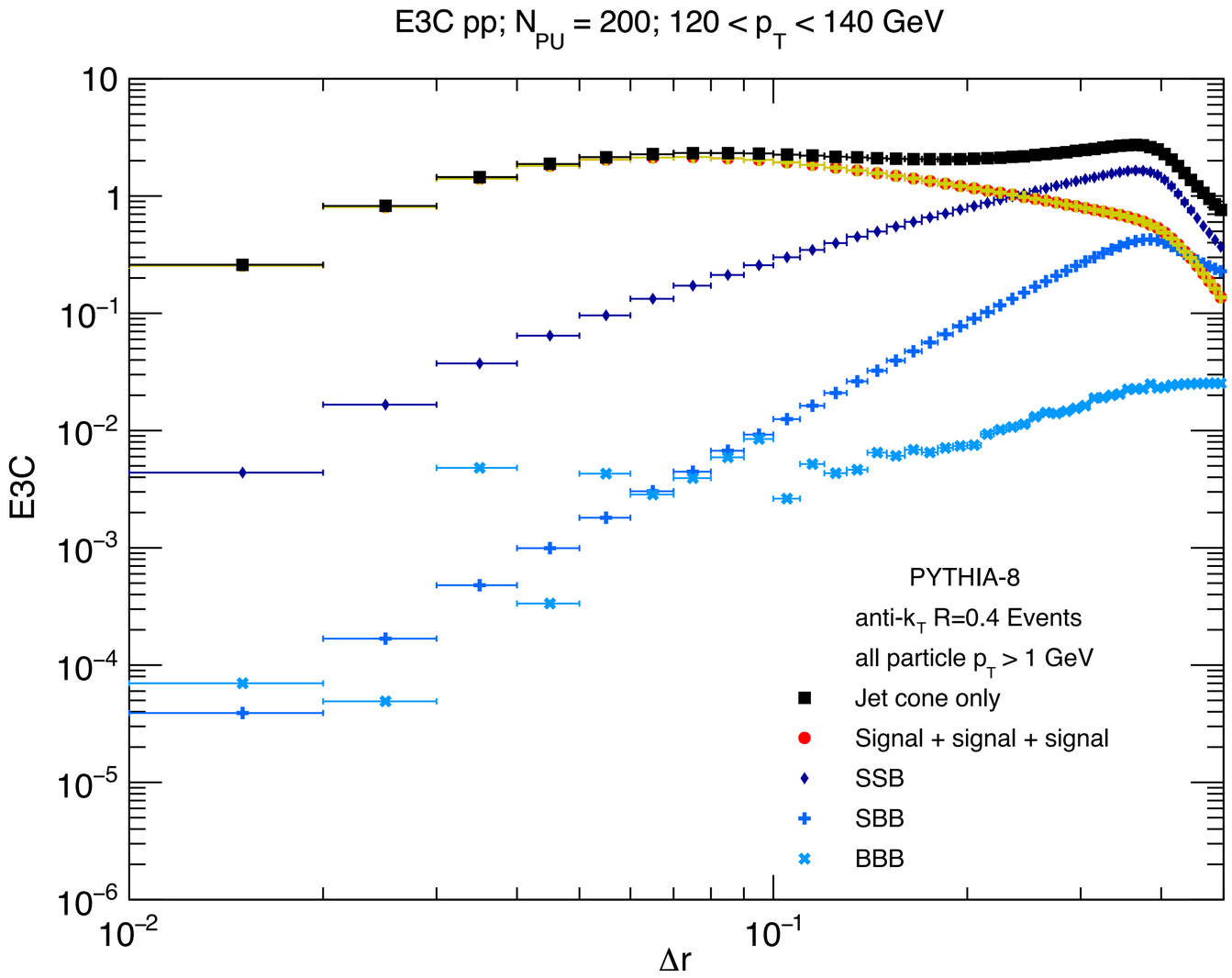
SSB — Bad

SBB — Weird

BBB — Ugly

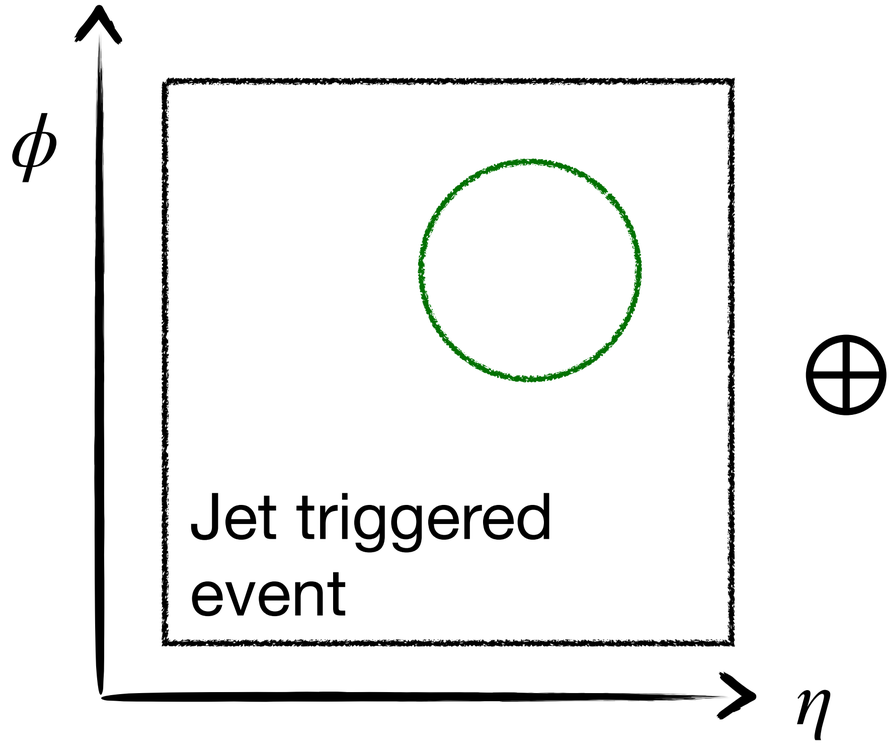
Note: these are from unique triplets!

Dealing with triplets!

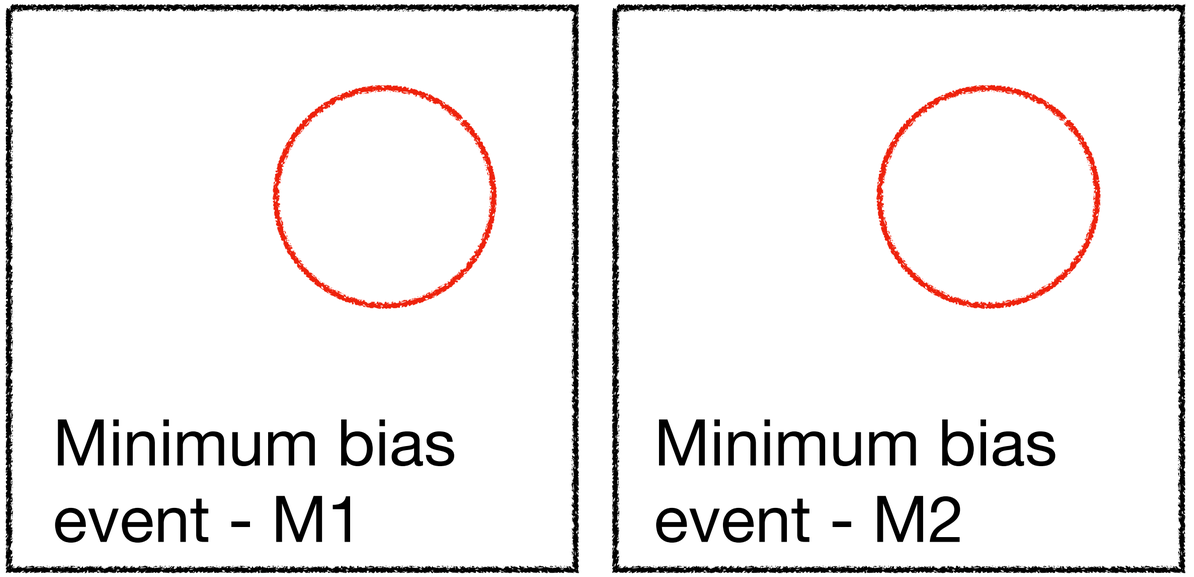


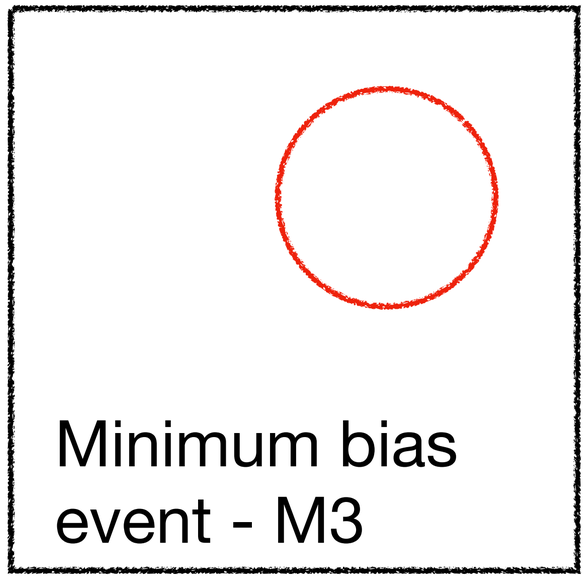
- Estimate the impact of the heavy ion underlying event with multiple pileup minimum bias events
- Significant correction needed especially when one considers the amount
- Lets try with the existing bkg sub method and see if we can expand it!

Note: these are from unique triplets!



$\oplus$

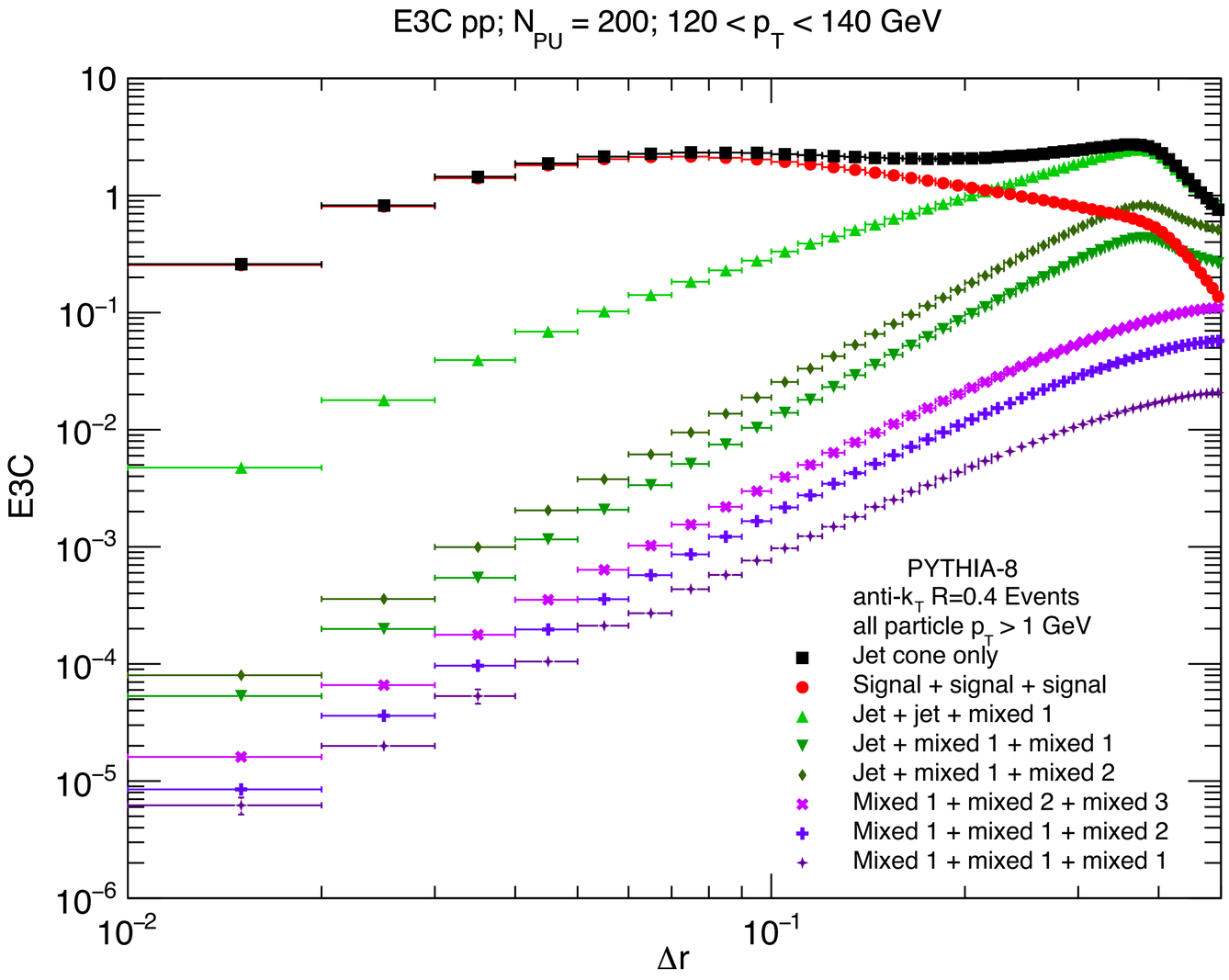




- What you measure = SSS + SSB + SBB + BBB
- Total Background = SSB + SBB + BBB [SSM1] + SBB + BBB [SM1M1] + BBB [M1M1M1] - 2 * BBB [M1M1M2] - SBB - BBB [SM1M2] + BBB [M1M2M3]

Note: these are from unique triplets!

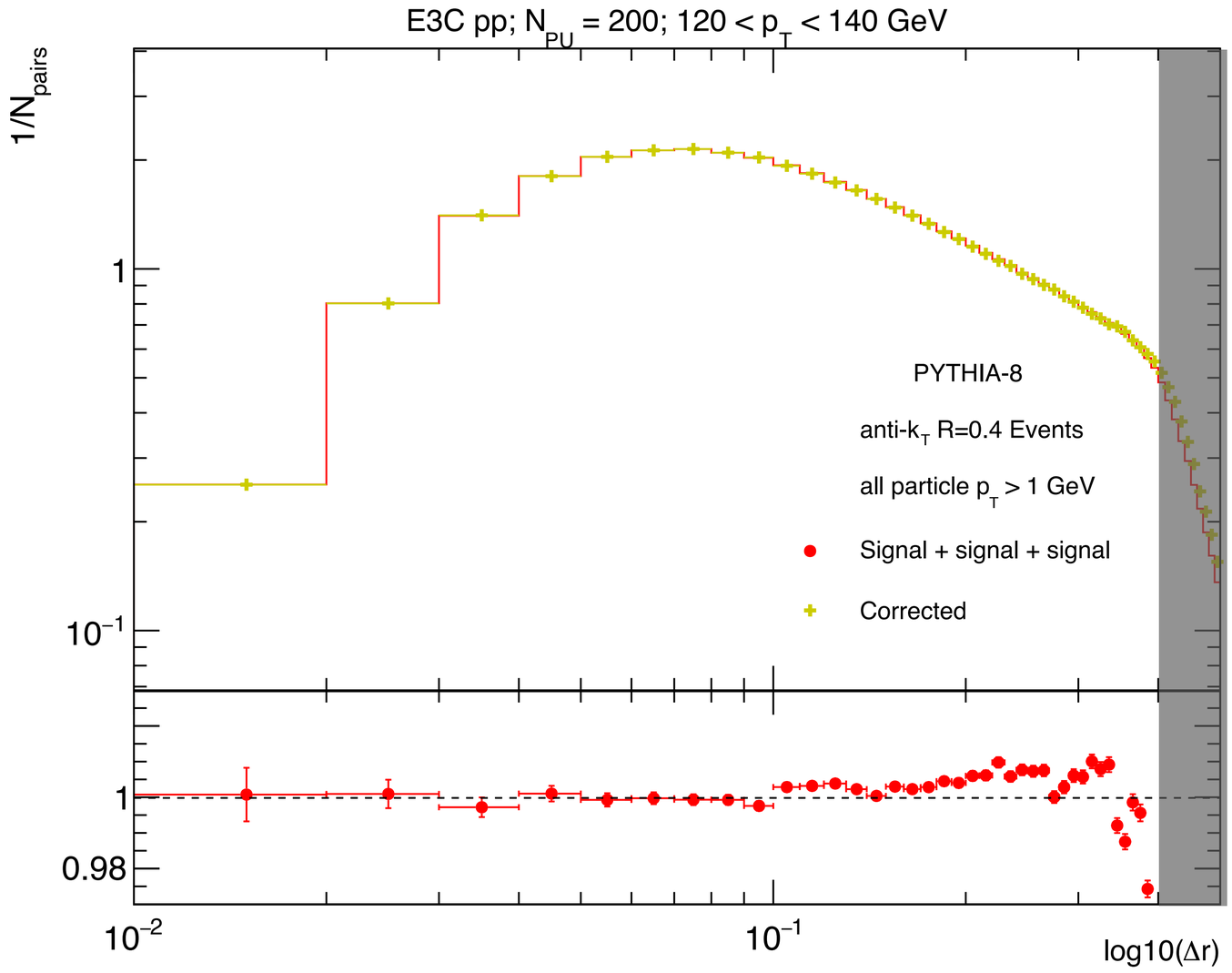
Performance of the subtraction



- These are all the relevant combinations
- There is a specific condition that we need to correct for -
- The mere fact that you do jet finding results in your background estimate needing to be adjusted

Note: these are from unique triplets!

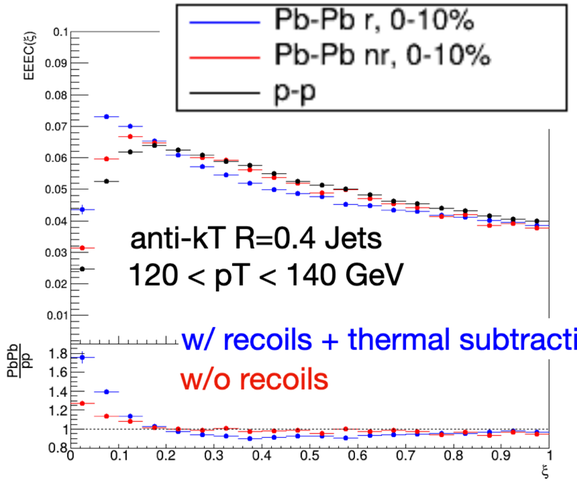
Performance of the subtraction

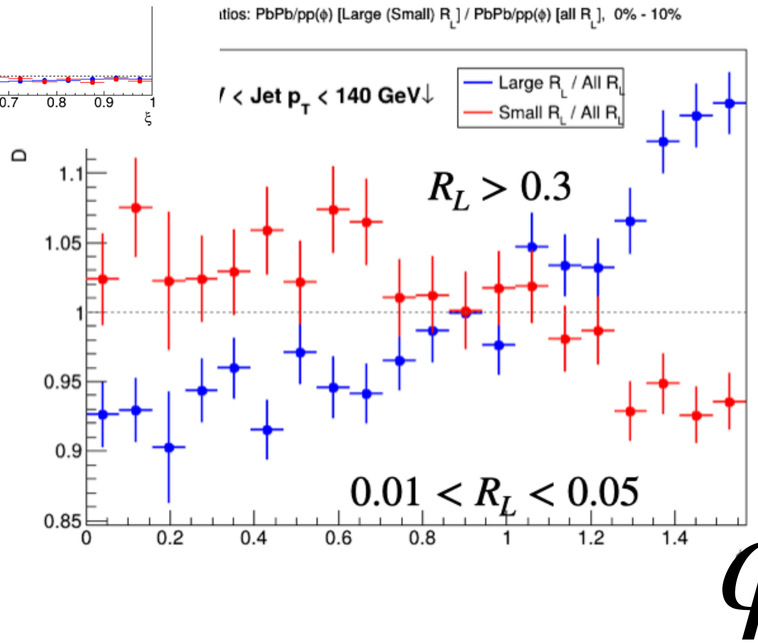


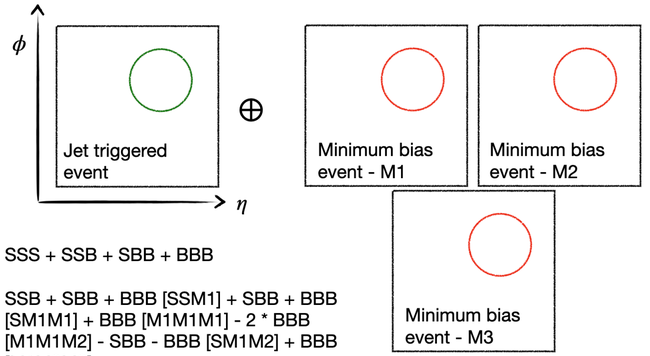
- Very good estimate of the background through the entire region of accessibility (experimentally)
- Sub percent non-closure until we get to the large angular region (which is the region of interest for wake physics)
- RS, RM, RL should be measurable similarly!
  (ξ, ϕ not clear at this point..)

Note: these are from unique triplets!

Conclusions

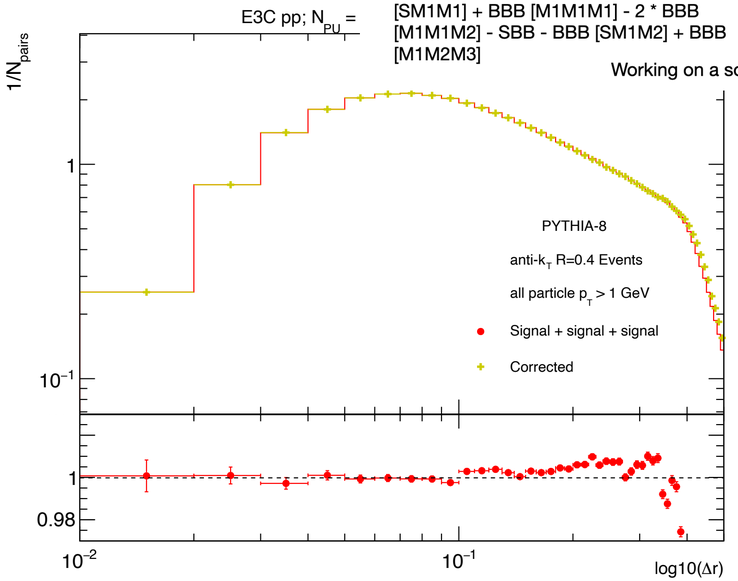






- SSS + SSB + SBB + BBB
- SSB + SBB + BBB [SSM1] + SBB + BBB [SM1M1] + BBB [M1M1M1] - 2 * BBB [M1M1M2] - SBB - BBB [SM1M2] + BBB [M1M2M3]

Working on a software package incoming!



R_L

- E3Cs offers a rich trove of observables sensitive to different aspects of jet modifications
- Each of the distances can be background subtracted with sensitivity to interesting physics!