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Monte Carlo Study on the Impact of jet quenching in Pb-Pb Collision

A JEWEL-based analysis on 3 – point correlator

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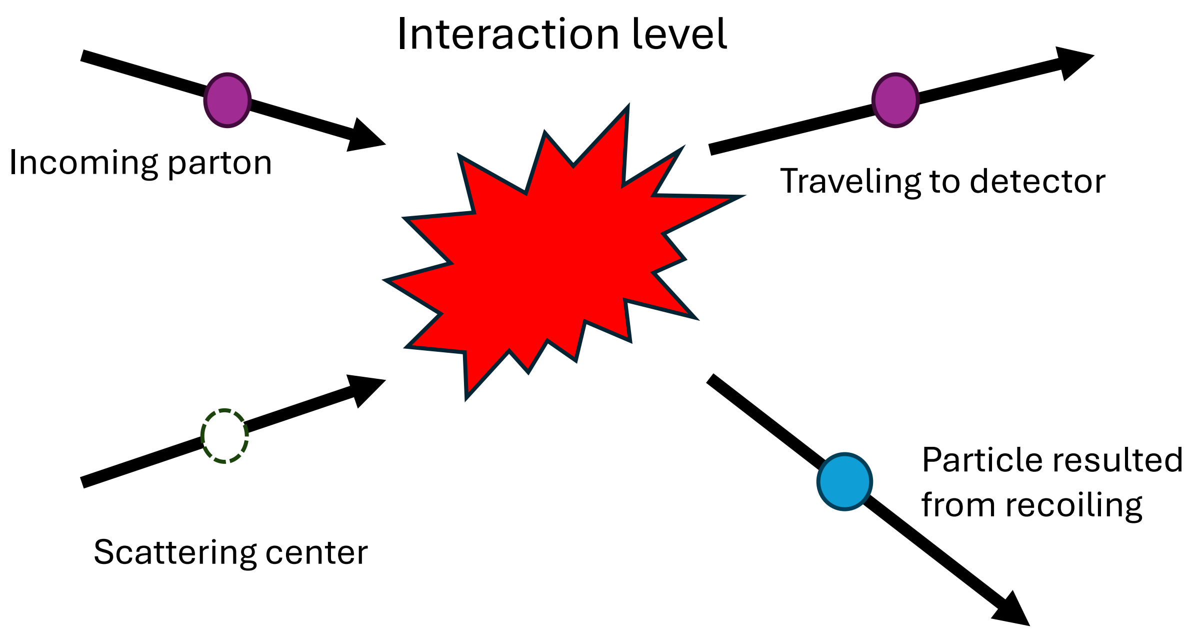
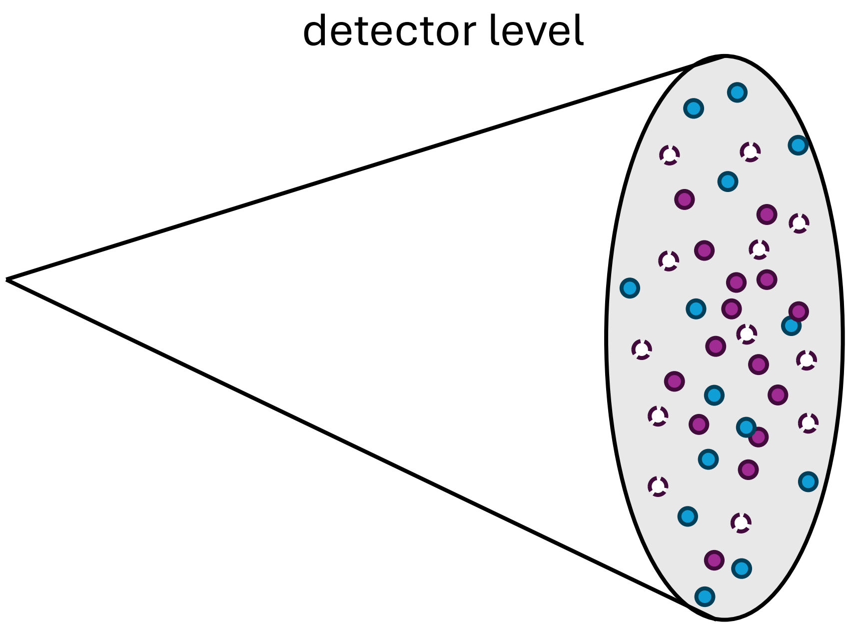
Overview

- Compare JEWEL w/ and w/o recoils for single inclusive jet events at certain fixed energy
- Investigate the QGP modification on the target jet and gain insights on how this medium effect acts on the EEEC for different dependencies
- Find potential invariance under JEWEL medium modification
- Identify the geometrical boost region corresponding to recoil effect with new coordinate system

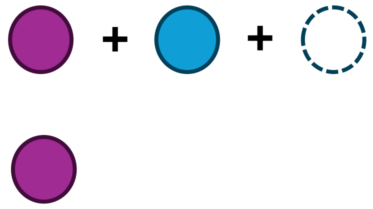
Quick introduction to JEWEL (2.4.0) recoil effect





JEWEL w/ recoil:

JEWEL w/o recoil:



[Korinna Zapp and José Guilherme Milhano arXiv:2207.14814.]

Quick introduction to projected n-point energy correlator

- **What is it?**

—— It is defined as the product of the energies of n particles chosen within the target jet.
—— Experimentally, it can be computed as weighted histogram with equation:

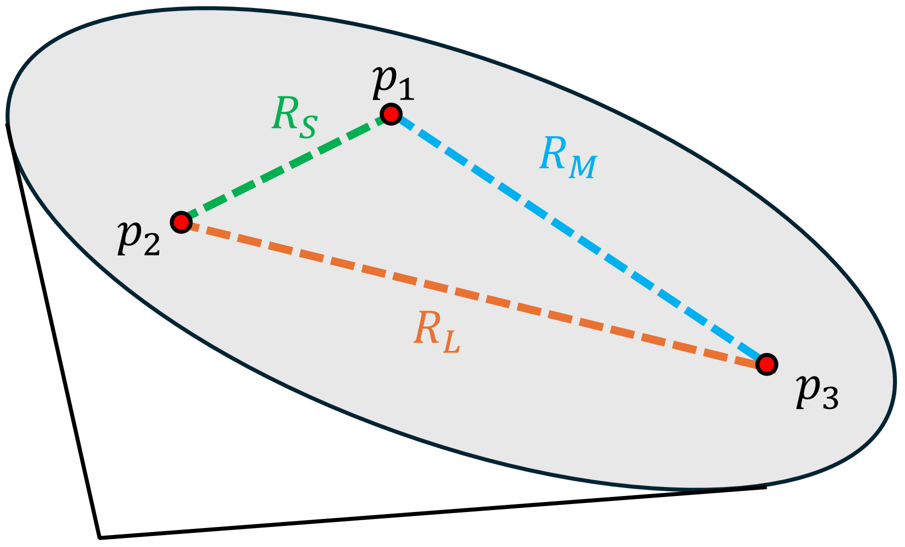
$$\mathrm{ENC}(R_L) = \left(\prod_{k=1}^{N} \int d\Omega_{\vec{n}_k}\right) \delta(R_L - \Delta\hat{R}_L) \cdot \frac{1}{(E_{\mathrm{jet}})^N} \langle \mathcal{E}(\vec{n}_1)\mathcal{E}(\vec{n}_2)\ldots\mathcal{E}(\vec{n}_N)\rangle$$

[P.T. Komiske, I. Moult, J. Thaler, and H.X. Zhu arXiv: 2201.07800.]

- **What makes the n-point correlator (ENCs) important?**

—— It is theoretically calculable in pQCD
—— It is scale sensitive.
—— It provides access to strong coupling constant α_S.
—— ***It can be used to probe the jet modification as it is sensitive to different types of energy loss.***

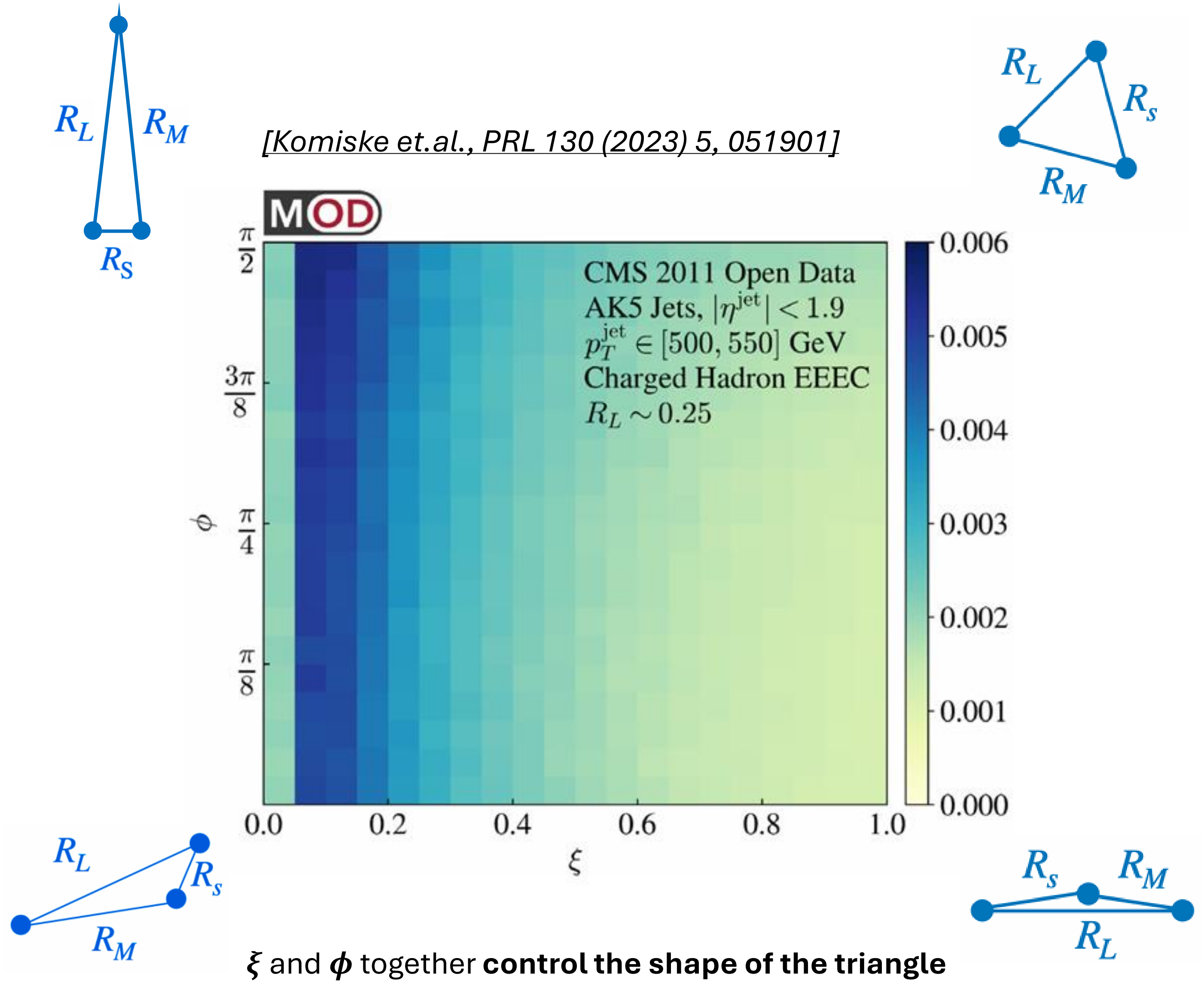
EEEC and its dependencies



R_L, R_M, R_S are longest side, medium side and shortest side of the triangle, respectively.

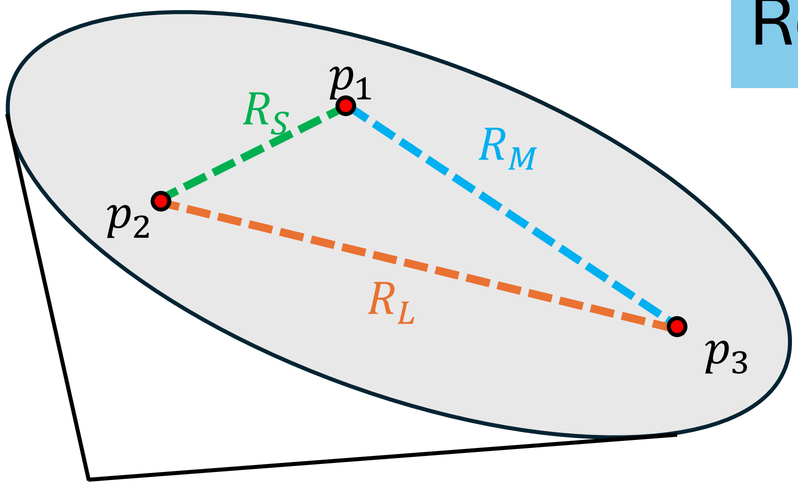
$$\xi = \frac{R_S}{R_M}, \qquad \phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_S^2}}.$$

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



ξ and ϕ together **control the shape of the triangle**

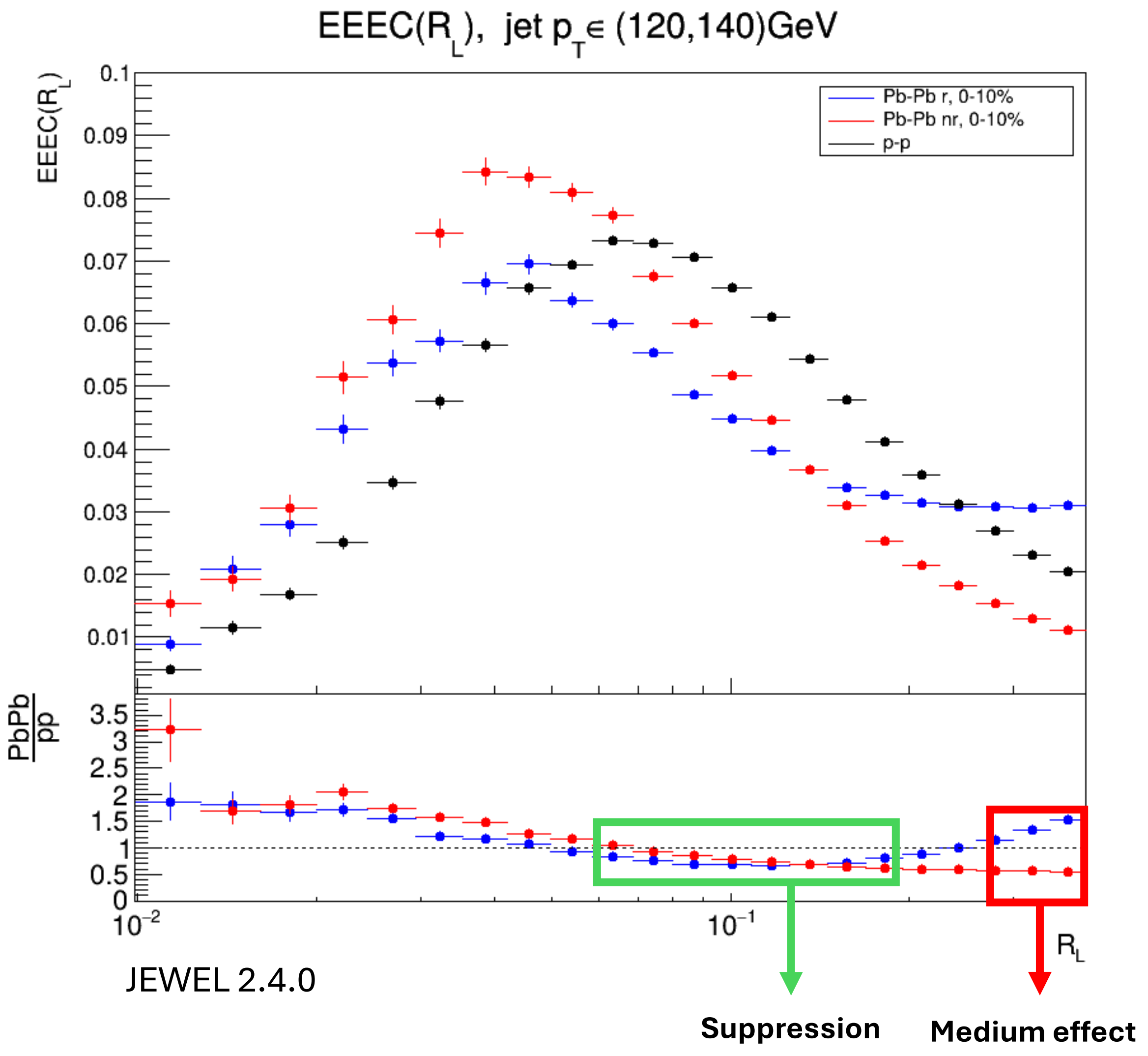
Result for EEEC (R_L)



$\mathbf{PbPb}\ \sqrt{s_{NN}} = 5.02\ \mathbf{TeV}$ anti_$k_T R = 0.4$

$\mathbf{pp}\ \sqrt{s_{NN}} = 5.02\ \mathbf{TeV}$ $|\eta_{jet}| < 2.5$

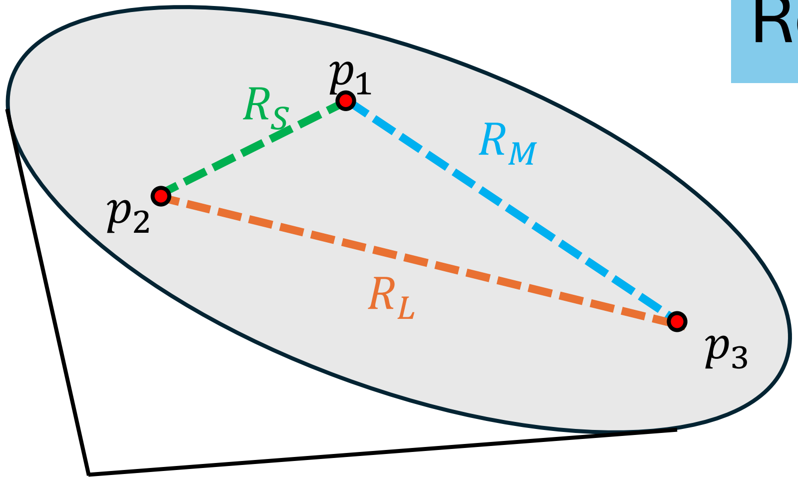
0% < Centrality < 10%



Observations:

1. Just like EEC(Δr), with medium enhancement at large angle
2. However, the medium effect seems to have less impact compared to EEC(Δr)

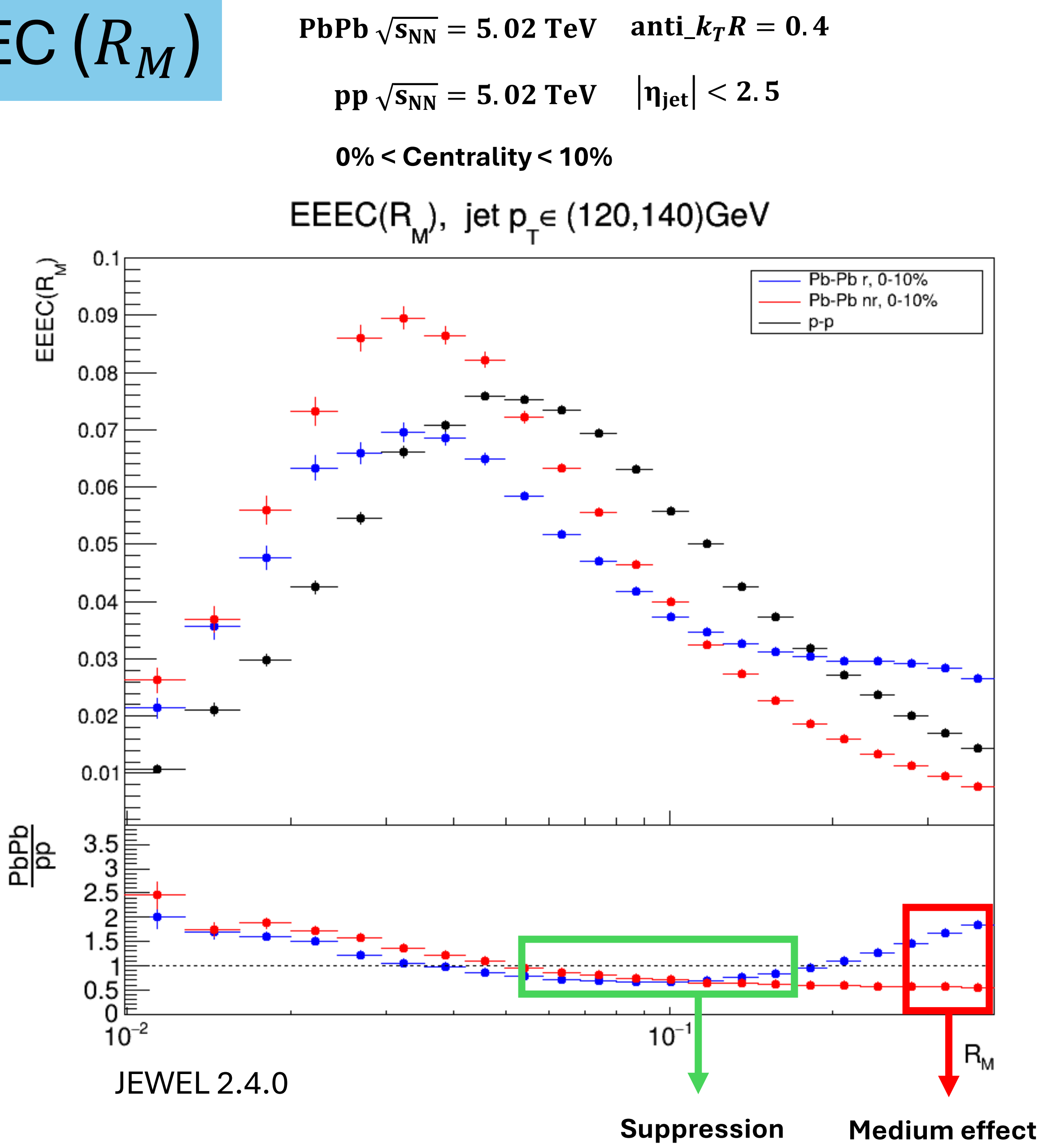
Result for EEEC (R_M)



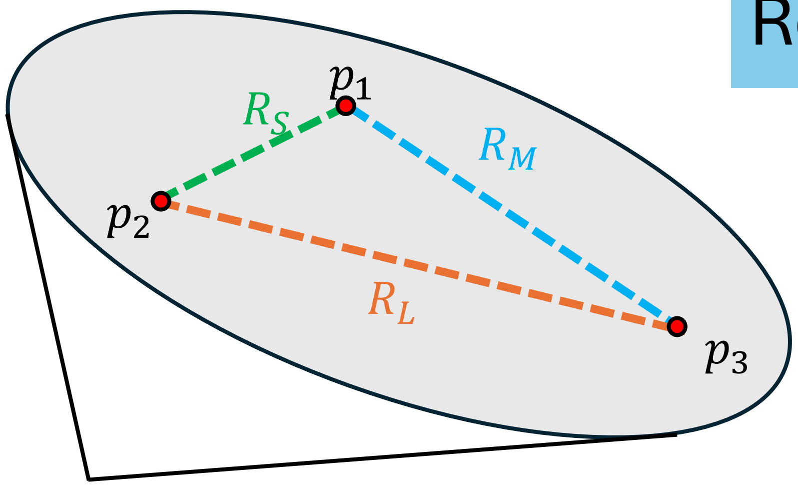
Observations:

1. The medium effect has larger enhancement compared to R_L

2. Suppression region shifts left.



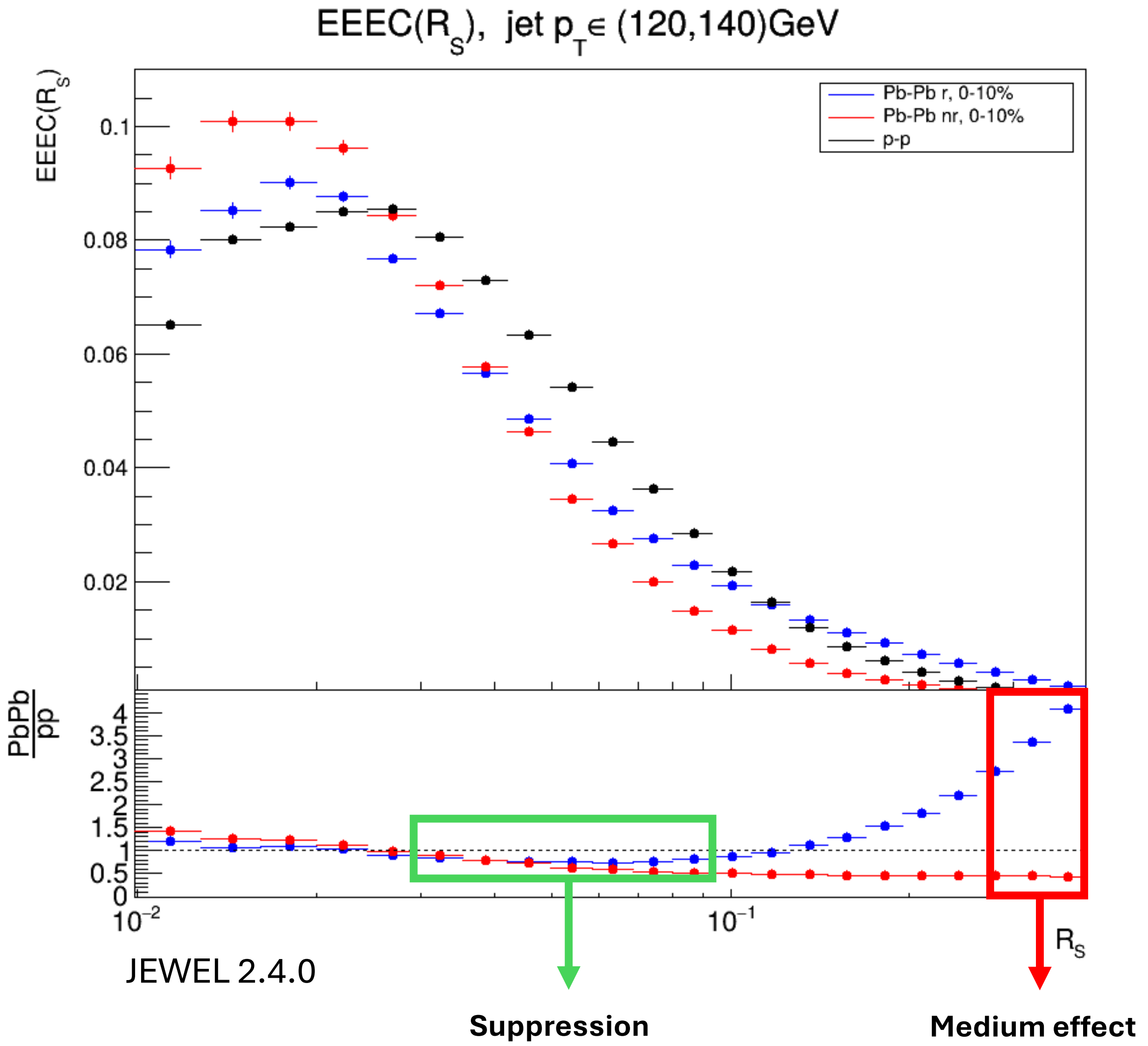
Result for EEEC (R_S)



PbPb $\sqrt{s_{NN}} = 5.02$ TeV anti_$k_T R = 0.4$

pp $\sqrt{s_{NN}} = 5.02$ TeV $|\eta_{jet}| < 2.5$

0% < Centrality < 10%

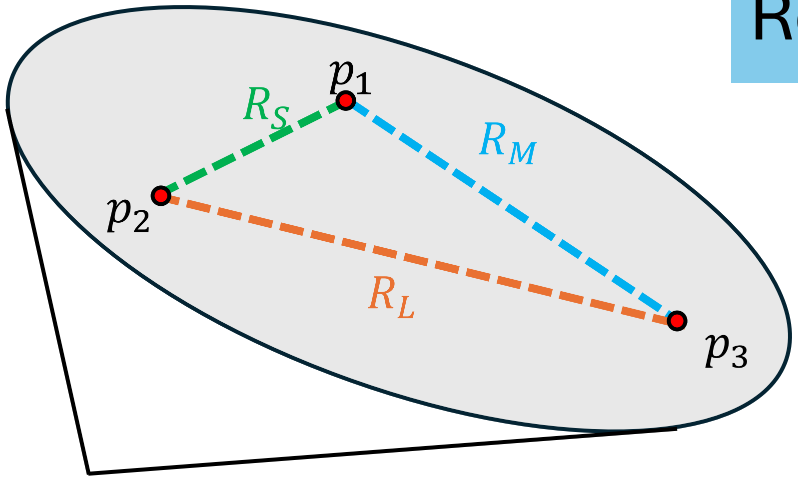


Observations:

1. Medium effect has ***even larger*** modification on the EEEC(R_S).

2. Suppression region shifts even more to the left.

Result for EEEC (ϕ)

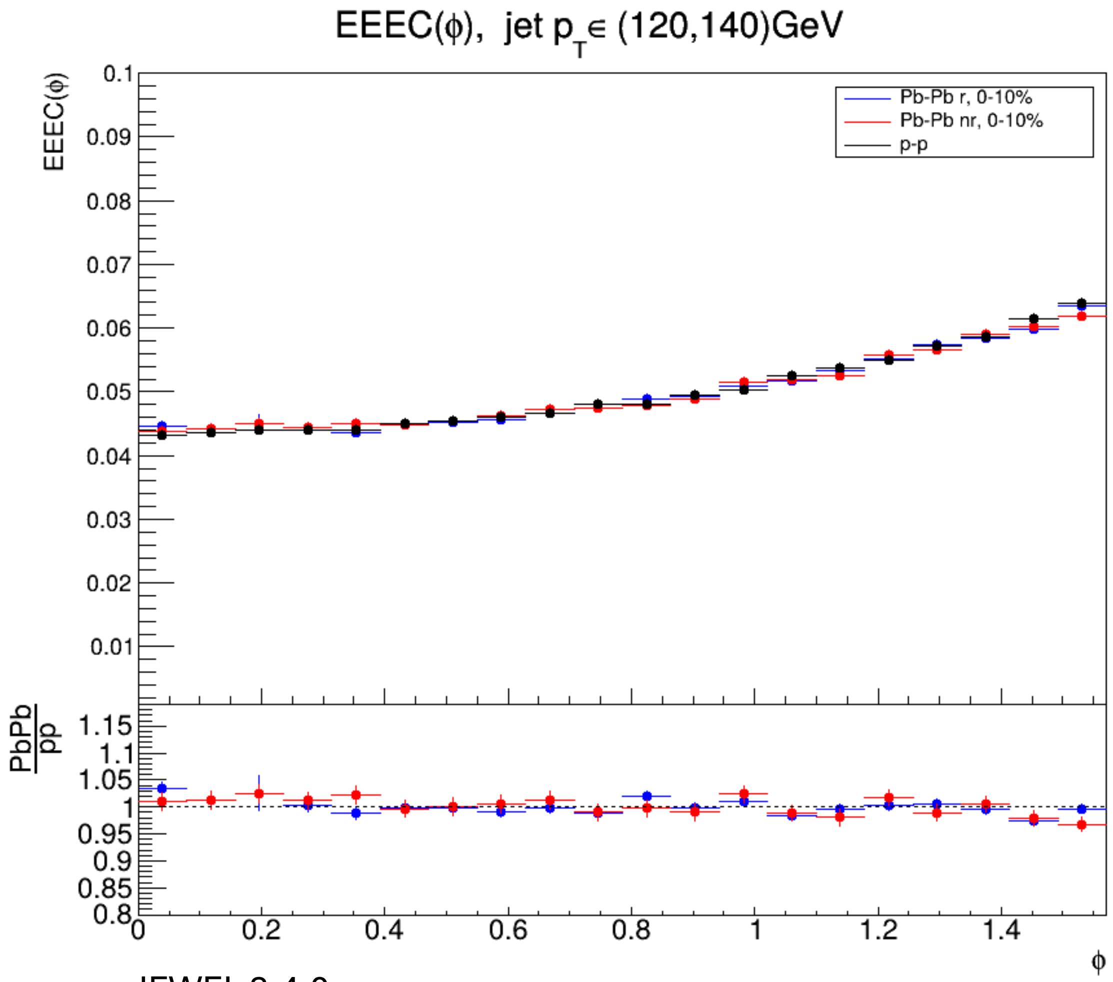


$$\phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_S^2}}$$

PbPb $\sqrt{s_{NN}} = 5.02$ TeV anti_$k_T R = 0.4$

pp $\sqrt{s_{NN}} = 5.02$ TeV $|\eta_{jet}| < 2.5$

0% < Centrality < 10%



JEWEL 2.4.0

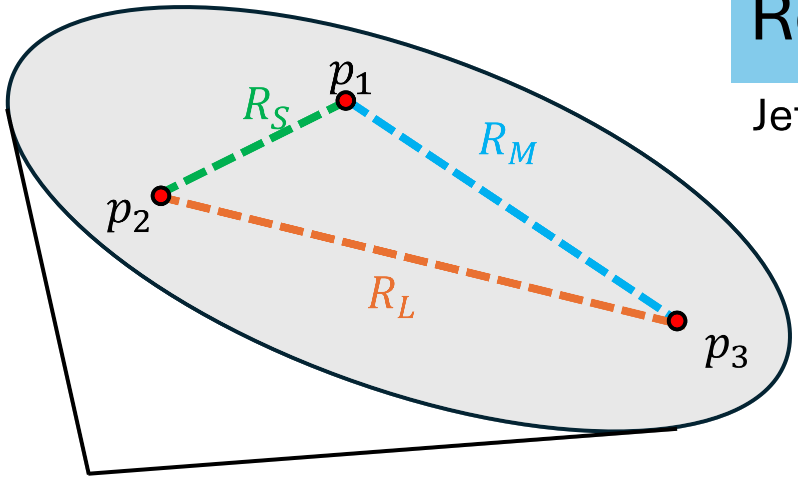
Observations:

1. These 3 curves are **statiscally indistinguishable!**

   This implies a **potential Invariance** under JEWEL's medium modification.

Result for EEEC (ϕ)

Jet p_T selection check

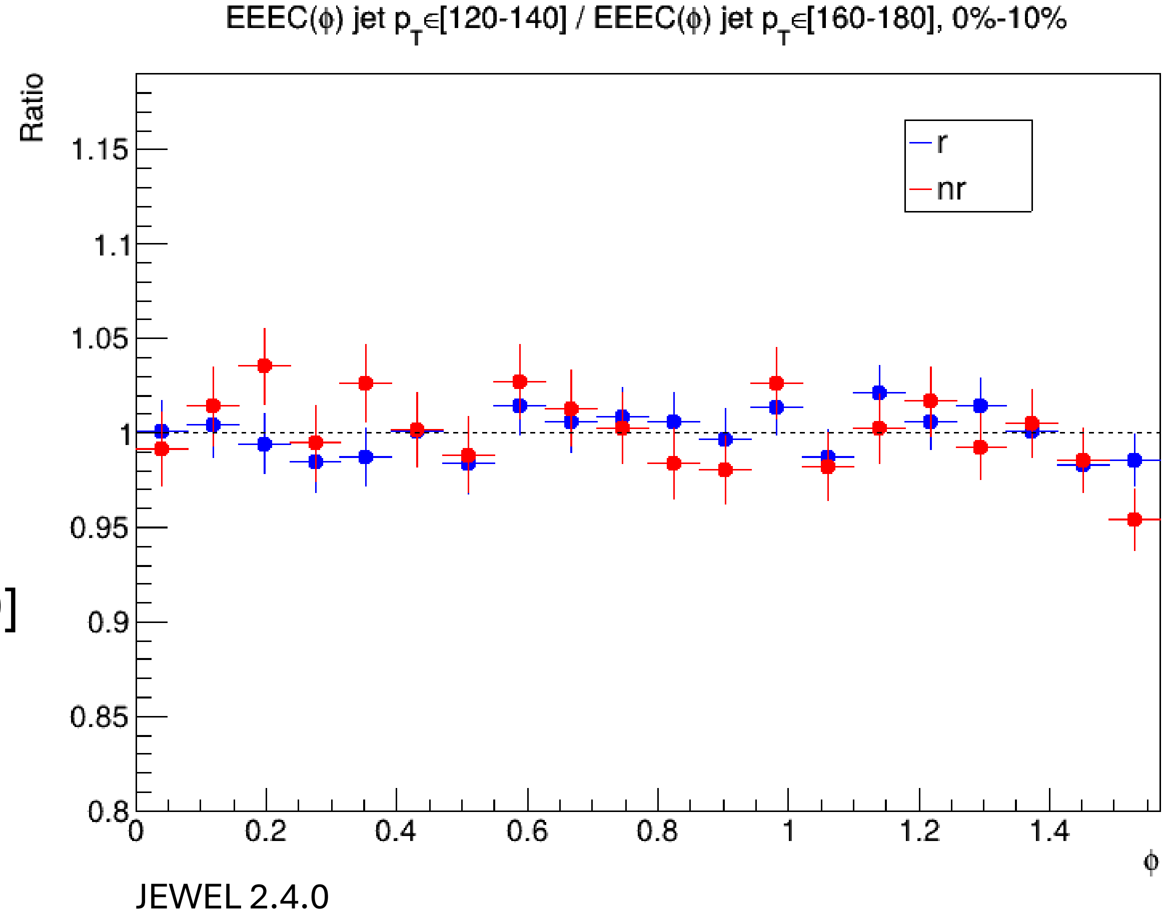


$$\phi = \arcsin\sqrt{1 - \frac{(R_L - R_M)^2}{R_S^2}}$$

PbPb $\sqrt{s_{NN}} = 5.02$ TeV anti_$k_T R = 0.4$

pp $\sqrt{s_{NN}} = 5.02$ TeV $|\eta_{jet}| < 2.5$

0% < Centrality < 10%

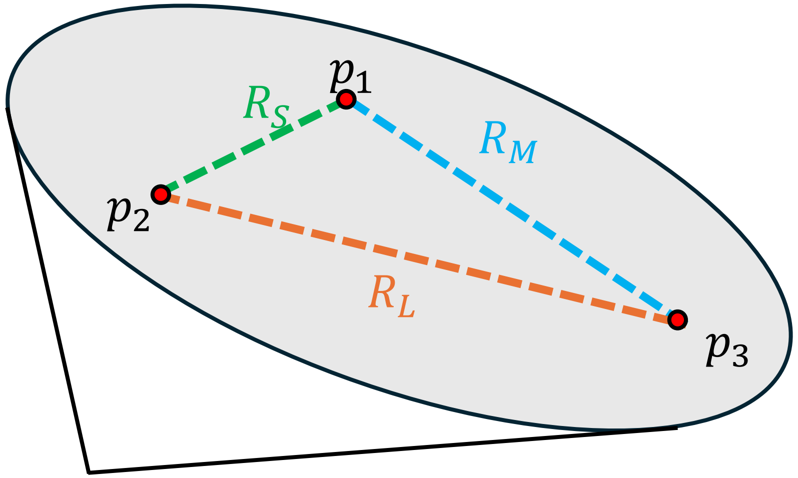


Observations:

1. The ratio EEEC(ϕ) [120 - 140] / EEEC(ϕ) [160 - 180] GeV is roughly **1**.

At least for these two jet p_T ranges, the invariance – like property **still holds**.

Result for EEEC (ϕ)



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

PbPb $\sqrt{s_{NN}} = 5.02$ TeV anti_$k_T R = 0.4$

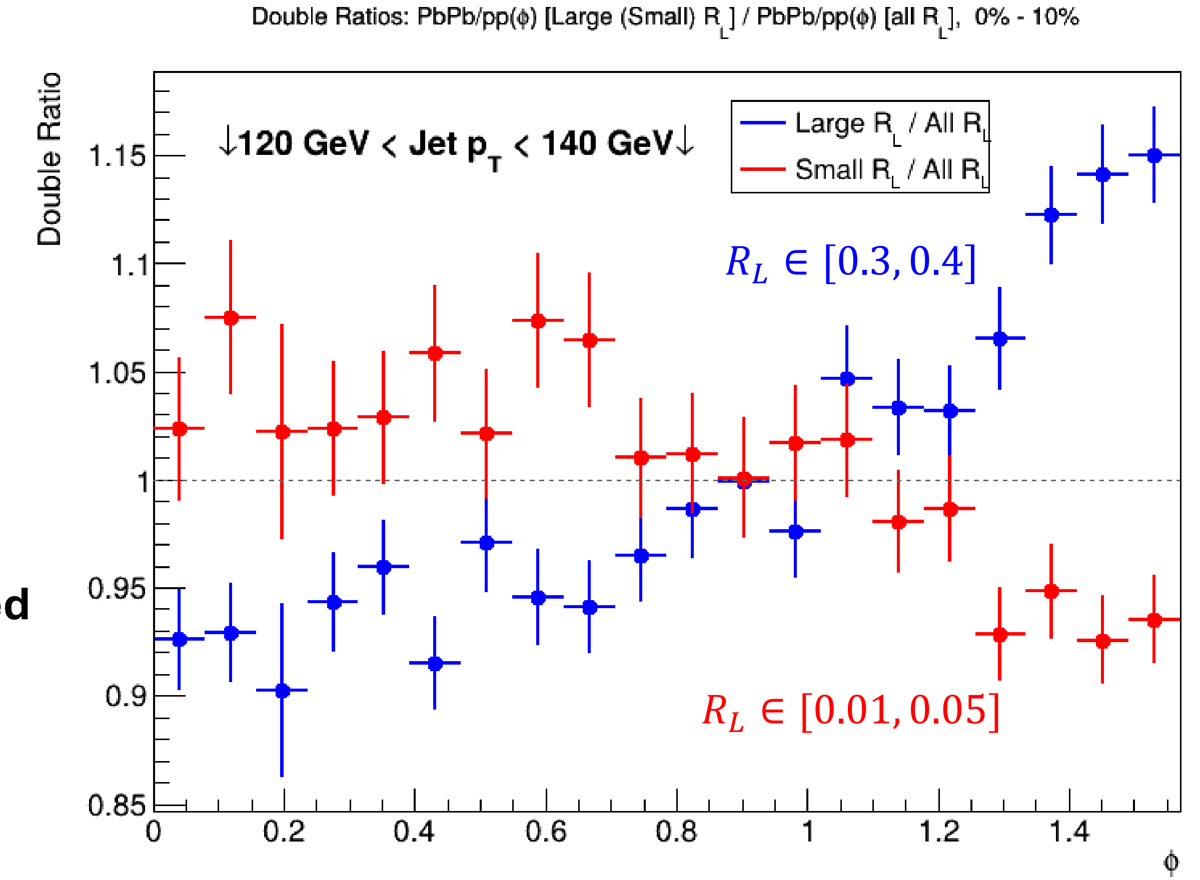
pp $\sqrt{s_{NN}} = 5.02$ TeV $|\eta_{jet}| < 2.5$

Small RL: [0.01 – 0.05] 0% < Centrality < 10%

Large RL: [0.3 – 0.4]

Blue curve: $\frac{EEEC(\phi)_{PbPb,\, R_L[0.3,0.4]}}{EEEC(\phi)_{pp,\, R_L[0.3,0.4]}} \Big/ \frac{EEEC(\phi)_{PbPb}}{EEEC(\phi)_{pp}}$

Red curve: $\frac{EEEC(\phi)_{PbPb,R_L[0.01,0.05]}}{EEEC(\phi)_{pp,\, R_L[0.01,\, 0.05]}} \Big/ \frac{EEEC(\phi)_{PbPb}}{EEEC(\phi)_{pp}}$



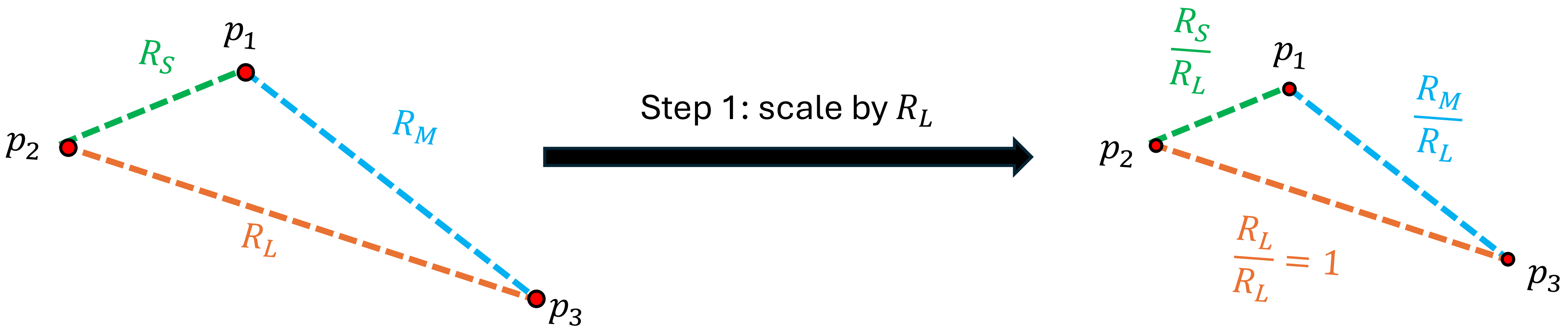
JEWEL 2.4.0

Observations:

1. These two double ratio curves shows **a cancellation effect**, which integrated over will result in the **unmodified EEEC(ϕ)**

   Q: Is this a JEWEL specific phenomenon, or this is true for other models?

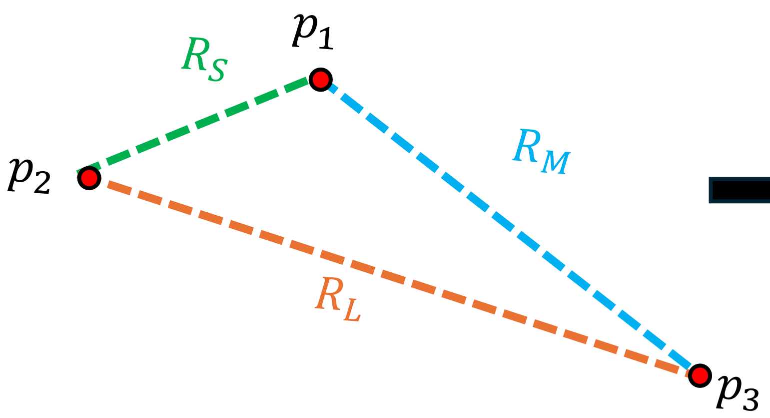
Quick Introduction to coordinate system (x, y)



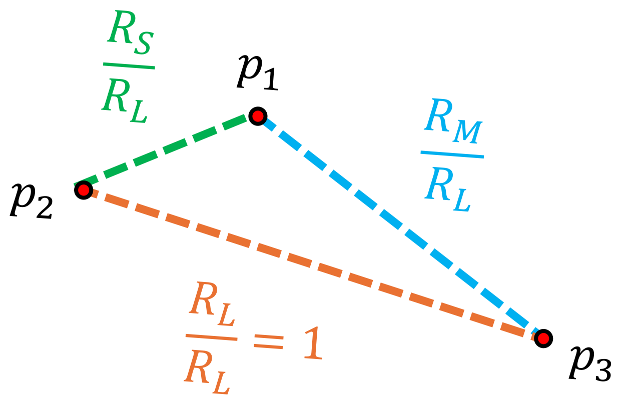
[H. Bossi, A.S. Kudinoor, I. Moult, D. Pablos, A. Rai, and K. Rajagopal arXiv: 2407.13818.]

Special thanks to Arjun Srinivasan Kudinoor and Dr. Zhong Yang

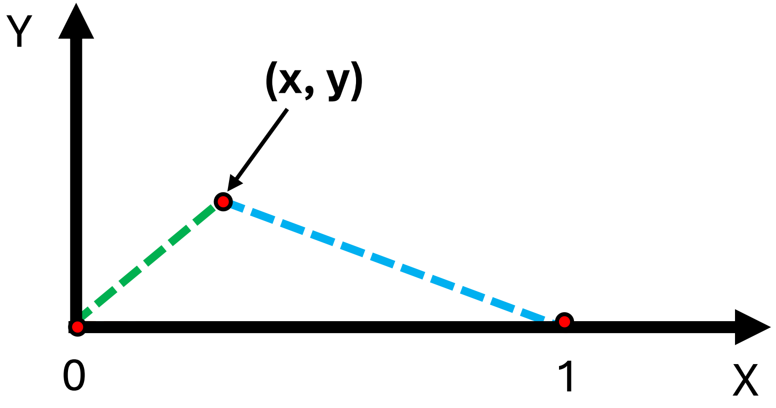
Quick Introduction to coordinate system (x, y)



Step 1: scale by R_L



Step 2: rotate and move to x axis



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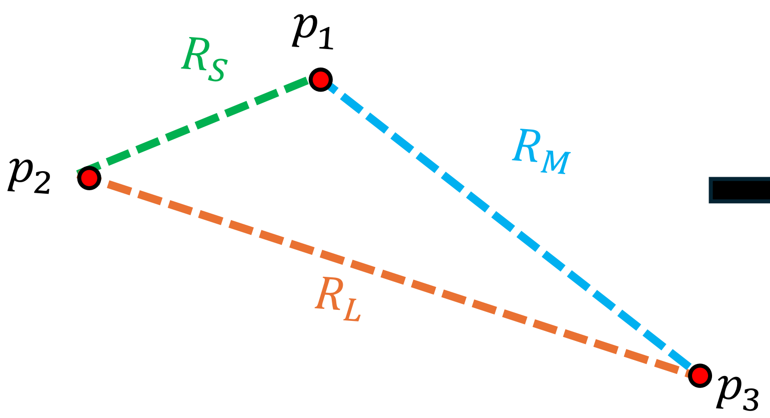
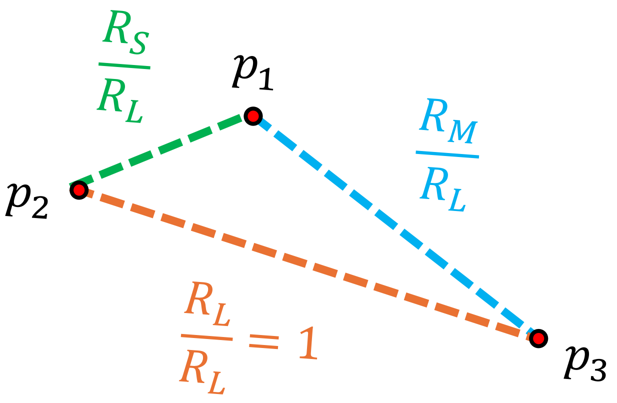
Quick Introduction to coordinate system (x, y)

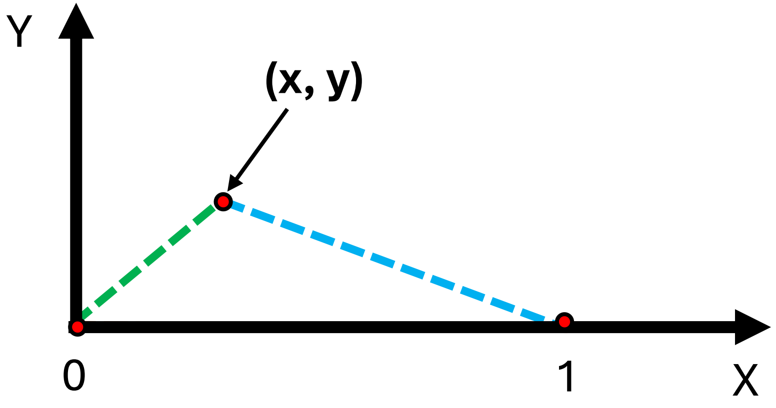


Step 1: scale by R_L

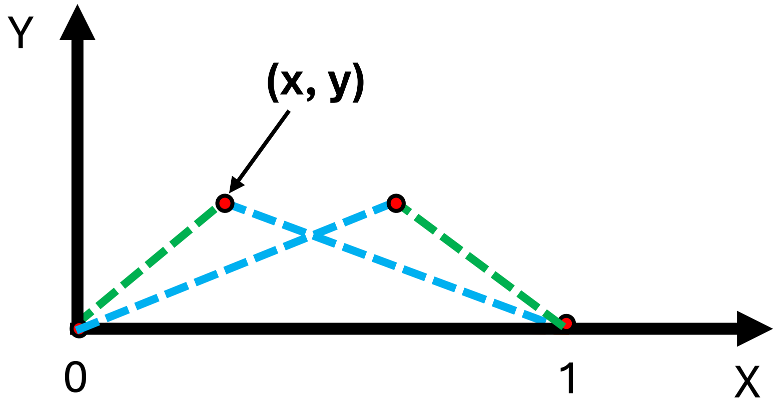


[H. Bossi, A.S. Kudinoor, I. Moult, D. Pablos, A. Rai, and K. Rajagopal arXiv: 2407.13818.]

Step 2: rotate and move to x axis



Step 3: averaging the degenerate pair



Special thanks to Arjun Srinivasan Kudinoor and Dr. Zhong Yang

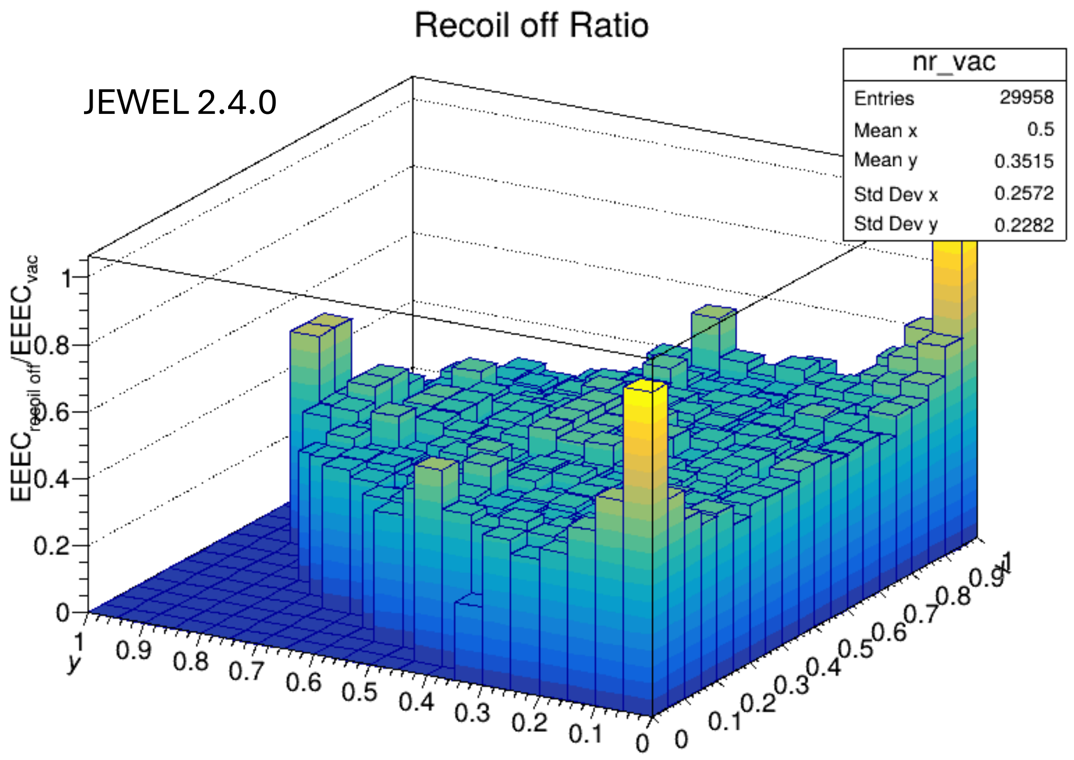
Result for EEEC (x, y)

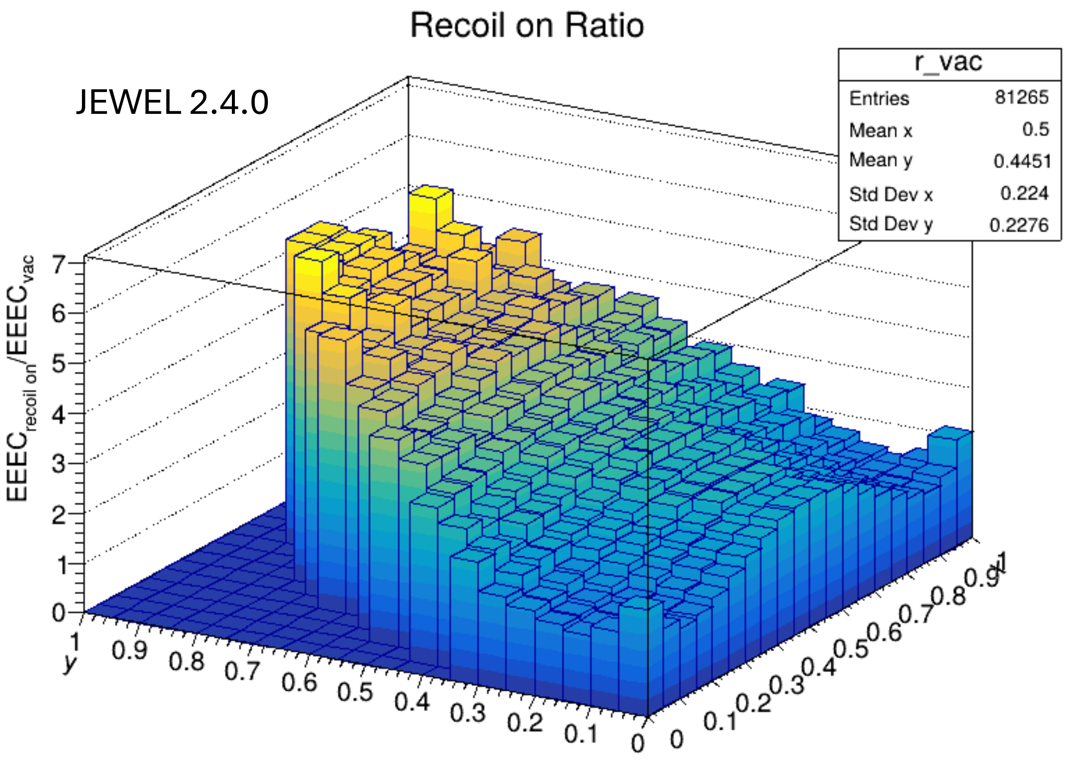
0.6 < R < 0.7
0% < Centrality < 10%

$\mathbf{PbPb}\ \sqrt{s_{NN}} = 5.02\ \mathbf{TeV}$ $\quad$ $\mathbf{anti\_}k_T R = 0.8$

$\mathbf{pp}\ \sqrt{s_{NN}} = 5.02\ \mathbf{TeV}$ $\quad$ $|\eta_{jet}| < 2.5$

$120\ GeV < Jet\ p_T < 140\ GeV$





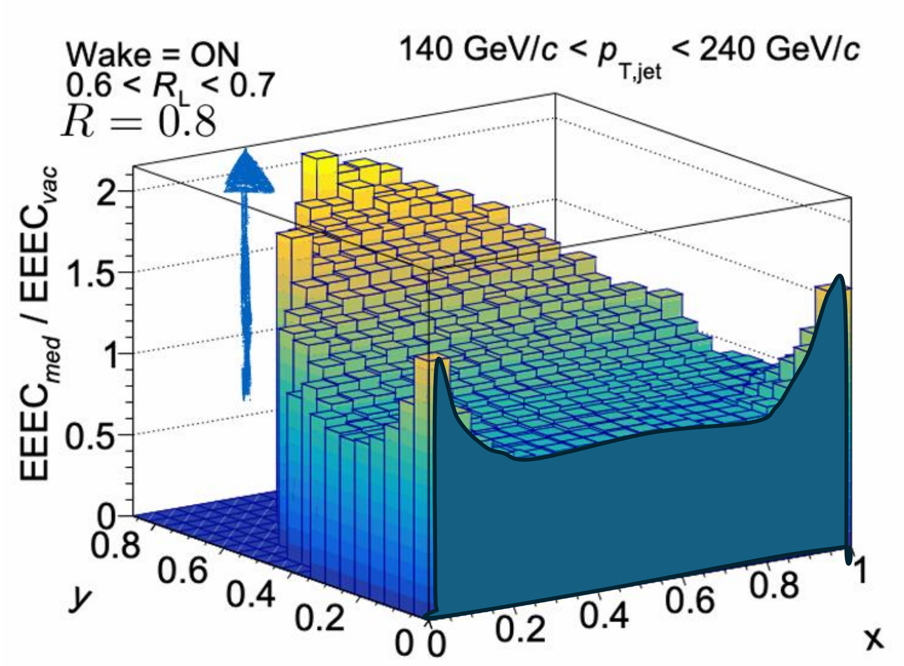
Turning on recoil effect gives **enhancement** to the EEEC in **isosceles** region (including equilateral region)

Conclusion:

1. The medium effect contributes to different boosted and suppressed regions when looking from R_L to R_S

2. There exists a potential invariance EEEC(ϕ) under JEWEL's medium modification

3. The recoil effect seems to enhance the isosceles region of the triangle, while wake effect enhances mostly equilateral region:



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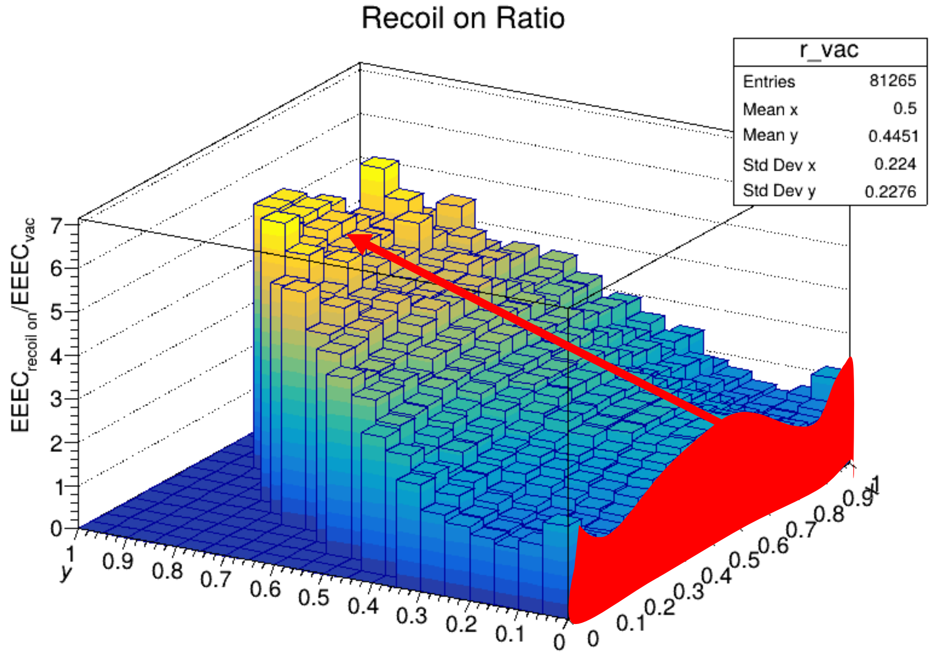


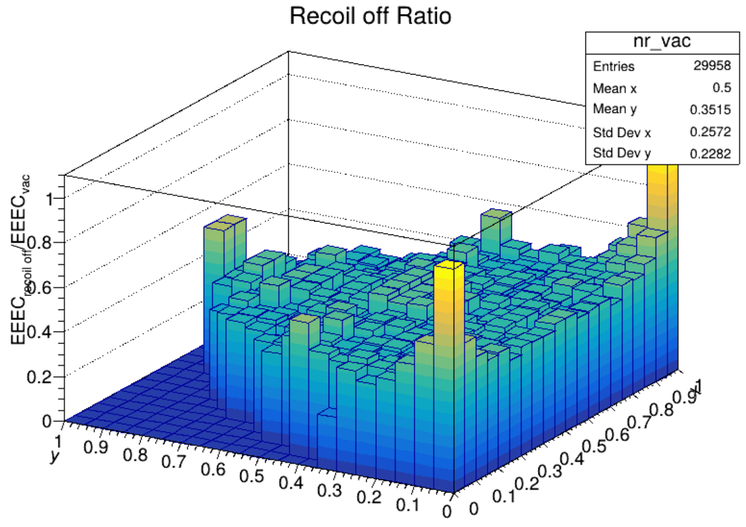
Next step:

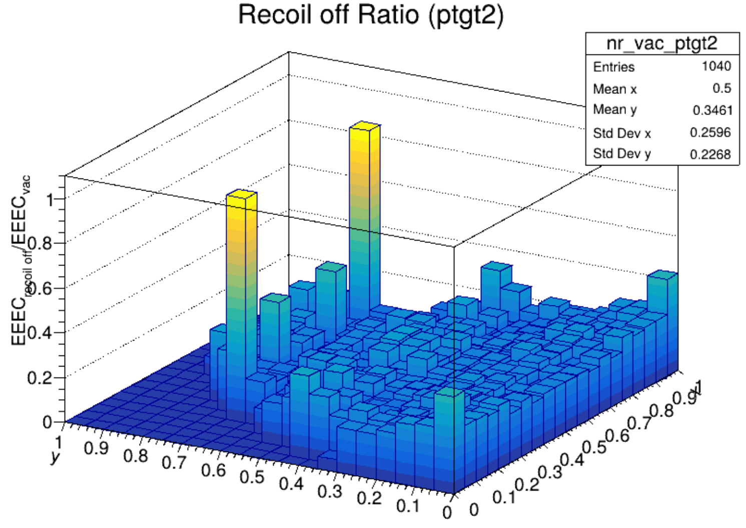
1. Do the same analysis with different models, like Hybrid Model, for instance, to check if this invariant property is just a JEWEL phenomenon.

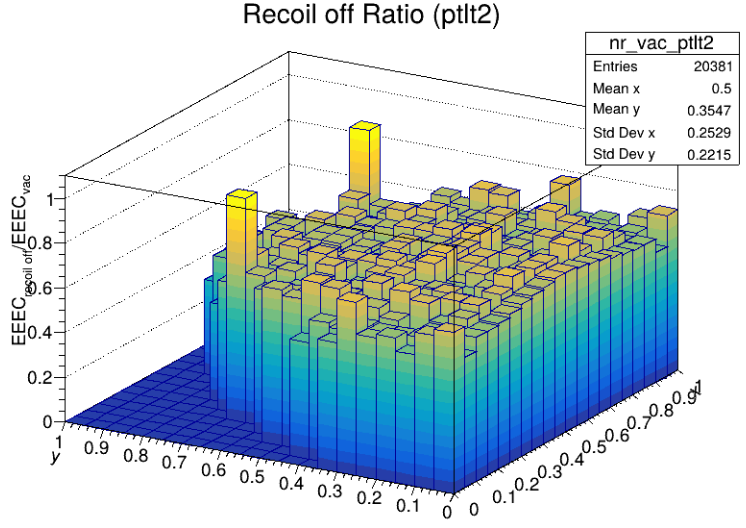
2. Check with lower $\sqrt{s} = 200\ GeV$ to see if the invariance – like property still holds.

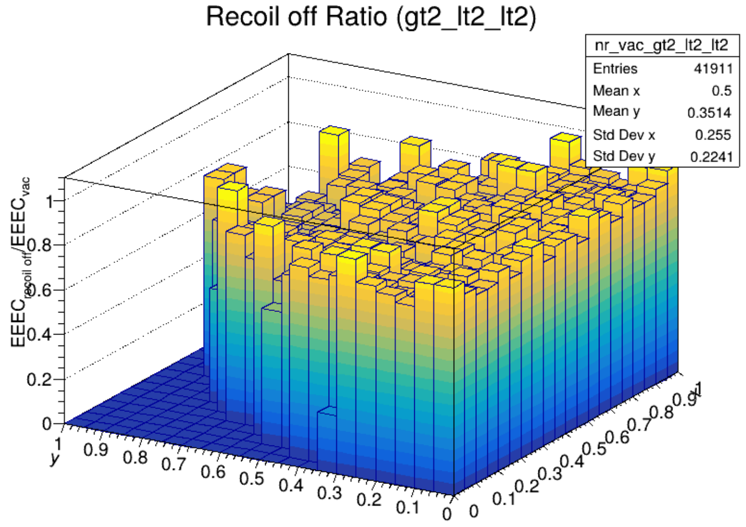
3. Provide possible explanation for the cancellation effect in EEEC(ϕ) with respect to different RL.

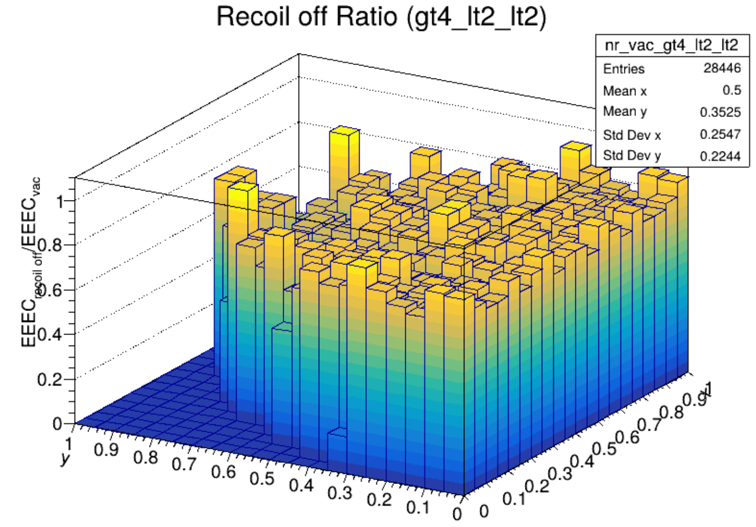
4. Further investigate the mechanism behind the different enhancement regions corresponding to wake and recoil effect.

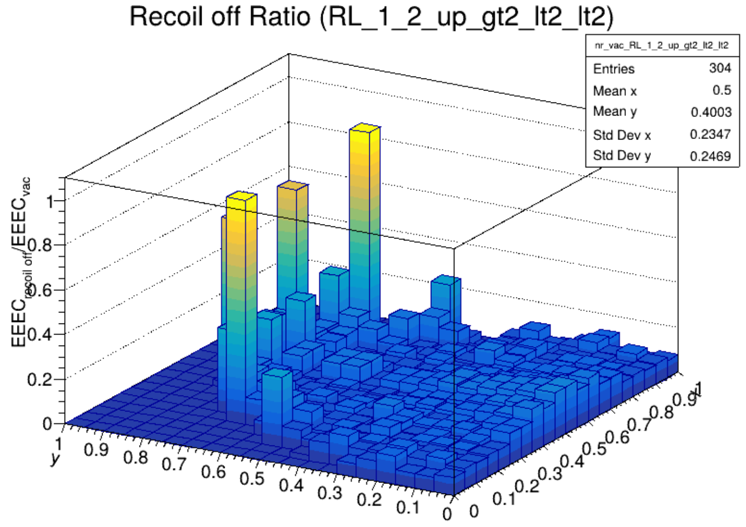

Recoil off Ratio
nr_vac
Entries 29958
Mean x 0.5
Mean y 0.3515
Std Dev x 0.2572
Std Dev y 0.2282
EEEC recoil off/EEEC vac
y

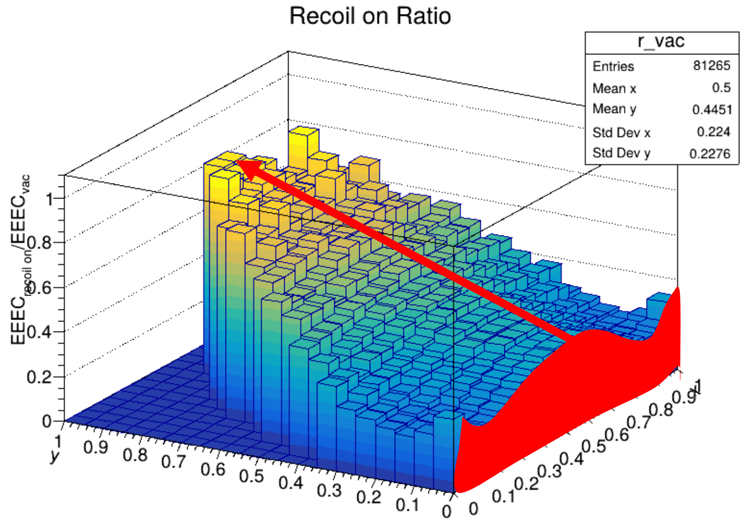

Recoil off Ratio (ptgt2)
nr_vac_ptgt2
Entries 1040
Mean x 0.5
Mean y 0.3461
Std Dev x 0.2596
Std Dev y 0.2268
EEEC recoil off/EEEC vac
y

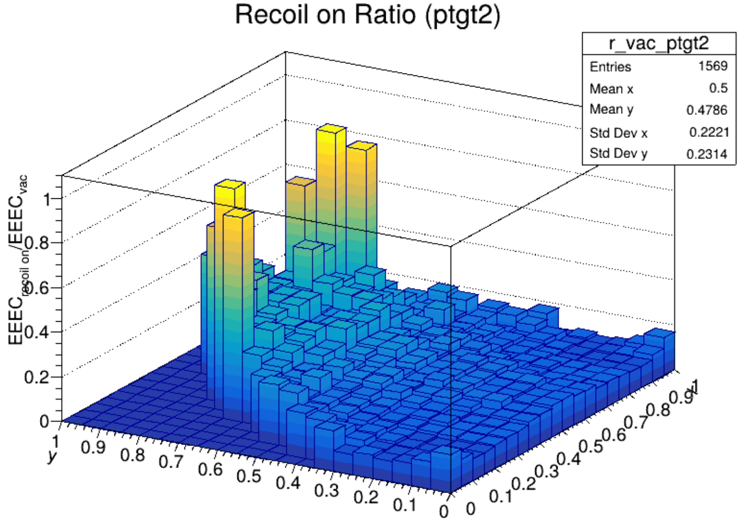

Recoil off Ratio (ptlt2)
nr_vac_ptlt2
Entries 20381
Mean x 0.5
Mean y 0.3547
Std Dev x 0.2529
Std Dev y 0.2215
EEEC recoil off/EEEC vac
y

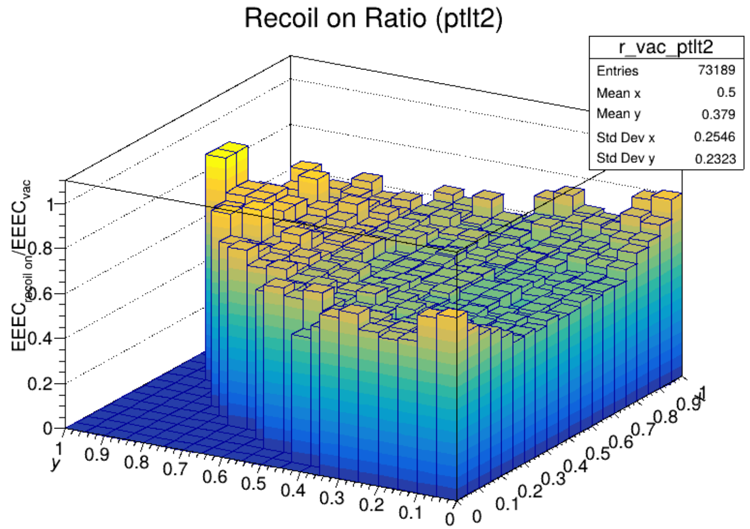

Recoil off Ratio (gt2_lt2_lt2)
nr_vac_gt2_lt2_lt2
Entries 41911
Mean x 0.5
Mean y 0.3514
Std Dev x 0.255
Std Dev y 0.2241
EEEC recoil off/EEEC vac
y

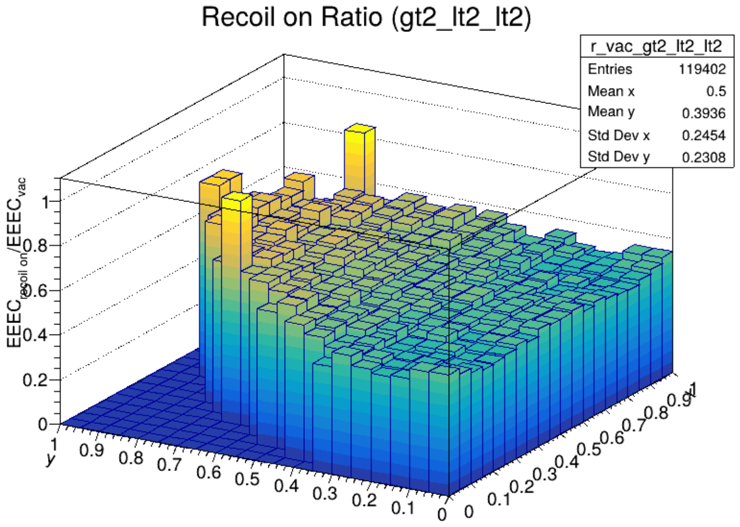

Recoil off Ratio (gt4_lt2_lt2)
nr_vac_gt4_lt2_lt2
Entries 28446
Mean x 0.5
Mean y 0.3525
Std Dev x 0.2547
Std Dev y 0.2244
EEEC recoil off/EEEC vac
y

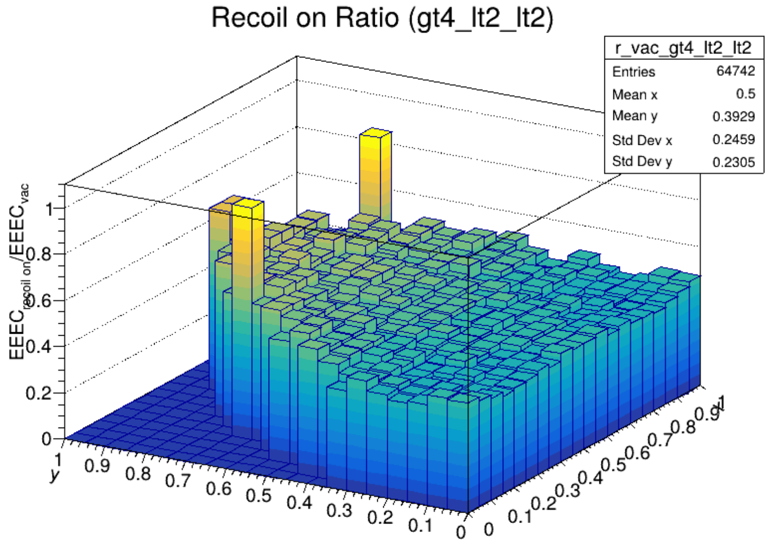

Recoil off Ratio (RL_1_2_up_gt2_lt2_lt2)
Entries 304
Mean x 0.5
Mean y 0.4003
Std Dev x 0.2347
Std Dev y 0.2469
EEEC recoil off/EEEC vac
y

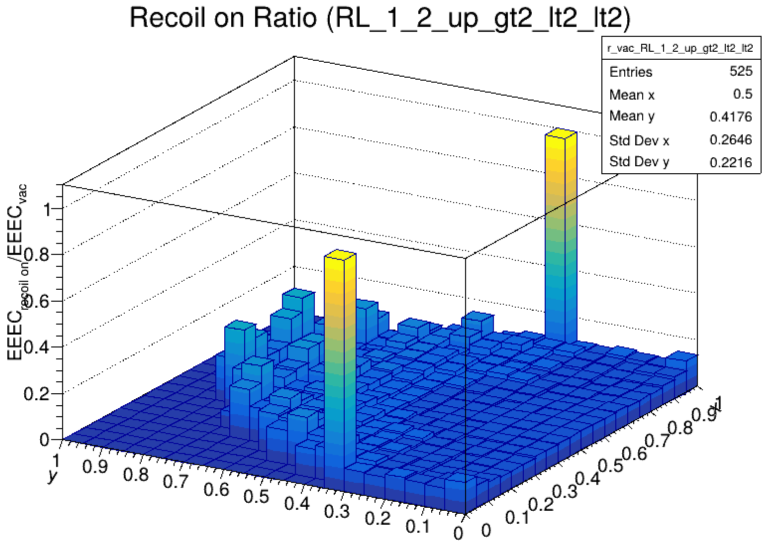

Recoil on Ratio
r_vac
Entries 81265
Mean x 0.5
Mean y 0.4451
Std Dev x 0.224
Std Dev y 0.2276

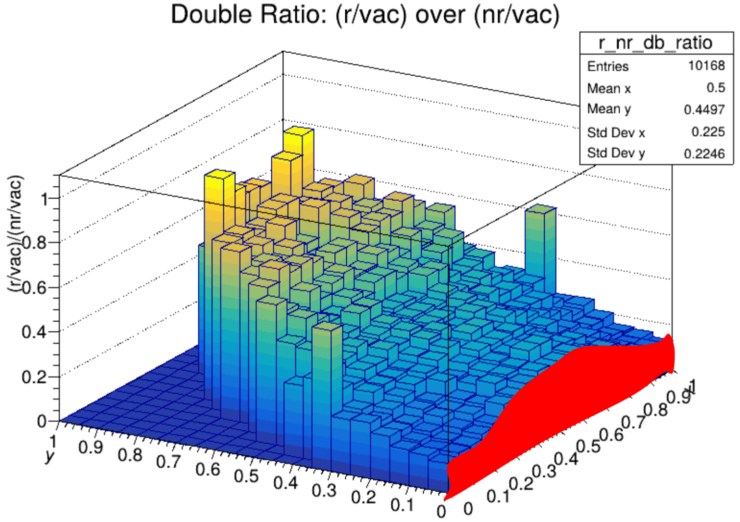

Recoil on Ratio (ptgt2)
r_vac_ptgt2
Entries 1569
Mean x 0.5
Mean y 0.4786
Std Dev x 0.2221
Std Dev y 0.2314

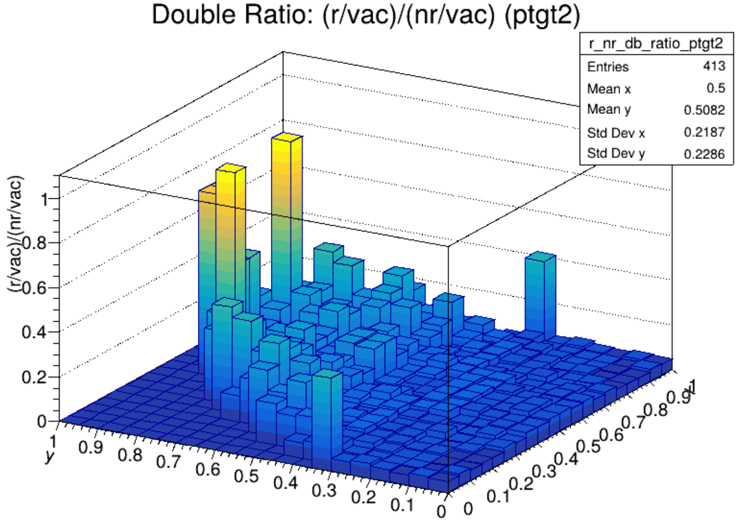

Recoil on Ratio (ptlt2)
r_vac_ptlt2
Entries 73189
Mean x 0.5
Mean y 0.379
Std Dev x 0.2546
Std Dev y 0.2323

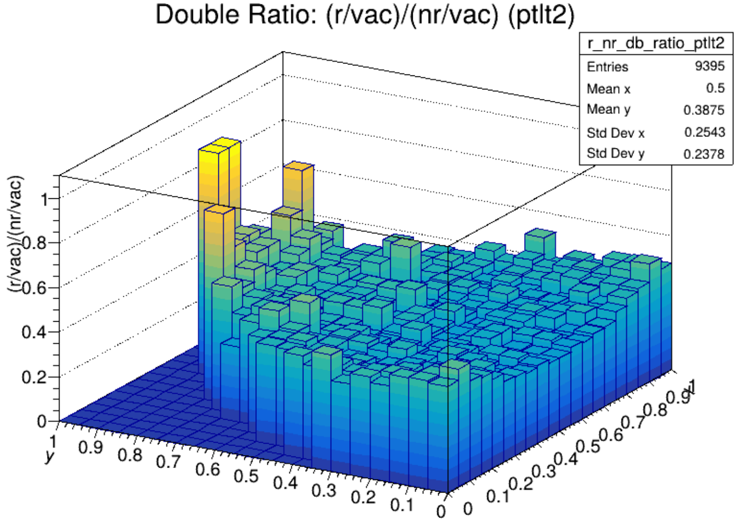

Recoil on Ratio (gt2_lt2_lt2)
r_vac_gt2_lt2_lt2
Entries 119402
Mean x 0.5
Mean y 0.3936
Std Dev x 0.2454
Std Dev y 0.2308

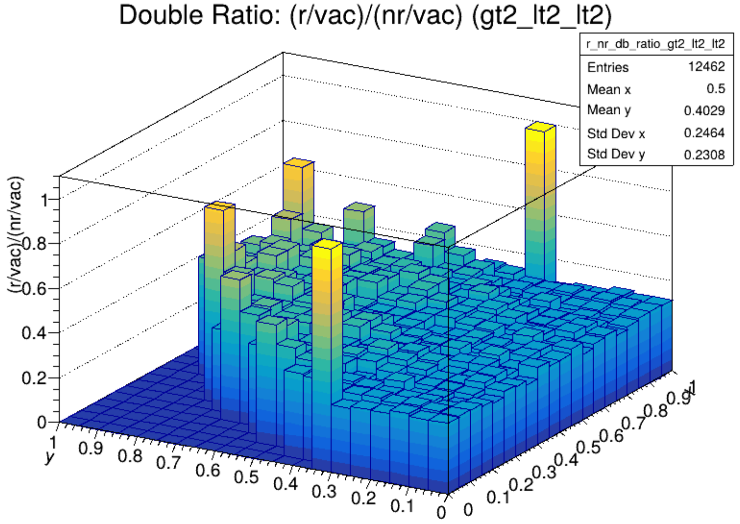

Recoil on Ratio (gt4_lt2_lt2)
r_vac_gt4_lt2_lt2
Entries 64742
Mean x 0.5
Mean y 0.3929
Std Dev x 0.2459
Std Dev y 0.2305

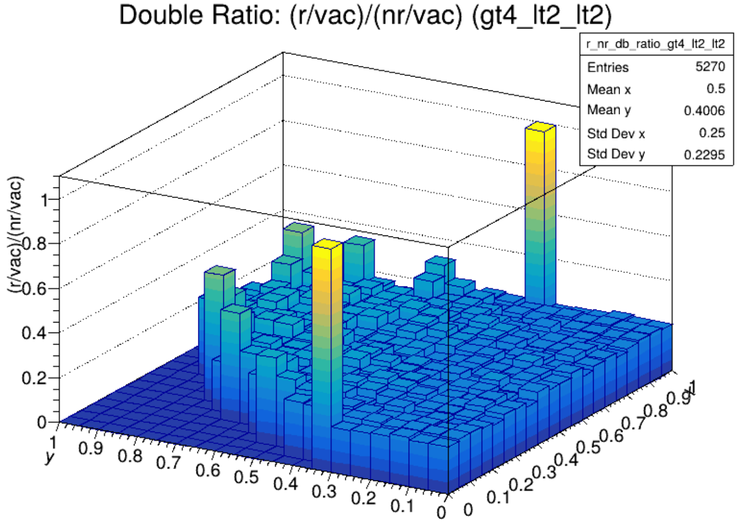

Recoil on Ratio (RL_1_2_up_gt2_lt2_lt2)
r_vac_RL_1_2_up_gt2_lt2_lt2
Entries 525
Mean x 0.5
Mean y 0.4176
Std Dev x 0.2646
Std Dev y 0.2216

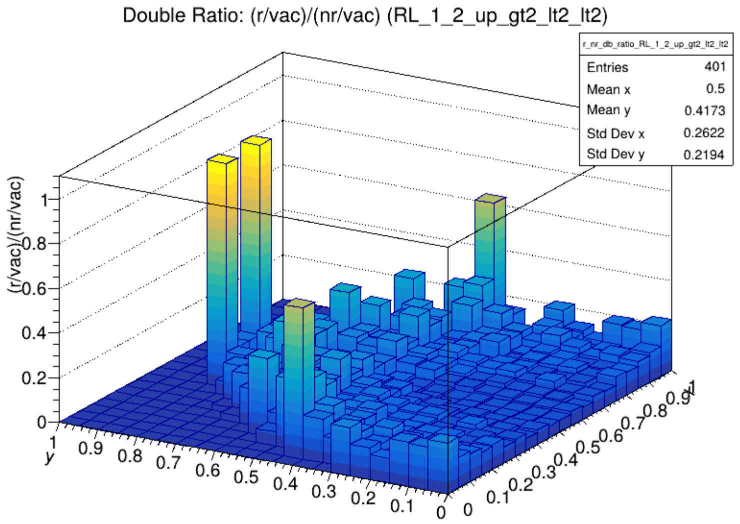

Double Ratio: (r/vac) over (nr/vac)
r_nr_db_ratio
Entries 10168
Mean x 0.5
Mean y 0.4497
Std Dev x 0.225
Std Dev y 0.2246
(r/vac)/(nr/vac)
y


Double Ratio: (r/vac)/(nr/vac) (ptgt2)
r_nr_db_ratio_ptgt2
Entries 413
Mean x 0.5
Mean y 0.5082
Std Dev x 0.2187
Std Dev y 0.2286
(r/vac)/(nr/vac)
y

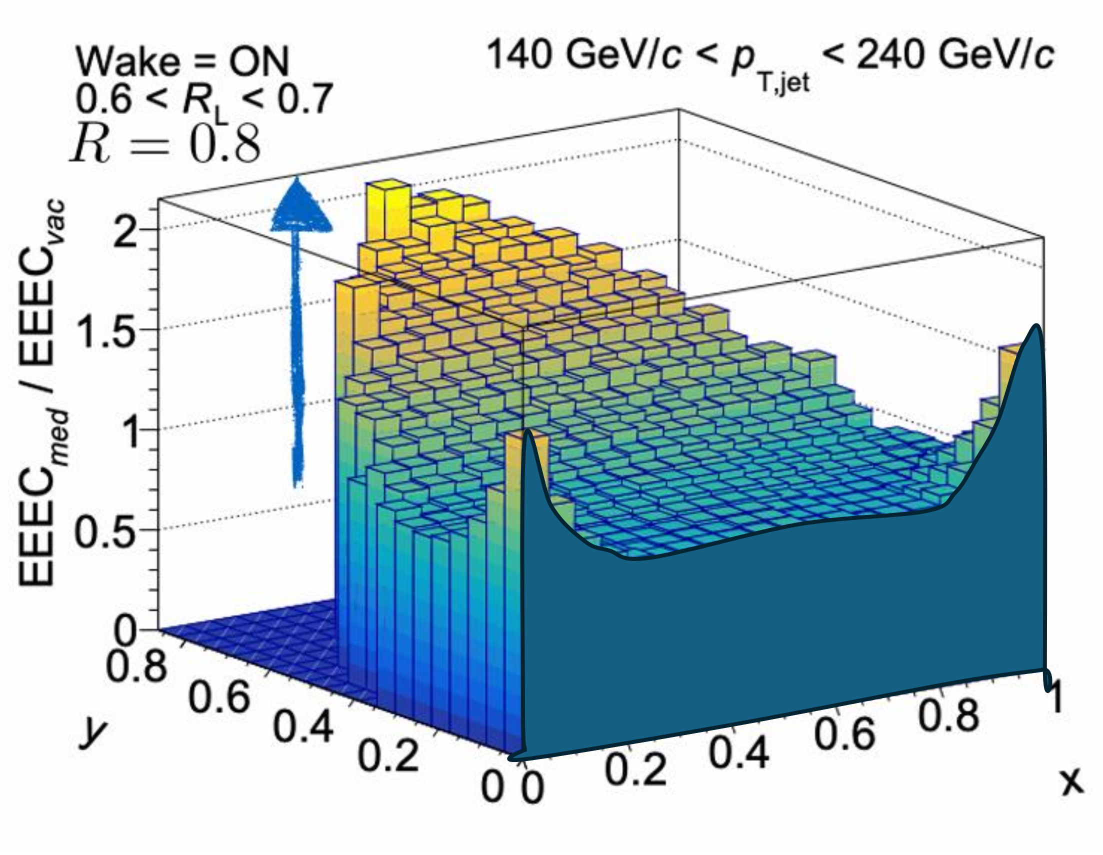

Double Ratio: (r/vac)/(nr/vac) (ptlt2)
r_nr_db_ratio_ptlt2
Entries 9395
Mean x 0.5
Mean y 0.3875
Std Dev x 0.2543
Std Dev y 0.2378
(r/vac)/(nr/vac)
y


Double Ratio: (r/vac)/(nr/vac) (gt2_lt2_lt2)
r_nr_db_ratio_gt2_lt2_lt2
Entries 12462
Mean x 0.5
Mean y 0.4029
Std Dev x 0.2464
Std Dev y 0.2308
(r/vac)/(nr/vac)
y


Double Ratio: (r/vac)/(nr/vac) (gt4_lt2_lt2)
r_nr_db_ratio_gt4_lt2_lt2
Entries 5270
Mean x 0.5
Mean y 0.4006
Std Dev x 0.25
Std Dev y 0.2295
(r/vac)/(nr/vac)
y


Double Ratio: (r/vac)/(nr/vac) (RL_1_2_up_gt2_lt2_lt2)
Entries 401
Mean x 0.5
Mean y 0.4173
Std Dev x 0.2622
Std Dev y 0.2194
(r/vac)/(nr/vac)
y

Wake Effect on EEEC (x, y)



Recoil Effect on EEEC (x, y)