Energy correlators in heavy-ion inclusive jets

Carlota Andres (she/her)
MIT

Jet modification and hard-soft correlation
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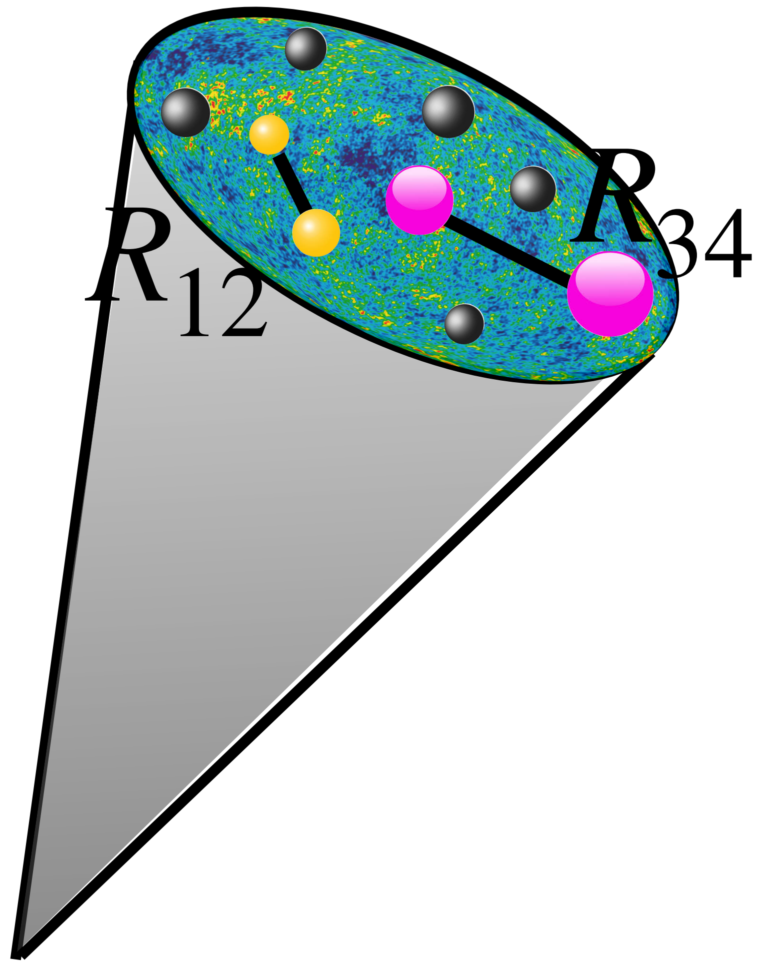
Massachusetts Institute of Technology

E2C within p-p jets

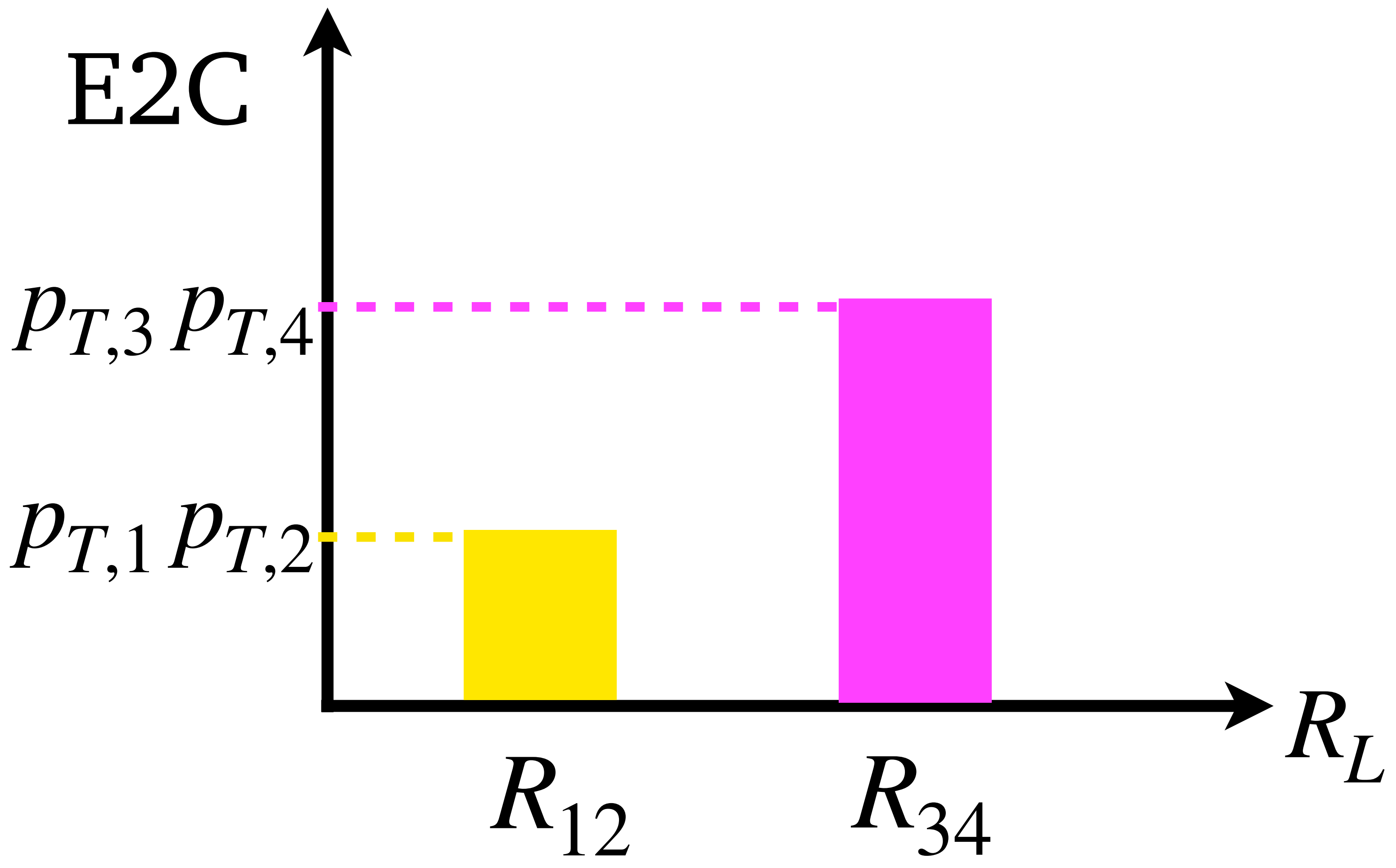
- Correlators $\langle \mathcal{E}(\vec{n}_1)\mathcal{E}(\vec{n}_2)\cdots\mathcal{E}(\vec{n}_k)\rangle$ of the **energy flux (collinear limit)**

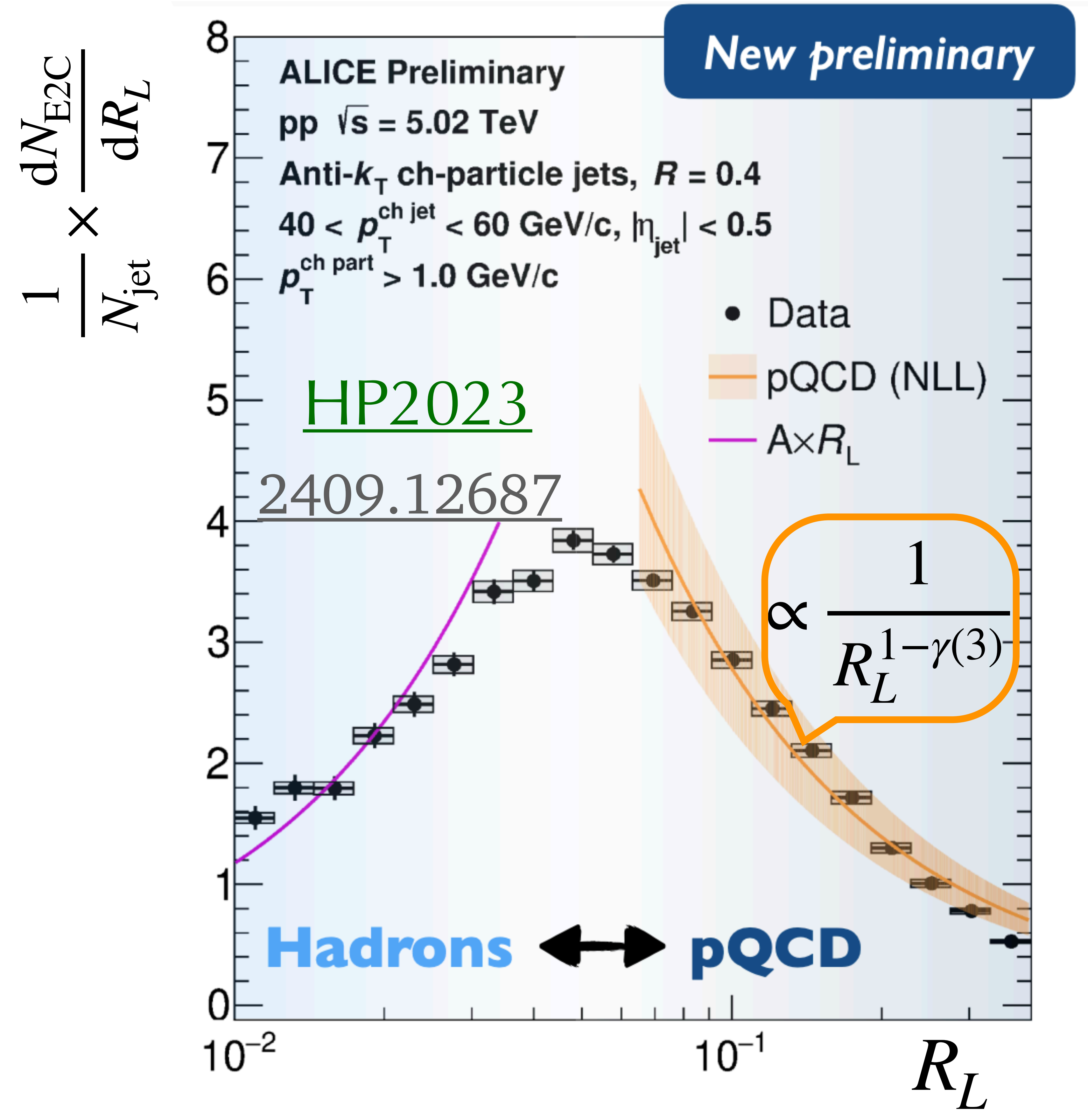
E2C in p-p jets

$$\text{E2C} = \frac{1}{N_{\text{jets}}}\sum_{\text{jets}}\sum_{i,j}\frac{P_{T,i}P_{T,j}}{P_{T,\text{jet}}^2}\,\delta(R_{ij}-R_L)$$



$R_{ij} = \sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$



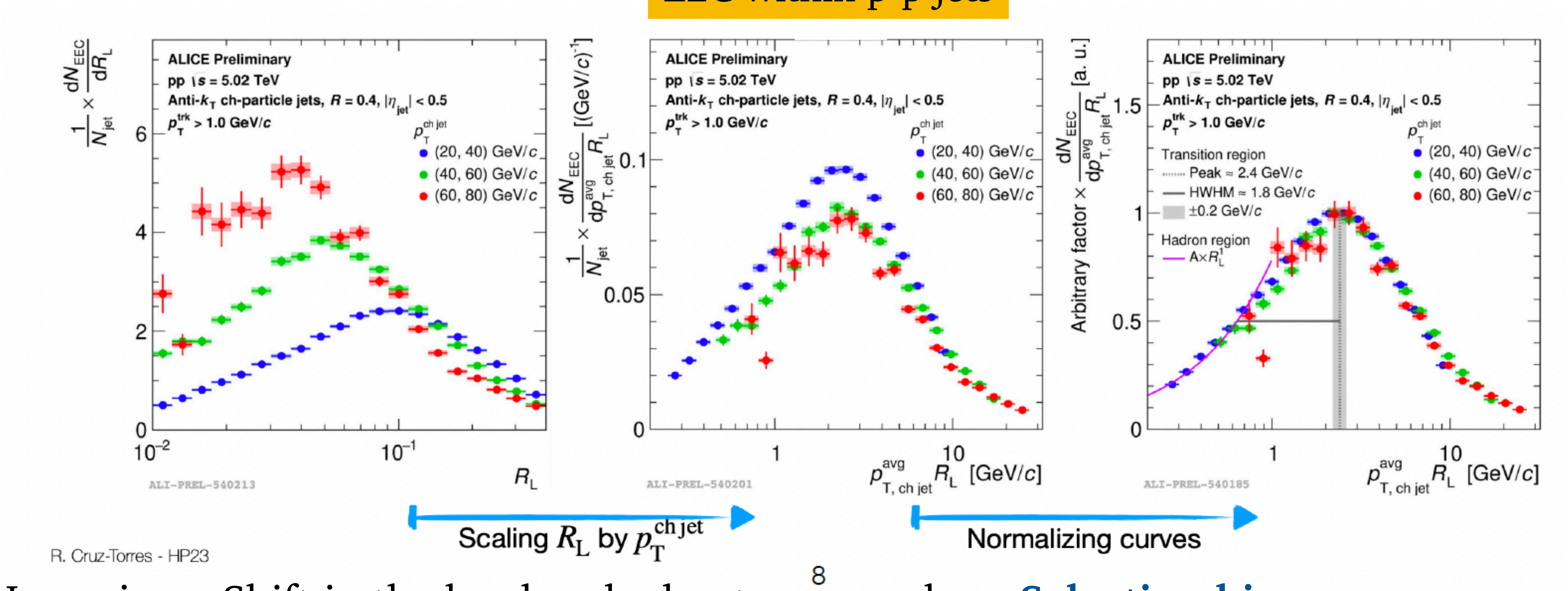


See also: CMS, 2402.13864, and STAR 2309.0576

The hard scale

- Features in the E2C appear at scales related to the (initial) **hard scale**

E2C within p-p jets

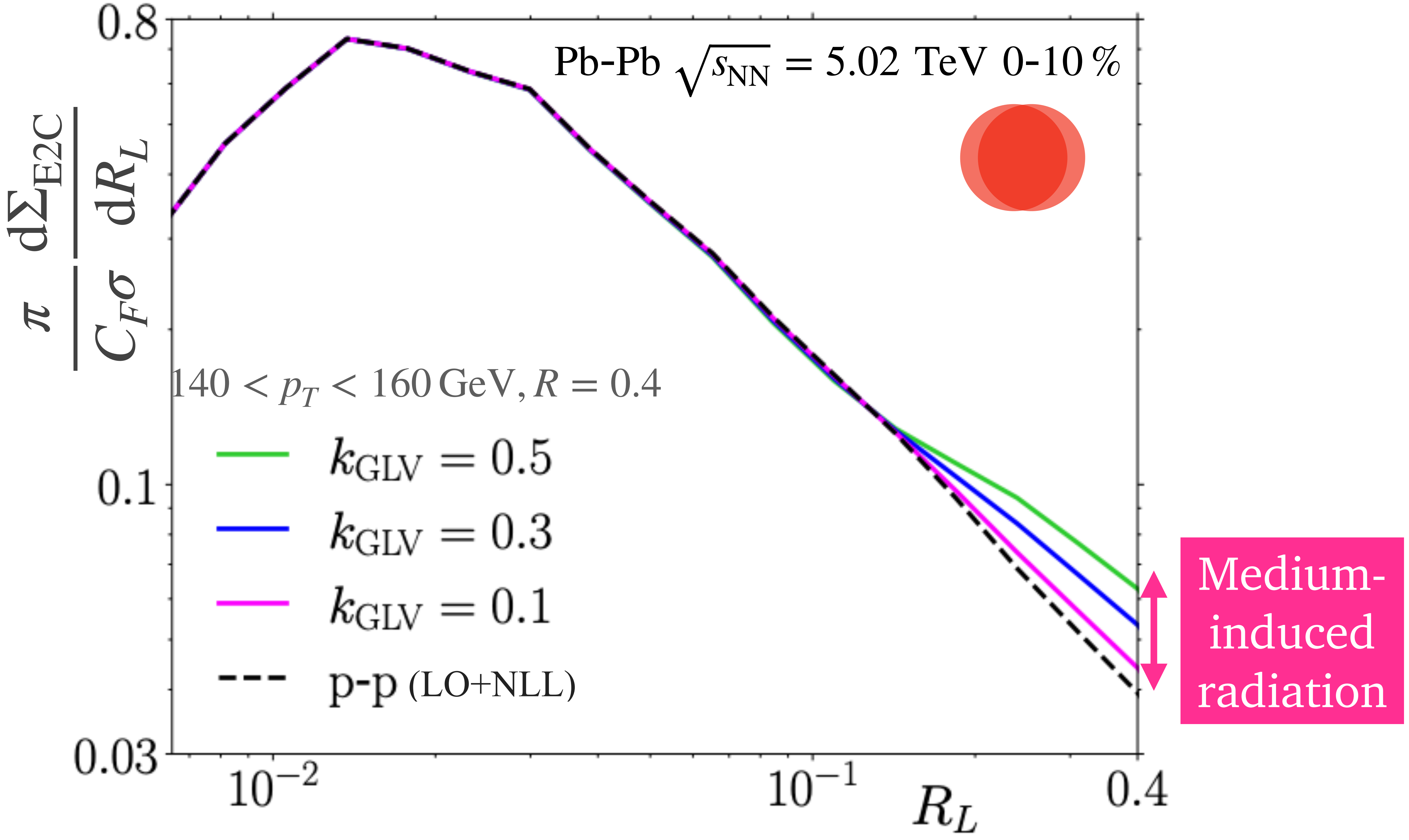


- Heavy ions: Shift in the hard scale due to energy loss. **Selection bias**

E2C in heavy-ions

CA, Dominguez, Elayavalli, Holguin, Marquet, Moult, 2209.11236, 2303.03413, 2407.07936

E2C γ-tagged jets



Medium response: can also appear at large angles!

Yang, He, Moult, Wang, 2310.01500 Bossi, Kudinoor, Moult, Pablos, Rai, Rajagopal, 2407.13818

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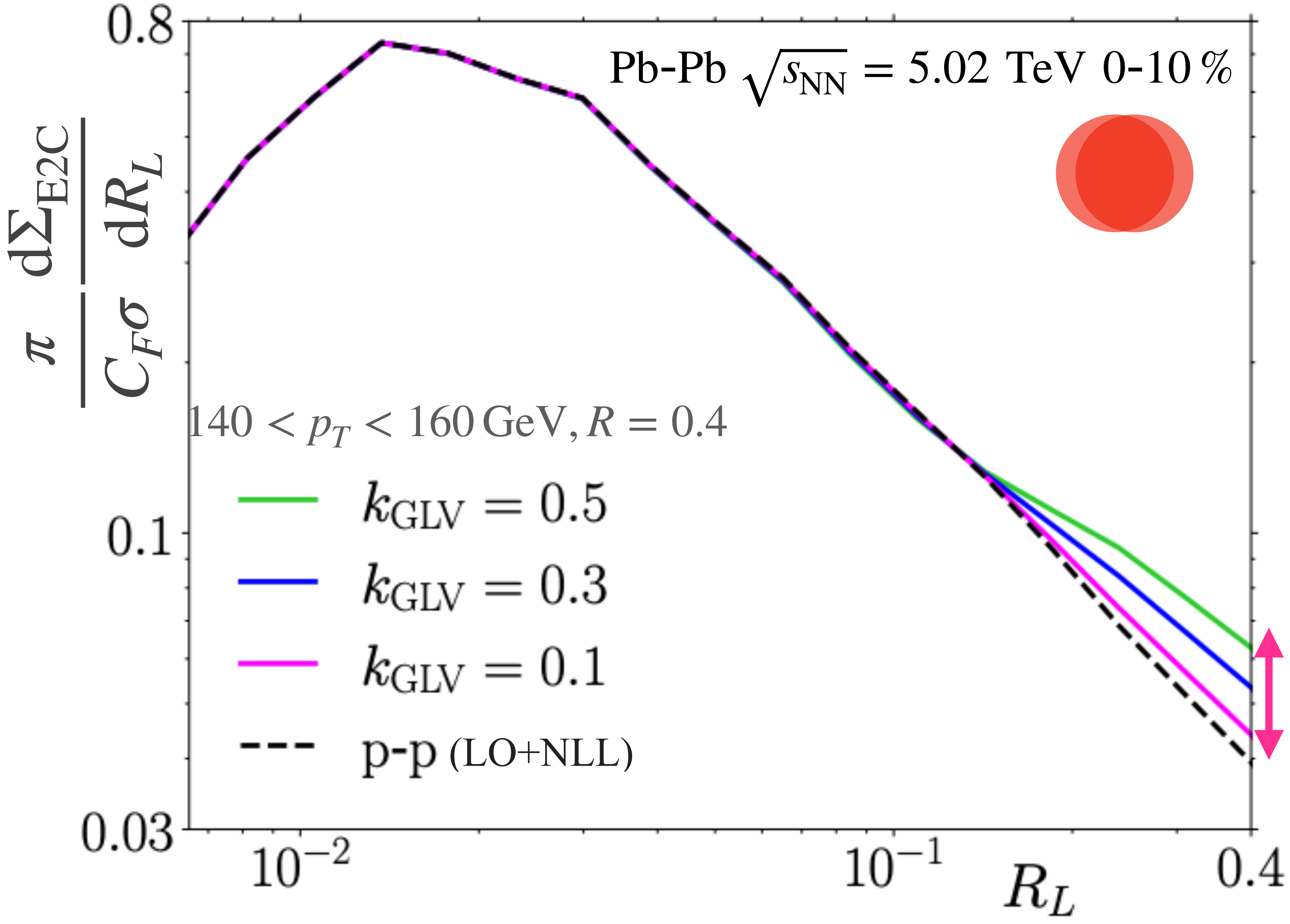
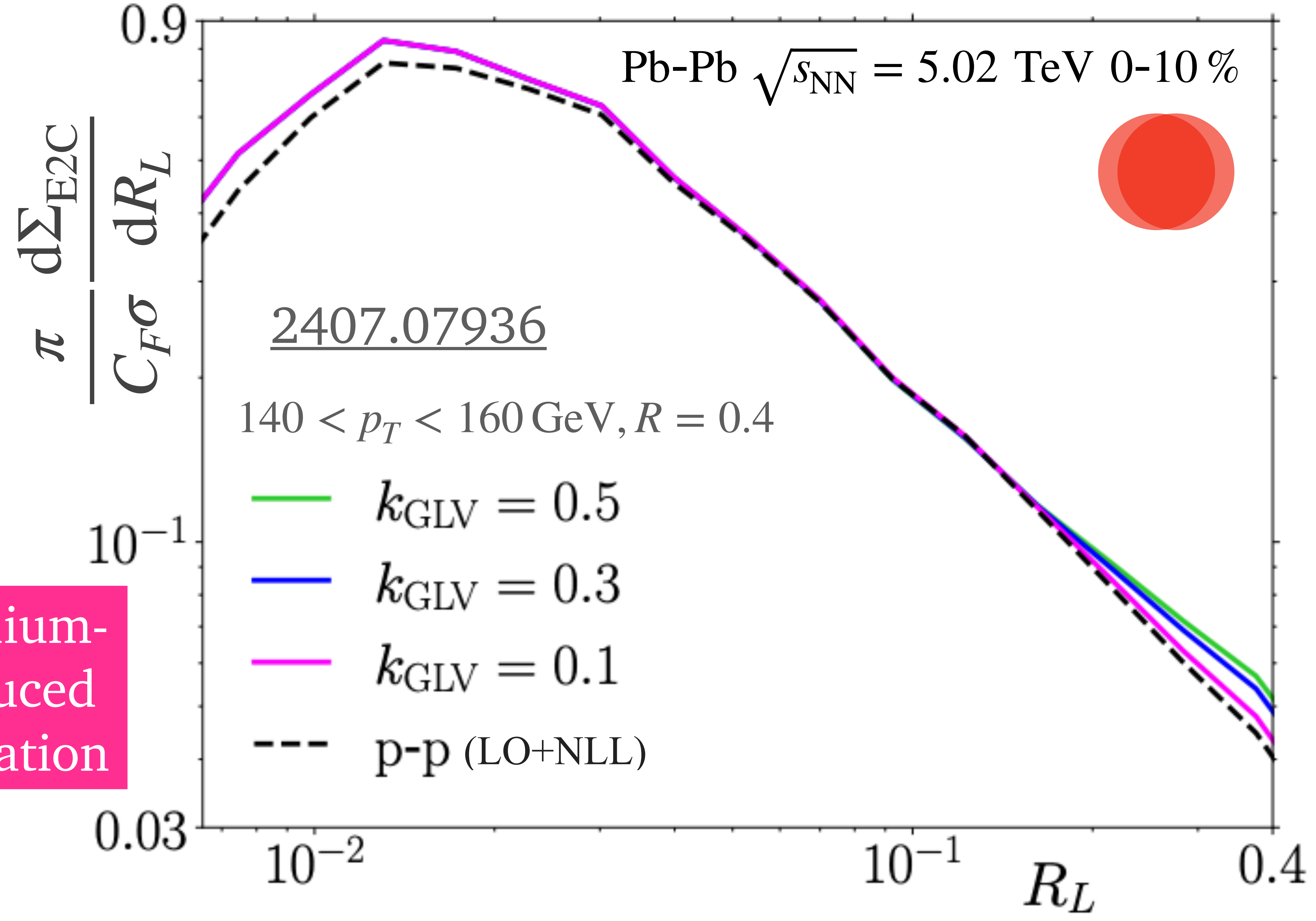


Medium-induced radiation

E2C Inclusive jets



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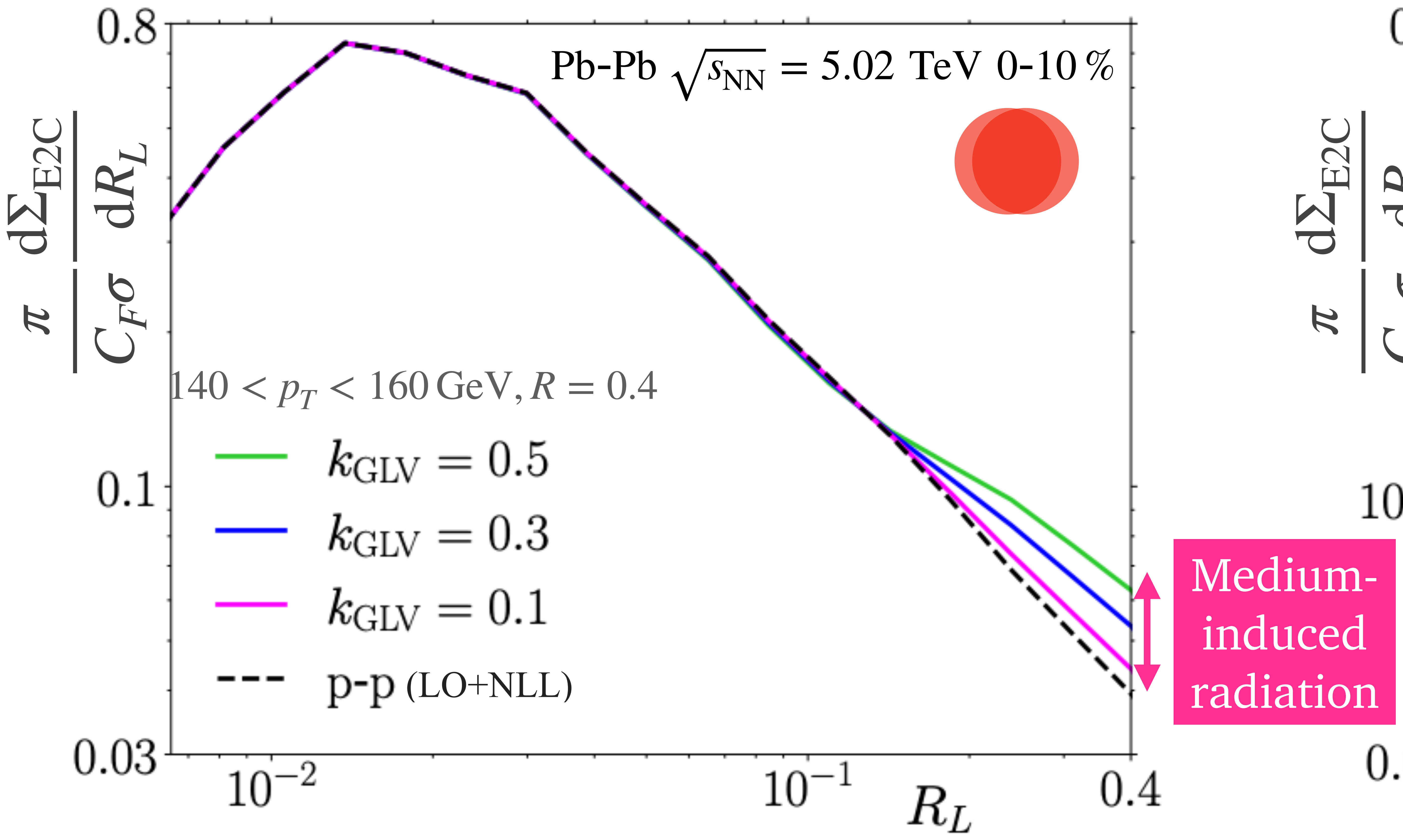
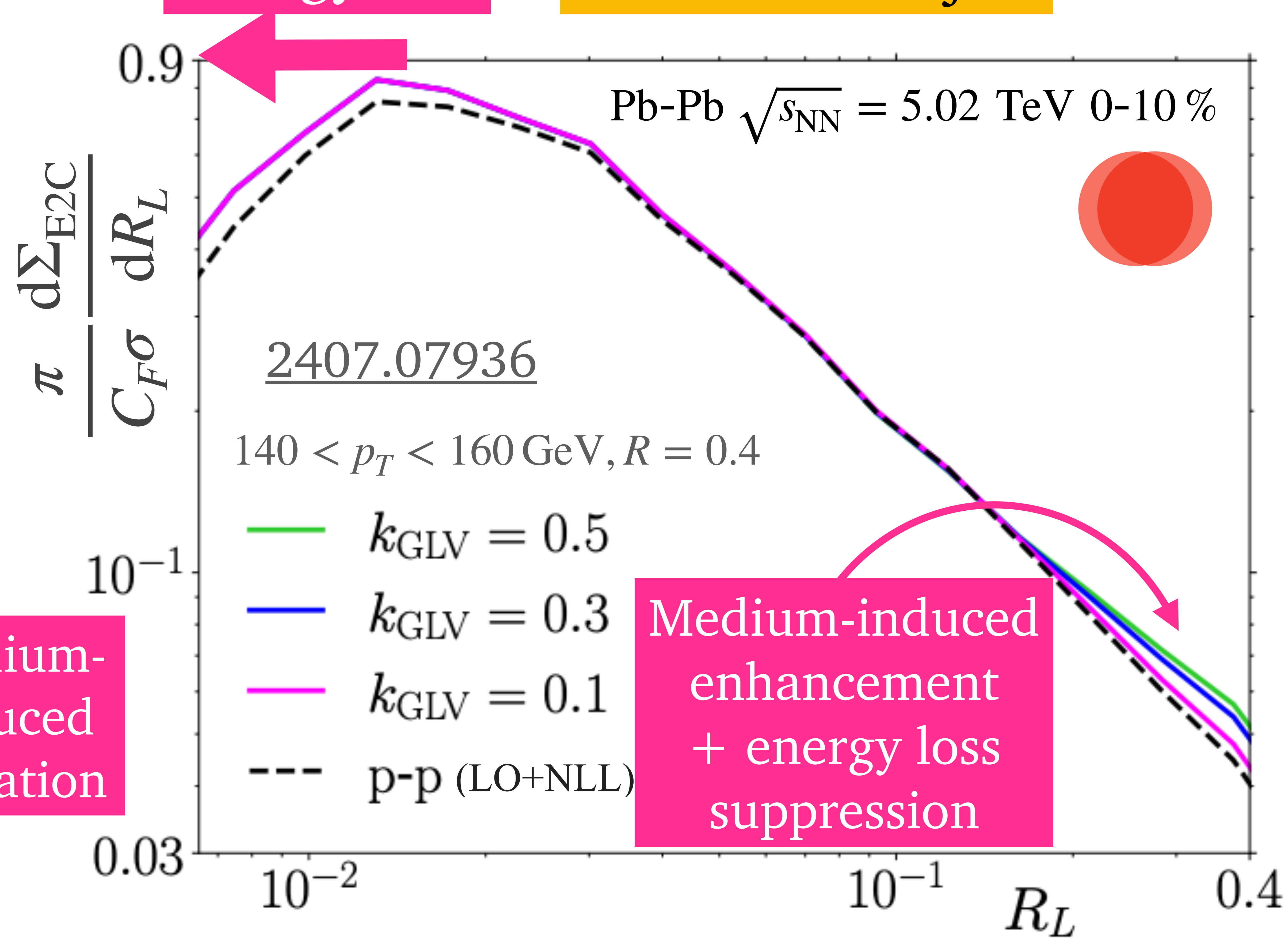


Energy loss

E2C Inclusive jets



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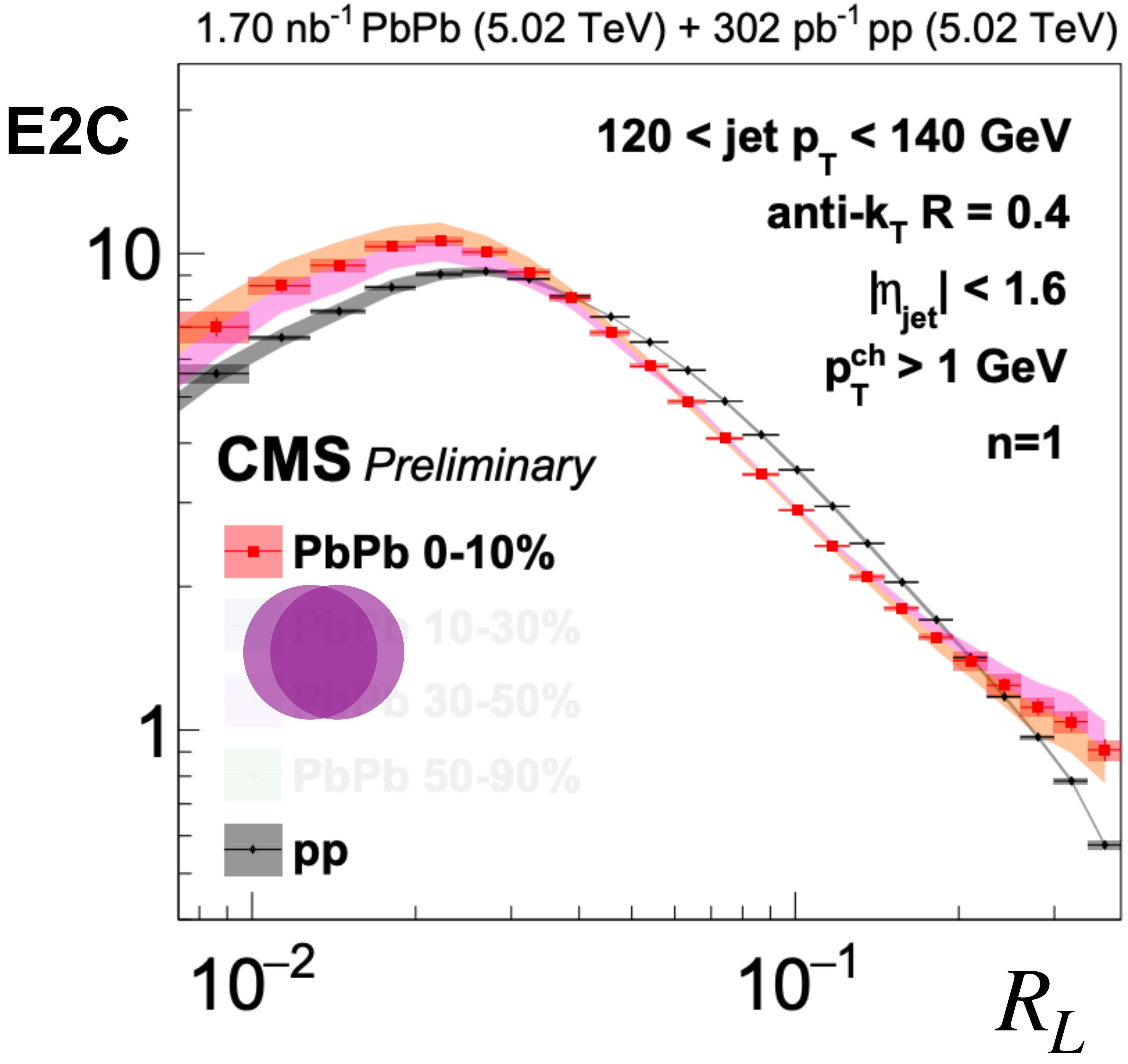
E2C within heavy-ion inclusive jets

CMS-PAS-HIN-23-004

Jussi Viinikainen's talk unveiling the measurement at the Energy Correlators at the Collider Frontier workshop



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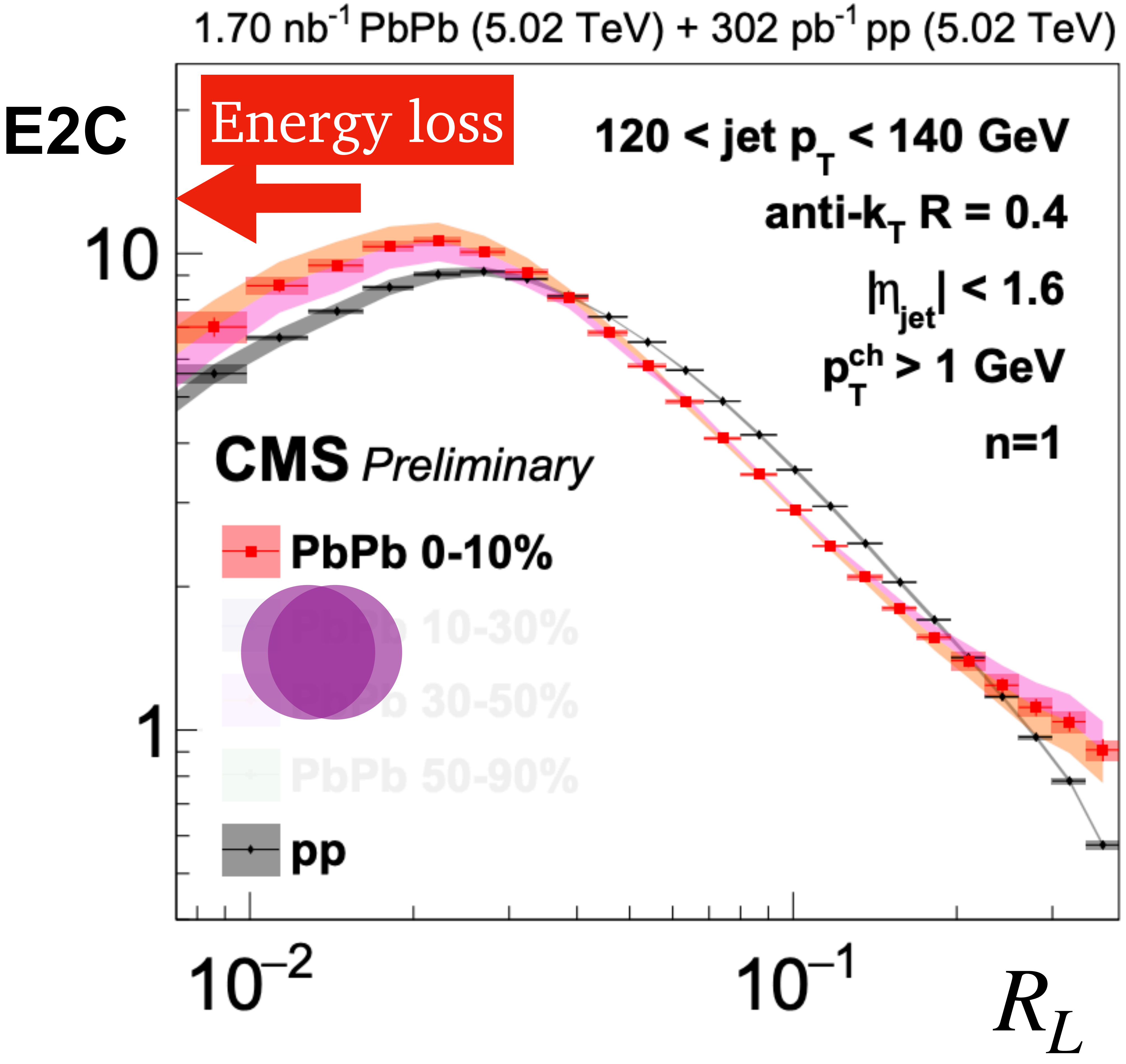

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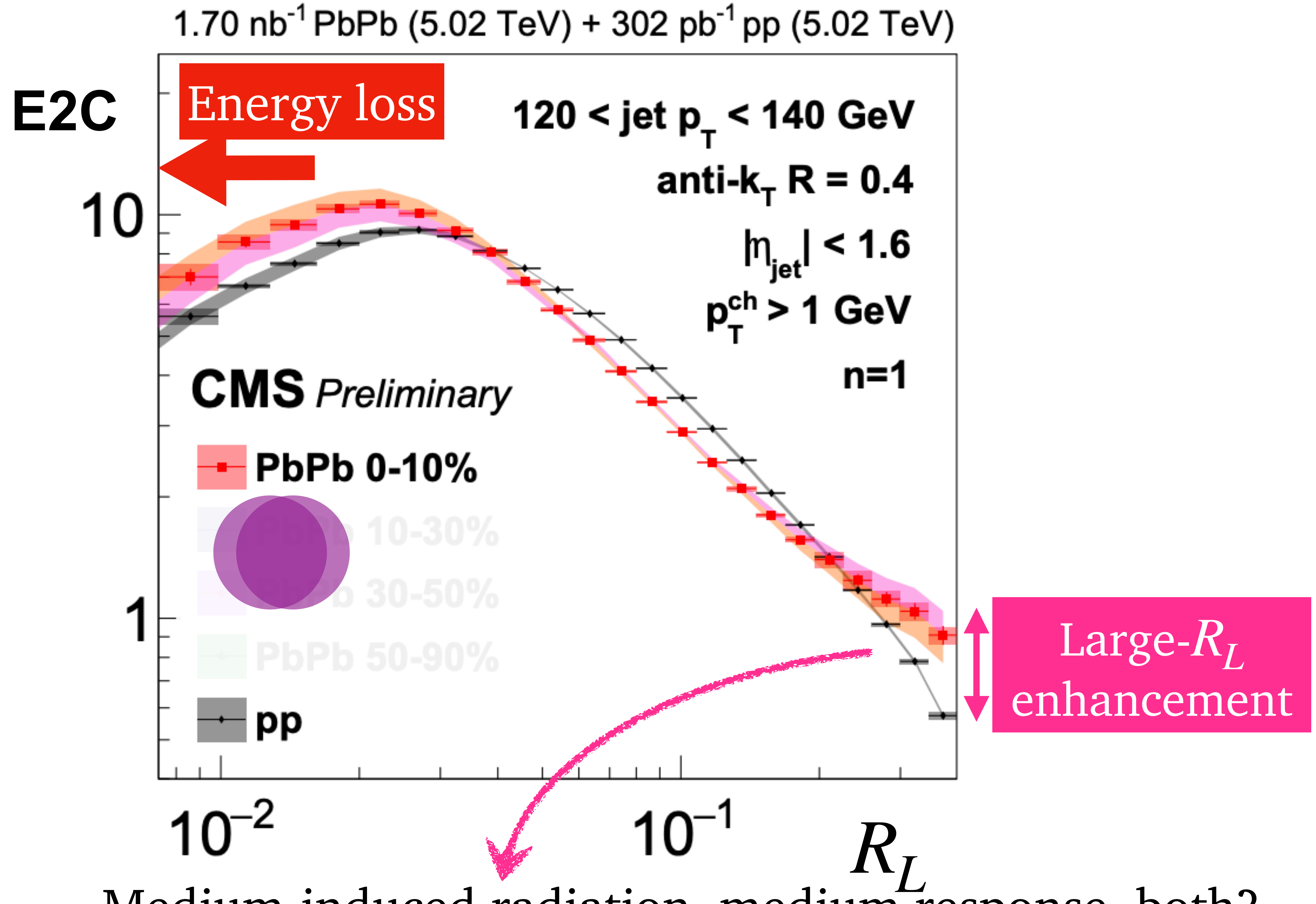

Medium-induced radiation, medium response, both?

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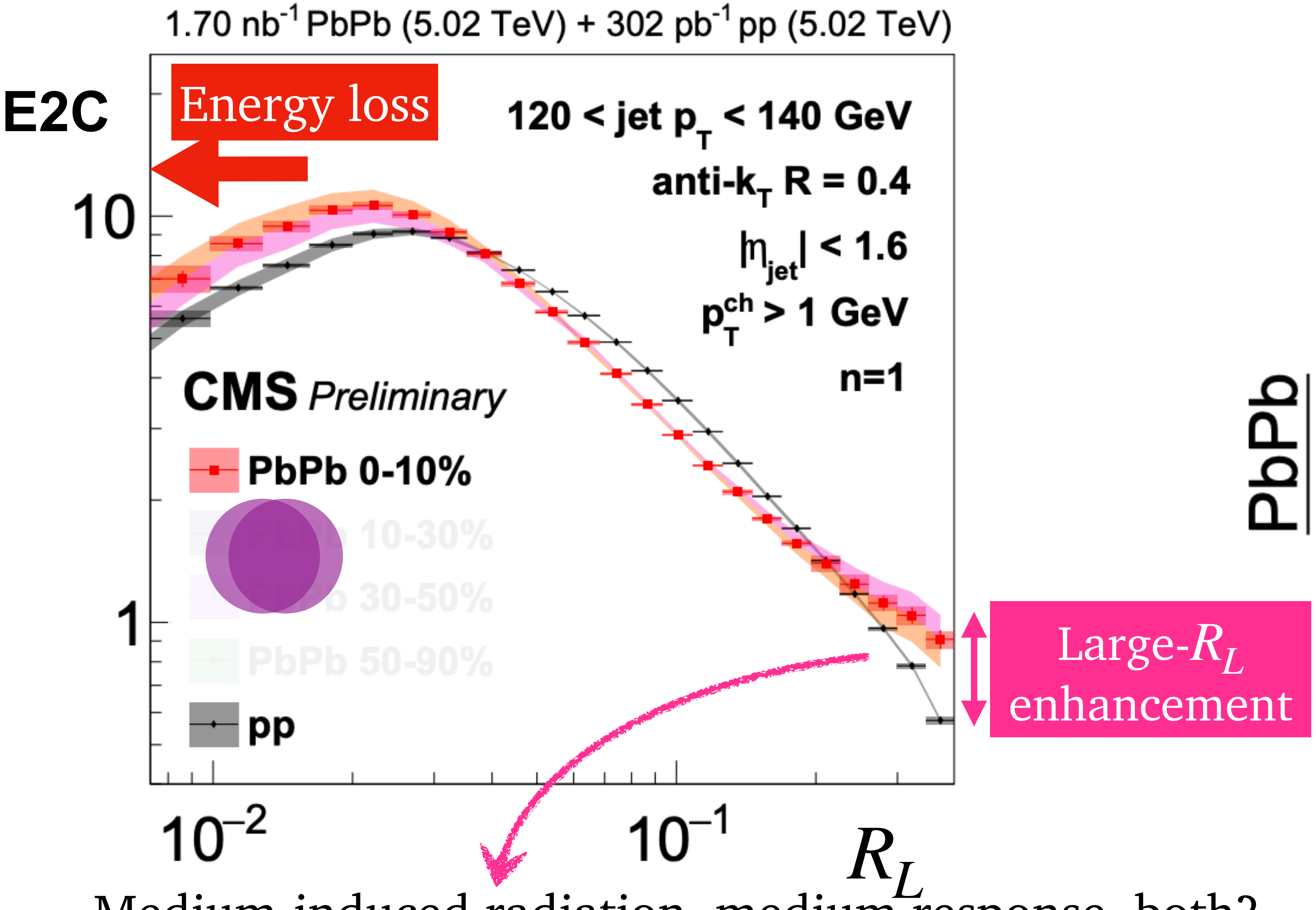

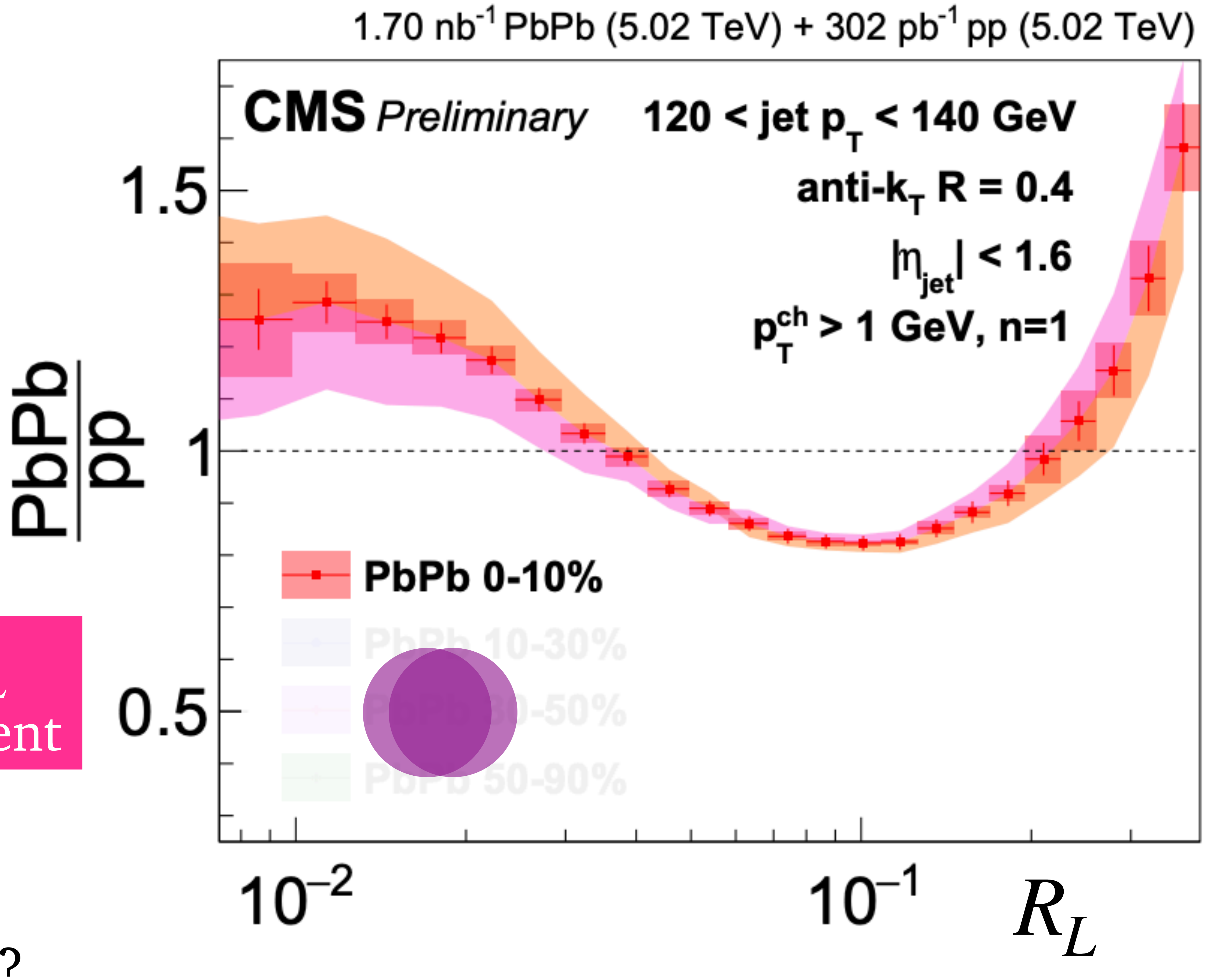

Medium-induced radiation, medium response, both?

Mitigating energy loss

CA, Holguin, Kunnawalkam Elayavalli, Viinikainen,
2409.07514, 2409.07526

The Generalized Cumulant

- Two-point correlator

$$f_{\mathrm{E2C}}\left(R_L\right) = \mathcal{N} \sum_{\mathrm{jets}} \sum_{i,j} \frac{P_{T,i} P_{T,j}}{P_{T,\mathrm{jet}}^2} \delta(R_{ij} - R_L)$$

- **Energy loss** results in a **shift**

$$f_{\mathrm{E2C}}^{\mathrm{AA}}(R_L) = \int \mathrm{d}\varepsilon \, p(\varepsilon) f_{\mathrm{E2C}}^{\mathrm{pp}}\left(R_L \left(1 + \frac{\varepsilon \, P(R_L)}{p_T} \right) \right)$$

- A-A/p-p ratio at $\mathcal{O}(\varepsilon/p_T)$

$$\frac{f_{\mathrm{E2C}}^{\mathrm{AA}}(R_L)}{f_{\mathrm{E2C}}^{\mathrm{pp}}(R_L)} = 1 + \frac{\bar{\varepsilon} \, P(R_L)}{p_T} \frac{\mathrm{d} \ln f_{\mathrm{E2C}}^{\mathrm{pp}}(R_L)}{\mathrm{d} \ln R_L}$$

The Generalized Cumulant

- Two-point correlator and its **Generalized Cumulant Distribution**

$$f_{\mathrm{E2C}}\left(R_L\right) = \mathcal{N} \sum_{\mathrm{jets}} \sum_{i,j} \frac{P_{T,i} P_{T,j}}{P_{T,\mathrm{jet}}^2} \delta(R_{ij} - R_L)$$

$$F_{\mathrm{E2C}}(R_L, p) \equiv \int_0^{R_L} \mathrm{d}R \, \left(f_{\mathrm{E2C}}(R)\right)^p$$

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$$\bar{\varepsilon} = \int \mathrm{d}\varepsilon \; p(\varepsilon)\varepsilon$$

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The Observable

- The derivatives can be computed in the perturbative and free hadron regimes

$$\left.\frac{\mathrm{d}\ln f^{\mathrm{pp}}_{\mathrm{E2C}}(R_L)}{\mathrm{d}\ln R_L}\right|_{\mathrm{pert}} = -1 \qquad \left.\frac{\mathrm{d}\ln F^{\mathrm{pp}}_{\mathrm{E2C}}(R_L)}{\mathrm{d}\ln R_L}\right|_{\mathrm{pert}} = 0$$

$$\left.\frac{\mathrm{d}\ln f^{\mathrm{pp}}_{\mathrm{E2C}}(R_L)}{\mathrm{d}\ln R_L}\right|_{\mathrm{free\ had}} = 1 \qquad \left.\frac{\mathrm{d}\ln F^{\mathrm{pp}}_{\mathrm{E2C}}(R_L)}{\mathrm{d}\ln R_L}\right|_{\mathrm{free\ had}} = p+1$$

Interpolating ⇒

$$\frac{\mathrm{d}\ln f^{\mathrm{pp}}_{\mathrm{E2C}}(R_L)}{\mathrm{d}\ln R_L} \approx \frac{2}{p+1}\frac{\mathrm{d}\ln F^{\mathrm{pp}}_{\mathrm{E2C}}(R_L,p)}{\mathrm{d}\ln R_L} - 1$$

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- The ***unbiasing function***

$$C_p(R_L) \equiv \left(\frac{F^{\mathrm{AA}}_{\mathrm{E2C}}(R_L,p)}{F^{\mathrm{pp}}_{\mathrm{E2C}}(R_L,p)}\right)^{\frac{2}{p+1}} - E_{\mathrm{peak}}\,\frac{p-1}{p+1}$$

Position of the hadronization peak in the E2C

$$E_{\mathrm{peak}} \equiv \frac{p+1}{p-1}\left[\left(\frac{F^{\mathrm{AA}}_{\mathrm{E2C}}(R_{\mathrm{peak}},p)}{F^{\mathrm{pp}}_{\mathrm{E2C}}(R_{\mathrm{peak}},p)}\right)^{\frac{2}{p+1}} - 1\right]$$

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- The **E2C-based** observable ($p = 2$)

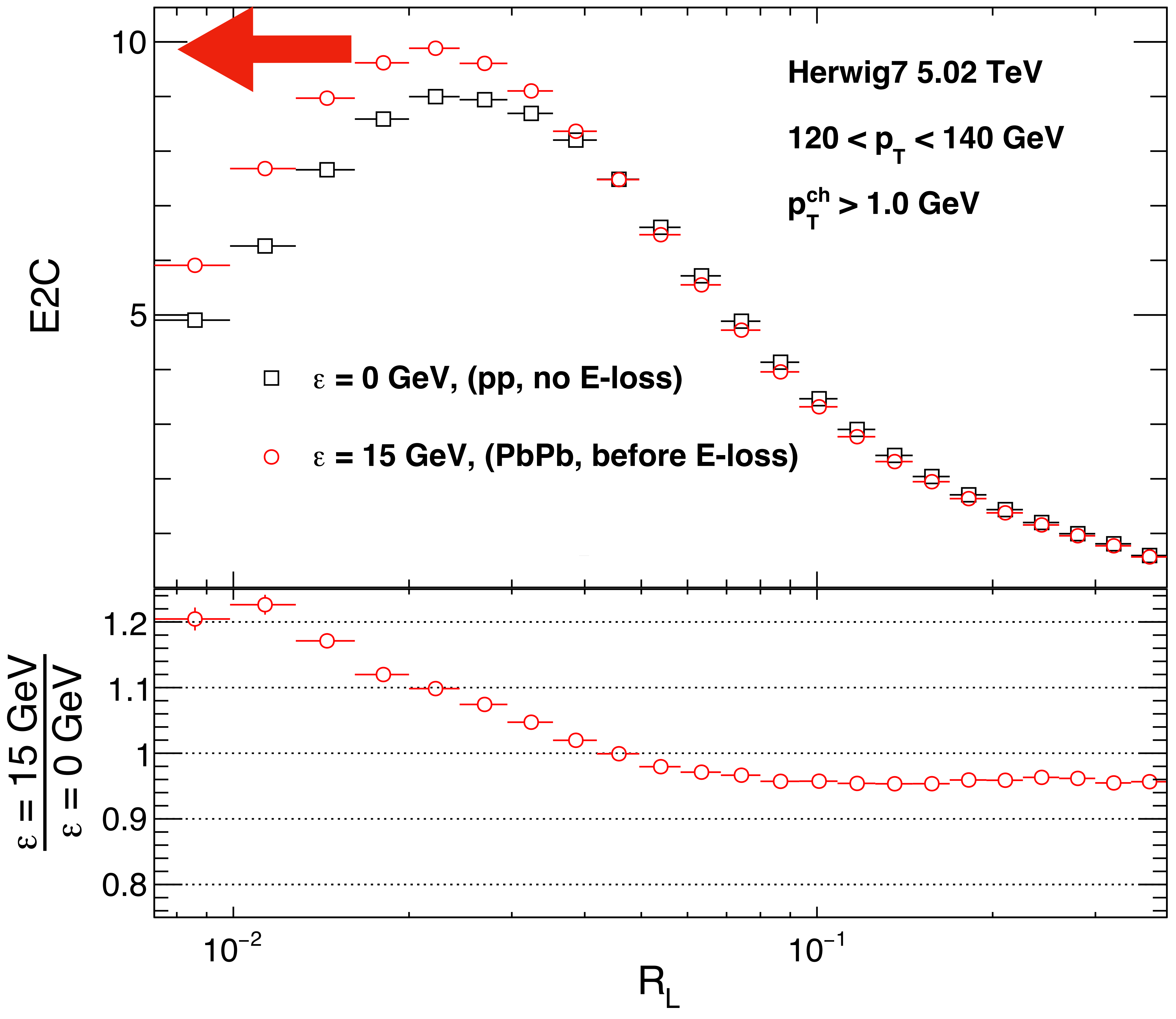
$$\mathrm{E2C}/C_2 = \frac{f^{\mathrm{AA}}_{\mathrm{E2C}}(R_L)}{C_2(R_L)}$$

C_2 can be directly obtained from the E2C!

Mitigating energy loss

CA, Holguin, Kunnawalkam Elayavalli, Viinikainen, 2409.07514

15 GeV shift



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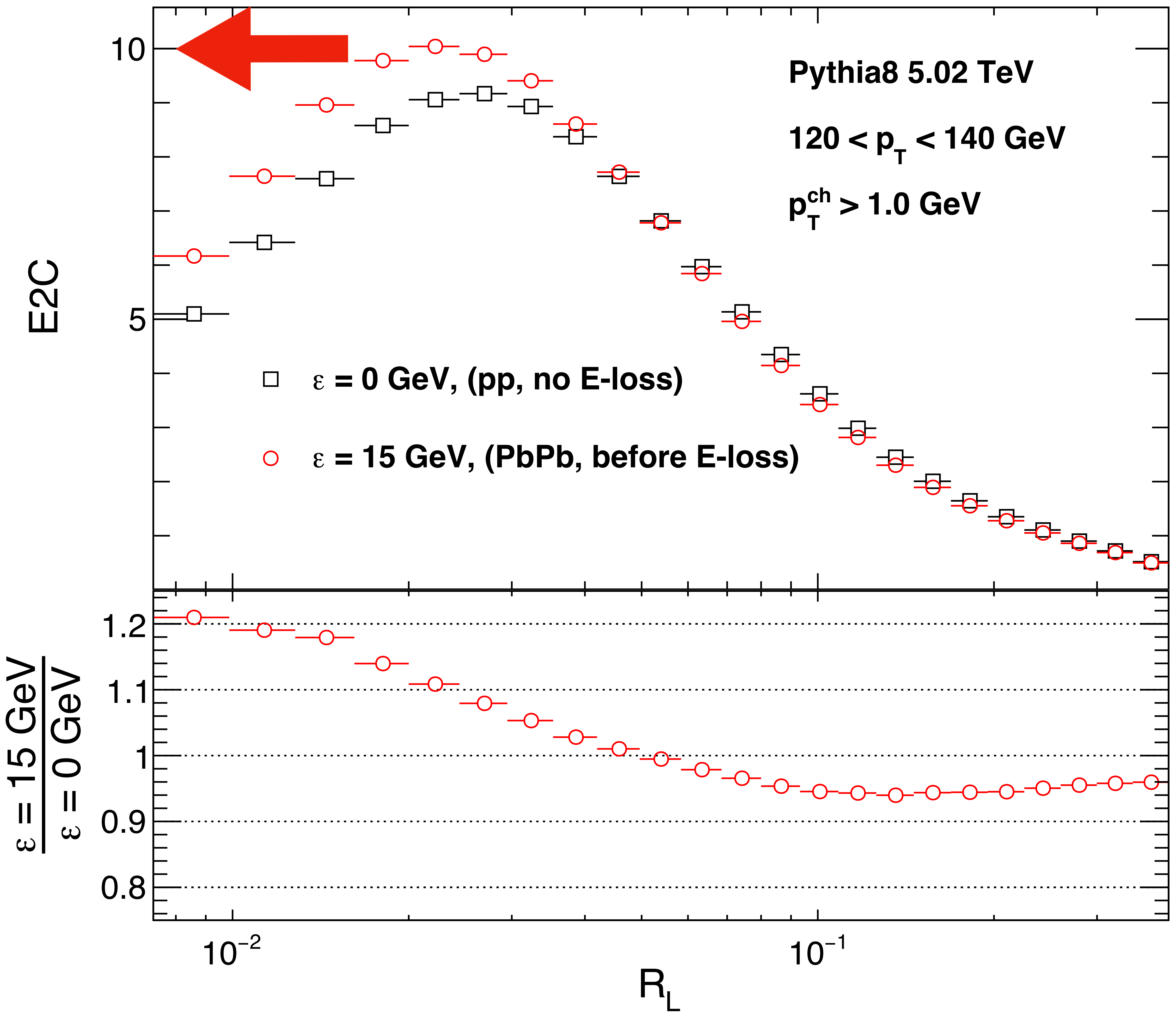

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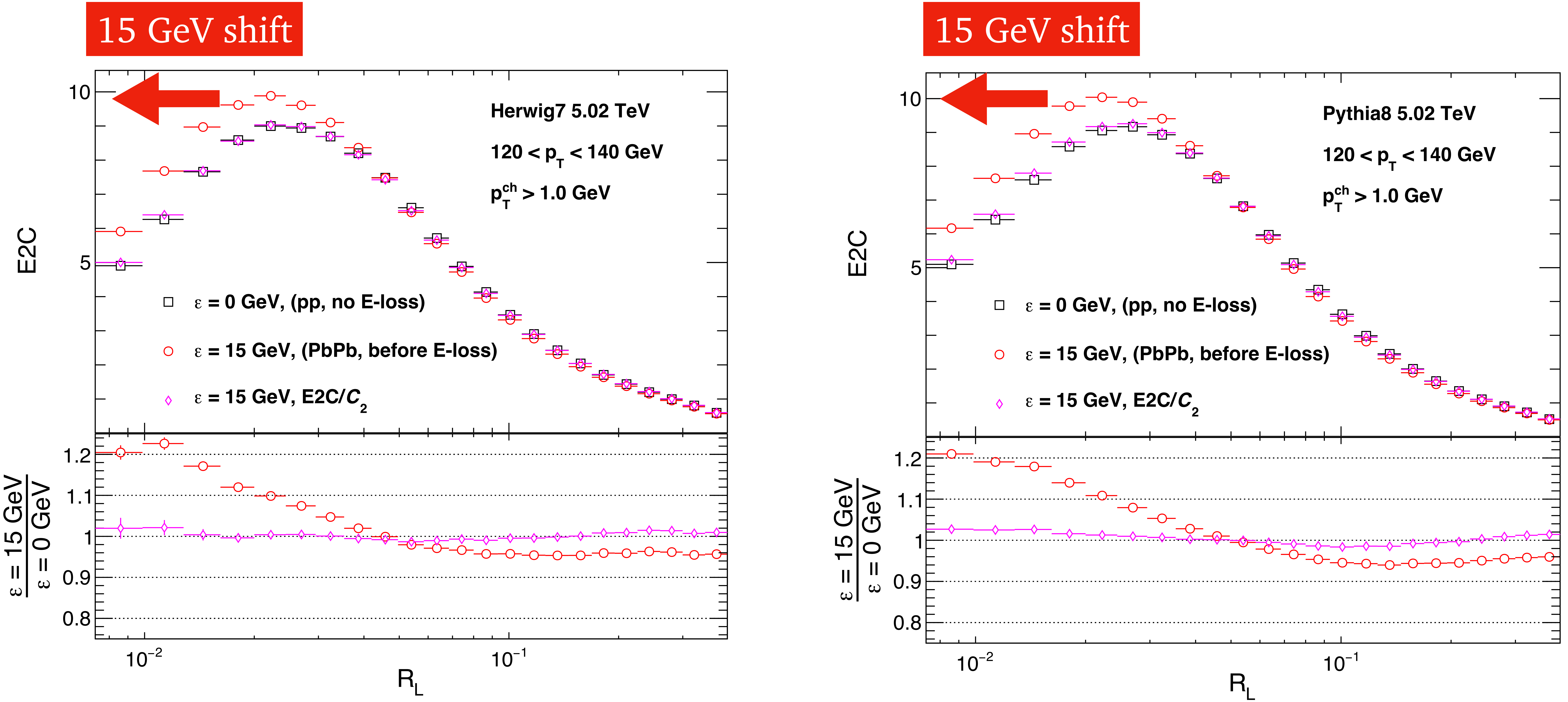
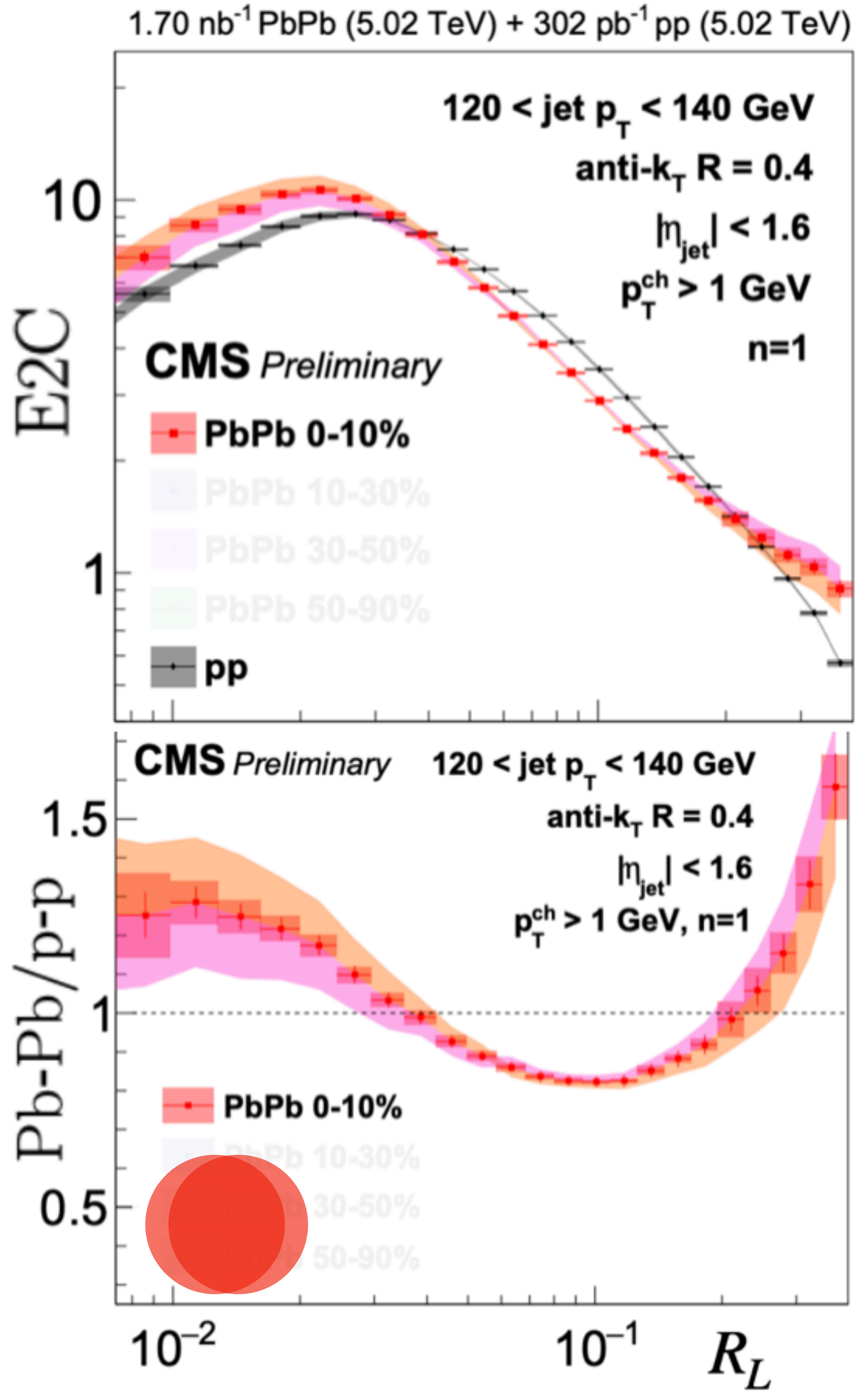


E2C/C_2: almost no selection bias effect!

Mitigating energy loss

E2C in inclusive jets



Mitigating energy loss

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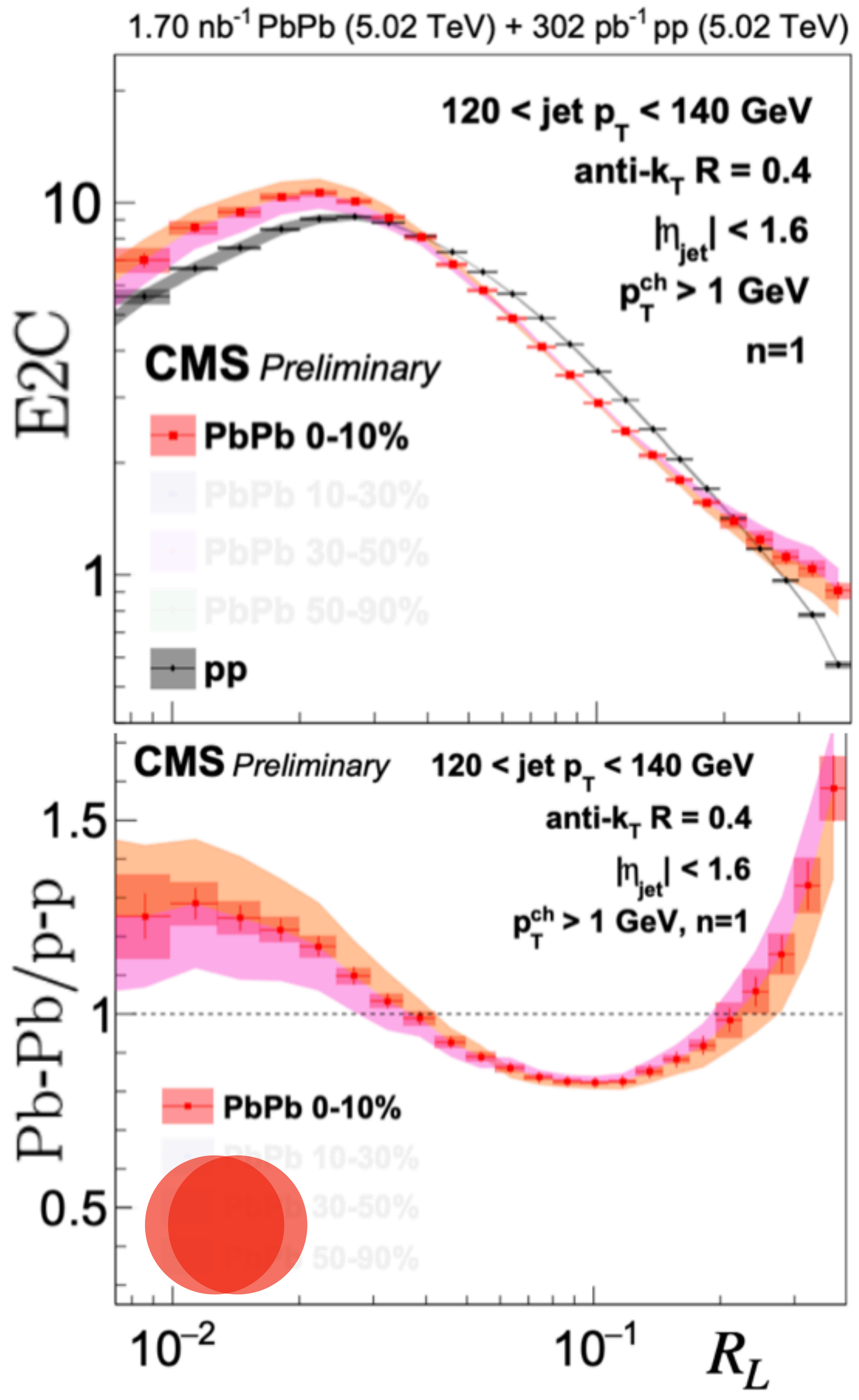
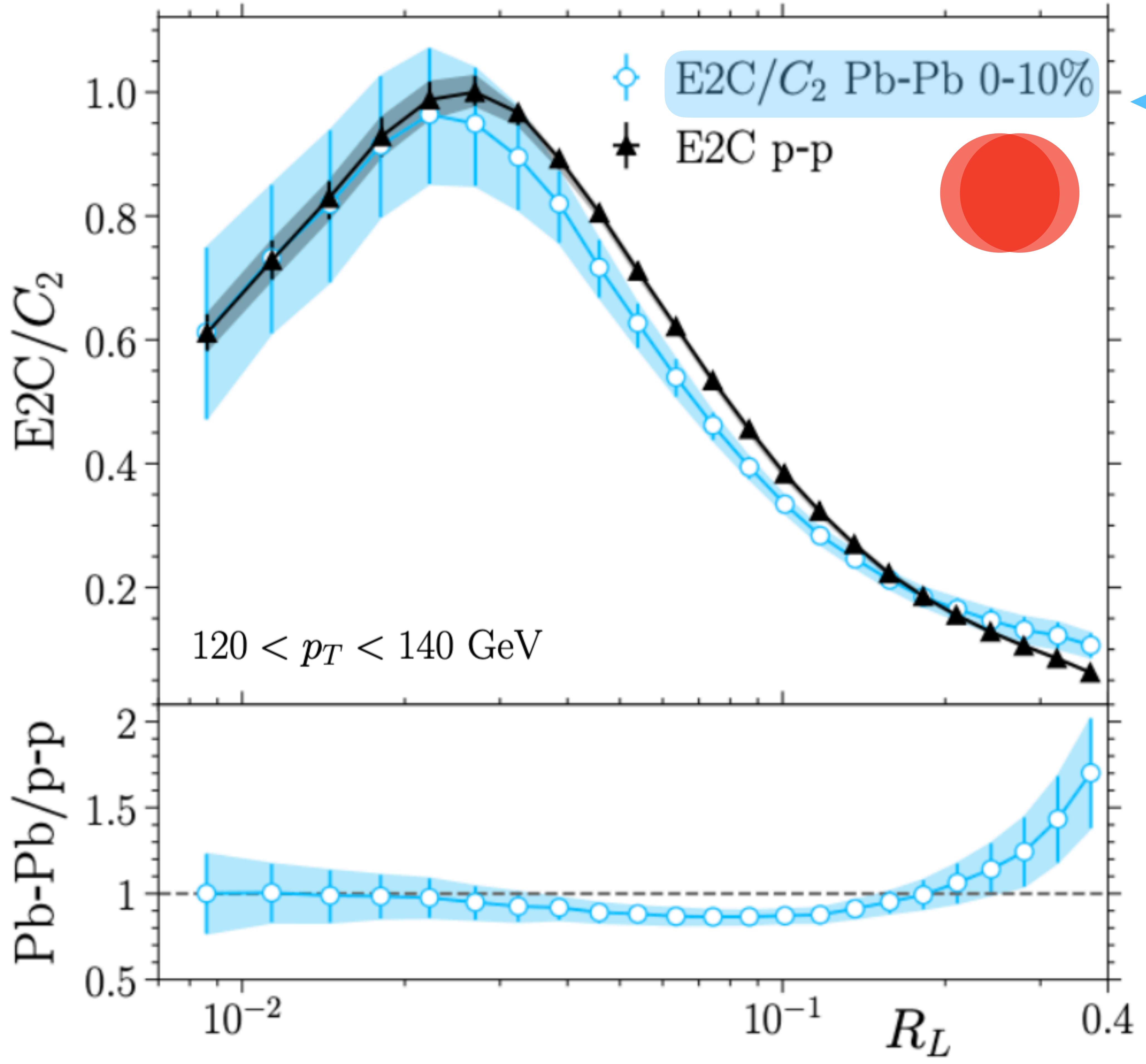


Unbiased E2C in inclusive jets



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Mitigating energy loss

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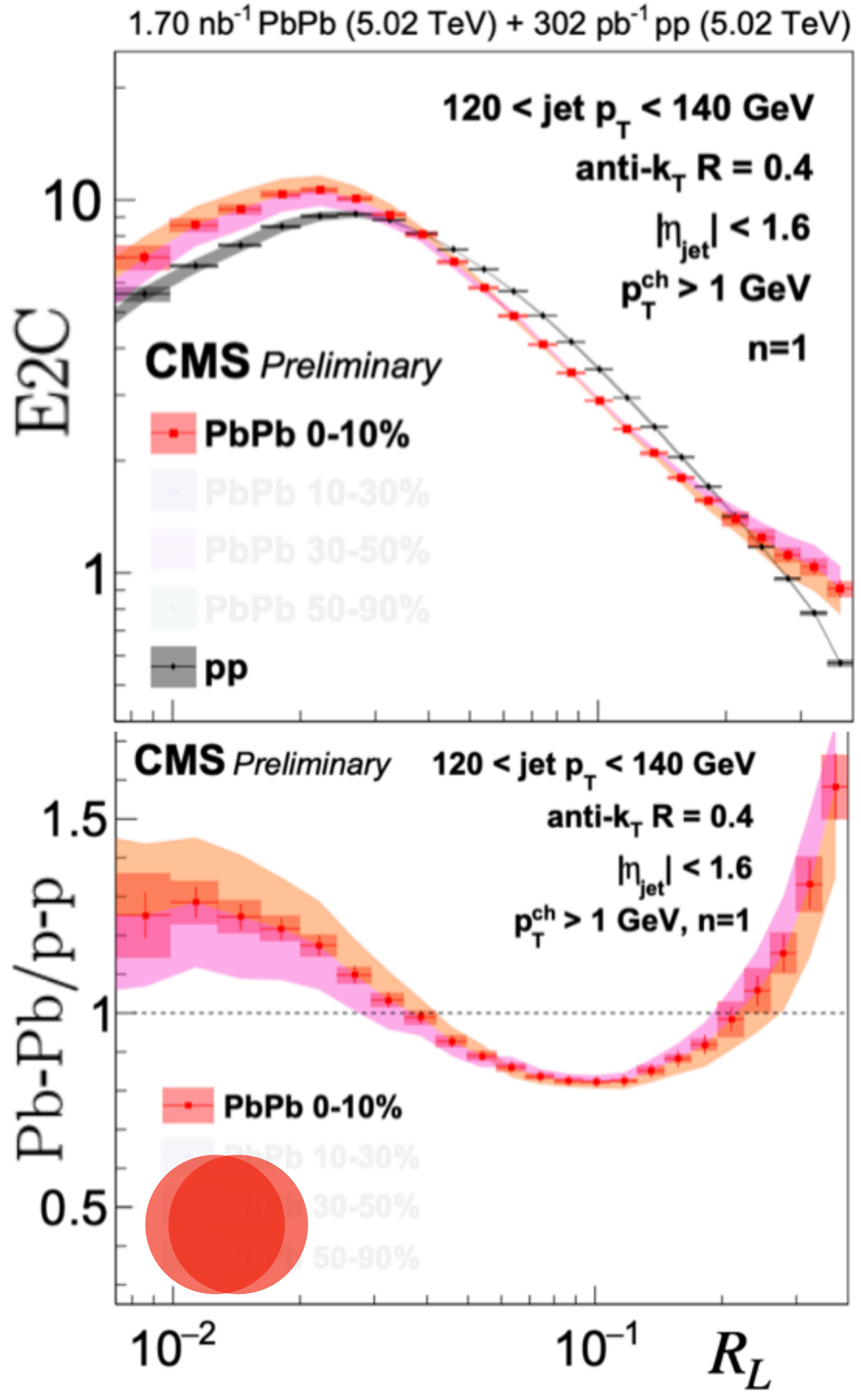

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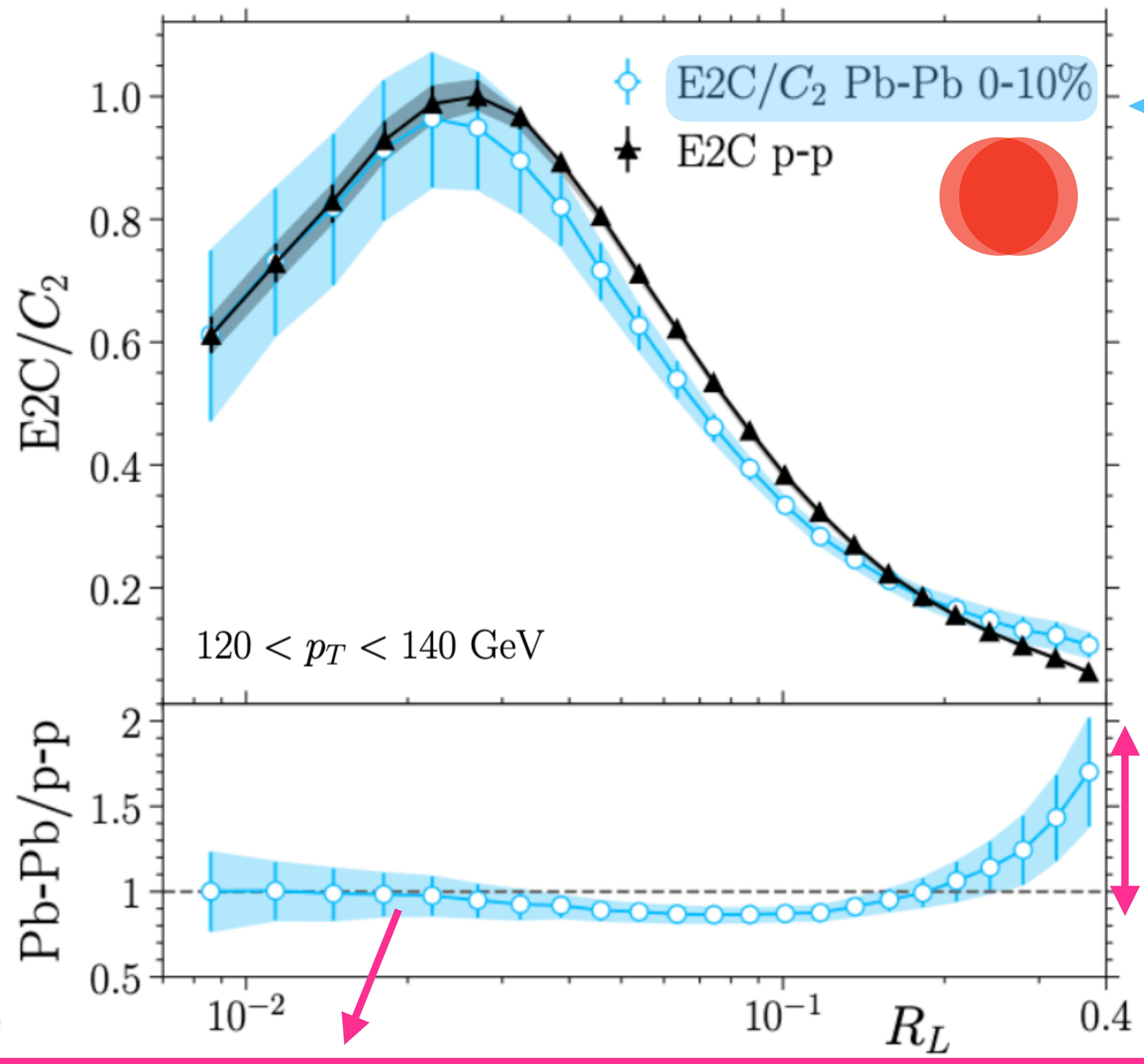
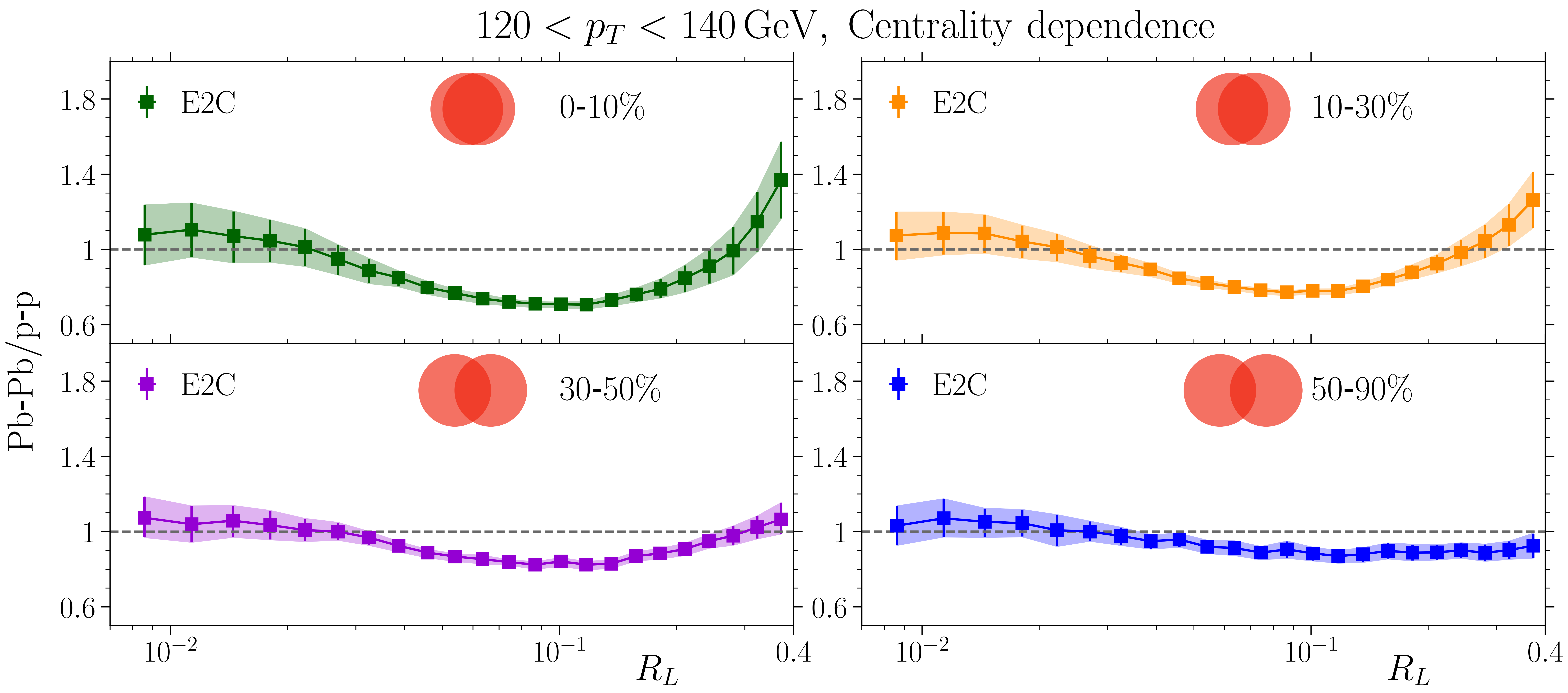


C_2 can be directly obtained from the E2C!

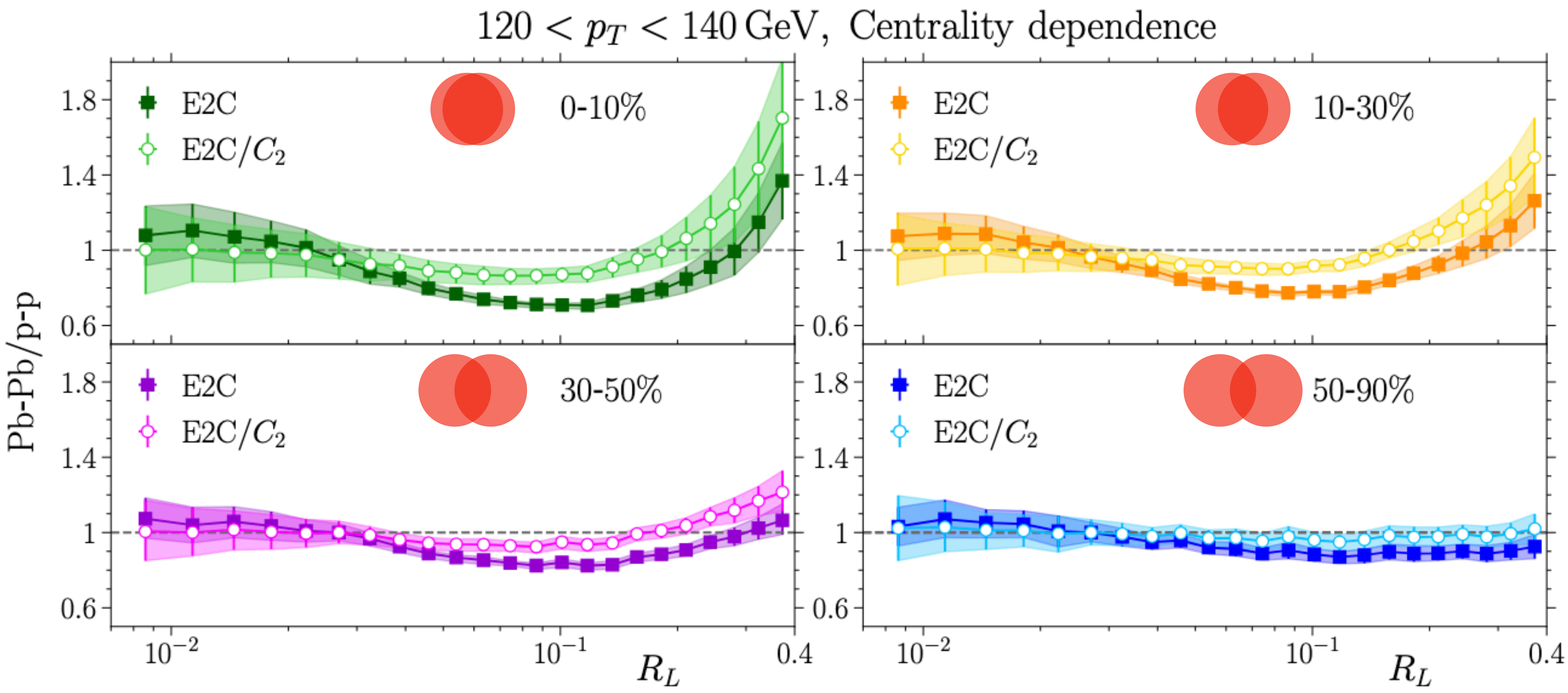
Larger enhancement

Within current uncertainties: the free hadron region is flat

Mitigating energy loss



Mitigating energy loss



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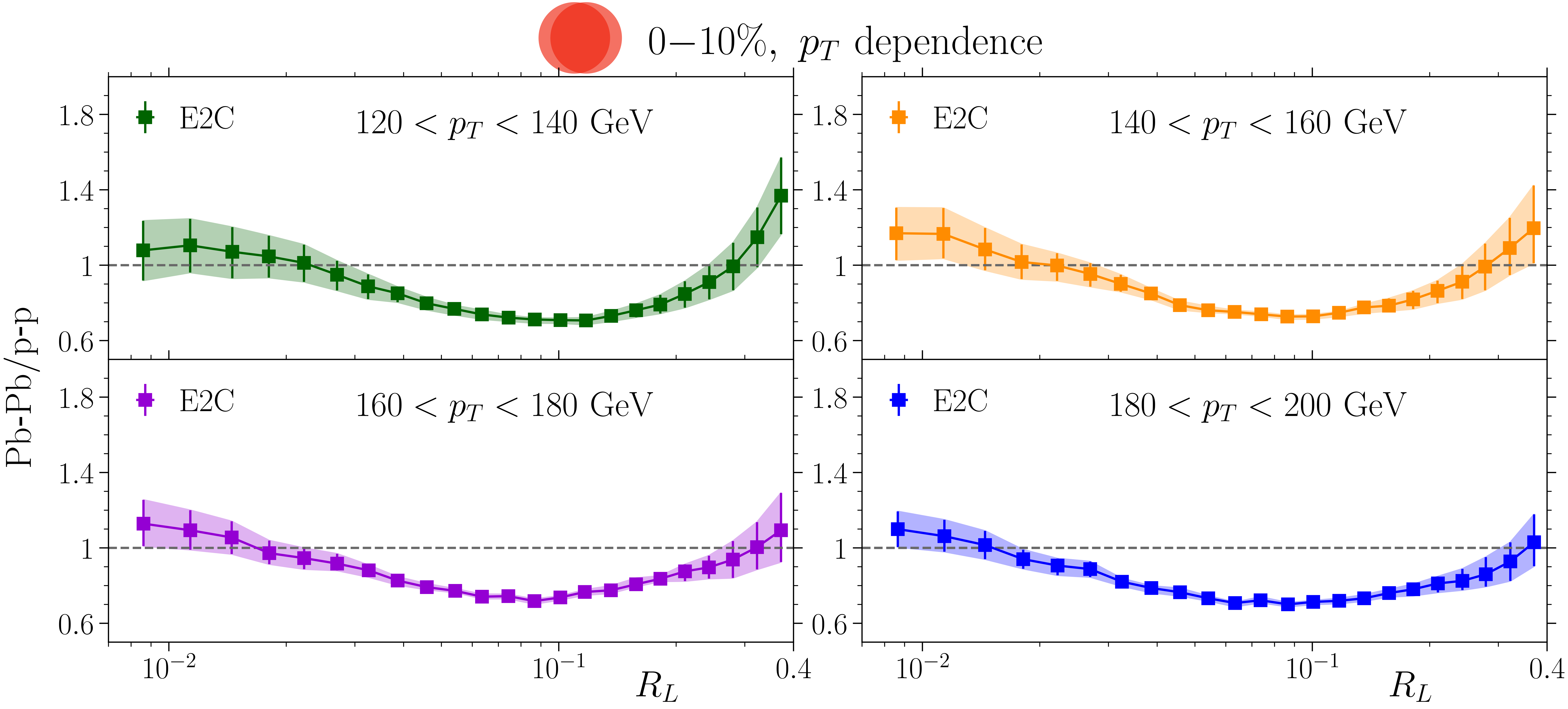
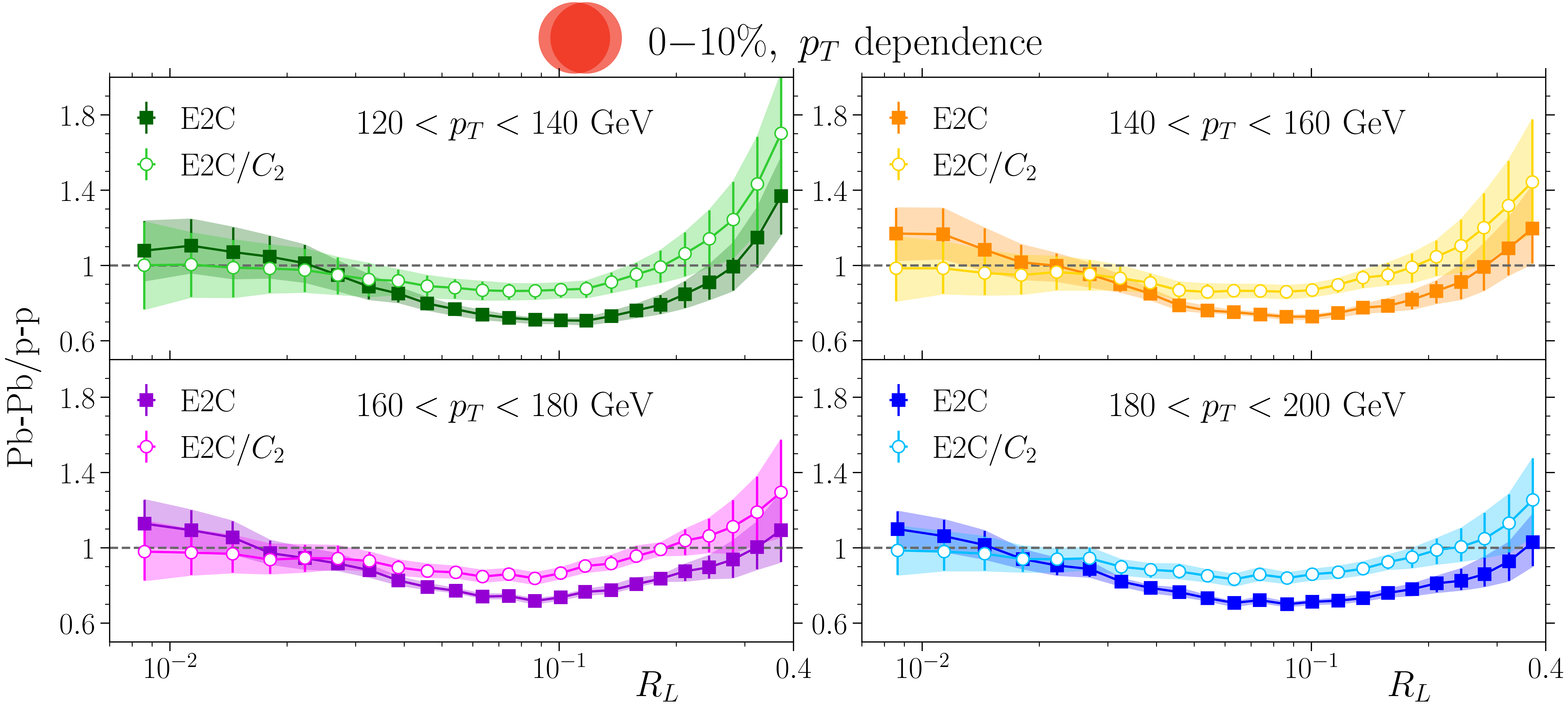


Mitigating energy loss



Conclusions

- **Energy loss: shifts** the E2C in Pb-Pb **towards small angles** w.r.t. the p-p result

  reduces the enhancement at large angles

- **E2C/C_2: new E2C-based** observable that **removes leading order energy loss effects!**

- **E2C/C_2**: first-ever substructure observable where energy loss does not play a leading role

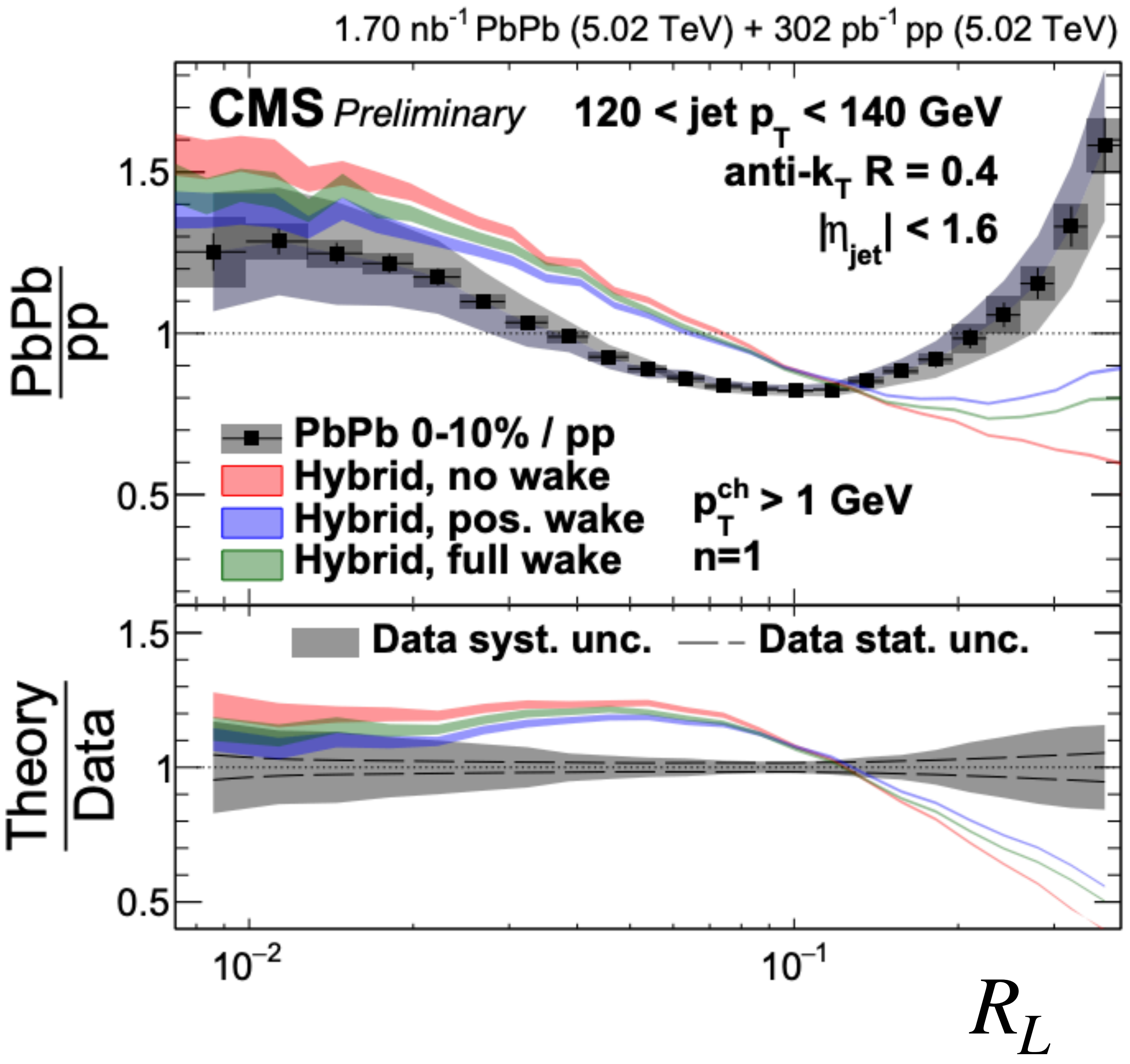
- Method applicable to N**-point projected correlators** in **inclusive, dijet** and γ/Z**-jets**

Thank you!

A-A E2C: theory predictions

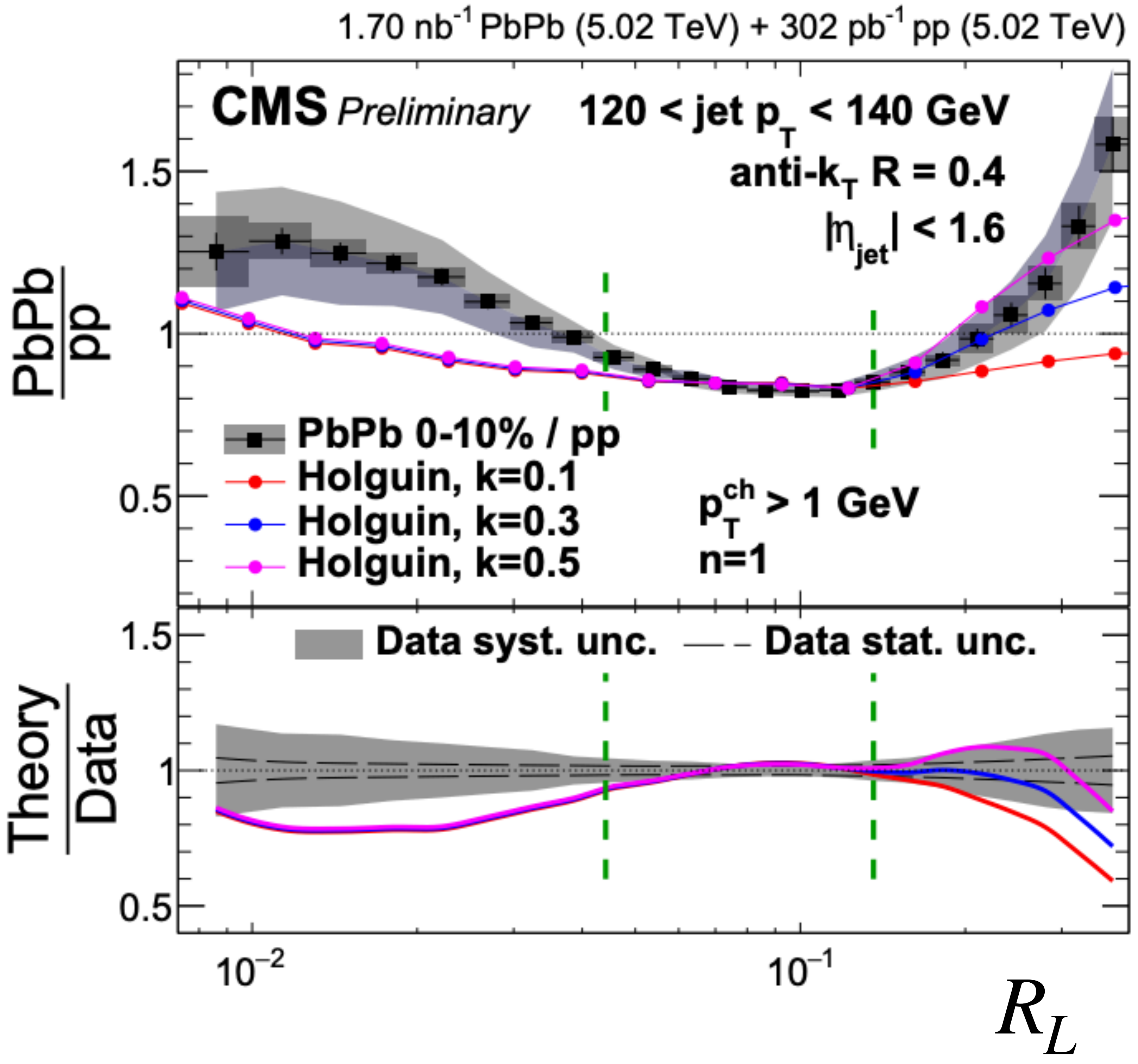
From Jussi's talk

Hybrid model
Pablos, Kudinoor, Rajagopal



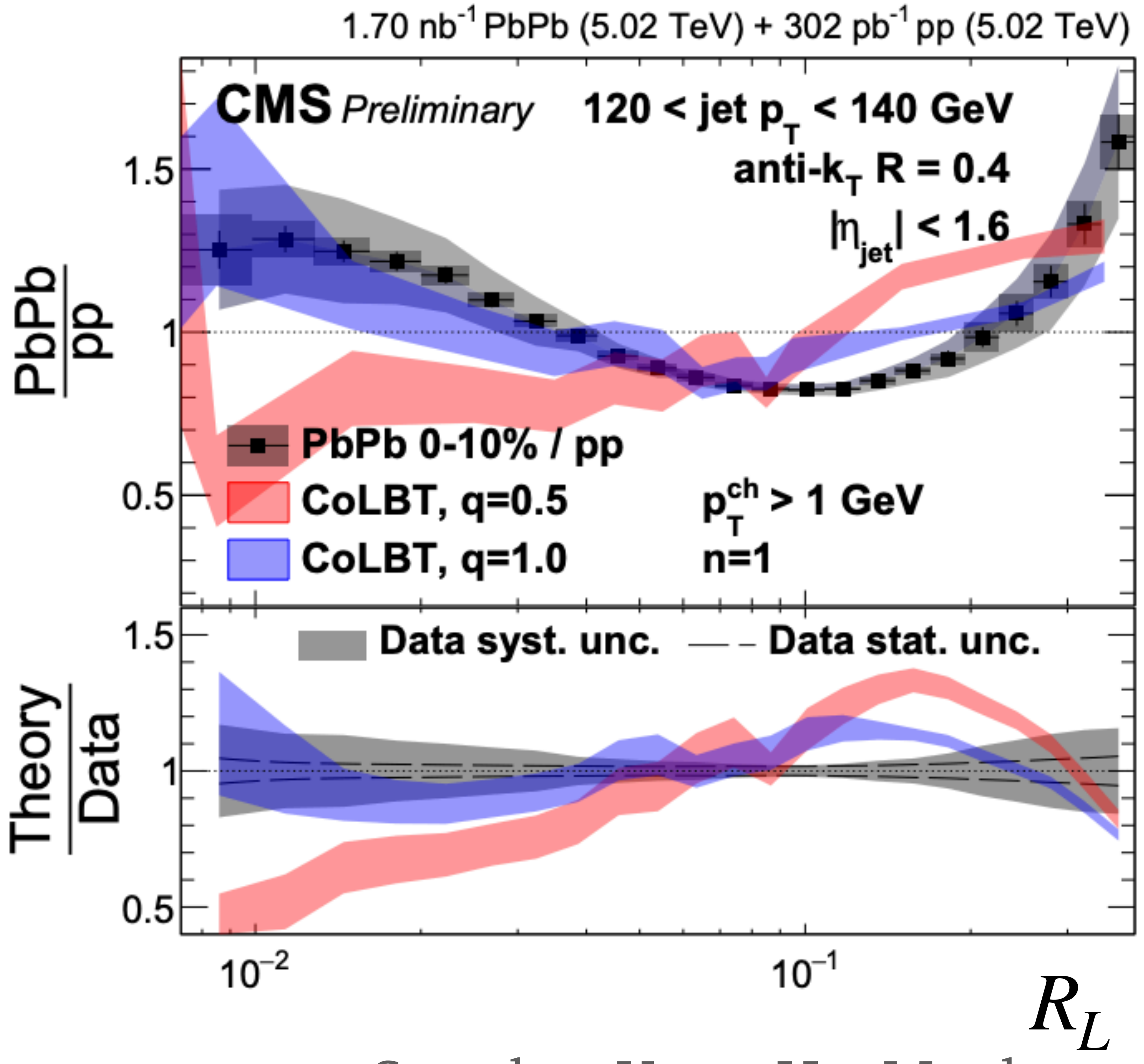
See also: Bossi, Kudinoor, Moult, Pablos, Rai, Rajagopal, 2407.13818

Andres, Dominguez, Holguin, Marquet, Moult



2407.07936

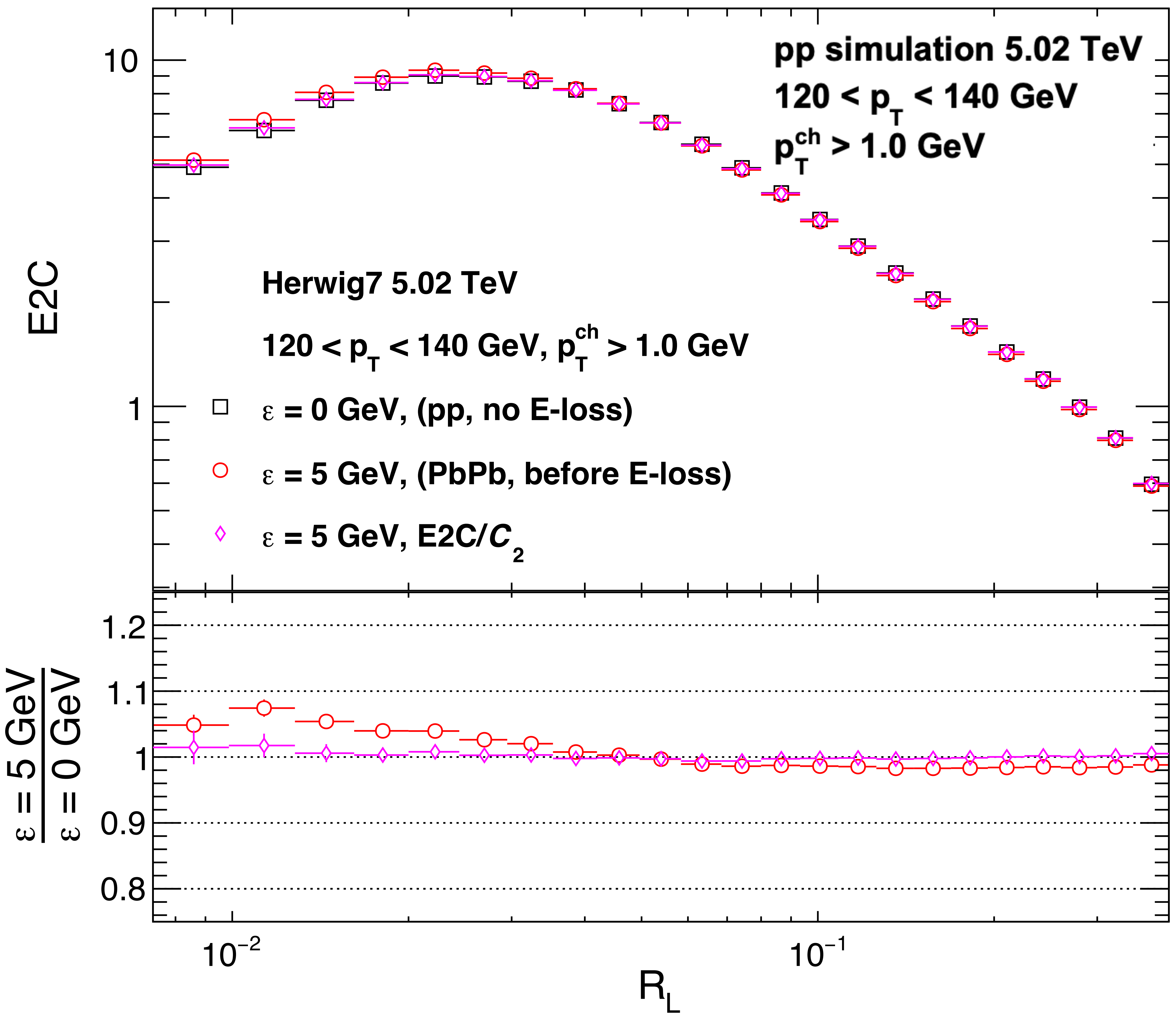
CoLBT
Yang, He, Wang



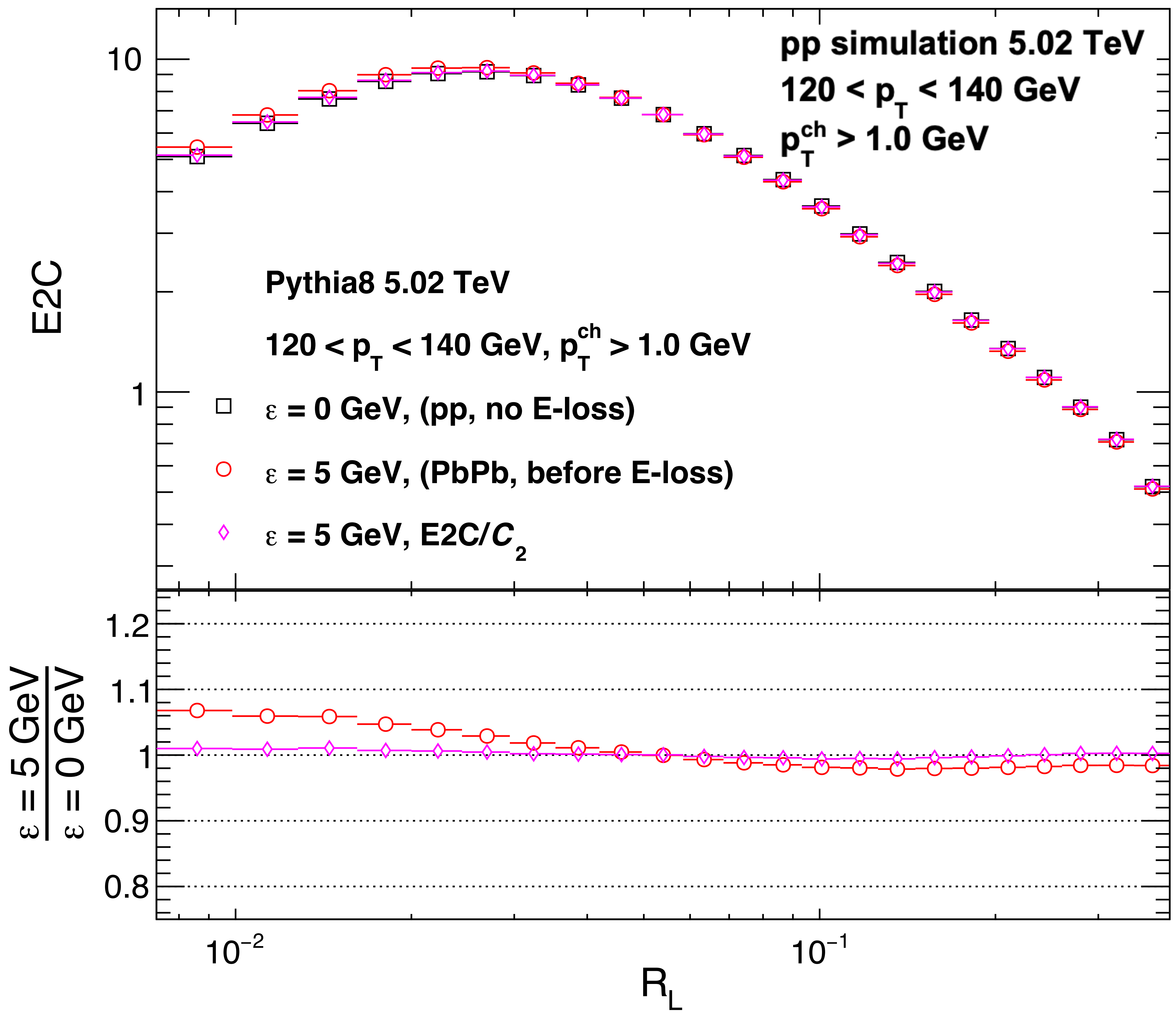
See also: Yang, He, Moult, Wang, 2310.01500

Mitigating energy loss: 5 GeV shift

Herwig7



Pythia8



Mitigating energy loss: 5 GeV shift

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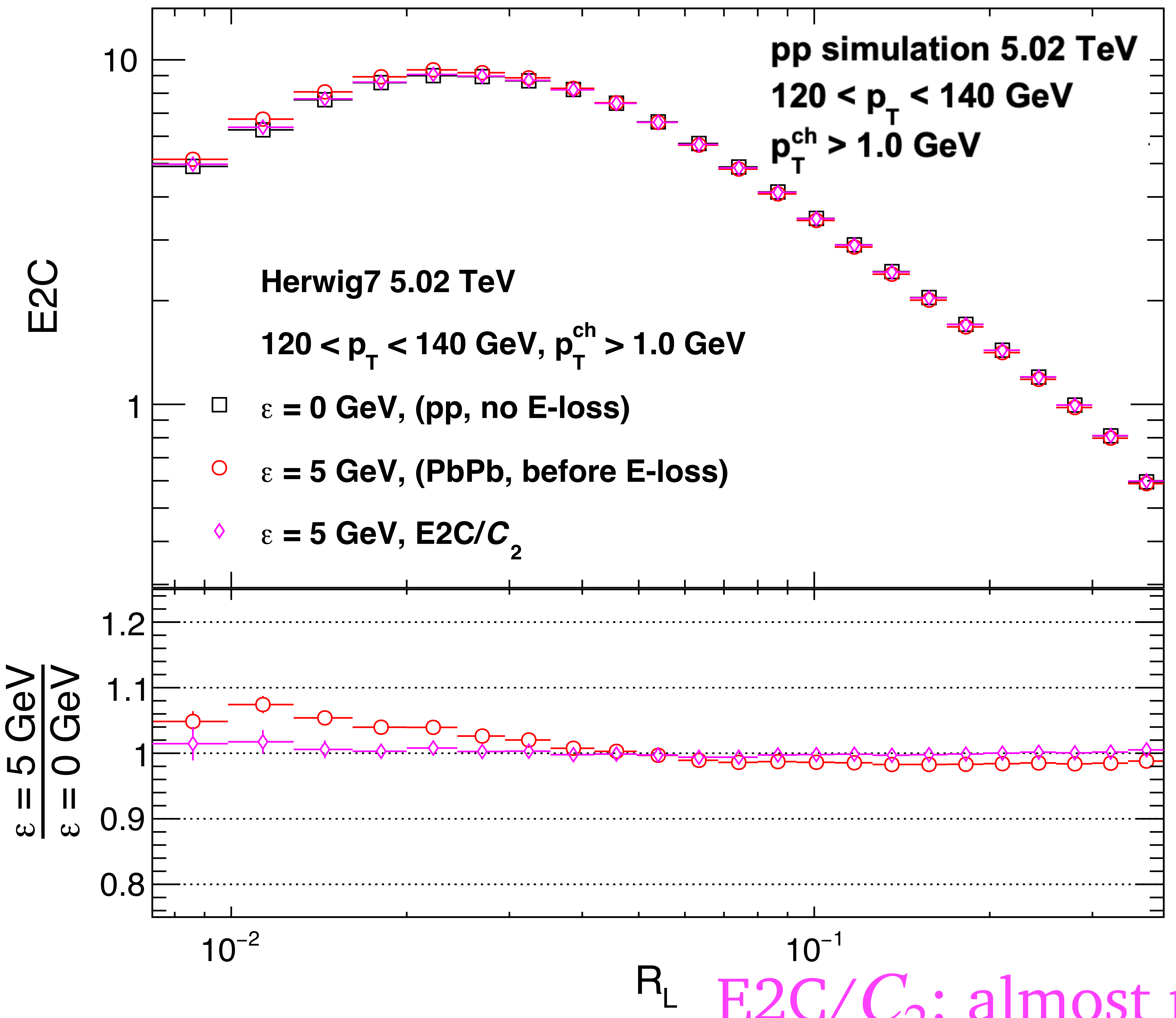

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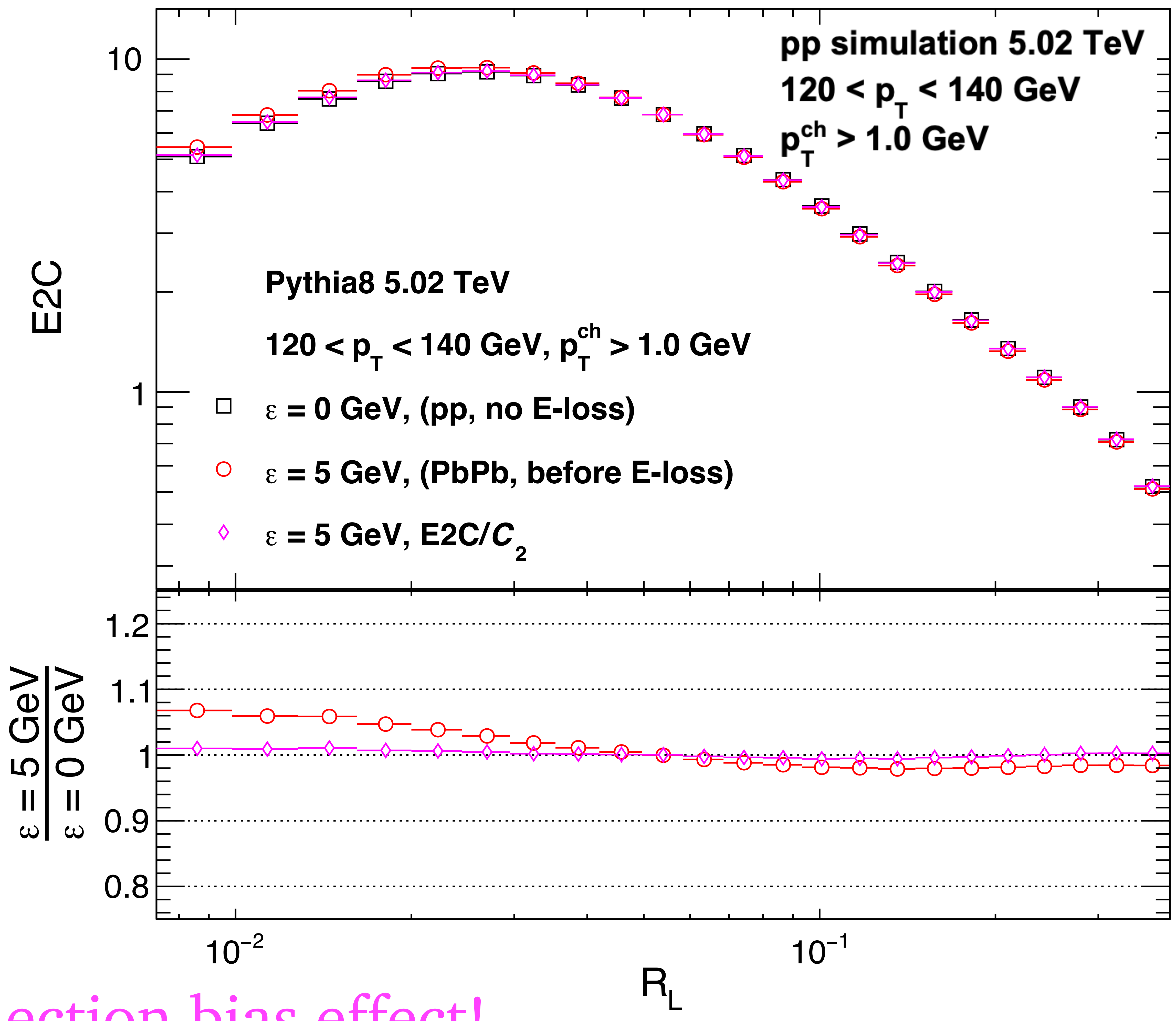

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