Universality in the Near Side EEC

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Beijing Normal University

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XL, Vogelsang, Yuan, Zhu, 2410.16371

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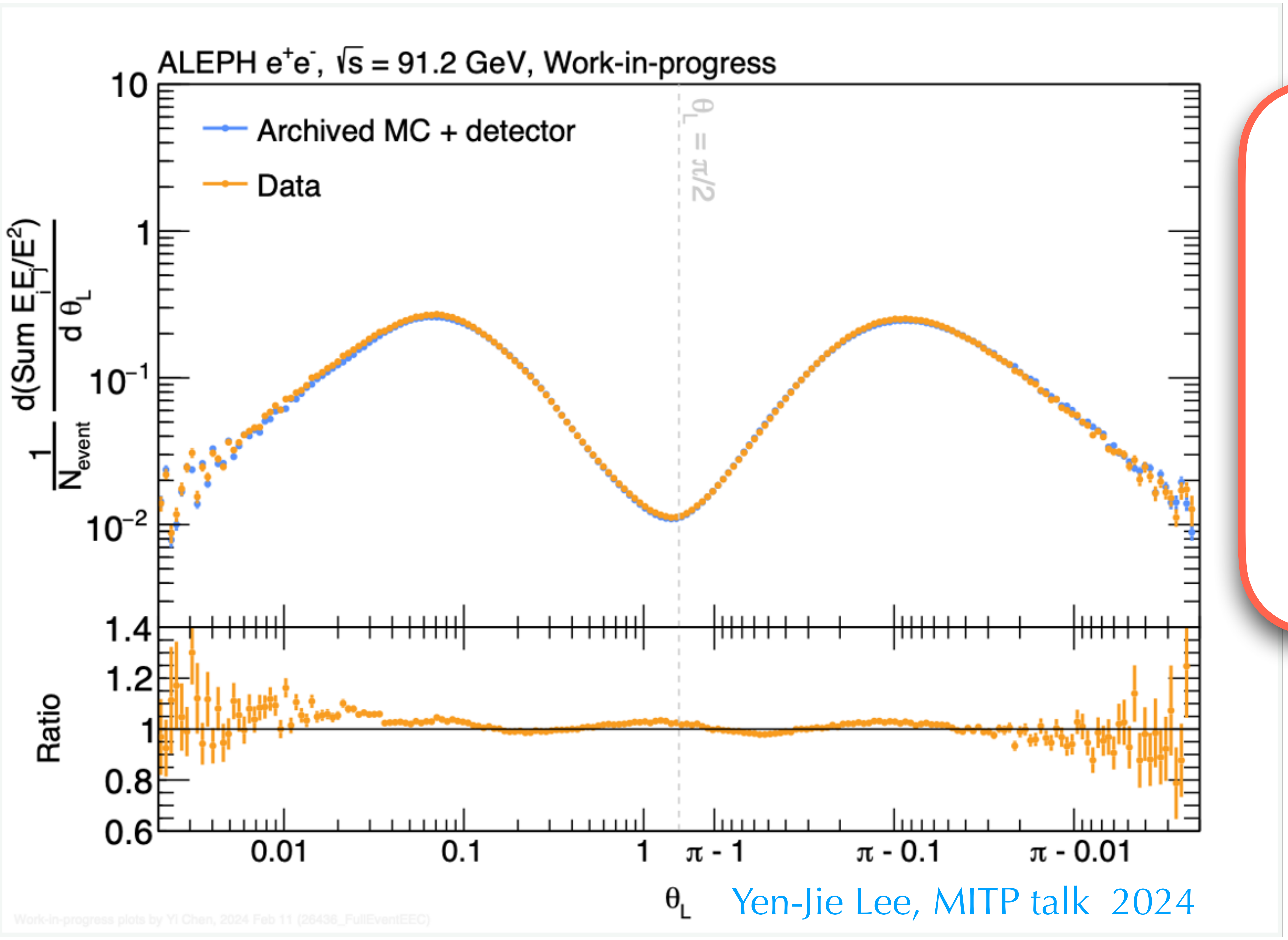
Energy Correlators



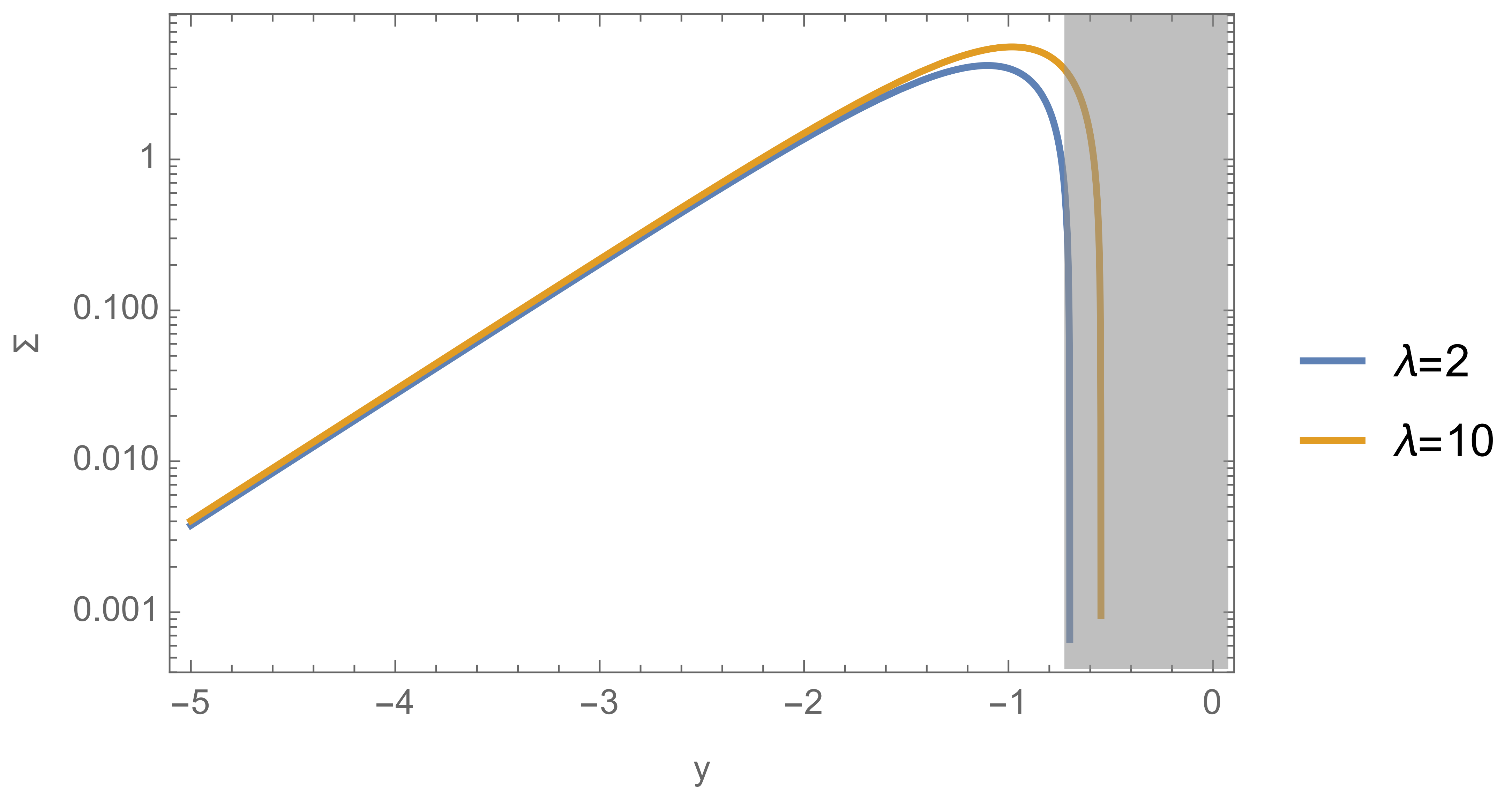
Yen-Jie Lee, MITP talk 2024

- $\chi \to \frac{\pi}{2}$, fixed order
- $\chi \to \pi$, TMD soft, $\sim e^{a \ln^2 \frac{1}{\chi}} e^{-2S_{NP}}$
- $\Lambda_{QCD} \ll Q\chi \ll Q$, Collinear, $\sim \theta^{-1+\gamma[3]}$
- $Q\chi \lesssim \Lambda_{QCD}$, **phase transition, ?**

Energy Correlators

$$\langle \mathcal{E}(\vec{n}_1')\mathcal{E}(\vec{n}_2')\rangle = (\frac{q^0}{4\pi})^2\left[1+\frac{6\pi^2}{\lambda}(\cos^2\theta_{12}-\frac{1}{3})+\cdots\right]$$

Hofman, Maldacena, 2008



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Non-Perturbative Aspects

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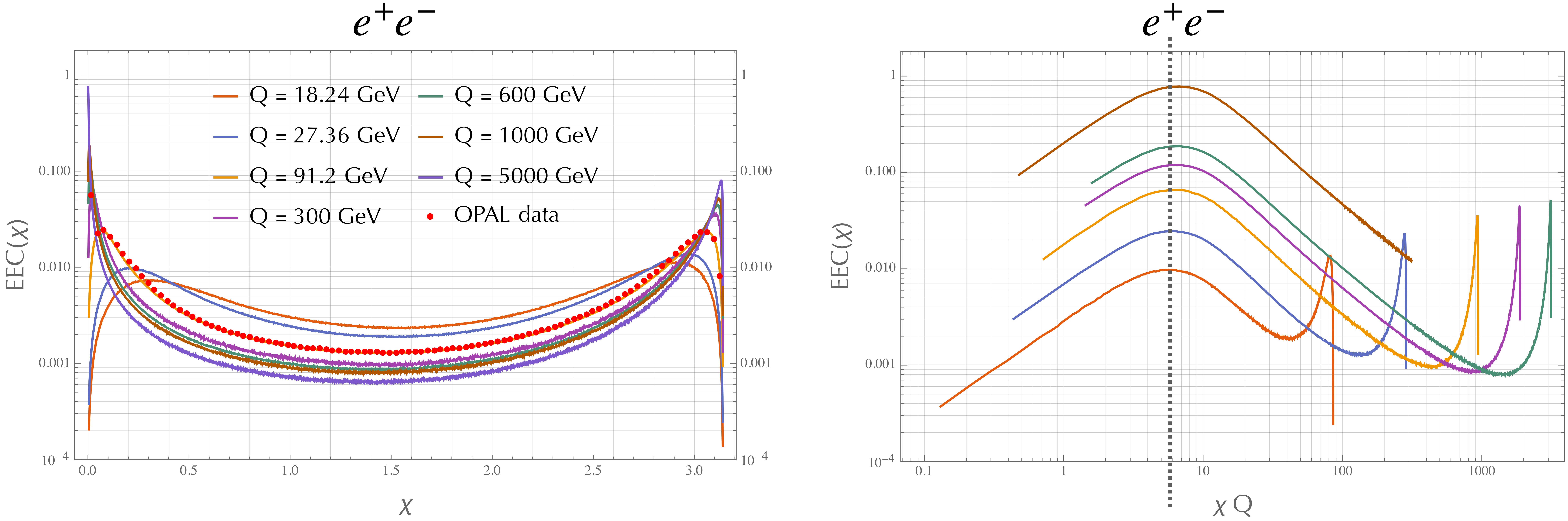

- Uncorrelated distribution in the deep NP regime, $d\Sigma/d\cos\theta \sim$ const.
- $\chi \to 0$ peaks almost position at the same $Q\chi$ →probing the same NP scale Λ_{QCD}
- $\chi \to 0$ peaks rise more dramatically ← collinear vs pert. Sudakov

Non-Perturbative Aspects

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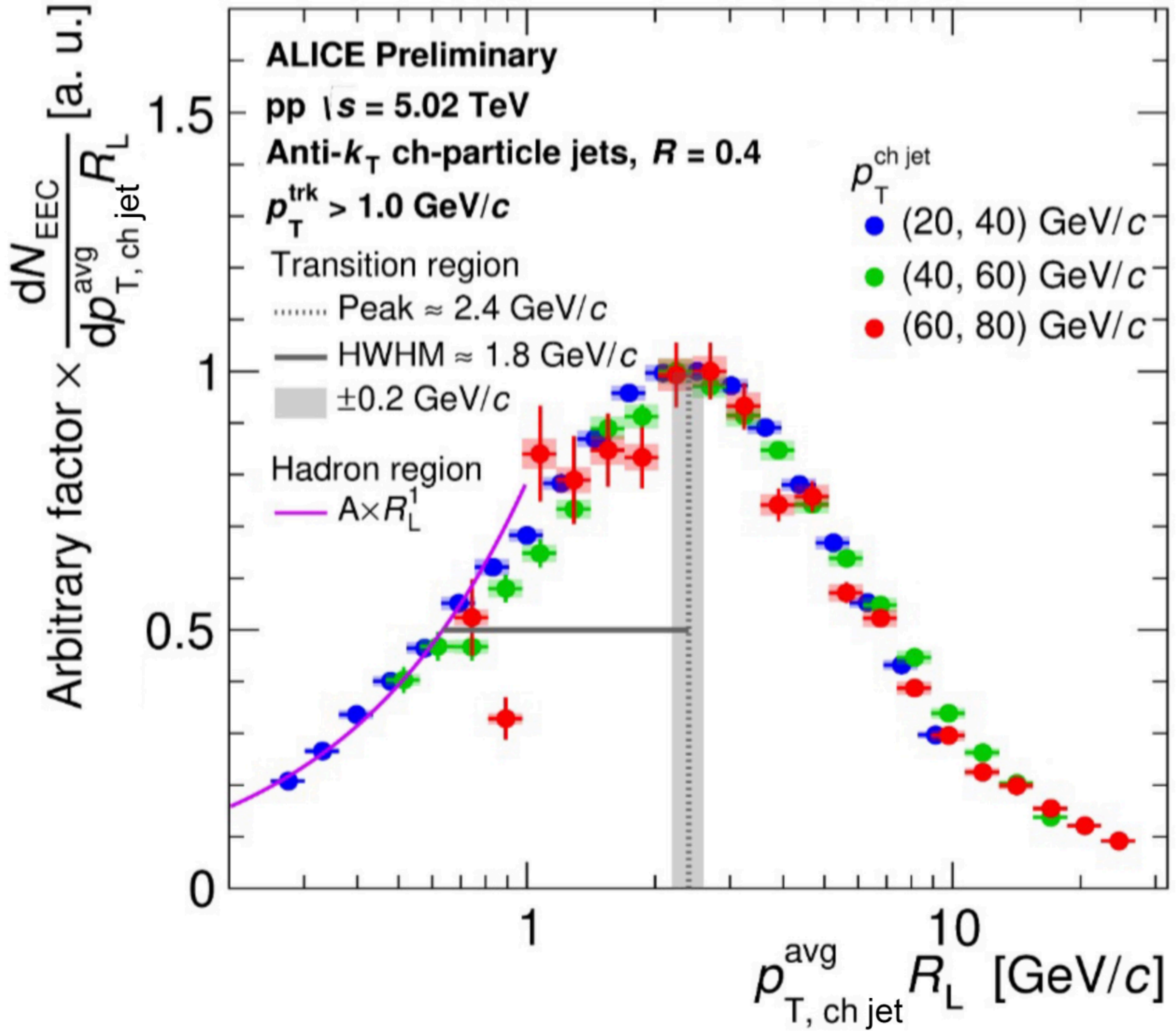
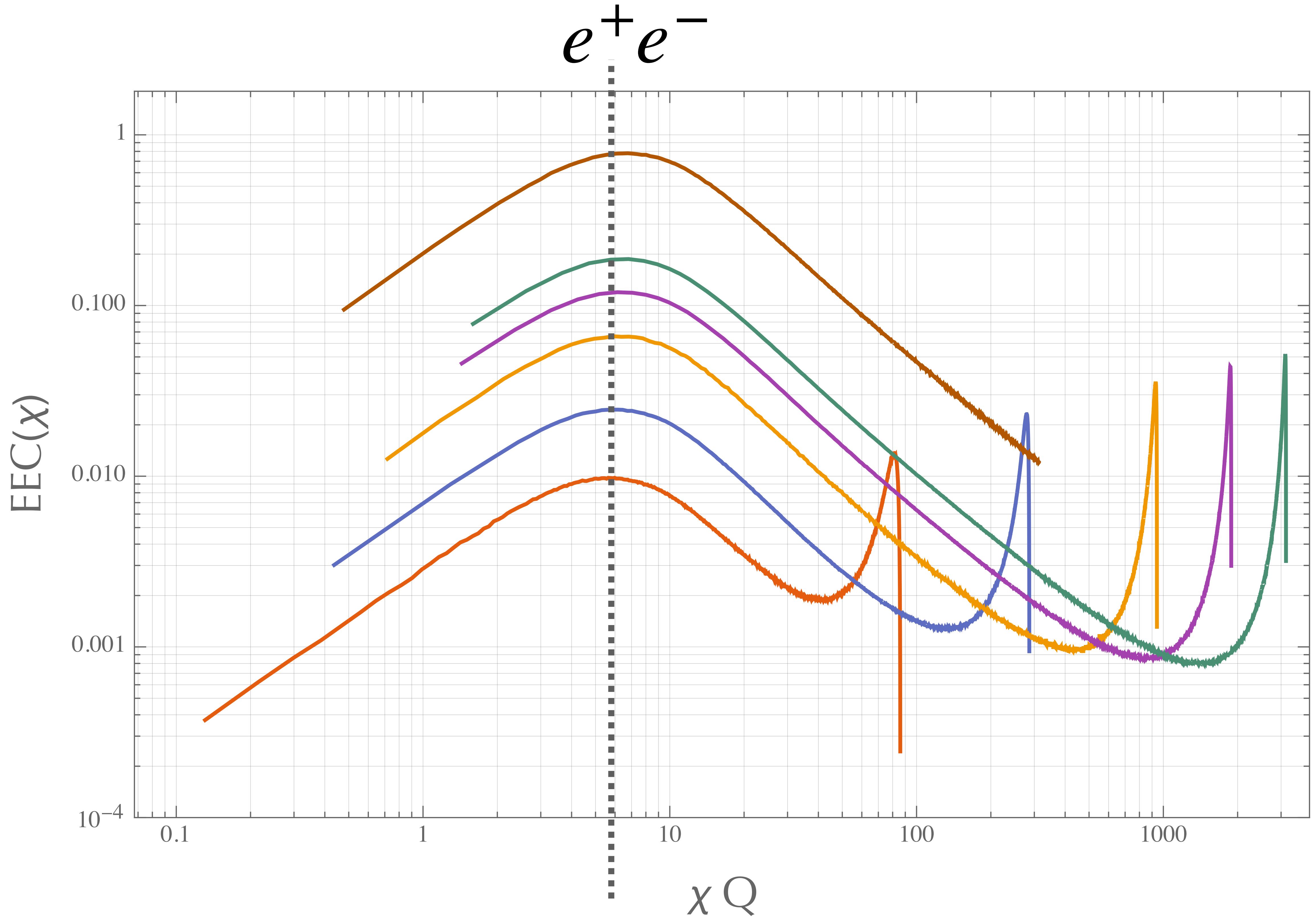
Seen in the LHC data





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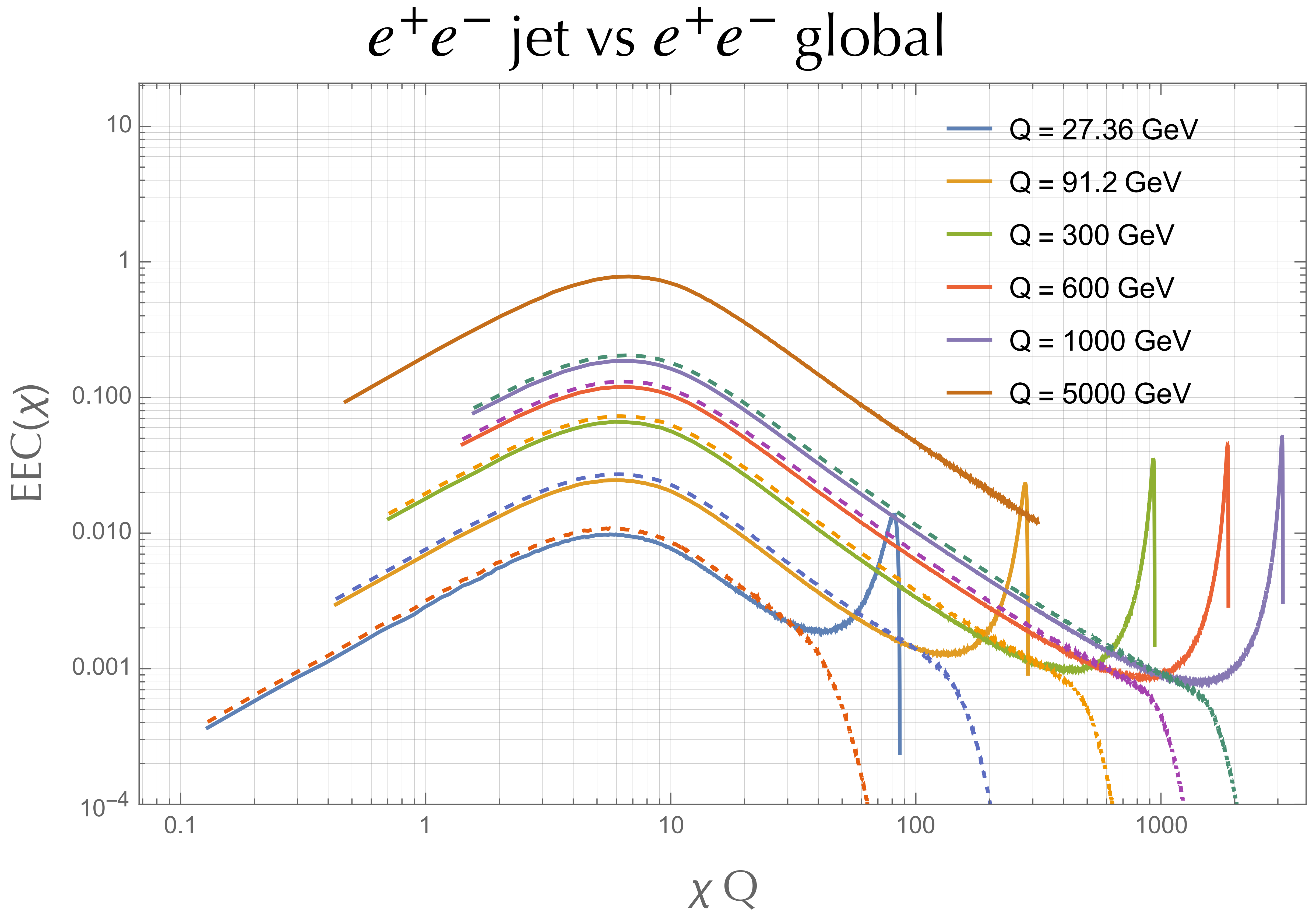

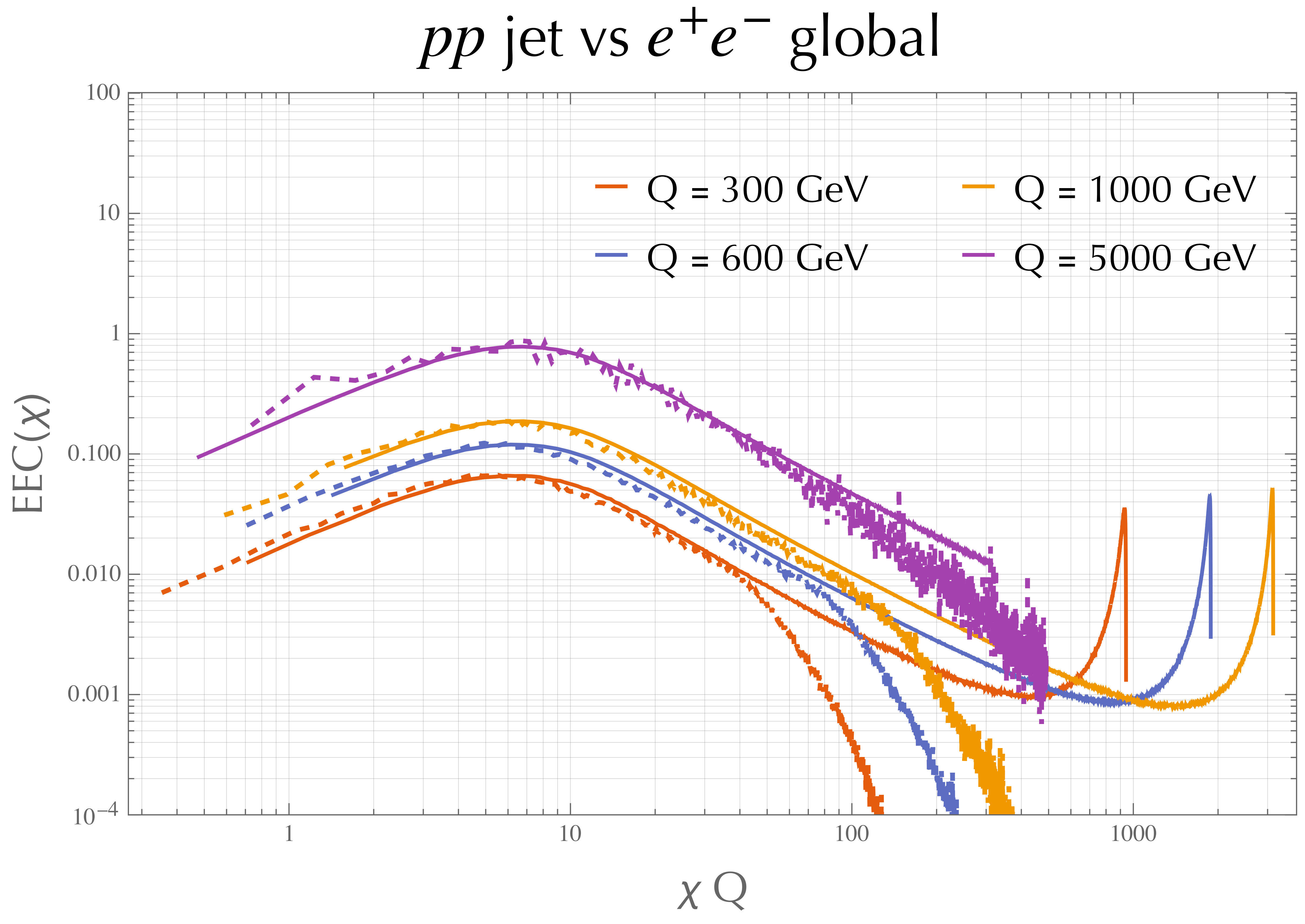

- Universal behavior in the near side region → probing the same NP physics

Non-Perturbative Aspects

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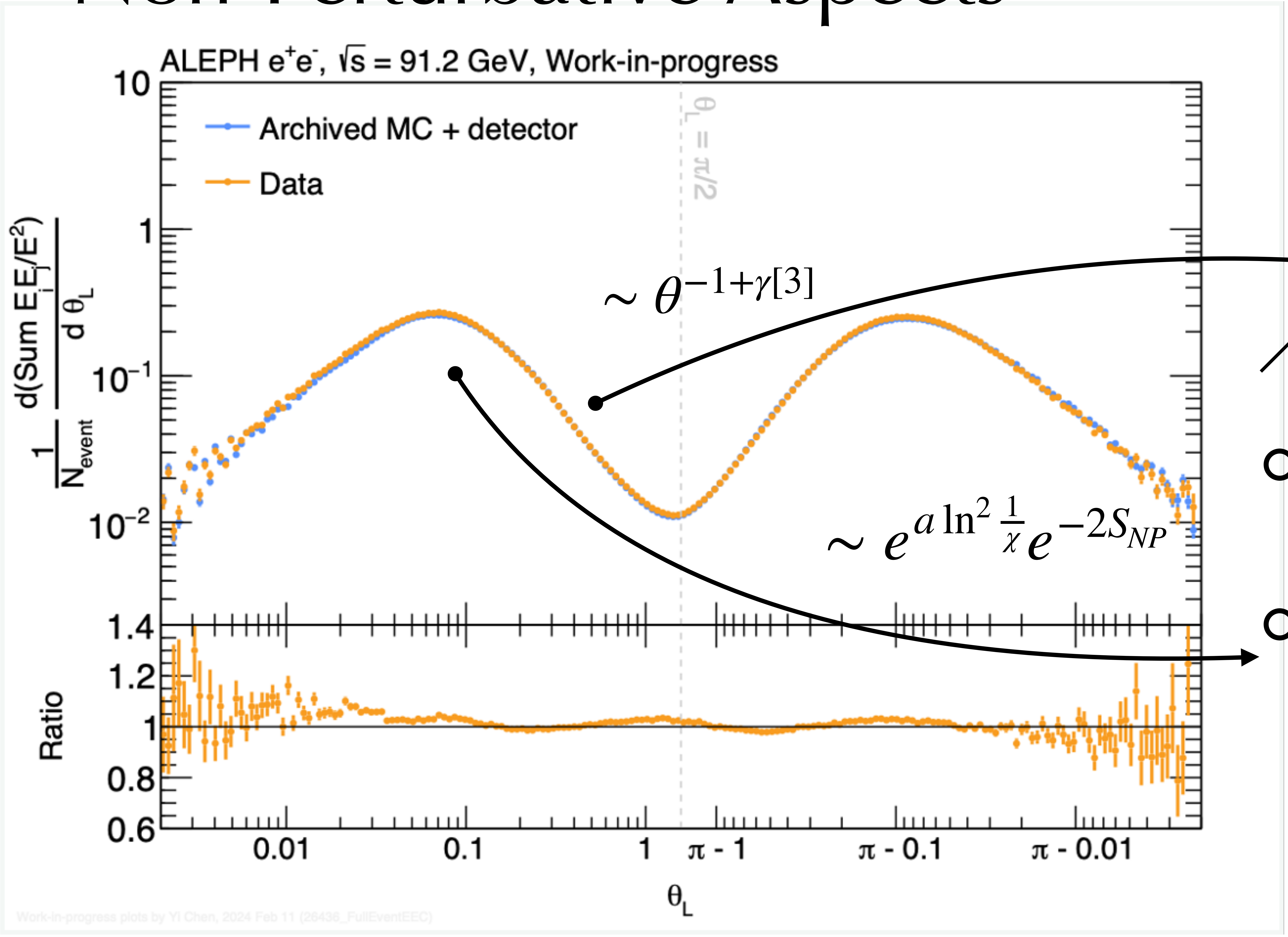
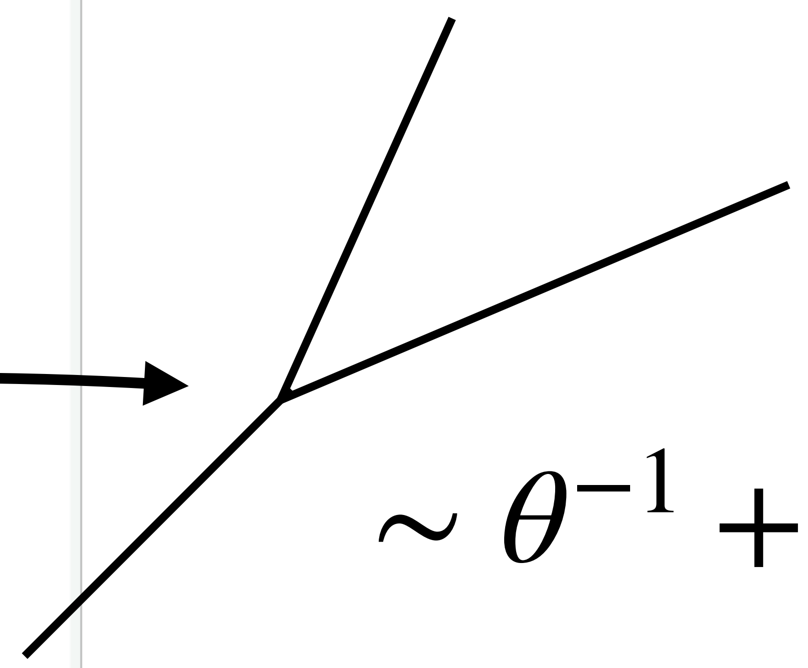
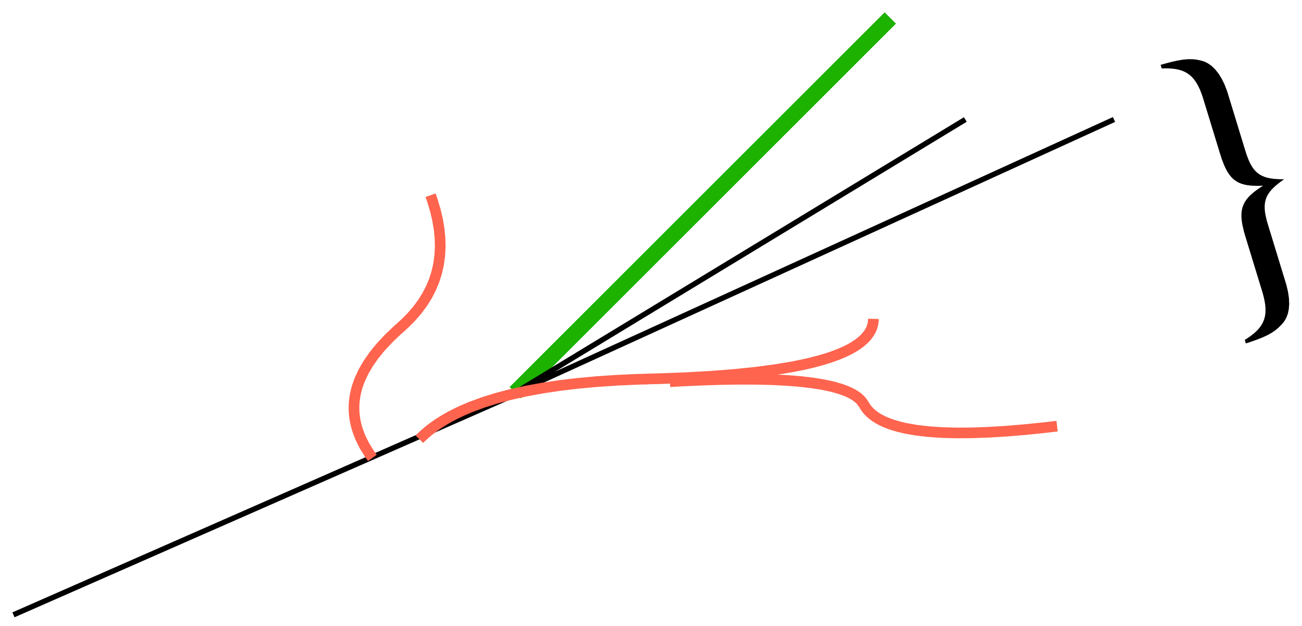




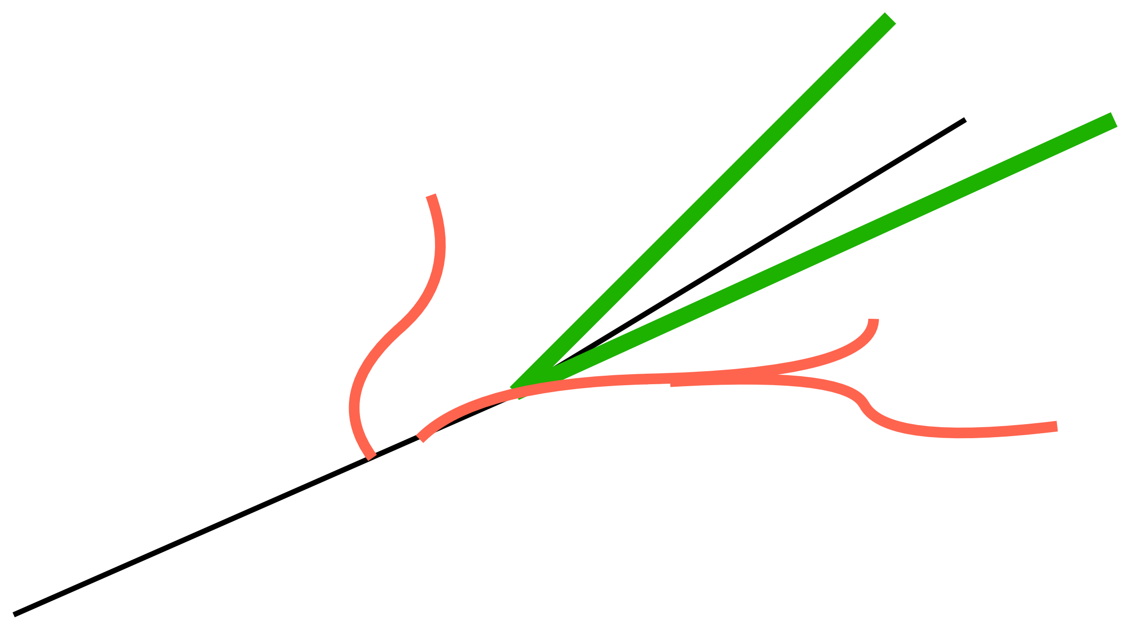
$\sim \theta^{-1}$ + all order splitting

- $\theta Q \gg \Lambda_{QCD}$, Intrinsic transverse momentum ignored
- $\theta Q \lesssim \Lambda_{QCD}$, Intrinsic transverse momentum becomes important

A TMD Model in the Small χ Regime



$$p_t = -\sum_X p_{X,t}$$



- TMD Fragmentation function is an (semi)-inclusive object
- EEC needs to now 2 hadrons, likely to be modeled by a di-hadron fragmentation, less known…

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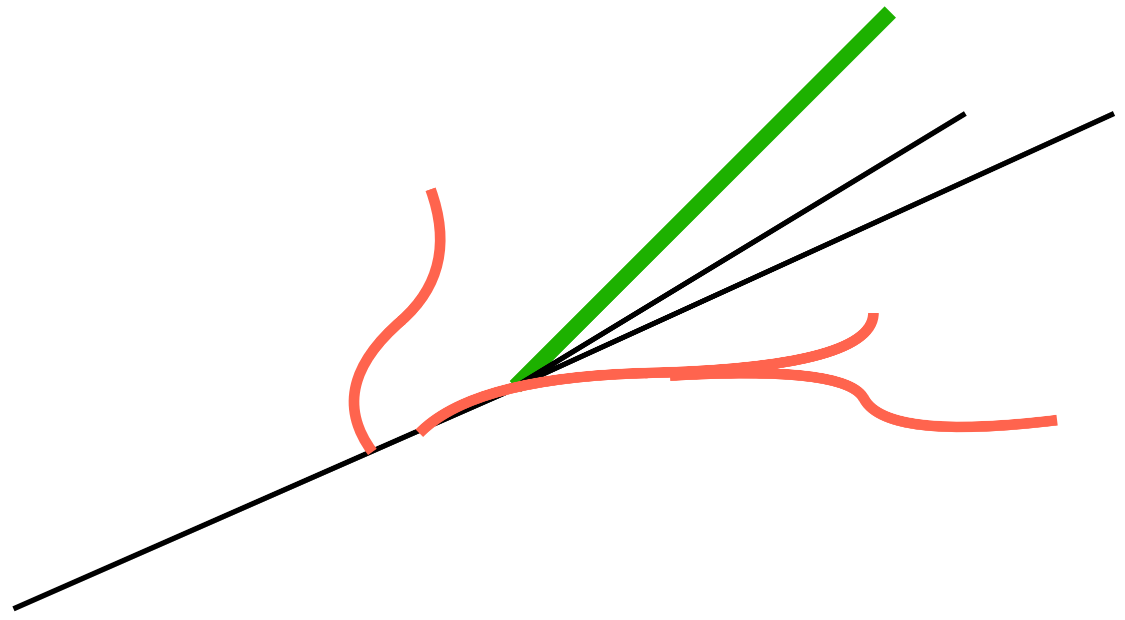

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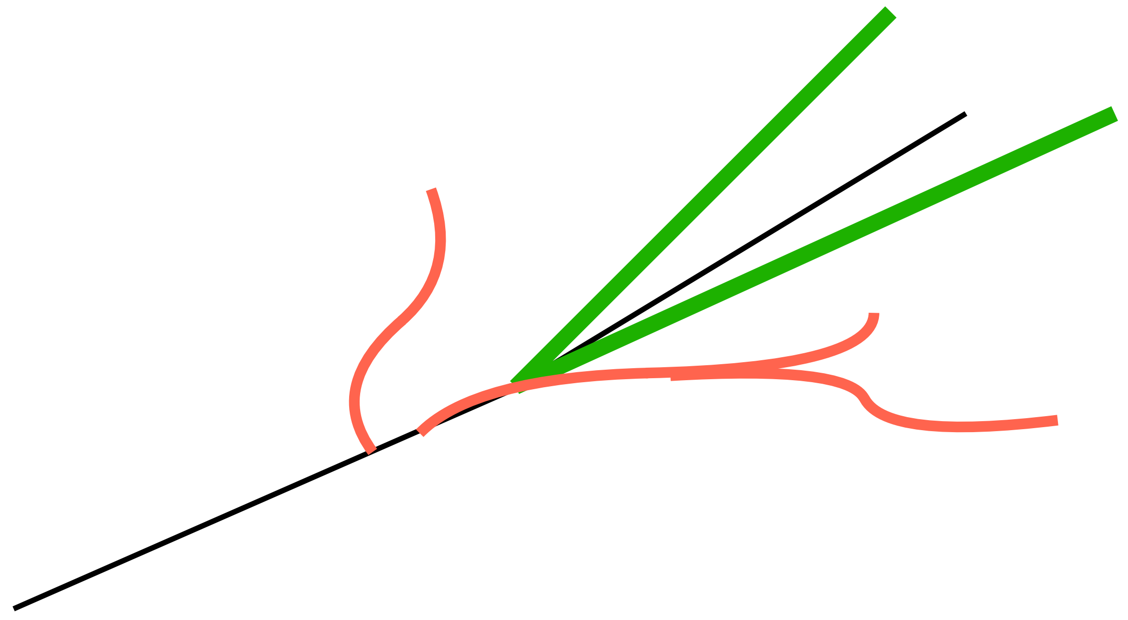

- TMD Fragmentation function is an (semi)-inclusive object, **encoding info. on the NP transverse dynamics** XL and Zhu, 2403.08874
- ~~EEC needs to now 2 hadrons, likely to be modeled by a di-hadron fragmentation, less known…~~

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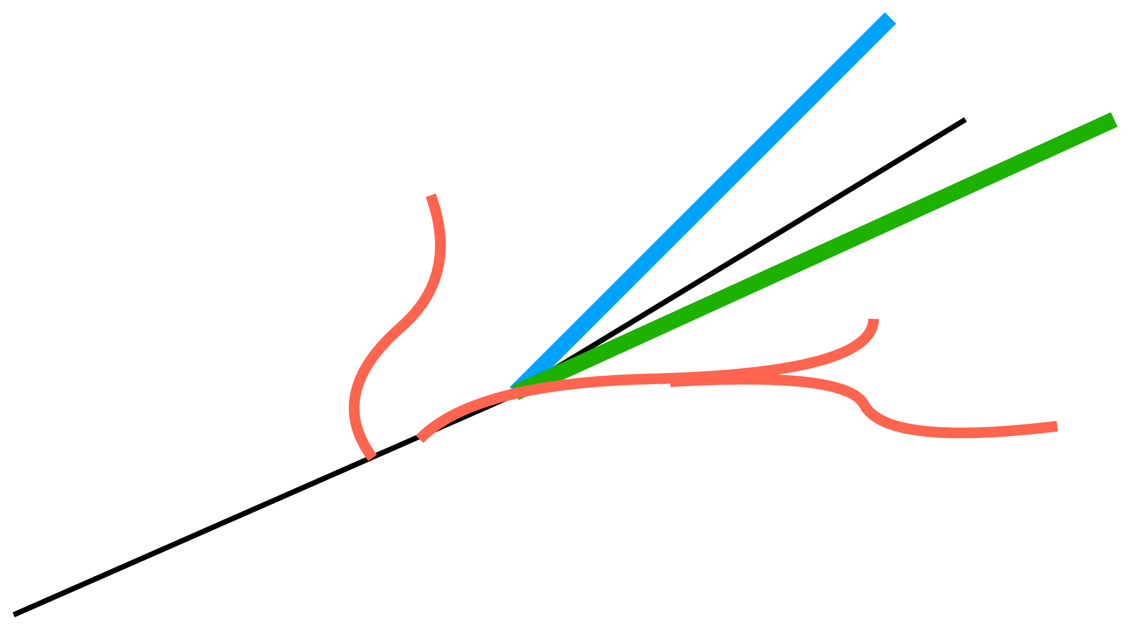
A TMD Model in the Small χ Regime

- Pick an arbitrary hadron h with momentum fraction z
- **Model all transverse kinematics w.r.t h, with some soft quanta**
- The transverse momentum of an arbitrary collinear line follows the transverse momentum distribution of the soft quanta
- Assuming the soft quanta are emitted identically and un-correlatedly



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A TMD Model in the Small χ Regime

a lonely boat drifting on a soft river

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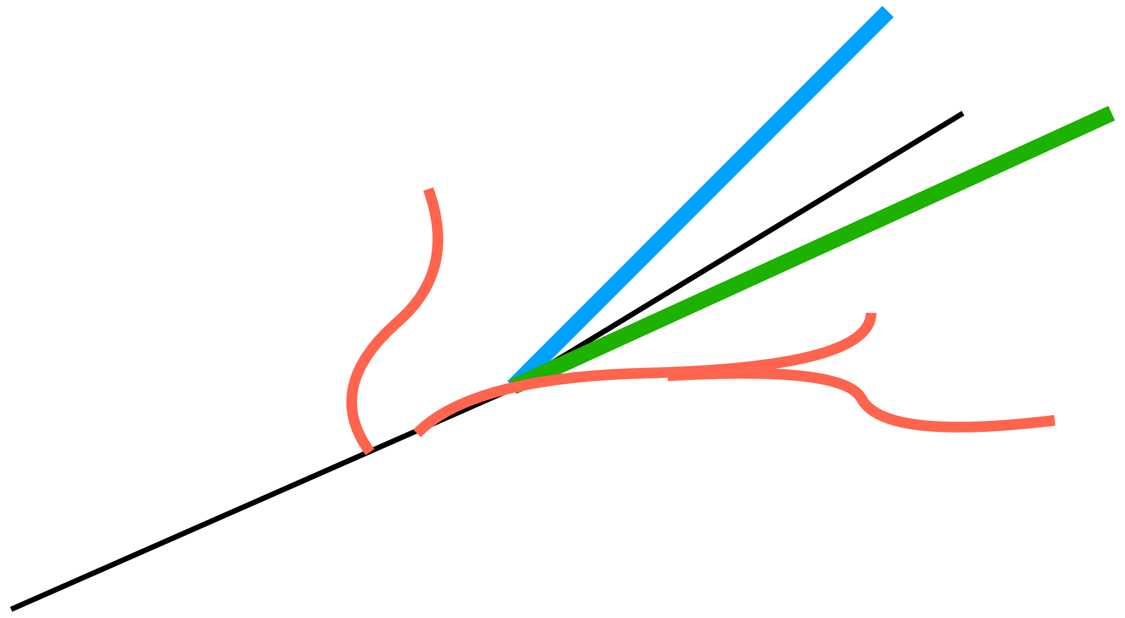

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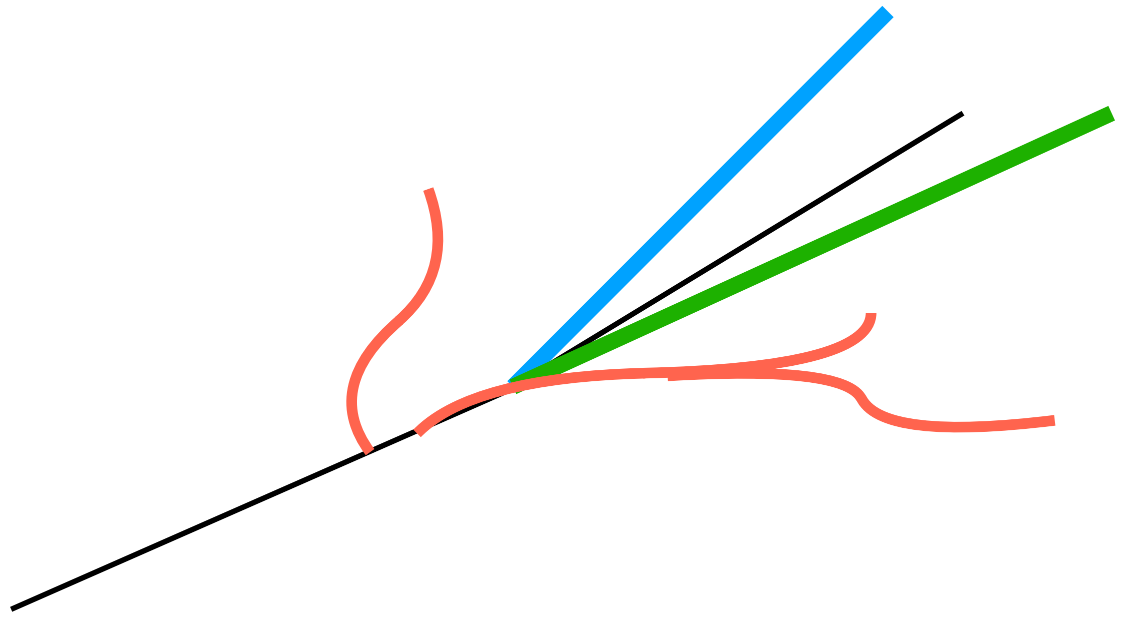

$$\frac{1}{\sigma}\frac{d^3\sigma}{dz d^2\mathbf{p}_t} = d_h(z)\int \frac{d^2\mathbf{b}}{(2\pi)^2} e^{-i\mathbf{b}\cdot\mathbf{p}_t}$$

$$\times \sum_{n=1}^{\infty} \frac{1}{n!}\left(\int [dk_i] M_{NP}(k_i)\left(e^{i\mathbf{k}_{i,t}\cdot\mathbf{b}} - 1\right)\right)^n$$

$$= d_h(z)\int \frac{db}{2\pi} b J_0(bp_t) e^{-S_{NP}(b,\mu)}$$

$p_t \approx c E_J \chi$ Purely NP no PT-Sudakov

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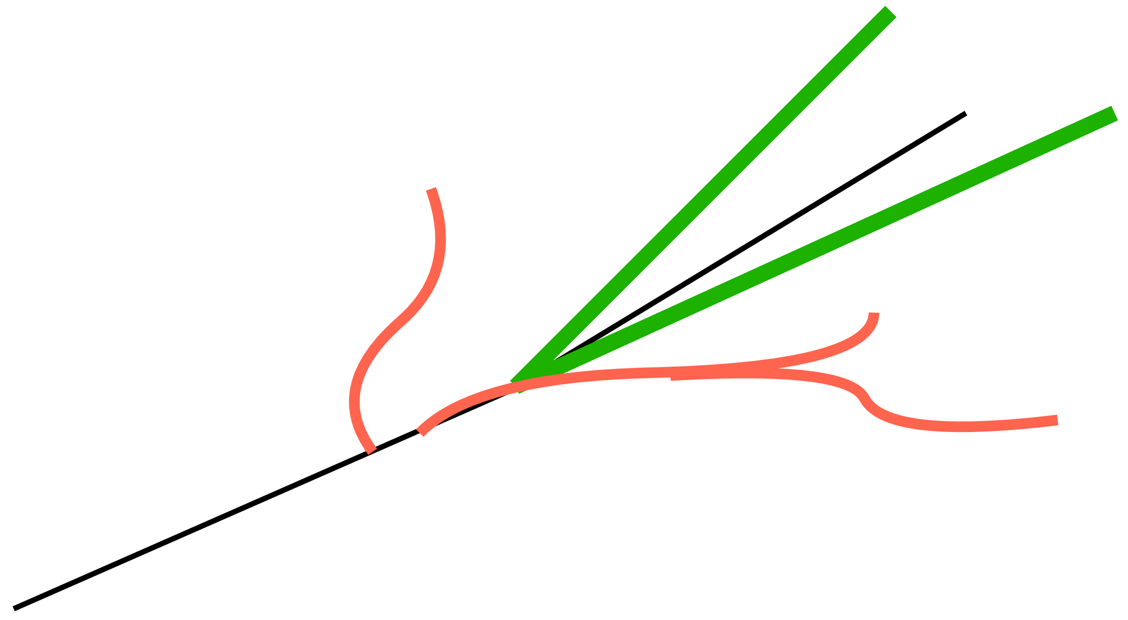
A TMD Model in the Small χ Regime

$$\mathrm{EEC}(\chi) = E_J^2 c^3 \chi \int dz z d_h(z) \int db\, b J_0(cE_J\chi b) e^{-S_{NP}(b,\mu)}$$

$$= E_J^2 c^3 N \chi \int db\, b J_0(cE_J\chi b) e^{-\frac{g_1}{c^2}b^2} e^{-\frac{g_2}{2}\ln\frac{b}{b_*}\ln\frac{RE_J}{\mu_0}}$$



with $S_{NP} = \frac{g_1}{z^2}b^2 + \frac{g_2}{2}\ln\left(\frac{b}{b_*}\right)\ln\frac{\mu}{\mu_0}$, $\quad Ne^{-\frac{g_1}{c^2}b^2} \approx \int dz \sum_h z d_h(z) e^{-\frac{g_1}{z^2}b^2}$

$c, N, g_1, g_2, \mu_0, b_*$, **6 parameters!!**

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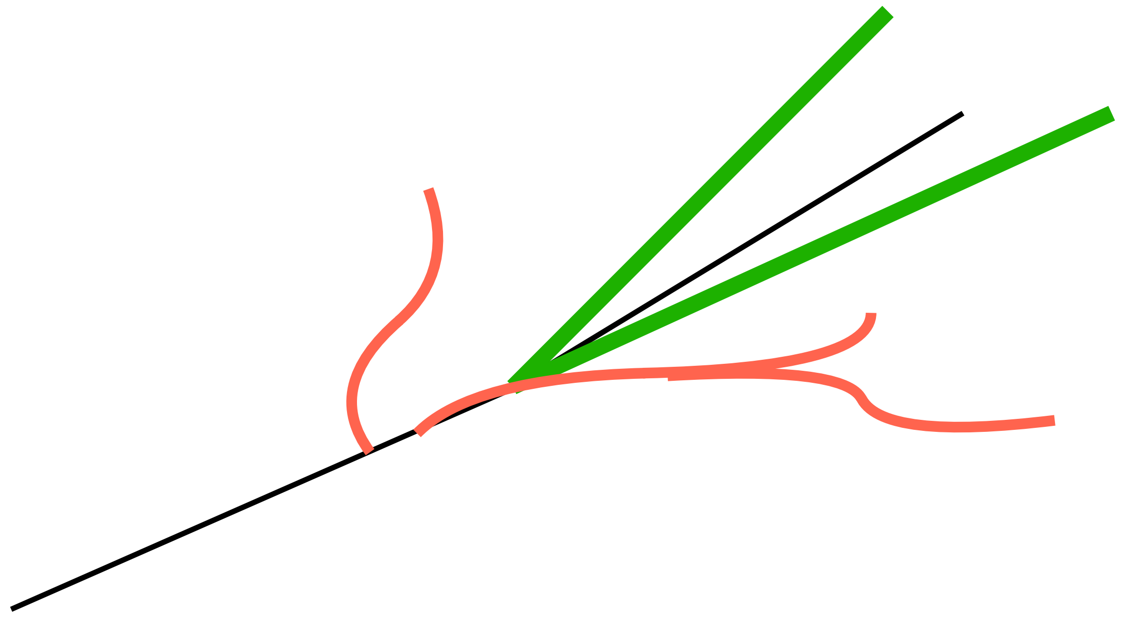

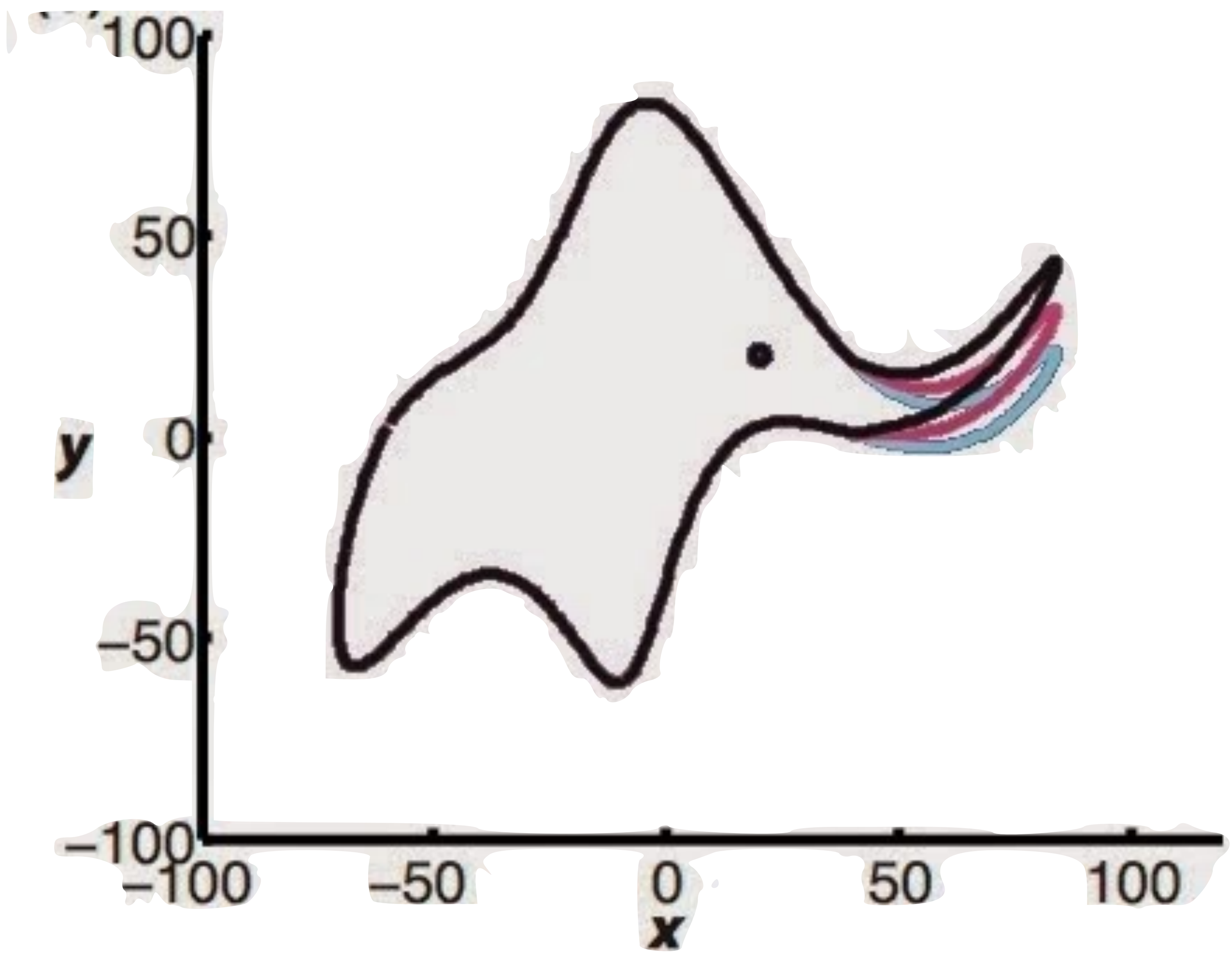

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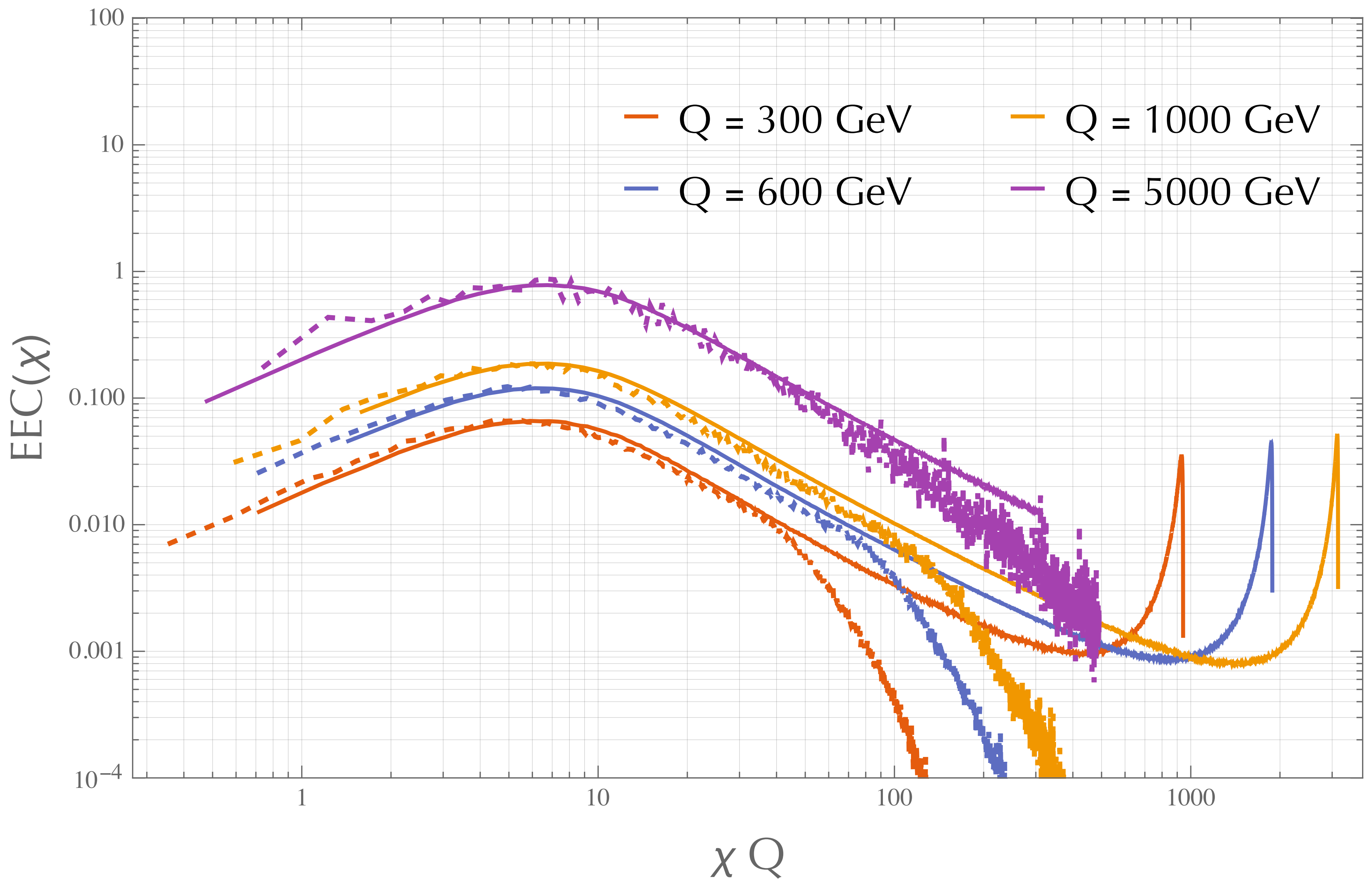

$c, N, g_1, g_2, \mu_0, b_*,$ 6 parameters!! Too many!!

4 parameters have already been determined, by SIDIS. Sun, Isaacson, Yuan, and Yuan, 2018

Only 2 free parameters left, overall normalization and position, can be soley determined by picking just one energy input

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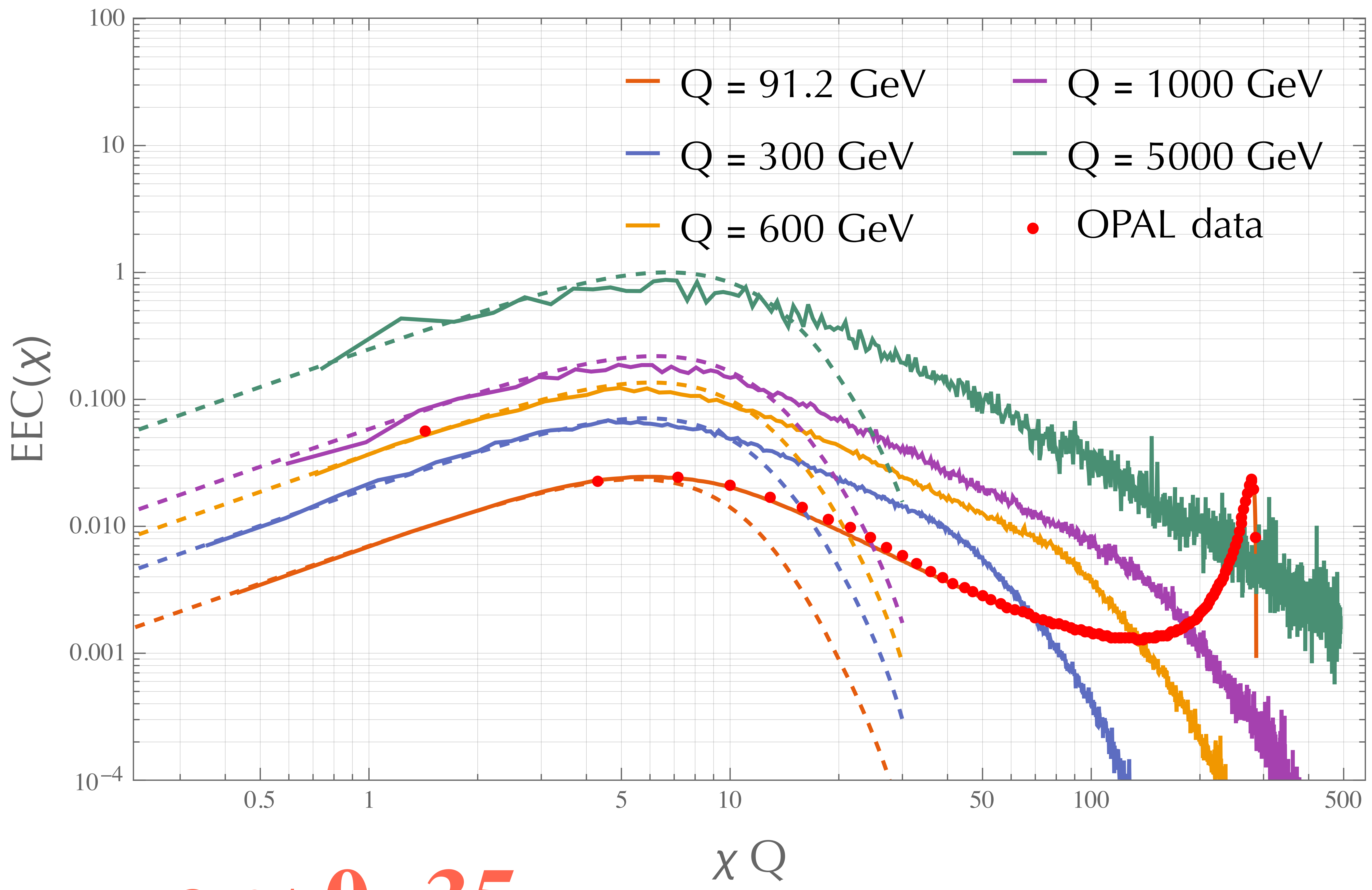
A TMD Model in the Small χ Regime

EEC from **quark** Jet



c ≈ 0.35

- determine c, N using $Q = 300\,\text{GeV}$ curve, others are obtained by varying $E_J = Q/2$
- Correct Q scaling, Good agreement between model and Pythia/data in the transition region, turning point driven by NP physics
- Larger χ region requires matching with pQCD calculations

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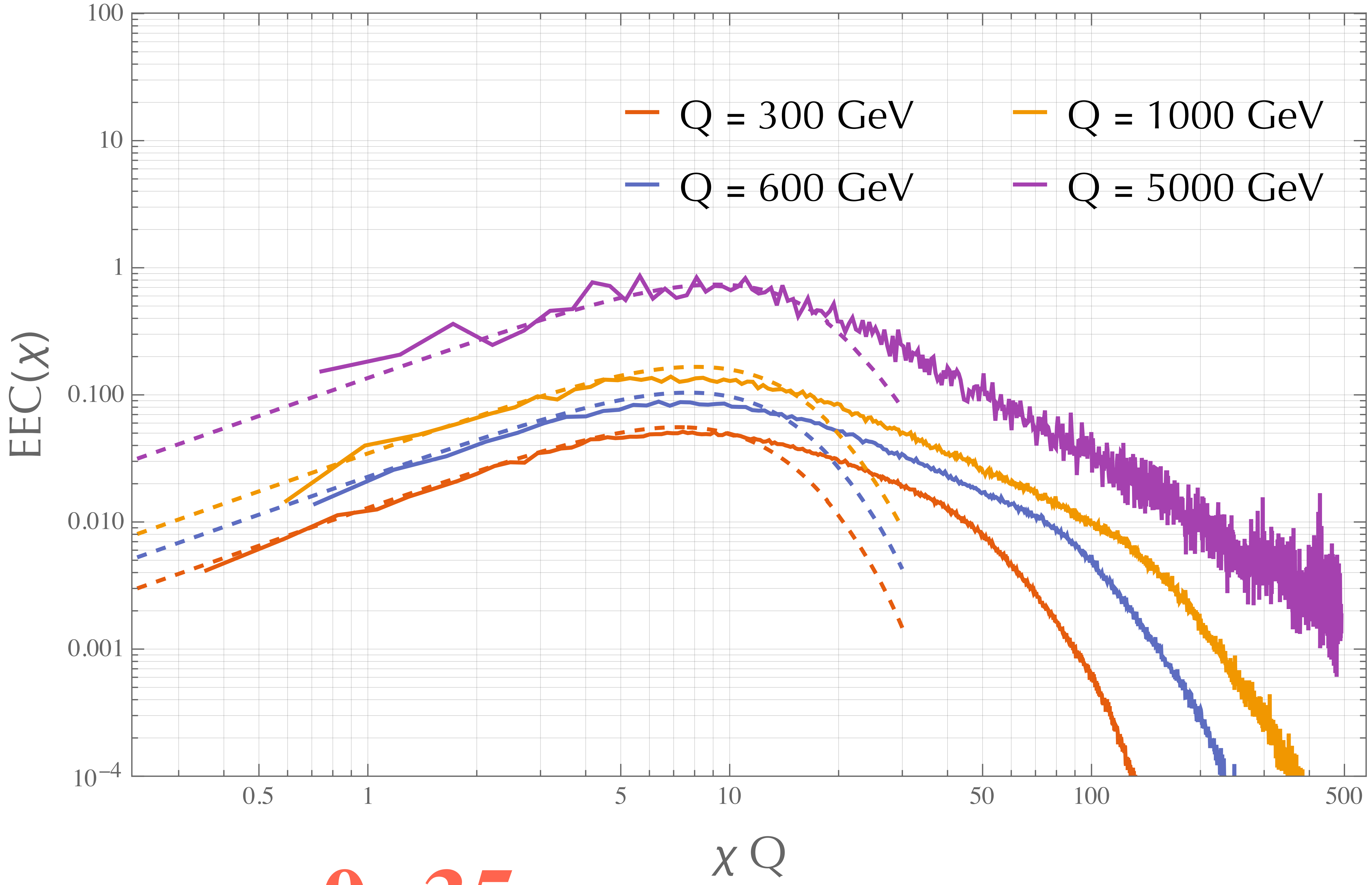
A TMD Model in the Small χ Regime

EEC from **gluon** Jet



c ≈ 0.35

- Everything is fixed, simply replace $\frac{g_2}{2}\ln\frac{b}{b_*}\ln\frac{RE_J}{\mu_0} \rightarrow g_2\frac{C_A}{C_F}\ln\frac{b}{b_*}\ln\frac{RE_J}{\mu_0}$
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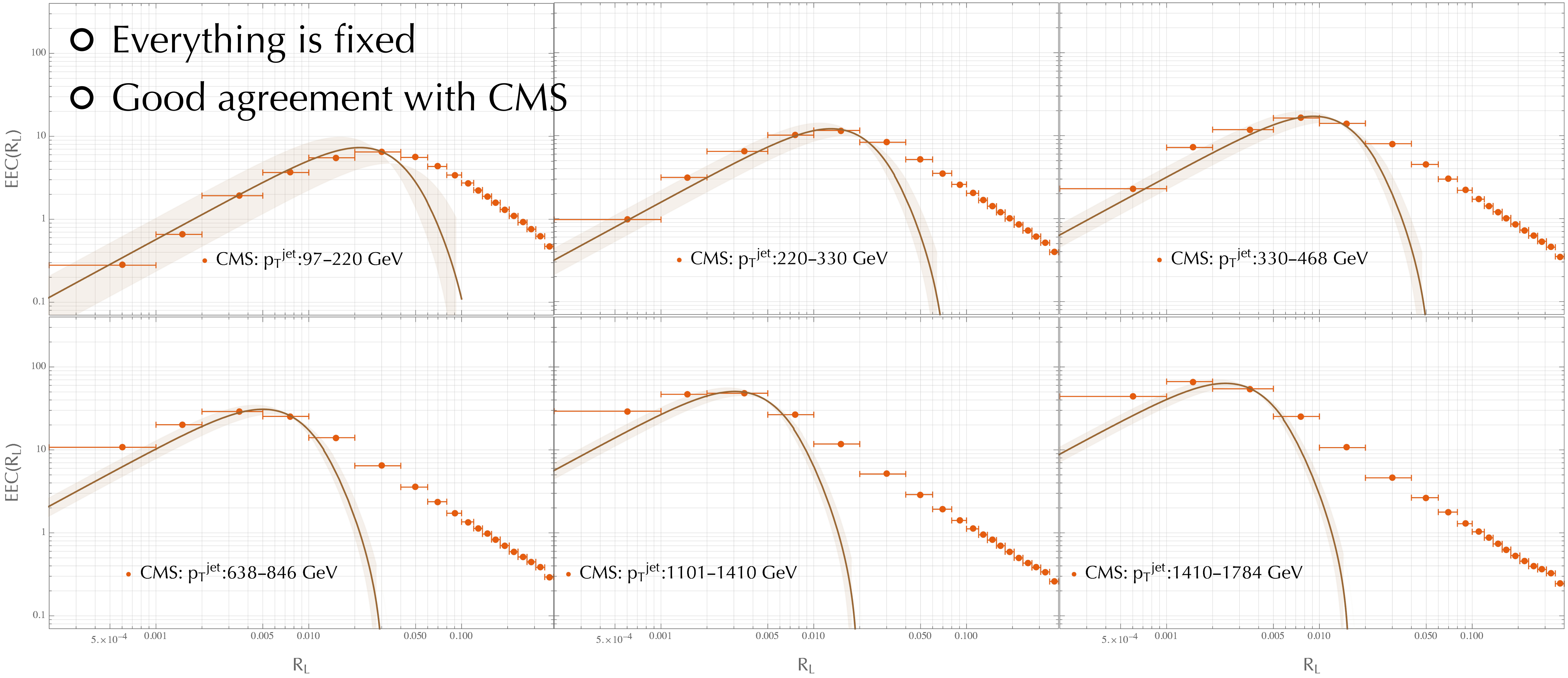
A TMD Model in the Small χ Regime

- Everything is fixed
- Good agreement with CMS



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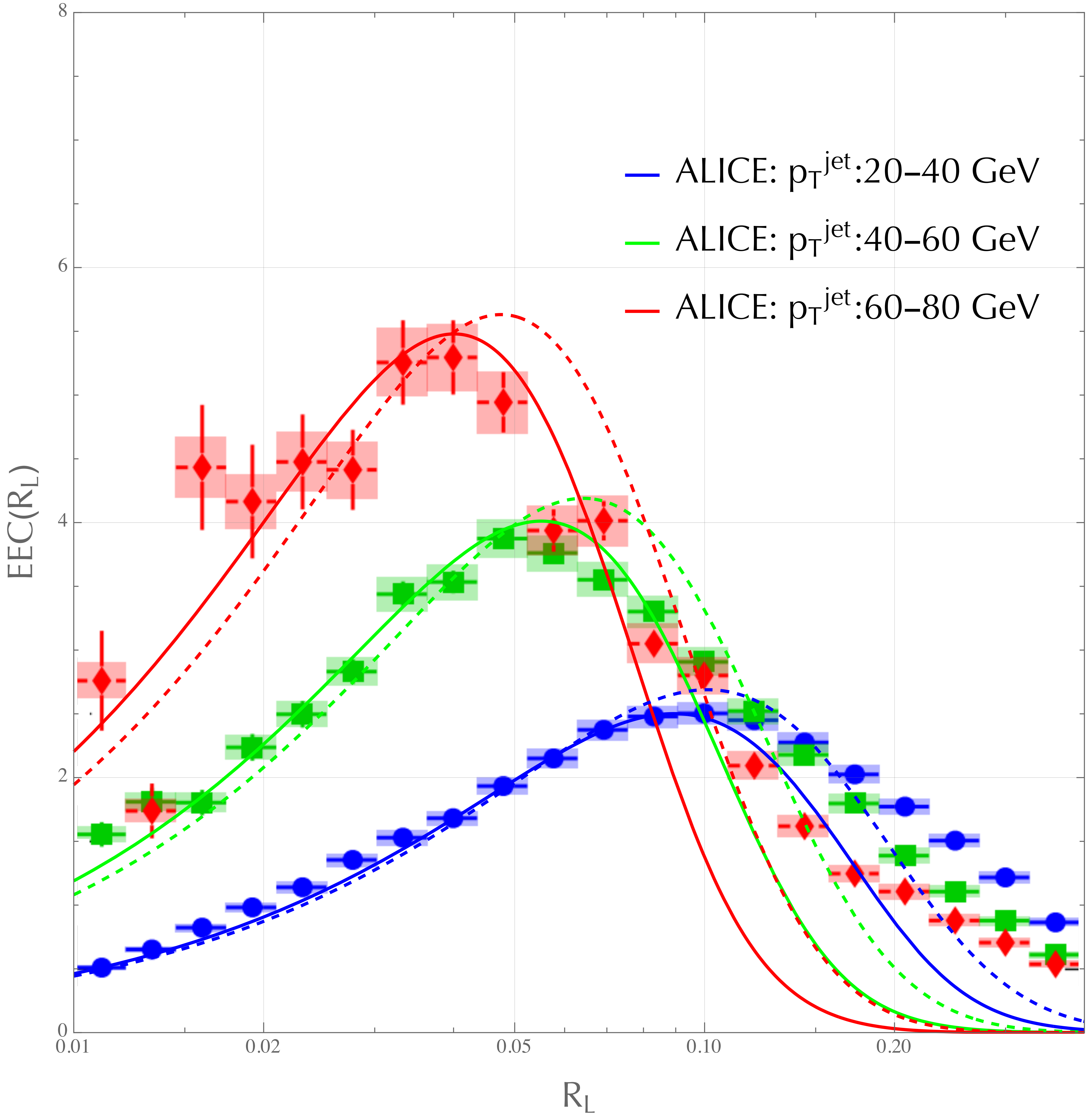
A TMD Model in the Small χ Regime

- ALICE used different normalization.
- Re-determine N, but fix other para.
- Gluon and quark jet fraction unknown in their measurements
- Correct Q scaling, good agreement with ALICE



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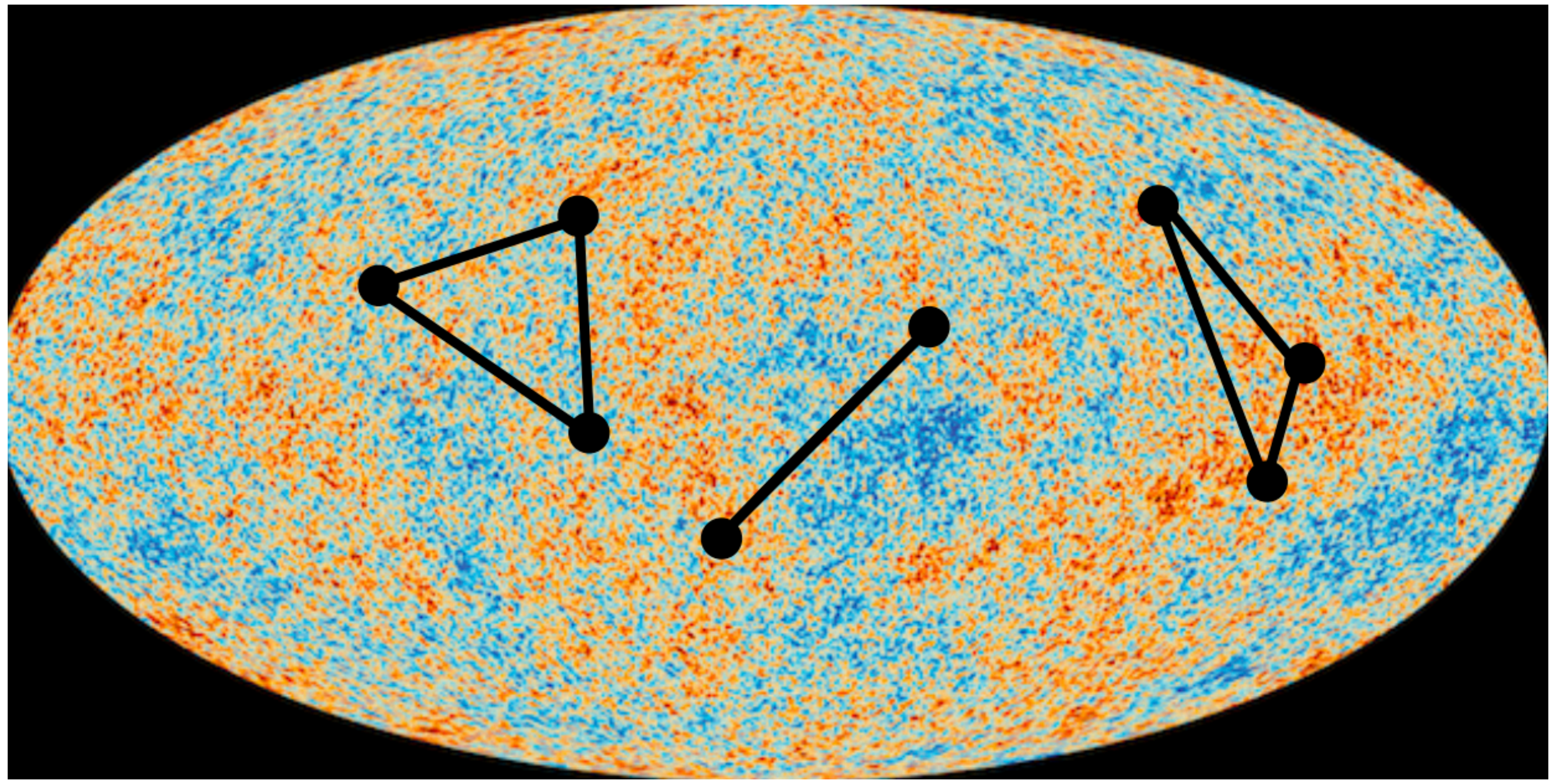
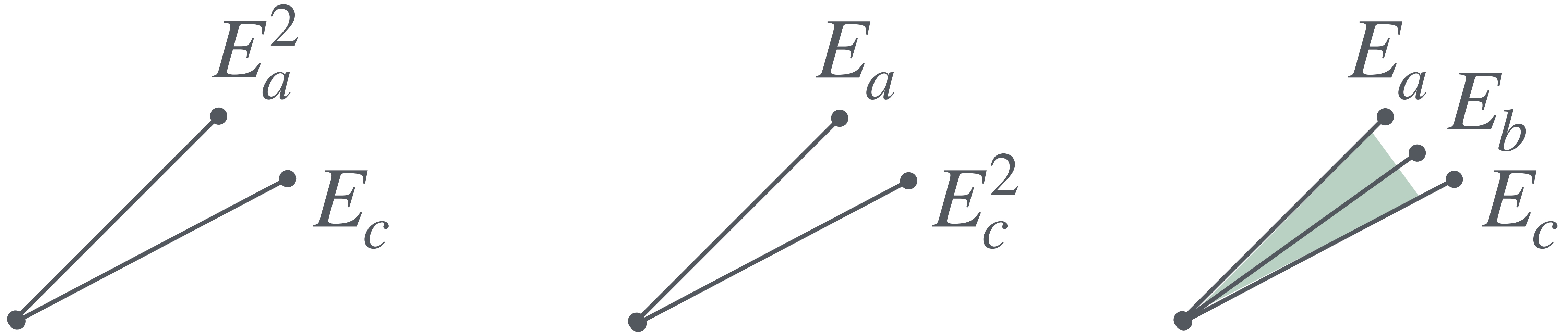
A TMD Model in the Small χ Regime

- Go beyond EEC



$$\text{E3C}(\chi) = \frac{1}{\sigma}\int \frac{E_a E_b E_c}{Q^3} d\sigma \delta(\chi - \max(\theta_{ab}, \theta_{ac}, \theta_{bc}))$$



Model prediction:

$\propto c\text{EEC}(\chi)$ $\propto c\text{EEC}(\chi)$ $\propto \chi^2$

$\mathbf{E3C}(\chi)/\mathbf{EEC}(\chi)\,|_{\chi\to 0} \to 2c \approx 0.7$

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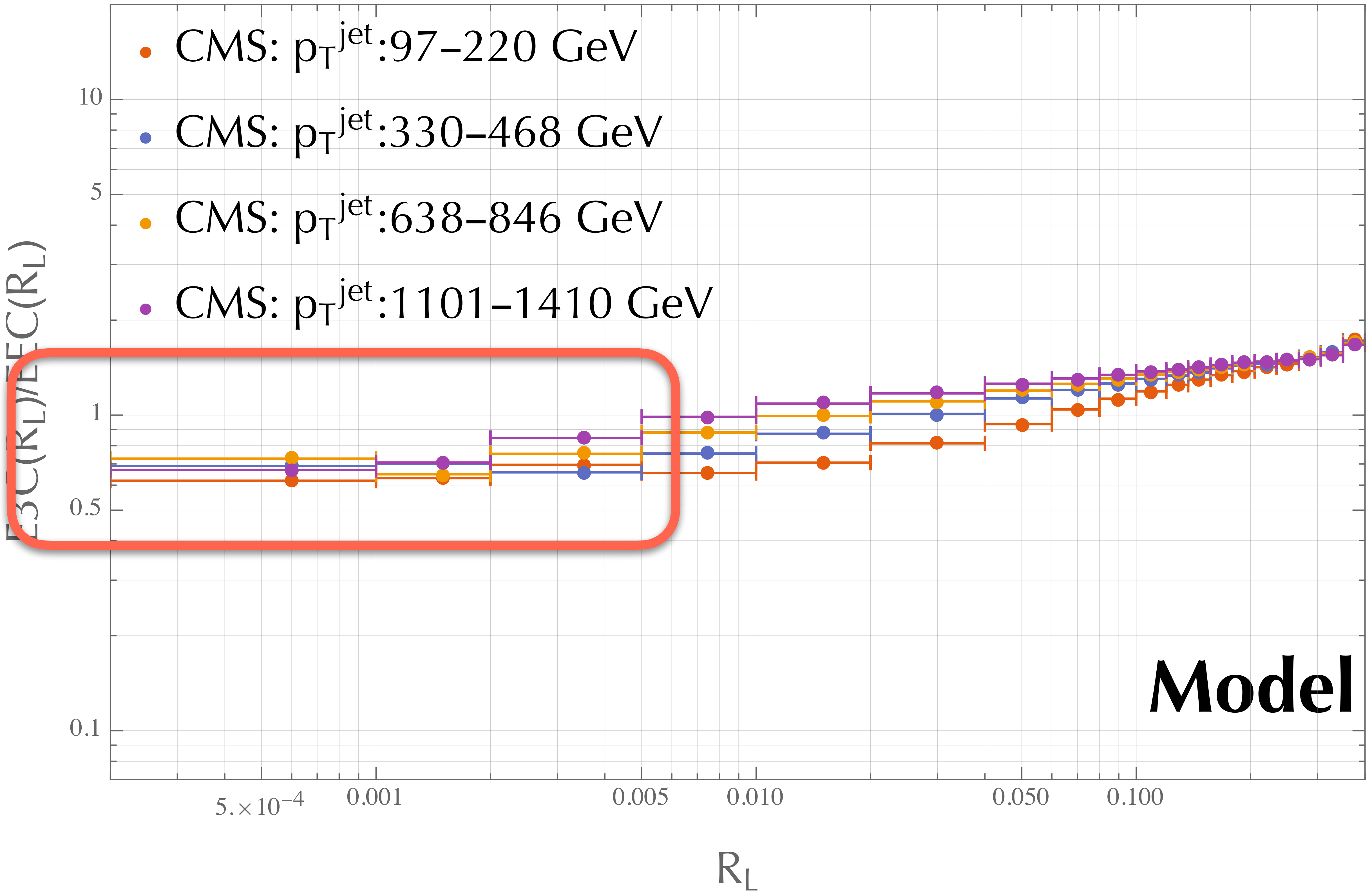

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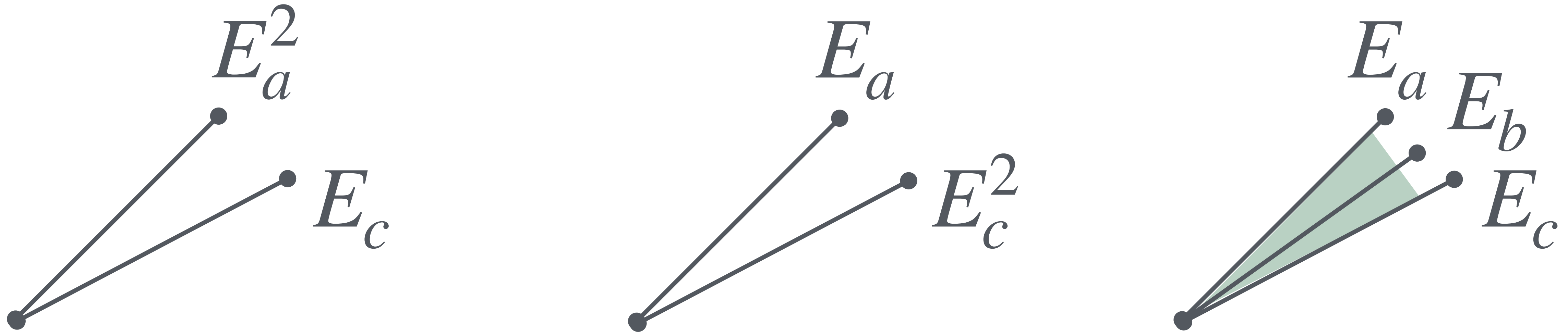

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- **c determined from an entirely unrelated observable !**

$\mathrm{E3C}(\chi)/\mathrm{EEC}(\chi)|_{\chi\to 0} \to 2c \approx 0.7$

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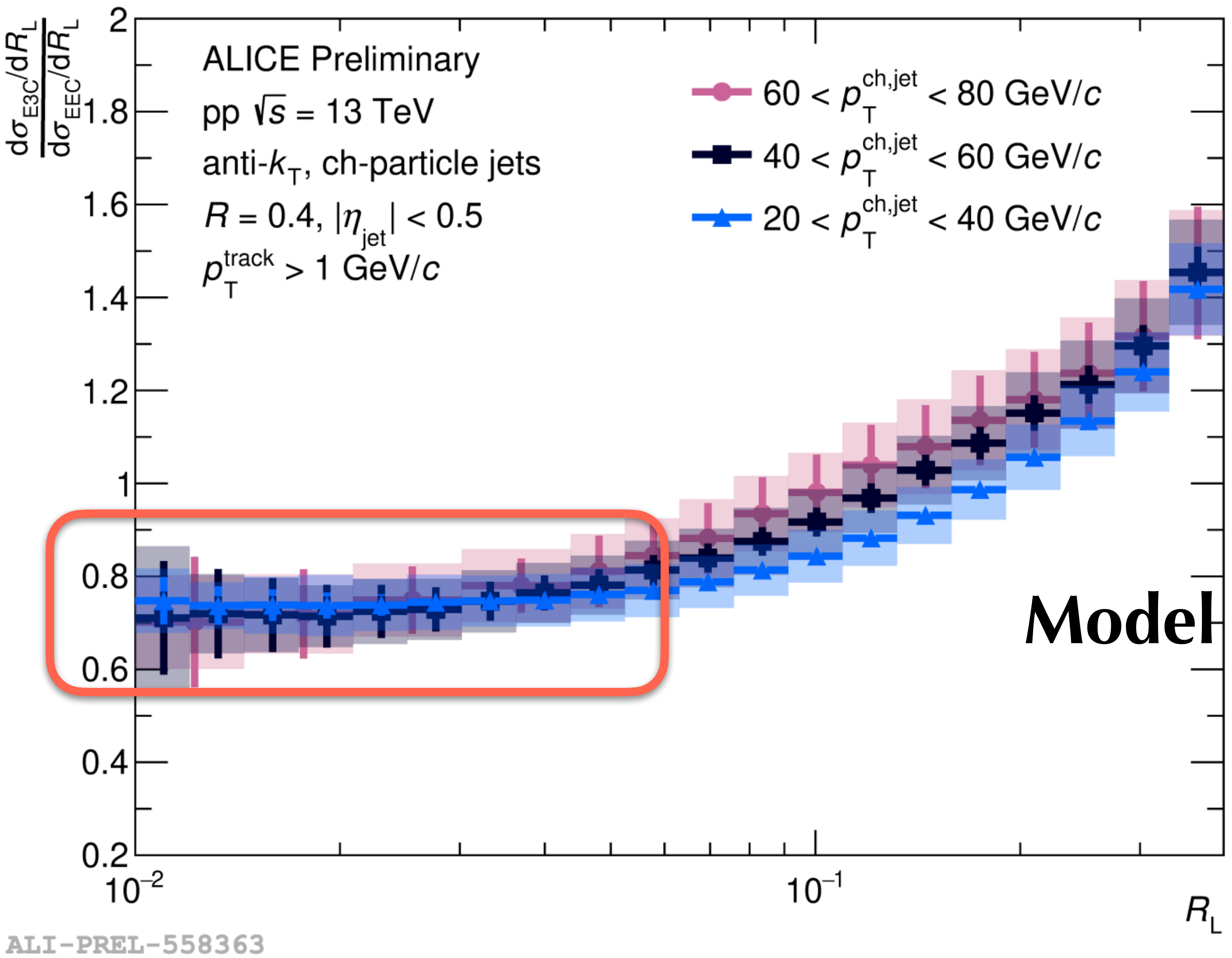

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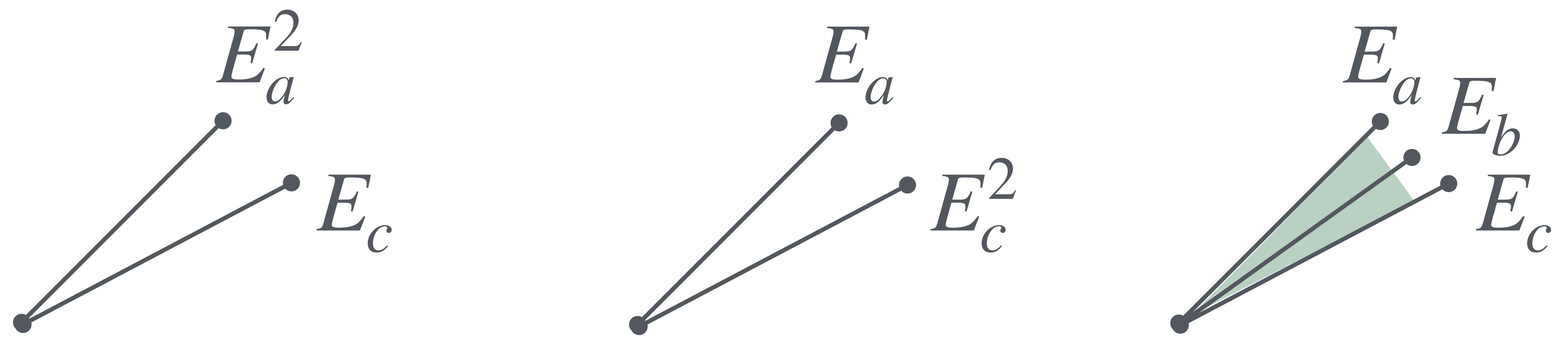

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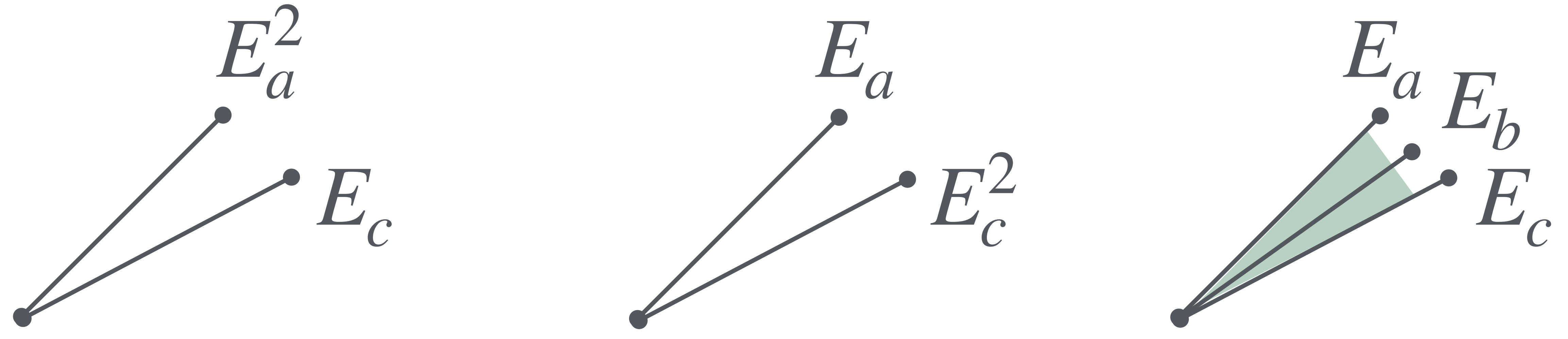
Model prediction:

$$\text{E3C}(\chi)/\text{EEC}(\chi)\,|_{\chi\to 0}$$

$$\to 2c$$

$$+c^3 E_J^2 \int d\Omega db b \Theta(\theta_{ab}, \theta_{ac} < \chi) J_0(cE_J \theta b) e^{-2S_{NP}}$$



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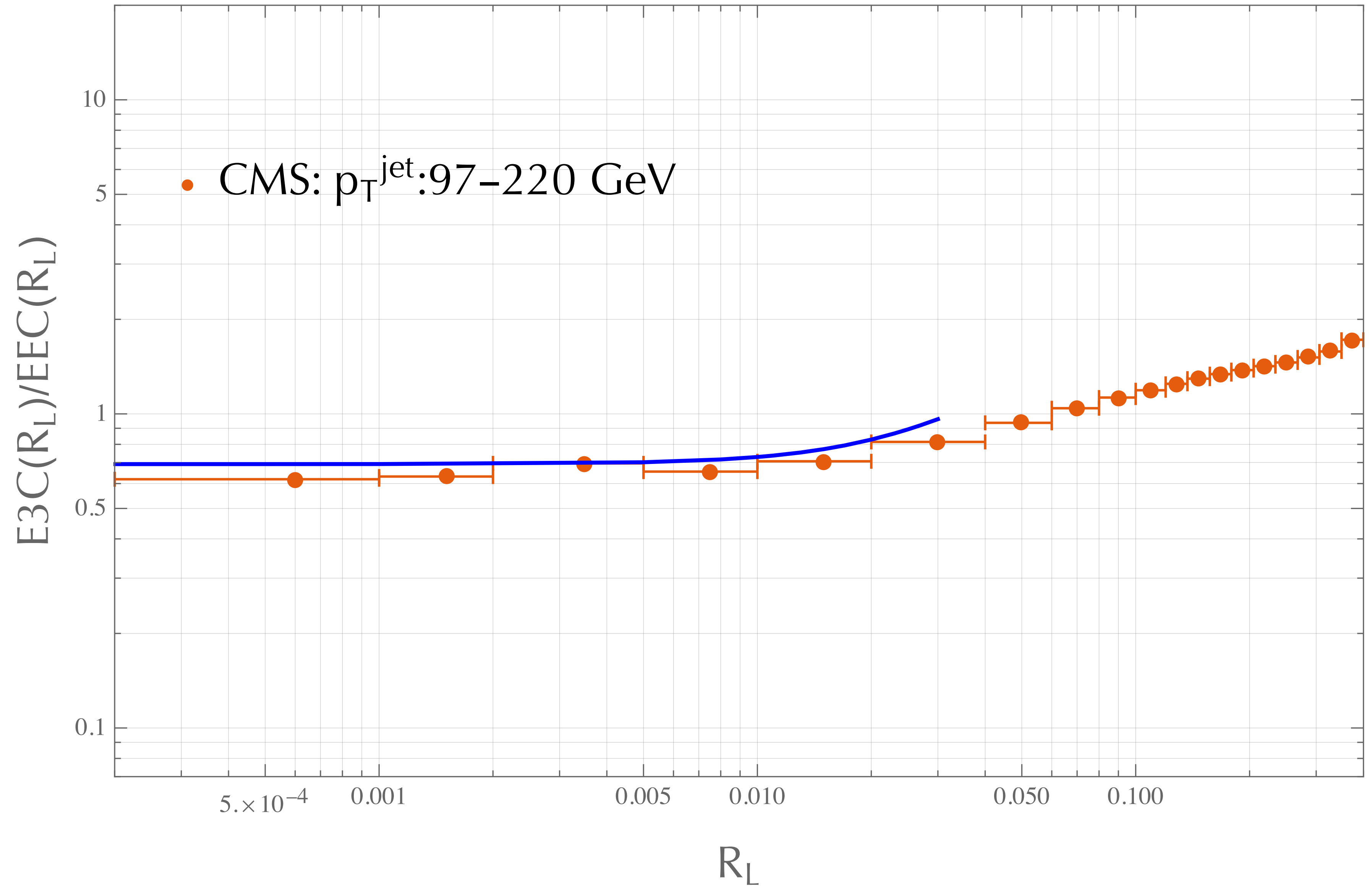
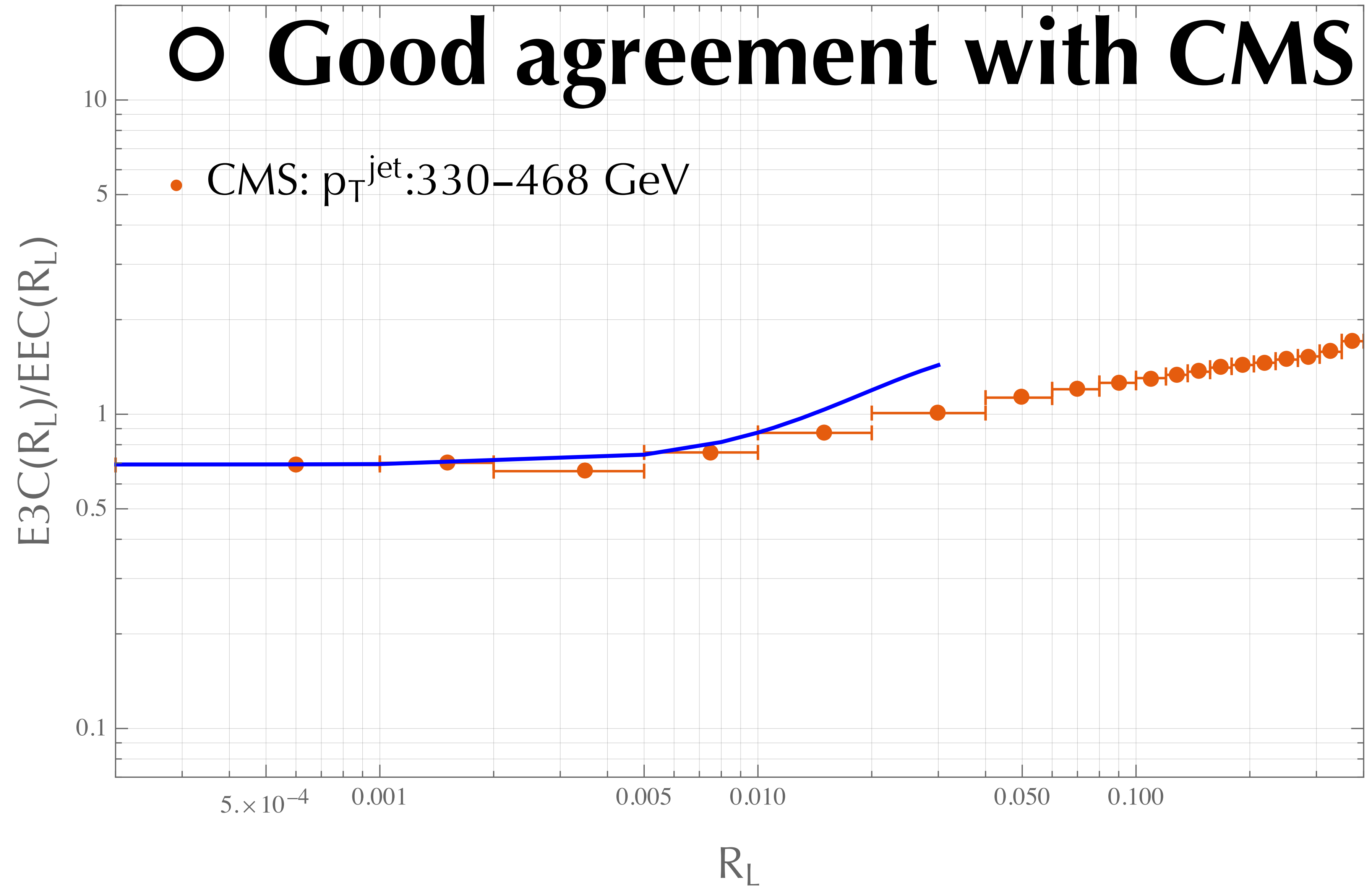
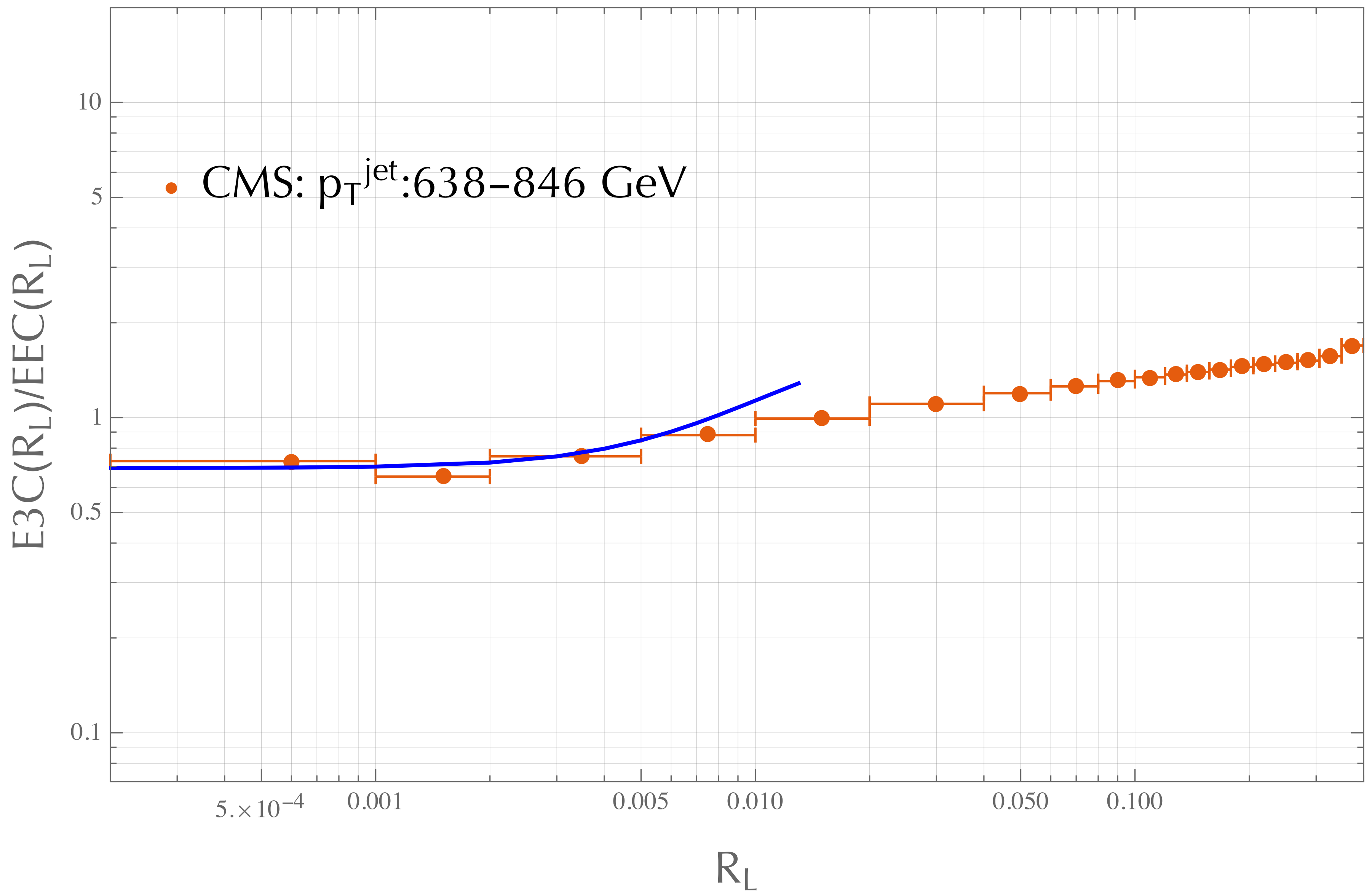
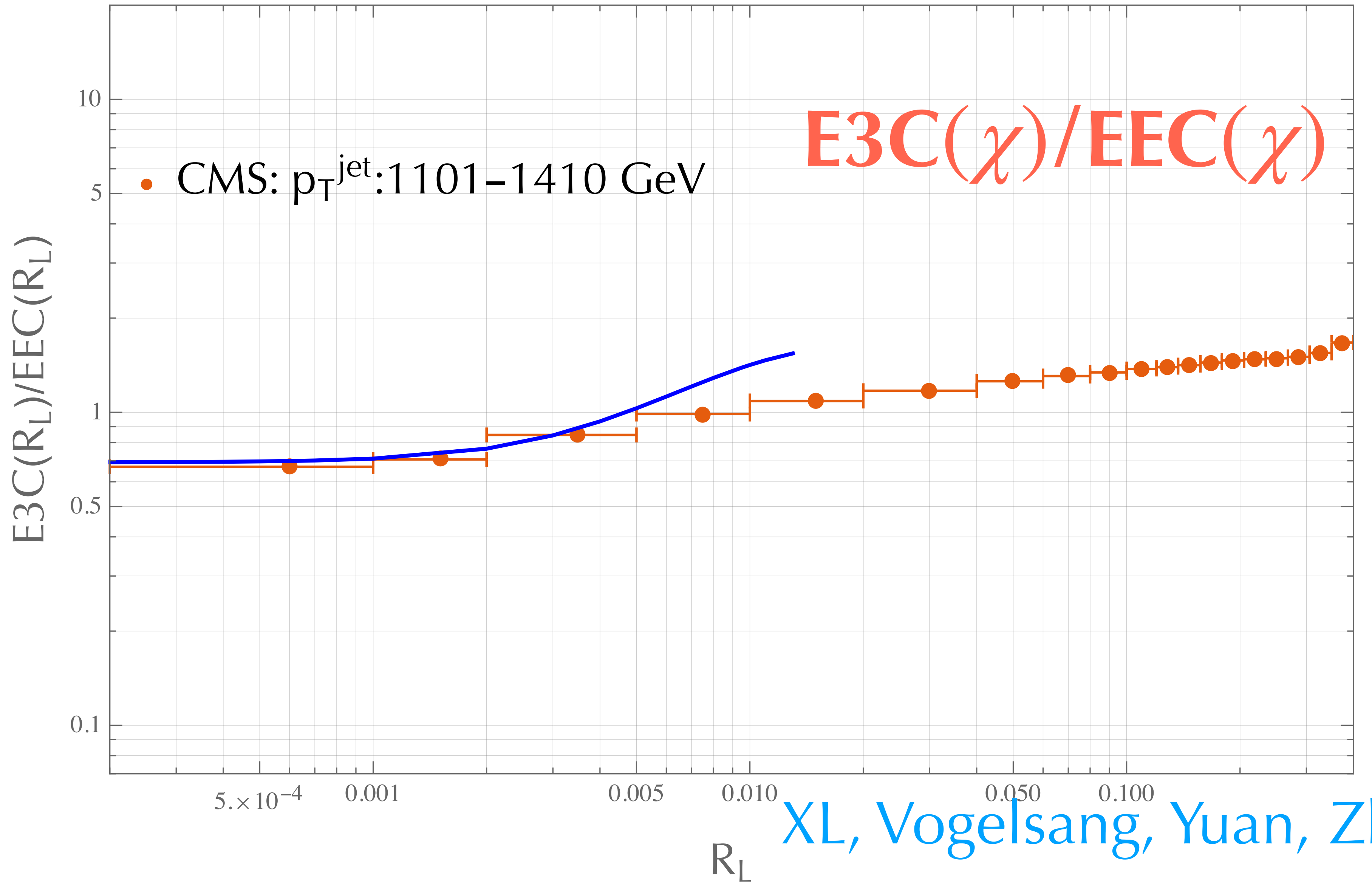


- **Good agreement with CMS**





E3C(χ)/EEC(χ)



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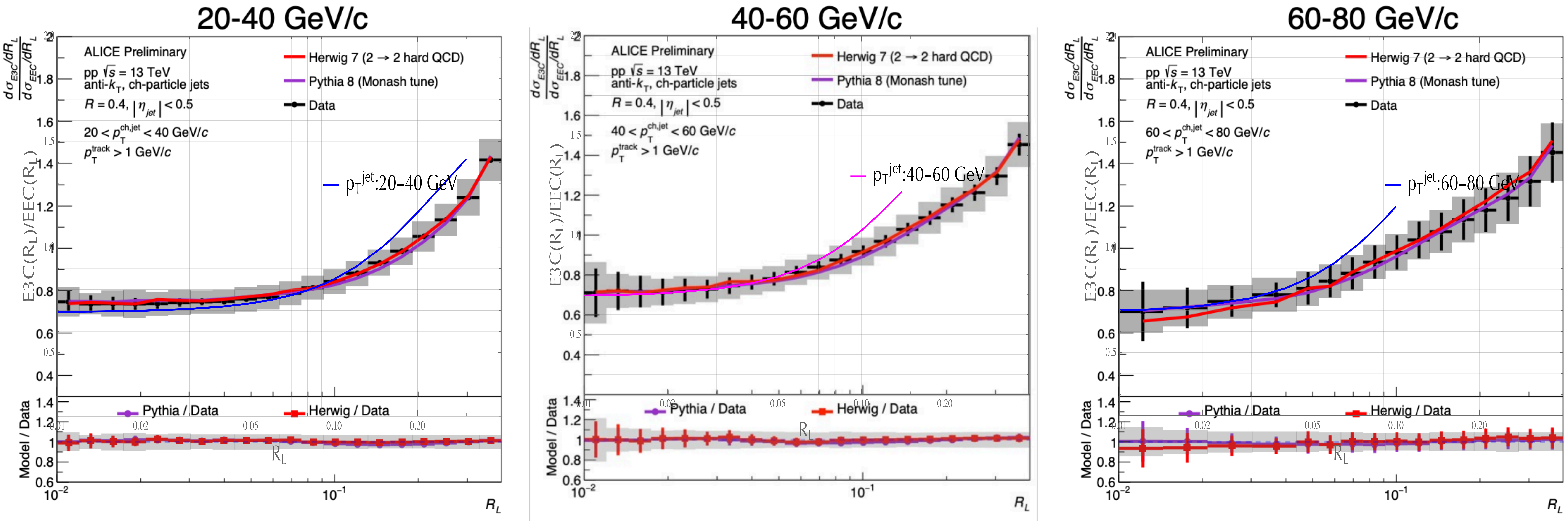

E3C(χ)/EEC(χ)

- Good agreement with ALICE

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A TMD Model in the Small χ Regime

E3C(χ)

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Conclusions

- Suggest a connection between the NP physics in the near side Energy Correlator and NP TMD
- Agree with Pythia/LHC data across several orders of magnitude in the input energy
- Deeper understanding?
- Should be applicable to NEEC, di-hadron fragmentation
- This in turn may indicate the possibility of understanding TMD physics using formal field theoretical tools
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Thanks