New toy model simulation for elucidating the parton energy loss mechanism depending on path-length within the quark-gluon plasma medium

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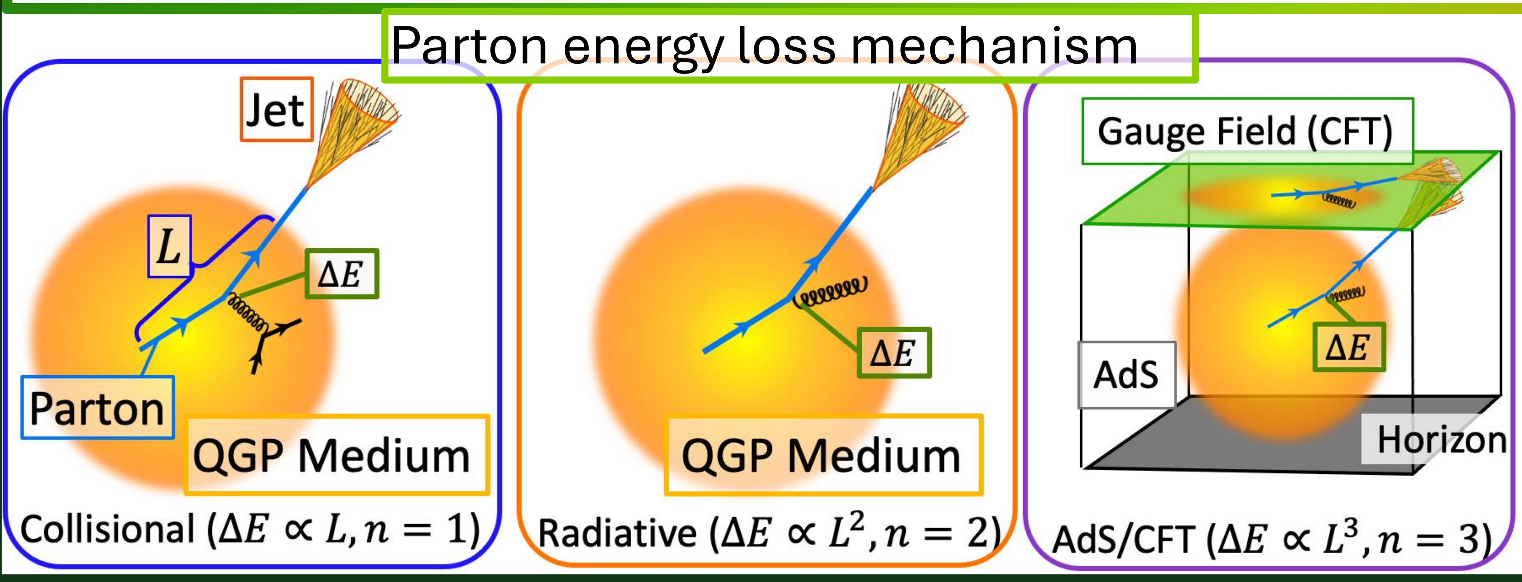
1. Purpose

Clarifying the mechanism of parton energy loss in the Quark-Gluon Plasma (QGP)

Parton energy loss mechanism



Parton energy loss

$$\Delta E = \hat{e}_n L^n$$

$\hat{e}_n$: Energy loss per unit path length [GeV/fm^n]

L: Path length in a QGP medium

2. Background

The QGP cannot be observed directly due to its tiny size and short lifetime.

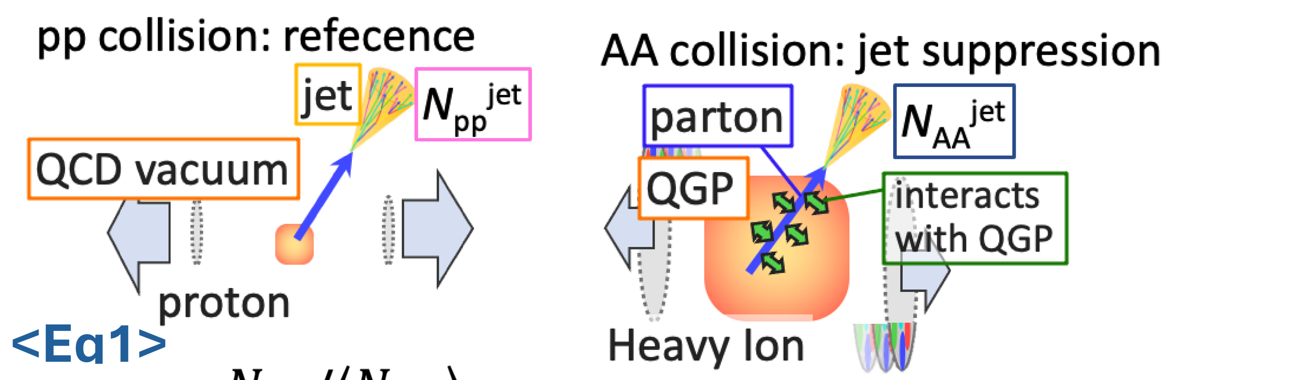
→ Observe high-momentum **parton** passing through in a QGP medium

→ Information on an energy that a parton losed by interaction with the QGP medium allows to study **properties of the QGP** and **interaction between the QGP and a parton.**

Parton is reconstructed as a collimated hadrons flux (**Jet**)

→ Parton energy loss is observed as jet yield suppression

- Measurements: **Nuclear modification factor (R_{AA}^{jet})**, **Azimuthal anisotropy (v_2^{jet})**

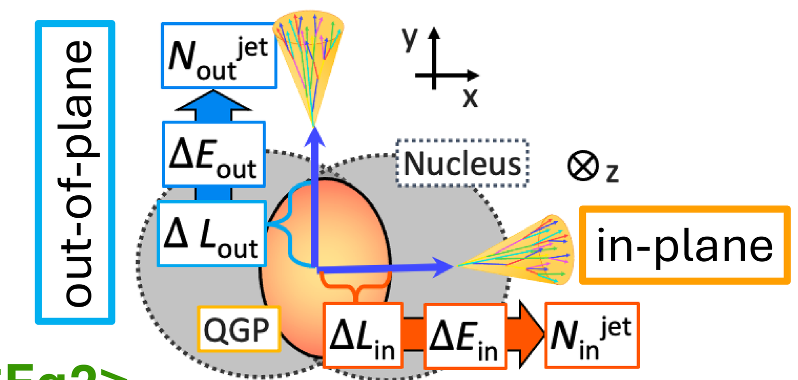


<Eq1>

$$R_{AA}^{jet} = \frac{N_{AA}/\langle N_{coll}\rangle}{N_{pp}}$$

N_{pp}, N_{AA}: Jet yield (pp, AA collision)

$\langle N_{coll}\rangle$: binary scaling



<Eq2>

$$v_2^{jet} \propto N_{in} - N_{out}$$

N_{in}, N_{out}: Jet yield (in-, out-of-plane)

Previous study: Indivisual R_{AA}^{jet} or v_2^{jet} measurements

✓ Jet suppression, ✓ Pass length dependency of the jet suppression

✗ The parton energy loss mechanism

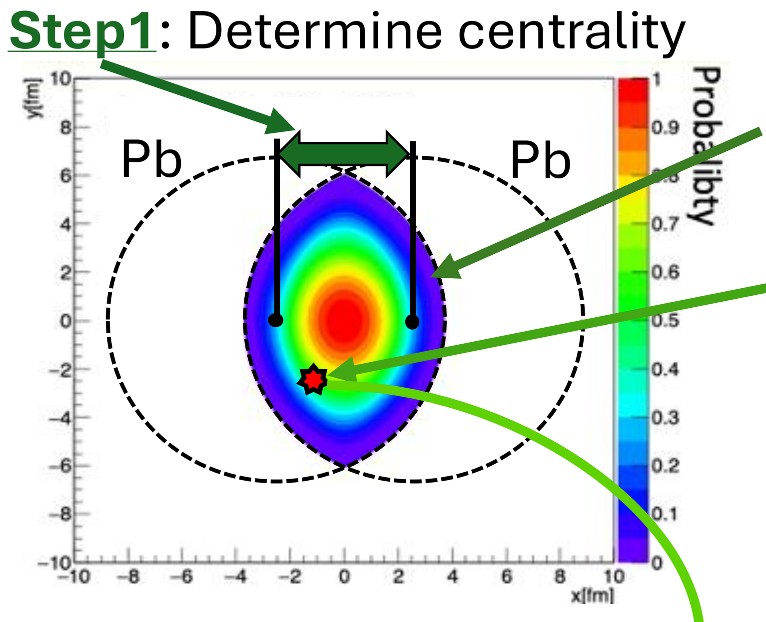
Developed a toy simulation in this study

+ Use the both results of the R_{AA}^{jet} and v_2^{jet} measured under the same conditions

→ Quantify the parameters ($\hat{e}_n$, n) of the parton energy loss $\Delta E = \hat{e}_n L^n$

3. Toy Model Simulation Algorithm

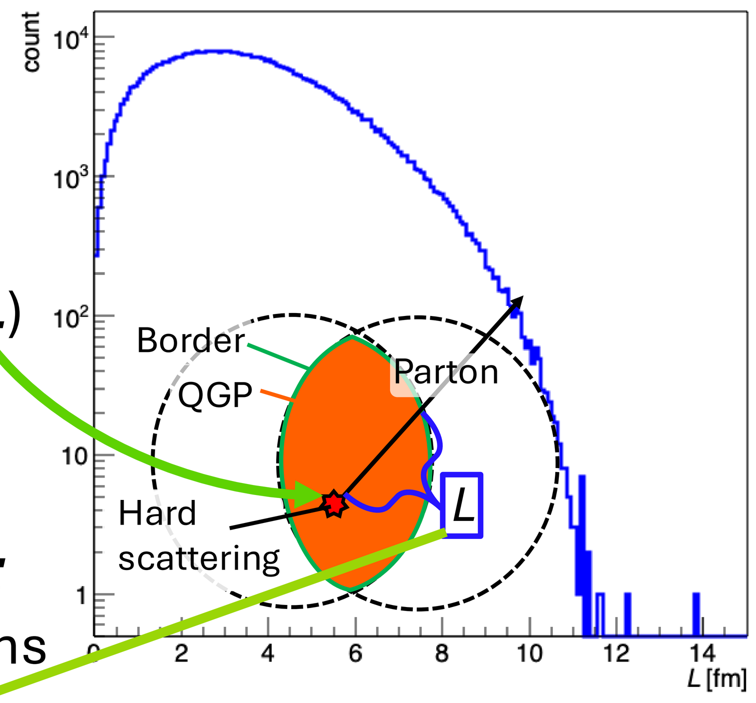
Step1: Determine centrality

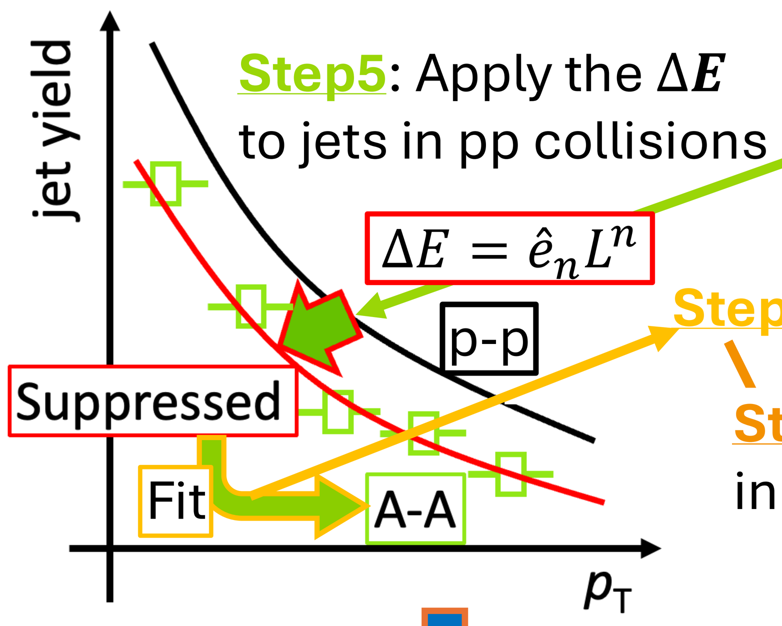


Step2: Calculate probablity density of a hard scattering

Step3: Determine a hard scattering position

Step4: Estiamte pass length (L)

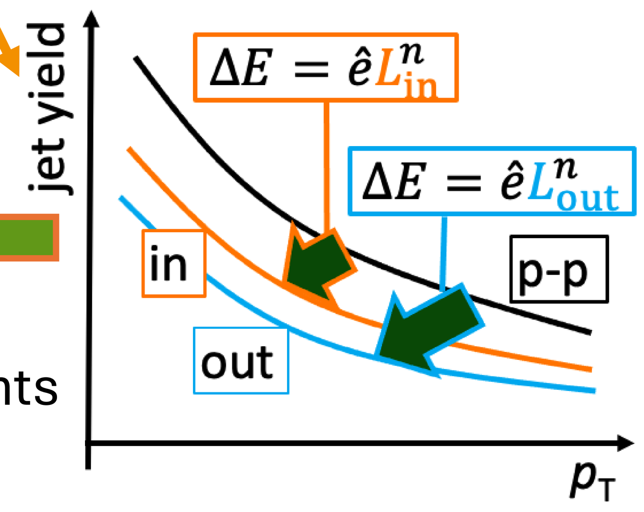




Step5: Apply the ΔE to jets in pp collisions

Step6: Determine the $\hat{e}_n$

Step7: Apply the $\hat{e}_n$ to jets in the in- and out-of- plane



Step8: Estimate R_{AA}^{jet} and v_2^{jet}

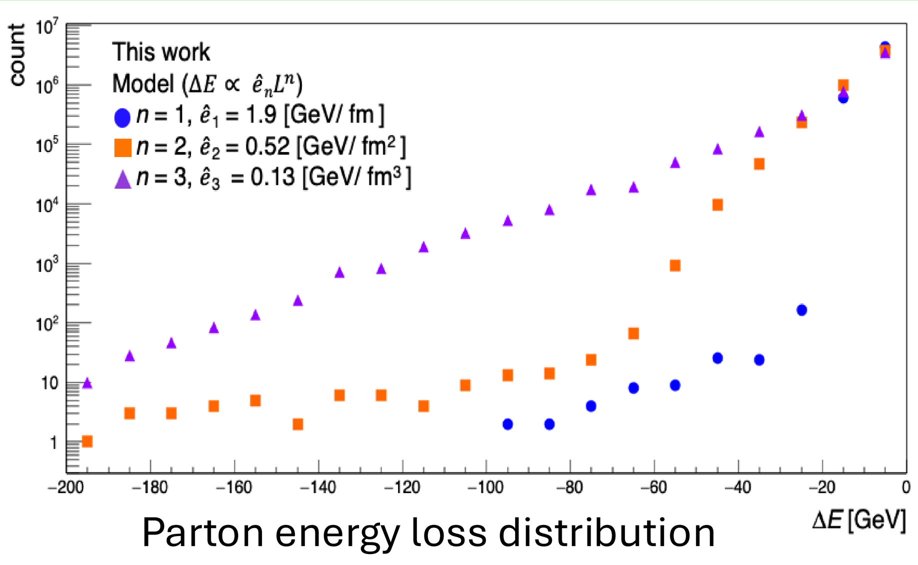
Step9: Compare with measurements and determine the n

< Assumption >

- No dependency on density of the QGP medium
- No dependency on time evolution of the QGP medium
- No dependency on the parton's p_T

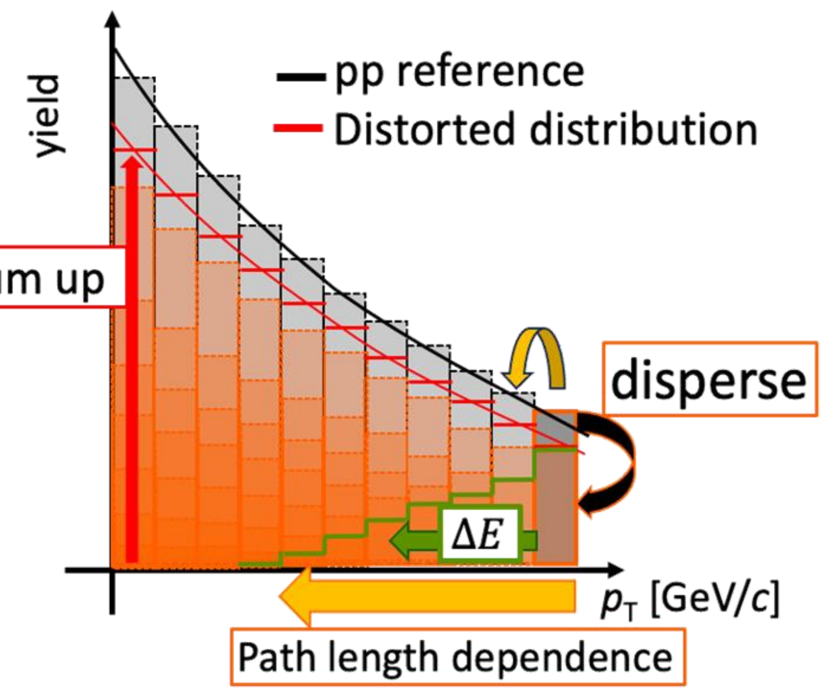
4. Jet's Yield p_T Distributions (Step 5-7)

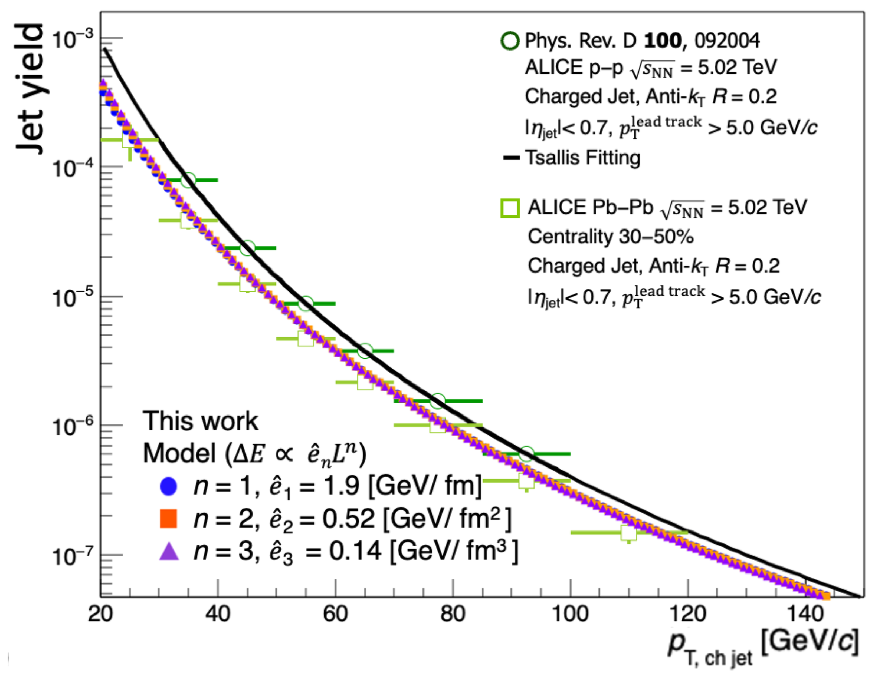
Estimate energy loss $\Delta E (= \hat{e}_n L^n)$ distribution using the evaluated path length distribution and an arbitrary $\hat{e}_n$.



Parton energy loss distribution

By dispersing each p_T bin value of the jet yield distribution according to the ΔE distribution, the suppressed jet yield distributions are obtained.





Jet yield p_T distributions

Determine the $\hat{e}_n$ to match the suppressed distribution with the measured jet yield distribution in heavy-ion collisions.

Apply the determined $\hat{e}_n$ to the L distributions in the **in-** / **out-of-plane**, and obtain p_T distributions for both regions.

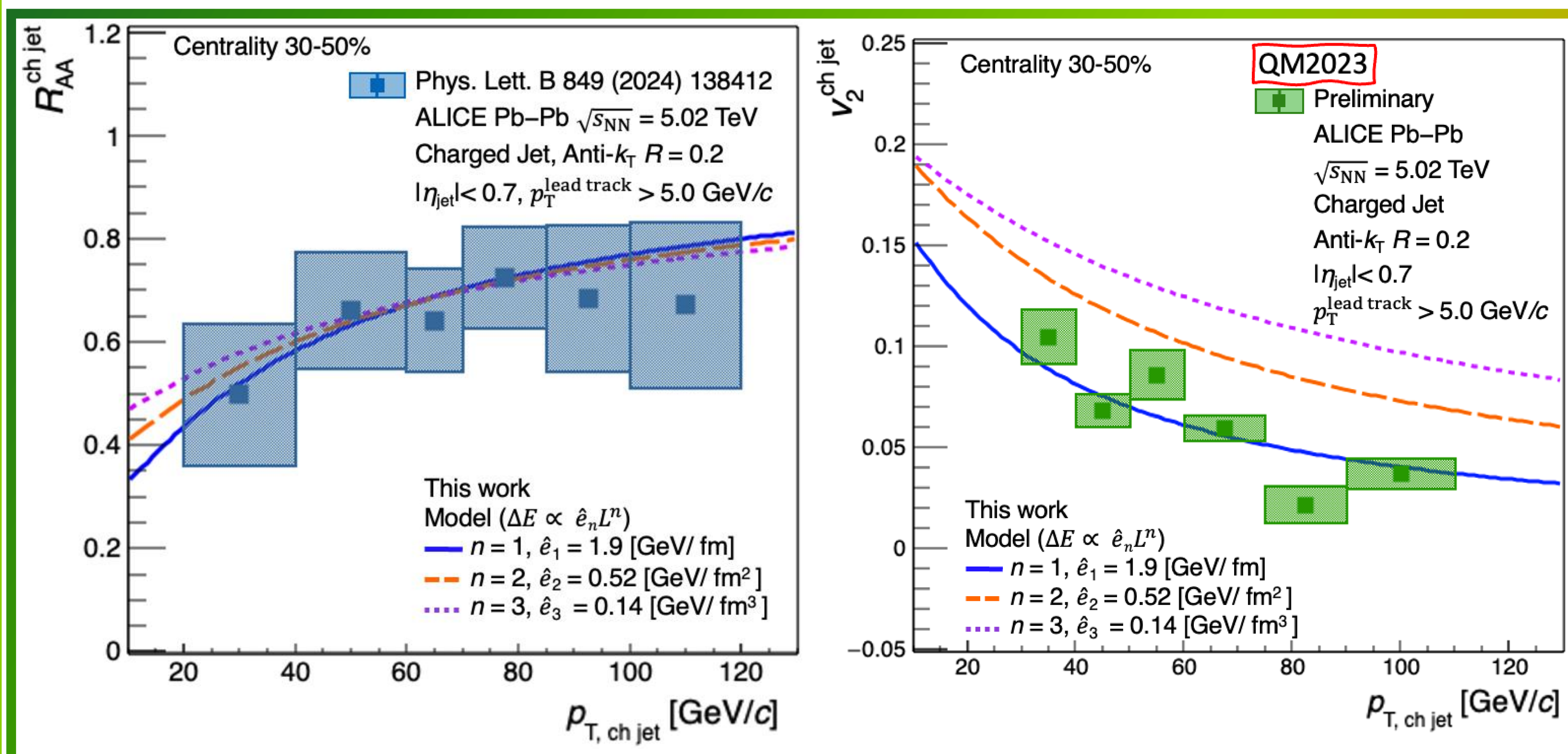
5. Results

The $\hat{e}_n$ values determined by the Step6.

$\hat{e}_1$ = 1.9 [GeV/fm], $\hat{e}_2$ = 0.52 [GeV/fm²], $\hat{e}_3$ = 0.14 [GeV/fm³]

Left Fig: **R_{AA}^{jet}** is obtaind by the **Eq1** using jet yield distributions of the Step5.

Right Fig: **v_2^{jet}** is obtained by the **Eq2** using jet yield distributions of the Step7.



Comparison of p_T distributions v_2^{jet} and R_{AA}^{jet} between simulation and measurement

	$n=1$	$n=2$	$n=3$
χ^2 (R_{AA}^{jet})	0.29	0.31	0.52
χ^2 (v_2^{jet})	**2.9**	31	72

$$\chi^2 = \sum_i \frac{(\mathrm{Obs}_i - \mathrm{Sim})^2}{(\sigma_{data,i})^2} / \mathrm{NDF}$$

Obs_i : Observed value , Sim: Simulaiton value

$\sigma_{data,i}$: Uncertainty of measurement

NDF = (# of p_T bin) − (Free paraemter: $\hat{e}_n$) = 5

Significance level 0.05: $\chi^2(5) < 11$

- **R_{AA}^{jet}**: All simulations are consistent with the measurement.
- **v_2^{jet}**: **Only $n = 1$ model is consistent** with the measurement.

6. Conclusion

- **Developed new parton energy loss simulation** using both R_{AA}^{jet} and v_2^{jet} under the same conditions.
- **Only the $n = 1$ model** is consistent with the measurements for both R_{AA}^{jet} and v_2^{jet}, and it determined the energy loss parameter **$\hat{e}_1$ = 1.9 [GeV/fm].**

7. Outlook

- Compare different **centrality** measurements
- Compare different experiments (ex. **ATLAS**, **sPHENIX**)
- Compare different simulation (ex. **JETSCAPE**)