Measurements of jet nuclear modification factor and azimuthal anisotropy in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\ \mathrm{TeV}$ with the LHC-ALICE to clarify the parton energy loss mechanism in Quark-Gluon Plasma and evaluate stopping power

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Introduction

Physics target: Parton Energy loss mechanism

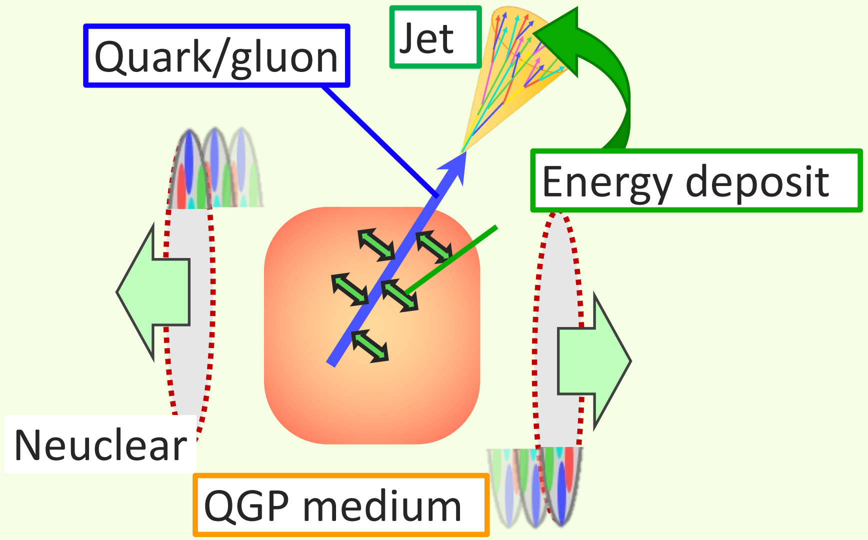
Partons deposit energy in the QGP medium.

Energy loss

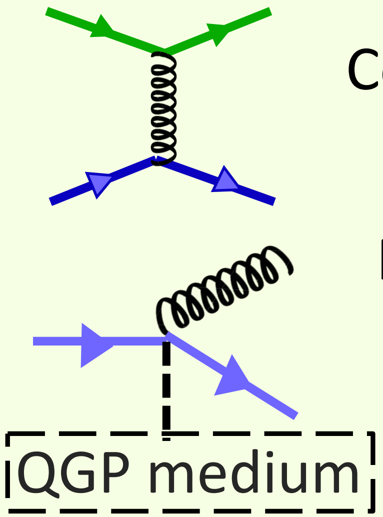
$$\Delta E \propto \hat{q} L^n$$

$\hat{q}$: transport coefficient

L: path length in QGP



Jet suppression mechanism



Collisional $\Delta E \propto L$

Radiative $\Delta E \propto L^2$

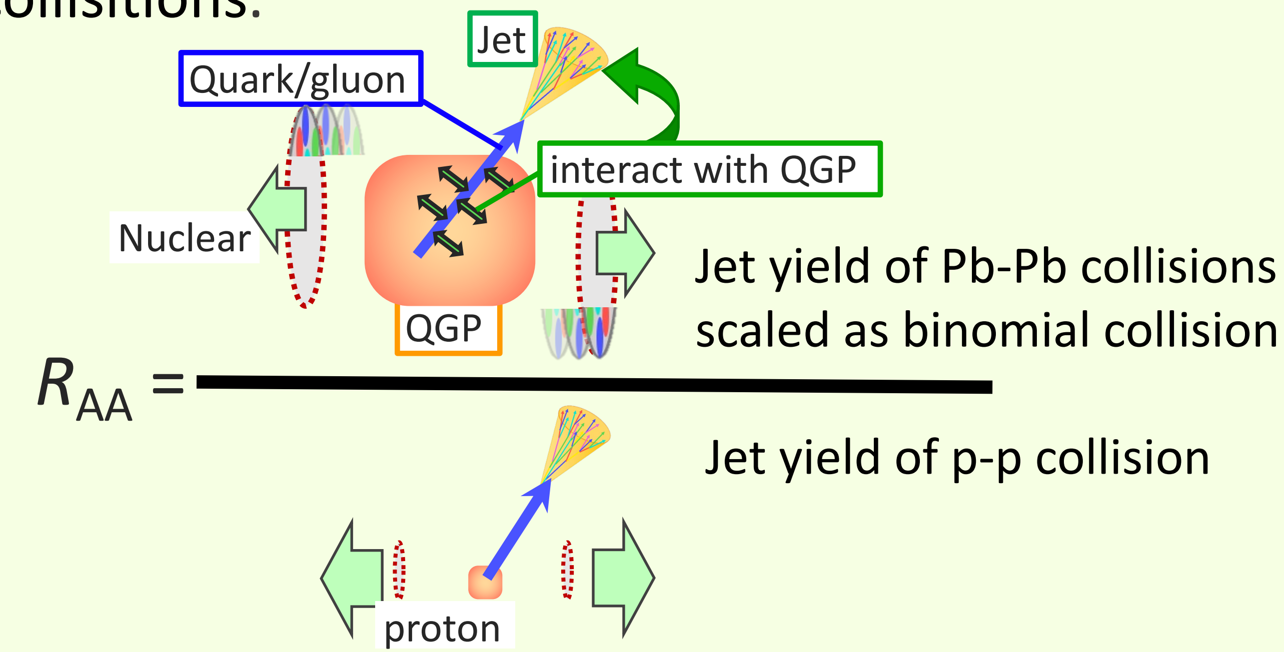
AdS/CFT $\Delta E \propto L^3$

There are some jet suppression mechanisms, but the detail ratio of suppression or correct model are not clarified.

Parton Energy Loss Analysis

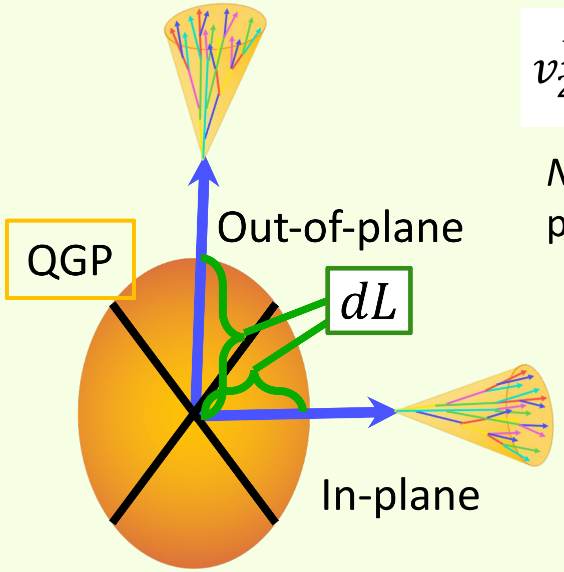
Energy loss: $\Delta E \propto \hat{q} L^n$

Nuclear modification factor (R_{AA}) is built by comparing *heavy-ion* collisions and *proton* collisitions.



Using the difference between with and without suppression allow to measure the **magnitude of suppression**. → **Quantify $\hat{q}$**

Jet v_2 is built by comparing in-plane jets and out-of-plane jets.



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

N_{in}, N_{out}: Jet yield at in-plane and at out-of-plane

Using difference of the path length between in-plane and out-of plane allows to study L **dependency** of ΔE.

→ **Quantify the power of n**

New points of my study for Energy loss ($\Delta E \propto \hat{q}L^n$)

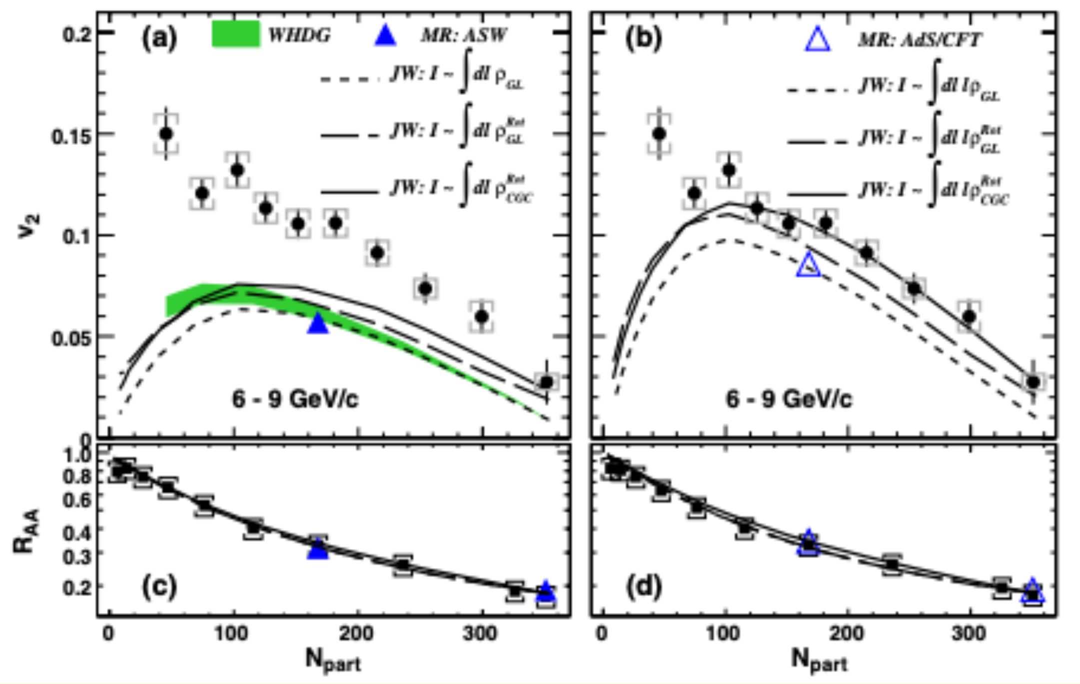
- New jet v_2 measurement at $\sqrt{s_{\rm NN}} = 5.02$ TeV as ALICE
- Simultaneous comparison of charged jet v_2 and $R_{\rm AA}$

→ <u>Expect strong model constraints and acquire accurate suppression parameter values.</u>

- Use **JETSCAPE** model simulation framwork

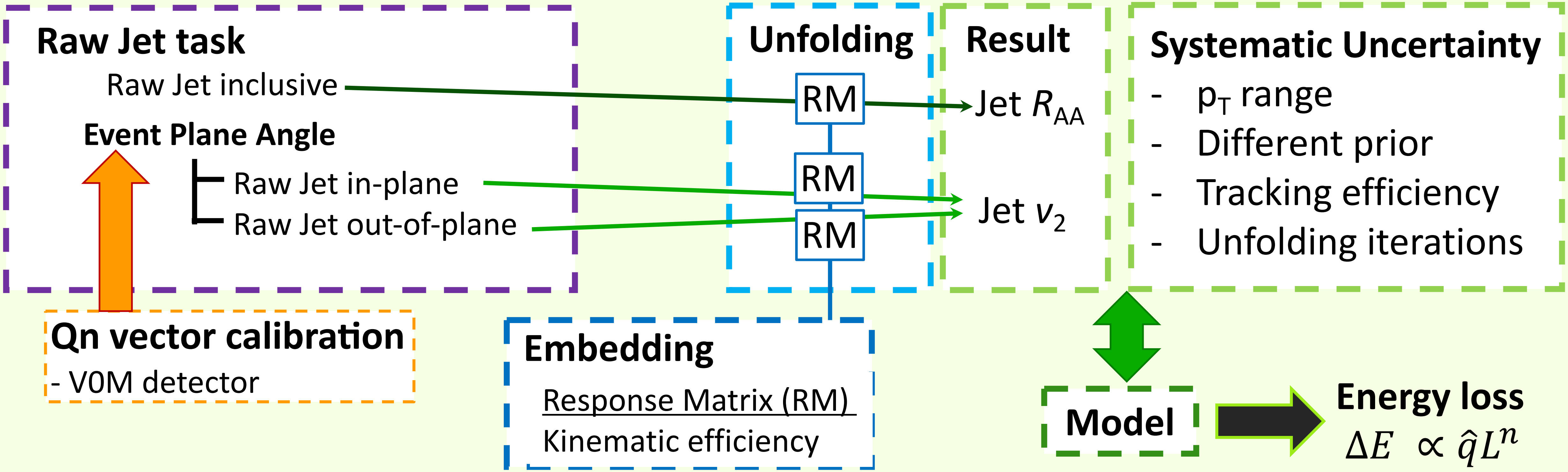
v_2 and $R_{\rm AA}$ of π^0 measurement using PHENIX $\sqrt{s_{\rm NN}} = 200$ GeV data (2010)

https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.105.142301



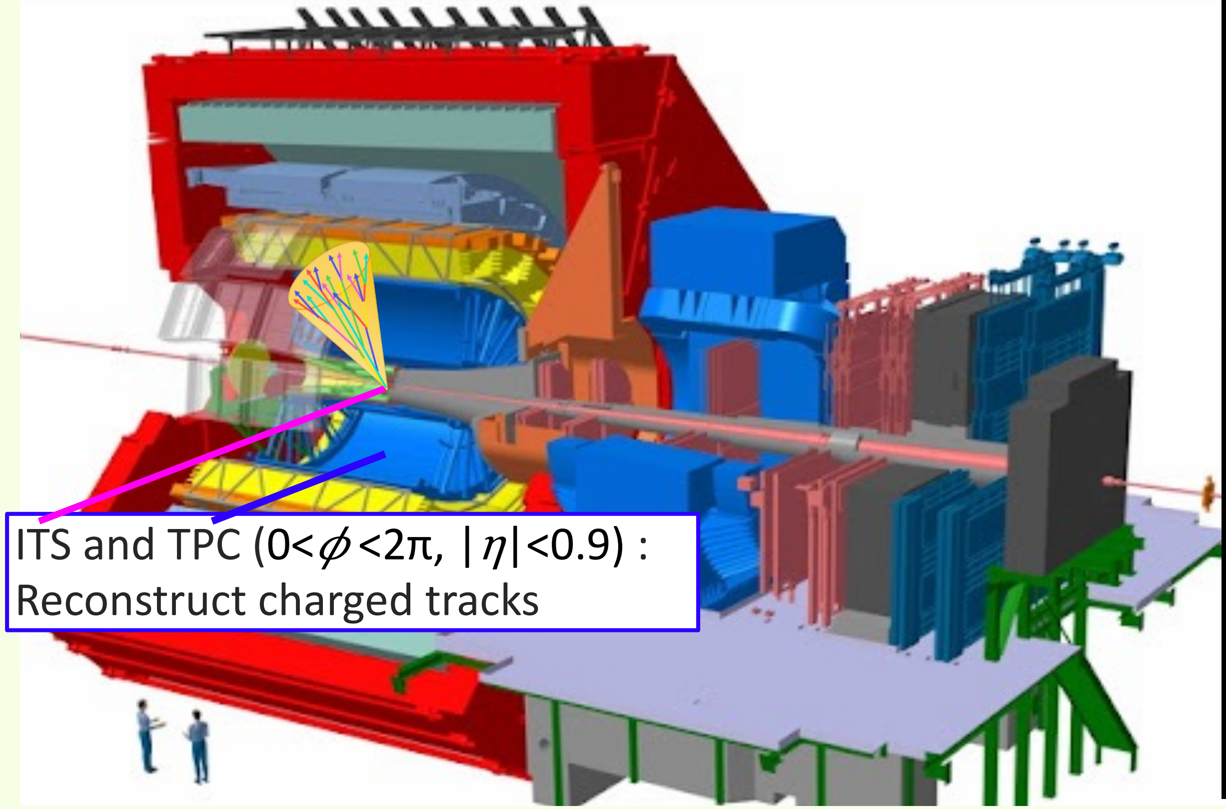
Analysis

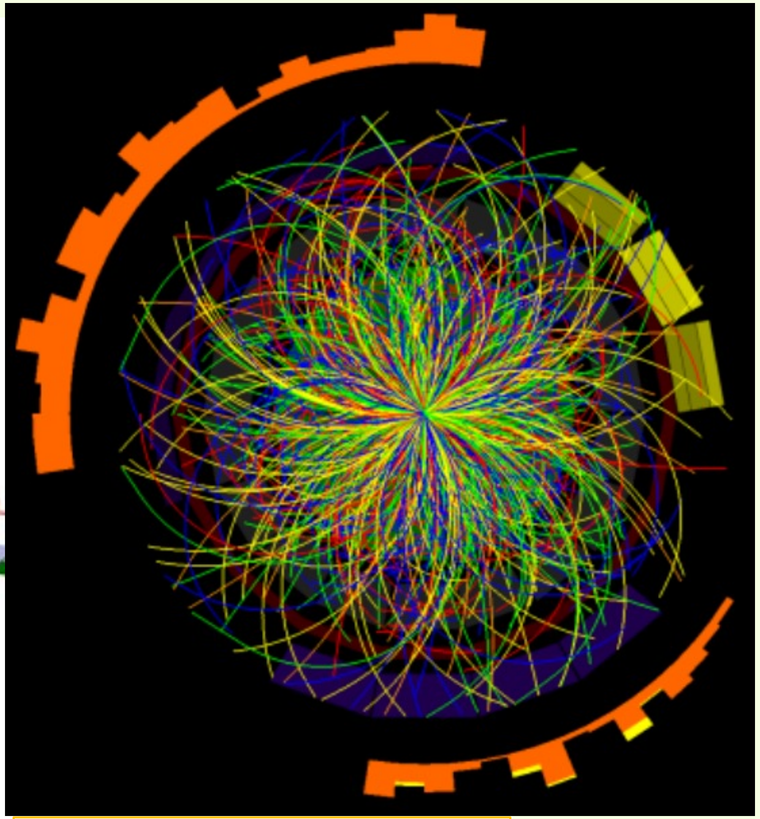
Analysis Flow



Charged Jet reconstruction in ALICE

Charged jet





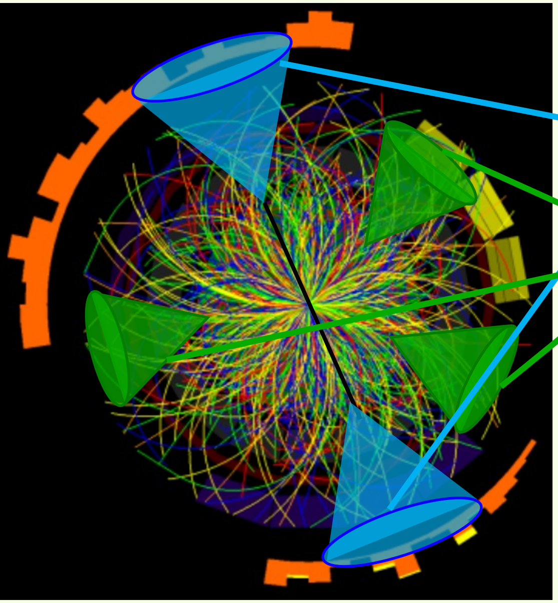
Reconstructed tracks

Fast jet package [Phys Lett B 641 (2006) 57]

Clustering track p_T in resolution pamareter (R) range.

- Signal Jet→ anti-k_T algorithm
- Background density→ k_T algorithm

Background p_T distribution (ordinary inclusive jet way)

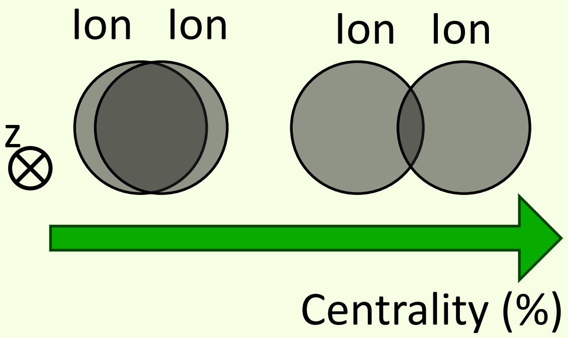


In HIC, a huge number of particles are produced.

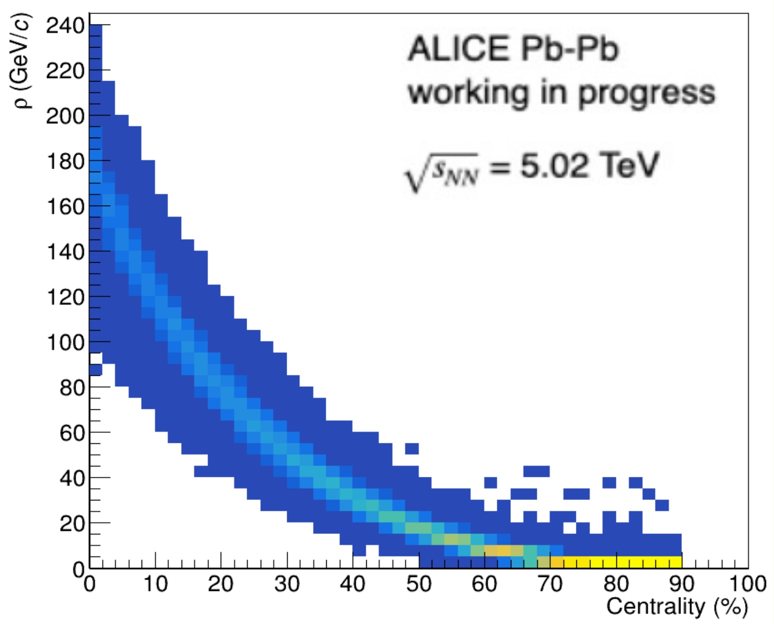
→ Signal jets are reconstructed with the background particles.

→Estimate background p_T density (ρ) except for signal jet area

$$\rho = \text{median}(p_{T,i}/A_i)$$ A : cluster area, *i:* cluster id



background p_T for centrality



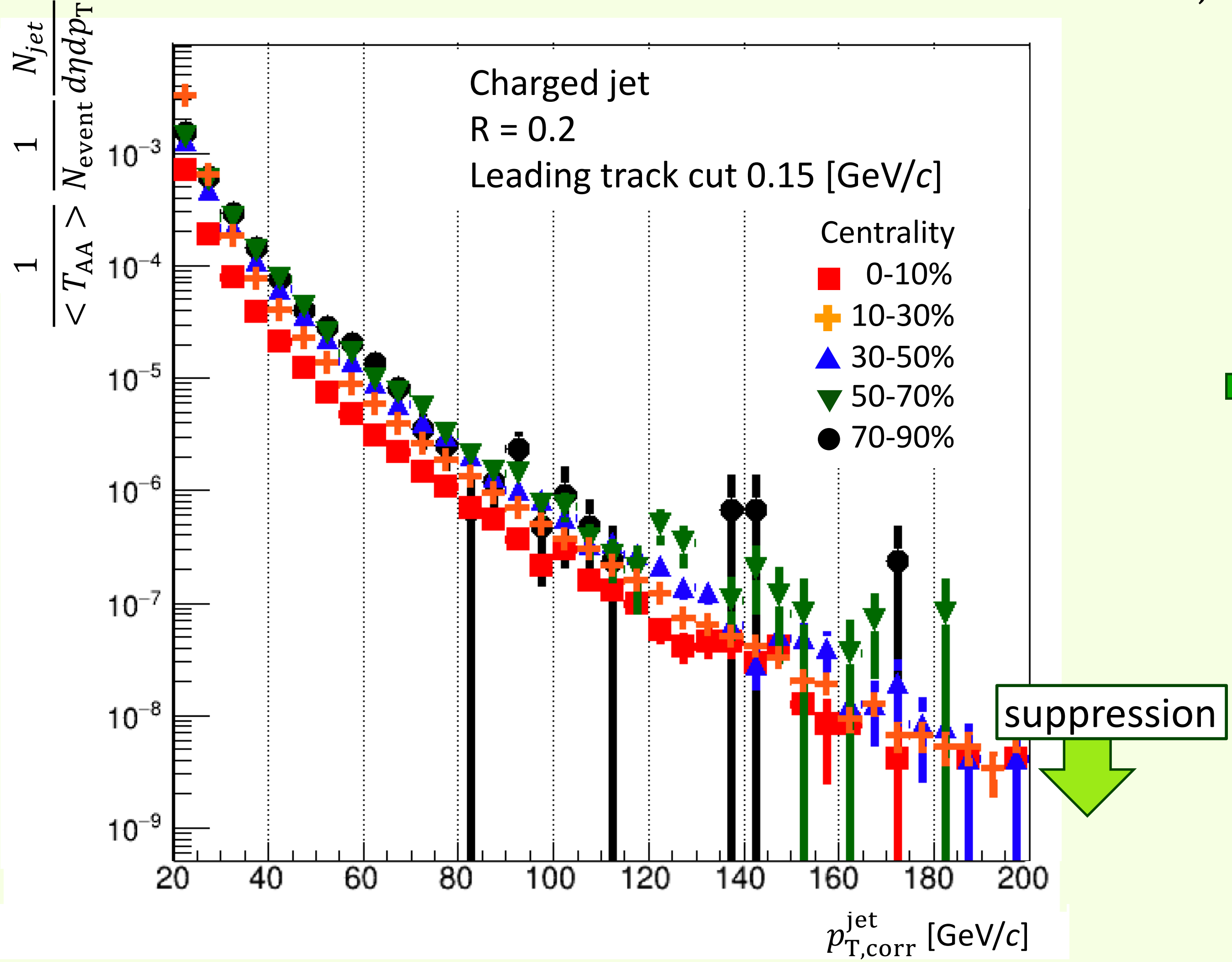
ρ is considered uniform for azimuthal angle and determined event by event
→ subtract the background from each signal jet

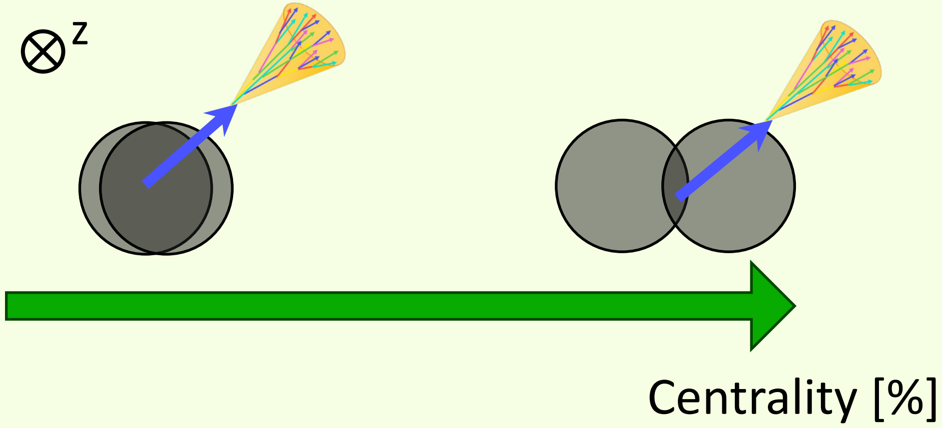
$$p_{T,corr}^{jet} = p_T^{jet} - \rho A$$

A : jet area

Inclusive Raw Charged Jet Yield

Corrected Raw jet p_T distribution (w/o unfolding): $p_{\mathrm{T,corr}}^{\mathrm{jet}} = p_{\mathrm{T}}^{raw} - \rho A$





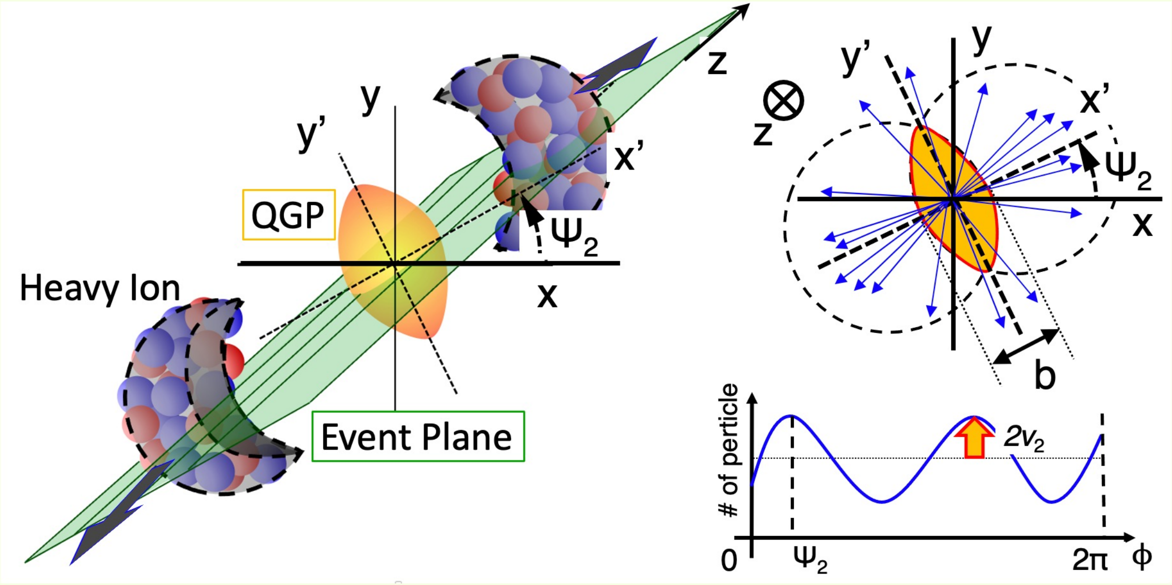
Event plane angle

$$\Psi_{\mathrm{EP}\,n} = \frac{1}{n}\arctan\frac{Q_{n,y}}{Q_{n,x}}$$

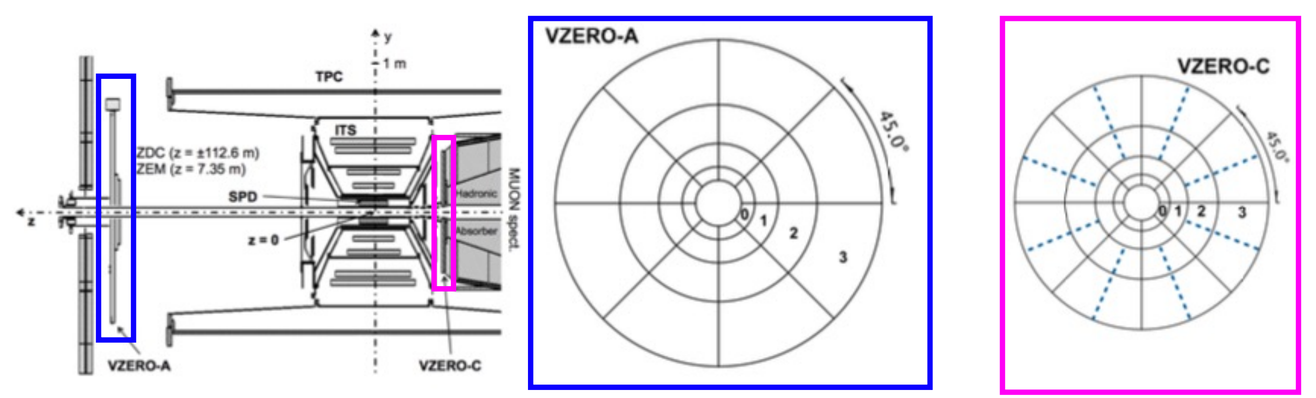
Flow Vector compornet

$$Q_{n,x} = \sum_i \omega_i \cos n\phi_i$$

$$Q_{n,y} = \sum_i \omega_i \sin n\phi_i$$



(ϕ_i : Track angle, ω_i :multiplicity weight, n: Fourier order)



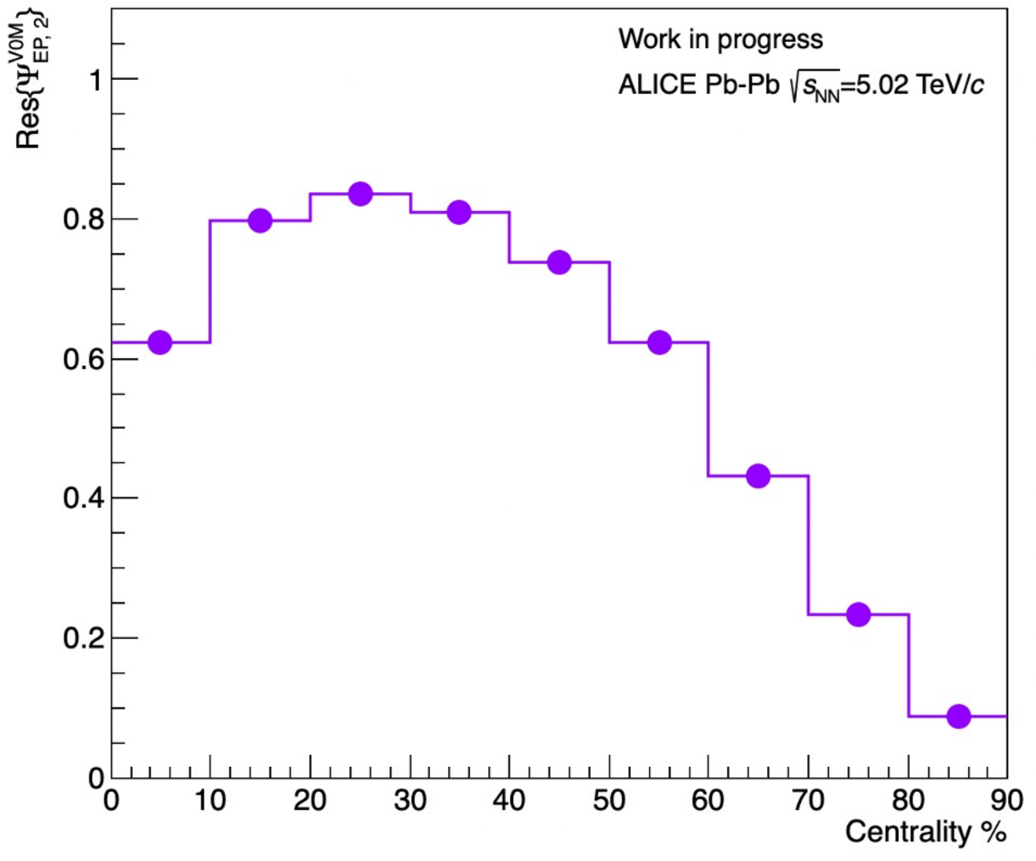
Event Plane Angle Resolution

$$\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\} = \langle \cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi_n]) \rangle = \sqrt{\frac{\langle \cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{b}}_{\mathrm{EP},n}]) \rangle \langle \cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{c}}_{\mathrm{EP},n}]) \rangle}{\langle \cos(n[\Psi^{\mathrm{b}}_{\mathrm{EP},n} - \Psi^{\mathrm{c}}_{\mathrm{EP},n}]) \rangle}}$$

$$v_2^{\mathrm{jet}} = \frac{1}{\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\}} \frac{\pi}{4} \frac{N_{in} - N_{out}}{N_{in} + N_{out}}$$

Ideally, $\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{truth}}_{\mathrm{EP},n}$ close to 0.
In that case, $\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\}$ close to 1.

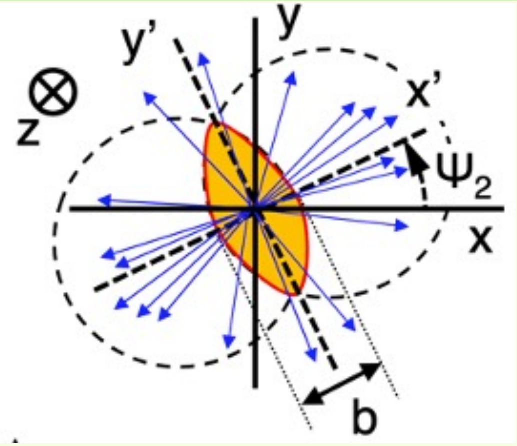
V0 sub-detector
(b: TPC $\eta<0$, c: TPC $\eta>0$)



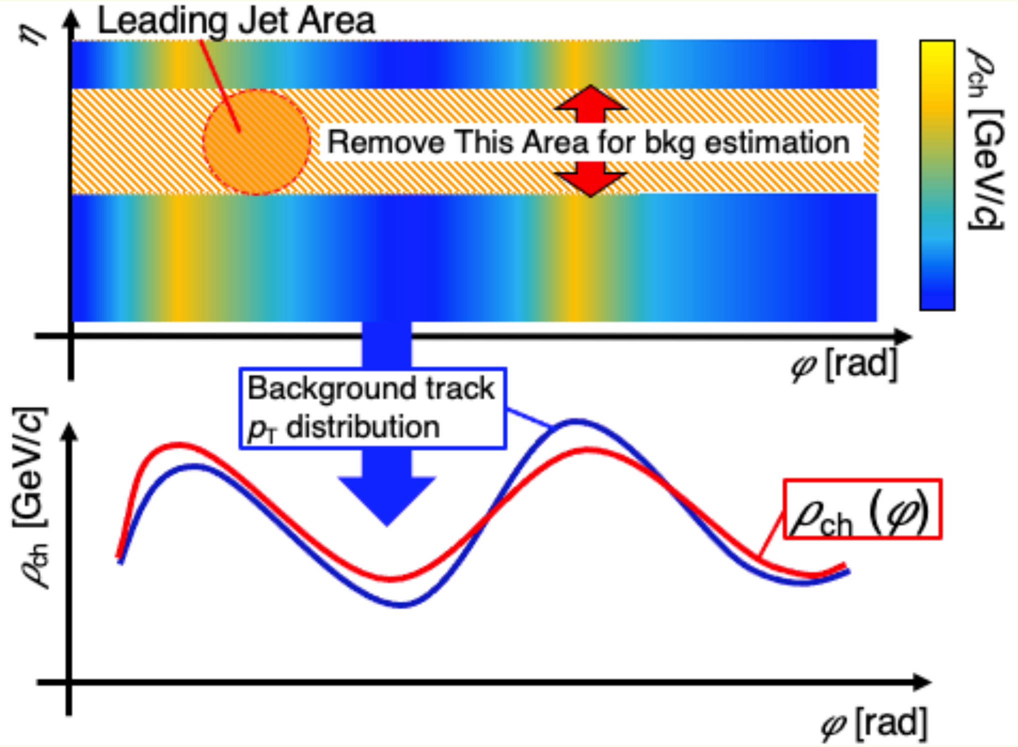
V0M (V0C and V0A) event plane angle resolution for centrality

Local background p_T estimation

The soft particle background is **not uniform** for azimuthal angle (φ).
→The background calculation should take the φ dependency into account.



The local rho is estimated using tracks except the leading jet η region. (Because of the statistic problem, it includes the sub-leading jet region.)

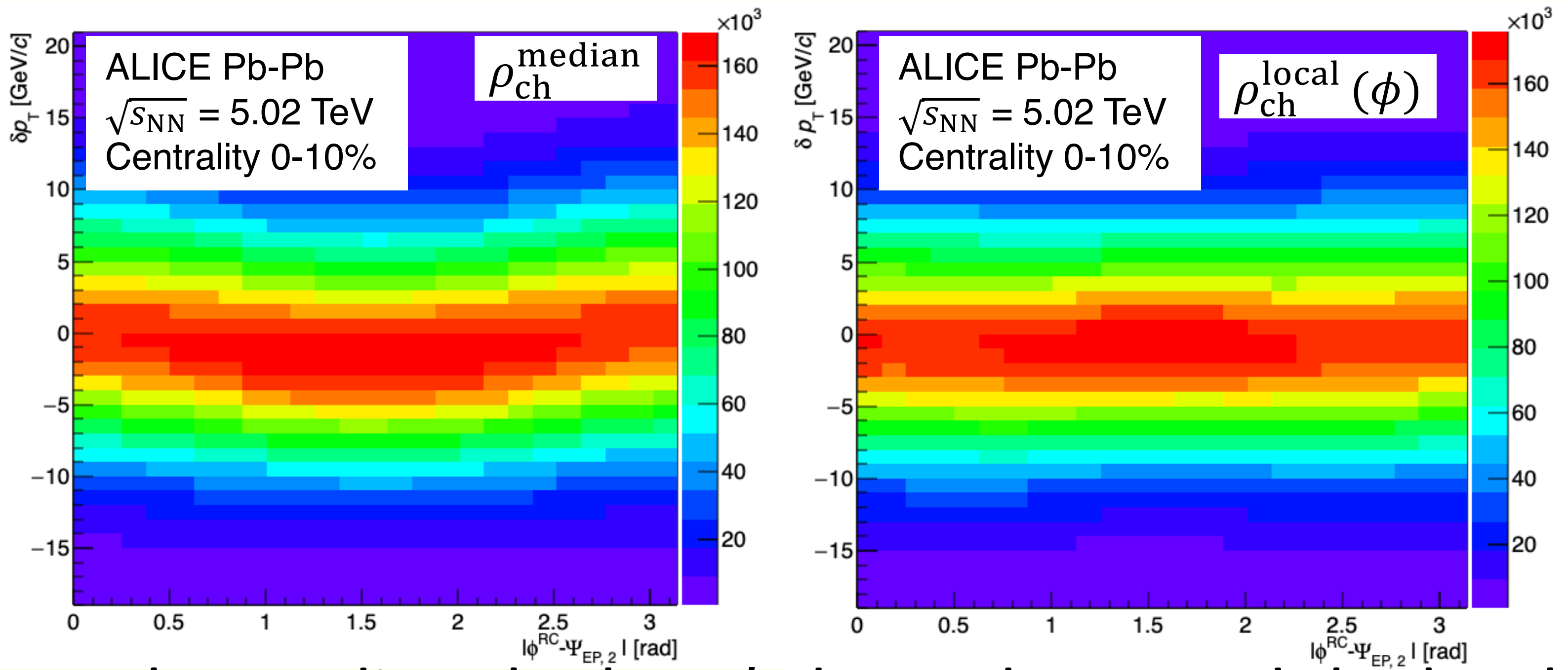


In this analysis, a following equation is used.

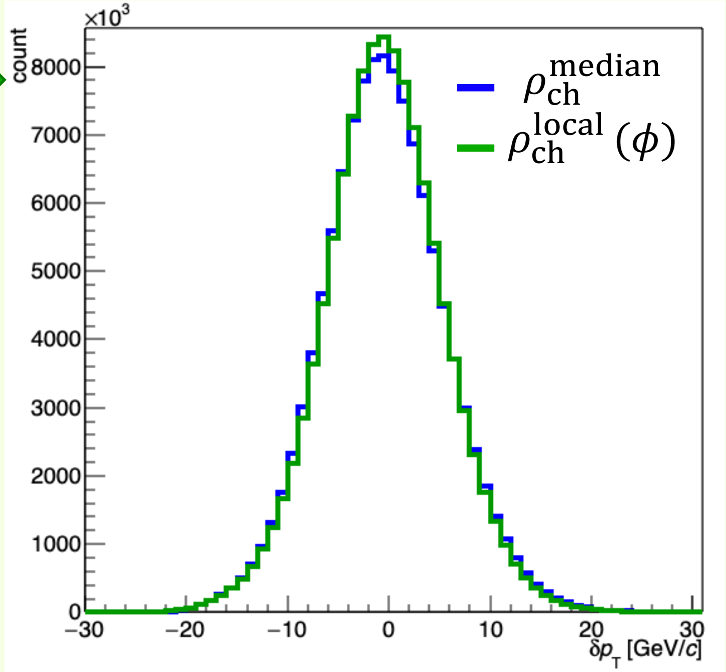
$$\rho_{\mathrm{ch}}(\varphi) = \rho_0 \times \left(1 + 2\left\{v_2^{\mathrm{obs}} \cos(2[\varphi - \Psi_{\mathrm{EP},2}]) + v_3^{\mathrm{obs}} \cos(3[\varphi - \Psi_{\mathrm{EP},3}])\right\}\right)$$

$\Psi_{EP,2}$ and $\Psi_{EP,3}$ are calculated by the Qn vectors.
And ρ_0, v_2^{obs}, and v_3^{obs} are fitting value.

$$\delta p_T = \sum_i p_{T,i}^{\text{track}} - \int_{-RC}^{RC} \rho(\phi)\, d\phi$$



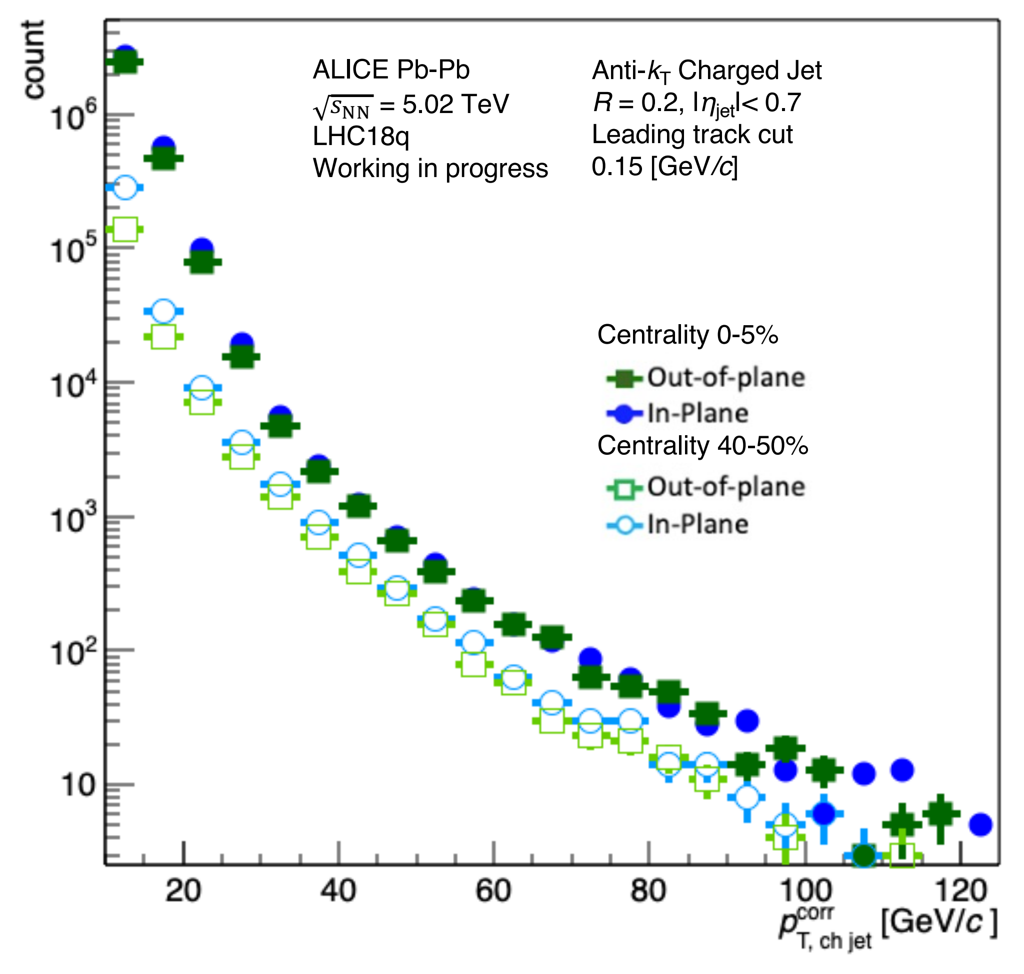
Projection on y axis



- The median rho has ϕ dependency and <u>the local rho makes smaller the ϕ dependency</u>.
- <u>The dispersion of local rho background is more narrow than median rho.</u>
  And these same tendency is seen in the all centrality regions.

Raw Charged Jet Spectrum for each Event Plane

Corrected Raw jet p_T distribution (w/o unfolding): $p_T^{raw} - \rho(\phi)A$

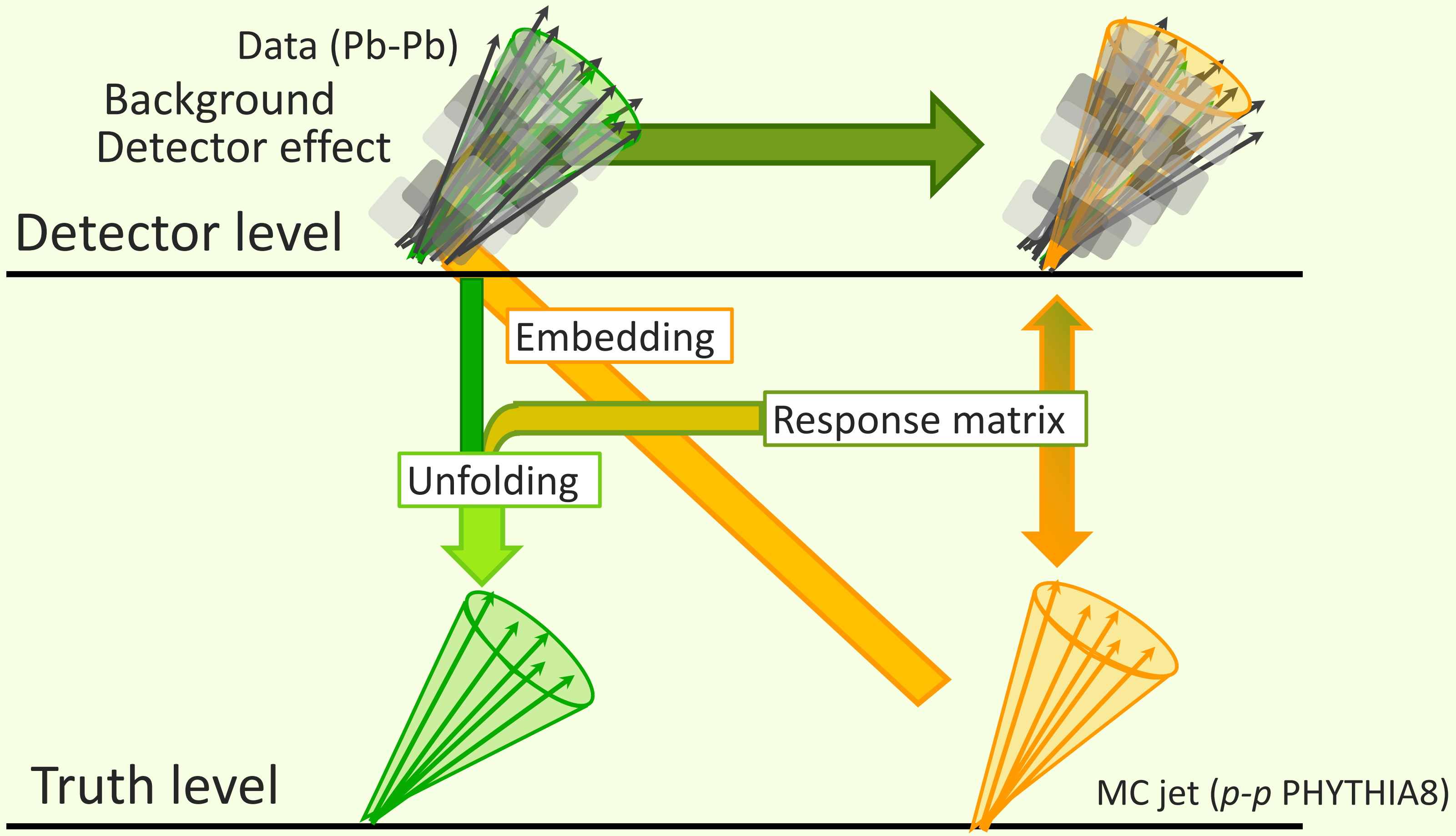


Out-Plane jets are more suppressed than In-plane ones for each centrality.

Unfolding Process

The measured jet p_T distribution is affected by the background fluctuations and the finite resolution / efficiency of the detector

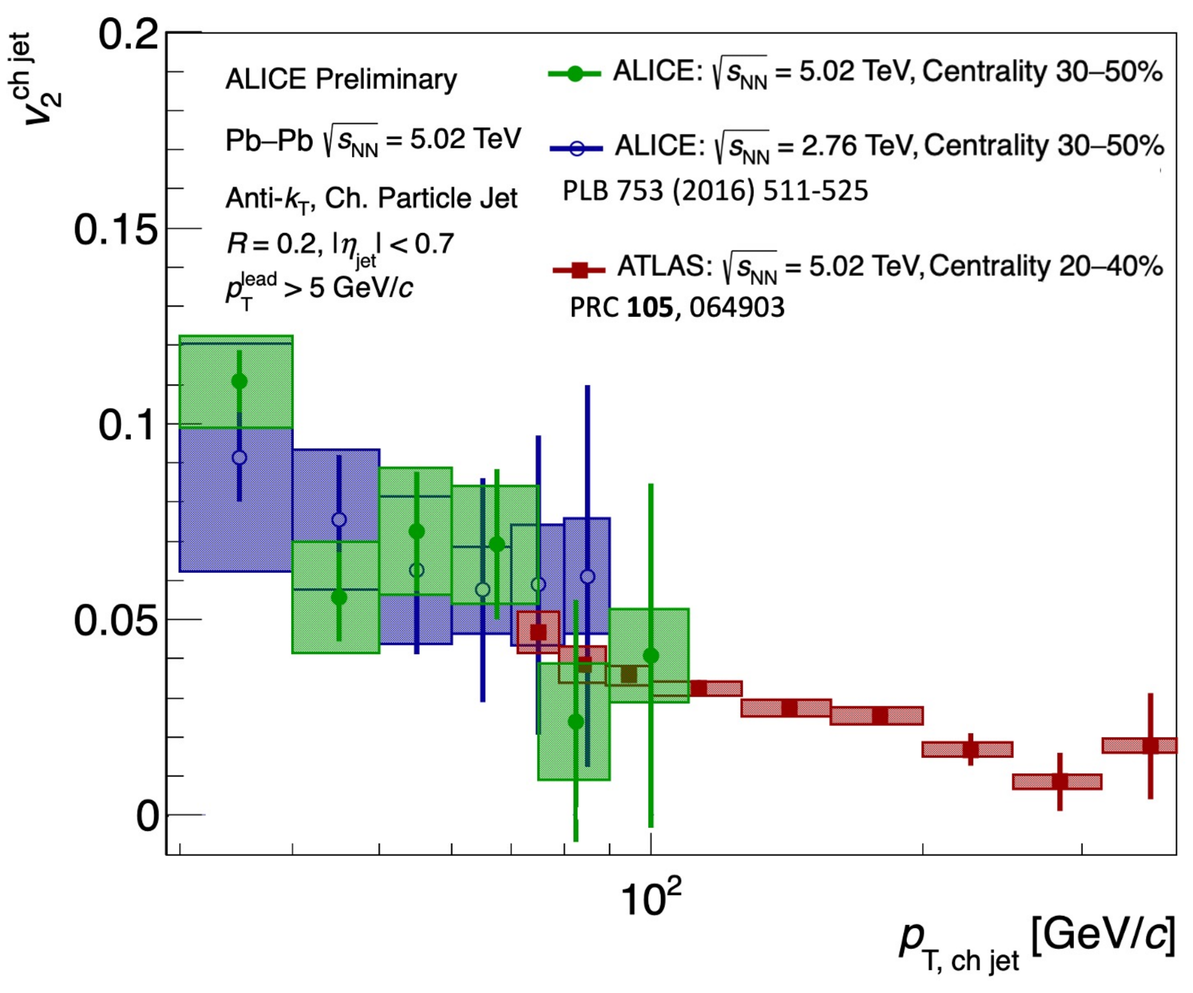
→ Correcting p_T distribution distortions by **Unfolding**.



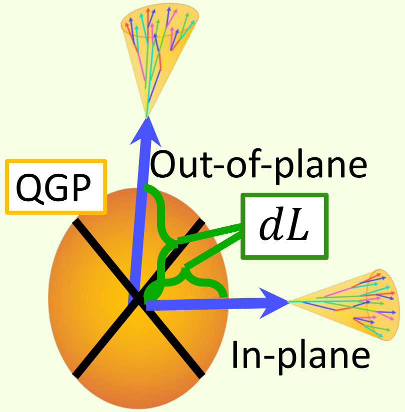
Kinds of Systematic Errors

- Detector level p_T range of response matrix
  - → $\pm 5\ \mathrm{GeV}/c$
- Different prior
  → Modify a prior distribution to unfolding by multiply a ratio of measurement distribution and MC detector level distribution.
- Tracking efficiency
  → Nominal (98%), Compare (94%)
- Unfolding iterations
  → ± 1 time
- Different event plane angle determination detector
  →Nominal(V0M), Compare (V0C and V0A)
- Different background fitting function
  → Nominal (v2 and v3 combine), Compare (only v2 component)

Inclusive charged jet v_2



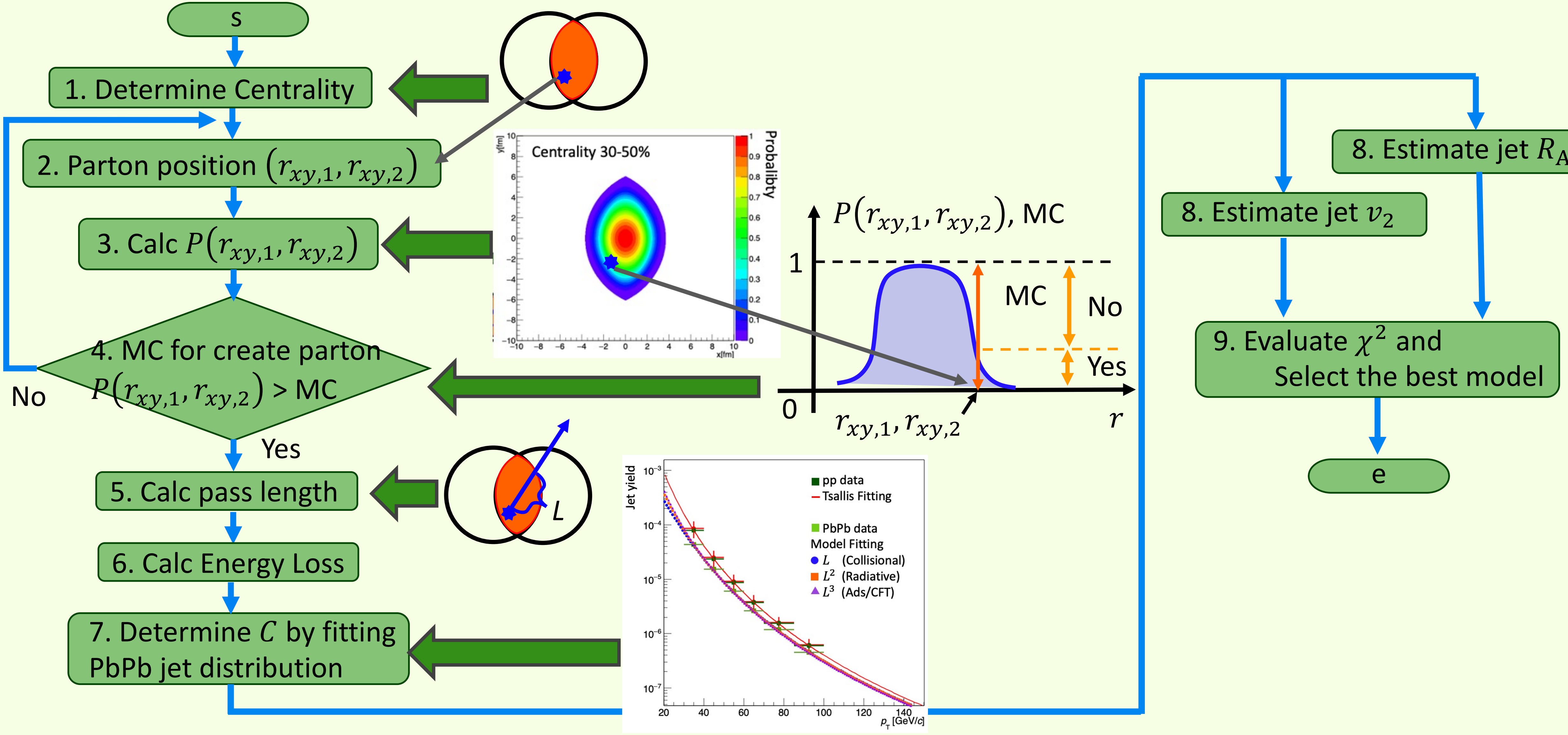
$$v_2^{ch\ jet}(p_T^{jet}) = \frac{\pi}{4}\frac{1}{\mathscr{R}_2}\frac{N_{in(p_T^{jet})} - N_{out(p_T^{jet})}}{N_{in(p_T^{jet})} + N_{out(p_T^{jet})}}$$



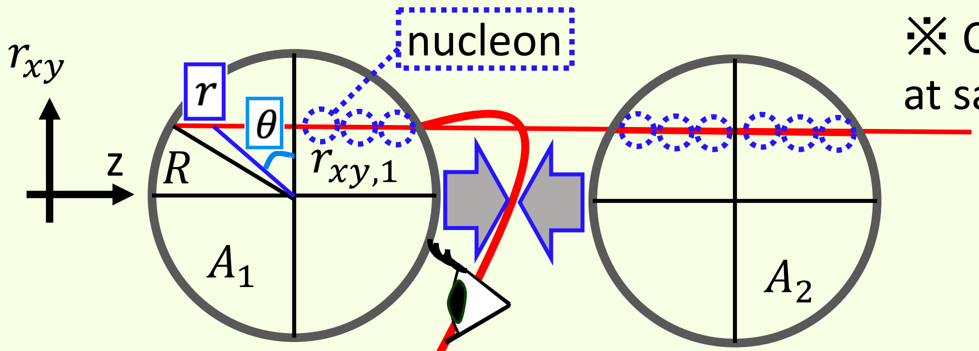
- At low p_T, the charged jet v_2 show **evidently positive value**. As it becomes high p_T, the charged jet v_2 gets **close to zero**.
- The charged jet v_2 of this measurement is **consistent with ATLAS result** within uncertainty around 70-110 GeV/c.

Model Simulation

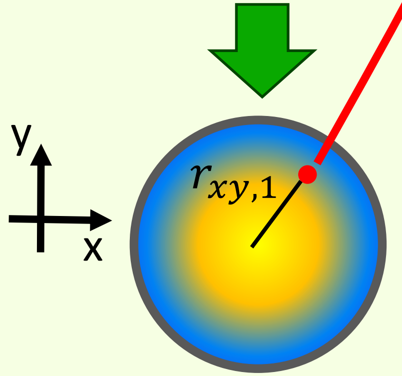
My Simple Toy Model Algorithm



3. Calculate Hard Scattering Probablity density ($P(r_{xy,1}, r_{xy,2})$)



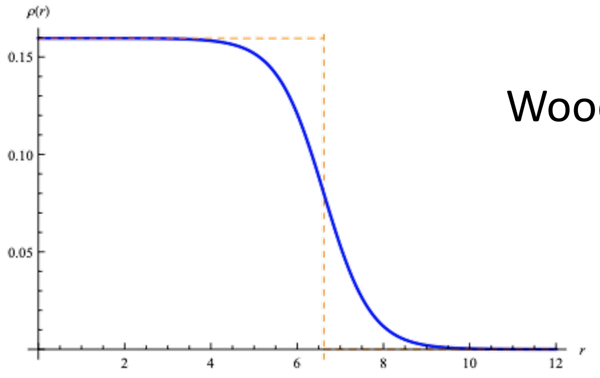
※ Consider collision at same position



Projection (Integral) on x-y plane

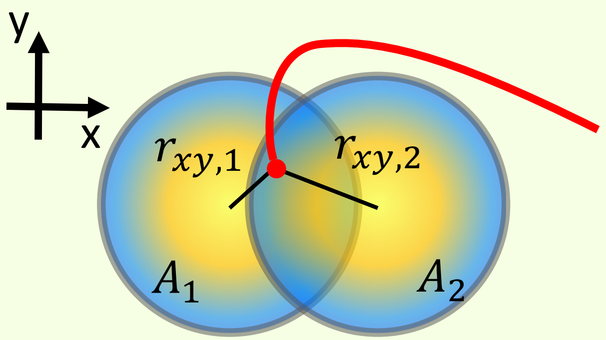
$$P_1(r_{xy,1}) = 2 \int_0^{\cos^{-1}\frac{r_{xy,1}}{R}} d\theta \frac{\rho_0}{1+\exp\left(\frac{\frac{r_{xy,1}}{\cos\theta} - R}{t}\right)}$$

$$\rho(r) = \frac{\rho_0}{1+\exp\left(\frac{r-R}{t}\right)} \qquad \rho_0 = 3/\left(4\pi R^3\left(1+\frac{\pi^2 t^2}{R^2}\right)\right)$$



Woods-Saxon

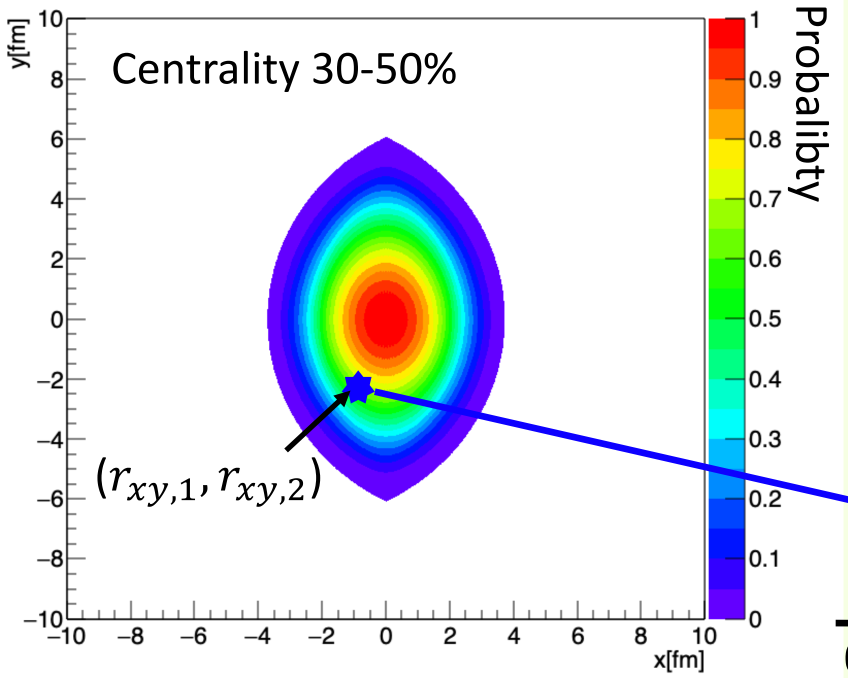
For case of Pb, the values are $t = 0.55$ fm and $R = 6.8$ fm.



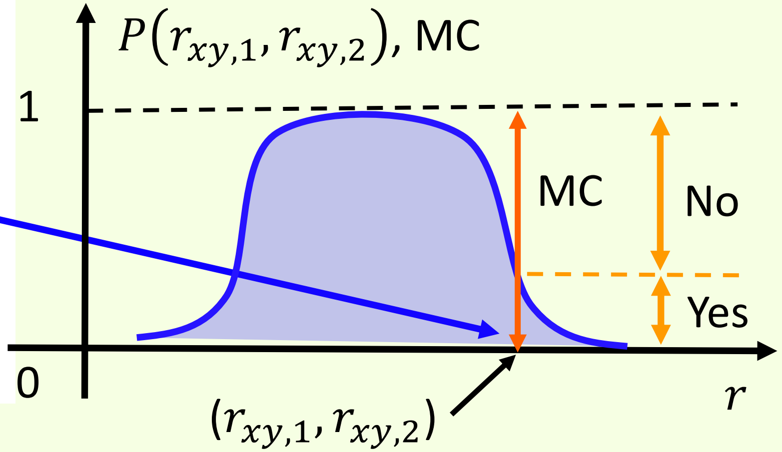
$$\mathrm{P}(r_{xy,1}, r_{xy,2}) = P_1(r_{xy,1}) \times P_2(r_{xy,2})$$

$$\varrho(r_{xy,1}, r_{xy,2}) = \frac{P(r_{xy,1}, r_{xy,2})}{P_{max}}$$

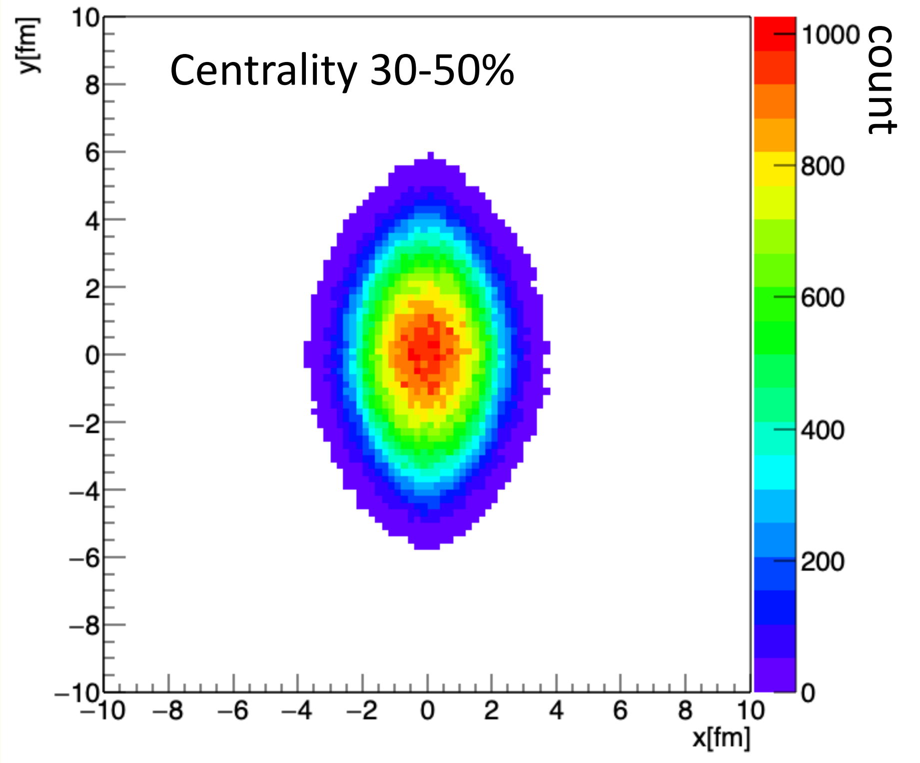
Calculate the probablity density
$P(r\_(xy,1),r\_(xy,2)\ )$ on the step.3

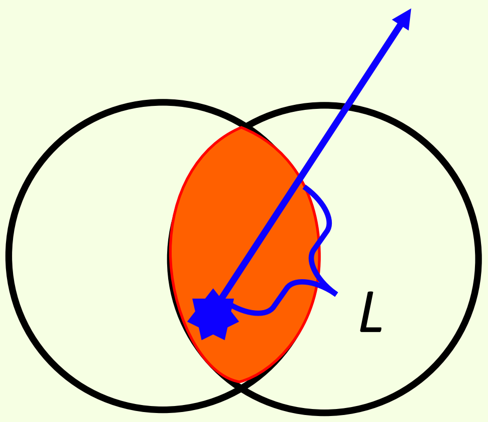


Based on the probablity density, judge creation of a parton at the parton point.

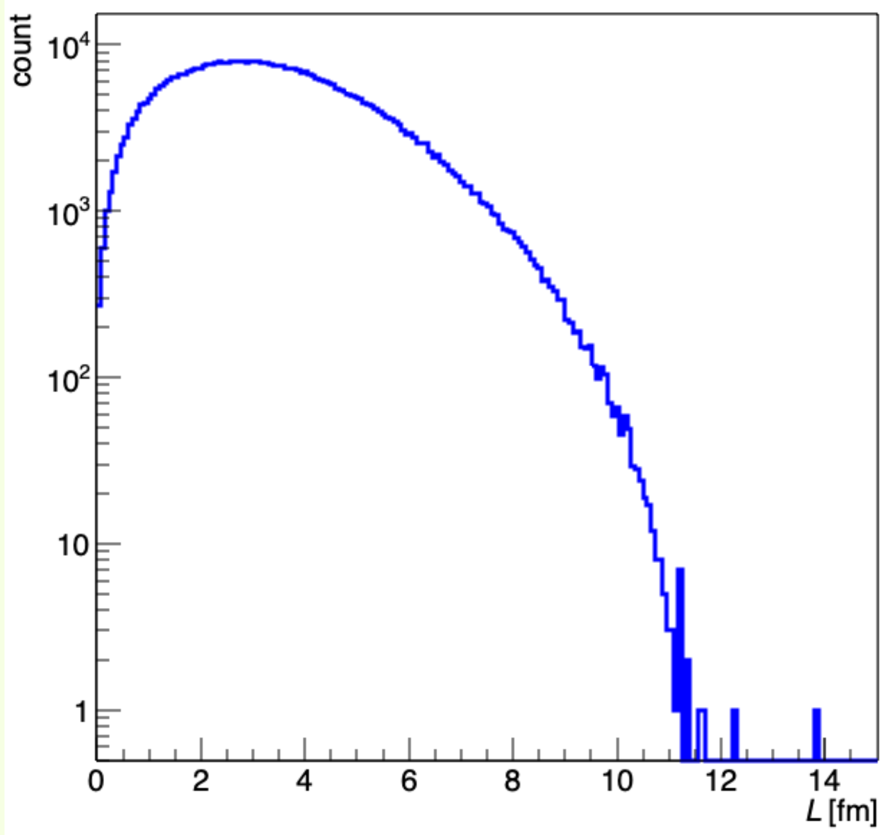


Actual parton creation points (50,000 events)



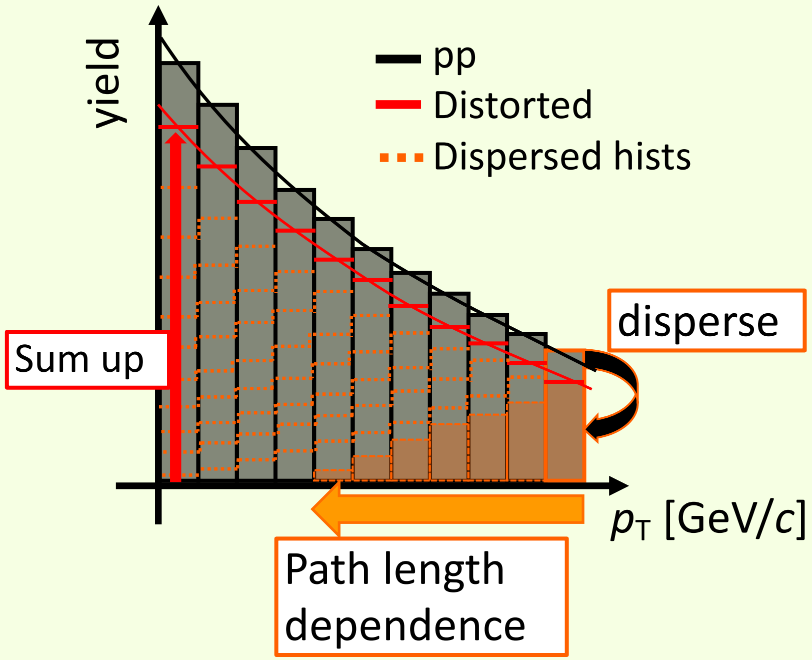


The edge is Woods-Saxon R

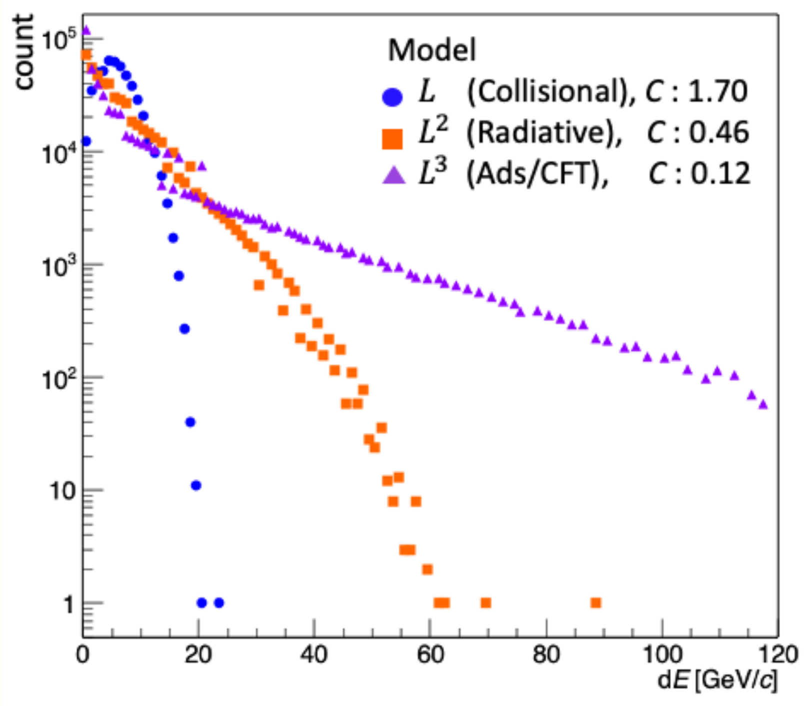


Regard the length from a parton creation point to a cross point of the original atom edge as the pass length.

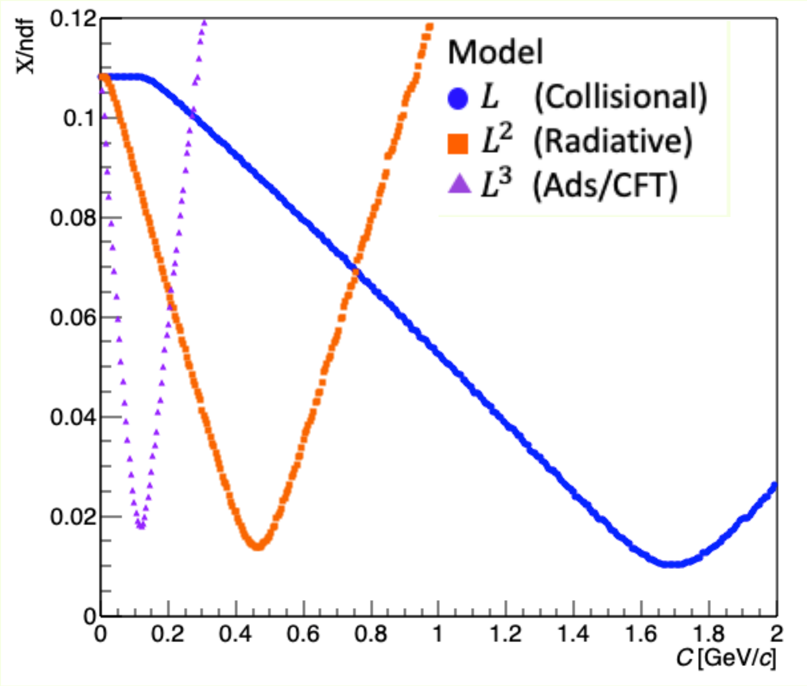
- The original atom is supposed as a cercle.
- The density of QGP is uniform on the reaction area.



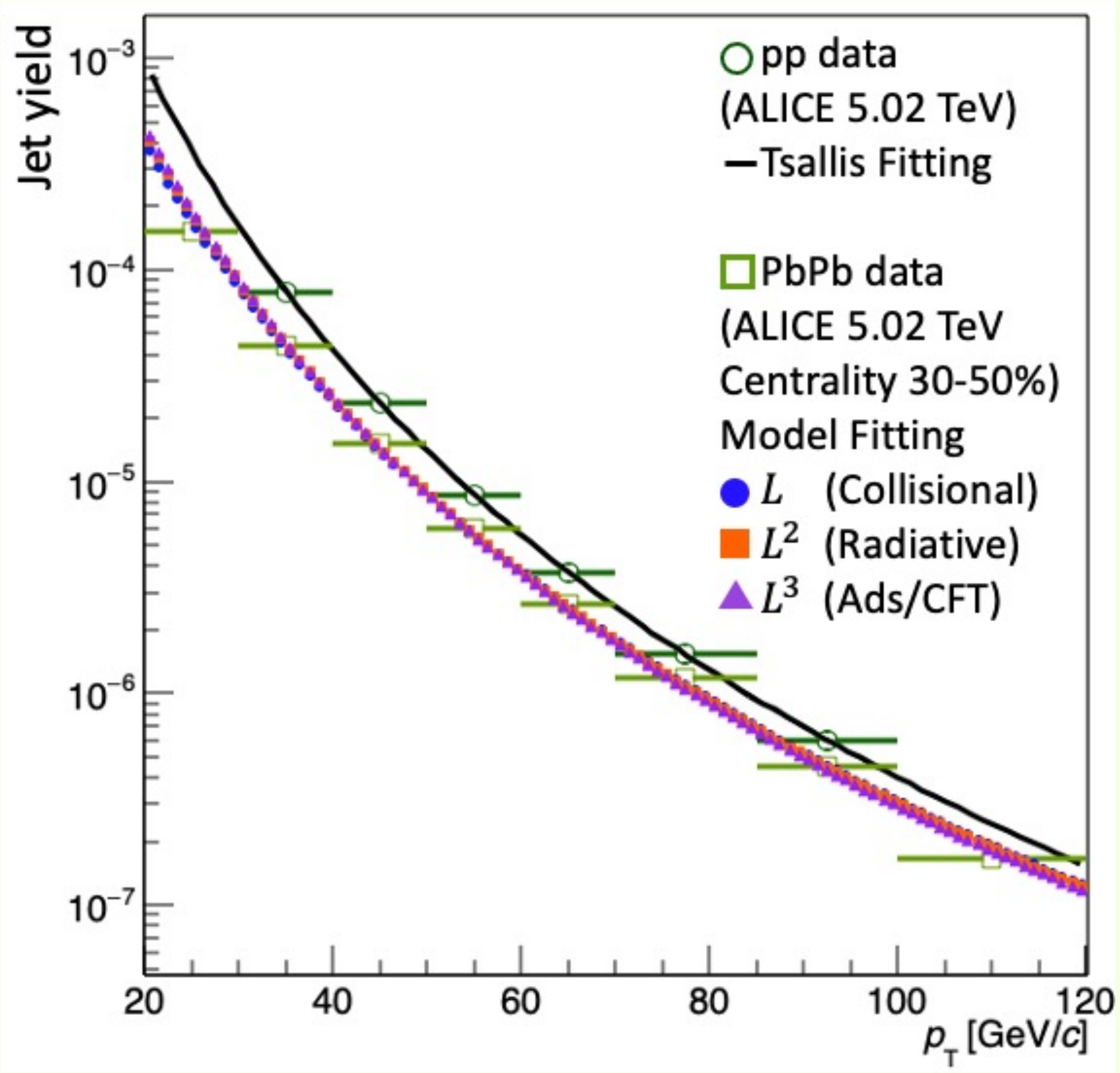
Disperse histogram (dE distribution)



C ditermination



1. Using the dE distribution, disperse each bin of the pp jet pT distribution (MC/Fitting function). The dE distribution is normalized by each pT bin counts.
2. Make a suppressed jet distribution by summing up distributions of each pT bin.
3. Determine the best C to match the suppressed jet distribution and data PbPb jet pT distribution.



pp fitting function (Tsallis)

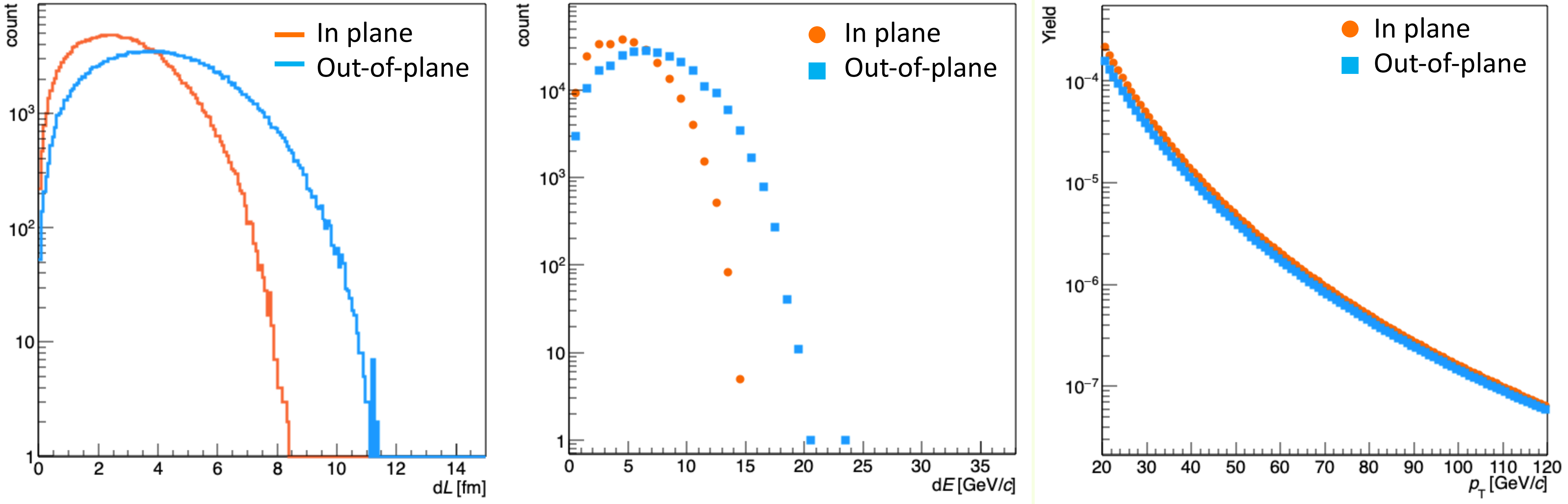
$$F(p_T) = p_0 \times p_T^{1+p_1} \times \left[1 + (p_2 - 1) \times \frac{p_T}{p_3}\right]^{-p_2/(p_2-1)}$$

p_0 : 0.524, p_1 :2.252, p_2 :1.127, p_3 :0.497

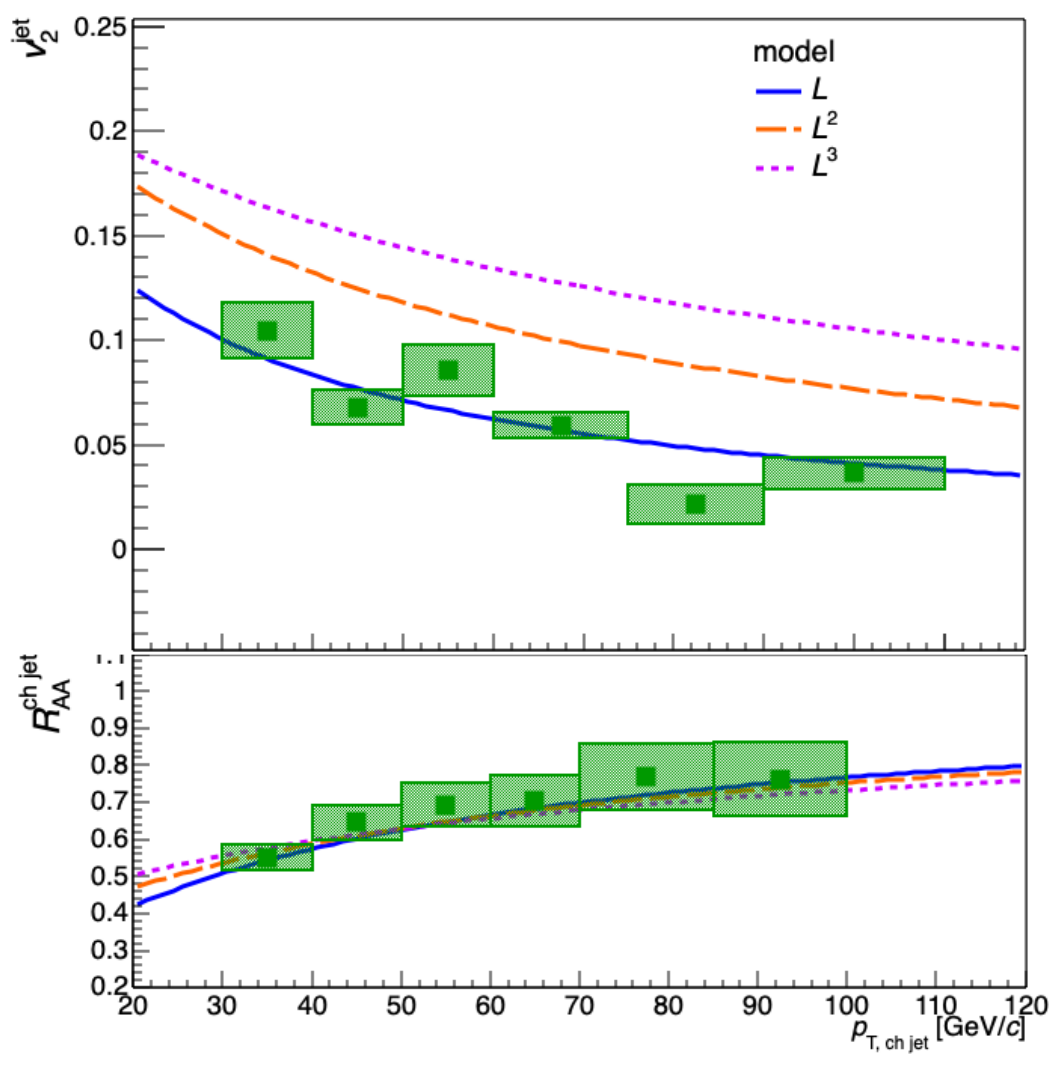
8. Make In/Out of plane jet yield distributions

Apply suppression parameter *C* estimated Step.7 to In/Out of plane jets, respectively.
(In: parton emission angle -π/4 – π/4 and 3π/4 – 5π/4,
Out: parton emission angle π/4 – 3π/4 and 5π/4 – 7π/4)

Path length | Energy Loss (*n*=1, collisional) | Jet Yield (*n*=1, collisional)



Use Tsallis fitting function for model R_{AA} distribution



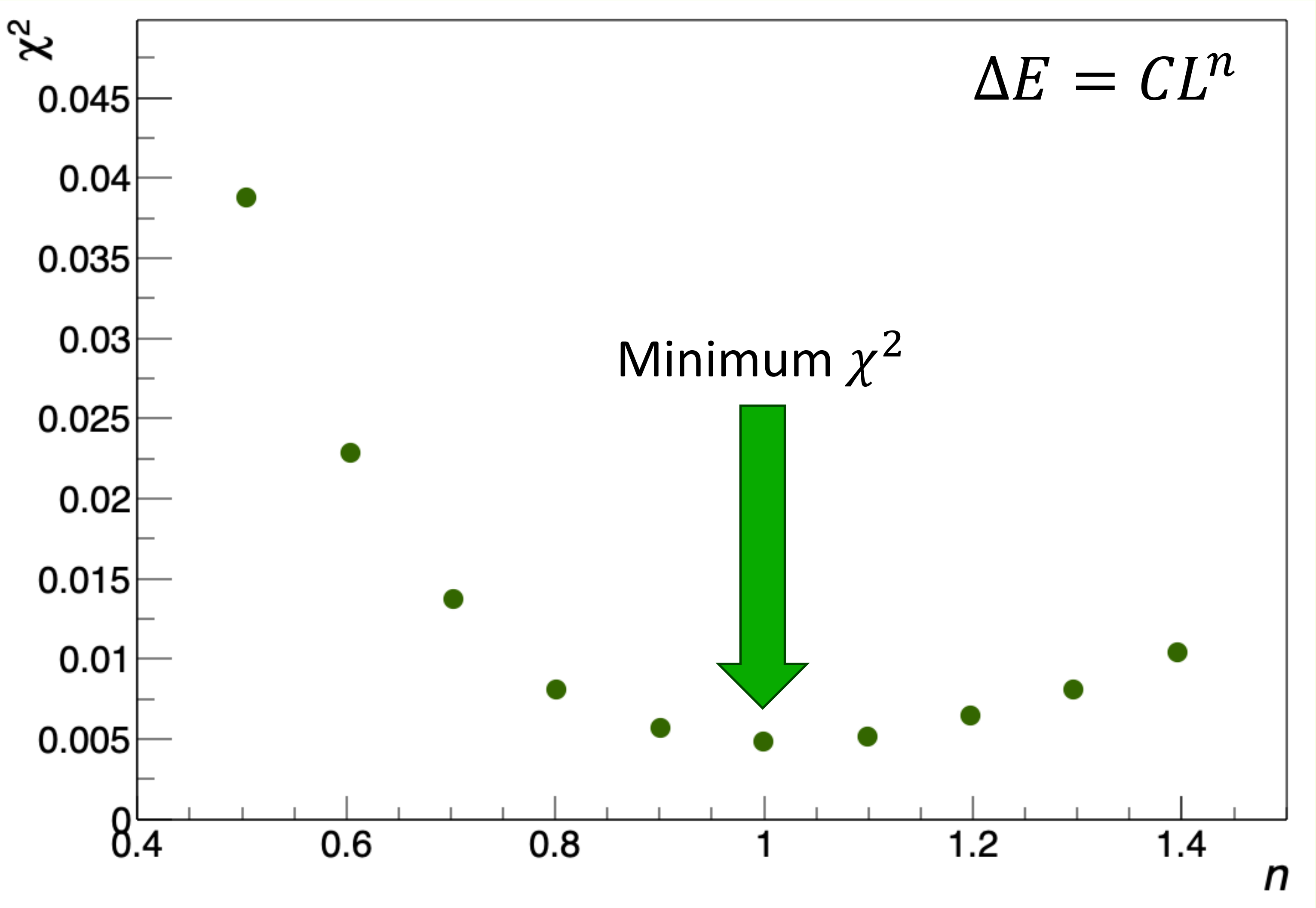
Chi^2/NDF Ch-Jet R_{AA}
(L, L^2, L^3) = (**0.017**, 0.018, 0.023)

Chi^2/NDF Ch-Jet v_2
(L, L^2, L^3) = (**0.0074**, 0.023, 0.036)

※ NDF: pT bins – 1 (Free parameter C)
(L, L^2, L^3) = (Collisional, Radiative, Ads/CFT)

→ Best model is ***dE = CL, (n = 1)***

Best L dependece Search

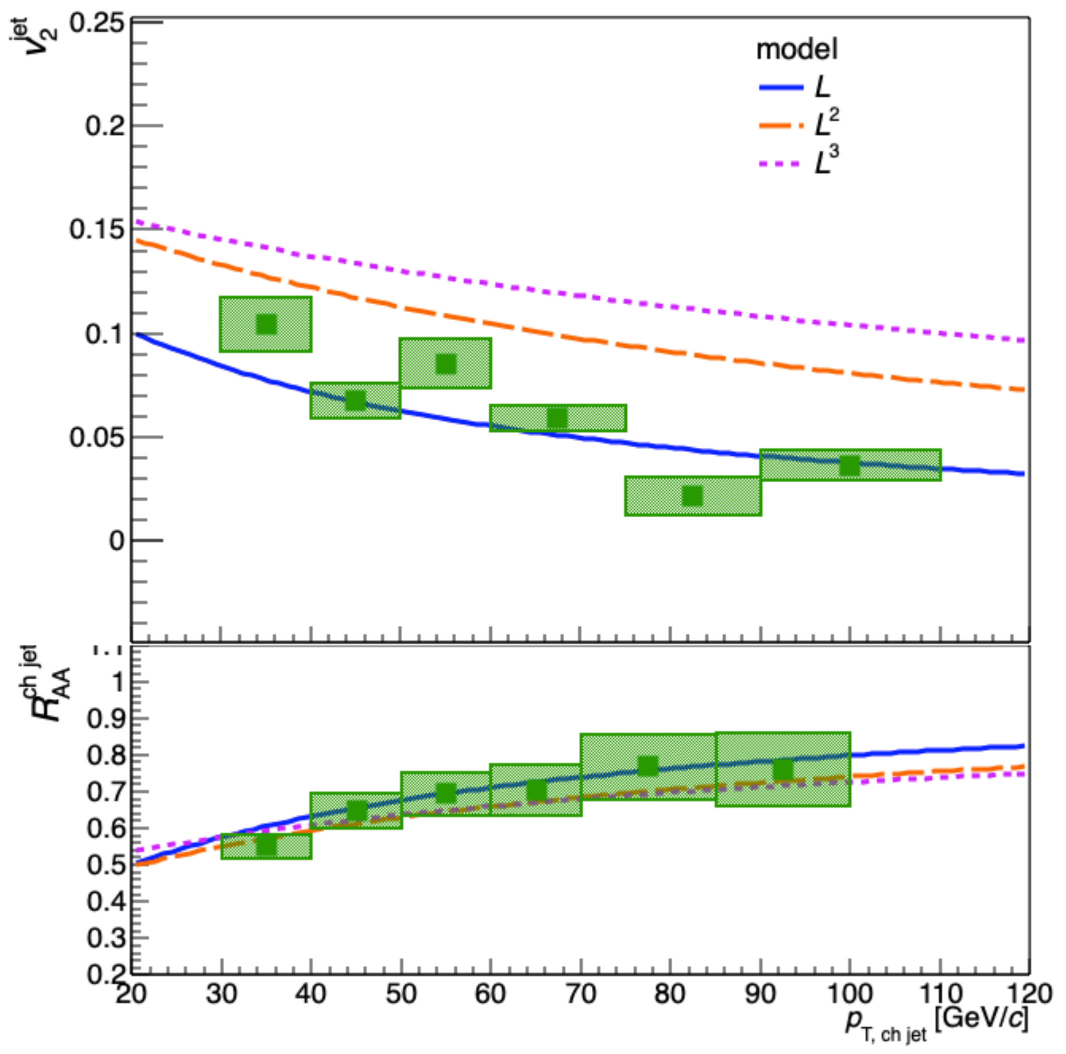


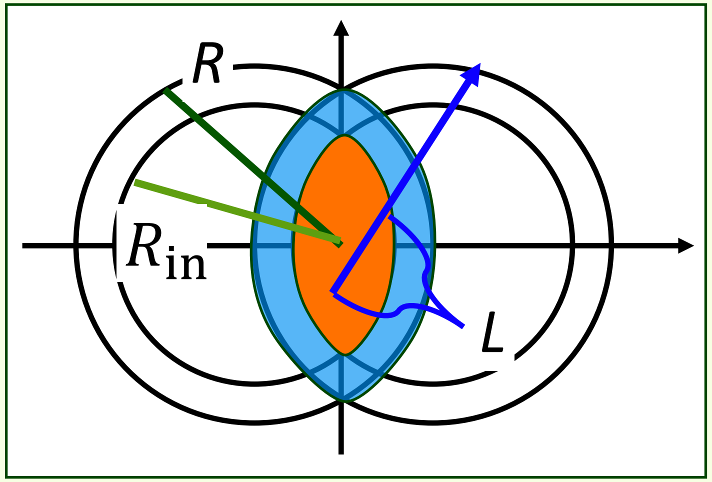
※ Each coefficiency of C is adjusted for each pass length dependency n.

Just n = 1 is the best pass length dependency for parton energy loss.

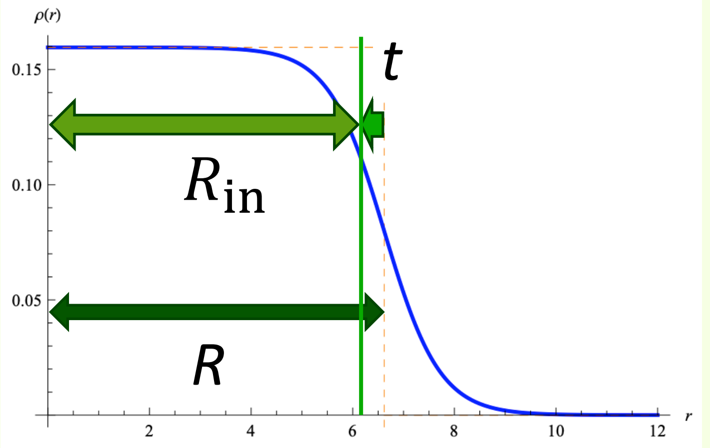
Different pass length edge

Use Tsallis fitting function for model R_{AA} distribution





$$\rho(r) = \frac{\rho_0}{1+\exp(\frac{r-R}{t})}$$



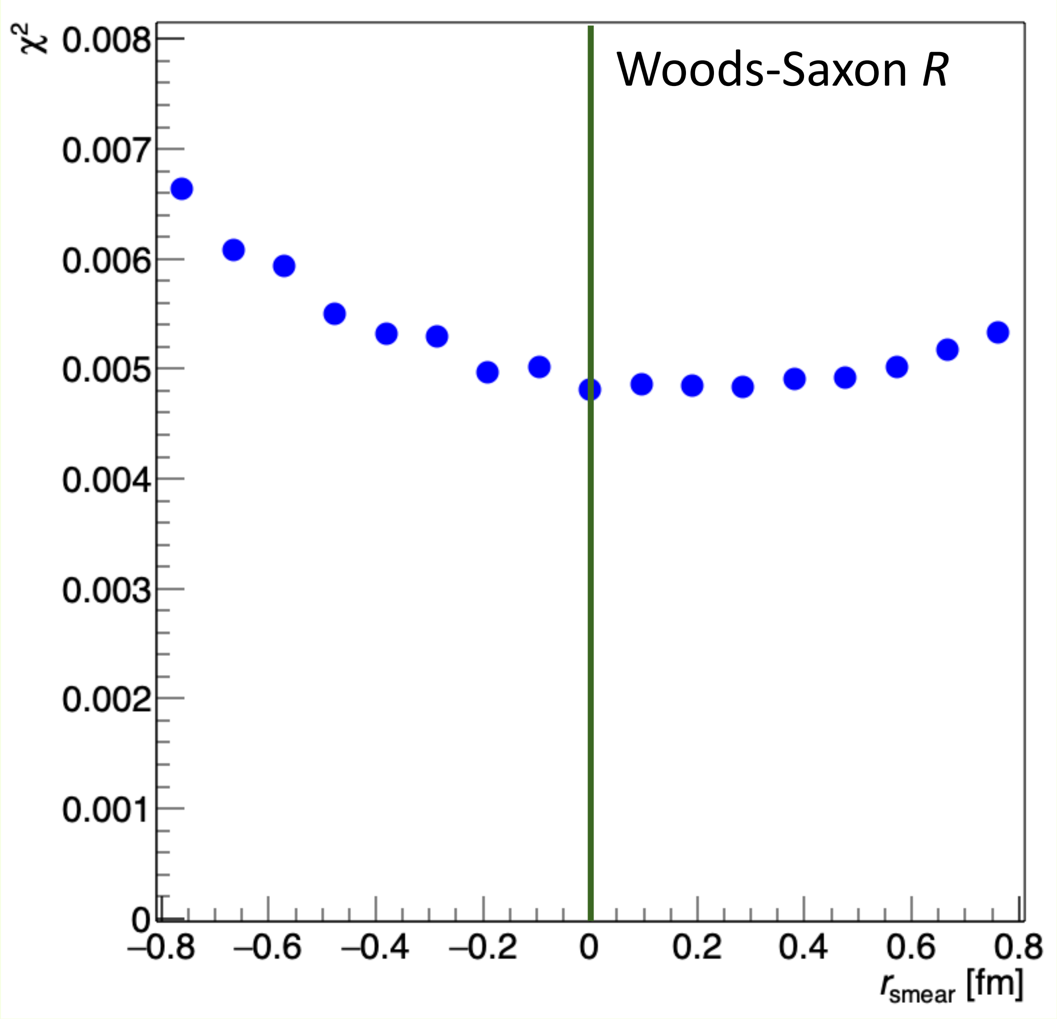
For case of Pb, the values are $t = 0.55$ fm and $R = 6.8$ fm.

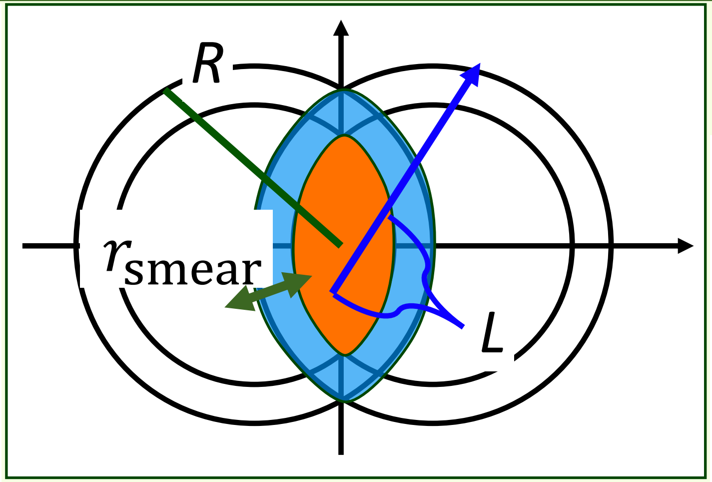
Chi^2/NDF Ch-Jet R_{AA}
(L, L^2, L^3) = (**0.013**, 0.021, 0.023)

Chi^2/NDF Ch-Jet v_2
(L, L^2, L^3) = (**0.0089**, 0.022, 0.031)

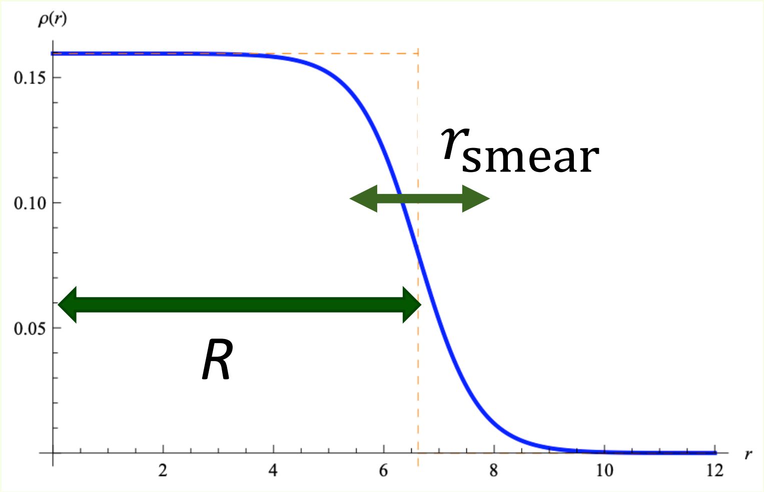
→ Best model is ***dE = CL, (n = 1)***

Best QGP Edge Search





$$\rho(r) = \frac{\rho_0}{1 + \exp(\frac{r-R}{t})}$$



The result of QGP edge indicates the Woods-Saxon R is the best.

→ Every participants contribute the QGP creation, and the thermarization of QGP happenes immediately.

(Do not need to consider density profile and dependency of energy loss for the density.)

Summary and Outlook

- To clarify jet quenching mechanism and estimate its parameters, charged jet v_2 is measured using the ALICE data of Pb–Pb collision $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV.
- The charged jet v_2 in centrality 30-50% show **positive value** and it is **consistent with other experiments**.
- Compare the data resulsts with my very simple toy model
- The simulation indicates that the parton energy loss is propotional to pass length (***dE = CL, (n = 1)***).
- The model with n=1 reproduces well the value and shape of both charged jet R_{AA} and $v_{2.}$
- Determining the quenching parameter requires more complex models in **JETSCAPE**.
- Additional analysis: Different centrality, Different jet resolution R(= 0.1, 0.4)

Backup Slides

JETSCAPE Framework

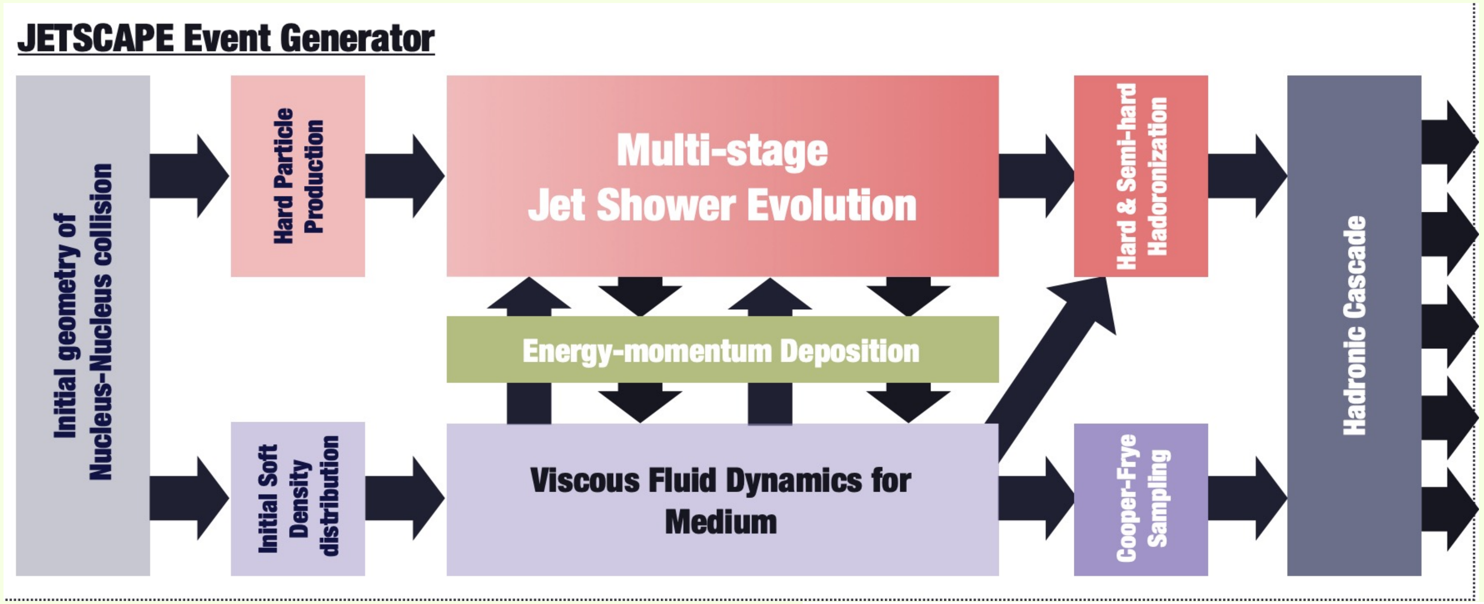


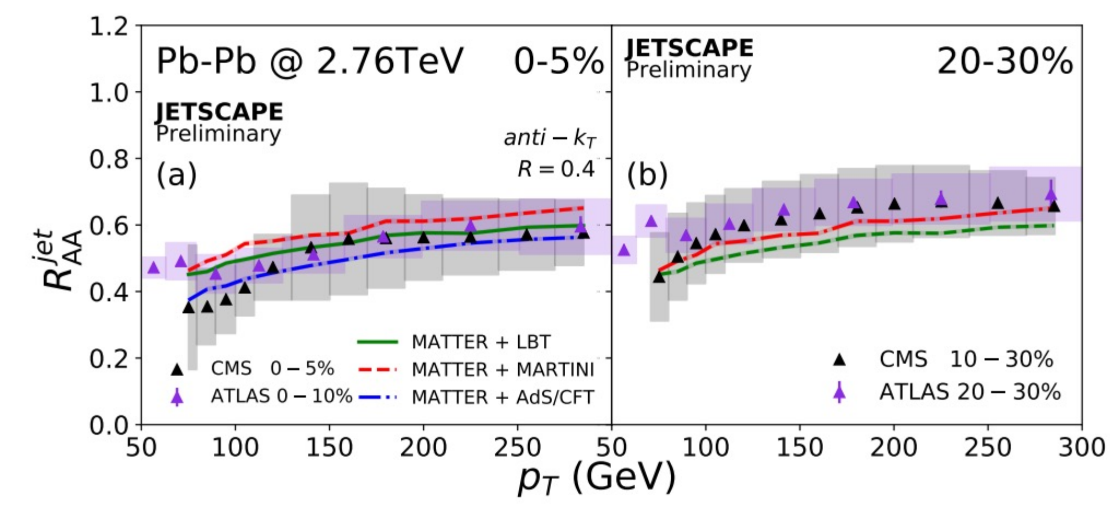
Diagram courtesy Y. Tachibana

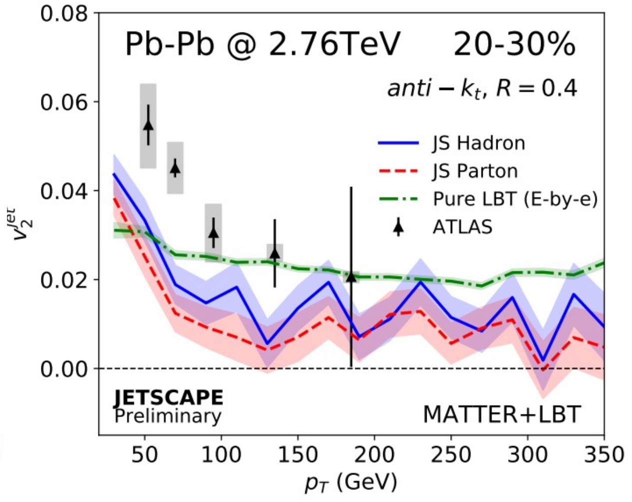
JETSCAPE https://arxiv.org/abs/1903.07706

(Jet Energy-loss Tomography with a Statistically and Computationally Advanced Program Envelope)

- It has $\hat{q}$ **as a variable parameter**.
- Some models having **different L dependency**.

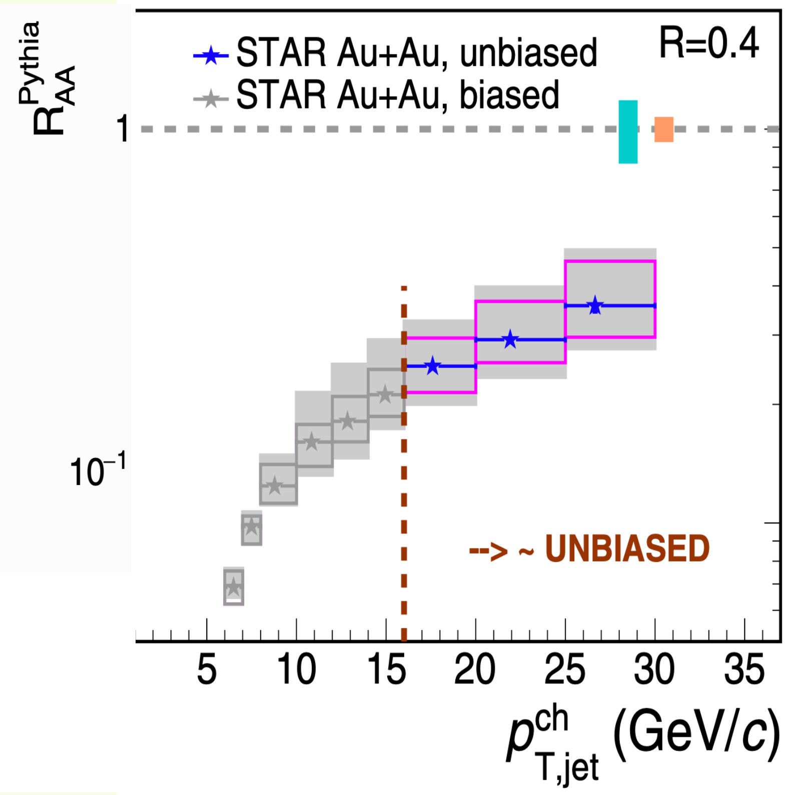
The JETSCPAE already represents close value of the jet R_{AA} and v_2



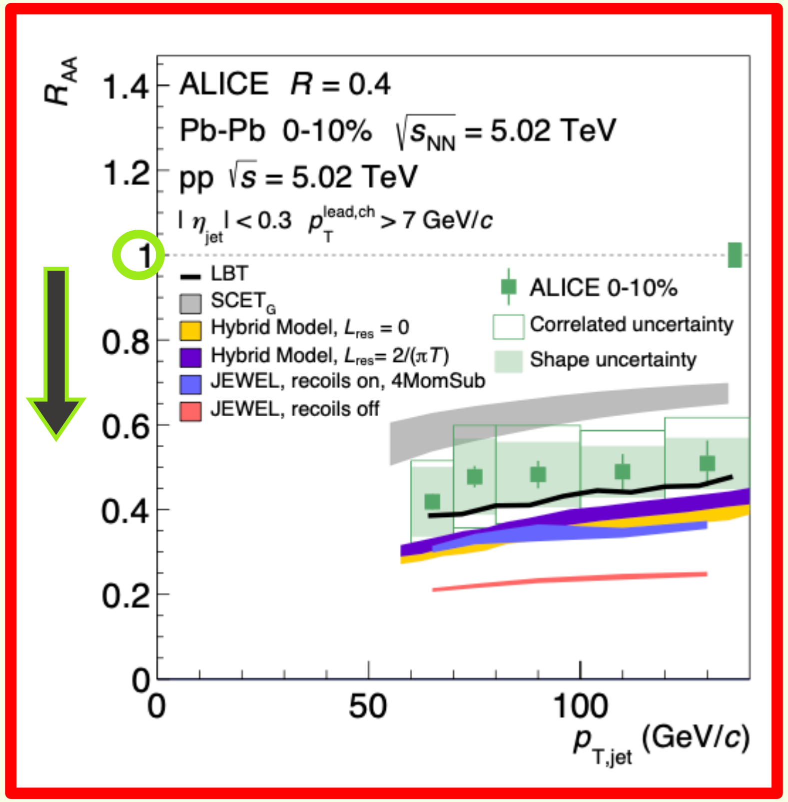


DOI: https://doi.org/10.22323/1.345.0072

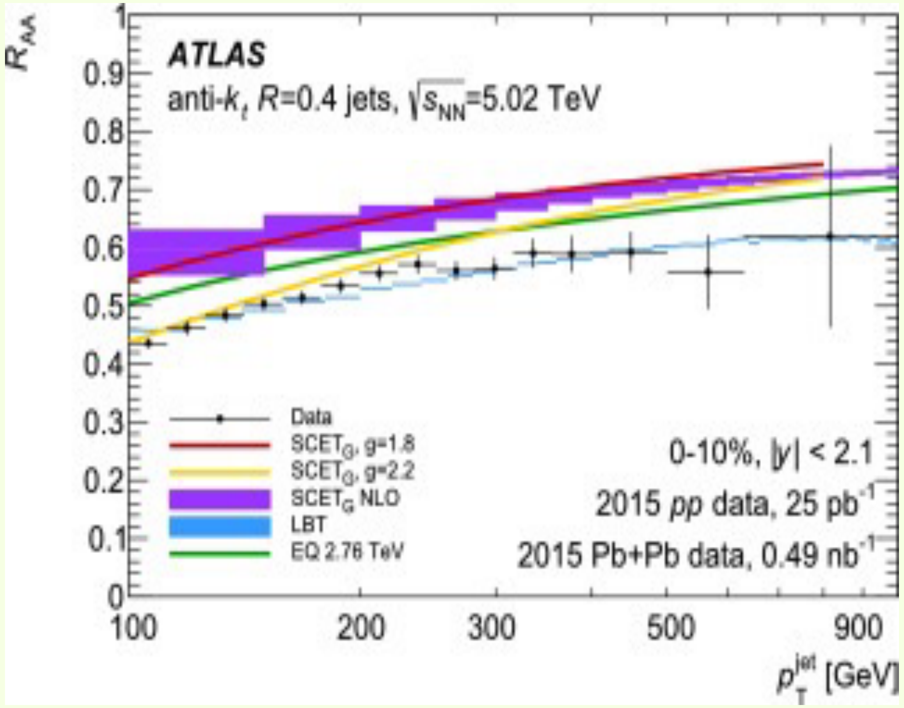
Nuclear modification factor (R_{AA})



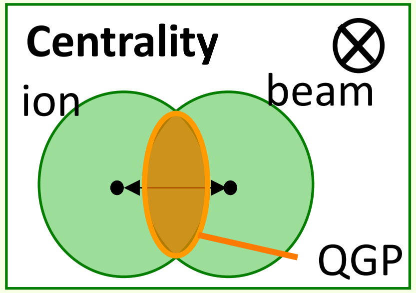
STAR Phys. Rev. C **102** (2020) 054913



ALICE Phys. Rev. C **101** (2018) 034911



ATLAS PLB 790 (2019) 108

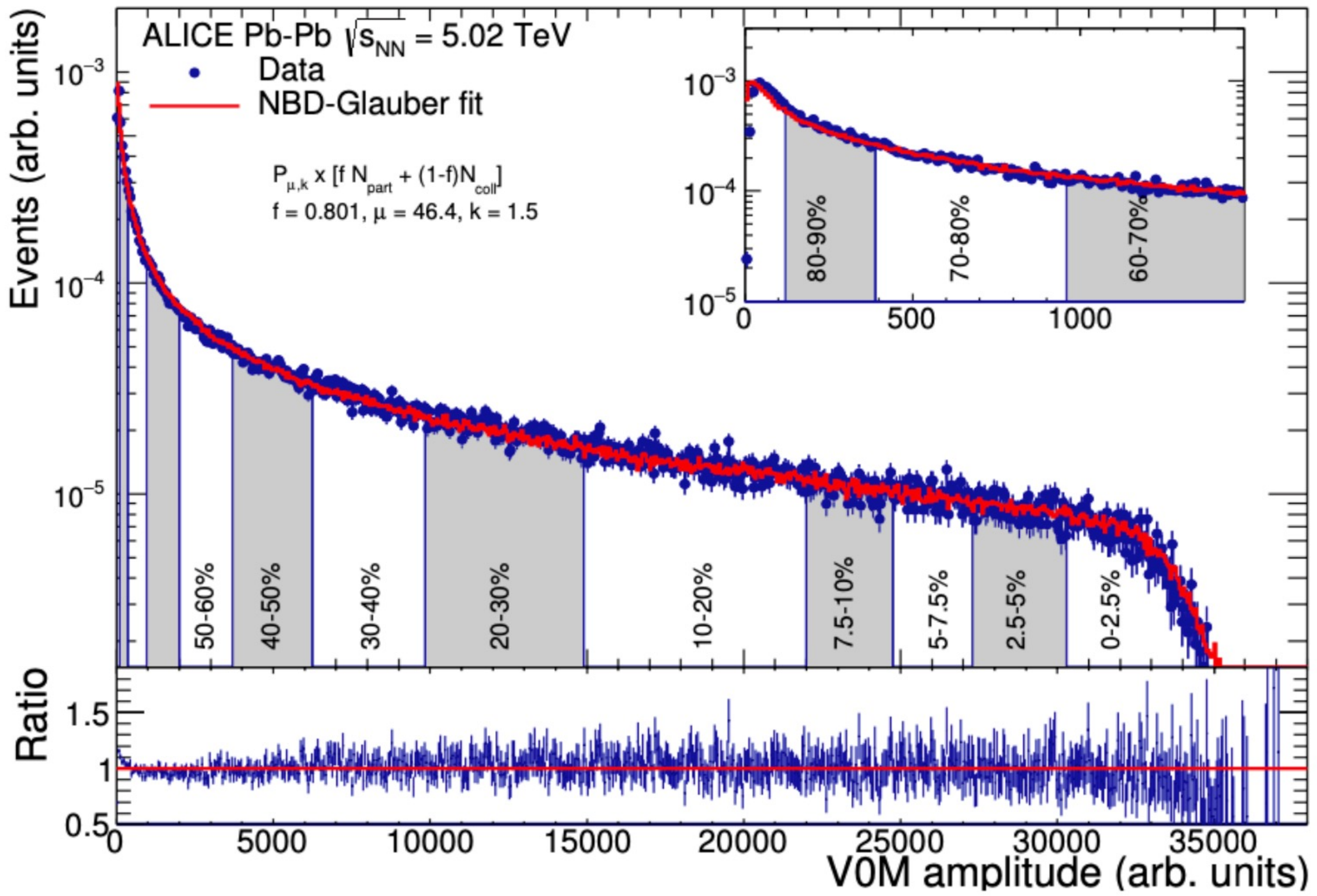


Event Selection

Number of events: 38×10^6 events

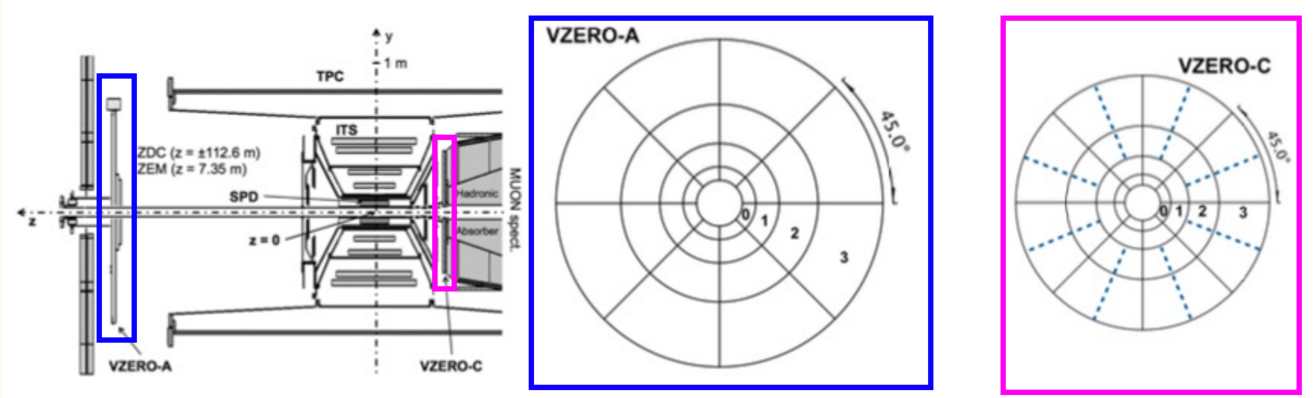
Primary vertex: $|z| < 10$cm.

Centrality determination



Using NBD-Glauber fit for V0M amplitude, the event centrality is determined

Qn vector calibration

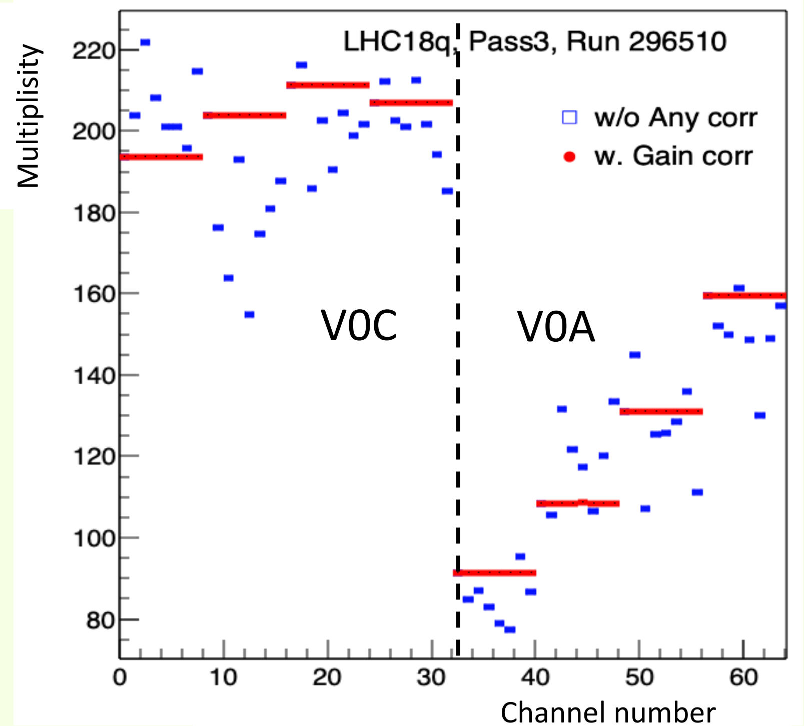


esimated for run-by-run.
Average means the run average.

Gain equalization

$$\omega_{\mathrm{ch}} = M_{\mathrm{i}} \frac{\langle M_{\mathrm{ref}} \rangle}{\langle M_{\mathrm{i}} \rangle}$$

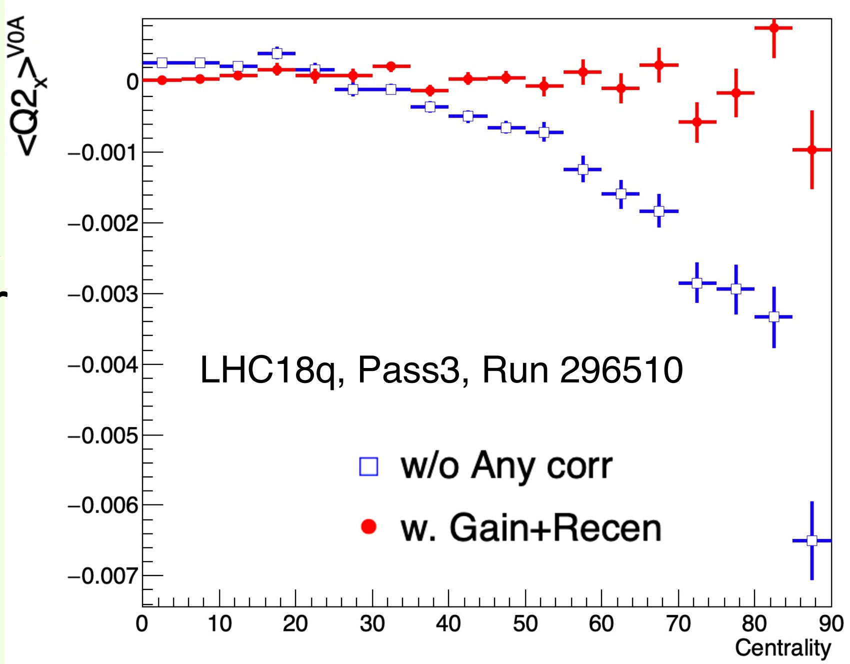
Equalizate gain to uniform the each channel value on the same ring.



Recentring

$$\boldsymbol{Q'}_n = \boldsymbol{Q}_n - \langle \boldsymbol{Q}_n \rangle$$

Equalizate $\boldsymbol{Q}_n$ to uniform for centrality



Event plane angle resolution

$$\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\} = \langle\cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi_n])\rangle = \sqrt{\frac{\langle\cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{b}}_{\mathrm{EP},n}])\rangle\langle\cos(n[\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{c}}_{\mathrm{EP},n}])\rangle}{\langle\cos(n[\Psi^{\mathrm{b}}_{\mathrm{EP},n} - \Psi^{\mathrm{c}}_{\mathrm{EP},n}])\rangle}}$$

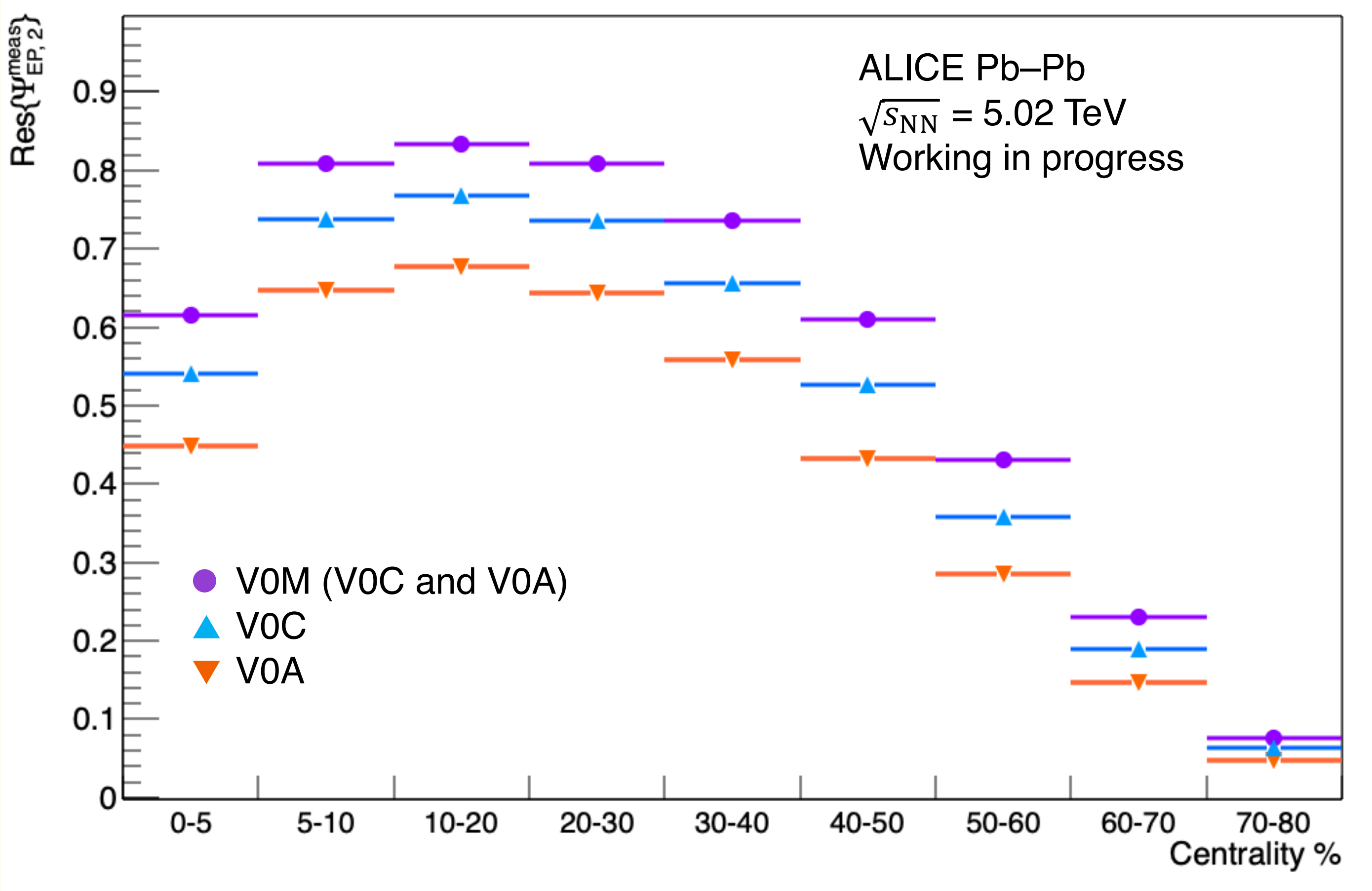
$$v_2^{\mathrm{jet}} = \frac{1}{\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\}}\frac{\pi}{4}\frac{N_{in} - N_{out}}{N_{in} + N_{out}}$$

Ideally, $\Psi^{\mathrm{a}}_{\mathrm{EP},n} - \Psi^{\mathrm{truth}}_{\mathrm{EP},n}$ close to 0.

In that case, $\mathrm{Res}\{\Psi^{\mathrm{meas}}_{\mathrm{EP},2}\}$ close to 1.

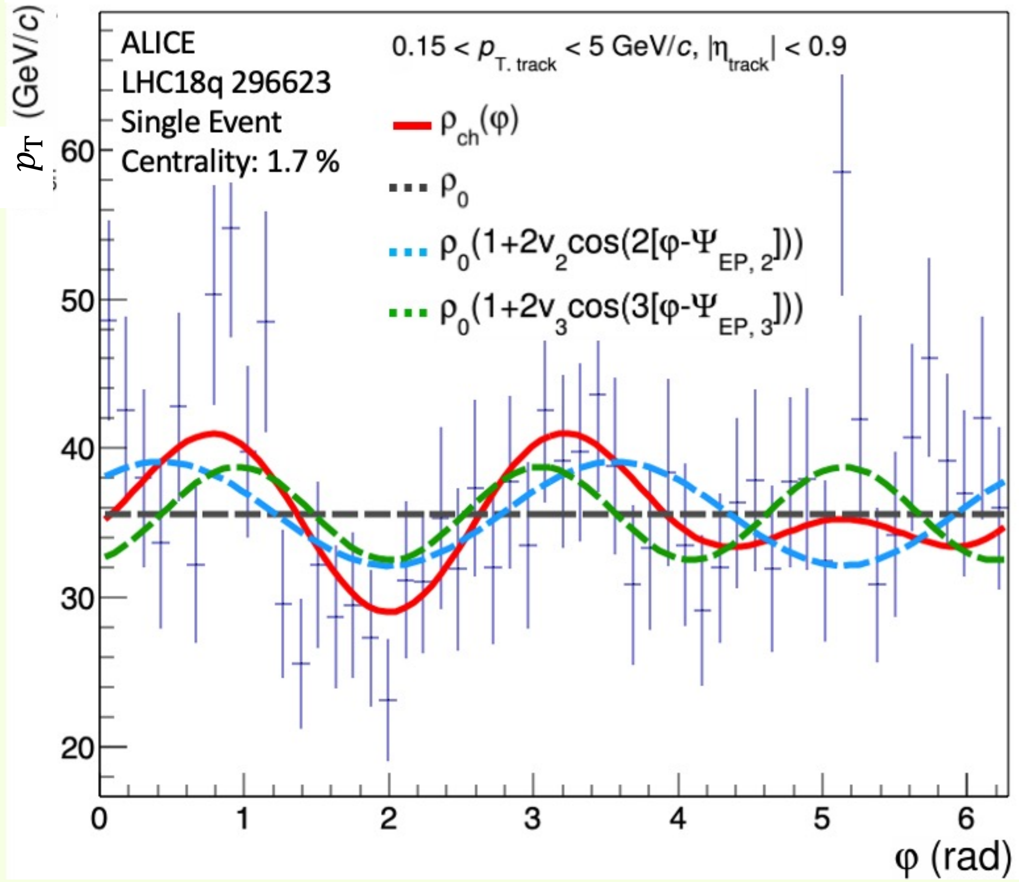
V0 sub-detector

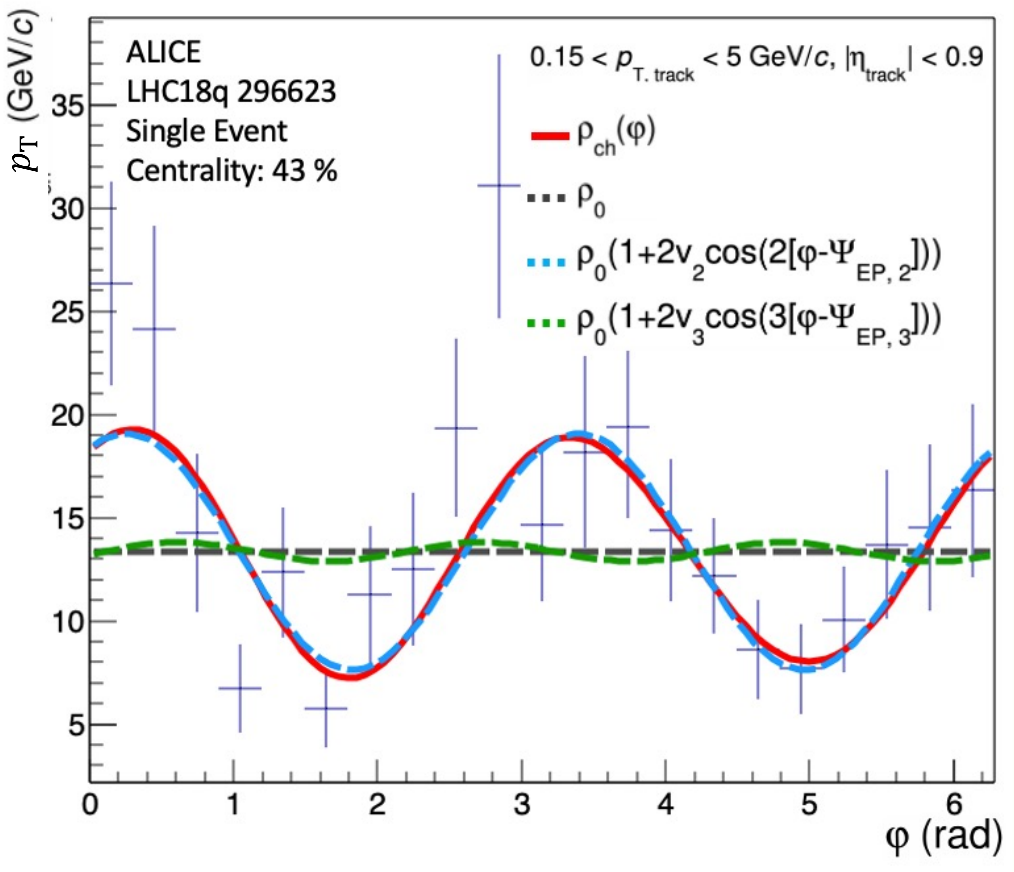
(b: TPC $\eta<0$, c: TPC $\eta>0$)



Local background p_T results

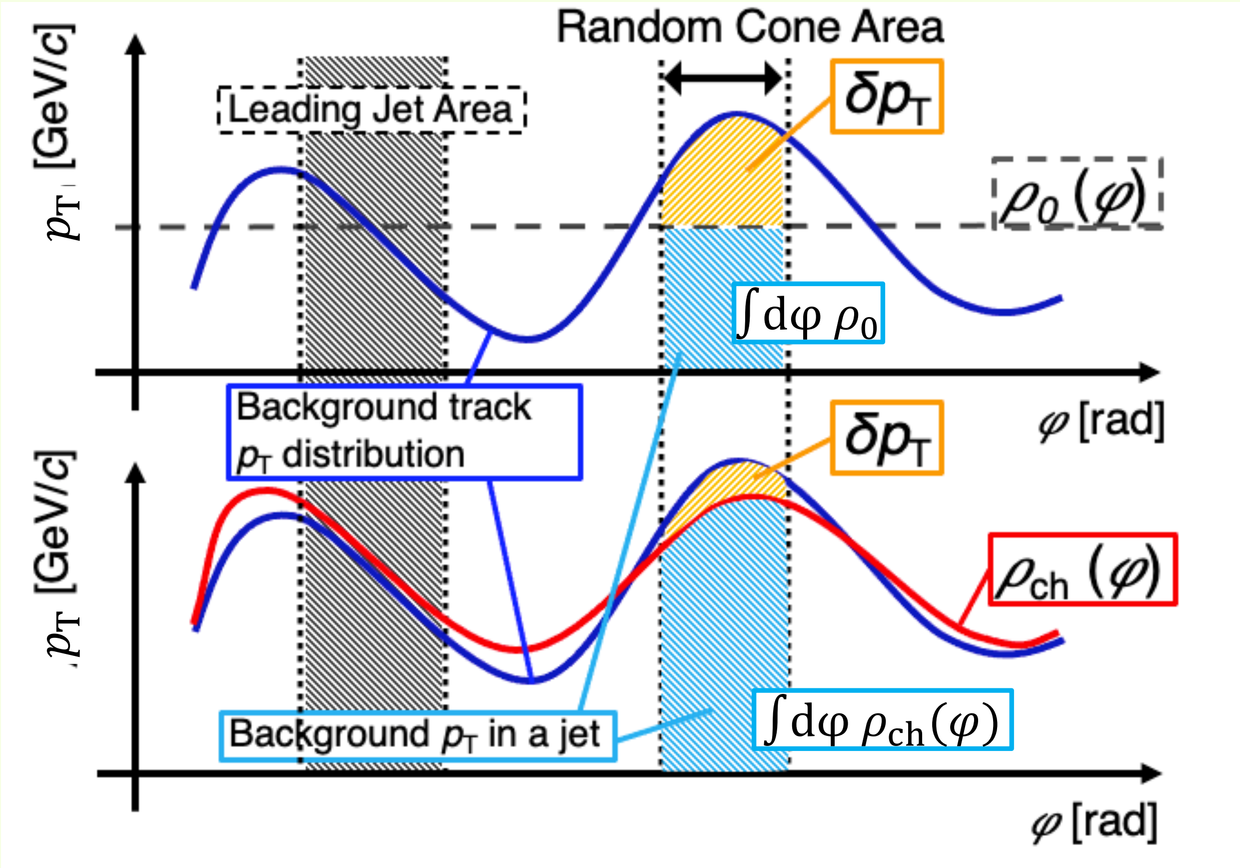
$$\rho_{ch}(\varphi) = \rho_0 \times \left(1 + 2\left\{v_2^{obs}\cos(2[\varphi - \Psi_{EP,2}]) + v_3^{obs}\cos(3[\varphi - \Psi_{EP,3}])\right\}\right)$$





# of bins = $\sqrt{N_{track}}$

Evaluation of background fit (δp_T)

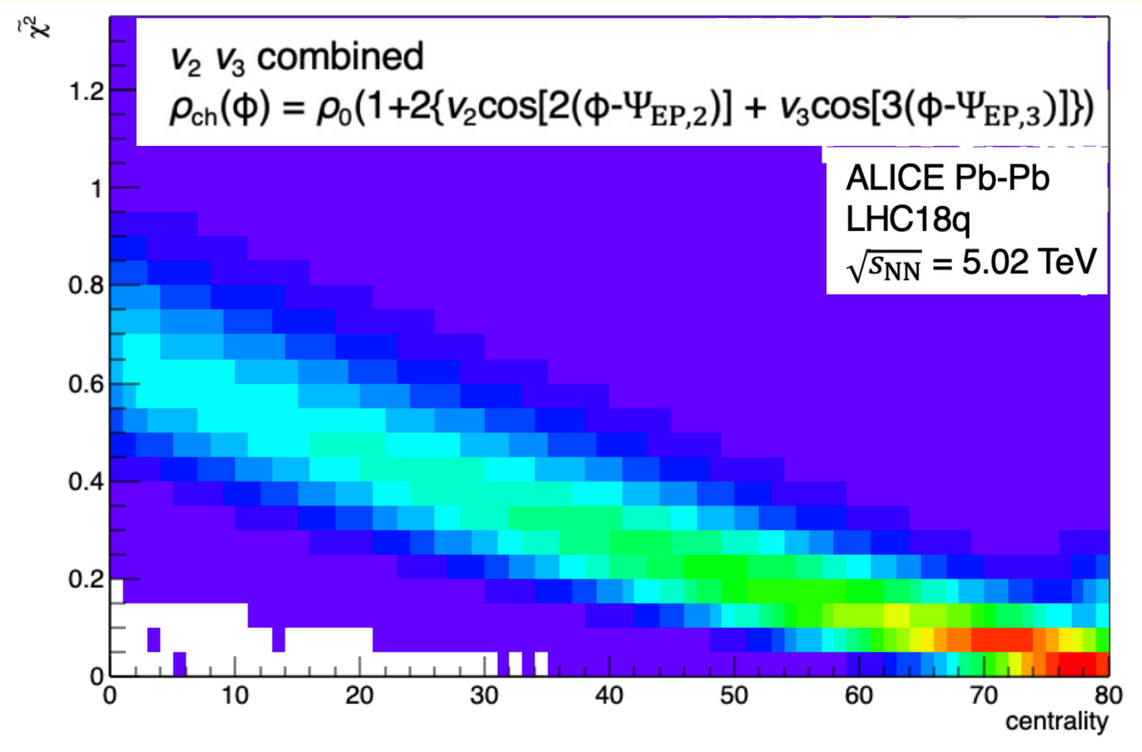


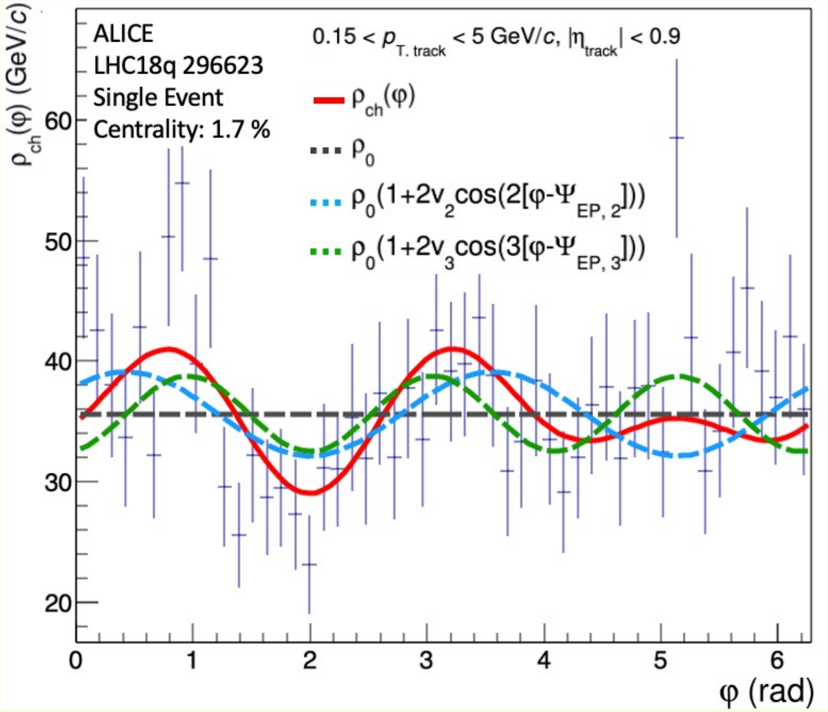
δp_T is a gap between integration of background tracks p_T and integration of background function in a random cone area.

We expect the local rho's δp_T should be smaller than the median one.
And in the local rho case, δp_T phi dependency is expected to make small.

The Random cone is created once per event except the leading jet region.

Background pT function fit quality





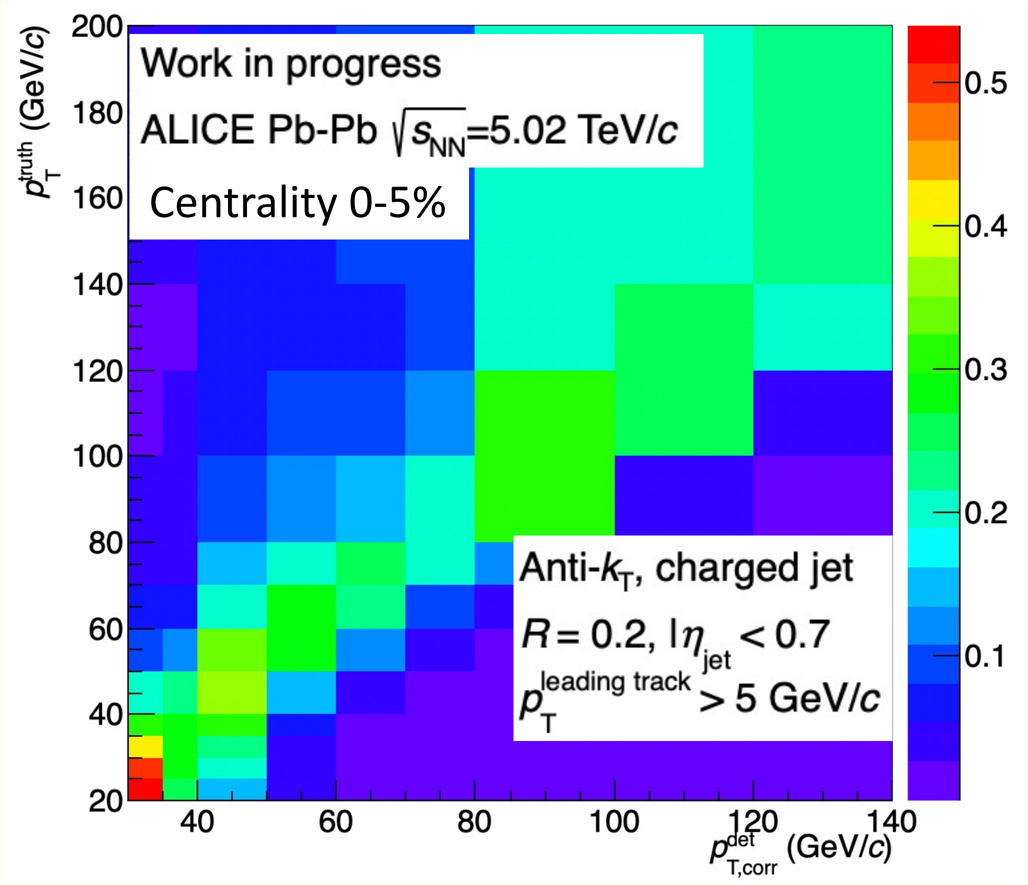
$$\tilde{\chi}^2 = \left(\sum_{n=0}^{i} \frac{\left(p_T^{track} - p_T^{function}\right)^2}{p_T^{track}}\right) \Big/ (\text{\# of bins} - 3)$$

# of free parameters (ρ_0, v_2, v_3)

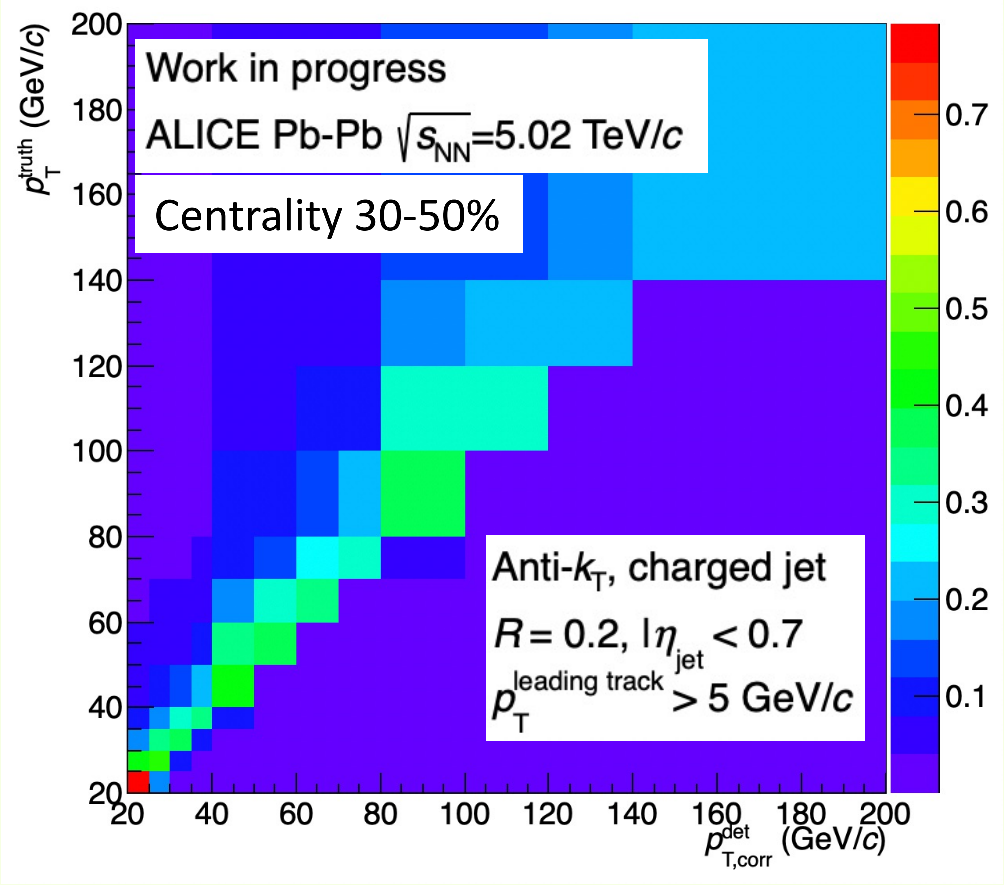
$\tilde{\chi}^2$ is smaller than 1. → Fitting quality is good.

Response Matrix

Centrality 0-5%



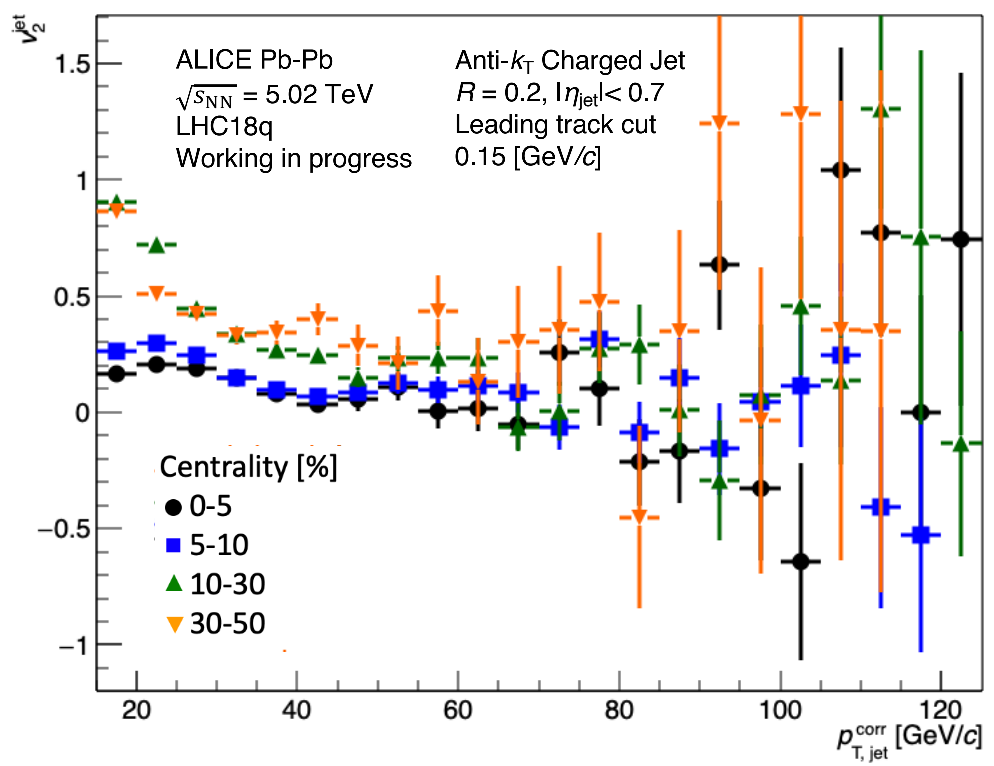
Centrality 30-50%



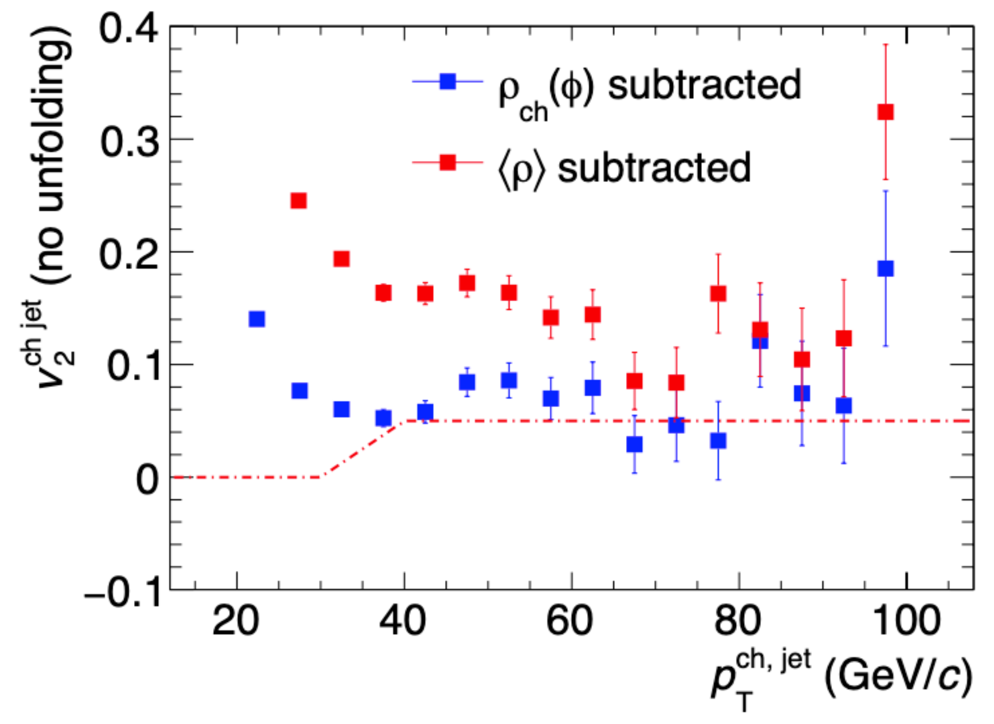
The corrilation between particle level and detector level jets seems well.
→ Embedding working well.

Raw charged jet v_2 (R=0.2)

$$v_2^{\mathrm{jet}} = \frac{1}{\mathrm{Res}\left\{\psi_2^{meas}\right\}} \frac{\pi}{4} \frac{N_{in} - N_{out}}{N_{in} + N_{out}}$$



Run1 ($\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV) Result (centrality ?)



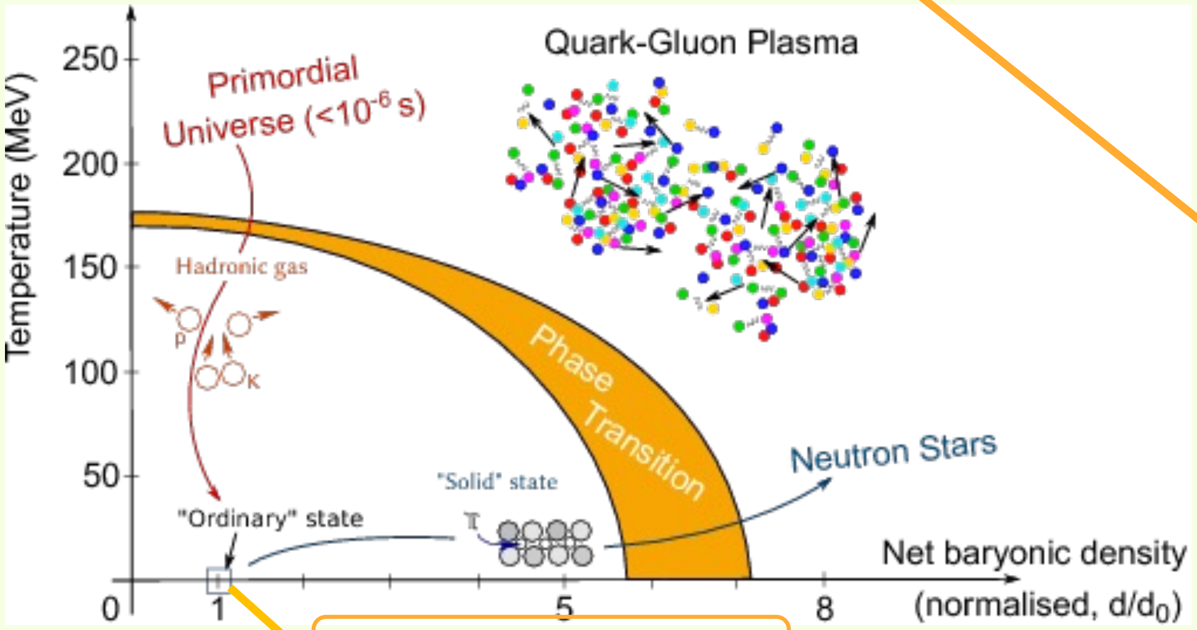
Value of jet v_2 is close to Run1 ($\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV) results.
And the shape around 20 – 60 GeV/c is also similar with Run1 results.

ASW model

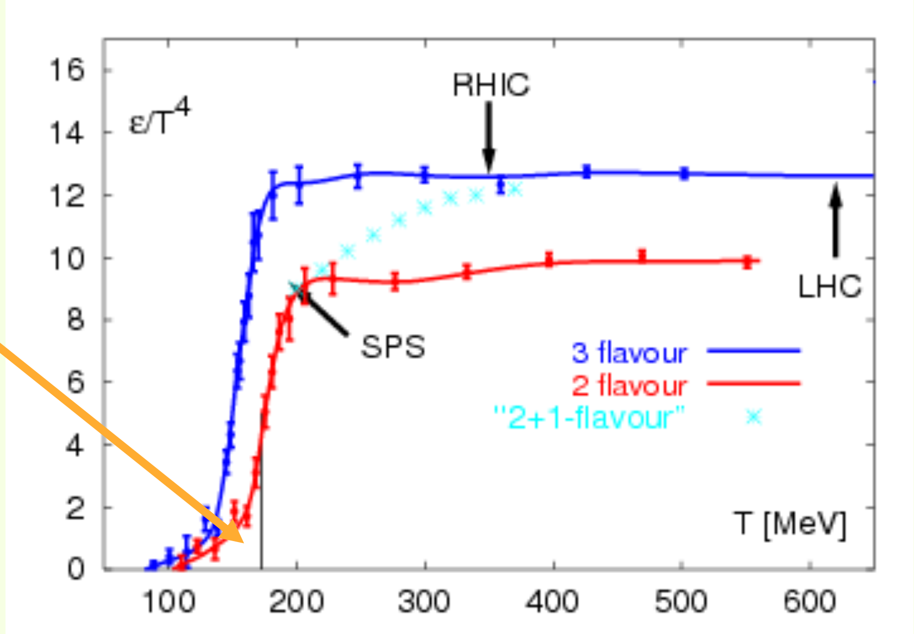
- Midium: Gyulassy-Wang model（A center of scattering is stationary, The transfer momentum is about Debye mass(μ)）
- Multiple emition: Independent random scattering→Poisson distribution
- Emitted gluons: soft

Quark-Gluon Plasma (QGP) is a state of matter made of deconfined quarks and gluons

- Predicted by QCD theory
- Formed at high temperature and/or density
- QGP has existed in the *early Universe* ($\approx 10^{-6}\ s$ after the Big Bang)
- Critical temperature $T_C = 173 \pm 15\ \mathrm{MeV}, \epsilon_c \sim 0.7\ \mathrm{GeV/fm^3}$ from Lattice QCD calculations



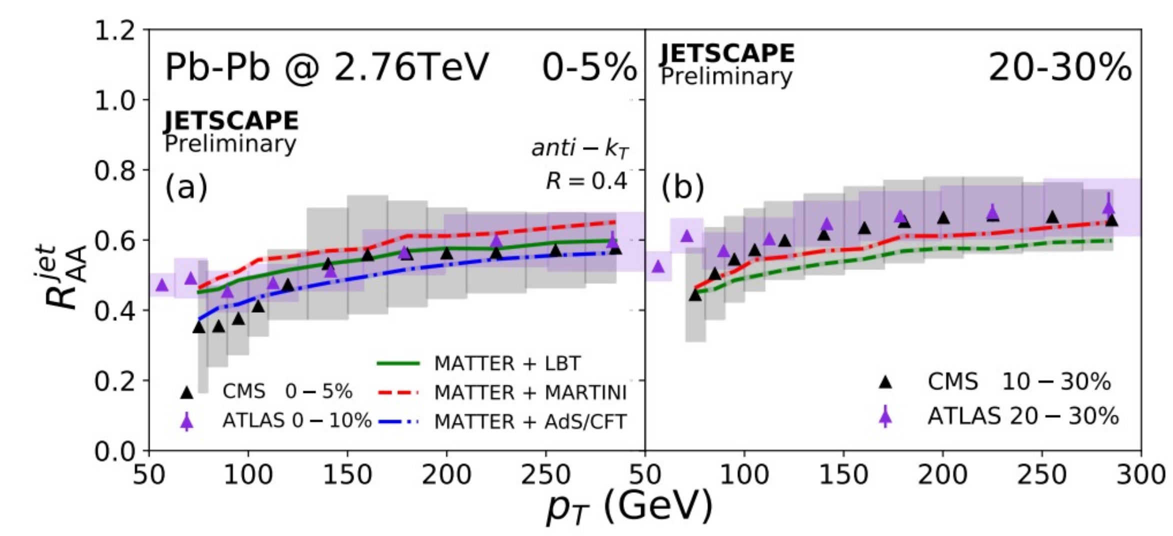
$\rho_0 \approx 0.15\ \mathrm{GeV}/fm^3$

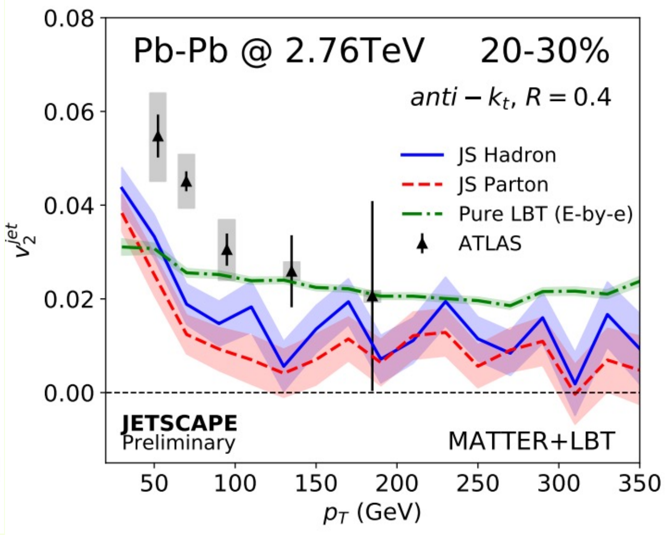


arXiv:1304.1452v1

- **JETSCAPE** (Jet Energy-loss Tomography with a Statistically and Computationally Advanced Program Envelope): https://arxiv.org/abs/1903.07706

1.Initial state → 2. Hydrodynamics → 3. Jet energy loss → 4. Hadronization





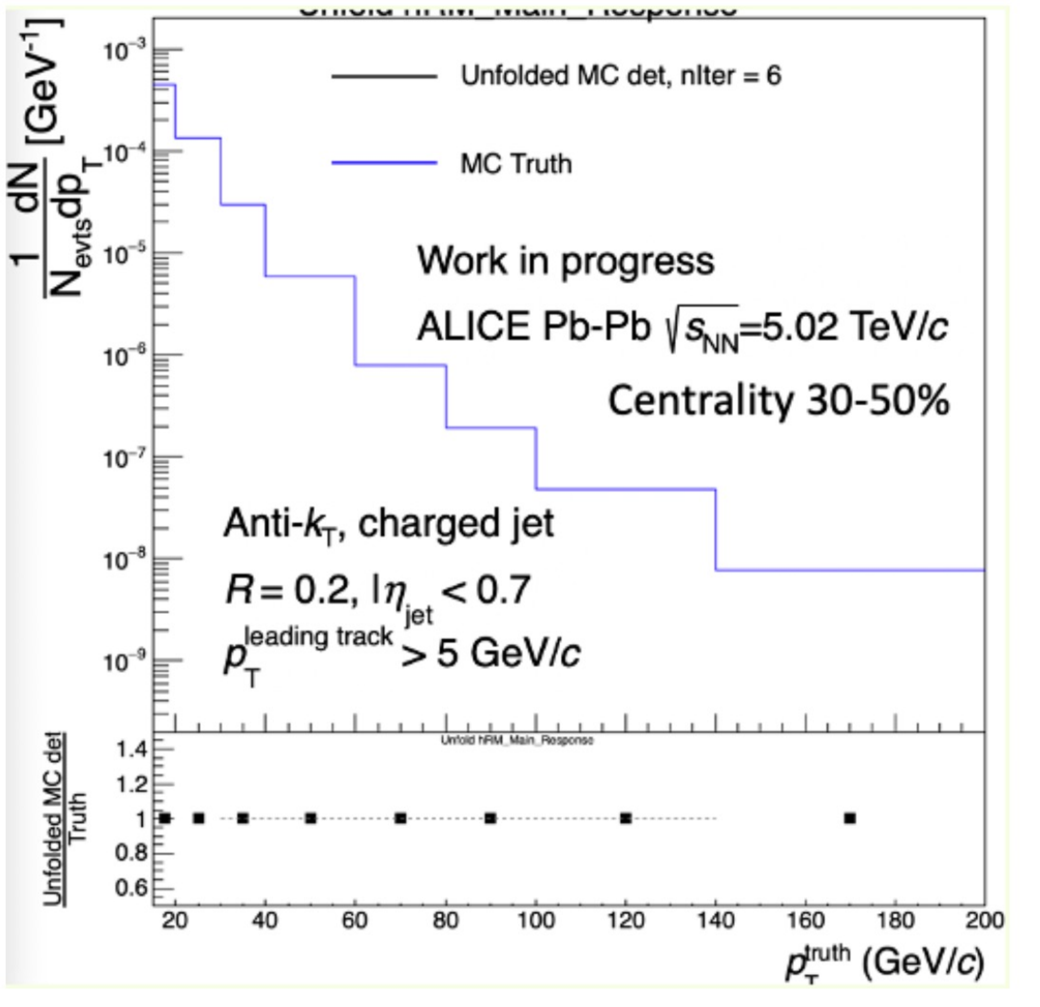
DOI: https://doi.org/10.22323/1.345.0072

The preceding study of JETSCAPE shows the jet transport coefficient $\hat{q}$ by comparing the result of R_{AA} in the two centralities of CMS/ATLAS

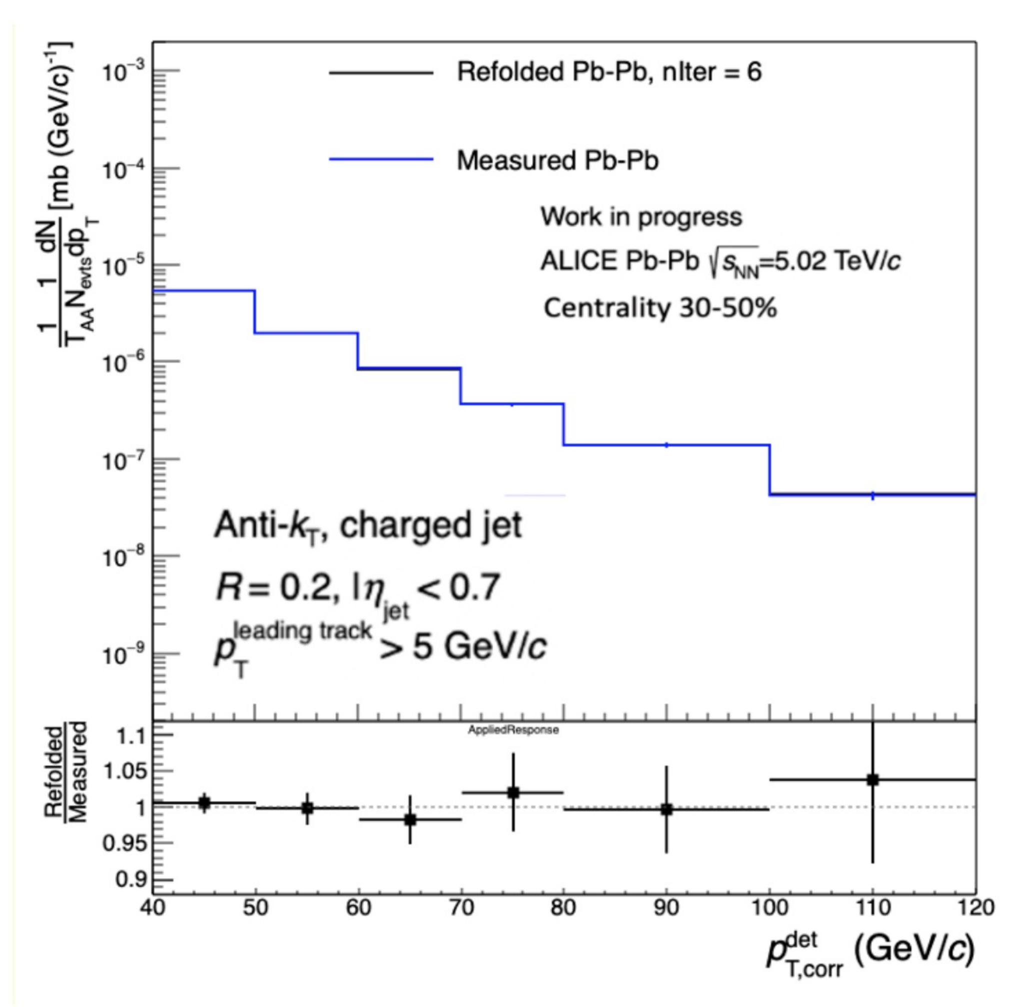
This study will constrain models and give more accurate the $\hat{q}$ value by more various centrality information and low p_T range distribution.

Unfolding QA

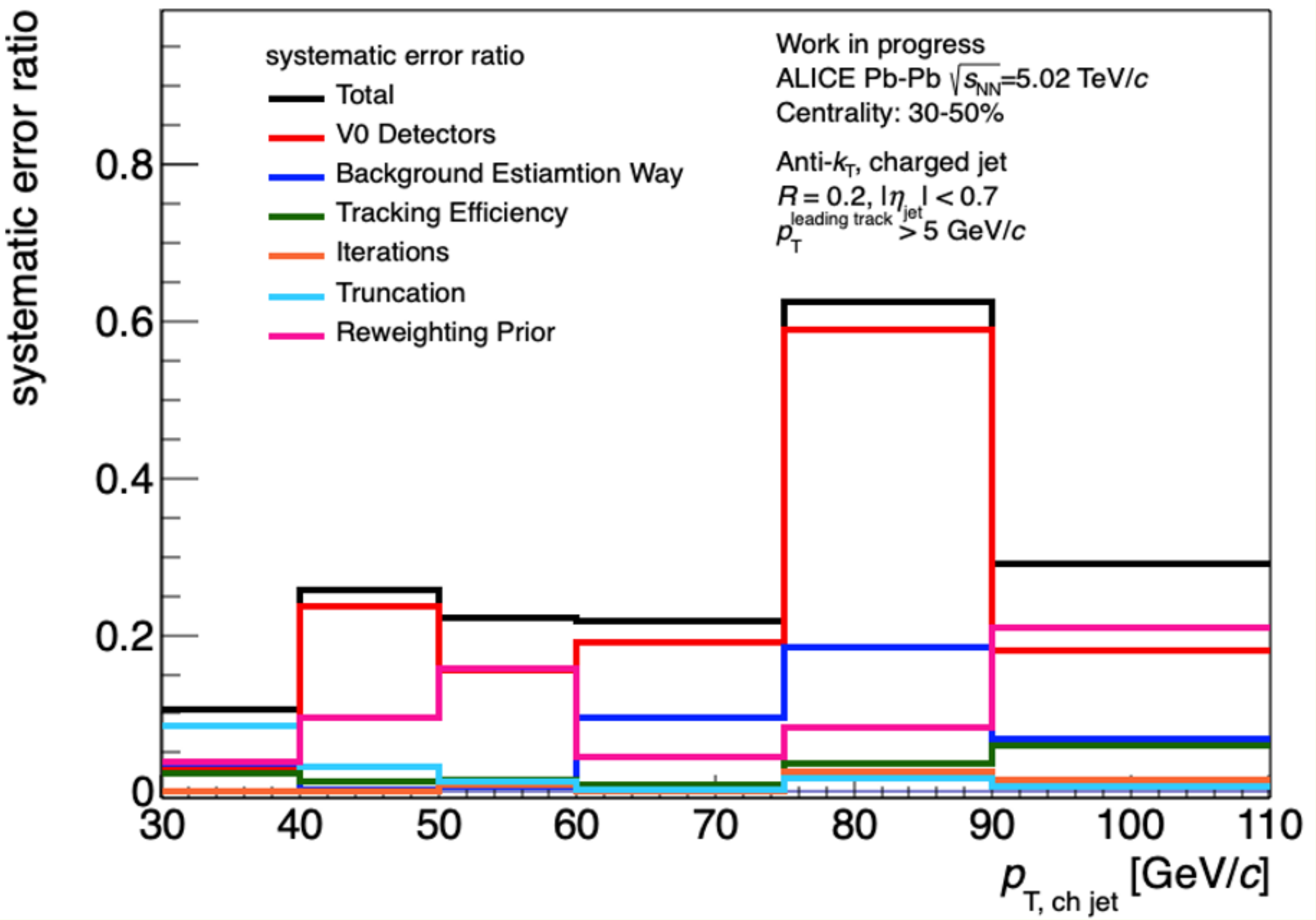
Closure test



ReFolding test

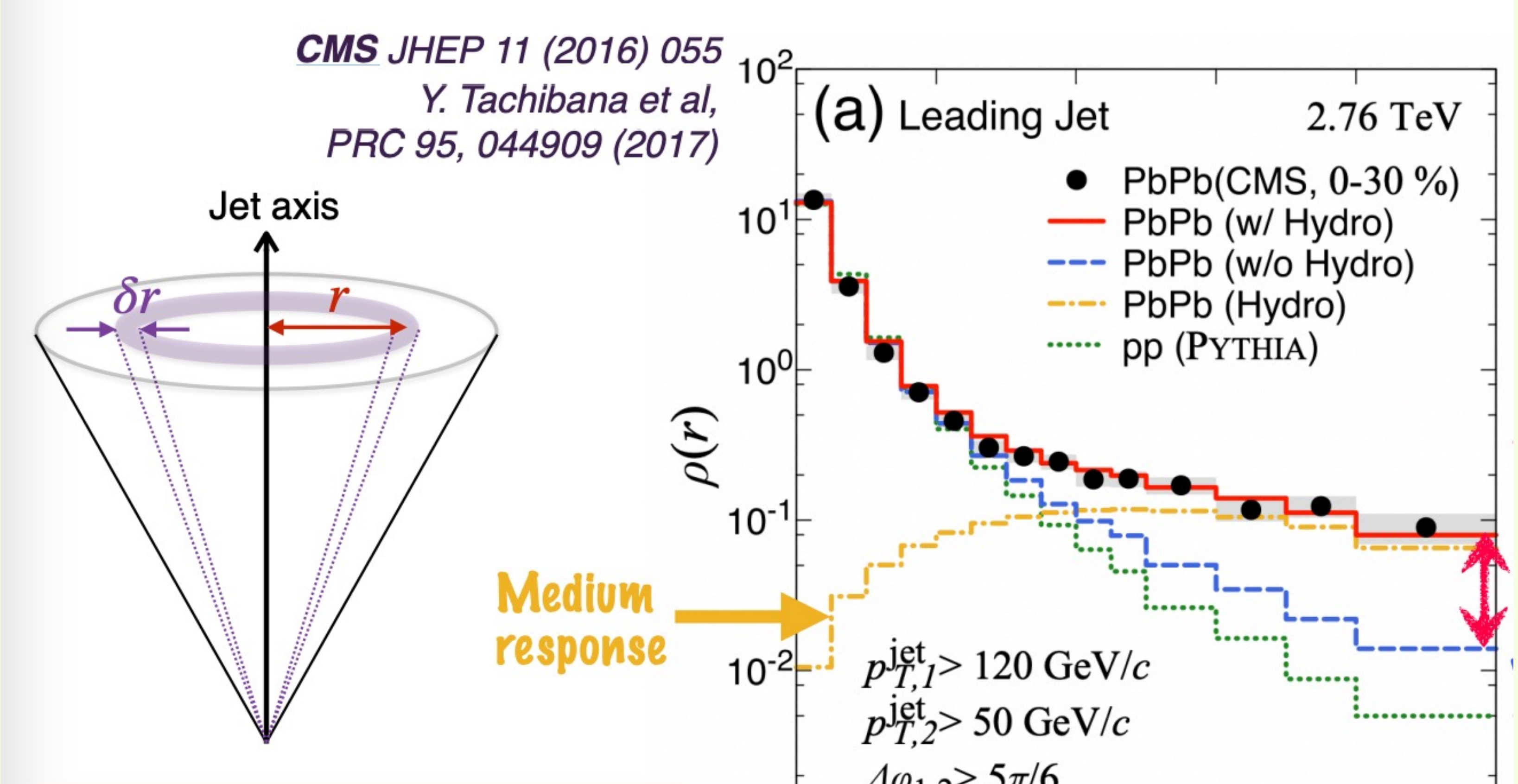


Systematic Error Ratio



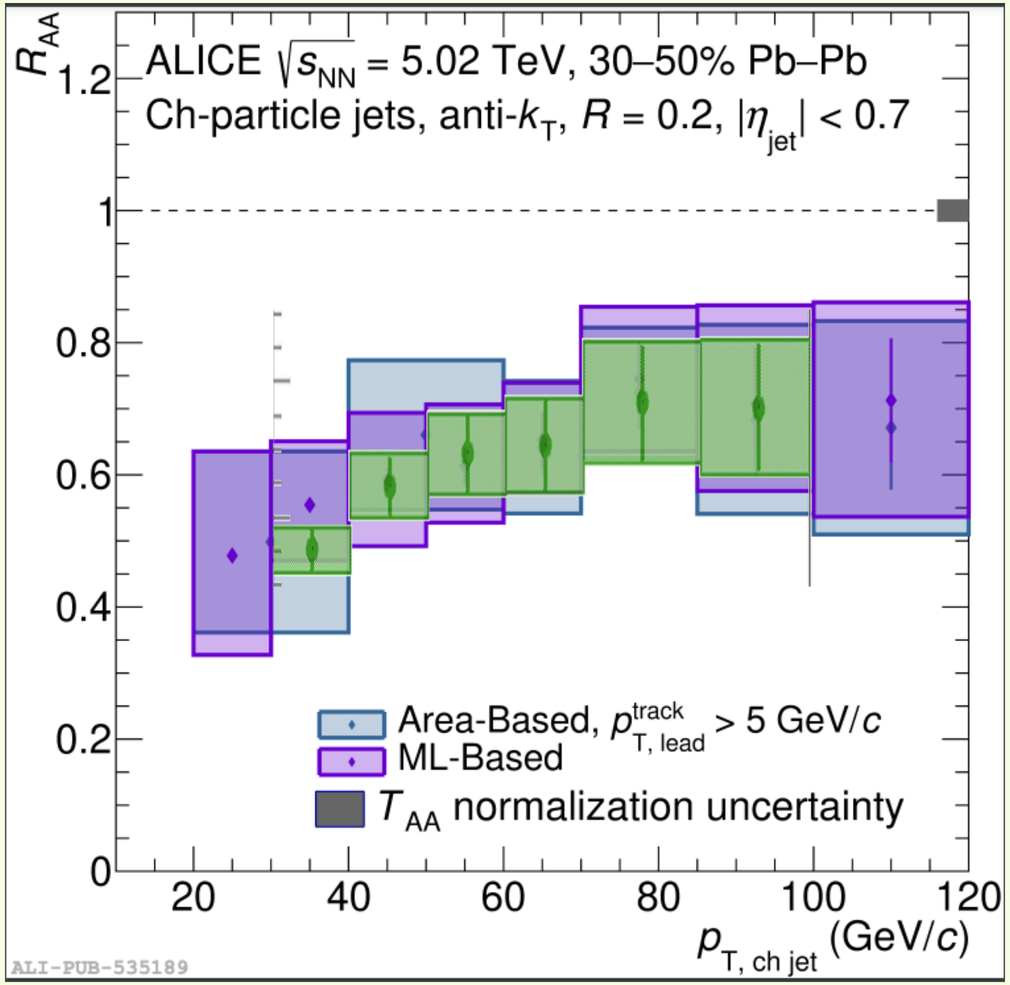
- $\delta_{sys} = \frac{|obs^{com} - obs^{Nomi}|}{obs^{Nomi}}$
- For all p_T range, the systematic error is lower than 1.
- The reason of the large error on 80-90 GeV/c is the observable value is very small.

R dependency



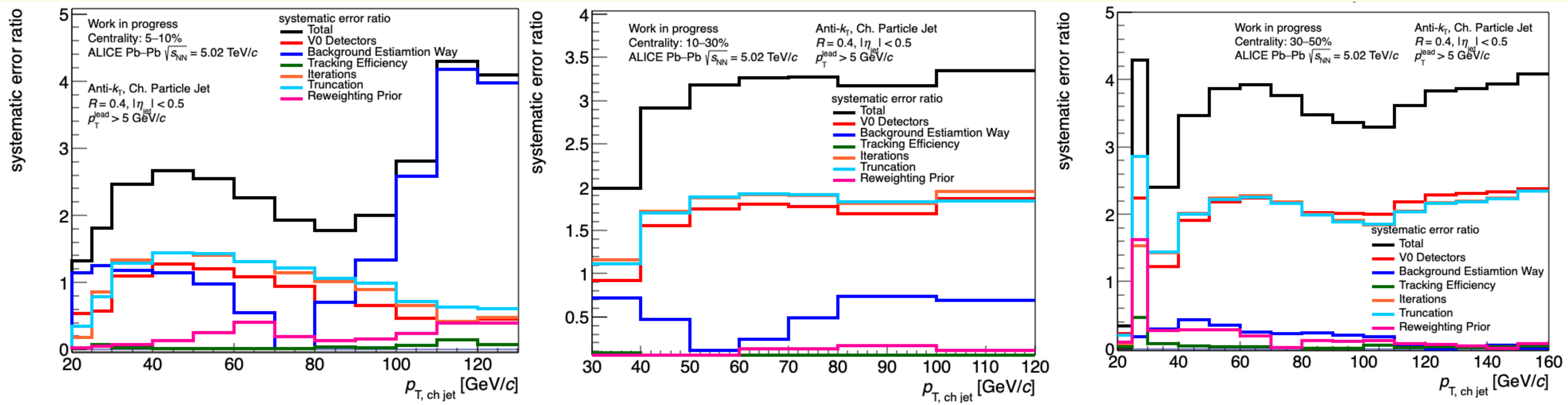
$$\rho_{\rm jet}(r) = \frac{1}{N_{\rm jet}} \sum_{\rm jet} \left[\frac{1}{p_{\rm T}^{\rm jet}} \frac{\sum_{{\rm trk} \in (r-\delta r/2, r+\delta r/2)} p_{\rm T}^{\rm trk}}{\delta r} \right]$$

Compare my results of R_{AA} with Hannah analysis results



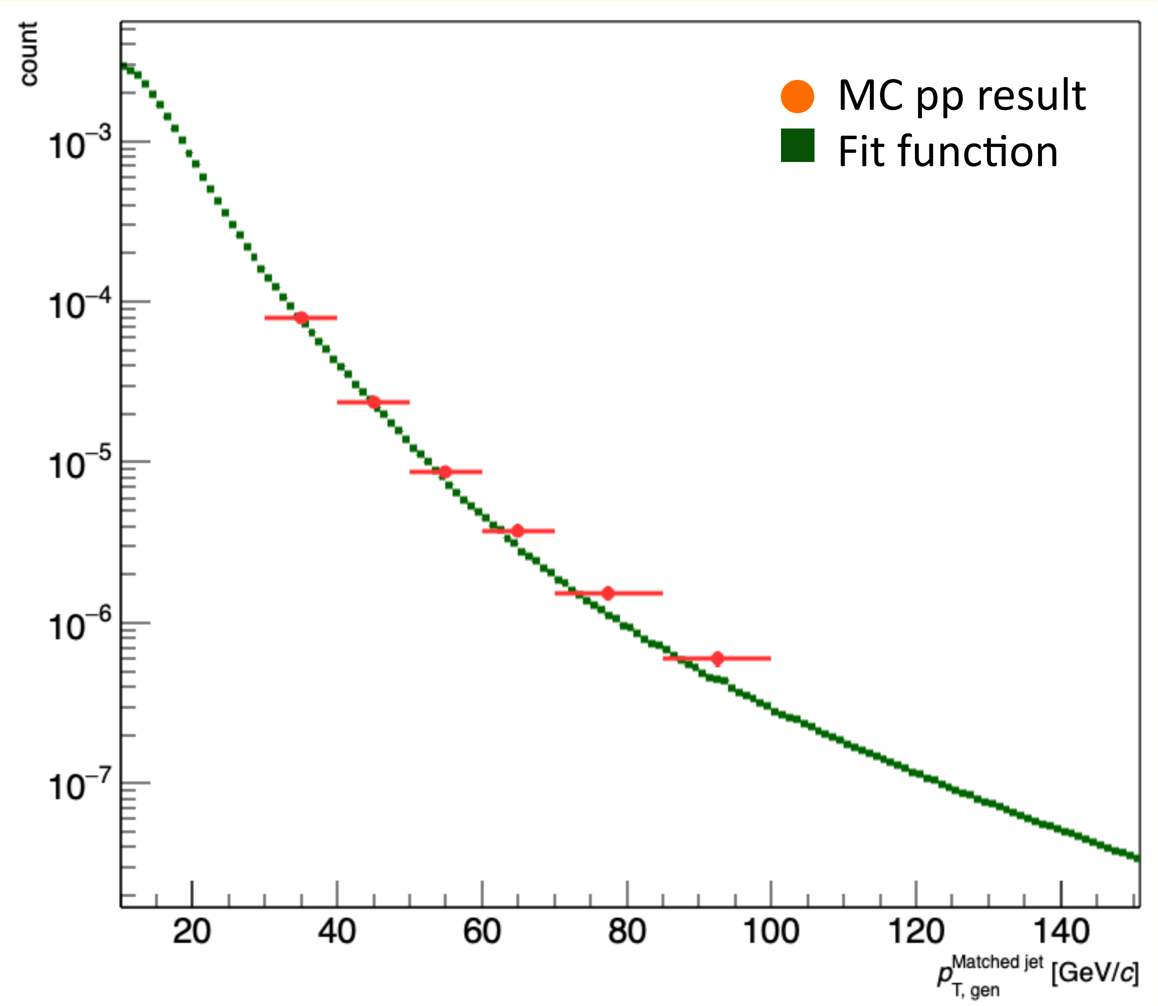
Centrality 30-50% result is consistent with Hannah's result

Systematic uncertainty of R = 0.4

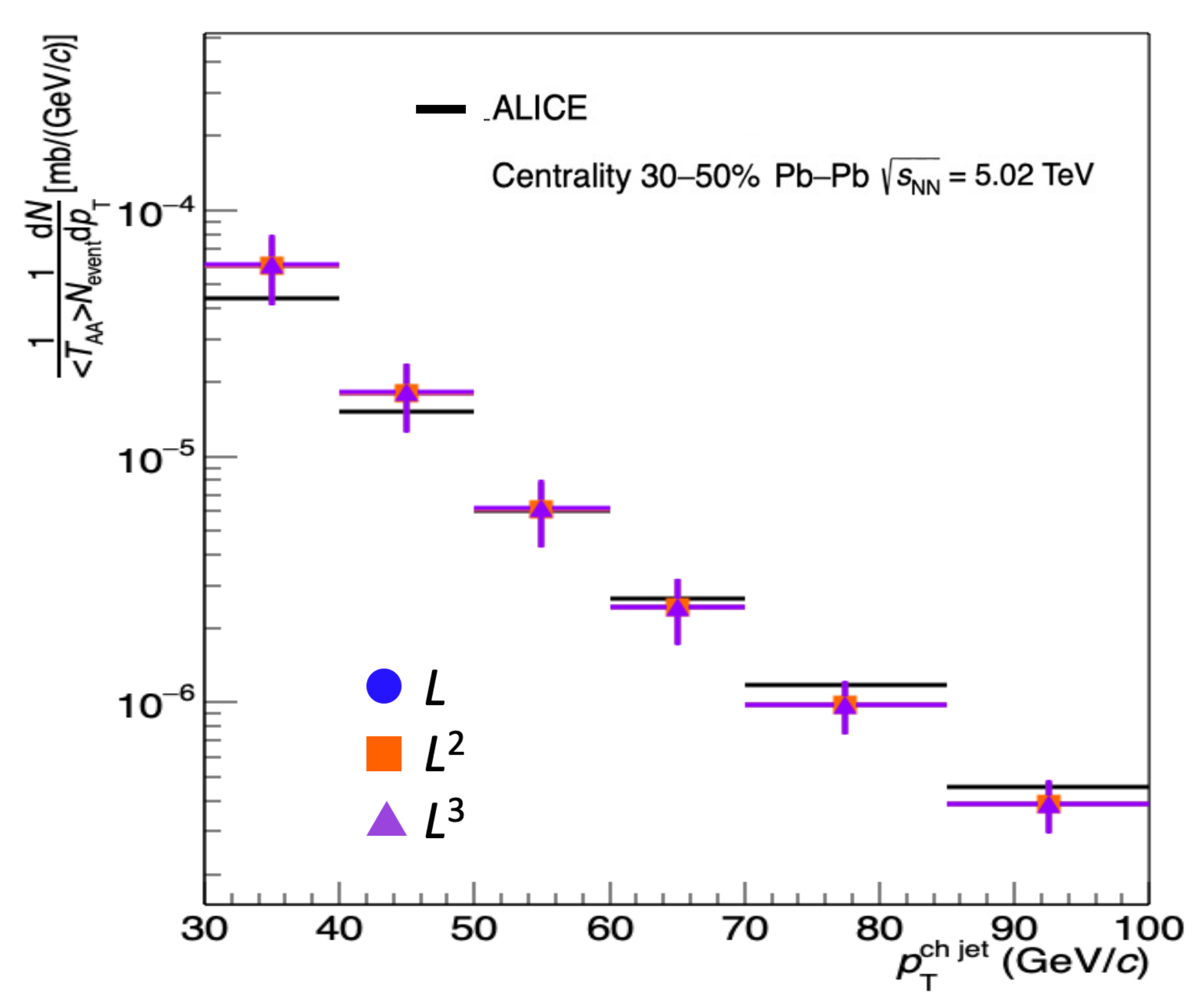


- For all centralities, itelation, V0Detector, and Turnication are very large.
- Background efficiency also too large.

Simulation fitting to data results

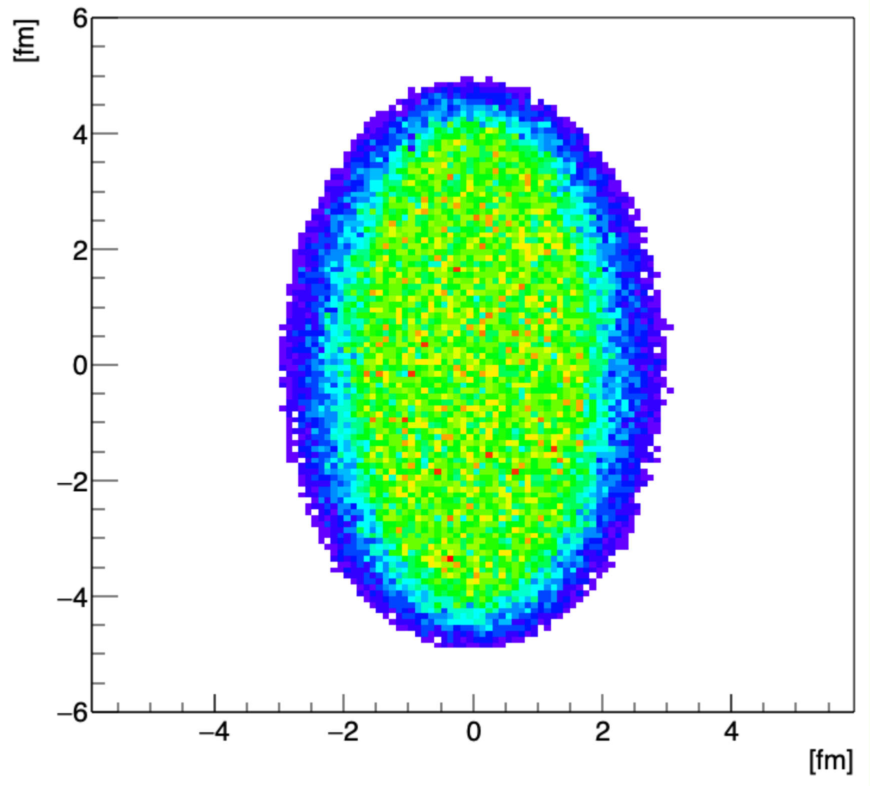


pp jet p_T distribution

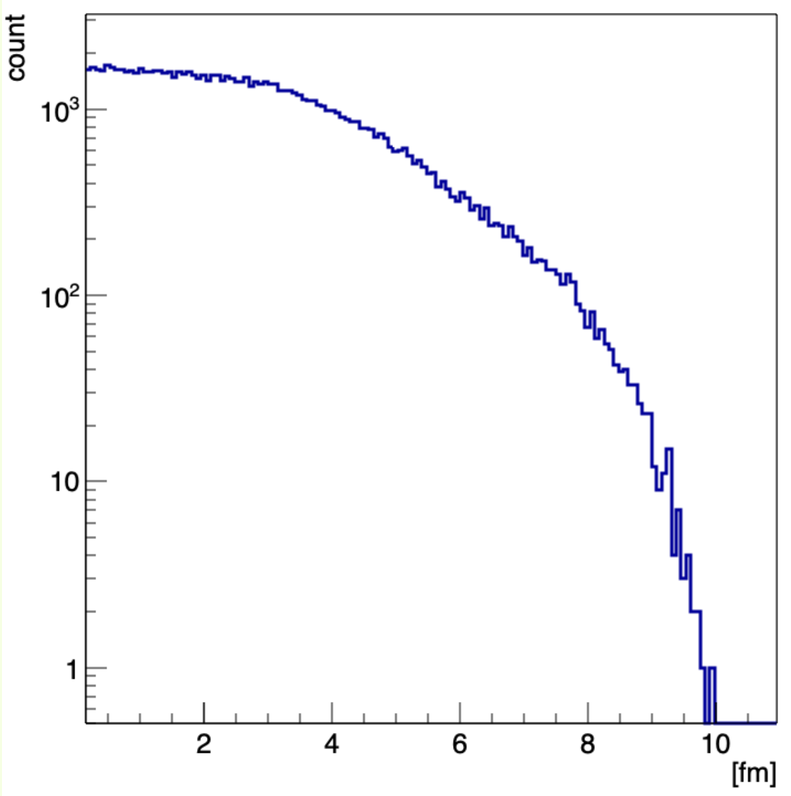


Fit disparsed model pT distribution to data PbPb one to determine energy loss coefficiency

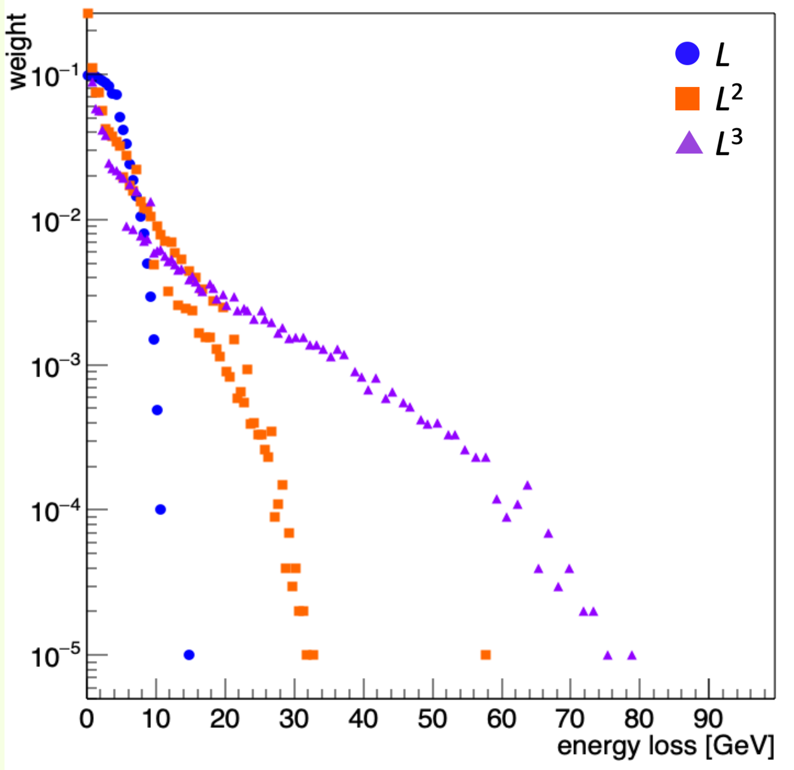
Progress figures



Parton creation points (Centrality 30-50%)



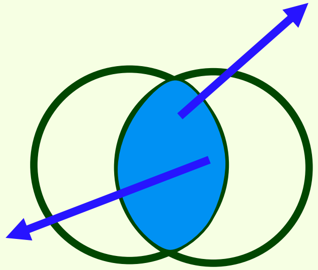
Path length distribution



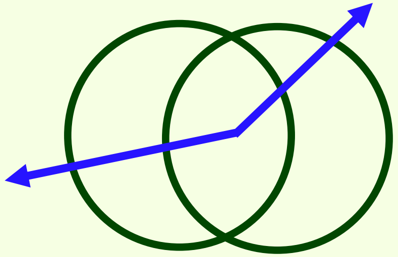
Energy loss distribution for each toy model ($dE = CL^n$)

Results comparison of different paton emission way

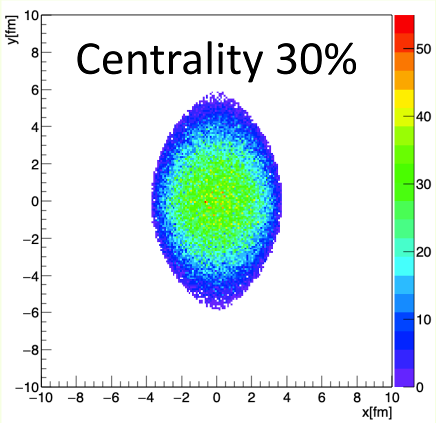
Use MC pp distribution, for model R_{AA} distribution

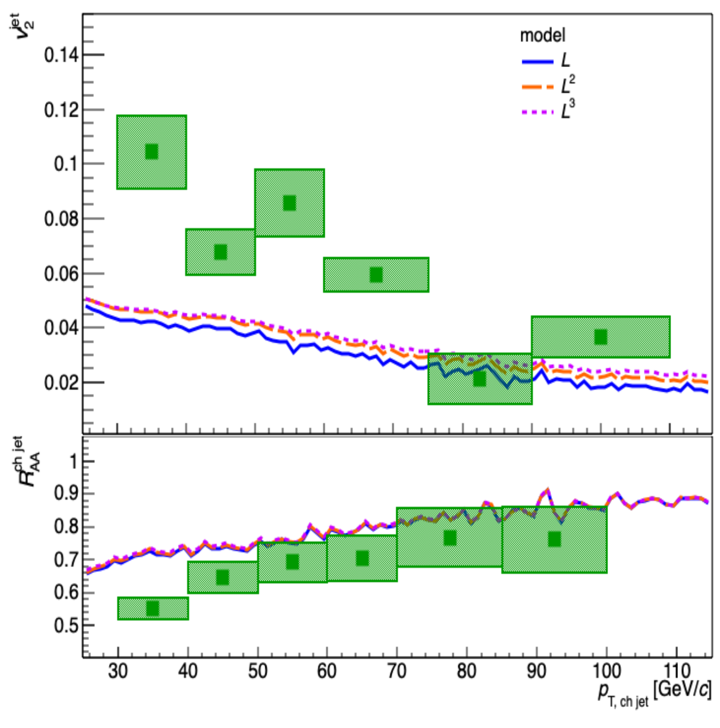


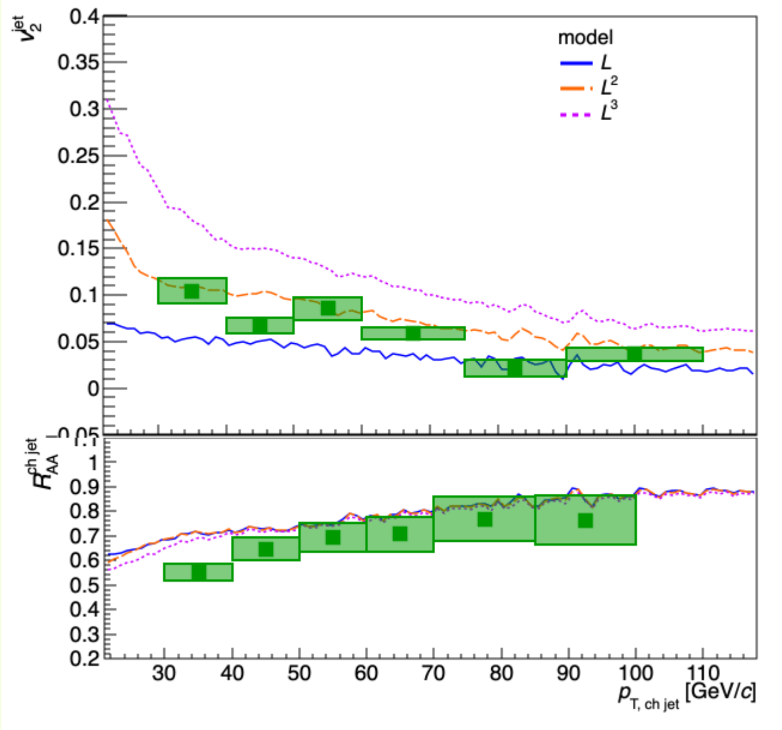
Flat parton creation

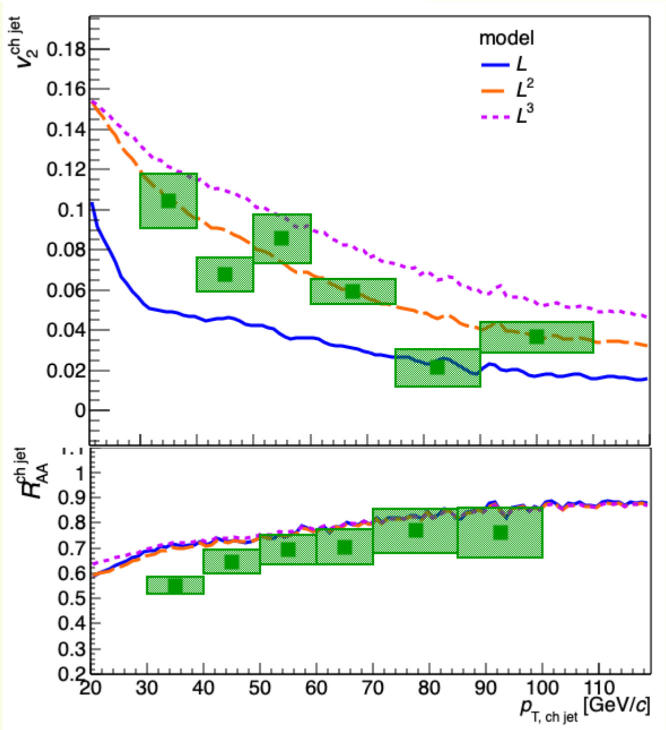


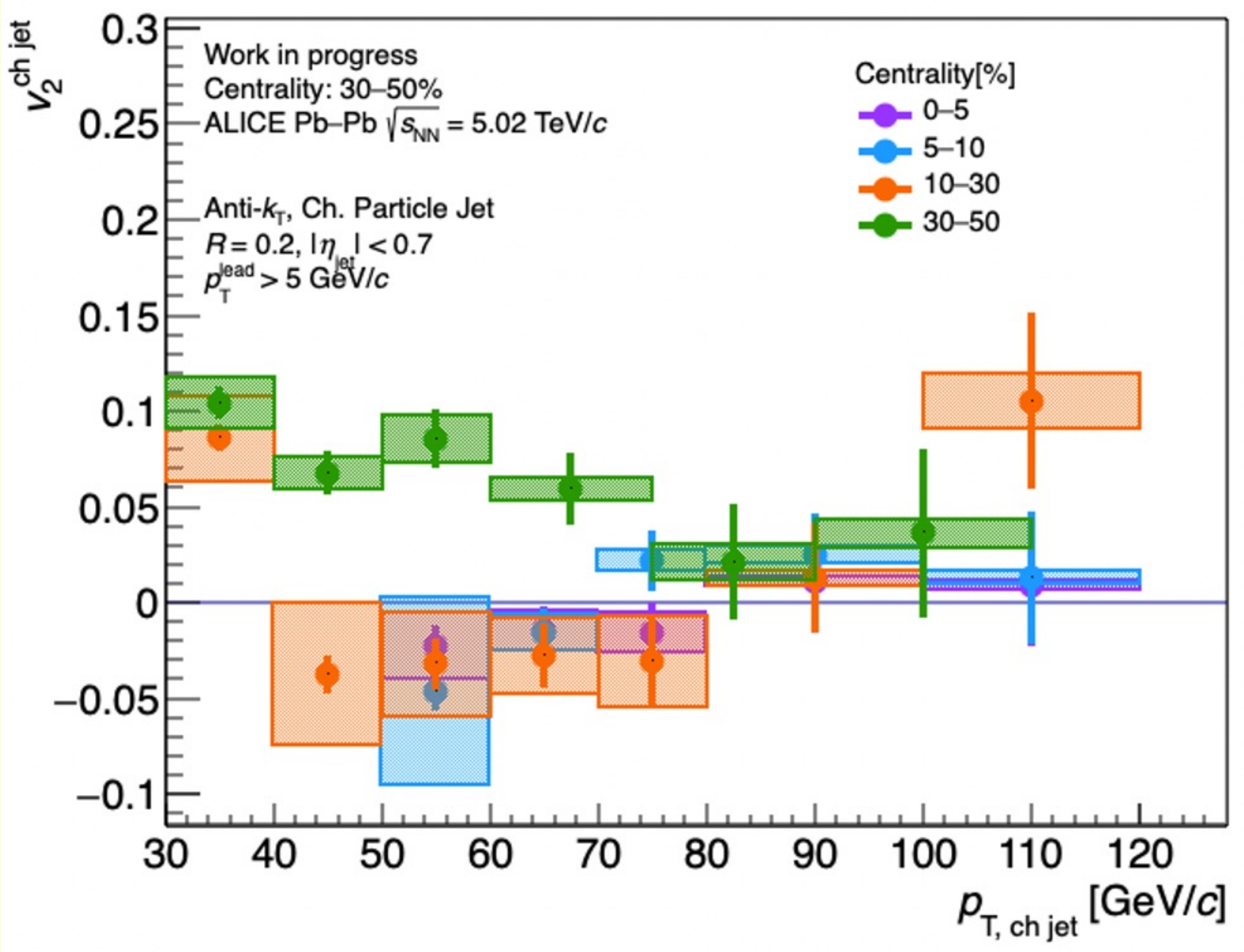
Fix center parton creation











Work in progress
Centrality: 30–50%
ALICE Pb–Pb $\sqrt{s_{NN}}$ = 5.02 TeV/c
Anti-k_T, Ch. Particle Jet
R = 0.2, $|\eta_{jet}|$ < 0.7
p_T^{lead} > 5 GeV/c
Centrality[%]
0–5
5–10
10–30
30–50
$v_2^{ch\ jet}$
$p_{T,\ ch\ jet}$ [GeV/c]

$\hat{q}$ Evaluation

$\Delta E \propto \alpha_s C_R \hat{q} L^n$

$\Delta E = C L^n$

$0.3 < \alpha_s < 0.5 \rightarrow \alpha_s = 0.5$

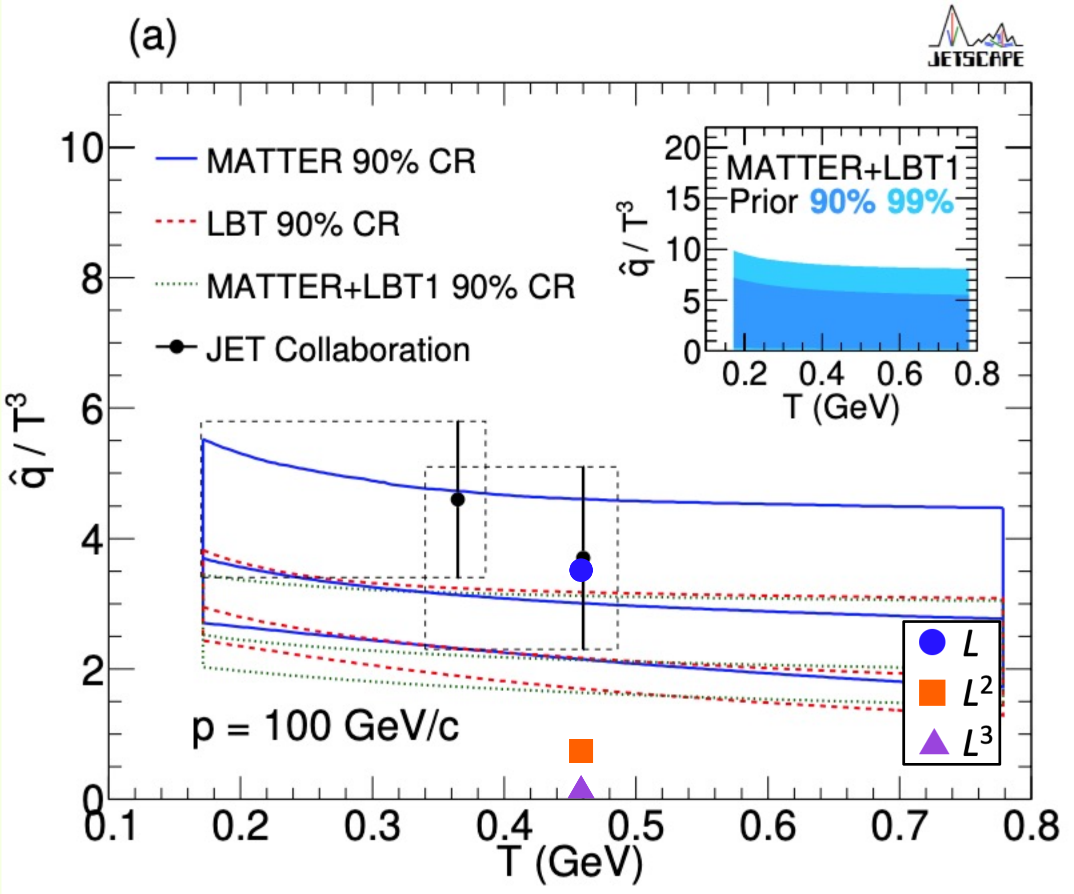
$C_R = \begin{cases} q: 4/3 \\ g: 3 \end{cases}$

$\alpha_s C_R = 1.5$

$$C = \begin{cases} 1.125 \text{ (collisional)} \\ 0.225 \text{ (raiation)} \\ 0.040 \text{ (Ads/CFT)} \end{cases}$$

$$\hat{q} = \begin{cases} 0.75 \text{ (collisional)} \\ 0.15 \text{ (raiation)} \\ 0.027 \text{ (Ads/CFT)} \end{cases}$$

$$\hat{q}/T^3 = \begin{cases} 3.47 \text{(collisional)} \\ 0.694 \text{(raiation)} \\ 0.125 \text{(Ads/CFT)} \end{cases}, (T^3 = 0.216)$$



https://doi.org/10.1103/PhysRevC.104.024905

$\hat{q}$ Estimation

$\Delta E \propto \alpha_s \, C_R \hat{q} L^n$

$\Delta E = C L^n$

$$C = \begin{cases} 1.695\,(\text{collisional}) \\ 0.46\,(\text{raiation}) \\ 0.12\,(\text{Ads/CFT}) \end{cases}$$

$0.3 < \alpha_s < 0.5 \;\rightarrow\; \alpha_s = 0.5$

$$C_R = \begin{cases} q: 4/3 \\ g: 3 \end{cases}$$

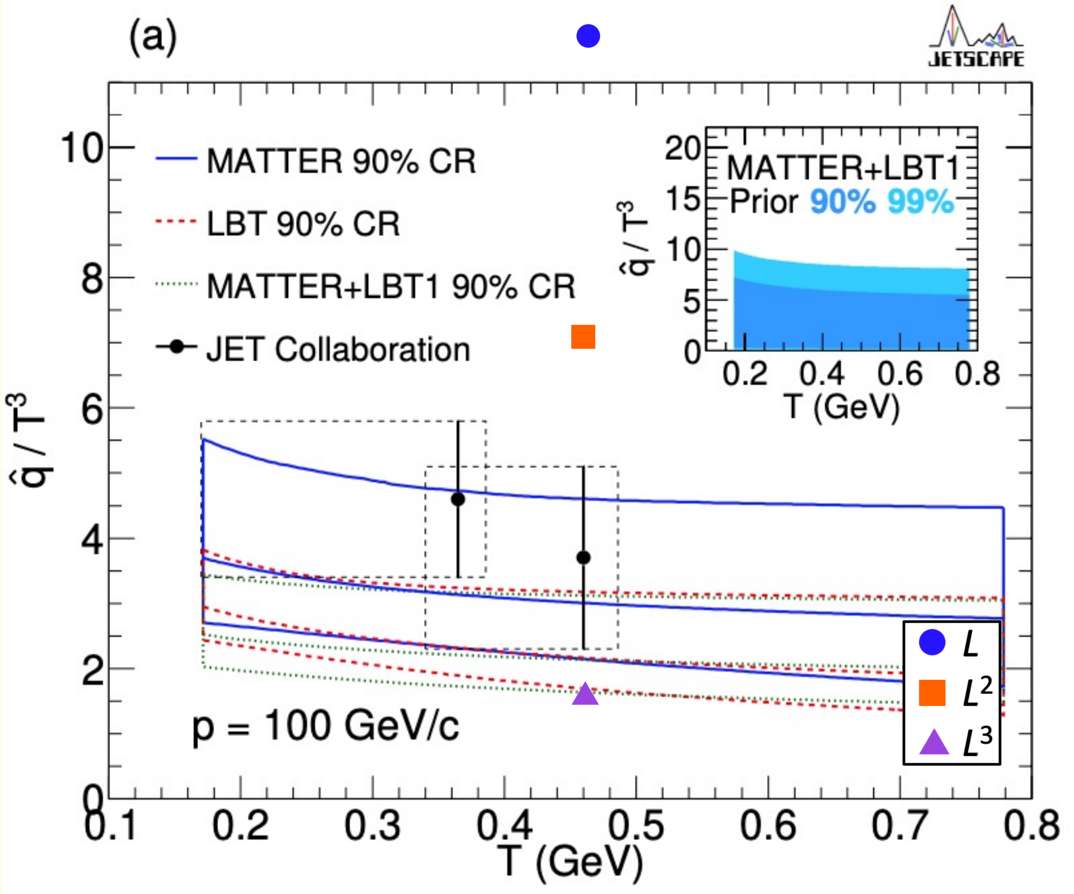
$\alpha_s C_R = 1.5$

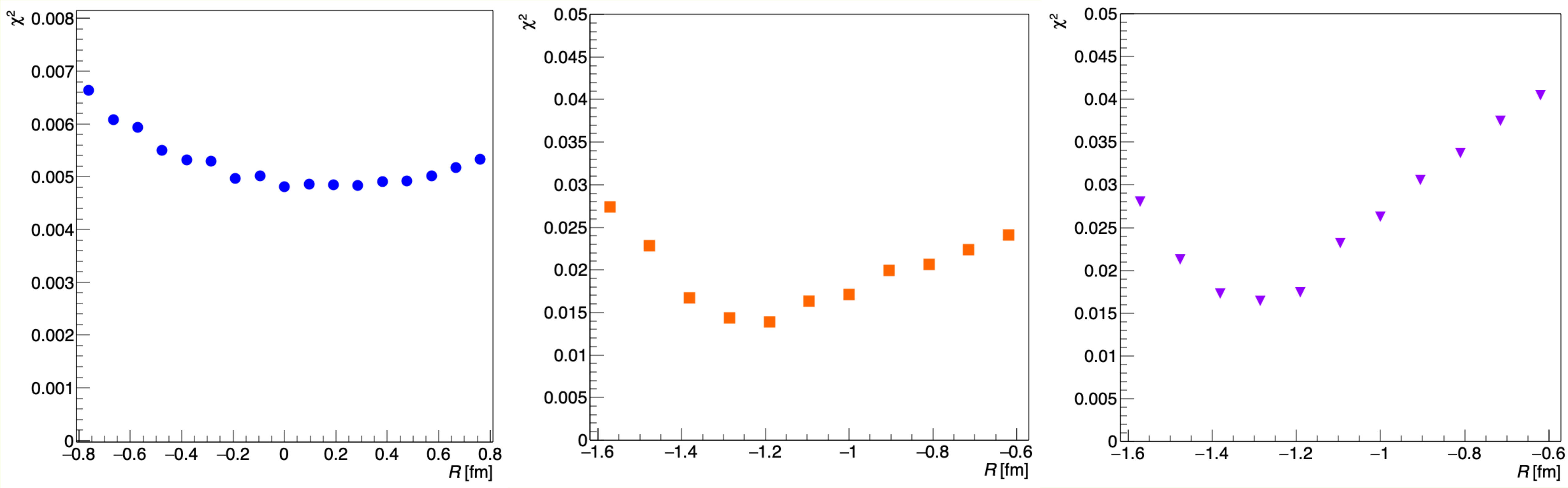
$$\hat{q} = \begin{cases} 1.13 - 4.24\,(\text{collisional}) \\ 0.31 - 1.15\,(\text{raiation}) \\ 0.08 - 0.30\,(\text{Ads/CFT}) \end{cases}$$

$$\hat{q}/T^3 = \begin{cases} 11.6 - 43.5\,(\text{collisional}) \\ 3.15 - 11.8\,(\text{raiation}) \\ 0.82 - 3.08\,(\text{Ads/CFT}) \end{cases}, (T = 0.46)$$

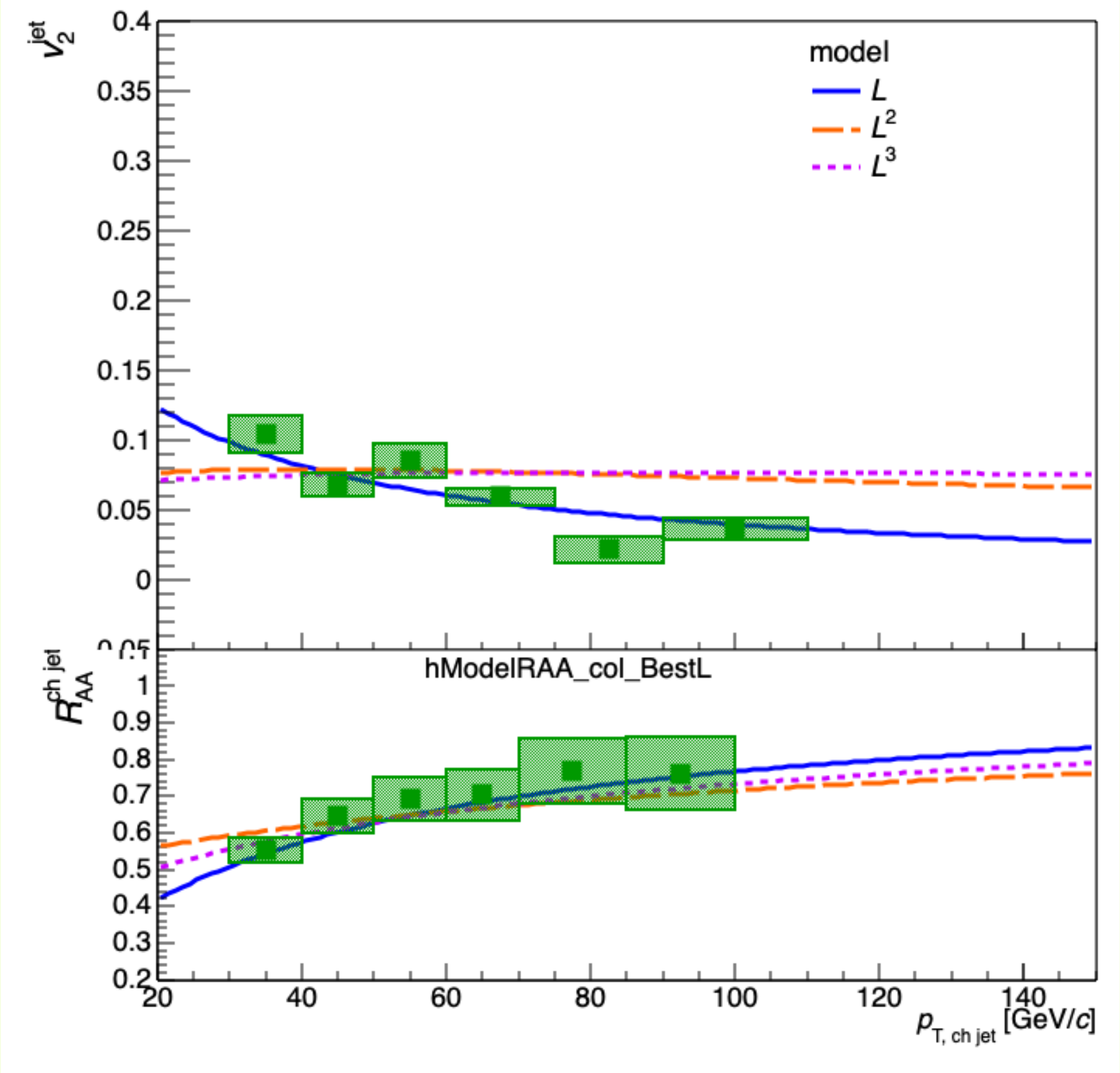
min q-hat: col, radi, AdsCft = 4.2375, 1.15, 0.3
max q-hat: col, radi, AdsCft = 1.13, 0.306667, 0.08

min q-hat/T^3: col, radi, AdsCft = 43.5348, 11.8147, 3.08211
max q-hat/T^3: col, radi, AdsCft = 11.6093, 3.1506, 0.821895





χ²
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
R [fm]
χ²
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
−1.6
−1.4
−1.2
−1
−0.8
−0.6
R [fm]
χ²
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
−1.6
−1.4
−1.2
−1
−0.8
−0.6
R [fm]



v_2^{jet}
model
L
L^2
L^3
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
hModelRAA_col_BestL
$R_{AA}^{ch\ jet}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
20
40
60
80
100
120
140
$p_{T,\ ch\ jet}$ [GeV/c]