Utilizing event topology analysis to understand the flow-like behavior in small systems

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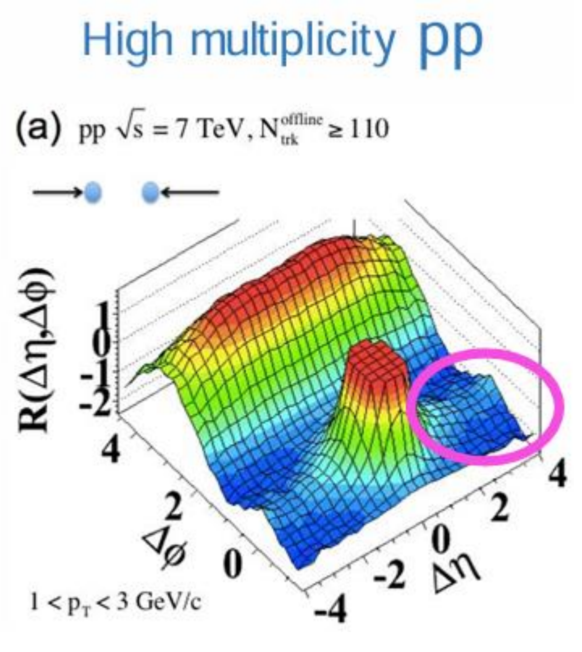
Collective flow in small system



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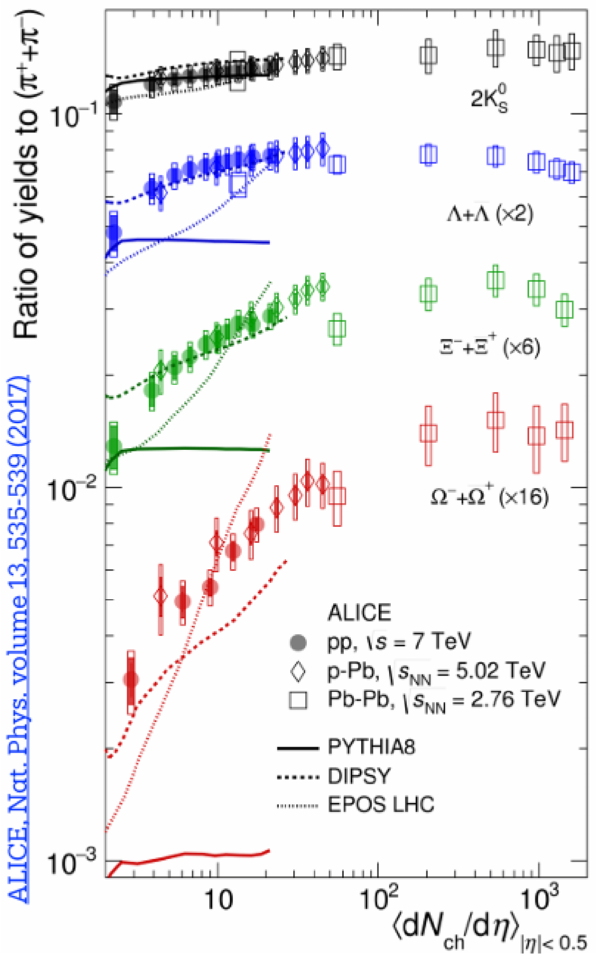
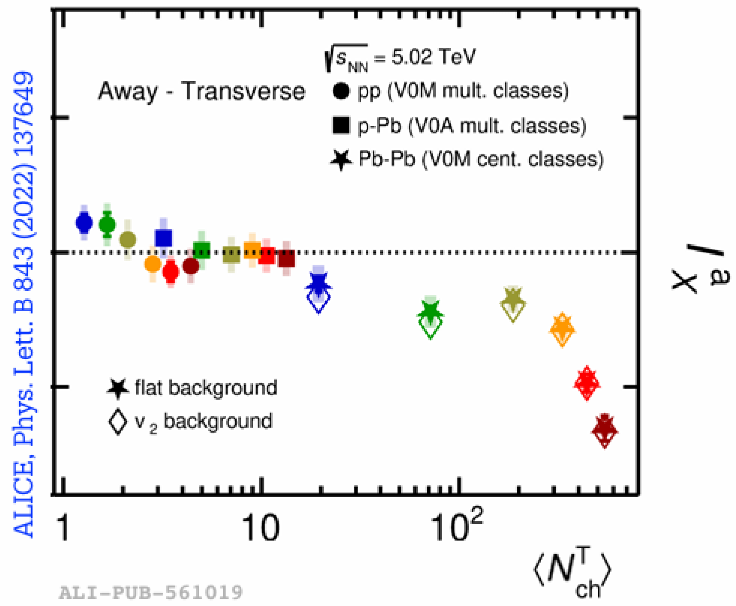




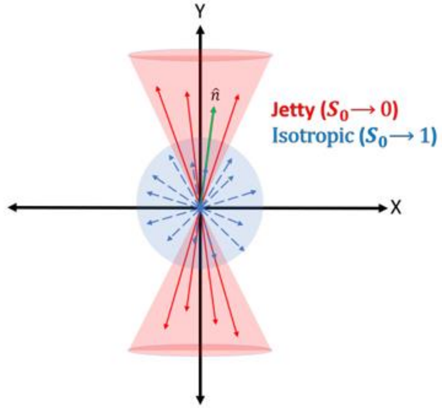
- Collective flow found in small system collisions
- Sizable multiplicity dependence of flow signal
- No hint of jet quenching in small system
- Jet bias in high multiplicity small system events
- Event shape engineering for small systems?

Event topology classifiers

Transverse Sphericity

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_{i=1}^{N_{\rm had}} |\vec{p}_{{\rm T}_i} \times \hat{n}|}{\sum_{i=1}^{N_{\rm had}} |\vec{p}_{{\rm T}_i}|} \right)^2$$

- Isotropy of particle distribution in transverse plane
- Pencil like $S_0 \to 0$ and sphere like $S_0 \to 1$



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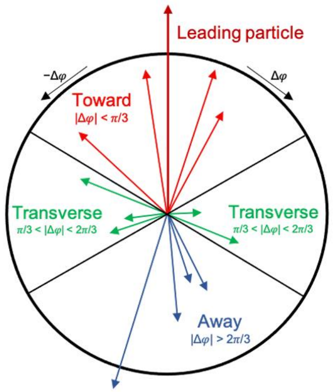
Relative Transverse Activity

$$R_{\rm T} = \frac{N_{\rm ch}^{\rm T}}{\langle N_{\rm ch}^{\rm T} \rangle}$$

- Toward/Away/Transverse region
- UE activity measured perpendicular to leading particle direction
- Separates events with higher/lower than average UE activity
- Low R_T jet dominated, high R_T UE dominated



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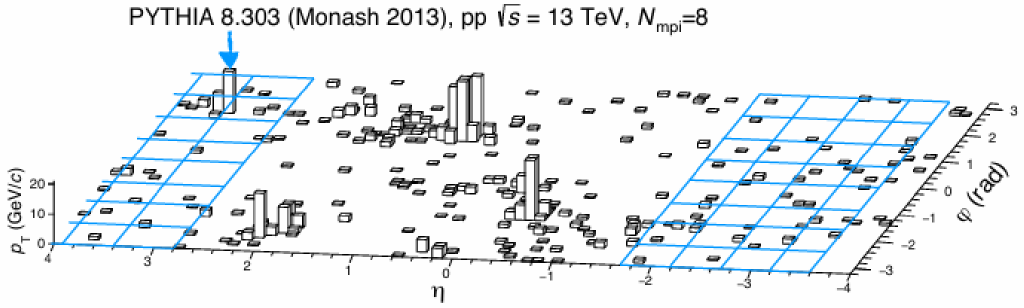
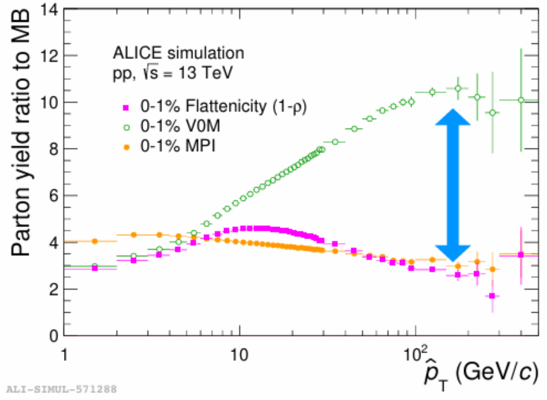
Flattenicity

$$\rho = \frac{\sqrt{\sum_i (N_{ch}^{cell,i} - \langle N_{ch}^{cell} \rangle)^2 / N_{cell}^2}}{\langle N_{ch}^{cell} \rangle}$$



- Local multiplicity fluctuations in V0 det
- Small ρ (high $1-\rho$) isotropic, large ρ clustered jet dominated
- Decouples jet-related biases from soft QCD dynamics



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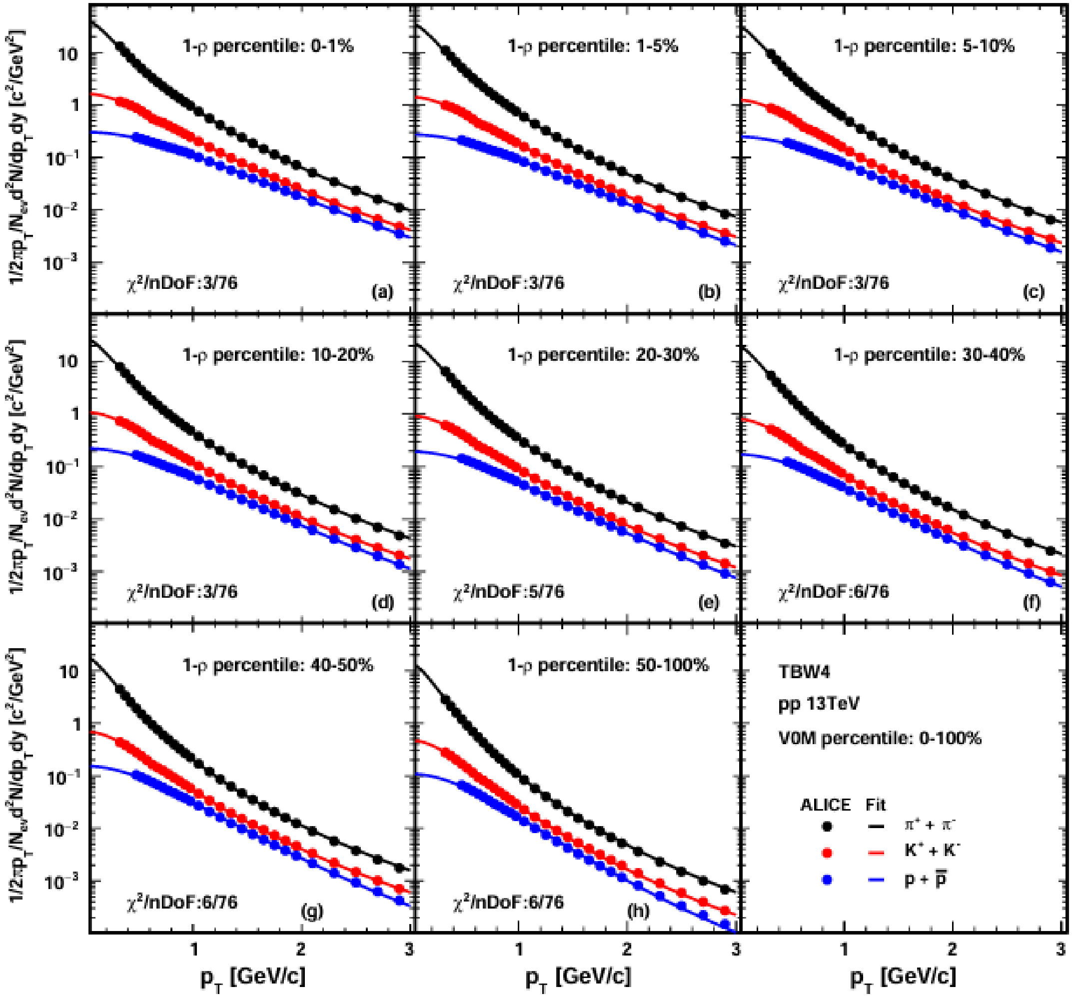
Tsallis Blast-Wave analysis

$$\frac{d^2N}{2\pi m_T dm_T dy}|_{y=0} = A\int_{-y_b}^{+y_b} m_T\cosh(y_s)dy_s \int_{-\pi}^{\pi} d\phi \times \int_0^R r dr[1+\frac{q-1}{T}(m_T\cosh(y_s)\cosh(\rho) -p_T\sinh(\rho)\cos(\phi))]^{-1/(q-1)}.$$

Tsallis Blast-Wave model

- Kinetic freeze-out temperature (T)
- Average radial flow velocity ($\langle\beta\rangle$)
- Non-extensive parameters: q_M (mesons), q_B (baryons)

- Data available for pp 13 TeV by ALICE with different event topological observables
- Tsallis Blast-Wave model reasonably describes the p_T spectra across different systems



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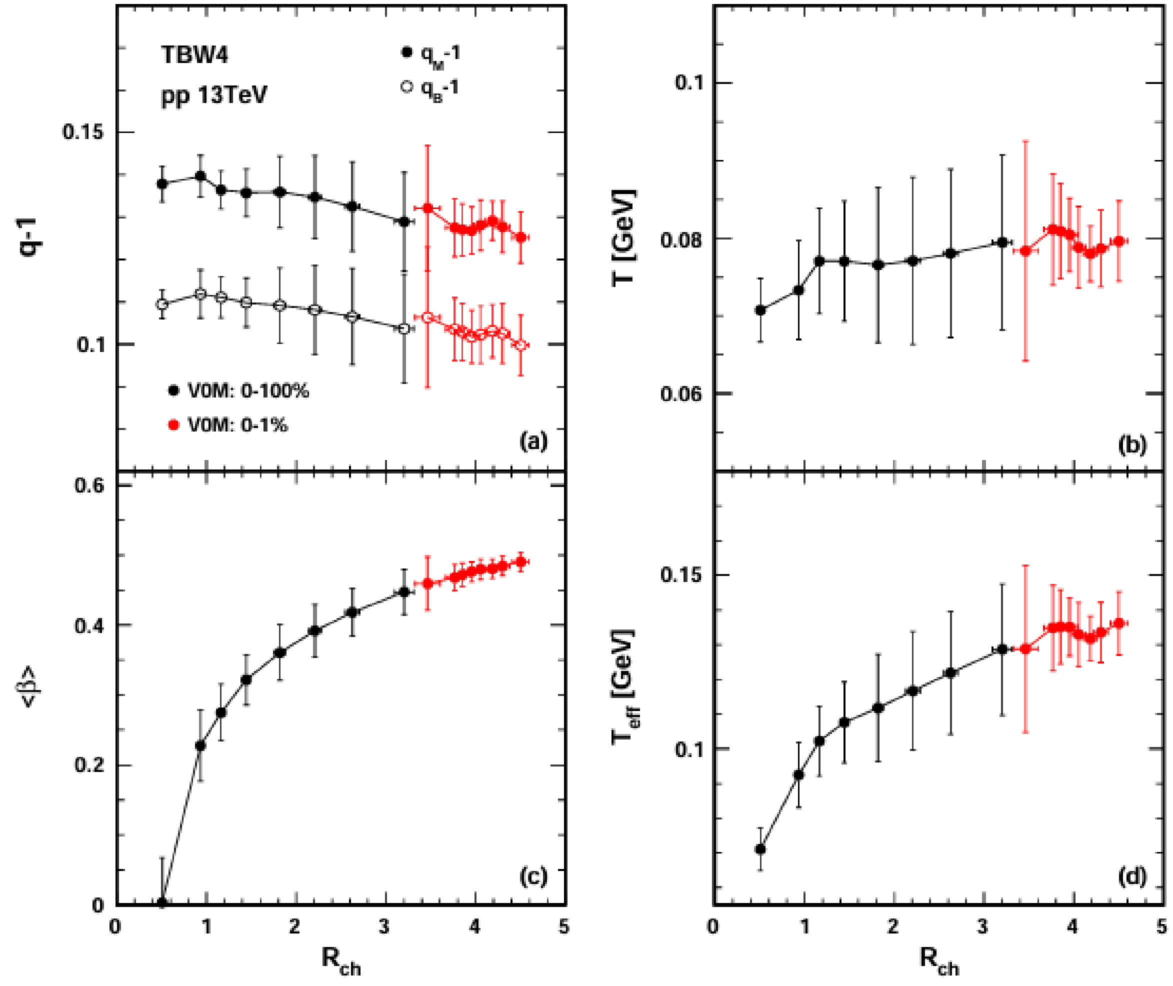
Event topology decouples flow effect

- Uniquely decouples jet-related hadronization from collective flow
- Non-extensive parameters and the local freeze-out temperature remain constant across the entire flattenicity
- Aligning pp evolution trends with the stack of UE parton interactions

$$R_{ch} = \frac{dN/d\eta}{\langle dN/d\eta \rangle} \qquad T_{eff} = \sqrt{\frac{1+\langle\beta\rangle}{1-\langle\beta\rangle}}T$$



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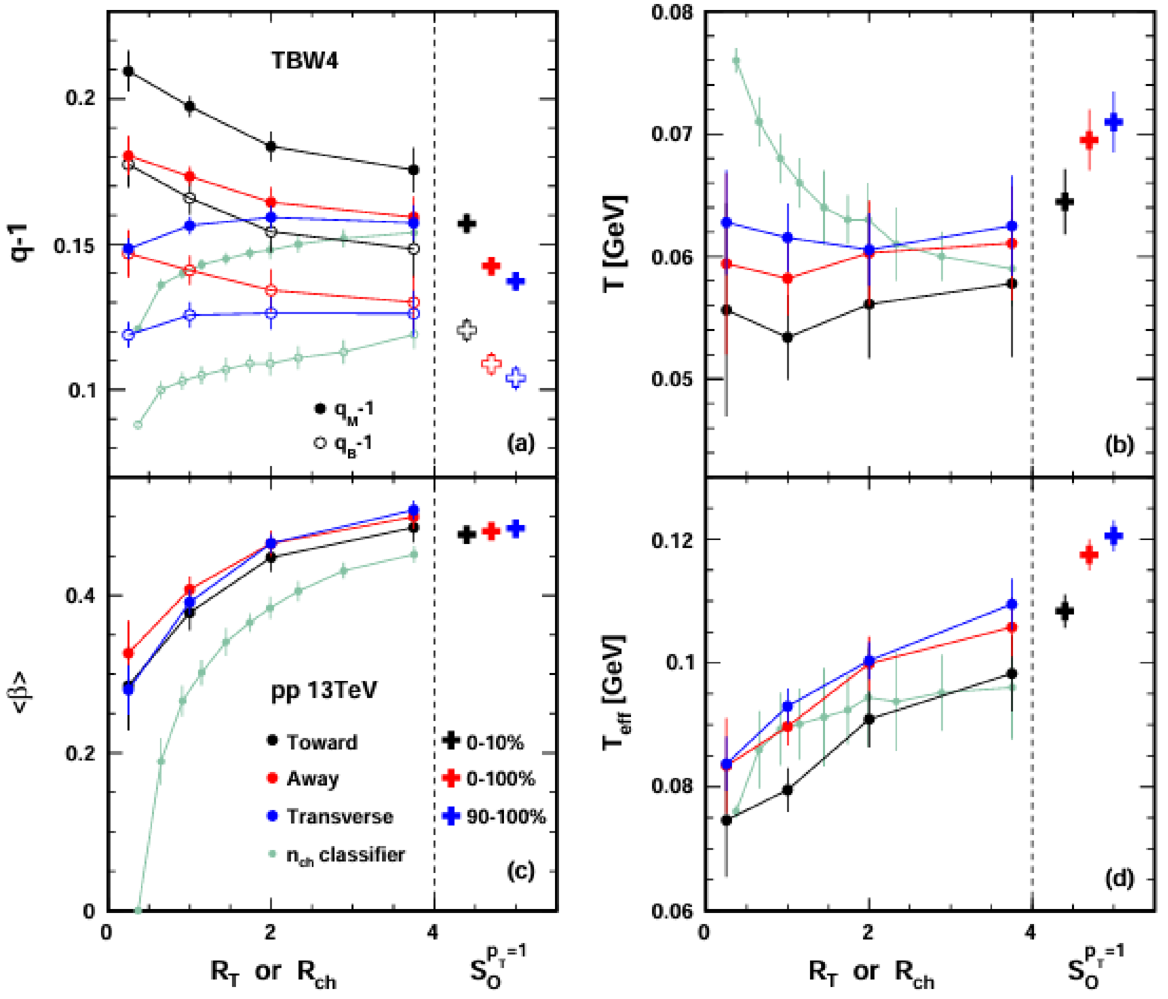
Event topology decouples flow effect

- Moving from jetty events (0–10% spherocity) to isotropic events (90–100% spherocity) reveals a systematic decline in *q*
- Radial flow velocity rises sharply as a function of R_T across all topologies
- Toward/Away region show different trend in q compared to Transverse region



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Event topology based subtraction

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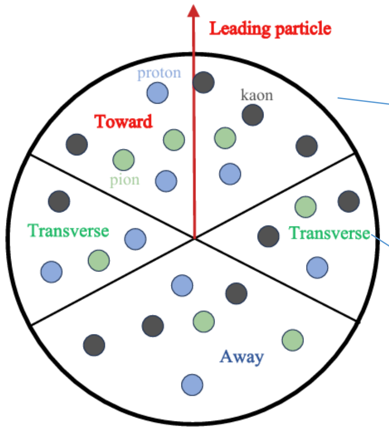

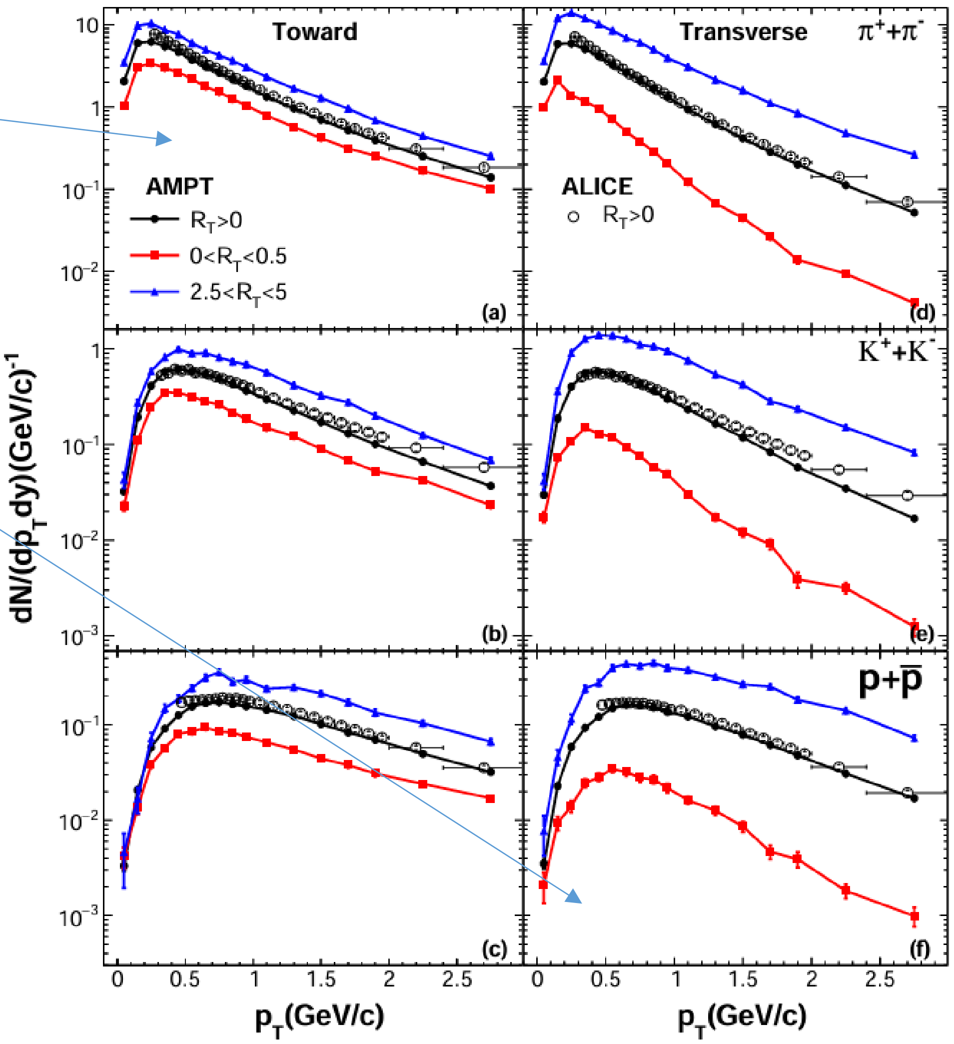

- Dividing the azimuthal plane into three regions with leading hadron (p_T>5)
- Get p_T spectra in different topological region
- AMPT to study the FSI in different event activity

Particle ratios in different topology region

- AMPT model with PYTHIA8 IC, successfully reproduces the data with both parton and hadron cascade effects on
- Weak R_T dependence when FSI off
- Pion wind in hadronic final state interactions drives the p/pi and K/pi ratios in high R_T events

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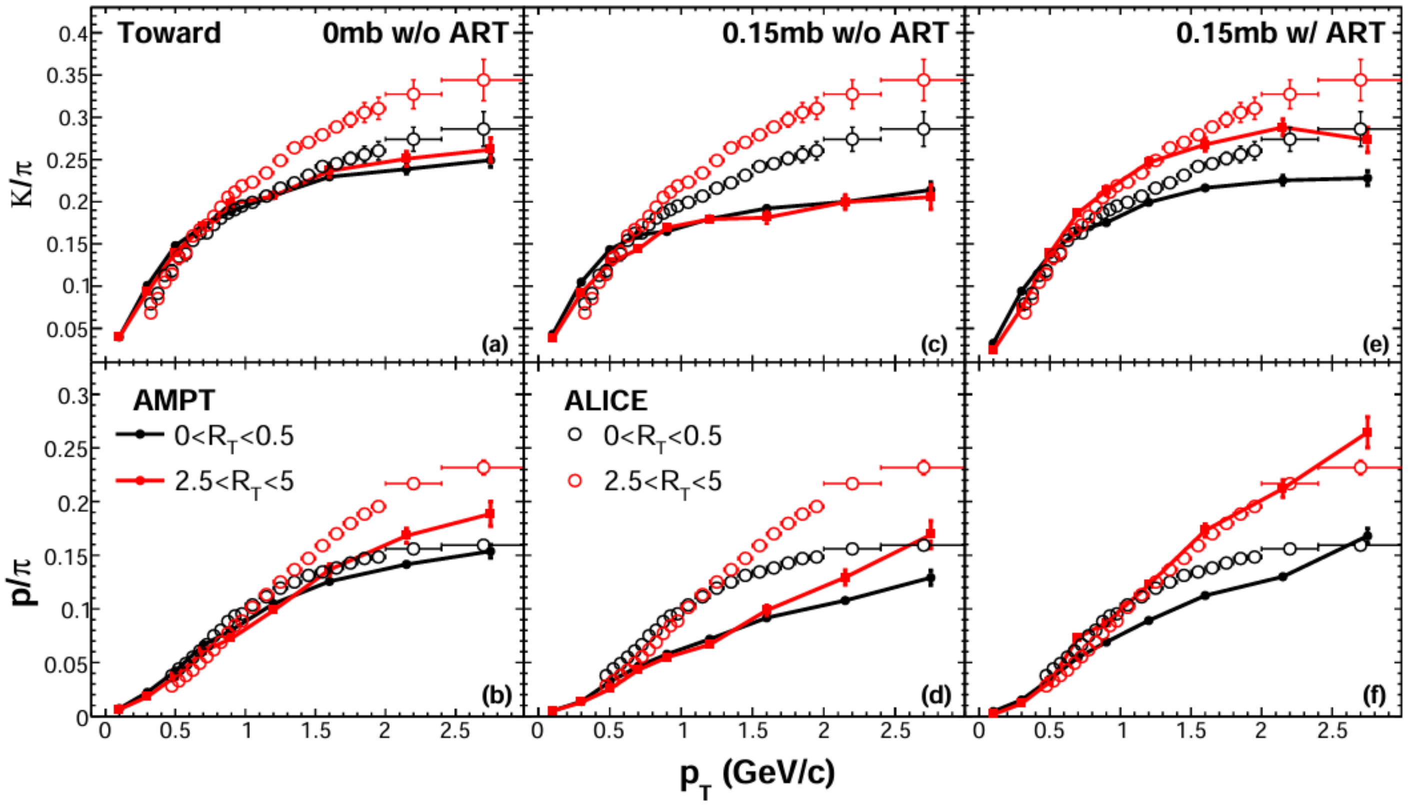

In-jet particle ratios

$$\frac{d^2N^{\mathrm{In-Jet}}}{dp_T dy} = \frac{d^2N^{\mathrm{Toward}}}{dp_T dy} - \frac{d^2N^{\mathrm{Transverse}}}{dp_T dy}$$

- Define in-jet yield to isolate the genuine fragmentation from UE.
- Probe jet modification and energy loss in the soft-to-intermediate p_T regime
- In-jet particle ratio can be a sensitive probe to jet-medium interactions

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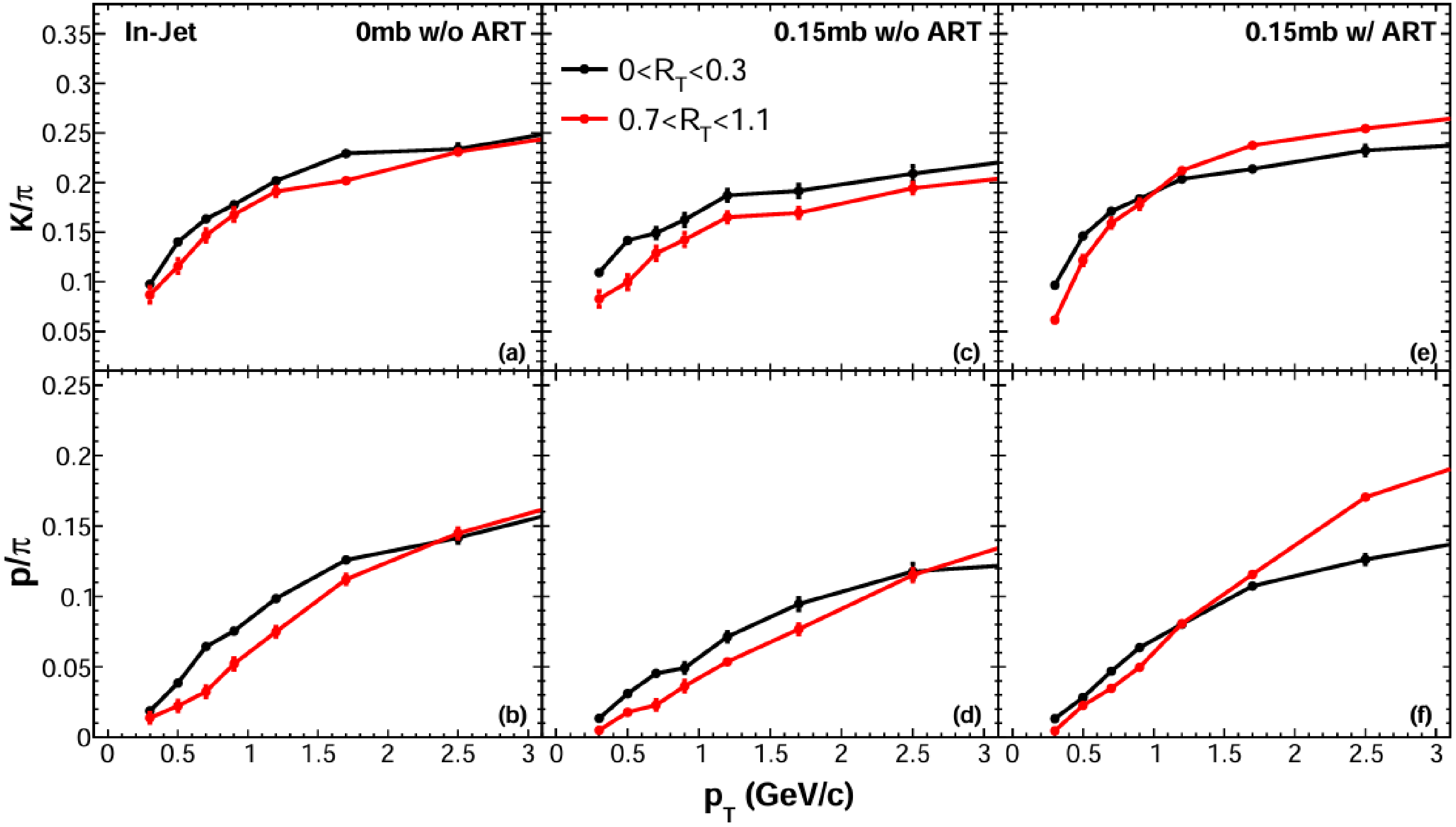
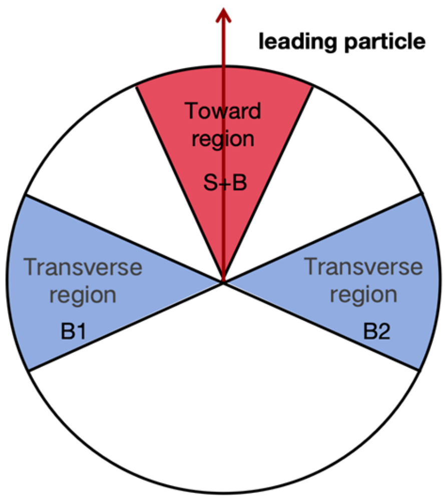


Jet-free energy-energy correlator (EEC)



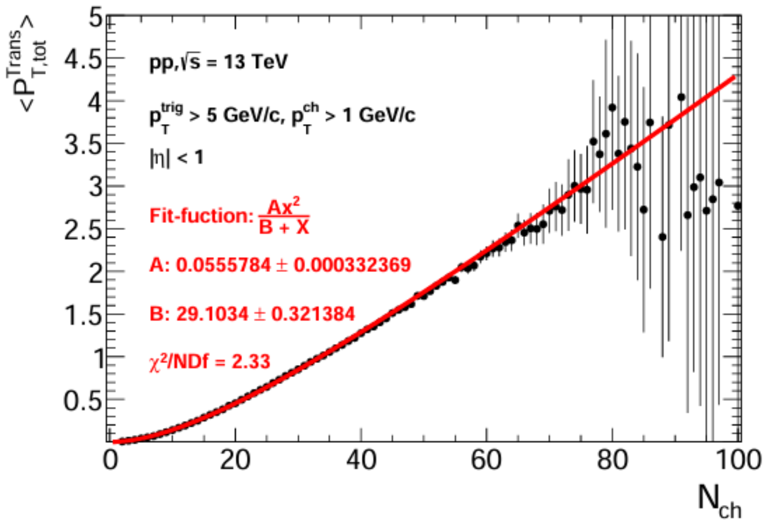
$$\frac{d\Sigma_{EEC}}{dR_L} = \frac{1}{\sigma_{trig}} \sum_{i,j} \frac{p_{T,i} p_{T,j}}{p^2_{T,tot}} \delta(R_L - R_{ij})$$

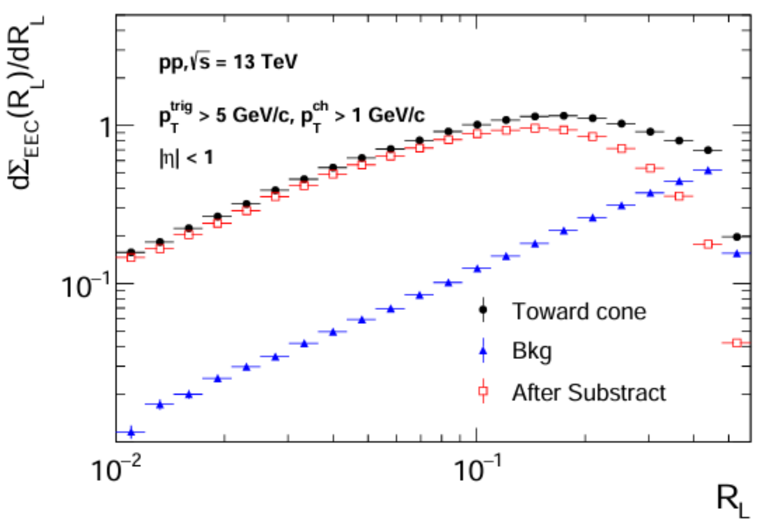
- Not IR safe but practical in Exp and MC comparison
- Possible to extend to low p_T where jet recon is difficult

- EEC measures angular correlation of energy flow
- Use leading charge hadron as reference axis, define Toward (S+B) and Transverse cones (B), subtract background via

$$\begin{aligned} N^{sub}_{\mathrm{EEC}} &= N^{Tow}_{\mathrm{EEC}} + N^{Trans}_{\mathrm{EEC}} - 2N^{Tow \otimes Trans}_{\mathrm{EEC}} \\ &= N^{Tow}_{\mathrm{EEC}} - N^{Bkg}_{\mathrm{EEC}}. \end{aligned}$$

- Correct Total p_T using scalar sum of Transverse cones $p^{corr}_{T,tot} = p^{Tow}_{T,tot} - \langle p^{Trans}_{T,tot} \rangle$





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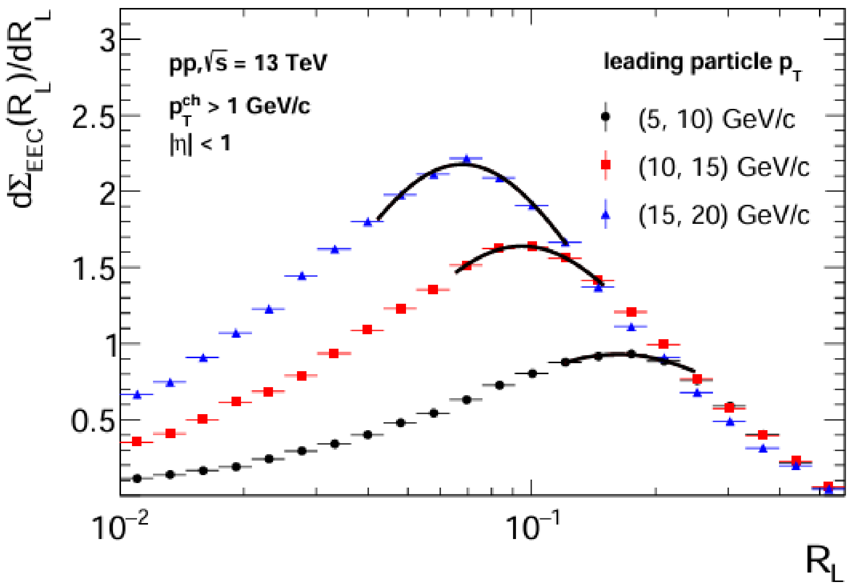
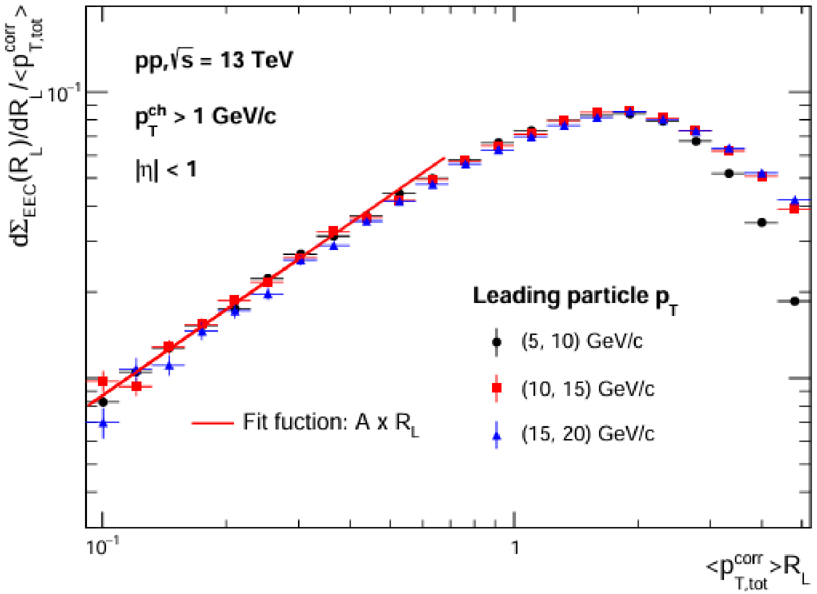
Scale dependence

- EEC peak shifts to smaller R_L as leading p_T increases
- Transition from non-perturbative small R_L to perturbative large R_L region
- Scaled distributions collapse onto a universal curve

$p_T^{trigger}$(GeV/c)	**(5,10)**	**(10,15)**	**(15,20)**
R_L^{peak}	0.162	0.095	0.067
EEC height	0.928	1.640	2.188
$< p_{T,tot}^{corr} >$	9.361	18.81	25.65
$< p_{T,tot}^{corr} > *R_L^{peak}$	1.516	1.787	1.719
EEC height$/< p_{T,tot}^{corr} >$	0.099	0.087	0.085





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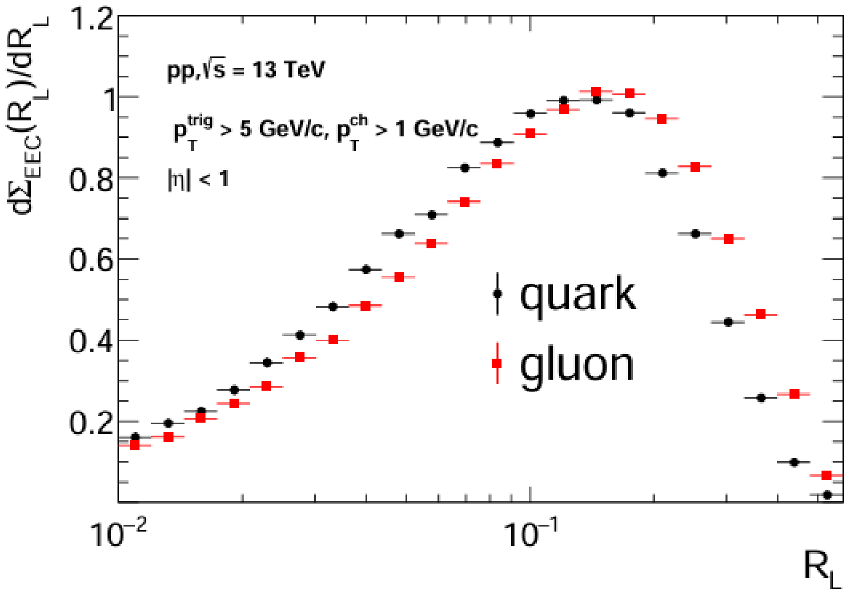
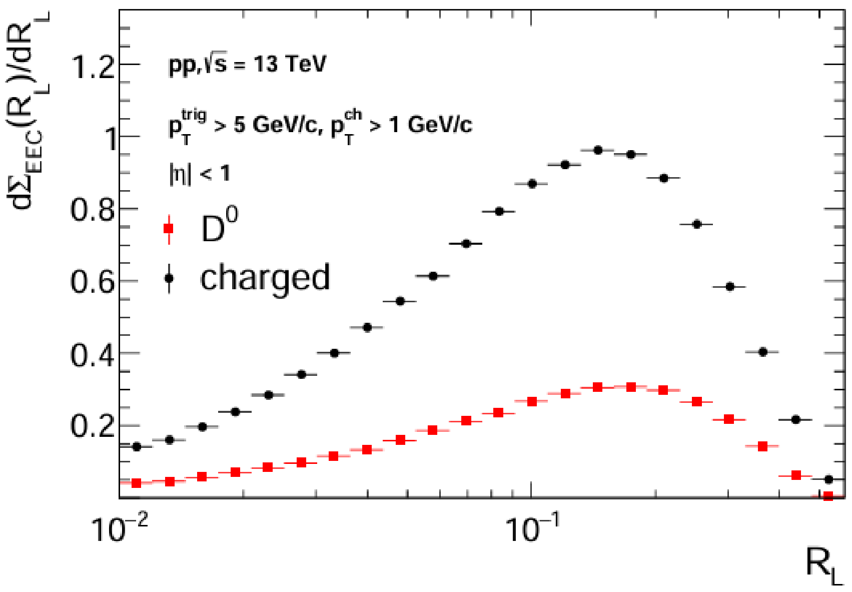
Flavor dependence

- Gluon initiated events exhibit broader and higher EEC due to $C_A > C_F$
- Heavy flavor EEC triggered by D0 shows suppressed and shifted peak due to dead cone effect.
- Jet-free method successfully captures fundamental QCD features.





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Summary

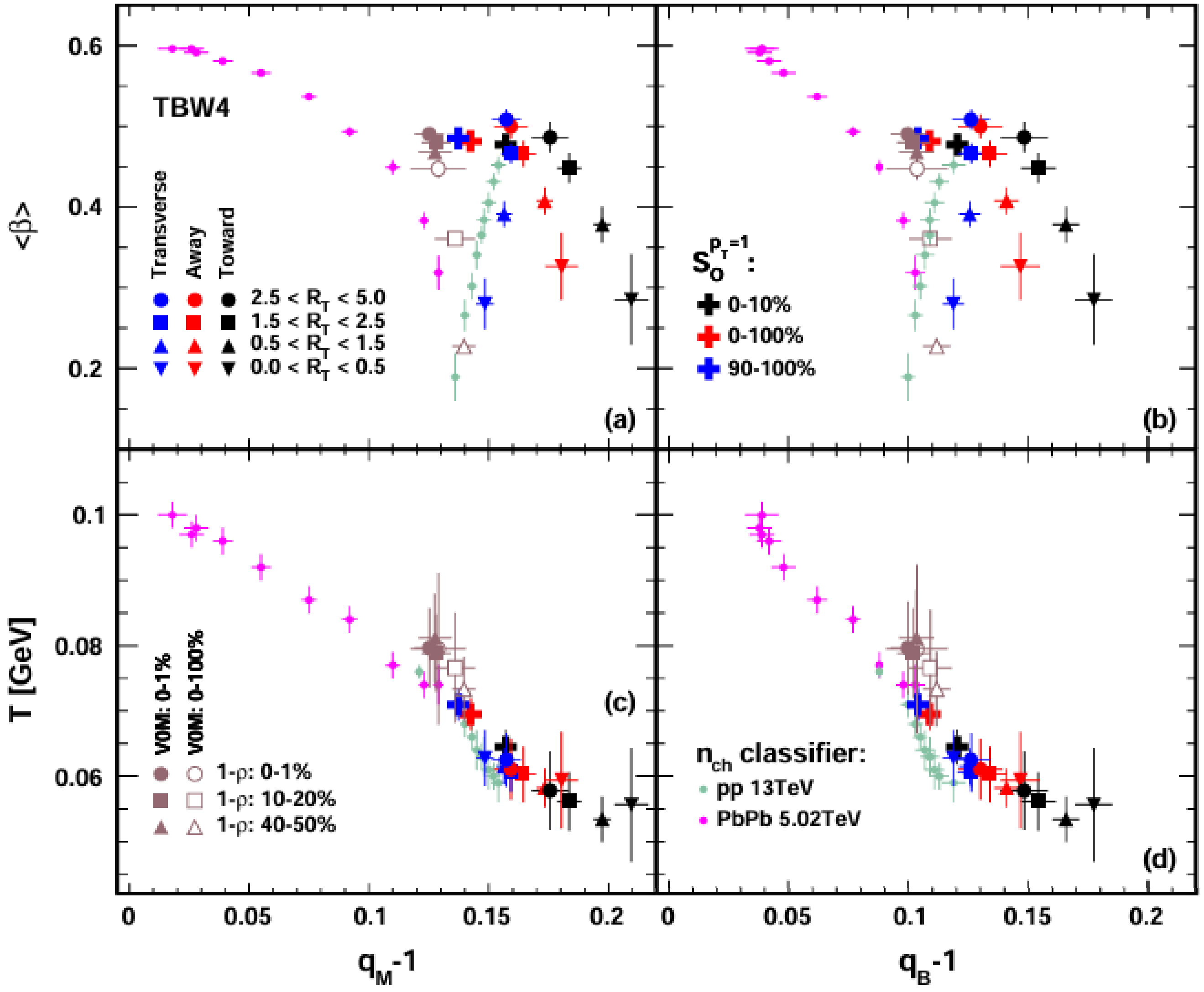
- Event topology observables provide avenues to access the event shape behavior of small systems
- Jet biases and collective flow might be decoupled through flattenicity measurement
- Event topology subtraction method is sensitive to low-p_T jet interactions and might be extended to different collision system
- Multi-dimensional event topology analysis to further pin down impacts from different stage

Thank You!

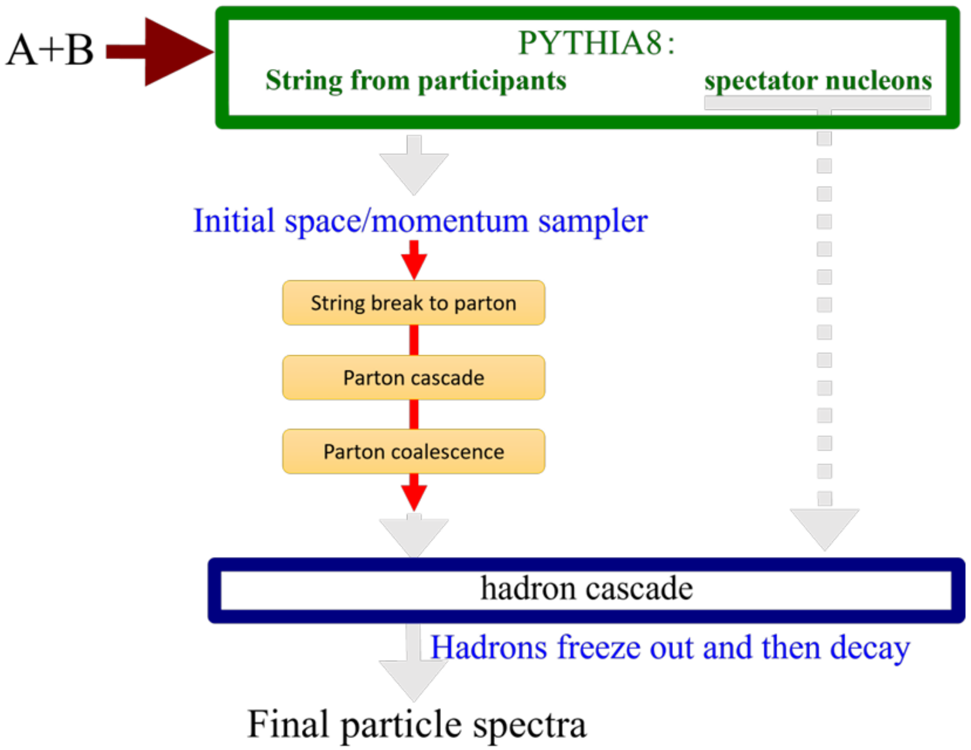
Backup

Freeze-out properties across system

- Aligning pp evolution trends with large-system PbPb collisions



AMPT × PYTHIA8



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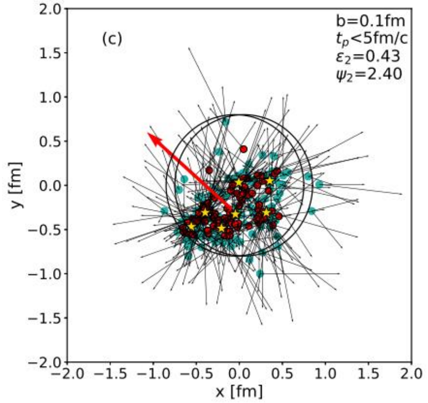
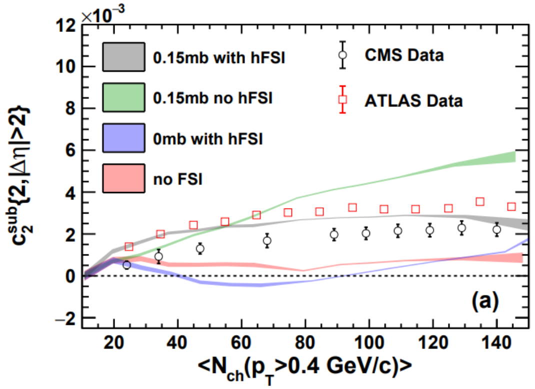
EPJC 84 (2024) 1029
PRD 113 (2026) 034008





- Introduce PYTHIA8 initial conditions
- Sub-nucleon spatial fluctuations
- Collective flow in pp well described

Validation of the jet-free EEC method

- Jet-free EEC method consistent with the jet based results