Strangeness enhancement in pp collisions from PACIAE model

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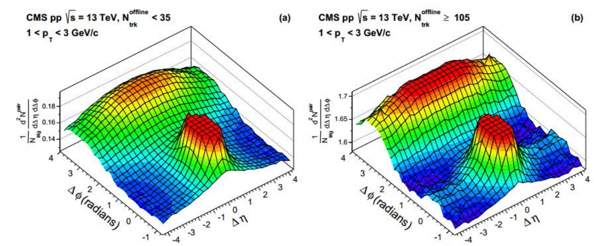
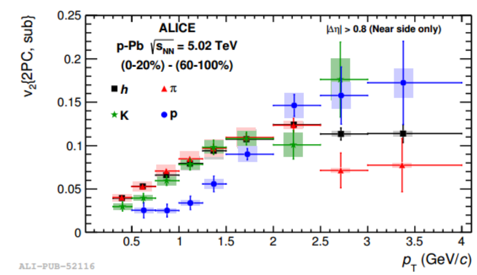
Outline

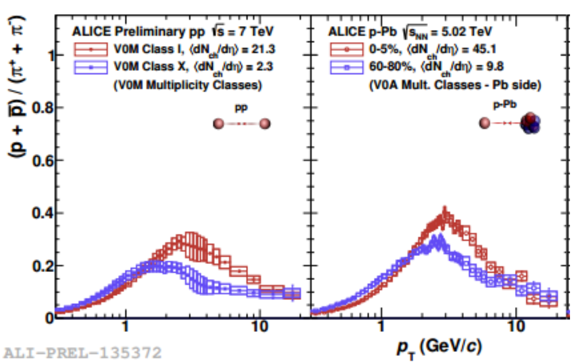
- QGP-like signals in small system
- Strangeness enhancement in pp
- PACIAE model and effective string tension
- Results and discussions

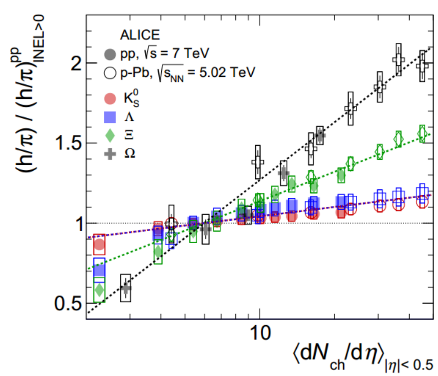
QGP-like signs in small system

- Near side ridge structure in particle correlations
- Anisotropic asymmetry
- Baryon to meson ratio
- Strangeness enhancement



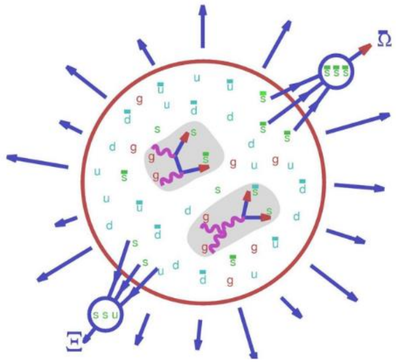


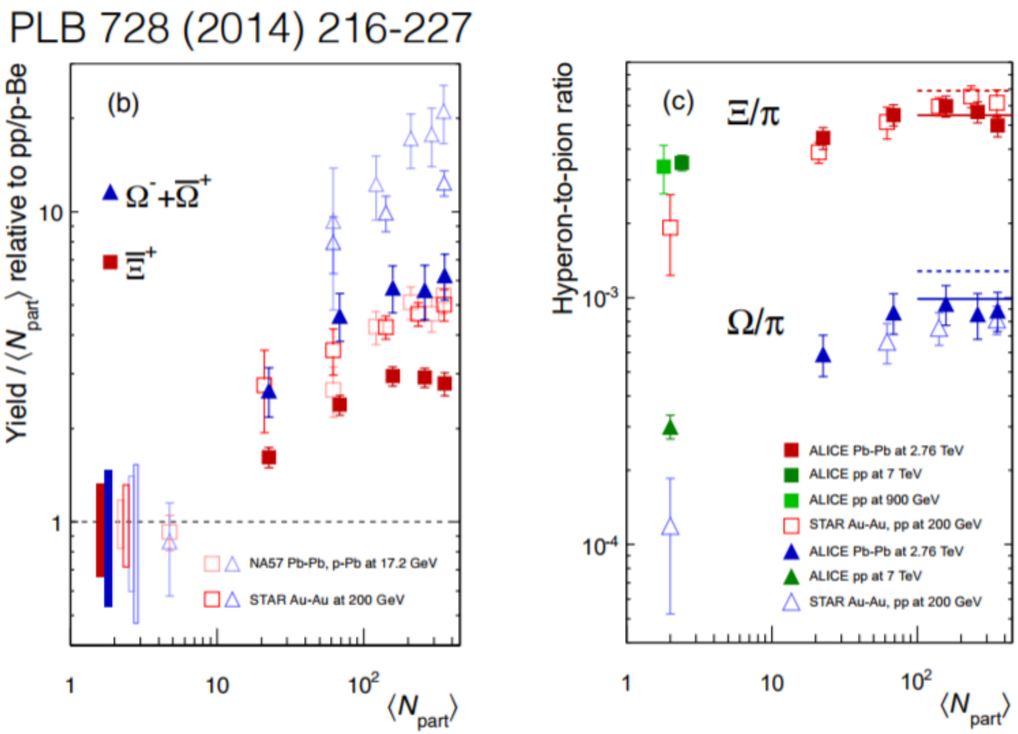




Strangeness enhancement

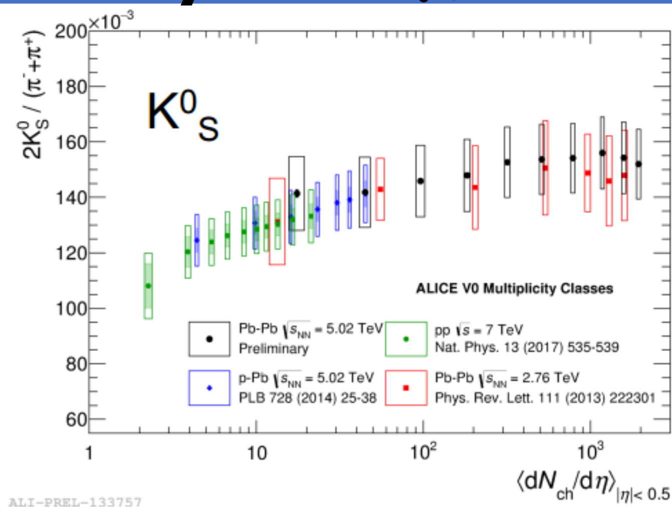
- Strangeness enhancement as a sign for QGP

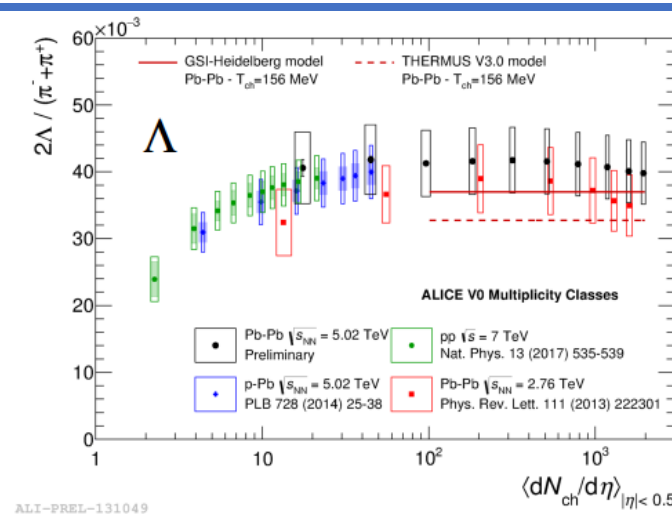


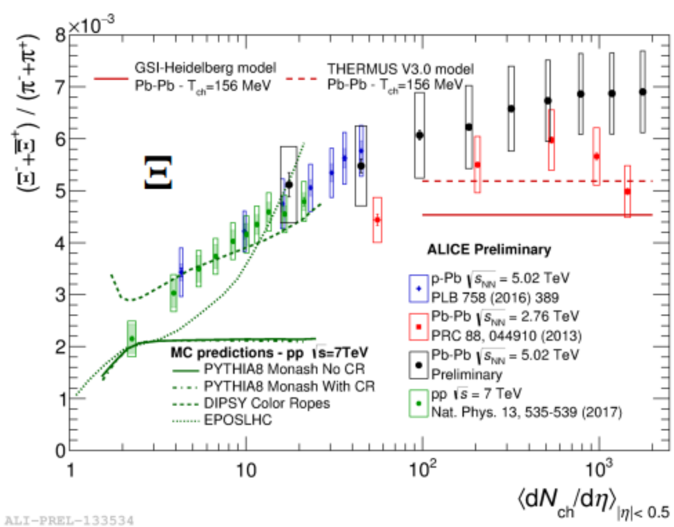


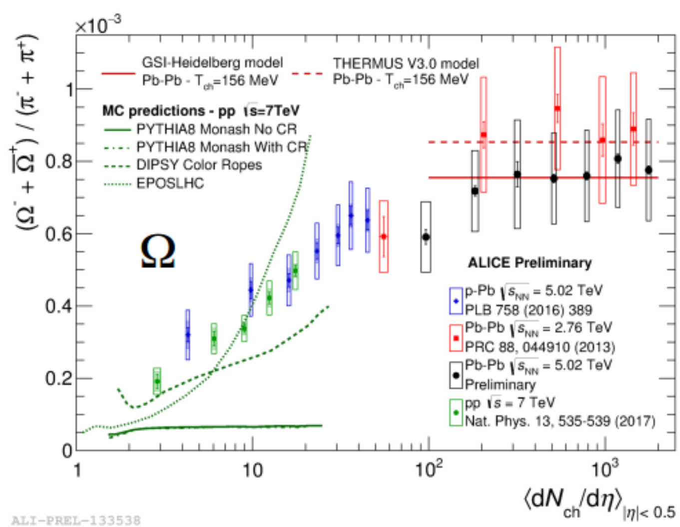
- Thermal gluon fusion
- Multi-strange baryon increasing with centrality
- Strangeness number dependent enhancement

Strange particle production across different collision systems





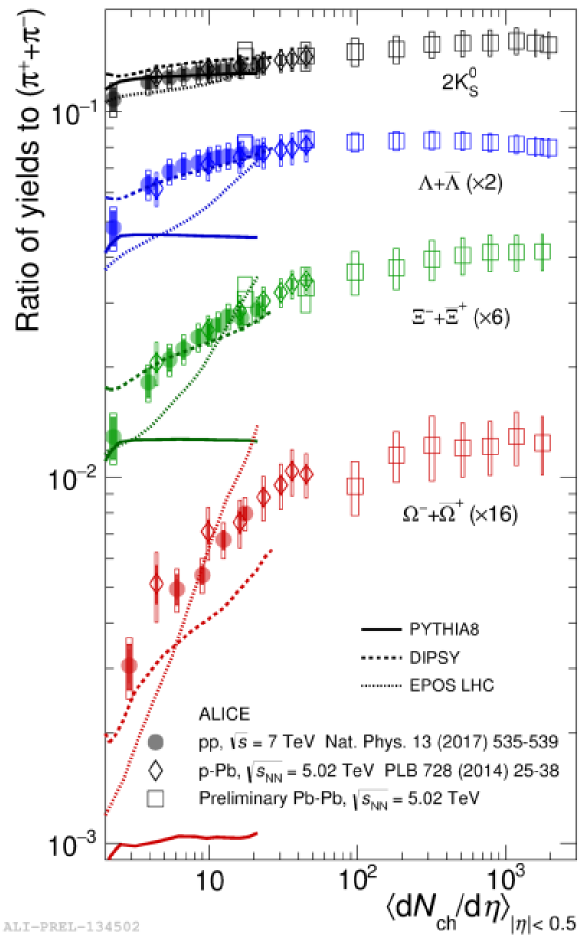




- Strange to pion ratio smoothly evolves between different system
- No significant dependence on collision energy

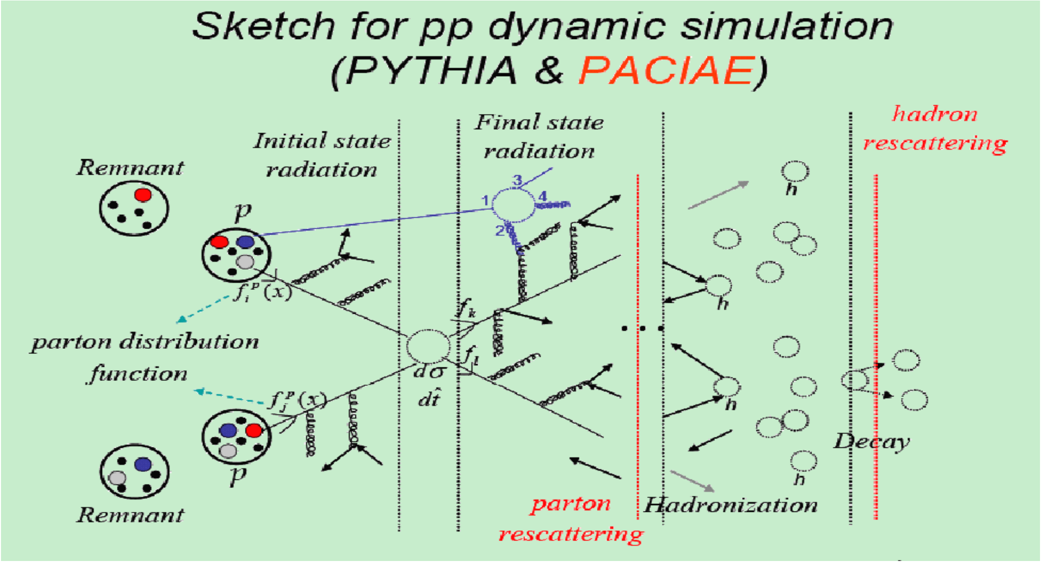
Relative strangeness production in all collision system

- Multiplicity dependent strangeness enhancement observed with a smooth evolution across pp/pA/AA collision systems
- Steeper slope with large strange number
- Saturated trend in most central AA collisions for all particles



PACIAE model

- Transport model with parton and hadron cascade effect
- Applicable for pp/pA/AA/eA etc.
- Based on PYTHIA6.4



Relevant channels in parton and hadron cascade

Parton rescattering channels

$$\frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd; \hat{s}, \hat{t}) = \frac{\pi\alpha_s^2}{\hat{s}^2}|\overline{M}(ab \to cd)|^2,$$

$$|\overline{M}(q_i q_j \to q_i q_j)|^2 = \frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} \approx \frac{8}{9}\frac{\hat{s}^2}{\hat{t}^2},$$

$$|\overline{M}(q_i q_i \to q_i q_i)|^2 = \frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right) - \frac{8}{27}\frac{\hat{s}^2}{\hat{u}\hat{t}} \approx \frac{8}{9}\frac{\hat{s}^2}{\hat{t}^2},$$

$$|\overline{M}(q_i \bar{q}_j \to q_i \bar{q}_j)|^2 = \frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} \approx \frac{8}{9}\frac{\hat{s}^2}{\hat{t}^2},$$

$$|\overline{M}(q_i \bar{q}_i \to q_j \bar{q}_j)|^2 = \frac{4}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2} \approx 0,$$

$$|\overline{M}(q_i \bar{q}_i \to q_i \bar{q}_i)|^2 = \frac{4}{9}\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right) - \frac{8}{27}\frac{\hat{u}^2}{\hat{s}\hat{t}} \approx \frac{8}{9}\frac{\hat{s}^2}{\hat{t}^2},$$

$$|\overline{M}(q_i \bar{q}_i \to gg)|^2 = \frac{32}{27}\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} - \frac{8}{3}\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2} \approx -\frac{32}{27}\frac{\hat{s}}{\hat{t}},$$

$$|\overline{M}(gg \to q_i \bar{q}_i)|^2 = \frac{1}{6}\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} - \frac{3}{8}\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2} \approx -\frac{1}{3}\frac{\hat{s}}{\hat{t}},$$

$$|\overline{M}(q_i g \to q_i g)|^2 = -\frac{4}{9}\frac{\hat{u}^2+\hat{s}^2}{\hat{u}\hat{s}} + \frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2} \approx \frac{2\hat{s}^2}{\hat{t}^2},$$

$$|\overline{M}(gg \to gg)|^2 = \frac{9}{2}\left(3 - \frac{\hat{u}\hat{t}}{\hat{s}^2} - \frac{\hat{u}\hat{s}}{\hat{t}^2} - \frac{\hat{s}\hat{t}}{\hat{u}^2}\right) \approx \frac{9}{2}\frac{\hat{s}^2}{\hat{t}^2}.$$

Hadron rescattering channels

$$\pi N \rightleftharpoons \pi\Delta \qquad \pi N \rightleftharpoons \rho N,$$

$$NN \rightleftharpoons N\Delta \qquad \pi\pi \rightleftharpoons k\bar{k},$$

$$\pi N \rightleftharpoons kY \qquad \pi\bar{N} \rightleftharpoons \bar{k}\bar{Y},$$

$$\pi Y \rightleftharpoons k\Xi \qquad \pi\bar{Y} \rightleftharpoons \bar{k}\bar{\Xi},$$

$$\bar{k}N \rightleftharpoons \pi Y \qquad k\bar{N} \rightleftharpoons \pi\bar{Y},$$

$$\bar{k}Y \rightleftharpoons \pi\Xi \qquad k\bar{Y} \rightleftharpoons \pi\bar{\Xi},$$

$$\bar{k}N \rightleftharpoons k\Xi \qquad k\bar{N} \rightleftharpoons \bar{k}\bar{\Xi},$$

$$\pi\Xi \rightleftharpoons k\Omega^- \qquad \pi\bar{\Xi} \rightleftharpoons \bar{k}\bar{\Omega}^-,$$

$$k\bar{\Xi} \rightleftharpoons \pi\bar{\Omega}^- \qquad \bar{k}\Xi \rightleftharpoons \pi\Omega^-,$$

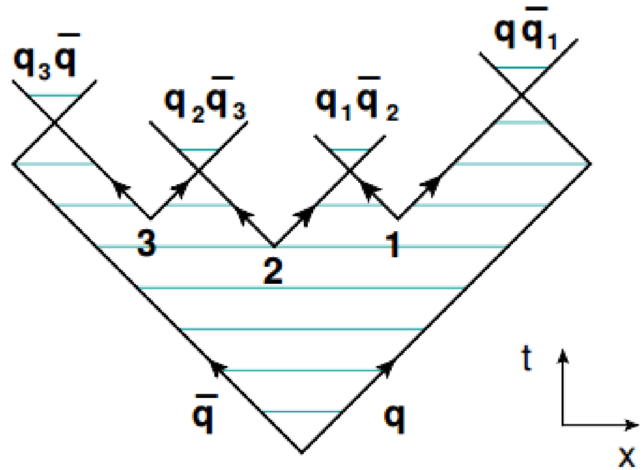
$$N\bar{N} annihilation, N\bar{Y} annihilation,$$

Lund string model

- Creation of $q_i\bar{q}_i$ pair at string break-ups
- Flavor selection regulated by string tension trough tunneling probability

$$P(m_{\perp q}) \propto \exp(-\frac{\pi}{\kappa} m_{\perp q}^2)$$
$$= \exp(-\frac{\pi}{\kappa} m_q^2) \exp(-\frac{\pi}{\kappa} p_{\perp q}^2)$$

- Empirical parameters to suppress strange quark, diquarks



Effective string tension

- Gluon wrinkling in a string

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$$\kappa^s_{eff} = \kappa_0(1-\xi)^{-\alpha}, \qquad \xi = \frac{\ln(\frac{k^2_{Tmax}}{s_0})}{\ln(\frac{s}{s_0}) + \sum_{j=2}^{n-1}\ln(\frac{k^2_{Tj}}{s_0})}.$$

- Multiple string interactions

$$\kappa^m_{eff} = \kappa_0(1+\frac{n_{MPI}-1}{1+p^2_{T\ ref}/p^2_0})^r$$

- Varying flavor parameters with effective tension

$$\rho_{eff} = \rho_0^{\kappa_0/\kappa_{eff}},$$

$$x_{eff} = x_0^{\kappa_0/\kappa_{eff}}$$

$$y_{eff} = y_0^{\kappa_0/\kappa_{eff}},$$

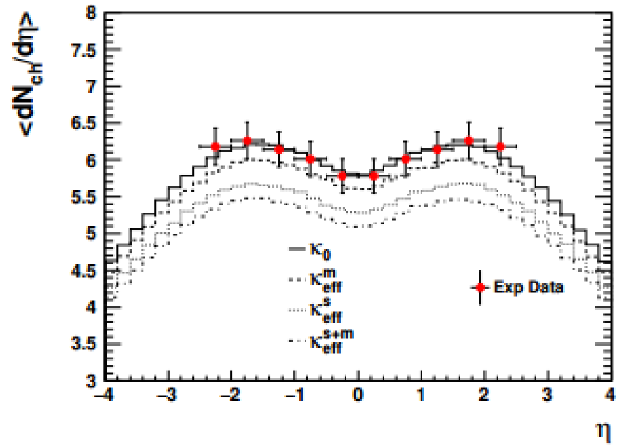
$$\sigma_{eff} = \sigma_0^{\kappa_{eff}/\kappa_0}$$

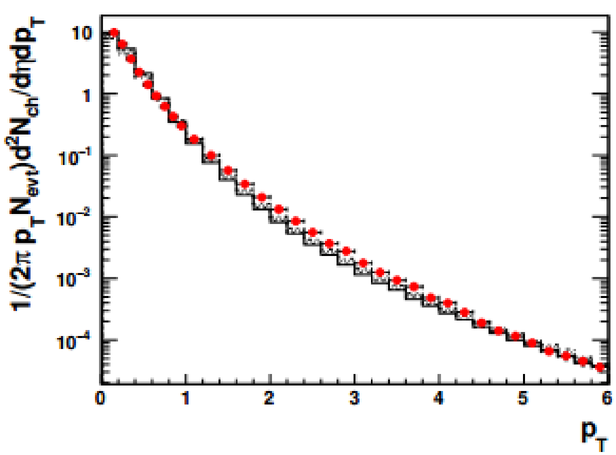
- ρ, strange to light quark ratio P(s)/P(u), PARJ(2) in PYTHIA;
- x, extra suppression on diquarks with strange content, PARJ(3) in PYTHIA;
- y, spin 1 to spin 0 diquark ratio, PARJ(4) in PYTHIA;
- σ, Gaussian width of the transverse momentum for primary hadrons in fragmentation, PARJ(21) in PYTHIA.

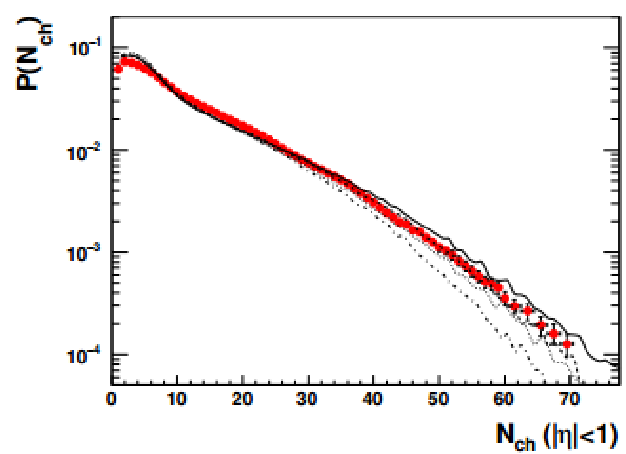
Charged particle productions

pp 7TeV NSD events

- Charged density drops with increasing string tension
- Transverse momentum spectra hardly changes
- Less high multiplicity events with large string tensions







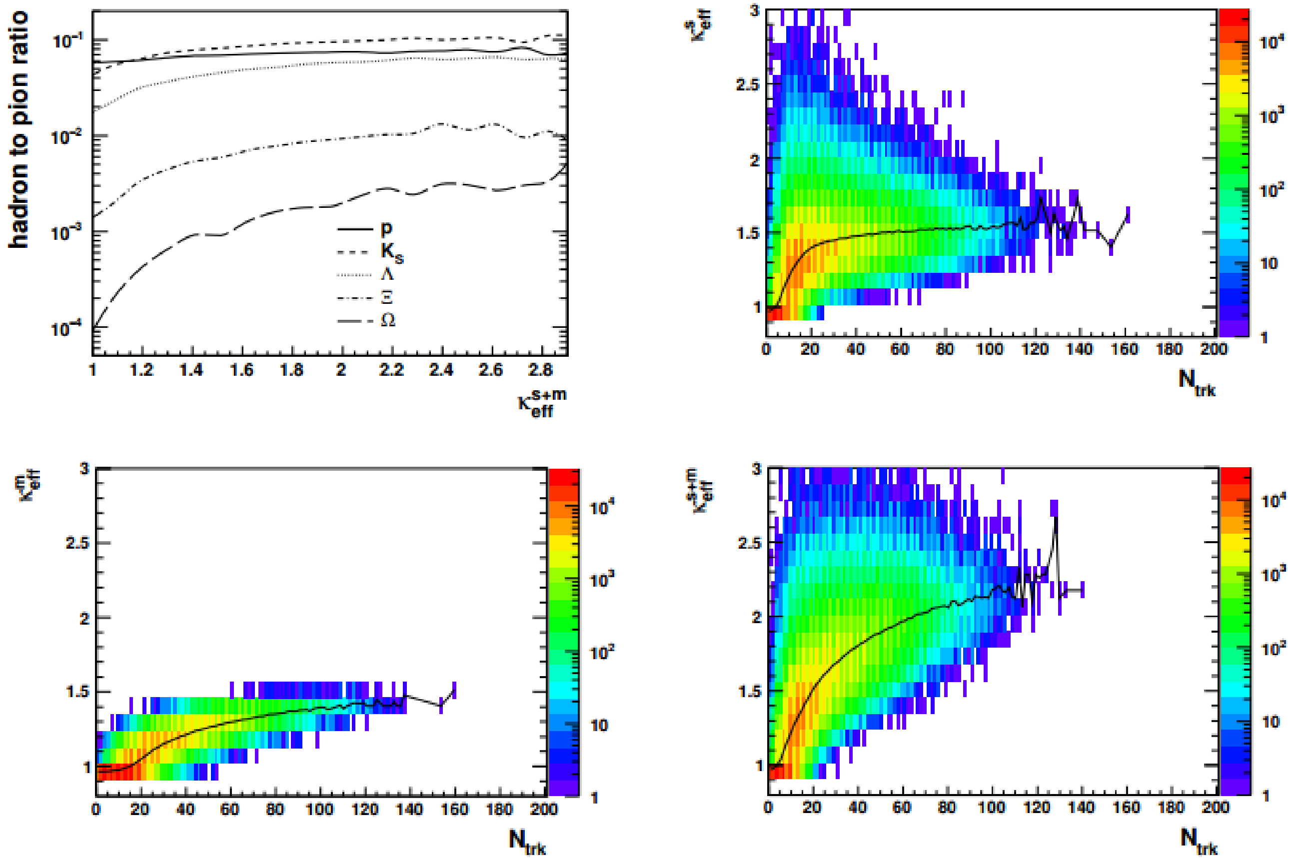
String tension variations

pp 7TeV
N_{trk}: charged number in "V0" region, within

$-3.7 < \eta < -1.7$

and

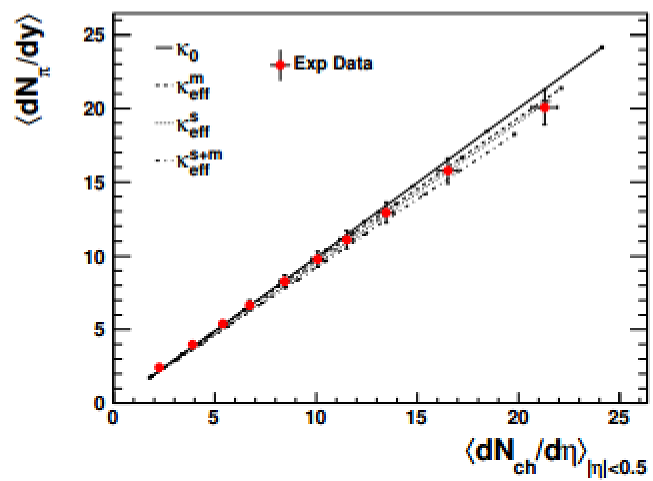
$2.8 < \eta < 5.1$

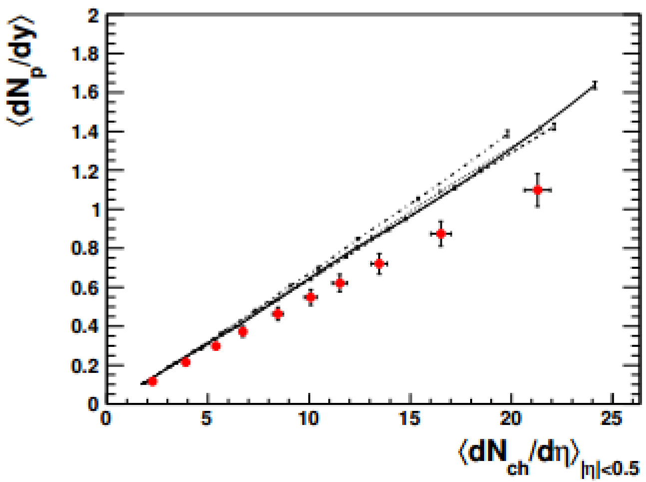


Integrated yield on multiplicity

pp 7 TeV
Event class defined with charged number in "V0" region

Event Class	I	II	III	IV	V	VI	VII	VIII	IX	X
σ/σ_{INEL}	0-0.95%	0.95-4.7%	4.7-9.5%	9.5-14%	14-19%	19-28%	28-38%	38-48%	48-68%	68-100%
Exp Data	21.3 ± 0.6	16.5 ± 0.5	13.5 ± 0.4	11.5 ± 0.3	10.1 ± 0.3	8.45 ± 0.25	6.72 ± 0.21	5.40 ± 0.17	3.90 ± 0.14	2.26 ± 0.12
$dN_{ch}/d\eta(\kappa_0)$	24.1	18.5	14.8	12.4	10.5	8.4	6.4	4.8	3.4	1.9
$dN_{ch}/d\eta(\kappa^m_{eff})$	22.1	17.2	14.0	11.8	10.1	8.1	6.1	4.7	3.4	1.9
$dN_{ch}/d\eta(\kappa^s_{eff})$	21.5	16.5	13.1	11.0	9.5	7.7	5.8	4.3	3.1	1.8
$dN_{ch}/d\eta(\kappa^{s+m}_{eff})$	19.8	15.4	12.4	10.4	9.1	7.4	5.6	4.3	3.1	1.8

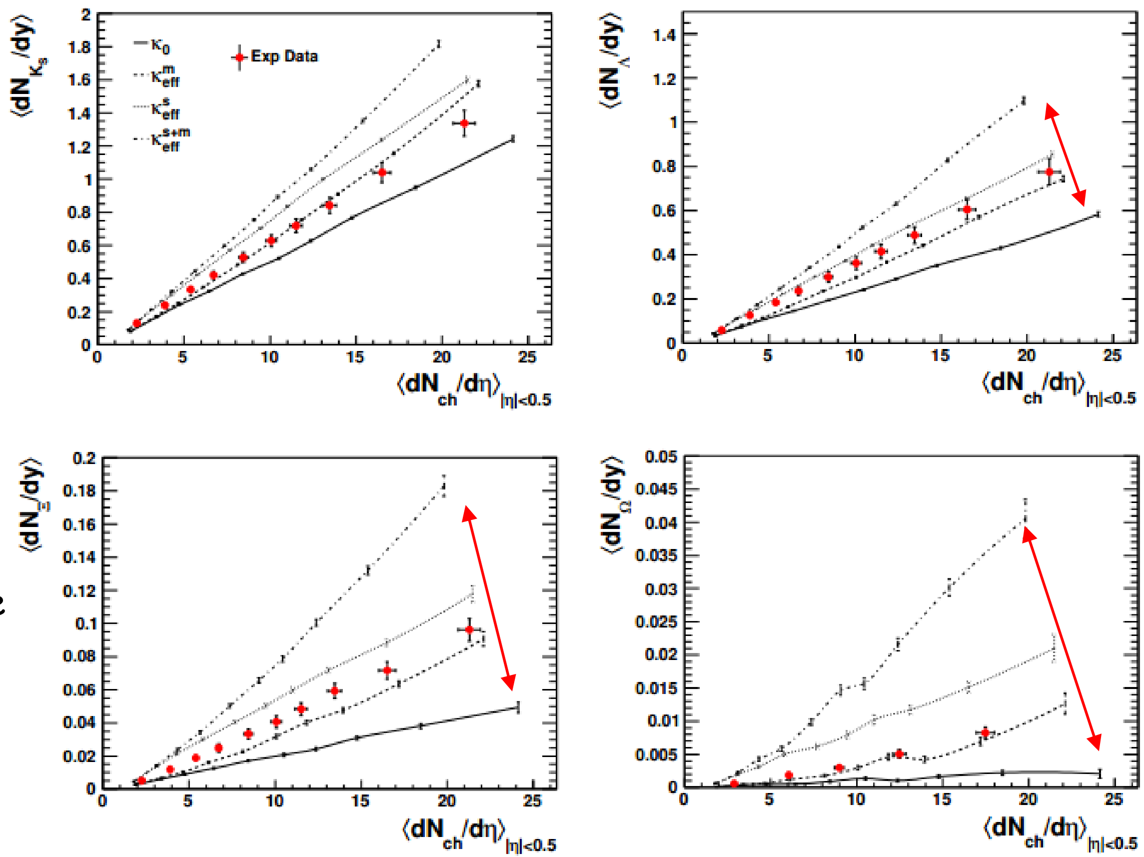




Pion and proton yields barely change with string tensions

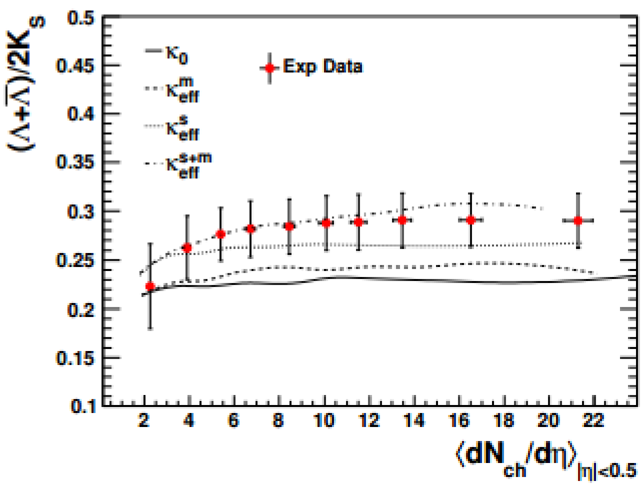
Integrated yield on multiplicity

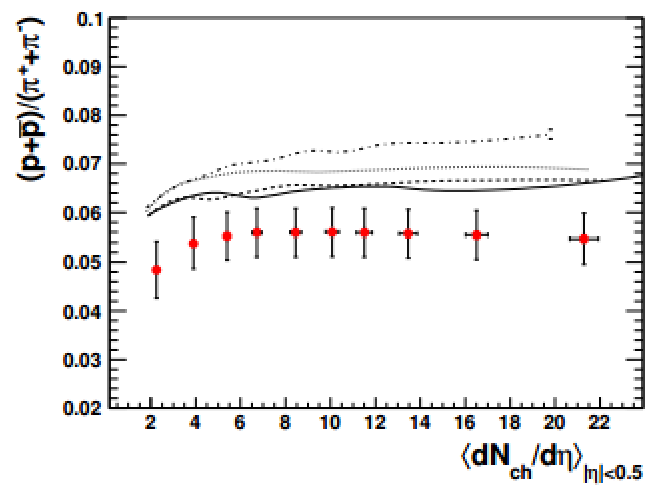
- Large string tension leads to strong dependence on multiplicity
- String tension moderated effects depend on strangeness number
- Multiple string interaction triggered fit with data magnitude



Baryon to meson ratio

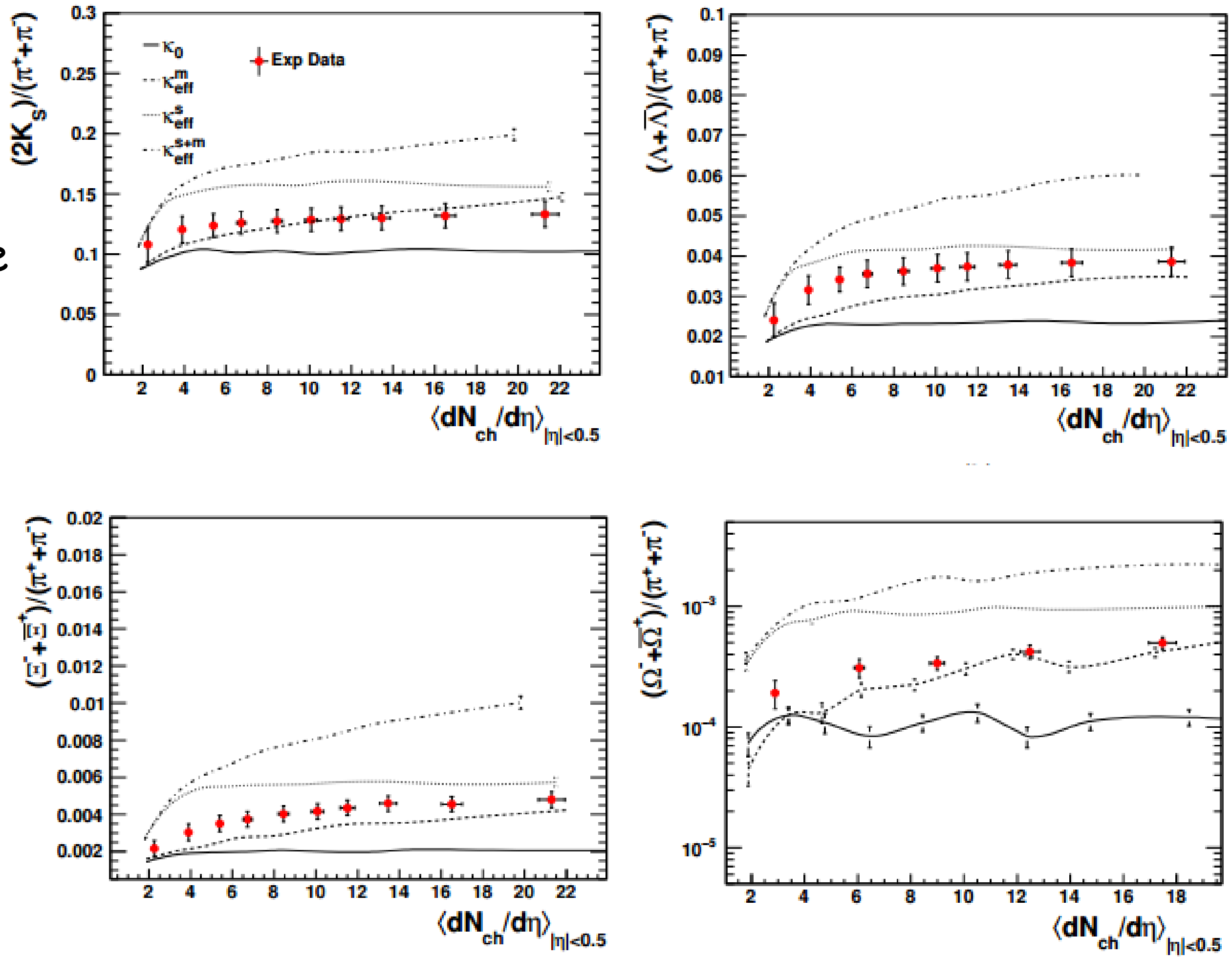
- Baryon to meson ratio underestimated in strange and overestimated in nonstrange
- Unlikely to fit both ratios at the same time





Relative strange production

- Strangeness to pion ratio can be largely depicted with κ_{eff}^{m}
- Different trend on multiplicity

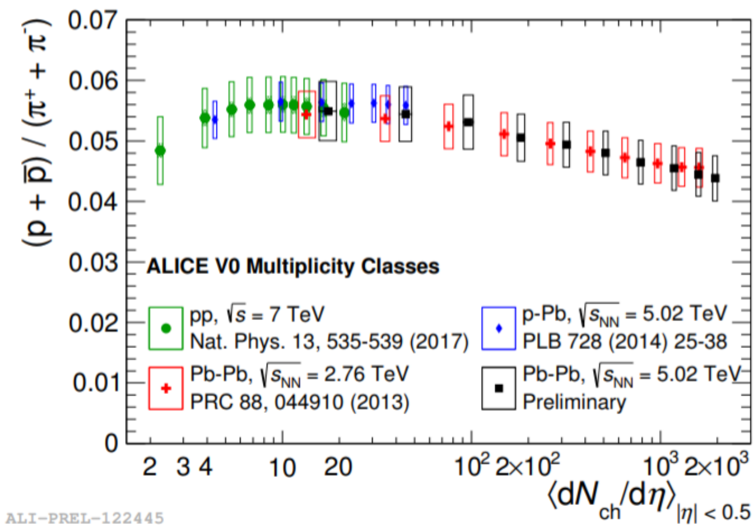


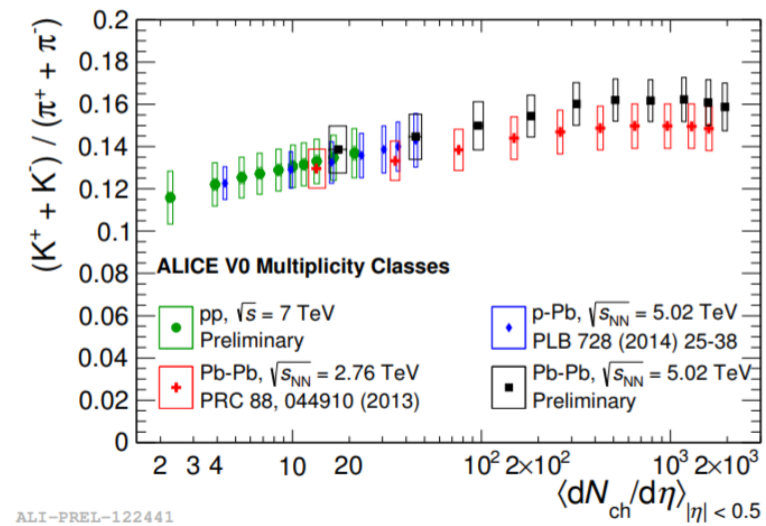
Summary

- Multiplicity dependent strangeness enhancement across a wide range of collisions system observed in data
- The origin of strangeness enhancement in pp is still largely unknown
- We test the strangeness enhancement in PACIAE model with an effective string tension approach
- It is possible to produce a strangeness enhancement in pp from a pure string fragmentation framework ☺

Back up

Chemical composition independent of energy/system

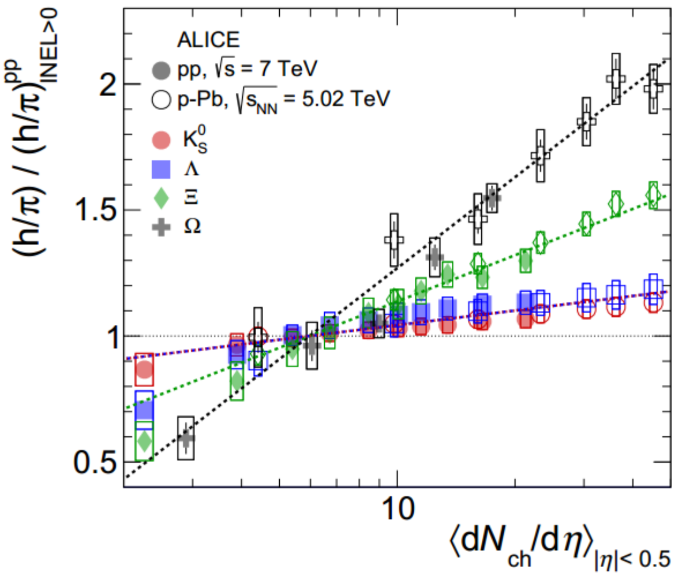


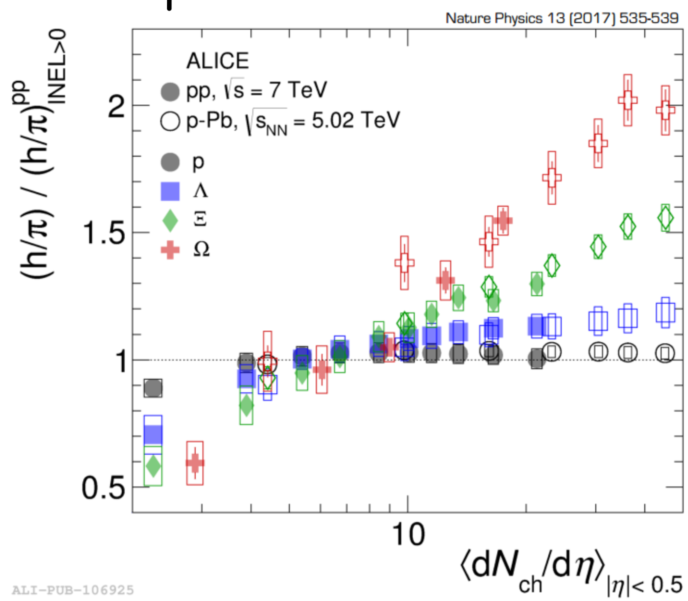


- No significant energy dependence
- Peripheral AA consistent with pp/pA at the same dN/deta
- p/pi slightly decrease in central AA
- K/pi slightly increase over dN/deta

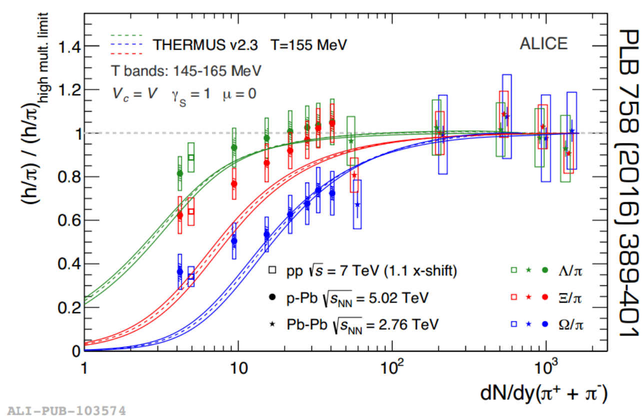
Strangeness enhancement in pp

A self-normalized double ratio maps out the strangeness enhancement slope.



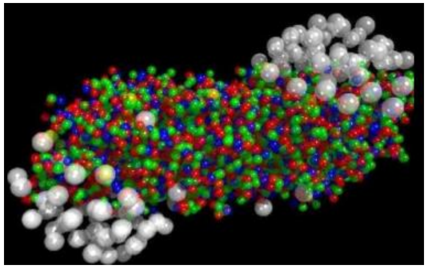


Integrated proton/pion almost no dependence on multiplicity



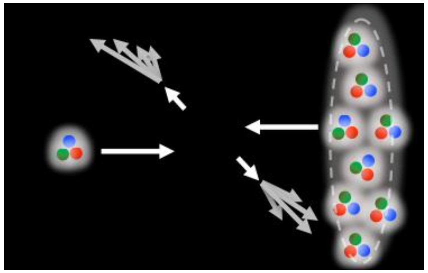
Grand canonical model can be extended to lower multiplicities implementing strangeness canonical suppression

Research paradigm in Heavy Ion Collisions



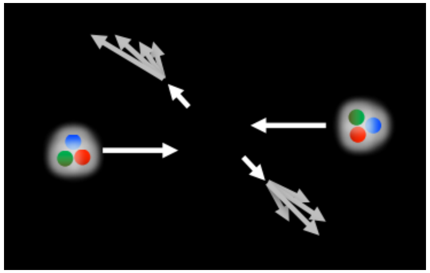
The AA collision system
Large system
Deconfined/Hot QCD matter

- Chemical equilibration
- Collectivity
- Energy loss



The pA collision system
Small system
Cold nuclear matter

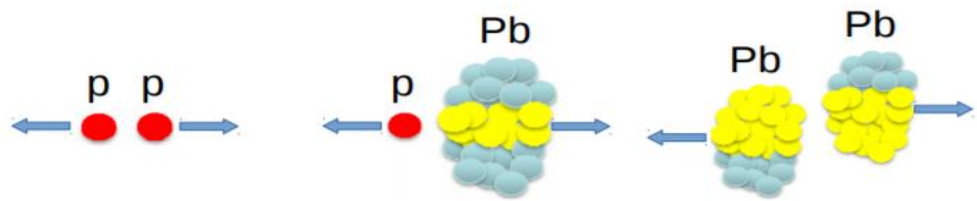
- Initial states: nPDF



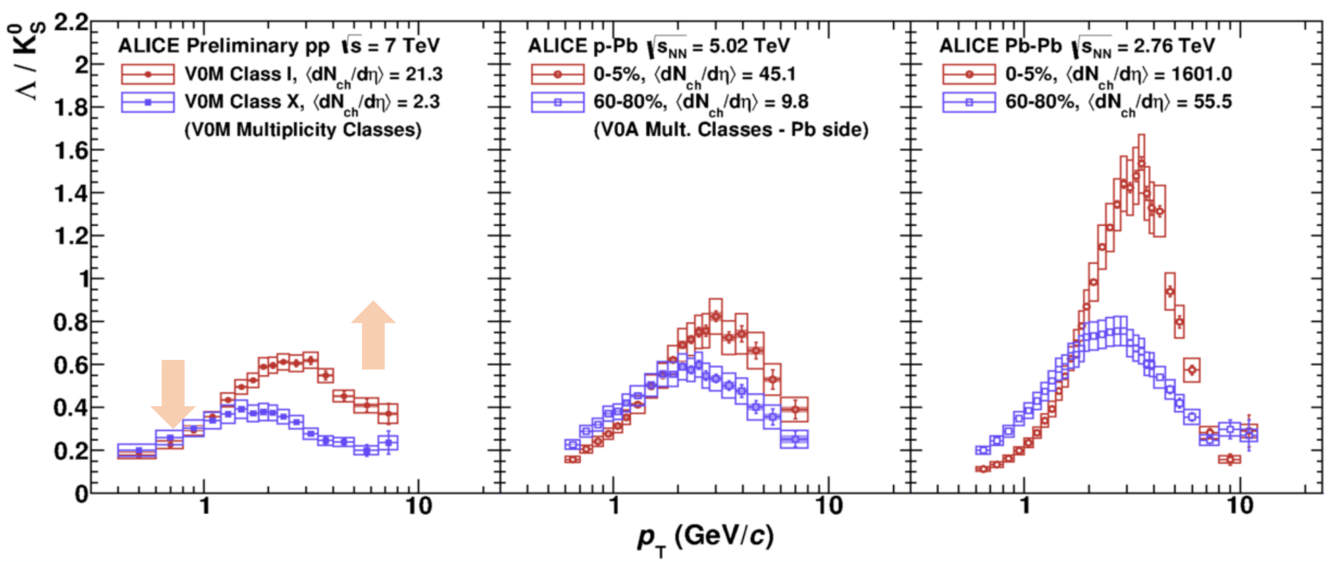
The pp collision system
Small system
Test of pQCD calculations, reference to understand all nuclear effects

Signs of collectivity in small system

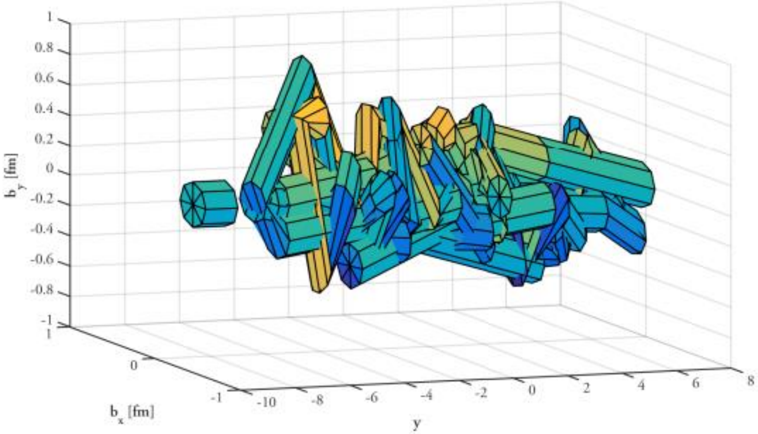
- Lambda to Kshort ratio
  - Similar feature for over all collision system

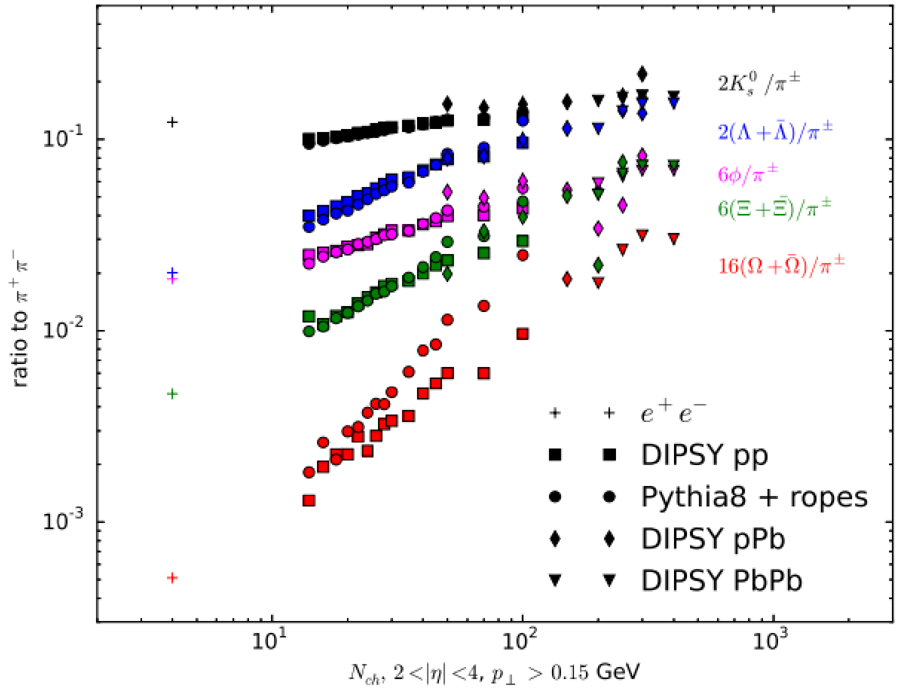


AA results well described by hadro models, B/M ratio manifestation of the radial flow.



- How do we treat strings that overlap in space–time?



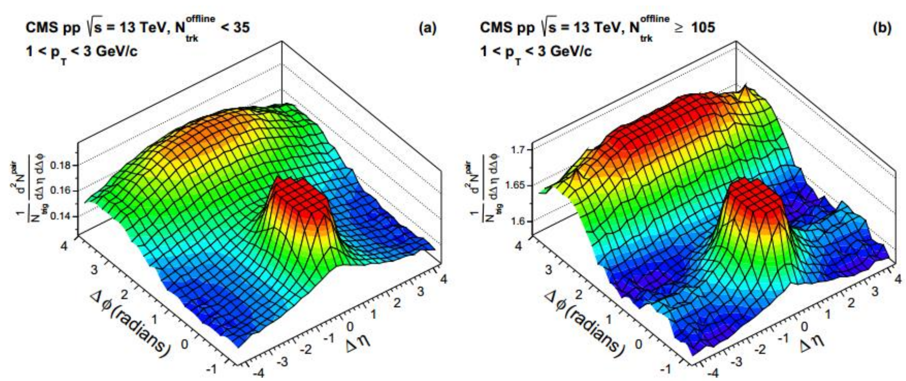


Collectivity in small system

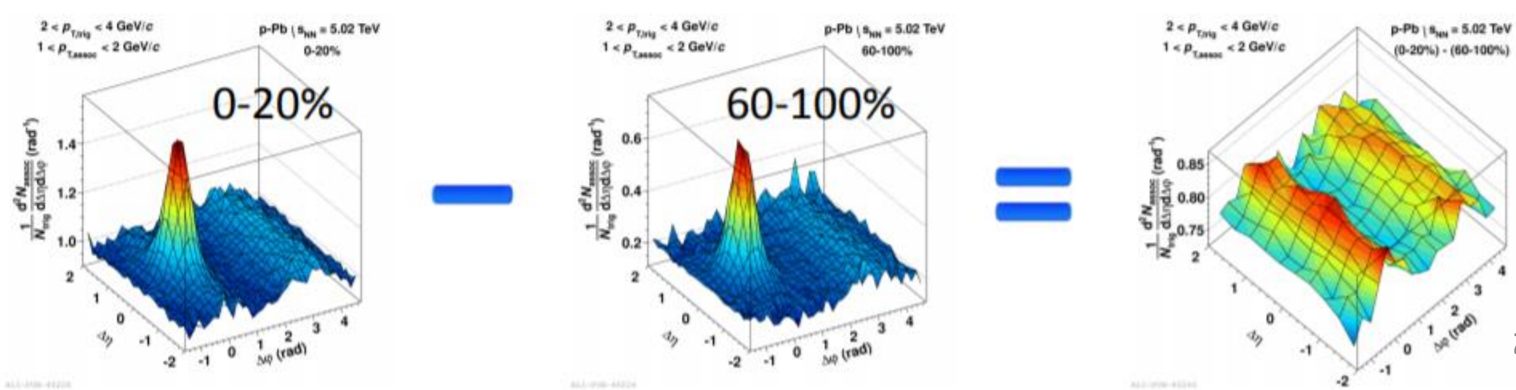
- Ridge structure in pp/pA

Near side ridge arises in high multiplicity pp

Particles with very different η are correlated



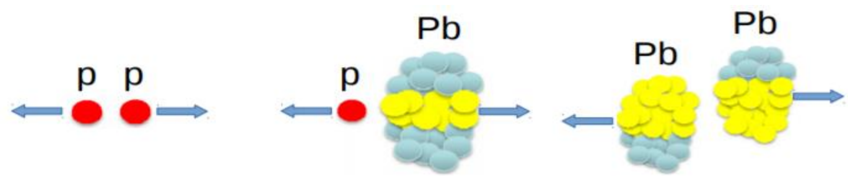
Double ridge appears in central pA after removing peripheral pA background

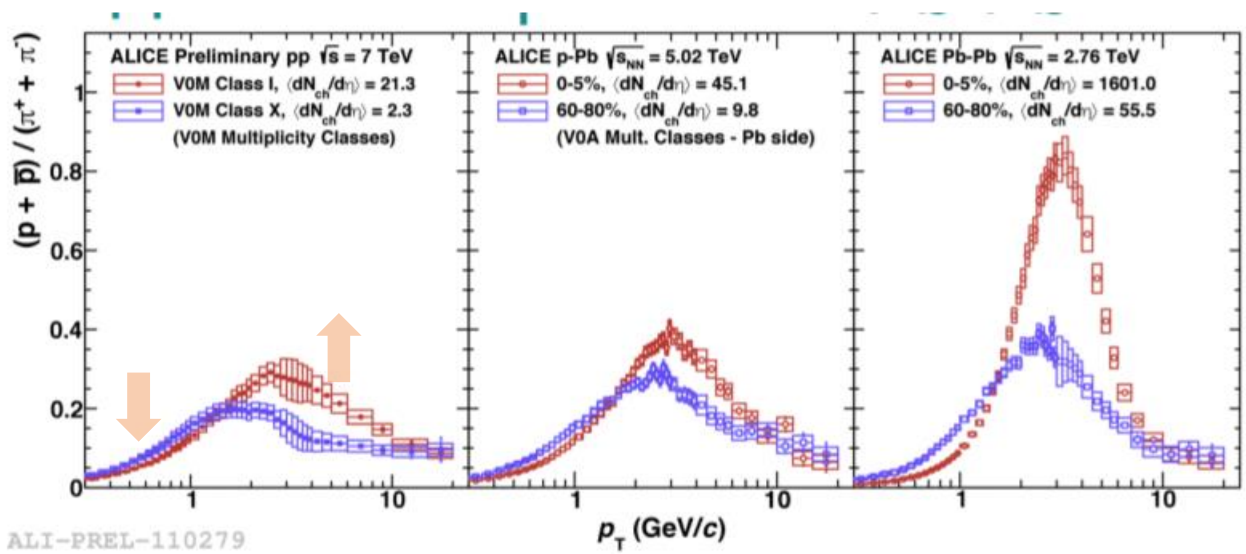


Signs of collectivity in small system

- Baryon to meson ratio
  - Similar feature for all collision system

AA results well described by hydrodynamic models, B/M ratio manifestation of the radial flow.



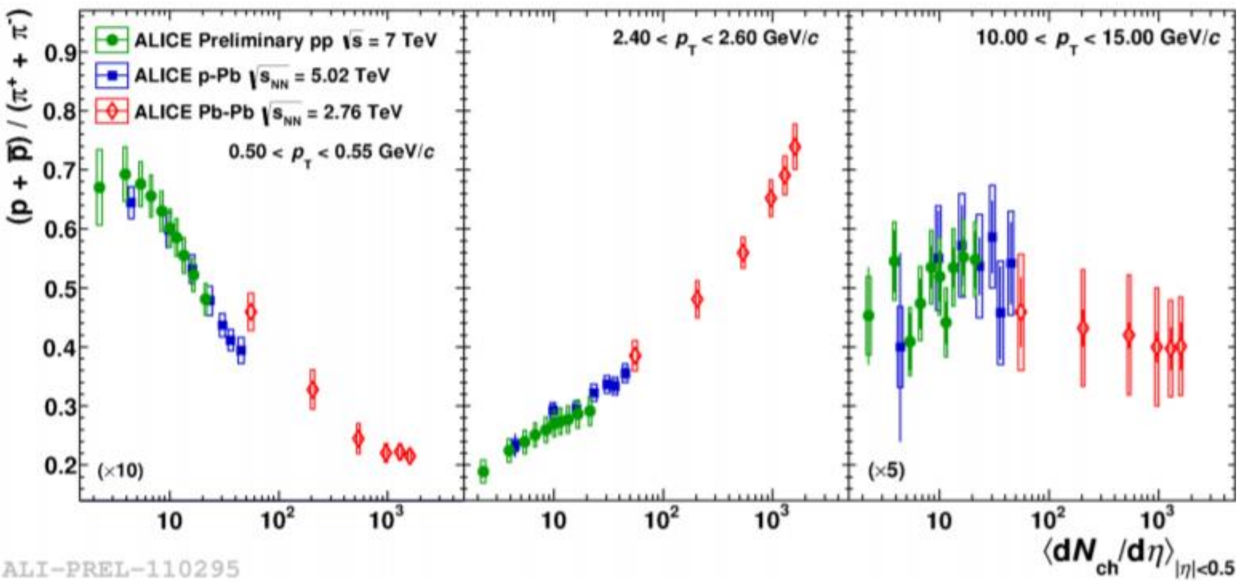


Similar thing for L/K ratio

Signs of collectivity in small system

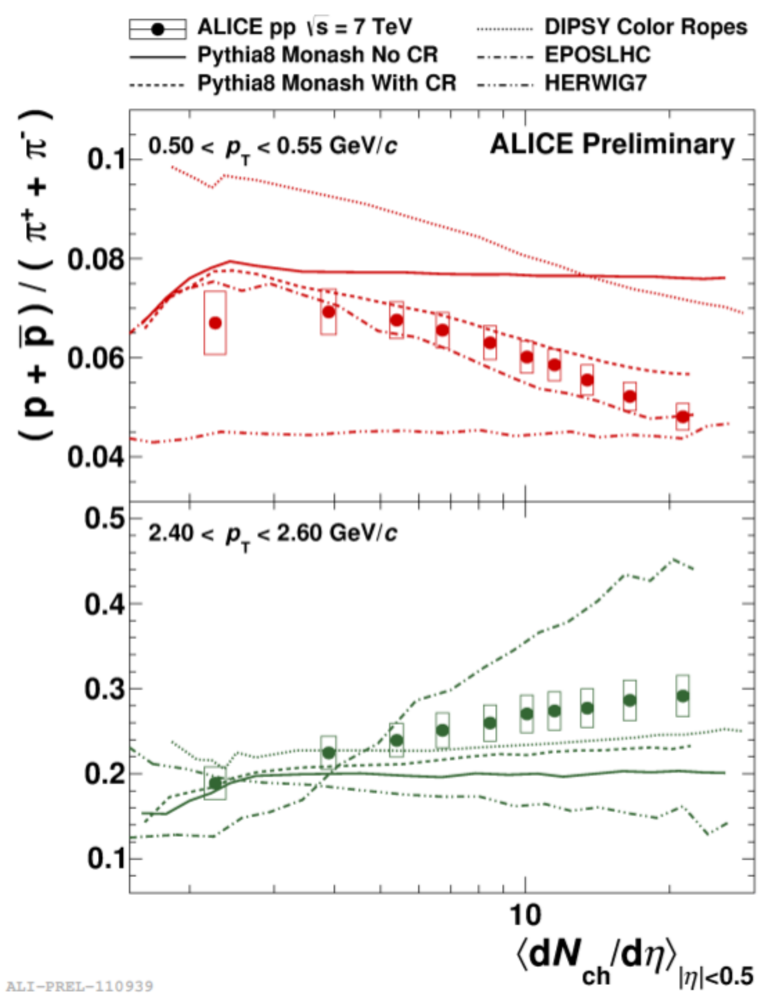
- Baryon to meson ratio
  - Similar feature for all collision system
  - Smooth evolution over multiplicity across all system at fixed p_T

Does concepts like radial flow or recombination apply to pp collisions?

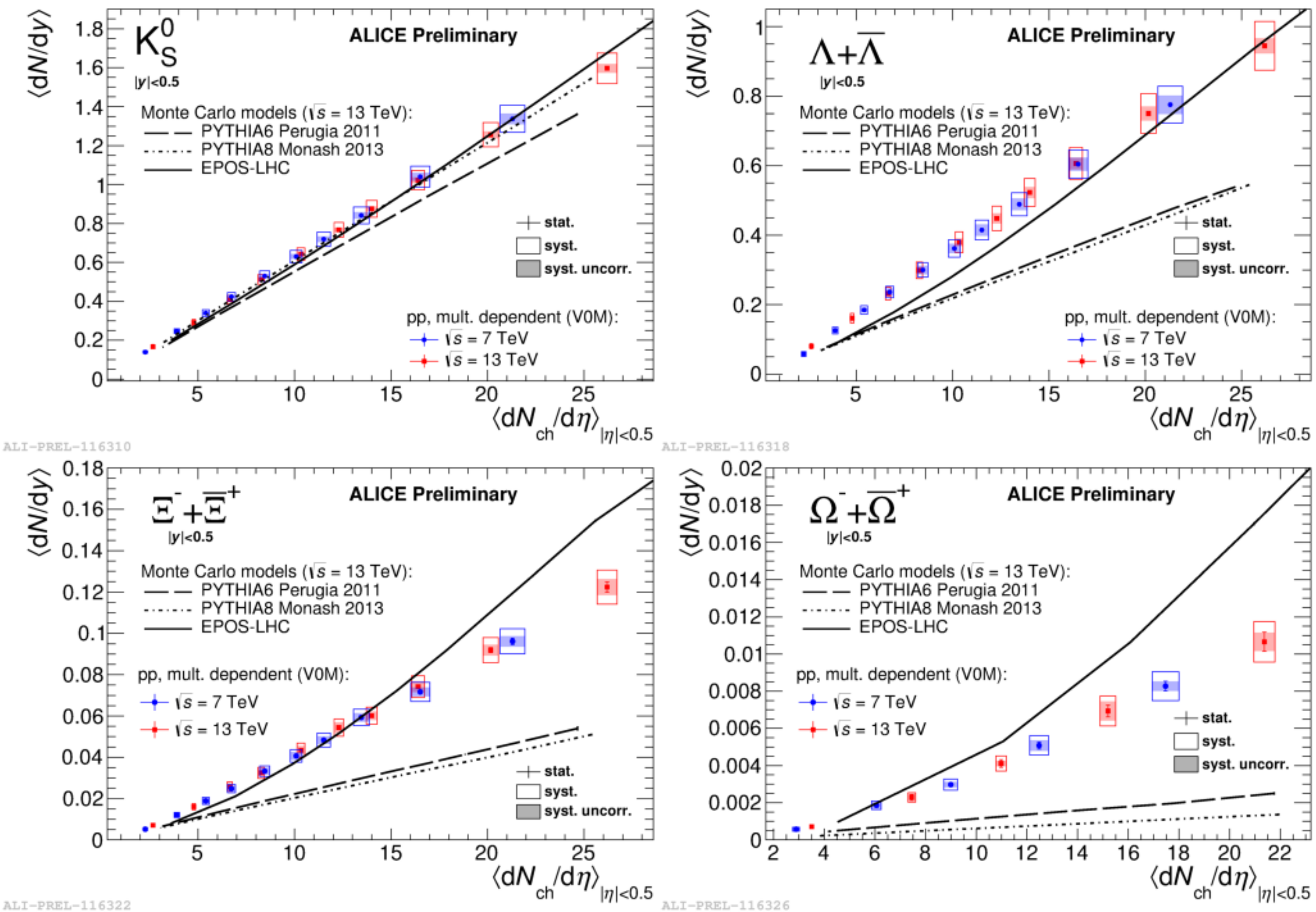


Signs of collectivity in small system: model comparison

- Do we have a "mini-QGP" created in pp?
- In pp, these thermo-equilibrium behaviors can be mimicked by QCD effects, e.g. Color Reconnection



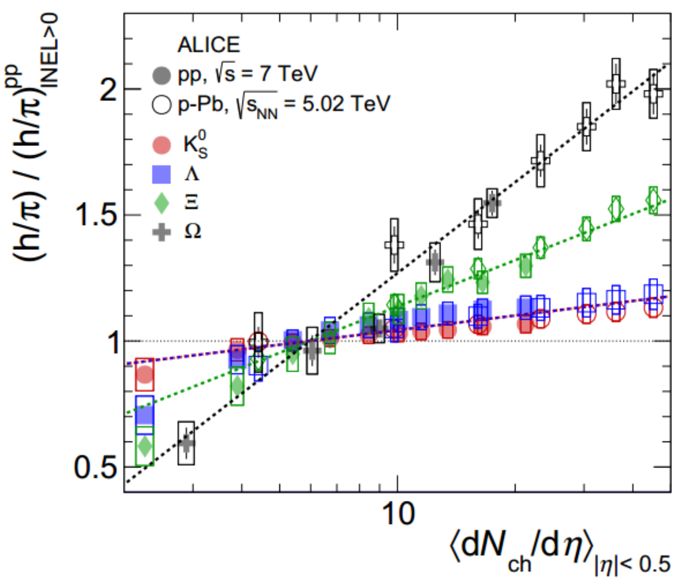
Strangeness production in pp

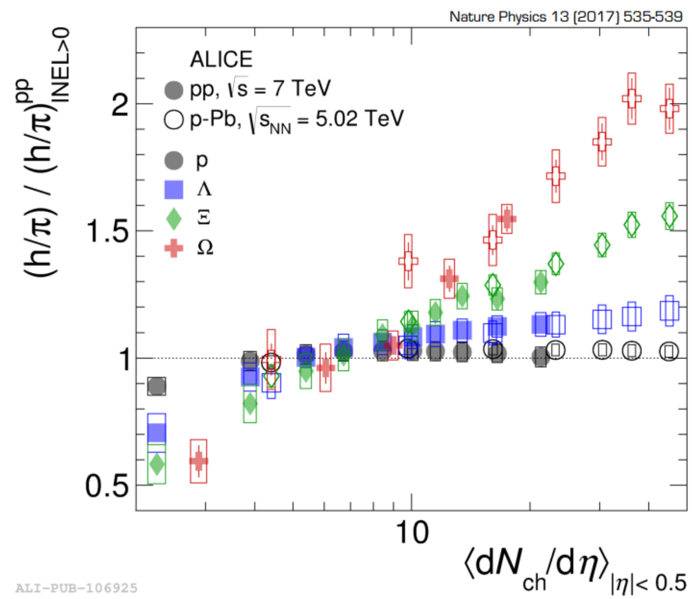


- Event activity drives particle production, energy independent
- EPOS reproduces the trend qualitatively

Strangeness enhancement in small system

A self-normalized double ratio maps out the strangeness enhancement slope.





Integrated proton/pion consistent with no dependence on multiplicity

Effective string tension

To quantify how different is a multi-gluon string compared to a pure qqbar string, we start with the mean multiplicity produced by a string. For a pure qqbar string:

$$\bar{n} \propto \ln(\frac{s}{s_0})$$

For a multi-gluon string:

$$\bar{n} \propto \ln(\frac{s}{s_0}) + \sum_{j=2}^{n-1} \ln(\frac{k_{\perp j}^2}{s_0}),$$

Since the string structure is governed by the hardest gluon, we construct the quantity to represent the scale of a gluon string is deviated from the pure qqbar string:

$$\xi = \frac{\ln(\frac{k_{Tmax}^2}{s_0})}{\ln(\frac{s}{s_0}) + \sum_{j=2}^{n-1} \ln(\frac{k_{Tj}^2}{s_0})}.$$

One can further parameterize the effective string tension as:

$$\kappa^{eff} = \kappa_0 (1-\xi)^{-a}$$