QCD string fragmentation with worldsheet axion excitations

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in collaboration with

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Other interests: Phase transitions, magnetic monopoles, wormholes, pop music

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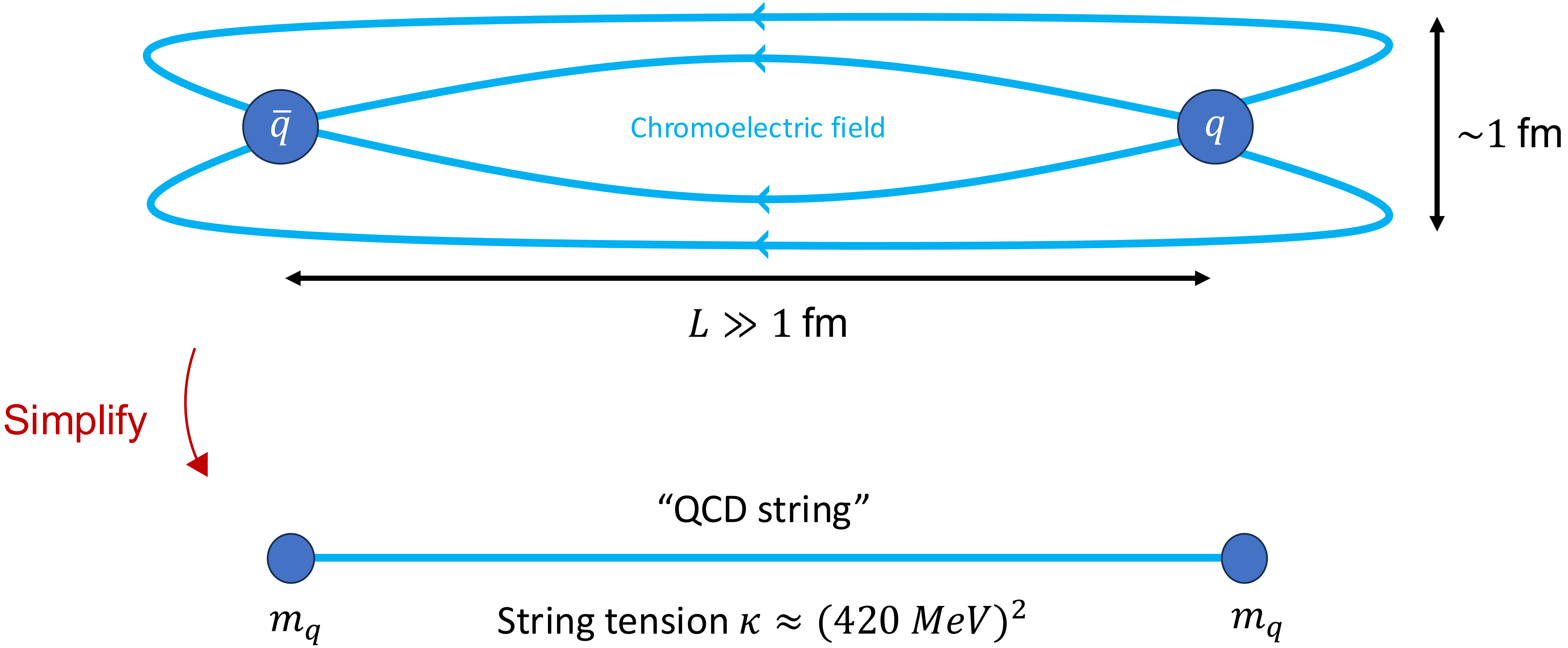
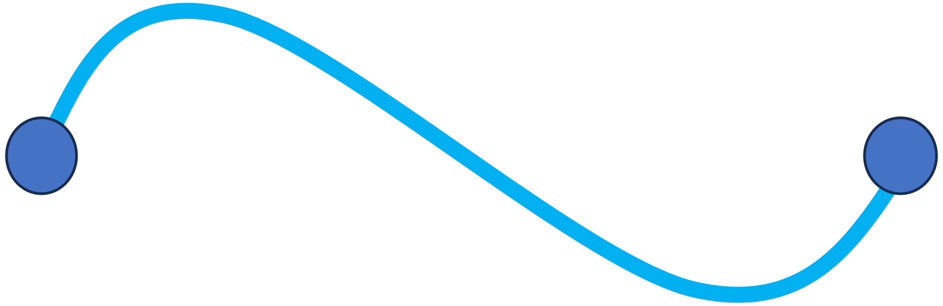
QCD strings



$\bar{q}$
Chromoelectric field
q
$\sim$1 fm
$L \gg 1$ fm
Simplify
"QCD string"
m_q
String tension $\kappa \approx (420\ MeV)^2$
m_q

QCD string excitations

Nambu-Goldstones: massless scalars $X^i \quad (i = 1, 2)$



"Worldsheet axion": massive pseudoscalar a

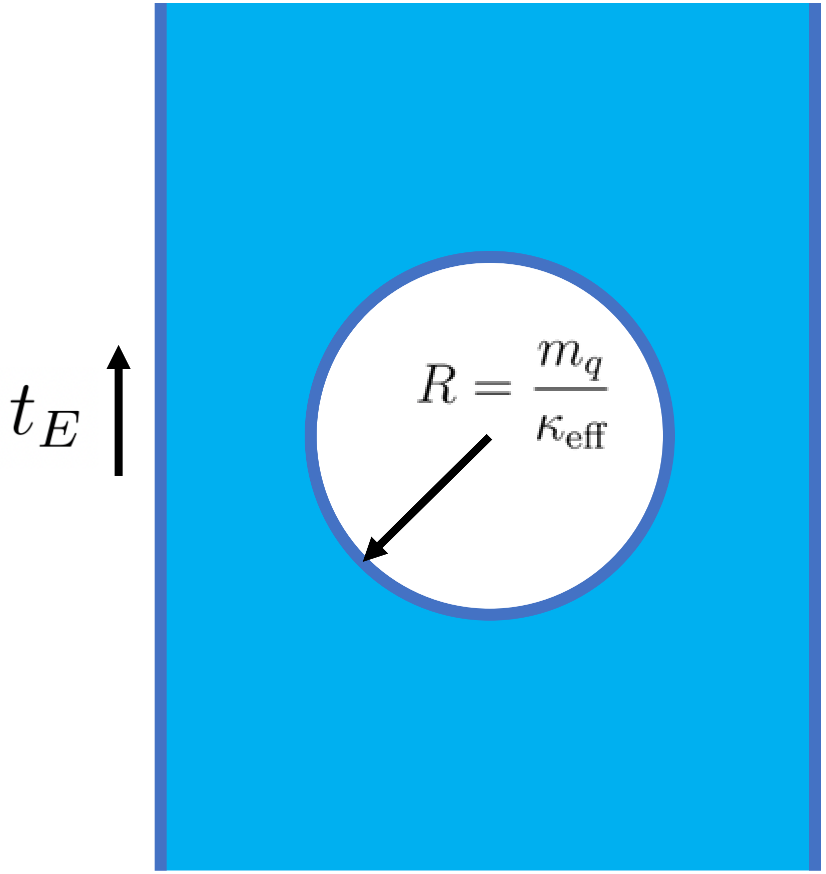
[Dubovsky, Flauger, Gorbenko, arXiv:1301.2325]

Action to leading order in derivatives is

$$S \approx \int dt dx \Big[-\kappa + \frac{1}{2}(\partial_t X^i)^2 - \frac{1}{2}(\partial_x X^i)^2 + \frac{1}{2}(\partial_t a)^2 - \frac{1}{2}(\partial_x a)^2 - \frac{1}{2} m_a^2 a^2 + c\, a\, \varepsilon^{\alpha\beta} \varepsilon_{ij} (\nabla_\alpha \partial_\gamma X^i)(\nabla_\beta \partial^\gamma X^j) + \mathcal{O}(\partial^4/\kappa) \Big] - \sum_{\text{endpoints}} m_q \int ds$$

How do these affect the breaking rate?

Fragmentation rate



Bounce

String breaking is a type of vacuum decay

Use Coleman and Callan's formalism to calculate decay rate per unit length as

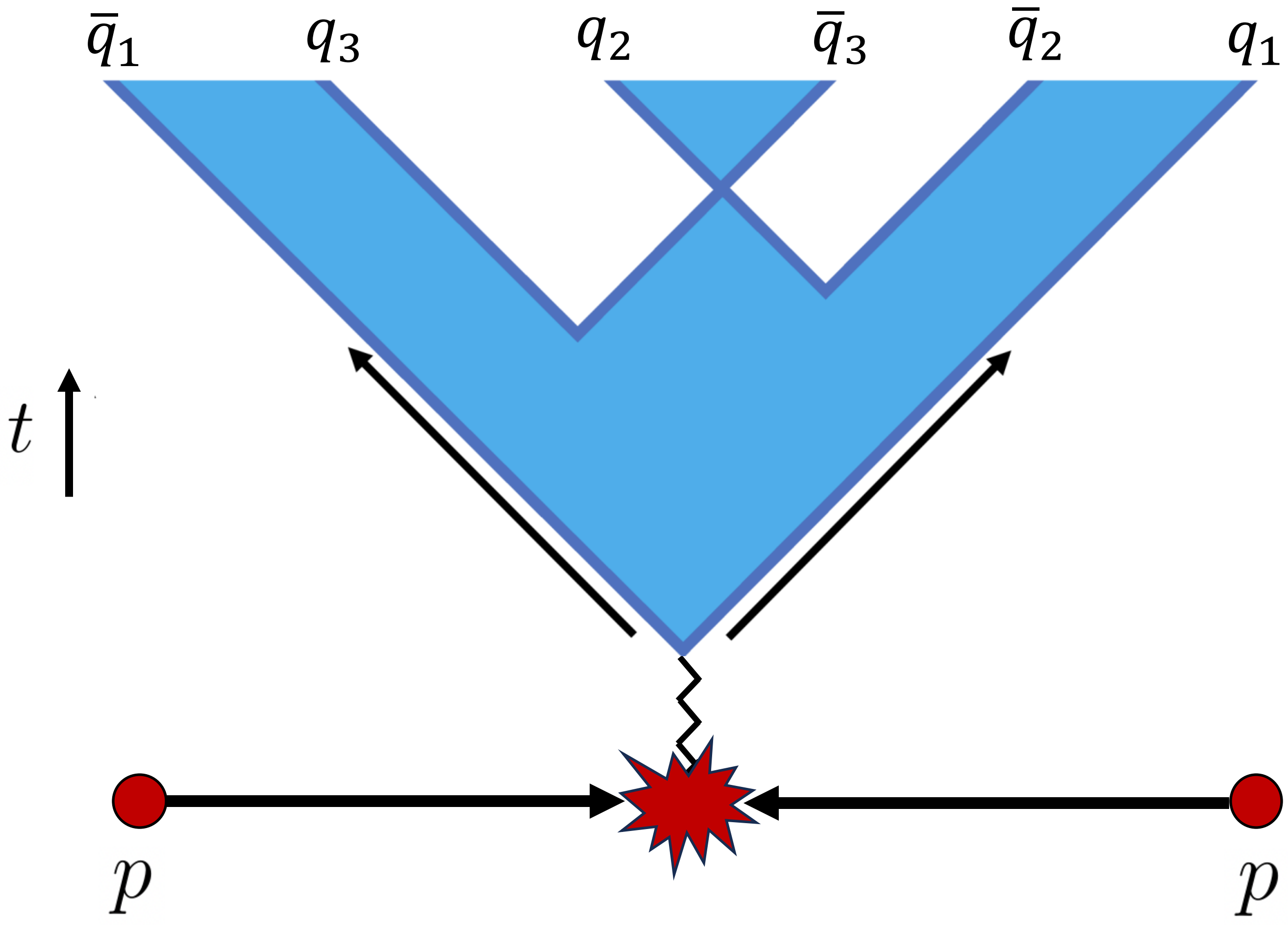
$$\Gamma \sim e^{-\Delta S_E}$$

evaluated on the "bounce" configuration

$\Longrightarrow$ For long-wavelength excitations ($\gg R$),

$$\Gamma \sim e^{-\frac{\pi m_q^2}{\kappa_{\text{eff}}}} \qquad \kappa_{\text{eff}}(t,x) = \kappa + \frac{1}{2}(\partial_t a)^2 + \frac{1}{2}(\partial_x a)^2$$

String model of hadronization



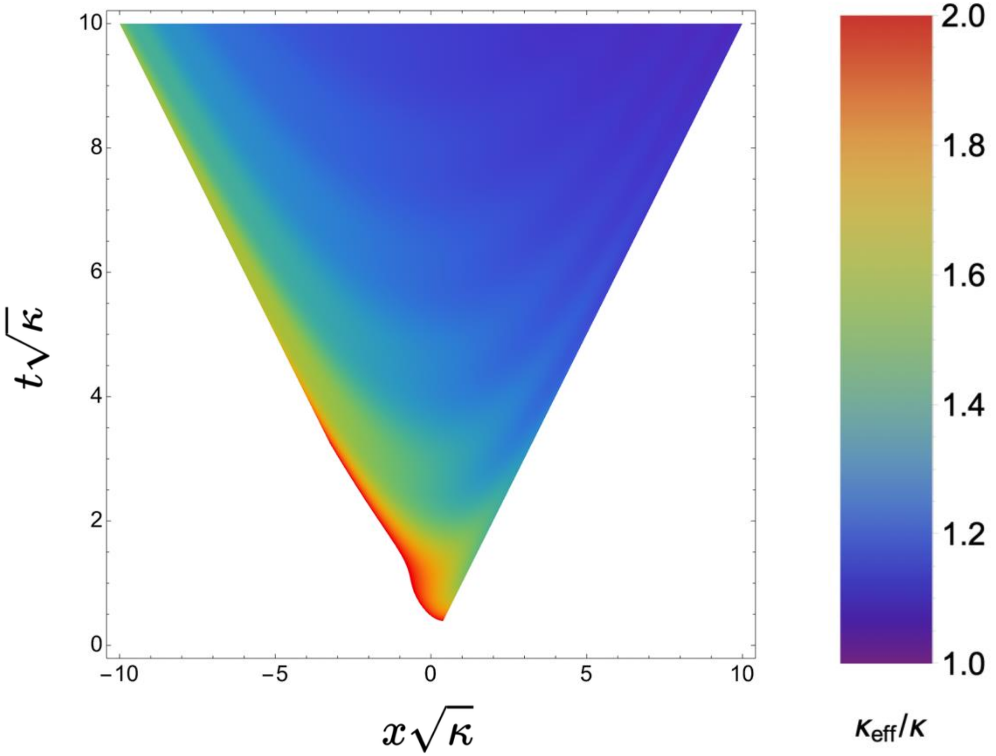
LHC event generator Pythia calculates distribution of final state hadrons using the constant-tension decay rate

Broadly works well, but fails to explain e.g. “strangeness enhancement”

Can axion excitations help?

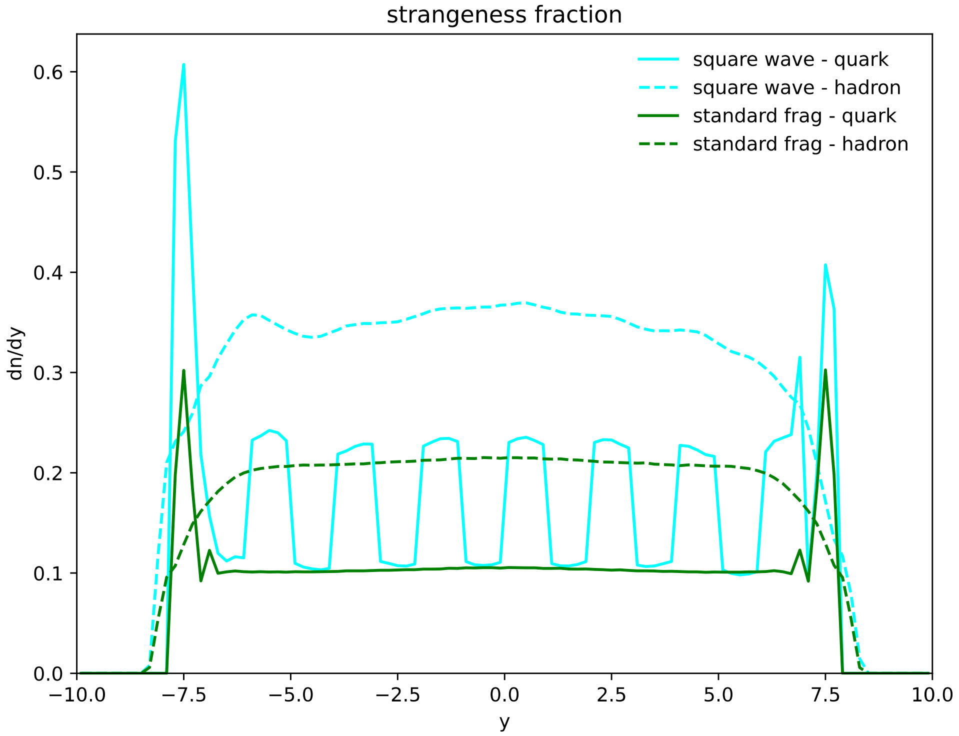
Variable effective tensions

Lowest four axion modes excited



All with occupation number $N_{occ} = 2$

Implementation in Pythia

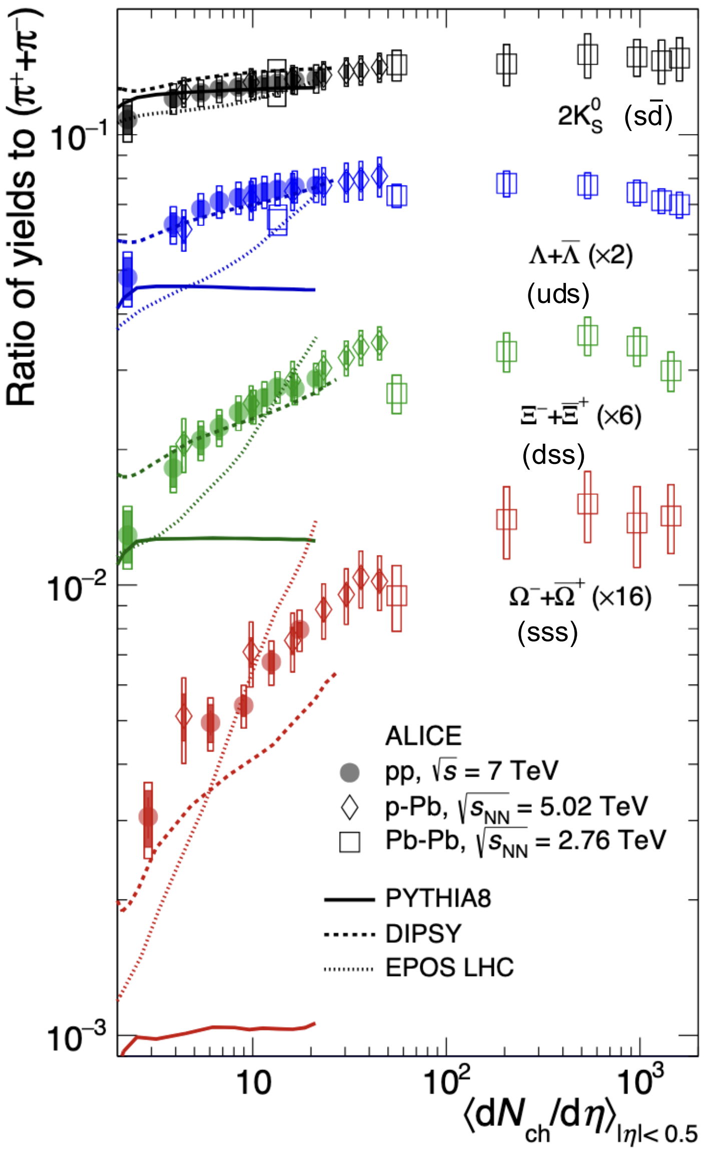


(Proof of concept test pattern)

Future: evidence for worldsheet axion in the data?

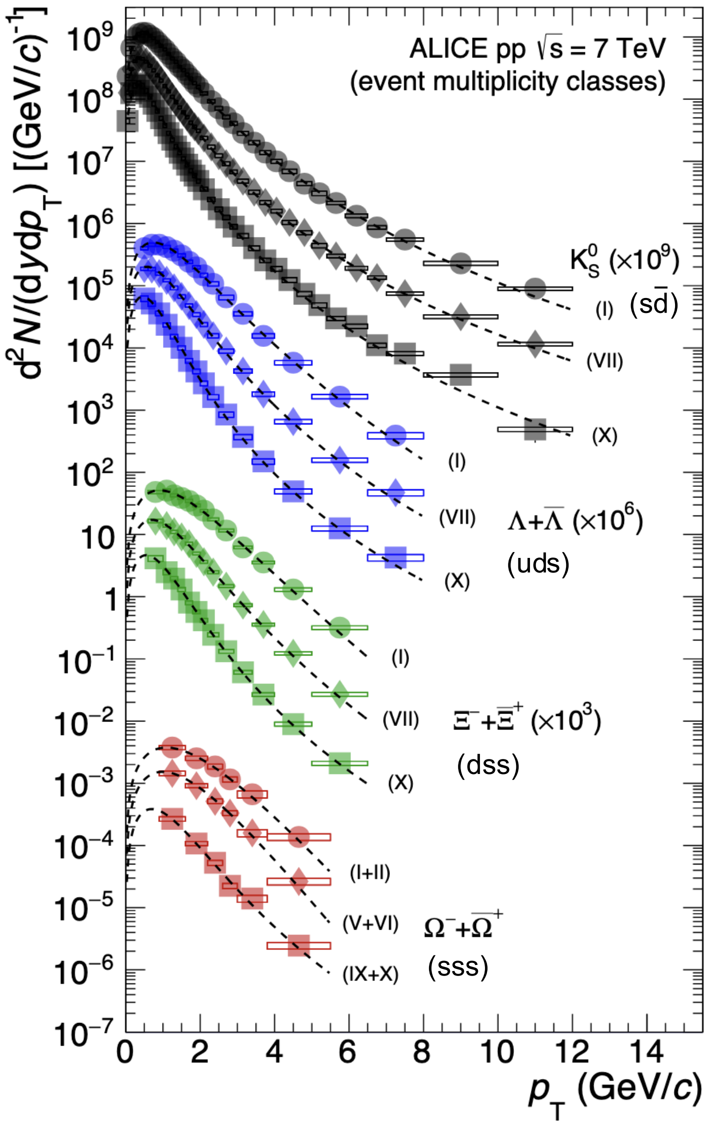
Backup Slides

Strangeness enhancement



[ALICE Collaboration, 1606.07424]

Transverse momentum distribution



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