Hadronization models and Colour Reconnection

arXiv:1412.6259 [hep-ph] and arXiv:1507.02091 [hep-ph]

Christian Bierlich
Jesper Roy Christiansen, Gösta Gustafson, Leif Lönnblad, Andrey Tarasov

Lund University

Apr 12, 2016
XXIV International Workshop on Deep-Inelastic-Scattering

LUND
UNIVERSITY

Introduction

- Hadronization models central for non-perturbative QCD.
- String model(s) (*eg.* Pythia 6+8) challenged by many MPIs.
- Many MPIs $\Rightarrow$ High density of strings $\Rightarrow$ Interference effects.
- Rope model: Change of string tension, based on lattice QCD.
- Universality is a requirement.

1. Introduction to strings.
2. The Rope model.
3. The DIPSY event generator.
4. Junction handling.
5. Results.

Strings: A simple model for mesons

- Strings predates QCD, leading Regge trajectories, $\alpha' \approx 0.9$ GeV^{-2}:

$$J(s) = J(0) + \alpha' s$$

- *What kind of force law could reproduce this?* Revolving string.
- String of length l, massless ends moving with c, string tension in rest is κ.

$$E = \frac{\pi l \kappa}{2} \ , \ J = \frac{l^2 \pi \kappa}{8}$$

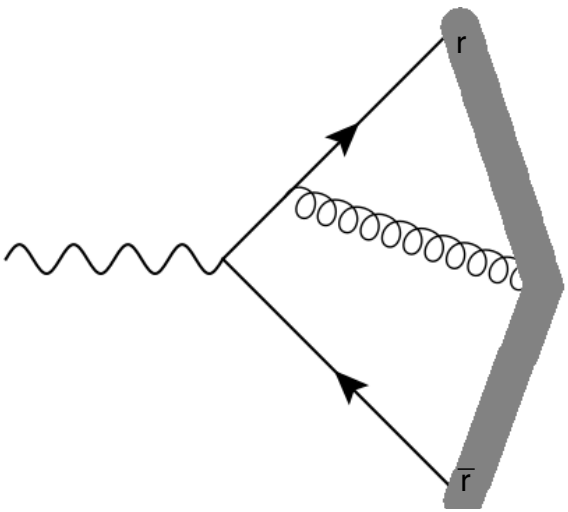
$$\Rightarrow \kappa = \frac{1}{2\pi\alpha} \approx 0.180\text{GeV}^2 = 0.91\text{GeV/fm}.$$

- Later confirmed on the lattice.

String Hadronization hep-ph/0603175

- Non-perturbative phase of final state.
- *Breaking*/tunneling with $\mathcal{P} \propto \exp\left(-\frac{\pi m_\perp^2}{\kappa}\right)$ gives hadrons.
- Left-right symmetry in the breaking gives

$$f(z) \propto z^{-1}(1-z)^a \exp\left(\frac{-bm_\perp}{z}\right).$$



- a and b related to total multiplicity.
- Flavours determined by relative probabilities:

$$\rho = \frac{\mathcal{P}_{\text{strange}}}{\mathcal{P}_{\text{u or d}}}, \xi = \frac{\mathcal{P}_{\text{diquark}}}{\mathcal{P}_{\text{quark}}}$$

- Probabilities are related to κ via tunneling equation.

Change of string tension

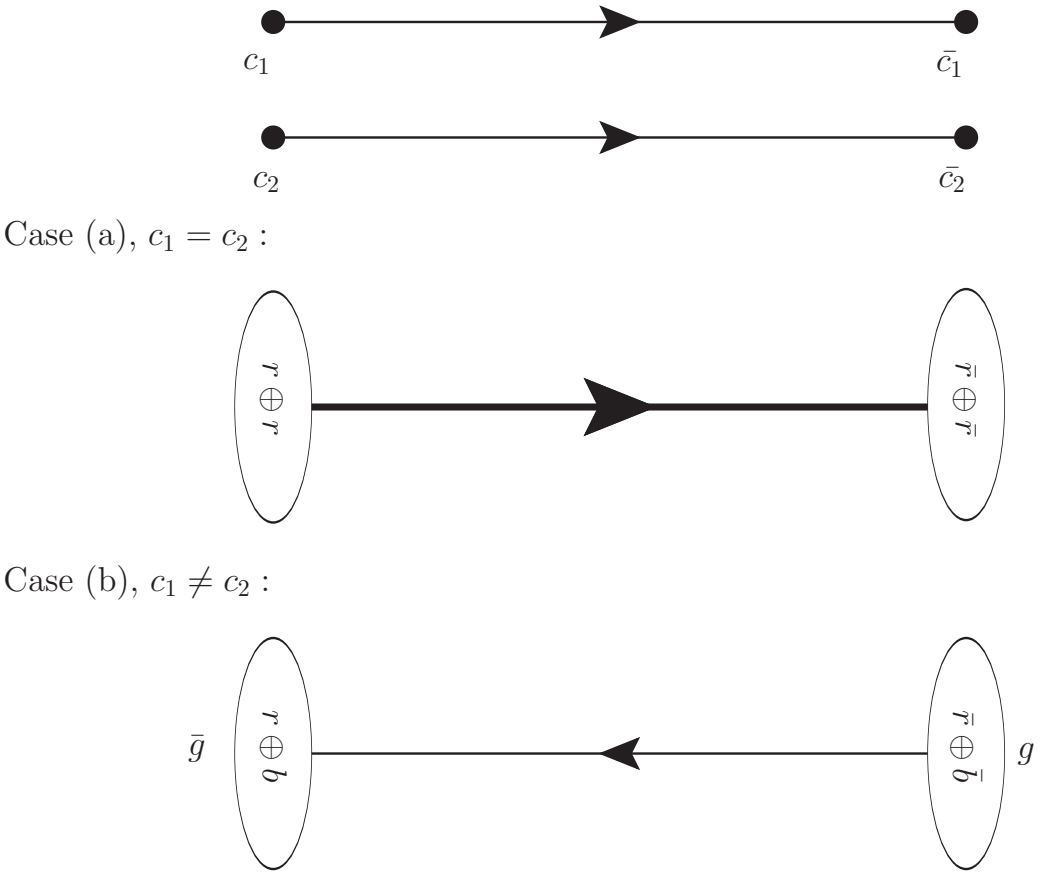
- Field changes when strings overlap - Simple Regge: $2\pi E/I = \kappa$.
- Effective string tension: $\kappa \mapsto \tilde{\kappa} = h\kappa$ from number of overlapping strings.
- Electrodynamics: Principle of superposition, simple.
- QCD: Not so simple. Secondary Casimir operator of multiplet.

$$\kappa \propto C_2 \Rightarrow h = \tilde{\kappa}/\kappa = \frac{C_2(\text{multiplet})}{1 \text{ GeV/fm}}$$

- Confirmed on the lattice, static case.

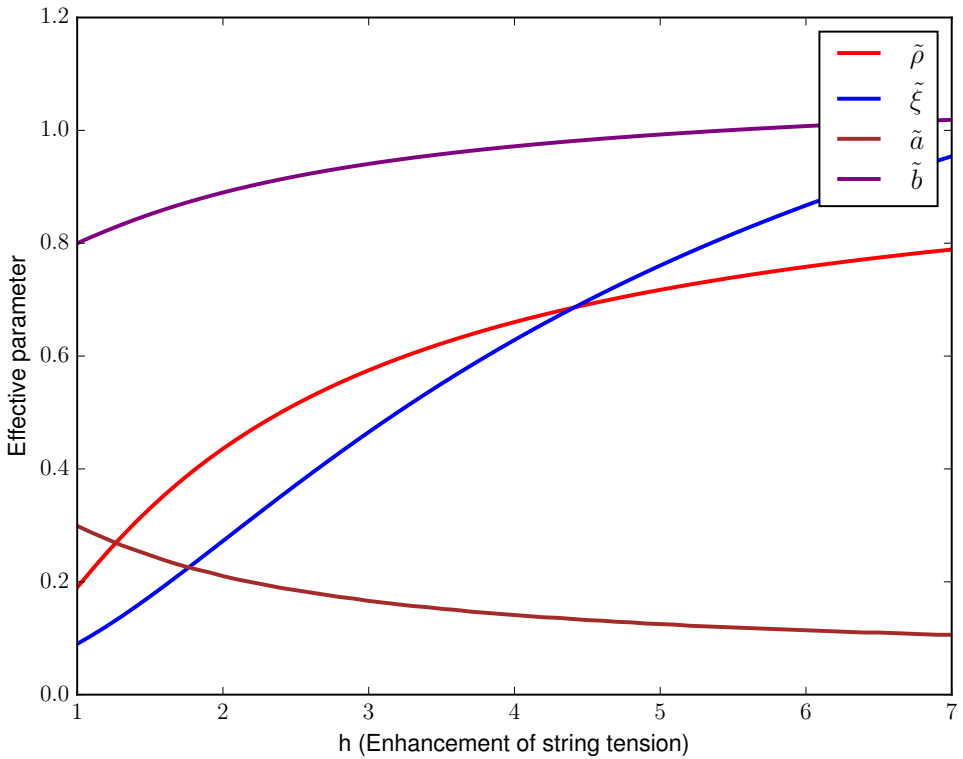
Example arXiv:1412.6259 [hep-ph]

- The simplest example: Two $q\bar{q}$ pairs act coherently.
- Two distinct possibilities:



Effect on hadronization parameters

- All parameters related through string tension.
- ρ (strange) and ξ (baryon) are very sensitive.



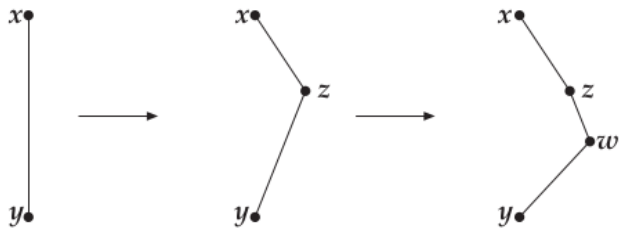
- Large effect on hadronic flavours.
- Smaller effect on hadron $p_\perp$ and multiplicity (tunable).

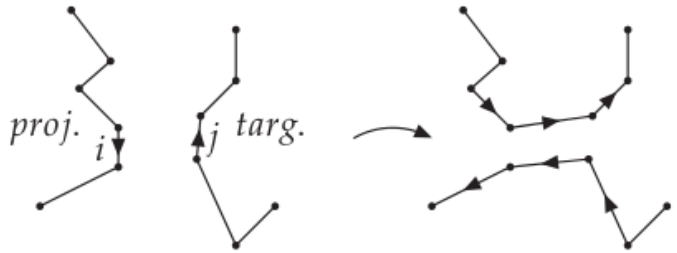
The DIPSY model arXiv:1103.4321 [hep-ph]

- Full $\vec{b}$-space information: Mueller dipoles (with corrections).
- MPIs $\Leftrightarrow$ Dipole Chain Loops $\Leftrightarrow$ Pomeron loops.
- A dipole $(\vec{x}, \vec{y})$ can emit a gluon at position $\vec{z}$ with probability (P) per unit rapidity (Y); dipoles i and j interacts with probability $2f_{ij}$:

$$\frac{dP}{dY} = \frac{3\alpha_s}{2\pi^2} d^2\vec{z} \frac{(\vec{x}-\vec{y})^2}{(\vec{x}-\vec{z})^2(\vec{z}-\vec{y})^2}$$

$$f_{ij} = \frac{\alpha_s^2}{8}\left[\log\left(\frac{(\vec{x}_i-\vec{y}_j)^2(\vec{y}_i-\vec{x}_j)^2}{(\vec{x}_i-\vec{x}_j)^2(\vec{y}_i-\vec{y}_j)^2}\right)\right]^2$$

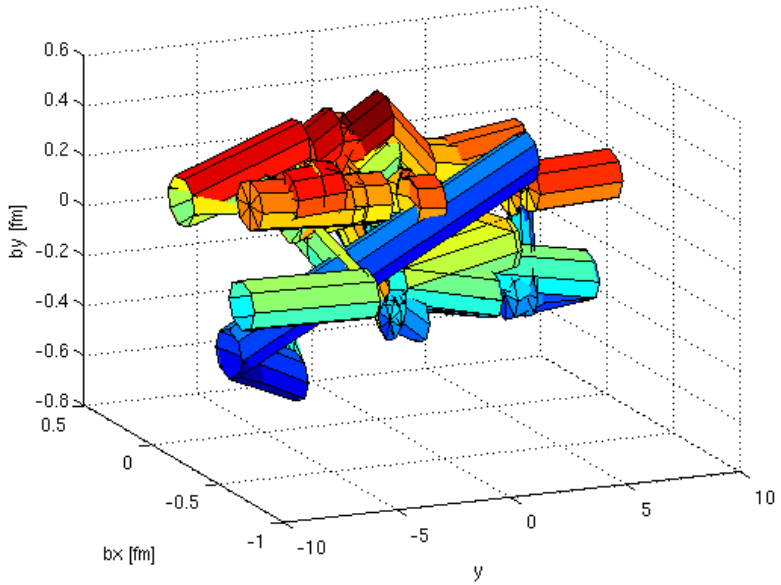


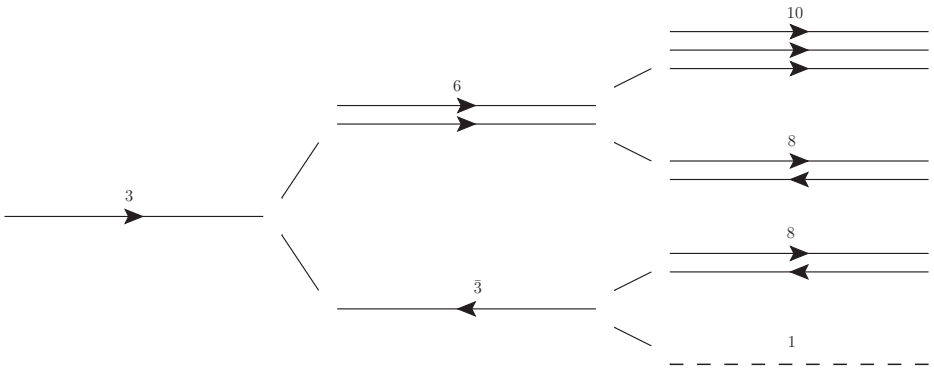


- Follow position through final state emissions.
- Full space-time information on all strings.

Building the rope

- Spatial overlap calculated for individual dipoles.
- Rope built from m, n fundamental strings.
- SU(3) multiplet structure decided by random walk.



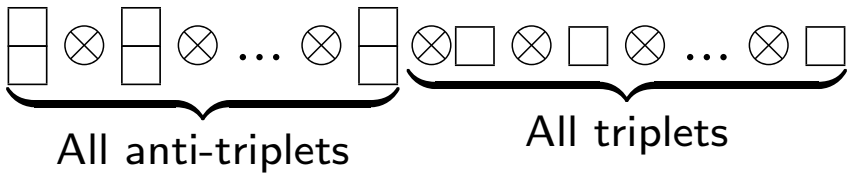


- Three options
  1. Highest multiplet.
  2. Lower multiplet (junction structure).
  3. Singlet.

Highest multiplet

- All higher multiplets represents a coherent interaction.
- Fundamental quantum numbers p and q from recursion relations.
- Number of random (anti)-triplets added decided by overlaps.

$$\{p,q\} \otimes \vec{3} = \{p+1,q\} \oplus \{p,q+1\} \oplus \{p,q-1\}$$



- Transform to $\tilde{\kappa} = \frac{2p+q+2}{4}\kappa$ and $2N = (p+1)(q+1)(p+q+2)$.
- N (multiplicity of the multiplet) serves as a state's weight.
- String hadronized with $\tilde{\kappa}$.

Junction handling

- Extra junctions handled through simplistic, popcorn-based approach.

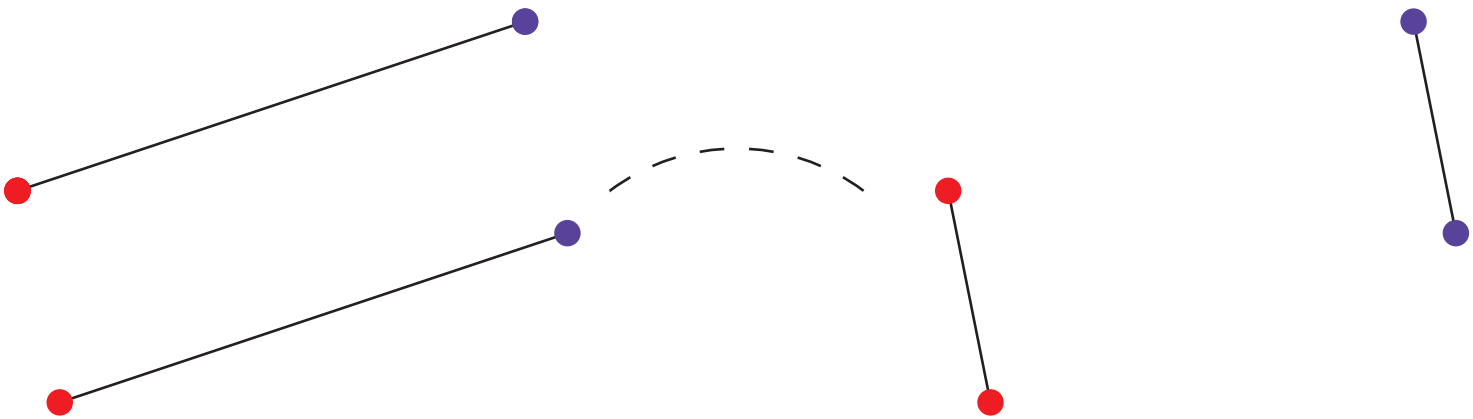
- Extra parameter for colour fluctuations (no data handle).
- Better: Dynamical handling in a "swing".

- Related: recent Pythia 8 model arXiv:1505.01681 [hep-ph]

The singlet swing

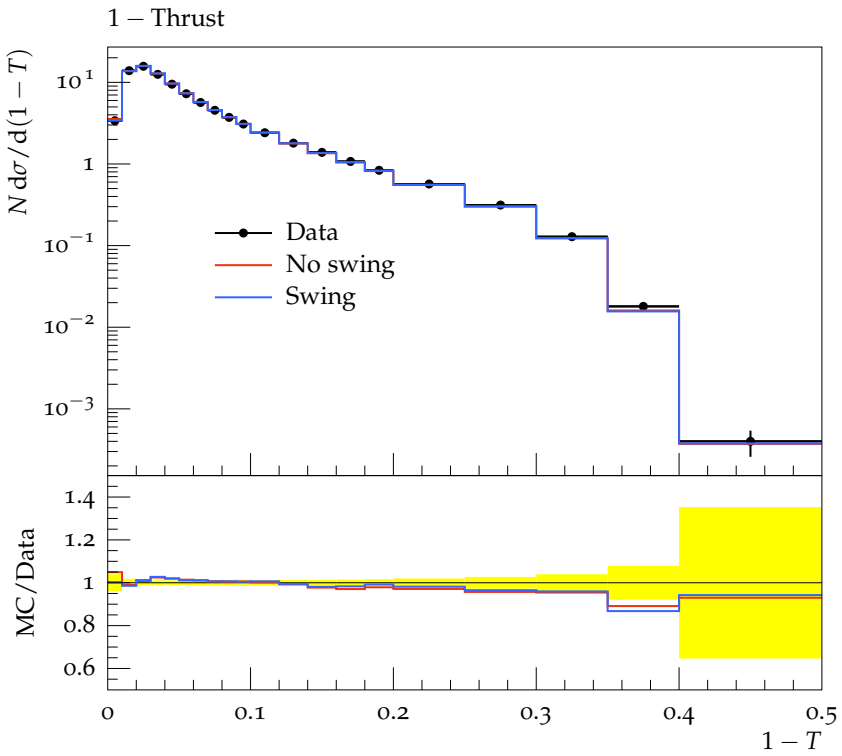
- Singlets are handled already in the FS shower (Ariadne).
- Matching colours *swings* with each other, competing w. emission.

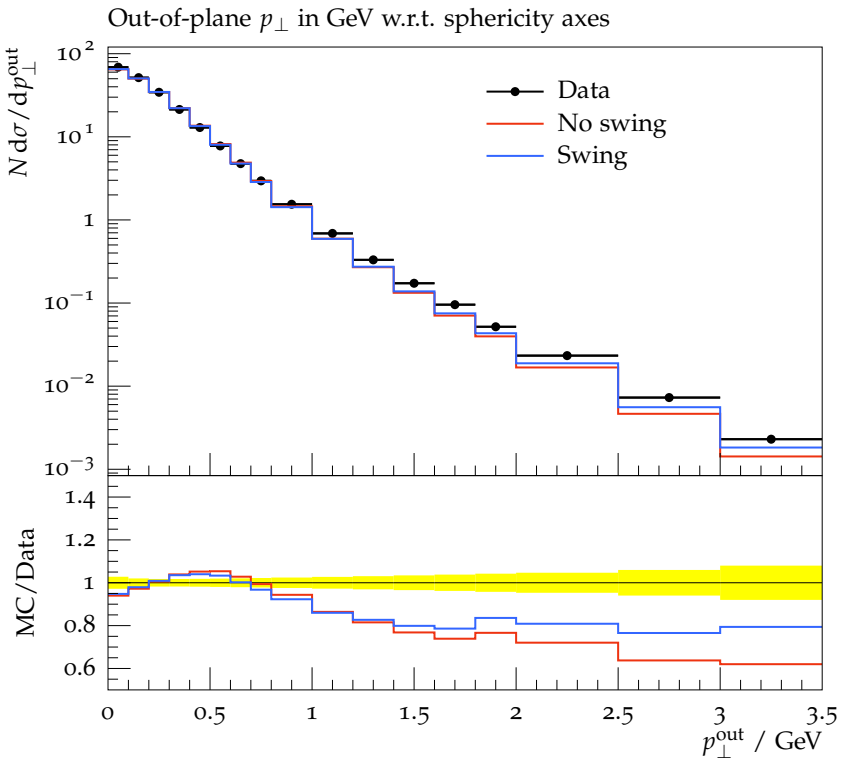
$$\frac{dP_e}{d\ln(p_\perp^2)} \approx dy \frac{C_F \alpha_s}{2\pi} \text{ and } \frac{dP_r}{d\ln(p_\perp^2)} = \lambda \frac{(\vec{p_1}+\vec{p_2})^2(\vec{p_3}+\vec{p_4})^2}{(\vec{p_1}+\vec{p_4})^2(\vec{p_2}+\vec{p_3})^2}$$



Singlet swing and LEP Data: DELPHI

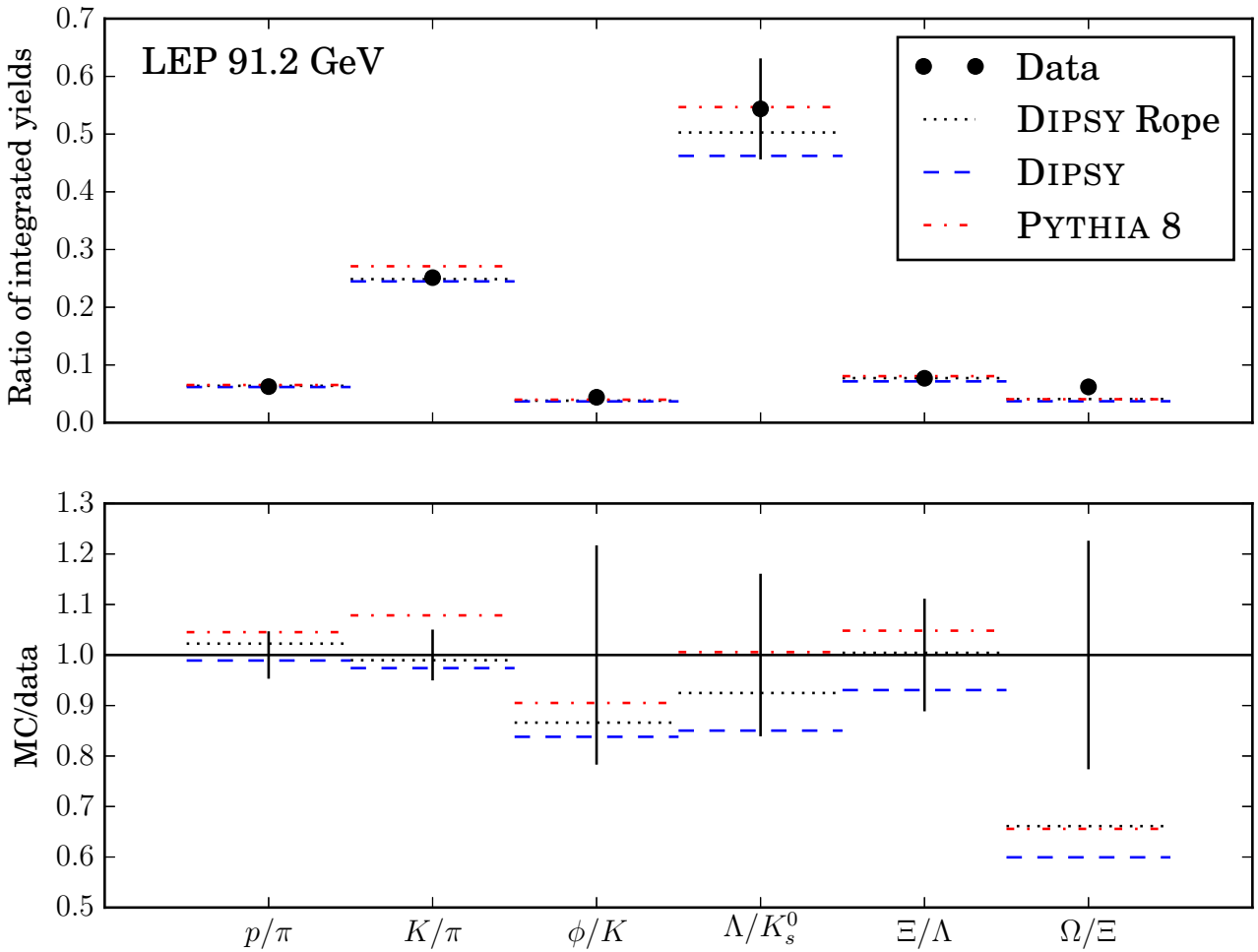
- Comes in already at perturbative level.
- Retuning of shower is neccesary.
- No large difference, $p_\perp^{out}$ somewhat improved.





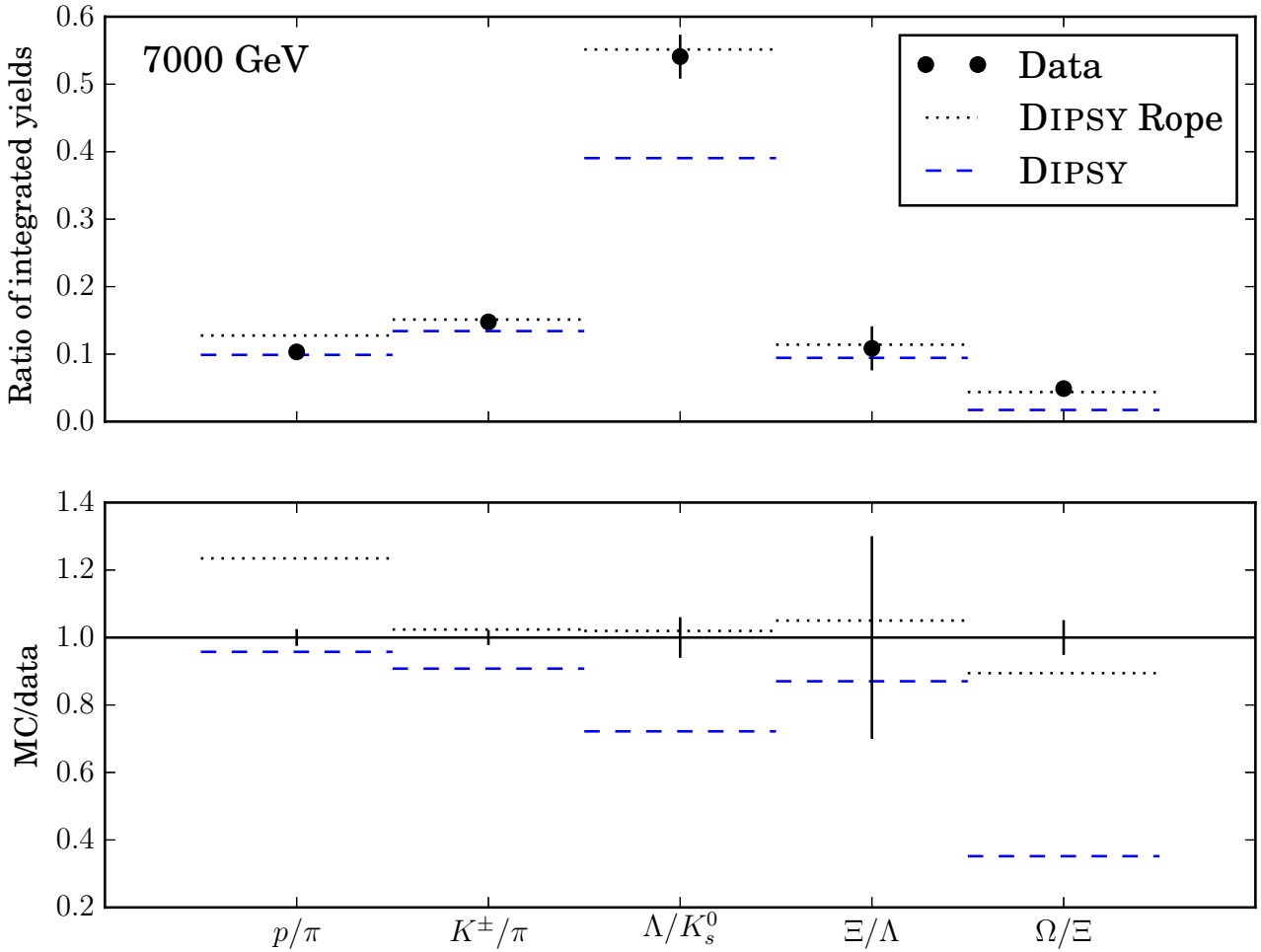
Flavour ratios - LEP Data: SLD, LEP and PDG Avg.

- String at LEPs. Agreement with data.
- Jet universality: Gain predictive power in *pp* by fixing parameters here.



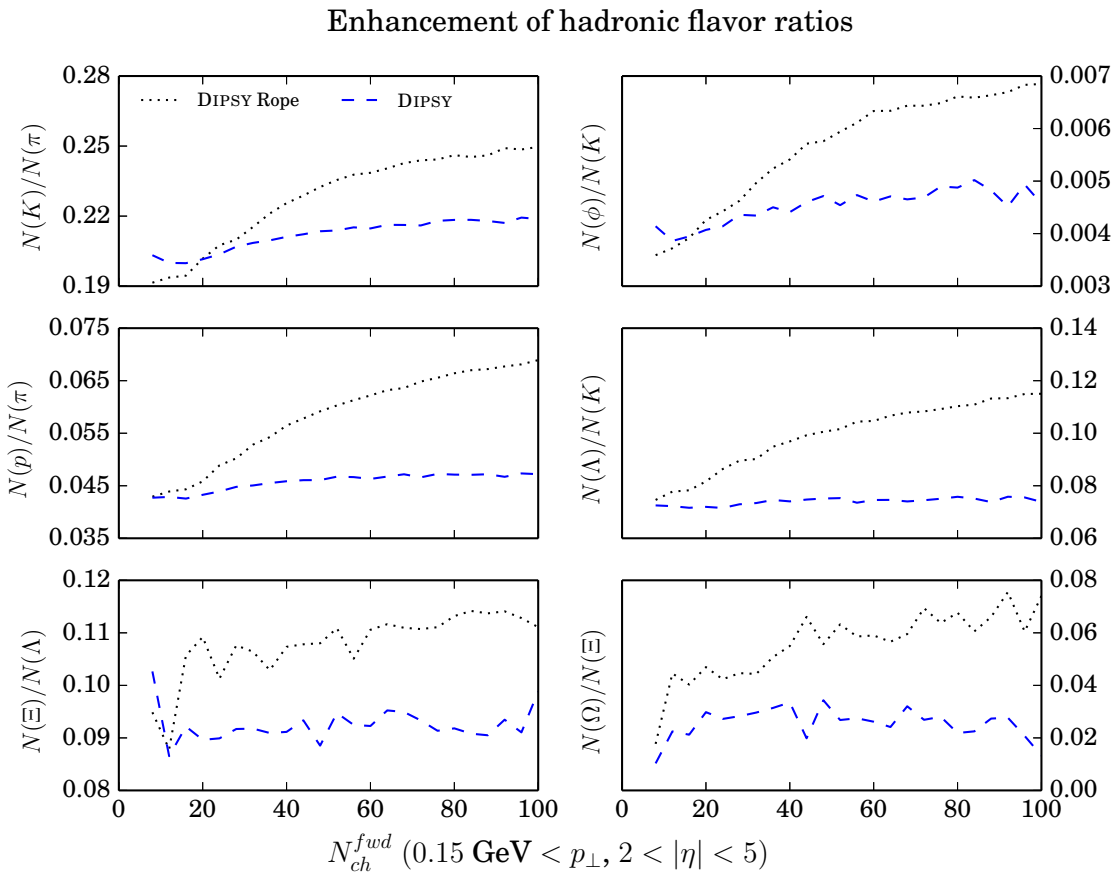
Flavour ratios - LHC Data: CMS and ALICE

- Ropes at LHC. Overall better agreement, problem with p/π.
- Integrated quantities, need per event quantities as function of activity.



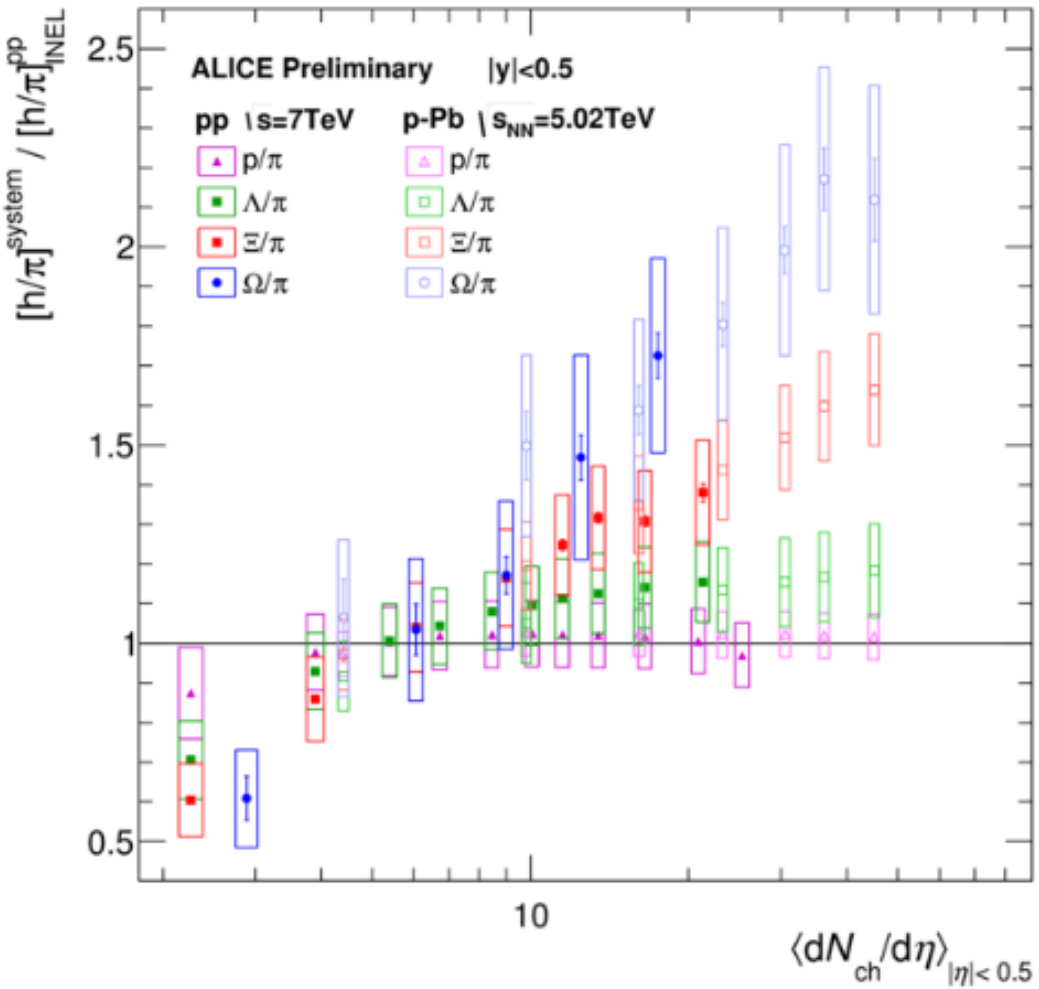
Multiplicity dependence

- Rise of ratios with event multiplicity.
- Even more exclusive: ratios(mult) in jets vs. bulk.



Results from ALICE CERN seminar, 10-11-2015

- Strange enhancement is confirmed, baryonic is not.
- Further work: Baryon enhancement and junctions.



Conclusions and future

- Corrections to string hadronization improves description of flavour data.
- Space-time picture important to go differential.
- Rise as function of activity confirmed.
- No rise of baryon/meson seen in data.
- Particle ratios in jets vs. bulk.
- Application to pA and AA.

Thank you!