The event structure in PP collisions at the LHC energies

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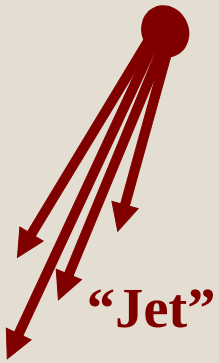


The message

- The LHC has allowed us to investigate the collisions in great details: many surprises , but the discovery potential has not yet been fully unleashed
- the good statistics allow going beyond multiplicity & identified particles avoiding as much as possible averages
- The generators may be not perfect yet we have not explored all their potentiality or we have not given the theorists sufficiently differentiated observables
- It is the duty of the experimentalists to provide new testing parameters

Instituto de Ciencias Nucleares UNAM

From:
Thoughts on opportunities from high-energy nuclear collision

- Our present understanding of the processes transforming the initial quantum-state of matter in a relativistic heavy-ion collision into a hydrodynamic fluid is substantially incomplete.
- Improved experimental and theoretical knowledge of the role of multiple partonic interactions (MPI) in hadron-nucleus collisions, can contribute to understanding the initial state and the earliest moments of the subsequent evolution of the produced matter.

Antinori et al
arXiv:1409.2981 [hep-ph]

Spherocity in proton proton collisions

- Can the use of event structure variables help distinguish better the components of the collision? Something similar to the separation of nonflow components in elliptic flow
- Possibility to investigate the number of multiple interactions
- The color reconnection&spherocity

Event shapes at hadron colliders

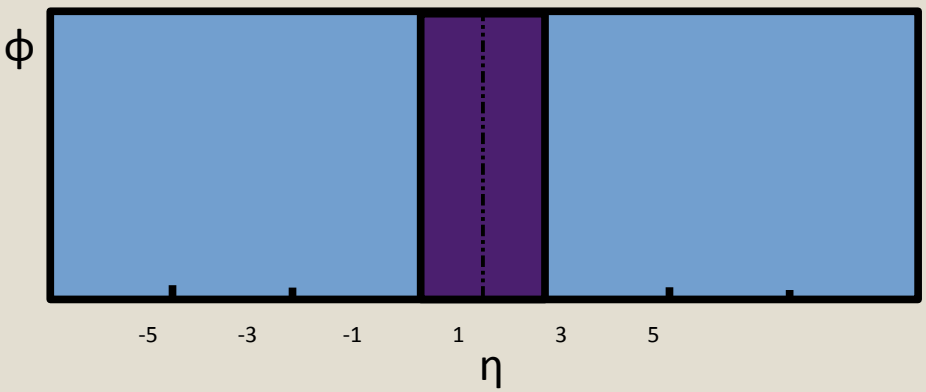
- They provide a measurement of the energy flow in a hadron-hadron collision.
- They are restricted to the transverse plane in order to avoid the bias from the boost along the beam axis.
- They can be used for MC tuning.

A. Banfi, G. P. Salam and G. Zanderighi, JHEP 0408, 062, 2004.

Example: Spherocity, S_O

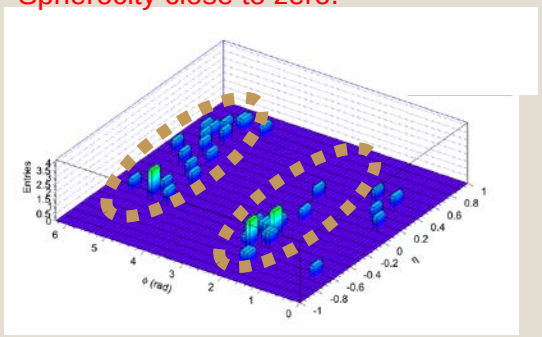
Defined for pp events having at least <u>three primary charged hadrons</u> within a given acceptance, <u>$|\eta|<\eta_D$</u>, and with <u>transverse momentum above a threshold</u>.

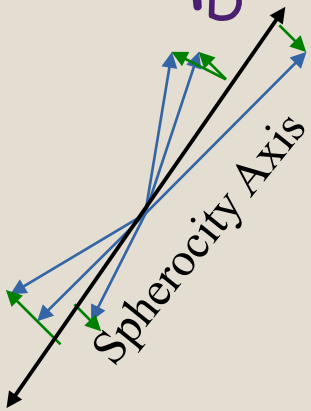
$0.15 < p_T < 10$ GeV/c



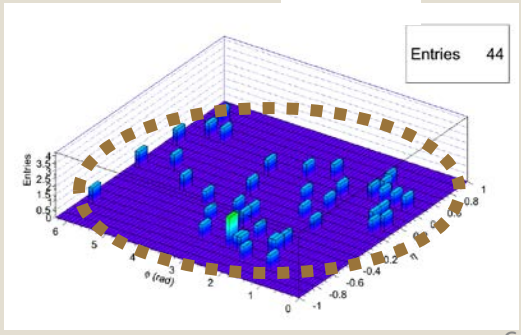
$\eta_D=1$

Spherocity close to zero.

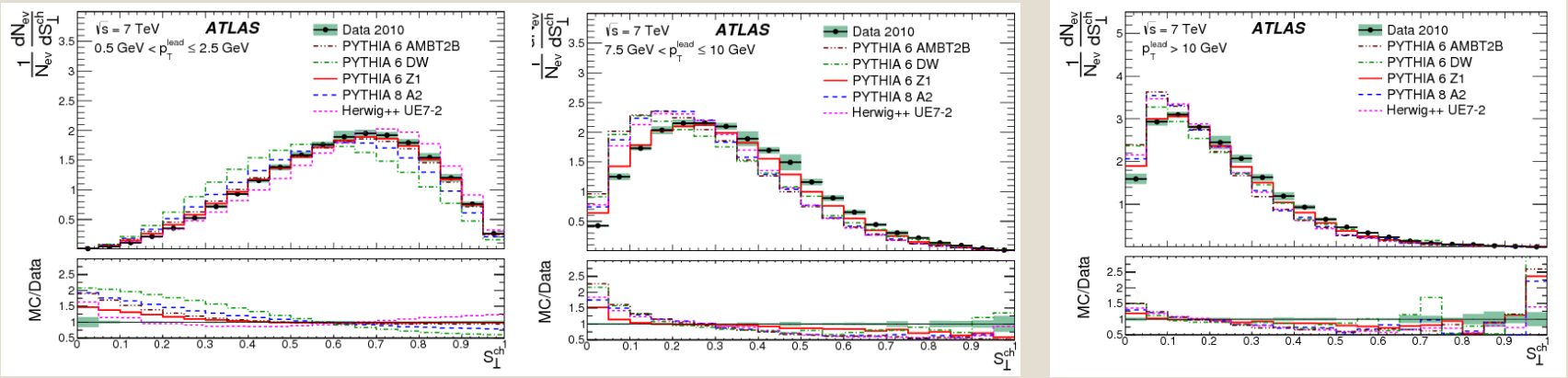




Spherocity close to one.



Sphericity and the generators



$0.15 < p_T < 10$ GeV/c

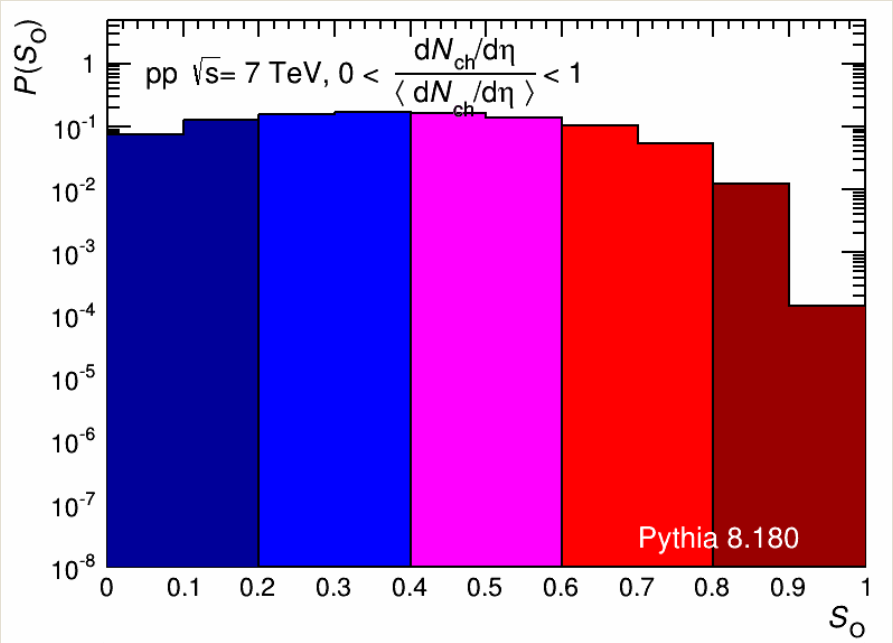
ATLAS Collaboration (Aad, Georges *et al.*) Phys.Rev. D88 (2013) 3, 032004

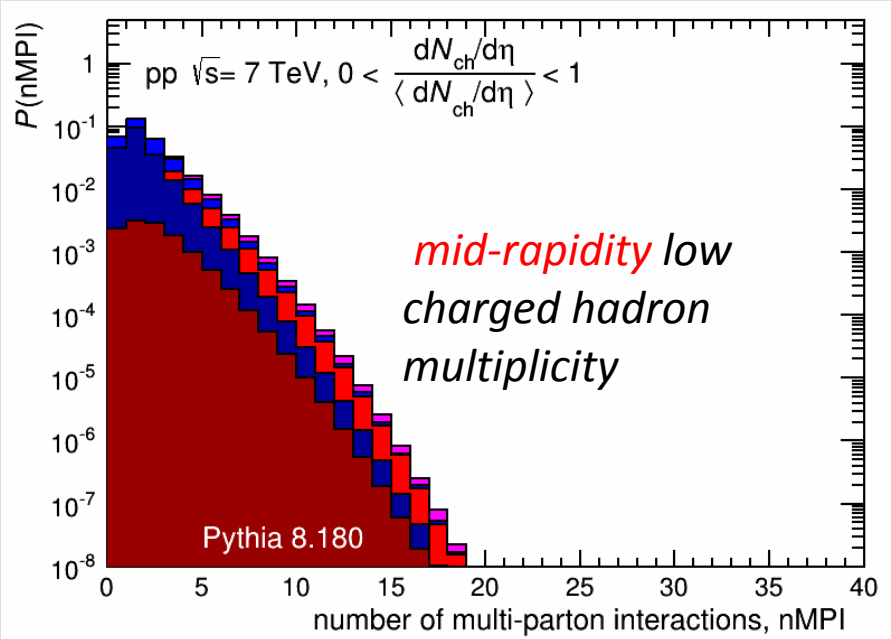
ALICE Collaboration (Betty Abelev (LLNL, Livermore) *et al.*). Eur.Phys.J. C72 (2012) 2124

Even if the average value is OK the generators miss the evolution of the events with sphericity …

N_{ch}, S_O (|η|<1) and MPI

Low multiplicity





Pencil-like limit

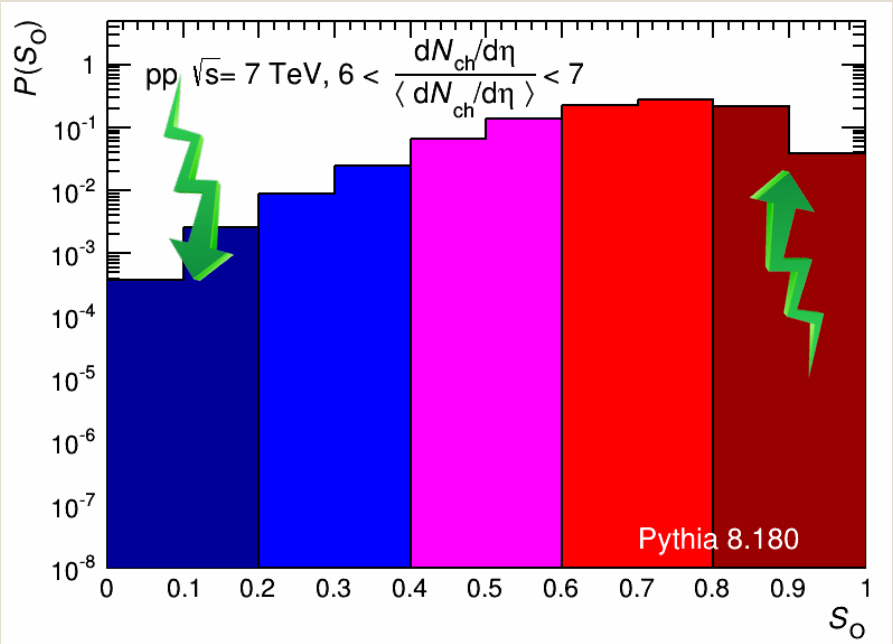
Isotropic limit

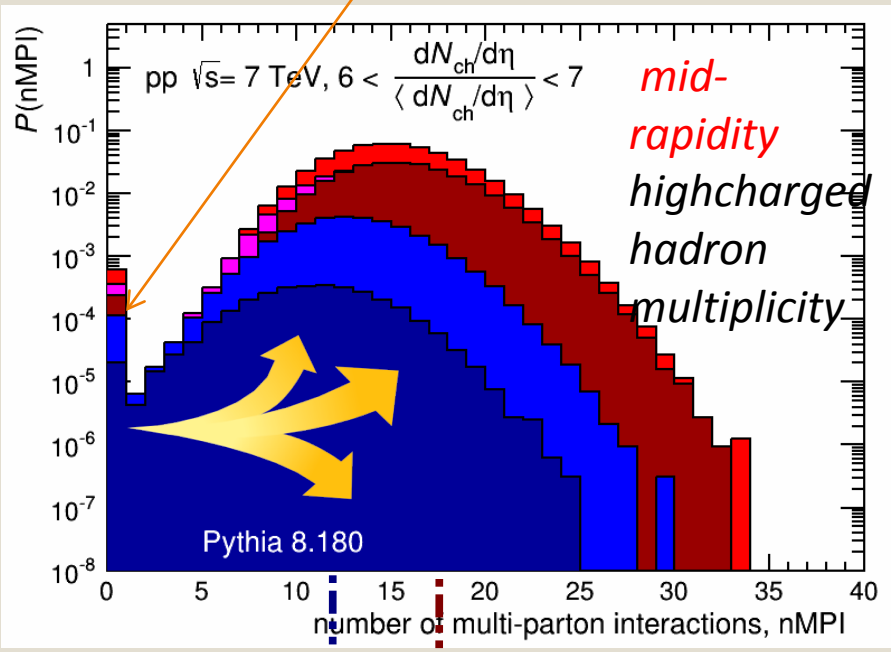
E. Cuautle et. al., arXiv:1404.2372

N_{ch}, S_O (|η|<1) and MPI

High multiplicity

Diffractive events





Pencil-like limit

Isotropic limit

E. Cuautle et. al., arXiv:1404.2372

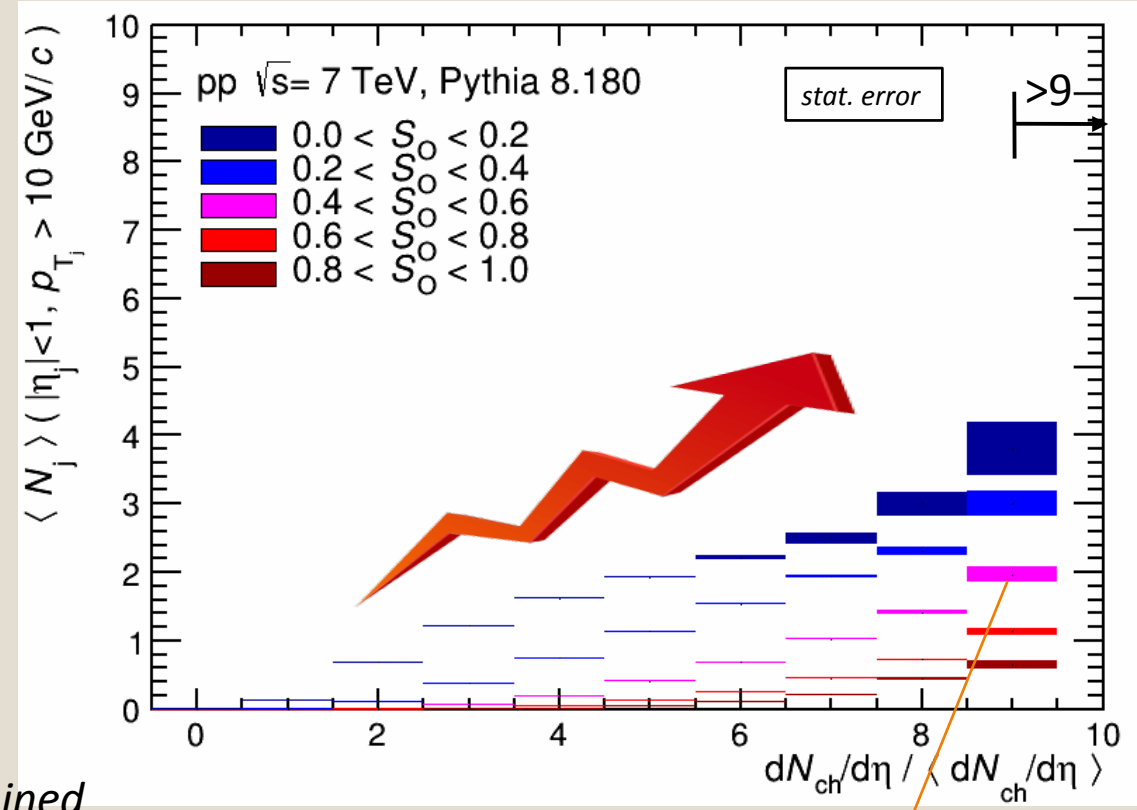
Jet production vs N_{ch} and S_O

- **Fast jet 3.0.6**

M. Cacciari, G.P. Salam and G. Soyez, EPJC72, 1896, 2012.

- Anti-k_T algorithm.
- Jet size, R = 0.4
- **Min p_T jet: 10 GeV/c**.
- Only charged constituents.

Average number of jets vs multiplicity



The results presented here were obtained using Pythia 8.180 tune 4C.

***The inclusive case (w/o any cut on S_O) roughly follows the magenta points**

Jet-p_T vs N_{ch} and S_O

- **Fast jet 3.0.6**

M. Cacciari, G.P. Salam and G. Soyez, EPJC72, 1896, 2012.

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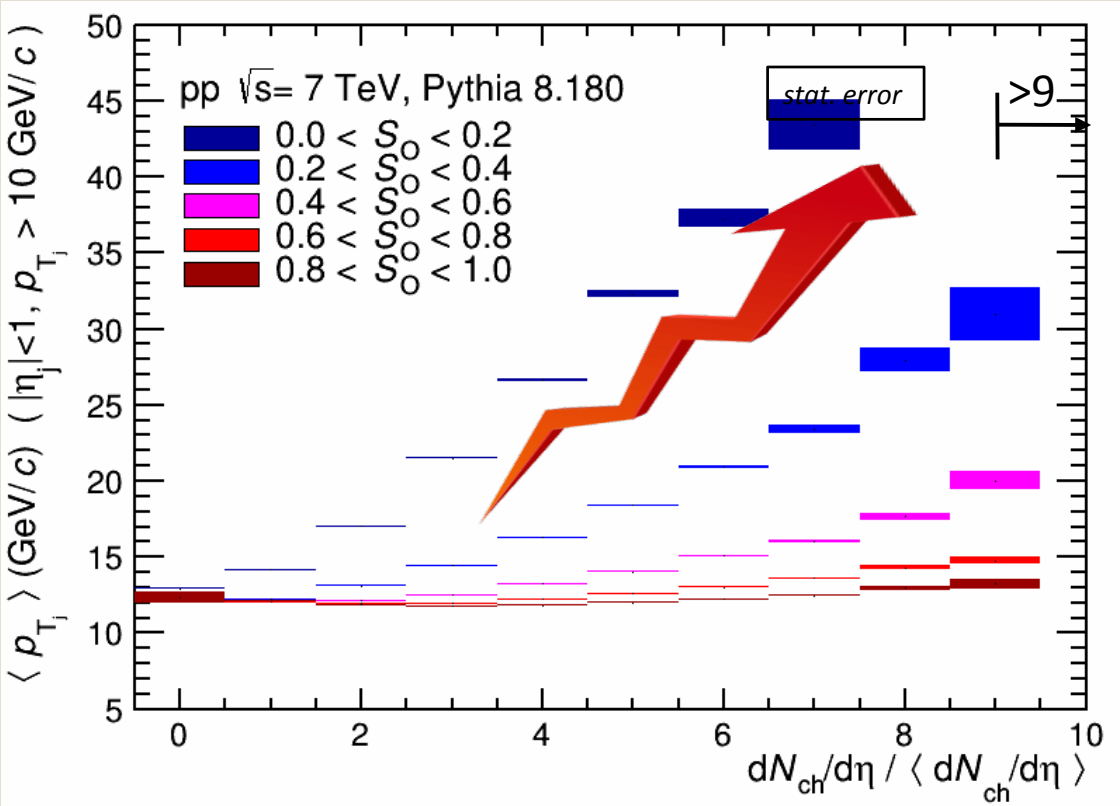
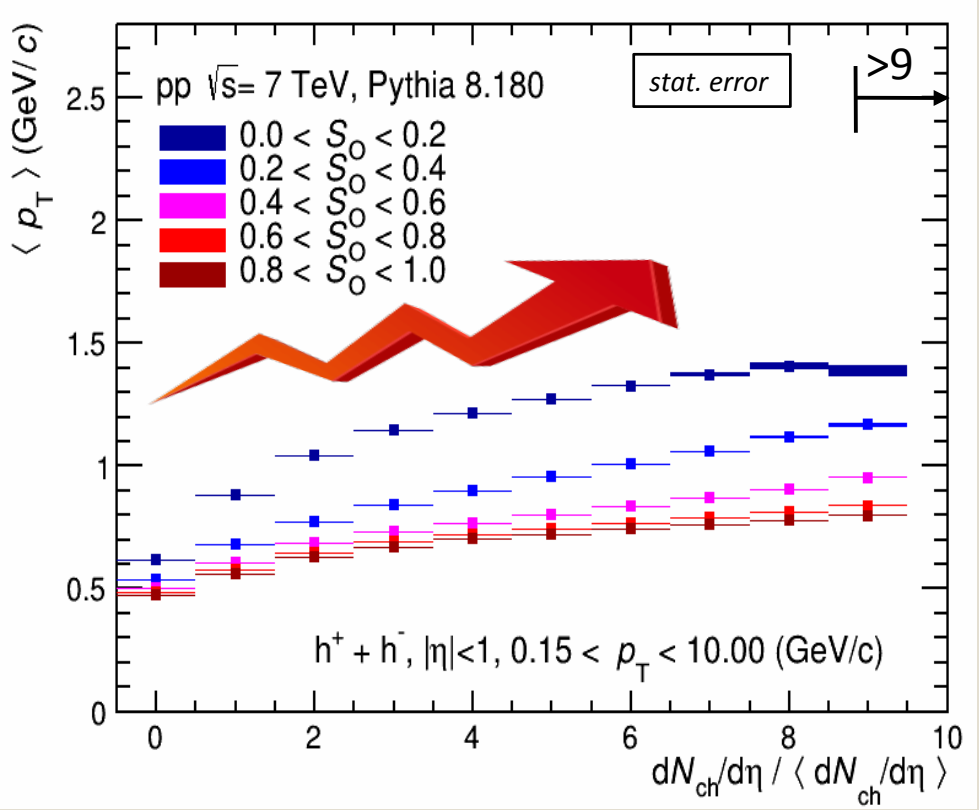
Average jet p_T vs multiplicity



$\langle p_T \rangle$ vs N_{ch} for charged hadrons

- A significant increase at low spherocity
- **Caution!!**
- **In a restricted eta range we have <u>different</u> events: some with only underlying events and some with only jets in the acceptance…**
- **What information from fluctuations?**



*The inclusive case (w/o any cut on S_O) roughly follows the magenta points

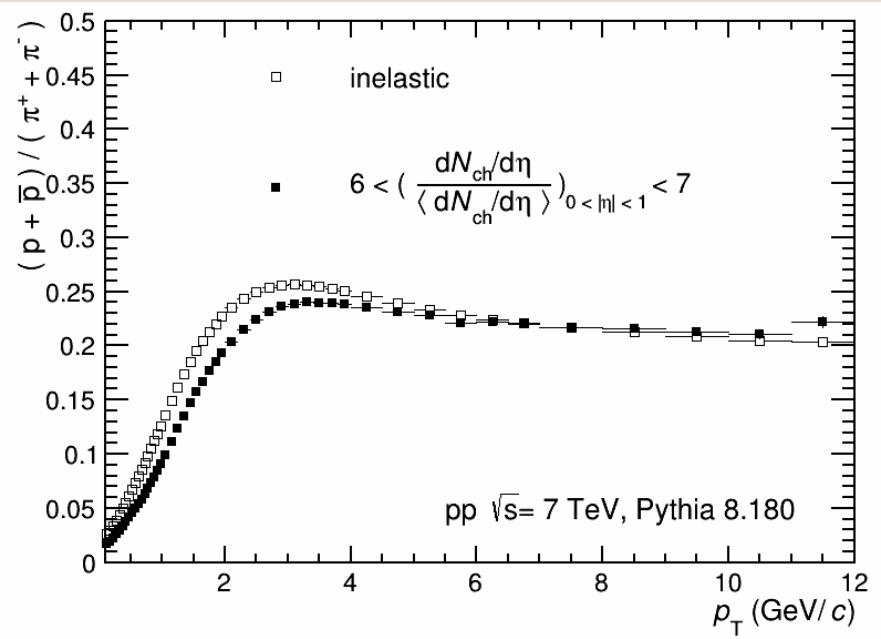
The role of the color reconnection

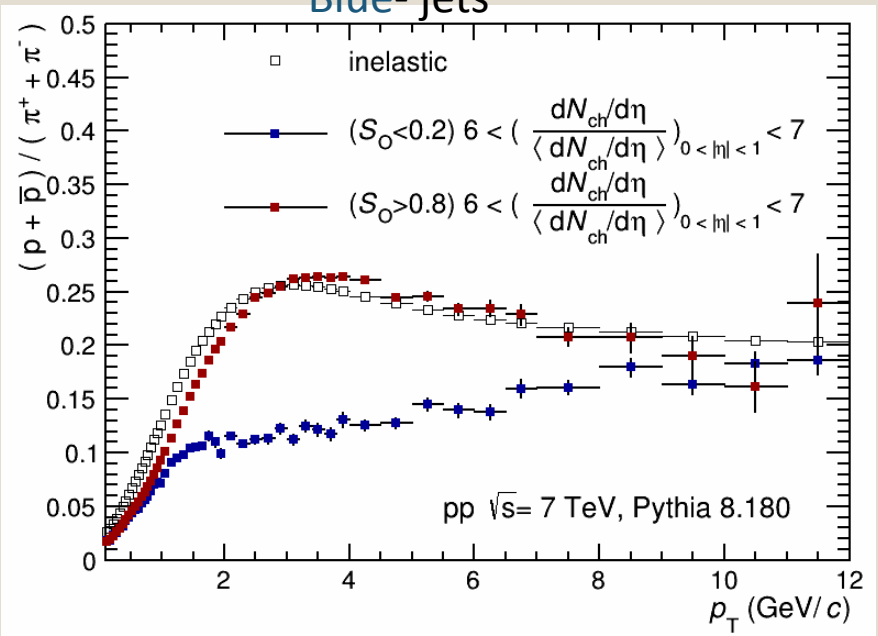
- All the results shown before were obtained with color reconnection in Pythia

Particle ratios multiplicity and spherocity

Using the multiplicity alone we are not sensitive to the details. The multiplicity selection mixes the different components of the spectra.

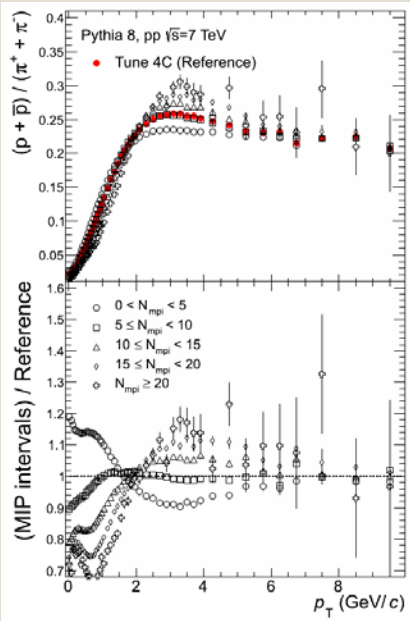
Red- Underlying event
Blue- jets



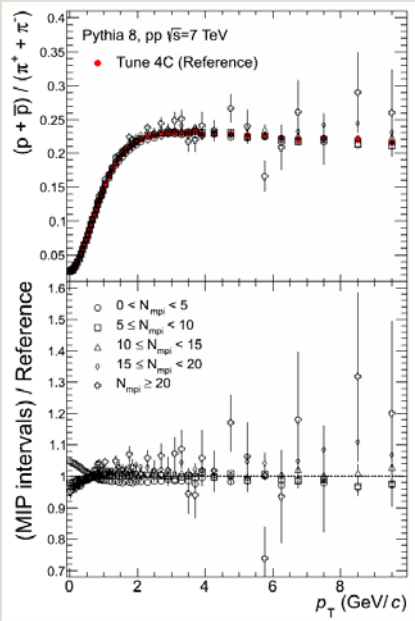


The effect of the MPIs and Color reconnection on the ratios

CR



No CR



A. Ortiz, P. Christiansen, E. Cuautle, I. Maldonado, G.P.
Phys.Rev.Lett. 111 (2013) 4, 042001

CR in pp events can give some of the observed effects similar to the collective flow of heavy-ion collisions, by a combination
of two factors:

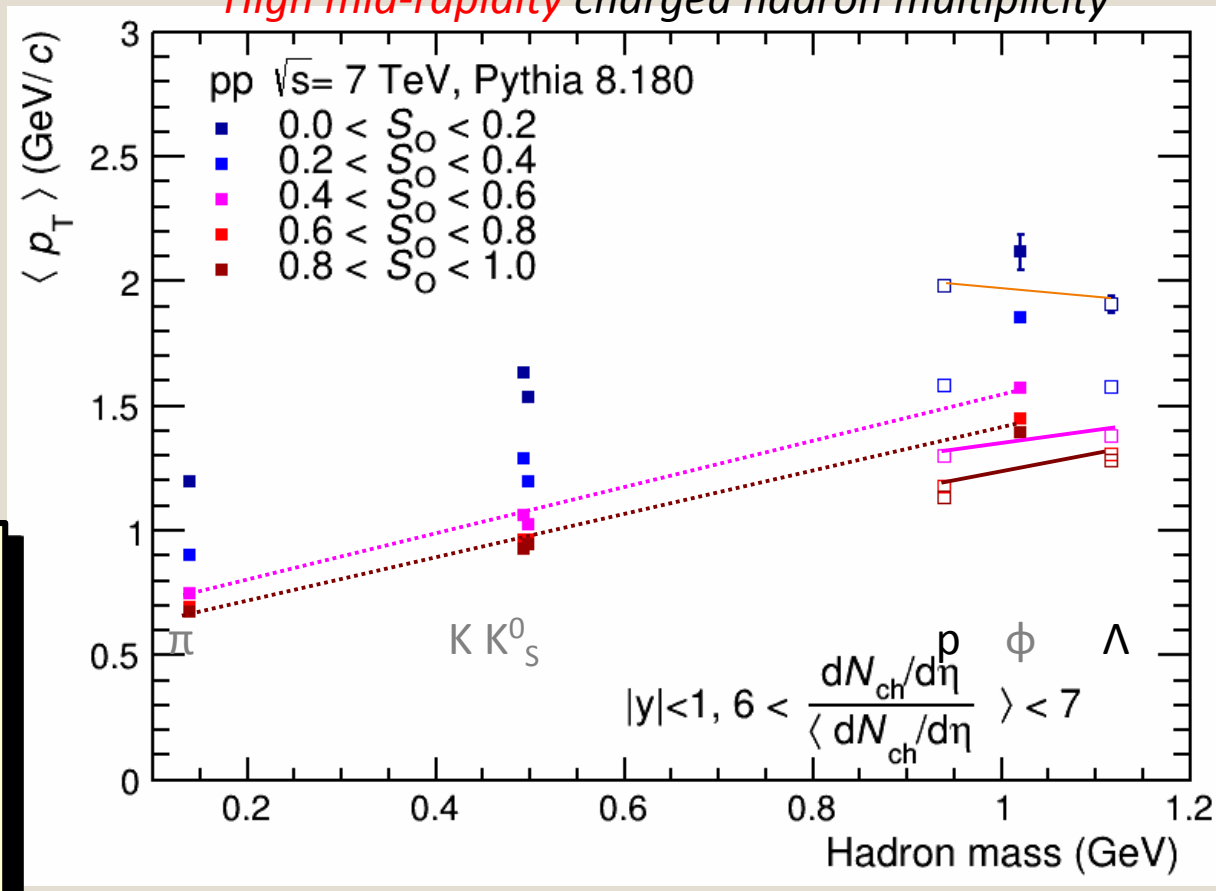
- a string piece moving with some transverse velocity tends to transfer that velocity to the particles produced from it, albeit
with large fluctuations, thereby giving larger transverse momenta to heavier hadrons.
- a string piece has a larger transverse velocity the closer to each other the two endpoint partons are moving, precisely what is favored by cr scenarios intended to reduce the string length.

T. Sjostrand arXiv:1310.8073 [hep-ph)

Mass ordering&spherocity

- An increase of the $\langle p_T \rangle$ with increasing hadron mass is observed for the different event classes.

High mid-rapidity charged hadron multiplicity

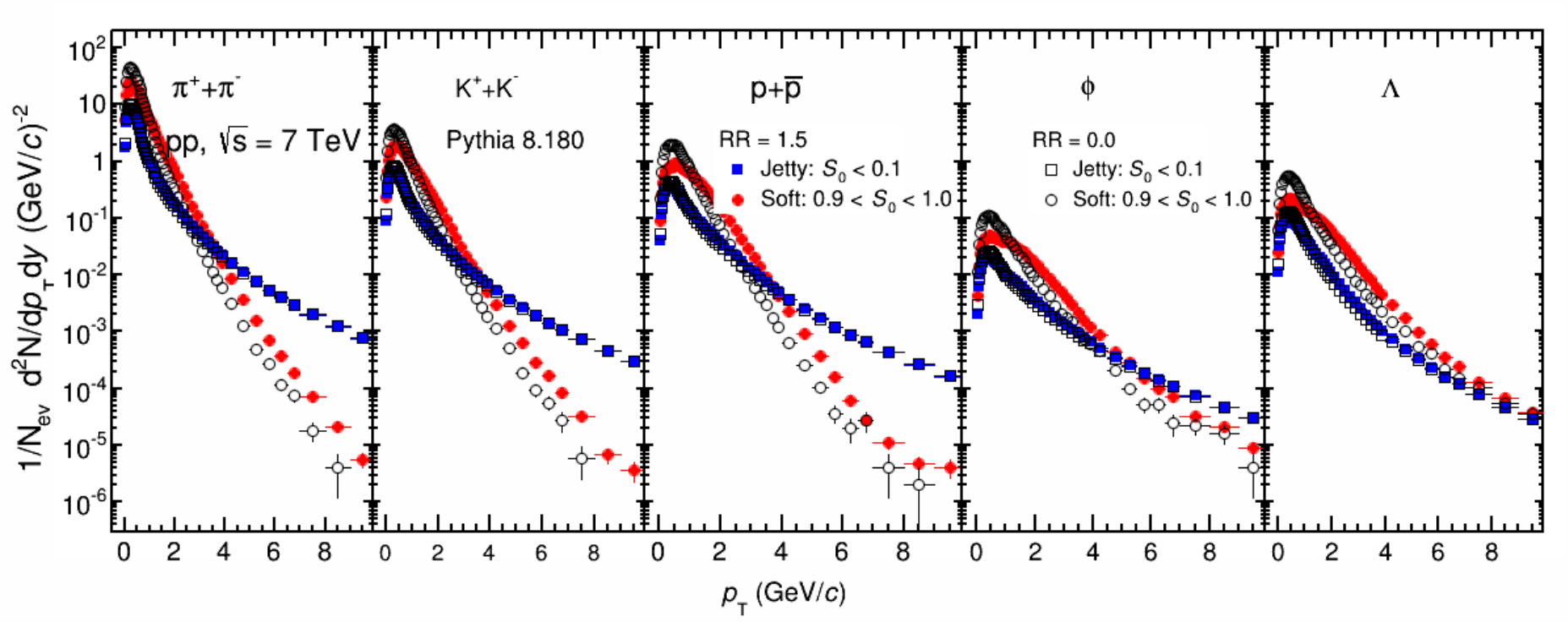


If baryons and mesons are observed separately, It seems that for isotropic events the $\langle p_T \rangle$ increases linearly with the meson mass, but for the baryons there is tension in jetty events –**EXPERIMENT??**

*The inclusive case (w/o any cut on S_O) roughly follows the magenta points

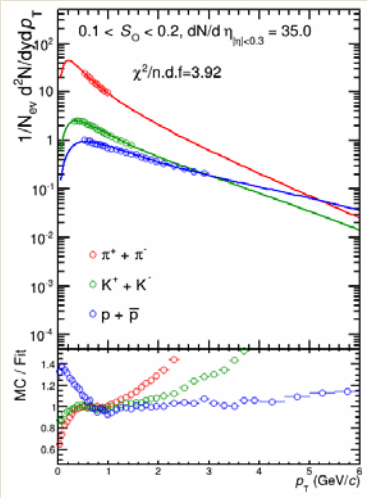
The spectra with and without color reconnection

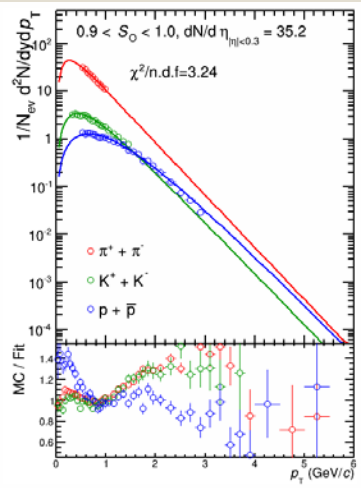
The color reconnection affects the high spherocity spectra and does not affect the jetty low spherocity spectra

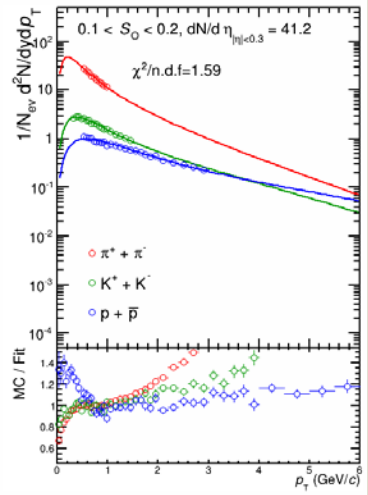


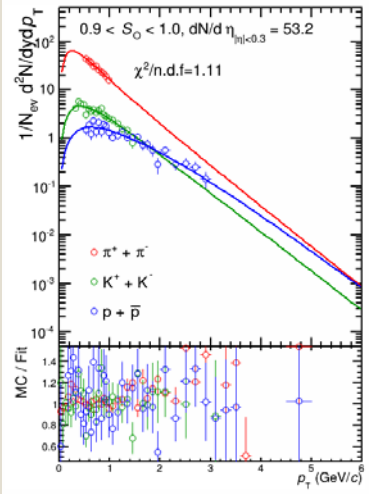
The blast wave fits in function of spherocity

Fits to particle spectra with growing multiplicity (pythia)

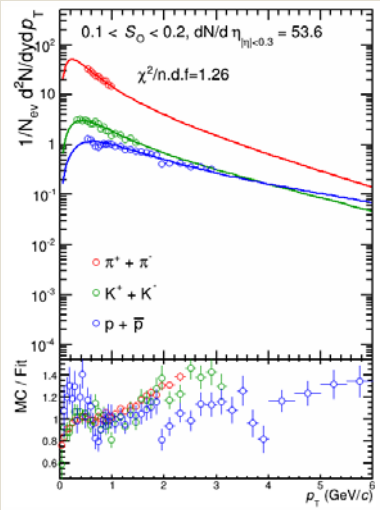


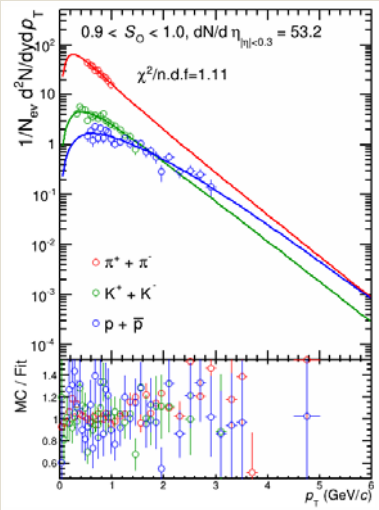






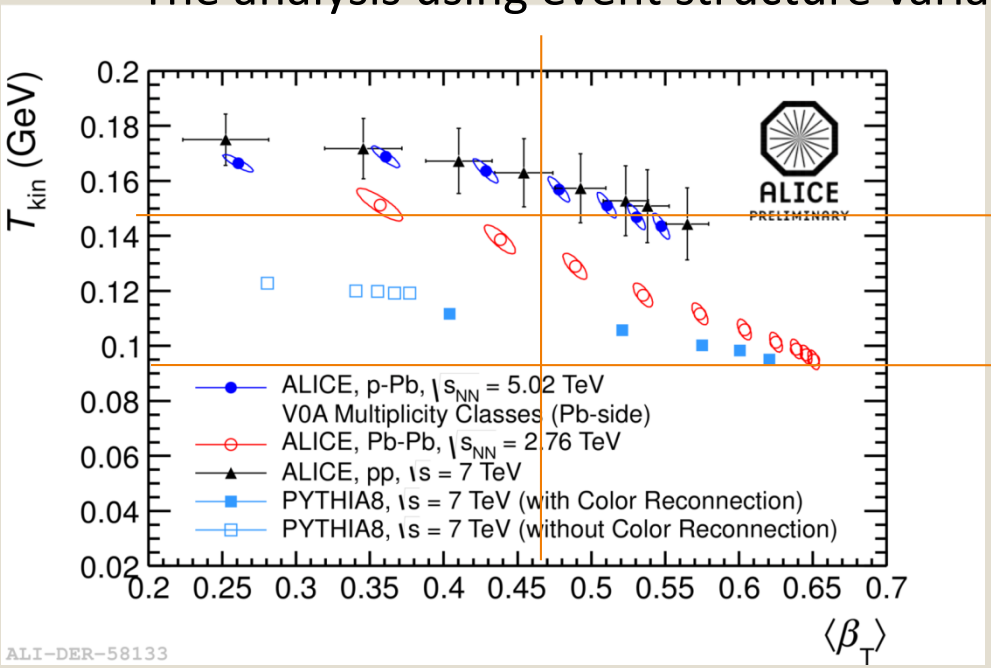
Aproximately equal chi2 for both low and high spherocity….

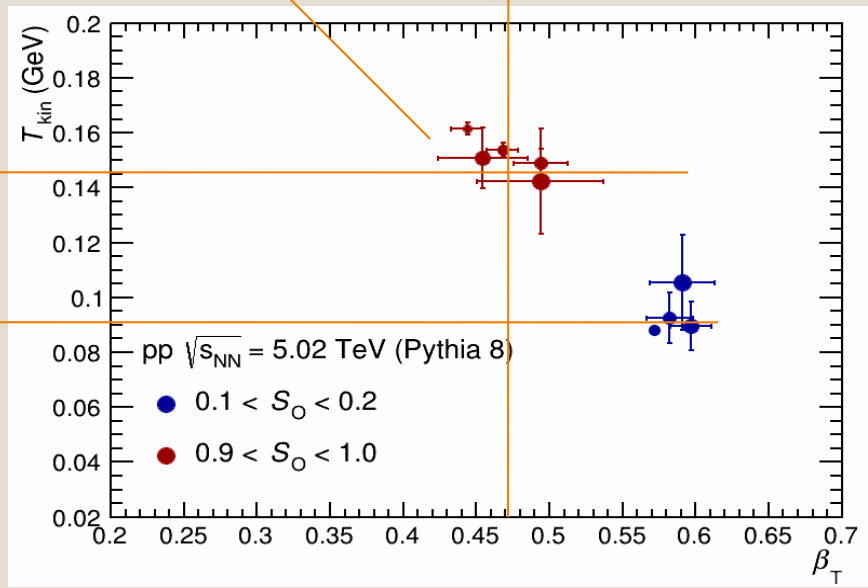




The message from the Blast Wave fits

The analysis using event structure variables allows to grasp details





The jets taken apart with low So show a high beta!

<u>As in azymuthal flow analyses the noncollective phenomena should be taken into account</u>

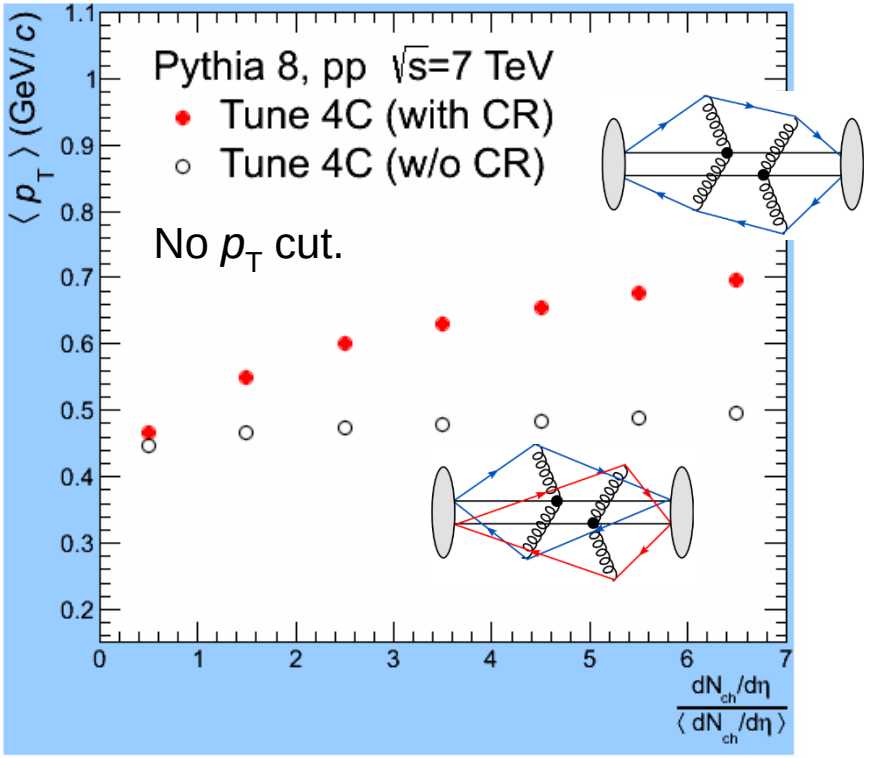
conclusions

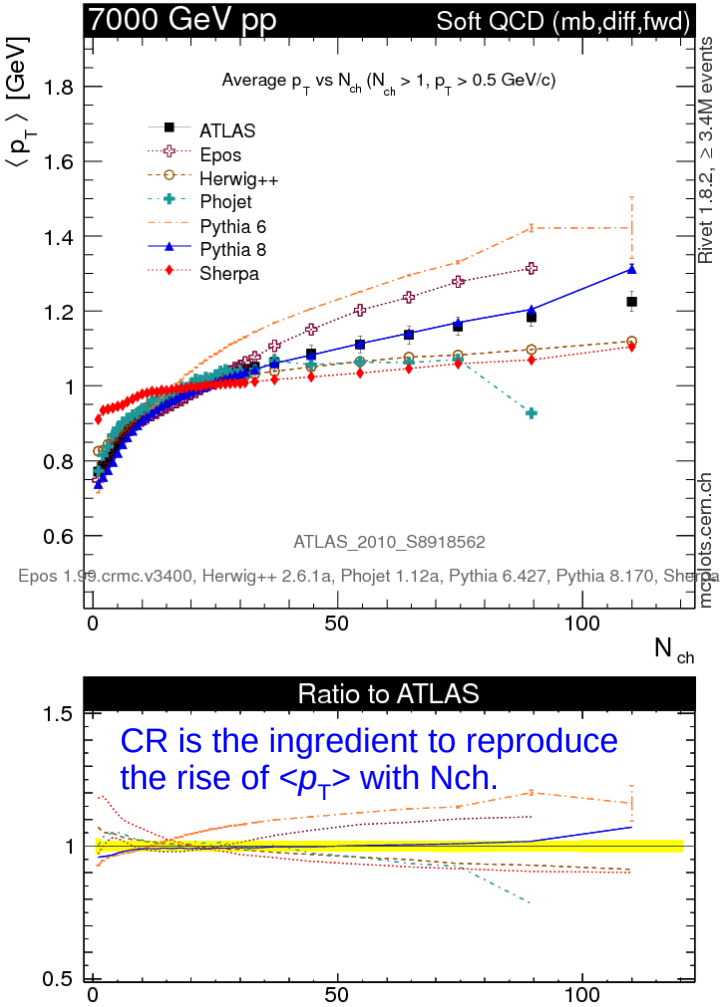
- The event structure method allows to analyze data in a more detailed way, using the whole statistics of the coming runs and identifying the importance of multiparton interactions, hadronization (color reconnection)
- We have shown that there are many areas of application:
  - Spectra,
  - ratios of identified species,
  - Mean pt
  - Flow like pattern caused by color reconnection.
  - It is hoped that new experimental observables may help the development of better models of the pp collisionsThe event structure method allows to analyze data in a more detailed way.
- Using the whole statistics of the coming LHC runs will allow to understand more about the role of the multiparton interactions.

backup

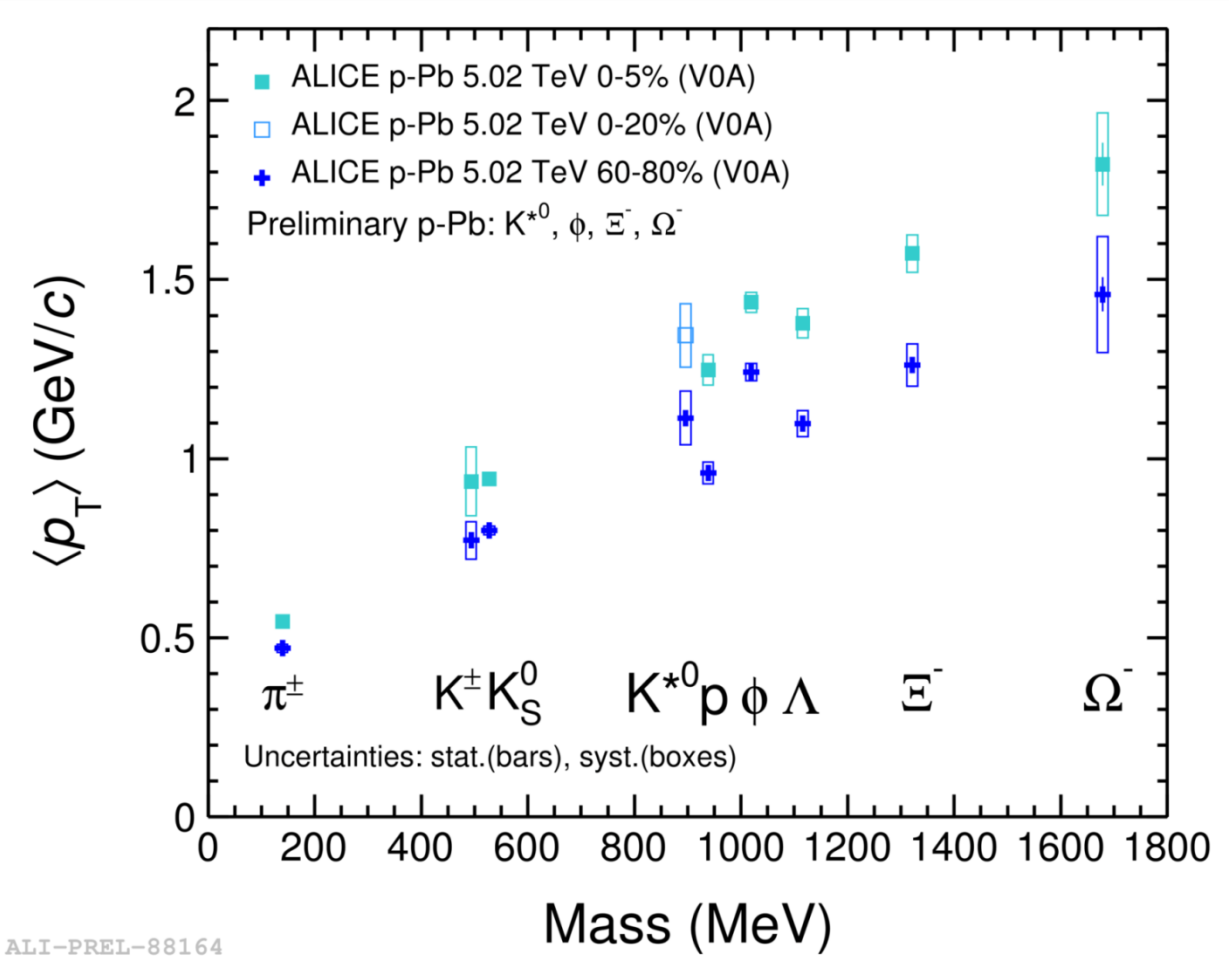
Color reconnection

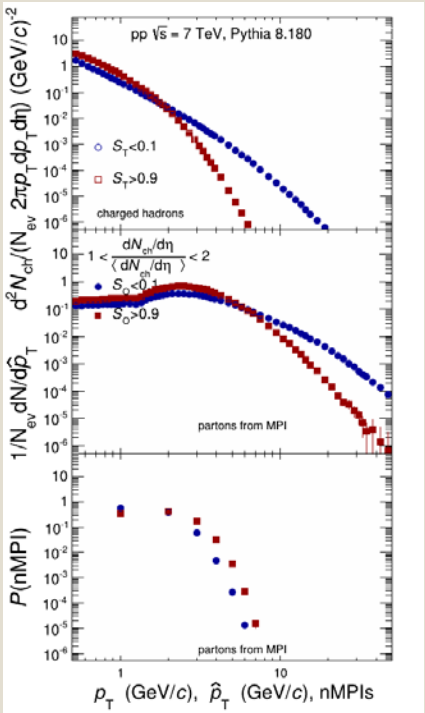
CR is the mechanism which produces the rise of $<p_T>$ with multiplicity

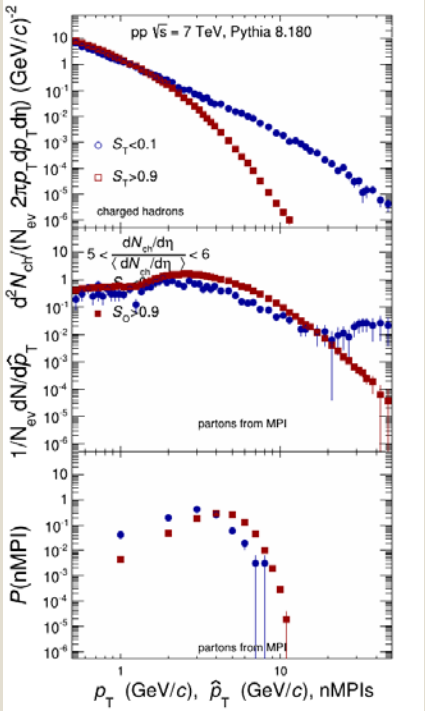


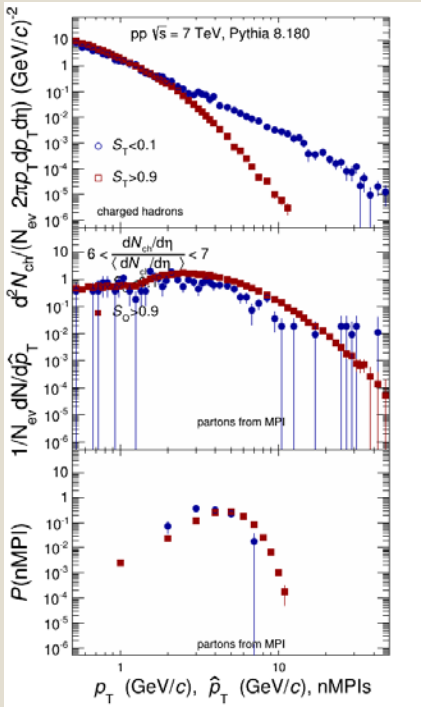


CR is the ingredient to reproduce the rise of $<p_T>$ with Nch.


ALICE p-Pb 5.02 TeV 0-5% (V0A)
ALICE p-Pb 5.02 TeV 0-20% (V0A)
ALICE p-Pb 5.02 TeV 60-80% (V0A)
Preliminary p-Pb: K*0, ϕ, Ξ-, Ω-
⟨pT⟩ (GeV/c)
π±
K±K0S
K*0p ϕ Λ
Ξ-
Ω-
Uncertainties: stat.(bars), syst.(boxes)
Mass (MeV)
ALI-PREL-88164


pp √s = 7 TeV, Pythia 8.180
S_T<0.1
S_T>0.9
charged hadrons
$1 < \frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle} < 2$
S_O<0.1
S_O>0.9
partons from MPI
partons from MPI
$d^2N_{ch}/(N_{ev}\, 2\pi p_T dp_T d\eta)$ (GeV/c)$^{-2}$
$1/N_{ev}\, dN/d\hat{p}_T$
P(nMPI)
p_T (GeV/c), $\hat{p}_T$ (GeV/c), nMPIs

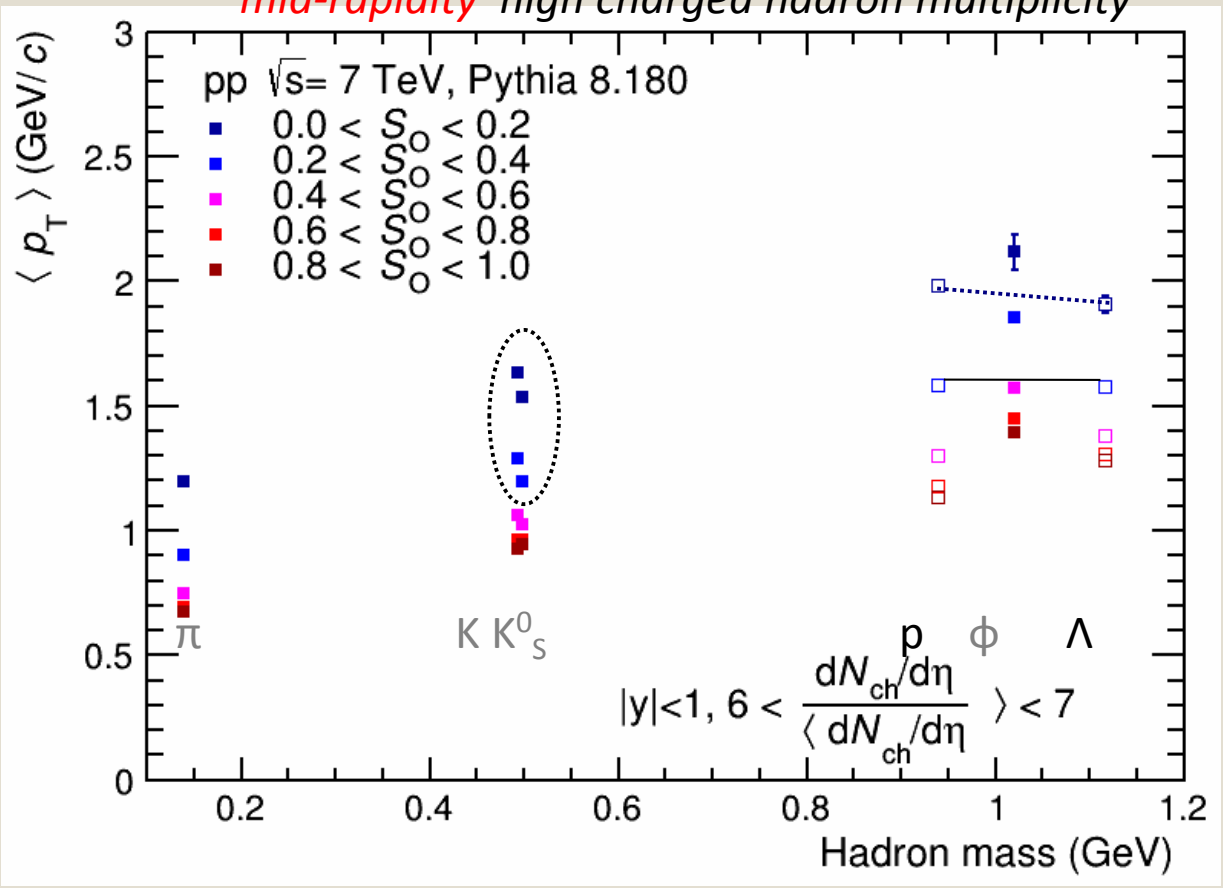

pp √s = 7 TeV, Pythia 8.180
S_T<0.1
S_T>0.9
charged hadrons
$5 < \frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle} < 6$
S_O>0.9
partons from MPI
partons from MPI
$d^2N_{ch}/(N_{ev}\, 2\pi p_T dp_T d\eta)$ (GeV/c)$^{-2}$
$1/N_{ev}\, dN/d\hat{p}_T$
P(nMPI)
p_T (GeV/c), $\hat{p}_T$ (GeV/c), nMPIs


pp √s = 7 TeV, Pythia 8.180
S_T<0.1
S_T>0.9
charged hadrons
$6 < \frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle} < 7$
S_O>0.9
partons from MPI
partons from MPI
$d^2N_{ch}/(N_{ev}\, 2\pi p_T dp_T d\eta)$ (GeV/c)$^{-2}$
$1/N_{ev}\, dN/d\hat{p}_T$
P(nMPI)
p_T (GeV/c), $\hat{p}_T$ (GeV/c), nMPIs

Mass ordering

If baryons and mesons are observed separately, It seems that for isotropic events the $\langle p_T \rangle$ increases linearly with the hadron mass.

mid-rapidity *high charged hadron multiplicity*



*The inclusive case (w/o any cut on S_O) roughly follows the magenta points