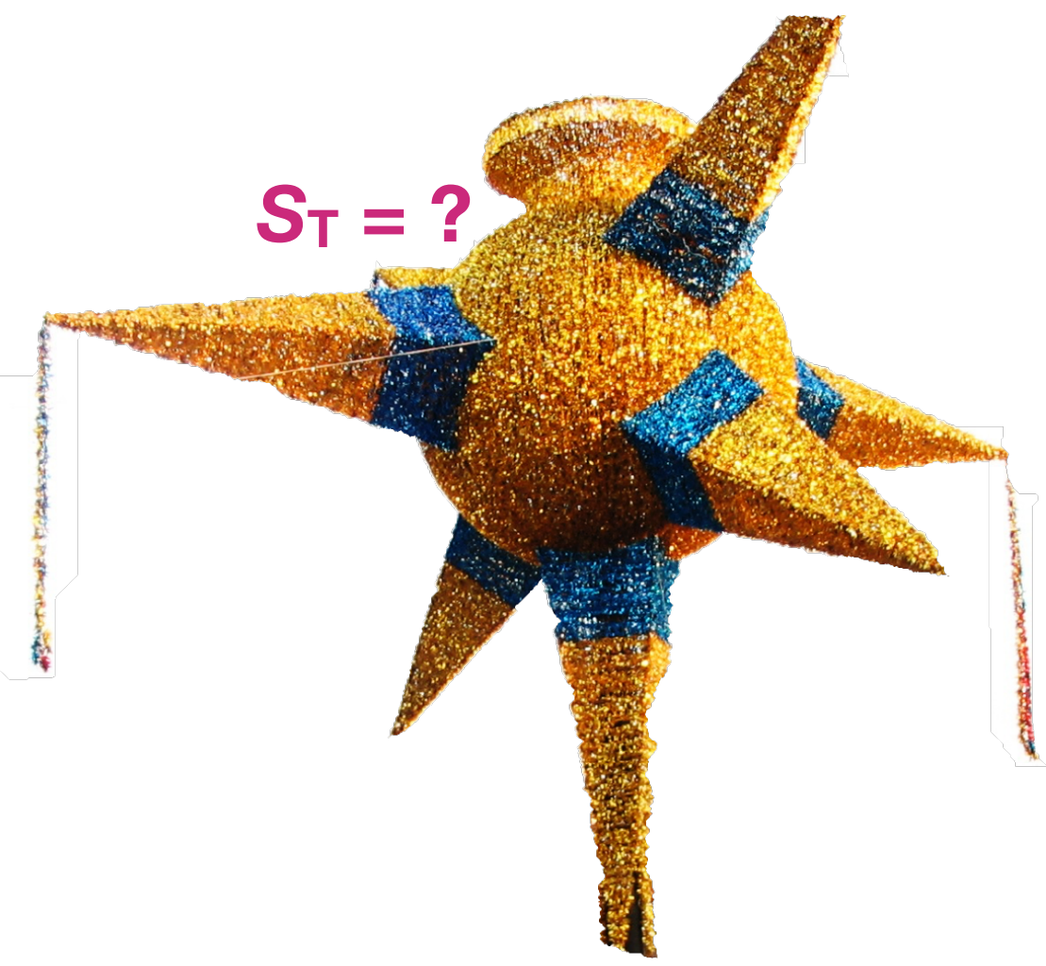
Guy's Quest for QGP-like Effects In Small Systems

Andreas Morsch
CERN



Symposium in Honour of Prof. Guy Paić
Mexico City, 30/10/2017

Preparing For Day One

Physic Coordinator 1997 - 2003

ALICE 2000-28
Internal Note / PHY
24 November 2000

Day One Proton-Proton Physics with the ALICE Central Detector

P. Giubellino, S. Kiselev, W. Klempt, A. Morsch, G. Paic, J.-P. Revol and K. Safarik

I. Introduction

From the Technical Proposal onwards the proton-proton programme was considered an integral part of the ALICE experiment. At the present stage we feel it is important to review the scope of that programme with a specific focus, i.e. we want to discuss the possibilities that ALICE will have in the first few months of LHC running, to make efficient use of the LHC proton beams in order to:

1. provide first insights into pp physics in a new energy domain ($\sqrt{s}$ = 14 TeV) far higher than that available today ($\sqrt{s}$ = 2 TeV at the Tevatron), to study soft hadronic physics and its gradual evolution to the better understood perturbative QCD (pQCD) regime. In this respect it is useful to recall that the important contribution of UA1 to minimum bias physics came mainly from the central detector chamber, see [1–16], and similarly for CDF [17];

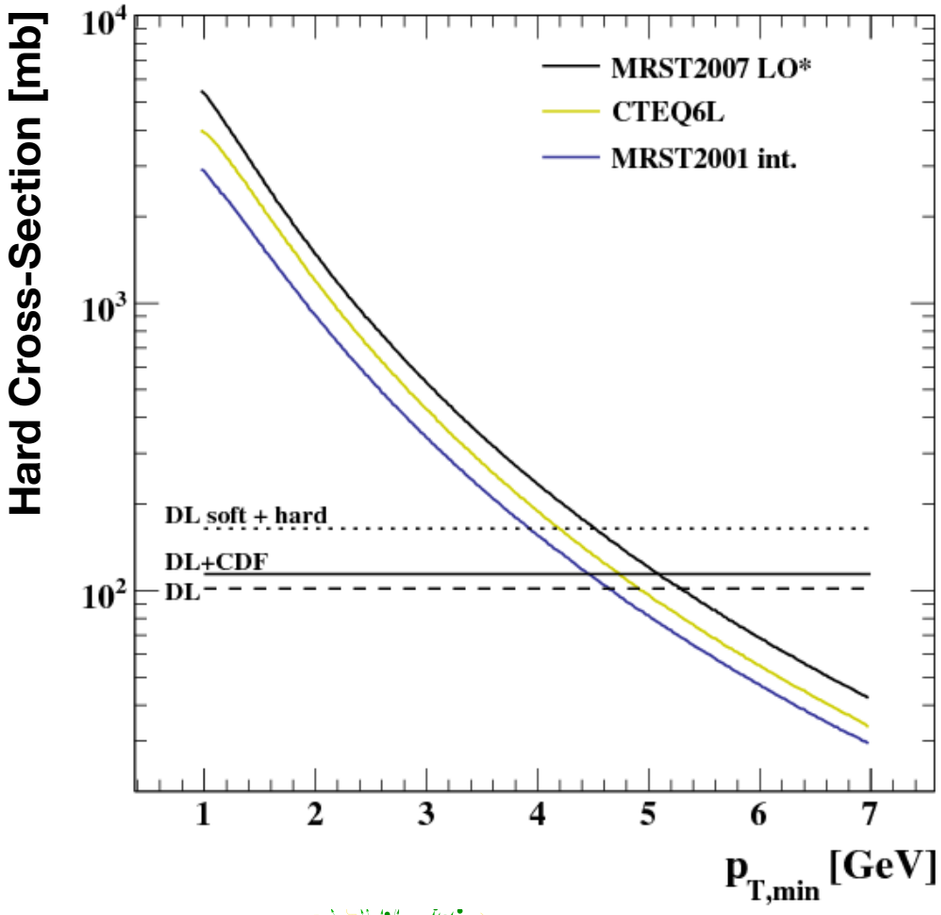
2. study pp collisions under conditions where they might reach energy densities in excess of what is achieved today in Heavy-Ion (HI) collisions at SPS and comparable to those expected at RHIC. Therefore, the pp data present a considerable interest for the study of the evolution of high energy densities (up to 10 GeV/fm^3) under conditions of small volumes (5 fm^3). Also, these data will be useful to check the nucleon-nucleon predictions of the event generators used in the HI simulation codes. For this particular check, and also for next item, some data taken at the same nucleon-nucleon energy as in HI collisions, i.e. at $\sqrt{s}$ = 5.5 TeV, would be very useful;

new phenomena? more simplicity?

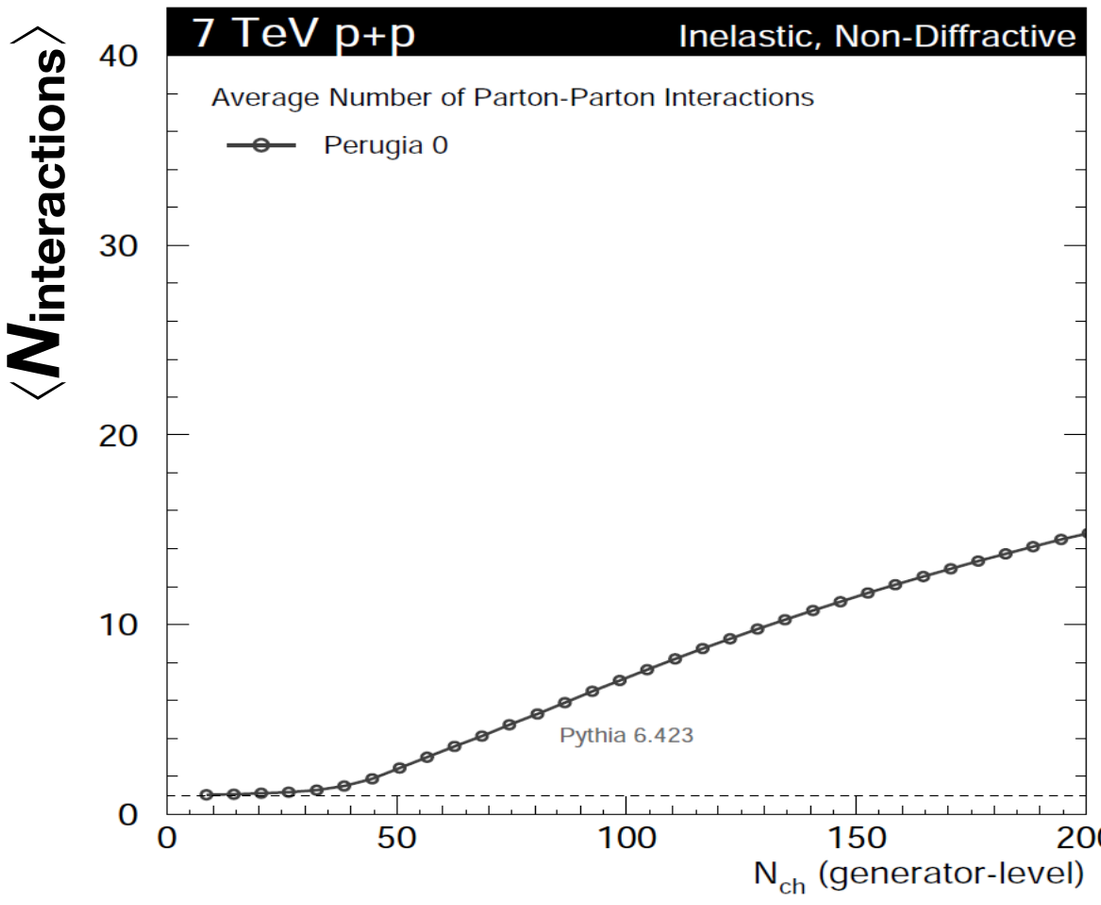
+ such profane topics as … 3. pp as reference for AA 4. pile-up 5. detector commissioning

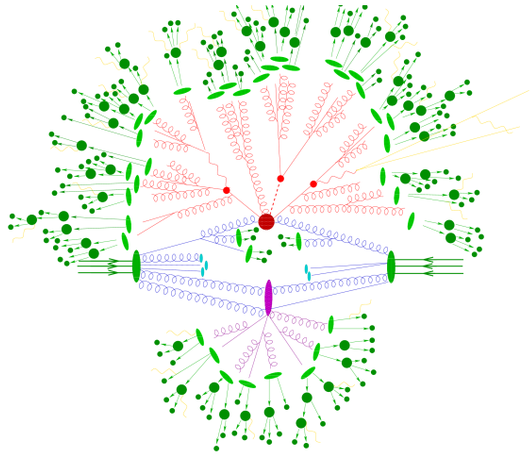
pp-Collisions in a New Energy Domain

Multiple collisions at perturbative scales



High Multiplicity a way to select events
with large number of semi-hard collisions





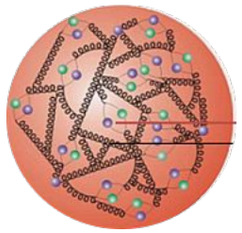
Understand complex events as superposition of elementary collisions (MPI) and their quantum fluctuations ? …

pp-Collisions in a New Density Domain

… or new surprises in the soft sector in a regime where energy densities reach those of heavy ion collisions ?

Two area scales:

proton size

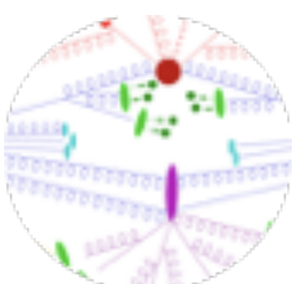


$$\varepsilon_i \approx \frac{3}{2} \times \frac{1}{\pi R_N^2 A^{2/3}} \langle E \rangle \frac{dN_{ch}}{dy}$$

Table 6: Comparison of average kinematic parameters for pp and Pb-Pb collisions.

	$\langle E \rangle$ (MeV)	$\frac{dN_{ch}}{dy}$	V_i (fm^3)	ε_i (GeV/fm^3)
$p\bar{p}$ ($\sqrt{s} = 630$ GeV)	400	4	4.5	0.5
$p\bar{p}$ ($\sqrt{s} = 1.8$ TeV)	400	5.3	4.5	0.7
pp ($\sqrt{s} = 14$ TeV)	500	7	4.5	1.2
Au-Au (RHIC)	500	650–850 [1]	153	3.1–4.1
Pb-Pb (LHC)	500	2000–8000	159	10–38

hard scattering scale



$$\frac{1}{p_T^2}$$

several scatterings in the same area

breaking of factorisation, saturation effects, ….

One paper changed his life …

Harvard Business Review

GOVERNMENT

Great Leaders Wear Big Hats

by Ron Ashkenas

Do you remember the old American Western movies where the sheriff with the big white hat rode onto the scene to bring law and order to the frontier town? Having grown up with these movies, the image of the heroic leader with the big hat still sticks in my mind. But today we don't see many big hats around anymore – and it's not just because 21st Century leaders dress differently.

In many ways, the current financial crisis has been caused, or at least exacerbated, by a lack of leaders with big hats. Instead of thinking about what's best in the long-term, most

Where do I find big hats …

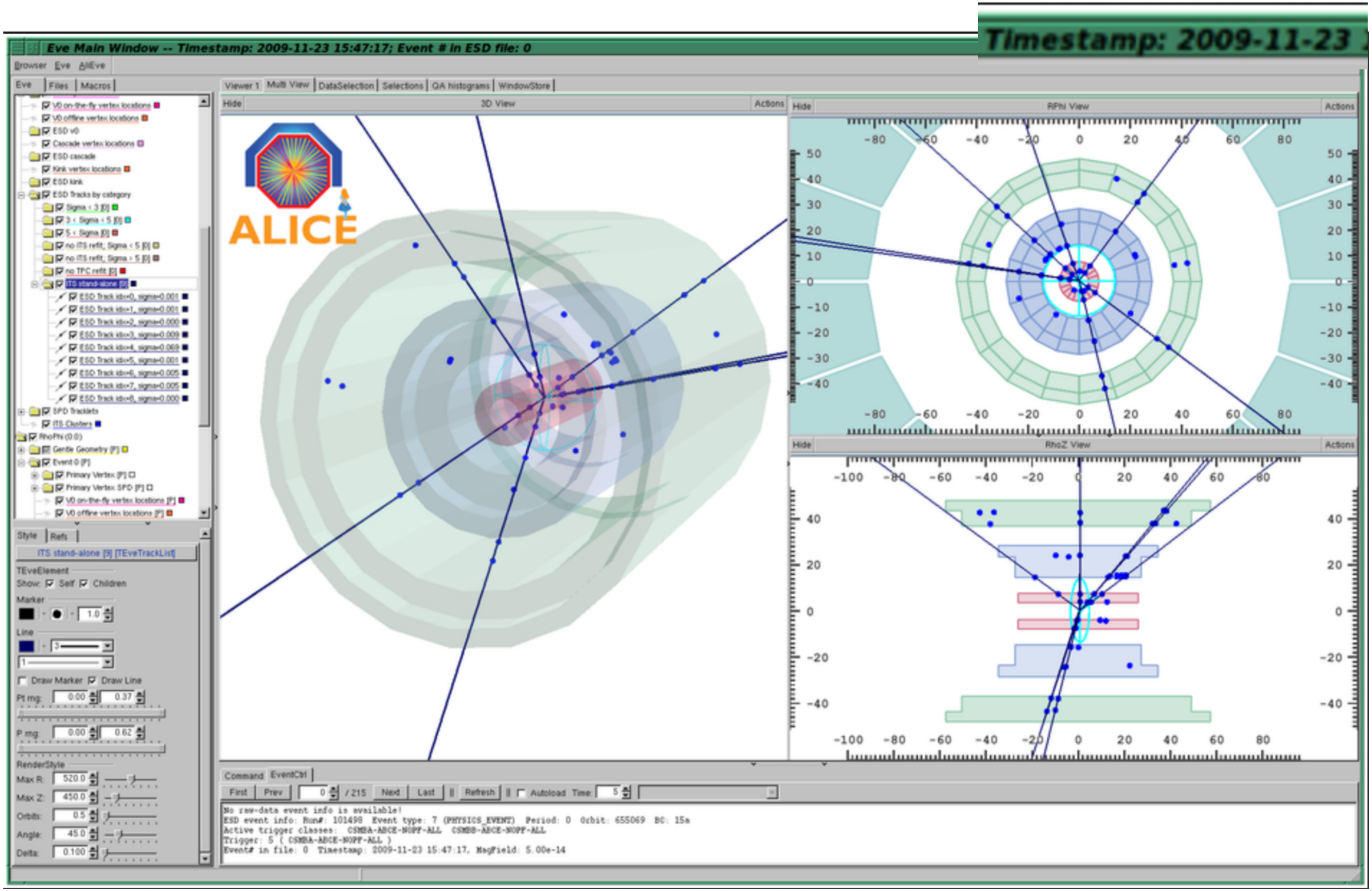
and great minds to lead ?

since 2003

As important as Guy's Scientific Work

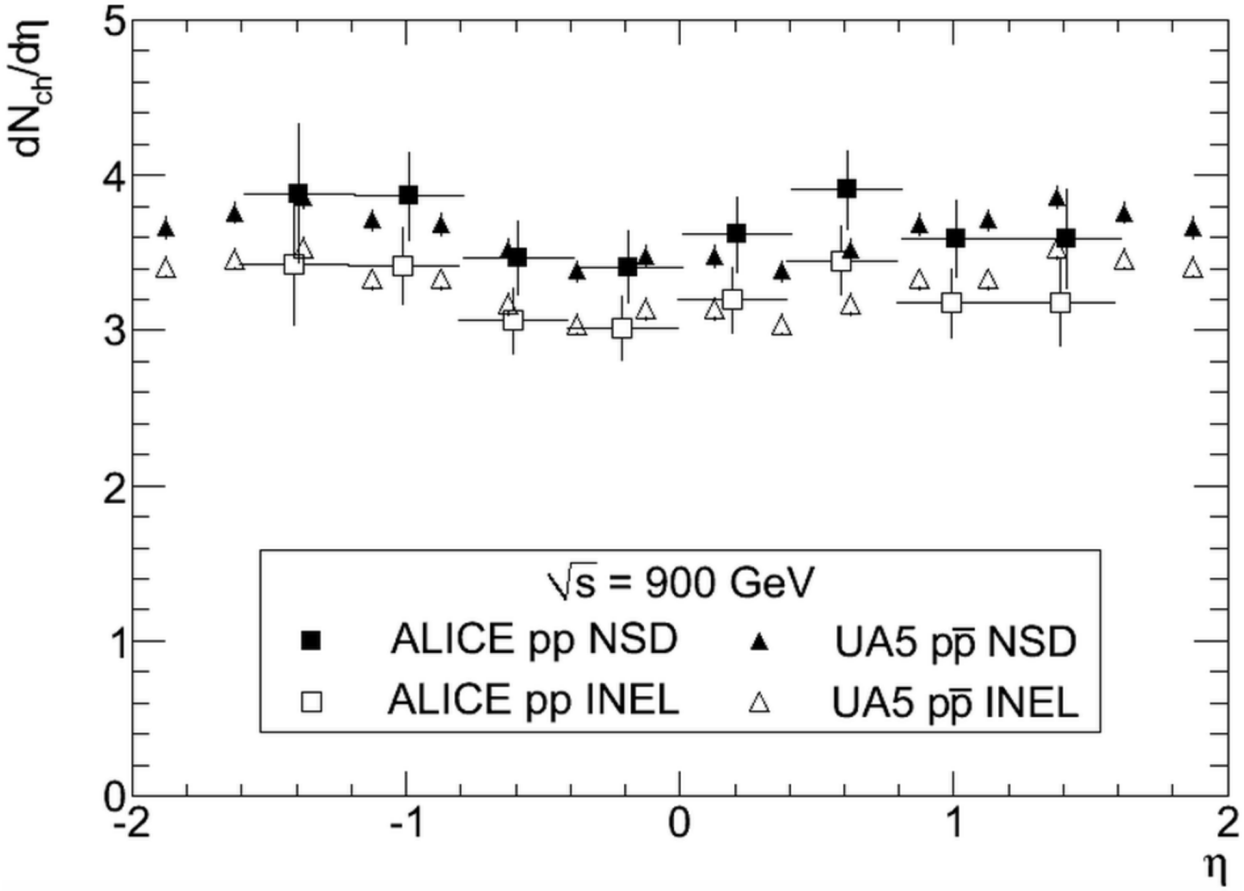
- Continuous effort of
  - passing his enthusiasm for science to young researchers
  - bringing the best out of them
  - encouraging them to spent time abroad …
    - … and to collaborate with larger teams

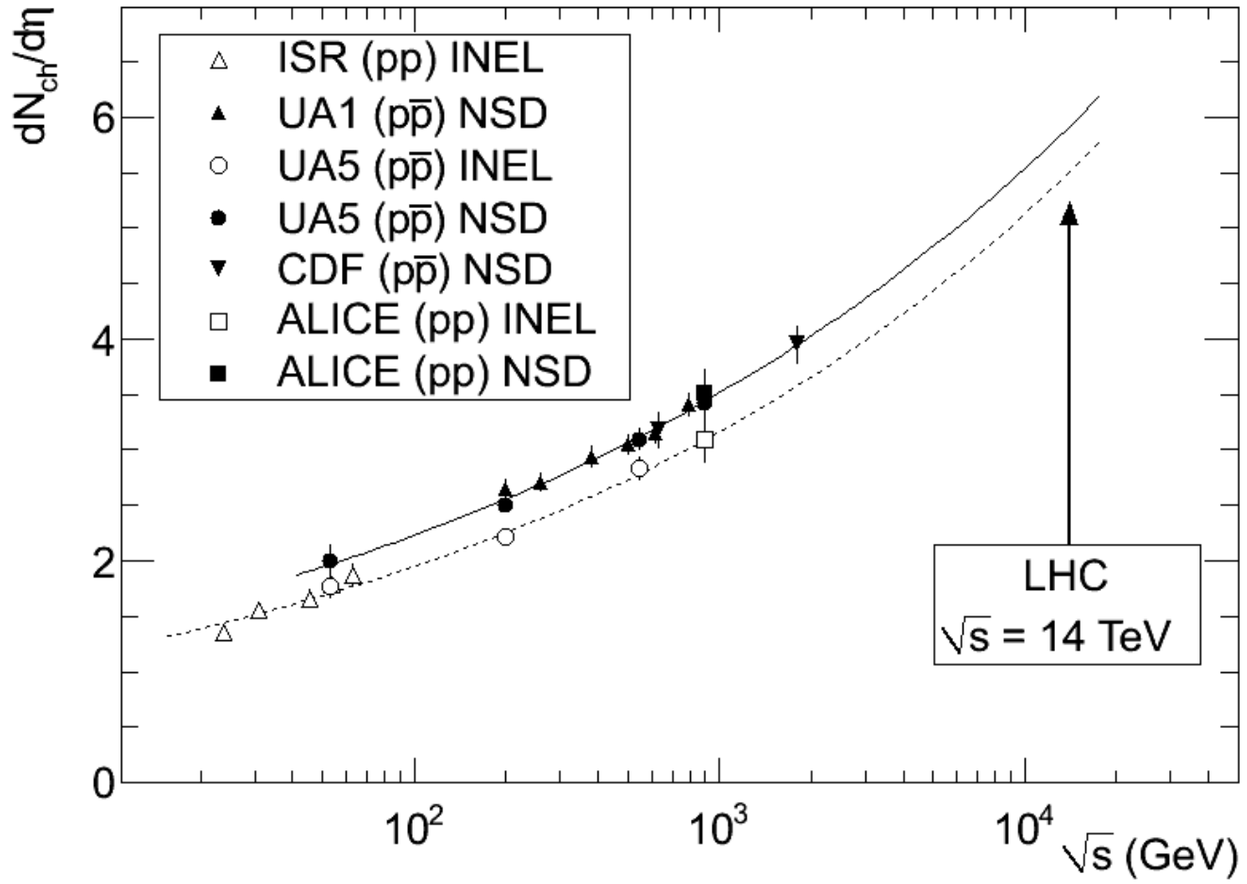
Almost exactly 9 years later …



5 days later … Le Coup d'ALICE

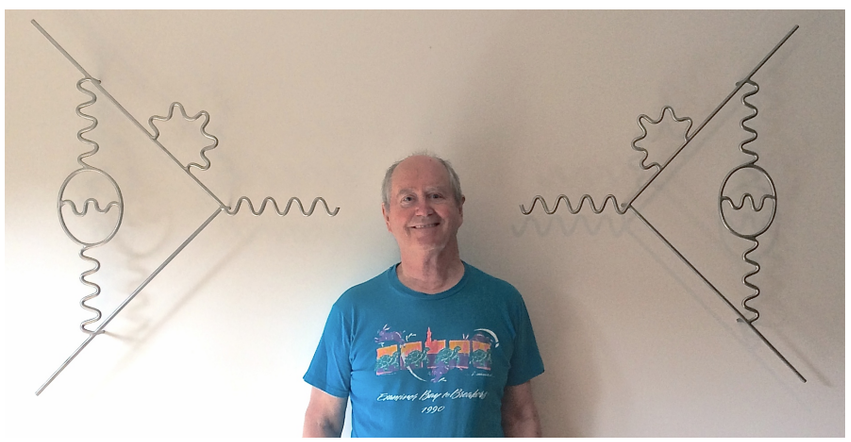
Eur. Phys. J. C 65 (2010) 111-125





(Submitted on 28 Nov 2009 (v1), last revised 28 Sep 2017 (this version, v3))

Another Influential Paper



Chris Quigg

a ~~pandora box~~
piñata full of phenomena
… hit it!

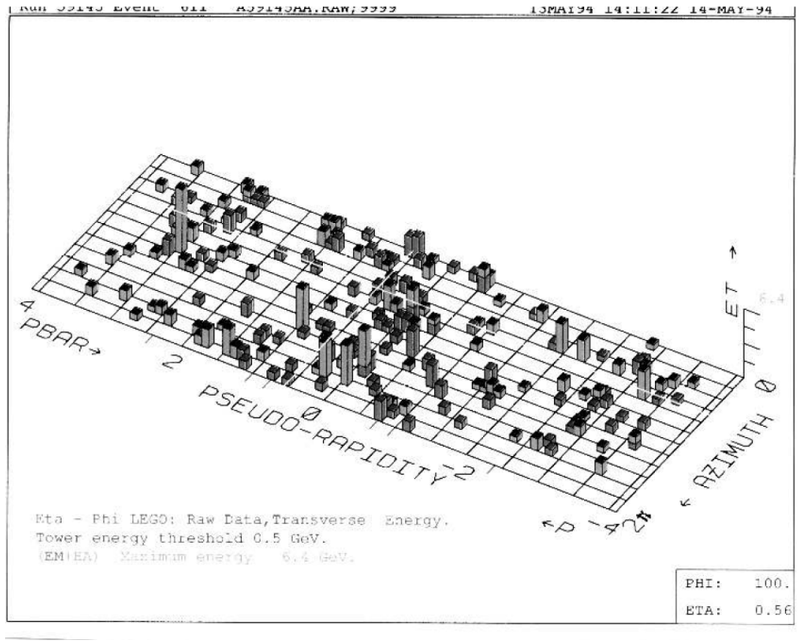
Looking into Particle Production at the Large Hadron Collider

arXiv: 1004.0975

CHRIS QUIGG(*)

Fermi National Accelerator Laboratory, Batavia, Illinois 60510 USA

CDF Hedgehog Event



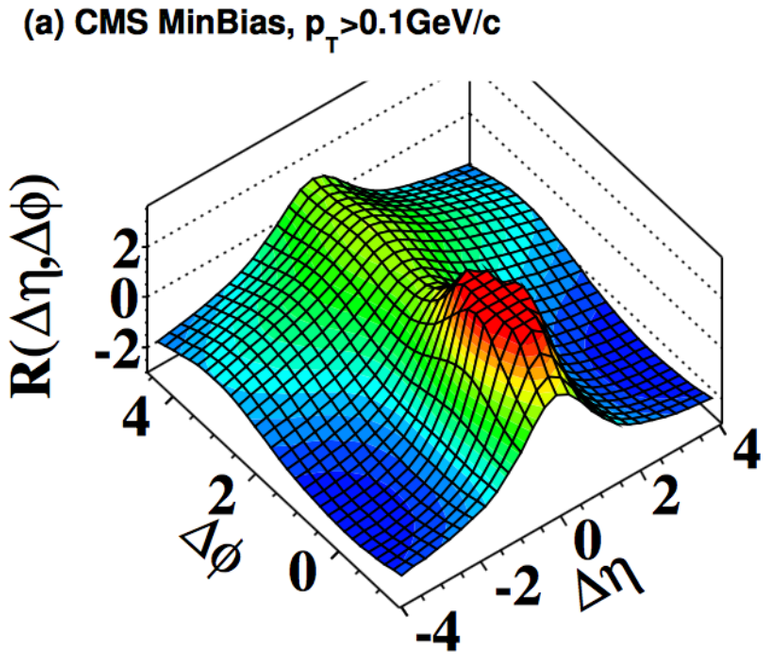
Unusual event or expected fluctuation?

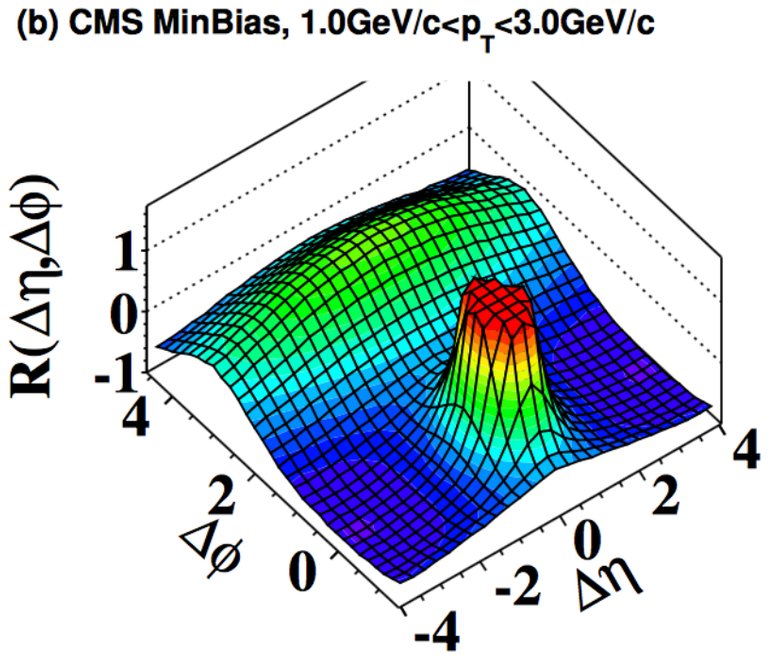
I advocate looking at individual events, not just distributions. Beyond honing intuition, the first effect of *looking at events*, displayed in appropriate coordinates, may be to validate in broad terms the prevailing picture of particle production. We should also be able to test the completeness of the Monte Carlo frameworks that have become so indispensable to the search for new (hard-scattering) phenomena. I think it likely that we will encounter suggestions of new event classes, to be pursued in focused studies that go beyond visual inspection. New trends may emerge with increasing beam energy, or at the extremes of high and low multiplicity. The comparison of events with and without a hard trigger should be revealing. The goal of the visual approach is to discover as completely as we can the richness of phenomena that our theories will have to explain, and to orient us for detailed exploration of the new worlds.

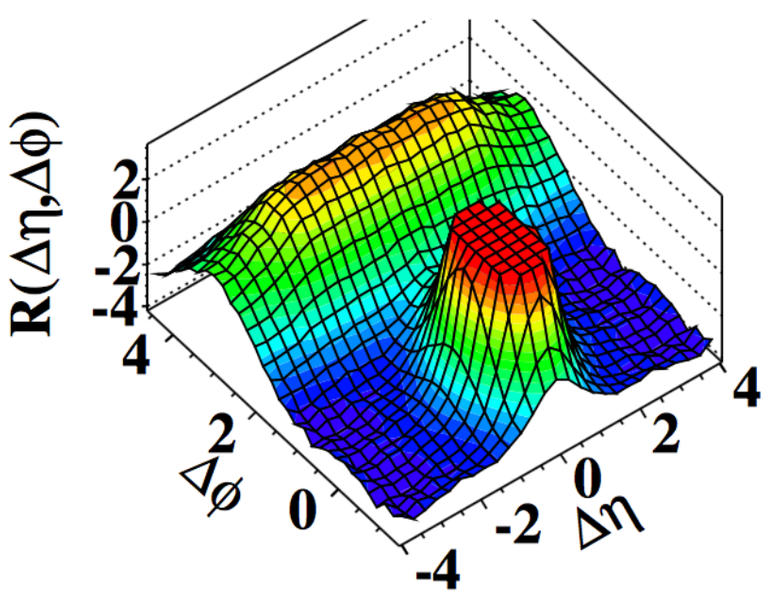
For some classes of events, analyses of bulk properties, such as studies of elliptic flow and determinations of thermodynamic parameters may prove powerful. We will need all the established methods plus novel techniques to learn to see what the LHC data have to show.

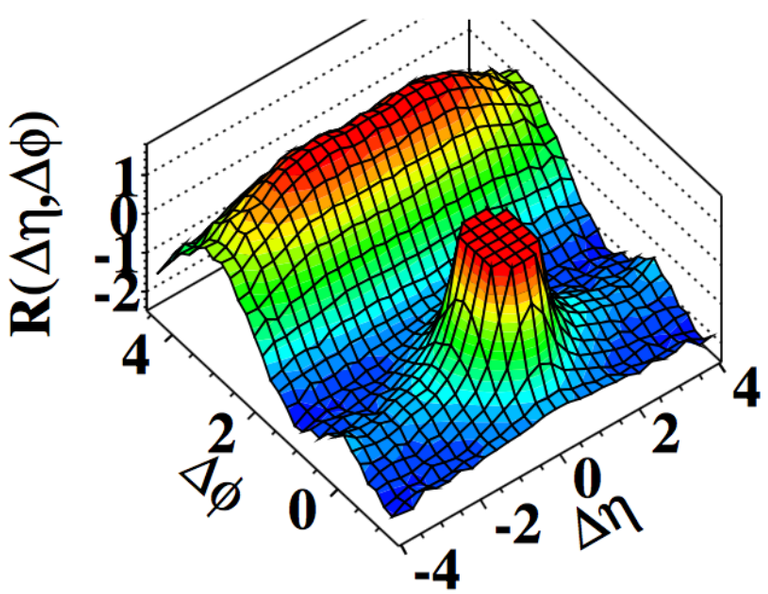
Surprises Indeed …

JHEP09(2010)091

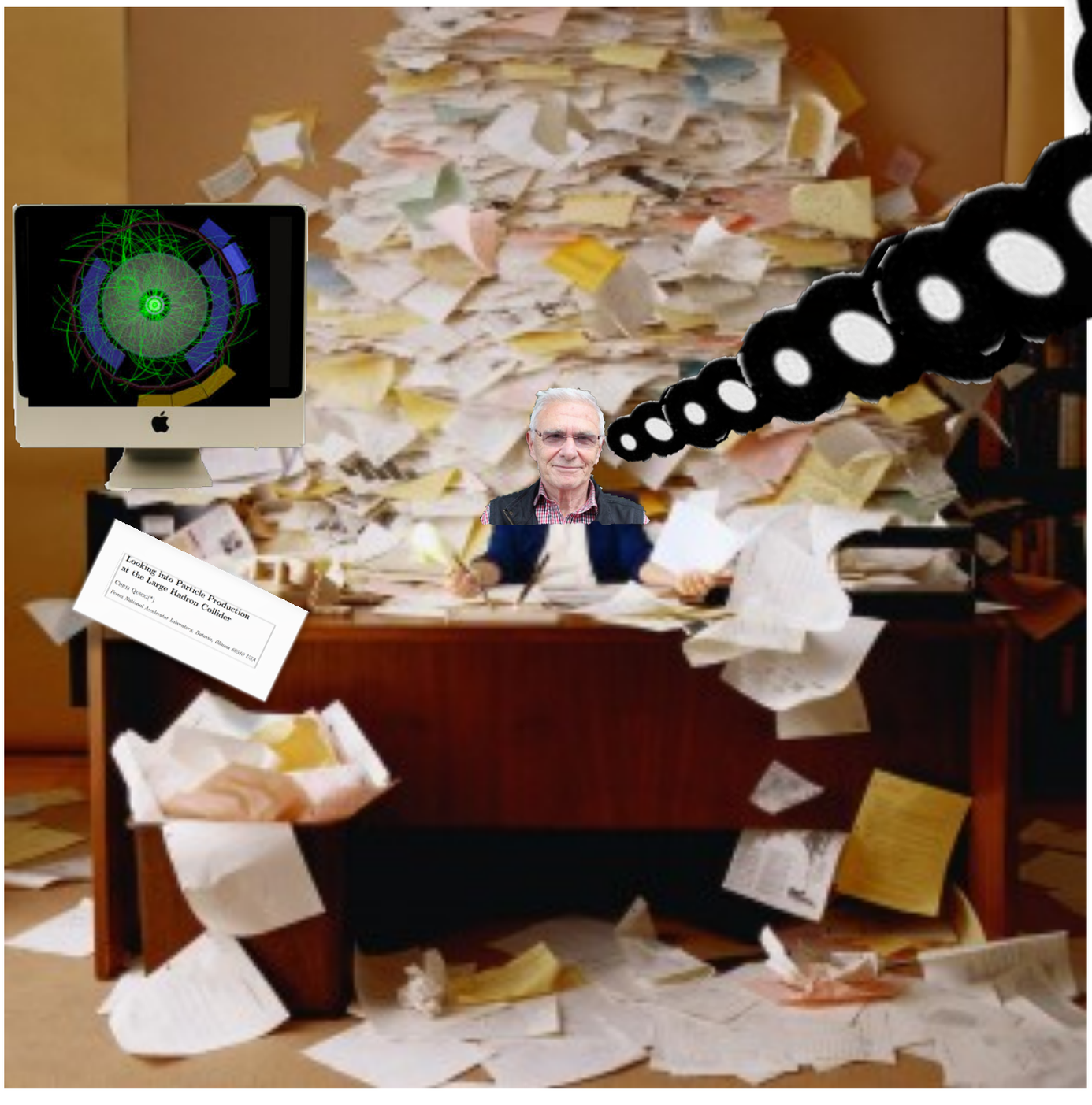








Meanwhile in Mexico …



Event Shapes

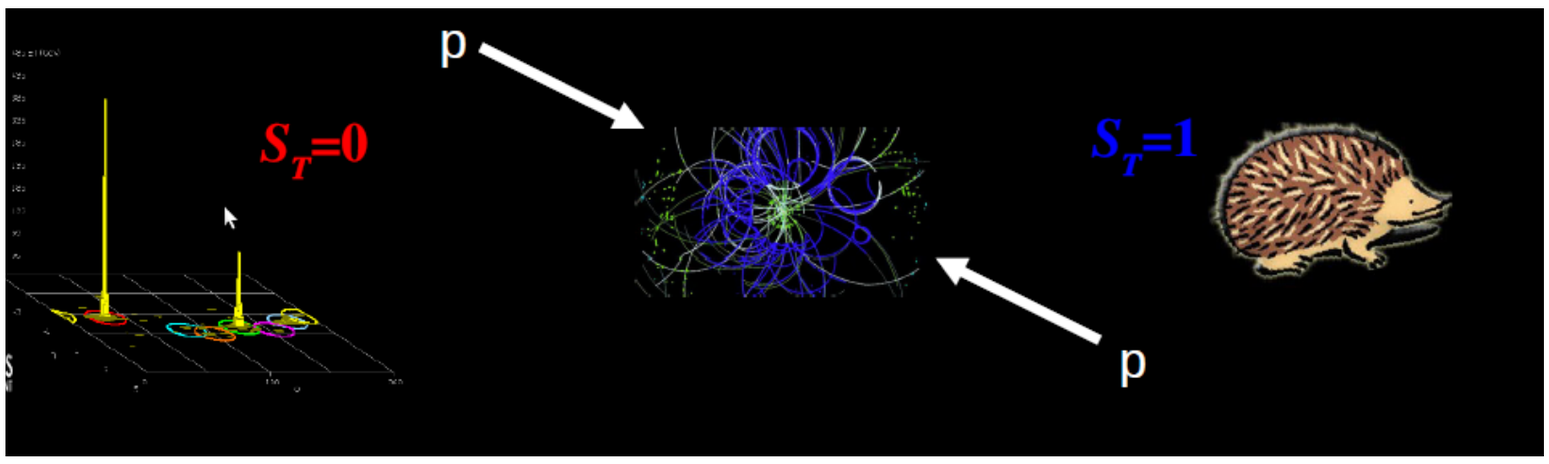
from  **to** 

- Event by Event Inspection using Transverse Sphericity.
- Technique to characterise final state topologies of elementary collisions
- Here applied to minimum bias pp
- Define soft events as events without particle $p_T > 2$ GeV

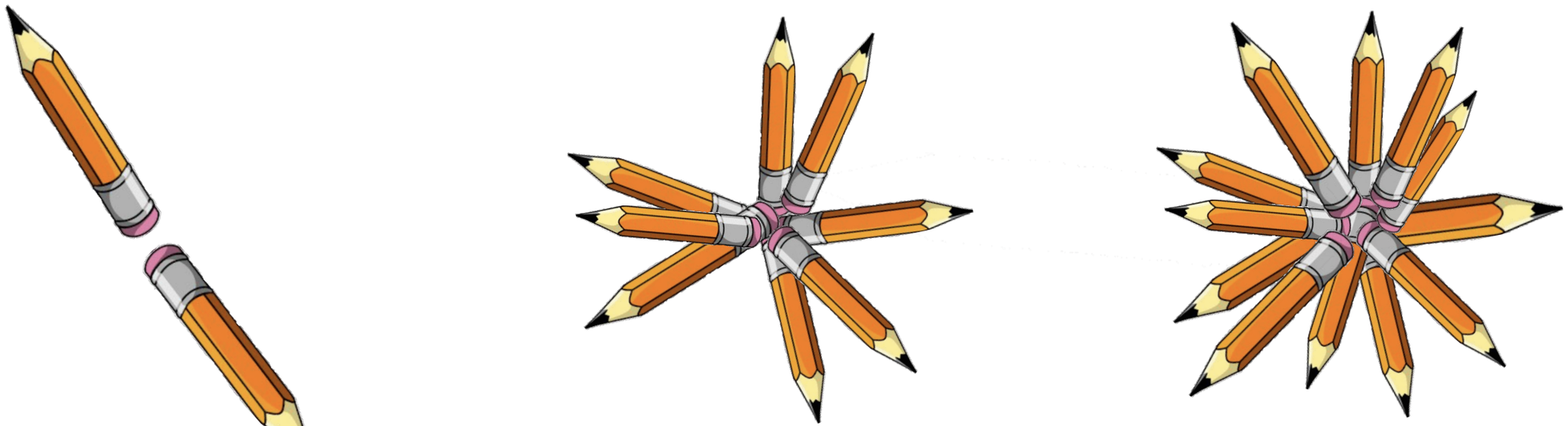
$$\mathbf{S_{xy}} = \frac{1}{\sum_j p_{\mathrm{T}\,j}} \sum_i \frac{1}{p_{\mathrm{T}\,i}} \begin{pmatrix} p_{\mathrm{x}\,i}^{\,2} & p_{\mathrm{x}\,i}\, p_{\mathrm{y}\,i} \\ p_{\mathrm{y}\,i}\, p_{\mathrm{x}\,i} & p_{\mathrm{y}\,i}^{\,2} \end{pmatrix}$$

Eigenvalues $\lambda_{1,2}$

$$S_{\mathrm{T}} = \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$



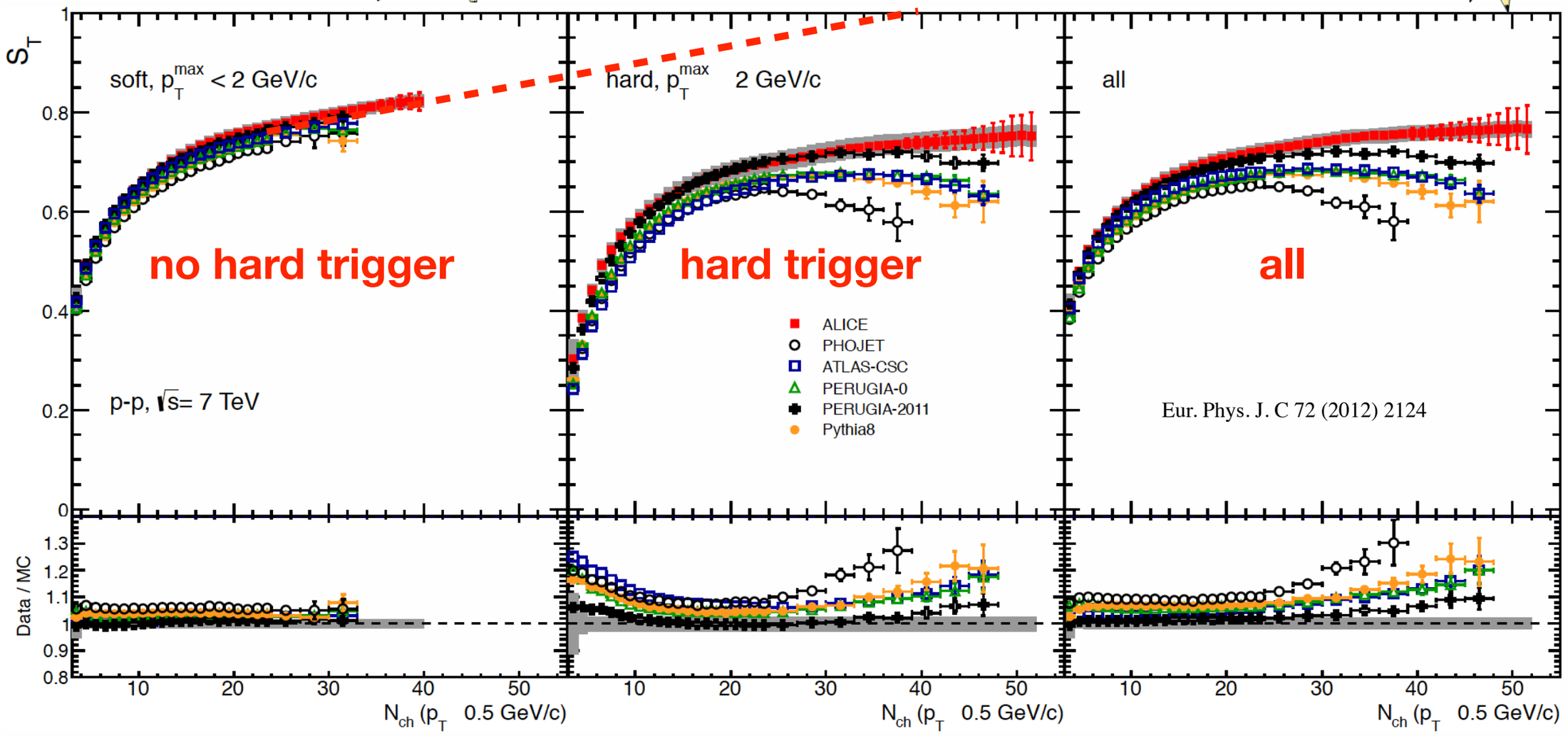
The Naive MPI Picture



$S_T \sim 0$

$S_T = 1$

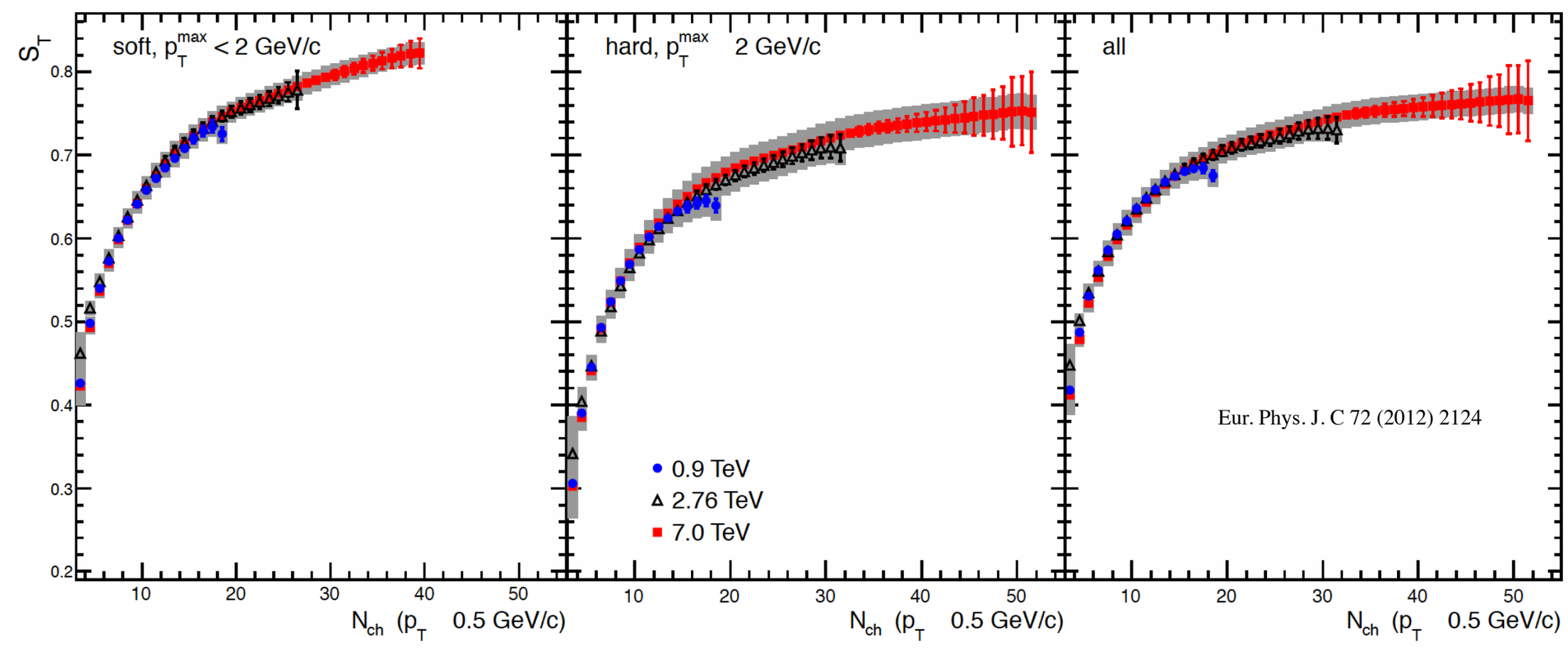
Multiplicity



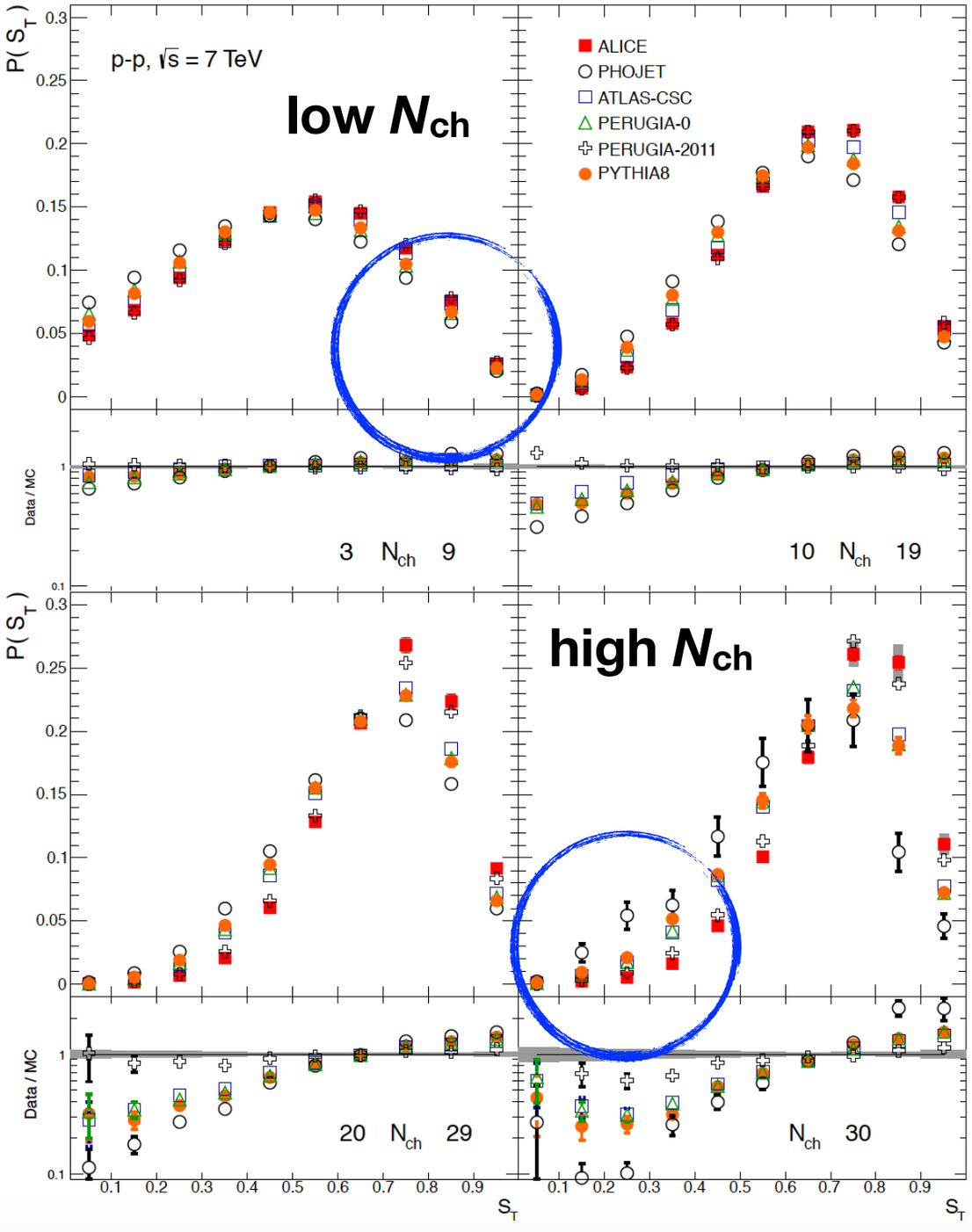
- Events become more isotropic with increasing multiplicity
  - overlap of increasing number of uncorrelated elementary collisions
- Increase saturates (in data), reverts (in MC) as consequence of bias on jet production.

Tests subtle interplay between
increase of MPI and increase of particle production per hard scattering.

Weak energy (0.9, 2.76, 7 TeV) dependence …



S_T Distributions

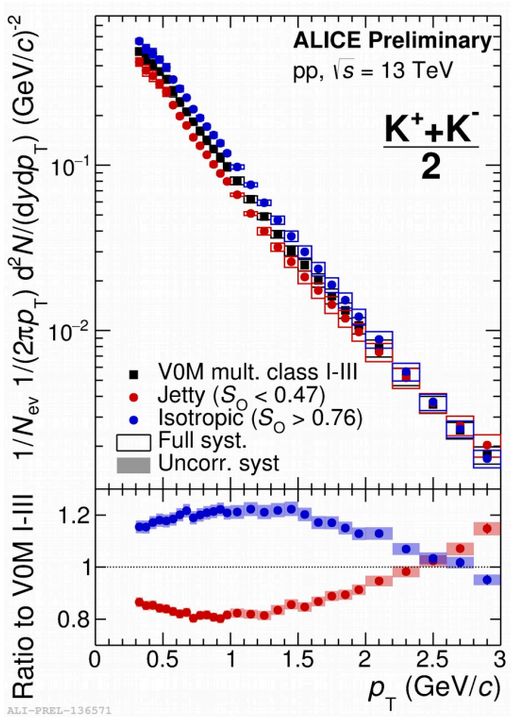


Eur. Phys. J. C 72 (2012) 2124

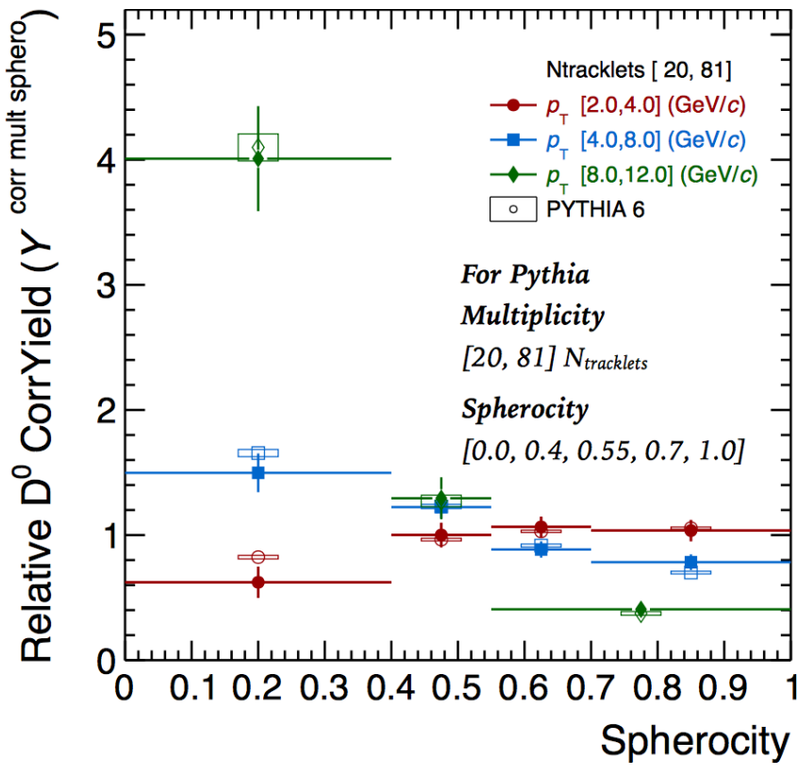
Challenge generators in the extreme limits of phase space:
low multiplicity/high sphericity and vice versa

Sphericity/Spherocity* has found applications in …

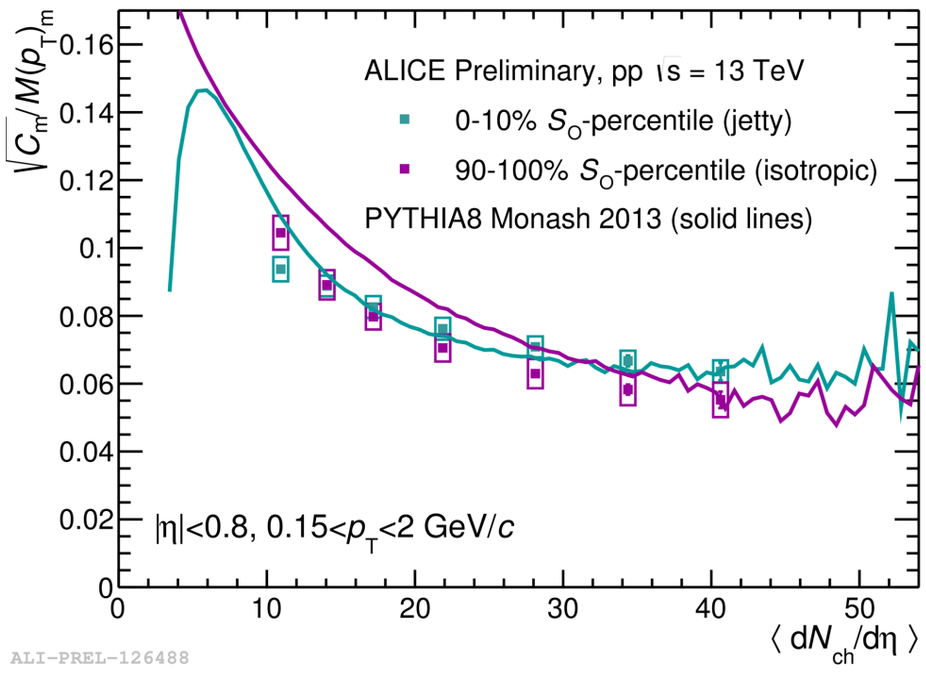
Light Flavour



Heavy Flavour



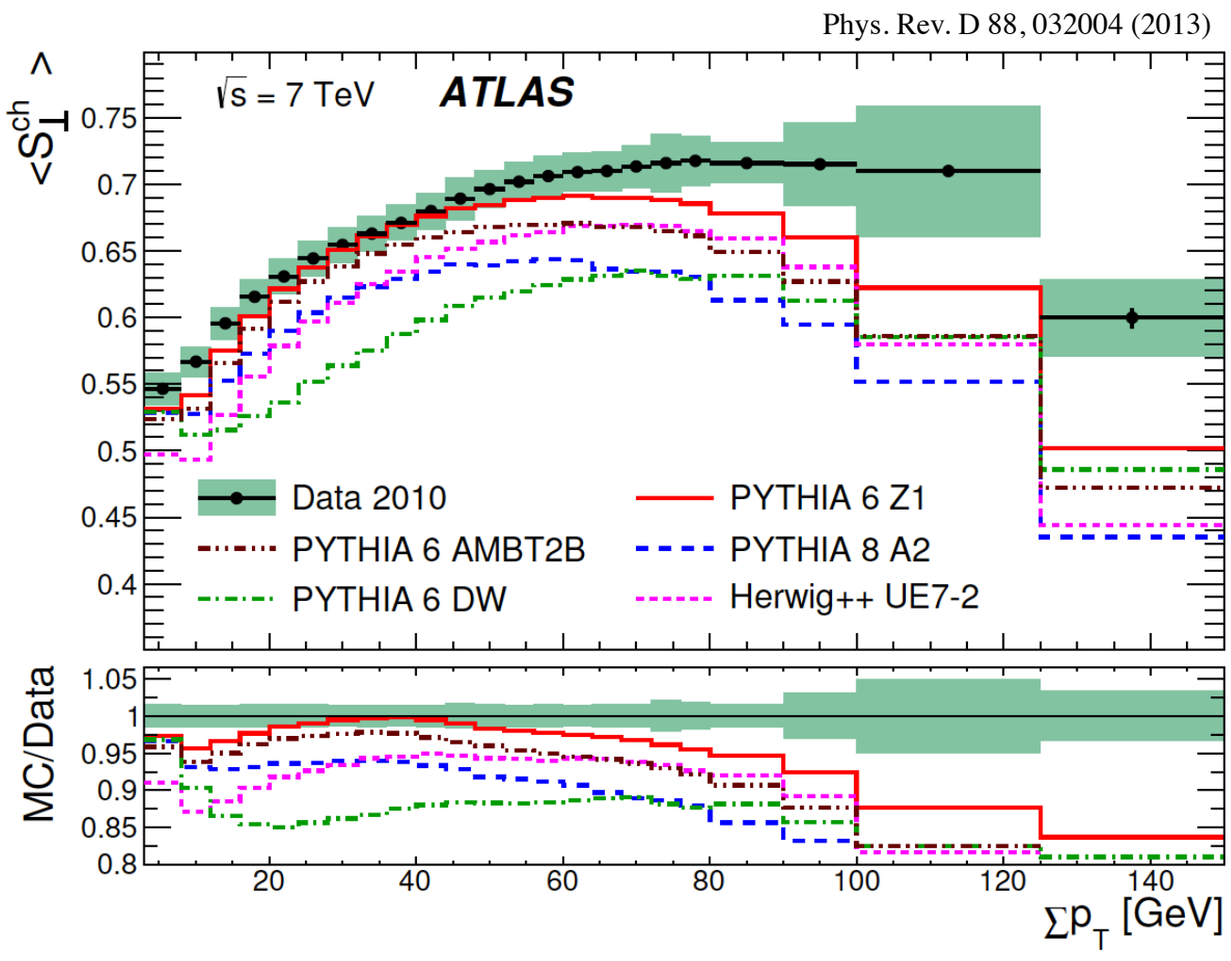
Event-by-Event Fluctuations



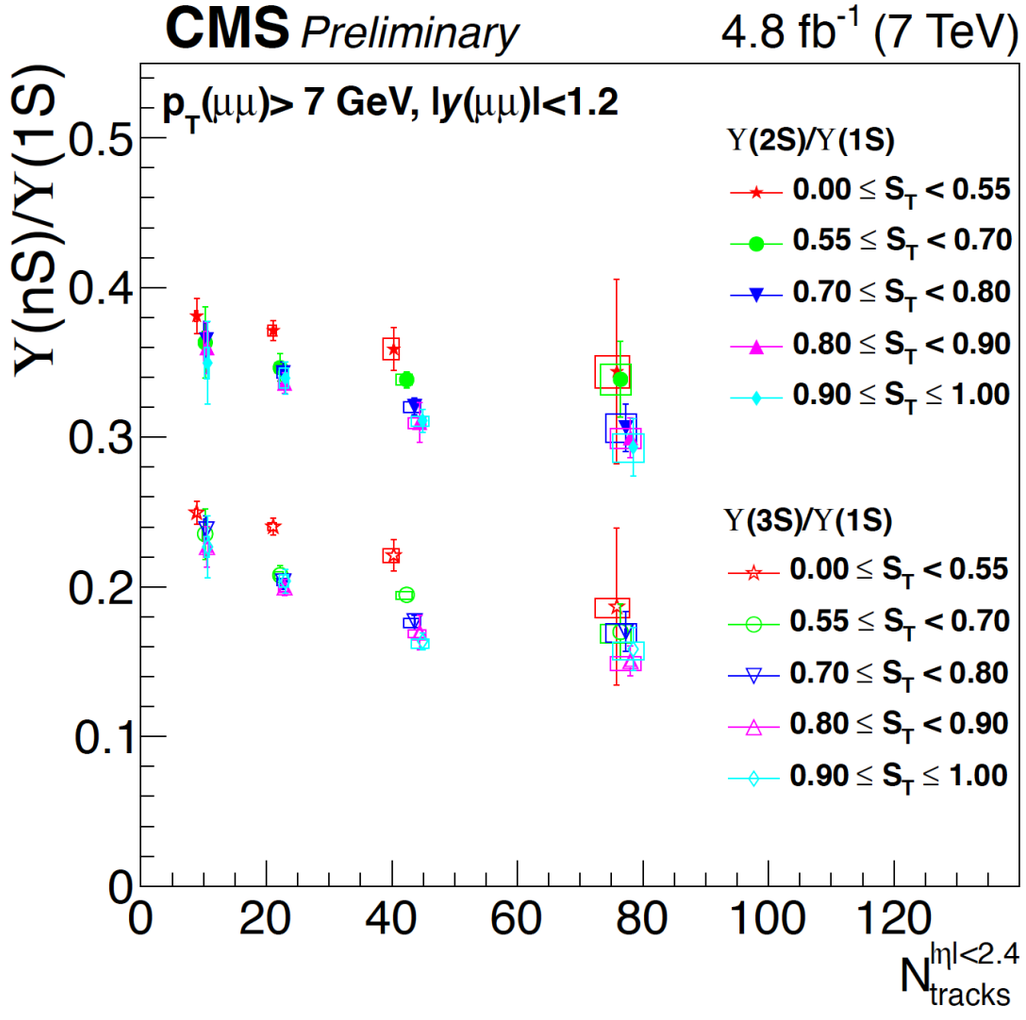
*see next talk

and also in ATLAS and CMS …

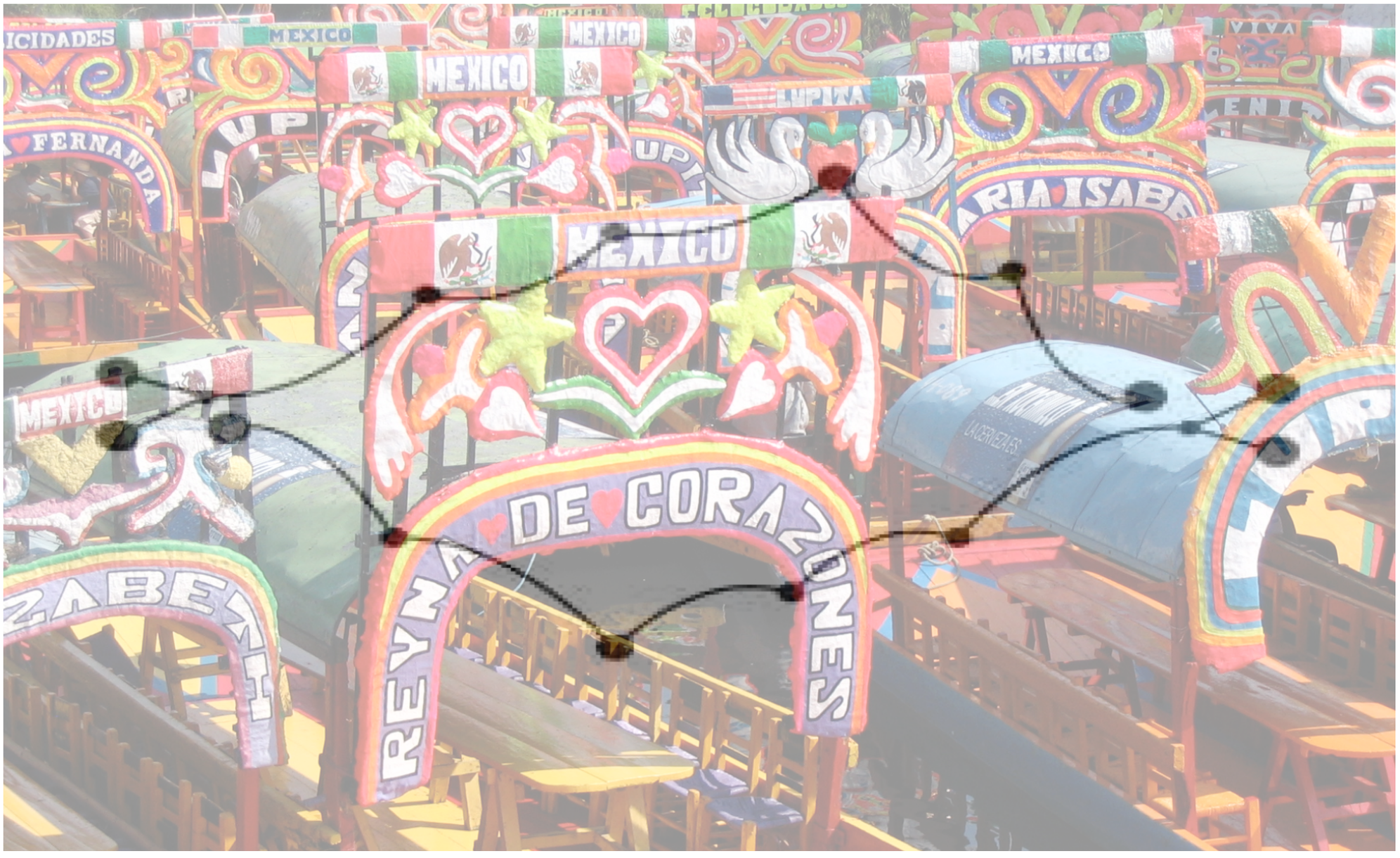
as a function of summed p_T



multiplicity dependence of Y production



Color Reconnections

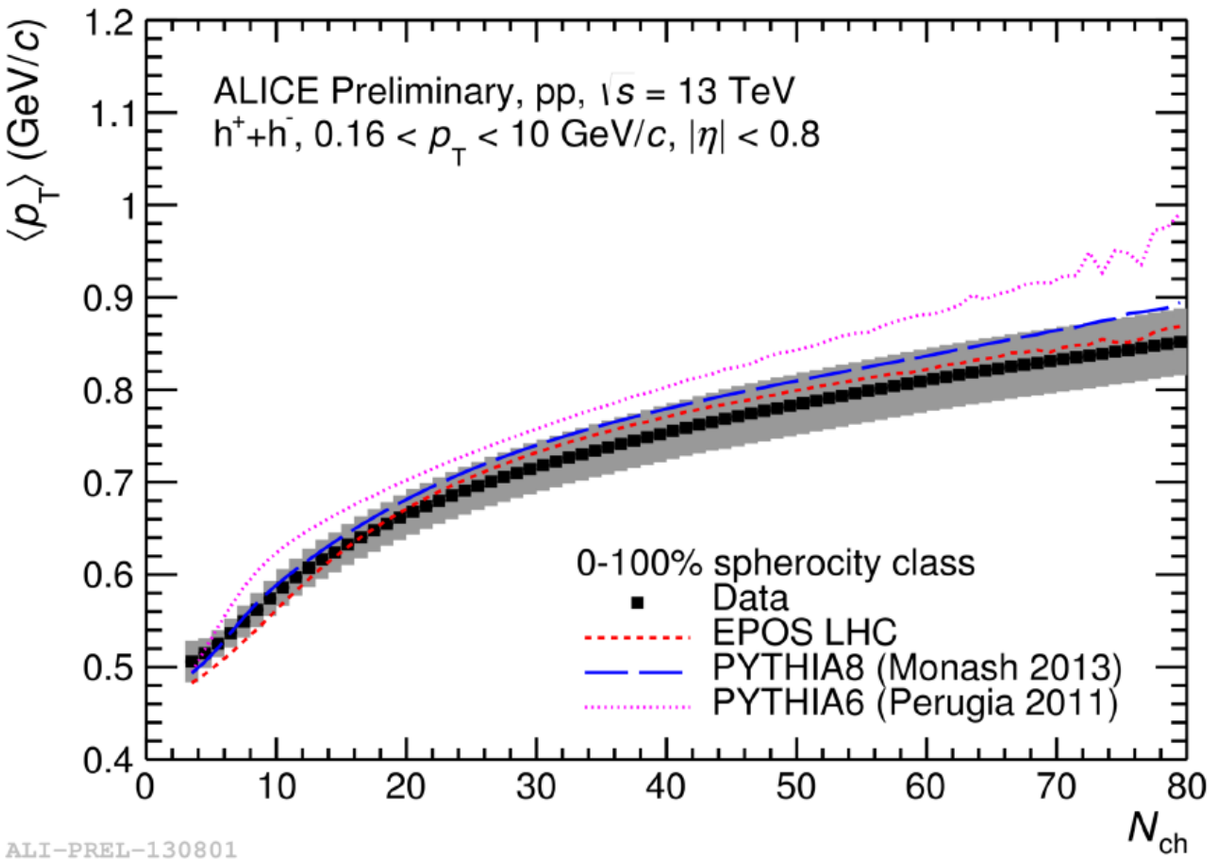


(coherence effects between MPI in pp)

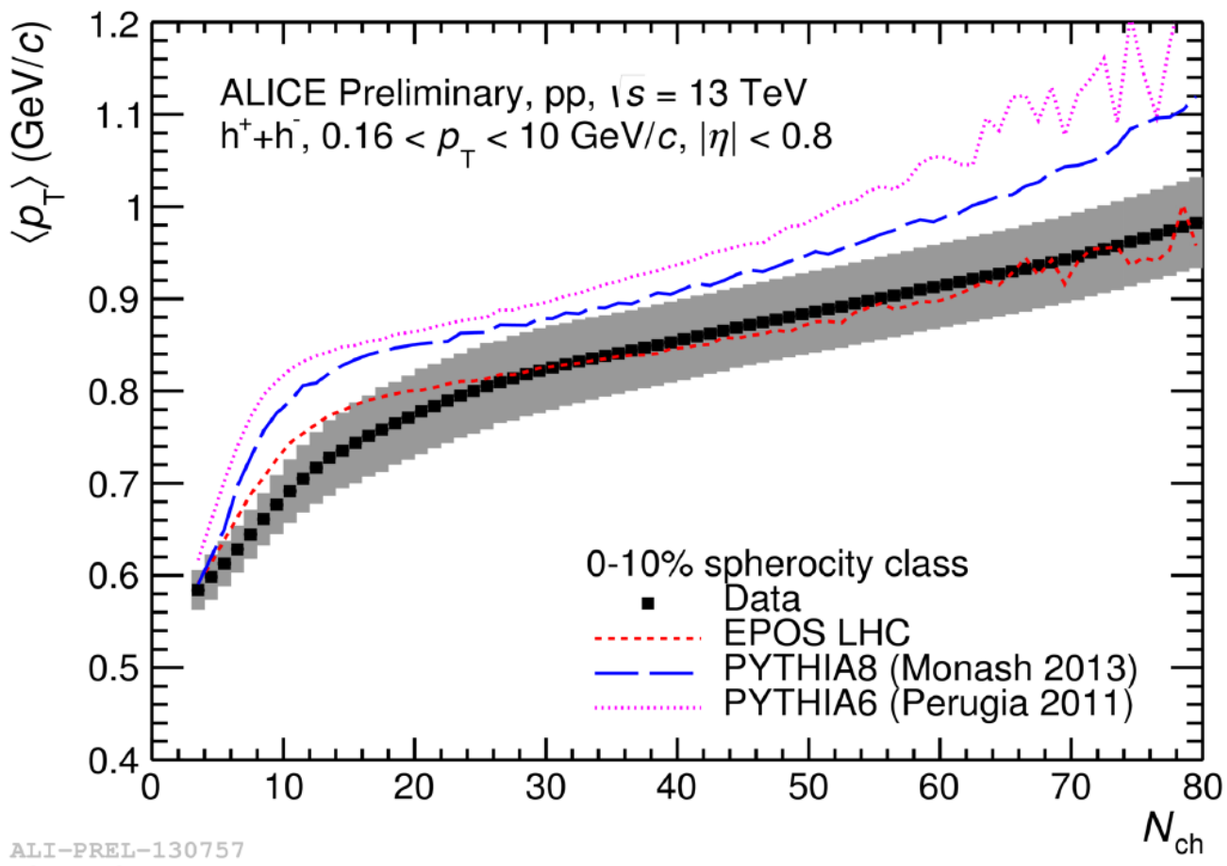
$\langle p_T \rangle$ vs Multiplicity

… hallmark measurement for coherence effects in pp

no sphericity selection



0-10% sphericity



- Naive MPI model (without coherence) would predict constant $\langle p_T \rangle$
- Any deviations from it a sign of coherence effects ?

A not so naive model …

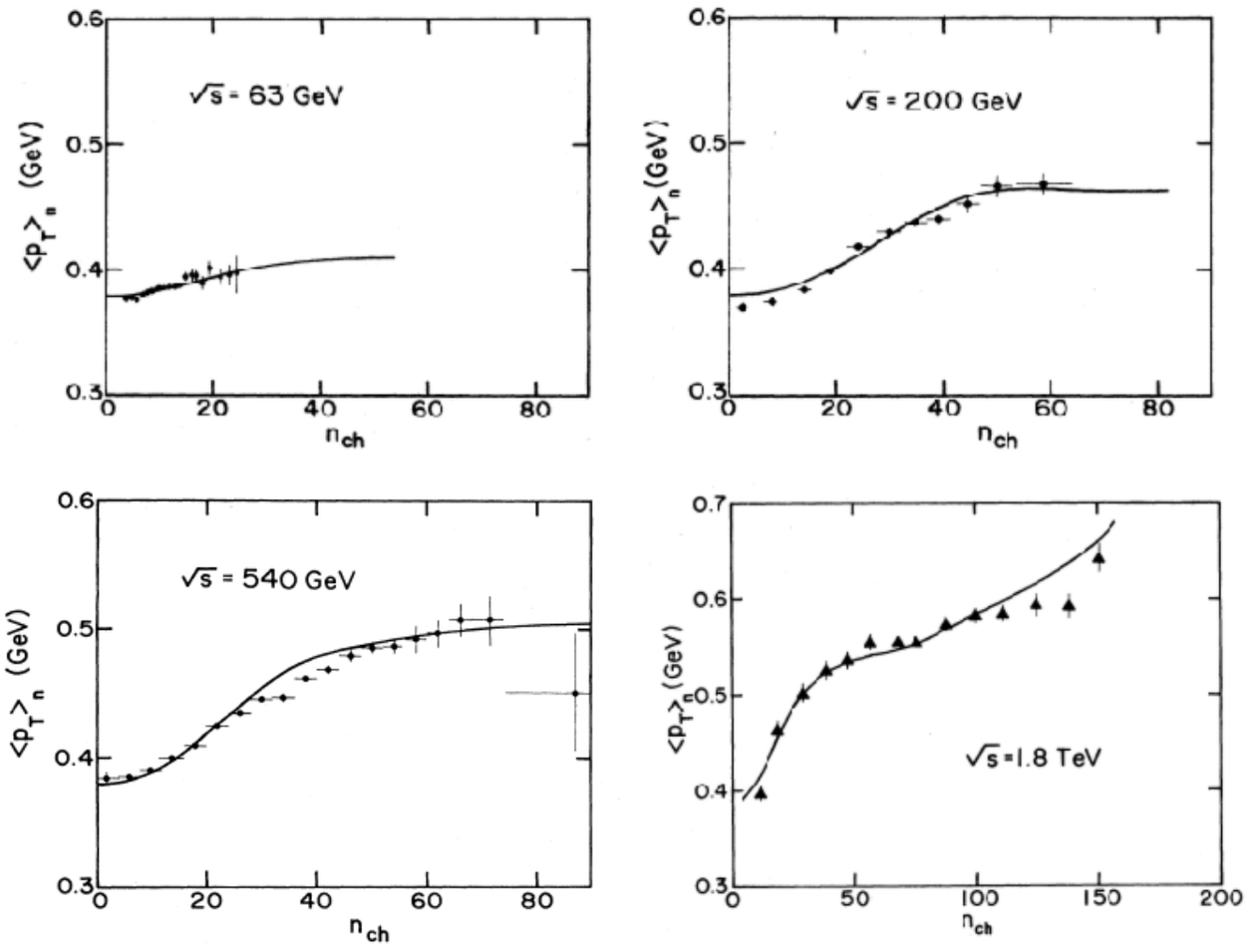
Add a soft component and low-p_T jets …

… and get structures

Geometrical Branching Model.

- two component model
- hard and soft process impact parameter dependent
- jet fragmentation

XN Wang and R Hwa (Phys.Rev. D39 (1989) 187)



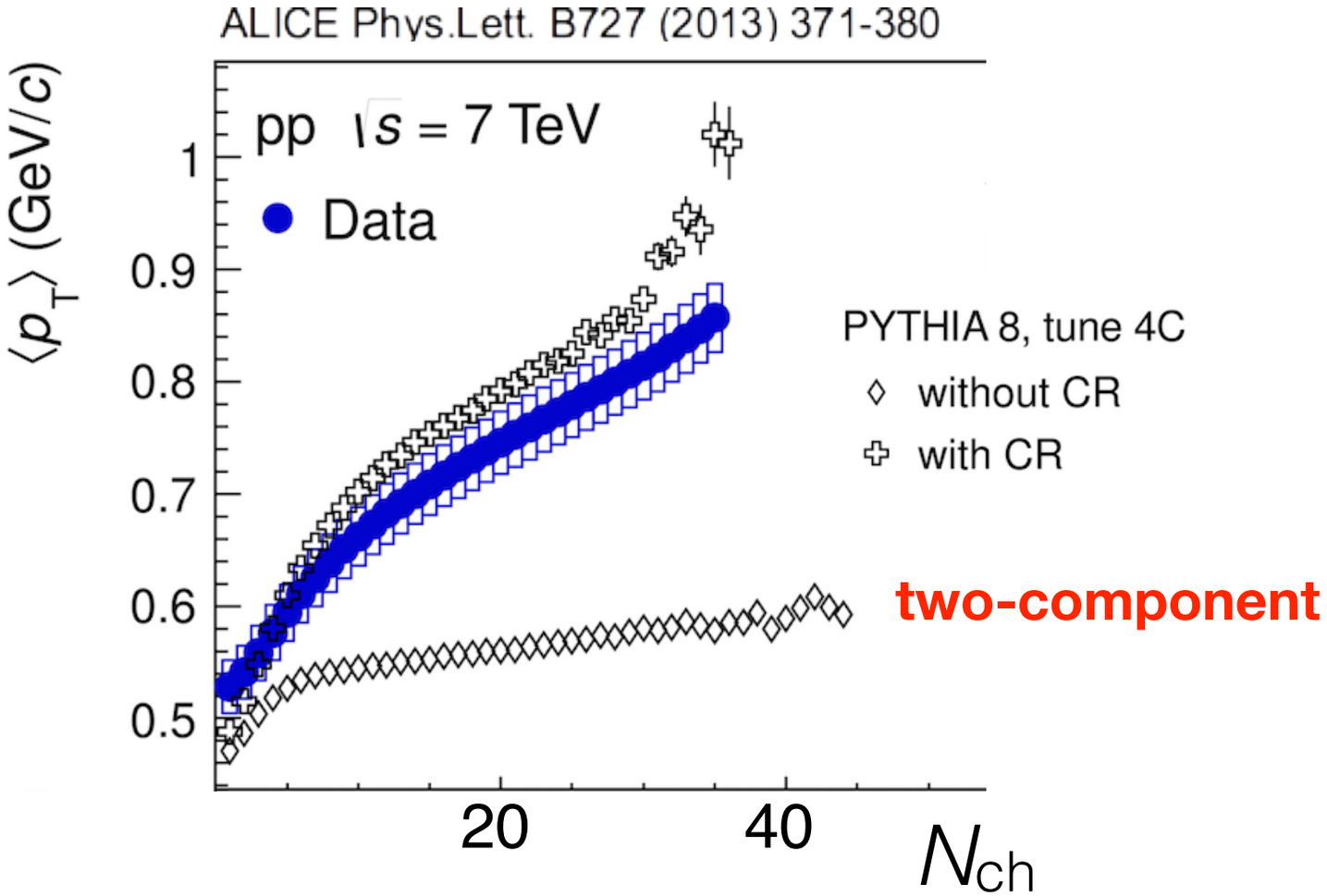
Ledge: rise – plateau – rise

1st rise: increased dominance of hard over soft interactions

2nd rise: jet bias

Coherence Effects

Modern implementations of 2-component models do not explain data …

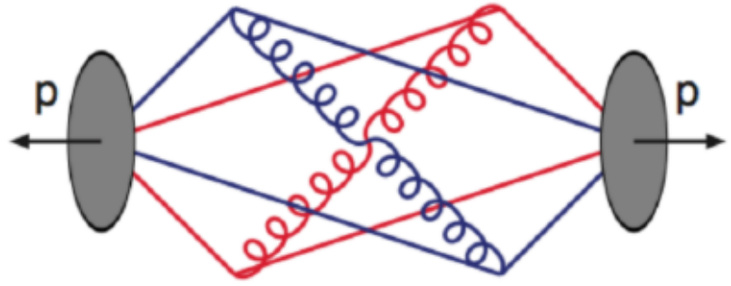


two-component

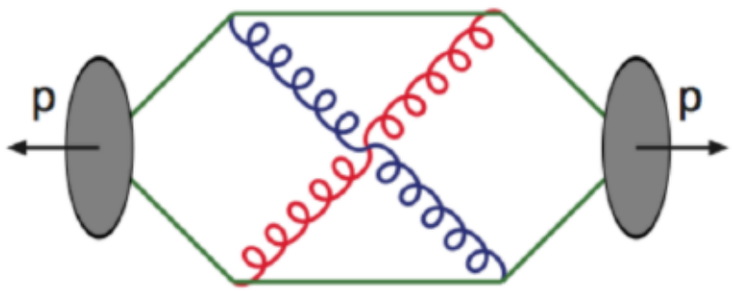
ALICE,charged particles

$|\eta|<0.3$, $0.15<p_T<10.0$ GeV/c

Color Reconnections (CR)



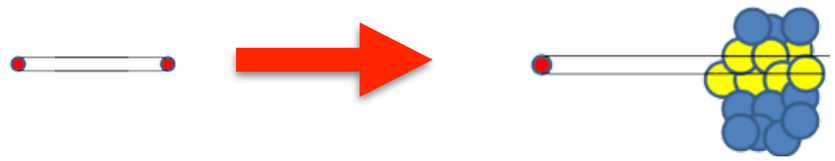
long strings to remnants
⇒ comparable n_{ch}/interaction
⇒ $\langle p_\perp \rangle (n_{ch}) \sim$ flat.

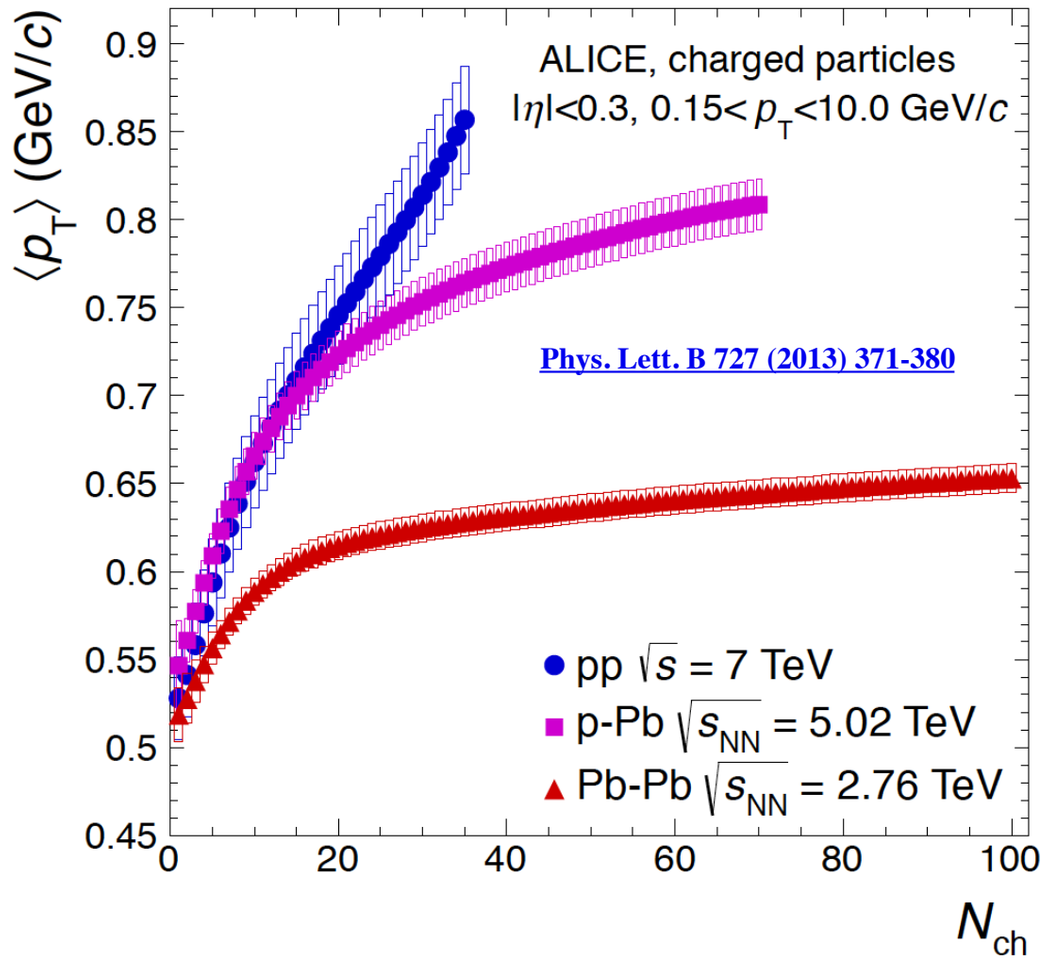


shorter extra strings
for each consecutive interaction
⇒ $\langle p_\perp \rangle (n_{ch})$ rising.

T. Sjostrand

From pp to p-Pb

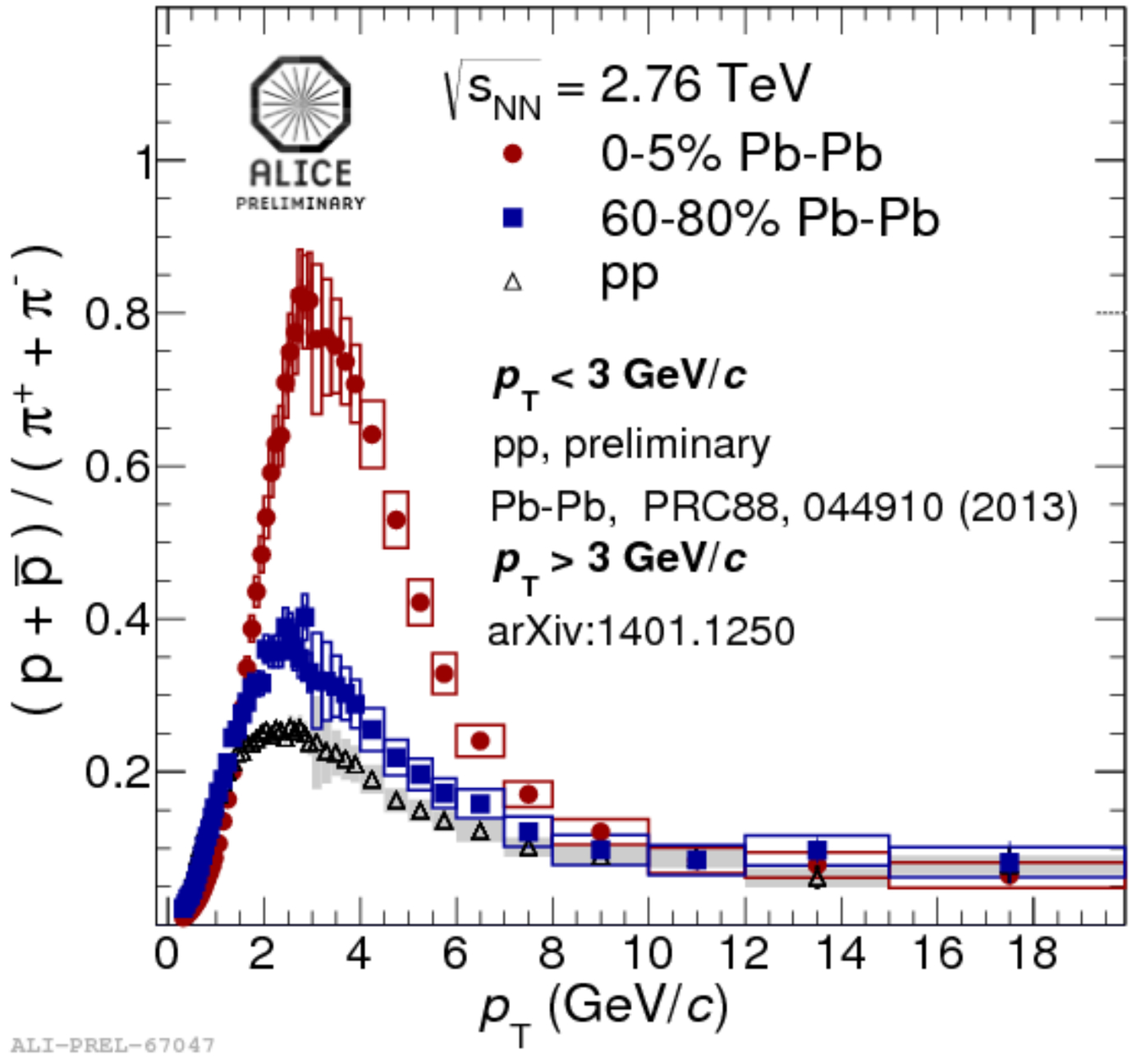




p-Pb follows pp up to N_{ch} = 14 (10% of the pp cross-section)

- deviation due to less (jet-)biased p-Pb system ?
- importance of coherence effects in p-Pb ?

Another Similarity: p/π Ratio vs p_T



Qualitatively same behaviour in all collisions systems

Color reconnection and flow-like patterns in pp collisions

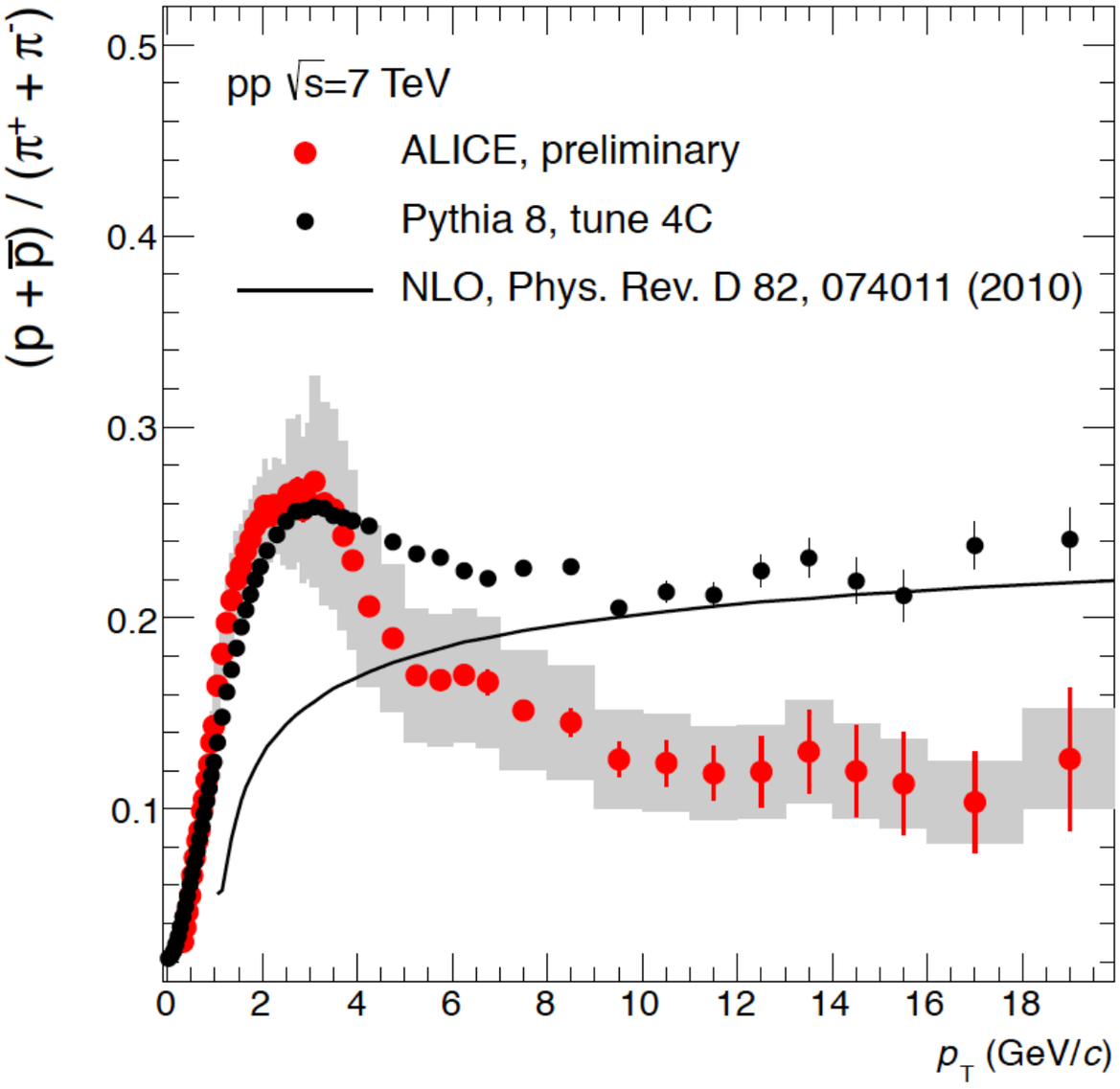
Antonio Ortiz, Peter Christiansen, Eleazar Cuautle, Ivonne Maldonado, Guy Paic

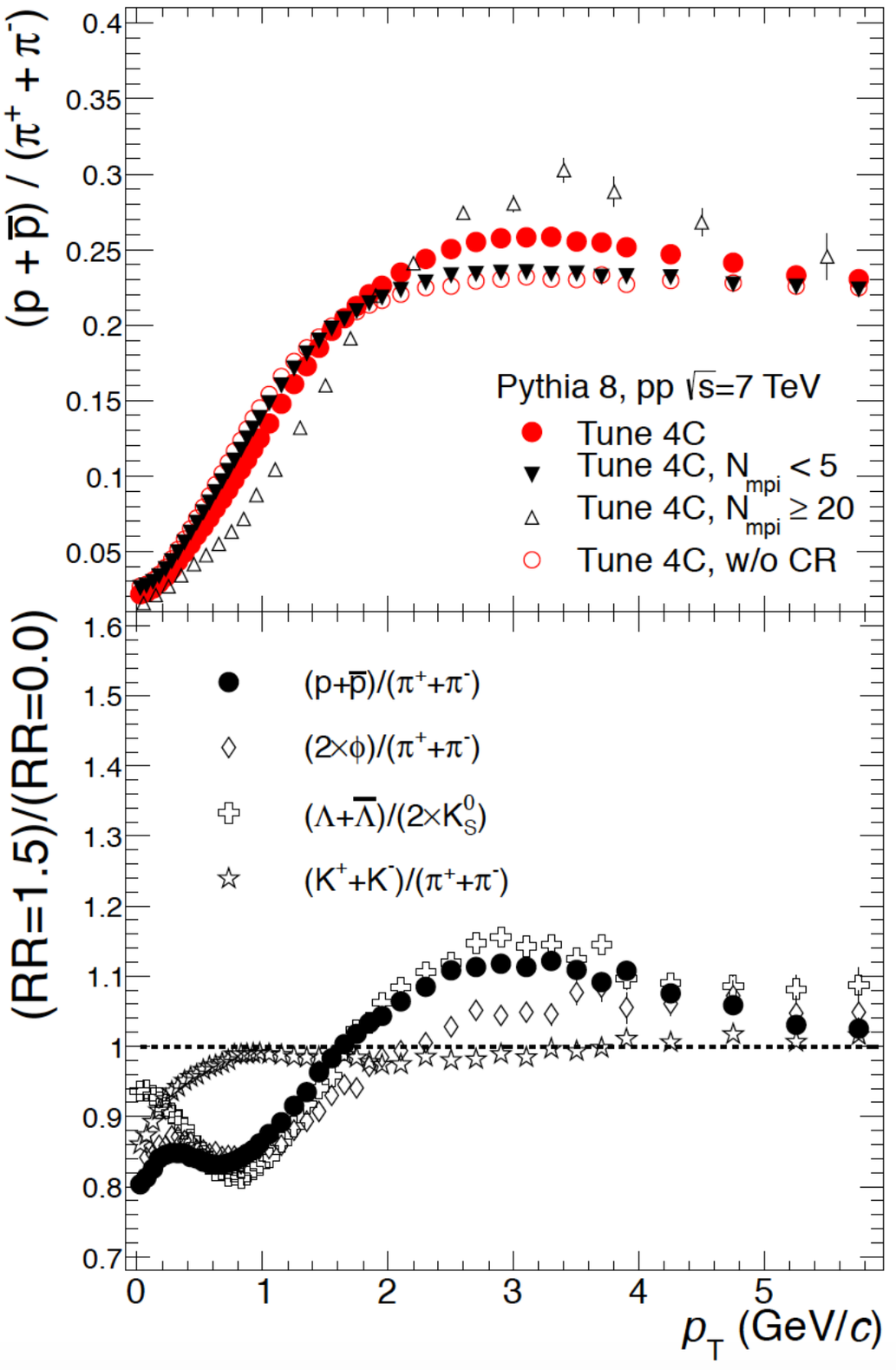
(Submitted on 25 Mar 2013 (v1), last revised 27 Jun 2013 (this version, v2))

Increasingly, with the data collected at the LHC we are confronted with the possible existence of flow in pp collisions. In this work we show that PYTHIA 8 produces flow-like effects in events with multiple hard subcollisions due to color string formations between final partons from independent hard scatterings, the so called color reconnection. We present studies of different identified hadron observables in pp collisions at 7 TeV with the tune 4C. Studies have been done both for minimum bias and multiplicity intervals in events with and without color reconnection to isolate the flow-like effect.

Phys. Rev. Lett. 111, 042001 (2013)

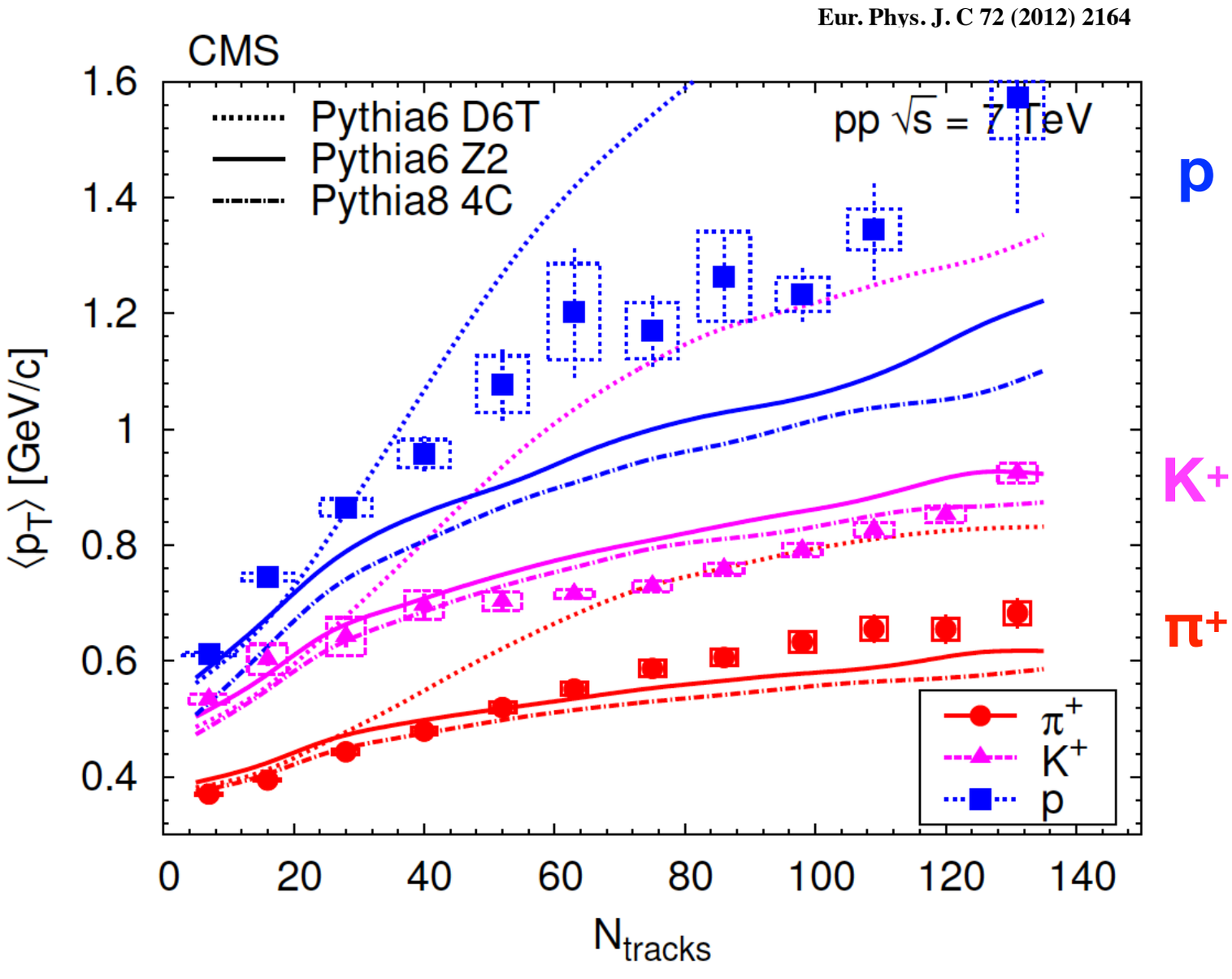
Phys. Rev. Lett. 111, 042001 (2013)





In Pythia characteristic peak structure consequence of color reconnections.

⟨p_T⟩ for Identified Particles



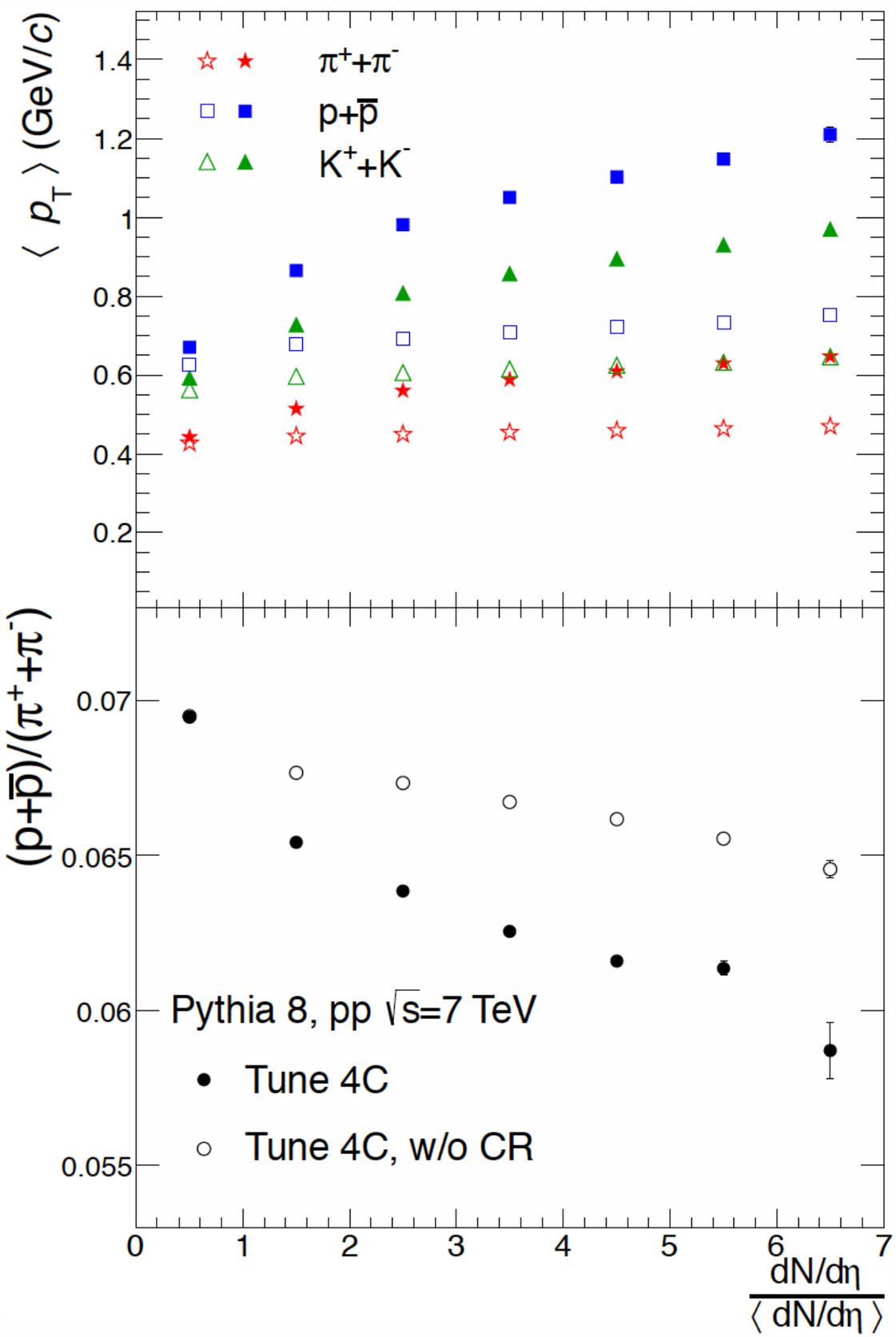
p

K+

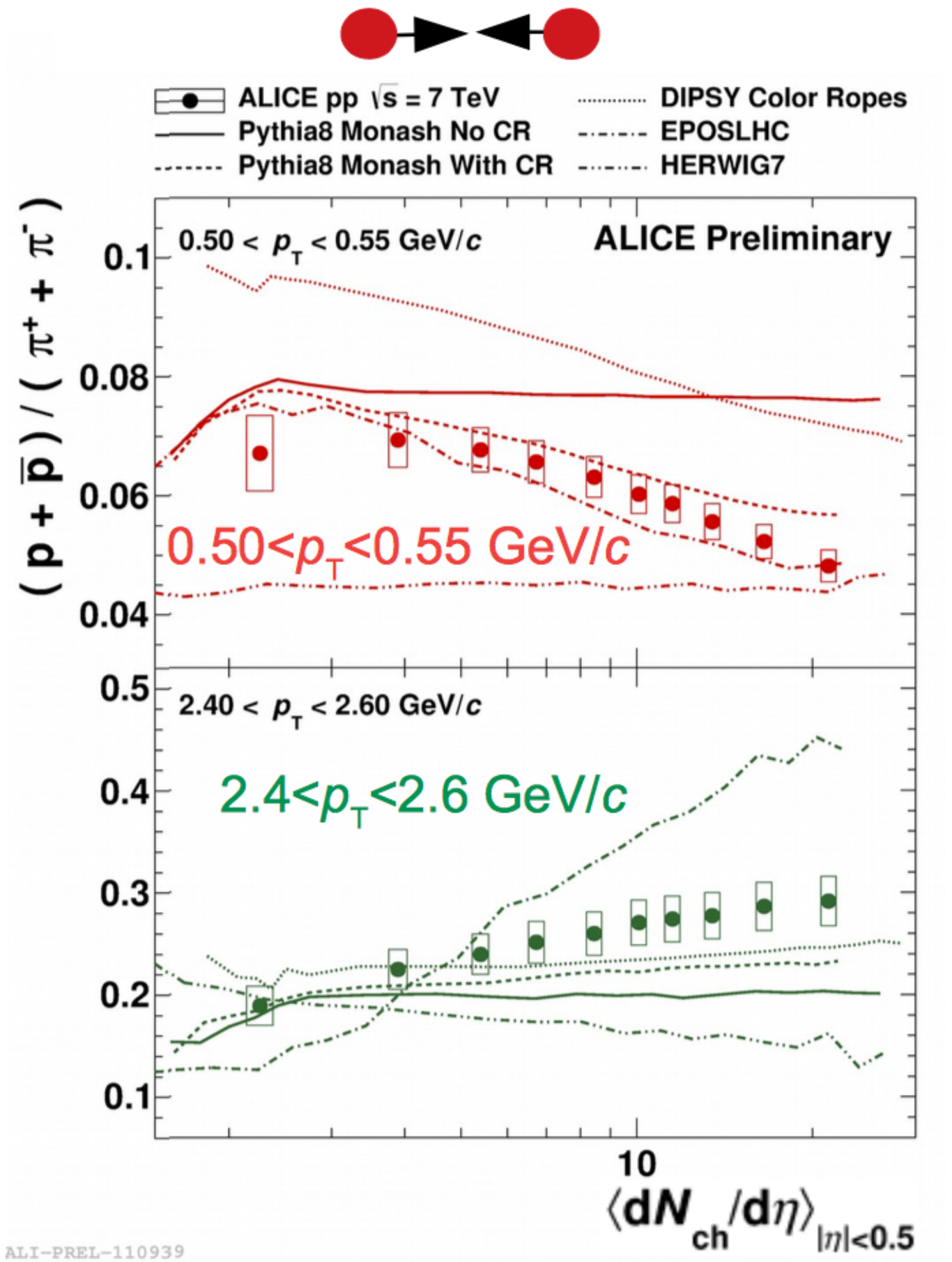
π+

- Slope of rise with multiplicity shows mass ordering
- Trend reproduced by Pythia (including coherence effects)

Phys. Rev. Lett. 111, 042001 (2013)

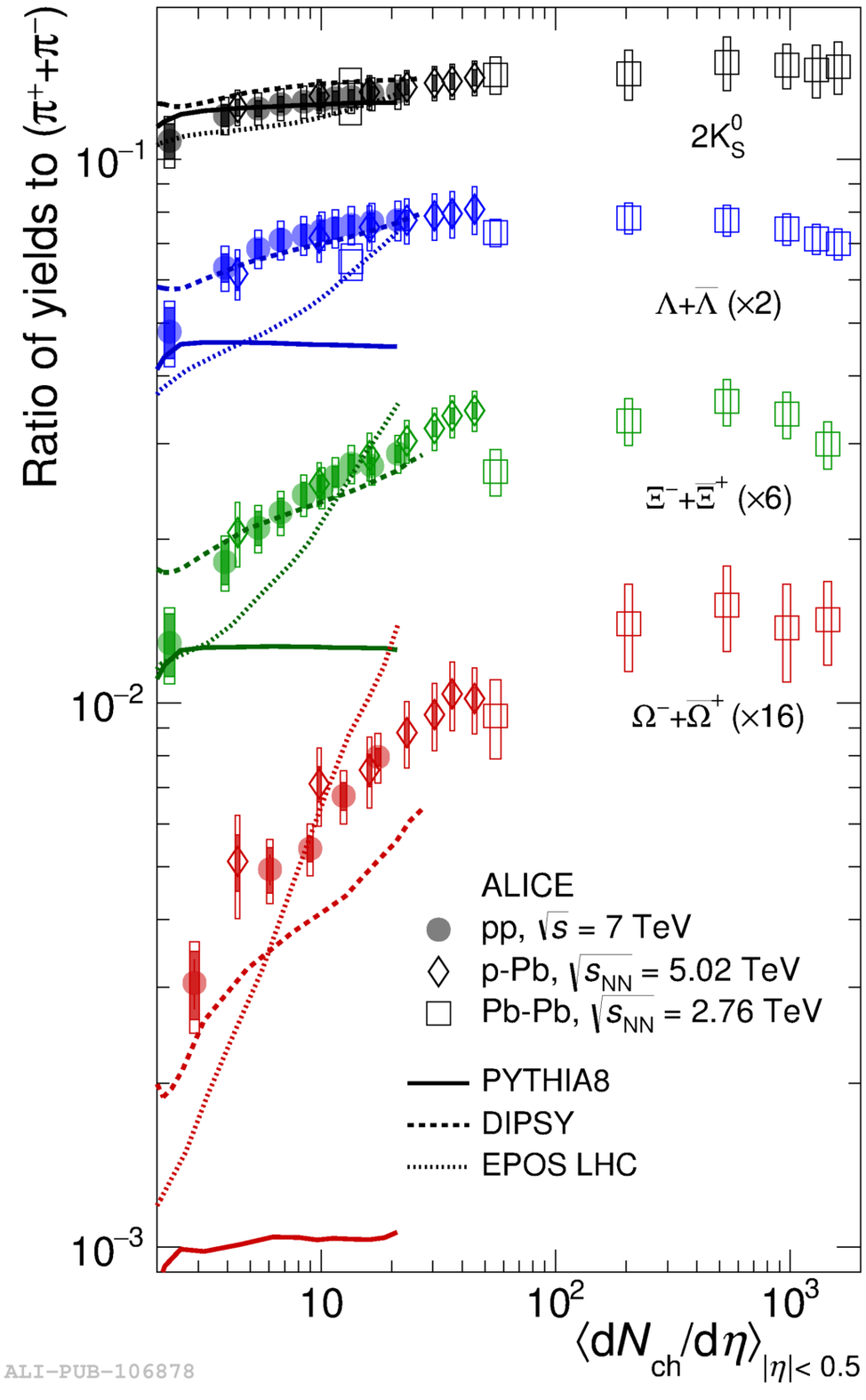


Pythia without CR cannot reproduce the trend!



ALI-PREL-110939

Strangeness Enhancement in pp



- Strong enhancement of strangeness with multiplicity in high multiplicity pp events
- Same trend in pp and p-Pb
- At high mult. pp ratio reaches values similar to the one in Pb-Pb (where ratio saturates)
- Models fail to reproduce data.
  - DIPSY agrees qualitatively

arXiv:1608.02101v1

The energy density representation of the strangeness enhancement from p+p to Pb+Pb

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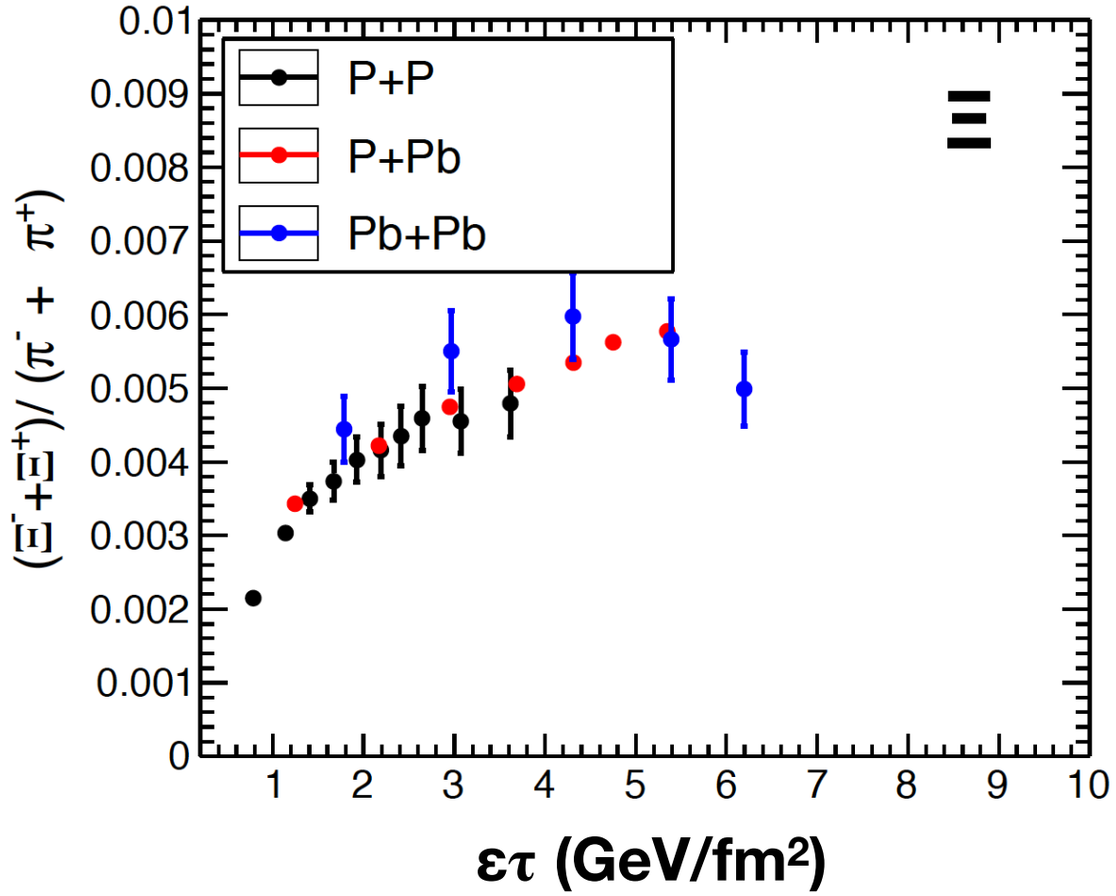
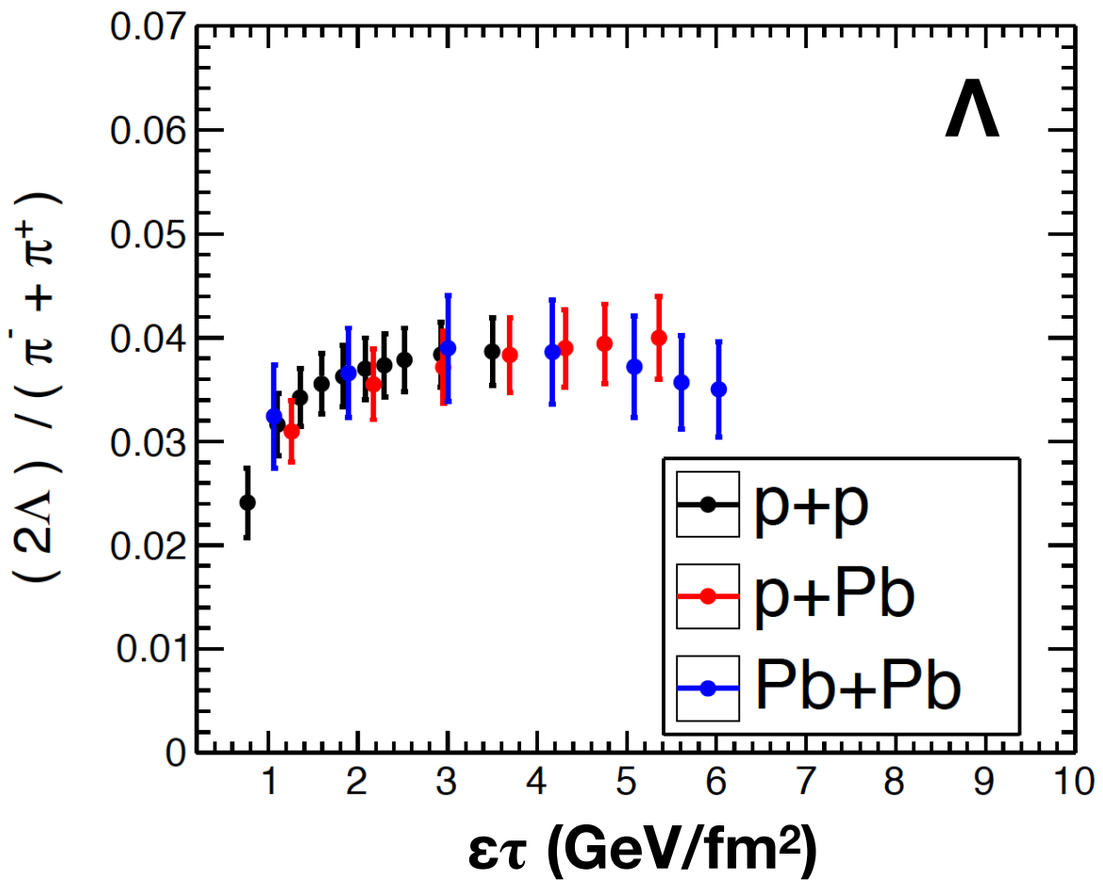
August 9, 2016

Abstract

The energy density is the prime parameter to define the deconfinement of quarks and gluons occurring in collisions of heavy ions. Recently, there is mounting evidence that many observables in proton-proton collisions behave in a manner very similar to the one observed in heavy ions. We present as an additional piece of evidence, a scaling of the strange particle yields as a function of the energy density of the three collision systems: p+p p+Pb and Pb+Pb, using the latest results of the ALICE collaboration.

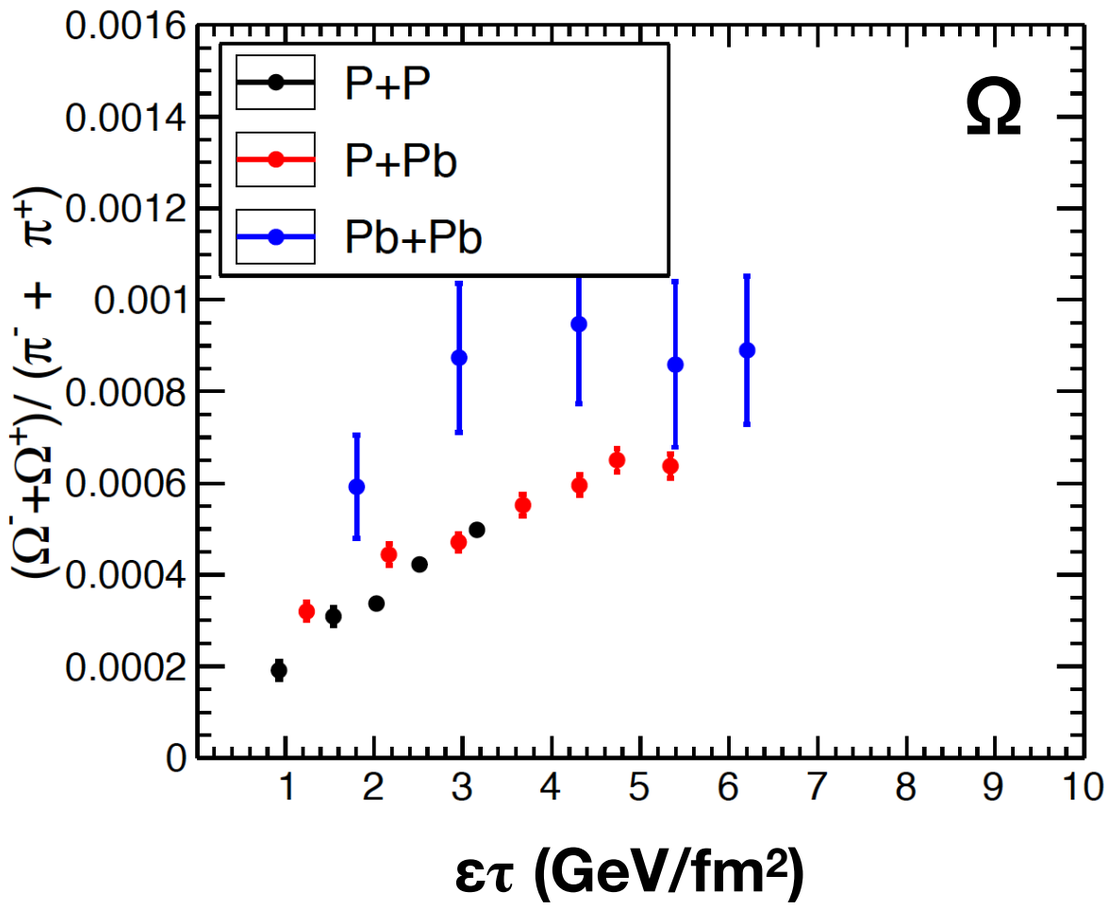




$$\epsilon\tau = \frac{3}{2}\frac{< p_{\mathrm{T}}^{k} > dN^{k}/d\eta}{A^{k}}$$

$$\epsilon \sim \frac{dE_T/dy}{\pi R^2 \tau}$$

k=pp, p-Pb, Pb-Pb



Dear Guy
Keep Thinking, Provoking, Discussing,
…. Enjoying Science and Life!