Unique LHCb Observables to constrain MC models

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(From October: Monash University, Melbourne)

LHCb Seminar
CERN, Aug 5th, 2014

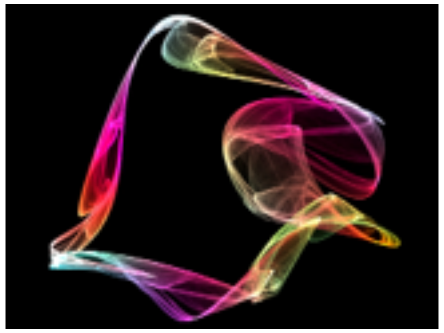
Collider Physics

Dominated by QCD

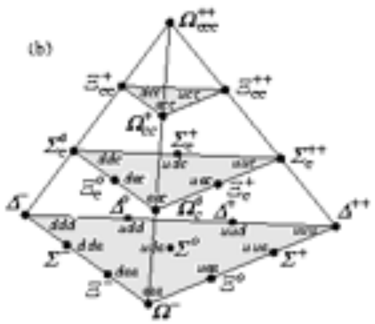
More than just a perturbative expansion in α_s

Emergent phenomena:

Jets (the QCD fractal) ⟷ amplitude structures ⟷ fundamental quantum field theory. Precision jet (structure) studies, jet vetoes



Strings (strong gluon fields) ⟷ quantum-classical correspondence. String physics. Dynamics of hadronization phase transition. Colour neutralization



Hadrons ⟷ Spectroscopy (incl excited and exotic states), lattice QCD, (rare) decays, mixing. Identified particles: rates, spectra (FFs), correlations. Hadron beams → PDFs, MPI, diffraction, …

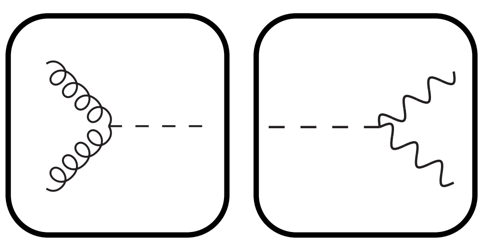
See eg TASI lectures, e-Print: arXiv:1207.2389

MC: Divide and Conquer

Factorization → Split the problem into many (nested) pieces

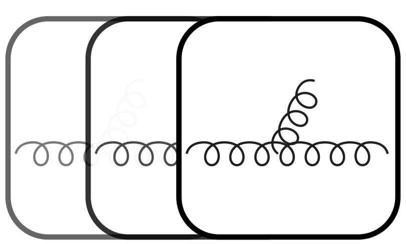
+ **Quantum mechanics** → Probabilities → Random Numbers (MC)

$$\mathcal{P}_{\mathrm{event}} = \mathcal{P}_{\mathrm{hard}} \otimes \mathcal{P}_{\mathrm{dec}} \otimes \mathcal{P}_{\mathrm{ISR}} \otimes \mathcal{P}_{\mathrm{FSR}} \otimes \mathcal{P}_{\mathrm{MPI}} \otimes \mathcal{P}_{\mathrm{Had}} \otimes \ldots$$



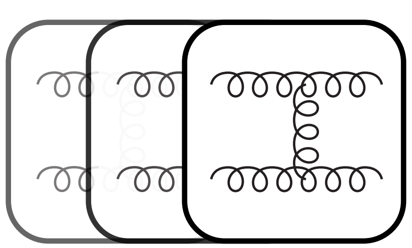
Hard Process & Decays:

Use (N)LO matrix elements



Initial- & Final-State Radiation (ISR & FSR):

DGLAP or antenna-dipole showers down to ~ 1 GeV

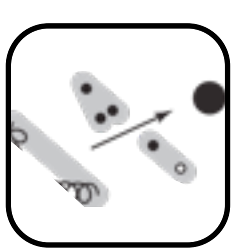


MPI (Multi-Parton Interactions)

Additional (soft) parton-parton interactions: LO matrix elements

→ Additional (soft) "Underlying-Event" activity

Dominated by low-x gluons (especially in FWD region)



Hadronization

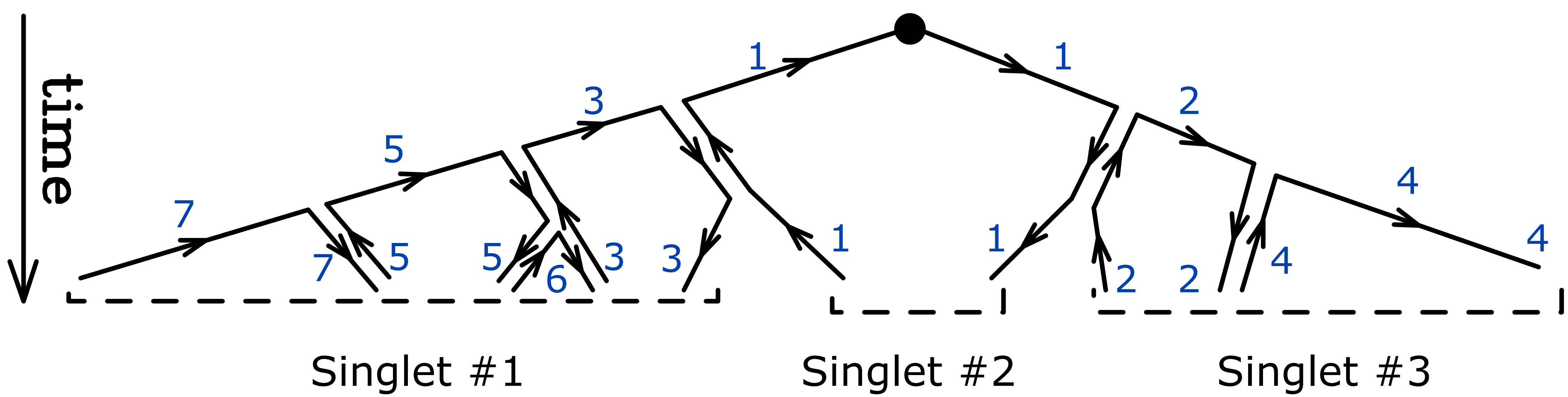
The process of colour neutralization

Non-perturbative model for parton systems → hadrons

Hadronization and Colour

Example of Color Flow in a Parton Cascade

Example: $Z^0 \rightarrow q\bar{q}$



Coherence of pQCD cascades → not much "overlap" between singlet subsystems
→ Leading-colour approximation pretty good

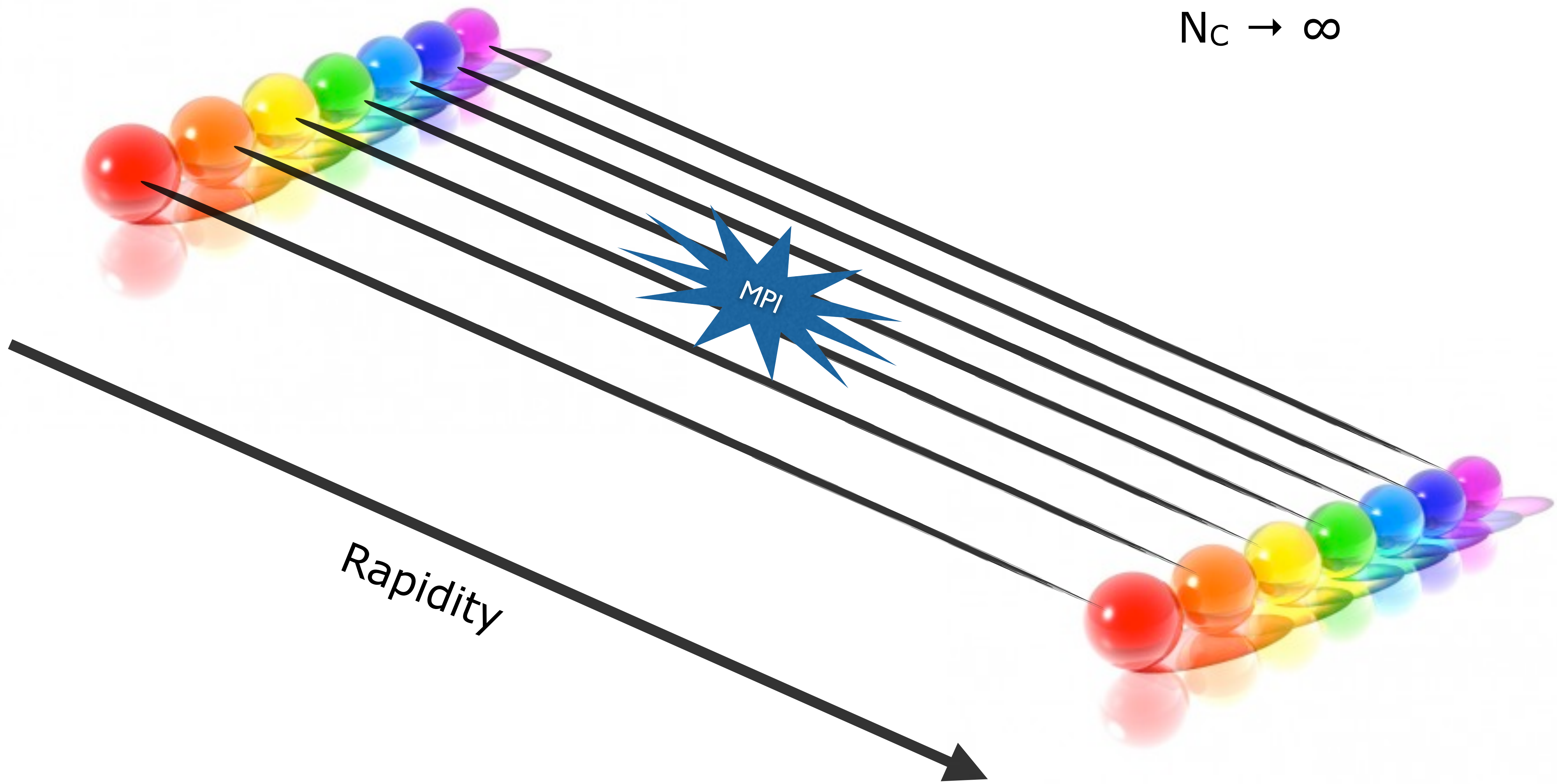
LEP measurements in WW confirm this (at least to order 10% ~ $1/N_c^2$)

Note: (much) more color getting kicked around in hadron collisions

MPI and Colour

Better theory models needed

$N_C \to \infty$



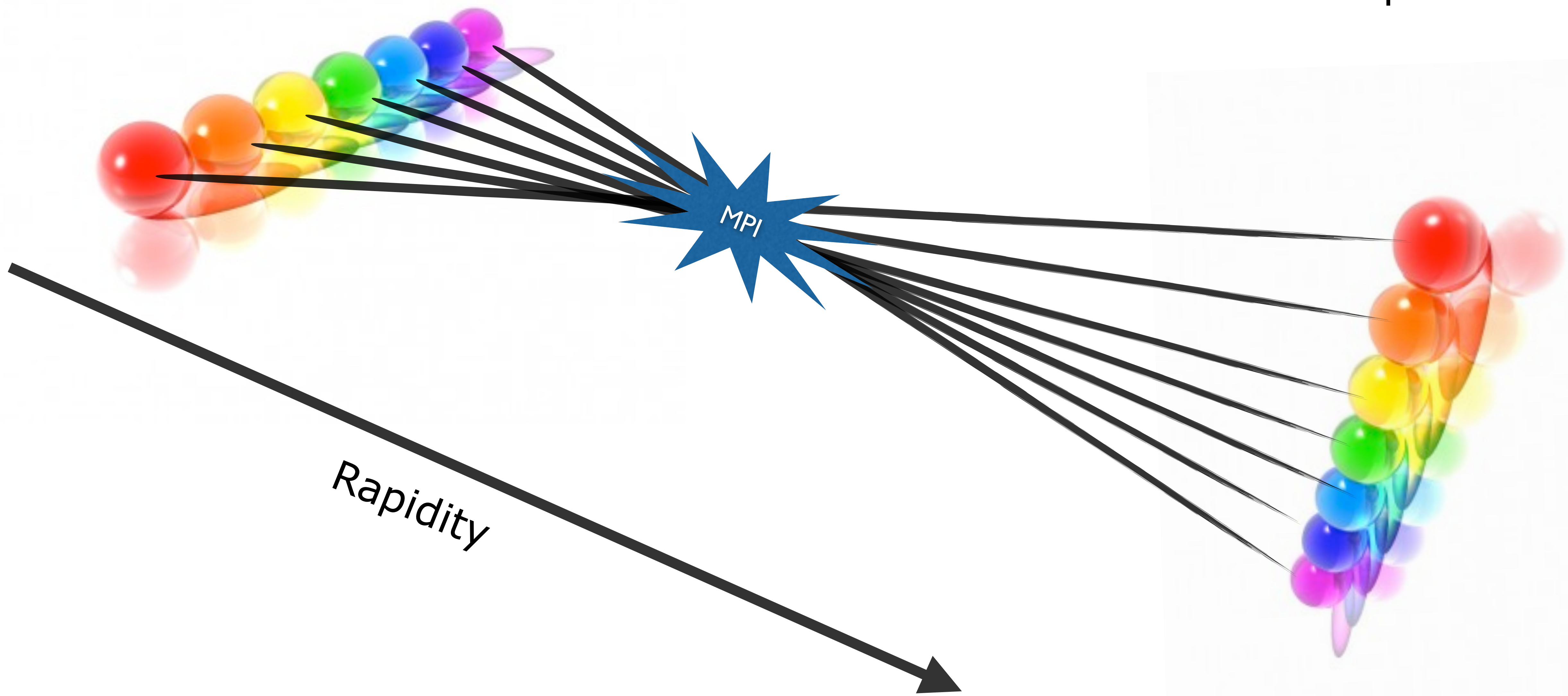
Multiplicity $\propto N_{MPI}$

Color Reconnections?

E.g.,
Generalized Area Law (Rathsman: Phys. Lett. B452 (1999) 364)
Color Annealing (P.S., Wicke: Eur. Phys. J. C52 (2007) 133)
…

Better theory models needed

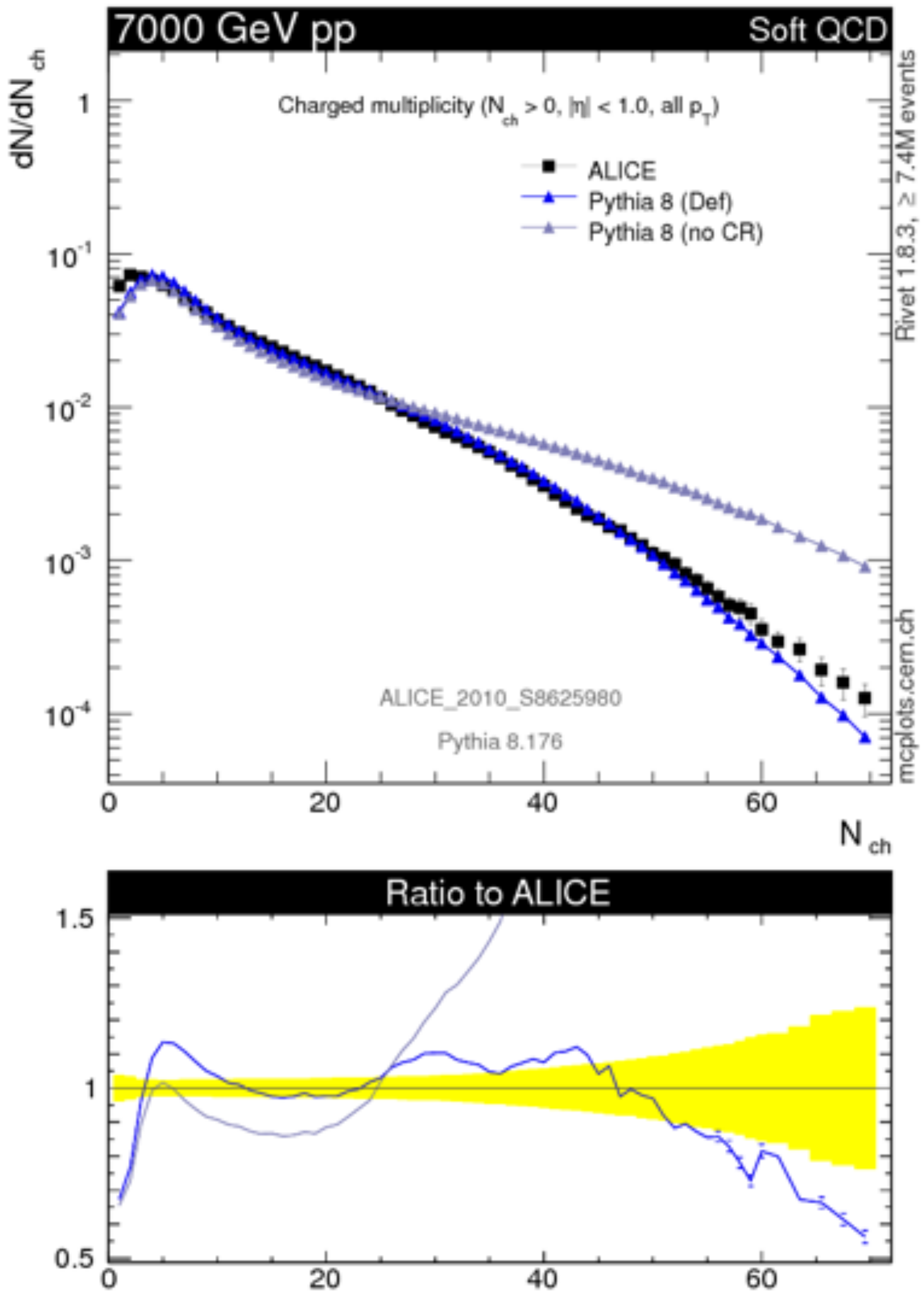
Do the systems really form
and hadronize independently?



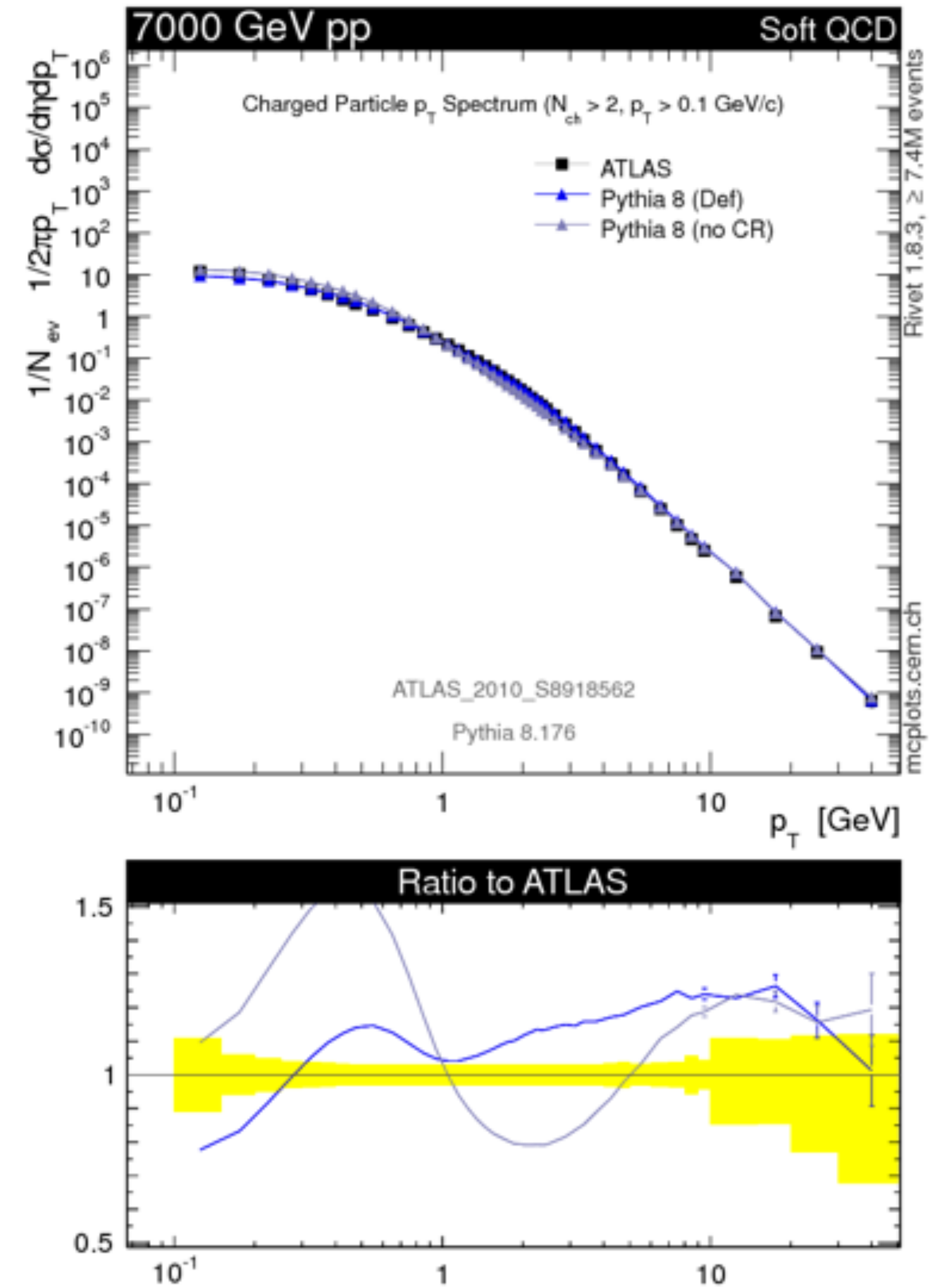
Multiplicity grows much slower than N_{MPI}

The Effects of CR

Fewer particles

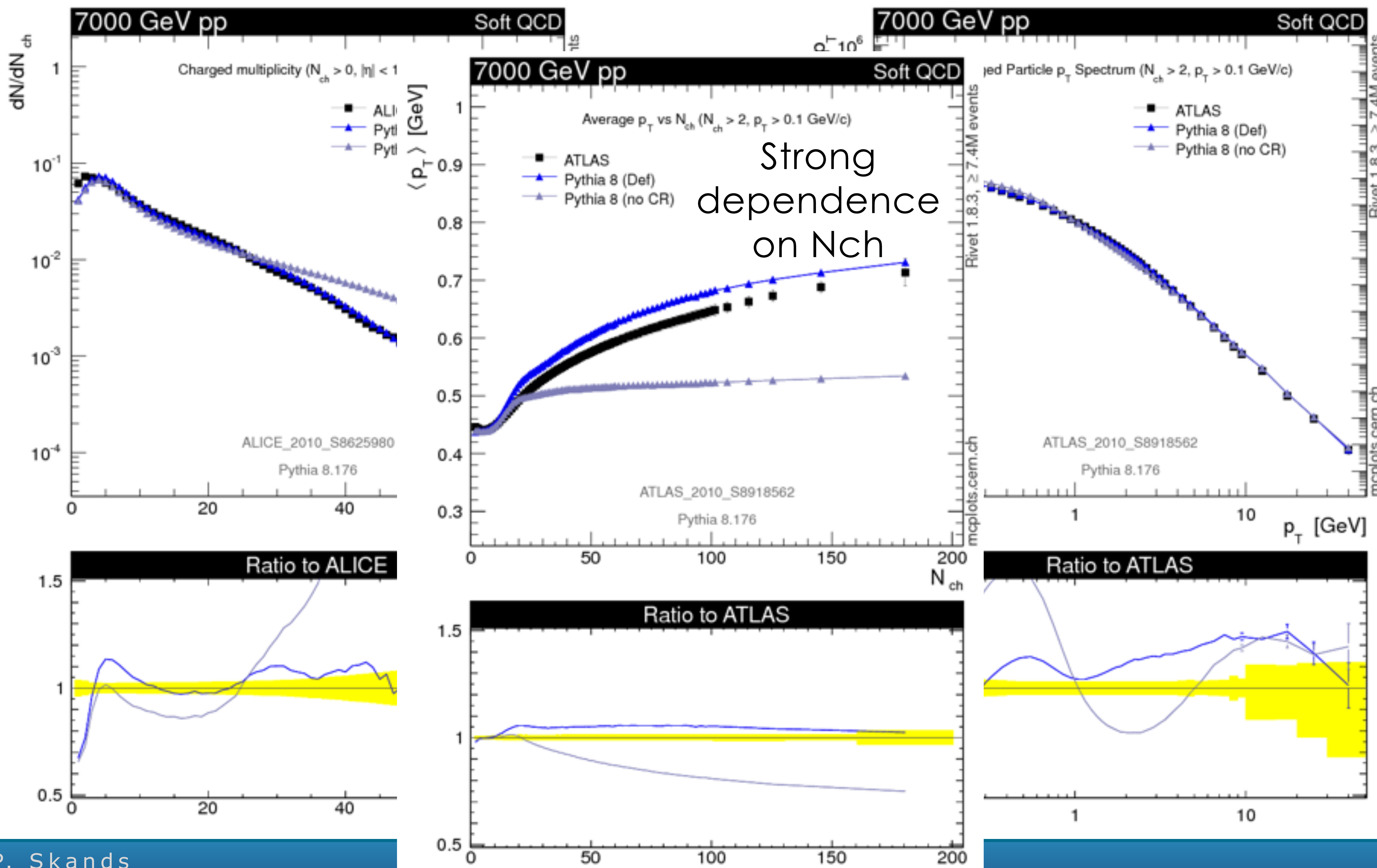


... with higher pT



The Effects of CR

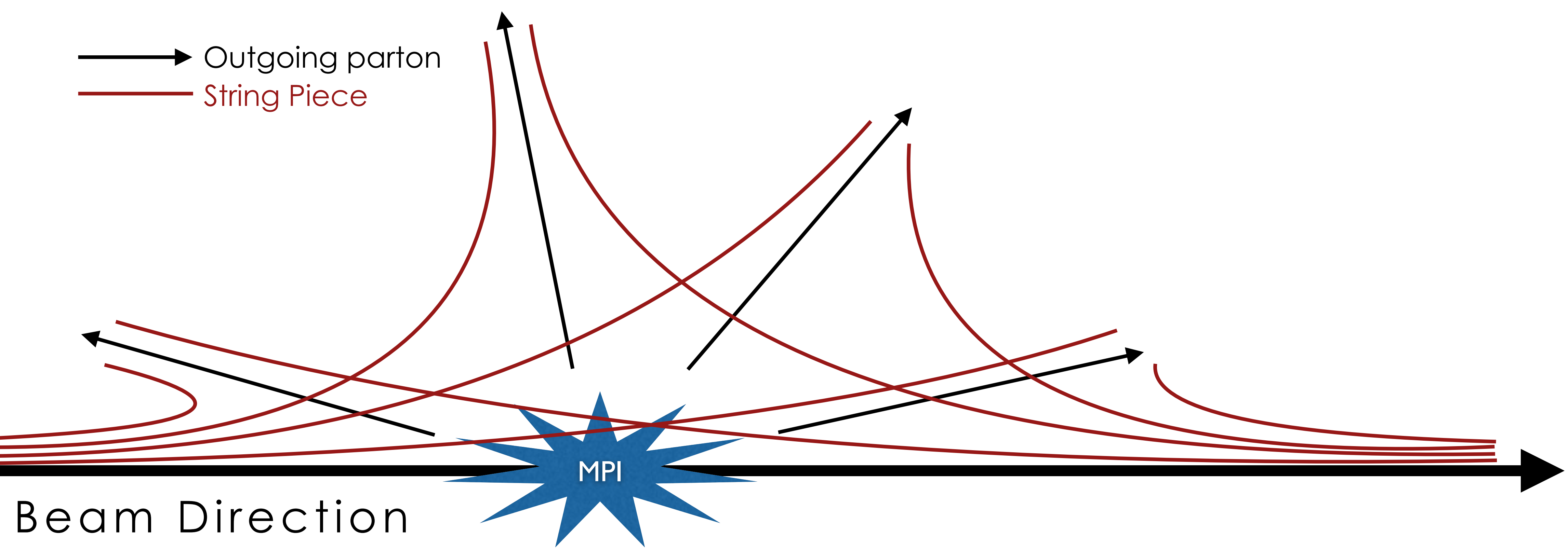
Fewer particles … with higher pT



Collective Flow?

See also Ortiz et al., Phys.Rev.Lett. 111 (2013) 4, 042001

Without Colour Reconnections
Each MPI hadronizes **independently** of all others

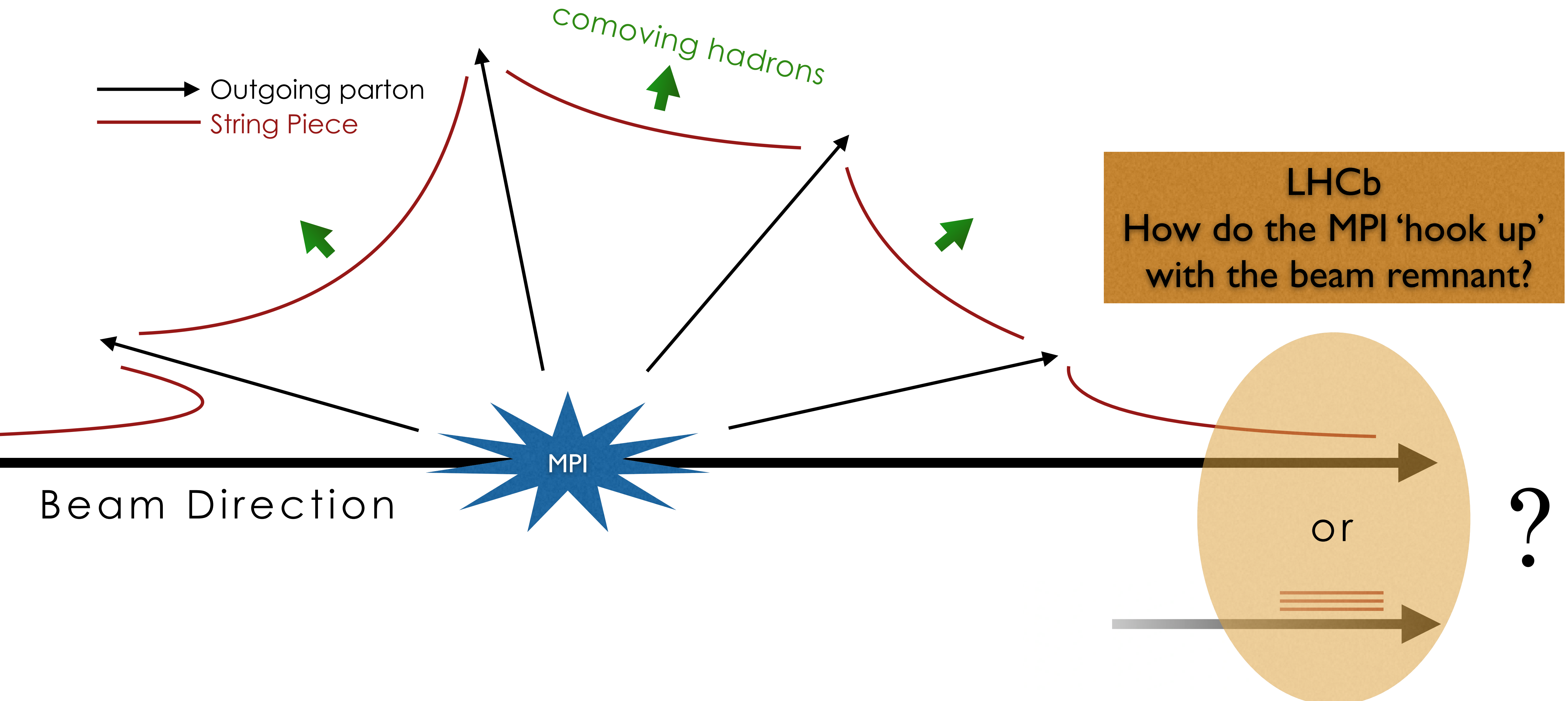


… from boosted strings?

See also Ortiz et al., Phys.Rev.Lett. 111 (2013) 4, 042001

With Colour Reconnections
MPI hadronize **collectively**

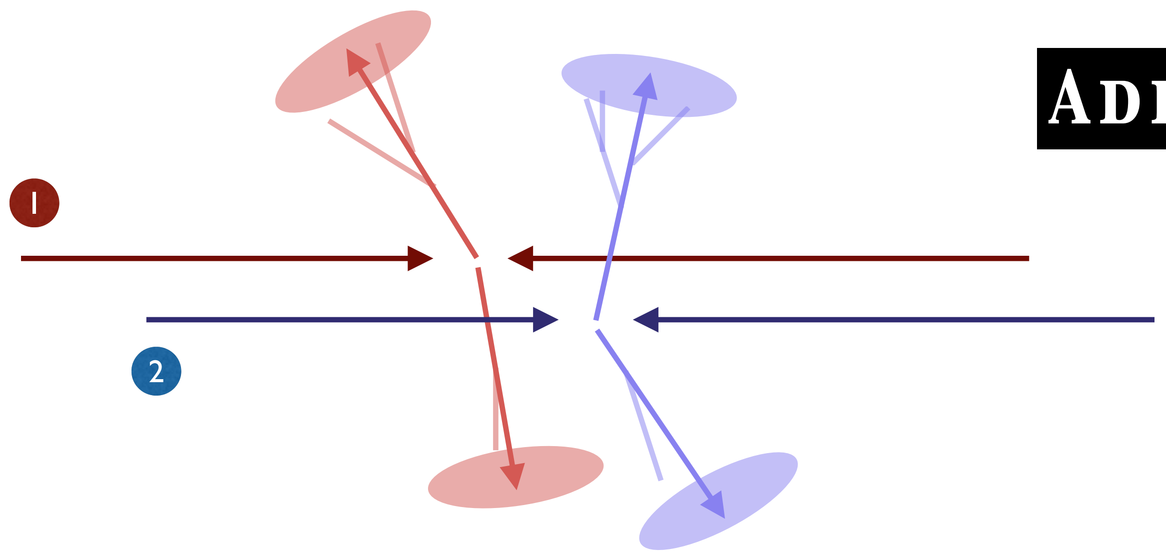
Highly important theory question now
Is there collective flow in pp? Or not?
Is it stringy, or hydrodynamic ? (or …?)



LHCb
How do the MPI 'hook up' with the beam remnant?

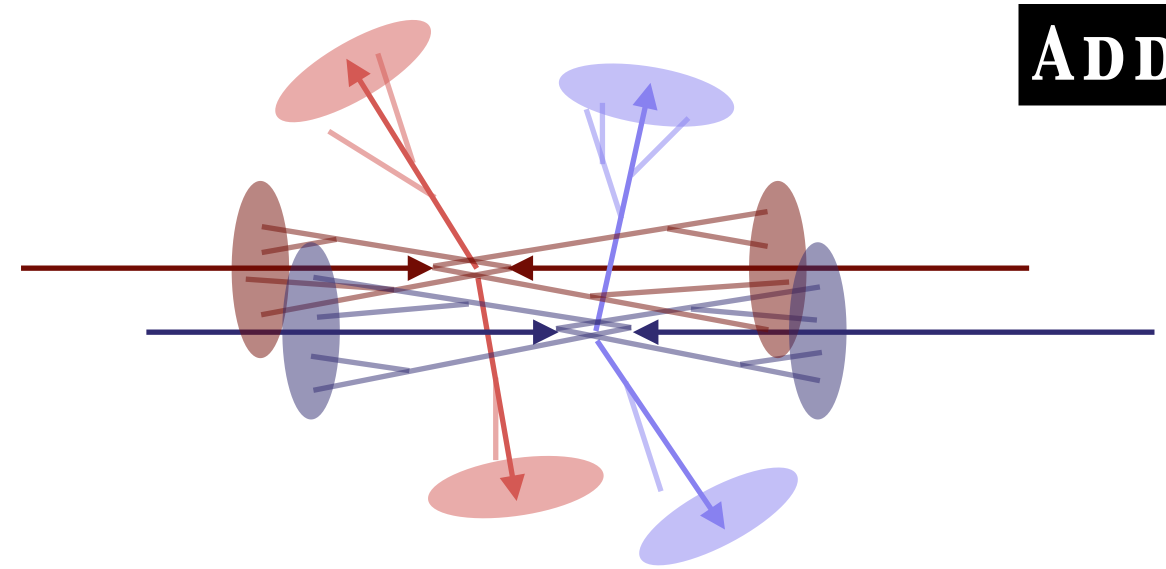
Central vs Forward

Take an extremely simple case of just 2 MPI



ADD FINAL-STATE RADIATION

Small overlaps between different jets
: main CR questions are
inter-jet and jet-beam
: boosted strings etc.



ADD INTIAL-STATE RADIATION

All the ISR radiation overlaps!
(each MPI scattering centre must reside within *one* proton radius of all others)
: expect significant 'colour confusion'
: intra-jet CR (unlike central and LEP)
: Strong effects in FWD region

Going Forward

The distributions shown so far were all measured in the central region

Within a given model, FWD region is essentially fixed by the parameters chosen to tune the central one : but there are discrepancies *(hence it also makes sense that LHCb pursue their own tuning efforts)*

There might be much more physics going on in the forward region, not accessed by the central measurements.

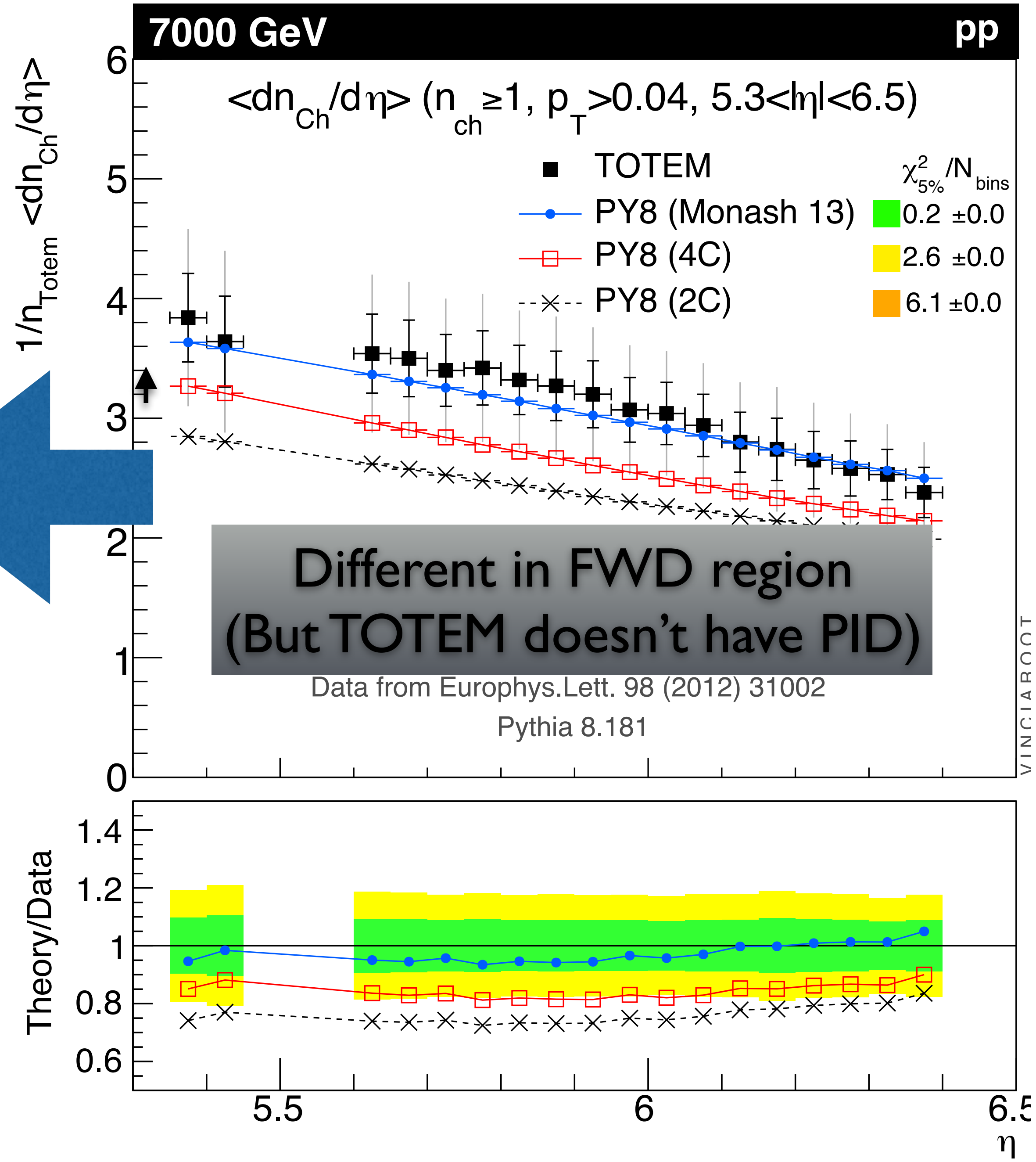
Only LHCb sees this region clearly (with PID, etc)

+ Feedback to central experiments since their pileup modeling depends on FWD modeling

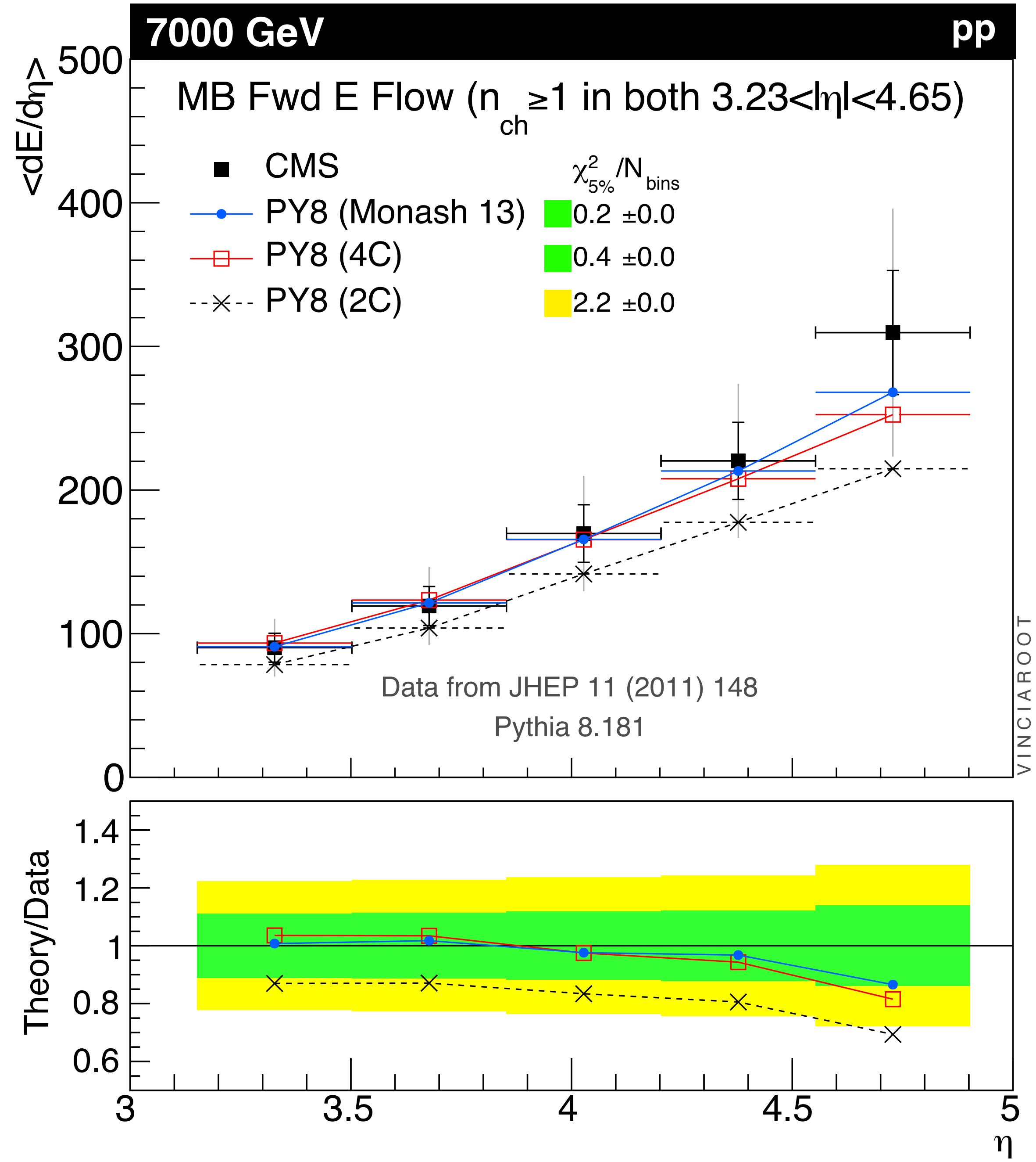
Examples: Nch and E Flow

4C and Monash 13 ~ same in central region

$2<\eta<4.8$ (LHCb): Eur. Phys. J. C: 74, 2014



Different in FWD region
(But TOTEM doesn't have PID)



Depends on low-x gluon PDF and on CR/remnant modeling → constraints!

1. Baryon Number Transport

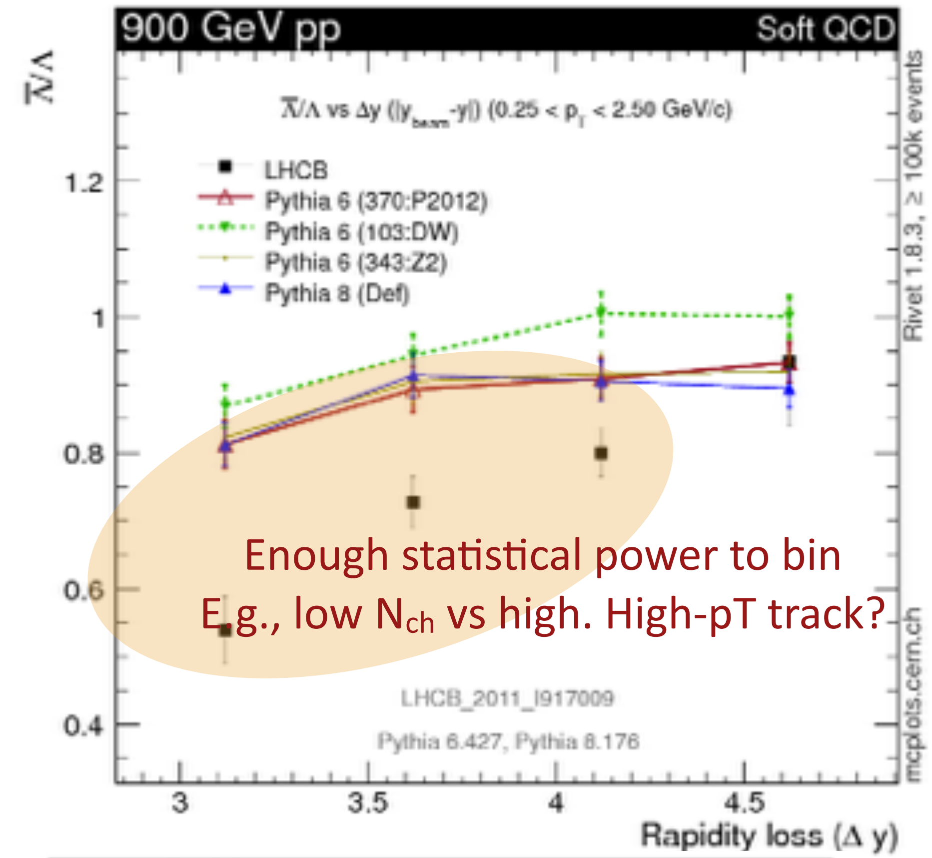
How much does the **beam remnant 'break up'** ?

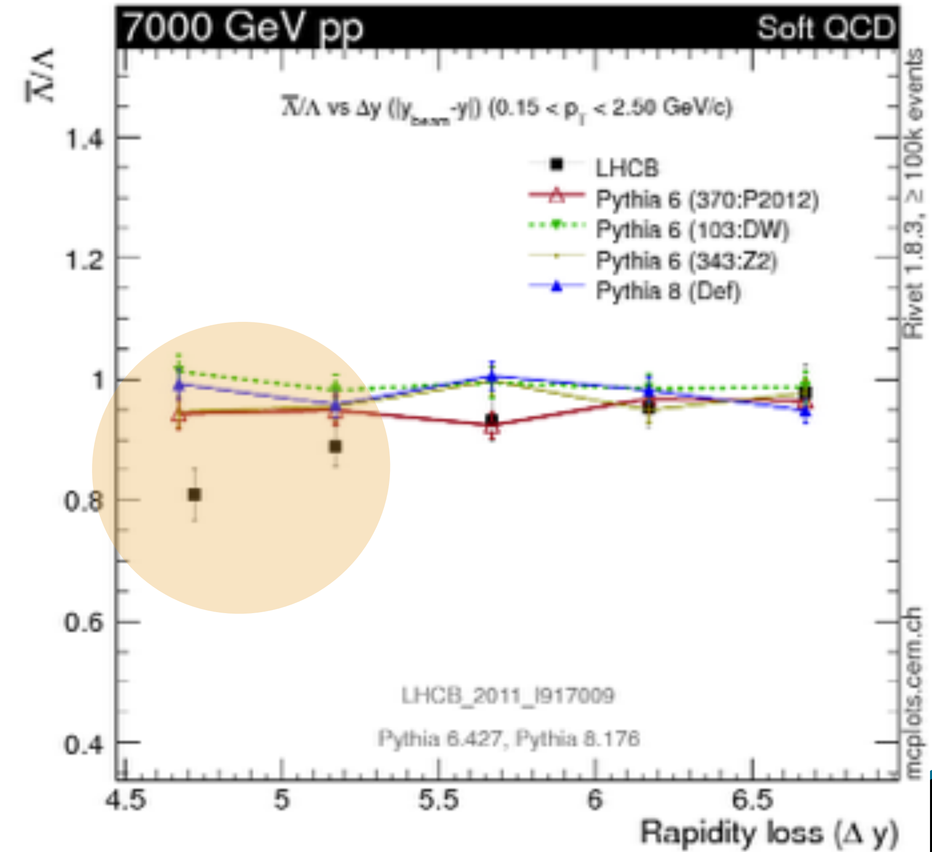
Good tracer: beam **baryon number**. How far does it get transported?

LHCb has already delivered beautiful **measurements** of Baryon Transport signal (Lambdabar/Lambda, & protons)

Λ has one strange quark (so could be beam ud diquark + s). How about multi-strange? Xi, Omega.

+ Spectra? $p_T(\Lambda) - p_T(\bar{\Lambda})$ in bin where asymmetry is large (Δy < 5), with higher-Δy bins as reference? What more can you tell us about these baryons?

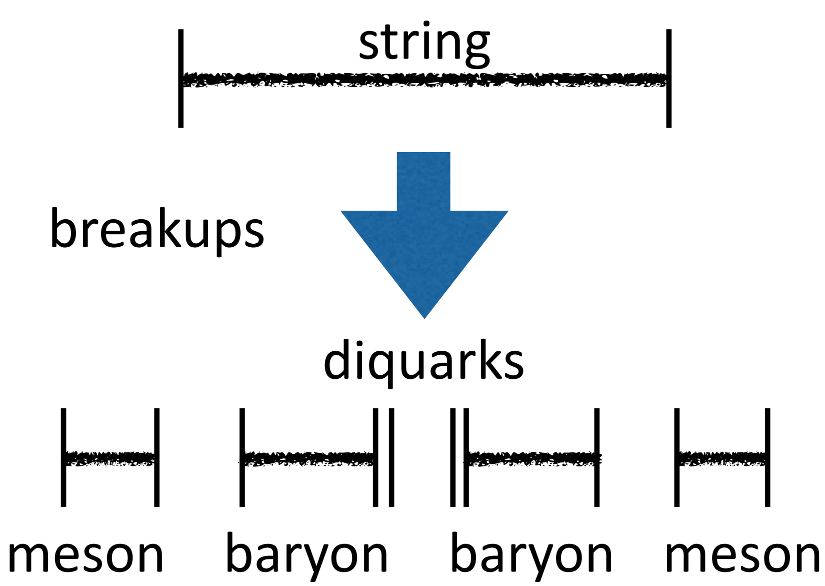




2. Baryon-Baryon Correlations

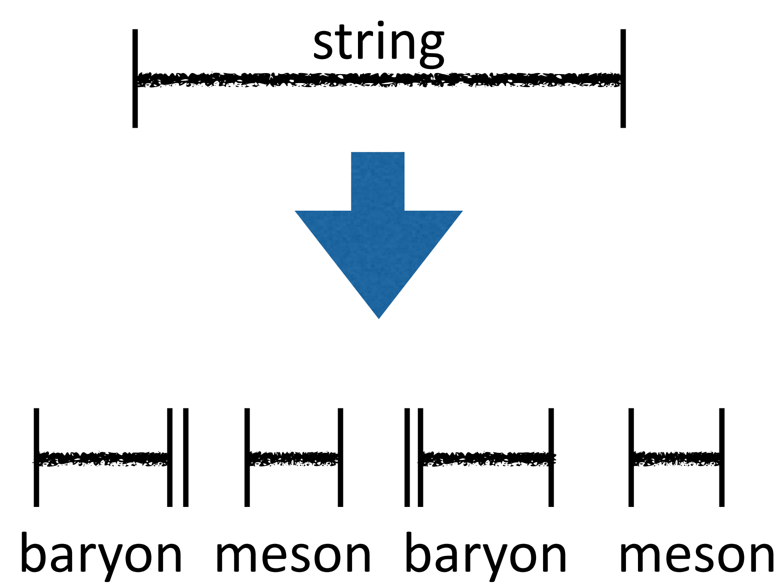
How global/local is baryon formation?
(esp in view of the strong possible CR effects expected in the FWD region)

A Conventional



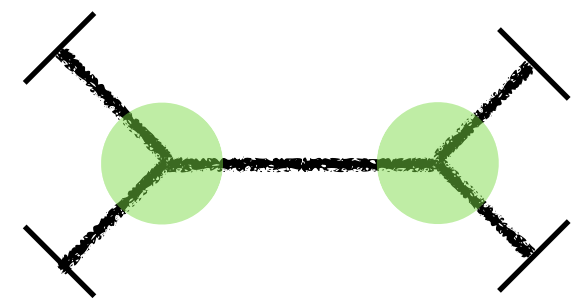
Strong local (anti)correlations in **flavor** and **momentum**

B Popcorn



Correlations act over slightly longer distance

C Junctions



e.g. from advanced CR

Baryon number conservation over arbitrarily long distance

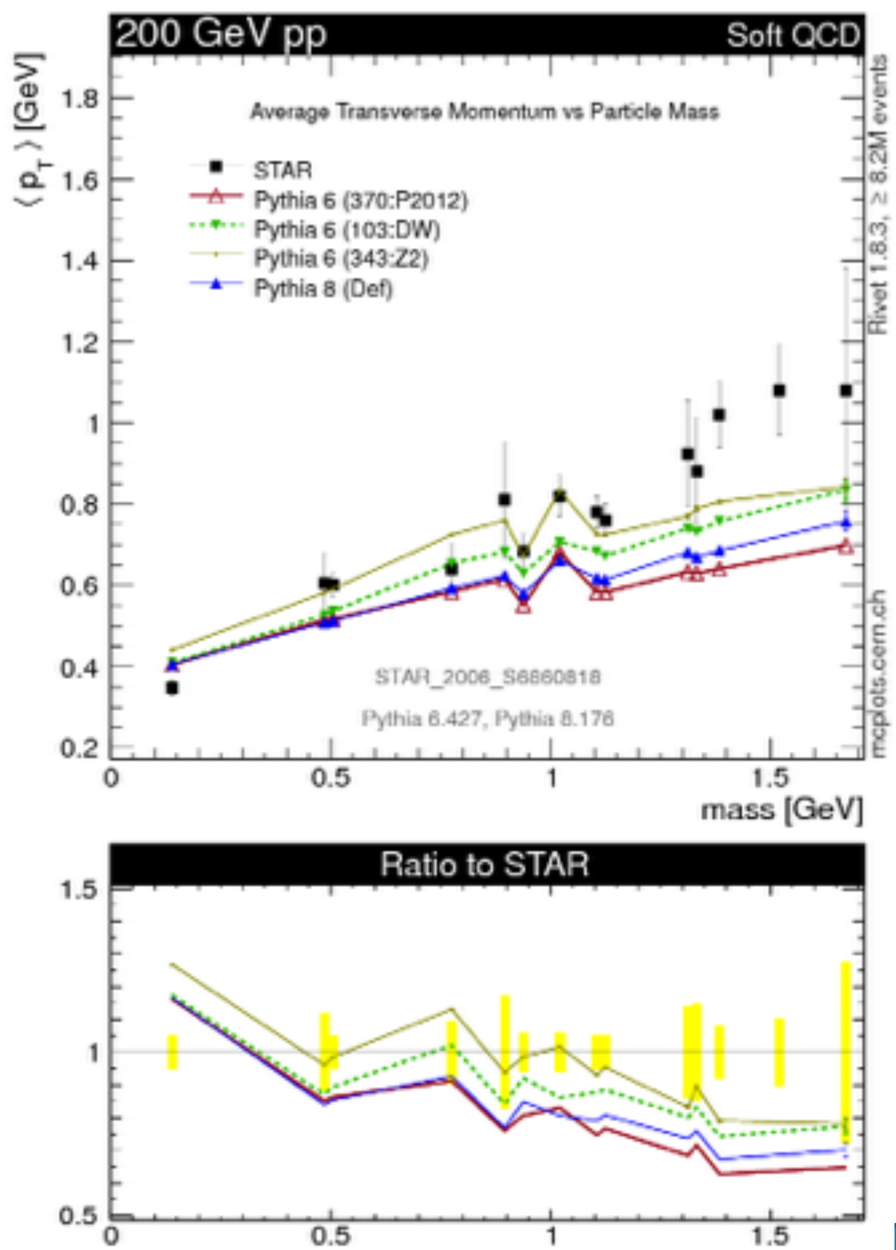
Or pick leading baryon: $\Lambda_{c,b}$

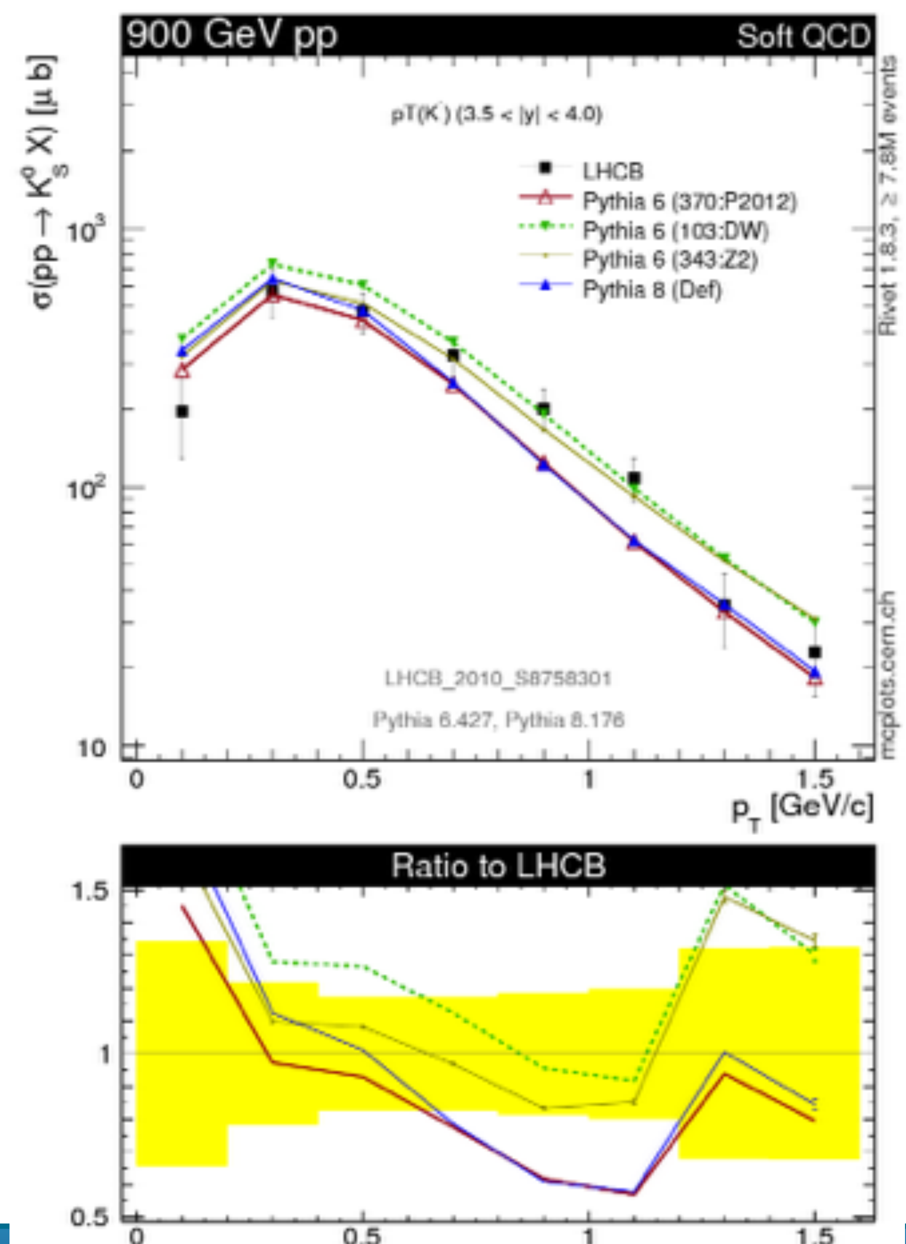
cf eg LHCb arXiv:1405.6842

3. Strangeness

$m_s \sim \Lambda_{QCD}$: Very sensitive to string tension

Right between relativistic and non-relativistic. Non-relativistic velocities good to probe for flow effects





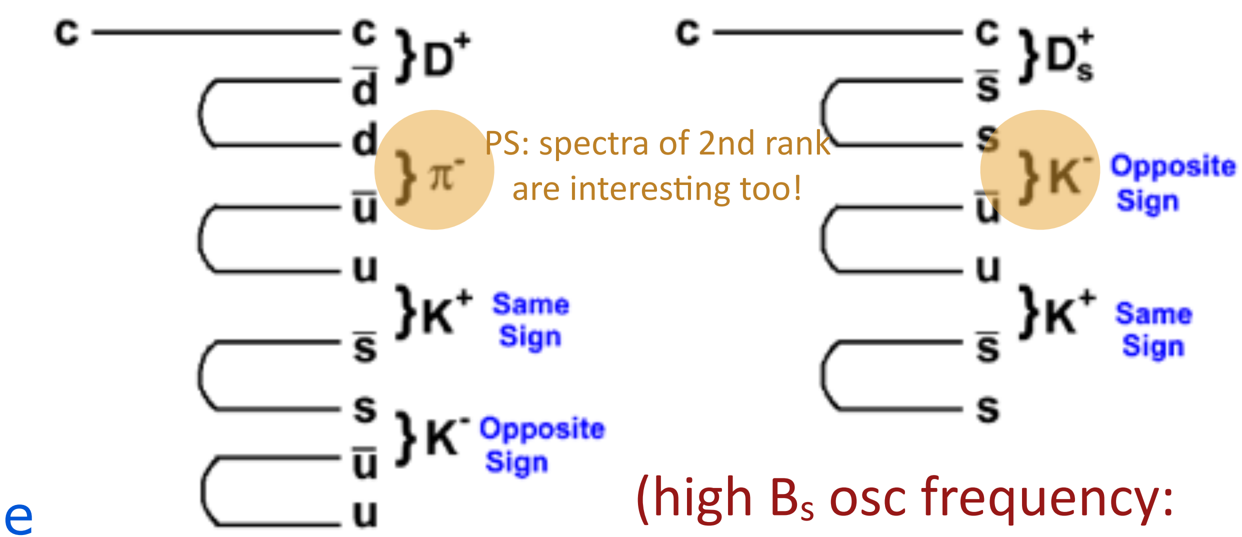
+ correlations:
strangeness compensation
(problem: K0S is both s and sbar)

4. Fragmentation around Charm

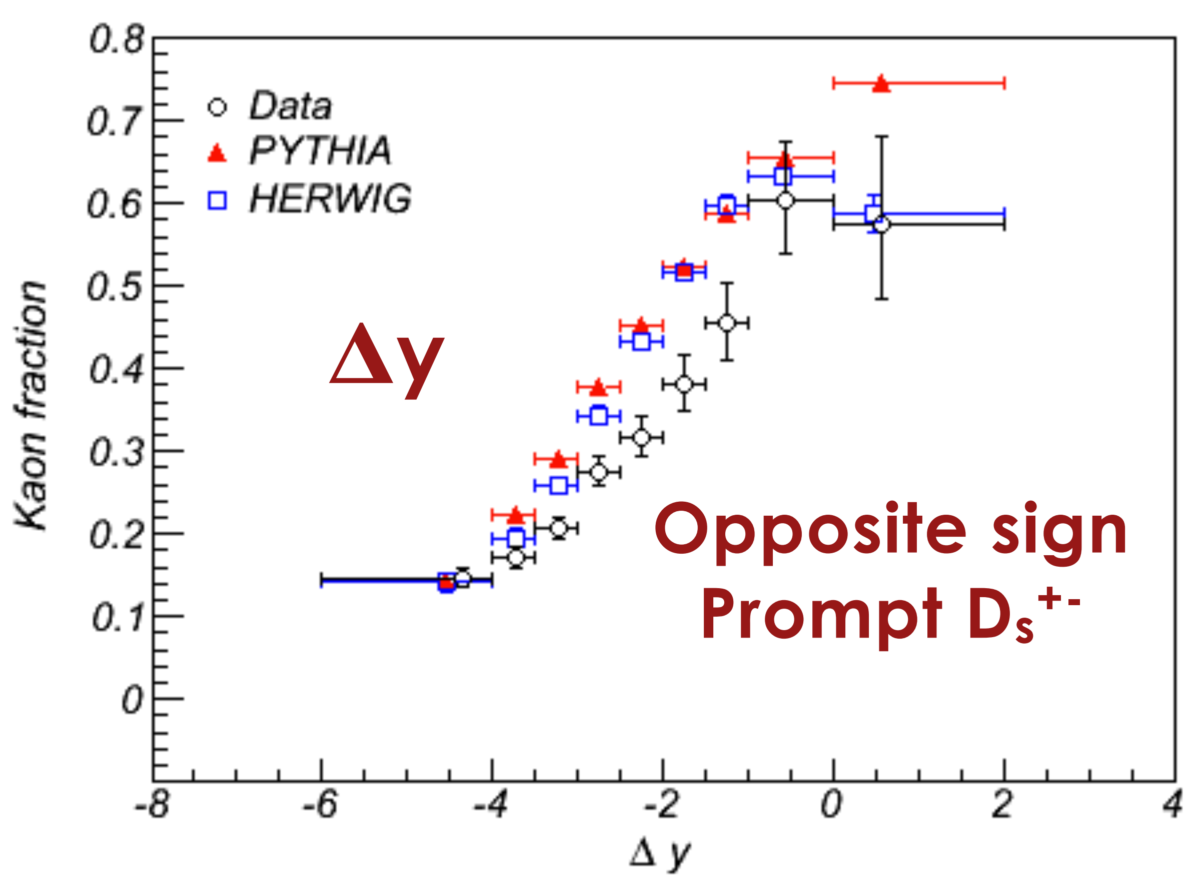
Can use c (& b) to identify hard string endpoint

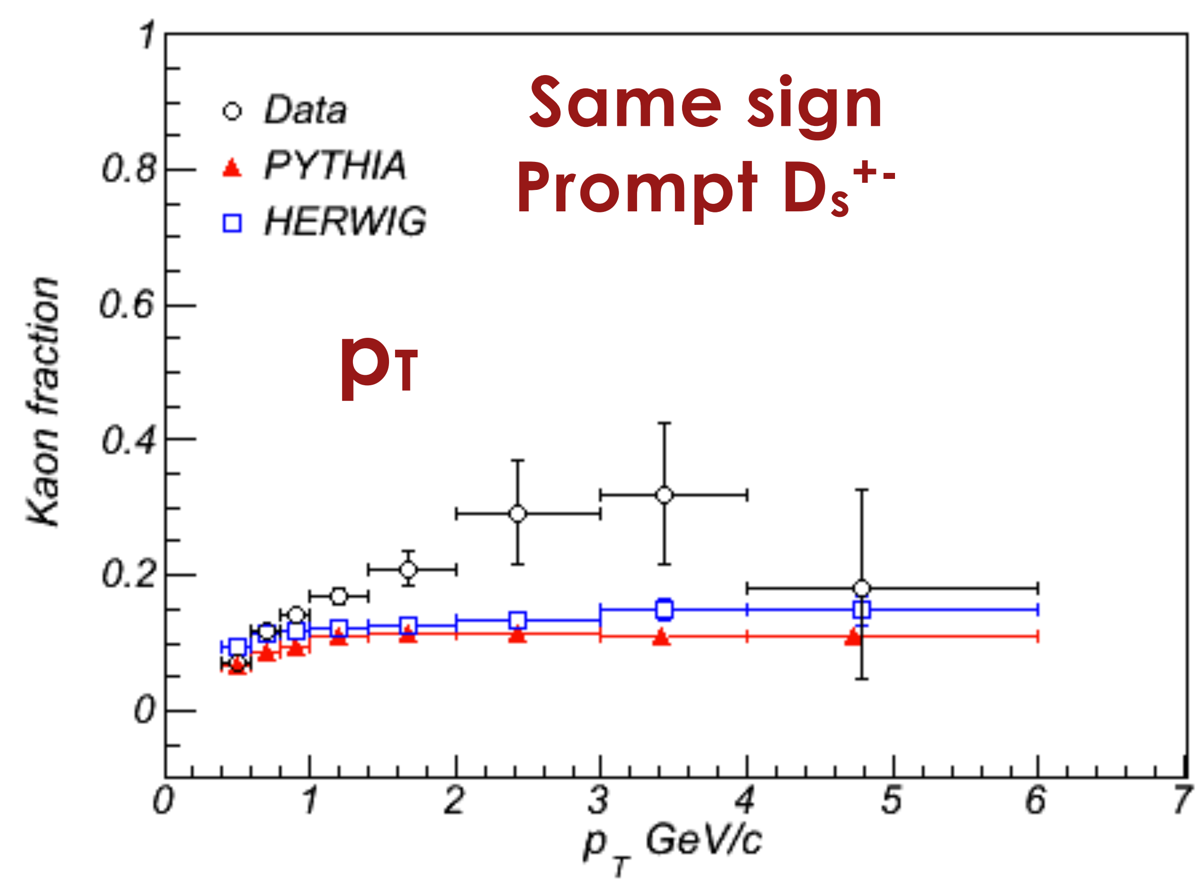
Then look for same/opposite-sign Kaons around D^+ mesons

E.g. M. Kreps pointed to a CDF PUB note (10704) that saw interesting discrepancies



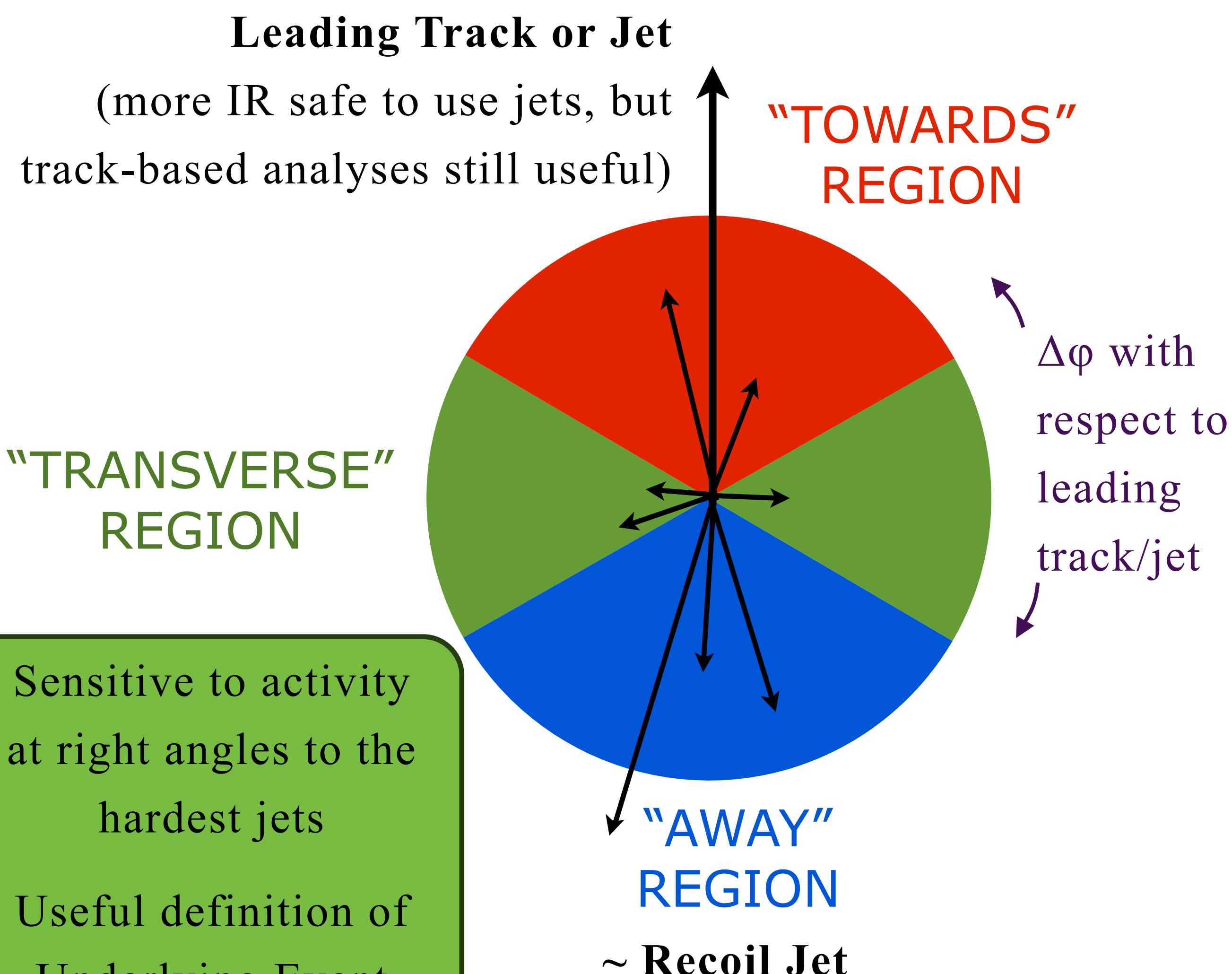
(high B_s osc frequency: less clean for B)





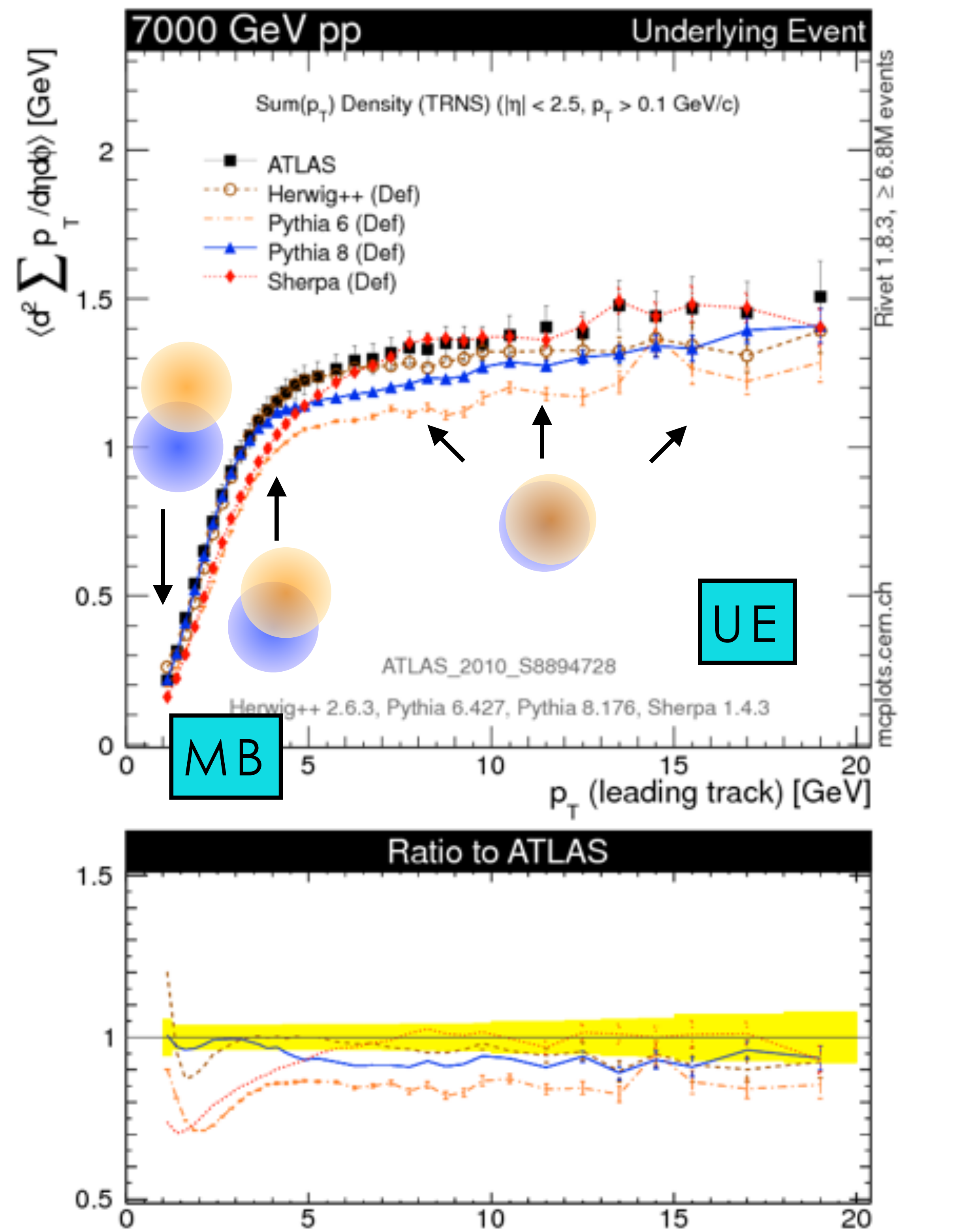
5: Jets: from min-bias to UE

There are many UE variables.
The most important is <Σp_T> in the "Transverse Region"

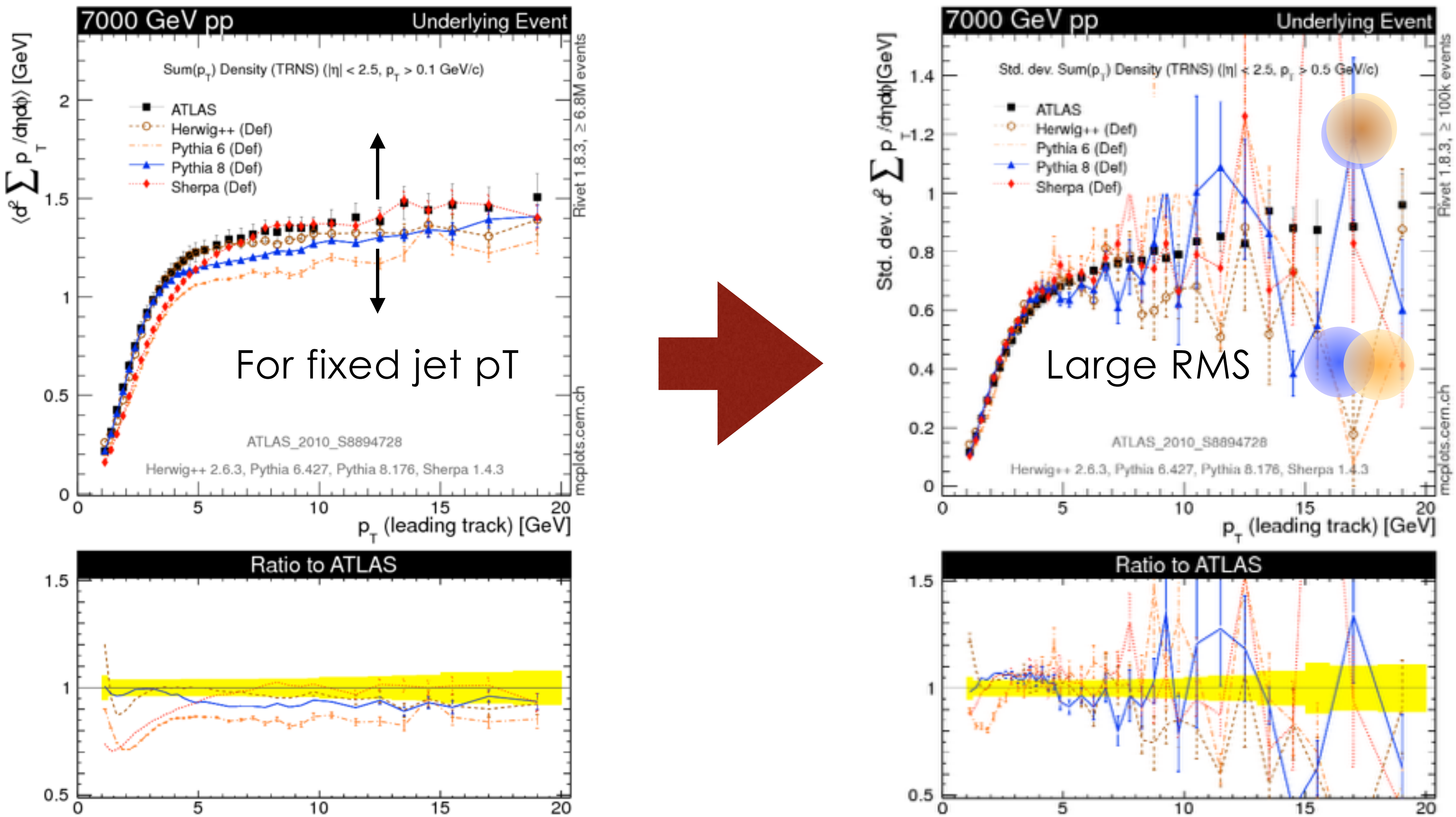


Sensitive to activity at right angles to the hardest jets

Useful definition of Underlying Event



Jets: scanning the pedestal



For fixed jet pT, study events with LARGE or SMALL transverse pTsum ~ scan over b ?

Tuning

means different things to different people

10% agreement is great for (N)LO + LL

MB/UE/Soft: larger uncertainties since driven by non-factorizable and non-perturbative physics

Complicated dynamics: "If a model is simple, it is wrong" *(T. Sjöstrand)*

Recent PYTHIA Models/Tunes

Note: I focus on default / author tunes here
(Important complementary efforts undertaken by LHC experiments)

PYTHIA 8.1

Current Default = **4C** (from 2010)

Tunes 2C & 4C: e-Print: arXiv:1011.1759

LEP tuning undocumented (from 2009)
LHC tuning only used very early data
based on CTEQ6L1

Aims for the Monash 2013 Tune

Monash 2013 Tune: e-Print: arXiv:1404.5630

Set M13 Tune: → in PYTHIA 8

Tune:ee = 7
Tune:pp = 14

- Revise (and document) constraints from e^+e^- measurements
  - In particular in light of possible interplays with LHC measurements
- Test drive the new NNPDF 2.3 LO PDF set (with $\alpha_s(m_Z) = 0.13$) for pp & ppbar
  - Update min-bias and UE tuning + energy scaling → 2013
  - Follow "Perugia" tunes for PYTHIA 6: use same α_s for ISR and FSR
  - Use the PDF value of α_s for both hard processes and MPI

PYTHIA 6.4 (*warning:* no longer actively developed)

Perugia Tunes: e-Print: arXiv:1005.3457
(+ 2011 & 2012 updates added as appendices)

Default: still rather old Q^2-ordered tune ~ Tevatron Tune A

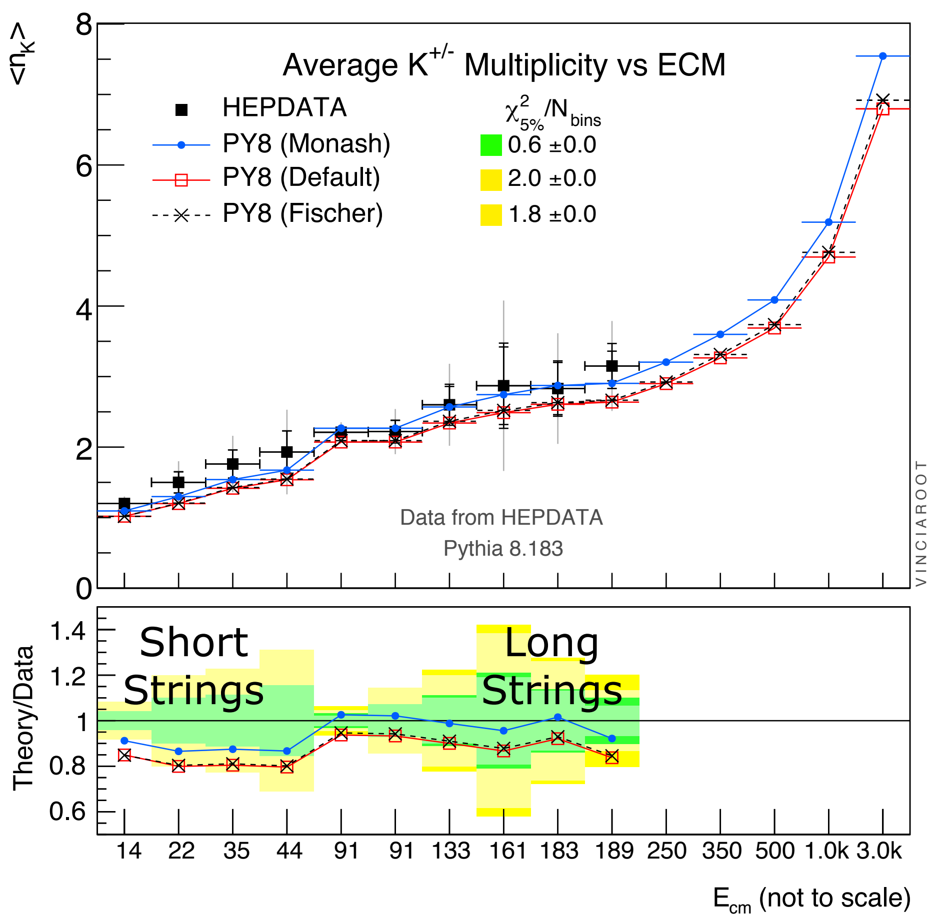
Most recent: Perugia 2012 set of p_T-ordered tunes (370 - 382) + Innsbruck (IBK) Tunes (G. Rudolph)

Comparisons to Tevatron tunes are not interesting any more … (Perugia 0, Perugia 2010, A, DW, …)

Monash 2013 Tune Highlights

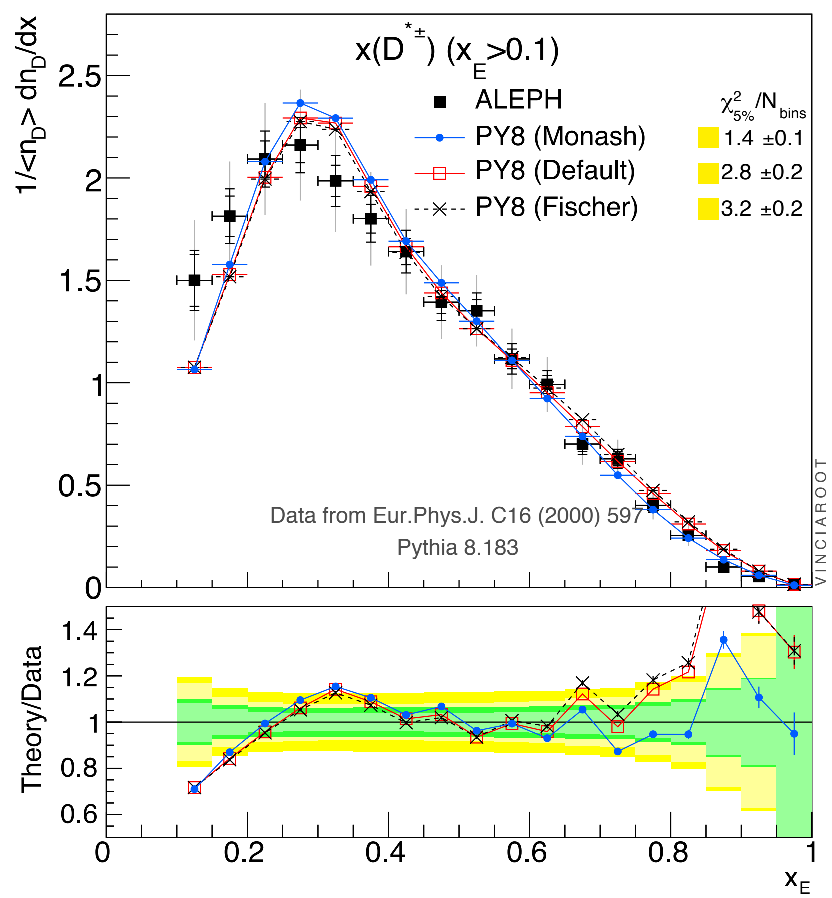
Monash 2013 Tune: e-Print: [arXiv:1404.5630]

10% more strangeness



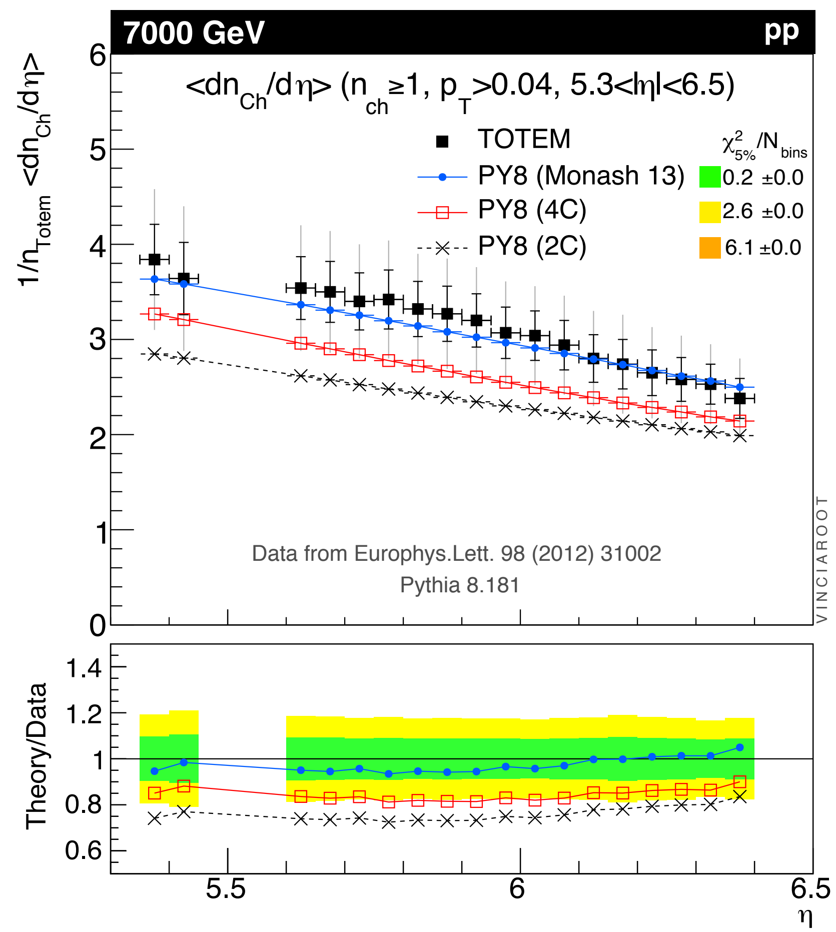
Better agreement with ee identified-strange measurements across all energies, and with Kaons at LHC

Softer D and B spectra near z = 1



Ultra-hard tail of c and b fragmentation agrees better with LEP and SLD, including event shapes in b-tagged events

More forward activity



Better agreement with TOTEM N_{ch} and with forward E and ET flows. Better pileup?

Set M13 Tune: → in PYTHIA 8

Tune:ee = 7
Tune:pp = 14

Puzzles (a selection of)

Identified-particles at LHC

- Multi-strange and baryon rates/transport
- p_T Spectra (esp dependence on N_{ch} and particle mass: collectivity?)
- Correlations (local vs global conservation laws)

The physics of Colour Neutralization

- Colour/string (re)connections vs Flow?
- Implications for Top Quark Mass

Forward physics and zero bias (pileup)

- The role and modeling of diffraction from low to high masses
- UE in diffractive jet events & hard diffraction?

Space-time picture of multi-parton interactions (MPI); interplay with multi-parton PDFs and hadronization

Gluon/Quark discrimination & G→QQ splittings in gluon jets