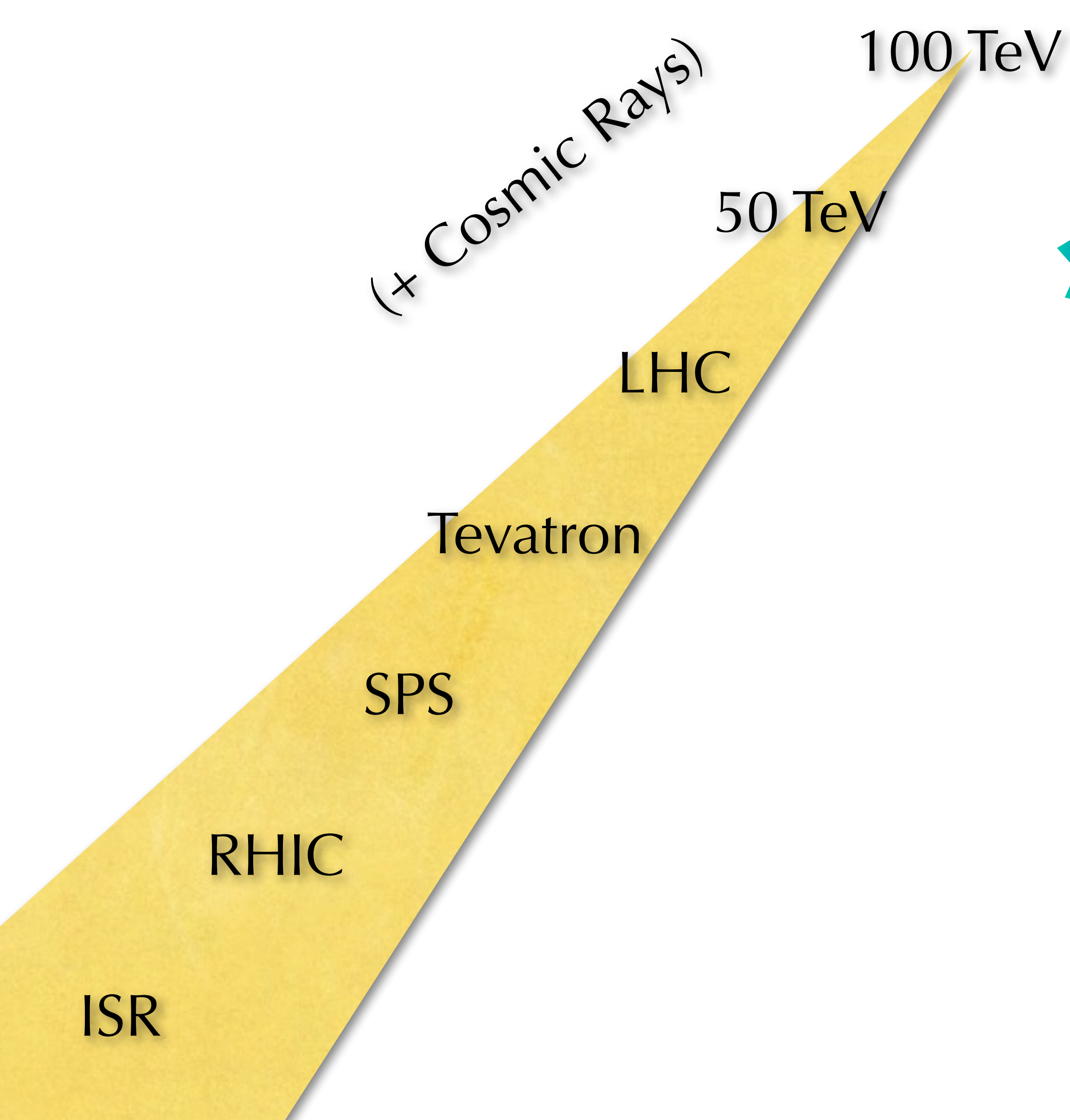
Updated PYTHIA Forecasts for 100 TeV

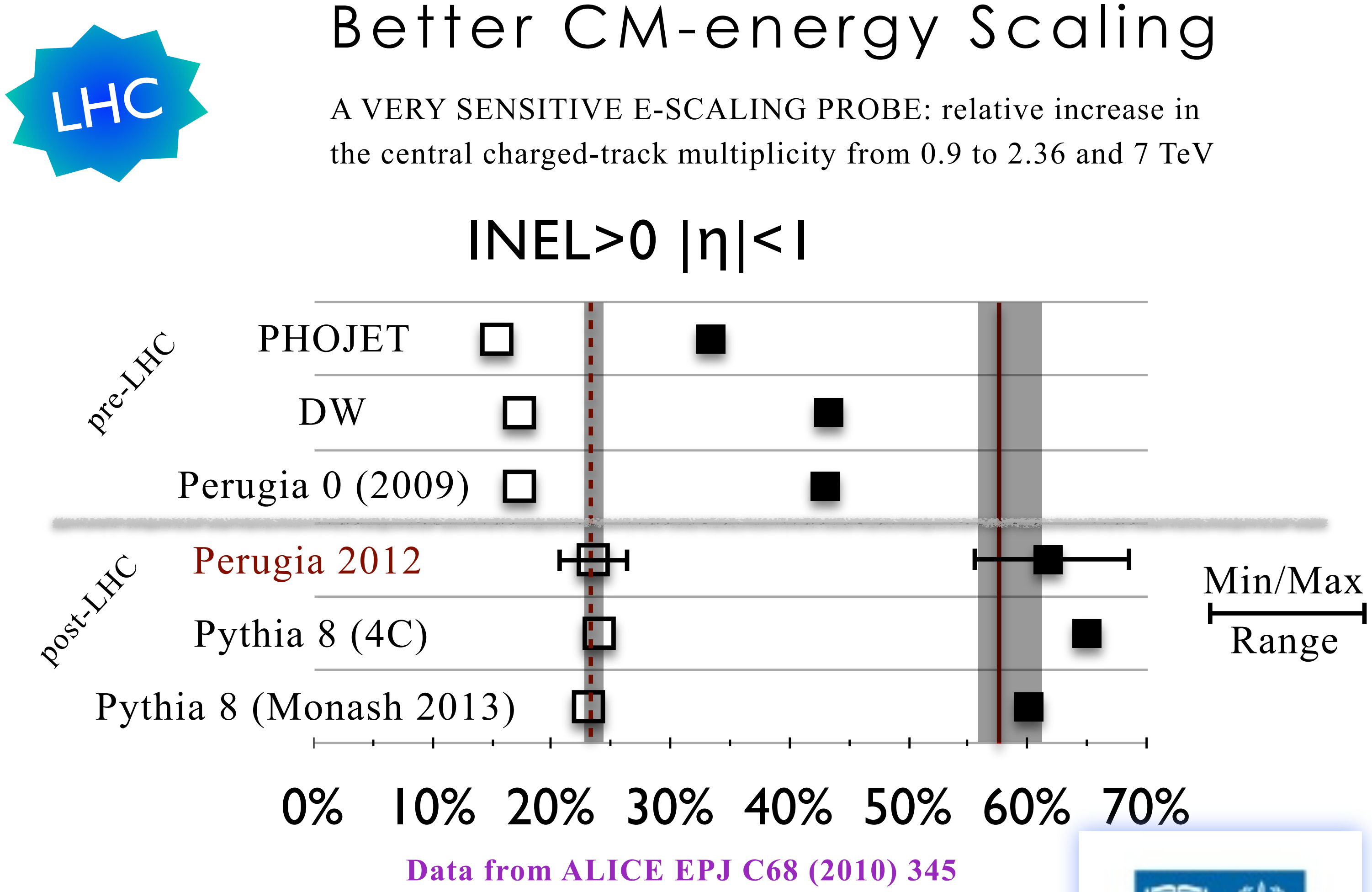
Peter Skands, Monash University



Last Update: August 2014 (ISVHECRI)

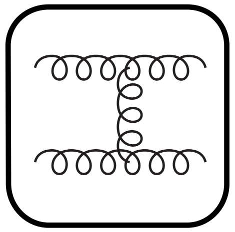
Better CM-energy Scaling

A VERY SENSITIVE E-SCALING PROBE: relative increase in the central charged-track multiplicity from 0.9 to 2.36 and 7 TeV



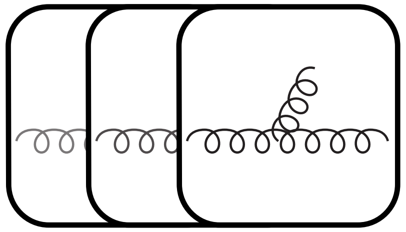
CERN, October 7-9, 2015
Workshop on QCD, EW and Tools at 100 TeV

Hadron Collisions in PYTHIA



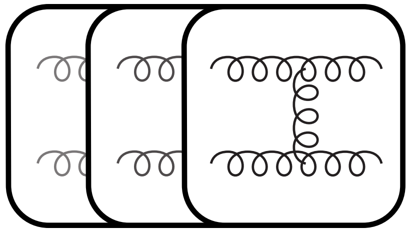
Perturbative QCD 2→2 scatterings

Typically LO perturbation theory, folded with PDFs



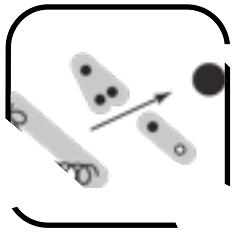
Initial- and Final-State Radiation

pT-ordered DGLAP evolution ➜ jets/bremsstrahlung



Multiple Parton Interactions

(additional perturbative 2→2 scatterings)



Beam Remnants and Hadronization

Strings (+ BE correlations? Colour reconnections? more?)

+ Soft (non-perturbative) processes: *Elastic and Diffractive*

Note: Most LHC tuning efforts have focused on Underlying Event and Inelastic, Non-Diffractive Min-Bias Events *(→above)*

➜ The softest parts of PYTHIA have not been updated for a while

Recent News (or lack thereof)

Released PYTHIA 8.2, with Monash 2013 tune as default (8.1 had 4C)

+ New physics manual writeup, less brief than for PYTHIA 8.1

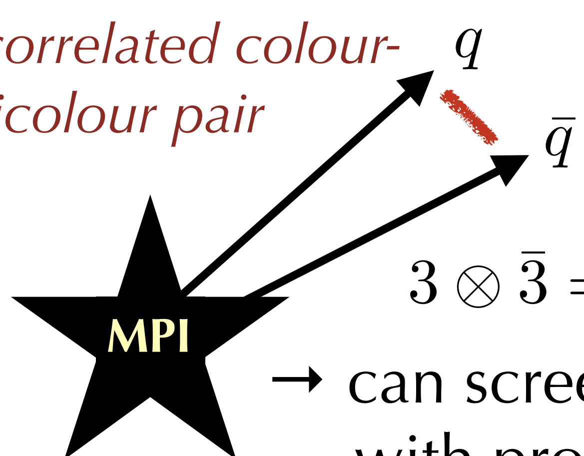
An introduction to PYTHIA 8.2, arXiv:1410.3012 | The Monash Tune; arXiv:1404.5630

New QCD-based model for Colour Reconnections

(Monash default still uses old PYTHIA6-like one, but new tunes available)

String Formation Beyond Leading Colour, arXiv:1505.01681

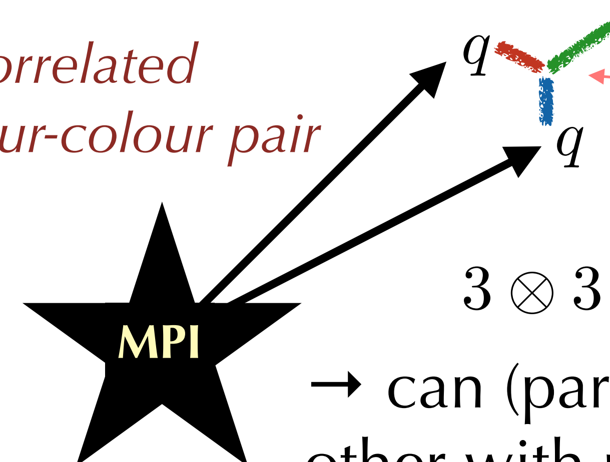
uncorrelated colour-anticolour pair



$3 \otimes \bar{3} = 8 \oplus 1$

→ can screen each other with probability 1/9

uncorrelated colour-colour pair



(new source of baryons)

$3 \otimes 3 = 6 \oplus \bar{3}$

→ can (partially) screen each other with probability ~ 1/3

(+ generalizations to gluons) ➜ multiple string topologies possible: select by length

+ Ongoing work on hard diffraction

Sjöstrand + Rasmussen

Soft diffraction (and total + elastic σ) on to-do list on longer time scale

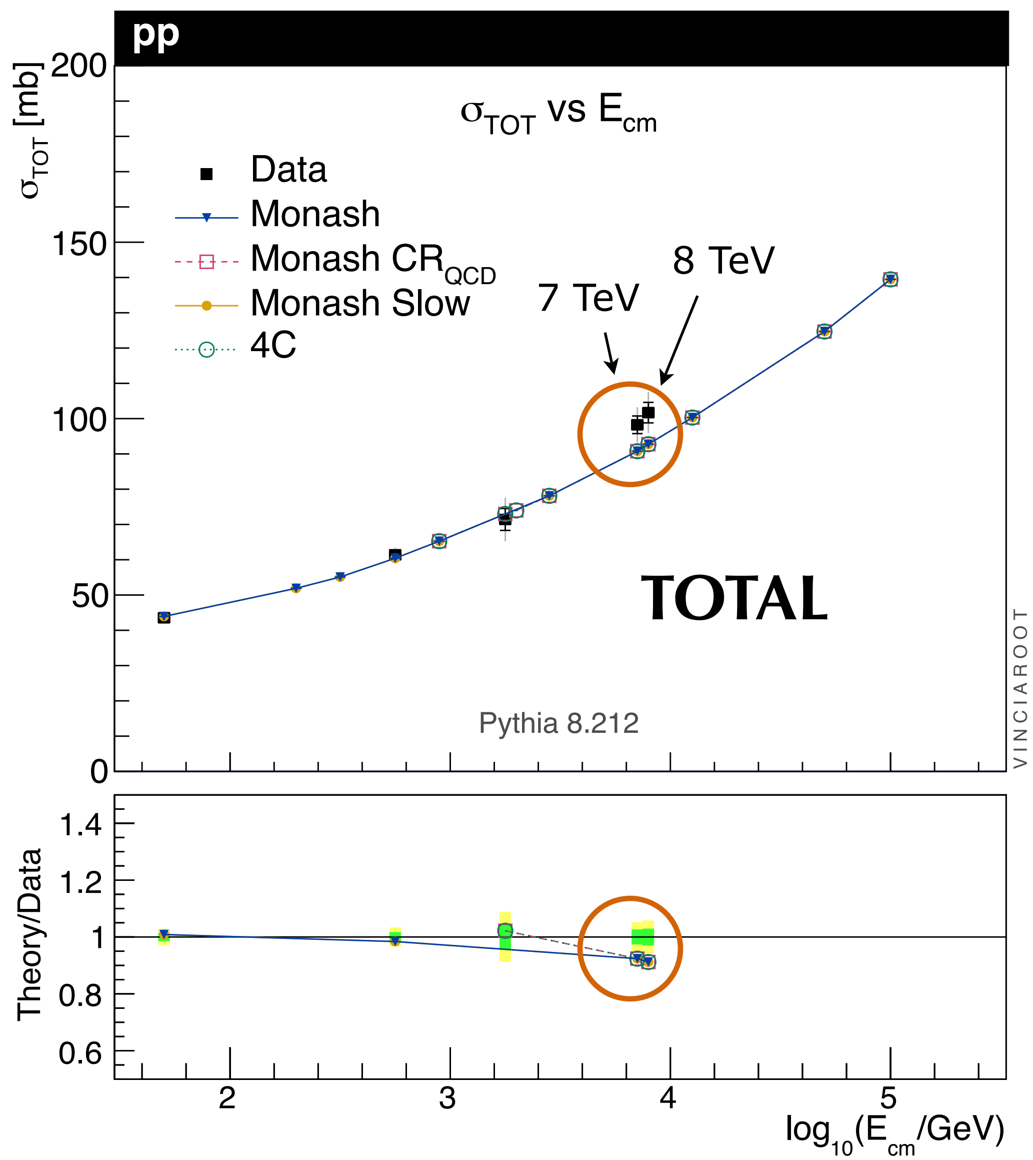
Total Cross Sections in PYTHIA

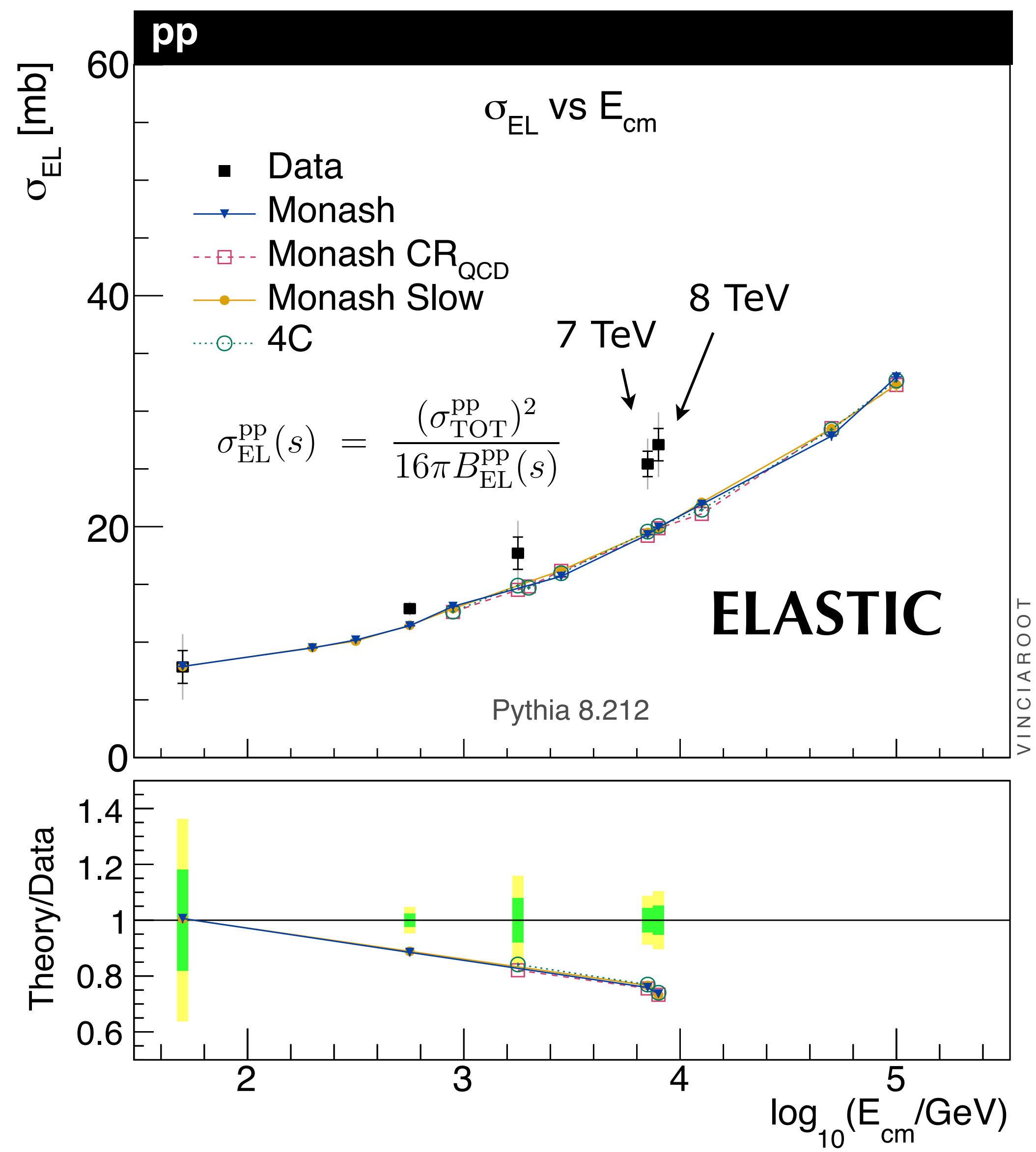
Reference: An introduction to PYTHIA 8.2, arXiv:1410.3012

Total Cross Section a la Donnachie & Landshoff '92

$$\sigma^{pp}_{TOT}(s) \;=\; (21.70\, s^{0.0808} + 56.08\, s^{-0.4525})\ \mathrm{mb},$$

hep-ph/9209205





Known for a while: too small σ_{TOT}. Chiefly due to σ_{EL} ➜ Needs updating!

e.g., DL: arXiv:1309.1292: $s^{0.096}$?

Reference: An introduction to PYTHIA 8.2, arXiv:1410.3012

Inelastic Cross Section ≝ Total ÷ Elastic

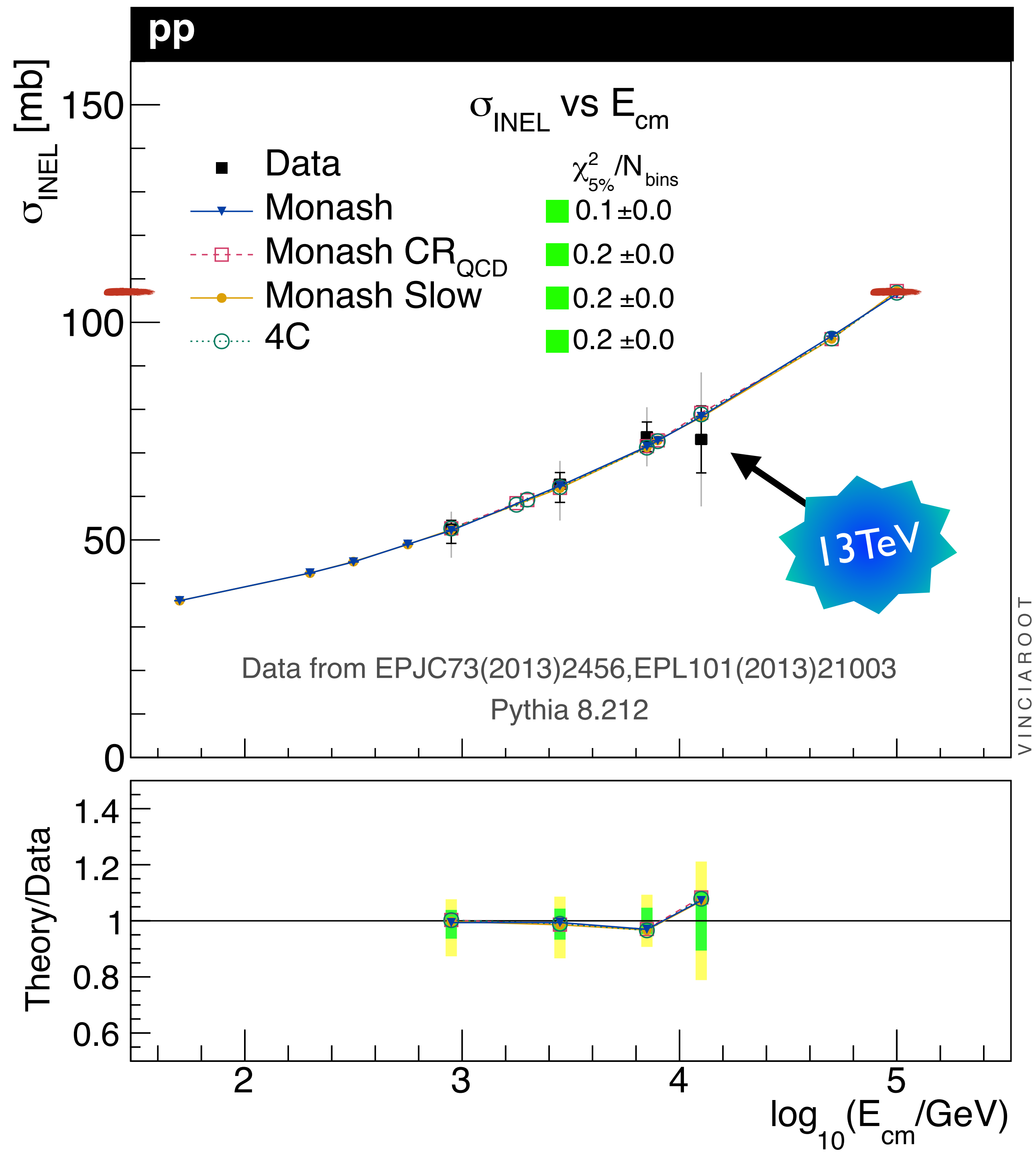
$$\sigma_{\mathrm{INEL}}(s) = \sigma_{\mathrm{TOT}}(s) - \sigma_{\mathrm{EL}}(s)\ .$$

Most relevant, for min-bias etc.

Current parametrisation agrees well with LHC measurements, including at 13 TeV

(summed over diffractive and non-diffractive components)

➜ *Not everything is wrong!*



Modelling Inelastic Events: Diffraction

Reference: An introduction to PYTHIA 8.2, arXiv:1410.3012

Inelastic Cross Section = ND + SD + DD (+CD)

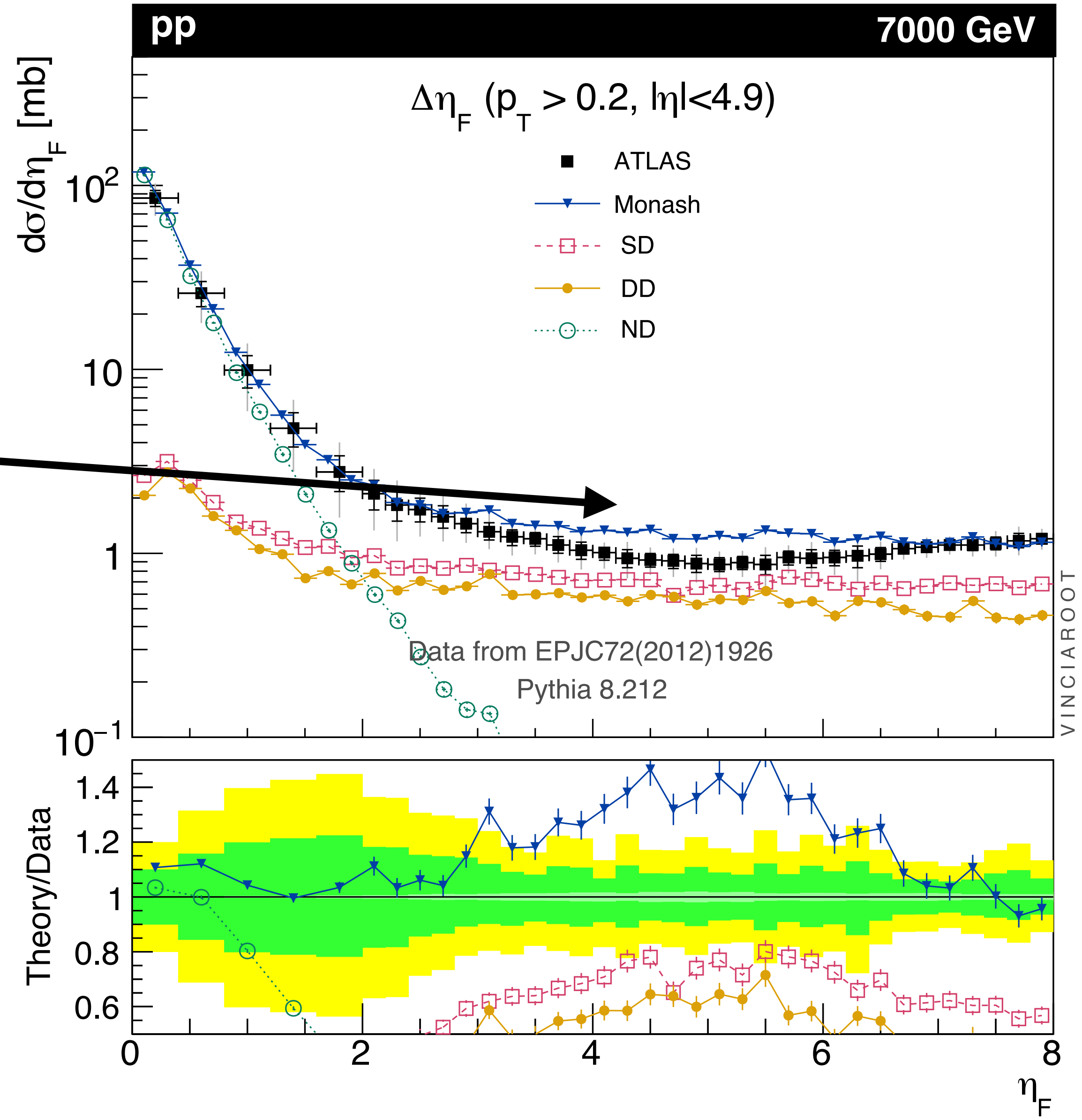
$$\sigma_{\mathrm{ND}}^{\mathrm{pp}}(s) \ = \ \sigma_{\mathrm{INEL}}^{\mathrm{pp}}(s) - \int \Big(\mathrm{d}\sigma_{\mathrm{SD}}^{\mathrm{pp}\to X\mathrm{p}}(s) + \mathrm{d}\sigma_{\mathrm{SD}}^{\mathrm{pp}\to \mathrm{p}X}(s) + \mathrm{d}\sigma_{\mathrm{DD}}^{\mathrm{pp}}(s) + \mathrm{d}\sigma_{\mathrm{CD}}^{\mathrm{pp}}(s) \Big)$$

Can in principle interfere

➜ model-dependent classification

Define physical observables

(large gaps, identified protons, …)



Too many large-gap events

Diffractive parameters in need of updating.

Spectra: 5 different possibilities. Default is Schuler-Sjöstrand:

$$\frac{\mathrm{d}\sigma_{\mathrm{SD}}^{\mathrm{pp}\to X\mathrm{p}}(s)}{\mathrm{d}t\,\mathrm{d}M_X^2} = \frac{g_{3\mathbb{P}}}{16\pi}\frac{\beta_{\mathrm{p}\mathbb{P}}^3}{M_X^2} F_{\mathrm{SD}}(M_X)\,\exp\left(B_{\mathrm{SD}}^{X\mathrm{p}}\,t\right) \ ,$$

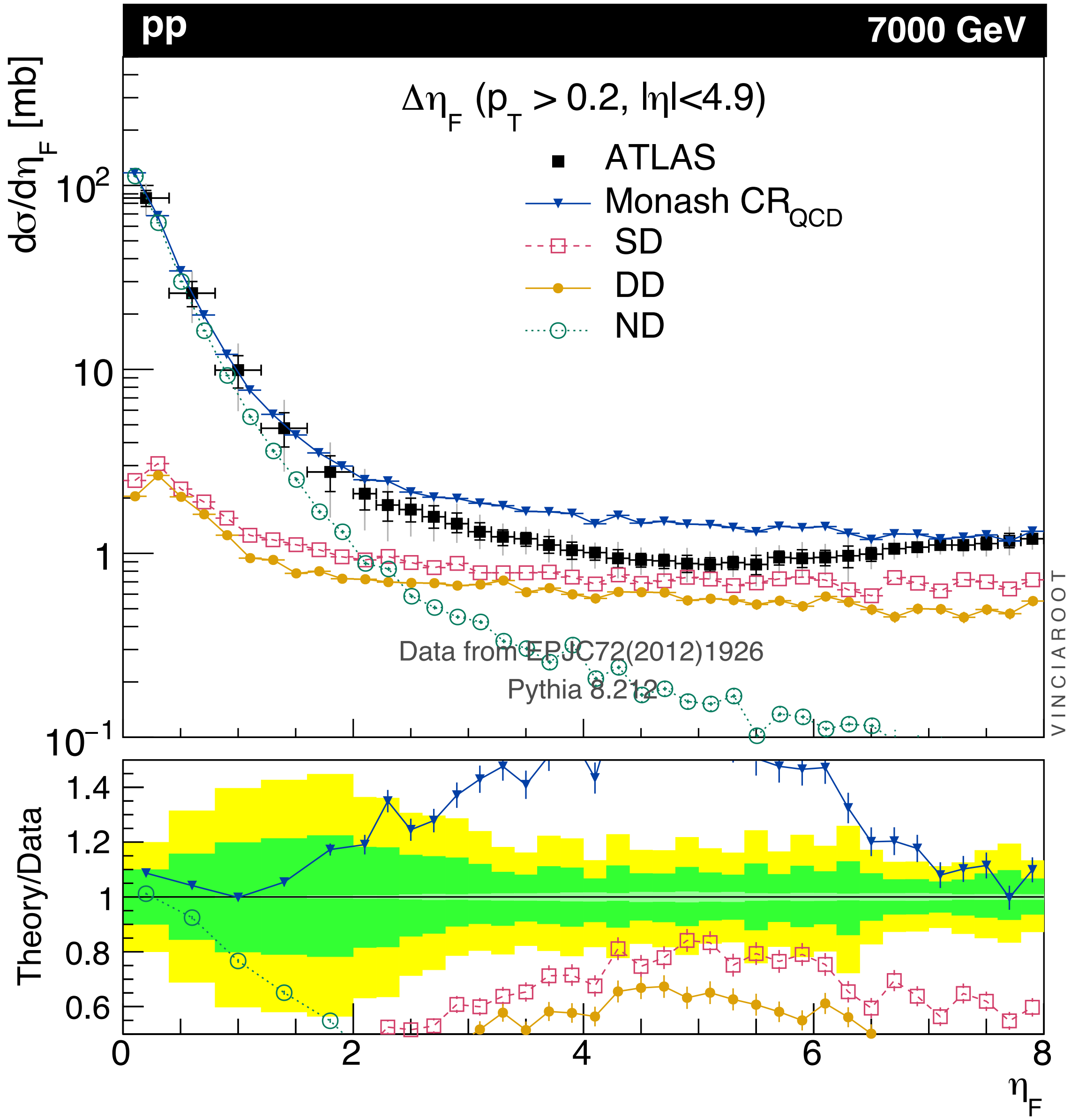
$$\frac{\mathrm{d}\sigma_{\mathrm{DD}}^{\mathrm{pp}}(s)}{\mathrm{d}t\,\mathrm{d}M_1^2\,\mathrm{d}M_2^2} = \frac{g_{3\mathbb{P}}^2}{16\pi}\frac{\beta_{\mathrm{p}\mathbb{P}}^2}{M_1^2 M_2^2} F_{\mathrm{DD}}(M_1, M_2)\,\exp\left(B_{\mathrm{DD}}\,t\right)$$

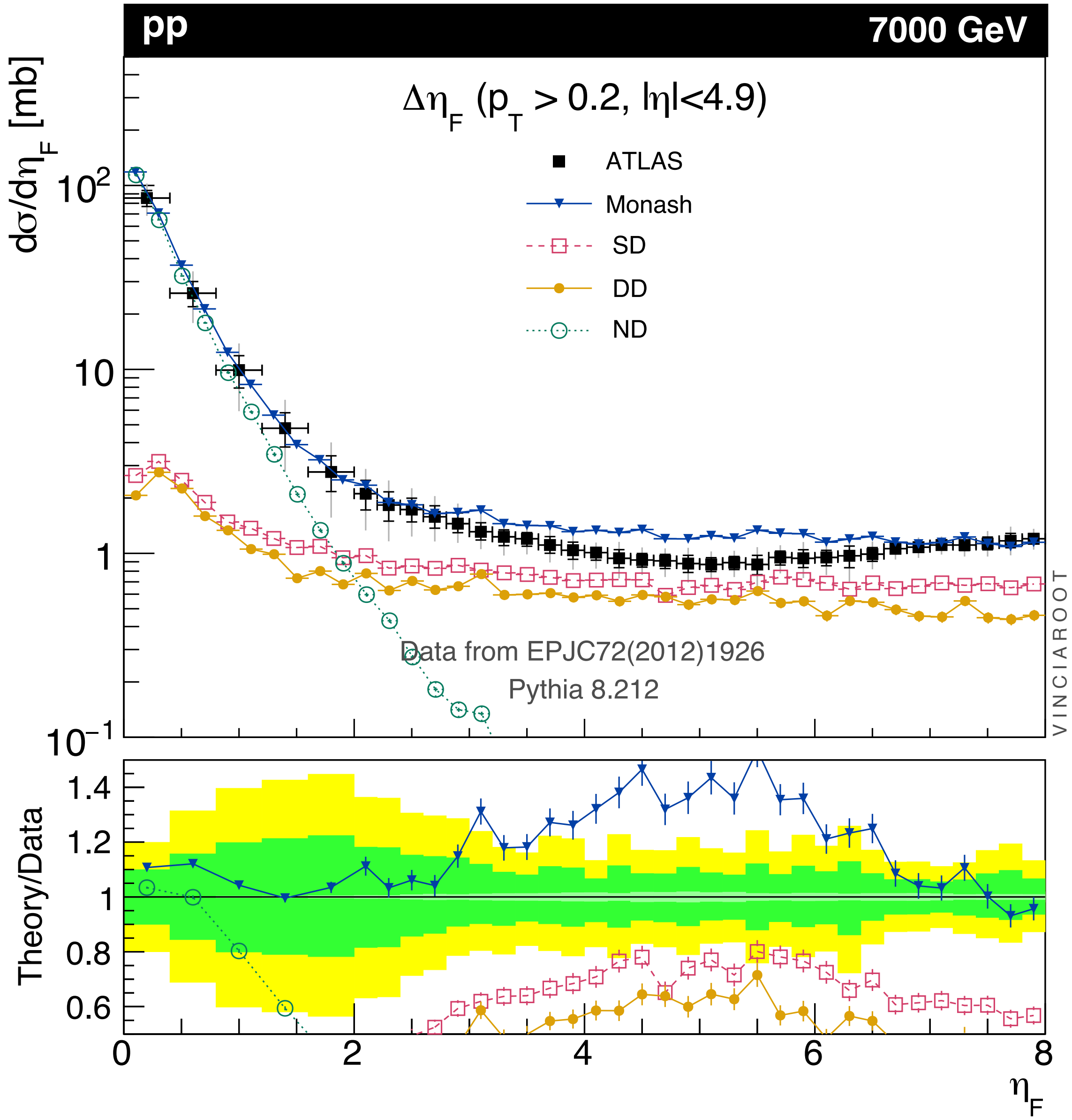
Low-mass diffraction (M_X < 10 GeV) represented as fragmenting string. High-mass includes partonic substructure.

(Note on Diffraction and CR)

Important note: **Colour Reconnections** may also produce rapidity gaps

➜ *Ideally, tune/constrain diffractive cross sections, spectra, and CR together*

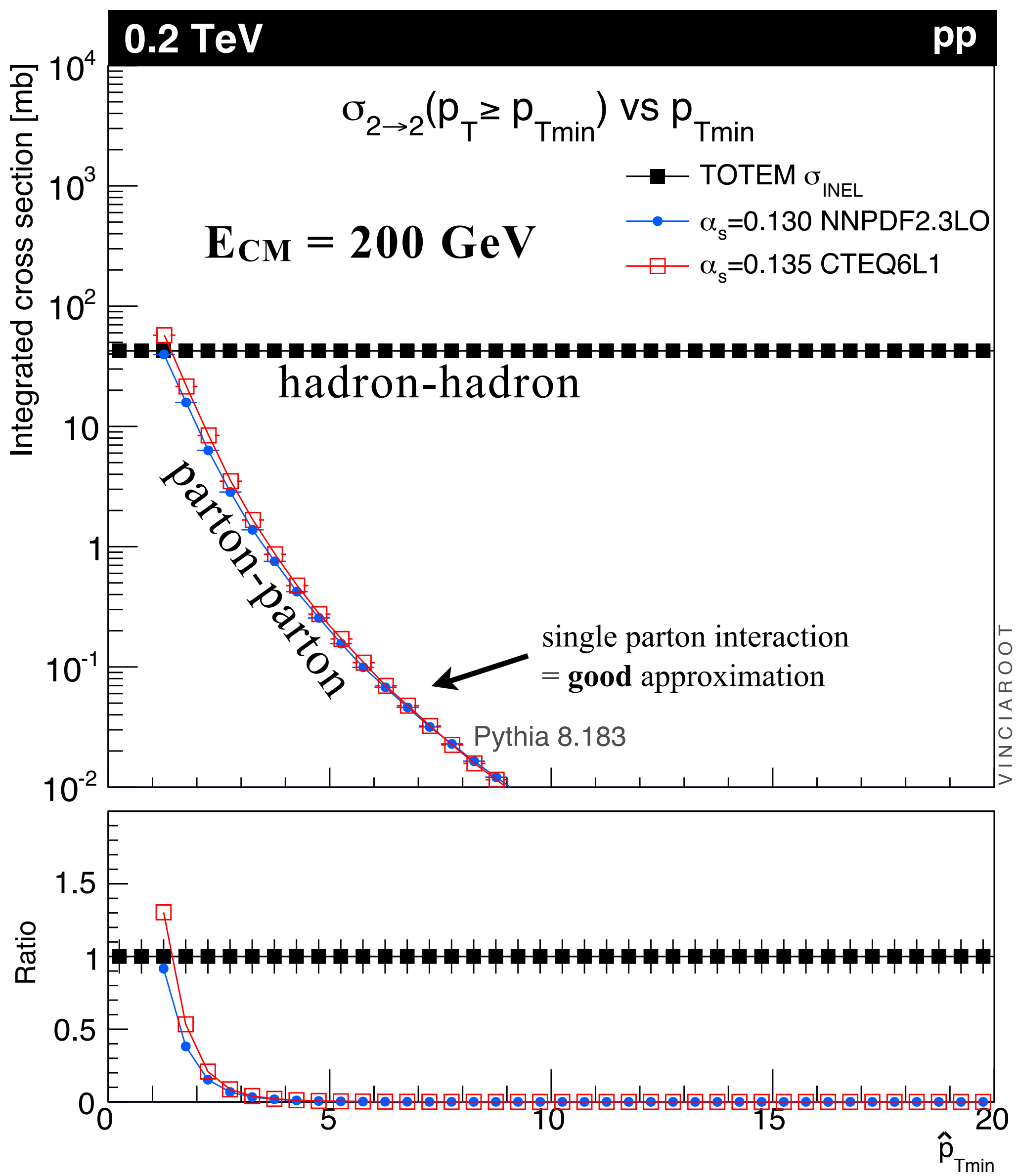


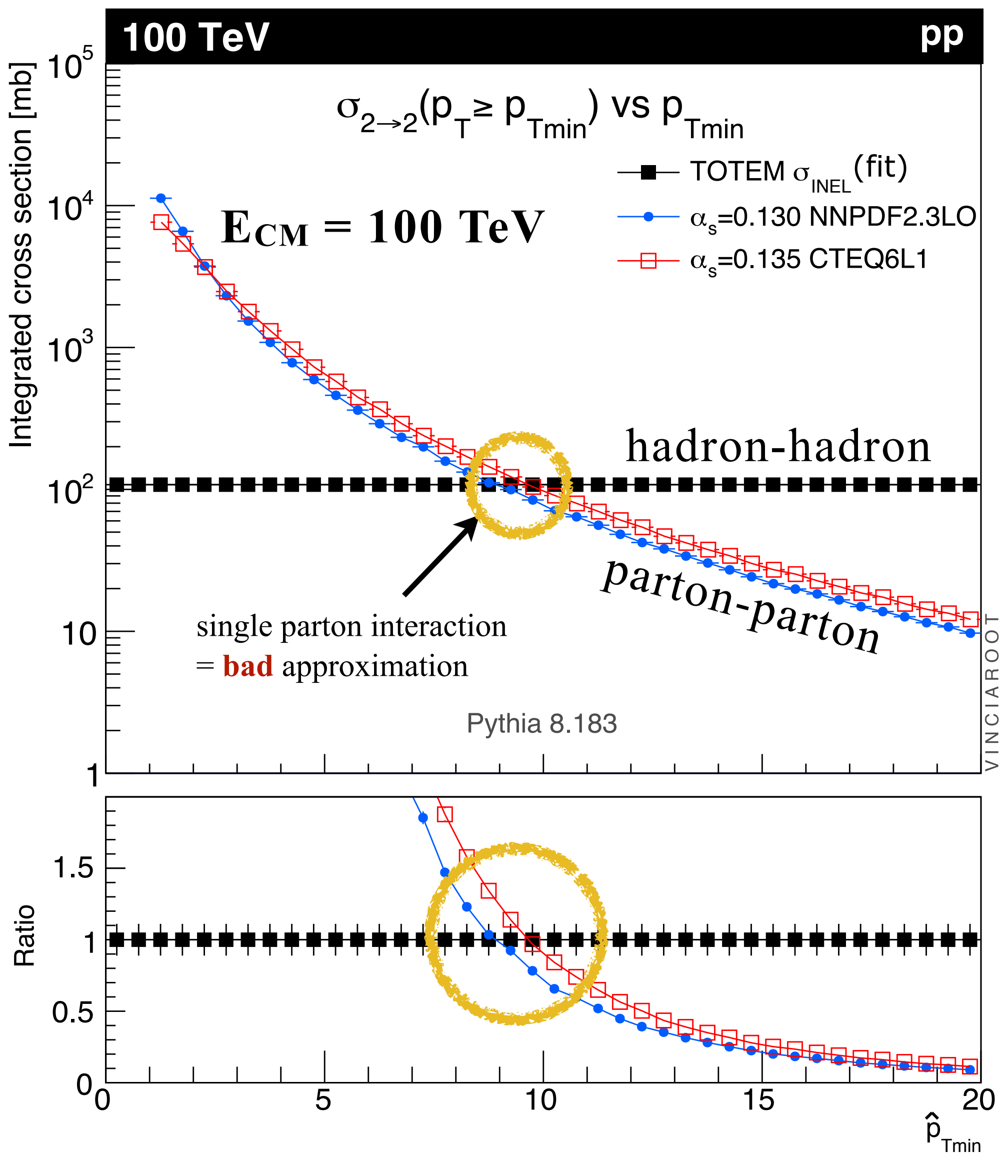


Modelling Inelastic Events: MPI

Consider the inclusive-jet cross section in QCD

At LO = perturbative parton-parton (2→2) QCD cross section (tree-level)





$\sigma_{2\to2} > \sigma_{pp}$ interpreted as consequence of each pp containing several 2→2 interactions: MPI

Modelling Inelastic Events: MPI

Interleaved Evolution (FSR + ISR + MPI)

Perturbative MPI evolution regulated by colour-screening scale p_{T0}

$$\frac{d\sigma_{2\to2}}{dp_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_\perp^2+p_{\perp0}^2)}{(p_\perp^2+p_{\perp0}^2)^2}$$

Main MB/UE tuning parameter

p_{T0} scales with CM energy: $p_{T0}^2(s) \propto s^\gamma$

Main energy-scaling parameter

```
Old Default (4C)   : γ = 0.19
Monash 2013        : γ = 0.215
New "Monash Slow"  : γ = 0.23
```
(➜ cutoff increases faster → N_{ch} grows slower)

Event structure (e.g., N_{ch} distributions) further significantly affected by:

Proton b profile; Low-x PDFs; Colour Reconnections; Other collective effects?

Hadronization: Lund String Model

Jet Universality: fundamental parameters constrained by LEP data

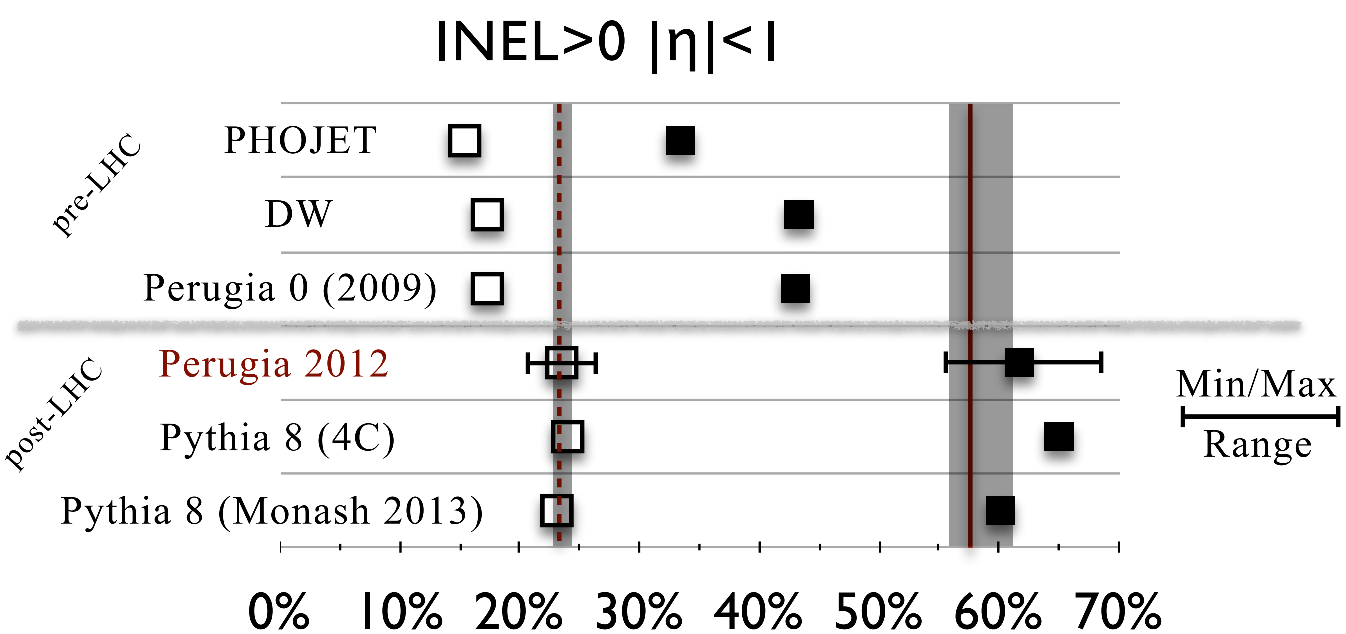
No additional parameters for gluon jets, nor for pp collisions (modulo dynamics)

Central Charged-Track Density

Per unit $\Delta\eta\Delta\varphi$

Best measured: INEL > 0
(at least one charged particle inside |eta| < 1)

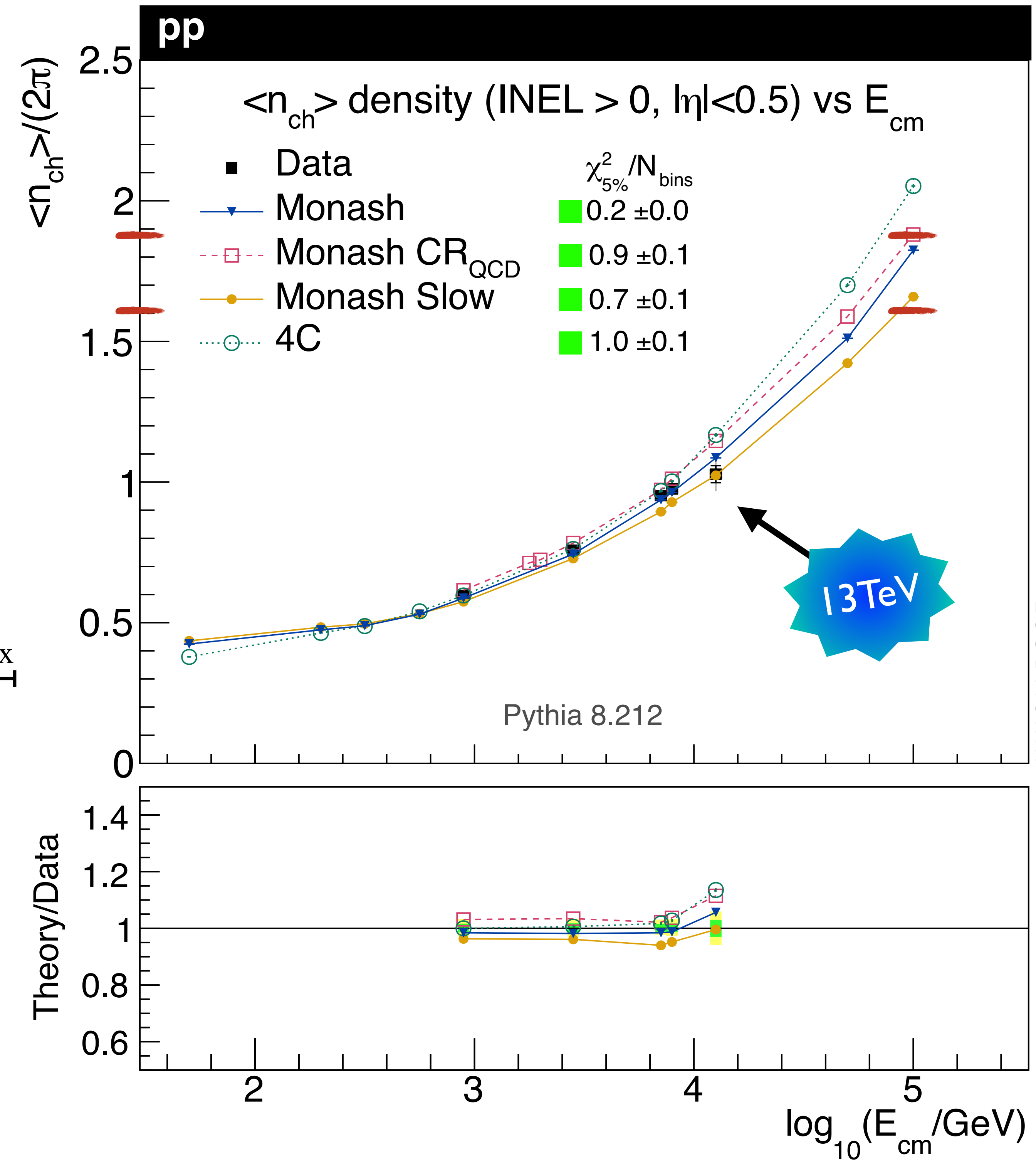
A VERY SENSITIVE E-SCALING PROBE: relative increase in the central charged-track multiplicity from 0.9 to 2.36 and 7 TeV



Data from ALICE EPJ C68 (2010) 345

INEL > 0

100 TeV: $\langle N_{ch}\rangle/\Delta\eta\Delta\varphi = 1.75 \pm 0.15$

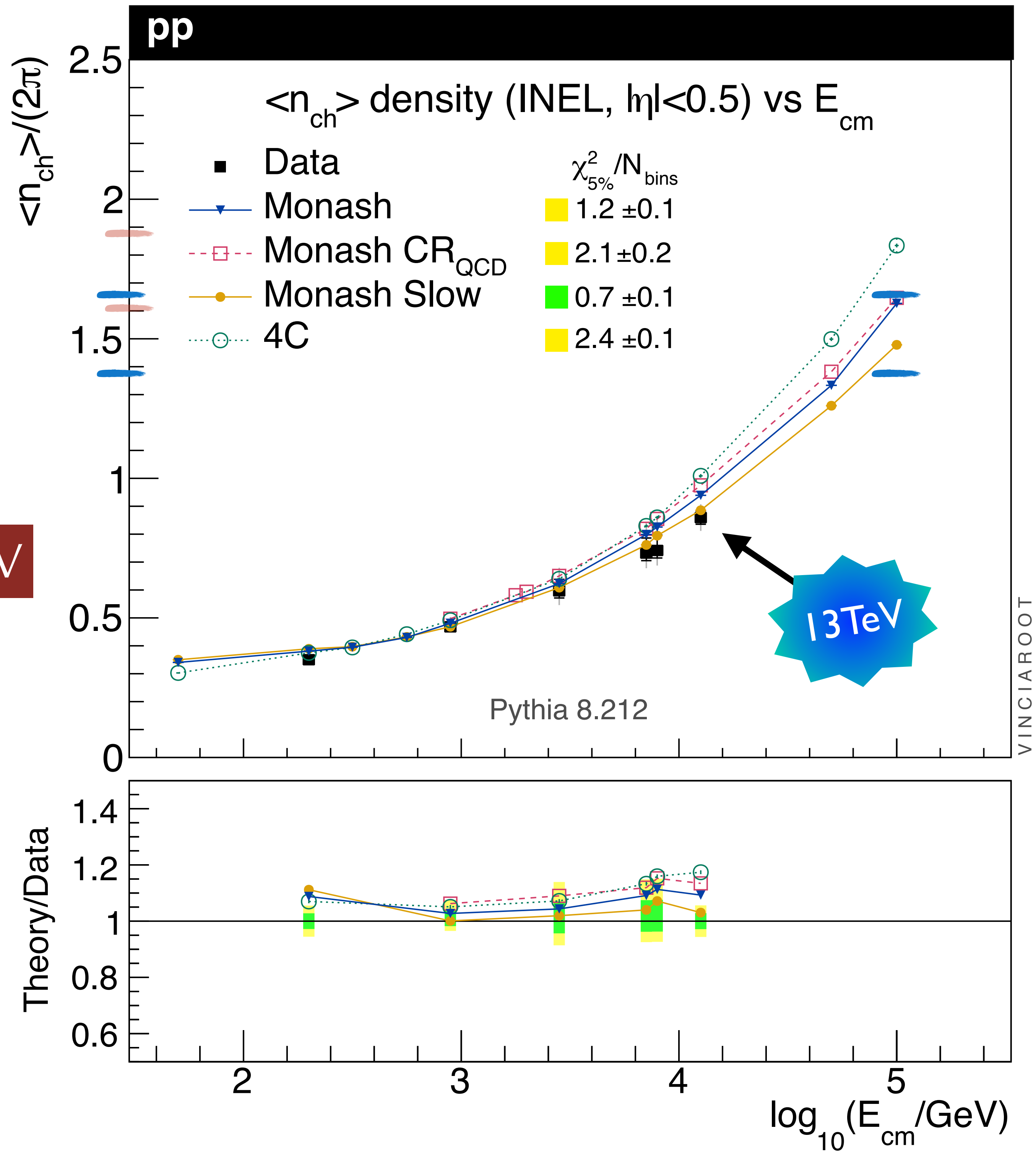


Extrapolation to all INEL

<Nch> per unit ΔηΔφ

Bear in mind
(larger uncertainties from diffractive contributions, in need of updating)

Densities @ 13 TeV
Monash 13 scales slightly fast?
Monash Slow scales slightly better?



"Monash Slow" parameters: lower at 100 TeV

```
MultiPartonInteractions:ecmPow = 0.23
MultiPartonInteractions:pT0ref = 2.36
MultiPartonInteractions:expPow = 1.65
ColourReconnection:range = 1.9
```

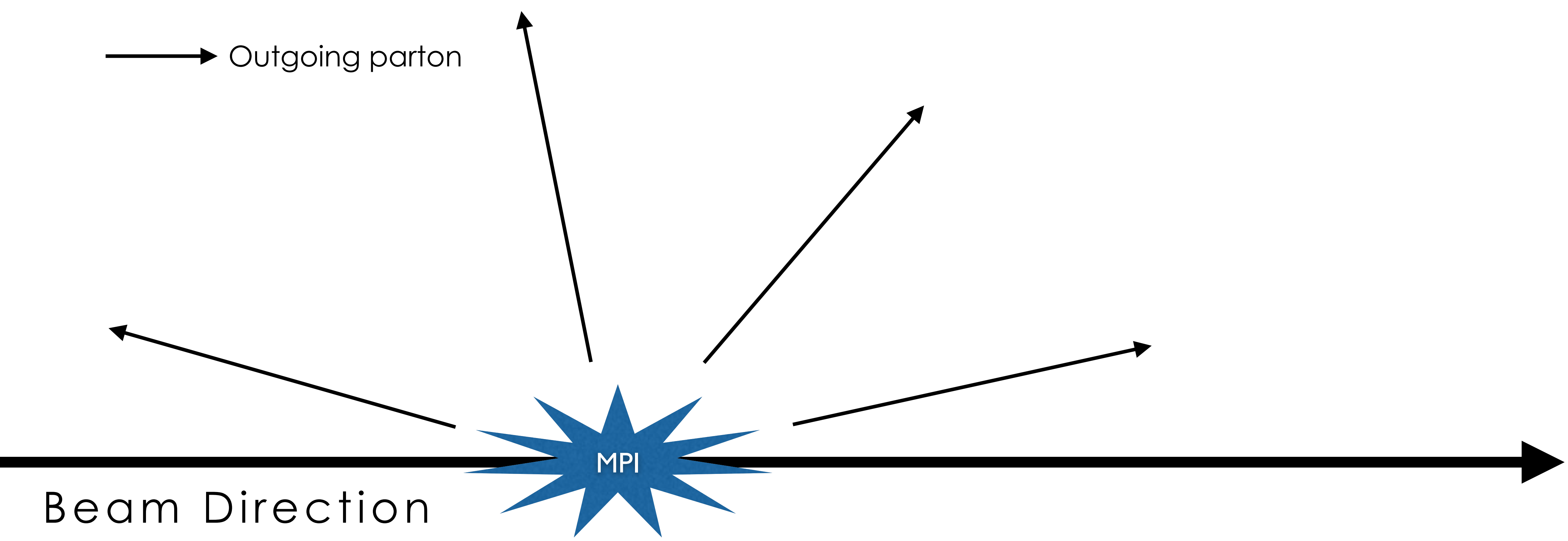
Default Monash = {0.215, 2.28, 1.85, 1.8} respectively

INEL

100 TeV: $\langle N_{ch} \rangle / \Delta\eta\Delta\varphi = 1.5 \pm 0.15$

Colour: What's the Problem?

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



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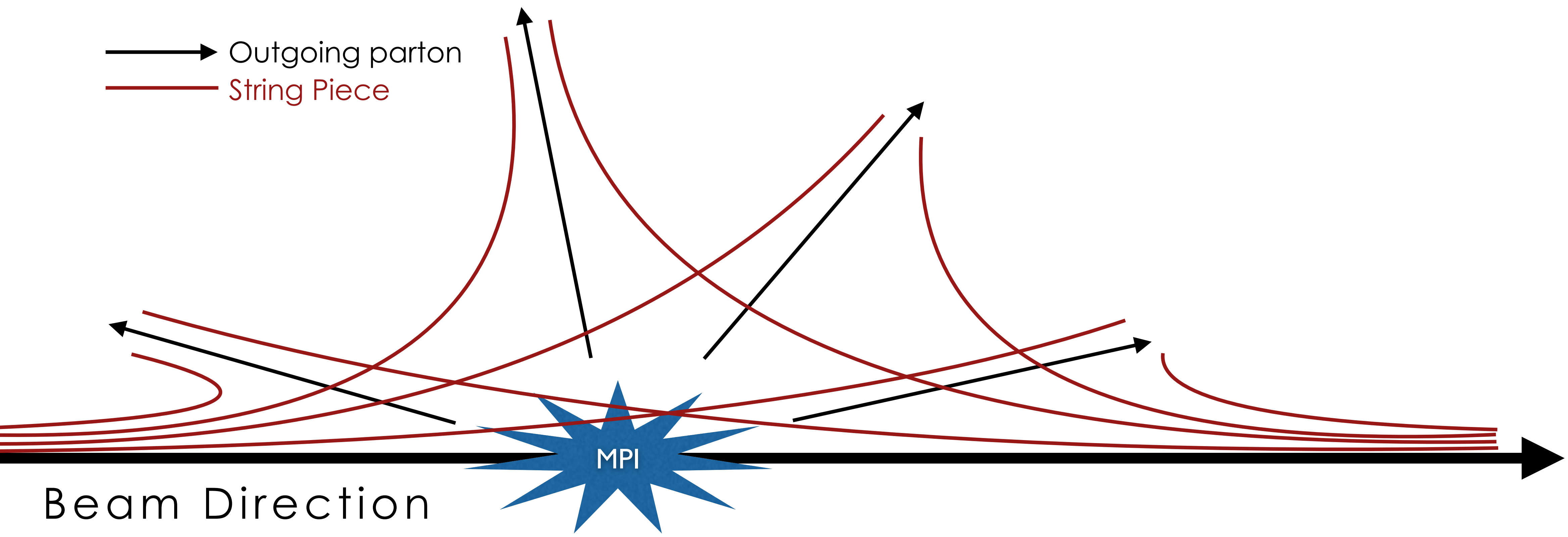
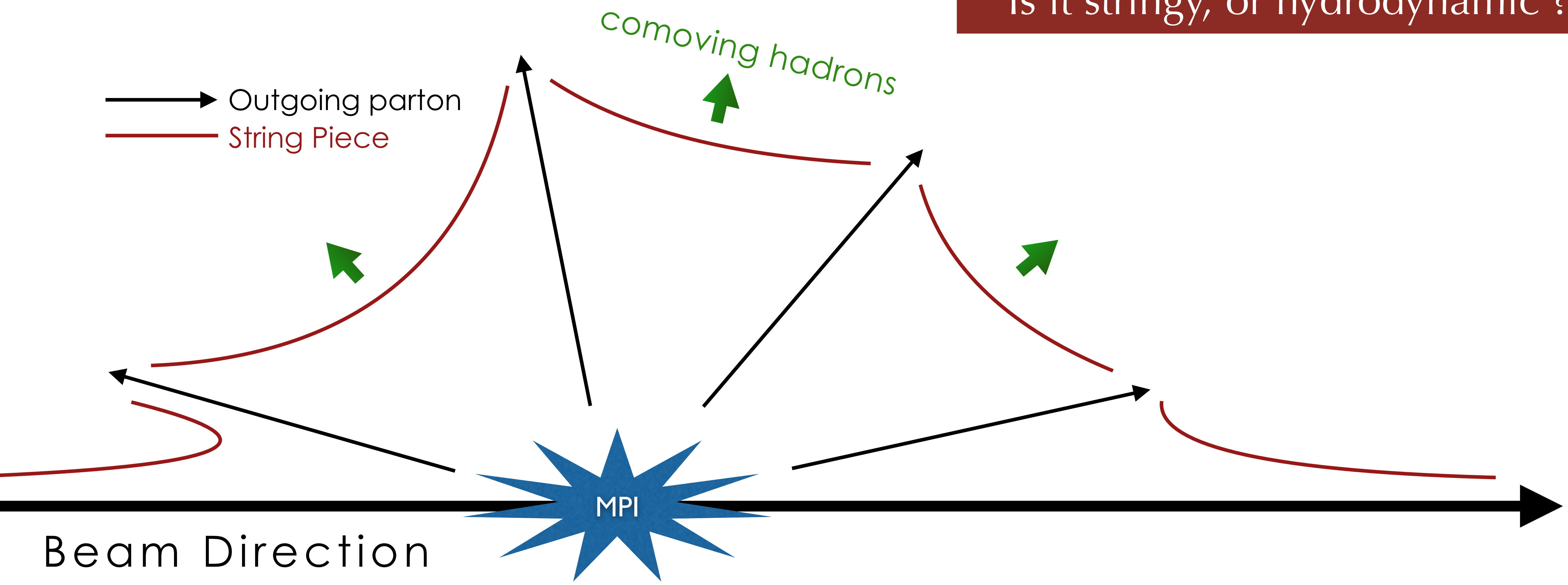


Collective Effects?

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

With Colour Reconnections
MPI hadronize **collectively**

Highly interesting theory questions now.
Is there collective flow in pp? Or not?
If yes, what is its origin?
Is it stringy, or hydrodynamic ? (or …?)



Or Thermal? E.g., EPOS

Or Higher String Tension? E.g., DIPSY rope

Collective Effects?

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

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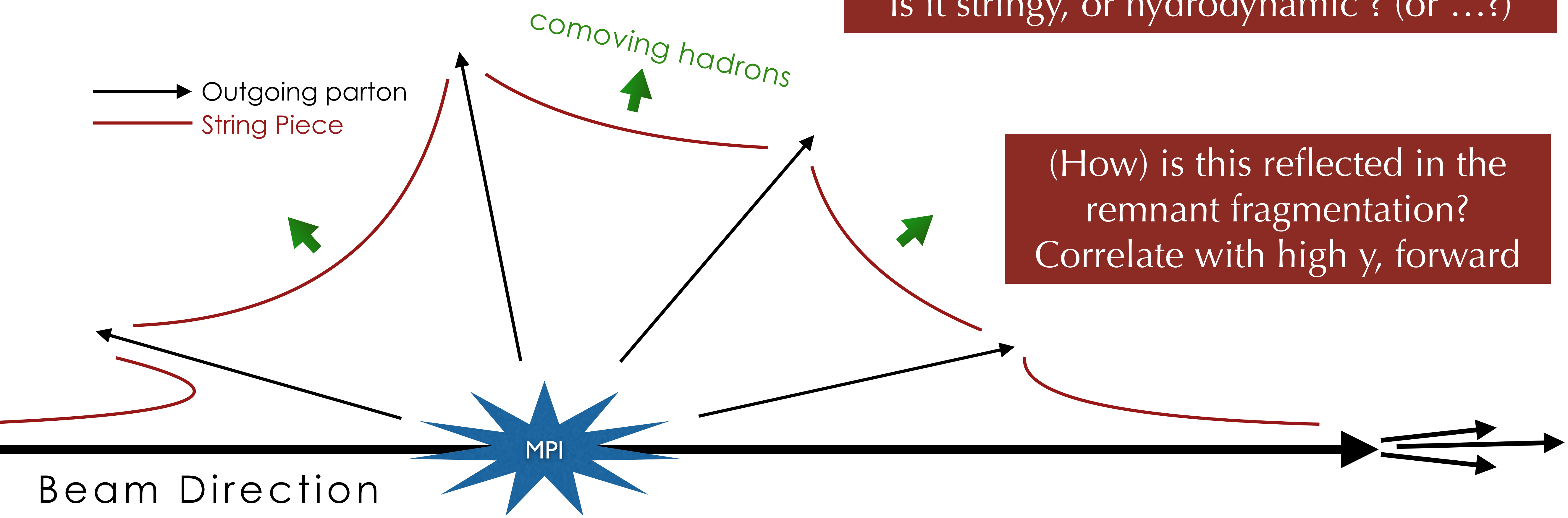


(How) is this reflected in the remnant fragmentation?
Correlate with high y, forward

Or Thermal? E.g., EPOS

Or Higher String Tension? E.g., DIPSY rope

Or?

Summary & Puzzles

HEP MC Models mainly target (and rooted in) high-p_T perturbative processes

- Jets (ISR & FSR: parton showers) + hadronization (strings/clusters)

Lesson from Tevatron (no doubt after LHC): Underlying Event requires MPI

PYTHIA, HERWIG, and SHERPA all include MPI models

- Under quite active development, mainly in response to LHC
- Also used as basis to model (nondiffractive) minimum-bias

Check e.g.: mcplots.cern.ch

Lessons from LHC

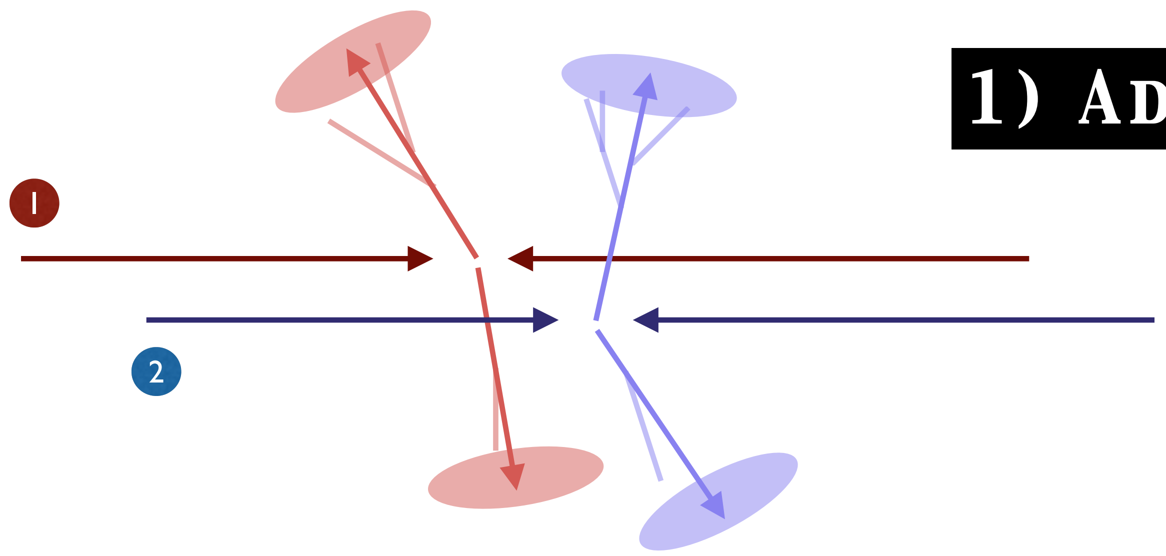
- Energy scaling is somewhat faster than Tevatron-era tunes. (Monash may be too fast)
- Hadronization in pp appears to be non-trivial extension wrt LEP
- Flow-like spectra? Nch and Mass dependencies. Correlations? (cf RHIC, Tevatron)
- Diffraction in need of update.

Quo Vadis?

- Understand process of color neutralization (CR) in pp vs hydro flow?
- Understand connection with initial state: low-x PDFs, saturation
- Understand interplay between diffraction and CR; role and modelling

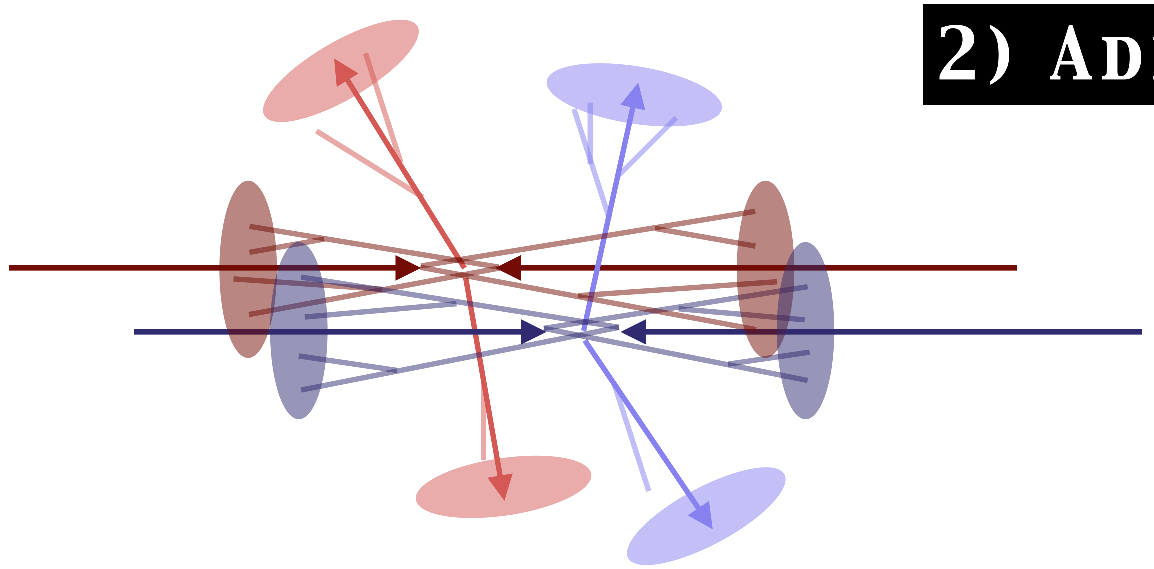
Central vs Forward

Take an extremely simple case of just 2 MPI



1) Add final-state radiation

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

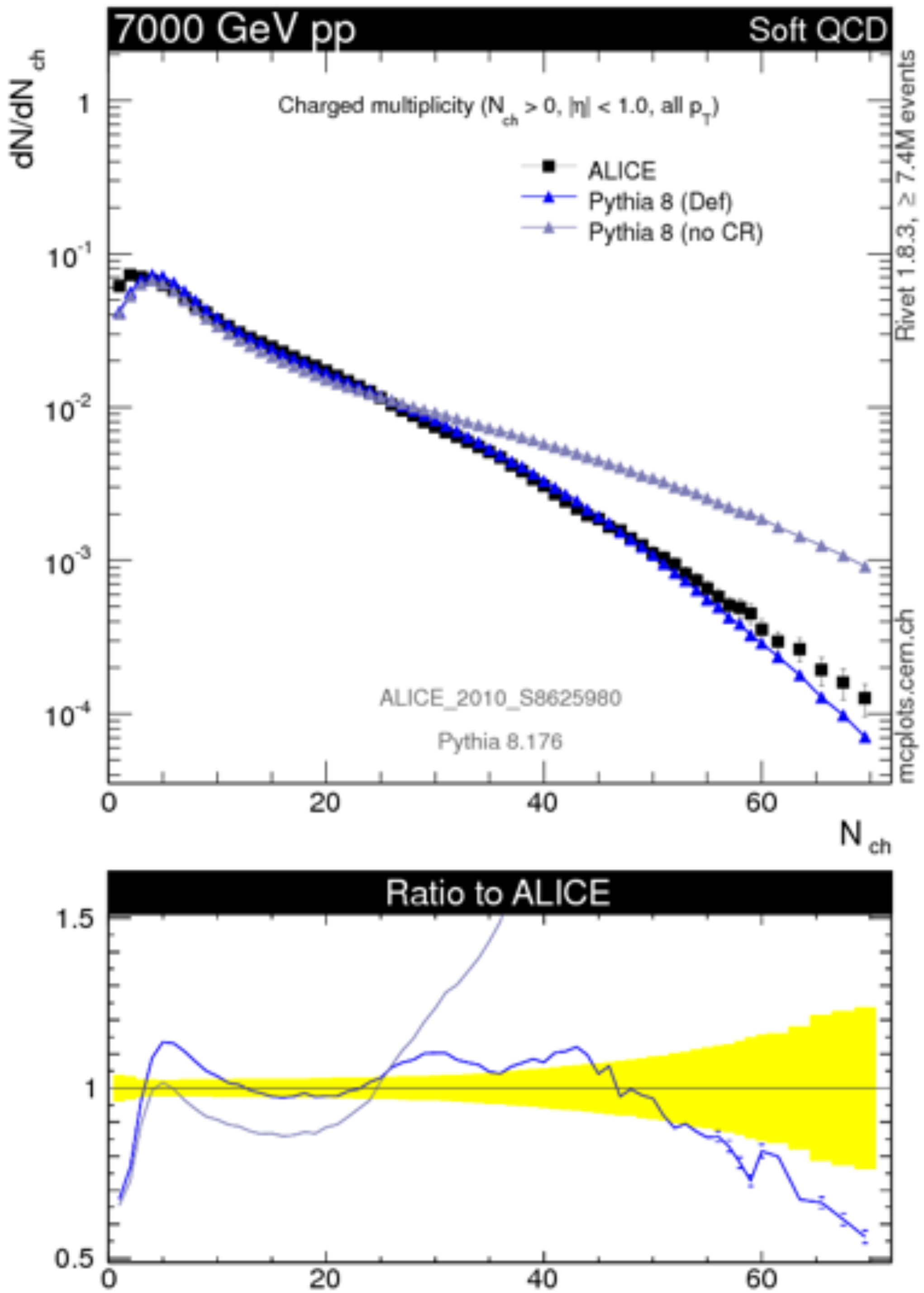


2) Add intial-state radiation

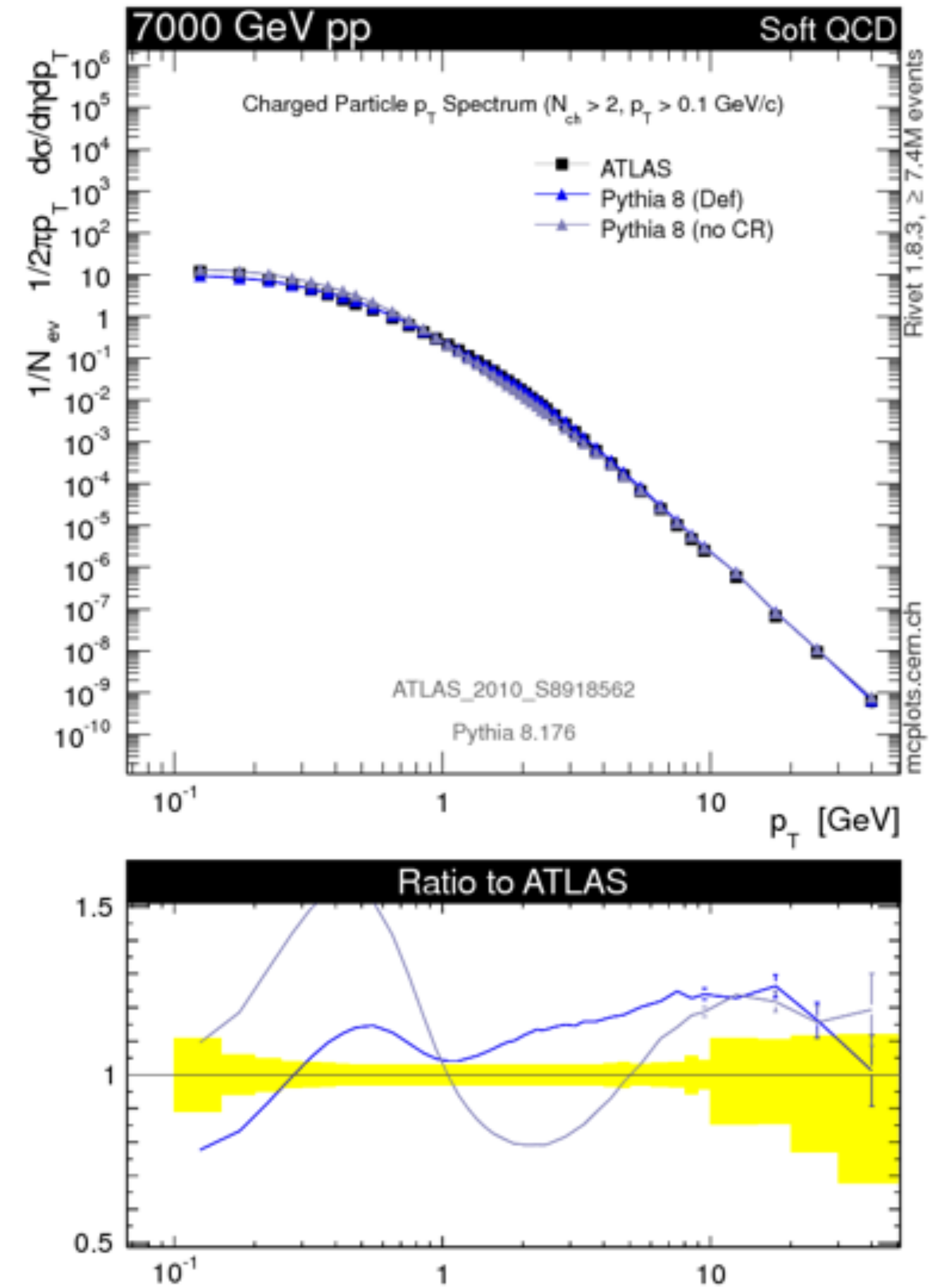
All the ISR radiation overlaps!
(each MPI scattering centre must reside within *one* proton radius of all others)
: expect significant 'colour confusion'
: intra-jet CR (unlike central and LEP)
: Strong effects in FWD region
(in addition to low-x gluon / saturation)

The Effects of CR

Fewer particles



... with higher pT



The Effects of CR

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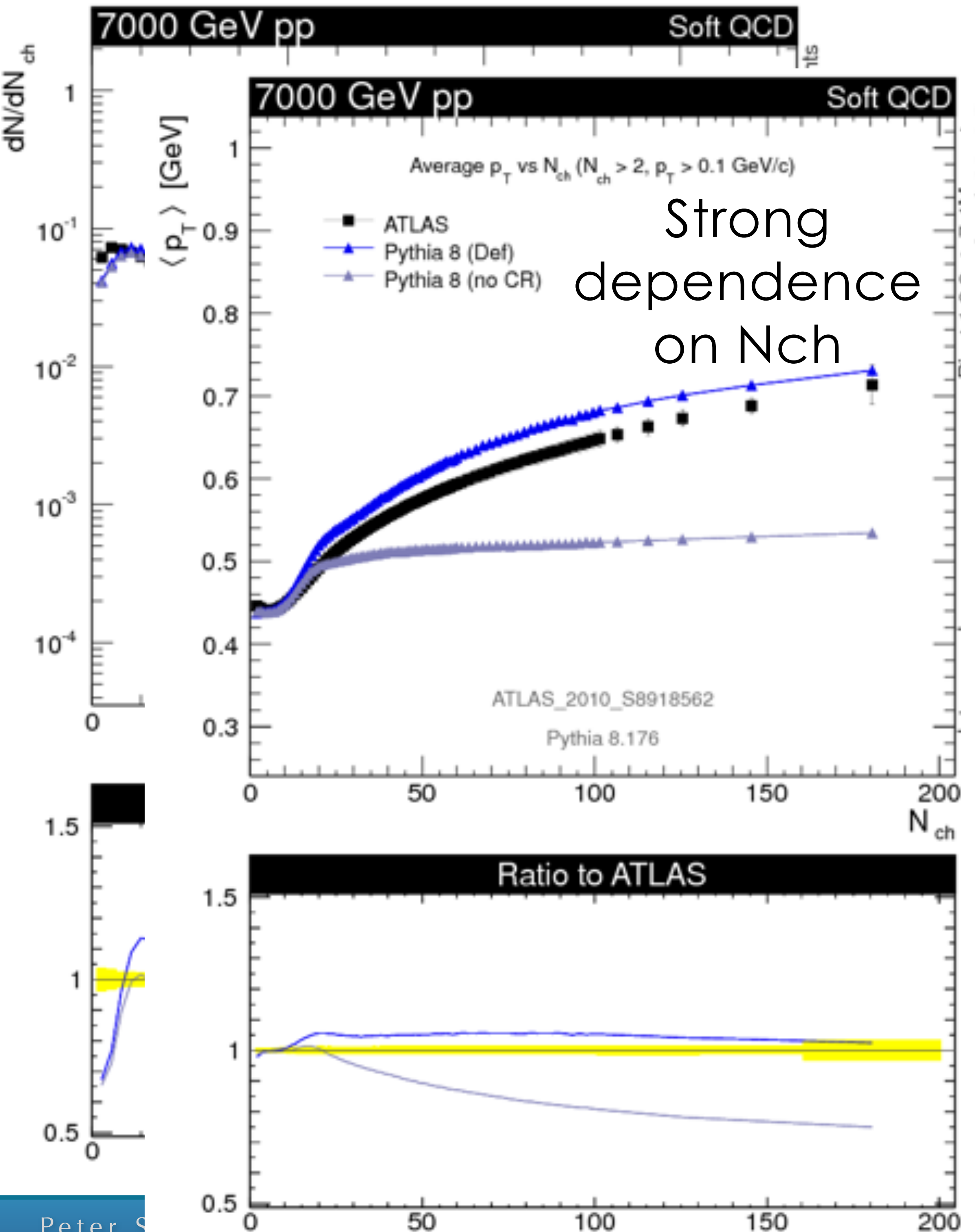
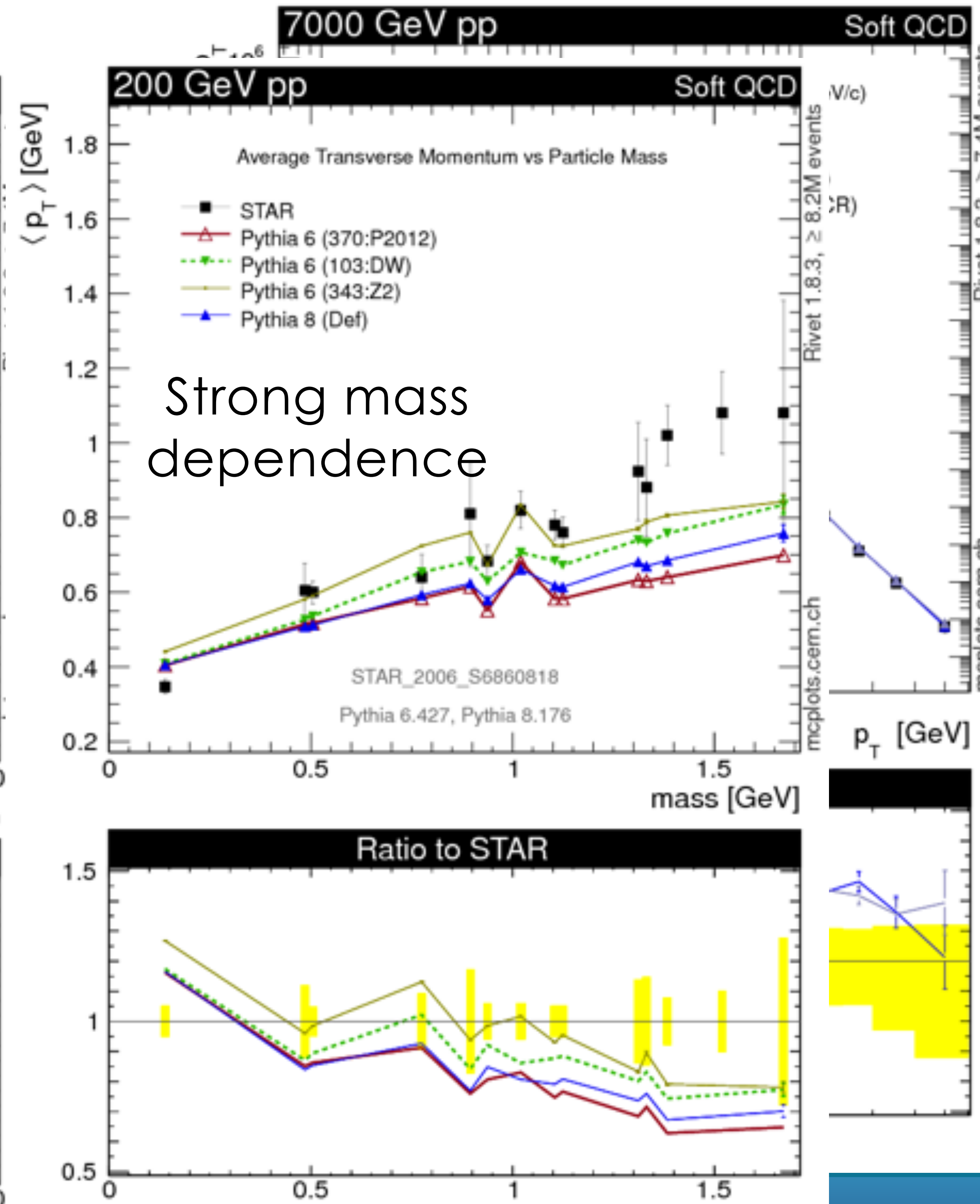


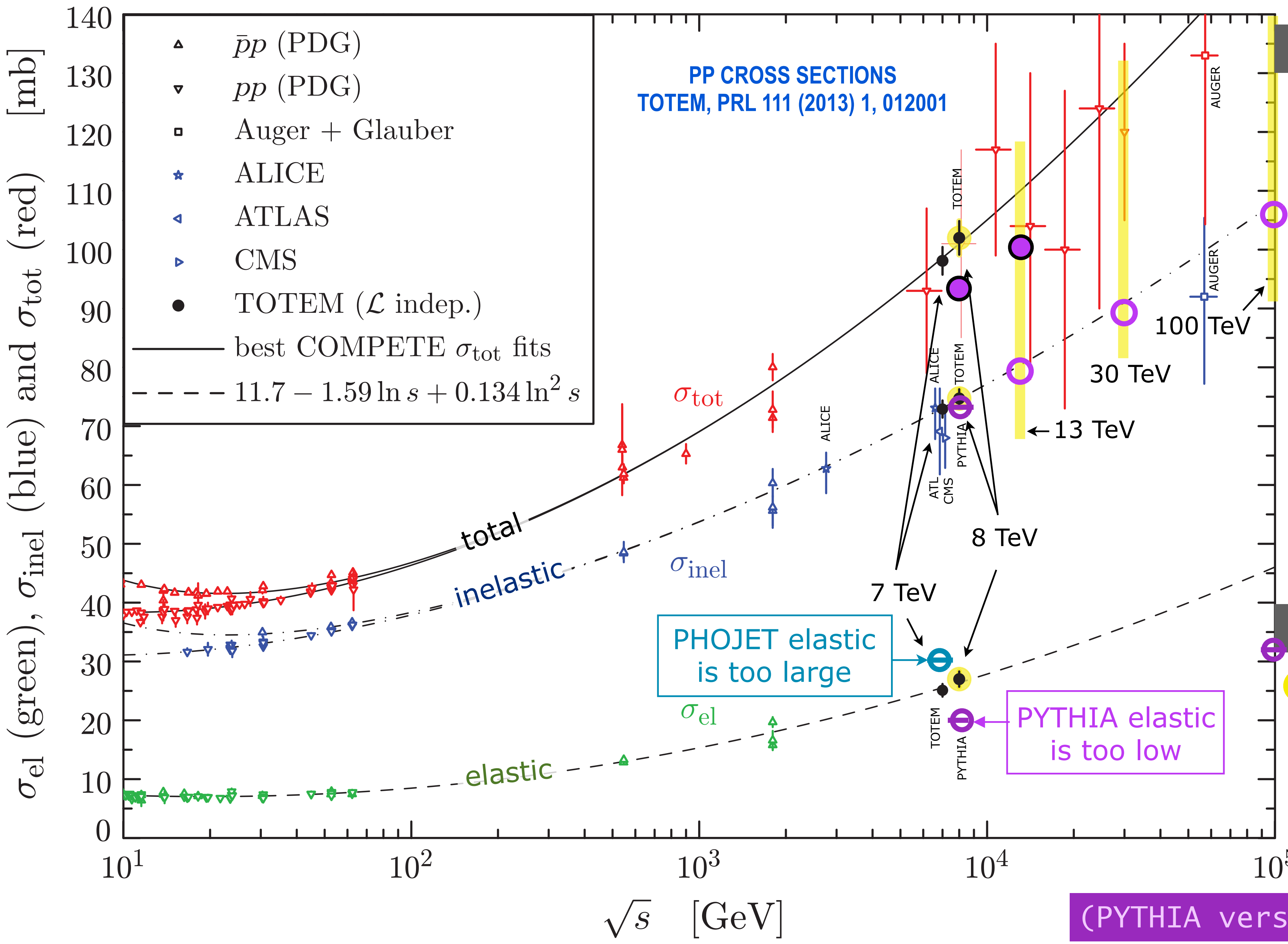
... with higher pT



Cross Sections & Energy Scaling

Pileup rate $\propto$ $\sigma_{\rm tot}(s) = \sigma_{\rm el}(s) + \sigma_{\rm inel}(s) \propto s^{0.08}$ or $\ln^2(s)$?

Donnachie-Landshoff (or 0.096?) Froissart-Martin Bound



INELASTIC

(INEL = SD+DD+CD+ND)

TOTEM (+COMPETE)

$\sigma_{\rm inel}(8\ {\rm TeV}) = 74.7 \pm 1.7$ mb

$\sigma_{\rm inel}(13\ {\rm TeV}) \sim 80 \pm 3.5$ mb

PYTHIA ($\mathrm{DL}_{0.08}$)

$\sigma_{\rm inel}$(8 TeV): 73 mb
$\sigma_{\rm inel}$(13 TeV): 78 mb
$\sigma_{\rm inel}$(30 TeV): 89 mb
$\sigma_{\rm inel}$(100 TeV): 107 mb

OK

ELASTIC

$\sigma_{\rm el}(8\ {\rm TeV}) = 27.1 \pm 1.4$ mb

PYTHIA: 20 mb

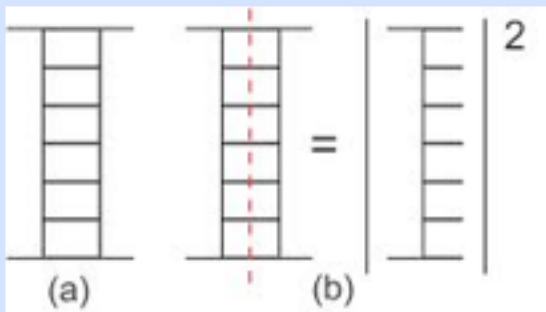
LOW

(PYTHIA versions: 6.4.28 & 8.1.80)

Soft Physics : Theory Models

See e.g. Reviews by MCnet [arXiv:1101.2599] and KMR [arXiv:1102.2844]

A — Regge Theory



Optical Theorem

+ Eikonal multi-Pomeron exchanges

$\sigma_{\mathrm{tot,inel}} \propto s^{\varepsilon}$ or $\log^2(s)$

Cut Pomerons → Flux Tubes (strings)

Uncut Pomerons → Elastic (& eikonalization)

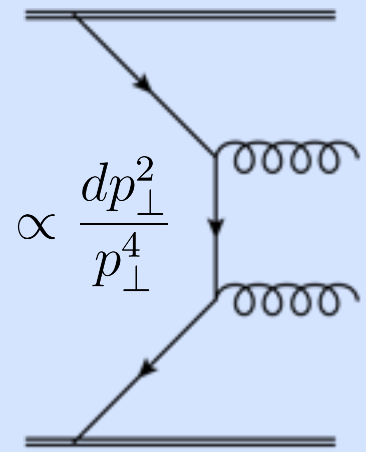
Cuts unify treatment of all soft processes

EL, SD, DD, … , ND

Perturbative contributions added above Q_0

B — Parton Based

$$d\sigma_{2\to2} \propto \frac{dp_\perp^2}{p_\perp^4} \otimes \mathrm{PDFs}$$



+ Unitarity & Saturation

→ Multi-parton interactions (MPI)

+ Parton Showers & Hadronization

Regulate $d\sigma$ at low $p_{T0} \sim$ few GeV

Screening/Saturation → energy-dependent p_{T0}

Total cross sections from Regge Theory

(Donnachie-Landshoff + Parametrizations)

+ "Mixed"

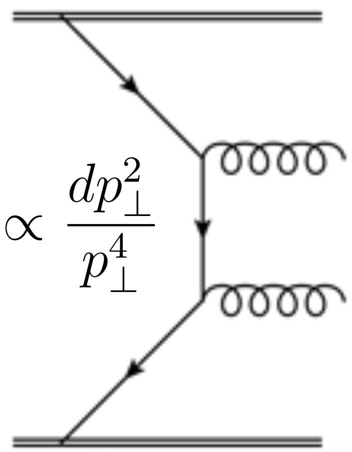
E.g., QGSJET

E.g., PHOJET, EPOS, SHERPA-KMR

E.g., PYTHIA, HERWIG, SHERPA, SIBYLL

Soft MPI

Starting Point: Perturbative QCD 2 → 2

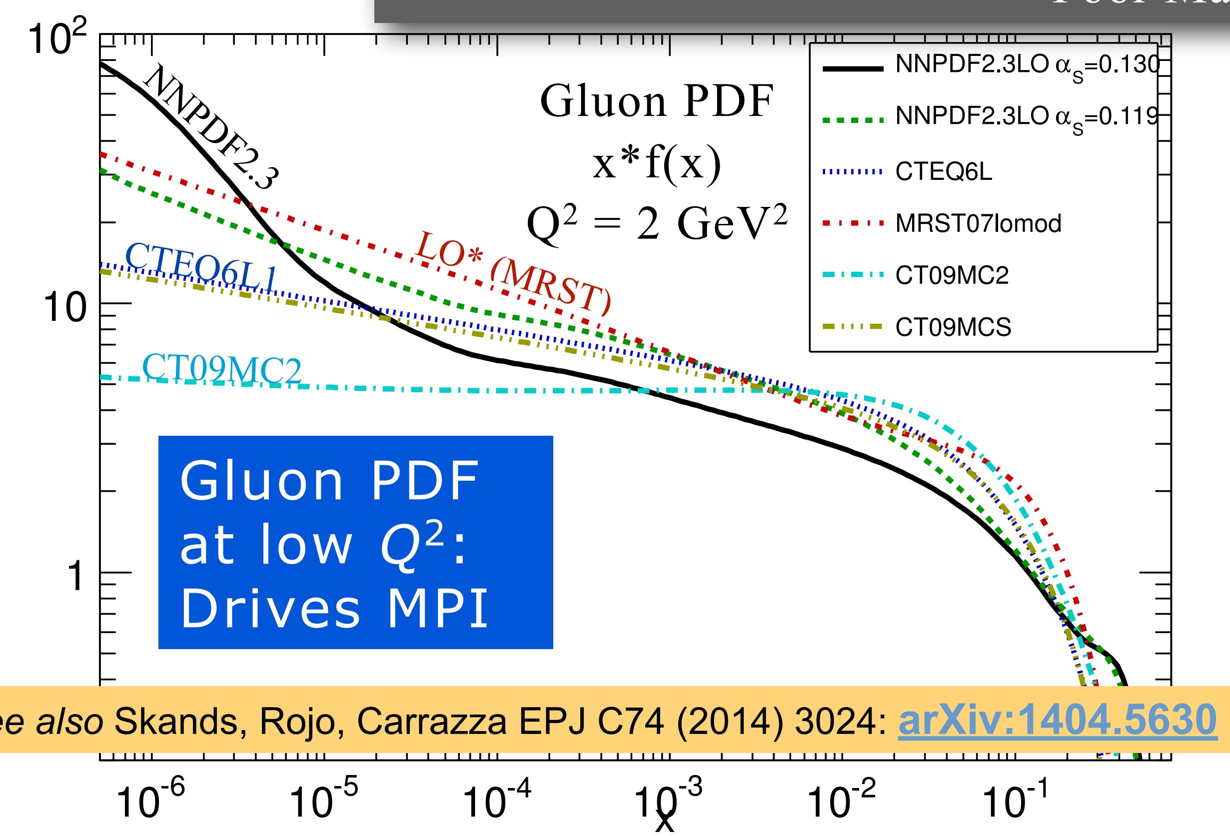
$$d\sigma_{2\to 2} \propto \frac{dp_\perp^2}{p_\perp^4}$$  $\otimes$ PDFs

Good at High Q^2 and finite x

Extrapolation to soft scales delicate.
Impressive successes with MPI-based models but still far from a solved problem

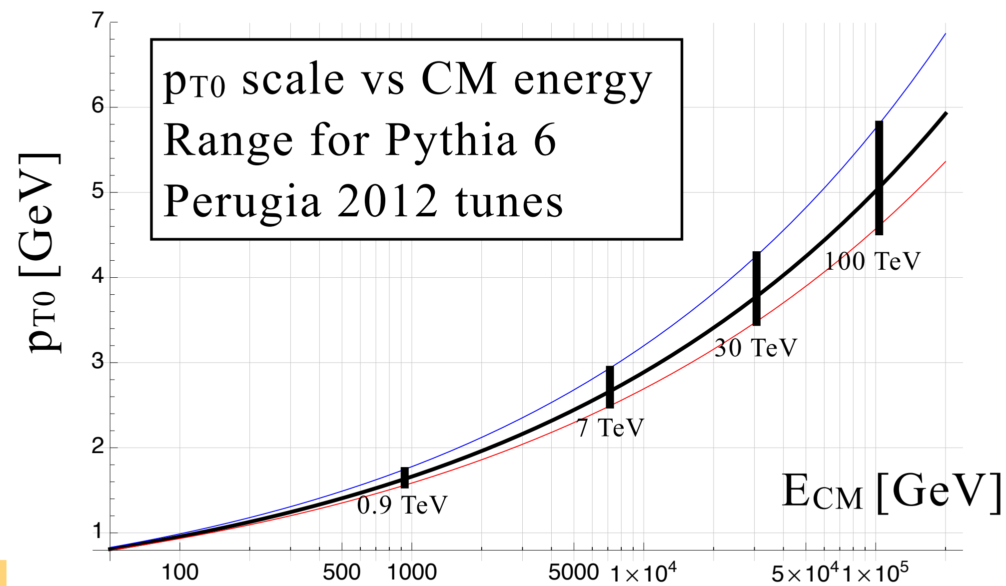
- Form of PDFs at small x and Q^2 ↔ Saturation
- Form and E_{cm} (and/or x) dependence of p_{T0} regulator ↔ Saturation
- Modeling of the diffractive component
- Proton transverse mass distribution
- Colour Reconnections, Collective Effects

Poor Man's Saturation



Gluon PDF at low Q^2: Drives MPI

See also Skands, Rojo, Carrazza EPJ C74 (2014) 3024: arXiv:1404.5630

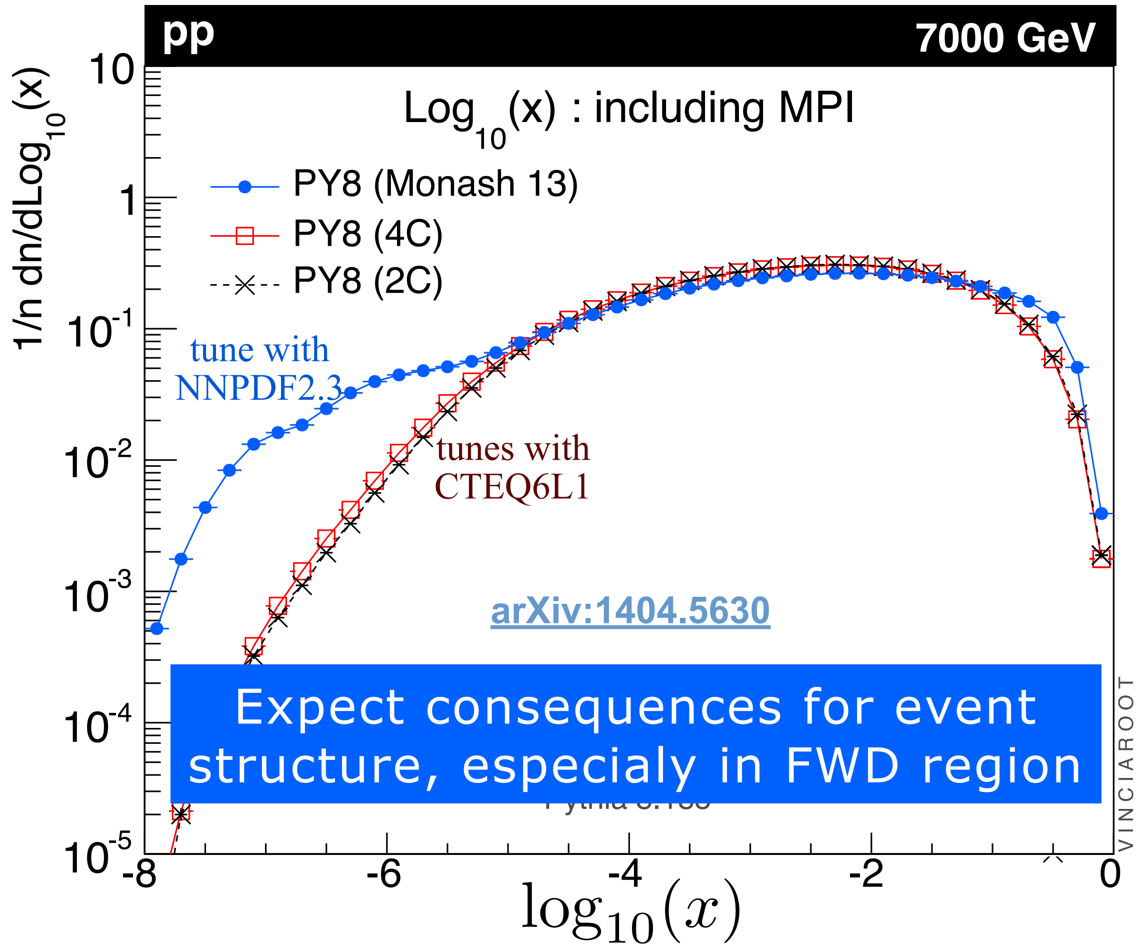


See also Connecting hard to soft: KMR, EPJ C71 (2011) 1617 + PYTHIA "Perugia Tunes": PS, PRD82 (2010) 074018

MPI models and Low x

What range of X values are actually probed?

EXAMPLE: PYTHIA 8
Range of x values probed by different MPI tunes



See also Skands, Rojo, Carrazza EPJ C74 (2014) 3024: arXiv:1404.5630

Controlling these issues will require an improved understanding of the interplay between low-x PDFs, saturation / screening, and MPI in MC context. (+ Clean model-independent experimental constraints!)

Warning: Not automatic: difficult cross-community communication (+ low visibility)

Monash 2013 Tune Highlights

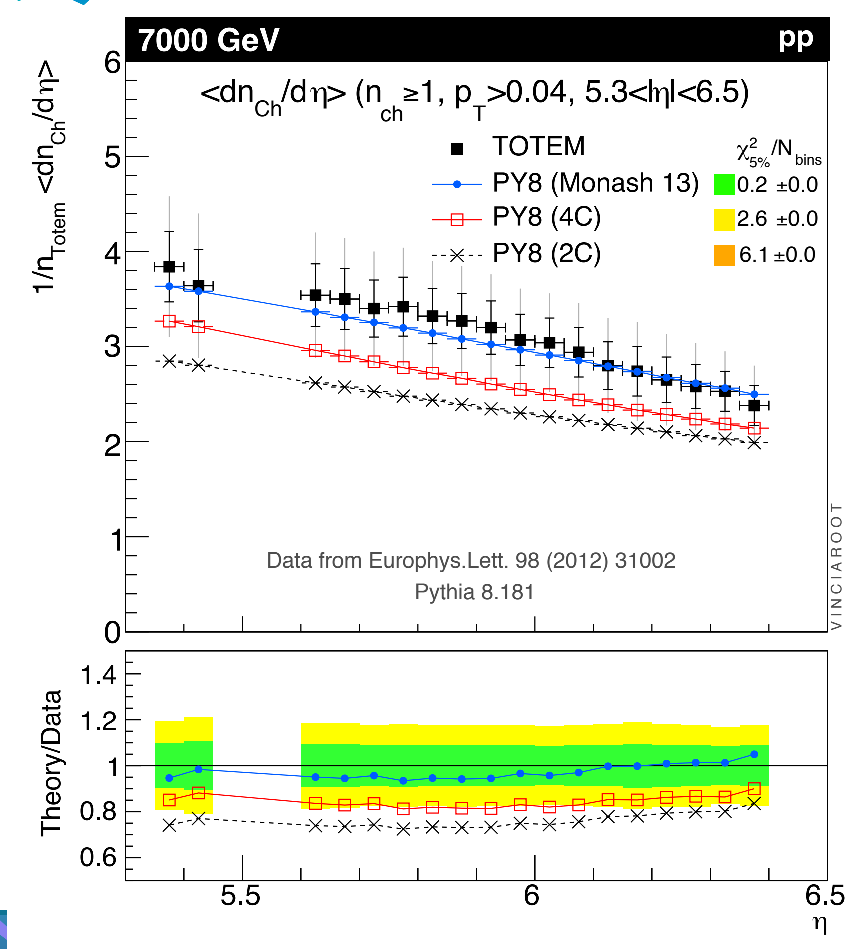
Monash 2013 Tune: Skands, Rojo, Carrazza EPJ C74 (2014) 3024: arXiv:1404.5630

10% more strangeness

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

More forward activity

LHC

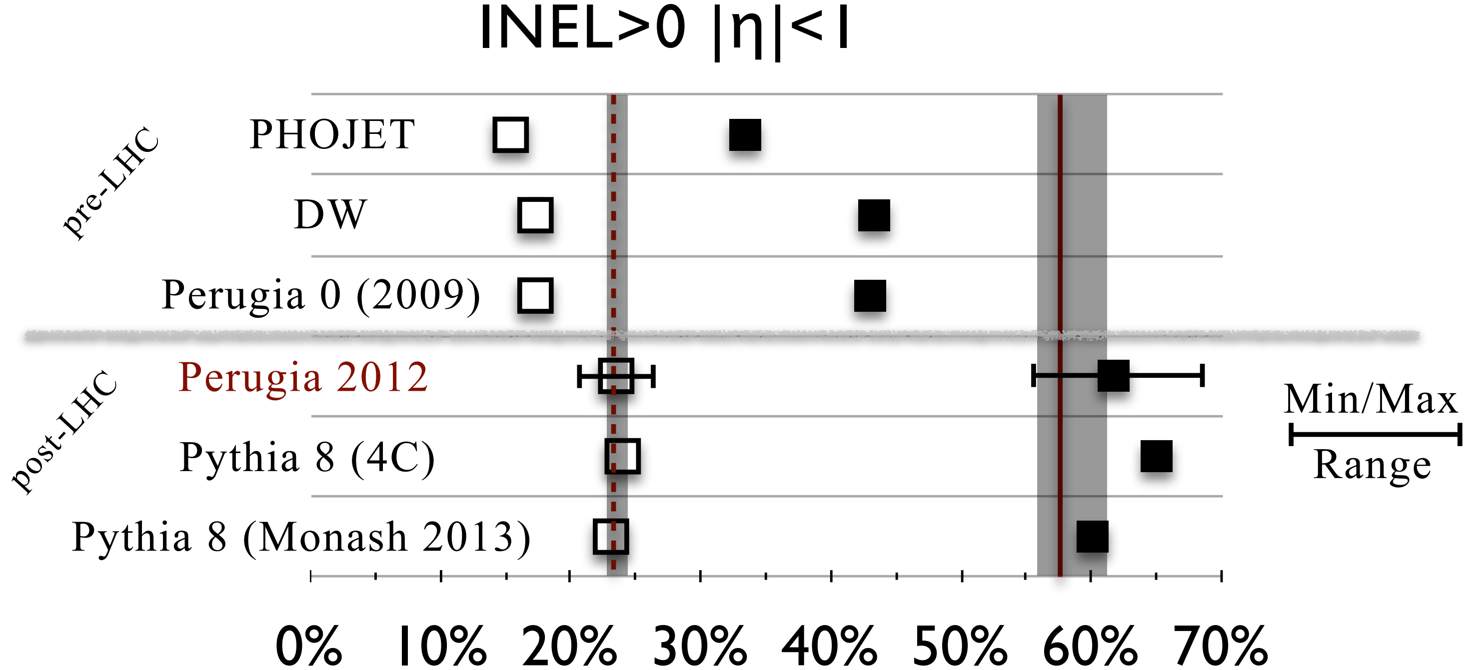


Better agreement with TOTEM N_{ch} and with forward E and ET flows. (Note: diffraction still needs tuning, and saturation not explicit)

Better CM-energy Scaling

LHC

A VERY SENSITIVE E-SCALING PROBE: relative increase in the central charged-track multiplicity from 0.9 to 2.36 and 7 TeV



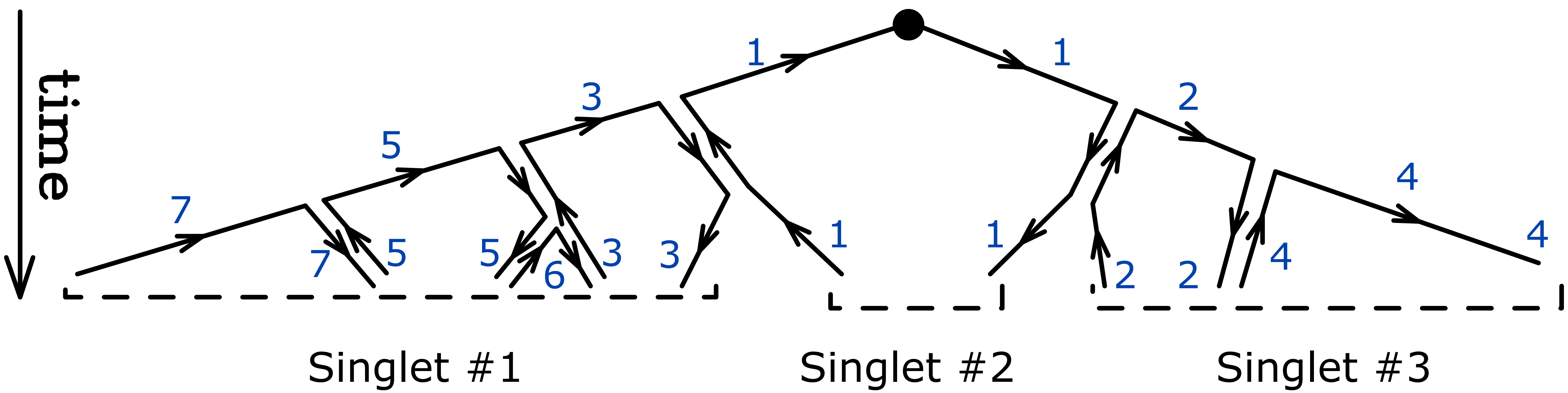
Data from ALICE EPJ C68 (2010) 345

Set M13 Tune: in PYTHIA 8 → Tune:ee = 7; Tune:pp = 14

Hadronization and Colour

Example of Color Flow in a Parton Cascade

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



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

Iterative String Breaks

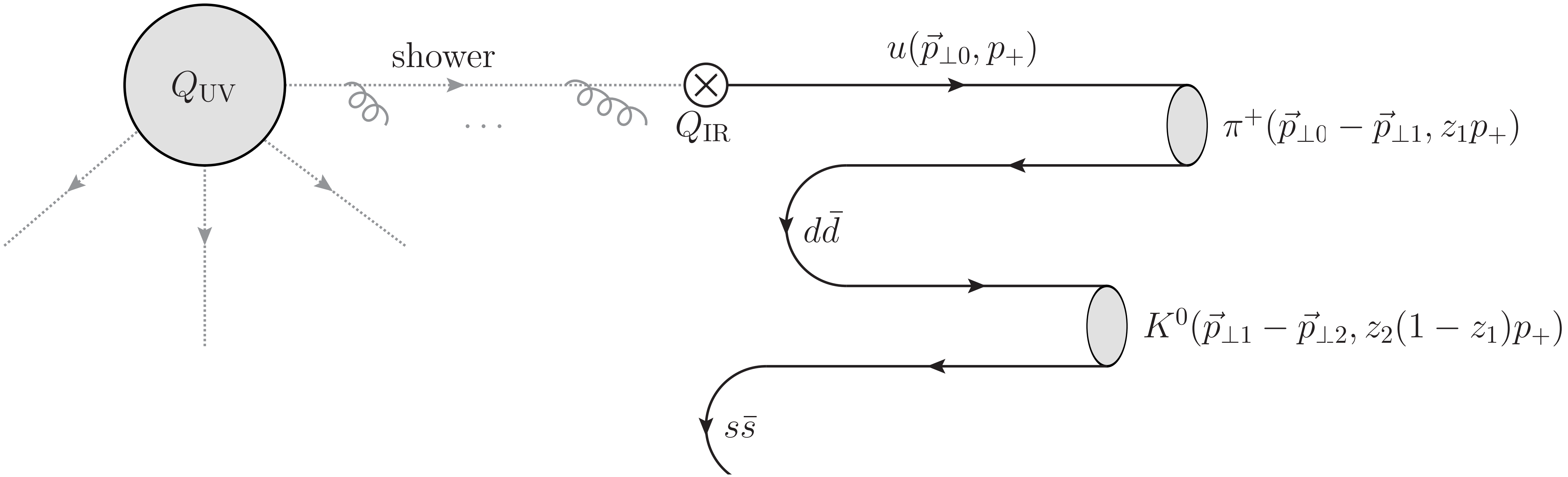
… the fragmentation of a fast parton into a jet …

Iterate String → Hadron + String'

Causality + Left-Right Symmetry:

$$f(z) \propto \frac{1}{z}(1-z)^a \exp\left(-\frac{b\,(m_h^2 + p_{\perp h}^2)}{z}\right)$$

Lund Symmetric String Fragmentation Function



The Lund

Low-x Issues (in MC/PDF context)

Low *x* : parton carries tiny fraction of beam energy.

E.g.: $x_\Lambda = \frac{2\Lambda_{\mathrm{QCD}}}{E_{\mathrm{CM}}}$ $\quad x_{\perp 0} = \frac{2p_{\perp 0}}{E_{\mathrm{CM}}}$

7 TeV: $x \sim 10^{-5}$ - 10^{-4}
100 TeV: $x \sim 10^{-6}$ - 10^{-4}

Higher *x* : momenta > Λ_{QCD}

→ pQCD ~ OK

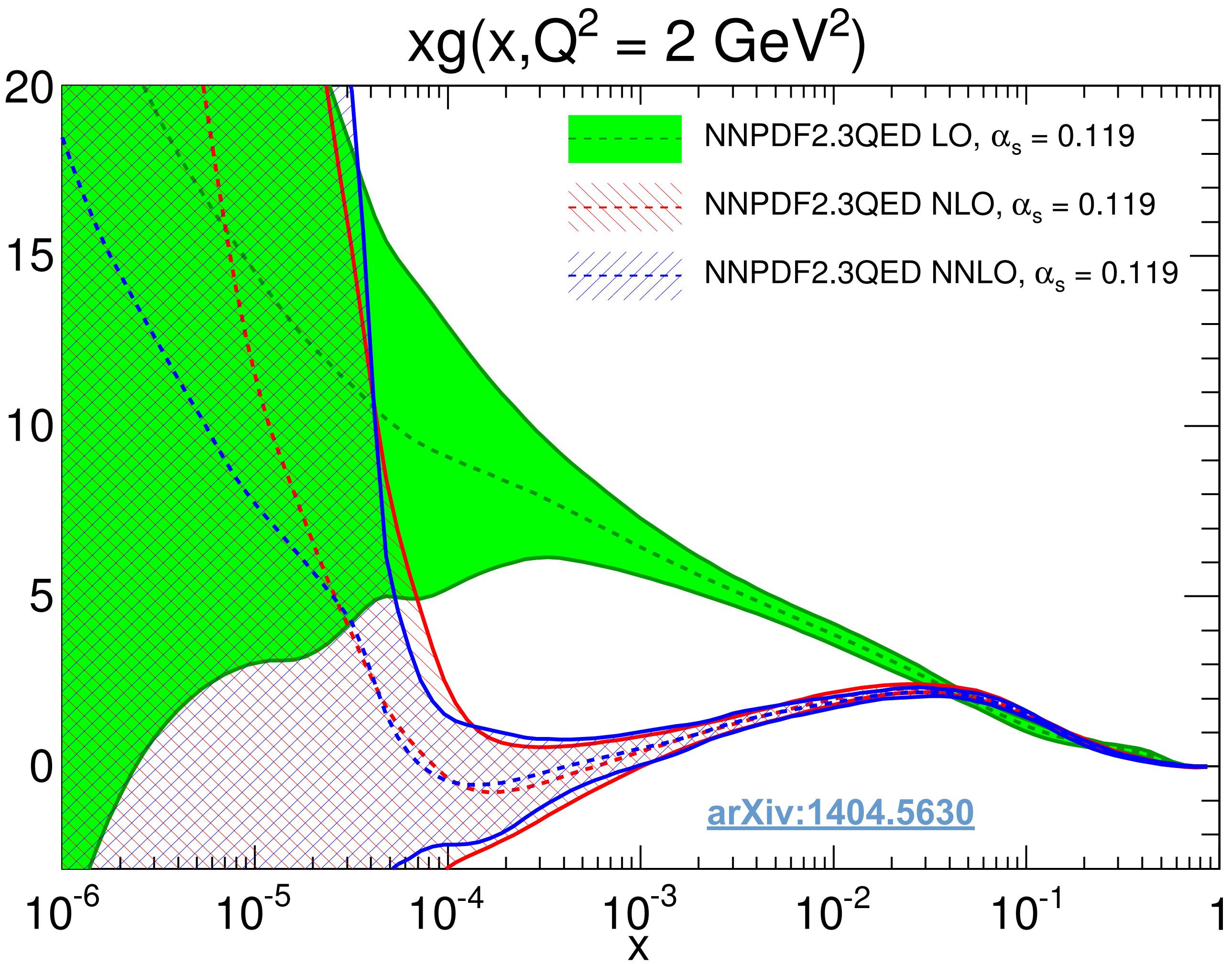
Smaller *x* : strong non-perturbative / colour-screening / saturation effects expected

What does a PDF even mean?

Highly relevant for MPI (& ISR)

PDF ***must*** be a probability density → can ***only*** use LO PDFs

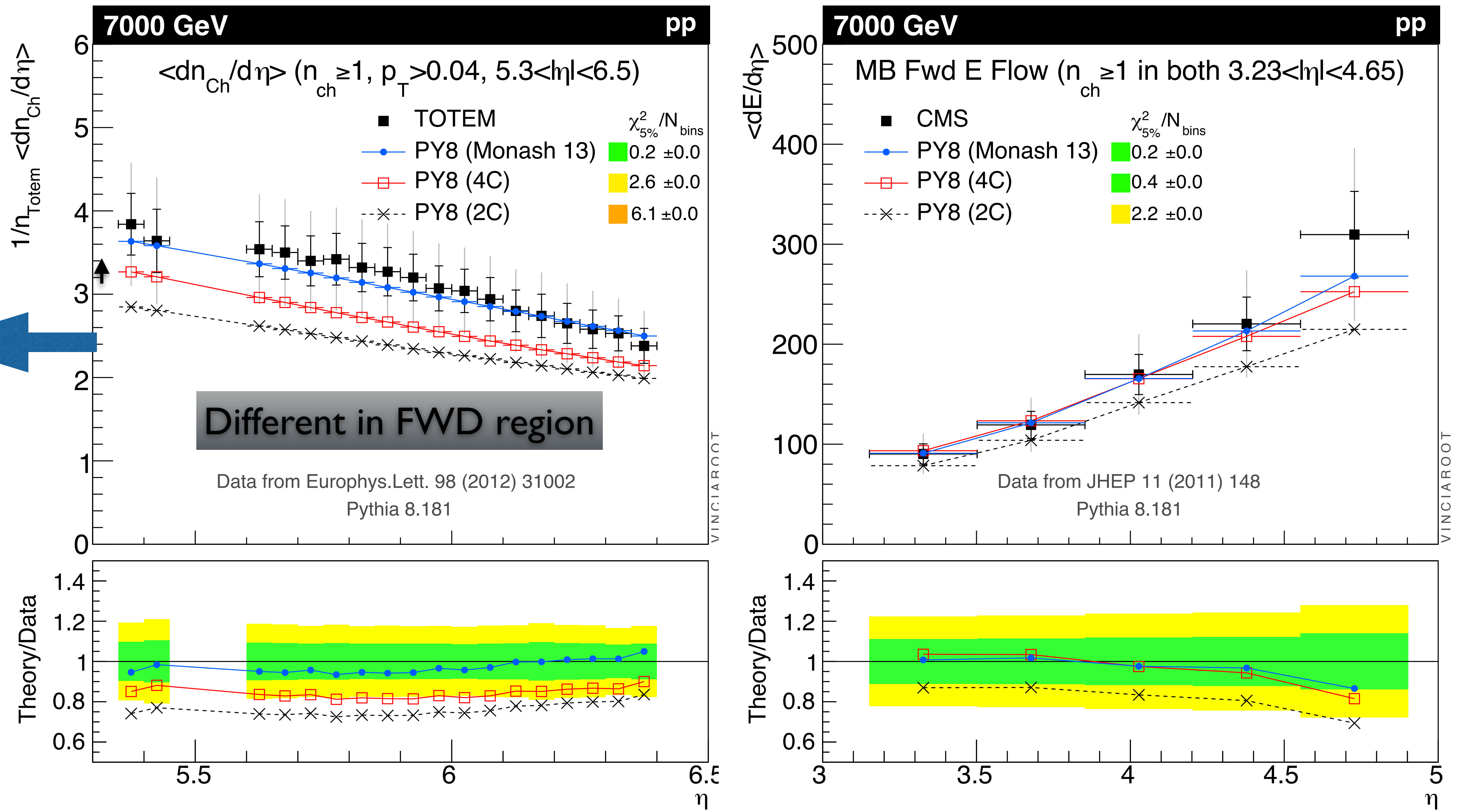
(+ Constraints below $x \sim 10^{-4}$ essentially just momentum conservation + flavour sum rules)



Examples: Nch and E Flow

4C and Monash 13 ~ same in central region

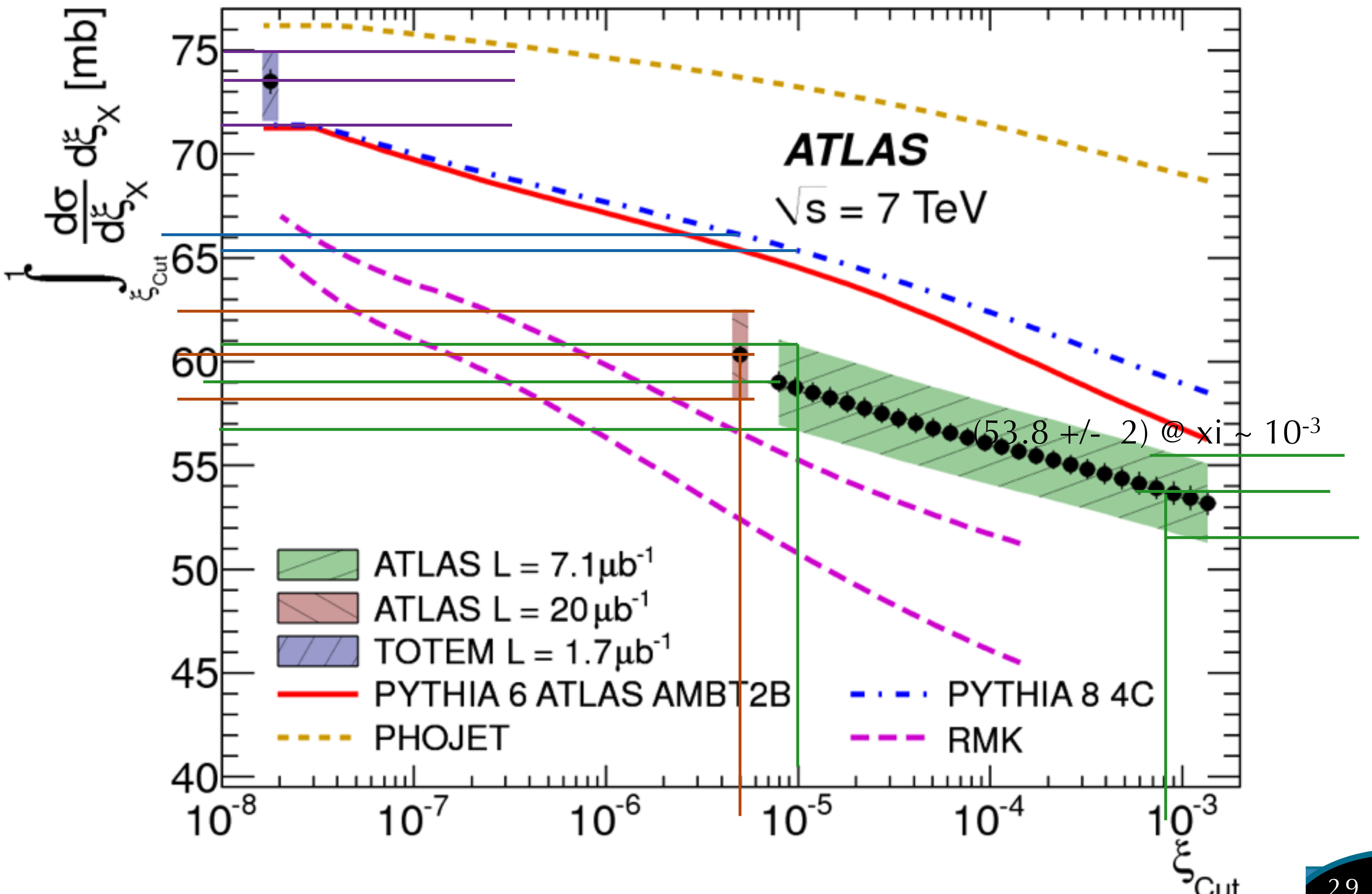
2<η<4.8 (LHCb): Eur. Phys. J. C: 74, 2014



Different in FWD region

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

Diffractive xi Spectrum



Single Diffraction

Eur. Phys. J. C (2013) 73:2456

Table 2 Measured 1-arm-L(R) to 2-arm ratios, and corresponding ratio of SD to INEL cross sections for three centre-of-mass energies. Corrected ratios include corrections for detector acceptance, efficiency, beam background, electronics noise, and collision pileup. The total corresponds to the sum of SD from the L-side and the R-side. The errors shown are systematic uncertainties. In the 1-arm-L(R) to 2-arm ratio, the uncertaities come from the estimate of the beam background. The uncertainty on the cross section ratio comes mainly from the efficiency error listed in Table 1. In all cases statistical errors are negligible

$\sqrt{s}$ (TeV)	Ratio definition	Ratio	Side	$\sigma_{SD}/\sigma_{INEL}$	
				Per side	Total
0.9	1-arm-L/2-arm	0.0576 ± 0.0002	L-side	0.10 ± 0.02	0.21 ± 0.03
	1-arm-R/2-arm	0.0906 ± 0.0003	R-side	0.11 ± 0.02	
2.76	1-arm-L/2-arm	0.0543 ± 0.0004	L-side	0.09 ± 0.03	$0.20^{+0.07}_{-0.08}$
	1-arm-R/2-arm	0.0791 ± 0.0004	R-side	$0.11^{+0.04}_{-0.05}$	
7	1-arm-L/2-arm	0.0458 ± 0.0001	L-side	$0.10^{+0.02}_{-0.04}$	$0.20^{+0.04}_{-0.07}$
	1-arm-R/2-arm	0.0680 ± 0.0001	R-side	$0.10^{+0.02}_{-0.03}$	

Their definition of NSD appears to be generator-level ("pure") NSD with a cut at M_X = 200 GeV/c^2

(alt def : $M_X^2 < 0.05s$)

Table 8 Proton–proton diffractive cross sections measured by ALICE at $\sqrt{s} = 0.9, 2.76$ and 7 TeV. Single diffraction is for $M_X < 200$ GeV/c^2 and double diffraction is for $\Delta\eta > 3$. The errors quoted are the total systematic uncertainties. Statistical errors are negligible

$\sqrt{s}$ (TeV)	σ_{SD} (mb)	σ_{DD} (mb)
0.9	$11.2^{+1.6}_{-2.1}$(syst)	5.6 ± 2.0(syst)
2.76	$12.2^{+3.9}_{-5.3}$(syst) ± 0.2(lumi)	7.8 ± 3.2(syst) ± 0.2(lumi)
7	$14.9^{+3.4}_{-5.9}$(syst) ± 0.5(lumi)	9.0 ± 2.6(syst) ± 0.3(lumi)

erators are referred to as "tuned for diffraction". Typically, $\sigma_{SD}/\sigma_{INEL} \approx 0.20$, where σ_{INEL} is the inelastic cross-section, σ_{SD} is the SD cross-section for $M_X < 200$ GeV/c^2, and $\sigma_{DD}/\sigma_{INEL} \approx 0.11$, where σ_{DD} is the double diffraction cross-section for $\Delta\eta > 3$ ($\Delta\eta$ is the size of the particle gap in the pseudorapidity distribution). These fractions have insignificant energy dependence between 0.9 and 7 TeV [50], and the values at 7 TeV were used for 8 TeV data.

Ecm	mX	xi	xi
200	200	1.000	1.0E+00
500	200	0.160	1.6E-01
900	200	0.049	4.9E-02
2760	200	0.0053	5.3E-03
7000	200	0.00082	8.2E-04
13000	200	0.00024	2.4E-04
100000	200	0.0000040	4.0E-06

Ecm	xi	mX	xi	mX	xi	mX
900	0.05	201	5.0E-06	2.0	1.0E-03	28.5
2760	0.05	617	5.0E-06	6.2	1.0E-03	87.3
7000	0.05	1565	5.0E-06	15.7	1.0E-03	221.4
13000	0.05	2907	5.0E-06	29.1	1.0E-03	411.1
100000	0.05	22361	5.0E-06	223.6	1.0E-03	3162.3

Double Diffraction

DD: defined (ALICE) as NSD events with a gap anywhere in the full phase space larger than 3 pseudorapidity units. They note that up to 50% of these can be events flagged as ND by the generator.

Table 4 Cross section ratios of DD with $\Delta\eta > 3$ to inelastic events, at $\sqrt{s} = 0.9$, 2.76 and 7 TeV. The errors shown are systematic uncertainties calculated in a similar way to that for Table 1, in all cases statistical errors are negligible

$\sqrt{s}$ (TeV)	$\sigma_{\mathrm{DD}}/\sigma_{\mathrm{INEL}}$
0.9	0.11 ± 0.03
2.76	0.12 ± 0.05
7	$0.12^{+0.05}_{-0.04}$

From Beate:
ATLAS has measured the total inelastic cross section using roman pots as 71.34+-0.90mb [arXiv:1408.5778]. ATLAS has also measured the inelastic cross section for xi>5x10^-6 (or mX>15.7 GeV) and found 60.3+-2.1 mb [arXiv:1104.0326]. So, the cross section for x<5x10^-6 is 11.0+-2.3 mb. Pythia predicts only 6 mb, and so disagrees by more than 2sigma. Using the DL model with the default parameter choice (epsilon=0.085, alpha'=0.25) gives a good description [see discussion on p34 of arxiv:1408.5778).

ALICE

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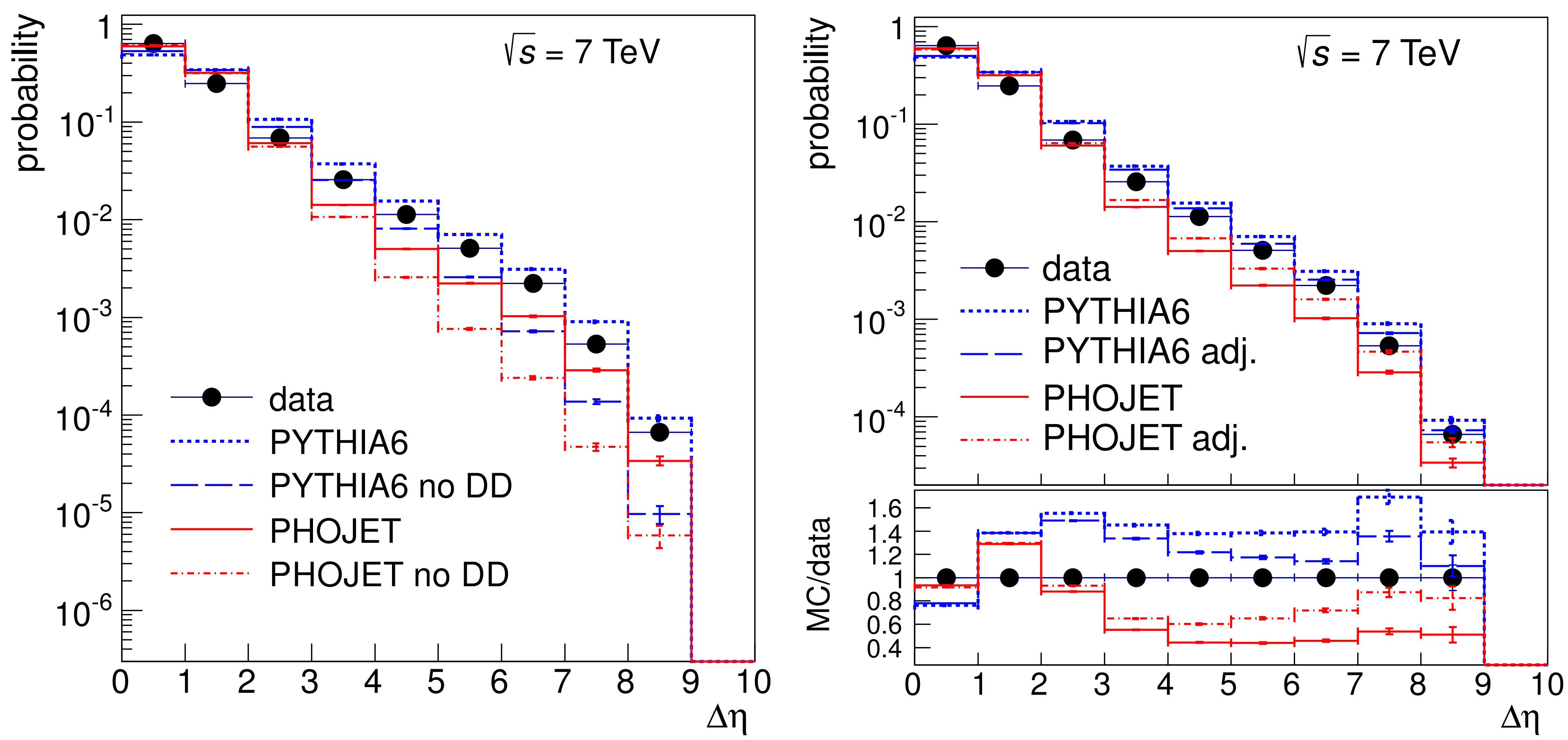
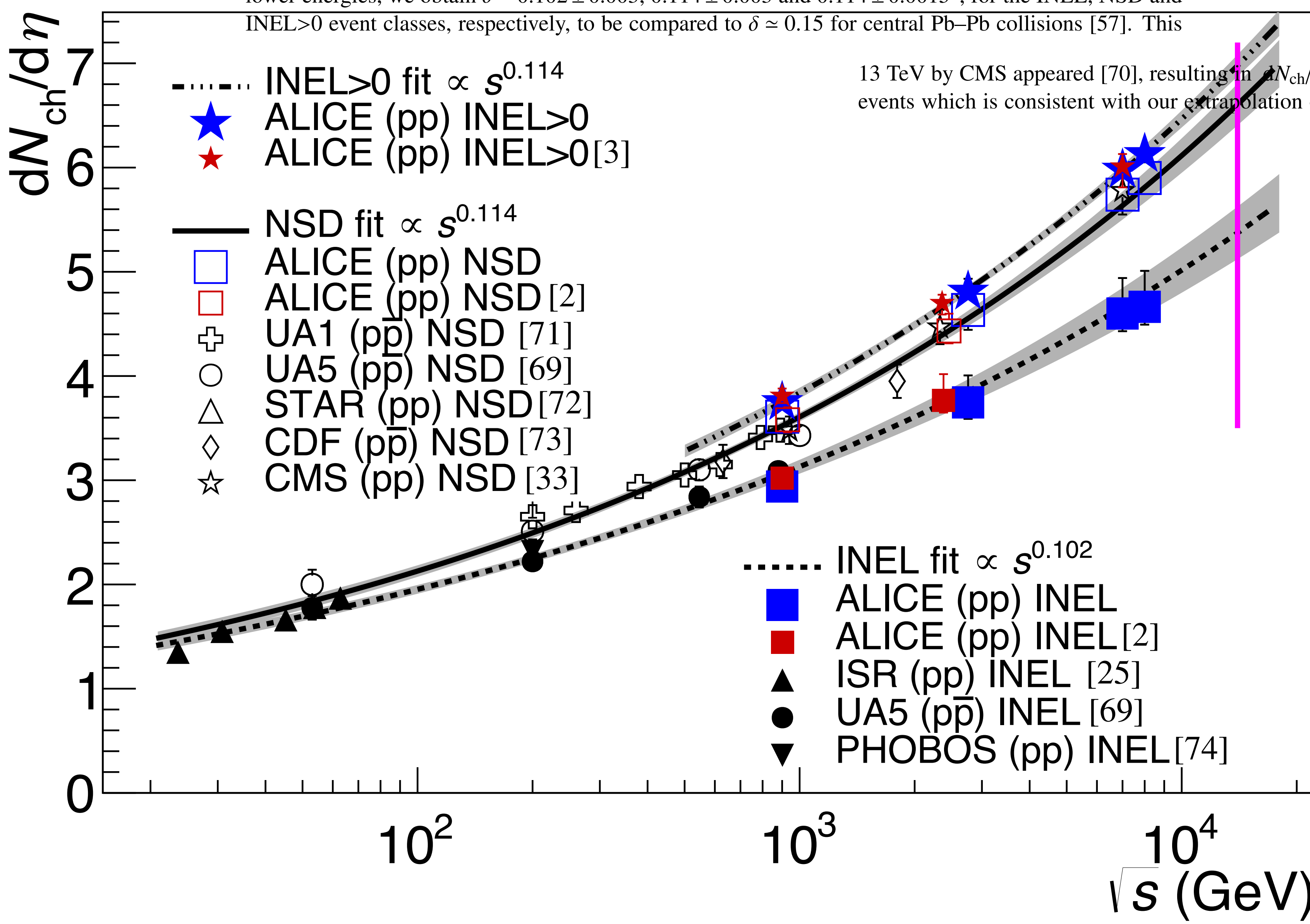


ALICE + CMS

Growth in multiplicity with energy http://arxiv.org/pdf/1509.07541.pdf

lower energies, we obtain $\delta = 0.102 \pm 0.003$, 0.114 ± 0.003 and 0.114 ± 0.0015[7], for the INEL, NSD and INEL>0 event classes, respectively, to be compared to $\delta \simeq 0.15$ for central Pb–Pb collisions [57]. This



13 TeV by CMS appeared [70], resulting in $dN_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01$ (stat) ± 0.17 (syst) for inelastic events which is consistent with our extrapolation of 5.30 ± 0.24. Over the LHC energy range, from 0.9

$\sqrt{s}$ (TeV)	INEL	NSD	INEL>0
0.9	$2.94^{+0.11}_{-0.05}$	$3.61^{+0.17}_{-0.16}$	$3.75^{+0.06}_{-0.05}$
2.36[6]	$3.77^{+0.25}_{-0.12}$	$4.43^{+0.17}_{-0.12}$	—
2.76	$3.75^{+0.26}_{-0.16}$	$4.63^{+0.30}_{-0.19}$	$4.76^{+0.08}_{-0.07}$
7	$4.60^{+0.34}_{-0.17}$	$5.74^{+0.15}_{-0.15}$	$5.98^{+0.09}_{-0.07}$
8	$4.66^{+0.35}_{-0.17}$	$5.90^{+0.15}_{-0.13}$	$6.13^{+0.10}_{-0.08}$

(integral of the data over $|\eta| < 0.5$),

ALICE fit predictions

$\sqrt{s}$ (TeV)	INEL	NSD	INEL>0
13	5.30 ± 0.24	6.50 ± 0.20	6.86 ± 0.10
13.5	5.33 ± 0.25	6.56 ± 0.20	6.92 ± 0.10
14	5.37 ± 0.25	6.62 ± 0.20	6.98 ± 0.10

CMS sees a slightly higher multiplicity

13 TeV by CMS appeared [70], resulting in $dN_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01$ (stat) ± 0.17 (syst) for inelastic events which is consistent with our extrapolation of 5.30 ± 0.24. Over the LHC energy range, from 0.9