Peter Skands
CERN Theoretical Physics

Constraints on MC models from forward multiplicity observables

TOTEM Collaboration Meeting, Dec 6 2011, CERN

Terminology

$\sigma_{tot} \approx$		EXPERIMENT		THEORY MODELS
ELASTIC	pp→pp	QED+QCD	~	(*QED = ∞)
SINGLE DIFFRACTION	pp→p+gap+X	Fiducial region, identified proton, and/or observable gap	≠	SD model: Small gaps suppressed but not zero
DOUBLE DIFFRACTION	pp→X+gap+X		≠	DD model: Small gaps suppressed but not zero
INELASTIC NON-DIFFRACTIVE	pp→X (no gap)		≠	Large gaps suppressed but not zero

(+ multi-gap diffraction)

Min-Bias, Zero Bias, Single-Gap, etc.

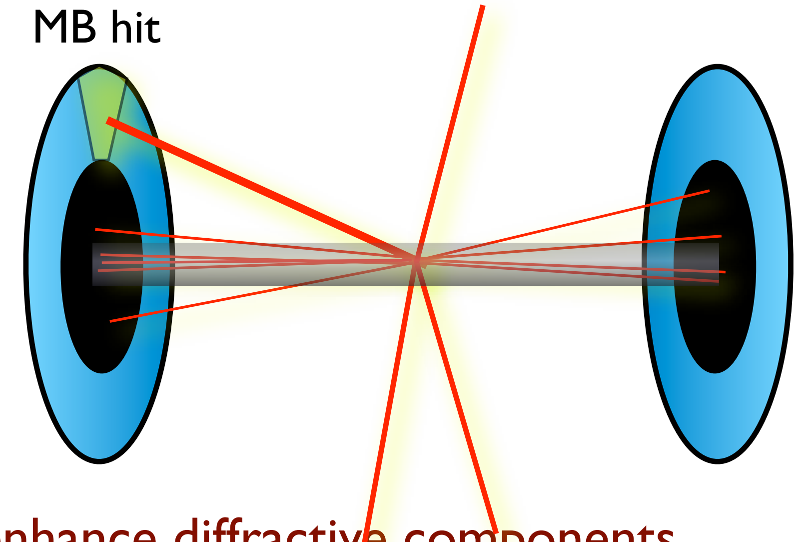
= Experimental trigger conditions **(hardware-dependent)**

Corrected to hardware-independent reference conditions

"Theory" for Min-Bias?

Really = Model for ALL INELASTIC incl diffraction **(model-dependent)**

Impose model-independent reference conditions to suppress or enhance diffractive components



… in minimum-bias, we typically do not have a hard scale, wherefore *all* observables depend significantly on IR physics …

PS, "Tuning MC Generators: the Perugia tunes", PRD82(2010)074018

QCD Models

A

A) Start from pQCD. Extend towards Infrared.
HERWIG/JIMMY, PYTHIA, SHERPA, EPOS

Elastic & Diffractive
Treated as separate class
No predictivity

Color Screening
Regularization of pQCD

Unitarity
Multiple 2→2
(MPI)

Quarks, Gluons
pQCD
2→2 (Rutherford)

Strings span entire rapidity region → Constraints in forward region impact global description.

PYTHIA uses **string fragmentation**, HERWIG & SHERPA use **cluster fragmentation**

Elastic — Min-Bias — Dijets

0 — Λ_{QCD} — 5 GeV — ∞

B

B) Start from Optical Theorem & Unitarity. Extend towards Ultraviolet.
PHOJET, DPMJET, QGSJET, SIBYLL, …

Hadrons
Optical Theorem
pp→pp

Pomerons: Diffraction
Cut Pomerons: Non-diffractive (soft)

Hard Pomeron?

Note: PHOJET & DPMJET use **string fragmentation** (from PYTHIA) → some overlap

Multi-Parton Interactions

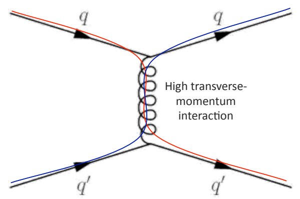
pQCD

2→2

= Sum of

$qq' \to qq'$
$q\bar{q} \to q'\bar{q}'$
$q\bar{q} \to gg$
$qg \to qg$
$gg \to gg$
$gg \to q\bar{q}$

≈ Rutherford
(t-channel gluon)



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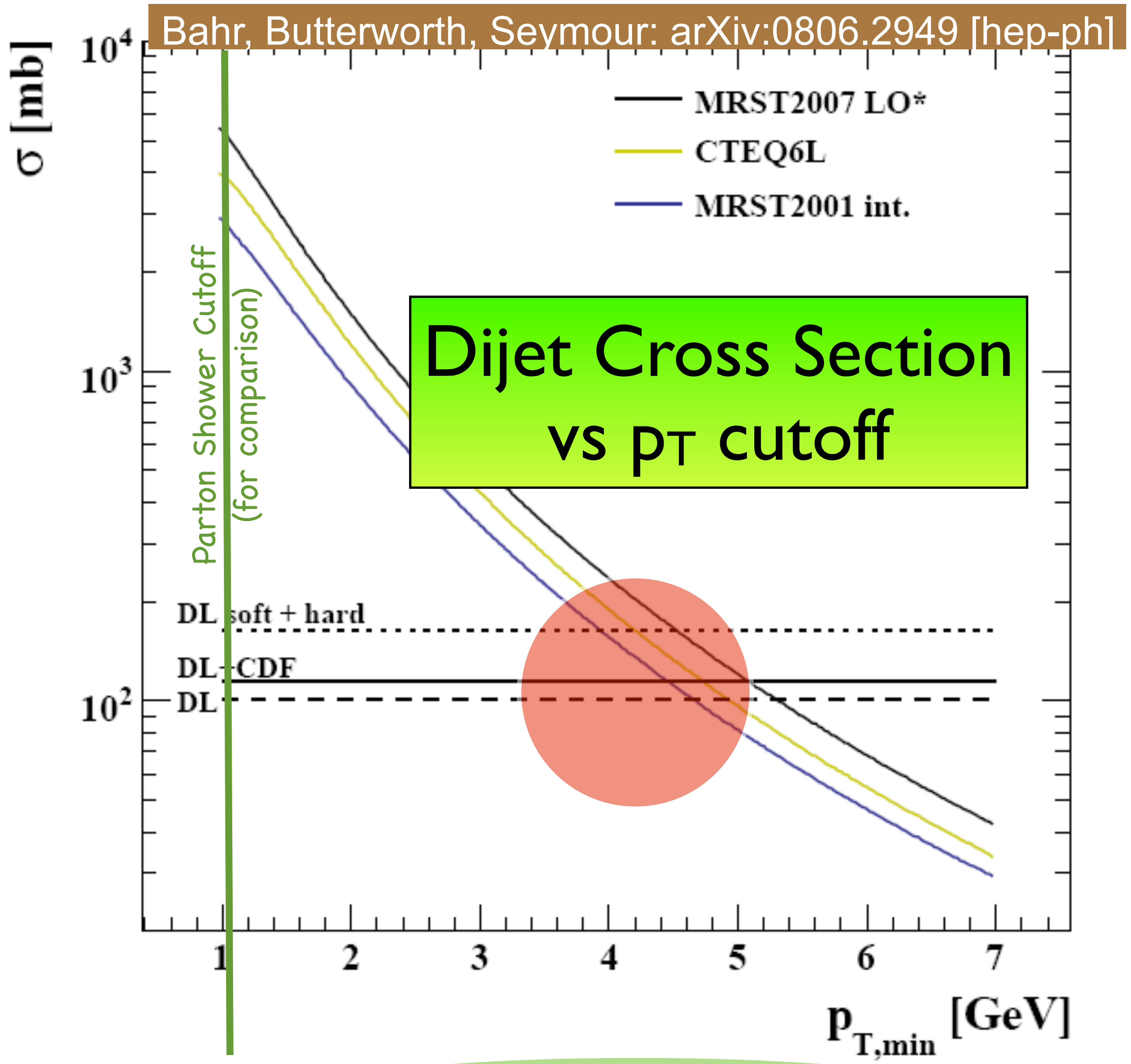


$$\Rightarrow \quad \sigma_{2\to 2}(p_{\perp\min}) = \langle n \rangle (p_{\perp\min})\ \sigma_{tot}$$

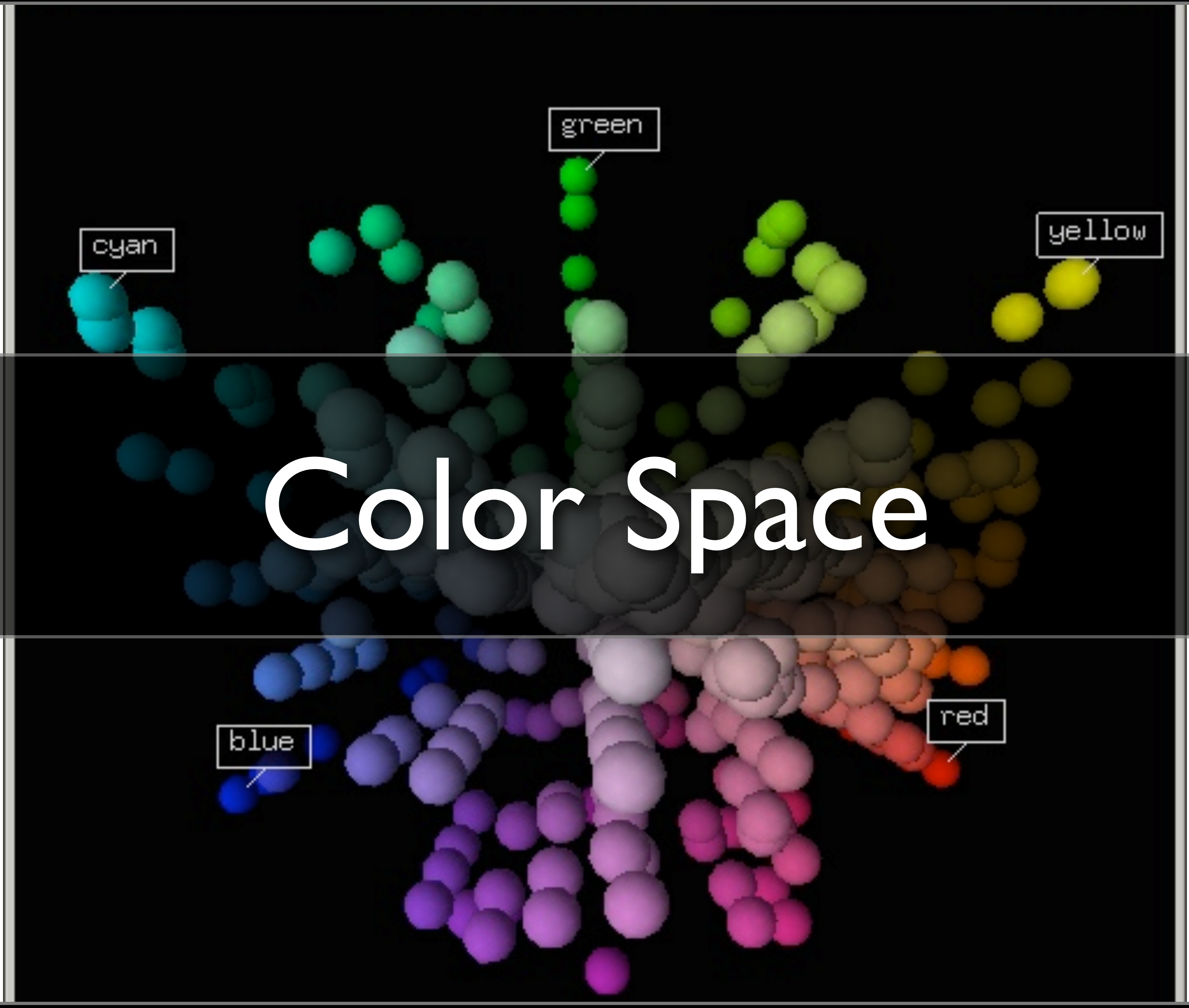
Becomes larger than total pp cross section?

At $p_\perp \approx 5$ GeV

Lesson from bremsstrahlung in pQCD: divergences → fixed-order unreliable, but resummation → pQCD still ok (unitarity)

→ Resum dijets?
Yes → MPI!

Color Space



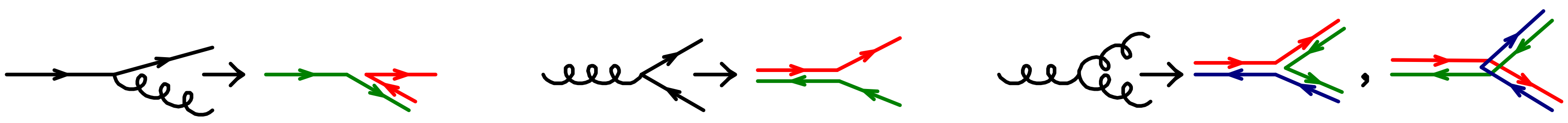
Color Flow in MC Models

"Planar Limit"

Equivalent to $N_C \to \infty$: no color interference*

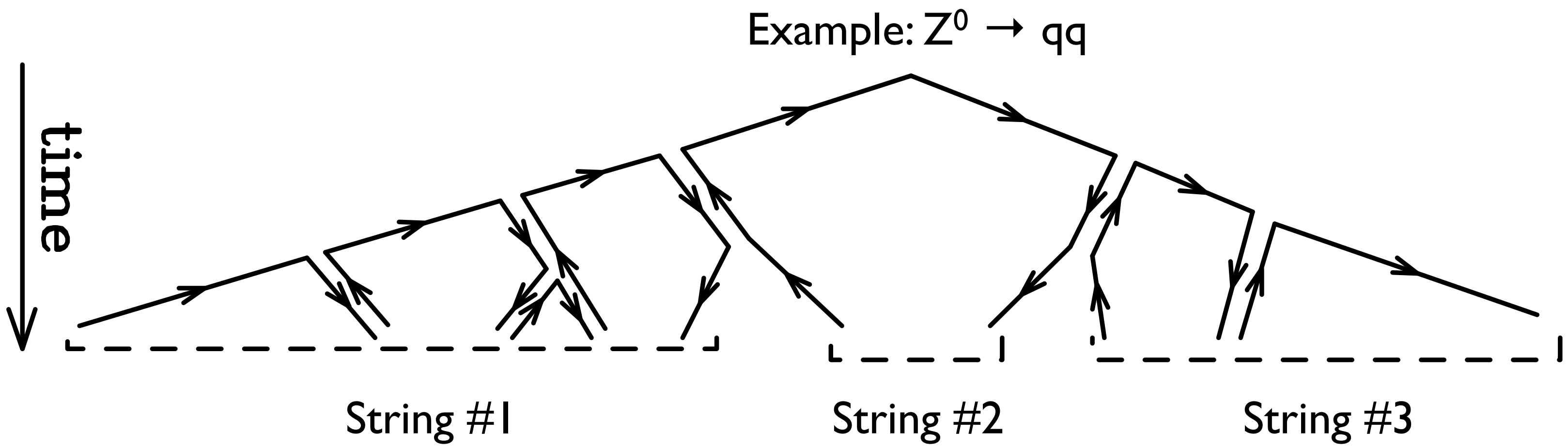
*) except as reflected by the implementation of QCD coherence effects in the Monte Carlos via angular or dipole ordering

Rules for color flow:



For an entire cascade:

Illustrations from: Nason + PS, PDG Review on *MC Event Generators*, 2012



Coherence of pQCD cascades → not much "overlap" between strings
→ planar approx pretty good
LEP measurements in WW confirm this (at least to order 10% ~ $1/N_c^2$)

Color Connections

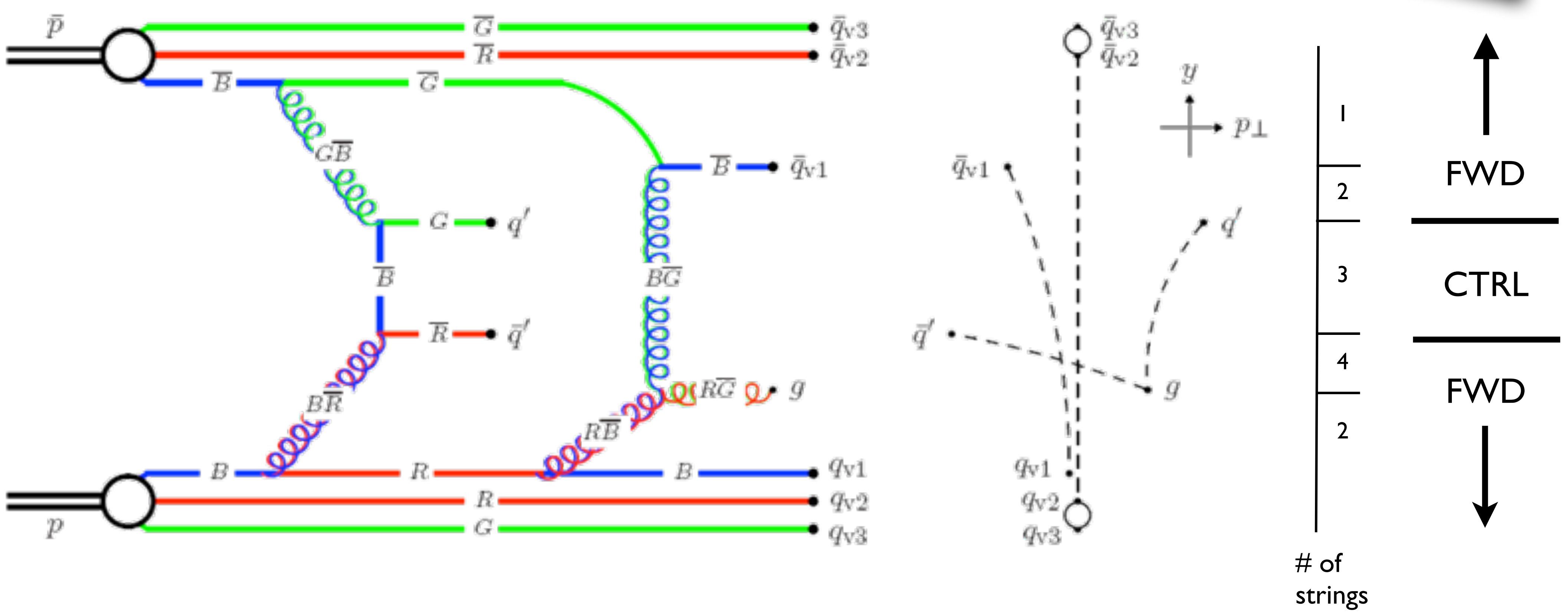
Questions

Each MPI (or cut Pomeron) exchanges color between the beams

▶ The colour flow determines the hadronizing string topology

- Each MPI, even when soft, is a color spark
- Final distributions crucially depend on color space

Different models make different ansätze



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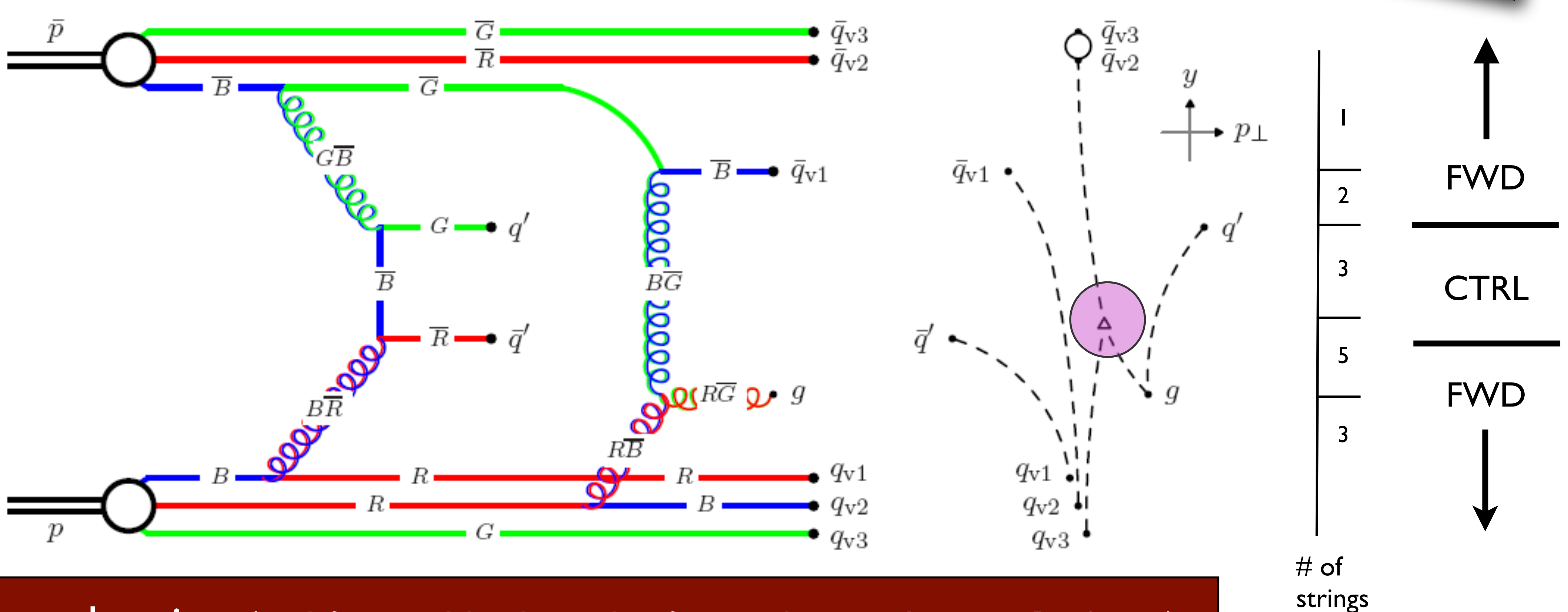
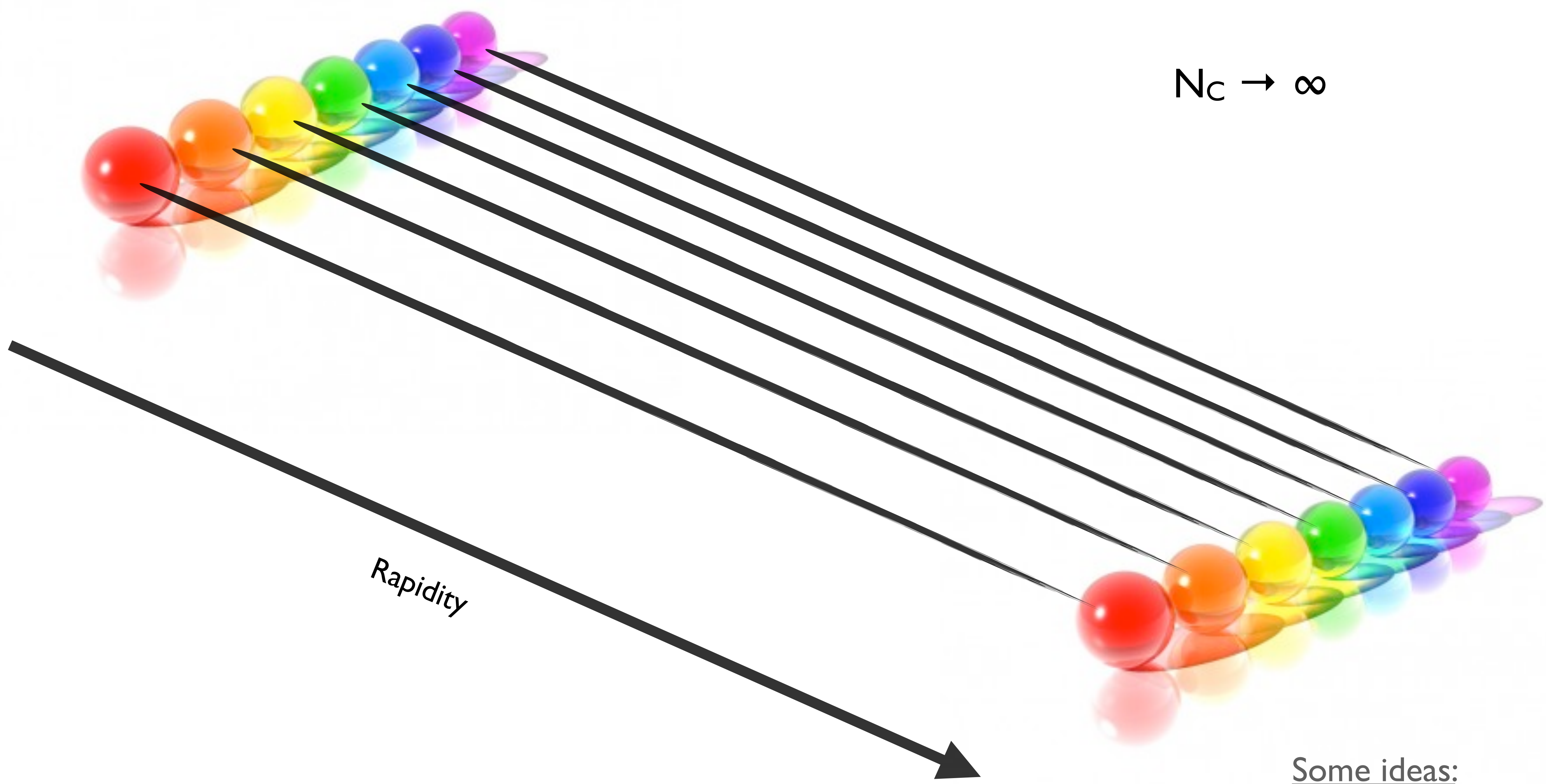


Forward region (and forward-backward + forward-central **correlations**) sensitive to beam-remnant break-up!

Color Reconnections?



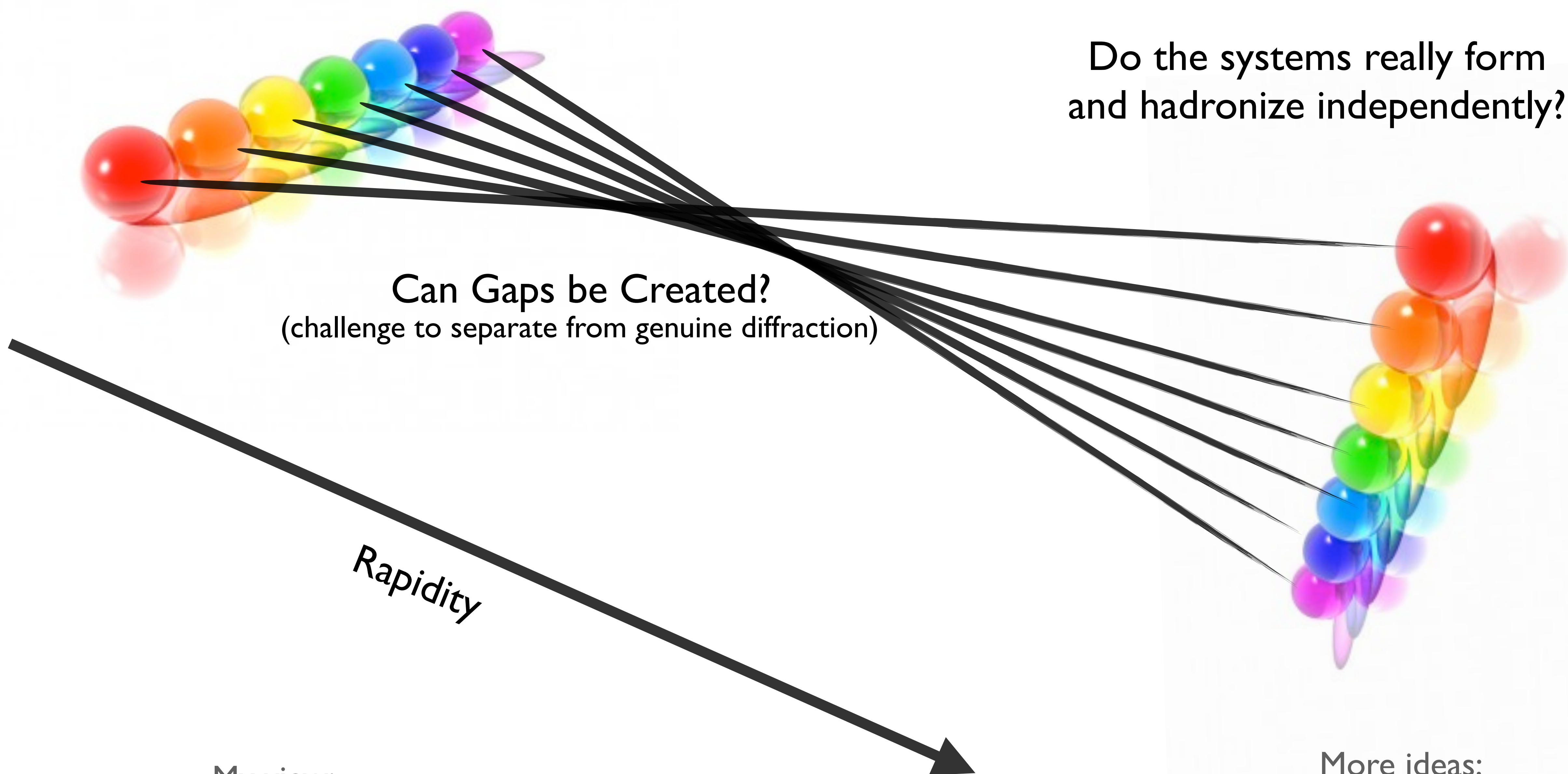
$N_C \to \infty$

Multiplicity $\propto N_{MPI}$

Some ideas:
Hydro? (EPOS)
E-dependent string parameters? (DPMJET)
"Color Ropes"?

Color Reconnections?

Do the systems really form and hadronize independently?



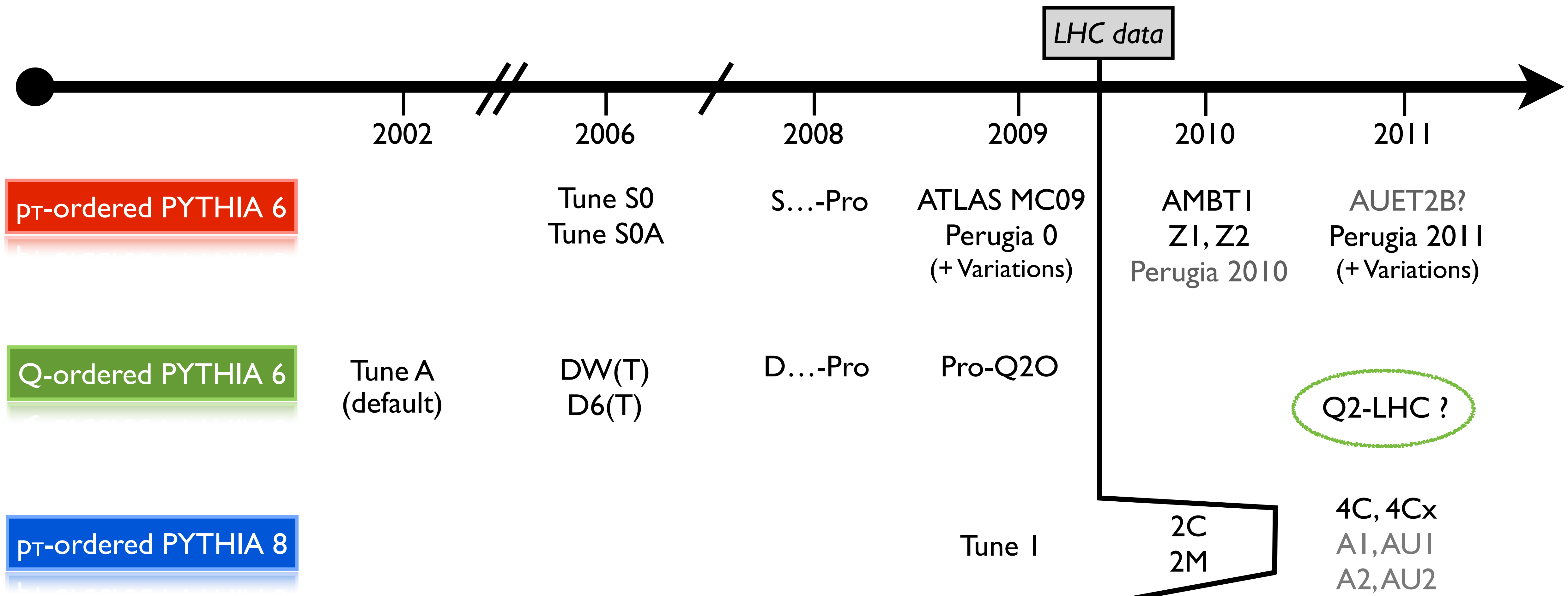
Can Gaps be Created?
(challenge to separate from genuine diffraction)

<u>My view:</u>
Universality is ok *(a string is a string)*
Problem is $3 \neq \infty$

Multiplicity $\overset{<}{\not\propto} N_{MPI}$

<u>More ideas:</u>
Coherent string formation?
Color reconnections?
String dynamics?

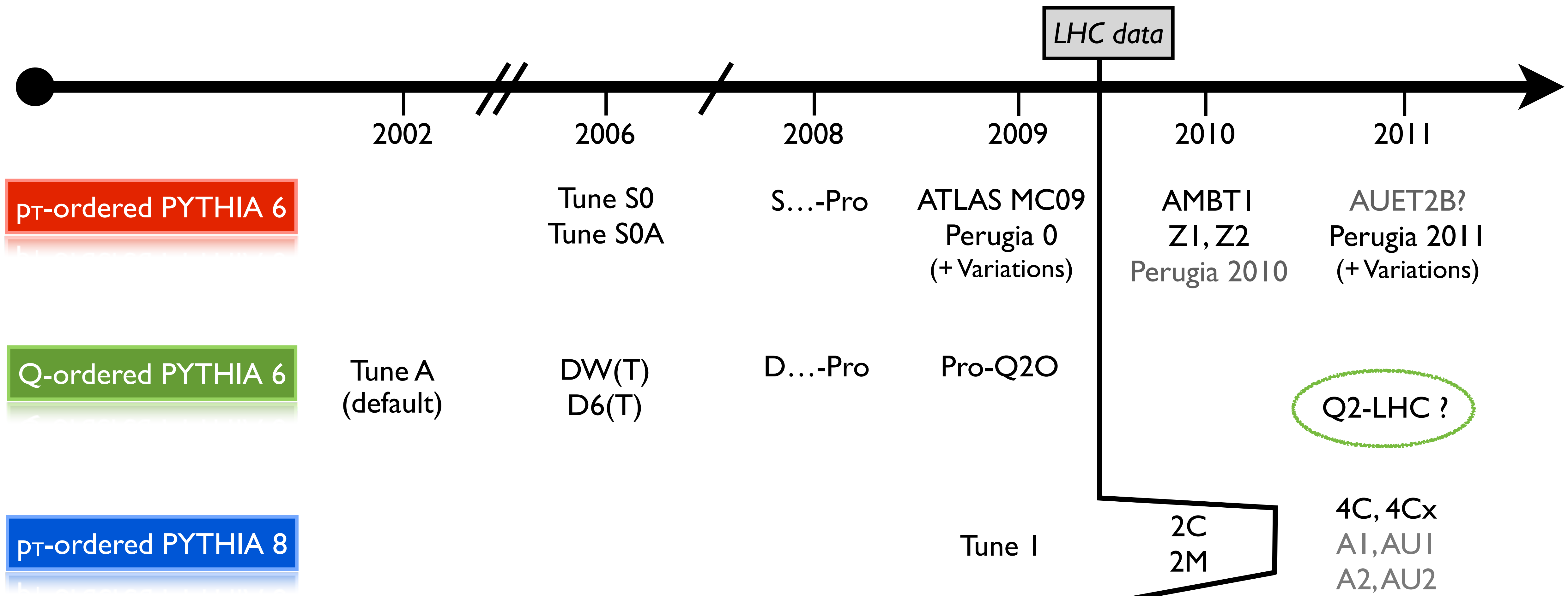
PYTHIA Models



Main Data Sets included in each Tune (no guarantee that all subsets ok)

	A	DW, D6, ...	S0, S0A	MC09(c)	Pro-..., Perugia 0, Tune 1, 2C, 2M	AMBT1	Perugia 2010	Perugia 2011	Z1, Z2	4C, 4Cx	AUET2B, A2, AU2
LEP					✔		✔	✔		✔	✔
TeV MB			✔	✔	✔		✔	✔		(✔)	?
TeV UE	✔	✔		✔	✔		✔	✔		(✔)	✔?
TeV DY		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
LHC MB						✔	✔	✔		✔	?
LHC UE								✔	✔		✔

PYTHIA Models



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LEP					✔		✔	✔		✔	✔
TeV MB			✔	✔	✔		✔	✔		(✔)	?
TeV UE	✔	✔		✔	✔		✔	✔		(✔)	✔?
TeV DY		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
LHC MB						✔	✔	✔		✔	?
LHC UE								✔	✔		✔

Diffraction (in PYTHIA 8)

Navin, arXiv:1005.3894

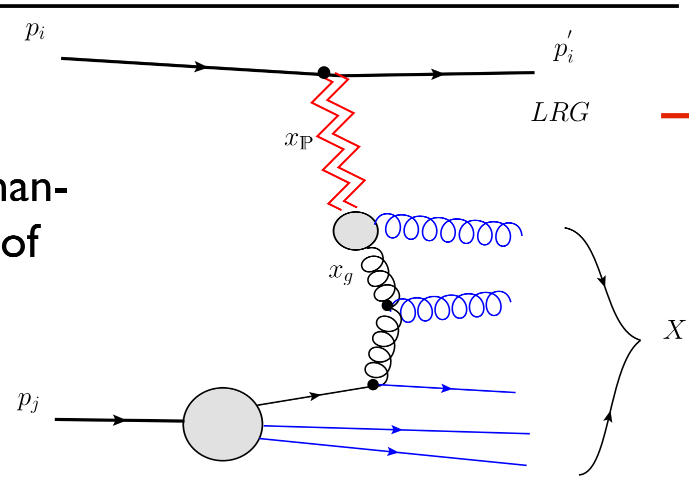
Diffractive Cross Section Formulæ:

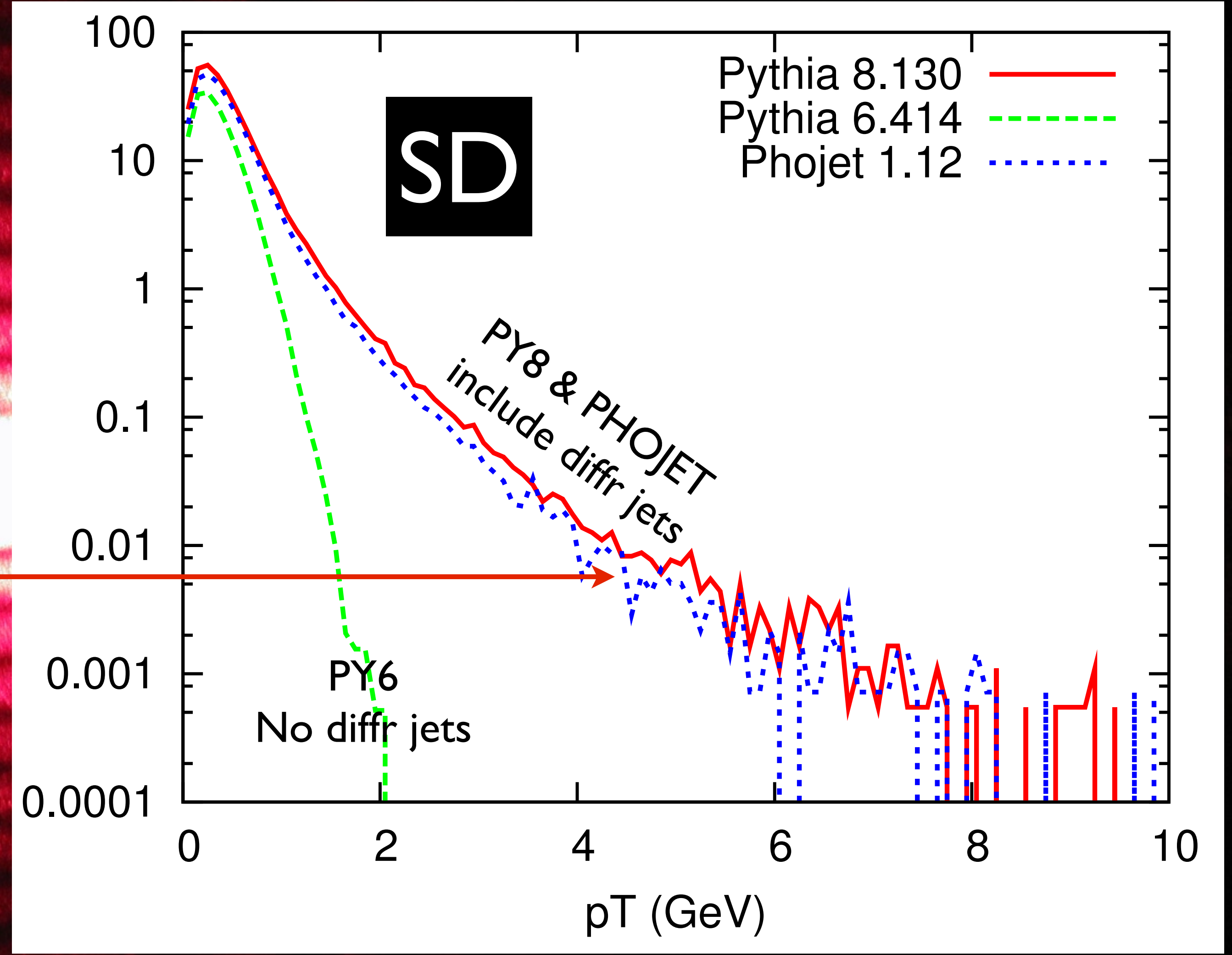
$$\frac{d\sigma_{sd(AX)}(s)}{dt\, dM^2} = \frac{g_{3\mathbb{P}}}{16\pi} \beta^2_{A\mathbb{P}} \beta_{B\mathbb{P}} \frac{1}{M^2} \exp(B_{sd(AX)} t) F_{sd} ,$$

$$\frac{d\sigma_{dd}(s)}{dt\, dM_1^2\, dM_2^2} = \frac{g^2_{3\mathbb{P}}}{16\pi} \beta_{A\mathbb{P}} \beta_{B\mathbb{P}} \frac{1}{M_1^2} \frac{1}{M_2^2} \exp(B_{dd} t) F_{dd} .$$

Partonic Substructure in Pomeron:

Follows the Ingelman-Schlein approach of Pompyt





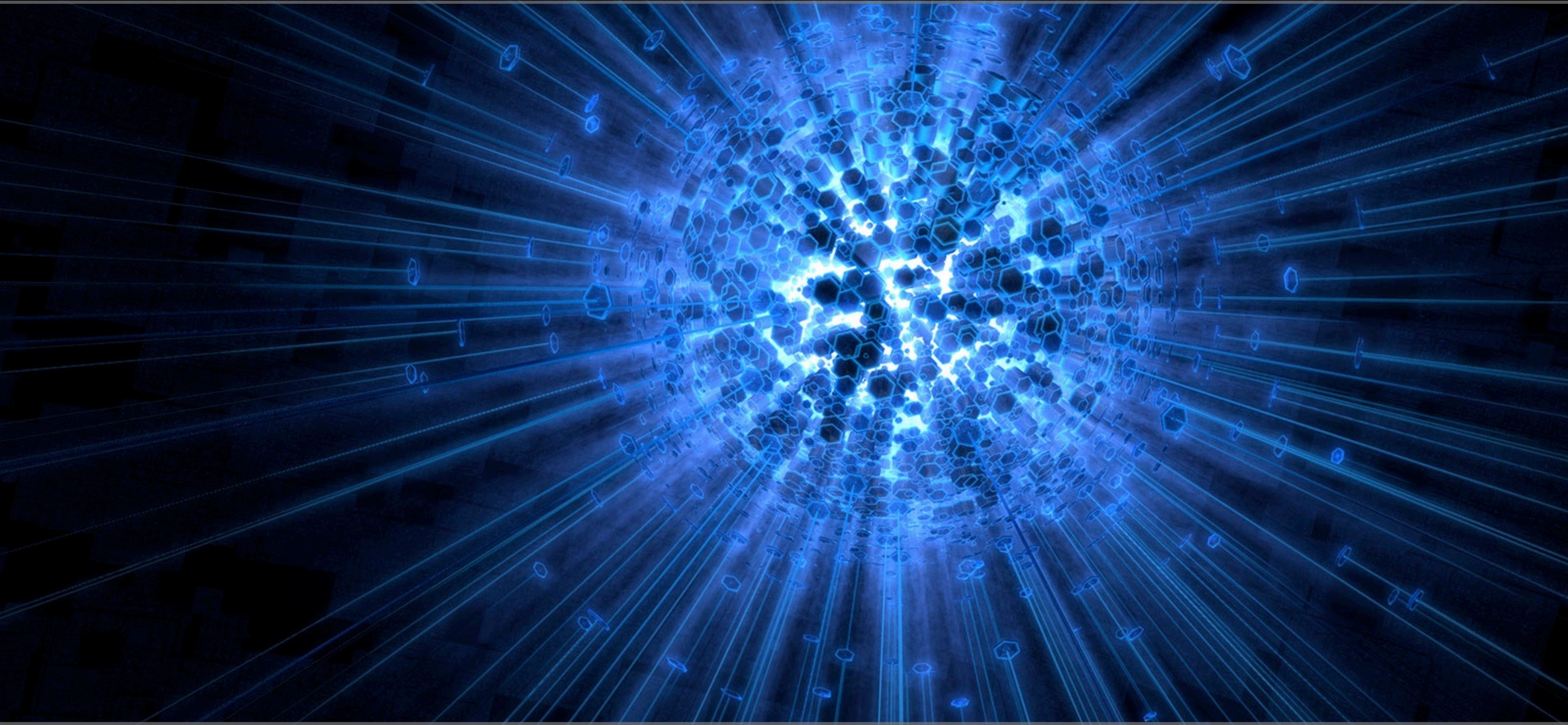
PYTHIA 8

- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used (incl full MPI+showers for $\mathbb{P}$p system)

Choice between 5 Pomeron PDFs. Free parameter $\sigma_{\mathbb{P}p}$ needed to fix $\langle n_{\mathrm{interactions}} \rangle = \sigma_{\mathrm{jet}}/\sigma_{\mathbb{P}p}$.

Framework needs testing and tuning, e.g. of $\sigma_{\mathbb{P}p}$.

Data



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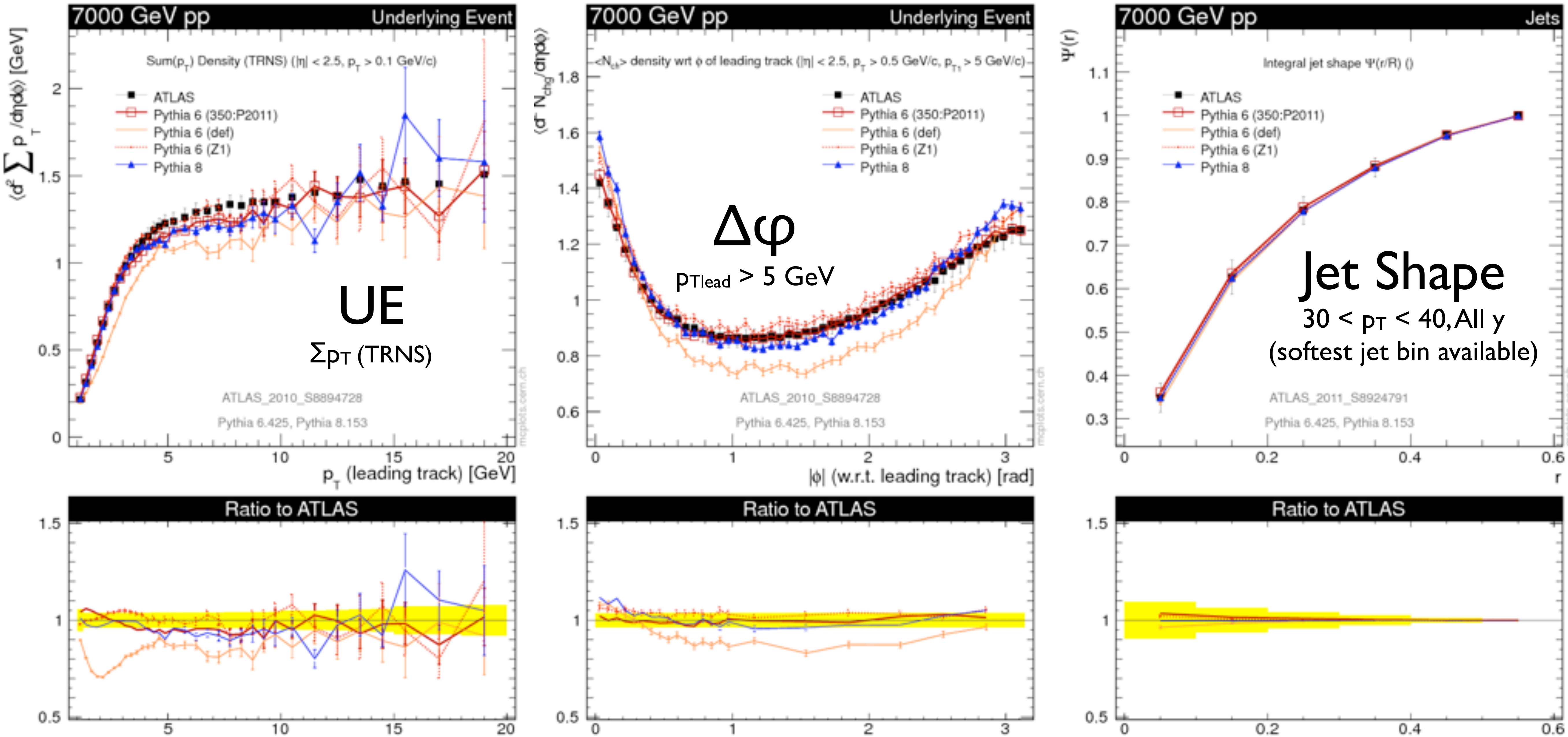
What Works*

*) if you use an up-to-date tune. Here comparing to PY6 default (~ Tune A) to show changes.

Underlying Event & Jet Shapes



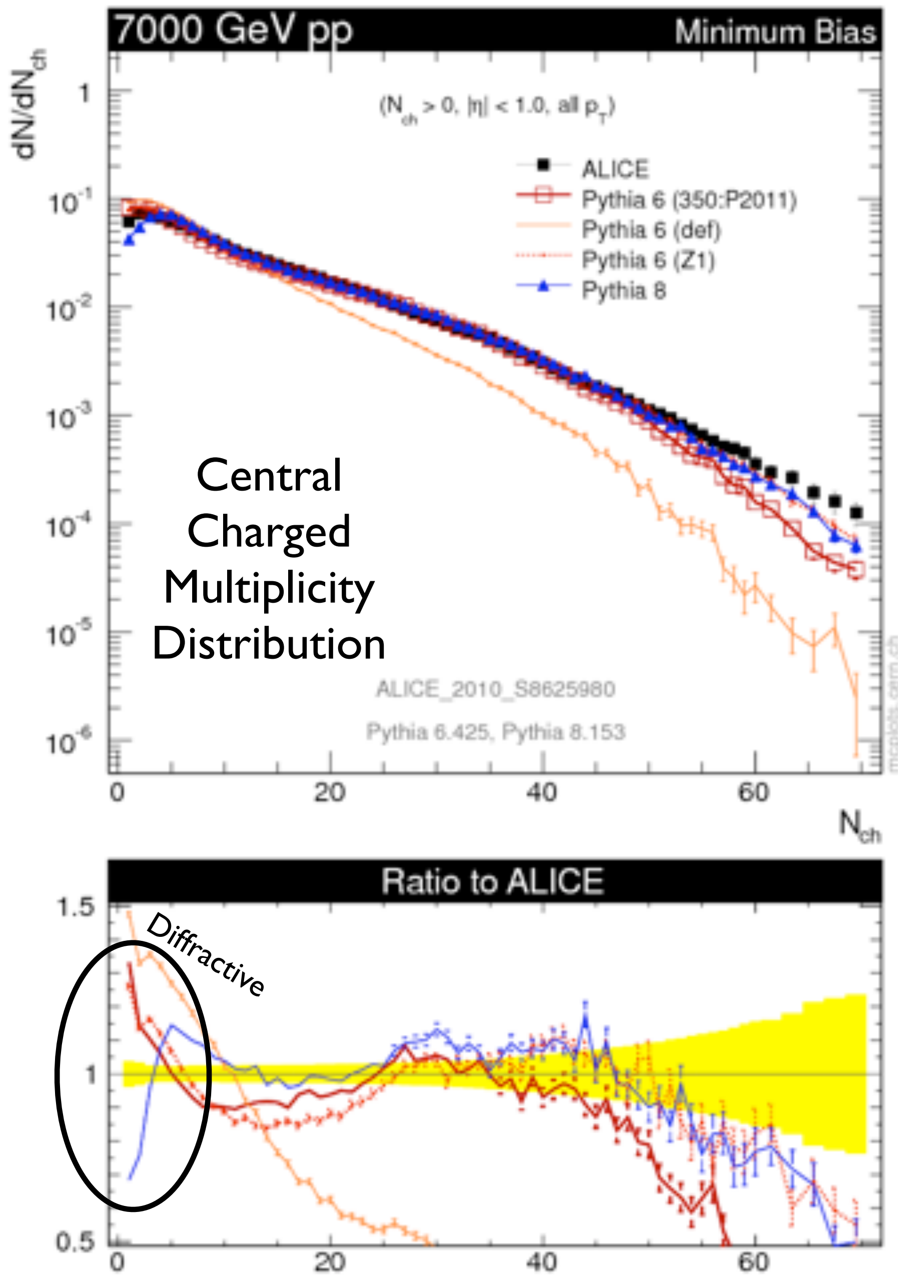
PS: yes, we **should** update the PYTHIA 6 defaults (tune A) ...

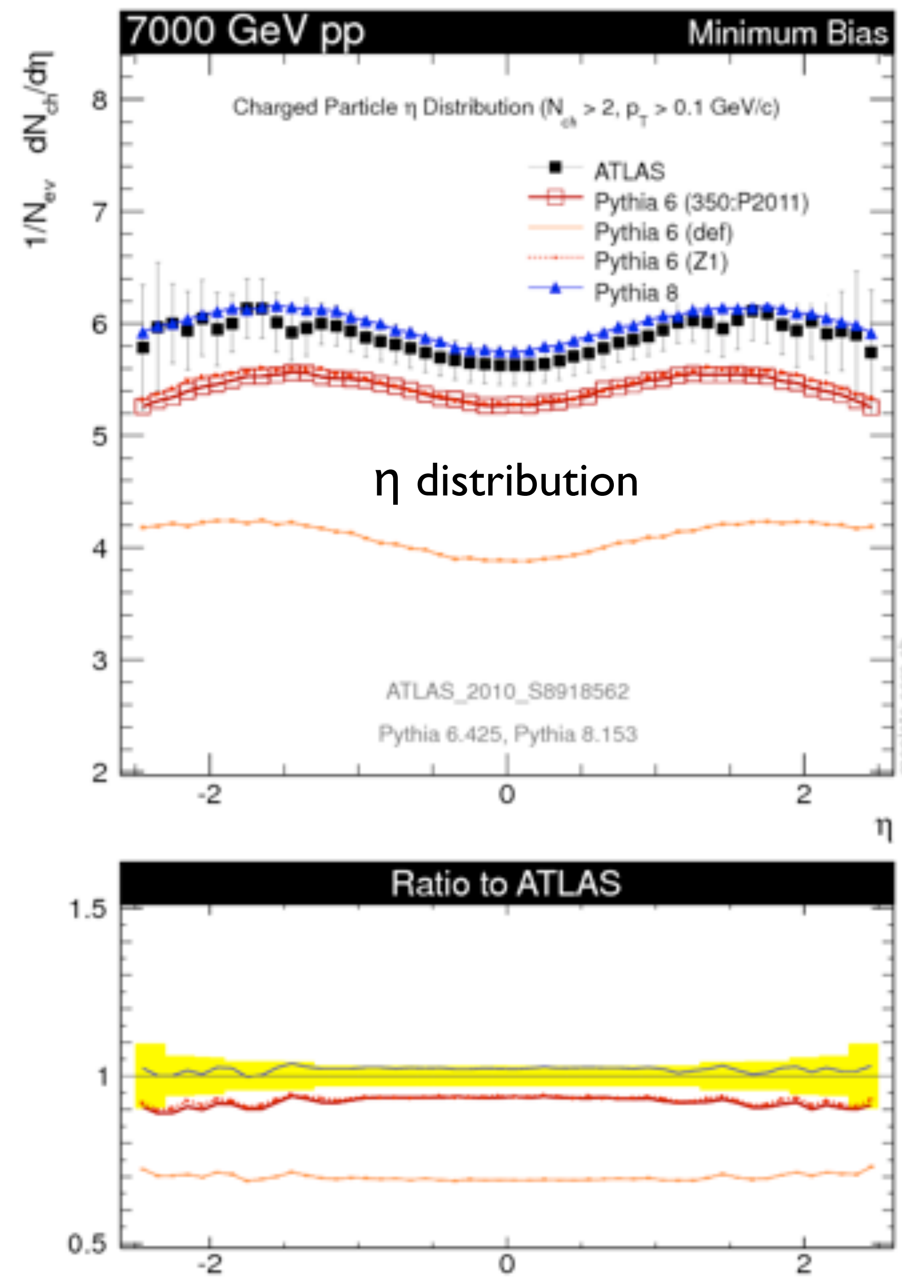
What Kind of Works*

*) if you use an up-to-date tune. Here comparing to PY6 default (~ Tune A) to show changes.

Minimum-Bias Multiplicities

(here showing as inclusive as possible)

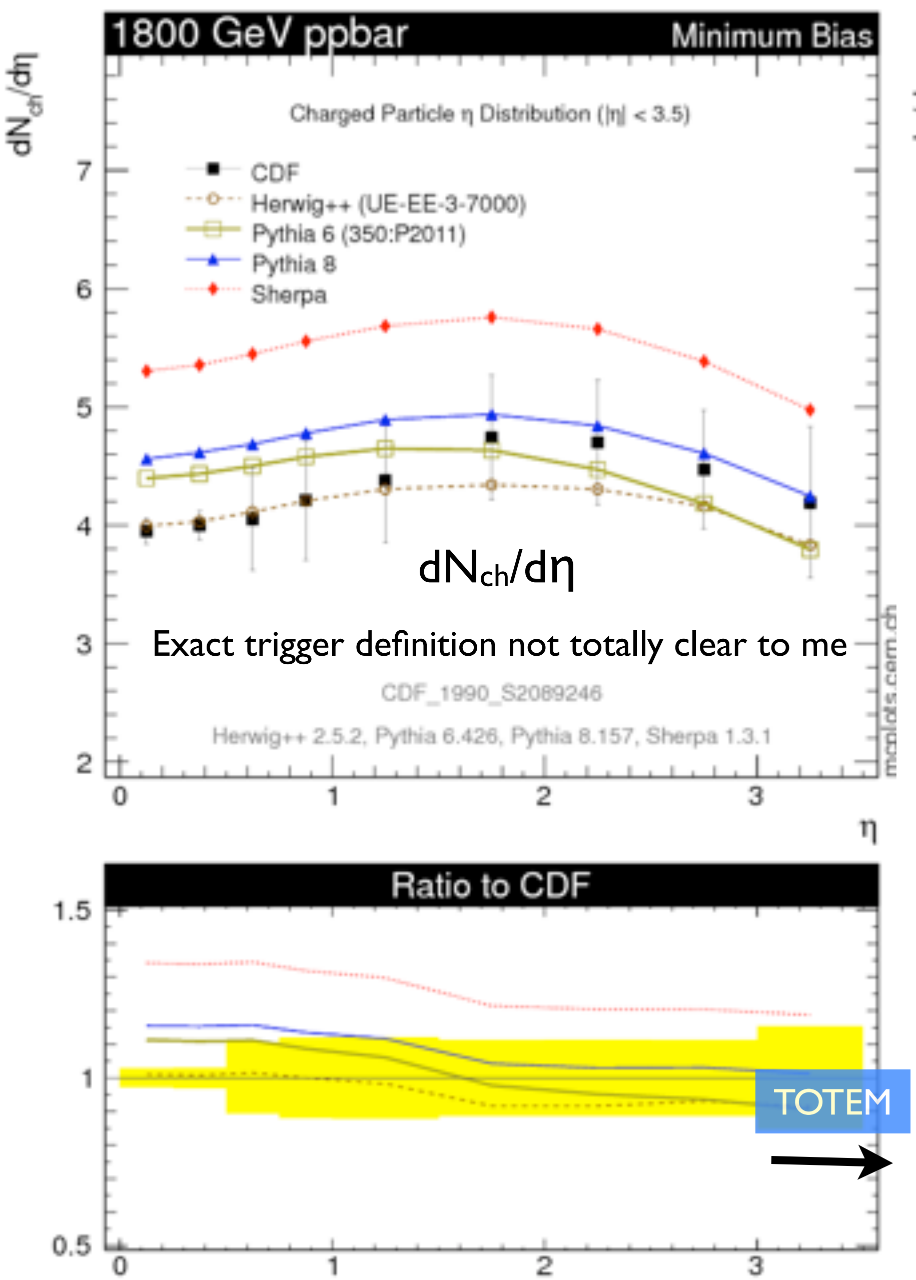




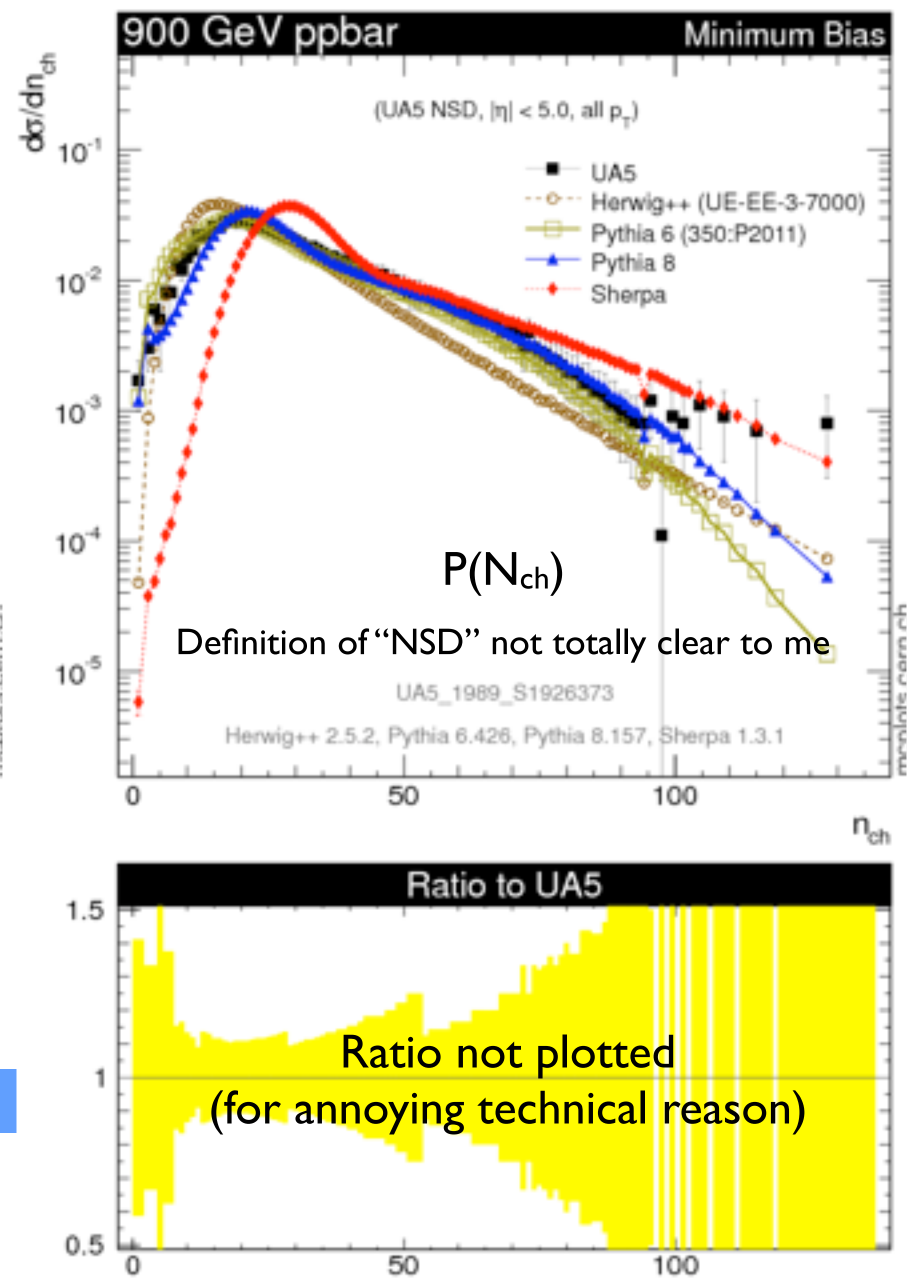
PS: yes, we **should** update the PYTHIA 6 defaults (tune A)...

Some Pre-LHC Forward Constraints

CDF **VTPC** up to |η|<3.5
(only dN/dη, only at 1800 GeV)



UA5 up to |η|<5.0
(only below 900 GeV)



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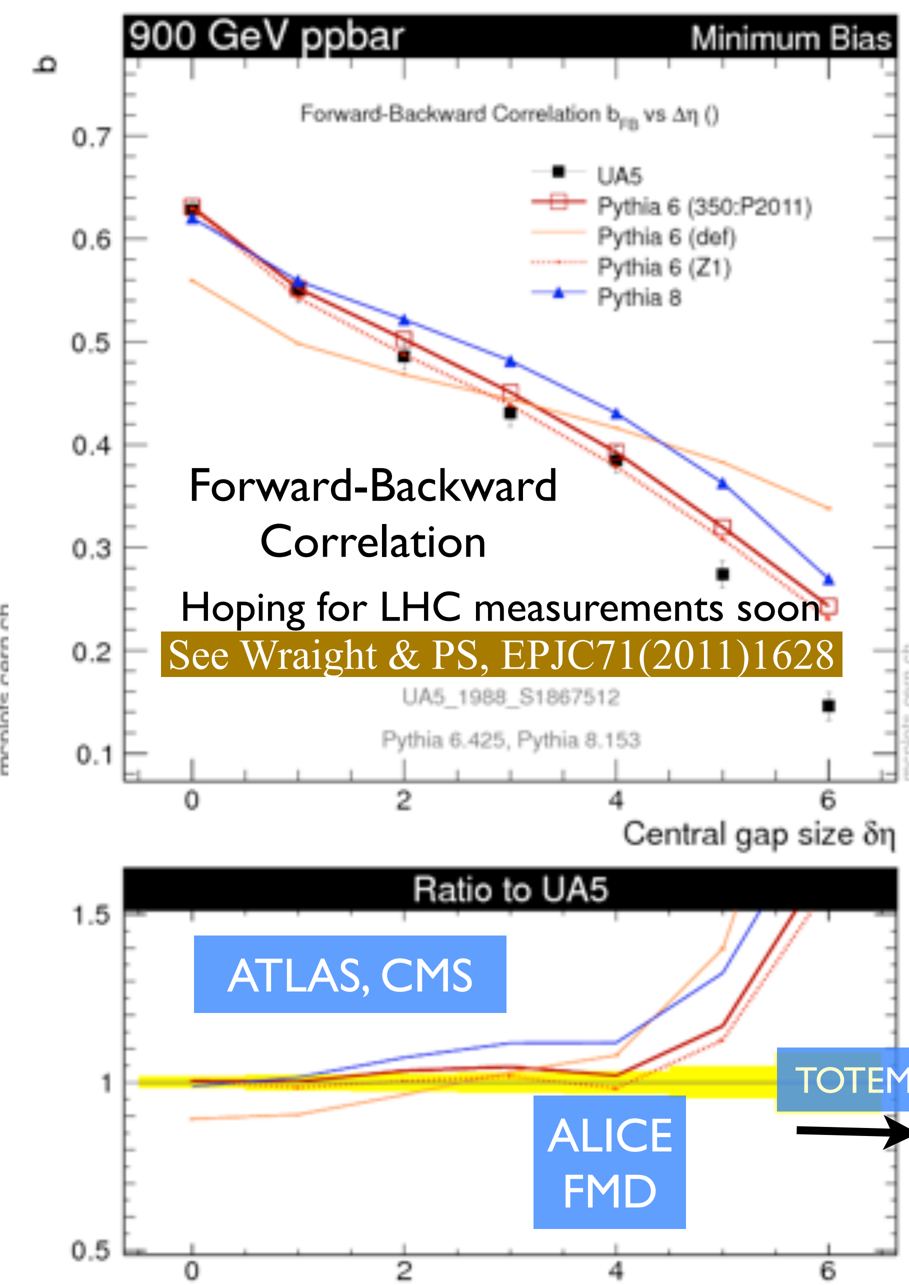
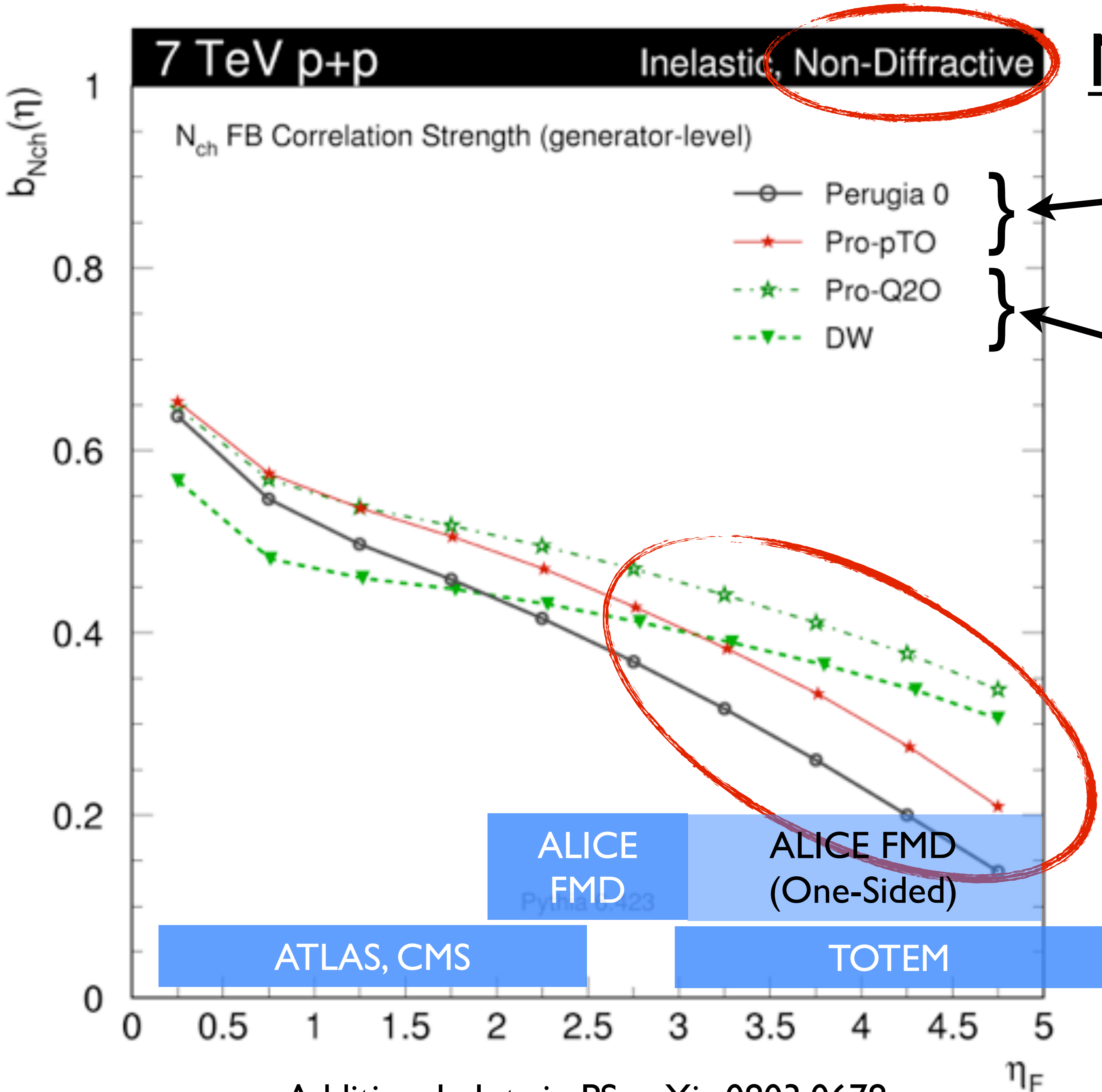


Forward-Backward Correlation

See, e.g., Wraight & PS, *"Forward-Backward Correlations and Event Shapes as probes of Minimum-Bias Event Properties"*, EPJ C71 (2011) 1628

$$b = \frac{\sigma(n_b, n_f)}{\sigma(n_b)\sigma(n_f)} = \frac{\langle n_b n_f \rangle - \langle n_f \rangle^2}{\langle n_f^2 \rangle - \langle n_f \rangle^2}$$



Additional plots in PS, arXiv:0803.0678

Models with:

Few MPI (each gives more multiplicity) → **Low** long-distance Correlations

Lots of MPI (each give little multiplicity) → **High** long-distance Correlations

+

Diffraction → uncorrelated fluctuations → expect to see higher correlation in diff-suppressed samples than in diff-enhanced ones

(e.g., by placing cuts on number of central tracks?)

Sensitive to balance between MPI (long-distance) and radiation (short-distance, tuned on ctrl observables) + color correlations (string-shortening) + diffraction → Use **multiplicity distribution** as cross-check

Components of b_{FB}

See, e.g., Wraight & PS, *"Forward-Backward Correlations and Event Shapes as probes of Minimum-Bias Event Properties"*, EPJ C71 (2011) 1628

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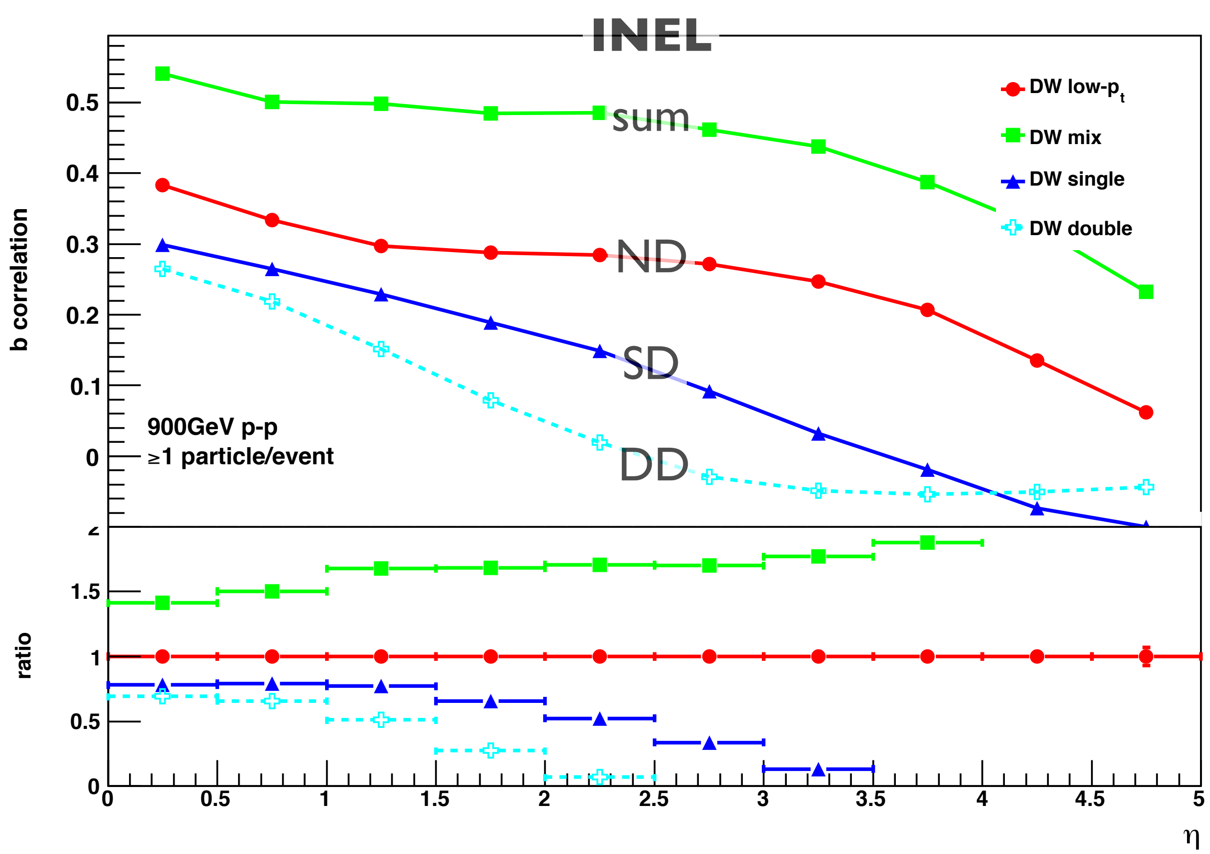


Figure 10: Inclusive b correlation distribution for tune DW minimum bias sub-processes. Lower pane: ratio to the distribution of the low-$p_\perp$ sample.

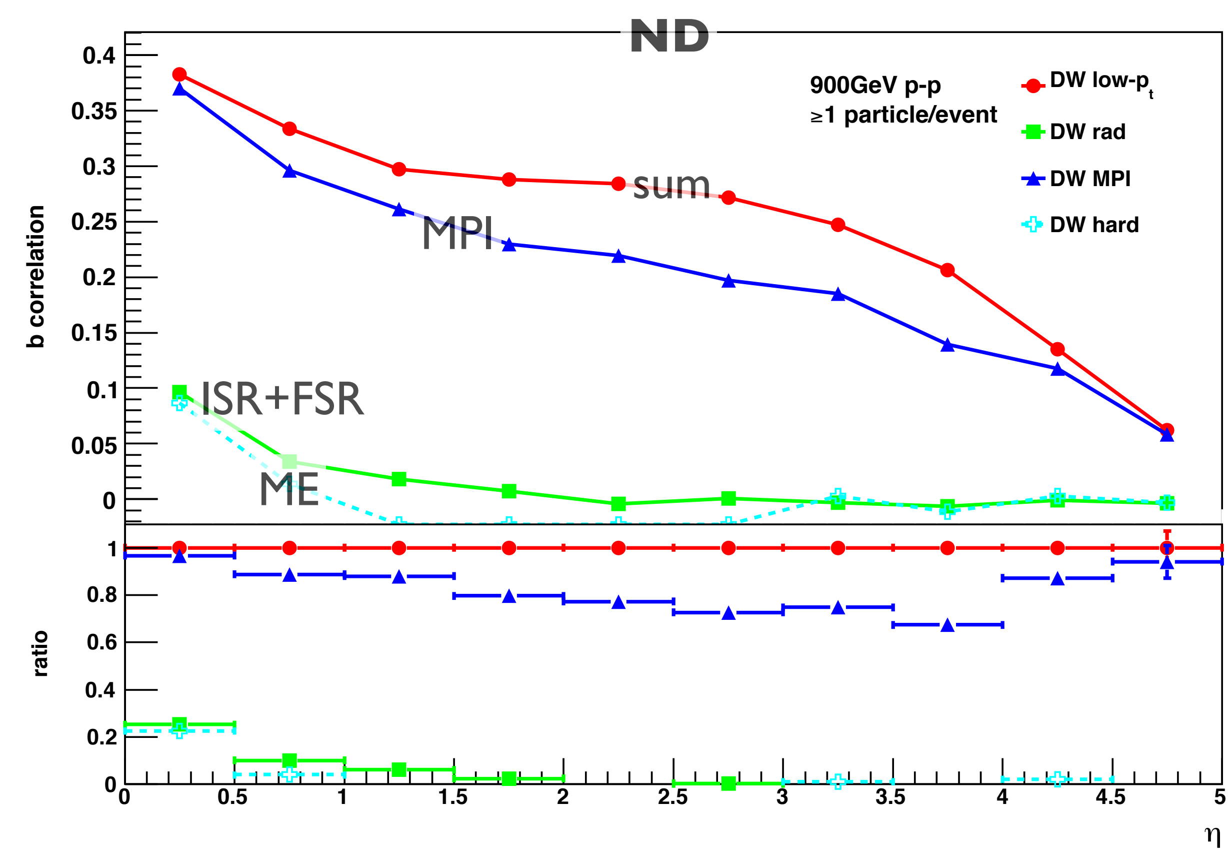


Figure 8: Inclusive b correlation distribution for tune DW particle production mechanisms: low-$p_\perp$, hard process (HARD), radiative production (RAD) and multi-parton interactions (MPI). Lower pane: ratio to the low-$p_\perp$ distribution.

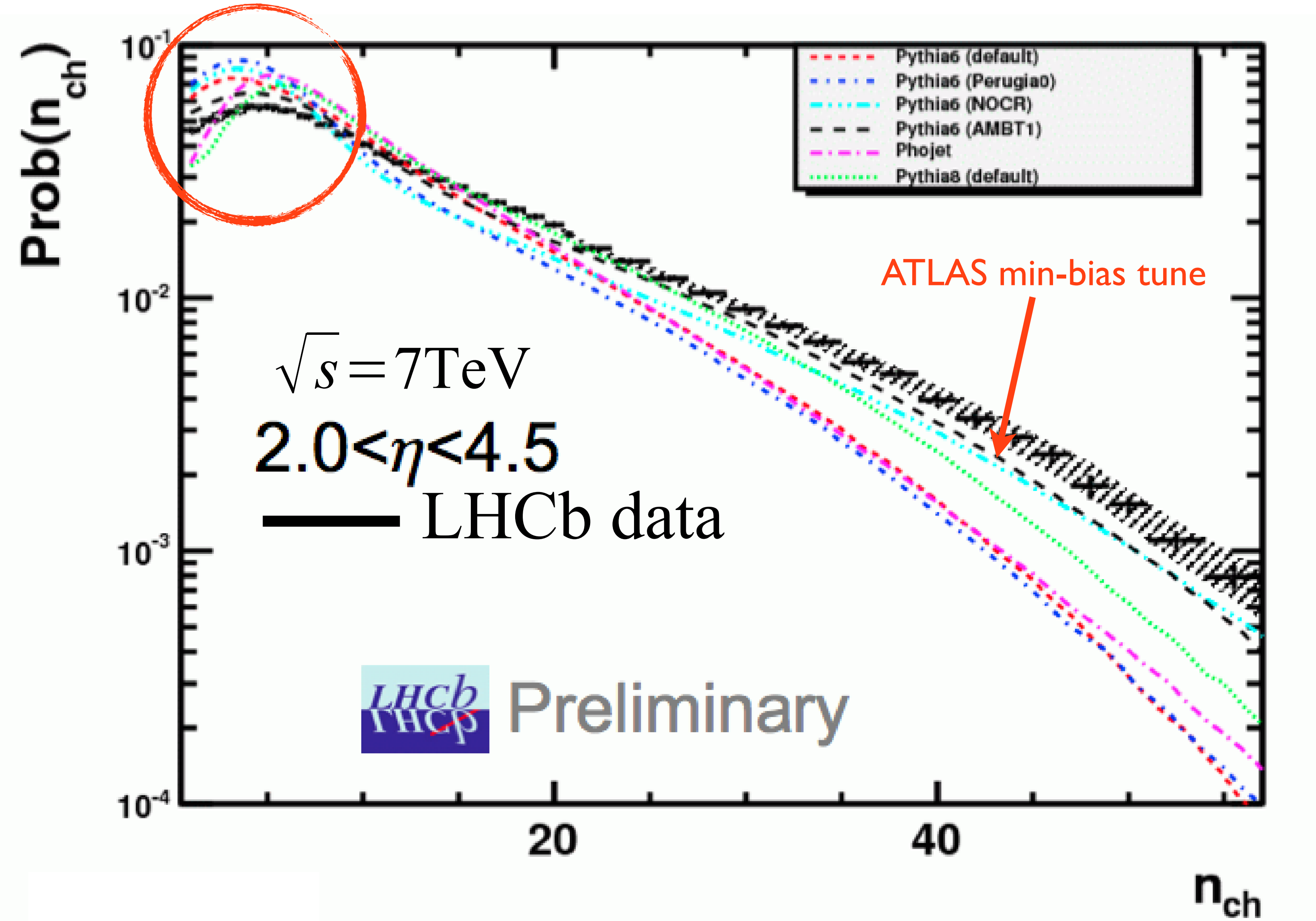
Warning: Model-dependent examples, but illustrate the principle

LHCb

Results shown at MPI, November 2011, DESY (Hamburg)

Charged multiplicity distribution in unbiased events, in 2.0<η<4.5

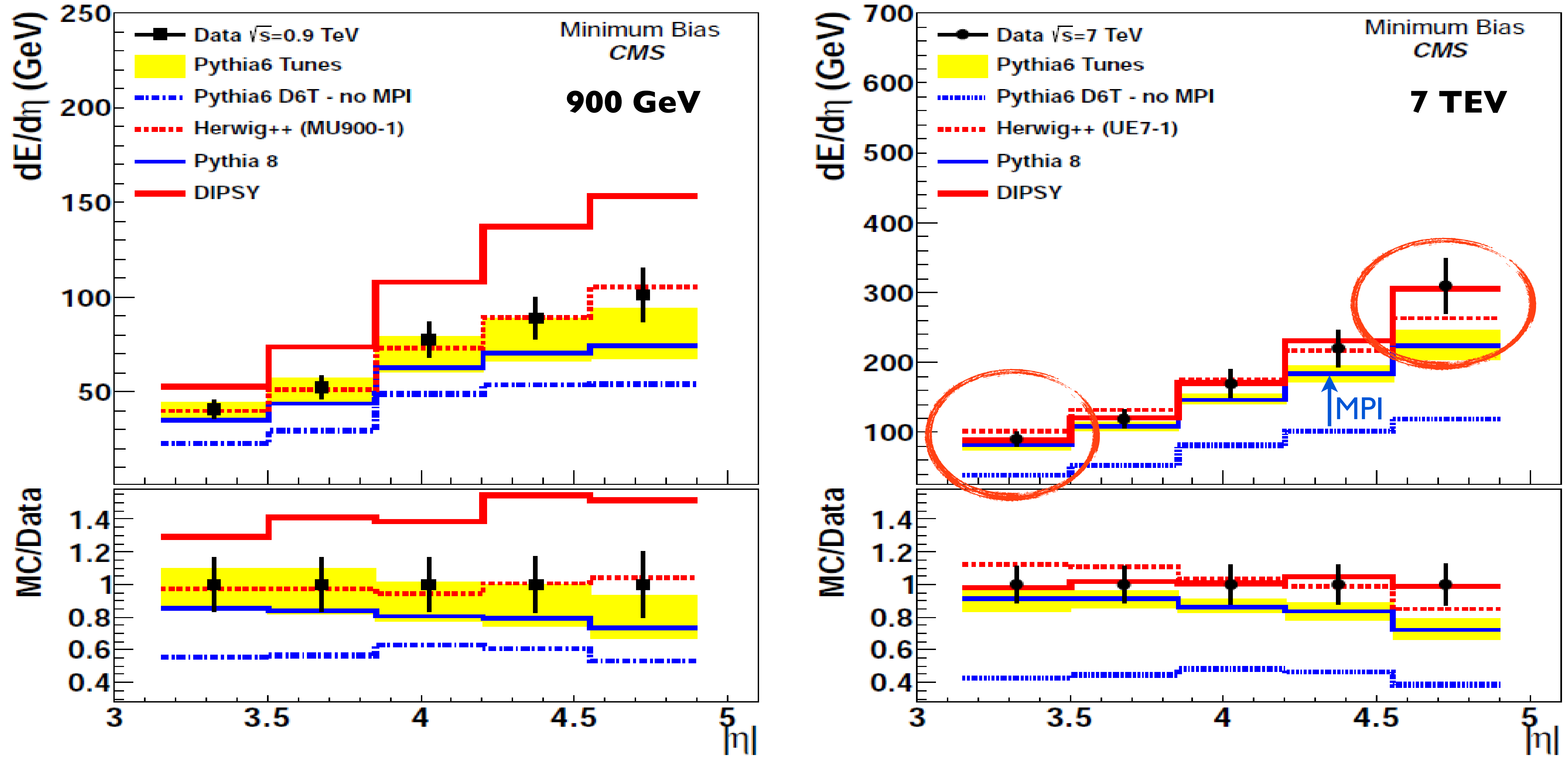
(also showed result with > 1 hard track → less diffraction, could also be done by requiring high multiplicity)



Beyond η=4.5, we do not know what the distribution looks like

Forward energy flow

(this analysis also comes with several cuts/regions designed to enhance/suppress diffraction → multi-dimensional constraints)



Identical models at η=3 → differences at η=5

Summary

Monte Carlo Event Generators

Aim to describe complete event structure

The MPI that produce the underlying event (UE) in the **central** region also disturb the beam remnant in the **forward** region

→ correlations between central and fwd fragmentation

Current MC constraints sum inclusively over FWD region → blind spot

If there are **big elephants** there, the central constraints would need to be thoroughly re-evaluated

Diffraction

Is not a big elephant for the UE or central physics program (mainly non-diff)

But important for fwd physics + all MCs in active development *(Hard diffraction model in Pythia 8, POMWIG-type model in Herwig++, KMR model in Sherpa)* → need good constraints: → study both diff-enhanced and diff-suppressed triggered samples