Status of diffractive models

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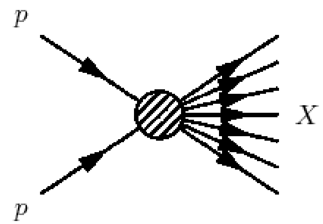
CTEQ Workshop, “QCD tool for LHC Physics: From 8 to 14 TeV, what is needed and why””
FNAL, 14 November, 2013

Main processes contributing to the total pp cross section

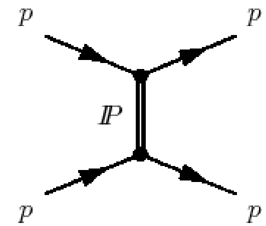
Non-diffractive:

pp → X

(exponentially-suppressed rapidity gap



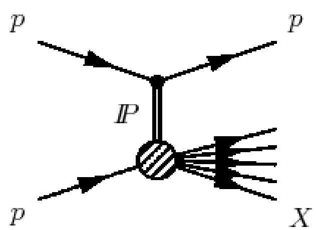
(a)



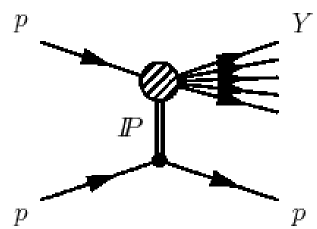
(b)

Elastic:

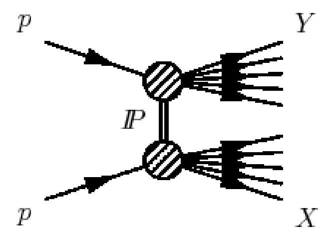
pp → pp



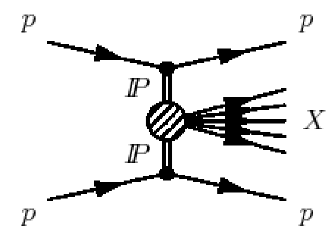
(c)



(d)



(e)



(f)

Single dissociation (SD),

pp → Xp , pp → pY

Double dissociation (DD),

pp → XY

Central diffraction (CD)

pp → pXp

or double-Pomeron exchange (DPE)

Diffractive processes (20-30% of total-inelastic cross section).
Large rapidity gap (LRG) present in the final state.

Outlook

Many models are available and used in diffractive measurements at the LHC.

<u>In this talk:</u>

- Compare PYTHIA family generators to preliminary CMS results (7TeV).
- Compare other MC generators to PYTHIA8-MBR model
  (indirect comparison to the data).

- Test hadronization models of diffractive MC generators.
- Diffractive hadronization tune for PYTHIA8 generator.

- Conclusions.

Diffractive models under study

PYTHIA family:
PYTHIA6-D6T, PYTHIA8-4C,
PYTHIA8-MBR (Min-Bias Rockefeller, new since PYTHIA8.165)

more details on next slides

Regge-Gribov phenomenology:
PHOJET,
COSMIC-RAY generatiors:
QGSJET-II-03, QGSJET-II-04, EPOS

Absorptive (unitary) corrections by multiple Pomeron exchanges, implemented differently in each model.

Diffraction in PYTHIA 6

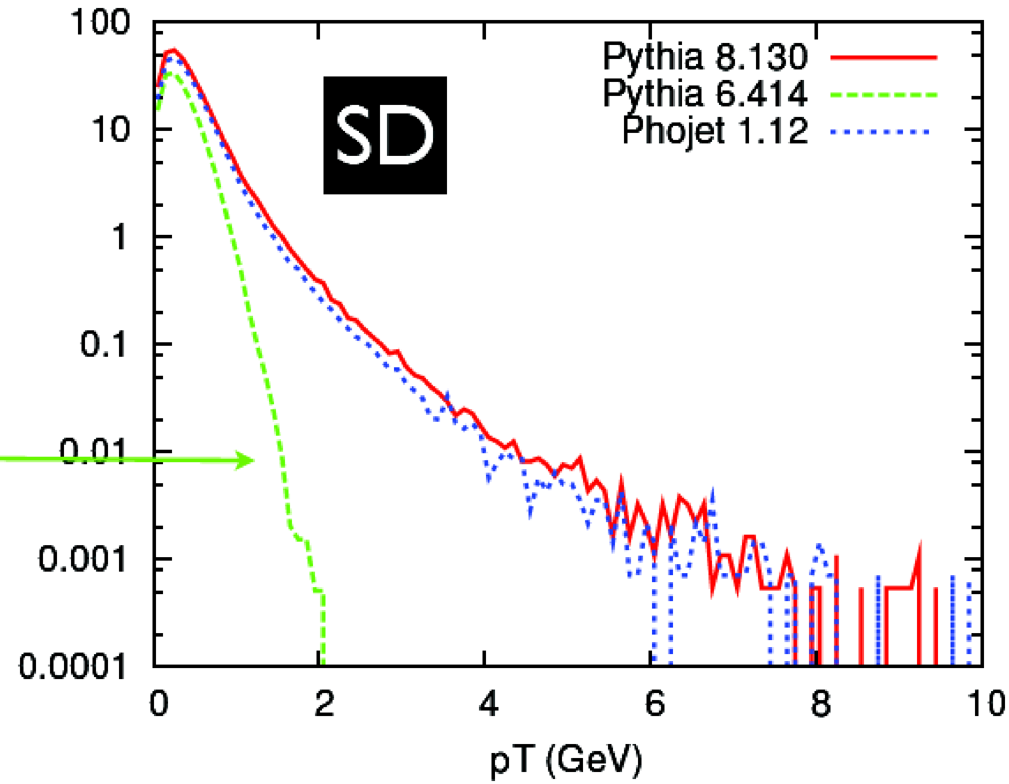
Diffractive Cross Section Formulæ:

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

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

Spectra:

$2\,m_{pi} < M_D < 1$ GeV: 2-body decay
$M_D > 1$ GeV : string fragmentation



Partonic Substructure in Pomeron:

Only in POMPYT addon (P. Bruni, A. Edin, G. Ingelman) ► high-p_T "jetty" diffraction absent

Very soft spectra without POMPYT

PYTHIA 6: Supported, but not actively developed

Diffraction in PYTHIA 8

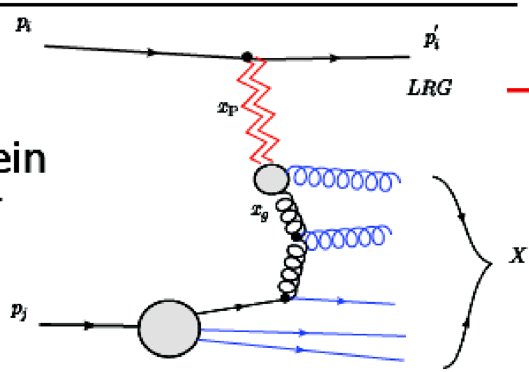
Diffractive Cross Section Formulæ:

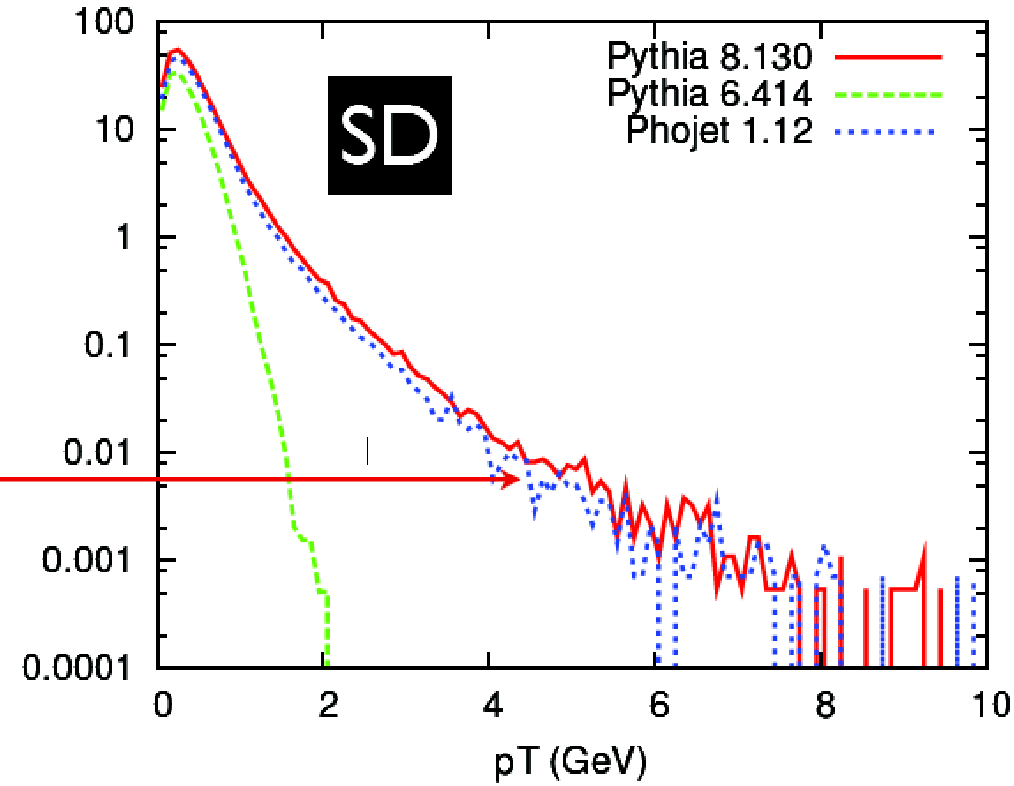
$$\frac{d\sigma_{sd(AX)}(s)}{dt\,dM^2} = \frac{g_{3\mathbb{P}}}{16\pi}\,\beta_{A\mathbb{P}}^2\,\beta_{B\mathbb{P}}\,\frac{1}{M^2}\,\exp(B_{sd(AX)}t)\,F_{sd}\,,$$

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

Partonic Substructure in Pomeron:

Follows the Ingelman-Schlein approach of Pompyt





- $M_X \leq 10\,\mathrm{GeV}$: 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 $\langle n_{\text{interactions}}\rangle = \sigma_{\text{jet}}/\sigma_{\mathbb{P}p}$.

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

Navin, arXiv:1005.3894

Diffraction in MBR: Min-Bias Rockfeller

Originally written for and tested at CDF (down to lowest masses, Mx).

Implemented in PYTHIA8.165: arXiv:1205.1446

- Calculated based on renormalized Regge theory.

- Differential cross sections vs rapidity gap width, Δy, and 4-momentum transfer squared, t:

$$\frac{d^2\sigma_{SD}}{dtd\Delta y} = \frac{1}{N_{\rm gap}(s)}\left[\frac{\beta^2(t)}{16\pi}e^{2[\alpha(t)-1]\Delta y}\right]\cdot\left\{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right\},$$

$$\frac{d^3\sigma_{DD}}{dtd\Delta y dy_0} = \frac{1}{N_{\rm gap}(s)}\left[\frac{\kappa\beta^2(0)}{16\pi}e^{2[\alpha(t)-1]\Delta y}\right]\cdot\left\{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right\},$$

$$\frac{d^4\sigma_{DPE}}{dt_1 dt_2 d\Delta y dy_c} = \frac{1}{N_{\rm gap}(s)}\left[\Pi_i\left[\frac{\beta^2(t_i)}{16\pi}e^{2[\alpha(t_i)-1]\Delta y_i}\right]\right]\cdot\kappa\left\{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right\},$$

$\leftarrow$ $\Delta y = \Delta y_1 + \Delta y_2$

DD: y_0 – center of rapidity gap, DPE: y_c – rapidity of dissociated system

$$\alpha(t) = 1 + \epsilon + \alpha' t = 1.104 + 0.25\ ({\rm GeV}^{-2})\cdot t$$

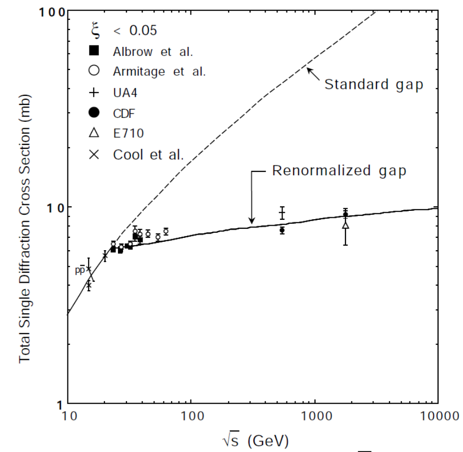
$$\beta^2(t) = \beta^2(0)F^2(t) \qquad \kappa \equiv g(t)/\beta(0)$$

$$\xi = e^{-\Delta y},\ \xi_{\rm SD} = M^2/s$$

$$\xi_{\rm DD} = M_1^2 M_2^2/(s\cdot s_0)$$

$$\text{DPE}\ \xi = \xi_1\xi_2 = M^2/s$$

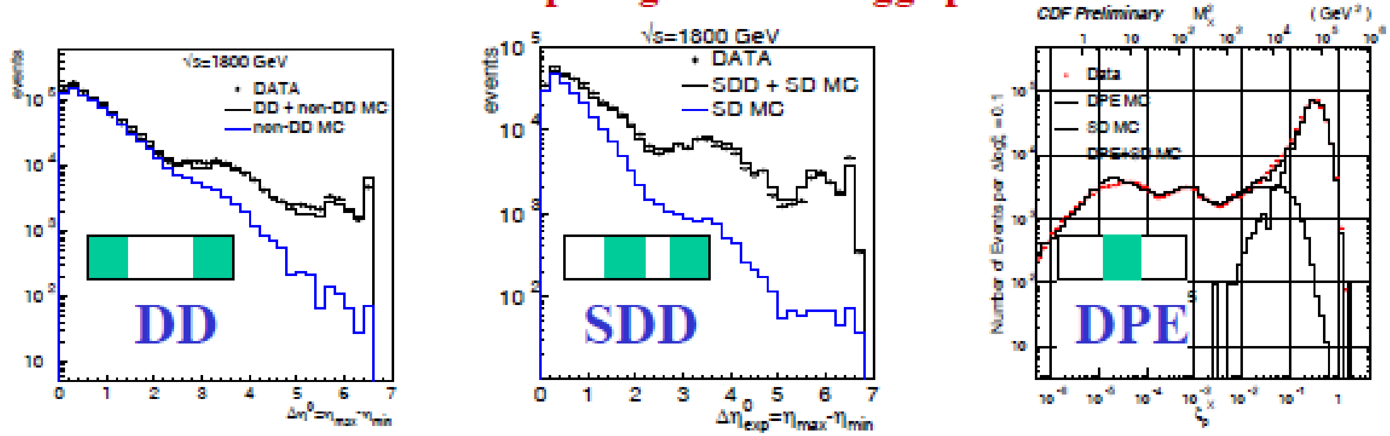
- Term in { } brackets: total Pomeron-p cross section at a reduced energy $s'=s\cdot e^{-\Delta y}$.
- Term in [ ] brackets: Pomeron flux.
- $N_{gap}(s)$: renormalization factor: *min(1,f)*, with *f* = integral of Pomeron flux
  $\rightarrow$ allows to interpret the flux as (diffractive) gap-formation probability.



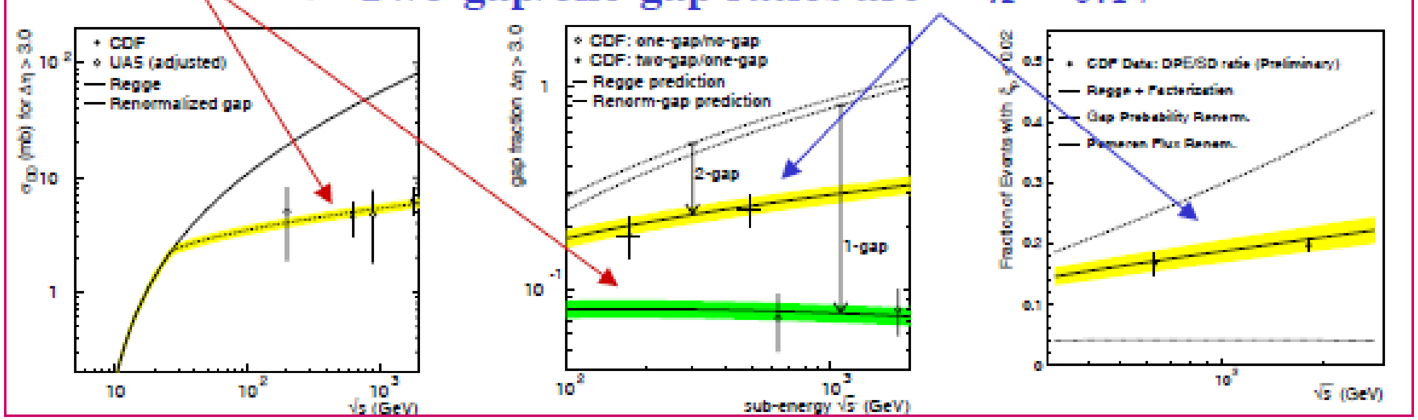
MBR vs CDF data

Central & Double-Gap CDF Results

Differential shapes agree with Regge predictions



- One-gap cross sections are suppressed
- Two-gap/one-gap ratios are $\approx \kappa = 0.17$

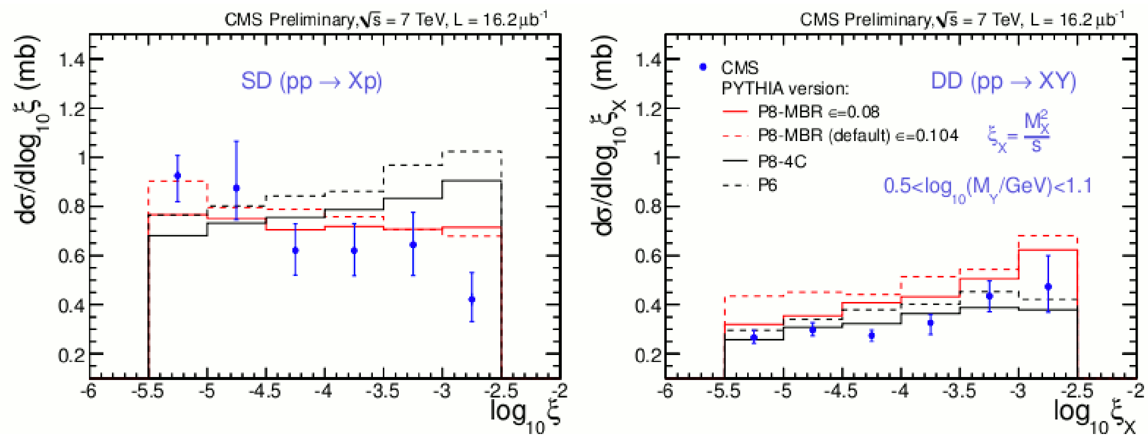


La Thuile07, 2-20 March   Diffraction and Exclusive (Higgs?) Production from CDF to LHC   K. Goulianos   30

Soft diffractive cross sections (CMS)

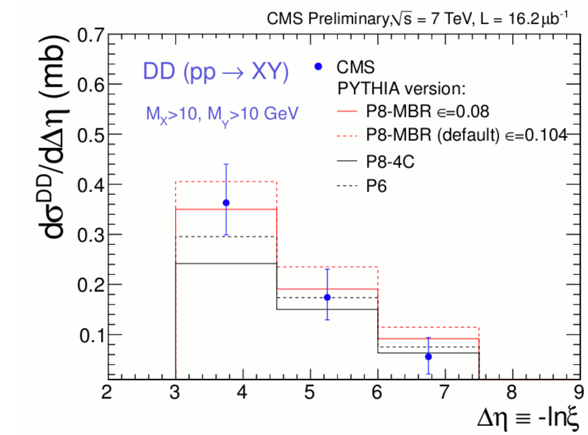
CMS PAS FSQ-12-005

SD and DD cross sections with forward LRG.
SD/DD separation with CASTOR calorimeter



$5.5 < \log_{10}\xi < -2.5$ ($12 < M_X < 394$ GeV)

DD cross section with central LRG.

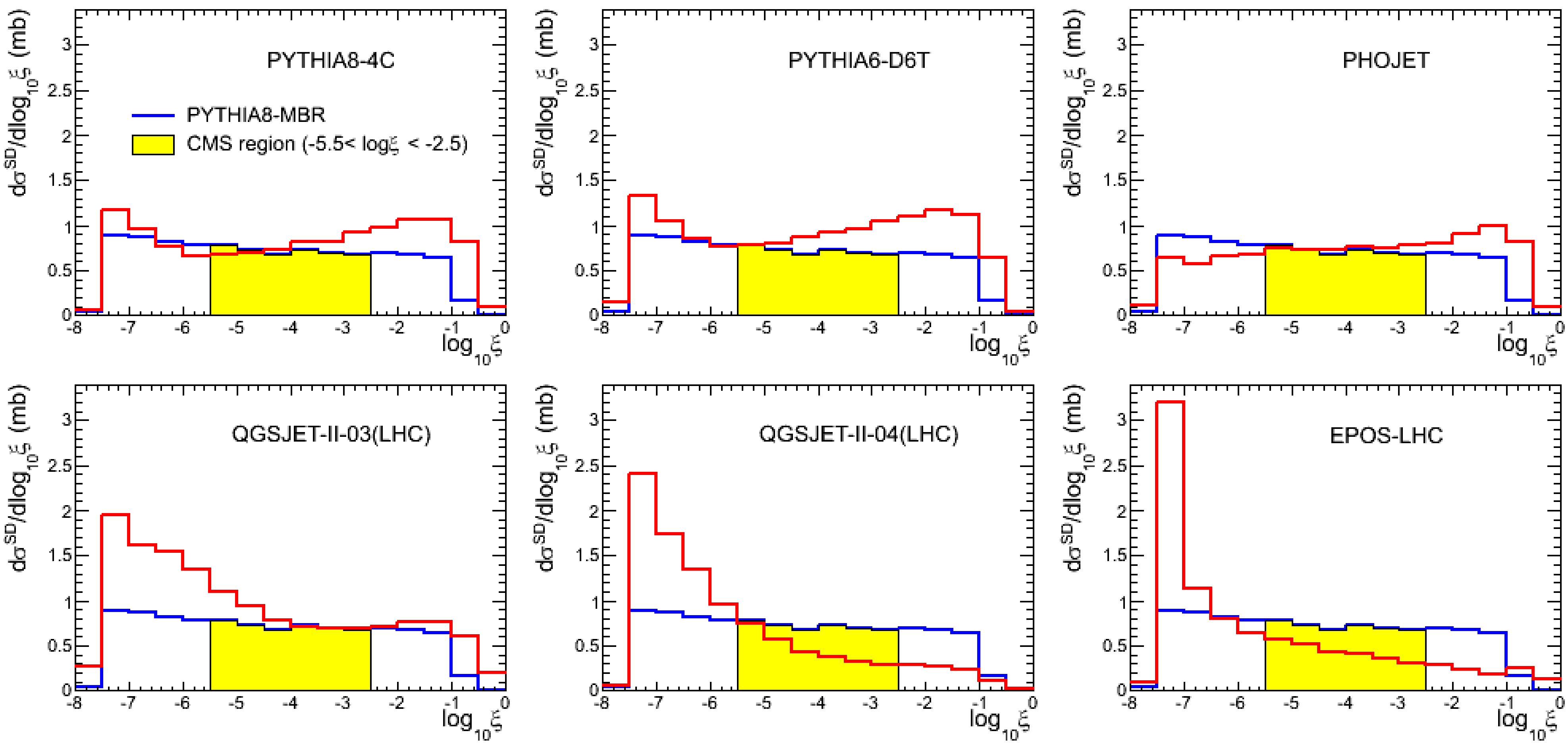


Results compared to predictions of PYTHIA8-MBR, PYTHIA8-4C. and PYTHIA6:

- PYTHIA8-MBR shown for two values of the Pomeron trajectory ($\alpha(t) = 1+\varepsilon+\alpha' t$), $\varepsilon=0.08$ and $\varepsilon=0.104$:
  Both describe the measured SD cross section well
  The DD data favour the smaller value of ε

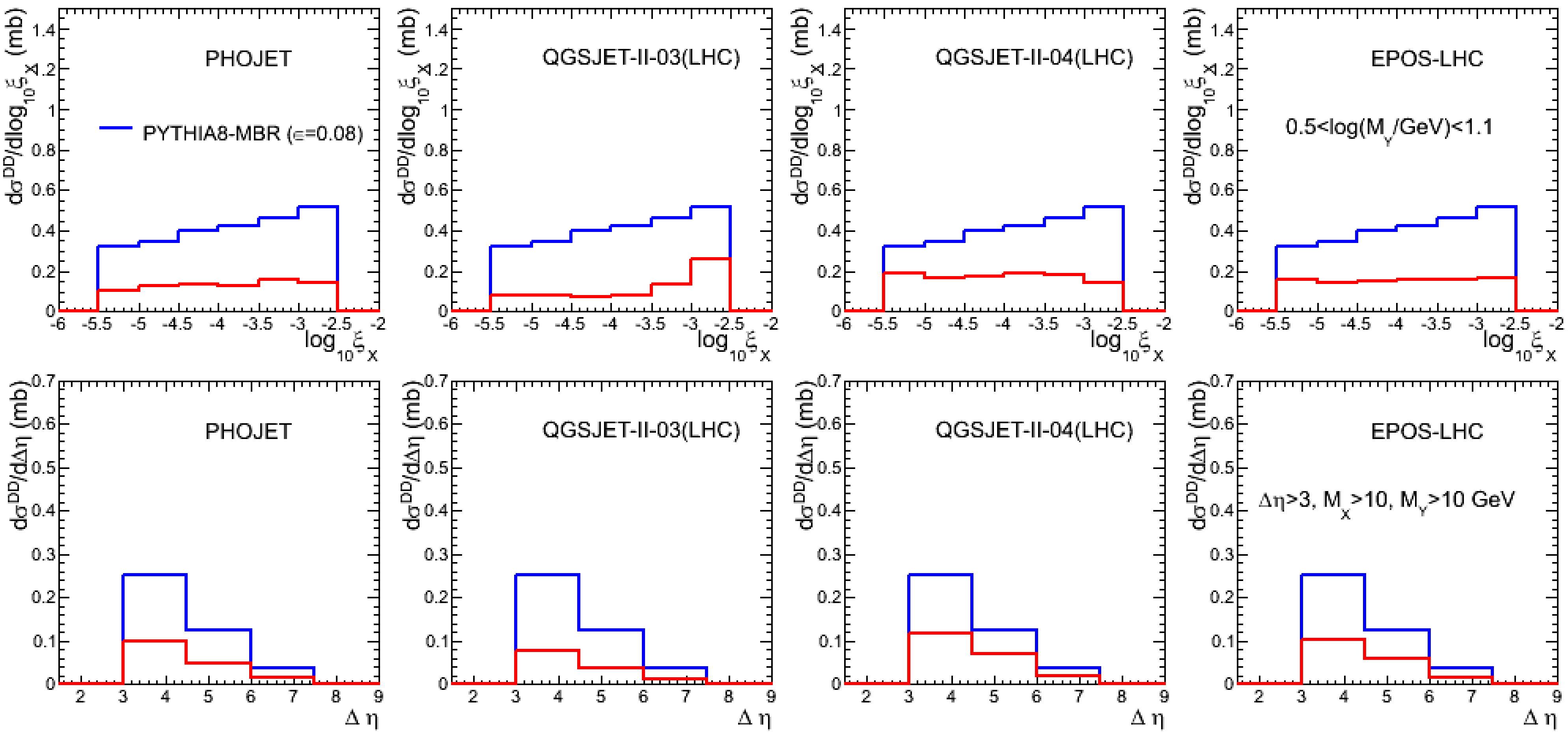
- Schuler&Sjostrand model used in PYTHIA8-4C and PYTHIA6:
  Describes well the DD cross section
  Fails to describe the falling behavior of the SD data

Mass dependence (SD) – all models vs PYTHIA8-MBR



PYTHIA8-4C, PYTHIA6-D6T, PHOJET – wrong ζ dependence ($\zeta = Mx^2/s$)
QGSJET-II-04, EPOS – underestimate SD cross section in the CMS region.

DD cross sections – all models vs PYTHIA8-MBR



PYTHIA8-4C, PYTHIA6-D6T satisfactory description (shown on slide 9)
PHOJET, QGSJET-II-03, QGSJET-II-04, EPOS underestimate DD cross section

MBR @ CDF – phenomenological model for hadronization

- In MBR at CDF the diffractive system of mass Mx hadronizes as a pp collision at $\sqrt{s}$ = Mx. (only one hadronic system in the game!)
- Toy model: mainly π+, π- and π0 → $\gamma\gamma$ in the final state.

Track multiplicities:

- Particle multiplicities follow a Modified Gamma Distribution from **K. Goulianos PLB 193, 151 (1987),** tested using existing pre-LHC and pre-Tevatron pp data in a wide range of $\sqrt{s}$:

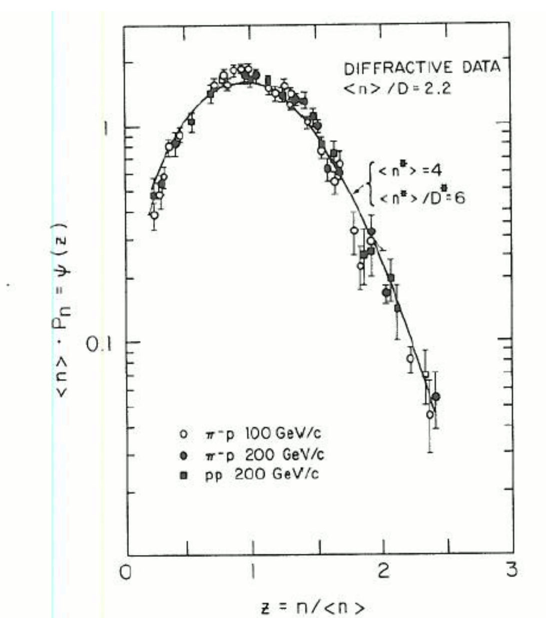


Fig. 1. The diffractive data of ref. [3] fitted with the modified gamma function.

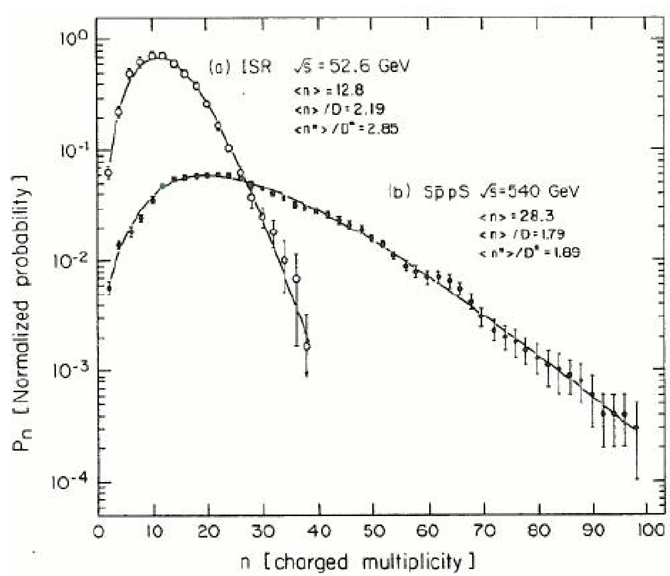


Fig. 2. Full phase space inelastic non-single-diffractive data fitted with the modified gamma function: (a) ISR data [5] at $\sqrt{s}=52.6$ GeV and (b) collider data [7] at $\sqrt{s}=540$ GeV.

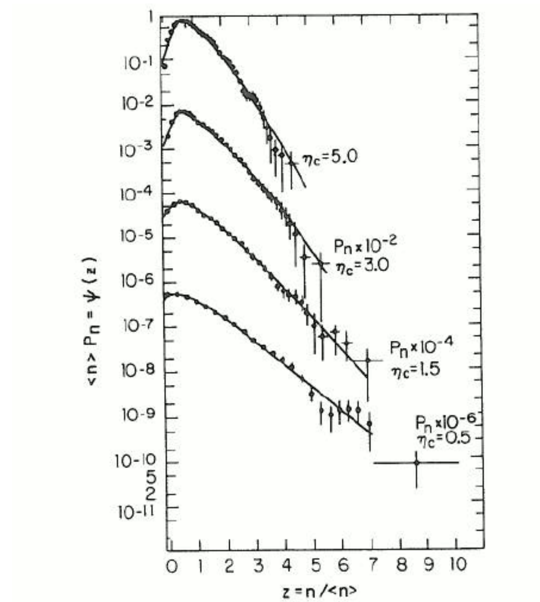


Fig. 3. Fits with the modified gamma function of charged-particle multiplicity distributions in restricted pseudorapidity intervals, defined by $|\eta| < \eta_c$, at $\sqrt{s}=540$ GeV (data from ref. [9]).

MBR @ CDF – phenomenological model for hadronization

pT spectra:

From MBR user guide at CDF

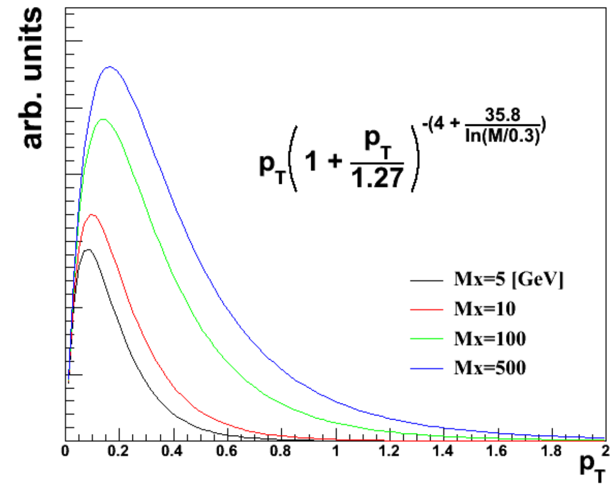
6.2 Transverse momentum distribution

For diffractive mass clusters with 2 or 3 particles, the direction of the nucleon is chosen from the angular distribution $dP/d\cos\theta \sim 1+\cos^2\theta$, and the momentum is balanced by the remaining pion(s). For $n > 3$, the transverse momentum of the particles is taken from the empirically determined distribution [15]

$$\frac{d\sigma}{dp_T} \sim p_T\left(1+\frac{p_T}{1.27\ \mathrm{GeV}}\right)^{-4-35.8/\ln(M/0.3\ \mathrm{GeV})} \tag{6.2}$$

for available mass M. The total p_T is then balanced, which changes the p_T of the particles only slightly.

[15] G. Arnison *et al.*, (UA1 Collaboration), Phys. Lett. B **118**, 167 (1982).

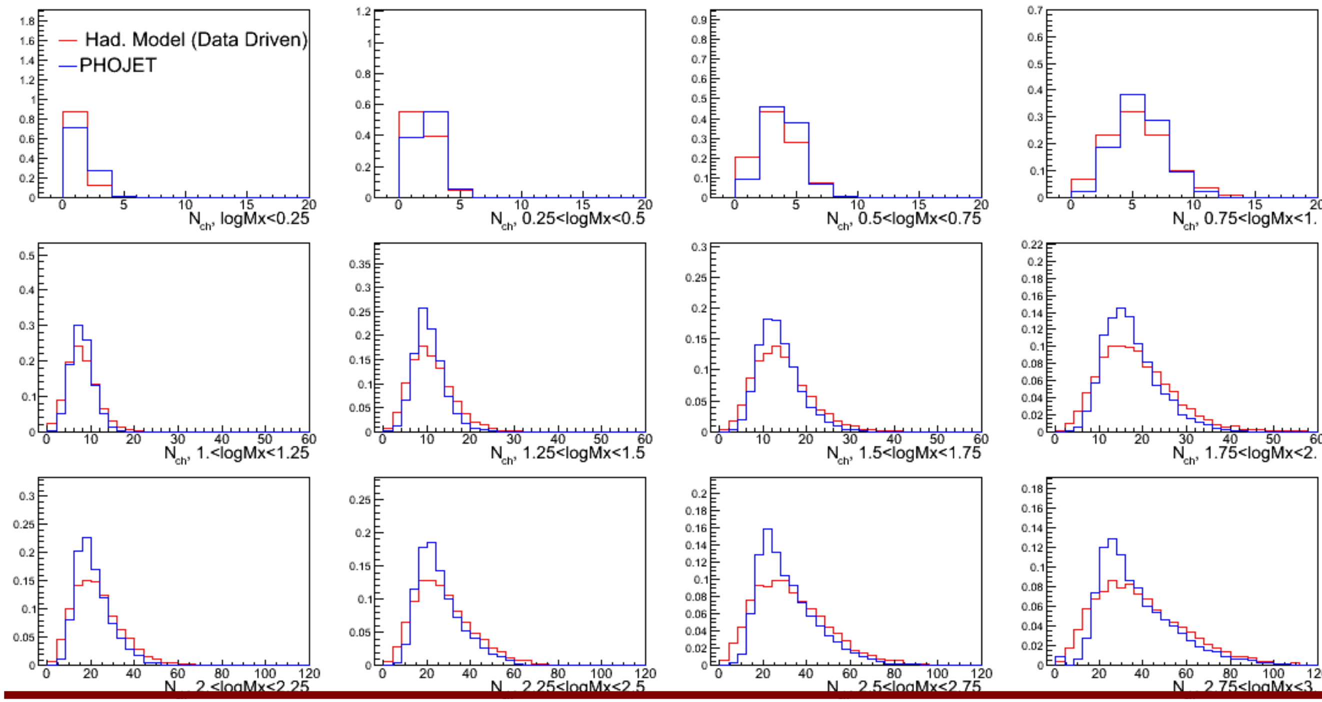


- Mx-dependent pT spectra (UA1).

1) Test Mx hadronization of diffractive models by comparing to MBR model. (data-driven reference)

2) Within PYTHIA8 framework:
Tune critical parameters of Diffraction and StringPT classes to bring multiplicity and pT spectra of Mx system close to MBR hadronization.

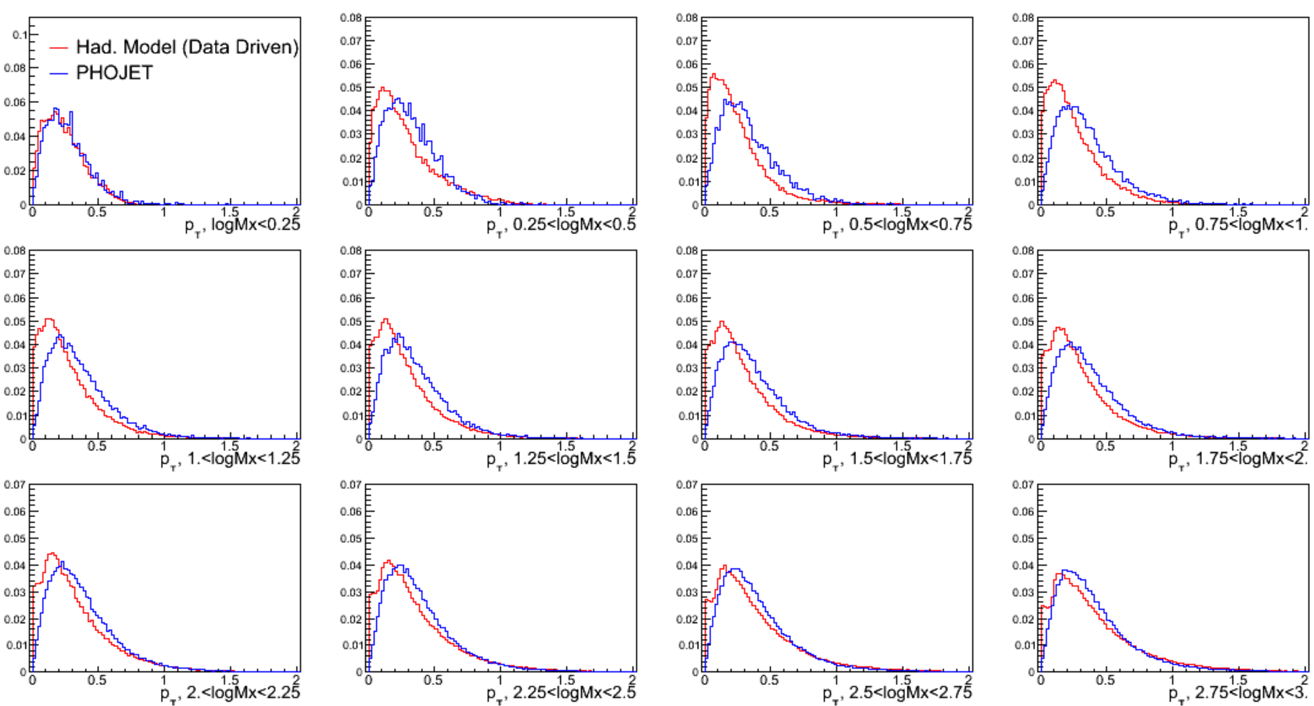
PHOJET hadronization model



Compared to data-driven reference (Hadronization model of MBR@CDF)

Charged multiplicities in bins of Mx (SD process)

Relatively good description

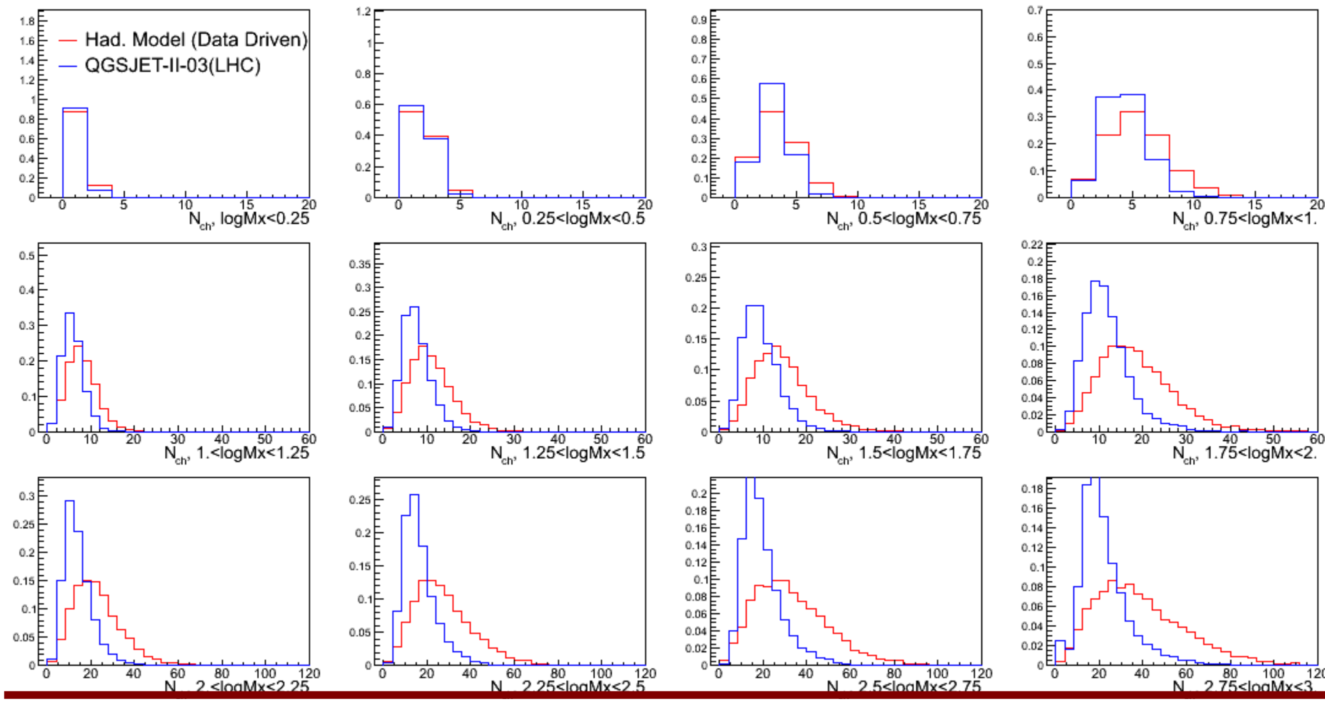


Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

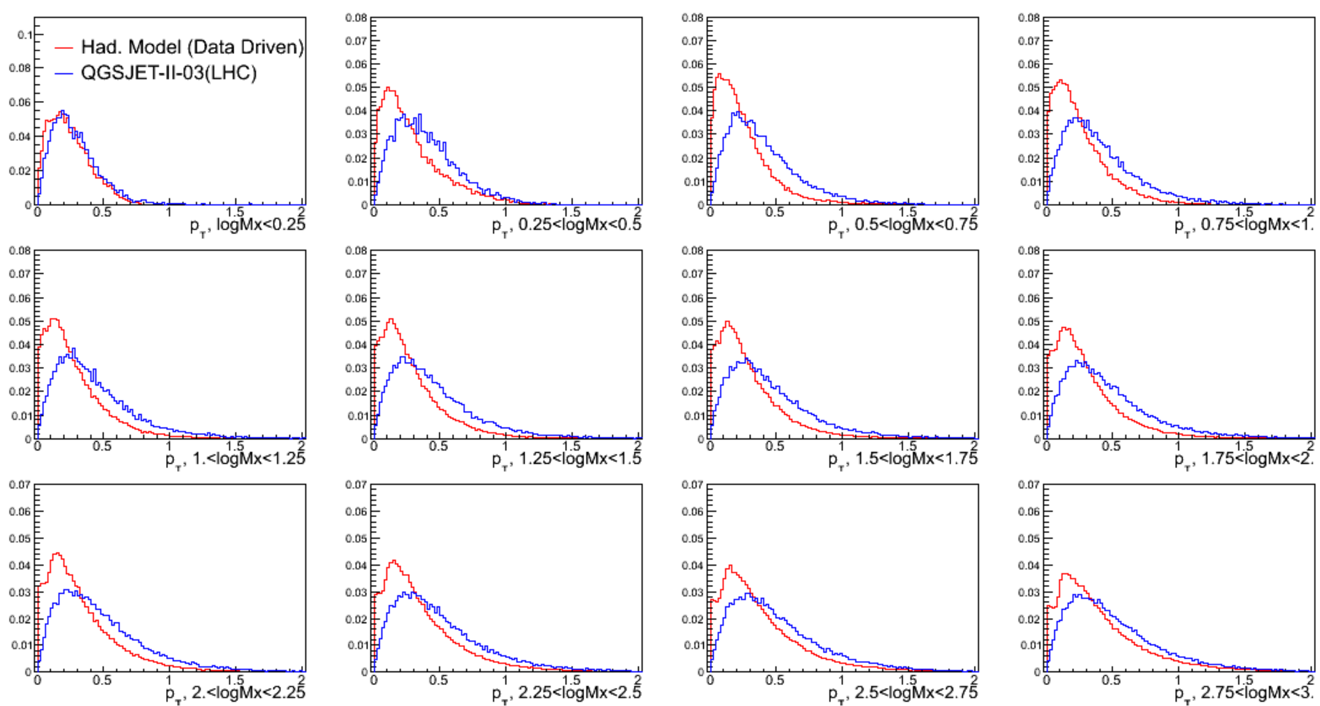
QGSJET-II-03 hadronization model

Compared to data-driven reference (Hadronization model of MBR@CDF)



Charged multiplicities in bins of Mx (SD process)

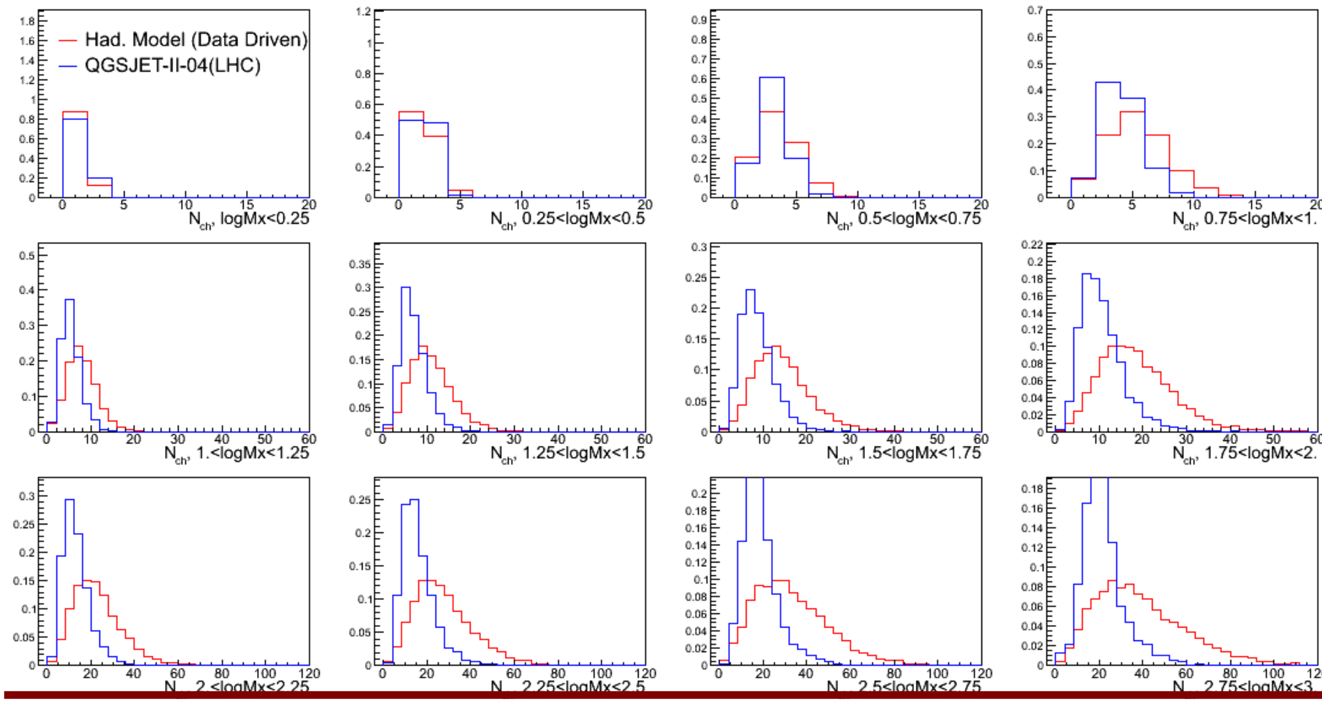
Too low multiplicities



Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

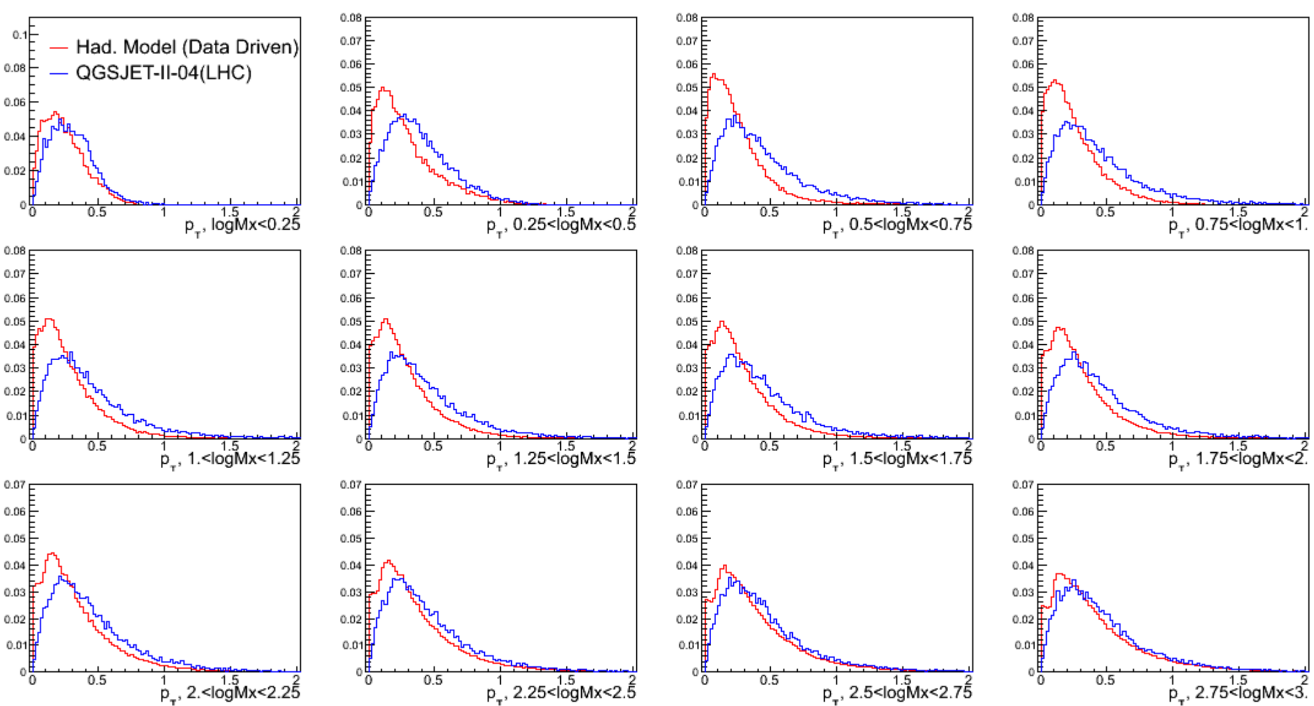
QGSJET-II-04 hadronization model



Compared to data-driven reference (Hadronization model of MBR@CDF)

Charged multiplicities in bins of Mx (SD process)

Too low multiplicities

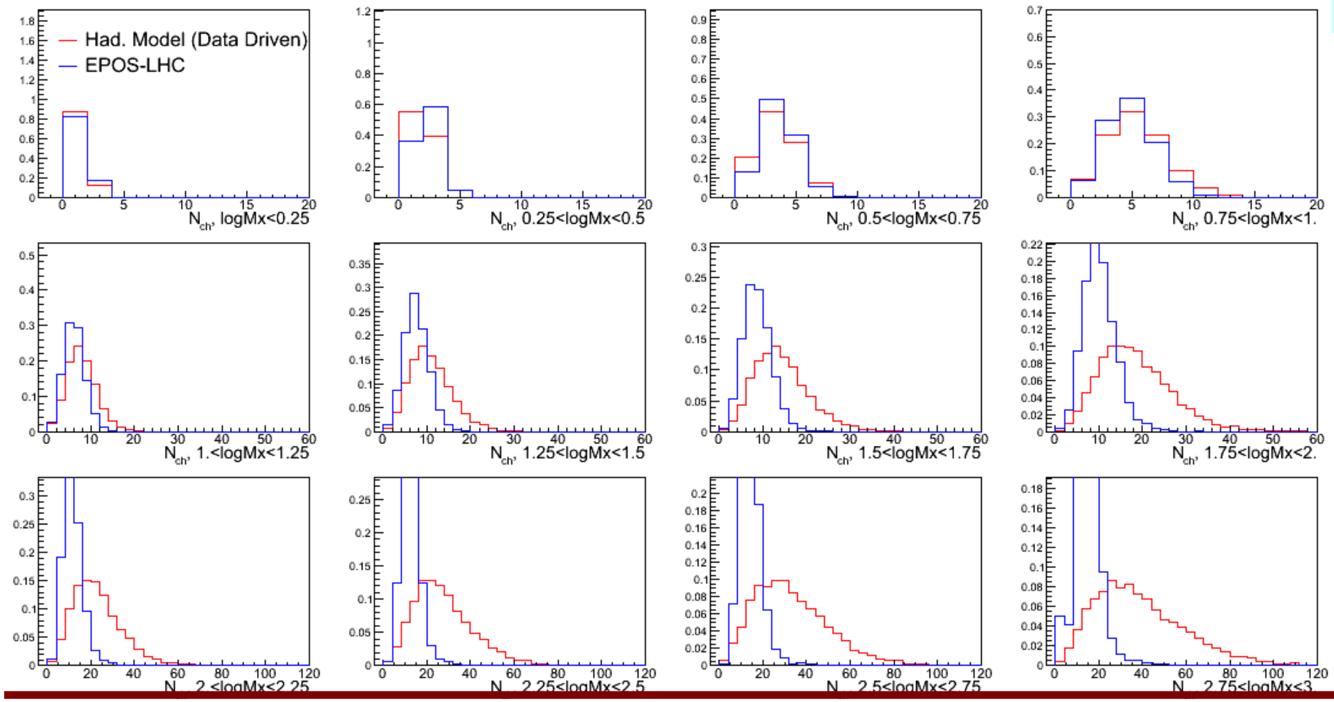


Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

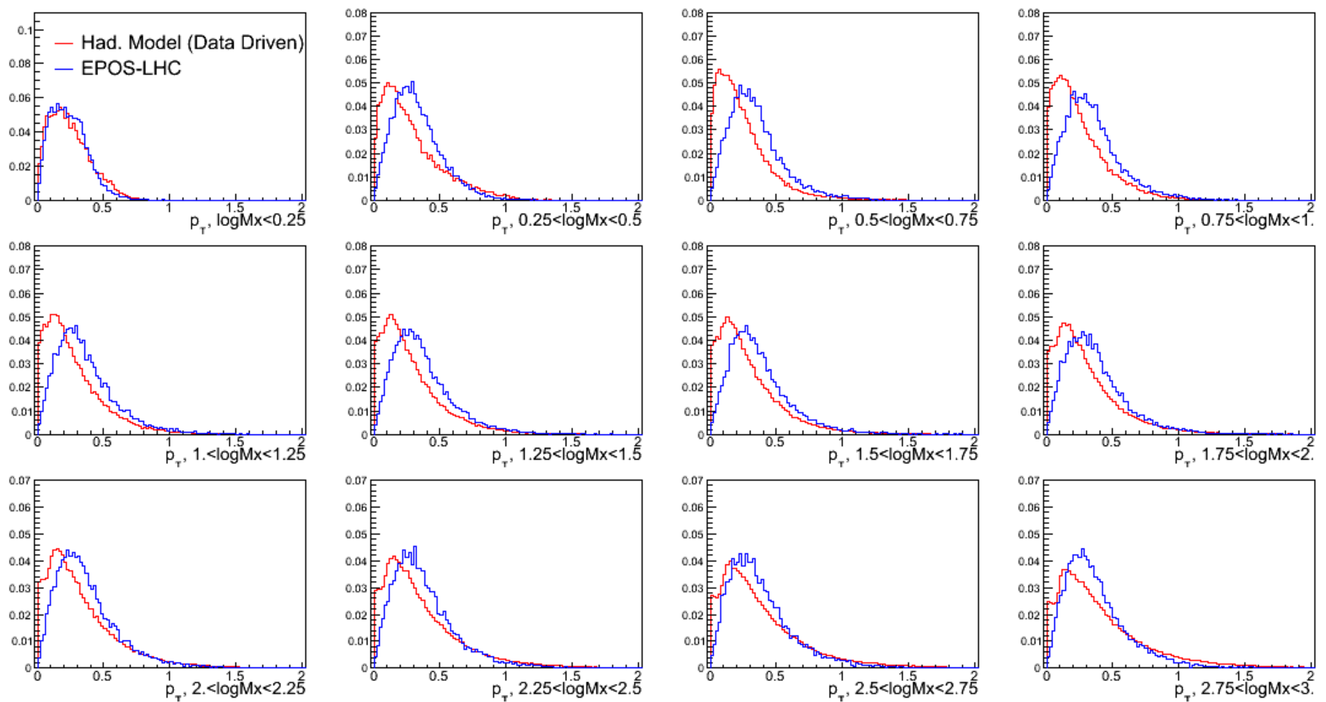
EPOS hadronization model

Compared to data-driven reference (Hadronization model of MBR@CDF)



Charged multiplicities in bins of Mx (SD process)

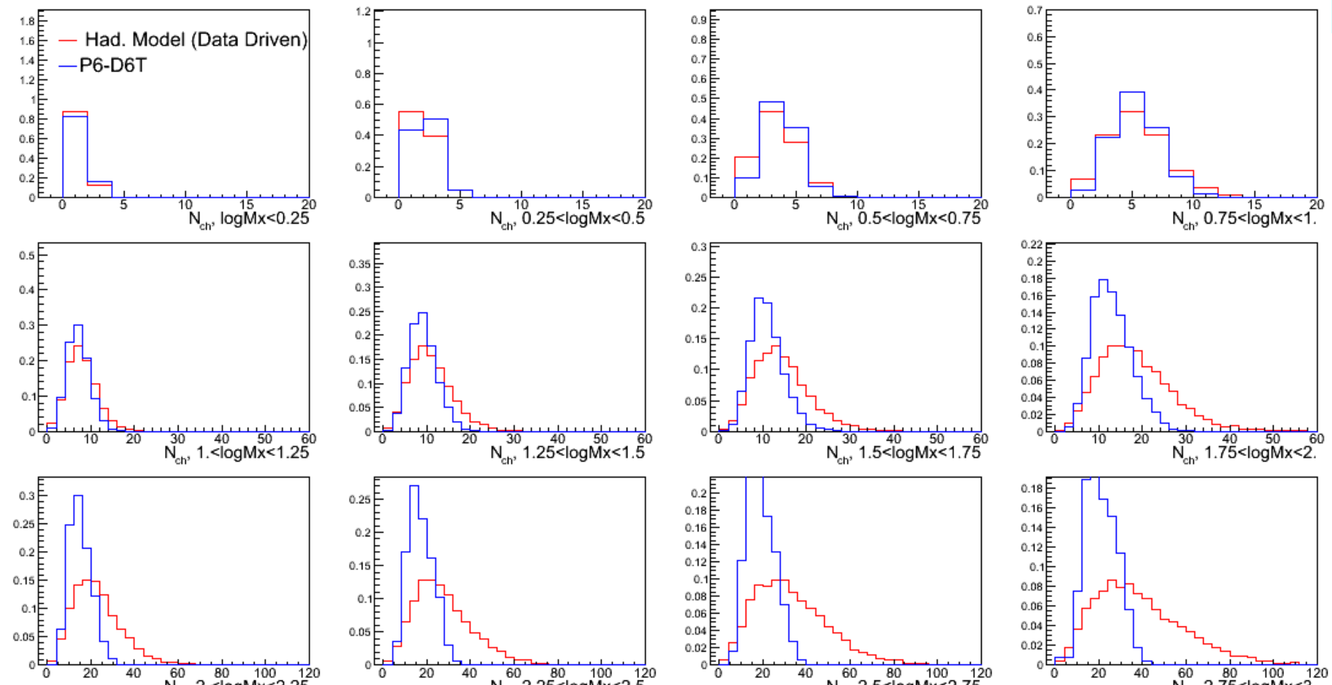
Too low multiplicities



Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

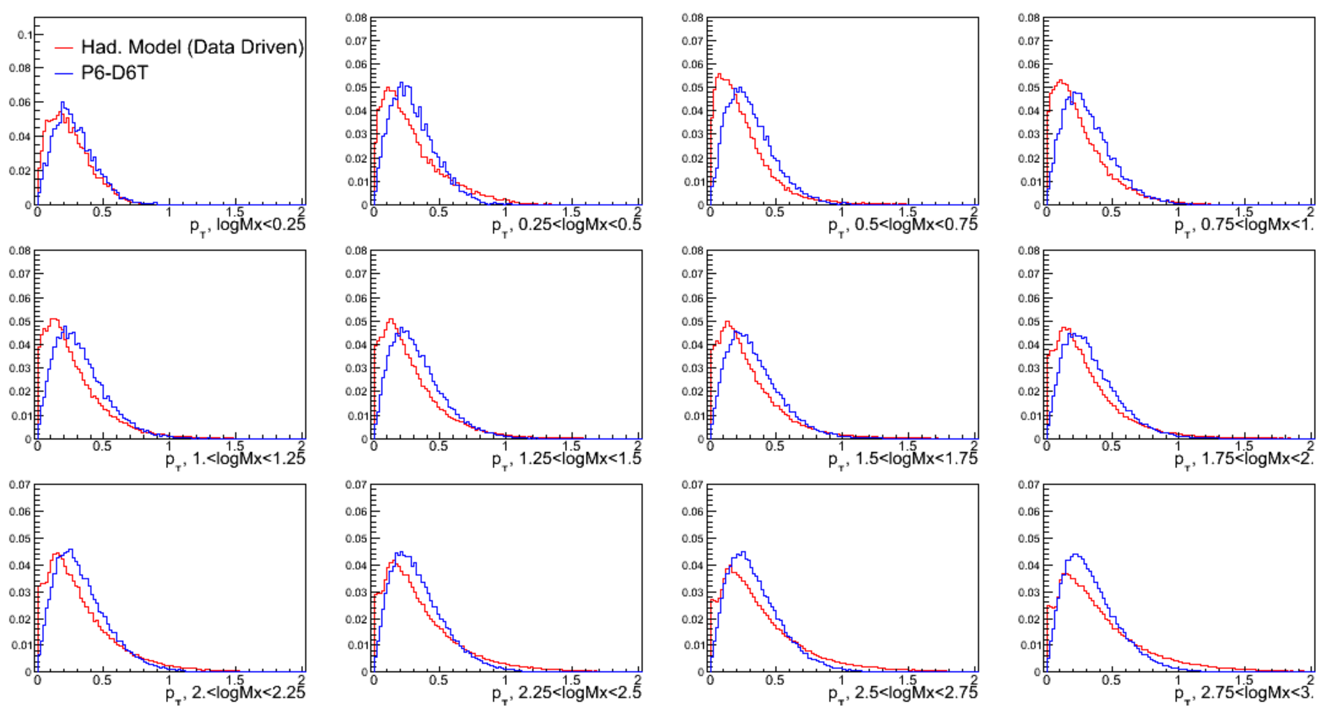
PYTHIA6-D6T hadronization model



Compared to data-driven reference (Hadronization model of MBR@CDF)

Charged multiplicities in bins of Mx (SD process)

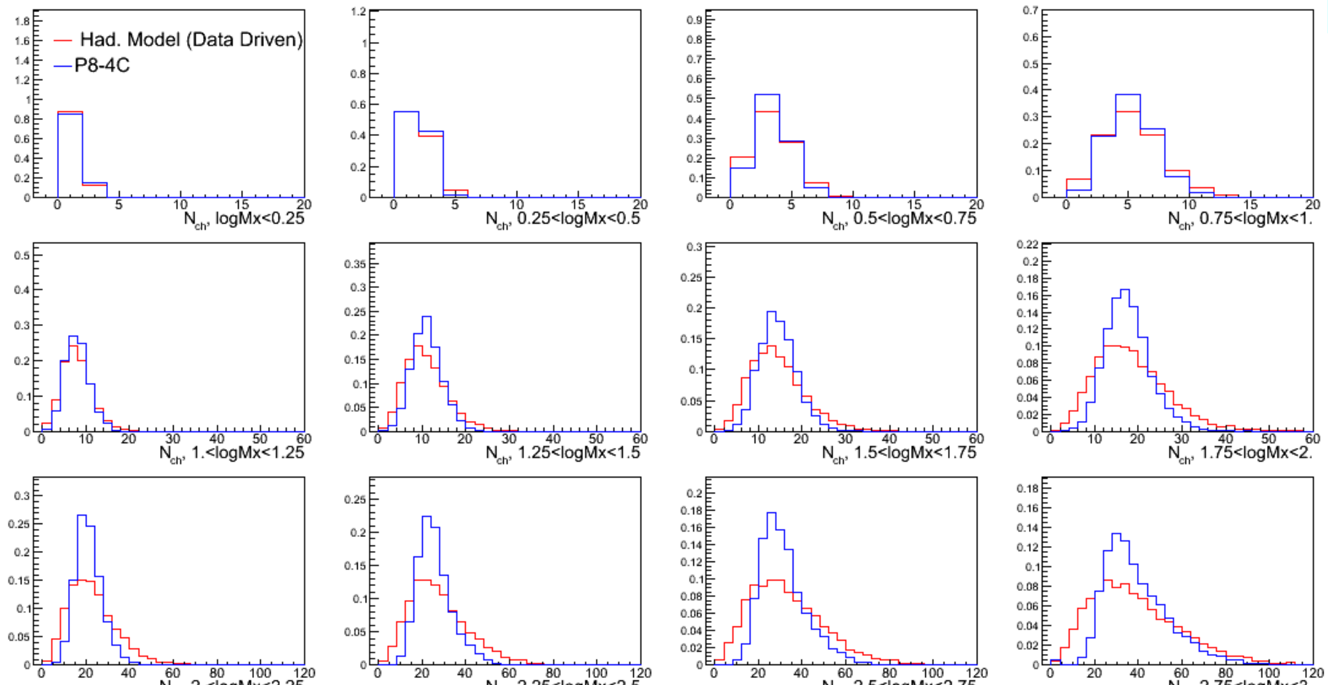
Too low multiplicities



Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

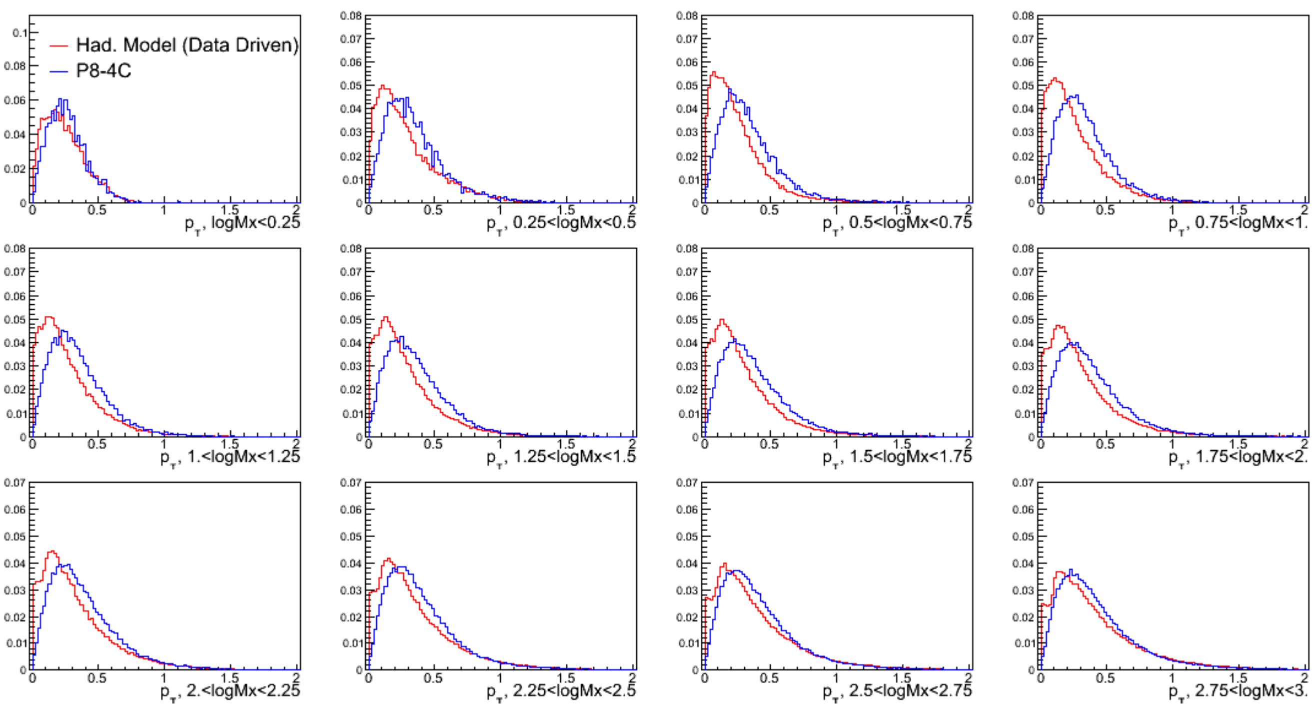
PYTHIA8-4C hadronization model



Compared to data-driven reference (Hadronization model of MBR@CDF)

Charged multiplicities in bins of Mx (SD process)

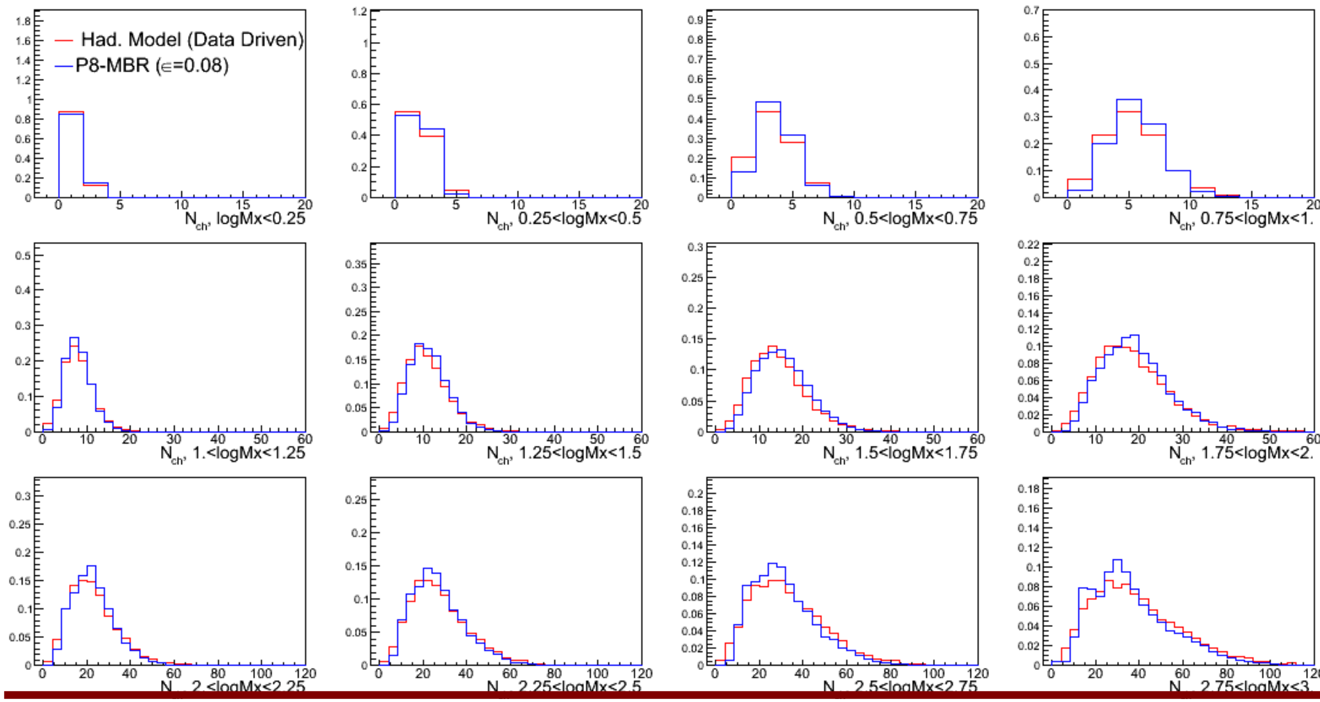
Mean multiplicities OK
Widths too narrow



Track pT spectra in bins of Mx (SD process)

Too hard pT spectra

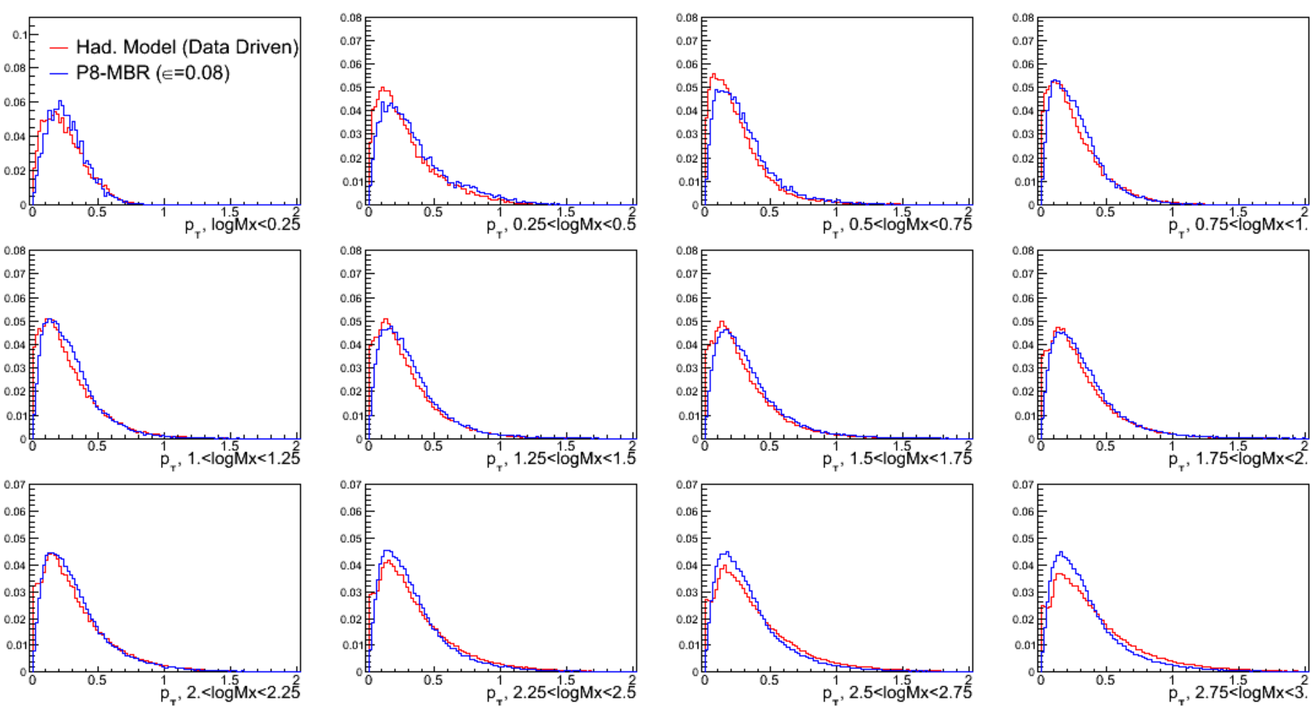
PYTHIA8-MBR hadronization model



Compared to data-driven reference (Hadronization model of MBR@CDF)

Charged multiplicities in bins of Mx (SD process)

OK;
Tuned to reproduce MBR@CDF



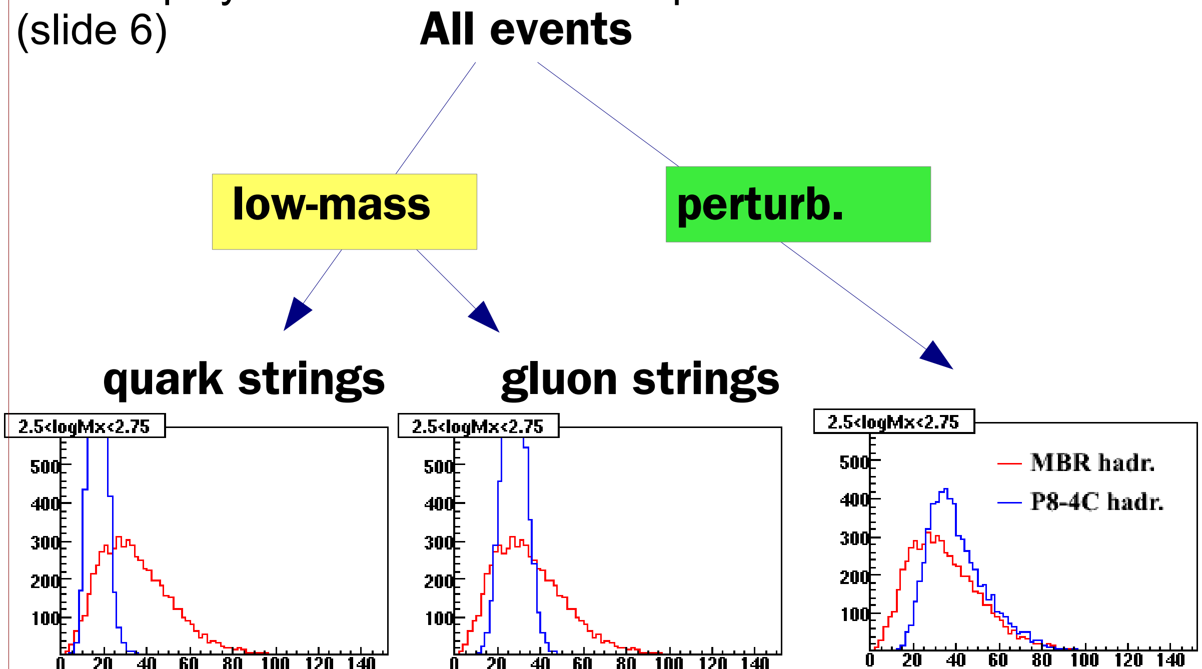
Track pT spectra in bins of Mx (SD process)

OK;
Tuned to reproduce MBR@CDF

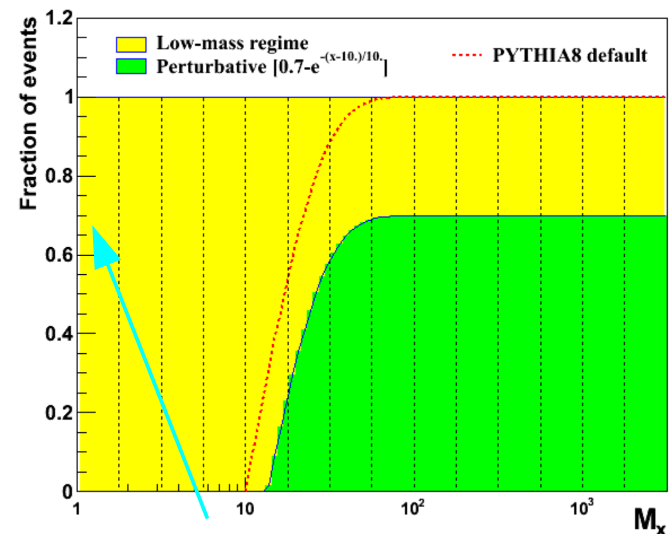
See next slides

PYTHIA8-MBR hadronization tune

An interplay between low-mass vs perturbative hadronization regimes (slide 6)



Contribution from q-string / g-string / perturbative-regime only (blue), compared to a full multiplicity spectrum (red).



Fraction of low-mass events in the perturbative regime is given by (1-ProbMaxPert), with ProbMaxPert=0.7 (default=1)

- Multiplicity spectra:
  - Higher multiplicities:
    - introduce low-mass regime for fraction of events
    - In perturbative regime: check energy dependence of the sigmaPomP parameter

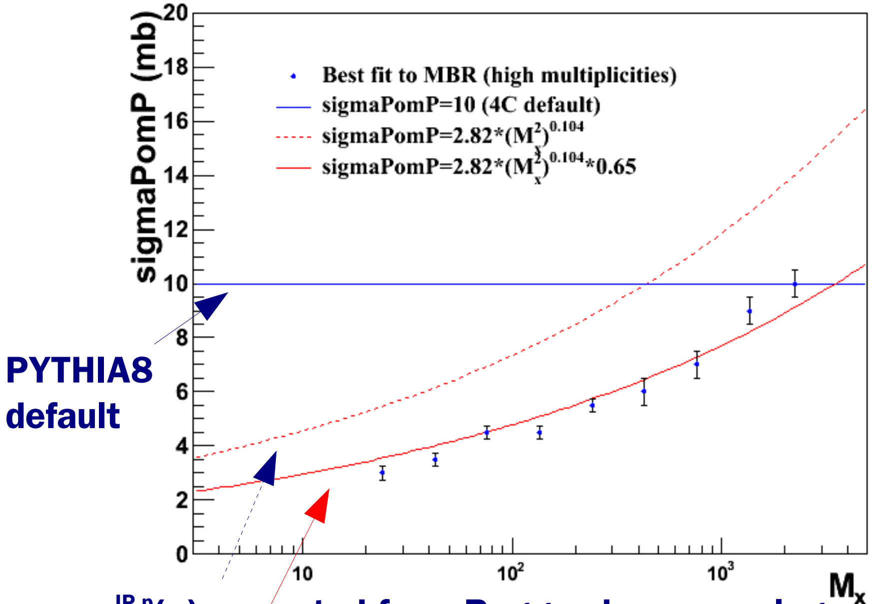
$$n_{ave} = \frac{\sigma_{QCD}}{\sigma_{IPp}}$$

  - Lower miltiplicities (low-mass regime) :
    - tune the ratio of a quark to gluon induced strings, driven by pickQuarkNorm/Power parameters

    quarks give lower multiplicities than gluons
- pT spectra: tune the parameters of the StringPT class.

PYTHIA8-MBR hadronization tune

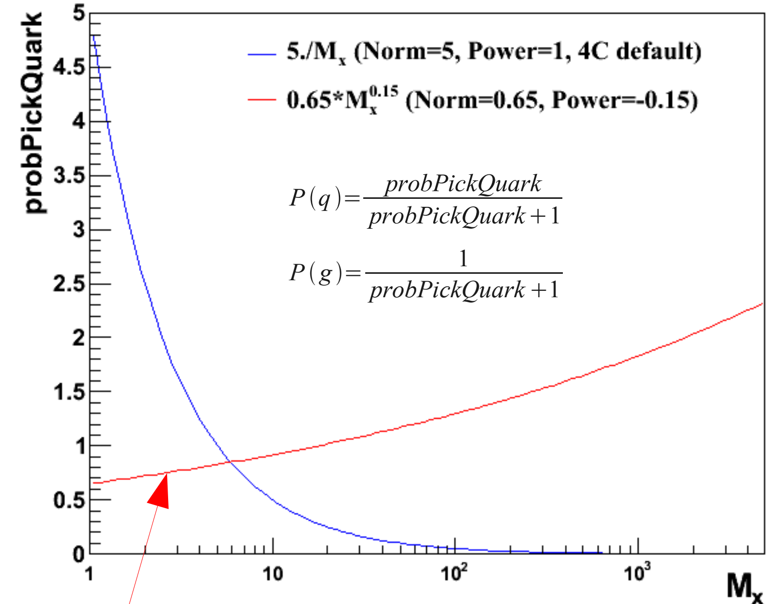
Diffraction: SigmaPomP parameter $n_{ave} = \frac{\sigma_{QCD}}{\sigma_{IPp}}$



$\sigma^{IP\,p}(s)$ expected from Regge phenomenology for s_0=1 GeV^2 and DL t-dependence.

Red line: best fit to multiplicity distributions.
(in bins of Mx, fits to higher tails only, default pT spectra)

Diffraction: pickQuarkNorm/Power parameter

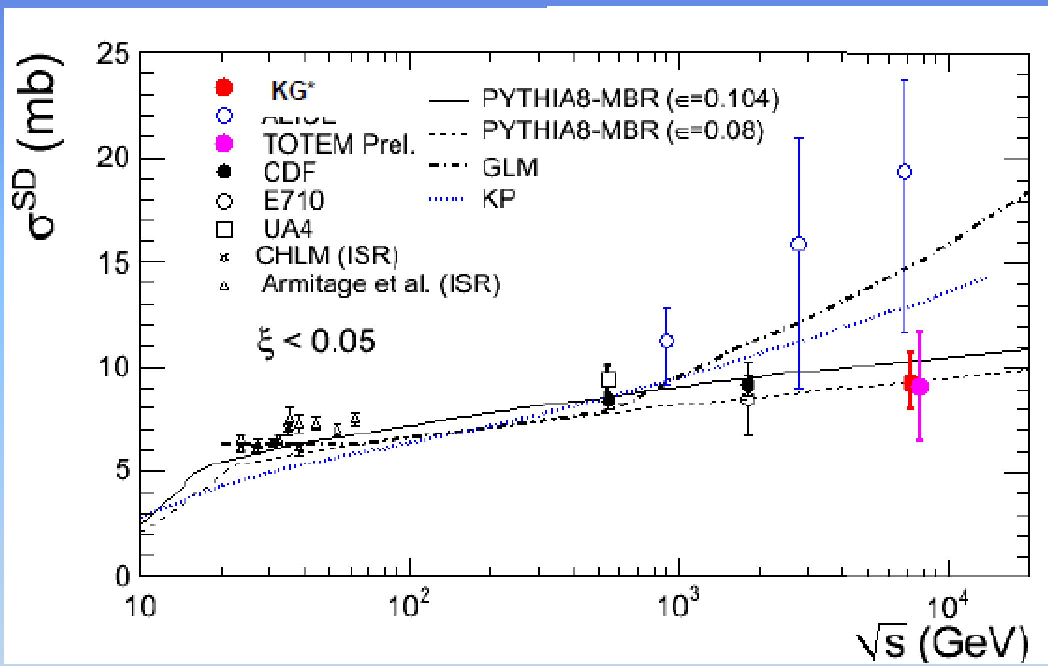


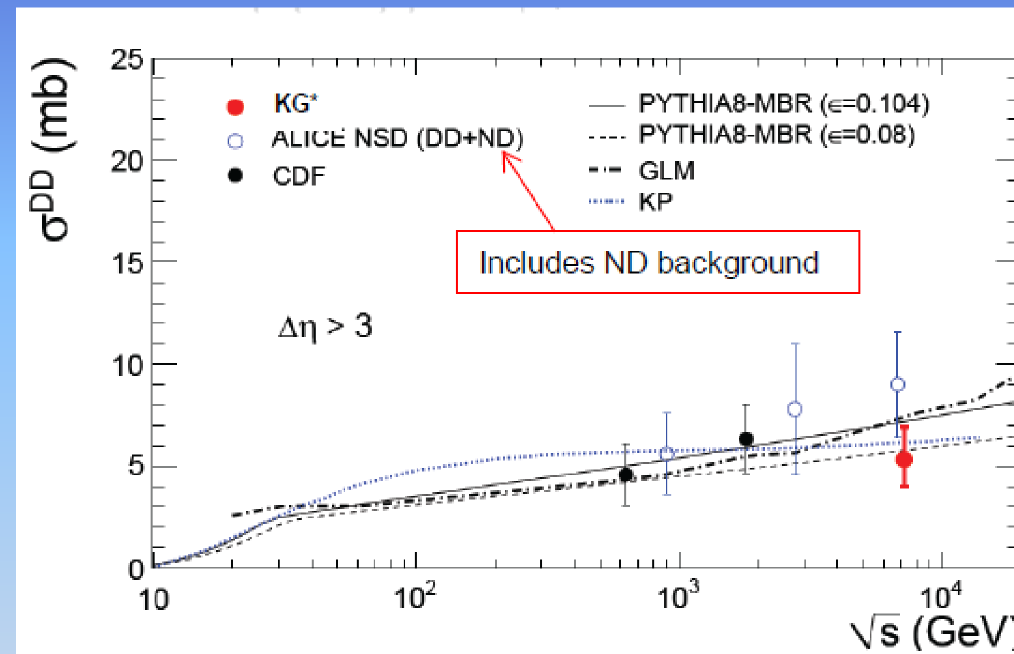
Red line: good description of low multiplicity tails.

pT spectra:
A set of StringPT:sigma=0.09, StringPT:enhancedWidth=5, StrangPT:enhancedFraction=0.2 describes well diffractive events, but is not expected to describe non-diffractive events.
(Mx/√s dependence of pT spectra expected, see slide 13, but in Pythia parameters are set globally)

SD and DD cross sections vs predictions

What to expect at 14 TeV





❖ KG*: from CMS measurements after extrapolation into low ξ using the KG model.

KG model = MBR model
TOTEM point – combined preliminary SD measurement for Mx>3.4 GeV and T2-invisible cross section measurement.

Summary

Compared most common MC models for diffraction with the preliminary CMS results on SD and DD cross sections @ 7TeV.

Compared charged-multiplicity and pT spectra among hadronization models for dissociation system Mx.

Most of the models either fail in describing the measured SD/DD cross sections or have unrealistic hadronization.

PYTHIA8-MBR simultaneously describes all aspects of the data.