

Predictions of Soft Processes at the LHC Implemented in PYTHIA8



Konstantin Goulios*

The Rockefeller University



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High Energy Physics - Phenomenology

MBR Monte Carlo Simulation in PYTHIA8

R. Ciesielski, K. Goulios

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* with:
Robert Ciesielski

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- Cross Sections
- (Event Generation)
- (Implementation in PYTHIA8)
- (Conclusion)

INTRODUCTION

- ❑ This is an adaptation of the MBR (Minimum Bias Rockefeller) simulation **RENORM** to PYTHIA8.
 - successfully tested at Fermilab fixed target and collider experiments.
- ❑ RENORM predictions are based on a parton model approach, in which **diffraction is derived from inclusive PDFs and color factors**.
- ❑ Gap Cross Sections:
 - Gap cross sections vs gap width:
 - ✓ **Absolute normalization!**
 - Hadronization of dissociated proton:
 - Implemented by introducing a (non-perturbative) **“quark string”** and tuning it to reproduce the MBR multiplicity and p_T distributions.
 - $dN/d\eta$, p_T , and particle ID (new in this implementation; the original MBR produced only π^\pm and π^0)
 - Unique unitarization procedure based on a saturated exchange.
- ❑ Total Cross section: based on a **saturated Froissart bound** leading to a $\ln^2 s$ dependence.
 - Immune to eikonalization models that plague the field!

STUDIES OF DIFFRACTION IN QCD

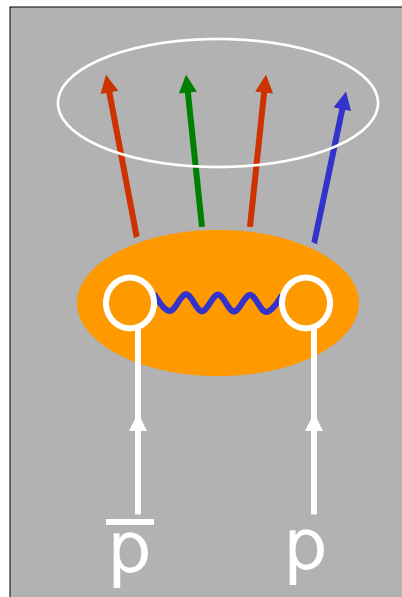
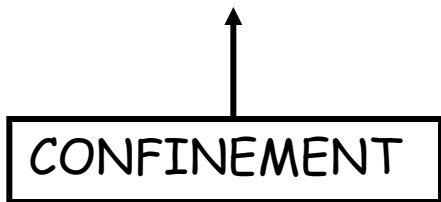
Non-diffractive

- ❖ color-exchange \rightarrow gaps exponentially suppressed

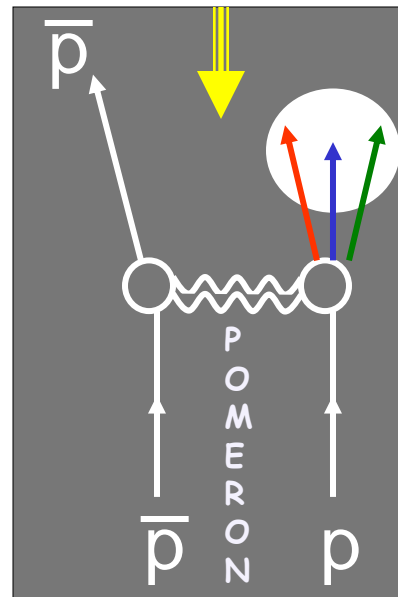
Diffractive

- ❖ Colorless vacuum exchange \rightarrow large-gap signature

Incident hadrons acquire color and break apart



rapidity gap



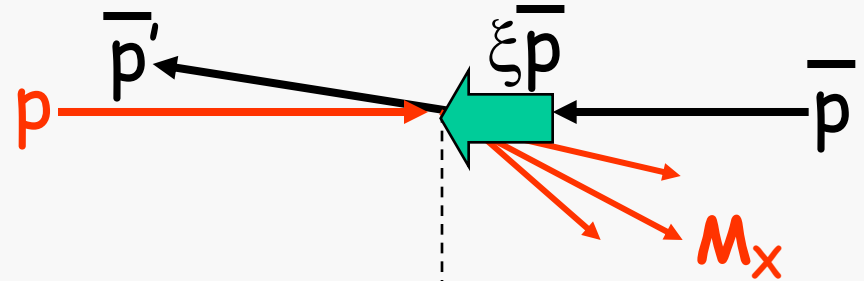
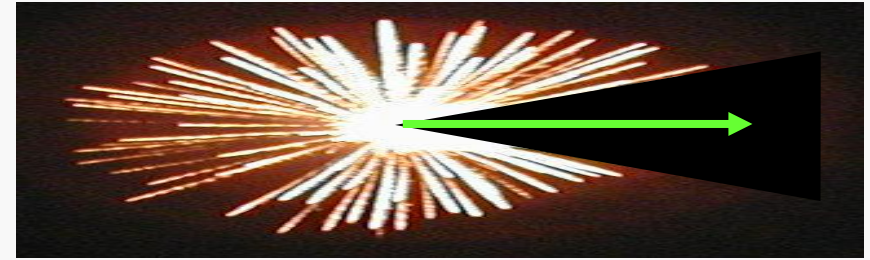
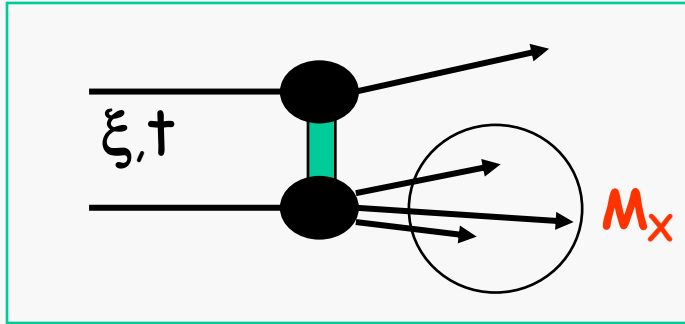
Incident hadrons retain their quantum numbers remaining colorless



Goal: probe the QCD nature of the diffractive exchange

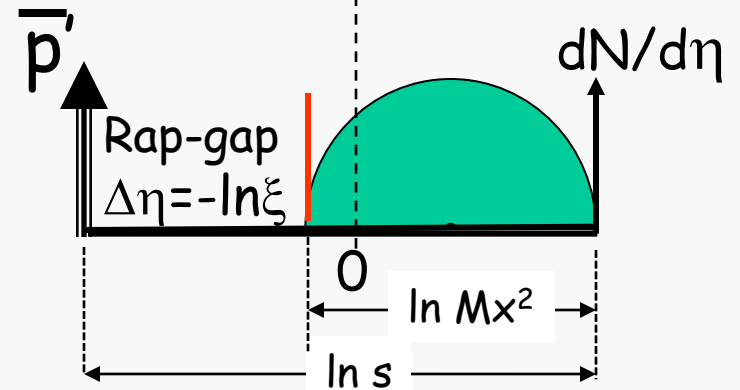
DEFINITIONS

SINGLE DIFFRACTION



$$1 - x_L \equiv \xi = \frac{M_X^2}{s}$$

$$\xi^{\text{CAL}} = \frac{\sum_{i=1}^{\text{all}} E_T^{i\text{-tower}} e^{-\eta_i}}{\sqrt{s}}$$

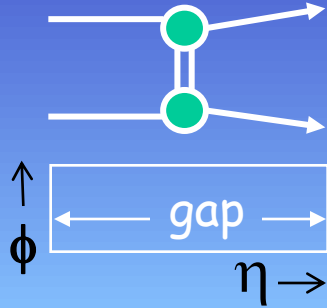


since no radiation \rightarrow
no price paid for increasing
diffractive gap size

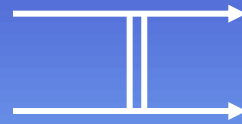
$$\left(\frac{d\sigma}{d\Delta\eta} \right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{dM^2} \propto \frac{1}{M^2}$$

DIFFRACTION AT CDF

Elastic scattering

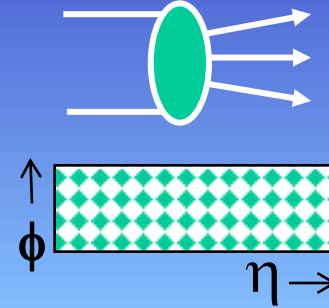


$\sigma_T = \text{Im } f_{el}(t=0)$

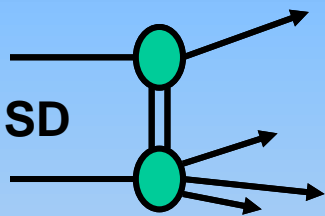


OPTICAL THEOREM

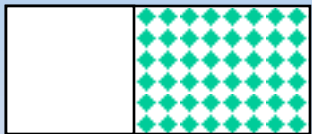
Total cross section



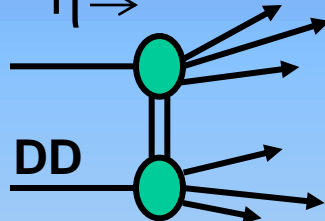
SD



Single Diffraction or Single Dissociation



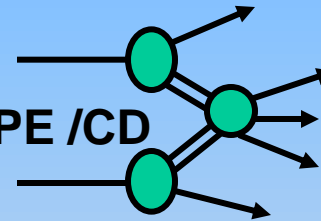
DD



Double Diffraction or Double Dissociation



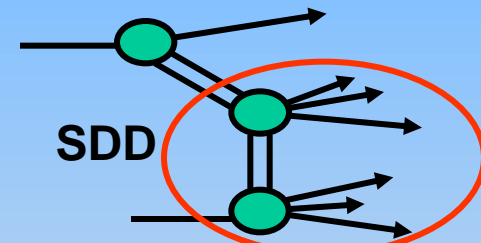
DPE / CD



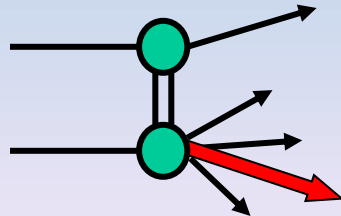
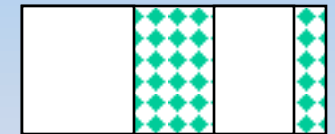
Double Pom. Exchange or Central Dissociation



SDD

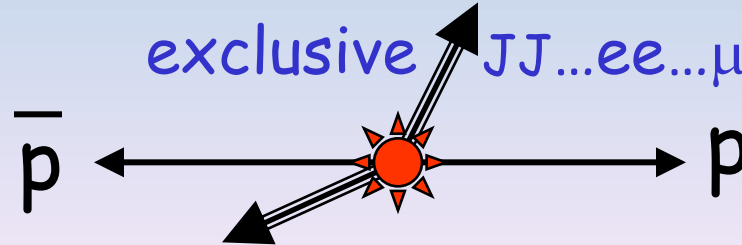


Single + Double Diffraction (SDD)



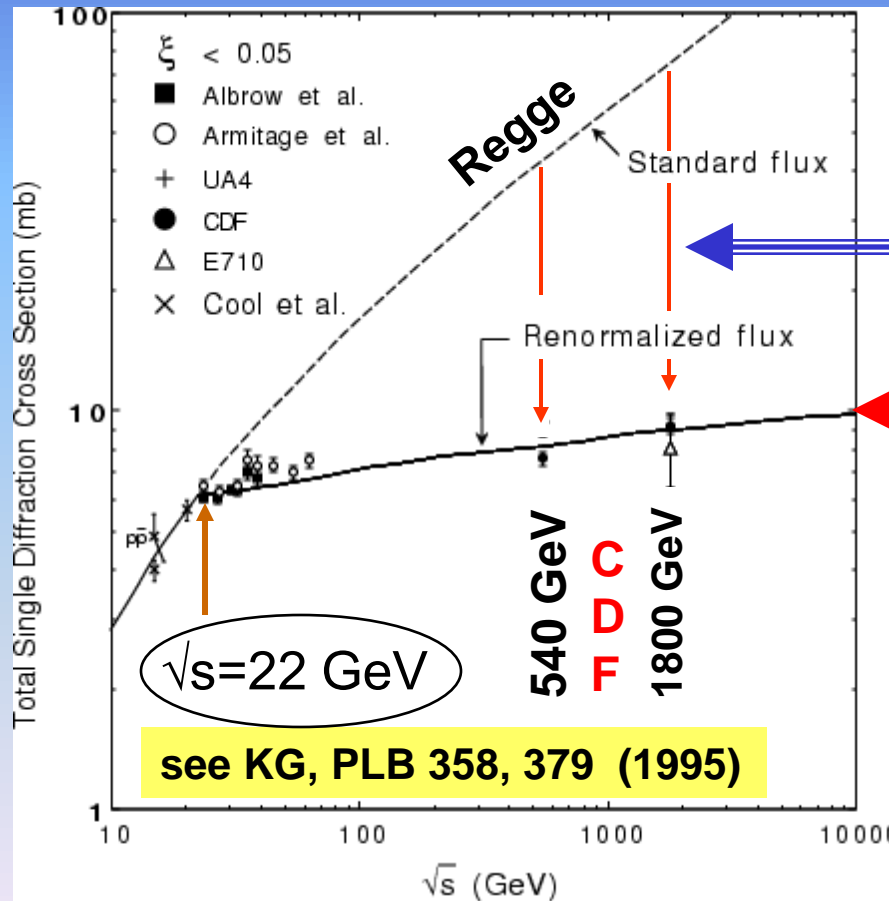
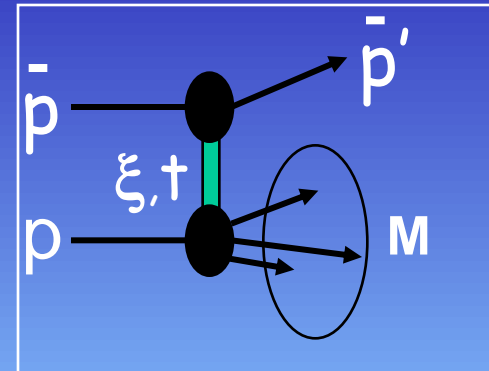
JJ, b, J/ψ, W

exclusive JJ...ee...μμ...γγ



FACTORIZATION BREAKING IN SOFT DIFFRACTION

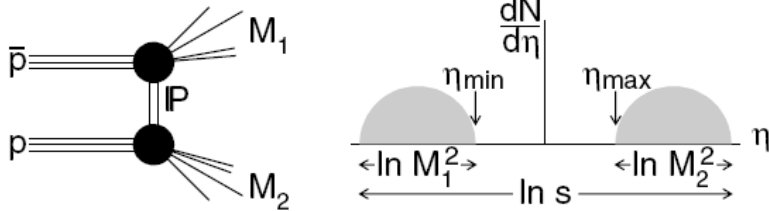
→ diffractive x-section suppressed relative to Regge prediction as \sqrt{s} increases



Factor of ~ 8 (~ 5)
suppression at
 $\sqrt{s} = 1800$ (540) GeV

RENORMALIZATION

DD at CDF

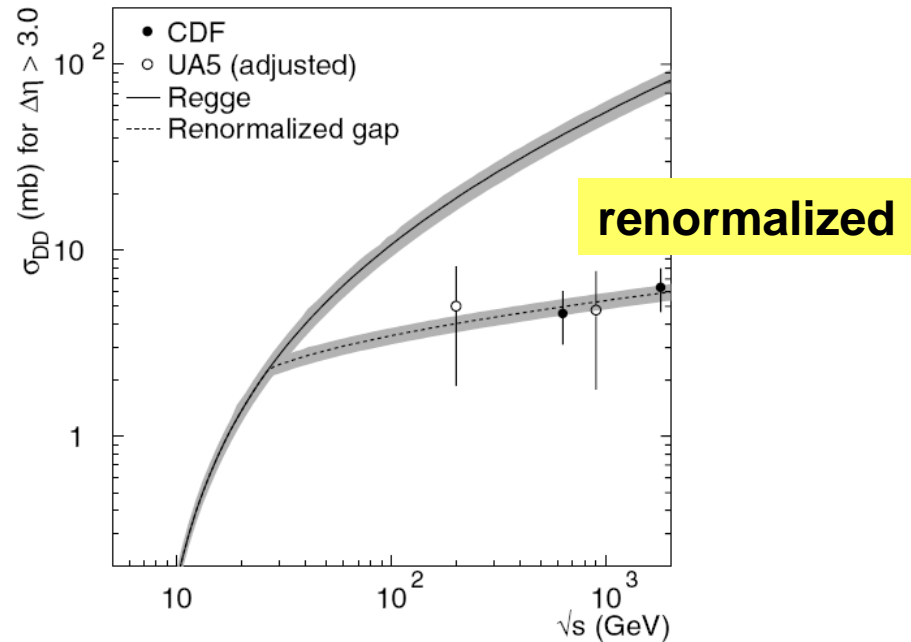
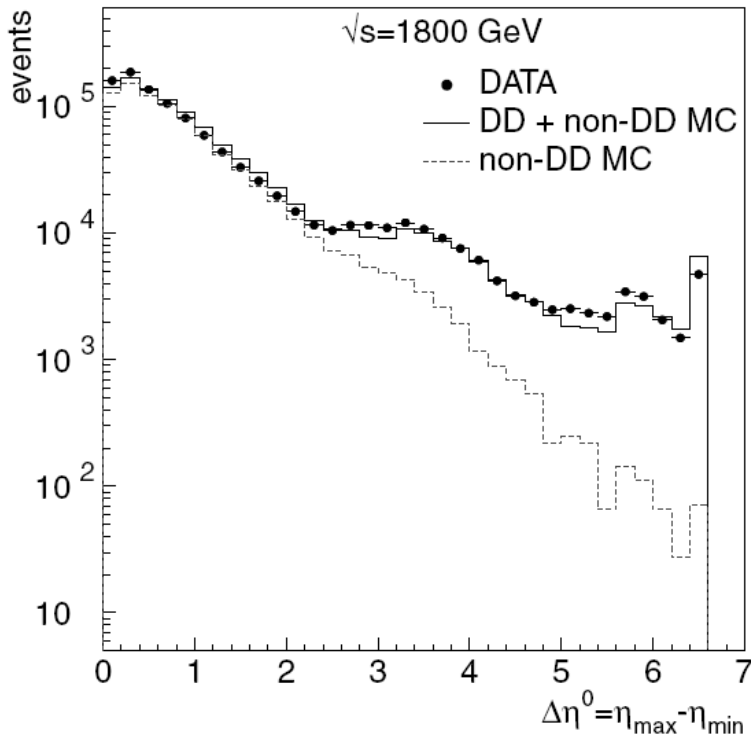


$$\frac{d^3\sigma_{DD}}{dtdM_1^2dM_2^2} = \frac{d^2\sigma_{SD}}{dtdM_1^2} \frac{d^2\sigma_{SD}}{dtdM_2^2} / \frac{d\sigma_{el}}{dt}$$

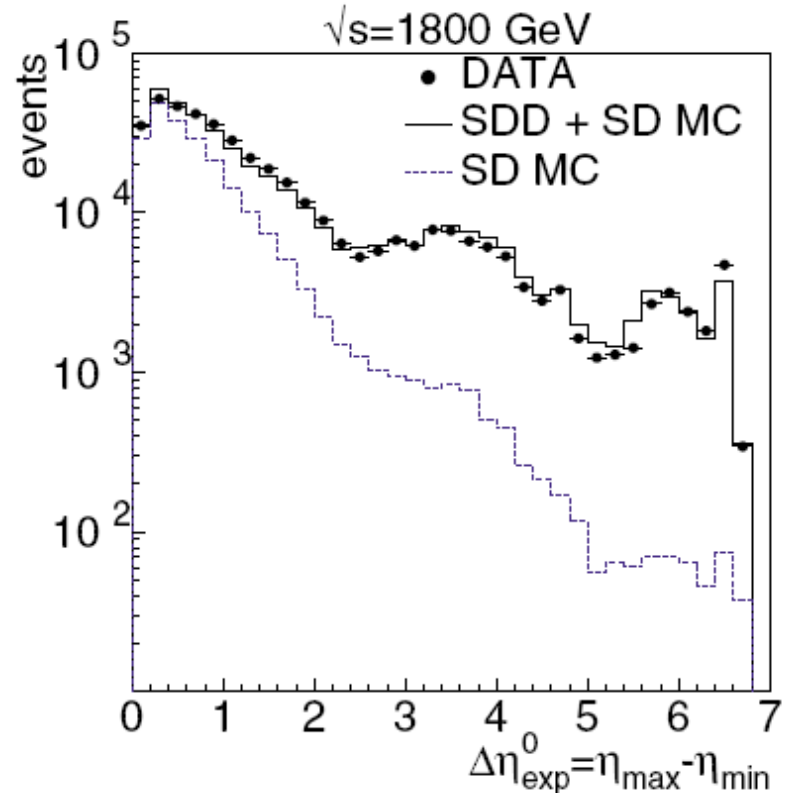
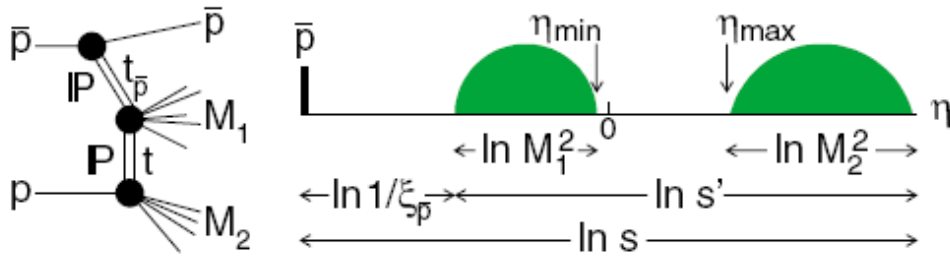
$$= \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi} \frac{s^{2\epsilon} e^{b_{DD}t}}{(M_1^2 M_2^2)^{1+2\epsilon}}$$

$$\frac{d^3\sigma_{DD}}{dtd\Delta\eta d\eta_c} = \left[\frac{\kappa\beta^2(0)}{16\pi} e^{2[\alpha(t)-1]\Delta\eta} \right] \left[\kappa\beta^2(0) \left(\frac{s'}{s_0} \right)^\epsilon \right]$$

gap probability x-section



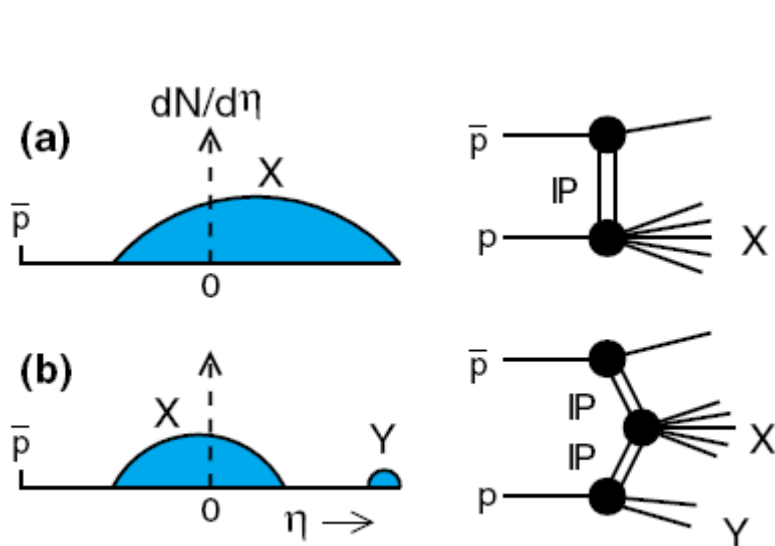
SDD at CDF



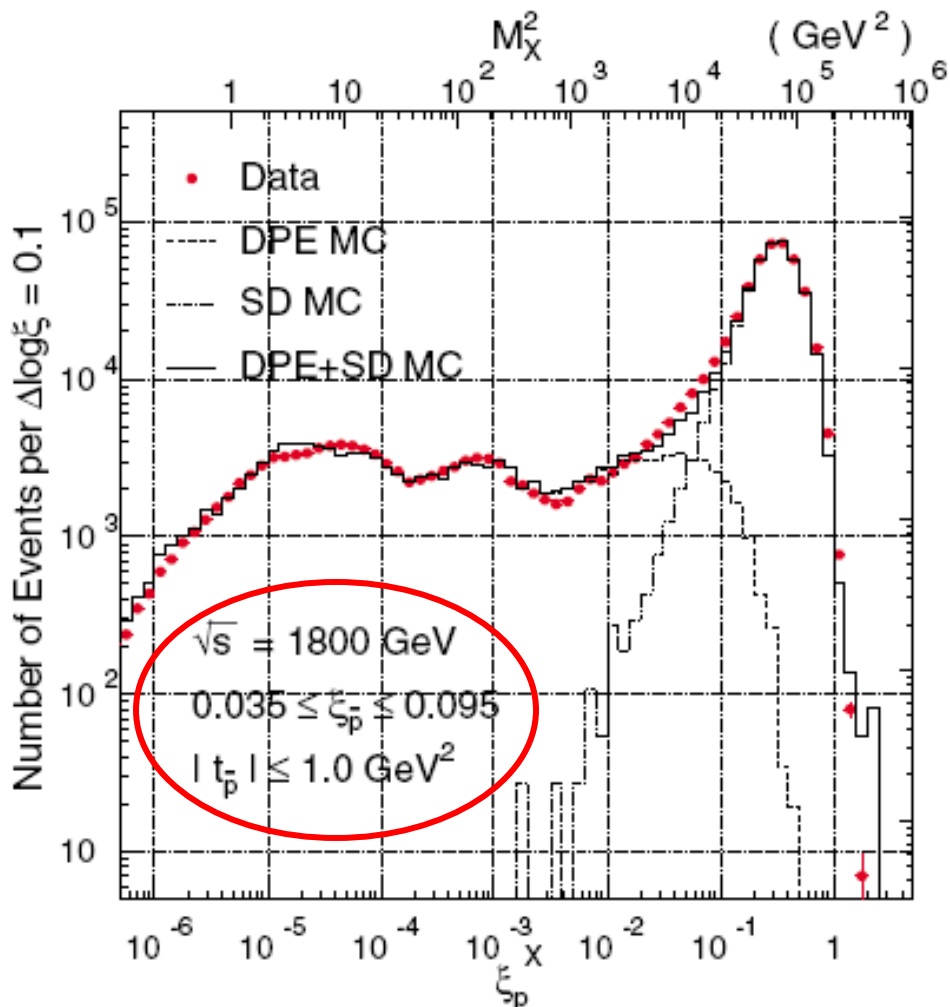
■ Excellent agreement between data and MBR (MinBiasRockefeller) MC

$$\frac{d^5\sigma}{dt_{\bar{p}} dt d\xi_{\bar{p}} d\Delta\eta d\eta_c} = \left[\frac{\beta(t)}{4\sqrt{\pi}} e^{[\alpha(t_{\bar{p}})-1]\ln(1/\xi)} \right]^2 \times \kappa \left\{ \kappa \left[\frac{\beta(0)}{4\sqrt{\pi}} e^{[\alpha(t)-1]\Delta\eta} \right]^2 \kappa \left[\beta^2(0) \left(\frac{s''}{s_0} \right)^\epsilon \right] \right\}$$

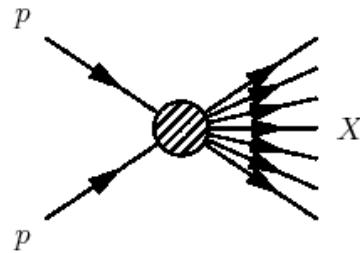
CD (DPE) at CDF



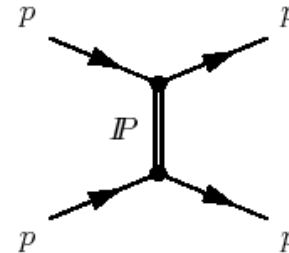
- Excellent agreement between data and MBR
- ➔ low and high masses are correctly implemented



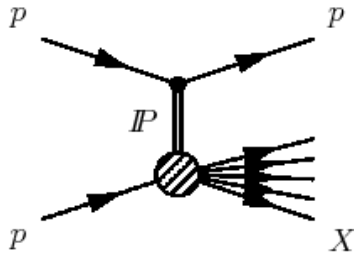
Cross Sections



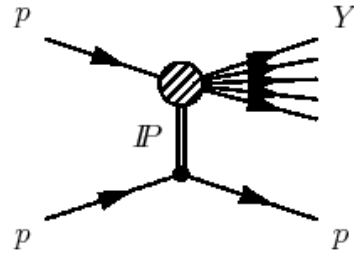
(a) tot



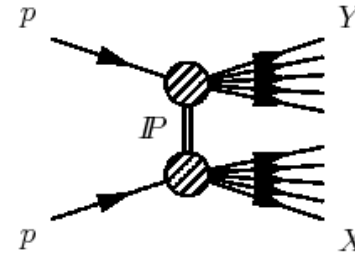
(b) el



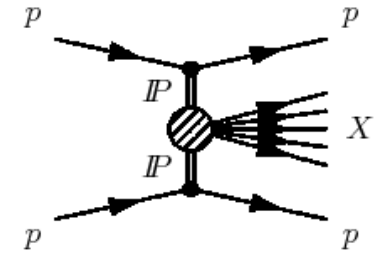
(c) SD



(d) SD



(e) DD



(f) CD

- SD → single diffraction (single dissociation)
- DD → double diffraction (double diffraction)
- CD → central dissociation (double pomeron exchange)

Total, elastic, and inelastic x-sections

$$\sigma_{\text{ND}} = (\sigma_{\text{tot}} - \sigma_{\text{el}}) - (2\sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{CD}})$$

R. J. M. Covolan, K. Goulios, J. Montanha, Phys. Lett. B **389**, 176 (1996)

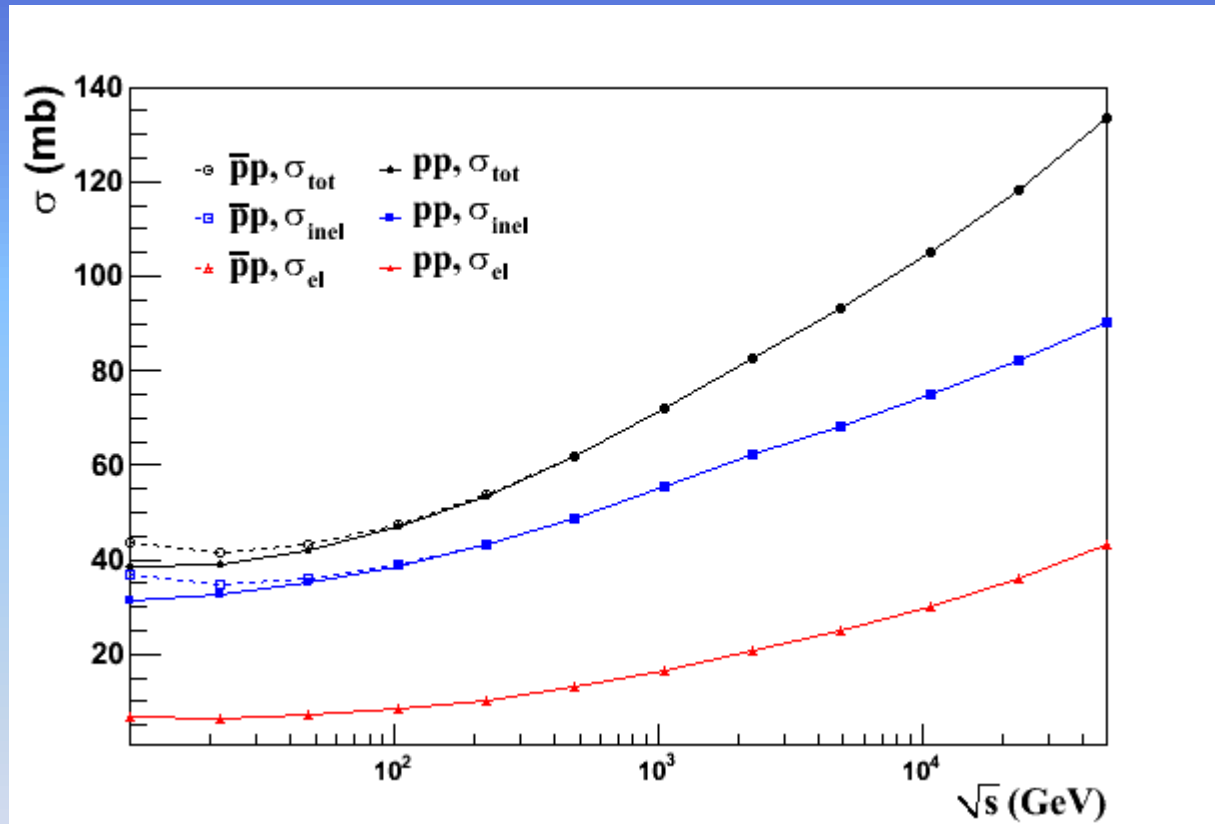
$$\sigma_{\text{tot}}^{p^\pm p} = \begin{cases} 16.79s^{0.104} + 60.81s^{-0.32} \mp 31.68s^{-0.54} & \text{for } \sqrt{s} < 1.8 \\ \sigma_{\text{tot}}^{\text{CDF}} + \frac{\pi}{s_0} \left[\left(\ln \frac{s}{s_F} \right)^2 - \left(\ln \frac{s^{\text{CDF}}}{s_F} \right)^2 \right] & \text{for } \sqrt{s} \geq 1.8 \end{cases}$$

K. Goulios, *Diffraction, Saturation and pp Cross Sections at the LHC*, arXiv:1105.4916.

$$\sqrt{s^{\text{CDF}}} = 1.8 \text{ TeV}, \sigma_{\text{tot}}^{\text{CDF}} = 80.03 \pm 2.24 \text{ mb}$$

$$\sqrt{s_F} = 22 \text{ GeV} \quad s_0 = 3.7 \pm 1.5 \text{ GeV}^2$$

Total, elastic, and inelastic x-sections versus \sqrt{s}



Diffractive x-sections

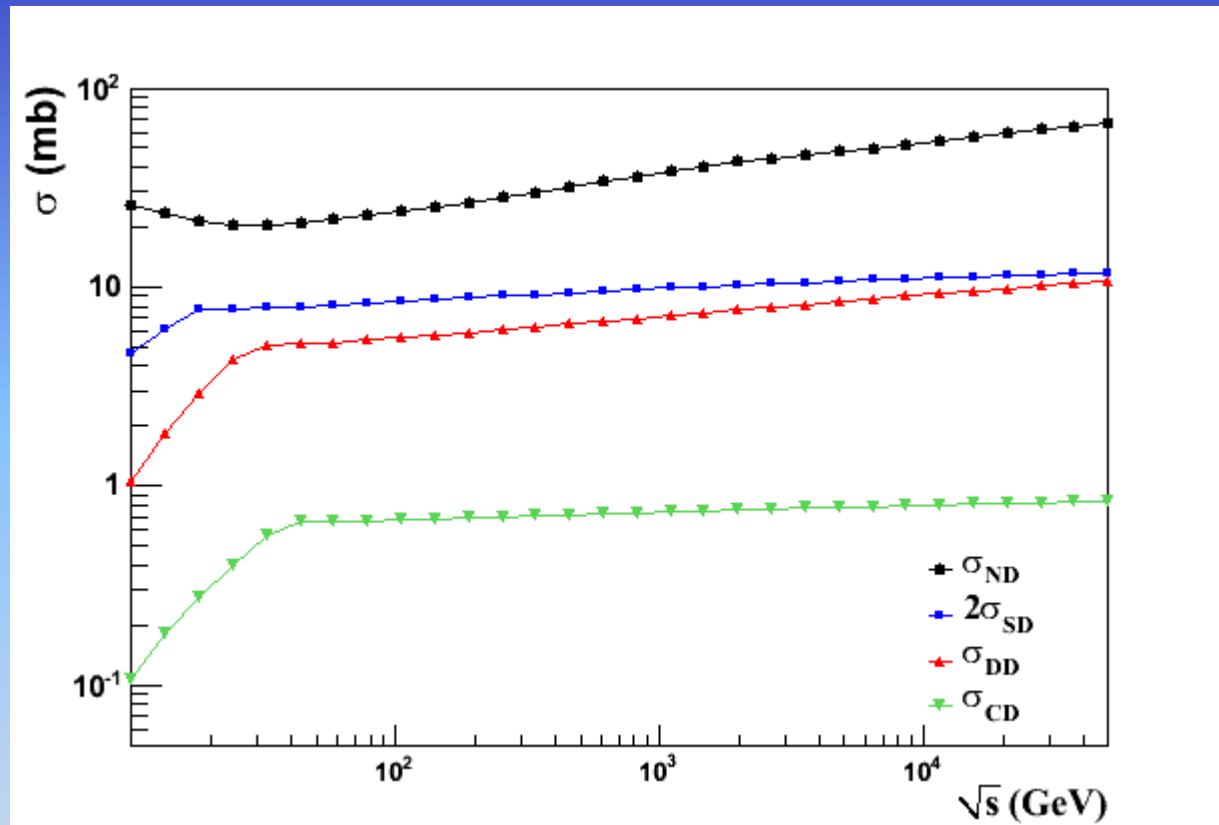
$$\begin{aligned} \frac{d^2\sigma_{SD}}{dt d\Delta y} &= \frac{1}{N_{\text{gap}}(s)} \left[\frac{\beta^2(t)}{16\pi} e^{2[\alpha(t)-1]\Delta y} \right] \cdot \left\{ \kappa \beta^2(0) \left(\frac{s'}{s_0} \right)^\epsilon \right\}, \\ \frac{d^3\sigma_{DD}}{dt d\Delta y dy_0} &= \frac{1}{N_{\text{gap}}(s)} \left[\frac{\kappa \beta^2(0)}{16\pi} e^{2[\alpha(t)-1]\Delta y} \right] \cdot \left\{ \kappa \beta^2(0) \left(\frac{s'}{s_0} \right)^\epsilon \right\}, \\ \frac{d^4\sigma_{DPE}}{dt_1 dt_2 d\Delta y dy_c} &= \frac{1}{N_{\text{gap}}(s)} \left[\prod_i \left[\frac{\beta^2(t_i)}{16\pi} e^{2[\alpha(t_i)-1]\Delta y_i} \right] \right] \cdot \kappa \left\{ \kappa \beta^2(0) \left(\frac{s'}{s_0} \right)^\epsilon \right\} \end{aligned}$$

$$\beta^2(t) = \beta^2(0) F^2(t)$$

$$F^2(t) = \left[\frac{4m_p^2 - 2.8t}{4m_p^2 - t} \left(\frac{1}{1 - \frac{t}{0.71}} \right)^2 \right]^2 \approx a_1 e^{b_1 t} + a_2 e^{b_2 t}$$

$$\alpha_1=0.9, \alpha_2=0.1, b_1=4.6 \text{ GeV}^{-2}, b_2=0.6 \text{ GeV}^{-2}, s'=s e^{-\Delta y}, \kappa=0.17, \kappa\beta^2(0)=\sigma_0, s_0=1 \text{ GeV}^2, \sigma_0=2.82 \text{ mb or } 7.25 \text{ GeV}^{-2}$$

Diffractive x-sections of \sqrt{s}

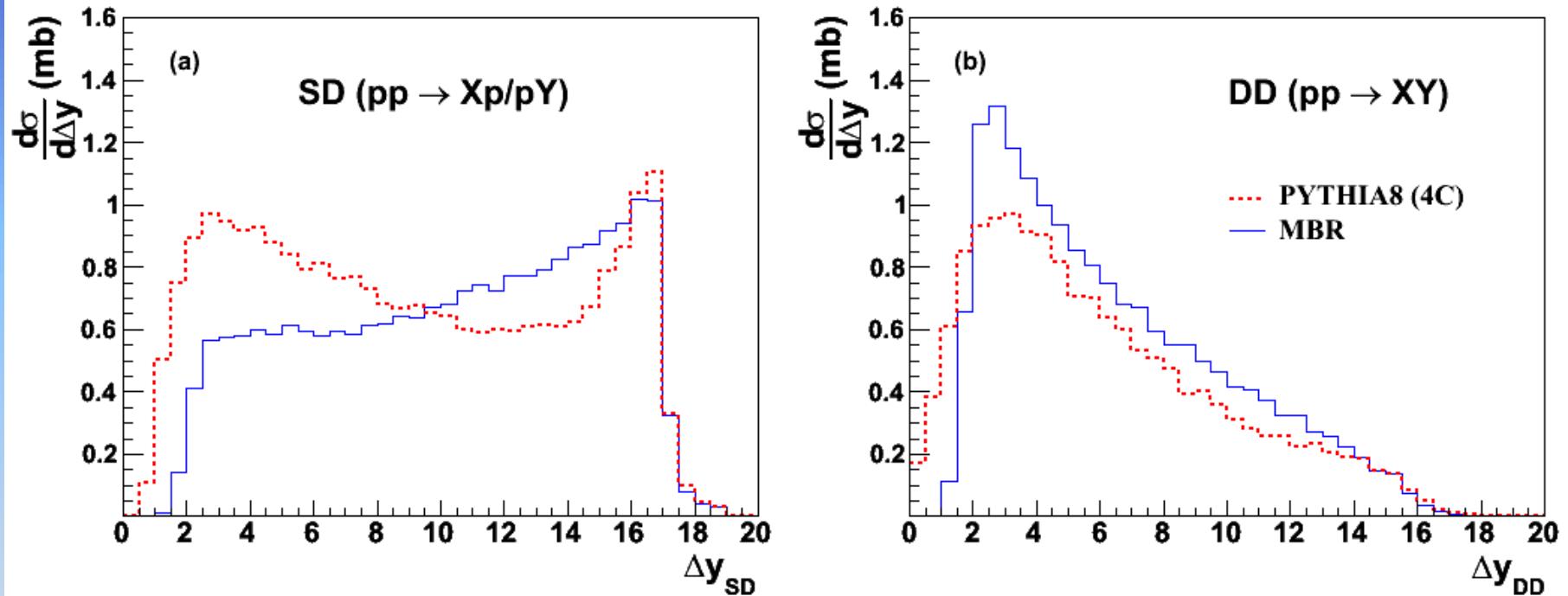


- Suppress x-sections at small gaps by a factor S using the error function with $\Delta y_S = 2$ for SD and DD, and $\Delta y = \Delta y_1 + \Delta y_2 = 2$ for CD (DPE).

$$S = \frac{1}{2} \left[1 + \text{erf} \left(\frac{\Delta y - \Delta y_S}{\sigma_S} \right) \right]$$

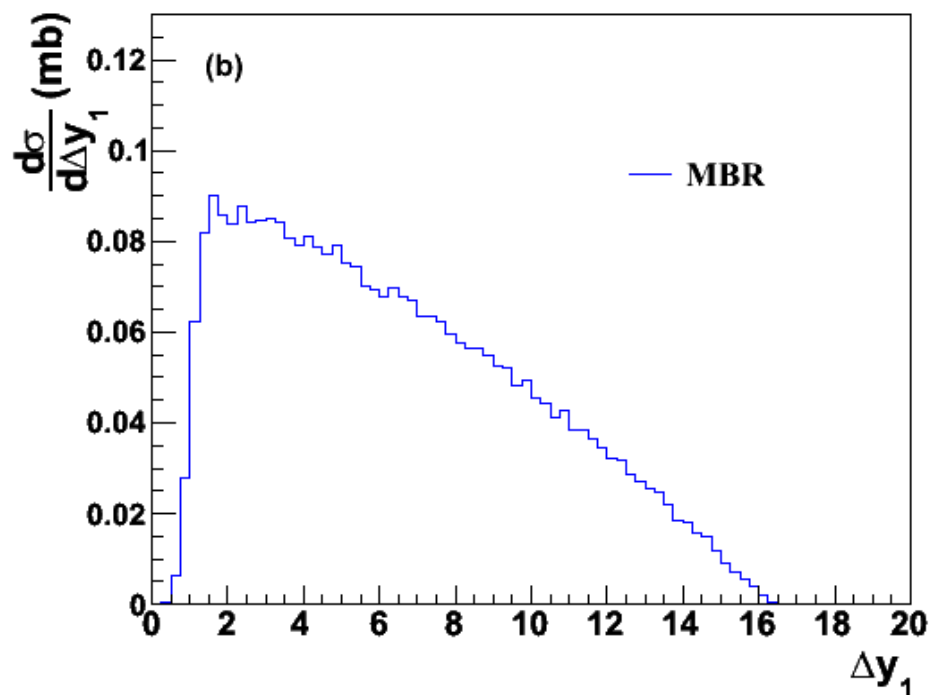
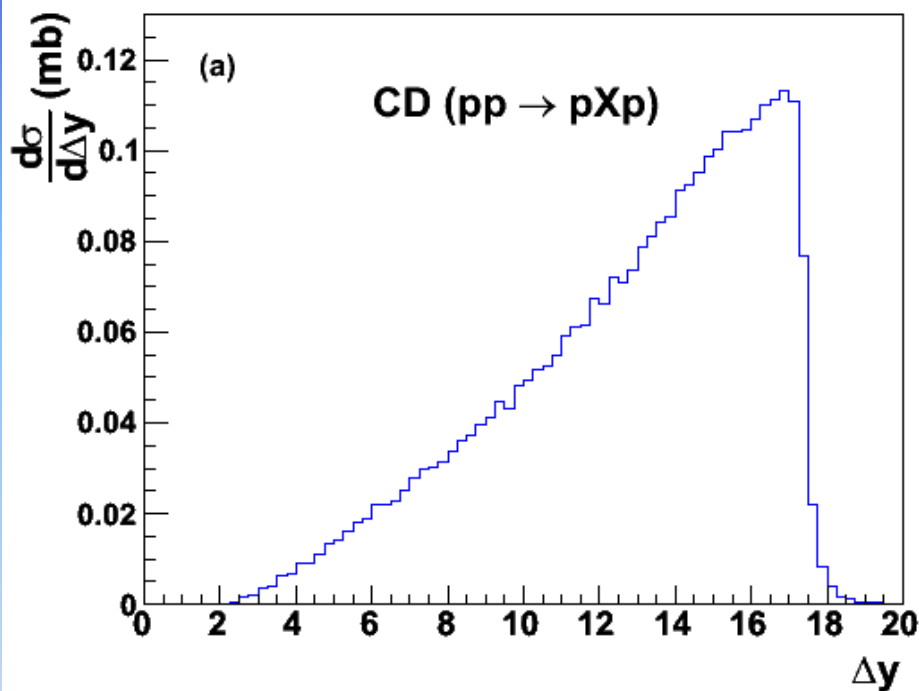
SD and DD at 7 TeV

MBR vs PYTHIA8-4C



- The differences between the PYTHIA8(4C) and MBR predictions are mainly due to the $(1/M^2)^{1+\varepsilon}$ behavior, with $\varepsilon=1.104$ in MBR vs 1,08 in PYTHIA8(4C).

CD (DPE) x-sections at 7 TeV versus (a) $\Delta y = \Delta y_1 + \Delta y_2$ and (b) Δy_1



- ❑ Both figures are MBR predictions with a $\Delta y=2$ cut-off in the error function.
- ❑ The normalization is absolute with no model uncertainty other than that due to the determination of the parameters in the formulas as determined from data

*Thank you for your
attention*

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