Predictions of Diffractive Cross Sections in Proton-Proton Collisions

Konstantin Goulianos*

The Rockefeller University

arXiv.org > hep-ph > arXiv:1205.1446

High Energy Physics - Phenomenology

MBR Monte Carlo Simulation in PYTHIA8

R. Ciesielski, K. Goulianos

(Submitted on 7 May 2012)

CONTENTS

For details on the phenomenology of the predictions see:

DIFFRACTION 2010
"Diffractive and total *pp* cross sections at the LHC and beyond" (KG)
http://link.aip.org/link/doi/10.1063/1.3601406

This talk: an implementation of these cross sections in PYTHIA8.

INTRODUCTION

- The RENORM (renormalization model) soft *pp* cross sections previously used in MBR (Minimum Bias Rockefeller) simulation are adapted to PYTHIA8.
  - MBR was successful at Fermilab in 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.
- Diffractive cross sections and final states are both predicted:
  - Cross sections vs gap width or vs forward momentum loss of proton(s):
    - ✓ Absolute normalization!
  - Hadronization of dissociated proton:
    - A (non-perturbative) “quark string” is introduced and tuned to reproduce the MBR multiplicity and p_T distributions.
    - $dN/d\eta$, p_T, and particle ID: new in this PYTHIA8 implementation (the original MBR simulation produced only $\pi^{\pm}$ and π^0).
  - Unique unitarization based on a saturated “glue-ball” exchange.
- Total Cross section $\sim\ln^2 s$ based on a glue-ball-like saturated-exchange.
  - Immune to eikonaalization-model dependences.

STUDIES OF DIFFRACTION IN QCD

Non-diffractive

- color-exchange ➔ gaps exponentially suppressed

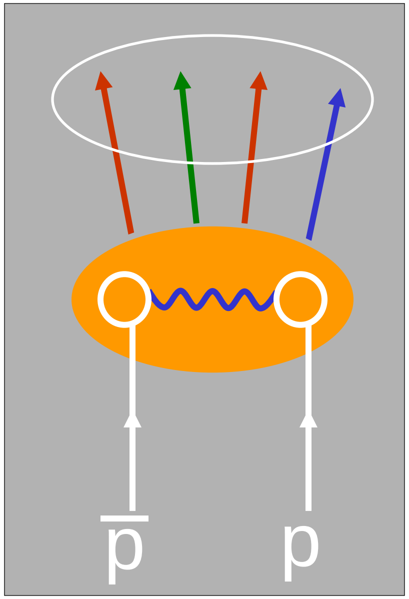
Diffractive

- Colorless vacuum exchange

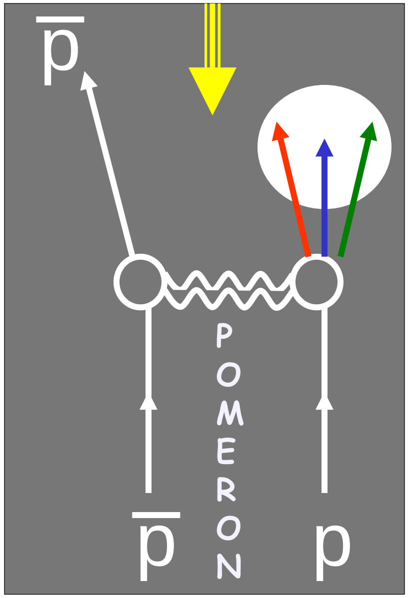
➔ large-gap signature

Incident hadrons acquire color and break upart

CONFINEMENT



rapidity gap

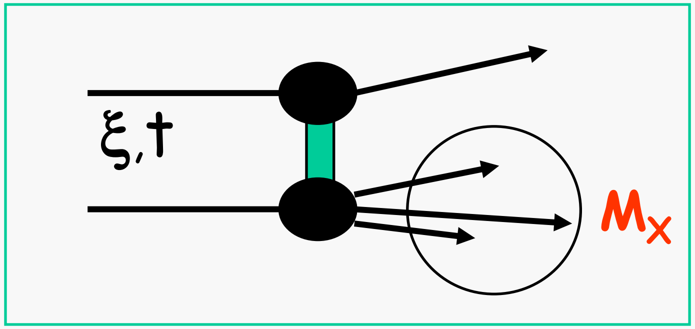


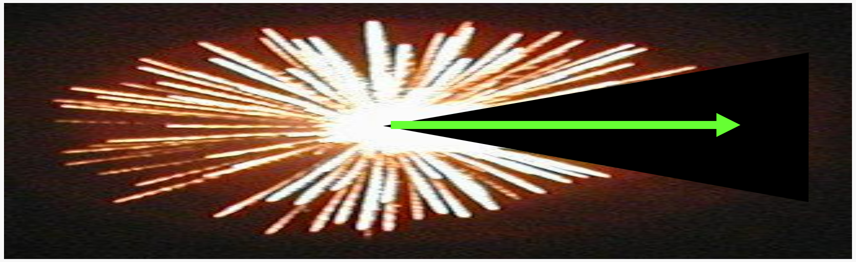
Incident hadrons retain their quantum numbers remaining colorless

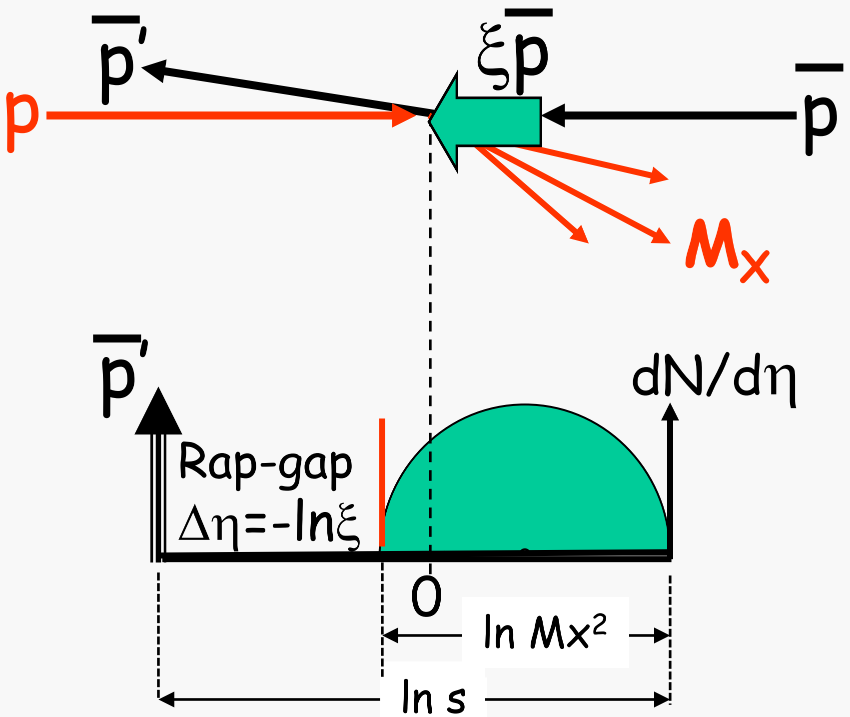
Goal: probe the QCD nature of the diffractive exchange

DEFINITIONS

SINGLE DIFFRACTION







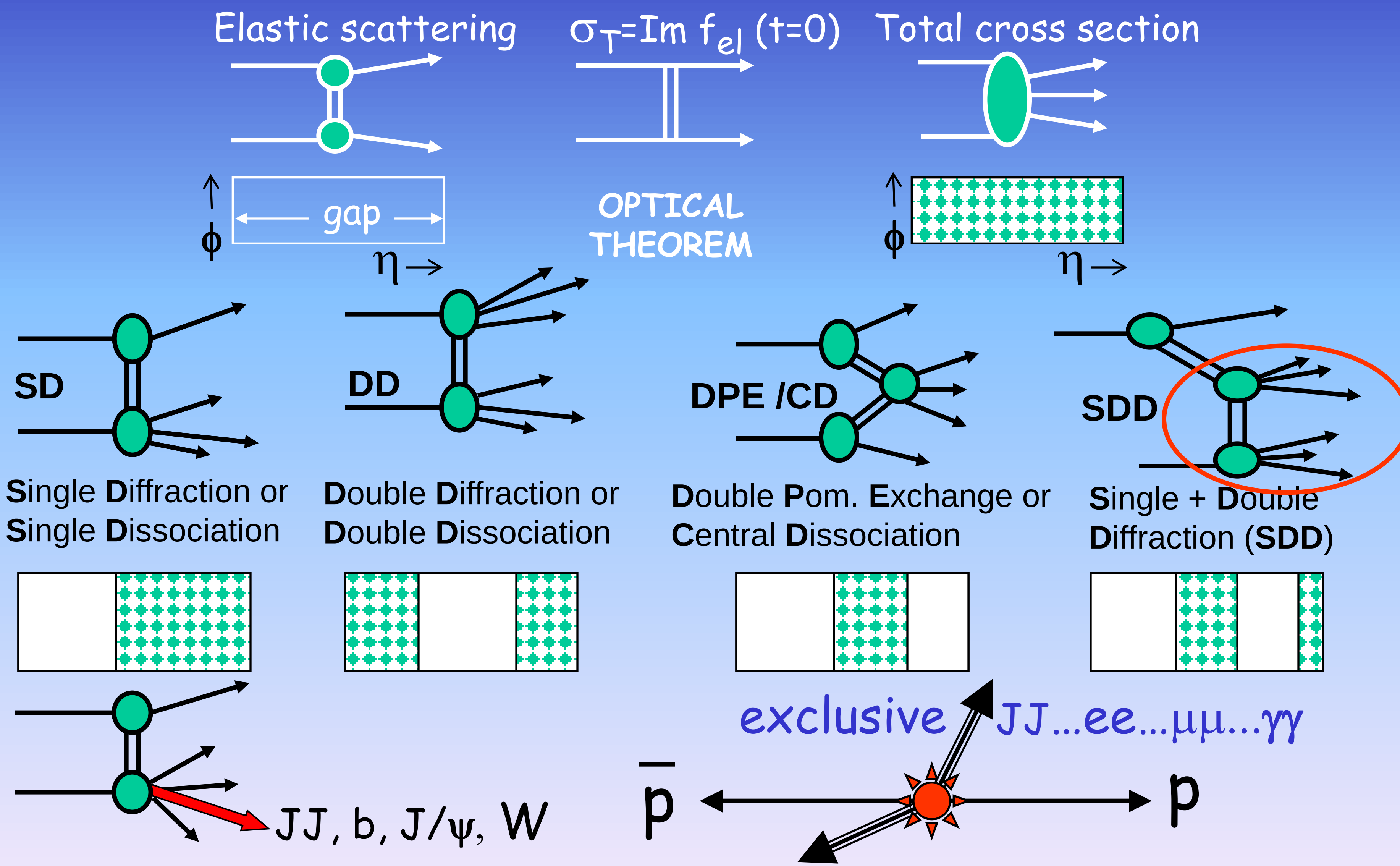
$$1 - x_L \equiv \xi = \frac{M_X^2}{s}$$

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

since no radiation →
no price paid for increasing diffractive gap size

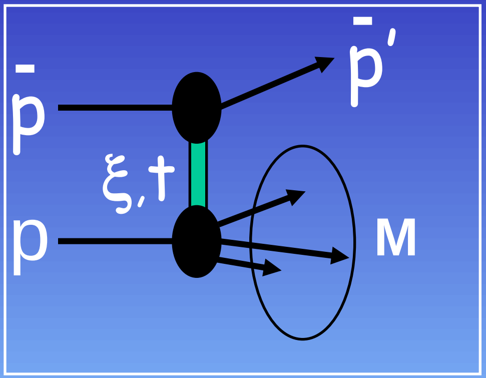
$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{dM^2} \propto \frac{1}{M^2}$$

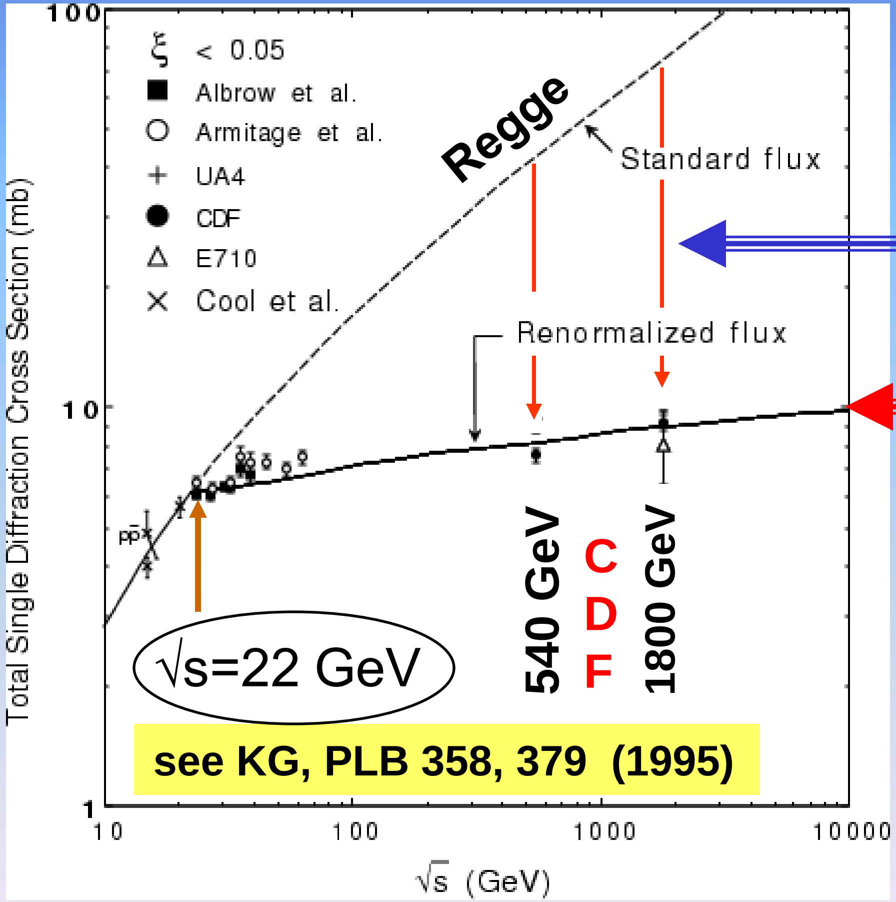
DIFFRACTION AT CDF



FACTORIZATION BREAKING IN SOFT DIFFRACTION

➔diffractive x-section suppressed relative to Regge prediction as √s increases

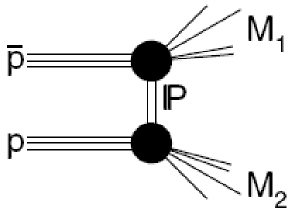


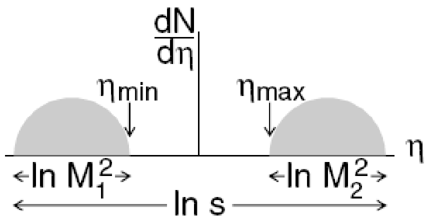


Factor of ~8 (~5) suppression at √s = 1800 (540) GeV

RENORMALIZATION

DD at CDF



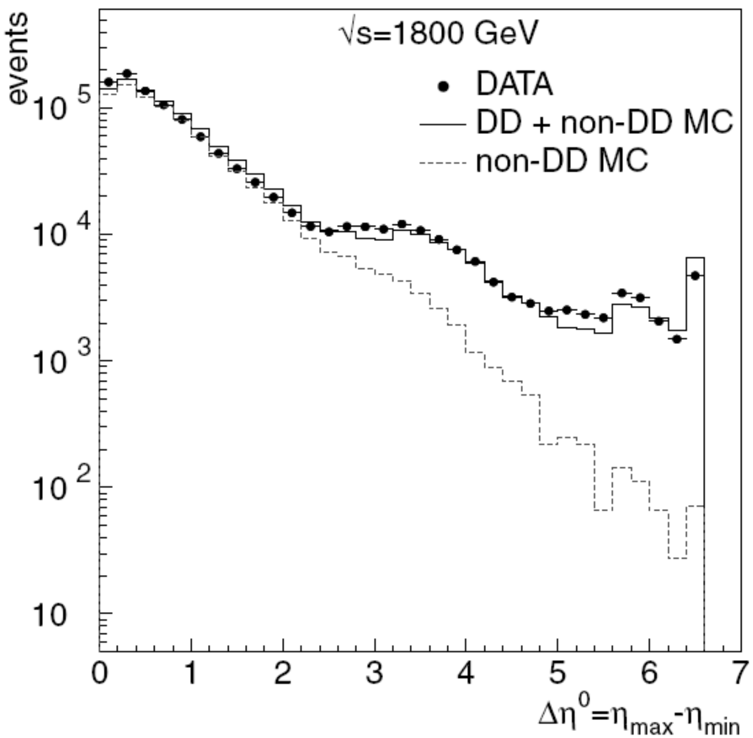


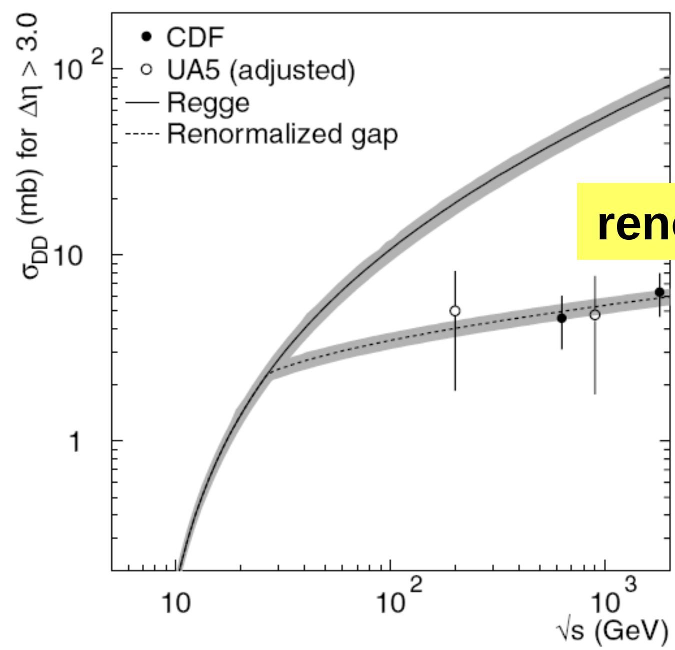
$$\frac{d^3\sigma_{DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{SD}}{dt\,dM_2^2} \Big/ \frac{d\sigma_{el}}{dt}$$

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

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

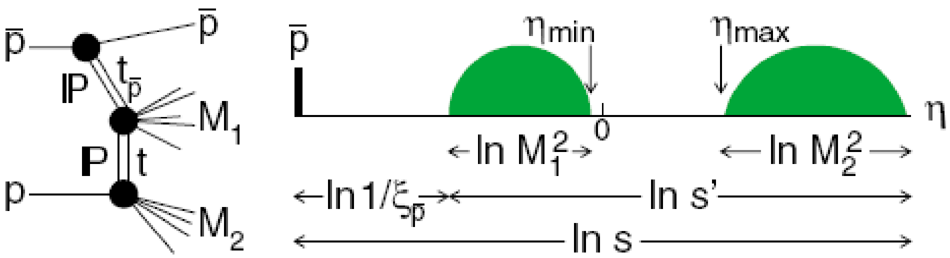
gap probability　　x-section

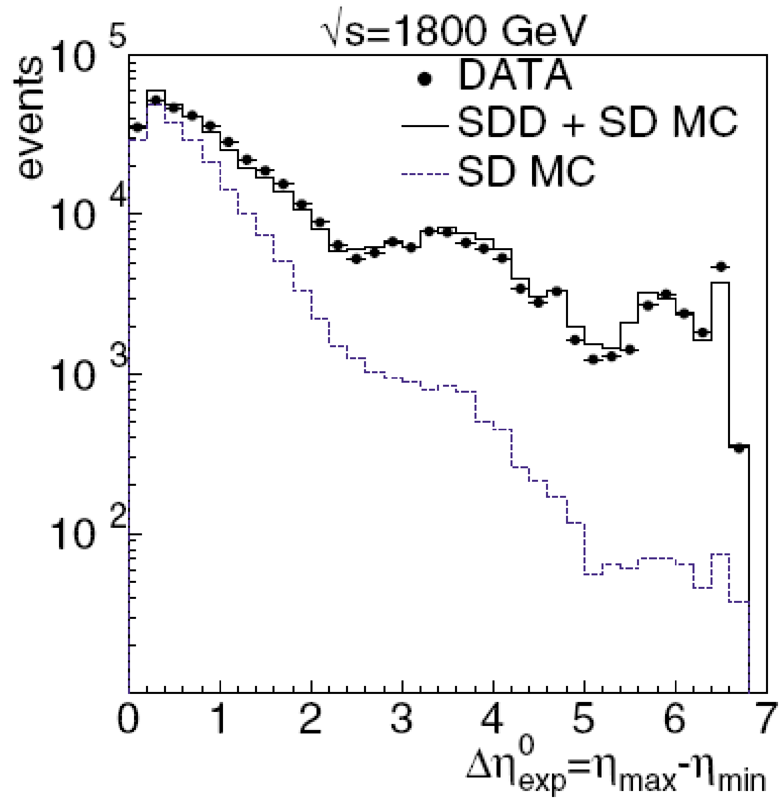




renormalized

SDD at CDF

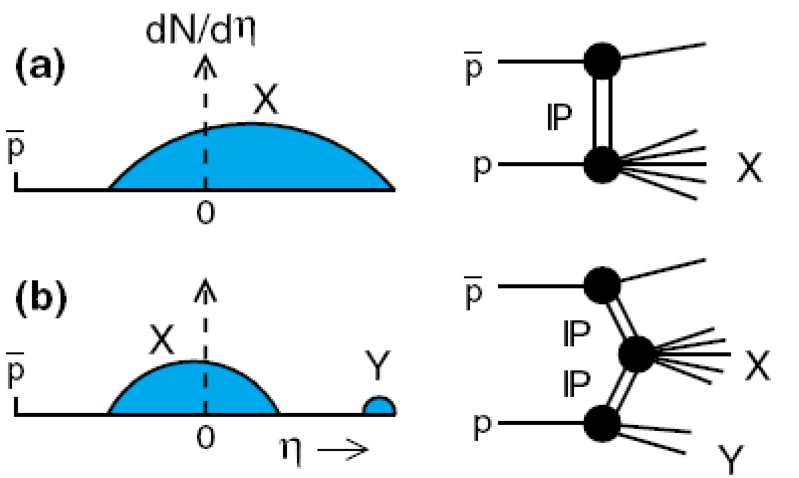




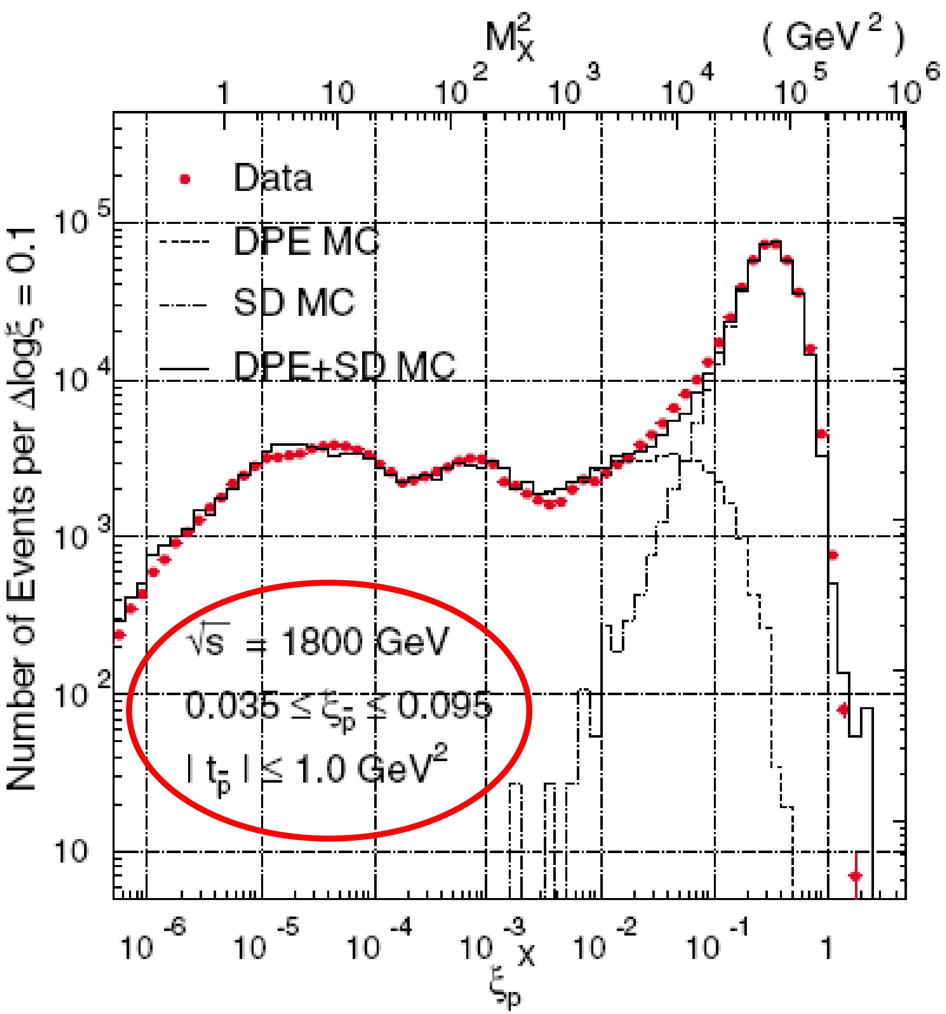
- Excellent agreement between data and MBR (MinBiasRockefeller) MC

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

CD (DPE) at CDF



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

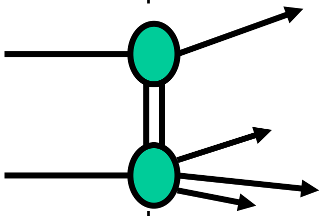


Scale s_0 and triple-pom coupling

Slide #16
Ddffr. 2012

Pom. flux: interpret as gap probability
➔set to unity: determines g_{PPP} and s_0

KG, PLB 358 (1995) 379



$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = f_{IP/p}(t,\xi)\cdot\sigma_{IP-\bar{p}}(s\xi)$$

s_0^{ε}

$s_0^{-\varepsilon/2}\cdot g_{PPP}(t)$

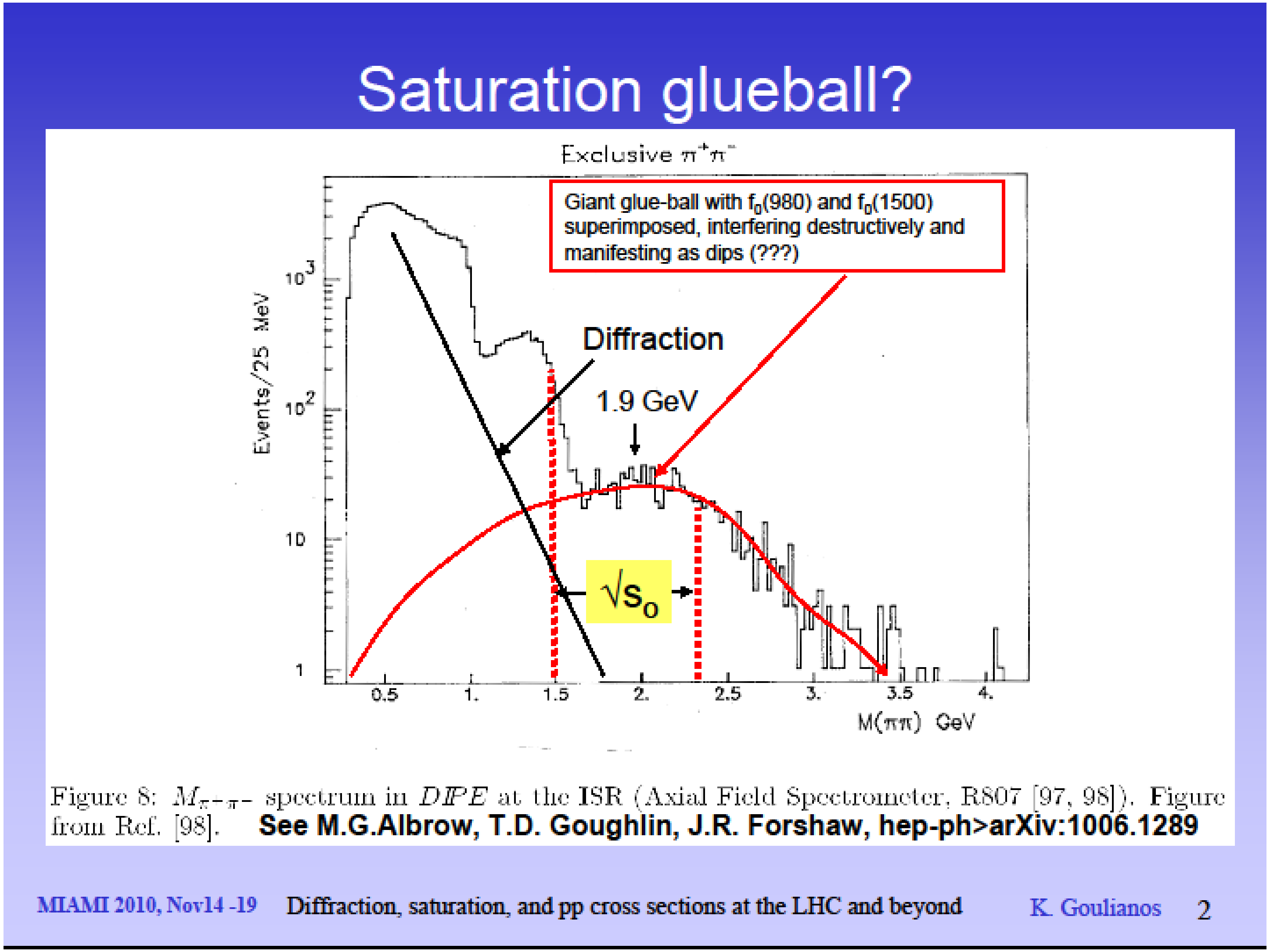
Pomeron-proton x-section

- Two free parameters: s_0 and g_{PPP}
- Obtain product $g_{PPP}\bullet s_0^{\varepsilon/2}$ from σ_{SD}
- Renormalized Pomeron flux determines s_0
- Get unique solution for g_{PPP}

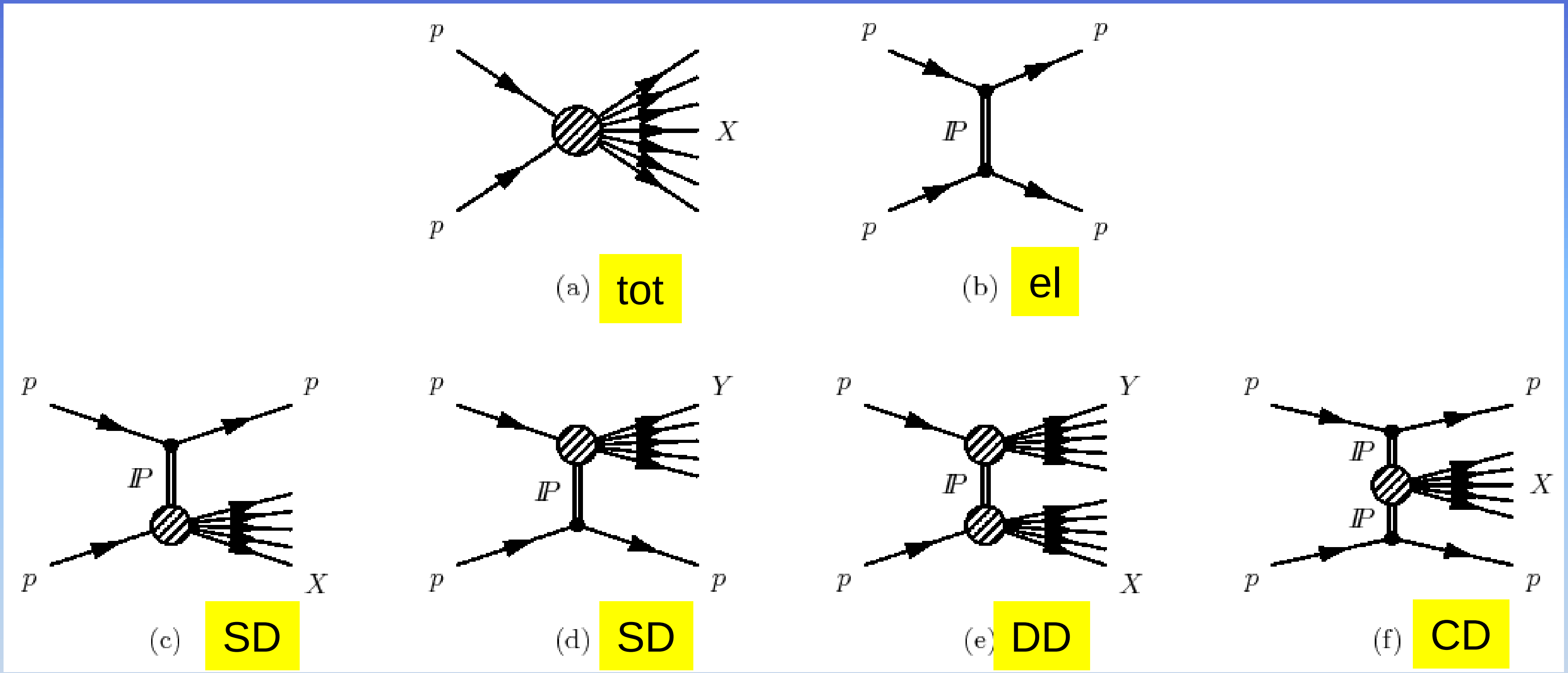
g_{PPP}=0.69 mb$^{-1/2}$=1.1 GeV^{-1}

s_o=3.7±1.5 GeV^2

Reduce the uncertainty in s_0



Cross Sections



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

Total, elastic, and inelastic x-sections

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

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

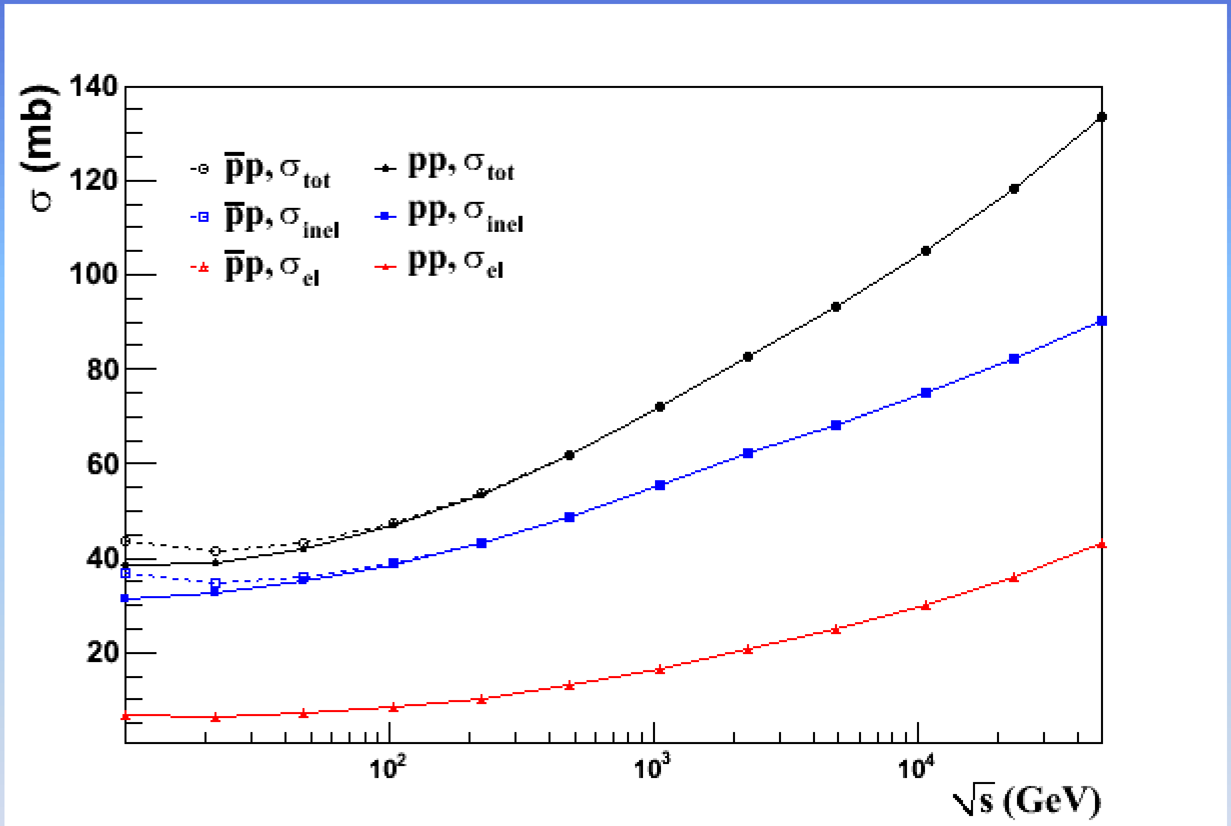
$$\sigma_{\rm tot}^{p^{\pm}p} = \begin{cases} 16.79 s^{0.104} + 60.81 s^{-0.32} \mp 31.68 s^{-0.54} & \text{for } \sqrt{s} < 1.8 \\ \sigma_{\rm tot}^{\rm CDF} + \frac{\pi}{s_0}\left[\left(\ln\frac{s}{s_F}\right)^2 - \left(\ln\frac{s^{\rm CDF}}{s_F}\right)^2\right] & \text{for } \sqrt{s} \geq 1.8 \end{cases}$$

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

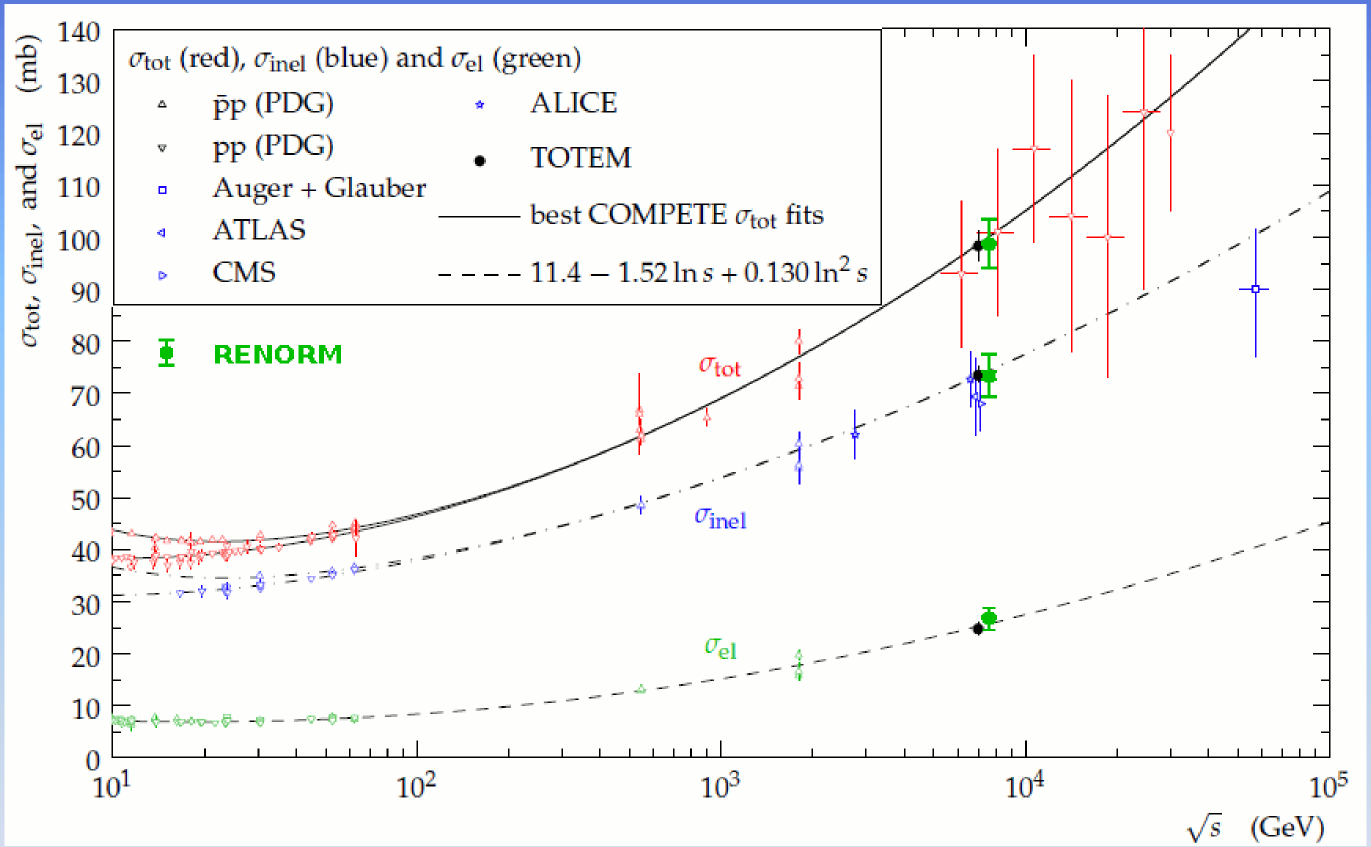
$$\sqrt{s^{\rm CDF}} = 1.8 \text{ TeV},\ \sigma_{\rm tot}^{\rm CDF} = 80.03 \pm 2.24 \text{ mb}$$

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

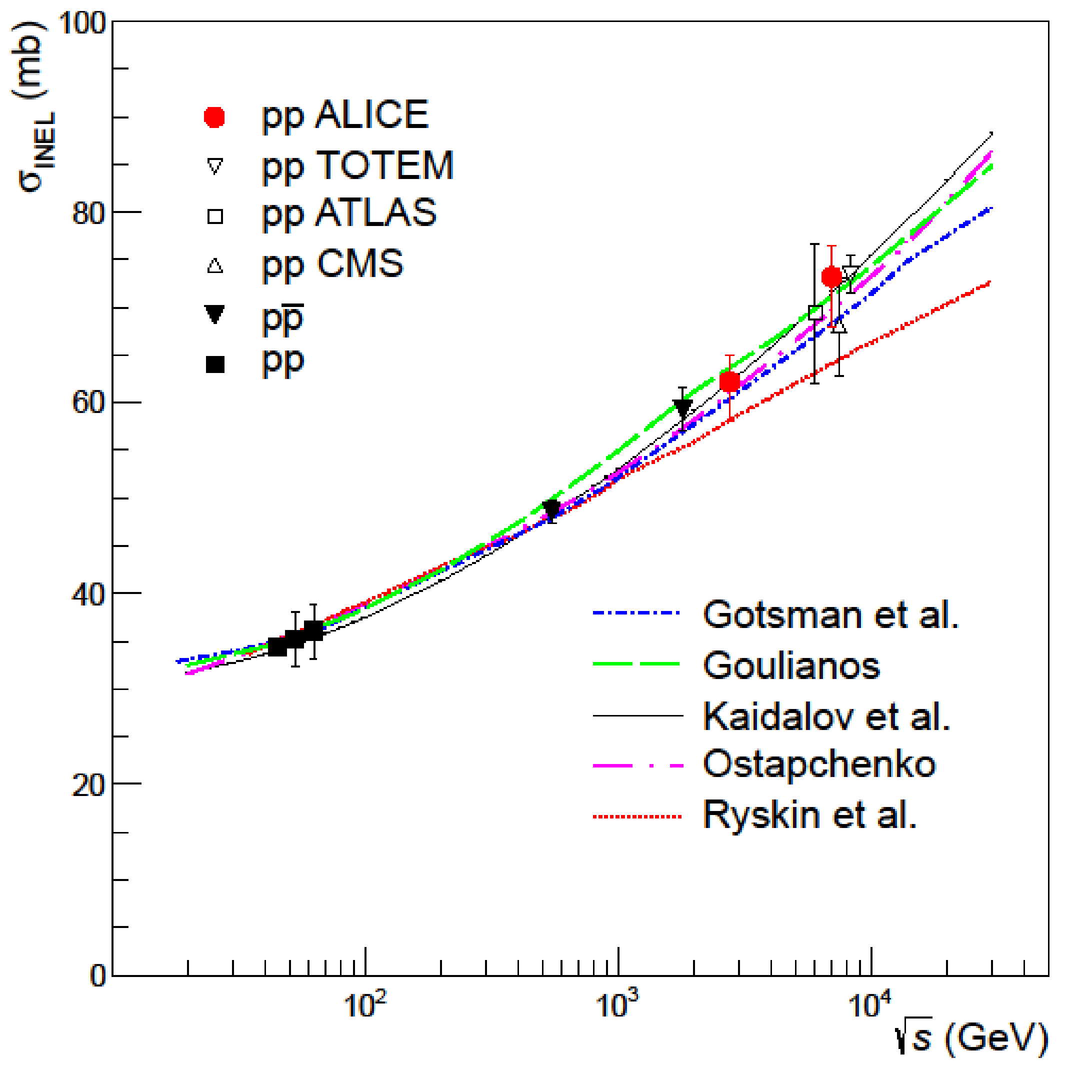
Total, elastic, and inelastic x-sections versus √s



TOTEM vs PYTHIA8-MBR



ALICE tot-inel vs PYTHIA8-MBR



More on cross sections

Slide 12 from Uri Maor's talk at the LowX-2012

	7 TeV			14 TeV			57 TeV		100 TeV			$1.2 \cdot 10^{16}$ TeV	
	GLM	KMR	BH	GLM	KMR	BH	GLM	BH	GLM	KMR	BH	GLM	BH
σ_{tot}	94.2	97.4	95.4	104.0	107.5	107.3	125.0	134.8	134.0	138.8	147.1	393	2067
σ_{inel}	71.3	73.6	69.0	77.9	80.3	76.3	92.2	92.9	98.5	100.7	100.0	279	1131
$\frac{\sigma_{inel}}{\sigma_{tot}}$	0.76	0.76	0.72	0.75	0.75	0.71	0.74	0.70	0.74	0.73	0.68	0.71	0.55
MBR sigma_tot			98			109		136			144		2257

Difractive x-sections

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

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

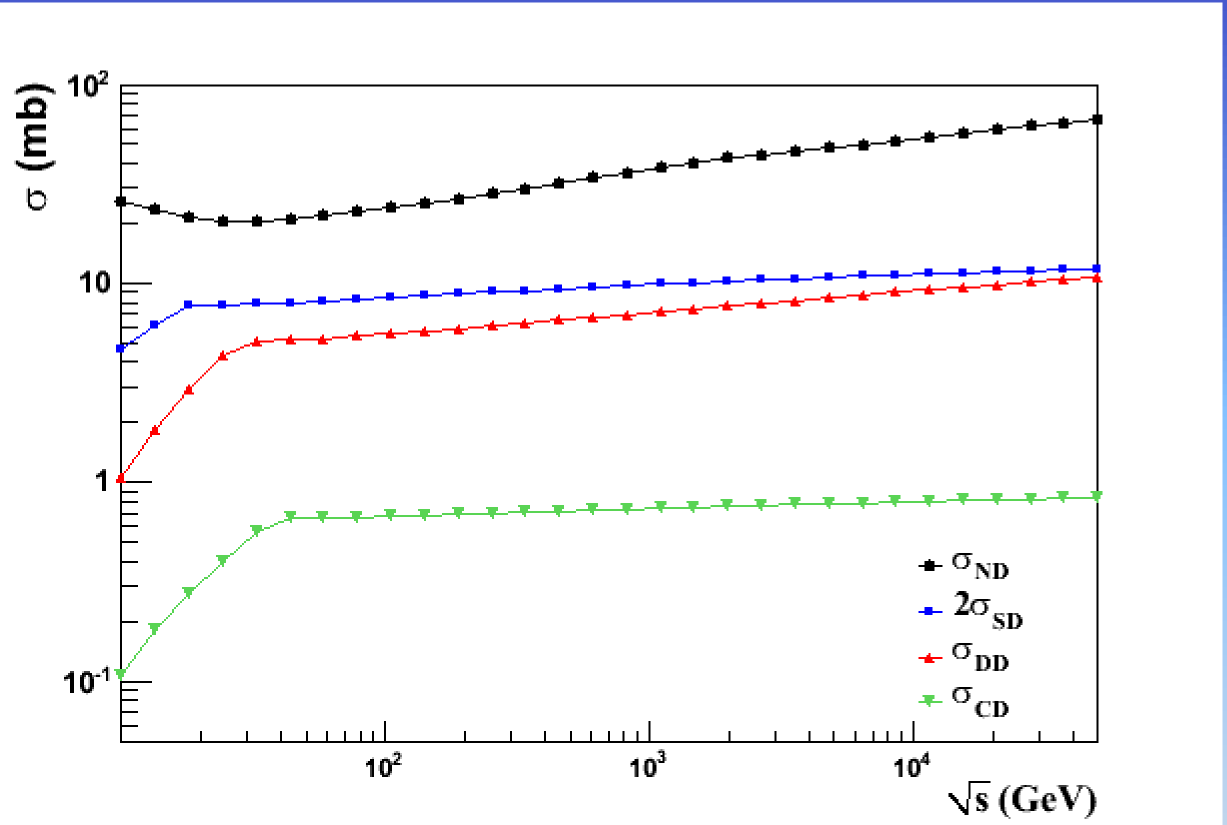
$$\frac{d^4\sigma_{DPE}}{dt_1 dt_2 d\Delta y dy_c} = \frac{1}{N_{\rm gap}(s)}\left[\Pi_i\left[\frac{\beta^2(t_i)}{16\pi}e^{2[\alpha(t_i)-1]\Delta y_i}\right]\right]\cdot\kappa\left\{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right\}$$

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

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

α_1=0.9, α_2=0.1, b_1=4.6 GeV^{-2}, b_2=0.6 GeV^{-2}, s'=s $e^{-\Delta y}$, κ=0.17, $\kappa\beta^2(0)=\sigma_0$, s_0=1 GeV^2, σ_0=2.82 mb or 7.25 GeV^{-2}

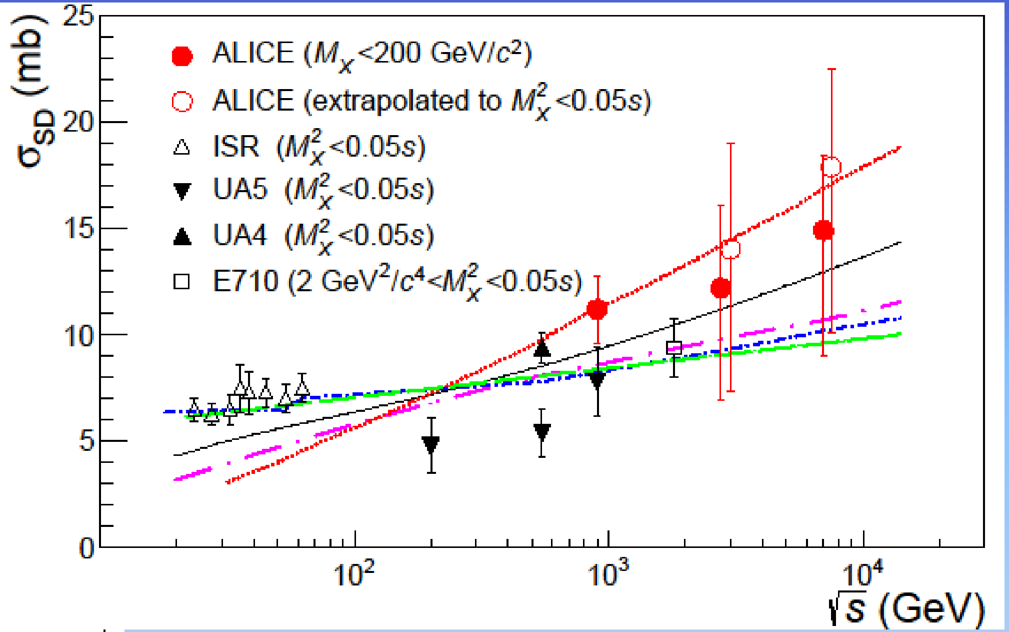
Difractive x-sections of √s

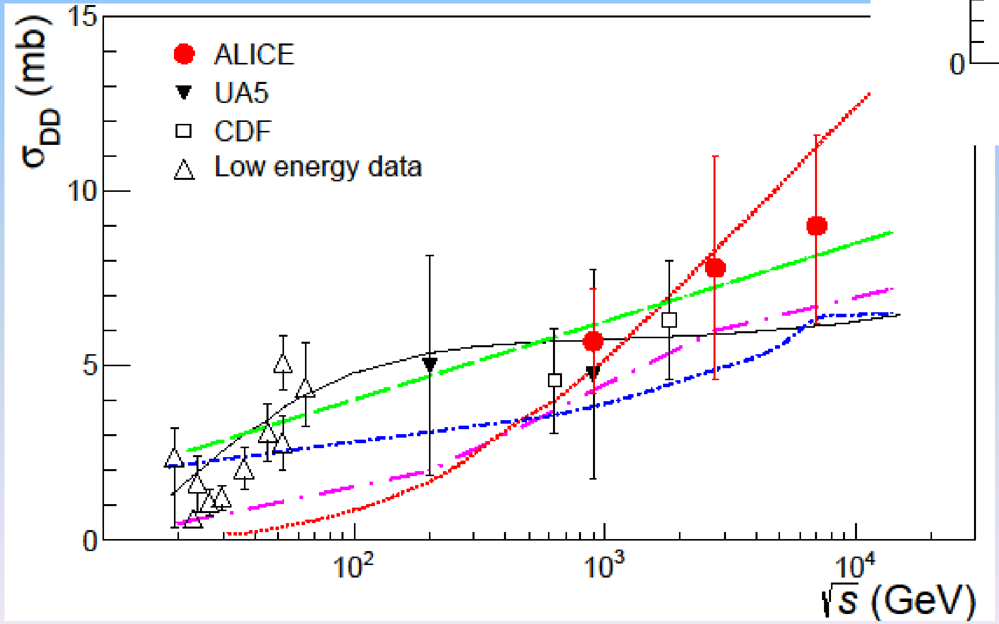


- Supress x-sections at small gaps by a factor S using the error function with Δy_S=2 for SD and DD, and $\Delta y=\Delta y_1+\Delta y_2$ =2 for CD (DPE).

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

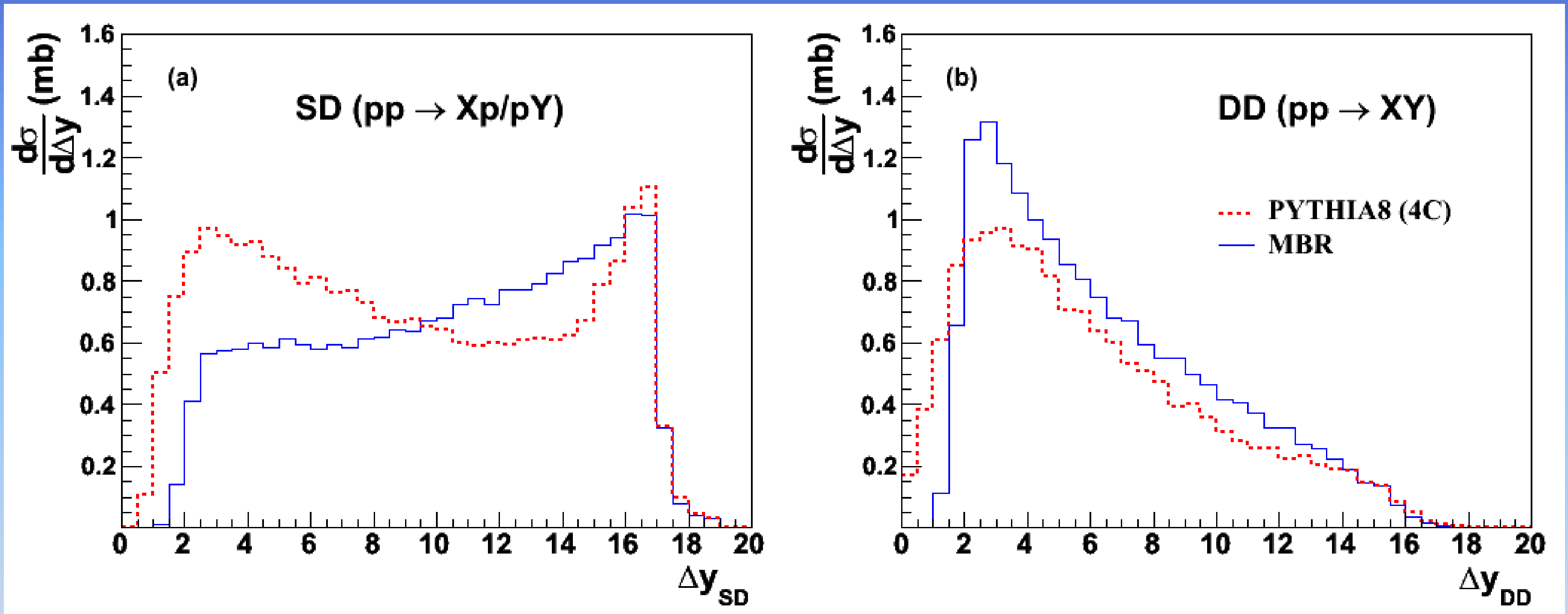
ALICE SD and DD vs PYTHIA8-MBR





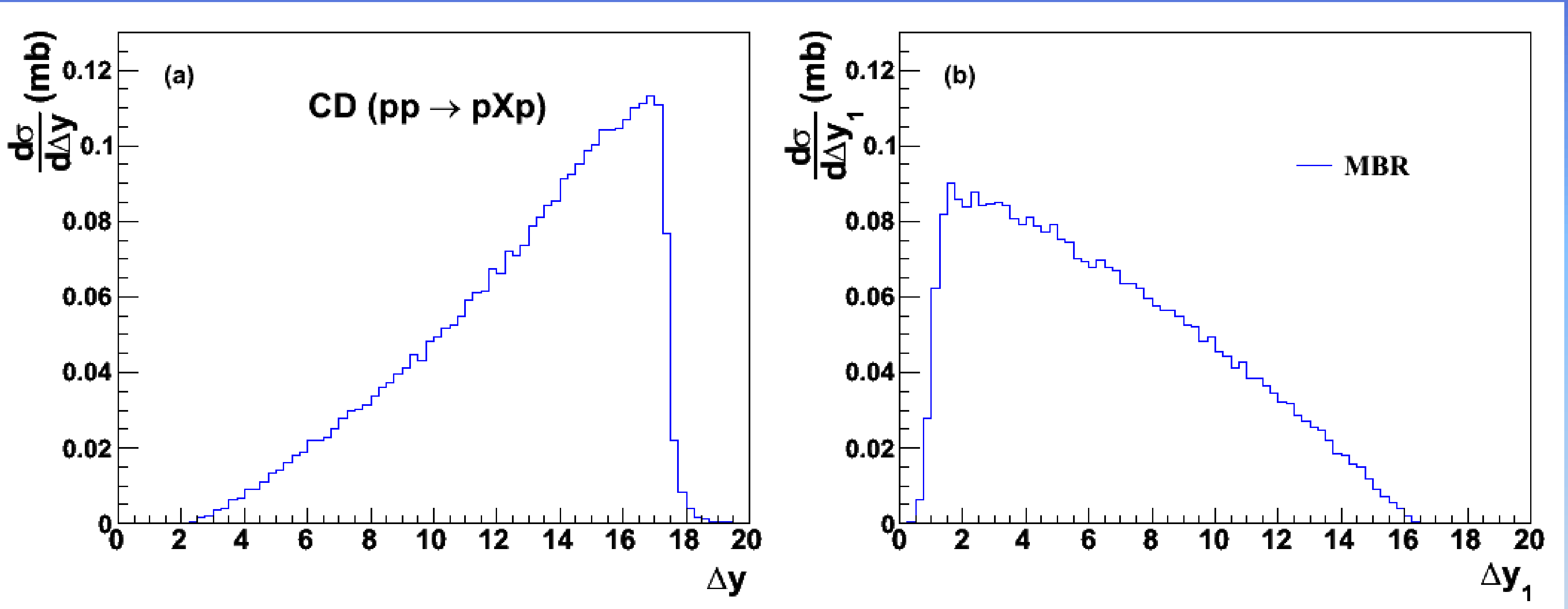
SD and DD at 7 TeV

MBR vs PYTHIA8-4C



- The differences between the PYTHIA8(4C) and MBR predictions are mainly due to the $(1/M2)^{1+\varepsilon}$ behavior, with ε=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 Δy=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

SUMMARY ← introduction

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- Total Cross section ~$\ln^2 s$ based on a glue-ball-like saturated-exchange.
  - Immune to eikonaalization-model dependences.

Thank you for your attention

References in arXiv:1205.1446v2 [hep-ph]

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[2] T. Sjöstrand, S. Mrenna and P. Skands, JHEP05 (2006) 026, Comput. Phys. Comm. 178 (2008) 852, arXiv:hep-ph/0603175,arXiv:0710.3820.

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10] `http://en.wikipedia.org/wiki/Error_function`

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