Diffraction, saturation and *pp* cross sections at the LHC

Moriond QCD and High Energy Interactions
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CONTENTS

Why study diffraction?

Two reasons: one fundamental / one practical.

- *fundamental*

σ_T
↕ **optical theorem**
Im $f_{el}(t=0)$
↕ **dispersion relations**
Re $f_{el}(t=0)$

measure σ_T & ρ-value at LHC:

check for violation of dispersion relations

→ **sign for new physics**

Bourrely, C., Khuri, N.N., Martin, A.,Soffer, J., Wu, T.T
http://en.scientificcommons.org/16731756

Diffraction ➡ ➢ **saturation → σ_T**

- *practical*: underlying event (UE), triggers, calibrations

→ the UE affects all physics studies at the LHC

NEED ROBUST MC SIMULATION OF SOFT PHYSICS

MC simulations: Pandora's box was unlocked at the LHC!

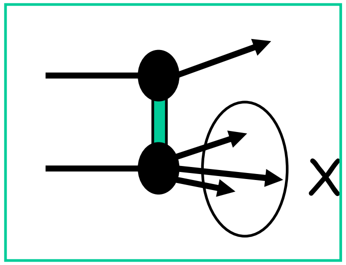
- **Presently available MCs** based on pre-LHC data were found to be inadequate for LHC
- **MC tunes:** the "evils of the world" were released from Pandora's box at the LHC

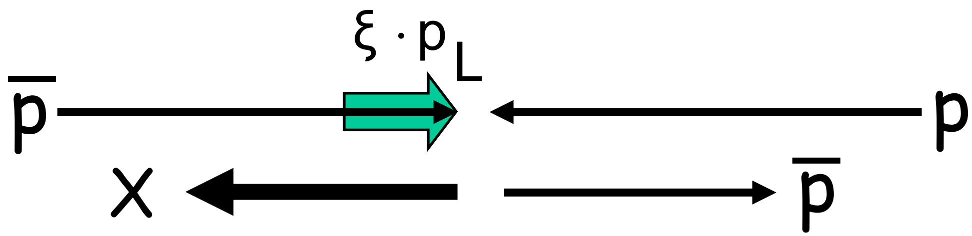
… but fortunately, hope remained in the box
→ a good starting point for this talk

Pandora's box is an artifact in Greek mythology, taken from the myth of Pandora's creation around line 60 of Hesiod's *Works And Days*. The "box" was actually a large jar (πιθος *pithos*) given to Pandora (Πανδώρα) ("all-gifted"), which contained all the evils of the world. When Pandora opened the jar, the entire contents of the jar were released, but for one – hope. *Nikipedia*

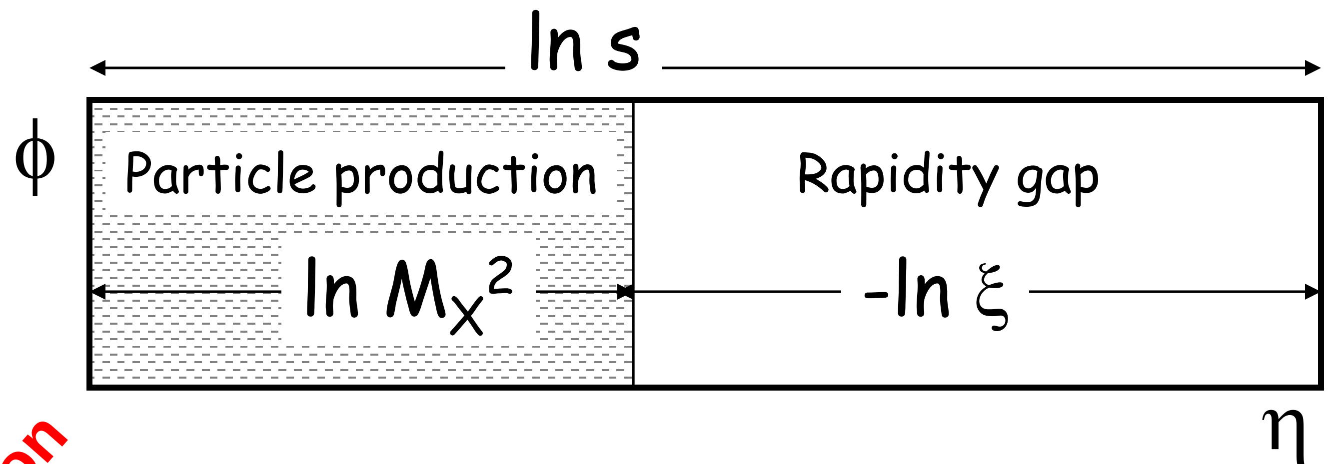
Diffractive gaps

definition: gaps not exponentially suppressed





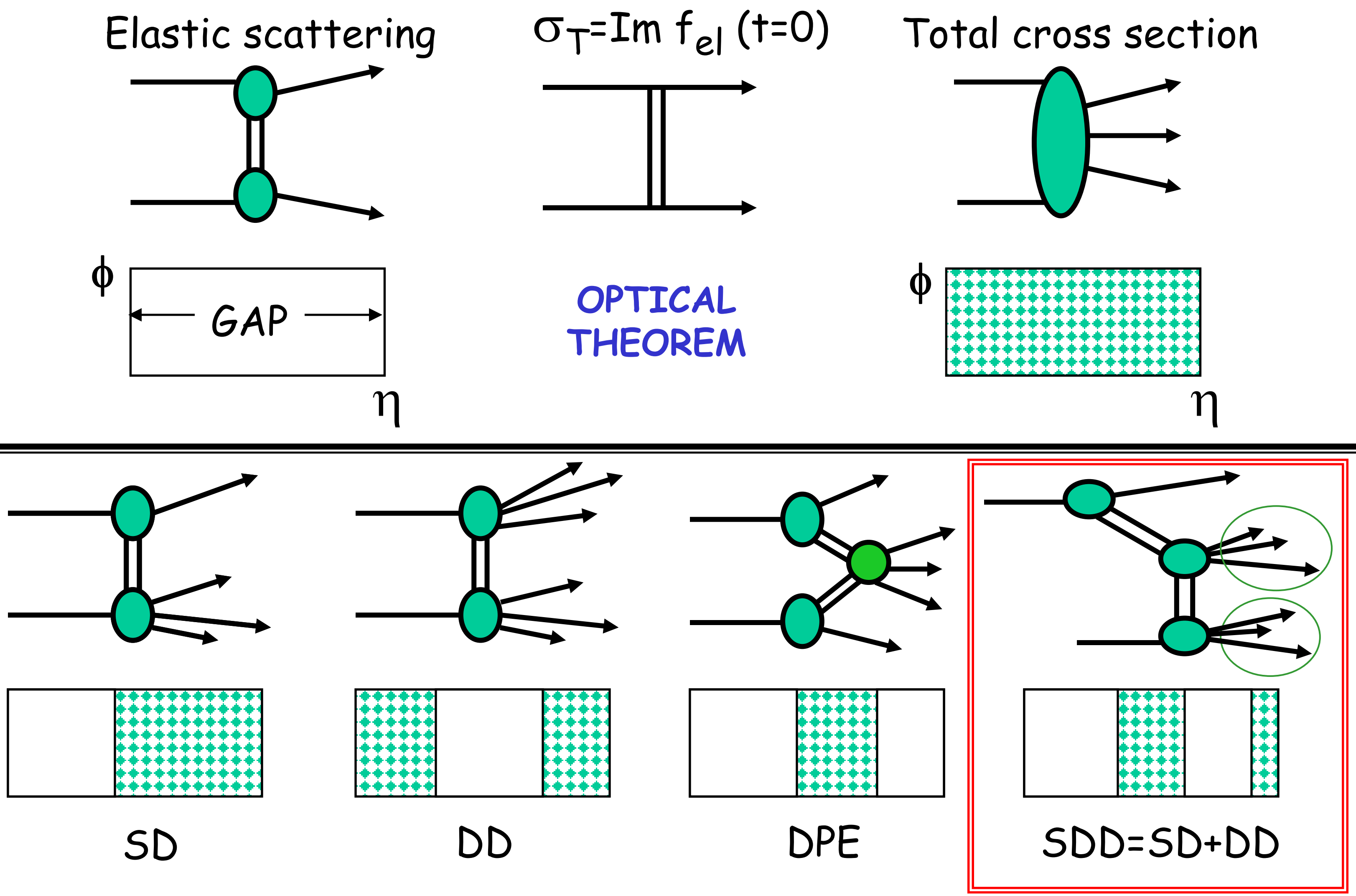
$$\xi \approx \frac{M_x^2}{s}$$



No radiation

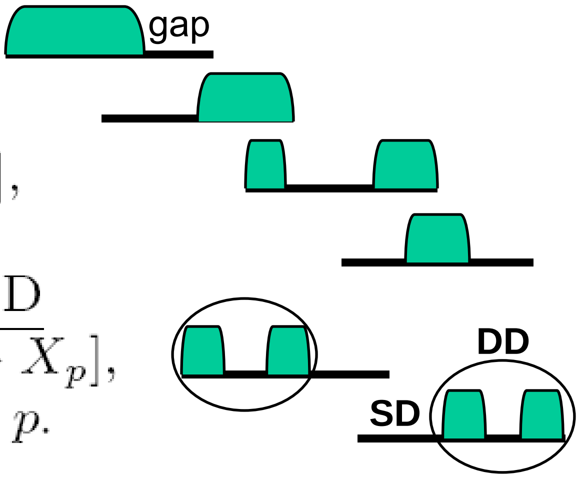
$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

Diffractive pbar-p studies @ CDF

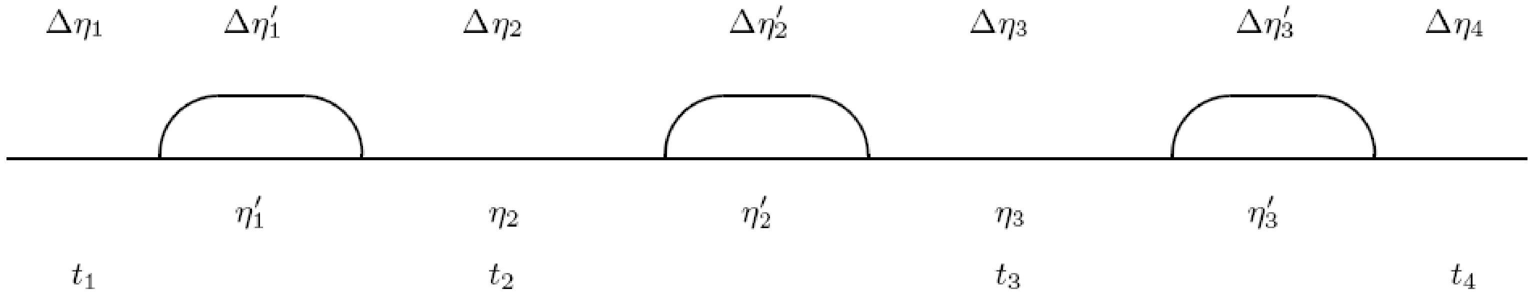


Basic and combined diffractive processes

acronym	basic diffractive processes
$\mathbf{SD}_{\bar{p}}$	$\bar{p}p \to \bar{p} + \text{gap} + [p \to X_p]$,
$\mathbf{SD}_{p}$	$\bar{p}p \to [\bar{p} \to X_{\bar{p}}] + \text{gap} + p$,
DD	$\bar{p}p \to [\bar{p} \to X_{\bar{p}}] + \text{gap} + [p \to X_p]$,
DPE	$\bar{p}p \to \bar{p} + \text{gap} + X_c + \text{gap} + p$,
	2-gap combinations of SD and DD
$\mathbf{SDD}_{\bar{p}}$	$\bar{p}p \to \bar{p} + \text{gap} + X_c + \text{gap} + [p \to X_p]$,
$\mathbf{SDD}_{p}$	$\bar{p}p \to [\bar{p} \to X_{\bar{p}}]\text{gap} + X_c + \text{gap} + p$.

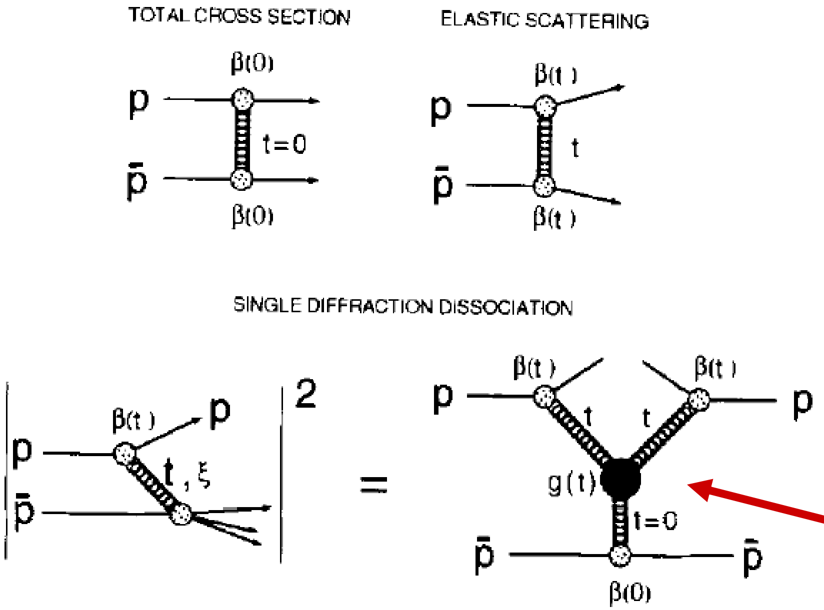


a 4-gap diffractive process



Regge theory – values of s_o & g?

KG-1995: PLB 358, 379 (1995)



$$\sigma_T = \beta_1(0)\beta_2(0)\left(\frac{s}{s_0}\right)^{\alpha(0)-1} = \sigma_0^{p\bar{p}}\left(\frac{s}{s_0}\right)^{\epsilon} \quad (1)$$

$$\frac{d\sigma_{el}}{dt} = \frac{\beta_1^2(t)\beta_2^2(t)}{16\pi}\left(\frac{s}{s_0}\right)^{2[\alpha(t)-1]} = \frac{\sigma_T^2}{16\pi}\left(\frac{s}{s_0}\right)^{2\alpha' t} F^4(t) \approx \frac{\sigma_T^2}{16\pi} e^{b_{el}(s)t} \quad (2)$$

$$F^4(t) \approx e^{b_{0,el}t} \Rightarrow b_{el}(s) = b_{0,el} + 2\alpha' \ln\left(\frac{s}{s_0}\right) \quad (3)$$

$$\frac{d^2\sigma_{sd}}{dt d\xi} = \frac{\beta_1^2(t)}{16\pi}\xi^{1-2\alpha(t)}\left[\beta_2(0)\, g(t)\left(\frac{s'}{s'_0}\right)^{\alpha(0)-1}\right] = f_{\mathcal{P}/p}(\xi,t)\, \sigma_T^{\mathcal{P}\bar{p}}(s',t) \quad (4)$$

Parameters:

- s_0, s_0' and g(t)
- set $s_0' = s_0$ (universal *IP*)
- determine s_0 and g_{PPP} – **how?**

A complication … ➔ Unitarity!

$$\left(\frac{d\sigma_{el}}{dt}\right)_{t=0} \sim \left(\frac{s}{s_o}\right)^{2\epsilon}, \quad \sigma_t \sim \left(\frac{s}{s_o}\right)^{\epsilon}, \quad \sigma_{sd} \sim \left(\frac{s}{s_o}\right)^{2\epsilon}$$

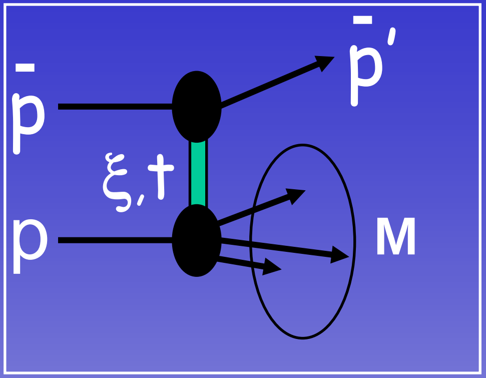
- ❑ $d\sigma/dt$ σ_{sd} grows faster than σ_t as *s* increases
  - ➔ unitarity violation at high *s*

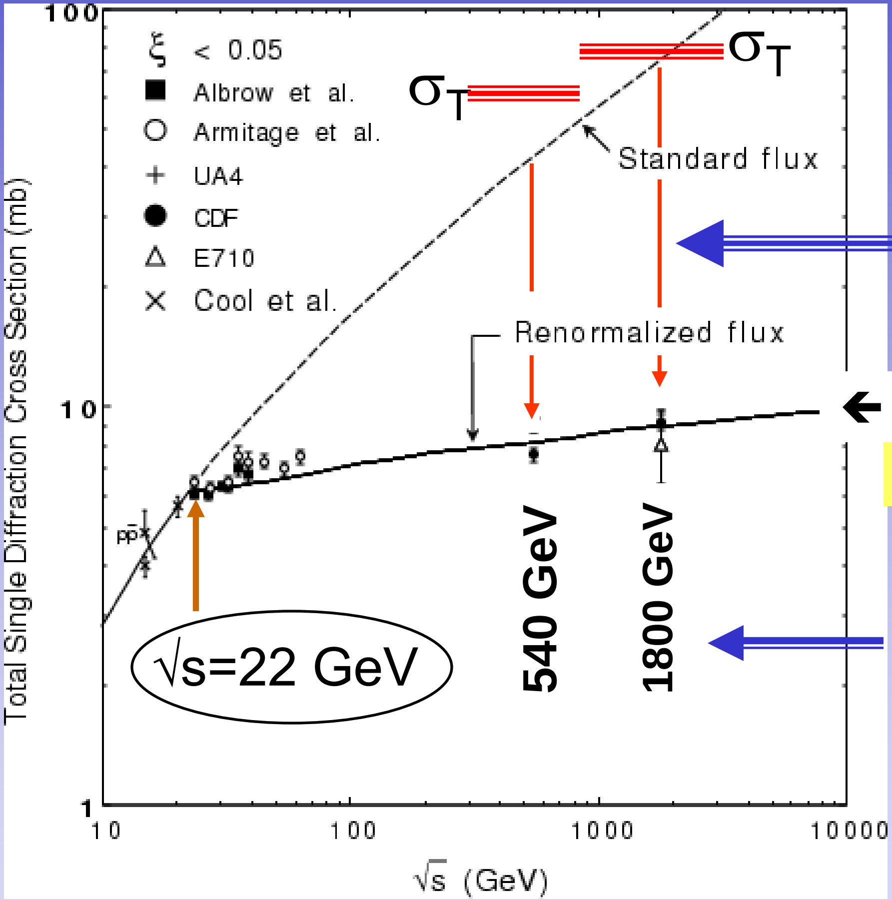
(similarly for partial x-sections in impact parameter space)

- ❑ the unitarity limit is already reached at $\sqrt{s} \sim 2$ TeV

σ^{T}_{SD} vs σ_T (pp & $\bar{p}$p)

➔ suppressed relative to Regge for √s>22 GeV





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

← **RENORMALIZATION MODEL**

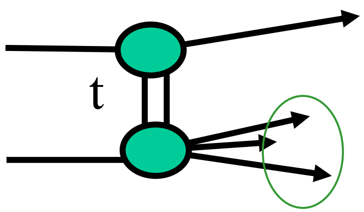
KG, PLB 358, 379 (1995)

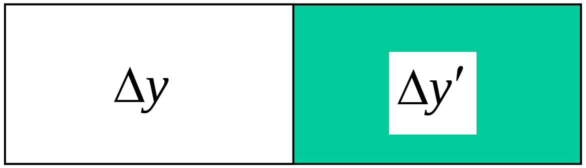
CDF Run I results

Single diffraction renormalized – (1)

KG ➔ CORFU-2001: hep-ph/0203141

KG ➔ EDS 2009: http://arxiv.org/PS_cache/arxiv/pdf/1002/1002.3527v1.pdf





2 independent variables: $t, \Delta y$

color factor

$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p-p}(0)} \approx 0.17$$

$$\frac{d^2\sigma}{dt\,d\Delta y} = \underbrace{C \cdot F_p^2(t) \cdot \left\{e^{(\varepsilon+\alpha' t)\Delta y}\right\}^2}_{\text{gap probability}} \cdot \kappa \cdot \underbrace{\left\{\sigma_o\, e^{\varepsilon\,\Delta y'}\right\}}_{\text{sub-energy x-section}}$$

Gap probability ➔ (re)normalize to unity

Single diffraction renormalized – (2)

color factor

$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p-p}(0)} \approx 0.17$$

Experimentally:

KG&JM, PRD 59 (114017) 1999

$$\kappa = \frac{g_{IP-IP-IP}}{\beta_{IP-p}} = 0.17 \pm 0.02, \quad \varepsilon = 0.104$$

QCD: $\kappa = \mathrm{f}_g \times \frac{1}{N_c^2 - 1} + \mathrm{f}_q \times \frac{1}{N_c} \xrightarrow{Q^2 = 1} \approx 0.75 \times \frac{1}{8} + 0.25 \times \frac{1}{3} = 0.18$

Single diffraction renormalized - (3)

$$\frac{d^2\sigma_{sd}(s,M^2,t)}{dM^2dt} = \left[\frac{\sigma_\circ}{16\pi}\sigma_\circ^{I\!Pp}\right] \frac{s^{2\epsilon}}{N(s,s_o)} \frac{e^{bt}}{(M^2)^{1+\epsilon}}$$

$$b = b_0 + 2\alpha' \ln\frac{s}{M^2} \qquad s_o^{\mathrm{CMG}} = (3.7 \pm 1.5)\ \mathrm{GeV}^2$$

$$N(s,s_o) \equiv \int_{\xi_{\min}}^{\xi_{\max}} d\xi \int_{t=0}^{-\infty} dt\, f_{I\!P/p}(\xi,t) \overset{s\to\infty}{\to} \sim s_o^{\epsilon}\frac{s^{2\epsilon}}{\ln s}$$

$$\frac{d^2\sigma_{sd}(s,M^2,t)}{dM^2dt} \overset{s\to\infty}{\to} \sim \ln s \frac{e^{bt}}{(M^2)^{1+\epsilon}}$$

$$\sigma_{sd} \xrightarrow{s\to\infty} \sim \frac{\ln s}{b\to\ln s} \Rightarrow const$$

set to unity
➔ determine s_o

Single diffraction renormalized – (4)

$$\frac{d^2\sigma}{dt\, d\Delta y} = N_{gap} \cdot \underbrace{C \cdot F_p^2(t) \cdot \left\{ e^{(\varepsilon + \alpha' t)\Delta y} \right\}^2}_{P_{gap}(\Delta y, t)} \cdot \kappa \cdot \left\{ \sigma_o \, e^{\varepsilon \, \Delta y'} \right\}$$

$$N_{gap}^{-1}(s) = \int_{\Delta y, t} P_{gap}(\Delta y, t)\, d\Delta y\, dt \xrightarrow{s \to \infty} C' \cdot \frac{s^{2\varepsilon}}{\ln s}$$

$$\frac{d^2\sigma}{dt\, d\Delta y} = C'' \left[e^{\varepsilon(\Delta y - \ln s)} \cdot \ln s \right] e^{(b_0 + 2\alpha' \Delta y)t}$$

grows slower than s^{ε}

→ Pumplin bound obeyed at all impact parameters

M^2 distribution: data

➔ $d\sigma/dM^2|_{t=-0.05}$ ~ independent of s over 6 orders of magnitude!

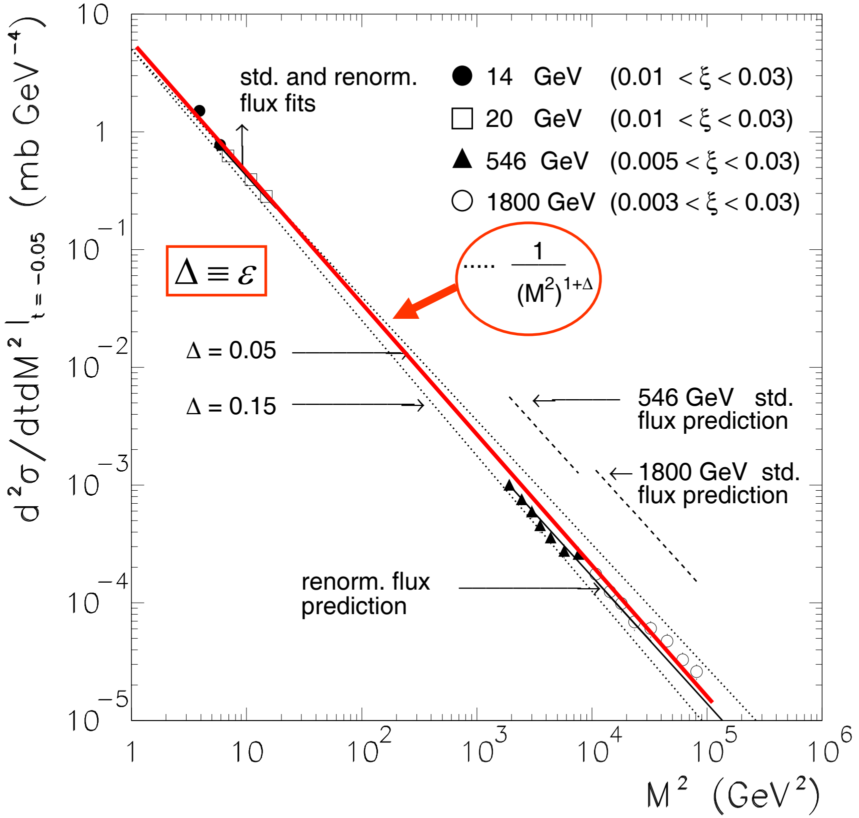
KG&JM, PRD 59 (1999) 114017

Regge ➔ data

$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon}}{(M^2)^{1+\varepsilon}} \quad s^{2\varepsilon} \rightarrow 1$$

Independent of S over 6 orders of magnitude in M^2

➔ M^2 scaling



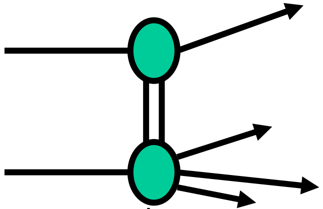
➔ factorization breaks down to ensure M^2 scaling

Scale s_o and triple-pom coupling

Pomeron flux: interpret as gap probability

➔set to unity: determines g_{PPP} and s_0

KG, PLB 358 (1995) 379



$$s_o^{\varepsilon}$$

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

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

Pomeron-proton x-section

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

$g_{PPP}=0.69\ \text{mb}^{-1/2}=1.1\ \text{GeV}^{-1}$ $S_o=3.7\pm1.5\ \text{GeV}^2$

Saturation "glueball" at ISR?

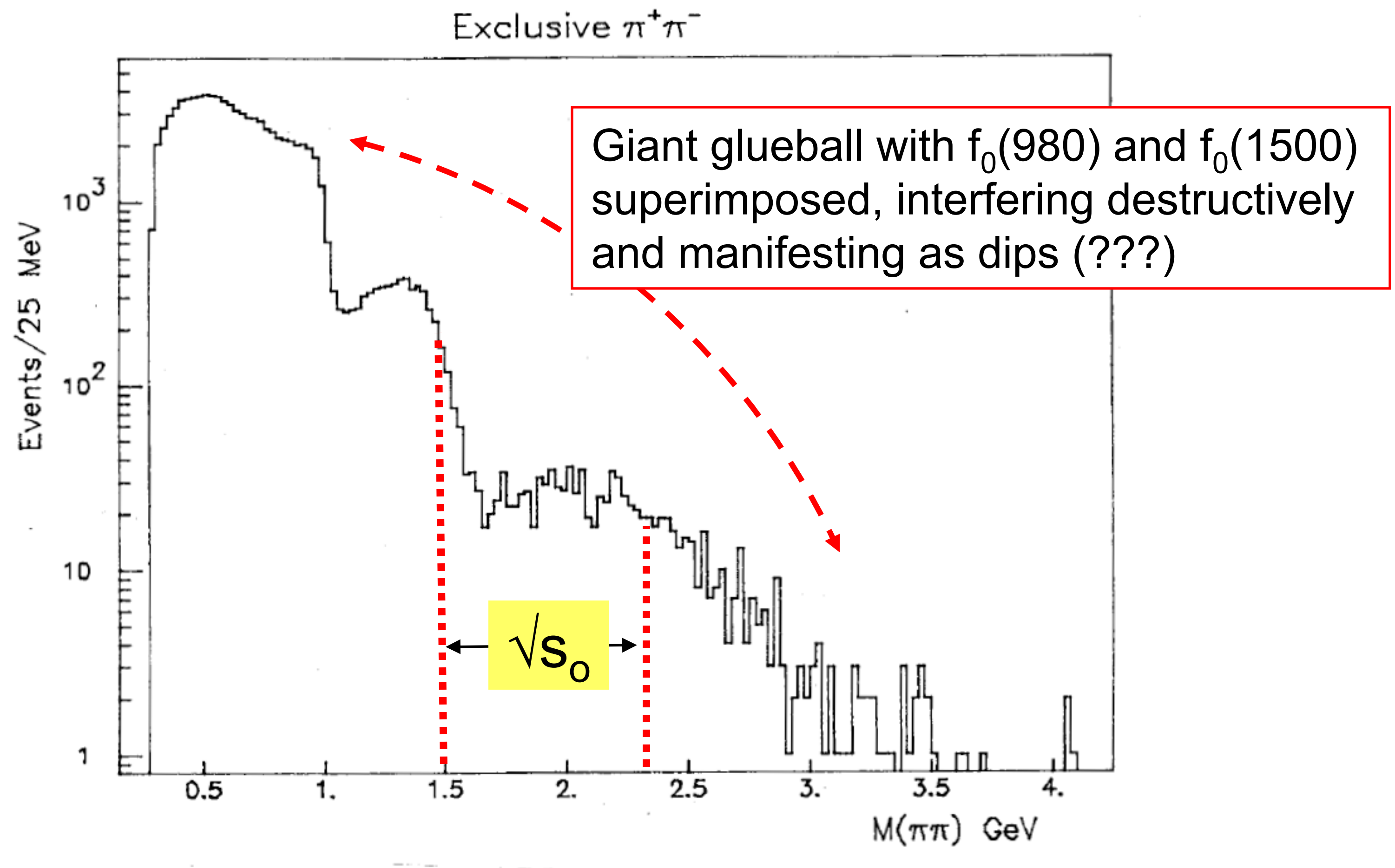
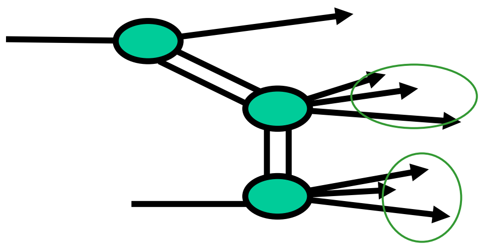


Figure 8: $M_{\pi^+\pi^-}$ spectrum in $DIPE$ at the ISR (Axial Field Spectrometer, R807 [97, 98]). Figure from Ref. [98]. **See M.G.Albrow, T.D. Goughlin, J.R. Forshaw, hep-ph>arXiv:1006.1289**

Multigap cross sections, e.g. SDD

KG, hep-ph/0203141



Δy_1	$\Delta y_1'$	Δy_2	$\Delta y_2'$

5 independent variables: y_1', y_2, t_1, $\Delta y = \Delta y_1 + \Delta y_2$, t_2

color factor

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{\text{i=1-2}} \left\{ e^{(\varepsilon+\alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y_1' + \Delta y_2')} \right\}$$

Gap probability

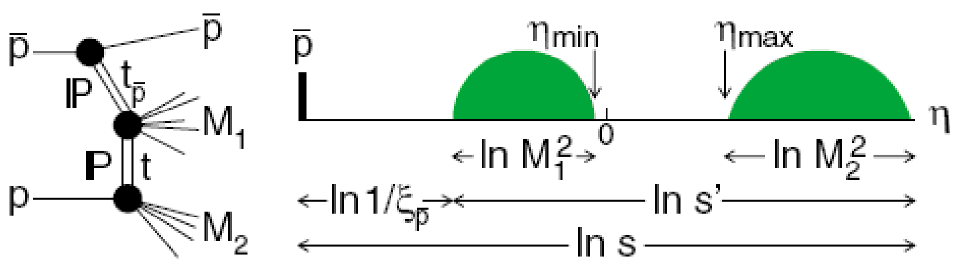
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

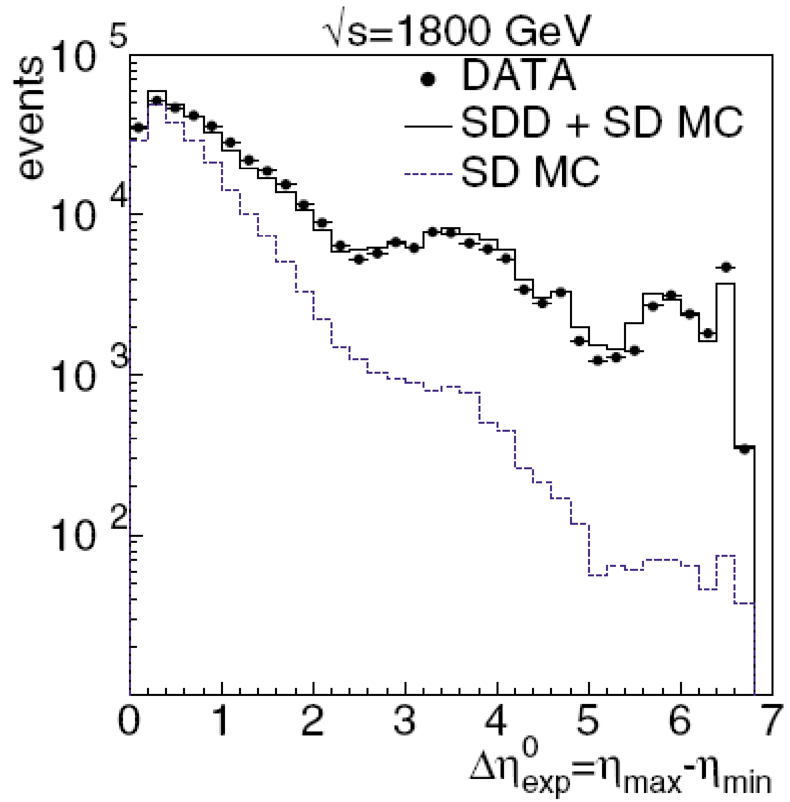
Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

SDD in CDF: data vs NBR MC

http://physics.rockefeller.edu/publications.html





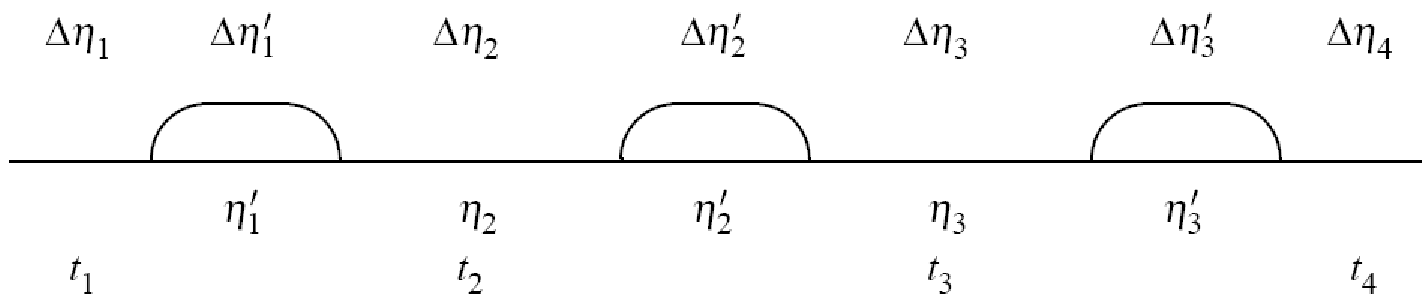
- Excellent agreement between data and NBR (MinBiasRockefeller) MC

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

Multigaps: a 4-gap x-section

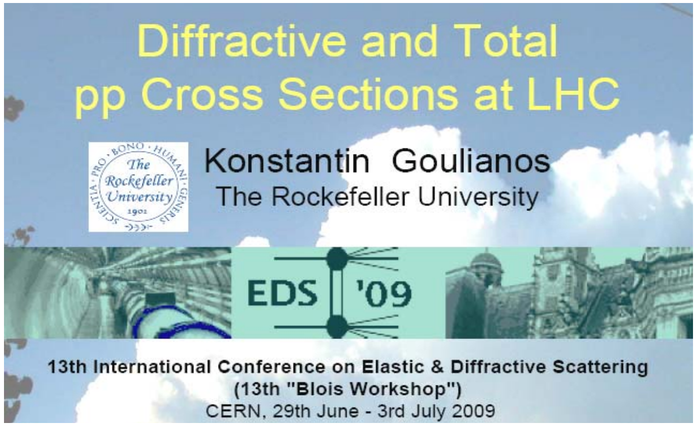
Presented at DIS-2005, XIIIth International Workshop on Deep Inelastic Scallering,
April 27 - May 1 2005, Madison, WI, U.S.A.

Multigap Diffraction at LHC

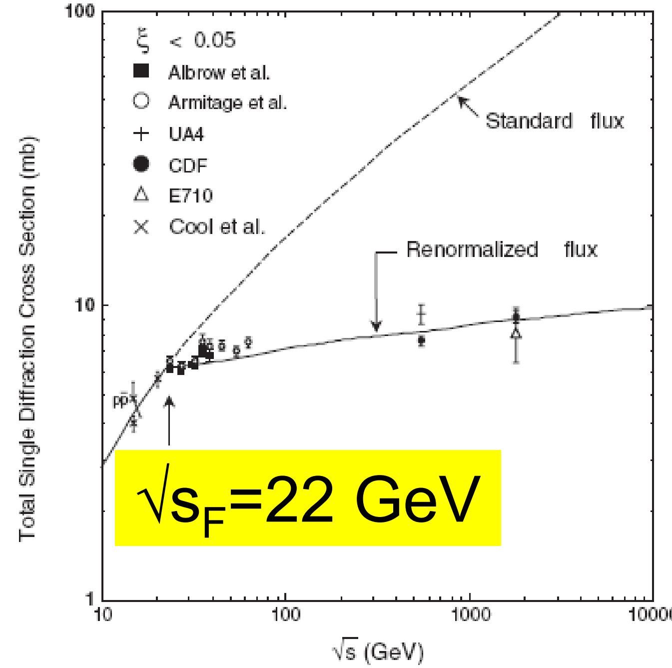


10 independent variables t_i, η_i, η'_i, and $\Delta\eta \equiv \Sigma_{i=1}^{4} \Delta\eta_i$

$$\frac{d^{10}\sigma^D}{\Pi_{i=1}^{10} dV_i} = N_{gap}^{-1} \underbrace{F_p^2(t_1)F_p^2(t_4)\Pi_{i=1}^{4}\left\{e^{[\varepsilon+\alpha' t_i]\Delta\eta_i}\right\}^2}_{\text{gap probability}} \times \kappa^4 \left[\sigma_0\, e^{\varepsilon \Sigma_{i=1}^{3}\Delta\eta'_i}\right]$$



http://arxiv.org/abs/1002.3527



- Use the Froissart formula as a *saturated* cross section

$$\sigma_t(s > s_F) = \sigma_t(s_F) + \frac{\pi}{m^2} \cdot \ln^2 \frac{s}{s_F}$$

- This formula should be valid above the *knee* in σ_{sd} vs. $\sqrt{s}$ at $\sqrt{s_F} = 22$ GeV (Fig. 1) and therefore valid at $\sqrt{s} = 1800$ GeV.
- Use $m^2 = s_o$ in the Froissart formula multiplied by $1/0.389$ to convert it to mb^{-1}.
- Note that contributions from Reggeon exchanges at $\sqrt{s} = 1800$ GeV are negligible, as can be verified from the global fit of Ref. [7].
- Obtain the total cross section at the LHC:

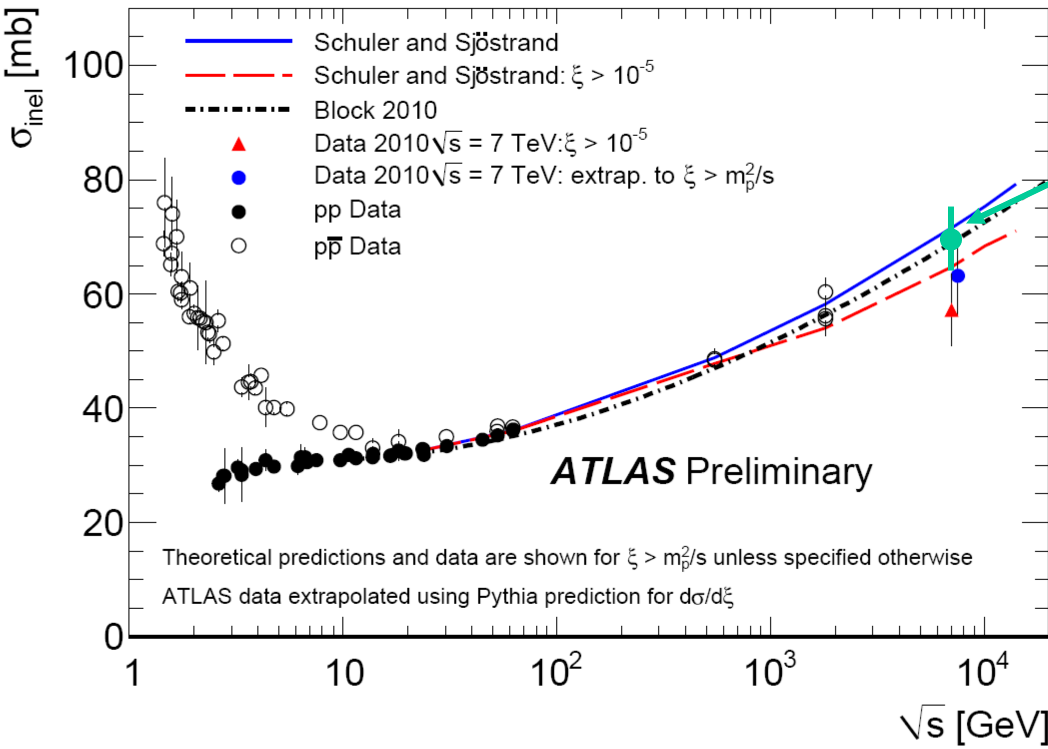
$$\sigma_t^{\text{LHC}} = \sigma_t^{\text{CDF}} + \frac{\pi}{s_o} \cdot \left(\ln^2 \frac{s^{\text{LHC}}}{s_F} - \ln^2 \frac{s^{\text{CDF}}}{s_F} \right)$$

SUPERBALL MODEL

98 ± 8 mb at 7 TeV
109 ±12 mb at 14 TeV

Total inelastic cross section

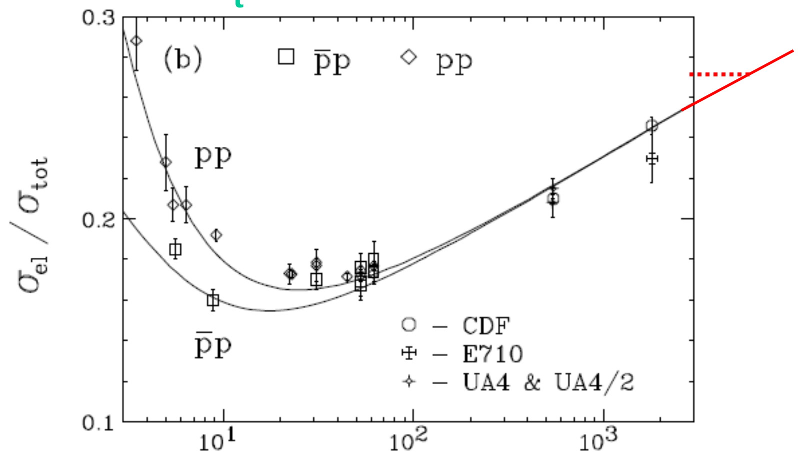
ATLAS measurement of the total inelastic x-section



Renormalization model

$\sqrt{s}$	σ_t	σ_{el}	σ_{inel}
7 TeV	98 ± 8	27 ± 2	71 ± 6
8 TeV	100 ± 8	28 ± 2	72 ± 6
14 TeV	109 ± 12	32 ± 4	76 ± 8

The σ_{el} is obtained from σ_t and the ratio of el/tot



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

σ^{SD} and ratio of α'/ϵ

PHYSICAL REVIEW D **80**, 111901(R) (2009)

Pomeron intercept and slope: A QCD connection

Konstantin Goulianos

$$\frac{d^2\sigma_{sd}(s,M^2,t)}{dM^2dt} = \left[\frac{\sigma_\circ}{16\pi}\sigma_\circ^{\mathbb{P}p}\right]\frac{s^{2\epsilon}}{N(s)}\frac{1}{(M^2)^{1+\epsilon}}e^{bt}$$

$$\overset{s\to\infty}{\Longrightarrow}\left[2\alpha' e^{(\epsilon b_0)/\alpha'}\sigma_\circ^{\mathbb{P}p}\right]\frac{\ln s^{2\epsilon}}{(M^2)^{1+\epsilon}}e^{bt}$$

$$\sigma^{tot}_{pp/\bar{p}p} = \sigma_\circ \cdot e^{\epsilon\Delta\eta}.$$

$$\sigma_{sd}^{\infty} = 2\sigma_\circ^{\mathbb{P}p}\exp\left[\frac{\epsilon b_\circ}{2\alpha'}\right] = \sigma_\circ^{pp}$$

$$\sigma_\circ^{\mathbb{P}p} = \beta_{\mathbb{P}pp}(0)\cdot g(t) = \kappa\sigma_\circ^{pp}$$

$$\kappa = \frac{f_g^\infty}{N_c^2-1} + \frac{f_q^\infty}{N_c}$$

$$b_\circ = R_p^2/2 = 1/(2m_\pi^2).$$

$$r = \frac{\alpha'}{\epsilon} = -[16m_\pi^2\ln(2\kappa)]^{-1}$$

$$r_{pheno} = 3.2 \pm 0.4\ (\text{GeV}/c)^{-2}$$

$$r_{exp} = 0.25\ (\text{GeV}/c)^{-2}/0.08 = 3.13\ (\text{GeV}/c)^{-2}$$

Diffraction in PYTHIA -1

$$\sigma_{\rm tot}^{AB}(s) = X^{AB}\, s^{\epsilon} + Y^{AB}\, s^{-\eta} \qquad \boxed{\epsilon = 0.0808}$$

$$\sigma_{\rm tot}^{AB}(s) = \sigma_{\rm el}^{AB}(s) + \sigma_{{\rm sd}(XB)}^{AB}(s) + \sigma_{{\rm sd}(AX)}^{AB}(s) + \sigma_{\rm dd}^{AB}(s) + \sigma_{\rm nd}^{AB}(s)$$

$$\begin{aligned}
\frac{d\sigma_{{\rm sd}(XB)}(s)}{dt\, dM^2} &= \frac{g_{3\mathbb{P}}}{16\pi}\, \beta_{A\mathbb{P}}\, \beta_{B\mathbb{P}}^2\, \frac{1}{M^2}\, \exp(B_{{\rm sd}(XB)}t)\, F_{\rm sd} \\
\frac{d\sigma_{{\rm sd}(AX)}(s)}{dt\, dM^2} &= \frac{g_{3\mathbb{P}}}{16\pi}\, \beta_{A\mathbb{P}}^2\, \beta_{B\mathbb{P}}\, \frac{1}{M^2}\, \exp(B_{{\rm sd}(AX)}t)\, F_{\rm sd} \\
\frac{d\sigma_{\rm dd}(s)}{dt\, dM_1^2\, dM_2^2} &= \frac{g_{3\mathbb{P}}^2}{16\pi}\, \beta_{A\mathbb{P}}\, \beta_{B\mathbb{P}}\, \frac{1}{M_1^2}\, \frac{1}{M_2^2}\, \exp(B_{\rm dd}t)\, F_{\rm dd}
\end{aligned}$$

some comments:

- $1/M^2$ dependence instead of $(1/M^2)^{1+\varepsilon}$
- F-factors put "by hand" – next slide
- B_{dd} contains a term added by hand - next slide

Diffraction in PYTHIA -2

$$B_{\mathrm{sd}(XB)}(s) = 2b_B + 2\alpha' \ln\left(\frac{s}{M^2}\right),$$

$$B_{\mathrm{sd}(AX)}(s) = 2b_A + 2\alpha' \ln\left(\frac{s}{M^2}\right),$$

$$B_{\mathrm{dd}}(s) = 2\alpha' \ln\left(e^4 + \frac{s s_0}{M_1^2 M_2^2}\right)$$

note:

- $1/M^2$ dependence
- e^4 factor

Fudge factors:

- suppression at kinematic limit
- kill overlapping diffractive systems in dd
- enhance low mass region

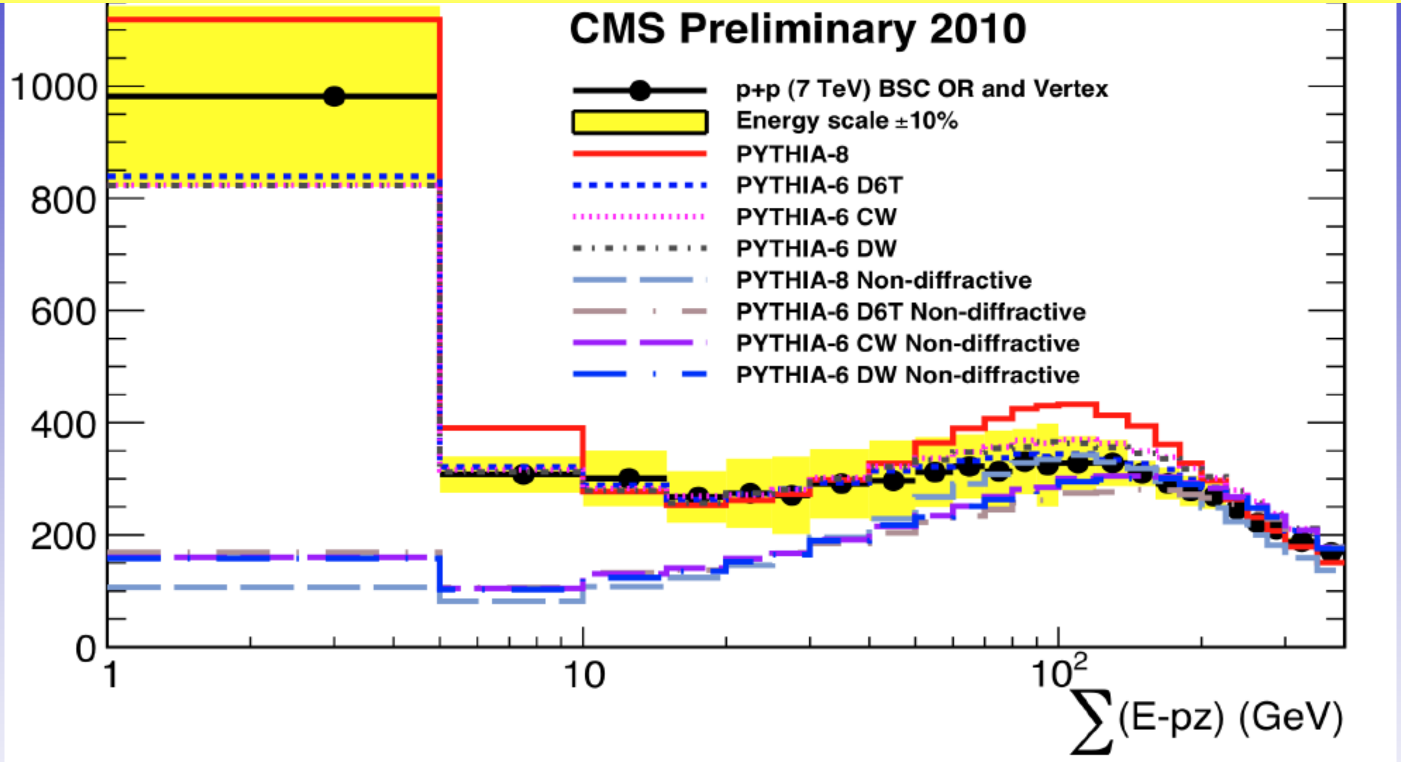
$$F_{\mathrm{sd}} = \left(1 - \frac{M^2}{s}\right)\left(1 + \frac{c_{\mathrm{res}}\, M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + M^2}\right),$$

$$F_{\mathrm{dd}} = \left(1 - \frac{(M_1 + M_2)^2}{s}\right)\left(\frac{s\, m_{\mathrm{p}}^2}{s\, m_{\mathrm{p}}^2 + M_1^2 M_2^2}\right)$$

$$\times \left(1 + \frac{c_{\mathrm{res}}\, M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + M_1^2}\right)\left(1 + \frac{c_{\mathrm{res}}\, M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + M_2^2}\right)$$

CMS: observation of Diffraction at 7 TeV

An example of a beautiful data analysis and of MC inadequacies



13: CMS inclusive single diffraction observation: data vs. MC.

- No single MC describes the data in their entirety

Monte Carlo Strategy for the LHC

MONTE CARLO STRATEGY

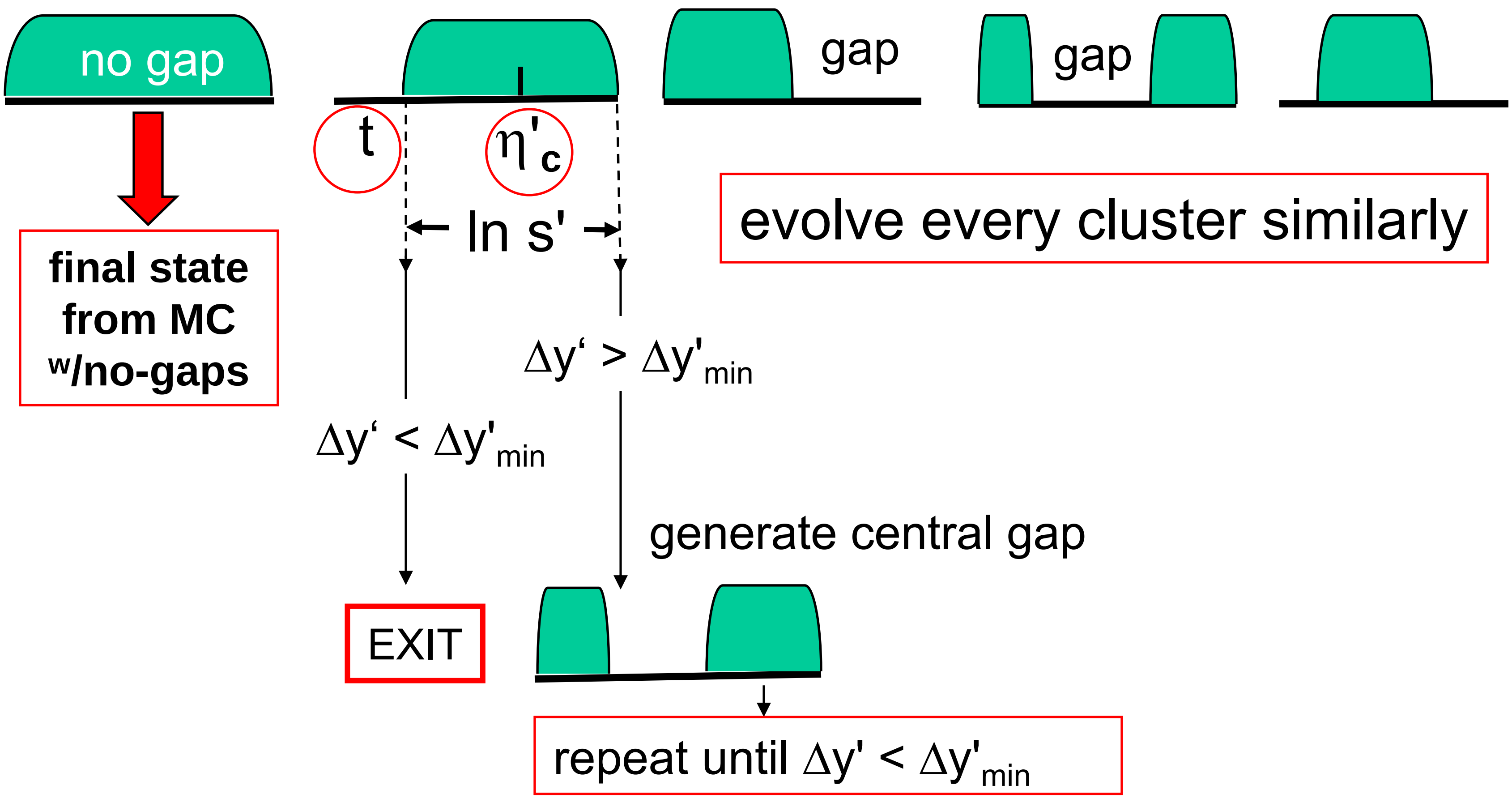
- ❑ σ^T → from SUPERBALL model
- ❑ optical theorem → Im $f_{el}(t=0)$
- ❑ dispersion relations → Re $f_{el}(t=0)$
- ❑ σ^{el}
- ❑ σ^{inel}
- ❑ differential σ^{SD} → from RENORM
- ❑ use *nesting* of final states (FSs) for *pp* collisions at the *IP-p* sub-energy √s'

σ_T
↕ **optical theorem**
Im $f_{el}(t=0)$
↕ **dispersion relations**
Re $f_{el}(t=0)$

Strategy similar to that employed in the MBR (Minimum Bias Rockefeller) MC used in CDF based on multiplicities from: K. Goulianos, Phys. Lett. B 193 (1987) 151 pp "A new statistical description of hardonic and e^+e^- multiplicity distributions "

Monte Carlo algorithm - nesting

Profile of a *pp* inelastic collision



SUMMARY

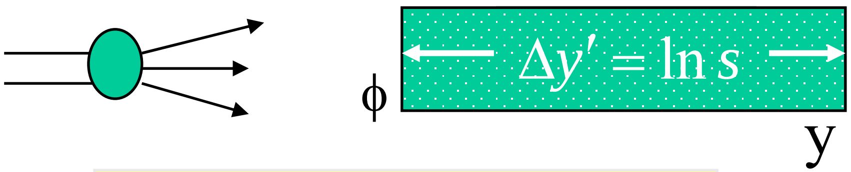
- ❑ Introduction
- ❑ Diffractive cross sections
  - ➢ basic: SD_p, $SD_{\bar{p}}$, DD, DPE
  - ➢ combined: multigap x-sections

  } derived from ND and QCD color factors

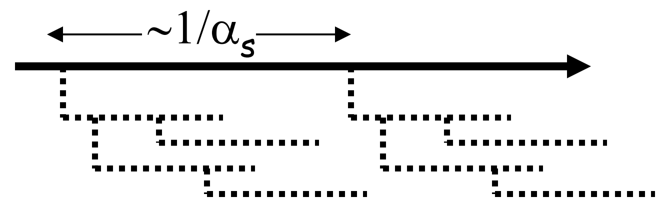
  - ➢ ND → no-gaps: final state from MC with no gaps
    - ❖ this is the only final state to be tuned
- ❑ The total, elastic, and inelastic cross sections
- ❑ Monte Carlo strategy for the LHC – use “nesting”

BACKUP

RISING X-SECTIONS IN PARTON MODEL



$$\sigma_T(s) = \sigma_o\, e^{\varepsilon \Delta y'} = \sigma_o\, s^{\varepsilon}$$



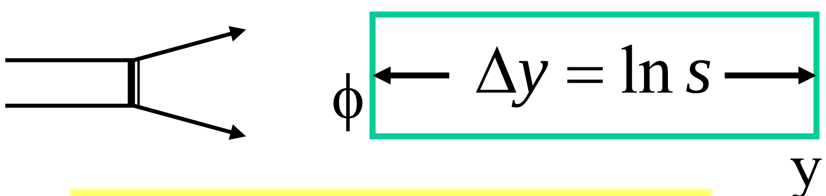
Emission spacing controlled by α-strong

➔ σ_T : power law rise with energy

(see E. Levin, An Introduction to Pomerons,Preprint DESY 98-120)

α' reflects the size of the emitted cluster,

which is controlled by 1 /α_s and thereby is related to ε

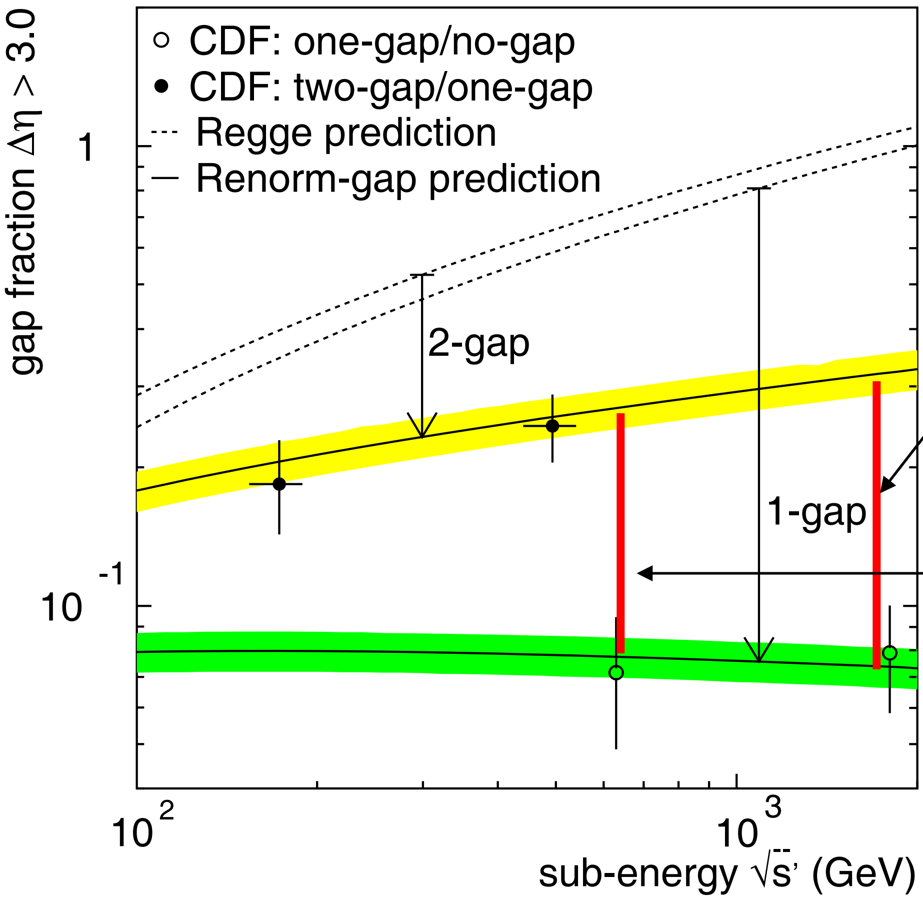


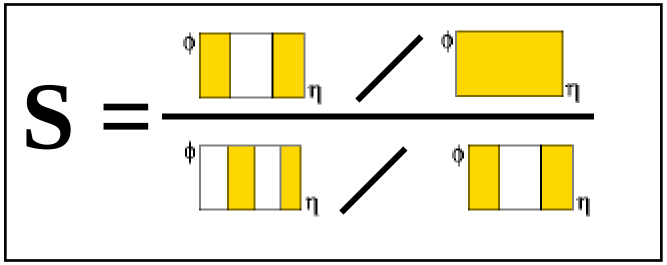
$$\mathrm{Im}\ f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

← assume linear t-dependence

Forward elastic scattering amplitude

Gap survival probability



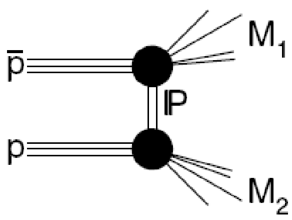


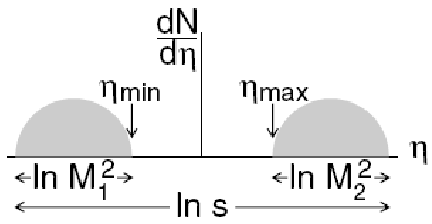
$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \mathrm{GeV}) \approx 0.23$$

$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \mathrm{GeV}) \approx 0.29$$

Diffraction in MBR: dd in CDF

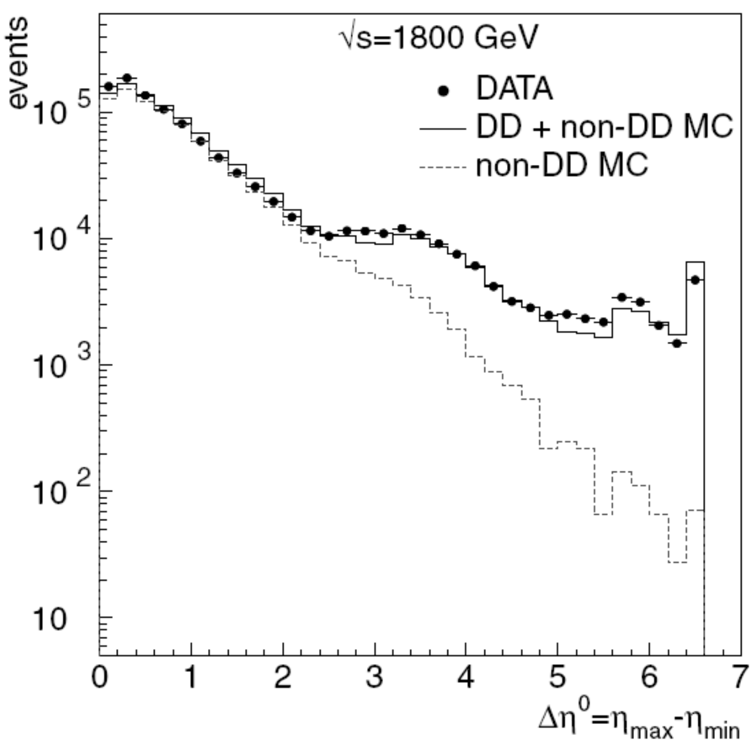
http://physics.rockefeller.edu/publications.html

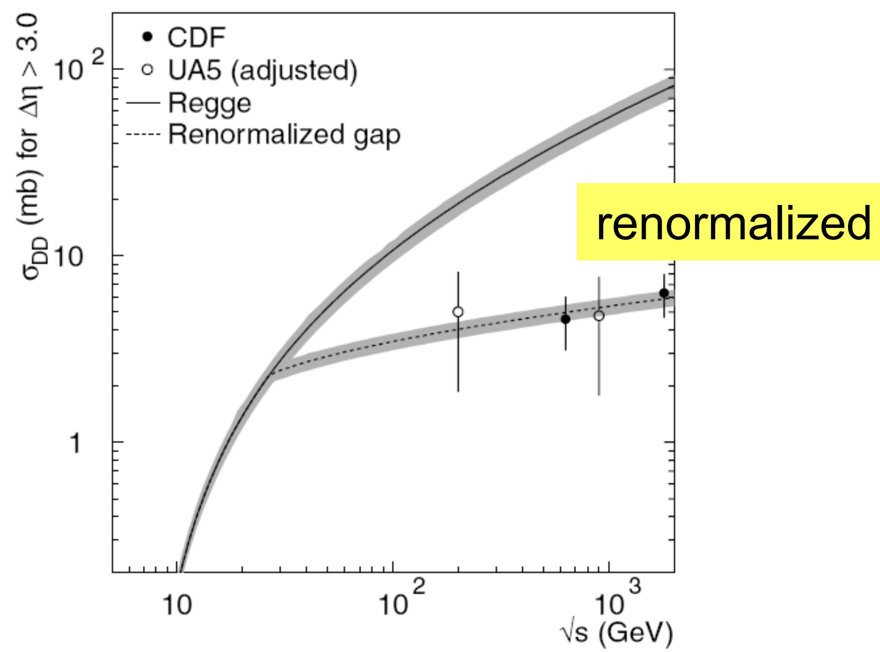




$$\frac{d^3\sigma_{DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{SD}}{dt\,dM_2^2}\Big/\frac{d\sigma_{el}}{dt} = \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi}\,\frac{s^{2\epsilon}e^{b_{DD}t}}{(M_1^2M_2^2)^{1+2\epsilon}}$$

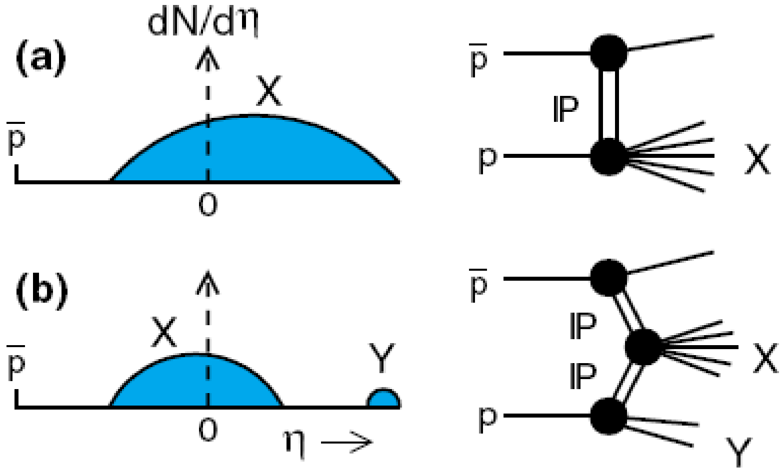
$$\frac{d^3\sigma_{DD}}{dt\,d\Delta\eta\,d\eta_c} = \underbrace{\left[\frac{\kappa\beta^2(0)}{16\pi}\,e^{2[\alpha(t)-1]\Delta\eta}\right]}_{\text{gap probability}}\underbrace{\left[\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right]}_{\text{x-section}}$$

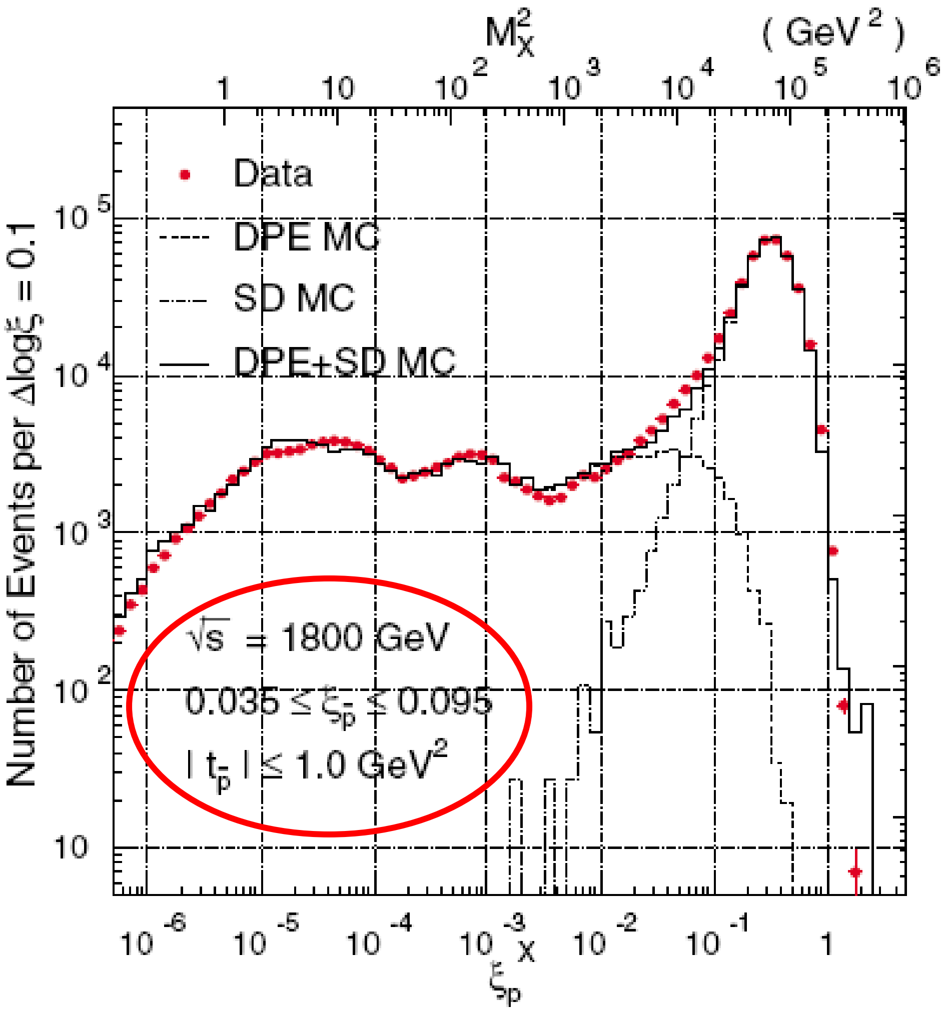




Diffraction in MBR: DPE in CDF

http://physics.rockefeller.edu/publications.html



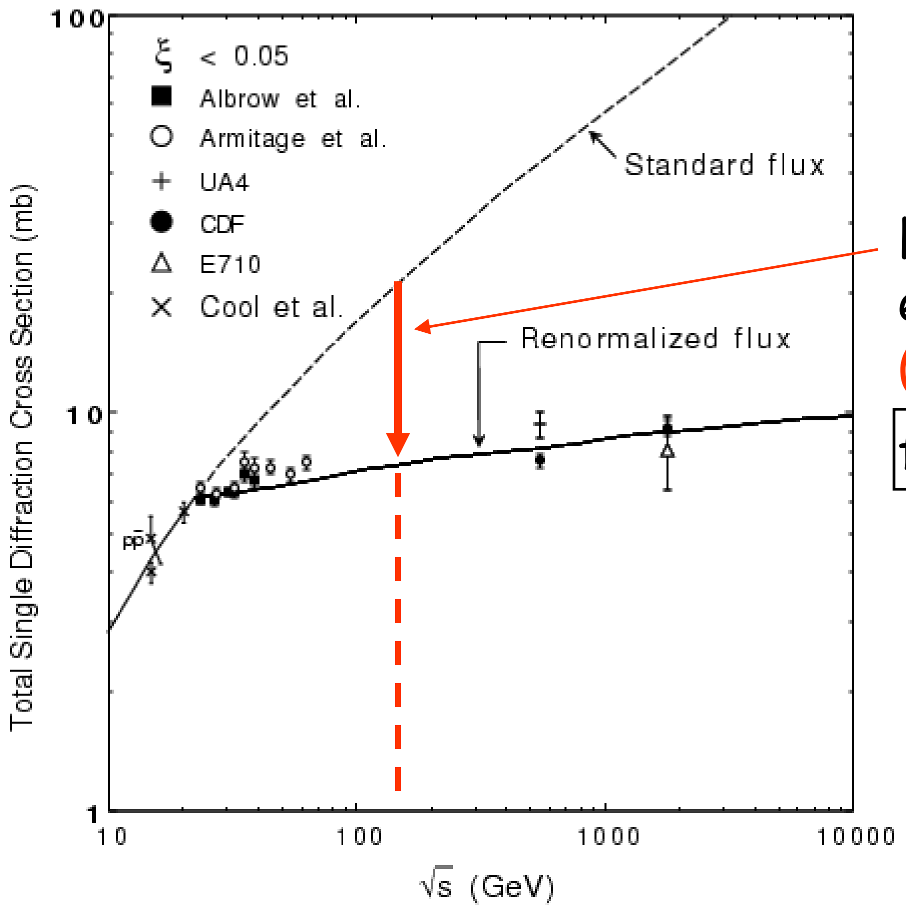


- Excellent agreement between data and MBR

➔ low and high masses are correctly implemented

Dijets in γp at HERA from RENORM

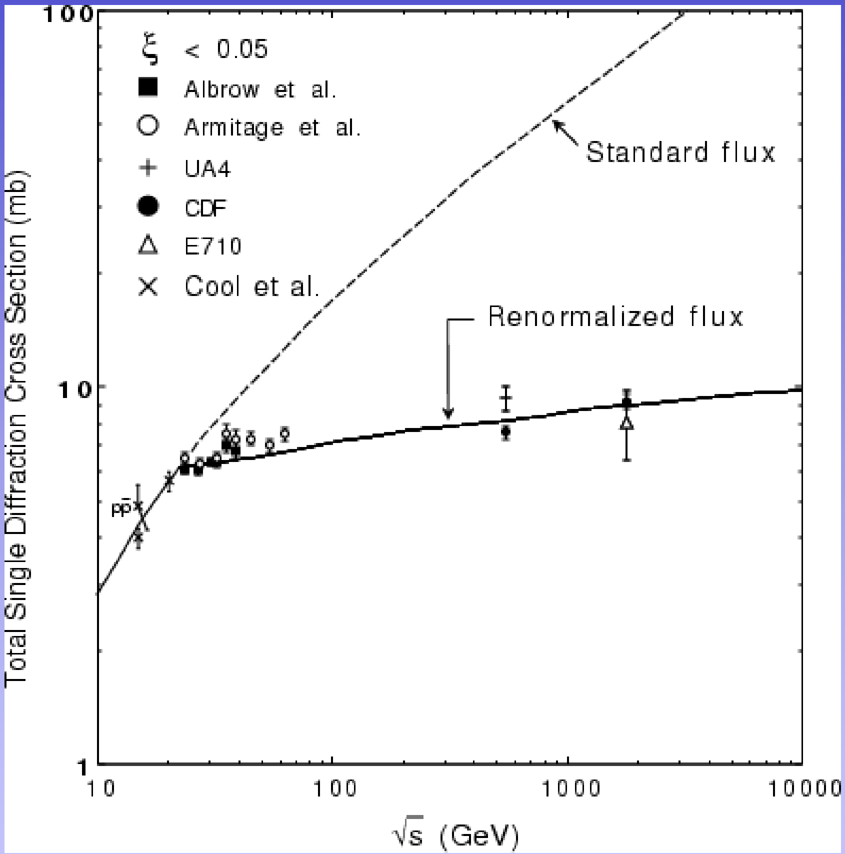
K. Goulianos, POS (DIFF2006) 055 (p. 8)



Factor of ~3 suppression expected at W~200 GeV (just as in pp collisions)

for both direct and resolved components

Saturation at low Q^2 and small-x



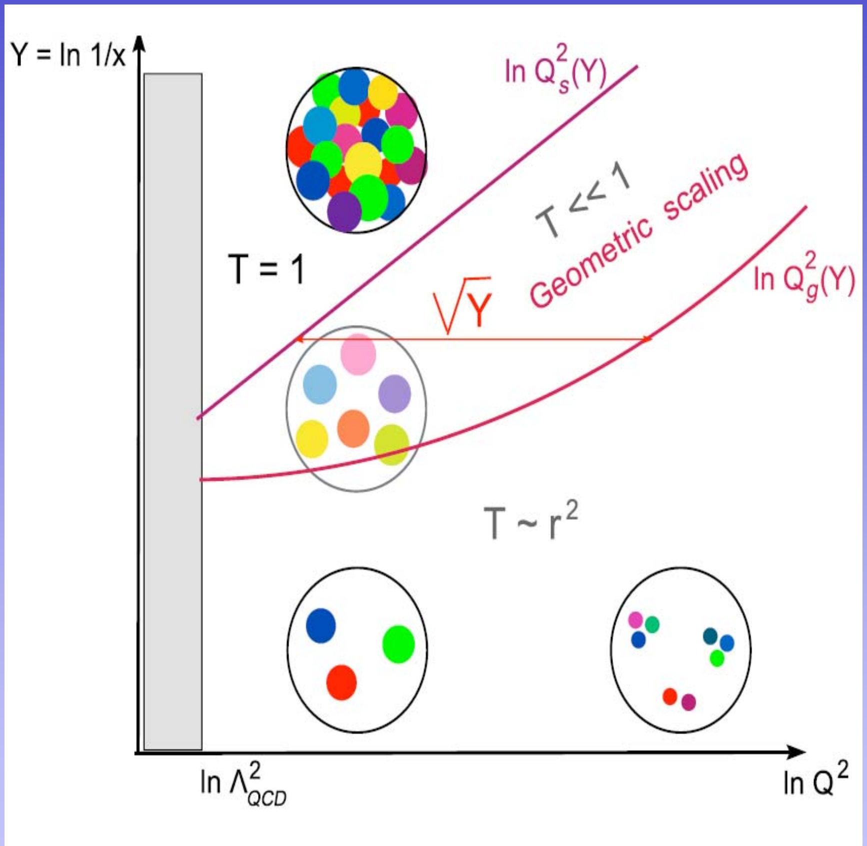


figure from a talk by Edmond Iancu

The end