Predicting and measuring the total inelastic cross section at the LHC

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Contents

Sec. 1

1) Introduction gaps

diffraction, saturation and pp cross sections at LHC

- http://physics.rockefeller.edu/dino/myhtml/talks/HEP2006.pdf
- http://physics.rockefeller.edu/dino/myhtml/talks/moriond11_dino.pdf

2) Predicting the total σ — σ_t

3) Predicting the total-elastic σ — σ_{el}

→ total-inelastic σ — $\sigma_{inel} = \sigma_t - \sigma_{el}$

4) Measuring the "visible"-inelastic σ — σ_{inel}^{vis}

5) Extrapolating to measured-inelastic σ — σ_{inel}^{meas}

6) A Monte Carlo algorithm for the LHC — nesting

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, acceptance, …→ the UE affects all physics studies at 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
- **MCs disagree** in the way they handle diffraction
- **MC tunes:** the "evils of the world" were released from Pandora's box at the LHC

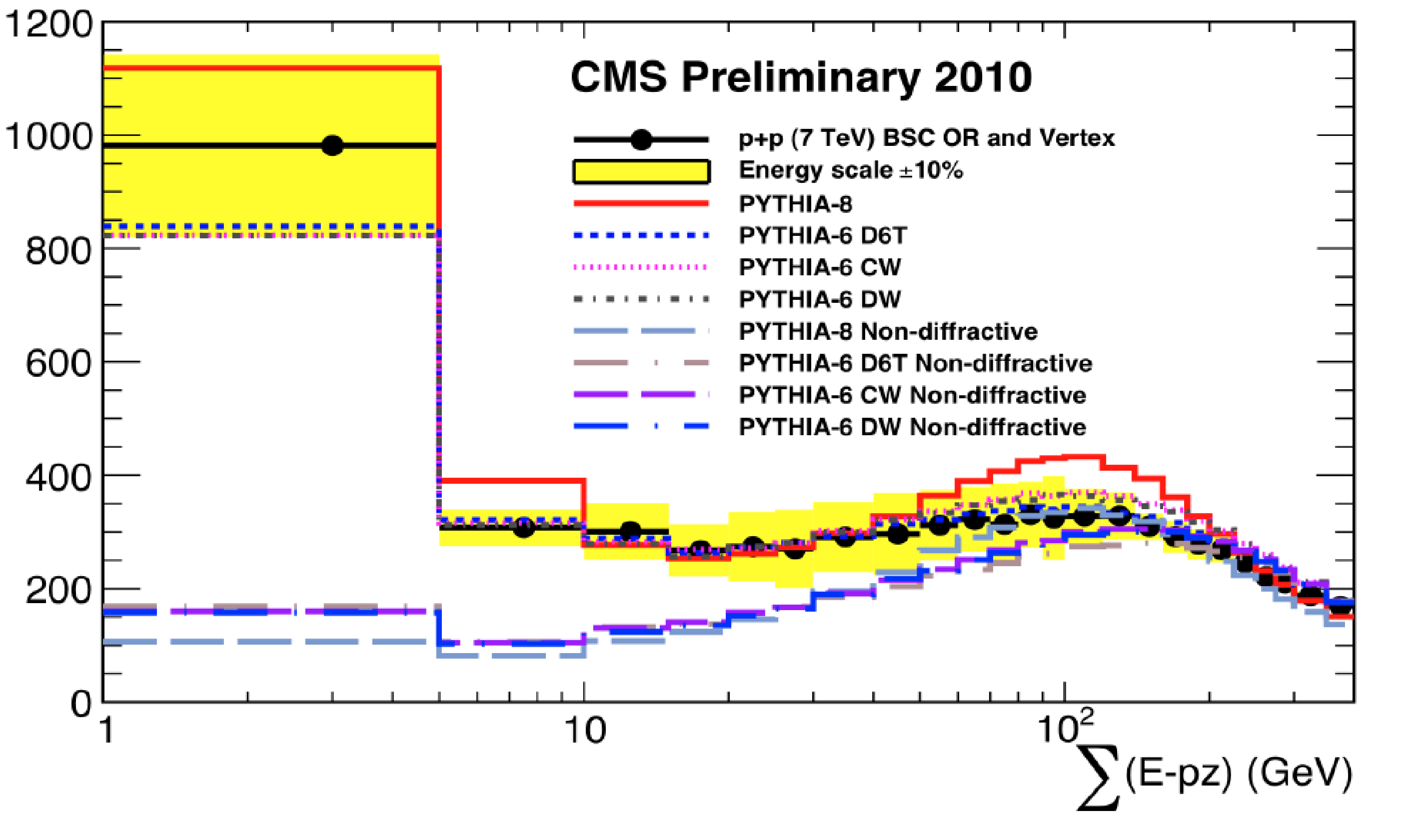
… but fortunately, *hope* remained in the box

→ 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

CMS: observation of Diffraction at 7 TeV

(an early example of MC inadequacies)

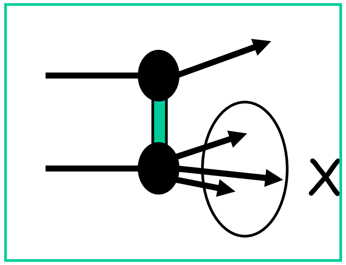


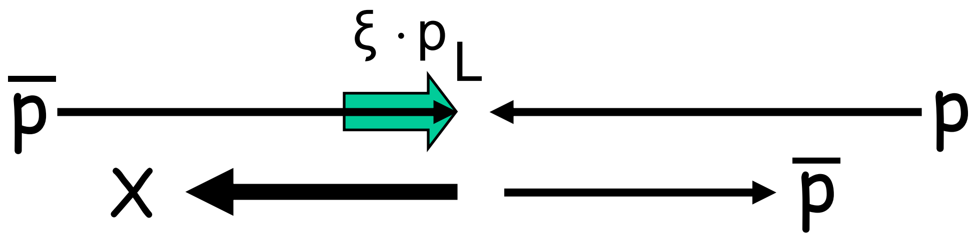
13: CMS inclusive single diffraction observation: data vs. MC.

- No single MC describes the data in their entirety

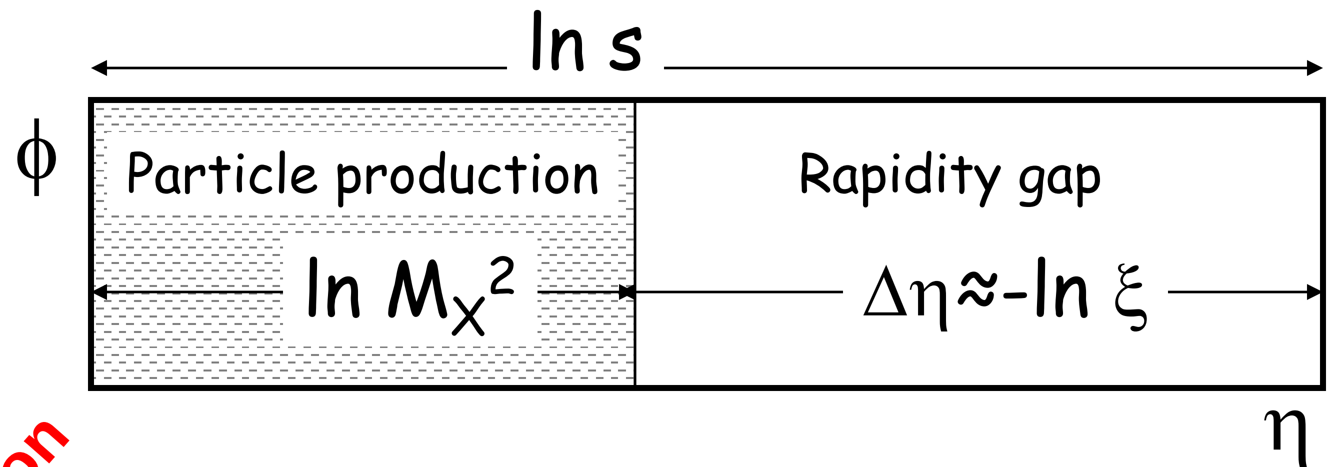
Diffractive gaps

definition: gaps not exponentially suppressed





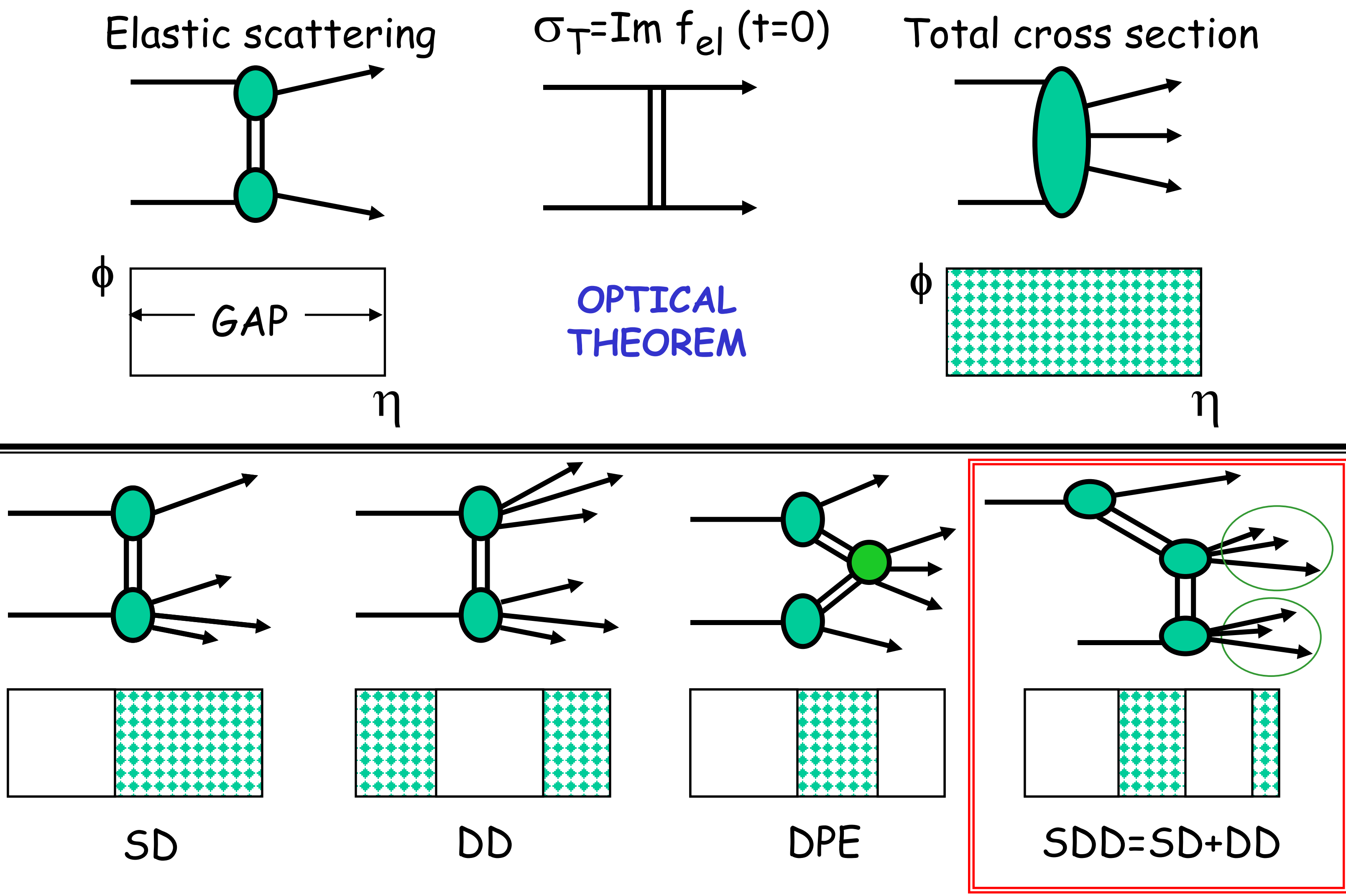
$$\xi \approx \frac{M_x^2}{s}$$



No radiation

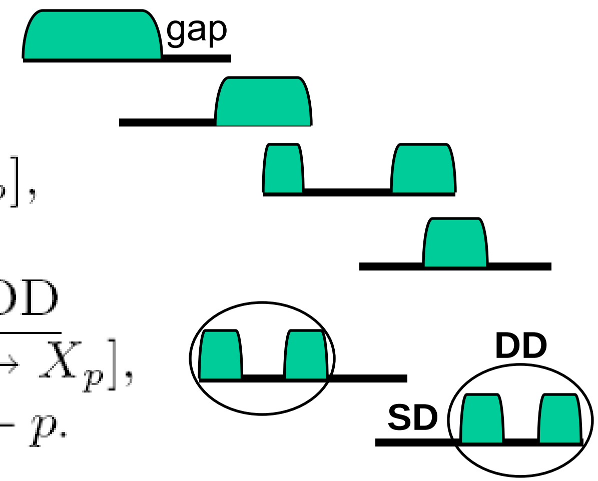
$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

Diffractive pbar-p studies @ CDF

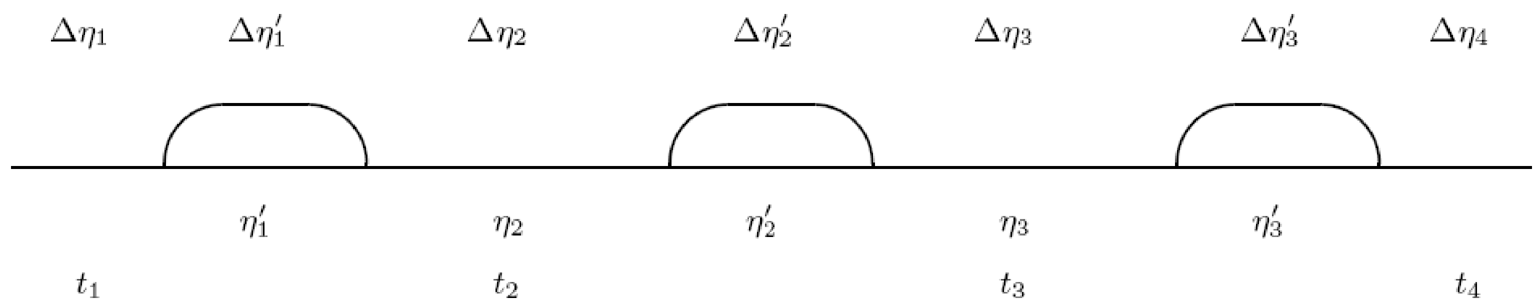


Basic and combined diffractive processes

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

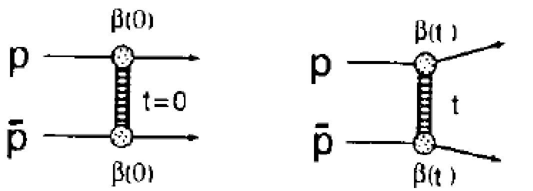


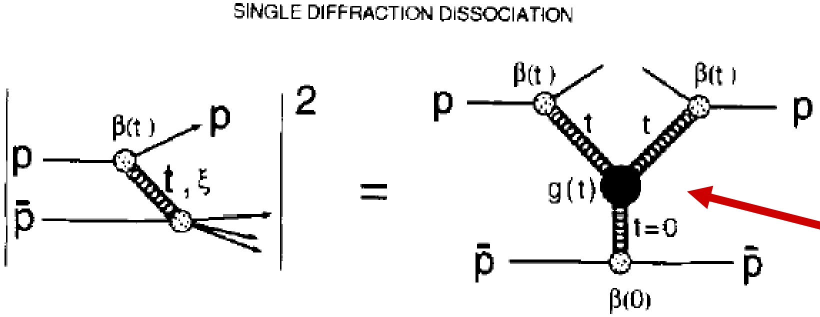
a 4-gap diffractive process



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!

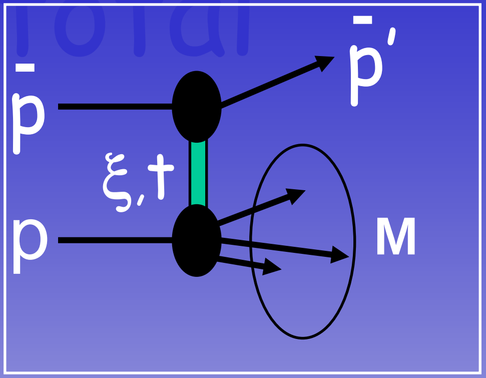
$$\left(\frac{d\sigma_{el}}{dt}\right)_{t=0} \sim \left(\frac{s}{s_o}\right)^{2\epsilon}, \quad \sigma_t \sim \left(\frac{s}{s_o}\right)^{\epsilon}, \quad \sigma_{sd} \sim \left(\frac{s}{s_o}\right)^{2\epsilon}$$

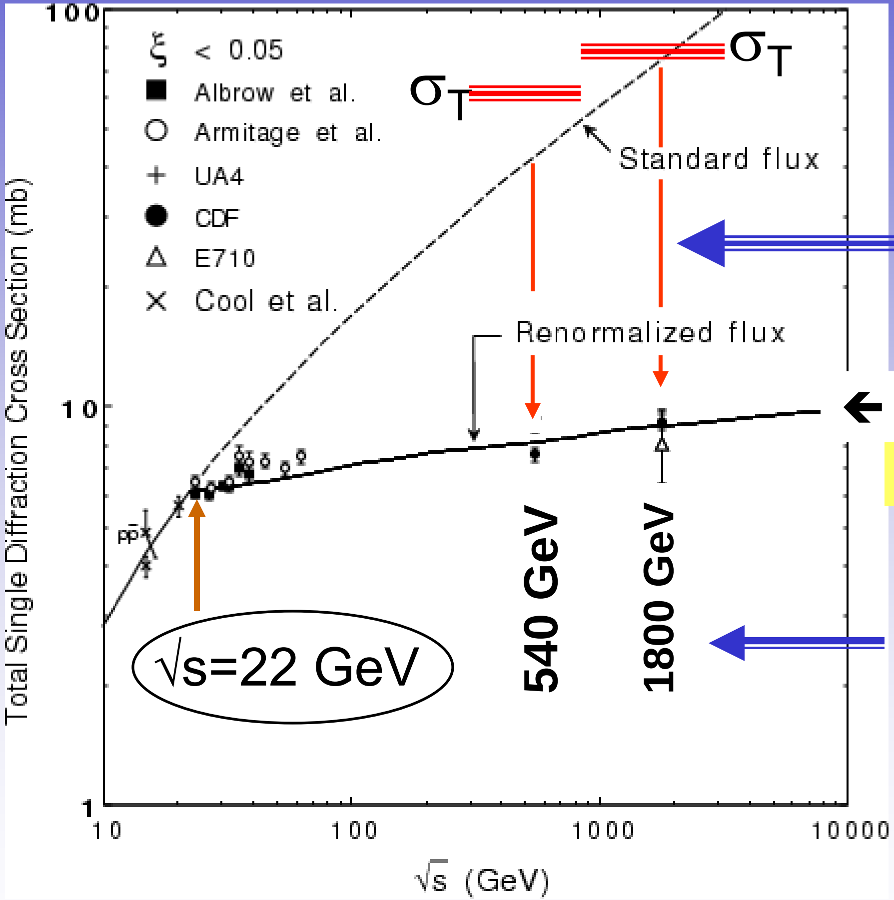
❑ $d\sigma/dt$ σ_{sd} grows faster than σ_t as *s* increases
➔ unitarity violation at high *s*
(similarly for partial x-sections in impact parameter space)

❑ the unitarity limit is already reached at $\sqrt{s}$ ~ 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

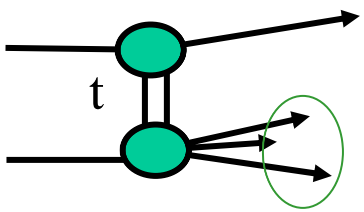
KG, PLB 358, 379 (1995)

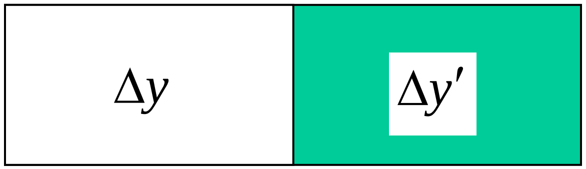
CDF Run I results

Single diffraction renormalized – (1 of/4)

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 of/4)

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 of/4)

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

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

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

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

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

set to unity
➔ determine s_o

Single diffraction renormalized - (4 of/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!

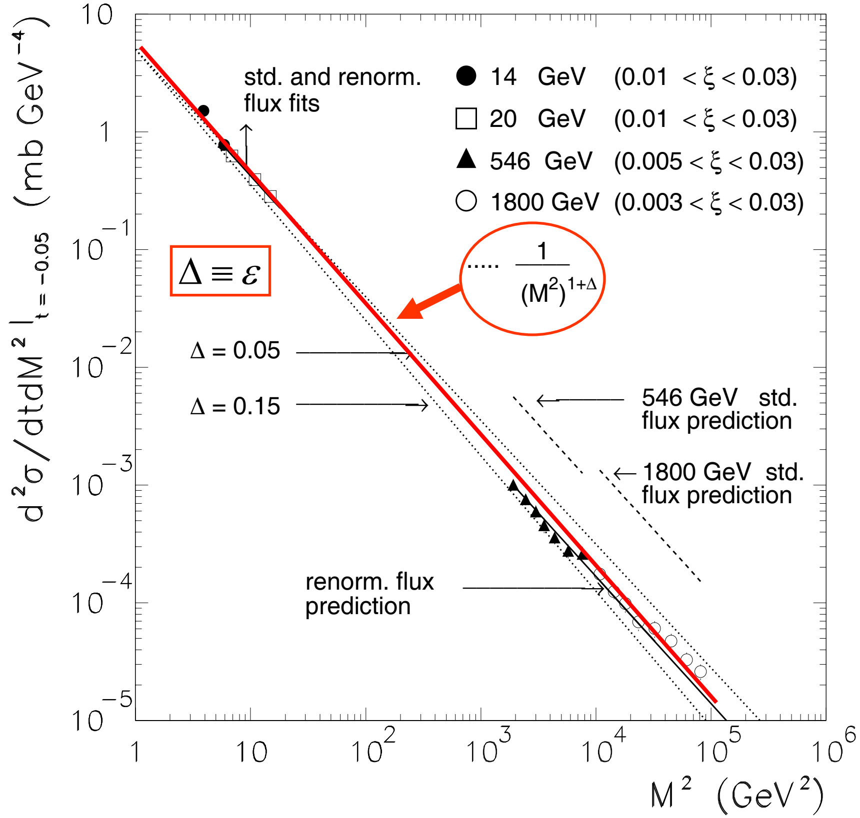
KG&JM, PRD 59 (1999) 114017

Regge ➔ data

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

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

➔ M^2 scaling

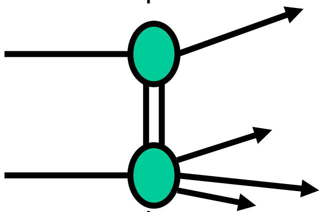


➔ factorization breaks down to ensure M^2 scaling

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



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

s_o^{ε}

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

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?

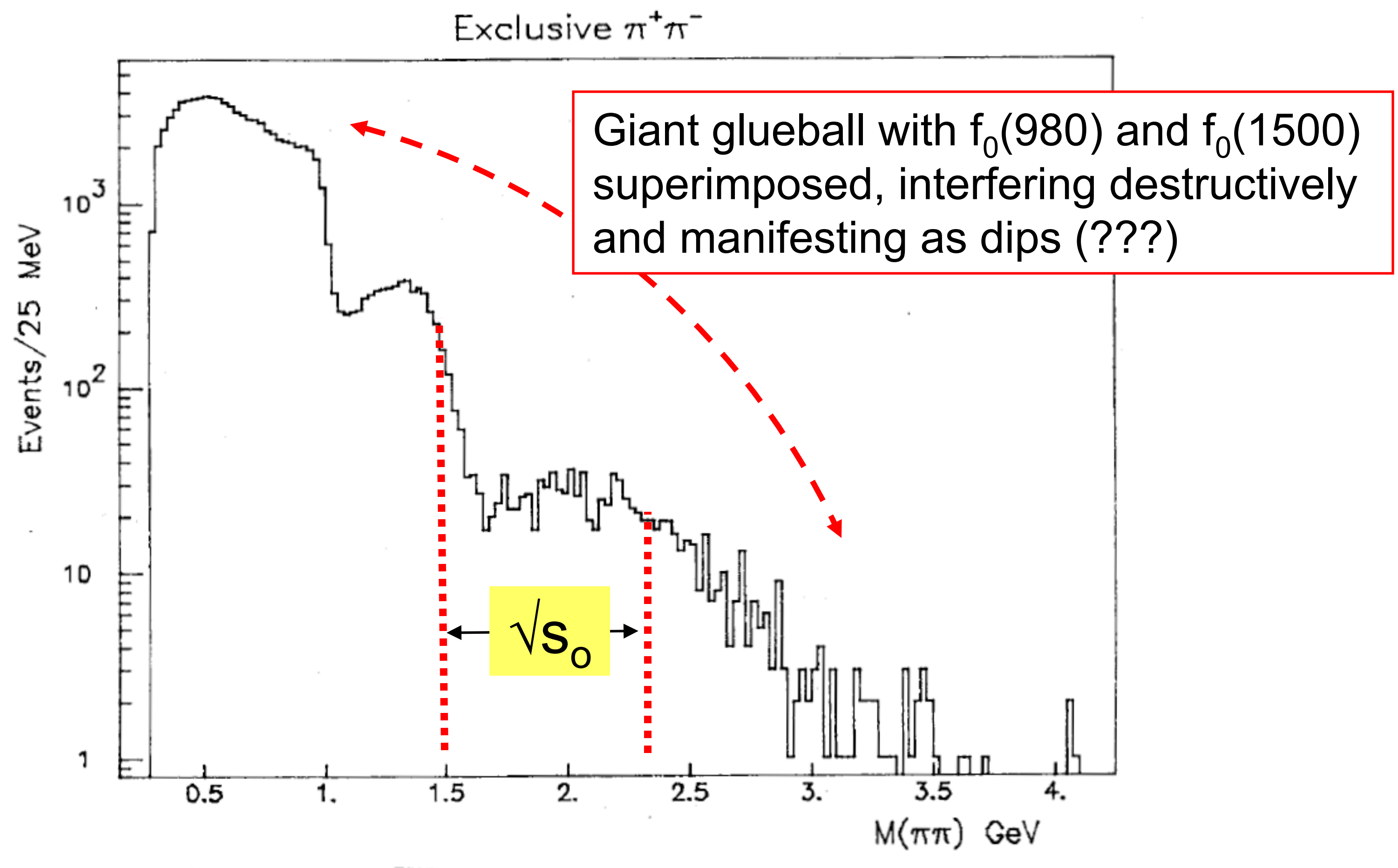
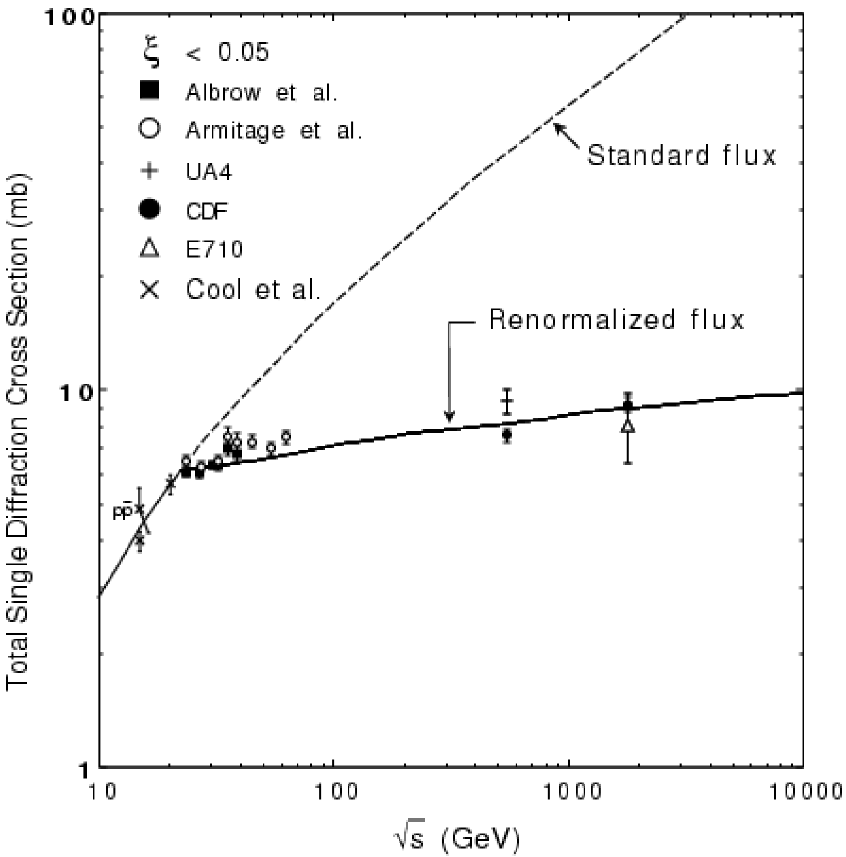


Figure 8: $M_{\pi^+\pi^-}$ spectrum in $DIPE$ at the ISR (Axial Field Spectrometer, R807 [97, 98]). Figure from Ref. [98]. **See M.G.Albrow, T.D. Goughlin, J.R. Forshaw, hep-ph>arXiv:1006.1289**

Saturation at low Q^2 and small-x



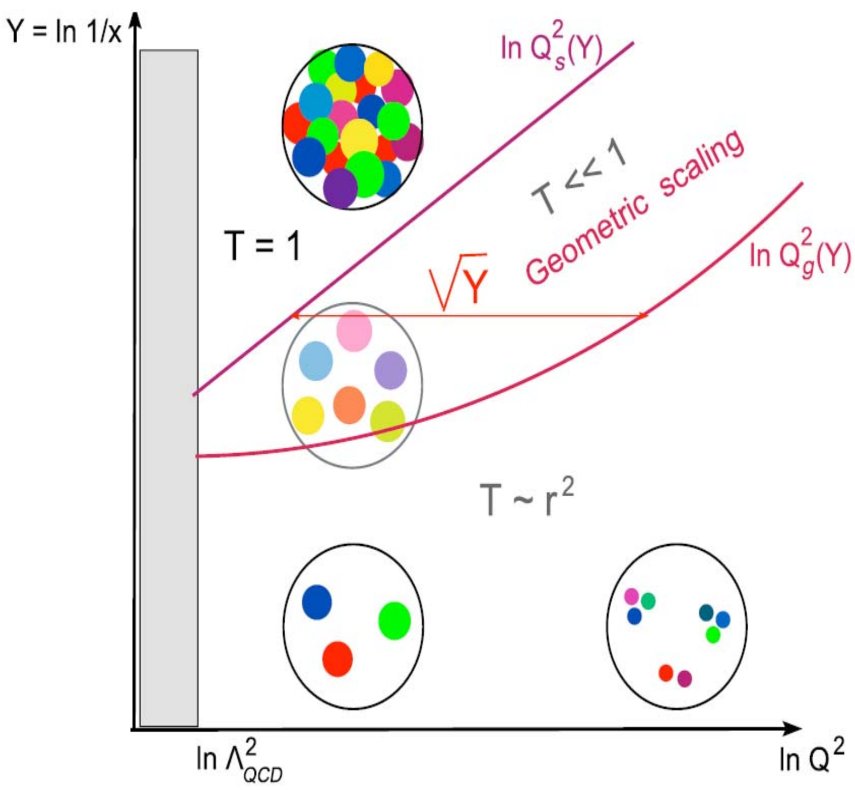
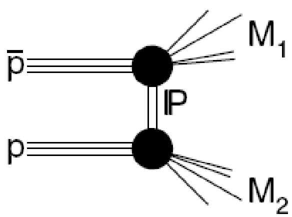
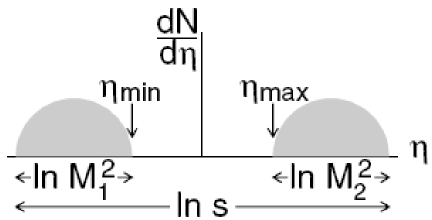


figure from a talk by Edmond Iancu

DD at CDF: comparison with MBR

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

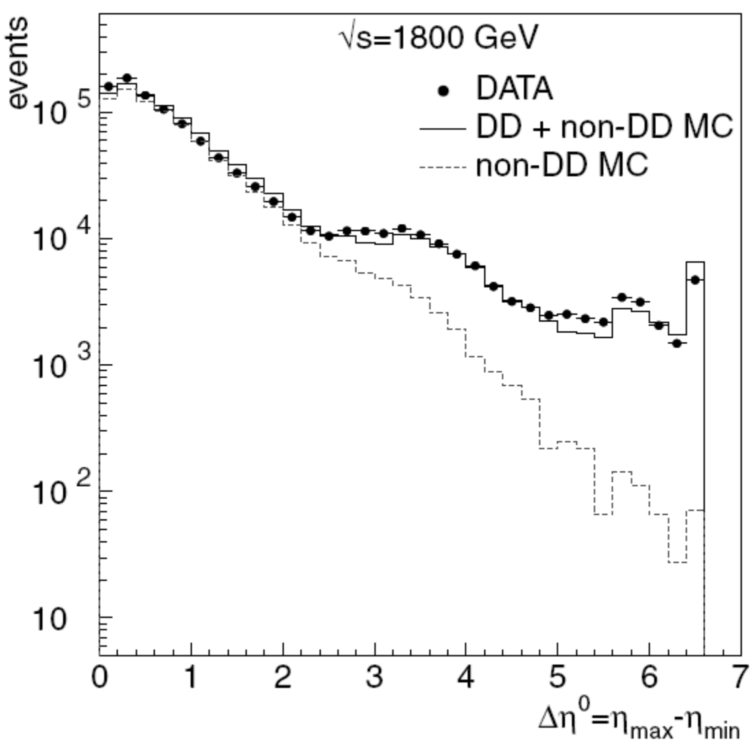


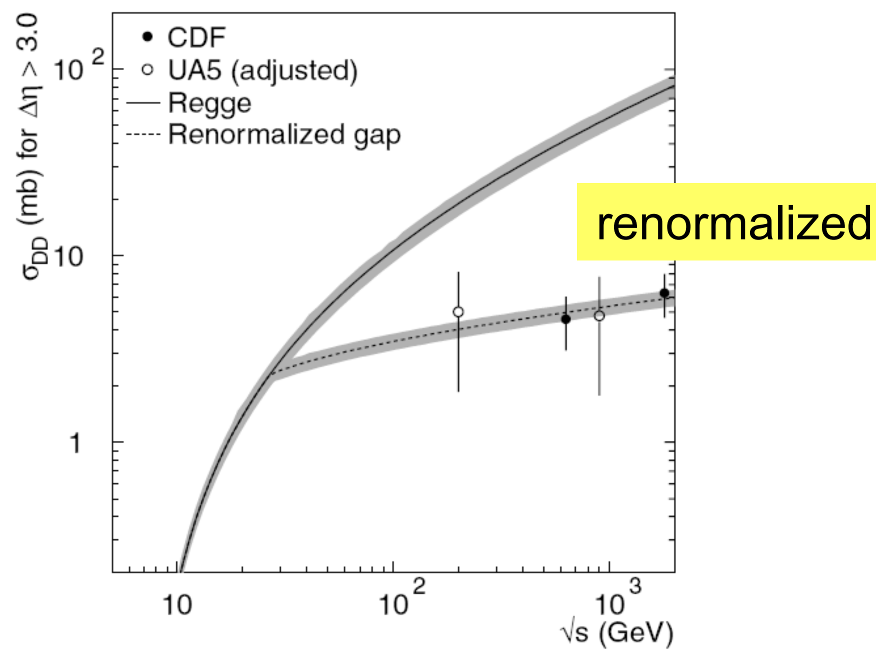


$$\frac{d^3\sigma_{DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{SD}}{dt\,dM_2^2} \Big/ \frac{d\sigma_{el}}{dt}$$
$$= \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi}\,\frac{s^{2\epsilon}e^{b_{DD}t}}{(M_1^2M_2^2)^{1+2\epsilon}}$$

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

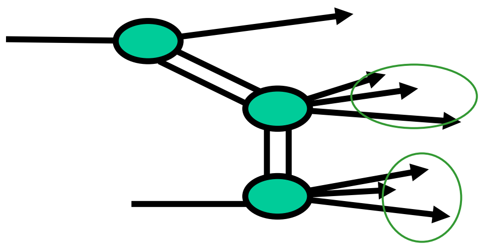
gap probability x-section

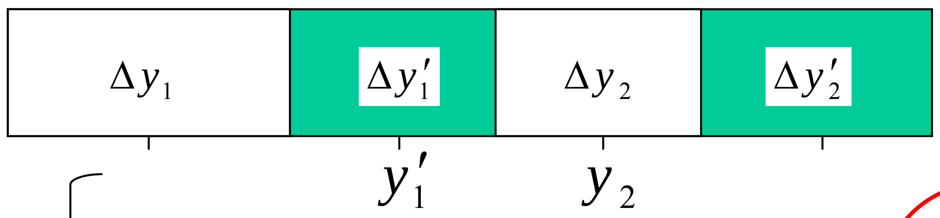




Multigap cross sections, e.g. SDD

KG, hep-ph/0203141





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

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

color factor: κ^2

Gap probability

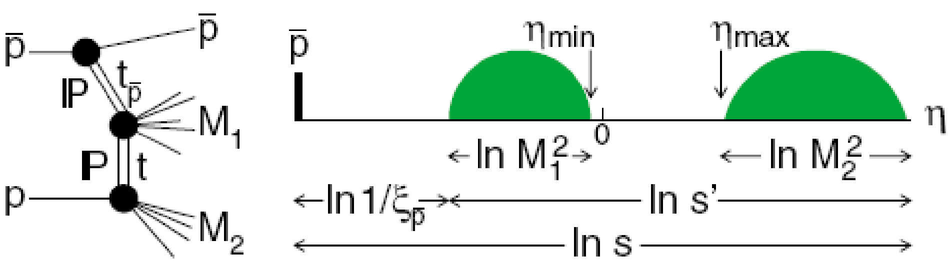
$$\int_{\Delta y,t} \sim s^{2\varepsilon} / \ln s$$

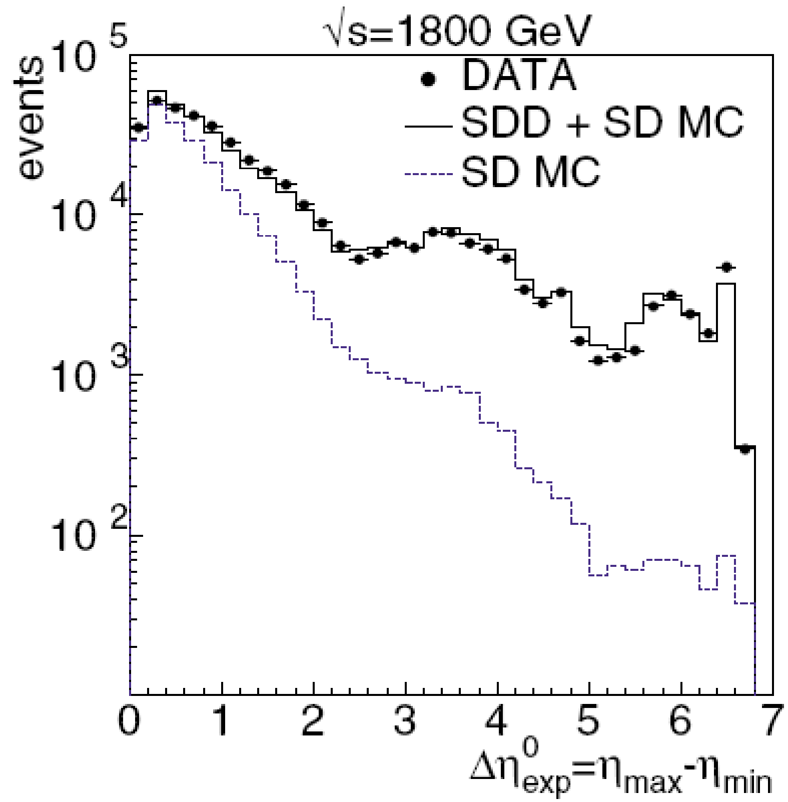
Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

SDD in CDF: data vs MBR MC

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





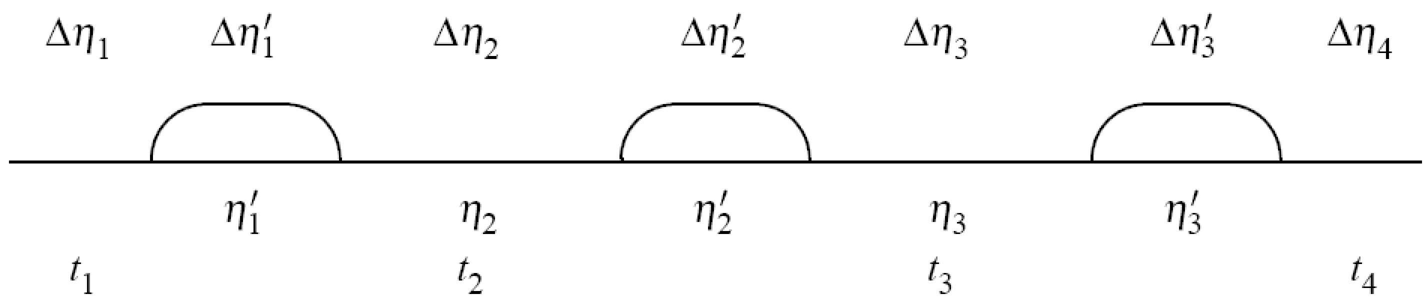
- Excellent agreement between data and NBR (MinBiasRockefeller) MC

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

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.

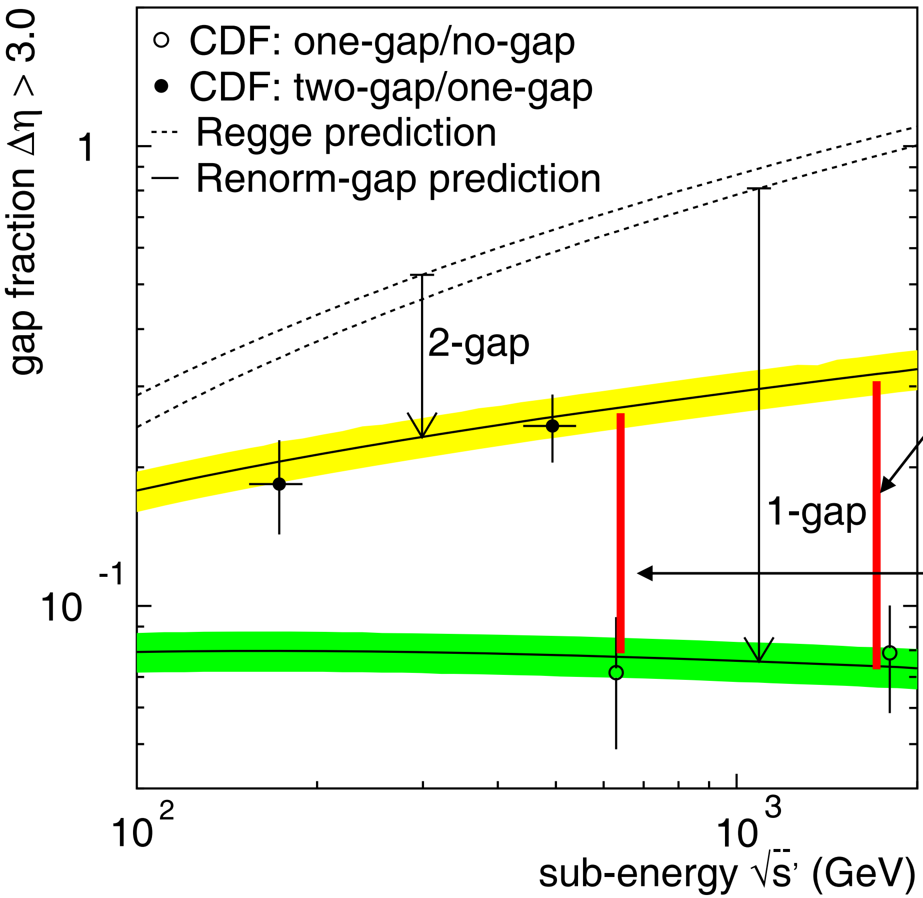
Multigap Diffraction at LHC

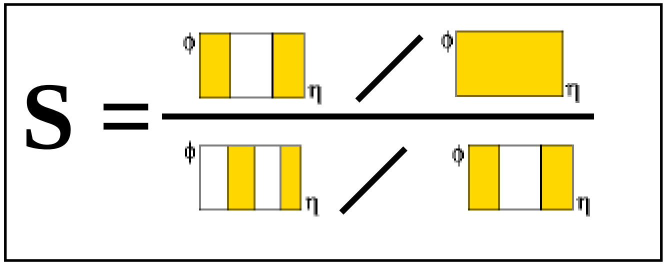


10 independent variables t_i, η_i, η'_i, and $\Delta\eta \equiv \Sigma_{i=1}^{4}\Delta\eta_i$

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

Gap survival probability





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

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

σ^{SD} and ratio of α'/ε

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

Pomeron intercept and slope: A QCD connection

Konstantin Goulianos

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

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

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

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

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

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

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

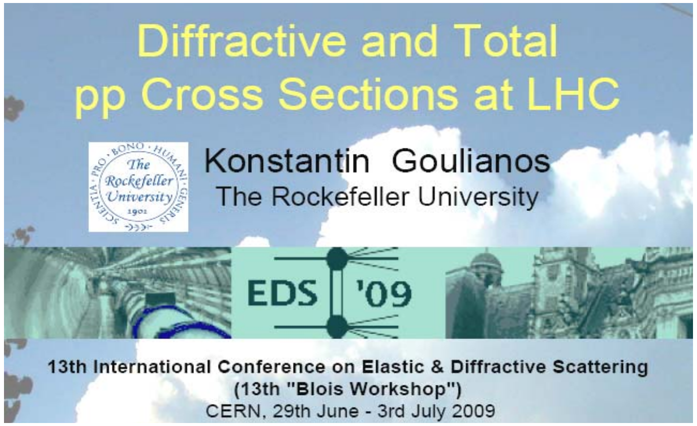
$$r = \frac{\alpha'}{\epsilon} = -[16m_\pi^2\ln(2\kappa)]^{-1}$$

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

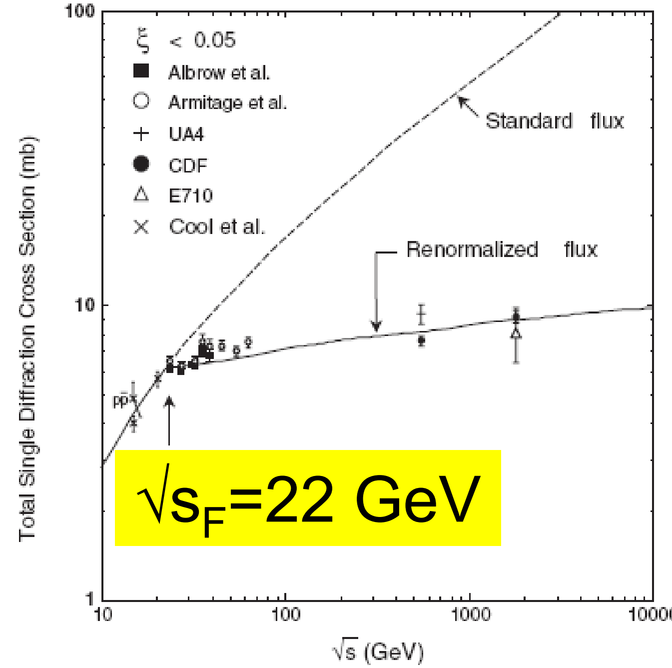
$$r_{\rm exp} = 0.25\ ({\rm GeV}/c)^{-2}/0.08 = 3.13\ ({\rm GeV}/c)^{-2}$$

Sec. 2

1) Introduction	gaps
2) Predicting the total σ	σ_t
3) Predicting the total-elastic σ	σ_{inel}
→ total-inelastic σ	$\sigma_{inel} = \sigma_t - \sigma_{el}$
4) Measuring the "visible"-inelastic σ	σ_{inel}^{vis}
5) Extrapolating to measured-inelastic σ	σ_{inel}^{meas}
6) A Monte Carlo algorithm for the LHC	nesting



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:

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

SUPERBALL MODEL

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

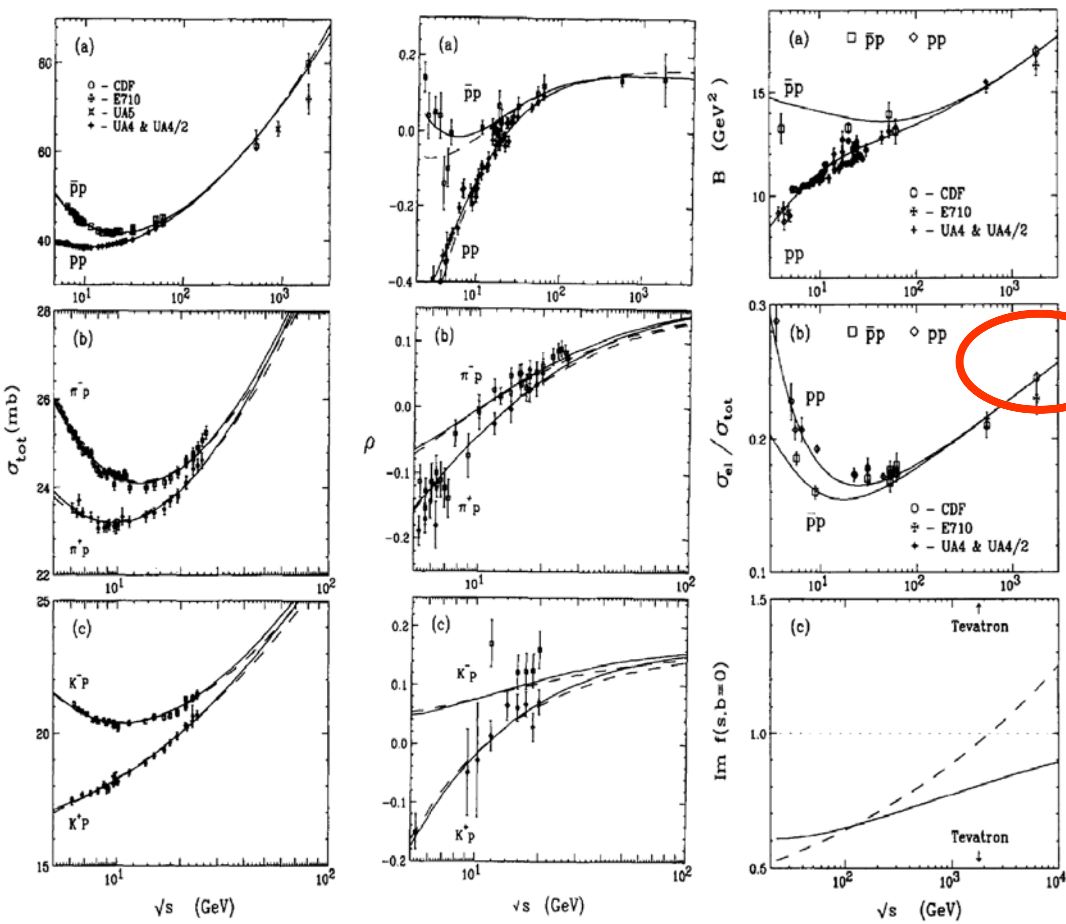
Sec. 3

1) Introduction	gaps
2) Predicting the total σ	σ_t
3) Predicting the total-elastic σ	σ_{inel}
→ total-inelastic σ	$\sigma_{inel} = \sigma_t - \sigma_{el}$
4) Measuring the "visible"-inelastic σ	σ_{inel}^{vis}
5) Extrapolating to measured-inelastic σ	σ_{inel}^{meas}
6) A Monte Carlo algorithm for the LHC	nesting

Global fit to p±p, π±, K±p x-sections

PLB 389, 176 (1996) **A new determination of the soft pomeron intercept**

R.J.M. Covolan[1], J. Montanha[2], K. Goulianos[3]



Regge theory eikonalized

❑ INPUT

$$\alpha_{f/a} = 0.68 + 0.82\,t$$

$$\alpha_{\omega/\rho} = 0.46 + 0.92\,t$$

$$\alpha'_{\mathbb{P}} = 0.25\ \mathrm{GeV}^{-2}$$

el/tot slowly rising

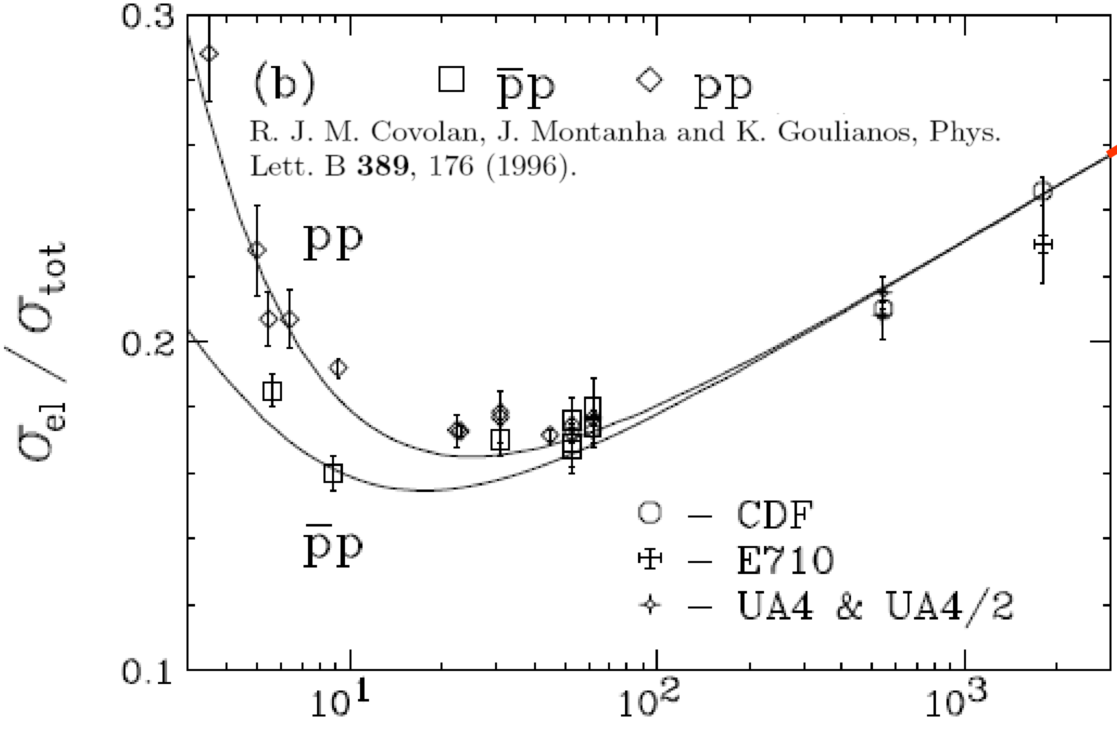
❑ RESULTS

$$\alpha_{0,\mathbb{P}}^{\mathrm{Born}} = 1.104 \pm 0.002\,, \quad \alpha_{0,\mathbb{P}}^{\mathrm{Eik}} = 1.122 \pm 0.002$$

$$\sigma_{\mathrm{tot}}^{p^{\pm}p} = 16.79\, s^{0.104} + 60.81\, s^{-0.32} \mp 31.68\, s^{-0.54}$$

negligible

The total-inelastic cross section

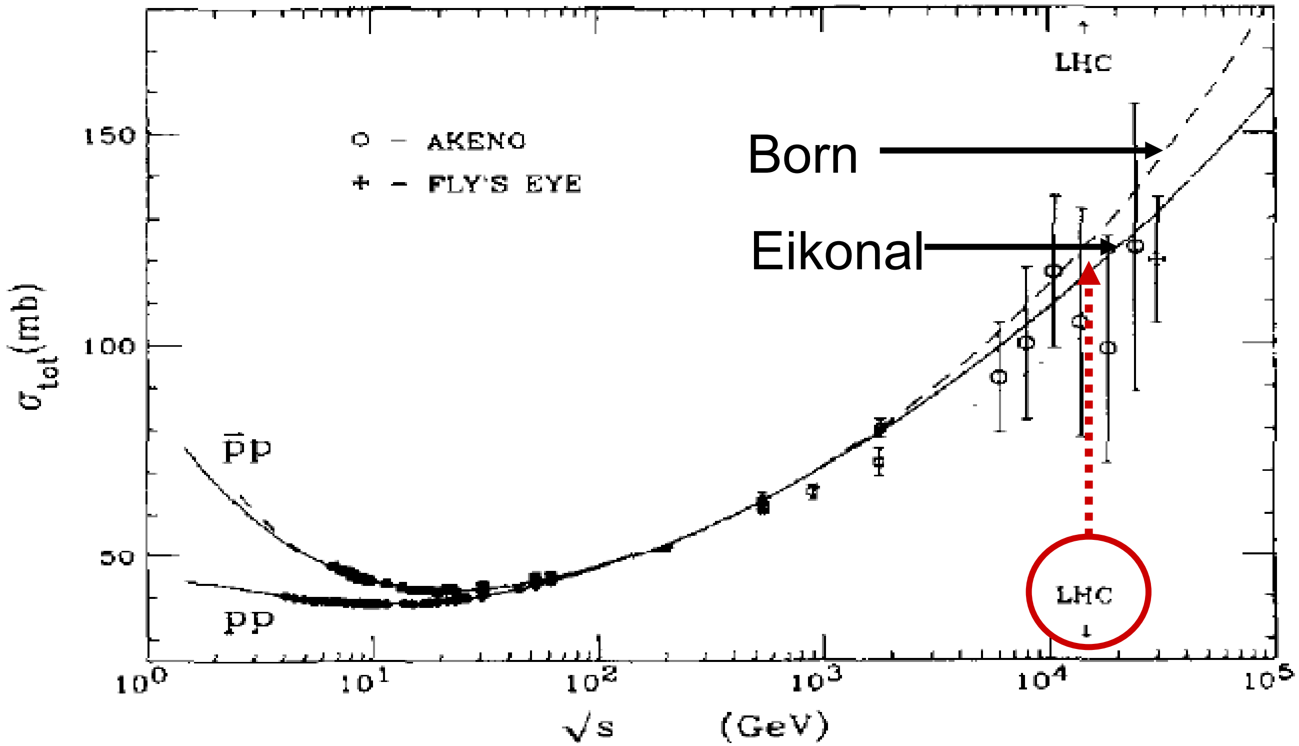


Small extrapolation to 7 TeV

$$\sigma_{el}=(\sigma_{el}/\sigma_t)\bullet\sigma_t$$

$\sqrt{s}$	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

σ_t at LHC from CMG global fit



- σ @ LHC $\sqrt{s}$=14 TeV: 122 ± 5 mb Born, **<u>114 ± 5 mb</u>** <u>eikonal</u>
  ➔ error estimated from the error in ε given in CMG-96

Compare with **SUPERBALL** σ(14 TeV) = **109 ± 6 mb**

caveat: s_o=1 GeV^2 was used in global fit!

Secs. 4 & 5

1) Introduction	gaps
2) Predicting the total σ	σ_t
3) Predicting the total-elastic σ	σ_{inel}
➔ total-inelastic σ	$\sigma_{inel} = \sigma_t - \sigma_{el}$
4) Measuring the "visible"-inelastic σ	σ_{inel}^{vis}
5) Extrapolating to measured-inelastic σ	σ_{inel}^{meas}
6) A Monte Carlo algorithm for the LHC	nesting

Visible/total inelastic cross sections

ATLAS

Pre-Moriond 2011

ATLAS-CONF-2011-002 Feb. 6 2011

$$\sigma_{inel}(\xi > 10^{-5} = 57.2 \pm 0.1(stat) \pm 0.4(syst) \pm 6.3(Lumi)\ \mathrm{mb}$$

➔ $\sigma_{inel} = 63.3 \pm 7.0\ \mathrm{mb}\ \ (60.1 \pm 6.6\ \mathrm{mb})$

with pythia (phojet) extrapolation

Post-Moriond 2011

arXiv:1104.023v1

$$\sigma_{inel}(\xi > 10^{-6} = 60.33 \pm 2.10(exp.) \pm 0.4\ \mathrm{mb}$$

$$\sigma_{inel}(\xi > m_p^2/s) = 69.4 \pm 2.4(exp.) \pm 6.9(extr.)\ \mathrm{mb}$$

CMS (DIS-2011), also post-Moriond 2011

visible σ_{vtx}^{inel}=59.9±0.1(stat)±1.1(syst)±2.4(Lumi)

$66.8 \leq \sigma_t^{inel} \leq 74.8\ \mathrm{mb}$ (range due to uncertainty in MC extrapolation)

Prediction: σ_{tinel}=71±6 mb

Sec. 6

1) Introduction	gaps
2) Predicting the total σ	σ_t
3) Predicting the total-elastic σ	σ_{inel}
➔ total-inelastic σ	$\sigma_{inel} = \sigma_t - \sigma_{el}$
4) Measuring the "visible"-inelastic σ	σ_{inel}^{vis}
5) Extrapolating to measured-inelastic σ	σ_{inel}^{meas}
6) A Monte Carlo algorithm for the LHC	nesting

Diffraction in PYTHIA - (1 of/3)

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

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

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

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

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

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 of/3

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

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

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

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

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

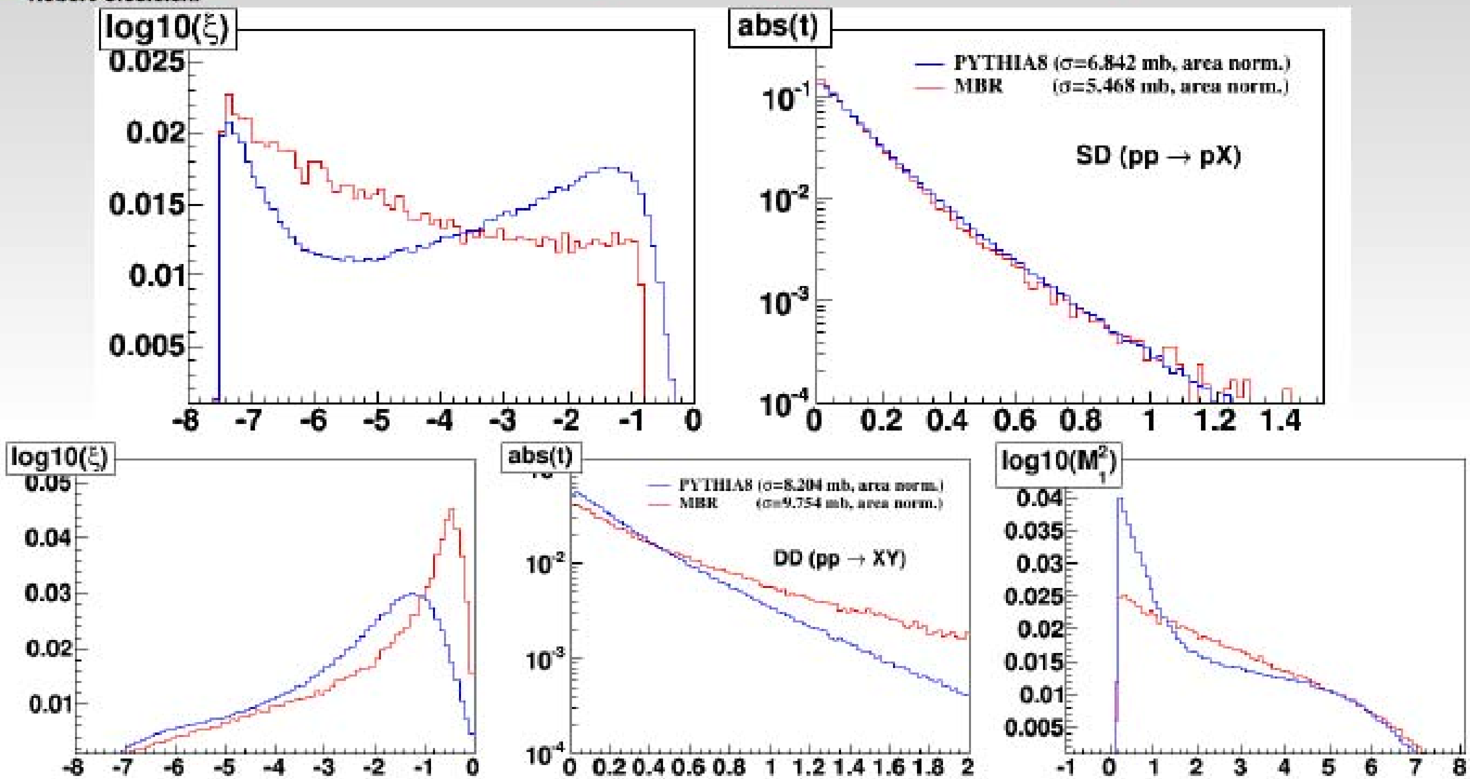
$$F_{\mathrm{sd}} = \left(1 - \frac{M^2}{s}\right)\left(1 + \frac{c_{\mathrm{res}} M_{\mathrm{res}}^2}{M_{\mathrm{res}}^2 + M^2}\right) ,$$

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

Diffraction in PYTHIA – (3 of/3)

Robert Ciesielski

MBR vs. Pythia8 (generator level)



We generate SD events up to $\xi = m_\pi / m_p \simeq 0.15$ (coherence limit)

29 Apr 2011 DD events up to $\xi = 1$. 3

Pythia6 D6T and Pythia8: the same cross sections on generator level

Monte Carlo Strategy for the LHC

MONTE CARLO STRATEGY

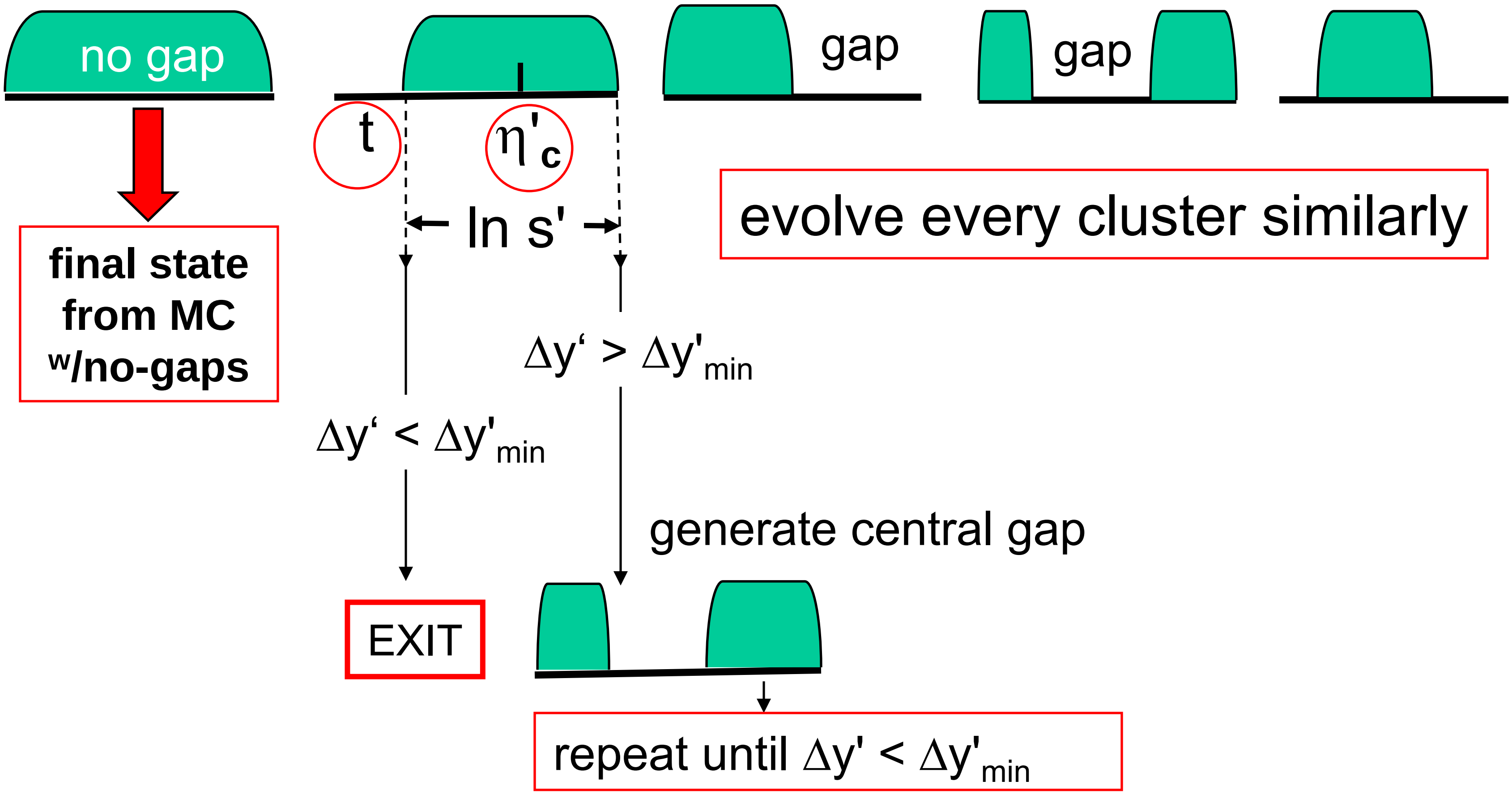
- ❑ σ^T → from SUPERBALL model
- ❑ optical theorem → Im $f_{el}(t=0)$
- ❑ dispersion relations → Re $f_{el}(t=0)$
- ❑ σ^{el}
- ❑ σ^{inel}
- ❑ differential σ^{SD} → from RENORM
- ❑ use *nesting* of final states (FSs) for *pp* collisions at the *IP-p* sub-energy √s'

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

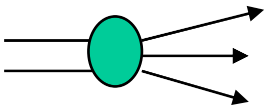
  } **derived from ND and QCD color factors**

  - ➢ 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 – "nesting"

BACKUP

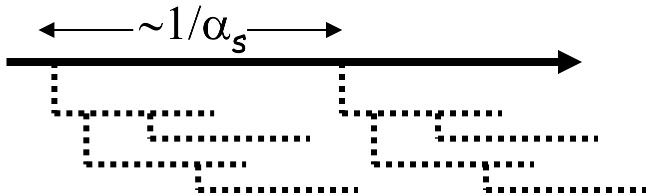
BACKUP

RISING X-SECTIONS IN PARTON MODEL



ϕ $\longleftarrow \Delta y' = \ln s \longrightarrow$ y

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



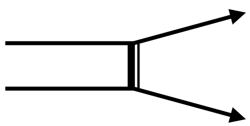
Emission spacing controlled by α-strong

➔ 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 $1/\alpha_s$ and thereby is related to ε



ϕ $\longleftarrow \Delta y = \ln s \longrightarrow$ y

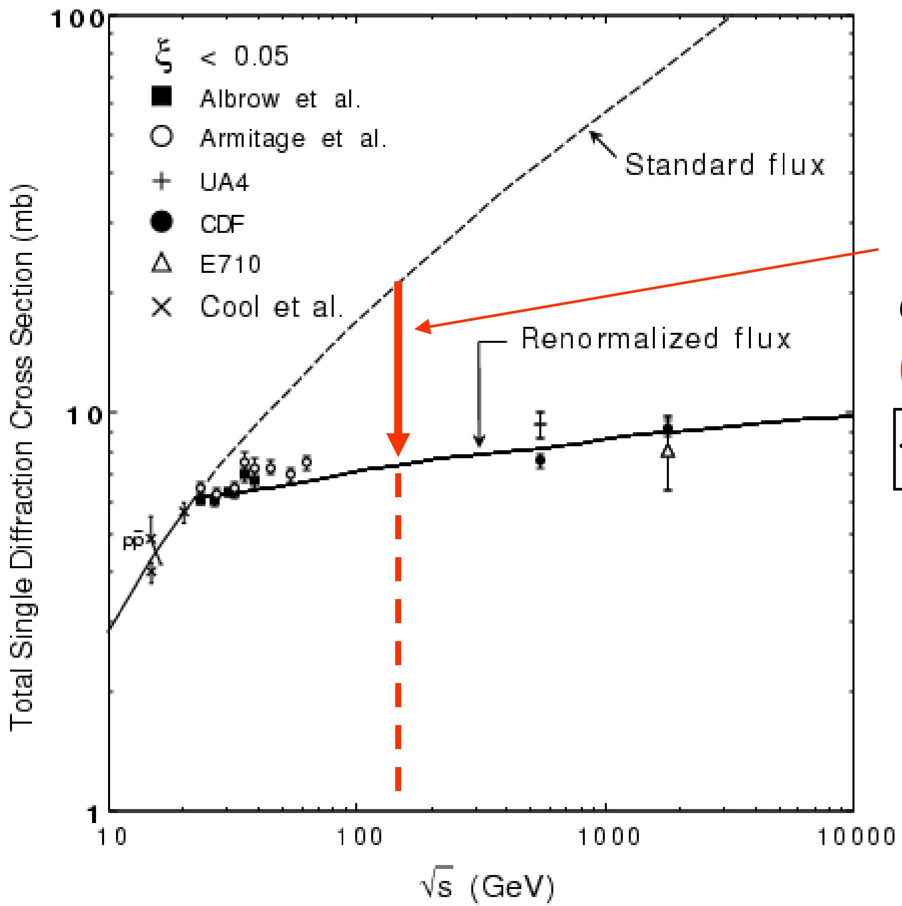
$$\mathrm{Im}\ f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

← assume linear t-dependence

Forward elastic scattering amplitude

Dijets in γp at HERA from RENORM

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

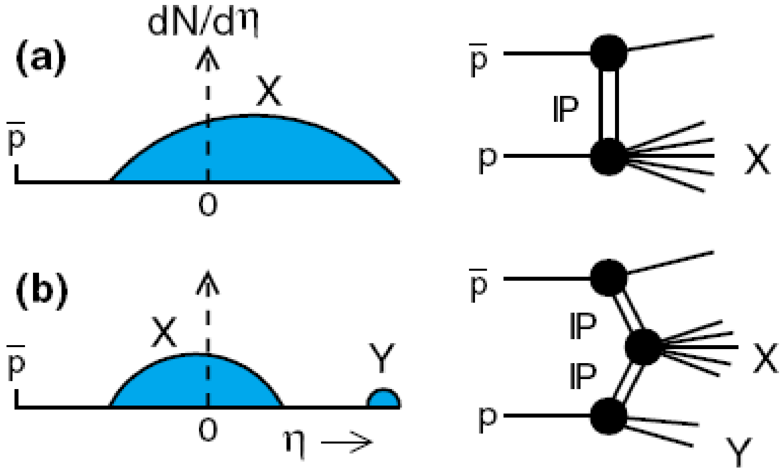


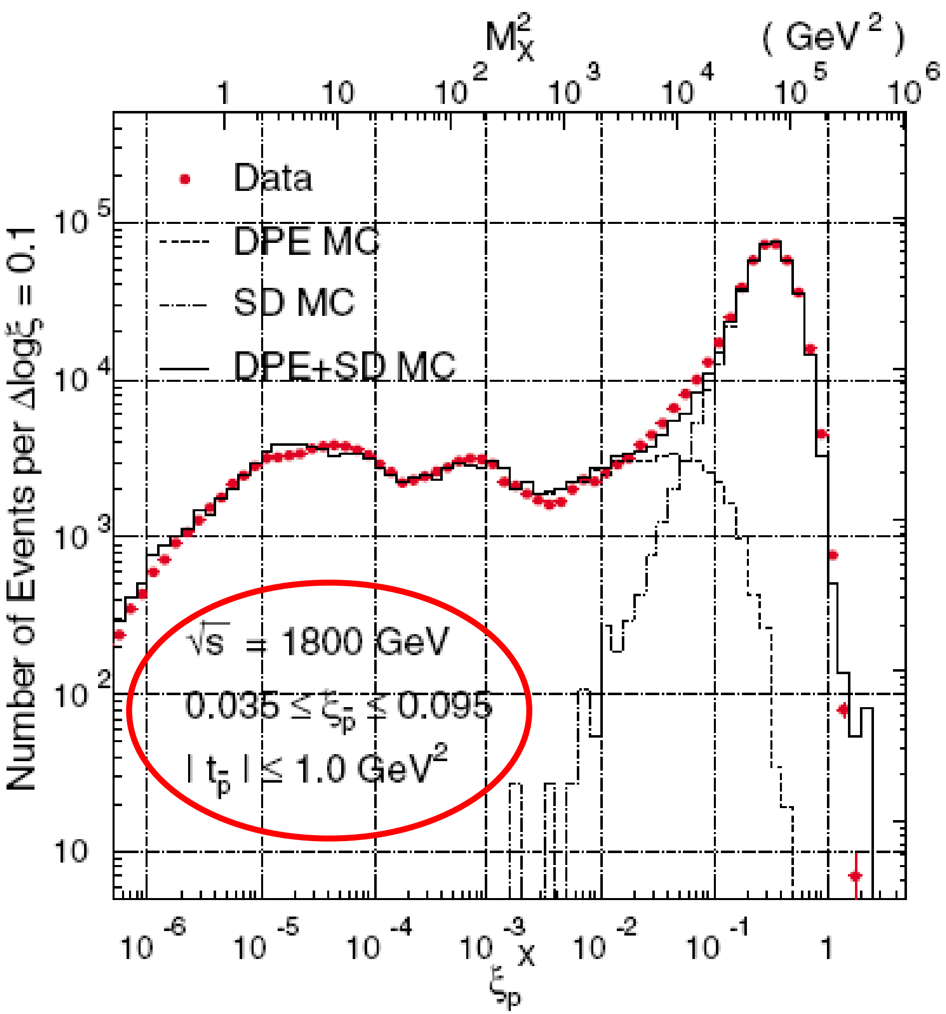
Factor of ~3 suppression expected at W~200 GeV (just as in pp collisions)

for both direct and resolved components

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

The end

the end