Dip-bump structure in pp single diffraction

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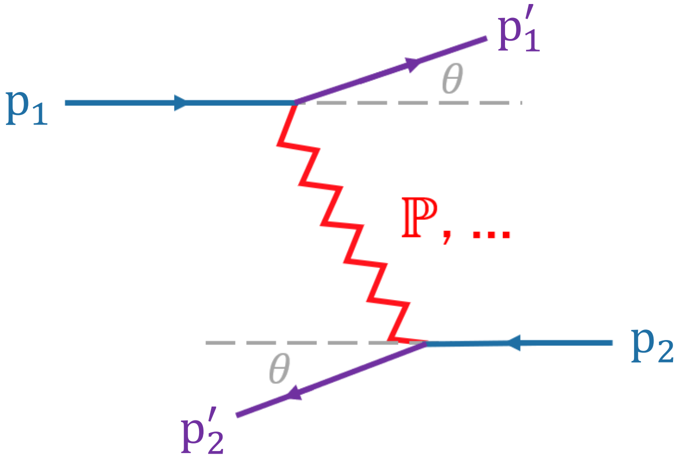
MATE

Elastic pp scattering and single diffractive dissociation

in pp elastic scattering and single diffraction (diffractive dissociation) the dominant exchange is the **pomeron exchange** and the final states are characterized by **large rapidity gaps**

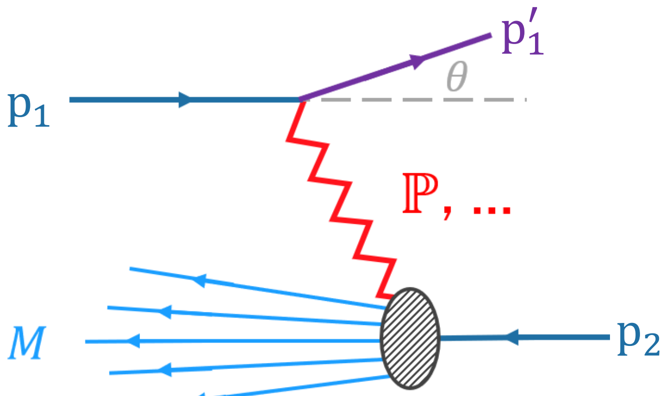


elastic scattering: both protons remain intact, only their direction of motion changes

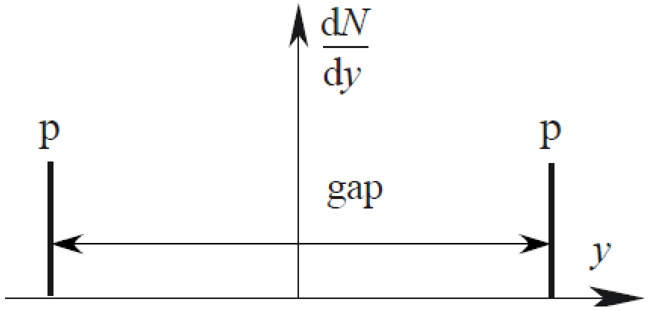
$$s = (p_1 + p_2)^2$$

$$t = (p_1 - p'_1)^2$$

$$\xi = M^2/s$$



single diffraction: one of the protons remain intact but the other dissociates producing a hadronic system of mass M



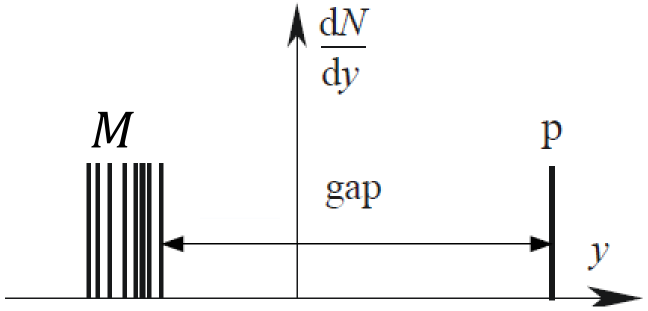
Schematic rapidity distribution of outgoing particles in pp elastic scattering

$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z} ,$$

when $M \ll |\vec{p}| \to E \approx |\vec{p}|$

and $y \simeq \eta$,

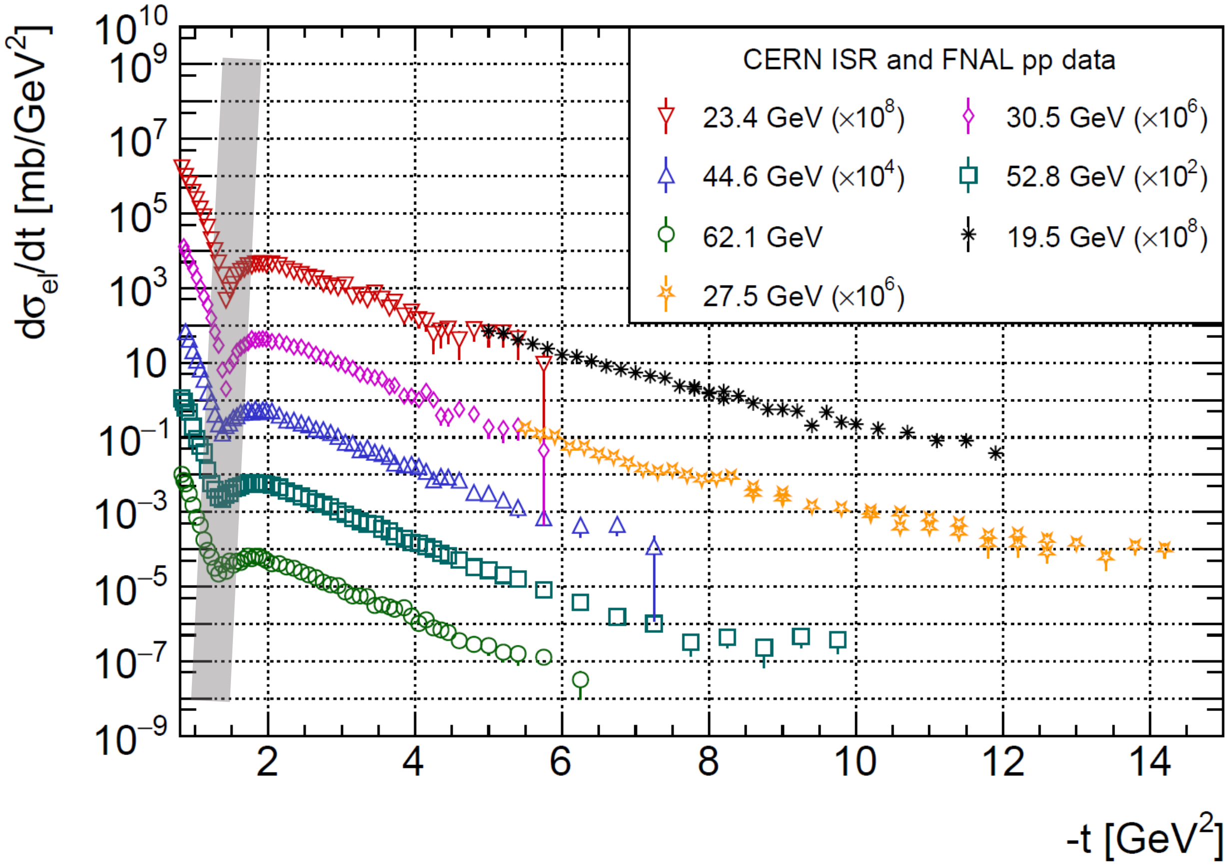
$$\eta = -\ln \tan(\theta/2)$$



Schematic rapidity distribution of outgoing particles in pp single diffraction

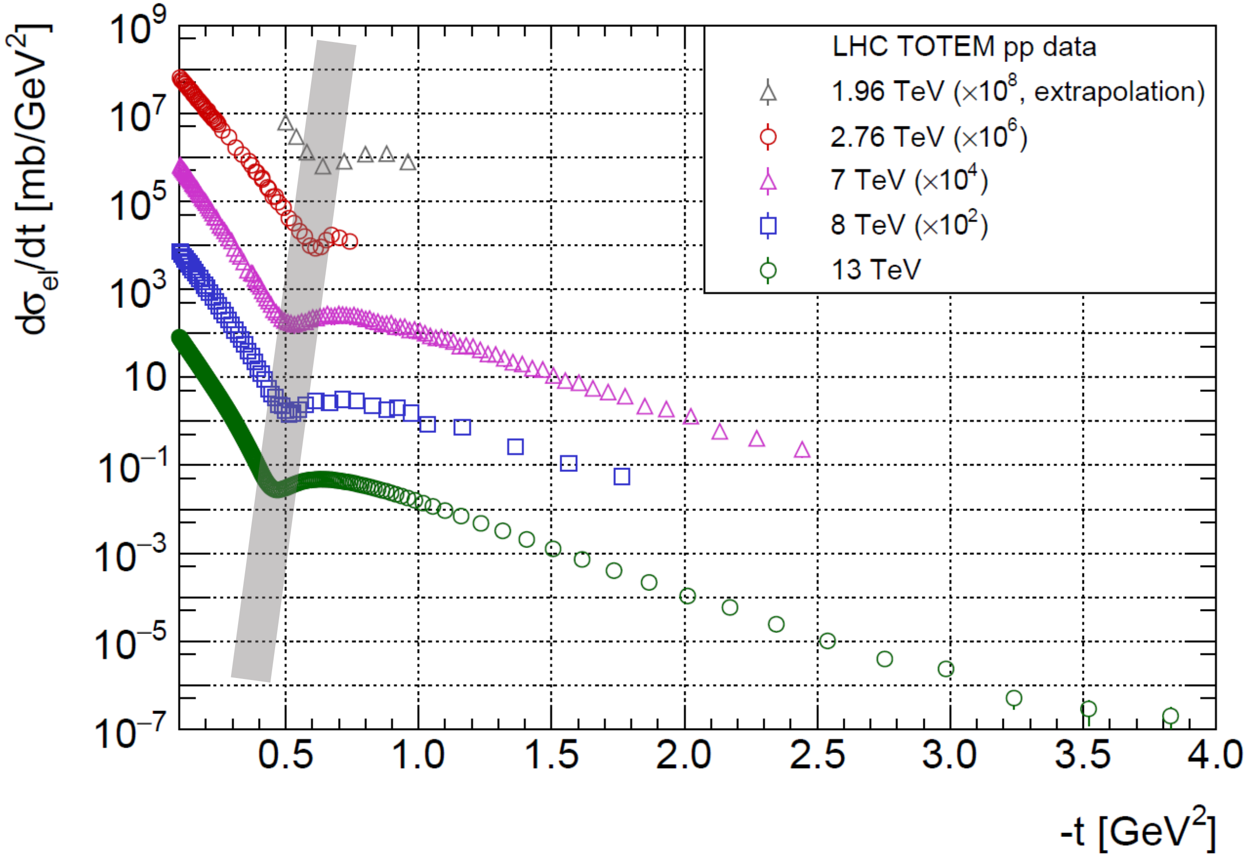
Dip-bump structure in elastic pp $d\sigma_{el}/dt$

E. Nagy et al., Nucl. Phys. B 150, 221 (1979)
W. Faissler et al., Phys. Rev. D 23, 33 (1981)



the position of the dip and the bump moves to lower $-t$ values as the CM energy increases

TOTEM Collab., EPL 95:4, 41001 (2011)
TOTEM Collab., Eur. Phys. J. C 79:10, 861 (2019)
TOTEM Collab., Eur. Phys. J. C 80:2, 91 (2020)
TOTEM Collab., Eur. Phys. J. C 82:3, 263 (2022)
TOTEM & D0 Collabs., Phys. Rev. Lett. 127:6, 062003



no secondary dip-bump structures are observed in the $-t$ range measured up to now

Dipole Regge model

L. L. Jenkovszky and A. N. Wall, Czech. J. Phys. B26, 447 (1976)
L. L. Jenkovszky, Fortsch. Phys.34, 791 (1986)

- **basic assumptions**:
  - the relativistic partial wave amplitude can be analytically continued to complex *j* angular momentum values
  - the high energy behaviour of the amplitude is determined by an isolated *j*-plane pole of the second order (dipole)
  - the residue at the pole is independent of t, t-dependence enters only through the Regge trajectory

- **the dipole pomeron scattering amplitude is obtained as a derivative of a simple pole pomeron scattering amplitude**

$$\mathrm{A}^{\mathrm{DP}}(s,\alpha) = \frac{\mathrm{d}}{\mathrm{d}\alpha}\mathrm{A}^{\mathrm{SP}}(s,\alpha)$$

$$= e^{-\frac{i\pi\alpha}{2}}\left(\frac{s}{s_0}\right)^{\alpha}\left[G'(\alpha) + \left(L - \frac{i\pi}{2}\right)G(\alpha)\right]$$

  - $\mathrm{A}^{\mathrm{SP}}(s,\alpha) = e^{-\frac{i\pi\alpha}{2}}G(\alpha)\left(\frac{s}{s_0}\right)^{\alpha}$ is the simple pole scattering amplitude
  - $G(\alpha)$ is some function of α
  - $\alpha = \alpha(t)$ is the Regge trajectory
  - $L = \ln(s/s_0)$

Dipole Pomeron model

L. L. Jenkovszky and A. N. Wall, Czech. J. Phys. B26, 447 (1976)
L. L. Jenkovszky, Fortsch. Phys.34, 791 (1986)

$$A^{DP}(s,\alpha) = e^{-\frac{i\pi\alpha}{2}}\left(\frac{s}{s_0}\right)^{\alpha}\left[G'(\alpha) + \left(L - \frac{i\pi}{2}\right)G(\alpha)\right]$$

- the Regge trajectory is approximated by a real and linear function

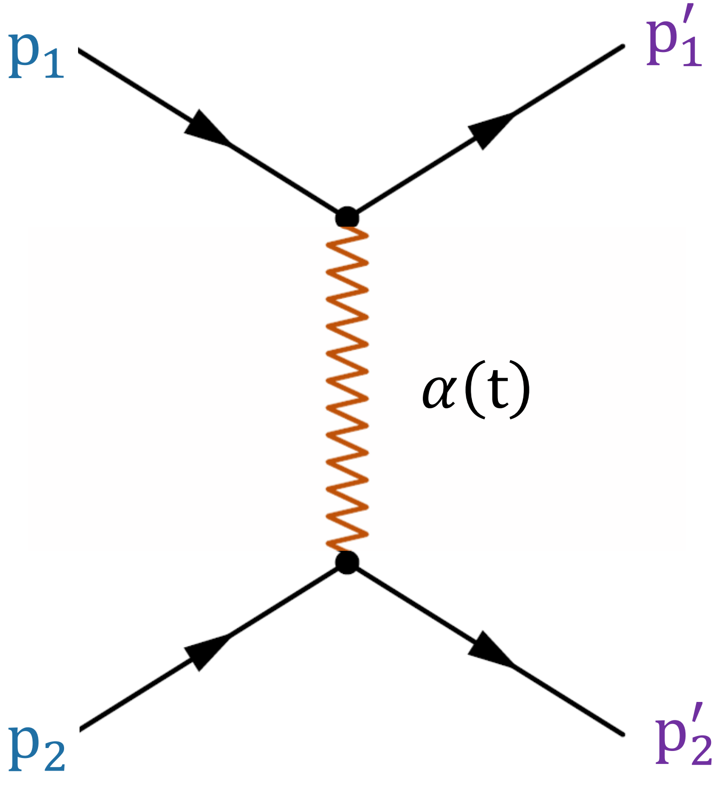
$$\alpha \equiv \alpha(t) = 1 + \delta + \alpha' t$$

- motivated by the shape of the $d\sigma_{el}/dt$ (exponential decrease), the paramterization of $G'(\alpha)$ is

$$G'(\alpha) = a e^{b[\alpha - \alpha_0]}$$ with $\alpha_0 \equiv \alpha(t=0)$

- $G(\alpha)$ is obtained by integrating $G'(\alpha)$:

$$G(\alpha) = \int G'(\alpha) d\alpha = a\left(e^{b[\alpha-\alpha_0]}/b - \gamma\right)$$



Exchange of a trajectory interpreted as a virtual particle with running mass squared t and spin $\alpha(t)$

Model for elastic pp and $\bar{p}p$ scattering amplitude

$$A(s,t)^{\bar{p}p}_{pp} = A_P^{DP}(s,t) \pm A_O^{DP}(s,t)$$

- the dipole pomeron amplitude is

$$A_P^{DP}(s,t) = e^{-\frac{i\pi\alpha_P(t)}{2}} \left(\frac{s}{s_{0P}}\right)^{\alpha_P(t)} \left[G'_P(t) + \left(L_P(s) - \frac{i\pi}{2}\right) G_P(t)\right]$$

$$\alpha_P(t) = 1 + \delta_P + \alpha'_P t$$

$$G_P(t) = a_P\left(e^{b_P[\alpha_P(t)-\alpha_P(0)]}/b_P - \gamma_P\right)$$

$$G'_P(t) = a_P e^{b_P[\alpha_P(t)-\alpha_P(0)]}$$

$$L_P(s) = \ln(s/s_{0P})$$

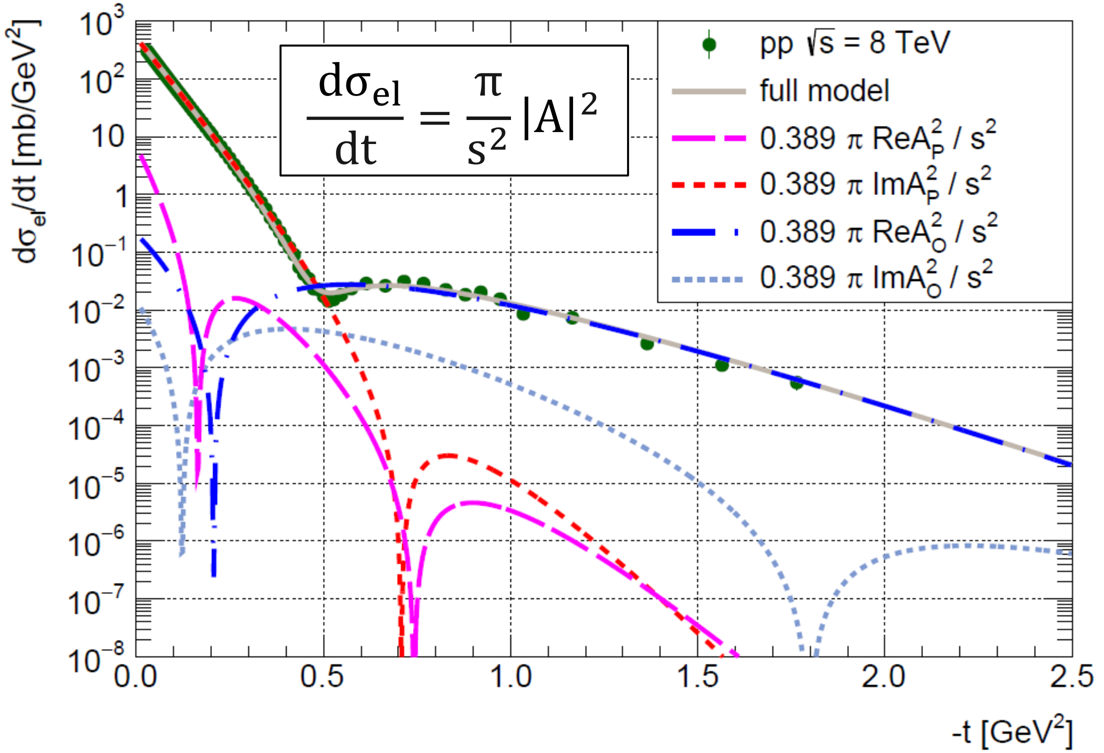
- the dipole odderon amplitude is

$$A_O^{DP}(s,t) = -iA^{DP}_{P\to O}(s,t)$$

(with free parameters labeled by "O")

the odderon contribution is small at low-|t| but dominates completely after the bump

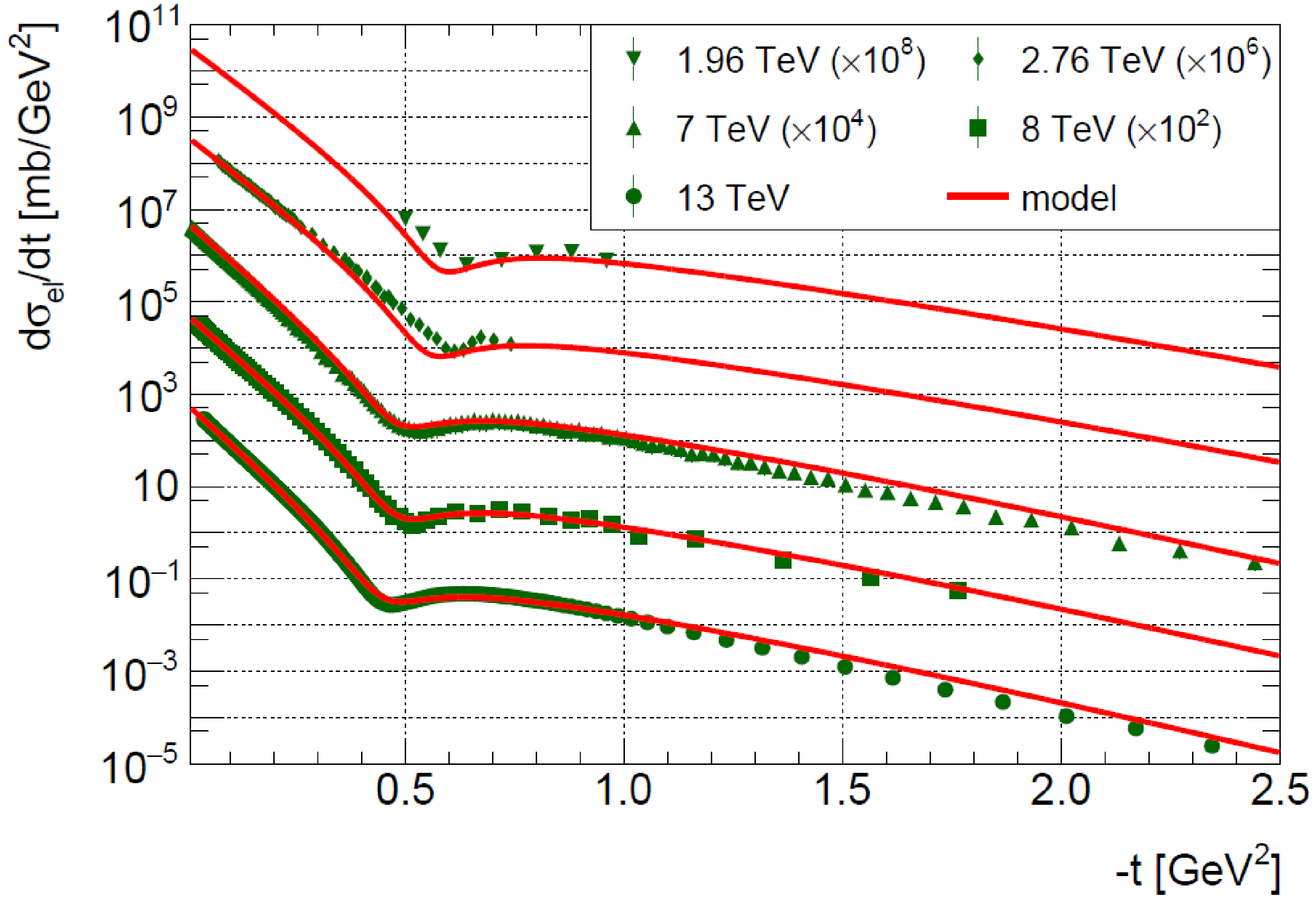
the inclusion of the dipole odderon is important to describe the data around the dip-bump and at higher |t| values



Pomeron and odderon contributions to proton-proton differential cross section

SPS + TEVATRON + LHC $d\sigma_{el}/dt$ data and the model

qualitative description to the data in a wide kinematic (s, t) range



Result of the fit to the proton-proton differential cross section data

Pomeron	Odderon
$\delta_P = 0.02865$	$\delta_O = 0.2042$
$\alpha'_P = 0.4284$	$\alpha'_O = 0.1494$
$a_P = 45.63$	$a_O = 0.01934$
$b_P = 4.873$	$b_O = 2.160$
$\gamma_P = 0.06085$	$\gamma_O = 0.4866$
$s_{0P} = 11.26$	$s_{0O} = 1.03$

Parameters resulting from a fit to the proton-proton and proton-antiproton differential cross section, total cross section, and real to imaginary part of the forward scattering amplitude data in the kinematic range $0.5\ \text{TeV} \leq \sqrt{s} \leq 13\ \text{TeV}$ & $0.01\ \text{GeV}^2 \leq -t \leq 2.5\ \text{GeV}^2$

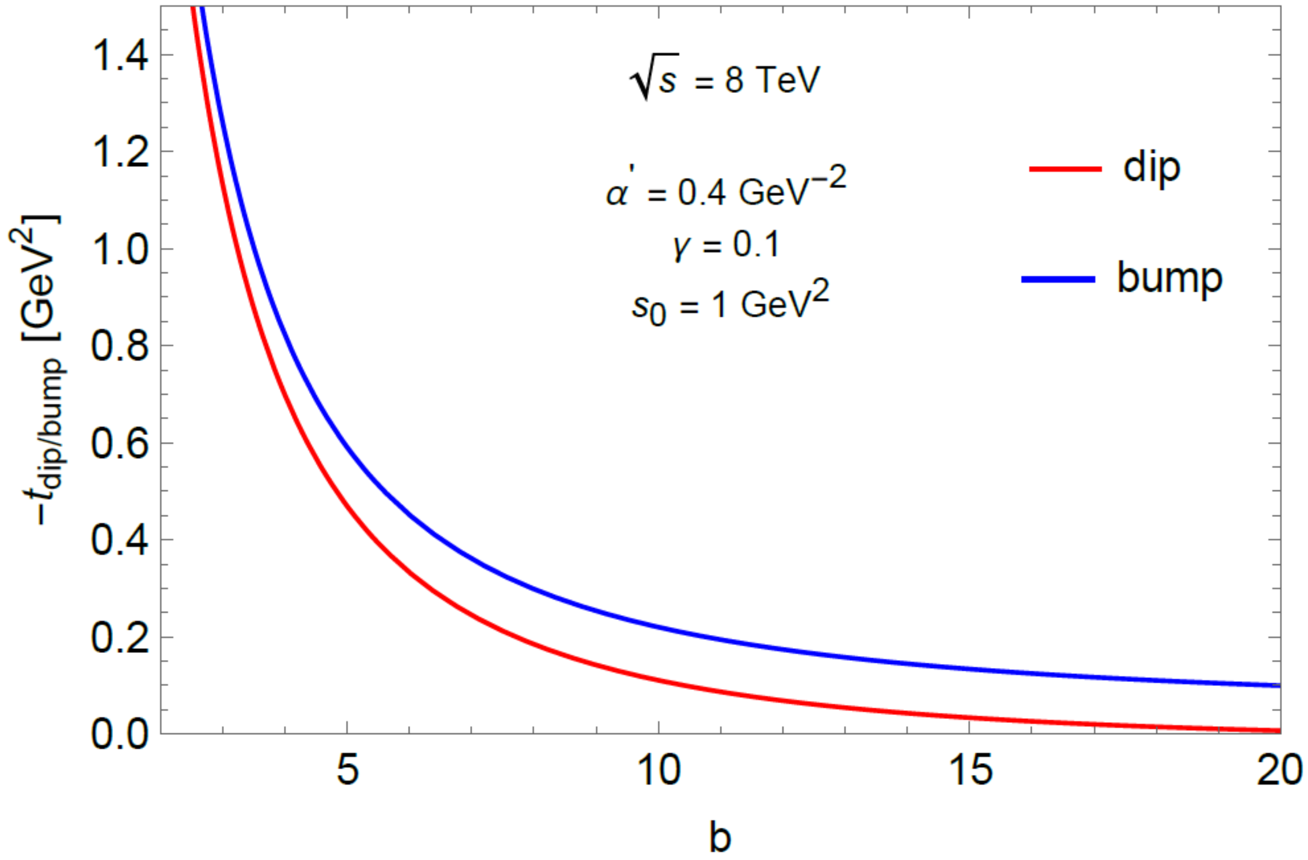
Dip and bump position in the dipole model

in the dipole Regge model the position of the dip and the bump of $d\sigma_{el}/dt$ depends on the slope parmeter b

$$-t_{dip} = \frac{1}{\alpha' b} \ln \frac{b+L}{\gamma b L}$$

$$-t_{bump} = \frac{1}{\alpha' b} \ln \frac{4(b+L)^2 + \pi^2}{\gamma b (4L^2 + \pi^2)}$$

the position of the dip and of the bump goes to smaller –t values as slope parameter rises



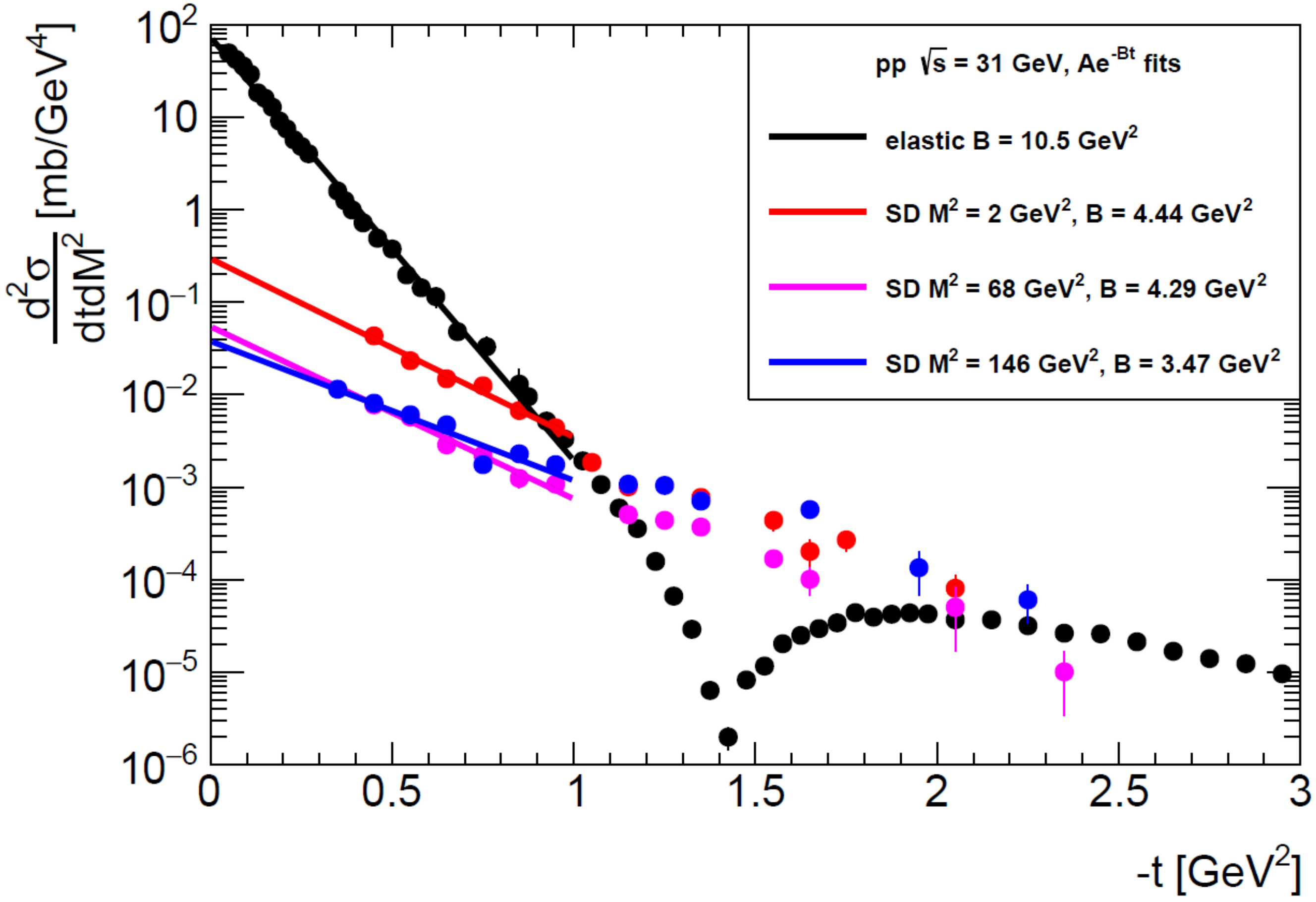
Position of the dip and bump of the pp differential cross section in the dipole model as a function of the slope parameter

Dip-bump structures in single diffractive dissociation?

- measurements of pp single diffractive dissociation at ISR do not show a dip-bump structure at |t| values where such a structure is observed in elastic pp scattering

  M.G. Albrow et al., Nucl. Phys. B72, 376 (1974)

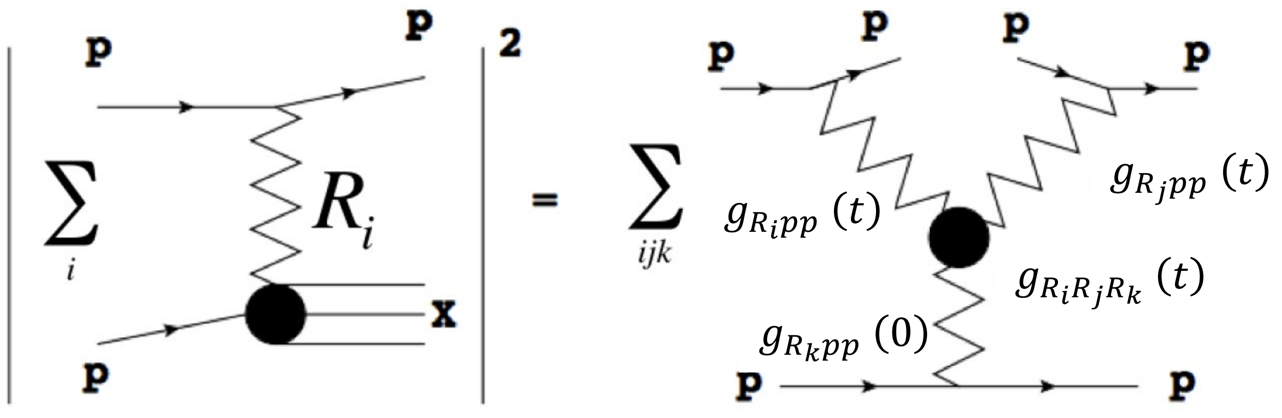
- it can be explained in a framework of a dipole Regge model in which the dip-bump structure moves to higher |t| values as the value of the slope parameter decreases
- **a dipole odderon+pomeron Regge approach can be used to predict dip-bump structures in pp single diffractive dissociation at LHC energies**



pp elastic and single diffractive dissociation differential cross section data at $\sqrt{s}$ = 31 GeV as a function of $-t$

Regge approach for single diffraction (SD)

when $s \gg M^2 \gg t$, the differential cross section is given by a sum of triple-Reggeon contributions



$R_i, R_j, R_k \in \{P, O, f_2, \omega, \rho, a_2\}$ but with respecting conservation laws

$$\frac{d^2\sigma_{SD}}{dt dM^2} = \sum_{ijk} \frac{d^2\sigma^{ijk}{}_{SD}}{dt dM^2}$$

P. D. B. Collins, Cambridge University Press (1977)

K. A. Goulianos et al., *Phys. Rev. D* **59**, 114017 (1999)

$$\frac{d^2\sigma^{ijk}{}_{SD}}{dt dM^2} = \frac{1}{16\pi^2}\frac{s_0}{s^2} g_{R_i pp}\ (t) g_{R_j pp}\ (t) \left(\frac{s}{M^2}\right)^{\alpha_i(t)+\alpha_j(t)} g_{R_i R_j R_k}\ (t) g_{R_k pp}\ (0) \left(\frac{M^2}{s_0}\right)^{\alpha_{R_k}(0)} \cos\left(\frac{\pi}{2}\left(\alpha_i(t) - \alpha_j(t)\right)\right)$$

Dipole Regge approach for single diffraction (SD)

- in the triple Regge approach the triple pomeron vertex results the following contribution for the double differential SD cross section:

$$\frac{d^2\sigma_{SD}^{PPP}}{dtdM^2} = \frac{1}{16\pi^2}\frac{1}{M^2} g_{Ppp}^2(t)\left(\frac{s}{M^2}\right)^{2\alpha_P(t)-2} g_{PPP}(t) g_{Ppp}(0)(M^2)^{\alpha_{0P}-1}$$

- g_{PPP} is found to be t-independent
- **assumption: the t-dependent part of the amplitude of the SD process has the form in case the pomeron a simple pole:**

$$A_{SD}^{SP}(s, M^2, \alpha(t)) \sim \mathrm{e}^{-\frac{\mathrm{i}\pi\alpha}{2}} G(\alpha)(s/M^2)^{\alpha}$$

- $G(\alpha)$ incorporates the t-dependece coming from $\mathrm{g}_{\mathrm{Ppp}}(t)$
- a dipole pomeron amplitude is obtained as:

$$A_{SD}^{DP}(s, M^2, \alpha) = \frac{d}{d\alpha} A_{SD}^{SP}(s, M^2, \alpha) \sim e^{-\frac{i\pi\alpha}{2}}\left(\frac{s}{M^2}\right)^{\alpha}\left[G'(\alpha) + \left(L_{SD} - \frac{i\pi}{2}\right) G(\alpha)\right]$$

$$L_{SD} \equiv \ln(s/M^2)$$

Dipole Regge approach for single diffraction (SD)

- the double differential cross section for the SD process resulting from the dipole pomeron PPP amplitude is:

$$\frac{d^2\sigma_{SD}^{PPP}}{dtdM^2} = \frac{1}{M^2}\left(G_P'^2(\alpha_P) + 2L_{SD}G_P(\alpha_P)G_P'(\alpha_P) + G_P^2(\alpha_P)\left(L_{SD}^2 + \frac{\pi^2}{4}\right)\right)\left(\frac{s}{M^2}\right)^{2\alpha_P(t)-2}\sigma^{Pp}(M^2)$$

$$G_P'(\alpha_P) = a_P e^{b_P[\alpha_P - 1 - \delta_P]}$$

$$\alpha_P = 1 + \delta_P + \alpha_P' t$$

$$L_{SD} \equiv \ln(s/M^2)$$

$$G_P(\alpha_P) = \int G'(\alpha_P)d\alpha_P = a_P\left(\frac{e^{b_P[\alpha_P - 1 - \delta_P]}}{b_P} - \gamma_P\right)$$

$$\sigma^{Pp}(M^2) = g_{PPP}g_{Ppp}(0)(M^2)^{\delta_P}$$

- the dipole odderon contribution is considered in the form of an odderon-odderon-pomeron OOP vertex and written as:

$$\frac{d^2\sigma_{SD}^{OOP}}{dtdM^2} = \frac{1}{M^2}\left(G_O'^2(\alpha_O) + 2L_{SD}G_O(\alpha_O)G'(\alpha_O) + G_O^2(\alpha_O)\left(L_{SD}^2 + \frac{\pi^2}{4}\right)\right)(s/M^2)^{2\alpha_O(t)-2}\sigma^{Pp}(M^2)$$

RRP and pion contribution in SD

- RRP contribution:

$$\frac{d^2\sigma_{SD}^{RRP}}{dt dM^2} = \frac{1}{M^2} a_R^2 e^{2b_R \alpha_R(t)} (s/M^2)^{2\alpha_R(t)-2} \sigma^{Pp}(M^2)$$

$$\alpha_R(t) = 1 + \delta_R + \alpha_R' \, t$$

- the pion exchange contribution:

$$\frac{d^2\sigma_{SD}^{\pi}}{dt dM^2} = \frac{1}{M^2} \frac{1}{4\pi} \frac{g_{\pi pp}^2}{4\pi} \frac{|t|}{(t - m_\pi^2)^2} G_\pi(t) \left(\frac{s}{M^2}\right)^{2\alpha_\pi(t)-2} \sigma^{\pi p}(M^2)$$

$$\frac{g_{\pi pp}^2}{4\pi} = 13.3$$

$$G_\pi(t) = \frac{2.3 - m_\pi^2}{2.3 - t}$$

$$\alpha_\pi(t) = 0.93(t - m_\pi^2)$$

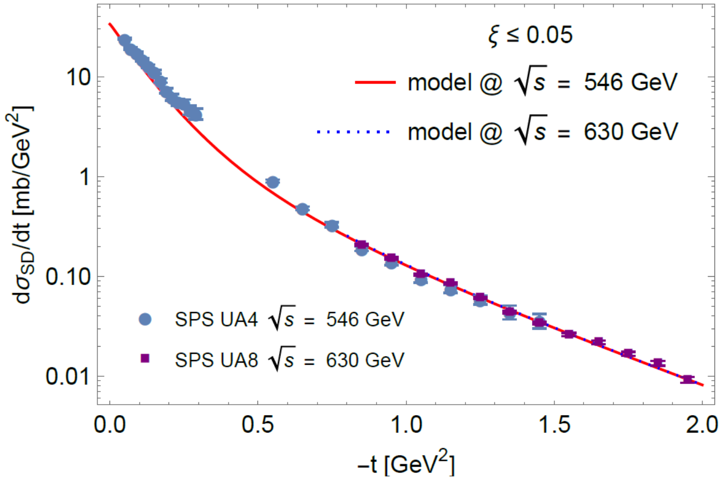
$$\sigma^{\pi p}(M^2) = 13.63(M^2)^{0.08} + 31.79(M^2)^{-0.45}$$

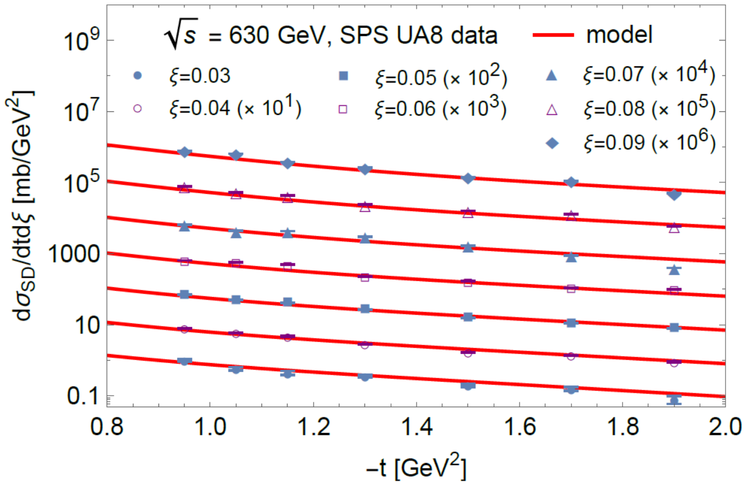
- The full double SD differential cross section is written as:

$$\frac{d^2\sigma_{SD}}{dt dM^2} = \frac{d^2\sigma_{SD}^{PPP}}{dt dM^2} + \frac{d^2\sigma_{SD}^{OOP}}{dt dM^2} + \frac{d^2\sigma_{SD}^{RRP}}{dt dM^2} + \frac{d^2\sigma_{SD}^{\pi}}{dt dM^2}$$

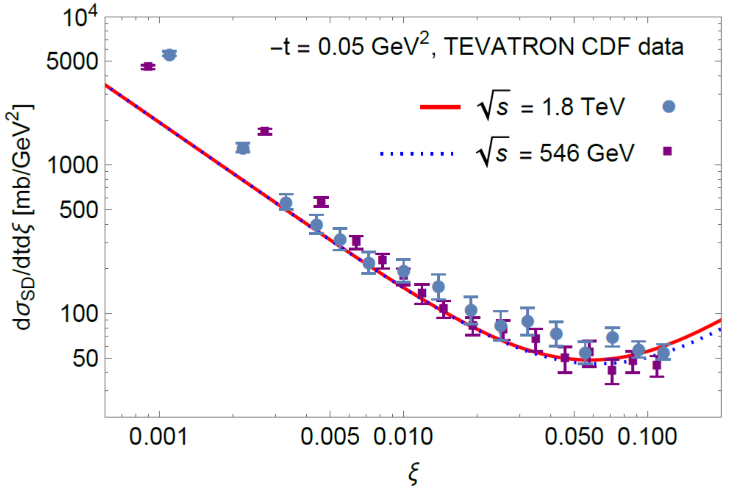
Description of the SD data

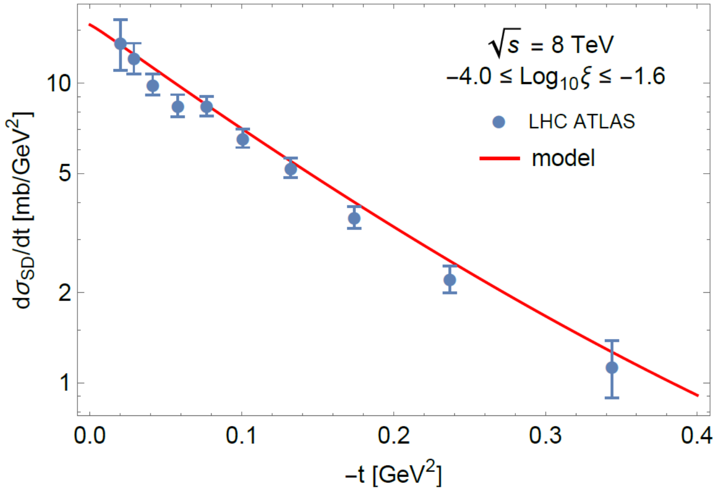
qualitative description to the data in a wide kinematic (s, t, M^2) range which includes SPS, TEVATRON and LHC energies

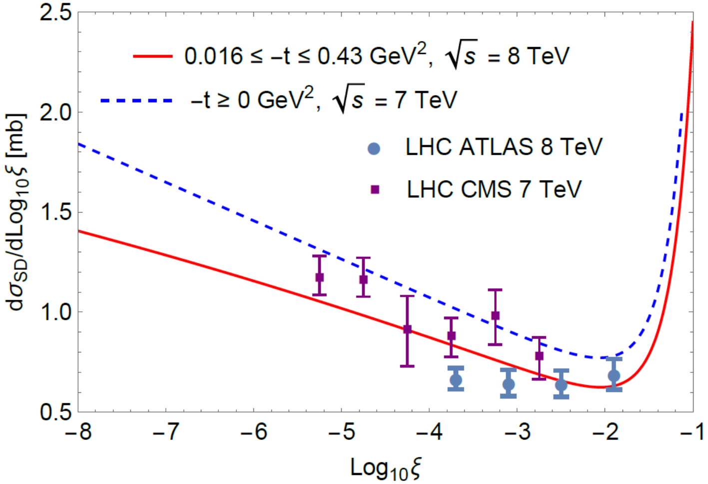




PPP	OOP	RRP
$\delta_P = 0$	$\delta_O = 0$	$\delta_R = -0.45$
$\alpha'_P = 0.43$	$\alpha'_O = 0.15$	$\alpha'_R = 0.93$
$a_P = 0.32$	$a_O = 0.084$	$a_O = 2.5$
$b_P = 2.86$	$b_O = 1.18$	$b_O = 0.0$
$\gamma_P = 0.061$	$\gamma_O = 0.49$	-







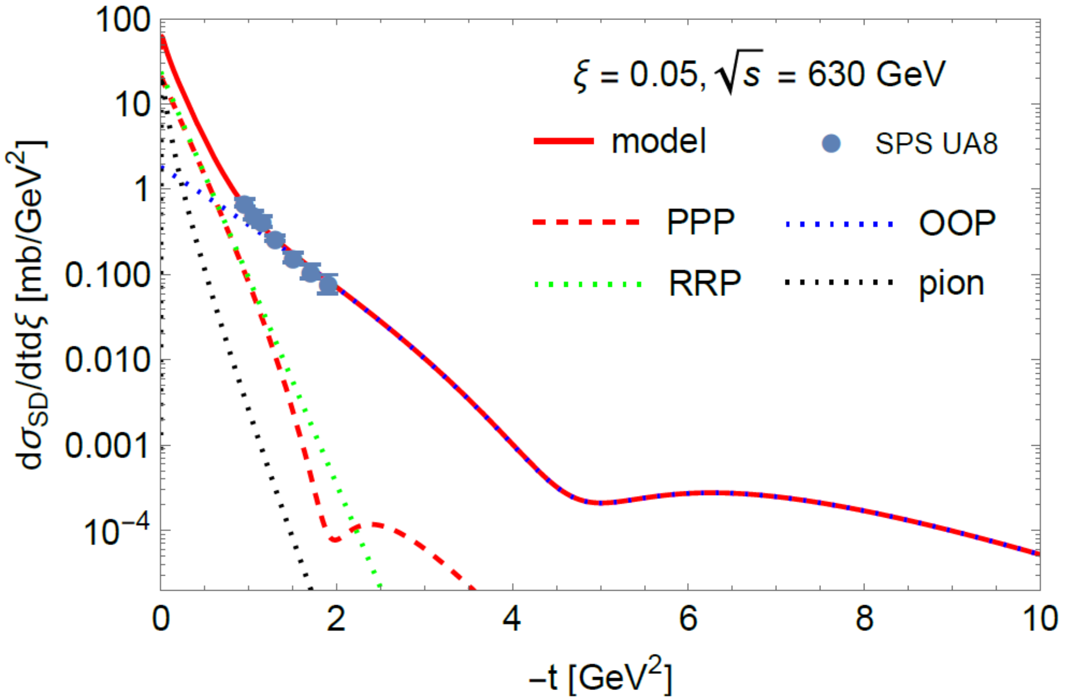
Dip-bump in SD at SPS and LHC energies

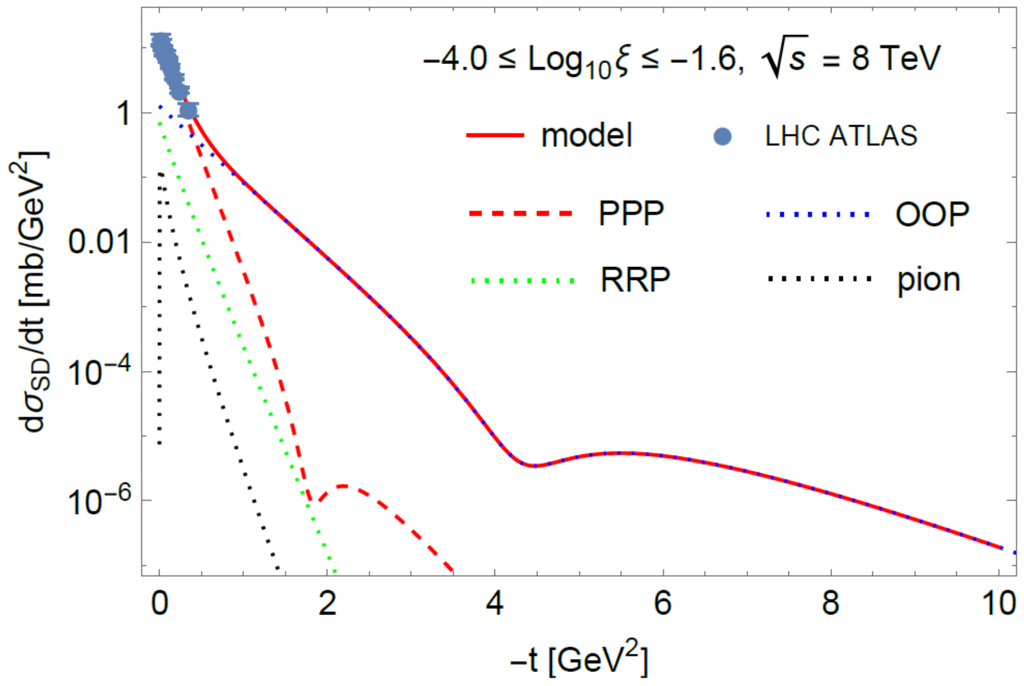
the position of the dip and bump in $-t$ in the SD process changes slowly with M^2 (or $\xi = M^2/s$) and determined by the OOP triple contribution

$$-t^{SD}_{dip} = \frac{1}{\alpha'_O b_O} \ln \frac{b_O + L_{SD}}{\gamma_O b_O L_{SD}}$$

$$-t^{SD}_{bump} = \frac{1}{\alpha'_O b_O} \ln \frac{4(b_O + L_{SD})^2 + \pi^2}{\gamma_O b_O (4L^2_{SD} + \pi^2)}$$

$$L_{SD} = \ln(s/M^2)$$





the dip and bump structure is predictced in SD at SPS and LHC energies in the squared four-momentum transfer range 3 GeV$^2 \lesssim -t \lesssim$ 7 GeV^2

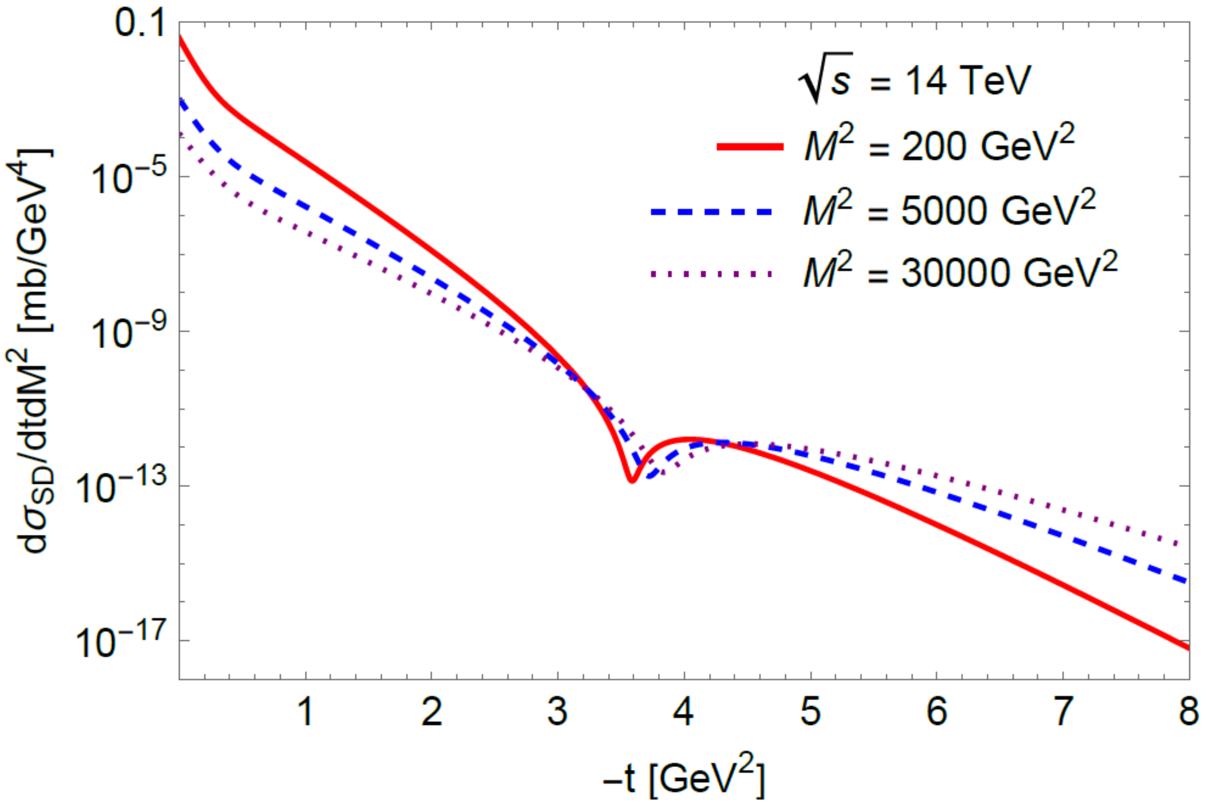
Dip-bump in SD at LHC energies (M^2 and $\sqrt{s}$ dependence)

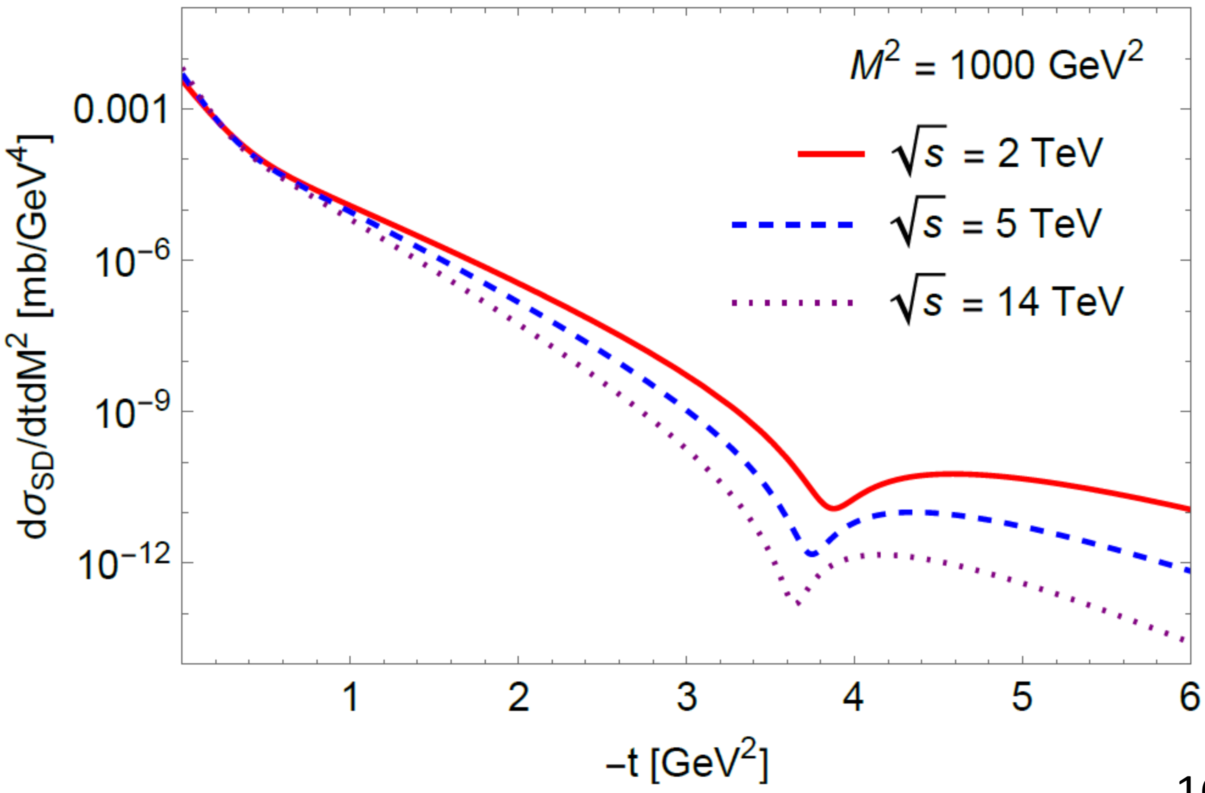
with increasing energy at a fixed M^2 value or with decreasing M^2 at a fixed energy the position of the dip-bump structure slowly goes to smaller $-t$ values

$$-t_{dip}^{SD} = \frac{1}{\alpha_0' b_O} \ln \frac{b_O + L_{SD}}{\gamma_O b_O L_{SD}}$$

$$-t_{bump}^{SD} = \frac{1}{\alpha_0' b_O} \ln \frac{4(b_O + L_{SD})^2 + \pi^2}{\gamma_O b_O (4L_{SD}^2 + \pi^2)}$$

$$L_{SD} = \ln(s/M^2)$$





Summary

- a Regge phenomenological model with dipole pomeron+odderon contribution is applied to describe experimental data on pp single diffraction at energies higher than 0.5 TeV

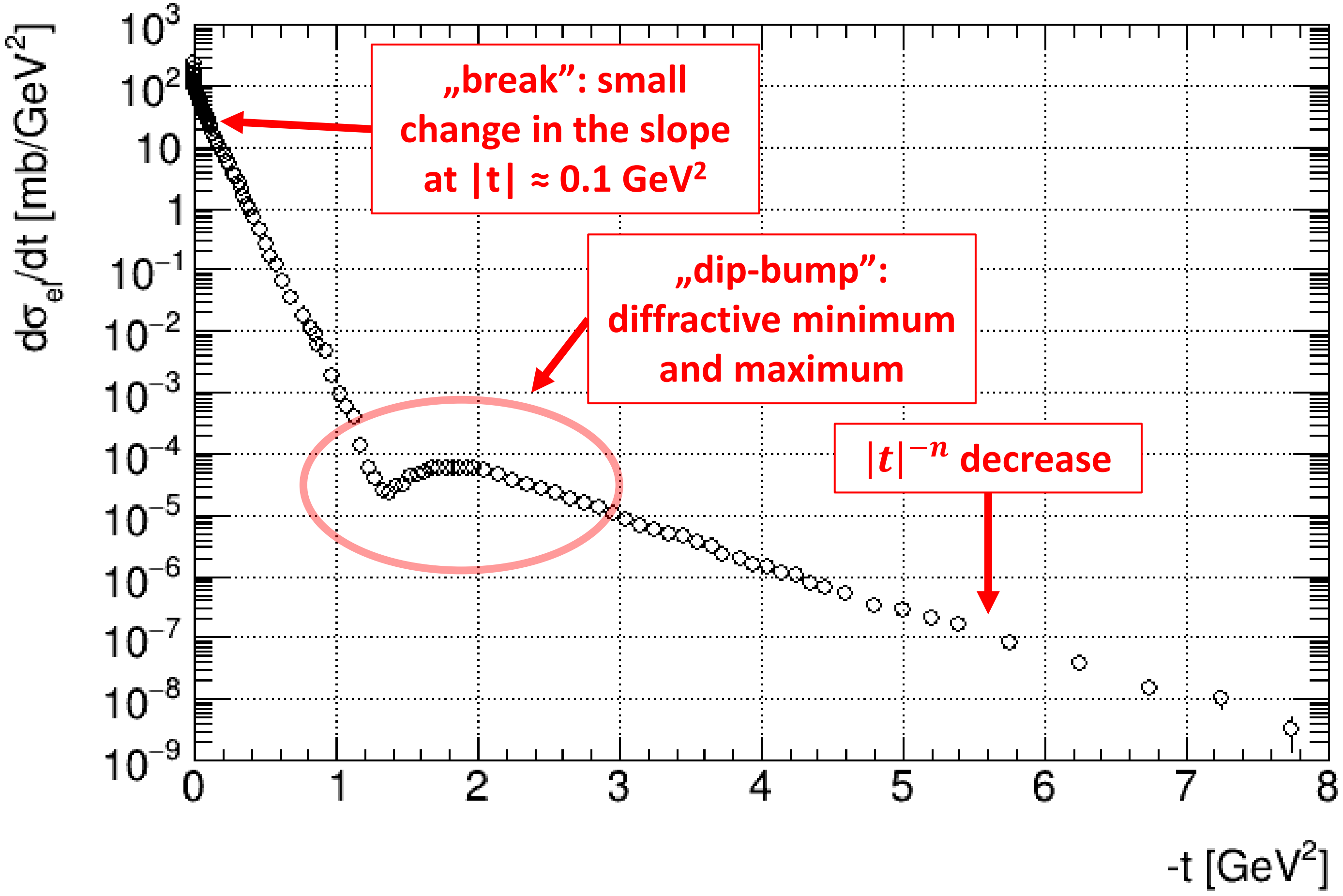
- dip-bump structure is predicted in the SD process in the squared four-momentum transfer range 3 $\text{GeV}^2 \lesssim -t \lesssim 7\ \text{GeV}^2$ and it is resulted from a dipole odderon contribution (OOP vertex)

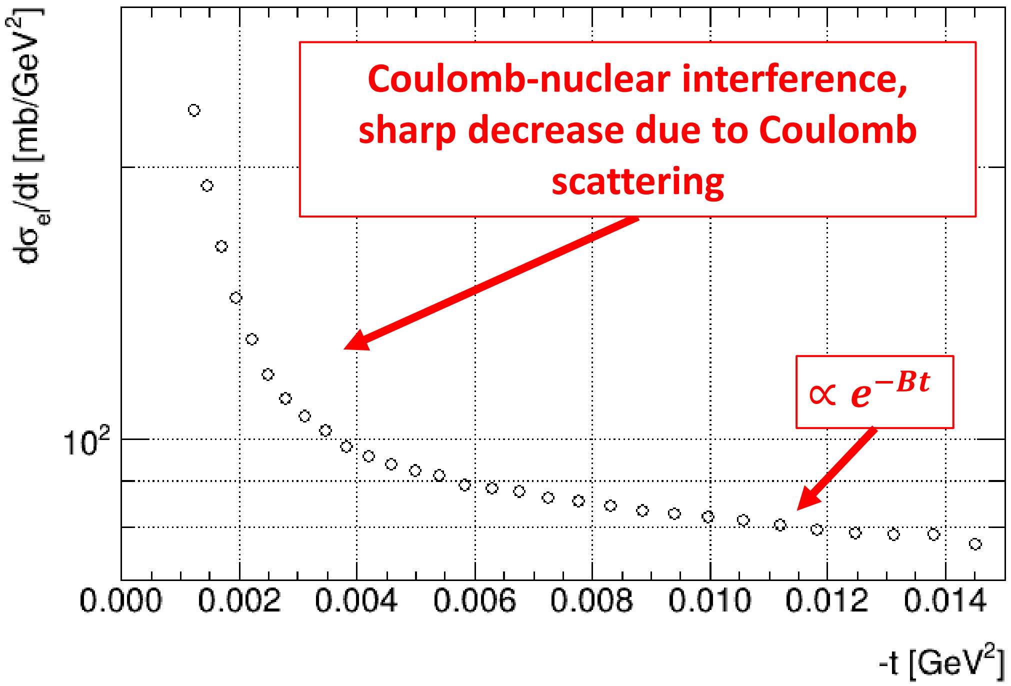
- an experimental check of the predicted structure would be interesting

Thank you for your attention!

Structures in elastic pp differential cross section

- measurements at CERN ISR in the 1970s revealed the characteristic structures of the high energy elastic pp differential cross section





Elastic pp differential cross section measured at CERN ISR at $\sqrt{s} = 53.8$ GeV

Dipole Regge model

L. L. Jenkovszky and A. N. Wall, Czech. J. Phys. B26, 447 (1976)
L. L. Jenkovszky, Fortsch. Phys.34, 791 (1986)

$$A^{DP}(s,\alpha) = e^{-\frac{i\pi\alpha}{2}}\left(\frac{s}{s_0}\right)^{\alpha}\left[G'(\alpha) + \left(L - \frac{i\pi}{2}\right)G(\alpha)\right]$$

- motivated by the shape of the $d\sigma_{el}/dt$ (exponential decrease), the paramterization of $G'(\alpha)$ is:

$$G'(\alpha) = a e^{b[\alpha-\alpha_0]}$$

(α_0 is the intercept of the trajectory)

- $G(\alpha)$ is obtained by by integrating $G'(\alpha)$:

$$G(\alpha) = \int G'(\alpha)d\alpha = a\left(\frac{e^{b[\alpha-\alpha_0]}}{b} - \gamma\right)$$

- introducing that $\varepsilon = \gamma b$ the amplitude can be rewritten as:

$$A^{DP}(s,t) = i\frac{a}{b}\left(\frac{s}{s_0}\right)^{\alpha_0} e^{-\frac{i\pi}{2}(\alpha_0-1)}\left[r_1^2(s)e^{r_1^2(s)[\alpha(t)-\alpha_0]} - \varepsilon\, r_2^2(s)e^{r_2^2(s)[\alpha(t)-\alpha_0]}\right]$$

$$r_1^2(s) = b + L(s) - i\pi/2 \qquad r_2^2(s) = L(s) - i\pi/2$$

Model for elastic pp and $\bar{p}p$ scattering amplitude

$$A(s,t)_{pp}^{\bar{p}p} = A_P^{DP}(s,t) + A_f^{SP}(s,t) \pm [A_O^{DP}(s,t) + A_\omega^{SP}(s,t)]$$

- **the dipole pomeron and odderon amplitudes are:**

$$A_P^{DP}(s,t) = e^{-\frac{i\pi\alpha_P(t)}{2}}\left(\frac{s}{s_{0P}}\right)^{\alpha_P(t)}\left[G_P'(t) + \left(L_P(s) - \frac{i\pi}{2}\right)G_P(t)\right]$$

$$A_O^{DP}(s,t) = -iA_{P\to O}^{DP}(s,t)$$

$$G_P'(t) = a_P e^{b_P[\alpha_P(t)-\alpha_P(0)]}$$

$$G_P(t) = a_P\left(e^{b_P[\alpha_P(t)-\alpha_P(0)]}/b_P - \gamma_P\right)$$

(with free parameters labeled by "O")

$$L_P(s) = \ln\frac{s}{s_{0P}}$$

$$\alpha_P(t) = 1 + \delta_P + \alpha_P' t$$

- **the simple pole f and ω reggeon amplitudes are:**

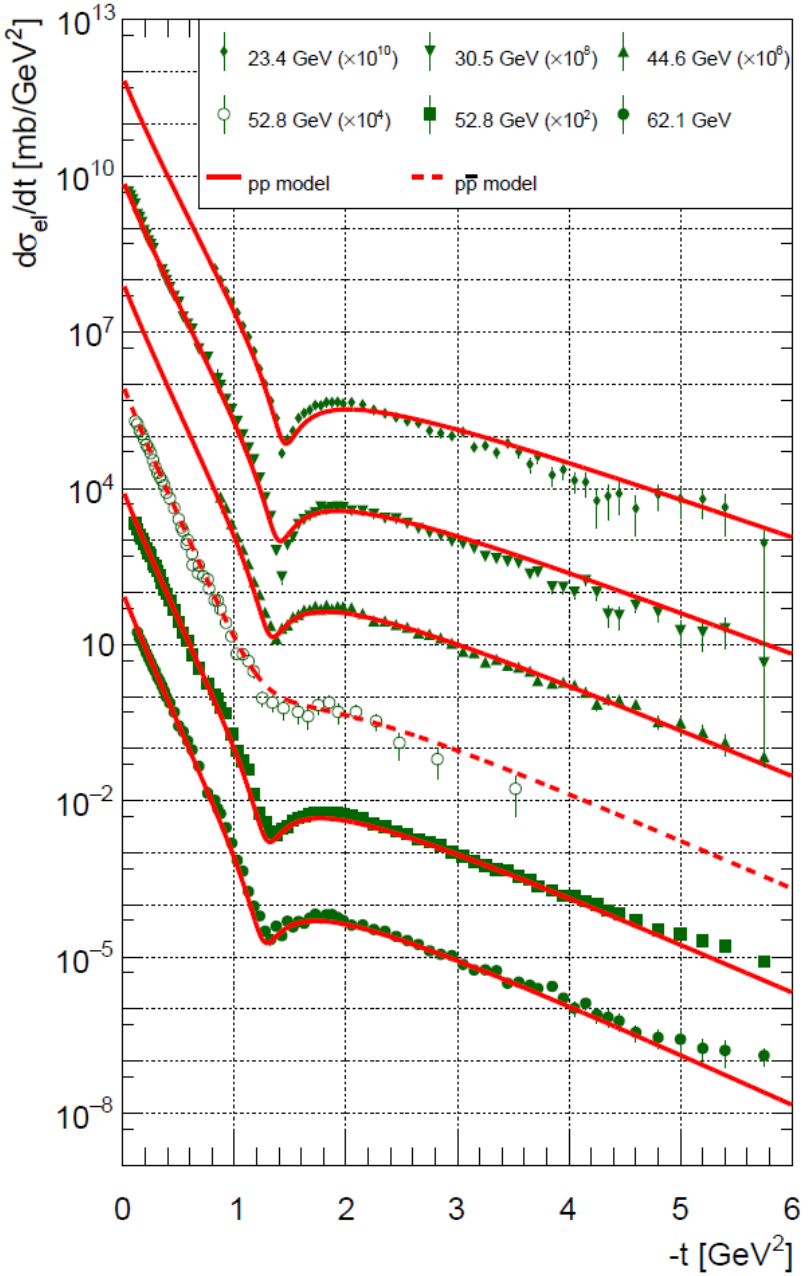
$$\mathbf{A_f}(s,t) = -a_f e^{-\frac{i\pi\alpha_f(t)}{2}}(s/s_{0f})^{\alpha_f(t)} e^{b_f t}$$

$$\mathbf{A_\omega}(s,t) = -i\mathbf{A_{f\to\omega}}(s,t)$$

$$\alpha_f(t) = \alpha_f^0 + \alpha_f' t$$

(with free parameters labeled by "ω")

ISR $d\sigma_{el}/dt$ data and the model

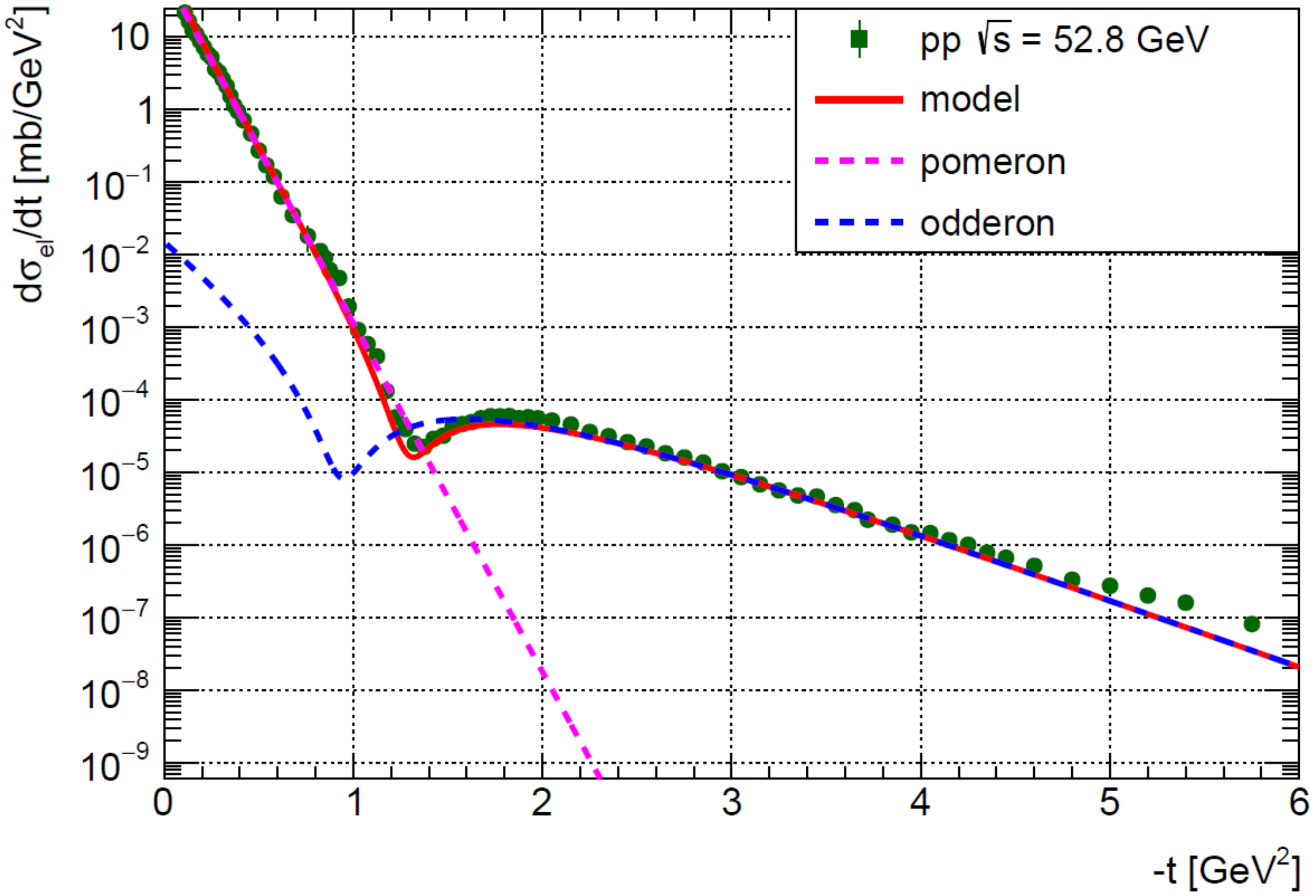


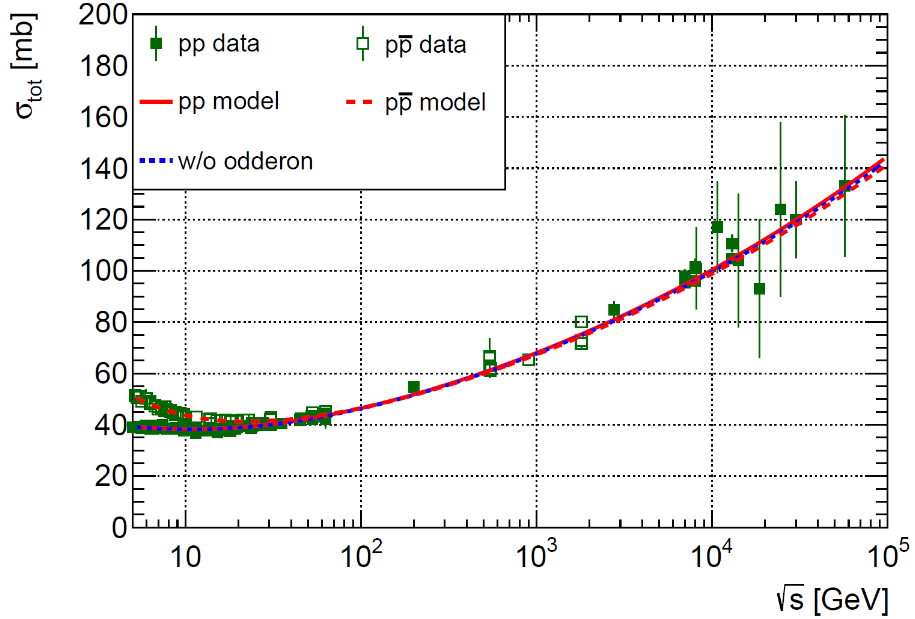
pomeron	odderon	f-reggeon	ω-reggeon
$\delta_P = 0.043$	$\delta_O = 0.14$	$\alpha_f^0 = 0.69$	$\alpha_\omega^0 = 0.44$
$\alpha'_P = 0.36$	$\alpha'_O = 0.13$	$\alpha'_f = 0.84$	$\alpha'_\omega = 0.93$
$a_P = 9.10$	$a_O = 0.029$	$a_f = 15.4$	$a_\omega = 9.69$
$b_P = 8.47$	$b_O = 6.96$	$b_f = 4.78$	$b_\omega = 3.5$
$\gamma_P = 0$	$\gamma_O = 0.11$	-	-
$s_{0P} = 2.88$	$s_{0O} = 1$	$s_{0f} = 1$	$s_{0\omega} = 1$

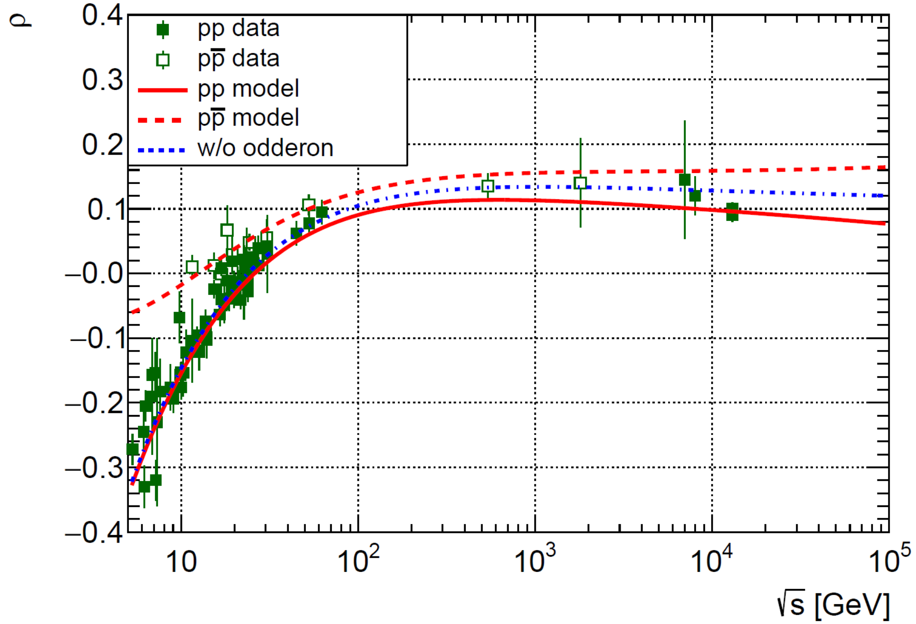
Fit to proton-proton and proton-antiproton differential cross section data at ISR energy region, and to ρ and total cross section data from 5 GeV up to the highest energies

$d\sigma_{el}/dt$ with P and O contribution, ρ and σ_{tot} w/o O

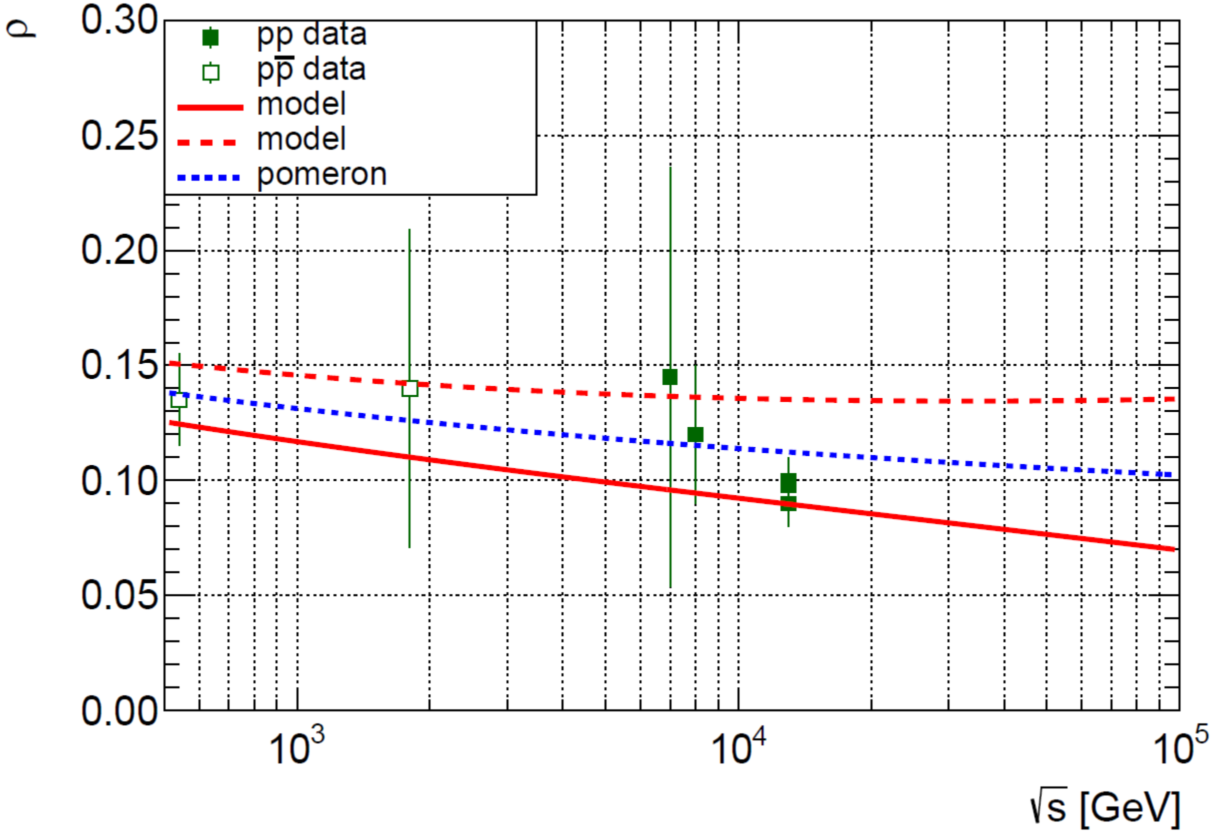
the odderon contribution takes over completely after the bump but at low-|t| the odderon contribution is small

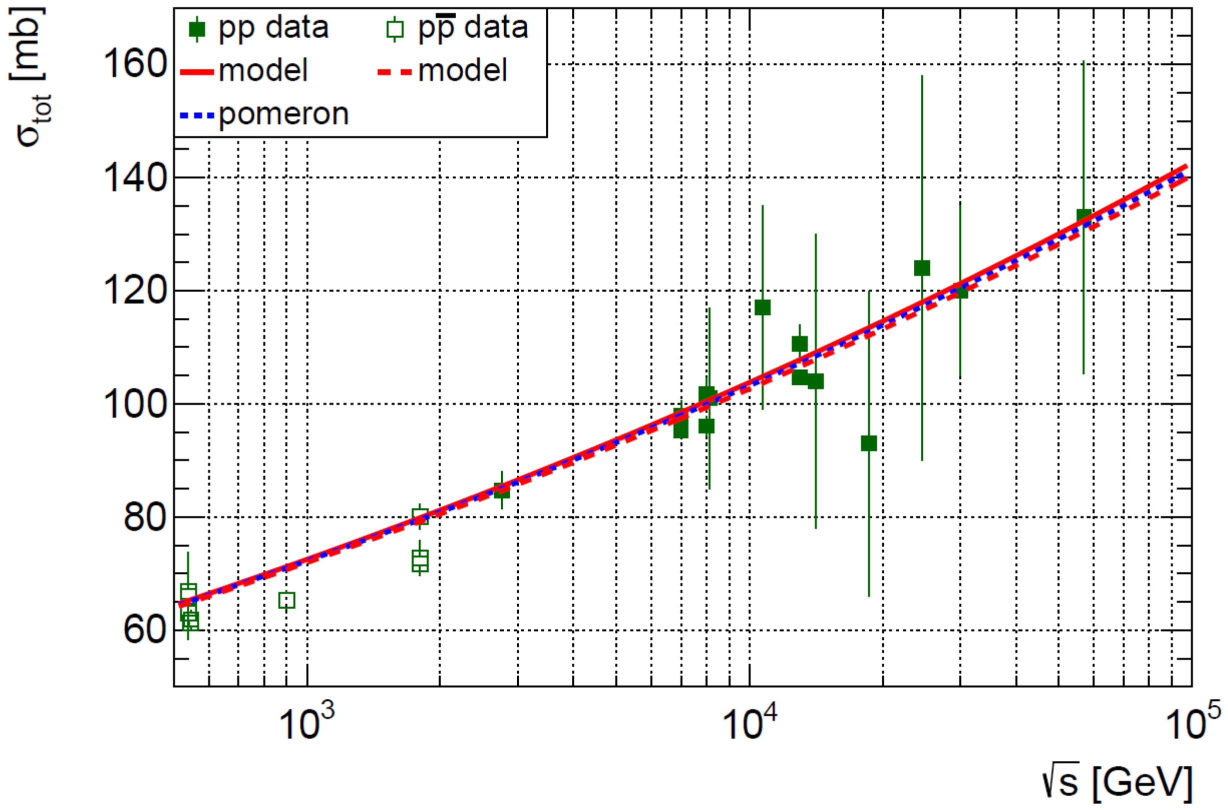


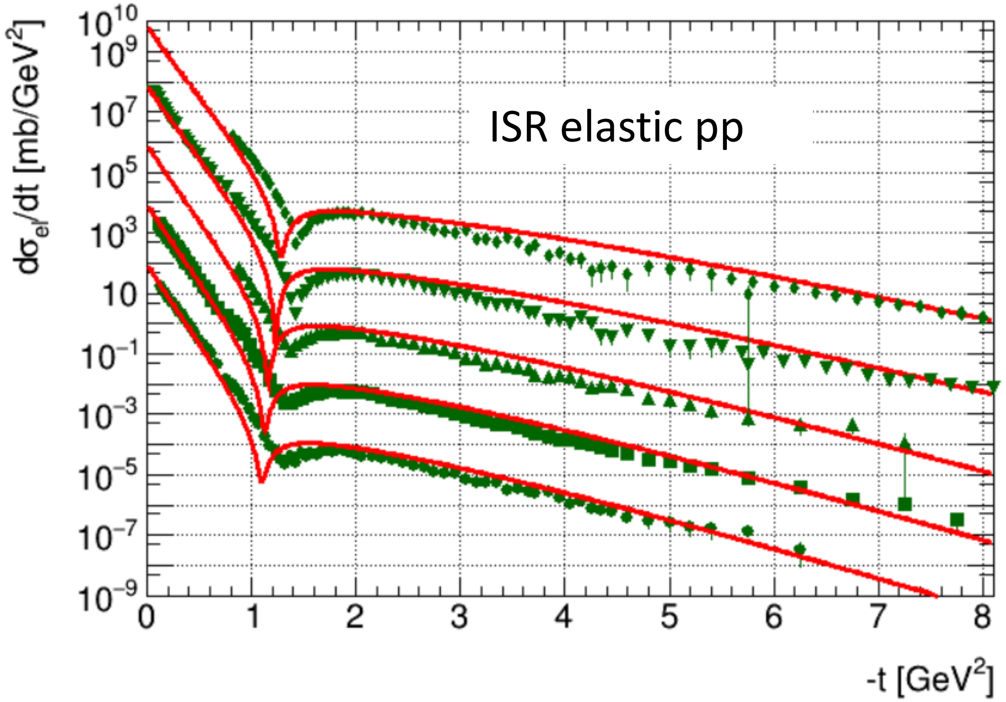


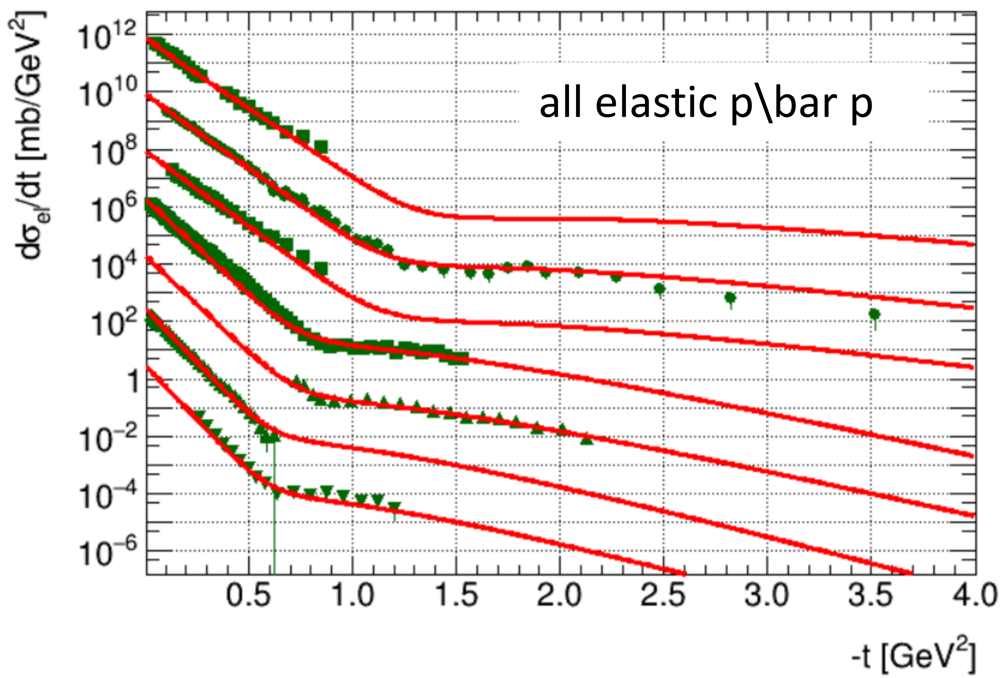


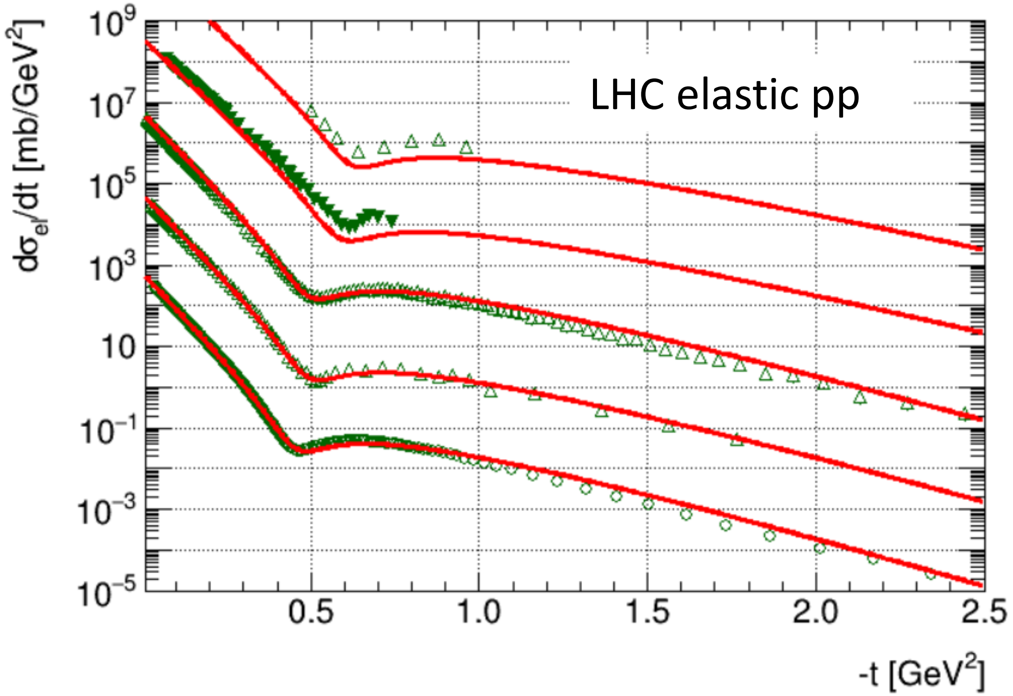
ρ and σ_{tot} w/o O





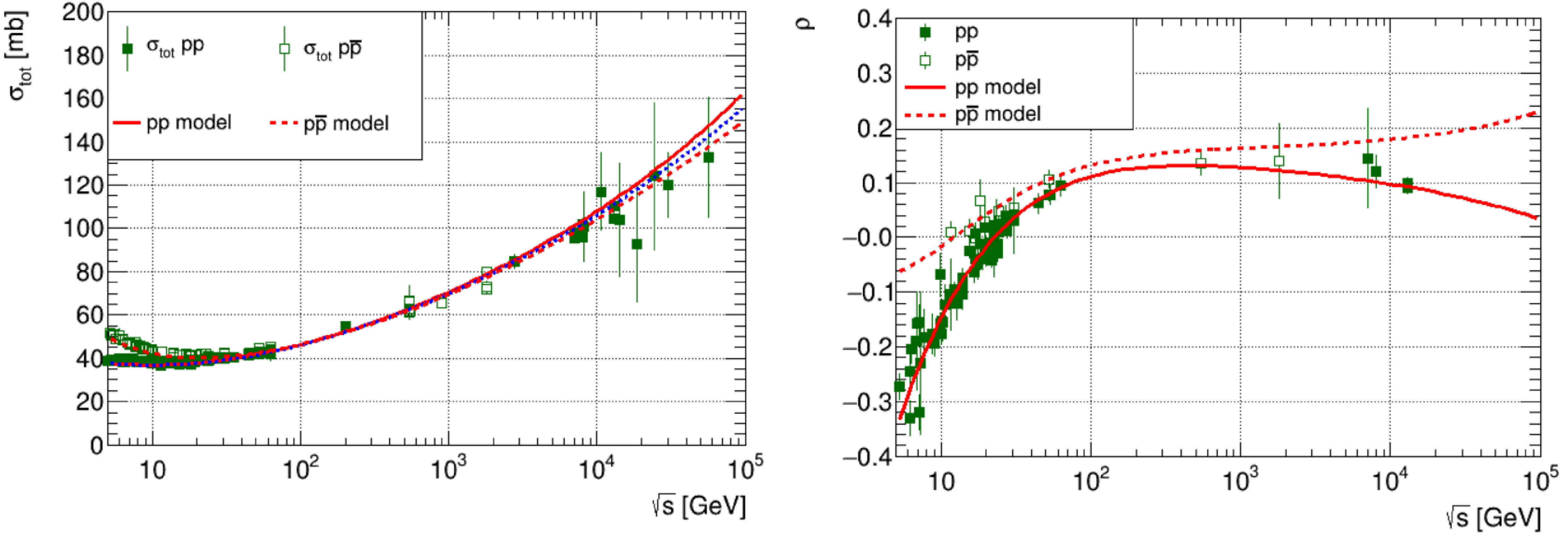






Pomeron	Odderon
$\delta_P = 0.04677 \pm 0.00004$	$\delta_O = 0.28606 \pm 0.00013$
$\alpha_{1P} = 0.4144 \pm 0.0002$	$\alpha_{1O} = 0.1745 \pm 0.0001$
$\alpha_{2P} = 0.0000$ (fixed)	$\alpha_{2O} = 0.0000$ (fixed)
$a_P = 2.2488 \pm 0.0036$	$a_O = 0.0202 \pm 0.0001$
$b_P = 5.5835 \pm 0.0139$	$b_O = 0.4015 \pm 0.0013$
$\epsilon_P = 0.0604 \pm 0.0005$	$\epsilon_O = 1.0036 \pm 0.0000$
$s_{0P} = 1.0001 \pm 0.0003$	$s_{0O} = 2.7211 \pm 0.0038$

f-reggeon	ω-reggeon
$\alpha_{0f} = 0.6869$ (fixed)	$\alpha_{0\omega} = 0.4380$ (fixed)
$\alpha_{1f} = 0.8400$ (fixed)	$\alpha_{1\omega} = 0.9300$ (fixed)
$a_f = -15.4042$ (fixed)	$a_\omega = 9.6945$ (fixed)
$b_f = 4.7842$ (fixed)	$b_\omega = 3.5101$ (fixed)
$s_{0f} = 1.0000$ (fixed)	$s_{0\omega} = 1.0000$ (fixed)



σ_tot [mb]
σ_tot pp
σ_tot pp̄
pp model
pp̄ model
√s [GeV]
ρ
pp
pp̄
pp model
pp̄ model
√s [GeV]

Dipole Regge approach for single diffraction (SD)

- in the triple Regge approach the triple pomeron vertex results the following contribution for the double differential SD cross section:

$$\frac{d^2\sigma_{SD}^{PPP}}{dtdM^2} = \frac{1}{16\pi^2}\frac{1}{M^2} g_{Ppp}^2(t)\left(\frac{s}{M^2}\right)^{2\alpha_P(t)-2} g_{PPP}(t) g_{Ppp}(0)(M^2)^{\alpha_{0P}-1}$$

- g_{PPP} is found to be t-independent
- **assumption: the t-dependent part of the amplitude of the SD process has the form in case the pomeron a simple pole:**

$$A_{SD}^{SP}(s, M^2, \alpha(t)) \sim \mathrm{e}^{-\frac{\mathrm{i}\pi\alpha}{2}} G(\alpha)(s/M^2)^{\alpha}$$

- $G(\alpha)$ incorporates the t-dependece coming from $\mathrm{g}_{\mathrm{Ppp}}(t)$
- a dipole pomeron amplitude is obtained as:

$$A_{SD}^{DP}(s, M^2, \alpha) = \frac{d}{d\alpha} A_{SD}^{SP}(s, M^2, \alpha) \sim e^{-\frac{i\pi\alpha}{2}}\left(\frac{s}{M^2}\right)^{\alpha}\left[G'(\alpha) + \left(L_{SD} - \frac{i\pi}{2}\right) G(\alpha)\right]$$

$$L_{SD} \equiv \ln(s/M^2)$$

Odderon contribution in SD in form of an OOP vertex

- the odderon-odderon-pomeron vertex results the following contribution for the double differential SD cross section:

$$\frac{d^2\sigma_{SD}^{OOP}}{dtdM^2} = \frac{1}{16\pi^2}\frac{1}{M^2} g_{Opp}^2(t)(s/M^2)^{2\alpha_O(t)-2} g_{OOP}(t) g_{Ppp}(0)(M^2)^{\delta_P}$$

- **assumption: $g_{OOP}(t)$ is t-independent and the t-dependent part of the odderon amplitude of the SD process has the form:**

$$A_{SD}^{SP}(s, M^2, \alpha_O) \sim \mathrm{e}^{-\frac{\mathrm{i}\pi\alpha}{2}} G_O(\alpha_O)(s/M^2)^{\alpha_O}$$

$$G_O'(\alpha_O) = a e^{b[\alpha_O - 1]}$$

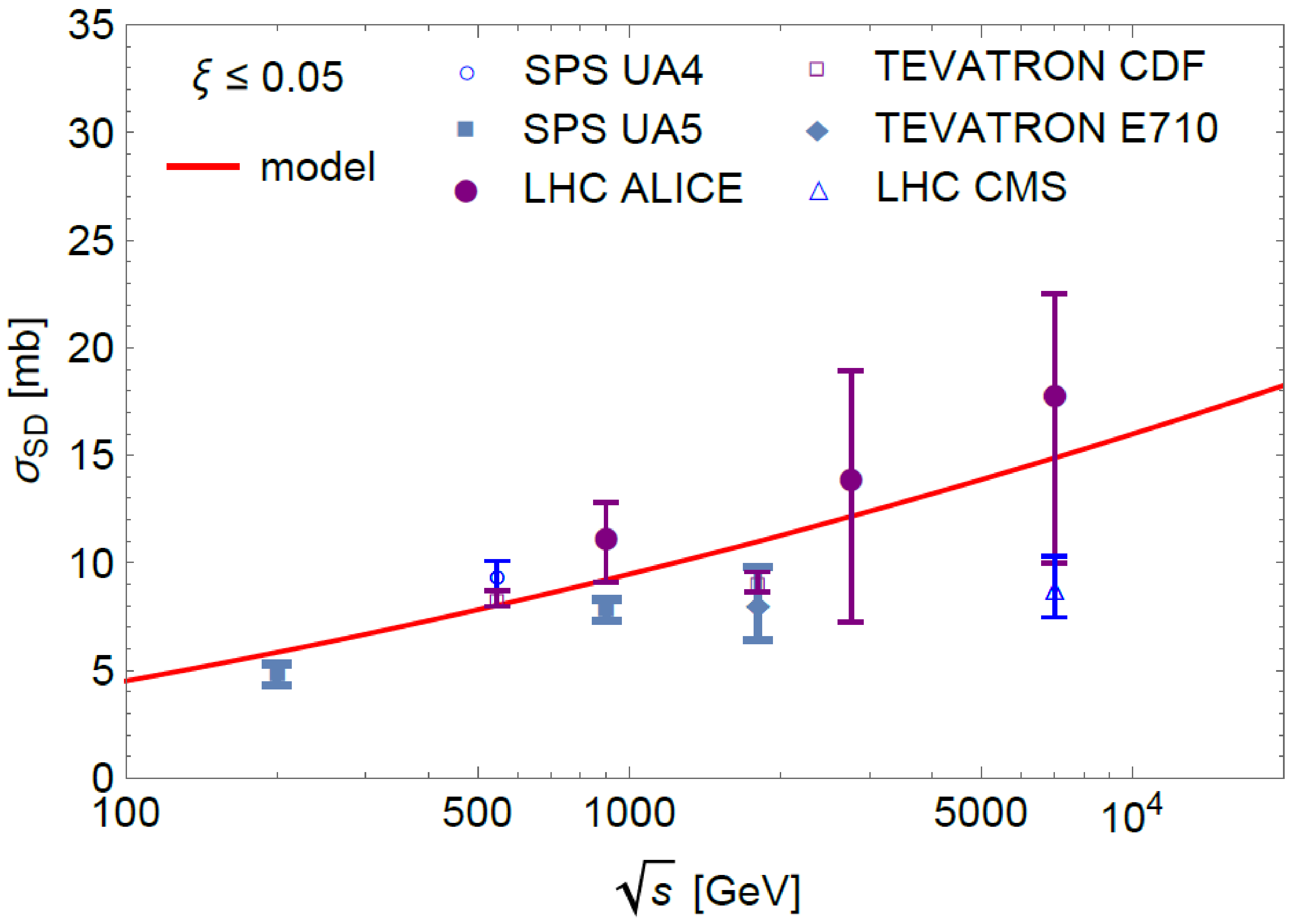
$$G_O(\alpha_O) = \int G_O'(\alpha_O) d\alpha_O$$

- $G_O(\alpha_O)$ incorporates the t-dependece coming from $g_{Opp}(t)$
- a dipole odderon contribution to the cross section is obtained as:

$$\frac{d^2\sigma_{SD}^{OOP}}{dtdM^2} = \frac{1}{M^2}\left(G_O{'}^2(\alpha_O) + 2L_{SD} G_O(\alpha_O) G'(\alpha_O) + G_O^2(\alpha_O)\left(L_{SD}^2 + \frac{\pi^2}{4}\right)\right)(s/M^2)^{2\alpha_O(t)-2}\sigma^{Pp}(M^2)$$

(the a parameter of $G_O(\alpha_O)$ accounts also in the defference between g_{OOP} and g_{PPP})

Teljes SD hatáskeresztmetszet

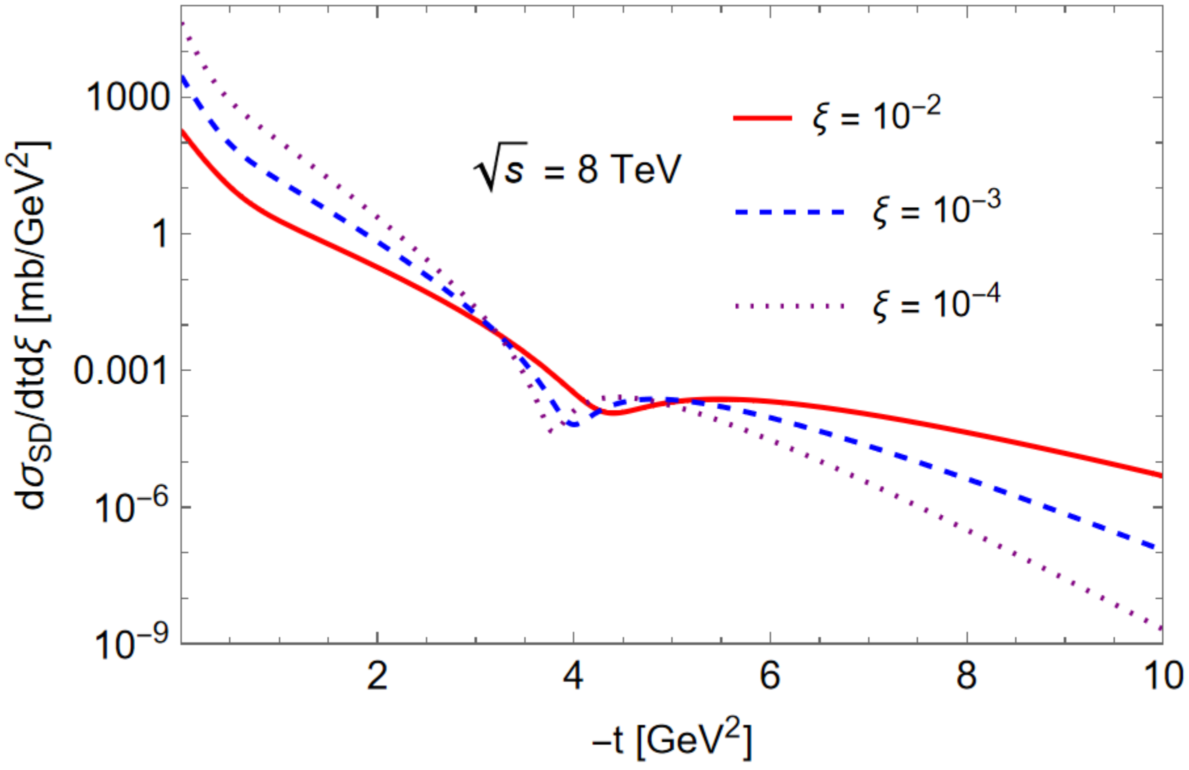


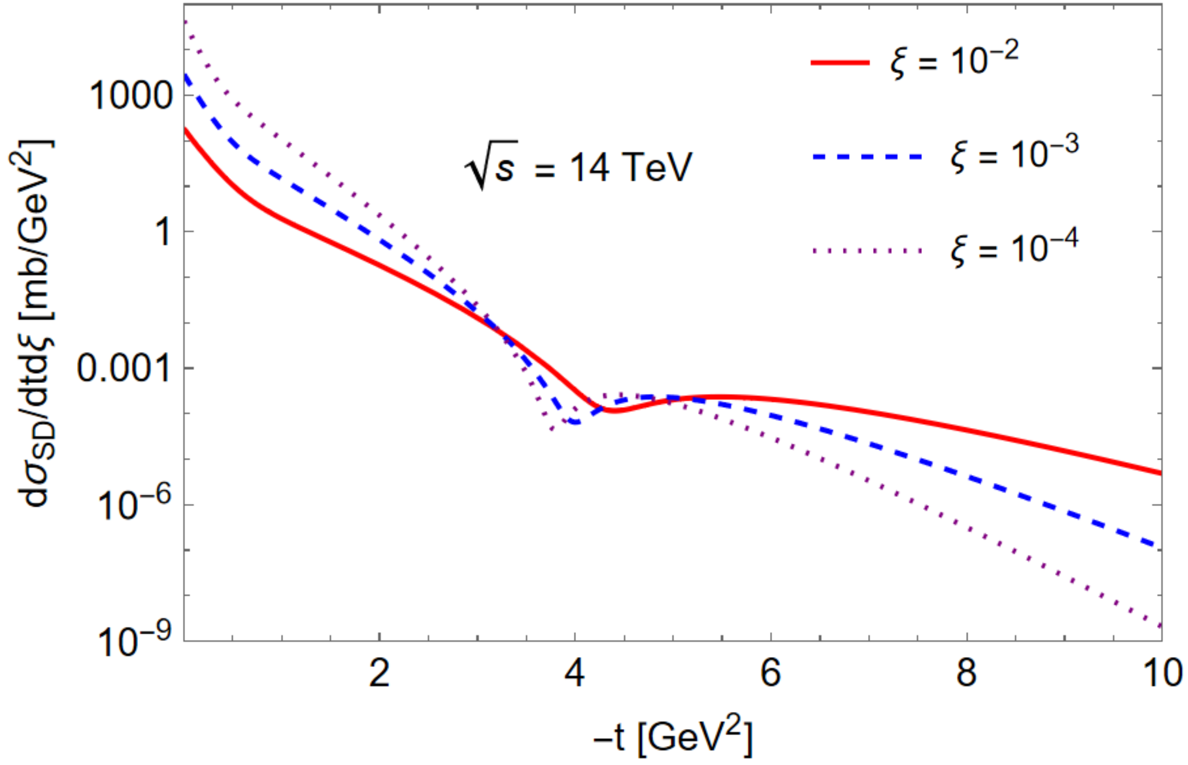
$\xi = M^2/s$

$$\sigma_{SD}(s) = \int_{\xi_{min}}^{\xi_{max}} d\xi \int_{t_{min}}^{t_{max}} dt \frac{d^2\sigma_{SD}}{d\xi dt}$$

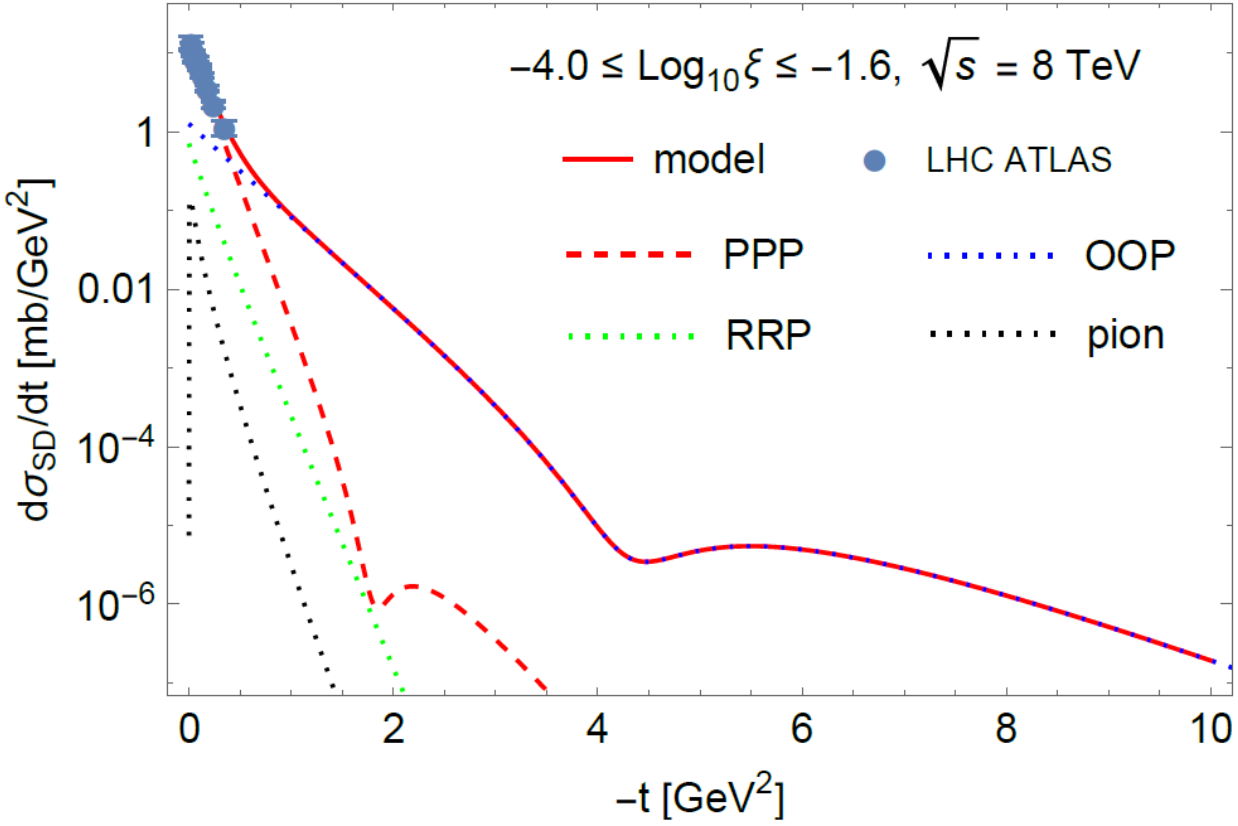
Dipole Pomeron	Dipole Odderon	Simple pole Reggeon
$\delta_P = 0$	$\delta_O = 0$	$\delta_R = -0.45$
$\alpha'_P = 0.43$	$\alpha'_O = 0.15$	$\alpha'_R = 0.93$
$a_P = 0.32$	$a_O = 0.084$	$a_O = 2.5$
$b_P = 2.86$	$b_O = 1.18$	$b_O = 0.0$
$\gamma_P = 0.061$	$\gamma_O = 0.49$	-

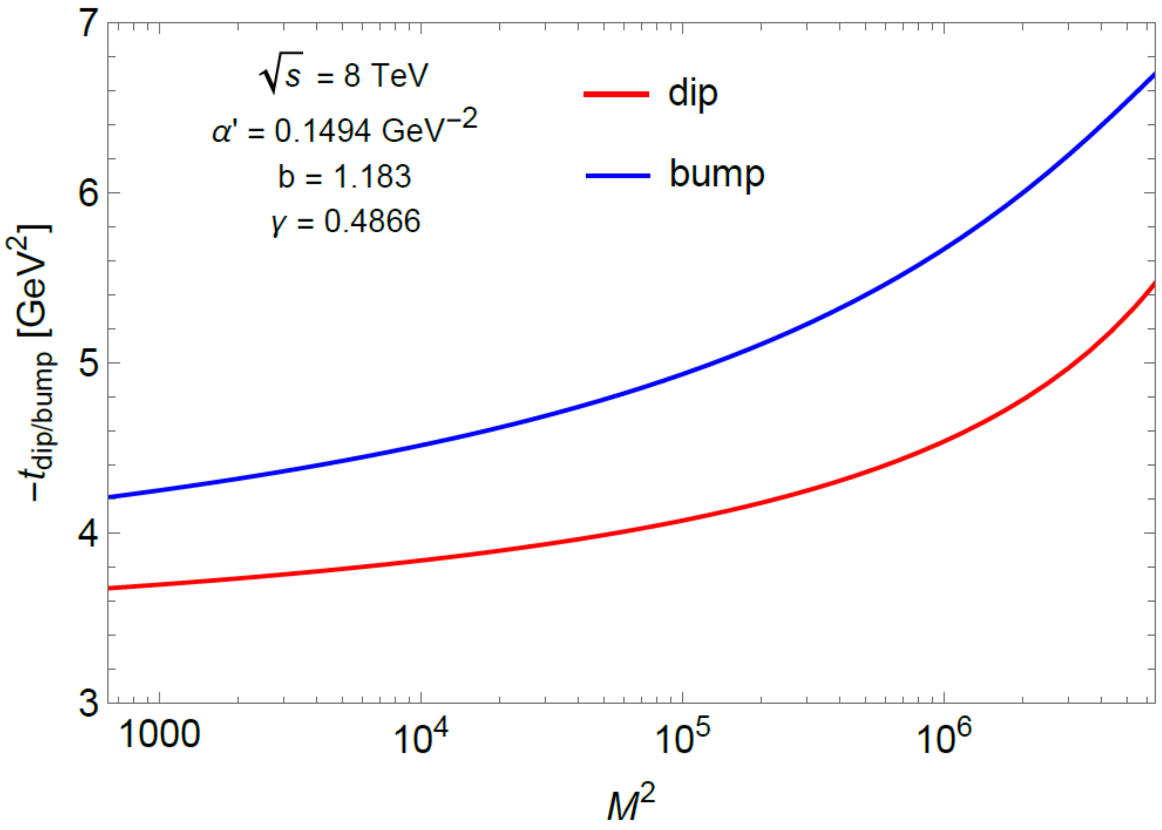
t and ξ dependence of the SD process at LHC energies





dip-bump in –t at LHC





$$-t_{dip}^{SD} = \frac{1}{\alpha' b} \ln \frac{b + L_{SD}}{\gamma b L_{SD}}$$

$$-t_{bump}^{SD} = \frac{1}{\alpha' b} \ln \frac{4(b + L_{SD})^2 + \pi^2}{\gamma b (4L_{SD}^2 + \pi^2)}$$

$$L_{SD} = \ln(s/M^2)$$