Comments on the Odderon discovery

M.G. Ryskin PNPI

"The TOTEM collaboration at the LHC, in collaboration with the D0 collaboration at the former Tevatron collider at Fermilab, have announced the discovery of the odderon an elusive three-gluon state predicted almost 50 years ago.

The combined significance of these results is larger than 5σ" (CERN Courier)

This is good from the sociology and PR viewpoints

(these measurements should be continued)

Misleading form the physical viewpoint

Odderon was "discovered" 4 times:

- difference in $d\sigma(p\bar{p})/dt$ and $d\sigma(pp)/dt$ in dip region at $\sqrt{s} = 53$ GeV
- Large Re/Im = 0.28 ratio for $p\bar{p}$ at 546 GeV (UA4)
- small Re/Im = 0.10 at 13 TeV (TOTEM)

- NOW – difference in $d\sigma(p\bar{p})/dt$ in dip region at $\sqrt{s} = 1.96$ TeV (D0) for $p\bar{p}$ and $d\sigma(pp)/dt$ at 2.76, 7 TeV (TOTEM) extrapolated to 1.96 TeV

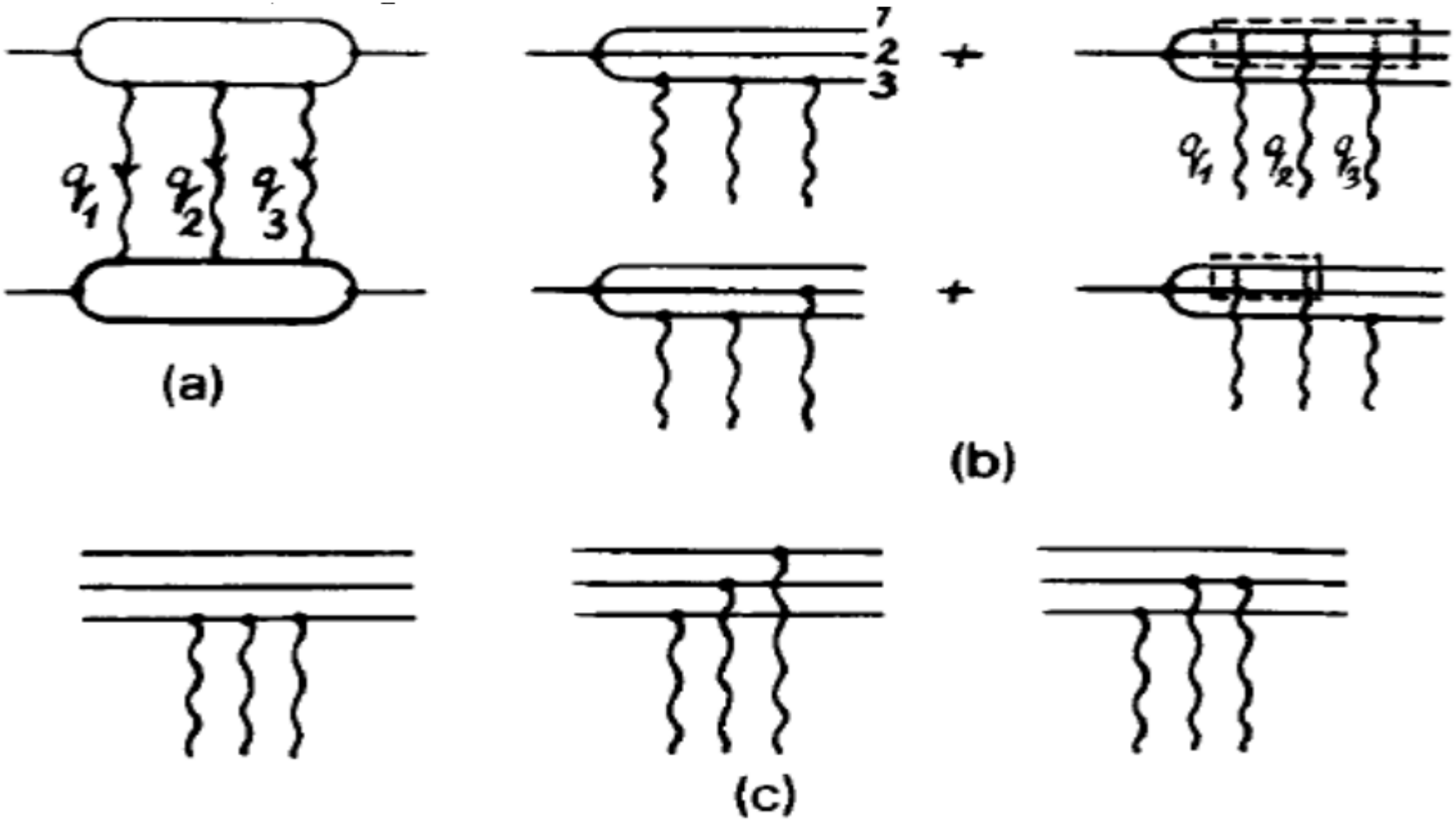
TOTEM-D0 2012.03981

I believe that Odderon exists
(i.e. C-odd amplitude which contribution does not
decreases (or decreases very slowly) with energy)
It is exists in pert.QCD (at least at very small distances).

However I never trust 5-6σ
before the value of the C-odd amplitude will be evaluated.

Theory:

At the lowest α_s order (Born approx.)
Odderon = 3 gluon exchange



Properties: C-odd

1. Odderon does not couple to pion/meson (due to C-parity)

2. $\alpha(0)_{Odd} = 0.96 \; - \; 1 \leq 1$

3. Odd. coupling is small

$$\sigma_{Odd} \sim \alpha^3{}_s \cdot < r^2_{min} > \sim \; 1mb \otimes \mathrm{BKP}$$

$$\sigma_{Pom} \sim \alpha^2{}_s \cdot < r^2_{max} > \sim \; 40mb \otimes \mathrm{BFKL}$$

4. Small size (=small t-slope and small α'_{Odd})

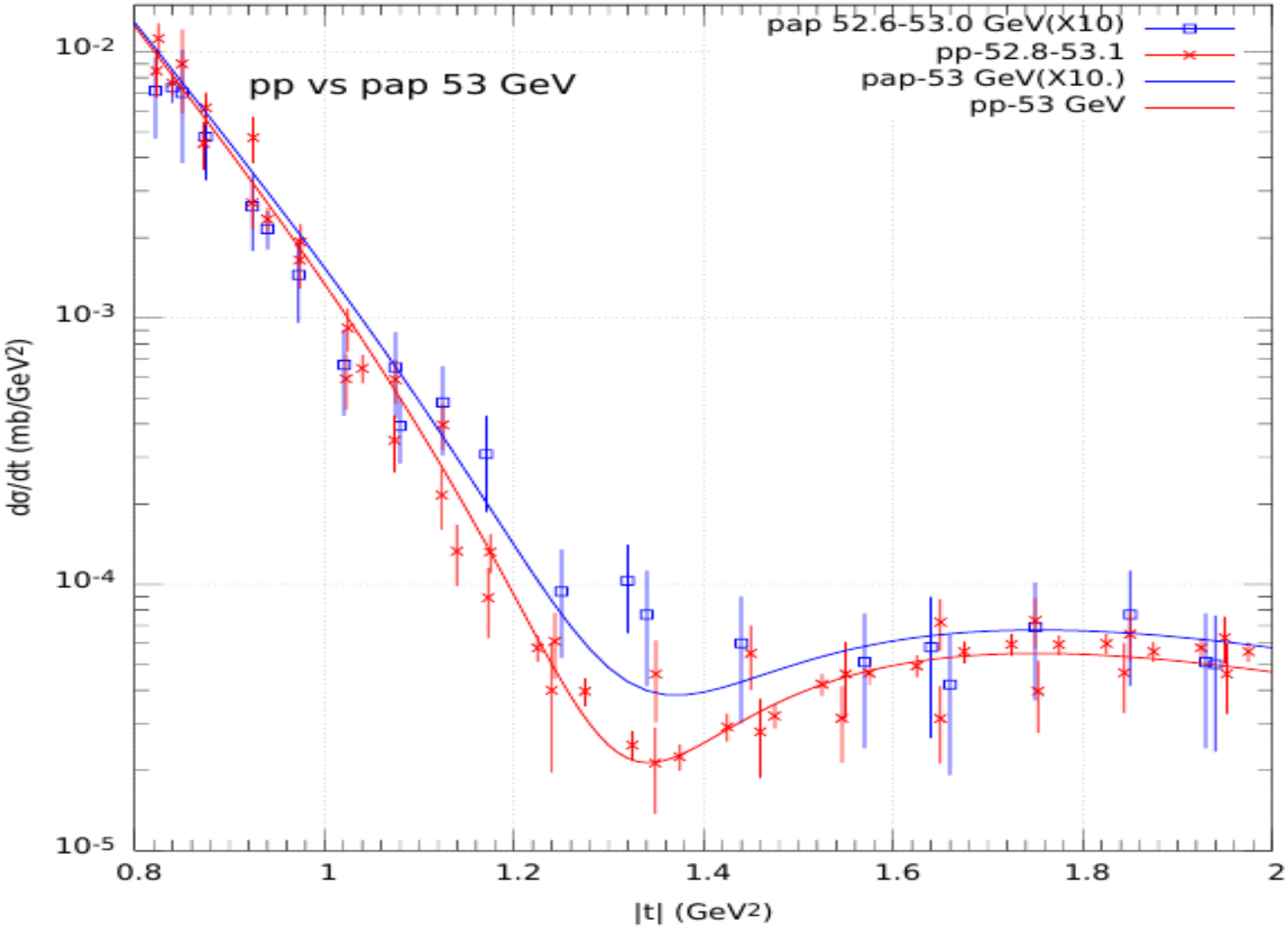
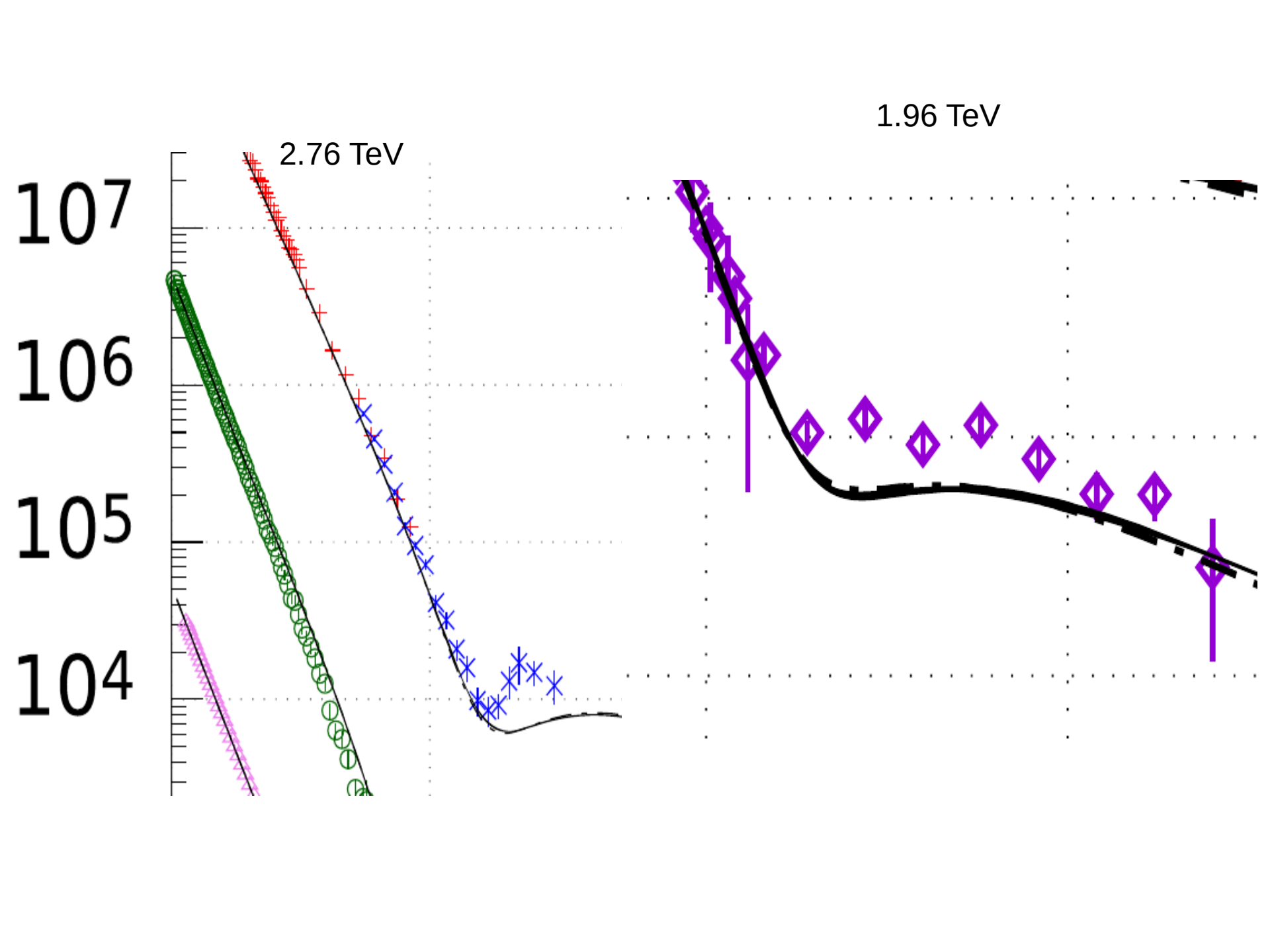
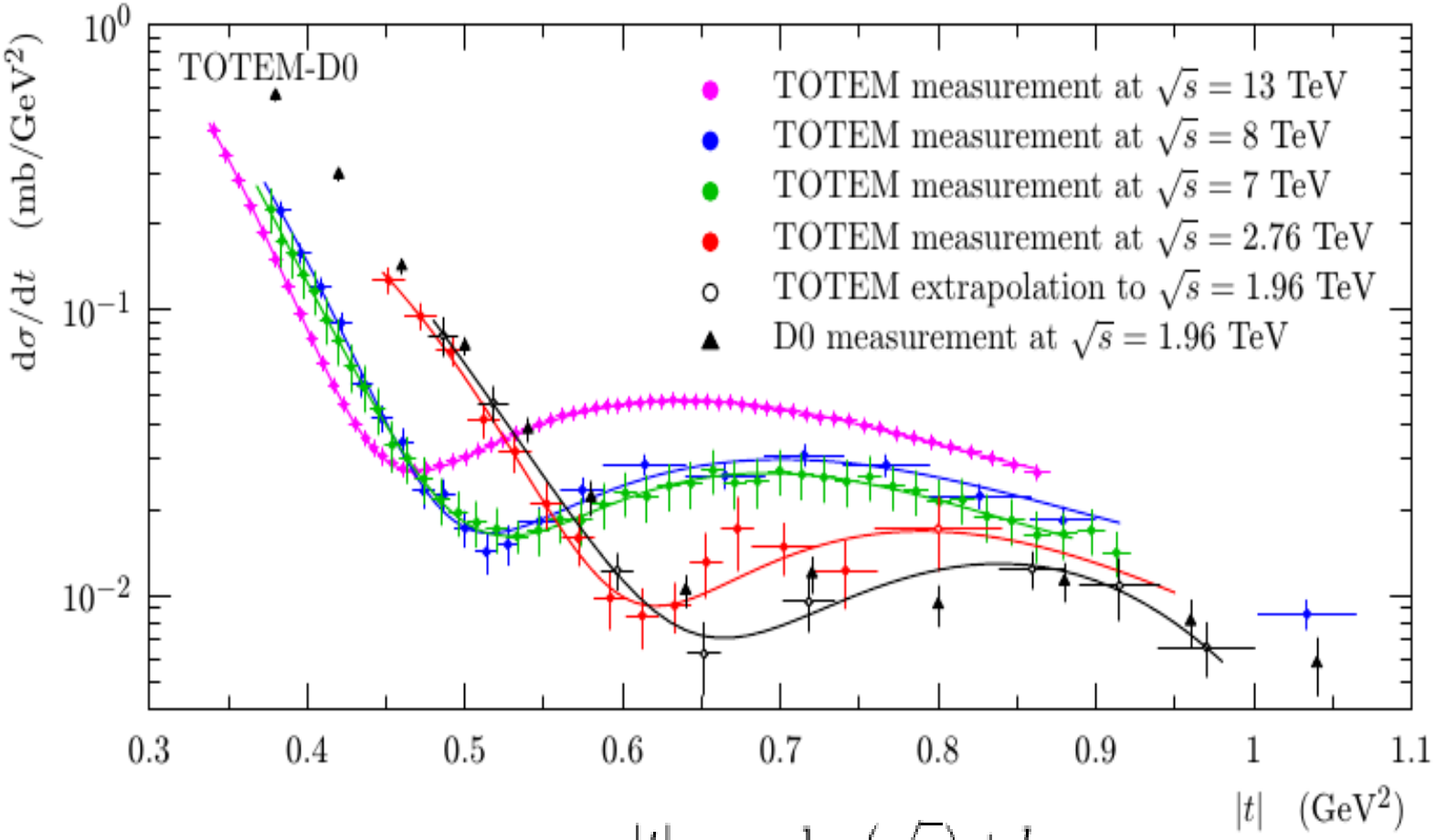


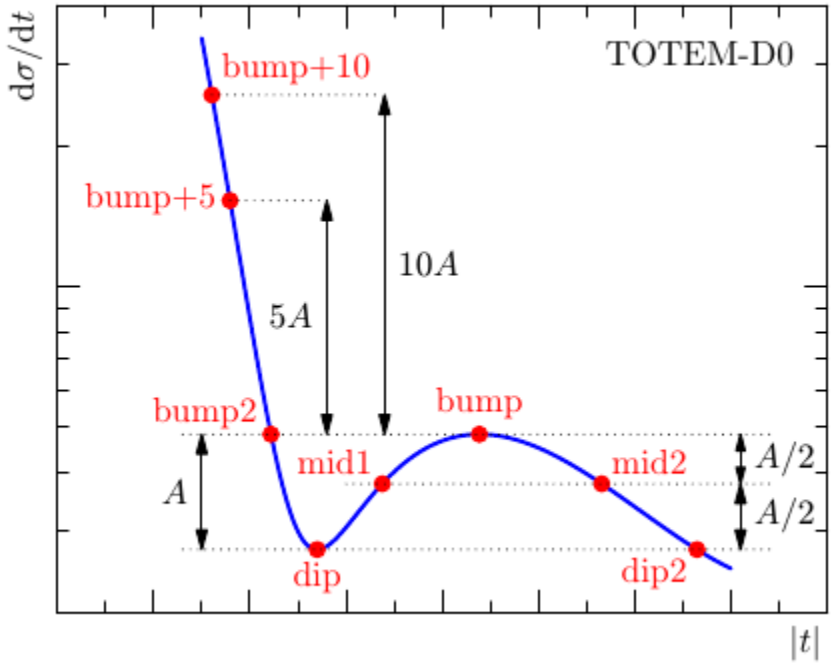
Fig. 6 pp and $\bar{p}p$ differential cross sections at $\sqrt{s} = 53$ GeV


2.76 TeV
1.96 TeV
10^7
10^6
10^5
10^4



$$|t| = a \log(\sqrt{s}) + b$$

$$(d\sigma/dt) = c\sqrt{s} + d.$$



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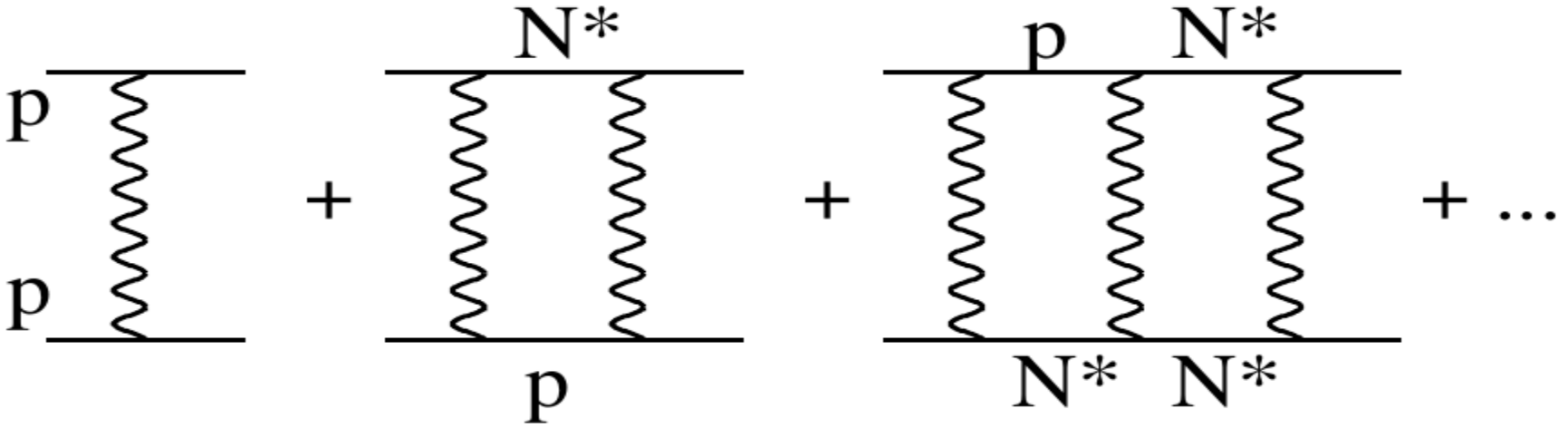
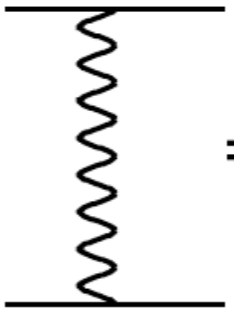
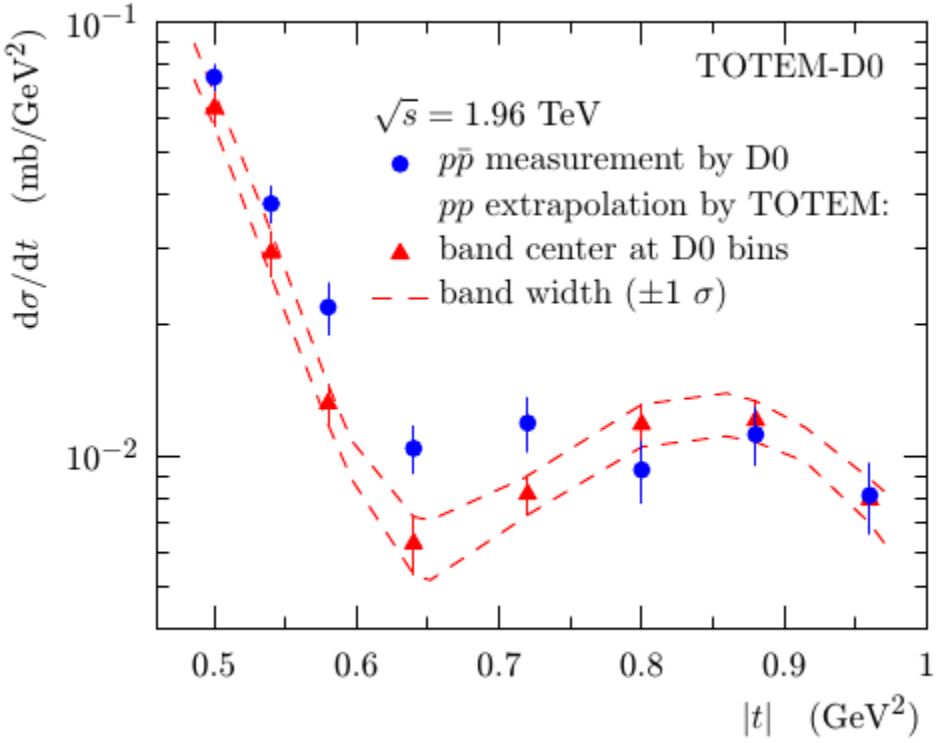


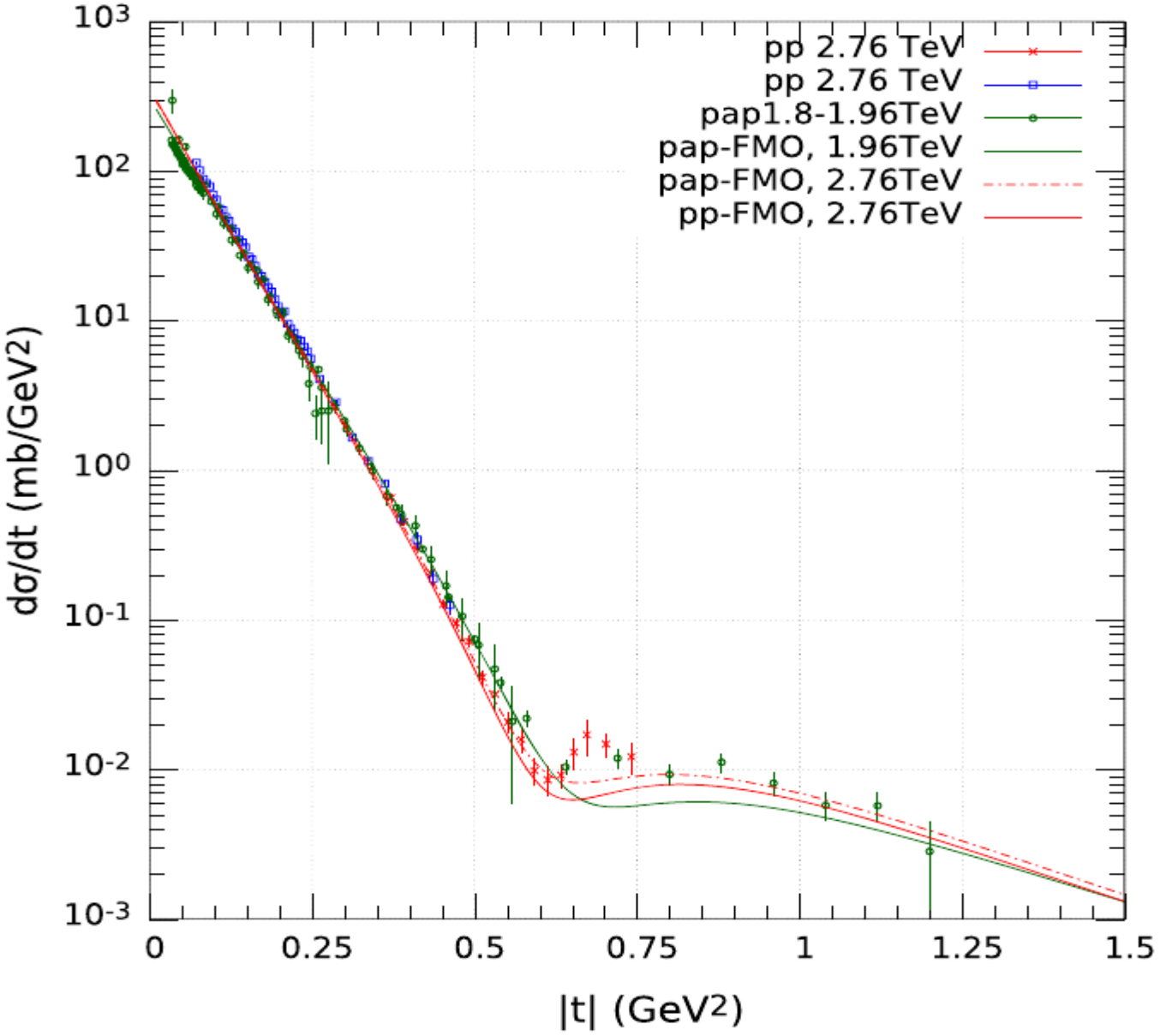
$$A(b) = i(1 - e^{i\chi(b)})$$



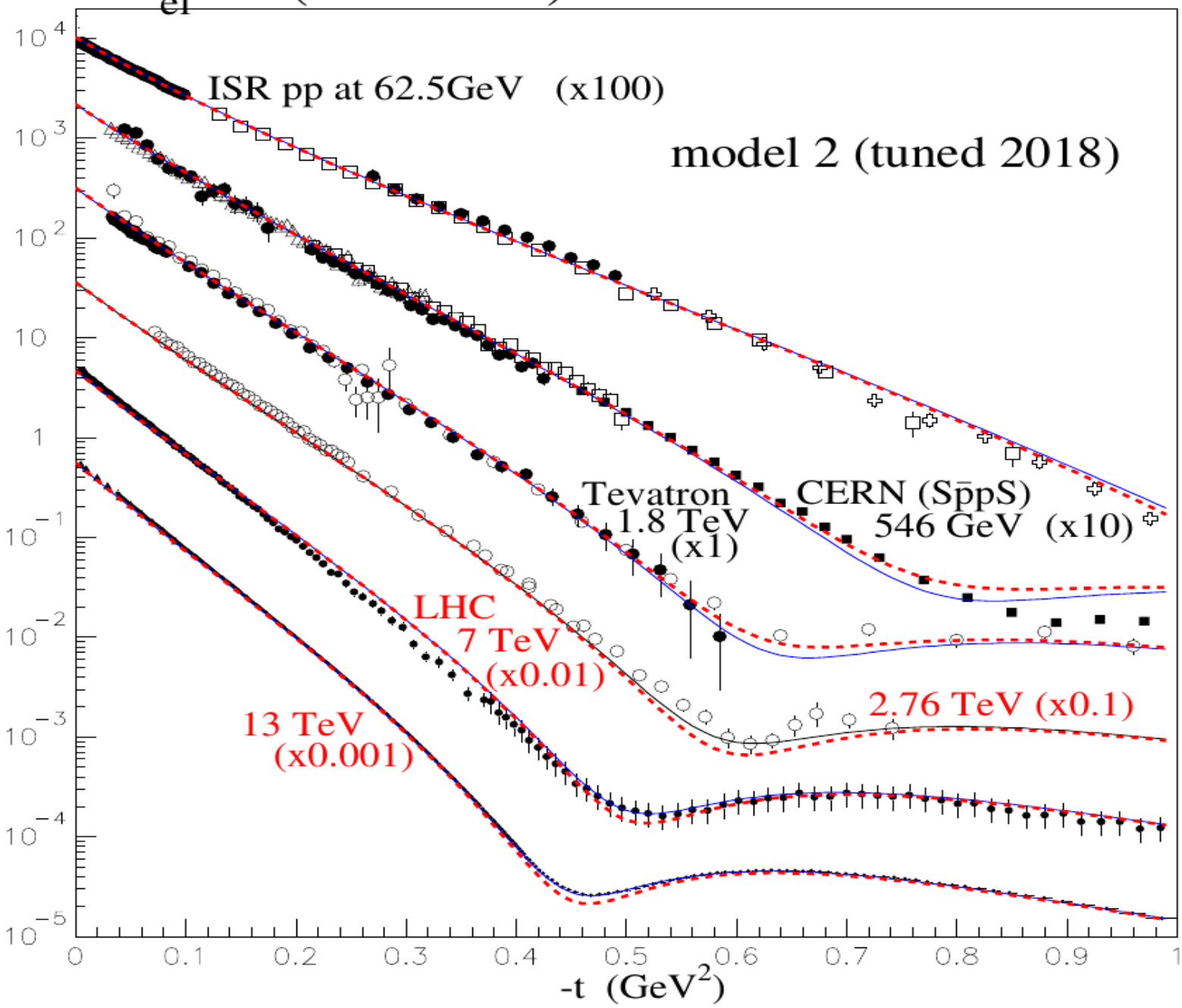
=χ(b)=Pom + Odd

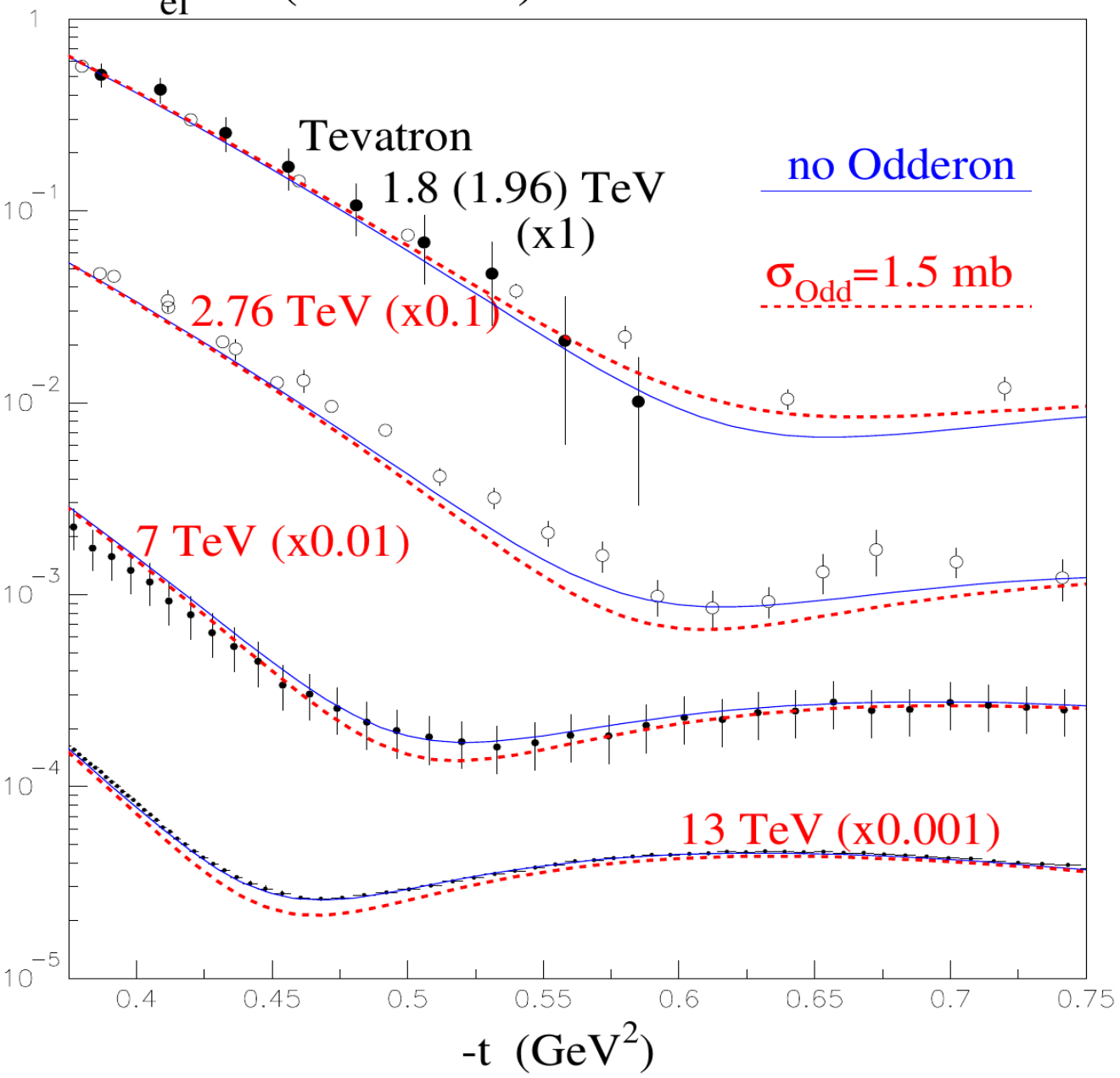
$$A(t = -q^2) = \frac{s}{4\pi^2} \int A(b) e^{ibq} d^2b$$


TOTEM-D0
$\sqrt{s} = 1.96$ TeV
$p\bar{p}$ measurement by D0
pp extrapolation by TOTEM:
band center at D0 bins
band width ($\pm 1\ \sigma$)
10^{-1}
10^{-2}
$\mathrm{d}\sigma/\mathrm{d}t$ (mb/GeV^2)
0.5
0.6
0.7
0.8
0.9
1
$|t|$ (GeV^2)



Martynov-Nicolesku, Eur. Phys. J. C (2019) 79:461


dσel/dt (mb/GeV2)
ISR pp at 62.5GeV (x100)
model 2 (tuned 2018)
Tevatron
1.8 TeV
(x1)
CERN (SppS)
546 GeV (x10)
LHC
7 TeV
(x0.01)
2.76 TeV (x0.1)
13 TeV
(x0.001)
-t (GeV2)

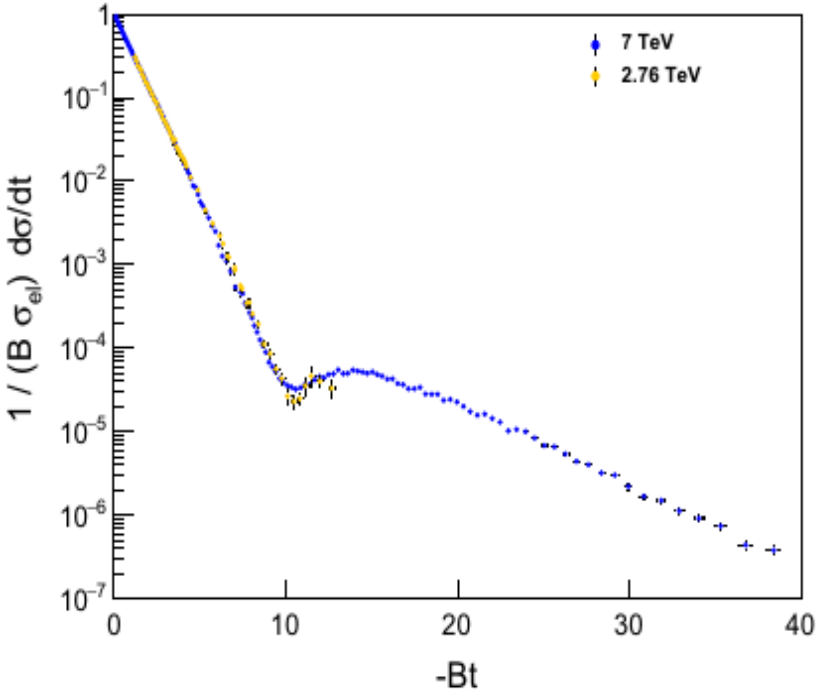

$d\sigma_{el}/dt$ (mb/GeV^2)
Tevatron
1.8 (1.96) TeV
(x1)
no Odderon
σ_{Odd}=1.5 mb
2.76 TeV (x0.1)
7 TeV (x0.01)
13 TeV (x0.001)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
-t (GeV^2)

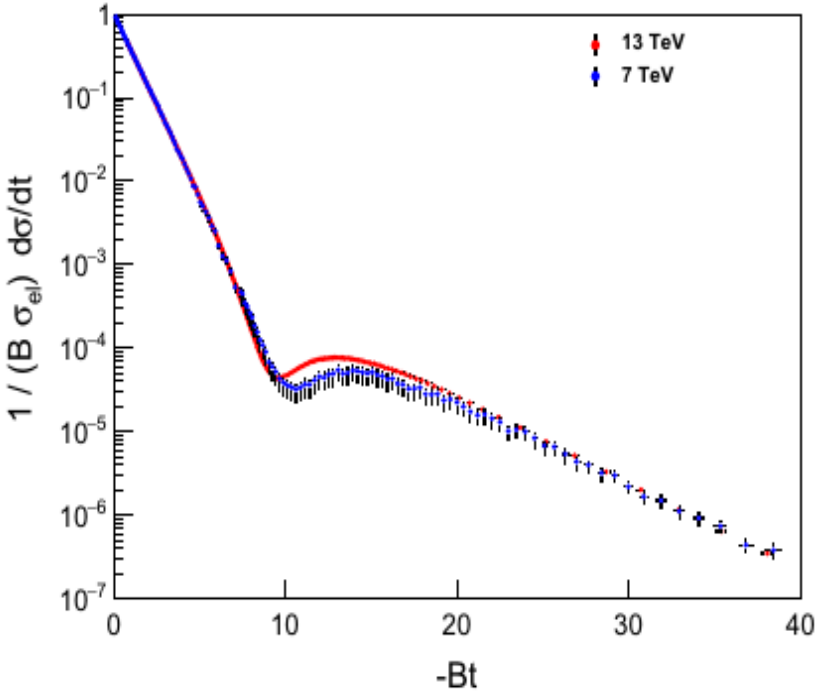
$$F^{MO} = \ln s \left[O_1 \ln^2(-is) + O_2 \ln(-is) + O_3 \right]$$

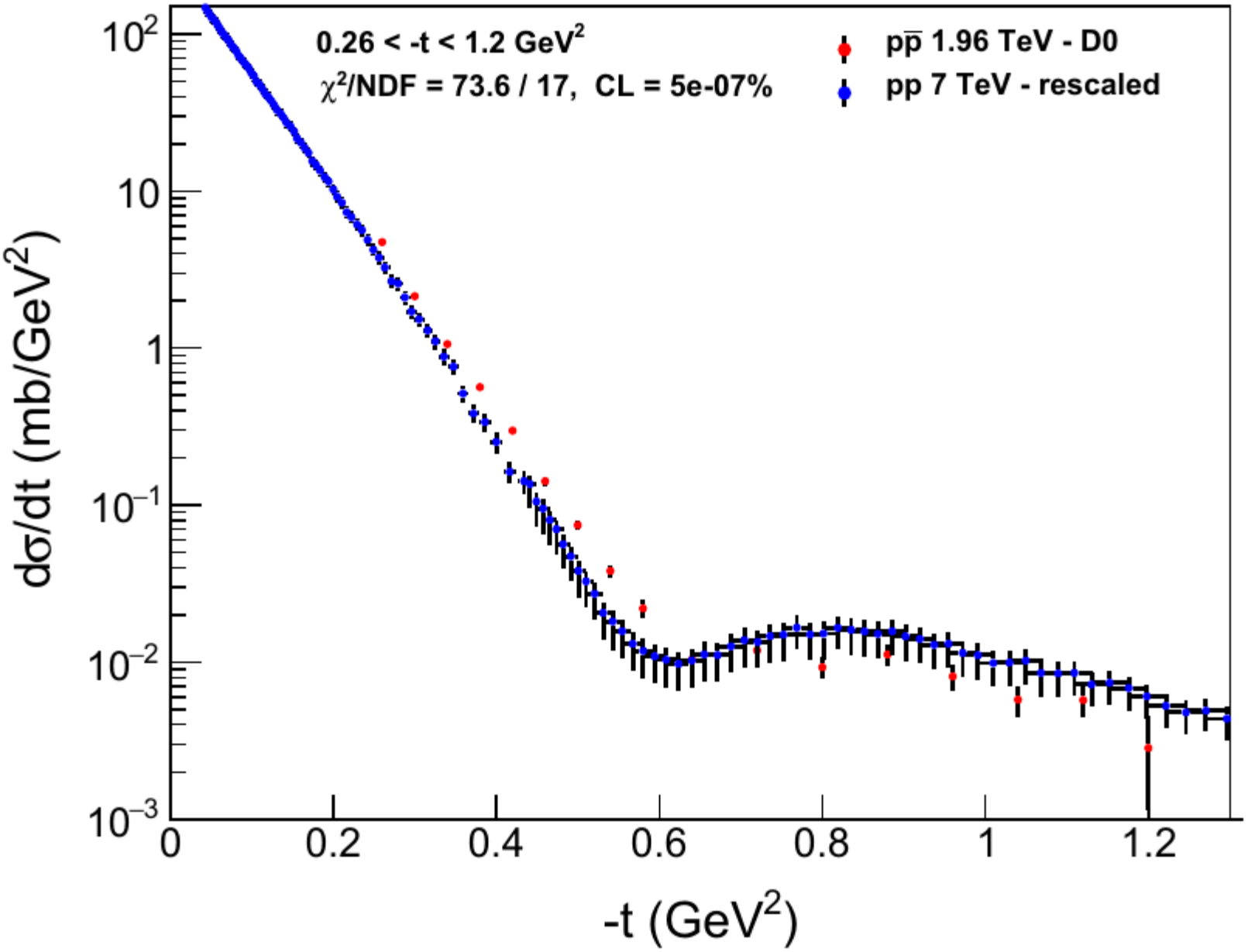
	FMO		FMO-C	
O_1 (mb)	−0.44278E−01	0.20397E−03	0.42841E−01	0.17151E−03
O_2 (mb)	0.93254E+00	0.14218E−01	0.83063E+00	0.14265E−01
O_3 (mb)	−0.17655E+02	0.80820E−01	0.17510E+02	0.76993E−01

$$\chi^2/NDF \simeq 1.6$$

$$H(x) \equiv \frac{1}{B(s)\sigma_{\rm el}(s)}\frac{d\sigma}{dt},$$
$$x = -tB(s).$$

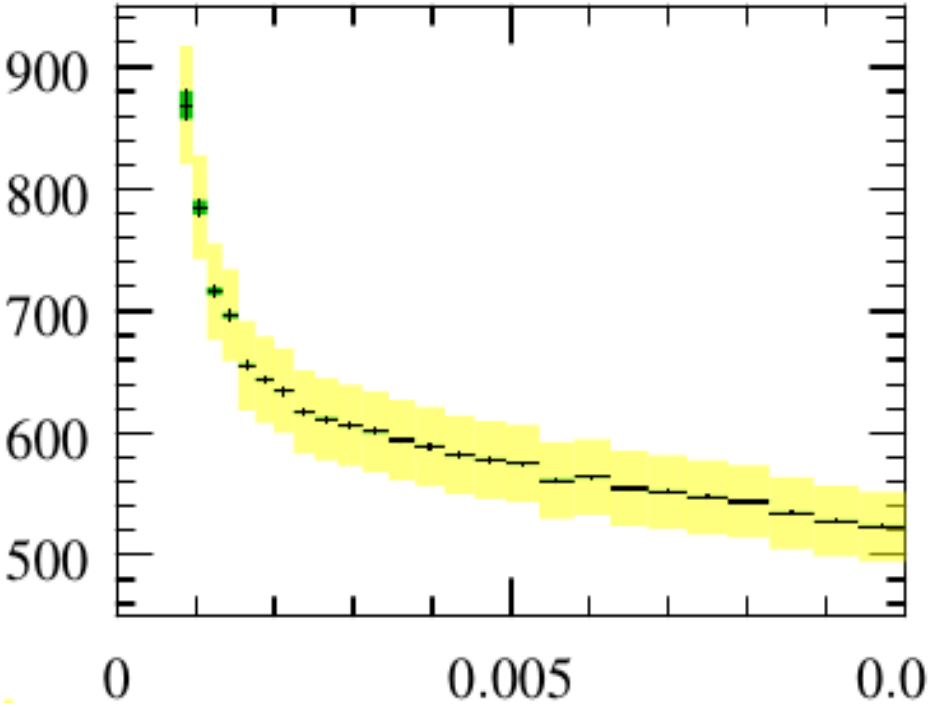


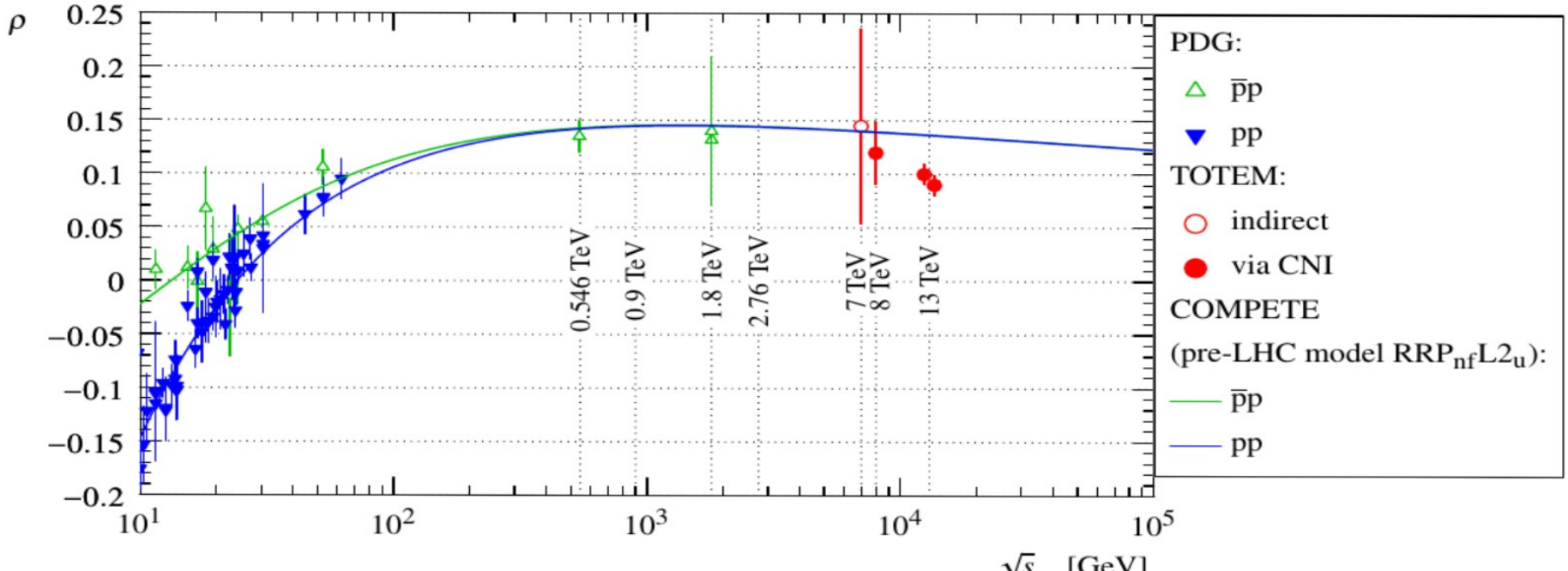



0.26 < -t < 1.2 GeV²
χ²/NDF = 73.6 / 17, CL = 5e-07%
pp̄ 1.96 TeV - D0
pp 7 TeV - rescaled
dσ/dt (mb/GeV²)
-t (GeV²)
10²
10
1
10⁻¹
10⁻²
10⁻³
0
0.2
0.4
0.6
0.8
1
1.2

σ_{el} (mb)	interpolation	direction of comparison	χ^2	NDF	CL [%]	Odderon significance in units of σ
17.6 ± 1.1	lin-exp	7 --> 1.96 TeV	84.6	17	5.8E-09	6.55
		1.96 --> 7 TeV	289	65	5.3E-28	11.38
	lin-lin	7 --> 1.96 TeV	91.1	17	3.8E-10	6.94
		1.96 --> 7 TeV	314	65	2.6E-32	12.22
20.2 ± 1.4	lin-exp	7 --> 1.96 TeV	90	17	6.1E-10	6.88
		1.96 --> 7 TeV	309	65	1.9E-31	12.05
	lin-lin	7 --> 1.96 TeV	96.2	17	4.5E-11	7.24
		1.96 --> 7 TeV	335	65	5.4E-36	12.89

σ_{el} (mb)	interpolation	direction of comparison	χ^2	NDF	CL [%]	Odderon significance in units of σ
17.6 ± 1.1	lin-exp	2.76 --> 1.96 TeV	7.64	11	74.5	0.33
		1.96 --> 2.76 TeV	20.30	27	81.8	0.23
	lin-lin	2.76 --> 1.96 TeV	7.90	11	72.2	0.36
		1.96 --> 2.76 TeV	24.50	27	60.2	0.52
20.2 ± 1.4	lin-exp	2.76 --> 1.96 TeV	3.85	11	97.4	0.03
		1.96 --> 2.76 TeV	15.40	27	96.3	0.05
	lin-lin	2.76 --> 1.96 TeV	4.32	11	96.0	0.05
		1.96 --> 2.76 TeV	18.20	27	89.7	0.13


900
800
700
600
500
0
0.005
0.01


ρ
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
10^1
10^2
10^3
10^4
10^5
0.546 TeV
0.9 TeV
1.8 TeV
2.76 TeV
7 TeV
8 TeV
13 TeV
PDG:
p̄p
pp
TOTEM:
indirect
via CNI
COMPETE
(pre-LHC model RRP_nfL2_u):
p̄p
pp

Dispersion relation

$$\mathrm{Re}A(s,t=0) = \frac{1}{\pi}\int_{-\infty}^{0}\frac{ds'\mathrm{Im}A(s',t)}{s'-s} + \frac{1}{\pi}\int_{4m^2}^{\infty}\frac{ds'\mathrm{Im}A(s',t)}{s'-s}$$

$$\mathrm{Im}A(s,0) = \sigma_{tot}$$

$$\mathrm{Re}A(s,t=0) = \frac{1}{\pi}\int_{-\infty}^{0}\frac{ds'\sigma(p\bar{p})(-s'+4m^2)}{s'-s} + \frac{1}{\pi}\int_{4m^2}^{\infty}\frac{ds'\sigma(pp)(s')}{s'-s}$$

for $\alpha_{Odd} \simeq 1$

$$\mathrm{Re}A_{Odd} \sim \ln s \cdot \mathrm{Im}A_{Odd} \text{ i.e. } \mathrm{Re}A_{Odd} >> \mathrm{Im}A_{Odd}$$

$$\mathrm{Re}A_{even} << \mathrm{Im}A_{even}$$

$$\mathrm{Re}A_{even}(s,t=0) \simeq \frac{2s}{\pi}\int_{4m^2}^{\infty}\frac{ds'\sigma(pp)}{s'^2-s^2} \simeq \frac{\pi}{2}\frac{\partial\sigma(s)}{\partial\ln s}$$

TOTEM 13 TeV $\sigma_{tot} = 110.6 \pm 3.4$ **mb**

$(110.3 \pm 3.5)_{Coulomb}$ ==> 110.5 ± 2.4 **mb**

$\rho = Re/Im = 0.10 \pm 0.01_{N=3}$ $(0.09 \pm 0.01_{N=1})$

arXiv: 1712.06153; 1812.04732

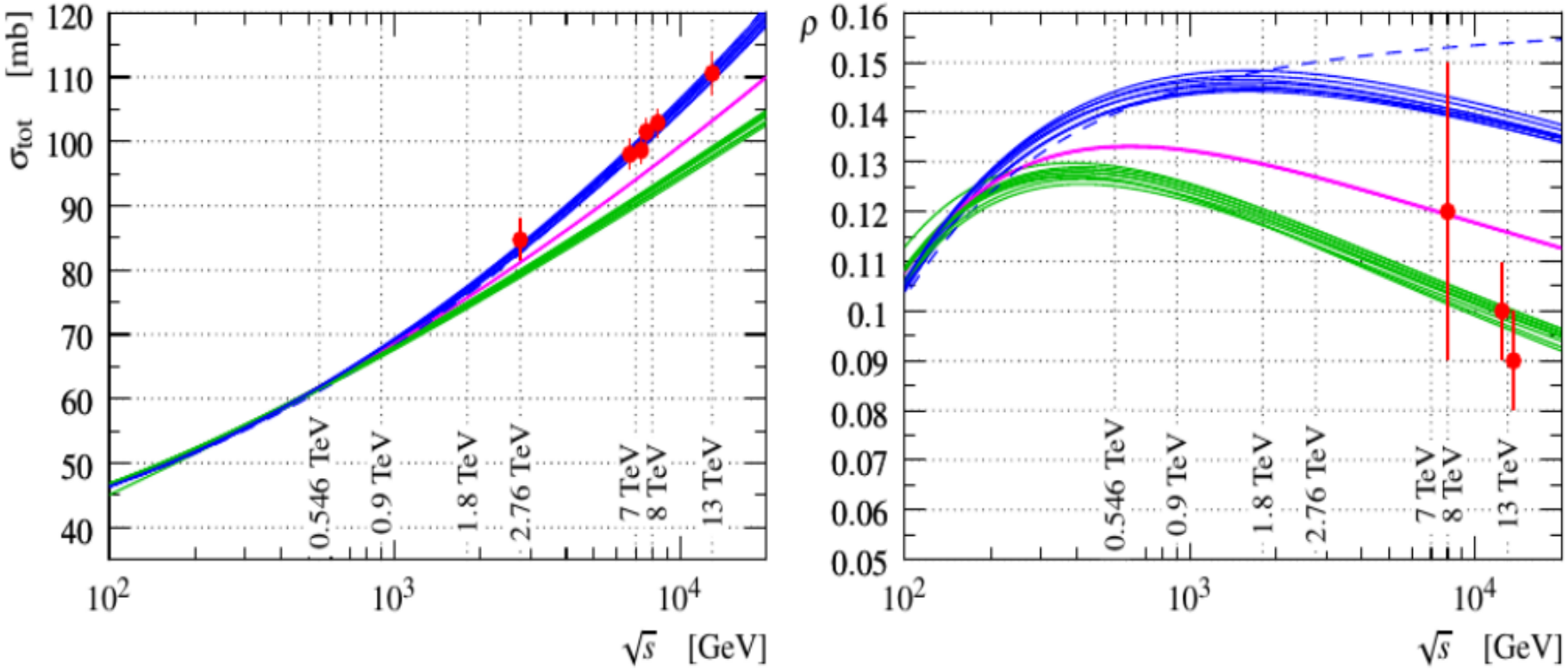
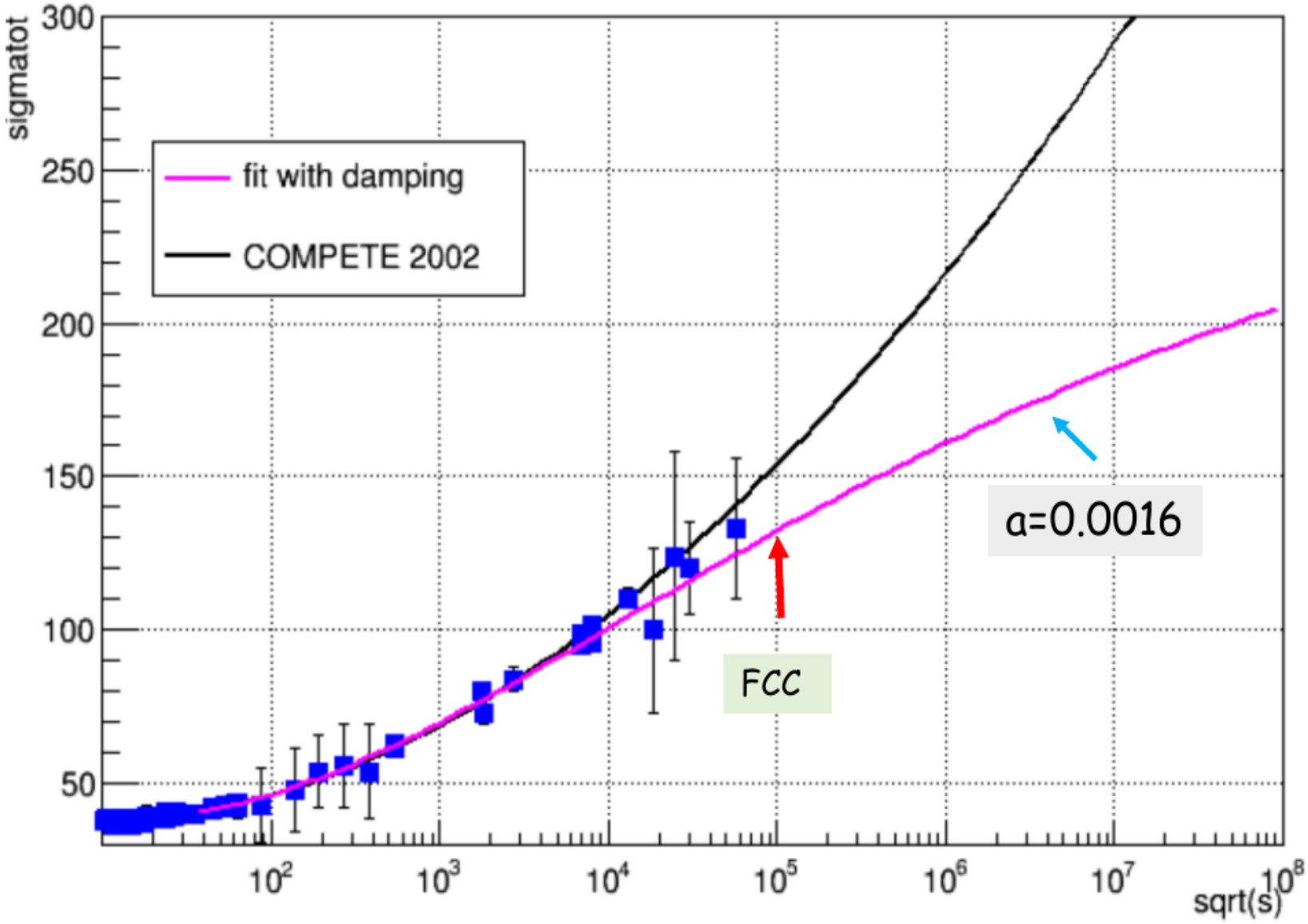
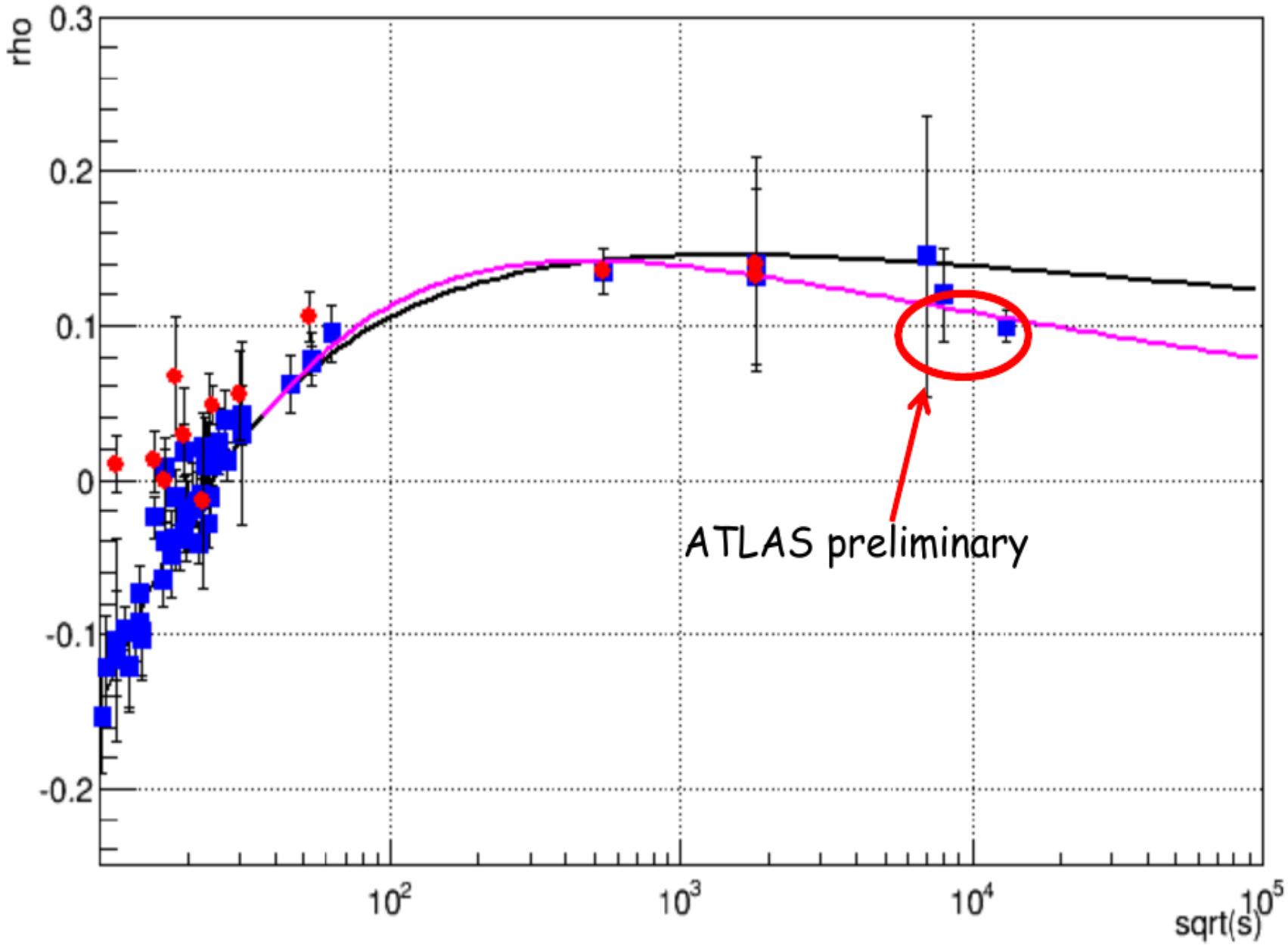


Fig. 18: Predictions of COMPETE models [32] for pp interactions. Each model is represented by one line (see

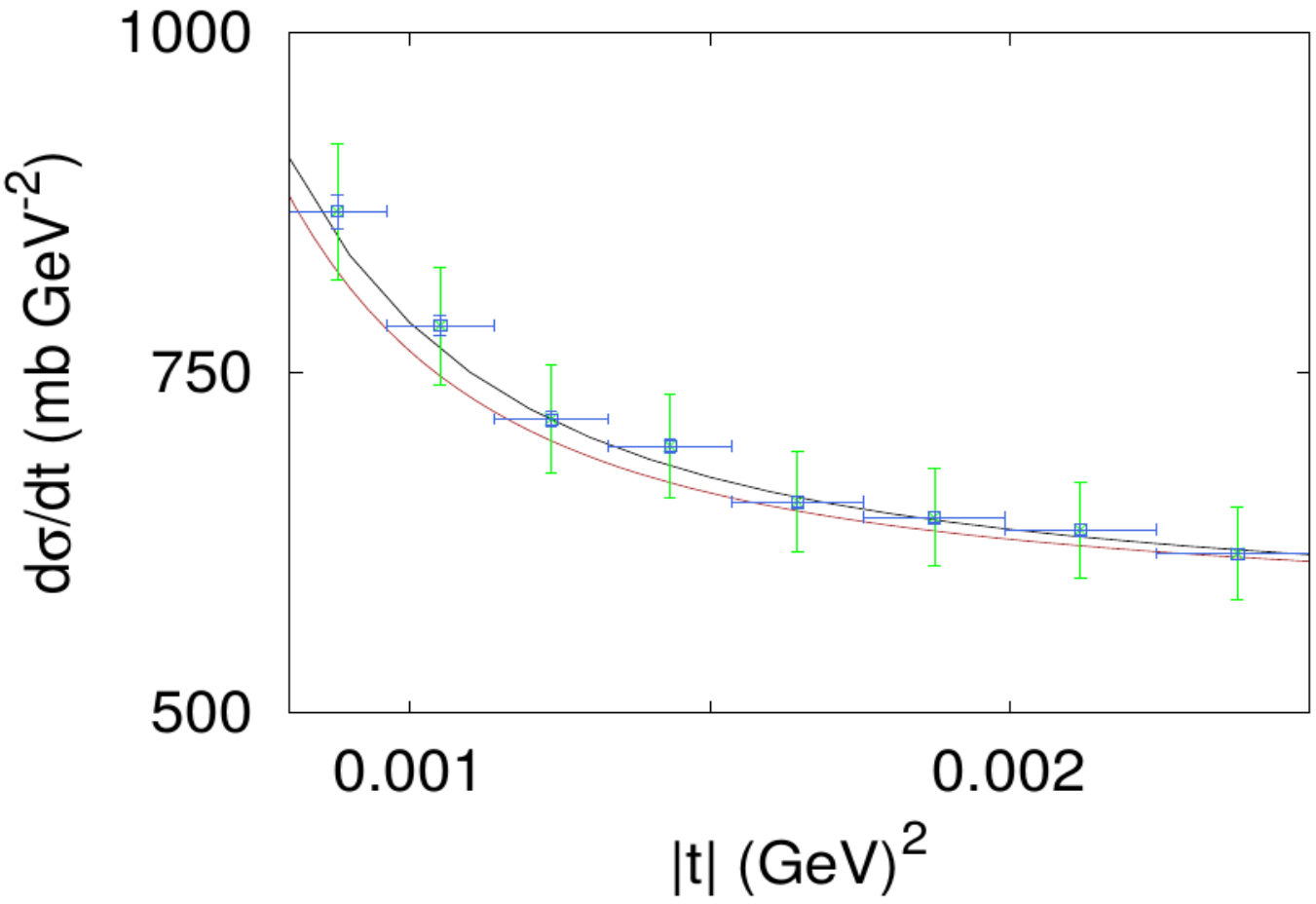


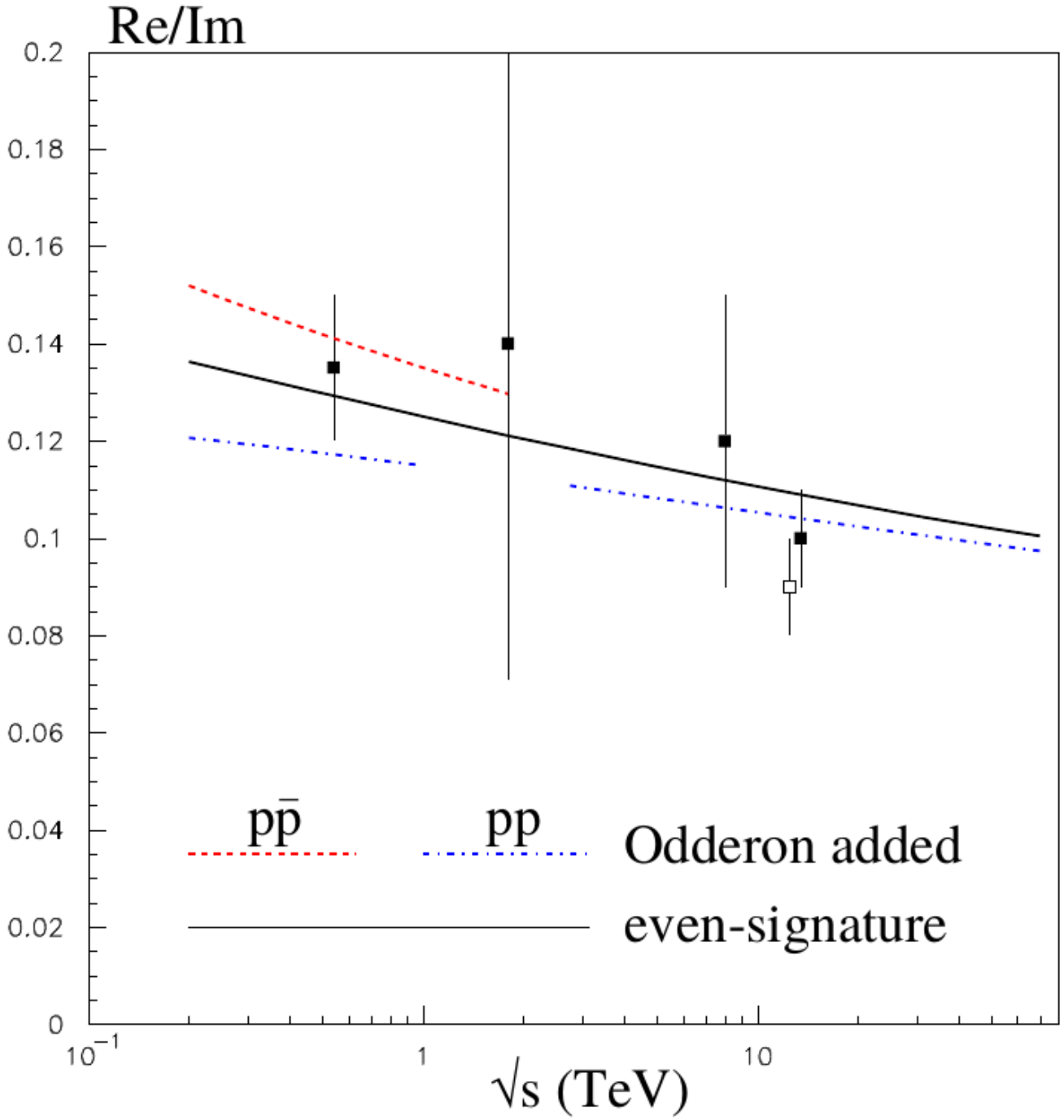
Per Grafstrom
University of Bologna
November 2020


rho
0.3
0.2
0.1
0
-0.1
-0.2
10^2
10^3
10^4
10^5
sqrt(s)
ATLAS preliminary

Donnachie-Landshoff, Phys.Lett.B 798 (2019) 135008

No Odderon ($0 < |t| < 0.1$ GeV^2)




Re/Im
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10^{-1}
1
10
√s (TeV)
pp̄
pp
Odderon added
even-signature

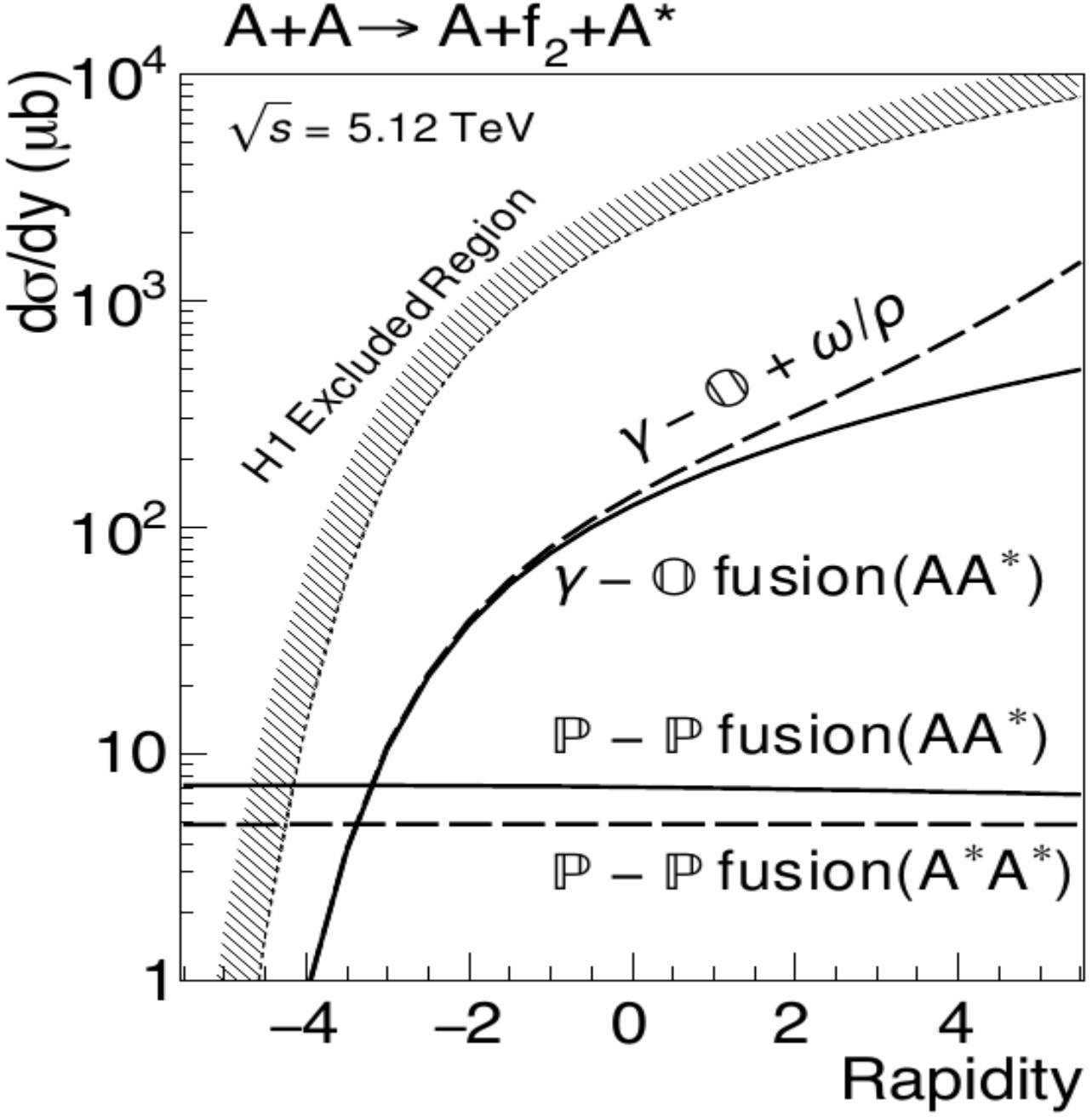
C-even meson photoproduction

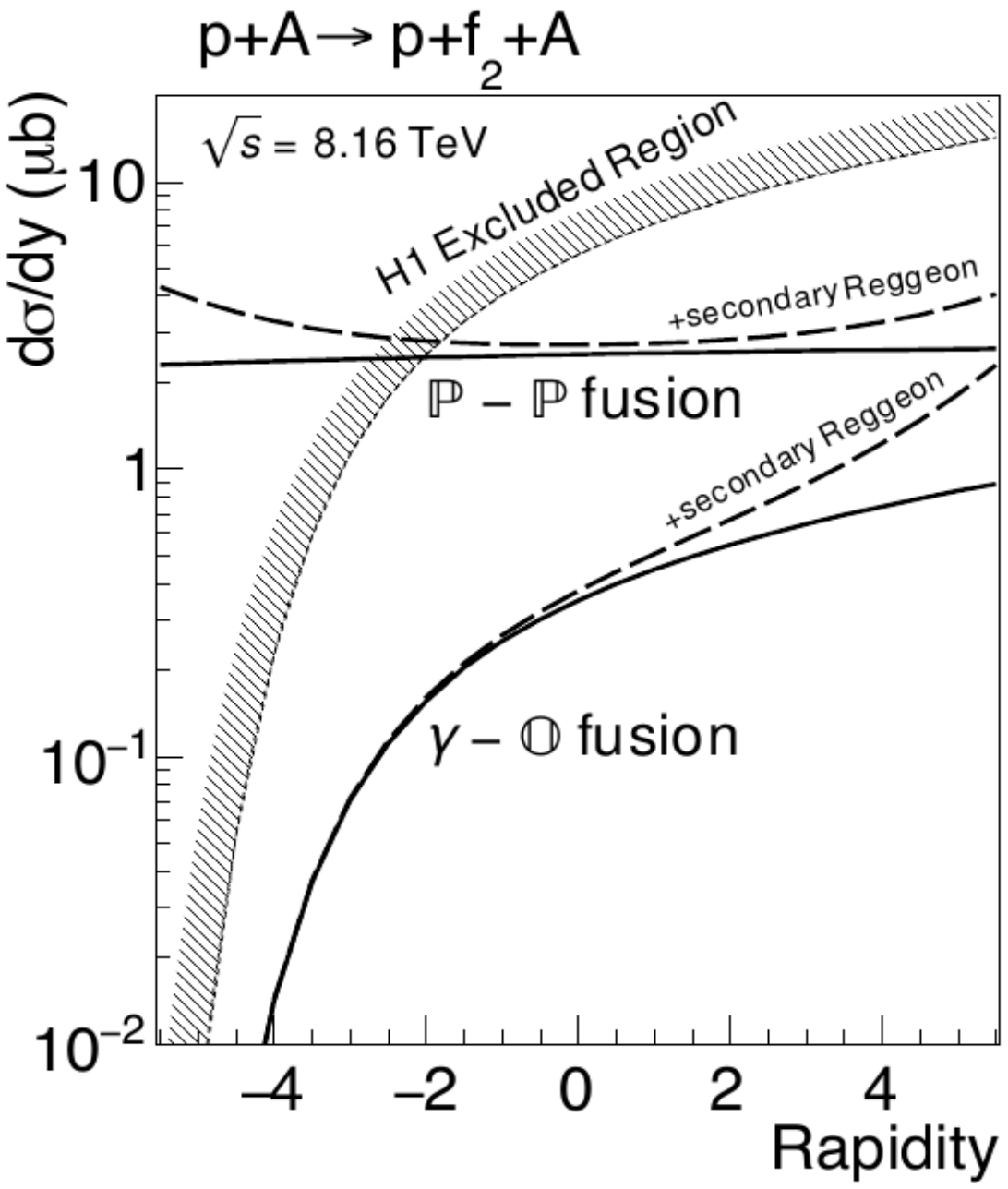
$\sigma(\gamma p \to \pi^0 p) \sim 300$ **nb** $(< 39$**nb - HERA**$)$

(Rueter, Dosch, Nachtmann Ph.Rev. D59 (1999) 014018)

C-even meson (M)	Odderon Signal		Backgrounds		
	Upper Limit	QCD Prediction	$\gamma\gamma$	Pomeron-Pomeron	$V \to M + \gamma$
π^0	7.4	0.1 - 1	0.044	–	30
$f_2(1270)$	3	0.05 - 0.5	0.020	3 - 4.5	0.02
$\eta(548)$	3.4	0.05 - 0.5	0.042	negligible	3
η_c	–	$(0.1 - 0.5) \cdot 10^{-3}$	0.0025	$\sim 10^{-5}$	0.012

Table 3: The expected cross sections ($d\sigma/dY_M$ at $Y_M = 0$ in μb) of the Odderon signal and backgrounds in the CEP* ultraperipheral production of C-even mesons (M) in high-energy proton-lead collisions $(Pb + p \to Pb + M + X)$ integrated over the interval $0.2 < p_\perp < 1$ GeV. In the η_c case a total branching ratio of 0.05 has been applied, i.e. summing over the channels discussed in


A+A→ A+f2+A*
√s = 5.12 TeV
dσ/dy (μb)
10^4
10^3
10^2
10
1
H1 Excluded Region
γ – 𝕆 + ω/ρ
γ – 𝕆 fusion(AA*)
ℙ – ℙ fusion(AA*)
ℙ – ℙ fusion(A*A*)
–4
–2
0
2
4
Rapidity


p+A→ p+f2+A
√s = 8.16 TeV
H1 Excluded Region
+secondary Reggeon
ℙ – ℙ fusion
+secondary Reggeon
γ – ℙ fusion
dσ/dy (μb)
10
1
10−1
10−2
–4
–2
0
2
4
Rapidity

THANK YOU

Bethe phase $\phi = \ln \frac{B|t|}{2} + \gamma + const$

ρ **depends on const. For** $\phi = 0$

Kohara-Ferreira-Rangel (Ph.Lett. B789, p.1)

got $\rho = 0.131$ **with** $\chi^2/ndf = 0.94$

$\rho = 0.112 \pm 0.005$ **for const=2** $(\chi^2/ndf = 0.96)$

Cudell-Selyugin (1901.05863) accounts for correlated errors and normalization factor n**.**

They got (const=0):

$\sigma_{tot} = 106.4 \pm 2.2$ **mb,** $\rho = 0.098 \pm 0.008$**,**

$n = 0.91 \pm 0.04$ $(\chi^2/ndf = 0.81)$

(79 points $0.0008 < |t| < 0.07$ $\mathbf{GeV}^2$**)**

$\sqrt{s}$	ρ	$\sigma_{\rm tot}$	$\sigma_{\rm el}$	$B_{\rm el}(t=0)$	σ^{D}_{lowM}
(TeV)		mb	mb	(GeV^{-2})	mb
0.1	0.141	48.3	8.8	12.6	2.6
0.546	0.129	64.6	13.8	14.8	3.5
1.8	0.121	78.1	18.2	16.7	4.2
7	0.113	95.5	24.1	19.1	5.0
8	0.112	97.4	24.7	19.4	5.1
13	0.109	104.2	27.1	20.4	5.4
100	0.099	136.2	38.6	25.4	6.9

Maximal Odderon Violates unitarity

2Im$A_{el}(b) = |A_{el}(b)|^2 + G_{inel}(b)$ **(s-unit.)**

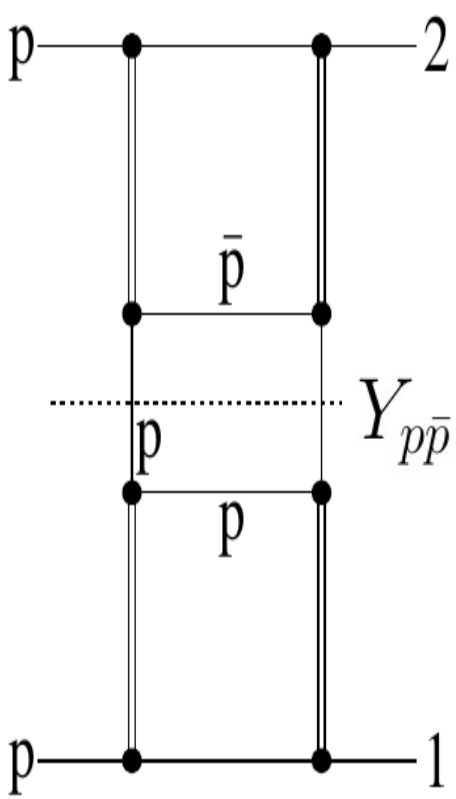
Solution: $A_{el}(b) = i(1 - e^{2i\delta(b)})$ $\qquad l = b\sqrt{s}/2$

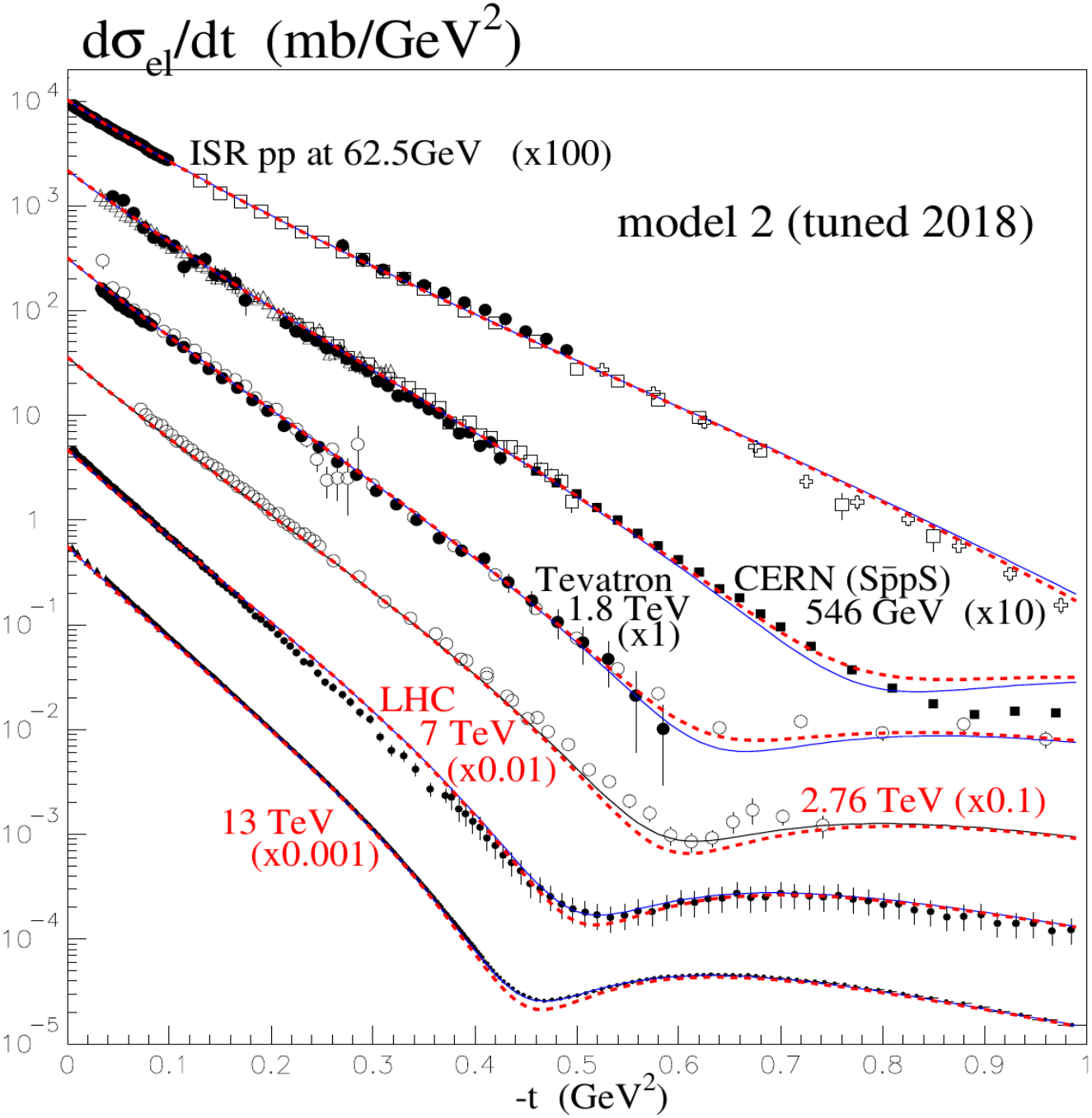
$\delta(b) = \delta_{even} + \delta_{Odd}$ $\quad$ **Im**$\delta_{even}(b) > 0$

Max.Odd. assume $A_{Odd} = a\theta(c \ln s - b)$

Then $\sigma(pp \to p + p\bar{p} + p)(b) \geq c' \ln s$

i.e. **Im**$\delta_{even}(b) \propto \ln s ==> A_{el} = i$

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CERN (S̄ppS)
546 GeV (x10)
LHC
7 TeV
(x0.01)
2.76 TeV (x0.1)
13 TeV
(x0.001)
-t (GeV2)

QCD Odderon

A. Theory

B. Experiment ($d\sigma/dt$)

1. Small $|t|$ $\rho = Re/Im$ at $t = 0$
2. Dip region ($\sqrt{s} = 53$ GeV, $\sqrt{s} = 2.76$ TeV)

C. Vector meson photoproduction

1. HERA limits
2. p+Pb collisions (expectations and background)