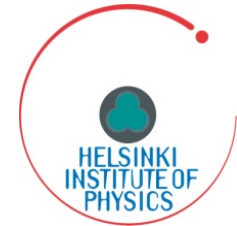


Recent TOTEM results – implications on t-channel exchange of a C-odd colourless 3-gluon compound



K. Österberg,
Department of Physics & Helsinki Institute of
Physics, University of Helsinki
on behalf of the **TOTEM collaboration**

Particle Physics Day 7.11.2019



Outline:

- ✓ Elastic scattering & t-exchange of colourless C-odd 3-gluon compound
- ✓ ρ & σ_{tot} in pp @ $\sqrt{s} = 13$ TeV
- ✓ Elastic pp differential cross-section @ $\sqrt{s} = 2.76$ & 13 TeV
- ✓ Comparison with elastic $p\bar{p}$
- ✓ Summary & next steps



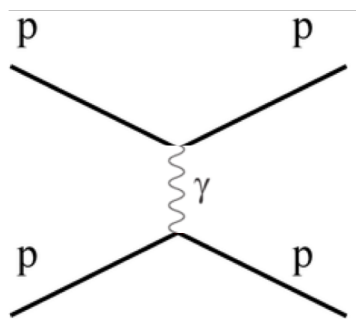
Elastic scattering: t-channel particle exchange

Elastic proton (anti)proton scattering at TeV scale: gluonic exchange

Experimental variable: $t \approx -P^2\theta^2$, four-momentum transfer squared

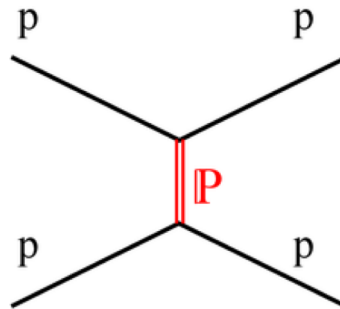
Strong interaction (non-pertutative QCD)

Electromagnetism
(QED): $J^{PC} = 1^{--}$



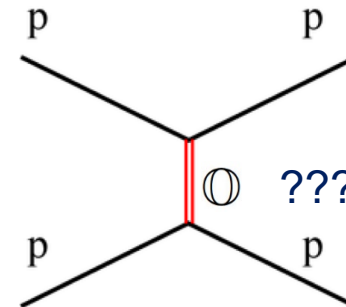
Photon exchange

Crossing even
 $P = C = +$



"Pomeron" exchange:
system of 2 (or more
number of) gluons

Crossing odd
 $P = C = -$



"Odderon" exchange:
system of 3 (or more
number of) gluons



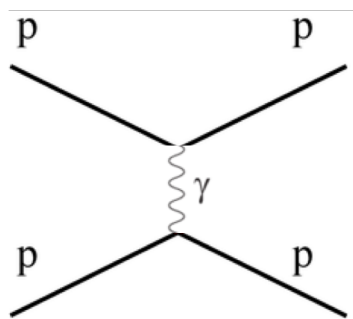
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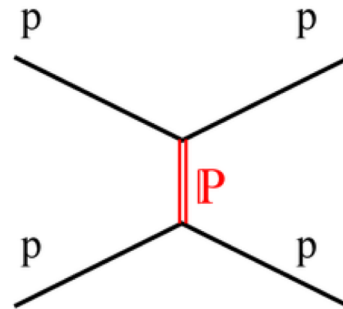
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Photon exchange

dominates at very low $|t|$ ($< \approx 10^{-3}$)

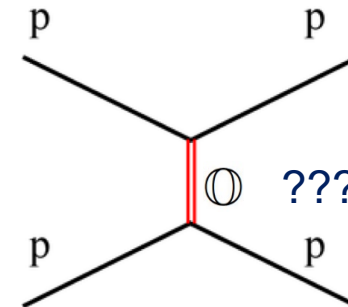
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"Pomeron" exchange:
system of 2 (or more number of) gluons

dominates at low $|t|$,
 \approx imaginary part of A_{el}^{nucl}

Crossing odd
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"Odderon" exchange:
system of 3 (or more number of) gluons

mostly suppressed,
mainly real part of A_{el}^{nucl}
different for pp & $p\bar{p}$

High $|t|$ (\gtrsim few GeV^2): perturbative QCD



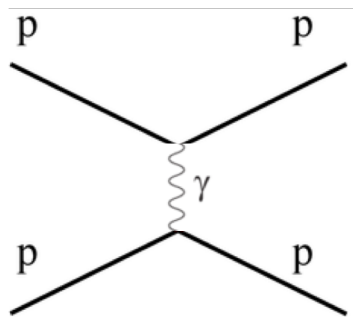
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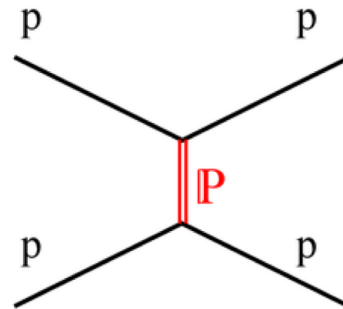


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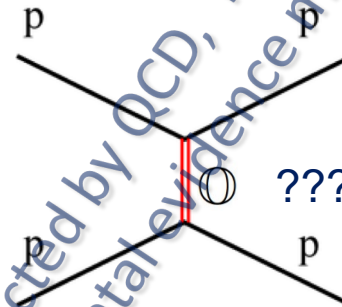
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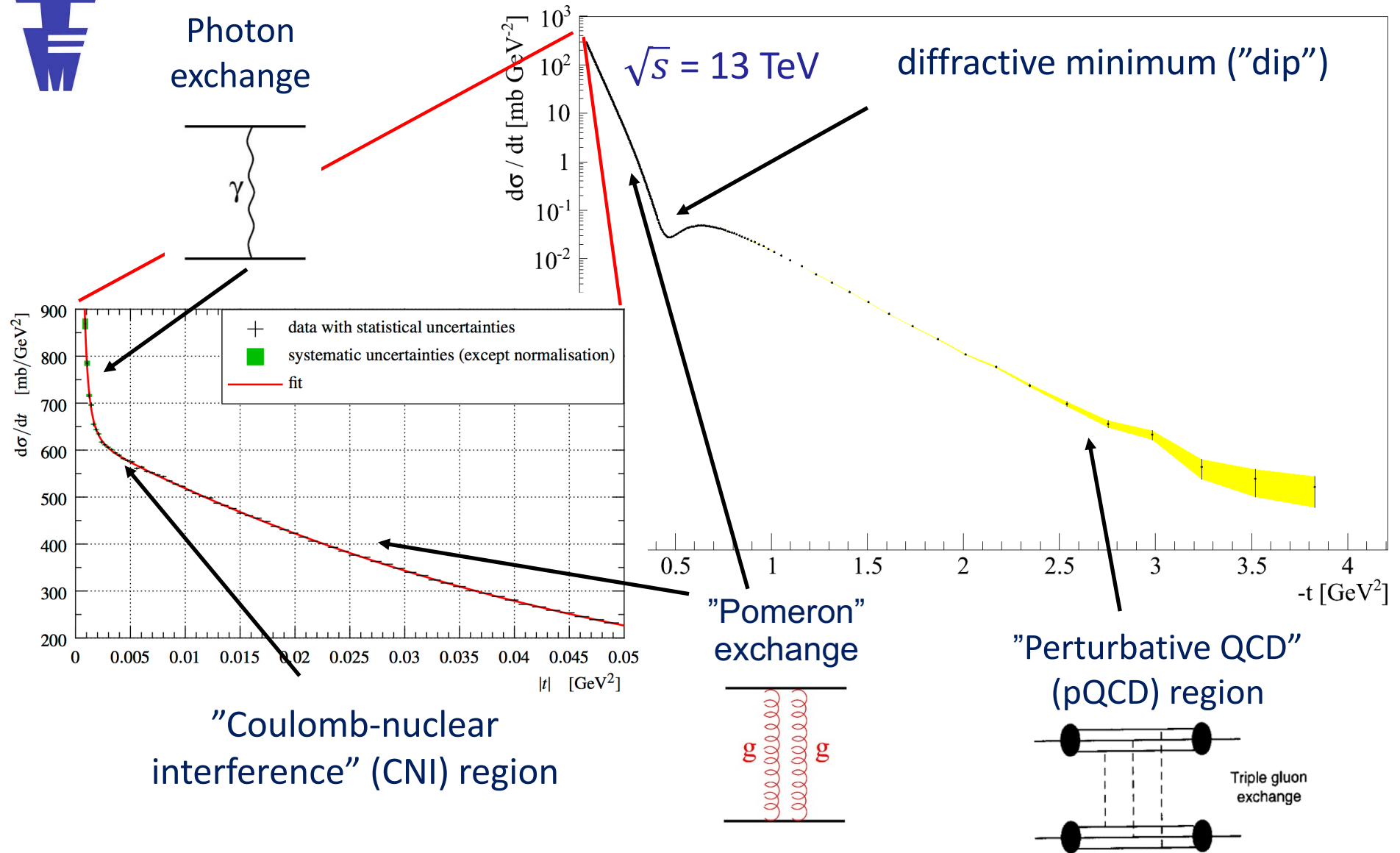
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Predicted by QCD, firm experimental evidence missing



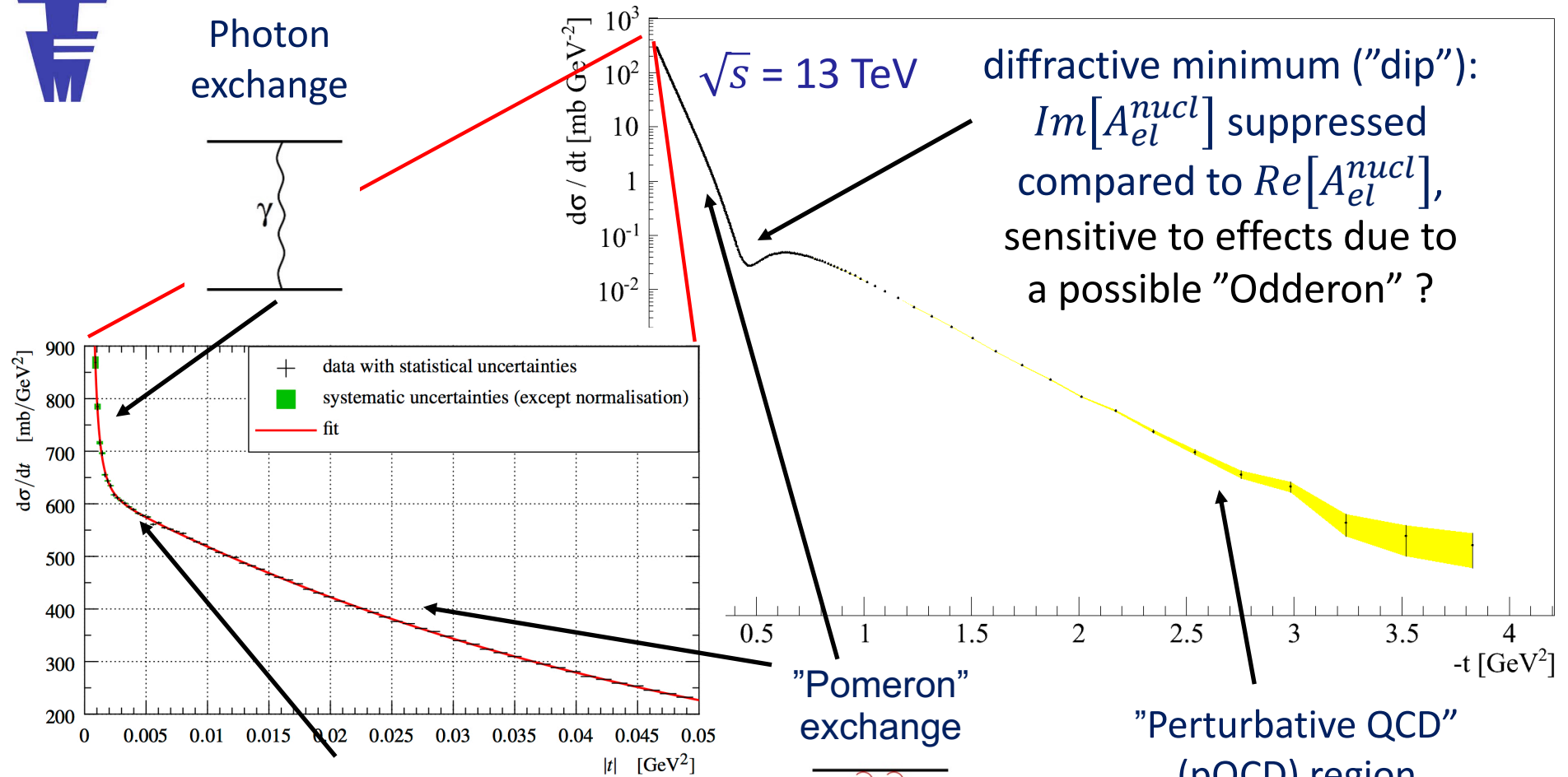
Elastic differential cross-section in pp



A. Donnachie, P. V. Landshoff,
Z. Phys. C 2 (1979) 55.



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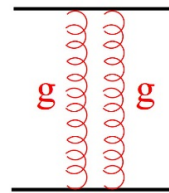


"Coulomb-nuclear interference" (CNI) region

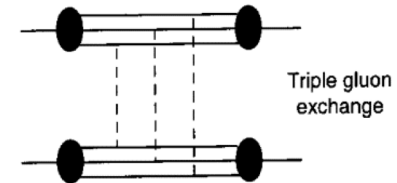
$$\rho \equiv Re[A_{el}^{nucl}] / Im[A_{el}^{nucl}] \Big|_{t=0}$$

sensitive to effects due to a possible "Odderon" ?

"Pomeron" exchange



"Perturbative QCD" (pQCD) region



A. Donnachie, P. V. Landshoff, *Z. Phys. C 2* (1979) 55.

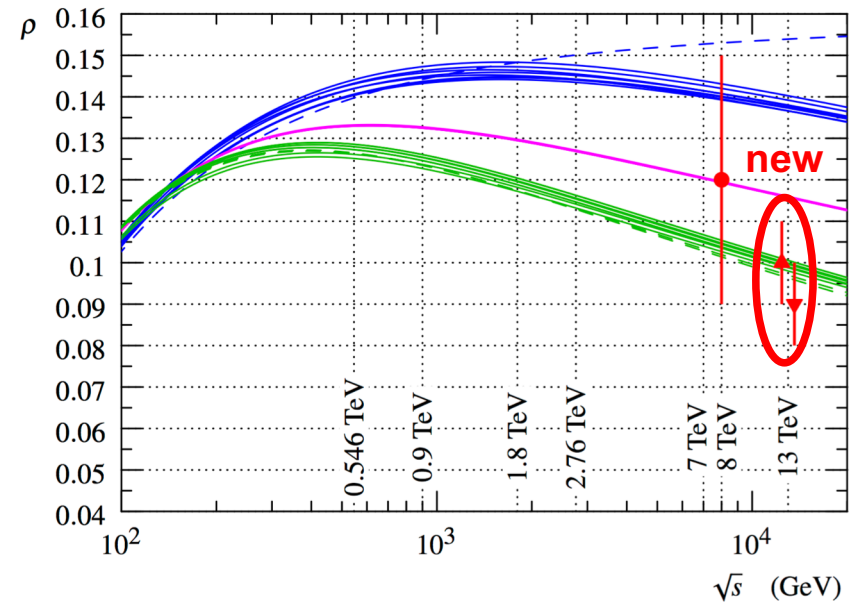
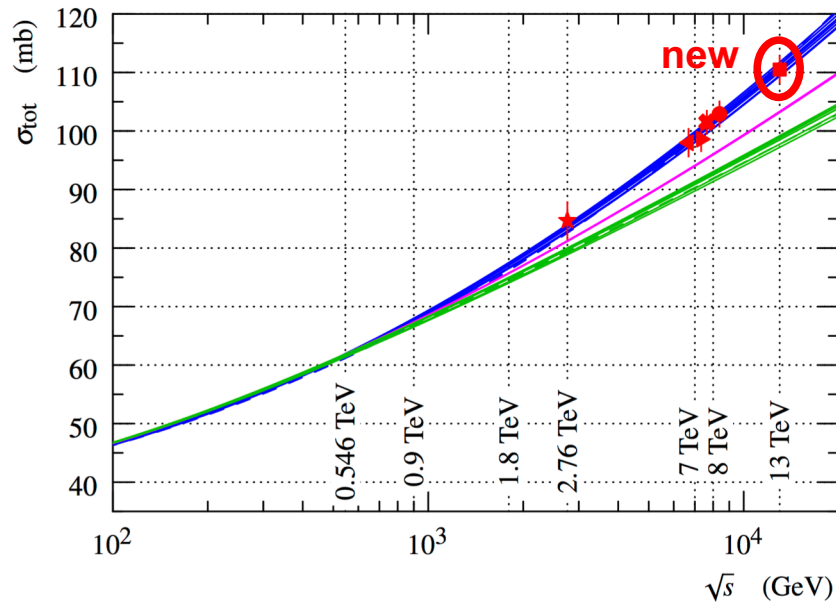


σ_{tot} & ρ measurement in pp @ $\sqrt{s} = 13$ TeV

TOTEM @ $\sqrt{s} = 13$ TeV: $\sigma_{\text{tot}} = 110.5 \pm 2.4$ mb, $\rho = 0.09/0.10 \pm 0.01$
EPJC 79 (2019) 785

Comparison to conventional (no-Odderon) model predictions (*PRL 89 (2002) 201801*):

- (RR)^dPL2 (20), (RR)^dPL2_u (17), (RR)^dPL2_u (19), (RR)^dP^{qc}L2_u (16), (RR_c)^dPL2_u (15), (RR_c)^dP^{qc}L2_u (14), RRPL2_u (19), RRP_{nf}L2_u (21)
- - - RRPE_u (19)
- R^{qc}R_cL2^{qc} (12), RR_cL2^{qc} (15), RRL2 (18), RRL2^{qc} (17)
- R^{qc}R_cL^{qc} (12), R^{qc}RL^{qc} (14), RR_cL^{qc} (15), RR_cPL (19), RRL (18), RRL_{nf} (19), RRL^{qc} (17), RRPL (21)
- - - RR(PL2) (20), RR(PL2)^{qc} (18)



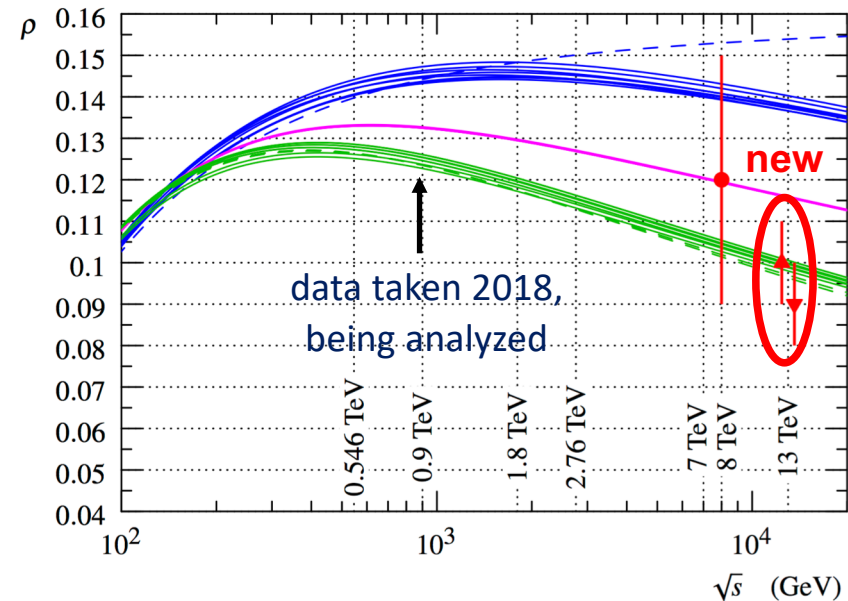
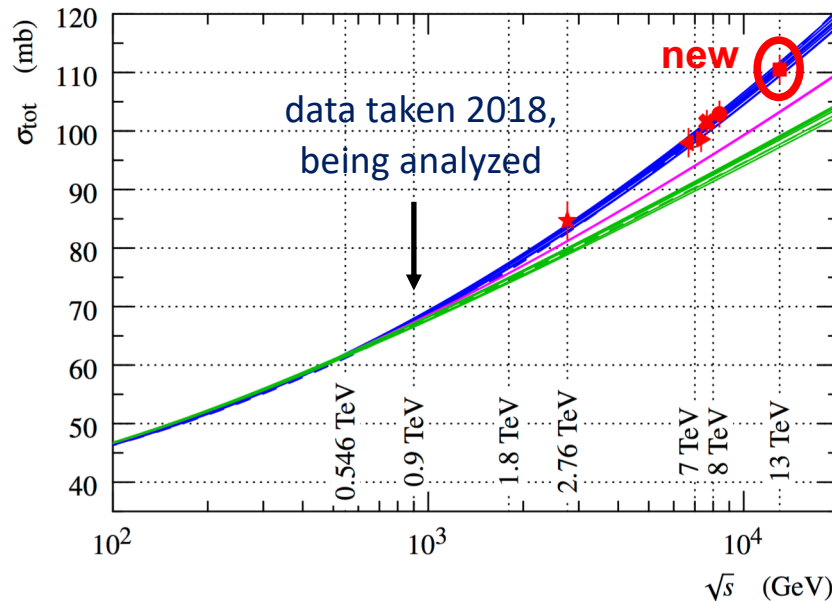


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- R^{qc}R_cL2^{qc} (12), RR_cL2^{qc} (15), RRL2 (18), RRL2^{qc} (17)
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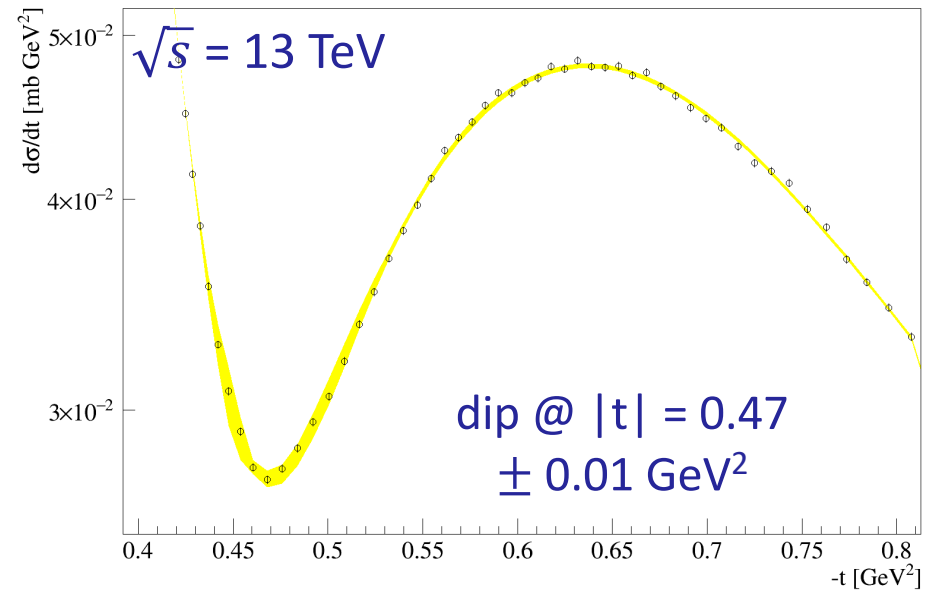
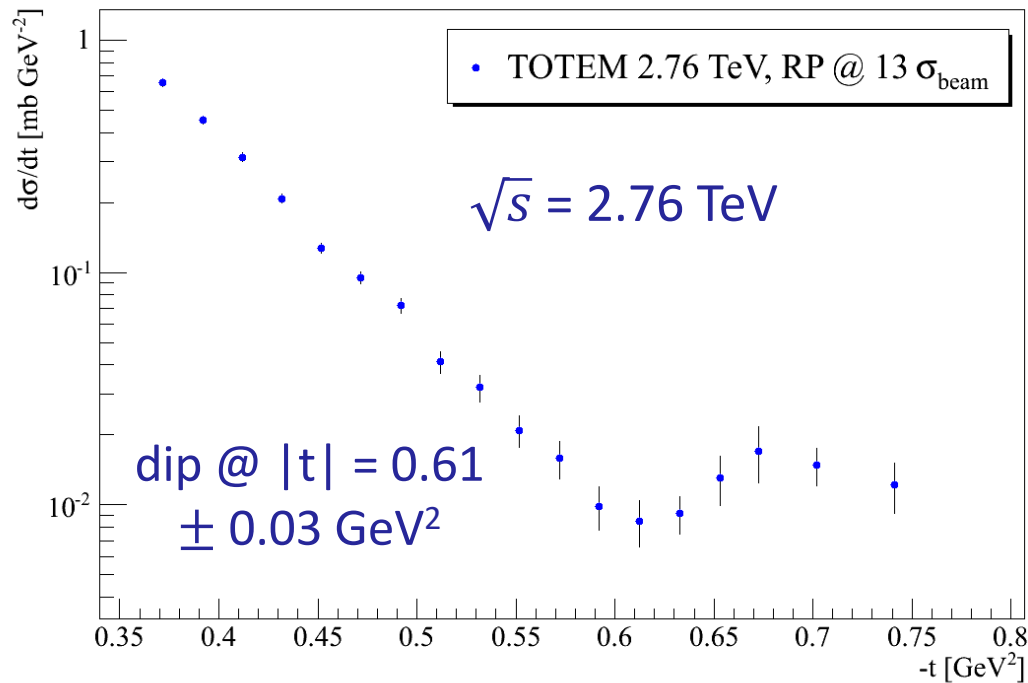
no conventional (no-Odderon) model able to describe simultaneously TOTEM σ_{tot} & ρ measurements \Rightarrow adding t-channel exchange of a "Odderon" improves model descriptions



$d\sigma_{el}/dt$ in pp @ $\sqrt{s} = 2.76$ & 13 TeV

TOTEM @ $\sqrt{s} = 2.76$ & 13 TeV: **observation of diffractive dip in $d\sigma_{el}/d|t|$**

arXiv: 1812.08610, submitted to EPJC; EPJC 79 (2019) 861

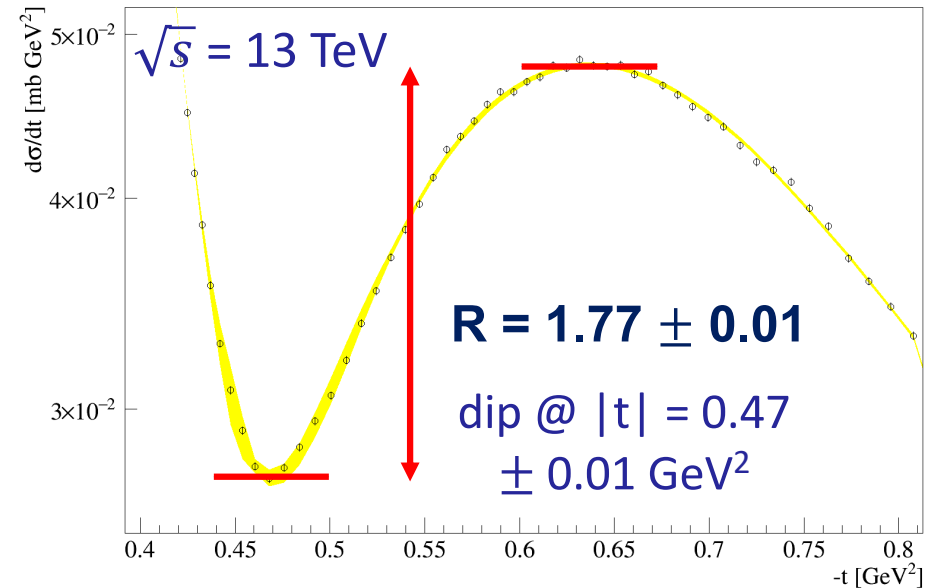
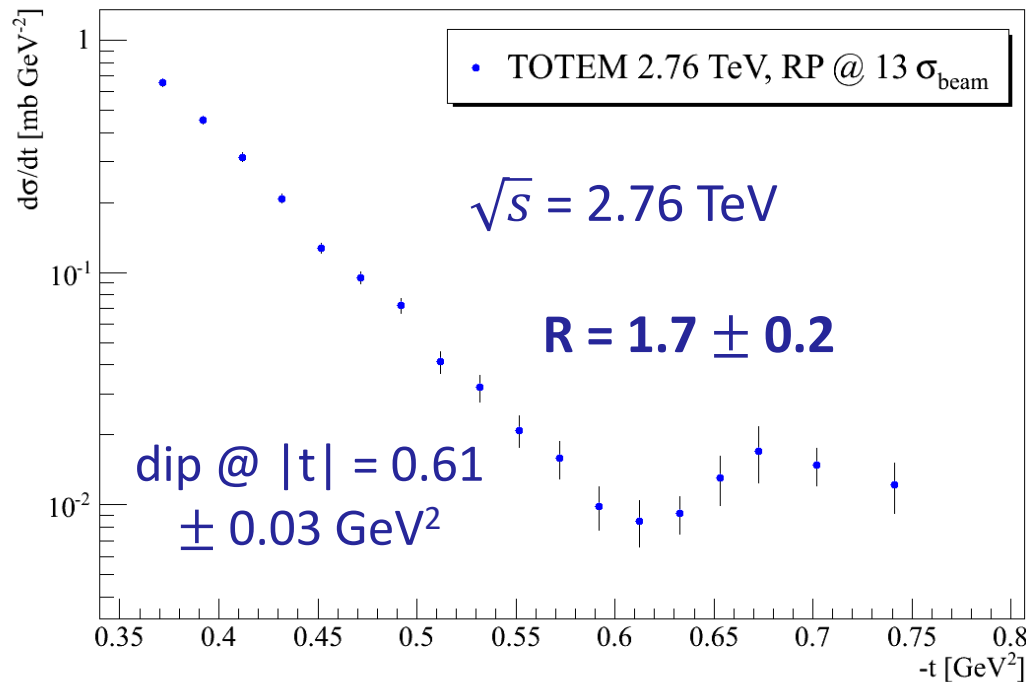




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Characteristic for pp scattering:

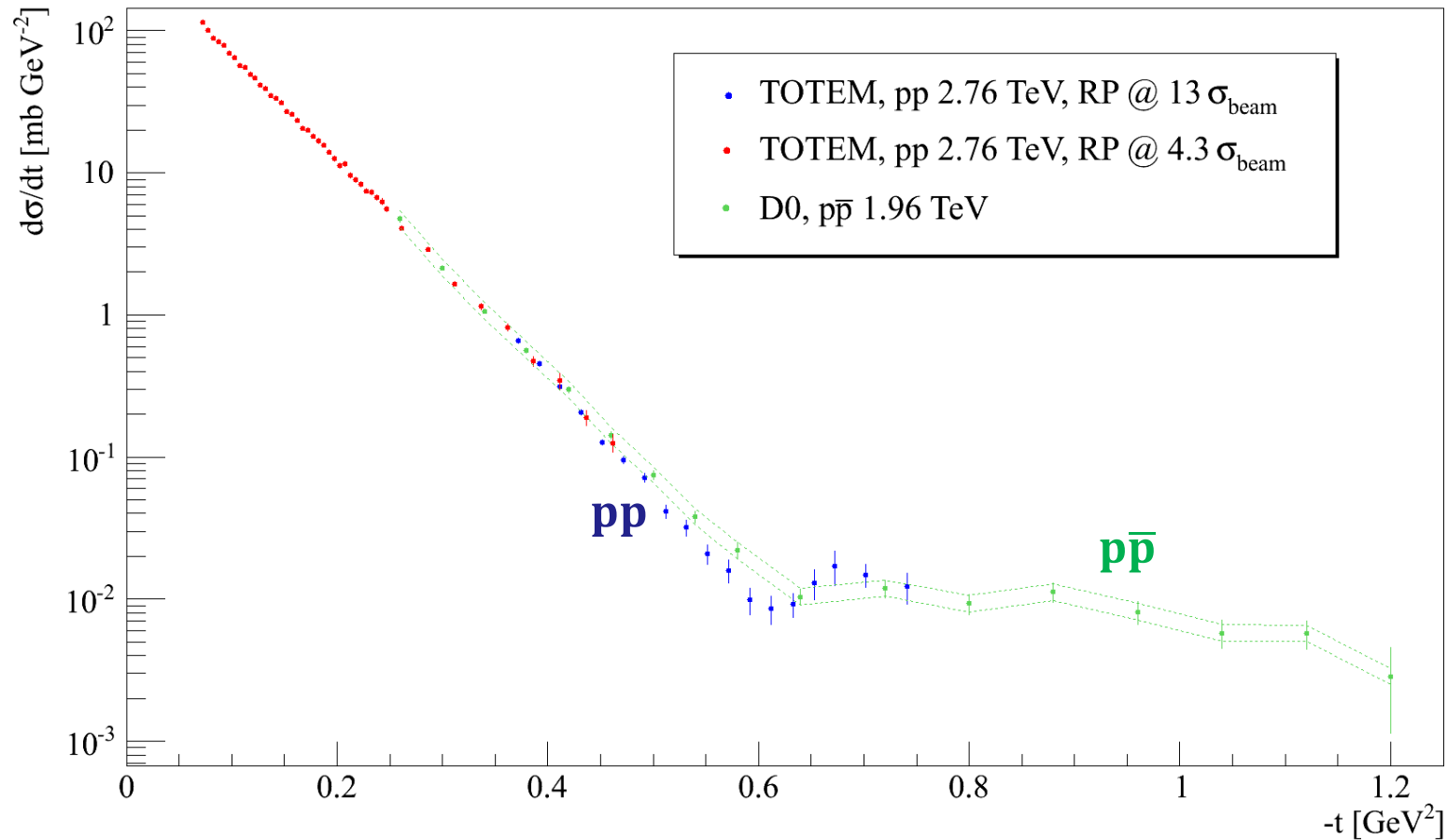
- persistency of dip at all TeV energies
- position of dip in $|t|$ decreases with energy
- cross-section ratio between 2nd max & dip, R , remains \sim constant

$$R \equiv \frac{d\sigma_{el}/d|t|^{2\text{nd max}}}{d\sigma_{el}/d|t|^{\text{diff min}}}$$



Comparison of $d\sigma_{el}/dt$ pp & p \bar{p} @ TeV scale

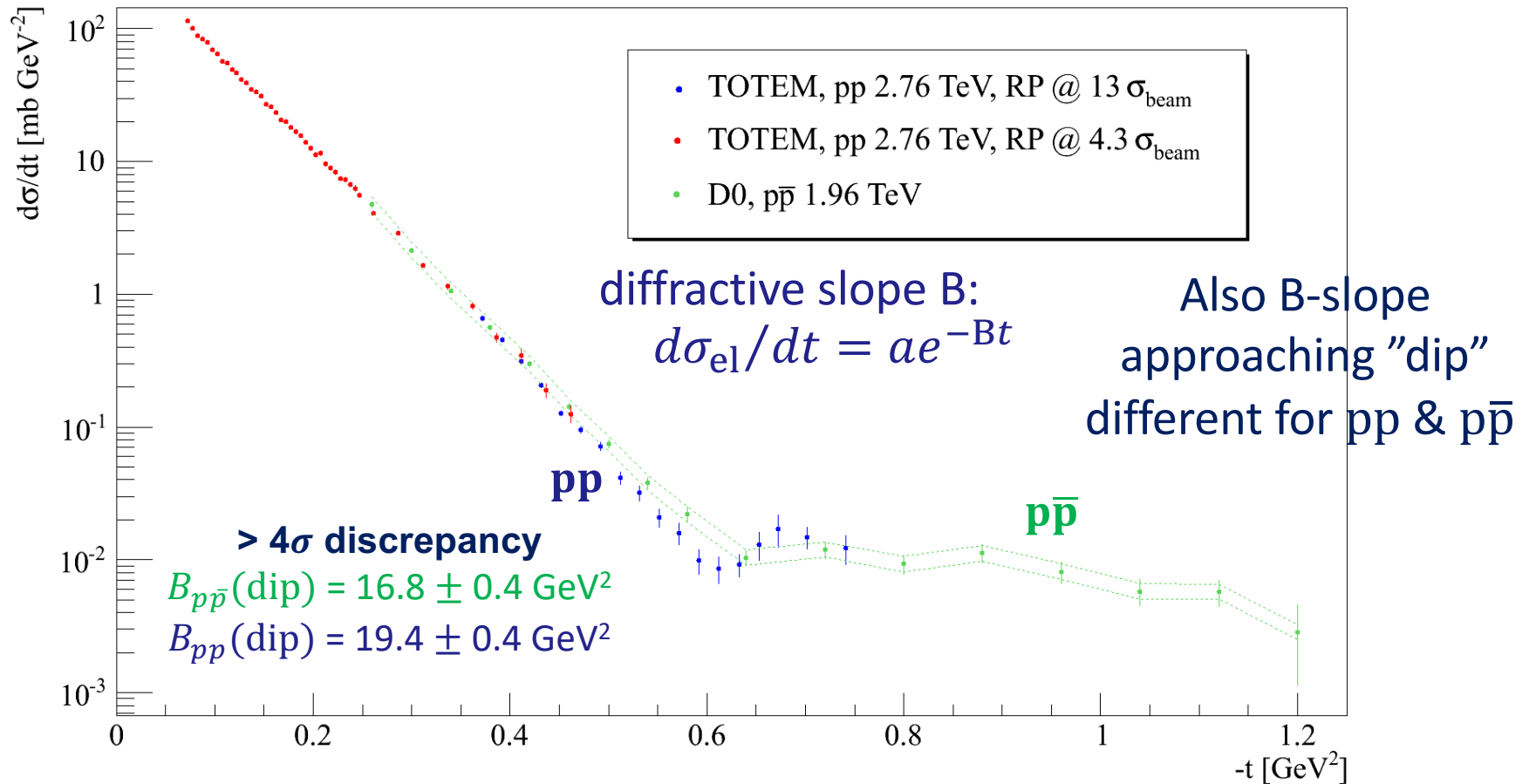
D0: PRD 86 (2012) 012009; TOTEM: arXiv: 1812.08610, submitted to EPJC



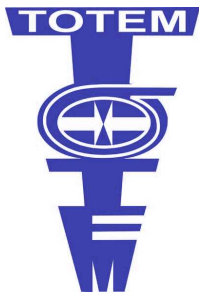


Comparison of $d\sigma_{el}/dt$ pp & p \bar{p} @ TeV scale

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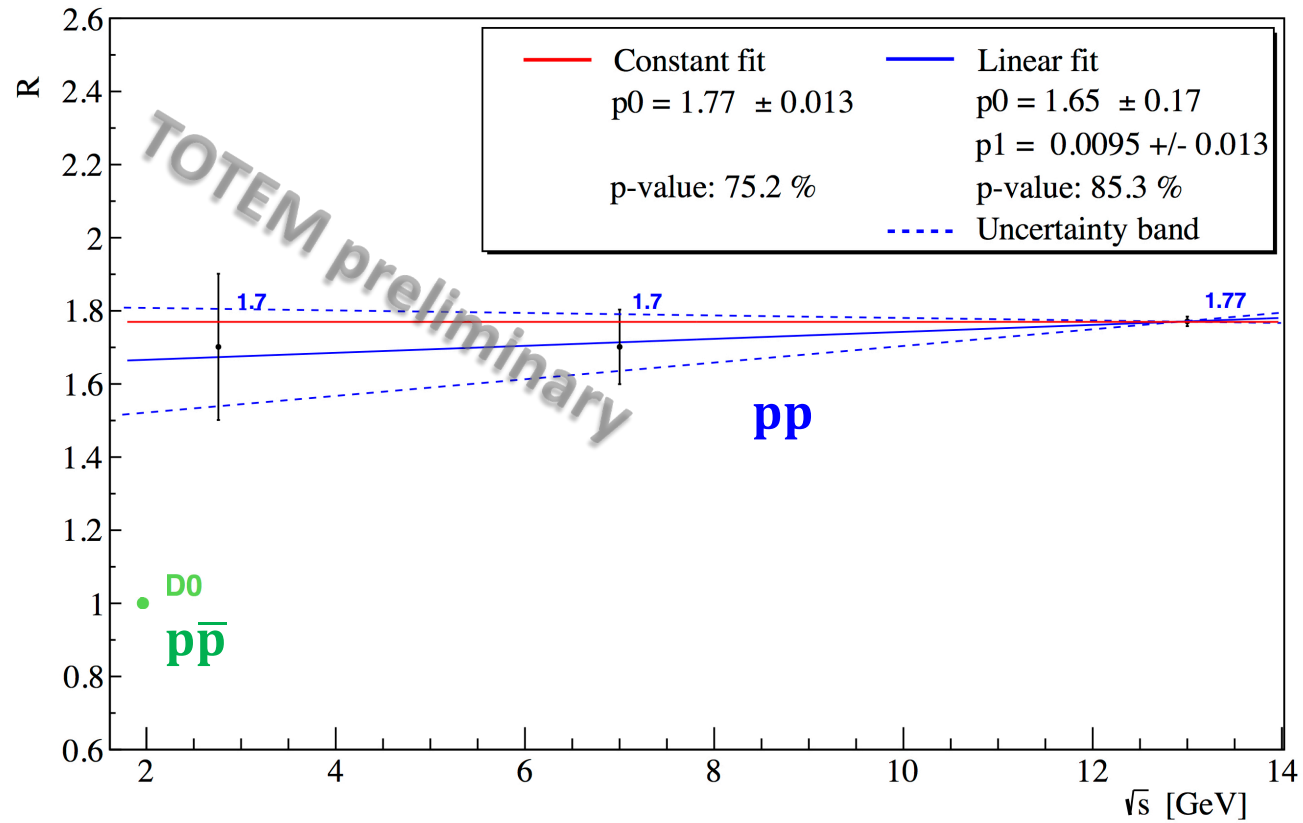


Persistency of dip for pp & absence of dip for p \bar{p}
 $\Rightarrow d\sigma_{el}/dt$ in pp & p \bar{p} significant different at TeV scale
 \Rightarrow expected effect of t-channel exchange of "Odderon"



R-ratio in pp & p \bar{p} @ TeV scale

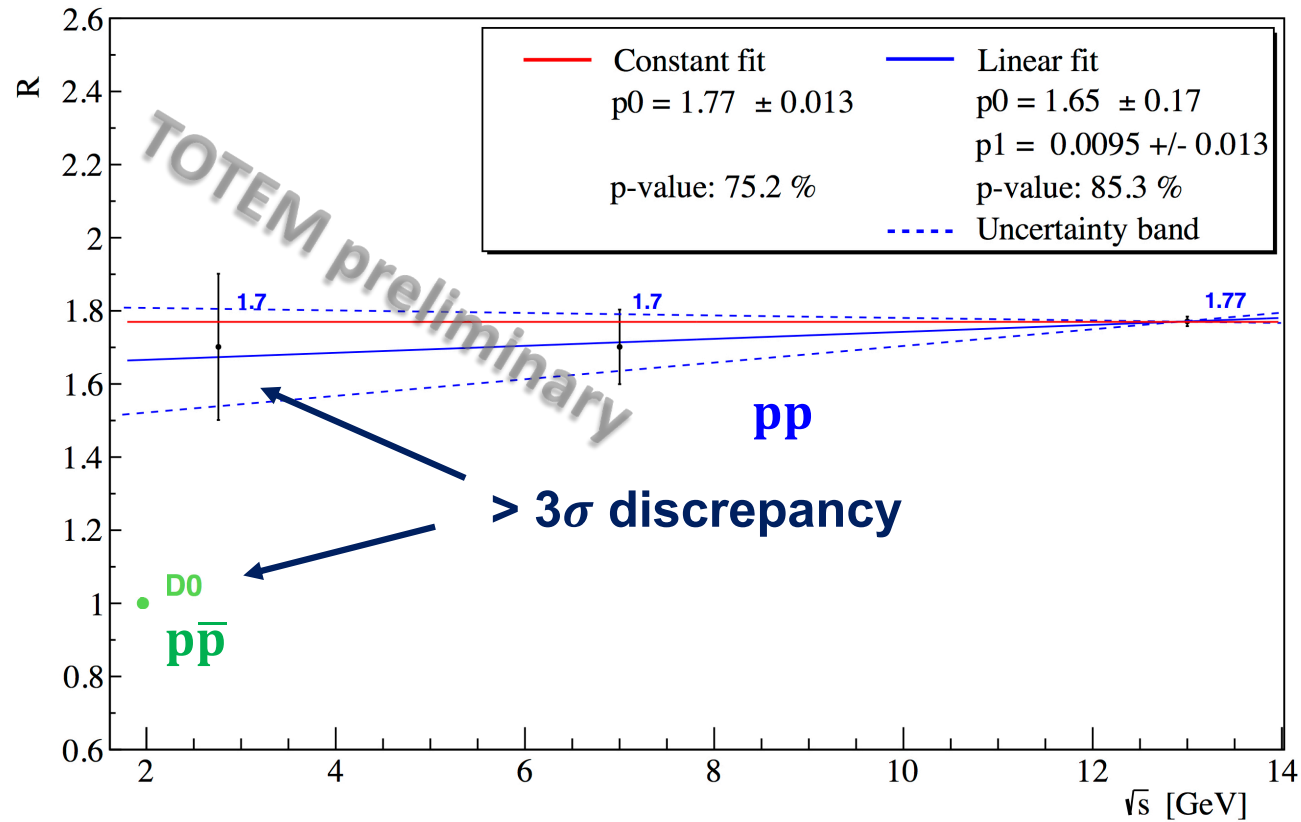
$$R \equiv d\sigma_{el}/d|t|^{2nd\ max} / d\sigma_{el}/d|t|^{diff\ min}$$





R-ratio in pp & p \bar{p} @ TeV scale

$$R \equiv d\sigma_{el}/d|t|^{2nd \max} / d\sigma_{el}/d|t|^{diff \min}$$



$R \sim \text{constant in pp} \ \& \ R \text{ in pp} \gg R \text{ in p}\bar{\text{p}} \Rightarrow$
 $\text{pp} \ \& \ \text{p}\bar{\text{p}} \ d\sigma_{el}/dt$ significant different at TeV scale \Rightarrow
 expected effect of t-channel exchange of "Odderon"



Summary & next steps

- TOTEM σ_{tot} & ρ measurements not compatible with conventional (no-Odderon) models \Rightarrow t-channel exchange of a colorless C-odd 3-gluon compound state ("Odderon") ?
- Data (to be) taken in 2018 (2021?) at $\sqrt{s} = 0.9$ (14) TeV to confirm σ_{tot} & ρ trends vs energy & quantify observed effect
- Constructing a new scintillator-based T2 for inelastic rate determination in a σ_{tot} measurement at $\sqrt{s} = 14$ TeV in 2021(?)
- Observation of diffractive dip in pp @ $\sqrt{s} = 2.76$ & 13 TeV \Rightarrow persistence of dip @ TeV scale in pp & absence in $p\bar{p}$ \Rightarrow expected effect of t-channel exchange of a colorless C-odd 3-gluon compound state ("Odderon")
- Making together with D0 model-independent extrapolations of $d\sigma_{el}/dt$ pp characteristics to same \sqrt{s} as D0 measurement of $d\sigma_{el}/dt$ $p\bar{p}$ to quantify difference between pp & $p\bar{p}$