

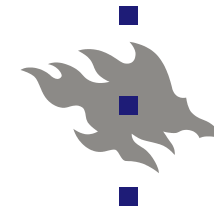
New results from TOTEM



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on behalf of
TOTEM collaboration

**LHC working group on Forward
Physics and Diffraction 18.12.2018**



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Outline:

- ✓ Diffractive dip observation @ $\sqrt{s} = 2.76$ & 13 TeV
- ✓ σ_{tot} @ $\sqrt{s} = 13$ TeV with $\beta^* = 2.5$ km
- ✓ Summary of the 900 GeV run



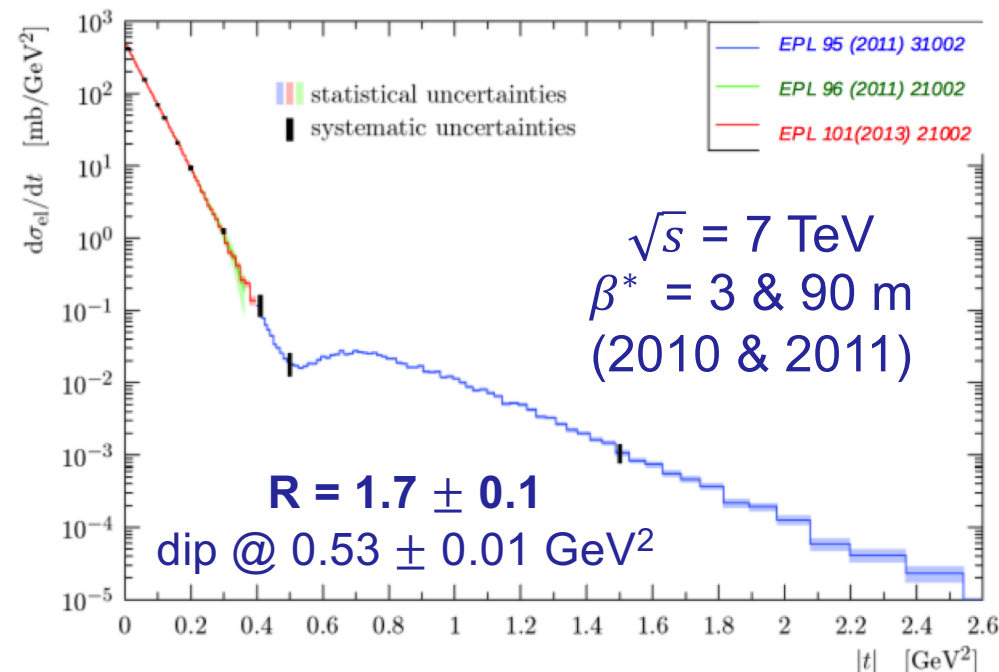
Diffraction dip in pp @ LHC

Hadronic elastic @ TeV \sqrt{s} dominated by t-channel exchange of colourless gluon states:

- 2 (or even) gluon exchange ($J^{PC} = 0^{++}, 2^{++}$): "Pomeron" \Rightarrow pp vs $p\bar{p}$ invariance
- 3 (or odd) gluon exchange ($J^{PC} = 1^{--}$): "Odderon" \Rightarrow no pp vs $p\bar{p}$ invariance

@ dip: 2g exchange (\sim imaginary) suppressed \Rightarrow 3g exchange (\sim real) observable ?

TOTEM: observation of diffractive dip in $d\sigma_{el}/d|t|$ @ $\sqrt{s} = 7$ TeV

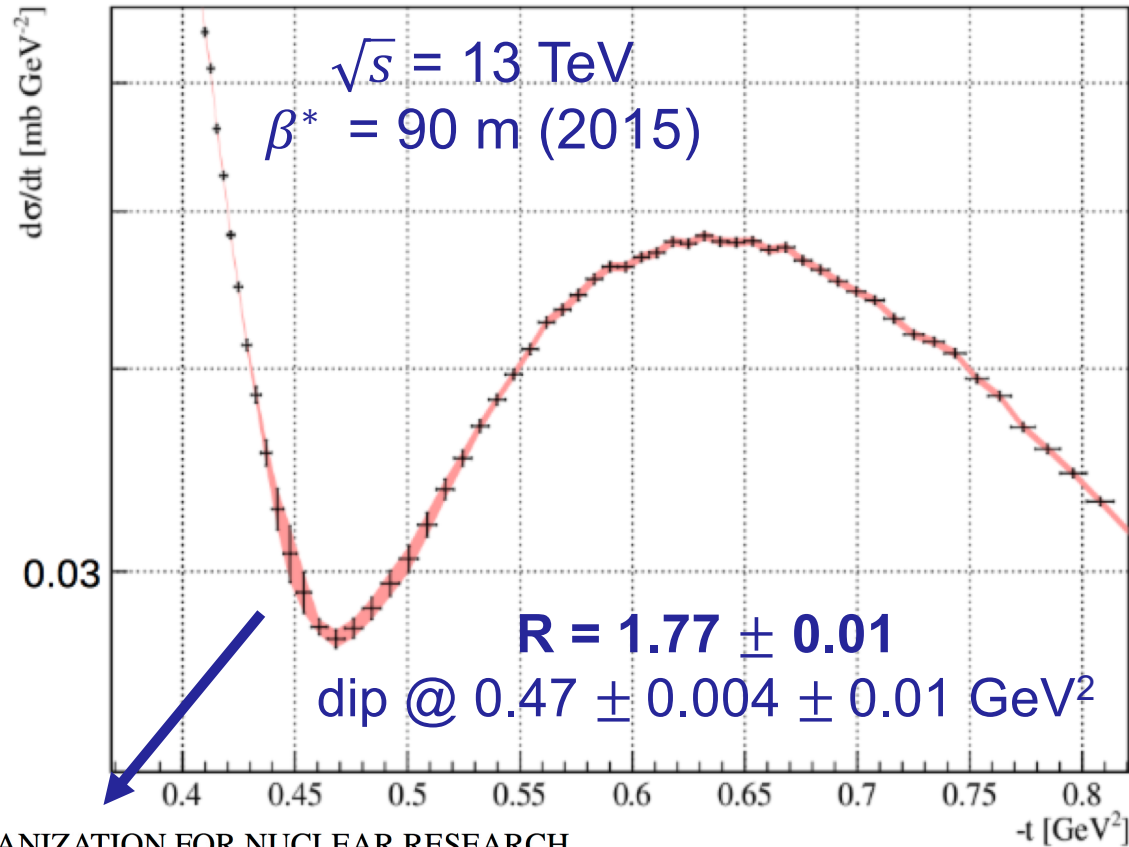


$R \equiv \text{max/dip ratio of } d\sigma_{el}/d|t|$



Diffractive dip in pp @ $\sqrt{s} = 13$ TeV

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



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



TOTEM 2018-003
December 13, 2018



CERN-PH-EP-2018-?
December 13, 2018

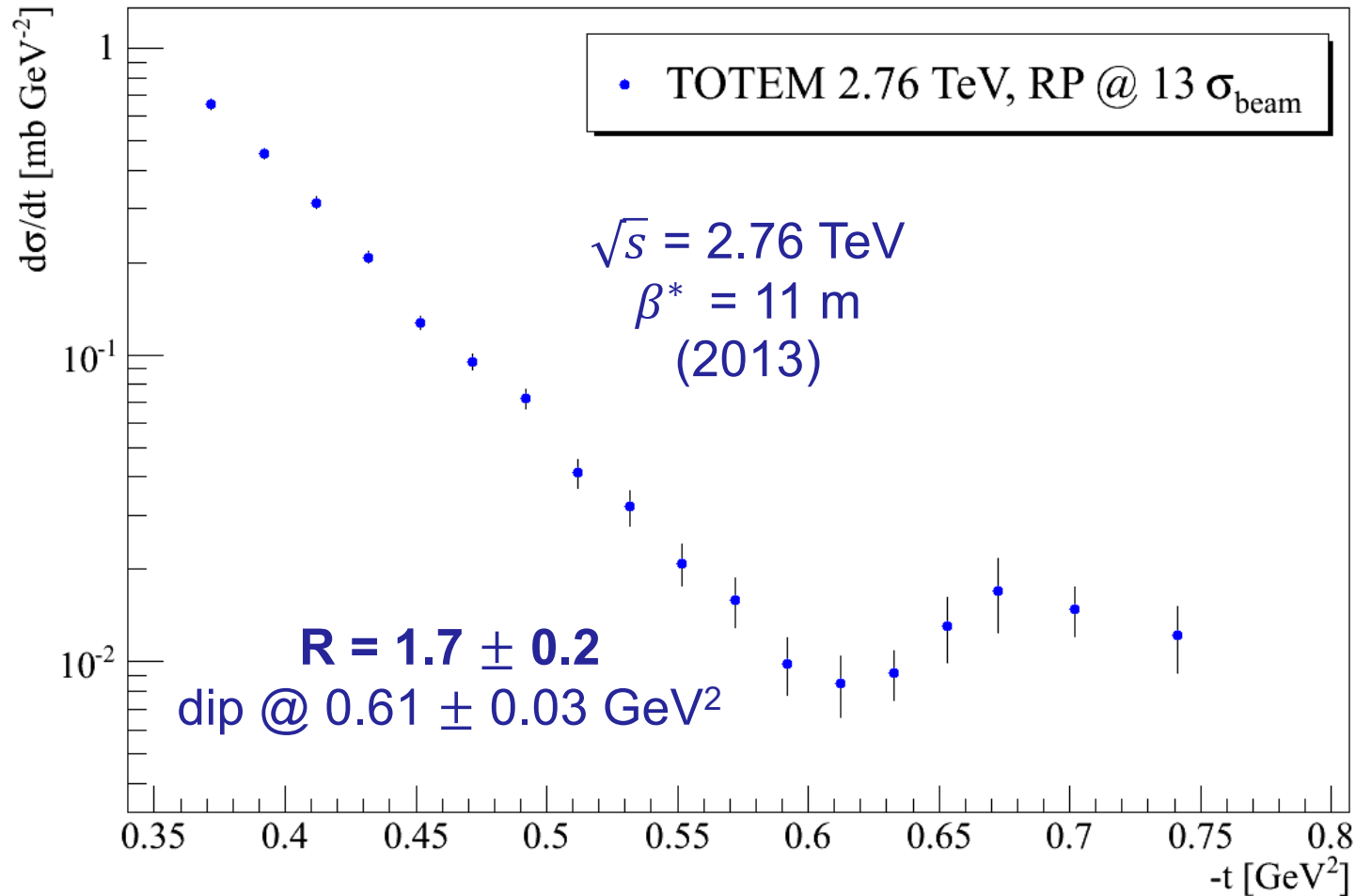
paper approved
by CERN-PH,
soon in CDS !!

Elastic differential cross-section measurement at $\sqrt{s} = 13$ TeV by TOTEM



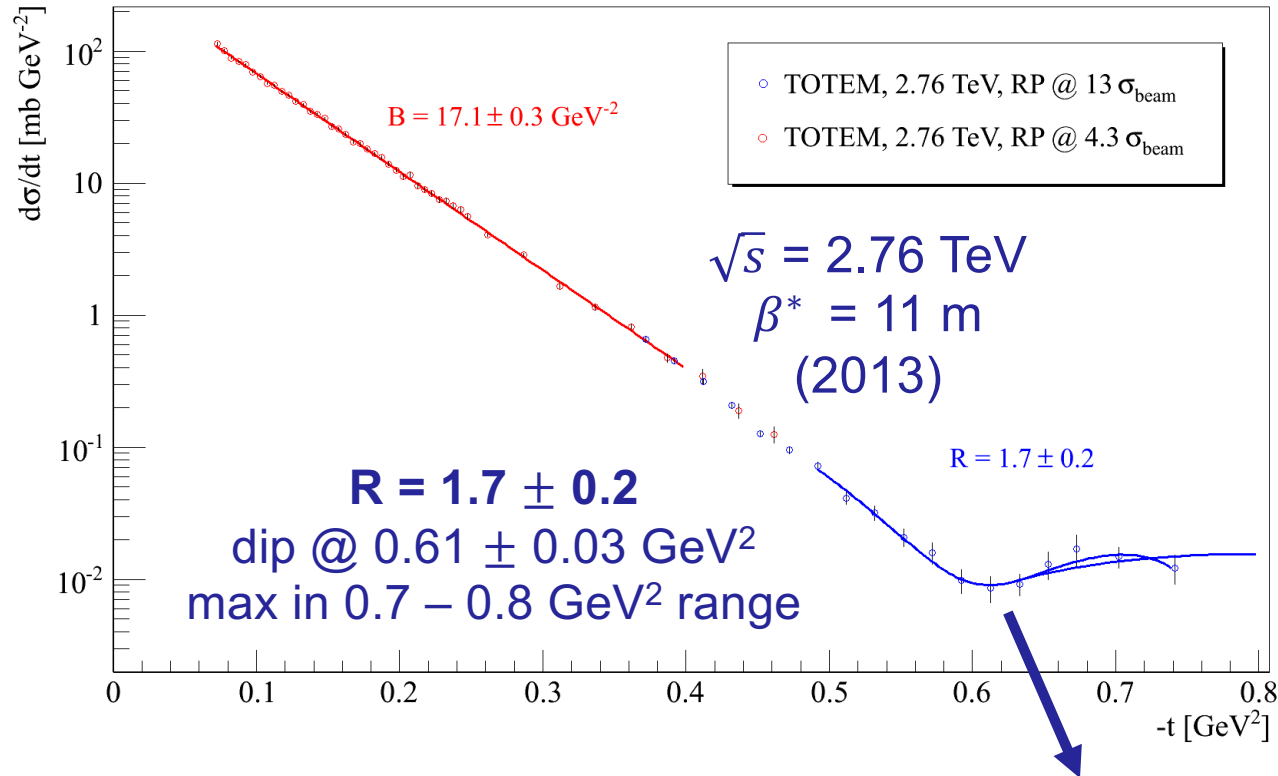
Diffractive dip in pp @ $\sqrt{s} = 2.76$ TeV

Observation of diffractive dip in $d\sigma_{el}/d|t|$ @ $\sqrt{s} = 2.76$ TeV !!





Diffractive dip in pp @ $\sqrt{s} = 2.76$ TeV



Persistency of diffractive dip for pp at any TeV \sqrt{s}

paper submitted to CERN-PH !!

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



TOTEM 2018-002
December 13, 2018

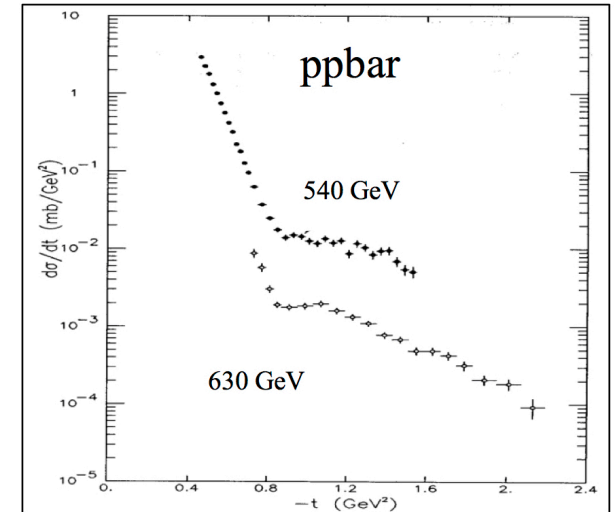
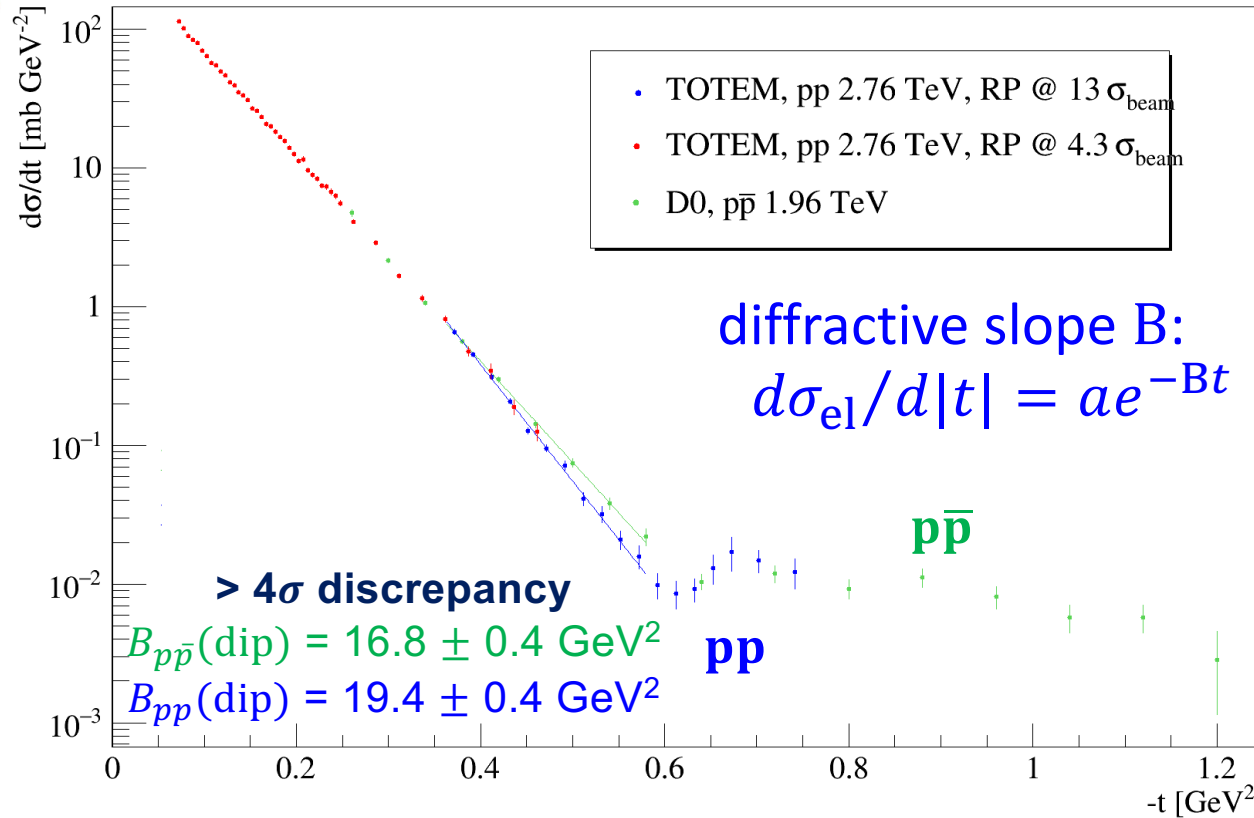


CERN-PH-EP-2018-?
December 13, 2018

Elastic differential cross-section $d\sigma/dt$ at $\sqrt{s}=2.76$ TeV and implications on the existence of a colourless 3-gluon bound state



Diffractive dip in pp & p \bar{p} @ TeV scale



Also B-slope
 approaching "dip"
 different for pp & p \bar{p}
 (NB! D0 B-slope estimated
 from published $d\sigma_{\text{el}}/dt$)

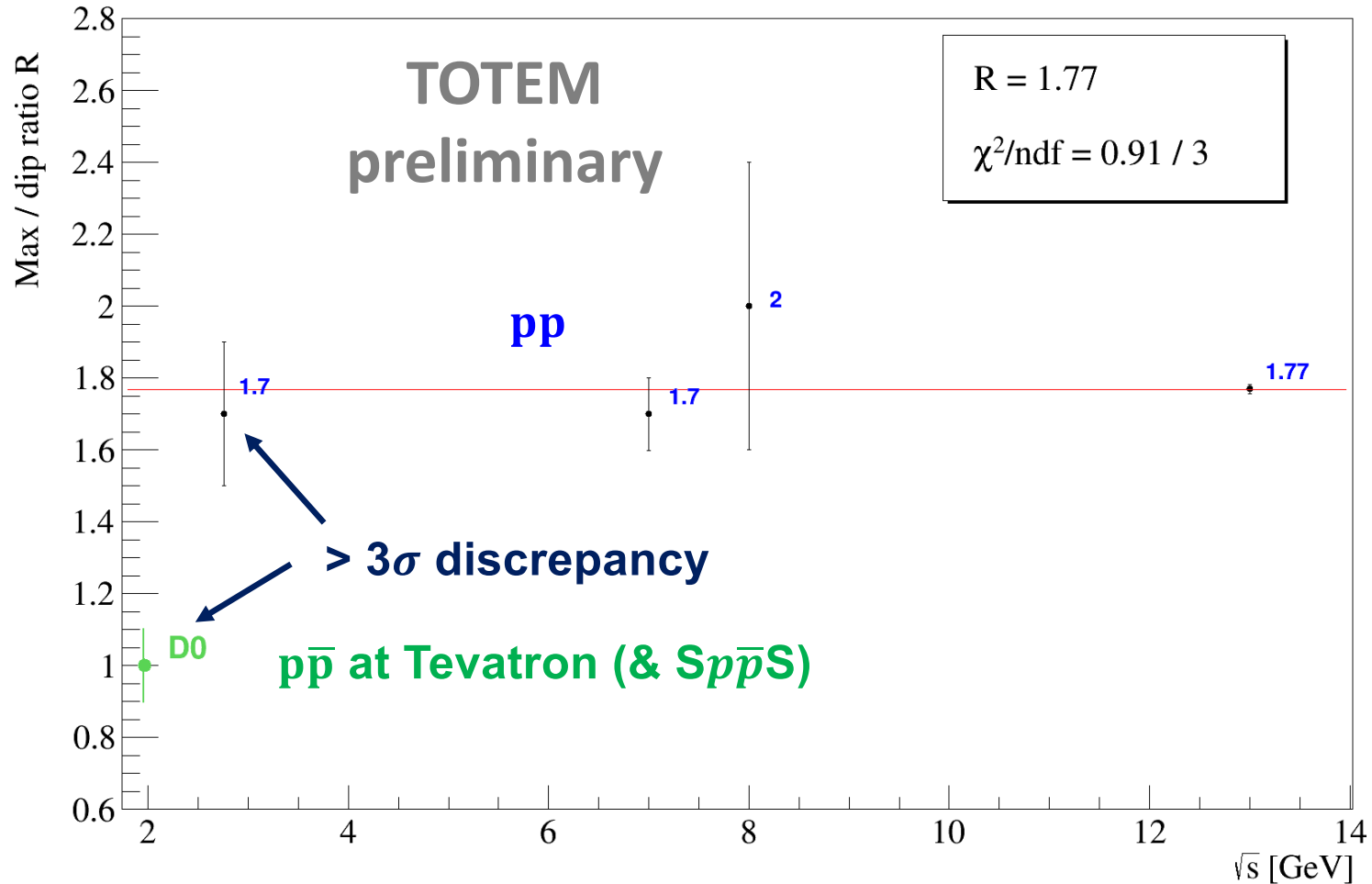
D0 Collaboration, Phys. Rev. D 86 (2012) 012009: "A comparison of the shape of our measured $d\sigma/dt$, but, as in the UA4 data, we do not see a distinct minimum as observed in pp elastic scattering [TOTEM 7 TeV publication]."

Persistency of dip for pp & absence of dip for p \bar{p}



Diffractive dip in pp & $p\bar{p}$ @ TeV scale

$$R \equiv \text{max/dip ratio of } d\sigma_{e1}/d|t|$$



Max/dip $d\sigma_{e1}$ ratio $R \sim$ constant in pp & R in $pp \gg R$ in $p\bar{p}$

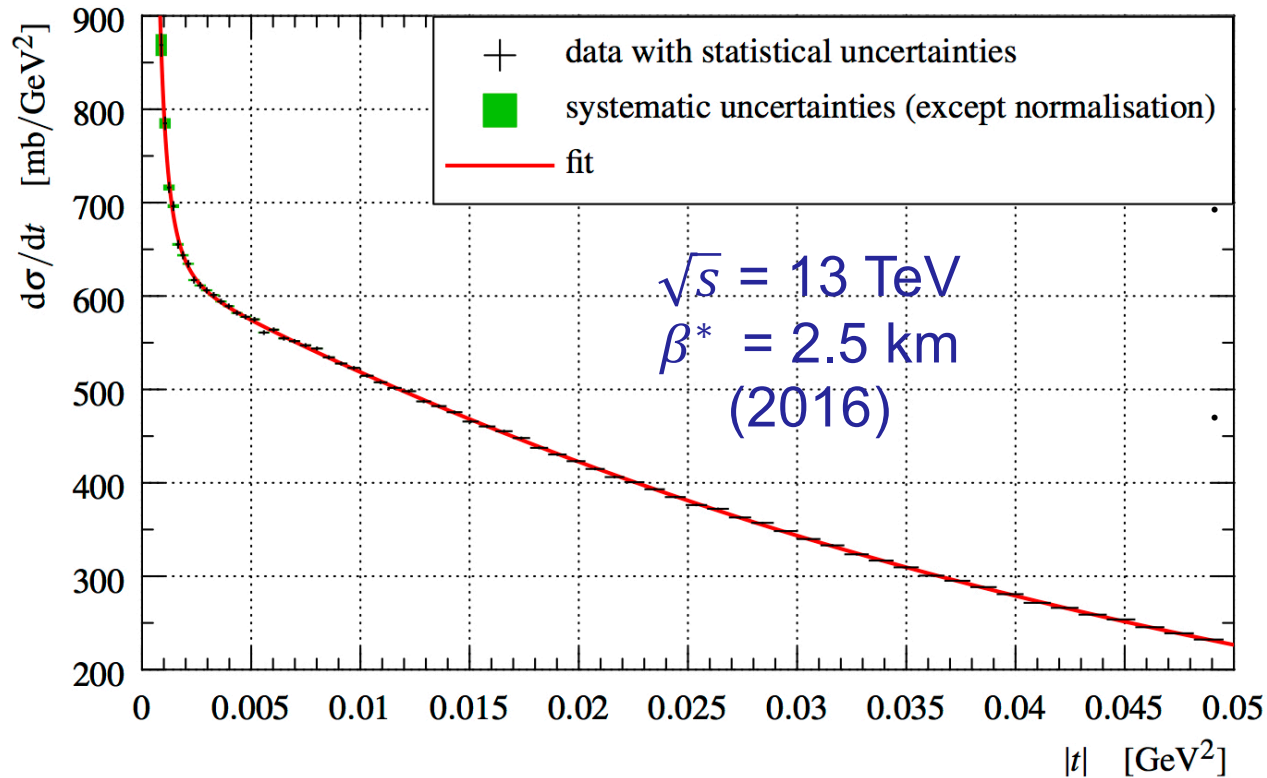


pp vs p \bar{p} @ TeV scale

- **Sep 2018 LHCC minutes:** "A joint working group with D0 has been set up, to compare TOTEM results with those in proton-antiproton collisions at comparable energy of 1.96 TeV. A significant difference would be evidence for odderon exchange in hadronic elastic scattering".
- **V.A. Khoze:** "any significant difference in $d\sigma_{e1}/dt$ between pp and p \bar{p} @ $\sqrt{s} > 0.5 - 1$ TeV would be evidence of the odd signature term – the Odderon contribution"
- Already @ ISR difference between pp & p \bar{p} regarded as "Odderon" evidence
 \Rightarrow **classical "Odderon" evidence** [*L. Lukaszuk & B. Nicolescu, Lett. Nuovo Cim. 8 (1973) 405*]
- **Observed TOTEM/D0 difference \Rightarrow Odderon \Rightarrow $3g J^{PC} = 1^-$ in QCD !!**
(modulo \sqrt{s} difference D0 @ 1.96 TeV vs TOTEM @ 2.76 TeV)
 \Rightarrow implication: tensor nature of QCD & existence of vector glueballs !!
- Major effort together with D0 to make model-dependent & -independent extrapolations of $d\sigma_{e1}/d|t|$ characteristics of pp to same \sqrt{s} as D0 measurement of $d\sigma_{e1}/d|t|$ in p \bar{p} for ultimate quantification of difference



σ_{tot} @ $\sqrt{s} = 13$ TeV with $\beta^* = 2.5$ km



$$\sigma_{tot}^2 = \frac{16\pi (\hbar c)^2}{1 + \rho^2} a$$

Fits to determine hadronic B-slope & amplitude a , ρ & absolute normalisation.

Resolve Coulomb hadronic interference contribution

Very low- $|t|$ reach allows to determine normalisation using Coulomb amplitude for first time at LHC !!

- approach 1: normalisation from lumi-independent σ_{tot} @ $\beta^* = 90$ m.
- approach 2: normalisation estimated from $\beta^* = 2.5$ km data adding to χ^2 a term reflecting deviation from lumi-independent σ_{tot} in standard deviations.
- approach 3: normalisation estimated from $\beta^* = 2.5$ km data using only part sensitive to QED cross-section.



$\sigma_{\text{tot}} @ \sqrt{s} = 13 \text{ TeV}$ with $\beta^* = 2.5 \text{ km}$

Table 6: Summary of ρ and total cross-section results.

data	method	ρ	σ_{tot} [mb]
$\beta^* = 90 \text{ m}$	lumi-ind.	-	110.6 ± 3.4
$\beta^* = 2500 \text{ m}$	approach 1	0.09 ± 0.01	111.8 ± 3.2
	approach 2	0.09 ± 0.01	111.3 ± 3.2
	approach 3	$0.08(5) \pm 0.01$	110.3 ± 3.5
	approach 3 (single fit)	0.10 ± 0.01	109.3 ± 3.5
$\beta^* = 90 \text{ and } 2500 \text{ m}$	lumi-ind. \oplus approach 3		110.5 ± 2.4



combining two independent data sets & methods !!

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TOTEM-2017-002
30 November 2018



CERN-EP-2017-335-v3
30 November 2018

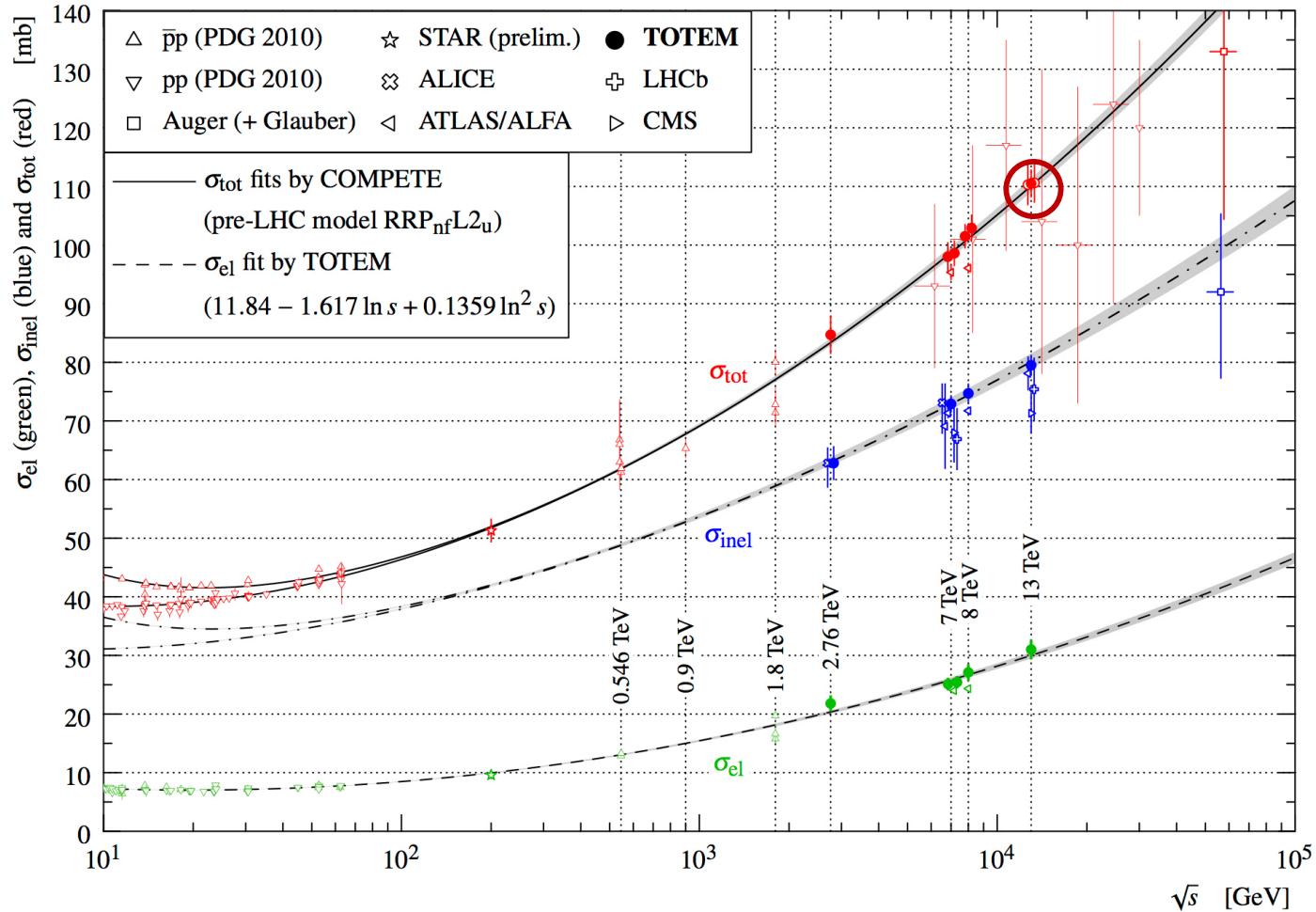
For more details see dedicated talk by J. Kaspar

First determination of the ρ parameter at $\sqrt{s} = 13 \text{ TeV}$ – probing the existence of a colourless three-gluon bound state

CERN-EP-2017-335 & arXiv:1812.04732 !!



σ_{tot} , σ_{inel} & σ_{el} VS \sqrt{s}



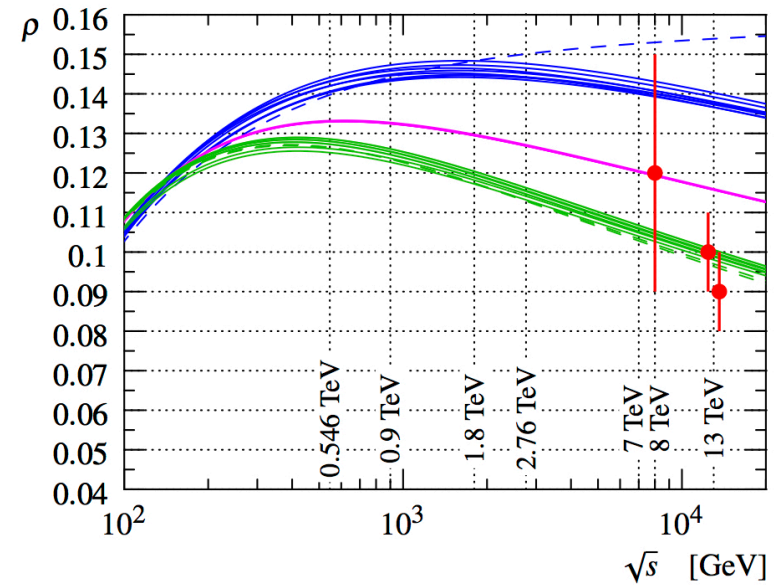
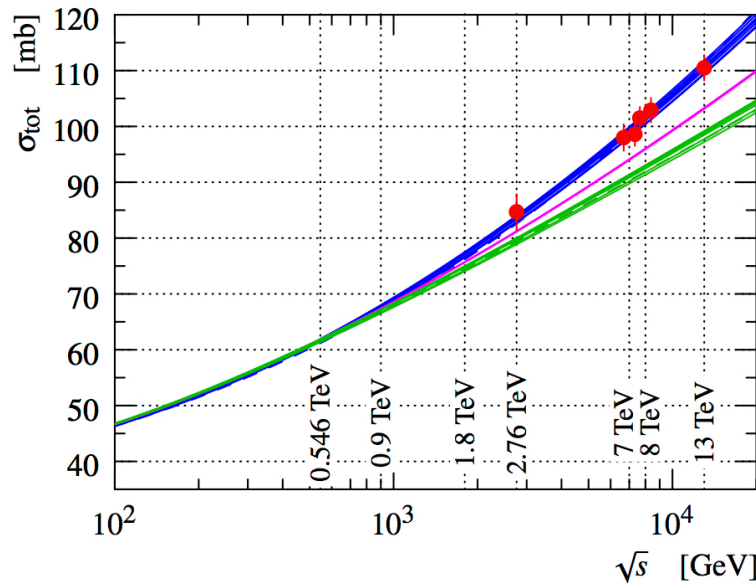
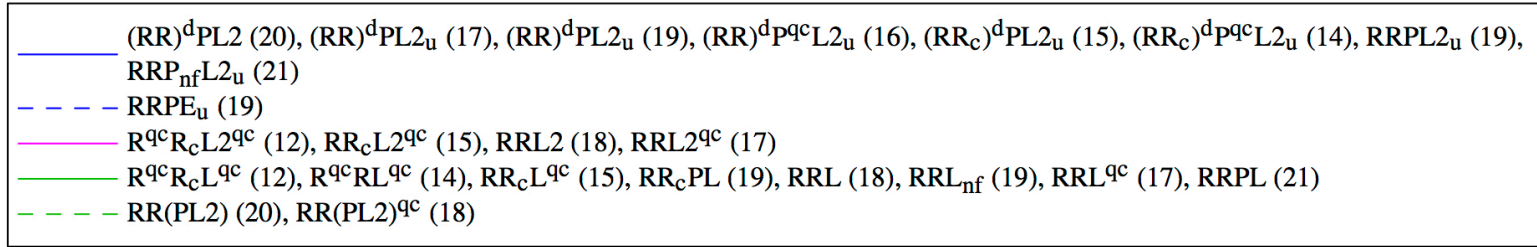
new TOTEM average @ $\sqrt{s} = 13$ TeV: **$\sigma_{\text{tot}} = 110.5 \pm 2.4$ mb**



Compatibility with model predictions

Comparison with conventional (no-Odderon) model predictions:

J.R. Cudell et al. PRL 89 (2002) 201801.



no conventional (no-Odderon) model able to describe simultaneously TOTEM σ_{tot} & ρ measurements

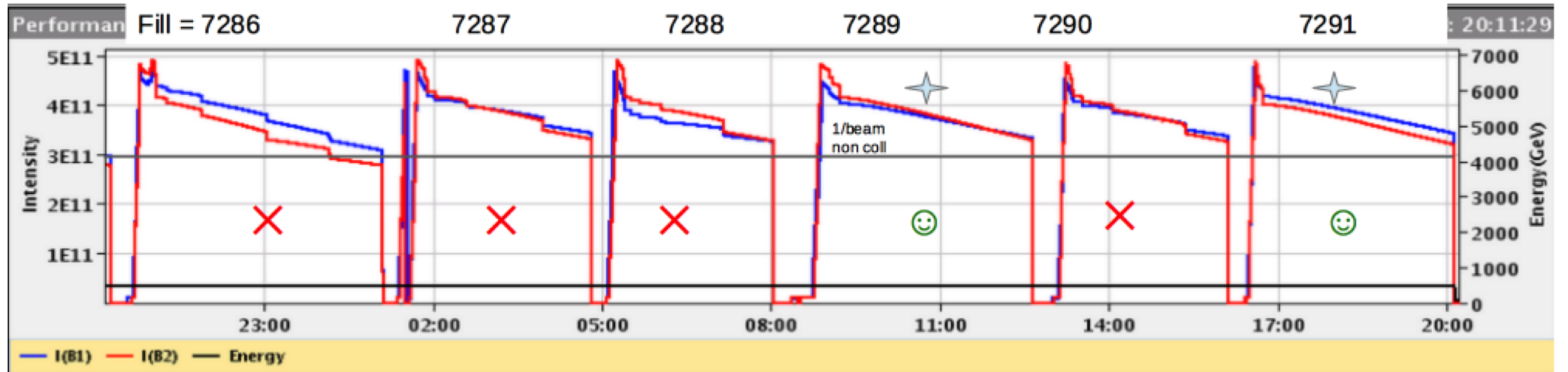
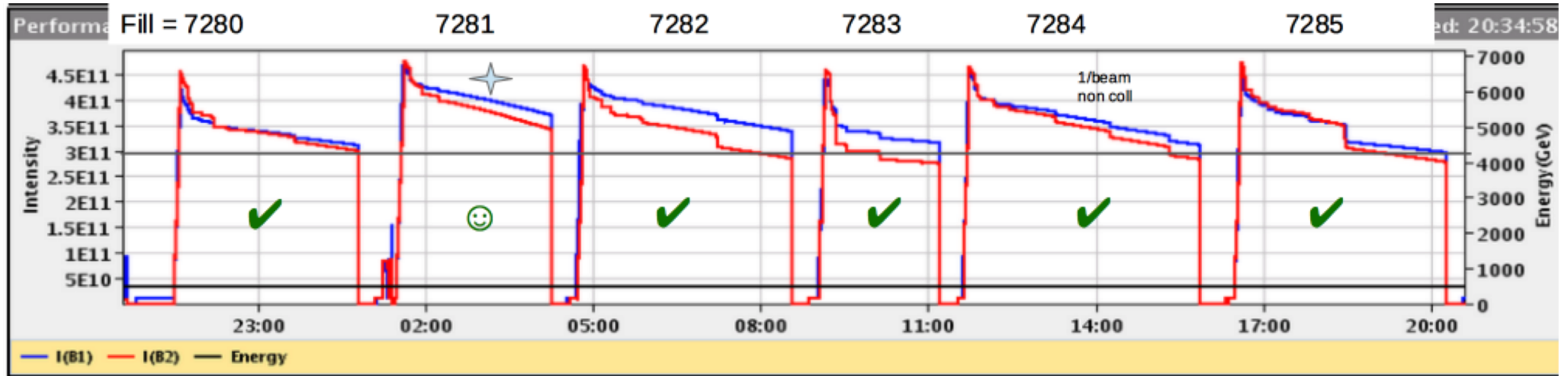
(increased significance w.r.t. before) \Rightarrow

adding 3g t-exchange improves model descriptions (t = 0 Odderon!)

recently taken 900 GeV data able to provide characteristics of the t-channel colourless 3g bound state



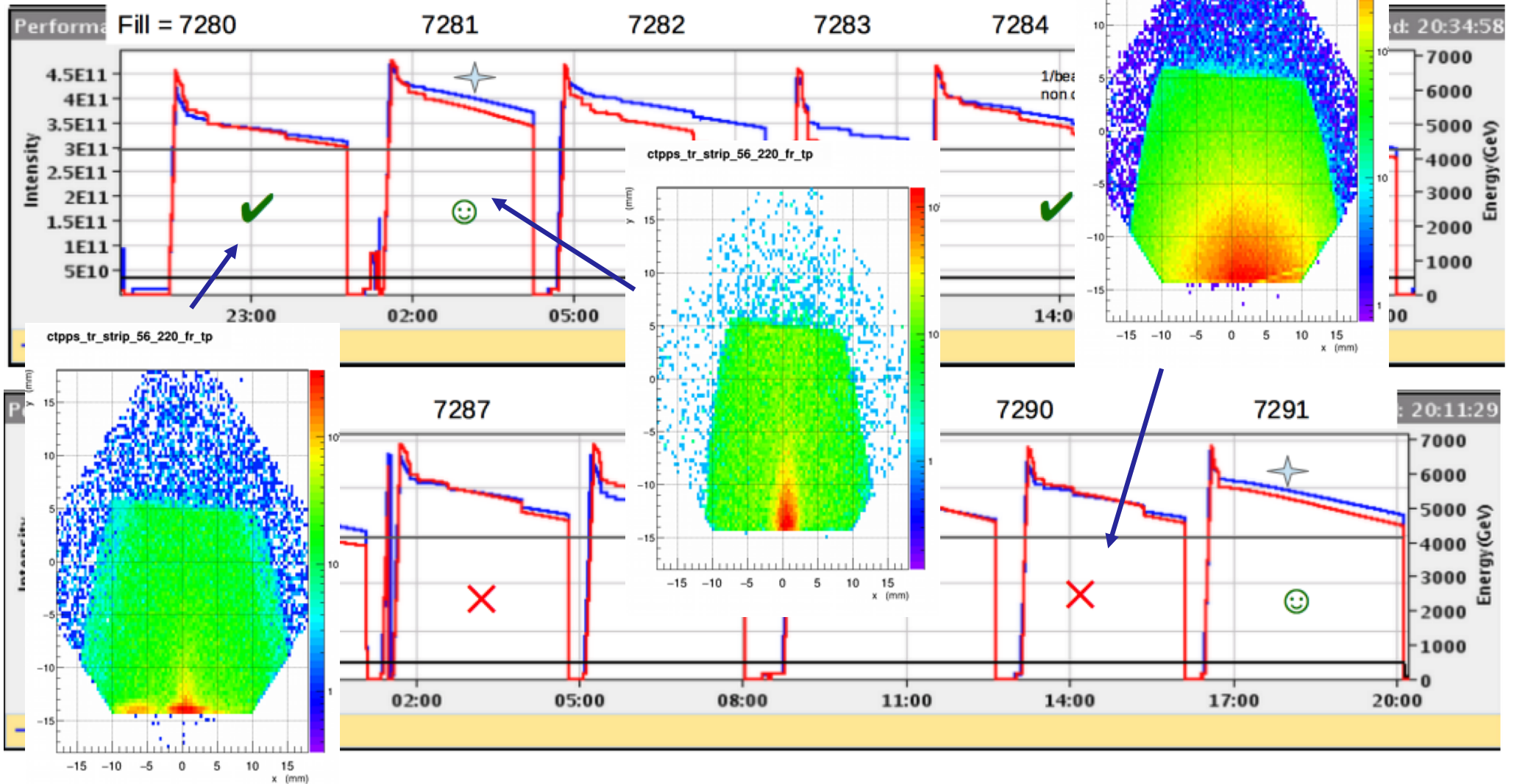
900 GeV run: summary high β^* fills





900 GeV run: summary high β^* fills

Hit map examples: signal & background visible

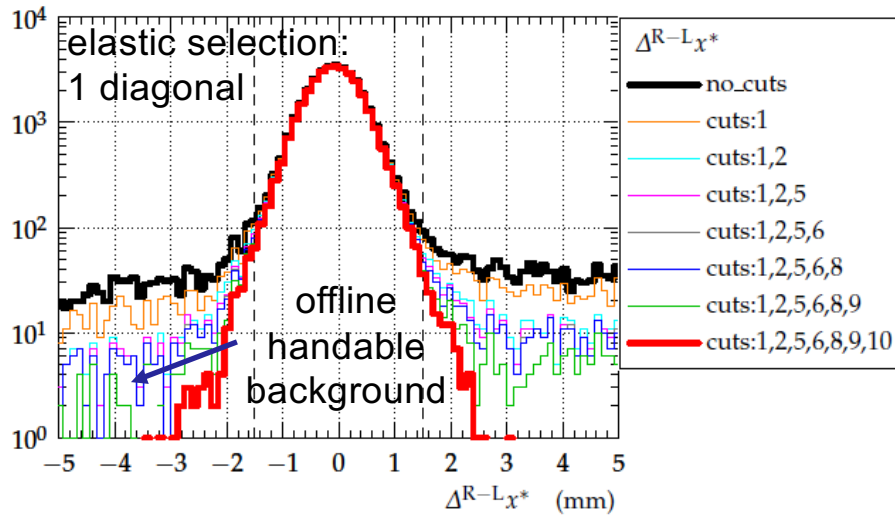




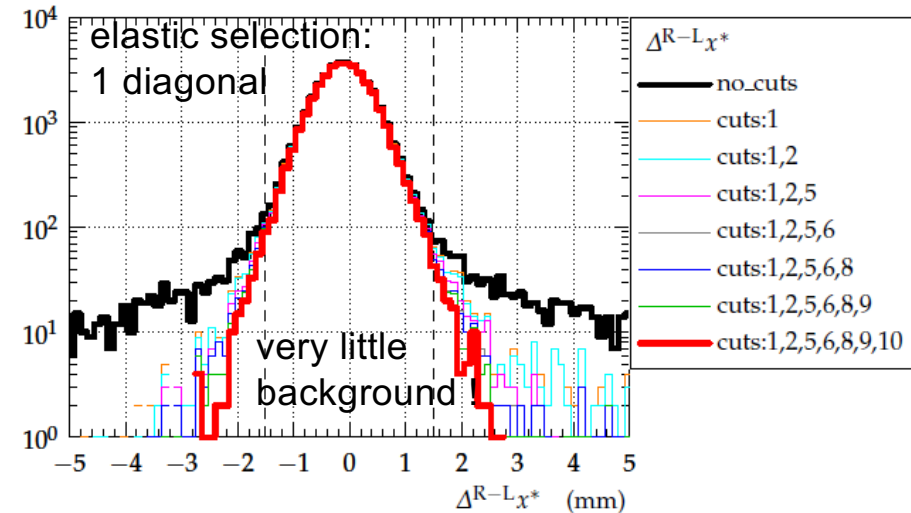
900 GeV run: operations & summary

- Two collimation scheme: standard (tight) & crystal
- Both challenging: required stability $\sim 0.2\sigma$

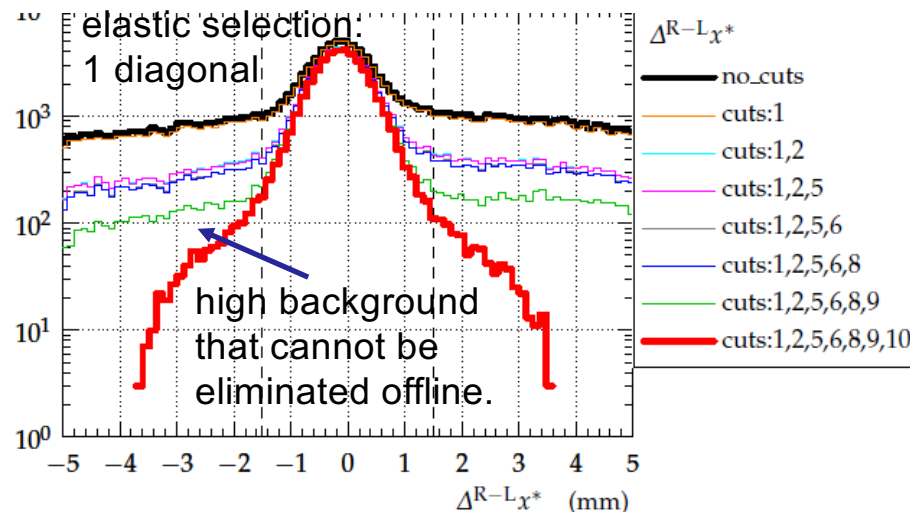
standard collimation working (✓)



crystal collimation (✦)



standard collimation NOT working (✗)



- # of collected good elastics:
 $\sim 1\text{M high } \beta^* \text{ \& } \sim 2\text{M } \beta^* = 11\text{m}$

**Big thanks both to LHC team
(especially collimation team) & CMS
for the succesful run & data taking !!**



Summary

- ✓ Observation of diffractive dip @ $\sqrt{s} = 2.76$ & 13 TeV \Rightarrow **persistence of dip @ TeV scale in pp & absence in $p\bar{p}$ \Rightarrow expected behaviour of t-channel exchange of colorless 3-gluon bound state ("Odderon")**
- ✓ pp & $p\bar{p}$ difference to be quantified in joint TOTEM-D0 analysis
- ✓ First σ_{tot} at LHC using QED for normalisation; giving consistent ρ & σ_{tot} with lumi-independent σ_{tot}
- ✓ Combined with lumi-independent σ_{tot} to give **$\sigma_{tot} = 110.5 \pm 2.4$ mb** (significantly improved precision)
- ✓ TOTEM σ_{tot} & ρ measurements not compatible with conventional (no-Odderon) models \Rightarrow **indication of t-channel exchange of colorless 3-gluon bound state ("Odderon")**
- ✓ Successful run & data taking @ $\sqrt{s} = 900$ GeV; stay tuned for the results