TOTEM Update

Fredrik Oljemark
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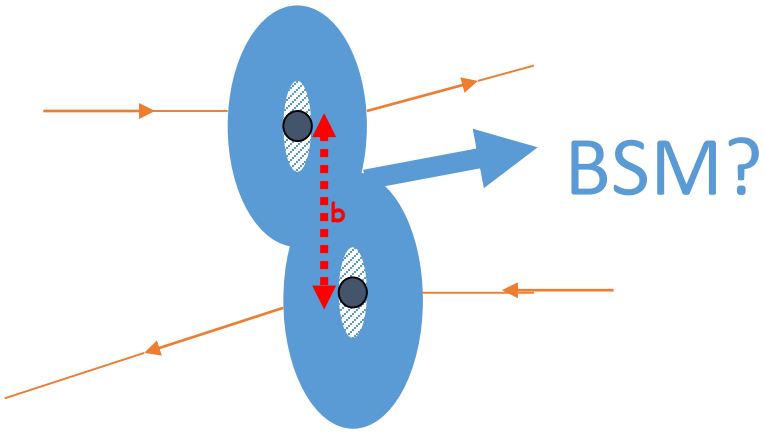
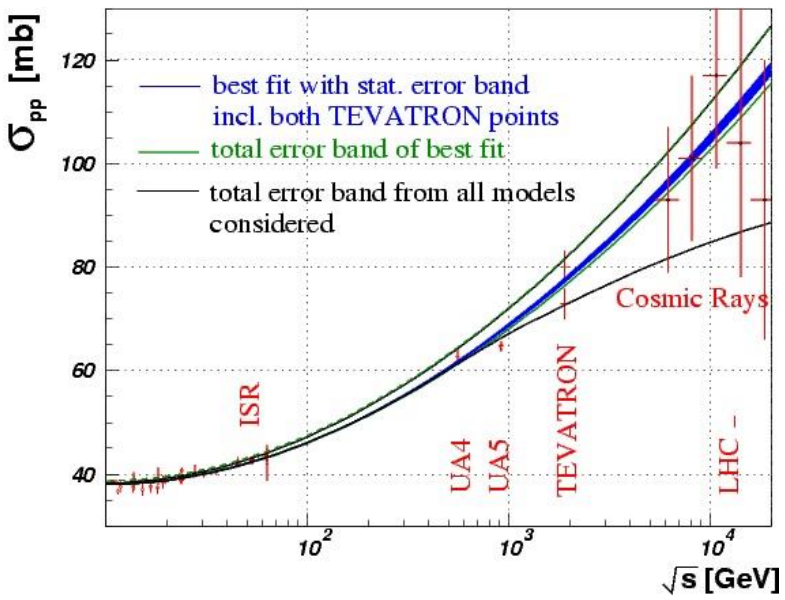


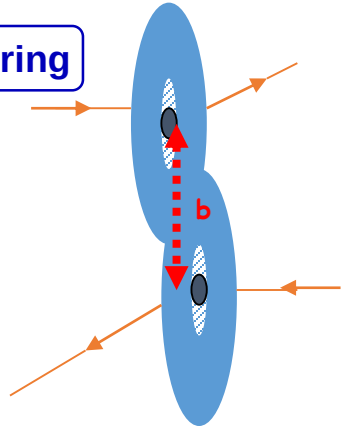
On behalf of the TOTEM Collaboration
Jyväskylä, 25.11.2016

TOTEM Physics Overview

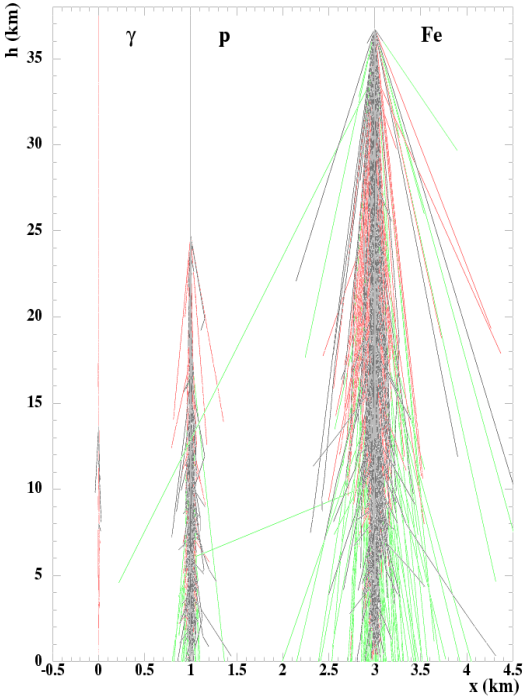
Total cross-section



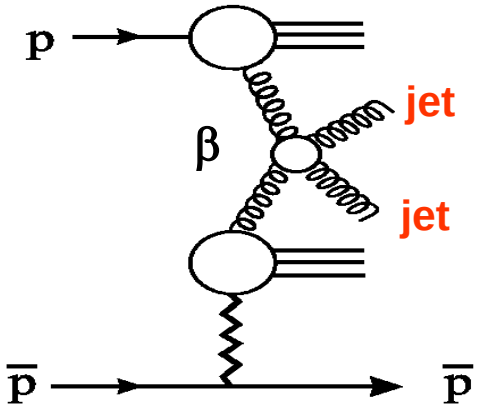
Elastic Scattering



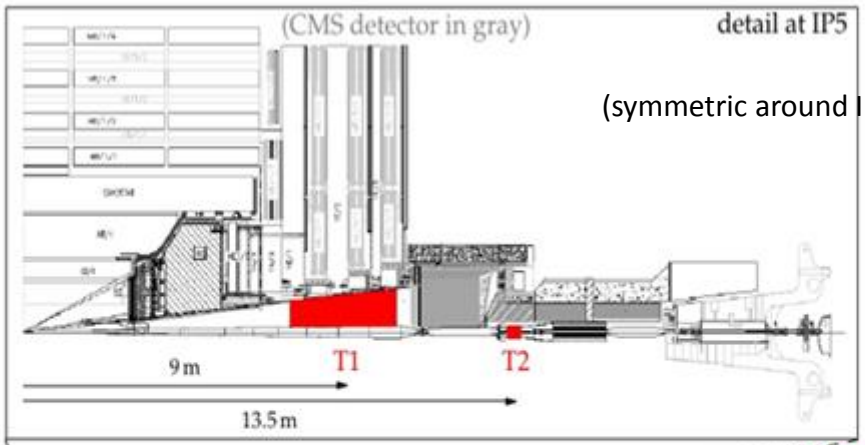
Forward physics



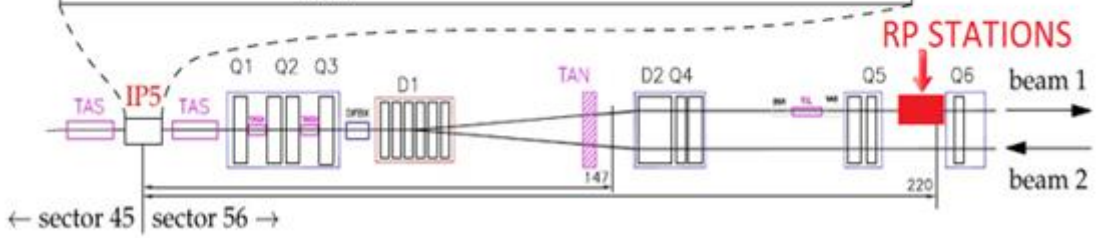
Diffraction: soft and hard



The TOTEM Experimental apparatus in RUN-2

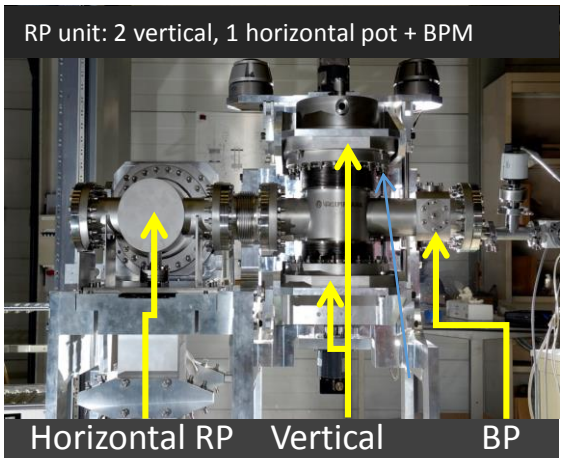


(symmetric around IP5)

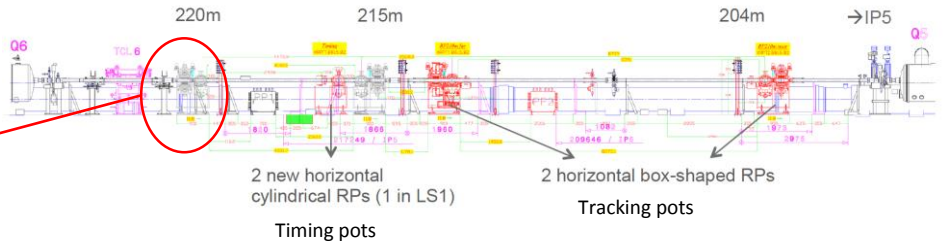


T1, T2 telescope:
Very forward detectors for tracking of charged particle produced in inelastic collisions (3-90 mrad)

RP detectors:
Silicon detectors placed in movable beam-pipe insertions, to approach the beam to less than a millimetre: detection of protons with scattering angles of only a few µrad



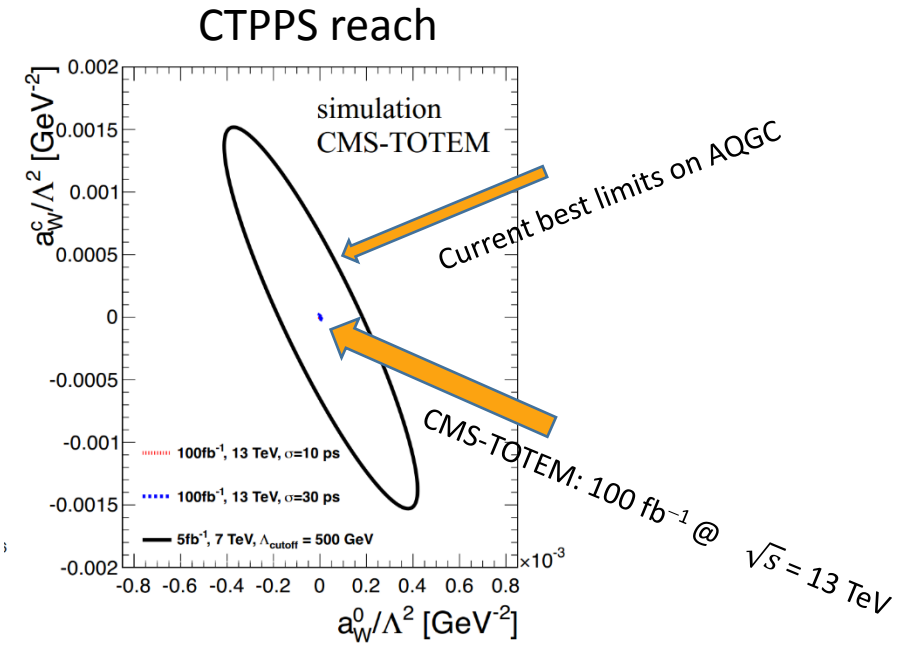
Sector 45 (left arm)



- **Larger set of RP ever operating simultaneously in a collider: 26**
- **147 m stations relocated to 210 m (increase lever arm)**
- **RPs at 214 m rotated by 8° (multi-track capability)**
- **Two new horizontal RPs for timing detectors (CT-PPS, high luminosity)**

TOTEM high luminosity data taking

- **RP detectors previously used only in special TOTEM runs**
  - **High β* (90m, 1km, 2.5km)**
  - **Low angular beam dispersions**
  - **~Low luminosity (wide beam)**
  - **Short runtime (few weeks/year)**
  - **Integrated luminosity size O(pb^{-1})**
  - **Common running with CMS, trigger bit interchange**



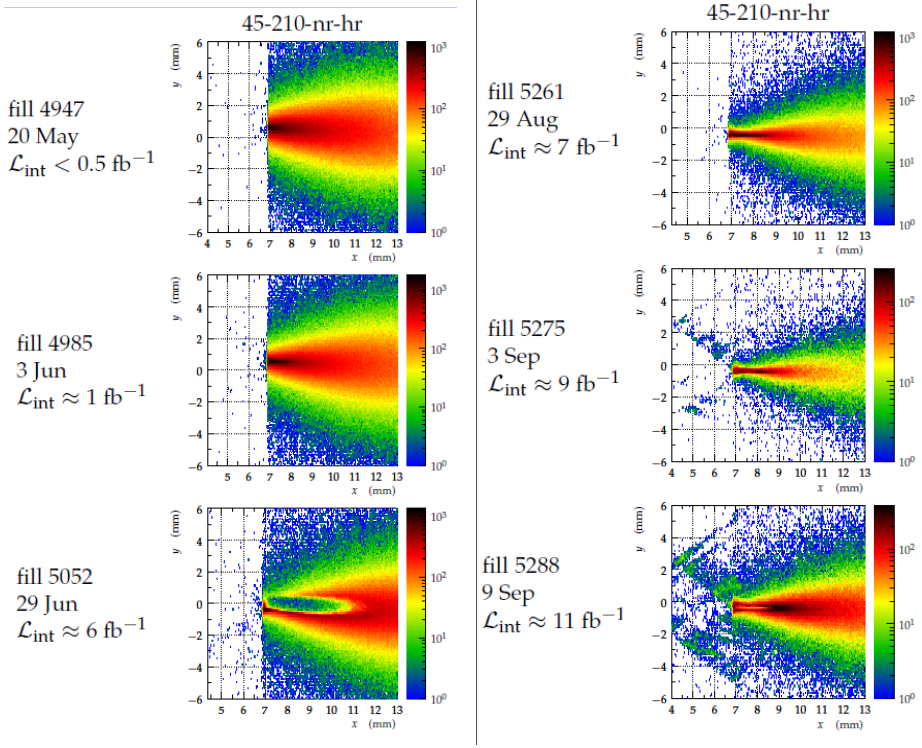
AQGC with CEP WW: comparison with current best limits

TOTEM high luminosity data taking

- **Now in Run-2, RP's commissioned for insertion during all regular high luminosity runs**
  - **Low β***
  - **CTPPS: RP's fully integrated in CMS**
  - **Excellent for central diffraction:**
    - **exclusive W^+W^- or γ γ/ZZ/Z γ with mass measurement from protons. AQGC: non-SM 4-gauge boson vertices**
  - **Collected ~15 fb^{-1} this year**
  - **Mass threshold higher (few hundred GeV)**
  - **First stage CTPPS: use existing detectors for tracking**
    - **Present RP detectors Si, not rad hard**

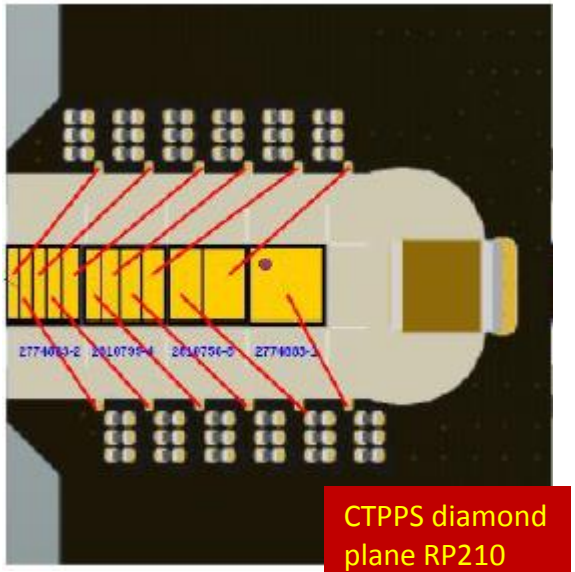
Before HV increase

After

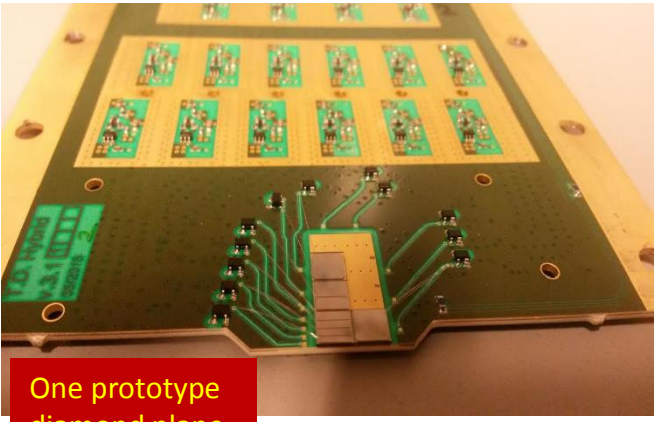


- **Most beam halo protons hit very small area , increase life by moving pot up/down by 2mm**
- **Performance recuperated by increasing the voltage**
- **Replace with rad-hard 3D Si (RP214: 2017)**
- **Only horizontal pots inserted during low β* runs**

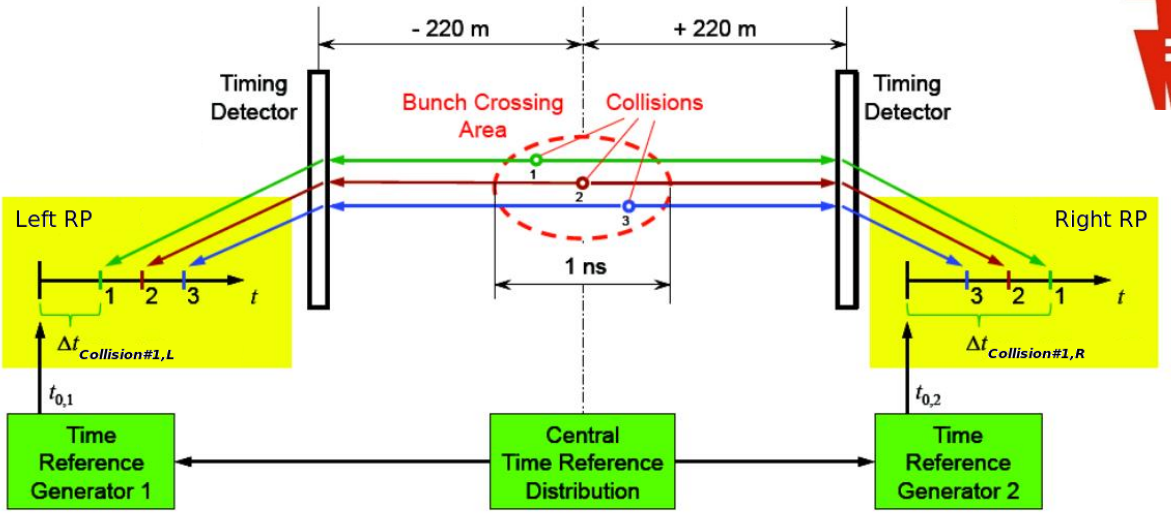
TOTEM upgrade with timing detectors



CTPPS diamond plane RP210



One prototype diamond plane



Position of Collision 1 $\sim \Delta t_{Collision\#1,L} - \Delta t_{Collision\#1,R}$

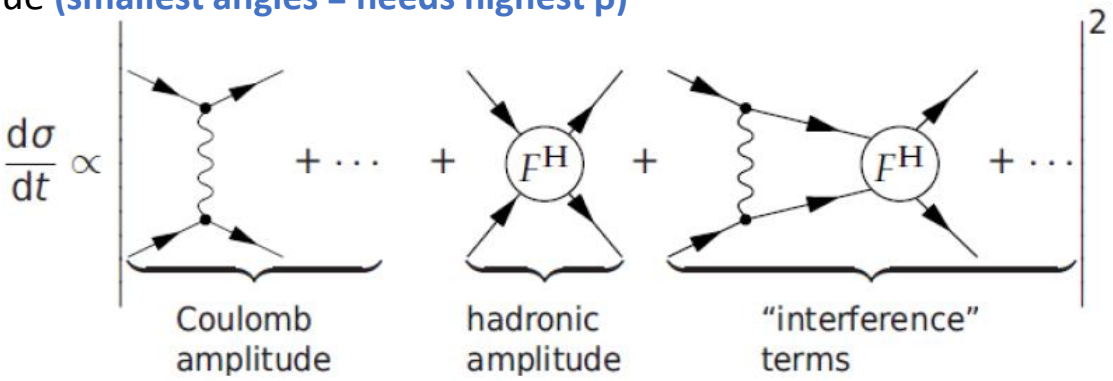
- **Timing detectors have been installed inside the RPs at 210m, on the two sides of the IP.**
- **Detectors based on diamond (rad hard) sensors, expected <50 ps time resolution per arm (measured 80 ps per plane).**
- **Detector readout in commissioning**
- **For CD events the difference of the arrival time of the protons gives the longitudinal vertex position.**
- **Only way to associate the proton vertex to the CMS one.**

→ Background suppression and possibility of common runs at higher pile-up with CMS

TOTEM special Run @ 13 TeV (Sept 2016)

- **New beam optics β*=2500m to have very low t-acceptance limit (0.0006 to 0.2 GeV^2)**
- **Analysis starting, elastic event sample ~7 M**
- **Elastic main interest, T1 & T2 not on during run**
- **Measure ρ parameter**

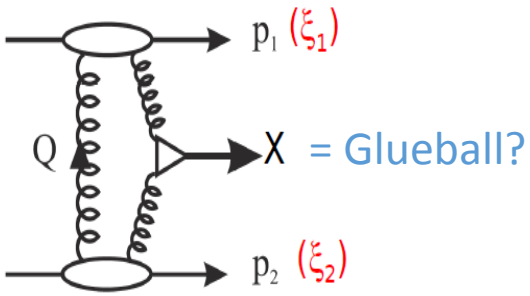
At small enough *t* the pp scattering is also affected by the Coulomb interaction: low-t Odderon would affect ρ, existence deducible from measured ρ-value **(smallest angles = needs highest β)**



TOTEM special Runs: Physics

A few examples of what we can learn from these data:

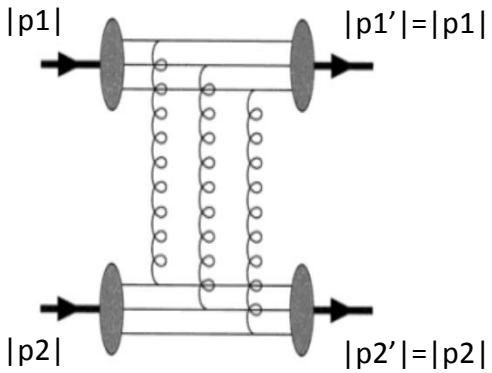
- Central diffractive productions: **Glueball (discovery potential):** particle consisting only of gluons



  - Predicted by QCD, searched for decades, never confirmed, but:
    - Lattice QCD predicts the lowest possible masses
  - Central diffraction is mediated by gluons, natural place where to find it: 0^{++},2^{++} favoured.
  - By tagging the protons: 100% sure of the process exclusivity (nothing lost by the central detector)

    (~high luminosity & β=90m: Oct 2015 680bunch ~0.4pb^{-1})

- Elastic scattering:



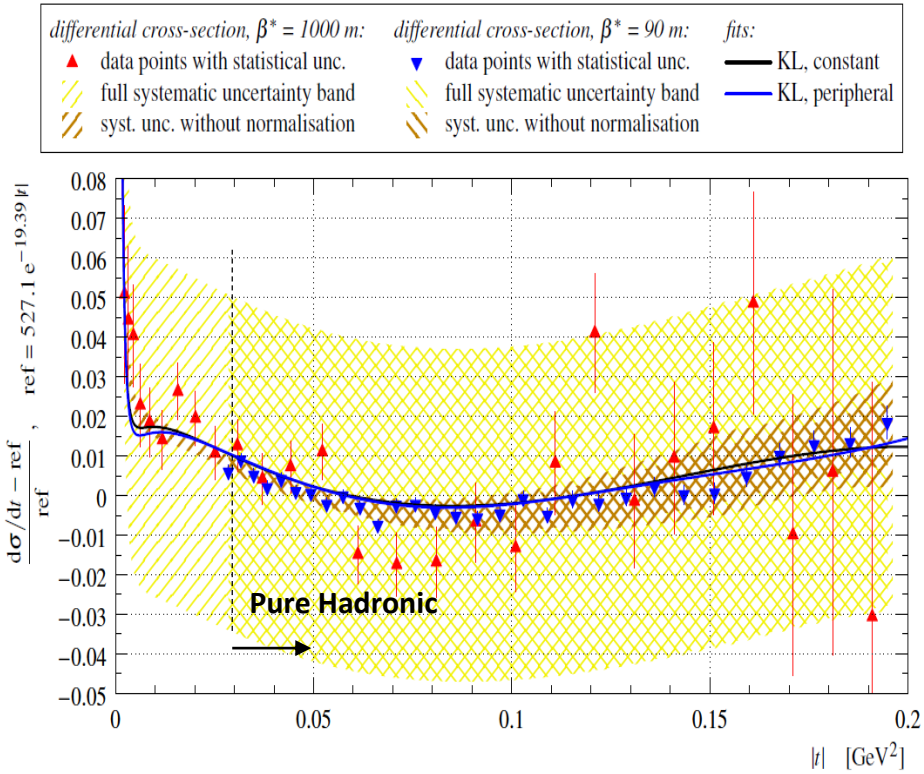
Very large-t scattering:

- QCD based models can be used to describe the process
- 3 individual gluons mediating the elastic interaction (if $J^{PC}=1^{--}$, this would be a high-t Odderon)
- (~high luminosity; exponentially falling spectrum)

New results on differential elastic cross section dσ/dt at low 4-momentum transfer t

- Pure exponential $d\sigma_{EL}/dt$ excluded with unprecedented significance (>7σ)

$d\sigma_{EL}/dt$ Difference with respect to an exponential



➢ *Hint for more than one channel at work in the low-t elastic scattering*

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 899 (2015) 527–546
www.elsevier.com/locate/nuclphysb

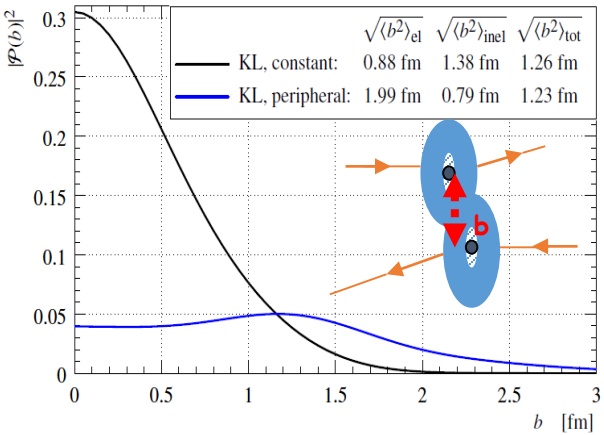
Evidence for non-exponential elastic proton–proton differential cross-section at low $|t|$ and $\sqrt{s} = 8$ TeV by TOTEM

TOTEM Collaboration

New results on differential elastic cross section dσ/dt at low 4-momentum transfer t

- **By measuring the elastic scattering in the region of the Coulomb-Nuclear interference:**

Access to the Hadronic phase (sensitivity to the impact parameter description of the collision)



- Data fit allowed a peripheral description of the elastic collision
- Centrality of the elastic collisions are possible but not necessary

New results on total pp cross section σ_{TOT} and ρ

- Thanks to the study of the Coulomb-Hadronic interference we can:
  - Quantify and remove the effect of the electromagnetic interaction for a better determination of the hadronic one and its better extrapolation to t=0:

$$\sigma_{\mathrm{tot}}^2 = \frac{16\pi\,(\hbar c)^2}{1+\rho^2}\left.\frac{\mathrm{d}\sigma_{\mathrm{el}}}{\mathrm{d}t}\right|_{t=0}$$

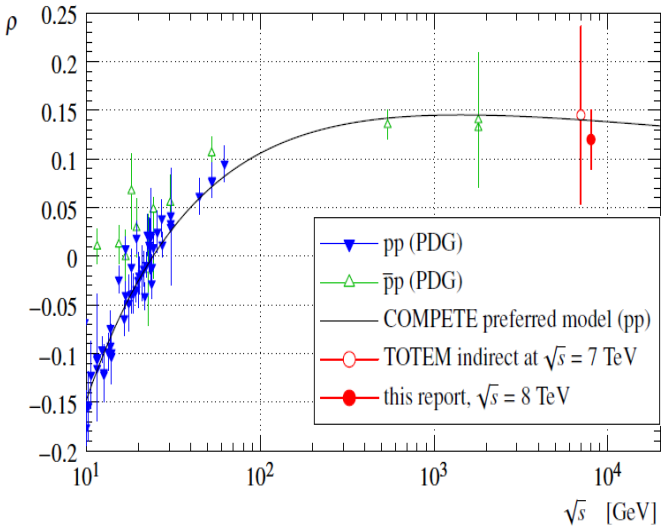
σ_{TOT}=102.9 mb

New, luminosity-independent determination of σ_{TOT}: consistent with the previously published by TOTEM (PRL 111, 012001) but this time no external parameter has been used

  - Make the first determination of ρ at the LHC :

$$\rho = \left.\frac{\mathrm{Re}\,F^H}{\mathrm{Im}\,F^H}\right|_{t=0}$$

  - *The precise knowledge of this parameter is needed by theory: discovery of a 3-gluon ($J^{PC}=1^{--}$) state as mediator contributing to the elastic interaction.*
  - *This data: it exists at 2-3σ, Run-2 data will be crucial.*

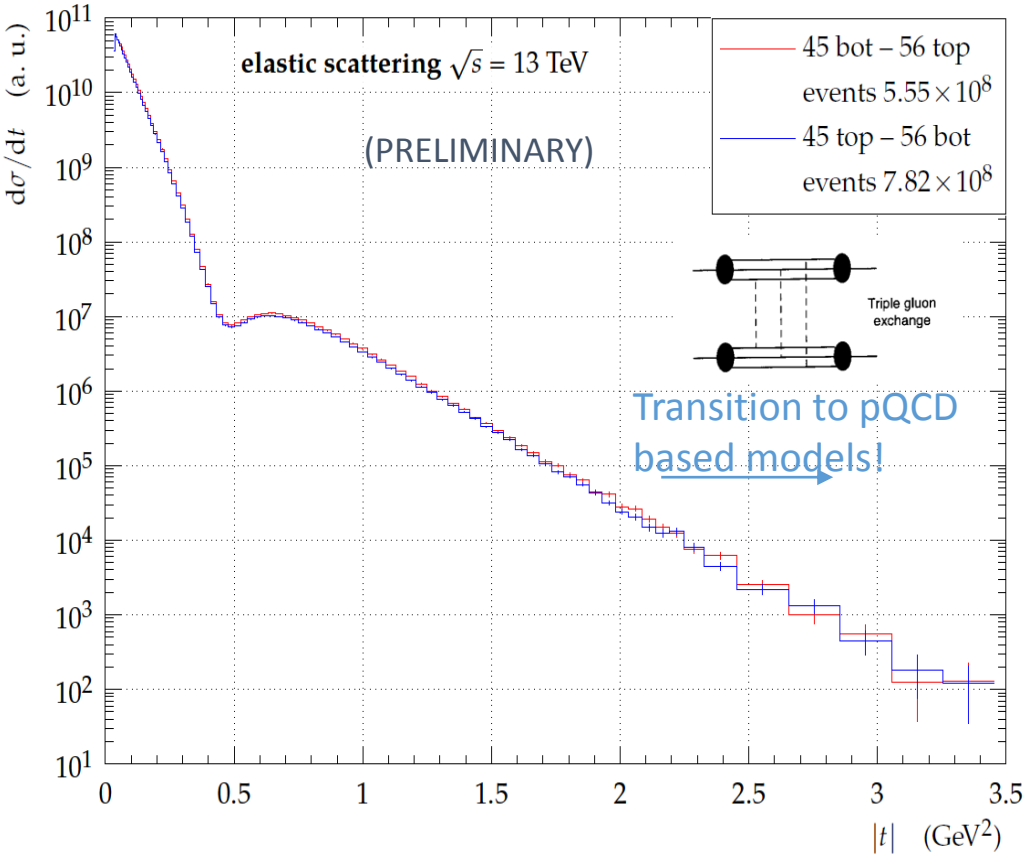


To know more:

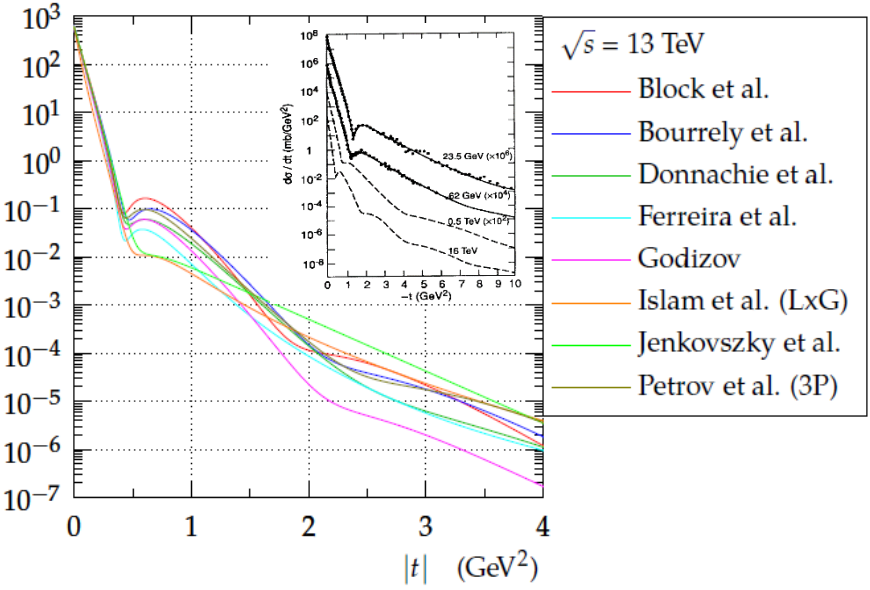
Nuclear Physics B
Volume 899, October 2015, Pages 527–546

CERN-PH-EP-2015-325

RUN-2 Preliminary results @ 13 TeV

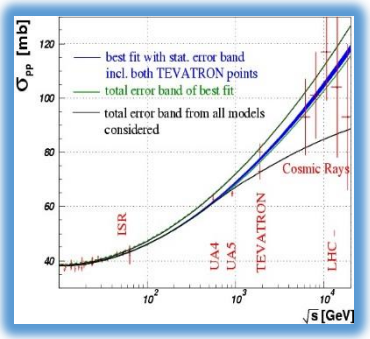


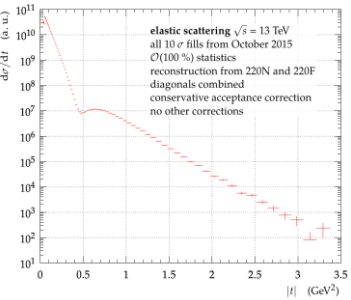
Models predictions:

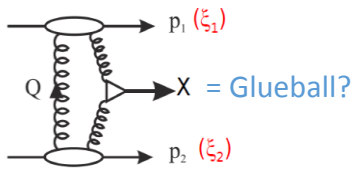


- No structure (dips/waves) observed after the first dip:
  Excluding vast majority of the theoretical models published in the last decades

Outlook 2016-17







- High precision elastic differential and total cross section at 13 TeV.
- Lower energy analysis at 2.76 TeV.
- Sensitivity to $J^{PC}=1^{--}$ three gluon colourless state from ultra low-t elastic scattering at 13 TeV.
- Central diffraction at 13 TeV: unique CMS+TOTEM apparatus to discover glueballs and study hard diffraction.
- Upgrade tracking with rad-hard 3D Si (see multiple tracks)
- Data-taking with the timing detectors for central diffraction at higher luminosity jointly with CMS
  - Look for high-mass central system (BSM?)

…… Stay tuned and thanks for your attention !

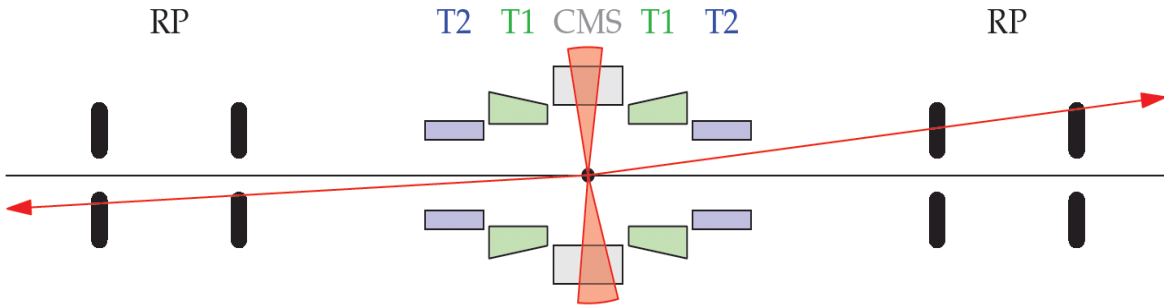
BACKUP

TOTEM special Run @ 13 TeV (October 2015)

- **UPGRADED TOTEM trigger rate @ 80 KHz: capability x 50 with respect to Run-1**
- **~30h of stable beam, special 90m optics, μ=7%-10% , up to 680 bunches (never before)**

CMS+TOTEM data

- **TOTEM Triggers → CMS**
  - Roman Pots Double Arm & T2 Veto
  - Roman Pots Double Arm (TopTop/BottomBottom)
  - T2 Min Bias, Zero Bias
- **CMS Triggers → TOTEM**
  - Dijets (P_T threshold 20, 32 GeV)
  - Dimuon
  - Single μ & HF veto.



Integrated Luminosity

• LHC delivered:	~ 0.74 pb^{-1}
• CMS recorded:	~ 0.68 pb^{-1}
• TOTEM Trigger & CMS data:	~ 0.55 pb^{-1}
• **CMS + TOTEM data:**	**~ 0.4 pb^{-1}**

- **x 500** statistics with respect to the Run1
- **> 10^9** elastics candidates available
- >100M low mass central diffraction

Unprecedented statistics for the study of the elastic scattering and of the central diffraction (including low mass resonances)

Non-exponential elastic dσ/dt

Available online at www.sciencedirect.com
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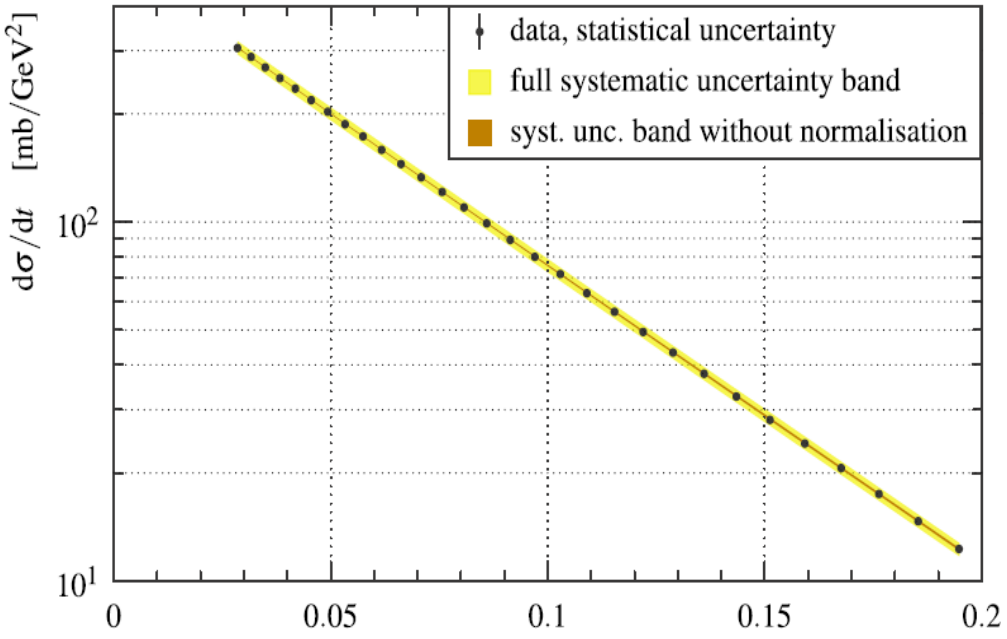
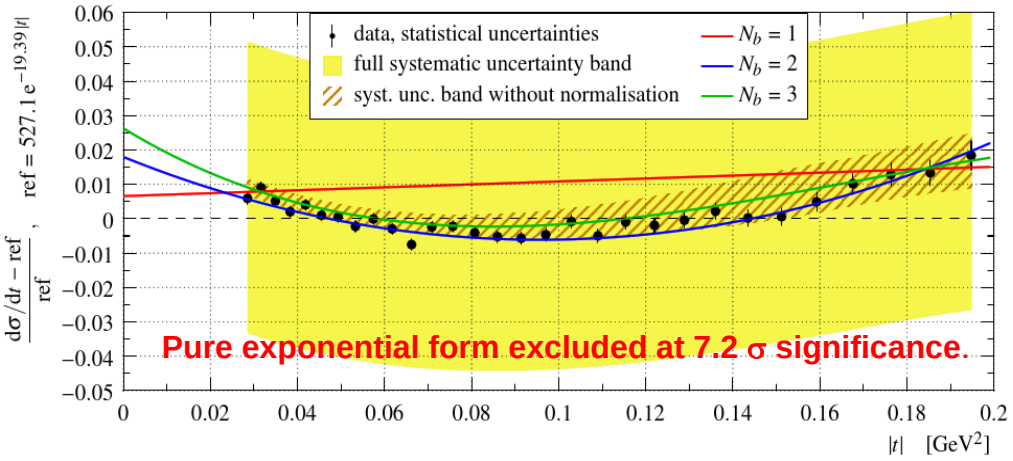
Nuclear Physics B 899 (2015) 527–546
www.elsevier.com/locate/nuclphysb



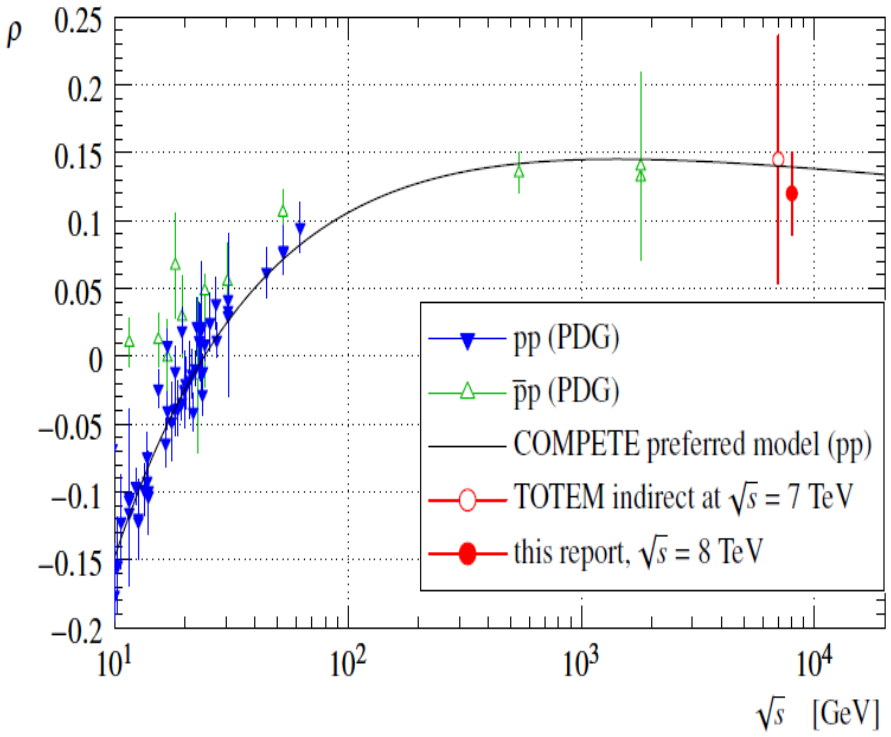


- In this range the elastic scattering is mediated by peripheral exchange of coherent gluonic systems
- Thanks to the high statistics data set (7M elastic events) the pure exponential behavior of the elastic scattering has been excluded

$$\frac{d\sigma}{dt}(t) = \left.\frac{d\sigma}{dt}\right|_{t=0} \exp\left(\sum_{i=1}^{N_b} b_i\, t^i\right)$$

- Non exponentiality may suggest that more than one mechanism is at work.
- Pure exponential excluded for the first time with such large significance.

Hadronic-Coulomb interference



	KL, constant	KL, peripheral
step 1: χ^2/ndf	25.7/25 = 1.03	25.0/25 = 1.00
step 2: χ^2/ndf	57.5/56 = 1.03	57.6/56 = 1.03
a [mb/GeV^2]	549 ± 24	549 ± 24
b_1 [GeV^{-2}]	20.47 ± 0.14	19.56 ± 0.13
b_2 [GeV^{-4}]	8.8 ± 1.6	−3.3 ± 1.5
b_3 [GeV^{-6}]	20 ± 6	−13 ± 5
ρ	0.12 ± 0.03	0.12 ± 0.03
σ_{tot} [mb]	102.9 ± 2.3	103.0 ± 2.3

Measurement of Elastic pp Scattering at $\sqrt{s}$ = 8 TeV in the Coulomb-Nuclear Interference Region – Determination of the ρ-Parameter and the Total Cross-Section

The TOTEM Collaboration

G. Antchev[1], P. Aspell[q], I. Atanassov[1], V. Avati[q], J. Baechler[q], V. Berardi[j,i], M. Berretti[q,o], E. Bossini[o], U. Bottigli[o], M. Bozzo[l], P. Broulím[a], A. Buzzo[l], F. S. Cafagna[i], C. E. Campanella[k,i], M. G. Catanesi[i], M. Csanád[g,2], T. Csörgő[g,b], M. Deile[q], F. De Leonardis[k,i], A. D'Orazio[k,i], M. Doubek[c], K. Eggert[r], V. Eremin[5], F. Ferro[l], A. Fiergolski[j,4], F. Garcia[e], V. Georgiev[a], S. Giani[q], L. Grzanka[p,3], C. Guaragnella[k,i], J. Hammerbauer[a], J. Heino[e], A. Karev[q], J. Kašpar[b,q], J. Kopal[b], V. Kundrát[b], S. Lami[n], G. Latino[o], R. Lauhakangas[e], R. Linhart[a], E. Lippmaa[d], J. Lippmaa[d], M. V. Lokajíček[b], L. Losurdo[o], M. Lo Vetere[m,l], F. Lucas Rodríguez[q], M. Macrí[l], A. Mercadante[i], N. Minafra[q,i], S. Minutoli[l], T. Naaranoja[e,f], F. Nemes[g,2], H. Niewiadomski[r], E. Oliveri[q], F. Oljemark[e,f], R. Orava[e,f], M. Oriunno[6], K. Österberg[e,f], P. Palazzi[q], L. Paločko[a], V. Passaro[k,i], Z. Peroutka[a], V. Petruzzelli[k,i], T. Politi[k,i], J. Procházka[b], F. Prudenzano[k,i], M. Quinto[j,i], E. Radermacher[q], E. Radicioni[i], F. Ravotti[q], E. Robutti[l], L. Ropelewski[q], G. Ruggiero[q], H. Saarikko[e,f], A. Scribano[n], J. Smajek[q], W. Snoeys[q], J. Sziklai[g], C. Taylor[r], N. Turini[o], V. Vacek[c], J. Welti[e,f], P. Wyszkowski[p], K. Zielinski[p]

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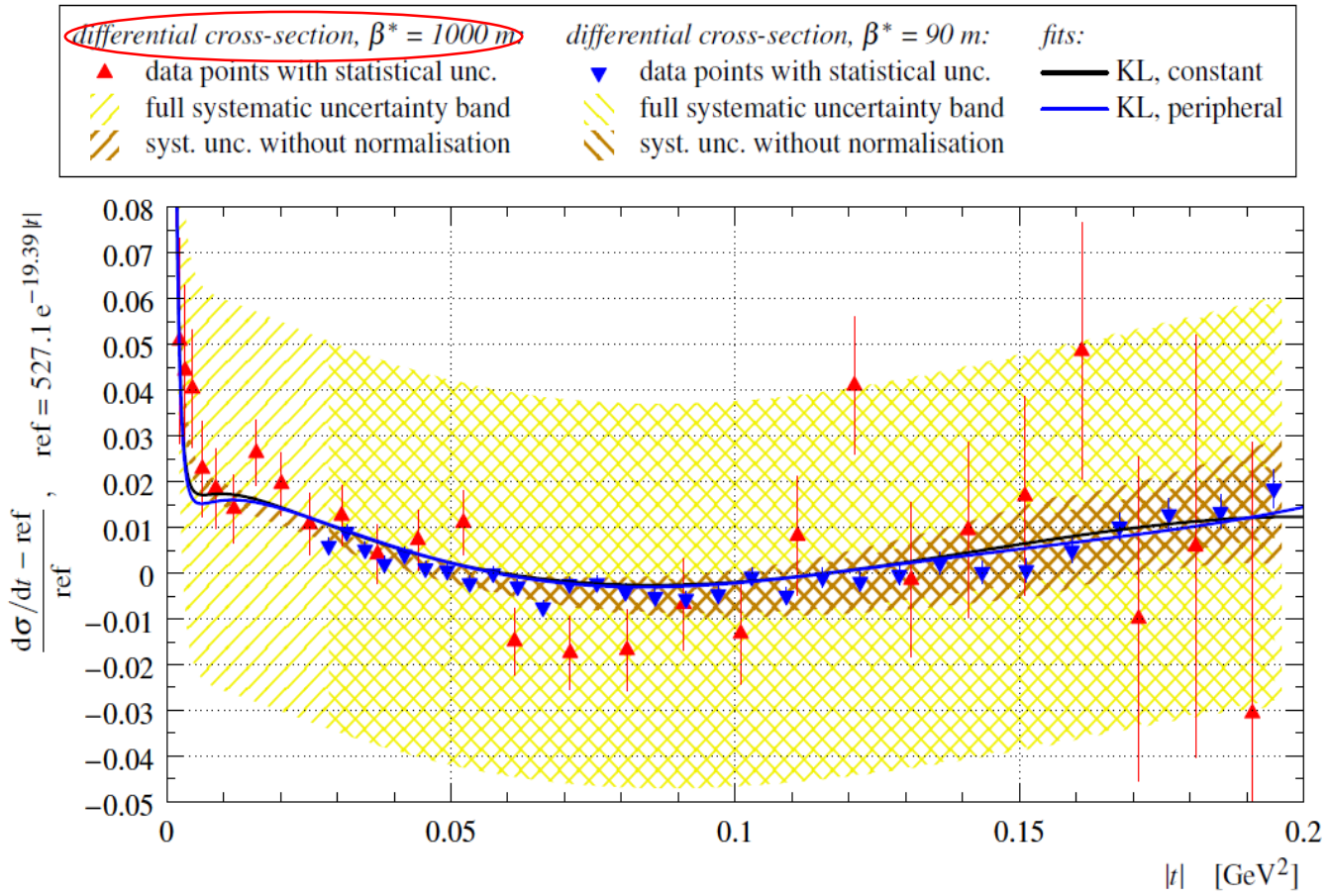
[6]SLAC National Accelerator Laboratory, Stanford CA, USA.

Preprint submitted to Nuclear Physics B *December 10, 2015*

- Total cross section compatible with previous measurement (no external parameter used!)
- First measurement of the Coulomb/Hadronic interference and ρ at the LHC!

Hadronic-Coulomb interference



- Constant hadronic phase and exponential modulus excluded by the analysis
- **Polynomial** (>1 degree) exponential hadronic slope seems necessary for describe the data
- **Both *central*** and ***peripheral*** description of the pp scattering is compatible with data

TOTEM upgrade with timing detectors

First detector test in the tunnel (Nov 2015):

- The first timing detector package has been tested inside the tunnel.
- *Good test for the full system : noise was found to be compatible to the one measured in during the tests.*
- *Stable temperature and pressure for all the data taking period ~20h (pp at 5 TeV).*
- Time resolution measurement compatible with the project specification.

Two full diamond boards were installed in RP210 pots (Jun 2016):

- Installed during TS1, for CTPPS; working.
- Detector readout to be fully commissioned soon.