Elastic and Diffractive Proton-Proton Scattering Measurements by TOTEM at the LHC

Warsaw,
28 April - 2 May 2014

XXII. International Workshop on
Deep-Inelastic Scattering and Related Subjects

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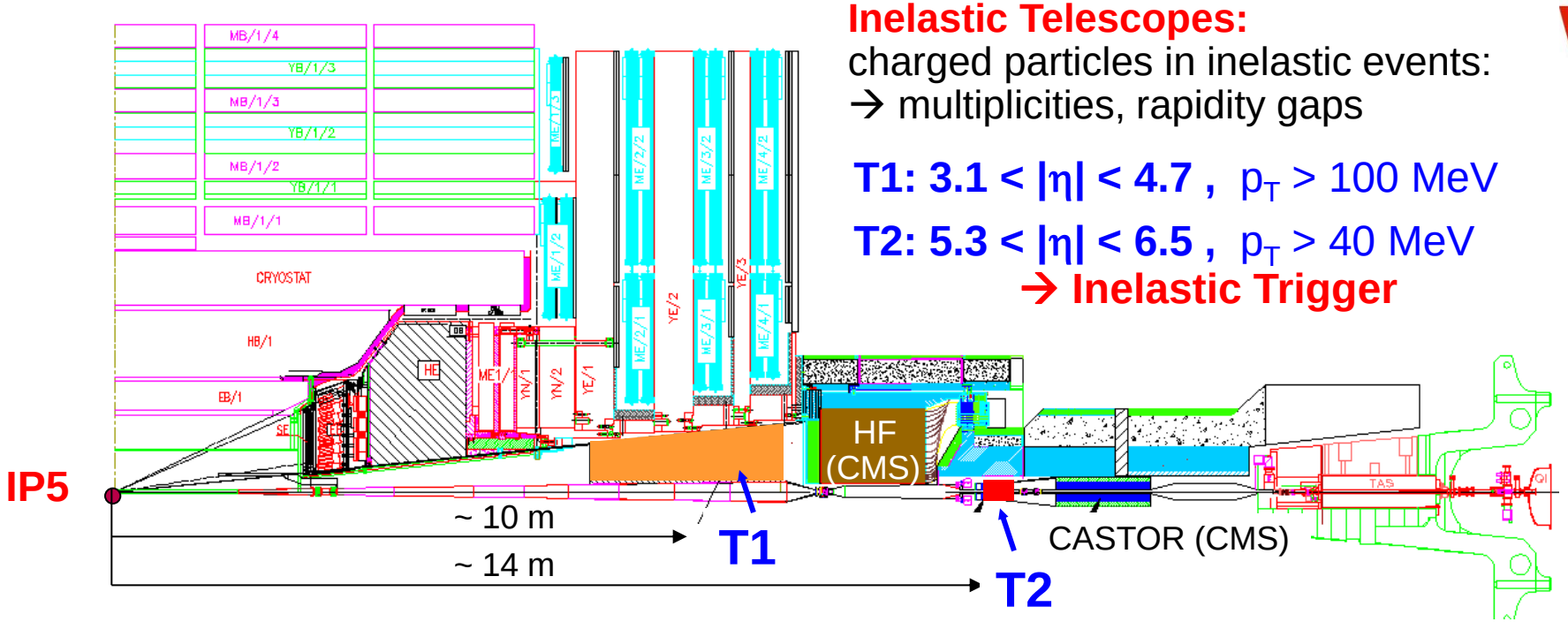
on behalf of the TOTEM Collaboration

Overview

- pp Elastic Scattering (7 TeV, 8 TeV)
- Coulomb-Nuclear Interference (CNI), ρ Parameter
- Total pp Cross-Section (7 TeV, 8 TeV)
- Diffractive Dissociation: Results and Analyses in Progress
- Outlook: Consolidation and Upgrade

Experimental Setup at IP5

[Ref.: JINST 3 (2008) S08007]



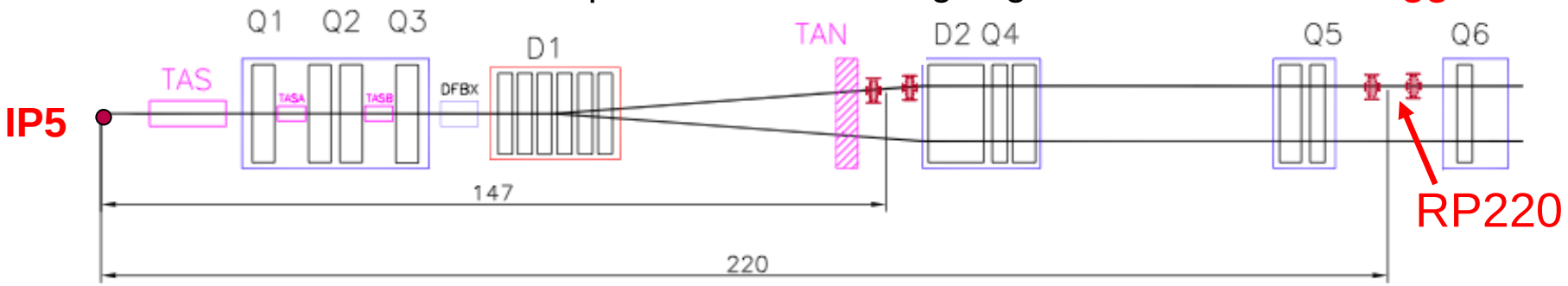
Inelastic Telescopes:
charged particles in inelastic events:
→ multiplicities, rapidity gaps

T1: 3.1 < |η| < 4.7 , p_T > 100 MeV

T2: 5.3 < |η| < 6.5 , p_T > 40 MeV

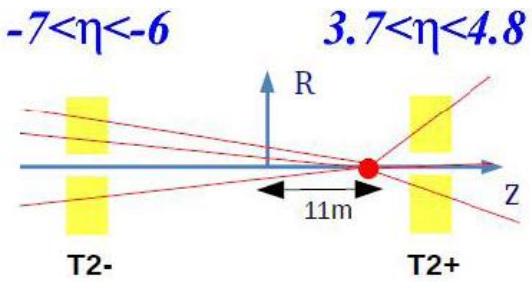
→ Inelastic Trigger

Roman Pots: elastic & diffractive protons close to outgoing beams **→ Proton Trigger**

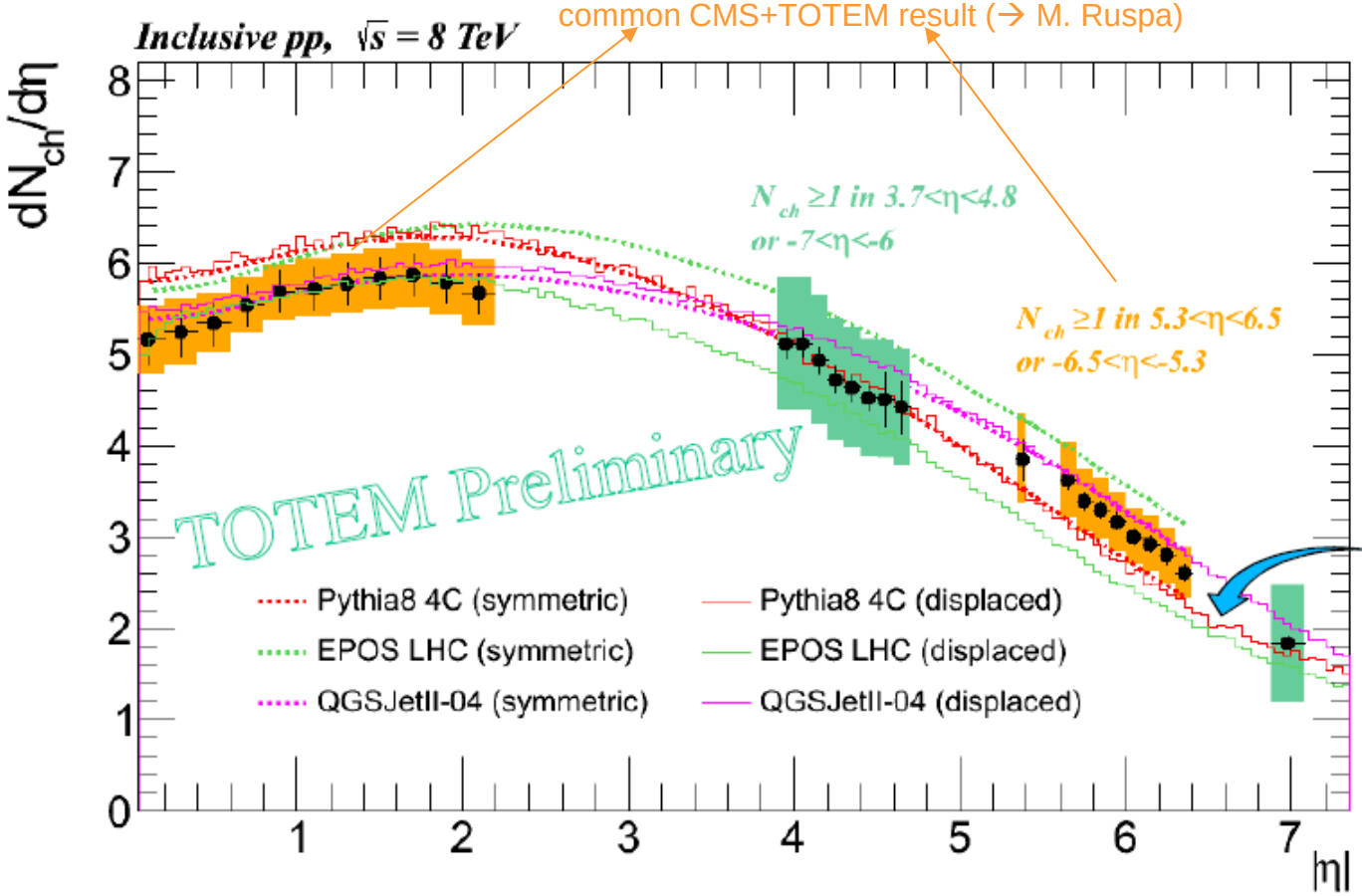


Forward $dN_{ch}/d\eta$ at 8 TeV with Displaced Vertex

run with accidentally shifted collision point along beam line
⇒ asymmetric T2 acceptance



common CMS+TOTEM result (→ M. Ruspa)



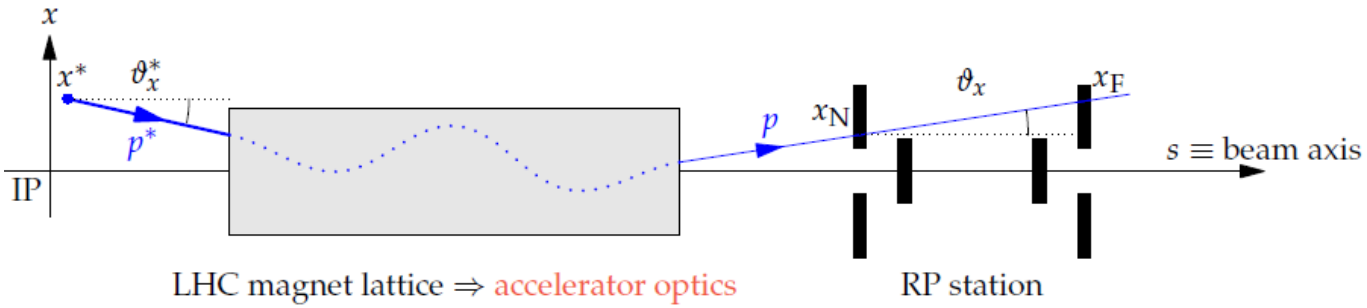
- decrease of $dN_{ch}/d\eta$ with $|\eta|$ well described by NC generators

measurement with bin-to-bin uncertainty

total uncertainty

not possible to make reliable measurement in $-6.8 < \eta < -6$ due to large material amount

Proton Transport and Reconstruction via Beam Optics



(x^*, y^*): vertex position

(θ_x^*, θ_y^*): emission angle: $t \approx -p^2 (\theta_x^{*2} + \theta_y^{*2})$

$\xi = \Delta p/p$: momentum loss (elastic case: $\xi = 0$)

Measured in RP

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \\ \Delta p/p \end{pmatrix}_{IP5}$$

Values at IP5 to be reconstructed

Product of all lattice element matrices

$$x_{RP} = L_x \Theta_x^* + v_x x^* + D_x \xi$$

$$y_{RP} = L_y \Theta_y^* + v_y y^*$$

L_x, L_y: effective lengths (sensitivity to scattering angle)

v_x, v_y: magnifications (sensitivity to vertex position)

D_x: dispersion (sensitivity to momentum loss); $D_y \sim 0$

Reconstruction of proton kinematics = "inversion" of transport equation

Transport matrix elements depend on ξ ➔ non-linear problem (except in elastic case!)

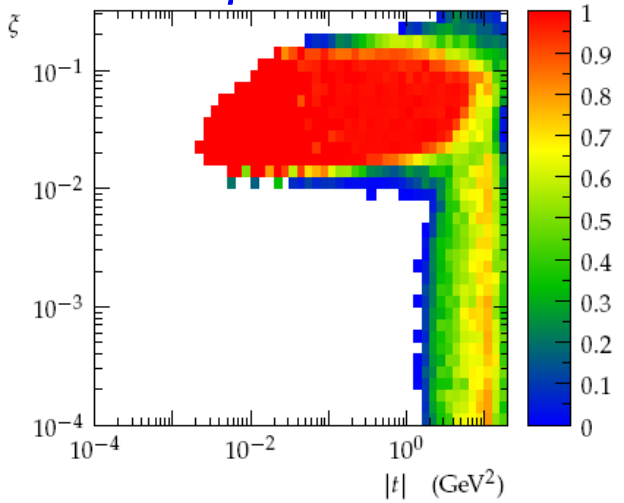
Excellent optics understanding needed: CERN-PH-EP-2014-066

LHC Optics and TOTEM Running Scenario

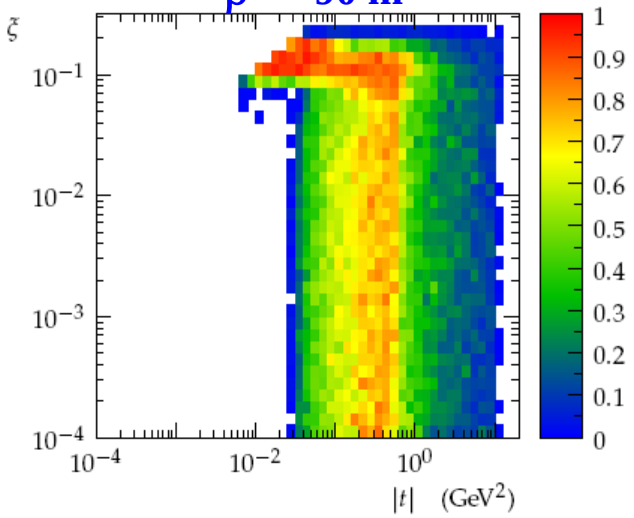
Acceptance for diffractive protons:

$t \approx -p^2 \Theta^{*2}$: four-momentum transfer squared; $\xi = \Delta p/p$: fractional momentum loss

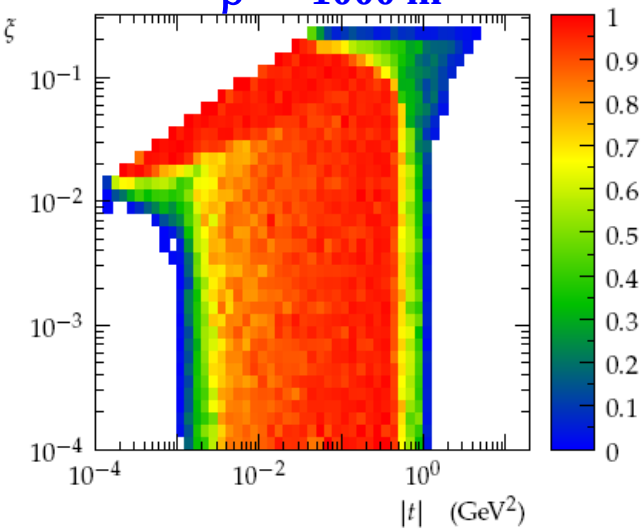
β* = 0.55 m



β* = 90 m



β* = 1000 m



$> 10^{33}$ cm^{-2} s^{-1} ← $\mathcal{L} \propto \frac{1}{\beta^*}$ → $\sim 10^{27}$ cm^{-2} s^{-1}

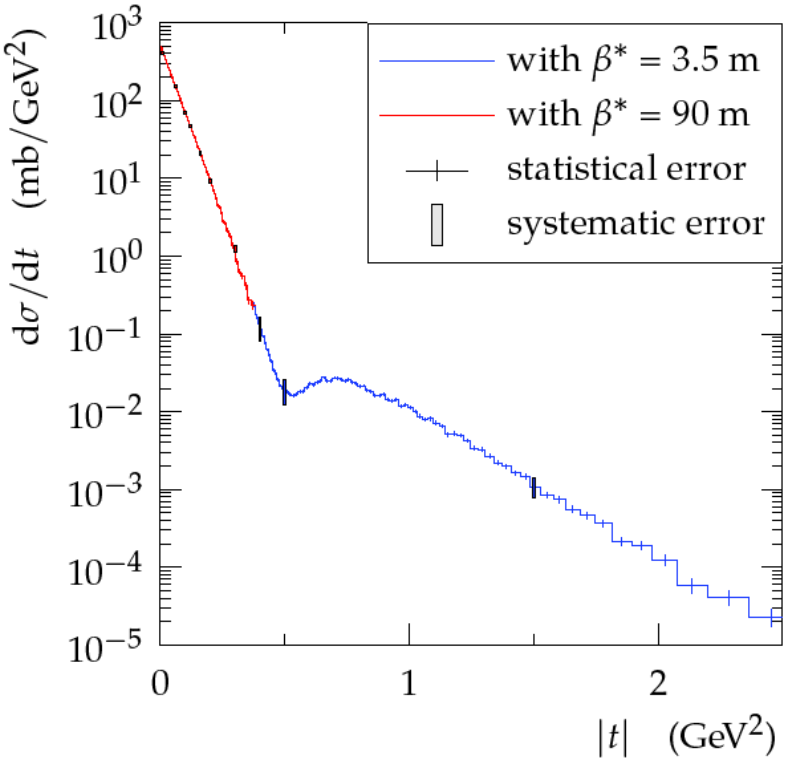
Diffraction:
$\xi > \sim 0.01$
low cross-section processes
(hard diffraction)
Elastic scattering: large |t|

Diffraction:
all ξ if $|t| > \sim 10^{-2}$ GeV^2
Elastic scattering: low to mid |t|
Total Cross-Section

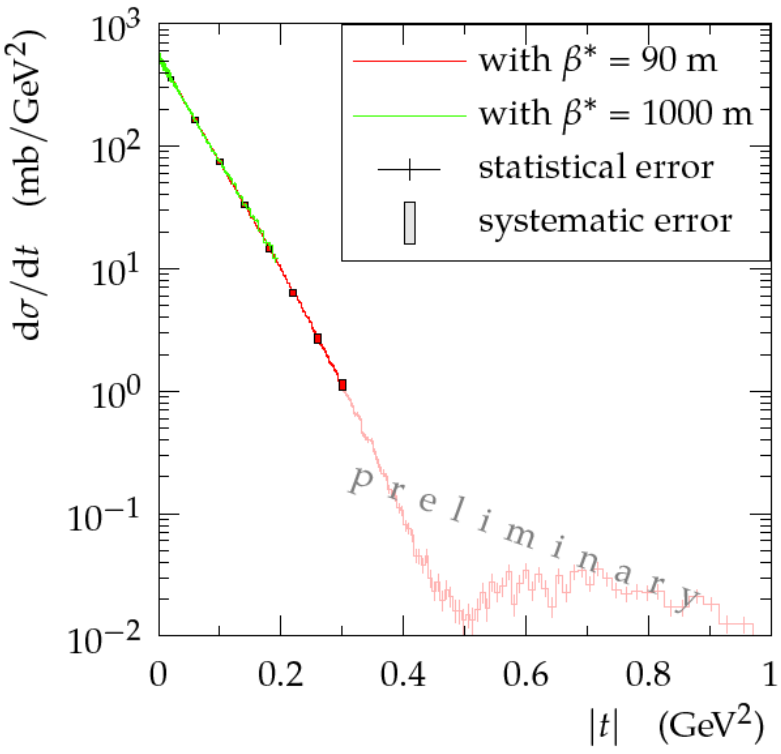
Elastic scattering: very low |t|
Coulomb-Nuclear Interference
Total Cross-Section

Elastic pp Scattering at 7 and 8 TeV: Differential Cross-Sections

$\sqrt{s} = 7\,\text{TeV}$



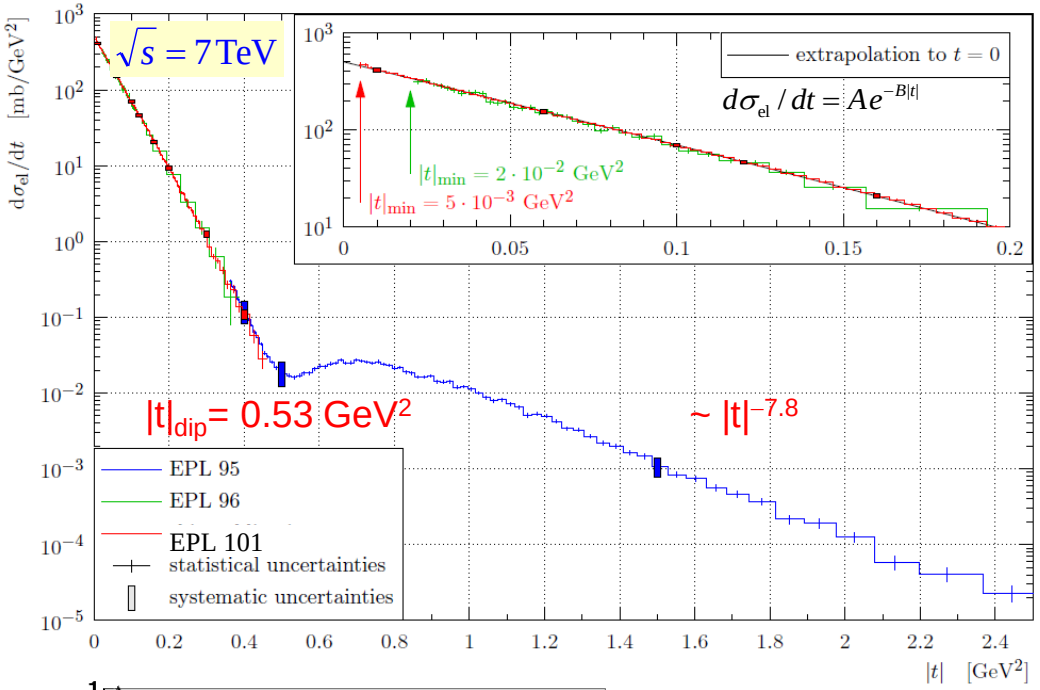
$\sqrt{s} = 8\,\text{TeV}$

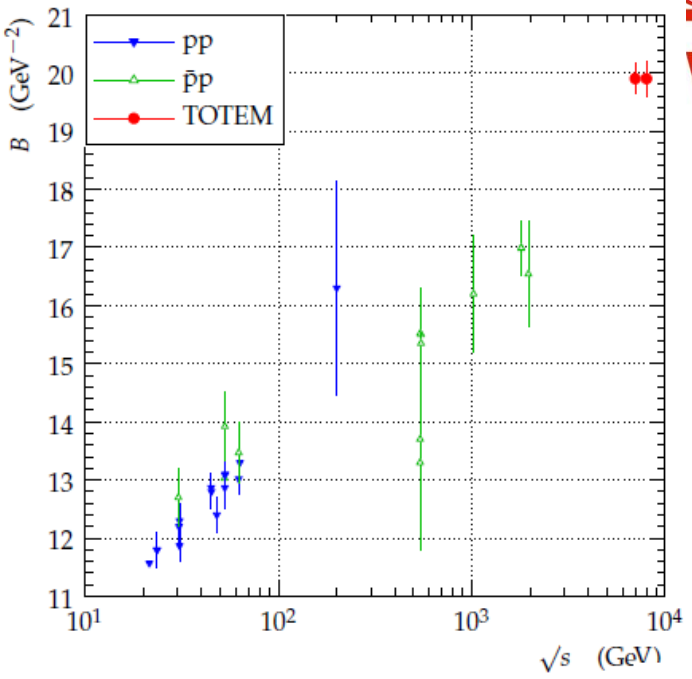


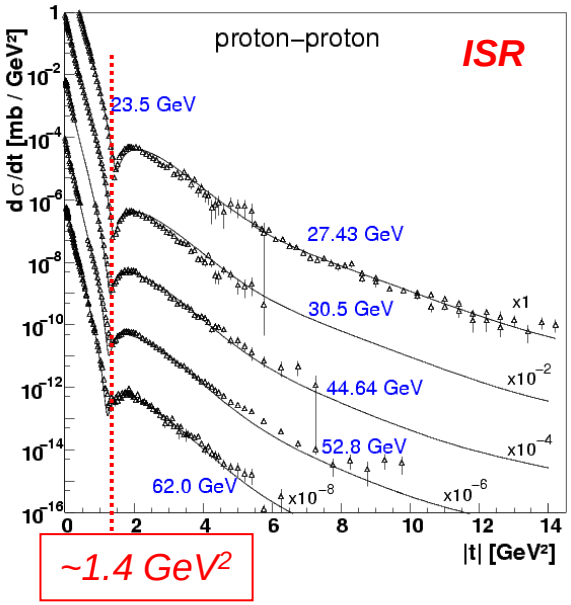
E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events
7	90	4.8-6.5σ	83	$7{\cdot}10^{-3}$ - 0.5	1M
	90	10σ	1.7	0.02 - 0.4	14k
	3.5	7σ	0.07	0.36 - 3	66k
	3.5	18σ	2.3	2 - 3.5	10k
8	90	6-9σ	60	0.01 - 1	8M
	1000	3σ	20	$6{\cdot}10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		0.05-0.6	45k

[EPL 101 (2013) 21002]
[EPL 96 (2011) 21002]
[EPL 95 (2011) 41001]

Some Lessons on Hadronic Elastic pp Scattering







At low |t|: nearly exponential decrease:

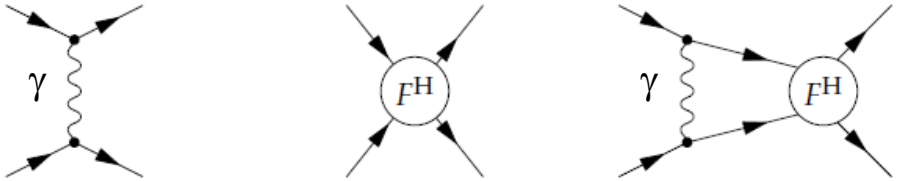
$B_{7TeV} = (19.89 \pm 0.27)\ \text{GeV}^{-2}$

$B_{8TeV} = (19.90 \pm 0.30)\ \text{GeV}^{-2}$

Old trends for increasing s are confirmed:

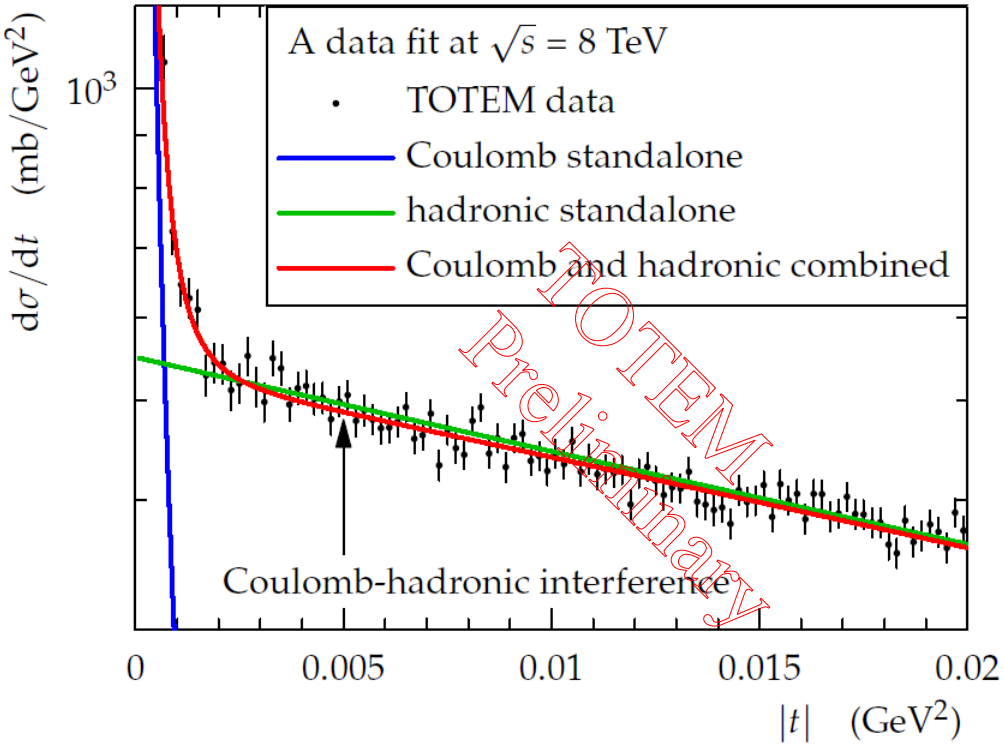
- "shrinkage of the forward peak": minimum moves to lower |t|
- forward exponential slope B increases

Elastic Scattering in the Coulomb-Nuclear Interference Region



Measure elastic scattering at |t| as low as 6 x 10^{-4} GeV^2:

- $\beta^* = 1000$ m optics: large effective lengths L_x and L_y, small beam divergence
- RP approach to 3 σ from the beam centre



$d\sigma / dt \propto |F^{C+h}|^2$ = Coulomb + interference + hadronic

Elastic Scattering in the Coulomb-Nuclear Interference Region

$$F^{C+H} = F^{C} + F^{H} e^{i\alpha\Psi}$$

$$F^{C} = \frac{\alpha s}{t}\,\mathcal{F}^2(t)$$

- Modulus constrained by measurement: $d\sigma/dt \cong A\, e^{-B(t)\,|t|}$

  $B(t) = b_0 + b_1\, t + \ldots$

- Phase $\arg(F^H)$: guidance by data difficult

Simplified West-Yennie (SWY) formula (standard in the past):

- constant slope $B(t) = b_0$
- constant hadronic phase $\arg(F^H) = p_0$
- $\Psi(t)$ acts as real interference phase: $\Psi(t) = \ln\frac{B(t)}{2} + \gamma_{\text{Euler}}$

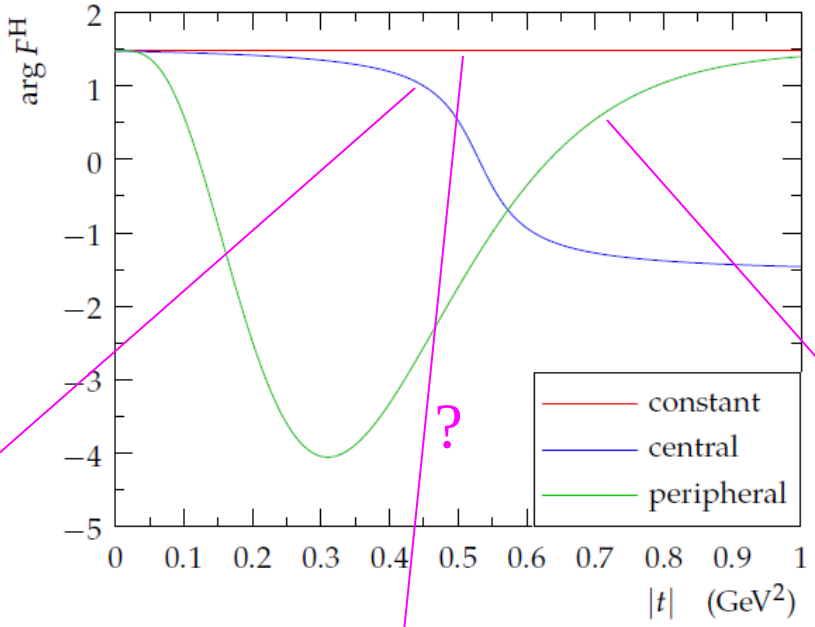
Kundrát-Lokajíček (KL) formula:

- any slope B(t)
- any hadronic phase $\arg(F^H)$
- complex $\Psi(t)$:

$$\Psi(t) = \mp \int_{t_{min}}^{0} dt' \ln\frac{t'}{t}\frac{d}{dt'}\mathcal{F}^2(t') \pm \int_{t_{min}}^{0} dt' \left(\frac{F^H(t')}{F^H(t)} - 1\right)\frac{I(t,t')}{2\pi}$$

$$I(t,t') = \int_0^{2\pi} d\varphi\, \frac{\mathcal{F}^2(t'')}{t''}, \qquad t'' = t + t' + 2\sqrt{tt'}\cos\varphi$$

Elastic Scattering in the Coulomb-Nuclear Interference Region



?

?

?

"central phase":

$$\arg F(t) = \frac{\pi}{2} - \operatorname{atan} \frac{\cot p_0}{1 - \frac{t}{t_d}}$$

constant phase:

$$\arg F(t) = p_0$$

"peripheral phase":

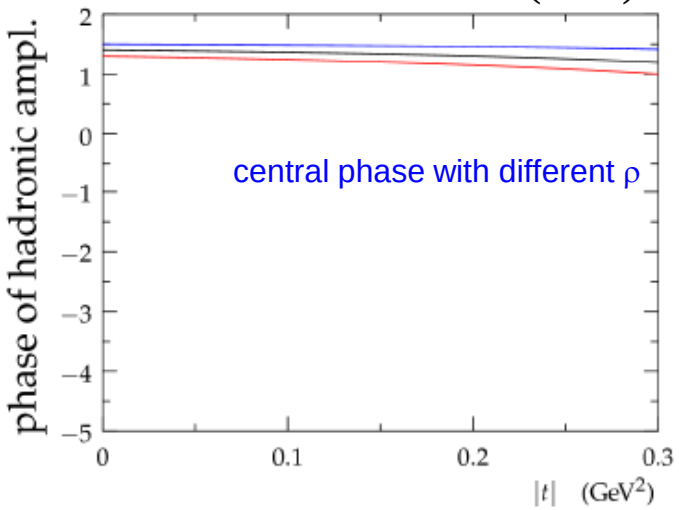
$$\arg F(t) = p_0 + p_A \exp\left[\kappa\left(\ln \frac{t}{t_m} - \frac{t}{t_m} + 1\right)\right]$$

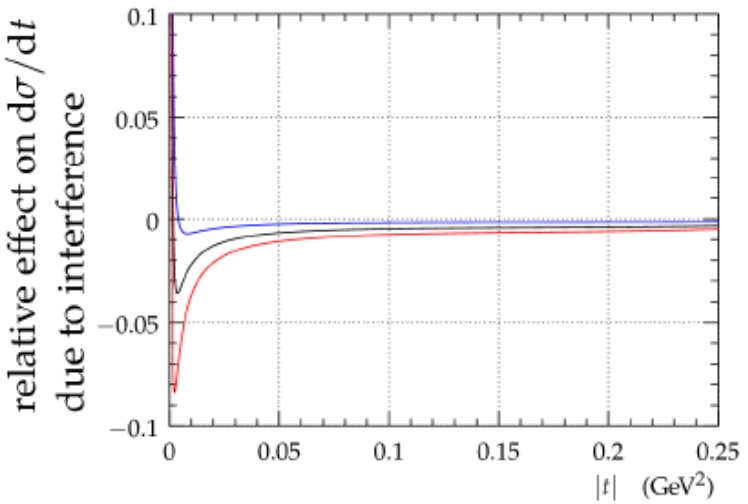
Only 1 free parameter: p_0 ➔

$$\rho = \frac{\Re F^H(0)}{\Im F^H(0)} = \cot \arg F^H(0) = \cot p_0$$

Effects of Hadronic Phase on dσ/dt

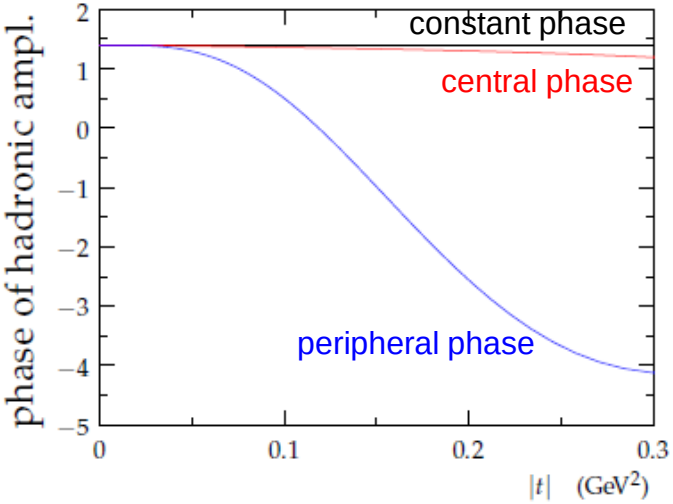
low-|t| effect from $\rho = \frac{\Re F^H(t=0)}{\Im F^H(t=0)}$ (for any interference formula)

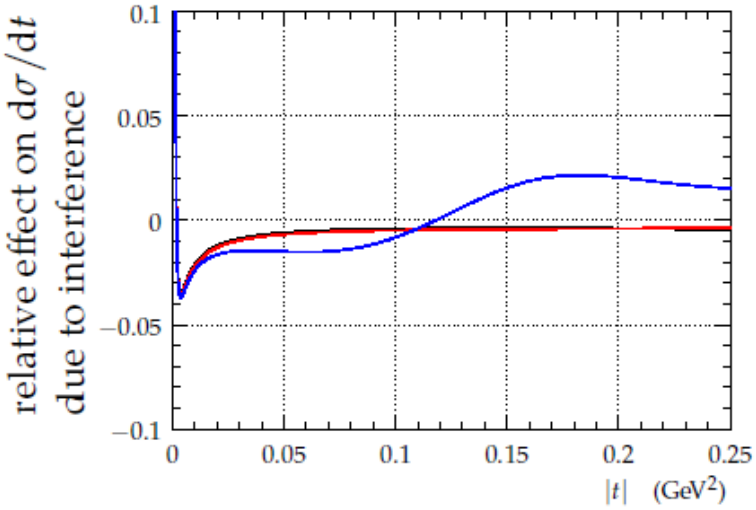




study with β* = 1000m data

higher-|t| effect from functional form of phase(t), only compatible with KL interference formula

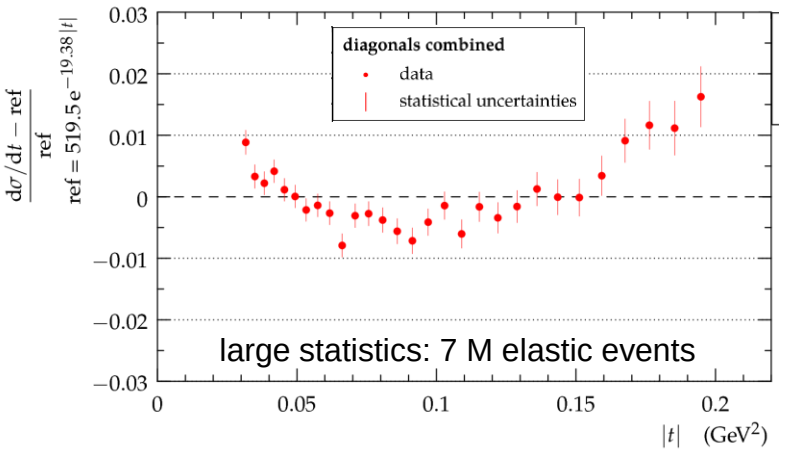




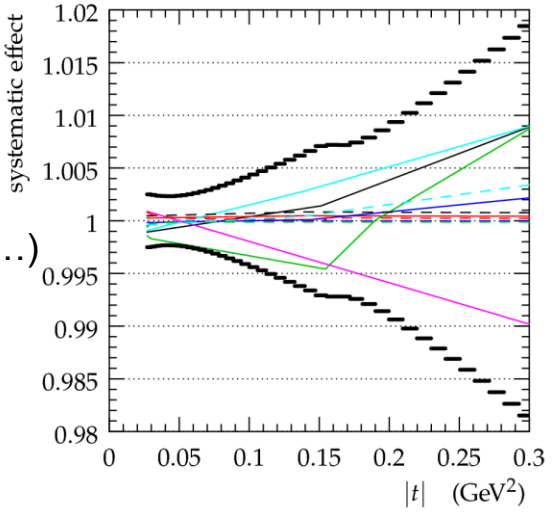
study with β* = 90m data

Higher-|t| Studies with β* = 90m Data

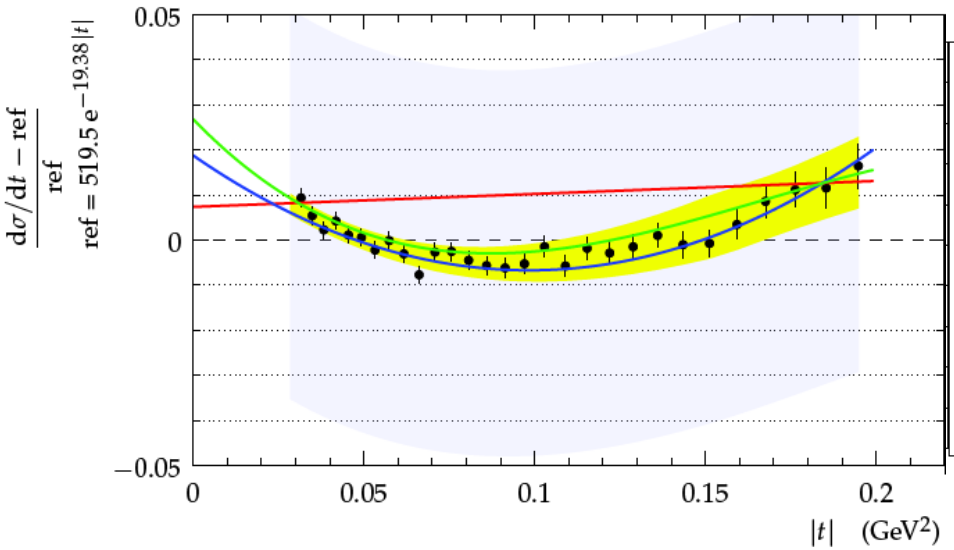
Deviation of dσ/dt from pure exponential:



Extensive study of systematics (alignment, optics, beam momentum, …)



Fit $d\sigma/dt = A\, e^{-B(t)\,|t|}$, with $B(t) = b_0$ or $B(t) = b_0 + b_1 t$ or $B(t) = b_0 + b_1 t + b_2 t^2$



diagonals combined

- data (binning ob)
- statistical uncertainties
- systematic uncertainty band: analysis+normalisation
- systematic uncertainty band: analysis only

fit parametrisation: $a \exp(\sum_{n=1}^{N_b} b_n t^n)$

fits with statistical and systematic uncertainties:

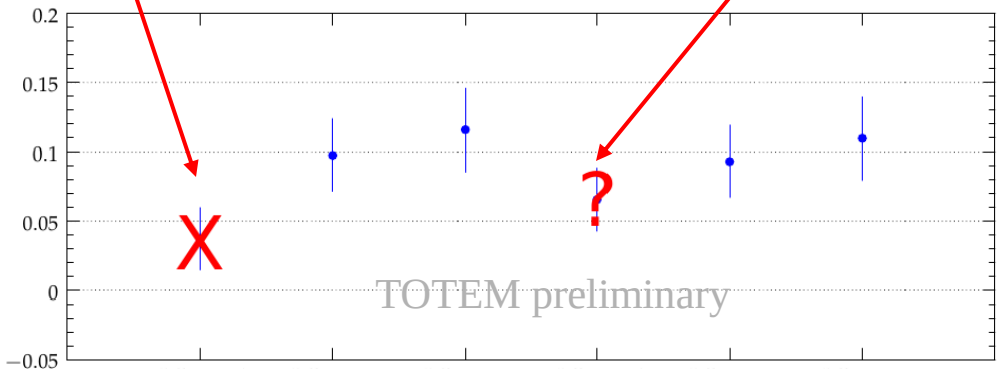
- $N_b = 1$: $\chi^2/\text{ndf} = 117.5/28 = 4.198 \Rightarrow$ p-value $= 6.14 \times 10^{-13}$, significance $= 7.20\ \sigma$
- $N_b = 2$: $\chi^2/\text{ndf} = 29.3/27 = 1.085 \Rightarrow$ p-value $= 3.47 \times 10^{-1}$, significance $= 0.94\ \sigma$
- $N_b = 3$: $\chi^2/\text{ndf} = 25.5/26 = 0.980 \Rightarrow$ p-value $= 4.92 \times 10^{-1}$, significance $= 0.69\ \sigma$

Pure exponential form excluded at ~7 σ significance.

Preliminary Result for ρ

Pure exponential form ruled out
→ SWY interference formula ruled out
(cannot produce non-exponentiality)

Constant B with peripheral phase unlikely but possible (if non-exponentiality is caused entirely by peripheral phase). Under study.

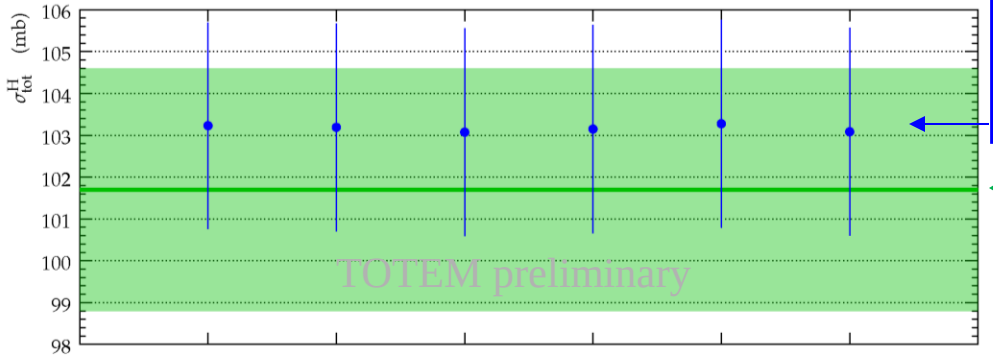


ρ from fits with different forms for B(t) and phase(t)

B(t): 1 par. 2 par. 3 par. 1 par. 2 par. 3 par.

Phase: central or constant peripheral

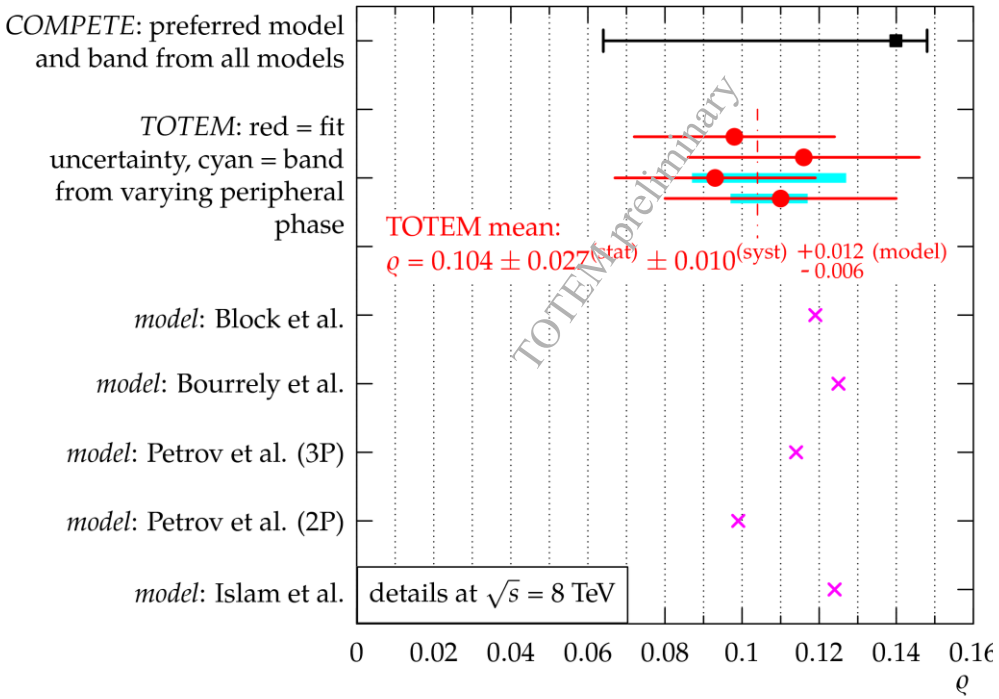
σ_{tot}^{H} (mb)

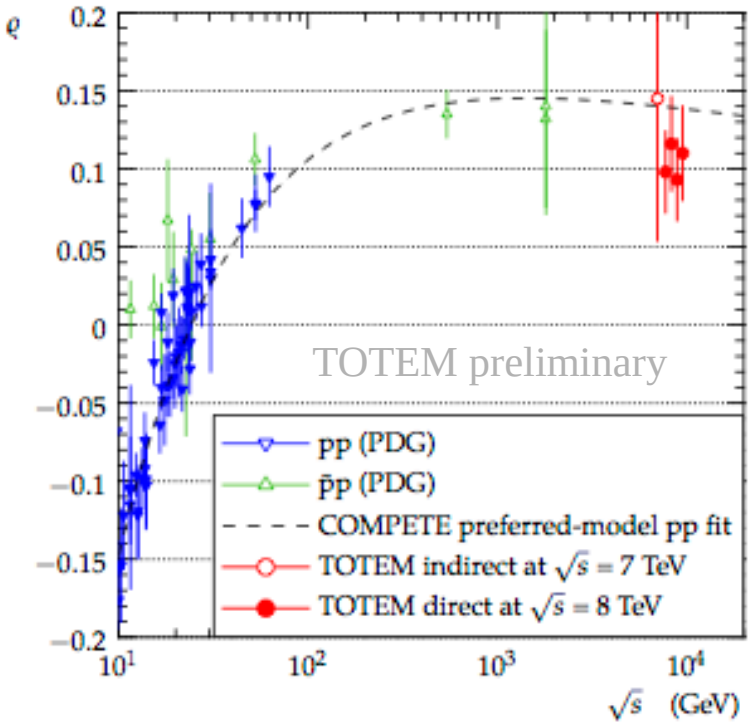


$$\sigma_{tot}^2 = \frac{16\pi}{(1+\rho^2)} \frac{1}{\mathcal{L}} \left(\frac{dN_{el}}{dt} \right)_{t=0}^{had}$$

σ_{total} = 101.7 ± 2.9 mb
luminosity independent
[PRL 111 (2013) 012001]

Synopsis of ρ Measurements





Indirect crude measurement at 7 TeV:

From optical theorem:

$$\rho^2 = 16\pi \mathcal{L}_{\text{int}} \frac{\left.\frac{dN_{\text{el}}}{dt}\right|_{t=0}}{\left(N_{\text{el}} + N_{\text{inel}}\right)^2} - 1 \quad = \quad 0.009 \pm 0.056 \quad \rightarrow |\rho| = 0.145 \pm 0.091$$

Inelastic and Total pp Cross-Section Measurements

7 TeV

8 TeV

First measurements of the total proton-proton cross section at the LHC energy of $\sqrt{s}$ = 7TeV
[EPL 96 (2011) 21002]

Measurement of proton-proton elastic scattering and total cross-section at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21002]

Measurement of proton-proton inelastic scattering cross-section at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21003]

Luminosity-independent measurements of total, elastic and inelastic cross-sections at $\sqrt{s}$ = 7 TeV
[EPL 101 (2013) 21004]

A luminosity-independent measurement of the proton-proton total cross-section at $\sqrt{s}$ = 8 TeV
[Phys. Rev. Lett. 111, 012001 (2013)]

3 Ways to the Total Cross-Section

Optical Theorem: $\sigma_{tot}^2 \propto \left[\Im F_{el,had}(t=0)\right]^2 = \frac{1}{1+\rho^2}\left|F_{el,had}(t=0)\right|^2$ with $\rho = \left.\frac{\Re F_{el,had}}{\Im F_{el,had}}\right|_{t=0}$

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\left.\frac{d\sigma_{el}}{dt}\right|_{t=0}$$

7 TeV

elastic observables only:

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\frac{1}{\mathcal{L}}\left.\frac{dN_{el}}{dt}\right|_0$$

(ρ=0.14 [COMPETE extrapol.])

June 2011 (EPL96): σ_{tot} = (98.3 ±2.8) mb

Oct. 2011 (EPL101): σ_{tot} = (98.6 ±2.2) mb

different beam intensities !

test validity of optical theorem at ~3.5 % level

σ_{tot}

ρ independent:

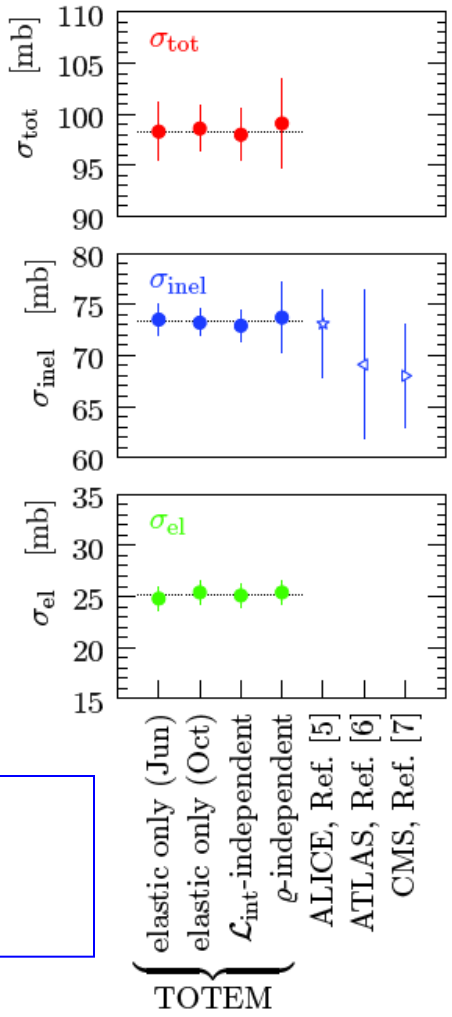
$$\sigma_{tot} = \frac{1}{\mathcal{L}}(N_{el} + N_{inel})$$

σ_{tot} = (99.1 ± 4.3) mb

luminosity independent:

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2}\frac{dN_{el}/dt|_0}{N_{el}+N_{inel}}$$

σ_{tot} = (98.0 ± 2.5) mb



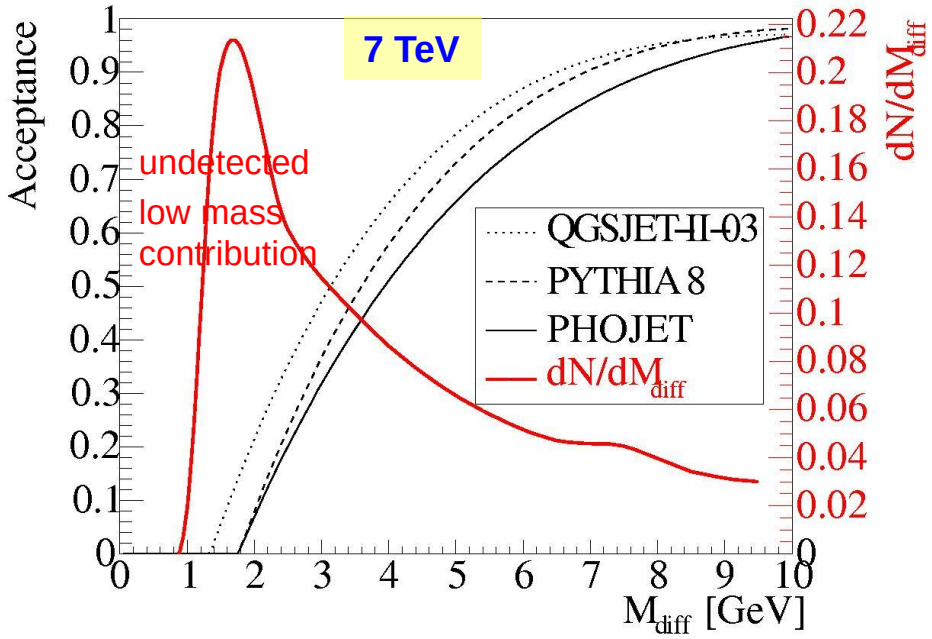
Excellent agreement between cross-section measurements at 7 TeV using
- runs with different bunch intensities,
- different methods with different external inputs.

8 TeV: only luminosity independent method (no external lumi. meas. available)

σ_{tot} (8 TeV) = (101.7 ± 2.9) mb

Inelastic Cross-Section: The Unseen Low-Mass Diffractive Part

Low-mass diffraction with $\eta > 6.5$ or $M < 3.4$ GeV (~4% of inelastic events): outside T2 acceptance (too far forward)



Correction of inelastic measurement:

based on QGSJET-II-3 Monte Carlo:

$\sigma_{M < 3.4\ \mathrm{GeV}} = 3.2 \pm 1.6$ mb

Estimate of unseen part from the data:

$$\sigma_{\mathrm{tot}}^2 = \frac{16\pi}{1+\varrho^2}\,\frac{1}{\mathcal{L}}\,\left.\frac{\mathrm{d}N_{\mathrm{el}}}{\mathrm{d}t}\right|_0$$

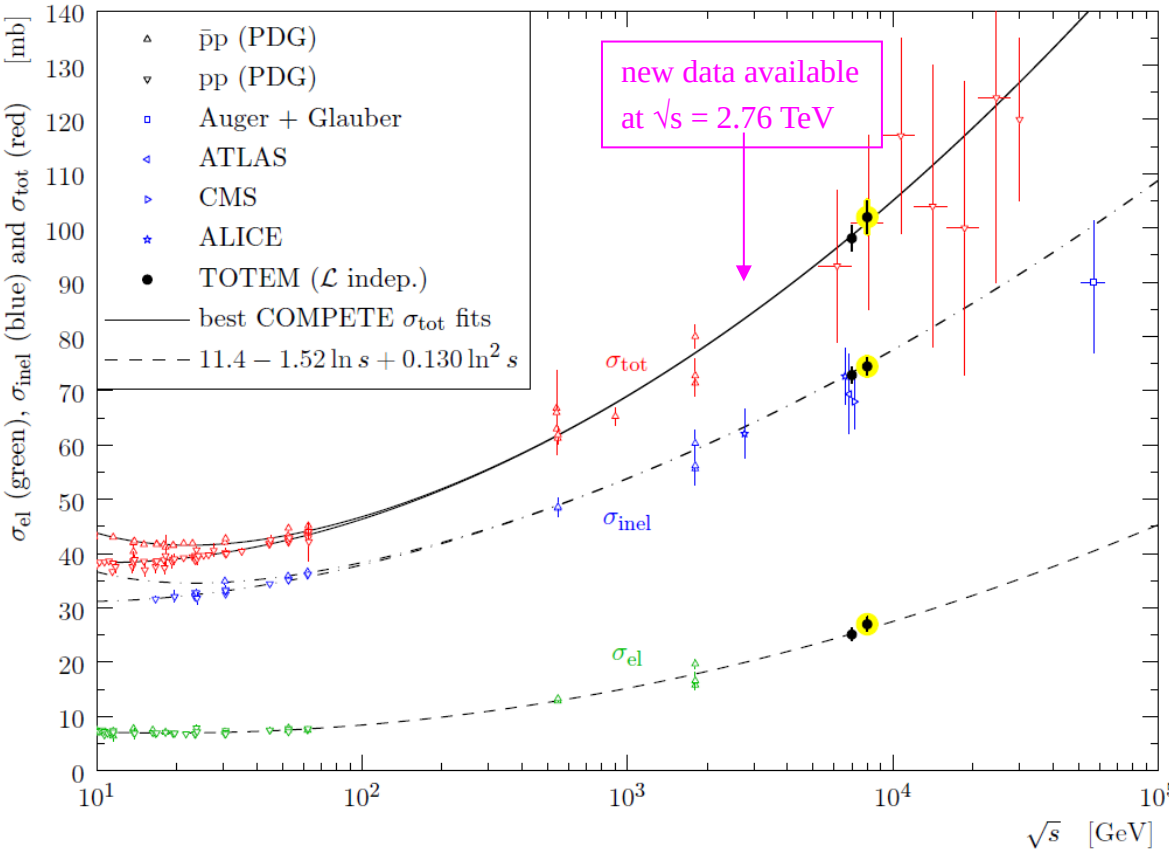
➔ $\sigma_{\mathrm{inel}} = \sigma_{\mathrm{tot}} - \sigma_{\mathrm{el}} = 73.15 \pm 1.26$ mb

visible part (T1, T2): $\sigma_{\mathrm{inel},\,|\eta| < 6.5} = 70.53 \pm 2.93$ mb

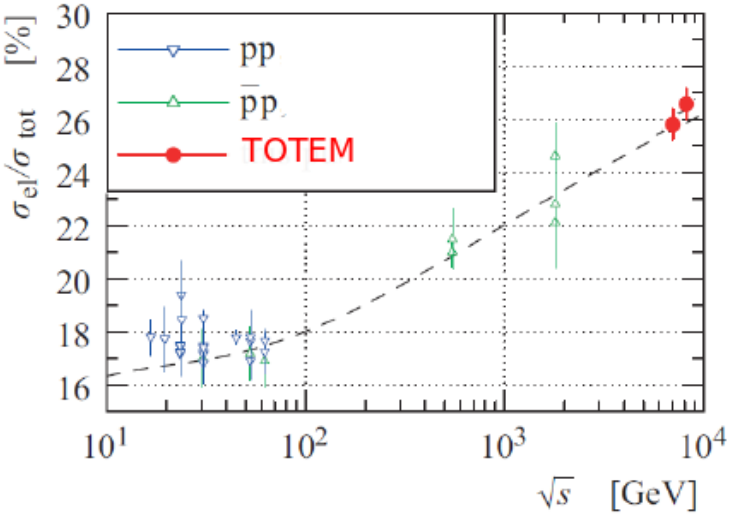
$\sigma_{\mathrm{inel},\,|\eta| > 6.5} = 2.62 \pm 2.17$ mb

< 6.31 mb (95% CL)

pp Cross-Section Measurements



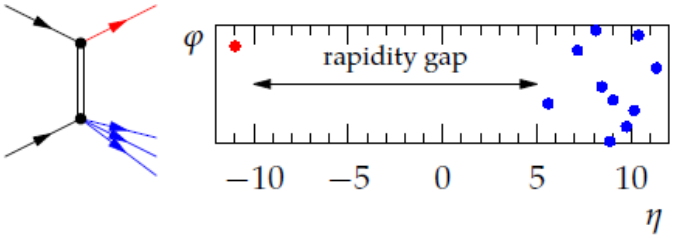
Ratio elastic / total:



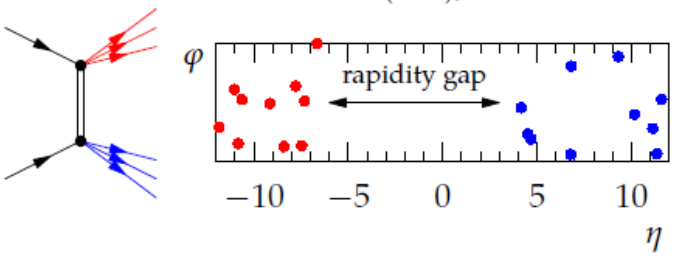
Ongoing Analyses of Diffractive Processes: Standalone and Common Runs with CMS

- A Selection -

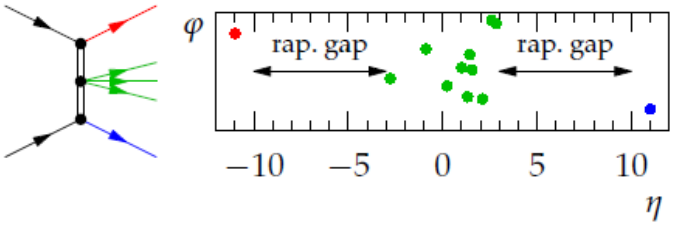
Single Diffraction (SD), $\approx 10\,\text{mb}$



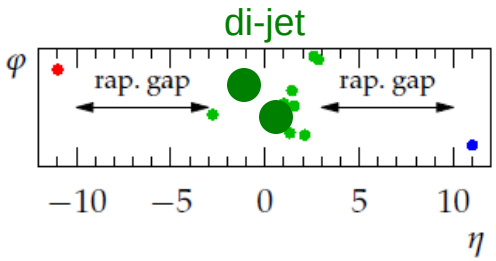
Double Diffraction (DD), $\approx 5\,\text{mb}$



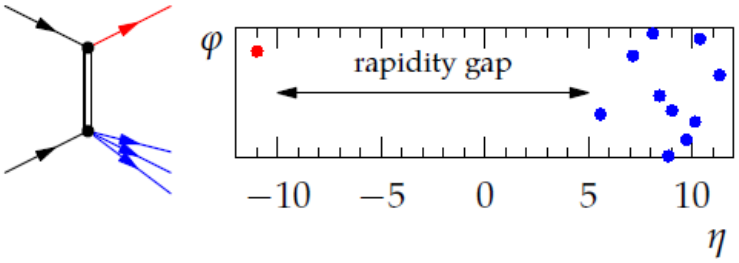
Central Diffraction (CD), $\approx 1\,\text{mb}$



→ **Measure topologies and σ (M,ξ,t)**

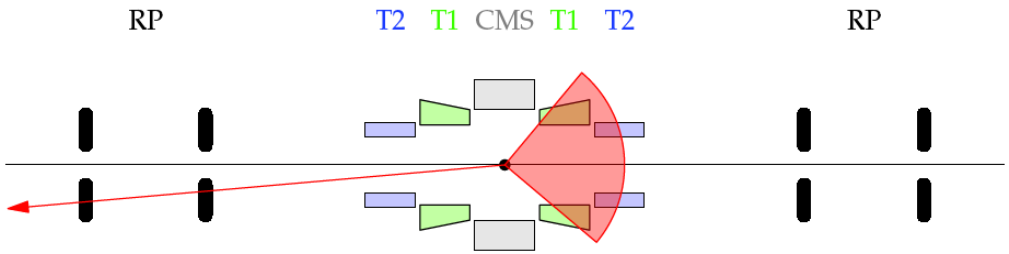


Soft Single Diffraction (SD)



- 1 proton breaks up
  → diffractive mass M
- 1 proton survives with momentum loss ξ
- rapidity gap Δη between proton and M

$$\Delta\eta = -\ln\xi, \quad M^2 = \xi s$$



Trigger on T2, require 1 proton

2 ways for measuring ξ:

1. via the proton trajectory (RP): $x_{RP} = L_x\Theta_x^* + v_x x^* + D_x\xi$

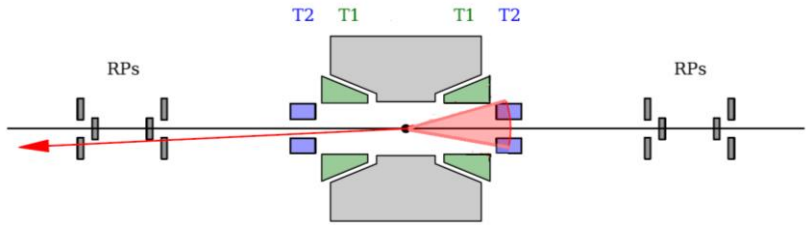
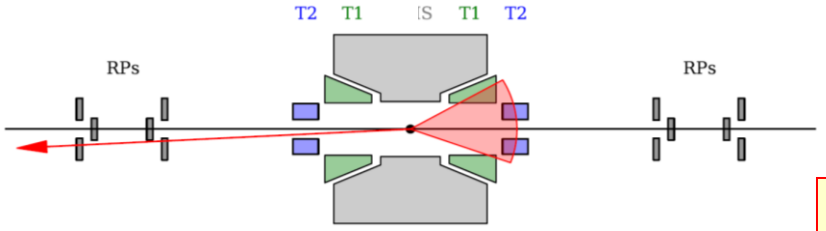
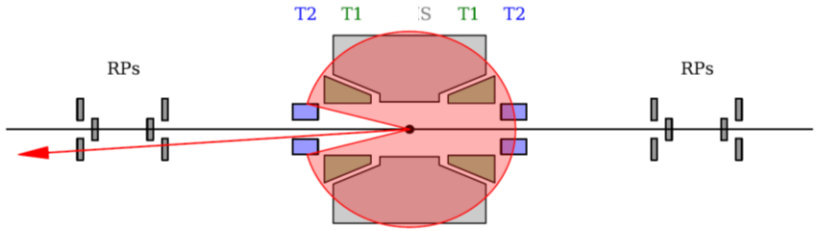
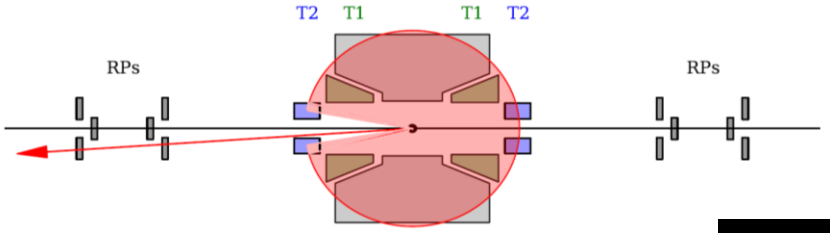
   resolution at β*=90m:
   δξ ~ 0.004 – 0.01
   (dependent on t, ξ)

2. via the rapidity gap (T1, T2)
   Note: $\eta_{max,T2} = 6.5 \quad \Leftrightarrow \quad M_{min} = 3.4$ GeV

   δξ ~ ξ

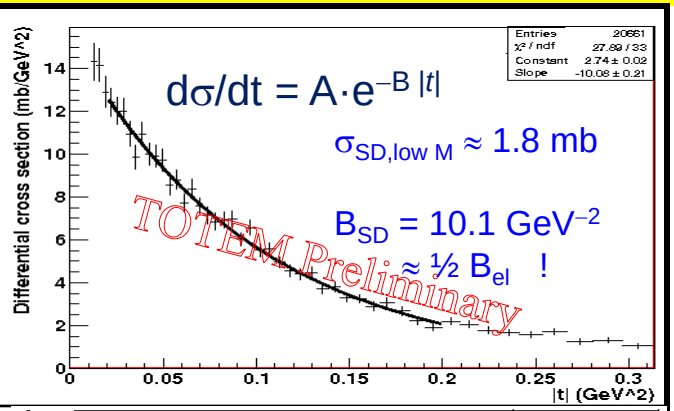
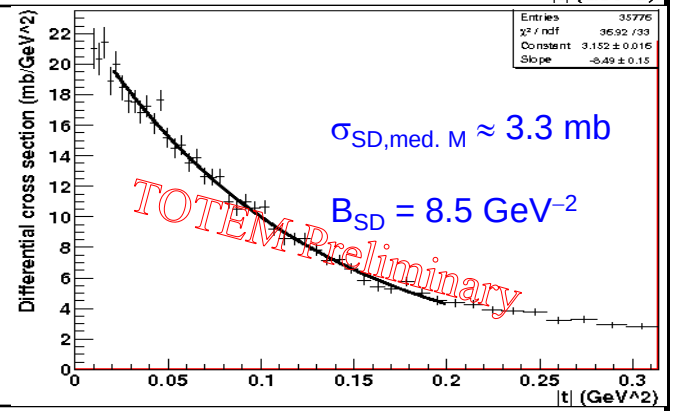
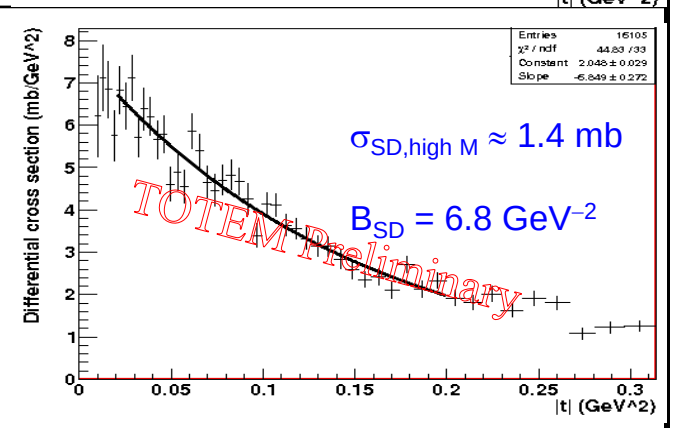
Full differential cross-section: $\dfrac{d^2\sigma}{d\xi\, dt}$

SD Topologies for Different Mass Ranges

M = 3.4 – 7 GeV	$2 \times 10^{-7} < \xi < 1 \times 10^{-6}$	proton & opposite T2 
M = 7 – 350 GeV	$1 \times 10^{-6} < \xi < 2.5 \times 10^{-3}$	proton & opposite T1 + T2 
M = 0.35 – 1.1 TeV	$2.5 \times 10^{-3} < \xi < 2.5 \times 10^{-2}$	proton & opposite T2 (+ T1) & same side T1 
M > 1.1 TeV	$\xi > 2.5 \times 10^{-2}$	proton & opposite T2 (+ T1) & same side T2 (+ T1) 

$$\Delta\eta = -\ln\frac{M^2}{s}$$

SD for Different Mass Ranges (7 TeV Data)

M = **3.4 – 7 GeV**	$2 \times 10^{-7} < \xi < 1 \times 10^{-6}$	
M = **7 – 350 GeV**	$1 \times 10^{-6} < \xi < 2.5 \times 10^{-3}$	
M = **0.35 – 1.1 TeV**	$2.5 \times 10^{-3} < \xi < 2.5 \times 10^{-2}$	
M > **1.1 TeV**	$\xi > 2.5 \times 10^{-2}$	in progress

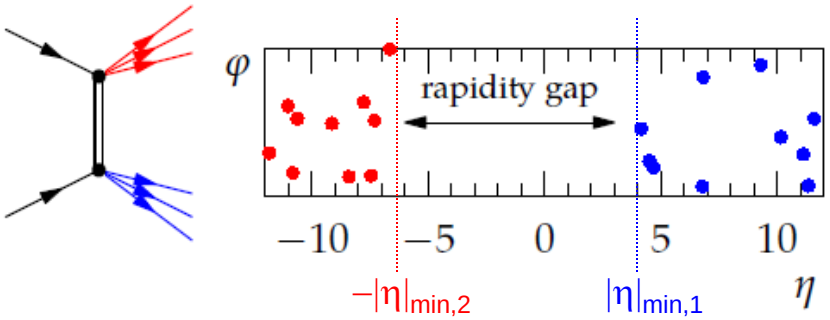
Work in progress !
Missing corrections:
- class migrations
- ξ resolution, beam divergence effects

estimated uncertainties:
δσ/σ ~ 20 %
δB/B ~15 %

very preliminary:

$\sigma_{SD} = 6.5 \pm 1.3$ mb
$(3.4 < M_{diff} < 1100$ GeV)

Soft Double Diffraction



- Both protons break up
→ 2 diffractive masses M_1, M_2
- Central rapidity gap

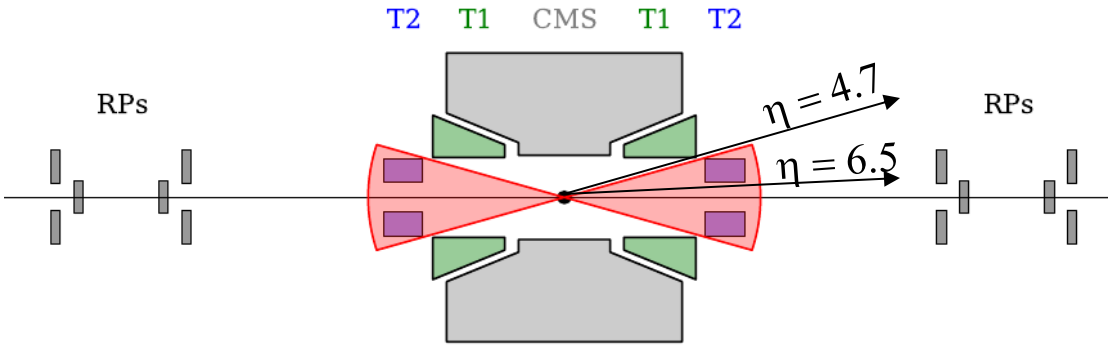
Ultimate goal: 2-dim. cross-section $\frac{d^2\sigma}{dM_1\,dM_2}$ or $\frac{d^2\sigma}{d|\eta|_{min,1}\,d|\eta|_{min,2}}$

Difficulties:

- no leading protons to tag
- for large masses (→ small central gap) not easy to separate from non-diffractive events

First step: sub-range with particles **triggering both T2** hemispheres, **veto on T1**:

$4.7 < |\xi|_{min,1/2} < 6.5$ or $3.4\ GeV < M_{1/2} < 8\ GeV$



Event selection with high DD purity (~ 70 %)

Double Diffraction: Results at 7 TeV

Partial 2-dim. cross-section in 2 x 2 bins:

	$-4.7>\eta_{min2}\geq-5.9$	$-5.9>\eta_{min2}\geq-6.5$
$4.7<\eta_{min1}\leq5.9$	65±20 μb	26±5 μb
$5.9<\eta_{min1}\leq6.5$	27±5 μb	12±5 μb

Sum:

$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 116 \pm 25 \text{ μb}$$

[PRL 111 (2013) 262001]

Leading systematics:

- missing DD events with unseen particles at $\eta < \eta_{min}$
- backgrounds from non-diffractive, single diffractive, central diffractive events

So far, only a small part of DD measured: 116 μb out of ~5 mb, but:

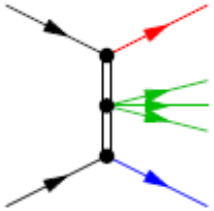
benchmark for Monte Carlos:

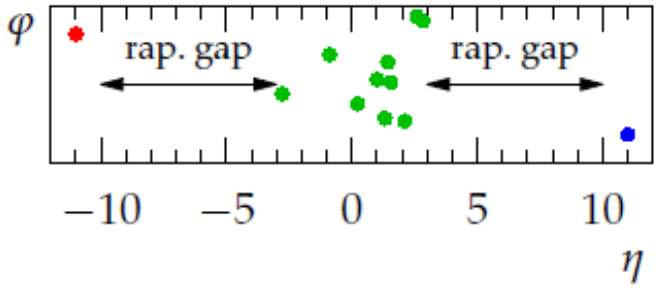
Pythia 8: $\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 159$ μb

Phojet: $\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 101$ μb

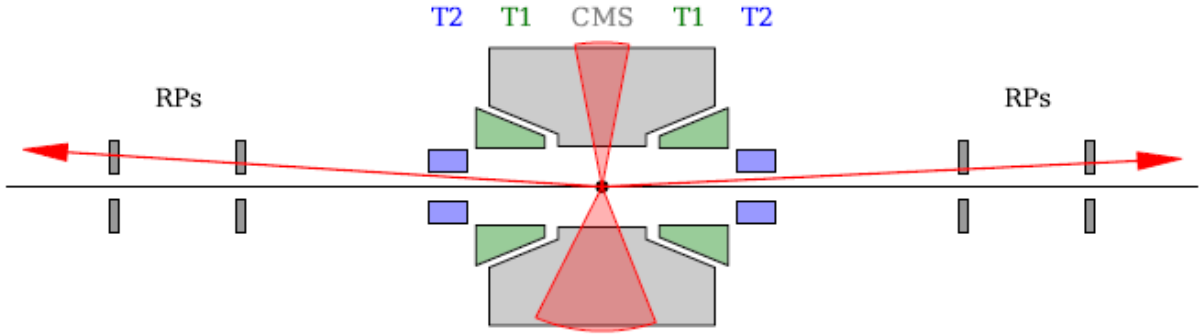
Improvement expected with 8 TeV data: also CMS detector information available (joint run).

Central Diffraction ("Double Pomeron Exchange")





- both protons survive with momentum losses ξ_1, ξ_2
- diffractive mass M in the centre
- 2 rapidity gaps $\Delta\eta_1$, $\Delta\eta_2$



$$\Delta\eta_{1,2} = -\ln \xi_{1,2}, \quad M^2 = \xi_1 \xi_2 s$$

Joint data taking CMS + TOTEM:

kinematic redundancy between protons and central diffractive system

$M_{CMS} = M_{TOTEM}(pp)$?

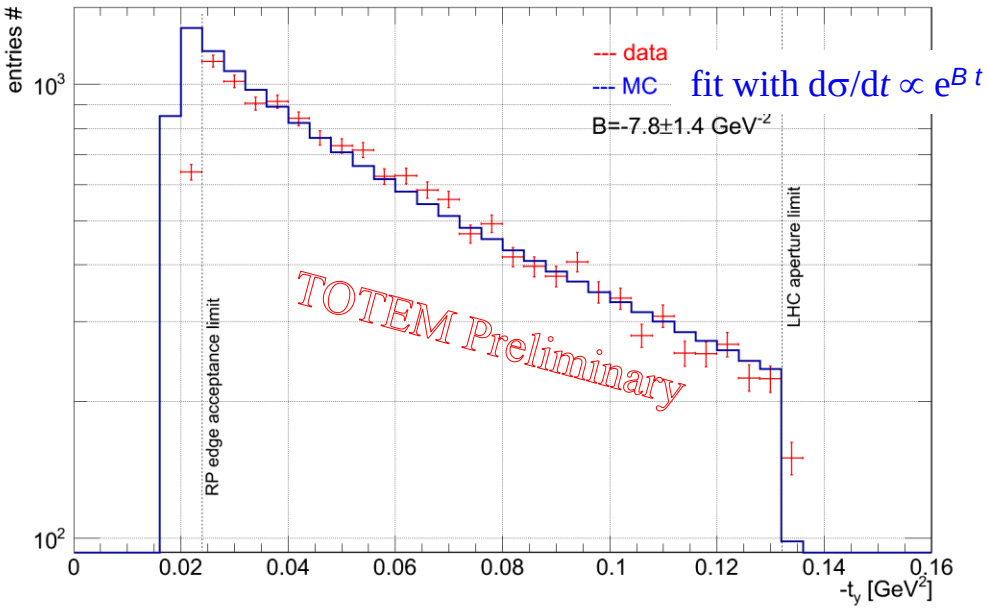
Central Diffraction ("Double Pomeron Exchange")

Soft DPE: study differential cross-section with correlations:

(in progress: $d\sigma/dM$, $d\sigma\, dt_1$)

$$\frac{d^5\sigma}{d\xi_1\, d\xi_2\, dt_1\, dt_2\, d\Delta\Phi}$$

Single arm CD event rate (integrated ξ, acceptance corrected)

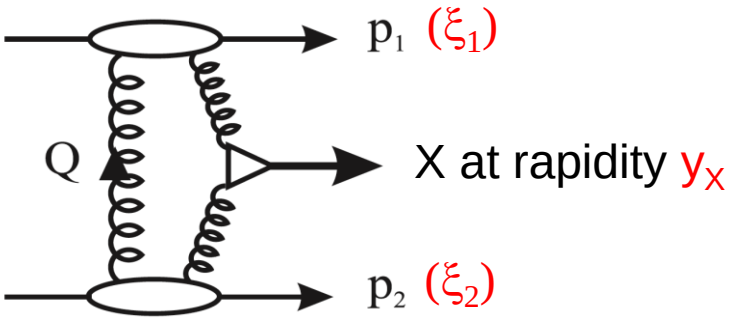


Estimate on the integral:

$\sigma_{CD} \sim 1$ mb

Central Production of Particles or Di-Jets (with CMS)

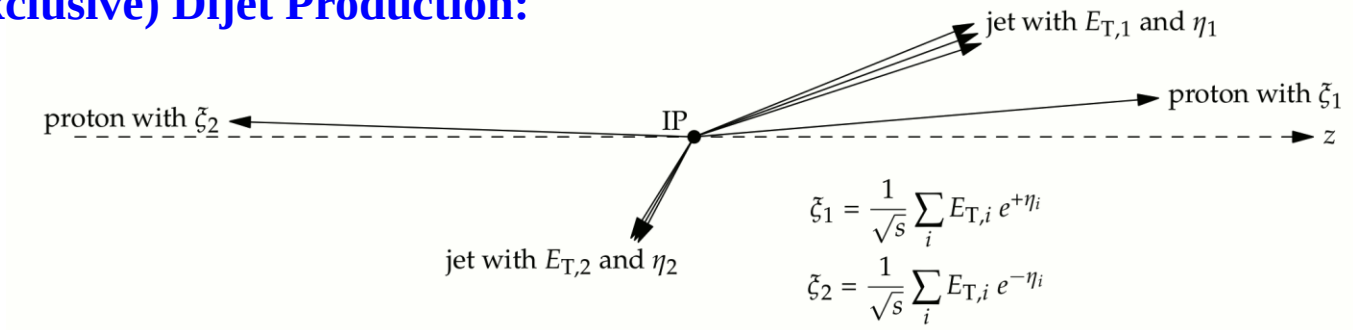
Exclusive Particle Production:



$$M_X^2 = \xi_1 \, \xi_2 \, s$$

$$y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

(Exclusive) Dijet Production:



Joint analysis of special run at 8 TeV, β* = 90 m, in progress:

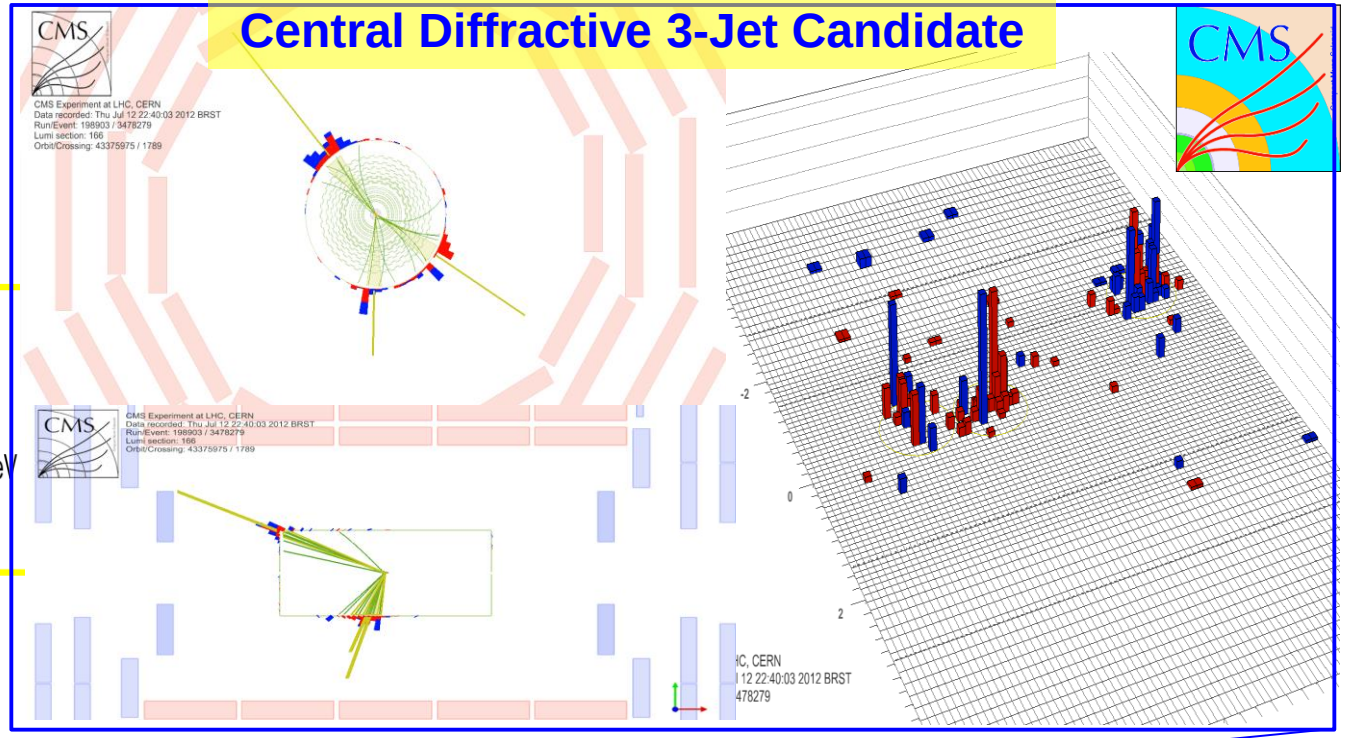
- central-diffractive jet production
- low-mass resonances (ππ, πππ, …)
- missing/escaping mass

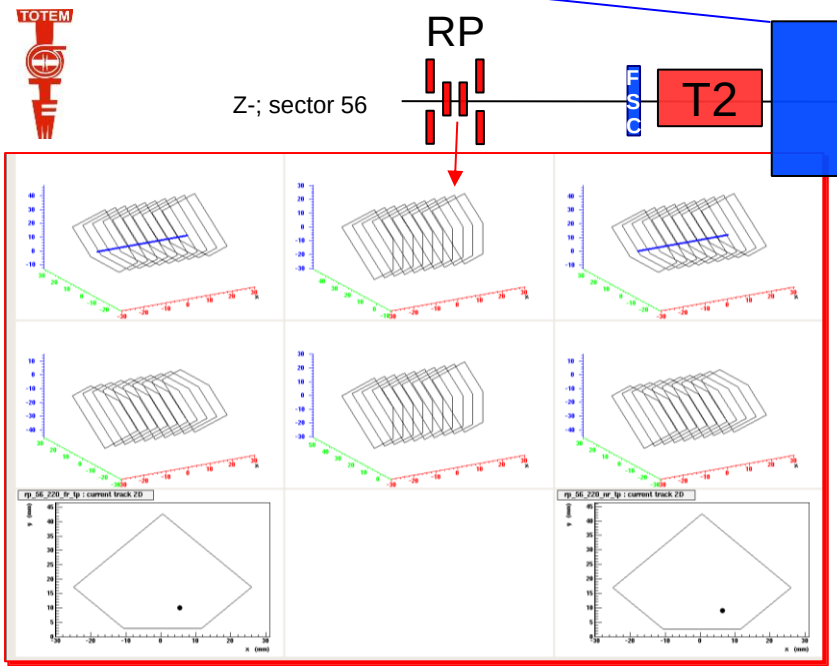
Central Diffractive 3-Jet Candidate

CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV

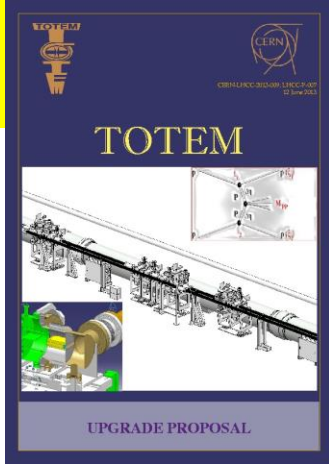
MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) = 244 GeV
$\xi^- = 0.1$; $\xi^+ = 0.01$





TOTEM Consolidation and Upgrade Programme



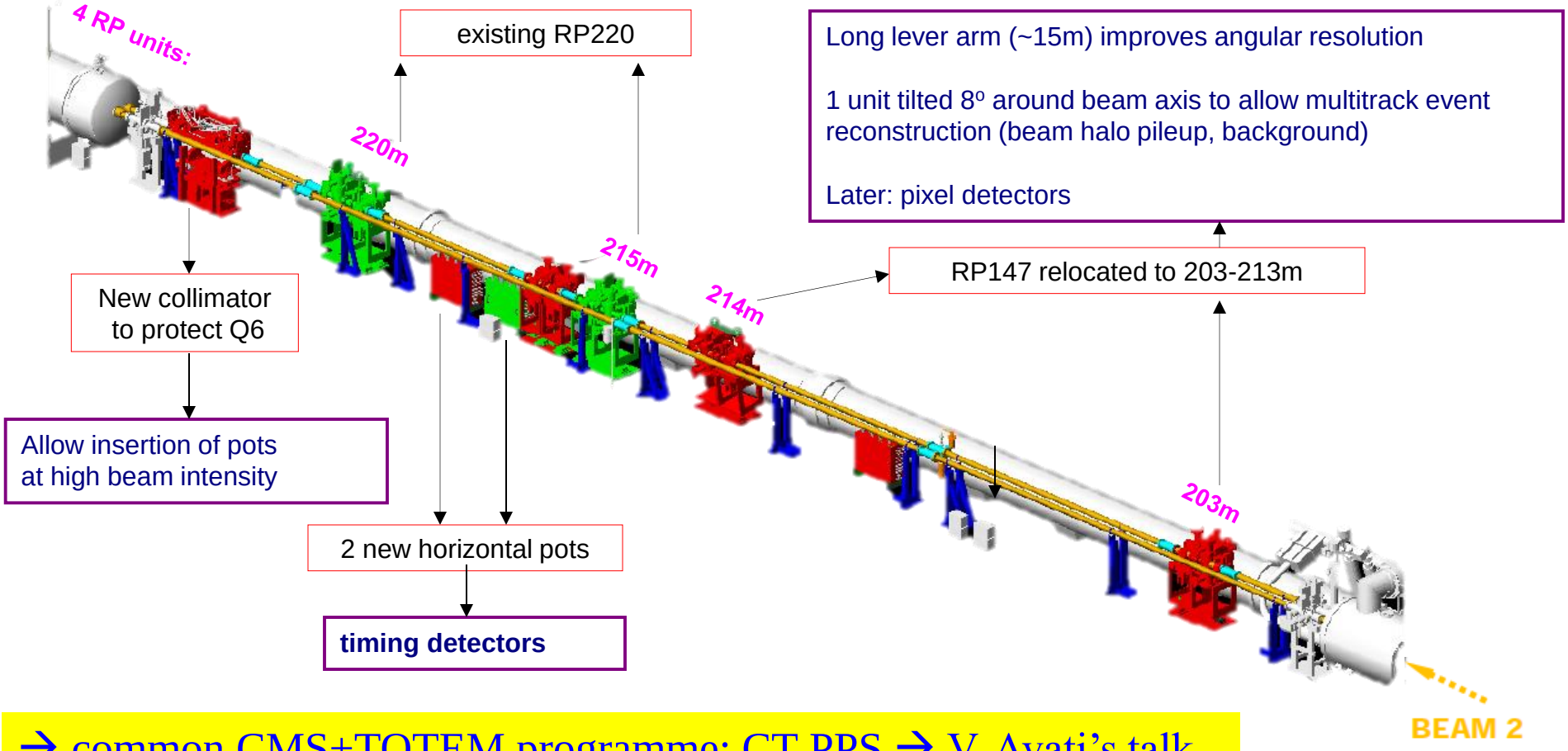
In 2012: successful data taking together with CMS in special runs

→ first studies of central production, diffractive dijets, other hard diffractive processes

Problems: limited statistics, pileup

→upgrade RP system for operation at higher luminosities

→resolve event pileup: timing measurement, multi-track resolution



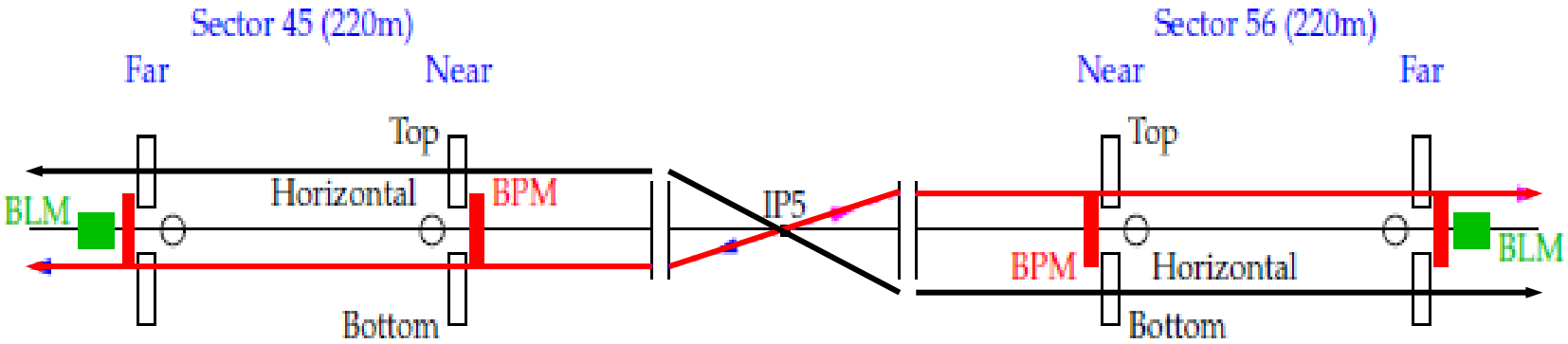
→ common CMS+TOTEM programme: CT-PPS → V. Avati's talk

TOTEM

Backup

Elastic pp Scattering: Event Topology and Hit Maps

Two diagonals analysed independently



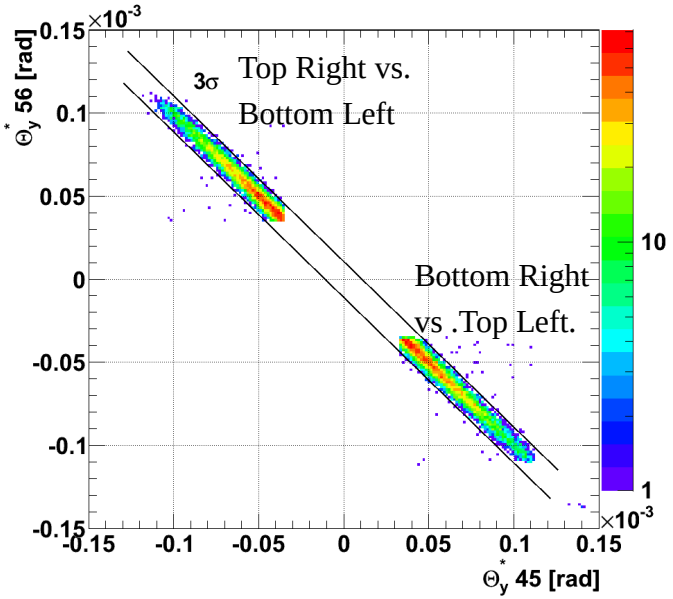
Elastic Tagging

Selection cuts:

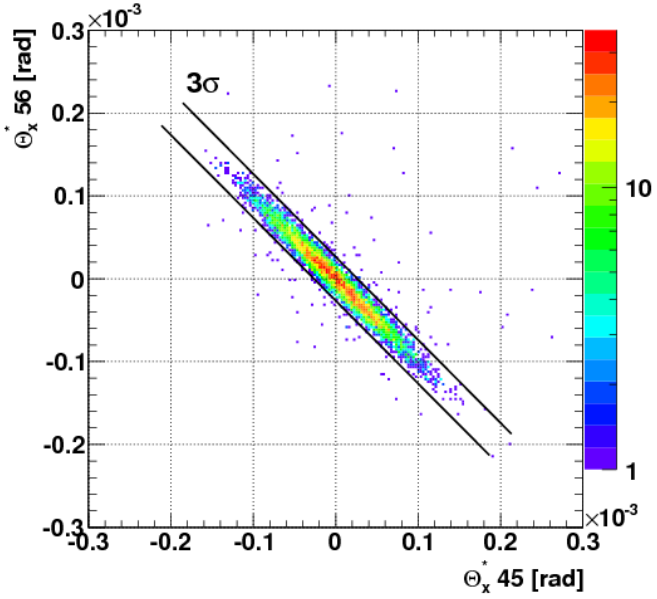
number	cut	RMS	
diagonal	track reconstructed in all 4 diagonal RPs		
1	$\theta_x^{*R} - \theta_x^{*L}$	9.2 μrad	collinearity
2	$\theta_y^{*R} - \theta_y^{*L}$	3.5 μrad	collinearity
3	$\lvert x^{*R} \rvert$	200 μm	low $\lvert\xi\rvert$
4	$\lvert x^{*L} \rvert$	200 μm	low $\lvert\xi\rvert$
5	$\alpha\, y^{R,N} - (y^{R,F} - y^{R,N})$	17 μm	low $\lvert\xi\rvert$
6	$\alpha\, y^{L,N} - (y^{L,F} - y^{L,N})$	17 μm	low $\lvert\xi\rvert$
7	$x^{*R} - x^{*L}$	9 μm	common vertex for both protons

Example: elastic collinearity : Scattering angle on one side versus the opposite side

Collinearity in y



Collinearity in x



Width of correlation band in agreement with beam divergence (~ 2.4 μrad)

Absolute Luminosity Calibration

$$\mathcal{L} = \frac{(1+\rho^2)}{16\pi} \frac{(N_{el}+N_{inel})^2}{(dN_{el}/dt)_{t=0}}$$

7 TeV

June 2011: $\mathcal{L}_{\text{int}} = (1.65 \pm 0.07)\ \mu b^{-1}$ [CMS: $(1.65 \pm 0.07)\ \mu b^{-1}$]

October 2011: $\mathcal{L}_{\text{int}} = (83.7 \pm 3.2)\ \mu b^{-1}$ [CMS: $(82.0 \pm 3.3)\ \mu b^{-1}$]

Excellent agreement with CMS luminosity measurement.

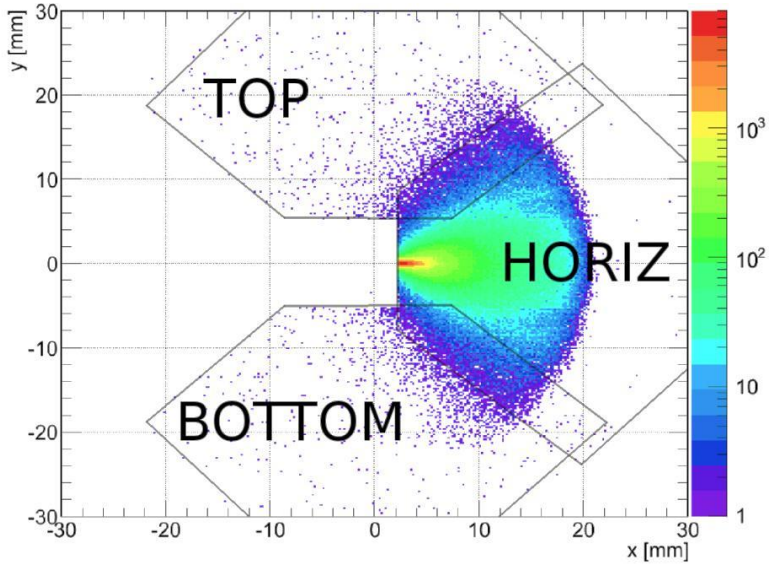
Absolute luminosity calibration for T2

Different LHC Optics

Hit maps of simulated diffractive events for 2 optics configurations

(labelled by β* = betatron function at the interaction point)

β* = 0.55 m (low β* = standard at LHC)



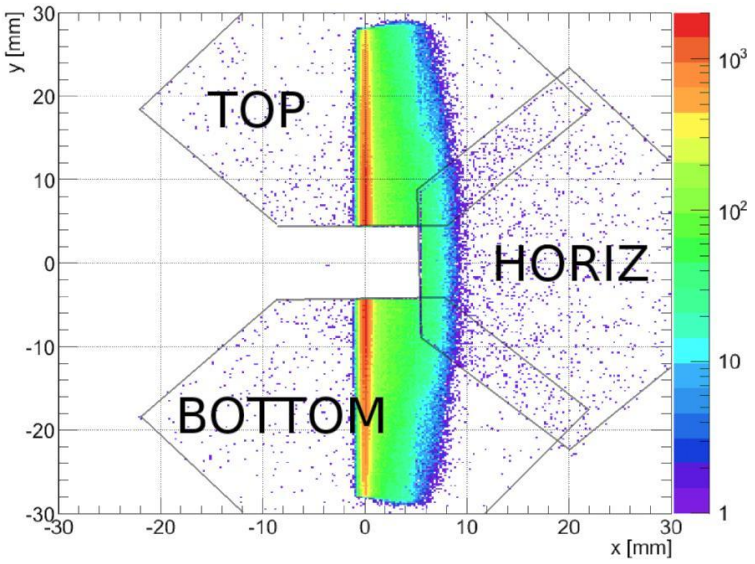
L_x = 1.7 m, L_y = 14 m, D_x = 8 cm

diffractive protons: mainly in **horizontal** RP

elastic protons: in vertical RP near x ~ 0

sensitivity only for large scattering angles

β* = 90 m (special development for RP runs)



L_x = 0, L_y = 260 m, v_y = 0, D_x = 4 cm

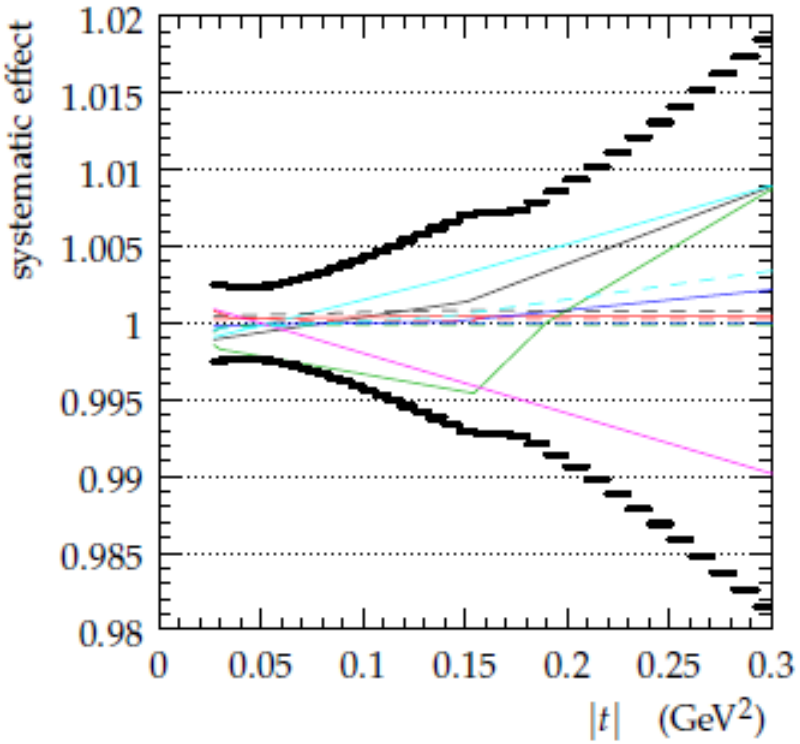
diffractive protons: mainly in **vertical** RP

elastic protons: in narrow band at x ≅ 0,

sensitivity for small vertical scattering angles

	Beam width @ vertex	Angular beam divergence	Min. reachable |t|
β* ~ 0.5–3.5 m	$\sigma^*_{x,y} = \sqrt{\varepsilon_n \beta^* / \gamma}$ small	$\sigma(\Theta^*_{x,y}) = \sqrt{\varepsilon_n / \beta^* \gamma}$ large	$\lvert t_{\min} \rvert = \frac{n_\sigma^2 p \varepsilon_n m_p}{\beta^*}$ ~ 0.3–1 GeV^2
β* = 90 m	large	small	~ 10^{-2} GeV^2

Systematic Errors on dσ/dt at β*=90m



alignment: shift in ϑ_x^*

alignment: shift in ϑ_y^*

alignment: xy tilt

optics: $\vartheta_{x,y}^*$ scaling – mode 1

optics: $\vartheta_{x,y}^*$ scaling – mode 2

beam momentum offset

3-out-of-4 efficiency correction: slope uncertainty

"divergence acceptance correction": uncertainty of beam divergence RMS

"divergence acceptance correction": uncertainty due to possible left-right asymmetry

"divergence acceptance correction": uncertainty due to beam divergence non-gaussianity

unfolding correction: uncertainty of ϑ_x^* smearing RMS

$\pm 1\ \sigma$ *envelope*

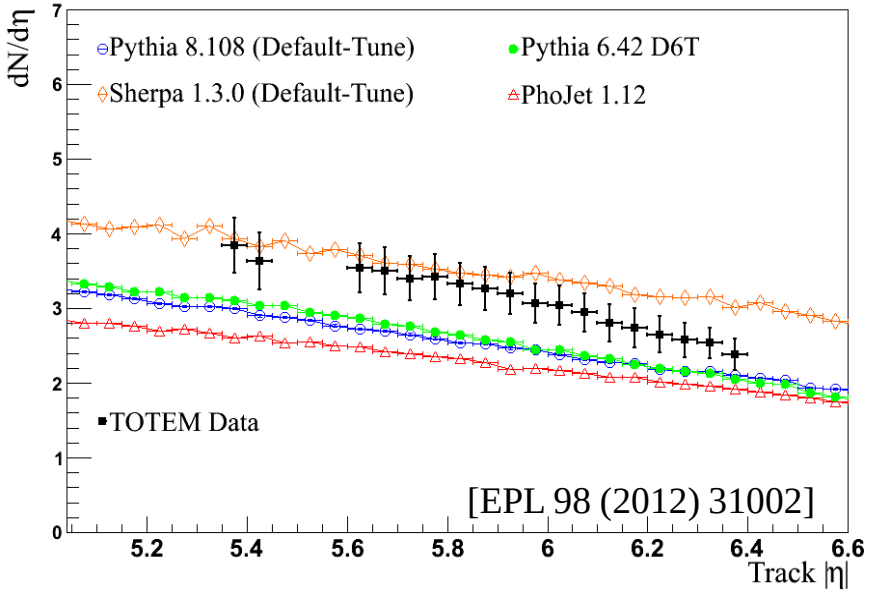
Charged Particle Pseudorapidity Density dN / dη

$dN_{ch}/d\eta$: mean number of charged particles per event and per unit of pseudorapidity:
primary particles only, i.e. lifetime > 30 ps (convention among LHC experiments)

- probes hadronisation → constrains phenomenological models used in event generators
- input for cosmic ray simulations

7 TeV

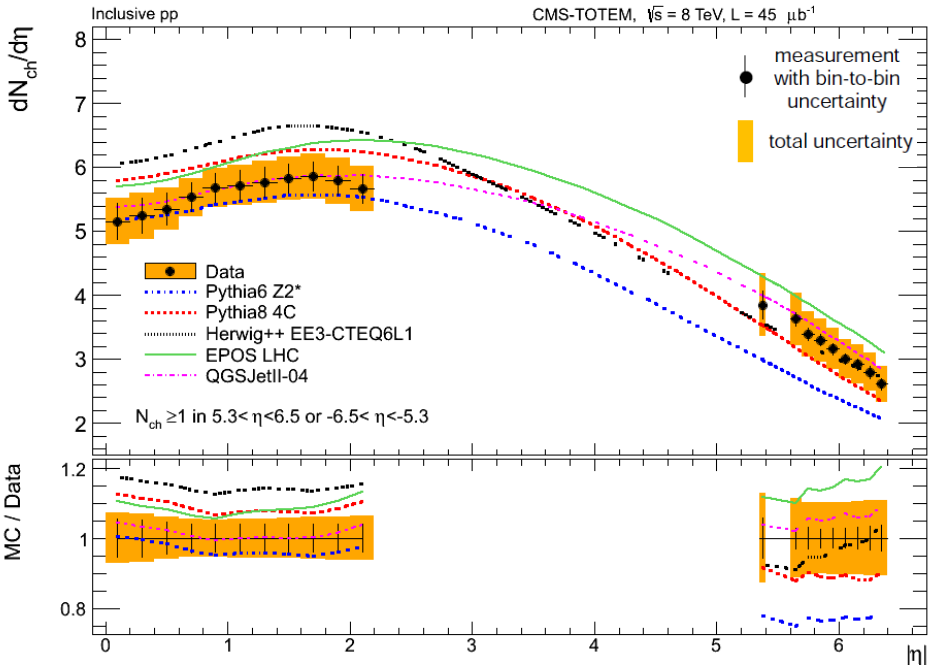
TOTEM standalone (T2)



8 TeV

CMS + TOTEM (T2)

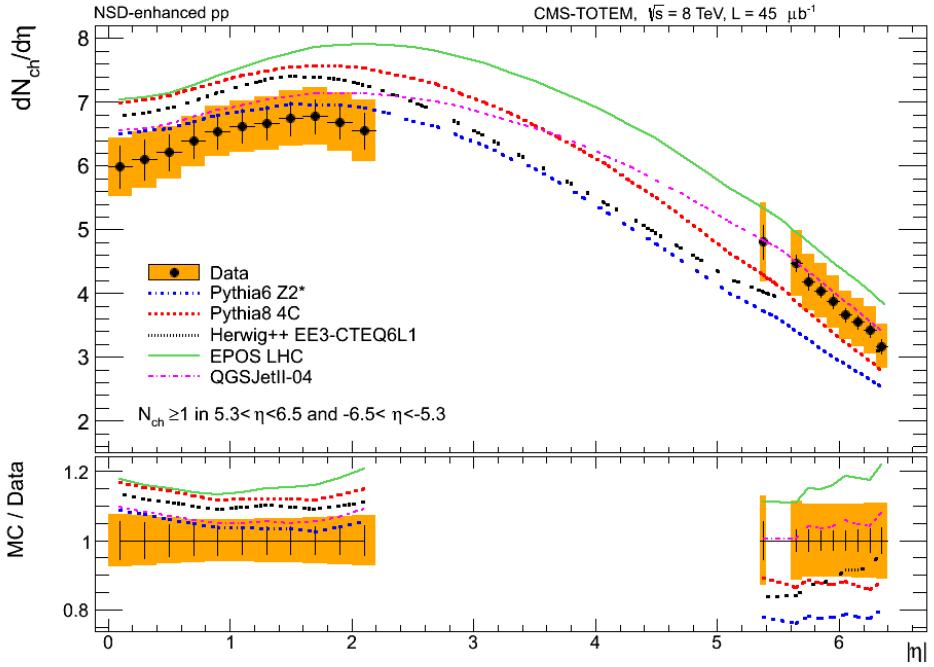
analysis of **same** T2-triggered events (>90% of inelastic)



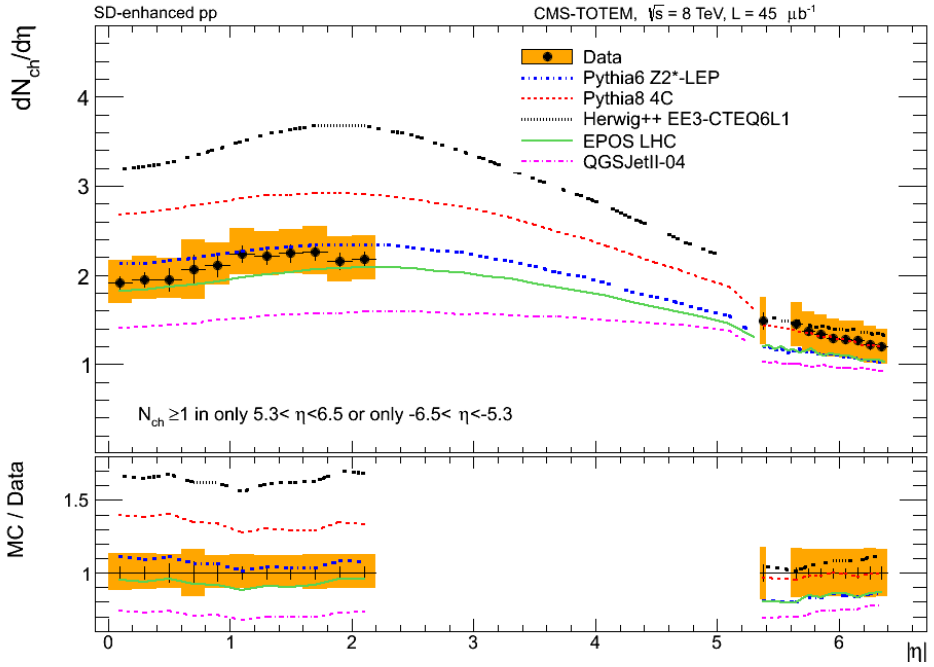
CMS FSQ -12-026, TOTEM-2014-02

Central & Forward $dN_{ch}/d\eta$ @ 8 TeV (with CMS)

"Non-Single diffractive (NSD) enhanced":
≥ 1 primary charged particle in each T2 arm



"Single diffractive (SD) enhanced":
≥ 1 primary charged particle in only one T2 arm



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- Multiplicity of SD events significantly smaller than NSD (as expected)
- No MC able to describe $dN_{ch}/d\eta$ of all event samples & in the whole rapidity region (especially SD-enhanced problematic, description of central-forward correlations?)