TOTEM Results on Total pp Cross-Section and Diffractive Dissociation

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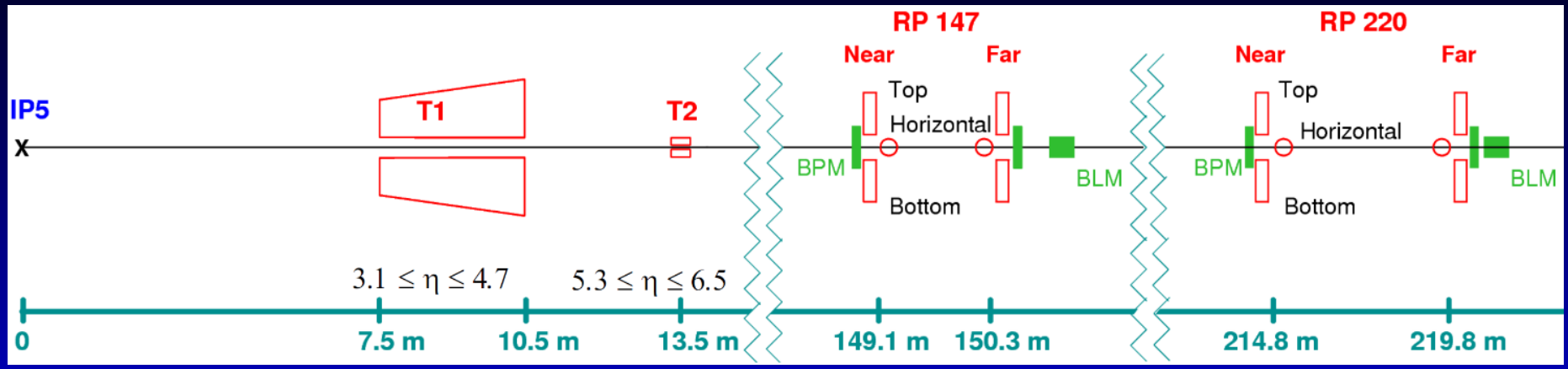
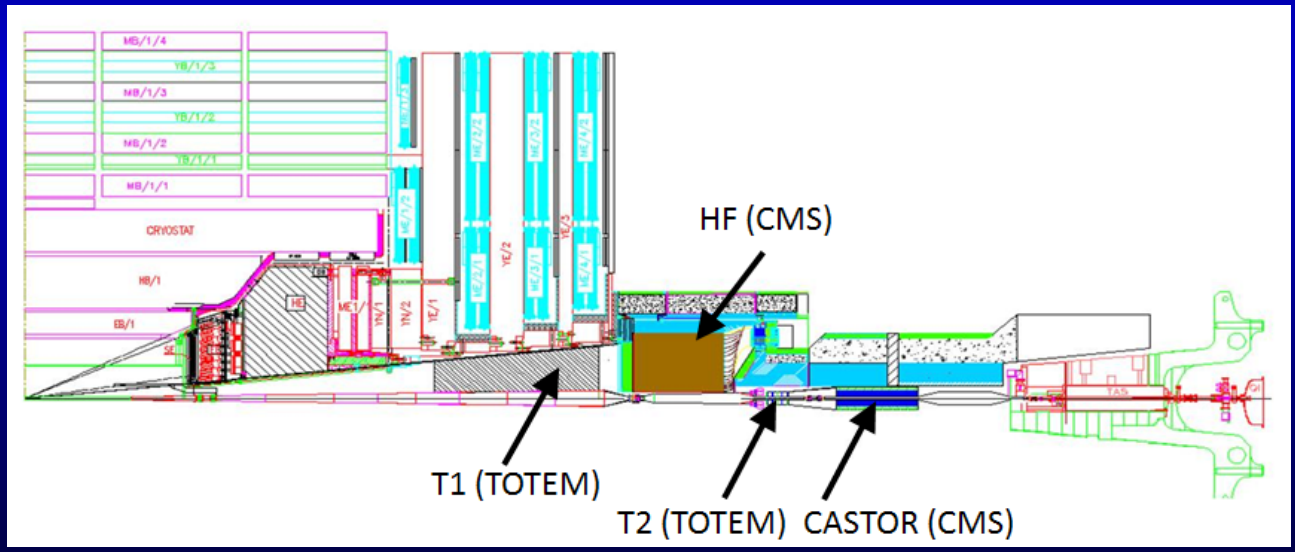
TOTEM physics
LHC Optics Determination
σtot @ 7 and 8 TeV
Single Diffraction
Double Diffraction
Summary

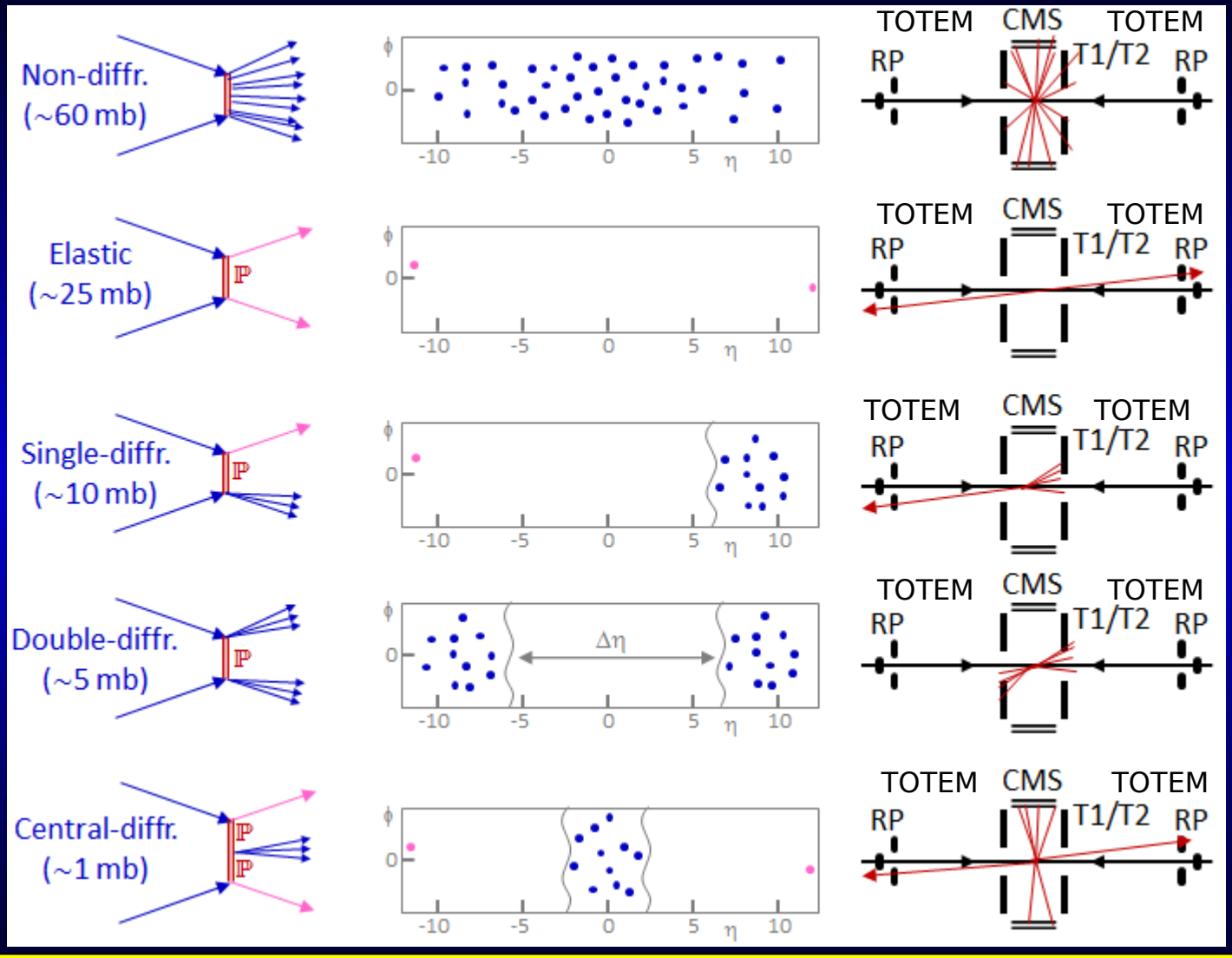
TOTEM – Experimental Setup at IP5





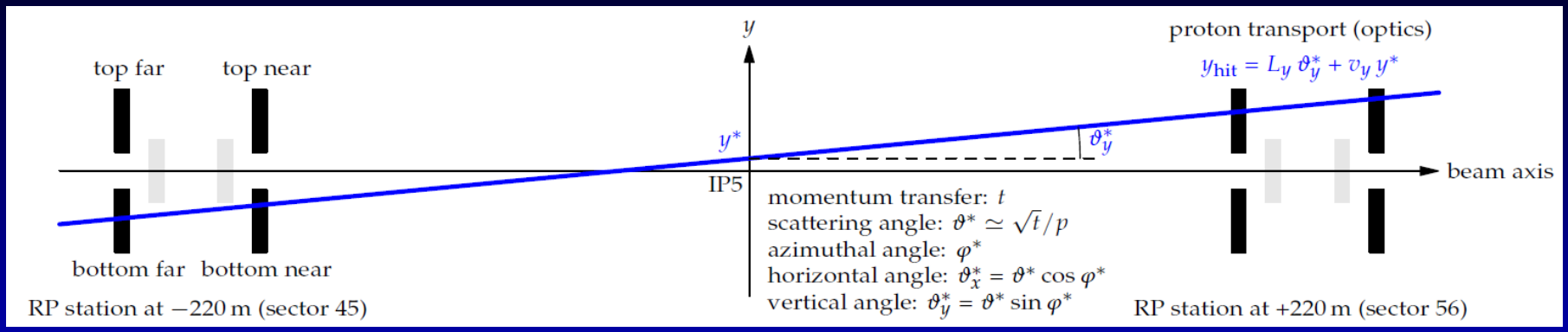
T1, T2: CSC and GEM Inelastic telescopes; RP: Roman Pots
[Details: JINST 3 (2008) S08007 and F. Ferro's talk at this meeting]

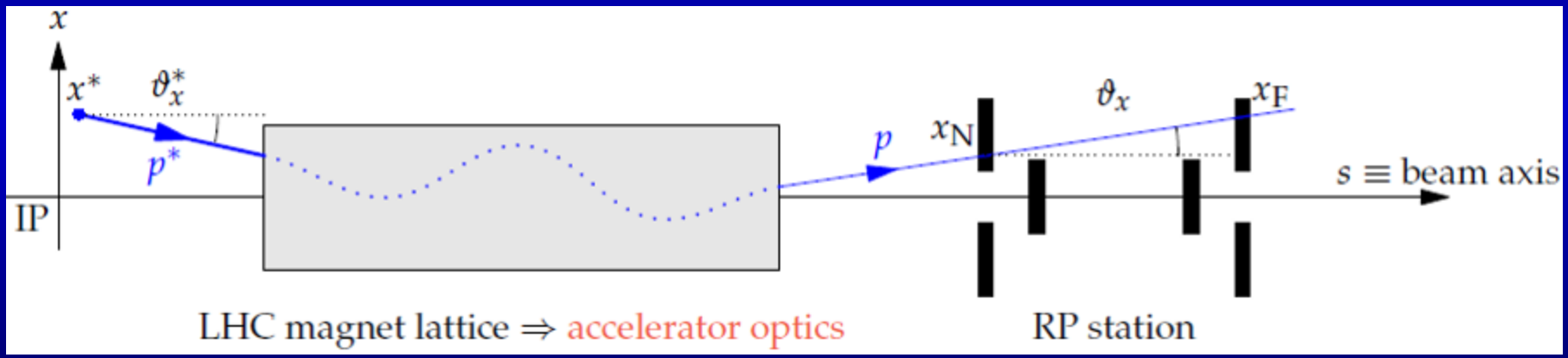
TOTEM physics at LHC



Elastic and diffractive scattering: colorless exchange

LHC Optics for elastic pp scattering

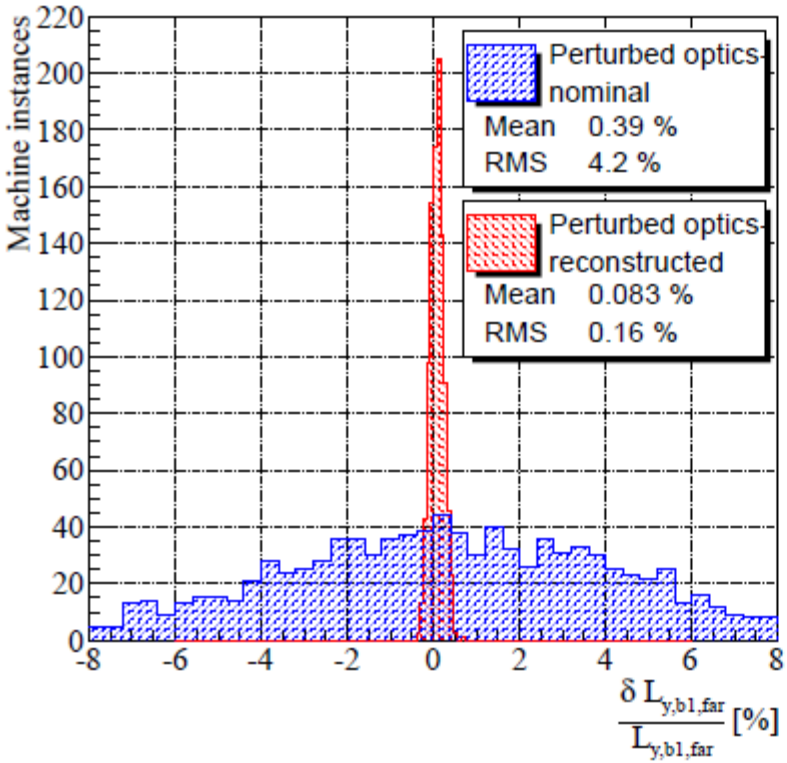




$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \\ \Delta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

Precise σtot determination needs excellent controll of LHC optics from TOTEM data

LHC Optics Determination, β*= 3.5 m



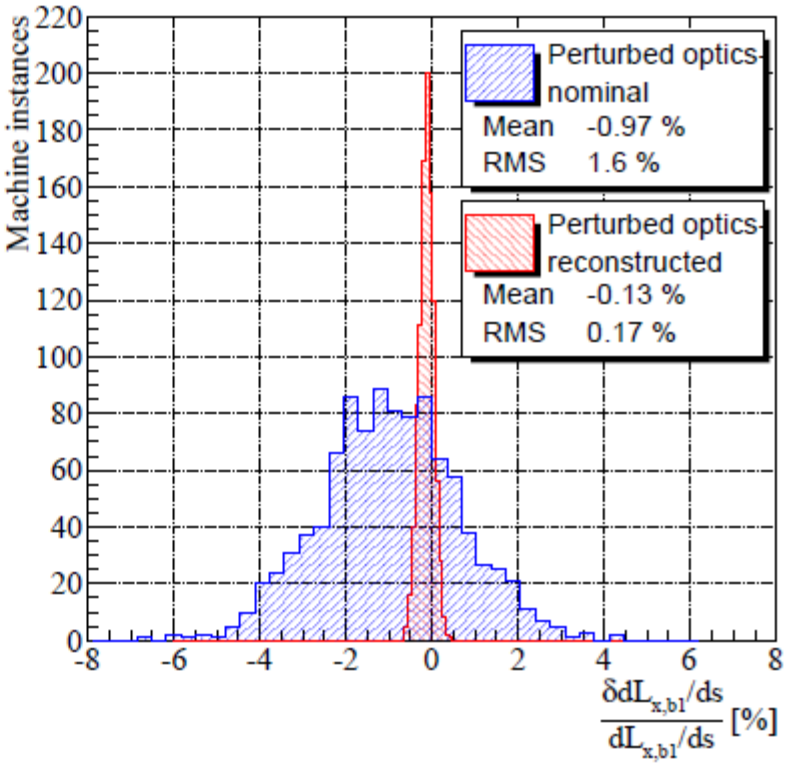
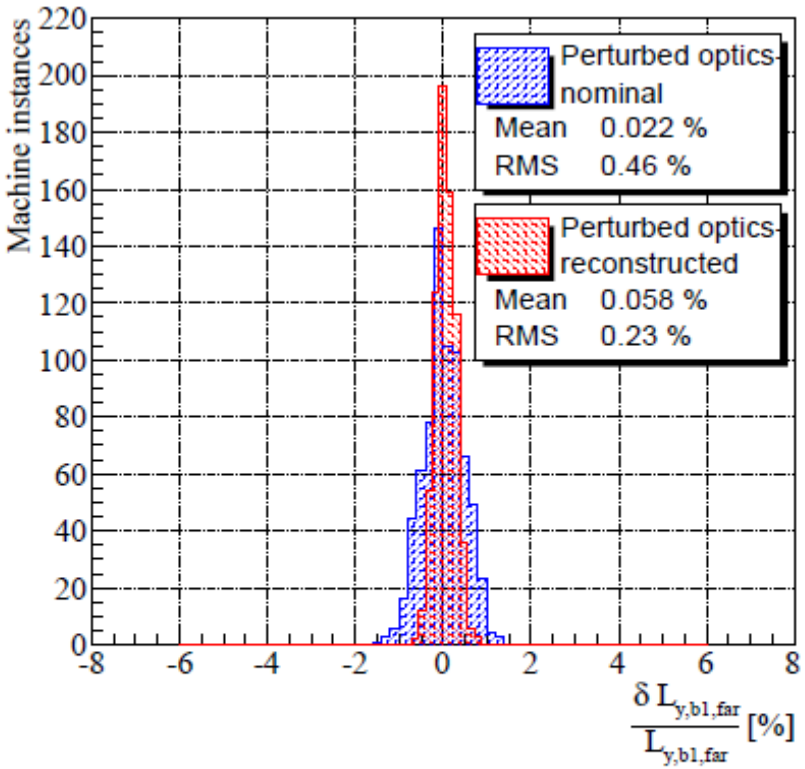


Figure 11. (color online) The MC error distribution of $\beta^* = 3.5$ m optical functions L_y and $\mathrm{d}L_x/\mathrm{d}s$ for Beam 1 at $E = 3.5$ TeV, before and after optics estimation.

Precise control of LHC imperfections with perturbed LHC optics and recalibration from data at IP5 – optics error reduction by factors of 10 - 20, arXiv:1406.0546

LHC Optics Determination, β*= 90 m



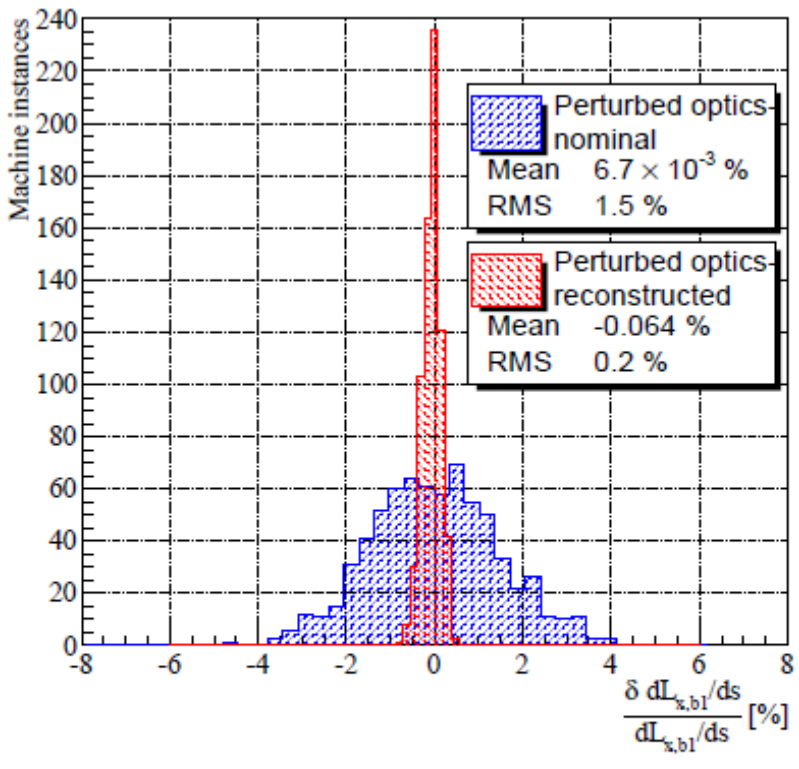
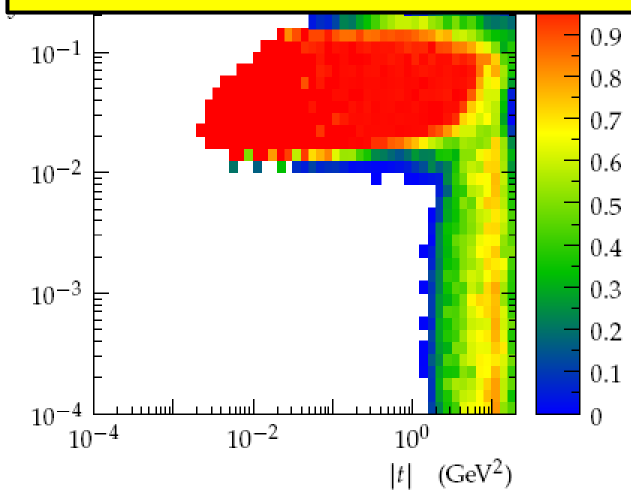


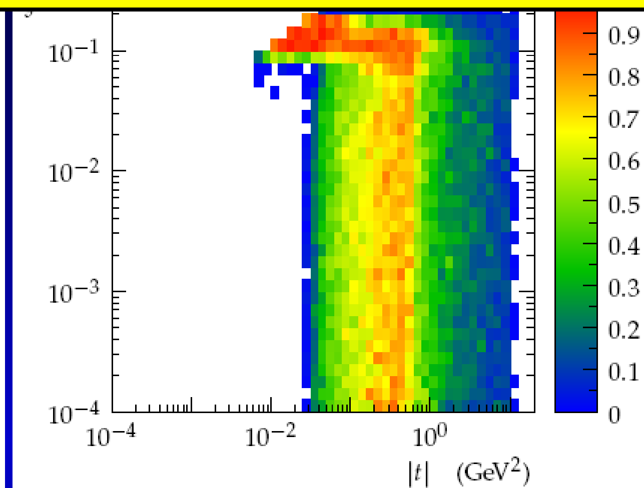
Figure 12. (color online) The MC error distribution of $\beta^* = 90$ m optical functions L_y and $\mathrm{d}L_x/\mathrm{d}s$ for Beam 1 at $E = 4$ TeV, before and after optics estimation.

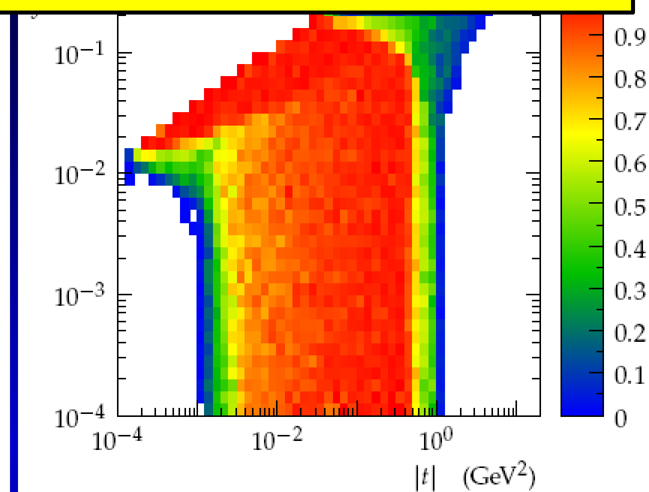
Precise control of LHC imperfections with perturbed LHC optics and recalibration from data at IP5: factors of 2 - 10
arXiv:1406.0546

LHC optics and proton acceptance

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



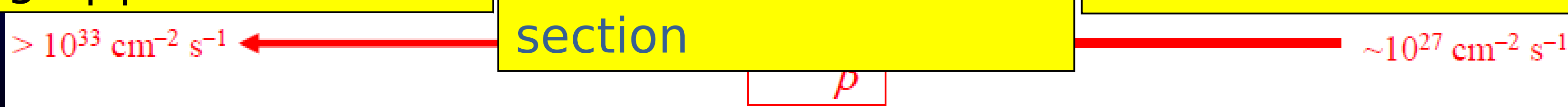




$\beta^* = 0.55$ m
Diffraction:
$\xi \geq 0.03$,
low cross-sections,
hard diffraction
Elastic scattering:
large |t|

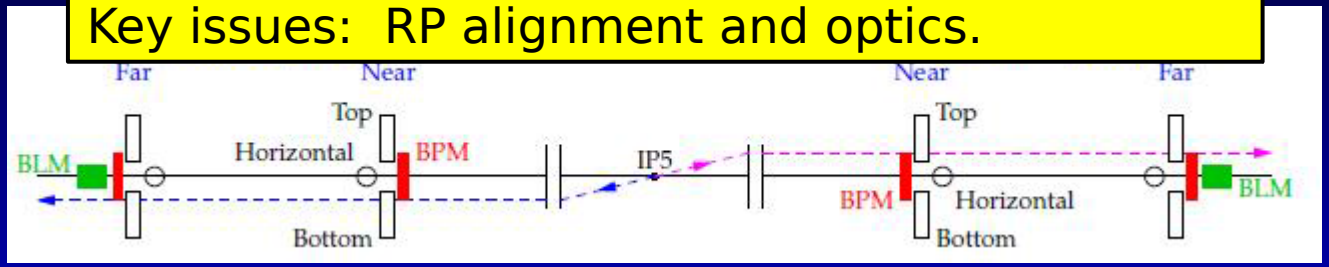
$\beta^* = 90$ m
Diffraction:
all ξ if $|t| \geq 10^{-2}$ GeV^2,
soft & semi-hard diffr.
Elastic: low to mid |t|
Total cross-section

$\beta^* = 1000$ m
Elastic scattering:
very low |t|,
Coulomb- Nuclear Interference
Total cross-Section



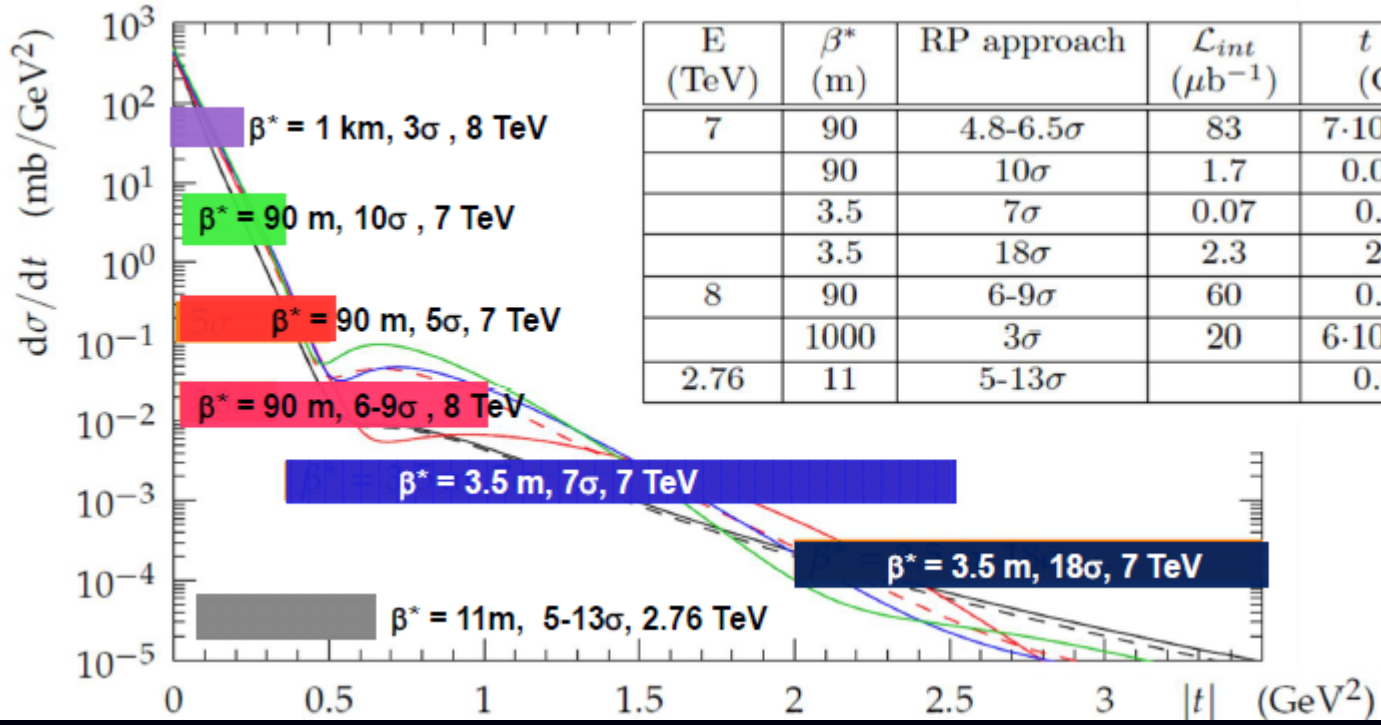
Event selection, data sets

Selected based on topology, low |ξ|, collinearity, & vertex .
Key issues: RP alignment and optics.



Data sets at different conditions to measure elastics over wide t-range including very low |t|

E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events	
7	90	4.8-6.5σ	83	$7\cdot10^{-3}$ - 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	$6\cdot10^{-4}$ - 0.2	0.4M	←
2.76	11	5-13σ		0.05-0.6	45k	



Show results from data sets indicated by arrows

3 methods to measure σtot

elastic only
(T1,T2 independent)

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

ρ independent

$$\sigma_{tot} = \sigma_{el} + \sigma_{inel}$$

L independent

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

7 TeV

σ_{TOT} = 98.3 mb ± 2.0 mb
EPL 96 (2011) 21002

σ_{TOT} = 98.6 mb ± 2.3 mb
EPL 101 (2013) 21002

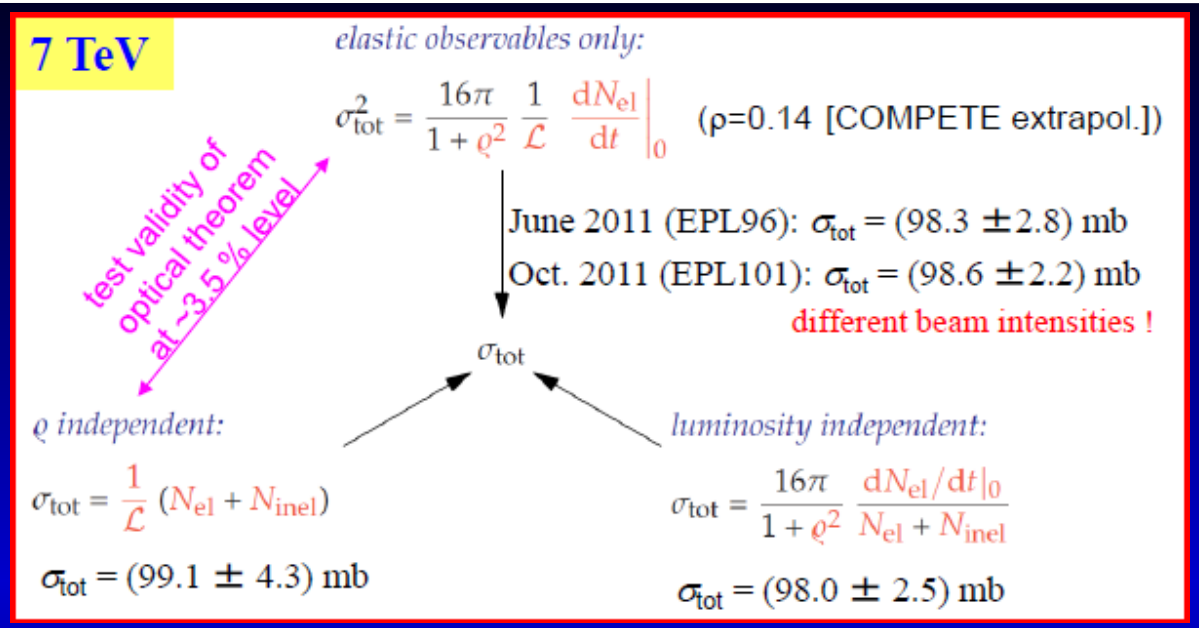
σ_{TOT} = 99.1 mb ± 4.3 mb
EPL 101 (2013) 21004

σ_{TOT} = 98.1 mb ± 2.4 mb
EPL 101 (2013) 21004

8 TeV: PRL 111, 012001

σ_{TOT} = 101.7 mb ± 2.9 mb

TOTEM total cross-section results



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)]

TOTEM total cross-section @ 8TeV with luminosity-independent method

TABLE I. Description of the available data samples. The RP position is given as the RP approach to the beam in multiples of the transverse beam size ($\sigma_{\text{beam}} \sim 0.7$ mm). The third column shows the lowest $|t|$ values reached in the elastic sample after all cuts. The last two columns show the number of elastic and inelastic events collected.

Data set	RP position	$\lvert t\rvert_{\text{min}}$ (GeV^2)	Elastic events	Inelastic events
1	$6.0\sigma_{\text{beam}}$	0.01	416×10^3	2.30×10^6
2	$9.5\sigma_{\text{beam}}$	0.02	238×10^3	1.72×10^6

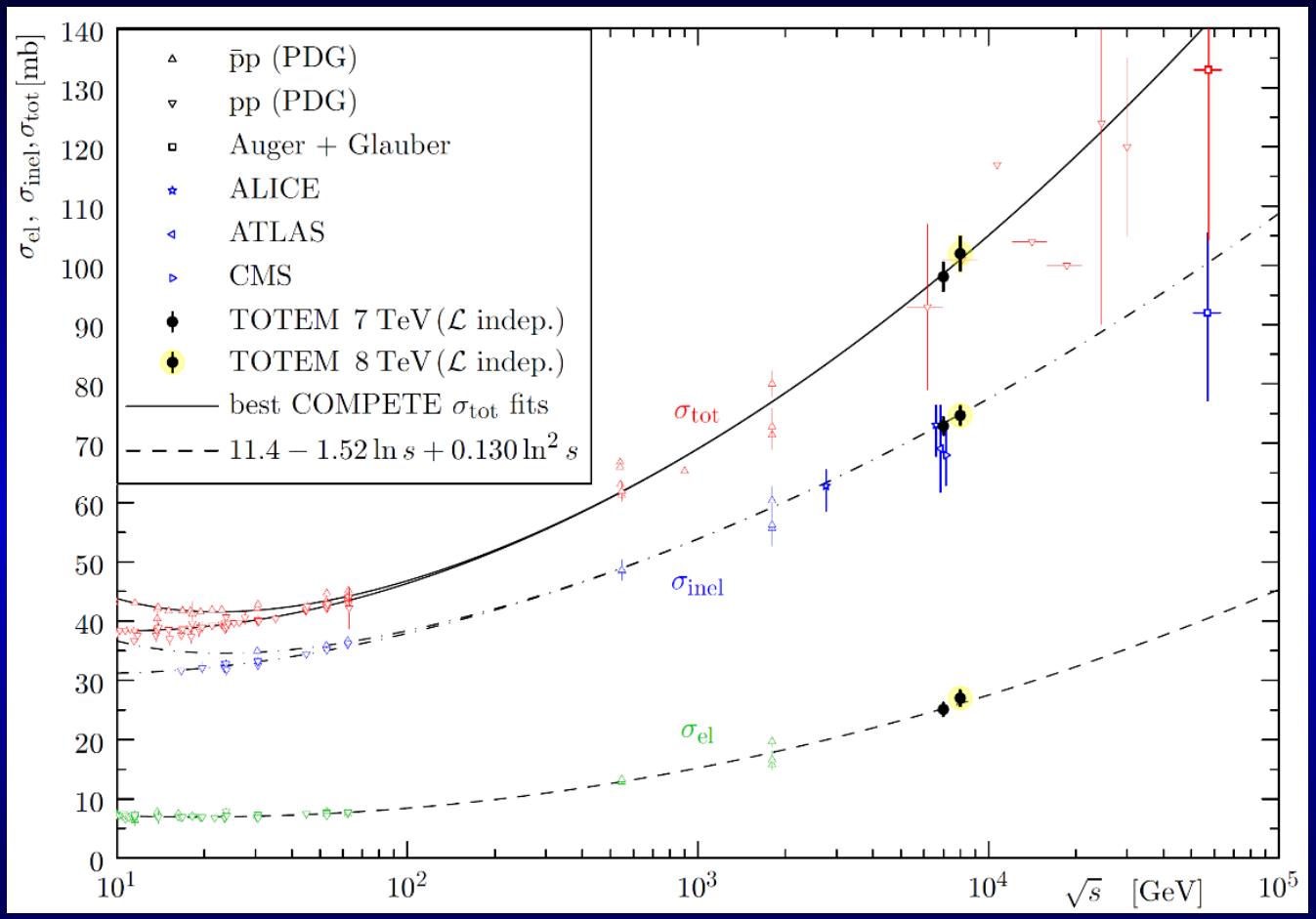
Needs precise control of LHC imperfections and recalibration from data at IP5: β*=90m, optics error reduction by 2-10,

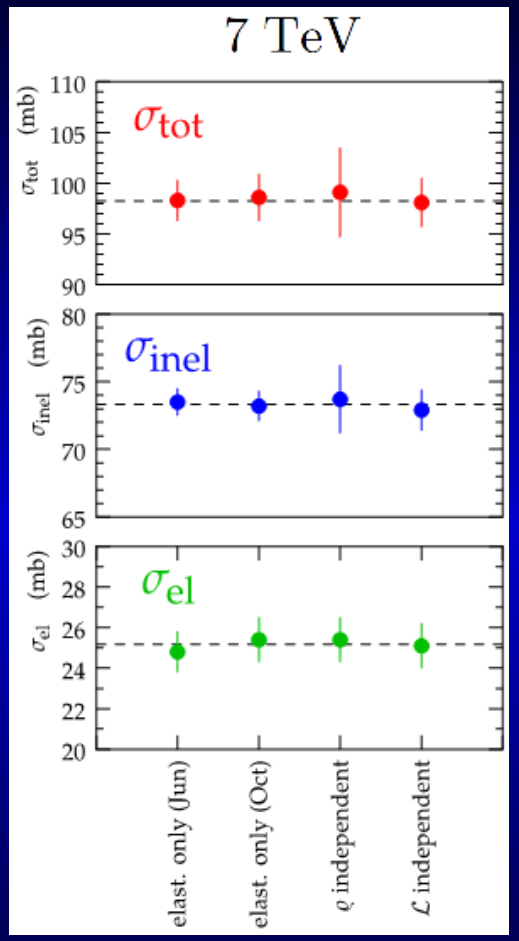
arXiv:1406.0546

TABLE II. Overview of the analysis steps, associated corrections, and systematic uncertainties to the differential and total elastic rate.

Source	Effect on	$\lvert t\rvert = 0.01$ GeV^2	0.1 GeV^2	0.2 GeV^2
Alignment	t	$\pm 0.21\%$	$\pm 0.3\%$	$\pm 0.57\%$
Kinematics reconstruction: Optics, beam energy	t	$\pm 1.09\%$	$\pm 0.72\%$	$\pm 4.3\%$
Selection	norm.		$\pm 0.5\%$	
Acceptance (correction factor)	dN/dt	3.3 ± 0.024	1.2 ± 0.002	1.8 ± 0.004
Resolution unfolding	t	$(0.5 \pm 0.1)\%$	$(-0.2 \pm 0.003)\%$	$(-2.6 \pm 0.1)\%$
Efficiency	norm.	Uncorrelated inefficiency: $(10 \pm 0.6)\%$ Correlated inefficiency: $(3 \pm 1)\%$ Pileup: $(4.7 \pm 0.4)\%$		
Extrapolation/Fit		$dN_{\text{el}}/dt\rvert_{t=0}$	$\pm 2.5\%$	
		B	(19.9 ± 0.3) GeV^{-2}	

TOTEM: total cross-sections

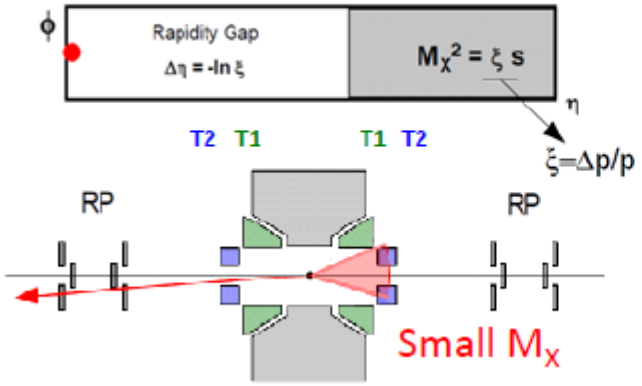


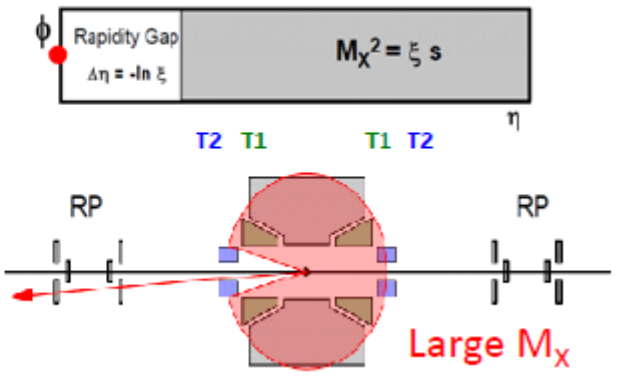


7 TeV: Excellent agreements between different methods.
Ongoing analysis for 8 and 2.6 TeV with different optics/methods.

TOTEM for single diffraction

Rapidity gap ($\Delta\eta = -\ln\xi$) determines diffractive mass ($M_X^2 = \xi s$)

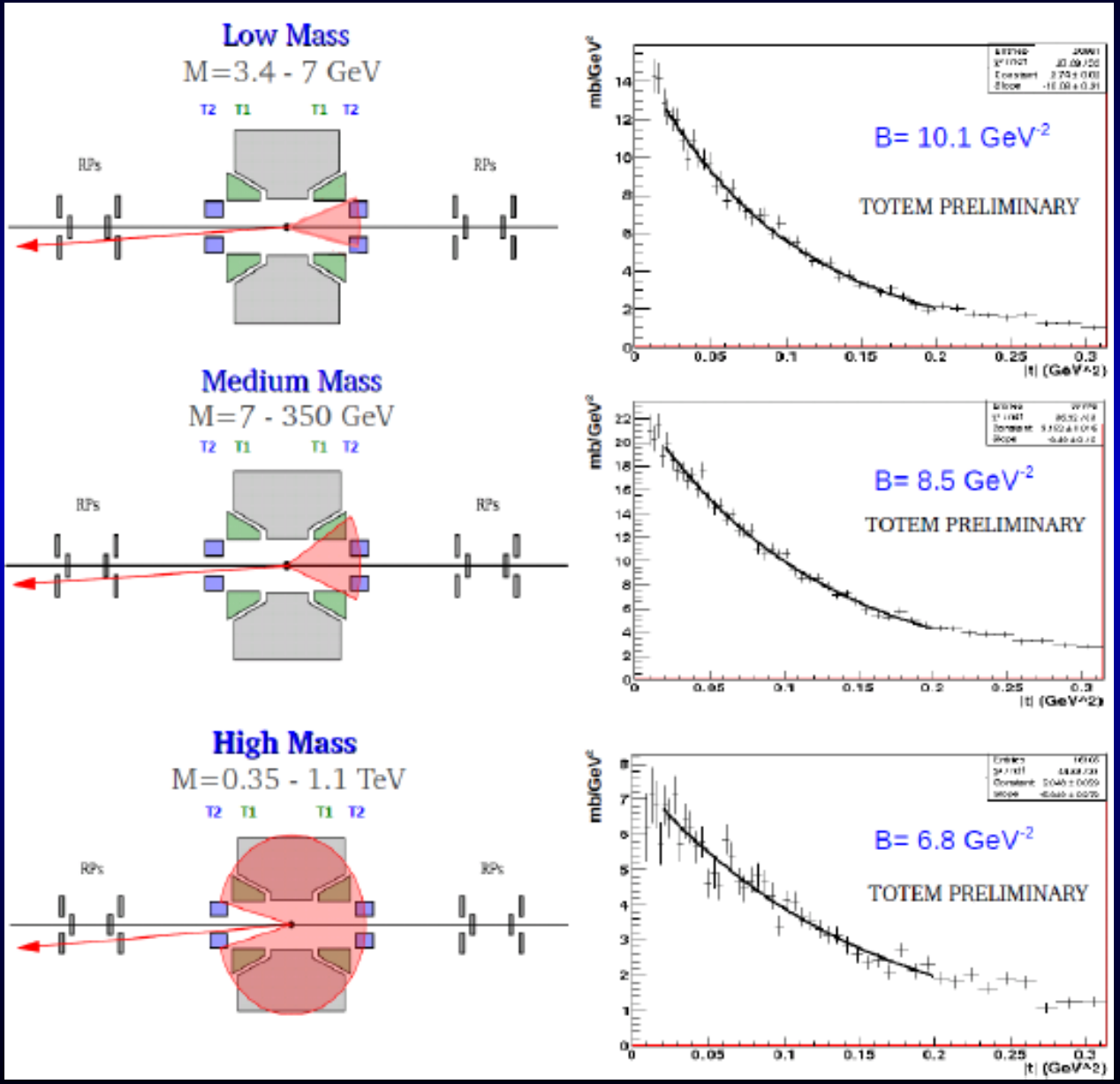




Event classification based on tracks in T1 & T2, proton in RP

SD class	Configuration	M_X [GeV]	$\xi = \Delta p/p$
Low mass	1 RP + opp. T2	3.4 – 8	2x 10^{-7} – 10^{-6}
Medium mass	1 RP + opp. T2 + opp. T1	– 350	10^{-6} – 0.0025
High mass	1 RP + opp. T2 + same T1	350 – 1100	0.0025 – 0.025
Very high mass	1 RP + both T2	1100 – ...	0.025 – ...

TOTEM on single diffraction, 7 TeV



Corrections included:
- Trigger efficiency
- Proton acceptance & reconstruction efficiency
- Background subtraction
- Extrapolation to t = 0

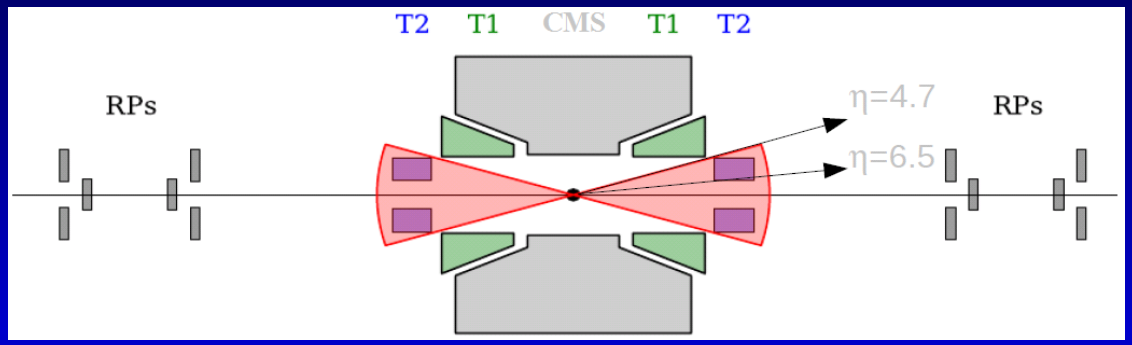
Missing corrections:
- Class migration
- ξ resolution & beam divergence effects

Estimated uncertainties:
B ~ 15% ; σ ~ 20%

TOTEM preliminary:
σSD = 6.5 ± 1.3 mb
3.4 GeV < Mdiff < 1.1 TeV

TOTEM for double diffraction

Aim: Measurement of soft double diffractive cross section with particle η_{min} visible to TOTEM T2 ($4.7 < |\eta_{min}| < 6.5$). → $\sigma_{DD}(|\eta_{min}|)$ for $3.4 < M_{DIFF} < 8$ GeV



Event selection: Trigger with T2, at least one track in both T2 hemispheres , no tracks in T1 "(0T1+2T2) topology".

- ND background estimated scaling the MC prediction using a control sample from data dominated by ND (2T1+2T2 events)
- SD background estimated completely from data using a SD-dominated control sample (0T1+1T2) with protons in the RP

TOTEM results on double diffraction

Phys. Rev. Lett. 111, 262001

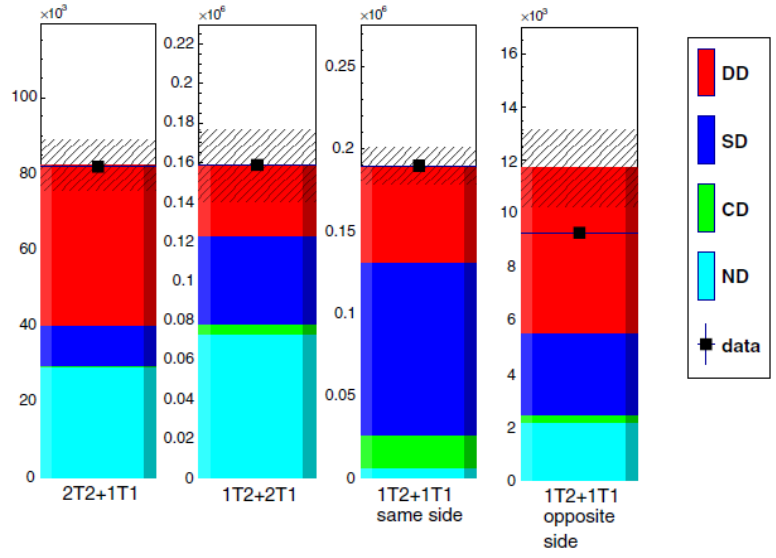


FIG. 1 (color online). Validation of background estimates for the full selection I_{track}. Each plot shows the corrected number of events in data (black squares) and the combined estimate with background uncertainties. The combined estimate is the sum of all components, from bottom to top: the ND estimate (cyan), CD estimate (green), SD estimate (blue), and DD estimate (red).

$$\sigma_{\text{DD}} = \frac{E(N_{\text{data}}^{2T2+0T1} - N_{\text{bckg}}^{2T2+0T1})}{\mathcal{L}},$$

E: experimental correction includes acceptance, tracking, reconstruction efficiencies (T2) and for only neutrals in T2

E = 0.9 ± 0.1

L = 40.1 ± 1.6 μb-1

TOTEM result:
σDD = 116 ± 25 μb
4.7 < |η|min < 6.5
for both diffractive systems

TOTEM for double diffraction

TABLE III. Double diffractive cross-section measurements (μb) in the forward region. Both visible and η_{min} corrected cross sections are given. The latter is compared to PYTHIA and PHOJET predictions. PYTHIA estimate for total $\sigma_{DD} = 8.1$ mb and PHOJET estimate $\sigma_{DD} = 3.9$ mb.

	I_{track}	$D11_{track}$	$D22_{track}$	$D12_{track}$	$D21_{track}$
Visible	131 ± 22	58 ± 14	20 ± 8	31 ± 5	34 ± 5
	I	$D11$	$D22$	$D12$	$D21$
η_{min}	116 ± 25	65 ± 20	12 ± 5	26 ± 5	27 ± 5
PYTHIA η_{min}	159	70	17	36	36
PHOJET η_{min}	101	44	12	23	23

TABLE IV. Summary of statistical and systematic uncertainties (μb).

	I	$D11$	$D22$	$D12$	$D21$
Statistical	1.5	1.1	0.7	0.9	0.9
Background estimate	9.0	6.0	3.5	2.7	2.2
Trigger efficiency	2.1	1.2	1.0	0.9	0.9
Pileup correction	2.4	2.1	0.4	1.1	1.0
$T1$ multiplicity	7.0	3.9	0.7	1.6	1.7
Luminosity	4.7	2.6	0.5	1.1	1.1
Experimental correction	14.7	14.1	2.6	2.0	2.0
η_{min}	15.4	11.0	1.5	2.9	2.9
Total uncertainty	24.8	19.6	4.8	5.1	4.9

Event cathegories:
I: $|\eta|_{min}$ corrected

D11:
$4.7 < |\eta\pm|_{min} < 5.9$

D22:
$5.9 < |\eta \pm|_{min} < 6.5$

SD & DD results combined seems to indicate factorisation breaking:

$\sigma_{DD}\ (4.7 \le |\eta_{min}| \le 6.5) >>$
$\sigma_{SD}\ (-4.7 \ge \eta_{min} \ge -6.5) \times$
$\sigma_{SD}\ (4.7 \le \eta_{min} \le 6.5) / \sigma_{elastic}$

Note: $|\eta|_{min}$ correction: the dominant source of the uncertaintly

Summary 1

TOTEM has measured
the total pp cross section
using the luminosity independent method
at 7 and 8 TeV
and calibrated the LHC absolute luminosity

At 7 TeV, 3 different methods
of σtot measurements in excellent
agreement.

Work in progress for 2.76 and 8 TeV σtot
with similar methods.

High precision of these measurements
impossible without the recalibration of LHC
optics from TOTEM RP data.

Summary 2

TOTEM has shown
preliminary data
for single diffractive scattering at 7 TeV
and the σSD cross section at large mass.

The first measurements of
double diffractive cross section
are published.

Common TOTEM-CMS work started
on central diffraction
but this topic is
not reported in this talk.

Stay tuned for Run-2
with a new TOTEM setup

The TOTEM Collaboration

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8
countries
11
institutions
78
people

Thank you!

The TOTEM Acknowledgments

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Thank you!

Backup slides – Questions?