TOTEM Operations, Upgrade and Physics Potential

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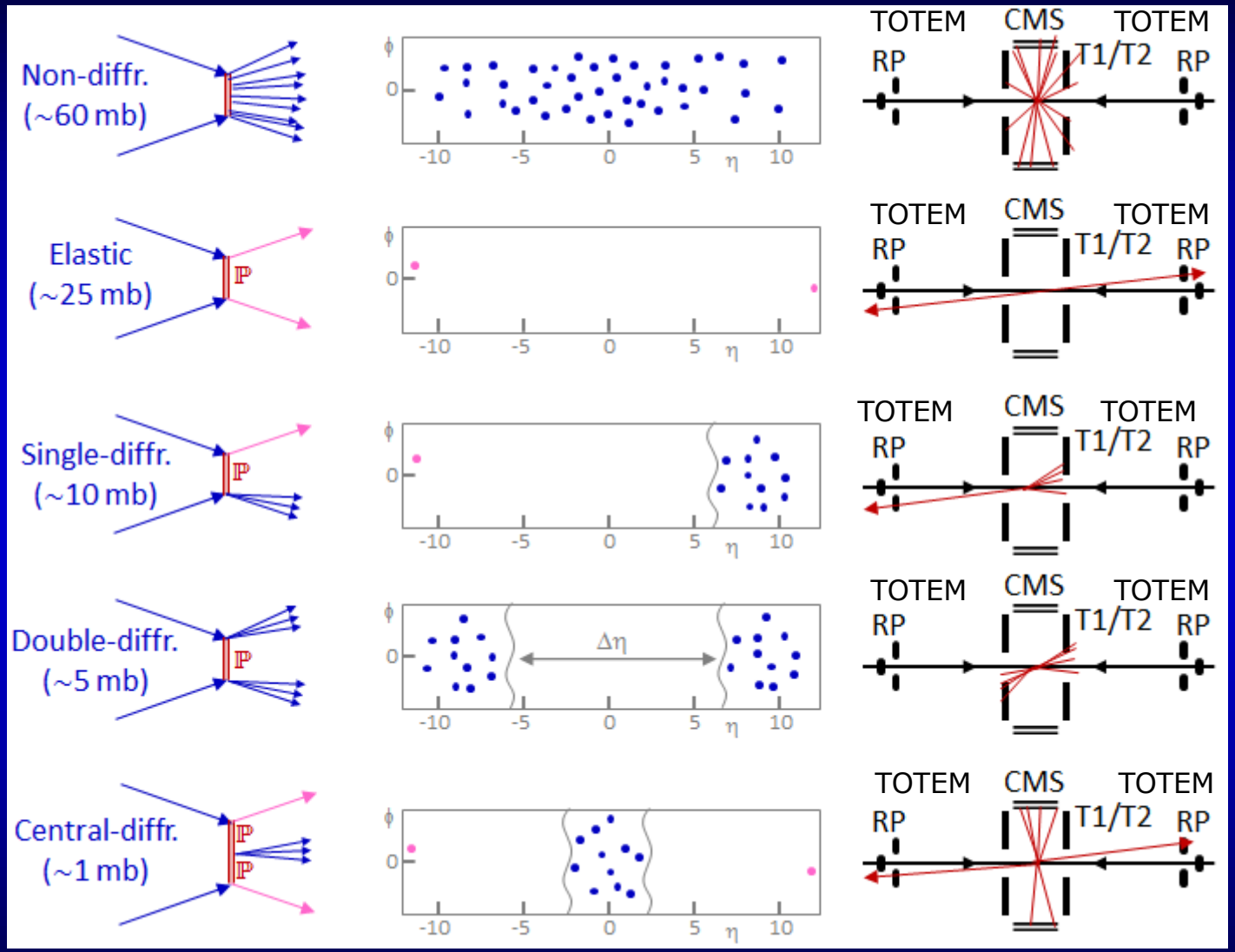
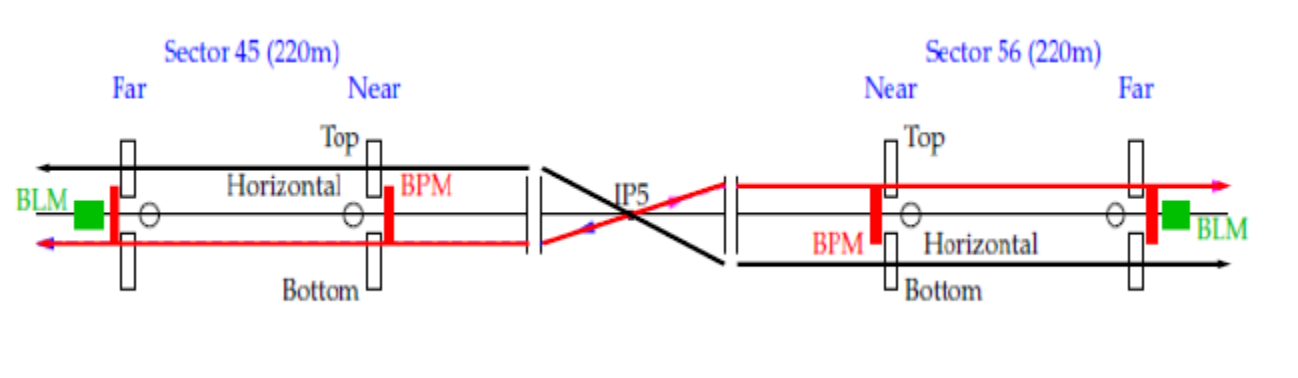
Physics Results: in F. Nemes's talk
Introduction to TOTEM'15
Run operations in 2015
Future physics perspectives
Insertions with CT-PPS
Upgrade strategy
Summary

Introduction: TOTEM physics at LHC



Elastic and diffractive scattering: colorless exchange

RP stations for elastic scattering

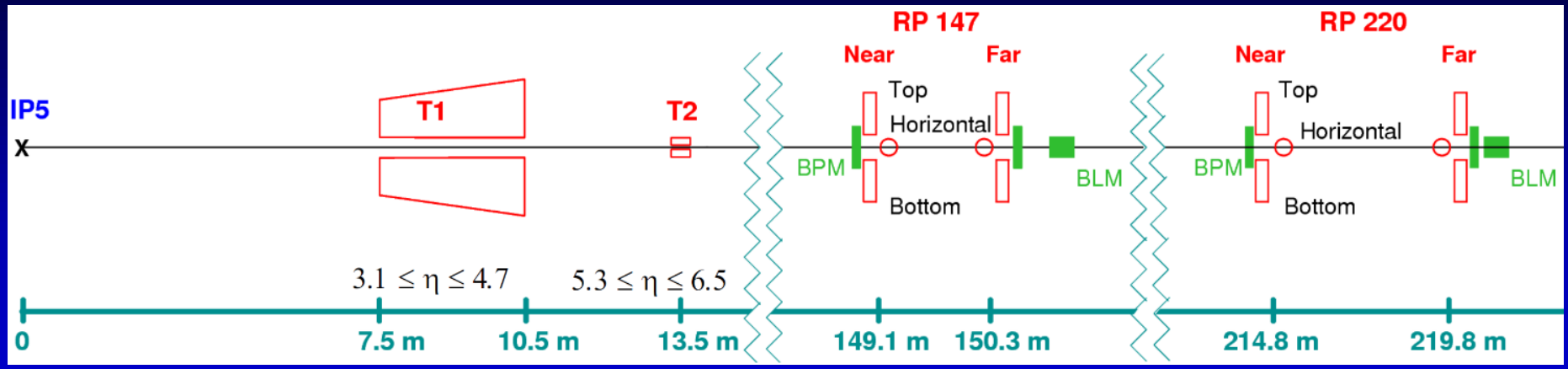


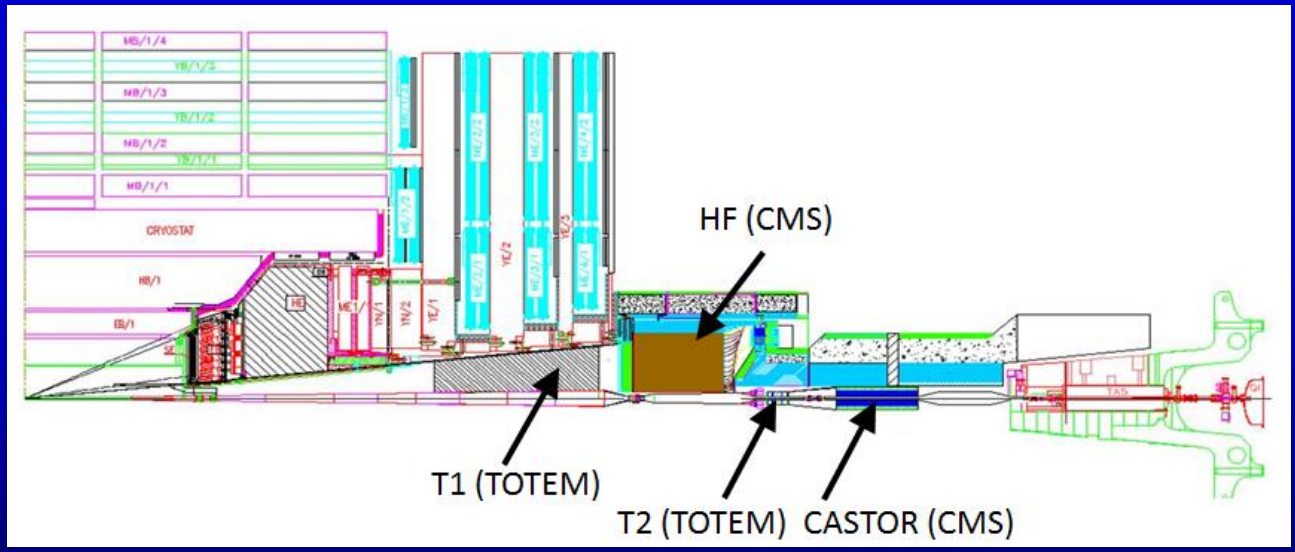
Near(214 m) and Far(220 m) TOTEM RP units on both sides of IP5

Three RP-s in each unit:
(top, horizontal, bottom)
Each RP:
Stack of 10 silicon strips (pitch 66 μm)
„edgeless" (active in few x 10 μm)
Trigger capable electronics

Elastic scattering: two anti-parallel protons
→ Two independent topologies:
45 bottom-56 top, 45 top-56 bottom

TOTEM before LS1: Experimental Setup @ IP5

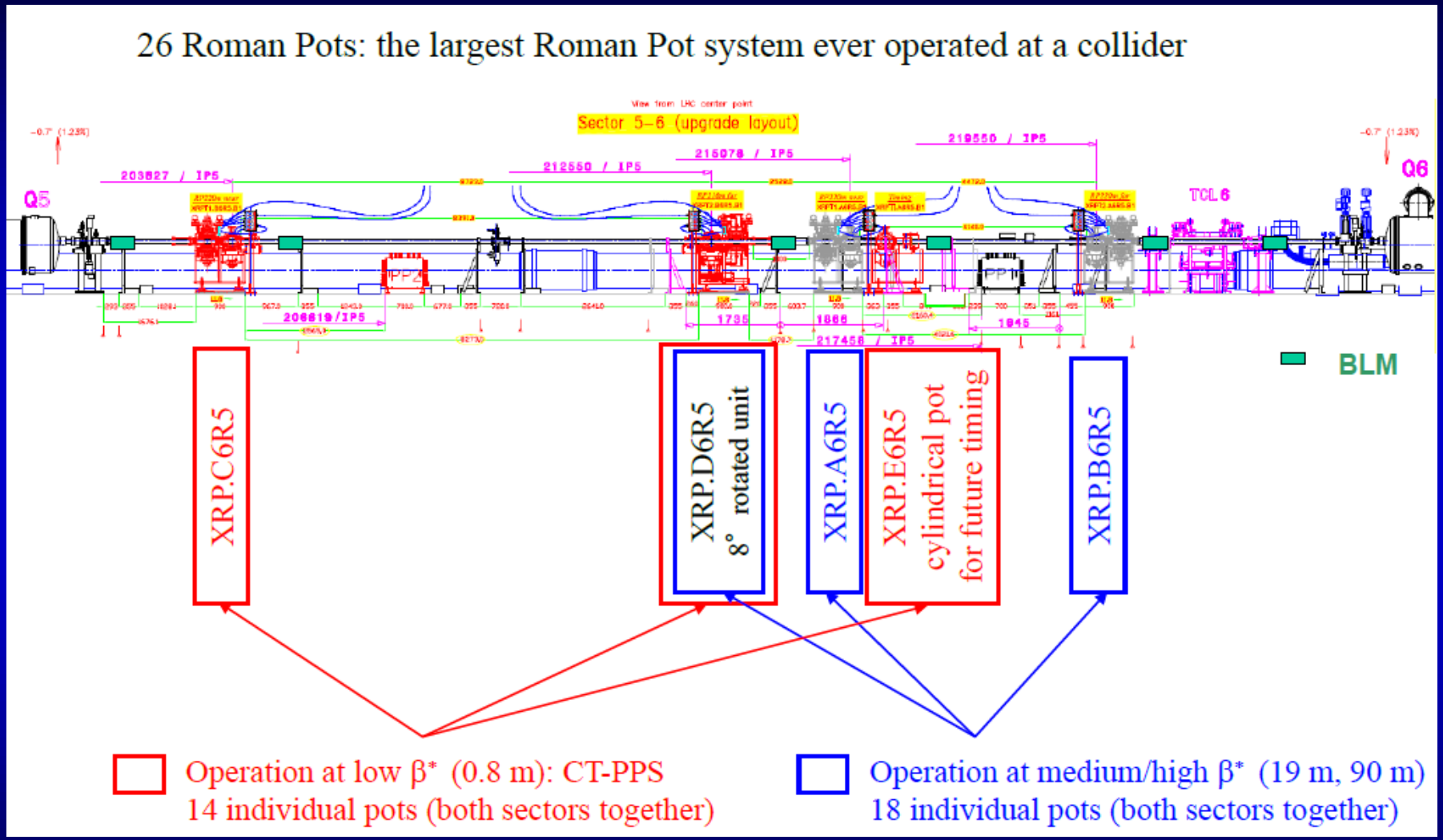




T1, T2: CSC and GEM Inelastic telescopes; RP: Roman Pots
[Details: JINST 3 (2008) S08007]. TOTEM Roman Pots at 220 m from IP5

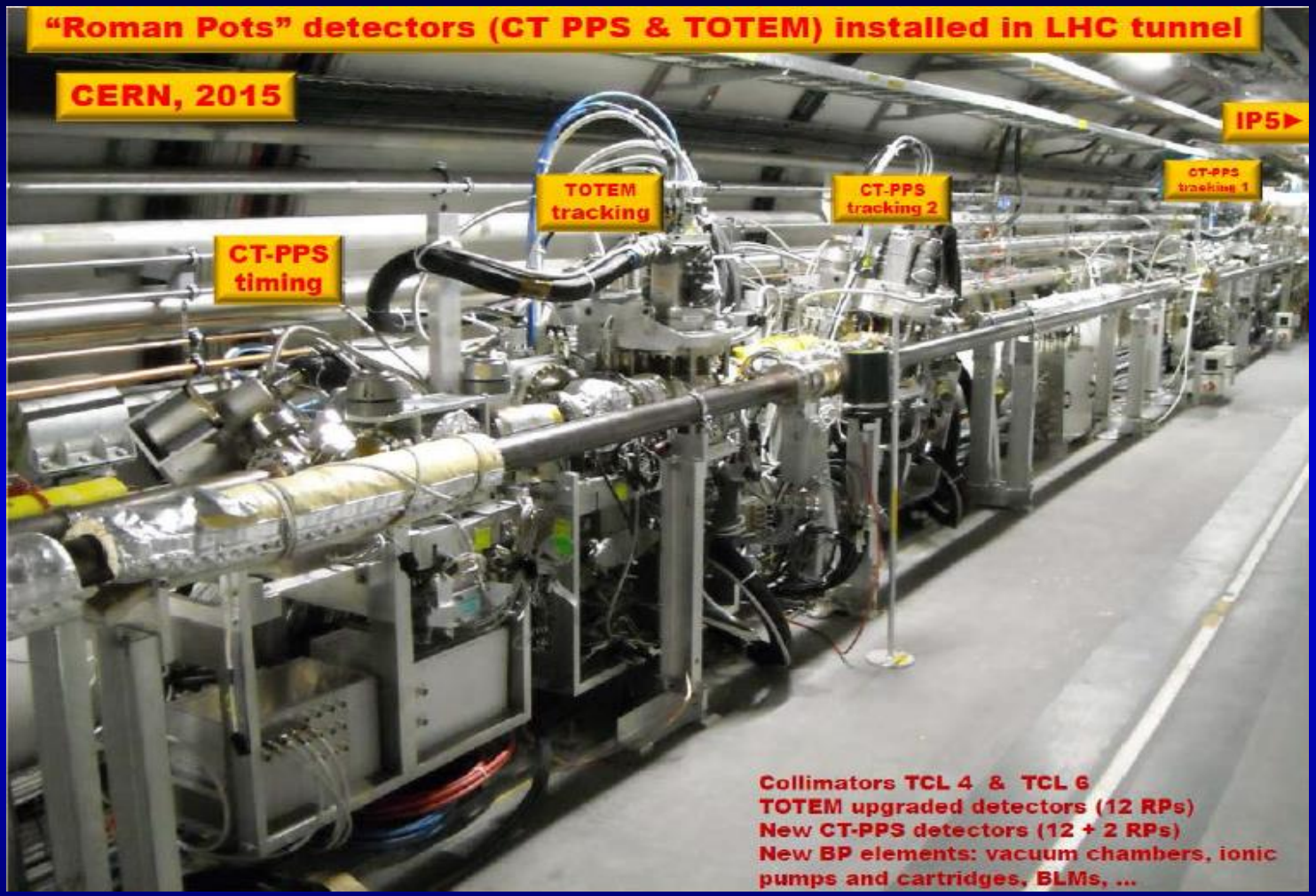
TOTEM after LS1: Experimental Setup @ IP5

26 Roman Pots: the largest Roman Pot system ever operated at a collider



All RP insertions successfull so far, standalone operations as well as common runs with CMS.
First TOTEM preliminary results for 13 TeV approved last week, see F. Nemes's talk.

TOTEM Run Operations in 2015



(1) LHCf run and van der Meer scans, $\beta^* = 19$ m – enough data for elastic, but low priority

(2) Special runs, $\beta^* = 90$ m → successful data taking

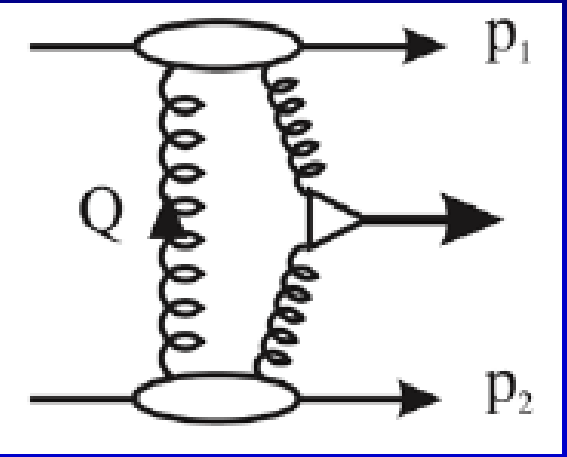
(3) RP insertions at low and high β^* → successful tests

October 2015: β* = 90 m run

[see CERN-LHCC-2014-020 (TOTEM-TDR-002)
and CERN-LHCC-2014-024 (TOTEM-TDR-002-ADD-1)]

a) Low-Luminosity Programme
- for elastic scattering, total cross-section
- needs RPs very close to the beam (~ 5 – 6 σ)
  → use RP alignment fill (few hours of data taking after alignment)

b) High-Luminosity Programme
- low-mass central diffractive spectroscopy, glueball searches
- missing mass searches
in a joint run with CMS



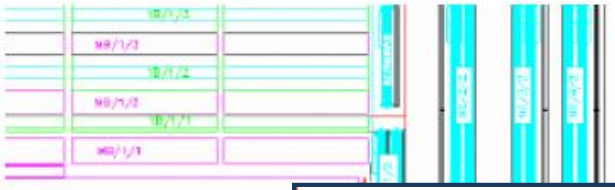
100 ns bunch spacing → up to 702 bunches
~700 bunches to be reached after intensity ramp-up: 1 fill of 3–4 hours at ~50 and ~250 bunches

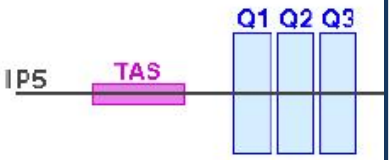
→ needs new version of 90 m optics with crossing angle (~ ±50 μrad):
First optics commissioning step successfully completed on 12 September !

bunch population (6 – 7) x 10^{10} p/b, emittance ε_n ~ 2.5 μm rad
→ pileup μ ~ 0.1
→ $\mathcal{L} = (0.6 – 0.8)$ pb^{-1} / 24 h

Common request by CMS and TOTEM in the LPC: $\mathcal{L}_{int} \geq 1$ pb^{-1}

TOTEM setup, DAQ: β* = 90 m run





Roman Pot stations

Hardware:

- Replacement of the VME back-end with Ethernet 1Gb links, using RD51 Front-End Concentrator (FEC) cards.
- Installed in IP5 in August : 12 SRS-FEC + 1 Scalable Read-out Unit (SRU)
- New 4+1 readout machines installed S2 (each machine connects to 4 SRS-FEC)
- New 10Gb network deployed
- New 5+1 servers work as event builders and storage nodes

Firmware:

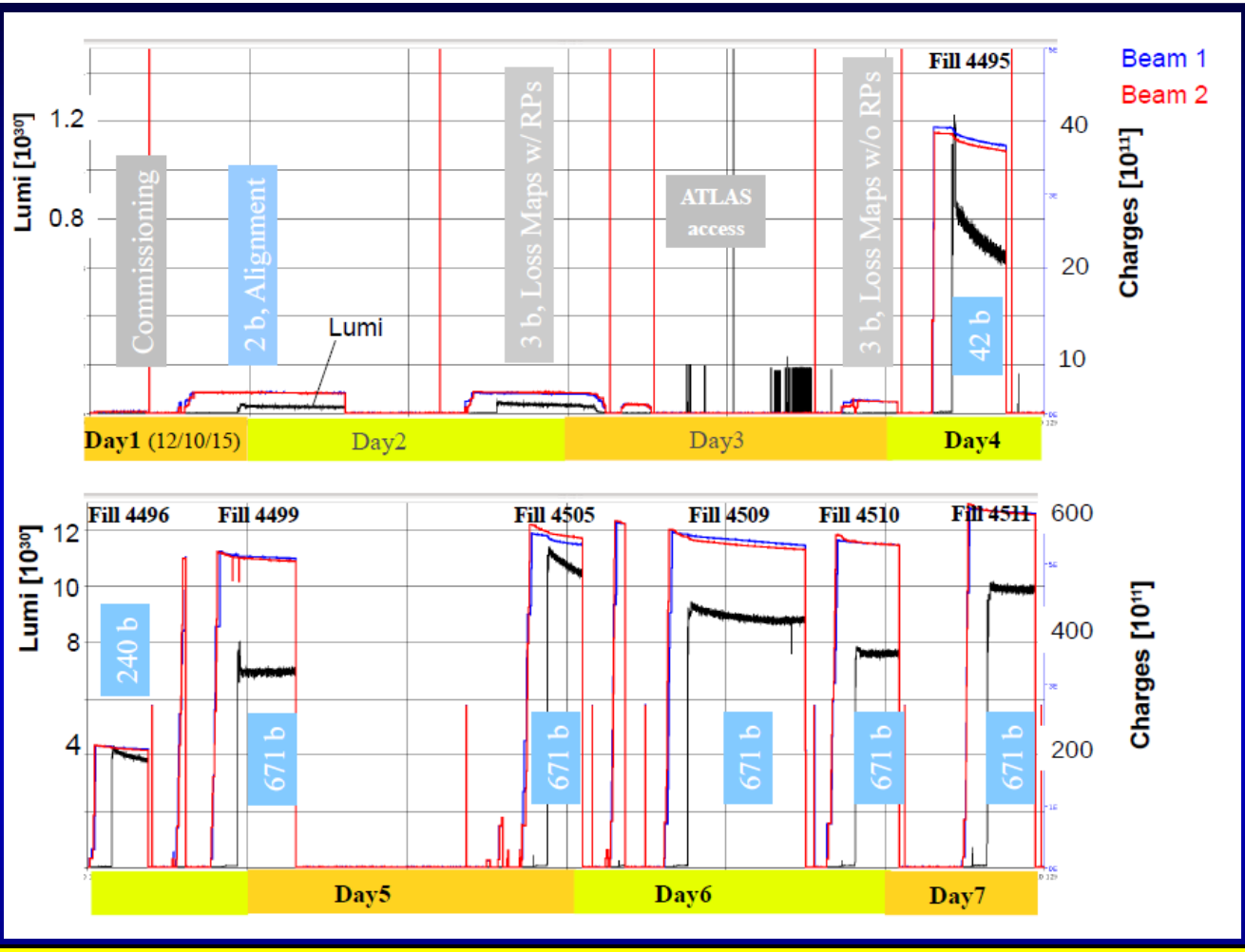
New firmware allows data taking in two modes: RAW event (as in the old system) and ZERO SUPPRESSION (based on cluster counting)

⇩

Trigger rate sustained during special run
~ 20 kHz, raw mode
~ 50 kHz, zero suppression

TOTEM Trigger Rate (Run2) ~ 50 x Trigger Rate (Run 1)

Operations at β* = 90 m



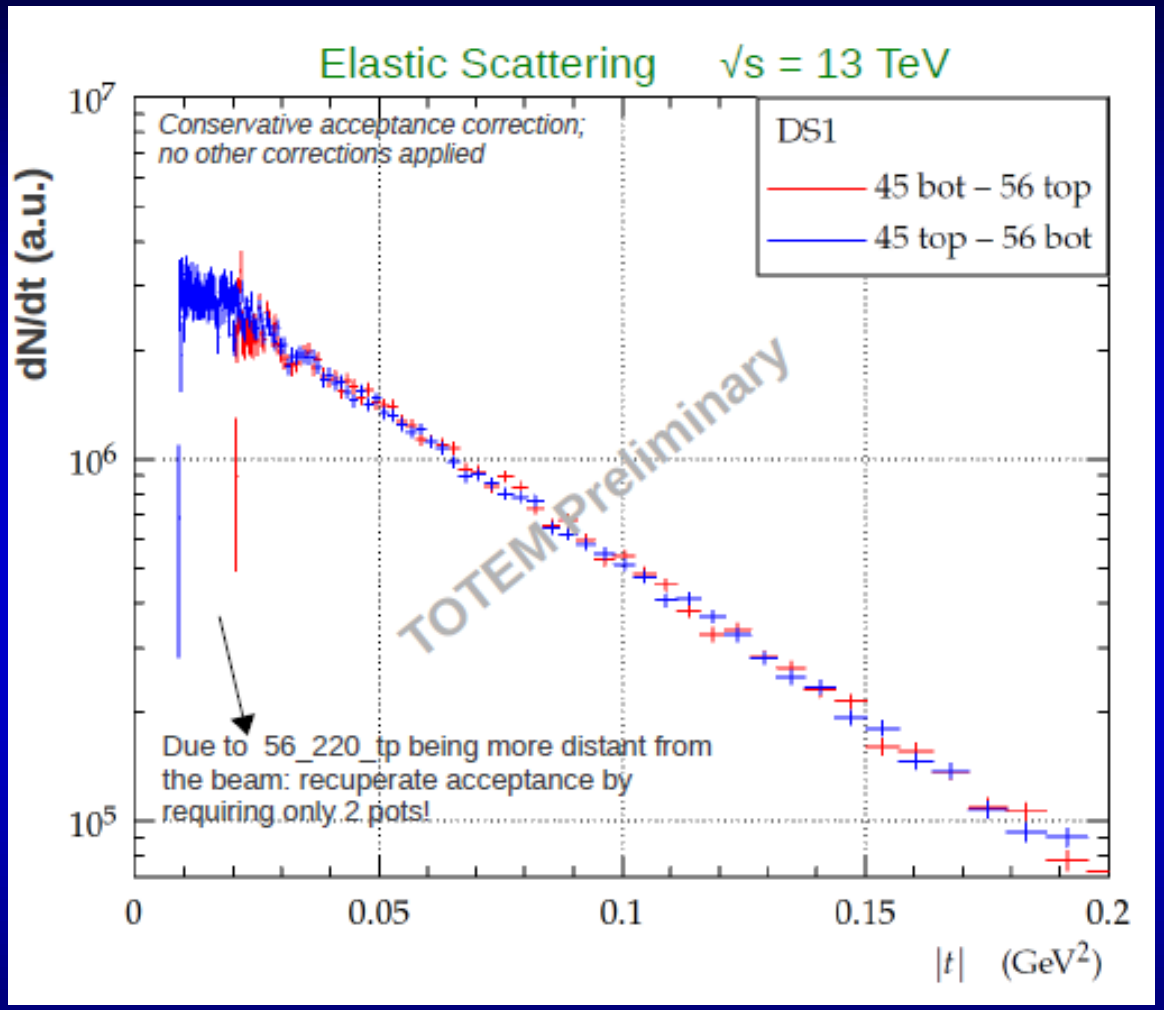
Day 1: Commissioning. Day 2: RPs at 5 σ, scraping the beam to align the pots
Day 3: ATLAS access, loss maps w/o RPs
Days 4 - 7: Physics data
TOTEM standalone data with T1, T2, RP: 11.6 M triggers, (8 x triggers of 8 TeV, Run-1)

TOTEM Alignment Run, β* = 90 m

RPs at 5 σ
After quiet beams, data taking with T1, T2, RPs

Triggers:
RP double arms
T2 inelastic
(1-2 kHz)

Two arms: elastics



Physics potential: Luminosity indepenent total cross-section measurement
Low-t elastic scattering
Inelastic cross-section, direct measurement with T2

Luminosity recorded, β* = 90 m

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 mu & HF Veto

CMS+TOTEM:

independent DAQ
Level 1 Trigger exchange
Offline merging

Totem LV1 Rate ~ 50kHz → recorded
~ 3 · 10^9 events collected!

CMS HLT Rate ~ 10kHz → recorded

	Bunches	Duration (h)	Luminosity ($\mu b\ s)^{-1}$	Pileup
Alignment run	2	2	~ 0.03	~ 0.1
Physics runs	42	3.6	0.7	0.15
	240	2.6	3.9	0.09
	671	4.2	6.9	0.065
	"	2.7	10.6	0.095
	"	8.8	9.0	0.085
	"	3.3	7.6	0.07
	"	5.5	9.8	0.096

Integrated Luminosity

LHC delivered : 0.74/pb

CMS recorded ~ 0.68/pb

Totem Trigger & CMS data : 0.55/pb

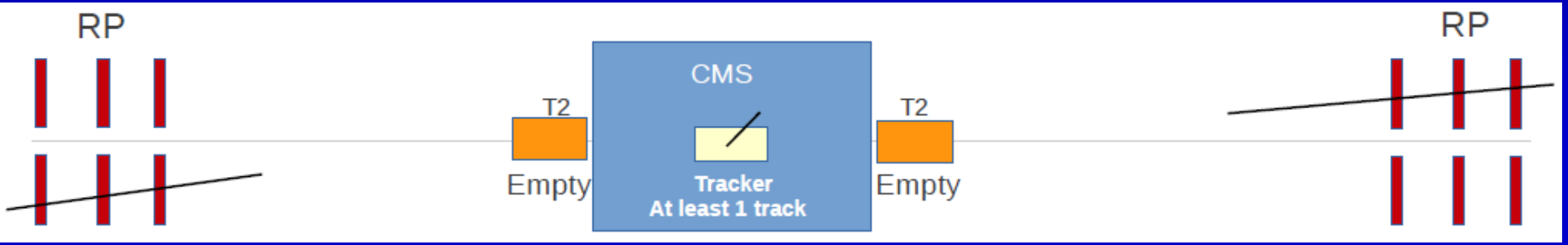
CMS+Totem data ~ 0.4/pb

Analysis samples

LHC delivered 0.74/pb
CMS+TOTEM recorded for analysis 0.4/pb

CMS+TOTEM Trigger Menu 1
$\beta^* = 90$ m

Roman Pots Double Arm and T2 Veto + at least 1 track in CMS
Right topology for low-mass central diffraction (DPE), glueball searches

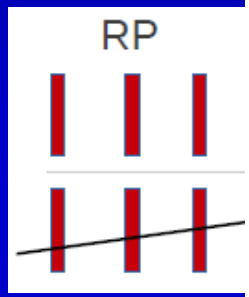


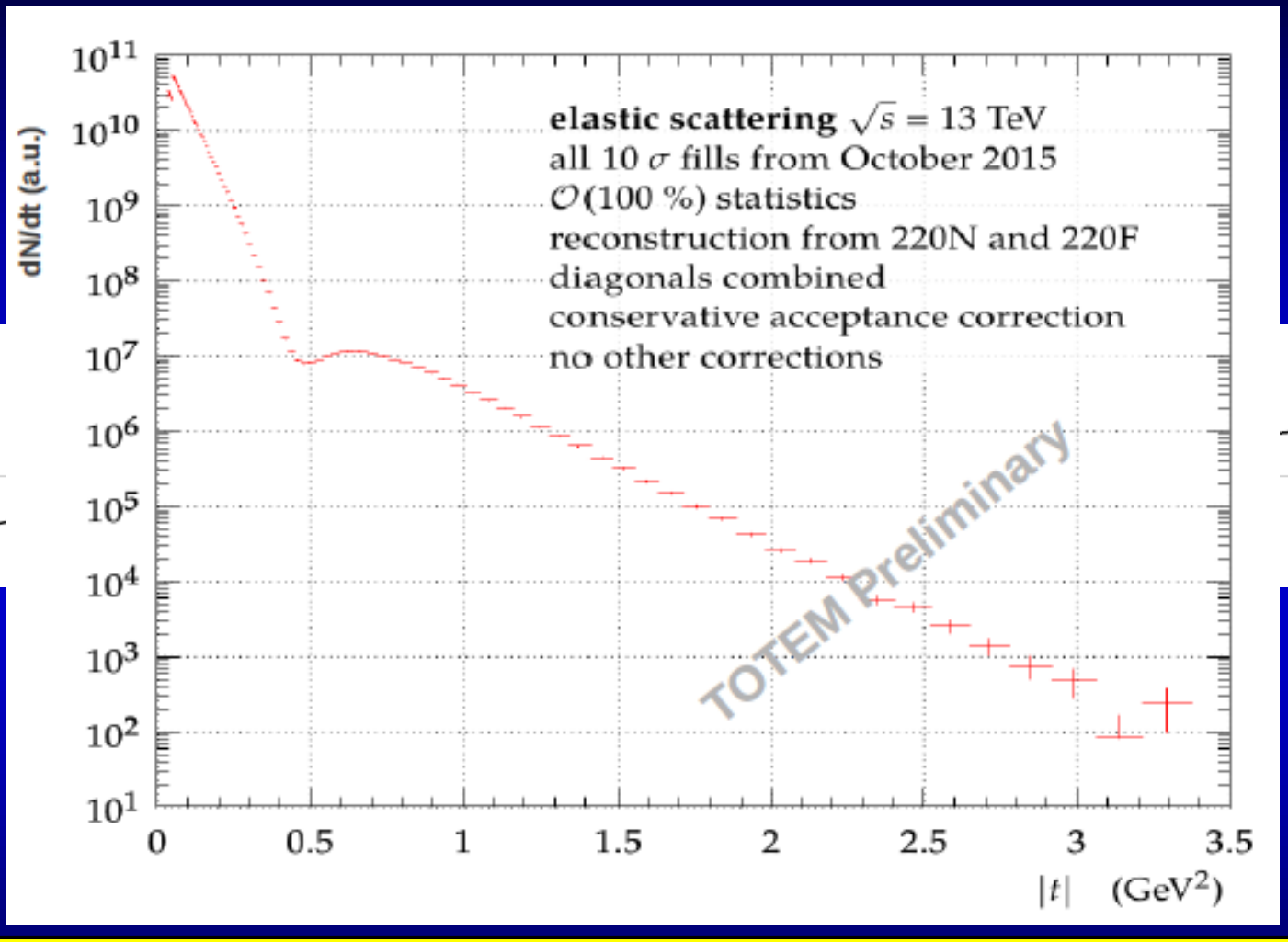
New in 2015:
3 RP Units/arm !
→ Improved acceptance

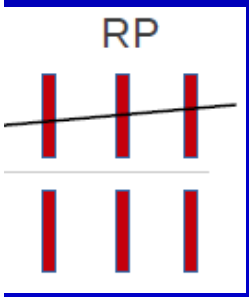
CMS HLT rate 1.5- 2kHz, TOTEM LV1 rate ~ 50 kHz (~10^8 low mass DPE candidate events)

In TOTEM: very high statistics for elastics (> 2×10^9 events)

Physics: large-t elastic at 13 TeV



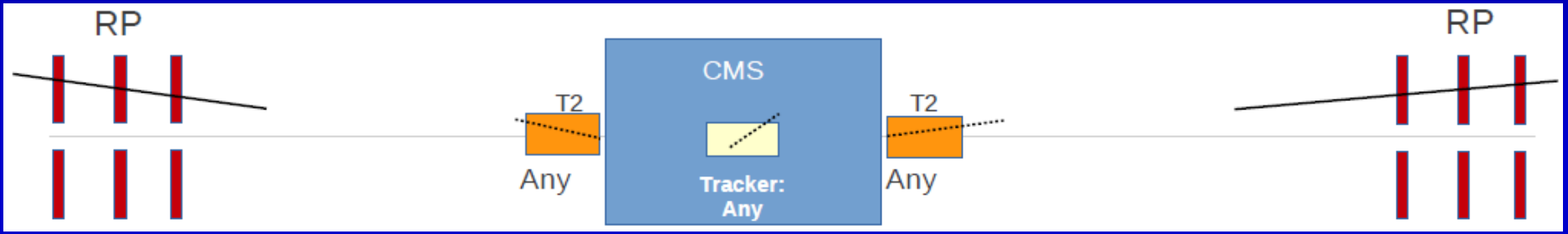




Physics potential: large-t elastics may indicate QCD effects
Donnachie and Landshoff power-law tail
May exclude interpretations based on quantum optical models at large t

CMS+TOTEM Trigger Menu 2: β* = 90 m

Roman Pots Double Arm, TopTop or BottomBottom, T2 any, CMS any
Right topology for central diffraction, elastic „background” excluded

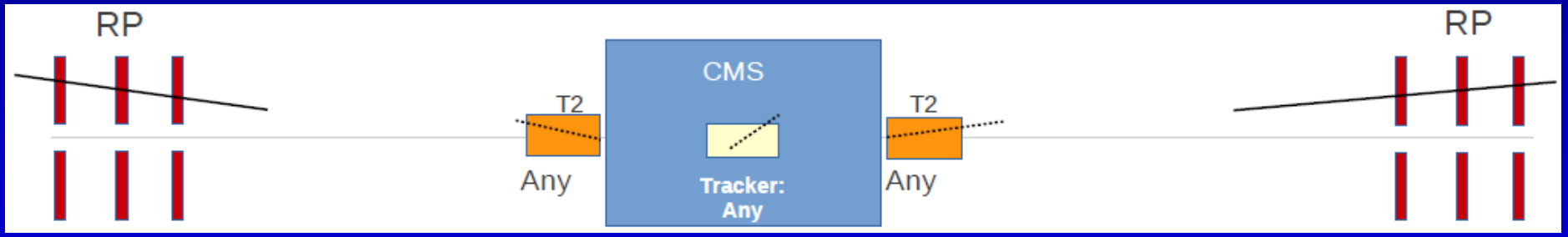


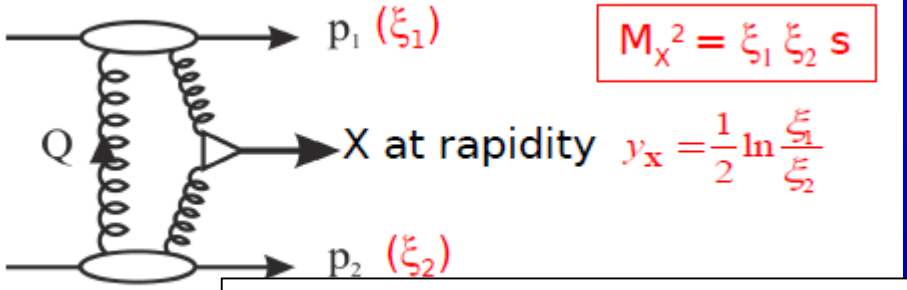
Control sample for CMS and T2 performance

CMS HLT rate ~ 5 kHz, TOTEM LV1 rate ~ 5 kHz (~10^7 DPE candidate events)

CMS+TOTEM Physics Potential: Central Diffraction, β* = 90 m

CMS HLT rate ~ 5 kHz, TOTEM LV1 rate ~ 5 kHz (~10^7 DPE candidate events)





$M_X^2 = \xi_1 \xi_2 s$

Exchange of colour singlets with vacuum quantum numbers

⇒ selection rules for system X: $J^{PC} = 0^{++}, 2^{++},...$

Low mass resonances and glueball studies: **x 500** statistics(2012) [should allow full decay characterization]

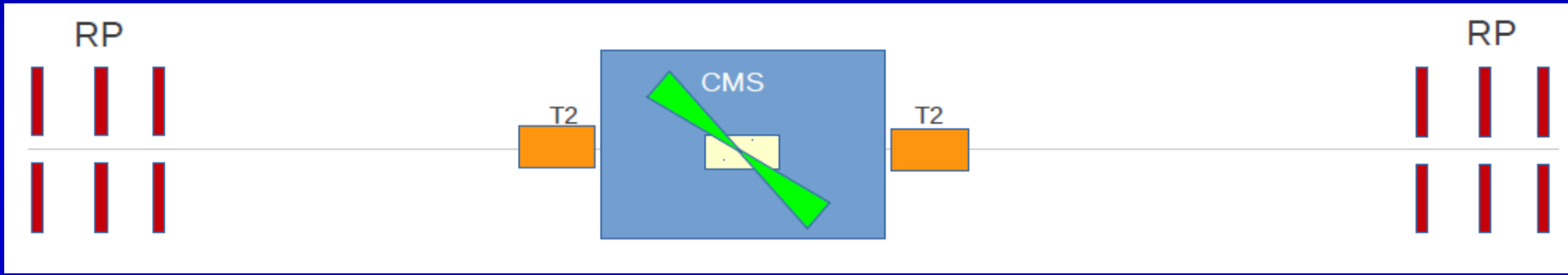
Exclusive charmonium production: expect ≥ **few hundred** χ_{c0} in all-hadronic decay modes

Non-exclusive central diffractive dijets (p^T_{jet} > 30, 40 GeV) : **x 100** statistics(2012)

Exclusive dijets central diffractive dijets (p^T_{jet} > 40 GeV) ~ **O(10)** events

CMS+TOTEM Trigger Menu 3: β* = 90 m

Roman Pots empty, T2 empty,
CMS dijets w pT ~ 20-32 GeV, DiMuon, SingleMu & FH gap



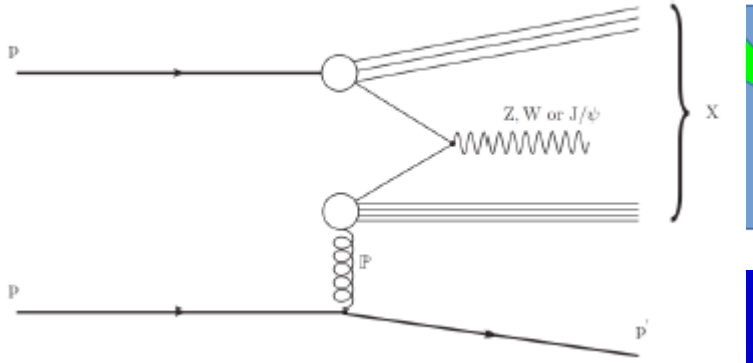
Single Diffractive Dijets, Exclusive Dijets, Hard Diffraction

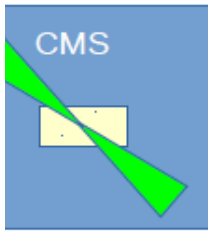
CMS rate ~ 1 kHz

Desirable for future upgrade: neutral veto in CMS ZDC

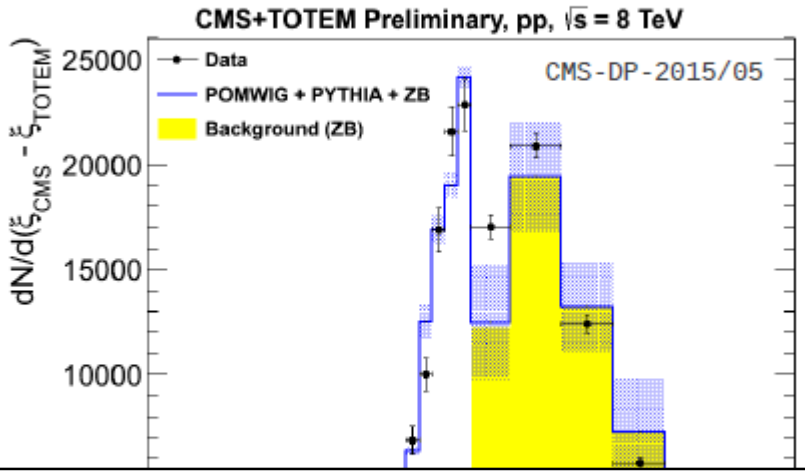
CMS+TOTEM dijets, SD, HD: Physics potential, β* = 90 m

Single Diffractive Dijets, Exclusive Dijets, Hard Diffraction





Background removal demonstrated on common CMS+TOTEM β* = 90 m data at √s = 8 TeV (SD dijets)



Estimate of visible cross sections at √s = 13 TeV and x 10 statistics (2012)

[CMS PAS FSQ-14-001, TOTEM-NOTE-2014-002]

- SD jet production: $p_{T,jet} > 40$ GeV ⇒ O(10k) events
- J/ψ production (POMPYT): $\mu^+\mu^-$ $3.05 < M_{\mu\mu} < 3.15$ GeV ⇒ O(100) events
- W production (POMWIG): $\mu^\pm/e^\pm$ ($p_T > 20$ GeV), $60 < M_T < 110$ GeV ⇒ O(10) events

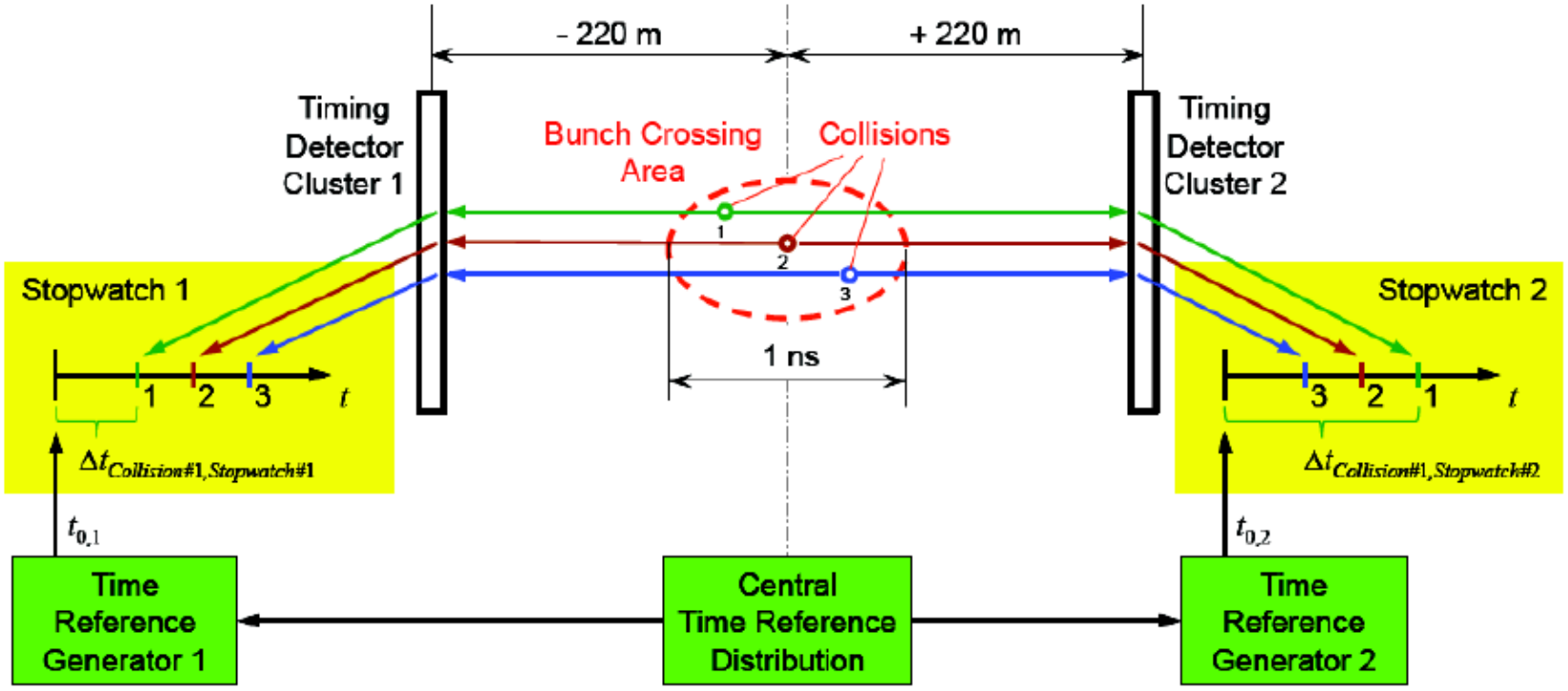
Longitudinal vertex reconstruction

Pileup problem:

High luminosity → multiple events in 1 bunch collision !

- CMS tracker can separate multiple vertices longitudinally,
- leading proton tracks have angles in μrad range → insufficient vertex precision

→ for double-arm events (CD) reconstruct vertex from time-of-flight difference



Position of Collision 1 $\sim \Delta t_{Collision\#1,Stopwatch\#1} - \Delta t_{Collision\#1,Stopwatch\#2}$

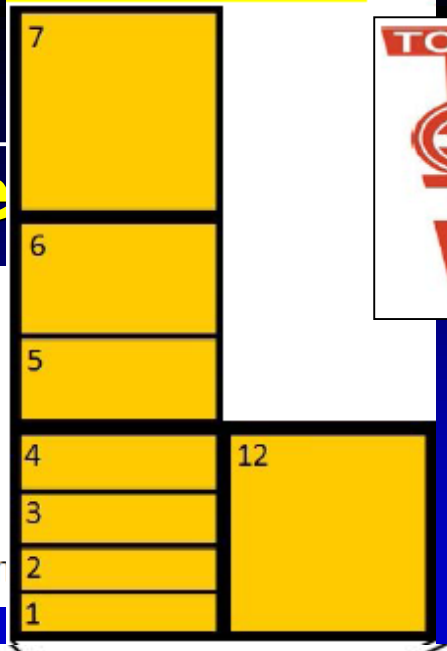
TOTEM Upgrade
Timing detectors for me

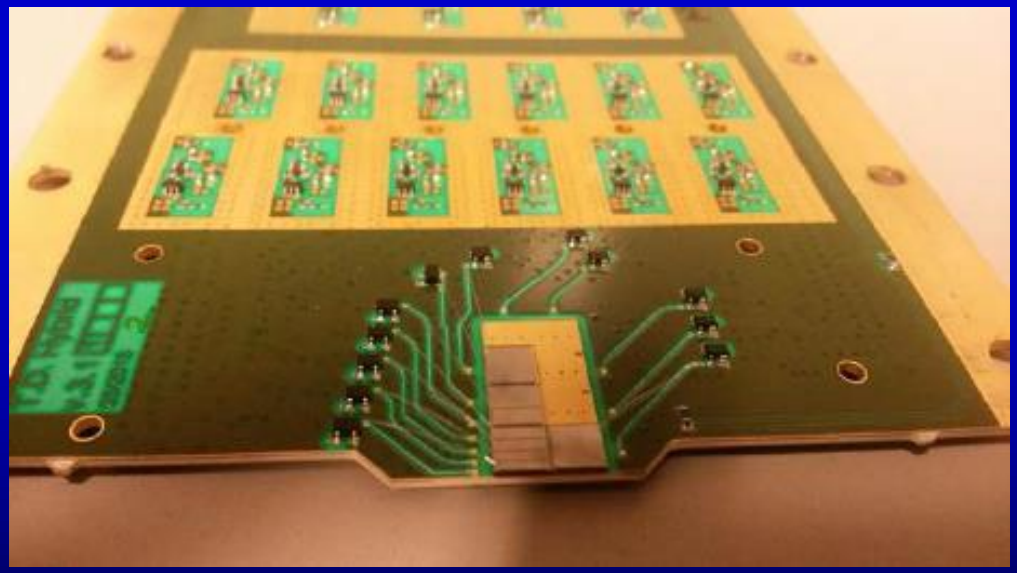
Objective:

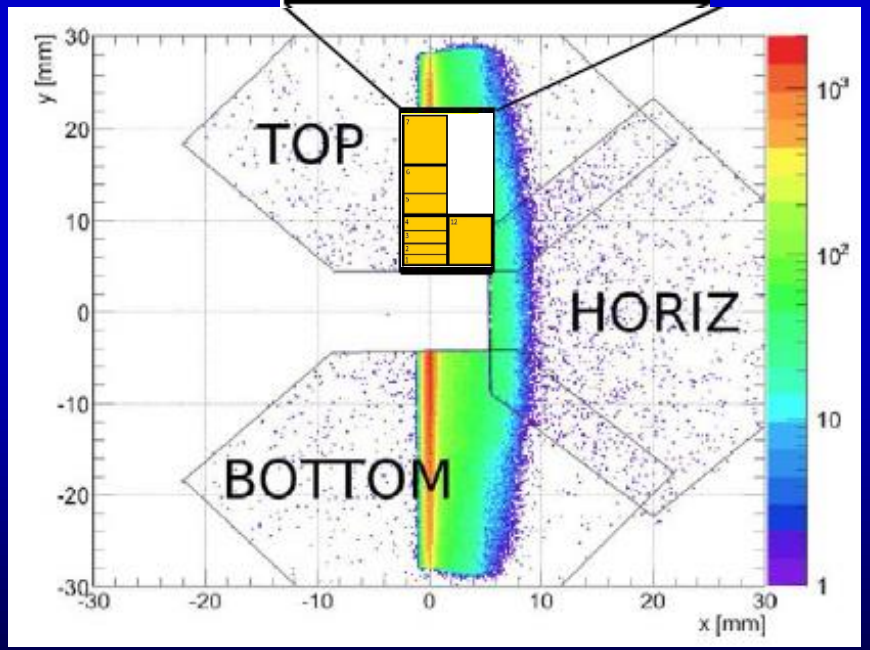
- 3 timing detector planes in 4 vertical RPs (1 pot pair per arm)
- Detector installation in TS3 – YETS
- ~ 60 ps resolution per arm ; ~100 ps / plane (enough for pileup $\mu \sim 0.6$)

Development of Diamond Detectors:

Segmentation follows the diffractive hit distribution: almost constant occupar

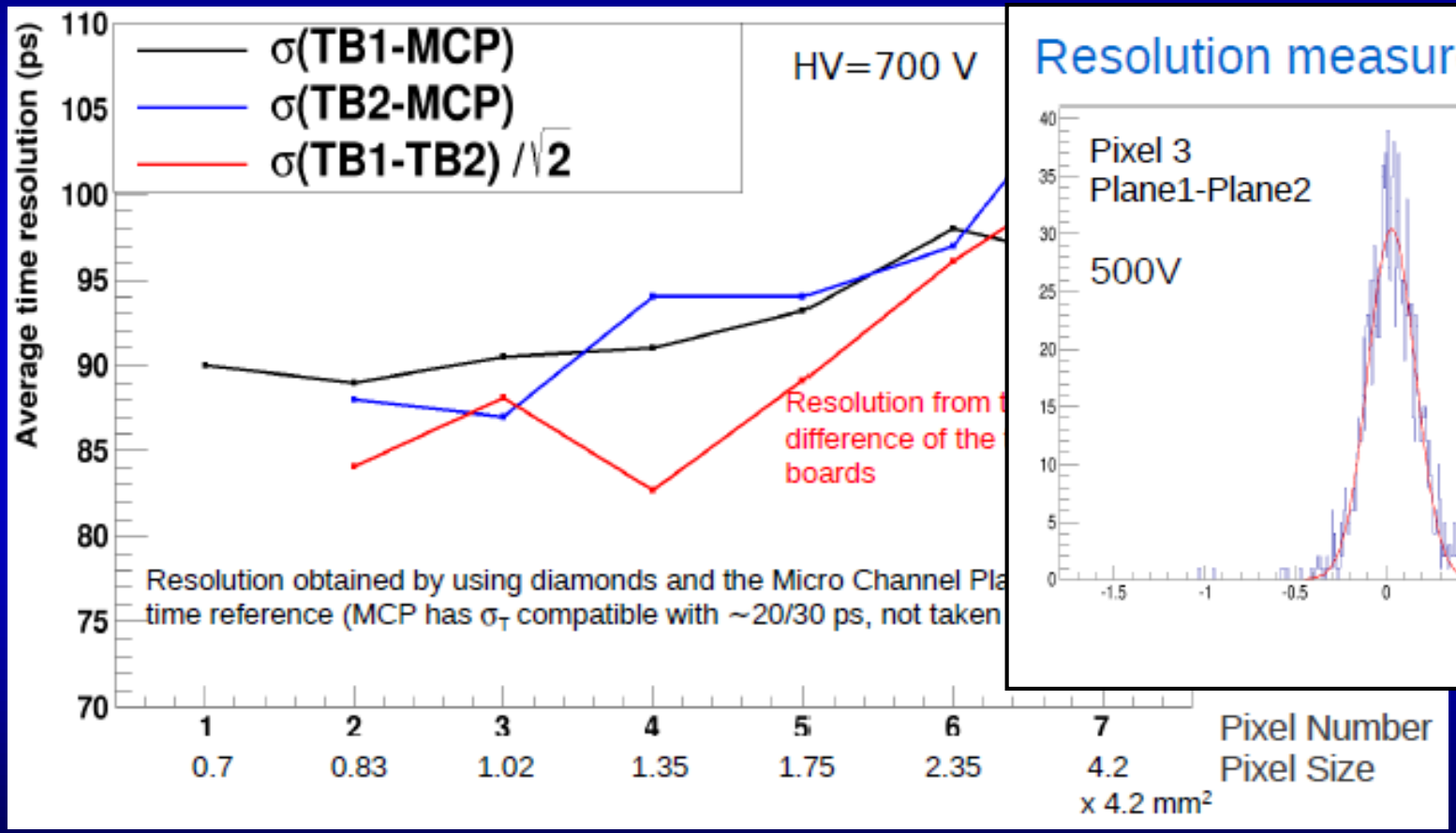






Medium pile-up TOTEM timing ~ 100 ps, different from CT-PPS upgrade ~ 10 ps

TOTEM Diamond Timing Development and Upgrade Status



~ 100 ps timing resolution achieved for all channels in tests. Installation in TS3 - YETS

CT-PPS: CMS-TOTEM Precision Proton Spectrometer

- Roman Pot Insertion Commissioning
  - Beam-based RP alignment
  - RP insertion tests are carried out in end-of-fill studies
  - Start with beams separated by 5- 6 sigma in IP5 ($L=10^{30-31}$)
  - Find an optimal set of positions of RPs and collimators.
- Timing Detector Commissioning
  - Commissioning of the timing detector as a function of luminosity
  - End-of-fill studies with separated beams
- Data Production Phase
  - RP insertion movements will executed by the LHC operator immediately after declaration of stable beams.
  - Aim at accumulating 100 fb^{-1} of data before LS2

RP insertions for CT-PPS upgrade

Objective:

Establish Roman Pot insertions for physics operation in all regular fills from 2016 on

…lems during first Insertion Tests in 2012:

…bined with outgassing:

…tronics cards inside RPs despite active cooling

…intensity ramp-up

3 – 4 July: Beam-based …
afterwards 45 minutes of diagnos…

5 – 14 July: RP insertions in all intensity steps of 50 ns intensity …
still nominal TCL configuration: TCL5 in, TCL6 out,
very conservative RP positions due to orbit uncertainties: ~ **30 σ horizontally, ~ 20.5 σ vertically**
3, 50, 152, 296, 476 bunches per beam → lumi up to 1.3 x 10^{33} cm^{-2} s^{-1}

Since 5 Sept (ongoing): RP insertions in second part of 25ns intensity ramp-up
So far: 2, 49, 219, 459, 745, 1033, 1177 bunches per beam → lumi up to 2.3 x 10^{33} cm^{-2} s^{-1}

RP insertions in regular low-β* fills in all intensity steps (~25σ horizontal, ~19.5σ vertical)
- No beam instabilities due to RP insertions observed (temperature, vacuum, BLM: OK)
- Maximum luminosity ~ 5 · 10^{33} $cm^{-2}s^{-1}$
- Record fill: RP inserted for 21 h !
- Extrapolation to L = 10^{34} $cm^{-2}s^{-1}$ and to smaller distances (~15 σ) is well within the BLMs thresholds (assuming the pots in the shadow of TCT collimators).

CT-PPS: Upgrade strategy and R&D

RP insertions in regular low-β* fills in all intensity steps (~25σ horizontal, ~19.5σ vertical)
- No beam instabilities due to RP insertions observed (temperature, vacuum, BLM: OK)
- Maximum luminosity ~ $5 \cdot 10^{33}$ $cm^{-2}s^{-1}$
- Record fill: RP inserted for 21 h !
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Tracking Detectors

- Pixel 3D sensors will be delivered in ~ 1 month
- Front-end electronics foreseen in 3 months

Timing detectors

- Quartic (Cherenkov bars) modules tested, integrated in the cylindrical pot, with complete electronic chain
- Four modules ready for installation at the end of YETS

Timing detectors R&D

- Development going much faster than foreseen
- Ultra Fast Silicon Detector and/or Diamond Sensors: possible installation in fall 2016

Stay tuned for Zimányi 2016!

Summary

TOTEM consolidation and RP relocation:
Ready and operational
First data taken in Run-2,
$\sqrt{s}$ = 13 TeV
in special β^* = 90 m runs.

Data rates / volumes:
more than 10x increase,
extended physics objectives in reach

TOTEM upgrade:
Diamond timing detectors in vertical RPs
Design resolution:
100 ps per plane achieved
Four planes installed in LHC

CT-PPS Project:
Successfull RP test insertions
Si timing detector R&D faster than expected

The TOTEM Collaboration

The TOTEM Collaboration

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8
countries
18
institutions
85
people

Thank you!

Backup slides – Questions?

VdM scans and LHCf runs in 2015

June: LHCf Run

Data taken with T1, T2 (minimum bias) → performance as in Run 1

August: VdM Scans

RPs inserted during all fills, even during IP5 scans:

Vertical RP: 12 σ

Horizontal RP: 15 σ

Successful data-taking with RPs, T2, and combined with CMS:

Trigger:

- RP single arm, T2 in veto
- RP double arm
- bunch crossings (zero bias)
- T2 minimum bias
- CMS: dijets, double muons

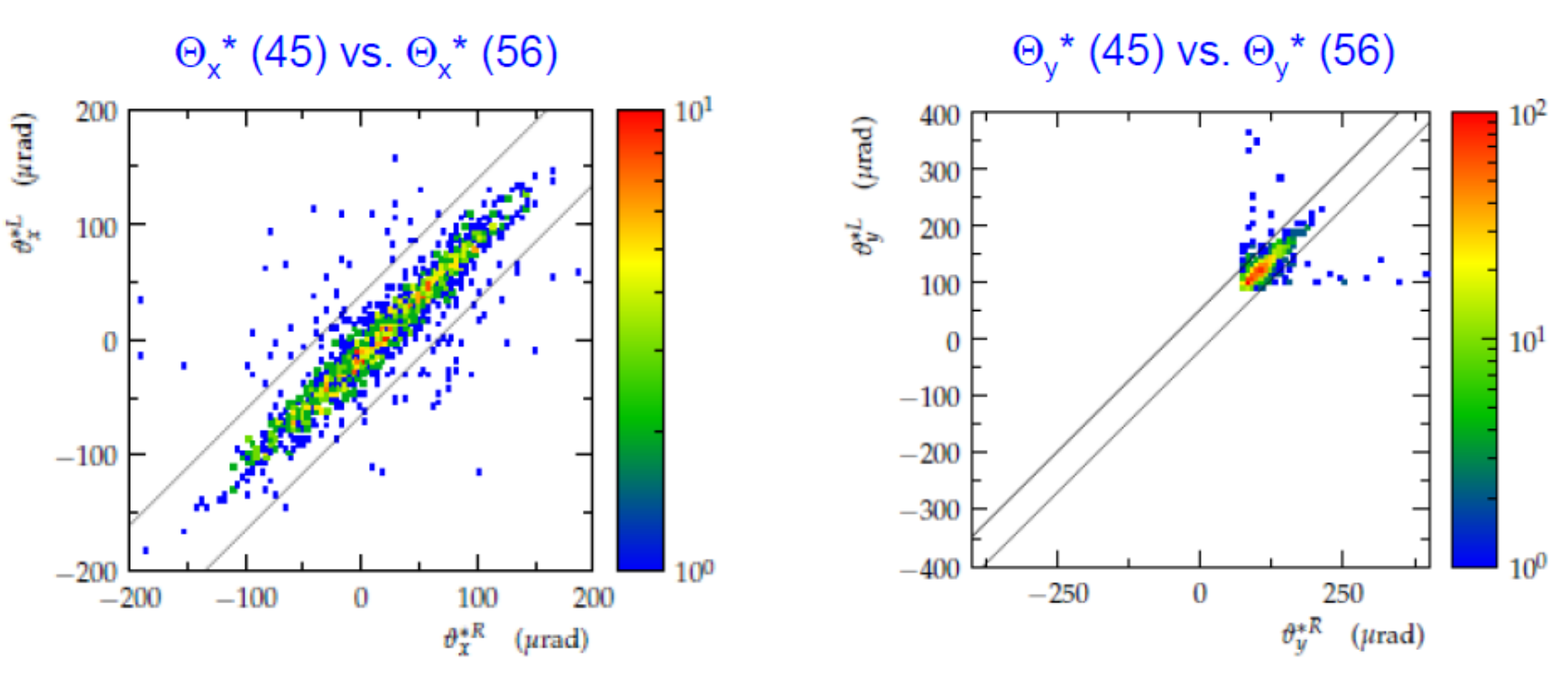
Pileup: $\mu = 0.05$ and 0.4, Luminosity from 9×10^{28} to 3×10^{30} cm^{-2} s^{-1}

DAQ consolidation: 25 kHz rate measured: factor 25 w.r.t. Run 1

Total integrated luminosity taken: ~ 40 nb^{-1}

All TOTEM detectors operational and ready for the special $\beta^* = 90$ m run in October

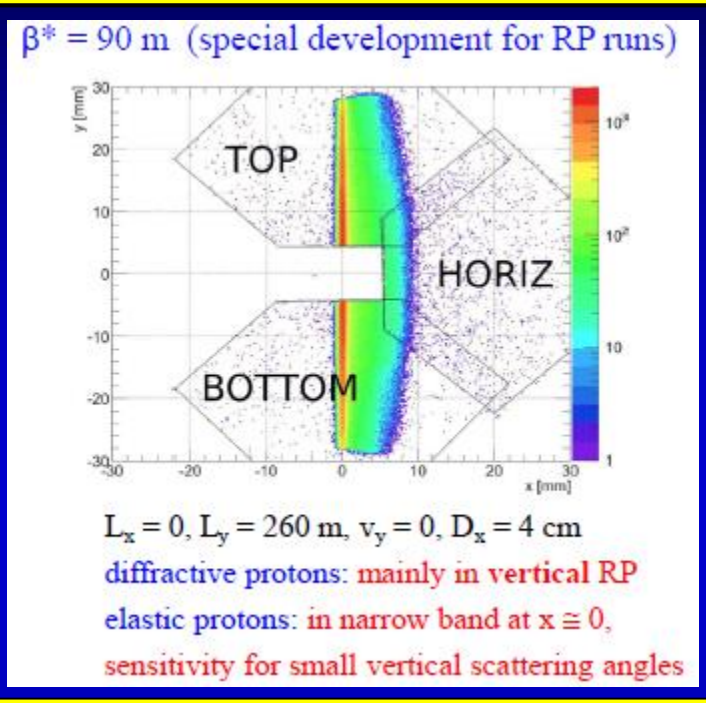
VdM scans and LHCf runs (2)

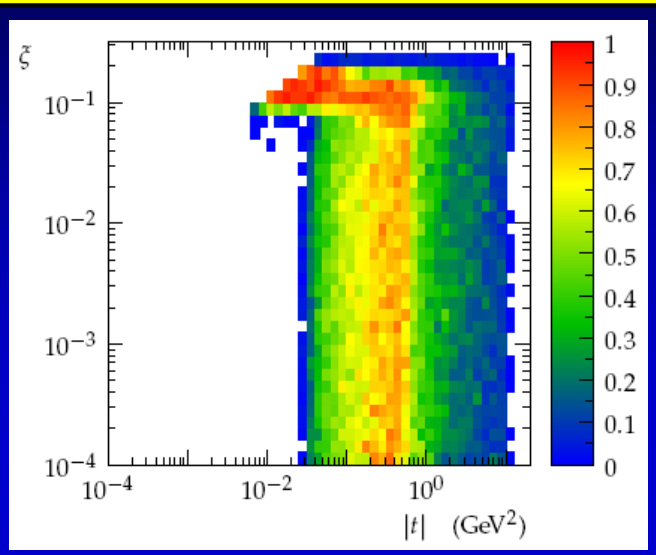


Diagonal double arm selection: 45 bottom, 56 top
Selection cuts for elastic events based on
correlations of scattering angles in the two arms

LHC optics and proton acceptance

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



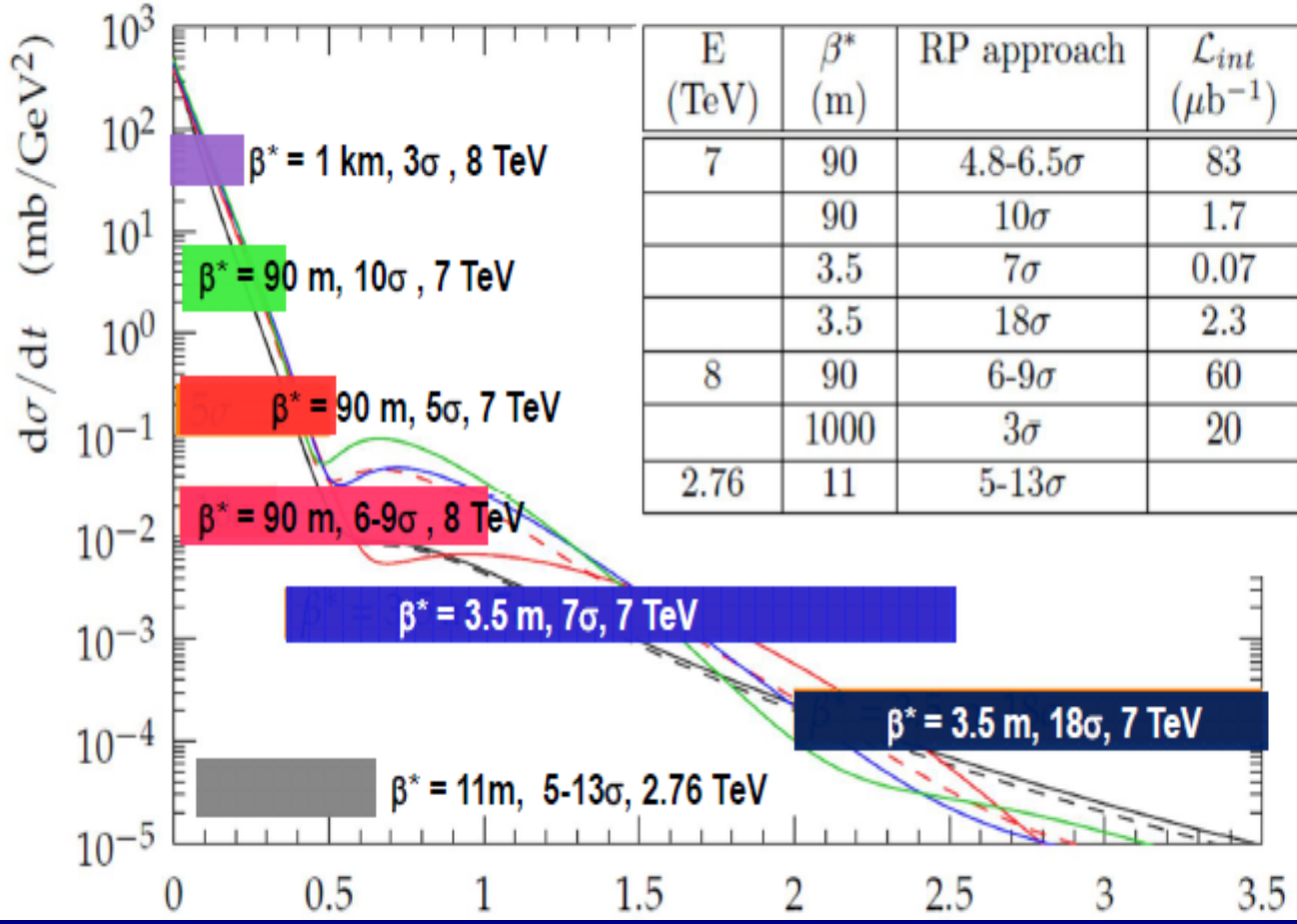


β* = 90 m MC simulation shown
Parallel to point focussing, $v_y \sim 0$
Large effective lenght L_y
Elastic scattering events: in vertical RPs

β* = 90 m
Diffraction:
all ξ if $|t| \geq 10^{-2}$ GeV², soft & semi-hard diffr.
Elastic: low to mid |t|
Total cross-section

RP unit	L_x	v_x	L_y	v_y
near	2.45 m	−2.17	239 m	0.040
far	−0.37 m	−1.87	264 m	0.021

LHC Run-1 TOTEM data taking



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	

TOTEM Run-1 published results from data sets indicated by arrows

CMS+TOTEM data processing: $\beta^* = 90$ m

Status of data processing, as of December 2015

CMS data (full statistics) : reconstruction ready
"miniDST" (special for common data)
completed for Stream "RP Double Arm & T2 Veto"
In progress for all other streams

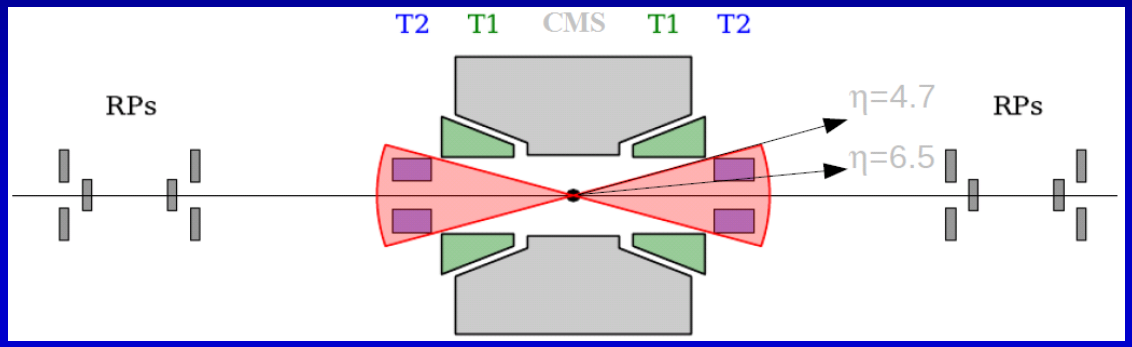
TOTEM data (full statistics) : reconstruction ready
RP Alignment completed
"miniDST" ready

First iteration of data synchronization and merging : in progress

Stay tuned for Zimányi 2016

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

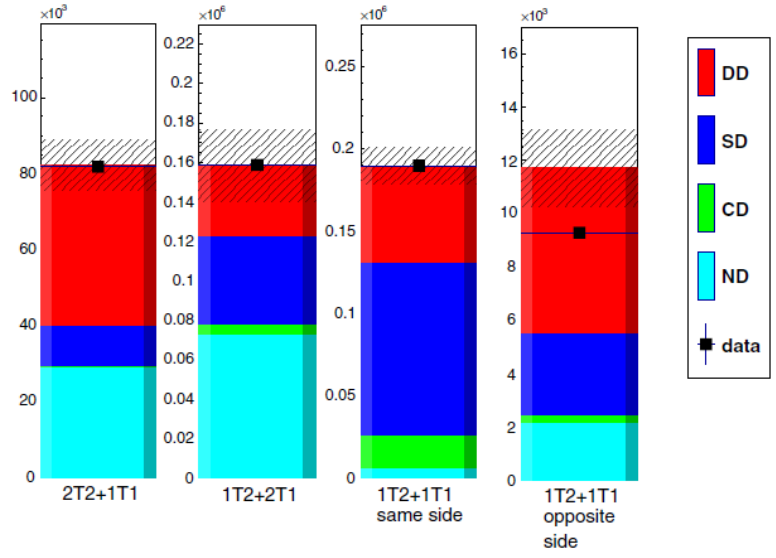


FIG. 1 (color online). Validation of background estimates for the full selection I_{track}. Each plot shows the corrected number of events in data (black squares) and the combined estimate with background uncertainties. The combined estimate is the sum of all components, from bottom to top: the ND estimate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

$E = 0.9 \pm 0.1$

$L = 40.1 \pm 1.6\ \mu b^{-1}$

TOTEM result:
$\sigma_{DD} = 116 \pm 25\ \mu b$
$4.7 < |\eta|_{min} < 6.5$
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:
$5.9 < |\eta^{\pm}|_{min} < 6.5$

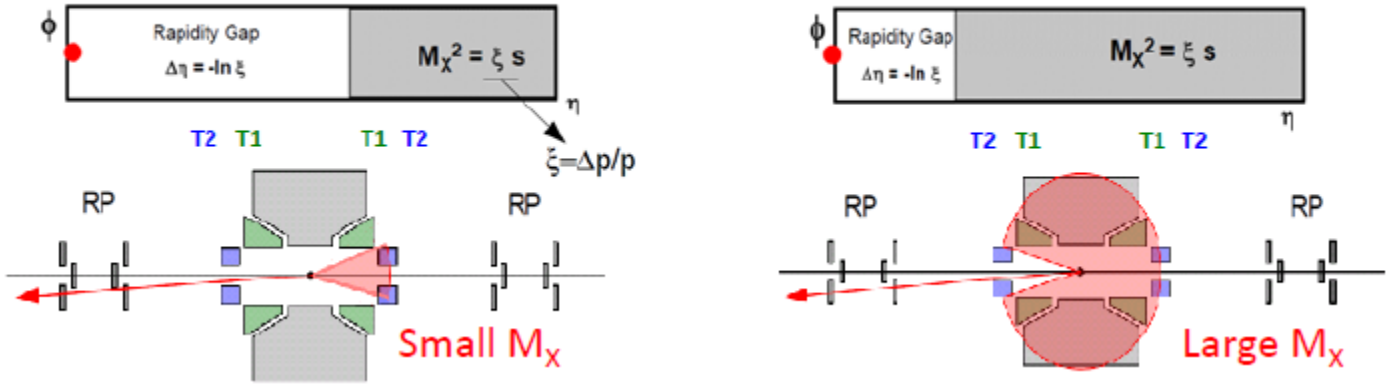
SD & DD results combined seems to indicate factorisation breaking:

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

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

TOTEM for single diffraction

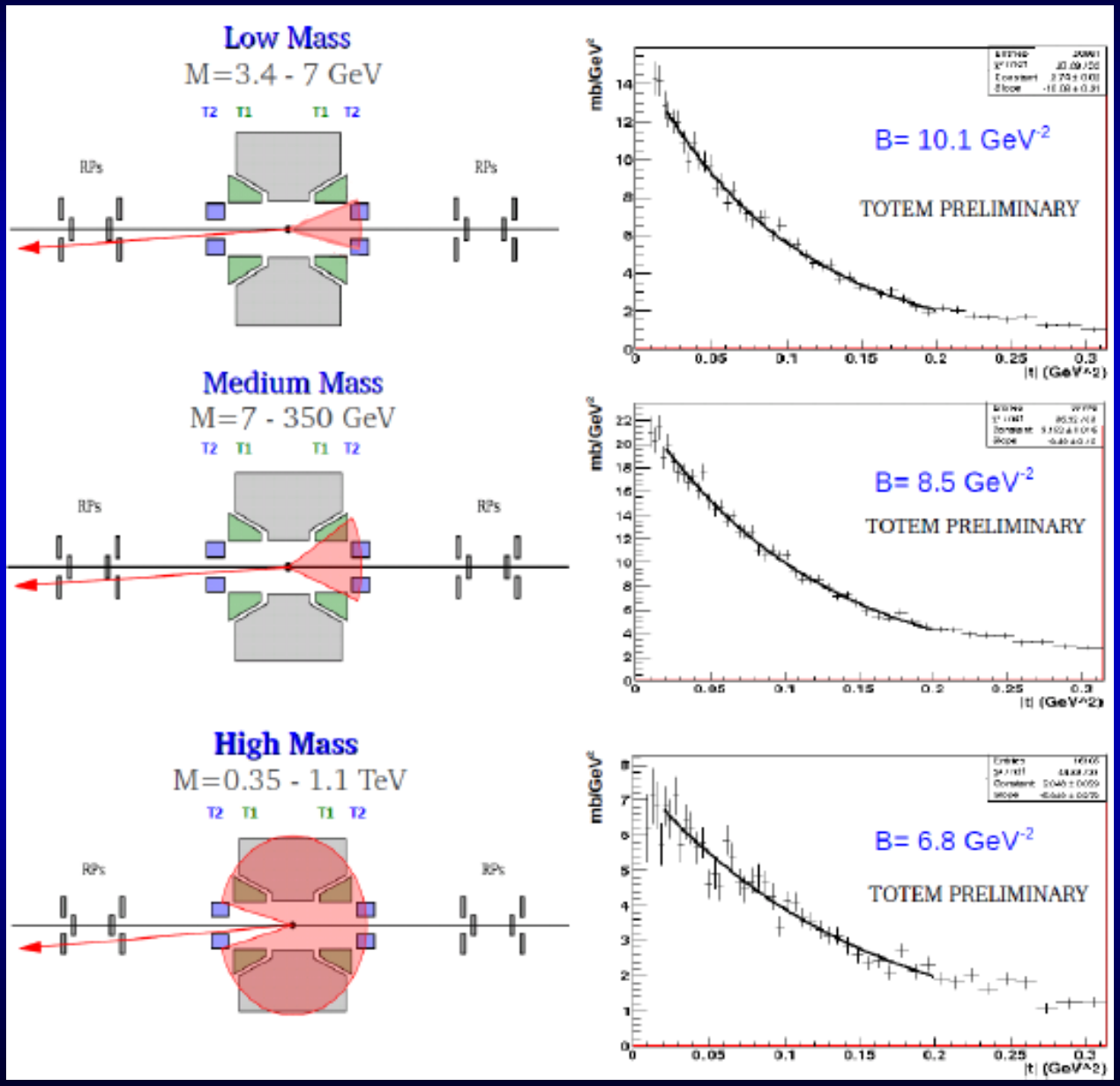
Rapidity gap ($\Delta\eta = -\ln\xi$) determines diffractive mass ($M_X^2 = \xi s$)



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	8 – 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

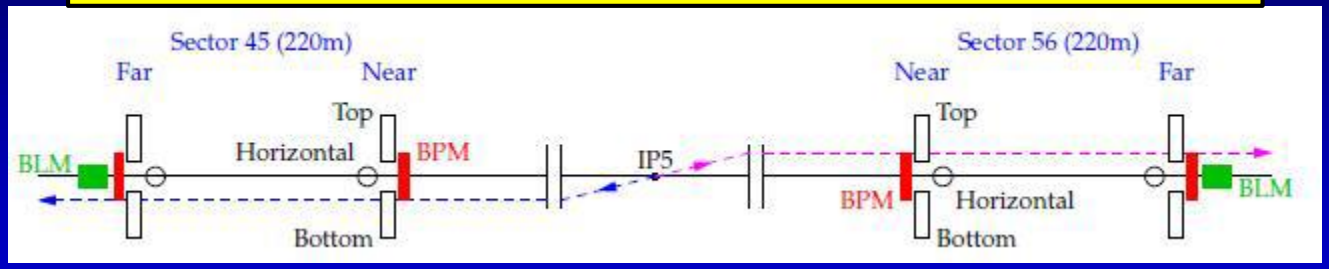
Missing corrections:
- Class migration
- ξ resolution & beam divergence effects

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

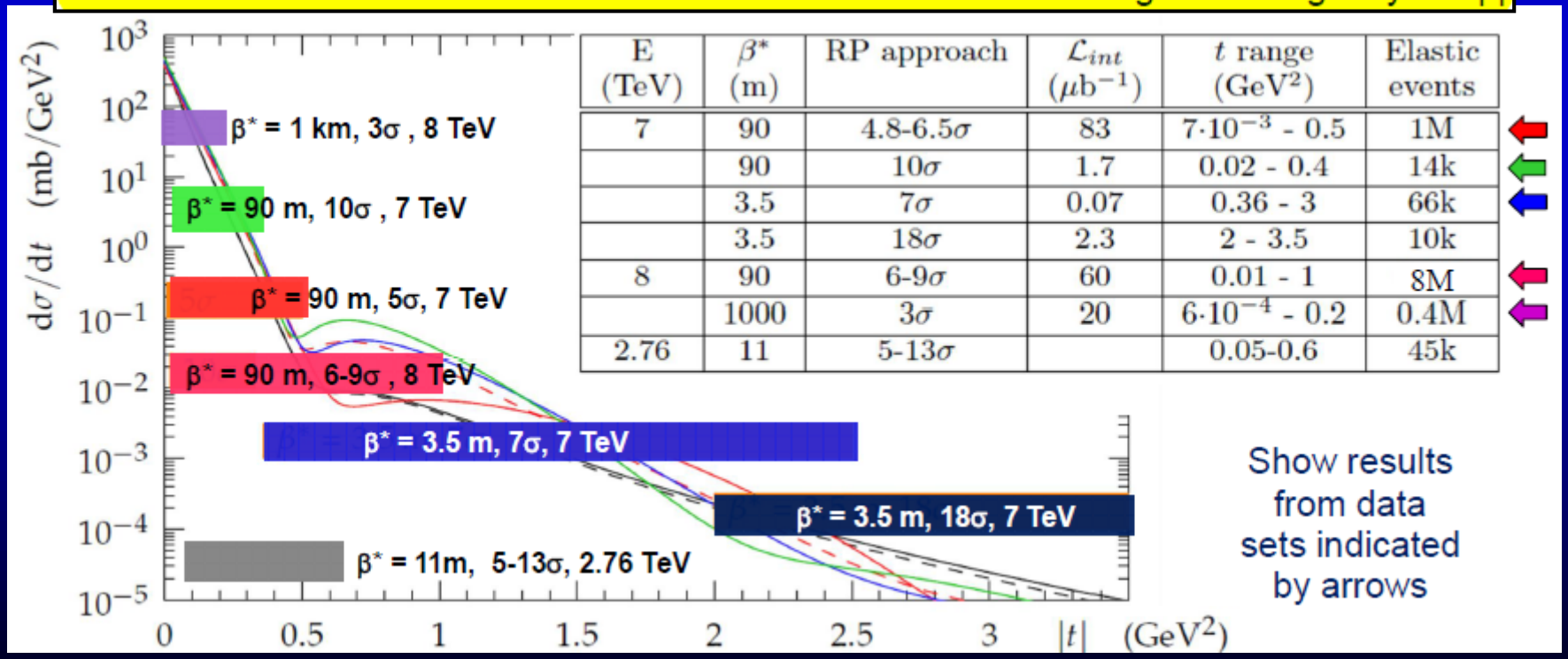
TOTEM preliminary:
σ_{SD} = 6.5 $\pm$ 1.3 mb
3.4 GeV < M_{diff} < 1.1 TeV

Event selection, data sets

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



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



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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 σ_{tot}

elastic only
(T1,T2 independent)

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

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

ρ independent

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

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

L independent

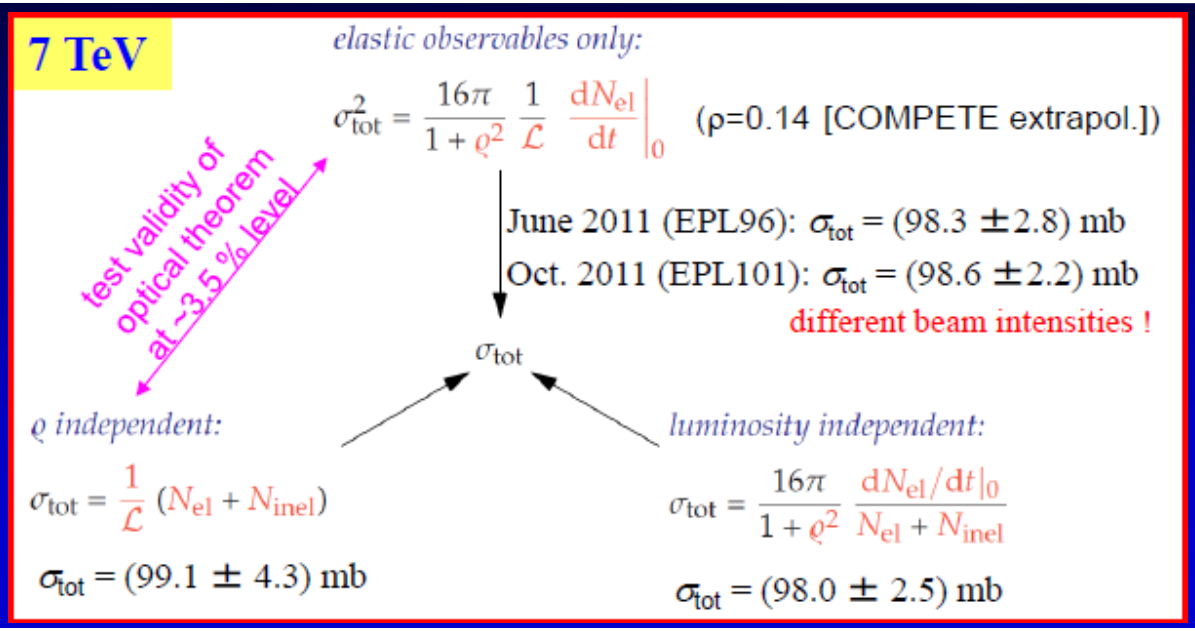
$$\sigma_{tot} = \frac{16\pi}{(1+\rho^2)} \frac{(dN_{el}/dt)_{t=0}}{(N_{el} + N_{inel})}$$

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 ($\sigma_{beam} \sim 0.7$ 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.

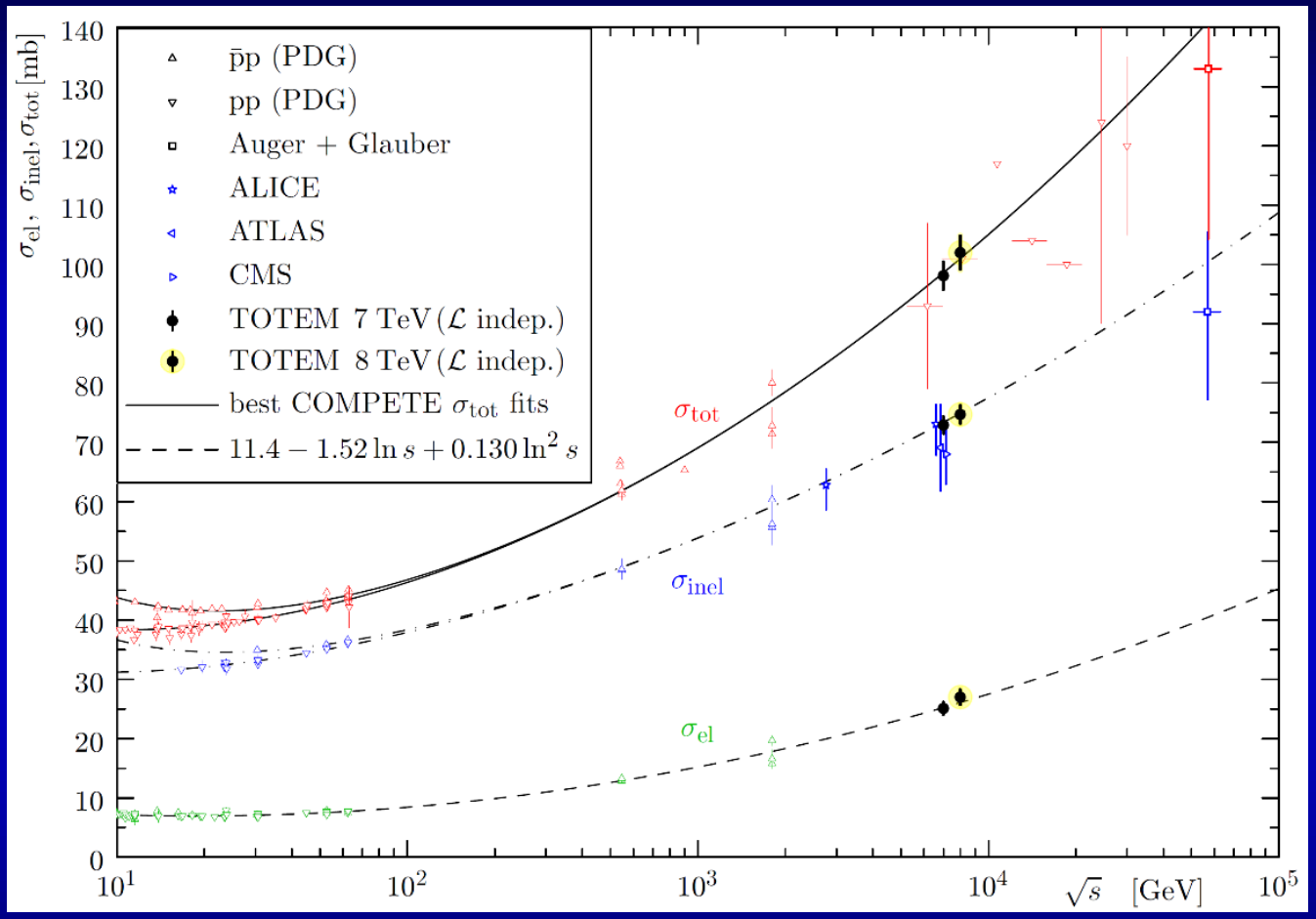
Data set	RP position	$\|t\|_{min}$ (GeV^2)	Elastic events	Inelastic events
1	$6.0\sigma_{beam}$	0.01	416×10^3	2.30×10^6
2	$9.5\sigma_{beam}$	0.02	238×10^3	1.72×10^6

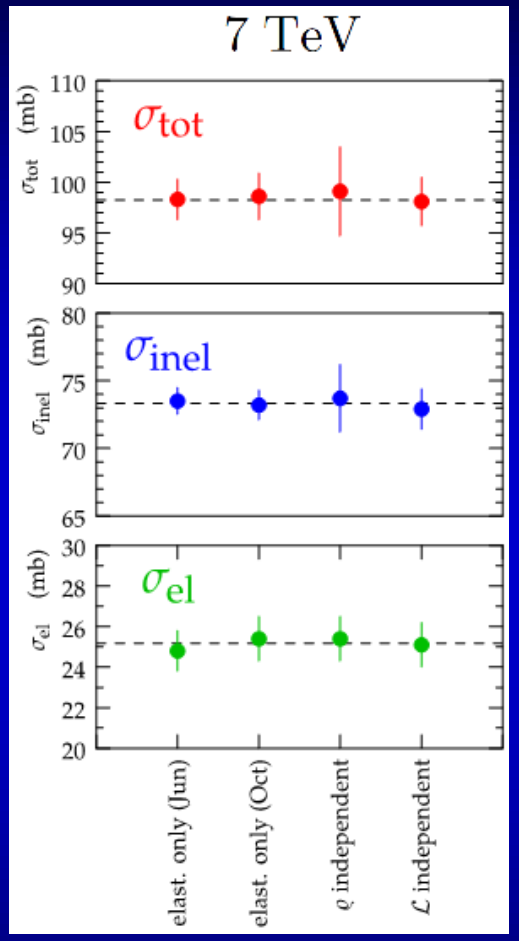
Needs precise control of LHC imperfections and recalibration from data at IP5:
β*=90m,
optics error reduction by 2-10,
arXiv:1406.0546

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

Source	Effect on	$\|t\| = 0.01$ 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		$dN_{el}/dt\|_{t=0}$	$\pm 2.5\%$	
		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.