Soft diffraction and forward multiplicity measurements with TOTEM

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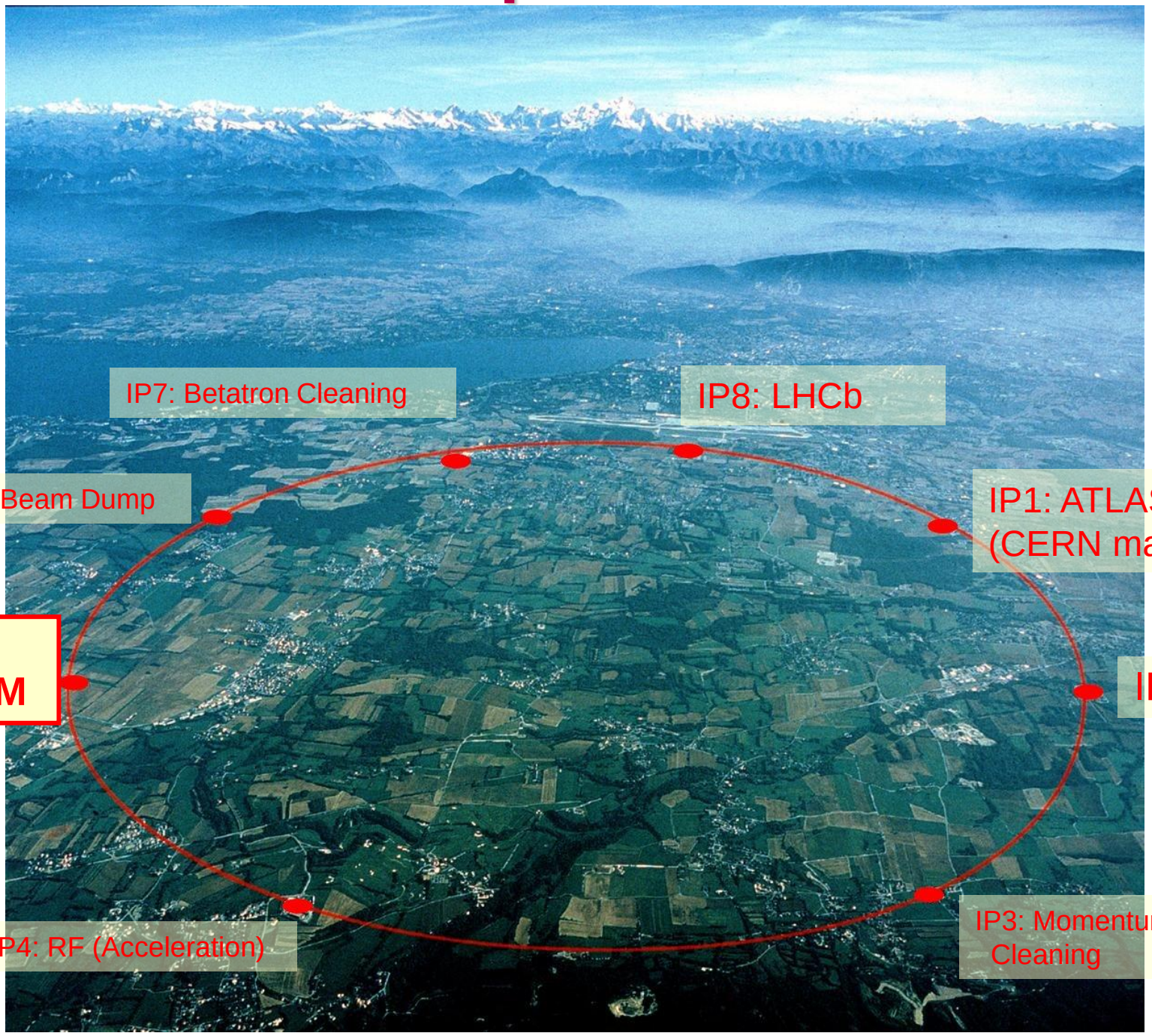
Sep 10th, Saariselkä

- **Introduction**
- **Forward multiplicity in pp**
- **Soft diffraction in pp (Single, double, central – standalone & with CMS)**

The TOTEM experiment at the LHC



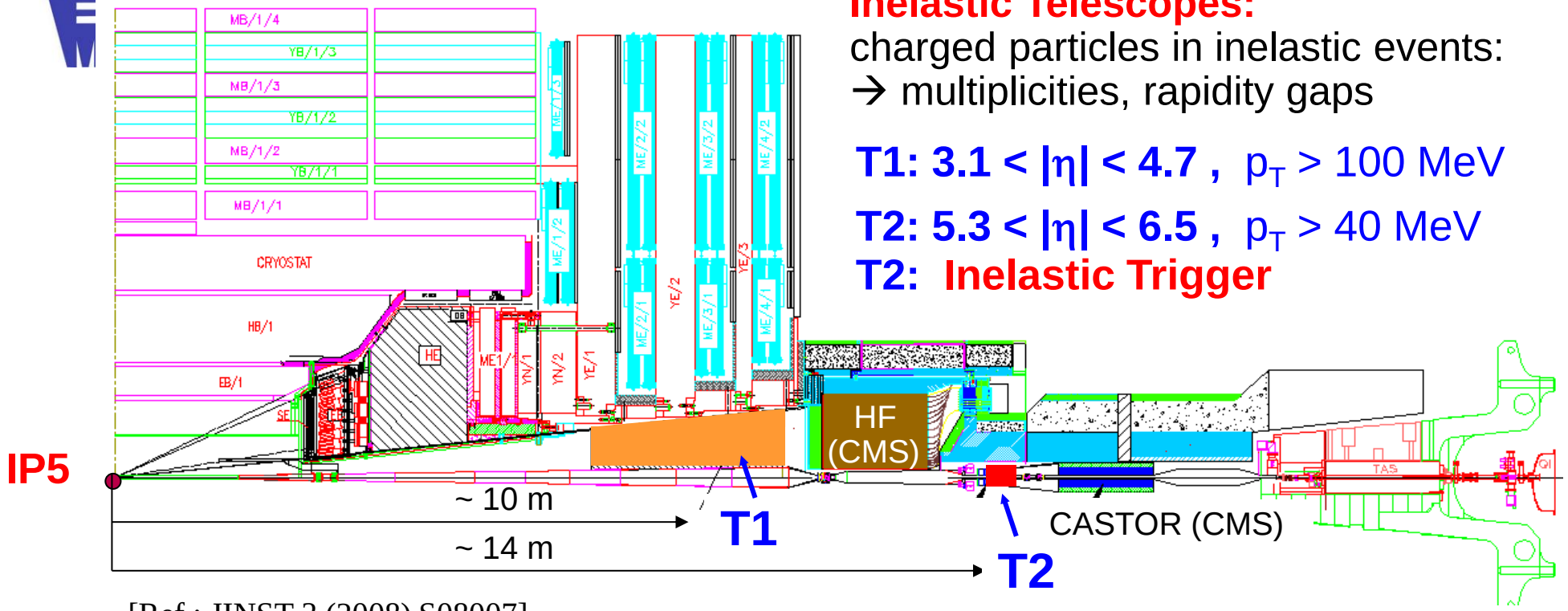
Experimental setup at IP5

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

T1: 3.1 < |η| < 4.7 , p_T > 100 MeV

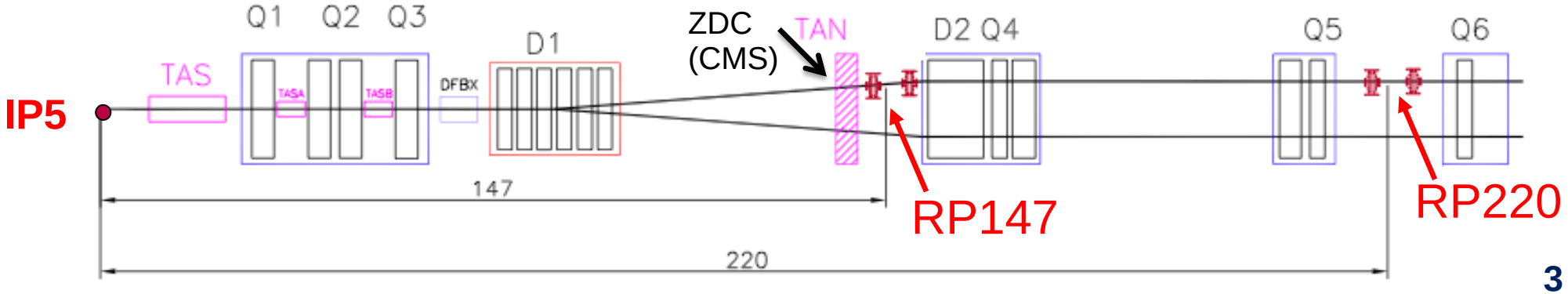
T2: 5.3 < |η| < 6.5 , p_T > 40 MeV

T2: Inelastic Trigger



[Ref.: JINST 3 (2008) S08007]

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

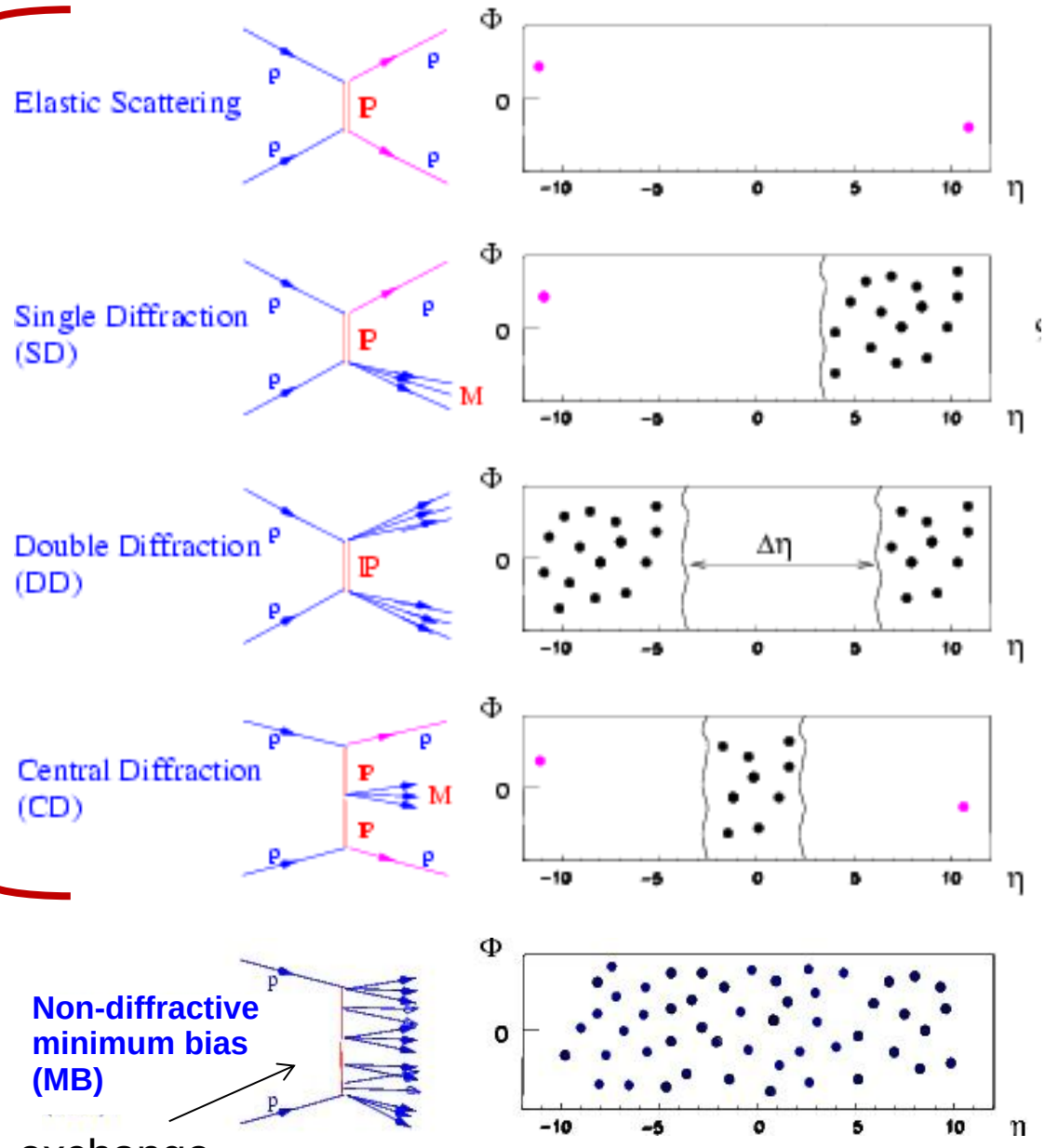


Soft pp processes

σ @ LHC

Diffraction a large fraction of total pp cross-section !!

Colourless multi-gluon ("Pomeron") exchange reactions:



~25 mb

~10 mb

~5 mb

~1 mb

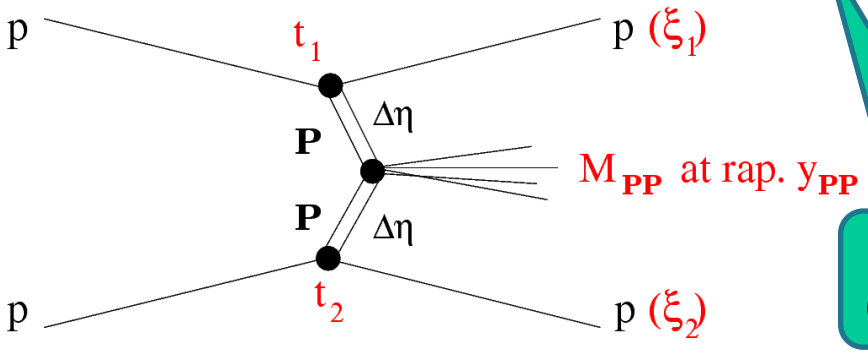
~60 mb

Measure σ (M,ξ,t)

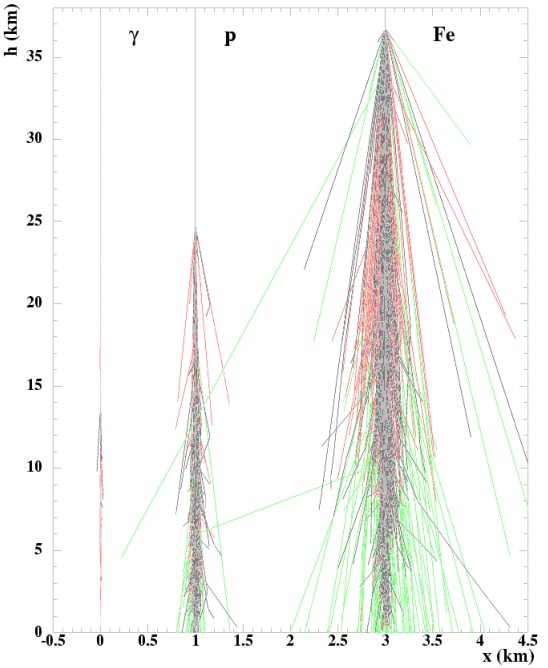
TOTEM diffractive physics menu

Forward particle production

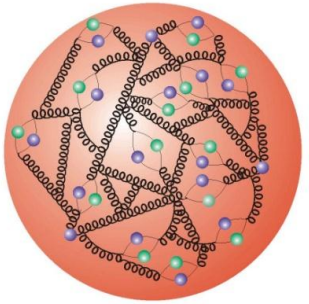
Diffraction: soft and hard



Cosmic ray connection



Understand QCD nature

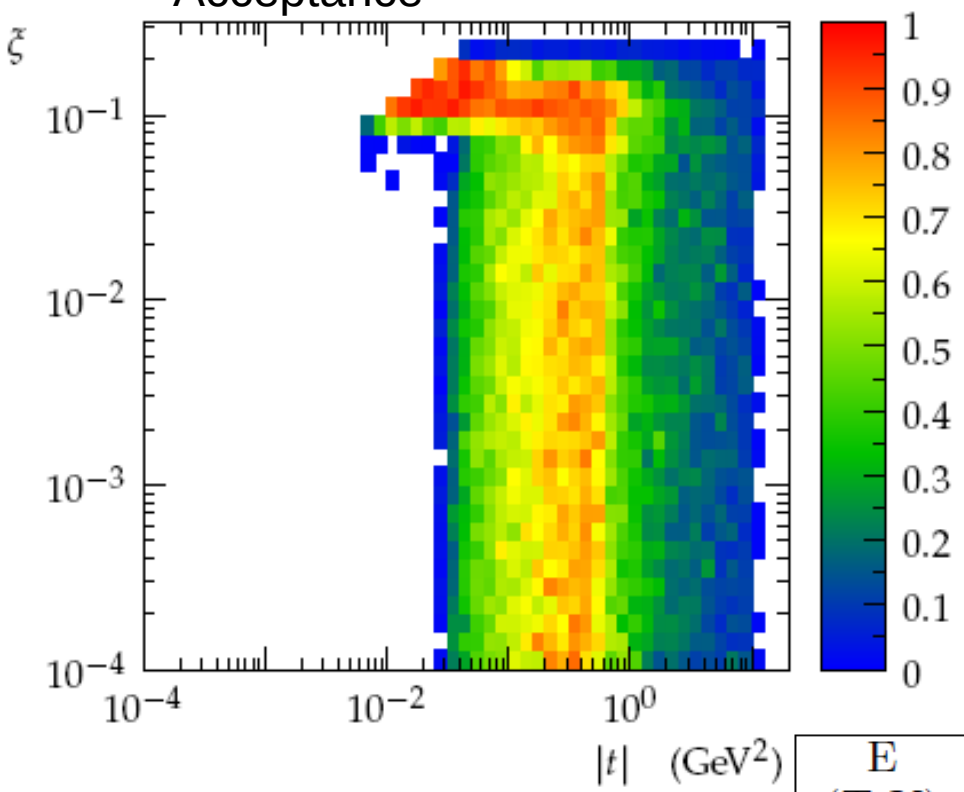


Proton

Acceptance for diffractive protons & special TOTEM runs analyzed

t ≈ –p² Θ*²: four-momentum transfer squared; $\xi = \Delta p/p$: fractional momentum loss

Acceptance



Diffraction: all ξ if |t| > ~10^{-2} GeV²

$$\mathcal{L} \propto \frac{1}{\beta^*}$$

β* = 90 m
Low beam divergence (parallel to point focusing in x-coordinate at RP220)

Runs analyzed for this presentation:
- 90m β*
- 7 & 8TeV
- TOTEM standalone & together with CMS

TOTEM special runs:

E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV²)	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	0.6M
	1000	3σ	20	$6 \cdot 10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		0.05-0.6	45k

Charged particle pseudorapidity density dN/dη

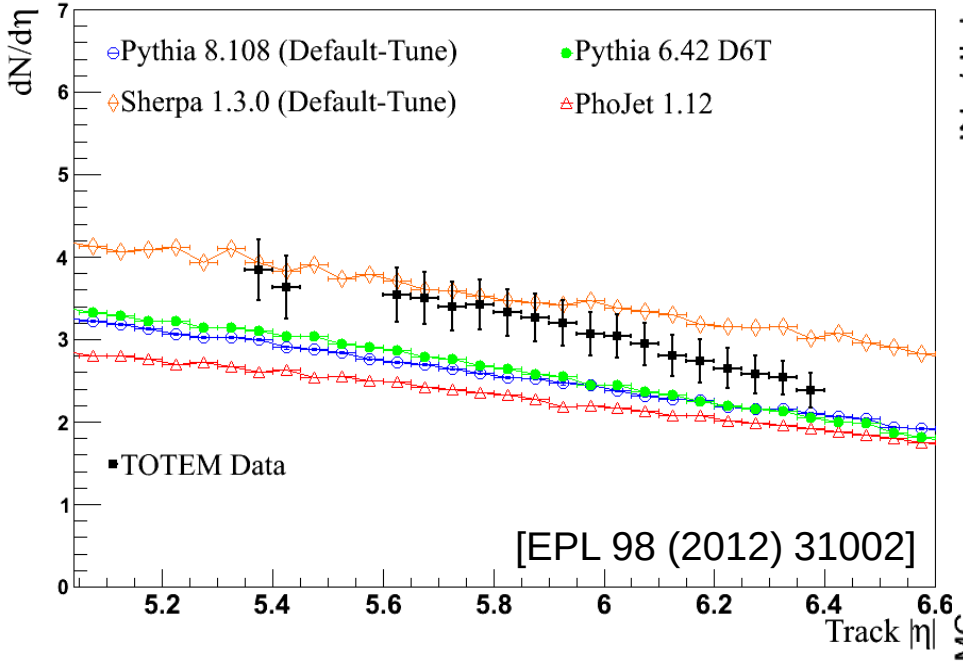
$dN_{ch}/d\eta$: mean number of charged particles per event and per unit of pseudorapidity: primary particles only, i.e. lifetime > 30 ps (convention among LHC experiments)

→ probes hadronisation → constrains phenomenological models used in MC event generators

→ input for cosmic ray simulations

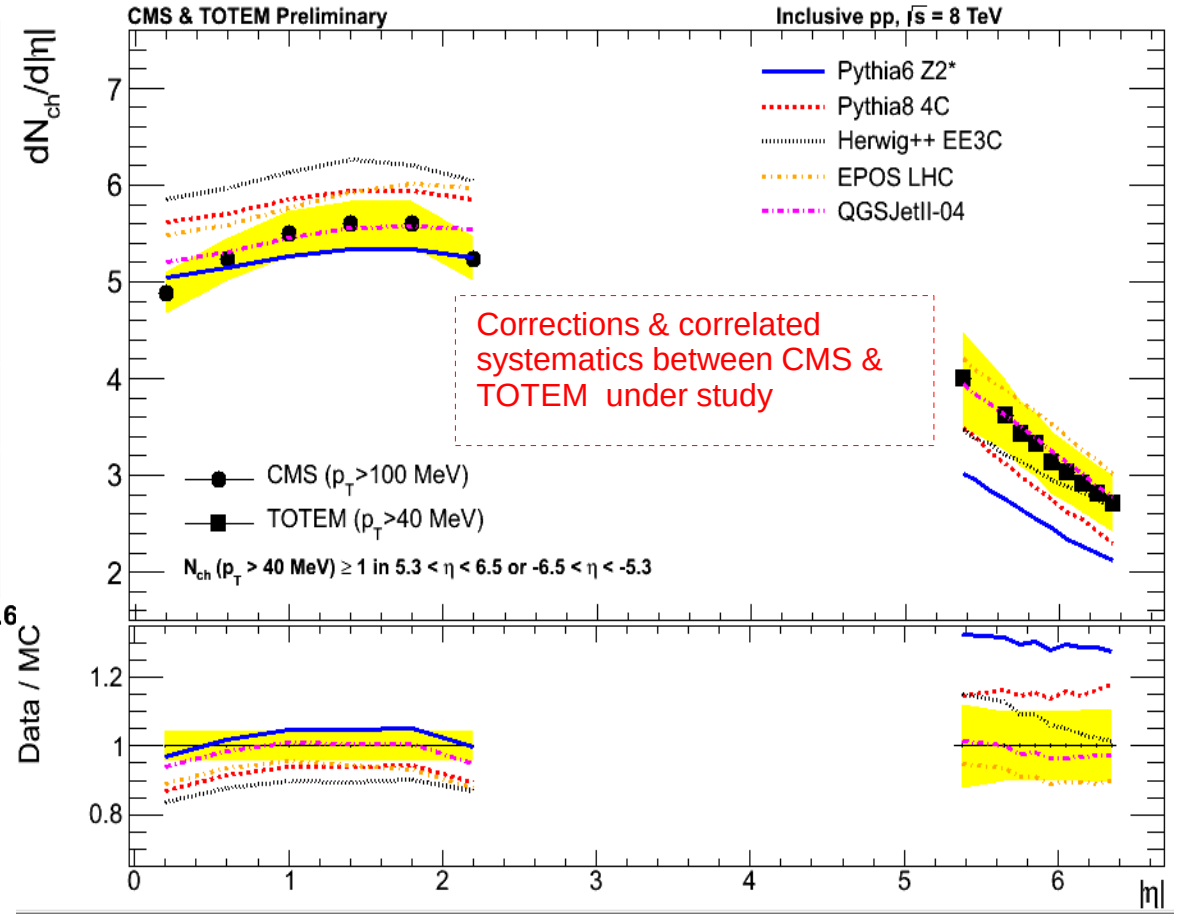
7 TeV

TOTEM standalone (T2)



8 TeV

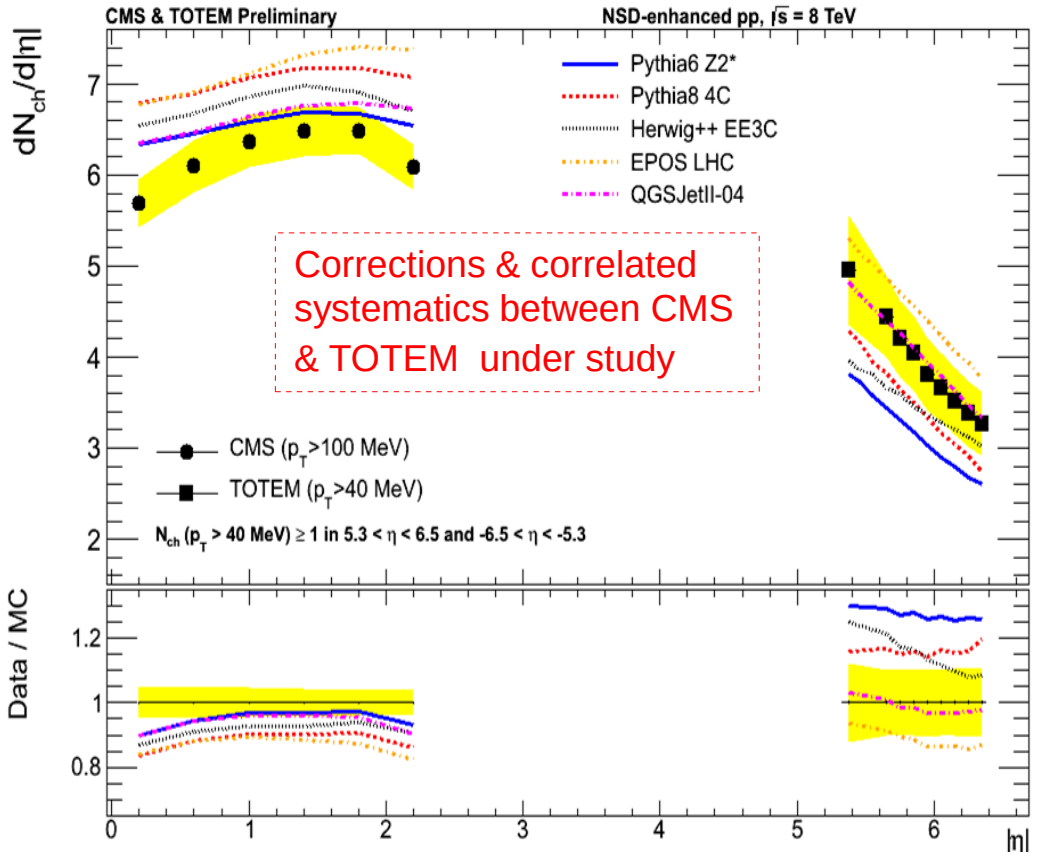
CMS + TOTEM (T2),
covering >90% of inelastic events



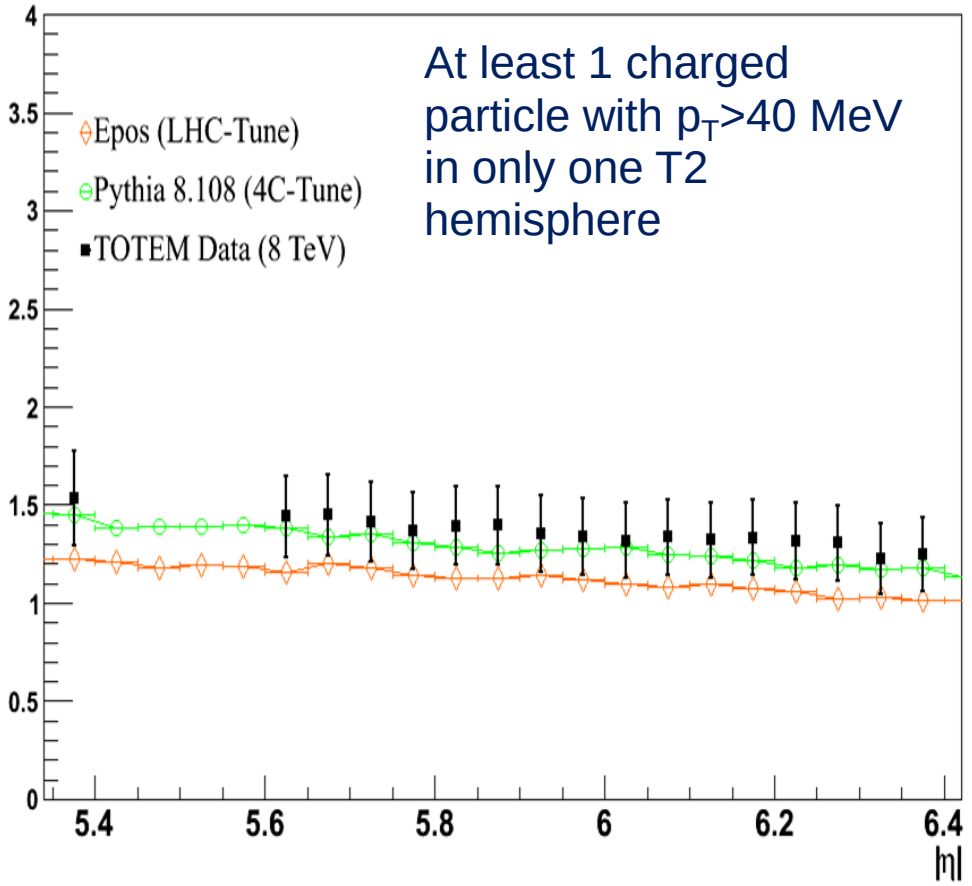
Very forward $dN_{ch}/d\eta$ at 8 TeV: different event classes

"Non-Single diffractive enhanced": primary tracks in both T2 hemispheres
"Single diffractive enhanced": primary tracks in only one T2 hemispheres

NSD-enhanced

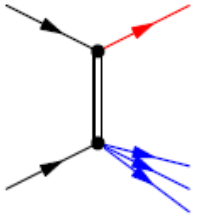


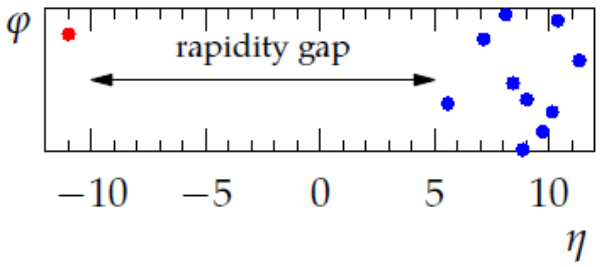
SD-enhanced

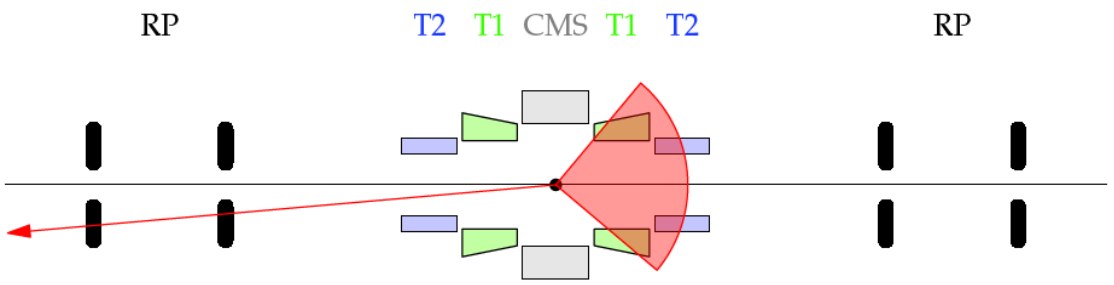


Updated analysis with a common $p_T = 0$ thresholds ongoing in both CMS & TOTEM !

Soft Single Diffraction (SD) at 7 TeV







- 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):

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

2. via the rapidity gap (T1, T2)

Note: $\eta_{max,T2} = 6.5 \Leftrightarrow M_{min} = 3.4$ GeV

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

δξ ~ ξ

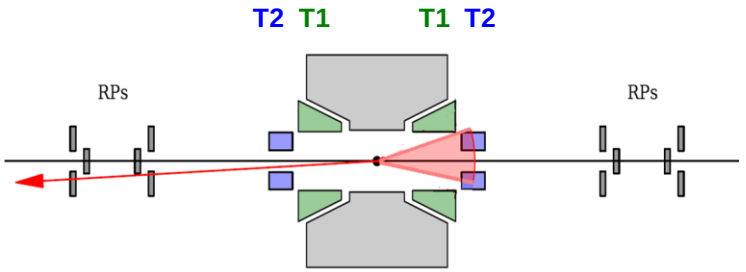
SD events classified into 4 classes, based on rapidity gap:

SD class	Inelastic telescopes configuration	Mass	ξ
Low Mass	p + T2 opposite only (no T1)	3.4 - 8 GeV	$2\cdot10^{-7} < \xi < 10^{-6}$
Medium Mass	p + T2 opposite + T1 opposite	8 - 350 GeV	$10^{-6} < \xi < 0.25\%$
High Mass	p + T2 opposite + T1 same	0.35 - 1.1 TeV	$0.25\% < \xi < 2.5\%$
Very High Mass	p + both T2 arms	> 1.1 TeV	> 2.5%

Soft Single Diffraction at 7 TeV

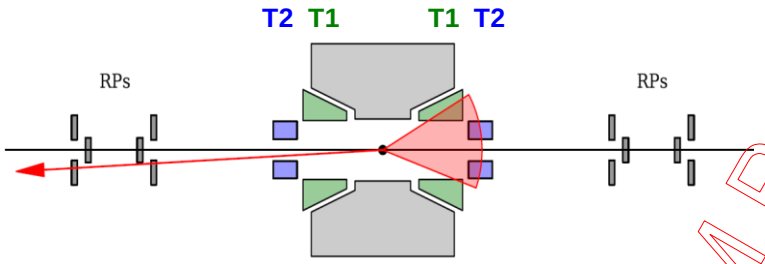
Low mass

M_{diff} = 3.4 - 8 GeV



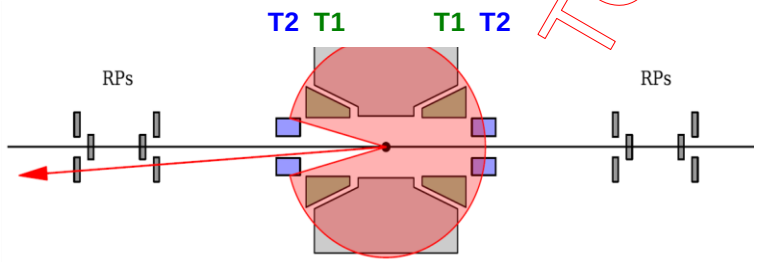
Medium mass

M_{diff} = 8 - 350 GeV

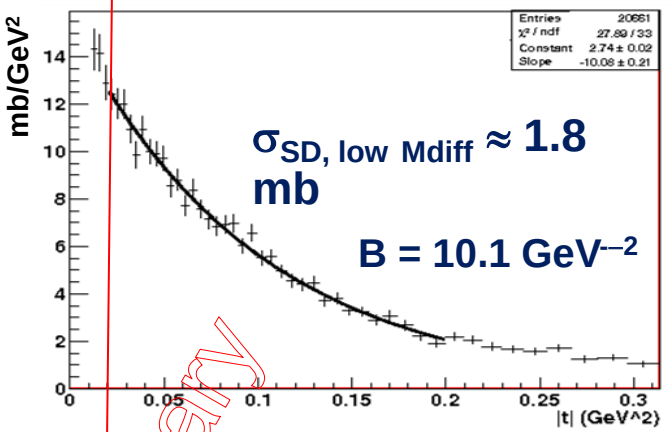


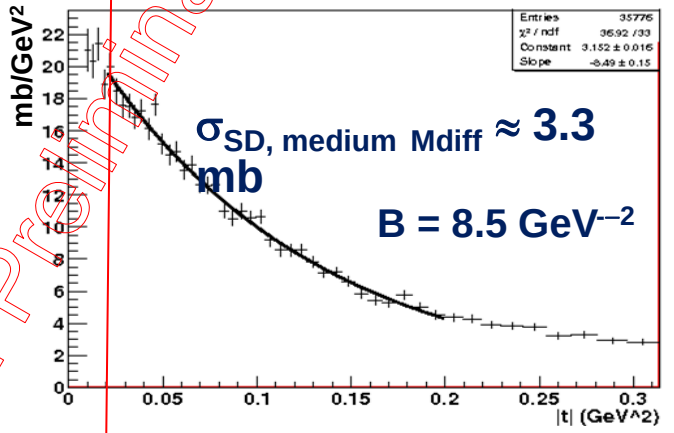
High mass

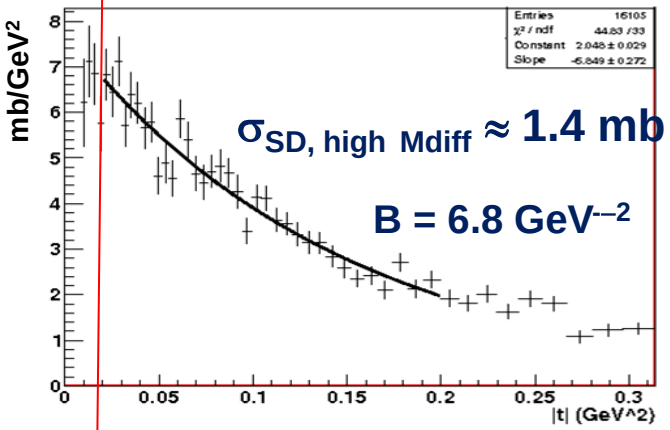
M_{diff} = 0.35 - 1.1 TeV



$d\sigma/dt \sim A \cdot e^{-Bt}$







Corrections included:
- Trigger efficiency
- Proton acceptance & reconstruction efficiency
- Background subtraction
- Extrapolate fitted exponential from red line to t = 0

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

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

σ_{SD} = 6.5 ± 1.3 mb
(3.4 < M_{diff} < 1100 GeV)

Analysis of very high mass events ongoing

8 TeV SD analysis started

Soft Single Diffraction at 7 TeV

Very preliminary TOTEM result: $\sigma_{SD} = 6.5 \pm 1.3$ mb ($3.4 < M_{diff} < 1100$ GeV, p in any arm)

Does not include Very High Mass (1p+2*T2) > 1100 GeV, nor very low mass (1p+0*T2)

Estimate of very low mass SD ($M < 3.4$ GeV) from $\sigma_{tot} - \sigma_{el} - \sigma_{inel,visible}$:

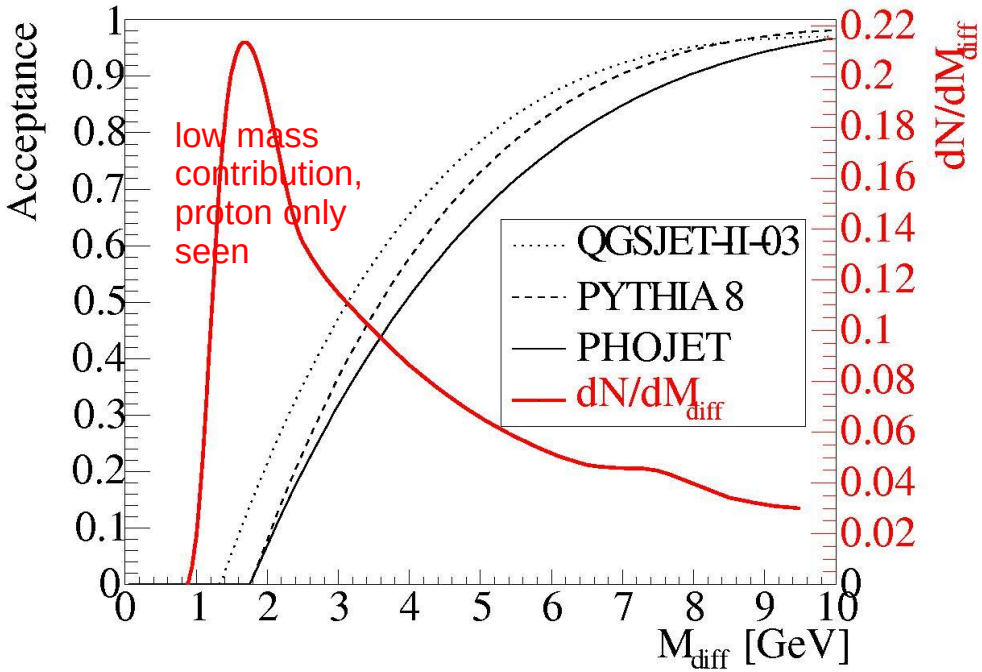
Very low mass diffraction:

$\sigma_{inelastic,\ |\eta| > 6.5} =$

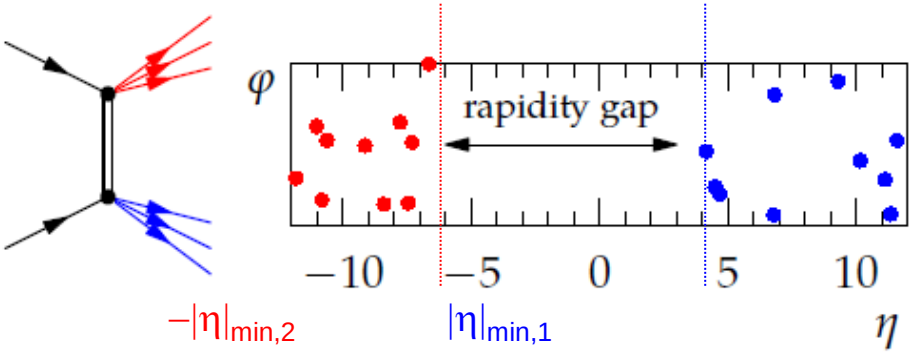
$\sigma_{total} - \sigma_{elastic} - \sigma_{inelastic,\ |\eta| < 6.5}$

$= 2.62 \pm 2.17$ mb

$\sigma_{inelastic,\ |\eta| > 6.5} \leq 6.3$ mb @ 95 % CL

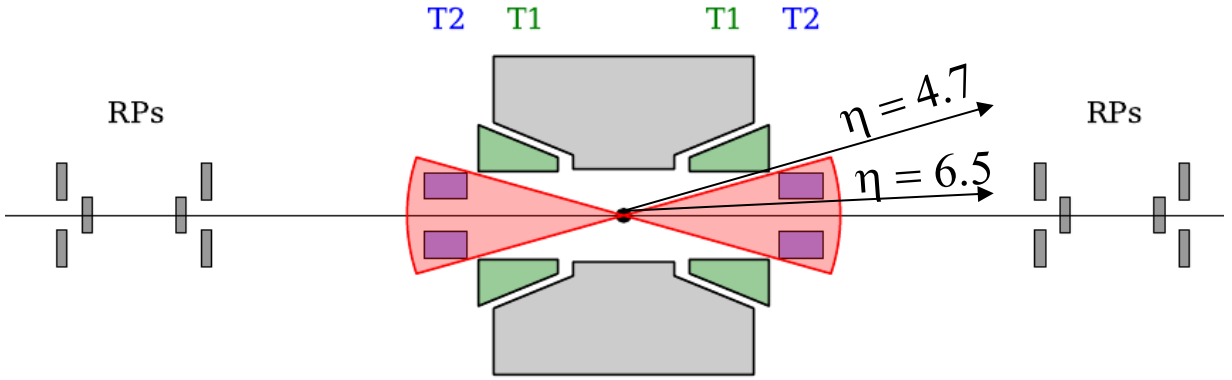


Soft Double Diffraction at 7 TeV



- 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 $\frac{d^2\sigma}{d|\eta|_{min,1}\,d|\eta|_{min,2}}$



Challenge:

- Large DD masses → small central gap

First step: sub-range with particles **triggering both T2** hemispheres, **veto on T1** **(2T2,0T1)**:

Backgrounds estimated using 1T2,0T1 (SD, from data) & 2T2,2T1 (nondiffractive, MC scaled with data)

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

Double Diffraction: results at 7 TeV

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

	$-4.7>\eta_{min,2}\geq-5.9$	$-5.9>\eta_{min,2}\geq-6.5$
$4.7<\eta_{min,1}\leq5.9$	65±20 μb	26±5 μb
$5.9<\eta_{min,1}\leq6.5$	27±5 μb	12±5 μb

Sum:

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

[CERN-PH-EP-2013-170] (arXiv:1308.6722)
NEW!

So far, only a small part of DD measured: 116 μb out of ~5 mb, but:
Selection 2T2,0T1 gives high (>70%) DD purity & benchmark for Monte Carlos:

Pythia 8:

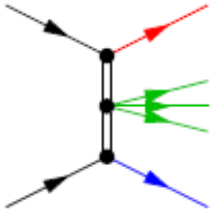
$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 159 \text{ μb}$$

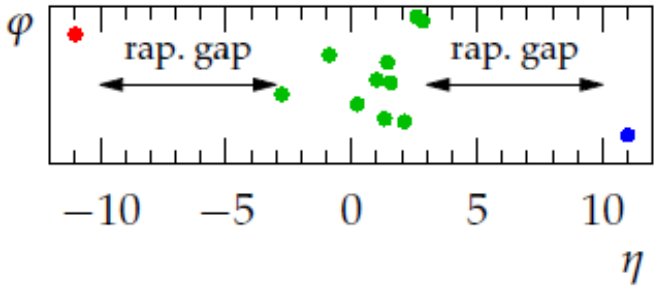
Phojet:

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

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

Central Diffraction at 7 TeV ("Double Pomeron Exchange")



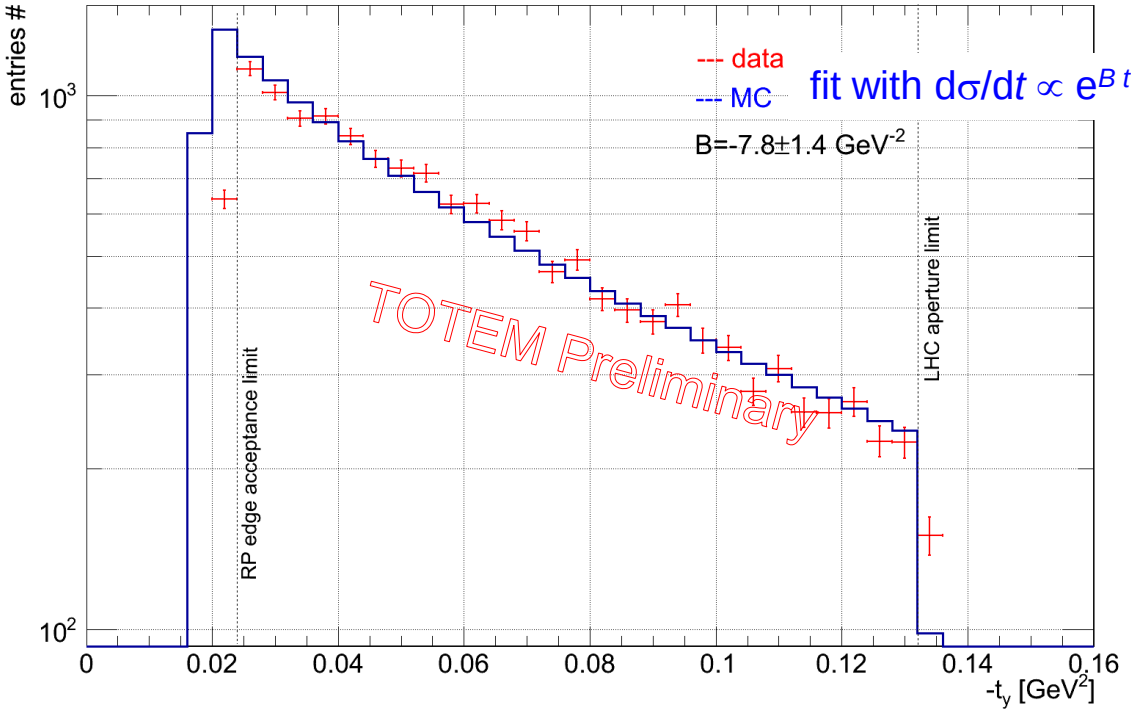


- both protons survive with momentum losses ξ_1, ξ_2
- diffractive mass M in the centre
- 2 rapidity gaps $\Delta\eta_1$, $\Delta\eta_2$

Soft DPE: study differential cross-section with correlations:
(in progress: $d\sigma/dM$, $d\sigma\ dt_1$)

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

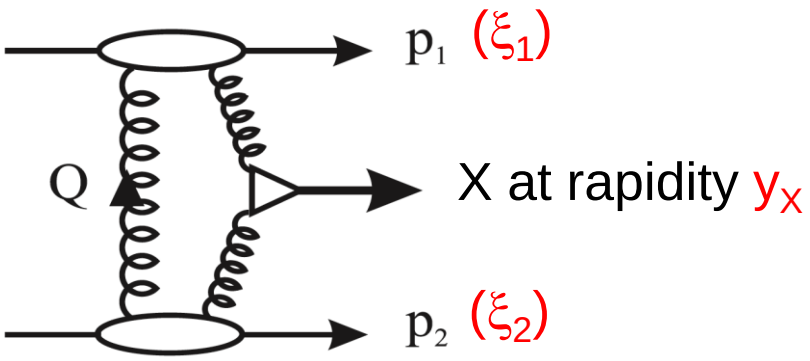
Single arm CD event rate (integrated ξ, acceptance corrected)



Estimate of the integral (including extrapolation to t=0):
$\sigma_{CD} \sim 1$ mb

Central production of particles and di-jets

Exclusive Particle Production:

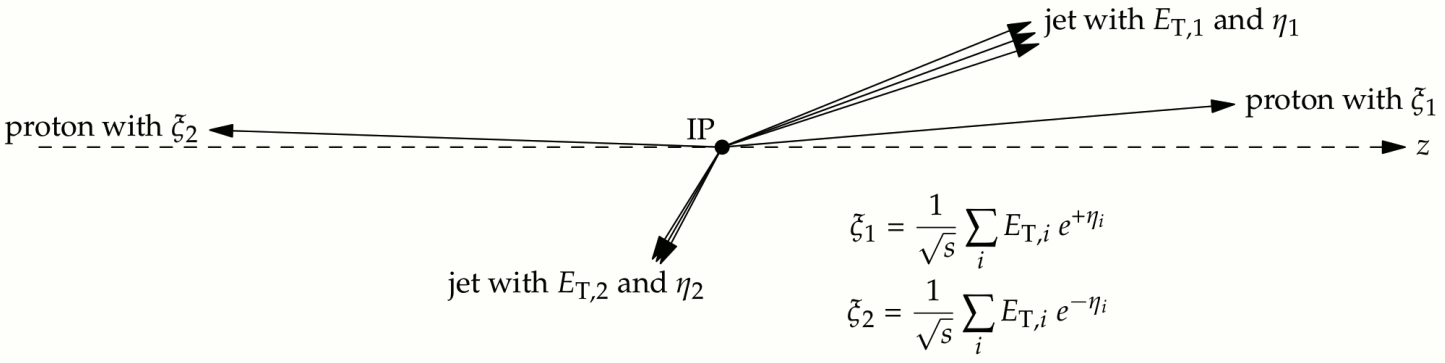


$M_X^2 = \xi_1 \xi_2 s$

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

exchange of colour singlets with vacuum quantum numbers
$\Rightarrow$ Selection rules for system X: $J^{PC} = 0^{++}$ (mainly) ➔ X = χ_{c0}, χ_{b0}, H, glueballs?

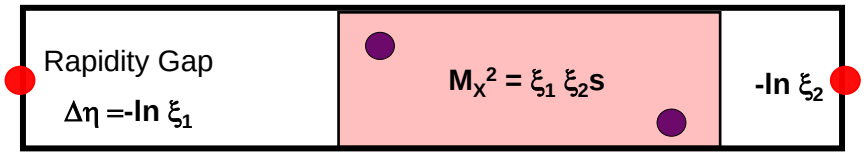
(Exclusive) Dijet Production:

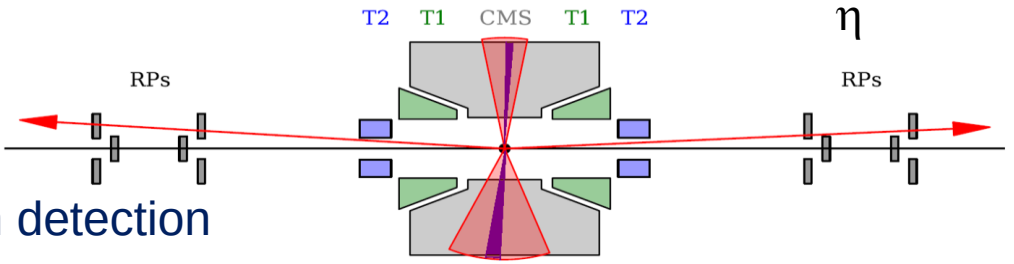


Joint analysis of special run at 8 TeV, $\beta^* = 90$ m together with CMS in progress

Central Diffraction: TOTEM + CMS

CD (aka DPE):





Large η-coverage:

- CMS: -5.5<η<5.5
- T1: 3.1 < |η| < 4.7
- T2: 5.3 < |η| < 6.5
- FSC: 6 < |η| < 8

Double-arm proton detection

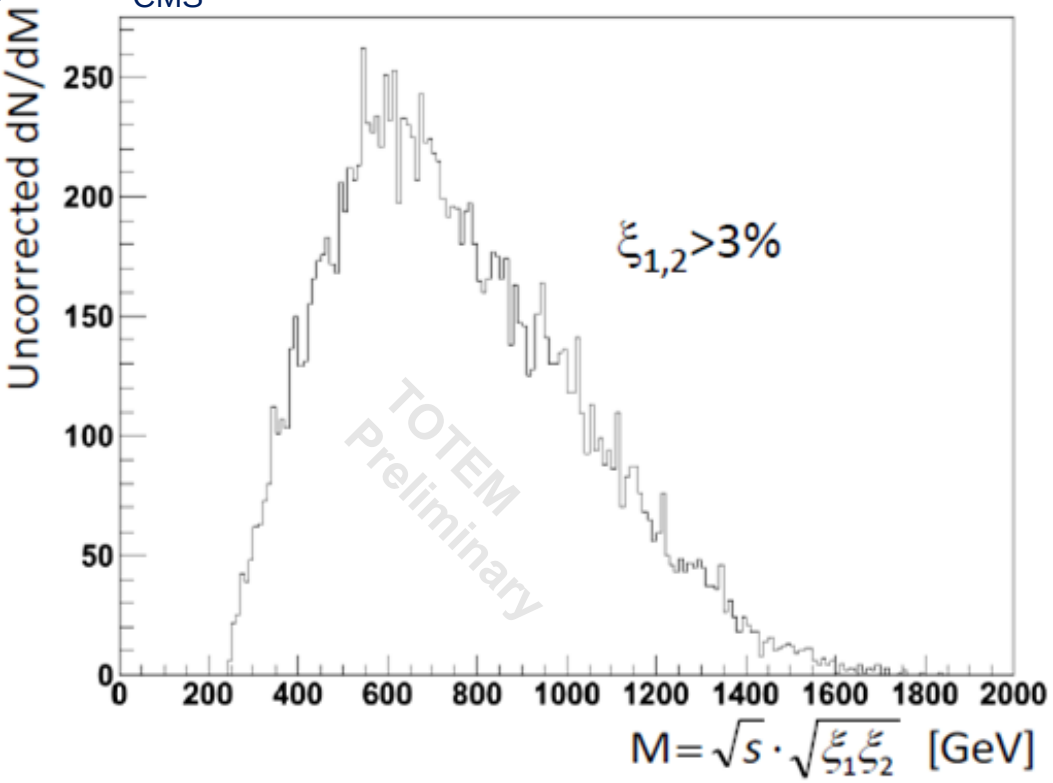
Prediction of mass to be seen in CMS from reconstructed protons: $M^2 = s\,\xi_1\xi_2$

Initial vs. final state comparison: M_{TOTEM} (pp) =? M_{CMS}

Prediction of central particle flow topology from proton ξ's (rapidity gaps):
$\Delta\eta_{1,2} = -\ln\xi_{1,2}$

Masses up to 1.8 TeV with pp survival!

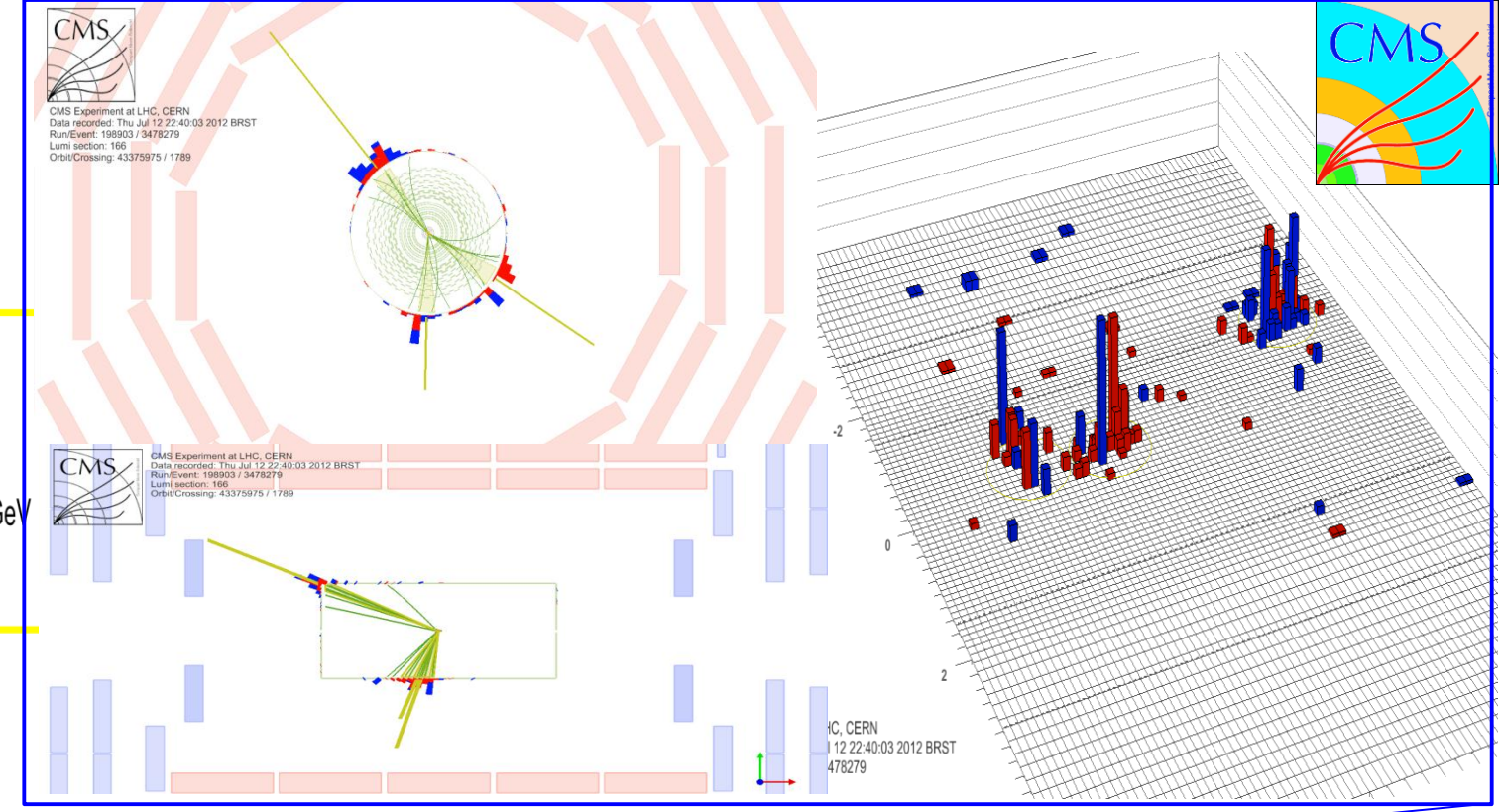
Analysis ongoing.
Good statistics for soft central diffraction & single diffractive dijets; limited for hard central diffraction

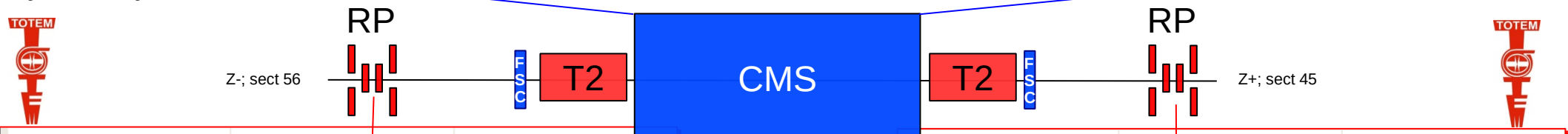


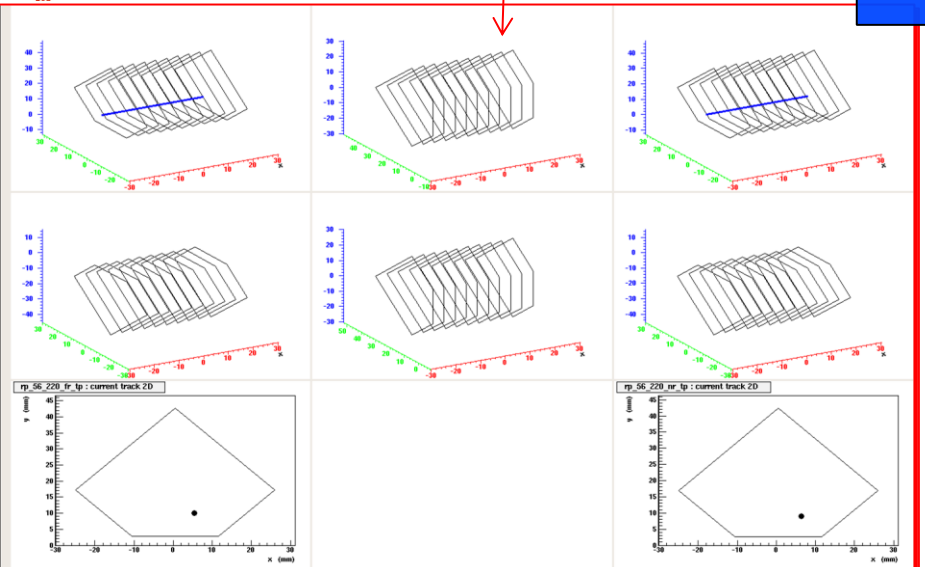
CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV

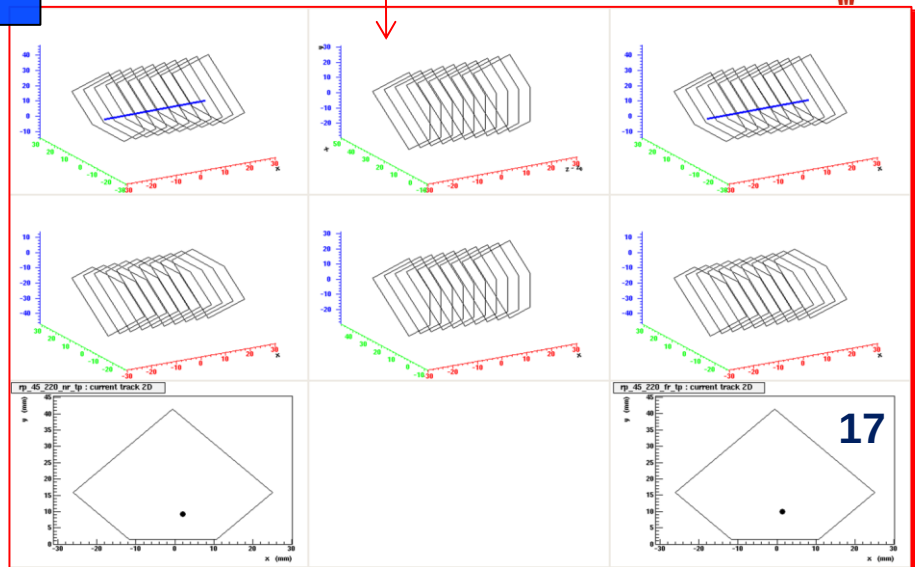
MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) ~ 244 GeV
(TOTEM & CMS compatible)
ξ_-=0.1 ξ=0.01









Summary

Soft diffraction

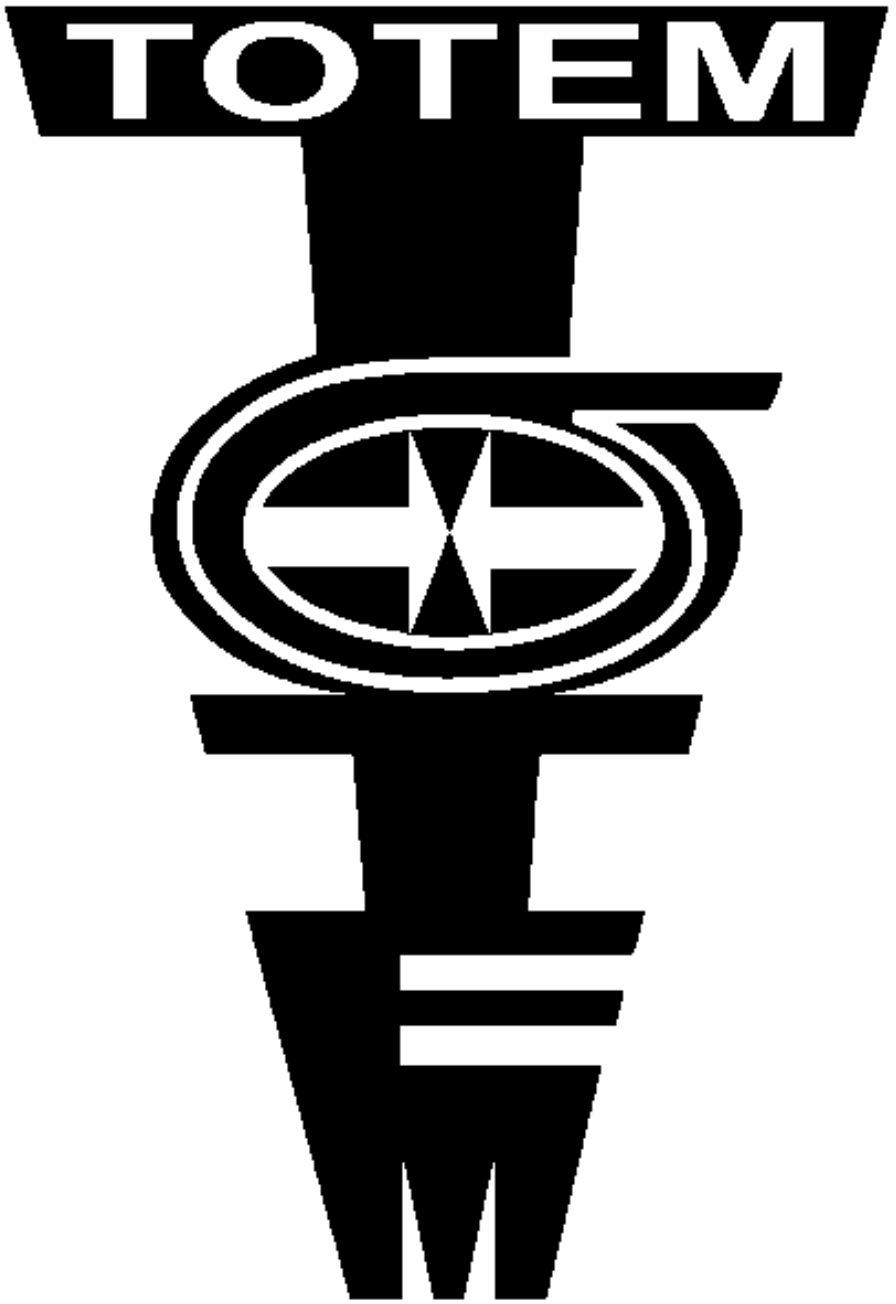
Preliminary results
on SD & CD presented.
DD paper finalized & submitted.
Many analyses
in progress.

Forward particle production

Forward charged multiplicity
measured at 7 & 8 TeV

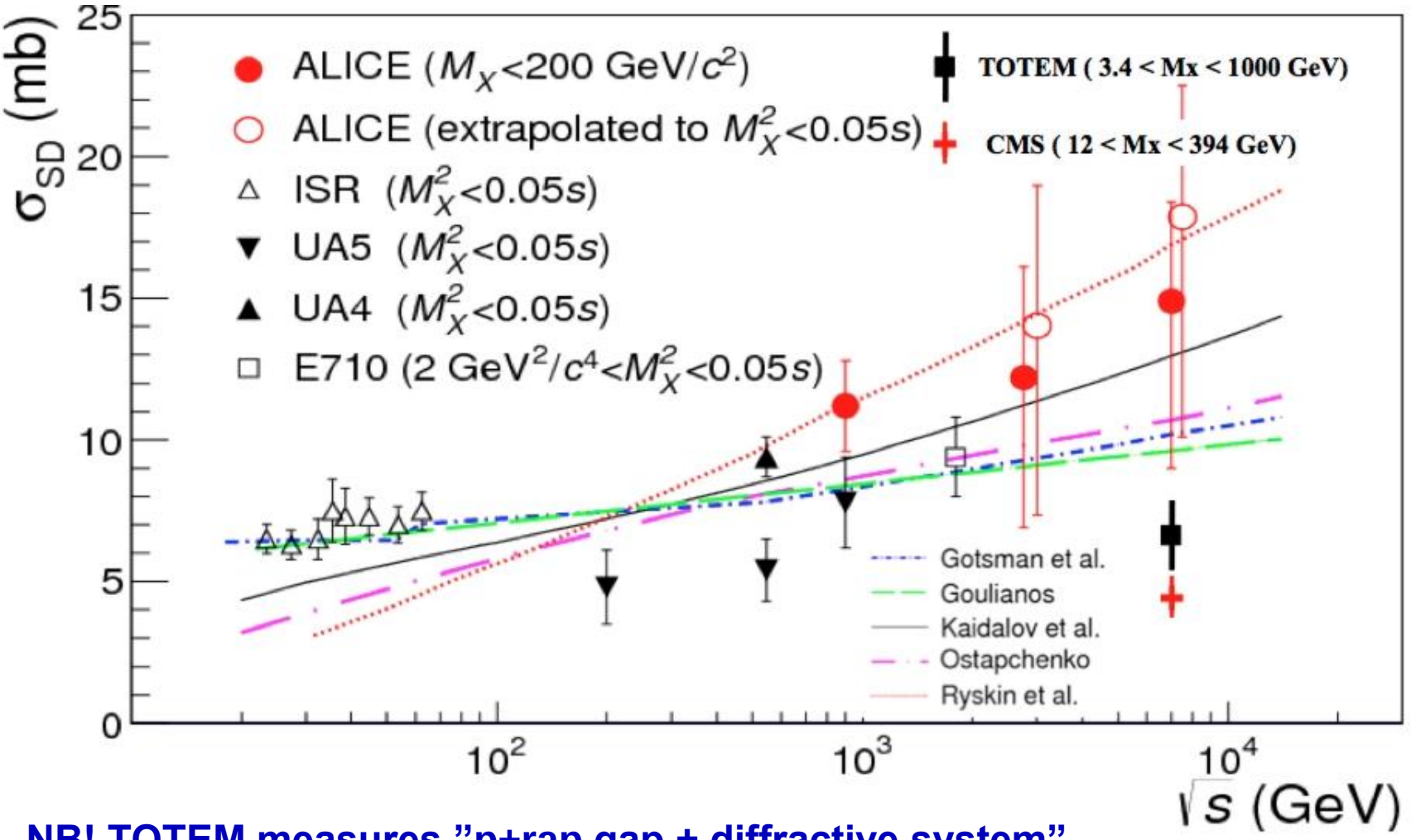
Started with CMS to explore
capability of the large
combined η coverage !

The End



SD cross-section comparison

Courtesy N. Cartiglia



NB! TOTEM measures ”p+rap gap + diffractive system”, ALICE & CMS ”rap gap + diffractive system”

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

Leading systematics:

- missing DD events with unseen particles at $\eta < \eta_{min}$ ("Internal migration": real DD events that have a $|\eta|_{min}$ smaller than T1 but with no tracks in T1 η-range)

- backgrounds from non-diffractive, single diffractive & central diffractive events

Comparison with MC generators:

Pythia 8 **(σ_{DD} = 8.1 mb)**

$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 159\ \mu b$$

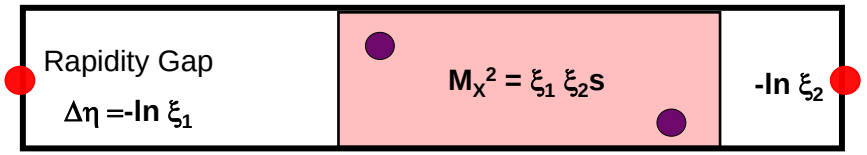
	$-4.7>\eta_{min}>-5.9$	$-5.9>\eta_{min}>-6.5$
$4.7<\eta_{min}<5.9$	70 μb	**36 μb**
$5.9<\eta_{min}<6.5$	**36 μb**	17 μb

Phojet **(σ_{DD} = 3.9 mb)**

$$\sigma_{DD(4.7<|\eta_{min}|<6.5)} = 101\ \mu b$$

	$-4.7>\eta_{min}>-5.9$	$-5.9>\eta_{min}>-6.5$
$4.7<\eta_{min}<5.9$	44 μb	23 μb
$5.9<\eta_{min}<6.5$	23 μb	12 μb

Central Diffraction: TOTEM + CMS



Cuts:
- Vertex ≤ 1
- RP near edge area removed (background suppression)
- RP top-top/bot-bot topology
- ξ> 1.5%, better resolution
- FSC empty (background suppression)

Categories of events :

- CMS and TOTEM consistent (within resolution)

  M_{CMS}(Particle Flow) = M_{TOTEM}(pp)

  p_{CMS}(Particle Flow) = p_{TOTEM}(pp) → Many candidates in the soft sample

  Few candidates in the dijet sample; none exclusive!

- Missing "tracks" in CMS

  M_{CMS}(Particle Flow + missing momentum) ≤ M_{TOTEM}(pp)

➢Additional tracks seen in forward detectors beyond the ξ-predicted rapidity gap

→ Large fraction of soft events

Several candidates in the dijet sample

➢Tracks seen within predicted rapidity gap → No candidates in the dijet sample;

Background issue in the soft sample

➢<u>escaping-mass candidates</u>

NO tracks seen in forward detectors beyond the ξ -predicted rapidity gap → few candidates with $\Delta M \geq 400$ GeV