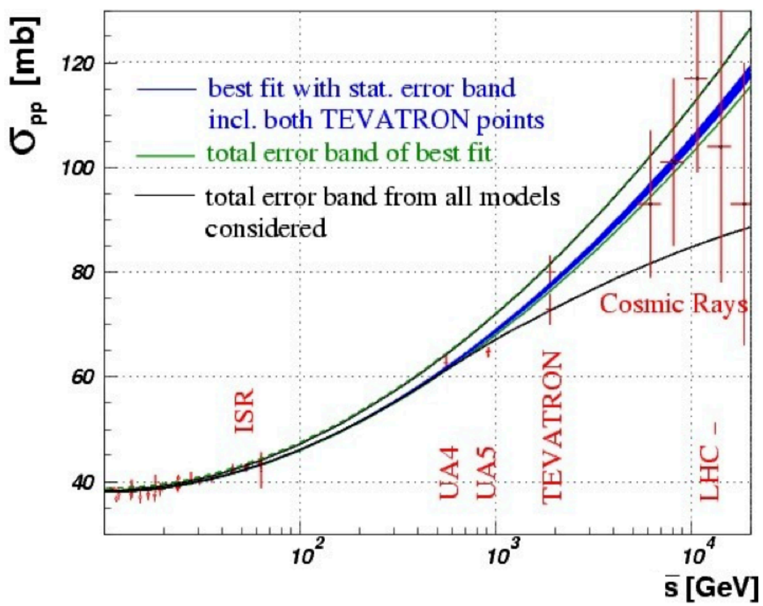
TOTEM

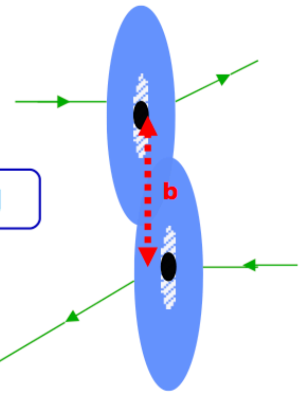
Recent results on elastic and inelastic diffractive physics.

Totem physics

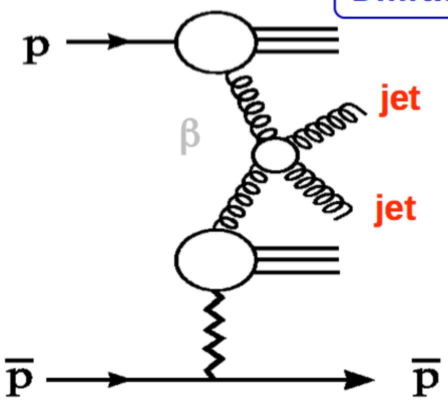
Total cross-section



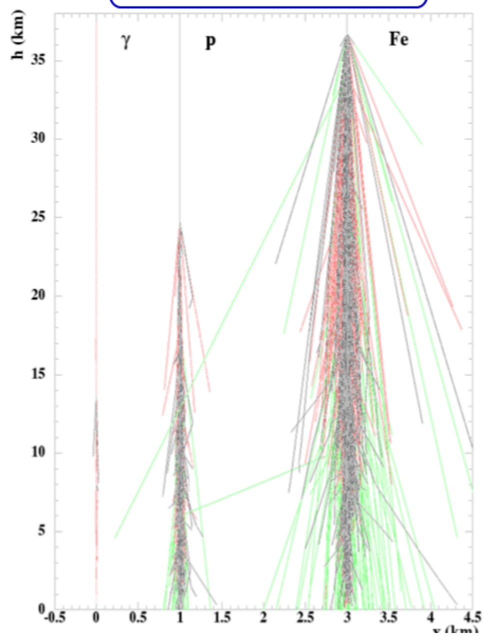
Elastic Scattering



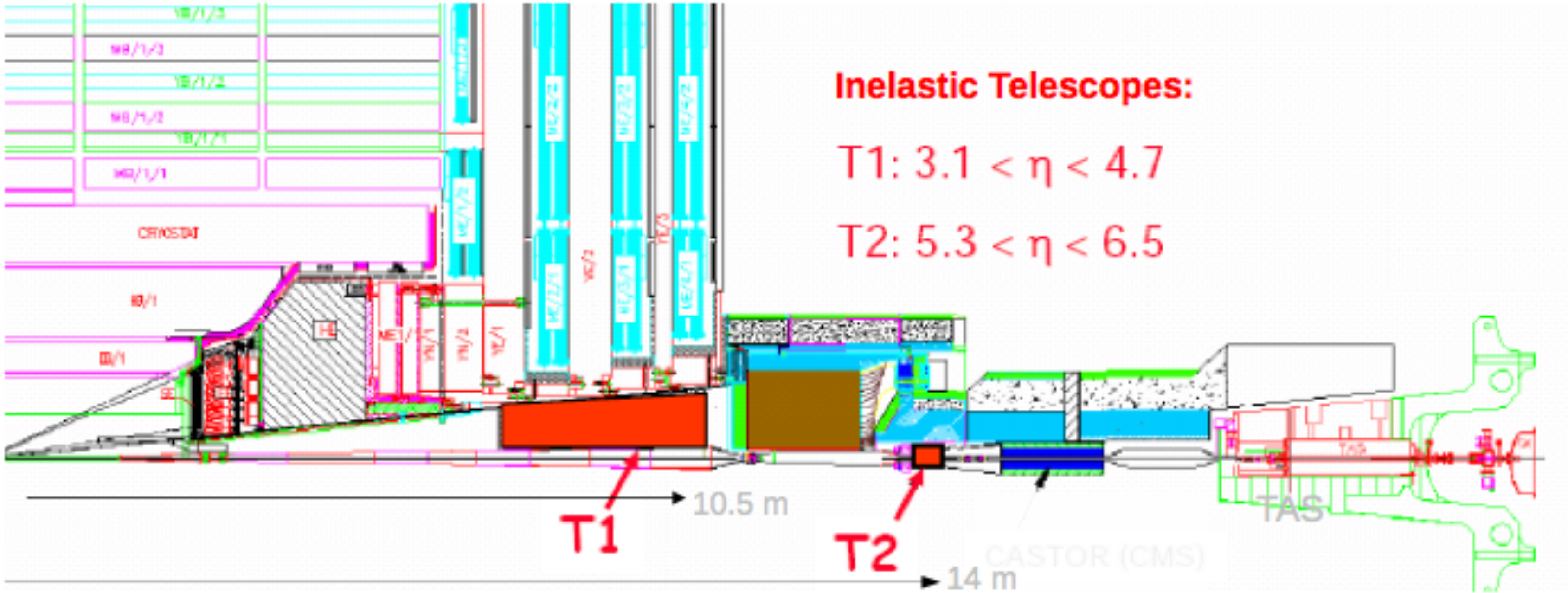
Diffraction: soft and hard

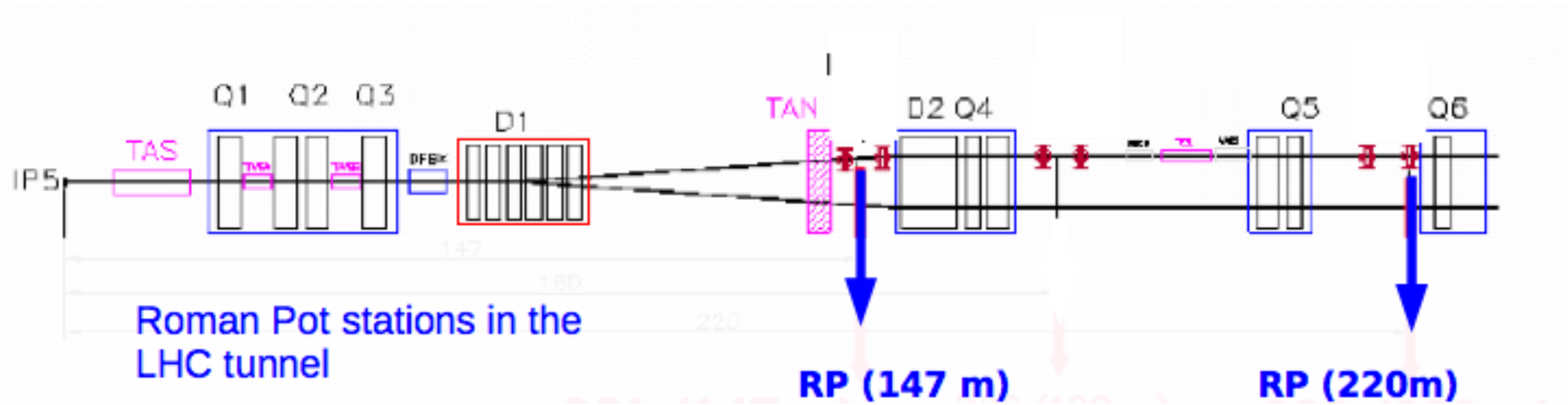


Forward physics

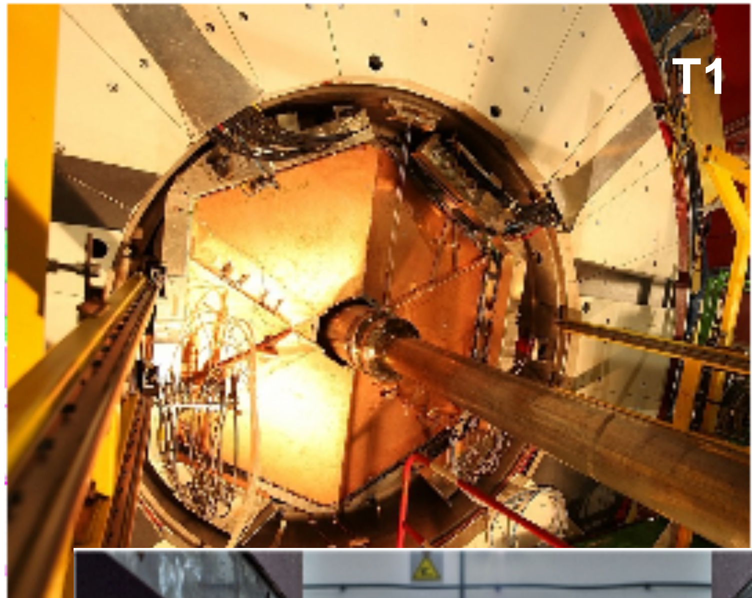


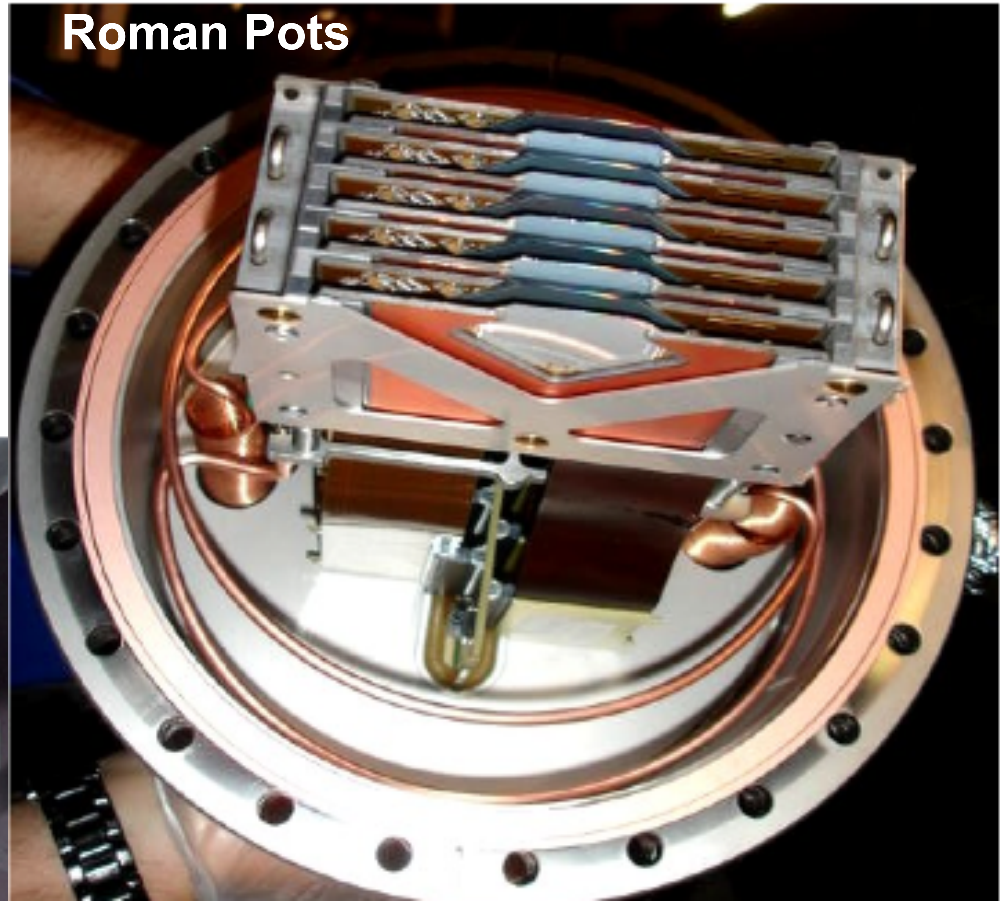
Totem detectors

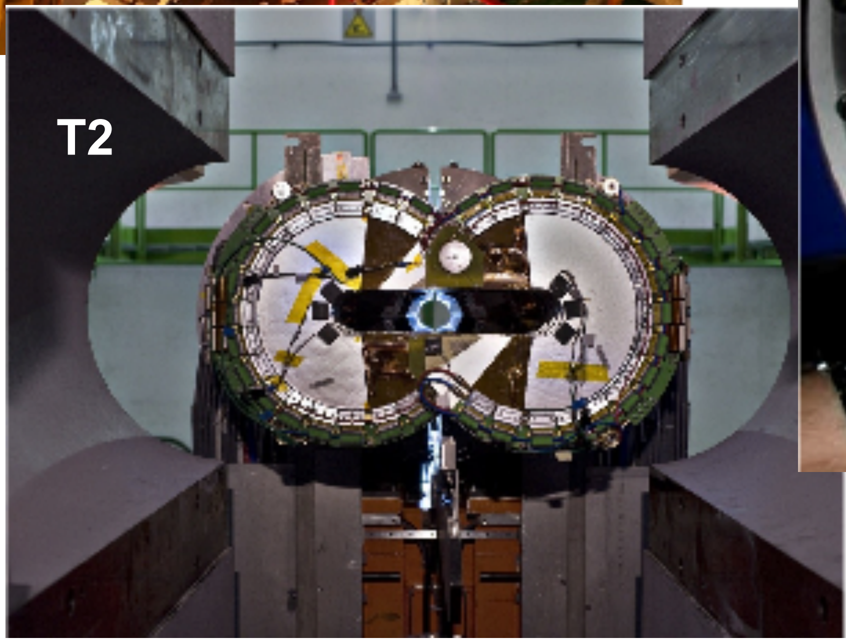




Detectors



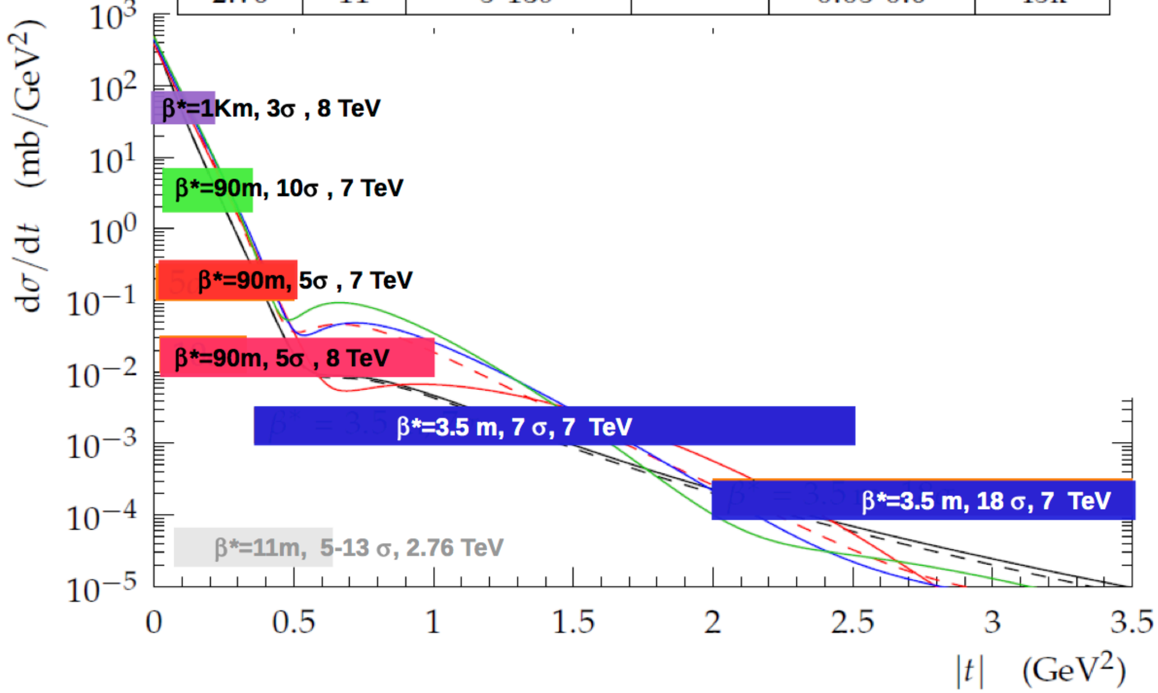




Totem operation

Several data sets at different conditions to measure wide range and very low-t

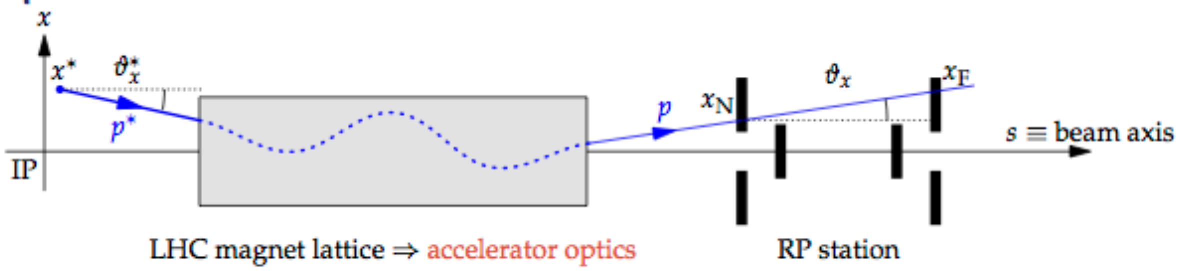
E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events
7	90	4.8-6.5σ	83	$7 \cdot 10^{-3}$ - 0.5	1M
	90	10σ	1.7	0.02 - 0.4	14k
	3.5	7σ	0.07	0.36 - 3	66k
	3.5	18σ	2.3	2 - 3.5	10k
8	90	6-9σ	60	0.01 - 1	0.6M
	1000	3σ	20	$6 \cdot 10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		0.05-0.6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



Low β*=0.6m high intensity runs were taken only to test the insertion of the pots in view of future upgrades. Large pileup cannot be handled by this setup and a 4D tracks reconstruction is needed.

Protons in the RP

- proton transport IP5 → RP detectors:

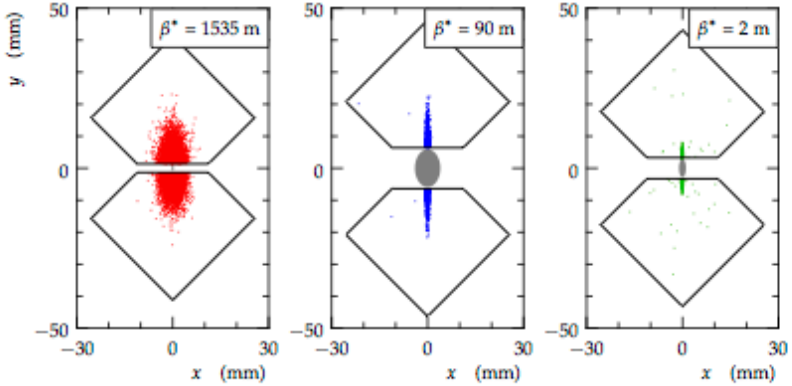


- optics

hit position at RP — optical functions — proton kinematics at IP

$$x(\mathrm{RP}) = (\text{effective length } L_x) \cdot (\text{scattering angle } \vartheta_x^*) + (\text{magnification } v_x) \cdot (\text{vertex } x^*) + (\text{dispersion } D_x) \cdot (\text{rel. momentum loss } \xi \equiv \frac{\Delta p}{p})$$

- example: elastic sample seen with 3 different optics:



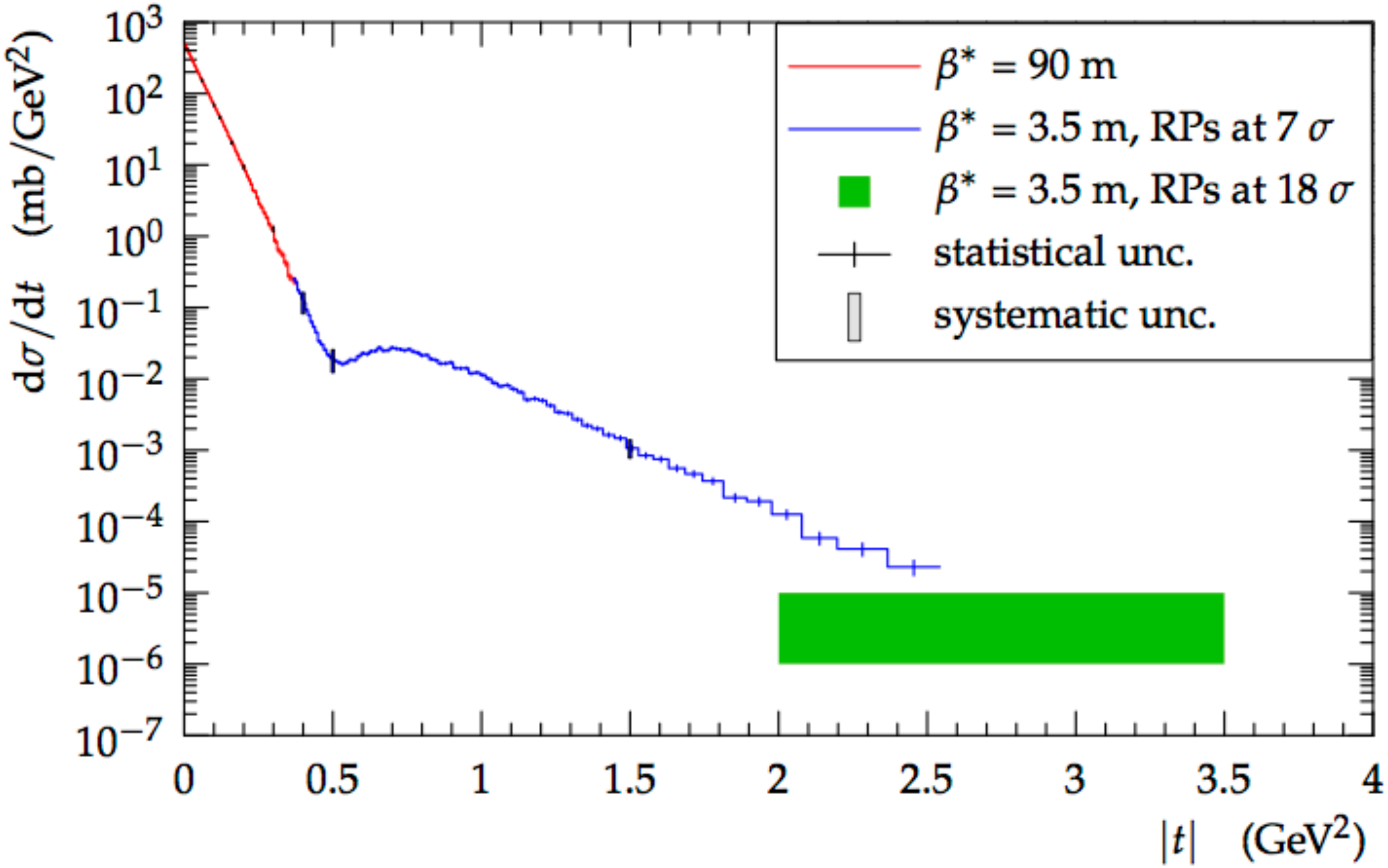
⇒ *optics knowledge essential*

⇓

TOTEM can improve optics accuracy

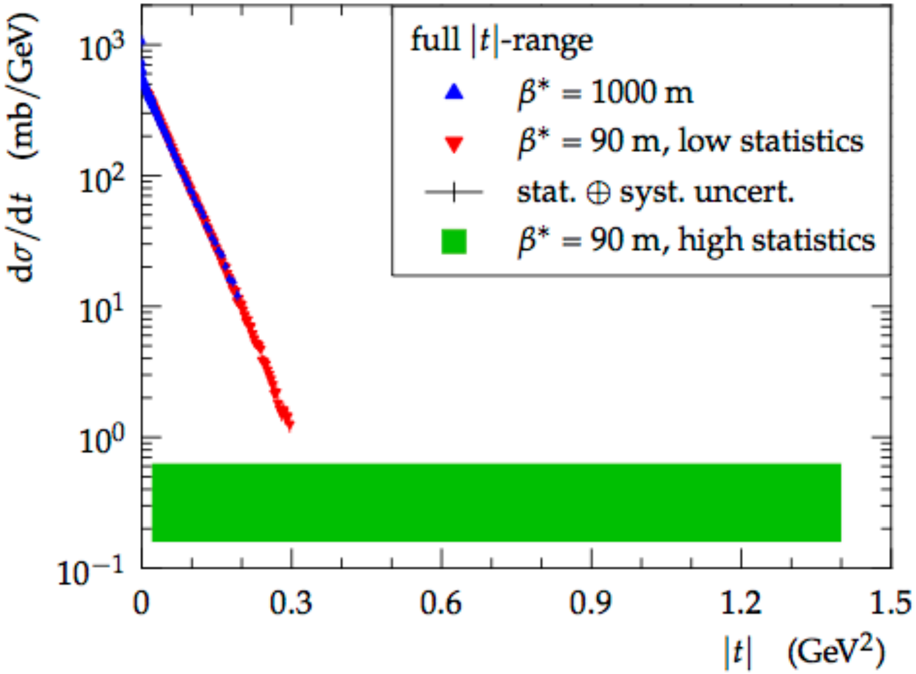
Elastic scattering at 7 TeV

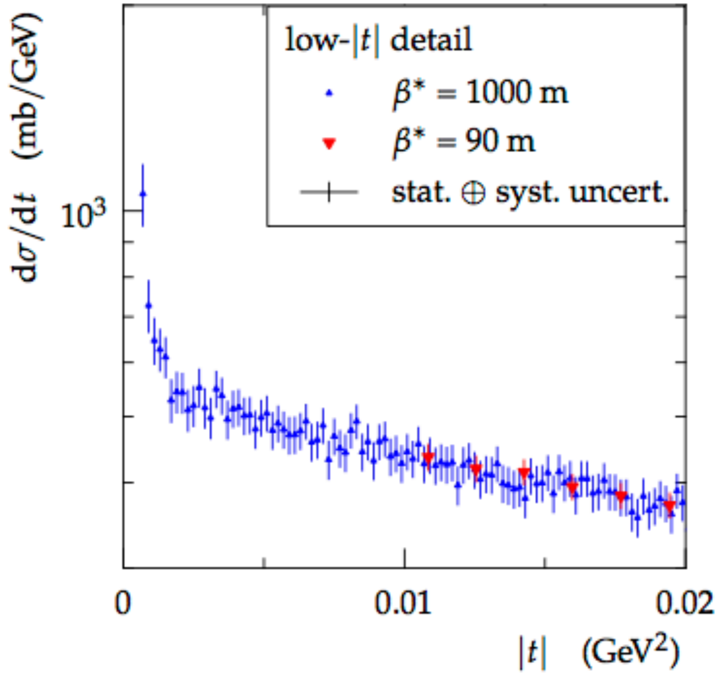
β^*	RP approach	$\|t\|$ range	el. events	status
90 m	4.8 to 6.5 σ	0.005 to 0.4 GeV^2	1 M	[EPL 101 (2013) 2100]
3.5 m	7 σ	0.4 to 2.5 GeV^2	66 k	[EPL 95 (2011) 41001]
3.5 m	18 σ	$\approx$ 2 to 3.5 GeV^2	10 k	anal. advanced



Elastic scattering at 8 TeV

β^*	RP approach	$|t|$ range	el. events	status
1000 m	3 or 10 σ	0.0006 to 0.2 GeV^2	352 k	publ. in prep.
90 m	6 to 9.5 σ	0.01 to 0.3 GeV^2	0.68 M	[PRL 111 (2013)]
90 m	9.5 σ	0.02 to 1.4 GeV^2	7.2 M	anal. advanced





- dip well visible in the combined $\beta^* = 90$ m data

Cross Section

3 complementary methods:

$$\rho \equiv \left.\frac{\Re \mathcal{A}_{el}}{\Im \mathcal{A}_{el}}\right|_{t=0}$$

elastic observables only:

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

σ_{tot}

ϱ-independent:

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

luminosity-independent:

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

$$\mathcal{L} = \frac{1+\varrho^2}{16\pi}\frac{(N_{el}+N_{inel})^2}{dN_{el}/dt|_0}$$

N_{el} from RPs N_{inel} from T2 $\mathcal{L}$ from CMS ρ from COMPETE or TOTEM

Cross Section

$\sqrt{s}$ = 7 TeV

elastic observables only:

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

$\sigma_{tot} = (98.6 \pm 2.3)$ mb

$\downarrow$

σ_{tot}

ρ-independent:

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

$\sigma_{tot} = (99.1 \pm 4.4)$ mb

luminosity-independent:

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

$\sigma_{tot} = (98.1 \pm 2.4)$ mb

$\sqrt{s}$ = 8 TeV

elastic observables only:

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

$\downarrow$

σ_{tot}

ρ-independent:

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

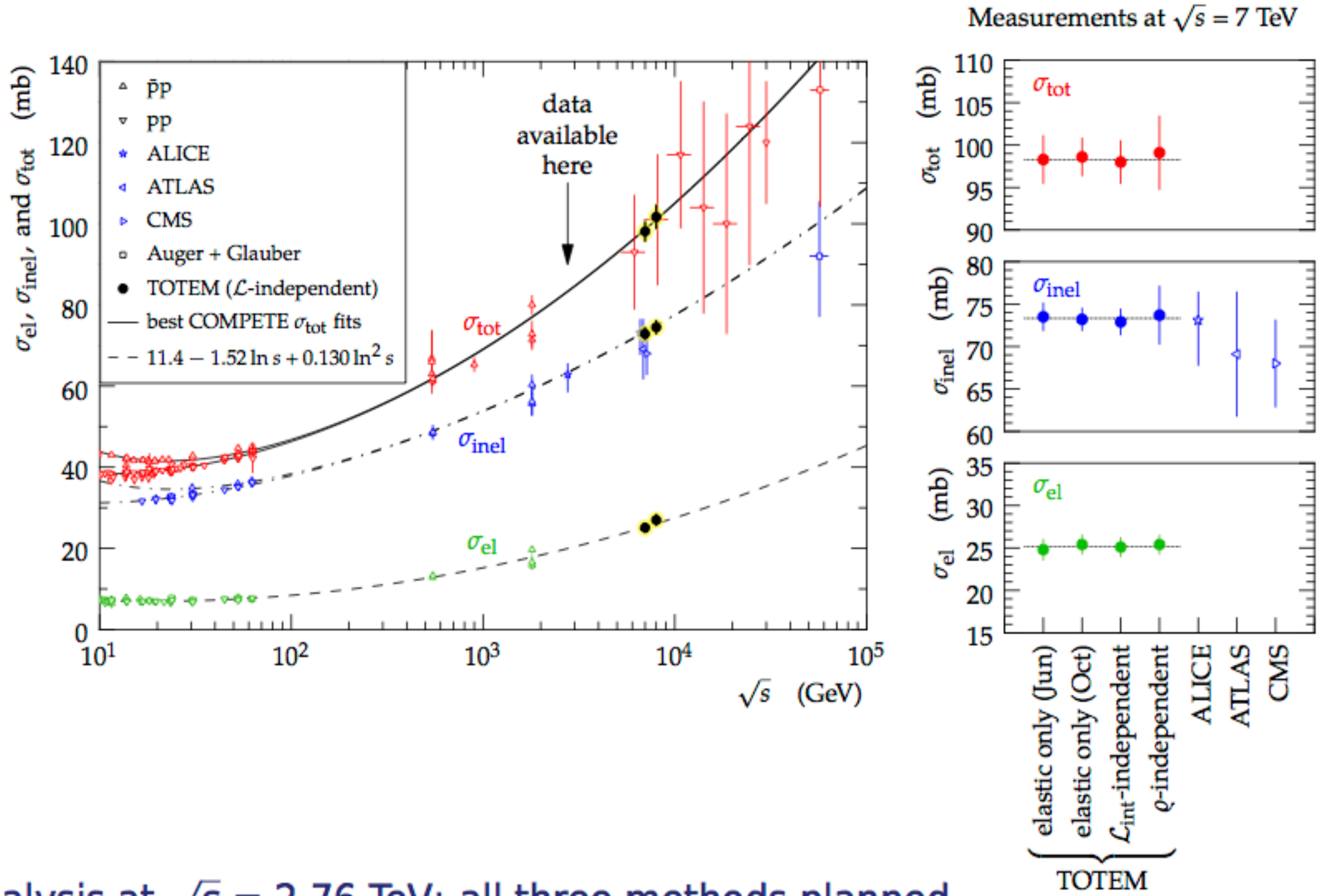
luminosity-independent:

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

$\sigma_{tot} = (101.7 \pm 2.9)$ mb

- CMS luminosity unavailable
- $\mathcal{L}$ from luminosity-independent method
  $\Rightarrow$ normalisation of $d\sigma/dt$ both at $\beta^* = 90$ and 1000 m

Cross Section



- analysis at $\sqrt{s}$ = 2.76 TeV: all three methods planned
  - elastic analysis: ongoing
  - inelastic analysis: almost finished

Coulomb Hadronic interference

$d\sigma/dt \propto |F^{C+N}|^2$ = Coulomb + "Interference" + Hadronic

↓ from theory

↓ Modulus constrained by measurement ~*exp[B(t)]*
B(t) described by n>1 parameters

Key elements considered:

- number of parameters to describe B(t)
- description of interference term: from simplified West-Yennie formula to general Kundrát-Lokajícek formula
- ψ, phase of the hadronic amplitude (not constrained by measurements): central or peripheral

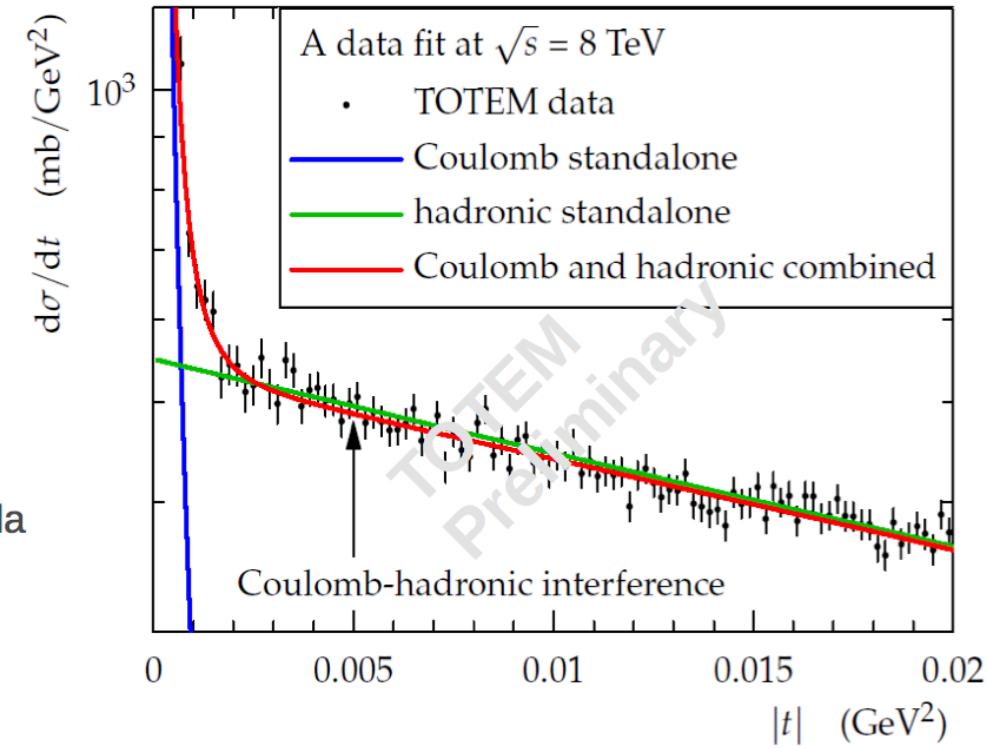
⇨ $\rho = 1 / \tan(\psi|_0)$

Example: χ^2 fit with **K**undrát-**L**okajícek formula

$B(t) \sim b_0 + b_1 t + b_2 t^2$

Central hadronic phase

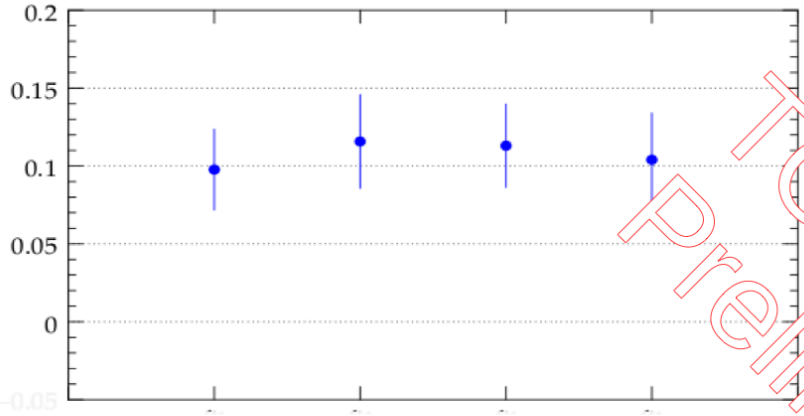
All errors included



ρ measurement

Elastic pp scattering : ρ measurement

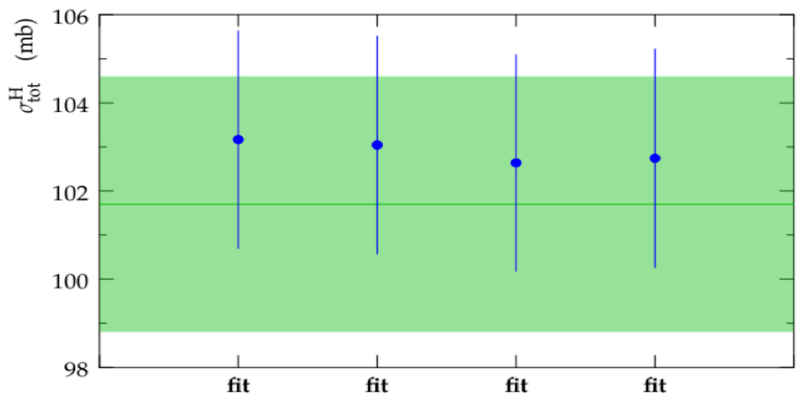
$$\varrho \equiv \left.\frac{\Re F^{\mathrm{H}}}{\Im F^{\mathrm{H}}}\right|_0$$



Method: χ^2 fit
KL formula

B(t) parameters:	2	3	2	3
Phase:	central	central	periph.	periph.

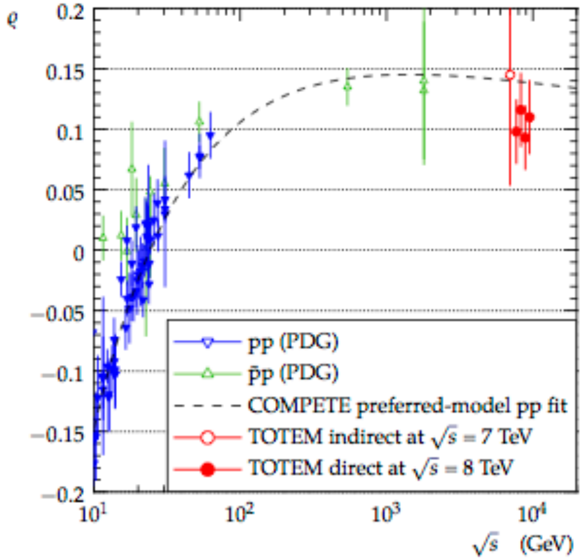
ρ=0.104±0.027(stat) ± 0.010(syst) $^{+0.012}_{-0.006}$(model)

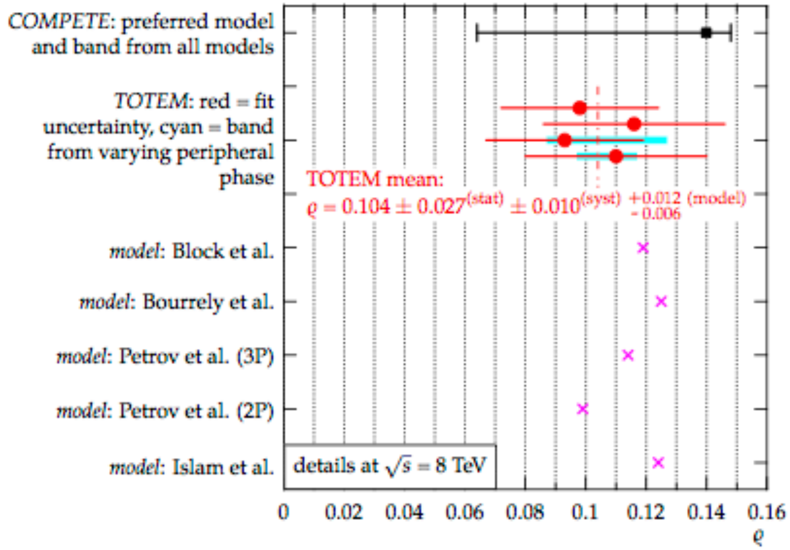


σ_{TOT}= 101.7 ± 2.9 mb
Measured by TOTEM
(*CERN-PH-EP-2012-354*)

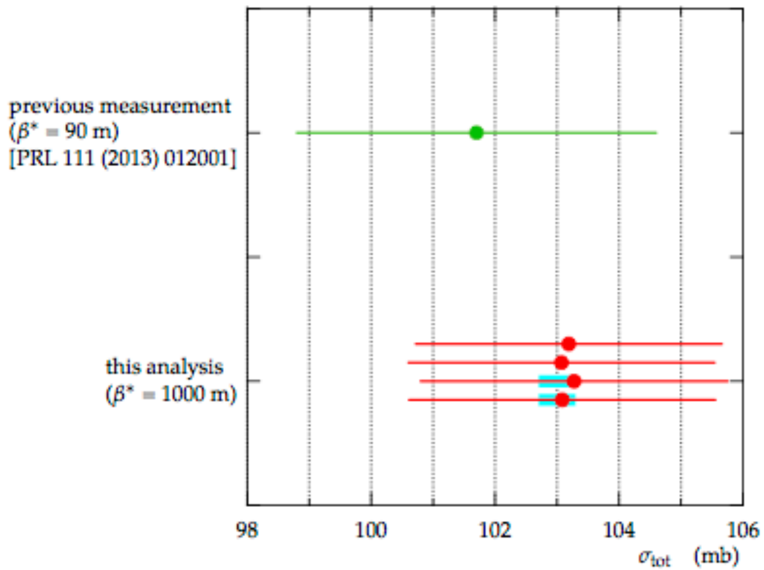
ρ measurement

ρ →



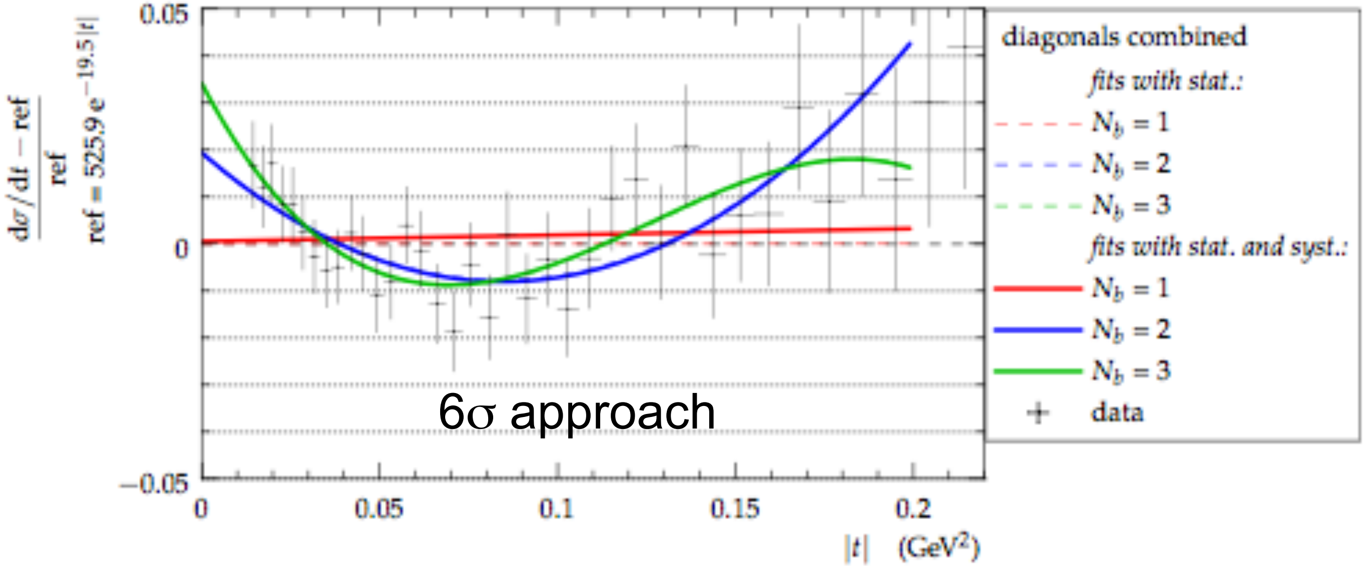


σ_{tot} →

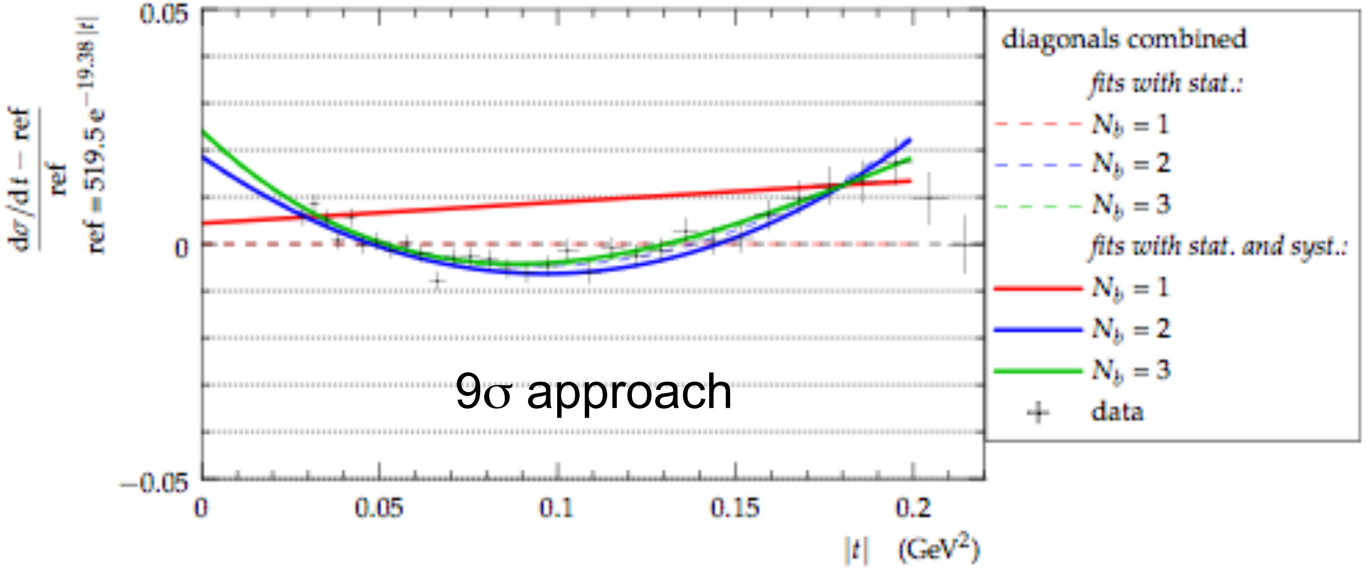


t distribution characteristics

DS2



DS4



Non exponential behavior

t distribution characteristics

Fits up to 0.195 GeV^2

DS4										
chi^2 metr	paramete	chi^2	ndf	chi^2/nd	p-value	gaussia	A	A_unc	si_tot	si_tot unc
stat only	1	138,7	28	5,00	1,30E-16	7,75				
	2	22,2	27	0,80	7,30E-1	0,35	529,1	1,0	100,8	0,1
	3	18,6	26	0,70	8,50E-1	0,18	532,6	2,1	101,1	0,2
stat+syst	1	83,2	28	3,00	2,20E-7	5,18				
	2	21,5	27	0,80	7,60E-1	0,30	528,8	20,9	100,7	2,0
	3	18,2	26	0,70	8,70E-1	0,16	533,4	21,0	101,2	2,0

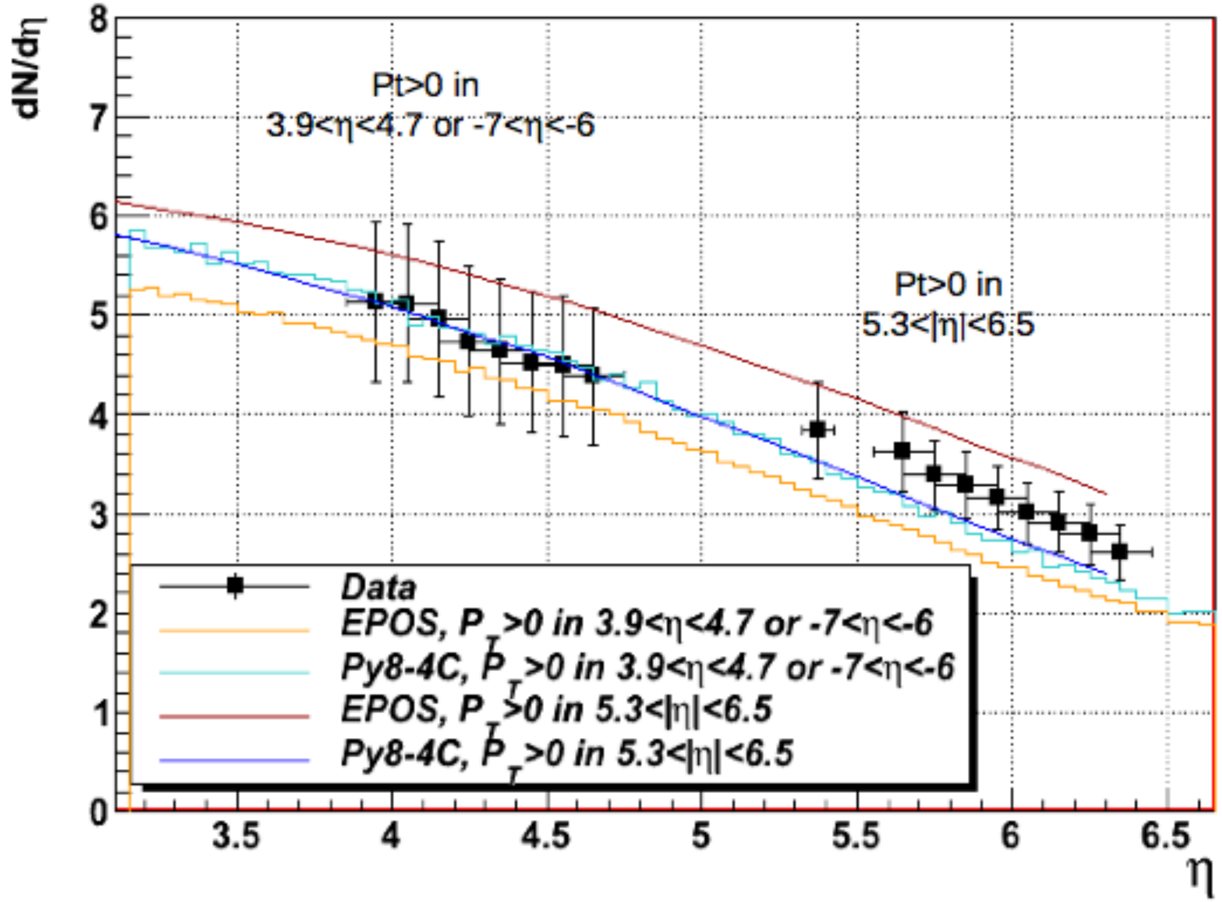
Fits up to 0.065 GeV^2

DS4										
chi^2 metr	paramete	chi^2	ndf	chi^2/nd	p-value	gaussia	A	A_unc	si_tot	si_tot unc
stat only	1	6,7	9	0,70	0,67	0,43	528,9	1,2	100,8	0,1
stat+syst	1	6,7	9	0,70	0,67	0,43	528,9	21,3	100,8	2,0

Inelastic Studies

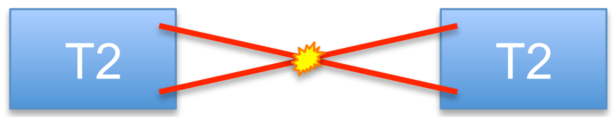
- Charged particle density ($3<\eta<7$)
- Cross Sections
  - Single diffraction (ongoing)
  - Double diffraction (**Phys. Rev. Lett. 111 (2013) 262001**)
  - Central diffraction (ongoing)
- Totem CMS diffractive studies
  - CD Dijet production (ongoing)
  - Low mass resonances ($\pi\pi$ $\eta\eta$ $\rho\rho$ …..)(ongoing)
  - Missing mass (ongoing)

Charged Particle Distribution

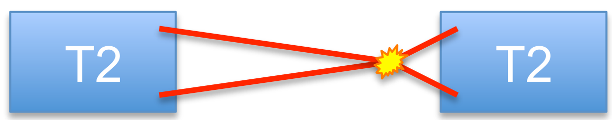


T2 detector only

From 5.3<η<6.5 data taken in normal beam condition

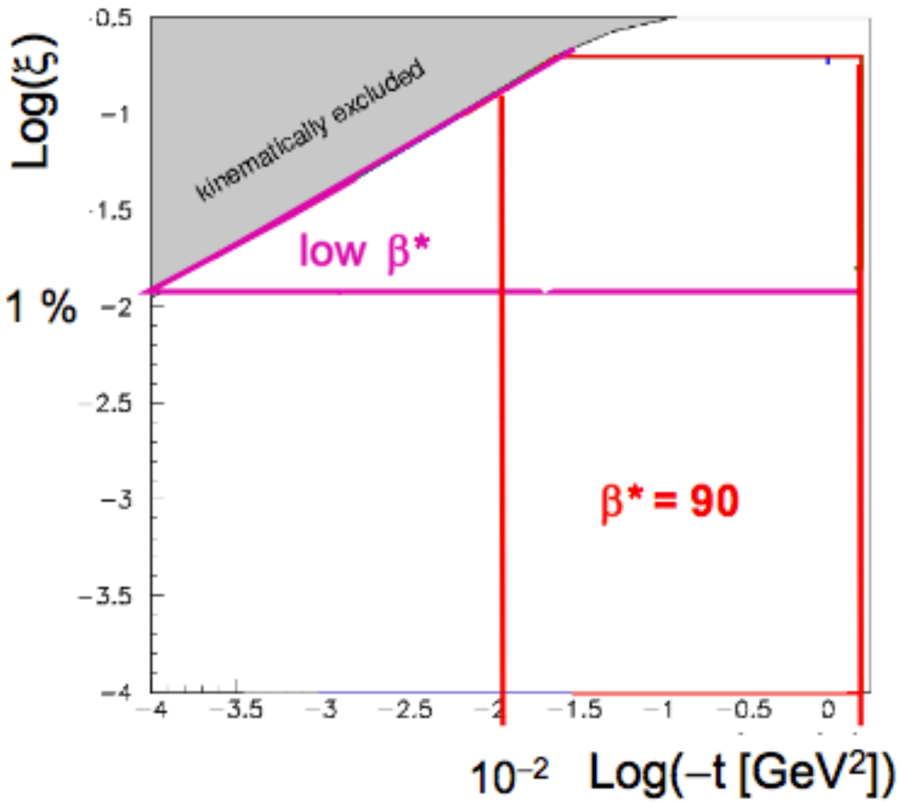


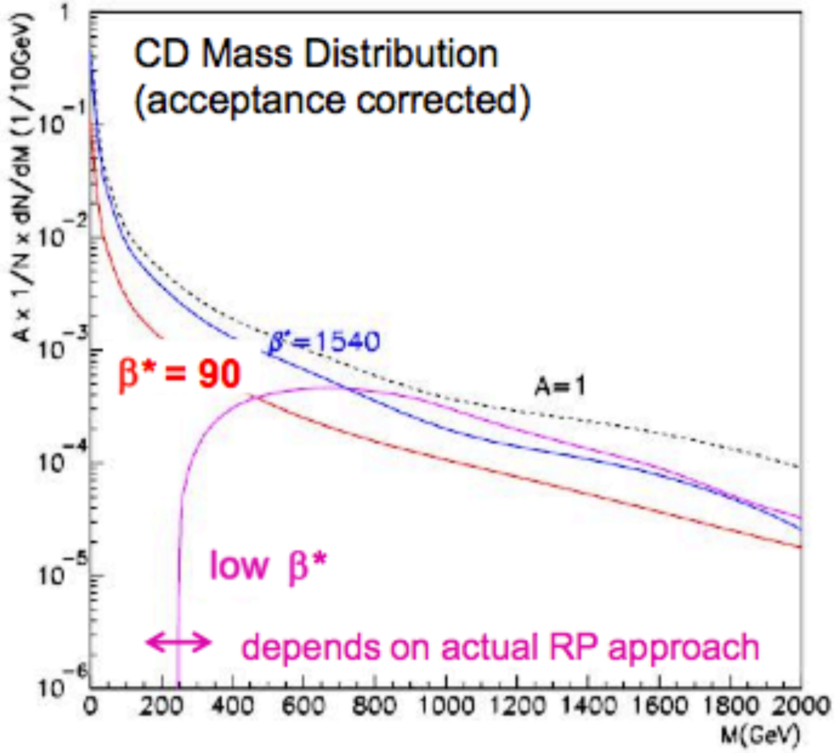
From 3.9<η<4.7 and η=7 (not blessed) taken with the interaction vertex displaced by 11m from nominal position.



This data tacking and analysis has been performed with the CMS detector with the T2 min bias trigger. The full η range will be released soon

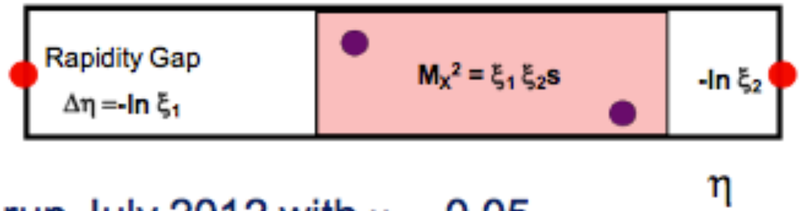
Proton & CD mass acceptance





β^* [m]	$\sigma(\Theta_x^*)$ [μrad]	$\sigma(\Theta_y^*)$ [μrad]	$\sigma(t)$ [GeV^2]	$\sigma(\Phi^*)$ [rad]	$\sigma(\xi)$	$\sigma(M)$ [GeV]
90 (no vtx.)	17	2.3	$0.22\|t\|^{0.67}$	$0.075/\|t\|^{0.59}$	$0.003 \div 0.006$	$40 \div 200$
90 (w. vtx.)	5	2.3	$0.13\|t\|^{0.79}$	$0.026/\sqrt{\|t\|}$	0.0012	$10 \div 100$
0.55	$32 \div 35$	30	$0.45\sqrt{\|t\|}$	$0.23/\sqrt{\|t\|}$	$0.001 \div 0.007$	$(0.025 \div 0.03)M$

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 (suppress background)

Demo: common run July 2012 with $\mu \sim 0.05$
Dijet (diproton) triggered sample: 40 nb^{-1} (1 nb^{-1})

Categories of events :

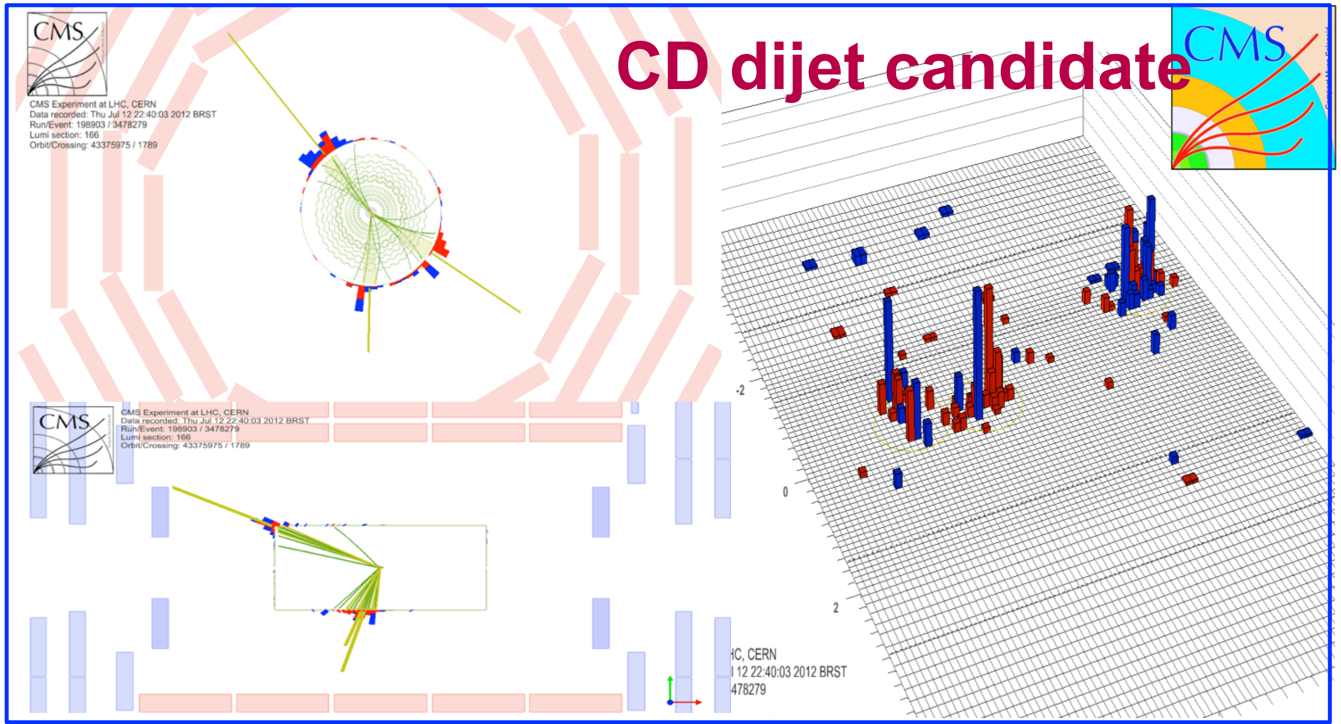
- Forward and central consistent (within resolution)
  M_{CMS}(Particle Flow) = M_{TOTEM}(pp)
  p_{CMS}(Particle Flow) = p_{TOTEM}(pp) → Few candidates in dijet sample; none exclusive!

- Missing "objects" in central
  M_{CMS}(Particle Flow + missing momentum) ≤ M_{TOTEM}(pp)

➢ particles violating ξ-predicted gaps $\Delta\eta_{1,2}$ → No candidates in dijet sample

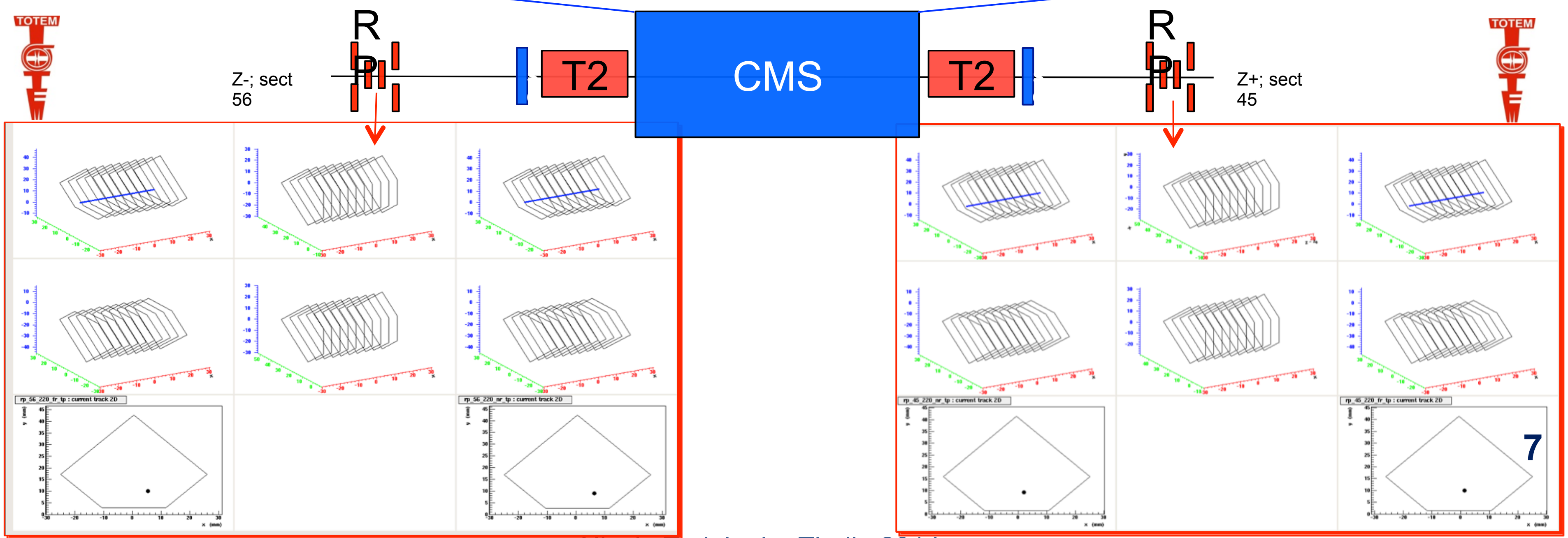
➢ escaping-mass candidates
Additional particles NOT observed in forward detectors where allowed by ξ-predicted gaps → Few candidates with $\Delta M \geq 400$ GeV

Additional particles NOT observed in forward detectors forbidden by ξ-predicted gaps → No candidates



CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV
ξ+ :
MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) = 244 GeV ≈ M(central)
ξ_1 = 0.1 ξ_2= 0.01



Conclusions

- Totem experiment has performed a detailed analysis of the elastic scattered protons at 8 TeV with different optics.
- This has allowed to explore the Coulomb Hadronic interference region for very low t=0.001.
- Due to the large statistics of of stored data with the optic at $\beta^*=90$m we are able to explore the t distribution from 0.02 GeV^2<t<0.02 GeV^2 behavior with high precision.
- Thanks to the data taken with $\beta^*=90$m together with the CMS detector we started a full analysis of diffractive channels with the largest η acceptance and direct proton tagging.
- We are currently upgrading the detectors in the pots, together with CMS, to have a 4D (position and time) tracks reconstruction to cope with large pileup for the future LHC runs. The detectors will cover with both vertical and horizontal pots all the possible optics that LHC will deliver with special runs and standard low β runs.