TOTEM: total cross section, elastic scattering, diffraction

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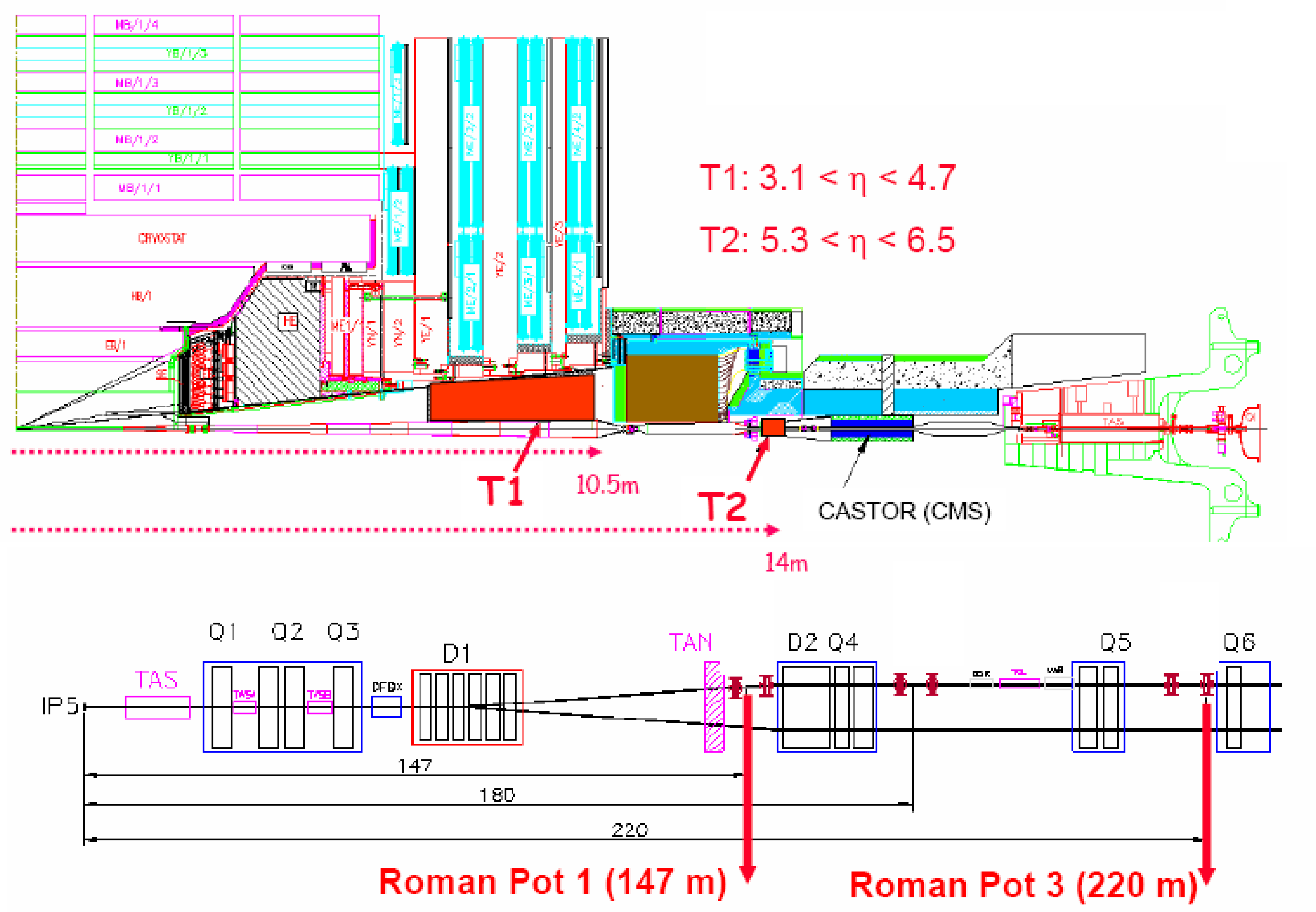
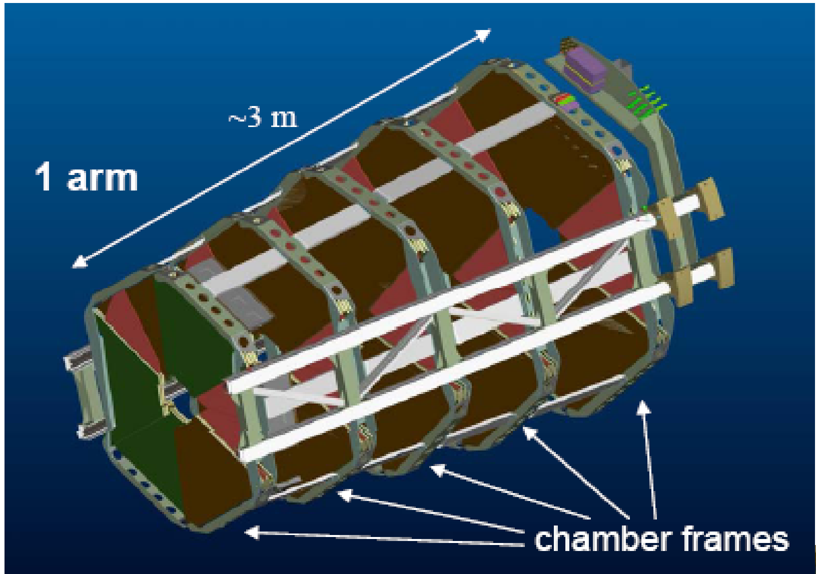
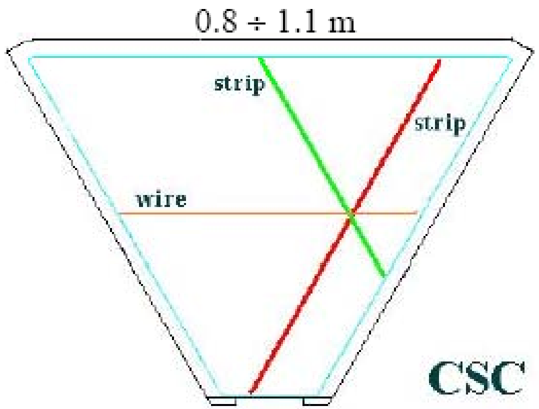
Experimental layout

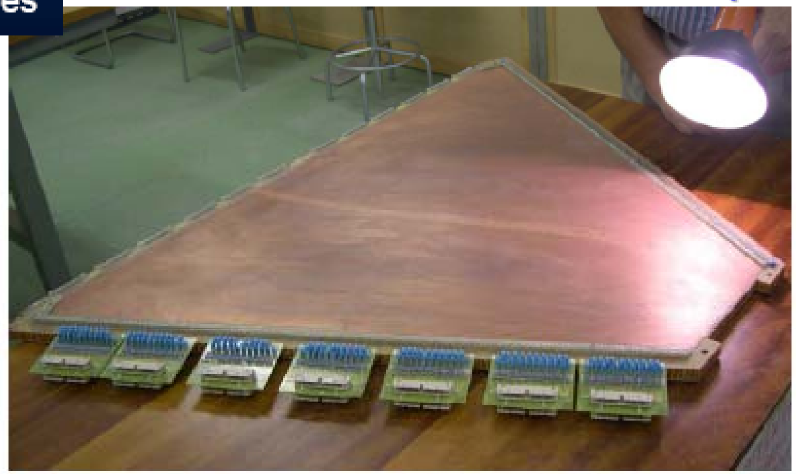


T1 telescope

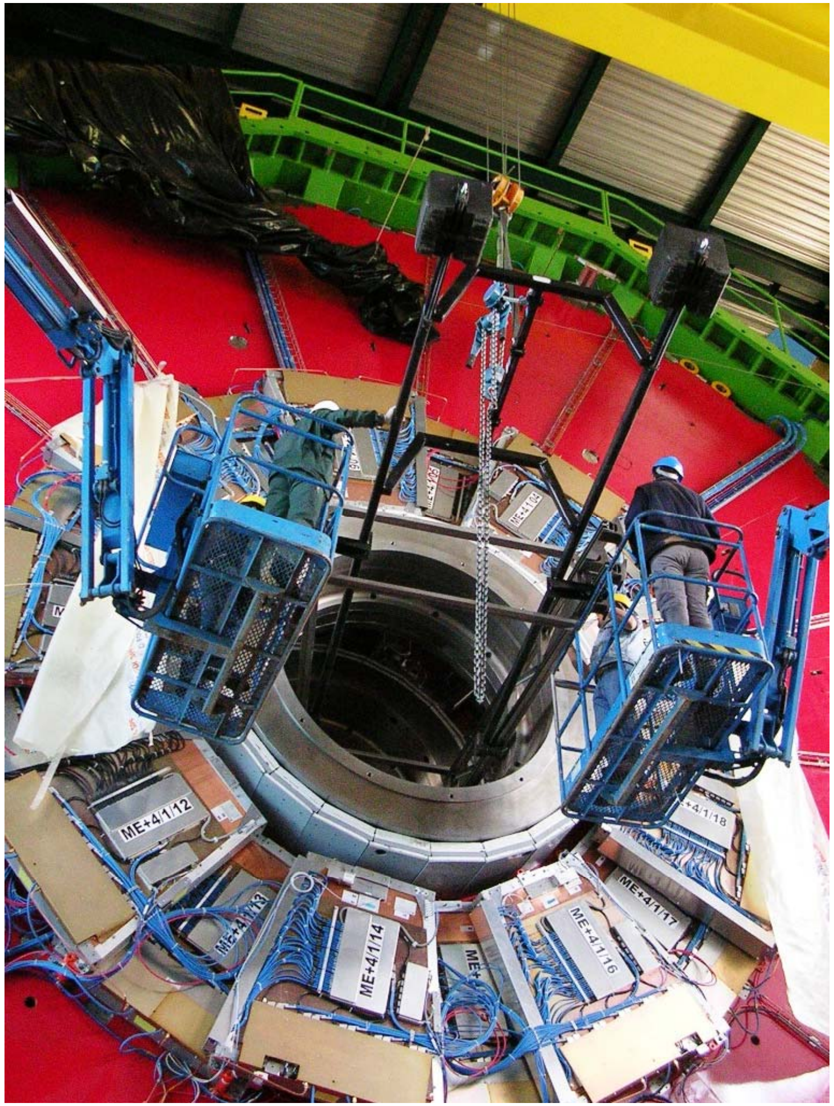


- Cathode Strip Chambers (CSC)
- $3.1 < |\eta| < 4.7$
- 5 planes with measurement of three coordinates per plane.
- 3 degrees rotation and overlap between adjacent planes
- Primary vertex reconstruction (beam-gas interaction removal)
- Trigger with anode wires
- Connected to new VFAT chips





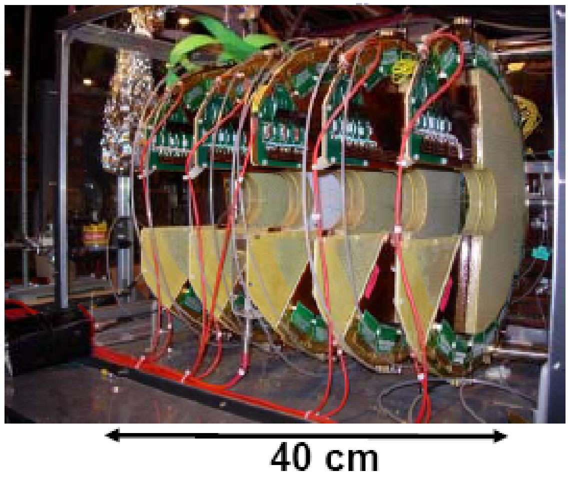
T1 support installation

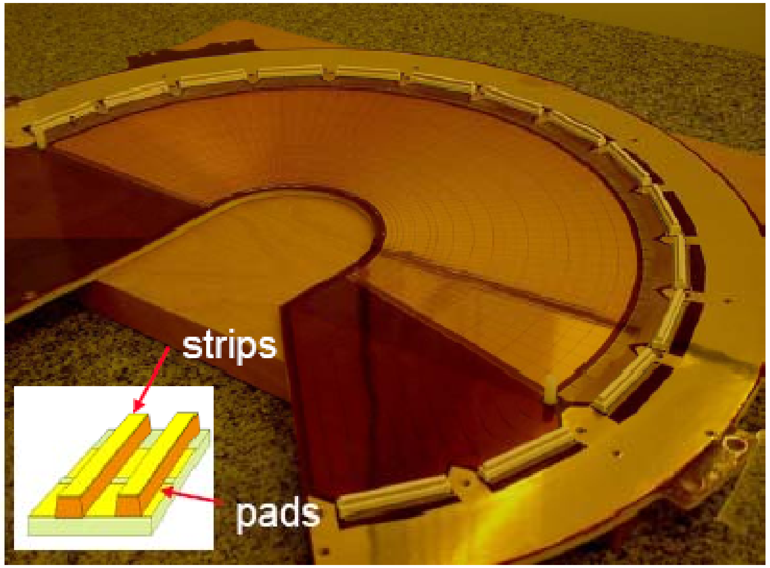


T2 telescope

- Gas Electron Multiplier (GEM)
- $5.3 < |\eta| < 6.5$
- 10 half-planes @ 13.5 m from IP5
- Half-plane:
  - 512 strips (width 80 μm, pitch of 400 μm)
  - 65*24=1560 pads (2x2 mm^2 -> 7x7 mm^2)
- Primary vertex reconstruction (beam-gas interaction removal)
- Trigger using (super) pads

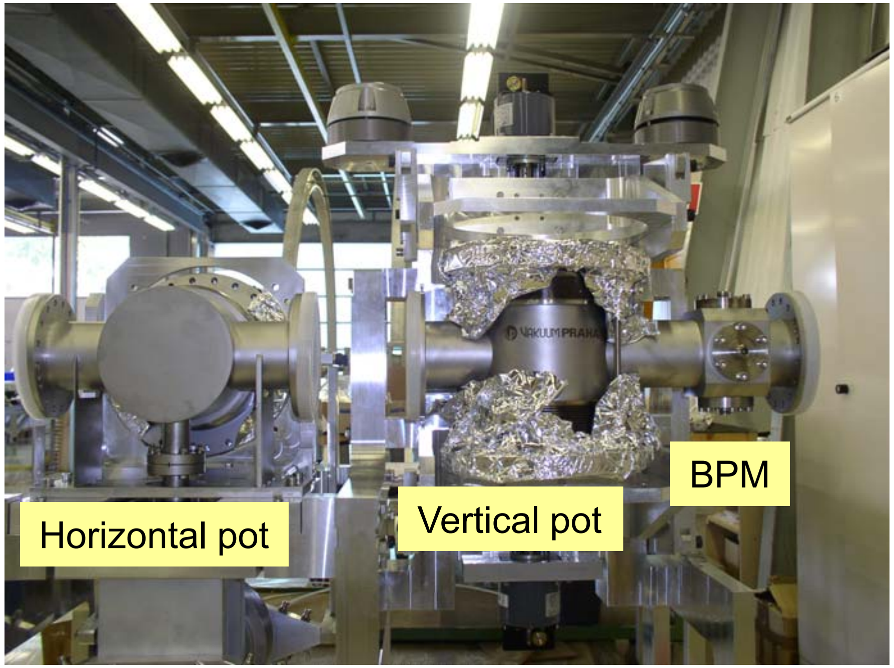
- Detectors tested in a testbeam with new VFAT chips
- First beam profiles, cluster distributions and detector characteristics



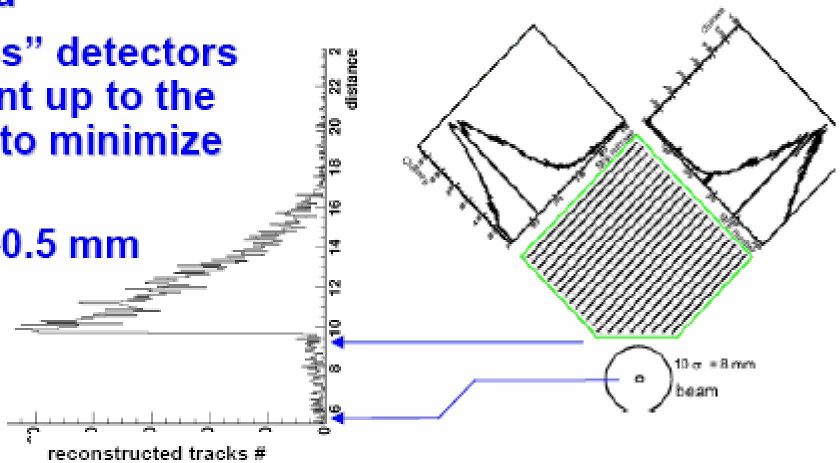


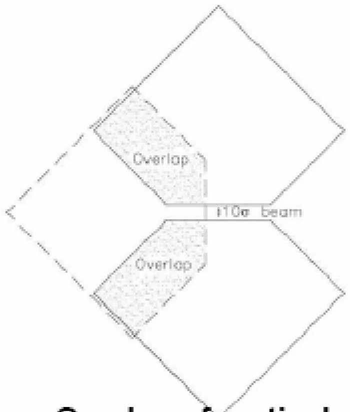
Roman pots

10 planes of edgeless detectors



- Leading proton detection at distances down to $10\times\sigma(\text{beam}) + d$
- Need "edgeless" detectors that are efficient up to the physical edge to minimize "d"
- $\sigma(\text{beam}) \approx 0.1–0.5$ mm (optics dep.)

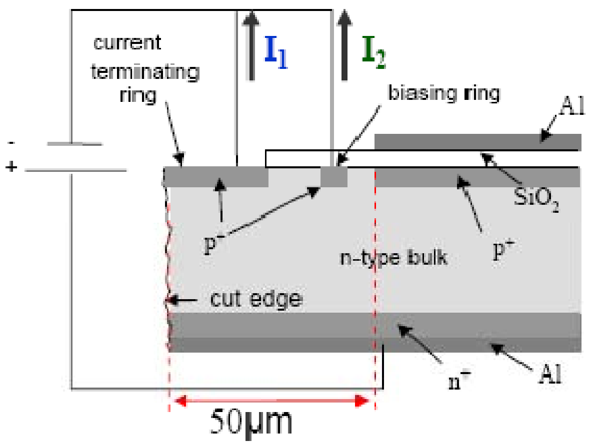




Overlap of vertical and horizontal dets.

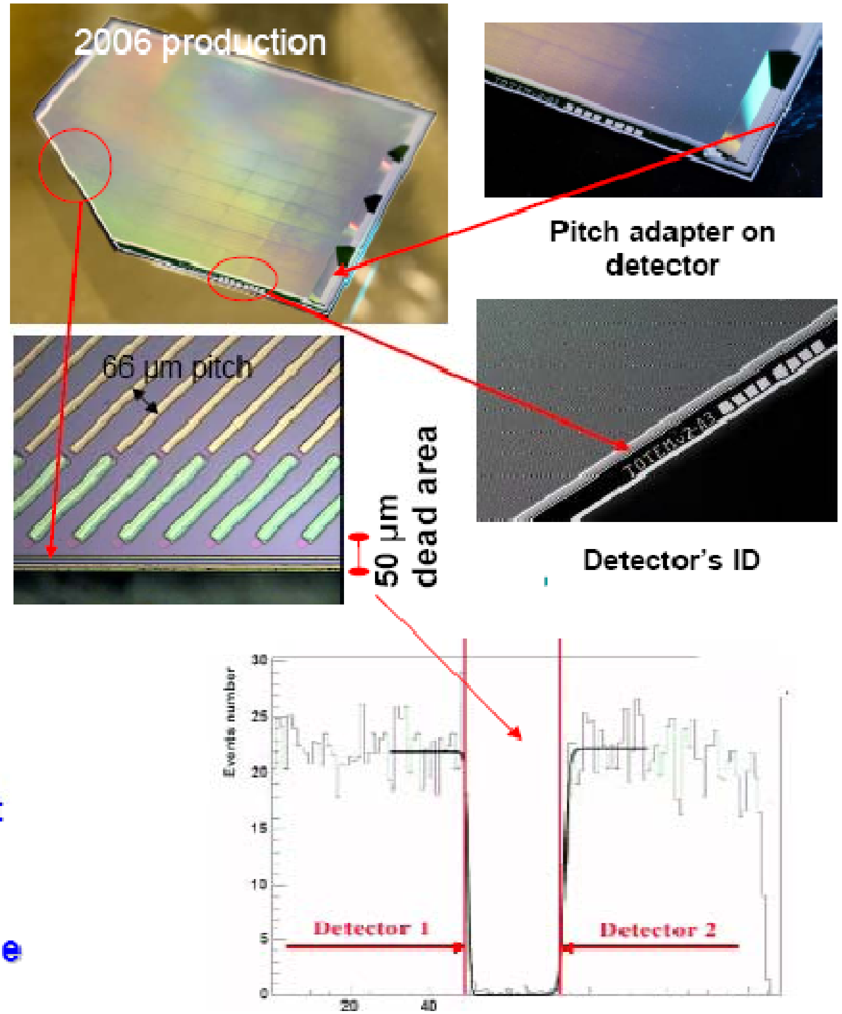
Edgeless detectors

Planar technology with CTS (Current Terminating Structure)



- AC coupled microstrips made in planar technology with novel guard-ring design and biasing scheme
- In production, all expected by June 2007
- First measurement of leakage current at CERN:

  60 nA at 200 V (excellent)
- Strong improvements on the cut at the sensitive edge



Physics program

- Total cross section with a precision of 1%
- Elastic pp scattering in a wide t-range $10^{-3} < |t| < 10$ GeV^2
- Soft single and central diffraction
- Low-x dynamics
- Charged particle multiplicity and energy flow in the forward direction
- Semi-hard and hard single and central diffraction: production of jets, W, heavy flavours, etc.
- Exclusive particle production in central diffraction
- $\gamma\gamma$ and γp physics

TOTEM

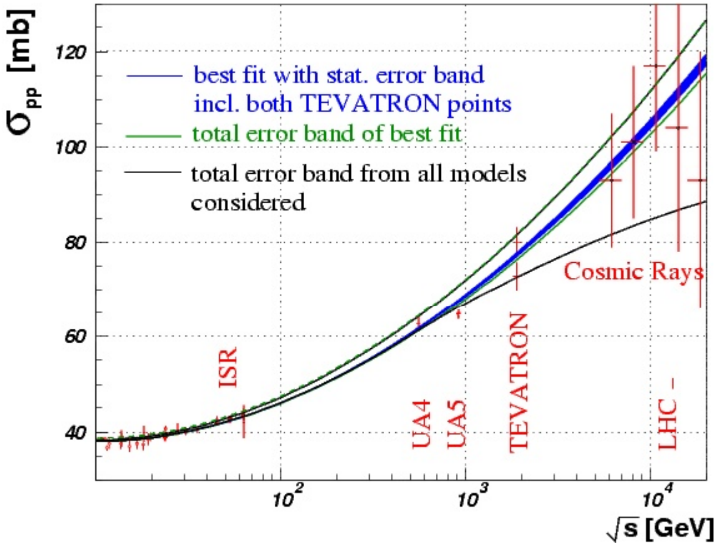
TOTEM + CMS

For the LHC start
Total cross section with a precision <5%
Multiplicity distributions
Diffraction at low/medium luminosity: SD and DPE

Running scenarios

Physics:	low |t| elastic, σ_{tot}, min bias	large |t| elastic	Soft diffraction	Soft & semi-hard diffraction
β^*[m]	1540 (90)	18, 2, 0.5	1540	90
N of bunches	43	2808	156	156
N of part. per bunch ($\times 10^{11}$)	0.3	1.15	(0.6 - 1.15)	1.15
Half crossing angle [μrad]	0	160	0	0
Transv. norm. emitt. [μm rad]	1 (3.75)	3.75	1 - 3.75	3.75
RMS beam size at IP [μm]	454 (200)	95	454 - 880	200
RMS beam diverg. [μrad]	0.29 (2.3)	5.28	0.29 - 0.57	2.3
Peak luminosity [$cm^{-2}\ s^{-1}$]	1.6 (7.3) $\times 10^{28}$	3.6 $\times 10^{32}$	2.4 $\times 10^{29}$	2 $\times 10^{30}$

Total cross section



Disagreement E811–CDF: 2.6 σ

Best combined fit by COMPETE:

$$\sigma_{tot} = 111.5 \pm 1.2 \; {}^{+4.1}_{-2.1} \text{ mb}$$

But models vary within (at least) ${}^{+10}_{-20}$ %.

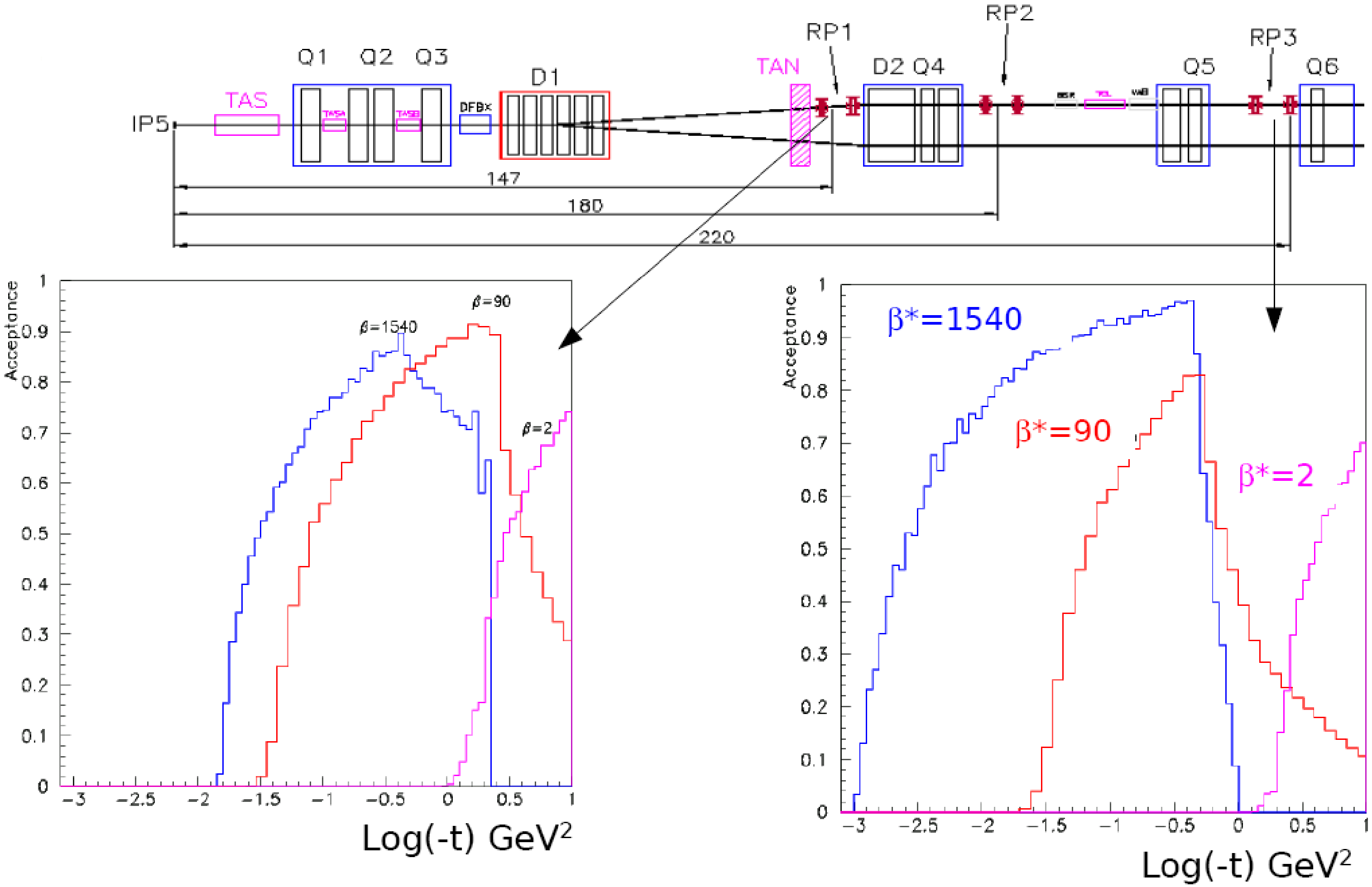
Luminosity independent measurement using the **Optical theorem**.

- Inelastic rate
- Elastic rate
- Extrapolation to the optical point
- ρ - COMPETE extrapolation $\rho = 0.1361 \pm 0.0015 \; {}^{+0.0058}_{-0.0025}$

} Depend on optics

Necessary optics with acceptance at low |t|:
β*=1540m (difficult to have at the beginning)
→ proposal: **β*=90m** (easier: un-squeezing of existing injection optics)

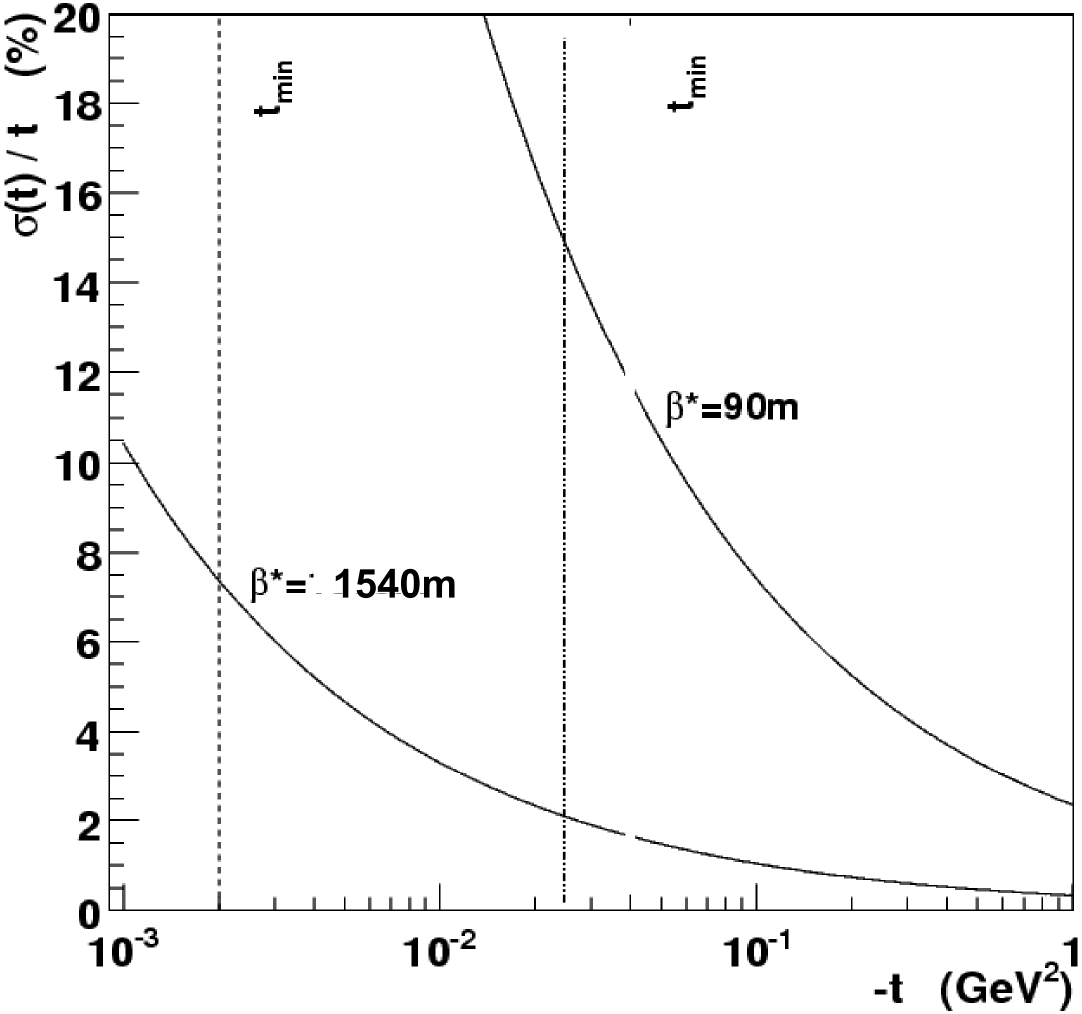
Elastic scattering: acceptance

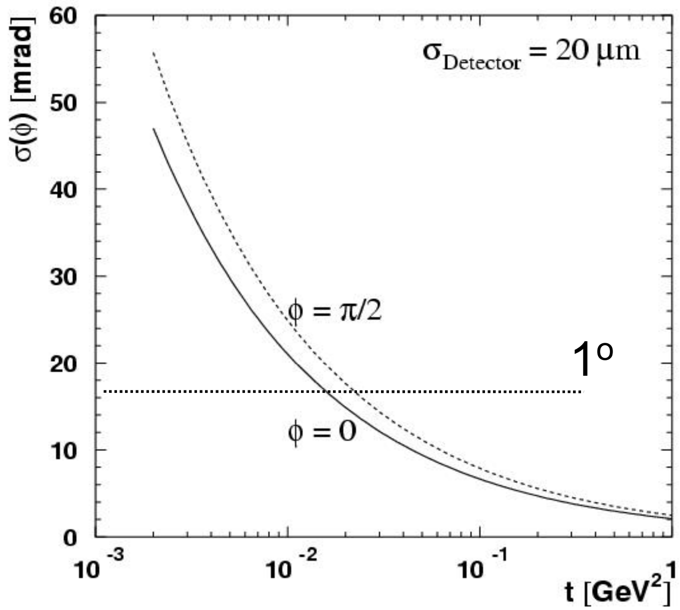


Good acceptance for high-t values

Parallel-to-point focusing

Elastic scattering: resolution

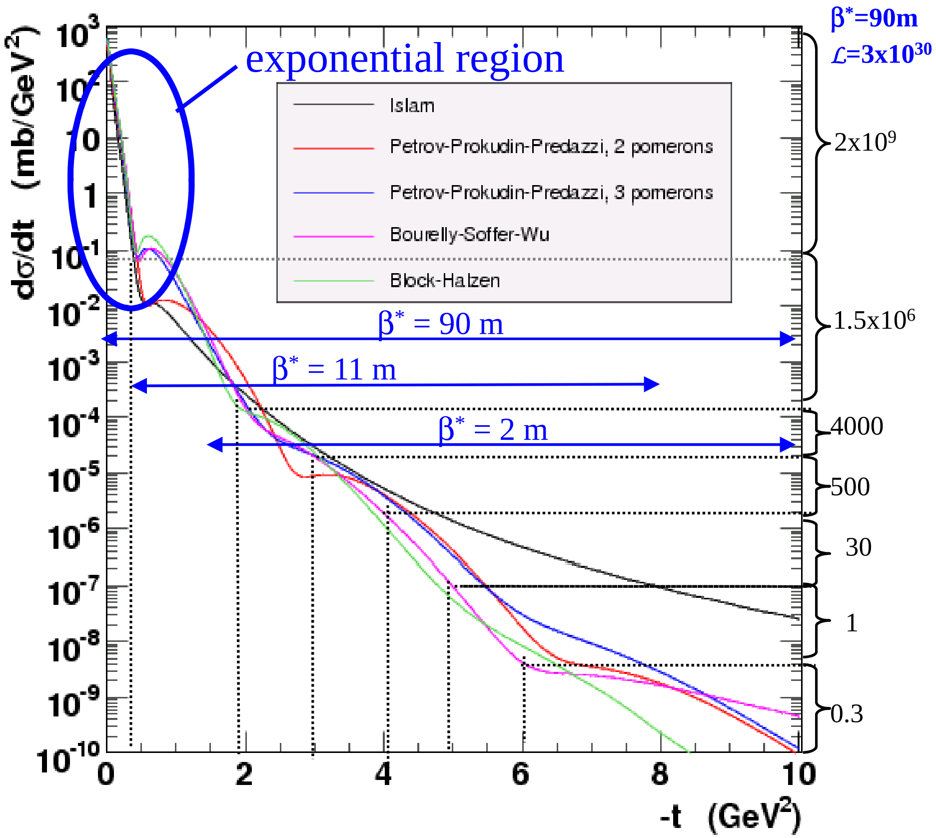


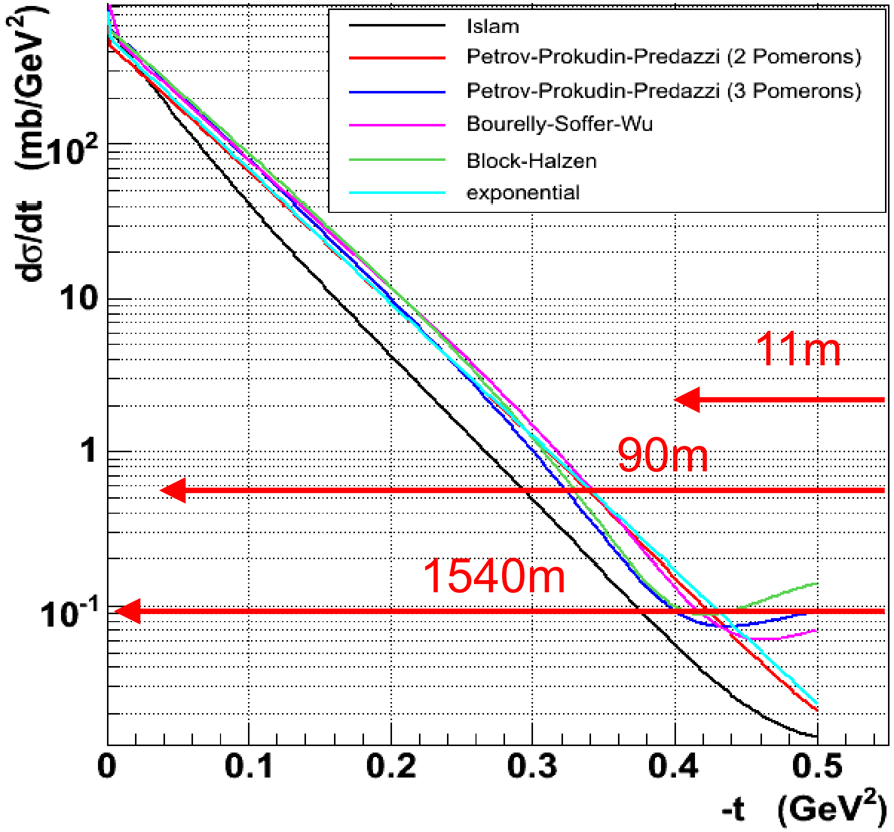


ϕ resolution: test collinearity of particles in the 2 arms
→ background reduction

Elastic scattering: event rate

Events (BSW model) at 220m in 1 nominal day (10^5) s

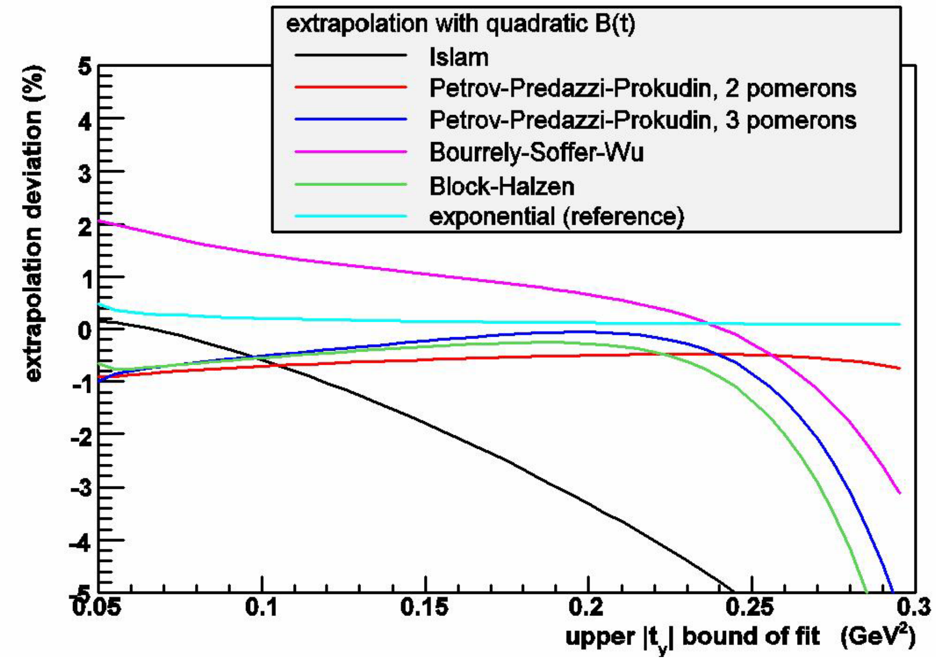




Proposal for early runs: Optics with $\beta^* = 90$ m

- |t|-acceptance down to 0.03 GeV^2 , covering well the exponential region of $d\sigma/dt$;
- beam rather thick (σ_y = 0.6 mm): $\delta t/t \propto \delta y/\sigma_y \Rightarrow$ RP position systematics less critical
- Typical luminosity L ~ $10^{29} – 10^{30}$ cm^{-2} s^{-1}

Systematic error of extrapolation of the elastic cross-section to t = 0:



Fitting function: $\frac{d\sigma}{dt} = A\,e^{B(t)\,t}$

with $B(t) = a + bt + ct^2$

Uncertainty < 5 % (most cases < 2 %)

(not as good as with $\beta^* = 1540$ m, but optics easier to commission → ideal for an early run)

Total event rates

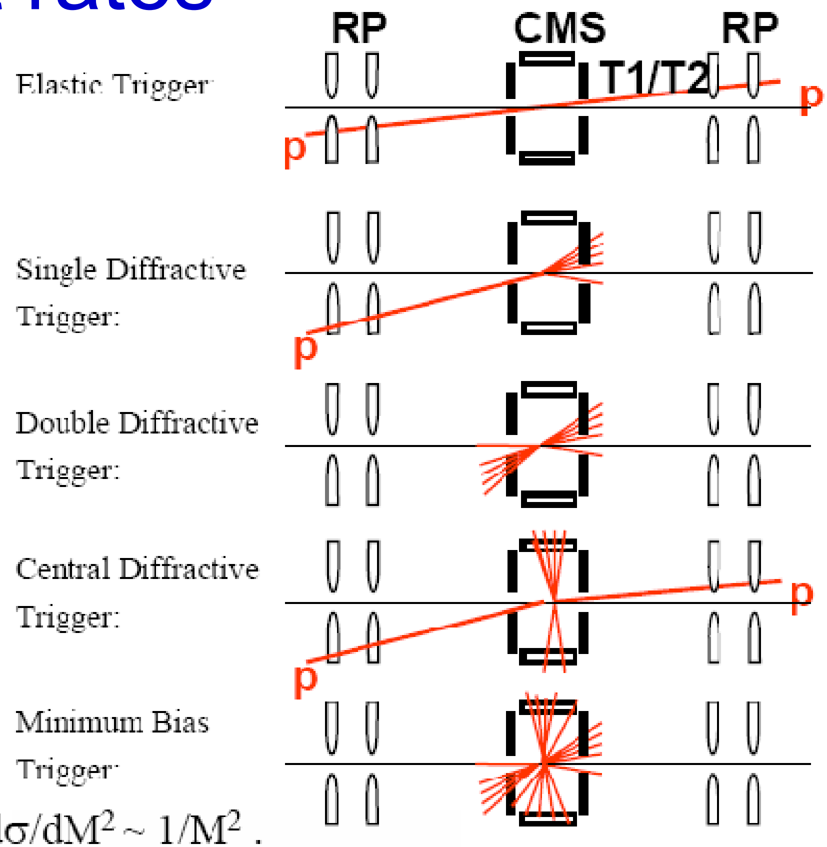
T1&T2 + RP provide fully inclusive trigger:

reconstruct primary vertex to discriminate against beam-gas interactions

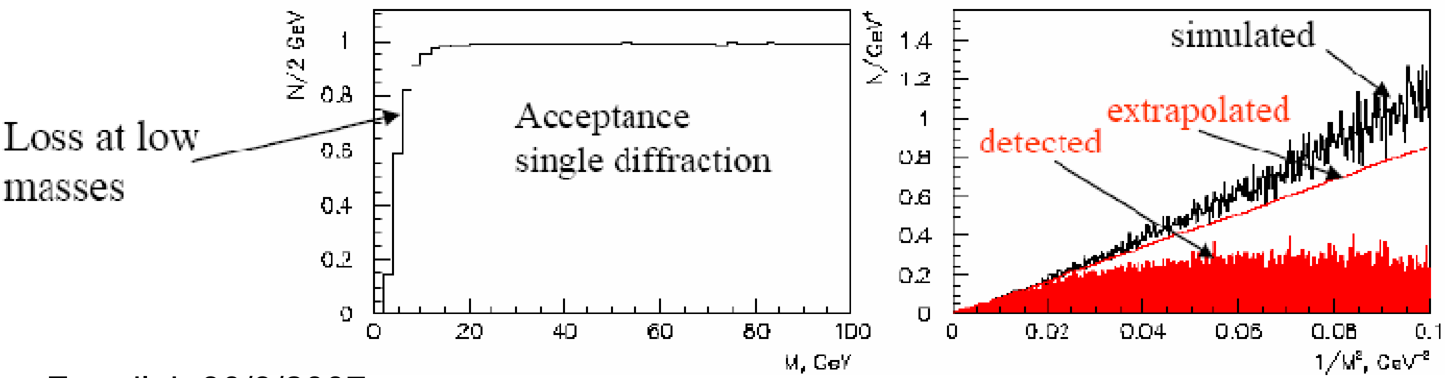
TOTEM Trigger efficiency:

SD: 82 %,

NSD > 99 % !



Extrapolation of SD cross-section to large $1/M^2$ using $d\sigma/dM^2 \sim 1/M^2$.



Error on σ_{tot}

Trigger losses for TOTEM minimum bias trigger

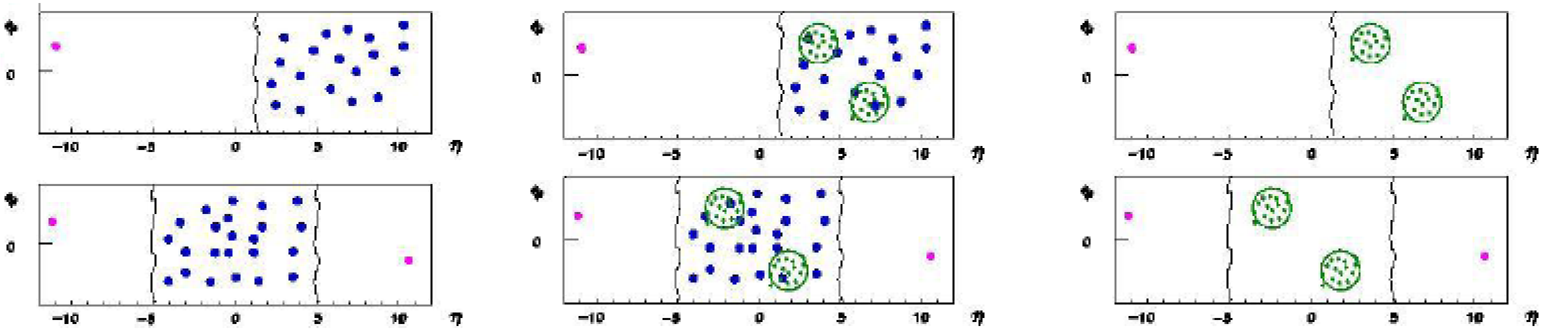
	σ [mb]	T1/T2 double arm trigger loss [mb]	T1/T2 single arm trigger loss [mb]	Systematic error after extrapolation [mb]
Minimum bias	58	0.3	0.06	0.06
Single diffractive	14	–	3	0.6
Double diffractive	7	2.8	0.3	0.1
Double Pomeron	1	0.2		0.02
Elastic Scattering	30	–	–	0.2 (0.6)

β* = 1540 m β* = 90 m

Error on extrapolation to t=0:
- ~0.5% @ β* = 1540 m
- 3 – 5% @ β* = 90 m

Error on σ_{tot}
- ~1 % @ β* = 1540 m
- 3 – 5 % @ β* = 90 m

Diffraction: running scenario



pp->pX pp->pXp	pp->pjjX pp->pjjXp	pp->pjj (bosons, heavy pp->pjjp quarks,Higgs...
soft diffraction	(semi)-hard diffraction	hard diffraction

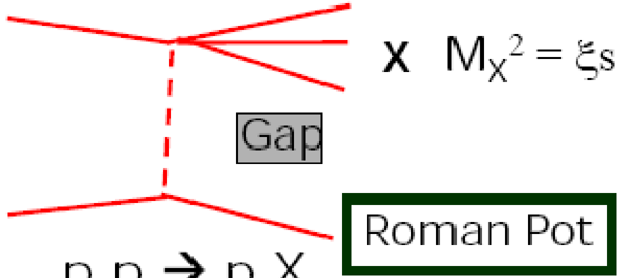
Cross section ← → Luminosity

σ	mb	μb	nb	
β* (m)	1540	90	2	0.5
L (cm^{-2} s^{-1})	10^{28}	10^{30}	10^{32}	10^{34}
	TOTEM runs		Standard runs	

Physics that can be studied depends on luminosity and optics (acceptance)

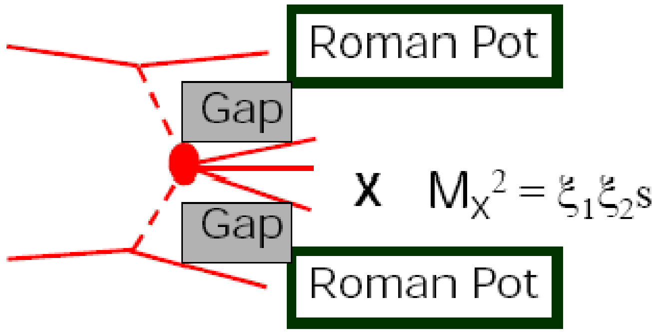
Diffraction at low luminosity: soft diffraction

Single diffraction:



p p → p X

Central diffraction:



p p → p X p

Inclusive cross sections & their t, M_X dependence

Event topology

Measure ξ and central mass via:

- proton(s)
- rapidity gap relation $\Delta\eta = -\ln\xi$
- calorimeters

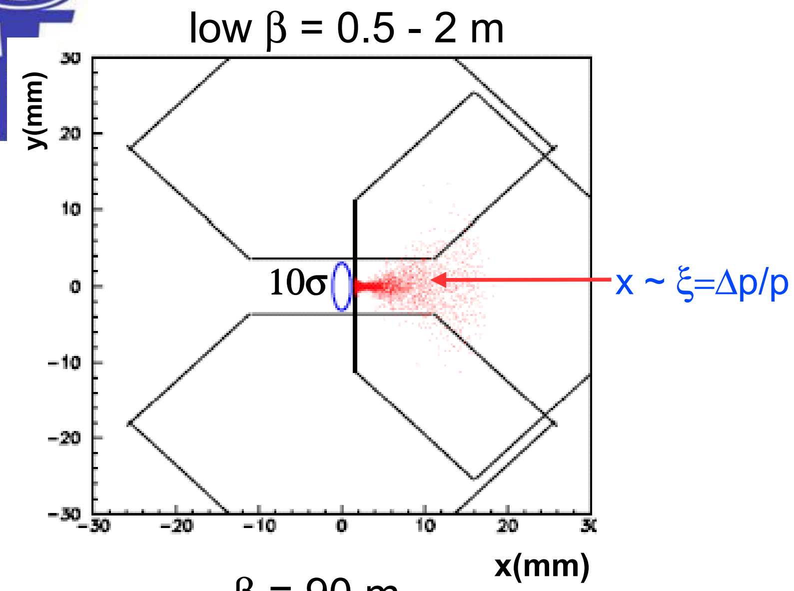
$$\xi^{\pm} = \Sigma_i E_T^i e^{\pm\eta_i} / \sqrt{s}$$

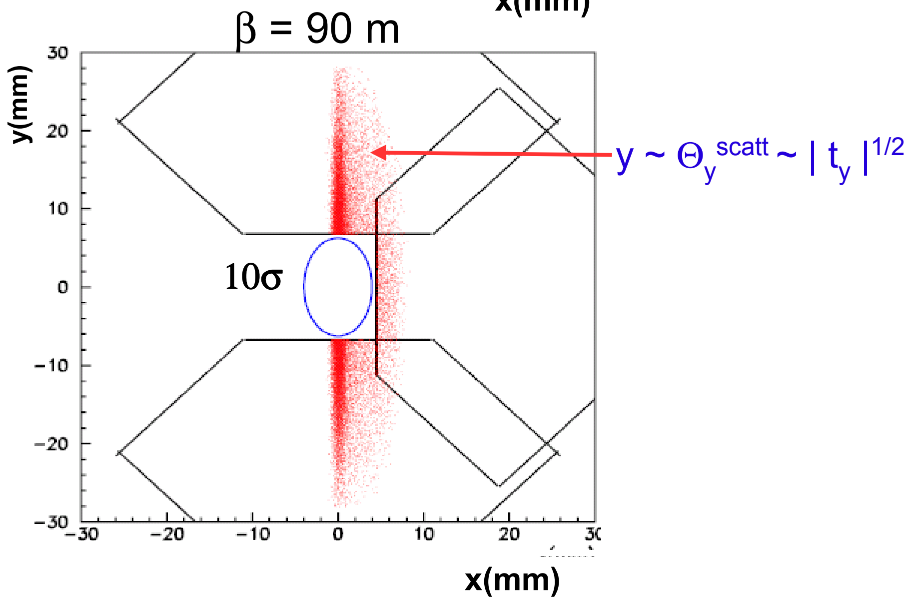
} with CMS

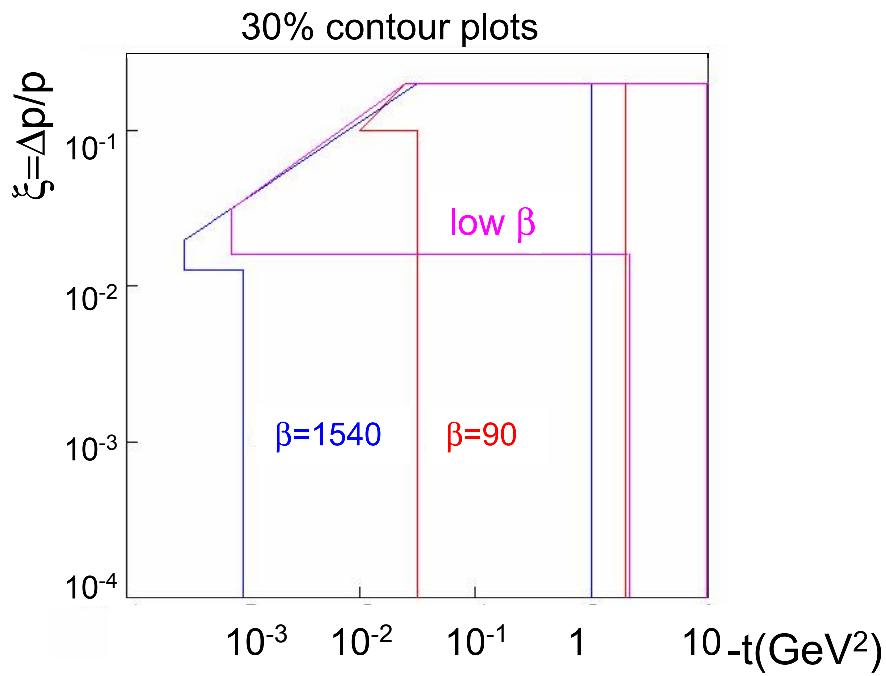
Wide t & ξ acceptance range with TOTEM optics

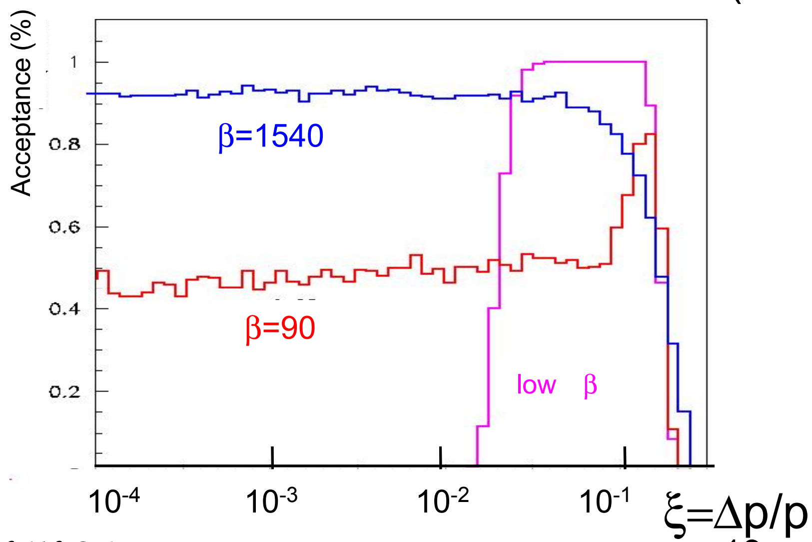
Soft diffraction important contribution to pile-up at high luminosity

Measurement of forward protons







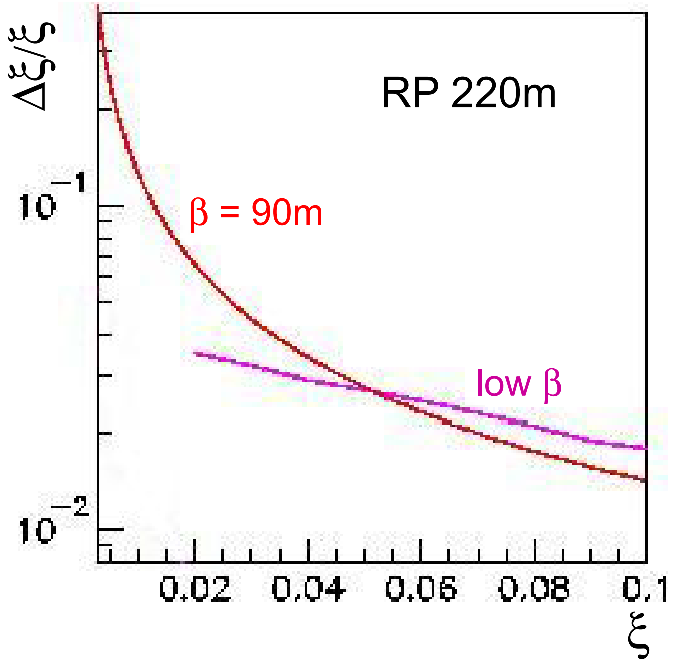


Double Pomeron Exchange (DPE) at low/medium luminosity

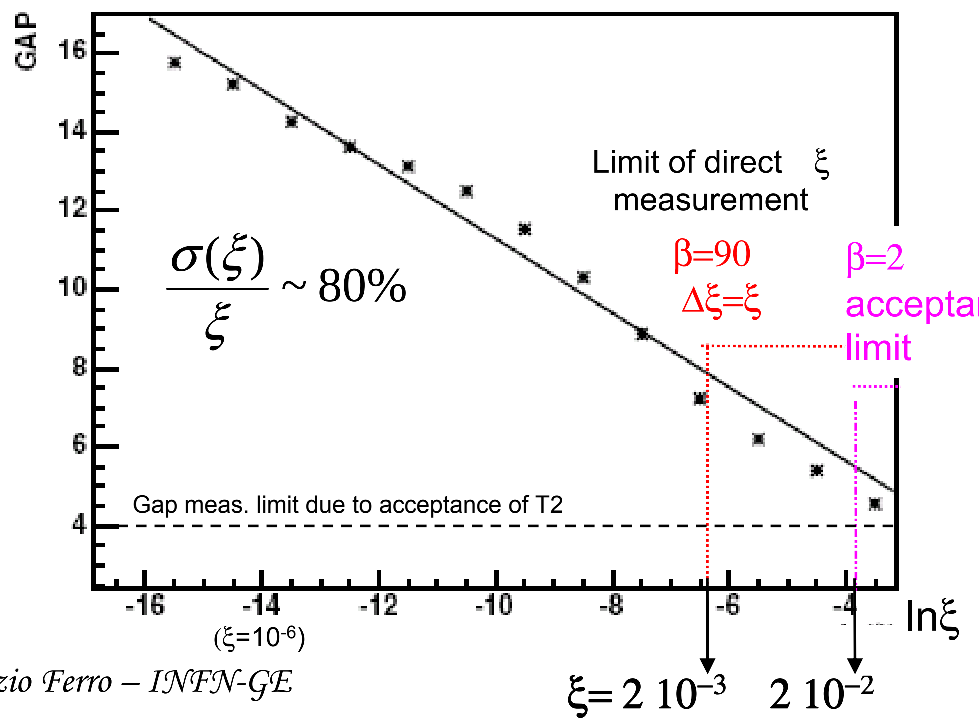
- Study of mass distributions via the 2 protons
  - trigger with 2p+T1/T2: rate ~200Hz @ β*=90m, L=10^{30}cm^{-2}s^{-1} (TOTEM limit ~2kHz)
- ξ measured directly (TOTEM) or
  - With rapidity gap Δη=-ln ξ
  - With calorimeters $\xi = \sum_i E_T^i e^{\mp\eta_i} / \sqrt{s}$

  } (TOTEM+CMS)

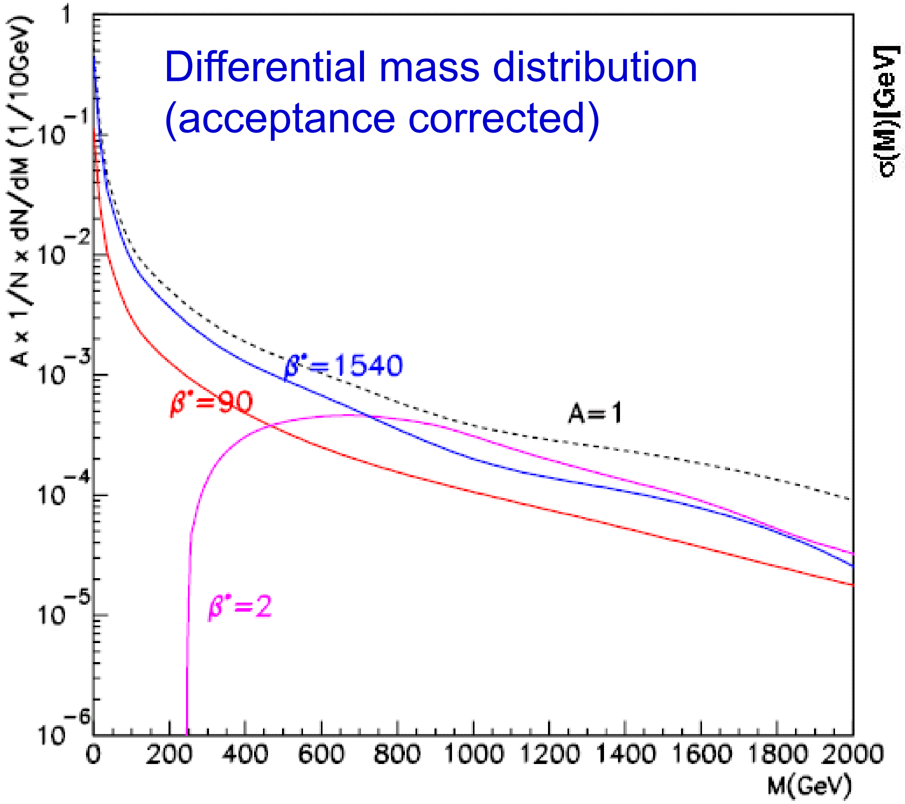
ξ resolution form direct measurement



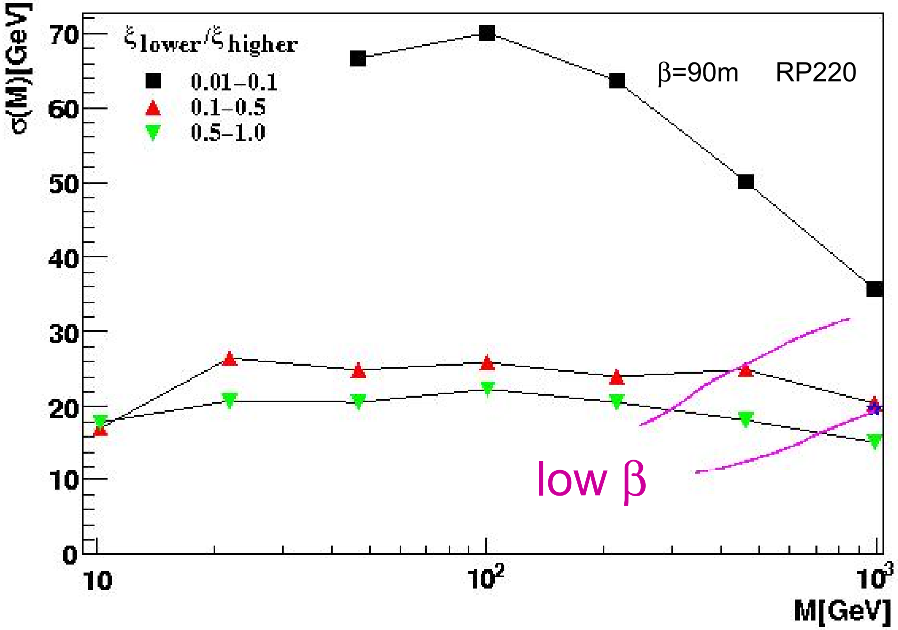
Gap vs ln (ξ) T1+T2+Calorimeters



Differential mass distribution in DPE



Mass resolution



Best resolution for symmetric events

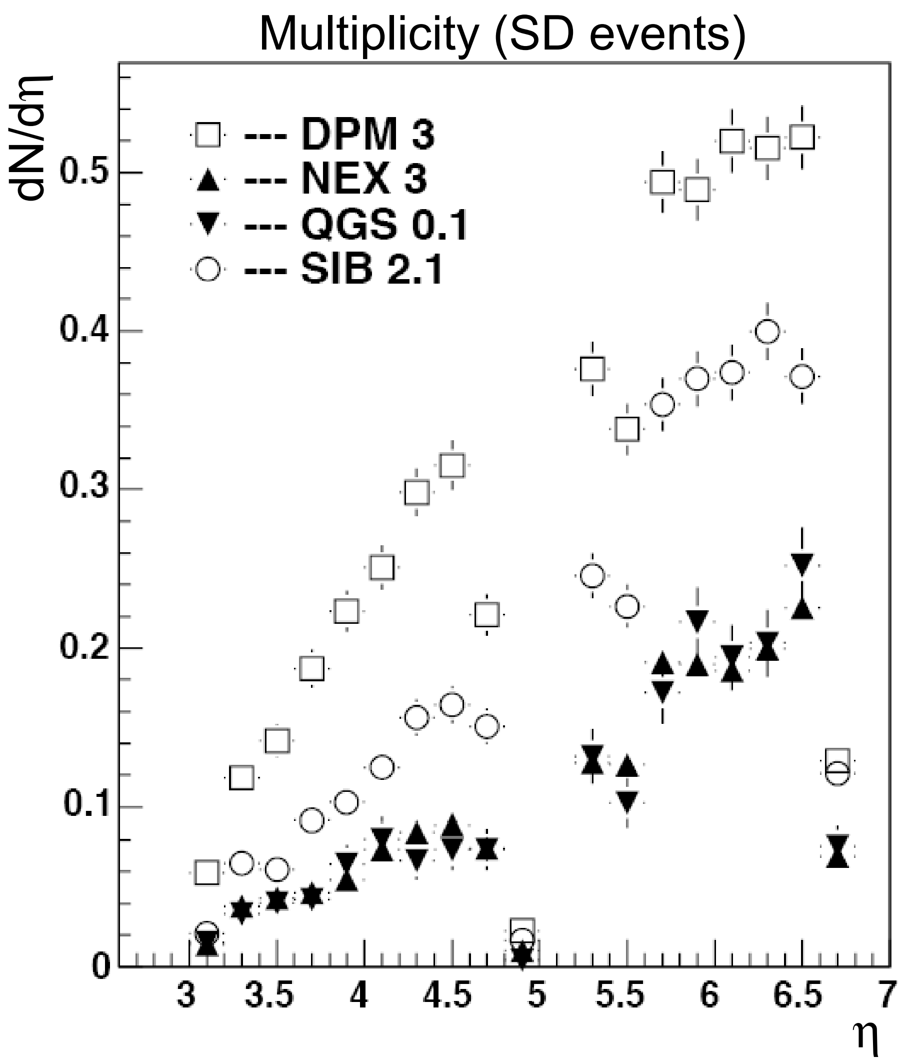
Events in 10^5 s:

β*=90m (L=10^{30}) → ~2·10^7 events in 1<M<2000 GeV

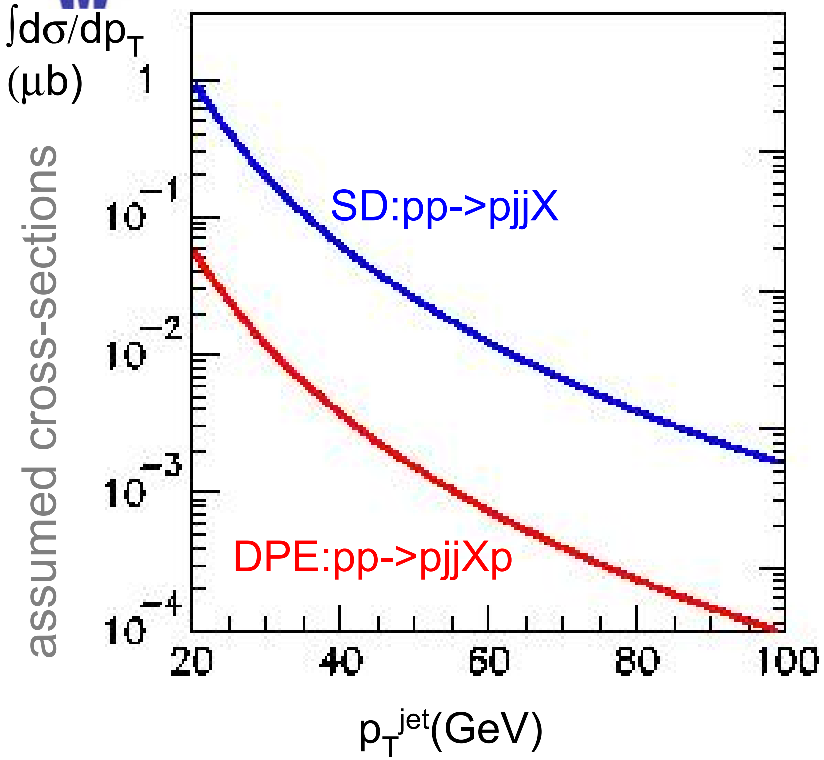
β*=2m (L=10^{32}) → ~10^8 events in 300<M<2000 GeV

Forward multiplicity: connection with cosmic rays physics

- Models used in hadronic simulation programs differ by more than a factor 2.
- Necessary measurement of forward particle and energy flow.
- SD events trigger: p+T1/T2 (opposite side)
- Study in details SD events



Diffraction at low luminosity (with CMS): semi-hard diffraction (SD and DPE)



In case of jet activity ξ can also be determined from calorimeter info:

$$\xi^{\pm} = \Sigma_i E_T^i e^{\pm\eta_i} / \sqrt{s}$$

$$\sigma(\xi)/\xi \sim 40\ \%$$

Measure the cross sections and their *t, M_X , p_T^{jet}* dependence

Event topology: exclusive vs inclusive jet production

		N event collected [acceptance included]
β^*=90m	**$\int Ldt$ = 0.3 (pb^{-1})**	
SD:	p_T>20 GeV	6×10^4
DPE:	"	2000
β^*=2m	**$\int Ldt$ = 100 (pb^{-1})**	
SD:	p_T>50 GeV	5×10^5
DPE:	"	3×10^4

Summary

- To measure Total Cross Section with 1% precision TOTEM needs β^*=1540m optics
- During first running (2008) an intermediate β^*=90m optics could be achieved un-squeezing the existing injection optics. In a few days TOTEM could measure σ_{tot} with (better than) 5% precision
- TOTEM and CMS can measure together at low and medium luminosity:
  - Inclusive diffractive processes from low masses up to a few TeV
  - Diffractive event topologies using rapidity gaps & calorimetry and correlated with leading proton measurements
  - Forward particle multiplicity as input for cosmic ray modelling
  - Inclusive diffractive p_T^{jet} cross section from ~20 GeV onwards by combining measurements from runs at different β^*'s