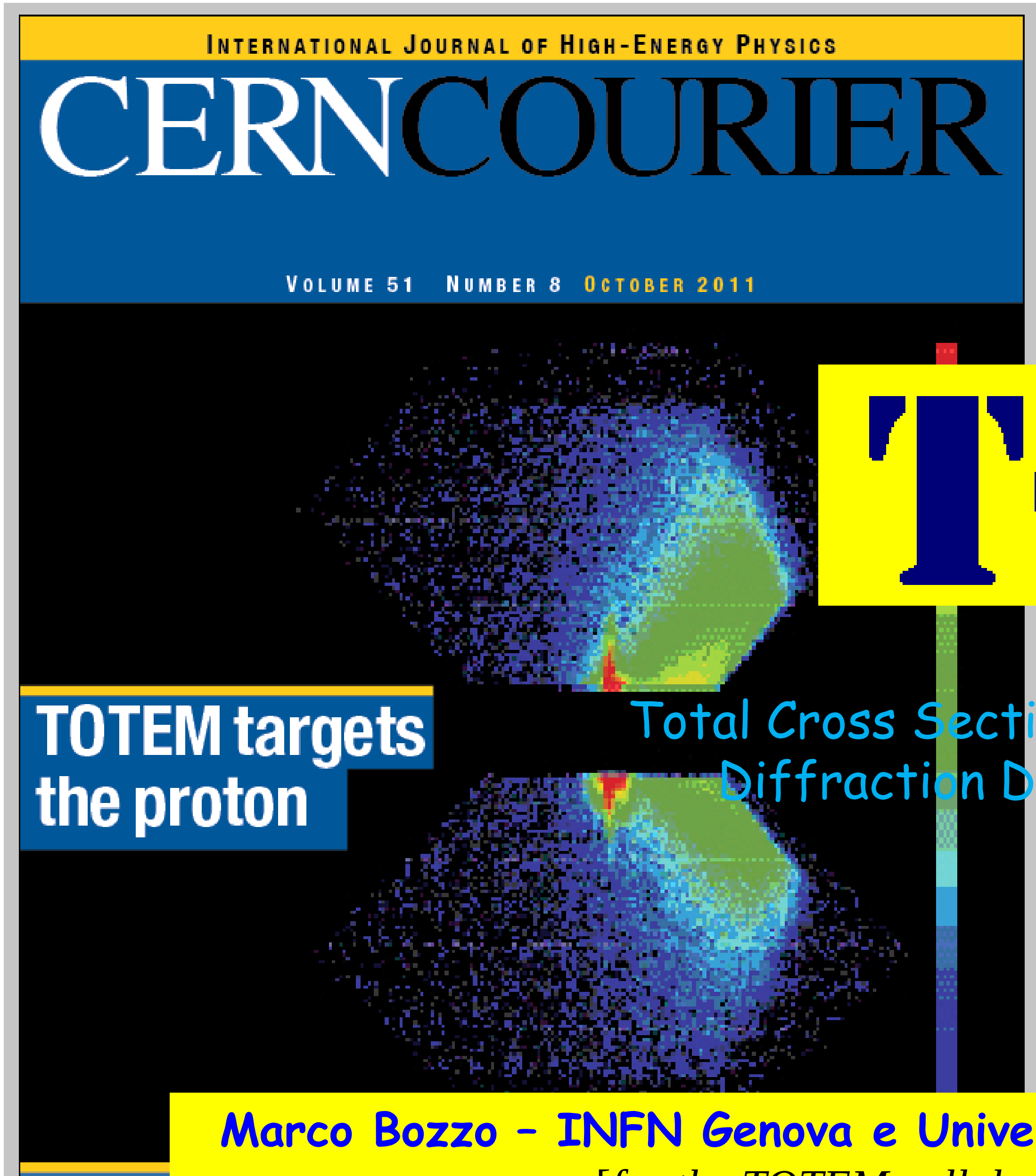


TOTEM

Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC

Marco Bozzo – INFN Genova e Universita' di Genova (Italy)

[for the TOTEM collaboration]

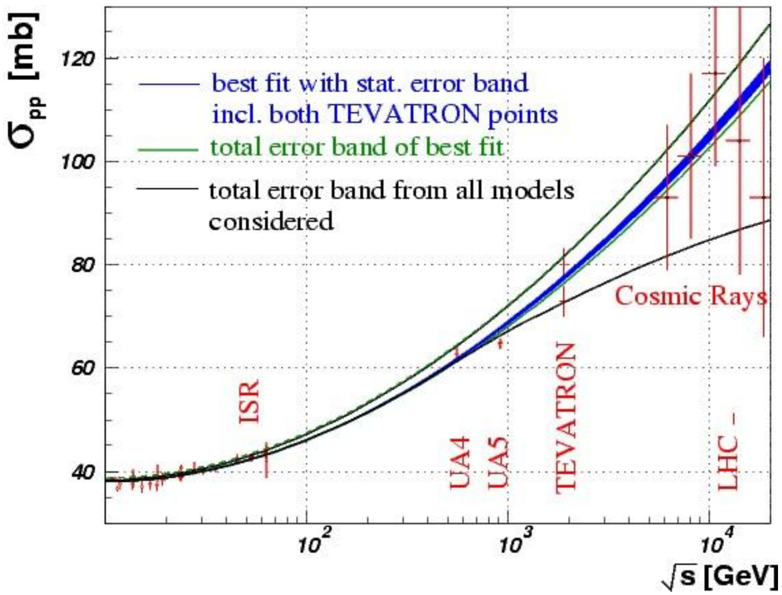
Outlook

- The TOTEM experiment
- LHC special runs and TOTEM data
- pp elastic scattering differential cross-section
  - *Large t* (0.36-2.5 GeV^2)
  - *Small t* (0.02-0.33 GeV^2)
- Total, elastic, and inelastic cross-sections
- Perspectives on diffractive physics & cross-sections

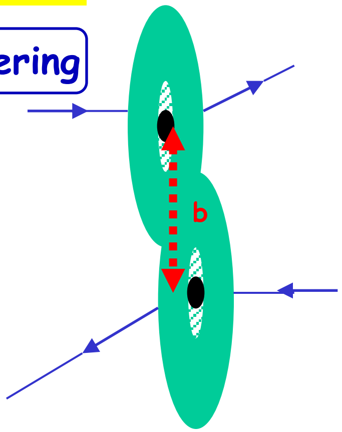
TOTEM EXPERIMENT

TOTEM Physics Overview

Total cross-section



Elastic Scattering



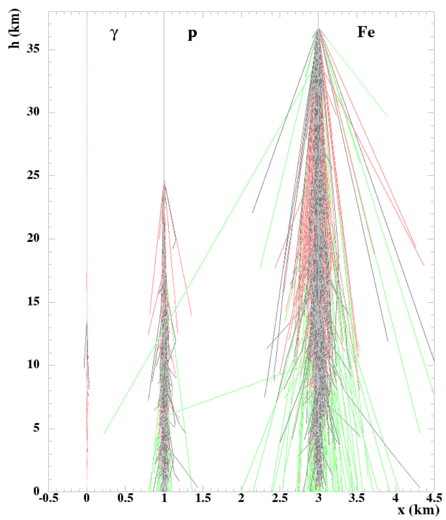
$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

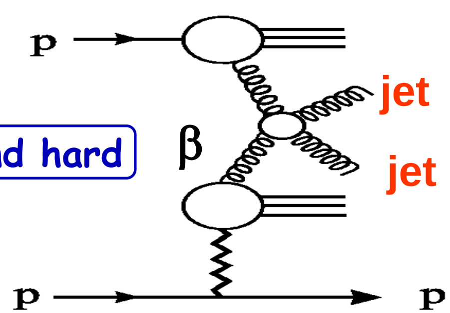
Optical Theorem

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{\left.(dN/dt)\right|_{t=0}}{N_{el} + N_{inel}}$$

Forward physics



Diffraction: soft and hard

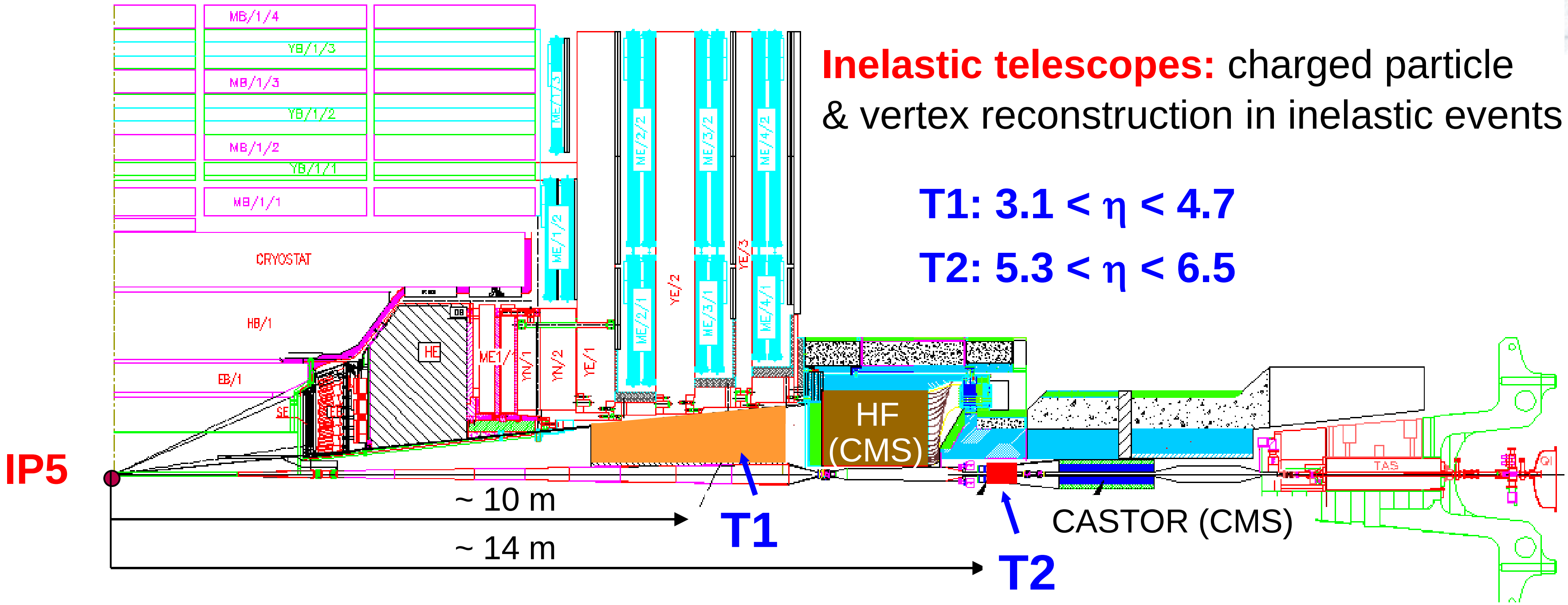


Experimental Setup @ IP5

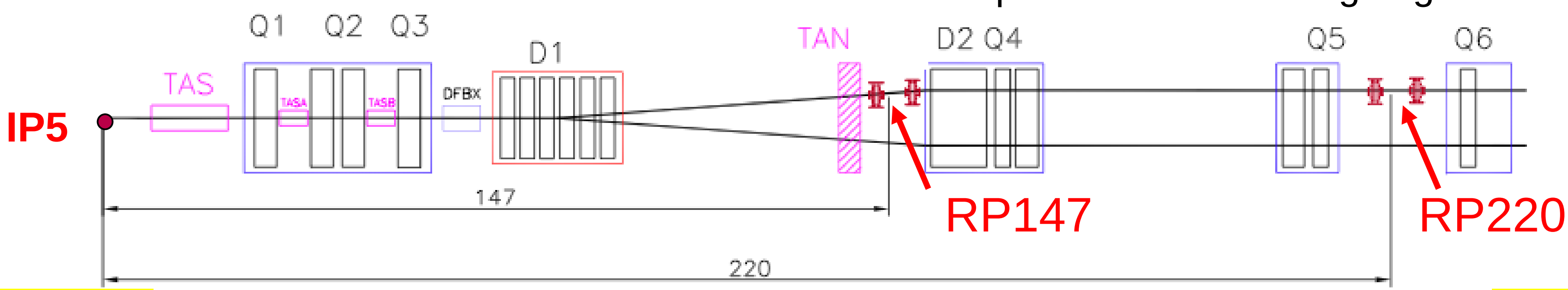
Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

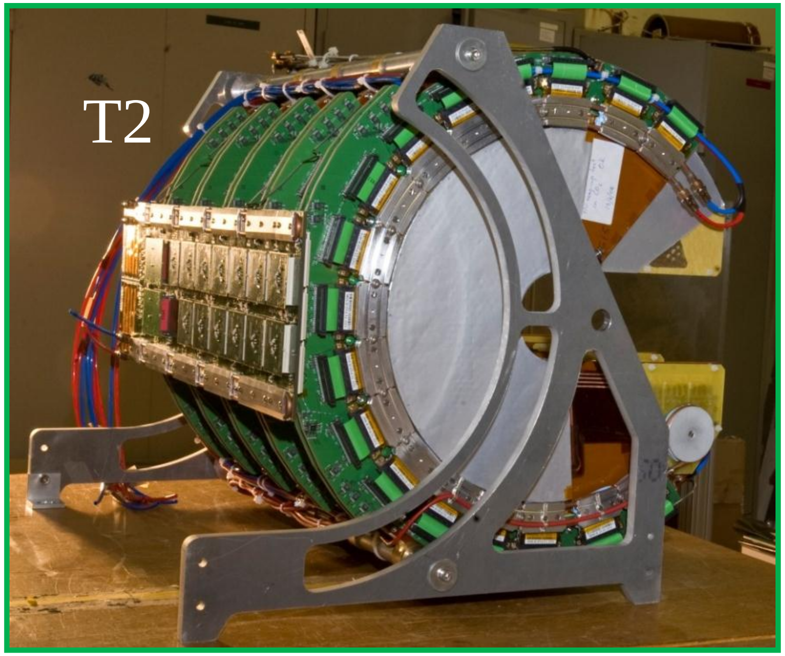
T1: 3.1 < η < 4.7

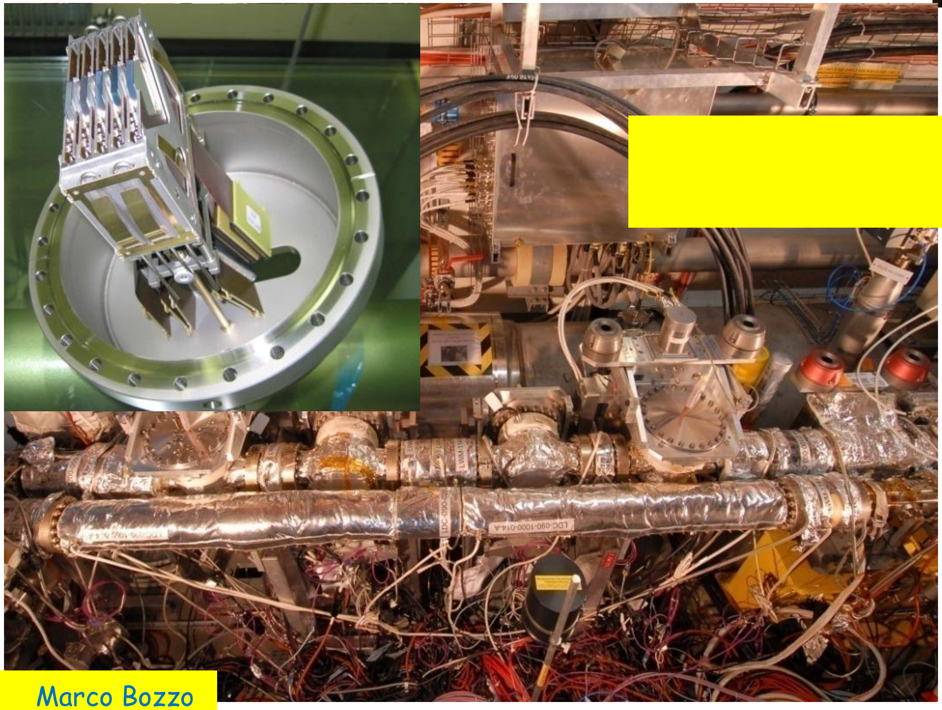
T2: 5.3 < η < 6.5



Roman Pots: measure elastic & diffractive protons close to outgoing beam







Detectors

- T1 and T2 detectors are installed and fully operational
- 220 m Roman Pot Silicon detectors are fully operational
- 147 m Roman Pot detectors are installed and tested

TOTEM nella regione forward di CMS

T1 Telescope $3.1 \leq \eta \leq 4.7$

5 CSC planes

Anode wires and both cathode strips

T2 Telescopio $5.3 \leq \eta \leq 6.5$

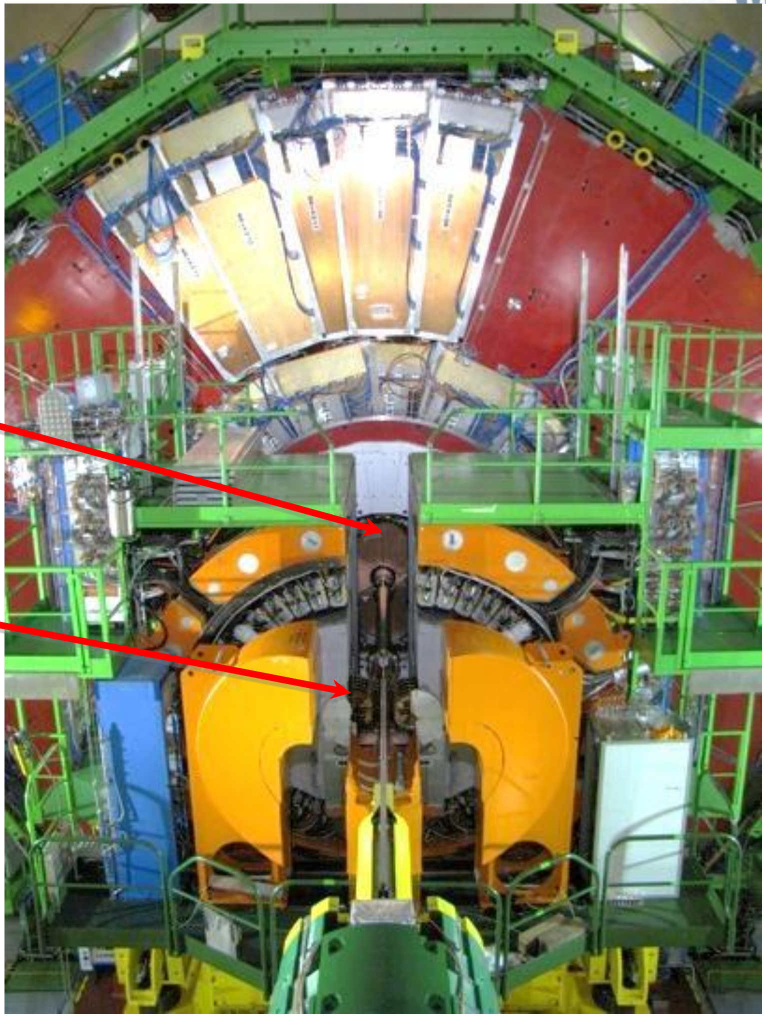
10 GEM planes

Strips and pads

Roman Pots $\sim 9.5 \leq \eta \leq \sim 11$

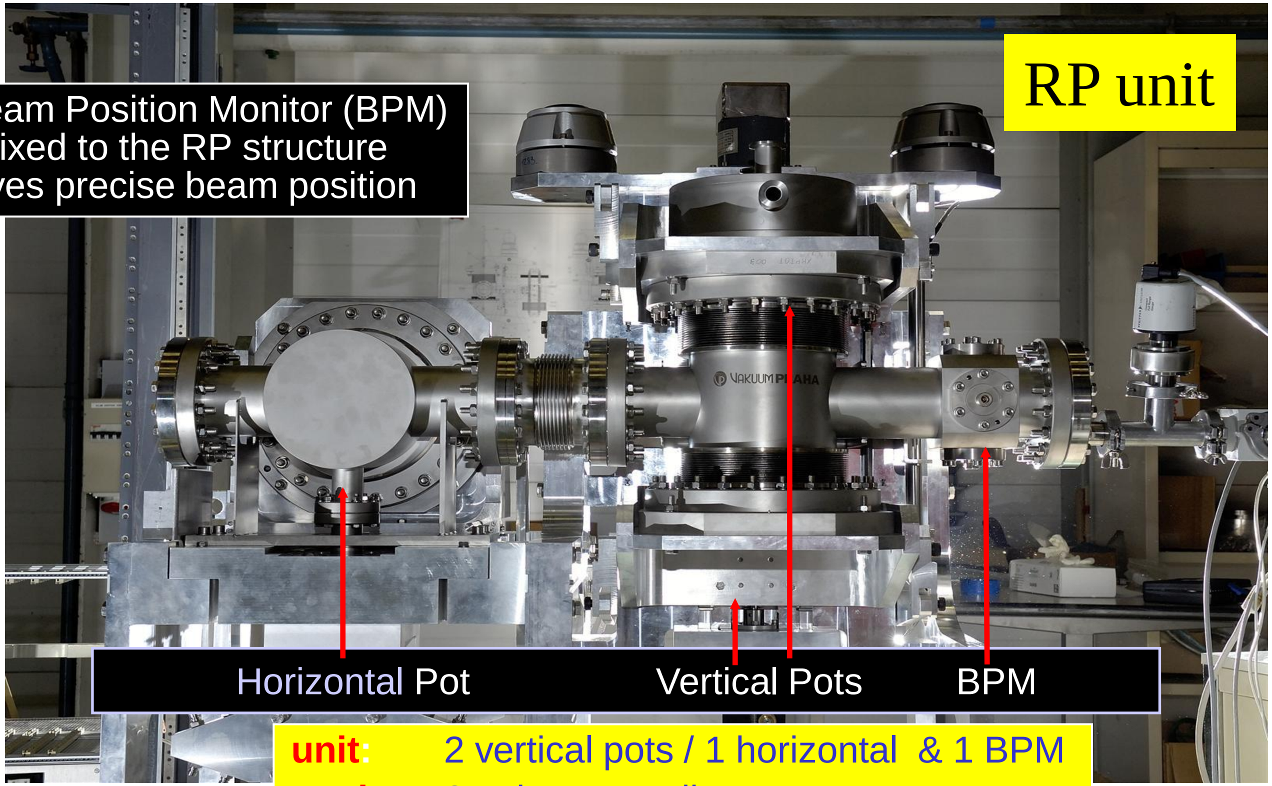
10 Si planes

u and v strips

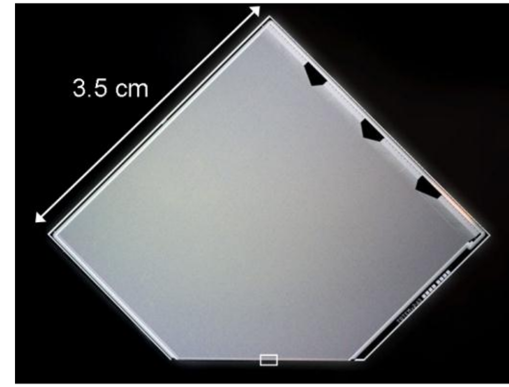


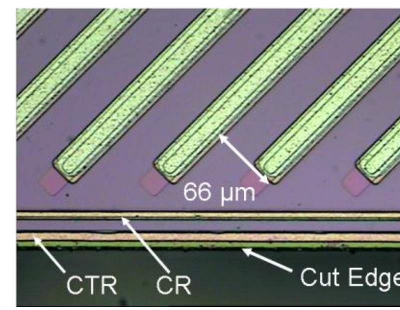
200 m away !

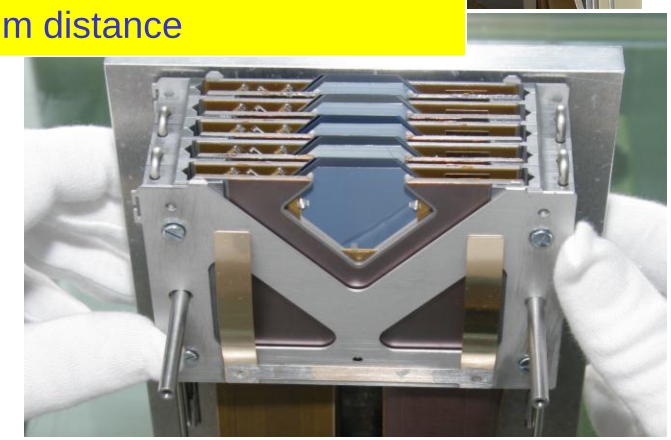
The Roman Pots



unit: 2 vertical pots / 1 horizontal & 1 BPM
station: 2 unit, at 4 m distance



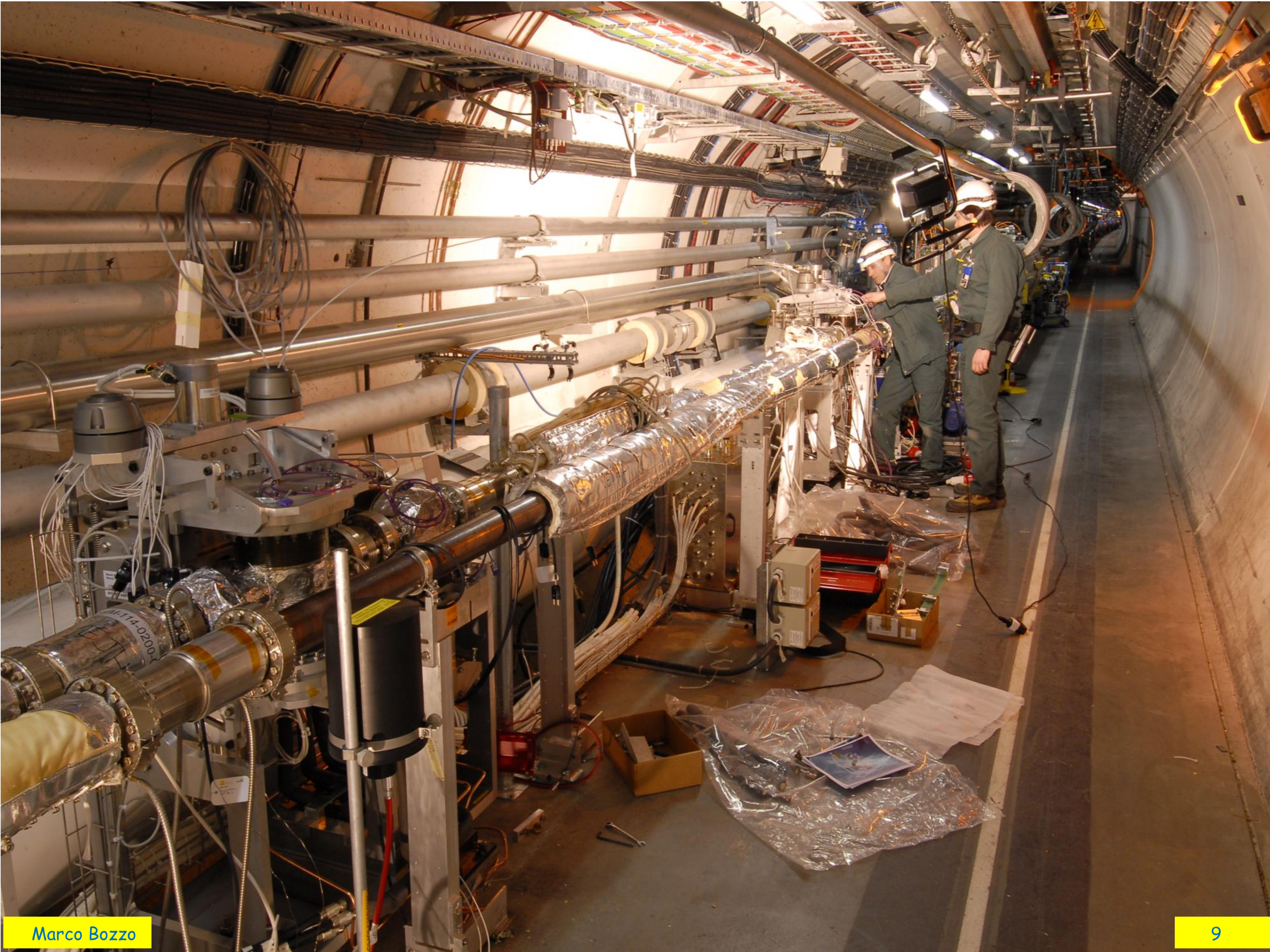




Detectors in 1 Pot

- 10 Si detector planes
- 512 strips at ± 45°
- Pitch: 66 µm
- Resolution: ~ 20 µm

Special development:
Detectors are efficient already 50 µm from mechanical edge

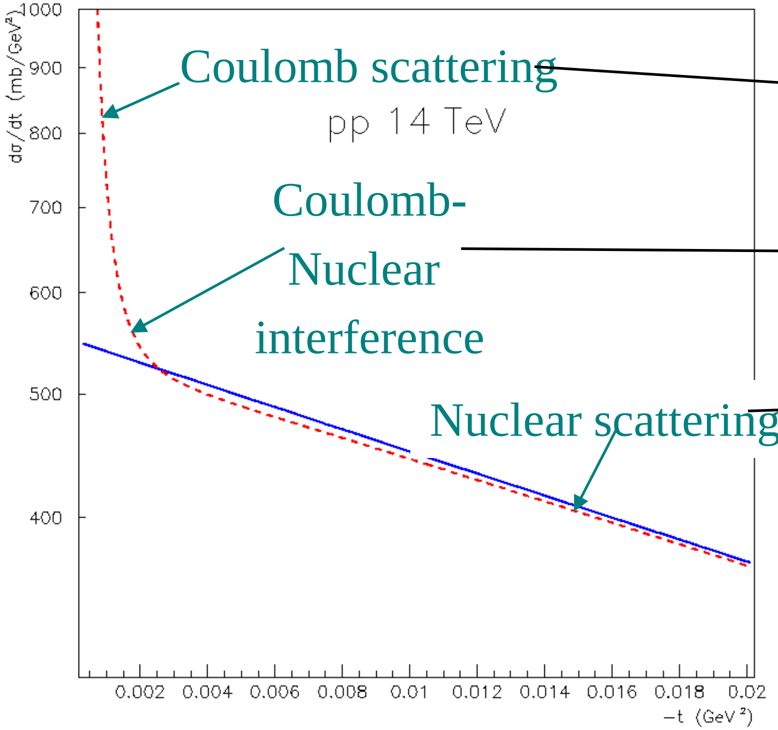


pp ELASTIC SCATTERING and TOTAL CROSS-SECTION

t-range: **0.36 – 2.5 GeV^2**

0.02 – 0.33 GeV^2

Determination of dσ/dt at t=0



$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2(\hbar c)^2 G^4(t)}{|t|^2} + \frac{\alpha(\rho-\alpha\phi)\sigma_{tot}G^2(t)}{|t|}e^{-B|t|/2} + \frac{\sigma_{tot}^2(1+\rho^2)}{16\pi(\hbar c)^2}e^{-B'|t|}$$

a = fine structure constant

ϕ = relative Coulomb-nuclear phase

G(t) = nucleon em form factor = $(1 + |t|/0.71)^{-2}$

ρ = Re/Im f(**p**←**p**)

Measure the exponential slope B in the t-range 0.002 - 0.2 GeV²

Requires beams with tiny angular spread (or large β*)

A special optics has to be implemented in the LHC

Special Optics with large β and low ε*

A precise measurement of scattering angles down to a few μrad requires a very large β*

beam angular spread:
$\sigma(\theta^*) = \sqrt{\varepsilon / \beta^*}$ = 0.3 μrad

beam size at the IP:
$\sigma^* = \sqrt{\varepsilon \beta^*}$ = 0.4 mm (large)

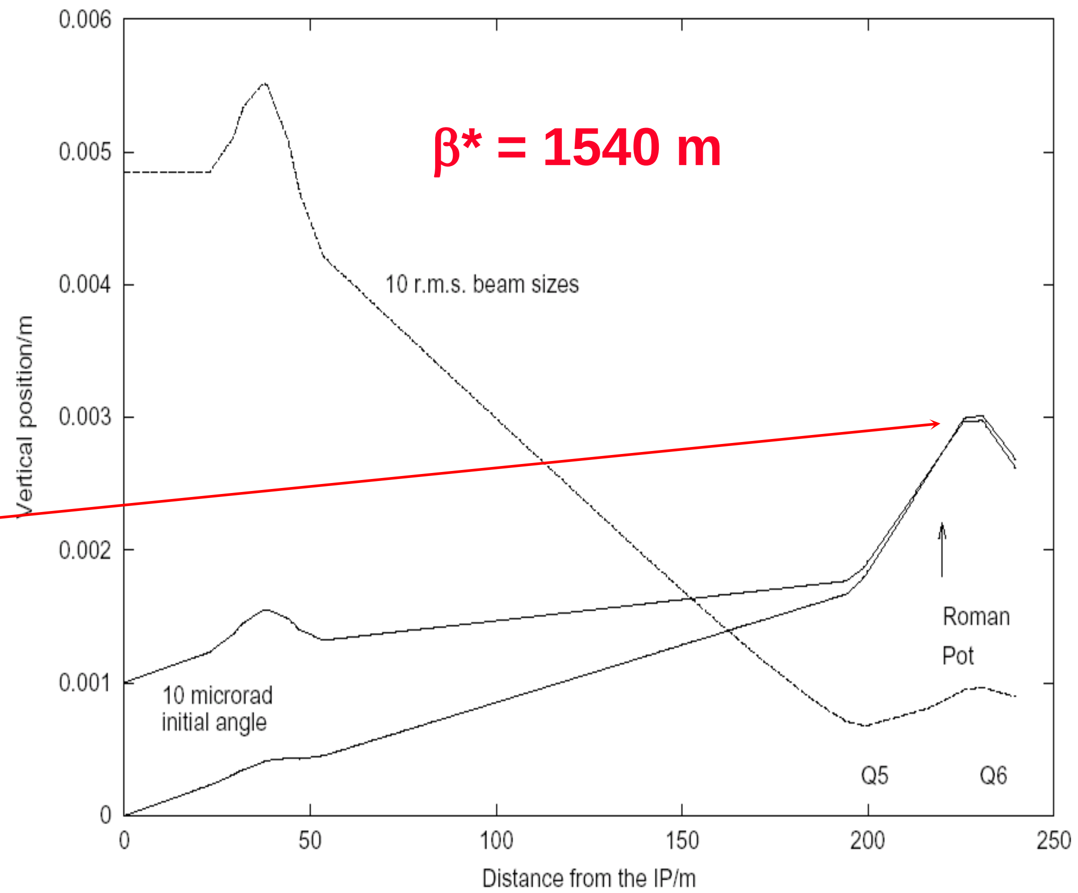
⇒ **Large beam size requires parallel-to-point focussing**

⇒ **Independence of measurement from vertex position**

Min detector distance from the beam determines minimum t.

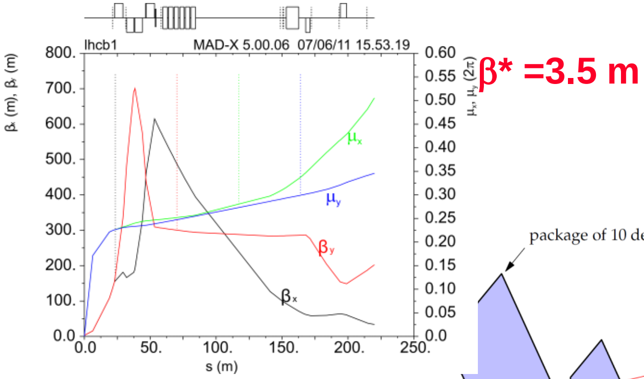
=> Si-detector as close as possible to the beam

(NEEDS edgeless detectors!)

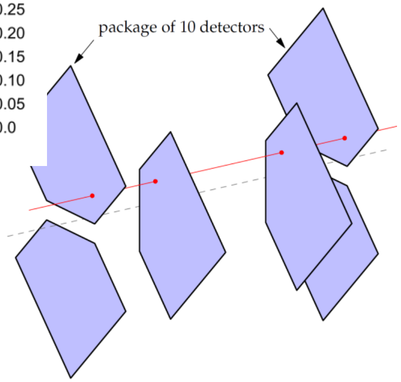


Proton reconstruction

- **Both scattering angle projections reconstructed: Θ_x^* and Θ_y^***
  - Θ_x^* from Θ_x @ RP220 (through dL_x/ds) $\Theta_x = dL_x/ds\ \Theta_x^*$
  - Θ_y^* from y @ RP220 (through L_y) $y = L_y\ \Theta_y^*$



→ **Excellent beam optics understanding**
- Magnet currents measured
- Measurements of actual beam optics parameters with elastic scattering
  - $\Theta_{left}^* = \Theta_{right}^*$ (proton pair colinearity)
  - Proton position ↔ angle correlations
  - L_x=0 determination, coupling corrections



Track based alignment

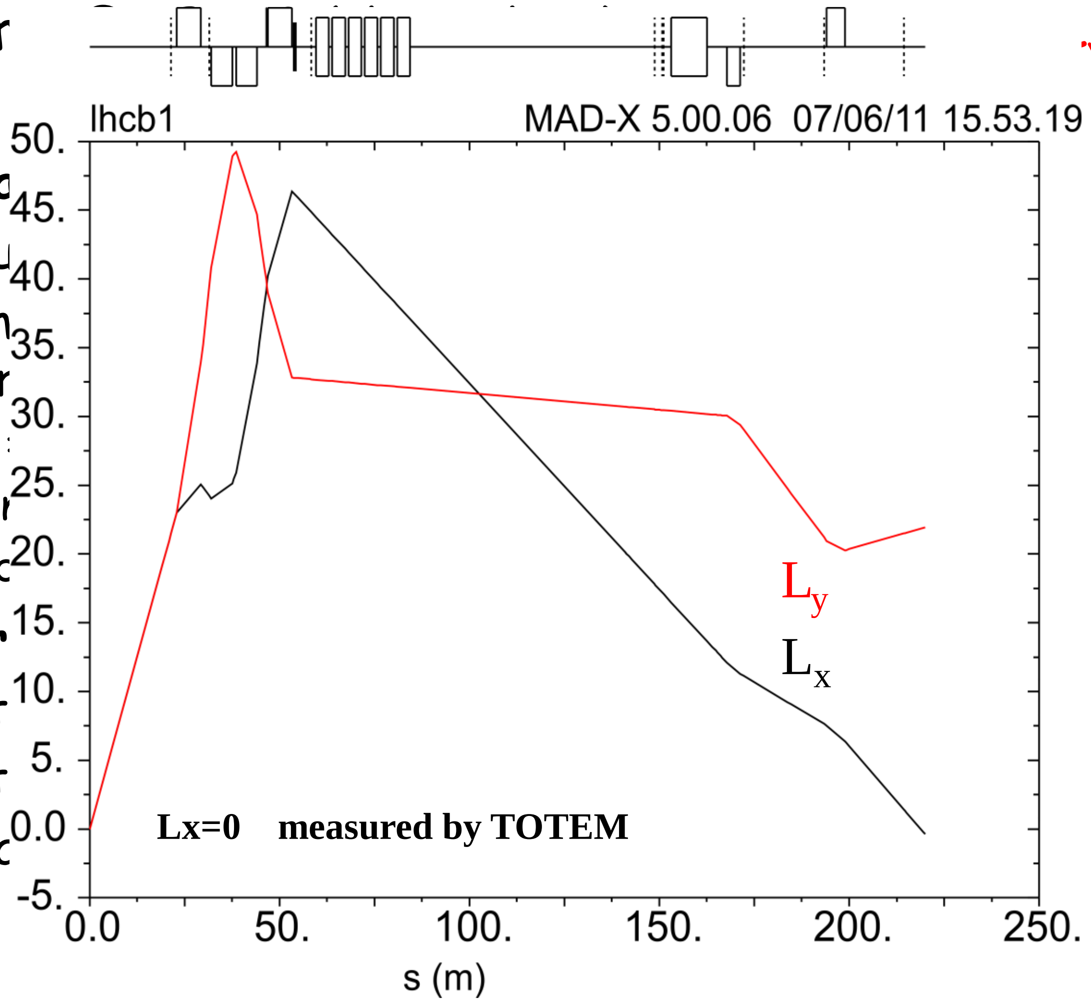
→ **Fine geometric alignment**
- Alignment between pots with overlapping tracks (~1μm)
- Alignment with respect to the beam – scraping exercise (~20μm)
- Mechanical constraints between top and bottom pots (~10μm)

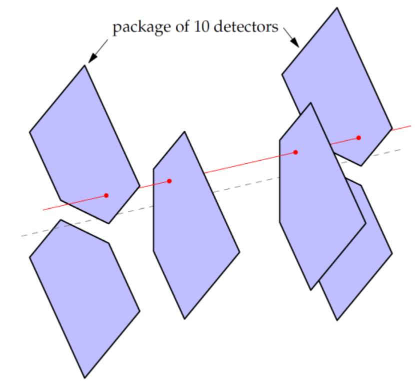
Proton reconstruction

- **Both scattering angle projections reconstructed: Θ_x^* and Θ_y^***
  - Θ_x^* from Θ_x @ RP220 (through dL_x/ds) $\Theta_x = dL_x/ds\ \Theta_x^*$
  - Θ_y^* from ... $_y\ \Theta_y^*$

→ **Excellent bea...**
- Magnet cu...
- Measurem... parameter...
  - Θ_{left}^* ...
  - Proto...
  - L_x=0 c...

→ **Fine geometr...**
- Alignment...
- Alignment...
- Mechanic...

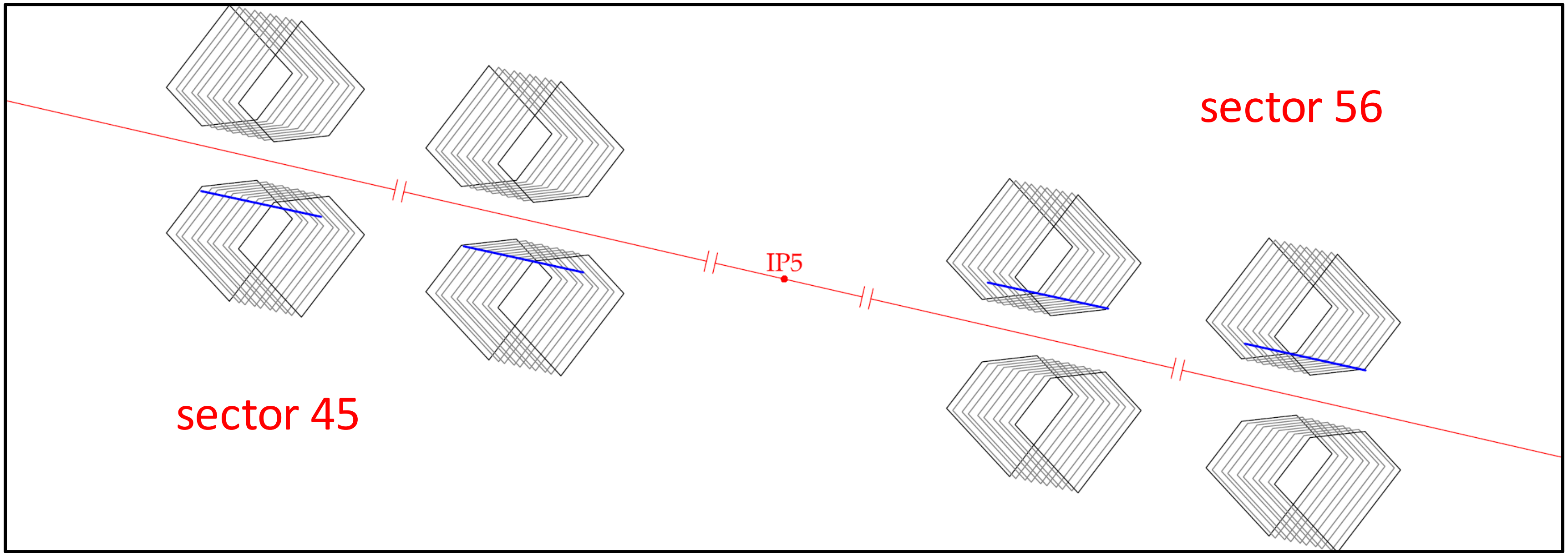


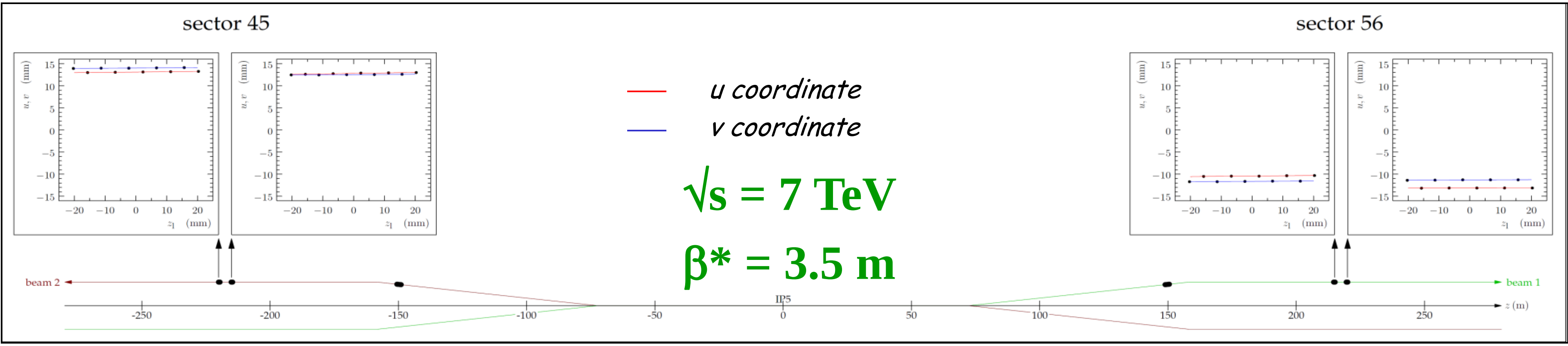


Track based alignment

2010: first Runs with RPs at 25σ (1.5nb^{-1})

First p-p Elastic Scattering Event Candidate [LPCC July 2010]

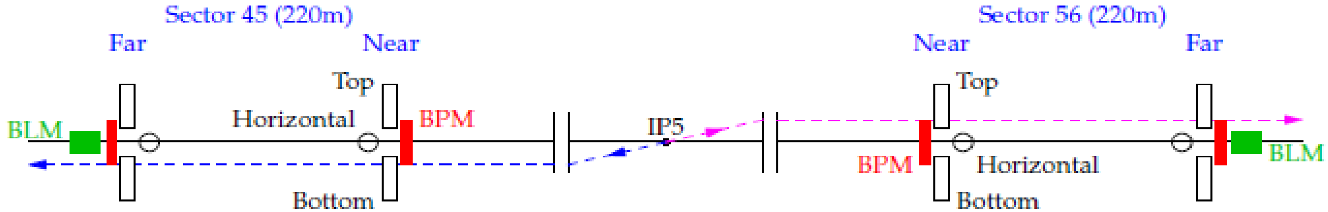




$\sqrt{s}$ = 7 TeV

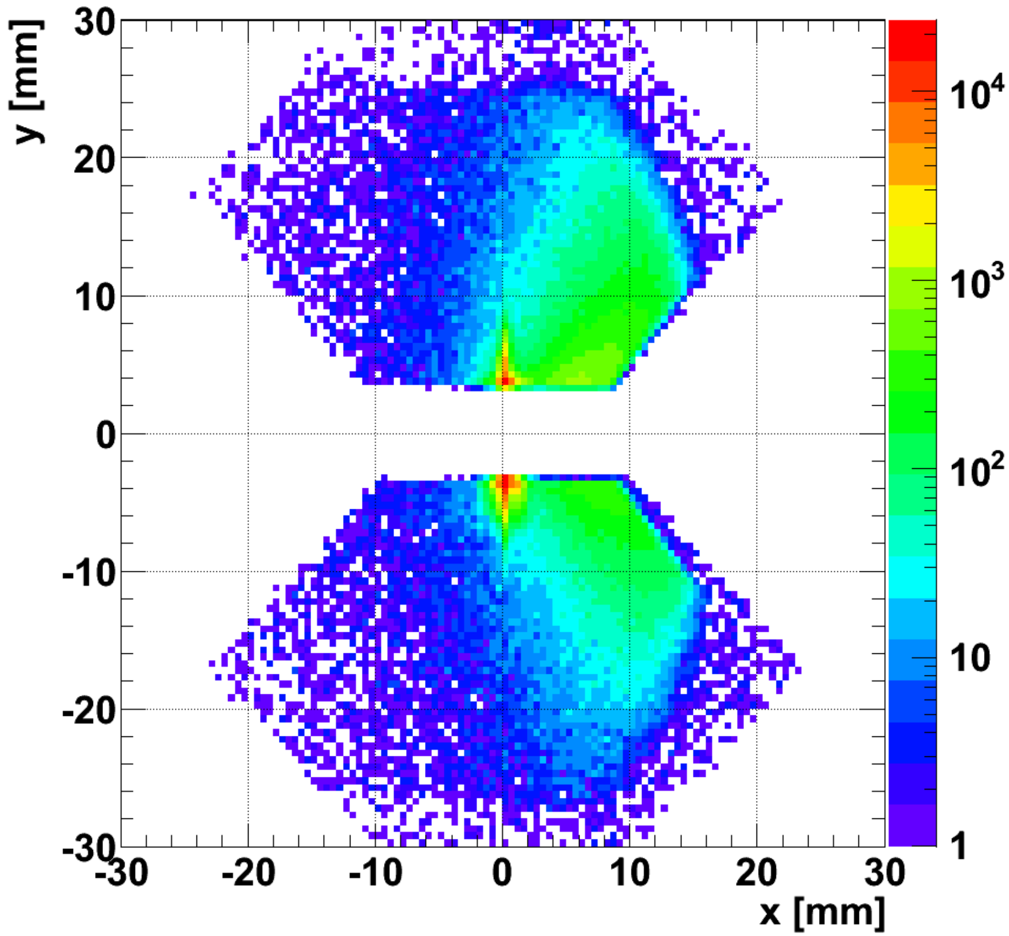
β^* = 3.5 m

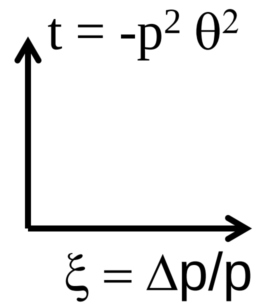
Proton tracks in one diagonal
(left-right coincidences)



Sector 56

Sector 45



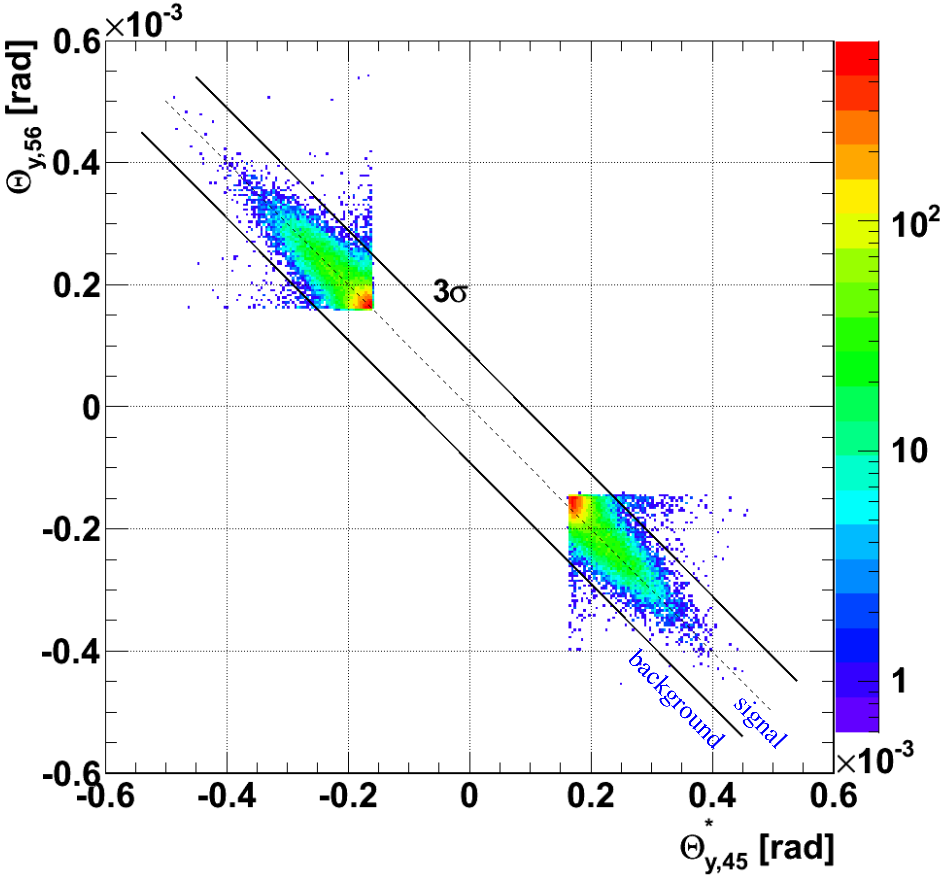


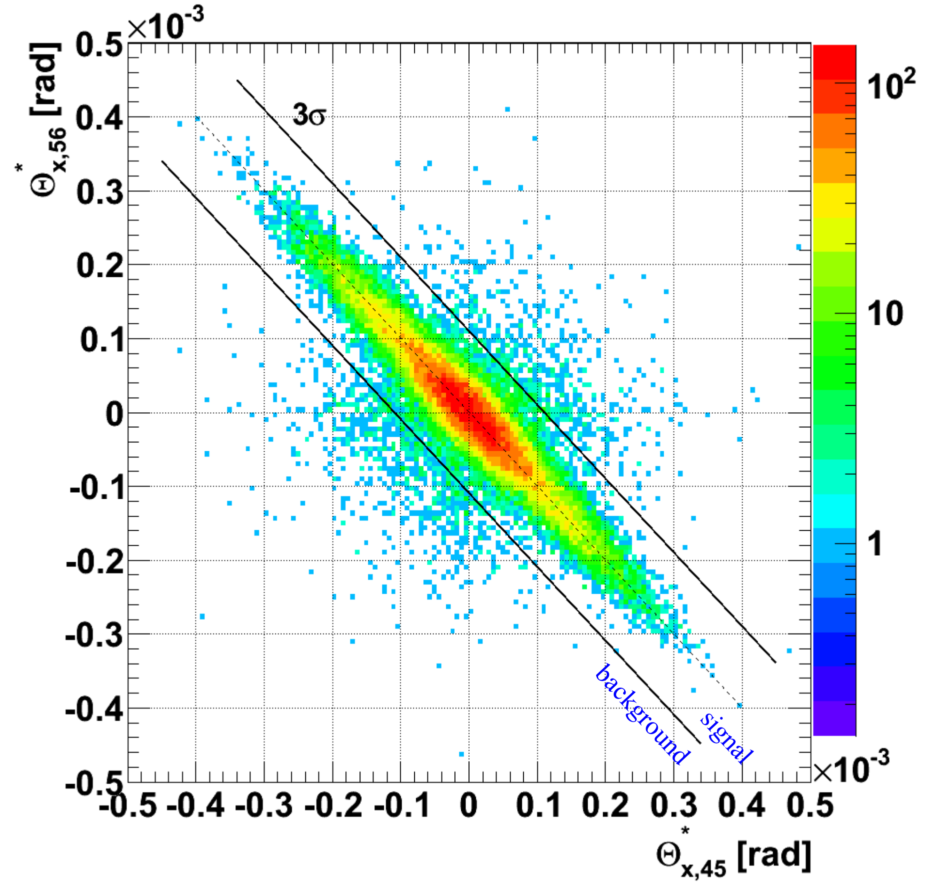
$y = L_y\,\Theta_y$

$x = L_x\,\Theta_x + \xi\,D$

$L_x \sim 0$

Elastic colinearity cuts





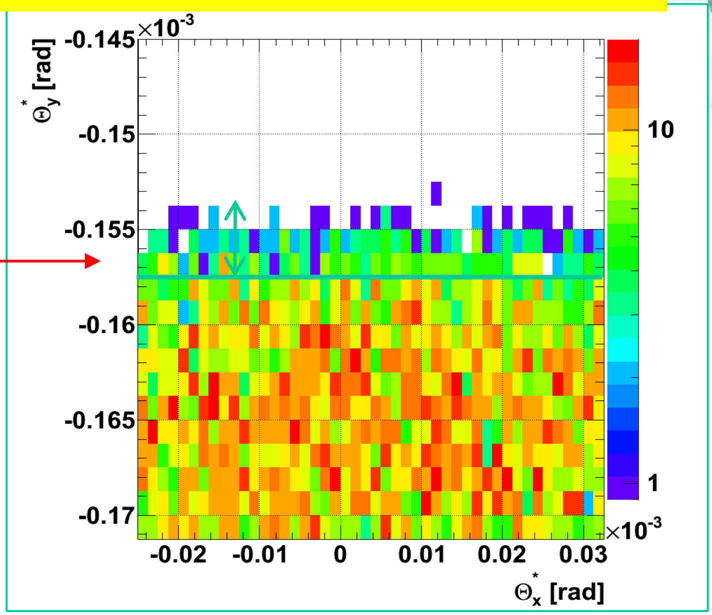
Co-linearity in θ_y , $\xi \sim 0$ Co-linearity in θ_x,

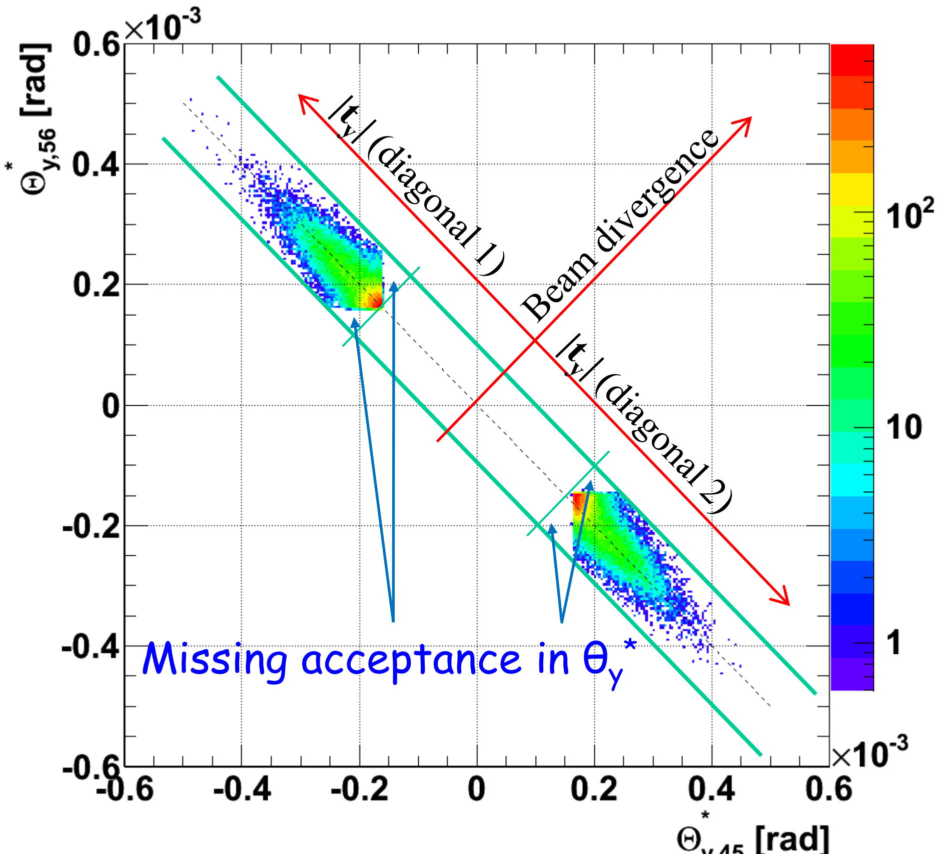
Data outside the 3σ cuts used for background estimation

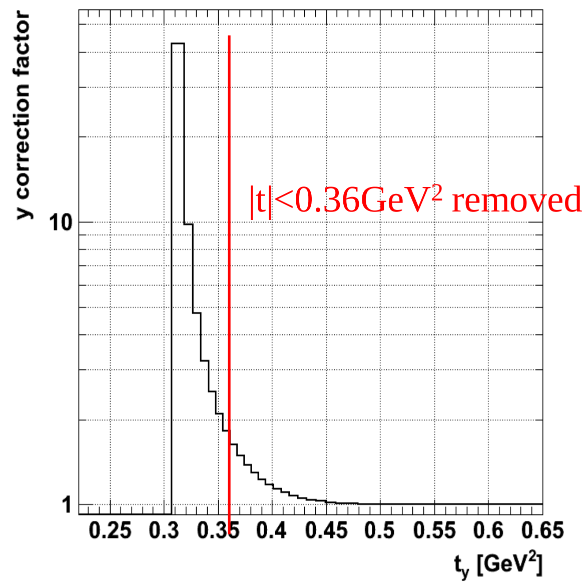
Acceptance (1)

y-acceptance corrections

Near edge efficiency transition 60 µm
(removed)

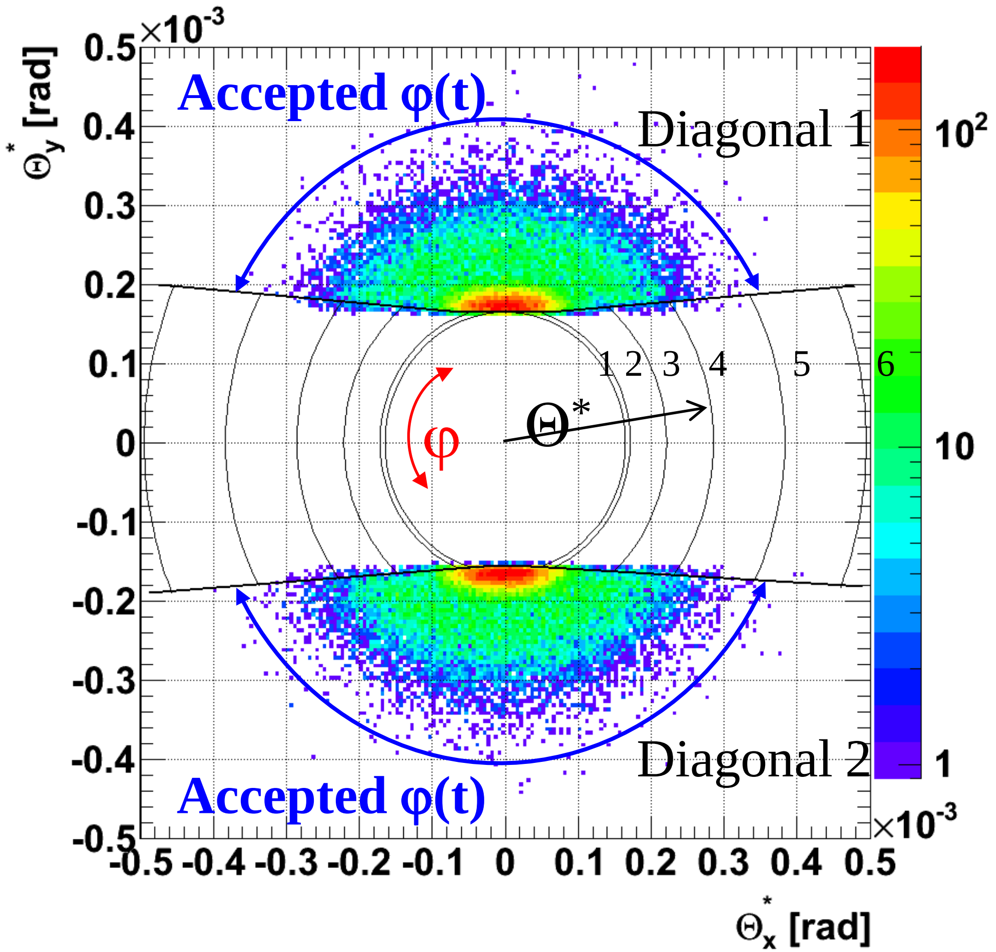






Acceptance (2)

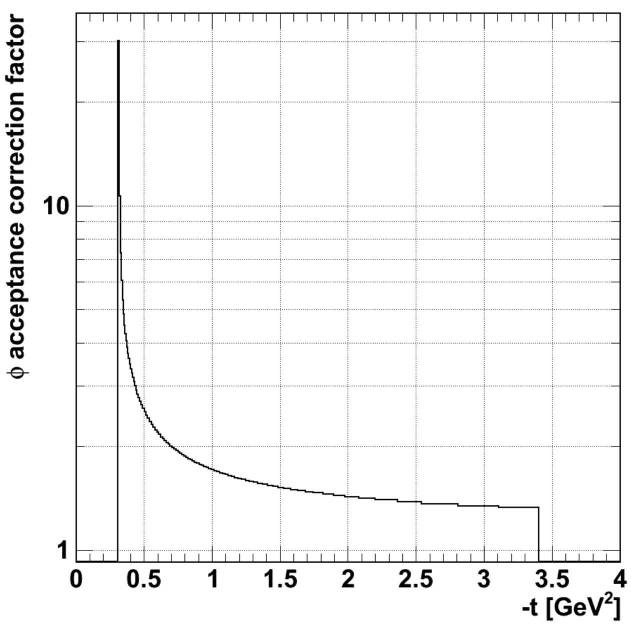
φ-acceptance corrections



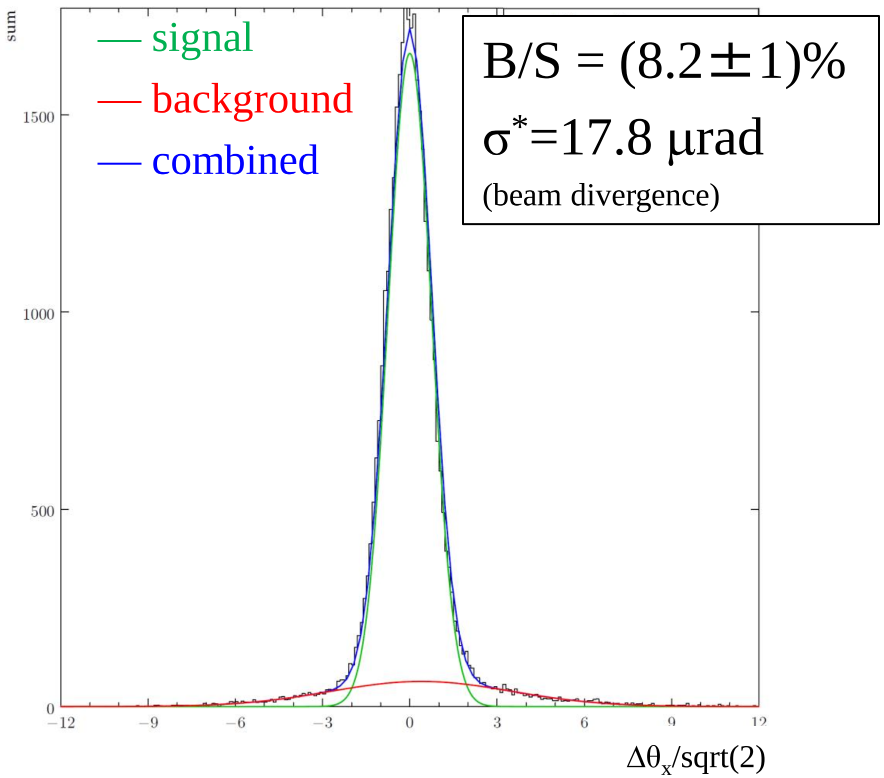
Correction critical at low t

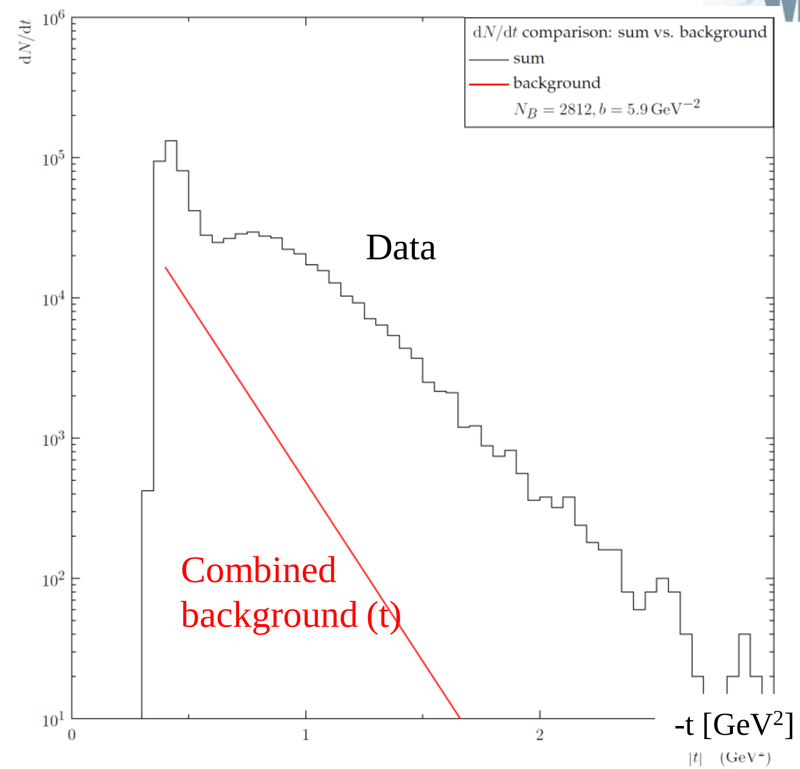
Total φ-acceptance correction

No.	t [GeV²]	Θ* [rad]	Accepted φ (2 diag.) [°]	φ accept. correct. factor
1	**0.33**	1.65E-04	38.6	**9.3**
2	**0.36**	1.71E-04	76.4	**4.7**
3	**0.60**	2.21E-04	162.5	**2.2**
4	**1.00**	2.86E-04	209.8	**1.7**
5	**1.80**	3.83E-04	246.3	**1.5**
6	**3.00**	4.95E-04	269.0	**1.3**



Background determination





Signal to background normalisation

(also as a function of $\Delta\theta_y$)

σ^* → t-reconstruction resolution:

$$\frac{\sigma(t)}{t} = \frac{\sqrt{2}p\sigma^*}{\sqrt{t}}:$$

0.4 GeV^2 : 14%

1 GeV^2 : 8.8%

3 GeV^2 : 5.1%

Signal vs. background (t)

|t|=0.4GeV^2: B/S = (11±2)%

|t|=0.5GeV^2: B/S = (19±3)%

|t|=1.5GeV^2: B/S = (0.8±0.3)%

Efficiency (1)

Method 3T/4:

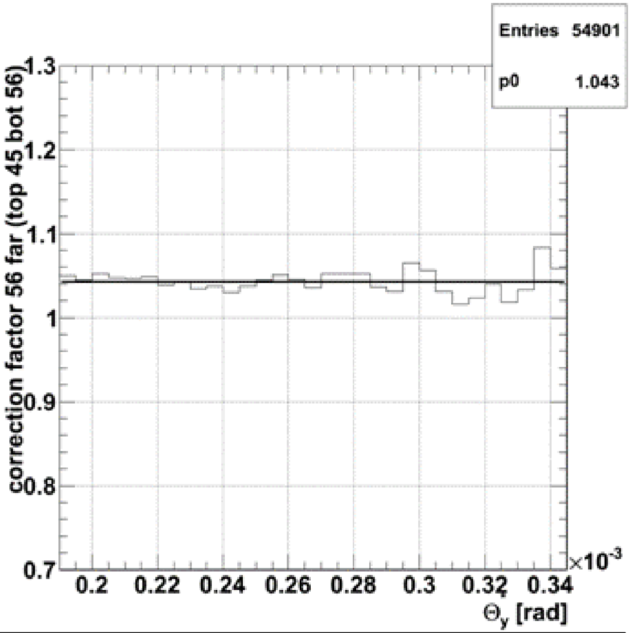
full elastic analysis with 3 track segments instead of 4

3 pots out of 4 used to determine efficiency of missing pot

4 pot-diagonal efficiency computed via consequent combinations

Efficiency correction t-independent = 1.18 - 1.19

5.9% + 2.9% + 4.3% + 4.7% + (5.9% + 2.9%) · (4.3% + 4.7%) = 17.8% + 0.792% = 18.6%



Huge data reduction factor before analysis sample ?

Checked :

Correlated inefficiencies pots for 2T/4

Goal : Understand the data reduction step-by-step

Criteria: select *pp candidates (elastic, 2*SD, DPE)*

reject MB,background,.....

Determine inefficiency in detection of *pp*

Events' scan

- **MiniDST (pots empty, shower, hits)**
- **Multi-track algorithm**
- **Theoretical rates vs observed**
- **Trigger vs detector acceptance**
- **Mini-bunch data reduction**
- **Events topology and rates**

>>> triggers: ~90% on background (showers) ; ~5% cut by RP acceptance ; ~5% pp pairs

Optics

56	dLx/ds	Ly [m]	ROT [mrad]
RP215	-0.311962	22.1464676	0.0432331
RP220	-0.311962	22.6191755	0.0396463
Δ RP215	-2.84%	+0.78%	
Δ RP220	-2.84%	+0.81%	

45	dLx/ds	Ly [m]	ROT [mrad]
RP215	-0.314508	20.3883272	0.0400268
RP220	-0.314508	20.6709463	0.0372828
Δ RP215	-4.51%	+10.19%	
Δ RP220	-4.51%	+10.79%	

Strong correlations of fitted parameters

Principle Component Analysis (PCA) should ideally be applied.

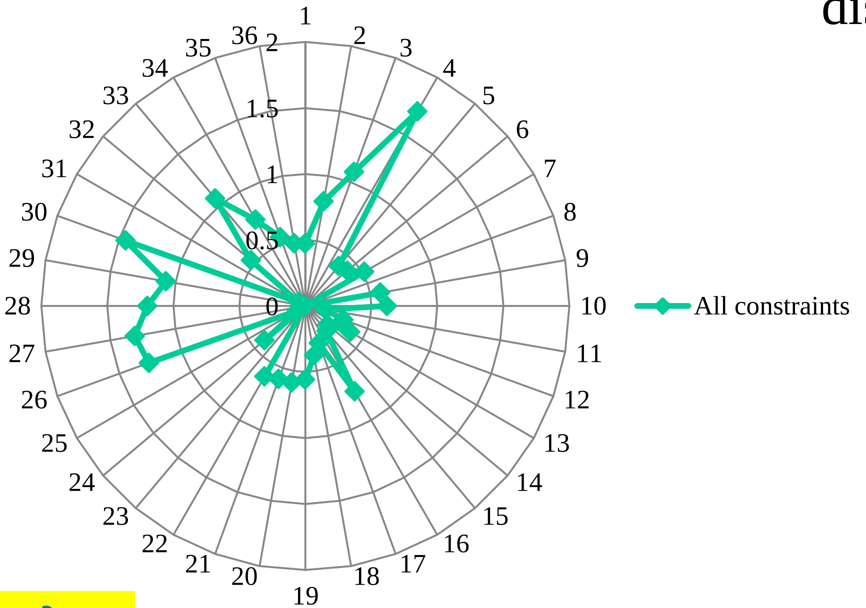
Results checked with MAD-X.

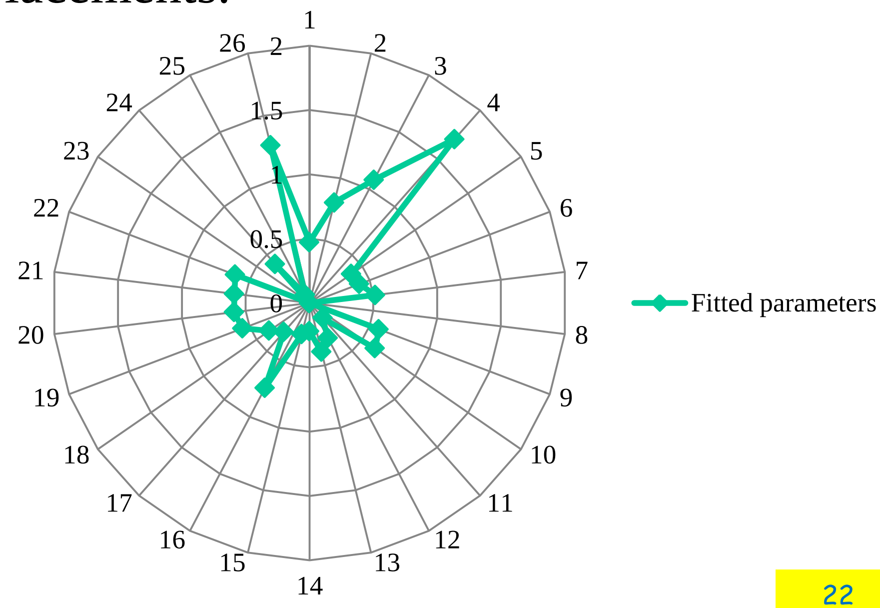
χ^2/NDF = 25.8/(36-26)=2.6

(lower if correlations elmininated)

Mean pull = 0.043 Pull RMS = 0.86

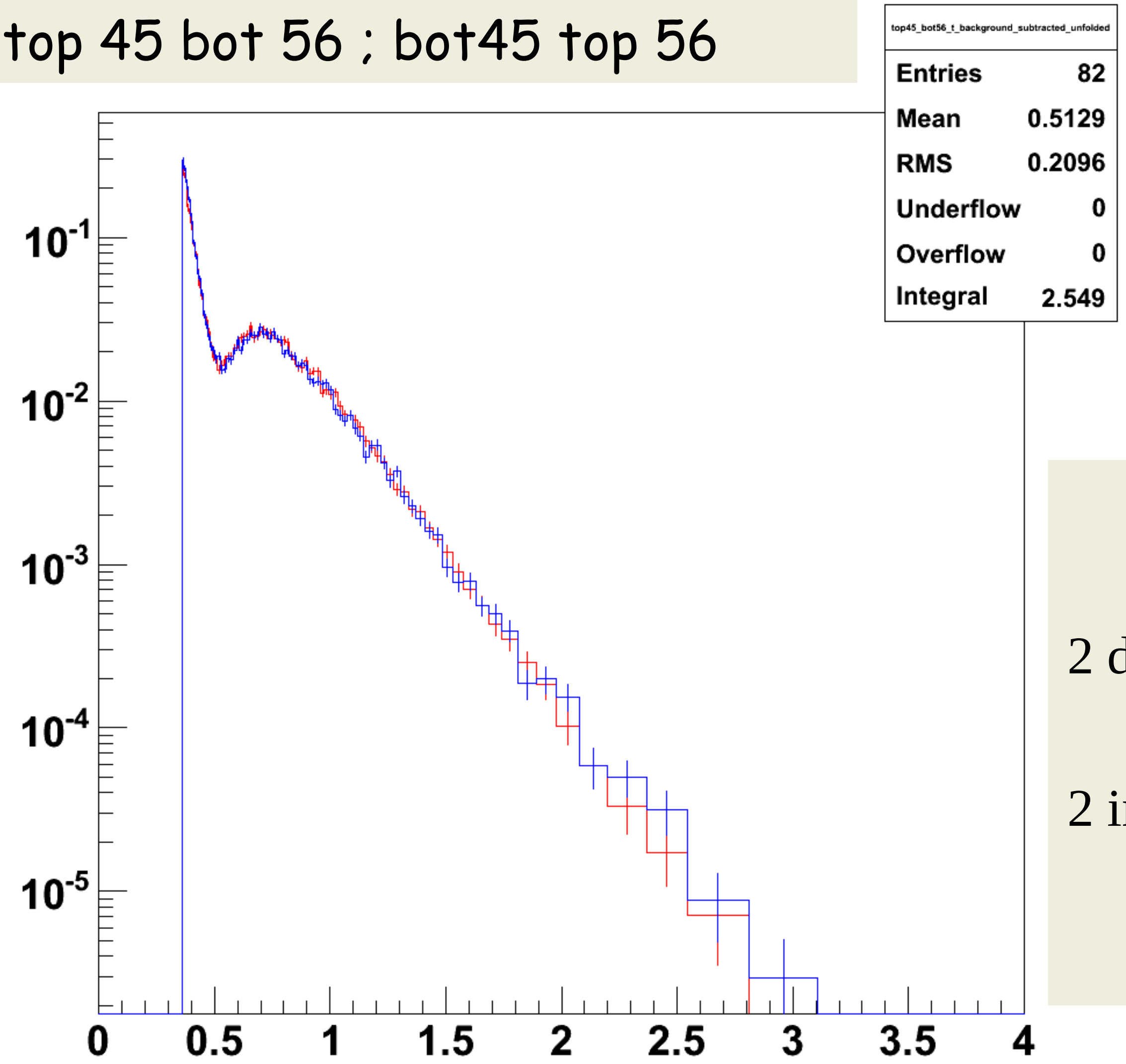
Full nonlinear fitting with harmonics and displacements.





TOTEM elastic : 2 “Experiments”

top 45 bot 56 ; bot45 top 56



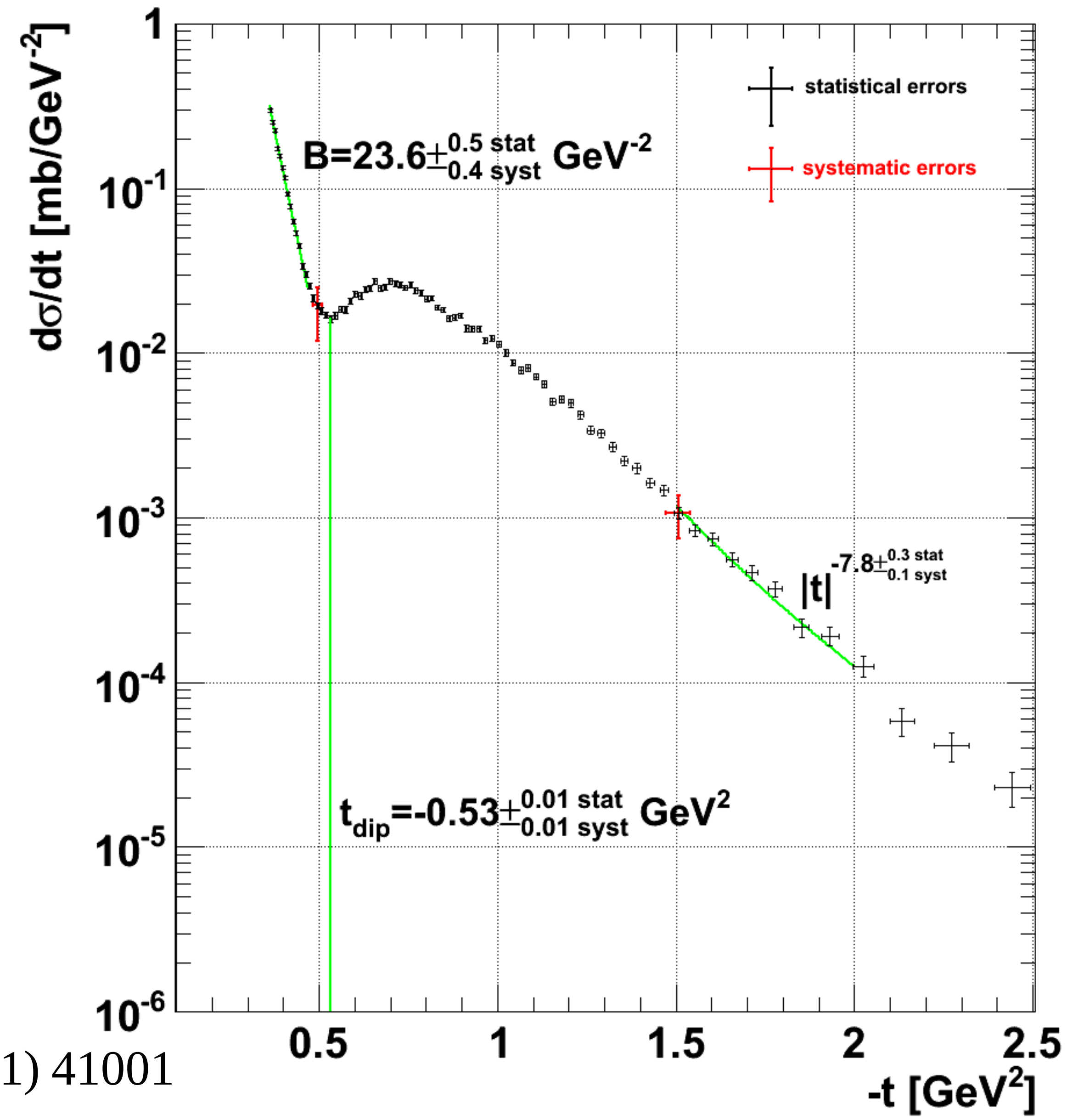
2 diagonals:

2 different experiments,

and NOT

2 independent experiments

TOTEM: large-t Result



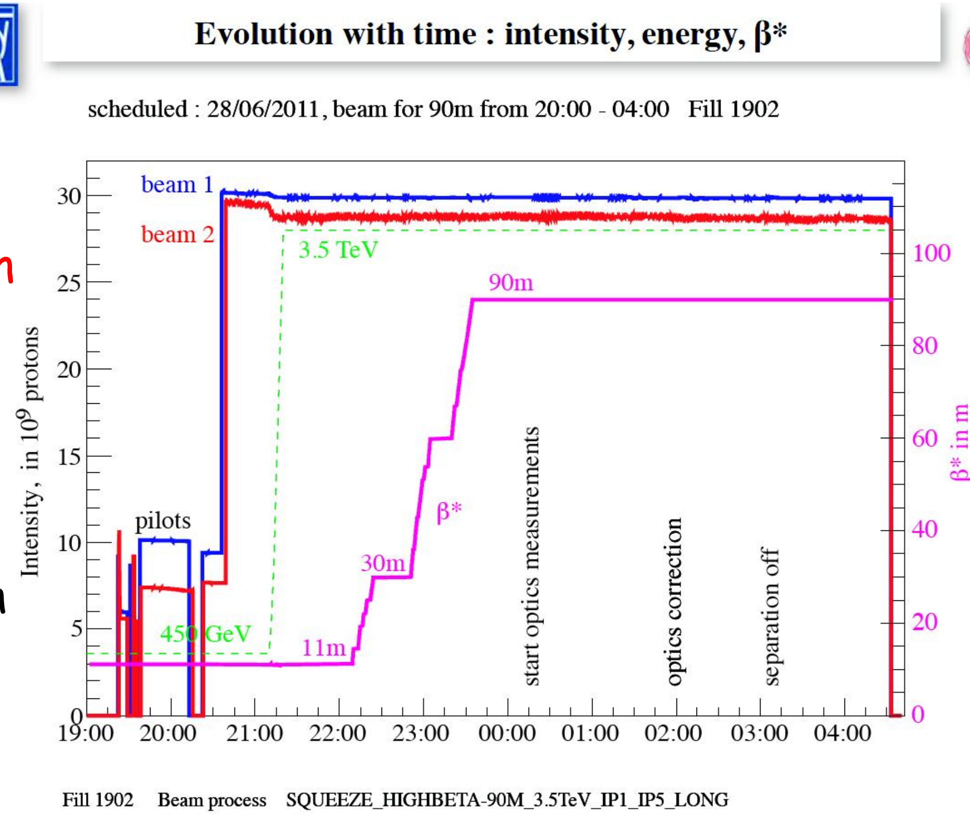
EPL, 95 (2011) 41001

Large β run
small-t ELASTIC SCATTERING
TOTAL CROSS-SECTIONS

June 2011 β* = 90 m optics

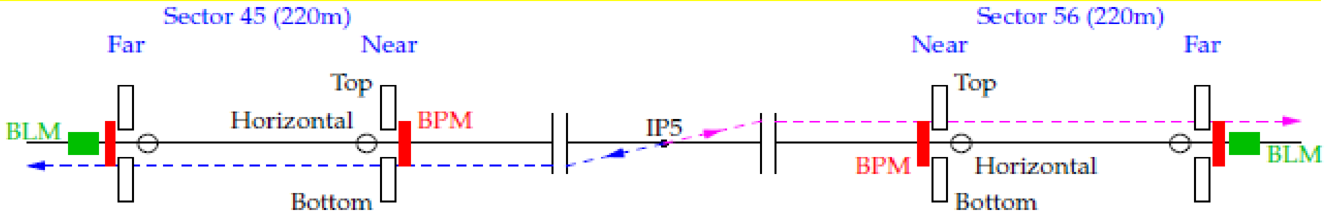
Un-squeeze from injection optics
β* from 11m to 90m
[Helmut Burkhardt, Andre Verdier]

Very robust optics with high precision (doesn't depend strongly on machine elements parameters)



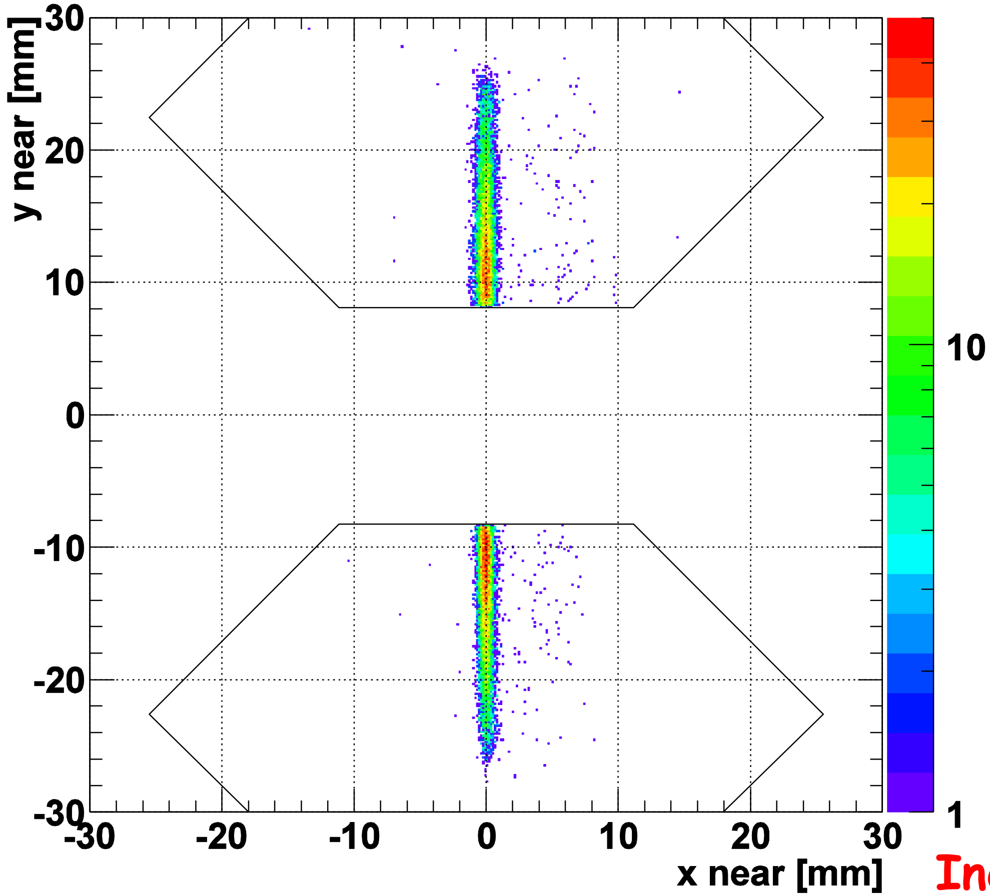
- Two bunches:
  - 1 and 2 x 10^{10} protons / bunch
- Instantaneous luminosity:
  - 8 x 10^{26} cm^{-2} s^{-1}
- Integrated luminosity: 1.7 μb^{-1}
- Estimated pile-up: ~ 0.5 %
- Vertical Roman Pots at 10 σ from beam center
- Trigger rate : ~ 50 Hz
- Recorded events in vertical Roman Pots: 66950

Proton tracks in one diagonal
(left-right coincidences)



Sector 56

Sector 45



$t = -p^2 \theta^2$

$\xi = \Delta p/p$

$$\begin{cases} y = L_y \Theta_y \\ x = L_x \Theta_x + \xi D \end{cases}$$

$L_x \sim 0$

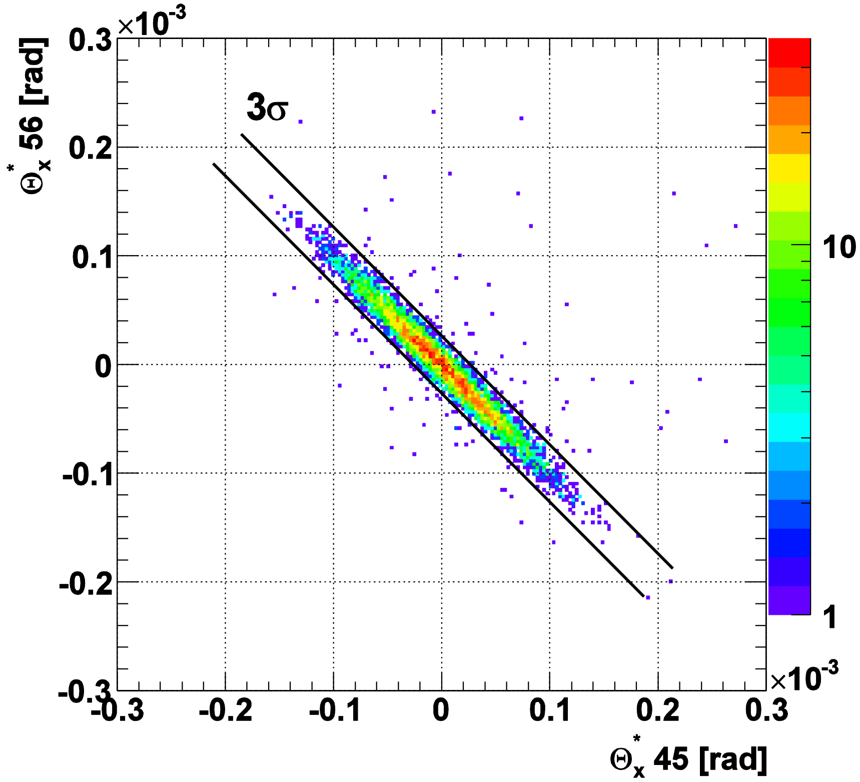
$L_y \sim 260$ m

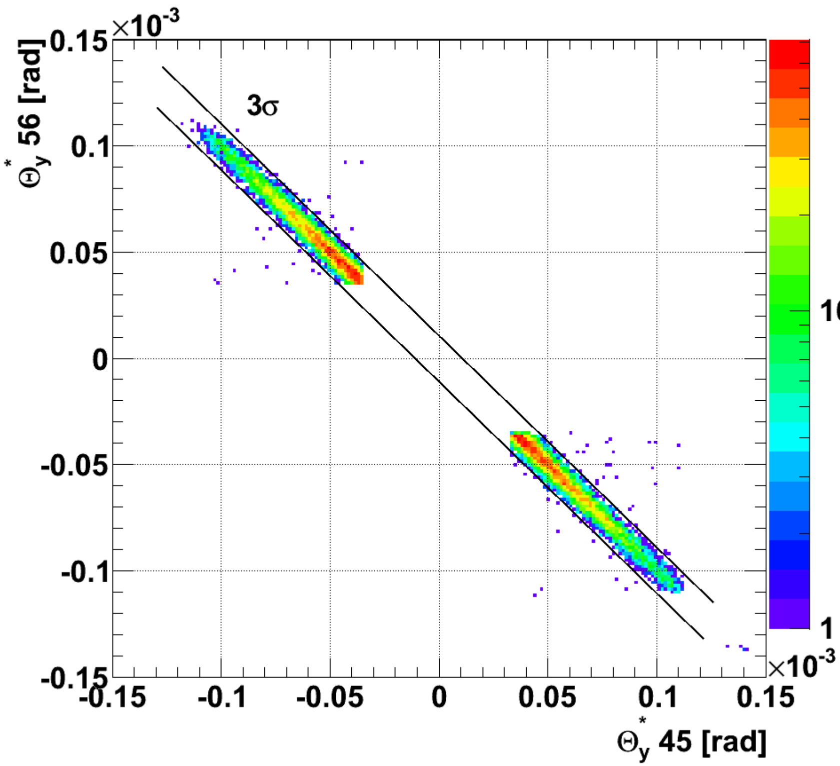
$L_x \sim$ 0-3 m

Inel. pile-up ~ 0.005 ev/bx

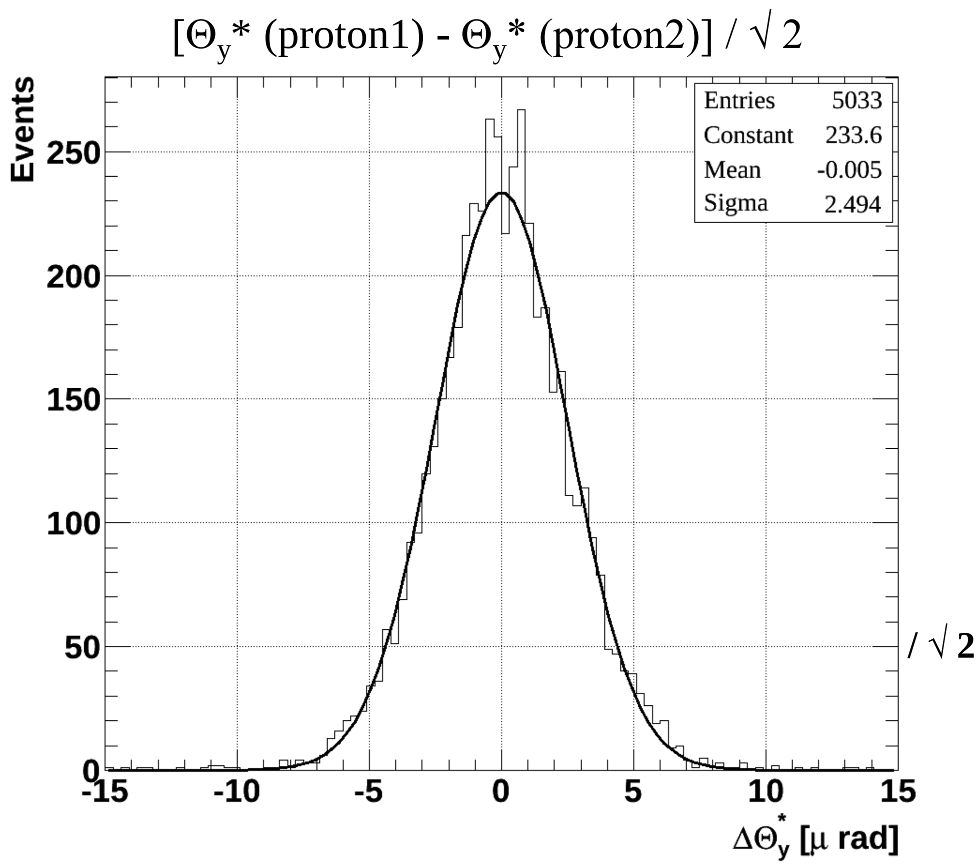
Colinearity

Colinearity plots – events with tracks in both arms





Angular difference between the two outgoing protons

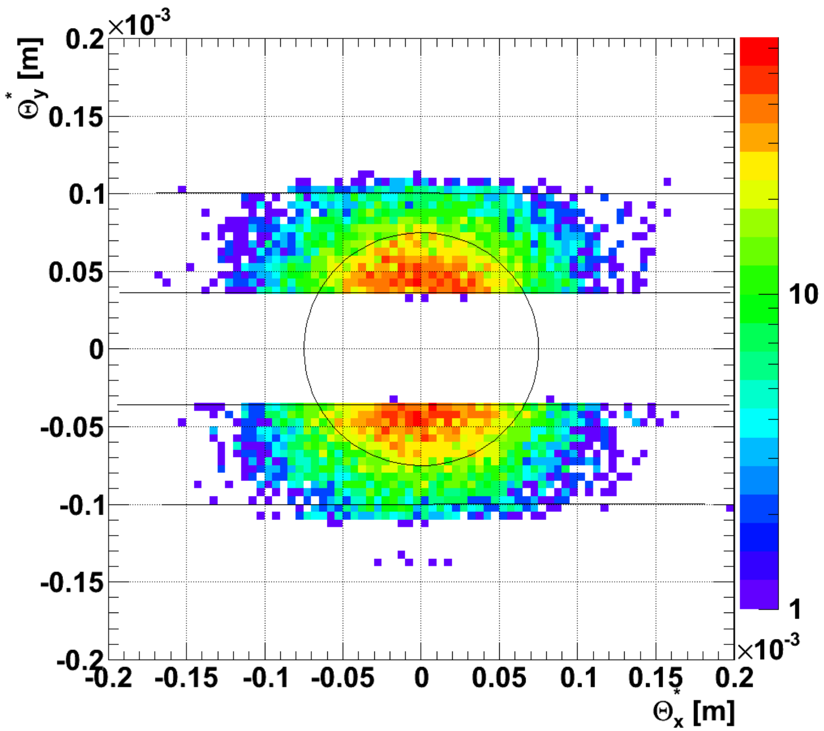


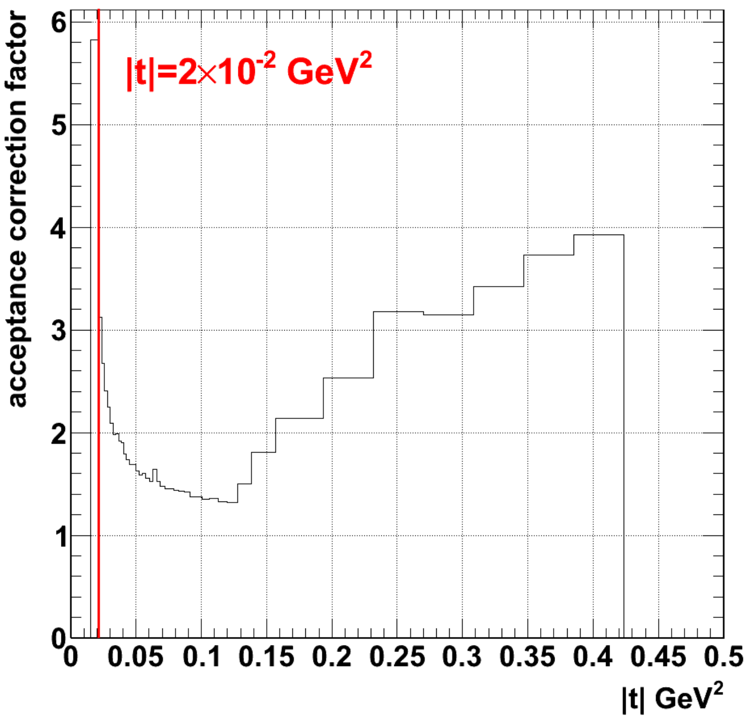
beam divergence σ_{Θ^*}

$$\sigma_{\Theta^*} = \sqrt{\frac{\varepsilon_n}{\gamma\beta^*}} = 2.4\,\mu\text{rad}$$

Optics, t-scale and acceptance

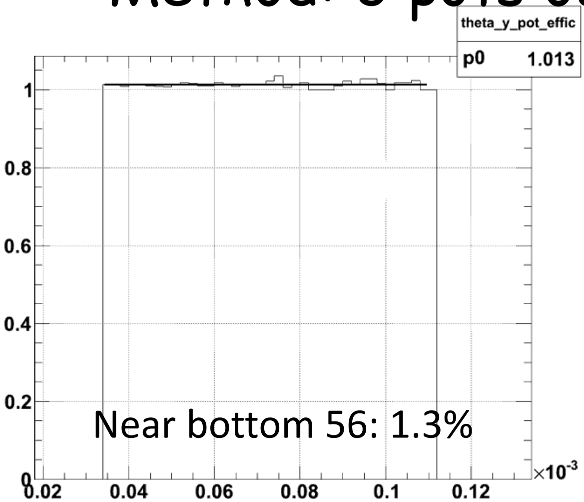
- Perturbations: optics very robust ($L_y \sim s_{RP}$), better than:
  - $d\Theta_x^*/\Theta_x^* = 1.3\%^{syst}$
  - $d\Theta_y^*/\Theta_y^* = 0.4\%^{syst}$
- Non-linearities in $\Theta_x^*(y)$ reconstruction due to dLx / ds measured and corrected for: (checked via Lx)
- t systematics: $dt\,/\,t$ = 0.8% (at low |t|) up to 2.6% (at large $|t|$)
- Acceptance cut correction at low $|t|$ is a factor < 3 (ϕ symmetry)

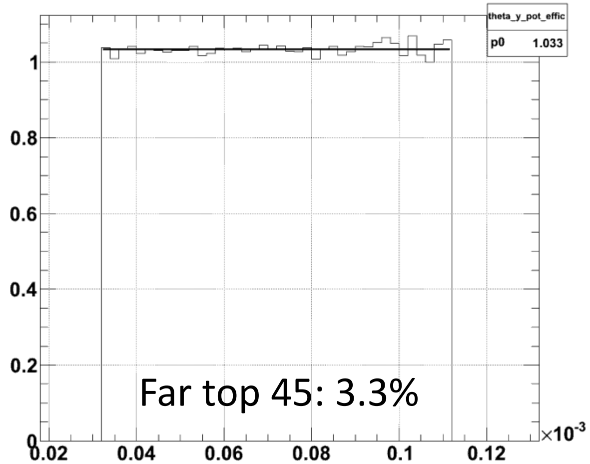


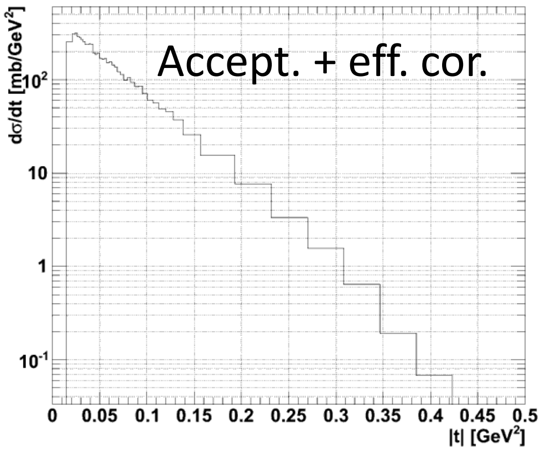


Efficiency Detector + Tracking

- Method: 3 pots out of 4







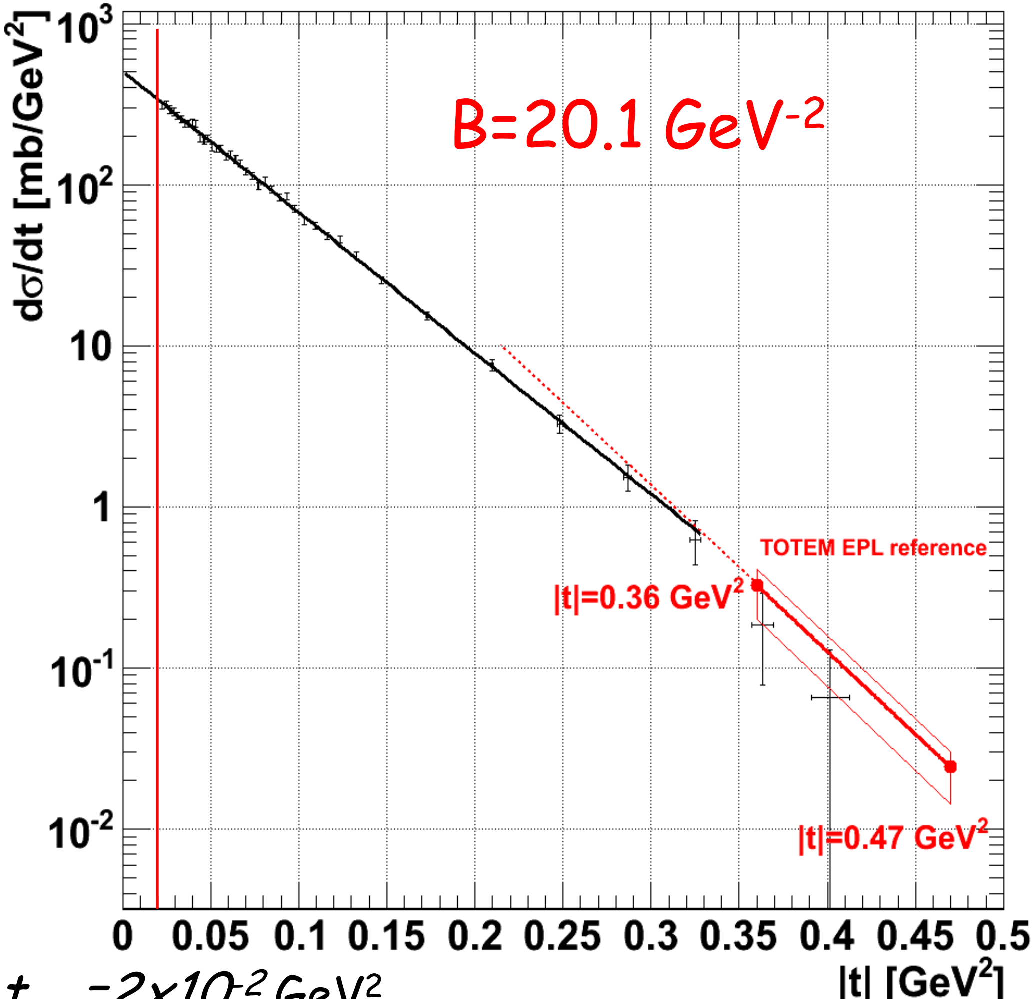
- Diag. "top56 bot45": 1.5+2.5+1.4+3.3+(1.5+2.5)(1.4+3.3) = 8.9%
- Diag. "bot56 top 45": 1.3+2.7+1.4+3.1+(1.3+2.7)(1.4+3.1)= 8.7%

- Uncorrelated 2 pots out of 4 taken into account
- No *far-far* or *near-near* correlations observed

Detector and tracking efficiency > 91%

Elastic $d\sigma/dt$ and σ_{el}

small t and large t data (published in EPL95(2011)41001) superimpose.



$t_{min}=2x10^{-2}$ GeV^2

Extrapolation to t=0

$d\sigma/dt|_{t=0} = 5.037\times10^2$ mb/GeV^2

Elastic cross section

$$\sigma_{EL} \begin{cases} = 8.3\ \text{mb}^{(\text{extrap})} + 16.5\ \text{mb}^{(\text{measured})} \\ = 24.8\ \text{mb} \end{cases}$$

Red zone delimits the uncertainty region from the large t measurement

Cross-Section Formulae

Optical Theorem: $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

Need

luminosity from CMS: $$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$$

ρ from COMPETE fit: $$\rho = 0.14^{+0.01}_{-0.08}$$

$$\sigma_{TOT} = \sqrt{19.20\,\text{mb GeV}^2 \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}}$$

$$\sigma_{TOT} = \sigma_{EL} + \sigma_{INEL}$$

TOTEM: pp Total Cross-Section

Elastic exponential slope: $B\big|_{t=0} = (20.1 \pm 0.2^{(stat)} \pm 0.3^{(syst)})\ \mathrm{GeV}^{-2}$

Elastic diff. cross-section at optical point: $\left.\frac{d\sigma_{el}}{dt}\right|_{t=0} = (503.7 \pm 1.5^{(stat)} \pm 26.7^{(syst)})\,\mathrm{mb / GeV}^2$

↓ Optical Theorem, $\rho = 0.14^{+0.01}_{-0.08}$

Total Cross-Section

$$\sigma_T = \left(98.3 \pm 0.2^{(\mathrm{stat})} \pm 2.7^{(\mathrm{syst})} \begin{bmatrix} +0.8 \\ -0.2 \end{bmatrix}^{(\mathrm{syst\ from}\ \rho)}\right)\ \mathrm{mb}$$

TOTEM: pp Inelastic Cross-Section

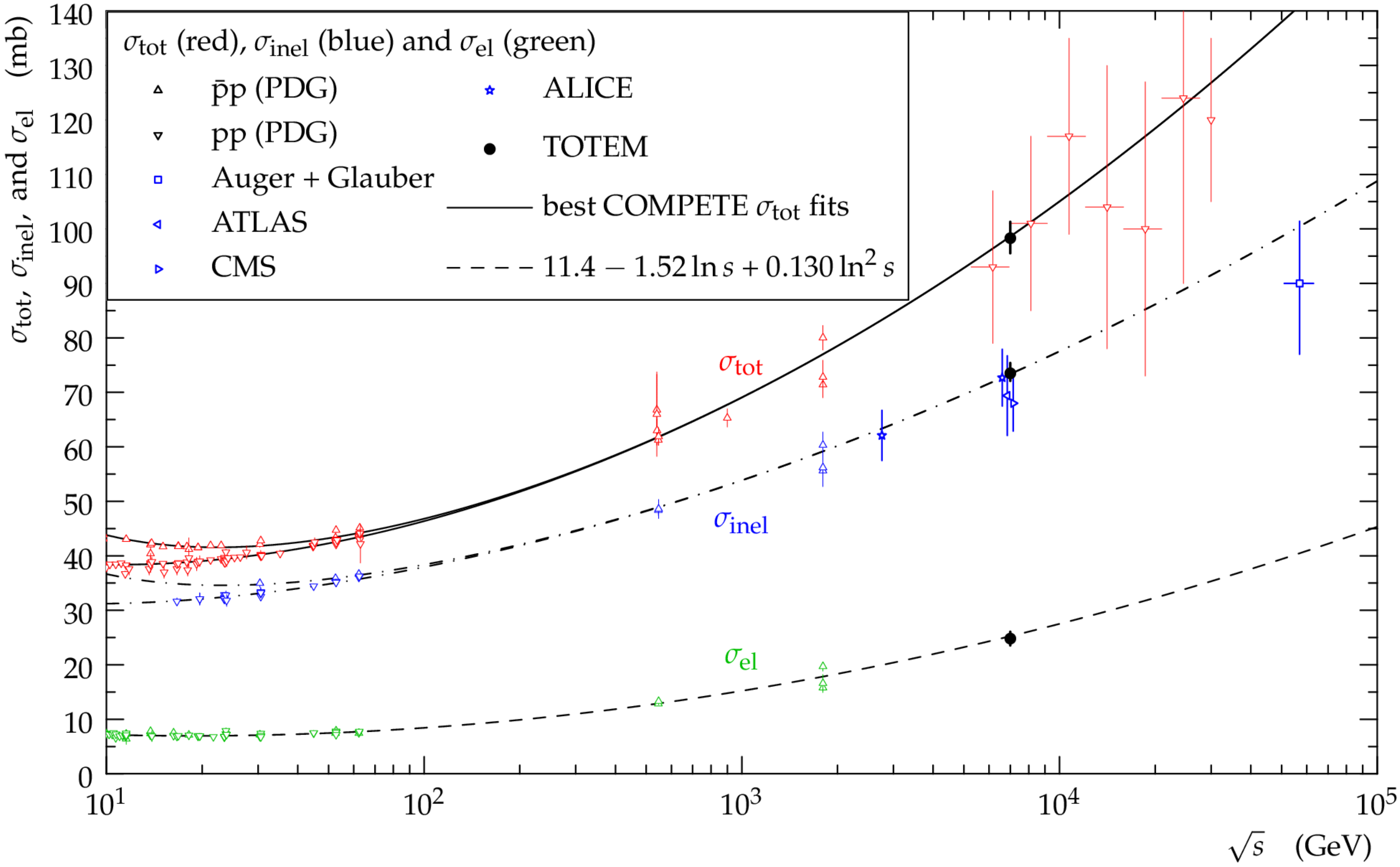
$$\sigma_{el} = \left(24.8 \pm 0.2^{(stat)} \pm 1.2^{(syst)}\right)\ \text{mb} \qquad \sigma_T = \left(98.3 \pm 0.2^{(stat)} \pm 2.7^{(syst)} \begin{bmatrix} +0.8 \\ -0.2 \end{bmatrix}^{(\text{syst from } \rho)}\right)\ \text{mb}$$

Inelastic Cross-Section

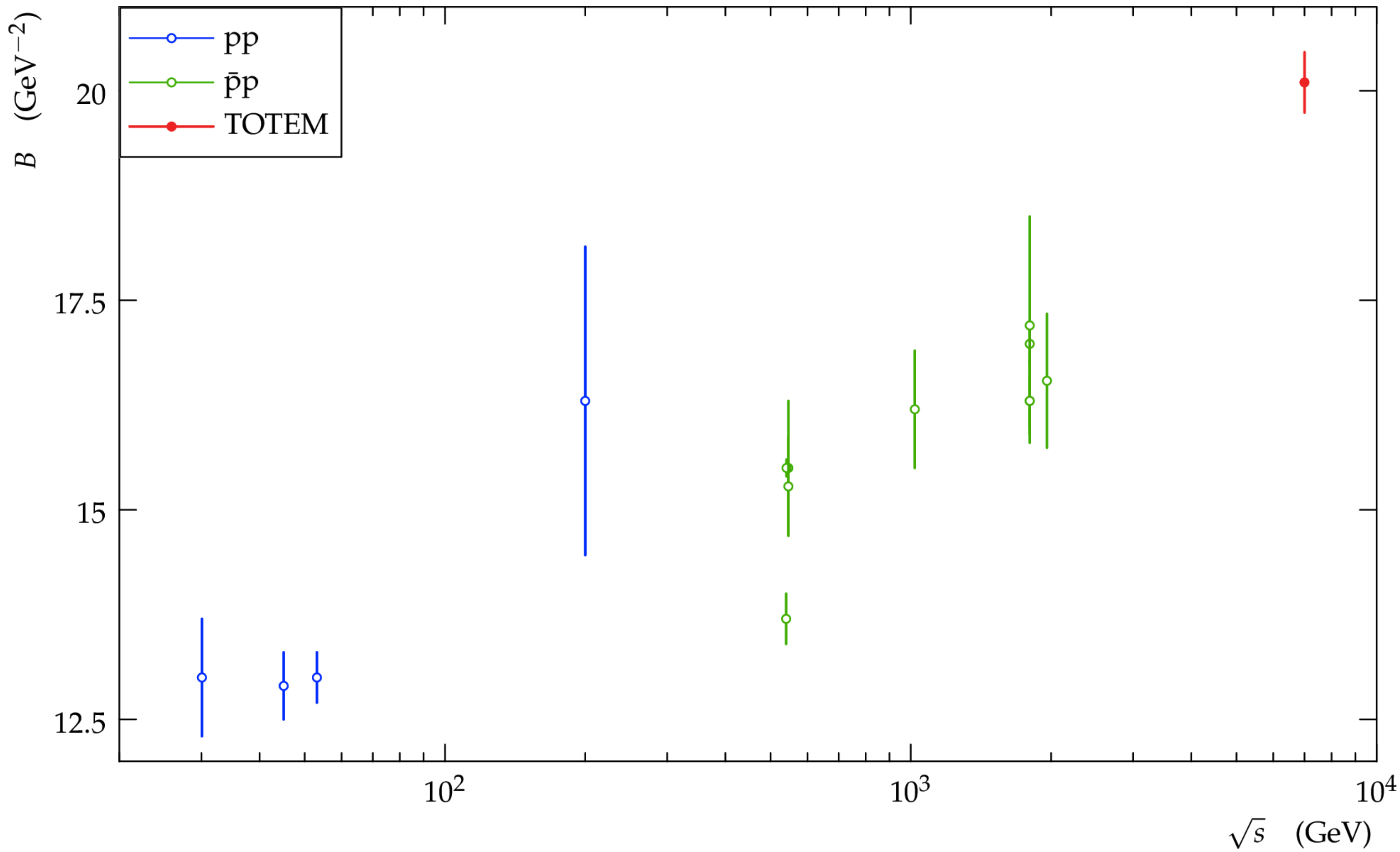
$$\sigma_{inel} = \sigma_{tot} - \sigma_{el} = \left(73.5 \pm 0.6^{(stat)} \begin{bmatrix} +1.8 \\ -1.3 \end{bmatrix}^{(syst)}\right)\ \text{mb}$$

σ_{inel} (CMS) = $(68.0 \pm 2.0^{(syst)} \pm 2.4^{(lumi)} \pm 4.0^{(extrap)})$ mb
σ_{inel} (ATLAS) = $(69.4 \pm 2.4^{(exp)} \pm 6.9^{(extrap)})$ mb
σ_{inel} (ALICE) = $(72.7 \pm 1.1^{(mod)} \pm 5.1^{(lumi)})$ mb

Compilation of σ_{tot} and σ_{el}

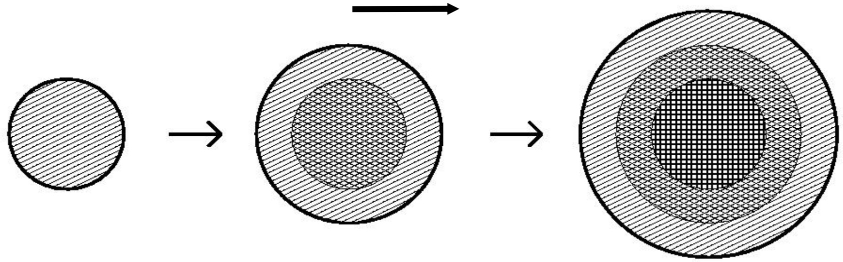


Energy dependence of the exponential slope B

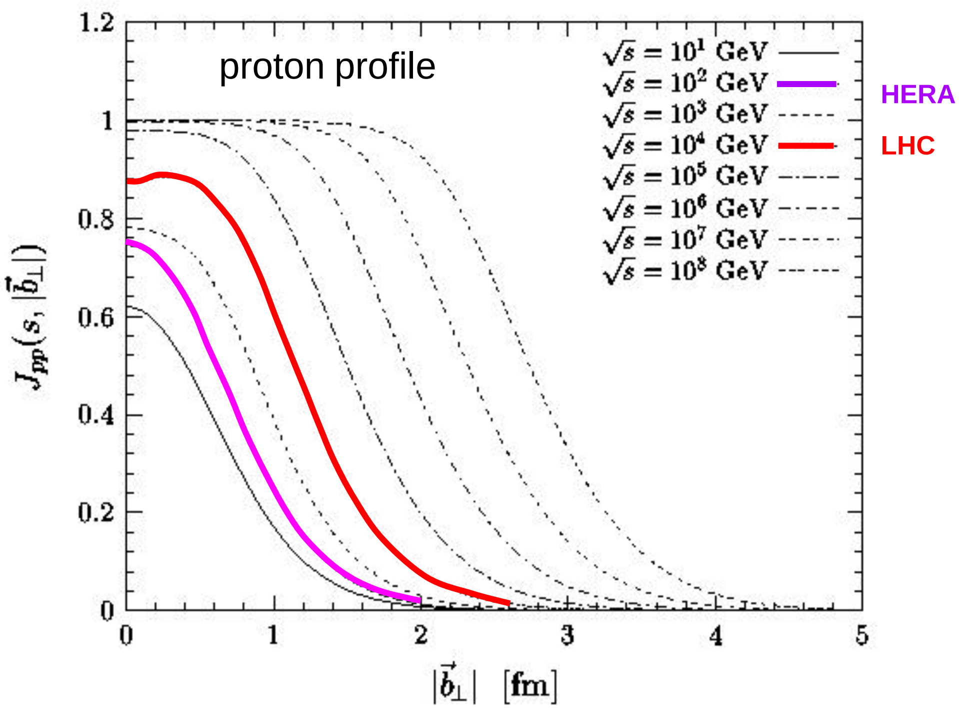


The proton structure

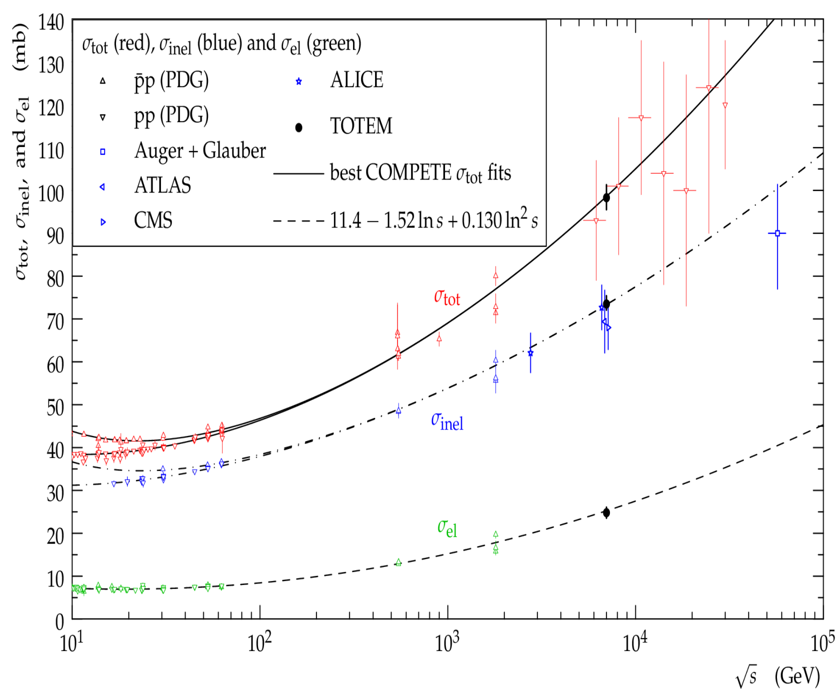
increasing energy



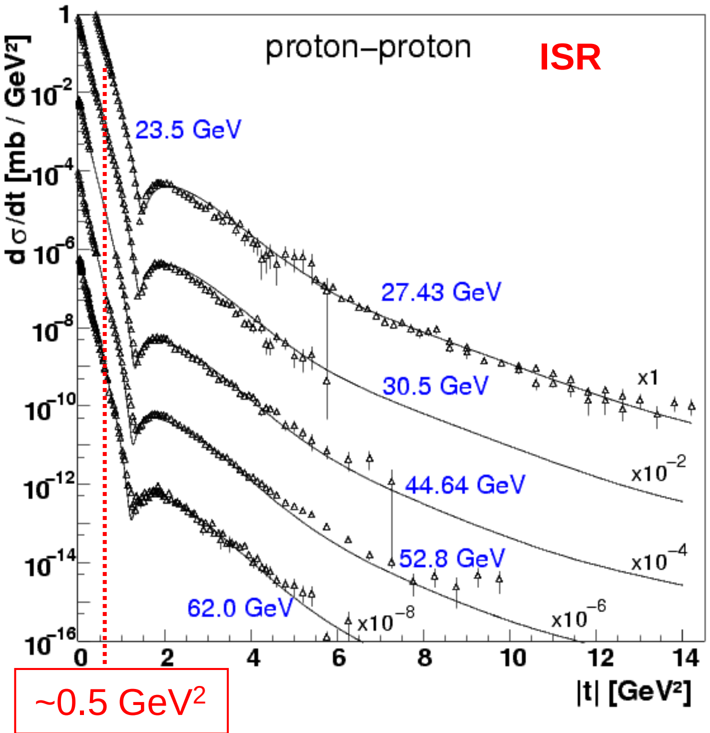
blacker
radius increases
edge area increases

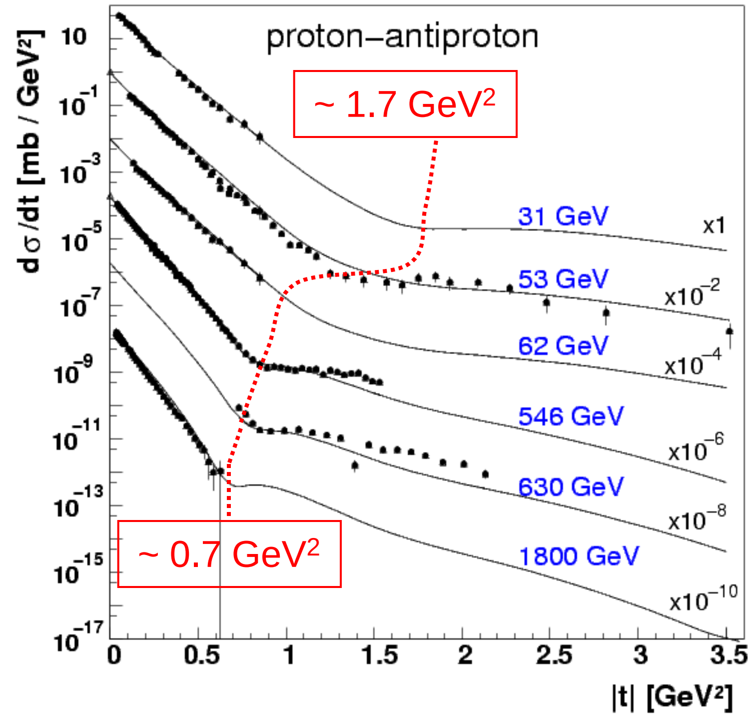


Total cross-section

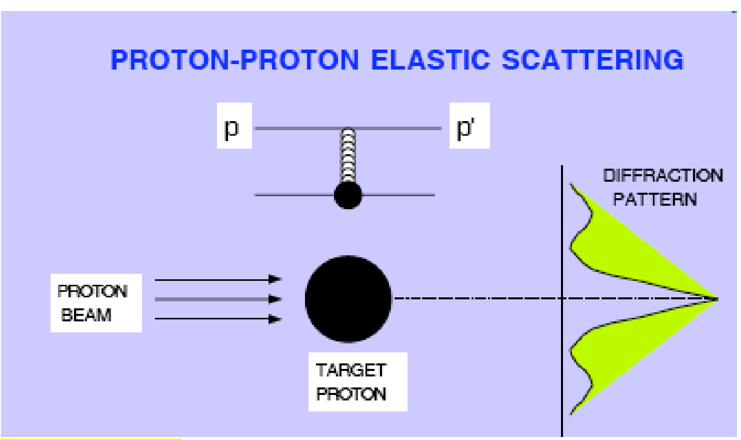


pp Elastic Scattering - ISR to Tevatron





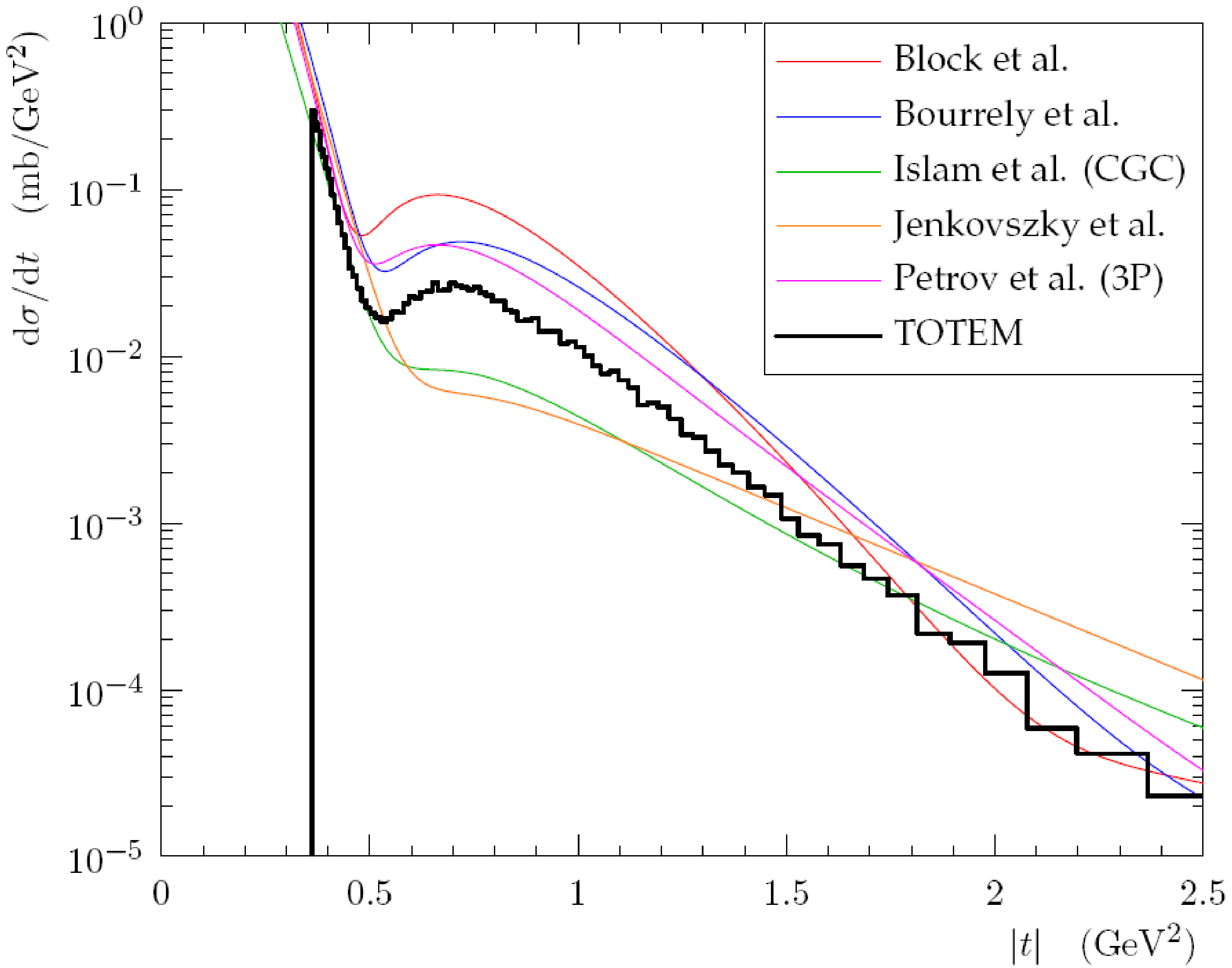
Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 q^2$



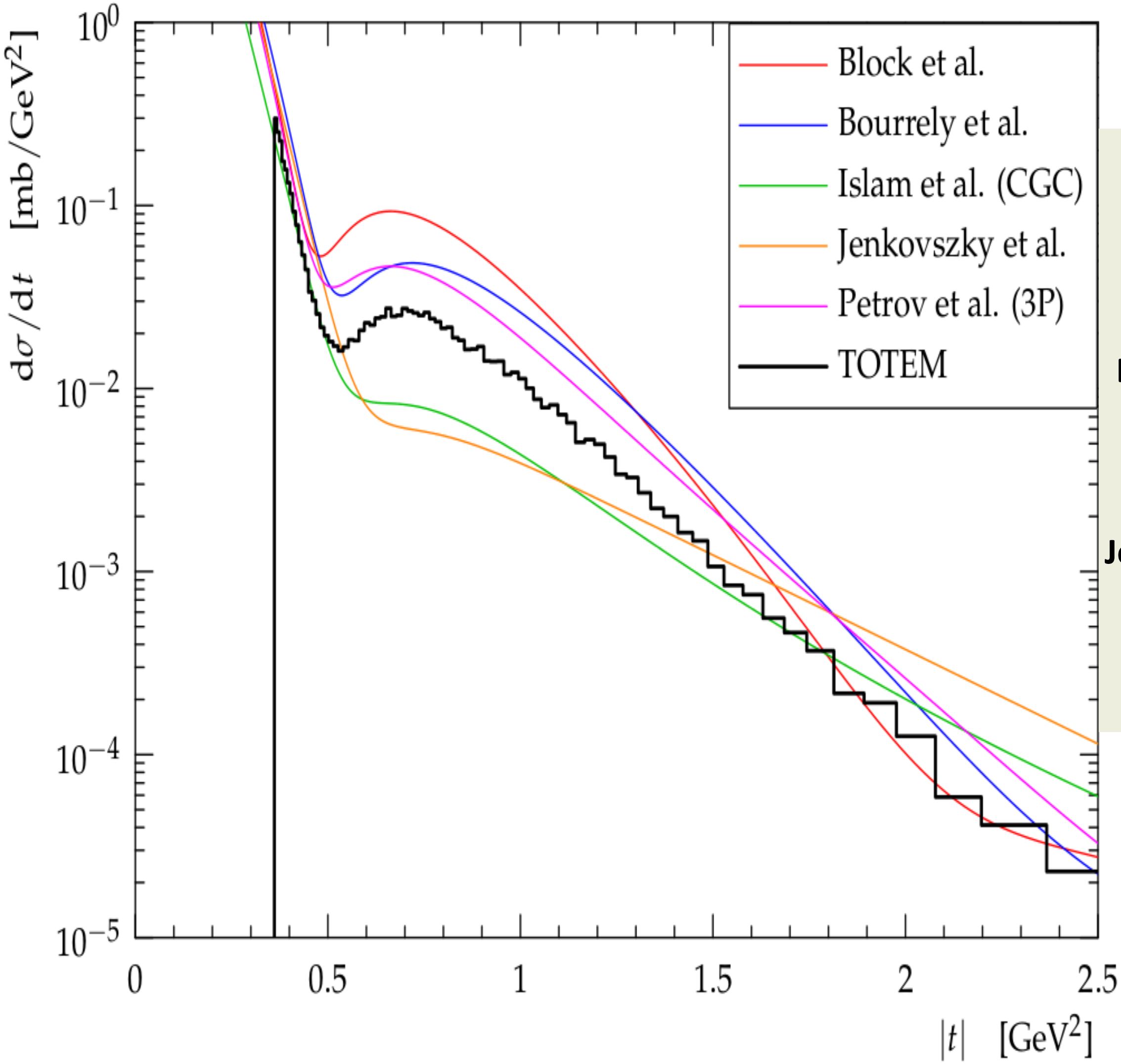
- exponential slope B at low |t| increases
- minimum moves to lower |t| with increasing s
  → interaction region grows (as also seen from σ_{tot})
- depth of minimum changes
  → shape of proton profile changes
- depth of minimum differs between pp, $\bar{p}p$
  → different mix of processes

Models and TOTEM, a Comparison

$\sqrt{s} = 7$ TeV



Comparison with models



	B (t=-0.4 GeV²)	t_{DIP}	t^{-x} [1.5–2 GeV²]
Block	**25.3**	**0.48**	**10.4**
Bourrely	**22.0**	**0.54**	**8.4**
Islam	**20.2**	**0.60**	**5.0**
Jenkovsky	**20.1**	**0.72**	**4.2**
Petrov	**23.3**	**0.51**	**7.0**
TOTEM	**23.6 ± 0.3**	**0.53 ± 0.01**	**7.8 ± 0.3**

PERSPECTIVES ON DIFFRACTIVE PHYSICS & CROSS-SECTIONS

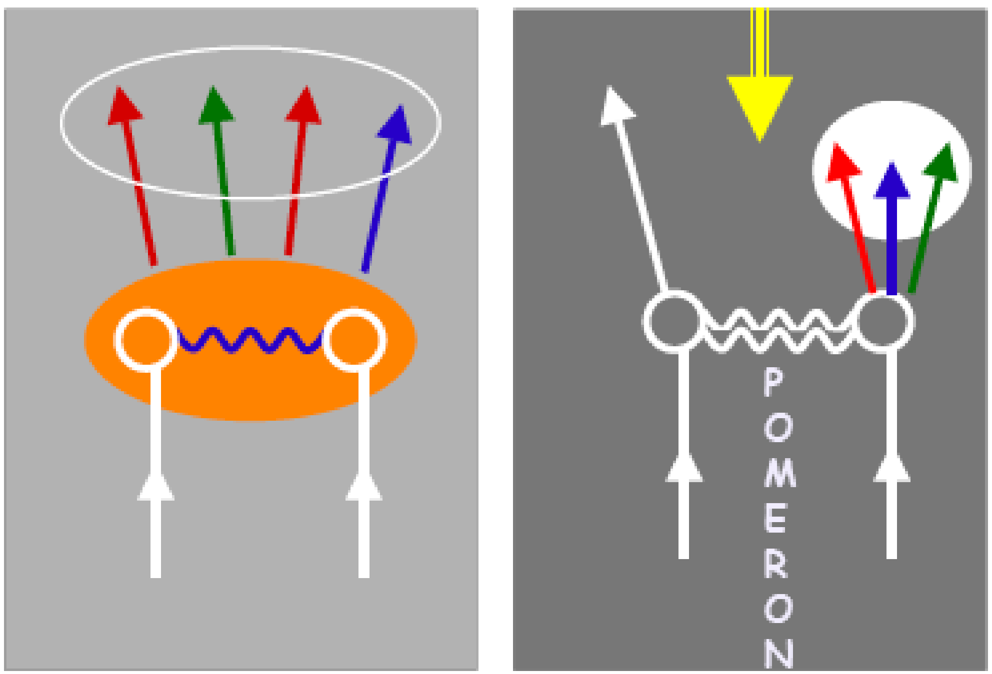
pp Interactions

TOTEM

Non-diffractive	**Diffractive**
Colour exchange	Colourless exchange with vacuum quantum numbers
dN / d Δη = exp (-Δη)	**dN / d Δη = const**

rapidity gap

Incident hadrons acquire colour and break apart



Incident hadrons retain their quantum numbers remaining colourless

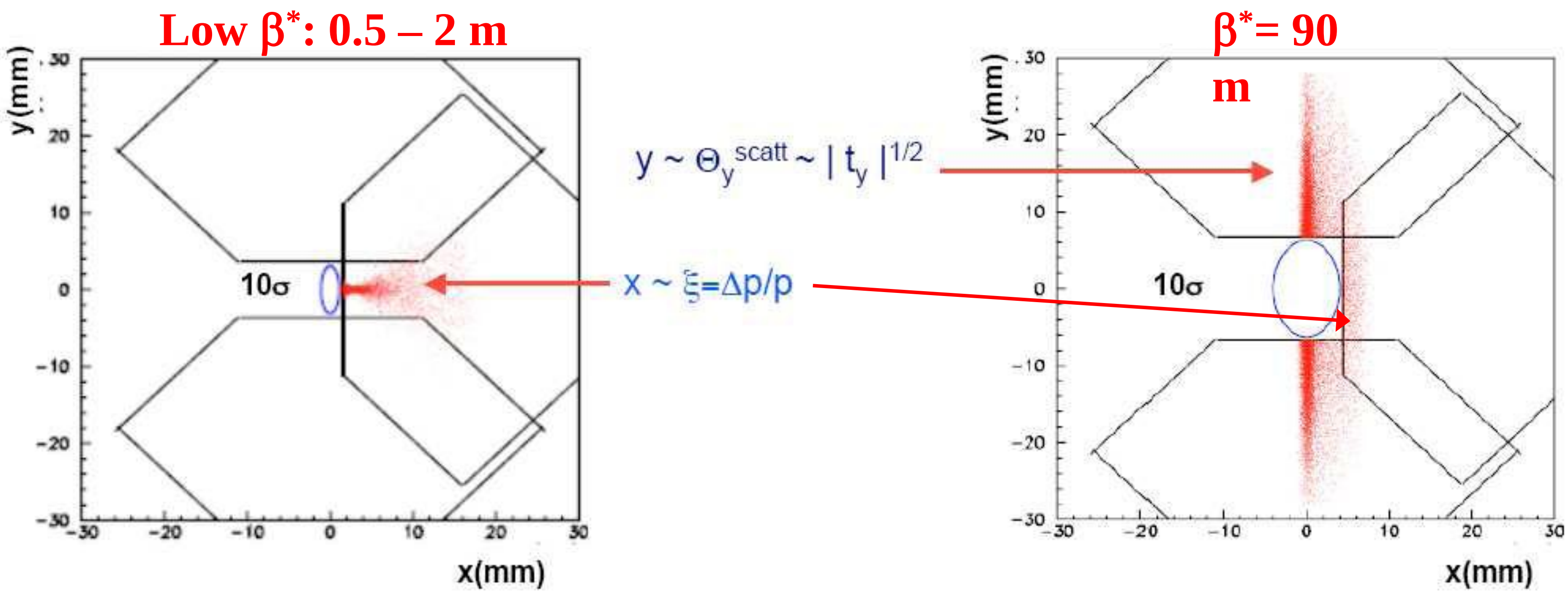
GOAL: understand the QCD nature of the diffractive exchange

Diffractive forward protons @ RPs

$$y(s) = v_y(s) \cdot y^* + L_y(s) \cdot \Theta_y^*$$
$$x(s) = v_x(s) \cdot x^* + L_x(s) \cdot \Theta_x^* + \xi \cdot \boxed{D(s)}$$

Dispersion shifts diffractive protons in the horizontal direction

Diffractive protons : hit distribution @ RP220

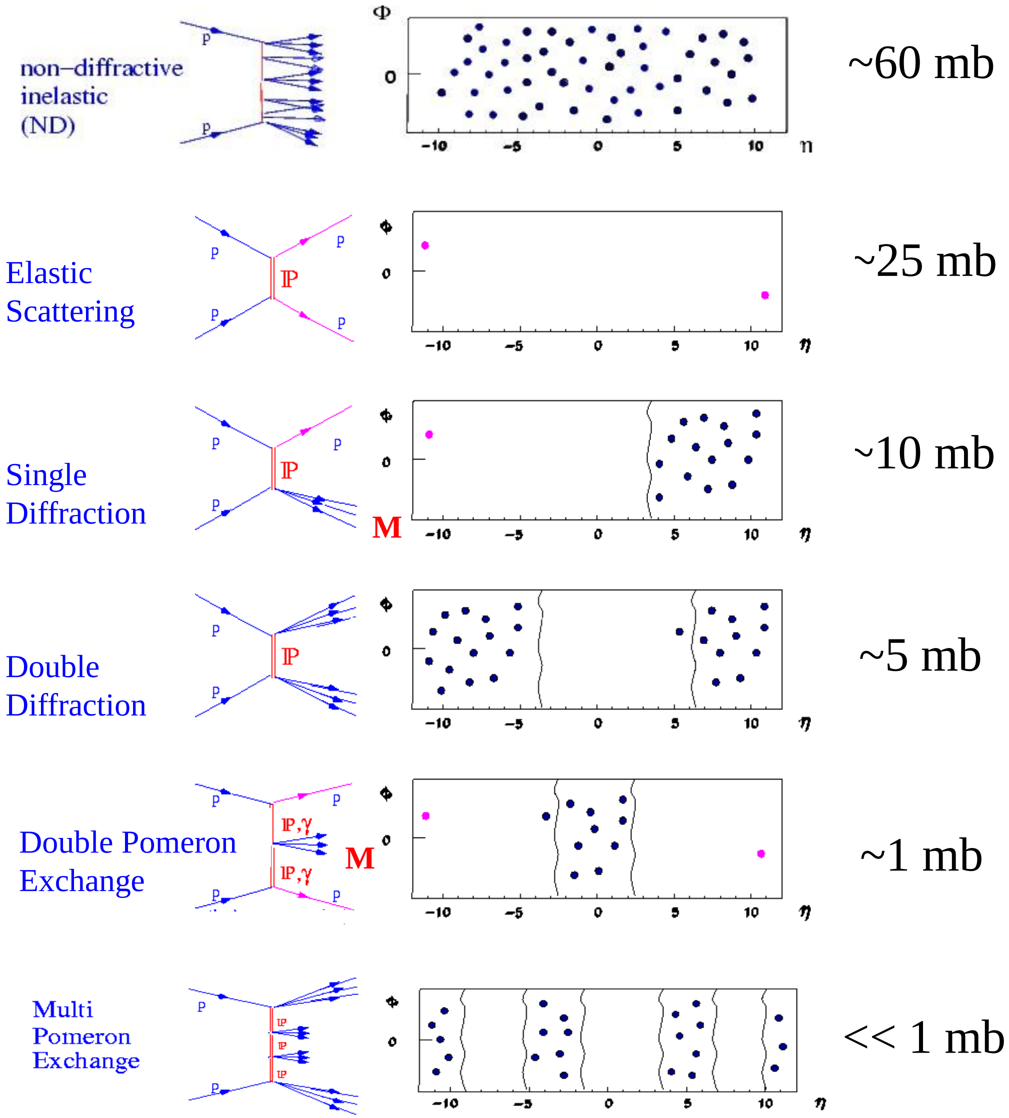


- For low-β* optics L_x, L_y are low
- v_x, v_y are not critical because of small IP beam size

- L_x=0, L_y is large
- beam σ = 212 μm → v_x, v_y important (deterioration of rec. resolution)

Inelastic and Diffractive Processes
($\eta = -\ln tg\, \theta/2$)

All the drawings show soft interactions.
In case of hard interactions there should be jets, which fall in the same rapidity intervals.

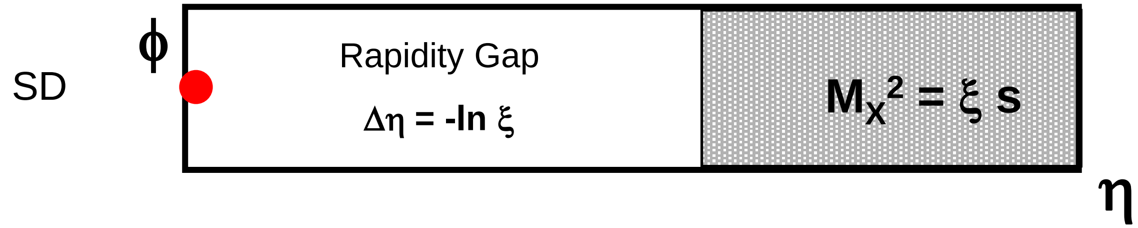


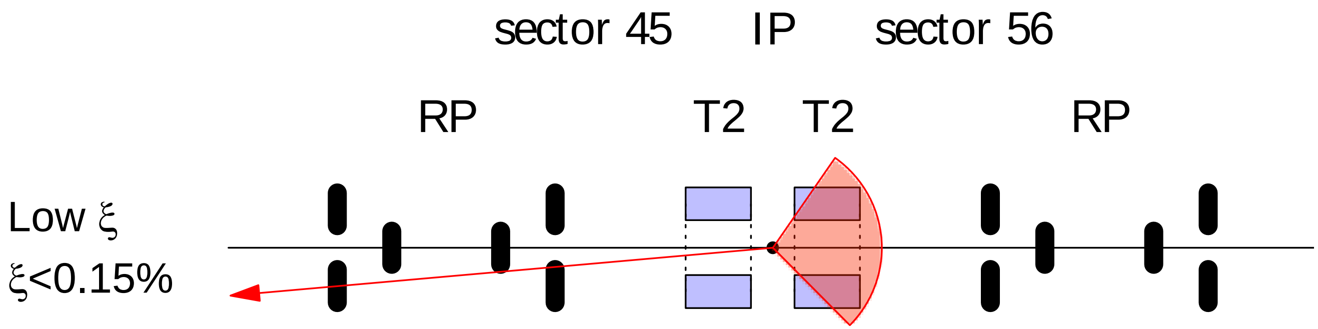
Diffractive scattering is a unique laboratory of confinement & QCD:
A hard scale + hadrons which remain intact in the scattering process.

Measure σ (M,ξ,t)

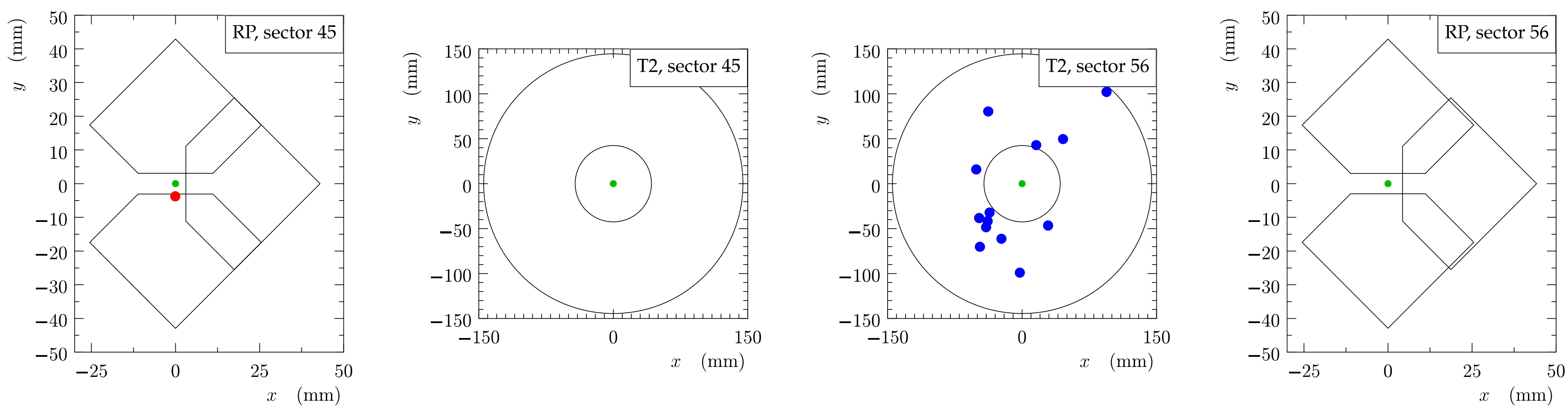
Single diffraction low ξ

Correlation between leading proton and forward detector T2



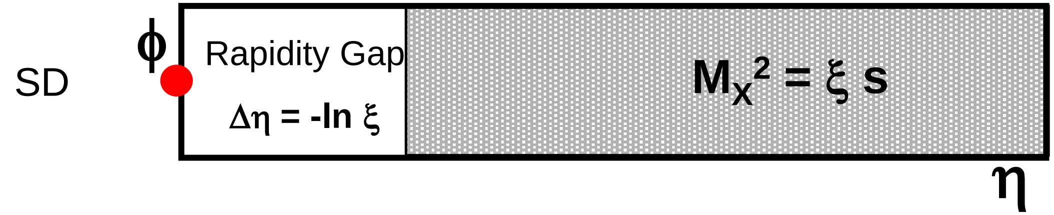


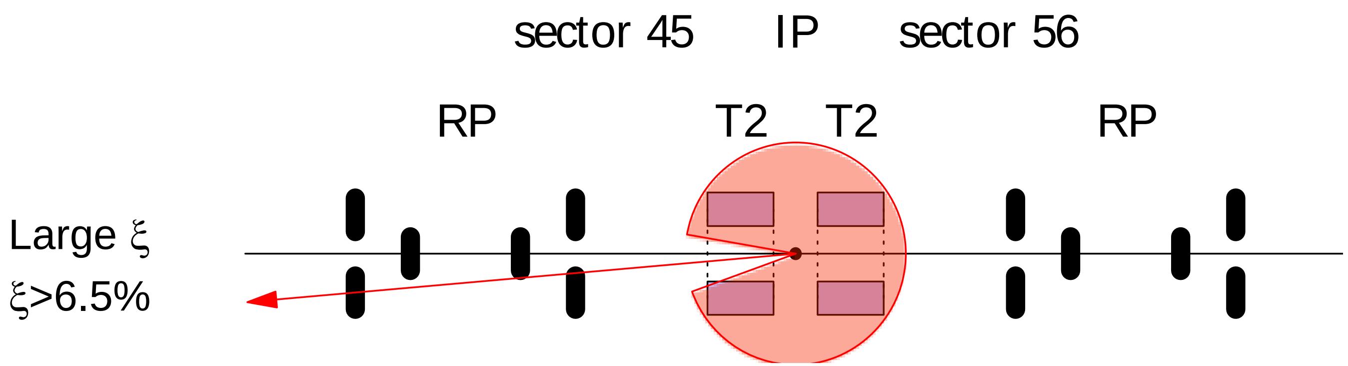
run: 37280003, event: 3000



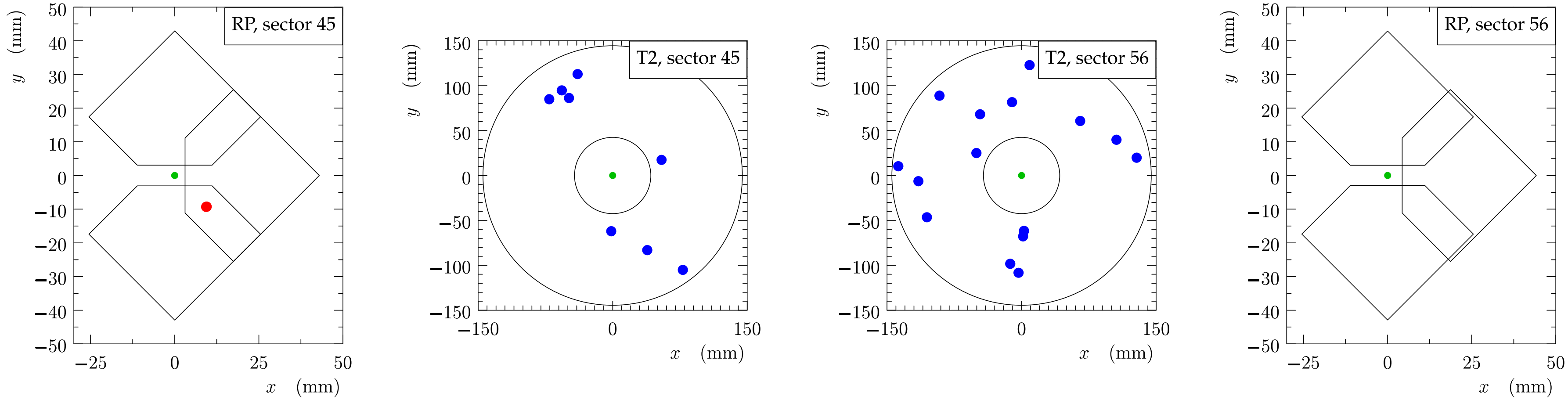
Single diffraction large ξ

correlation between leading proton and forward detector T2

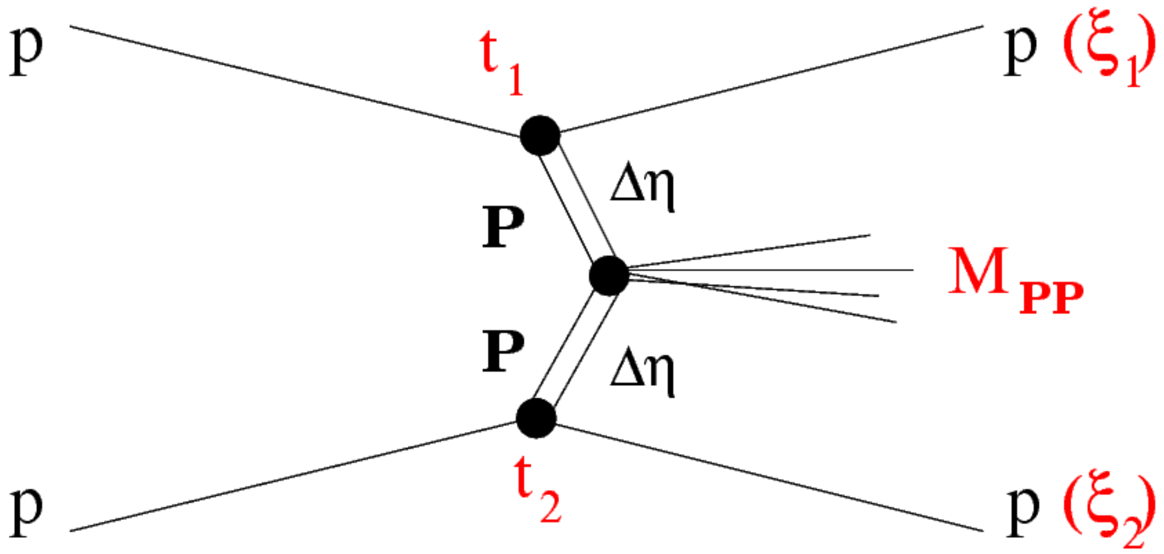


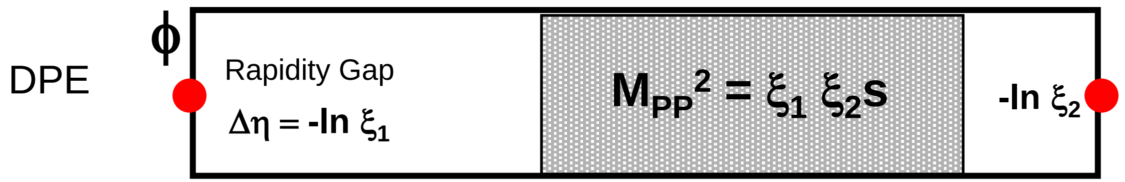


run: 37280006, event: 9522



Double Pomeron Exchange (DPE)





$$\eta = -\ln \tan \theta/2$$

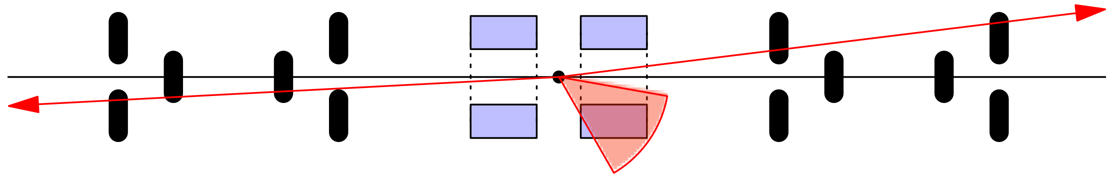
USE the LHC as a Pomeron-Pomeron (Gluon - Gluon) Collider

Double Pomeron Exchange

correlation between leading proton and forward detector T2

sector 45 IP sector 56

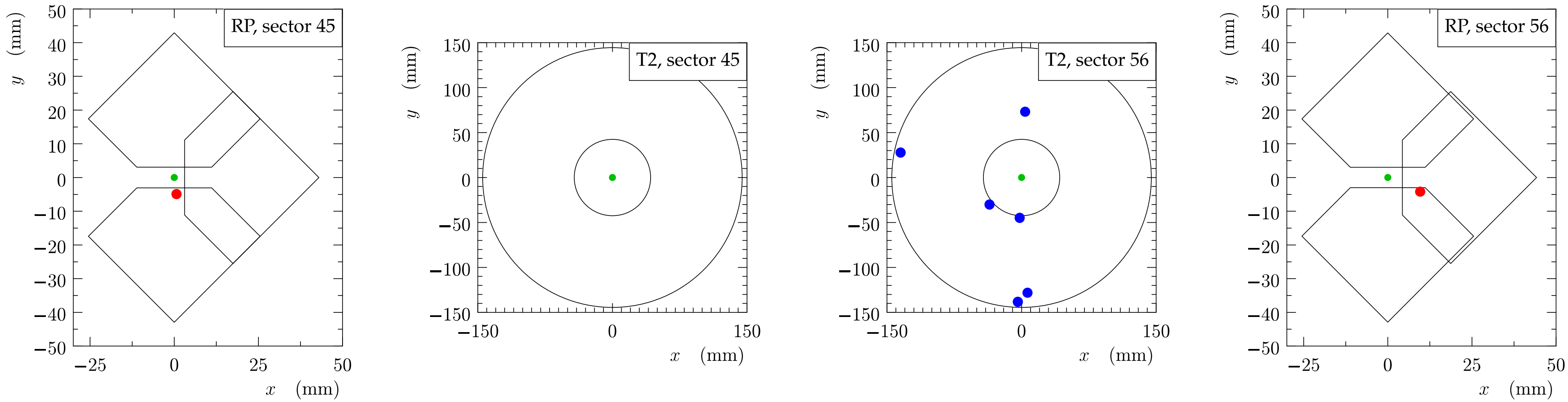
RP T2 T2 RP



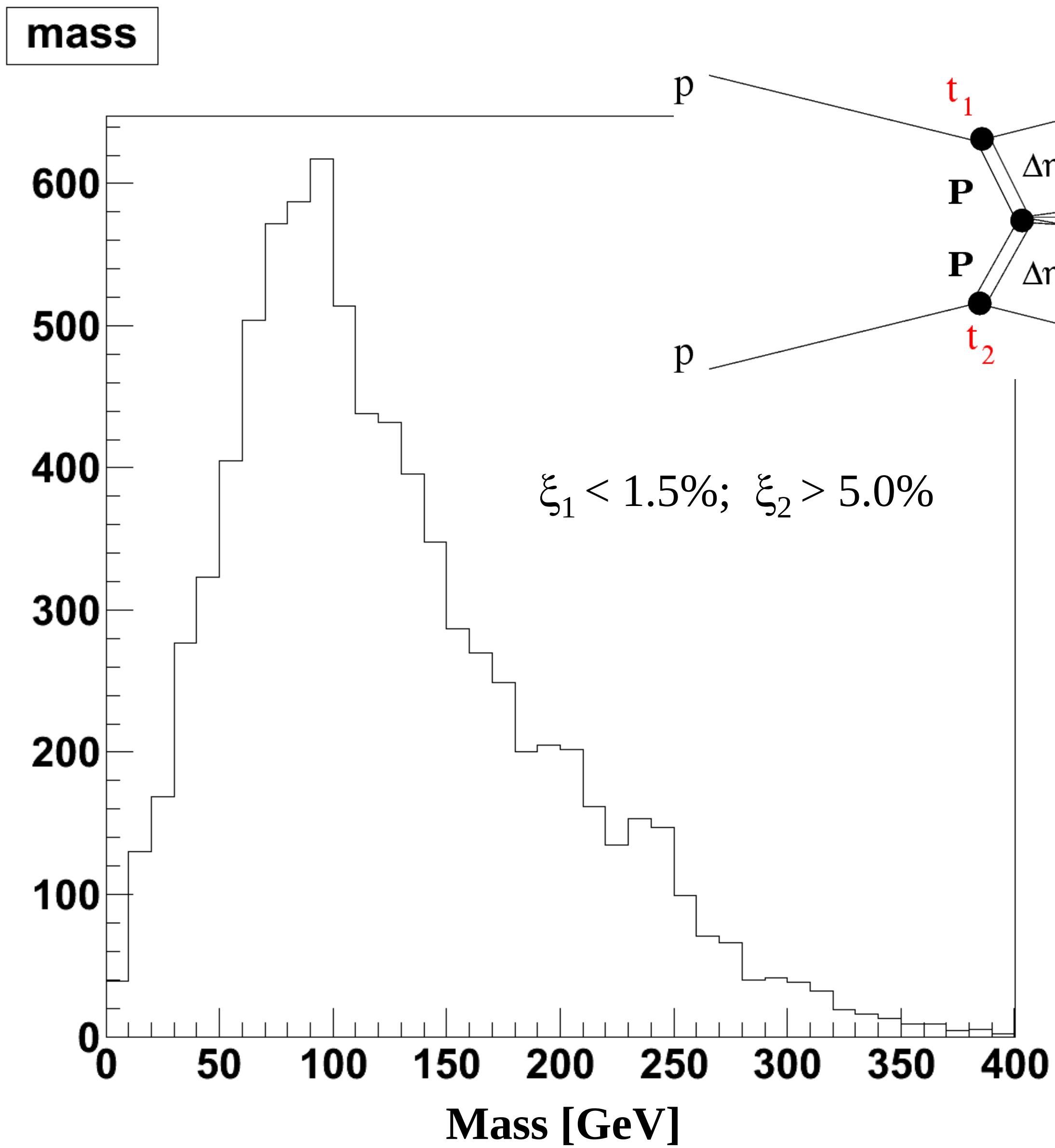
low ξ high ξ

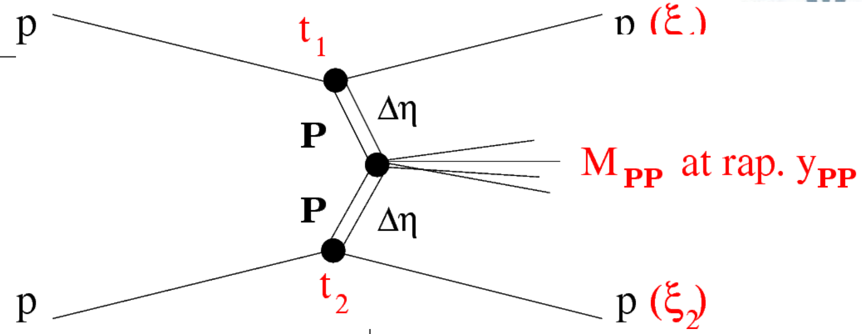
ξ<1.5% ξ>1.5%

run: 37220007, event: 9904



Example of DPE Mass Reconstruction



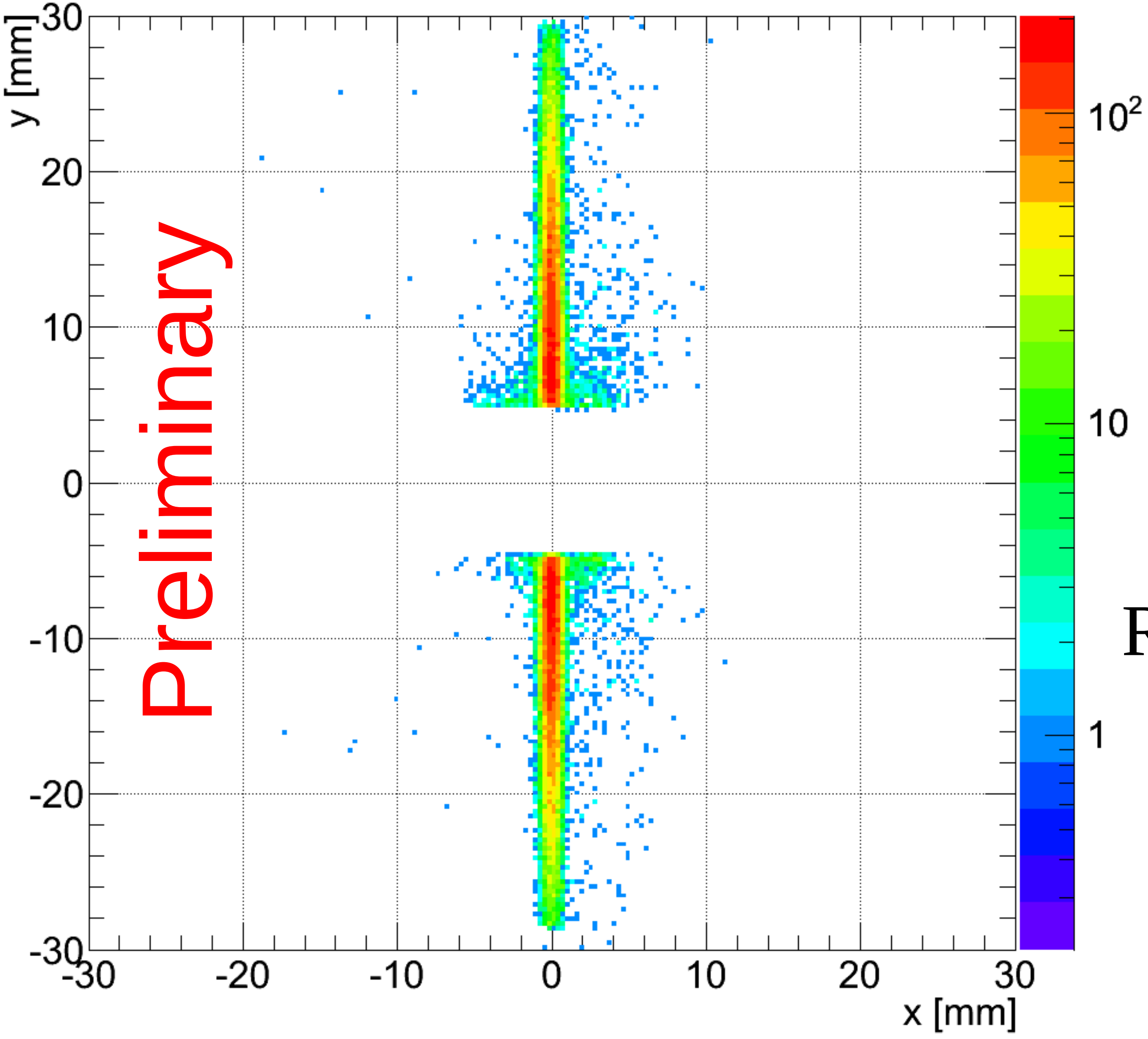


Conditions:

Low-β

Vertical RP
Horizontal RP
T2

β* = 90m Oct'11: Elastic + DPE



RP 45

AND

RP56

β* = 90m

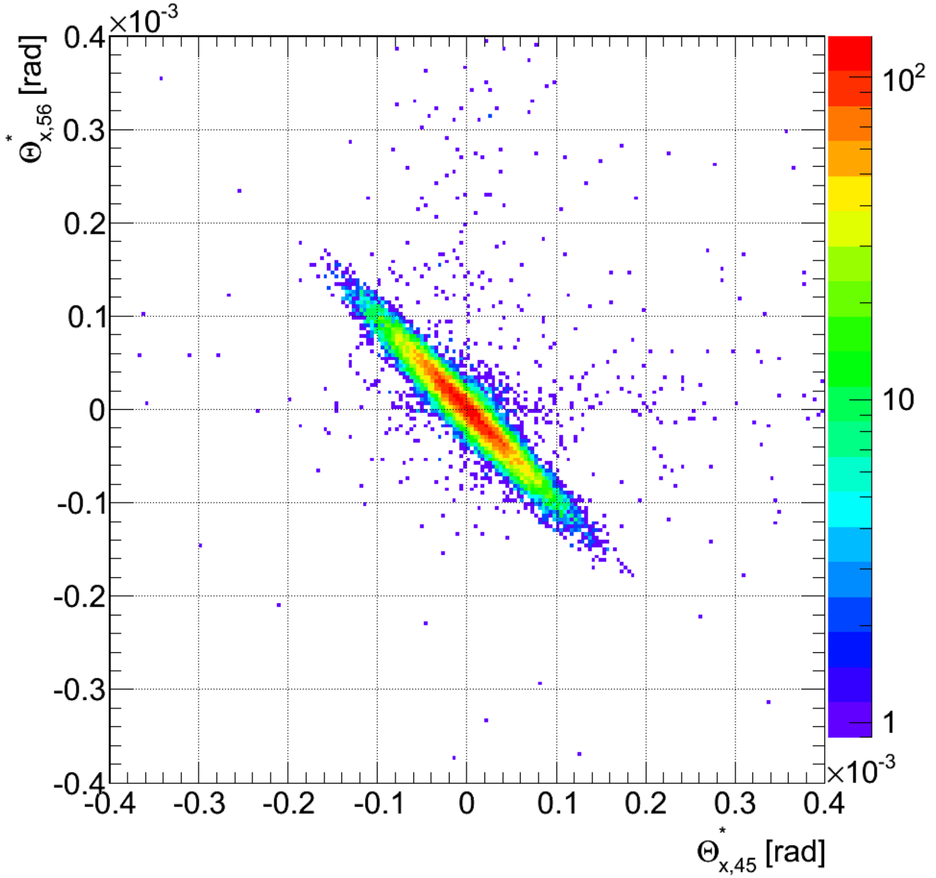
RP @ 4.8 σ

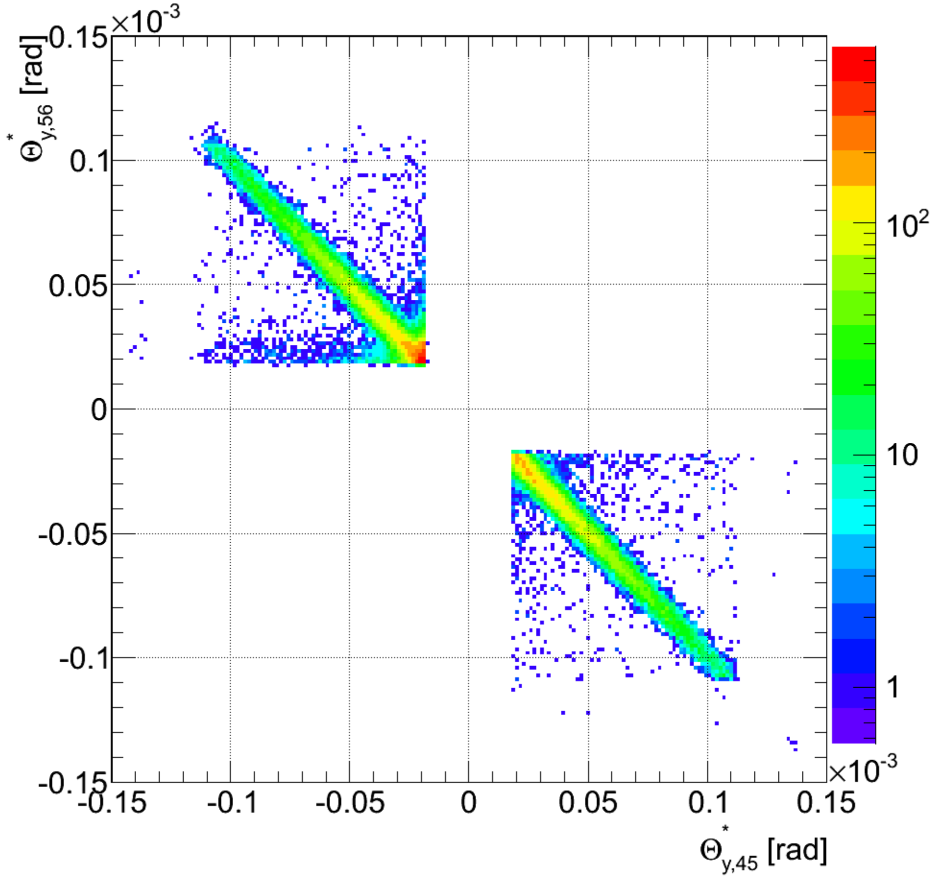
~no pile-up

β^* = 90m Oct'11: Elastic + DPE

Angular correlations

Preliminary

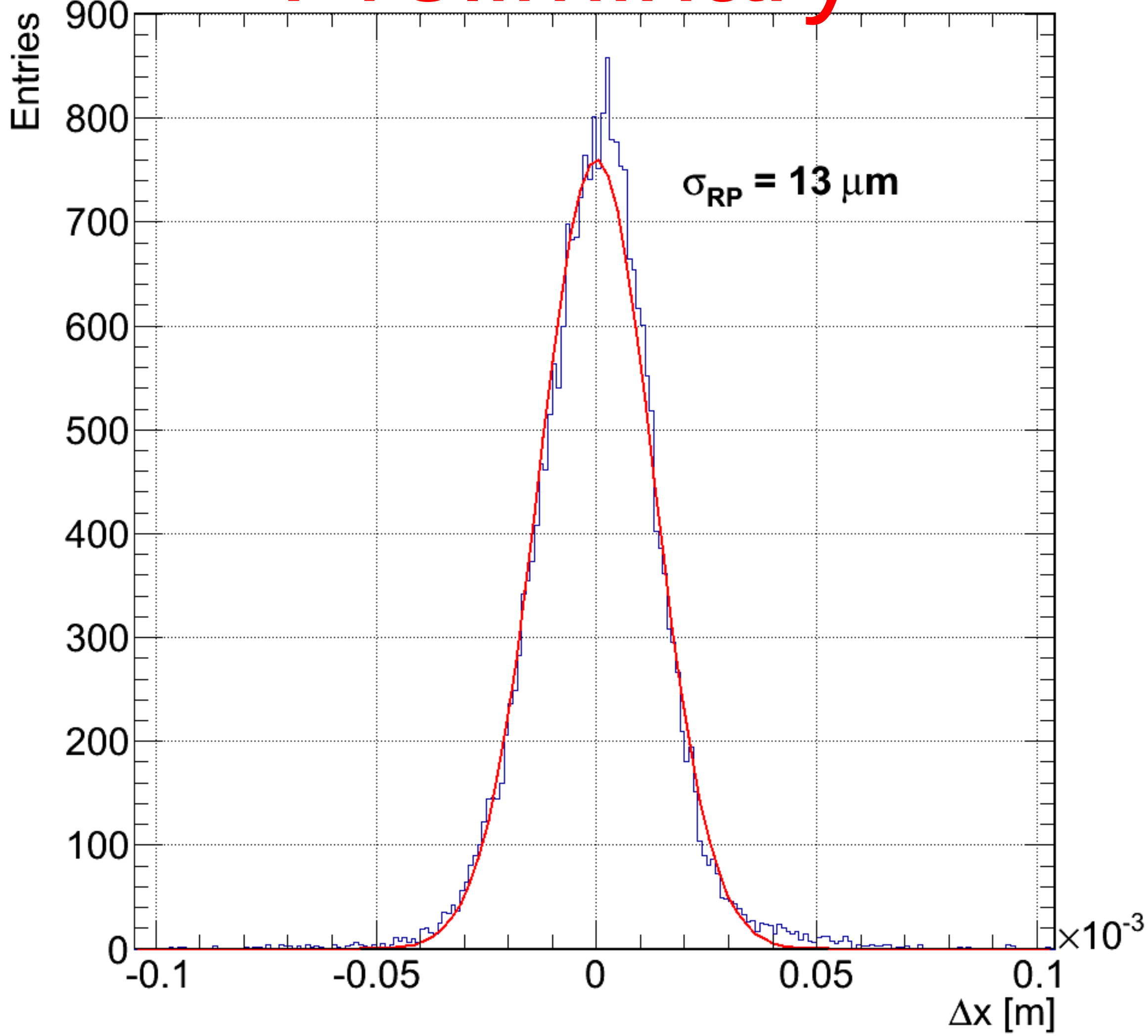




β^* = 90m Oct'11: Elastic + DPE

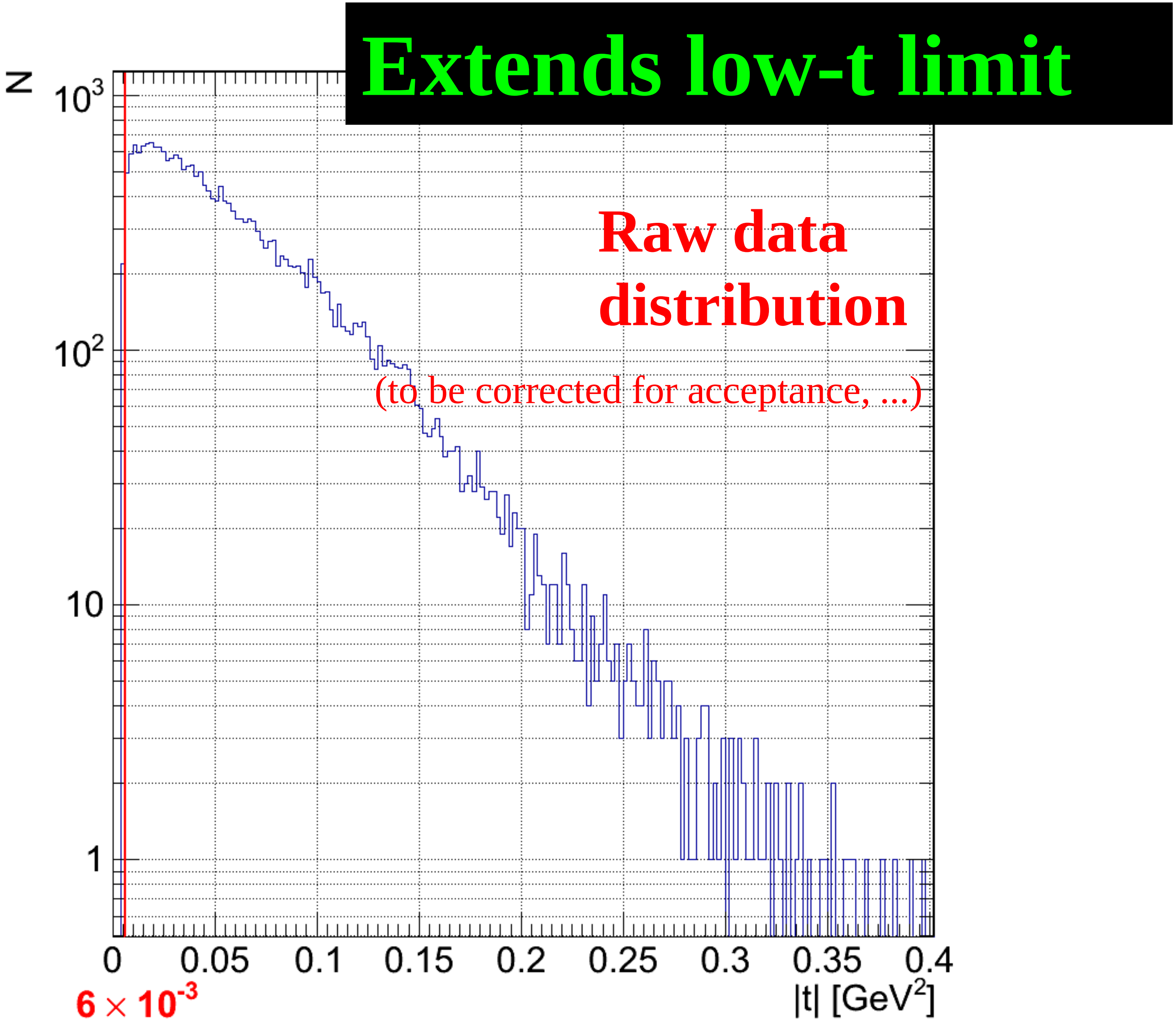
Resolution

Preliminary



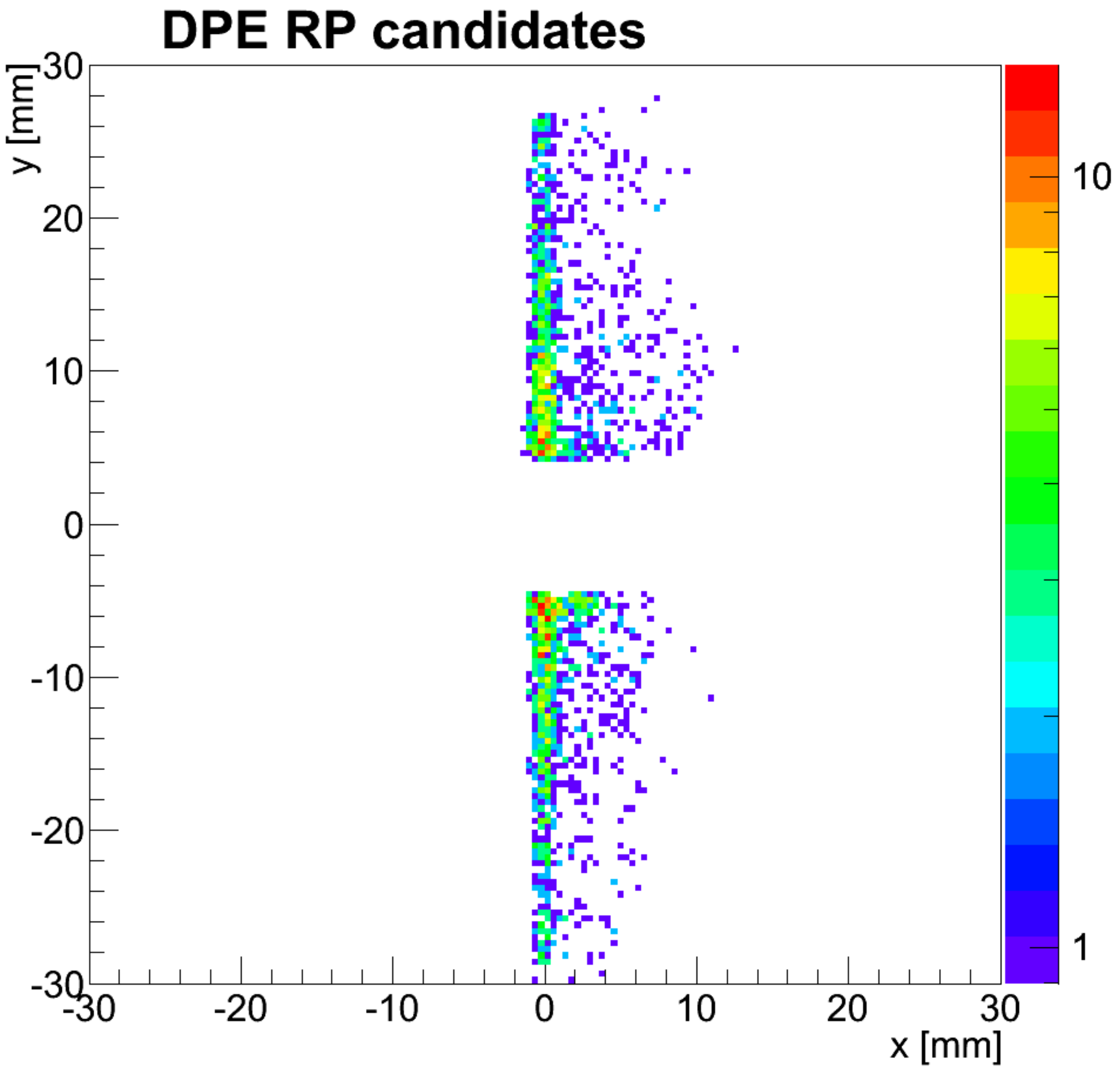
Data Oct'11: Elastic Differential Cross-Section

Preliminary

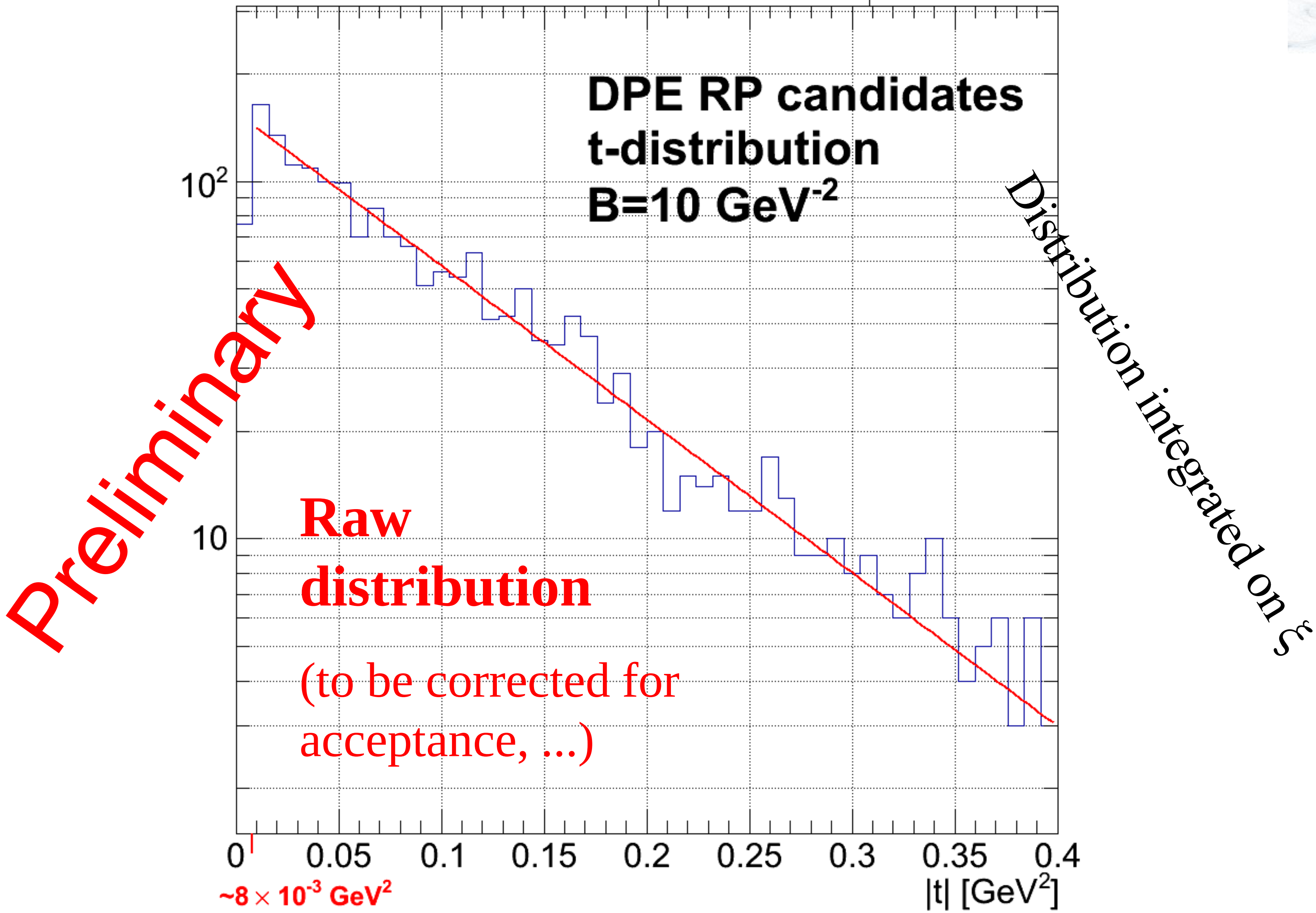


DPE *(logic complement to the elastic tag)*

Preliminary



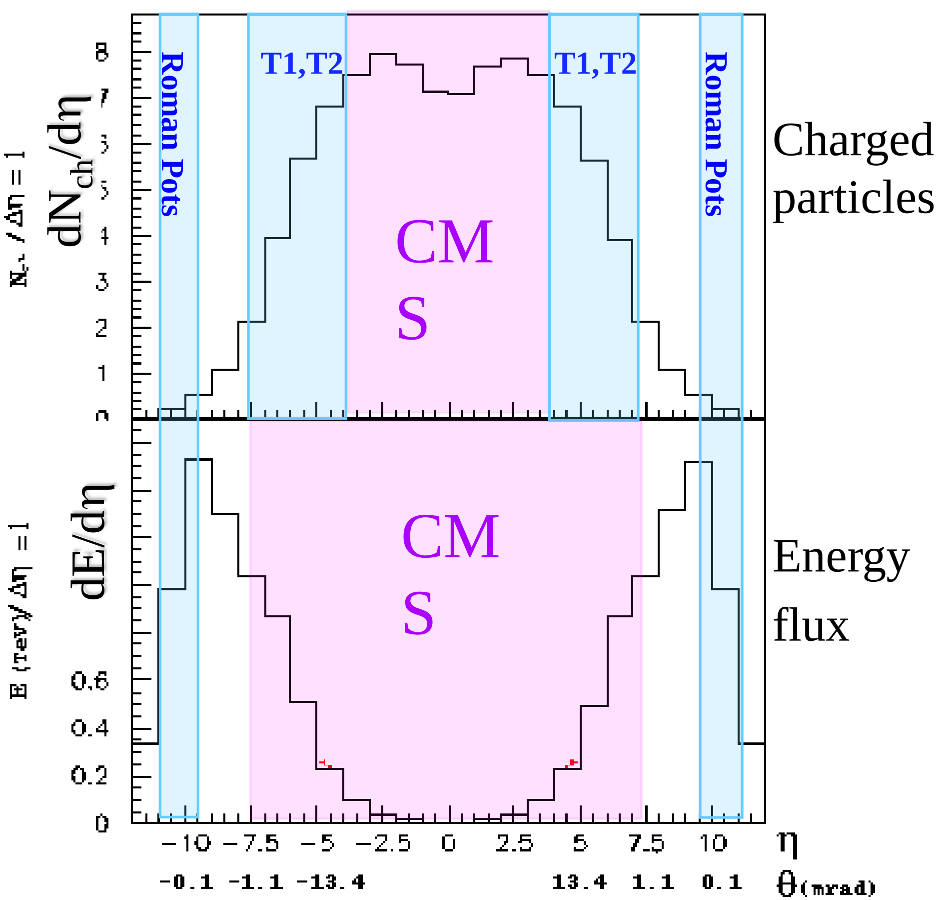
DPE Cross-Section

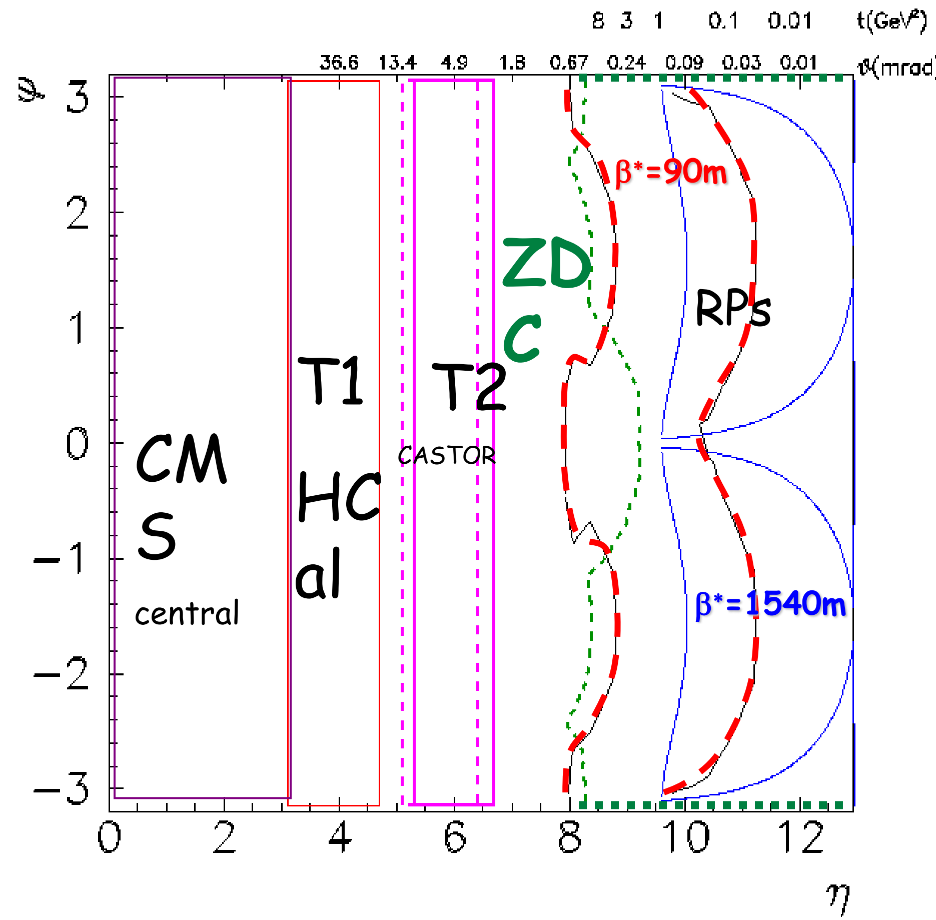


CMS + TOTEM: Acceptance

largest acceptance detector ever built at a hadron collider

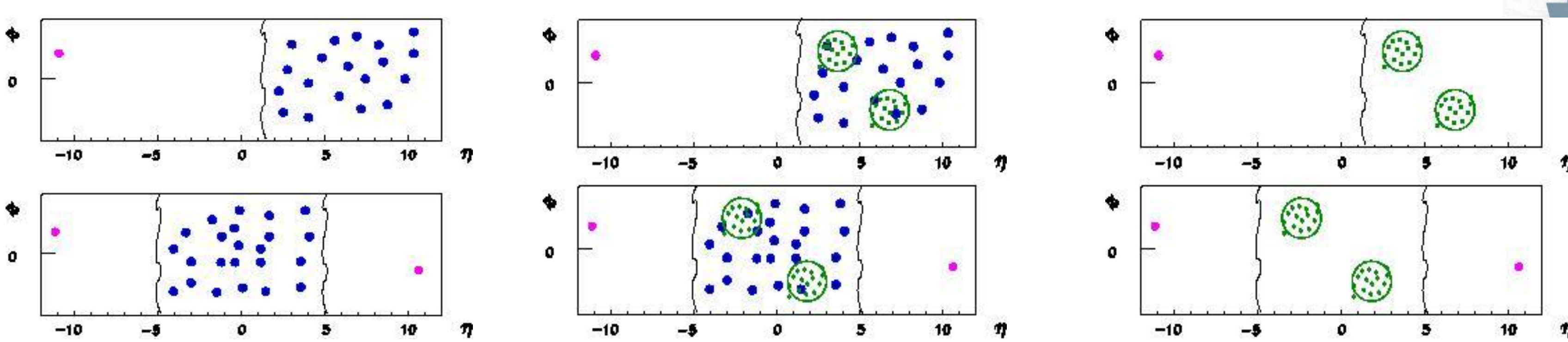
90% (65%) of all diffractive protons are detected for β* = 1540 (90) m





η = - ln tg θ/2

TOTEM + CMS running scenarios



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

β (m)	1540	90	2	0.5	
L (cm^{-2} s^{-1})	10^{29}	10^{30}	10^{32}		10^{34}

TOTEM LHC runs — Standard LHC runs

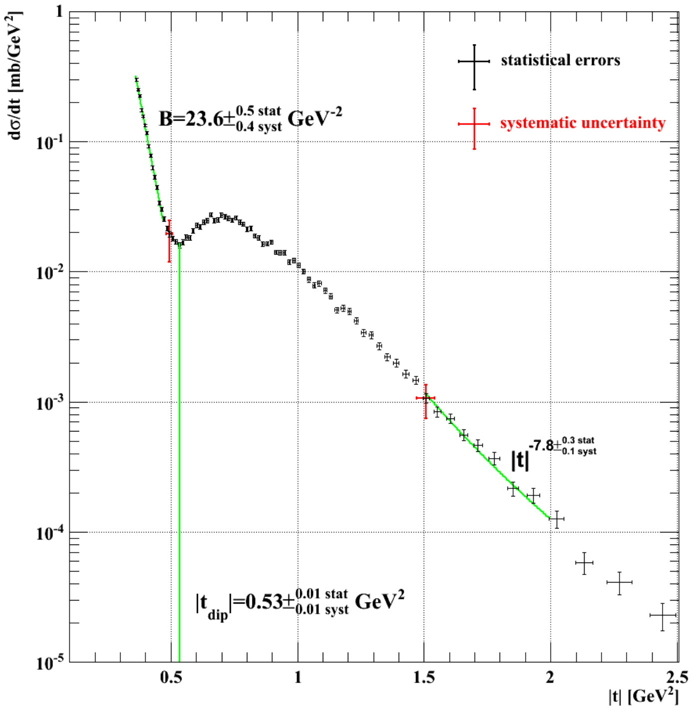
Acknowledgments

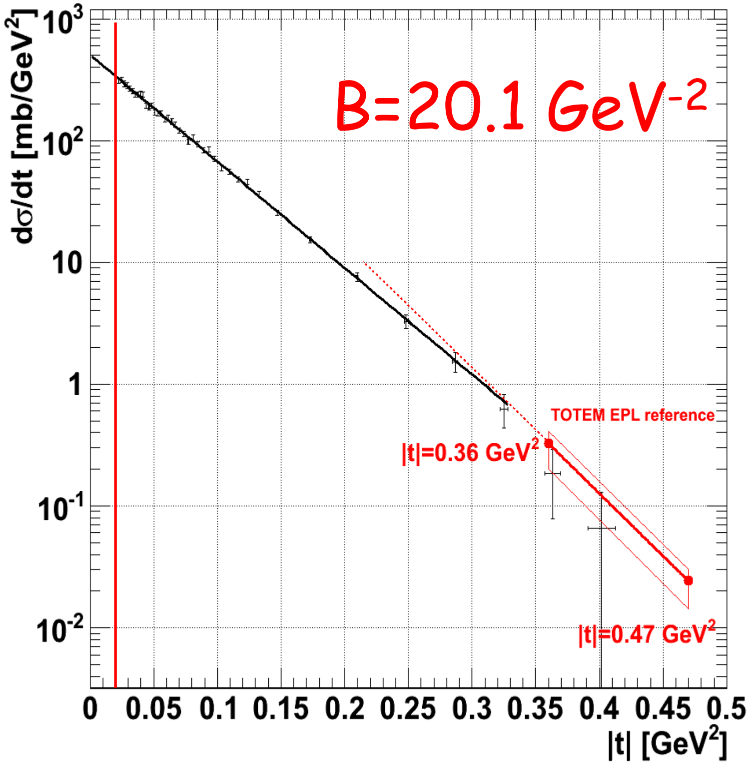
- Special acknowledgments to the LHC team for their support and for the development of the 90m optics.

- Special acknowledgments to CMS for their collaboration and for providing TOTEM with the luminosity measurements.

Thank you for your attention

Large-*t* elastic published in **EPL**, 95 (2011) 41001



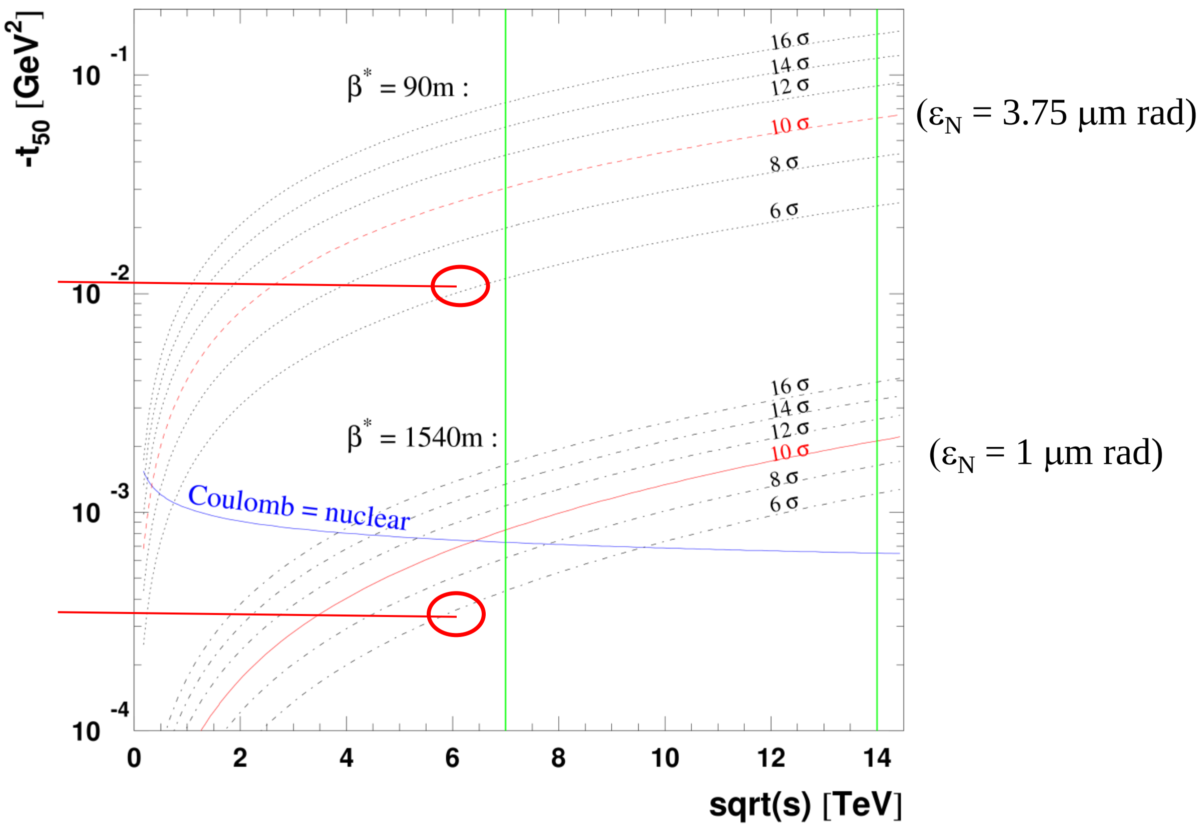


Small-*t* elastic and total cross-section published in **EPL**, 96(2011) 21002.

BACKUP

Measurement of ρ in the Coulomb-nuclear Interference Region?

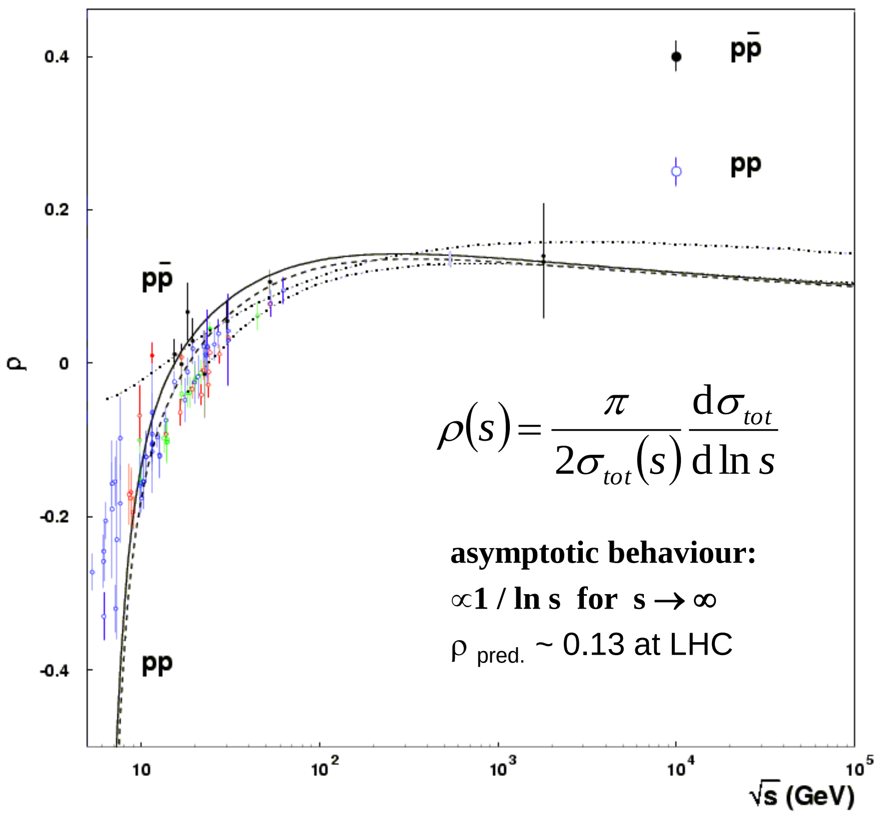
Obtain the last ingredient for σ_{tot} from measurement rather than from theory

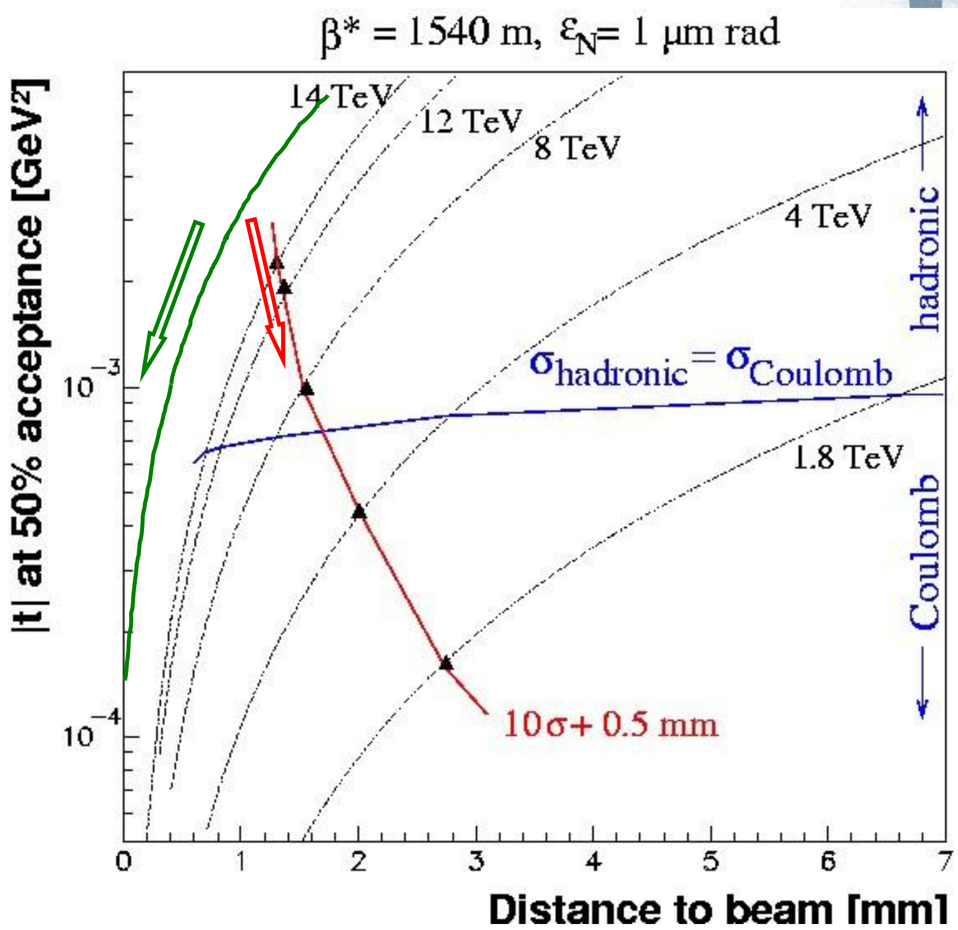


→might be possible at sqrt(s)=7 TeV with RPs at 5 to 6 σ

→incentive to develop very-high-β* optics before reaching 14 TeV !
e.g. try to use the same optics principle as for 90m and unsqueeze further.

Possibilities of ρ measurement





Try to reach the Coulomb region and measure interference:

- move the detectors closer to the beam than 10 σ + 0.5 mm
- run at lower energy @ √s < 14 TeV

[EPL 95 (2011) 41001]

Proton-proton elastic scattering at the LHC energy of $\sqrt{s} = 7$ TeV

THE TOTEM COLLABORATION
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First measurement of the total proton-proton cross-section at the LHC energy of $\sqrt{s} = 7$ TeV

THE TOTEM COLLABORATION (G. ANTCHEV *et al.*)

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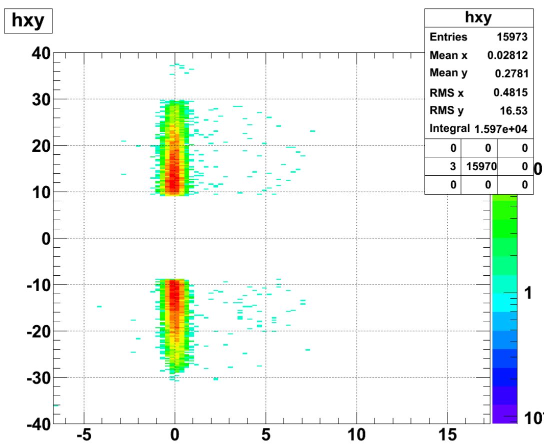
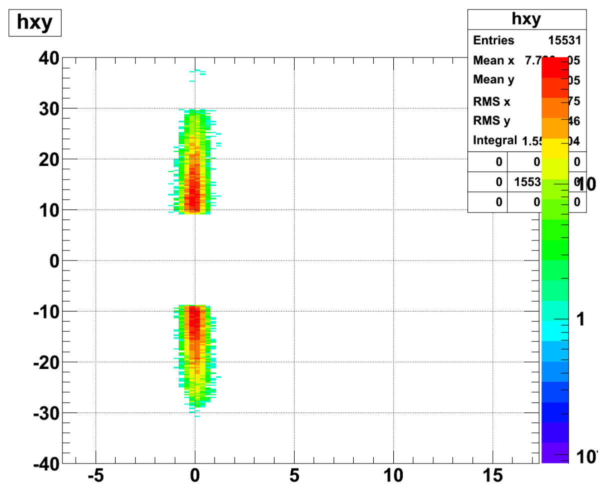
Background Subtraction

Extrapolation of the background of the EPL paper should be an upper limit (2SD + DPE +…) for the real contamination of the low t-distribution: found to be <=1% @ |t|<0.1 GeV^2



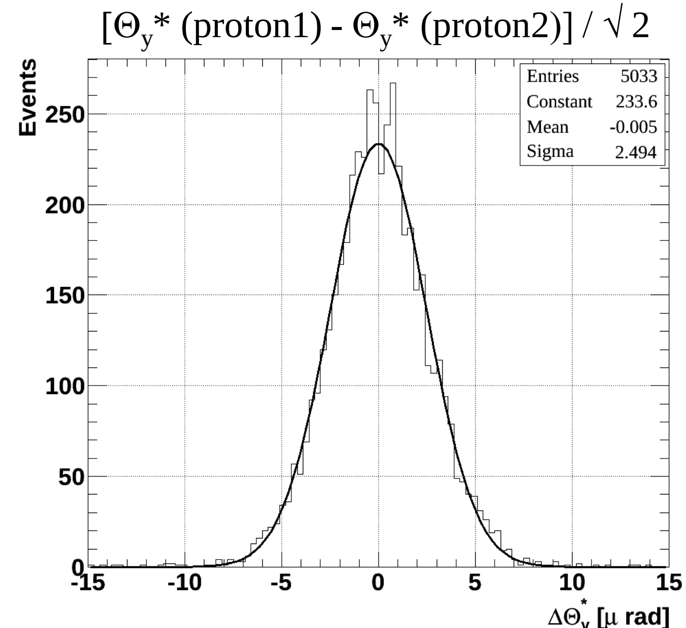
left:

before colinearity req



middle:

after colinearity req



right:

no tails

Data confirm that there is no measurable background.

Statistical and Systematic uncertainties for the t and dσ/dt results

Table 3: Statistical and systematic errors on t and $\mathrm{d}\sigma/\mathrm{dt}$.

	$\delta t = \sigma_t^{Stat}(t) \oplus \varepsilon_t^{Syst}(t)$	$\delta(\mathrm{d}\sigma/\mathrm{dt}) = \sigma_{\mathrm{d}\sigma/\mathrm{dt}}^{Stat}(t) \oplus \varepsilon_{\mathrm{d}\sigma/\mathrm{dt}}^{Syst}(t)$
$\lvert t\rvert = 0.4\mathrm{GeV}^2$	$\frac{\delta t}{t} = \pm 0.5\%^{Stat} \pm 2.6\%^{Syst}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 2.6\%^{Stat}\ {}^{+25}_{-37}\ \%^{Syst}$
$\lvert t\rvert = 0.5\mathrm{GeV}^2$	$\frac{\delta t}{t} = \pm 0.7\%^{Stat} \pm 2.5\%^{Syst}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 4.4\%^{Stat}\ {}^{+28}_{-39}\ \%^{Syst}$
$\lvert t\rvert = 1.5\mathrm{GeV}^2$	$\frac{\delta t}{t} = \pm 0.8\%^{Stat} \pm 2.3\%^{Syst}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 8.2\%^{Stat}\ {}^{+27}_{-30}\ \%^{Syst}$

σ_{tot}

Table 1: Results of the TOTEM measurements at the LHC energy of $\sqrt{s} = 7\,\text{TeV}$.

	Statistical uncertainties	Systematic uncertainties	Result
t	$\pm[3.4 \div 11.9]\%$ single measurement$^{(*)}$	$\pm[0.6 \div 1.8]\%^{\text{optics}} \pm < 1\%^{\text{alignment}}$	
$\frac{d\sigma}{dt}$	5% / bin	$\pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}} \pm 0.7\%^{\text{unfolding}}$	
B	$\pm 1\%$	$\pm 1\%^{t-\text{scale}} \pm 0.7\%^{\text{unfolding}}$	$\mathbf{(20.1 \pm 0.2^{stat} \pm 0.3^{syst})\ GeV^{-2}}$
$\frac{d\sigma}{dt}\vert_{t=0}$	$\pm 0.3\%$	$\pm 0.3\%^{\text{optics}} \pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}}$	$\mathbf{(503.7 \pm 1.5^{stat} \pm 26.7^{syst})\ mb/GeV^2}$
$\int \frac{d\sigma}{dt}\,dt$	$\pm 0.8\%^{\text{extrapolation}}$	$\pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}}$	
σ_{tot}	$\pm 0.2\%$	$\begin{pmatrix}+0.8\% \\ -0.2\%\end{pmatrix}^{(\rho)} \pm 2.7\%$	$\mathbf{(98.3 \pm 0.2^{stat} \pm 2.8^{syst})\ mb}$
$\sigma_{\text{el}} = \int \frac{d\sigma}{dt}\,dt$	$\pm 0.8\%$	$\pm 5\%$	$\mathbf{(24.8 \pm 0.2^{stat} \pm 1.2^{syst})\ mb}$
σ_{inel}	$\pm 0.8\%$	$\begin{pmatrix}+2.4\% \\ -1.8\%\end{pmatrix}$	$\mathbf{(73.5 \pm 0.6^{stat}\ {}^{+1.8}_{-1.3}\ {}^{syst})\ mb}$
σ_{inel} (CMS)			$(68.0 \pm 2.0^{\text{syst}} \pm 2.4^{\text{lumi}} \pm 4^{\text{extrap}})$ mb
σ_{inel} (ATLAS)			$(69.4 \pm 2.4^{\text{exp}} \pm 6.9^{\text{extrap}})$ mb
σ_{inel} (ALICE)			$(72.7 \pm 1.1^{\text{model}} \pm 5.1^{\text{lumi}})$ mb

$^{(*)}$corrected after unfolding

$^{\text{analysis}}$(includes tagging, acceptance, efficiency, background)