First Measurements of Proton-Proton Elastic Scattering and Total Cross-Section at the LHC

EDS 2011
Qui Nhon, Vietnam

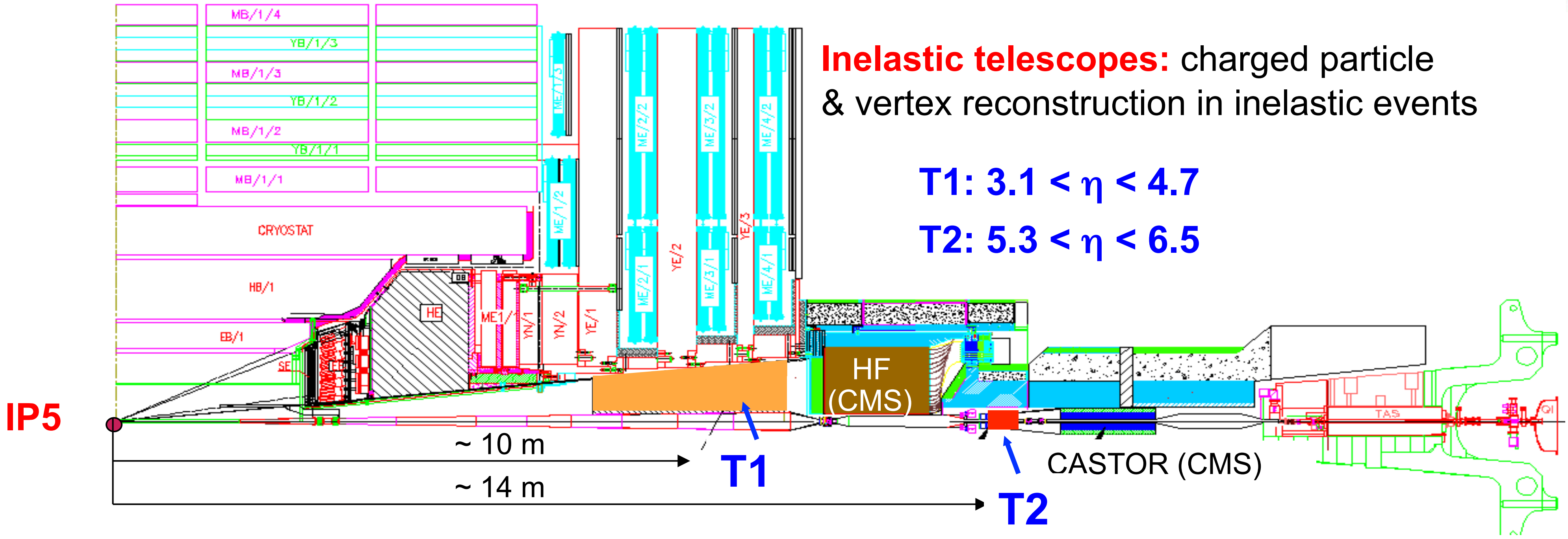
Mario Deile
on behalf of the TOTEM Collaboration

Experimental Setup @ IP5

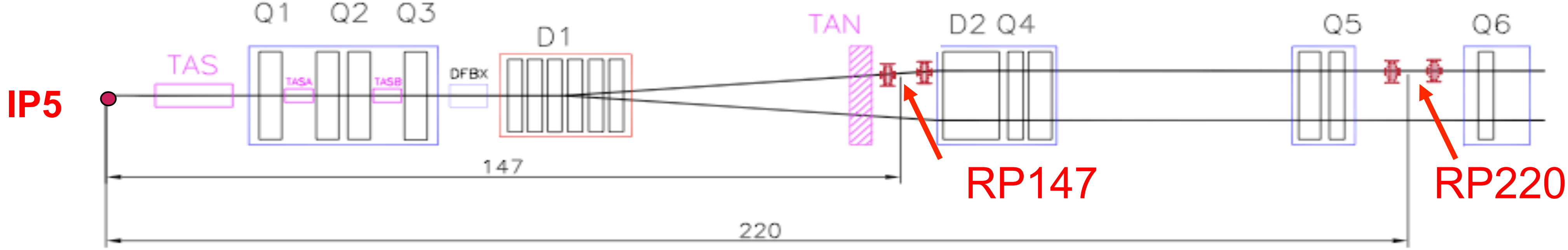
Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

T1: 3.1 < η < 4.7

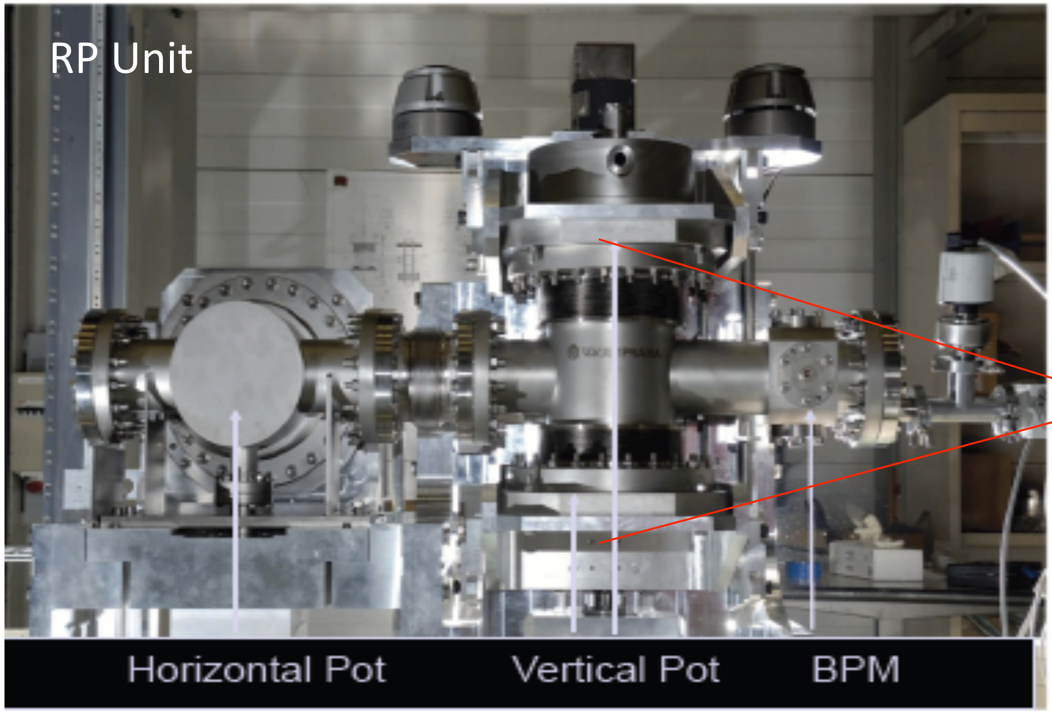
T2: 5.3 < η < 6.5

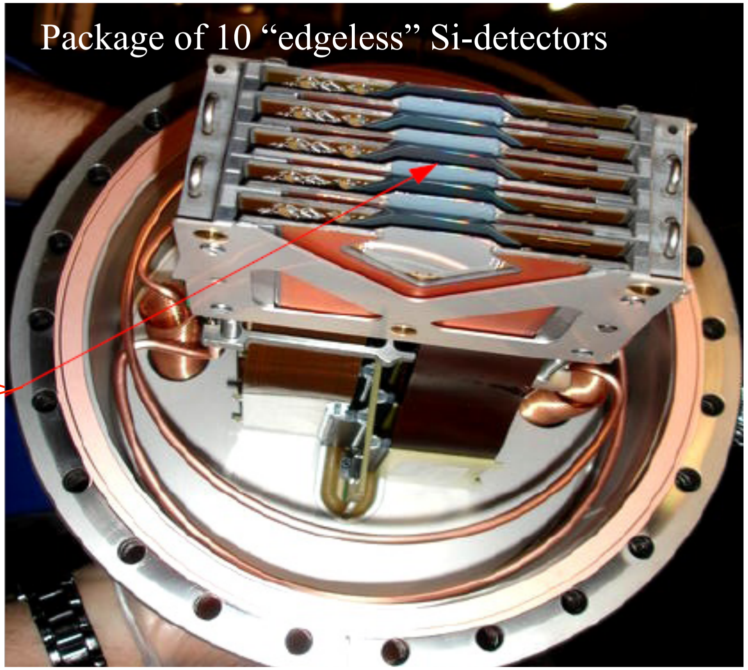


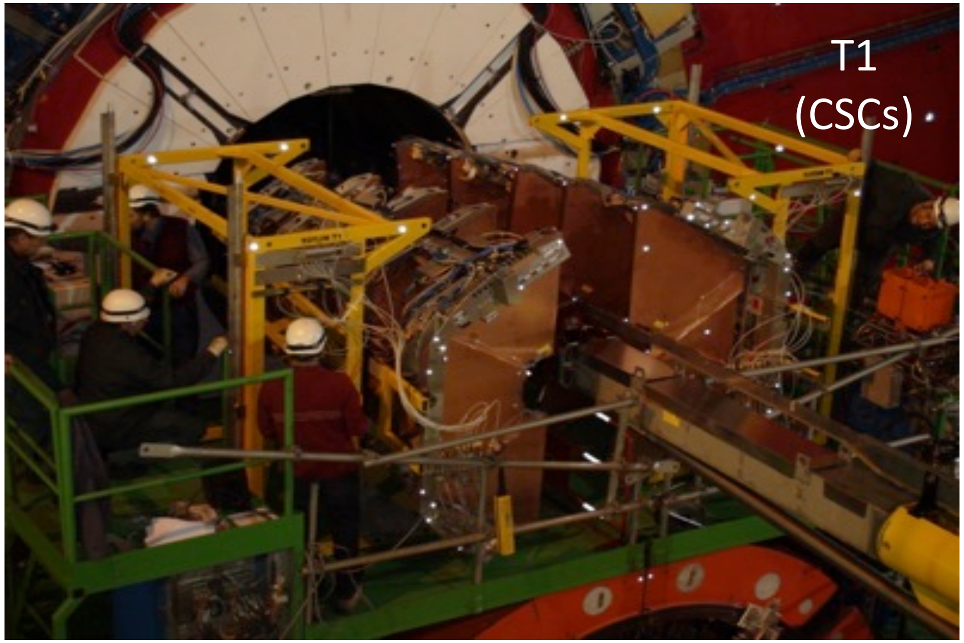
Roman Pots: measure elastic & diffractive protons close to outgoing beam

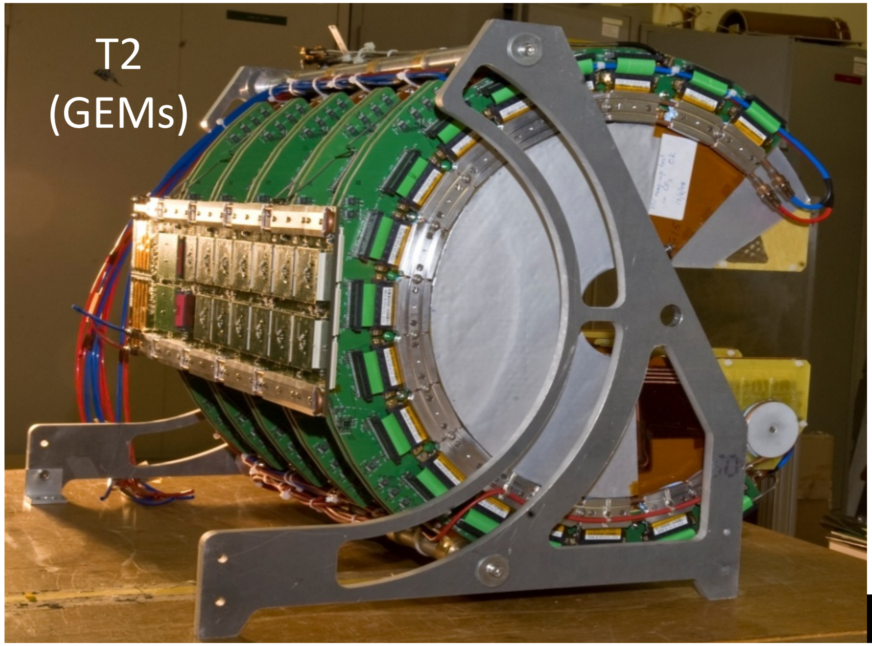


TOTEM Detectors









Outline

Presented here: data at √s = 7 TeV from 2010 and 2011

- Elastic scattering for |t| ∈ [0.36; 2.5] GeV^2
  [EPL 95 2011, 41001]

- Total pp cross-section measurement based on elastic scattering at |t| ∈ [0.02; 0.4] GeV^2
  [EPL 96 (2011) 21002]

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

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

  Normalisation with luminosity from CMS
  (uncertainty ± 4%)

  $$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$$

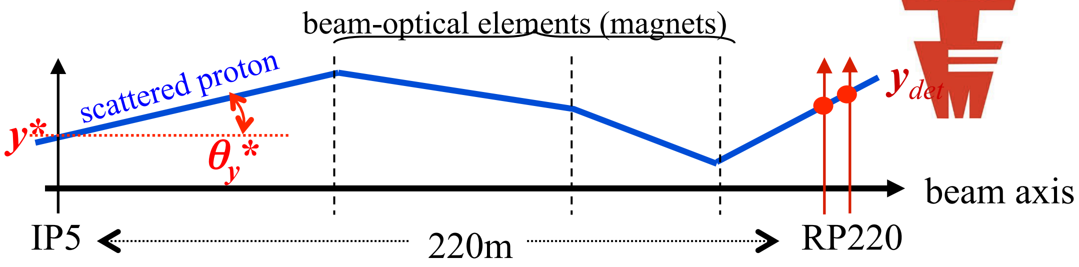
- Outlook:
  - ongoing analyses of existing data
  - plans for data taking in 2012 and beyond

Beam Optics and Proton Transport

(x^*, y^*): vertex position

(θ_x^*, θ_y^*): emission angle: $t \approx -p^2 (\theta_x^{*2} + \theta_y^{*2})$

$\xi = \Delta p/p$: momentum loss (diffraction)



$$\boxed{y_{\text{det}} = L_y \theta_y^* + v_y y^*}$$

$\beta^* = 90$ m: $L_y = 263$ m, $v_y \approx 0$

$\beta^* = 3.5$ m: $L_y \sim 20$ m, $v_y = 4.3$

→ Reconstruct via track positions

$$\boxed{x_{\text{det}} = L_x \theta_x^* + v_x x^* + \cancel{D\xi}}$$

Elastic: $\xi = 0$

$\beta^* = 90$ m: $L_x \approx 0$, $v_x = -1.9$

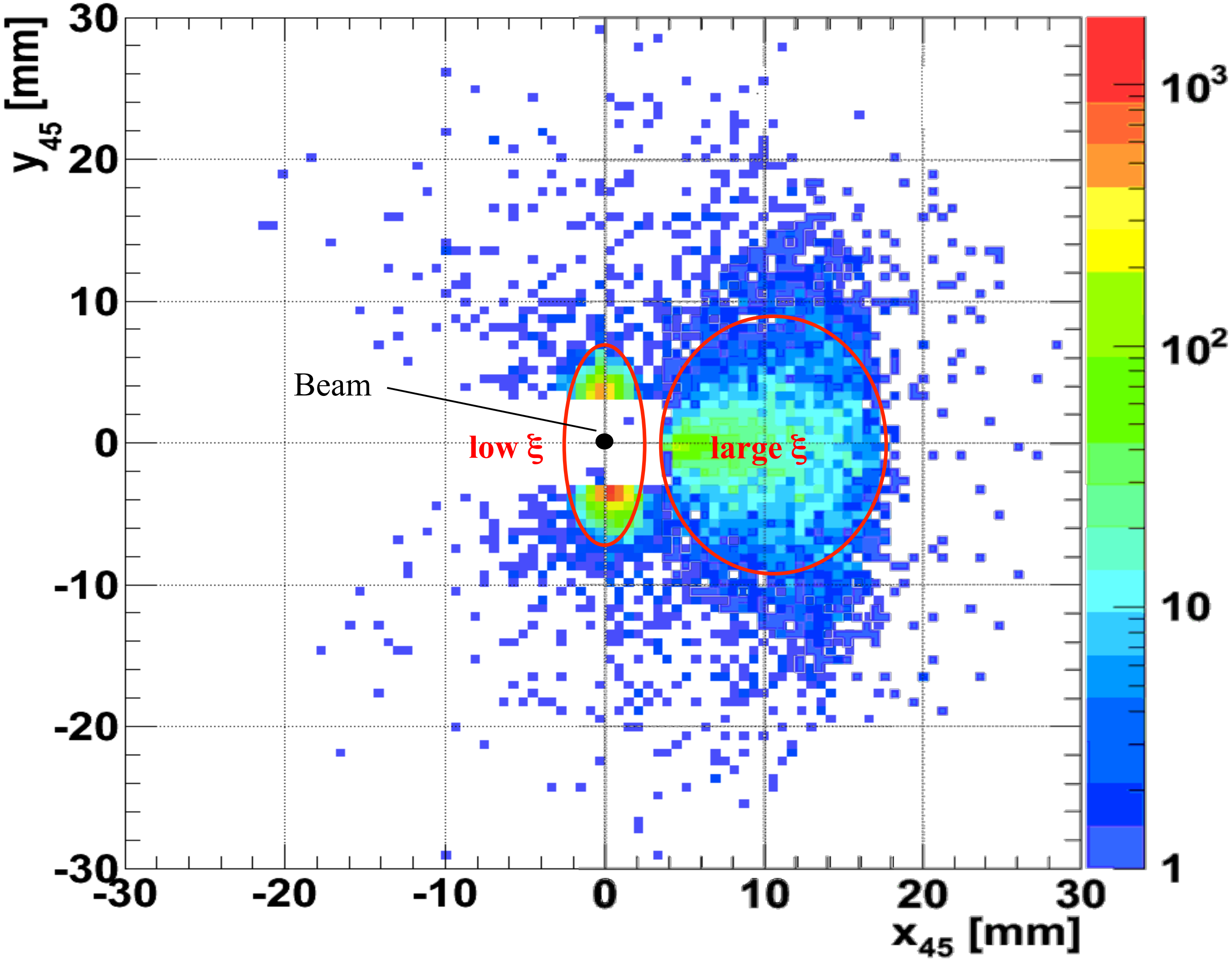
$\beta^* = 3.5$ m: $L_x \approx 0$, $v_x = 3.1$

→ Use derivative (reconstruct via local track angles):

$$\boxed{\frac{dx_{\text{det}}}{ds} = \frac{dL_x}{ds}\theta_x^* + \frac{dv_x}{ds} x^*}$$

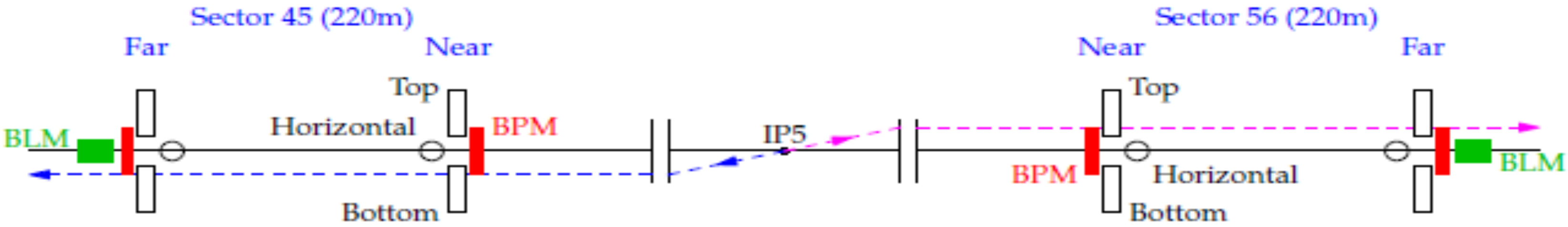
		Beam width @ vertex $\sigma_{x,y}^* = \sqrt{\frac{\varepsilon_n \beta^*}{\gamma}}$	Angular beam divergence $\sigma_{x,y}^* = \sqrt{\frac{\varepsilon_n}{\beta^* \gamma}}$	Min. reachable |t| $\lvert t_{\min} \rvert = \frac{n_\sigma^2 p \varepsilon_n m_p}{\beta^*}$
Standard optics	$\beta^* \sim 1\text{–}3.5$ m	$\sigma_{x,y}^*$ small	$\sigma(\theta_{x,y}^*)$ large	$\lvert t_{\min}\rvert \sim 0.3\text{–}1$ GeV^2
Special optics	$\beta^* = 90$ m	$\sigma_{x,y}^*$ large	$\sigma(\theta_{x,y}^*)$ small	$\lvert t_{\min}\rvert \sim 10^{-2}$ GeV^2

Track distribution for an inclusive trigger (global "OR")



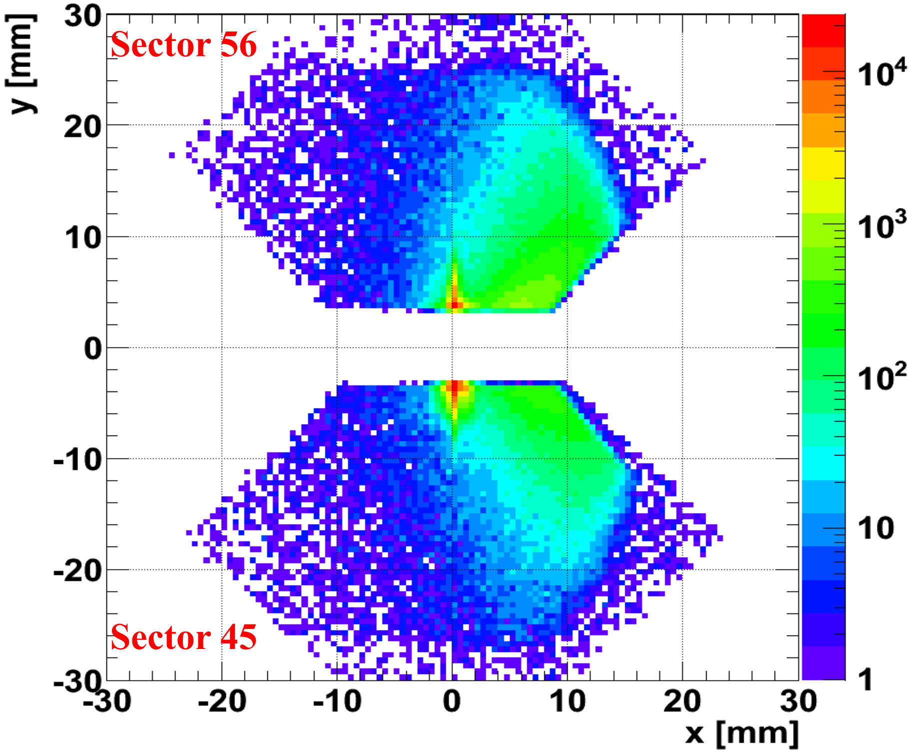
$\xi = \Delta p / p$

Proton tracks of a single diagonal (left-right coincidences)



$\beta^*=3.5$ m, big bunches (7 x10^{10} p/b)

RPs at 7 σ from beam centre

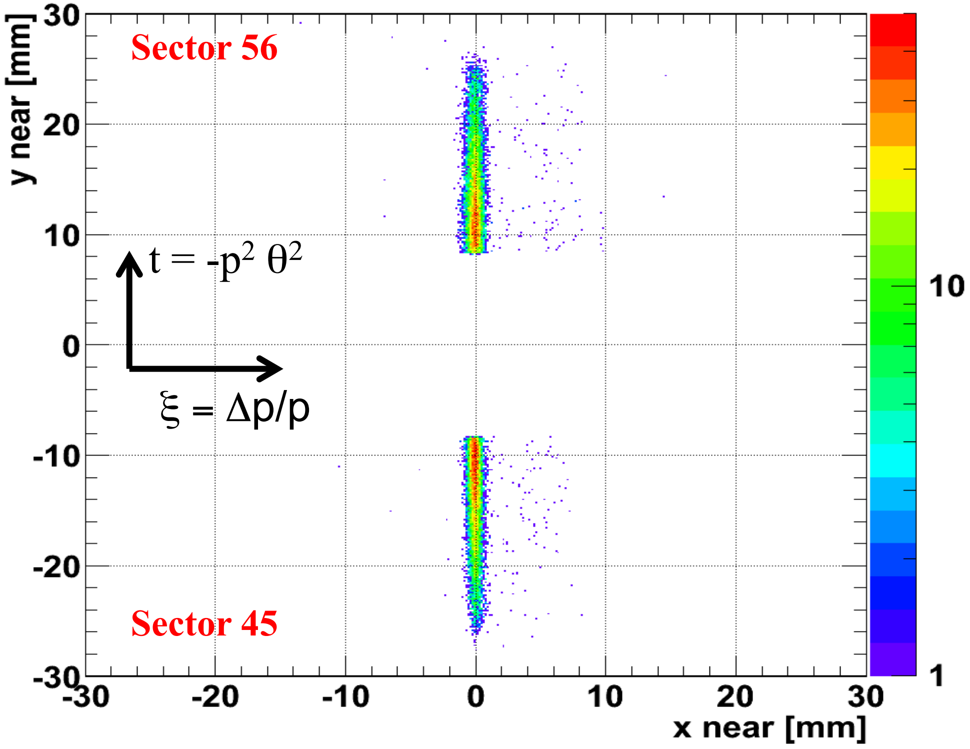


Integrated luminosity : 6.2 nbarn^{-1}

Inelastic pile-up ~ 0.8 ev / bx

$\beta^*= 90$ m, small bunches (1.5 x10^{10} p/b)

RPs at 10 σ from beam centre



Integrated luminosity : 1.65 μbarn^{-1}

Inelastic pile-up ~ 0.005 ev / bx

Elastic Tagging

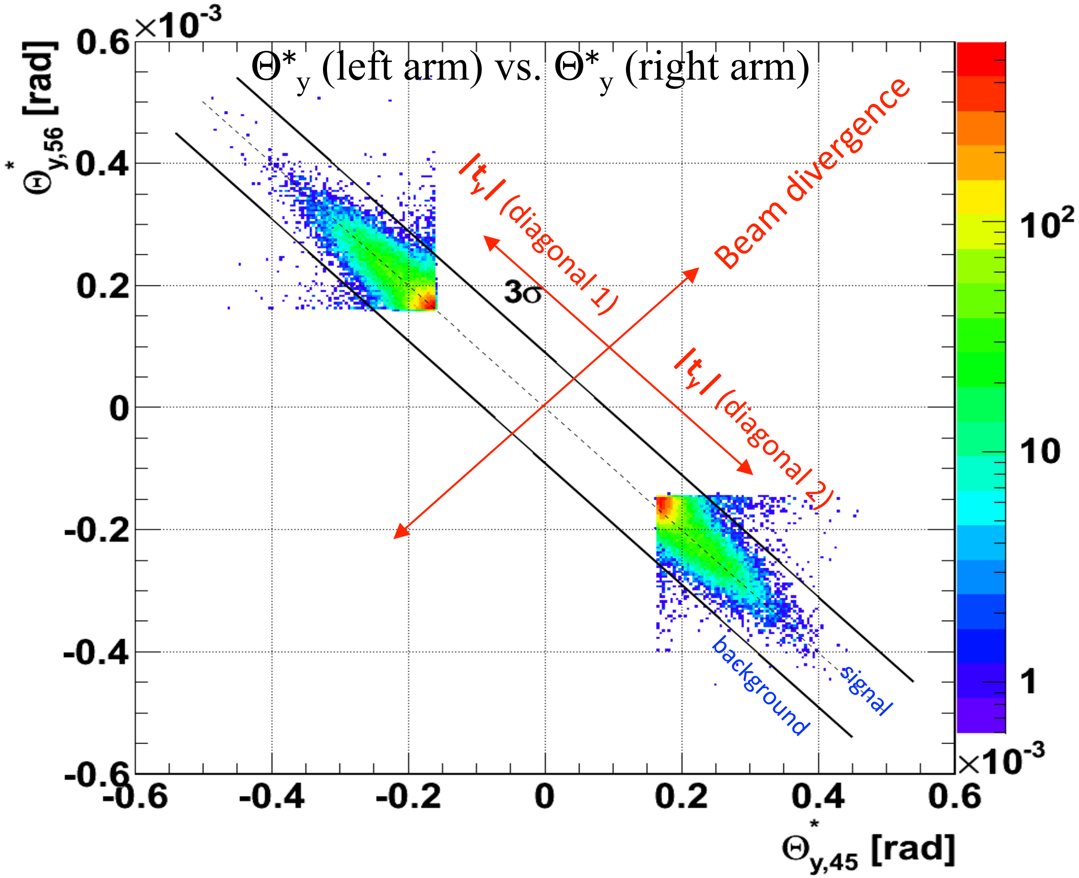
1. Low $|\xi|$ selection : $|x| < 3\ \sigma_x$ @ $L_x = 0$

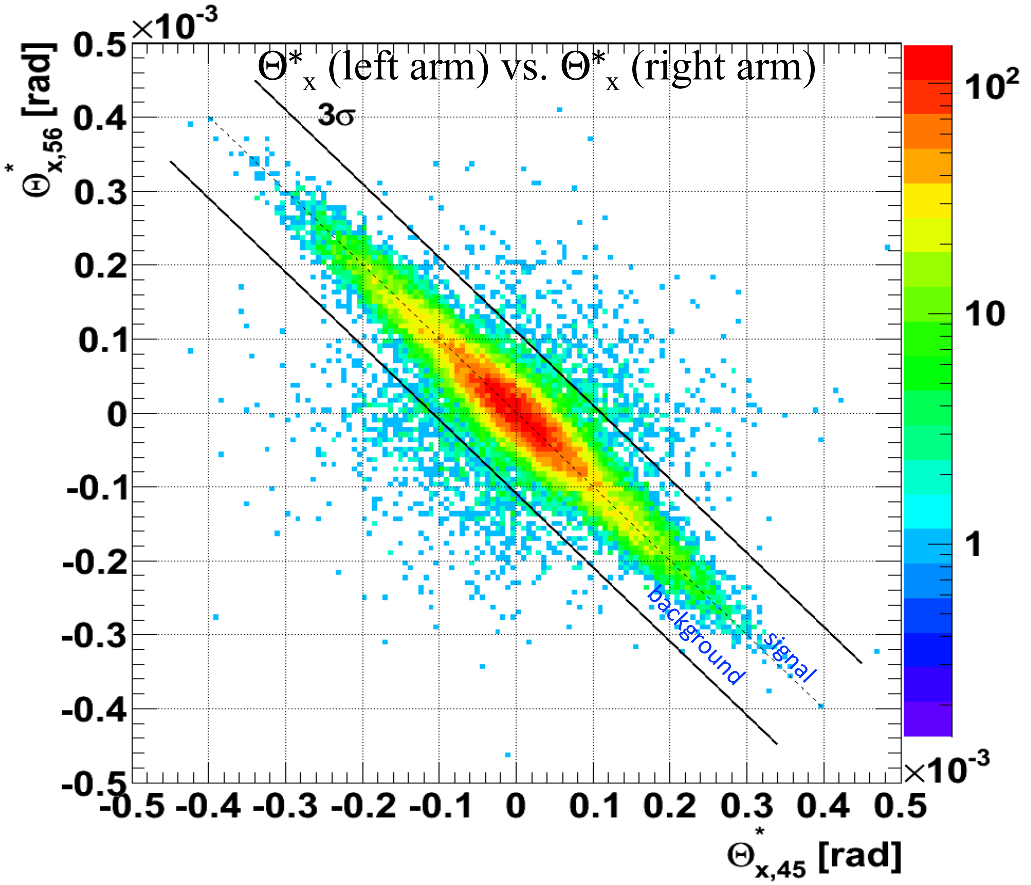
   $x = \cancel{L_x \Theta_x} + \xi\, D + v_x\, x^*$

Total triggers	5.28M
Reconstructed tracks & elastic topology	293k
Low $|\xi|$ selection	70.2k
Collinearity cuts	66.0k

showers

2. Elastic collinearity :





Data outside the 3σ cuts used for background estimation

Optics Matching

- Optics defined by the magnetic lattice elements $\mathbf{T}_i$ between IP5 and RP:

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \end{pmatrix}_{RP} = \mathbf{T} \begin{pmatrix} x^* \\ \Theta_x^* \\ y^* \\ \Theta_y^* \end{pmatrix}_{IP5} \qquad \mathbf{T} = \prod_{i=M}^{1} \left[\mathbf{T}_i(k_i) + \Delta\mathbf{T}_i \right] = \begin{pmatrix} v_x & L_x & re_{13} & re_{14} \\ \frac{dv_x}{ds} & \boxed{\frac{dL_x}{ds}} & re_{23} & re_{24} \\ re_{31} & re_{32} & v_y & \boxed{L_y} \\ re_{41} & re_{42} & \frac{dv_y}{ds} & \frac{dL_y}{ds} \end{pmatrix}$$

$\Delta\mathbf{T}_i$ – magnet imperfections

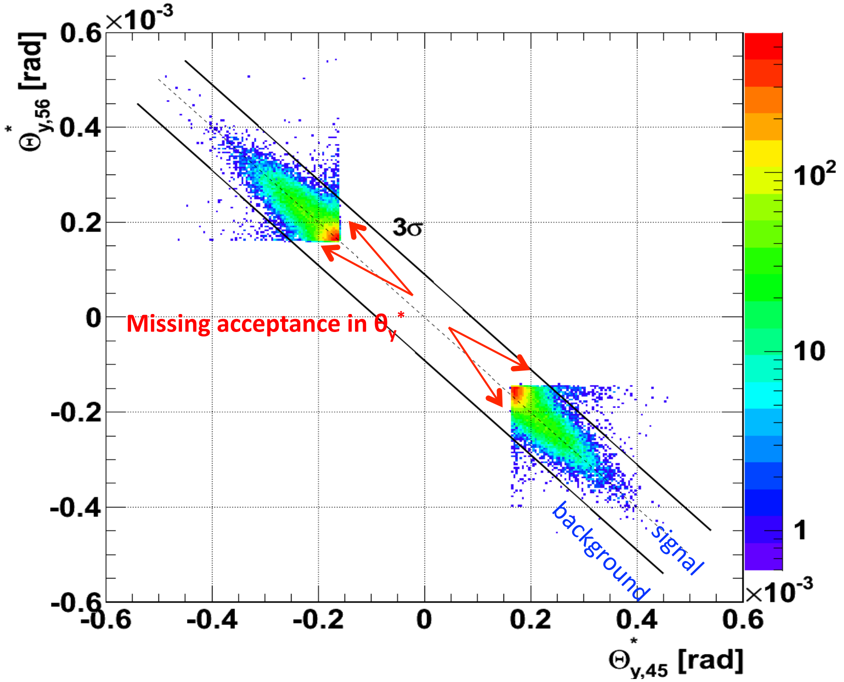
$\left.\begin{matrix} \frac{dL_x}{ds} \\ L_y \end{matrix}\right\}$ – values needed for proton reconstruction

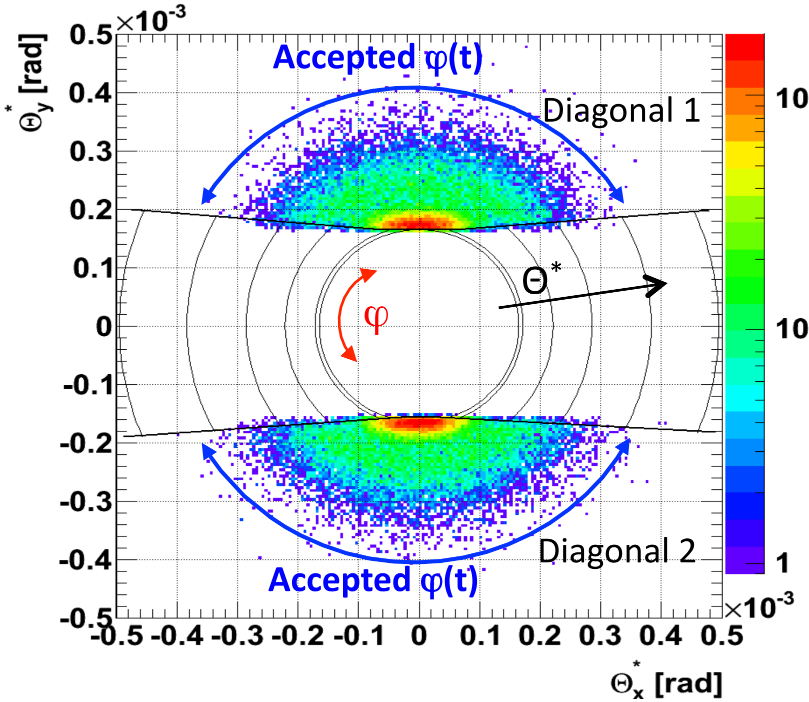
- $\mathbf{T}_i$ determined by magnet currents
- Magnet currents continuously measured, but tolerances and imperfections leading to $\Delta\mathbf{T}_i$:
  - Beam momentum offset ($\Delta p/p = 10^{-3}$)
  - Magnet transfer function error, I→B, ($\Delta B/B = 10^{-3}$)
  - Magnet rotations and displacements ($\Delta\psi < 1$mrad, Δx, $\Delta y < 0.5$mm, WISE database)
  - Power converter errors, k→I, ($\Delta I/I < 10^{-4}$)
  - Magnet harmonics ($\Delta B/B = O(10^{-4})$ @ $R_{ref} = 17$mm, WISE database)
  - The elements of **T** are correlated and cannot take arbitrary values
- The TOTEM RP measurements provide additional constraints:
  - single beam constraints (position – angle correlations, x-y coupling)
  - two-beam constraints via elastic scattering (Θ_{left}^* vs. Θ_{right}^*)

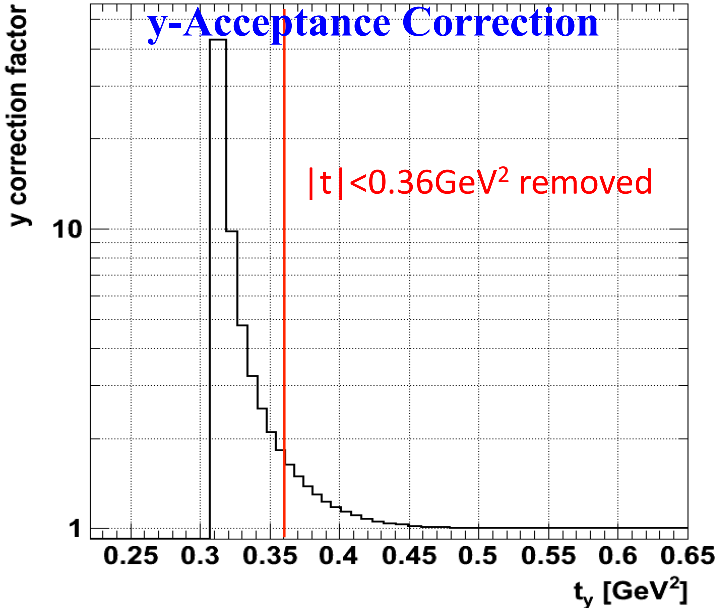
→Matching by a fit with 26 parameters (magnet strengths, rotations, beam energy) and 36 constraints.

→ Error propagation to relevant optical functions L_y (1%) and dL_x/ds (0.7%)

Acceptance



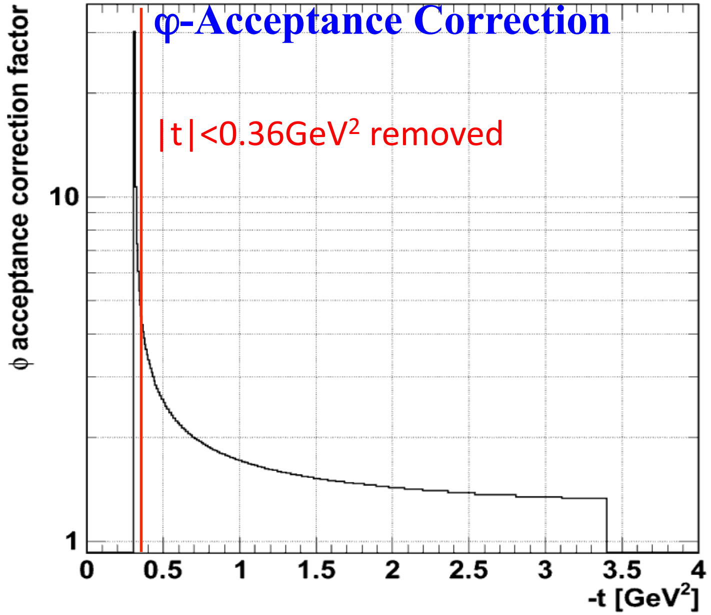



y-Acceptance Correction

|t|<0.36GeV² removed

total correction factor

≤ 10 ± 0.1

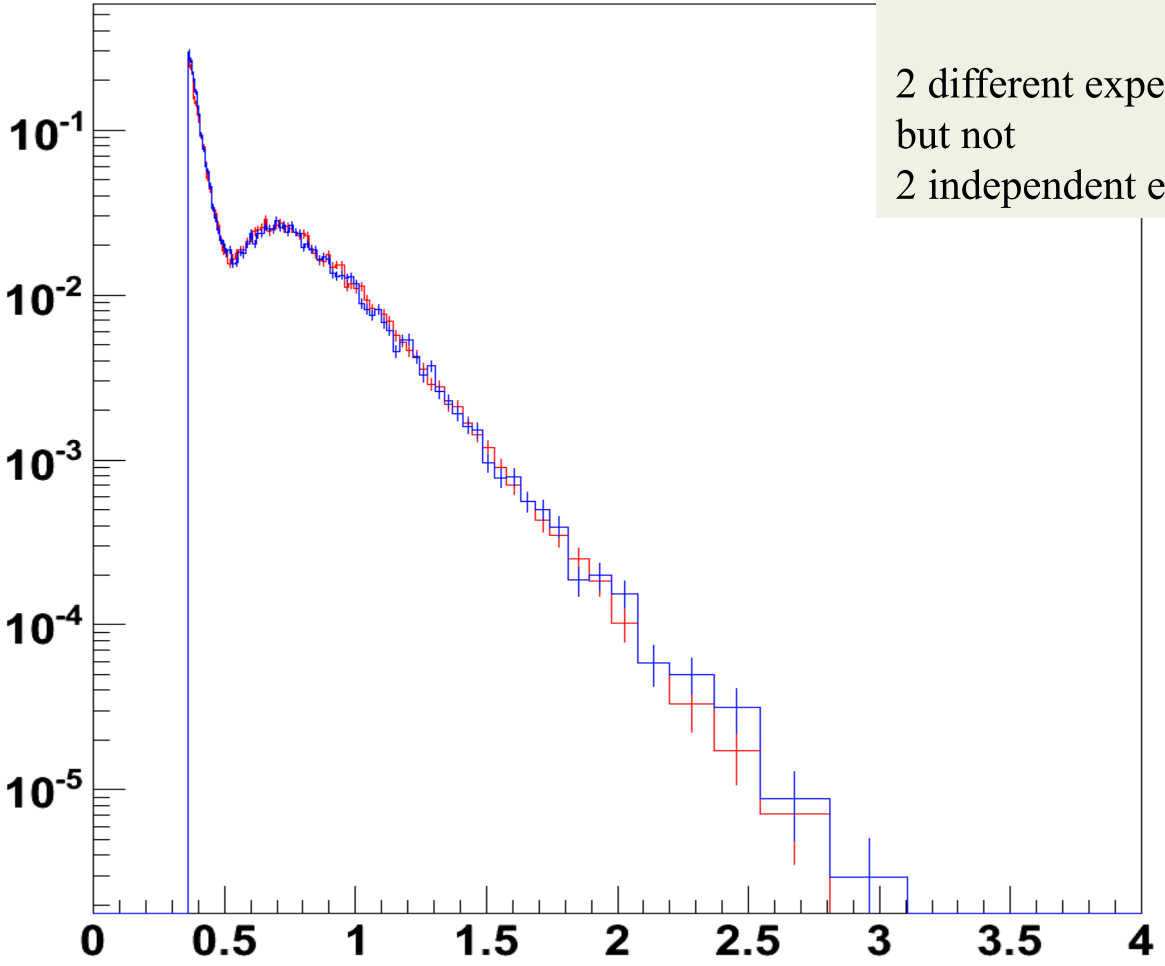

φ-Acceptance Correction

|t|<0.36GeV² removed

TOTEM: 2 “Experiments”

after resolution unfolding:

top 45 - bottom 56 ; bottom 45 - top 56

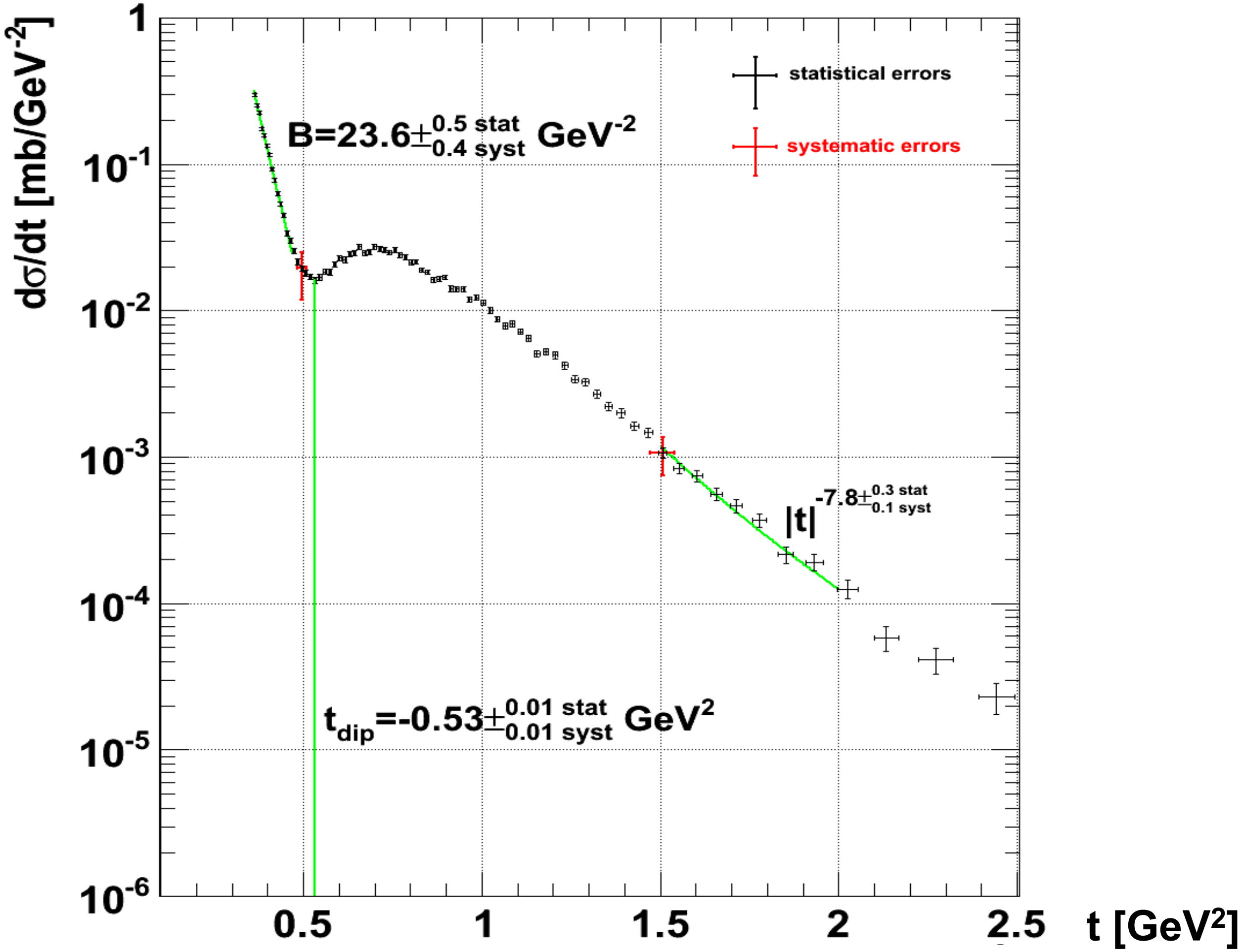


2 diagonals:

2 different experiments,
but not
2 independent experiments

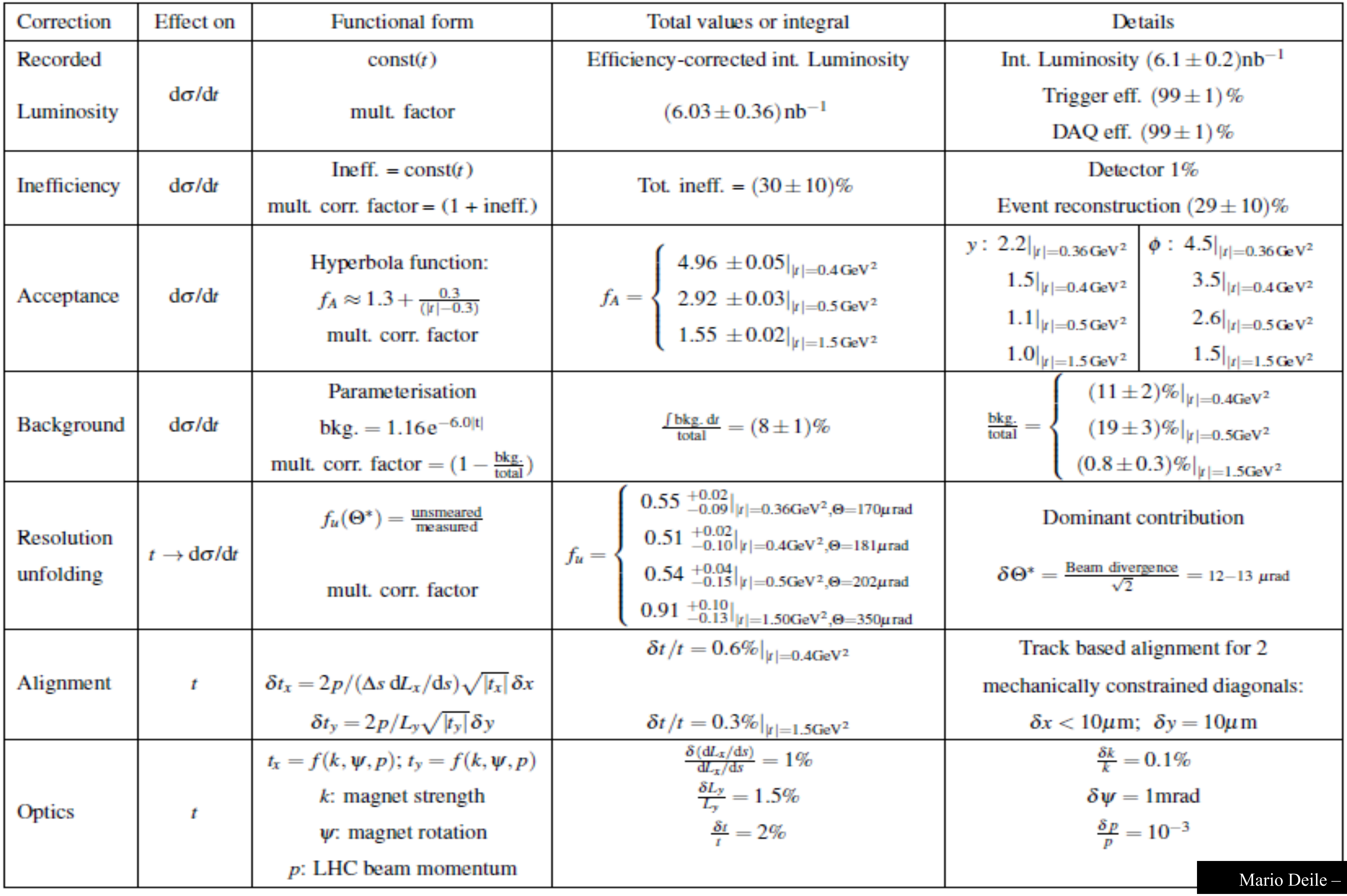
→verification of alignment

TOTEM Result



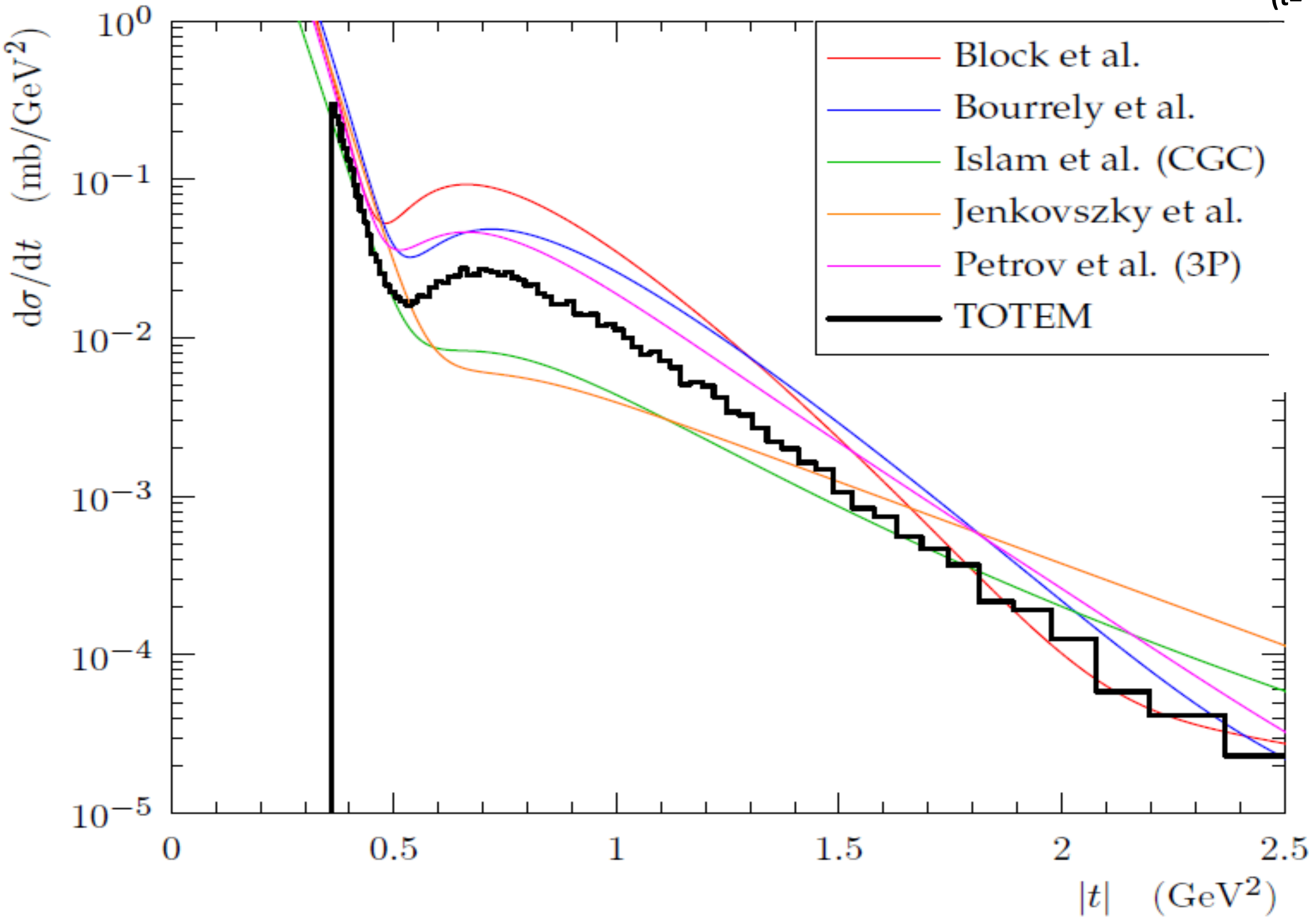
	$\frac{\delta t}{t}$ on single t meas.	$\delta t = \delta_t^{\text{stat}}(t) \oplus \delta_t^{\text{syst}}(t)$	$\delta(\mathrm{d}\sigma/\mathrm{dt}) = \delta^{\text{stat}}_{\mathrm{d}\delta/\mathrm{dt}}(t) \oplus \delta^{\text{syst}}_{\mathrm{d}\sigma/\mathrm{dt}}(t)$
$\lvert t \rvert = 0.4\,\mathrm{GeV}^2$	13 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.5\%^{\text{stat}} \pm 2.6\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 2.6\%^{\text{stat}} {}^{+25}_{-37}\ \%^{\text{syst}}$
$\lvert t \rvert = 0.5\,\mathrm{GeV}^2$	12 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.7\%^{\text{stat}} \pm 2.5\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 4.4\%^{\text{stat}} {}^{+28}_{-39}\ \%^{\text{syst}}$
$\lvert t \rvert = 1.5\,\mathrm{GeV}^2$	7 % (from beam div.)	$\frac{\delta t}{t} = \pm 0.8\%^{\text{stat}} \pm 2.3\%^{\text{syst}}$	$\frac{\delta(\mathrm{d}\sigma/\mathrm{dt})}{\mathrm{d}\sigma/\mathrm{dt}} = \pm 8.2\%^{\text{stat}} {}^{+27}_{-30}\ \%^{\text{syst}}$

Systematics



Correction	Effect on	Functional form	Total values or integral	Details
Recorded Luminosity	$d\sigma/dt$	$\mathrm{const}(t)$ mult. factor	Efficiency-corrected int. Luminosity $(6.03 \pm 0.36)\,\mathrm{nb}^{-1}$	Int. Luminosity $(6.1 \pm 0.2)\mathrm{nb}^{-1}$ Trigger eff. $(99 \pm 1)\,\%$ DAQ eff. $(99 \pm 1)\,\%$
Inefficiency	$d\sigma/dt$	Ineff. $= \mathrm{const}(t)$ mult. corr. factor $= (1 + \text{ineff.})$	Tot. ineff. $= (30 \pm 10)\%$	Detector 1% Event reconstruction $(29 \pm 10)\%$
Acceptance	$d\sigma/dt$	Hyperbola function: $f_A \approx 1.3 + \frac{0.3}{(\lvert t\rvert - 0.3)}$ mult. corr. factor	$f_A = \begin{cases} 4.96\ \pm 0.05\rvert_{\lvert t\rvert = 0.4\,\mathrm{GeV}^2} \\ 2.92\ \pm 0.03\rvert_{\lvert t\rvert = 0.5\,\mathrm{GeV}^2} \\ 1.55\ \pm 0.02\rvert_{\lvert t\rvert = 1.5\,\mathrm{GeV}^2} \end{cases}$	$y:\ 2.2\rvert_{\lvert t\rvert=0.36\,\mathrm{GeV}^2}$ $1.5\rvert_{\lvert t\rvert=0.4\,\mathrm{GeV}^2}$ $1.1\rvert_{\lvert t\rvert=0.5\,\mathrm{GeV}^2}$ $1.0\rvert_{\lvert t\rvert=1.5\,\mathrm{GeV}^2}$ $\phi:\ 4.5\rvert_{\lvert t\rvert=0.36\,\mathrm{GeV}^2}$ $3.5\rvert_{\lvert t\rvert=0.4\,\mathrm{GeV}^2}$ $2.6\rvert_{\lvert t\rvert=0.5\,\mathrm{GeV}^2}$ $1.5\rvert_{\lvert t\rvert=1.5\,\mathrm{GeV}^2}$
Background	$d\sigma/dt$	Parameterisation bkg. $= 1.16e^{-6.0\lvert t\rvert}$ mult. corr. factor $= (1 - \frac{\text{bkg.}}{\text{total}})$	$\frac{\int \text{bkg. } dt}{\text{total}} = (8 \pm 1)\%$	$\frac{\text{bkg.}}{\text{total}} = \begin{cases} (11 \pm 2)\%\rvert_{\lvert t\rvert=0.4\mathrm{GeV}^2} \\ (19 \pm 3)\%\rvert_{\lvert t\rvert=0.5\mathrm{GeV}^2} \\ (0.8 \pm 0.3)\%\rvert_{\lvert t\rvert=1.5\mathrm{GeV}^2} \end{cases}$
Resolution unfolding	$t \rightarrow d\sigma/dt$	$f_u(\Theta^*) = \frac{\text{unsmeared}}{\text{measured}}$ mult. corr. factor	$f_u = \begin{cases} 0.55\ ^{+0.02}_{-0.09}\rvert_{\lvert t\rvert=0.36\mathrm{GeV}^2, \Theta=170\mu\mathrm{rad}} \\ 0.51\ ^{+0.02}_{-0.10}\rvert_{\lvert t\rvert=0.4\mathrm{GeV}^2, \Theta=181\mu\mathrm{rad}} \\ 0.54\ ^{+0.04}_{-0.15}\rvert_{\lvert t\rvert=0.5\mathrm{GeV}^2, \Theta=202\mu\mathrm{rad}} \\ 0.91\ ^{+0.10}_{-0.13}\rvert_{\lvert t\rvert=1.50\mathrm{GeV}^2, \Theta=350\mu\mathrm{rad}} \end{cases}$	Dominant contribution $\delta\Theta^* = \frac{\text{Beam divergence}}{\sqrt{2}} = 12\text{–}13\ \mu\mathrm{rad}$
Alignment	t	$\delta t_x = 2p/(\Delta s\, dL_x/ds)\sqrt{\lvert t_x\rvert}\,\delta x$ $\delta t_y = 2p/L_y\sqrt{\lvert t_y\rvert}\,\delta y$	$\delta t/t = 0.6\%\rvert_{\lvert t\rvert=0.4\mathrm{GeV}^2}$ $\delta t/t = 0.3\%\rvert_{\lvert t\rvert=1.5\mathrm{GeV}^2}$	Track based alignment for 2 mechanically constrained diagonals: $\delta x < 10\mu\mathrm{m};\ \ \delta y = 10\mu\mathrm{m}$
Optics	t	$t_x = f(k, \psi, p);\ t_y = f(k, \psi, p)$ k: magnet strength ψ: magnet rotation p: LHC beam momentum	$\frac{\delta(dL_x/ds)}{dL_x/ds} = 1\%$ $\frac{\delta L_y}{L_y} = 1.5\%$ $\frac{\delta t}{t} = 2\%$	$\frac{\delta k}{k} = 0.1\%$ $\delta\psi = 1\mathrm{mrad}$ $\frac{\delta p}{p} = 10^{-3}$

Comparison to Some Models



B **($t=-0.4$ GeV^2)**	**t_{DIP}**	**n in t^{-n}** **[1.5–2.5 GeV^2]**
24.4	0.48	10.4
21.7	**0.54**	**8.4**
19.9	**0.65**	**5.0**
20.1	0.72	4.2
22.7	0.52	7.0
23.6	**0.53**	**7.8**
±0.5±0.4	**±0.01±0.01**	**±0.3±0.3**

Total Cross-Section Measurement

Optical Theorem:

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

Use ρ from COMPETE fit:

$$\rho = 0.14^{+0.01}_{-0.08}$$

Normalisation with luminosity from CMS

Uncertainty ± 4%

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$$

[Not yet done with luminosity-independent method; coming soon.]

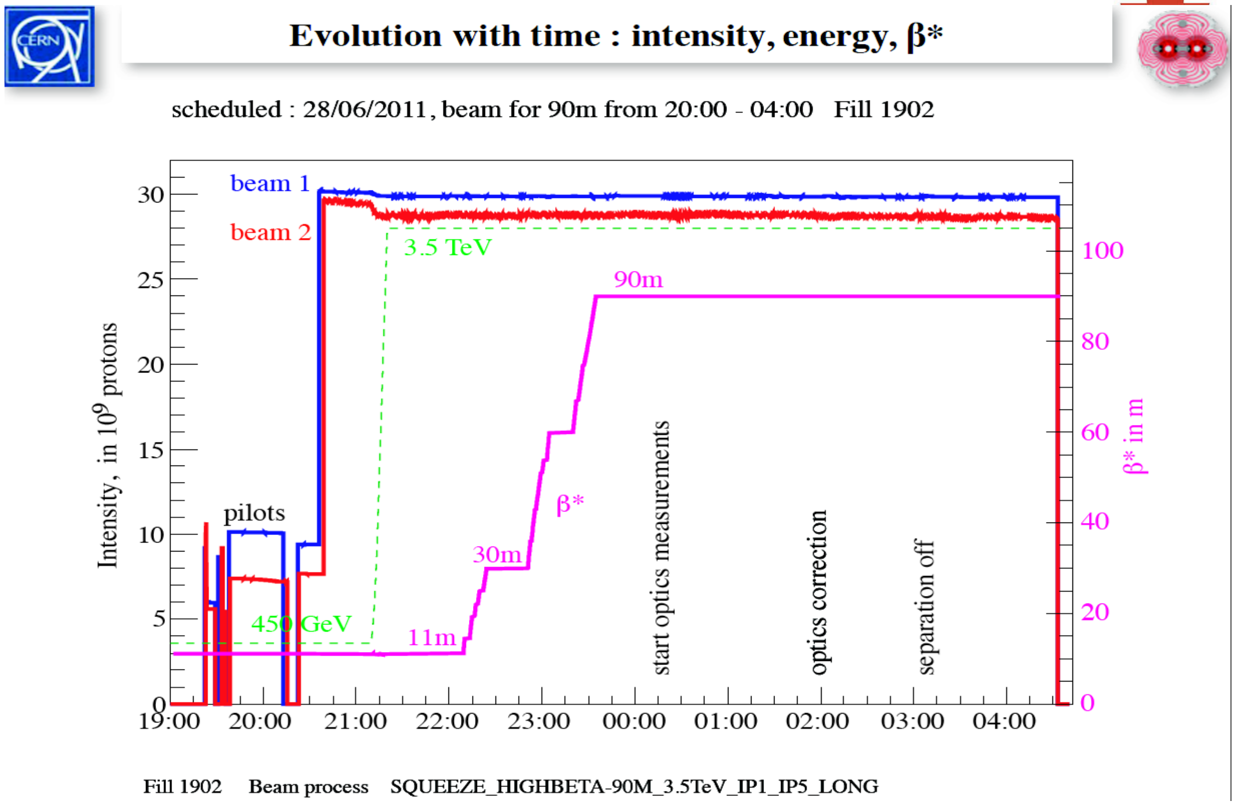
→ **Measure dσ $_{el}$ / dt at lowest possible |t|**

First run with the β* = 90 m optics and RP insertion

Un-squeeze from injection optics

β* = 11m to 90m

Very robust optics with high precision



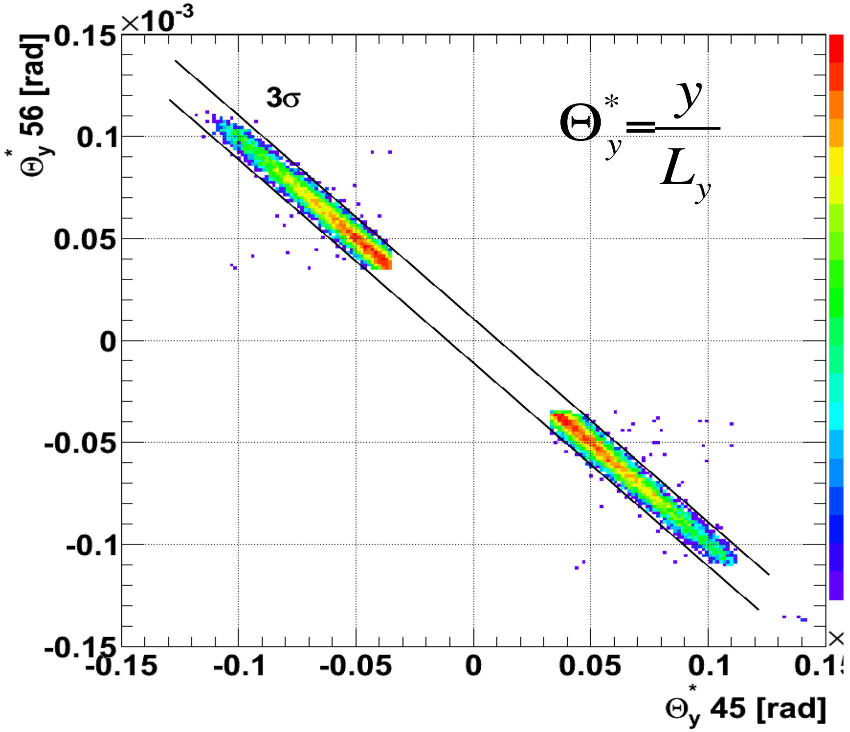
Evolution with time : intensity, energy, β*

scheduled : 28/06/2011, beam for 90m from 20:00 - 04:00 Fill 1902

Fill 1902 Beam process SQUEEZE_HIGHBETA-90M_3.5TeV_IP1_IP5_LONG

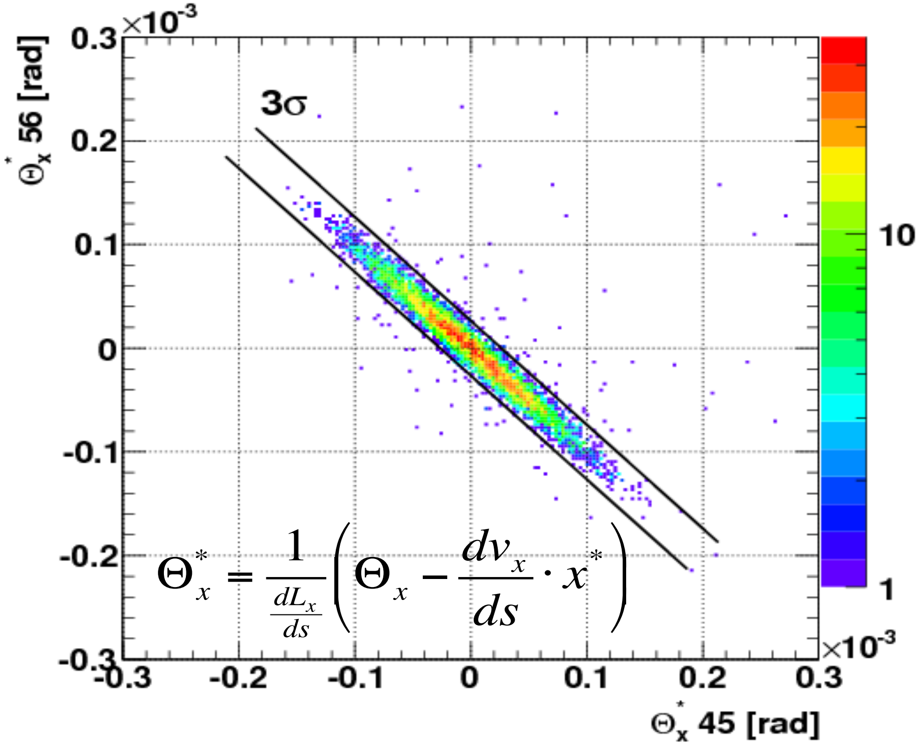
- Two bunches with 1 and 2 x 10^{10} protons / bunch
- Instantaneous luminosity: 8 x 10^{26} cm^{-2} s^{-1}
- Integrated luminosity: 1.7 μb^{-1}
- Estimated pile-up: ~ 0.5 %
- Vertical Roman Pots at 10 σ from beam center
- Trigger rate : ~ 50 Hz
- Recorded events in vertical Roman Pots: 66950 in ½ hour.

Angular Correlations between outgoing protons



$$\Theta^*_y = \frac{y}{L_y}$$

$L_y \sim 260$ m



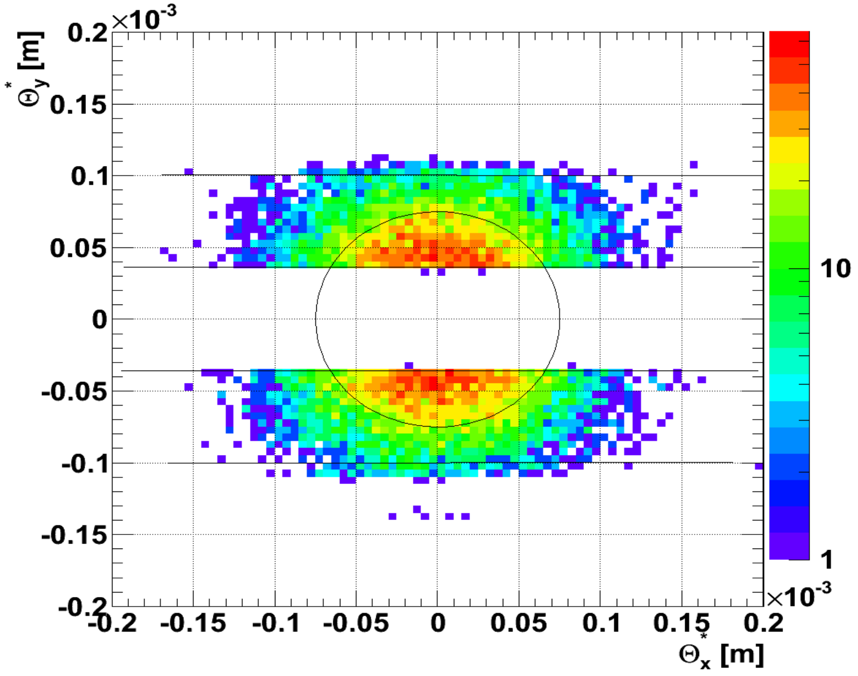
$$\Theta^*_x = \frac{1}{\frac{dL_x}{ds}}\left(\Theta_x - \frac{dv_x}{ds}\cdot x^*\right)$$

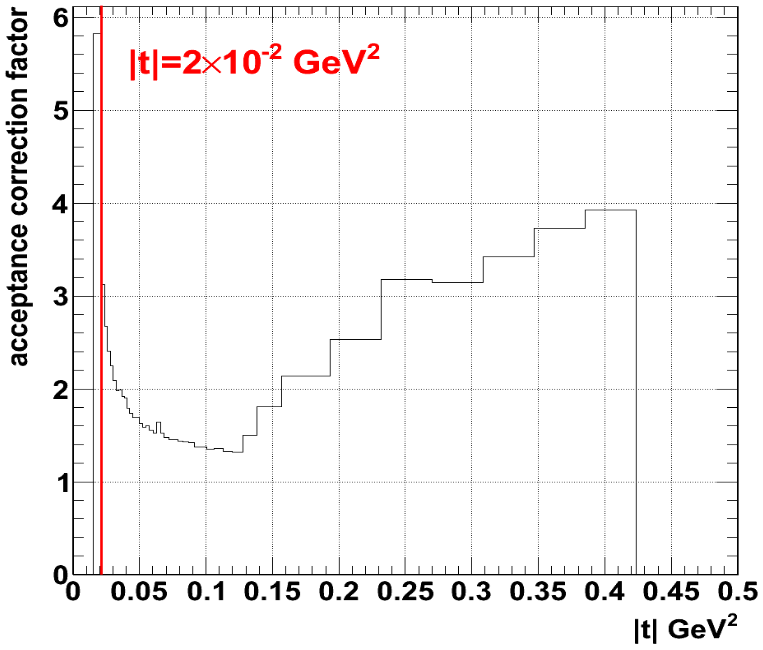
$L_x \sim 0$ - 3 m

- Background negligible $< 1\%$
- Width of correlation band in agreement with beam divergence (~ 2.4 μrad)

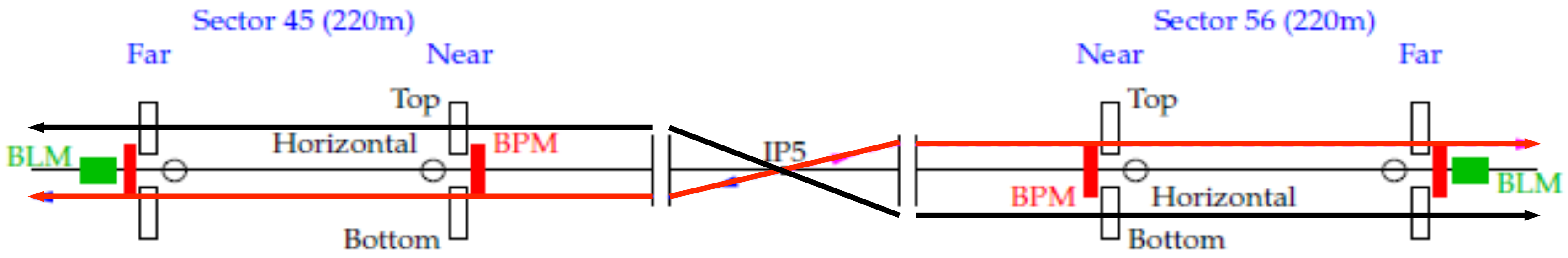
Optics, t-Scale and Acceptance

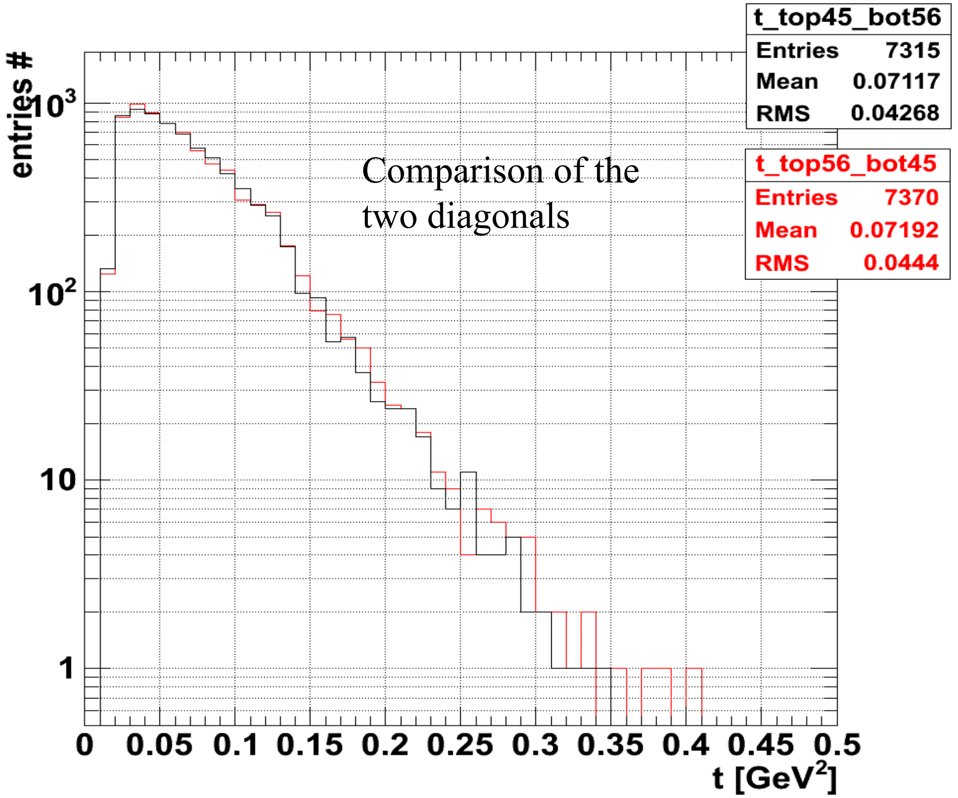
- Perturbations: optics very robust ($L_y \sim s_{RP}$):
  - $\delta\Theta_x^*/\Theta_x^* = 1.3\%^{syst}$
  - $\delta\Theta_y^*/\Theta_y^* = 0.4\%^{syst}$
- t systematics: $\delta t / t = 0.8\%$ (low t) up to 2.6% (large |t|)
- Acceptance correction factor < 3 at low |t|, based on ϕ symmetry



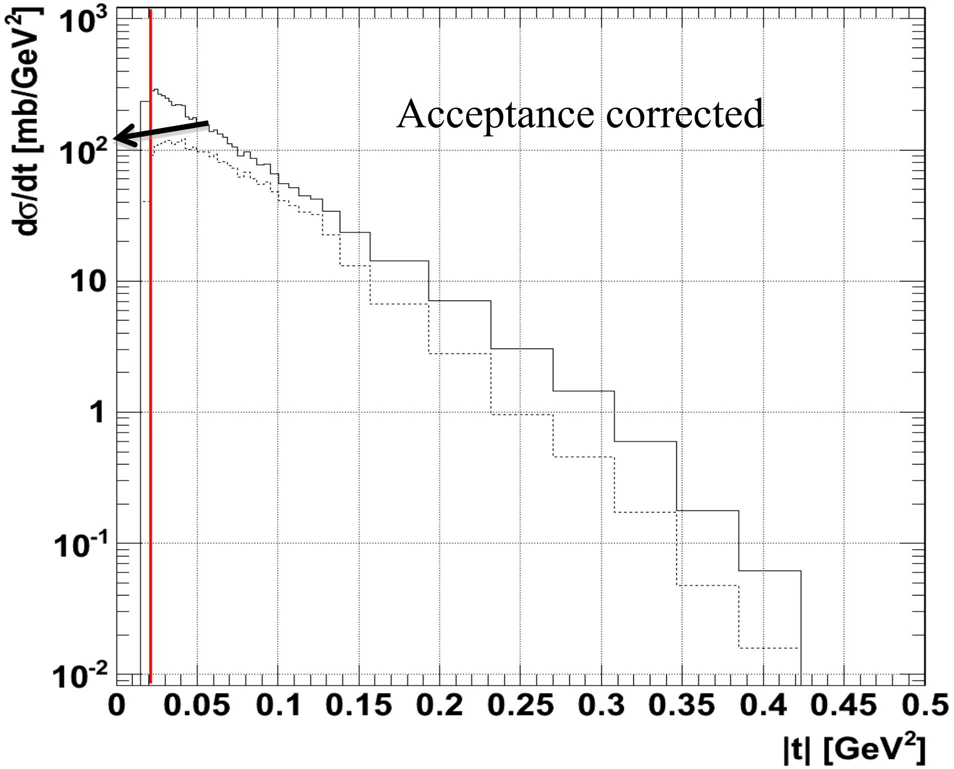


Raw t-Distributions





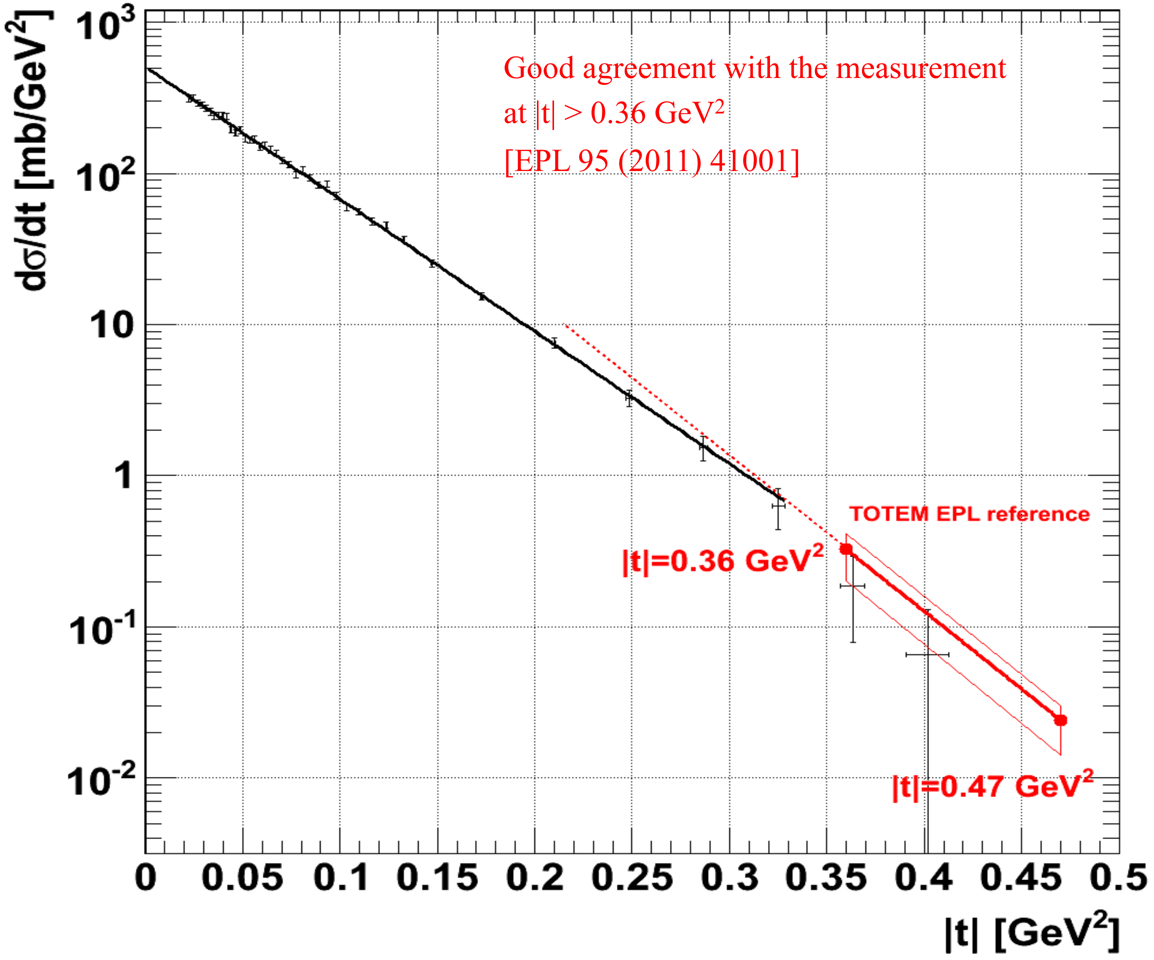
Comparison of the two diagonals



Acceptance corrected

Final Differential Cross-Section for t > 2 x 10^{-2} GeV^2

(Data taking: June 2011 for 30 min.)



Extrapolation to t = 0:

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = 5.037\times 10^{2}\,\mathrm{mb}\,/\,\mathrm{GeV}^{2}$$

Exponential slope

$$B\big|_{t=0} = 20.1\,\mathrm{GeV}^{-2}$$

Extract total cross-section

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

$\rho = 0.14^{+0.01}_{-0.08}$ from Compete Coll.

$$\frac{d\sigma_{EL}}{dt} = \frac{1}{L}\cdot\frac{dN_{EL}}{dt}$$

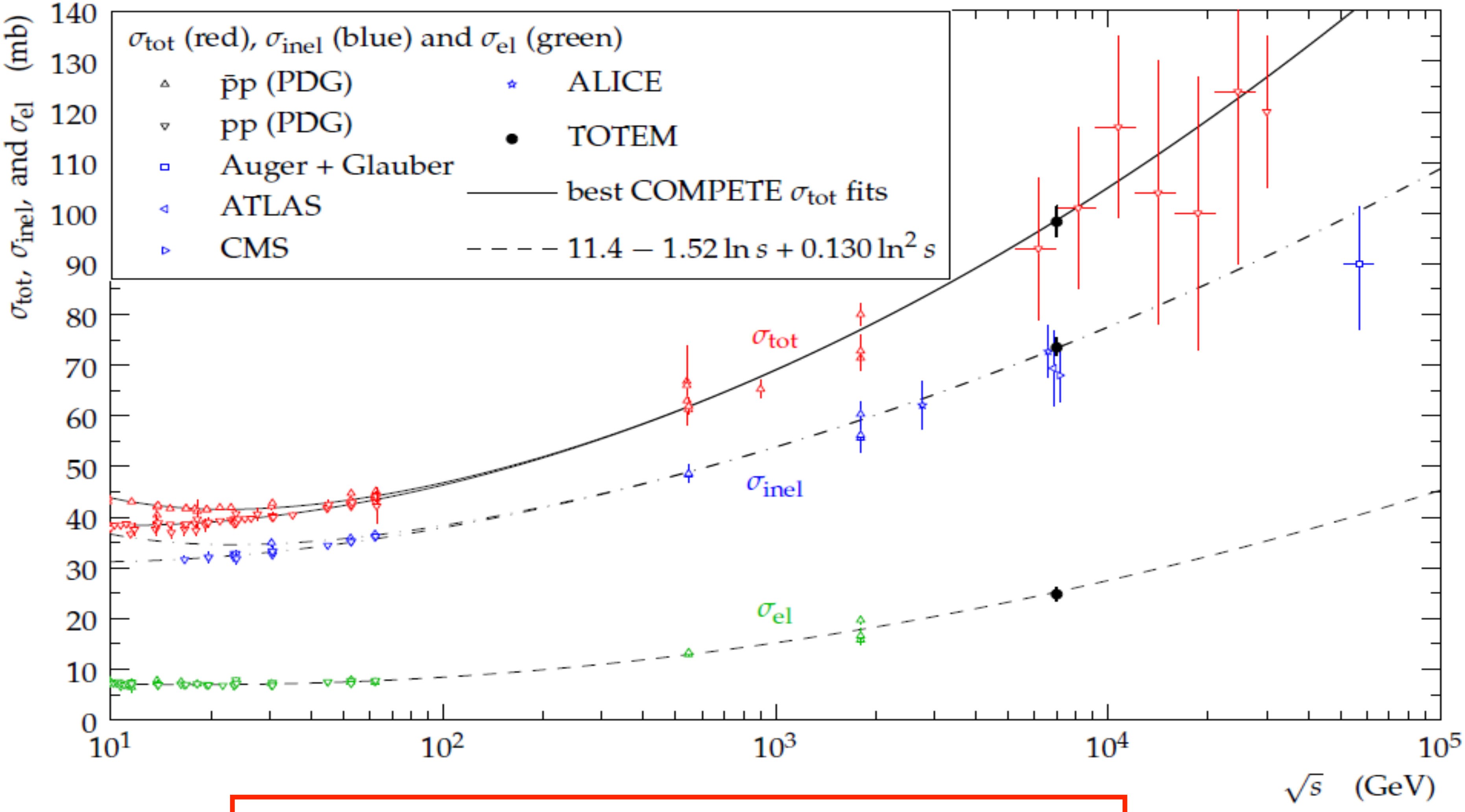
Normalisation with luminosity from CMS

Uncertainty ± 4%

Total elastic cross-section:

$$\sigma_{EL} = 8.3\,\mathrm{mb}^{(\mathrm{extrapol.})} + 16.5\,\mathrm{mb}^{(\mathrm{measured})} = 24.8\,\mathrm{mb}$$

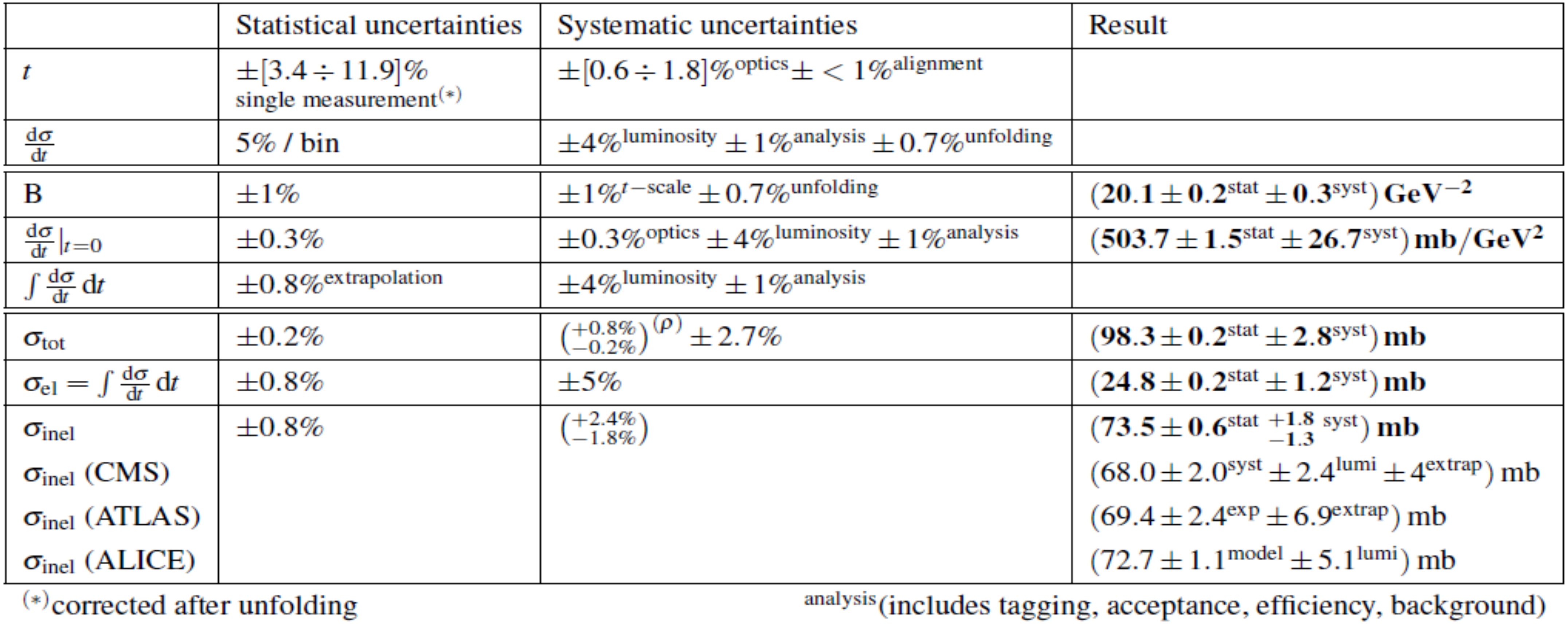
Comparison of Total, Inelastic and Elastic Cross-Section Measurements



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

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

Systematics and Statistics

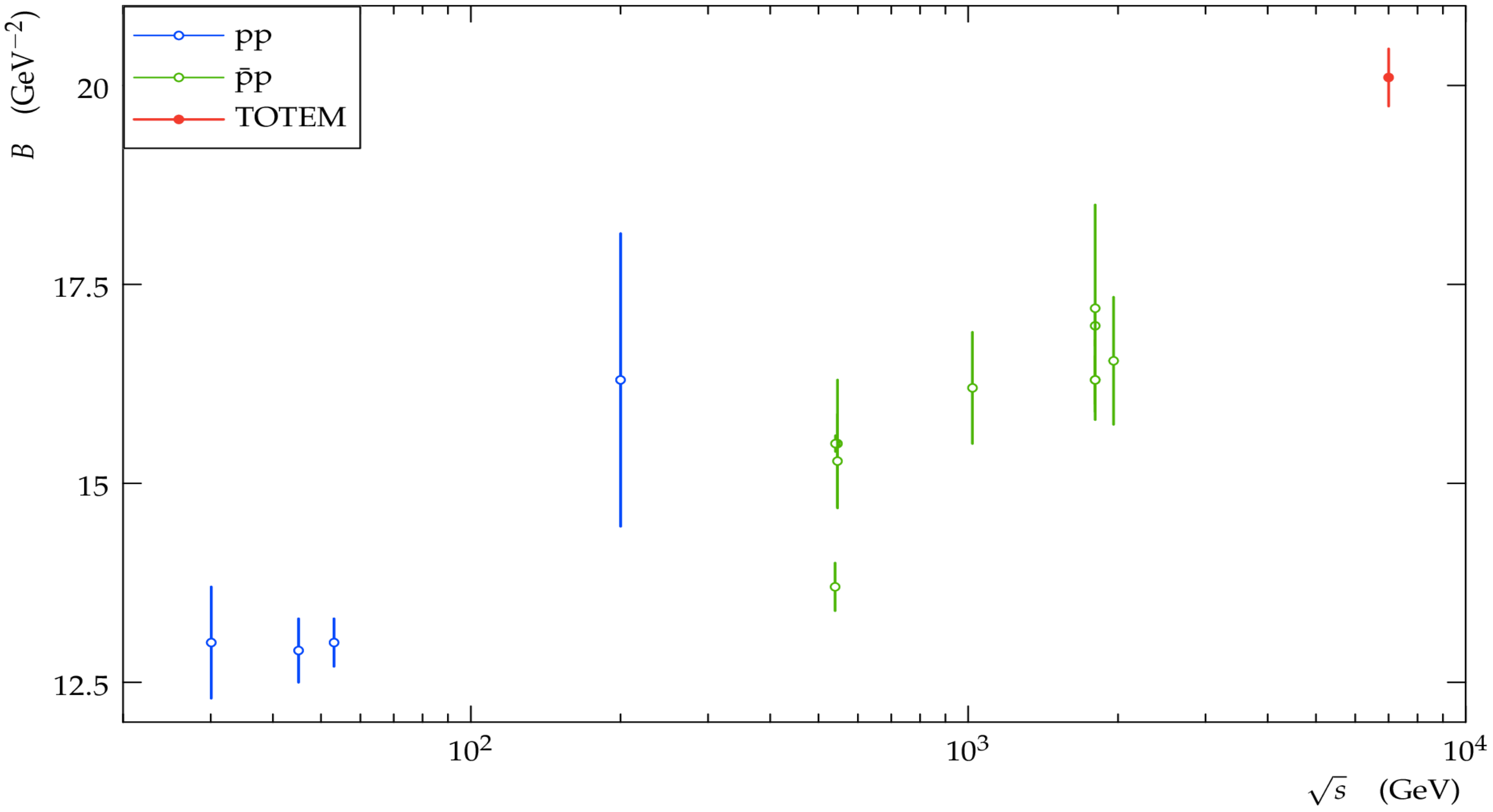


	Statistical uncertainties	Systematic uncertainties	Result
t	$\pm[3.4 \div 11.9]\%$ single measurement$^{(*)}$	$\pm[0.6 \div 1.8]\%^{\text{optics}} \pm < 1\%^{\text{alignment}}$	
$\frac{d\sigma}{dt}$	5% / bin	$\pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}} \pm 0.7\%^{\text{unfolding}}$	
B	$\pm 1\%$	$\pm 1\%^{t-\text{scale}} \pm 0.7\%^{\text{unfolding}}$	$\mathbf{(20.1 \pm 0.2^{\text{stat}} \pm 0.3^{\text{syst}})\ GeV^{-2}}$
$\frac{d\sigma}{dt}\big\|_{t=0}$	$\pm 0.3\%$	$\pm 0.3\%^{\text{optics}} \pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}}$	$\mathbf{(503.7 \pm 1.5^{\text{stat}} \pm 26.7^{\text{syst}})\ mb/GeV^2}$
$\int \frac{d\sigma}{dt}\, dt$	$\pm 0.8\%^{\text{extrapolation}}$	$\pm 4\%^{\text{luminosity}} \pm 1\%^{\text{analysis}}$	
σ_{tot}	$\pm 0.2\%$	$\left(^{+0.8\%}_{-0.2\%}\right)^{(\rho)} \pm 2.7\%$	$\mathbf{(98.3 \pm 0.2^{\text{stat}} \pm 2.8^{\text{syst}})\ mb}$
$\sigma_{\text{el}} = \int \frac{d\sigma}{dt}\, dt$	$\pm 0.8\%$	$\pm 5\%$	$\mathbf{(24.8 \pm 0.2^{\text{stat}} \pm 1.2^{\text{syst}})\ mb}$
σ_{inel}	$\pm 0.8\%$	$\left(^{+2.4\%}_{-1.8\%}\right)$	$\mathbf{(73.5 \pm 0.6^{\text{stat}}\ {}^{+1.8}_{-1.3}\ \text{syst})\ mb}$
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)

Energy dependence of the exponential slope B



Outlook: Ongoing Analyses

Data already available and being analysed:

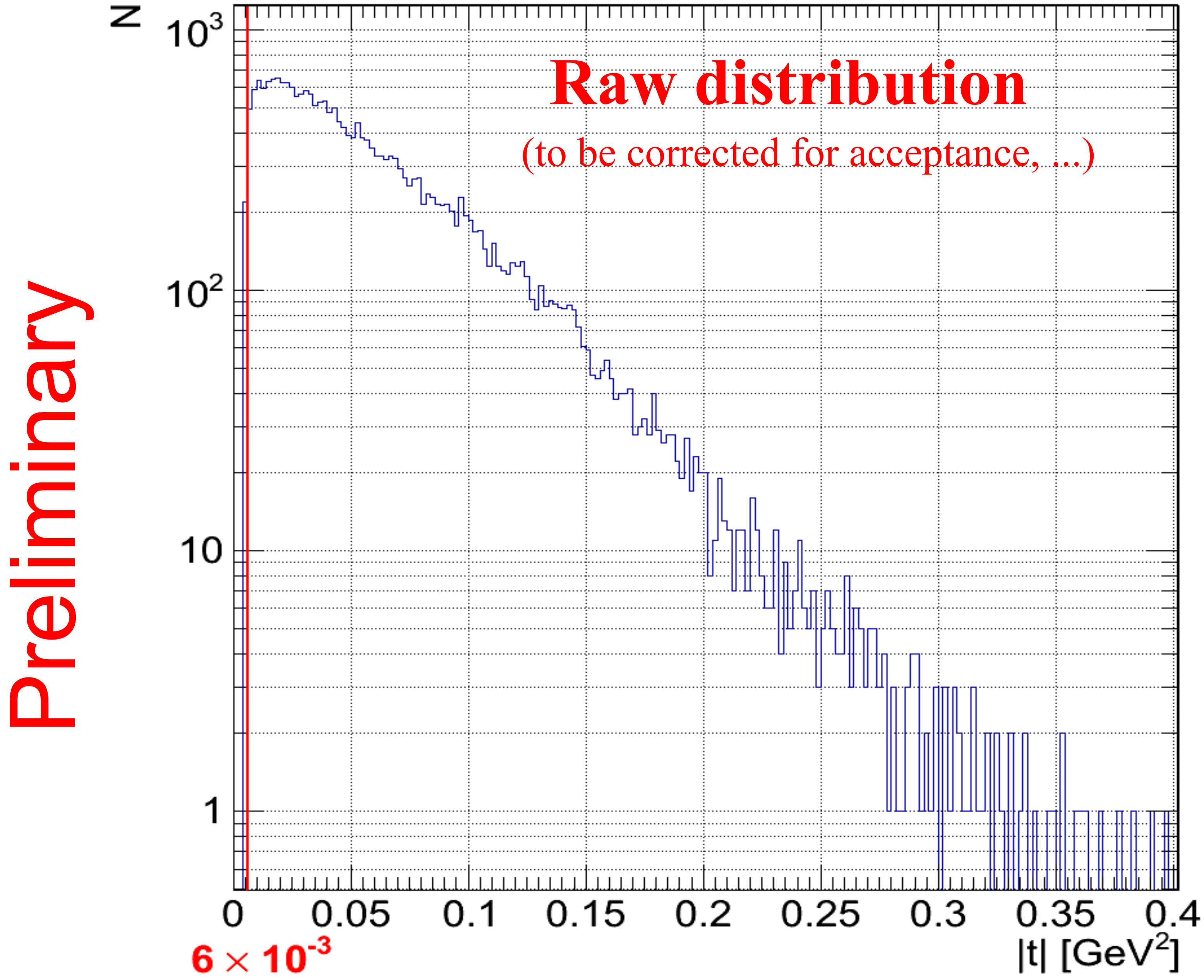
- β^* = 3.5 m: Elastic scattering extended to larger |t|: up to 3.5 GeV^2
- β^* = 90 m:
  - Elastic scattering extended to smaller |t|: down to 6 x 10^{-3} GeV^2

  \+ inelastic triggers (T1, T2, zero bias)

  → total cross-section with the luminosity independent method

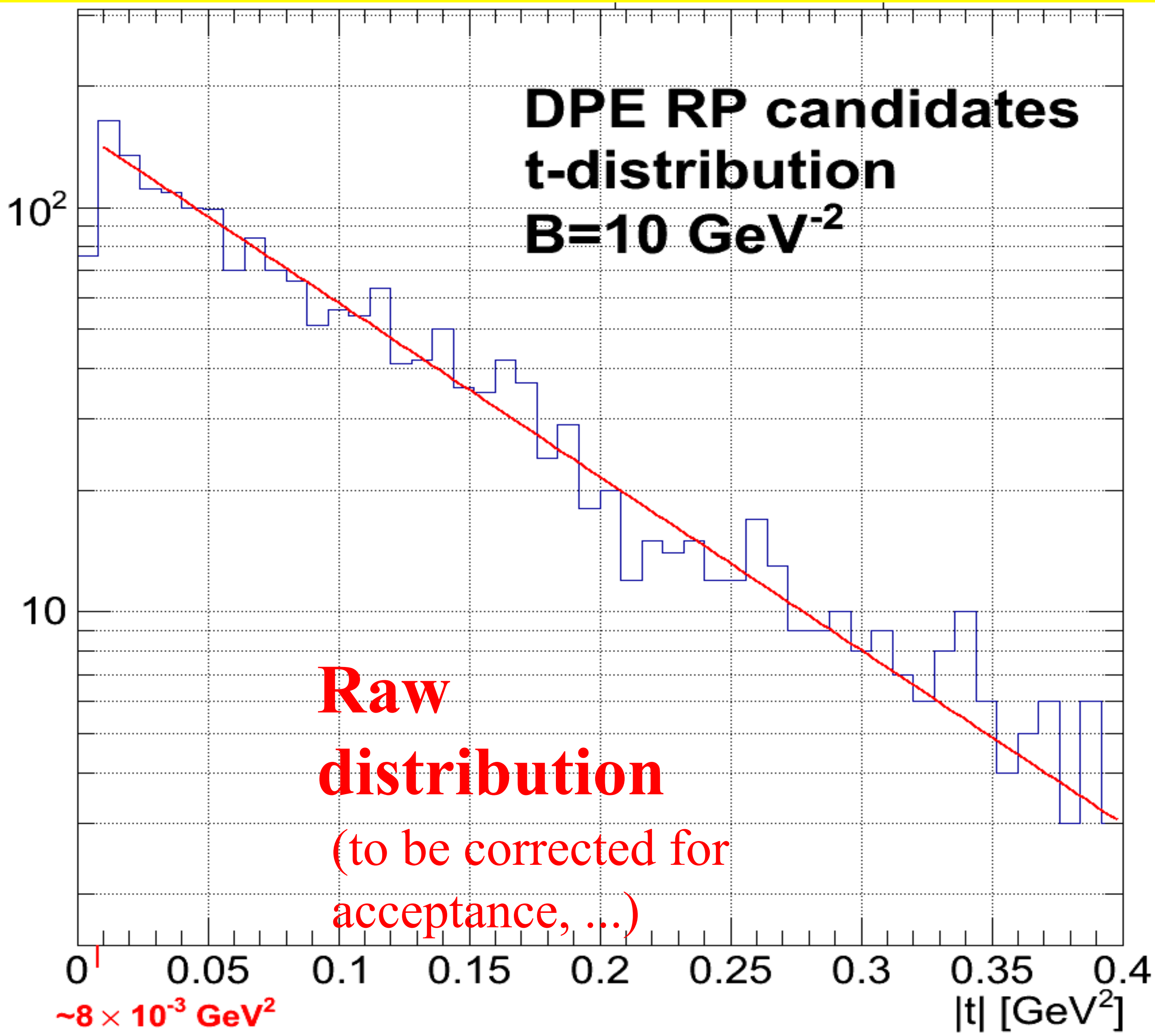
- Central Diffraction (DPE): t-spectrum, later mass spectrum
- Single Diffraction: t-spectrum
- dN / dη from T2, later also T1

Data October 2011: Elastic Differential Cross-Section



Data October 2011: DPE Cross-Section

Preliminary



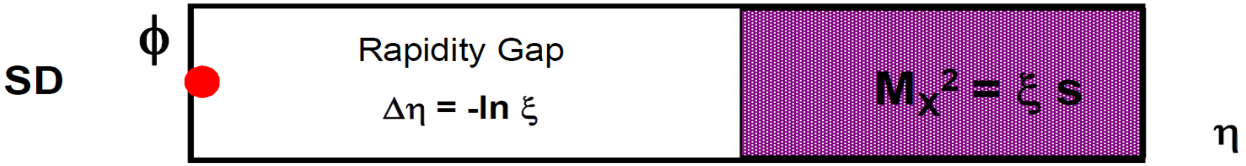
Raw distribution

(to be corrected for acceptance, ...)

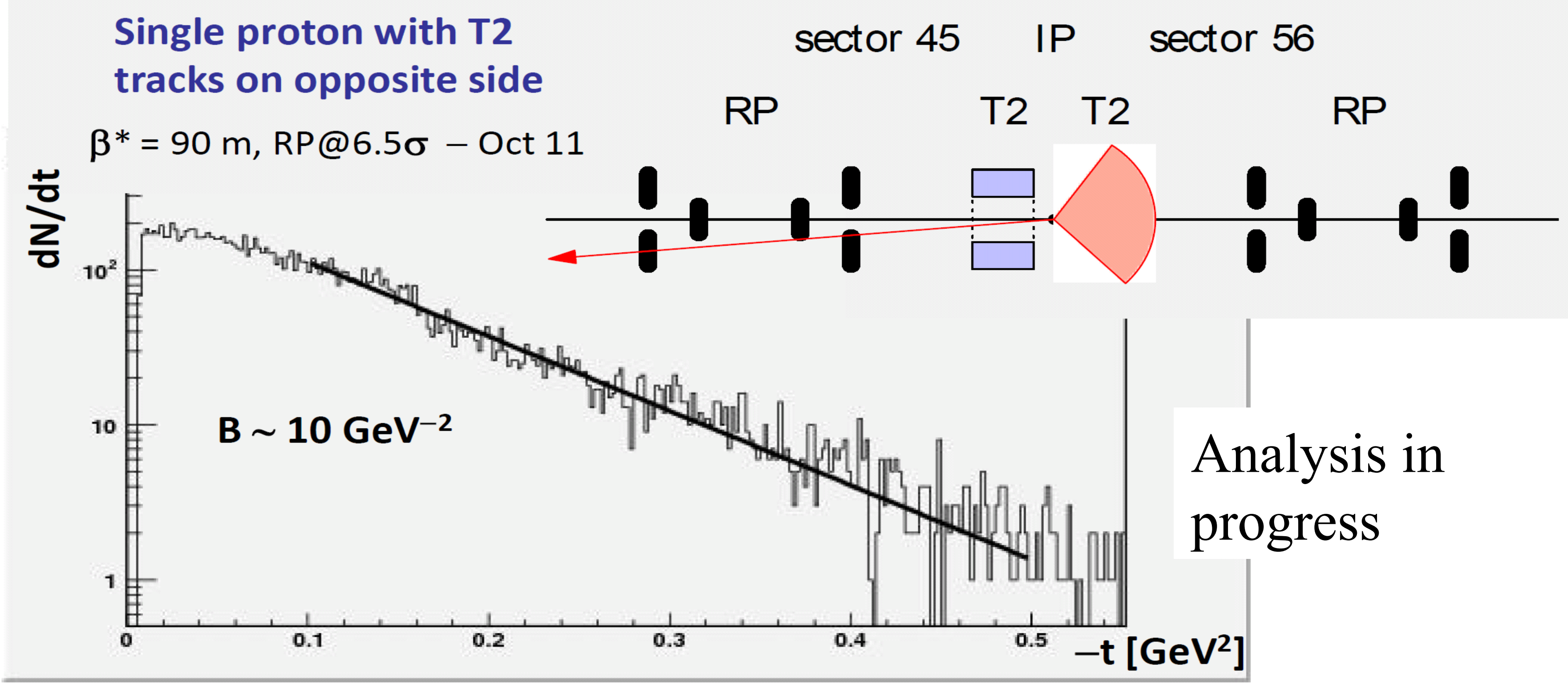
Distribution integrated over ξ

Data October 2011: SD Cross-Section

$d\sigma_{SD}/dt$ & σ_{SD}



Preliminary



Single proton with T2 tracks on opposite side

β^* = 90 m, RP@6.5σ – Oct 11

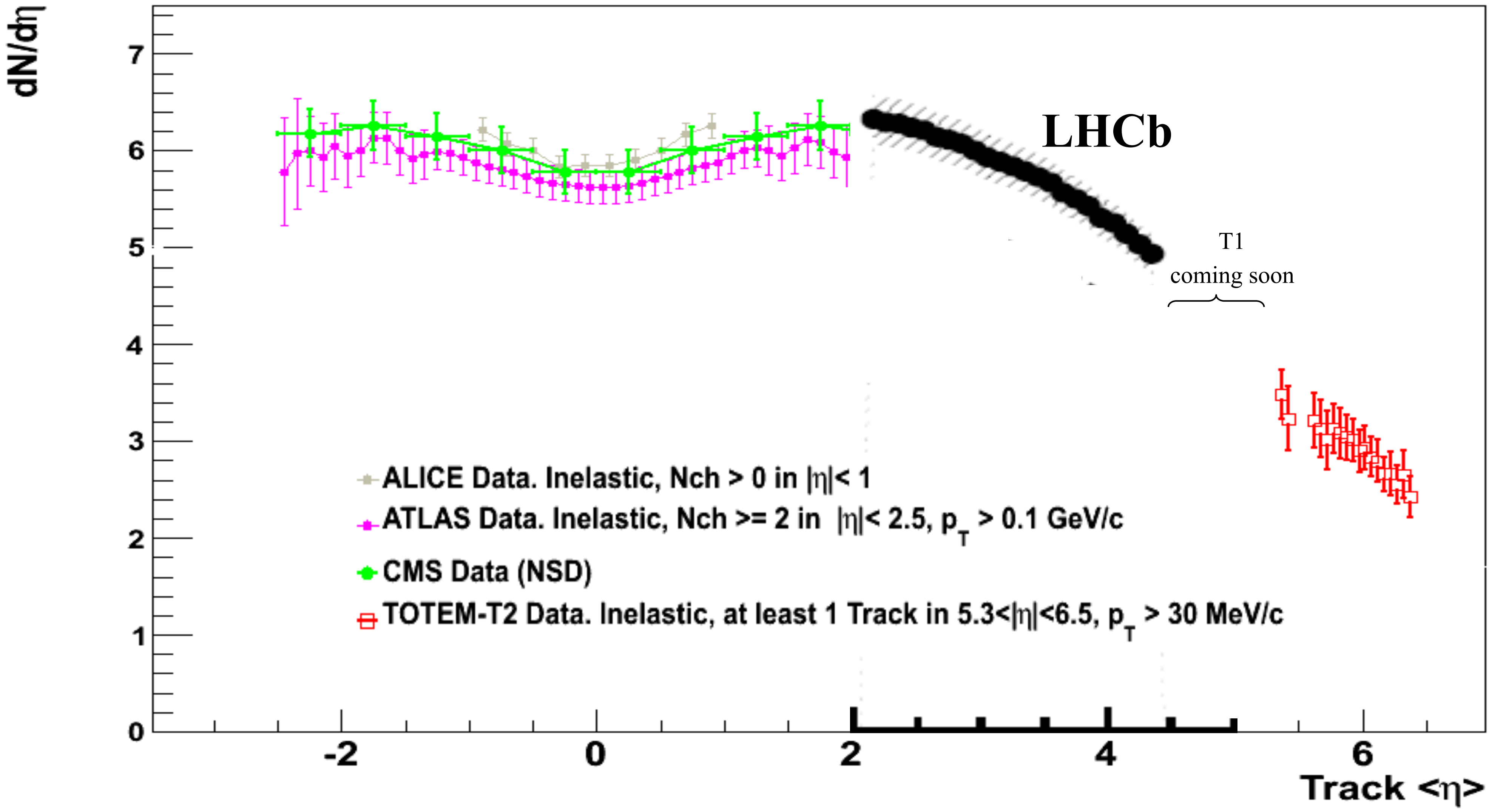
B ~ 10 GeV^{-2}

Analysis in progress

Raw distribution

(to be corrected for acceptance, ...)

dN/dη from ALICE, ATLAS, CMS, LHCb & TOTEM-T2



Plans for 2012 and beyond

2012:

- Try to measure elastic scattering down into the Coulomb region (|t| ~ 5 x 10^{-4} GeV^2) after development of an optics with β* ~ 800 – 1000 m.
  → ρ

- If LHC runs at a new energy (√s = 8 TeV), measure large |t| elastic scattering
- Trigger exchange between TOTEM and CMS being commissioned
  → common data taking (diffraction, total cross-section with optimal coverage)

Later (after long shutdown):

- Repeat all measurements at √s = 14 TeV
- Intensify cooperation with CMS on diffraction

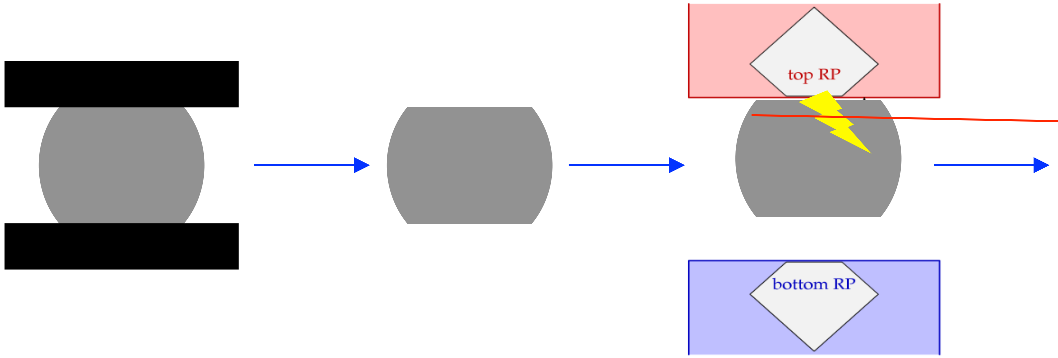
Backup

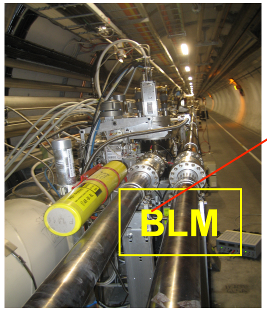
Beam-Based Roman Pot Alignment (Scraping)

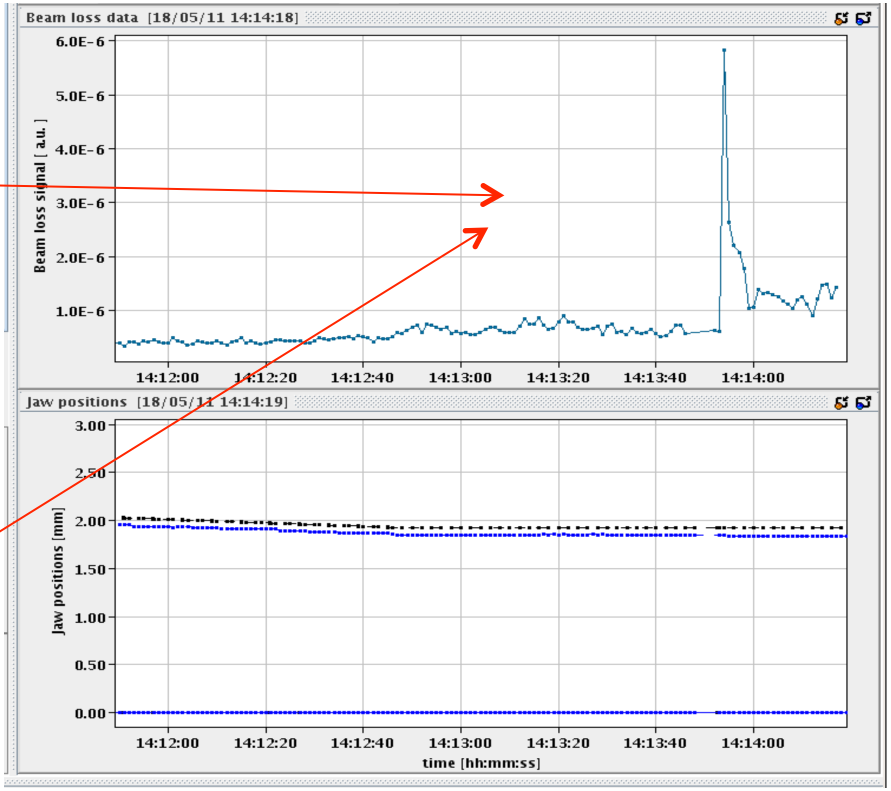
A primary collimator cuts a sharp edge into the beam, symmetrical to the centre

The top RP approaches the beam until it touches the edge

The last 10 μm step produces a spike in a Beam Loss Monitor downstream of the RP







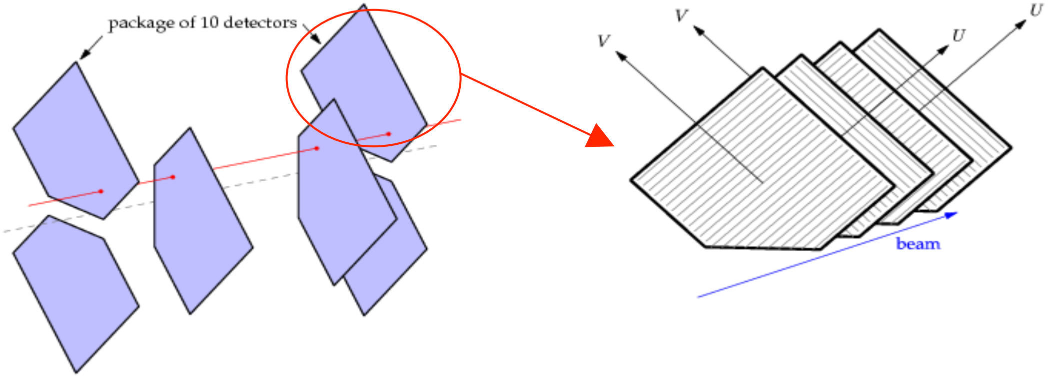
When both top and bottom pots are touching the beam edge:

- they are at the same number of sigmas from the beam centre as the collimator
- the beam centre is exactly in the middle between top and bottom pot

→ **Alignment of the RP windows relative to the beam (~ 20 μm)**

Software Alignment

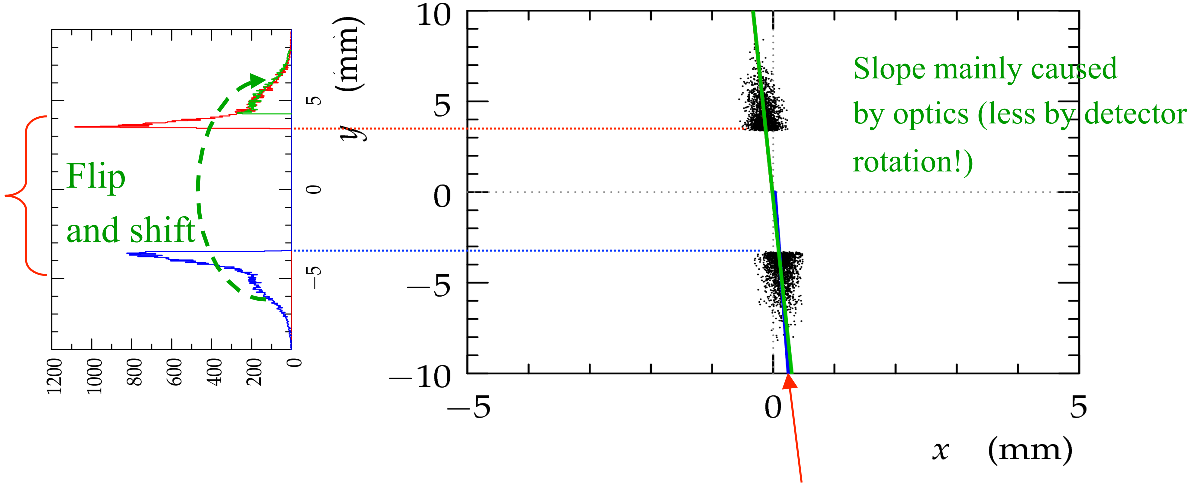
Track-Based Alignment



Residual-based alignment technique (similar to MILLEPEDE):
shifts and rotations within a RP unit

Alignment Exploiting Symmetries of Physics Processes

Map of all track intercepts after elastic selection



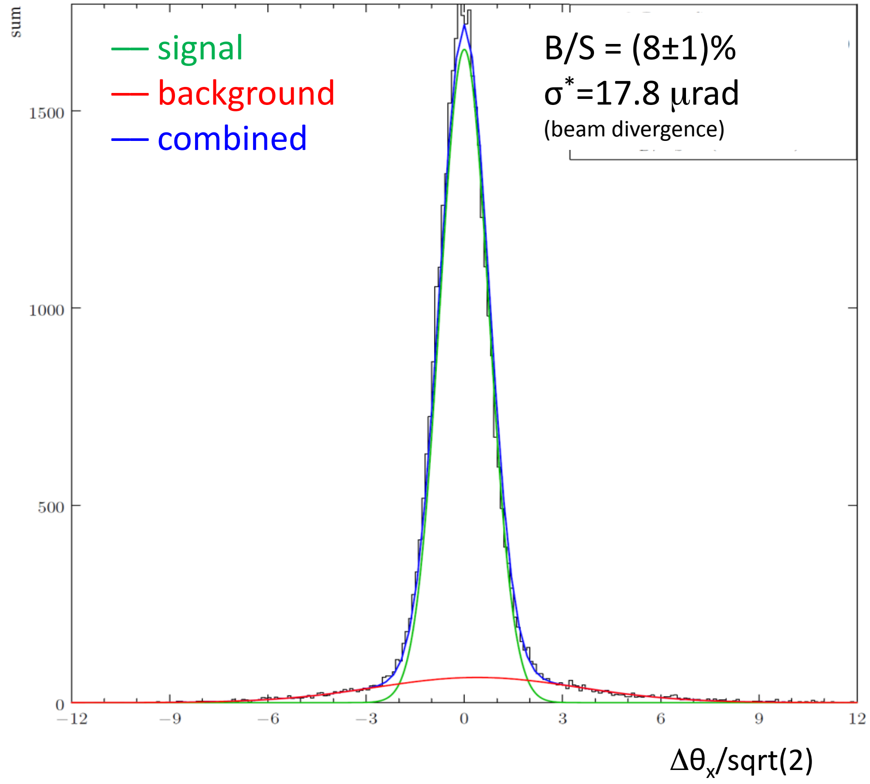
Flip and shift

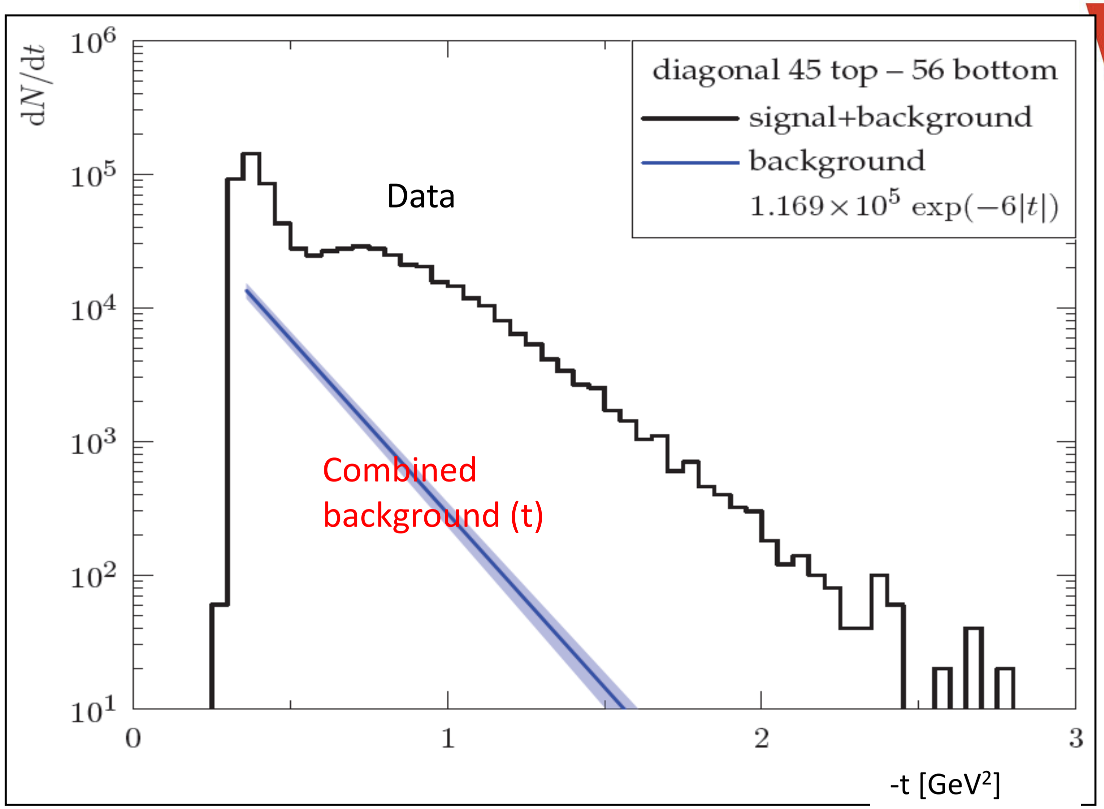
Slope mainly caused by optics (less by detector rotation!)

Fine vertical alignment: about 20 µm precision

→ Fine horizontal alignment: precision better than 10 µm

Background Subtraction, Resolution Determination





Signal to background normalisation

σ^* → t-reconstruction resolution:

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

$0.4\,\mathrm{GeV}^2 : 14\%$

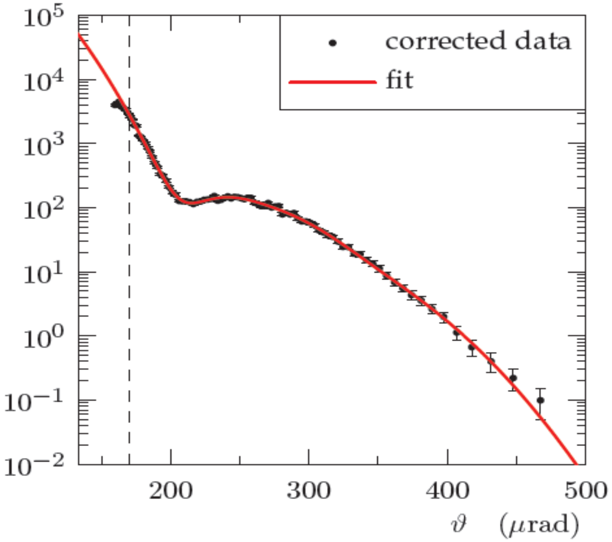
$1\,\mathrm{GeV}^2 : 8.8\%$

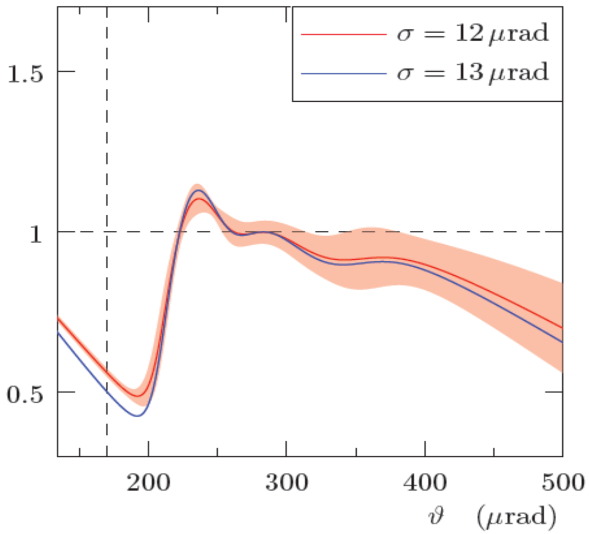
$3\,\mathrm{GeV}^2 : 5.1\%$

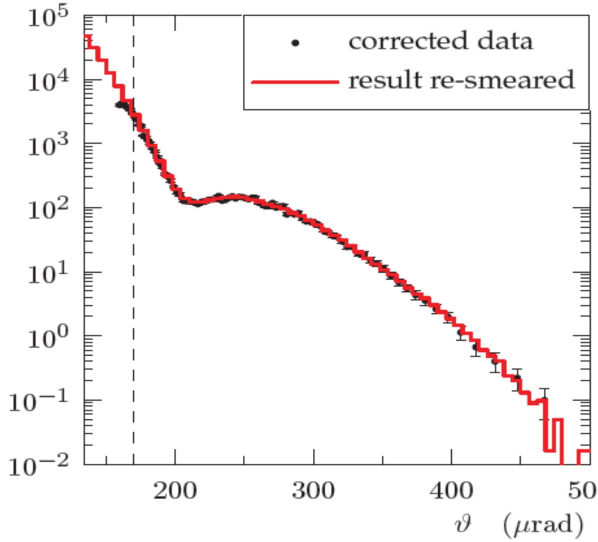
Signal vs. background (t)

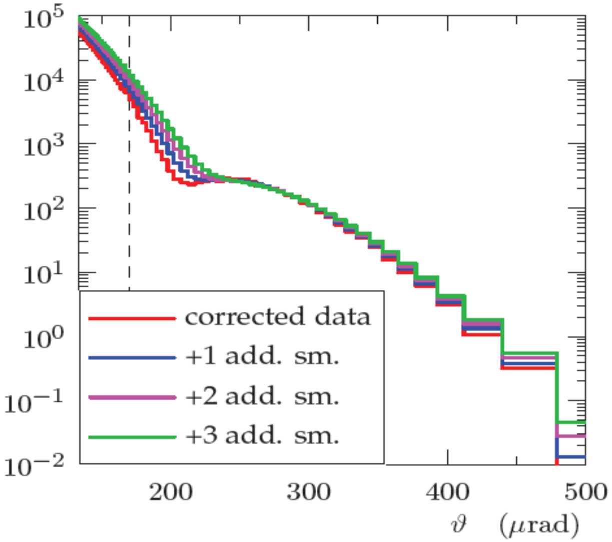
|t| = 0.4GeV^2: B/S = (11 ± 2)%
|t| = 0.5GeV^2: B/S = (19 ± 3)%
|t| = 1.5GeV^2: B/S = (0.8 ± 0.3)%

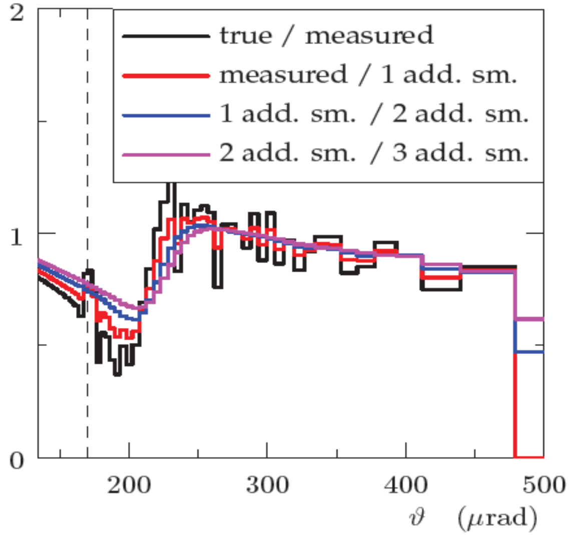
Resolution Unfolding

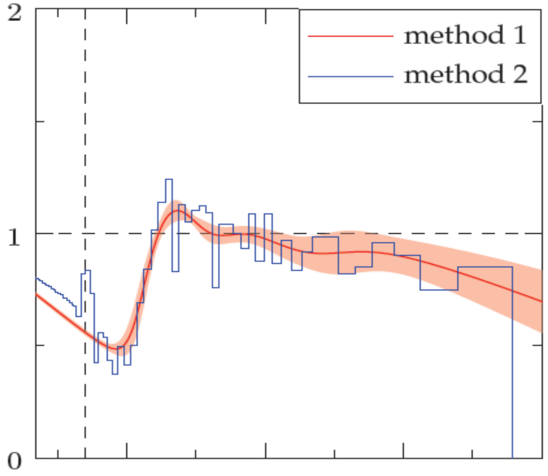

data fit


correction = unsmeared / fit

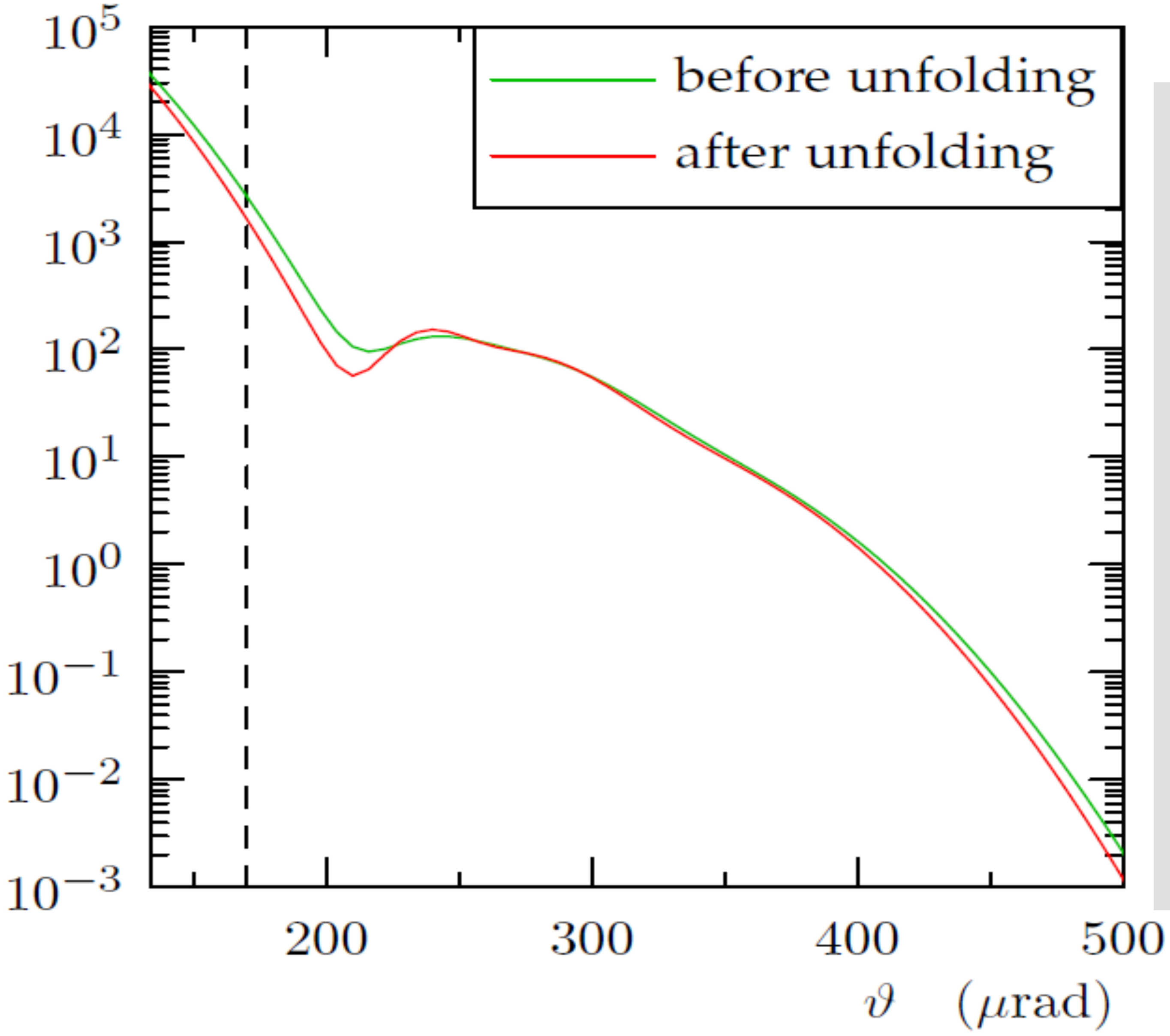

MC smearing of result


additional smearing steps


“learning” correction trend and backward application


method comparison

Resolution Unfolding



t → θ → θ′ → t′

σ_θ = const(θ)

Data parameterization

Extrapolation below acceptance cut

Analytical deconvolution

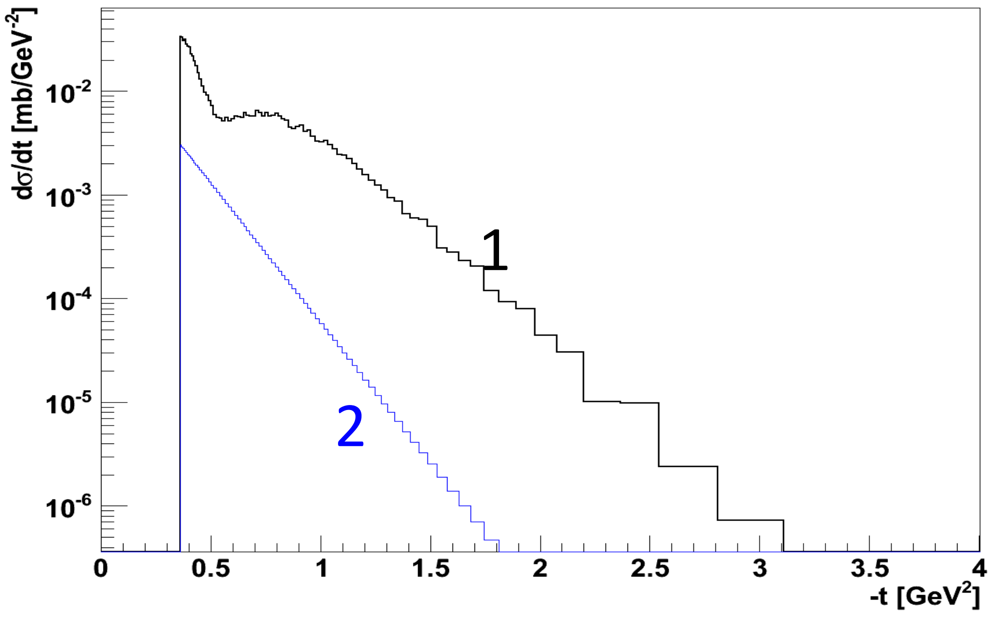
Consistency checked with random generator smearing and unsmearing

Consistency checked with golden sample selected within 0.5σ of resolution

Data transformations (after selection cuts)

Diagonal top 45 - bottom 56 alone

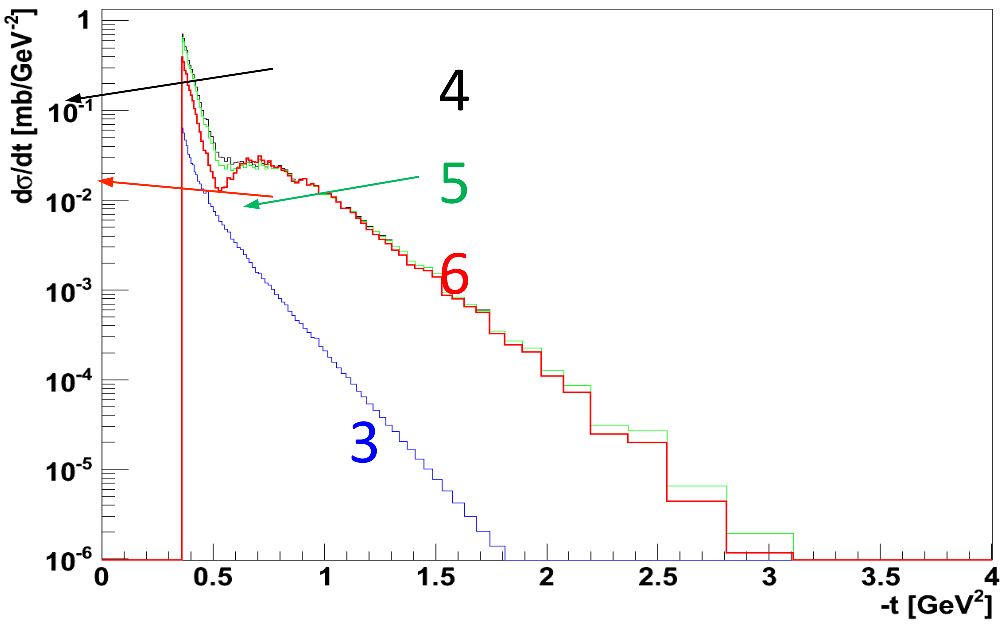
Raw data



1 – raw data (signal + background)

2 – estimated background

Acceptance corrected



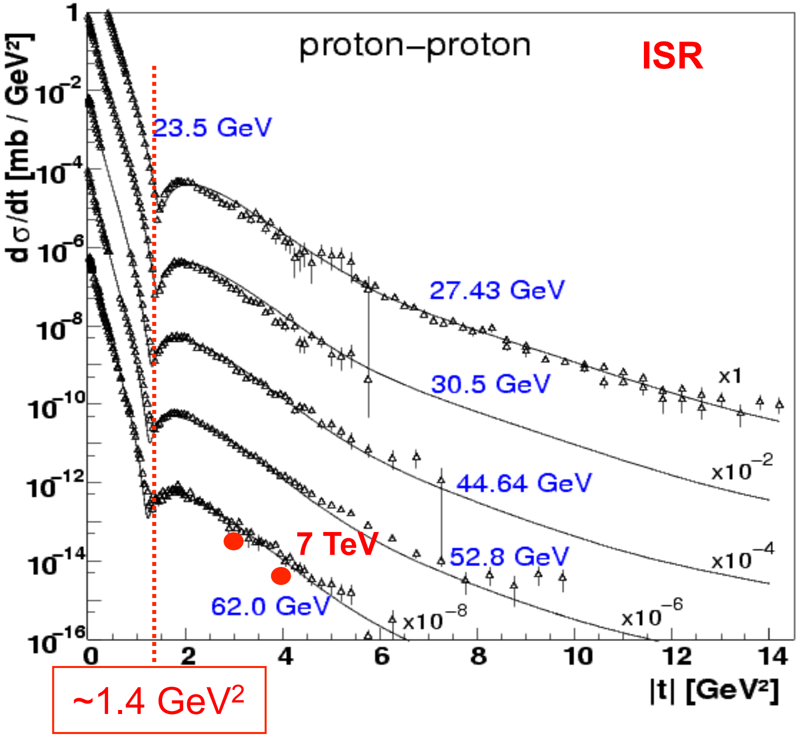
3 – estimated background acceptance corrected

4 – raw data acceptance corrected

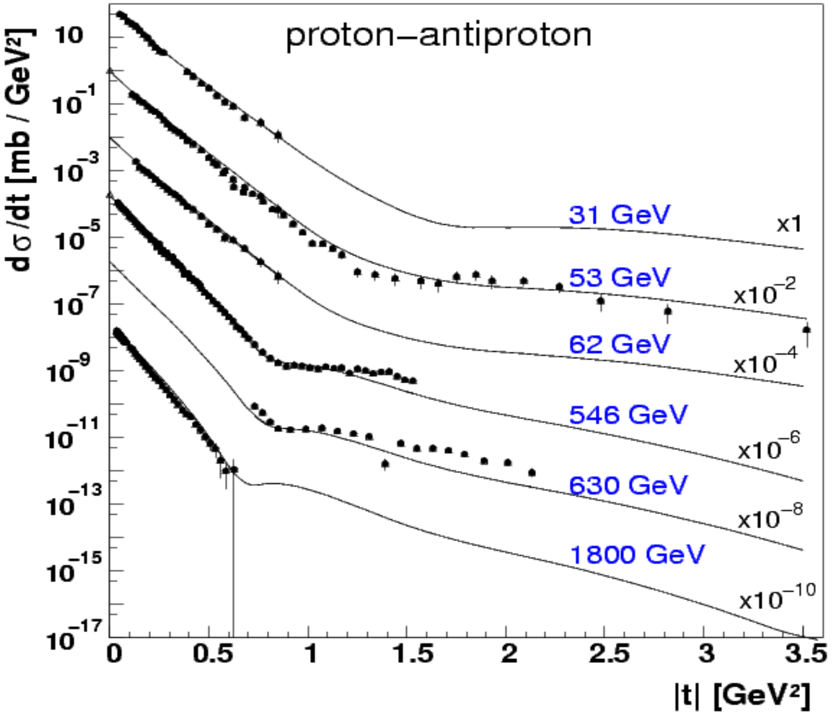
5 – raw data acceptance corrected - background

6 – final unfolded distribution

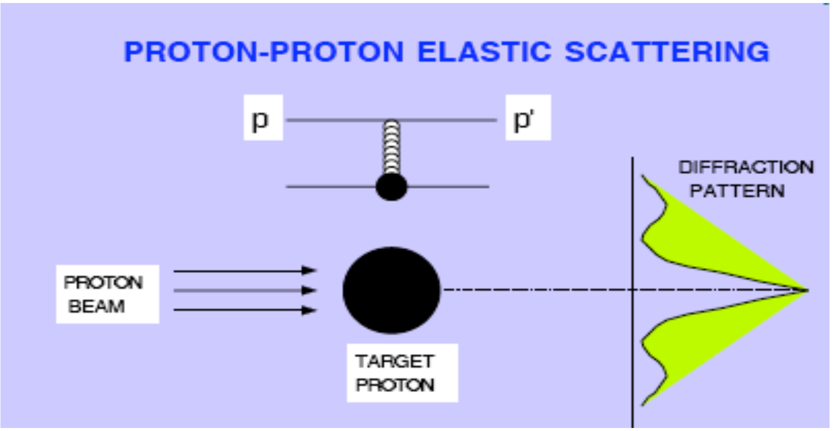
Elastic scattering – from ISR to Tevatron



~1.4 GeV^2



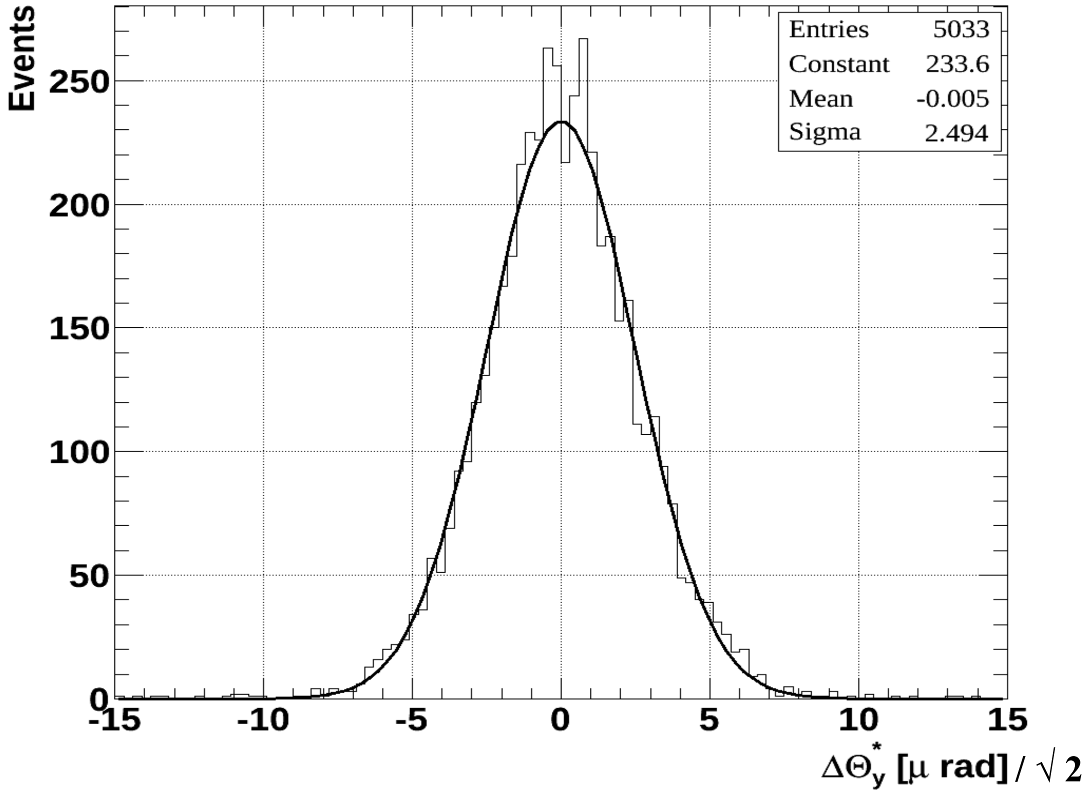
Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 \theta^2$



- 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

90 m: Angular difference between the two outgoing protons

$[\Theta_y^*\,(\text{proton1}) - \Theta_y^*\,(\text{proton2})] / \sqrt{2}$



beam divergence σ_{Θ^*}

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

90 m: Efficiency Correction and Resolution Unfolding

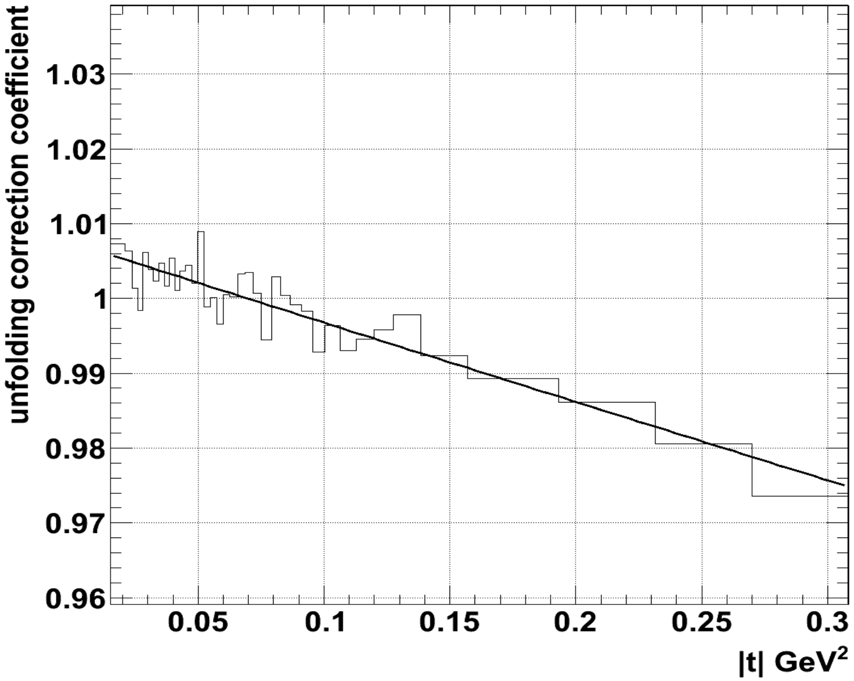
Trigger efficiency ~ 99.9 %

Reconstruction efficiency ~ 91 %

$$\sigma\left(\Theta_x^*\right) = \sqrt{1.7^2 \text{(from beam div.)} + 4^2 \text{(det. res.)}} = 4.4 \mu\text{rad}$$

$$\sigma\left(\Theta_y^*\right) = 1.7 \mu\text{rad (from beam div.)}$$

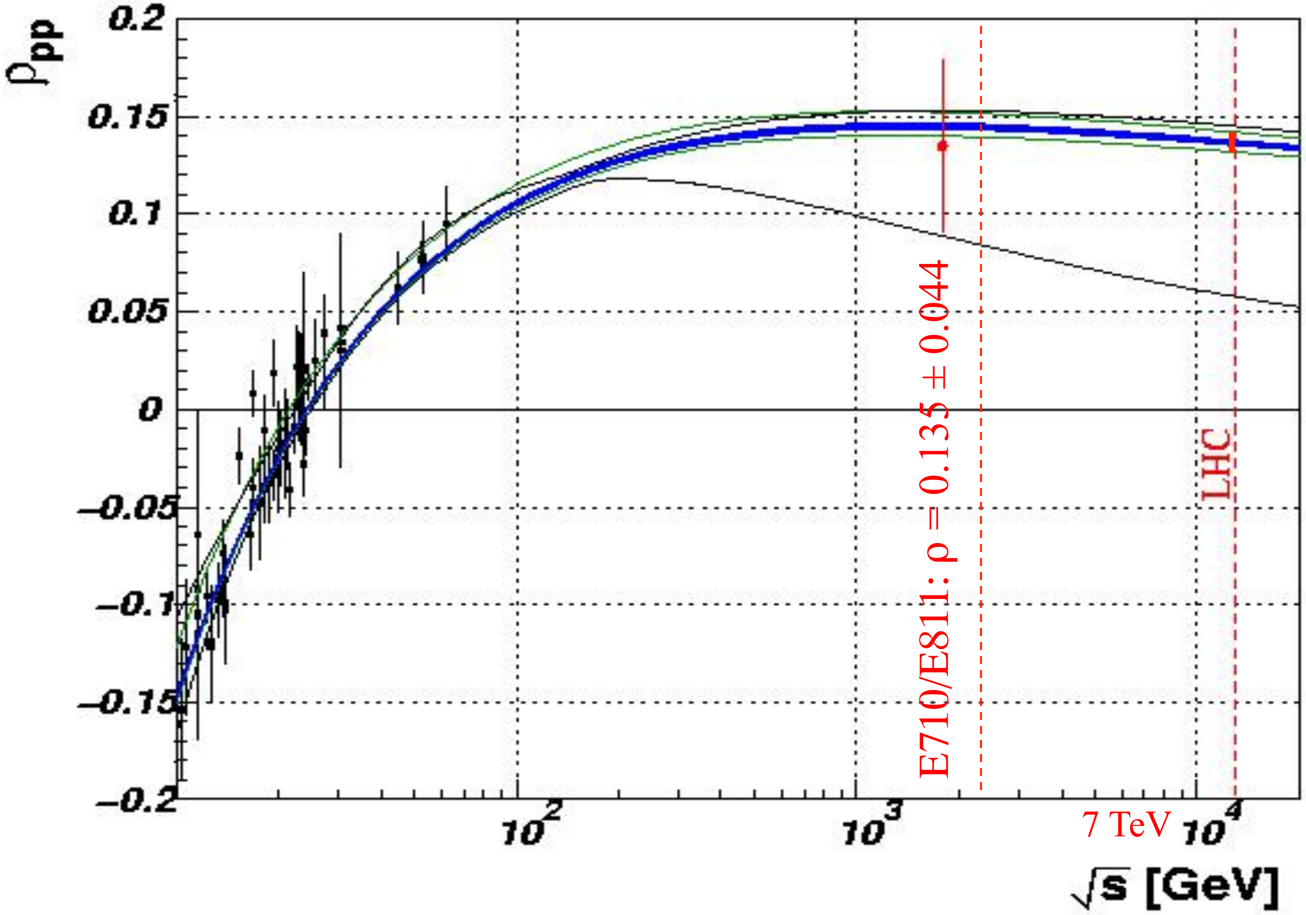
Unfolding correction



Effect on slope: $\Delta B = 0.11$ GeV^{-2}

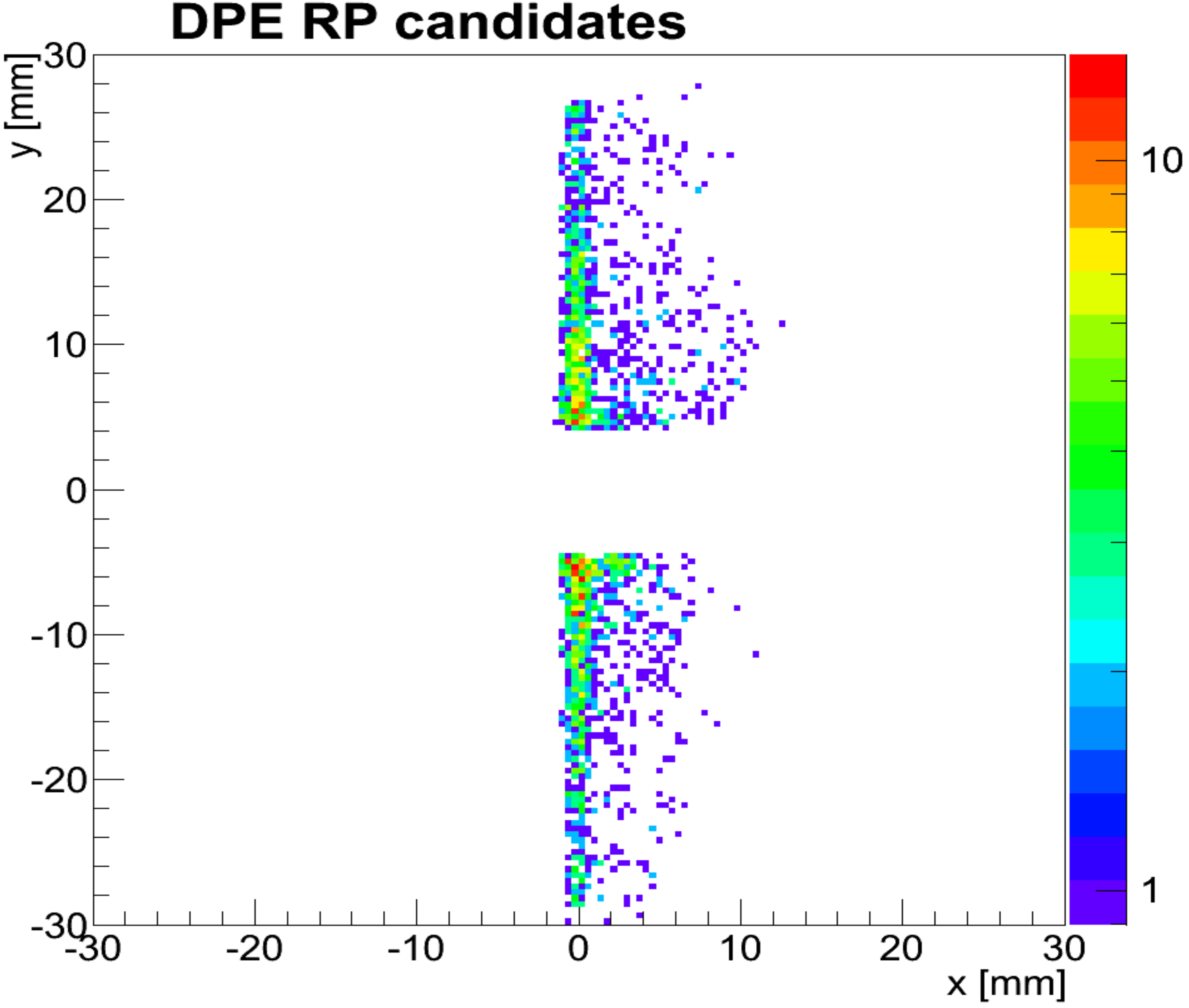
Elastic Scattering: ρ = ℜ f(0) / ℑ f(0)

COMPETE [PRL 89 201801 (2002)]

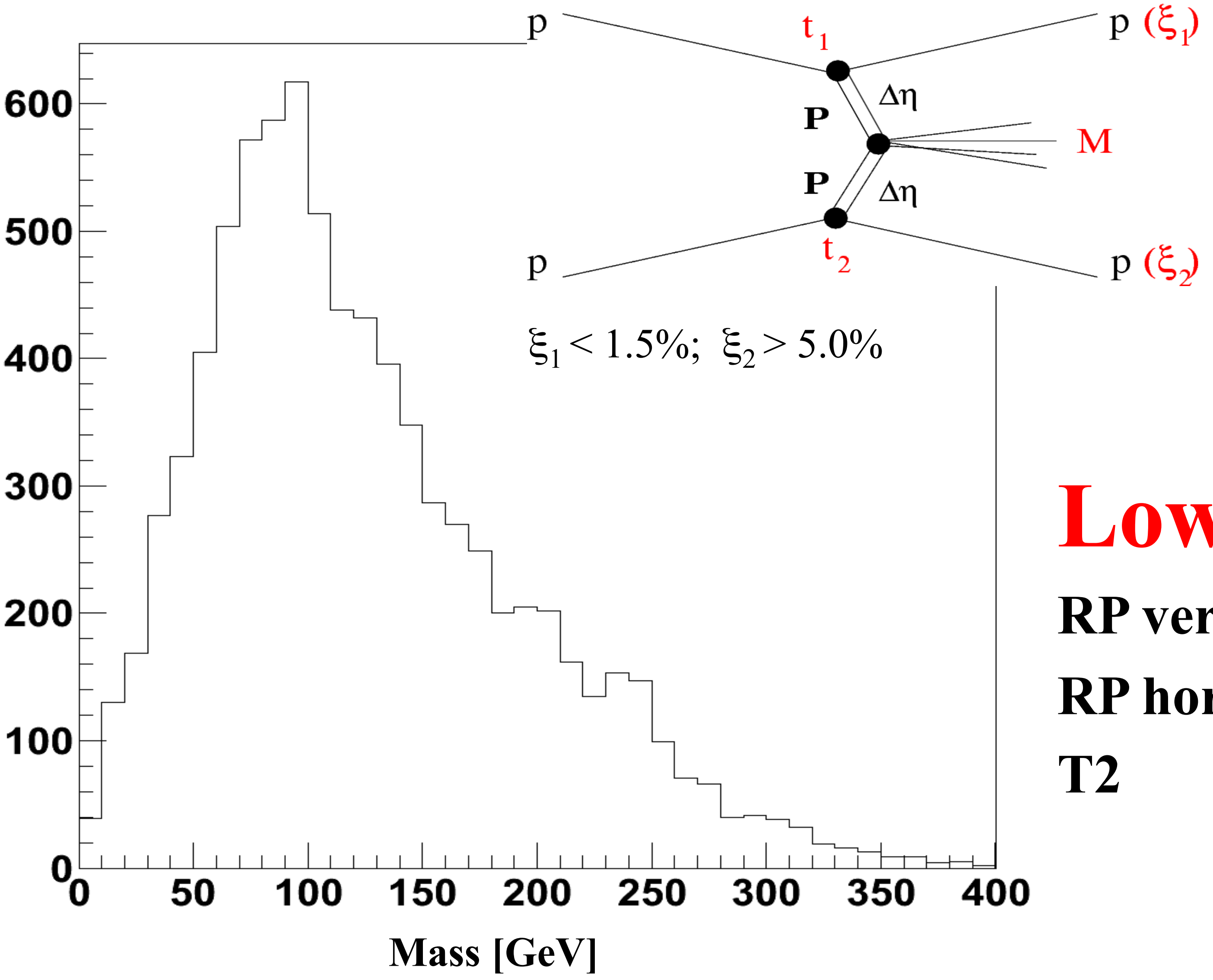


Data Oct'11: DPE tagging

Preliminary



Example of DPE Mass Reconstruction



$\xi_1 < 1.5\%$; $\xi_2 > 5.0\%$

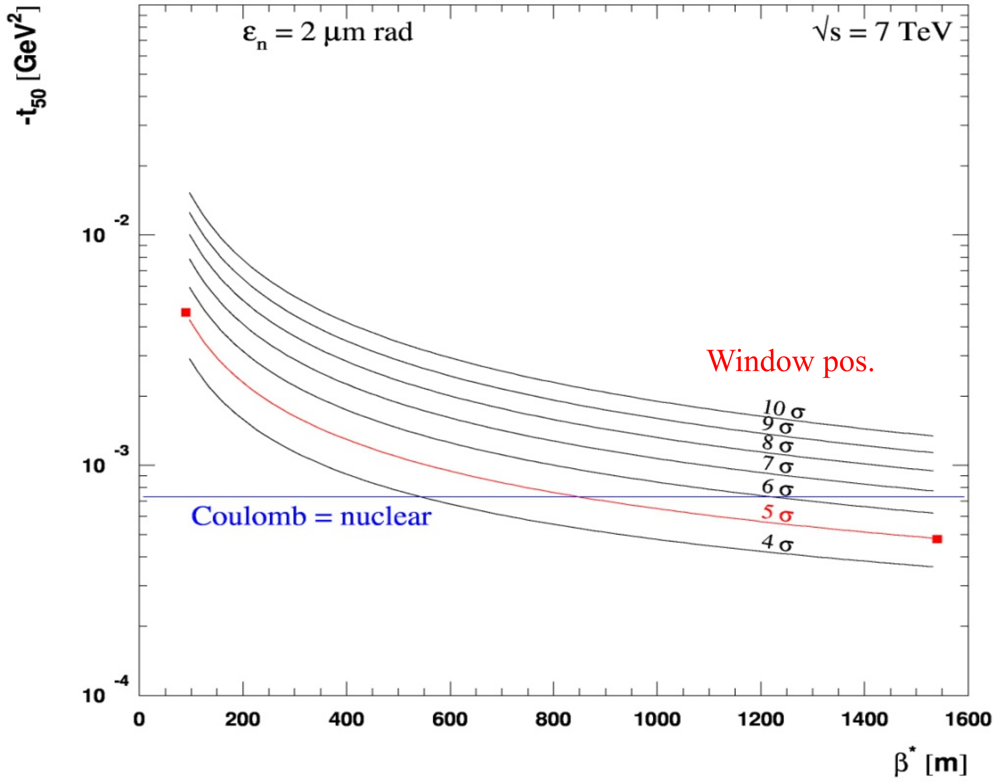
Low-β

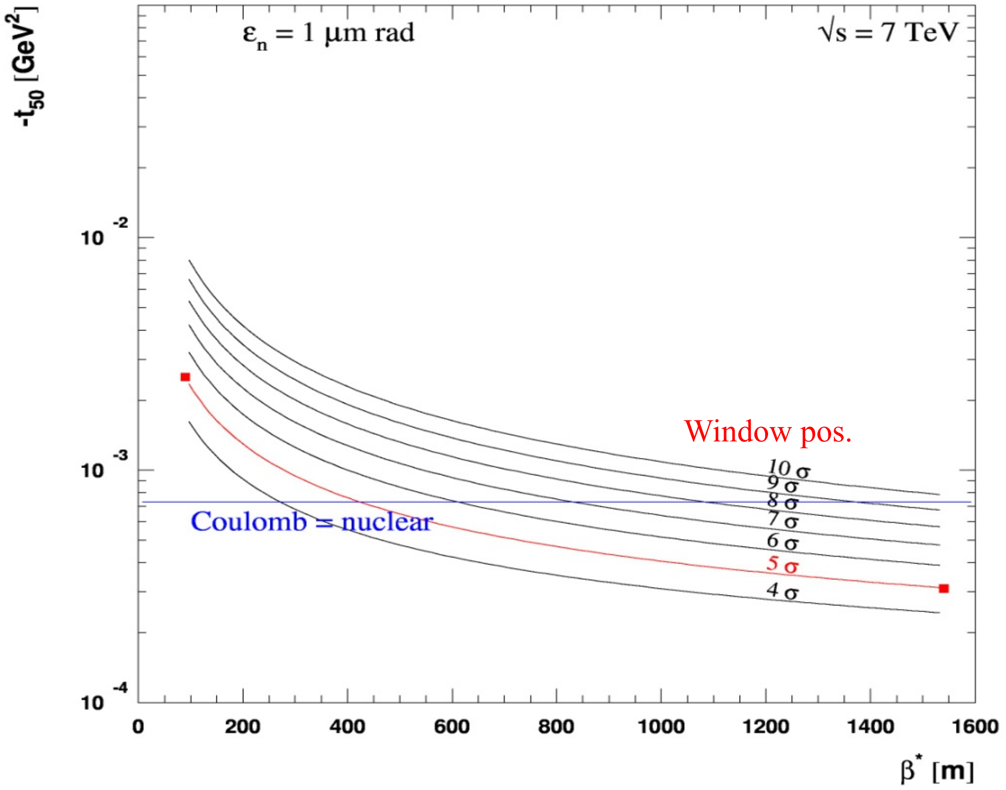
RP vertical

RP horizontal

T2

How to reach the Coulomb Region ?





At 8 TeV the pots have to move by ~1σ closer to reach the same t as at 7 TeV.

→ Challenging but possible