TOTEM
Experiment & Physics Results

Scientific Symposium 20th Rep.Czech - CERN
Academy of Sciences, Prague 26 October 2012

S.Giani

CERN – CH

[*on behalf of the TOTEM collaboration*]

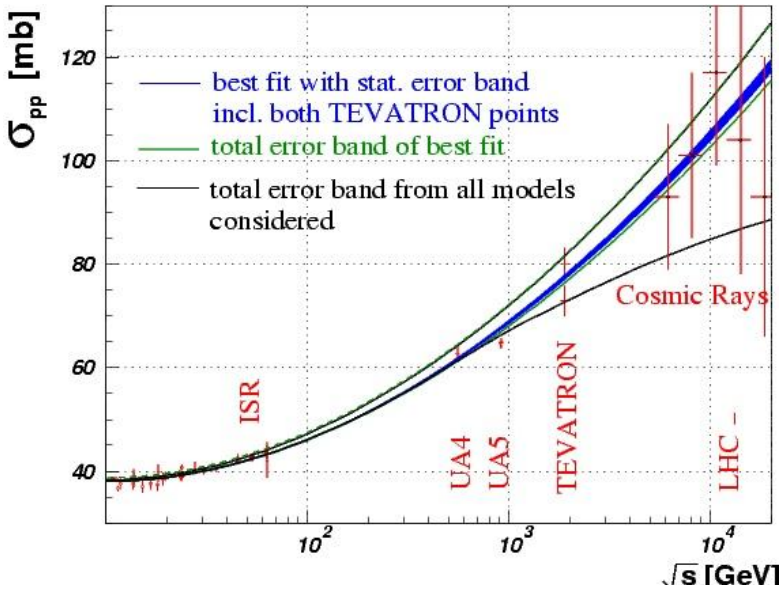
Outlook

- TOTEM Experiment
- LHC Special Runs and TOTEM Data
- PP Elastic Scattering Differential Cross-Section
- Total, Elastic, Inelastic Cross-Sections @ $\sqrt{s}$ = 7-8 TeV
- Perspectives on Forward and Diffractive Physics

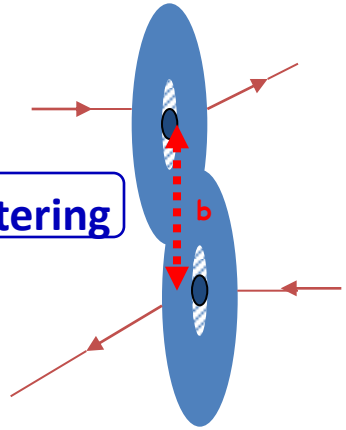
TOTEM EXPERIMENT

TOTEM Physics Overview

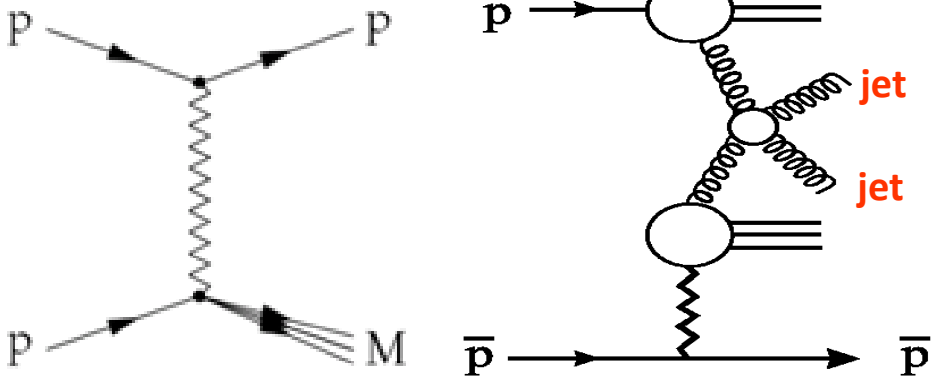
Total cross-section



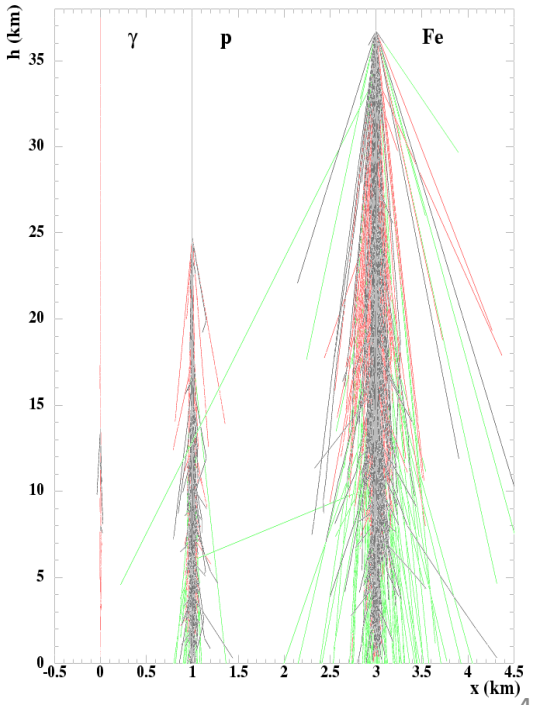
Elastic Scattering



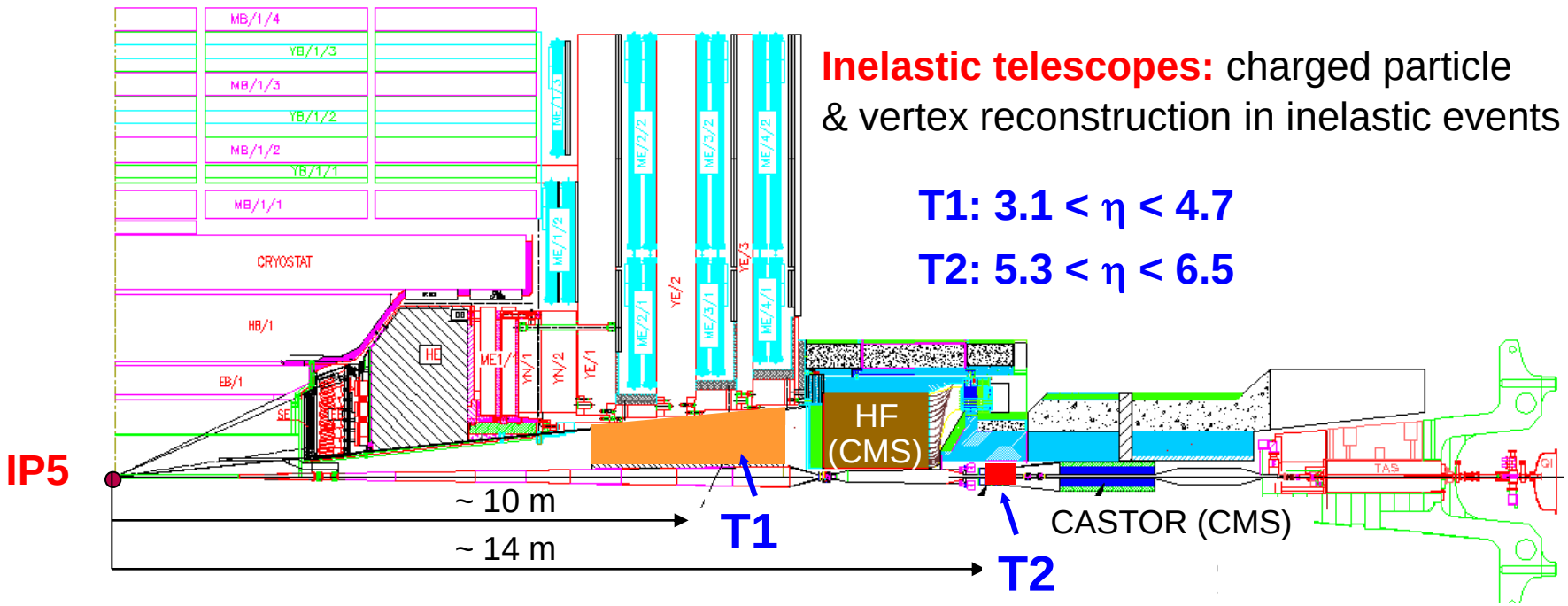
Diffraction: soft (and hard with CMS)



Forward physics



Experimental Setup @ IP5

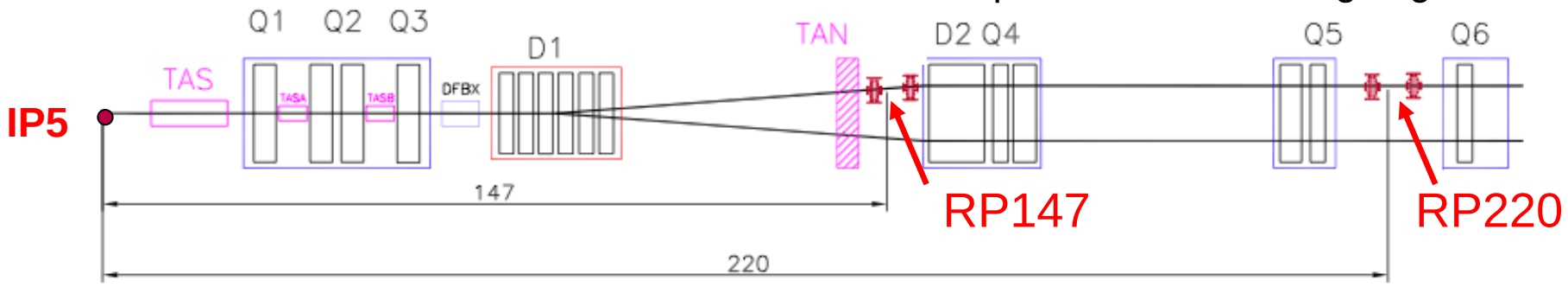


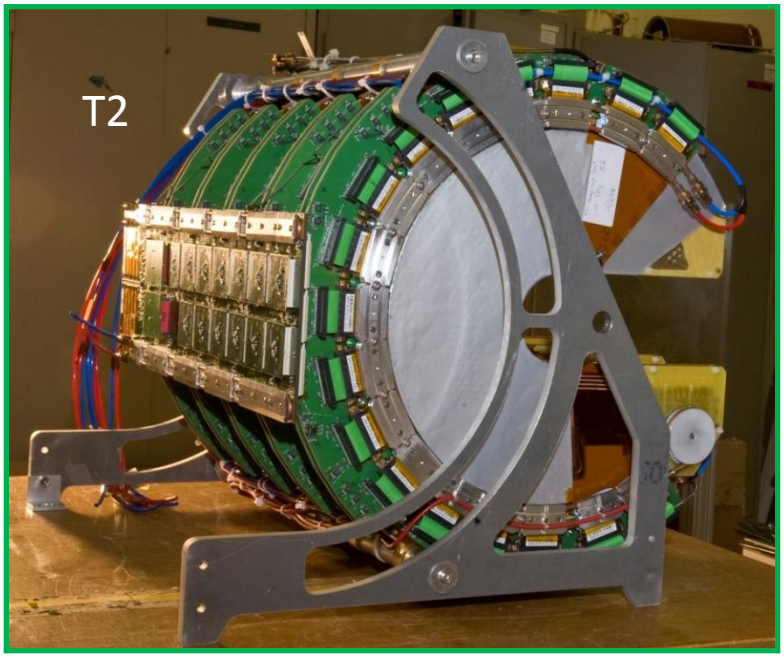
Inelastic telescopes: charged particle & vertex reconstruction in inelastic events

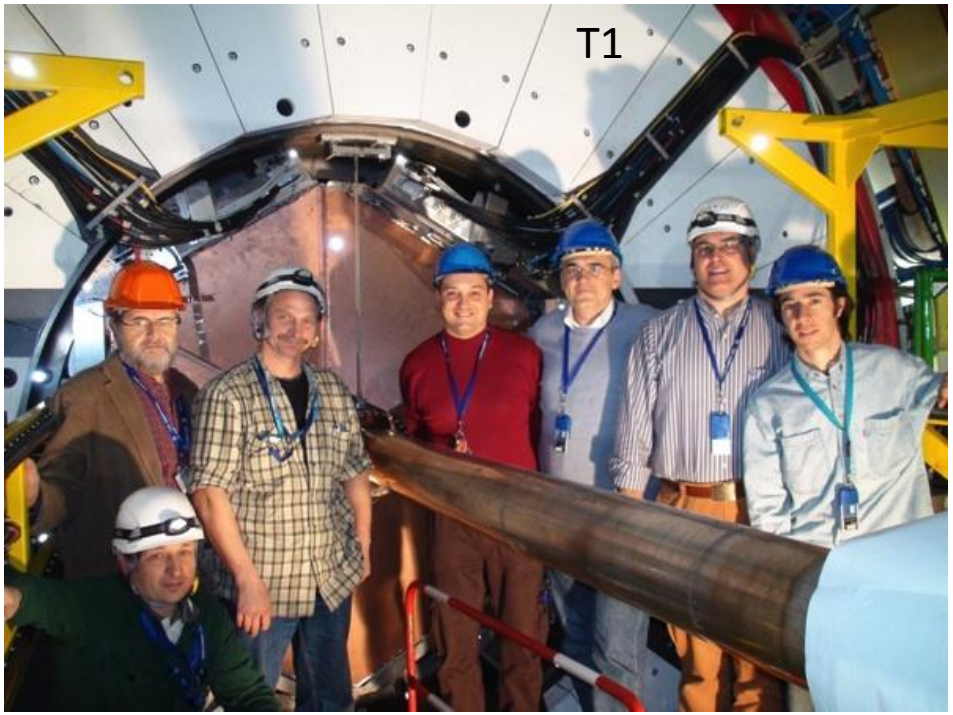
T1: 3.1 < η < 4.7

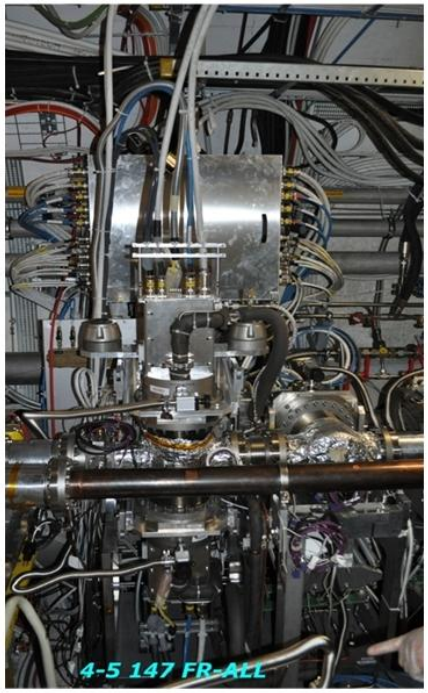
T2: 5.3 < η < 6.5

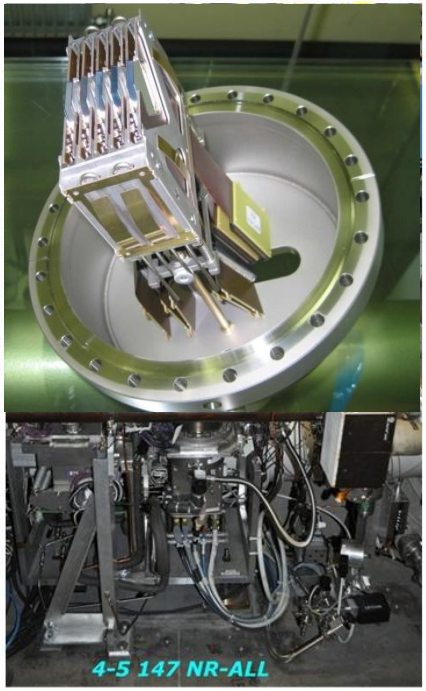
Roman Pots: measure elastic & diffractive protons close to outgoing beam











Detectors

- **T1 and T2 detectors are installed and fully operational**
- **Roman Pot Silicon detectors are fully operational**

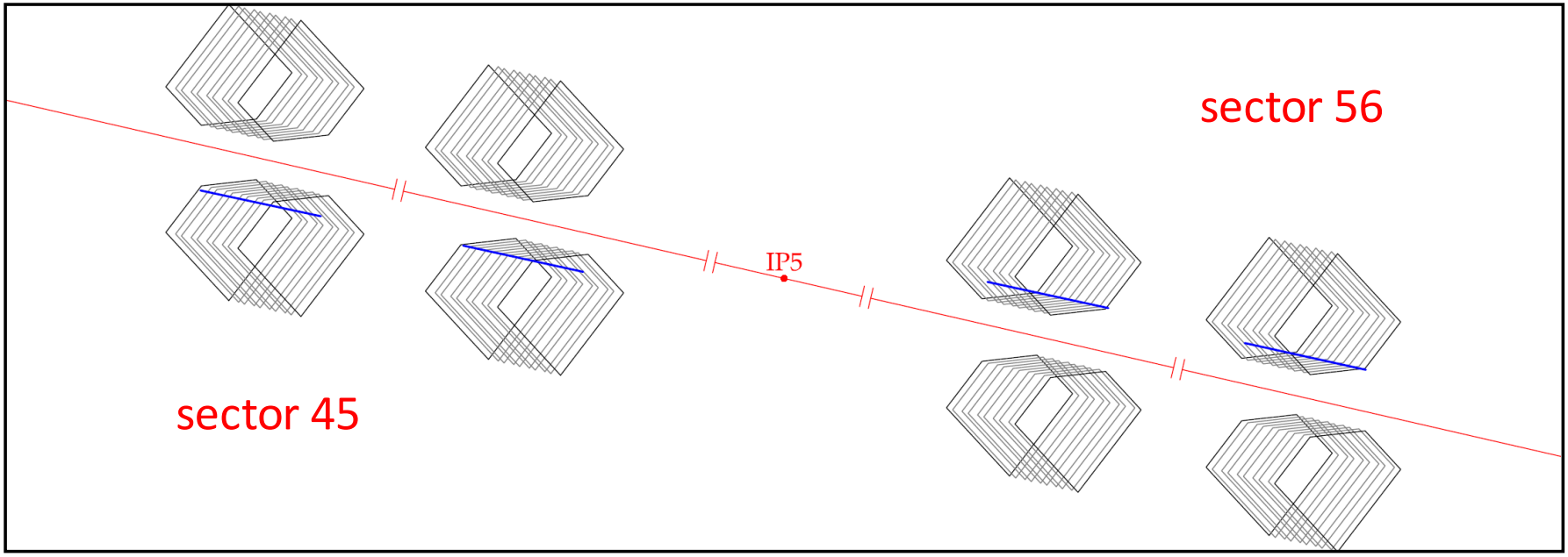
Prague's contributions on RP mechanics, cooling, electronics

TOTEM Collaboration

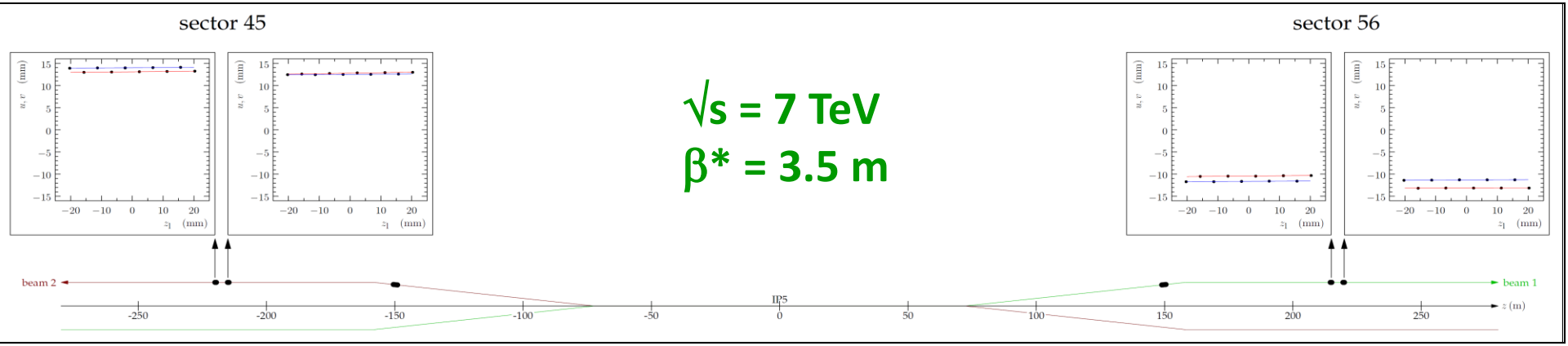
- **Countries: 7**
- **Institutes: 15**
- **Collaborators: ~ 100**
- **Authors: ~ 80**
- **Construction: ~ 7 MCHF**

LHC SPECIAL RUNS
AND
TOTEM DATA

2010 Data from Runs with RPs at 25σ (1.5nb^{-1})
First p-p Elastic Scattering Event Candidates [LPCC July 2010]



Event scanning and constraining analysis procedure



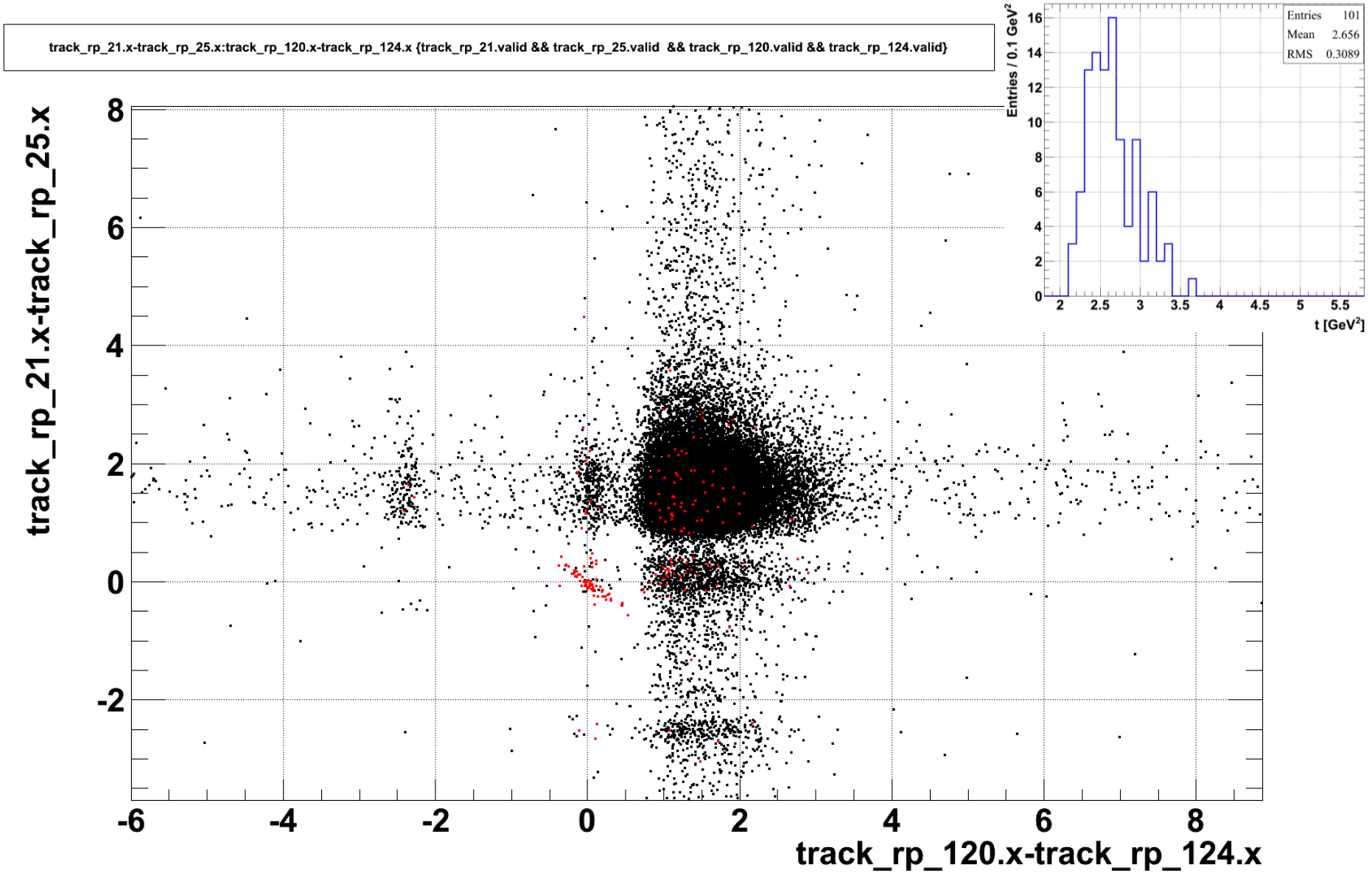
2010 Data from Runs with RPs at 20σ (total 185nb^{-1})

Large-t p-p Elastic Scattering 100 Events (80nb^{-1})

√s = 7 TeV

β* = 3.5 m

[LHCC Sep 2010]



Runs & Data Statistics 2010-2011

Date	Detector configuration	β* [m]	$\int L\,dt$ [nb^{-1}]	Analysis
Oct 2010	RP at 7σ; T2 in readout	3.5	6.8	Elastic scattering 0.36 < |t| < 2.5 GeV^2
Sep/Oct 2010	RP at 18σ	3.5	2300	Elastic scattering - large |t| (in progress)
May 2011	RP at 5σ; T1, T2 in readout	1.5	0.72	Alignment of 220m pots
June 2011	RP at 10σ; T1, T2 in readout	90	0.0017	Total cross section + elastic scattering 0.02 < |t| < 0.33 GeV^2
Aug/Sep 2011	RP at 5σ; T1, T2 in readout	90	beam lost	Alignment of RPs
18. Oct 2011	RP at 5σ; T1, T2 in readout	90		Several hours of data taking;

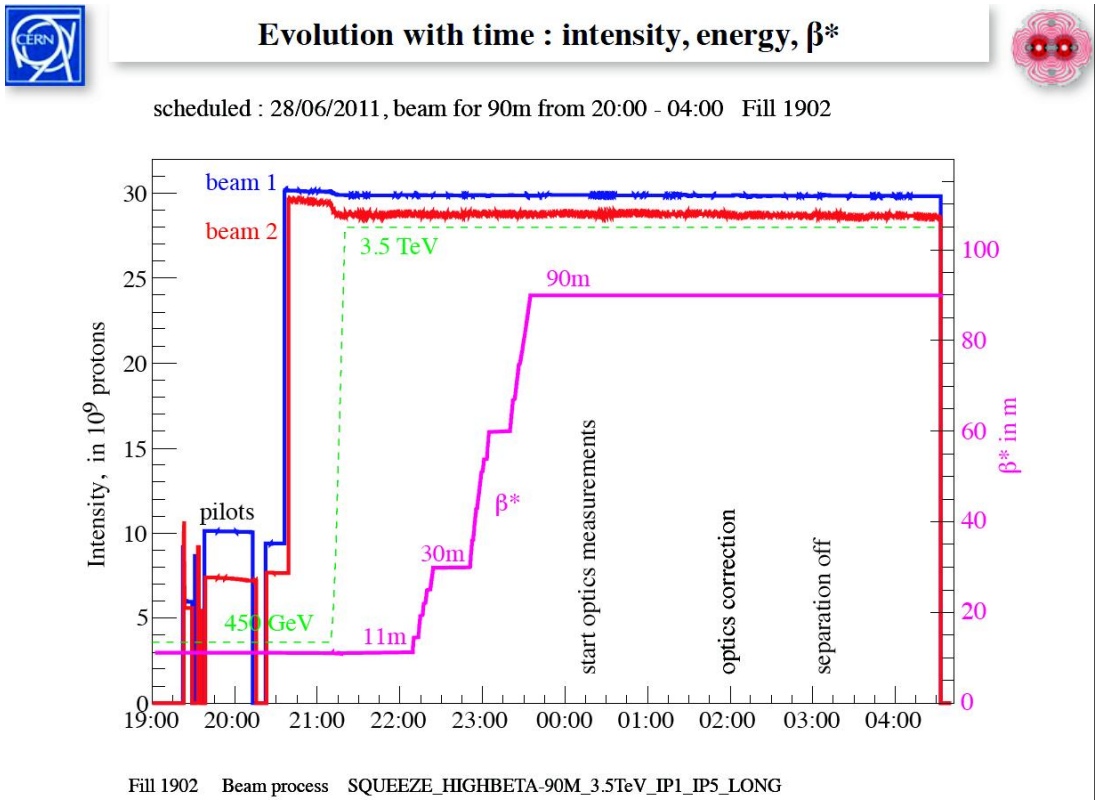
RP position (V) [sigma]	trigger schema	trigger on bunch	Run time [min]	Events	Integ. Lumi [ub^{-1}]
6.5	RP_all_OR + T2 + BX	1950,2000,2050 2100, 2200, 2300	64.9	2.4E+6	1.6
6.5	RP_V_and + T2 + BX	all	13.4	5.8E+5	5.2
6.5	RP_all_and + T2 + BX	all	217.5	9.3E+6	77
5.5	RP_all_and + T2 + BX	all	50.7	1.9E+6	16
4.8	RP_all_and + T2 + BX	all	16.4	6.2E+5	4.9
		sum	363	1.5E+7	104

A special run: 1st run with the β* = 90 m optics and RP insertion

June 2011

Un-squeeze from injection optics
β* = 11m to 90m
[Helmut Burkhardt, Andre Verdier]
Request of TOTEM (2005)

Very robust optics with high precision



- 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

At the end of machine development
0.5 hours data taking by TOTEM

Runs & Data 2012

Joint data-taking TOTEM-CMS @ √s = 8 TeV

Special optics β* 90m (July 2012) : ~100 bunches

Bi-directional exchange of triggers (via new TOTEM electrical trigger)

TOTEM triggers on RP pp coincidences >>> full CMS readout

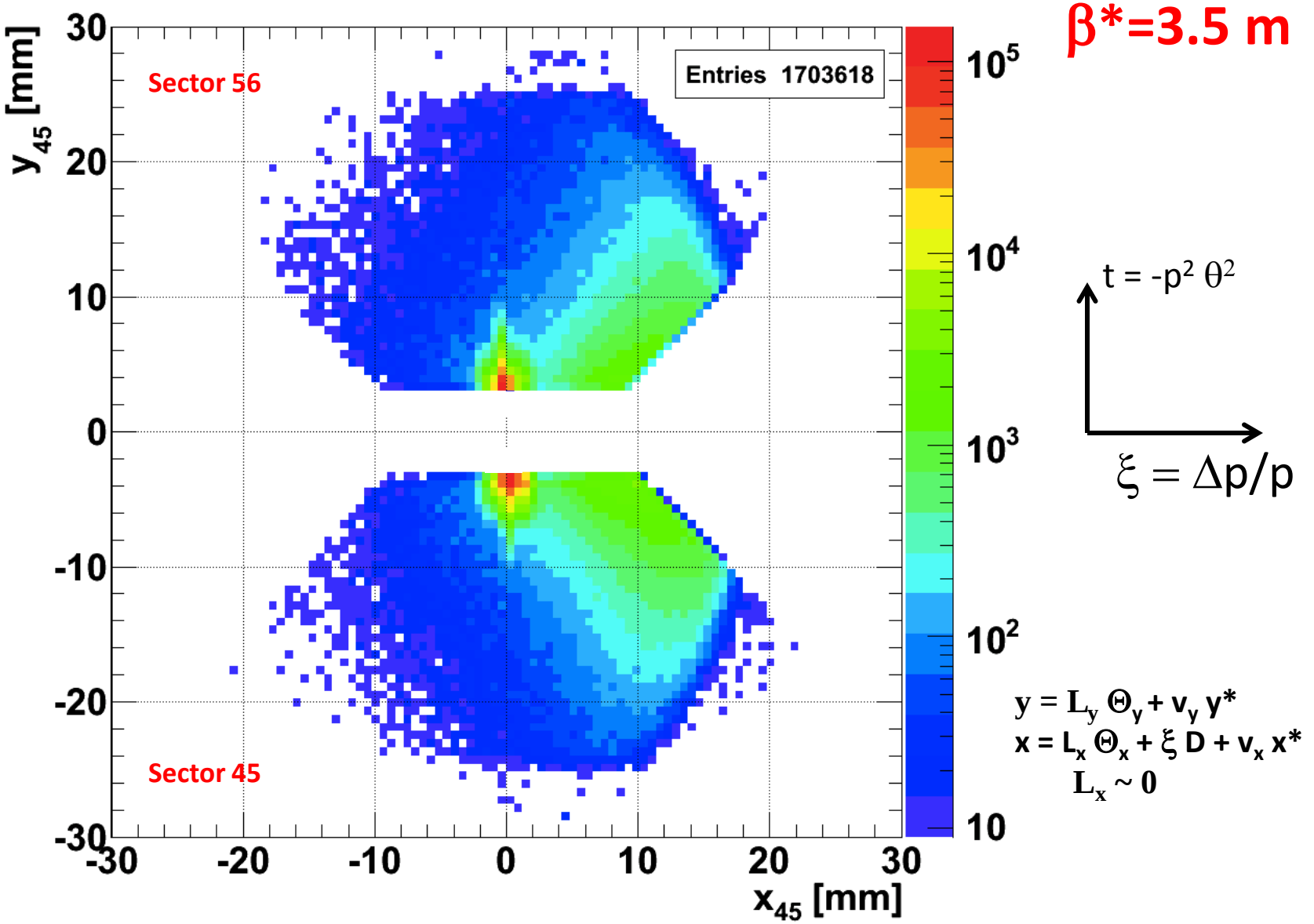
CMS triggers on di-jets >>> TOTEM RPs readout for protons signature

~25 M events

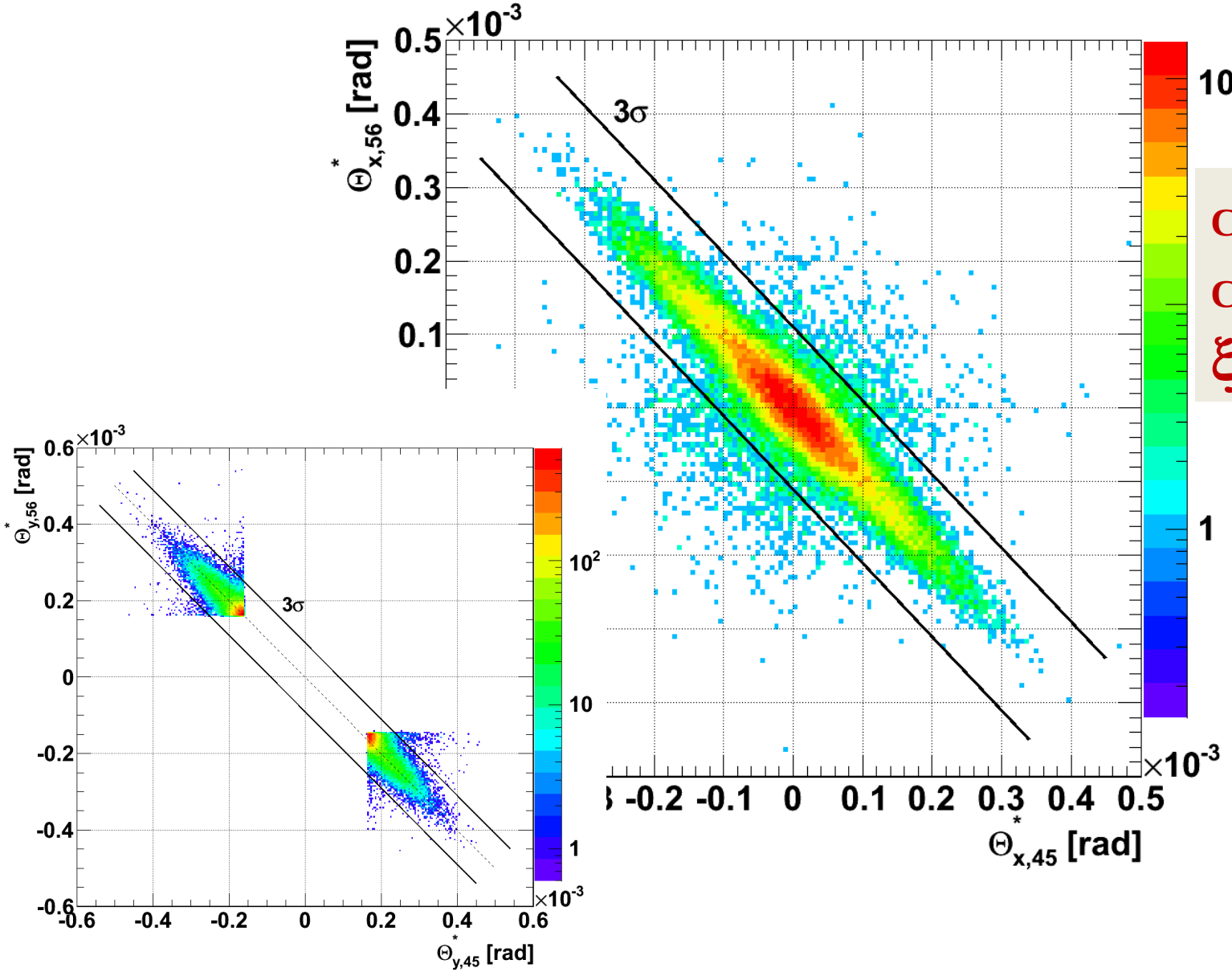
[Follow-up with new b* = 1km optics and pPb ions runs]

PP ELASTIC SCATTERING DIFFERENTIAL CROSS-SECTION

“Raw Data” Oct’10 – Vertical RPs@7σ



Tagging Elastic Scattering



Co-linearity in θ_X

Co-linearity in θ_Y

$\xi \sim 0$

Analysis

Prague's group strong involvement and contributions

Alignment

Normalization **(luminosity, trigger, daq)**

Efficiency **(detector and tracking)**

Acceptance **(geometry and beam)**

Background subtraction

Resolution unfolding

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%	

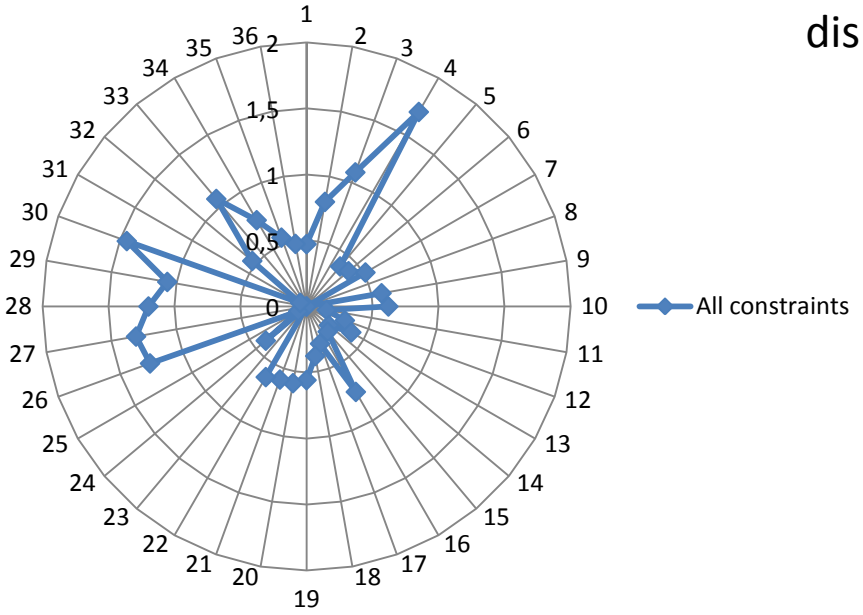
45	dLx/ds	Ly [m]	ROT [mrad]
RP215	-0.314508	20.3883272	0.0400268
RP220	-0.314508	20.6709463	0.0372828
Δ RP215	-4.51%	+10.19%	
Δ RP220	-4.51%	+10.79%	

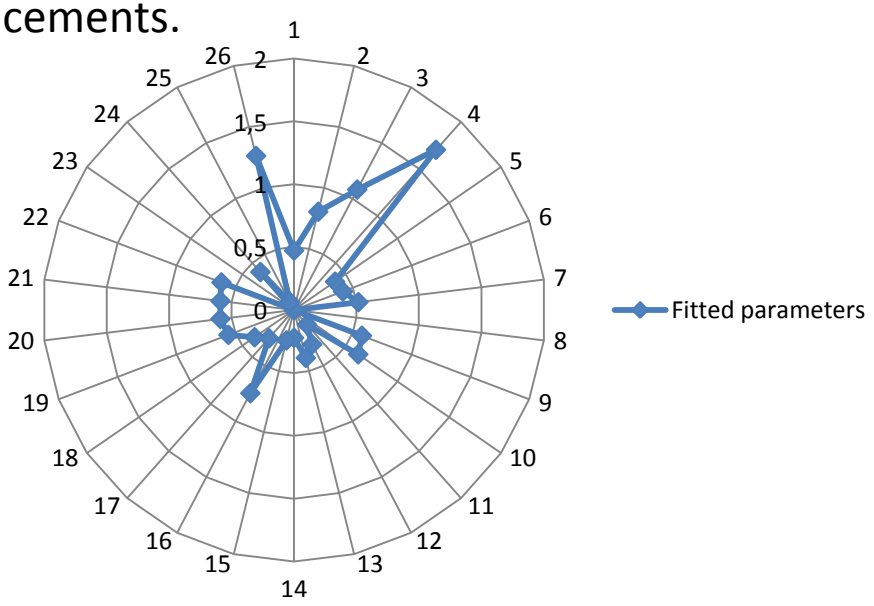
Strong correlations between fitted parameters

Principle Component Analysis (PCA) should ideally be applied. Anyway results checked with MAD-X.

χ^2/NDF = 25.8/(36-26)=2.6
(would be lower if correlations are elmininated)
Mean pull = 0.043
Pull RMS = 0.86

Full nonlinear fitting with harmonics and displacements.





Systematics

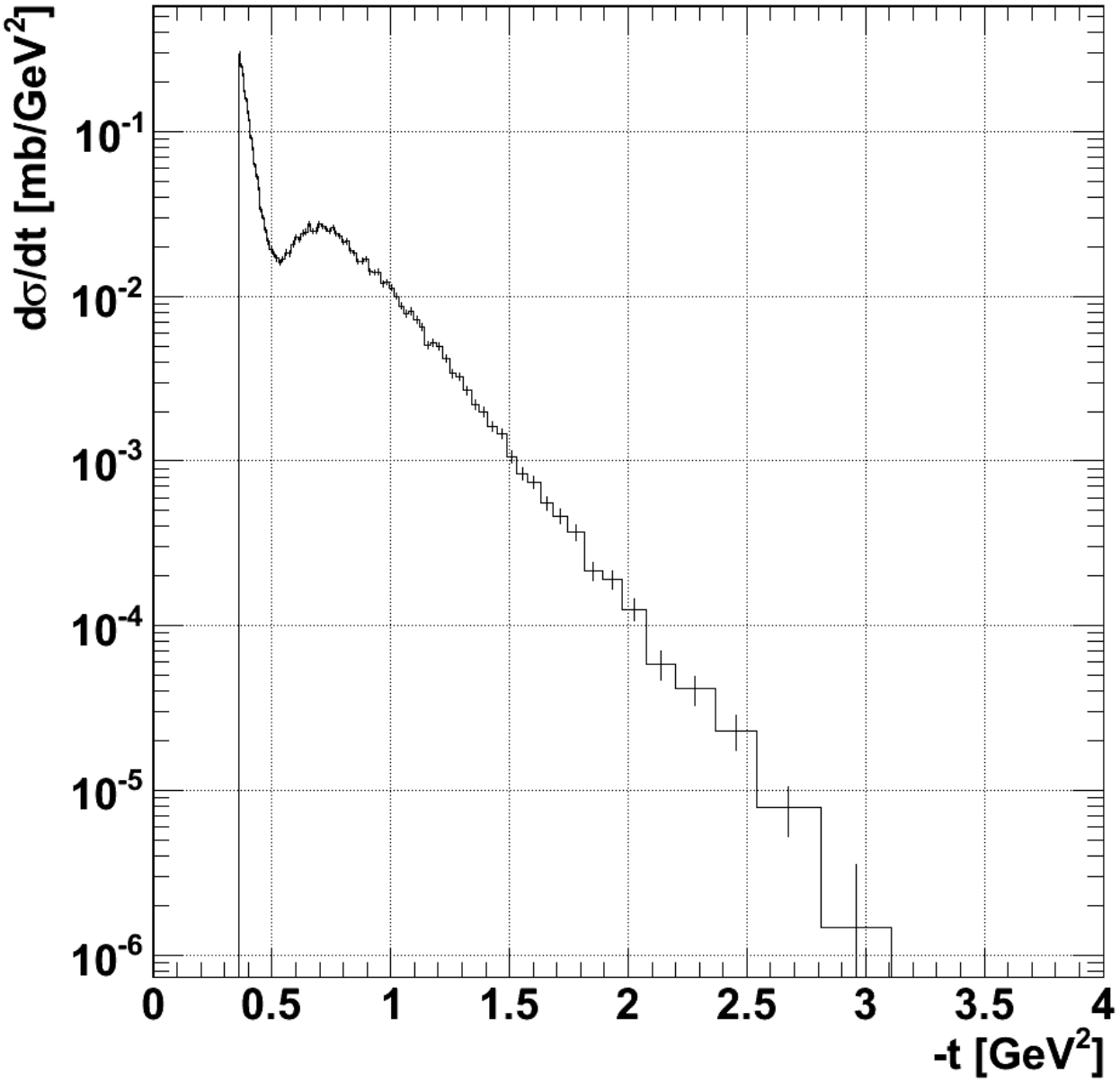
Analysis Corrections and Systematics				
Correction	Effect on	Functional form	Total values and integral	Details
Normalization	$d\sigma/dt$	const($\|t\|$) mult. factor	$6.03\,\mathrm{nb}^{-1} \pm 6\%$	Luminosity $6.1\mathrm{nb}^{-1} \pm 4\%$ Trigger eff. $99\% \pm 1\%$ DAQ eff. $99\% \pm 1\%$
Background	$d\sigma/dt$	$Ae^{-B\|t\|}$ mult. factor = (1 - bckg.%)	$(8 \pm 1)\%$	$(11 \pm 2)\%\|_{\|t\|=0.4\mathrm{GeV}^2}$ $(19 \pm 3)\%\|_{\|t\|=0.5\mathrm{GeV}^2}$ $(0.8 \pm 0.3)\%\|_{\|t\|=1.5\mathrm{GeV}^2}$
Inefficiency	$d\sigma/dt$	const($\|t\|$) mult. factor = (1 + ineff.%)	$(30 \pm 10)\%$	Detector 1% Tracking 29%
Acceptance	$d\sigma/dt$	$A(\|t\| - B)^{-C}$ mult. factor	$5.0 \pm 1\%\|_{\|t\|=0.4\mathrm{GeV}^2}$ $2.8 \pm 1\%\|_{\|t\|=0.5\mathrm{GeV}^2}$ $1.5 \pm 1\%\|_{\|t\|=1.5\mathrm{GeV}^2}$	Y: $2.2\|_{\|t\|=0.36\mathrm{GeV}^2}$ $1.1\|_{\|t\|=0.5\mathrm{GeV}^2}$ ϕ: $4.5\|_{\|t\|=0.36\mathrm{GeV}^2}$ $1.5\|_{\|t\|=1.5\mathrm{GeV}^2}$
Resolution unfolding	$t \to d\sigma/dt$	Fourier(θ) $\frac{\text{Beam divergence}}{\sqrt{2}} = 12\text{–}13\ \mu\mathrm{rad}$ mult. factor = $\frac{\text{unsmeared}}{\text{measured}}$	$0.55\,[0.46 \to 0.57]\|_{\|t\|=0.35\mathrm{GeV}^2}$ $0.47\,[0.38 \to 0.51]\|_{\|t\|=0.49\mathrm{GeV}^2}$ $1.09\,[1.05 \to 1.17]\|_{\|t\|=0.77\mathrm{GeV}^2}$ $0.91\,[0.78 \to 1.01]\|_{\|t\|=1.50\mathrm{GeV}^2}$	$0.55\,[0.46 \to 0.57]\|_{170\mu\mathrm{rad}}$ $0.47\,[0.38 \to 0.51]\|_{190\mu\mathrm{rad}}$ $1.09\,[1.05 \to 1.17]\|_{240\mu\mathrm{rad}}$ $0.91\,[0.78 \to 1.01]\|_{350\mu\mathrm{rad}}$
Alignment	t	$\delta t = \mathrm{const}\,\delta\theta\sqrt{\|t\|}$	$10\mu\mathrm{m} \to \delta t = 2p/L_y\sqrt{\|t\|}\,\delta y$ $\delta t/t = 0.6\%\|_{\|t\|=0.4\mathrm{GeV}^2}$ $\delta t/t = 0.3\%\|_{\|t\|=1.5\mathrm{GeV}^2}$	Track based alignment for 2 mechanically constrained diagonals
Optics	t	$t_x = f(k, \psi, p)$; $t_y = f(k, \psi, p)$ k: magnet strength ψ: magnet rotation p: LHC beam momentum	$\Delta(dL_x/ds) = 4\%$ $\Delta L_y = 6\%$ $\Delta t = 10\%$ $\frac{\delta t}{t} = 2\%$	$\frac{\delta k}{k} = 0.1\%$ $\frac{\delta\psi}{\psi} = 1\mathrm{mrad}$ $\frac{\delta p}{p} = 10^{-3}$

Statistical and Systematic uncertainties for the *t* and dσ/d*t* results

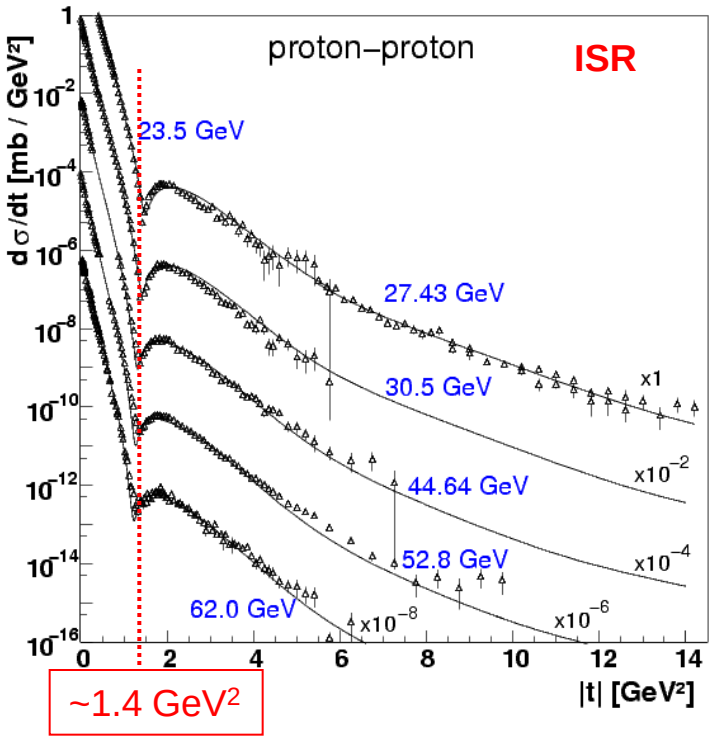
Table 3: Statistical and systematic errors on t and $d\sigma/dt$.

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

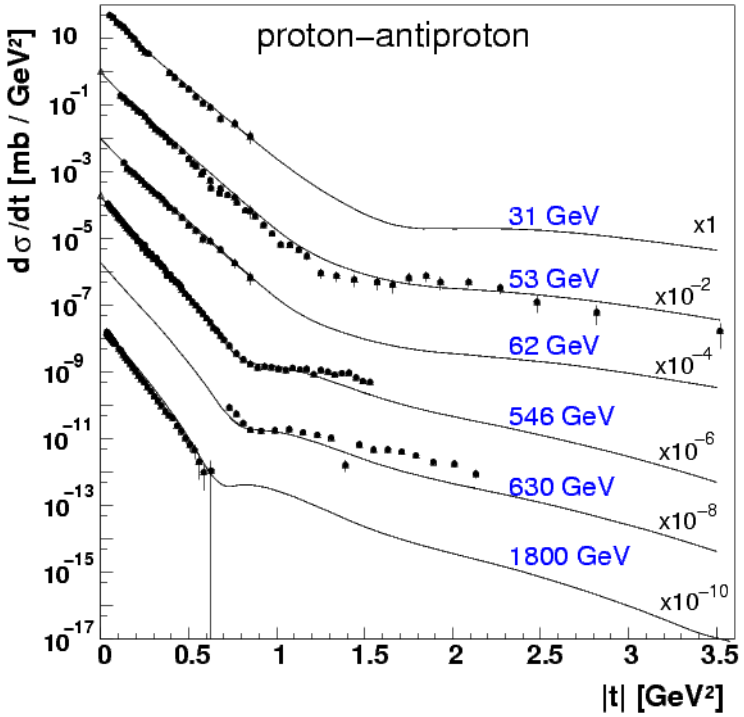
dσ/dt



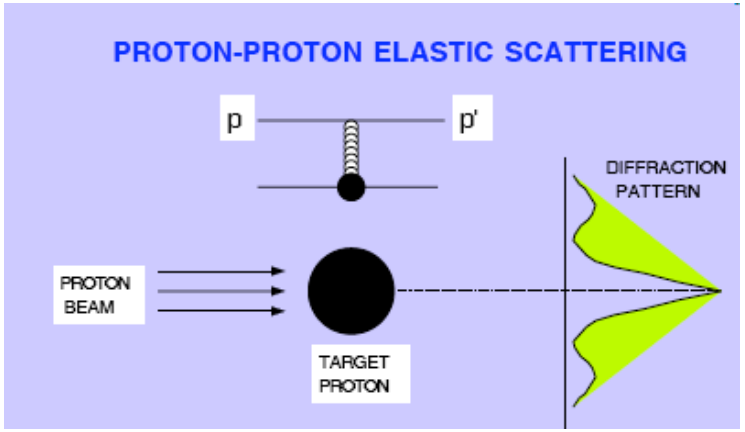
Elastic scattering – from ISR to Tevatron



~1.4 GeV²

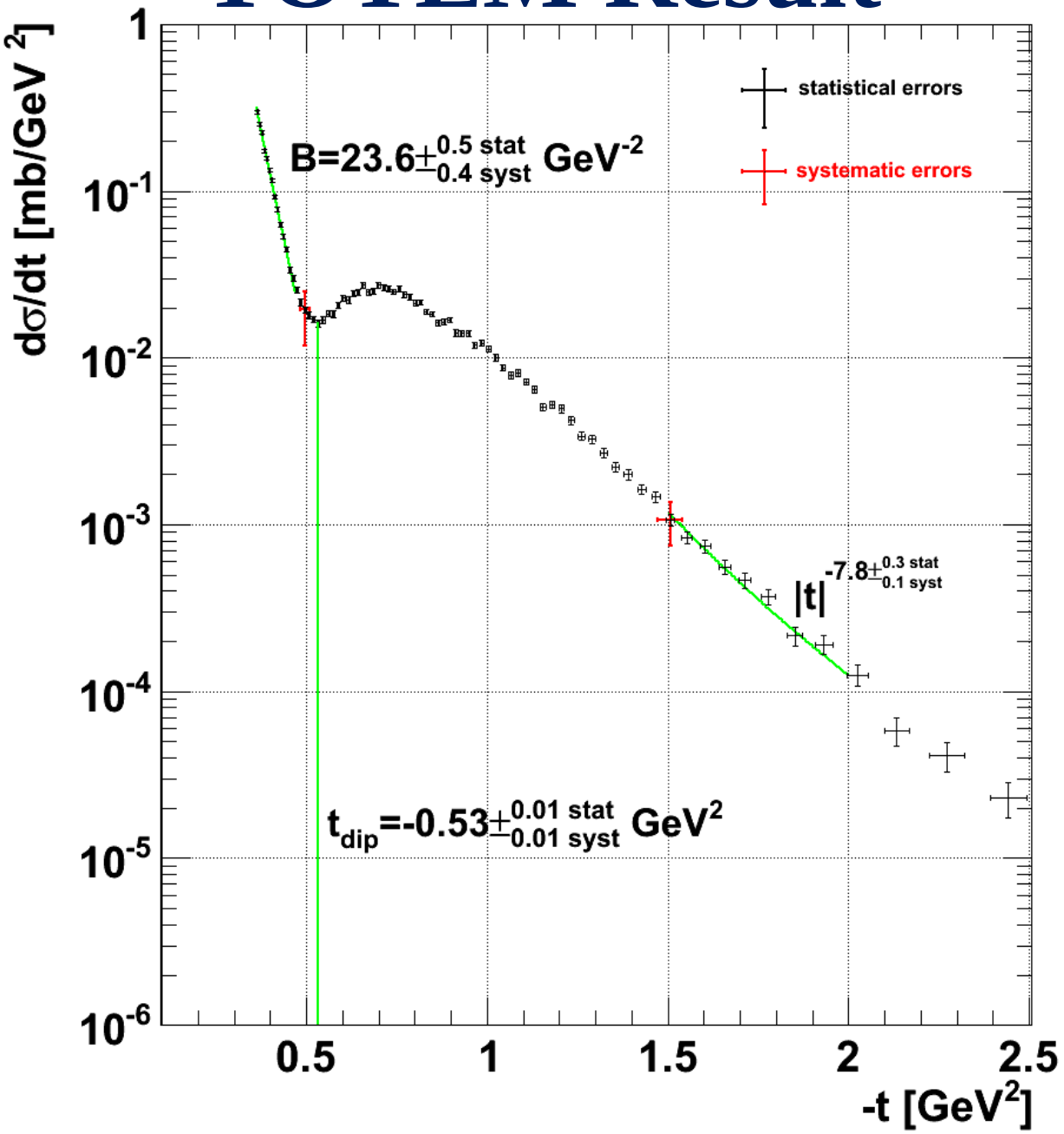


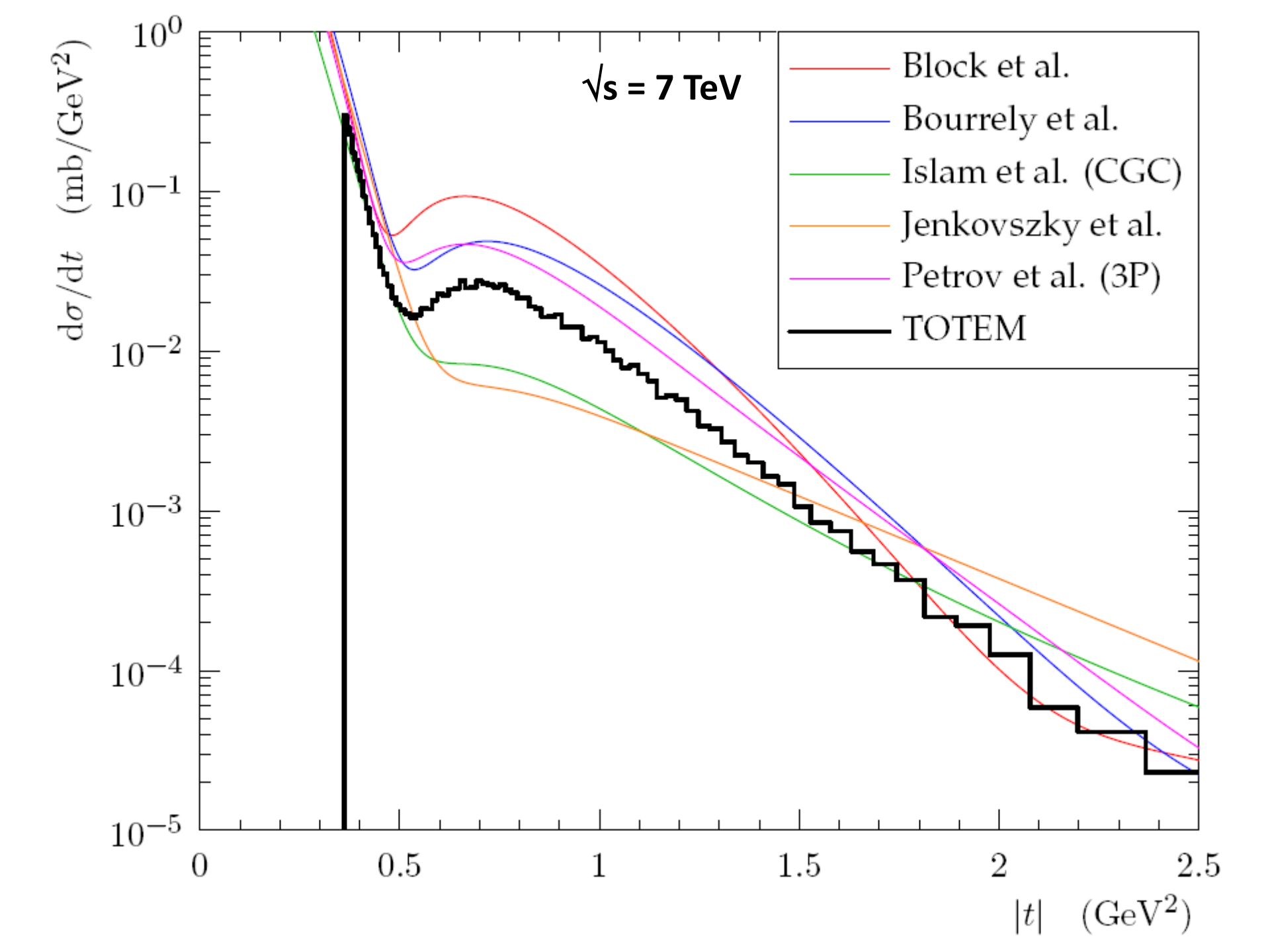
Diffractive minimum: analogous to Fraunhofer diffraction: $|t| \sim p^2 \theta^2$



- 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, $p^{-}p$
  → different mix of processes

TOTEM Result




√s = 7 TeV
Block et al.
Bourrely et al.
Islam et al. (CGC)
Jenkovszky et al.
Petrov et al. (3P)
TOTEM
dσ/dt (mb/GeV²)
|t| (GeV²)
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
0
0.5
1
1.5
2
2.5

TOTEM vs Models comparison

	B ($t=-0.4$ GeV^2) [GeV^{-2}]	t_{DIP} [GeV^2]	t^{-N} [1.5–2.0 GeV^2] [N]
Islam	19.9	0.65	5.0
Jenkovsky	20.1	0.72	4.2
Petrov	22.7	0.52	7.0
Bourrely	21.7	0.54	8.4
Block	24.4	0.48	10.4
TOTEM	23.6 ± 0.5 ± 0.4	0.53 ± 0.01 ± 0.01	7.8 ± 0.3 ± 0.1

[EPL 95 (2011) 41001]

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

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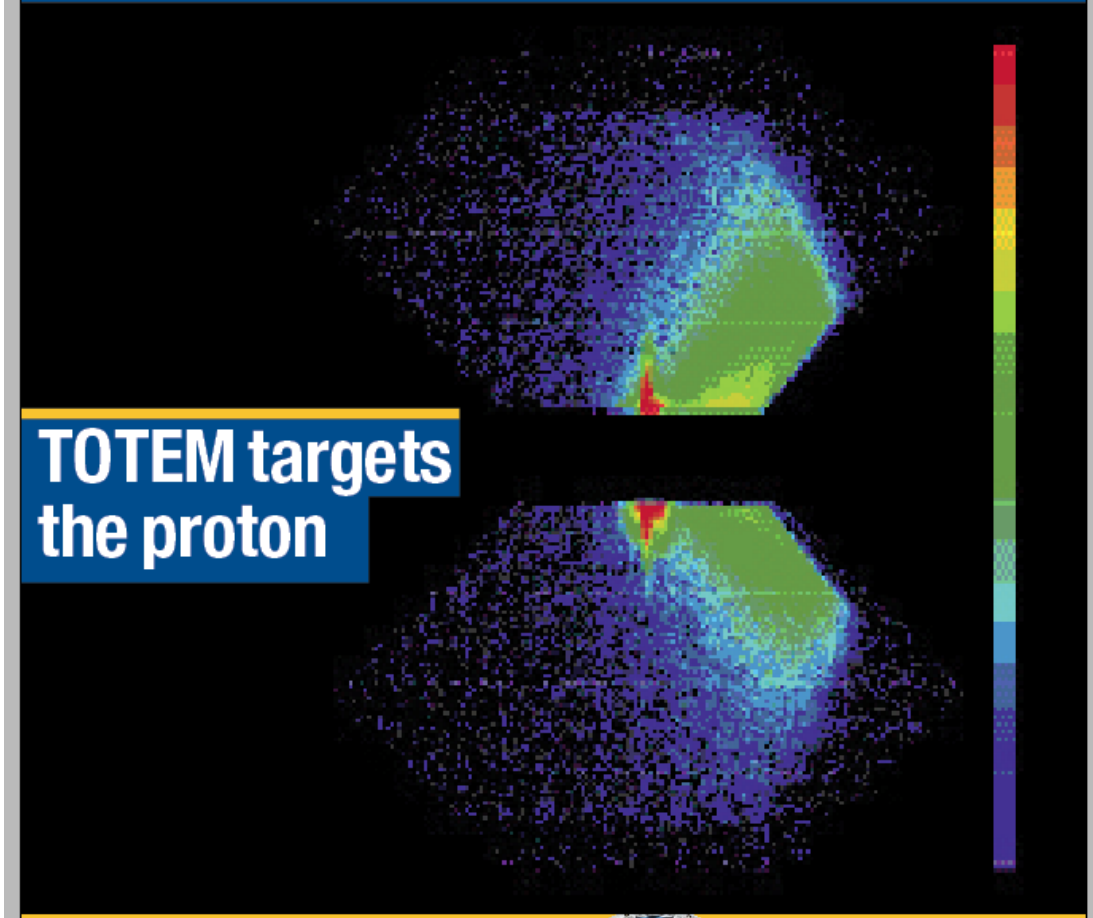


TOTEM targets the proton

EYEBROW

Strapline strapline strapline strapline strapline strapline **pXX**

EYEBROW

Strapline str strapline stra strapline stra **pXX**

HEADLINE IN CAPS

Strapline strapline strapline strapline **pXX**

TOTAL, ELASTIC, INELASTIC CROSS-SECTIONS @ $\sqrt{s} = 7$-8 TeV

Measurements and Results @ $\sqrt{s} = 7$ TeV

Cross-Section Formulae

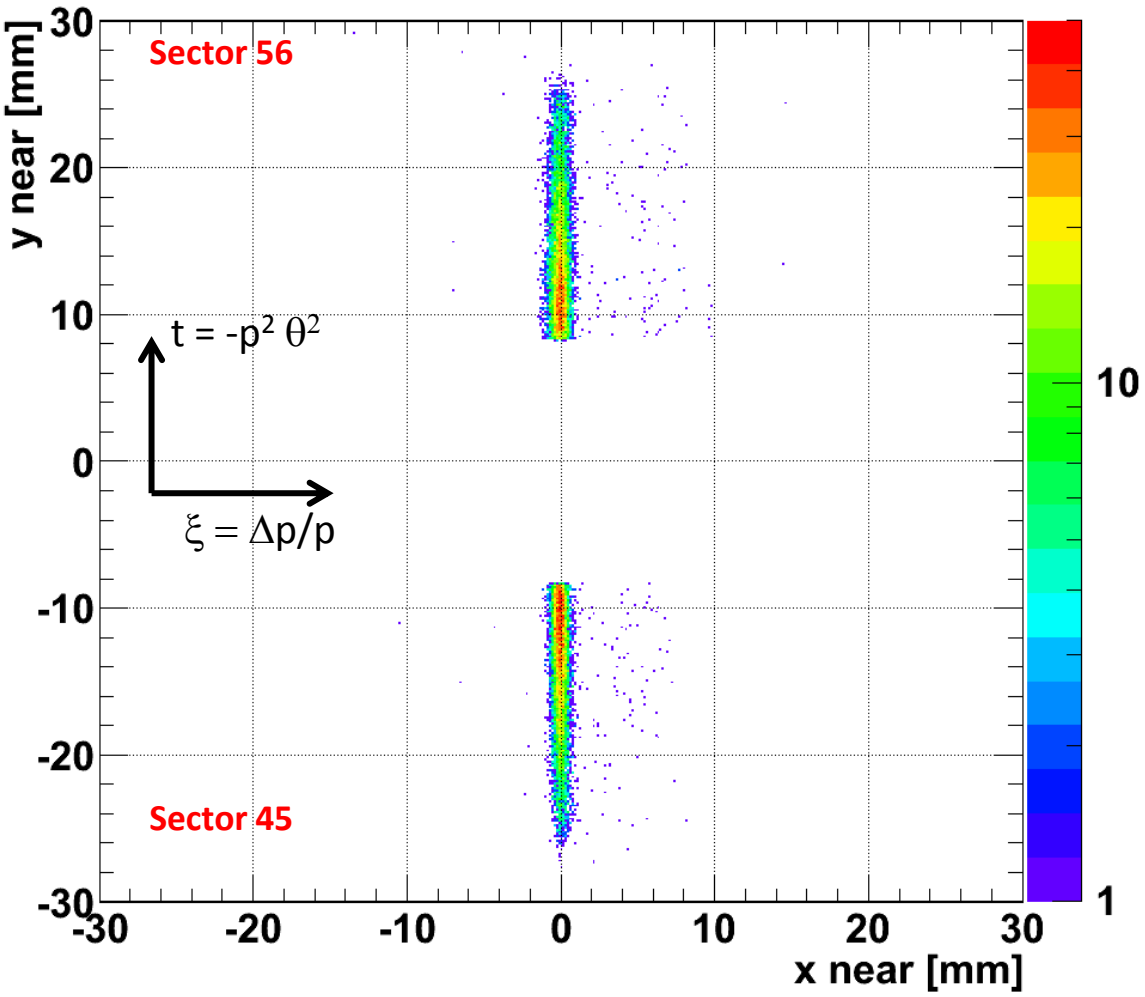
Optical Theorem: $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$

Using luminosity from CMS: $\frac{d\sigma_{EL}}{dt} = \frac{1}{L} \cdot \frac{dN_{EL}}{dt}$; and ρ from COMPETE fit: $\rho = 0.14^{+0.01}_{-0.08}$

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

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

“Raw Data” Jun’11 – Vertical RPs@10σ



β*= 90 m

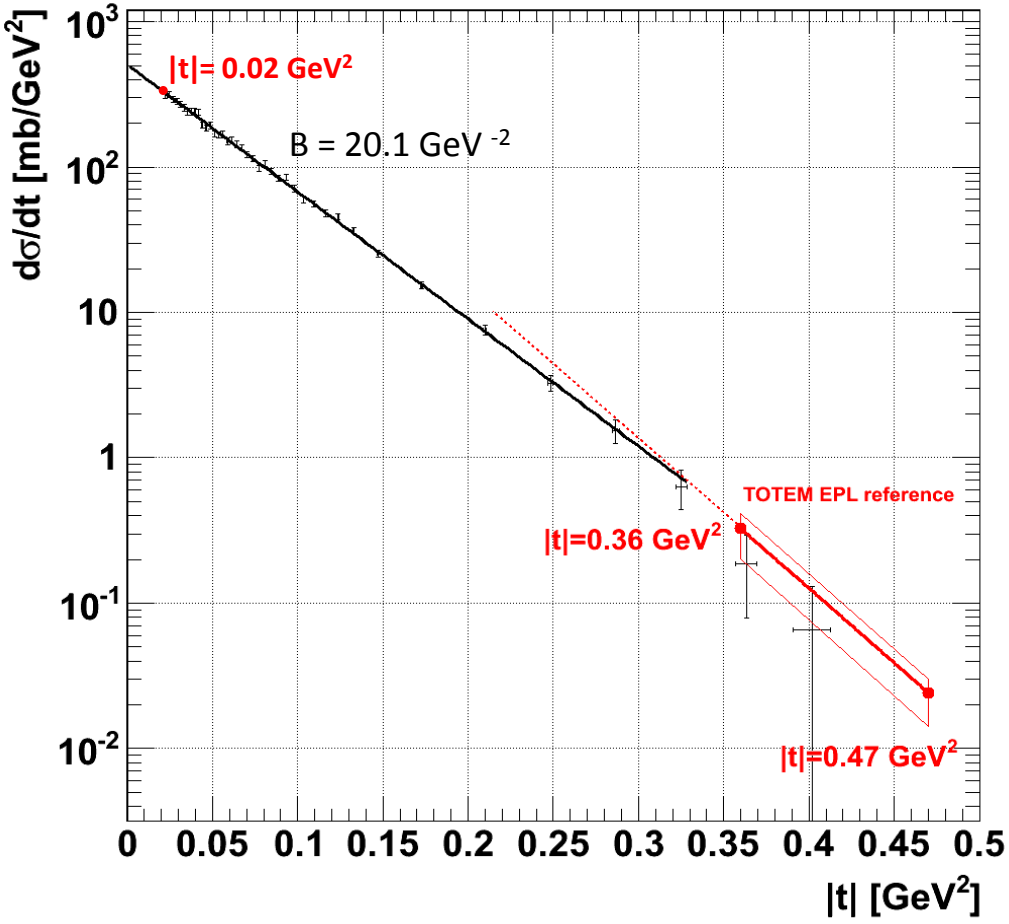
L_y ~ 260 m

L_x ~ 0-3 m

Integrated luminosity : 1.65 μbarn^{-1}

Inel. pile-up ~ 0.005 ev/bx

TOTEM: pp Elastic Cross-Section



Exponential slope:

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

Extrapolation to t = 0:

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = 5.037\times10^{2}\,\mathrm{mb}\,/\,\mathrm{GeV}^{2}$$

Integral Elastic Cross-Section

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

Systematics and Statistics

- t : $\pm$[0.6:1.8]%$^{\text{syst optics}}$ $\pm$ <1%$^{\text{align.}}$ $\pm$[3.4:11.9]%$^{\text{stat}}$ (before unfolding)
- dσ/dt : $\pm$4%$^{\text{syst lumin}}$; $\pm$1%$^{\text{syst}}$ (acc.+eff.+backg.+tag) $\pm$0.7%$^{\text{syst unfold.}}$
- B : $\pm$1%$^{\text{stat}}$ $\pm$1%$^{\text{syst from t}}$ $\pm$0.7%$^{\text{syst from unfolding}}$
- dσ/dt(t=0) : $\pm$ 0.3%$^{\text{stat}}$ $\pm$0.3%$^{\text{syst (optics)}}$ $\pm$4%$^{\text{syst lumin}}$ $\pm$1%$^{\text{syst}}$ (acc.+eff.+backg.+tag)
- $\int$ dσ/dt : $\pm$4%$^{\text{syst lumin}}$ $\pm$1%$^{\text{syst}}$ (acc.+eff.+backg.+tag) $\pm$0.8%$^{\text{stat extrap.}}$

- σTOT : (+0.8% -0.2%)$^{\text{syst }\rho}$ $\pm$ 0.2%$^{\text{stat}}$ $\pm$2.7%$^{\text{syst}}$ = (+2.8%-2.7%)$^{\text{syst}}$ $\pm$ 0.2%$^{\text{stat}}$
- σEL : $\pm$5%$^{\text{syst}}$ $\pm$0.8%$^{\text{stat}}$
- σINEL : (+2.4%-1.8%)$^{\text{syst}}$ $\pm$ 0.8%$^{\text{stat}}$

TOTEM: pp Total Cross-Section

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

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

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

Total Cross-Section

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

TOTEM: pp Inelastic Cross-Section

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

Inelastic Cross-Section

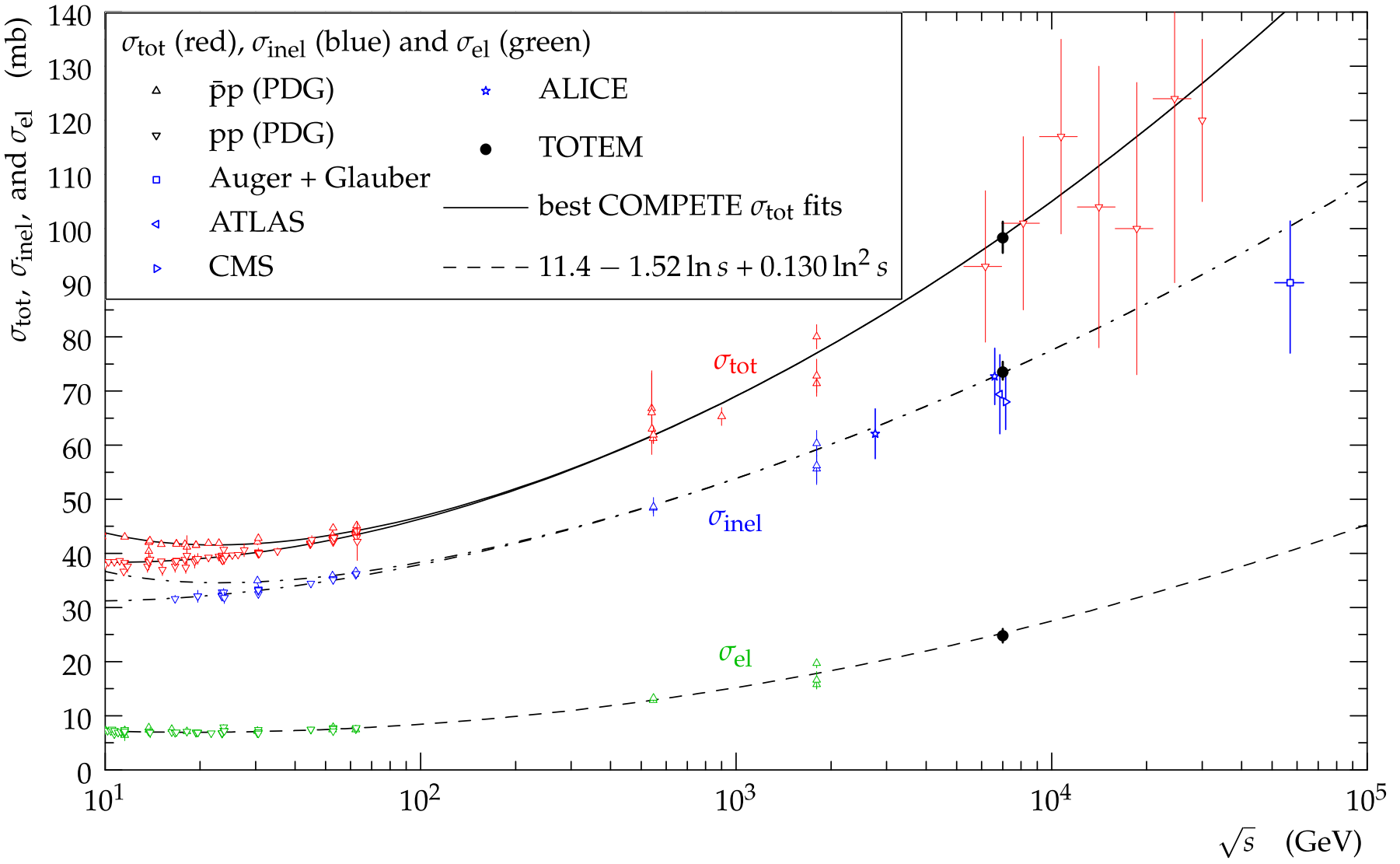
$$\sigma_{inel} = \sigma_{tot} - \sigma_{el} = \left(73.5 \pm 0.6^{(stat)} \begin{bmatrix} +1.8 \\ -1.3 \end{bmatrix} (syst)\right) \text{ mb}$$

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

Total, Elastic, Inelastic Cross-Section



A Letters Journal Exploring
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OFFPRINT

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.*)

EPL, **96** (2011) 21002

Luminosity-independent and ρ-independent pp Total Cross-Sections @ 7 TeV

pp Cross-Sections @LHC: 4 Methods
(& Luminosity calibration)

1. Low_L(CMS) + Elastic + Optical T.
   - depends on CMS luminosity for low-L bunches & elastic efficiencies & ρ

2. High_L(CMS) + Elastic + Optical T.
   - checks the CMS luminosity for high-L vs low-L bunches

3. High_L(CMS) + Elastic + Inelastic
   - minimizes dependence on elastic efficiencies and no dependence on ρ

4. (L-independent) + Elastic + Inelastic + Optical T.
   - eliminates dependence on luminosity

1. Low_L(CMS) + Elastic + Optical T.

June'11 data : RP 10σ ; L: bunches $1\text{-}2\cdot10^{10}$ p

- $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2}\cdot\left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$
- **σ_{TOT} = 98.3 mb ± [2.0(lum) 0.5(syst) $^{0.8}_{0.15}(\rho)$] mb**
- $\sigma_{EL} = \int d\sigma_{EL}/dt = 24.8$ mb
- $\sigma_{INEL} = \sigma_{TOT} - \sigma_{EL} = 73.5$ mb

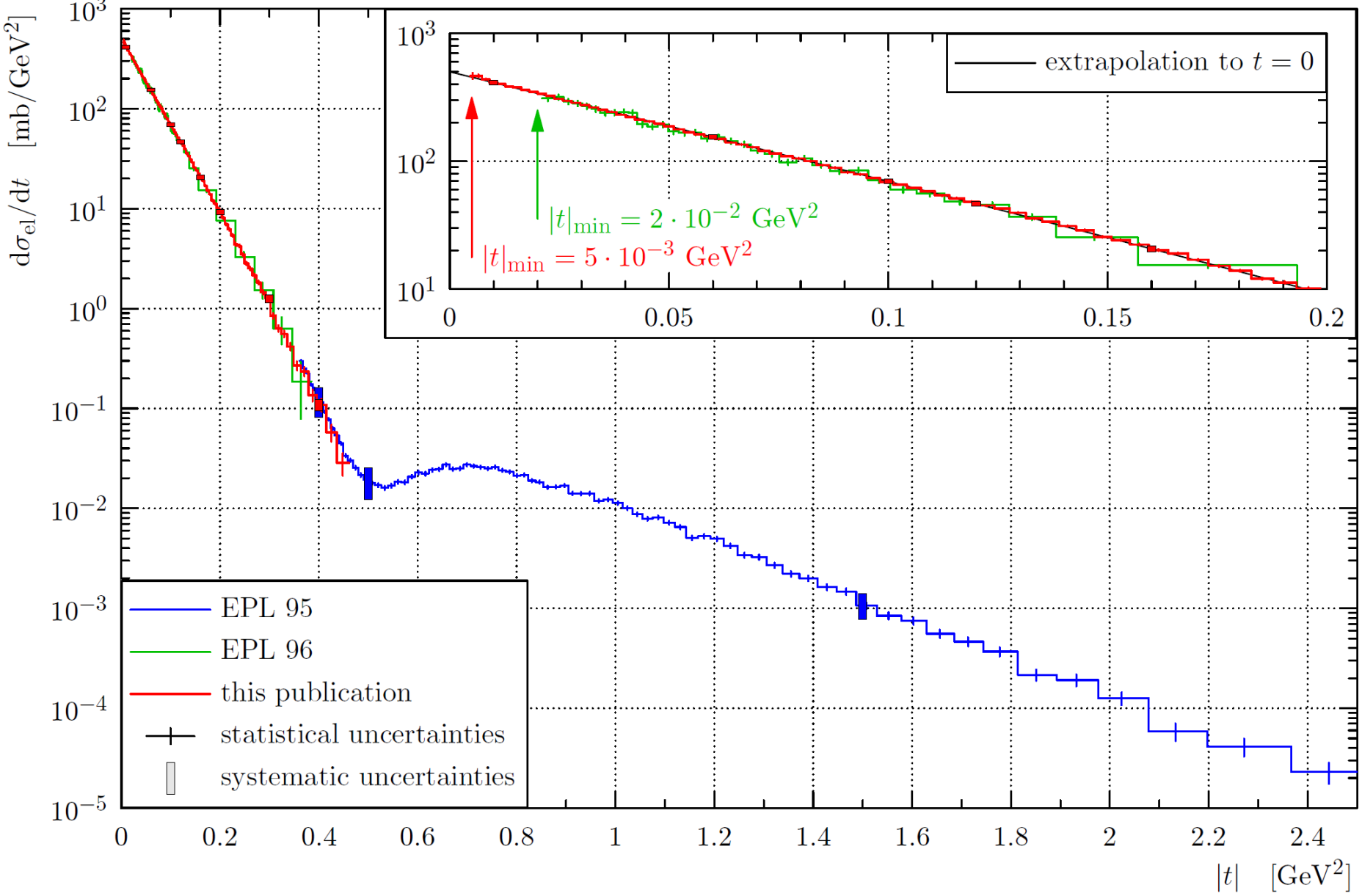
EPL, 96 (2011) 21002

2. High_L(CMS) + Elastic + Optical T.

October'11 data : RP 6.5/5.5/4.8σ ; L: bunches $7 \cdot 10^{10}$ p

- $$\sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$$
- **σ_{TOT} = 98.6 mb ± [2.0(lum) 1.0(syst) $^{0.8}_{0.15}$(ρ)] mb**
- $\sigma_{EL} = \int d\sigma_{EL}/dt = 25.4 \pm 1.1$ mb
- $\sigma_{INEL} = \sigma_{TOT} - \sigma_{EL} = 73.2 \pm 1.3$ mb

2. October'11 data : RP 6.5/5.5/4.8s ; L: bunches $7 \cdot 10^{10}$ p



$|t_{min}| \approx 5 \cdot 10^{-3}$ GeV2 → 91% of cross-section measured (9% extrapolated) ; B = 19.9 ± 0.3 GeV^{-2}

2.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

TOTEM 2012-002
14 August 2012

CERN-PH-EP-2012-239
17 August 2012

Measurement of proton-proton elastic scattering and total cross-section at $\sqrt{s} = 7$ TeV

The TOTEM Collaboration

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3. High_L(CMS) + Elastic + Inelastic

October'11 data : RP 6.5/5.5/4.8σ ; L: bunches $7 \cdot 10^{10}$ p

- $\sigma_{EL} = \int d\sigma_{EL}/dt = 25.4 \pm 1.1$ mb
- $\sigma_{INEL} = L^{-1} \cdot N_{INEL} = 73.7 \pm 3.4$ mb
- $\sigma_{TOT} = \sigma_{EL} + \sigma_{INEL}$

ρ - independent

- **σ_{TOT} = 99.1 mb ± [3.9(lum) 2.0(syst)] mb**

LHCC Report – Mar '12
[preprint upcoming]

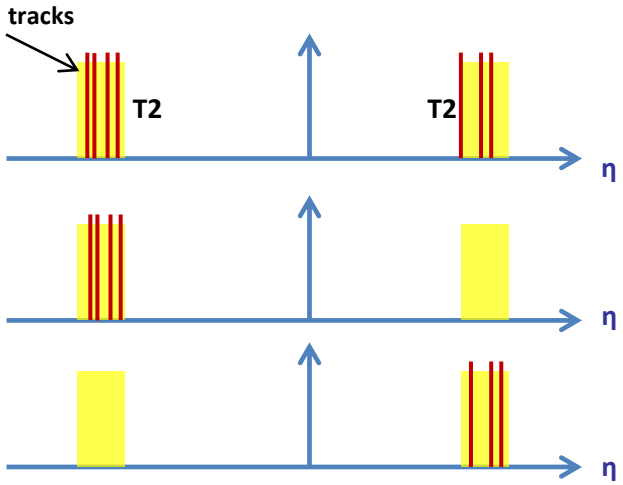
3. Inelastic Cross Section

direct T1 and T2 measurement

Inelastic events in T2: classification

- **tracks in both hemispheres**
  non-diffractive minimum bias
  double diffraction

- **tracks in a single hemisphere**
  mainly single diffraction
  $M_X > 3.4\ GeV/c^2$



Corrections to the T2 visible events

- Trigger Efficiency: **2.3 %**
  (measured from zero bias data with respect to track multiplicity)
- Track reconstruction efficiency: **1 %**
  (based on MC tuned with data)
- Beam-gas background: **0.54 %**
  (measured with non colliding bunch data)
- Pile-up (μ =0.03): **1.5 %**
  (contribution measured from zero bias data)

$$\sigma_{\text{inelastic, T2 visible}} = 69.7 \pm 0.1^{\text{stat}} \pm 0.7^{\text{syst}} \pm 2.8^{\text{lumi}}\ \text{mb}$$

3. Inelastic Cross Section

$\sigma_{\text{inelastic, T2 visible}} \Rightarrow \sigma_{\text{inelastic}}$

Missing inelastic cross-section

- Events visible in T1 but not in T2: **2.0 %**
  (estimated from zero bias data)
- Rapidity gap in T2 : **0.57 %**
  (estimated from T1 gap probability transferred to T2)
- Central Diffraction: T1 & T2 empty : **0.54 %**
  (based on MC, correction max ~0.25×σ_{CD} , quoted in systematic error)
- Low Mass Diffraction : **3.7 % ± 2 % syst**
  *(Several models studied, correction based on **QGSJET-II-4**,*
  imposing observed 2hemisphere/1hemisphere event ratio and the effect of 'secondaries')
  - constrained by the Total cross-section measurement :
    upper limit = 6.3 mb at 95% C.L. for $\eta \geq 6.5$, i.e. $M_{SD} \leq 3.4$ GeV
  - will be measured with a single proton trigger, large β^* optics and clean beam conds.

$$\sigma_{\text{inelastic}} = 73.7 \pm 0.1^{\text{stat}} \pm 1.7^{\text{syst}} \pm 2.9^{\text{lumi}} \text{ mb}$$

4. Elastic + Inelastic + Optical T.

October'11 data : RP 6.5/5.5/4.8σ ; L: bunches $7 \cdot 10^{10}$ p

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

Luminosity - independent

- **σ_{TOT} = 98.0 mb ± [2.4(syst) $^{1.6}_{0.3}$(ρ)] mb**

- σ_{EL} = 25.1 ± 1.1 mb
- σ_{INEL} = 72.9 ± 1.5 mb

LHCC Report – Mar '12

[preprint upcoming]

pp Total Cross-Sections @ √s=7TeV

Published EPL96

1. $\sigma_{TOT} = 98.3\ \text{mb} \pm {}^{2.2}_{2.0}\ \text{mb}$ $\qquad \sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$

PH-EP-2012-239

2. $\sigma_{TOT} = 98.6\ \text{mb} \pm {}^{2.4}_{2.2}\ \text{mb}$ $\qquad \sigma_{TOT}^2 = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \left.\frac{d\sigma_{EL}}{dt}\right|_{t=0}$

LHCC Mar '12 *ρ - independent*

3. $\sigma_{TOT} = 99.1\ \text{mb} \pm 4.4\ \text{mb}$ $\qquad \sigma_{TOT} = \sigma_{EL} + \sigma_{INEL}$

LHCC Mar '12 *L - independent*

4. $\sigma_{TOT} = 98.0\ \text{mb} \pm {}^{2.9}_{2.4}\ \text{mb}$ $\qquad \sigma_{TOT} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \frac{\left.\frac{dN_{EL}}{dt}\right|_{t=0}}{N_{EL} + N_{INEL}}$

Measurements and Results @ $\sqrt{s} = 8$ TeV

Luminosity-independent pp Cross-Sections @ $\sqrt{s} = 8$ TeV

July 2012 $\sqrt{s} = 8$ TeV $\beta^* = 90$m

Two data samples triggered by TOTEM RPs pp coincidences

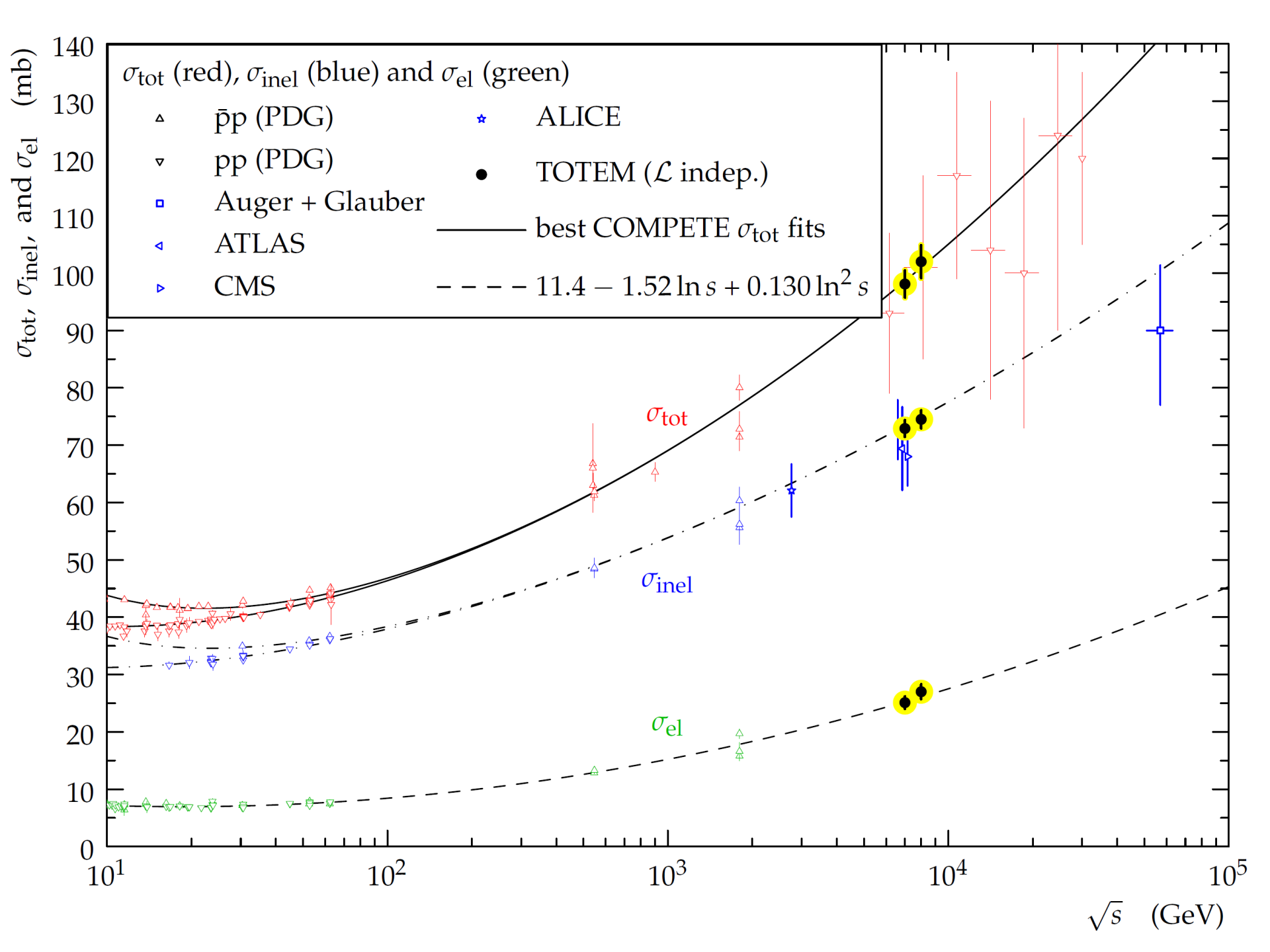
Luminosity-independent Elastic, Inelastic, Total Cross-Sections:

DS	σ_{tot} (mb)	σ_{el} (mb)	σ_{inel} (mb)
2	102 ± 2.8	27.1 ± 1.3	74.9 ± 1.6
3	101 ± 2.8	26.9 ± 1.3	74.2 ± 1.6

Key roles of Prague's group in the analysis

Internal refereeing completed – **1st public release of results**

Editorial Process started [***preprint upcoming***]


σ_{tot} (red), σ_{inel} (blue) and σ_{el} (green)
$\bar{p}p$ (PDG)
pp (PDG)
Auger + Glauber
ATLAS
CMS
ALICE
TOTEM ($\mathcal{L}$ indep.)
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
σ_{tot}
σ_{inel}
σ_{el}
σ_{tot}, σ_{inel}, and σ_{el} (mb)
$\sqrt{s}$ (GeV)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
10^1
10^2
10^3
10^4
10^5

PERSPECTIVES ON FORWARD AND DIFFRACTIVE PHYSICS

pp Interactions

Non-diffractive

Colour exchange

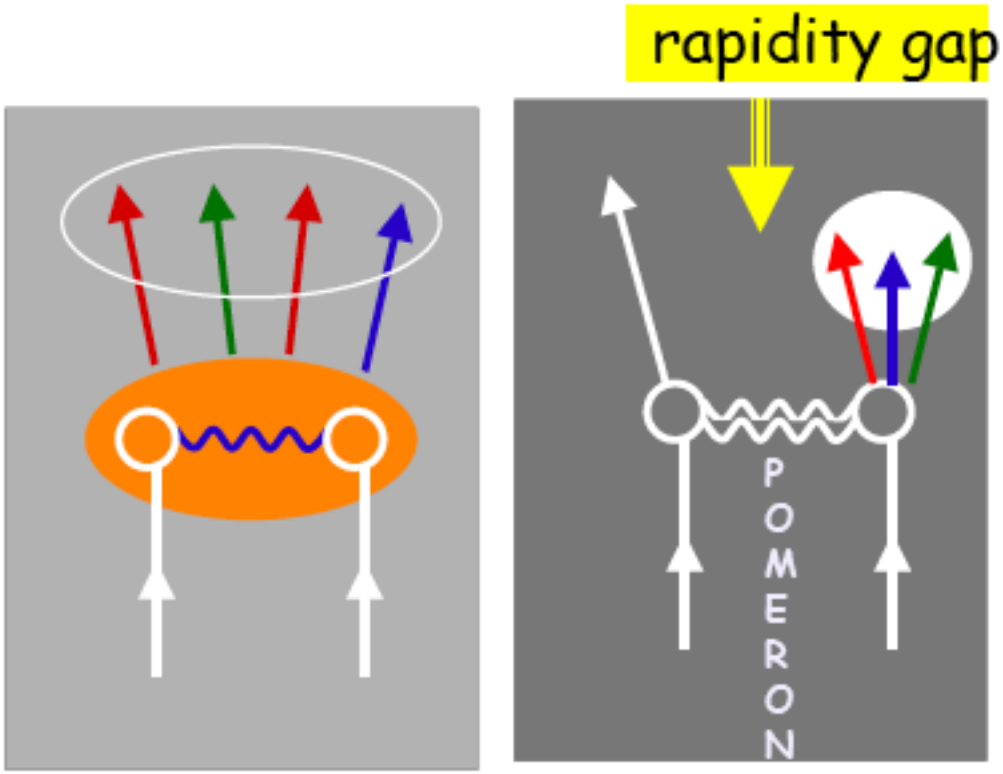
$dN / d\Delta\eta = \exp(-\Delta\eta)$

Diffractive

Colourless exchange with vacuum quantum numbers

$dN / d\Delta\eta = \text{const}$

Incident hadrons acquire colour and break apart

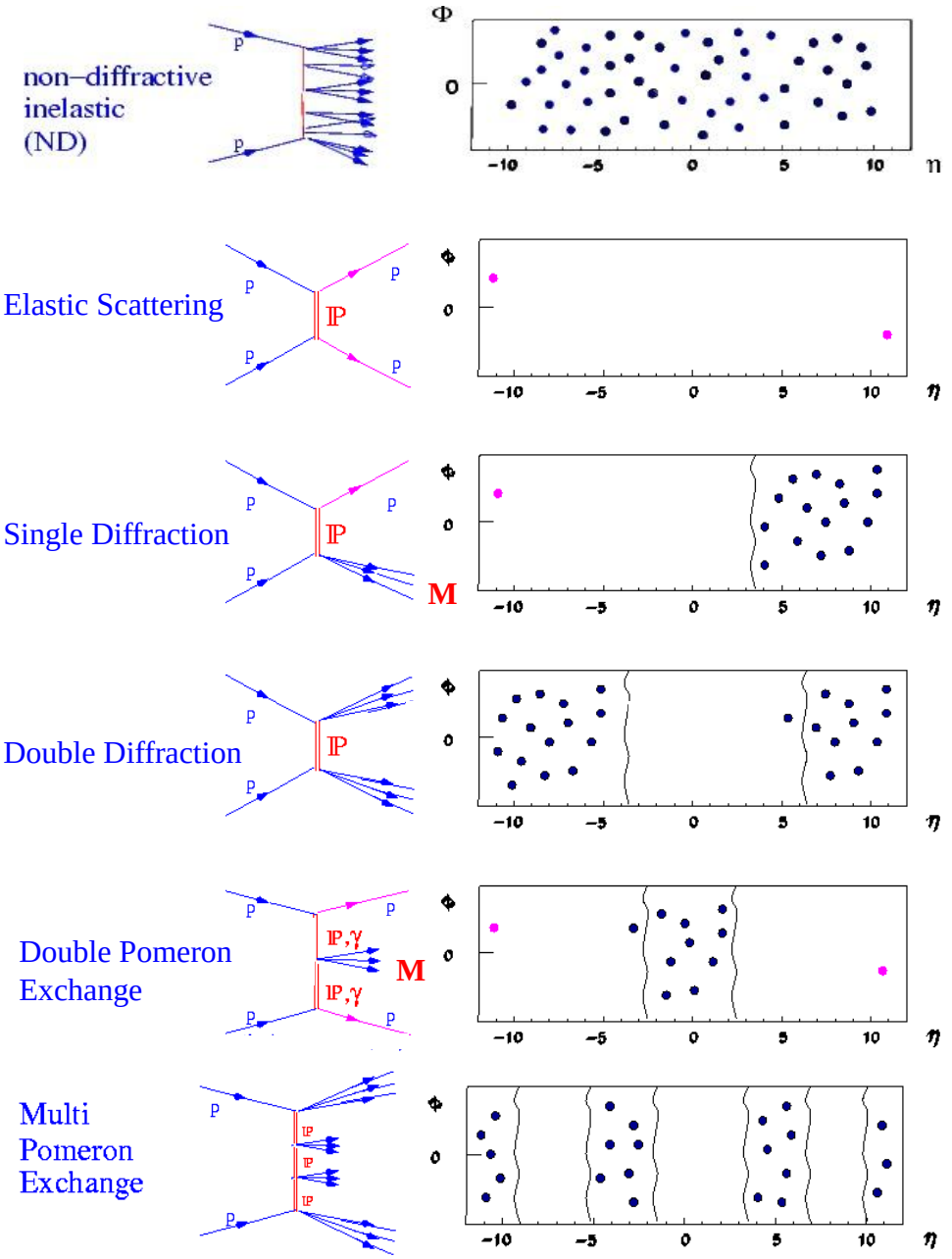


Incident hadrons retain their quantum numbers remaining colourless

GOAL: understand the QCD nature of the diffractive exchange

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

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



~60 mb

~25 mb

~10 mb

~5 mb

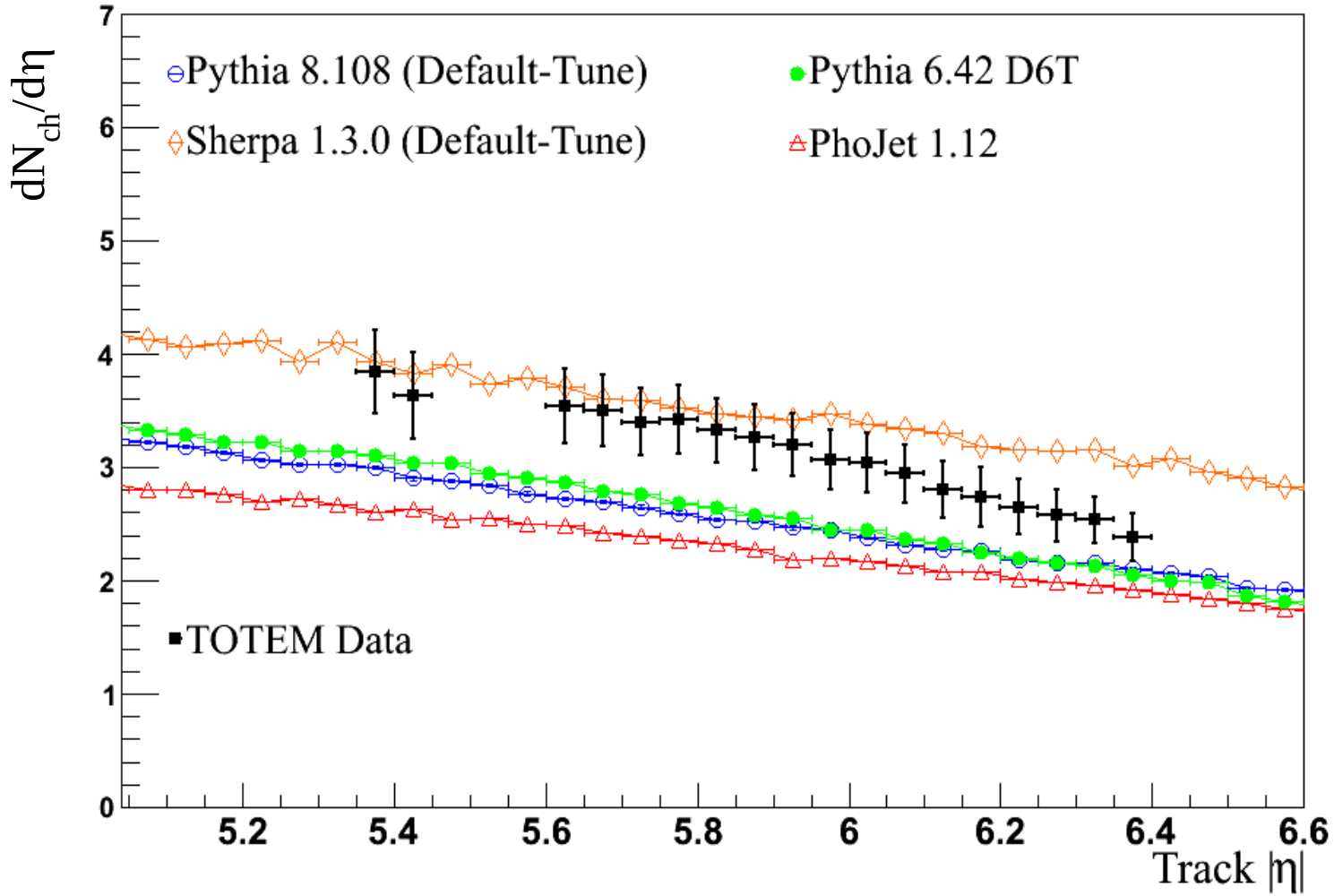
~1 mb

<< 1 mb

Measure σ (M,ξ,t)

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

$dN_{ch}/d\eta$ measured in T2 : results



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Measurement of the forward charged-particle pseudorapidity density in pp collisions at $\sqrt{s} = 7$ TeV with the TOTEM experiment

The TOTEM Collaboration

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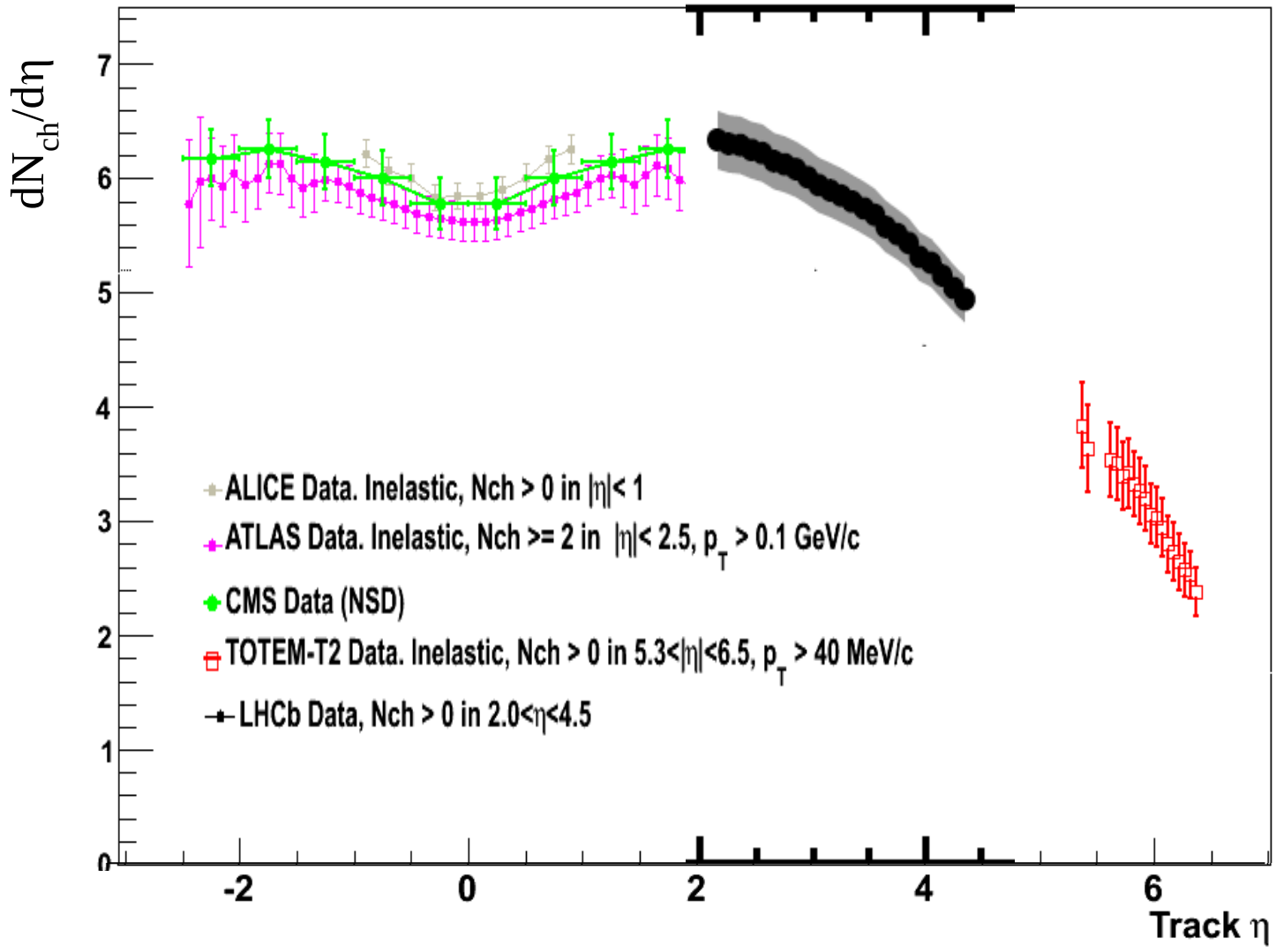
$dN_{ch}/d\eta$ combined with other LHC exp.



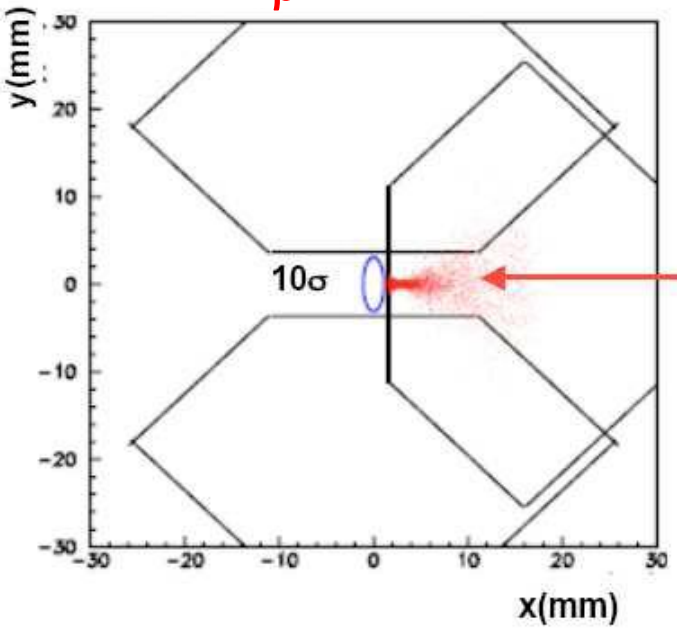
Diffractive forward protons @ RPs

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

Dispersion shifts diffractive protons in the horizontal direction

Diffractive protons : hit distribution @ RP220

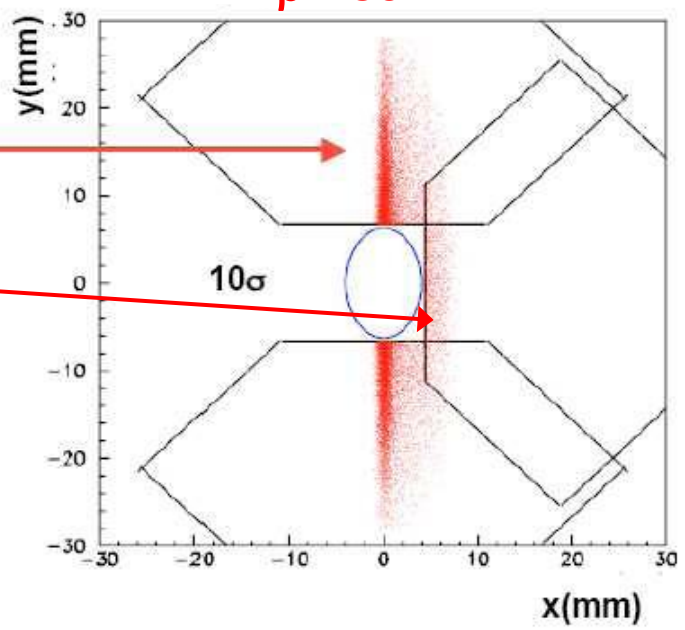
Low β^*: 0.5 – 2 m



$y \sim \Theta_y^{scatt} \sim |t_y|^{1/2}$

$x \sim \xi = \Delta p/p$

β^*= 90 m

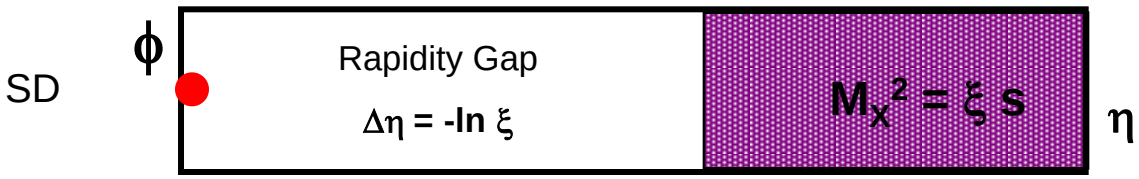


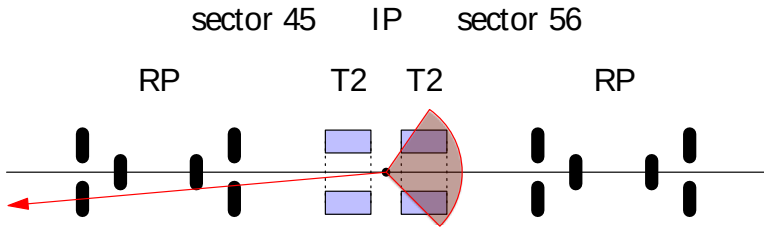
- For low-β^* optics L_x, L_y are low
- v_x, v_y are not critical because of small IP beam size

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

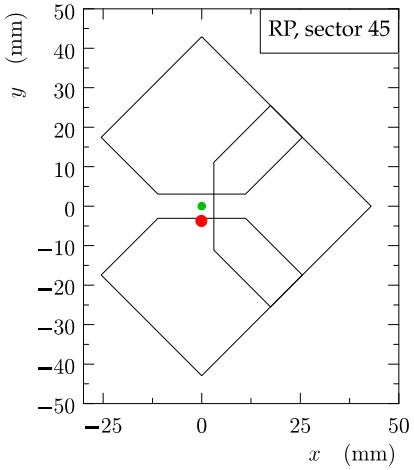
Single diffraction low ξ

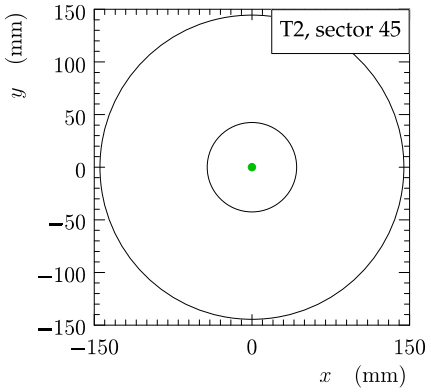
Correlation between leading proton and forward detector T2

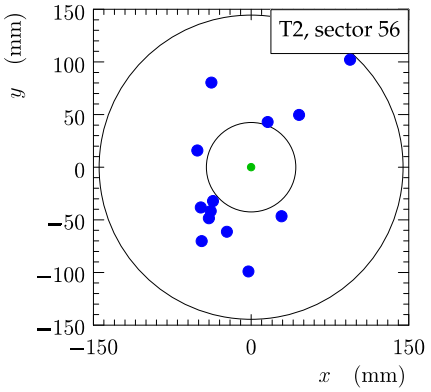


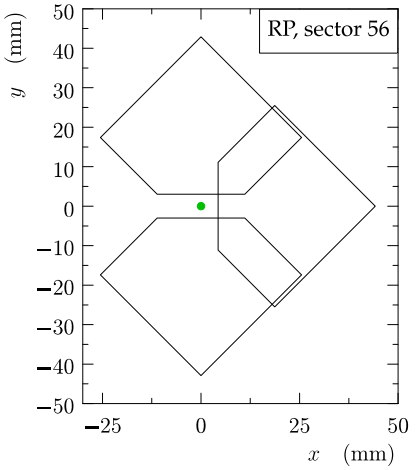


run: 37280003, event: 3000



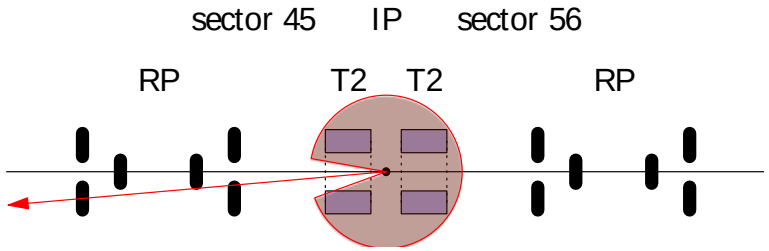




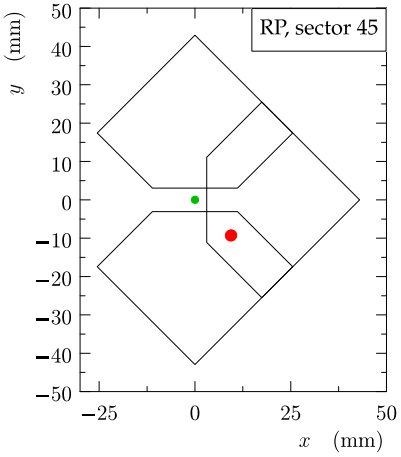


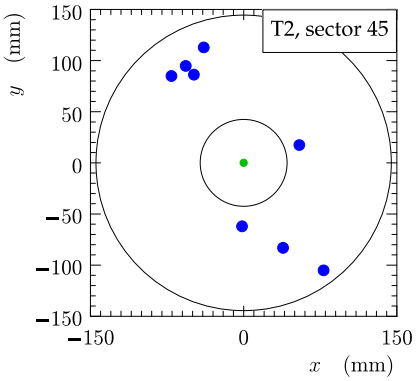
Single diffraction large ξ

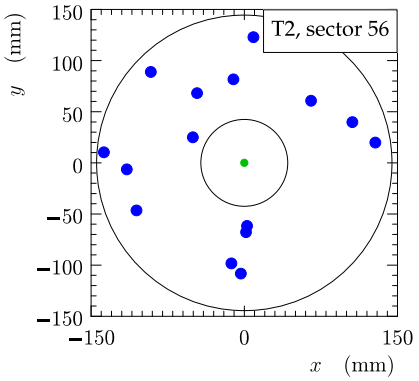
correlation between leading proton and forward detector T2

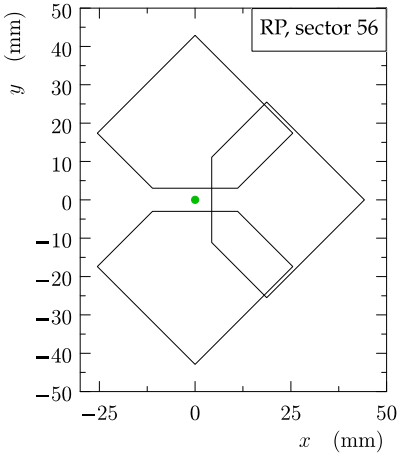


run: 37280006, event: 9522

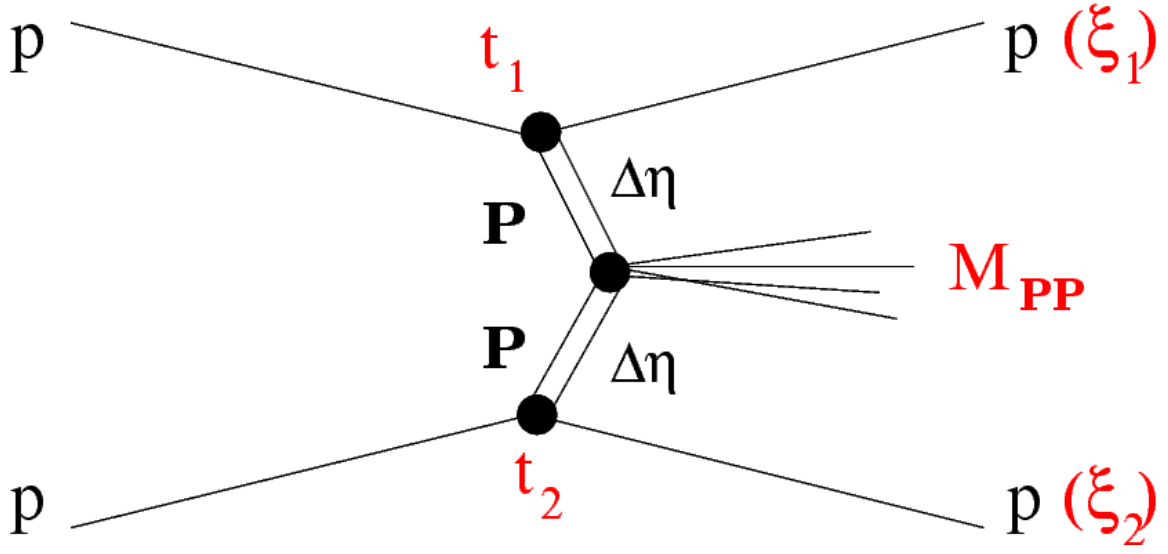


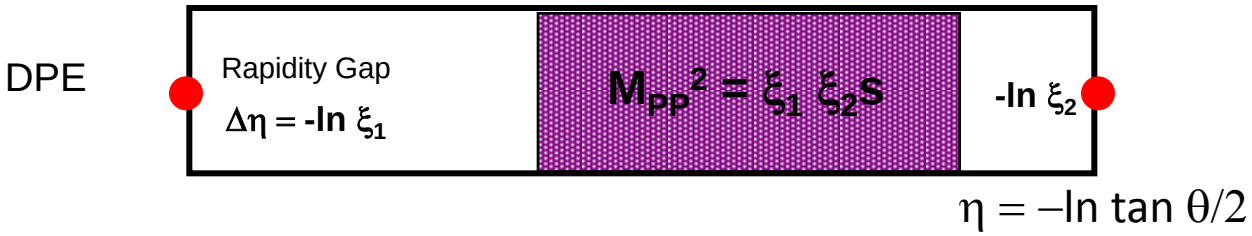






Double Pomeron Exchange (DPE)

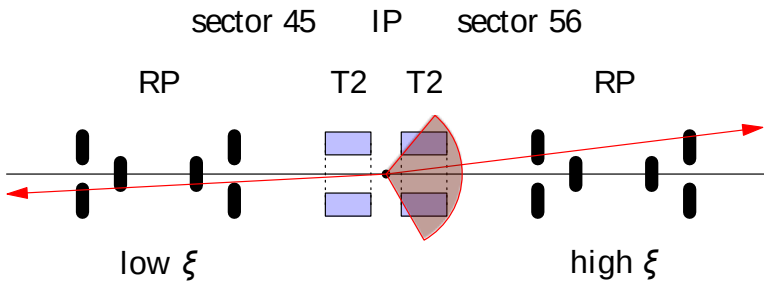




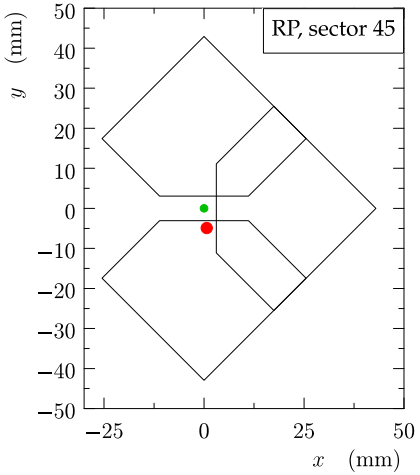
Use the LHC as a Pomeron-Pomeron (Gluon - Gluon) Collider

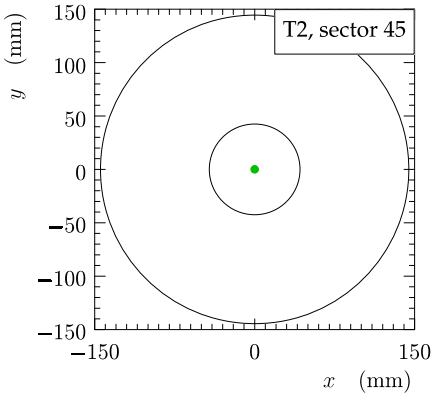
Double Pomeron Exchange (DPE)

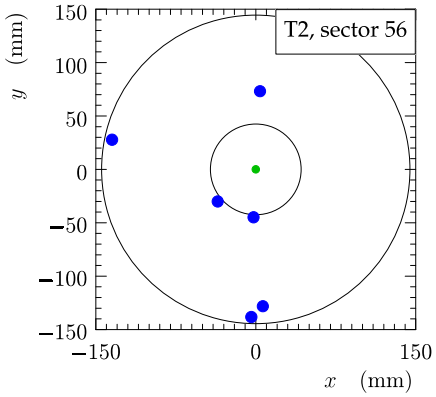
correlation between leading protons and forward detector T2

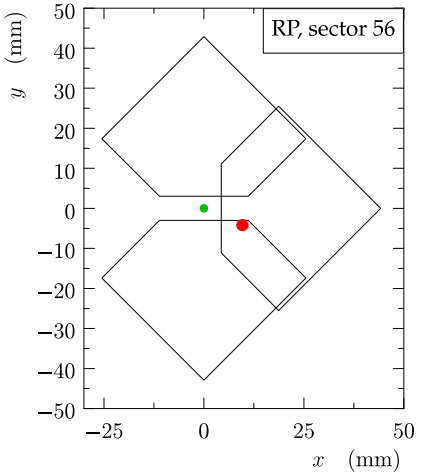


run: 37220007, event: 9904

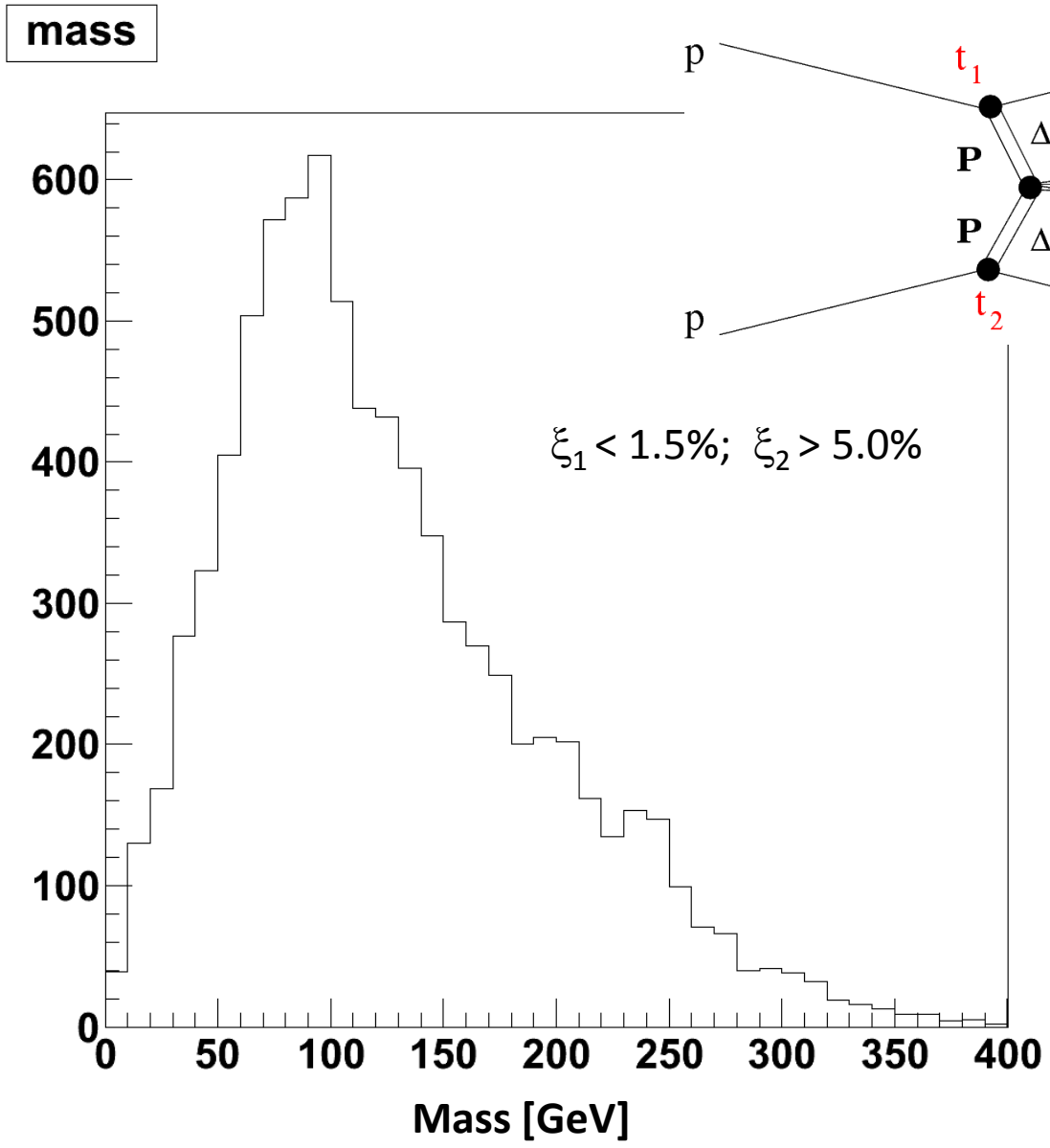


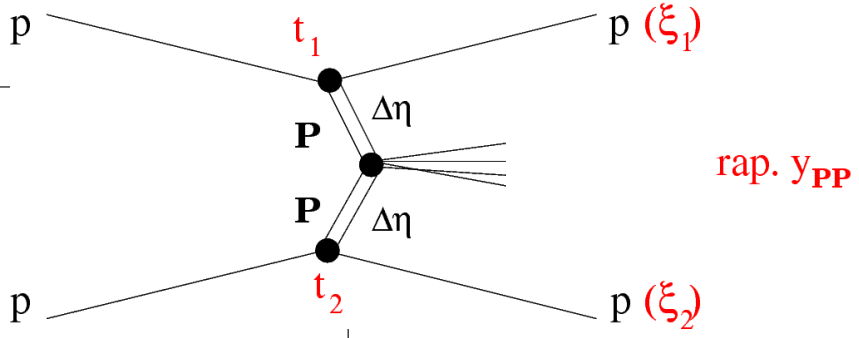






DPE Mass Reconstruction "proof of concept"





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

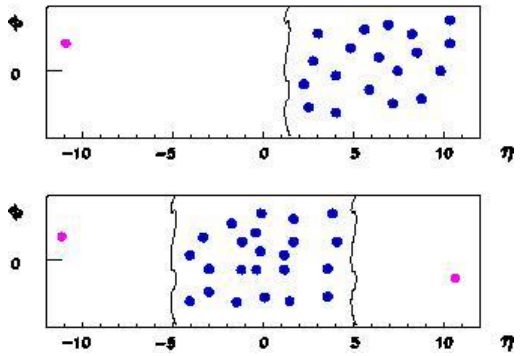
Low-β

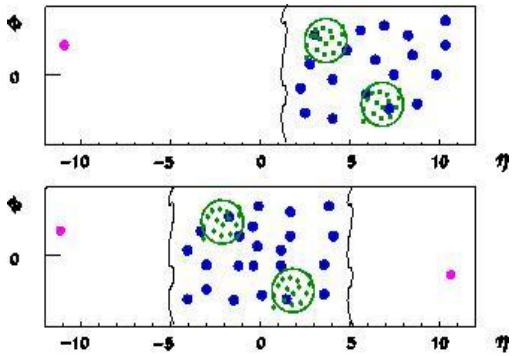
RP vertical

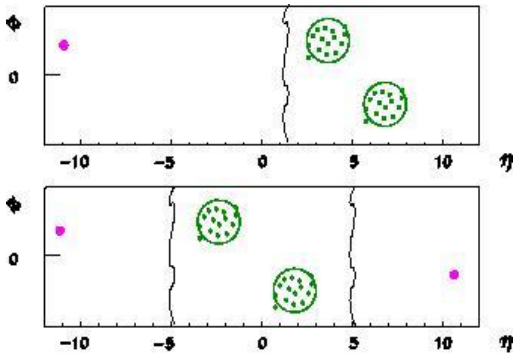
RP horizontal

T2

TOTEM + CMS running scenarios







pp->pX
pp->pXp

soft diffraction

pp->pjjX
pp->pjjXp

(semi)-hard diffraction

pp->pjj (bosons, heavy
pp->pjjp quarks,Higgs...)

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	

DPE Dijets Mass Reconstruction "proof of concept"