TOTEM elastic scattering etc.

Low-x meeting

YUKAWA INSTITUTE, KYOTO, JAPAN
June 17-21 2014

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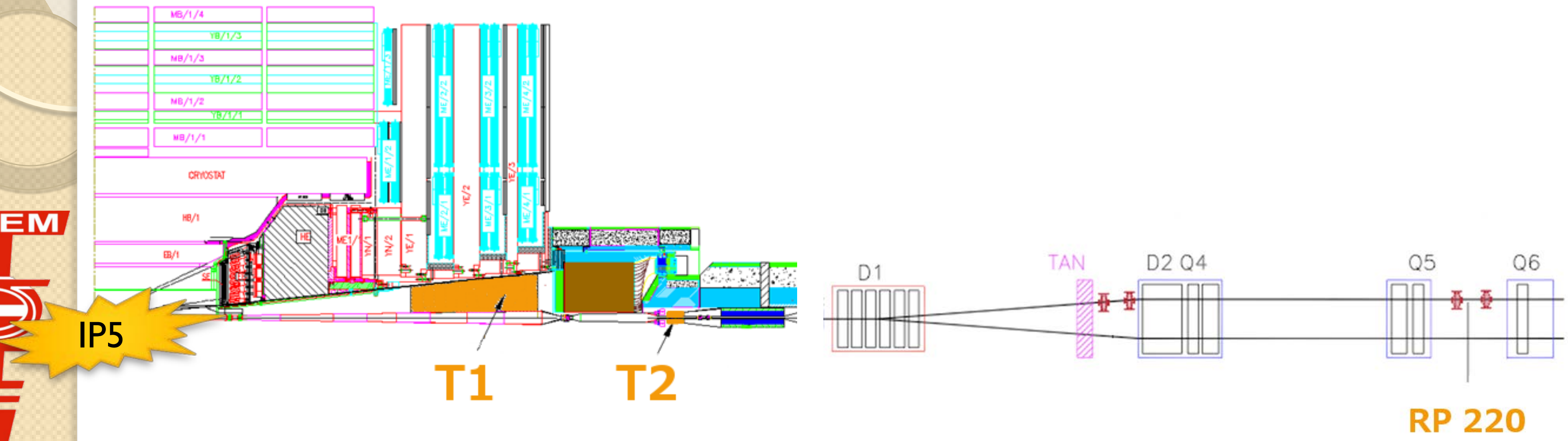
on behalf of the TOTEM Collaboration

Overview

- TOTEM detectors
- Elastic scattering at 7 and 8 TeV
- Coulomb-Nuclear Interference
- ρ determination
- $dN_{ch}/d\eta$ (TOTEM only)
- Outlook: consolidation and upgrade

Experimental setup



Inelastic Telescopes:
charged particles in inelastic events:
→ multiplicities, rapidity gaps

→ Inelastic Trigger

Roman Pots:
elastic & diffractive protons close to outgoing beams

→ Proton Trigger

T1: $3.1 < |\eta| < 4.7$, $p_T > 100$ MeV

T2: $5.3 < |\eta| < 6.5$, $p_T > 40$ MeV

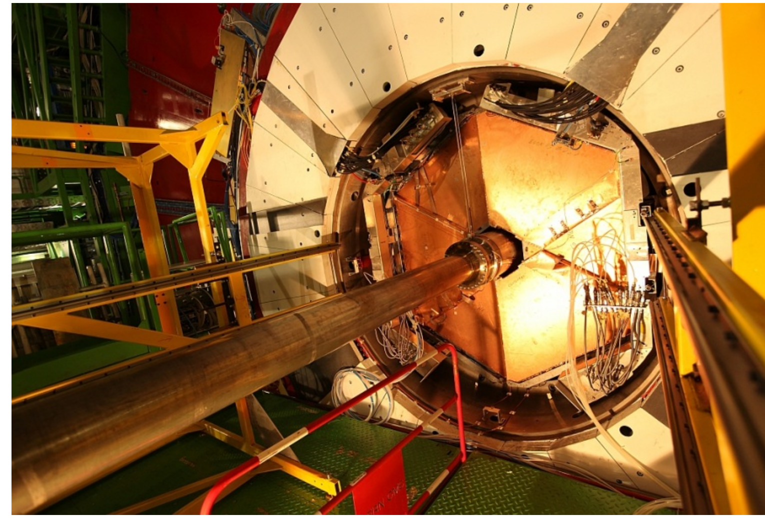
Inelastic telescopes

Inelastic event counting, charged multiplicity, rapidity gaps

TOTEM

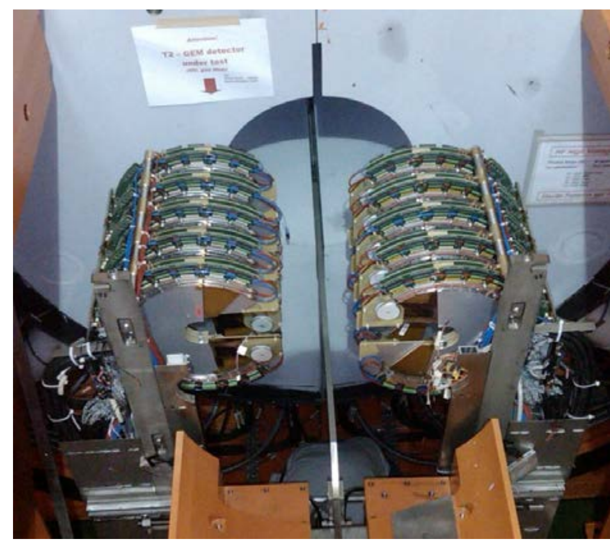
T1

- 5 planes of Cathode Strip Chambers (CSC)
- 6 chambers per plane
- $3.1<|\eta|<4.7$
- $\Delta\phi = 2\pi$



T2

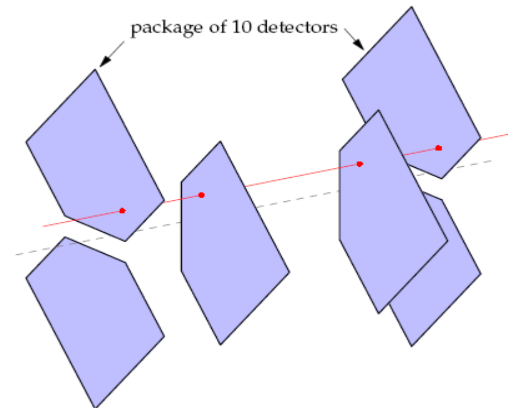
- 10 planes of Gas Electron Multipliers (GEM)
- $5.3<|\eta|<6.5$
- $\Delta\phi = 2\pi$



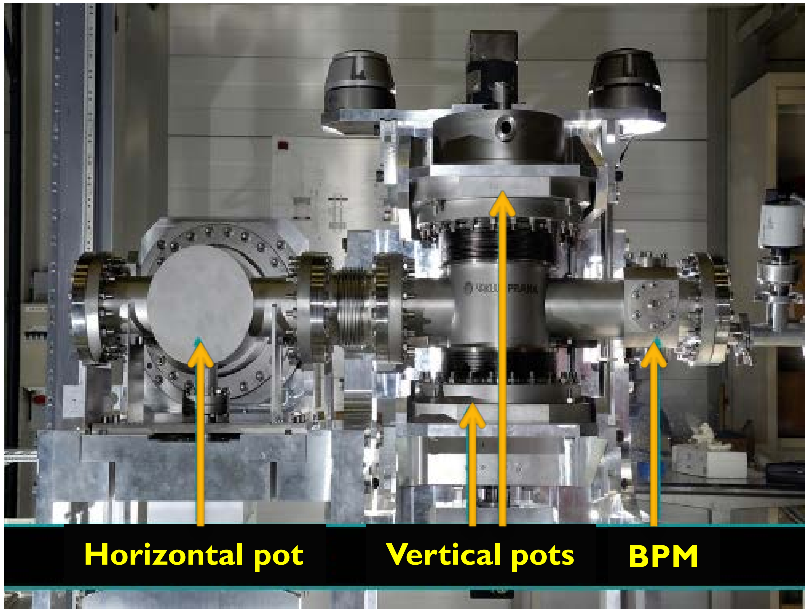
Roman Pot detectors

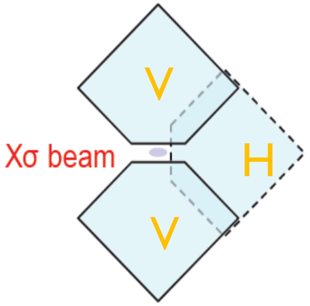
Leading proton detection

- Roman pot stations in the LHC tunnel at 147m and 220m from IP (both sides)
- 10 *edgeless* (<50μm) Si micro strip detectors per pot
- Resolution ~15μm

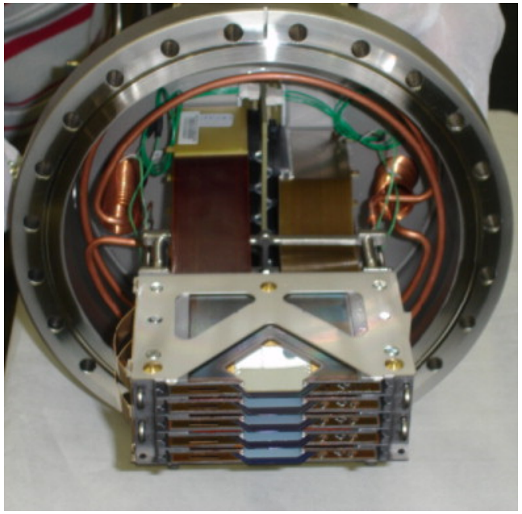


Roman pot unit

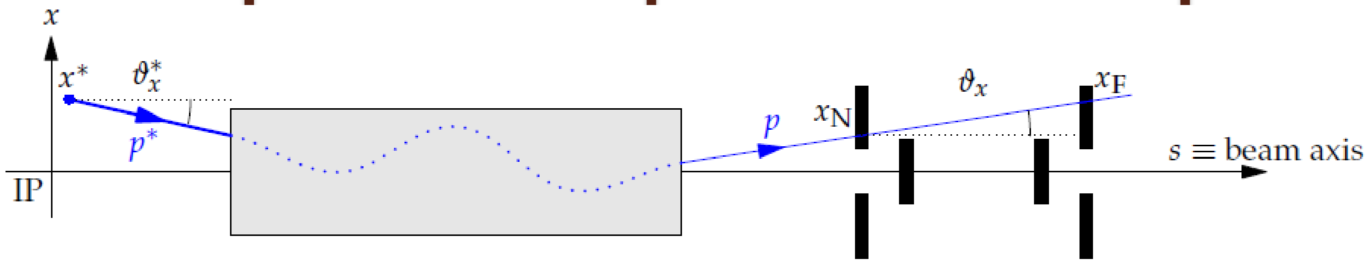




10 *edgeless* Si detectors



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 (elastic case: $\xi = 0$)

$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \Delta p/p \end{pmatrix}_{IP5}$$

measured **reconstructed**

$$y_{RP} = L_y \Theta_y^* + v_y y^*$$

$$x_{RP} = L_x \Theta_x^* + v_x x^* + D_x \xi$$

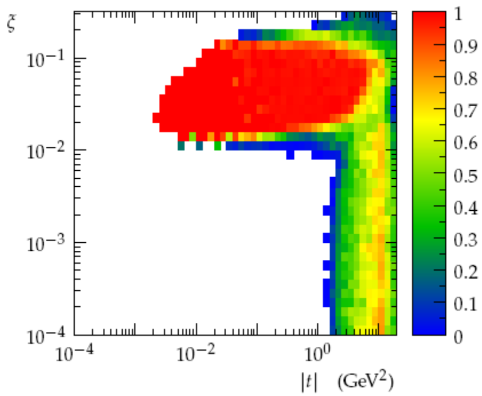
Reconstruction of proton kinematics needs an excellent understanding of the LHC optics.

arXiv:1406.0546

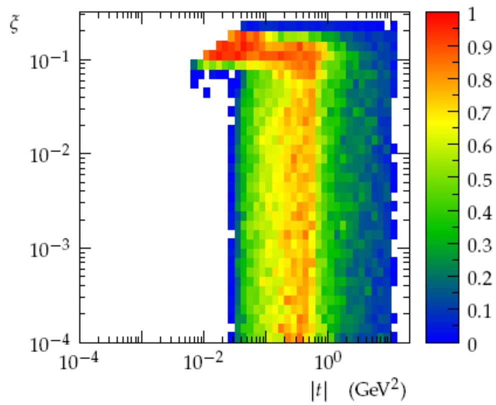
Running scenarios

- Different running scenario → different kinematic acceptance

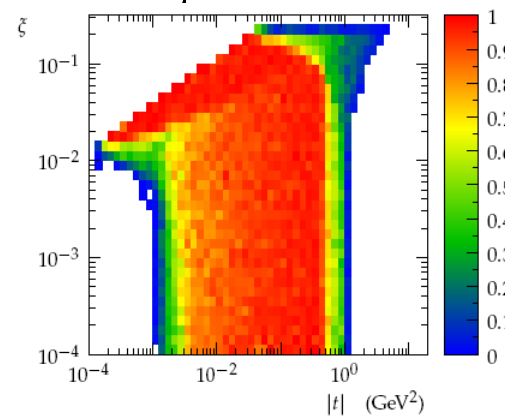
$\beta^* = 0.55$m



$\beta^* = 90$m



$\beta^* = 1000$m



- **Diffraction:**
  $\xi > \sim 0.01$
  low cross-section processes
  (hard diffraction)
- **Elastic scattering:** large |t|

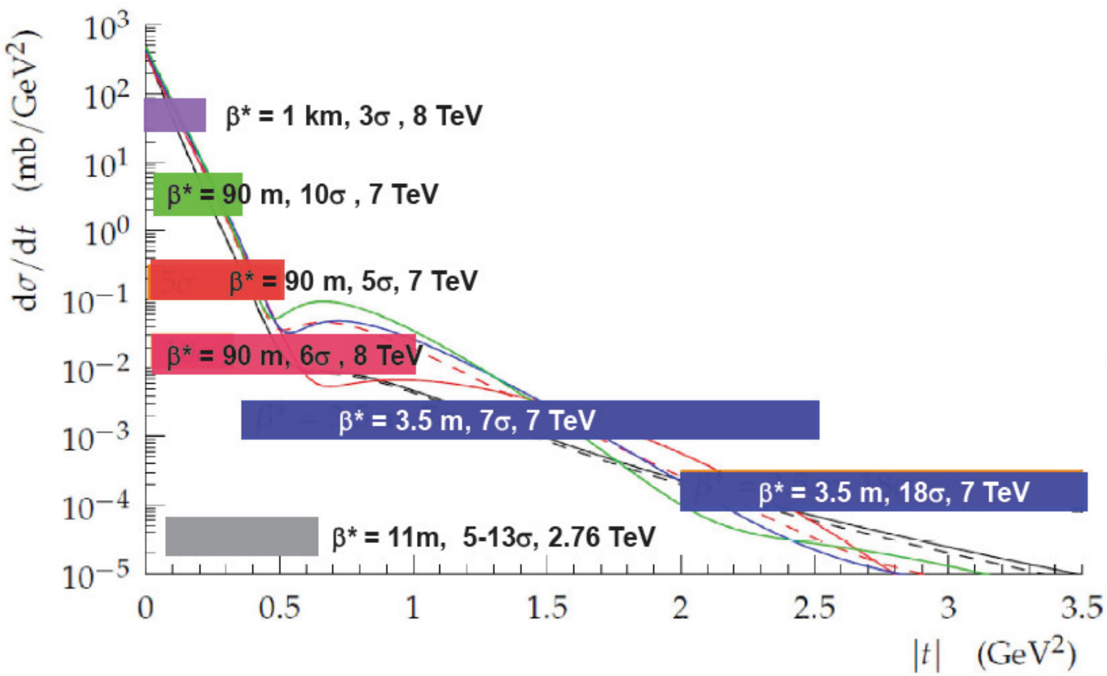
- **Diffraction:**
  all ξ if $|t| > \sim 10^{-2}$ GeV^2
- **Elastic scattering:**
  low to mid |t|
- **Total Cross-Section**

- **Elastic scattering:**
  very low |t|
  Coulomb-Nuclear Interference
- **Total Cross-Section**

High ← **Luminosity** — **Low**

$\sim 10^{33}$ cm^{-2}s^{-1} $\sim 10^{27}$ cm^{-2}s^{-1}

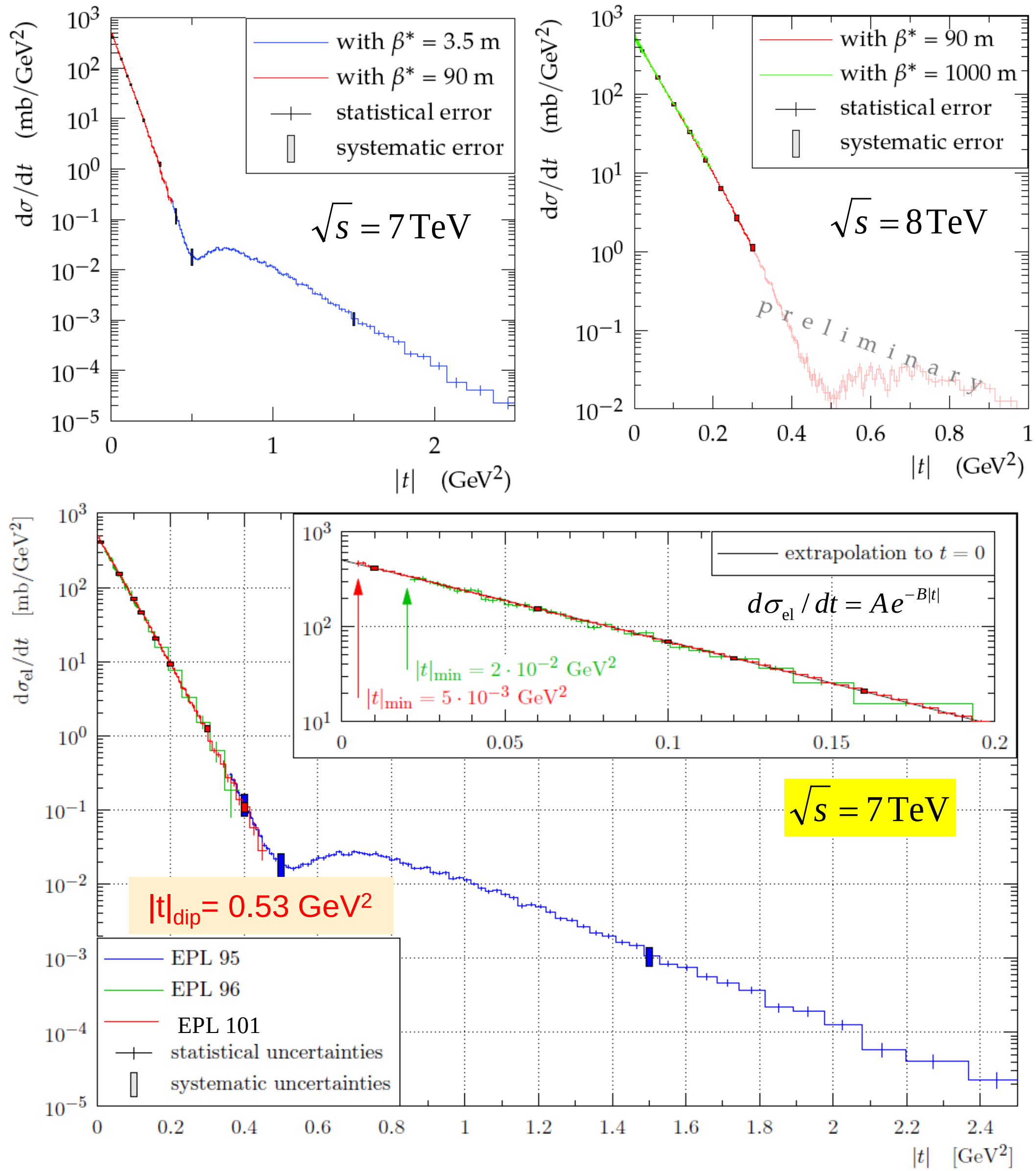
TOTEM operations



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

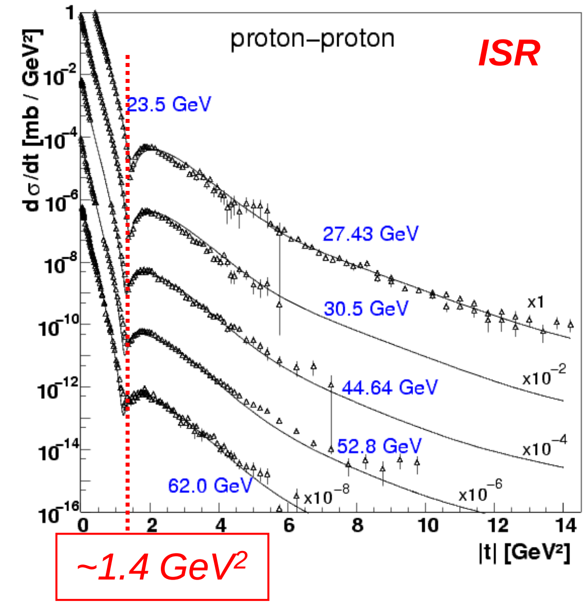
EPL 101 (2013) 21002]
EPL 96 (2011) 21002]
EPL 95 (2011) 41001]

Elastic differential cross section



Forward peak

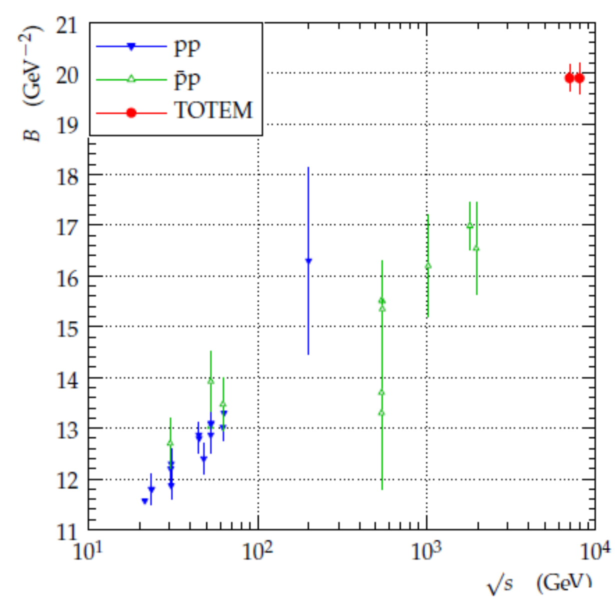
- Shrinking of the peak confirmed
  - t_{dip}(7 TeV) = 0.53 GeV^2
  - t_{dip}(ISR) ~ 1.4 GeV^2



- Nearly exponential decrease at low t

B_{7TeV} = (19.89 ± 0.27) GeV^{-2}

B_{8TeV} = (19.90 ± 0.30) GeV^{-2}



Elastic scattering at very low t

- Access to the Coulomb-Nuclear interference region

E (TeV)	β^* (m)	RP approach	$\mathcal{L}_{int}$ (μb^{-1})	t range (GeV^2)	Elastic events
7	90	4.8-6.5σ	83	$7\cdot10^{-3}$ - 0.5	1M
	90	10σ	1.7	0.02 - 0.4	14k
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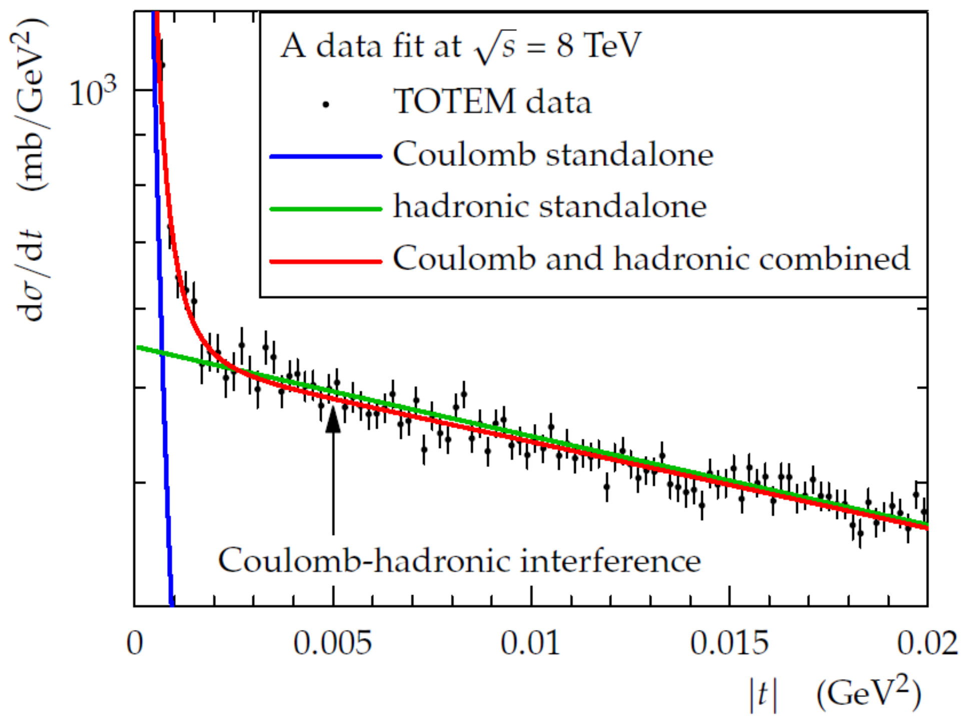
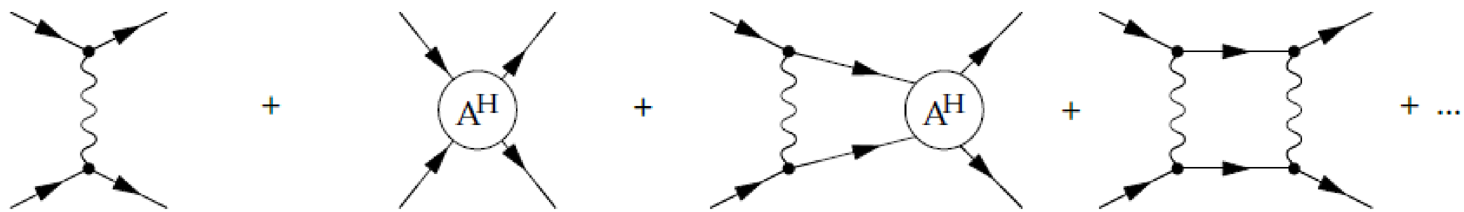
8	90	6-9σ	60	0.01 - 1	0.6M
	1000	3σ	20	$6\cdot10^{-4}$ - 0.2	0.4M
2.76	11	5-13σ		[illegible]	45k



Coulomb-Nuclear interference

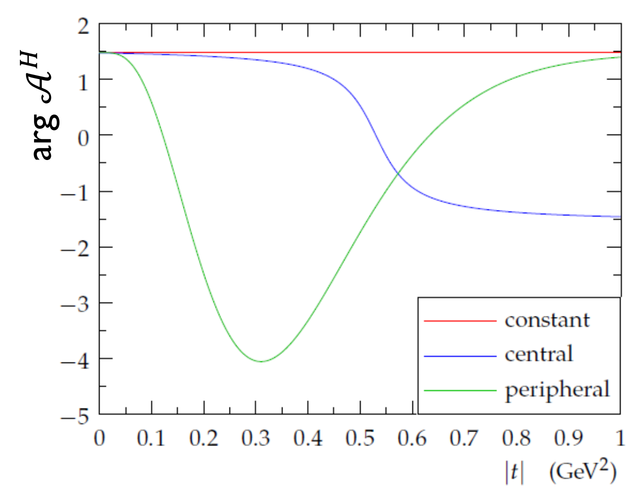
- Studying the interference region
  - gives sensitivity to the nuclear phase
  - allows to separate Coulomb and nuclear effects

$$\frac{d\sigma}{dt} \propto |\mathcal{A}^{C+H}|^2 \qquad \mathcal{A}^{C+H} = \text{interference formula}(\mathcal{A}^C, \mathcal{A}^H)$$



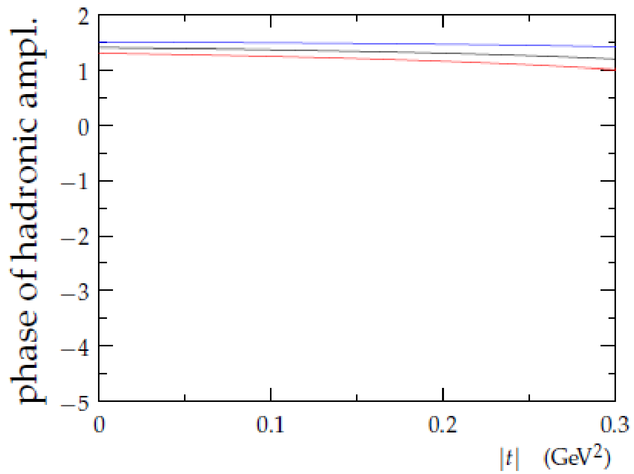
Interference formulas

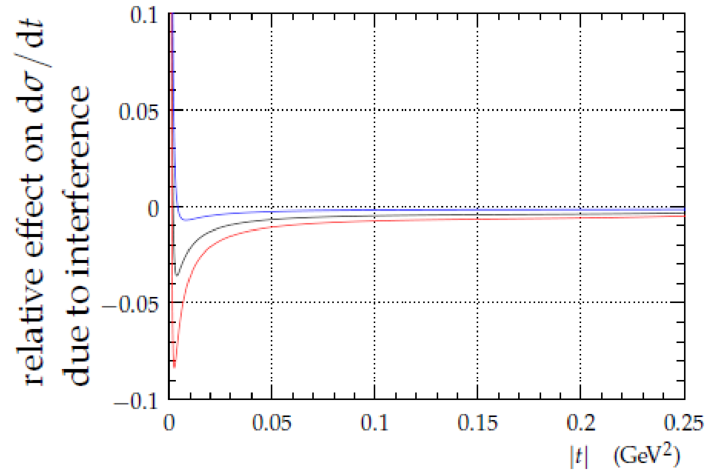
- Simplified West-Yennie (SWY)
  - a Feynman diagram approach
  - purely exponential nuclear amplitude and constant phase
- Kundrat-Lokaijcek (KL)
  - eikonal approach
  - no limitations on the nuclear amplitude



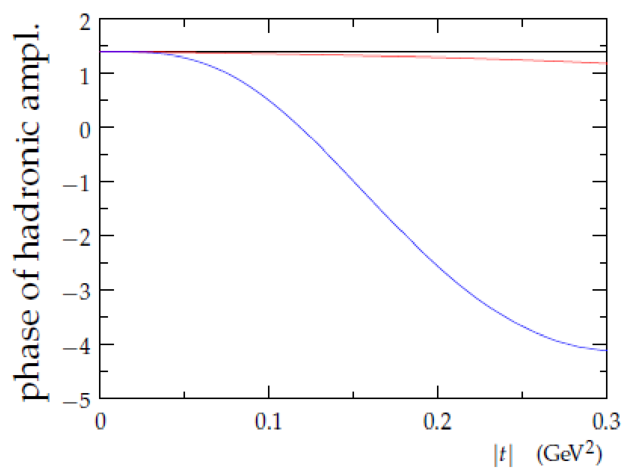
Effects of the CNI (simulation)

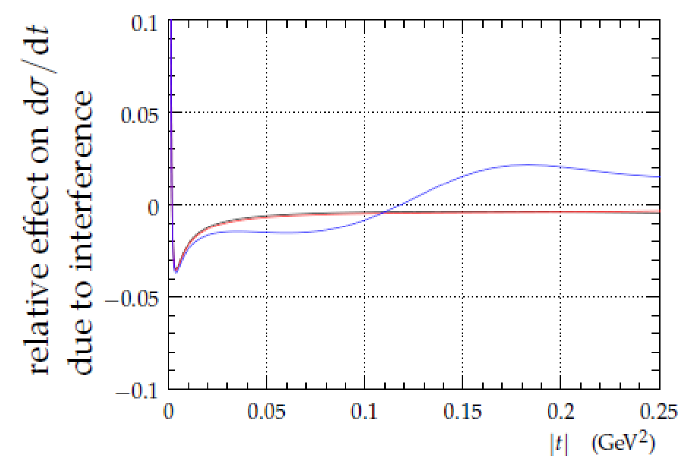
- **low t** (for any formula) mainly due to $\rho = {}^{\Re\mathcal{A}}/_{\Im\mathcal{A}}\,(t = 0)$





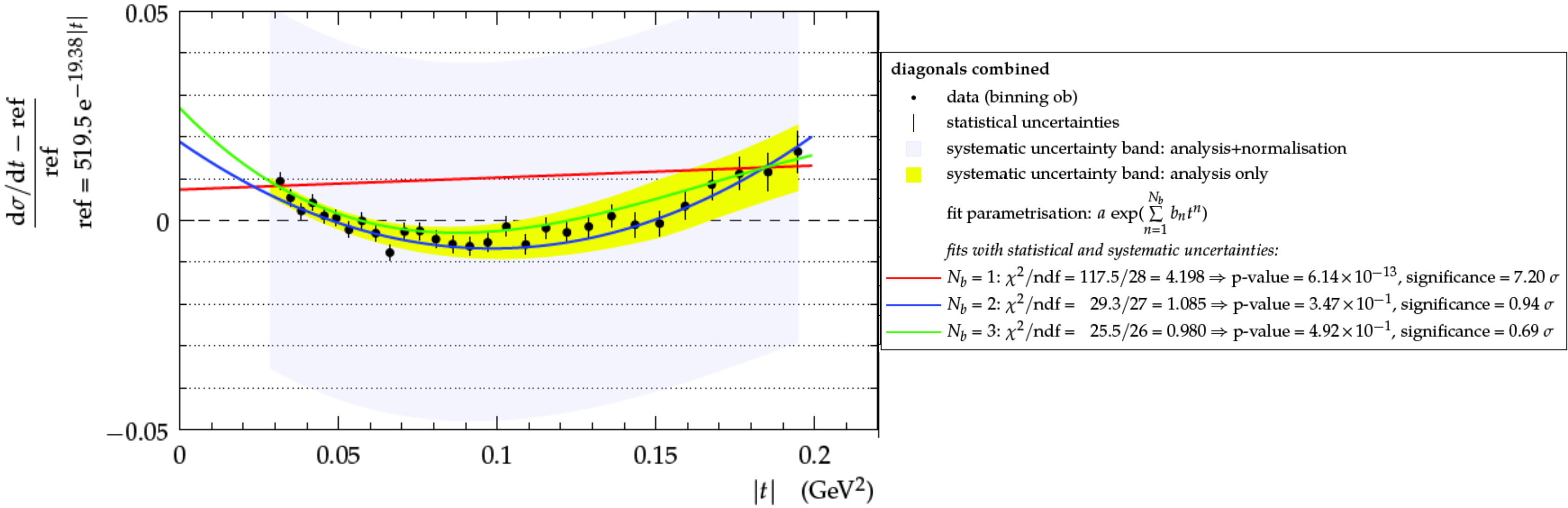
- **higher t** (for KL formula) from the functional form of the phase





Higher t studies (with β*=90m optics)

Deviation of dσ/dt from pure exponential:



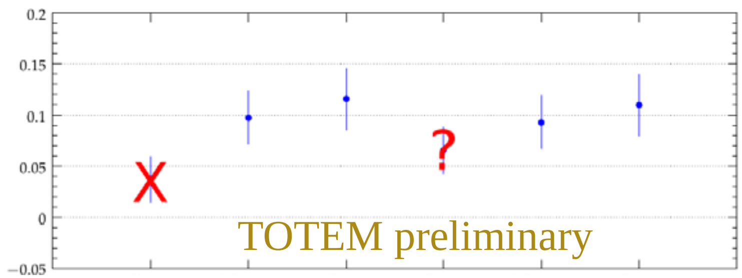
Fit $d\sigma/dt = A\, e^{-B(t)\,|t|}$, with $B(t) = b_0$ or $B(t) = b_0 + b_1 t$ or $B(t) = b_0 + b_1 t + b_2 t^2$

Pure exponential form excluded at ~7 σ significance.

Consequences:

- SWY formula ruled out
  - $d\sigma/dt^{H+C}$ can't be described by pure exponential
  - SWY CNI cannot produce non-exponentiality
  - $d\sigma/dt^{H}$ can't be described by pure exponential

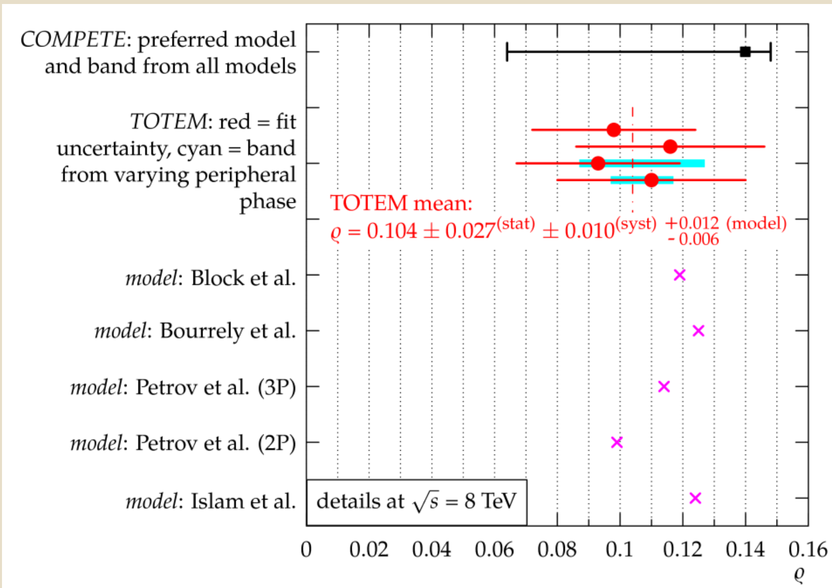
ρ determination

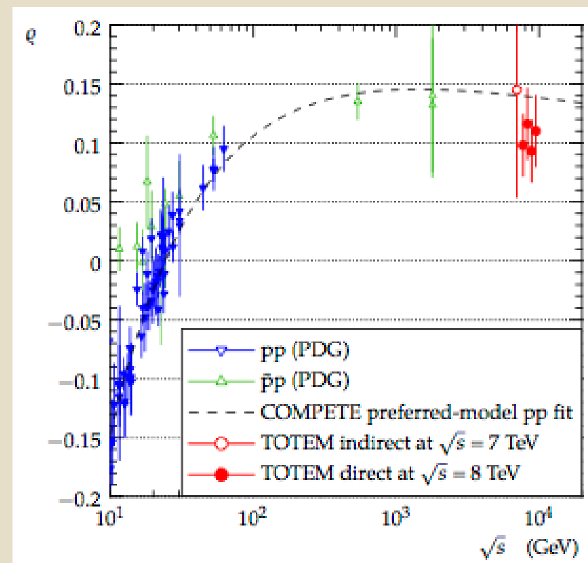


B(t): 1 par. 2 par. 3 par. 1 par. 2 par. 3 par.

Phase: central or constant — peripheral

ρ from fits with different forms for B(t) and phase(t)

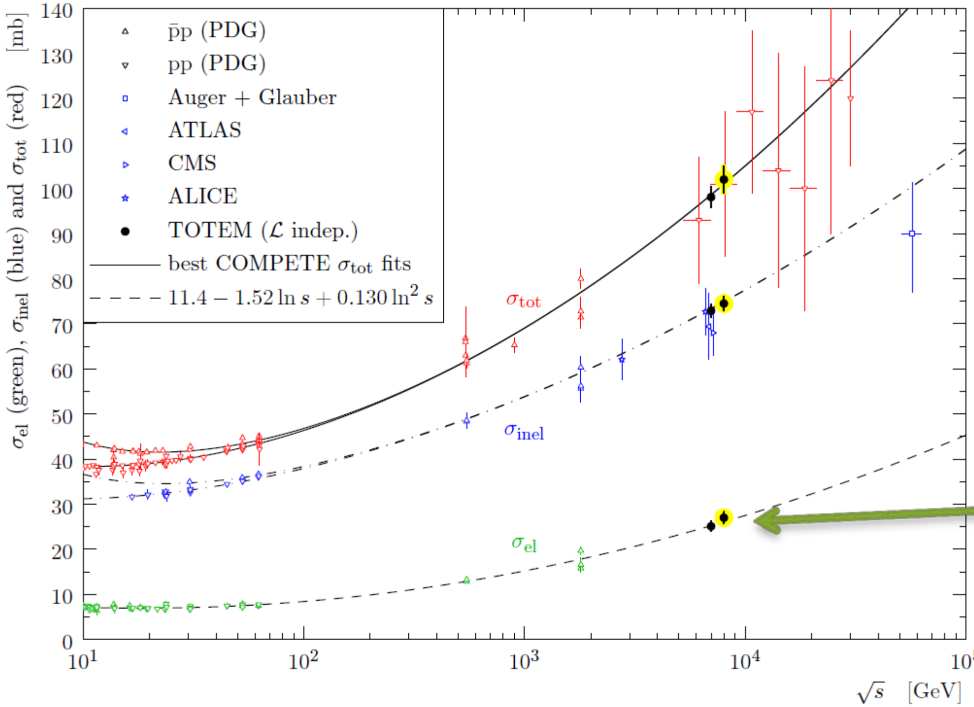




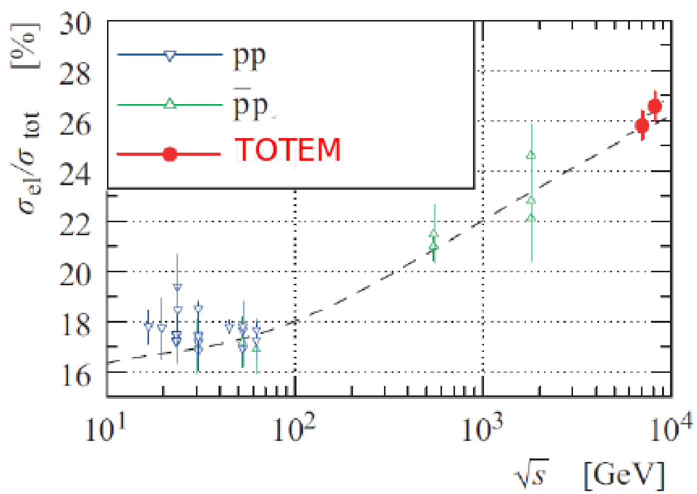
Indirect measurement at 7 TeV:

From optical theorem: $\rho^2 = 16\pi \mathcal{L}_{int} \frac{dN_{el}/dt|_{t=0}}{(N_{el}+N_{inel})^2} - 1 = 0.009 \pm 0.056 \rightarrow |\rho| = 0.145 \pm 0.091$

Elastic cross section

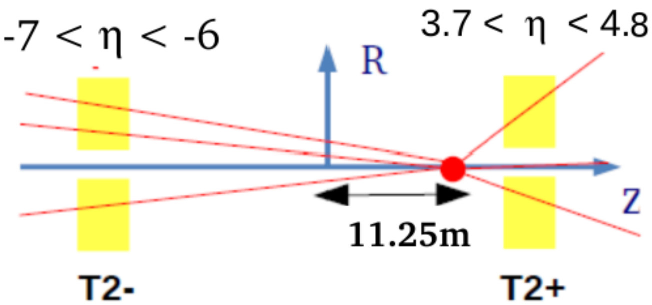


TOTEM
7 and 8 TeV

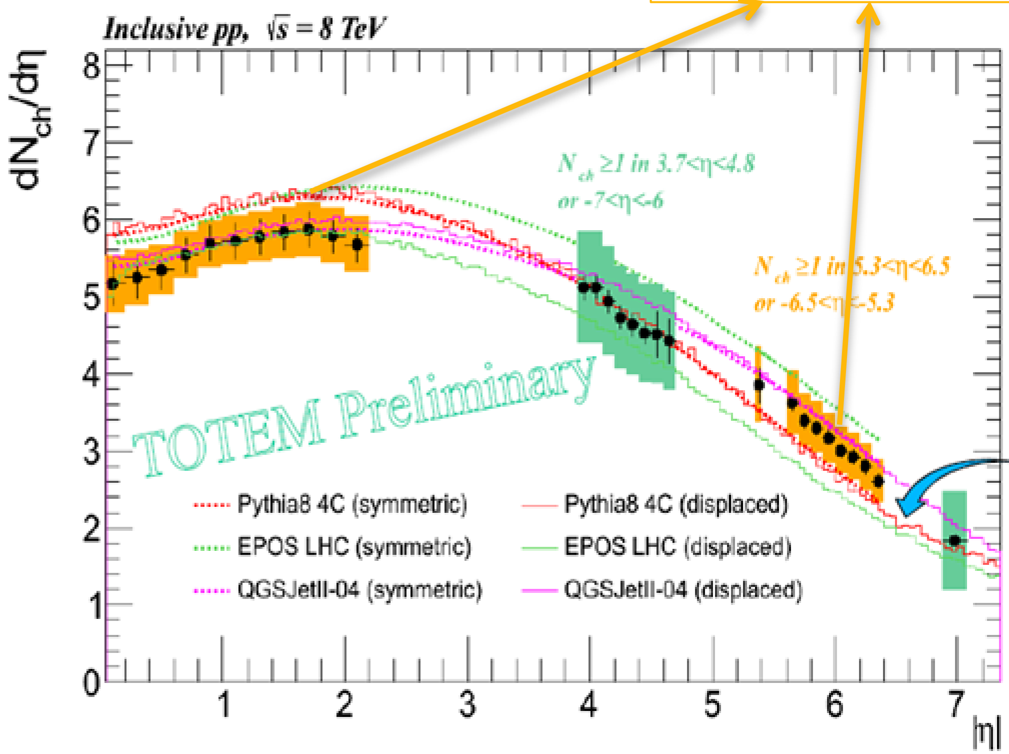


Forward $dN_{ch}/d\eta$ at 8 TeV with displaced vertex

Run with shifted collision p
→ asymmetric T2 acceptan



see CMS+TOTEM combined talk



not possible to make reliable measurement in - 6.8 < η < - 6 due to large material amount

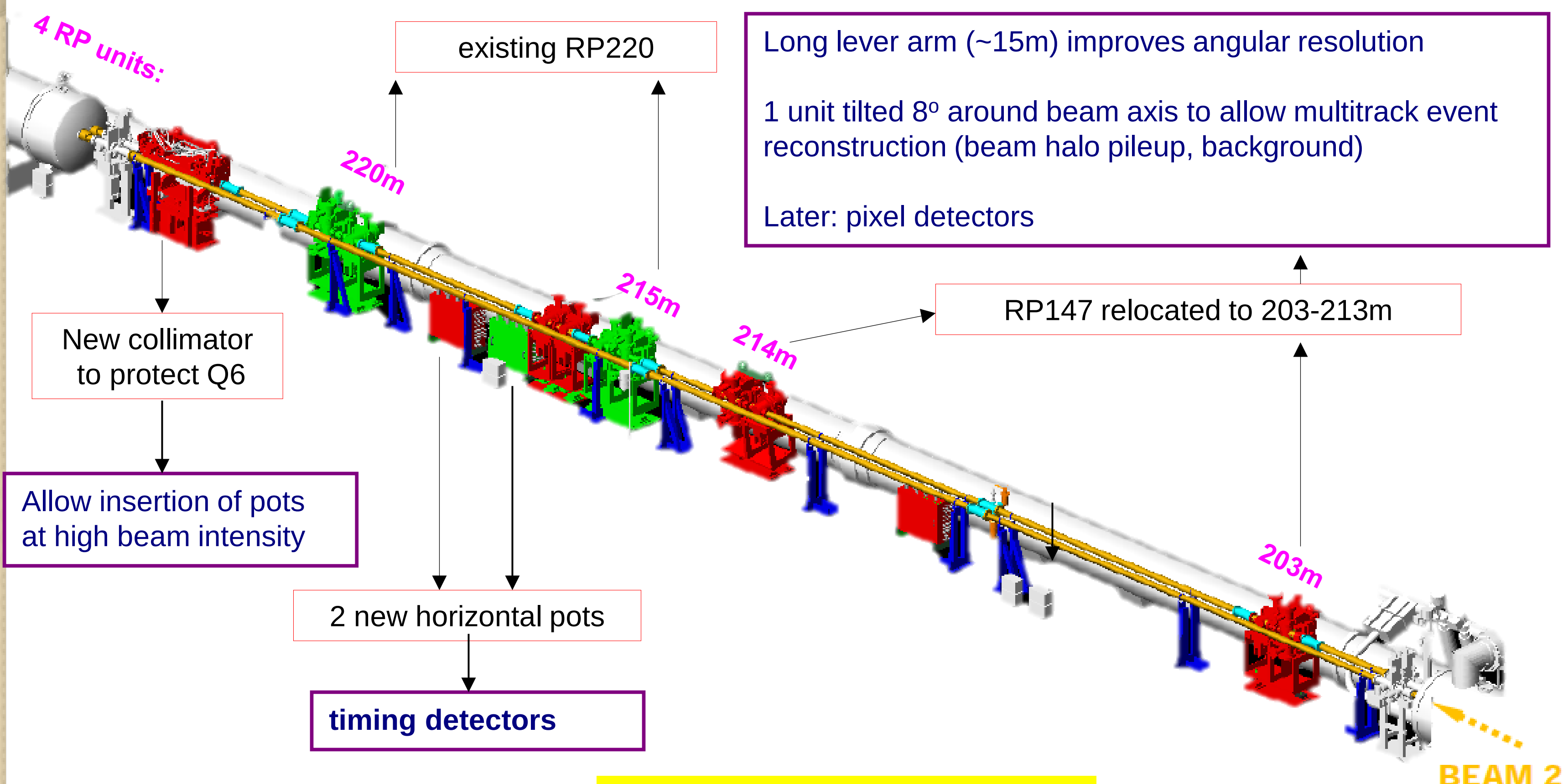
TOTEM consolidation and upgrade

In 2012: successful data taking **together with CMS** in special runs

- first studies of central production, diffractive dijets, other hard diffractive processes

Problems: limited statistics, pileup

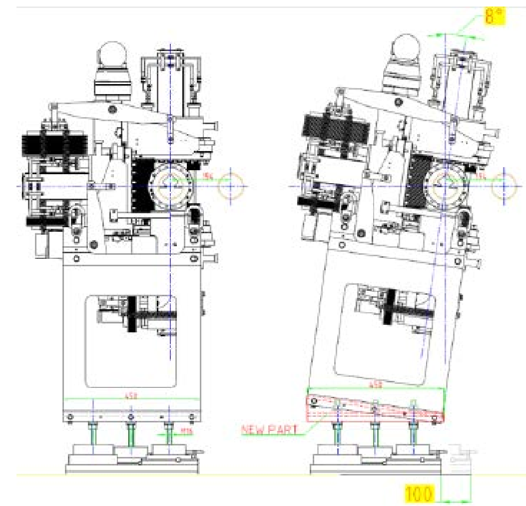
- upgrade RP system for operation at higher luminosities
- resolve event pileup: timing measurement, multi-track resolution

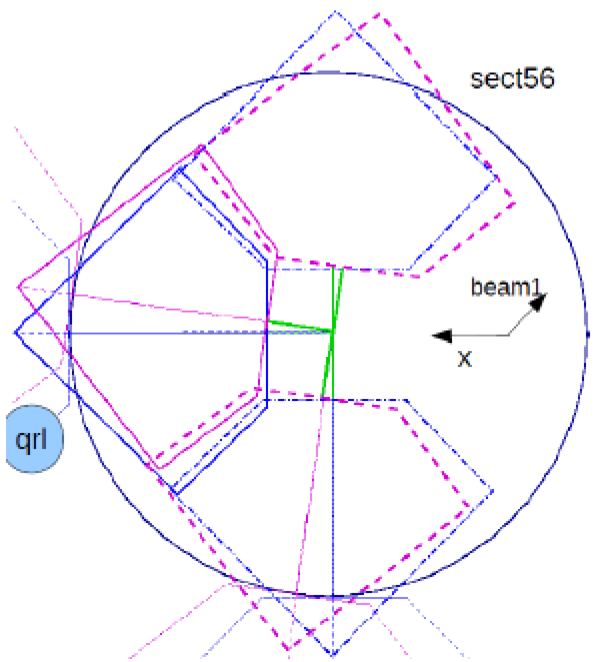


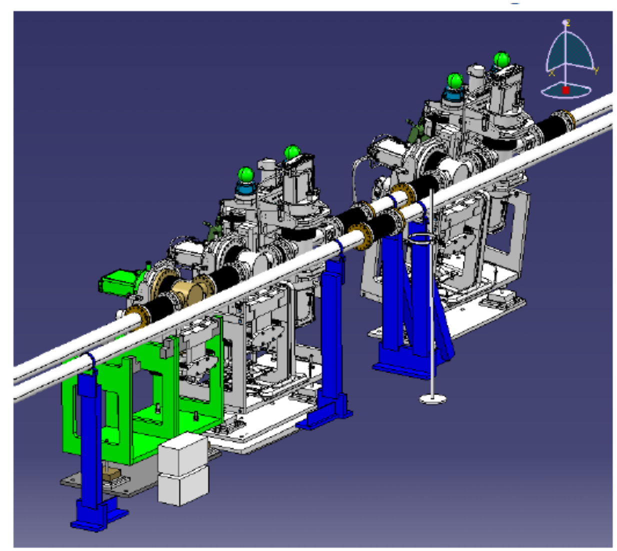
see also CT-PPS talk

Consolidation: RP tracking

RP stations at 147 moved to ~210m. One rotated by 8° to improve multitrack tracking efficiency.

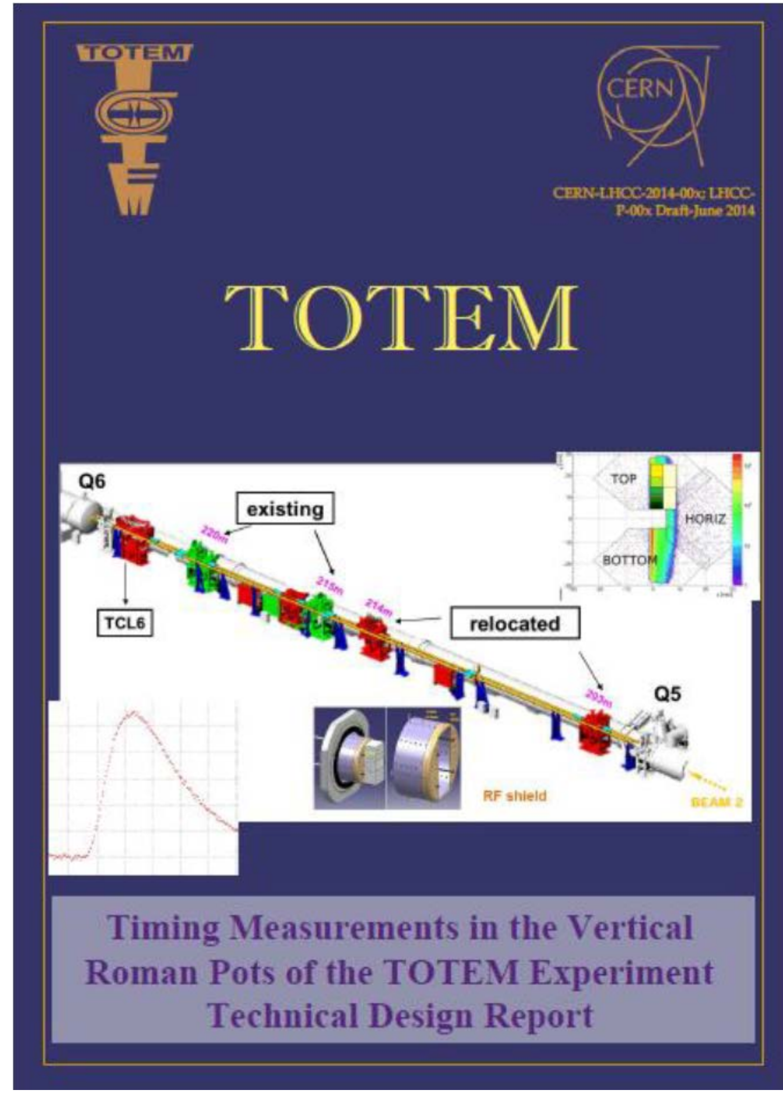






Timing in vertical RP

- Integrated luminosity of 100 pb^{-1} is necessary to probe O(pb) cross-sections
  - High statistics hard diffractive processes in CD (jet physics)
  - Study of BR and quantum numbers of gluonic states candidates
  - Missing mass candidates with inclusive production cross section of O(pb)
- Such integrated luminosity becomes reasonable for high β runs if a pile up μ~0.5 is generated by increasing bunch population
- Forward physics in special runs with vertical pots requires presence of timing to identify the collision vertex
- Timing improves background reduction also in low pileup runs
- Different detector options (diamonds, fast silicon)
- TDR in preparation
- Tests ongoing



Future physics program

- Elastic scattering, total, inelastic, diffractive cross sections at the new LHC energies

- Physics search on low mass spectroscopy
  - gluonic states
  - diffractive χ_c
- Central diffractive jet production
- Missing/escaping mass studies
- CT-PPS program (see dedicated talk)

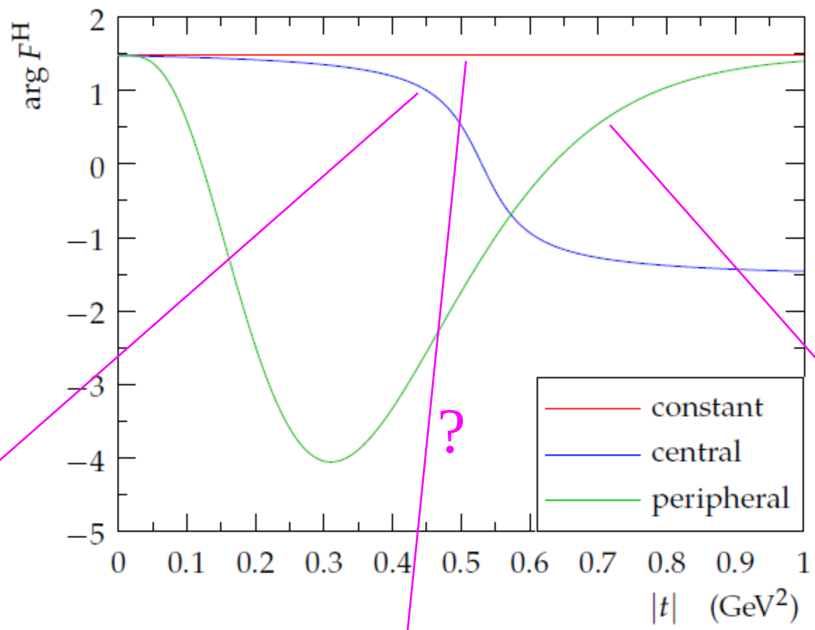
Conclusions

- During Run I TOTEM has measured the elastic scattering, the total and the inelastic cross sections at 7 and 8 TeV
- The elastic scattering has been studied in a wide t range. Measurements at very low t excluded a purely exponential behavior of the forward peak and allowed the study of the Coulomb-Nuclear interference
- An extensive study of the systematic effects has been carried on
- A measurement of the charged multiplicity using runs with a displaced vertex has been done complementary to the joint CMS-TOTEM measurement
- An extensive consolidation and upgrade program is being carried on with a new setup in the RP region

Looking forward to new results from Run II

Back up slides

Elastic Scattering in the Coulomb-Nuclear Interference Region



"central phase":

$$\arg F(t) = \frac{\pi}{2} - \operatorname{atan} \frac{\cot p_0}{1 - \frac{t}{t_d}}$$

constant phase:

$$\arg F(t) = p_0$$

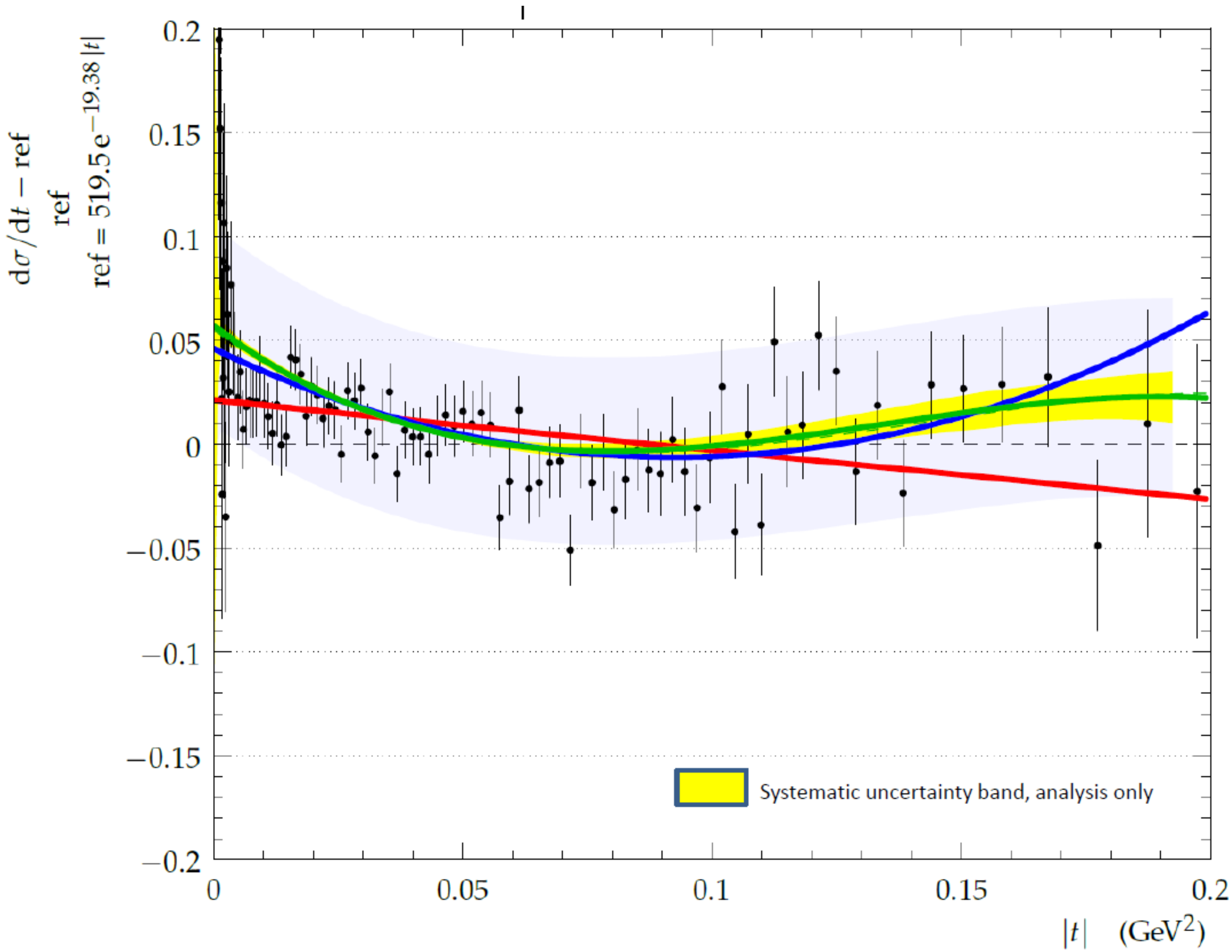
"peripheral phase":

$$\arg F(t) = p_0 + p_A \exp\left[\kappa\left(\ln\frac{t}{t_m} - \frac{t}{t_m} + 1\right)\right]$$

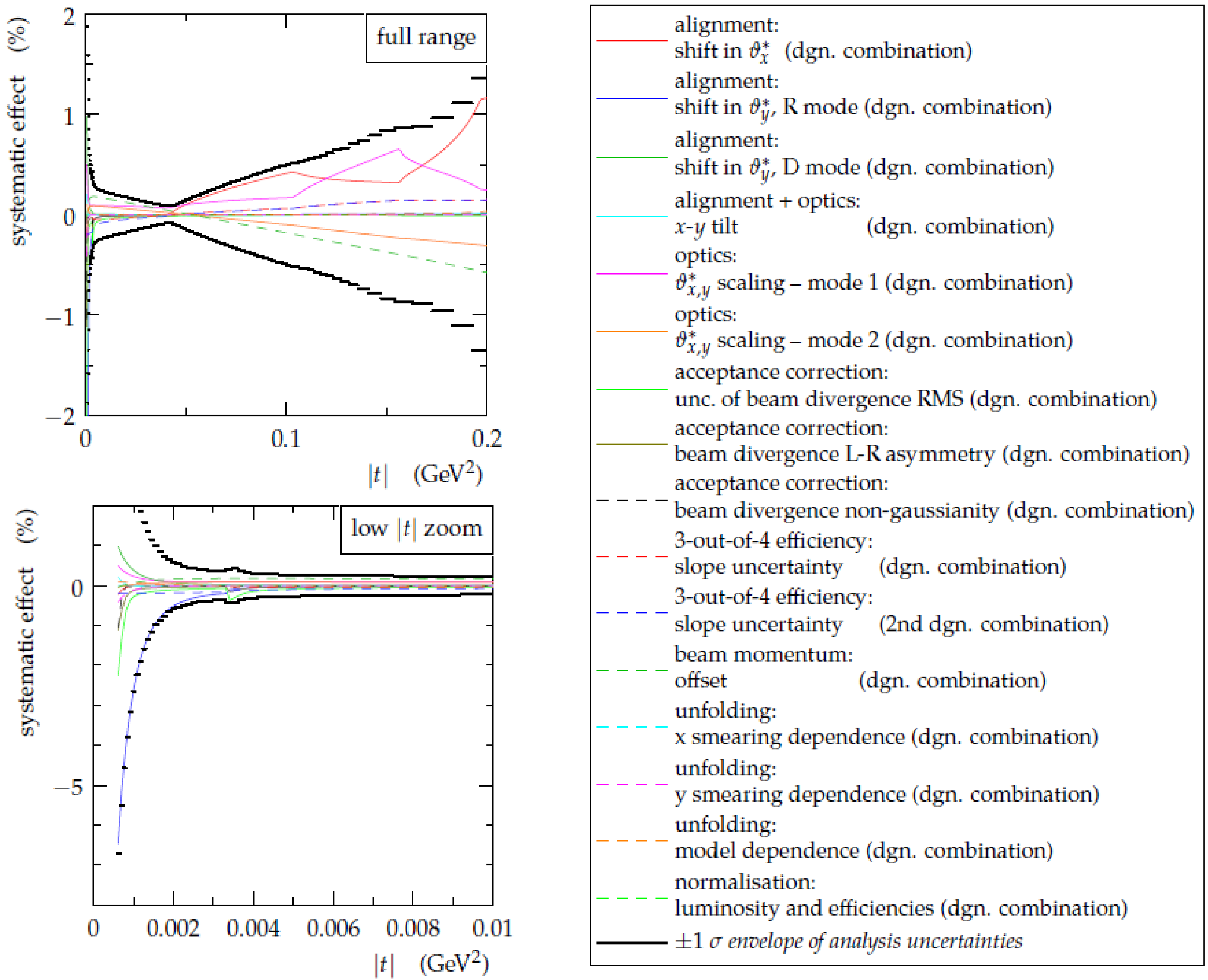
Only 1 free parameter: p_0 ➔

$$\rho = \frac{\Re F^H(0)}{\Im F^H(0)} = \cot \arg F^H(0) = \cot p_0$$

Preliminary results with 1km optics



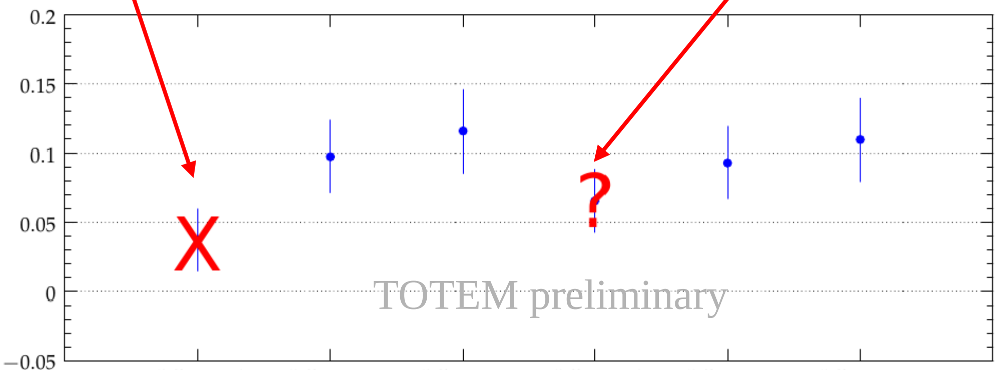
Systematics



Preliminary Result for ρ

Pure exponential form ruled out
→ SWY interference formula ruled out
(cannot produce non-exponentiality)

Constant B with peripheral phase unlikely but possible (if non-exponentiality is caused entirely by peripheral phase). Under study.

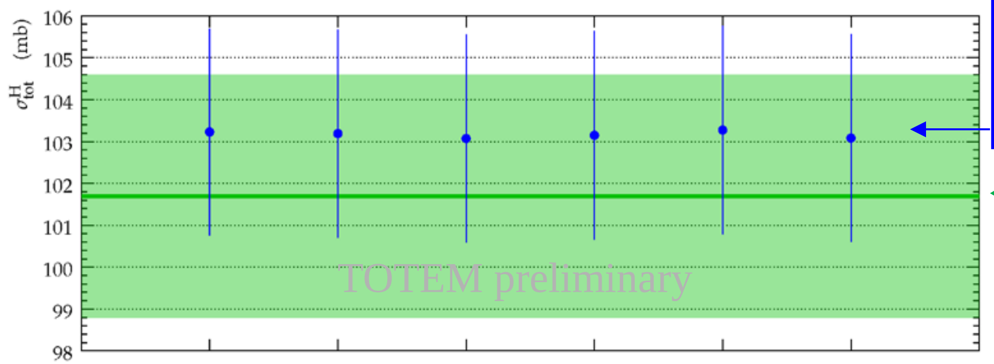


B(t): 1 par. 2 par. 3 par. 1 par. 2 par. 3 par.

Phase: central or constant | peripheral

ρ from fits with different forms for B(t) and phase(t)

σ^{H}_{tot} (mb)



$$\sigma^2_{tot} = \frac{16\pi}{(1+\rho^2)} \frac{1}{\mathcal{L}} \left(\frac{dN_{el}}{dt} \right)^{had}_{t=0}$$

σ_{total}= 101.7 ± 2.9 mb
luminosity independent
[PRL 111 (2013) 012001]

Overview of Running Scenarios

In the Upgrade Proposal: Pileup and Luminosity Reach

β^* [m]	cr. angle [μrad]	ε_N [μm rad]	N [10^{11} p/b.]	k bunches	μ	Luminosity [$cm^{-2}\,s^{-1}$]	
2500	0	2	$0.7 \div 1.5$	2	$0.004 \div 0.02$	$(1.2 \div 5.6) \times 10^{27}$	$= (0.1 \div 0.5)\,nb^{-1}/24h$
90	0	2	$0.5 \div 1.5$	156	$0.06 \div 0.5$	$(1.3 \div 12) \times 10^{30}$	$= (0.1 \div 1)\,pb^{-1}/24h$
90	100	2	$0.5 \div 1.5$	1000	$0.06 \div 0.5$	$(0.9 \div 7.7) \times 10^{31}$	$= (0.8 \div 7)\,pb^{-1}/24h$
11	$310 \div 390$	$1.9 \div 3.75$	1.15	$2520 \div 2760$ ($\Delta t = 25$ ns)	$1.3 \div 2.5$	$(5.3 \div 9.5) \times 10^{32}$	$= (46 \div 82)\,pb^{-1}/24h$
0.5	$310 \div 390$	$1.9 \div 3.75$	1.15	$2520 \div 2760$ ($\Delta t = 25$ ns)	$19 \div 34$	$(0.8 \div 1.3) \times 10^{34}$	$= (0.7 \div 1.1)\,fb^{-1}/24h$

- β* = 2500 m: for elastic Coulomb-Nuclear Interference studies **starting in 2016** (needs additional magnet cables): not discussed here.
- β* = 11 m: alternative idea for low-beta physics at each start of fill before squeeze: not further elaborated, not discussed here.
- β* = 90 m
- β* = 0.4 – 0.6 m

} Subjects of this presentation/discussion