TOTEM Status Report

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on behalf of the TOTEM collaboration

117th LHCC Meeting – Open Session
5 March, 2014

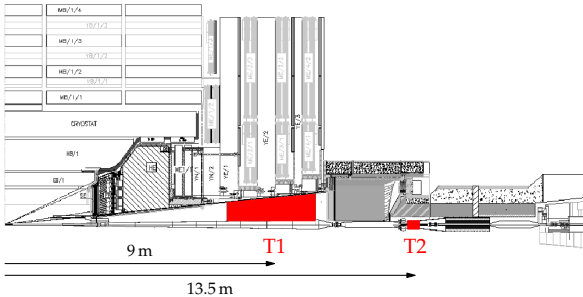
Consolidation / upgrade programme

- LS1 activities
- MoU with CMS on low β^* and high luminosity running

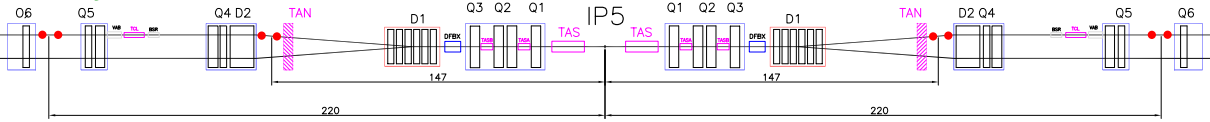
Analysis highlights

- $dN_{ch}/d\eta$, $\sqrt{s}$ = 8 TeV, β^* = 90 m, T2 and CMS tracker
  - paper in preparation
- $dN_{ch}/d\eta$, $\sqrt{s}$ = 8 TeV, β^* = 90 m, displaced interaction point, T2
  - promising results with extended η range
- elastic scattering, $\sqrt{s}$ = 8 TeV, β^* = 1000 and 90 m
  - new results with significant physics and theoretical implications

forward telescopes: charged → particles from inelastic collisions
T1: $3.1 < \eta < 4.7$
T2: $5.3 < \eta < 6.5$

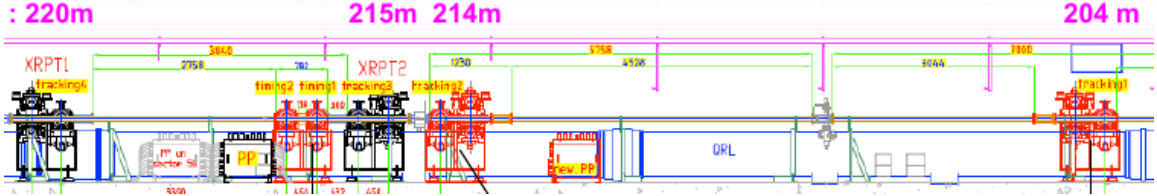


Roman Pots in the LHC: elastic+diffractive protons
↓
old layout:



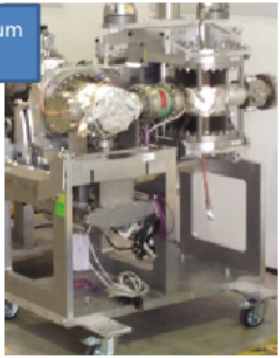
new layout:

- 147 m station relocated to 204 and 214 m (increased lever arm ⇒ better angular resolution)
- RPs at 214 m rotated by 8° ⇒ multi-track capability
- ≈ 216 m new two horizontal RPs for timing detectors (improved proton left–right correlation)

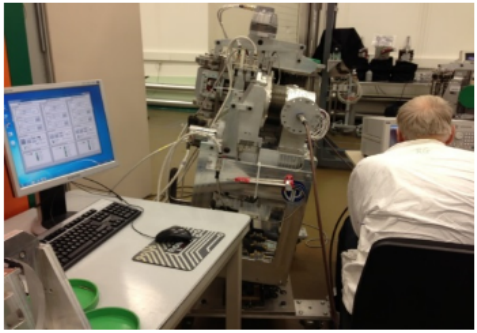


Selection of consolidation/upgrade activities

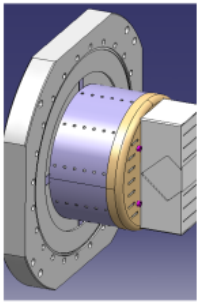
Preparation of RP units for vacuum test

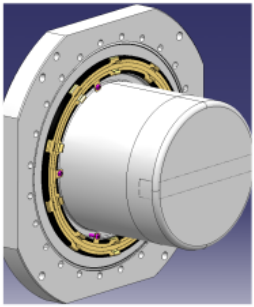


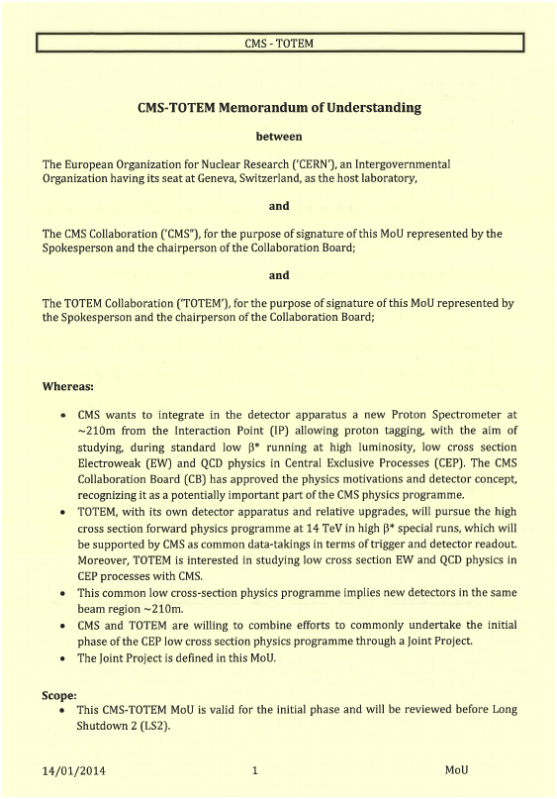
RF test of new Roman Pot design



Tunnel ready for installation of RP units







CMS - TOTEM

CMS-TOTEM Memorandum of Understanding

between

The European Organization for Nuclear Research ('CERN'), an Intergovernmental Organization having its seat at Geneva, Switzerland, as the host laboratory,

and

The CMS Collaboration ('CMS"), for the purpose of signature of this MoU represented by the Spokesperson and the chairperson of the Collaboration Board;

and

The TOTEM Collaboration ("TOTEM'), for the purpose of signature of this MoU represented by the Spokesperson and the chairperson of the Collaboration Board;

Whereas:

- CMS wants to integrate in the detector apparatus a new Proton Spectrometer at ~210m from the Interaction Point (IP) allowing proton tagging, with the aim of studying, during standard low β* running at high luminosity, low cross section Electroweak (EW) and QCD physics in Central Exclusive Processes (CEP). The CMS Collaboration Board (CB) has approved the physics motivations and detector concept, recognizing it as a potentially important part of the CMS physics programme.
- TOTEM, with its own detector apparatus and relative upgrades, will pursue the high cross section forward physics programme at 14 TeV in high β* special runs, which will be supported by CMS as common data-takings in terms of trigger and detector readout. Moreover, TOTEM is interested in studying low cross section EW and QCD physics in CEP processes with CMS.
- This common low cross-section physics programme implies new detectors in the same beam region ~210m.
- CMS and TOTEM are willing to combine efforts to commonly undertake the initial phase of the CEP low cross section physics programme through a Joint Project.
- The Joint Project is defined in this MoU.

Scope:

- This CMS-TOTEM MoU is valid for the initial phase and will be reviewed before Long Shutdown 2 (LS2).

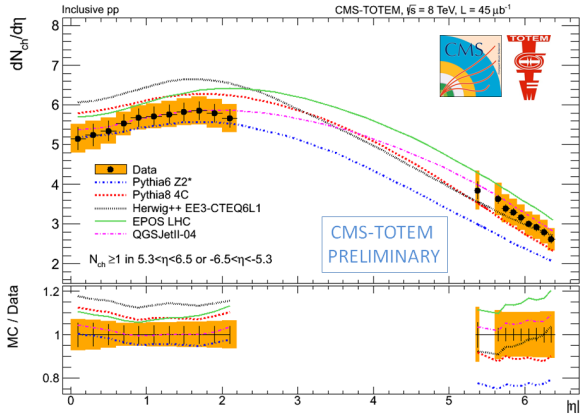
14/01/2014 1 MoU

CMS and TOTEM:
full diffractive physics programme and related new physics searches at high LHC luminosity

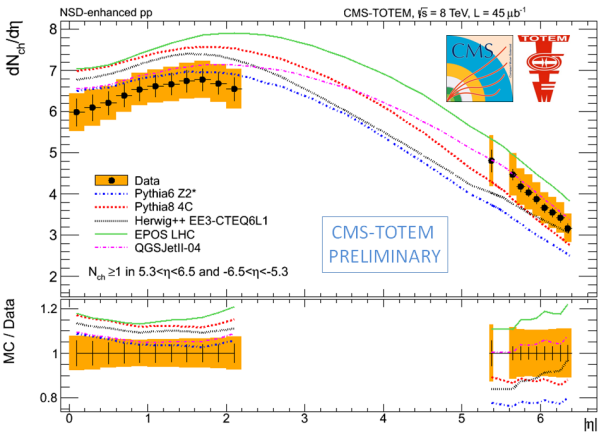
- high priority:
  - $dN_{ch}/d\eta$, $\sqrt{s}$ = 8 TeV, β^* = 90 m, T2 and CMS tracker
  - $dN_{ch}/d\eta$, $\sqrt{s}$ = 8 TeV, β^* = 90 m, displaced interaction point, T2
  - elastic scattering, $\sqrt{s}$ = 8 TeV, β^* = 1000 and 90 m
  - **low-mass DPE, $\sqrt{s}$ = 8 TeV, β^* = 90 m, with CMS**
- advanced state:
  - SD di-jets, $\sqrt{s}$ = 8 TeV, β^* = 90 m, with CMS
  - soft SD, $\sqrt{s}$ = 7 TeV, β^* = 90 m
  - inelastic cross-section, $\sqrt{s}$ = 2.76 TeV, β^* = 11 m, T1 + T2
  - large-$|t|$ elastic scattering, $\sqrt{s}$ = 7 TeV, β^* = 3.5 m
- selection from other ongoing analyses:
  - elastic and total cross-section, $\sqrt{s}$ = 2.76 TeV, β^* = 11 m
  - preparation: CMS CASTOR + TOTEM T2 physics
- posters this evening:
  - Nicola Minafra: RF Characterization of the New TOTEM Roman Pot
  - Josef Kopal: TOTEM Trigger System
  - Hauke Wöhrmann: Alignment of the CASTOR Calorimeter Relative to the TOTEM T2 Tracking Detector

- CMS + TOTEM pseudo-rapidity coverage: $|\eta| < 2.2$ and $5.3 < |\eta| < 6.5$
- same events (triggered by T2, more than 90 % of inelastic cross-section)
- corrected down to cut $p_T = 0 \Rightarrow$ direct comparison with Monte-Carlos
- 3 categories:
  - *Inclusive sample*: particle(s) in any T2 arm
  - *Non-single diffractive (NSD) enhanced sample*: particle(s) in both T2 arms
  - *Single diffractive (SD) enhanced sample*: particle(s) in only one T2 arm

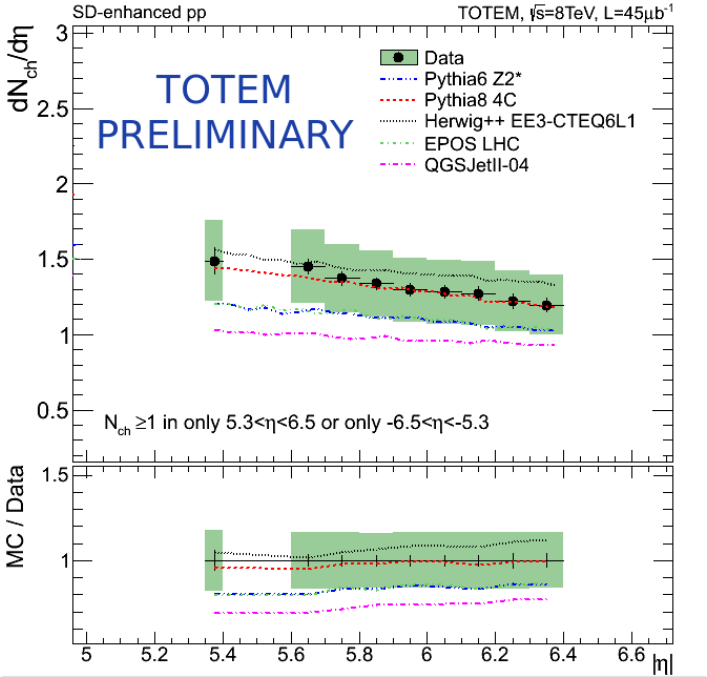
Inclusive



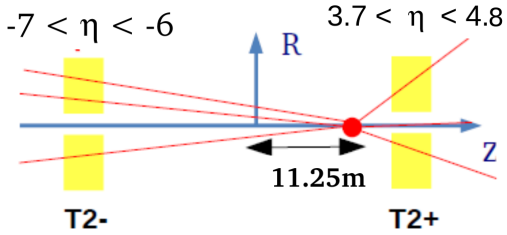
NSD-enhanced

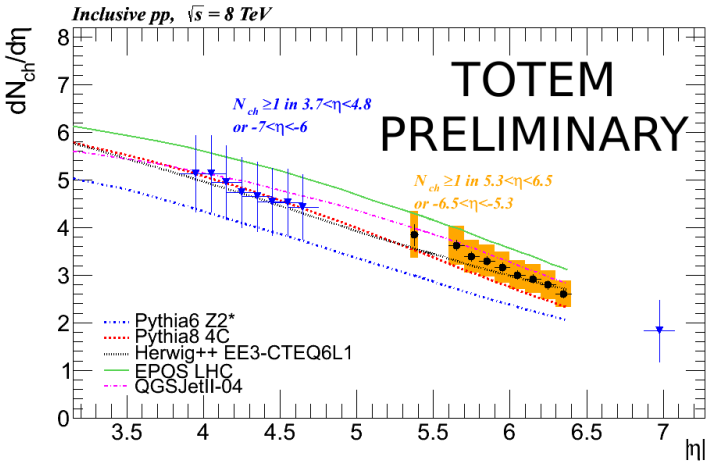


SD-enhanced


SD-enhanced pp
TOTEM, √s=8TeV, L=45μb⁻¹
TOTEM
PRELIMINARY
Data
Pythia6 Z2*
Pythia8 4C
Herwig++ EE3-CTEQ6L1
EPOS LHC
QGSJetII-04
dN_ch/dη
N_ch ≥1 in only 5.3<η<6.5 or only -6.5<η<-5.3
MC / Data
|η|

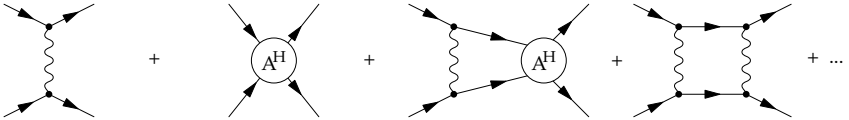
special run with longitudinally shifted collision point ⇒ asymmetric T2 acceptance:





- analysis details – more effects investigated, system better understood
- two independent analyses – confidence, alternative approaches
- cross-section level $\Rightarrow$ amplitude level (phase)
  - if $\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto |\mathcal{A}|^2 \Rightarrow$ phase of $\mathcal{A}$ inaccessible
  - elastic scattering = Coulomb + hadronic interaction

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

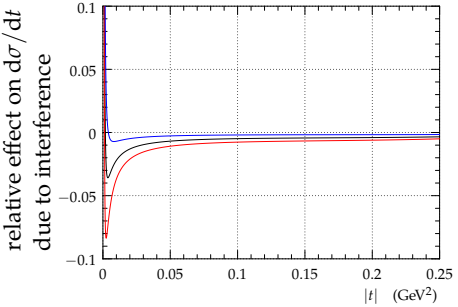


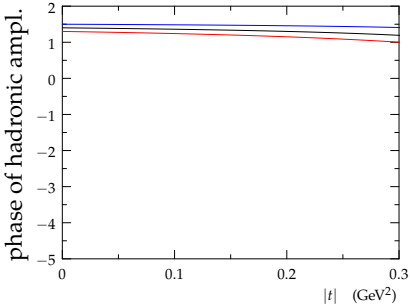
$\Rightarrow$ phase of $\mathcal{A}^{\mathrm{H}}$ accessible via interference with $\mathcal{A}^{\mathrm{C}}$ (known)

- interference formulae
  - *simplified West-Yennie (SWY)*
    - "the standard" in past
    - only compatible with purely exponential hadronic amplitude with constant phase
  - *Kundrát-Lokajíček (KL)*
    - no limitations on hadronic amplitude

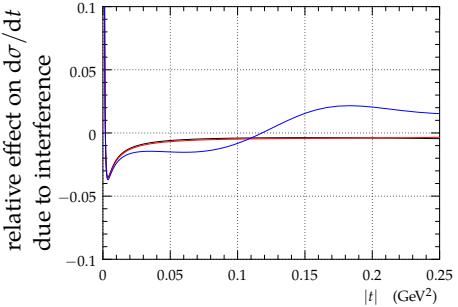
exploration – simulation of phases

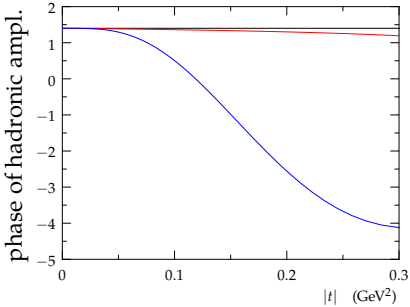
- low-$|t|$ effect: any interference formula, mostly due to $\rho \equiv \Re\mathcal{A}^{\mathrm{H}}/\Im\mathcal{A}^{\mathrm{H}}(t=0)$





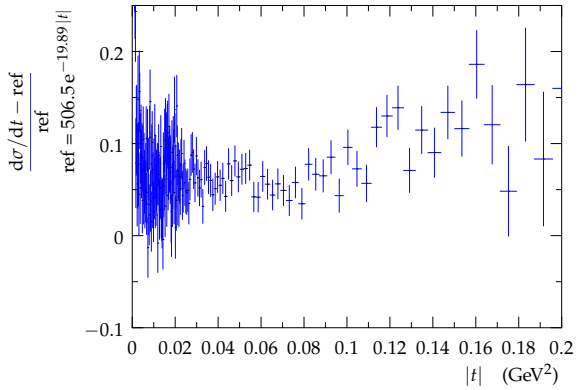
- higher-$|t|$ effect: only KL interference formula, hadronic phase rapidly varying





$\beta^* = 1000$ m

- $t_{\text{min}} \simeq 6 \cdot 10^{-4}$ GeV^2
- statistics: 0.3 M elastic events



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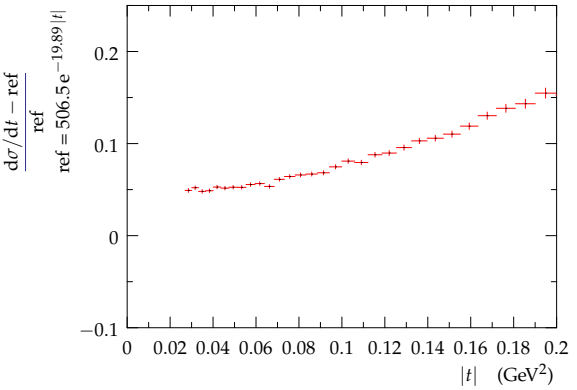
phase studies at low $|t|$ (ρ)

$\beta^* = 90$ m

- $t_{\text{min}} \simeq 2 \cdot 10^{-2}$ GeV^2
- statistics: 7 M elastic events



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phase studies at larger $|t|$

ultimate goal: combined analysis

(already reported to LHCC in September 2013)

- $\beta^* = 1000$ m
- differential cross-section fitted with different assumptions
  - interference formula
  - hadronic phase (central, peripheral)
  - hadronic modulus: $A \exp(b_1 t + b_2 t^2 + ...)$, N_b parameters in exponent

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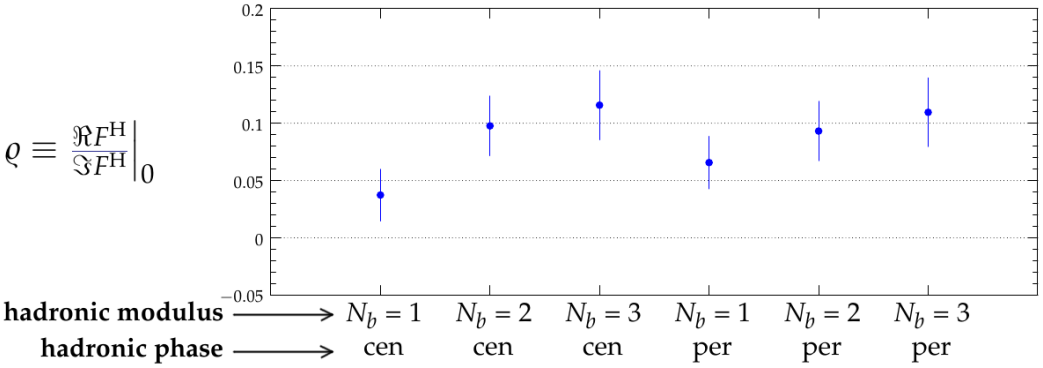
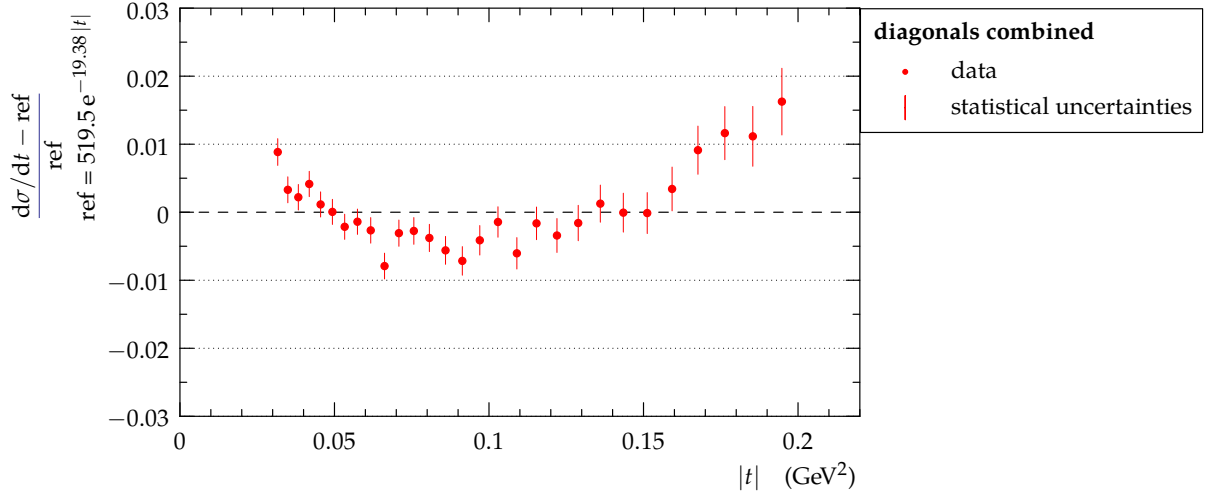
matrix of conditional results:

$$\varrho \equiv \left.\frac{\Re F^{\mathrm{H}}}{\Im F^{\mathrm{H}}}\right|_0$$

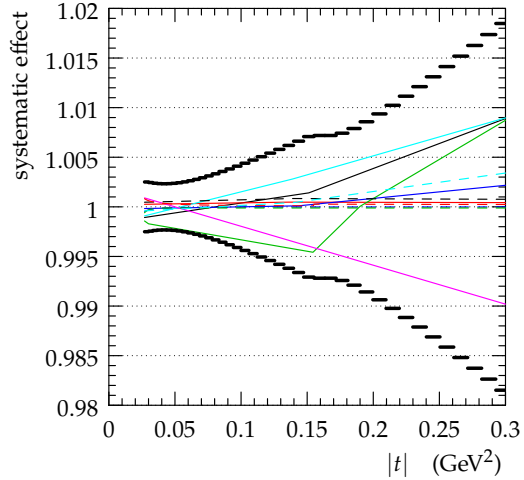


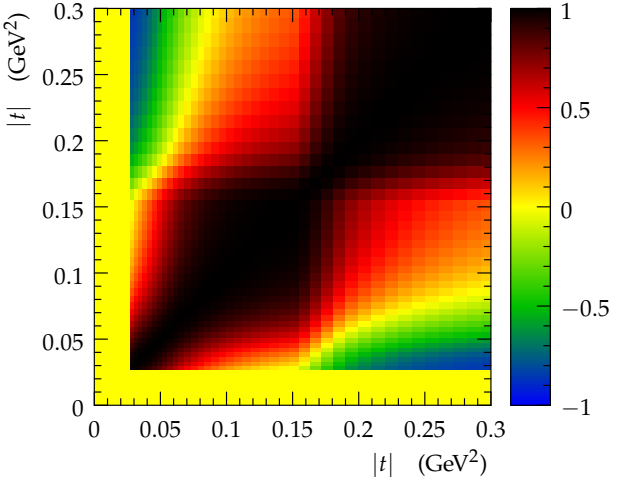
(note: purely-exponential fits, $N_b = 1$, stick out)

- $\beta^* = 90$ m data
- small statistical uncertainties allow for tight shape constraint:

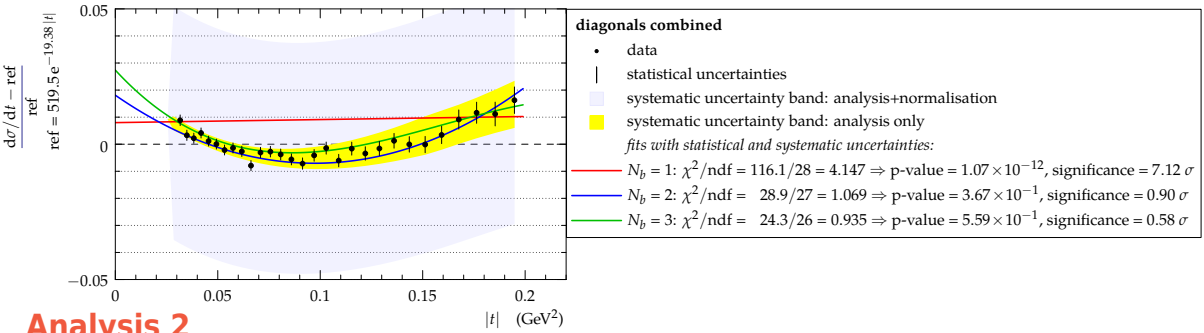


- extensive campaign to:
  - understand systematic effects
  - improve analysis procedure $\Rightarrow$ reduce uncertainty (e.g. optics matching)
- considered uncertainties:
  - alignment: x and y shifts, $x - y$ tilt
  - optics: correlated $\theta^*_{x,y}$ scaling modes
  - beam momentum offset
  - detector efficiency (including θ^*_y dependence)
  - acceptance correction due to beam divergence: distribution shape, RMS and L-R asymmetry
  - unfolding correction

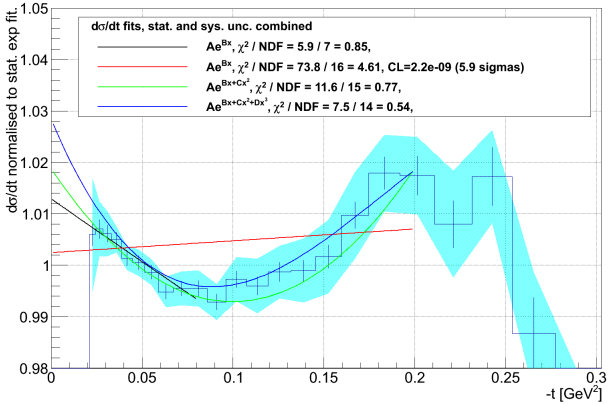




Analysis 1: fits $A\exp(b_1 t + b_2 t^2 + \ldots)$, N_b parameters in exponent



Analysis 2



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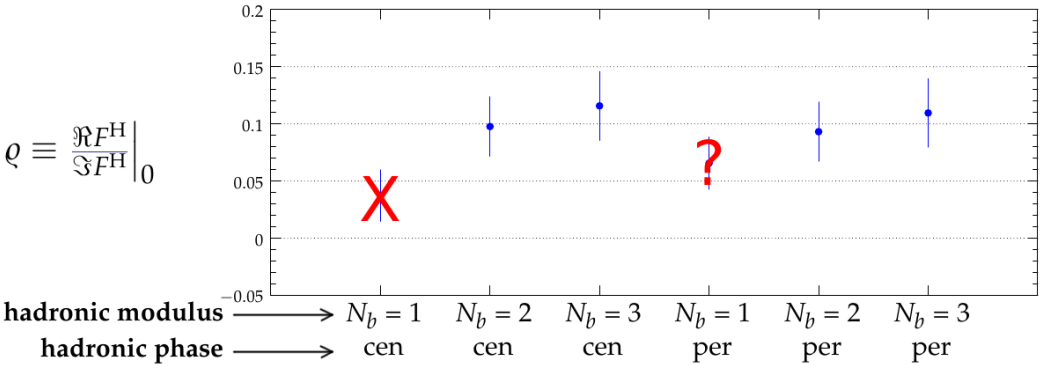
purely exponential fit excluded at 6 to 7σ significance

new determination
σ_{tot} = (101.4± 2.0) mb

- SWY interference formula ruled out
  - $d\sigma/dt^{C+H}$: cannot be described by pure exponential
  - non-exponentiality cannot be produced by SWY Coulomb-interference
  - $d\sigma/dt^{H}$: cannot be described by pure exponential

- ρ determination – matrix of combinations reduced:

$$\varrho \equiv \left.\frac{\Re F^{H}}{\Im F^{H}}\right|_{0}$$



- elastic cross-section at $\sqrt{s} = 8$ TeV non-exponential below $|t| \lesssim 0.2$ GeV^2
  - previously observed only in n-p: NA-6, Nucl. Phys. B232 (1984) 365-397

- TOTEM data exclude the centrality of elastic p-p scattering in the form it was derived via the simplified West-Yennie formalism

- combined $\beta^* = 90$ and 1000 m data will be used for study of the hadronic amplitude

- further total cross-section measurements at 8 TeV
  - $\beta^* = 90$ m: increased statistics, larger lever arm, better extrapolation to $t = 0$
  - $\beta^* = 1000$ m: partial Coulomb normalisation $\Rightarrow$ different systematics