Luminosity Measurement with TOTEM

- Overview
- Inelastic rates
- Absolute calibration
- Inelastic telescopes
- Monitoring Luminosity
TOTAL CROSS SECTION

Proton-proton
Proton-antiproton

Extrapolation to LHC energy:

- \( \log s \sim 95 \text{ mb} \)
- \( (\log s)^2 \sim 109 \pm 8 \text{ mb} \)

(UA4 and lower energy data)

Dispersion relation fit from

TOTEM designed to measure with accuracy \( \sim 1 \text{ mb} \)

Sufficient to discriminate between two options and current models prediction

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The experimental method

- Well known "luminosity independent" method
  - Only method of practical use
- Total cross section and machine integrated Luminosity
  \[ N_{el} + N_{inel} = L \sigma_{tot} \]
- Total cross section and imaginary part of forward amplitude (Optical Theorem)
  \[ \left( \frac{dN_{el}}{dt} \right)_{t=0} = L \left( \frac{d\sigma}{dt} \right)_{t=0} = L \frac{\sigma_{tot}^2 \left( 1 + \rho^2 \right)}{16 \pi} \]
- Combining the two, one writes the total cross section as a function of measurable quantities
  \[ \sigma_{tot} = \frac{16\pi \left( \frac{dN_{el}}{dt} \right)_{t=0}}{\left( 1 + \rho^2 \right) \left( N_{el} + N_{inel} \right)} \]
- Simultaneous measurement of low t elastic scattering and of inelastic interactions
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**The inelastic rate**

Inelastic detectors will measure over the pseudorapidity interval:

\[ 3 \leq \eta \leq 7 \]  
\[ 100 \geq \theta \geq 2 \text{ mrad} \]

- With **Fully inclusive trigger** (“Minimum bias”)
- “Normal events” (NSD) (80-85% of inel. cross section)

- Single diffractive events (SD) (15-20% of inel. cross section)

- Two main trigger combinations:
  - Left * Right (coinc)
  - Single arm

- Identification of beam-beam events against background
- Reconstruction of the collision vertex
Roman Pots
R.P. and T2

Seen in T1 (besides NSD)
NSD is the main component of the inelastic cross section, it is of the order of 85%.

Left-Right trigger is clean, low background.

Plot for “One track left, one track right”
Losses in NSD as a function of number of particles seen in each telescope.

Expected loss on NSD: ~1 - 2%
Efficiency of Single arm trigger for SD events

SD, minor component of inelastic cross section, of the order of 15%

Two tracks loss 10 - 15%
Estimated losses on the inelastic rate

- **NSD** - main component of the inelastic rate (about 85%)
  measured well with 1-2 % loss
- **SD** - minor component of the inelastic rate (about 15%)
  measured with 10-15 % loss

- The overall losses on the observed inelastic rate should be less than 3-4 %.
- With Monte Carlo tuned on the data calculate correction

  Final error around 1 %.
Inelastic rate detectors

- **T1 installed inside CMS (3.1 < η < 4.8)** measures mainly central interactions
  - Good efficiency, low background
  - Rejection of wrong direction halo, reconstruction of vertex position
- **T2 installed in front of fixed shielding (5.6 < η < 7.5)** sees mainly single diffractive events
  - Small masses (few GeV's) large rapidity gaps
  - At high β identify thin jet as SD by measuring the proton on the opposite side
  - Possibility to identify interaction vertex useful to identify beam-beam in low beta runs (when used as luminosity monitor)
- **Background measurement very important**
  - Single beam runs with high and low beta to directly measure correction
Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC

CMS/TOTEM Layout

Telescope 2

CMS End Cap

Telescope 1

HF calorimeter

Vacuum Chamber

Rotating Shielding Open

$\eta=3$ cone

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Single Diffraction triggers

- Topology of events very similar to beam gas
- Necessary to have good separation between beam-beam and beam-gas
- Two different triggers to identify the two components
  - T1 or T2 only on one side (with good single beam measurement to measure beam-gas and other backgrounds)
  - T1 or T2 only in one side and requiring a proton in roman pots on other side (>95% acceptance for high beta runs)
  - NOTE: at injection or low beta optics the fraction of SD (very energetic jets contained in small cone, order of cm at T2) will have a measured proton only in a very small fraction (~1%) of cases
    - This is an important subset of the data sample to track the absolute calibration from lower luminosities: Monte Carlo checks the relative efficiency.

Hence aim at the best $\xi$ acceptance for roman pots
Monitoring luminosity

- **Absolute measurement of Luminosity is performed during the special TOTEM runs**
- **Monitors/detectors calibrate their counting rates.**
  (run is at very low luminosity $10^{28}$ cm$^{-2}$ sec$^{-1}$)
- **To maintain precision in extrapolation to higher luminosity… problems may be due to rates and pile-up**
  - Cross correlate rates with ‘ones’ of detectors at larger angle or with reduced acceptance
  - Pile-up corrections to monitors by counting interactions’ vertices in z (feasible up to a ~10 events/crossing)
- **T2 will see SD (fraction of cross section $\rightarrow$ lower rate)**
  and also DD with possibility of regular calibration check with short runs at high beta
  - particular event topology less sensitive to pile-up
  - Runs at injection beta to check calibration at ‘intermediate’ Luminosity
  - Monitor capable to disentangle beam-beam and beam-gas with its limited vertex reconstruction capability (if event topology not sufficient by itself)
Requests to the machine

◆ The smallest beam emittance possible will allow to reach smaller t values in the special TOTEM run.
◆ We need to know the beam position at the 10 micron precision to check the consistency of our alignment procedures.
◆ We are interested in having the Machine monitors story recorded regularly and made available for the off-line analysis during the TOTEM runs.
◆ Bunch particle numbers and other related parameters with the best precision.
conclusions

- TOTEM will measure total cross section in special runs at low luminosity.
- Aim at total cross section measurement with 1% precision
- Absolute measurement of integrated machine luminosity will allow calibration of monitors in IP5 (CMS and others...)
- Extrapolation at higher luminosities with TOTEM forward Monitor (T2 telescope) and cross correlating detectors with different acceptance and background