Advanced Particle Physics Techniques

Case Study

The TOTEM Experiment at the LHC

By Jack Goddard

Overview

- Introduction
- Detector Overview
  - Roman Pots
  - T1 & T2 Tracking Detectors
- Physics Objectives
  - Total pp Cross-Section
  - Nuclear Elastic pp Scattering
  - Diffraction and Inelastic Scattering
- Summary

Introduction

- TOTEM = **TOT**al **E**lastic and diffractive cross section **M**easurement
- Forward physics detector
- Sits either side of CMS
- Combined with CMS will have the largest acceptance detector ever use at a hadron collider
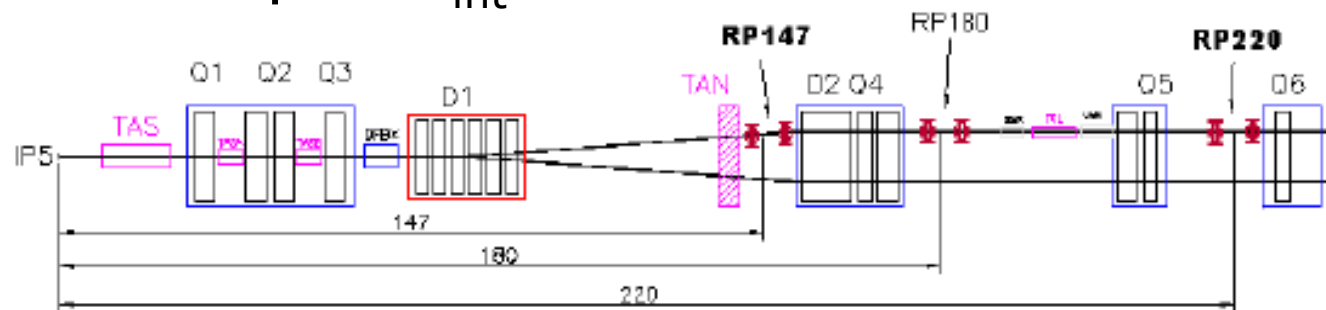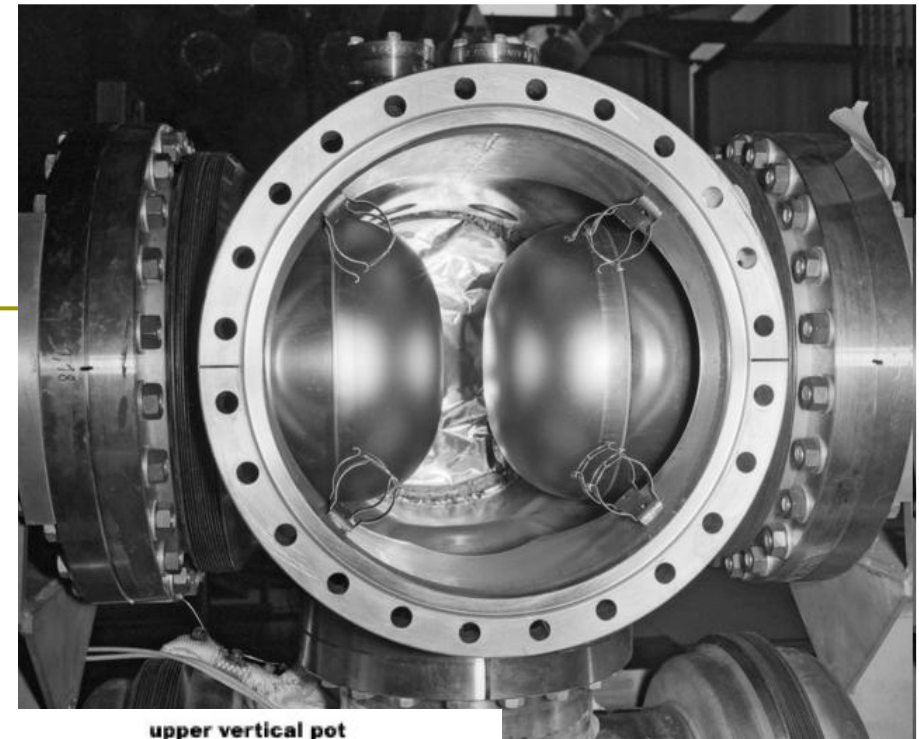- Optimal performance when used with special running conditions

Detector Overview:

T2

Castor (CMS)

CMS

T1

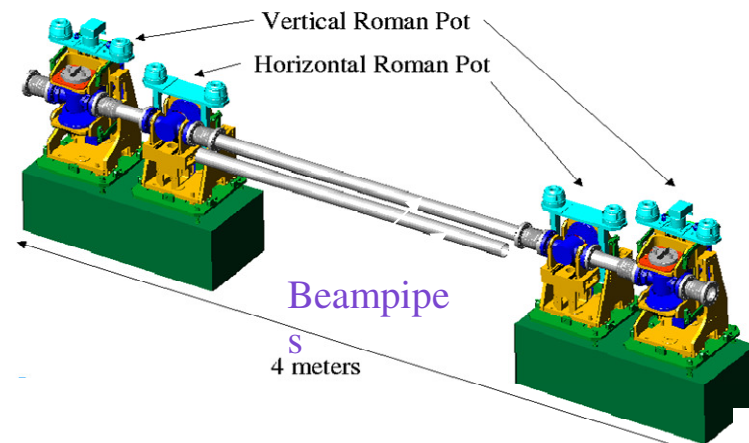**TOTEM** Experiment

T1

T2

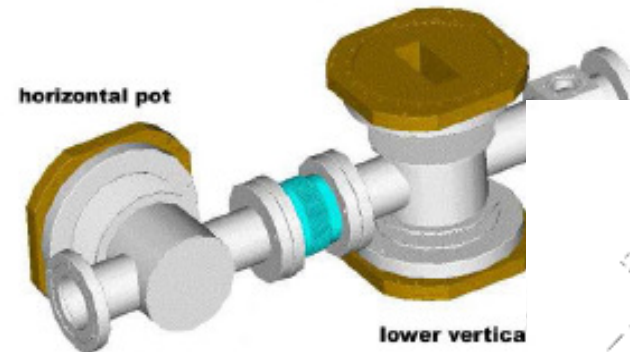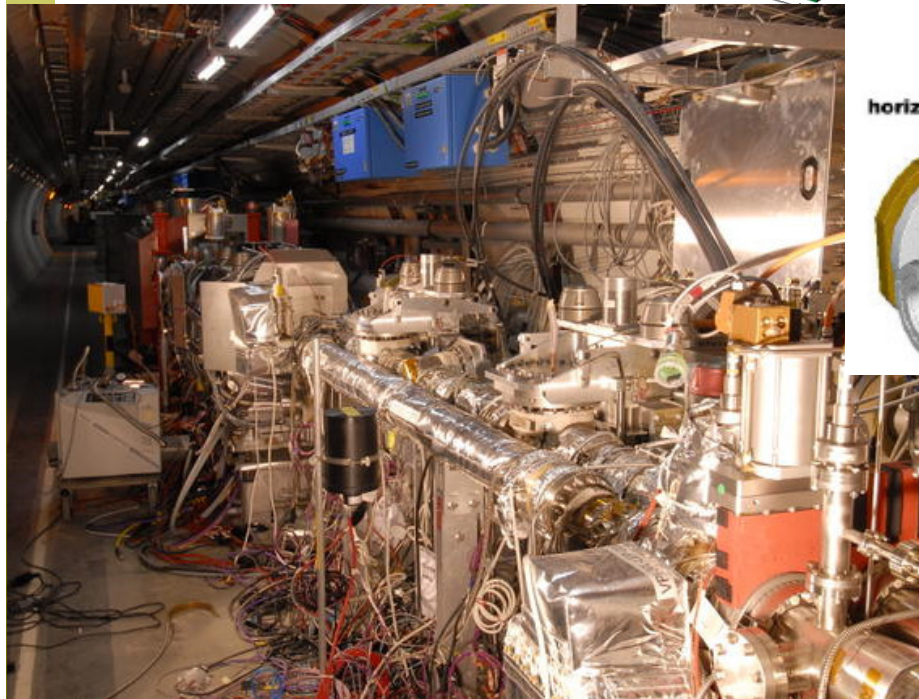Castor (CMS)
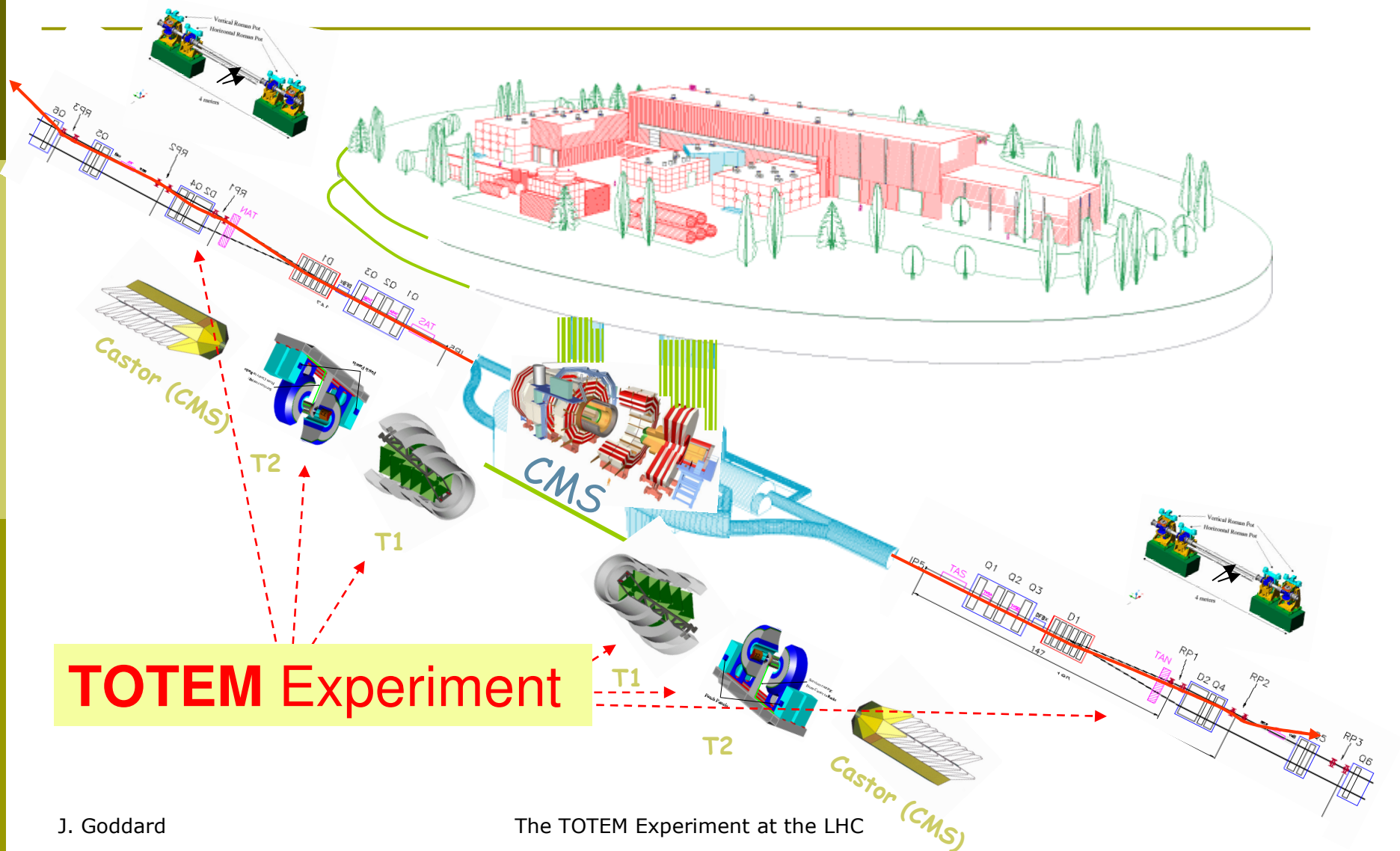
Detector Overview:

Roman Pots

- Mounted on outgoing beam pipe either side IP5
- Stainless steel containers
- Semiconductor detectors in a secondary vacuum
- Moved in close to the beam (800 μm)
- Each pot contains stack of 10 planes of silicon strip edgeless detectors
- Strips in stereo – half at angle 45°, half at -45°
- Each plane has 512 strips
- Single hit resolution of about 20μm
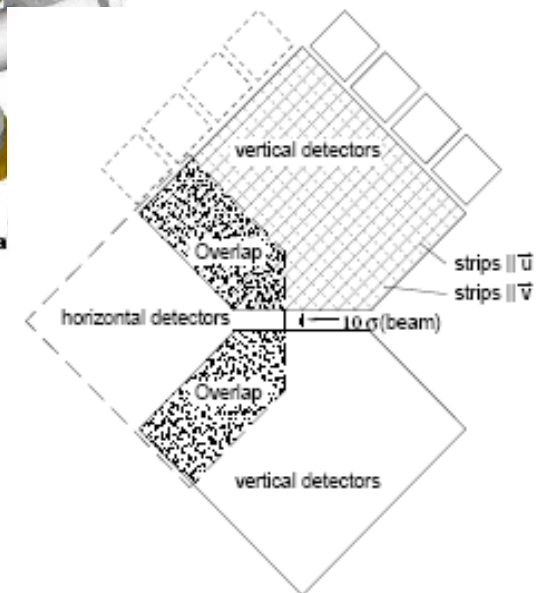- Should last up to $L_{int} \sim 1$ fb^{-1}

J. Goddard

Detector Overview:
Roman Pots

Vertical Roman Pot

Horizontal Roman Pot

Beampipes
4 meters

upper vertical pot

horizontal pot

lower vertical

vertical detectors

strips ∥ $\overline{u}$
strips ∥ $\overline{v}$

horizontal detectors

Overlap

Overlap

10 σ (beam)

vertical detectors

periment at the LHC

Detector Overview:
Roman Pots

58 mm

106 mm

Thin window

200μm thick

Bottom foil

3.5 cm

beam

66 μm

CTR   CR   Cut Edge
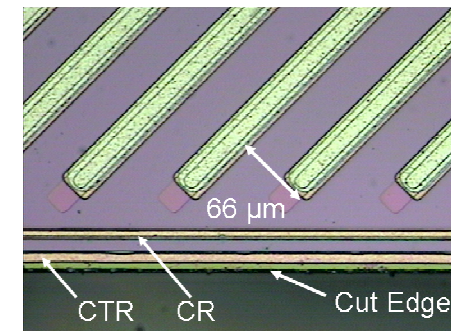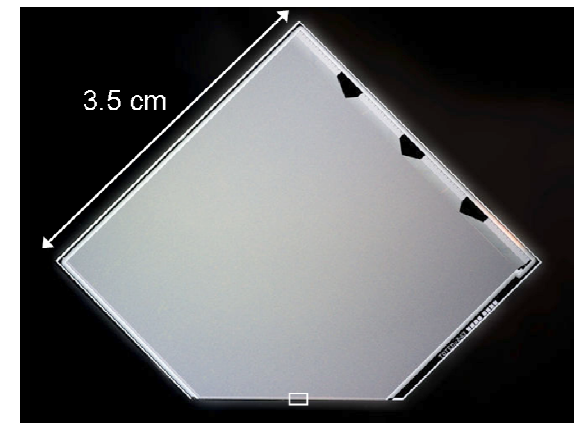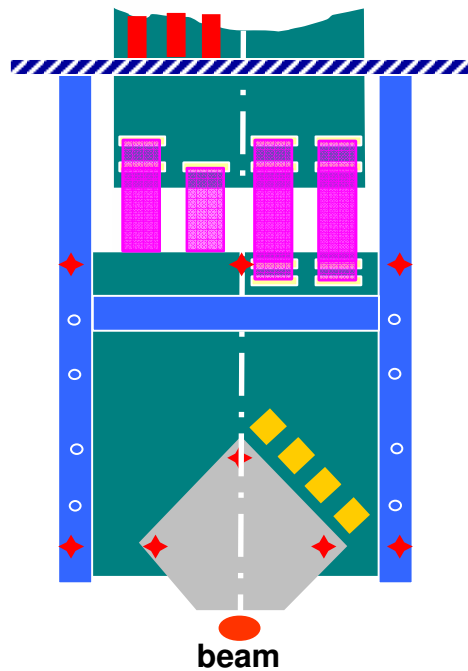
Tracking Detectors

- ❑ Two "telescope" tracking detectors
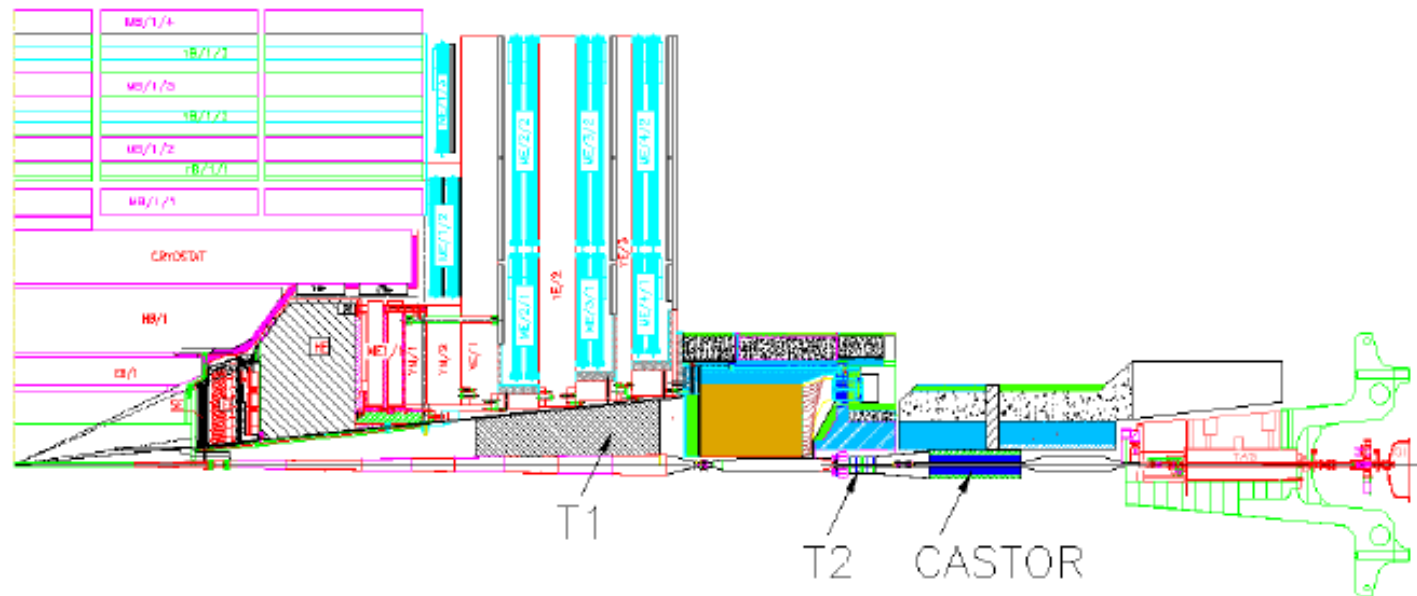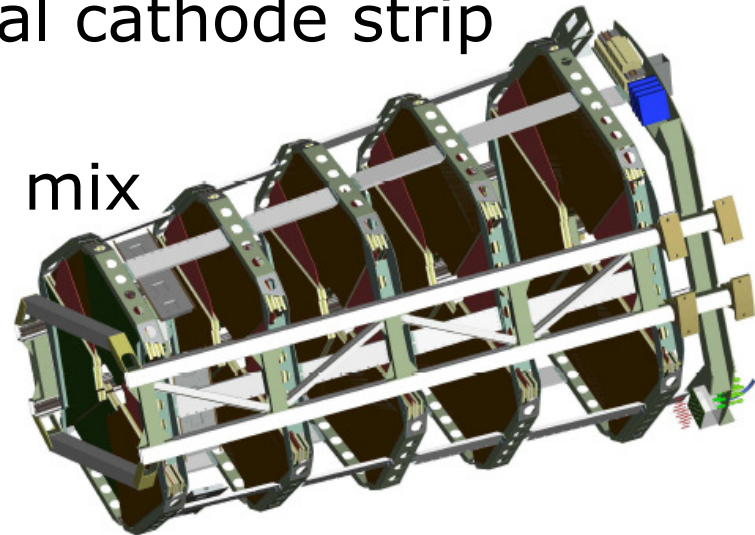- ❑ Sit within the CMS detector

Detector Overview:

T1 Telescope
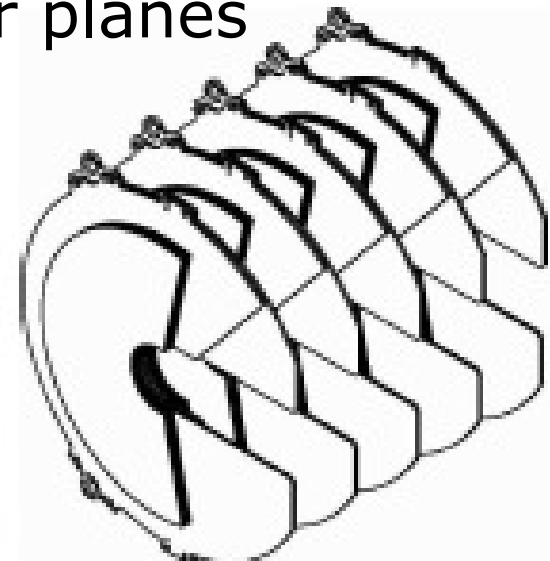
- Covers $3.1 \leq |\eta| \leq 4.7$
- Installed in CMS End Caps between vacuum chamber and iron of magnet
- Extends 7.5m to 10.5m from IP5
- 5 planes per arm
- Each plane has 6 trapezoidal cathode strip chambers (CSC)
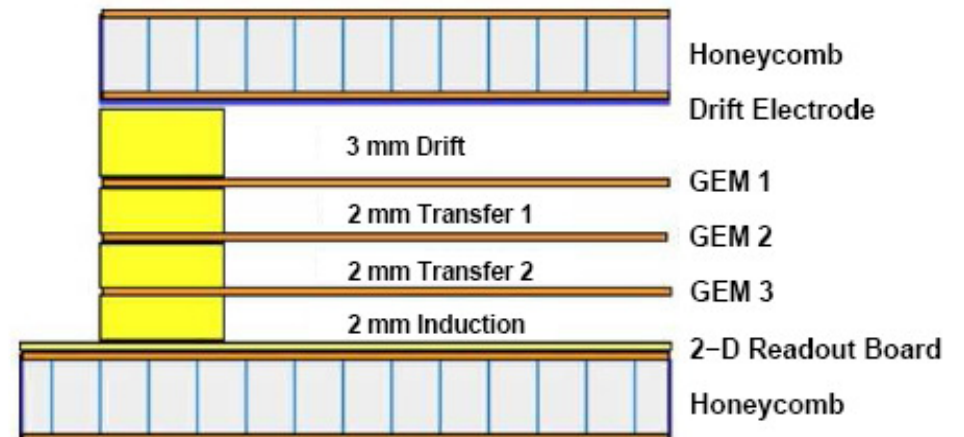- $Ar/CO_2/CF_4$ (40/50/10) gas mix
- Resolution: 0.88 mm

Detector Overview:

T2 Telescope

- Covers $5.3 \leq |\eta| \leq 6.5$
- Installed in forward shielding of CMS between vacuum chamber and inner shield of the HF calorimeter.
- Located ± 13.5m from IP5
- Each arm has 20 semi-circular GEM planes – installed in pairs to form 10 detector planes
- Ar/CO_2 70/30 gas mix
- Resolution ~100 μm

Detector Overview:

T2 Telescope

Cooling

Strip readout sector

Pad readout sectors

Mother board

HV divider

Support

Gas in/out

HV cables

Honeycomb

Drift Electrode

3 mm Drift

GEM 1

2 mm Transfer 1

GEM 2

2 mm Transfer 2

GEM 3

2 mm Induction

2–D Readout Board

Honeycomb
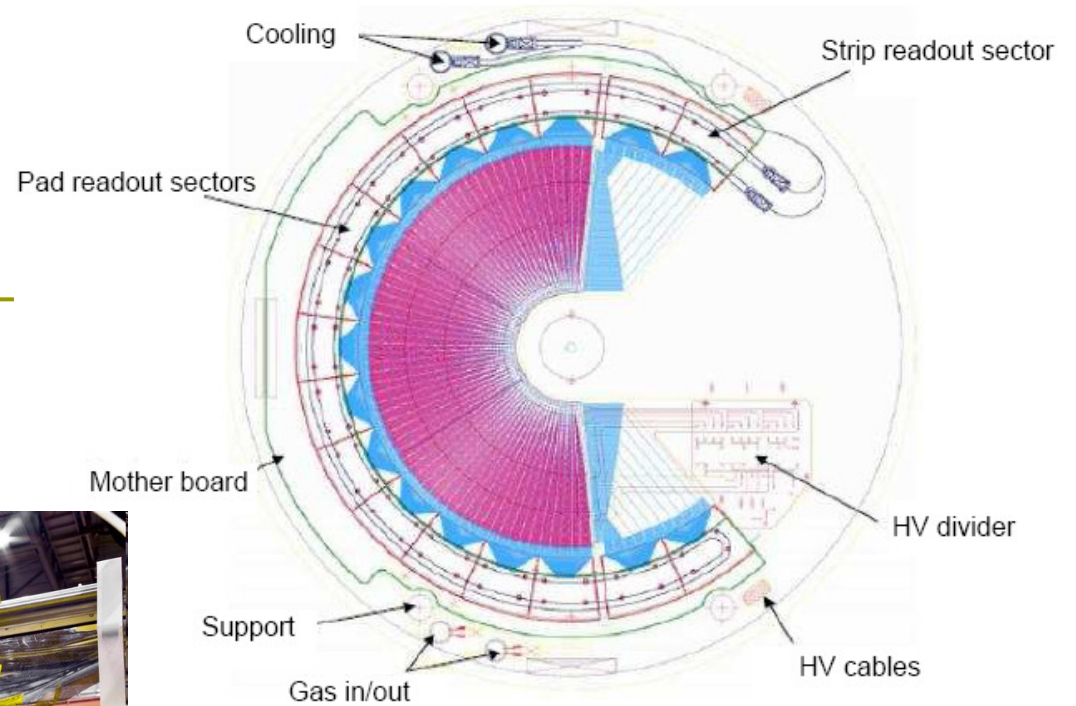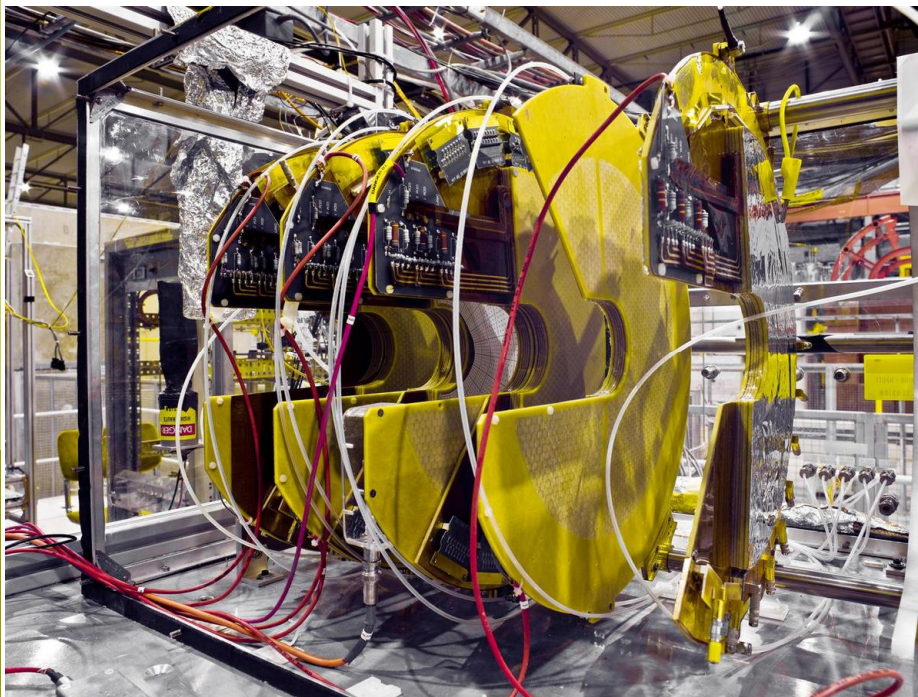
Physics Objectives

- Luminosity independent measurement of the total pp cross-section.
- Provides a measure of the luminosity of the beam.
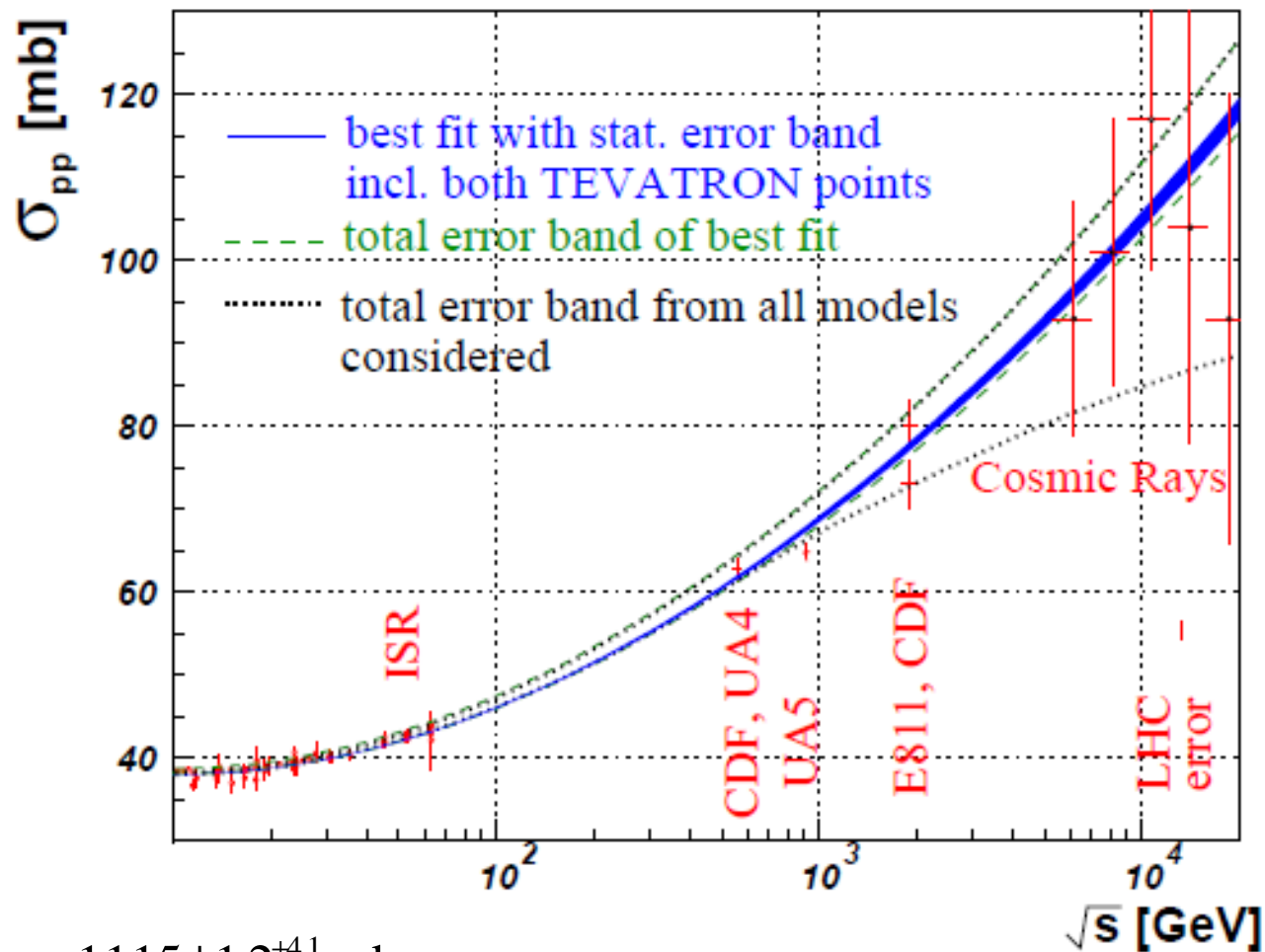- Study of forward phenomena such as elastic and detractive scattering.

Total pp Cross-Section

For LHC $\sigma_{tot} = 111.5 \pm 1.2^{+4.1}_{-2.1}$ mb

Total pp Cross-Section

- □ t = $-Q^2$ (squared four-momentum transfer)

- □ ρ = 0.14 – impact small
- □ $f_{el}(0)$ is the forward nuclear elastic amplitude - taken from theory
- □ Attempt will be made to measure ρ later on
- □ N_{el} measured by Roman Pots
- □ N_{inel} measured by T1 & T2

$$L\sigma_{tot} = \frac{16\pi}{1+\rho^2} \cdot \frac{dN_{el}}{dt}\bigg|_{t=0}$$

$$L\sigma_{tot} = N_{el} + N_{inel}$$

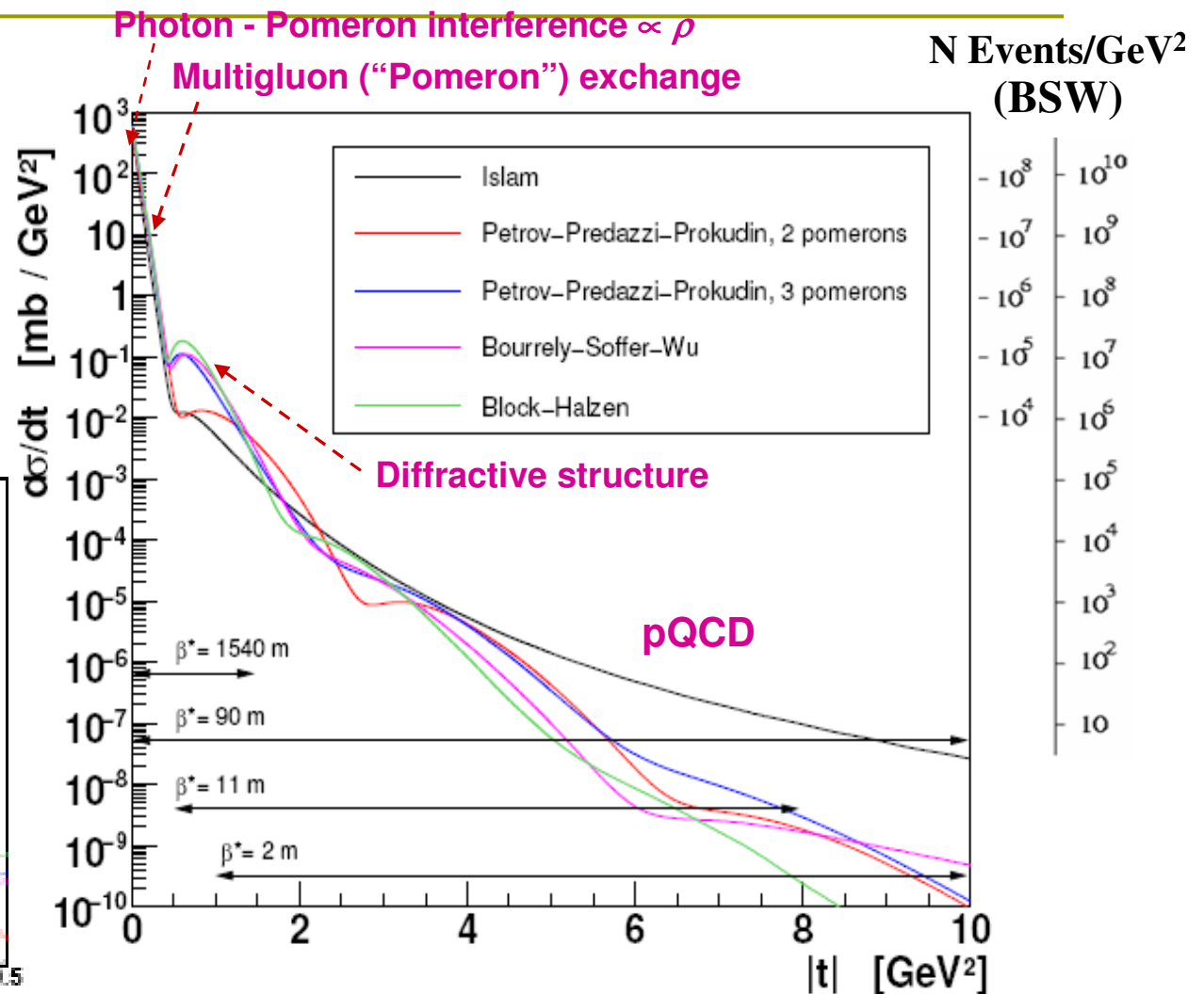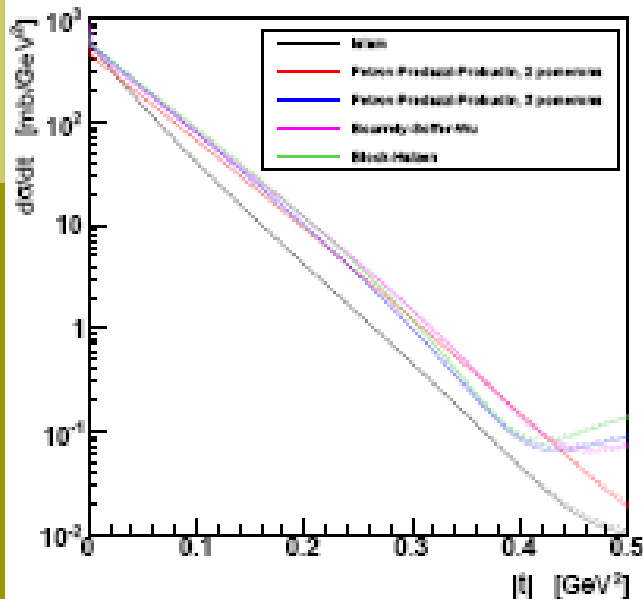$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \cdot \frac{dN_{el}/dt|_{t=0}}{N_{el} + N_{inel}}$$

$$L = \frac{1+\rho^2}{16\pi} \cdot \frac{(N_{el} + N_{inel})^2}{dN_{el}/dt|_{t=0}}$$

$$\rho = \frac{\Re[f_{el}(0)]}{\Im[f_{el}(0)]}$$

Elastic pp Scattering

- TOTEM will cover $|t| = 2\times10^{-3} - 10 \text{ GeV}^2$

- Uncertainty on extrapolation dependent on beam optics

Photon - Pomeron interference $\propto \rho$

Multigluon ("Pomeron") exchange

N Events/GeV²
(BSW)

Diffractive structure

pQCD

Islam

Petrov–Predazzi–Prokudin, 2 pomerons

Petrov–Predazzi–Prokudin, 3 pomerons

Bourrely–Soffer–Wu

Block–Halzen

$\beta^* = 1540$ m

$\beta^* = 90$ m

$\beta^* = 11$ m

$\beta^* = 2$ m

The TOTEM Experiment at the LHC

15

Inelastic Scattering

Non-diffractive

Colour exchange

Diffractive

Colourless exchange with vacuum quantum numbers

rapidity gap

Incident hadrons acquire colour and break apart
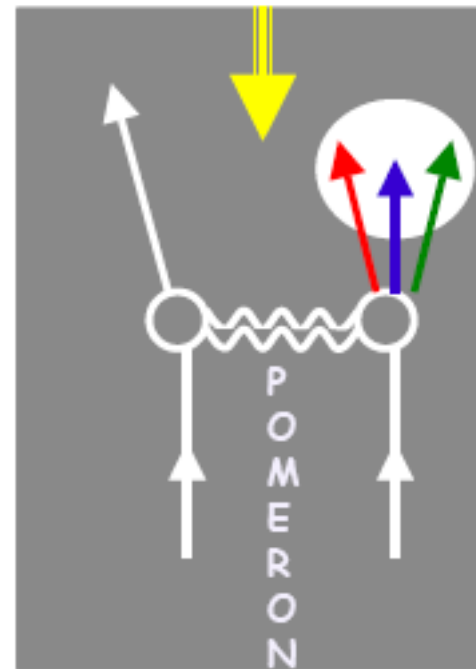
Incident hadrons retain their quantum numbers remaining colourless
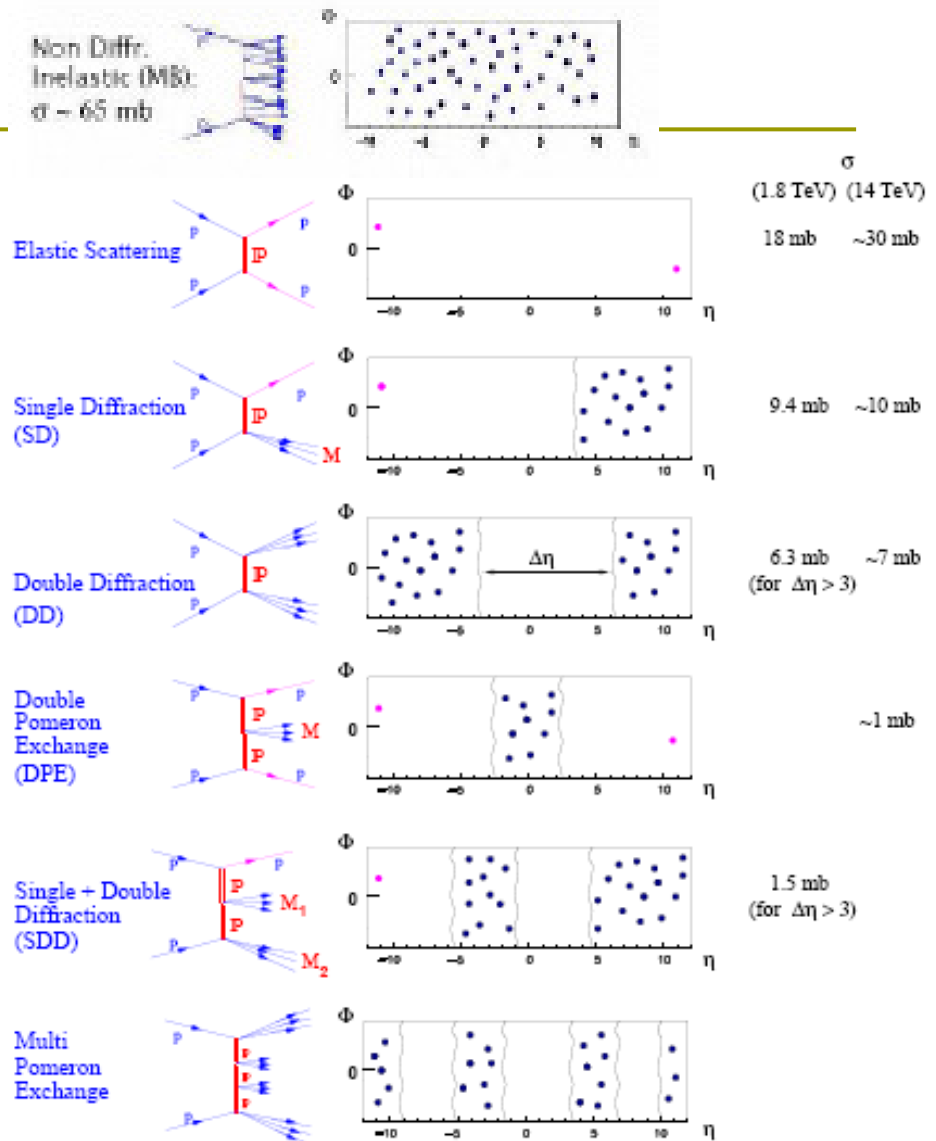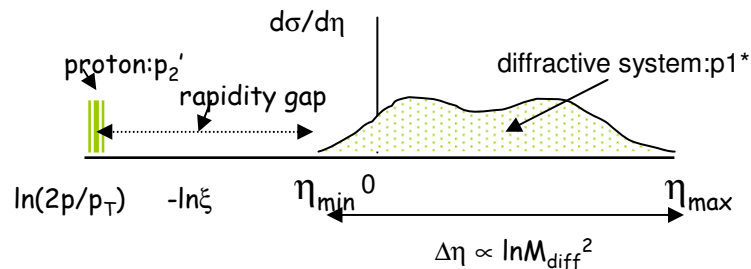
POMERON

Physics Objectives:
Scattering

- Elastic and diffractive scattering represent ~50% of the total cross-section
- Leading proton scattering within the beam pipe detected by the Roman Pots

Summary

- TOTEM will make luminosity independent measurements of the total pp cross-section
- Ready to start data taking at the start of LHC running
- ~5% precision using standard LHC beam optics
- ~1% precision using special run beam optics
- Allows discrimination between different models

The Dispersion Relation

- ρ might be measured via the interference of coulomb and hadronic contributions to the elastic scattering cross-section at a reduced centre-of-mass energy – about 8 TeV

- Interesting because it can predict σ_{tot} at higher energies via the dispersion relation,

$$\rho(s) = \frac{\pi}{2\sigma_{tot}(s)} \frac{d\sigma_{tot}}{d \ln s}$$

The Pomeron

- Postulated in 1961 to explain the slowly rising cross section of hadronic collisions at high energies.
- A "Regge Trajectory"
- No electric or colour charge
- Have the quantum numbers of the vacuum

Running Scenarios

- As beam travels down the beam pipe it oscillates around its equilibrium due to the focusing optics. The amplitude of this oscillation is the betatron function, β.

- As you near the IP, $\beta^* = \dfrac{L^{*2}}{\beta}$

Standard LHC running →

TOTEM Optics →

Scenario	β^* [m]	k	$\mathcal{L}\left[\mathrm{cm}^{-2}\mathrm{s}^{-1}\right]$	Objectives
$\beta 05$	$0.55 - 2$	$936 - 2808$	$10^{32} - 2 \cdot 10^{33}$	hard diffraction
$\beta 18$	18	$936 - 2808$	10^{32}	hard diffraction
$\beta 90$	90	156	$3 \cdot 10^{30}$	(semi-) hard diffraction
$\beta 1540$	1540	156	$2 \cdot 10^{29}$	soft diffraction