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TECHNICAL PROPOSAL

Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC

The **TOTEM** Collaboration [1]

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Abstract

In the TOTEM Letter of intent we proposed an experiment to measure the total cross section, elastic scattering and diffraction dissociation at the LHC. We discussed in details the physics motivations and the experimental method.

In this document we present the results of technical studies on the machine optics and on the installation of the experiment. We have reached positive conclusions on the three main issues which have been investigated following the recommendations of the LHCC:

- Feasibility of the experimental programme.
- Integration of TOTEM with the machine layout in I5.
- Integration of TOTEM with the host experiment (CMS).

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[1] The actual number of collaborating institutions will be expanded in due course as the project develops.

Contents

1 Introduction

The TOTEM collaboration submitted a Letter of intent [1] in August 1997 on the measurement of the total cross section, elastic scattering and diffraction dissociation at the LHC. Our Letter of intent was considered favourably by the LHC committee which encouraged our collaboration "... to submit a proposal addressing the installation of TOTEM in one of the four collision points (I1, I2, I5, I8) and its integration with the layout of the LHC and of the foreseen experiments." Afterwards the Research Board endorsed this encouragement.

Our experiment does not require intense beams and very high luminosities. It is therefore suited for running at the beginning of LHC operation.
We briefly recall the experimental programme of TOTEM as discussed in our Letter of intent :

1) Measurement of the **total cross section** with the luminosity independent method which requires simultaneous measurement of elastic scattering at low momentum transfer and of the total inelastic rate. We aim at an absolute error of about 1 mb. The measurement of the total cross section is our first objective at the earliest stage of operation of the LHC.

2) Elastic scattering in the largest possible interval of momentum transfer from the Coulomb region ($-t \sim 5 \times 10^{-4}$ GeV^2) up to at least $-t \sim 10$ GeV^2. The extrapolation to the optical point needed for the measurement of the total cross section requires detection of elastic scattering in the low momentum transfer region down to $-t \simeq 10^{-2}$ GeV^2.

3) The process of **diffraction dissociation**

$$p + p \to p + X$$

will be studied by measuring the momentum of the proton scattered quasi-elastically and detecting the decay products of the system X.

The experimental apparatus consists of:

1) Elastic scattering detectors of small size and high spatial resolution, placed symmetrically on both sides of the crossing region inside "Roman pots" which will approach the beam from above and below. Three Roman pot stations with a dipole magnet in between will be used to detect the proton which is scattered quasi-elastically in diffraction dissociation and measure its momentum.

2) A forward inelastic detector covering, on both sides of the crossing, an interval of nearly four pseudo-rapidity units in the forward direction with full azimuthal acceptance. This detector will be used for the measurement of the inelastic rate including events of diffractive type.

The luminosity independent method allows at the same time to measure the total cross section and to calibrate the TOTEM *inelastic detector* in an absolute way. This absolute calibration initially established in machine runs at low luminosity will then be used as a reference for the normal LHC runs.

The whole equipment is of small size in the direction transverse to the beam. No special infrastructure or civil engineering is needed.

Following the guidelines recommended by the committee we have performed extensive study of the feasibility of our experiment in two main directions :

- *Integration with the machine.* The design of a high-β insertion optics which is suitable for TOTEM should require neither additional magnetic elements nor a physical displacement of those already foreseen for the low-β optics to be used by the approved experiments. In addition the position of the Roman pots must be compatible with the machine hardware.

- *Integration with one of the approved experiments.* This implies the definition of an agreed layout where provision is made for the installation of the inelastic detector of TOTEM in a way which is compatible with the main experiment.

The study of the integration of TOTEM with the machine and with at least one of the approved experiments has required close interaction with the machine physicists on one side and with our experimental colleagues on the other side. We are grateful to all of them for the collaboration offered to us in the successful attempt to find a place for TOTEM at the LHC.

A first short report of the integration study was given in a Memorandum[2] sent to the LHC committee a few months ago. In that document we summarised our activity on the integration of TOTEM : we realized that TOTEM cannot be installed in I1 or I2 because our inelastic detector is not compatible with the detectors of ATLAS in I1 and ALICE in I2, as they are actually designed.

The LHC committee then made the following statement at its meeting in September 1998 : "The LHCC notes the physics interest of integrating TOTEM with a 4π experiment if possible. The collaboration is therefore encouraged to make further studies of installation at collision point 5 (with CMS), with a view to making a proposal early in 1999."

While our first objective (the measurement of the total cross section) can be carried out with our own inelastic detector, the integration of TOTEM with a full coverage experiment is certainly of interest since it opens a perspective for more detailed studies of diffractive processes.

We have then pursued the study of the integration of TOTEM with CMS in I5. The compatibility of our detector with the main experiment was studied in detail. The shape of the vacuum chamber and the sequence of operations for the installation and removal of the TOTEM inelastic detector have also been discussed.

The study of the integration of TOTEM with the machine both in terms of the optics and of the layout, has led to the design of an insertion optics [3] with a value of the beta function at the crossing β^*= 1100 m, tunable down to $\beta^* \simeq 20$ m which is the typical value for the injection. The basic guideline for this study was to avoid using new magnetic elements in addition to those already foreseen for the low-β optics. The tunable optics designed for TOTEM is suitable for measuring elastic scattering from about 10^{-2} GeV^2 (as needed for the total cross section) up to about 10 GeV^2. The high-β optics in I5 and I8 are about equivalent.

It also turns out that it is possible to implement a forward spectrometer based on three Roman pot stations with the dipole magnet D2 of the standard insertion between two of them. A good momentum resolution can be achieved as a result of the strong bending power of the insertion dipoles.

The possibility of measuring elastic scattering in the region of Coulomb interference for the determination of the real part of the amplitude is perhaps not out of reach. A solution has not been found yet but the problem is being further investigated.

It is worth noticing that if the LHC would make a special run at lower energies (for example at the Tevatron energy) elastic scattering in the Coulomb interference region could be measured even with the high-β optics presently designed ($\beta^* = 1100$ m).

The purpose of this Technical Proposal is to inform the LHCC of the successful conclusion of our study on the integration of TOTEM in intersection region I5 with CMS. The position of the Roman pot stations is practically defined as well as the size and position of the inelastic detector.
Discussions with LHCb on the possibility of installation in I8 have also taken place but no definite conclusion has been reached.

The final technical solution for several important items of our experiment is not defined yet. Crucial points are an innovative design of the Roman pot detectors which must have good spatial resolution and very small dead space at their edge and the design of a reliable and inexpensive inelastic detector suitable not only for the measurement of the total cross section but also as reference for absolute calibration of the machine luminosity. In this document we mention the different options that we are actually studying. For the inelastic detector which is linked to the host experiment we present our preliminary views on a technical solution which is being studied. We believe, however, that the modest size and complexity of our experiment do not demand an early definition of these items.

2 The operation of TOTEM

The measurement of the total cross section and diffractive processes at low t can be performed only with special optics at high-β (β^*= 1000 - 1500 m) which allows detection of particles emitted at very small angles. For these measurements TOTEM will have to be the main user in intersection I5.

The operation of TOTEM with high-β needs to be specified. The cross sections are large and therefore the measurements can be performed at relatively low luminosity during the early running-in phase of the LHC.

We propose to run with a small (*effective*) luminosity of the order of 10^{28} cm^{-2} s^{-1} and reduced number of bunches during short data taking periods typically of a few days.

The number of bunches could be 36 which is compatible with the LHC injection scheme and is foreseen for machine development studies. In this case the separation between bunches would be about 740 m corresponding to 2.5 μs. This scheme has two very desirable features. The large bunch spacing allows zero crossing angle and there is no time overlap between incoming and outgoing bunches as seen by the Roman pots which will be located at distances from 100 m to 200 m from the crossing point. The large bunch separation also greatly simplifies the detectors and the associated electronics eliminating a complication which is totally unnecessary for an experiment which does not require large luminosity.

The effective luminosity L_{TOTEM} of the TOTEM experiment is scaled down from the nominal LHC luminosity $L_{nom} = 10^{34}$ cm^{-2} s^{-1} at β^*= 0.5 m by two large factors, namely:

- the ratio of the beta functions at crossing for the nominal and for TOTEM operation, $\beta_{nom} \simeq 0.5$ m to $\beta_{TOTEM} \simeq 1000$ - 1500 m, i.e. a factor $\approx 10^{-3}$
- the ratio of the number of bunches, $n_{TOTEM}/\ n_{nom} \approx 10^{-2}$

The overall reduction factor is therefore of the order of 10^{-5}. As effective luminosity of TOTEM during the special high-β runs we then take the safe value L = 10^{28} cm^{-2} s^{-1}.

Due to the peculiar machine conditions, i.e. high-β optics and large bunch spacing, the experiment could best be done in special runs following the machine development sessions during the setting-up periods of the LHC.

While TOTEM can be physically integrated into the CMS detector, i.e. occupying part of the inner cone with $\mid \eta \mid \geq 3$ down to the limitation imposed by the size of the vacuum chamber, the actual running of TOTEM will have to take place in dedicated runs due to the special conditions of high-β and large bunch spacing.

The exact running scenario including the switchover procedure will be elaborated in due course. In order to minimize the switchover time needed between TOTEM and CMS runs no major changes are foreseen as far as mechanics and beam pipe are concerned. During the normal LHC runs when CMS is the main user, TOTEM will run parasitically for setting up. While it is desirable to have independent runs at the beginning, it is equally important to be able to run both experiments together.

Running at L $\sim 10^{28}$ cm^{-2} s^{-1} would allow to collect $\sim 10^7$ elastic events per day assuming σ_{tot} = 110 mb ($\sim$ 30% elastic) and an overall running efficiency of $\sim$ 50%. This value of the luminosity has been taken as a reference for the total cross section and low-t elastic scattering when discussing rates and backgrounds. It is clear that even a luminosity lower by one order of magnitude would not cause any problem.

The experimental programme of TOTEM also includes the measurement of elastic scattering at large momentum transfer which requires a medium-β optics. As a practical example we have considered the injection optics which has $\beta^* = 18$ m.

3 The Roman pot layout

In this Section we first present the proposed layout of the Roman pots in the straight section I5 of the LHC and the design of the insertion optics with high-β. Afterwards we discuss the measurement of elastic scattering and the performance of the forward magnetic spectrometer for diffraction dissociation.

3.1 The Roman pot system

The TOTEM Roman pots will be smaller than those used at the lower energy accelerators (SPS Collider and HERA) but similar to those used at the Tevatron which may serve as a basis for further technical developments. In Fig.1 we show the picture of a Roman pot that was designed and built at CERN. The pot itself is 8 cm wide. It has a 0.1 mm thick window whose effective area is 3 cm x 2 cm. The overall mechanical structure with two Roman pots connected by bellows to the machine pipe is shown in Fig.2. A design study of the adaptation of this system for the LHC is in progress.

Figure 1: Picture of the Roman pot. The thin window is clearly visible. The section facing the beam is concave in shape to allow a closer approach to the beam.

The detectors inside the pots are of small size (only few cm^2). As will be discussed in the next Sections, a space resolution of about 30 μm would match naturally our physics requirements and the properties of the beam optics. There is no critical requirement on the time resolution because we will operate the detectors in dedicated runs with large bunch spacing.
At present we are considering three options :

- Silicon detectors with (x,y,u) strips or of drift type.
- Scintillating fibers.
- Optoelectronic detectors.

Silicon detectors with strips or pads have been used as Roman pot detectors by the CDF collaboration[4] at the Tevatron and by ZEUS at HERA. The proton-proton elastic scattering experiment[5] in preparation at the BNL collider RHIC also plans to use silicon detectors. Scintillating fibers were used by UA4/2[6] at the SPS collider and recently by

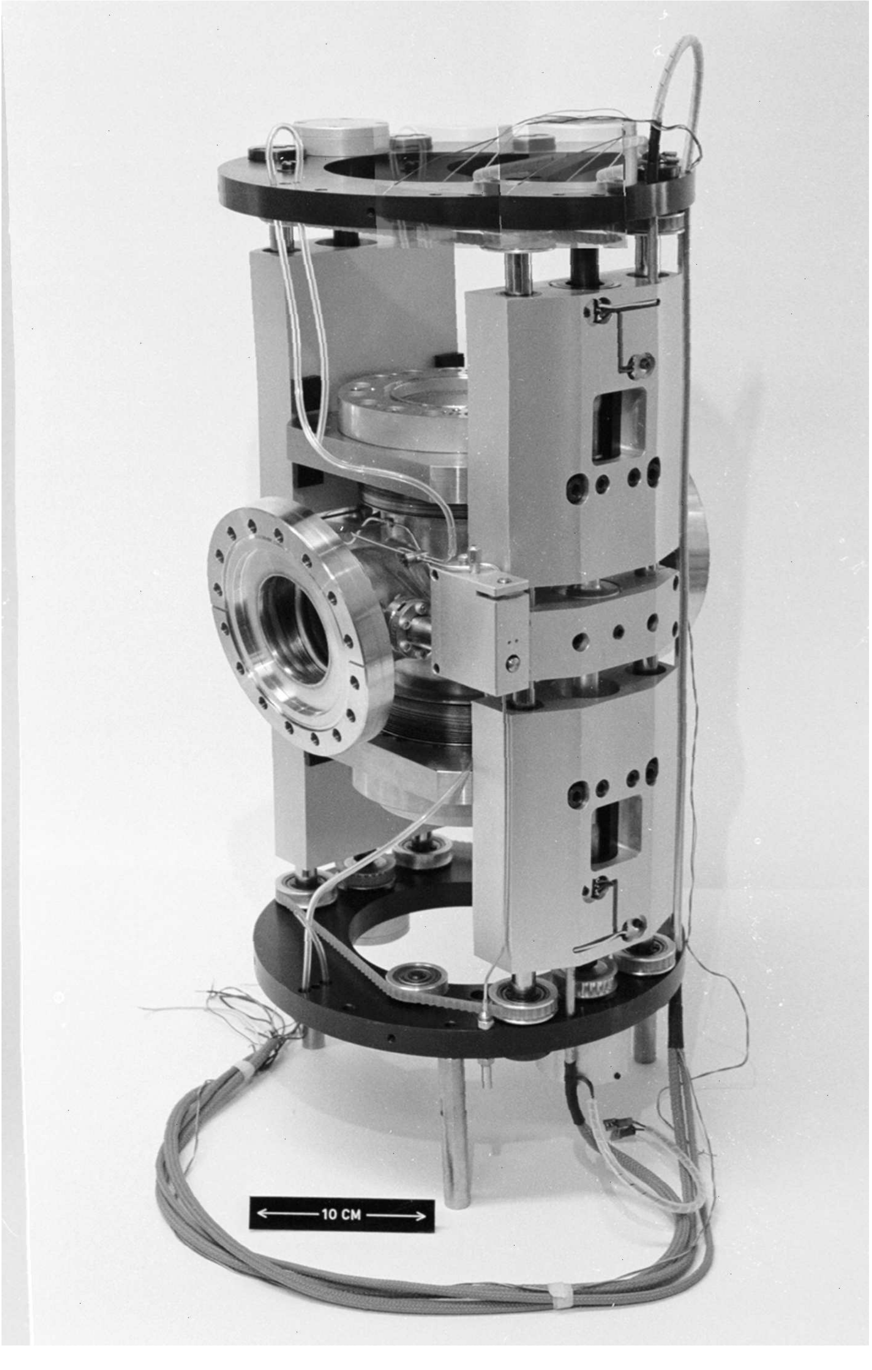

Figure 2: Picture of the mechanical structure of one Roman pot unit. The detectors approach the beam vertically from above and below.

CDF[7]. In addition to these classical and well known technical solutions, we wish to investigate innovative designs as for example an optoelectronic device[8].

The main technical problem is the need to have detectors efficient even very close to the physical edge of the detector itself. In other words the detector has to be “frameless” on one side (the side which is touching the bottom window of the Roman pot, i.e. facing the beam). This is a special and really peculiar requirement of our experiment. The choice and development of the detectors will proceed together with the design of the Roman pot mechanics.

We plan to combine two Roman pot units in a single rigid mechanical structure, the Roman pot station, as sketched in Fig.3 and 4. One station contains four detectors arranged in two symmetrical telescopes above and below the machine plane. Mounting on a rigid structure will allow accurate alignment of the detectors with respect to each other and is also very convenient for transportation and installation.

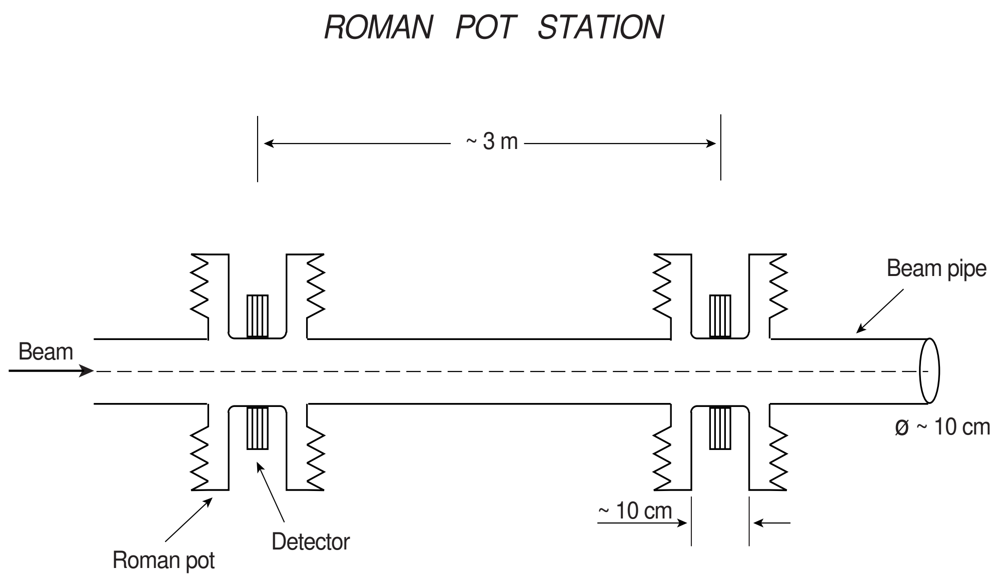

Figure 3: Sketch of a Roman pot station which consists of two units about 3 meters apart. The detectors are arranged in two symmetrical telescopes above and below the machine plane.

3.2 The insertion optics

The properties of the high-β optics required for the measurement of the total cross-section are discussed in detail in our Letter of intent and can be summarised as follows:

- A parallel to point focusing, in the vertical plane, between the crossing point and the Roman pots. This implies that the phase advance $\Delta\psi$ from crossing to the Roman pots must be $(2n+1)\pi/2$. This condition ensures that all protons scattered in the vertical plane at the same angle are brought together to the same vertical position in the detectors, independently of the actual vertical position of the collision point.

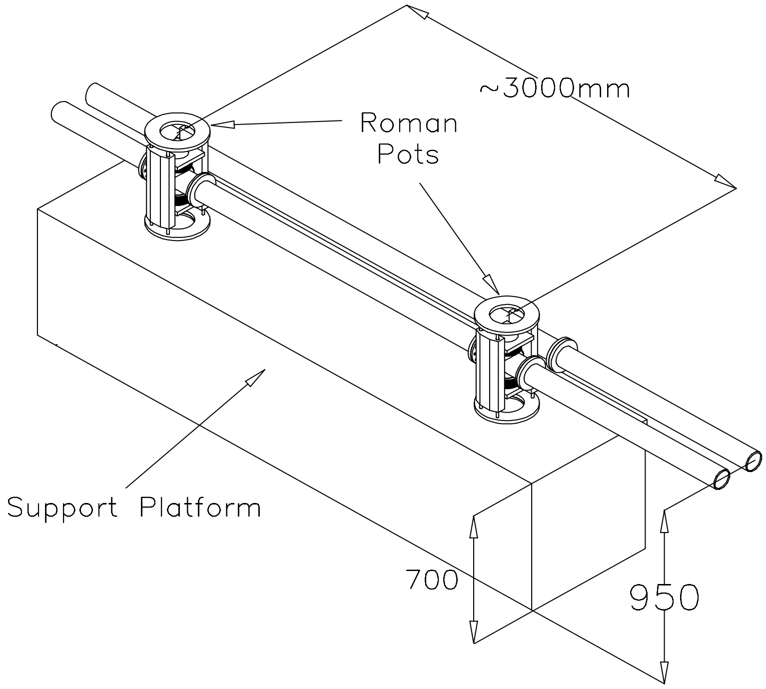

Figure 4: A station of two Roman pot units.

- Large value of the beta function β^* at the crossing to provide access to small scattering angles. For $\beta^* \simeq 1000$ m, the beam divergence is small compared to the scattering angles to be measured.
- The effective distance of the detectors from the crossing point, L_{eff}, must be at least 150 m in order to provide a sufficiently large value of the displacement of the proton trajectory with respect to the beam axis.

A detailed study was performed to implement a high-β optics at I5 without any modification of the layout of the machine elements, i.e. without adding new magnetic elements or displacing those which are already foreseen. Independent powering of the quadrupoles of the low-β triplet is required for this optics. As a consequence the insertion would remain optimised for high luminosity running and the installation of TOTEM would have no undesirable impact on the LHC performance. Various solutions for the high-β optics are presented in detail in ref.3 and summarised in ref.9. In addition an analytic approach is discussed in ref.10.

The behaviour of the beta functions and the dispersion of the optics designed for TOTEM in I5, are shown in Fig.5. For this optics the phase advance in the vertical plane is $\Delta\psi = \pi/2$ just at the entrance of the dipole D2, at the distance of 155 m from the crossing. This is the place where the Roman pot station for measuring elastic scattering at low-t must be placed.

The layout of the insertion is shown in Fig.6. From the optical point of view the system is quite simple because the quadrupoles of the inner triplet form a lens which, in

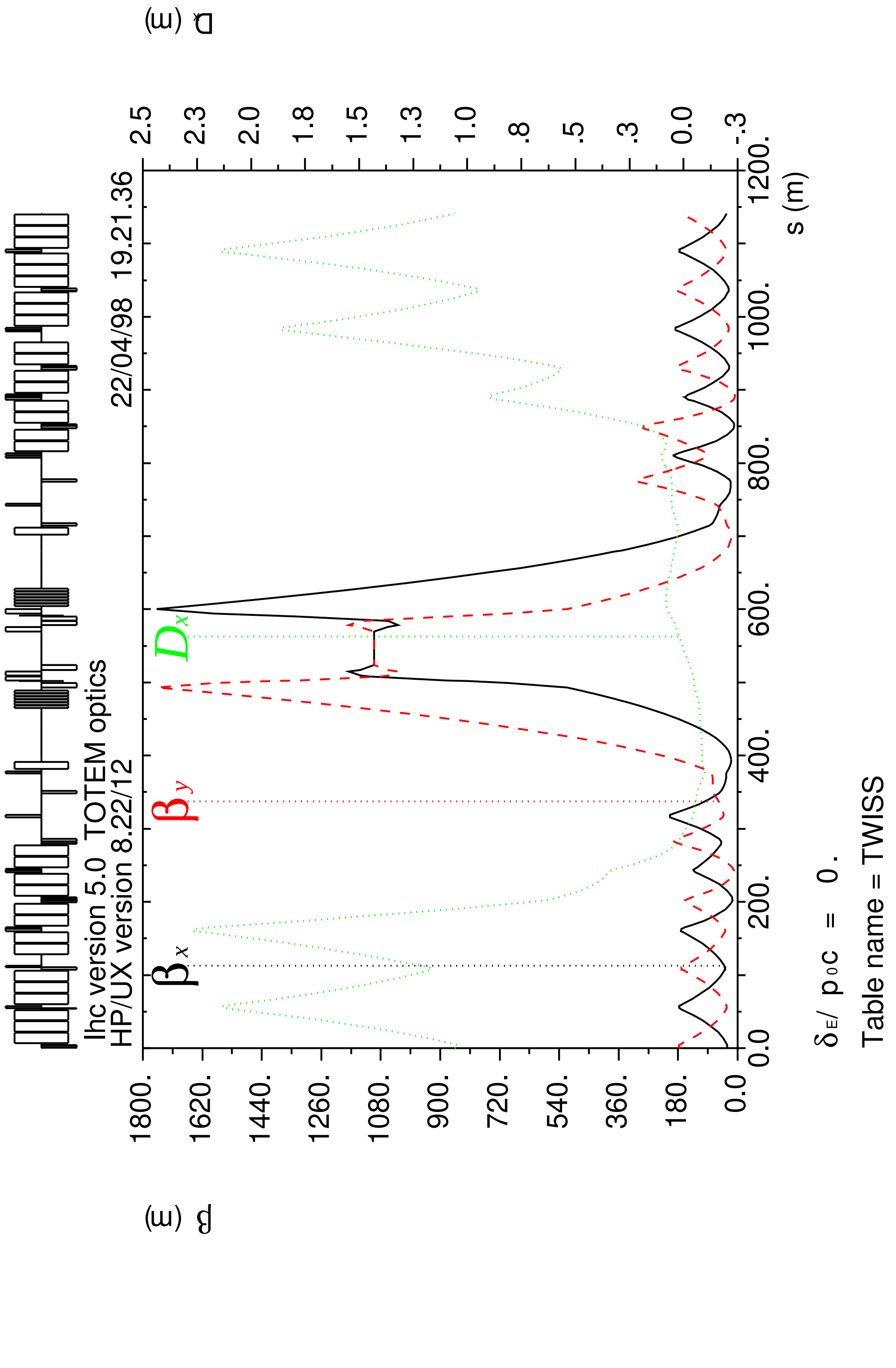

Figure 5: The high-β optics with β^*= 1100 m designed for TOTEM in I5. The beta functions in the horizontal plane (full line), in the vertical plane (dashed line) and the dispersion (dotted line) are shown.

the vertical plane, focuses the scattered protons just in front of D2. The dipole D1 has no focusing effect. This simplicity allows good understanding of the system itself. The calculation of the particle trajectories is therefore accurate and reliable.

There is a continuity of solutions from the injection optics to the high-β setting shown on Fig.5 which ensures that the intermediate t values can be measured under optimal conditions.

A high value of β^* means that the beams are large at the interaction point and therefore, if the bunches have the standard separation of 25 ns, the nominal crossing angle (about 150 μrad) is not sufficient to avoid parasitic collisions. The aperture of the focusing quadrupoles prohibits a substantial increase of this crossing angle and it is mandatory to increase the bunch spacing to ensure the stability of the beam. When this is achieved, there is no need for any crossing angle between the two counter-rotating beams, and this enlarges the geometrical aperture available in the low-β quadrupoles.

3.3 Integration with the LHC

We first give a short description of the main elements of the insertion I5 which is shown in Fig.6 while a sketch of the underground area is shown in Fig.7.

The strong focusing low-β inner triplet (Q1, Q2 and Q3) provides the small beam size required for high luminosity. The pairs of dipoles D1/D2 located on each side of the interaction point bend the orbits to collide and then back into their respective vacuum chambers. The twin aperture quadrupoles Q4 to Q7 are used to match the machine optics parameters to the arc.

The protection of the superconducting magnets against the flux of secondary particles produced in p-p collisions at high luminosity is a major concern in the design of the insertion:

• The TAS collimators intercept the secondary particles which otherwise would hit the coils of the low-β quadrupoles.

• A large fraction of the charged particles produced along the beam axis ends in the D1 dipoles which are warm magnets.

• Neutral particles which pass the TAS collimators go straight into the TAN absorbers which protect the D2 dipoles.

The cold sections thus start from the D2 magnets and extend to the LHC arcs. The cold-warm transitions that bring the power inside the cryostats are concentrated in the large DFB cryo-boxes located between the quadrupoles Q4 and Q5. The service caverns RR53 and RR57 excavated along these cryo-boxes host the power converters of the main LHC magnets (see Fig.7).

The integration of TOTEM in the LHC implies provision for warm locations of the Roman pots.

The long drift between the recombination/separation dipoles D1 and D2 is a warm section where Roman pots can be installed. The low-t station, RP2, will be close to D2. The large-t station, RP1, is closer to D1.

The general concept of the insertion, with a final focusing system of low-β quadrupoles and a matching section of four quadrupoles (Q4 to Q7) has proven to be very flexible. In fact optics with $\beta^* = 1100$ m and parallel to point transport from the collision point

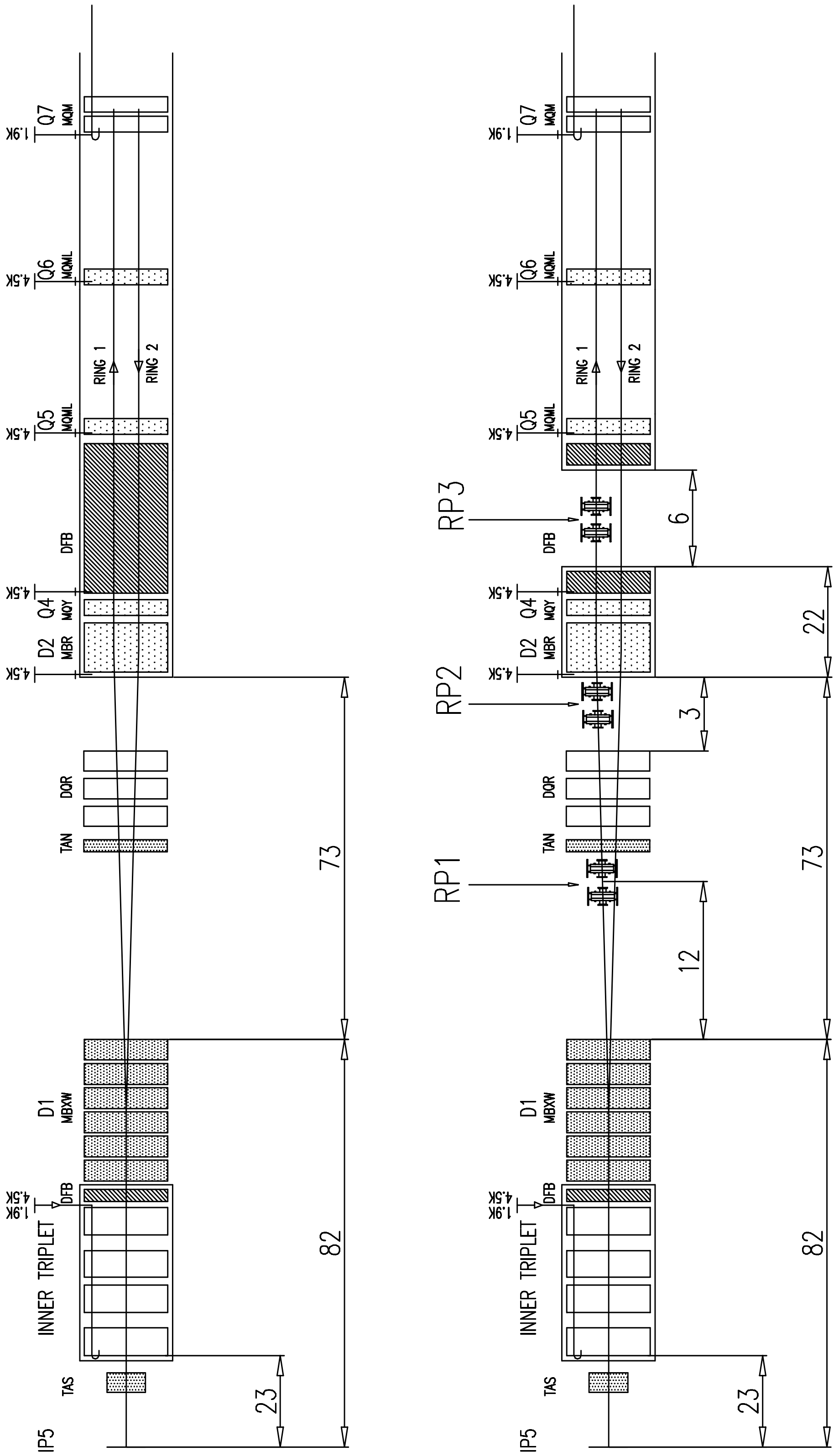

Figure 6: The insertion I5. The upper part reproduces the standard insertion while the lower part shows the location of the three Roman pot stations RP1, RP2 and RP3. The layout is symmetric with respect to the interaction point.

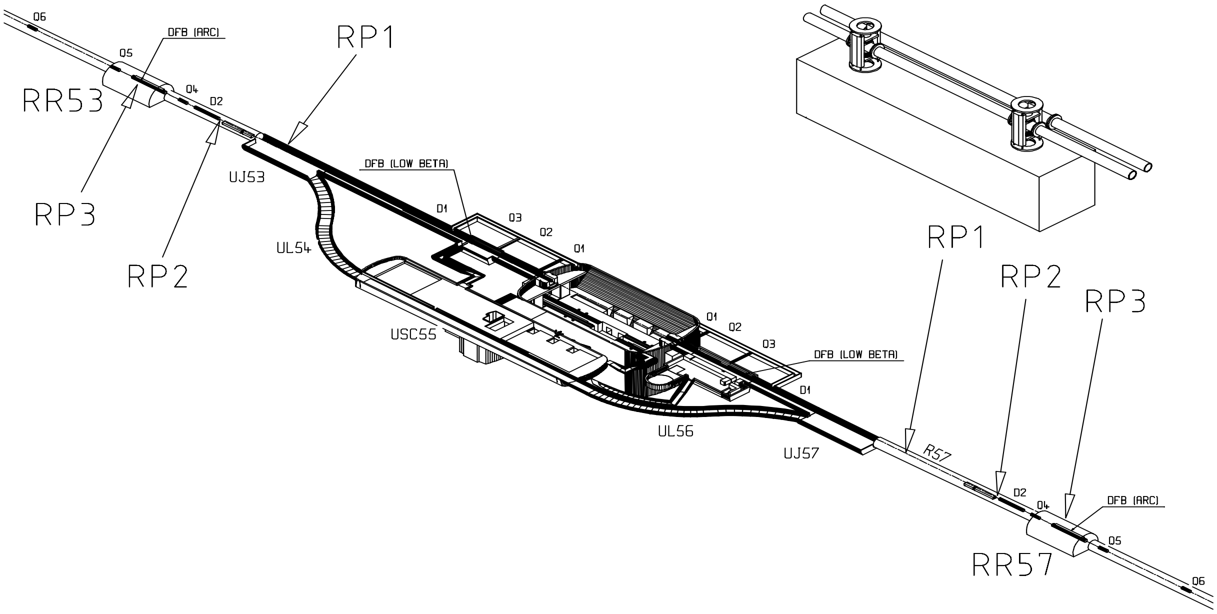

Figure 7: Sketch of the underground area and machine equipment at I5. The location of the Roman pot stations inside the LHC tunnel is also shown.

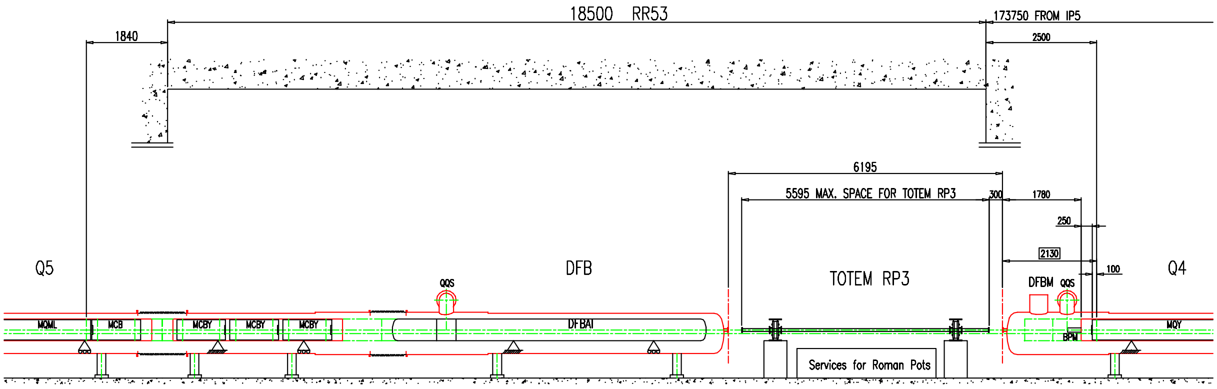

Figure 8: Detail of the region between Q4 and Q5.

to the Roman pots can be achieved with a simple re-tuning of the quadrupole strengths. However, while a pure triplet is the optimum focusing system for the small beam sizes required at high luminosity, independent adjustment of the three quadrupoles is required to get a high-β optics with $L_{eff} = 150$ m. This implies that an individual power supply for each of the low-β quadrupoles should be provided, instead of a common power supply that feeds the three quadrupoles in series. This modified powering scheme needs two extra cold-warm current leads in the cryo-feed box of the triplet.

In order to study diffraction dissociation, we need to measure the momentum of the scattered proton by using D2 as the spectrometer analysing dipole. The two Roman pot stations RP1 and RP2 situated between D1 and D2 provide a precise initial angular measurement while the third Roman pot station RP3 situated behind D2 measures the deflection angle. The provision of a warm section for this third Roman pot station implies that the long cryostat, starting at D2 and extending to the LHC arcs, has to be modified. The problem is to feed and transport the power to the main LHC dipoles and quadrupoles, and the solution retained is to split the cryostat between Q4 and Q5.

This solution presents important advantages:

• The caverns RR53 and RR57 are still adequate to host the power converters of the LHC magnets in the matching sections, dispersion suppressors and arcs. Therefore there is no need for extra civil engineering.

• The cryo-feed box for Q4 and D2 will be of the same type as the one foreseen in the insertions I2 and I8. Extra hardware development is therefore reduced.

Studies along this line are well advanced. A detailed drawing of the modified area is shown in Fig.8.

3.4 Elastic scattering

3.4.1 Low momentum transfer

Data on elastic scattering at low t will be extrapolated to t=0 in order to measure the total cross section with the luminosity independent method. As discussed in our Letter of intent, for an accurate extrapolation, measuring to values of the momentum transfer as low as $-t \approx 10^{-2}\mathrm{GeV}^2$ is required.

In this Section we discuss the measurement of elastic scattering at low momentum transfer using the high-β optics shown in Fig.5. We use the nominal value of the normalized transverse emittance, $\epsilon_n = 3.75 \times 10^{-6}$ m×rad. The corresponding actual emittance at 7 TeV is $\epsilon = 5 \times 10^{-10}$ m×rad. The parameters of the beam optics which are relevant for physics are listed below:

The beam size σ^* and the beam angular spread $\sigma^{*'}$ at the crossing (r.m.s. values) are:

• $\sigma^* = 0.74$ mm

• $\sigma^{*'} = 0.67$ μrad

The transfer matrices in the horizontal and vertical plane at the position with $\Delta\psi = \pi/2$ where the Roman pot station RP2 is placed, are (distances are expressed in *meters*):

$$M_H = \begin{pmatrix} 0.373 & 100.0 \\ -0.009 & 0.336 \end{pmatrix}$$

$$M_V = \begin{pmatrix} 0.001 & 148.7 \\ -0.007 & 1.030 \end{pmatrix}$$

In the vertical plane we have *parallel to point focusing* from the crossing to the Roman pots as required.

In practice the most relevant quantities are the elements M_{12} of the matrices that we call effective distances :

- L^H_{eff} = 100.0 m
- L^V_{eff} = 148.1 m

At the place of the detectors the beta functions and the beam size in the horizontal and vertical plane are:

- β^H_d = 162.5 m , σ^H_d= 0.28 mm
- β^V_d = 20.1 m , σ^V_d= 0.10 mm

As an illustration of the properties of the high-β optics we plot in Fig.9 the trajectories of protons scattered in the vertical plane at an angle of 20 μrad (corresponding to $-t = 2{\times}10^{-2}$ GeV^2) for two different vertical positions of the collision point, y*= 0 and y*=σ^*. The two trajectories join at the Roman pot position RP2, in front of the dipole D2. The vertical size of the beam σ_{beam} (r.m.s. value) as a function of the distance from the crossing point is also shown. For the value of t considered, the displacement of the trajectories at the detectors is about 30 times larger than σ_{beam}.

The ultimate angular resolution on the measured scattering angle is given by the intrinsic angular spread of the beams $\sigma^{*'}$. The corresponding size of the spot on the detectors is obtained by multiplying the angular spread by the effective distance.

- Δx_{spot}= 67 μm
- Δy_{spot}= 100 μm

As already mentioned in Sec.3.1, we assume for the space resolution of the detectors 30 μm which is certainly realistic for small size detectors using modern techniques. The detector resolution being less than 1/2 of the spot size due to the beam angular spread, the contribution of the detectors to the overall angular resolution is negligible.

Elastic scattering events will be observed with the two Roman pot stations RP2 placed symmetrically on both sides of the crossing region at $\Delta\psi = \pi/2$. Two units, forming a telescope, are needed on each side both for redundancy and for measuring the direction of the scattered protons.

Each telescope will not measure the direction of scattered protons with an accuracy sufficient for the determination of the scattering angle which is instead obtained from the position of the trajectory at the Roman pot telescopes and from the known values of the effective distances L_{eff}. Telescopes, however, are needed to reconstruct the position of the collision points on the transverse plane at z=0. We know from our previous experience at

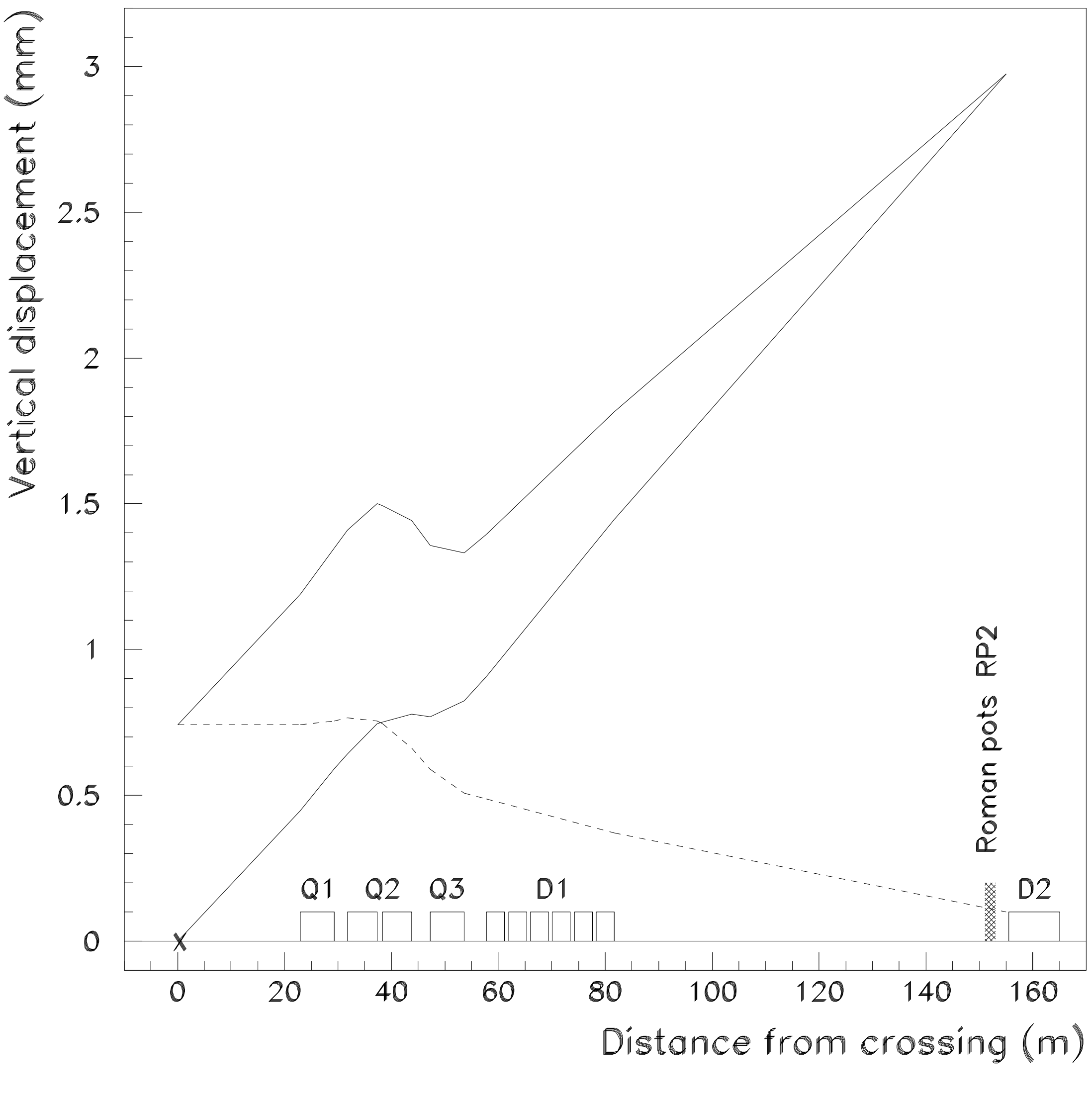

Figure 9: Trajectories of protons scattered in the vertical plane at the same angle of 20 μrad, corresponding to -t=2×10^{-2} GeV^2, with two different vertical positions of the collision point, $y^*=0$ and $y^*=\sigma^*$ (full lines). The r.m.s. value of the beam size is shown as a dashed line.

the SPS collider that this is important to remove background due to beam-gas and beam-wall interactions. Monte Carlo simulation of the track extrapolation to the transverse plane at the crossing is shown in Fig.10. The foreseen resolution of 30 μm together with the 3 m lever arm of the telescope is of course not sufficient to provide the actual shape of the interaction region but it allows clear separation of the collision points from the wall of the vacuum chamber. The determination of the longitudinal position of the crossing point cannot be done with this method because the scattering angles are so small that the extrapolation is too inaccurate. On the other hand a good measurement of the longitudinal position with precision of about 10 cm is obtained from the time of flight difference between the scintillation counters used on both arms for triggering.

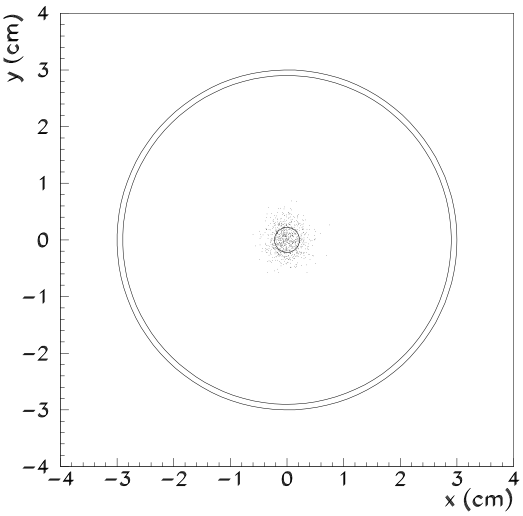

Figure 10: Distribution of the collision points for elastic events detected by the telescope RP2 and reconstructed by extrapolation to the transverse plane at z=0. The small circle represents the size of the crossing region at the $3\times\sigma$ level. The section of the Be vacuum chamber at I5 is also indicated.

Accurate knowledge of the acceptance at the lower extreme of the explored momentum transfer range is important because it affects the accuracy on the extrapolation to t=0 and therefore the precision on the total cross section.

As discussed in our Letter of intent, detailed calculations on the system of collimation foreseen for the LHC [11] have shown that the collimators will remove the halo of the beam at distances above $10\times\sigma_{beam}$. Therefore the value of $10\times\sigma_{beam}=$ 1 mm is presumably a lower limit for the edge of the pot while $15\times\sigma_{beam}=$ 1.5 mm should be a safe estimate. The window of the pot will be only 0.1 mm thick. The detectors located inside the Roman pot may not have full efficiency down to their physical edge. An inefficiency region of a few tenths of *millimeter* has to be foreseen.

It is clear that there are at present uncertainties on all these parameters. However, the behaviour of the efficiency close to the detector edge will be monitored from the data itself by studying the density population of elastic events having the same polar scattering angle, along the ellipse which corresponds to different azimuthal angles.

In Fig.11 Monte Carlo calculation of the geometrical acceptance at the lower extreme of the t-range is shown assuming the detector to be efficient at 2.0 mm from the beam (corresponding to $15\times\sigma_{beam}$ + 0.5 mm). At present we believe that the minimum value of the t-distribution where acceptance can be used with confidence should be $-t \simeq 2\times10^{-2}$ GeV^2. For this momentum transfer, the vertical displacement of the trajectories at RP2 is 30 times larger than σ_{beam}. The overall geometrical acceptance in the full t-range is shown in Fig.12. The size of the detector is of 3.0 cm $\times$ 2.5 cm (horizontal $\times$ vertical).

An illustration of the relevant geometrical parameters as the size of the beam, of the detectors and of the vacuum chamber is given in Fig.13.

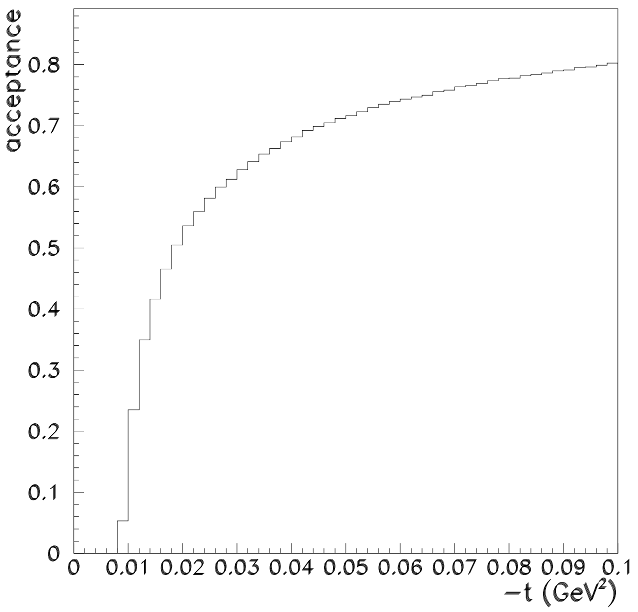

Figure 11: The geometrical acceptance of the Roman pots station RP2 in the low-t region for the high-β optics.

As already discussed, for the high-β runs the reference luminosity is L = 10^{28} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The elastic trigger rate will be of the order of 300 events/s. Assuming an overall running efficiency of about 50%, the effective integrated luminosity in one day of data taking is 5×10^5 mb^{-1}. In Table 1 the expected number of events per day as a function of t in a given t bin is listed. The quoted values of the differential cross section are obtained by extrapolating present data (see ref.1).

It is clear from the rates given in Table 1 that the measurement of low-t elastic scattering needed for the total cross section can very well be performed even with a luminosity at least one order of magnitude less than the reference value of 10^{28} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

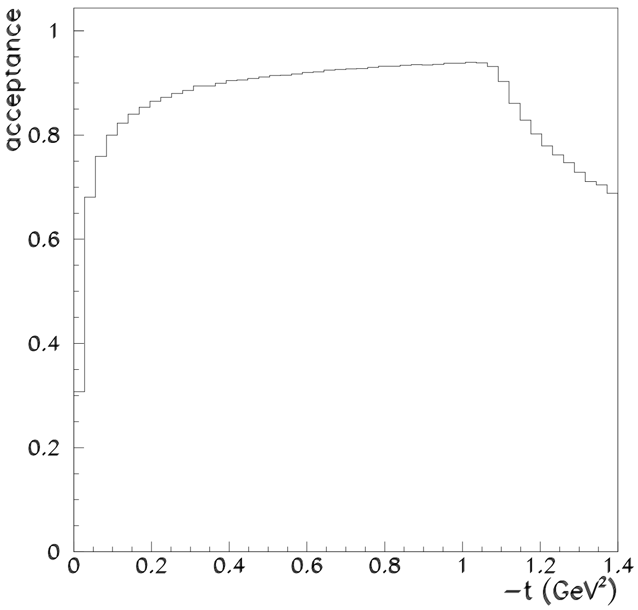

Figure 12: The full geometrical acceptance of RP2 for the high-β optics.

$\mid t \mid$(GeV^2)	$d\sigma/dt$ (mb/GeV^2)	t-bin (GeV^2)	Number of events/day
0.02	400.	0.001	1.1×10^5
0.05	220.	0.001	8×10^4
0.10	80.	0.002	6×10^4
0.25	1.	0.005	2×10^3
0.50	0.02	0.02	2×10^2
1.00	0.005	0.02	50

Table 1. Expected number of events per day in the high-β run as a function of t in a given t-bin. The luminosity of the high-β run is assumed to be L = 10^{28} cm^{-2}s^{-1}.

The error $\Delta\vartheta$ on the scattering angle is independent of ϑ. From the assumption we have made on the space resolution of the detectors it follows that $\Delta\vartheta \simeq \sigma^{*'}/\sqrt{2}$, i.e. the error on the scattering angle is essentially due to the angular spread of the beams. Numerically $\Delta\vartheta \simeq 0.5$ μrad, which can be compared to the smallest value of the scattering angle which is about 20 μrad.

In terms of momentum transfer the resolution is $\Delta t = 2p\sqrt{\mid t \mid}\ \Delta\vartheta$. Numerically, $\Delta t \approx 0.7 \times 10^{-2}\sqrt{\mid t \mid}$. This is adequate because in the low-t region where the cross section decreases fast, as $\exp(-B \mid t \mid)$ with B $\approx$ 20 GeV^{-2}, the variation of the cross section in a t-interval equal to the t-resolution is only of a few percent.

Operation with emittance reduced by a factor of about 3 is foreseen[12] during the commissioning of the LHC. All measurements with the Roman pots will of course benefit

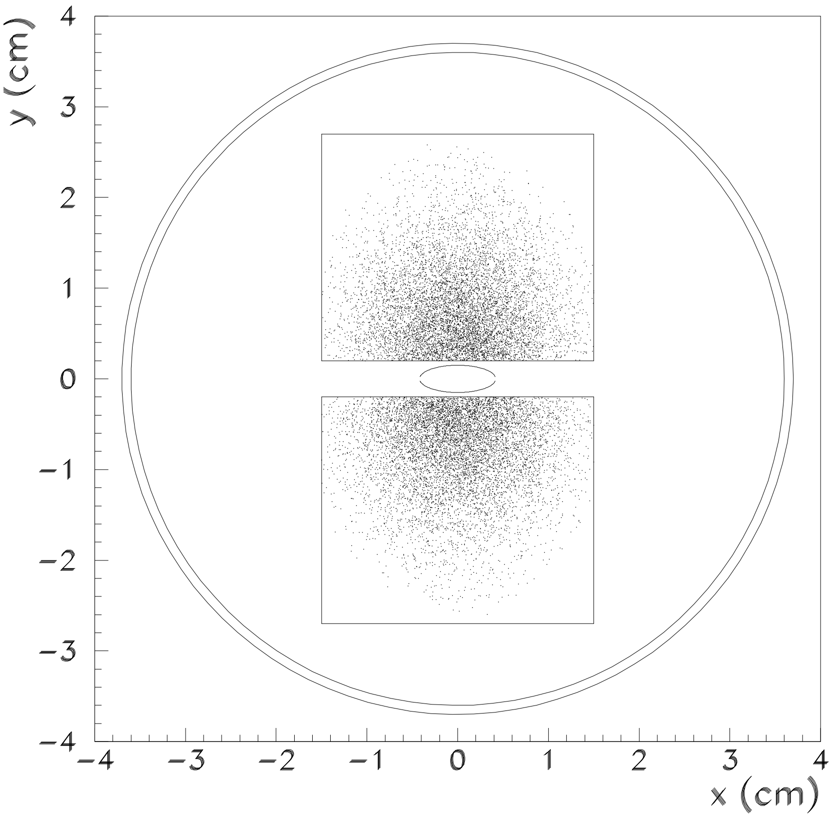

Figure 13: Sketch of the geometry at the Roman pot station RP2. The ellipse represents the contour of $15\times\sigma_{beam}$. In the vertical plane $15\times\sigma_{beam} = 1.5$ mm. The edge of the detector is 0.5 mm farther away. The distribution of the hits on the detectors (3 cm horizontal $\times$ 2.5 cm vertical) is also shown. The circle indicates the vacuum chamber.

from any decrease of the emittance which has the two desirable consequences of reducing both the beam size and the beam angular spread.

If the LHC will run at lower energy, the measurement of the real part will become feasible with this same optics. In fact the momentum transfer t scales down as p^2, while the emittance will increase because it goes as 1/p. Running at the Tevatron energy (1.8 TeV in the c.m.s.), the minimum accessible value of t would scale down to about 2.5×10^{-3} GeV^2. A modest reduction of the emittance would then make possible the measurement of Coulomb interference.

3.4.2 Large momentum transfer

As discussed in our Letter of intent, we envisage a scheme to study elastic scattering in a large range of momentum transfer as presented in Fig.14. For measuring elastic scattering at large momentum transfer (above $|\, t \,| \approx 1$ GeV^2) the high-β optics is not suitable because of the large reduction in counting rate due to low luminosity and of the limitations from the size of the vacuum chamber due to the large values of the effective distances L_{eff}. In fact at large momentum transfer, where the cross section is rather small, an optics with a relatively low value of β^* is needed.

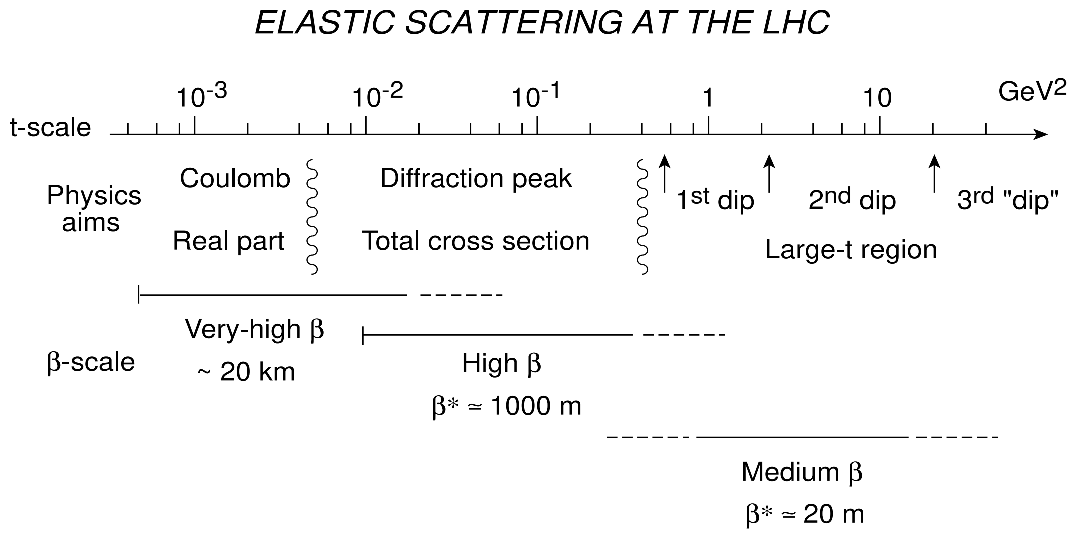

Figure 14: The proposed scheme for a complete study of elastic scattering at the LHC. The values of β^* were estimated assuming the nominal LHC emittance.

As an example we have considered the injection optics which has β^*=18 m. The appropriate position for the detectors (Roman pot station RP1 in Fig.6) is close to D1.

The beam size and the beam angular spread at the crossing are:

- $\sigma^* = 0.095$ mm
- $\sigma^{*'} = 5.3$ μrad

The effective distances are :

- $L^H_{eff} = 40.7$ m
- $L^V_{eff} = 38.5$ m

The acceptance, shown in Fig.15, was calculated with the same prescription as for the measurement of low-t elastic scattering with high-β optics, i.e. assuming the detectors to be efficient at a distance of $15\times\sigma_{beam}$ +0.5 mm. Detectors of the same size were considered. The large-t acceptance matches quite well the acceptance of the low-t measurement thus allowing study of elastic scattering to be performed in a large interval of momentum transfer with continuity.

The luminosity for the medium-β optics is calculated scaling down from the nominal LHC luminosity with the ratio of the β^* values. The reduction factor is 36. Conservatively we assume a luminosity of 10^{32} cm^{-2}s^{-1}. The expected rates, calculated from the models discussed in ref.1, are given in Table 2.

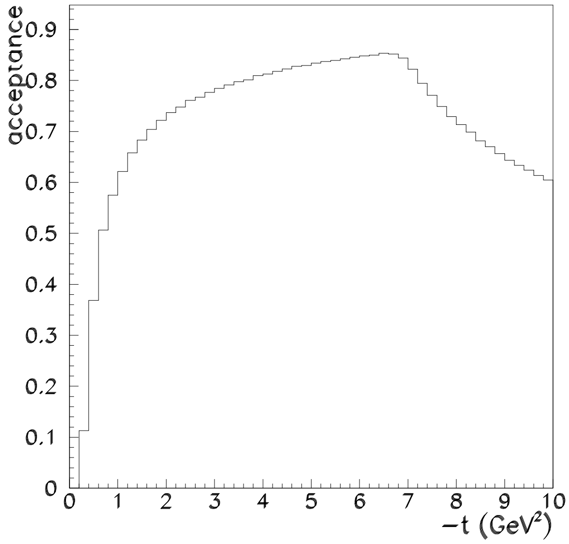

Figure 15: The geometrical acceptance for the medium-β optics of the Roman pot station RP1.

$\mid t \mid$(GeV^2)	$d\sigma/dt$ (mb/GeV^2)	t-bin (GeV^2)	Number of events/day
1	5×10^{-3}	0.2	$\approx 3\times10^6$
2.5	2×10^{-5}	0.2	$\approx 10^4$
5	2×10^{-7}	0.2	$\approx 10^2$
10	2×10^{-9}	0.2	≈ 1

Table 2. Expected number of events per day for the medium-β optics as a function of t in a given t-bin. The luminosity of the medium-β run is assumed to be L=10^{32}cm^{-2}s^{-1}.

The momentum transfer resolution for the medium-β optics turns out to be $\Delta t \approx 5 \times 10^{-2}\sqrt{\mid t \mid}$.

3.5 The forward magnetic spectrometer

A magnetic spectrometer can be naturally implemented in the standard insertion taking advantage of the strong bending power of the dipole D2. The concept, already used by CDF at the Tevatron[4], is quite simple: measure the particle trajectory, as deflected by the dipole, in three points, by three Roman pot stations.

The forward spectrometer will be used for inclusive study of the diffraction dissociation process,

$$p + p \to p + X$$

by measuring the momentum vector of the proton which is scattered quasi-elastically. The double differential cross section $d^2\sigma/dx\,dt$ (where $x = p/p_0$ is the ratio of the measured proton momentum to the beam momentum) will be studied in a wide range of momentum transfer for values of x close to one.

In perspective the integration of the TOTEM forward magnetic spectrometer with the 4π detector CMS will open the way to detailed studies of diffractive physics as the investigation of correlation between the forward proton and the decay products of the system X and, using both arms, to the study of double Pomeron exchange and similar processes.

The two Roman pot stations RP1 and RP2, already foreseen for large-t and low-t elastic scattering, respectively, will provide accurate measurement of the particle direction at the entrance of the dipole D2 whose bending angle is 1.074 mrad. The third station RP3, located behind the dipole D2, actually between Q4 and Q5 will measure the deflection.

Assuming, as in the previous Sections, a space resolution for the horizontal coordinate of 30 μm, the momentum resolution is 2.3×10^{-3}. If desirable, it can be improved to the 10^{-3} level by improving the resolution on the measurement of the horizontal coordinate of the stations RP2 and RP3. The r.m.s. energy spread of the machine is one order of magnitude less (about 10^{-4}). The calibration of the spectrometer will be done with elastic scattering events.

The spectrometer will be used with the high-β optics to have access to the low momentum transfer events. The momentum transfer acceptance of the spectrometer extends from $-t \approx 0.1$ GeV^2 (as determined by RP1) up to more than 1 GeV^2 for x close to one. The t-acceptance decreases drastically for values of x less than 0.85.

The prospects for the installation of the Roman pot station RP3 between Q4 and Q5 have been discussed in great detail with the machine physicists. A well studied technical solution was reported in Section 3.3.

4 The inelastic detector

The total cross section is measured with the luminosity independent method combining the measurement of elastic scattering at low-t with the measurement of the total rate of the inelastic events. In this Section we discuss the measurement of the inelastic rate.

We design the *forward inelastic detector* of TOTEM according to the following requirements.

- Fully inclusive trigger also for single diffractive events with expected loss on the inelastic rate at the 1% level (left-right trigger and single arm trigger are foreseen)
- Capability of reconstruction of the collision vertex in order to disentangle beam-beam events from background.
- The inelastic detector should preferably be left-right symmetric with respect to the collision point.

In our Letter of intent we reported Monte Carlo results obtained with the PYTHIA program[13] on the efficiency of the trigger for a range of angular intervals covered by the inelastic detector. We have shown that there is some flexibility in the choice of the angular range in the sense that a given loss can be obtained by choosing different combinations of η_{min} and η_{max} (see Fig.15 of ref.1).

This flexibility has allowed us to design the inelastic detector in a way which is compatible with the overall layout of the CMS experiment. In the present design of CMS there is free space for the installation of the TOTEM detectors in the forward cones for values of the pseudorapidity for $\eta \geq 3$ (corresponding to $\vartheta \leq 100$ mrad). The maximum value of η which may be accessible is determined by the size of the vacuum chamber.

Detailed considerations have shown that by appropriate splitting of the TOTEM inelastic detectors into two units, the pseudorapidity range which could be covered is $3 \leq \eta \leq 7$. The simulation shows that the loss of inelastic events is expected to be about 2%. This inefficiency will be corrected by means of the measured angular distribution of the tracks. The results of the simulation are listed in Table 3 for both non diffractive (NSD) and single diffractive (SD) events and for both trigger combinations. The covered pseudorapidity interval is from $\eta_{min}= 3$ to $\eta_{max} = 7$. It was assumed $\sigma_{SD}/\sigma_{inel} = 0.14$.

NSD (86%)	Left-right	0.991
SD (14%)	Single arm	0.890
overall		0.977

Table 3. Monte Carlo efficiencies of the left-right and of the single arm trigger for NSD, SD events and overall inelastic at the LHC. The trigger combinations relevant for the measurement are Left-right for NSD and Single arm for SD.

4.1 Layout and integration with CMS.

In this Section a preliminary solution on the integration of the inelastic detector of TOTEM with CMS is presented. A sketch of the overall layout is shown in Fig.16 and 17. The system is left-right symmetric with respect to the interaction point (IP). An overall view of the integration is shown in Fig.18. Each arm is split into two telescopes, T1 and T2.

The telescope T1.
T1 is placed inside the end cap region of CMS at a distance between 7.5 m and 10.5 m from the IP, covering the pseudorapidity interval $3 \leq \eta \leq 4.9$. It consists of 5 equally spaced measuring planes of wire chambers, as shown in Fig.19. The detector is divided vertically in two halves because, at the time of its installation, the beam pipe is already in place. The active planes and the services are supported from a thin lightweight shell structure in carbon fibre with high stiffness and stability.

The outer boundary of T1 is the $\eta = 3$ cone of the CMS end cap where rails for the installation are placed. The inner boundary is the beam pipe that has a conical shape pointing to the IP with an angle corresponding to $\eta = 4.9$.

In the two planes where the alignment channels for the muon chambers go trough T1, appropriate ducts will be provided in order to accommodate the laser beams.

The telescope T2.
T2 is placed at a distance between 15 m and 18 m from the IP and covers the pseudorapidity interval $5 \leq \eta \leq 7$. It has to be installed in the rotating shielding of CMS. It

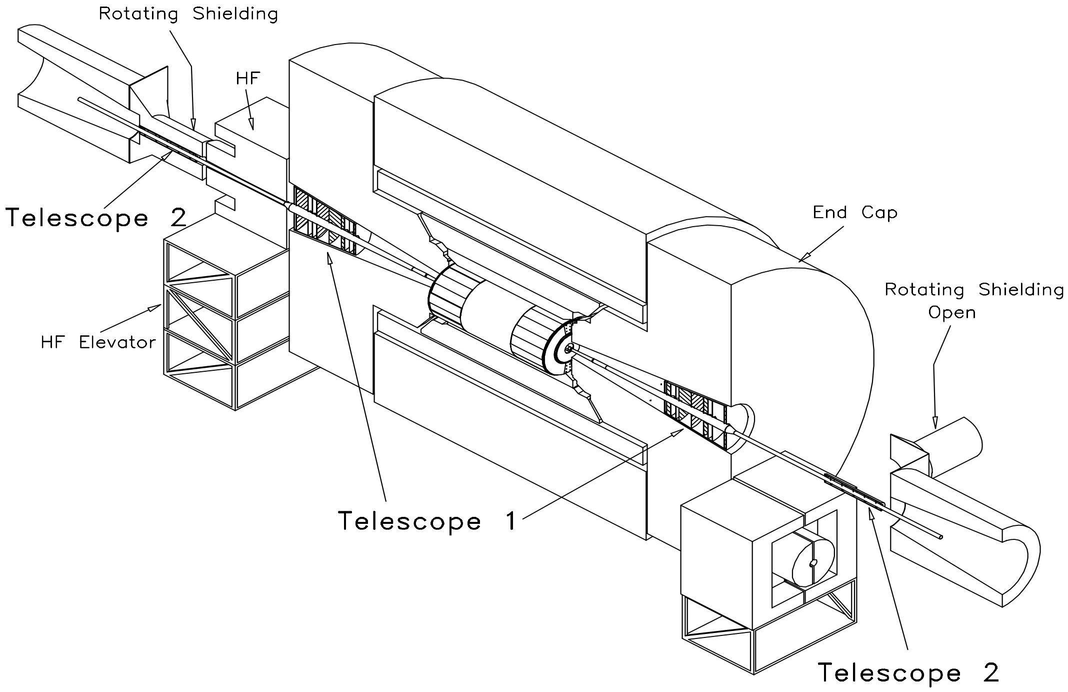

Figure 16: Sketch of the CMS / TOTEM layout.

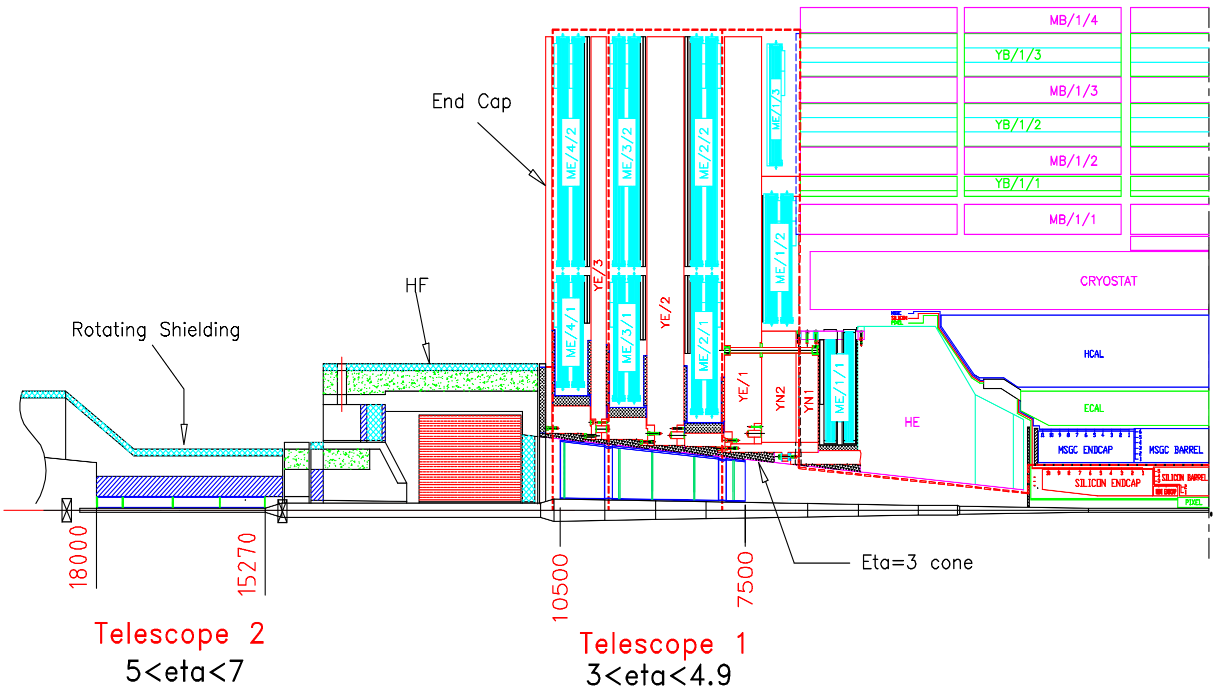

Figure 17: Section of the CMS experimental apparatus showing the integration of the TOTEM telescopes T1 and T2.

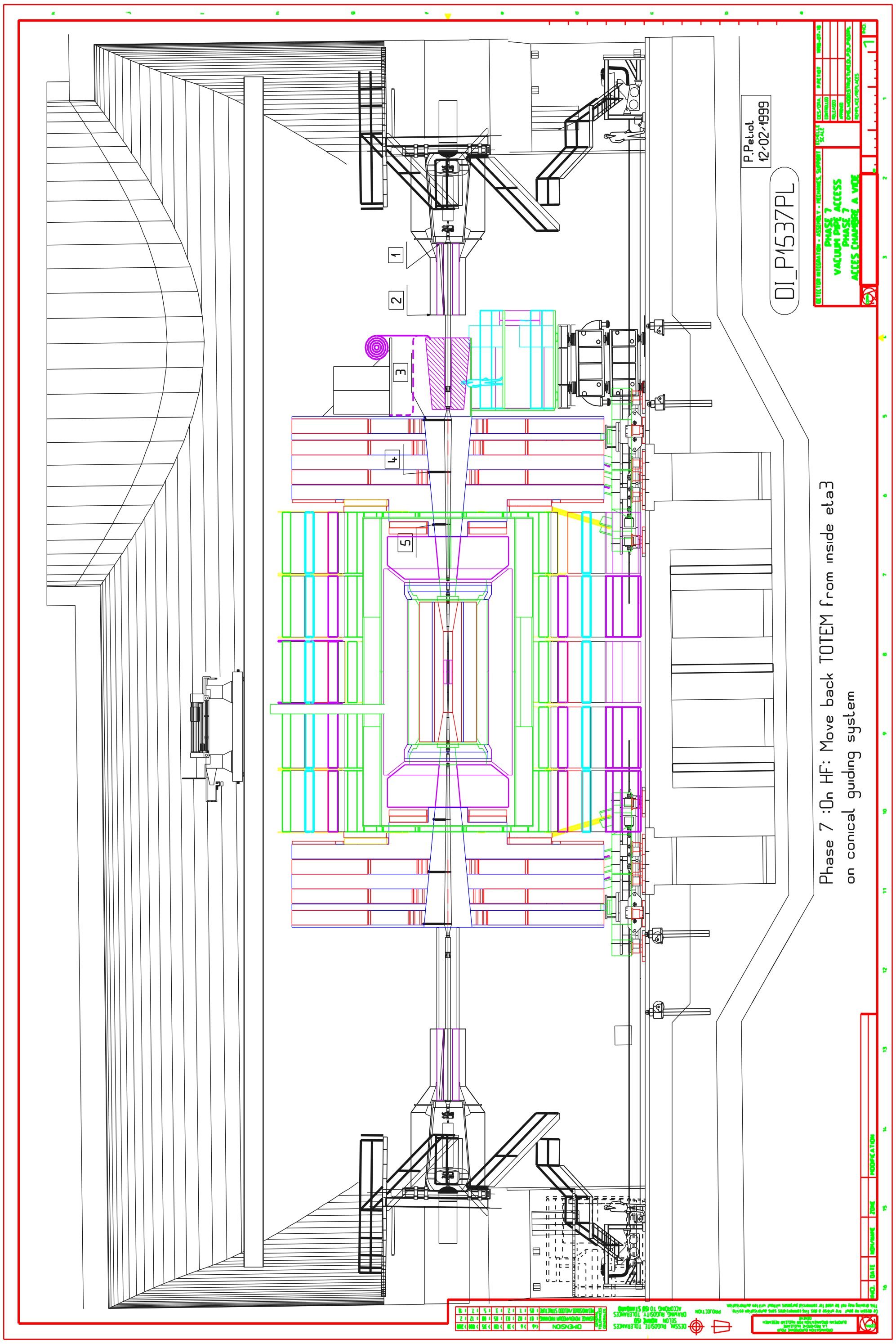

Figure 18: Overall wiew of the CMS/TOTEM integration. On the right side details of the installation of T1 are shown (courtesy CMS Integration Group).

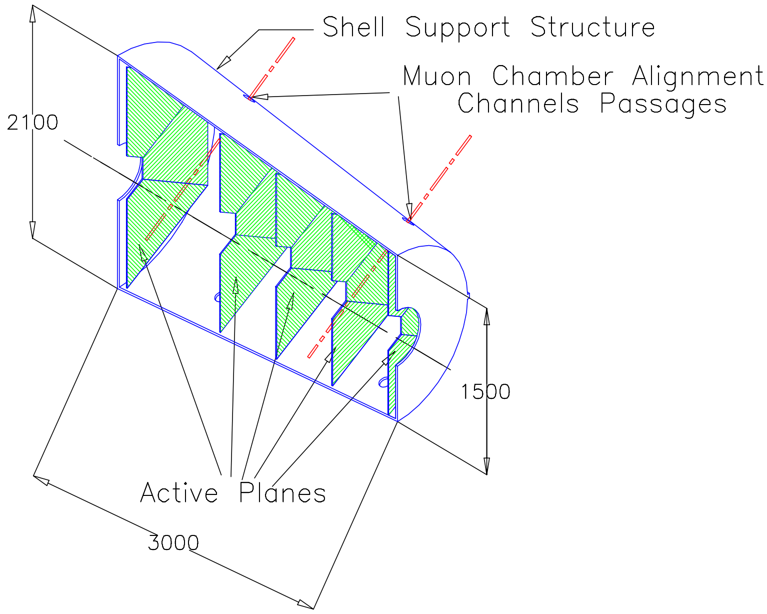

Figure 19: Sketch of the telescope T1.

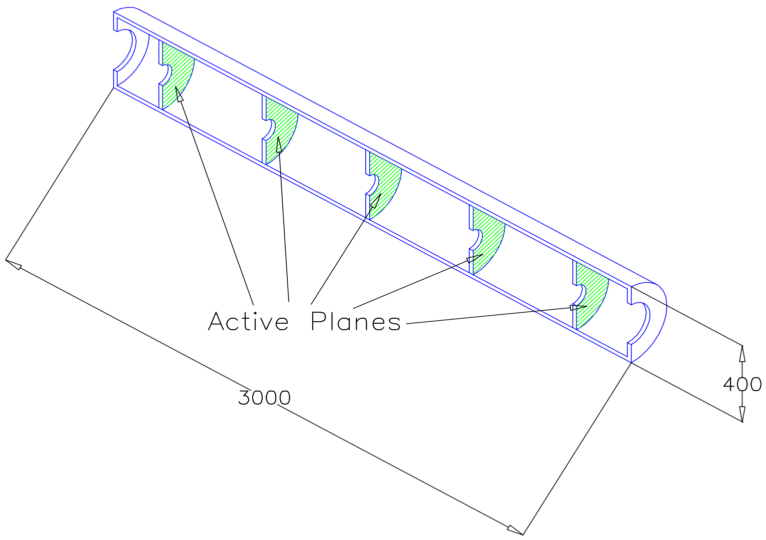

Figure 20: Sketch of the telescope T2.

consists of 5 equally spaced measuring planes of wire chambers as sketched in Fig.20. The telescope T2 is cylindrical, with external radius limited by the internal bore of the rotating shielding to 200 mm and internal radius limited by the vacuum chamber. It is mechanically split in two halves and each half is housed in a thin shell structure. The rotating shielding is composed of two parts that fold on hinges.

Different scenarios have been envisaged on the possibility to have the rotating shielding open or closed during the LHC running. This will be determined by the maximum radiation background tolerated by the muon chambers in the end caps of CMS. A preliminary simulation[14] shows that the shielding must be closed when the luminosity is larger than 10^{32} cm^{-2} s^{-1}. On the other hand, the luminosity required by TOTEM to measure the total cross section is much lower and dedicated runs of the machine will be used. Therefore we propose to run TOTEM with the rotating shielding open in order to reduce the background due to back-scattering. A special structure will have to be built to support T2, the beam pipe and the pump station between the HF calorimeter of CMS and T2. If, however, TOTEM has to be left in place when the machine luminosity is larger than 10^{32} cm^{-2} s^{-1}, the rotating shielding must be kept closed and will be used as support structure for T2.

Cables and services for each telescope come out from the back side where they are collected and routed towards racks installed on the end caps in a location suggested by CMS.

The luminosity monitor.
The measurement of the proton-proton total cross section provides an accurate absolute calibration for a luminosity monitor that we plan to install behind the telescope T2. This calibration will take place when TOTEM is running, i.e. under low luminosity conditions. The challenge is to design a detector that can operate over 6 orders of magnitude in luminosity, from 10^{28} cm^{-2} s^{-1} to 10^{34} cm^{-2} s^{-1}. This demands a simple and radiation hard device and we actually envisage to use a multi-layer secondary emission counter. This detector could also be filled with pure argon to run as an ionisation chamber, thus increasing its sensitivity by ~ 3 orders of magnitude at low luminosity. Such secondary emission counters[15] have been used at CERN for more than 35 years, at the PS and the SPS, on extracted beams and close to primary targets where the radiation environment is very hostile.

The forward electromagnetic calorimeter.
In our Letter of intent we mentioned the interest of measuring π^0 production in the forward direction with an electromagnetic calorimeter [16]. The possibility of installing this detector behind T2 is being considered. In addition a Roman pot type calorimeter behind D1 could be envisaged in due course.

4.2 The particle flux

The expected number of charged particles in the inelastic detector was estimated using the simulation program PYTHIA[13] with appropriate tuning of the parameters which control low-p_t production (see also ref.1).

The average number of charged particles per event expected in the telescopes T1 and T2 is 15 and 10, respectively. At the effective luminosity of 10^{28} cm^{-2} s^{-1}, the interaction rate will be about 1000 Hz and the corresponding number of interactions per bunch crossing, at reduced number of bunches, will be 2.5×10^{-3}. Therefore the measurement of the total cross section with high-β optics will not be affected by multiple interactions in the same crossing.

The expected flux in the telescopes T1 and T2 given as average number of charged particles/(cm^2 s) at the effective TOTEM luminosity of the high-β runs are shown in Fig.21 and 22. We do not expect problems to operate the gas chamber at these rather low levels of particle flux. The presence of a substantial background should be tolerable.

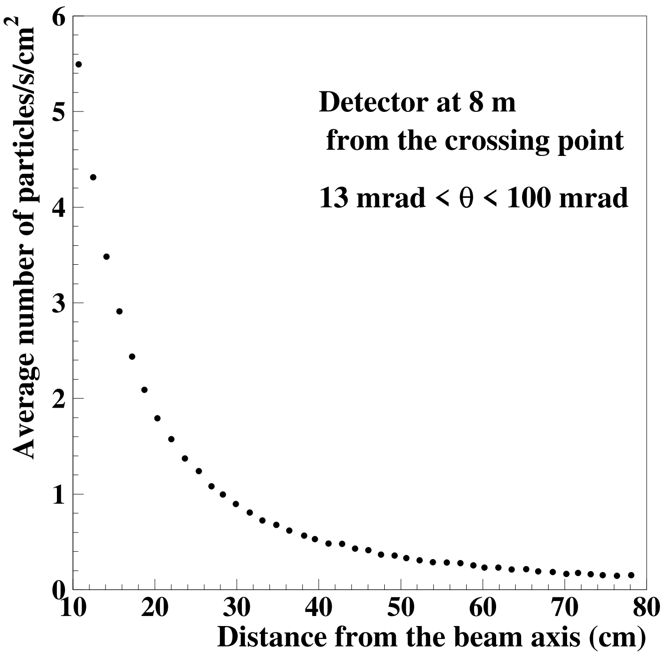

Figure 21: Expected flux of charged particles in telescope T1 for the high-β runs.

4.3 The detectors

In this Section we present our views on a possible realization of the inelastic detectors which are required to be simple, reliable, inexpensive and need only modest space resolution.

Each telescope is composed of five equally spaced detector planes capable to measure a space point. The space resolution needed for each point is of the order of the *millimeter* since it is only required to reconstruct the collision point accurately enough to disentangle beam-beam events from background. Capability of resolving ambiguities for an easy pattern recognition is also required.

This can be achieved by dividing each detector plane in six separate ϕ sectors. We assume that each sector will be a MWPC-like detector with simultaneous R/O of three

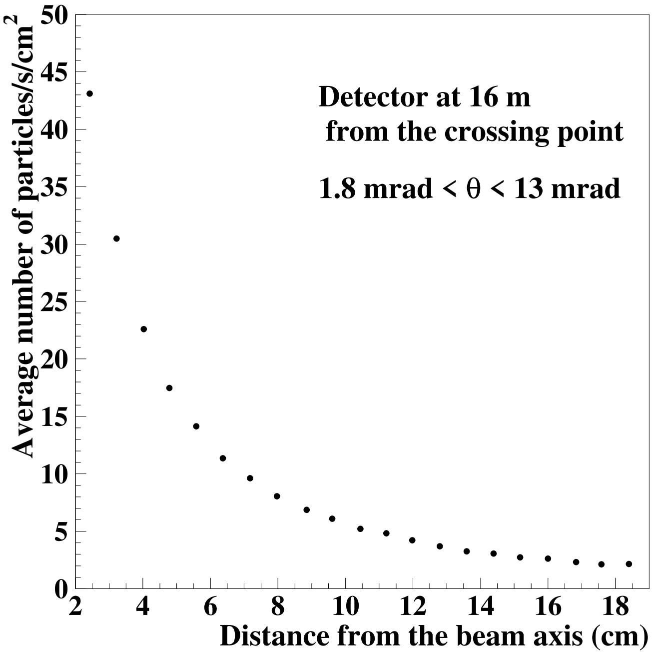

Figure 22: Expected flux of charged particles in telescope T2 for the high-β runs.

coordinates from the wires and from the two planes of cathode pad strips. If pattern recognition studies will show it necessary, one plane of cathode strips can be replaced by triangular pads of appropriate dimensions. This last solutions, however, leads to an increase in the total number of electronics R/O channels of about 30%.

The detectors needed for the two telescopes don't have to be particularly sophisticated nor will require the complicated electronics necessary for the short bunch spacing operation of the LHC at high luminosity.

The main parameters of the system are summarized in Table 4.

The detectors for the Telescopes T1 and T2

	T1	T2
Number of sectors	6	6
Length of the telescope	3 m	3 m
z Position of the telescope	7.5-10.5 m	15-18 m
Radial dimension	$\approx$ 70 cm	$\approx$ 15 cm
Number of wires /sector	300	75
Number of cathode strips /sector	800	200
Angle between strips and wires	60^o	60^o
Total number of R/O channels	$\approx 65\times10^3$	$\approx 15\times10^3$

Table 4. Parameters of the detector planes of the telescopes T1 and T2. It is assumed that both the sense wires and the strips have 2 mm pitch.

The requirement of maximum η coverage would ask for a large number of sectors to better approximate the circular region. However this would also increase the number of R/O

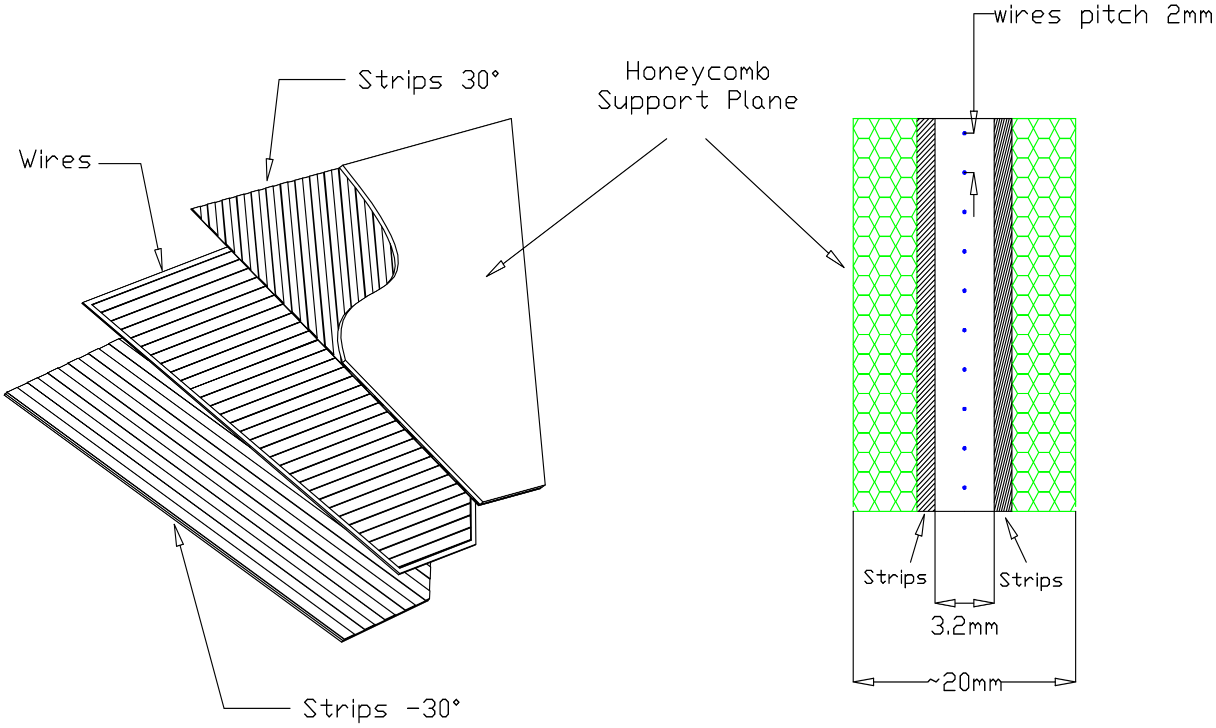

Figure 23: A possible configuration of the wires and strips of the detector planes of T1 and T2. The cathodes are supported by a honeycomb structure.

electronics channels. At this stage six sectors is considered a reasonable compromise.

A simulation of the distance between the particle tracks in each event indicates that this is for 90% of the tracks larger than 8 cm in T1 and larger than 2.5 cm in T2.

We envisage a cathode pad structure in the form of 2 mm wide strips running parallel to each one of the two sides while the wires are parallel to the base of the trapezoid as shown in Fig.23. The cathode planes for these MWPC-like detectors will be constructed using standard printed boards techniques. The printed board cathode planes will be glued to a honeycomb support plane. This technique provides sufficient mechanical rigidity and the width of the frames necessary to keep the wires under tension may become less than 1 cm. The small dead region between adjacent sectors can be totally eliminated by overlapping of the sectors. Even if at this stage the detectors are not completely defined, the average thickness of the T1 telescope is evaluated to be about 5% of absorption length.

Two types of well known MWPC-like detectors are suited for cathode pad R/O: the Thin Gap Chamber[17] and the Cathode Strip Chamber[18].

The Thin Gap Chamber (TGC) works in the saturated avalanche mode and has been proven that breakdown can be avoided with a suitable choice of the gas mixture. The large signals provided by the detector need only a very simple amplifier/ discriminator for the digitization.

The Cathode Strip Chamber (CSC) needs a more sophisticated analog R/O, however, by using the technique of the floating strip[19] largely studied and proven, one may reduce the number of R/O channels needed for a particular configuration by a factor up to three. The analog R/O of the CSC provides also a much better spatial resolution for the same pad configuration when compared to the TGC. If the resolution measured with a TGC prototype will prove insufficient, with small modifications to the surface resistivity of the detectors, one may switch to an analog R/O to measure the centroid of the charge deposited on each pad. The telescopes will then be equipped with Cathode Strip Chambers with the same geometry and improved R/O.

Both type of detectors envisaged are gas detectors: a gas mixing on the surface and a distribution system in the cavern have to be foreseen: the possible gas involved in the mixtures are different for TGC and CSC, requiring a flammable gas for the TGC to achieve saturated mode operation suitable for the simplified R/O and maximum efficiency.

If the CSC solution is adopted, the gas will be the safe mixture $Ar - CO_2 - CF_4$. The TGC, however, can also be operated with non-flammable gas mixtures. The maximum efficiency that can be obtained with *safe gas mixtures* is somewhat lower: most likely safety considerations will lead us to choose non-flammable gas mixtures and this might require the use of additional measuring planes to maintain a satisfactory overall efficiency of the telescope.

A large TGC system is at present working in the end-cap preshower and pole tip calorimeter of the OPAL experiment[20] and the CSC had been extensively studied[18] for the preparation of the LHC experiment proposals. Both types of detectors are presently proposed for use in the muon detectors of the end-cap of ATLAS and CMS.

4.4 The vacuum chamber.

The shape of the vacuum chamber should be designed to minimise the probability of interaction in front of the TOTEM inelastic detectors T1 and T2. Details of the vacuum chamber have been extensively discussed together with CMS and the LHC Vacuum Group. The solution presented in Fig.24 is not final but already takes into account most requirements of both experiments.

In order to minimise the amount of material traversed by the particles detected by T1, we proposed to extend the central beryllium section of the vacuum pipe, which is cylindrical 1 mm thick with 58 mm internal diameter, in order to cover the full angular range seen by T1. Therefore in the present design the central section will extend to 1948 mm on both sides of the crossing point.

The beam pipe then continues with a conical shape at an angle corresponding to η=4.9 up to the distance of 3.59 m from IP. Between 3.59 m and 4.33 m, a stainless steel cylindrical section with bellows at both ends is foreseen. In this region welding *in situ* will take place to join the central part of the pipe, pre-installed in the CMS Central Tracker, to the rest of the pipe inside the end cap. The vacuum chamber then continues again

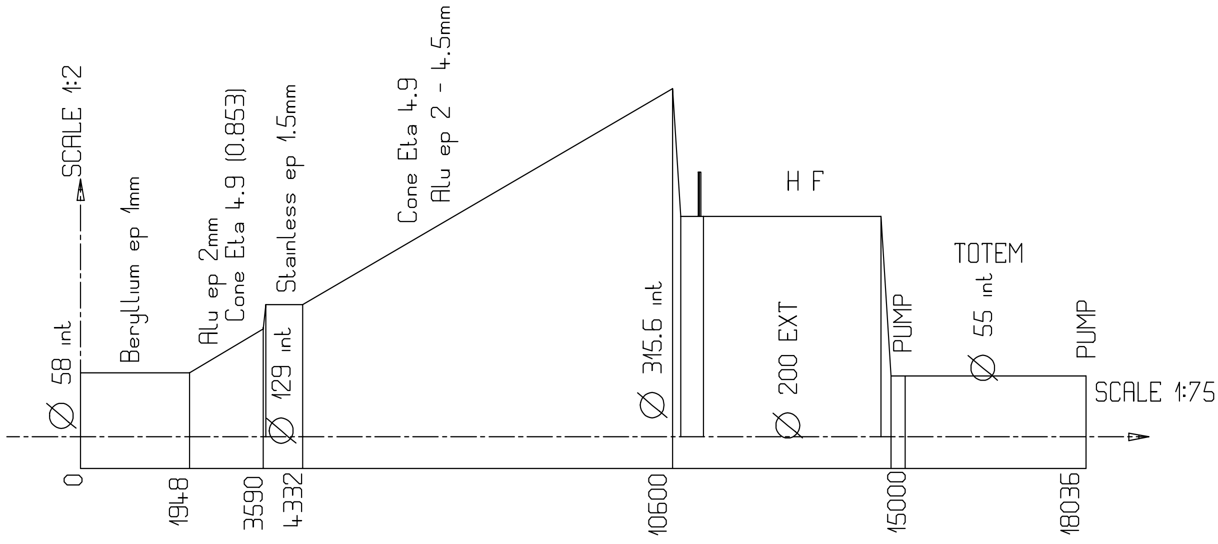

Figure 24: The present design of the vacuum chamber

with conical shape at an angle corresponding to $\eta = 4.9$, up to 10.6 m. The telescope T1 is installed around this conical section. In the region of the HF calorimeter, the diameter is reduced to 200 mm.

Inside the rotating shielding, between 15 m and 18 m where the telescope T2 is located, a further reduction of the pipe to the smallest acceptable value was requested by TOTEM in order to extend the angular coverage down to very small angles, i.e. to $\eta \simeq 7$. This is accomplished with a pipe of 55 mm diameter which could be accepted by the LHC Vacuum Group if an additional pump station is installed at 15 m. This pump station should be installed sufficiently far from the beam axis in order not to add material in front of T2. Another pump station is foreseen behind T2 at 18 m. This last narrow section will be replaced by a pipe of larger diameter at a later stage for the high luminosity runs.

The vacuum chamber is supported on a certain number of points with four wires, two vertical and two horizontal. A careful study of the mechanical stability by the LHC Vacuum Group, has shown that no supports are needed in the region of T1 and of T2. Support wires just in front and behind the detectors are sufficient.

Since the end caps move toward the IP when the magnetic field is switched on, the beam pipe support points attached to the magnet yoke would introduce longitudinal forces on the vacuum chamber. This effect can be eliminated by suspending the beam pipe only at the Central Tracker and at the rotating shield behind HF. This solution is being studied. The absence of support points inside the end cap would allow a further optimisation of the longitudinal position of T1 and of its length.

The inner part of the HF calorimeter is at $\eta = 5.3$ which is inside the acceptance of T2. Therefore, during the TOTEM runs HF should be open. The operation of opening and closing HF is already foreseen in the standard CMS installation procedure, independently of the TOTEM request. It could be done in a few hours.

4.5 Installation procedure.

The telescope T1 will be assembled on the surface in two mechanically independent half telescopes. The installation procedure discussed with CMS proceeds with the following main steps:

- The HF calorimeter is lowered removing two of the frames from the raiser. Therefore the top of HF is free to be used as installation platform.
- On this platform an appropriate support (cradle) receives each half of T1.
- The horizontal wires supporting the beam pipe are removed allowing the insertion of both halves of T1. During this phase the vacuum chamber is supported by only two vertical wires.
- The cradle is aligned with horizontal rails installed on the end cap yoke and the two halves are inserted in sequence inside the η=3 cone. The two halves will be displaced on non-parallel rails in order to obtain overlap of the two detectors thus avoiding dead zones.
- The horizontal wires are attached back to the beam pipe.
- The services (cables and gas pipes) are connected to the patch panel in a rack placed on the back of the end cap.

The telescope T2 is assembled on the surface in two halves and a similar installation procedure is followed:

- T2 is lowered on the top of the HF to a special cradle.
- The cradle is aligned with the support structure on the rotating shielding. The two halves are then moved to their final position.
- The HF is now raised to its place but the two halves are left open with a gap of 200 mm on each side of the beam pipe as requested for the TOTEM runs.

Once the inelastic detectors are in place a careful survey of their position will be performed.

4.6 Underground services.

Space for racks will be needed in the underground area to house trigger electronics, DAQ and the power supplies for both the inelastic detector and the Roman pots. The control system of the Roman pots will presumably be responsibility of the machine but will be duplicated in the TOTEM counting room for use by the experiment. At present we have estimated that eleven racks will be needed including the cooling system of the electronics and the gas distribution for the wire chambers. The possibility to allocate the TOTEM racks in the CMS counting room has been considered. The exact location of each rack will be defined in due course. The racks for electronics, trigger and R/O should be grouped together, while those for cooling and gas distribution may be put in another location.

For the inelastic detectors, cables and pipes from the experimental cavern to the counting rooms will follow the standard routing together with the cables of CMS. The Roman pots, however, are located inside the machine tunnel and therefore their cables have to be routed as prescribed by the machine group. The arrangement of the TOTEM racks inside the CMS underground counting room is shown in Fig.25.

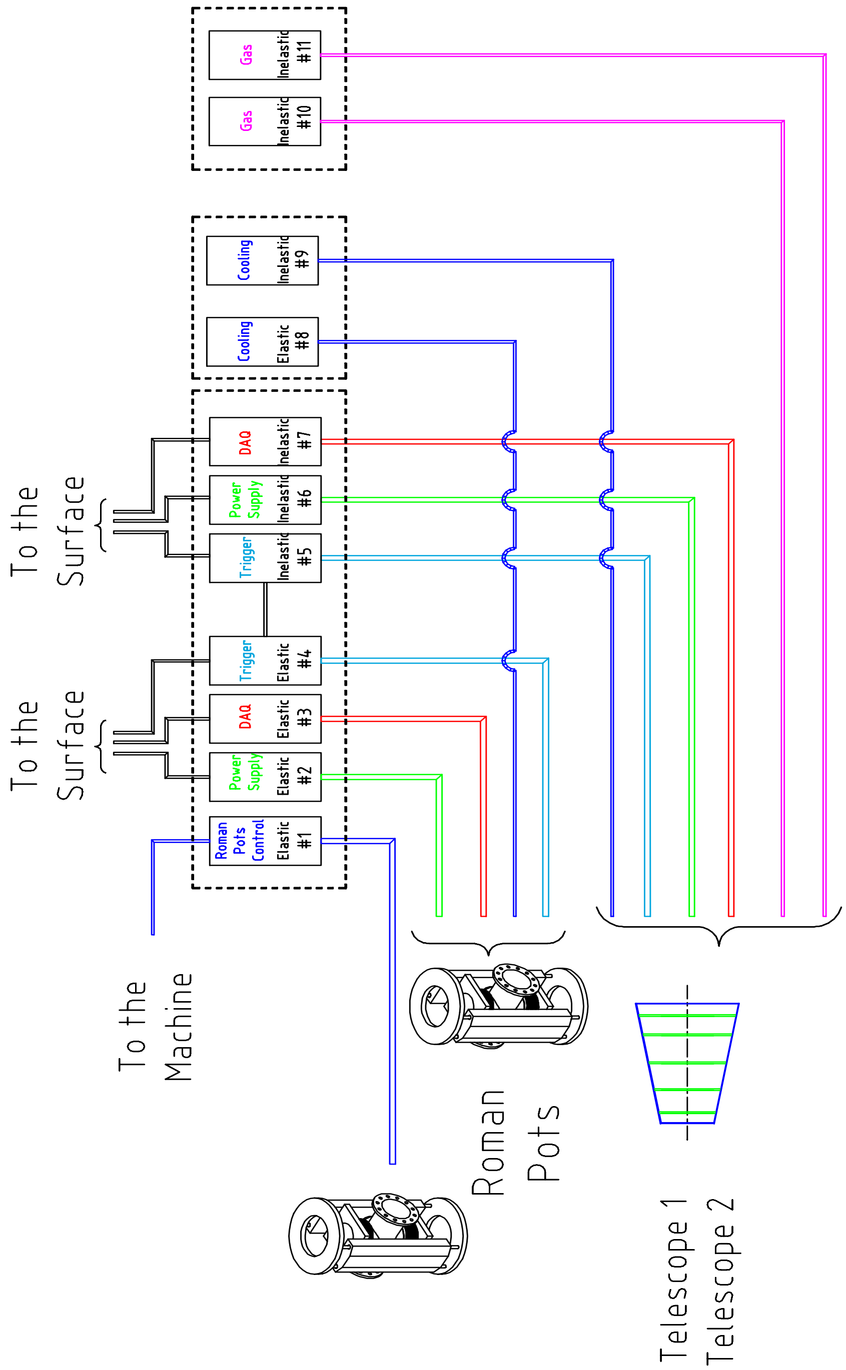

Figure 25: The arrangement of the racks in the I5 underground area.

5 Conclusions

Following the recommendation of the LHCC we have performed a feasibility study of the physics programme discussed in our Letter of intent. We have reached the following conclusions.

- An optics with high β ($\beta^* = 1100$ m) can be implemented using the magnetic elements already foreseen for the low-β insertion.

- The high-β optics allows measuring elastic scattering down to values of the momentum transfer $\mid t \mid \simeq 2\times10^{-2}$ GeV^2, which is sufficiently low to obtain an accurate value of the total cross section from extrapolation of the data to the optical point. The large-t range is accessible with medium-β optics.

- A forward magnetic spectrometer with momentum resolution close to 10^{-3} can be implemented by exploiting the strong bending power of the dipole D2 of the insertion.

- Suitable locations were found in I5 for the installation of three Roman pot stations (symmetrically on each side of the crossing): RP1 for large-t elastic scattering, RP2 for low-t scattering and RP3 for the forward magnetic spectrometer in conjunction with RP1 and RP2.

- The inelastic detector needed for the measurement of the overall inelastic rate and for the study of diffraction dissociation can be integrated in CMS. It is made of two pairs of telescopes placed symmetrically on each side of the crossing. A realistic technical study of the installation is available.

We have not discussed the cost of the experiment because it is premature at this early stage and it is expected to be quite modest. The cost of the detectors and associated electronics will be supported mostly by the external institutions.

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