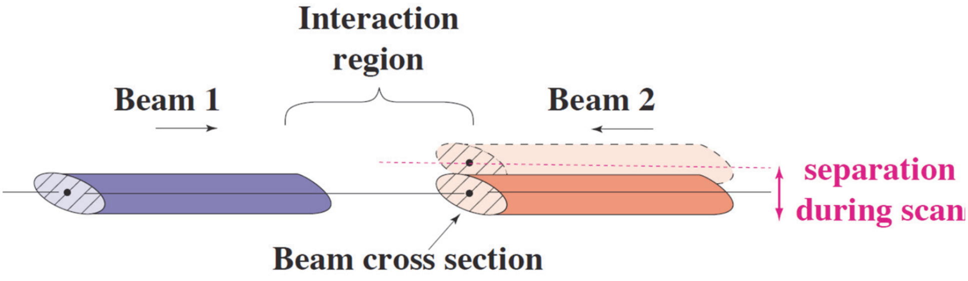

Fig. 4.11. Concept of the Van der Meer scan to determine the beam profile.

At the ISR the luminosity was determined with an accuracy of 1% [41]. This was helped by the fact that the ISR operated with continuous beams (not bunched), allowing absolute beam current measurements, and beam cross sections that were large enough for length scales to be calibrated precisely by mechanical means (using scrapers). For the Tevatron, which could not use the VdM method, the luminosity uncertainty was typically 15–20%.

The LHC renewed with the ISR tradition of VdM scans for determining luminosity [42] and optimizing the collisions [43]. After three years of operation, systematic uncertainties down to 1.5% have been achieved [42]. An automatic online procedure has also been developed for making VdM scans and directly sharing the results with the experiments [44]. The procedure includes a detailed analysis of beam dynamics uncertainties in VdM scans and has been adopted at both RHIC and the LHC. Automatic mini-VdM scans are now standard procedure in LHC operation and are used to optimize collisions for every physics run.

4.7 Roman Pots: Physics Next to the Accelerator Beam

Giorgio Matthiae

The “Roman pot” technique was invented at the ISR to study particles scattered at very small angles. These particles travel close to the circulating beams — in fact inside the vacuum chamber. They can only be detected by a special system able to place detectors a few millimetres from the beam. This system has come to be known as “Roman pots”.

One may wonder why it is interesting to detect particles scattered at very small forward angles. The main motivation was to find out how the total cross-section of the scattering of a proton on a proton depends on the centre-of-mass energy. This fundamental quantity defines the overall probability of interaction of the two colliding particles. The total cross section is related through the “Optical Theorem” to the probability of elastic scattering of the protons in the forward direction. It is of course impossible to detect particles which are scattered precisely in the forward direction because they travel inside the beam; so what it is done is to measure particles scattered at very small angles and extrapolate to the forward direction. Using the Roman pots, the first experiments at the ISR made the startling discovery that the proton–proton total cross-section increases at the new energies probed by the ISR.

The basic theoretical ideas on the energy behaviour of the total cross section are discussed in [45] while the ISR measurements are described in [46, 47].

The Roman pots are special, movable sections of the vacuum chamber which contain small detectors. They are connected to the main vacuum chamber of the collider by bellows (Fig. 4.12, left panel), which are compressed as the pots are pushed towards the beam circulating in the collider. In their retracted position, the Roman pots do not obstruct the beam, thus leaving the full aperture of the vacuum chamber free for the beam during the injection process when the beam is very wide. Once the collider reaches its coasting energy with stable beams, the Roman pot is moved towards the beam with the aim of getting as close as safely possible.

Why Roman? This is because they were first used by the CERN-Rome group in the early 1970s to measure the total cross section at the ISR. And why pots? A picture of the first Roman pot used at the ISR is shown in Fig. 4.12, right panel. It was of a rather simple design, its rounded shape being at the origin of the name. When the physicists of the CERN-Rome group first proposed to use the pots, several people said that they were insane, because the inside of the vacuum chamber is a very inhospitable place, and it would be impossible to perform sensible experiments.

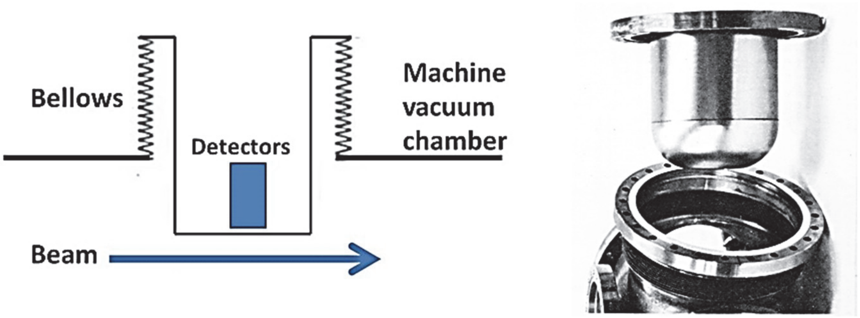

Fig. 4.12. Left: the concept of the Roman pot. Right: the first Roman pot used at the ISR.

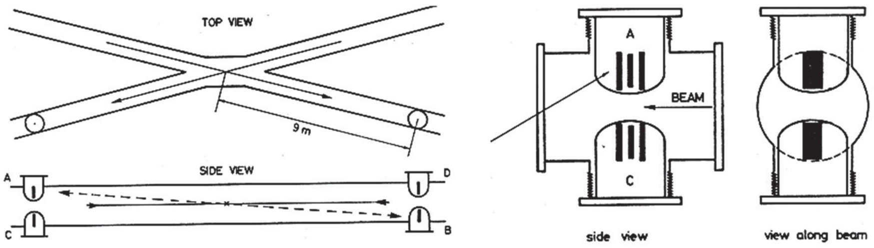

Fig. 4.13. Left: the two pairs of Roman pots of the CERN-Rome group were installed at the end of the ISR straight section, i.e. at about 10 m from the crossing. Right: sketch of the pots and of the detectors which could be approached to about 10 mm from the beam axis [47].

Connected with bellows to the vacuum chamber, a single Roman pot would be pushed strongly by the atmospheric pressure, increasing the difficulty of precise positioning with respect to the beam. This problem was solved by connecting mechanically the pots on either side of the chamber, bringing them into a nearly balanced state (Fig. 4.13).

Operation of the Roman pots required very close collaboration between the experimentalists and the machine physicists. It was crucial to have stable beams with minimal transverse haloes. Such very clean beams, resulting in very low background for the experiments, were obtained by "scraping", by inserting a thin absorber inside the machine vacuum chamber slowly and carefully — a simple but effective technique to remove the tails of the particle beams. By removing the tails it was possible to approach the beam, placing the pots within a few millimetres — in the best conditions at only 9 mm from the beam axis. This operation had to be repeated several times during a data-taking period because the tails of the beam built up again gradually after the "scraping" due to scattering of the circulating particles against molecules of the residual gas. In fact, a good, clean beam turned out to be the way for the detectors to work in the ferocious environment close by.

After the ISR, Roman pots were used at the CERN p–p̄ collider (Fig. 4.14), at the Fermilab Tevatron collider, at the DESY electron-proton collider, and are currently used by the TOTEM experiment at the CERN LHC proton collider.

The detector technique evolved with time, as required by the physics of elastic scattering at the new accelerators of higher energy [49]. The space resolution was of the order of 1 mm for the scintillator hodoscope at the ISR, of about 100 μm for the drift chambers at the SPS collider and eventually became as small as 10 μm for the Si microstrip detectors of TOTEM at the LHC [50].

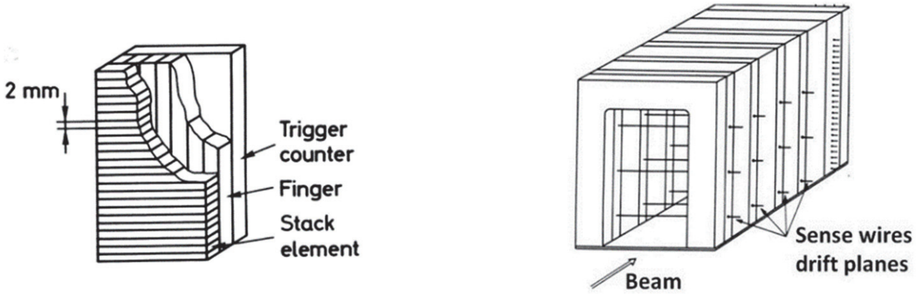

Fig. 4.14. Left: the small hodoscope of scintillation counters used by the CERN-Rome group at the ISR. Right: sketch of a special drift chamber used by the UA4 group at the CERN p–$\bar{p}$ collider. The U-shaped frame of the chamber allowed the sensitive region of the chamber to approach the beams to within a few mm. An improved pot with a flat bottom plate was used for this experiment [48].

4.8 The Gas Detector (R)evolution

Fabio Sauli

The physics models current at the time of the conception of the ISR favoured the design of experimental setups optimized for detection of particles generated by proton-proton collisions in the forward direction. This required a detector design capable of bringing the sensitive area as close as possible to the vacuum chamber of the machine, and able to handle very high particle fluxes. None of the devices used in the sixties could meet these requirements. The invention in 1968 at CERN by Georges Charpak of the Multi-Wire Proportional Chamber (MWPC) [Box 4.4] completely changed the scenario [51]. Capable of detecting and electronically recording particle positions at a high rate, and permitting the coverage of large areas, they could be tailored to be sensitive a few cm from the vacuum chamber. It started a revolution in particle physics, recognized with the Nobel Prize to Charpak in 1992. The choice of this novel technology as main tracker of the Split-Field Magnet Detector (SFMD) was natural, albeit daring. A large-size MWPC prototype built by Charpak and collaborators is shown in Fig. 4.15 [52].

The original MWPC design, making use of heavy frames to tension and hold the stretched wires, was found to be ill-suited for installation within a magnet, where the ratio of sensitive to total detector area is a premium. An alternative assembly offered a much improved aspect ratio: light honeycomb plates tailored to cover the sensitive area, with the wires soldered to slender frames glued to the support plates [53]. This structure is very light and easy to handle, and has since been used for a large number of experiments.