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Roman pots and the rise of the proton-proton cross section¹

TORD EKELOF

Uppsala University
E.mail: Tord.Ekelhof@physics.uu.se • ORCID:0000-0002-7341-9115

Abstract – The CERN Rome collaboration, in which Ugo Amaldi played a prominent role, introduced around 1970 the use of Roman Pots at the CERN ISR and used these to measure the proton-proton differential cross-section in the Coulomb interference region, discovering thereby, together with the Pisa Stony Brook collaboration, the rise of the proton-proton total cross-section at high energies. Roman Pots have been mounted on all hadron colliders built after the ISR. In particular, the Roman Pots technique is today used by ATLAS at the CERN LHC to measure proton-proton small angle scattering.

Keywords: CERN, Roman Pots, ISR, LHC, ATLAS, Proton-proton scattering, Coulomb interference, Differential cross-section, Total cross-section, Hadron colliders

Riassunto – La collaborazione CERN Roma, nella quale Ugo Amaldi ha svolto un ruolo di primo piano, ha introdotto intorno al 1970 l'uso dei Roman Pots al CERN ISR e li ha utilizzati per misurare la sezione d'urto differenziale protone-protone nella regione di interferenza di Coulomb, scoprendo così, insieme alla collaborazione Pisa-Stony Brook, l'aumento della sezione d'urto totale protone-protone ad alte energie. I Roman Pots sono stati montati su tutti i collisori adronici costruiti dopo l'ISR. In particolare, la tecnica dei Roman Pots è oggi utilizzata da ATLAS al CERN LHC per misurare la diffusione protone-protone a piccoli angoli.

Parole chiave: CERN, Roman Pots, ISR, LHC, ATLAS, diffusione protone-protone, interferenza di Coulomb, sezione d'urto differenziale, sezione d'urto totale, collisori adronici

1. Proton-proton total cross-sections 1970 and Asymptotia

Around 1970 the accelerator with the world's highest energy was the 70 GeV proton synchrotron in Serpukhov south of Moscow. The measurements made at Serpukhov of total proton-proton and anti-proton-proton cross-sections in the range 15-60 GeV in Figure 1 were published in 1971. Each of the six total cross-sections seem to flatten out with increasing energy towards a

¹ This peer reviewed article originates from contributions to the “Symposium for Ugo's 90 years” held at CERN (Geneva) on the 4th of April 2025 to celebrate the 90th birthday of Ugo Amaldi, member of the Accademia dei XL since 1992.

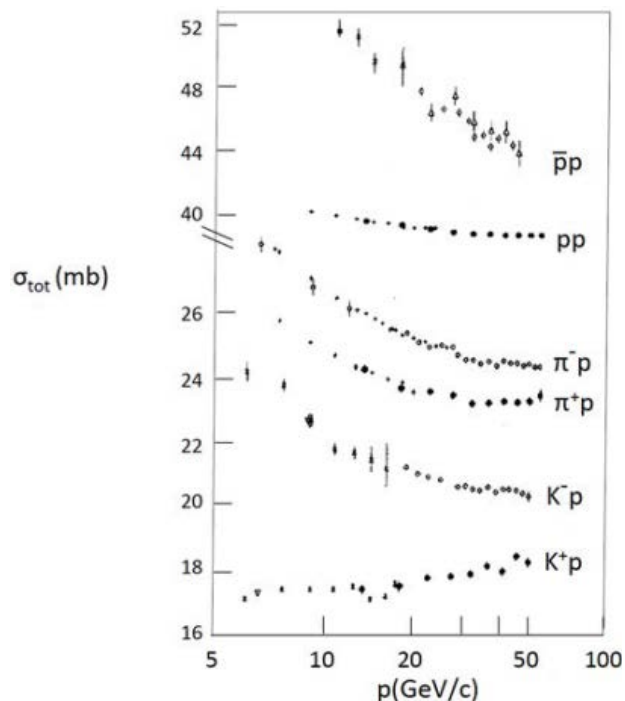


Fig. 1. Proton, pion and Kaon total cross sections on protons. The measurements in the range 15 to 60 GeV/c are the results obtained at the Serpukhov laboratory [1].

constant value. This gave rise to ‘Asymptotia’, the concept that the cross-sections would not change any more with energy when going to higher and higher energies and that there would in consequence be no interest in making experiments at higher energies. Ugo Amaldi, who had started to work at CERN around that time, was challenged by the idea of Asymptotia but did not know that soon he would have the possibility to study the phenomenon and falsify it.

2. The Intersecting Storage Rings

At CERN the operation of the ISR (Intersecting Storage Rings), two intersecting proton synchrotron rings each with a circumference of 942 m, were to start in 1971. Proton beams accelerated to 26 GeV/c in the CERN Proton Synchrotron (PS) were to be injected in opposite directions into the two ISR rings where they could be accelerated further up to 31.4 GeV/c, implying a maximum proton-proton center-of mass energy of 63 GeV. This was a 5-fold increase with regard to the proton-proton collisions of the Serpukhov fixed-target measurements which could reach a center-of-mass energy of only 12 GeV.

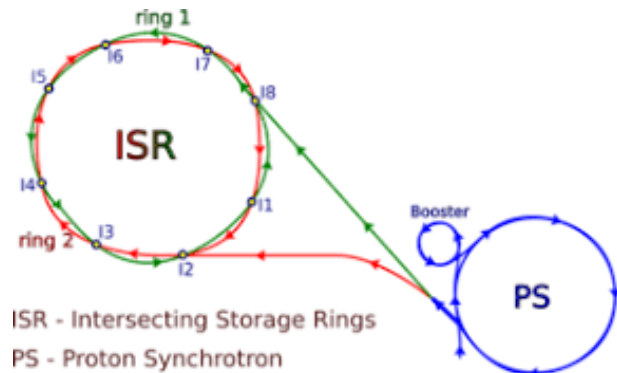


Fig. 2. A schematic showing how the CERN Intersecting Storage Rings (ISR) are fed with their two proton beams in opposite directions from the CERN Proton Synchrotron (from CERN Courier).



Fig. 3. Photograph showing one of the intersections of the ISR (CERN Photo).

3. The CERN-Rome experiment at ISR

The basic idea of the Roman pots was described in a memorandum sent in summer 1969 to the ISR Committee by the “Rome group” of *Istituto Superiore di Sanità* lead by Ugo Amaldi, with Giorgio Matthiae as senior physicist. In a later paper in 2015 titled “*An ISR discovery: the rise of the proton-proton cross-section*” Ugo refers to this memorandum and described the sequence of events that brought to the most important discovery to which he has contributed [2]; to measure the elastic differential cross-section at very small values of the four-momentum transfer squared t where the strong proton-proton scattering amplitude becomes comparable in

magnitude to the electric scattering amplitude, which is around the very small momentum transfer $t = -0.002$ $(\text{GeV}/c)^2$. This allows to determine at the same time the phase ρ of the strong elastic amplitude and, by extrapolation, the value of the differential elastic scattering at $t=0$. From these two quantities the total cross-section σ_{tot} can be evaluated using the optical theorem:

$$\sigma_{\text{tot}} = \frac{\sqrt{16\pi(d\sigma/dt)_0}}{(1 + \rho^2)}$$

To obtain the differential cross-section $d\sigma/dt$ of Fig. 4 it is necessary to know the collider “luminosity” measured in $\text{cm}^{-2}\text{s}^{-1}$ so that a cross-section can be computed as the ratio between the number of events per second, recorded by a certain set of detectors, and the luminosity. At the ISR a new method to determine the luminosity, the “Van der Meer method”, was developed and used for the first time and has been used in all colliders built since then. With this method the two colliding beams

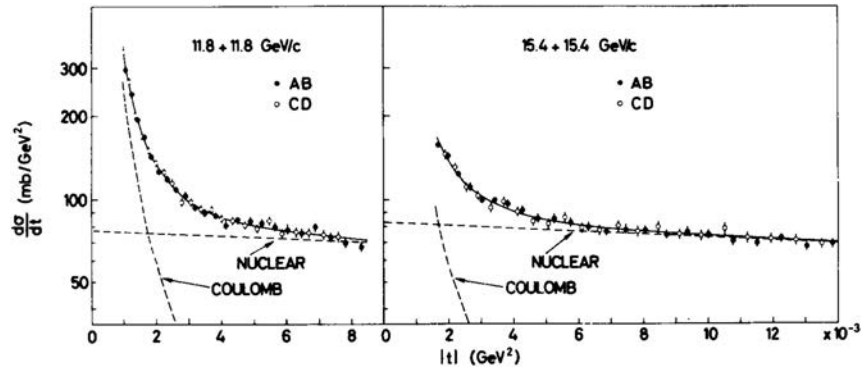


Fig. 4. Which illustrates how nuclear and Coulomb scattering combine to form the elastic differential cross section in the Coulomb interference region from which the relative phase ρ of the nuclear amplitude can be derived. It also illustrates how the differential elastic cross-section at $t=0$ can be obtained by extrapolation. The data points are results from measurements by the CERN-Rome group at ISR at two different collision energies [3].

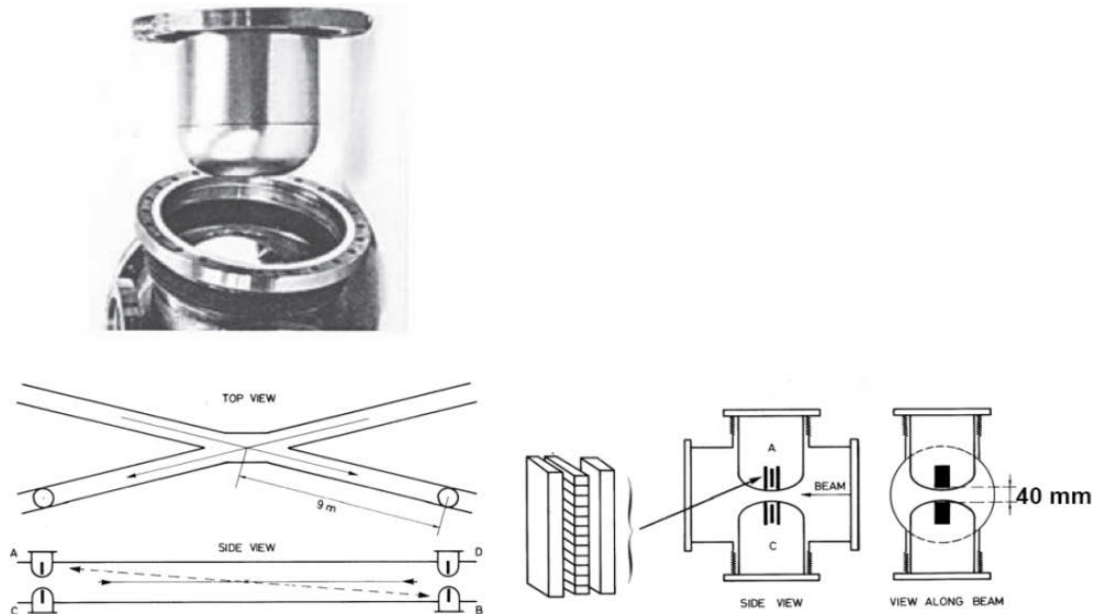


Fig. 5. A photo of one of the CERN-Rome Roman Pots and their installation in the two arms of the ISR intersection ca 18 m apart [3].

are displaced in very precise vertical steps and the rates, detected by large monitoring counters, are recorded.

With the aid of vacuum insertions, the Roman Pots, in the ISR vacuum chamber it would have been possible to measure very small scattering angles by installing in the Roman pots, on either side of the ISR collision region, hodoscopes made of very thin scintillation counters, just millimetres from the circulating beams, and measure elastically scattered protons in coincidence in the two arms of the ISR. The insertions got the name Roman Pots because they were designed by a French engineer working at CERN in the Franco Bonaudi support group, who was regularly visited by Ugo and Giorgio coming from Rome. This engineer called the objects under design "Pots de Rome" which was quickly translated as "Roman Pots" by the English-speaking members of the support group. This name has remained since then.

4. The discovery in 1972-1973 of the rise of the total pp cross-section

Ugo was the person analyzing the forward elastic data collected by the CERN-Rome Collaboration, which at that time had been joined by the CERN group led by Giuseppe Cocconi. In parallel, the Pisa-Stony Brook Collaboration was measuring, in another interaction region, the total cross-section σ_{tot} by recording the event rate with a very large array of scintillation counters covering the full solid angle. A first clear indication that the proton-proton total cross-section was rising at ISR energies was published by the CERN-Rome and the Pisa Stony Brook Collaborations together in October 1972.

In the next months more data were collected and in March 1973 Ugo gave a CERN seminar, on behalf of both Collaborations, announcing the discovery of an un-

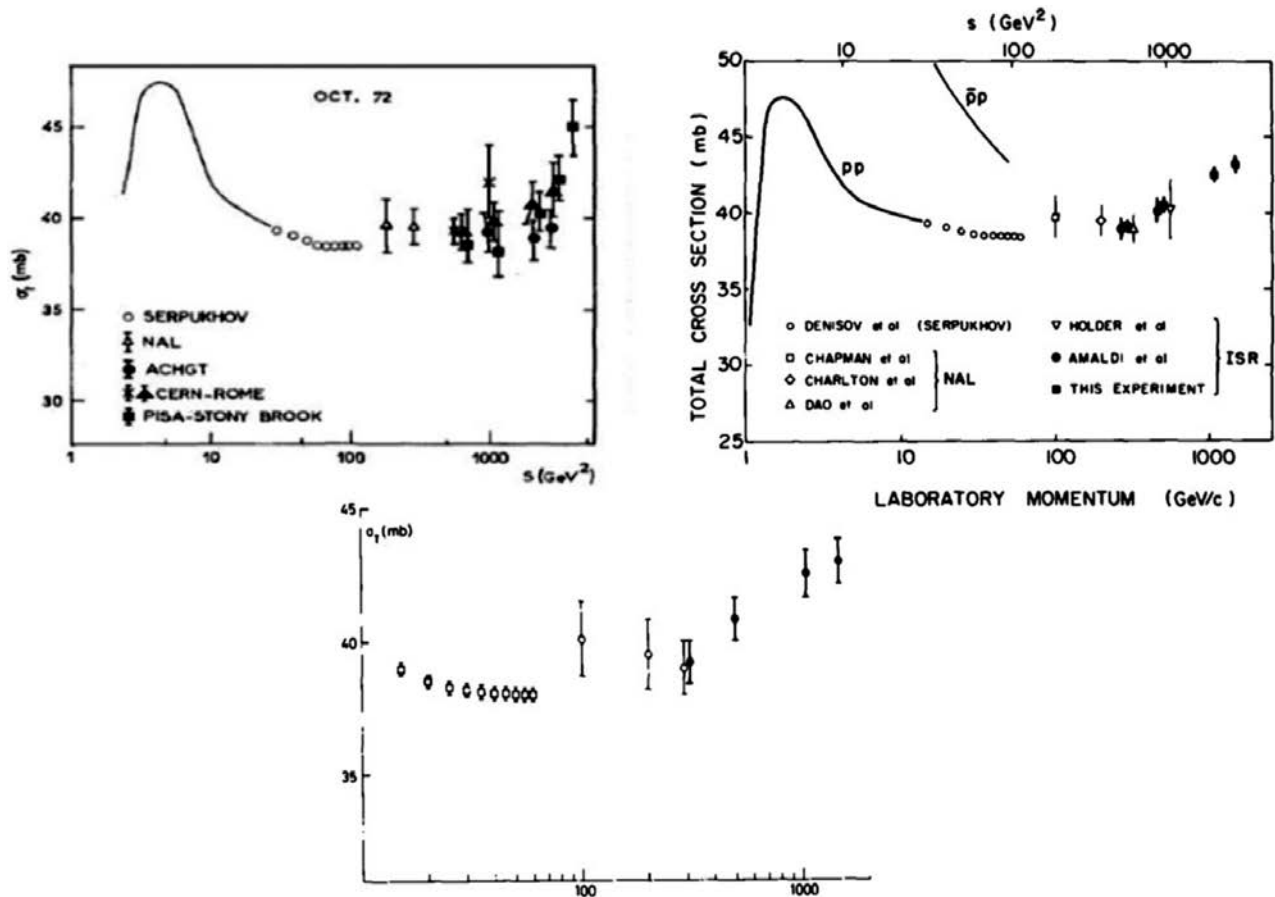


Fig. 6. The total proton-proton cross section measured at the ISR, *left* first data published in October 1972 by CERN Rome and Pisa Stony Brook, *middle* CERN-Rome final data [4] and *right* Pisa-Stony Brook final data [5] published in the same issue of Physics Letter in April 1973.

expected phenomenon: the proton-proton cross section is not constant but increases by 10% when the square of the center-of-mass energy increases from 400 GeV² to 4000 GeV². The final data were published by the two Collaborations in the 2 April 1973 issue of Physics Letters. Since then, one of the main hypotheses of the then generally accepted Regge model, which was that the Pomeron trajectory exchanged in all hadron-hadron elastic collisions has an intercept at $t = 0$ exactly equal to 1, had to be abandoned.

5. The use of dispersion relations to extrapolate the total cross-section to higher energies

A few years later, the CERN-Rome Collaboration published extrapolations of the total cross-section up to centre-of-mass energy of 500 GeV which they had derived by introducing dispersion relations to fit the new very accurate experimental data on both the total cross-sections and the phase of the strong elastic amplitude. Figure 7 shows that at 500 GeV the extrapolated cross-section is as large as 55-65 mb, more than 50% larger than at 10 GeV.

6. The method of measuring the total cross-section with Roman pots is currently used in the ATLAS experiment at the LHC

The Roman Pot technique developed by the CERN-Rome Collaboration for the ISR is currently used in the ATLAS experiment. The distance between the Roman Pots has been increased from about 18 m in the CERN-Rome experiment at the ISR to about 480 m in the ATLAS experiment at LHC.

7. Pion-proton small angle scattering

At the CERN proton colliders ISR and LHC only proton-proton small angle scattering can be measured. Pion-proton small angle scattering can only be measured in fixed-target experiments. In most such experiments, only the forward scattered particle has been measured. There are also experiments which have specialized in the measurement of the low-energy proton recoil only, the kinetic energy of which is ca. 1.5 MeV in the Coulomb interference region around $-t = 3 \times 10^{-3}$ independently of the beam momentum. In an experiment

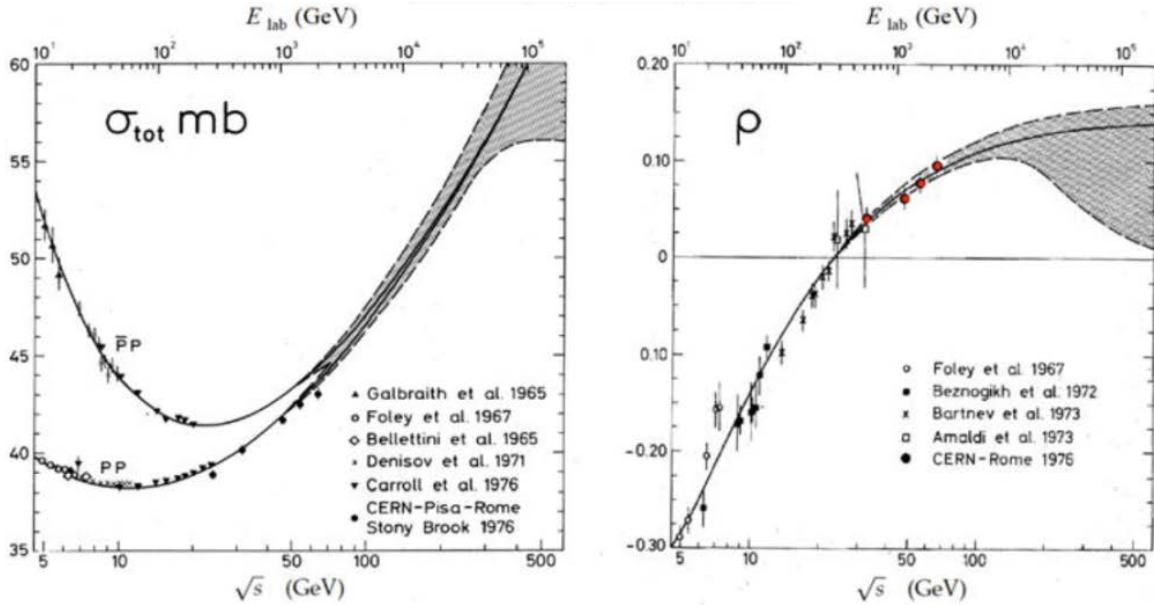


Fig. 7. The left figure shows the data on proton-proton and antiproton-proton total cross-section σ_{tot} and the right figure on the phase ρ of the strong elastic cross-section from the experiments indicated in the figures. The full curves are the result of a fit using dispersion relations simultaneously performed on the data on σ_{tot} and for ρ . The shaded areas represent the one standard deviation regions for σ_{tot} and for ρ , respectively [6].

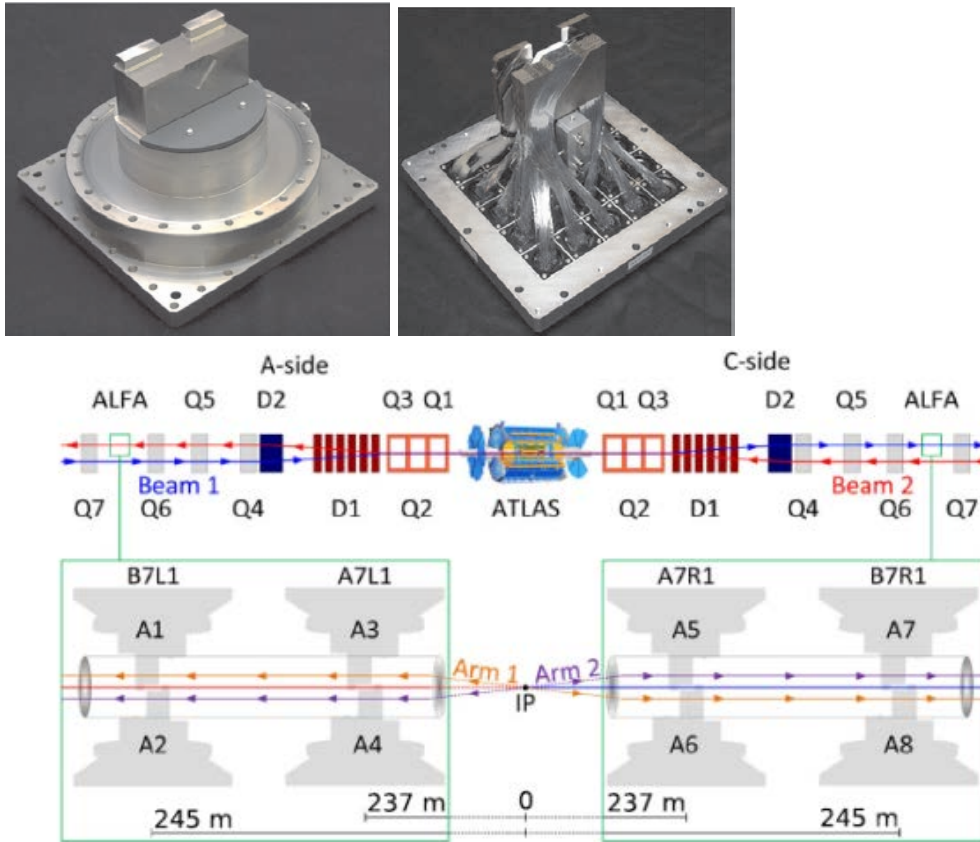


Fig. 8. Photo of one of the Roman Pots and its inside detector, called ALPHA (A1 to A8), in the ATLAS experiment at LHC and the installation of the Roman Pots ca. 240 m apart in the arms of the LHC intersection [7].

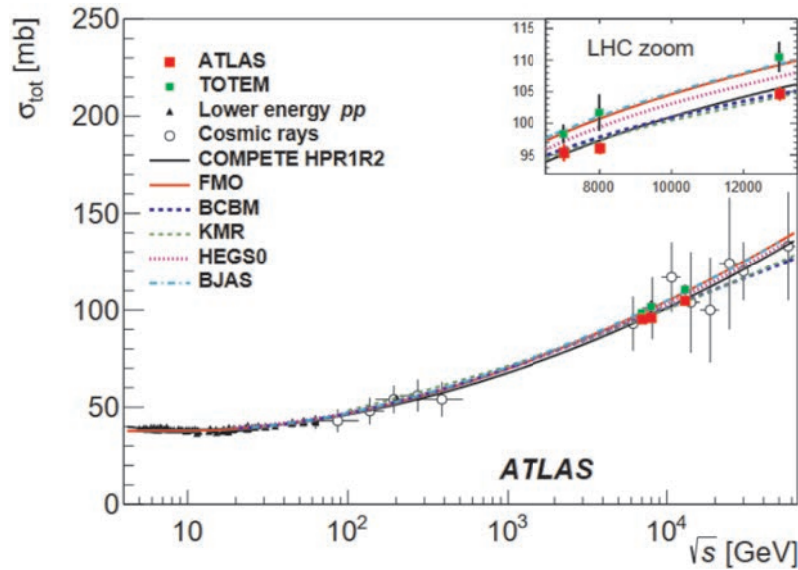


Fig. 9. The results of the Roman Pot measurements of the proton-proton total cross-section of ca. 105 mb at 13 TeV collision energy by ATLAS shown in this figure confirm approximately by interpolation the prediction by extrapolation of the ISR data of ca 60 mb at 450 GeV collision energy in Figure 7 left [8].

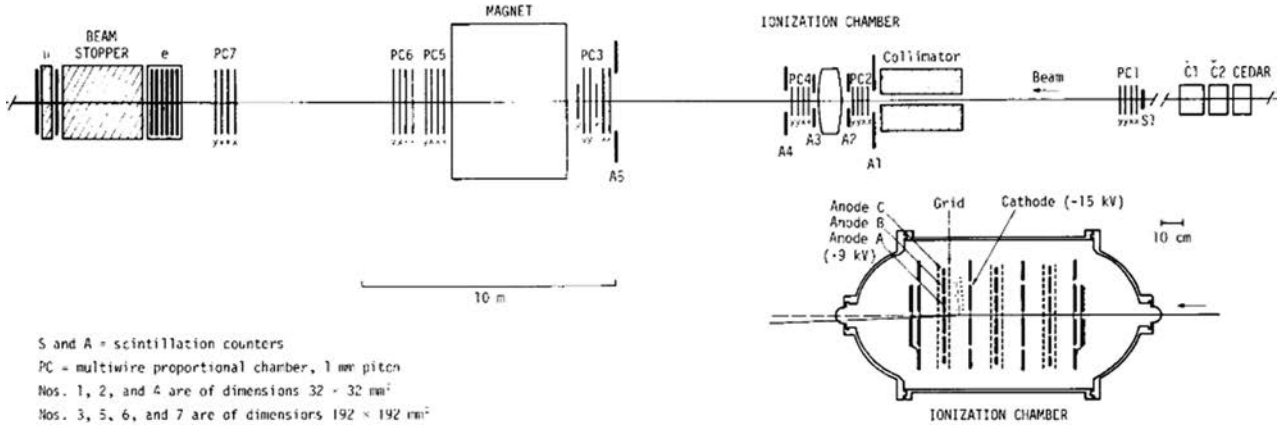


Fig. 10. At the lower right part of the figure is shown a cross-section of the hydrogen ionization-chamber recoil-detector used at the CERN SPS to measure the low energy proton recoils created by incoming beam pions of 30 to 345 GeV momentum. In the upper part of the figure is shown the layout of the pion beam spectrometer with the recoil detector placed between an incident beam-particle telescope and a scattered-particle telescope and magnetic spectrometer.

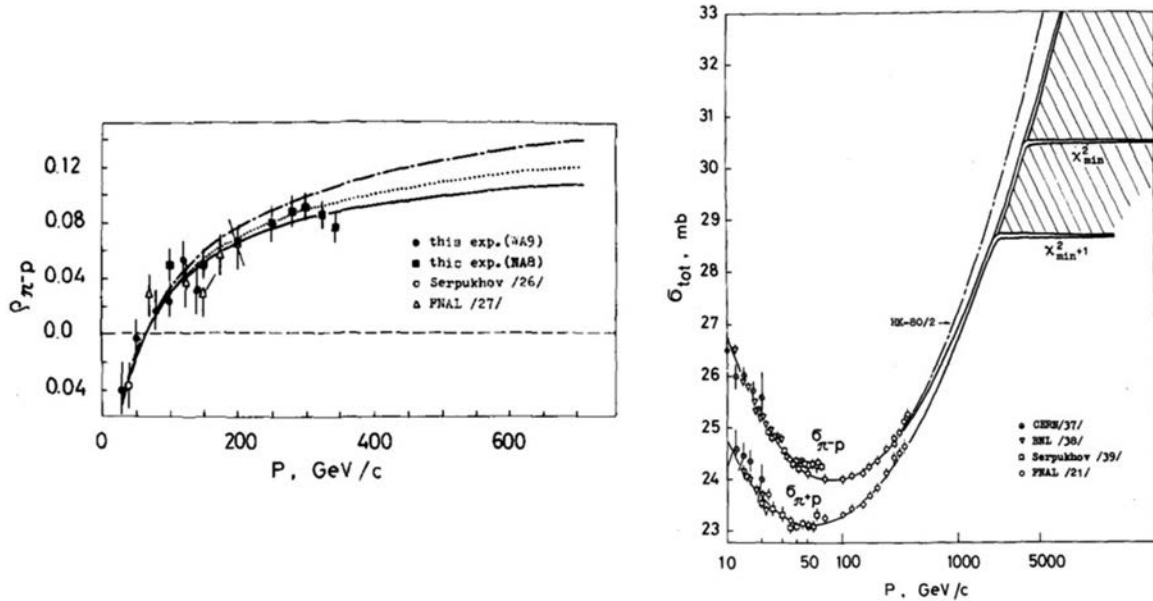


Fig. 11. To the left experimental data on phase of the πp strong elastic amplitude measured by the Clermont-Ferrand-Leningrad-Lyon-Uppsala collaboration ("this exp. (WA9)" and "this exp. (NA8)"). To the right experimental data on the total cross-section πp . In both figures the full line is a result of simultaneous dispersion-calculation fits to the data on σ_{tot} and ρ [9].

initiated and executed by the Clermont-Ferrand-Leningrad-Lyon-Uppsala collaboration in 1976-1983 at the CERN SPS we measured both the proton recoil, using a special ionization chamber spectrometer developed by the Leningrad group, and the forward scattered beam particle, using a multiwire proportional chamber (MWPC)-magnet spectrometer. An advantage of the use of a recoil detector is the better resolution in four-momentum transfer squared t in the Coulomb interference

region (error in t of the order of $10^{-4} (\text{GeV}/c)^2$) as compared to resolution obtained with the forward particle measurement (error in t of the order of $5 \cdot 10^{-4} (\text{GeV}/c)^2$). The advantage of combining the two methods is the more efficient background rejection obtained from the simultaneous measurement of the recoil and the forward particles, as compared with experiments where measurements are made of only one of these two particles.

8. A personal note

The small angle proton-proton elastic scattering measurements at ISR of the CERN-Rome Collaboration came for me to be an incitement to study small angle $\pi\pi$ elastic scattering, be it with the use of a very different experimental method. This method was based on the use of the ionization chamber technique of the Leningrad group, with which I had worked with during a stay at the

Leningrad Nuclear Physics Institute during 1972 and 1973. Ugo became for me an inspiring mentor in my study of this possibility, which led to the proposal to use the ionization chamber in a Coulomb interference experiment at the SPS at its start in 1976. Even more so when, at the end of the 1970s, I came to take an interest in the development of what was to become the Ring Imaging Cherenkov (RICH) particle identification detector, which Ugo invited me with colleagues to develop as a detector component of the DELPHI LEP experiment of which Ugo was the spokesman. For all this I owe deep gratitude to my friend and colleague Ugo Amaldi.



Fig. 12. Ugo and Clelia at the occasion of Ugo's promotion to Doctor Honoris Causa at Uppsala University in 1993.

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