PHYSICS AT SMALL ANGLES

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University of Milano Bicocca and TERA Foundation

Content

A personal account of the first ISR years:

1. **Nuclear and Coulomb elastic scattering**
2. **Total cross sections**
3. **(Soft inclusive) Diffraction Dissociation**

In the written report also:

Double Pomeron Exchange

Exclusive diffraction

Particle multiplicities

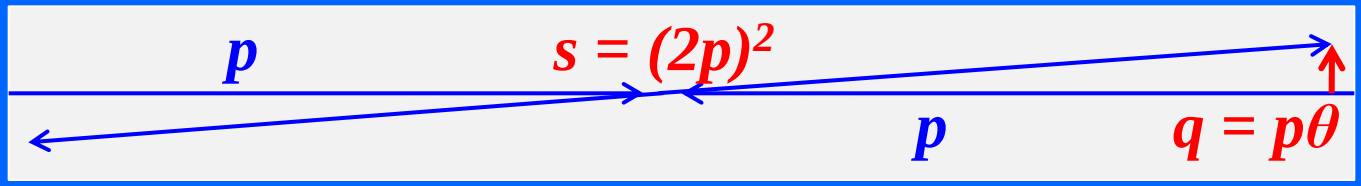
Feynman and KNO scaling

Leading effects

AND ANTIPROTONS -ALFAS IN THE ISR

General theoretical arguments

Unitarity and Optical Theorem



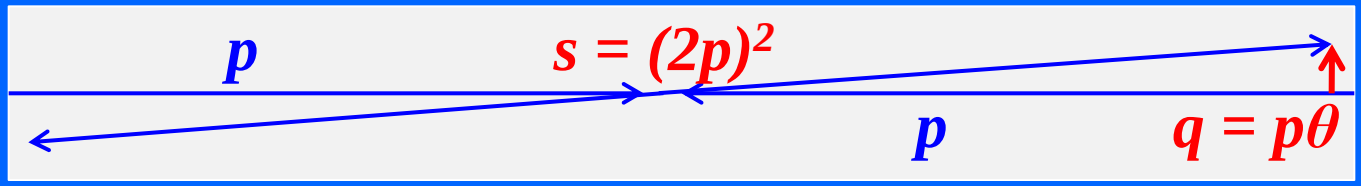
$t = -q^2 \leq 0$

$$4\pi \,\mathrm{Im}\, f(t)/k = G_{el}(t) + G_{in}(t).$$

overlap functions

For $t = 0$: $4\pi \,\mathrm{Im}\, f(0)/k = \sigma_{el}(s) + \sigma_{inel}(s) = \sigma_{tot}(s)$

Unitarity and Optical Theorem



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$$4\pi \,\mathrm{Im}\, f(t)/k = G_{el}(t) + G_{in}(t).$$

overlap functions

For $t = 0$: $4\pi \,\mathrm{Im}\, f(0)/k = \sigma_{el}(s) + \sigma_{inel}(s) = \sigma_{tot}(s)$

$$\left(\frac{d\sigma_{el}}{dt}\right)_{t=0} = \frac{(1+\rho^2)\,\sigma_{tot}^2}{16\pi}$$

$$\rho = \frac{\mathrm{Re}\, f(0)}{\mathrm{Im}\, f(0)}$$

Other general properties

Pomeranchuk theorem – 1958 $\sigma_{tot}(a+b) = \sigma_{tot}(\bar{a}+b) \qquad s \to \infty$.

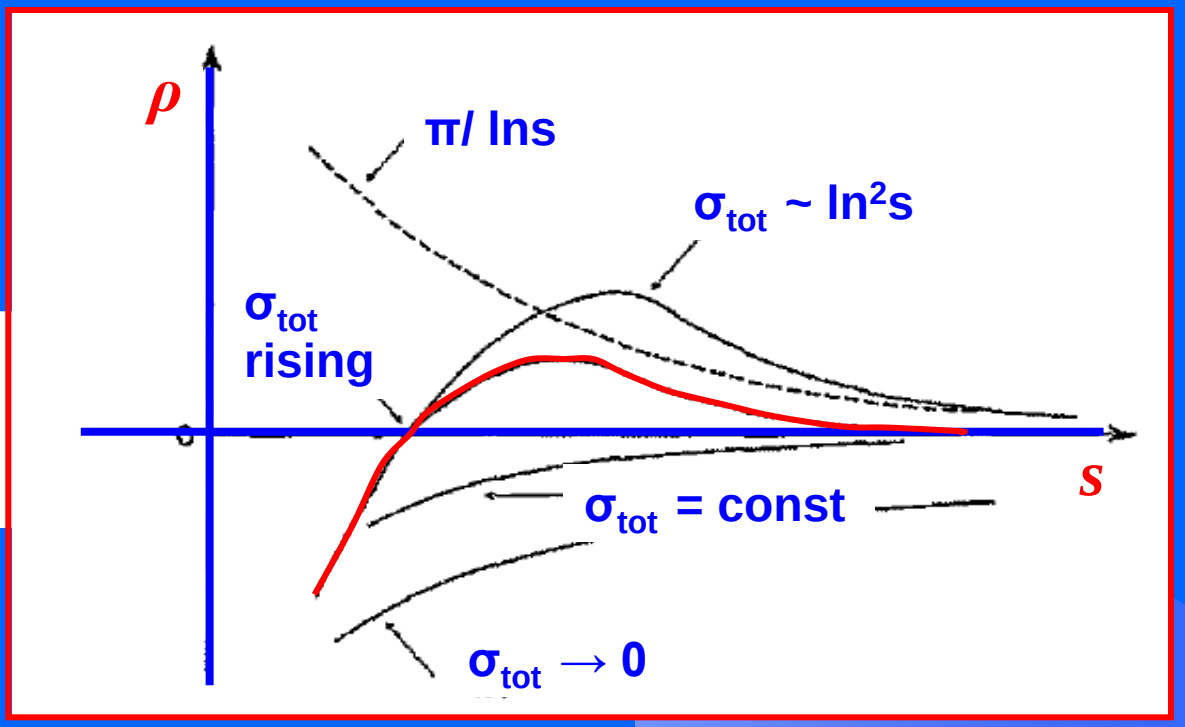
Froissart– Martin bound

1961-1965

$$\sigma_{tot} \leq C \ln^2 s = 60\, mb \ln^2 s$$

Khuri + Kinoshita – 1965

asymptotic real part



s-channel description: absorption models

Unitarity in impact parameter space

$t = -q^2 \leq 0$

$$4\pi \,\mathrm{Im}\, f(q)/k = G_{\mathrm{el}}(q) + G_{\mathrm{in}}(q).$$

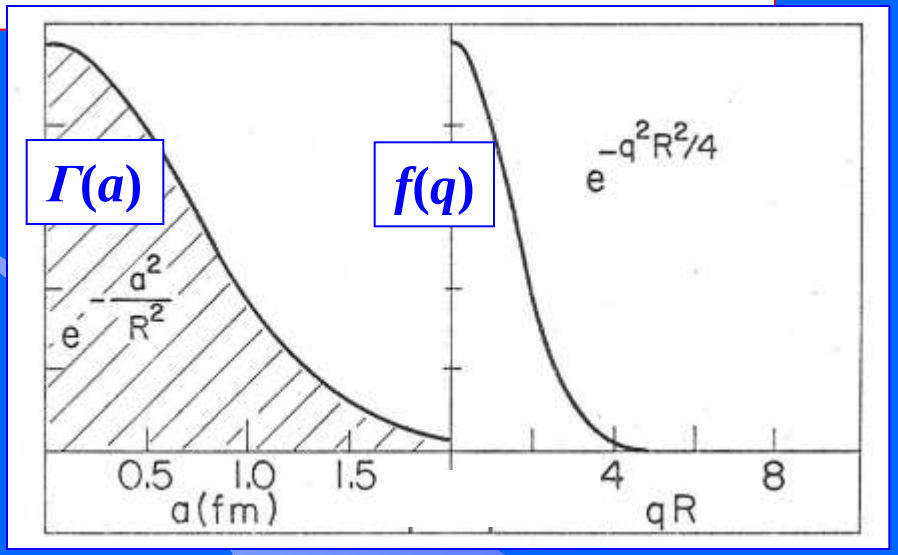
Impact parameter space

$t = -q^2 \leq 0$

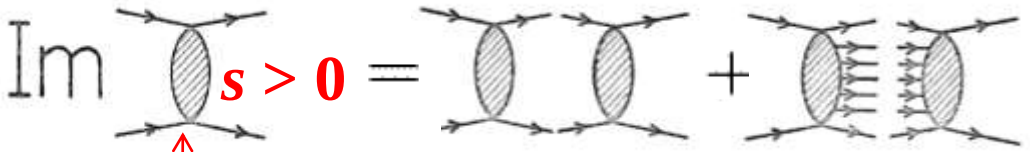
$$4\pi \,\mathrm{Im}\, f(q)/k = G_{el}(q) + G_{in}(q).$$

Elastic profile function

$$\Gamma(a) = \frac{1}{i\hbar c\sqrt{\pi}} \int_0^\infty \mathrm{d}q q f(q) J_0(qa/\hbar c)$$



Impact parameter space



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$$4\pi \,\mathrm{Im}\, f(q)/k = G_{\mathrm{el}}(q) + G_{\mathrm{in}}(q).$$

Elastic profile function

$$\Gamma(a) = \frac{1}{i\hbar c\sqrt{\pi}} \int_0^\infty \mathrm{d}q q f(q) J_0(qa/\hbar c)$$

Inelastic profile function

Unitarity in impact parameter space:

$$2\,\mathrm{Re}\,\Gamma(a) = |\Gamma(a)|^2 + G_{\mathrm{in}}(a)$$

$$0 \leq \Gamma(a) \leq 1 \qquad 0 \leq G_{\mathrm{in}}(a) \leq 1$$

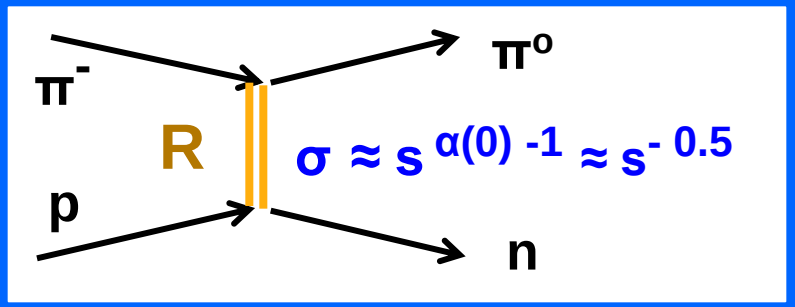
Froissart-Martin bound:

$$\Gamma(a) = G_{\mathrm{in}}(a) = 1 \qquad a \leq a_o \ln s$$

t-channel description: Regge model

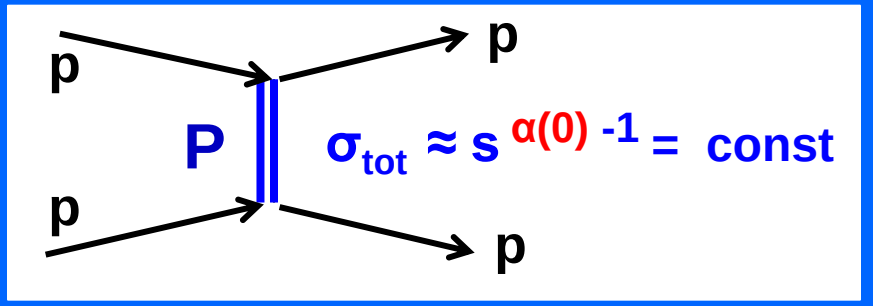
Reggeon and Pomeron exchanges

charge exchange

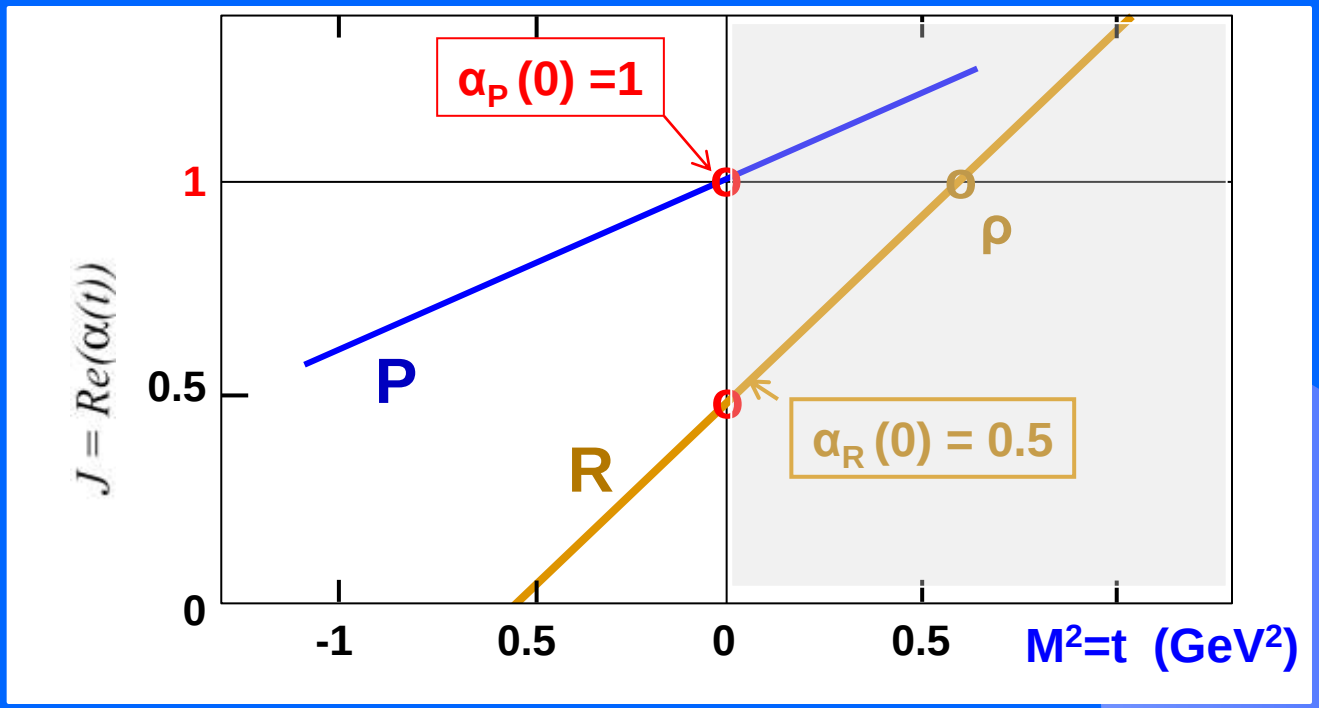


'trajectory' with quantum numbers

elastic scattering



'trajectory ' without quantum numbers



Reggeon and Pomeron exchanges

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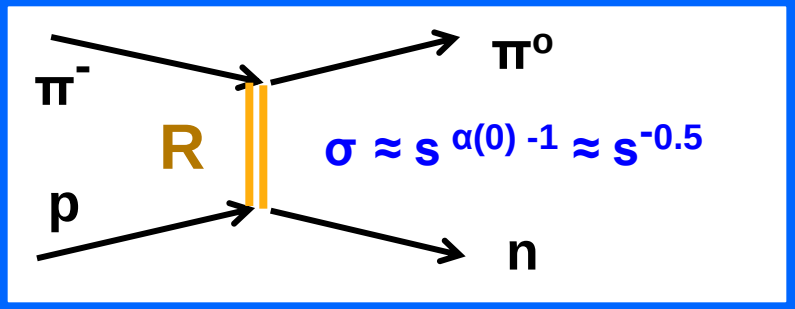
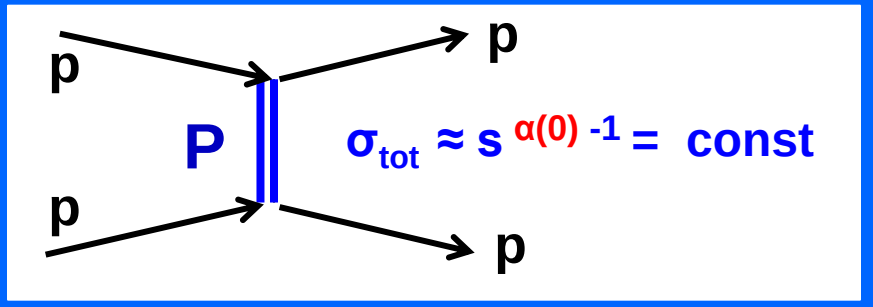


'trajectory' with quantum numbers

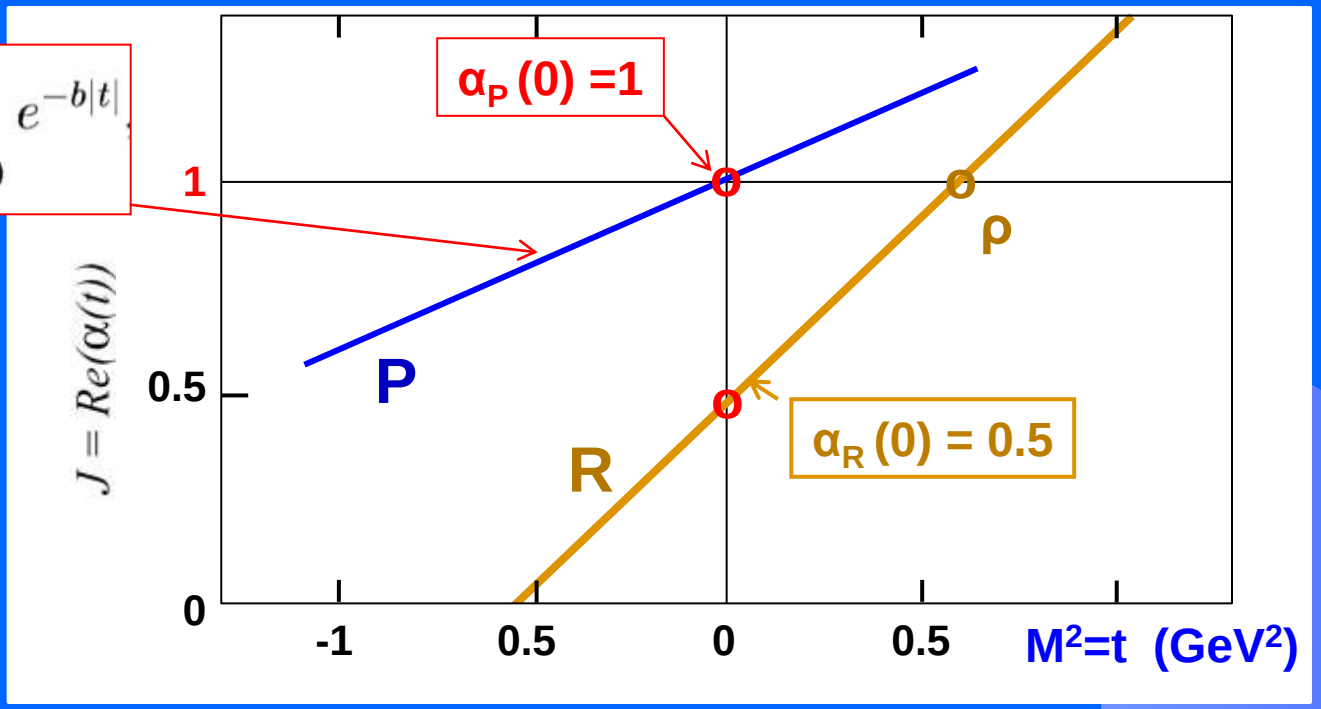
elastic scattering



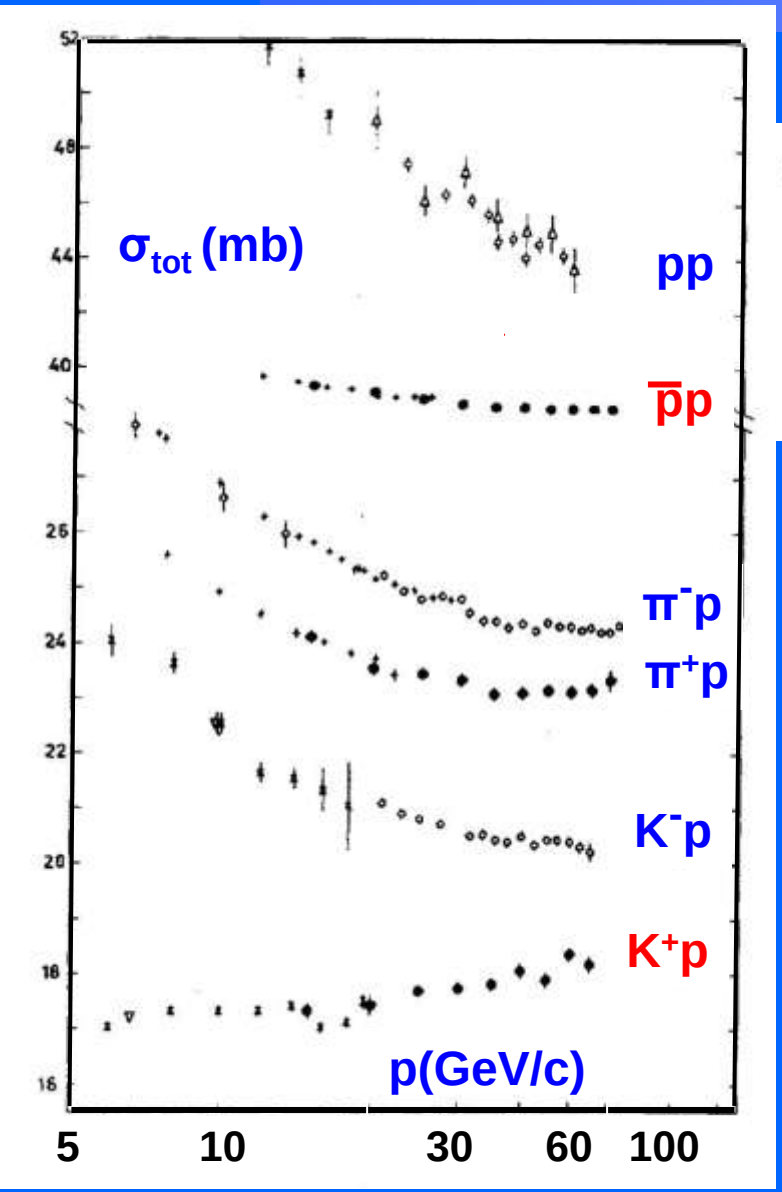
'trajectory ' without quantum numbers

$$\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{-b|t|}$$

Shrinking forward peak



Serphukov data : July 1971



TOTAL CROSS SECTIONS OF π^+, K^+ AND p ON PROTONS AND DEUTERONS IN THE MOMENTUM RANGE 15-60 GeV/c

S. P. DENISOV, S. V. DONSKOV, Yu. P. GORIN, A. I. PETRUKHIN, Yu. D. PROKOSHKIN
D. A. STOYANOVA, J. V. ALLABY* and G. GIACOMELLI**
Institute of High Energy Physics, Serpukhov, U.S.S.R.

Received 30 July 1971

This figure suggests that the total cross-section for K^+p will approach the asymptotic value from below, unless the cross-section oscillates in value.

Some models of rising cross sections:

W. Heisenberg

H. Cheng and T.T. Wu

Aix en Provence Int. Conference on Elementary Particles
6 -12 September 1973

Plenary speakers

Paul Musset	Neutrino interactions
Steven Weinberg	Recent progress in gauge theories of weak, electromagnetic and strong interactions
Daniele Amati	Strong interaction theory
Alex Mueller	High multiplicity reactions (theory)
J.D Bjorken	High transverse momentum process
U.A.	Elastic scattering and low multiplicities

Conclusions of "Elastic scattering and low multiplicities"

4. CONCLUSIONS

MAINLY EXPERIMENTAL INFORMATION THIS YEAR.

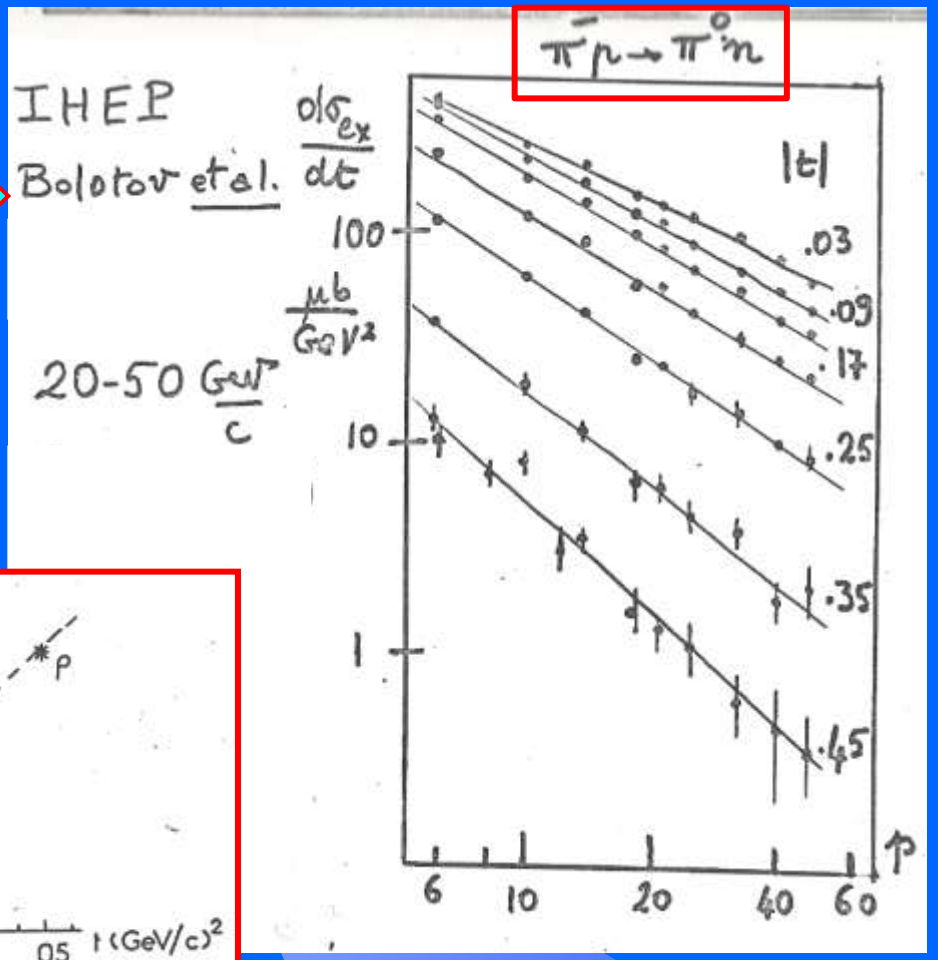
(i) CHARGE EXCHANGES ARE GOOD FOR REGGE MODELS

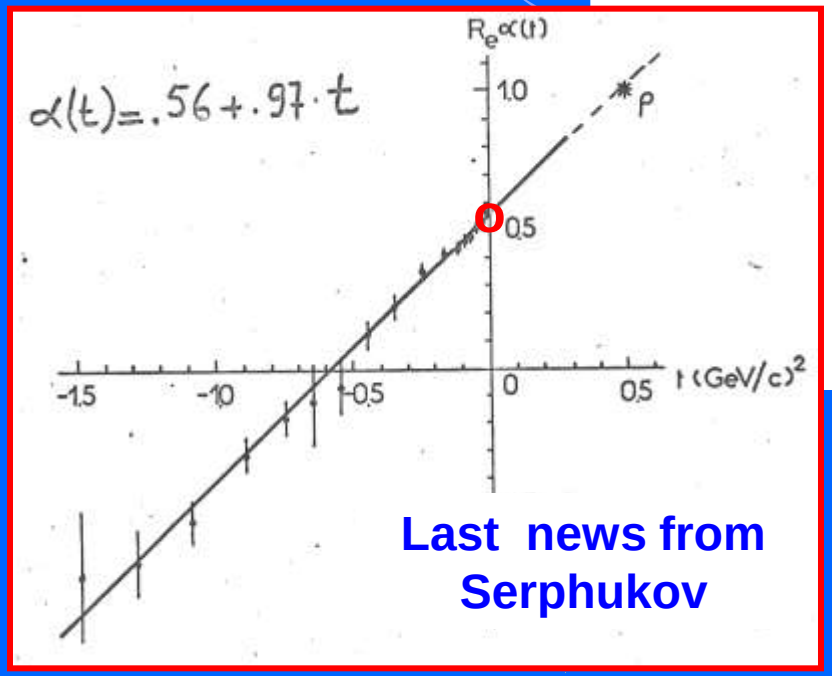
(ii) MANY DETAILED DATA ON OTHER REACTIONS

(iii) DIFFRACTIVE "BUMPS" HAVE ~ SAME BEHAVIOUR AT NAL

(iv) REAL PARTS ARE BECOMING INTERESTING

(v) THE PP ABSORPTION INCREASES "PERIFERALLY" AT THE ISR.





Last news from Serphukov

Conclusions of "Elastic scattering and low multiplicities"

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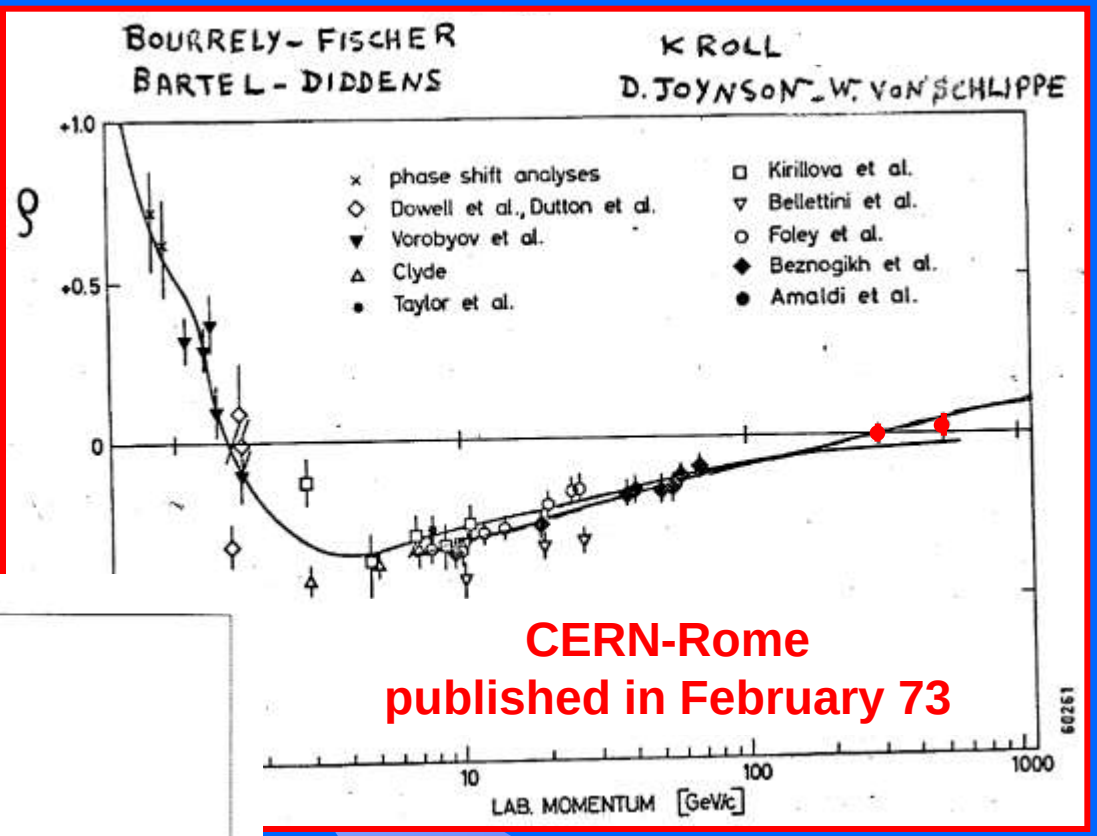
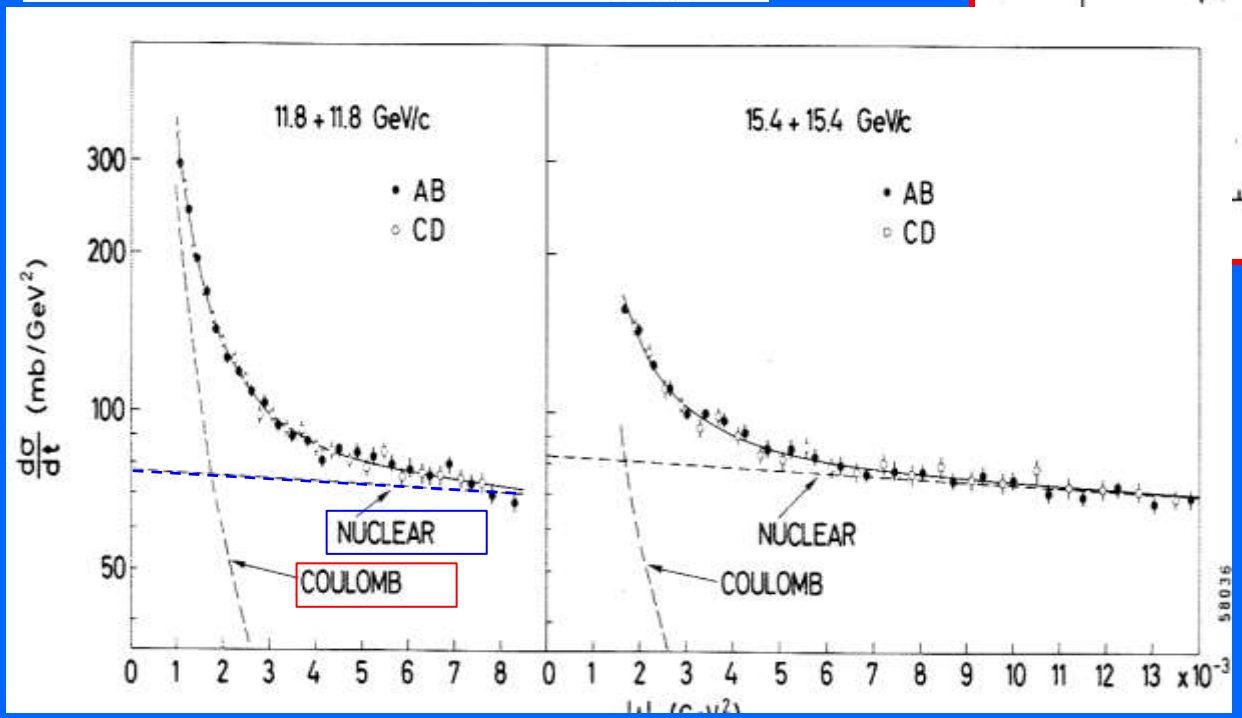


CERN-Rome published in February 73



Conclusions of "Elastic scattering and low multiplicities"

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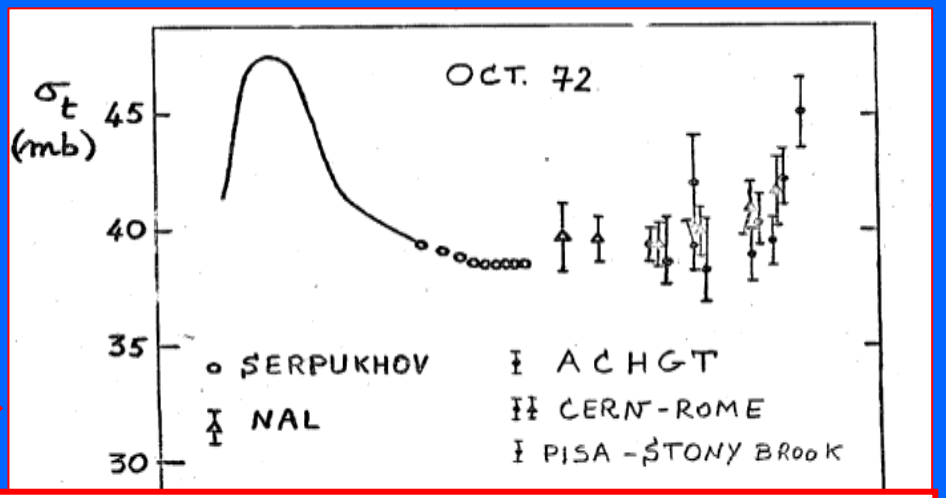

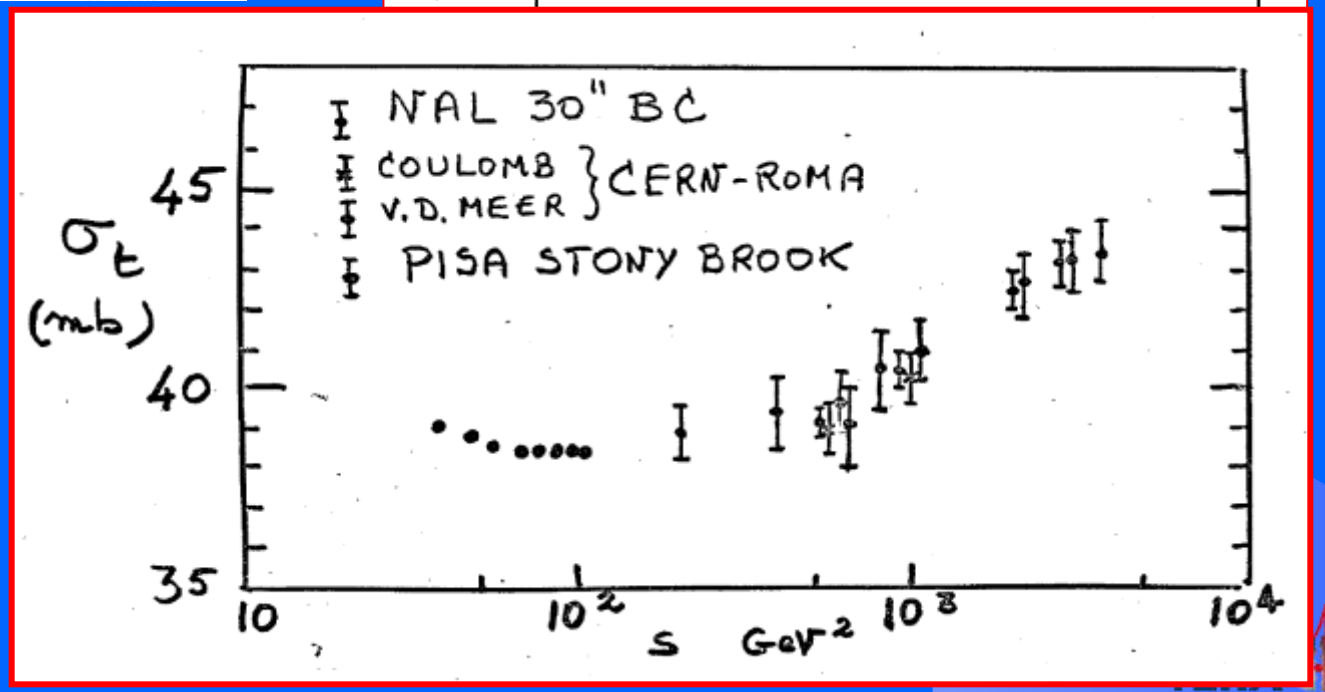

Conclusions of "Elastic scattering and low multiplicities"

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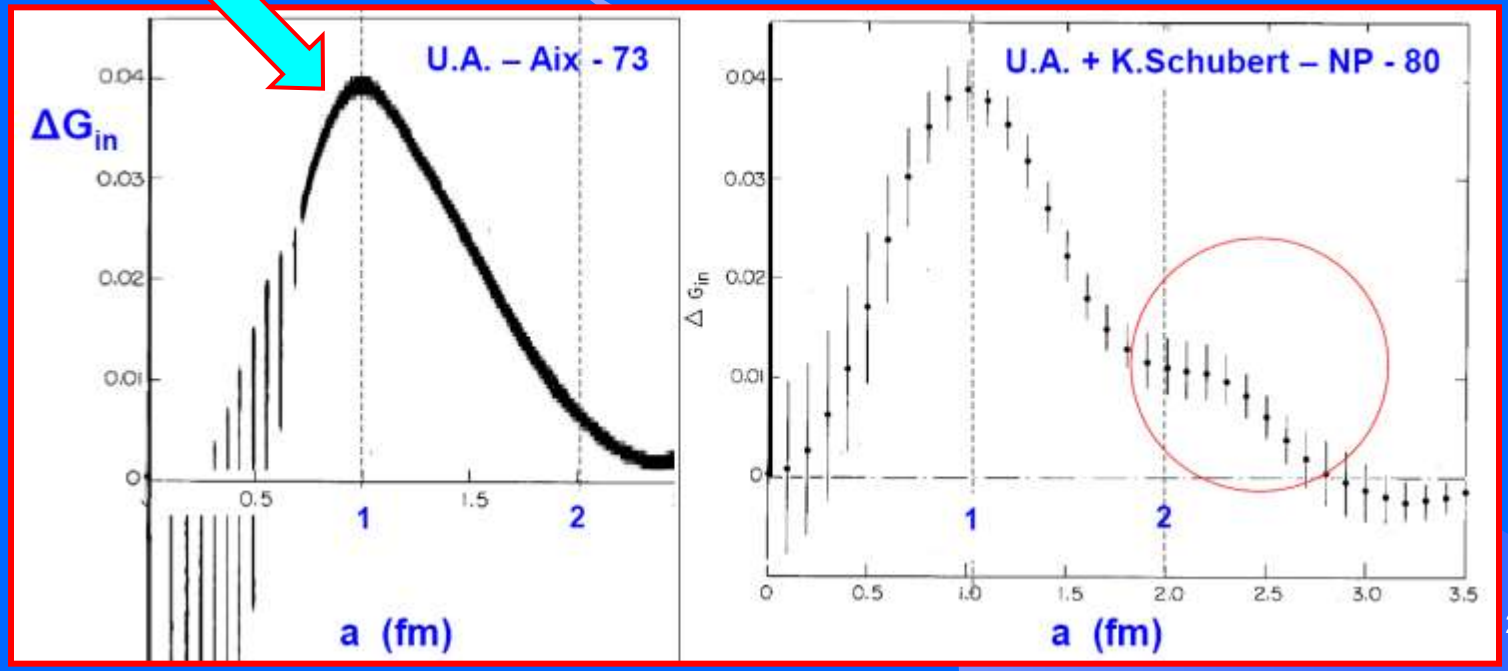
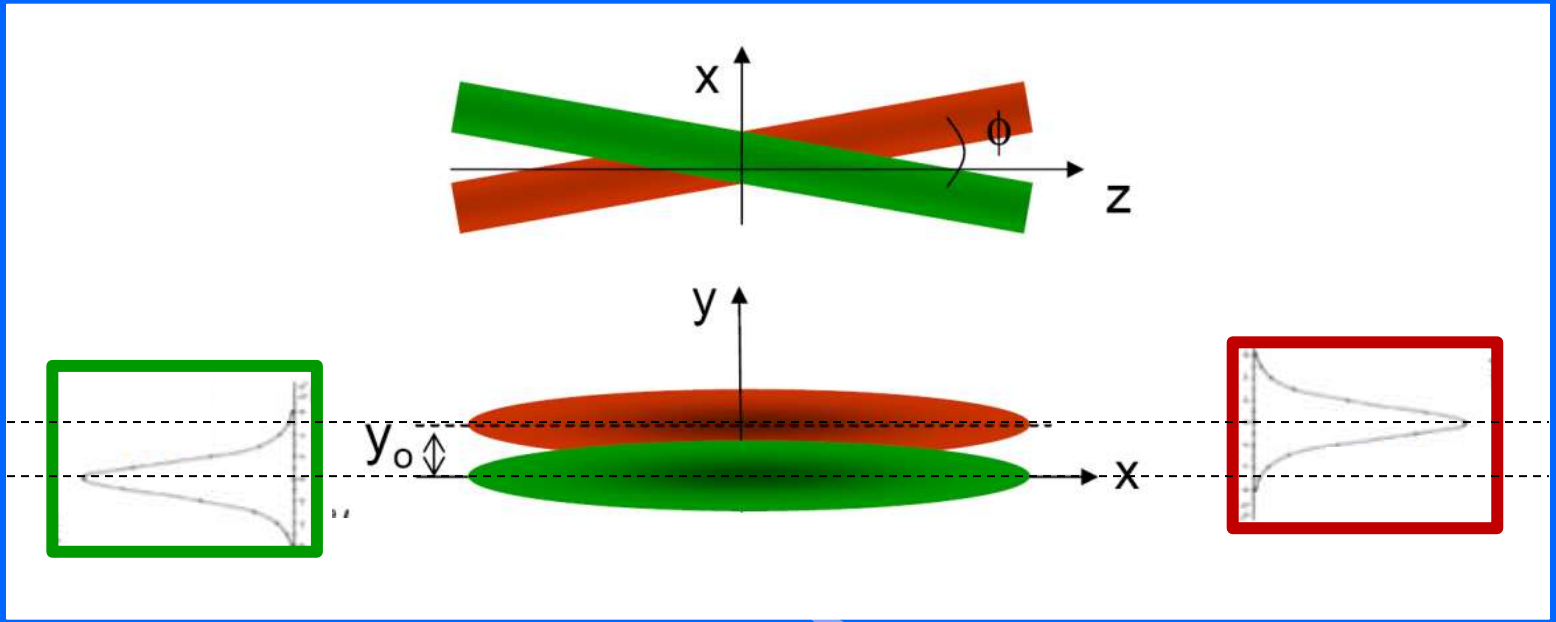


Luminosity measurements

The formula



beam factor

$$L(y_o) = \underbrace{\frac{I_1 I_2}{c\, e^2 \tan(\phi/2)}} \underbrace{\int \rho_1(y - y_o)\, \rho_2(y)\, dy}$$

$$R(y_o) = \sigma \cdot K \cdot \textit{(Overlap Integral)}$$

Rate **cross section**

Overlap integral from the two distributions $\rho(y)$

P. Darriulat and C. Rubbia, CERN Internal Report 68/340/5 SIS/si, 28 February, 1968.
C. Rubbia, Contribution to the ISR User's meeting, CERN, Geneva, 10-11 June, 1968.

W. Schnell, "A mechanical beam profile monitor for the ISR", June 1968.

J. Steinberger, "Suggestions for the luminosity measurement of the ISR", June, 1968.
A.P. Onuchin, NP Internal Report 68-26, 14 August, 1968.

Normalization to forward Coulomb cross section

G. Cocconi, CERN Internal Report NP/67/436/mk/5.

L. di Lella, "Elastic proton-proton scattering with the ISR", Contributed paper at the ISR User's Meeting CERN 10-11 June 1968.

C. Rubbia and P. Darriulat, CERN Internal Note on "High beta interaction region: a magnifying lens for very small angle proton-proton scattering", 1968.

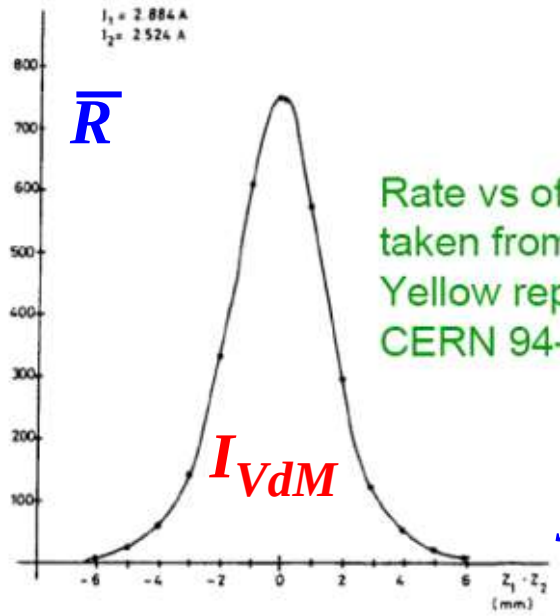
Method devised by Simon van deer Meer

S. Van der Meer, CERN Internal Report ISR-PO/68-31.

Monitor rate $\overline{R}(y_o) = \overline{\sigma} \cdot K \int \rho_1(y - y_o)\, \rho_2(y)\, dy$

$$I_{VdM} = \int \overline{R}(y_o)\, dy_o = \overline{\sigma} K \int\int \rho_1(y - y_o)\, \rho_2(y)\, dy\, dy_o$$

$$= \overline{\sigma} K \int \rho_2(y) \left(\int \rho_1(y - y_o)\, dy_o \right) dy = \overline{\sigma} K$$



Rate vs offset, taken from Potter in Yellow report CERN 94-01 v1

$$\sigma = \frac{R}{\overline{R}} \quad \overline{\sigma} = \frac{I_{VdM}}{K} \frac{R}{\overline{R}}$$

Small angle scattering and total cross sections

The Pisa proposal

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/69-12
14 March, 1969

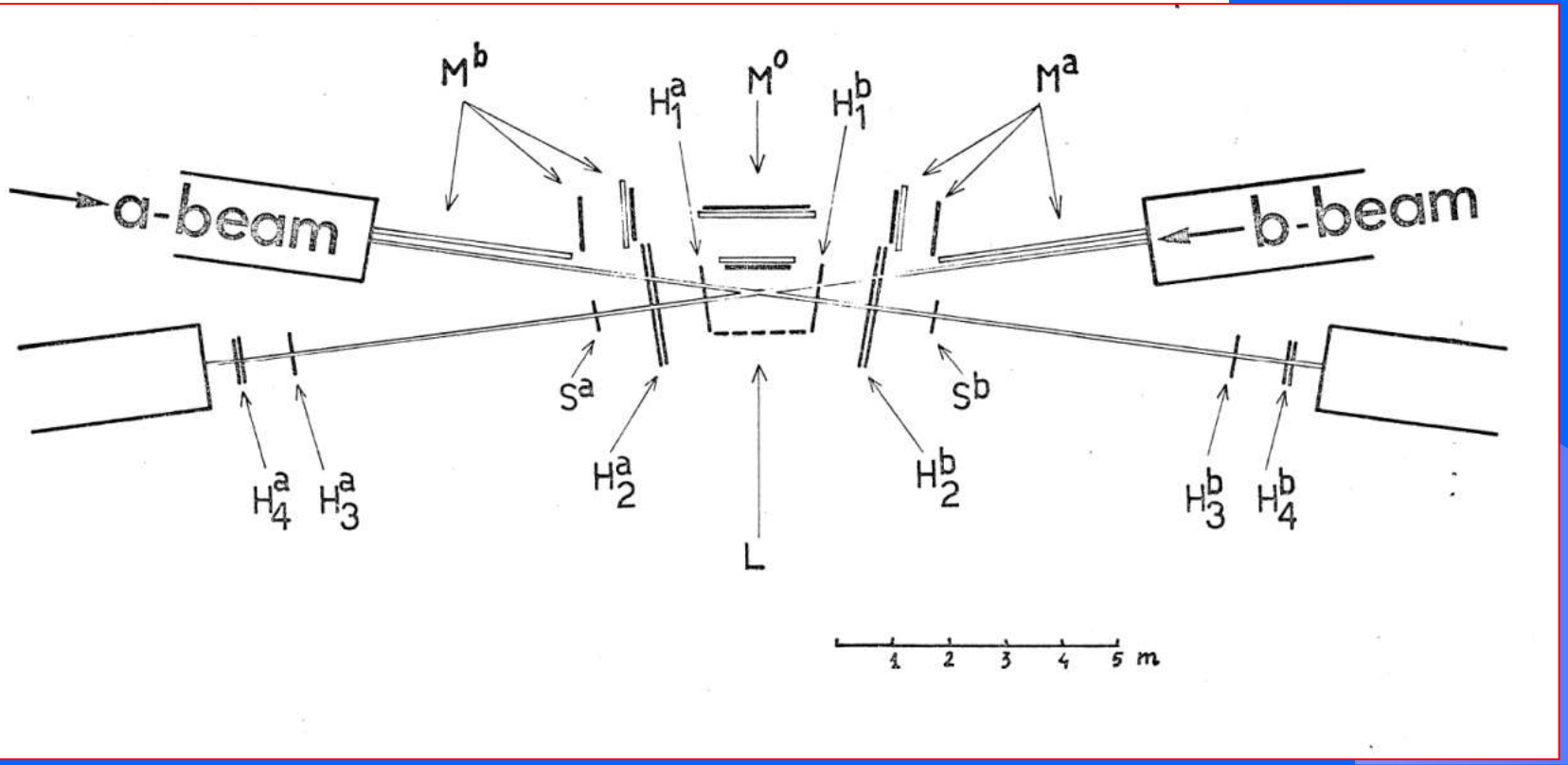
MEASUREMENT OF THE p-p TOTAL CROSS SECTION

G. Bellettini, P.L. Braccini, C. Bradaschia, R.R. Castaldi, C. Cerri,
T. Del Prete, L. Foà, A. Menzione, G. Sanguinetti

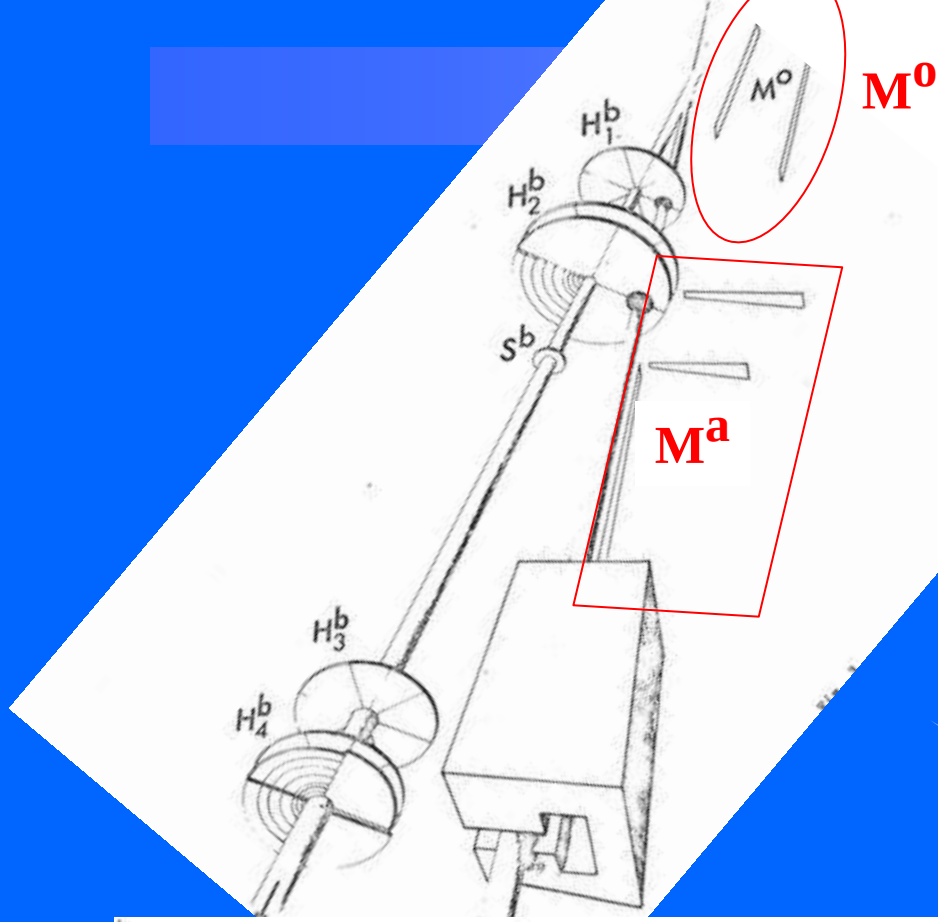
Istituto di Fisica, PISA

Scuola Normale Superiore di PISA

Istituto Nazionale di Fisica Nucleare,
Sezione di PISA.



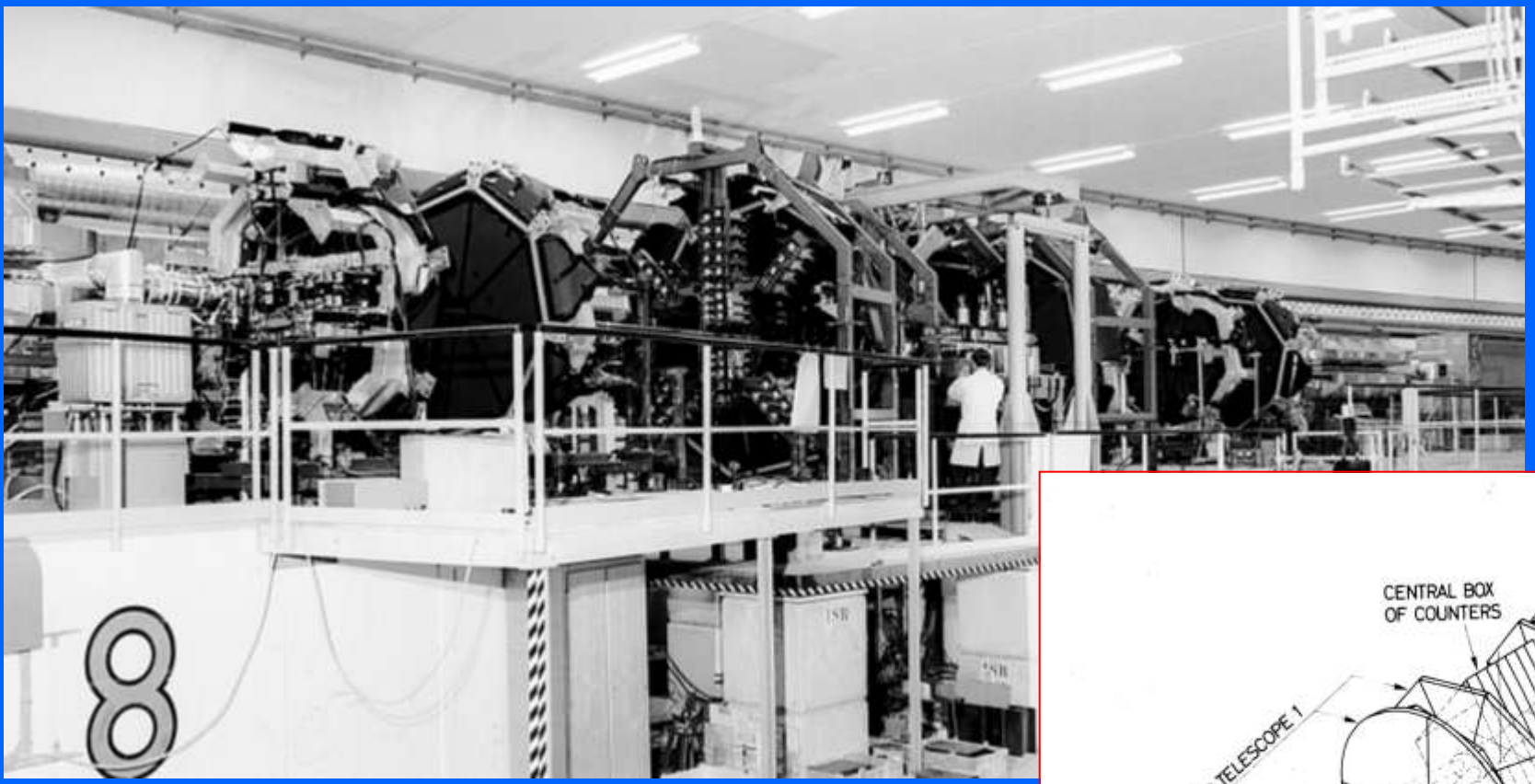
The Pisa proposal

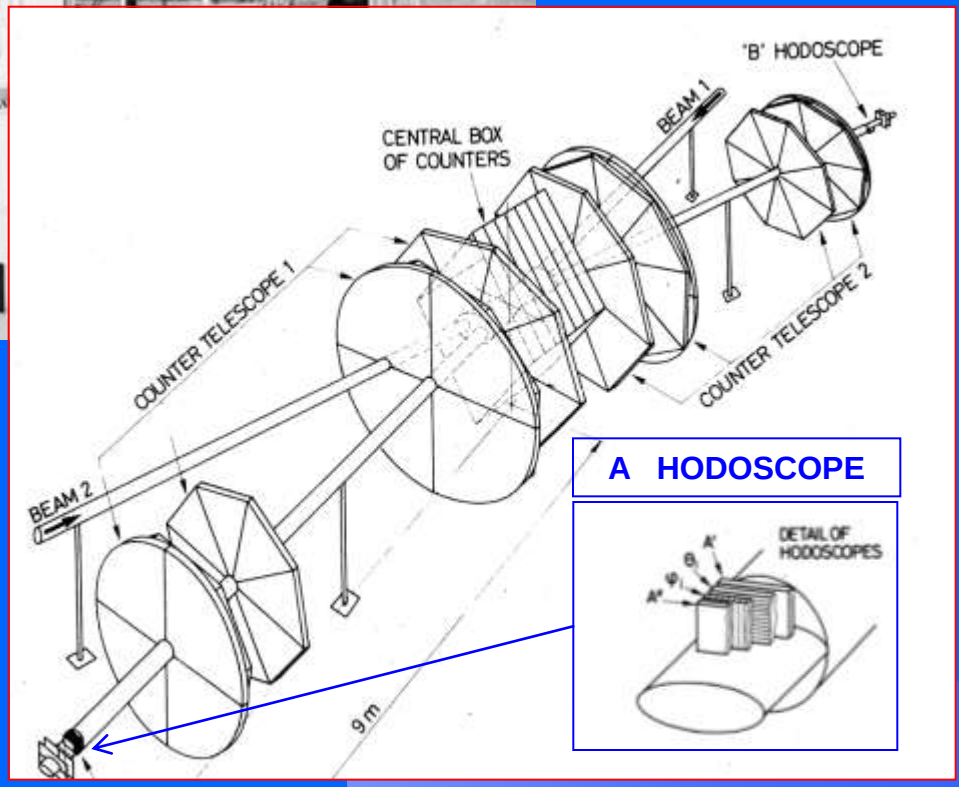


The Van der Meer method is not mentioned

The proposed monitor system comprises three spark chamber and counter telescopes M^a, M^b and M^0. These telescopes measure the z-distribution of the radiation centres produced in the beam-gas interactions over a path four metres long.

The Pisa - Stony Brook detector (May 1972)





Initially foreseen in I6 with Cern-Rome and ACHGT

The CERN – Genoa – Turin proposal

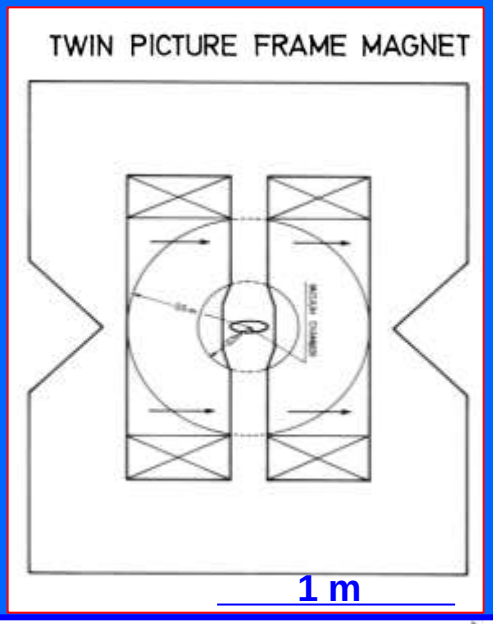
CERN/ISRC/69-19
16.3.1969

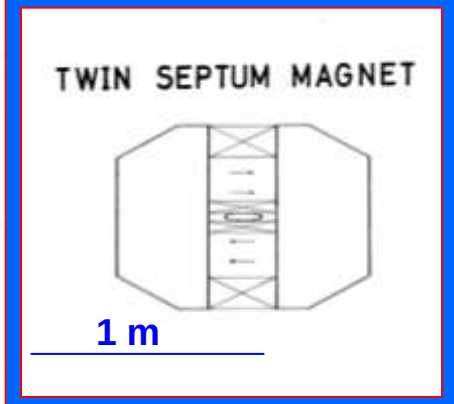
MEASUREMENT OF THE ELASTIC SCATTERING CROSS-SECTION AT THE ISR

P. Darriulat, C. Rubbia, P. Strolin and K. Tittel
CERN

G. Diambrini, I. Giannini, P. Ottonello, A. Santroni, G. Sette
INFN - Sezione di Genova

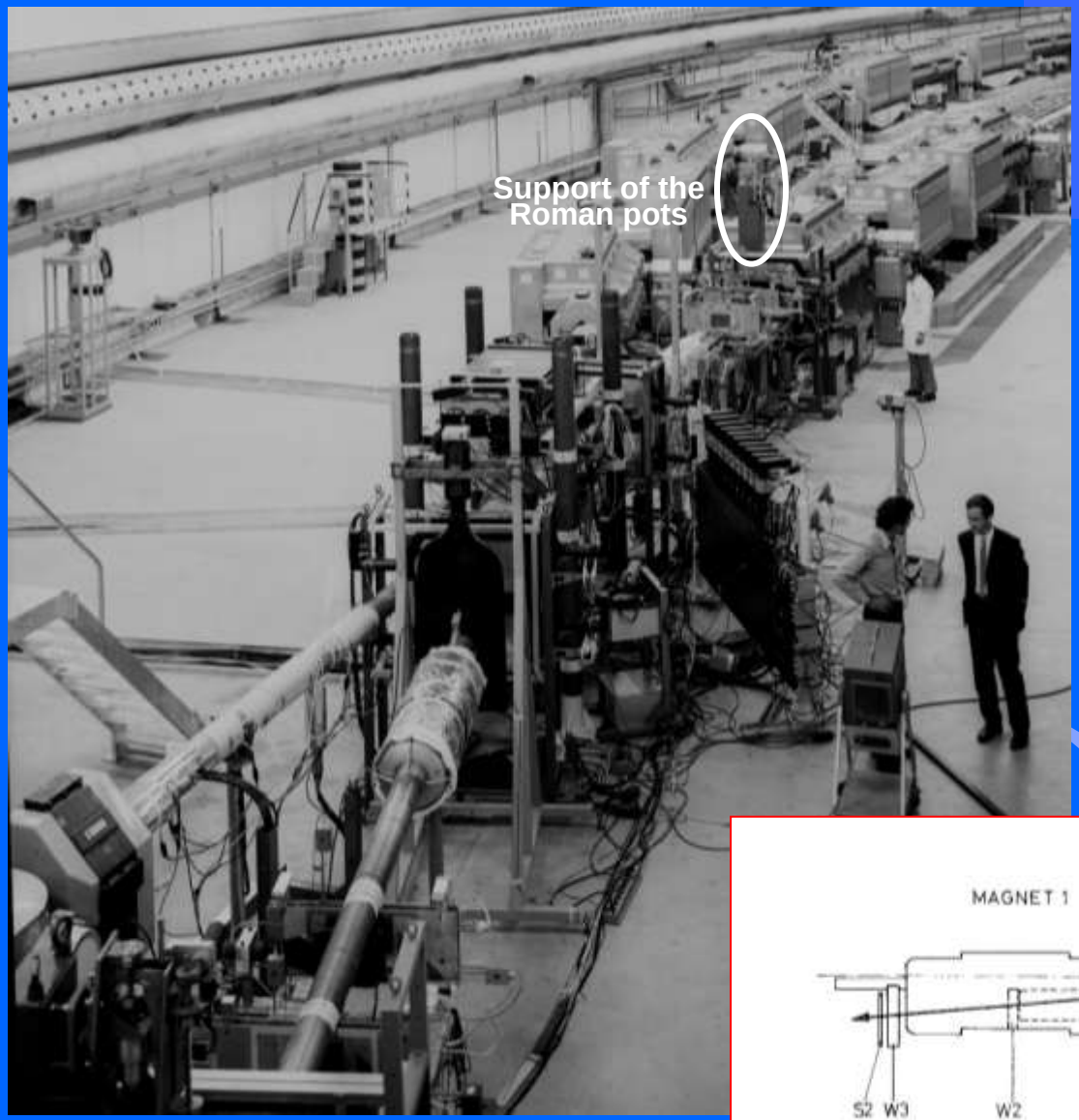
V. Bisi, A. Germak, C. Grosso, M.I. Ferrero
INFN - Sezione di Torino

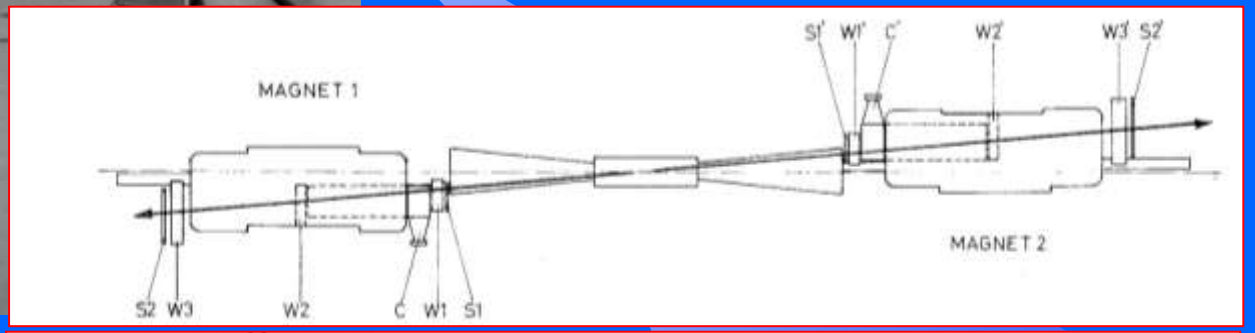


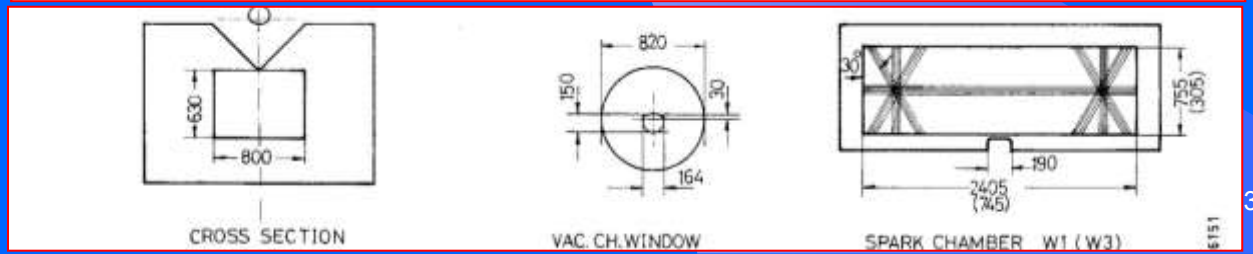


The whole angular range from 1 mrad to about 100 mrad can be covered. The very small angle events are detected by a two-arm spectrometer sharing with the storage ring system the first four magnets. The larger angle events are momentum analyzed with a pair of magnets which do not perturb the circulating beam.

Aachen-CERN-Genoa-Harvard-Turin detector in September 71







ACGHT: first measurement of σ_{tot} from $(d\sigma/dt)_0$

H. Holder et al. Phys. Letters 36B (1971) 400.

Calibration with VdM of the elastic cross section

$$\left(\frac{d\sigma_{\mathrm{el}}}{dt}\right)_{t=0} = \frac{(1+\rho^2)\,\sigma_{\mathrm{tot}}^2}{16\pi}$$

Advantage:

$$\frac{\Delta\sigma}{\sigma} = \frac{1}{2}\,\frac{\Delta I_{\mathrm{VdM}}}{I_{\mathrm{VdM}}}$$

Rome-Sanità proposal

CERN/ISRC/69-20
24 March 1969.

THE MEASUREMENT OF PROTON-PROTON DIFFERENTIAL CROSS-SECTION IN THE ANGULAR REGION OF COULOMB SCATTERING AT THE ISR

U. Amaldi, Jr., R. Biancastelli,
C. Bosio and G. Matthiae

Physics Laboratory, Istituto Superiore di Sanità and
Istituto Nazionale di Fisica Nucleare,
Sottosezione Sanità, Rome, Italy

P. Strolin
CERN, Geneva

oral presentation 22 April 1969

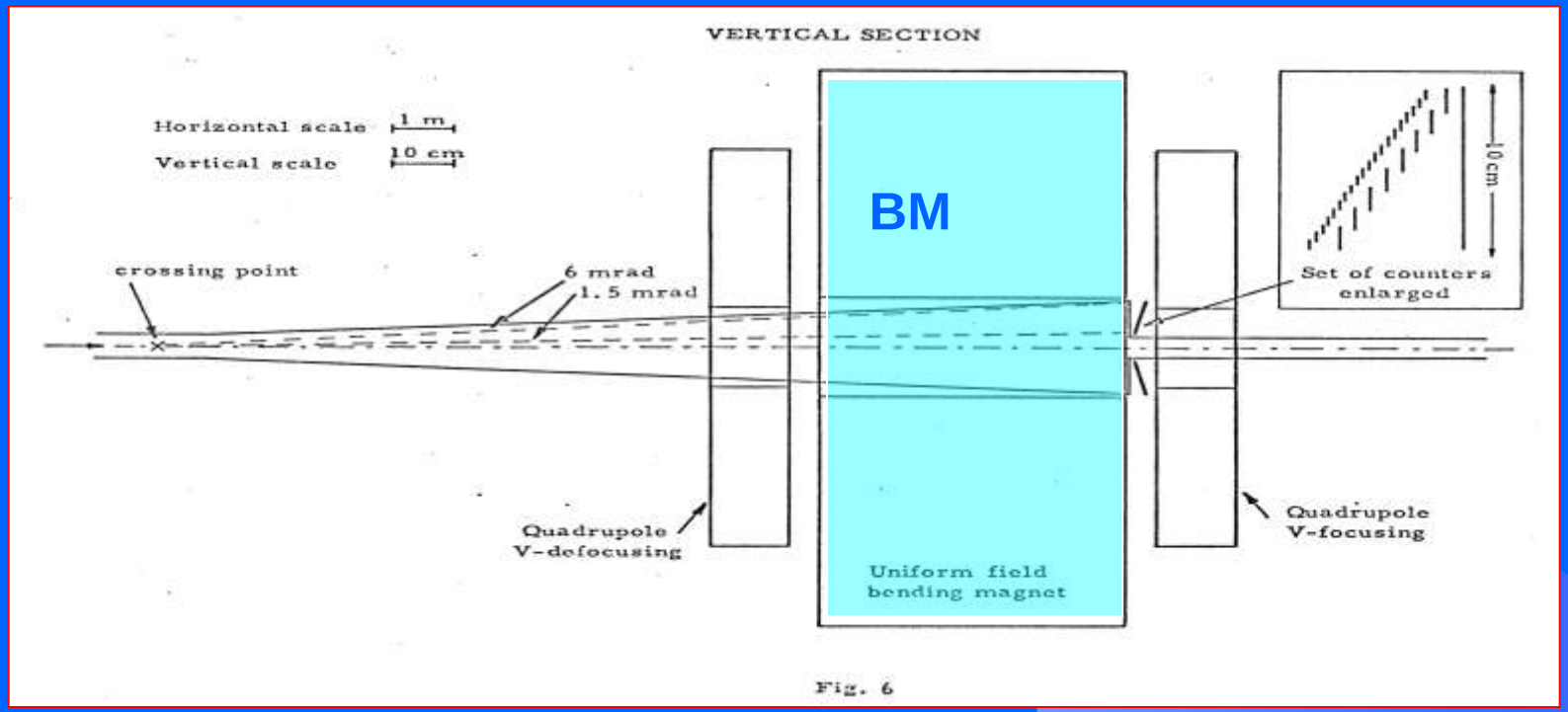


Fig. 6

The 'Pots'

THE MEASUREMENT OF PROTON-PROTON DIFFERENTIAL CROSS-SECTION IN THE ANGULAR REGION OF COULOMB SCATTERING AT THE ISR

Addendum to CERN/ISRC/69-20

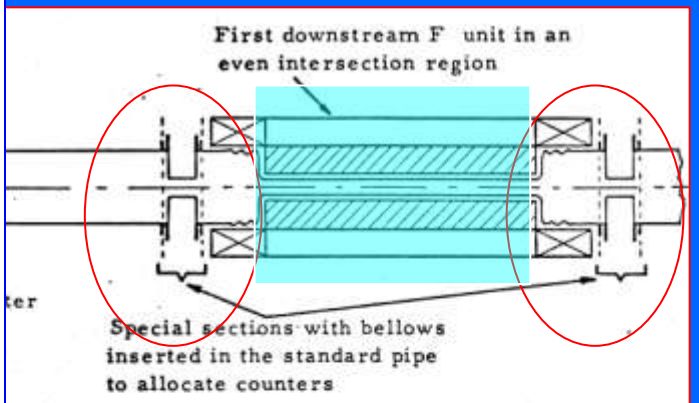
U. Amaldi, Jr., R. Biancastelli, C. Bosio and G. Matthiae
Physics Laboratory, Istituto Superiore di Sanità and
INFN Sottosezione Sanità, Rome, Italy

and

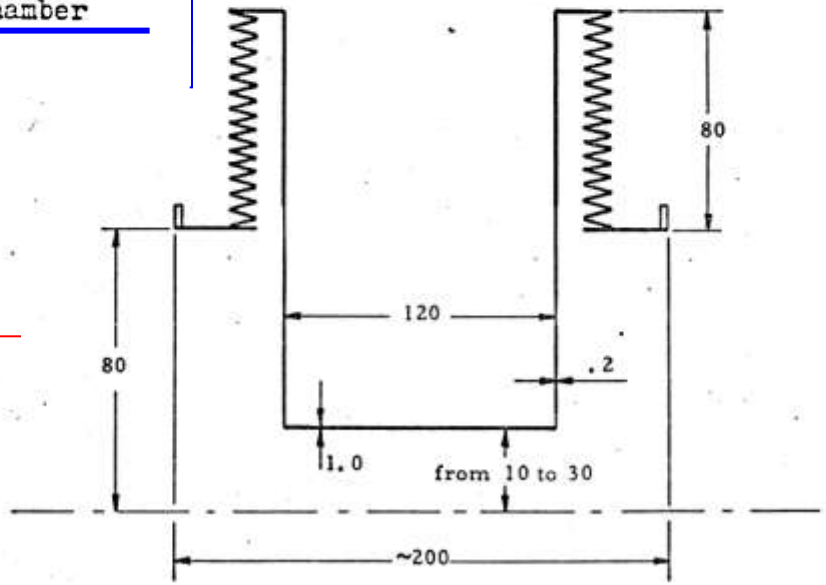
P. Strolin
CERN, Geneva

CM-P00062863

In discussions with specialists of the machine (R. Calder and E. Fischer) we found a simple way for allocating the detectors near to the beam, which does not imply a modification of the standard parts of the vacuum chamber



Detail of a special section



The pots at the PS

CERN-ISRC/70-25

INTERSECTING STORAGE RINGS COMMITTEE

REPORT ON BACKGROUND MEASUREMENTS AT THE PS

IN PREPARATION OF THE SMALL ANGLE ISR ELASTIC SCATTERING EXPERIMENT

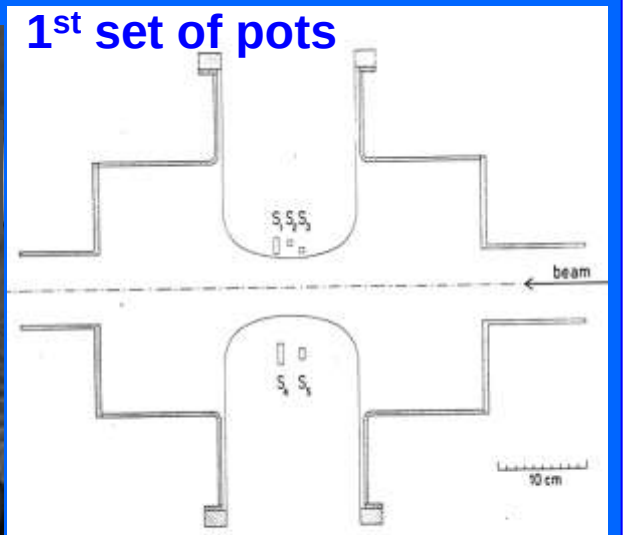
U. Amaldi, jr., R. Biancastelli, C. Bosio and G. Matthiae
Physics Laboratory, Istituto Superiore di Sanità

and

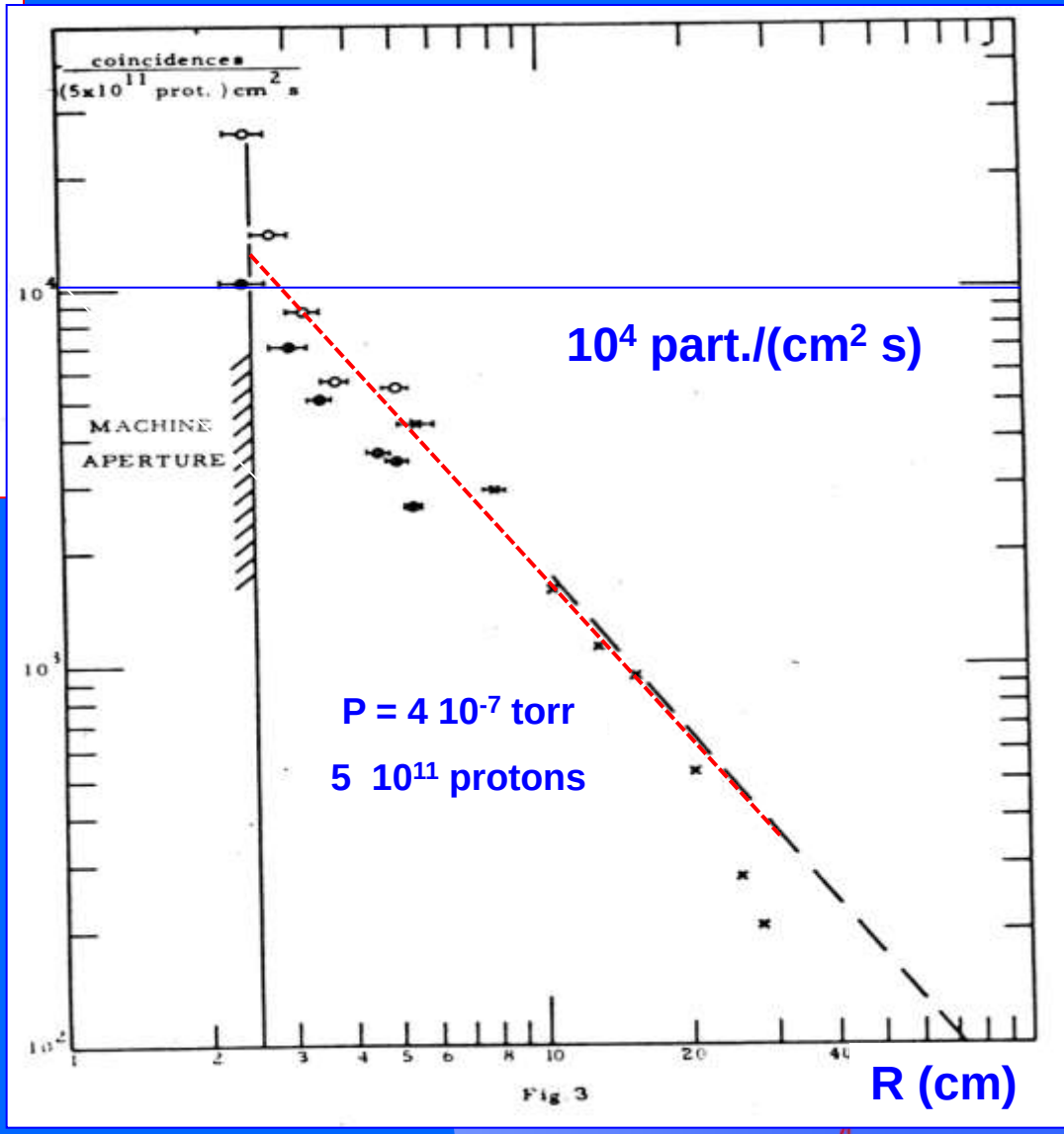
Istituto Nazionale di Fisica Nucleare, Sottosezione Sanità, Roma

E. Jones and P. Strolin
CERN

1st set of pots



'Roman pots' at the PS



November 1970: the CERN-Rome marriage

To : The Chairman and The Members of the ISRC

From : J.V. Allaby, G. Cocconi, A.N. Diddens, R.W. Dobinson, J. Litt, L.S. Rochester, K. Schlüpmann, C.A. Ståhlbrandt and A.M.Wetherell

Re ; Future activity at the ISR

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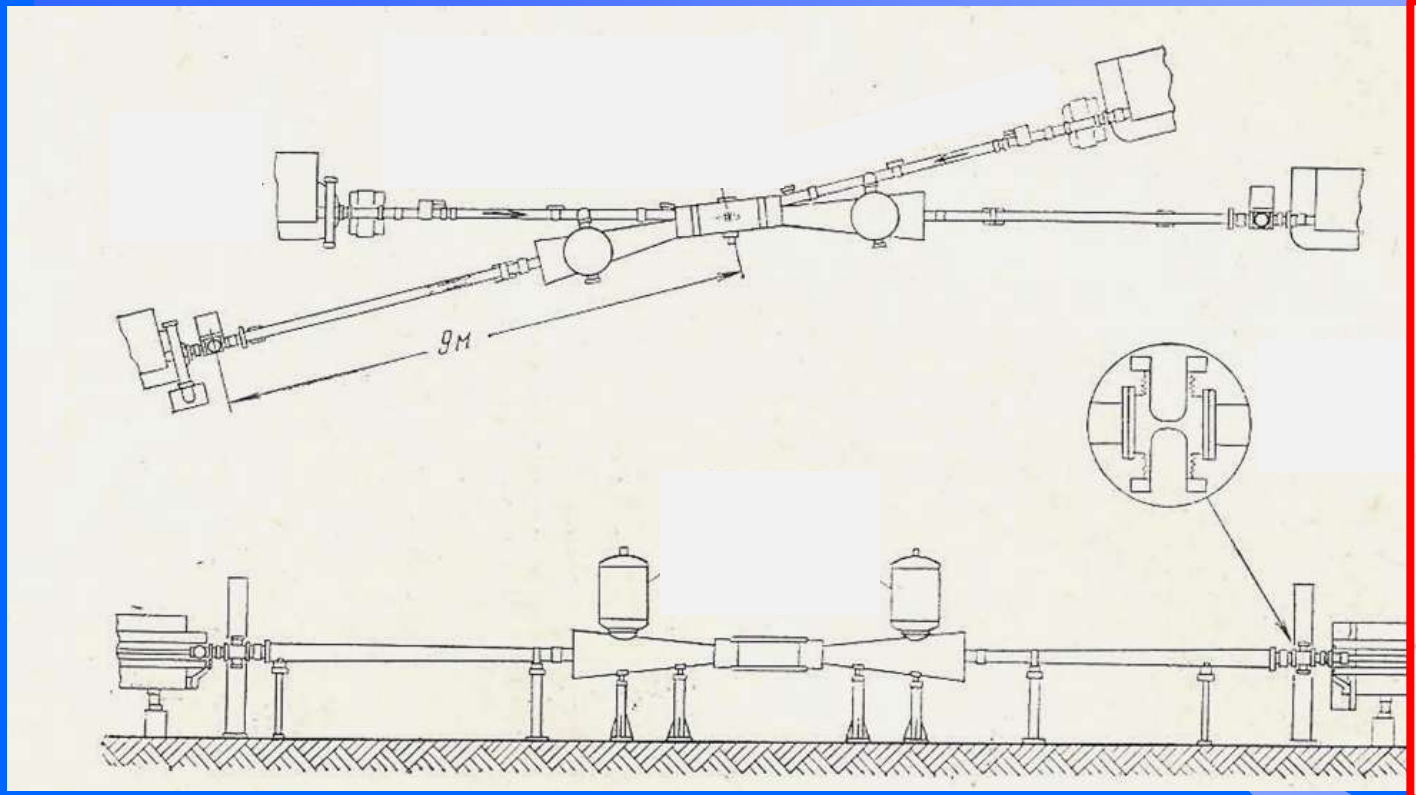
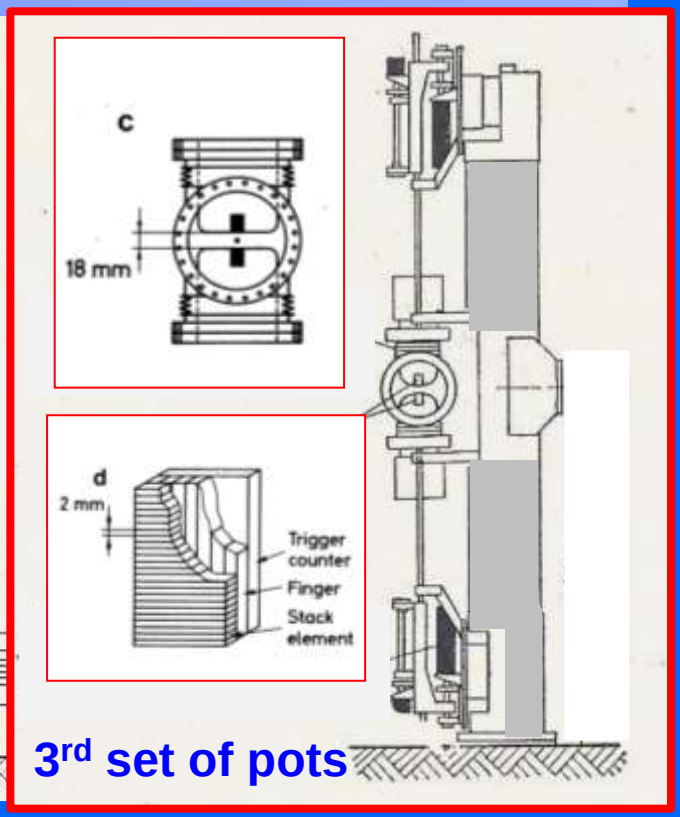
At the meeting of the ISRC on 14 October it was concluded that there is no way to fit the proposed experiment on deep inelastic scattering into the present ISR experimental programme.

As a result, we have decided, on their invitation, to collaborate with the Rome group (U. Amaldi et al) on the small angle elastic scattering experiment.

Two independent measurements of the total cross-sections





3rd set of pots

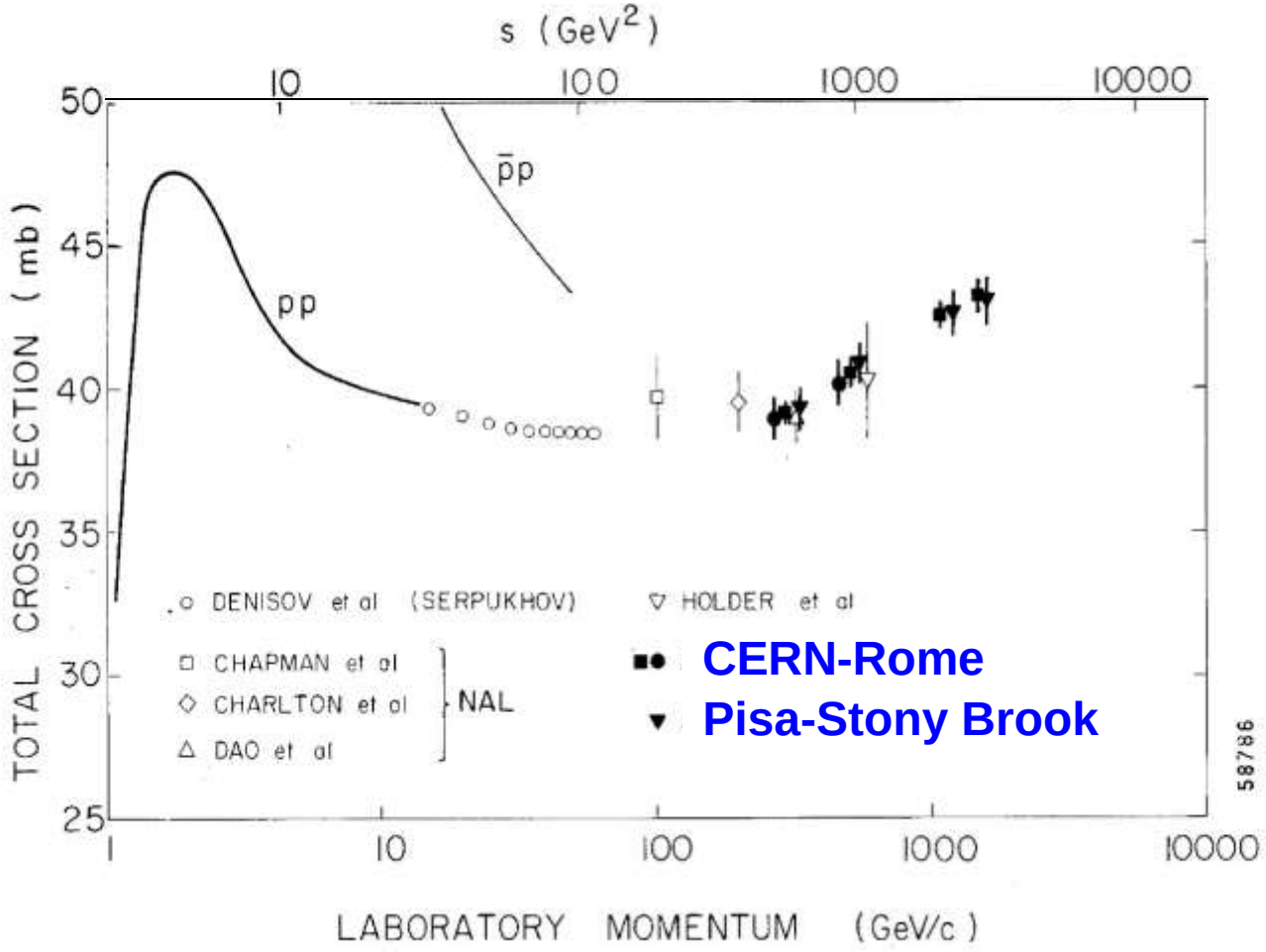
Extrapolation to $t = 0$ of the elastic cross section calibrated with

1. **The forward Coulomb cross section**

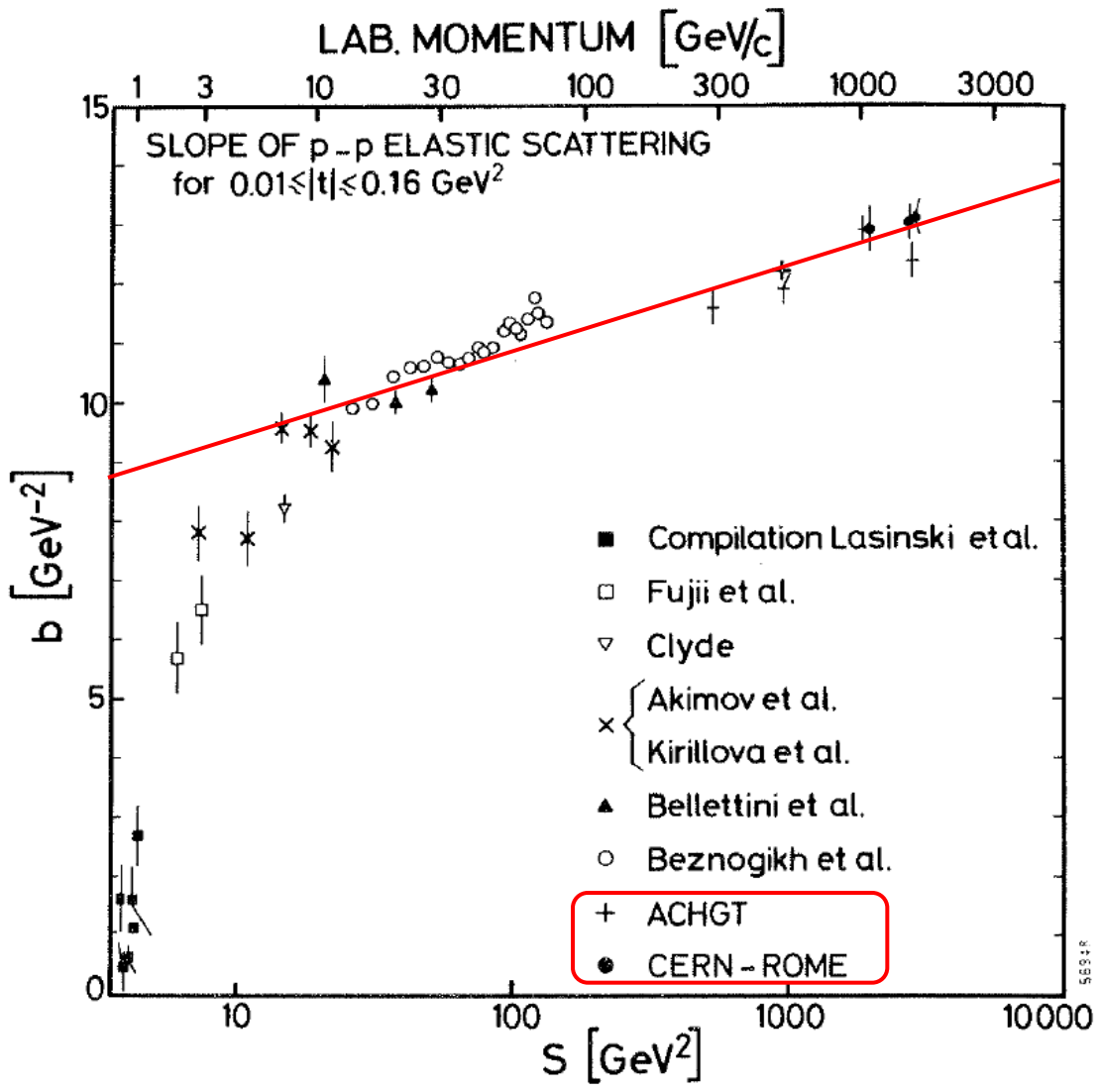
2. **The cross section of a monitor system measured with the Van der Meer method**

Results on small angle scattering and total cross sections

The total cross sections in 1973



The shrinkage of the forward peak continues...



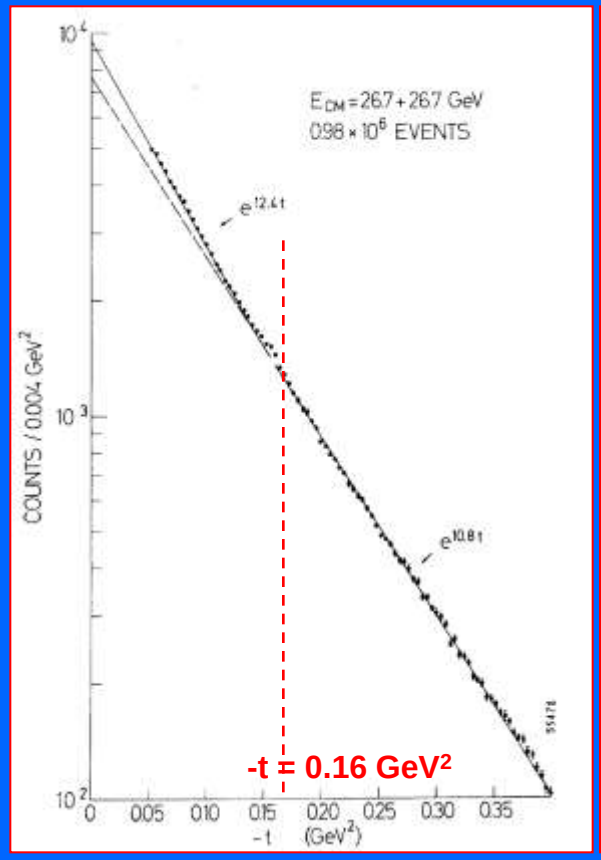
$$\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{-b|t|}$$

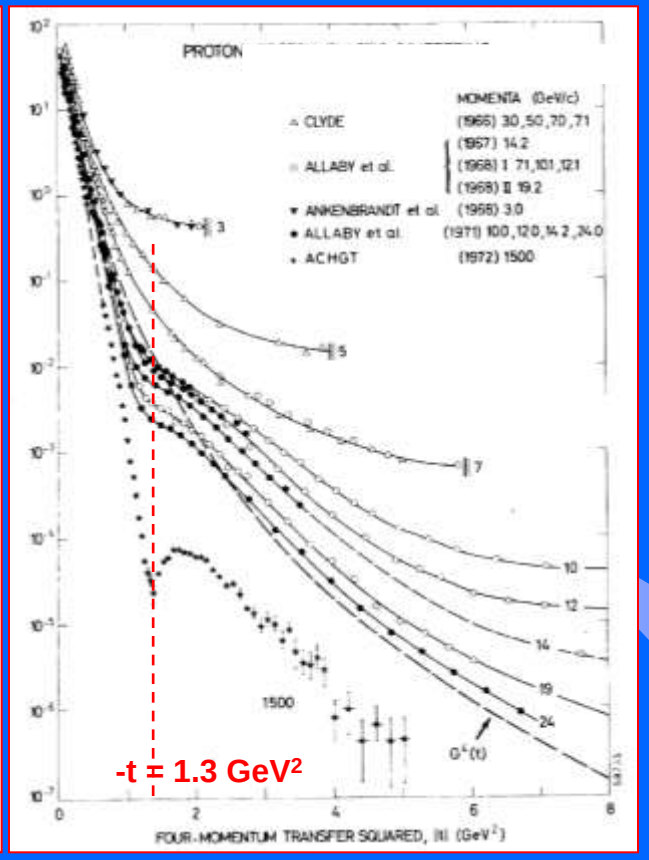
increasing b =

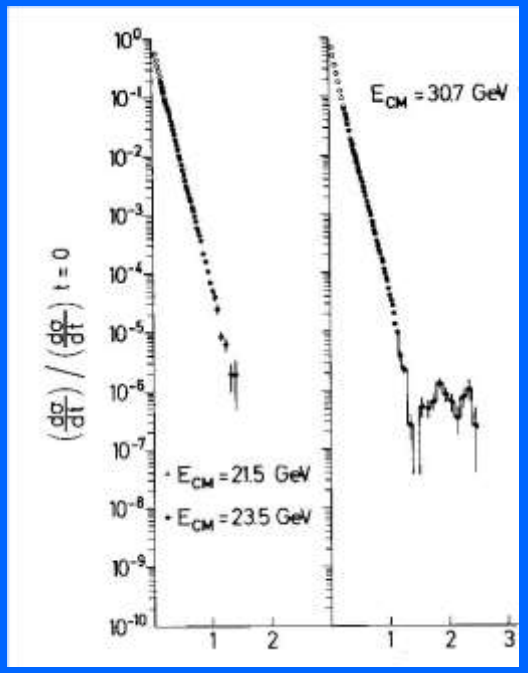
"Shrinking" forward peak =

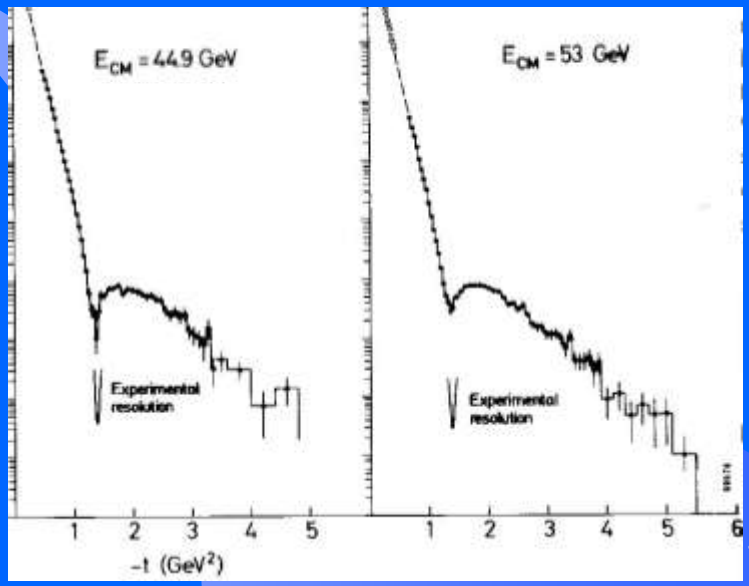
increasing radius

ACHGT results on elastic scattering obtained by 1973

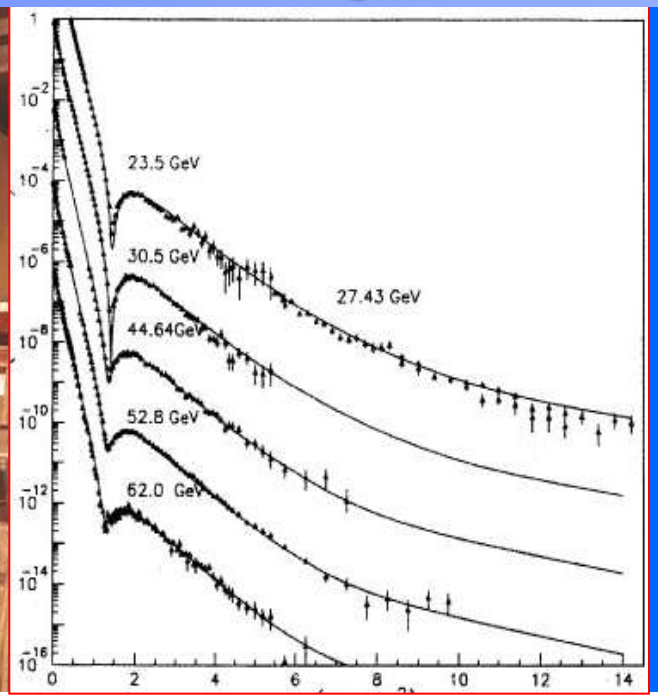


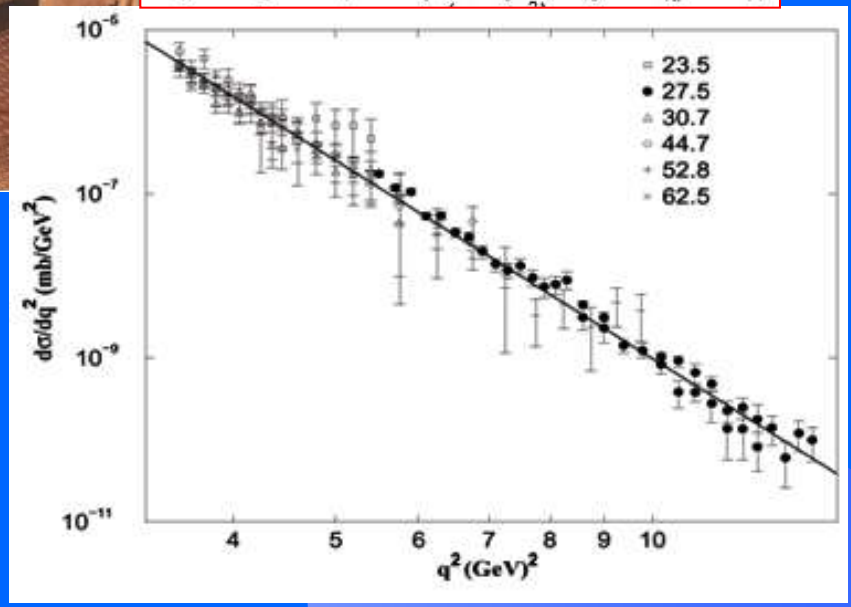






Elastic scattering at the SFM



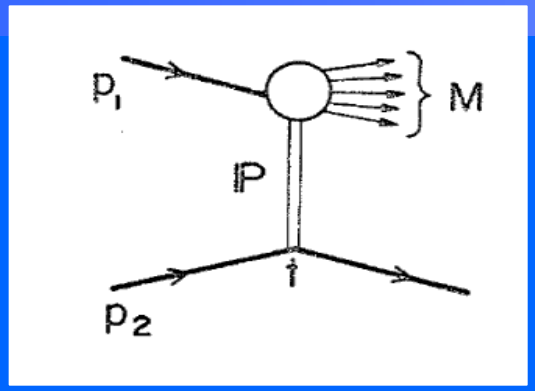


Nagy et al, Nucl. Phys B150 (1979) 221

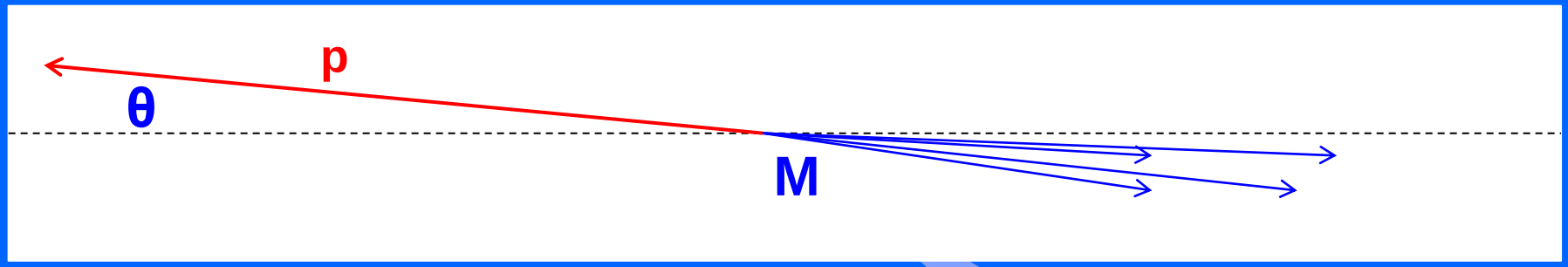
Annecy CERN Hamburg Heidelberg Vienna Collaboration

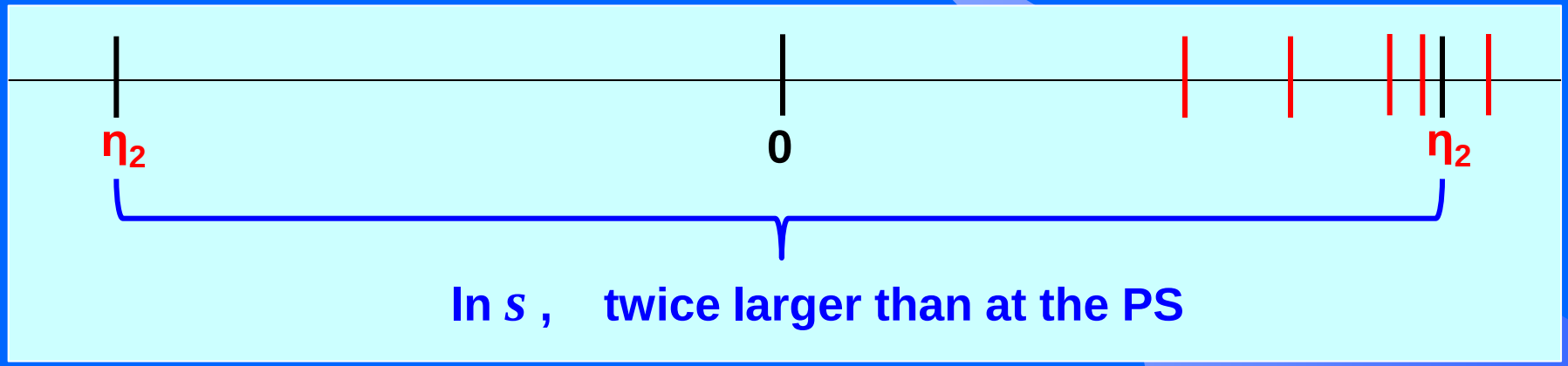
Diffraction dissociation

(Soft) diffraction dissociation

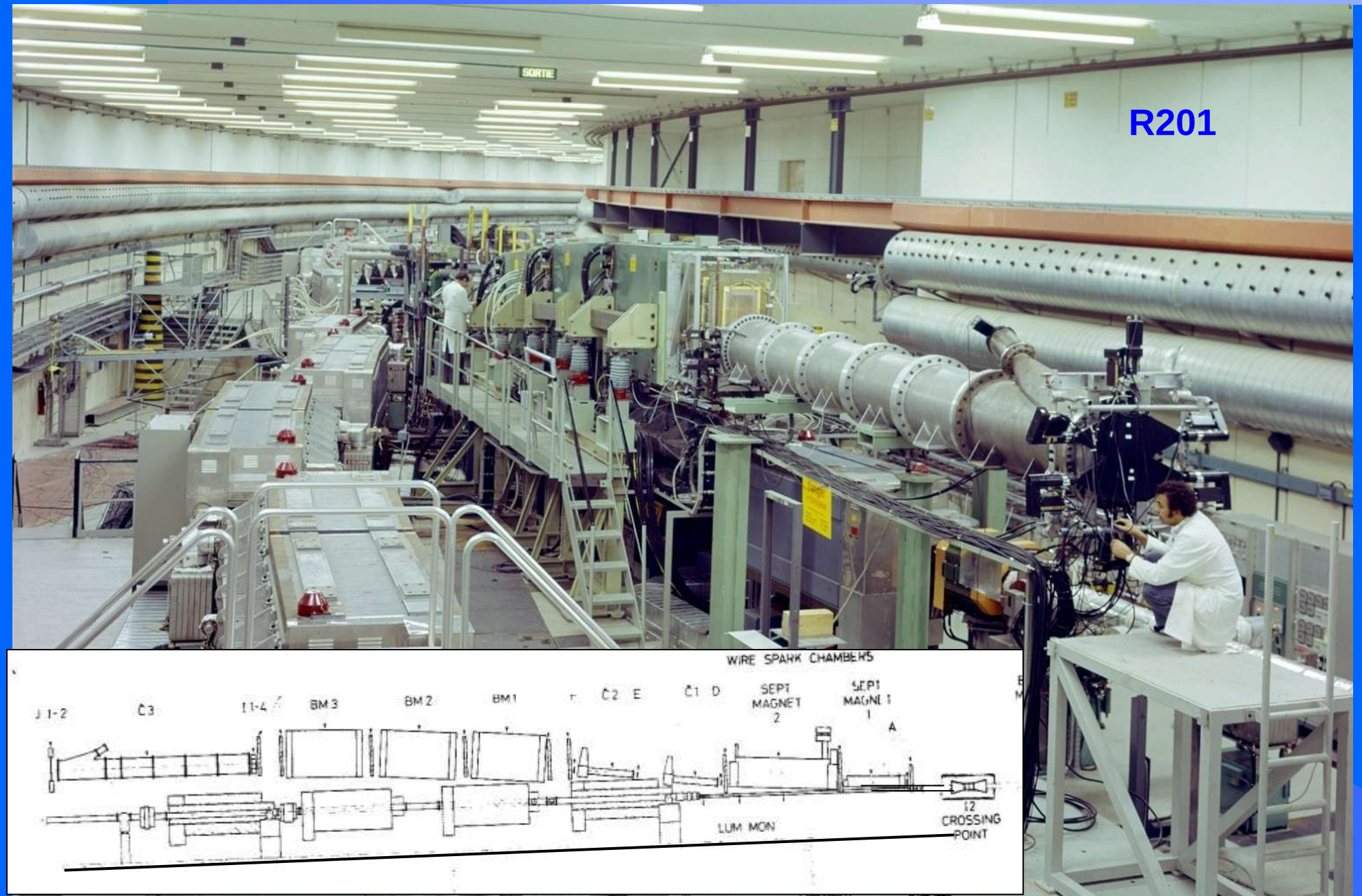


$$\eta = -\ln \tan\left(\frac{\theta}{2}\right),$$



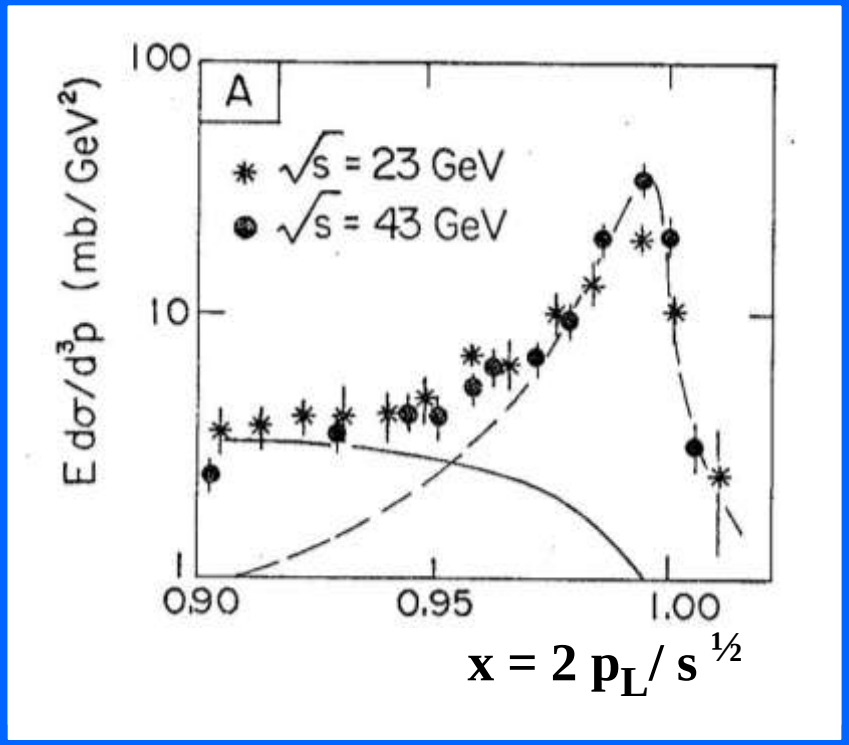


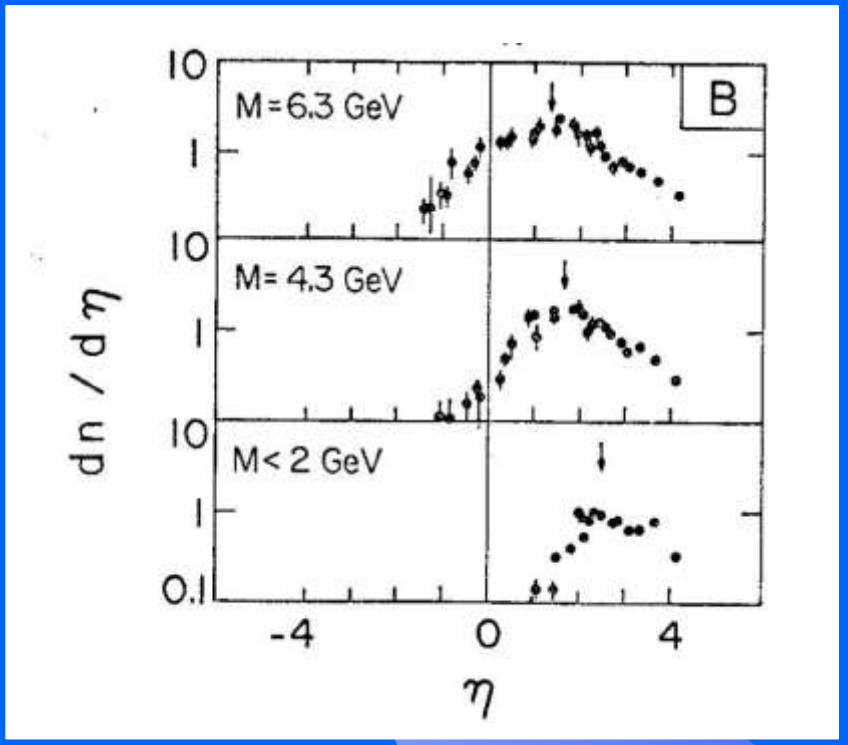
CERN-Holland-Lancaster-Manchester Collaboration



CHLM: Single diffraction dissociation

M.G. Albrow et al, Nucl. Phys. B51 (1973) 388;
B72(1974) 376; B108 (1976) 1





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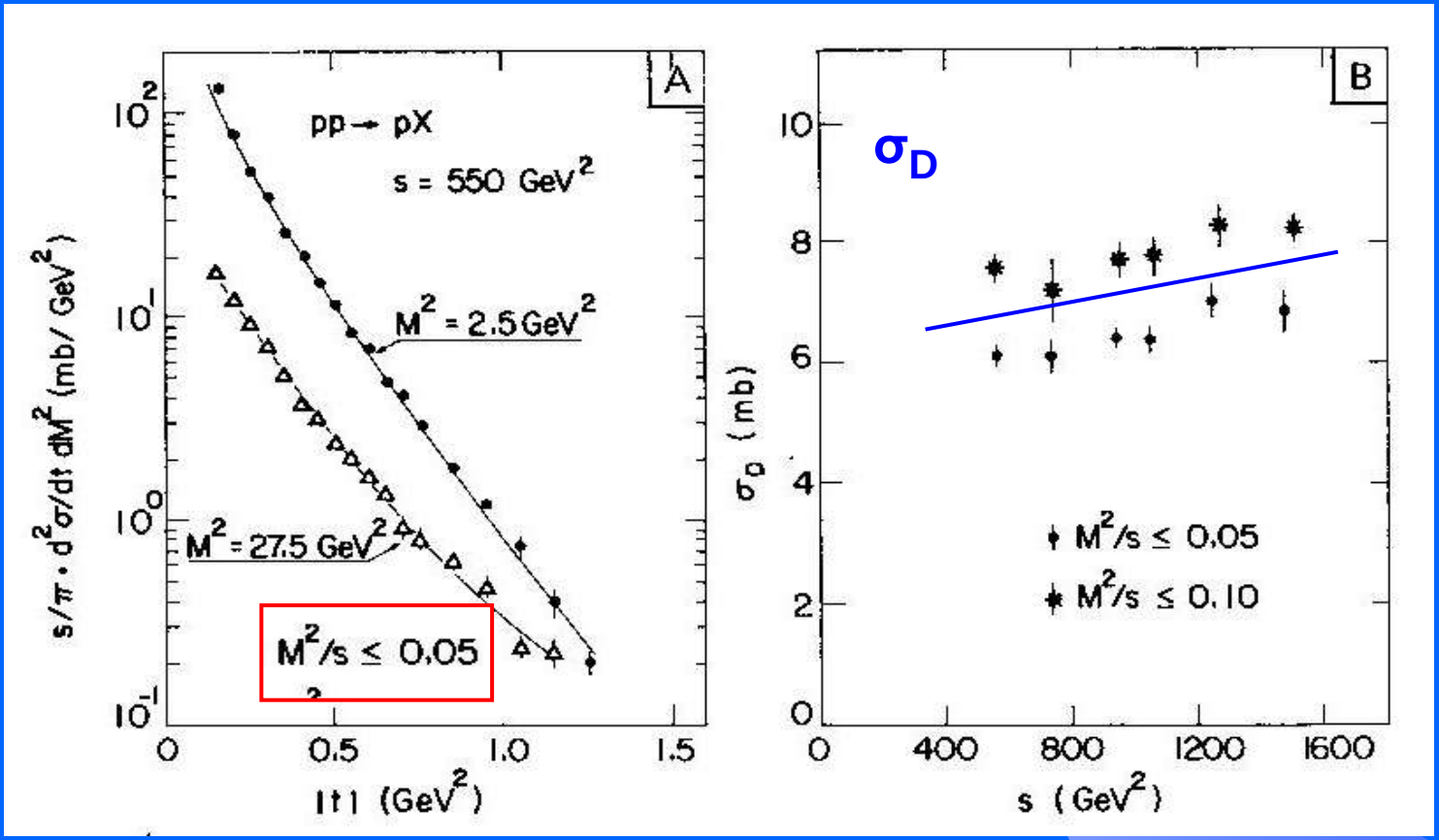


These results opened the way to
Double Diffraction Dissociation and to Double Pomeron Exchange

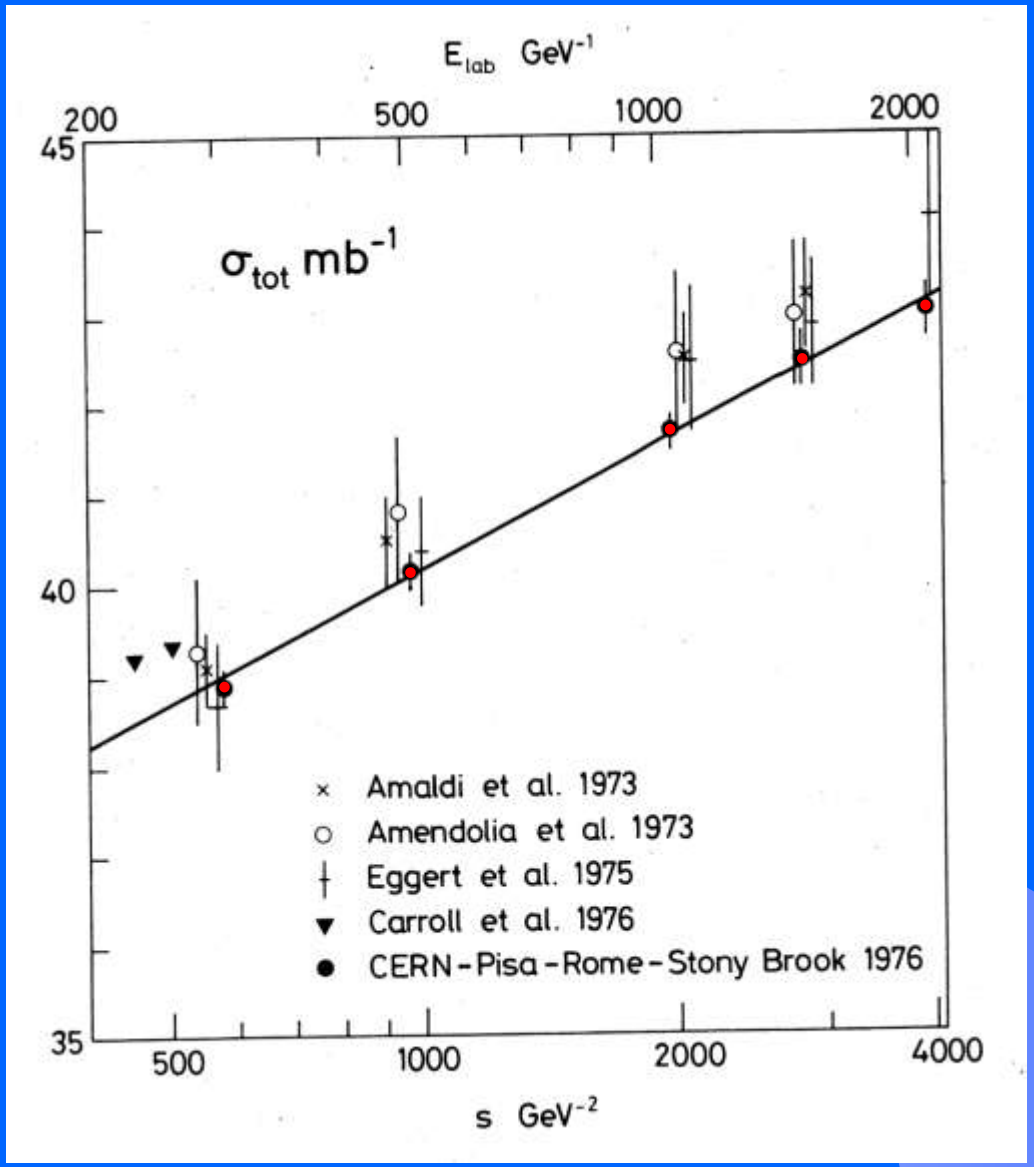
Improvements on σ_{tot} and ρ: 1974 -1976

The CERN-Pisa-Stony Brook-Rome experiment

Three methods for mesuring σ_{tot} :

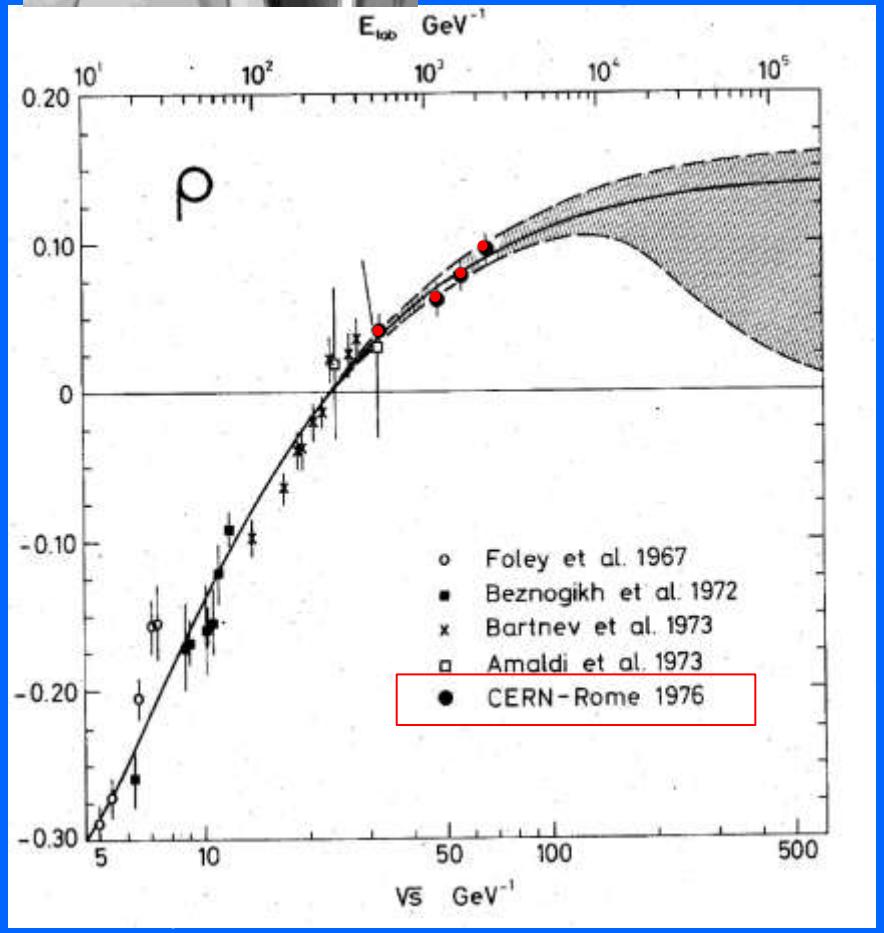
1. VdM for 'Total Rate' $R_{tot} \approx \sigma_{tot}$ (PSB)
2. 'Forward Rate' $FR \approx \sigma^2_{tot}$ (CR)
3. NEW: $FR / R_{tot} \approx \sigma_{tot}$ (CRPSB)

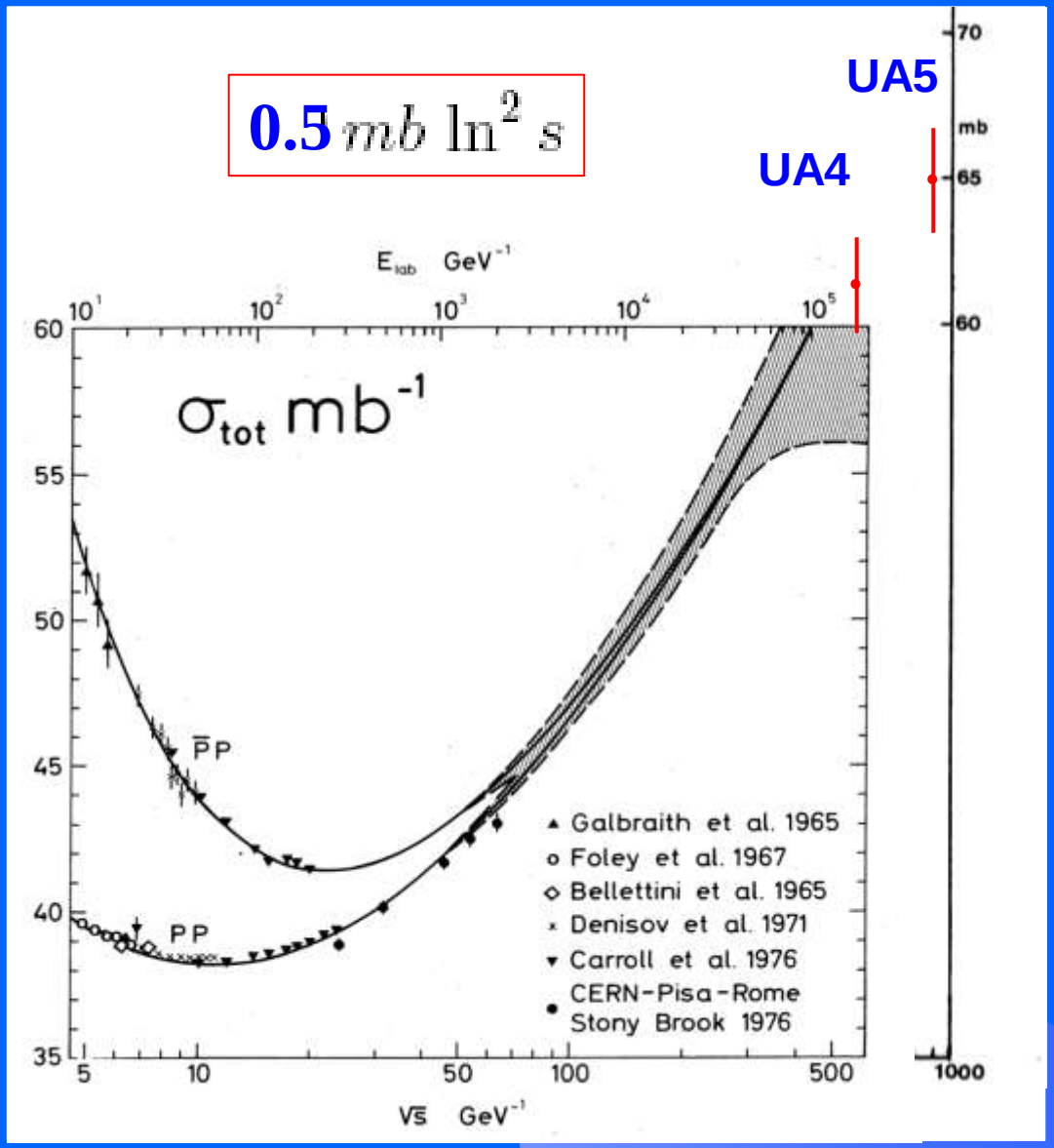
C-P-SB-R results in 1976



Extrapolation from ρ of the total cross-section

Giuseppe Cocconi and Jheroen Dorenbosch





Origins of the quantum O.T.

Very accurate measurements of total cross sections were possible at the ISR by applying the quantum Optical Theorem which was specified seventy years ago by

N. Bohr, R. Peierls and G. Placzek

Nature 144, 200 (1939)

The first experimental tast was performed in Rome, just after the war, by Edoardo Amaldi and collaborators, whs studied the scattering of 14 MeV neuttrons on lead:

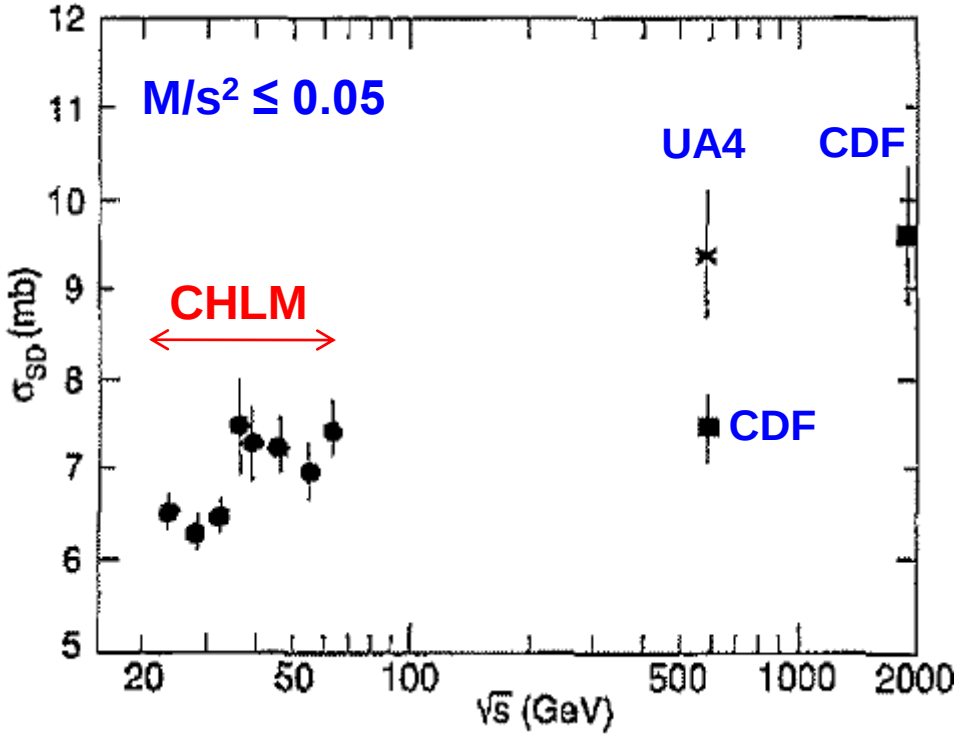
E. Amaldi, D. Bocclarelli, B. N. Cacciapuoti and G. C. Trabacchi

Nuovo Cimento 3, 203 (1946)

The ISR results seen from higher energies

Results by CHLM and antiproton colliders on SDD

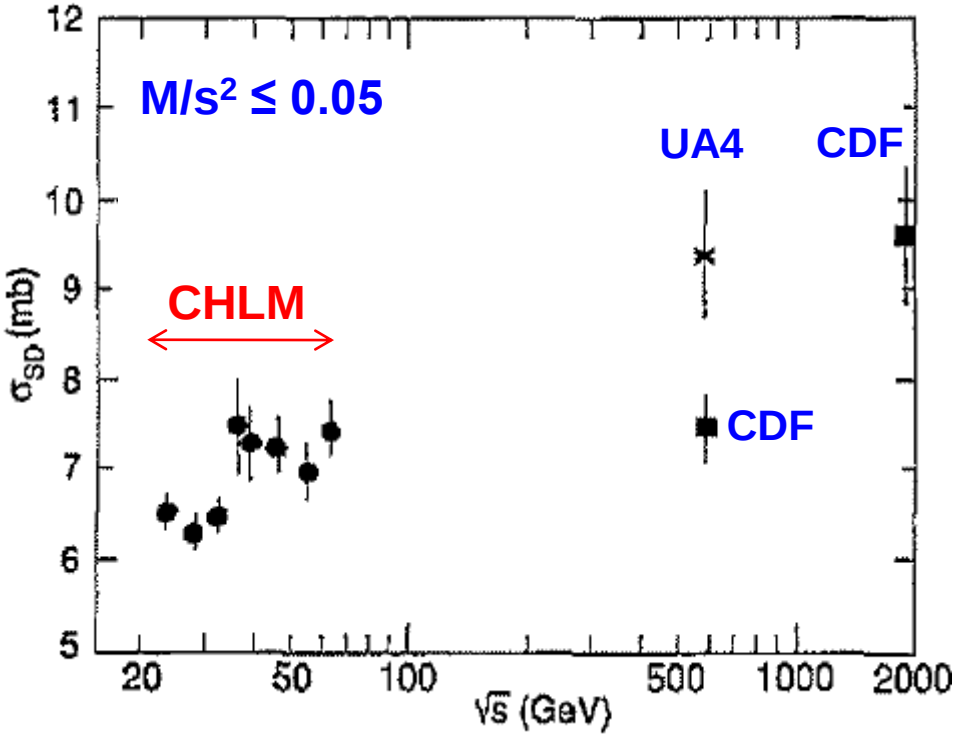
Single Diffractive Dissociation

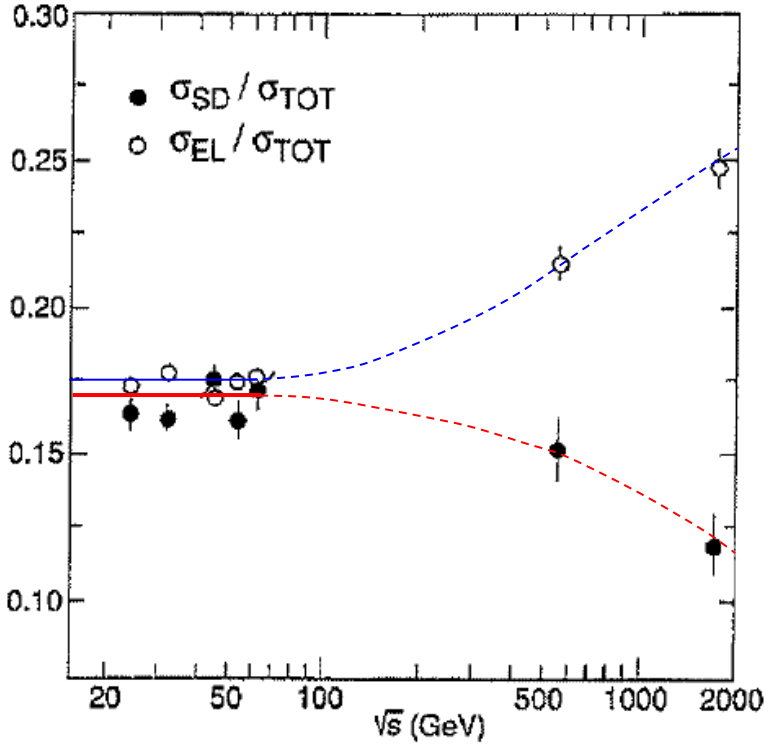


G. Matthiae 2000

Results by CHLM and antiproton colliders on SDD

Single Diffractive Dissociation

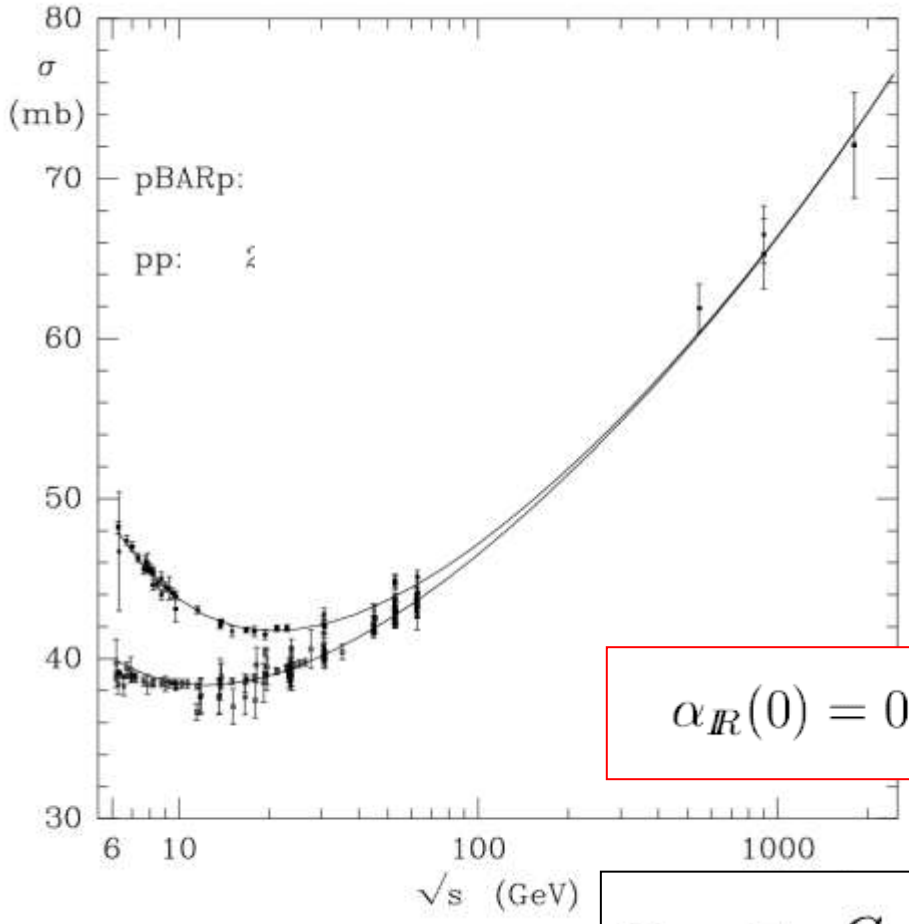


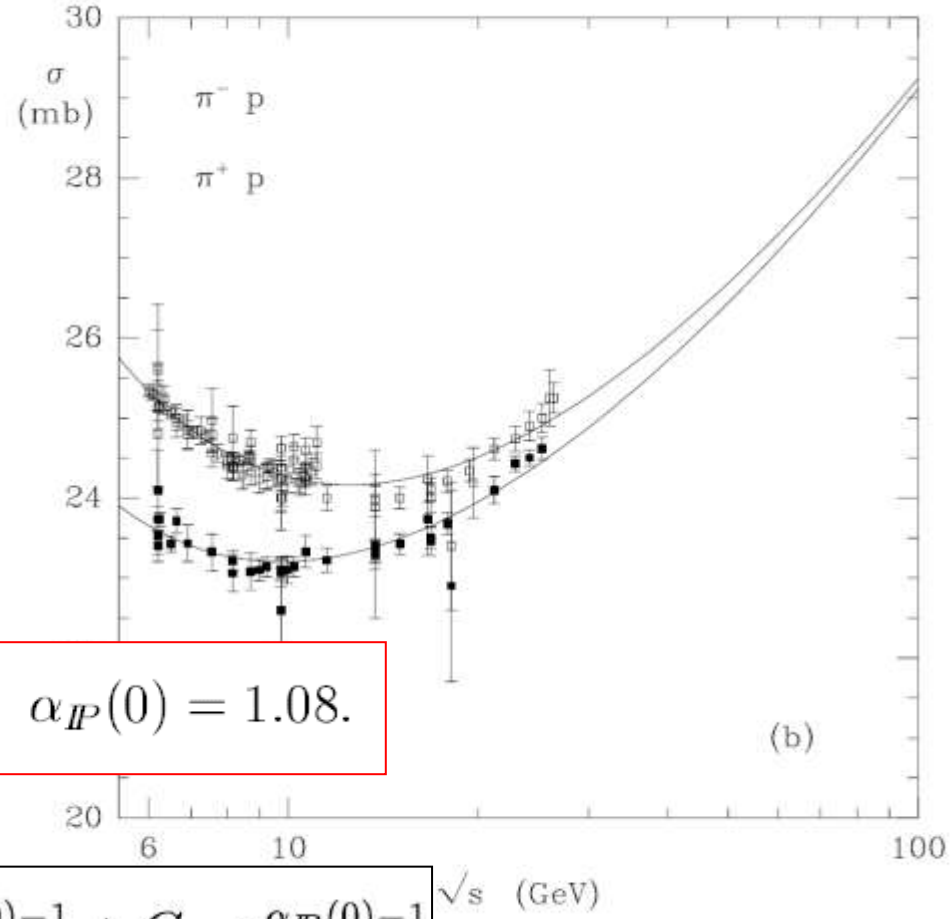


G. Matthiae 2000

t-channel approach to elastic scattering

A. Donnachie and P. V. Landshoff, "Total cross-sections", Phys. Lett. B **296** (1992) 227.

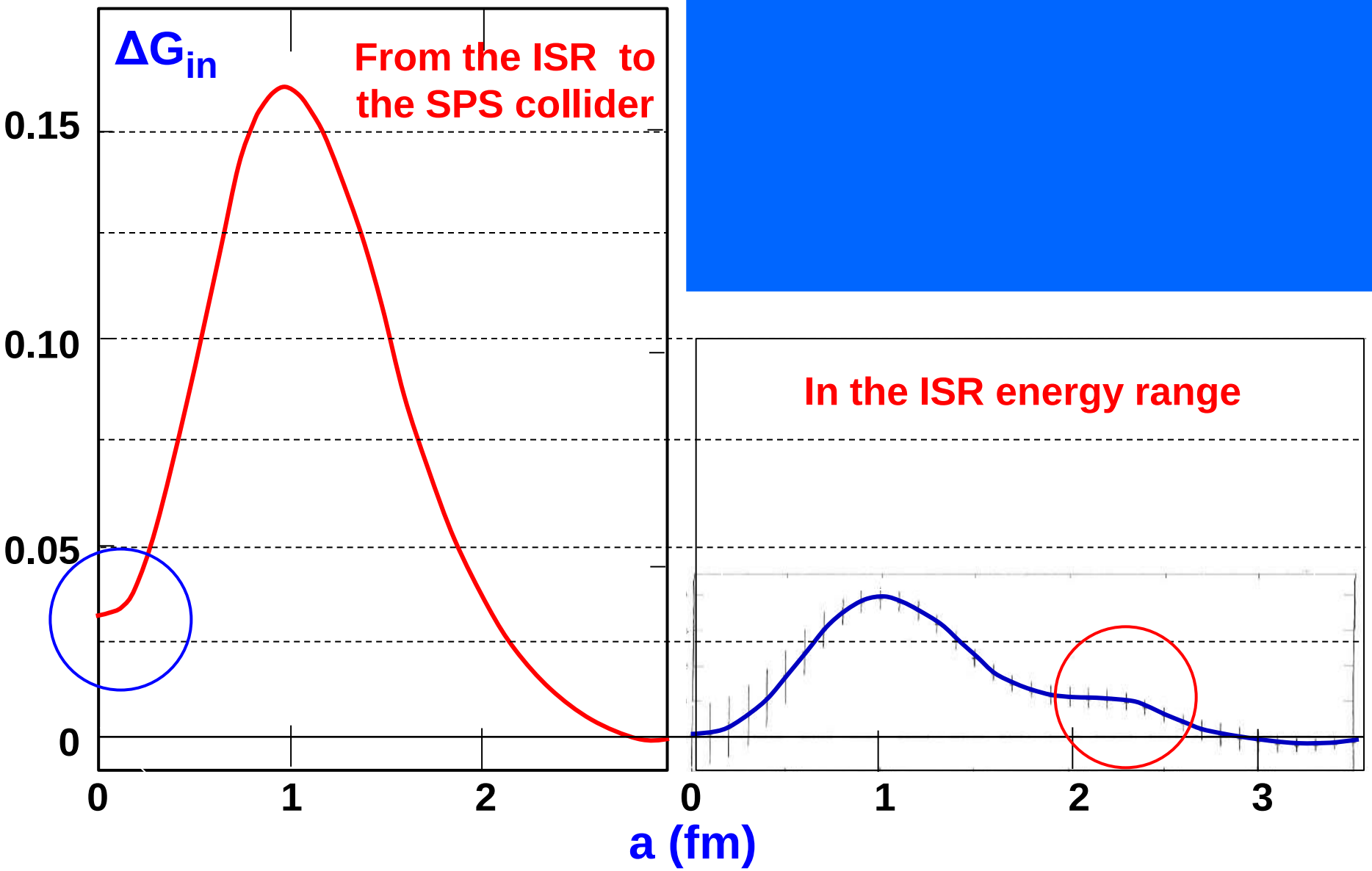




$$\alpha_{I\!R}(0) = 0.45, \qquad \alpha_{I\!P}(0) = 1.08.$$

$$\sigma_{tot} = C_{I\!R}\, s^{\alpha_{I\!R}(0)-1} + C_{I\!P}\, s^{\alpha_{I\!P}(0)-1}$$

s-channel approach to elastic scattering



Conclusions on forward physics at the ISR

The detectors were well suited to the tasks and performed better than foreseen

They had a lasting influence on the experimentation at other hadron colliders

New phenomena were discovered which changed the view of hadron-hadron interactions: it was proven that the Pomeron is complex but can be studied.

The collaboration between experimentalists and machine physicists was excellent and made all this possible

THE END