From Adone's multi-hadron production to the J/ψ discovery.

Mario Greco, INFN – Roma3

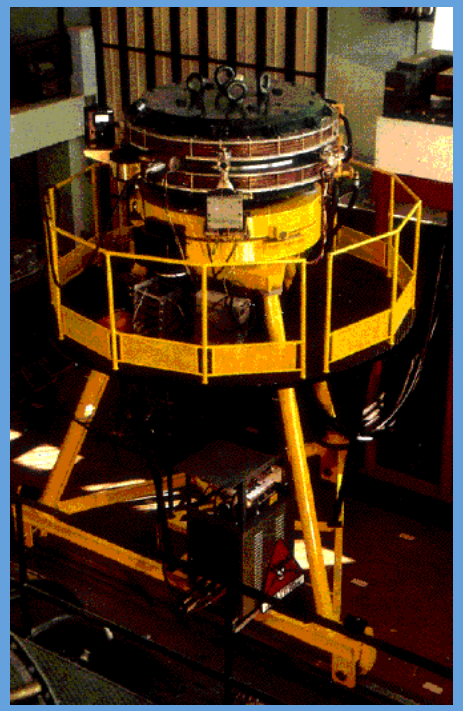
AdA

Feb. 1960: Bruno Touschek's seminar in Frascati

March 1960: Proposal and INFN's approval

Feb. 1961: First electrons accumulated

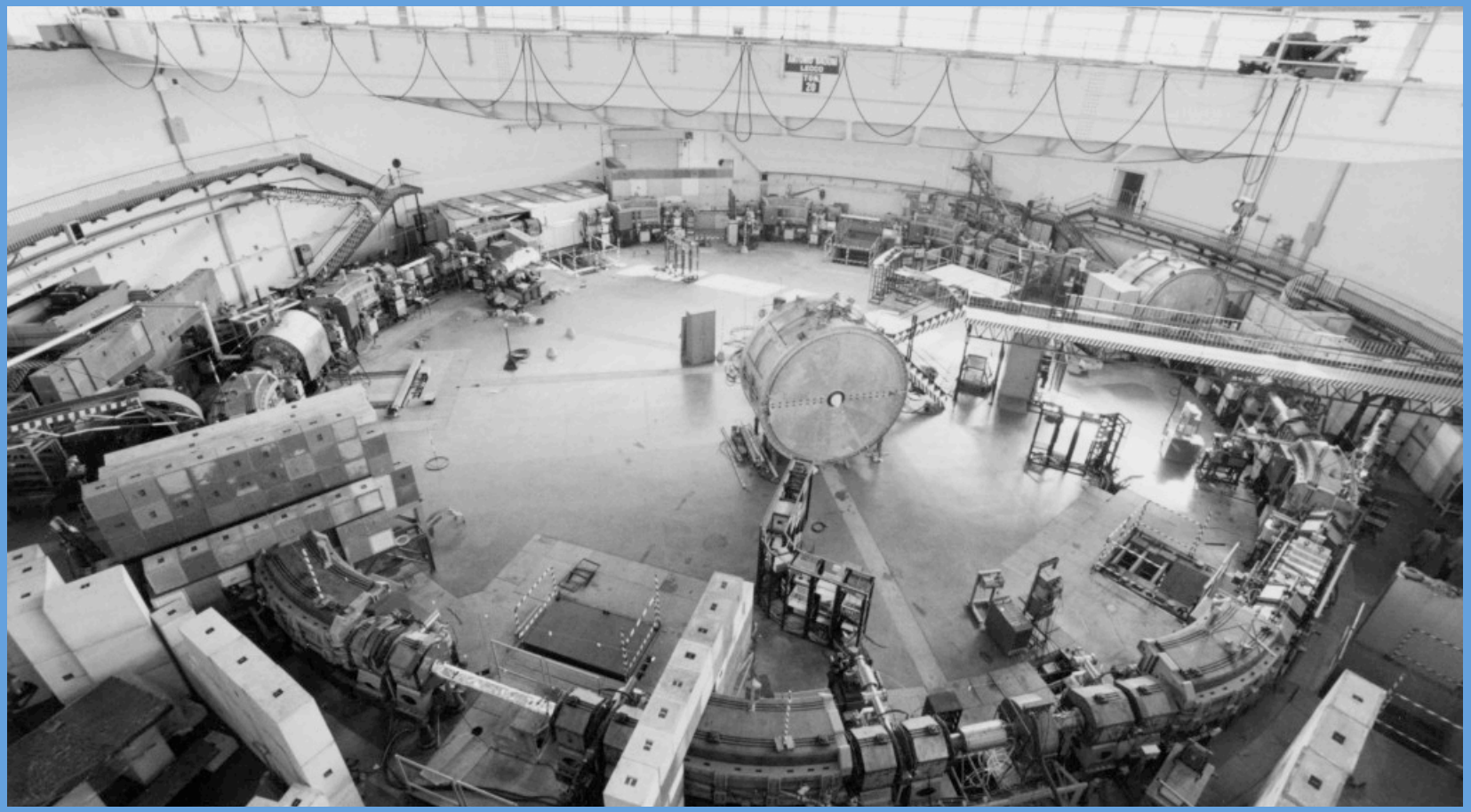
July 1961: AdA in Orsay



G. Pancheri, The Making of AdA, Springer Proc. Phys. 2023

Adone

November 1960: Bruno Touschek's notebook



A D O N E - a Draft Proposal for a Colliding Beam Experiment.

B.Touschek,
Rome, 9.Nov.60.

It is proposed to construct a synchrotron like machine capable of accelerating simultaneously electrons and positrons in identical orbits. The suggested maximum energy is 1.5 Gev for the electrons as well as the positrons. This energy allows one to produce pairs of all the so called 'elementary particles' so far known, with the exception of the neutrino, which only becomes accessible via a weak interaction channel.

It is assumed that experiments in which there are only two particles in the final state are most easy to interpret. There are 16 such reactions, namely:

(1) 2γ . This is the only reaction in which the intermediate state is 'quasi real' and in which therefore there should be no 'radiative corrections'. This reaction should serve as a 'monitor'. The crosssection is $2.6\ 10^{-31}\ cm^2$.

(2) e^+, e^- . This reaction will show strong

Adone

November 1960: Bruno Touschek's notebook

1963: Beginning of the machine

1967: First electron beams

1969: First generation experiments (4)

Adone: th. framework and expectations

i) e.m. properties of hadrons mediated by vector mesons ρ, ω and ϕ (VMD): J.J. Sakurai

ii) T.D.Lee, N. Kroll, B. Zumino tried to give a field th. approach to VMD

$$\sigma(s) \approx [1/s]^2$$

iii) Departures from VMD observed in radiative decays of mesons suggested possible existence of new vector mesons: A. Bramon, M. G., Lett. N. Cimento 152, 739 (1971), as also suggested by Regge trajectories (G. Veneziano model)

iv) DIS at Slac, Bjorken scaling, Feynman parton model, Drell-Yan pair prod.

$$R = \left.\frac{\sigma_{e^+e^-\to hadr}}{\sigma_{e^+e^-\to\mu^+\mu^-}}\right|_{q^2\to\infty} = \frac{1}{4}\sum_{i=spin0} Q_i^2 + \sum_{i=spin\,1/2} Q_i^2$$

N. Cabibbo, G. Parisi, M. Testa, Lett. N. Cimento **4**, 35 (1970)

Adone: experiments

- Bosone (C. Bernardini et al.) --> MEA

- $\gamma\,\gamma$ (G. Salvini et al.)

- $\mu\,\pi$ (M. Conversi et al.)

- Bologna - Cern - Frascati (A. Zichichi et al.)

- B–Bbar (Frascati, Napoli, Pisa)

--->> (i) High multi-hadronic production ($\sigma \approx 2\,\sigma(\mu\mu)$)

(ii) Evidence for $\rho\,'$ (1.6 GeV) --> 4 π^{+-} (G. Barbarino et al., Lett. N. Cimento 3, 689 (1972))
A. Bramon, M.G. Lett. N. Cimento **3**. 693 (1972))

e+ e- Physics at ADONE

C. Bernardini and L. Paoluzi 1974.

Conference: C74-01-28, p.3-19 Proceedings

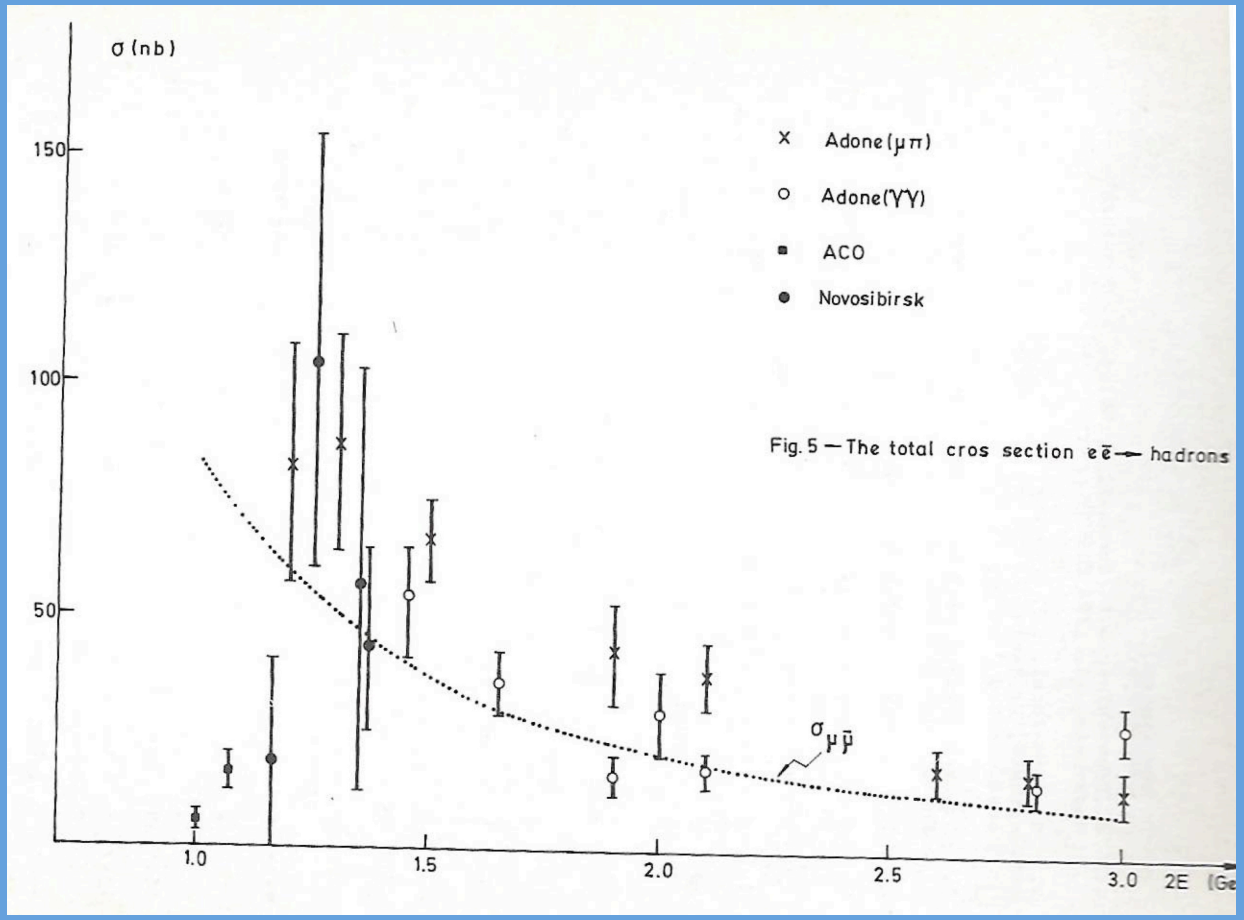
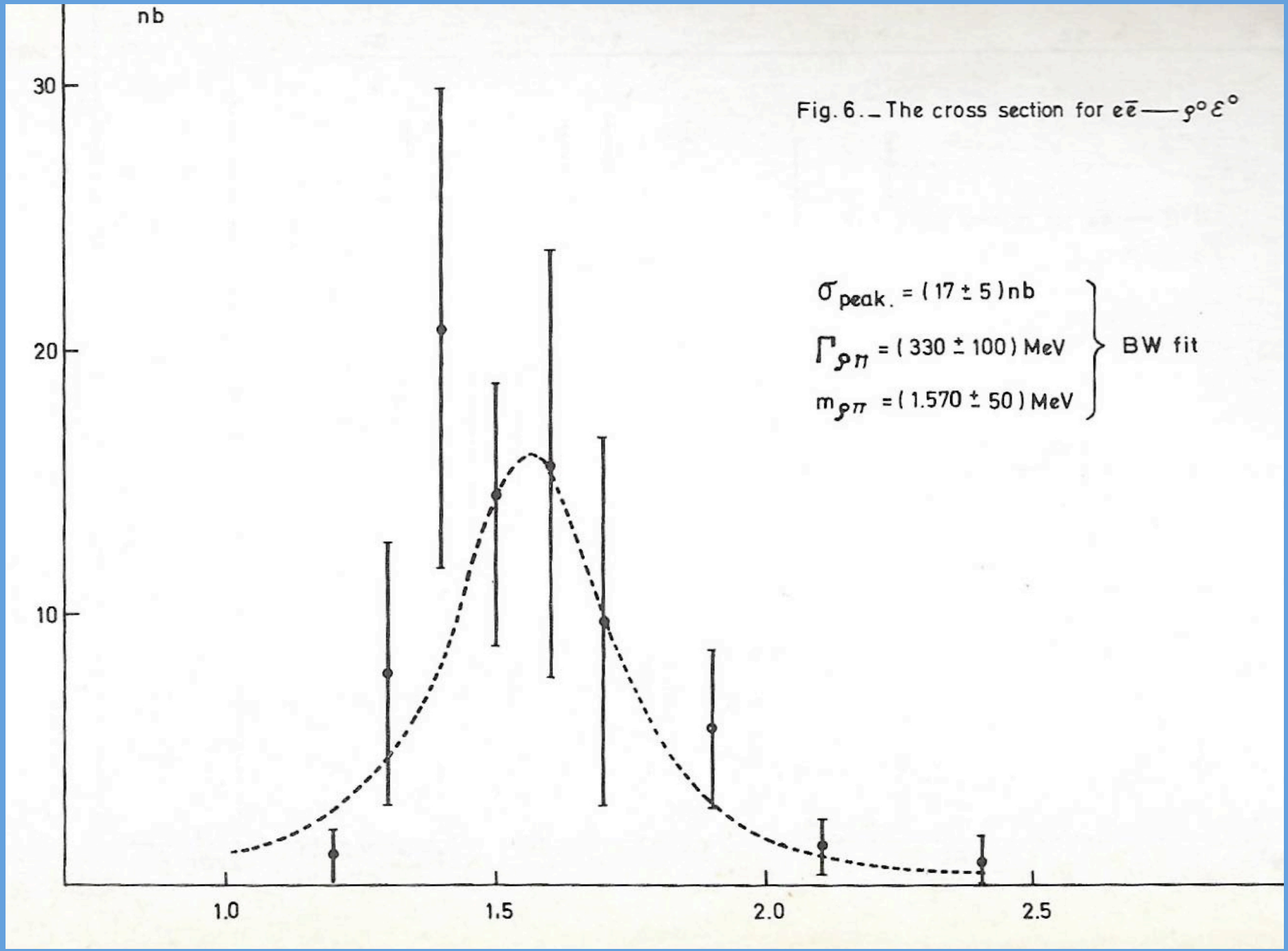


Fig. 5 — The total cros section $e\bar{e}$ → hadrons


nb
30
20
10
1.0
1.5
2.0
2.5
Fig. 6. – The cross section for $e\bar{e} \to \rho^0 \varepsilon^0$
$\sigma_{peak.} = (17 \pm 5)$ nb
$\Gamma_{\rho\pi} = (330 \pm 100)$ MeV
$m_{\rho\pi} = (1.570 \pm 50)$ MeV
BW fit

The Adone results + request of scaling (in DIS and e+ e- ann.) motivated:

(i) Extended VMD approach to scale invariance.
Approach to scaling by summing ∞ resonances (as in hadr. duality with Regge behav).
A. Bramon, E.Etim. M.G. Phys. Letts. *B* 41 (1972) 609.
Also J.J. Sakurai Phys. Letts. *B* 46 (1973) 207;
J.S. Bell, R. Bertlmann, Z. Phys.C4 (1980) 11; Nucl.Phys.B177 (1981) 218.

(ii) Duality sum rules in e+ e- annihilation (from Canonical Trace Anomaly)
E. Etim, M.G. Lett. N. Cimento 12 (1974) 91

$$\int_{s_0}^{\bar{s}} ds \left(Im\Pi(s) - \frac{\alpha R}{3} \right) = 0,$$

$$\mathrm{Im}\Pi\,(s) = s\ \sigma_{had}(s) / 4\pi\alpha$$

-→ Asymptotic value of R is related to low energy resonances (duality). With u, d, s colored quarks:

$$R \simeq \frac{8\pi^2}{f_\varrho^{\,2}} = 2.5$$

(No QCD yet)

CEA and SPEAR:

New intriguing data were showing R increasing for $\sqrt{s} \geq 3$ GeV

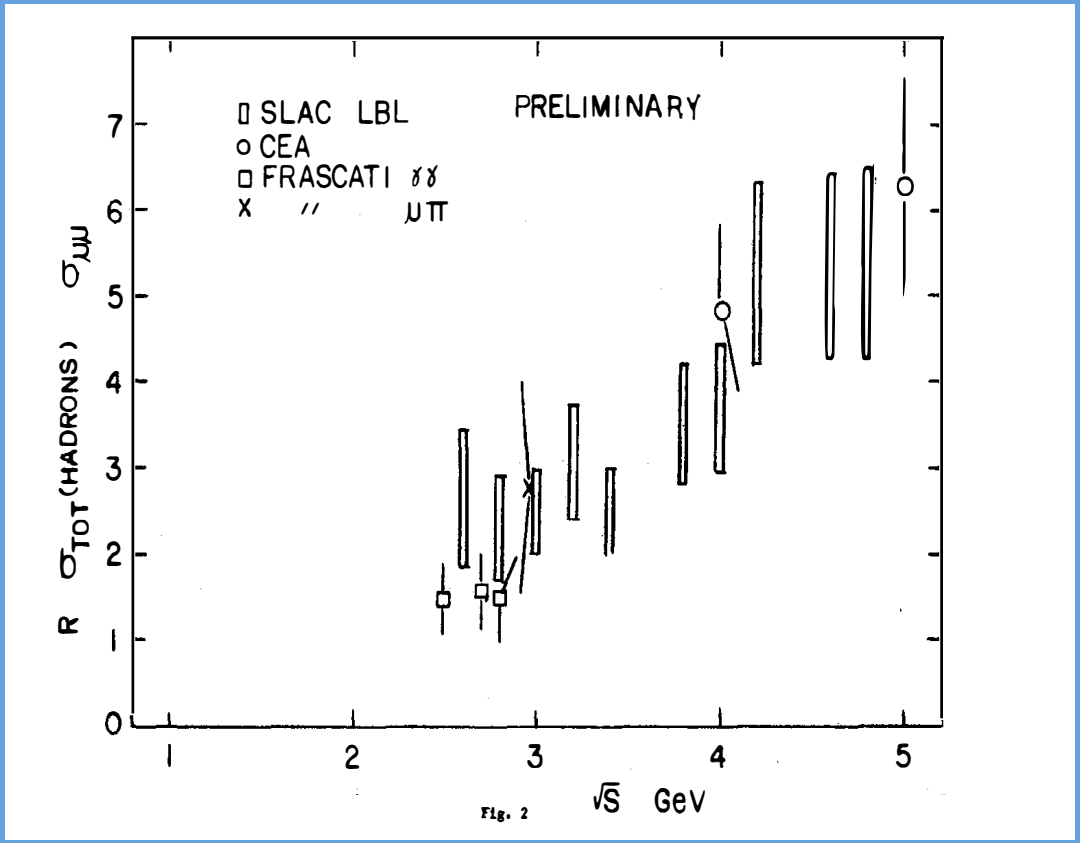


Fig. 2

LETTERE AL NUOVO CIMENTO VOL. 12, N. 3 18 Gennaio 1975

Duality Sum Rules in e^+e^- Annihilation from Canonical Trace Anomalies.

E. ETIM and M. GRECO

Laboratori Nazionali di Frascati del CNEN - Frascati (Roma)

(ricevuto il 24 Ottobre 1974)

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energies. This result is to be compared with that of SAKURAI (*) in which the uncertainties in the threshold factors of his $\sigma_{\text{comp}}(s)$ give rise to corresponding uncertainties in R ($R \approx 3 \div 5$).

In the light of the above considerations it is interesting to comment on the experimental situation of e^+e^- annihilation (1). The local average of the data over the prominent resonances ($\rho, \omega, \varphi, \rho', \ldots$) is approximately constant (~ 2.5) and agrees with the value of R found experimentally for q^2 up to about 10 $(\text{GeV})^2$. This is in agreement with our predictions and the duality sum rule (19). thus indicating the presence of a component of $\text{Im}\,\pi(s)$ which scales precociously.

From $q^2 \approx 10$ to about 25 $(\text{GeV})^2$ R apparently increases linearly with q^2. This suggests the presence of a new component in $\text{Im}\,\pi(s)$, with threshold at $s \approx 10$ $(\text{GeV})^2$, additive to the previous one and possibly responsible also for the violations of scaling observed at small x in the single inclusive distributions.

Future e^+e^- colliding-beam experiments at very high energies will be decisive in this respect.

November Revolution

- Stanford, November 11, 1974

B. Richter and S. Ting announced the discovery of the J/Ψ at Brookhaven and SPEAR

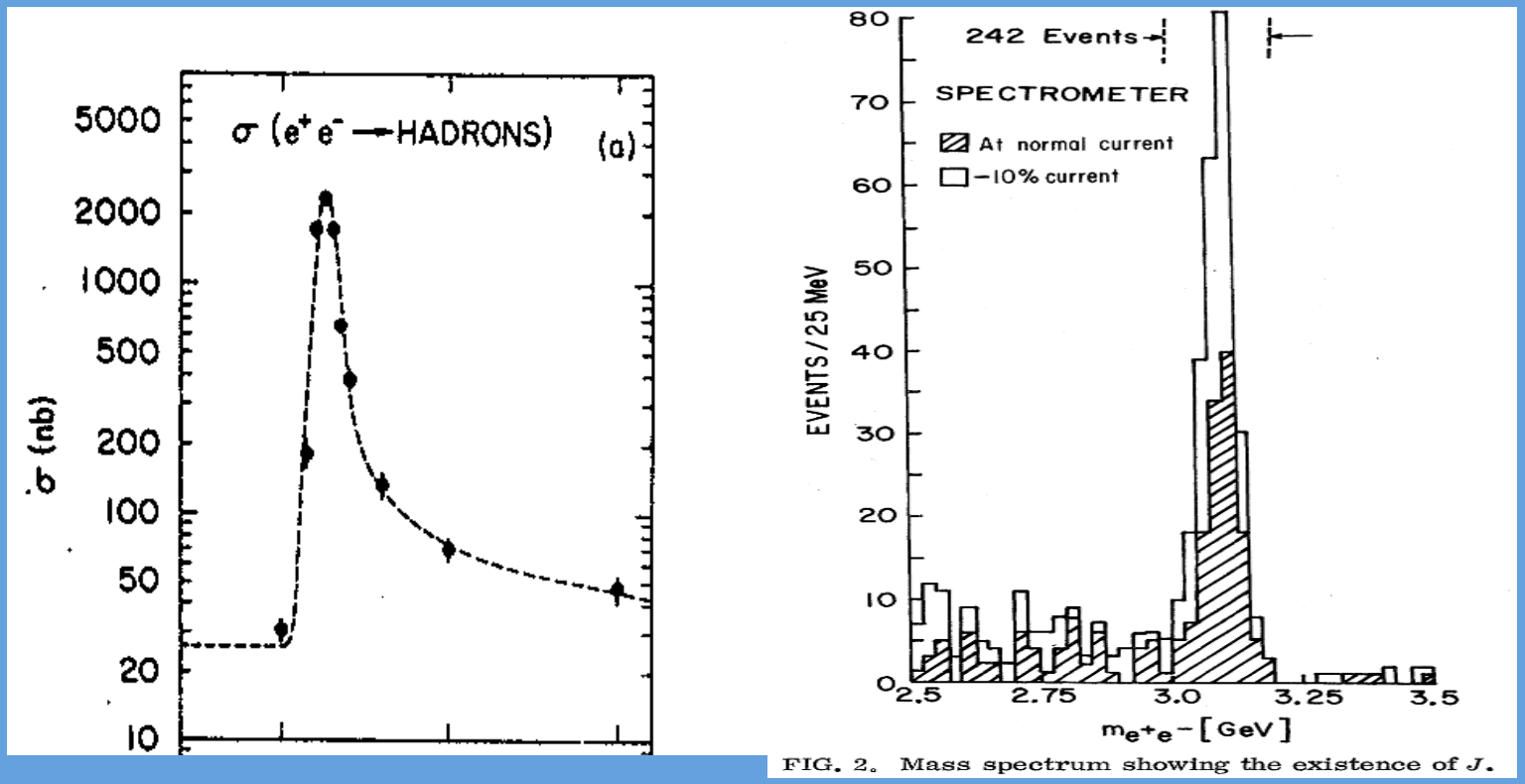

FIG. 2. Mass spectrum showing the existence of J.

November Revolution

- Stanford, November 12, 1974

M.G. arrived at SLAC invited by Sid Drell to give a seminar on the duality works.
Lot of excitement in th. discussion room.
From the details of the SLAC discovery, I realized that the J/Ψ could be seen at ADONE.
I called Giorgio Bellettini at LNF from the confidential office of Drell and gave him the exact position of J/Ψ.
The night after the resonance was observed at Frascati.

Frascati, November 18, 1974

Giorgio Salvini communicated the results of LNF to PRL on the phone and the paper was published in the same issue of the American results: *Phys.Rev.Lett.* 33 (1974) 1408.

I left SLAC after 2 days flying to Mexico City with the J/Ψ data and some hints for the Ψ'.

Theoretical interpretation of J/Ψ

Are the New Particles Baryon-Antibaryon Nuclei?

Alfred S. Goldhaber and Maurice Goldhaber

Interpretation of a Narrow Resonance in e+ e- Annihilation

Julian Schwinger

Possible Explanation of the New Resonance in e+ e- Annihilation

S. Borchardt, V. S. Mathur, and S. Okubo

Model with Three Charmed Quarks R. Michael Barnett

Heavy Quarks and e+ e- Annihilation Thomas Appelquist and H. David Politzer

Is Bound Charm Found? A. De Rújula and S. L. Glashow

Possible Interactions of the J Particle

H. T. Nieh, Tai Tsun Wu, and Chen Ning Yang

Is the 3104-MeV Vector Meson the psi - Charm or the W0?
G. Altarelli, N. Cabibbo, R. Petronzio, L. Maiani, G. Parisi

Charm, EVDM and Narrow Resonances in e^+e Annihilation
C. A. Dominguez and M. Greco

Fig. 15. Immediate interpretations of the J/ψ, with their titles. PRL is Phys. Rev. Lett. **4**, Jan. 6th, 1975. The last two papers[88,89] are in Lett. Nuovo Cim.

A. De Rujula, Int. J. Mod. Phys. A 34 (2019) 32 .

Sam Ting at Frascati for BTML 2013

Theoretical interpretation of J/Ψ

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Preprint

Title	**Charm, EVDM and narrow resonances in e+e- annihilation**
Author(s)	Domínguez, C A ; Greco, Mario
Affiliation	(CNEN Frascati) ; (Inst. Politech. Nac. Mexico City)
Imprint	18 Nov 1974. - 6 p.
Subject category	Particle Physics - Phenomenology

Our th. interpretation of J/Ψ

- J/Ψ , Ψ' indicate a new series of resonances, related to the apparent rise of R for s > ≈ 10 GeV ^{2}
- From the duality sum rule

$$\int_{s_0}^{\bar{s}} ds \left(Im\Pi(s) - \frac{\alpha R}{3} \right) = 0,$$

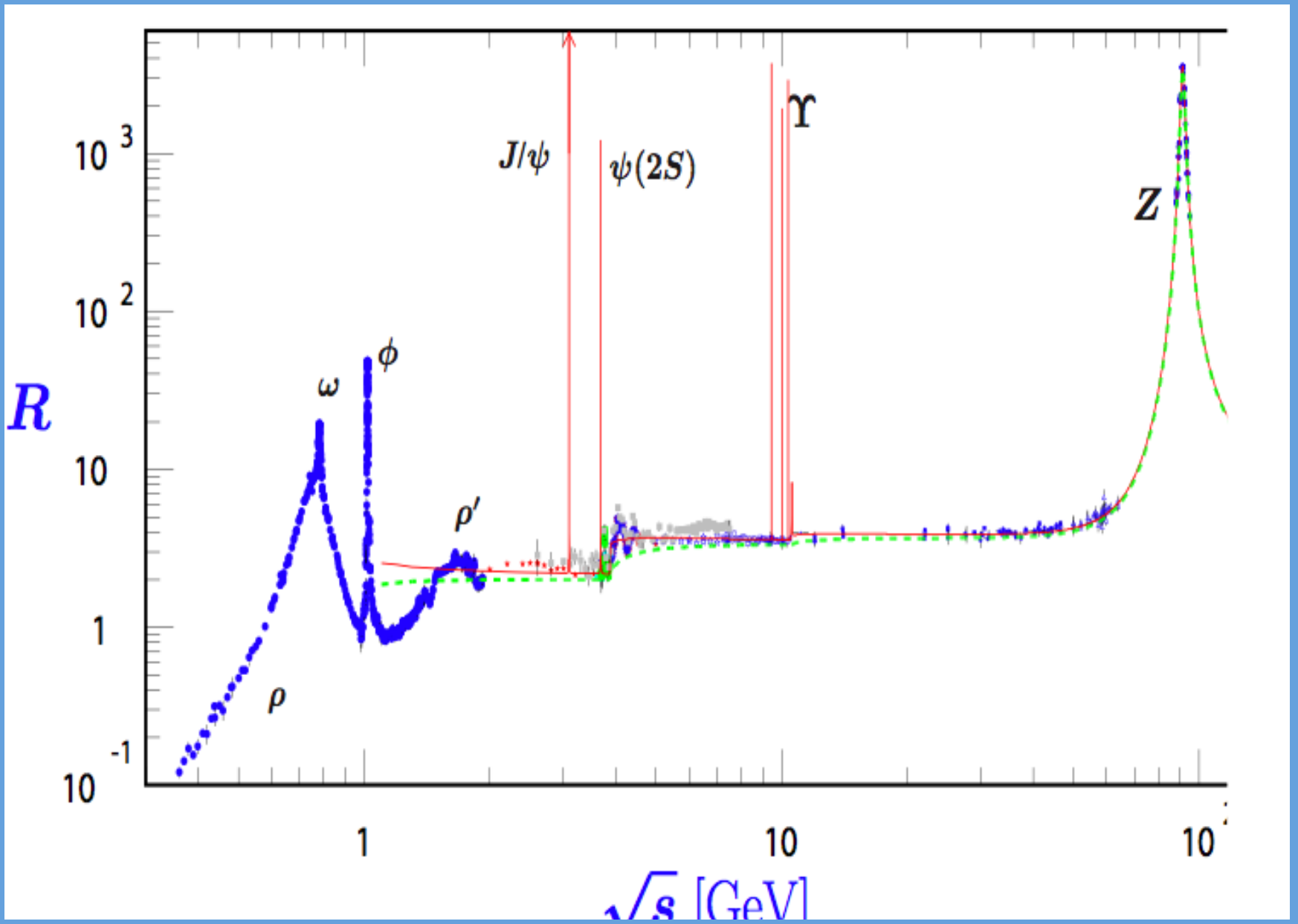
$$\mathrm{Im}\Pi\,(s) = s\ \sigma_{had}(s) / 4\pi\alpha$$

Predictions:

(i) Q=2/3 for the charge of the new quark → charm

(ii) The new series of c-cbar resonances gives:

$$R = R_{normal} + R_{charm} \approx 3.7$$


R
10 3
10 2
10
1
10 -1
1
10
10
J/ψ
ψ(2S)
ϒ
Z
ω
ϕ
ρ′
ρ
√s [GeV]

Limits of our J/Ψ's paper.

- No understanding of the smallness of the width Γ.
  Asymptotic freedom. (T. Appelquist and D. Politzer)

- Naïve assumption on the Ψ's mass spectum (linear).
  Internal dynamics of Charmonium states was given by
  A. De Rujula and S. L. Glashow

- Similar analysis for Y production → beauty
  M.G, Phys. Letts. (1978)

Radiative corrections for J/ψ, Z, H line-shapes

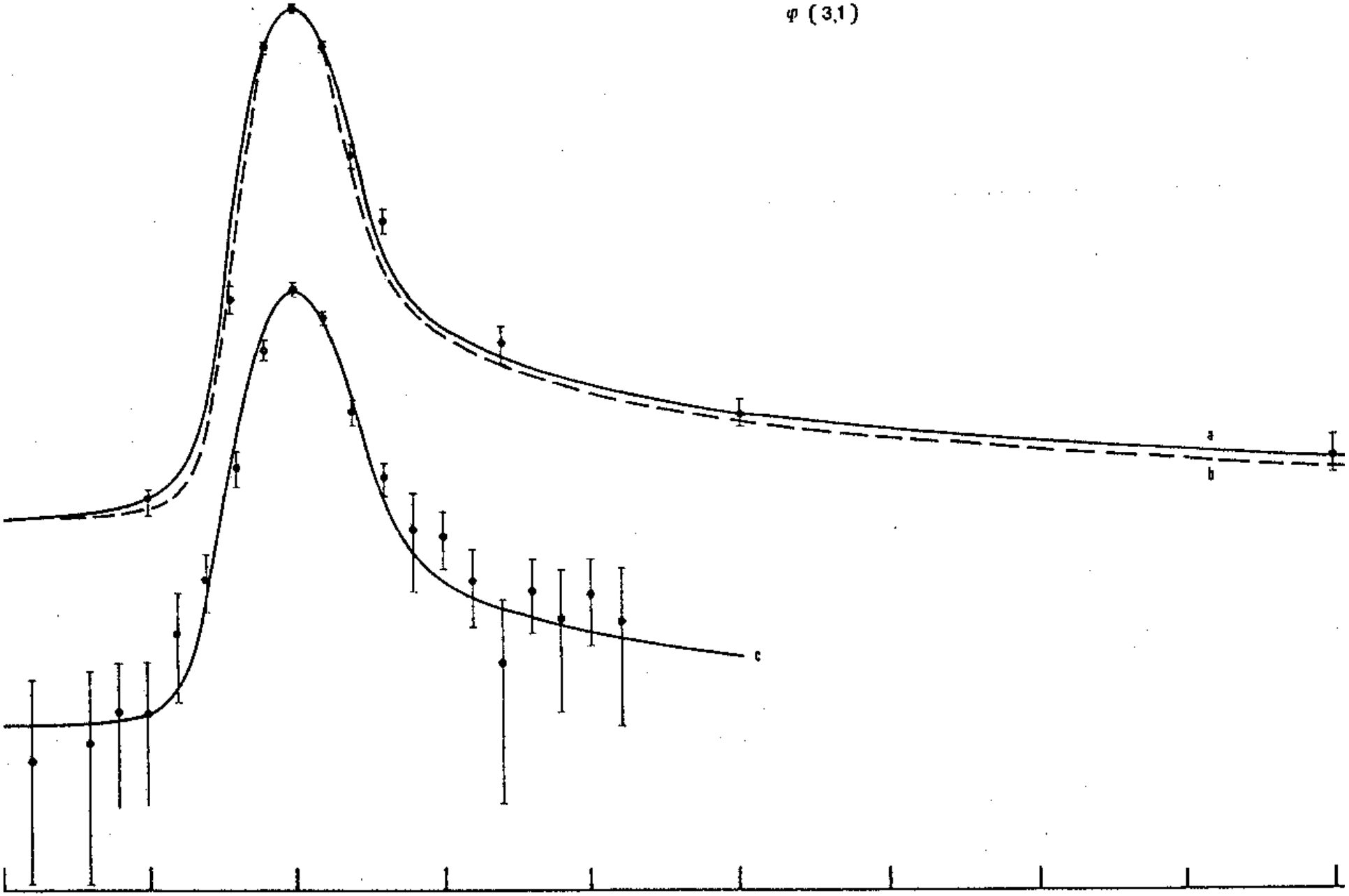
i) Crucial role for precision physics was played by the th. ideas of early times with B. Touschek (Exponentiation, Coherent States, …). Full study of rad. corrections for J/ψ to all orders:
M.G. , G. Pancheri, Y. Srivastava, Phys. Letts. and Nucl. Phys. (1975).

Correction factor for narrow reson. $\propto (\Gamma/M)^{(4\alpha/\pi)\log(2E/m)}$

ii) SLAC data had been analyzed with wrong rad. corrs. formulae for ≈ 15 years.
(D.R. Yennie, PRL (1975), J.D. Jackson and D.L Scharre, *Nucl.Instr.Meth.*(1975))
Right rad.corrs. -> change in 1988 in Particle Data Group properties of charmed particles.

iii) First study of rad. corrections for the Z line-shape (LEP/SLC).
M.G. , G. Pancheri, Y. Srivastava, Nucl. Phys. (1979).
Applied to all LEP experiments.

iv) H line-shape in a muon collider resonant Higgs factory.
M.G., T. Han, Z. Liu, Phys. Letts. (2016)
Strong constraints on the beam energy spread → Problem for resonant Higgs-factories



Data from SPEAR and ADONE

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Conclusions

From AdA/ADONE to LEP/LHC the seminal idea of Bruno Touschek has contributed with so many discoveries to the progress of the Standard Model of Particle Physics.

In addition some of his suggestions have also strongly contributed to the precision assessment of the S. M.

Duality has been a very powerful tool for the interpretation of e^+e^- colliding beams results and in particle phenomenology.