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Adone: from the multihadron production to the observation of the J/ψ

Bruno Touschek Memorial Lectures

Giorgio Bellettini

LNF, December 4, 2014

The BNL muon pair spectrum of J.H.Christenson et al.

J.H. Christenson, et al. Phys. Rev. Letters, 25 (1970)
Phys Rev D8, (1973)

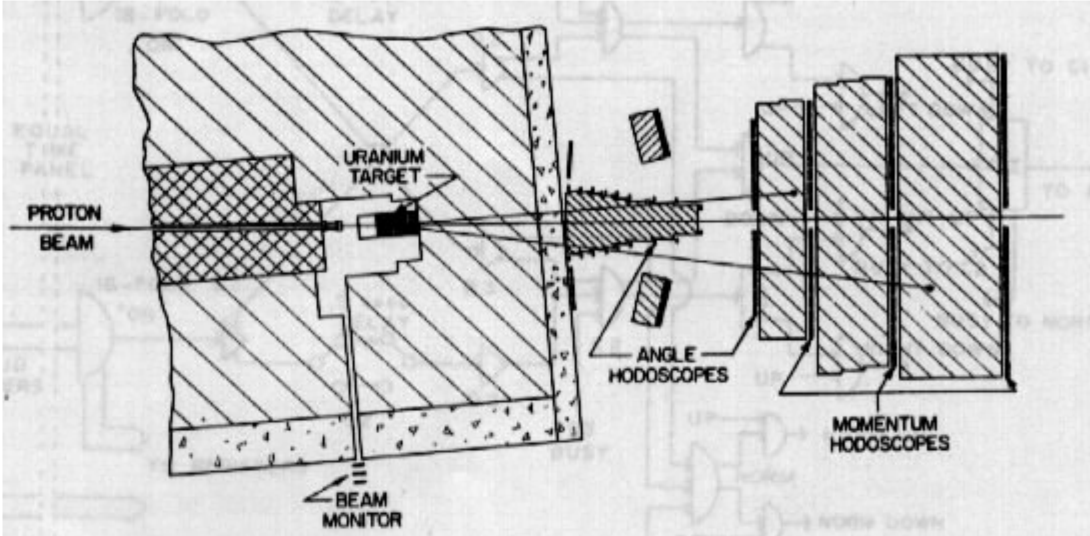


FIG. 1. Plan view of apparatus.

In 1970 an anomaly was seen in the μ-pair spectrum in a fixed target experiment at BNL.

$P + U \rightarrow \mu^+ \ \mu^- + X$

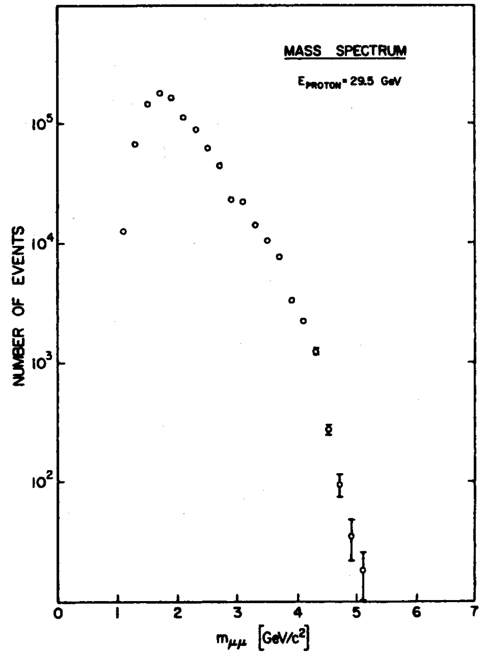


FIG. 4. Observed events as a function of the effective mass of the muon pair. Proton energy = 29.5 GeV.

The background-subtracted spectrum

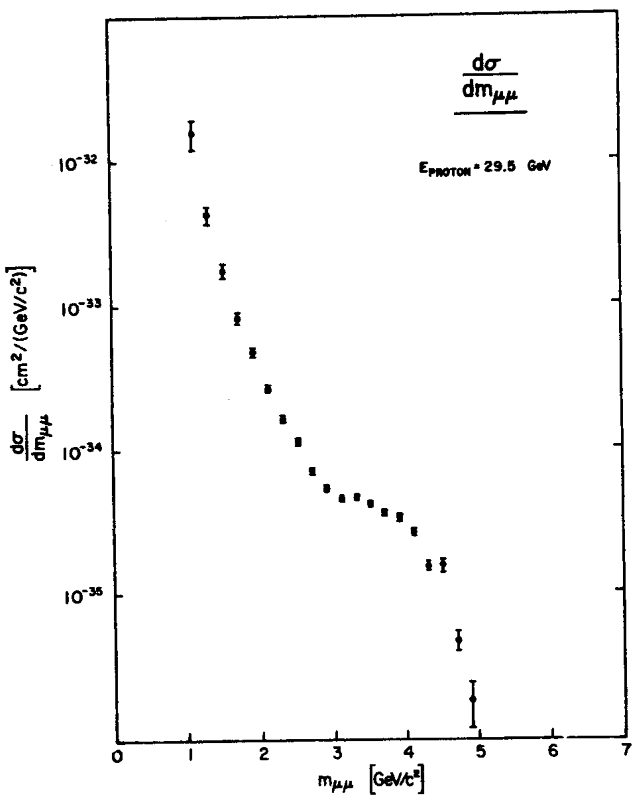


FIG. 6. $d\sigma/dm$. Proton energy = 29.5 GeV.

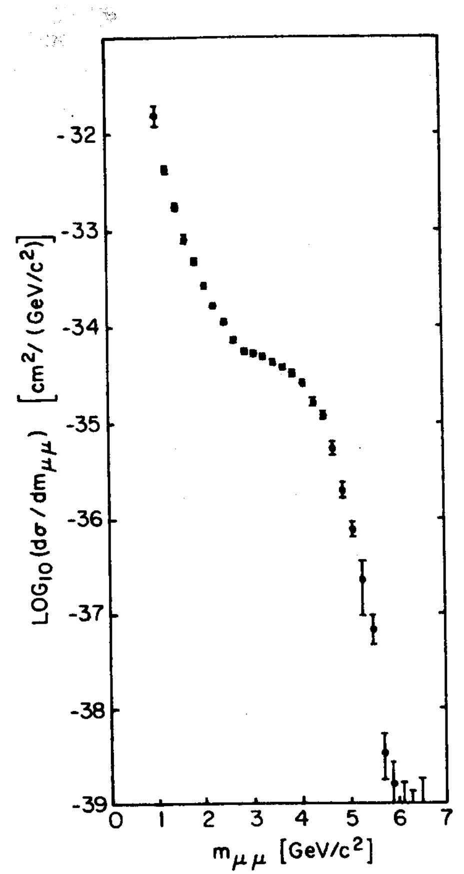


FIG. 10. $d\sigma/dm$. Weighted average of standard and "wide angle" events. Proton energy = 29.5 GeV.

A shoulder was better seen after removing the large background of accidental coincidences.

The BNL 598 spectrometers of the S.C.C. Ting group

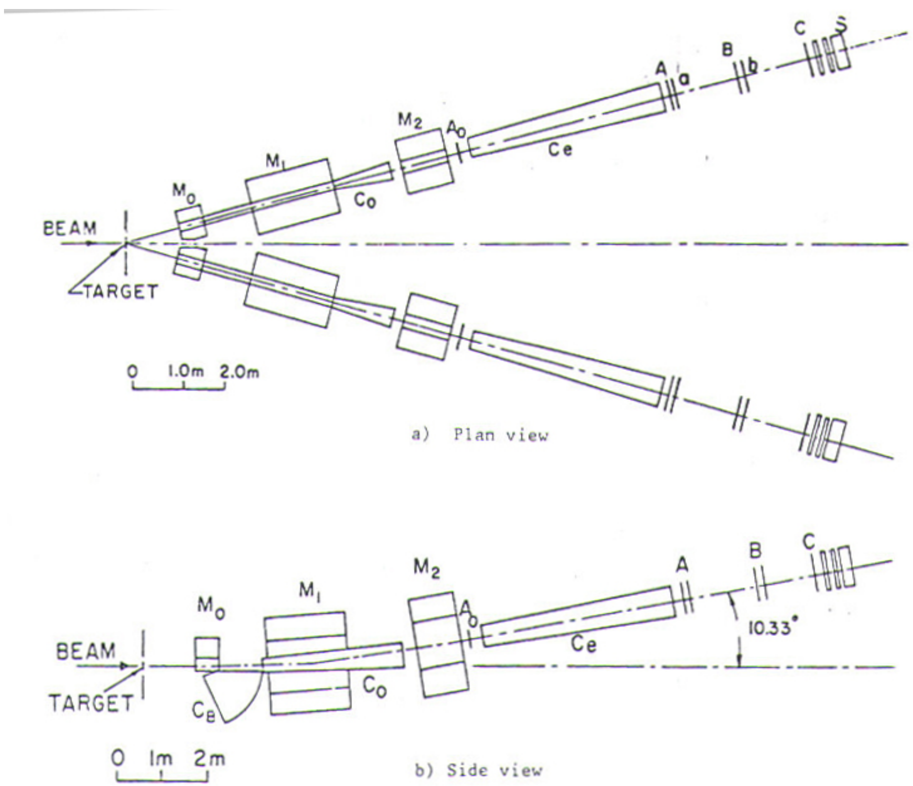


Fig. 5. Schematic diagram of the experimental set-up for the double-arm spectrometer used in our discovery of the J particle. M_0, M_1, and M_2 are dipole magnets; A_0, A, B, and C are 8000-wire proportional chambers; a and b are each 8×8 hodoscopes; S designates three banks of lead-glass and shower counters; C_B, C_0, and C_e are gas Cerenkov counters.

$P + Be \rightarrow e^+ \ e^- + X$

Samuel.C.C. Ting and collaborators built a high-resolution electron-pair spectrometer.

Discovery of the J particle

J.J Auber et al., Phys. Rev. Letters, 33 (1974)

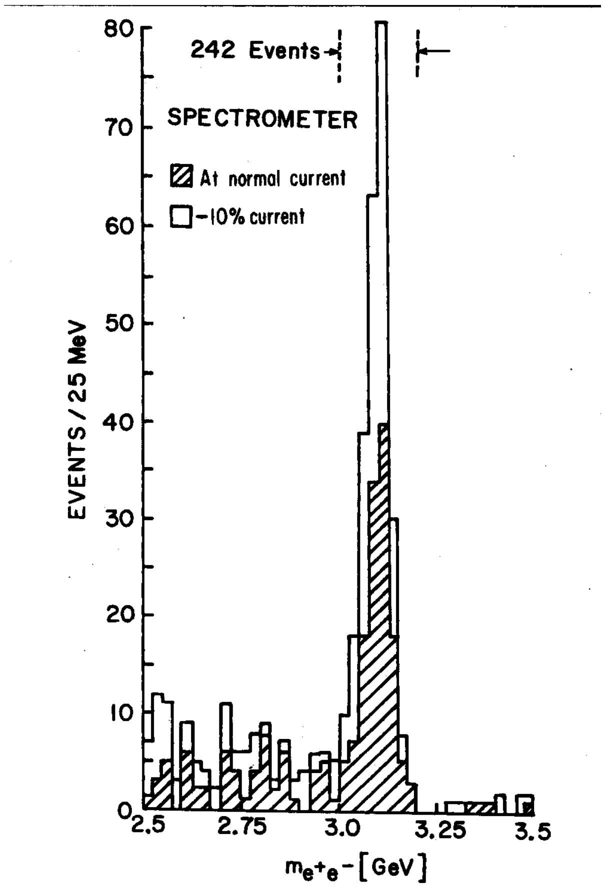


FIG. 2. Mass spectrum showing the existence of *J*. Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

The E598 experiment was proposed on May 11, 1972
The first data were collected in May 1974.

The "J" discovery was announced on November 11, 1974.

EW LETTERS 2 DECEMBER 1974

Discovery of the ψ

J.A. Augustin et al., Phys. Rev. Letters, 33 (1974)

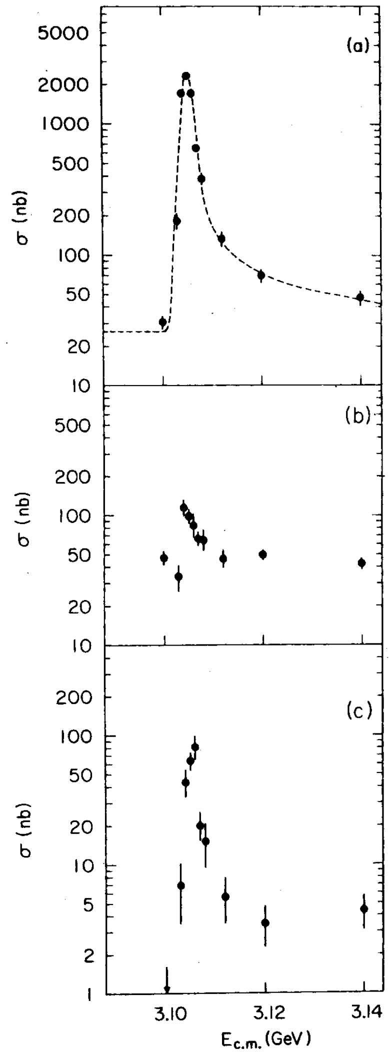


FIG. 1. Cross section versus energy for (a) multihadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- final states. The curve in (a) is the expected shape of a δ-function resonance folded with the Gaussian energy spread of the beams and including radiative processes. The cross sections shown in (b) and (c) are integrated over the detector acceptance. The total hadron cross section, (a), has been corrected for detection efficiency.

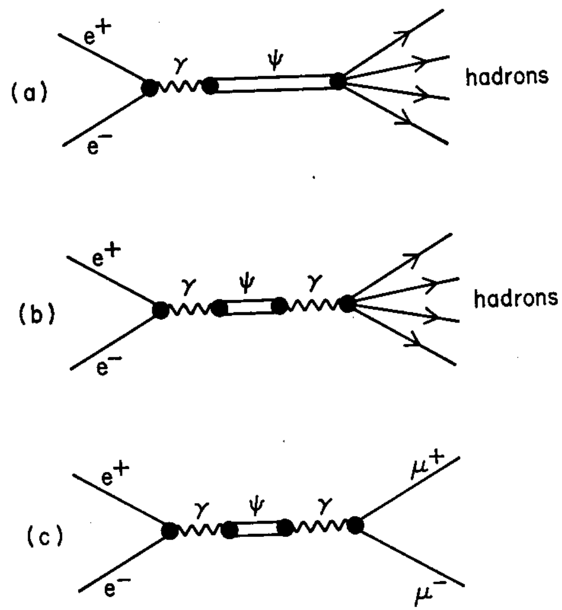


Fig. 7. Feynman diagrams for ψ production and (*a*) direct decay to hadrons, (*b*) second-order electromagnetic decay to hadrons, and (*c*) second-order electromagnetic decay to $\mu^+\mu^-$.

On the same Nov. 11, 1974 a large peak found at SPEAR in several e^+e^- annihilation channels was announced at SLAC, discovering the "Ψ".

Behind the curtains

Michael Riordan, “The Hunting of the quark”, Simon and Shuster, 1987

“At the end of October the start of a refined energy scan by MARK1 around 3.1 GeV was decided because of anomalous event rate seen in some older runs around that energy, and because Gerson Goldhaber reported an excess of kaons in hadron events in those runs. The BNL discovery did not play a role. “

However, in October 1994 rumors on E598 findings were flying around at BNL and at SLAC, so much that Mel Schwartz went to BNL, walked on Ting`s trailer and told him: “I heard that you have found a narrow peak at 3 GeV”. Sam denied.

Sau Lan Wu told me “we are making a big discovery”. I could not get more info.

Sam Ting went close to being scooped

Already on mid September 1974 a strong peak around 3,1 GeV was seen at BNL. However, Sam Ting wanted to discover more peaks at larger masses. He resisted publishing.

On November 10 a celebration was being organized at SLAC for the following day, to announce a new particle discovered at SPEAR at 3,1 GeV. The news reached Ting`s counting room at BNL. Sam happened to be on a flight to SLAC to attend some meeting on the following day. A message was sent to him at the TWA arrival desk in San Francisco.
By the middle of the night he was on-line with his group. He realized that he was being scooped.

A telephone call received on November 11th

An excited Sau Lan Wu calling G.B. from BNL:

"We have found a new particle!"
"What is so special about it?"
"It is very heavy and very narrow! It decays into e^+e^- "
"How heavy?"
"About 3.1 GeV."

In the conversation we considered that Adone`s energy could possibly be stretched to reach that value.

What was the precise mass?

Mario Greco had just landed at SLAC. He managed to know the exact narrow mass range and called me.

A scan in 10 MeV steps was started at Adone already on the 12^{th} .

7 days from hearing to publishing

Info received by S. L. Wu: November 11th

Resonance found at ADONE: November 13th

Data collected, paper written: November 17th

Paper-by-phone from G.B. to S. L. W.: night of November 17th

Paper received by P.R.L: November 18th.

Paper published third after the BNL and SLAC discovery papers.

The Frascati result

C.Bacci et al., Phys.Rev.Lett. 33, 1408, 1974

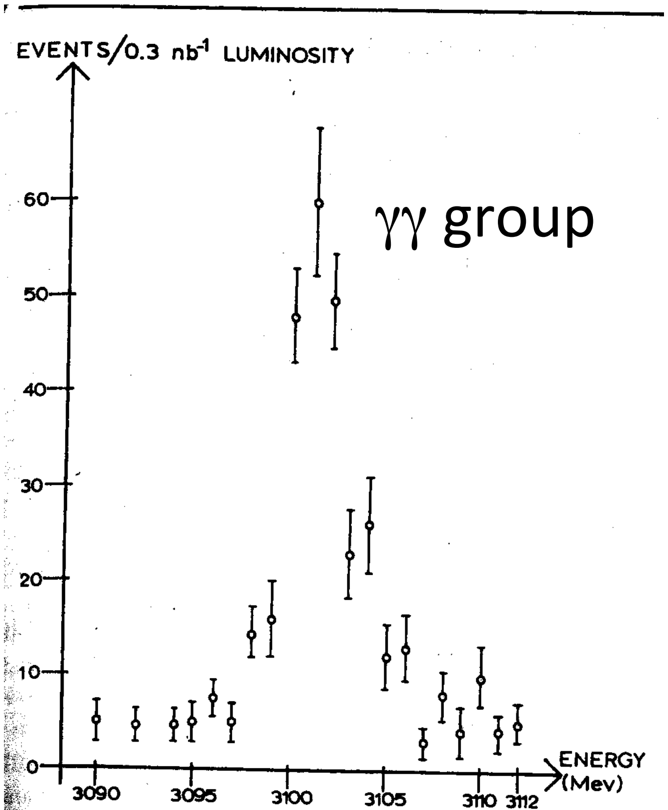


FIG. 1. Result from the Gamma-Gamma Group, total of 446 events. The number of events per 0.3 nb^{-1} luminosity is plotted versus the total c.m. energy of the machine.

The other Adone groups reported a similar evidence.

Adone found the ψ much faster than Doris, where it was observed only on November 19th. This proved the excellent quality of the machine.

However, the limited energy did not allow to contribute to the rich physics in the 3,1 - 4,5 GeV range.

The amazing spelling mistakes

Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Particle Produced in e^+e^- Annihilation*

C. Bacci, R. Balbini Celio, M. Berna-Rodini, G. Caton, R. Del Fabbro, M. Grilli, E. Iarocci, M. Locci, C. Mencuccini, G. P. Murtas, G. Penso, G. S. M. Spinetti, M. Spano, B. Stella, and V. Valente

The Gamma-Gamma Group, Laboratori Nazionali di Frascati, Frascati, Italy

and

B. Bartoli, D. Bisello, B. Esposito, F. Felicetti, P. Monacelli, M. Nigro, L. Paolufi, I. Peruzzi, G. Piano Mortemi, M. Piccolo, F. Ronga, F. Sebastiani, L. Trasatti, and F. Vanoli

The Magnet Experimental Group for ADONE, Laboratori Nazionali di Frascati, Frascati, Italy

and

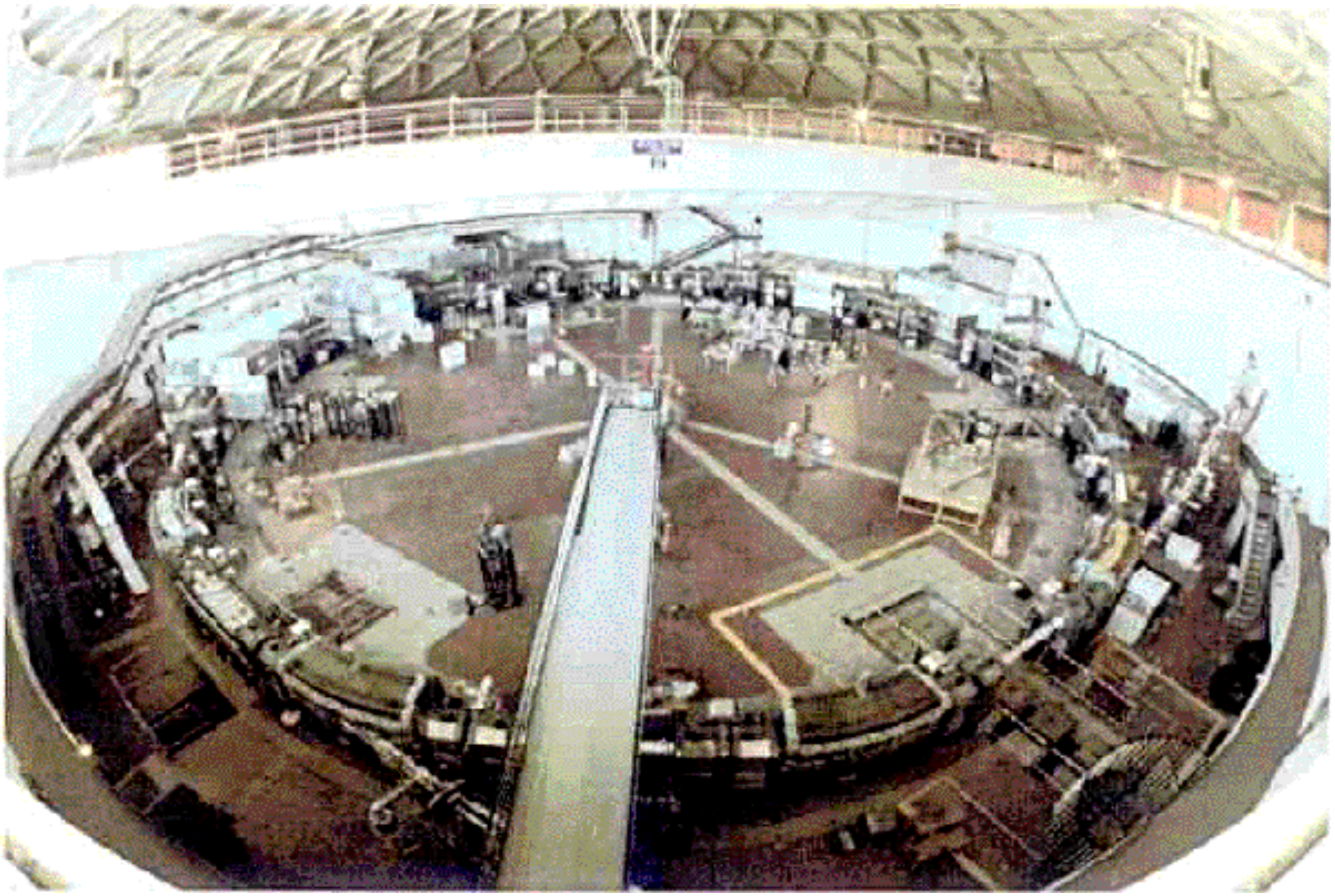
G. Barbarino, G. Barbiellini, C. Bemporad, R. Biancastelli, F. Cevenini, M. Celvetti, F. Costantini, P. Lariccia, P. Parascandalo, E. Sassi, C. Spencer, L. Tortora, U. Troya, and S. Vitale

The Baryon-Antibaryon Group, Laboratori Nazionali di Frascati, Frascati, Italy

(Received 18 November 1974)

We report on the results at ADONE to study the properties of the newly found 3.1-BeV particle.

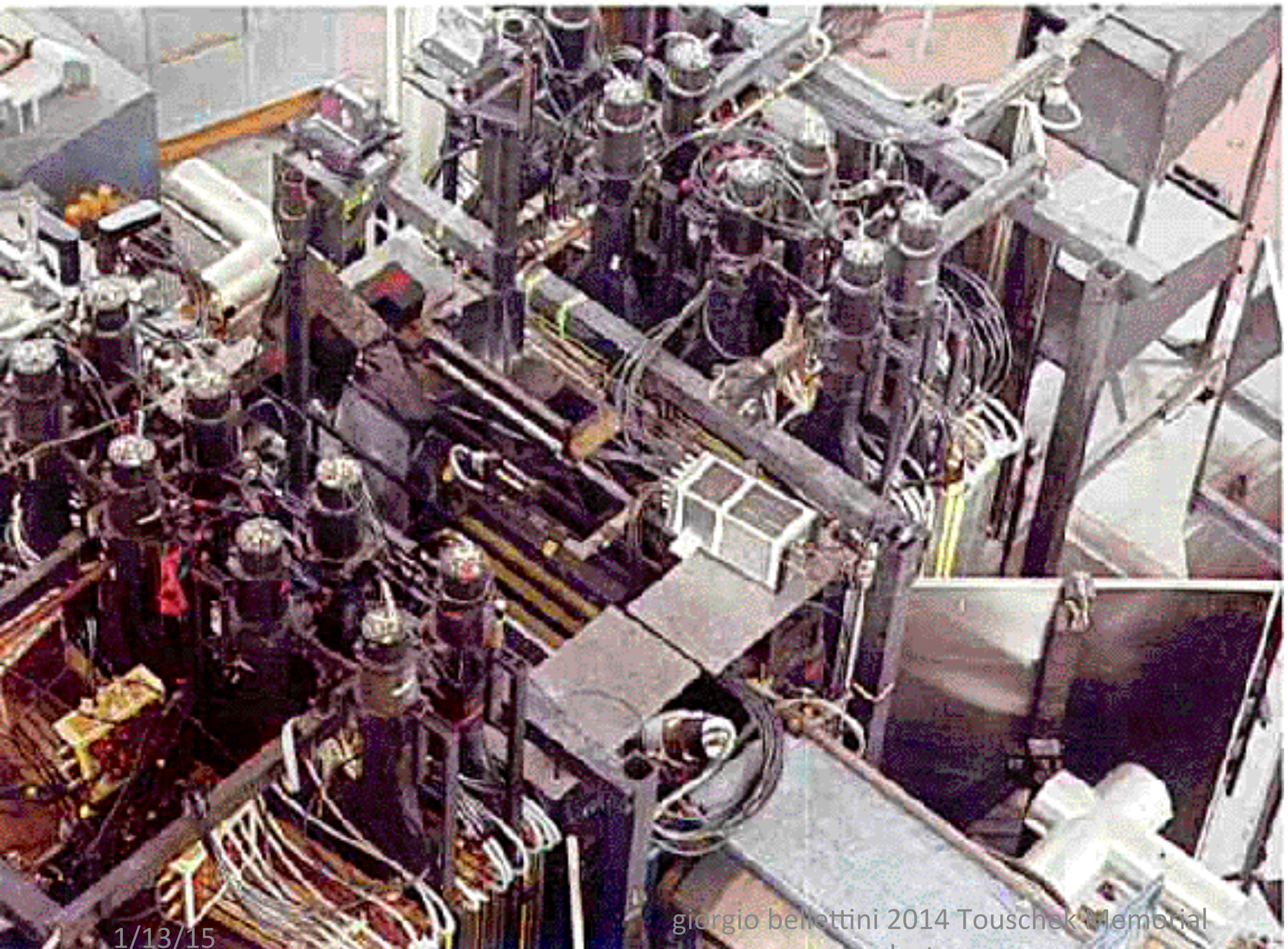
ADONE



The maximum Adone cms design energy was 3.0 GeV.

Adone was run safely at 2.8 GeV

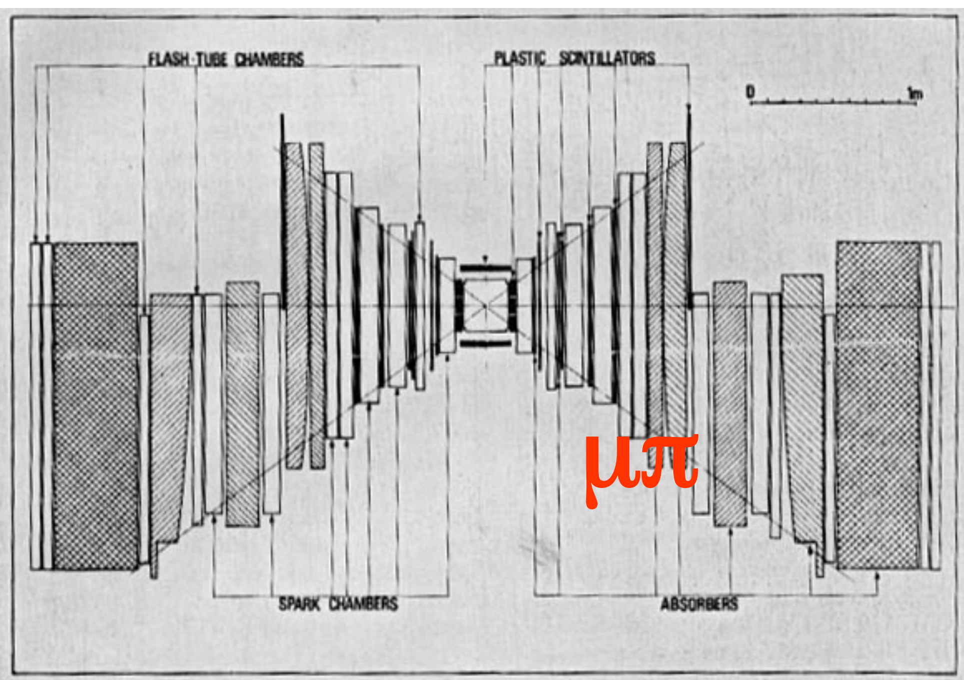
The BCF detector

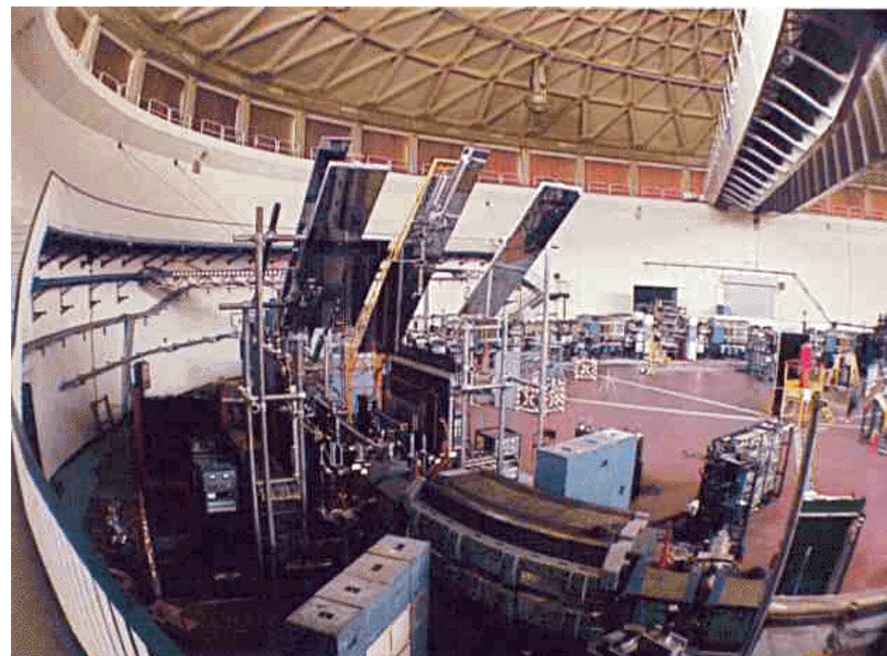


The Bologna-CERN-Frascati detector featured two telescopes at large angle.

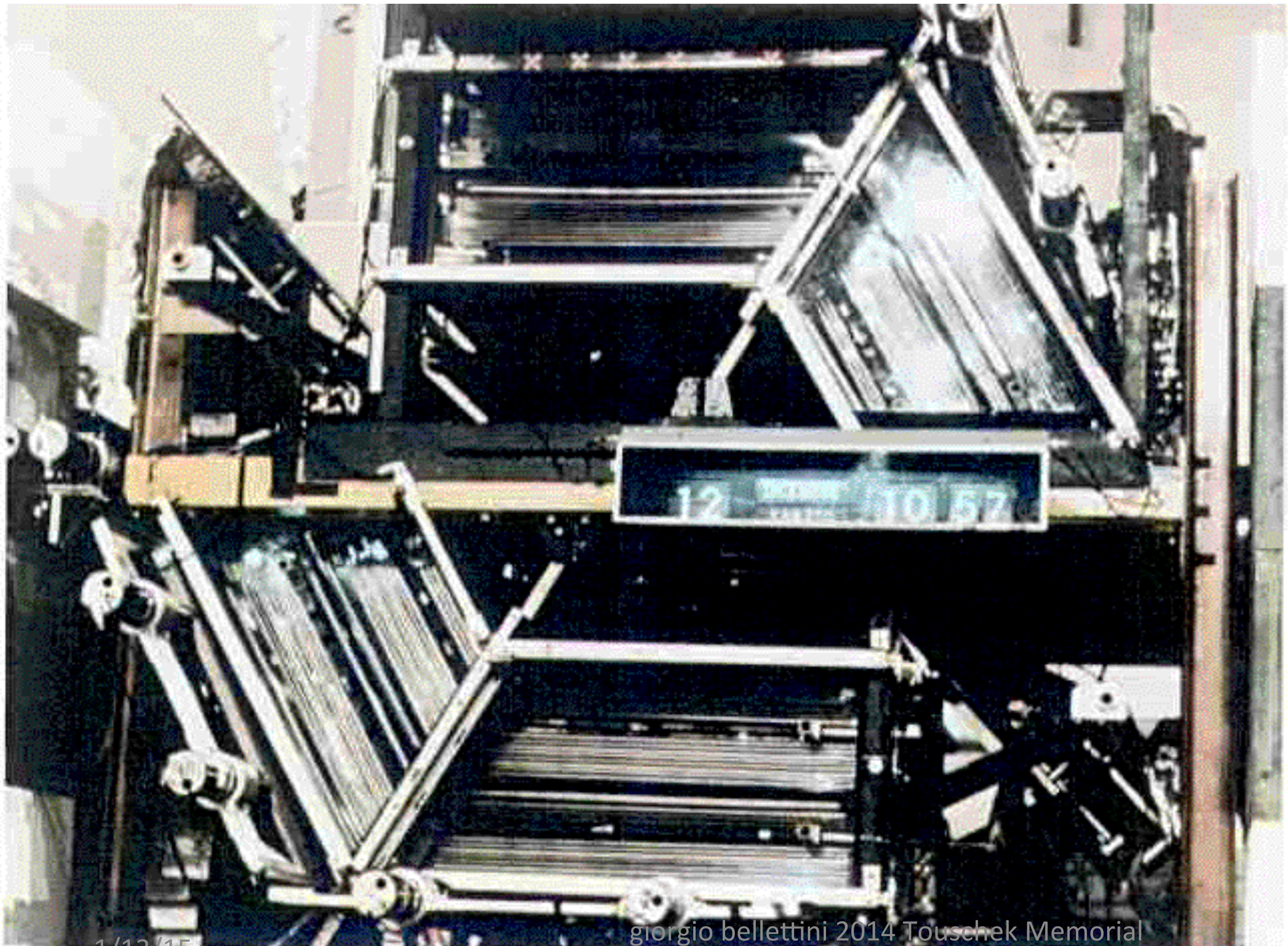
The "$\mu\pi$" detector at Adone

Two range telescopes with trigger counters and optical tracking chambers.



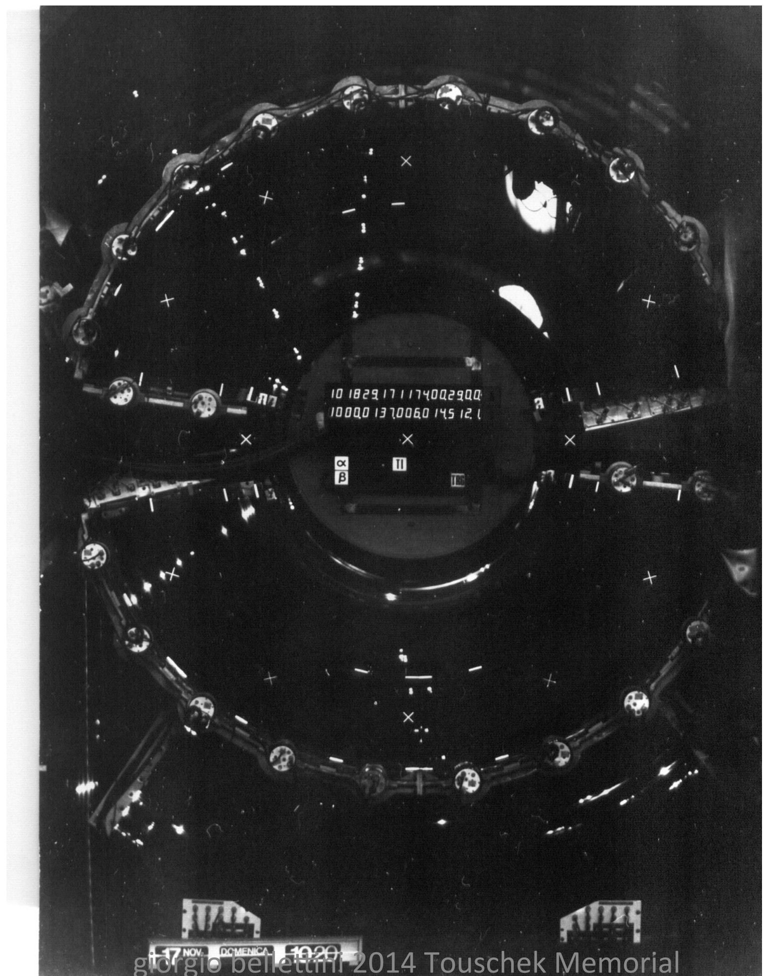


The γγ detector

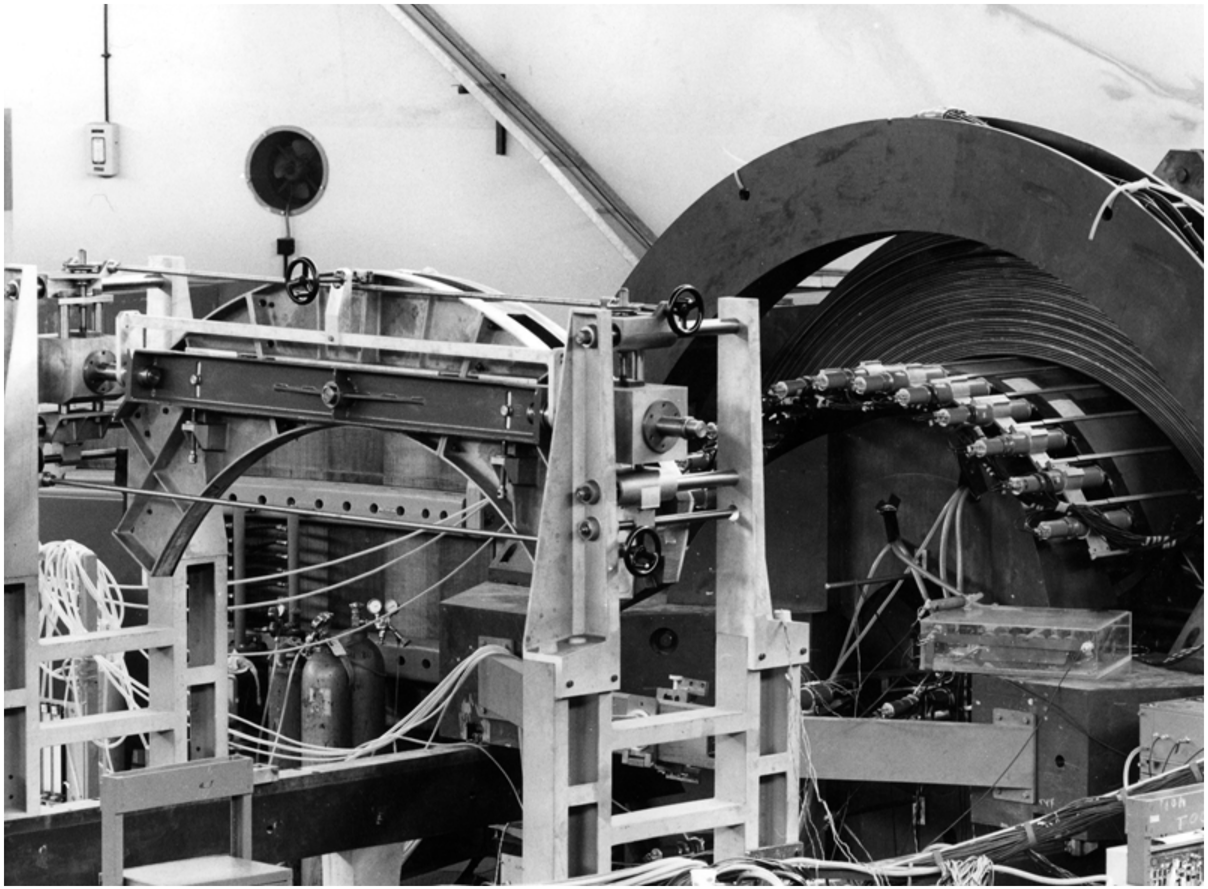


The γγ detector employed telescopes of optical spark and wire chambers interleaved with absorber plates, set orthogonal to the beams.

A ψ event in the γγ2 detector



The magnetic detector MEA at Adone

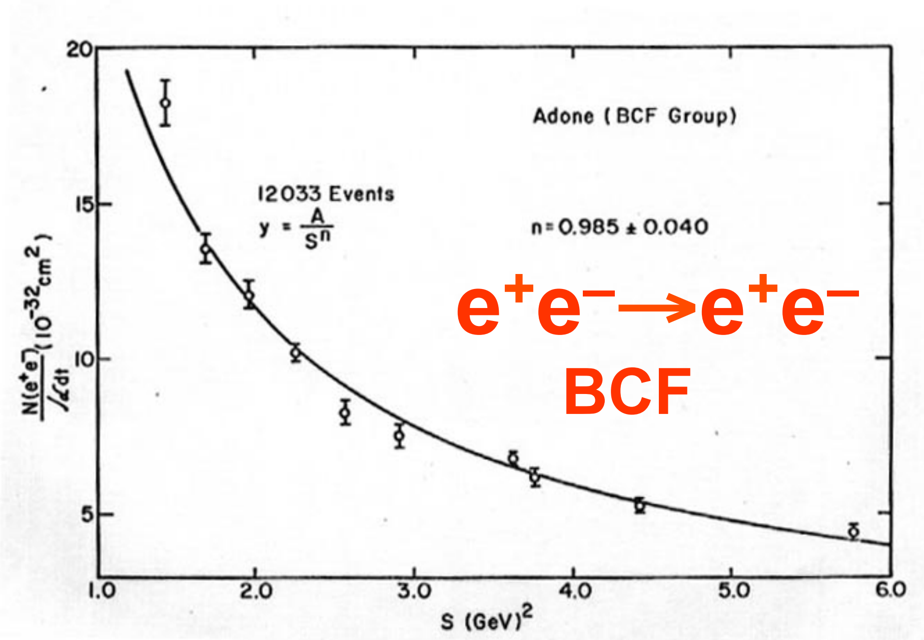


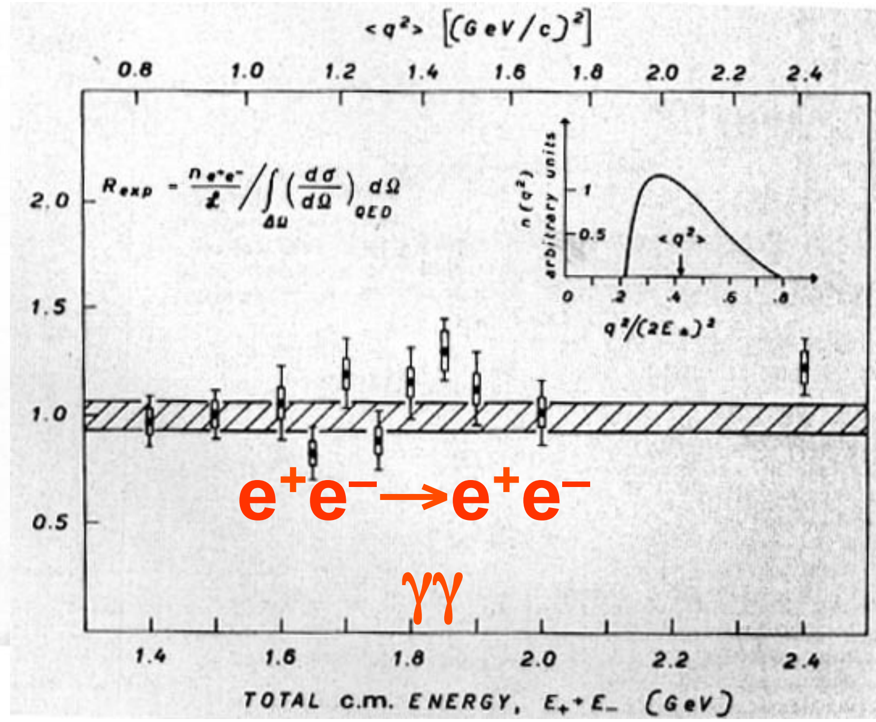
The MEA solenoid was orthogonal to the beams to allow taking pictures of the spark chamber tracks

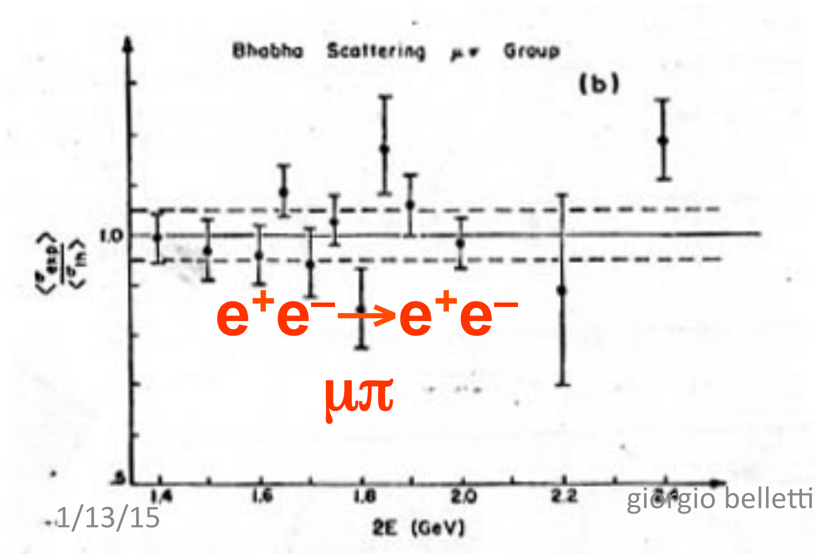
Adone physics

The measurements of electromagnetic processes agreed beautifully with QED.

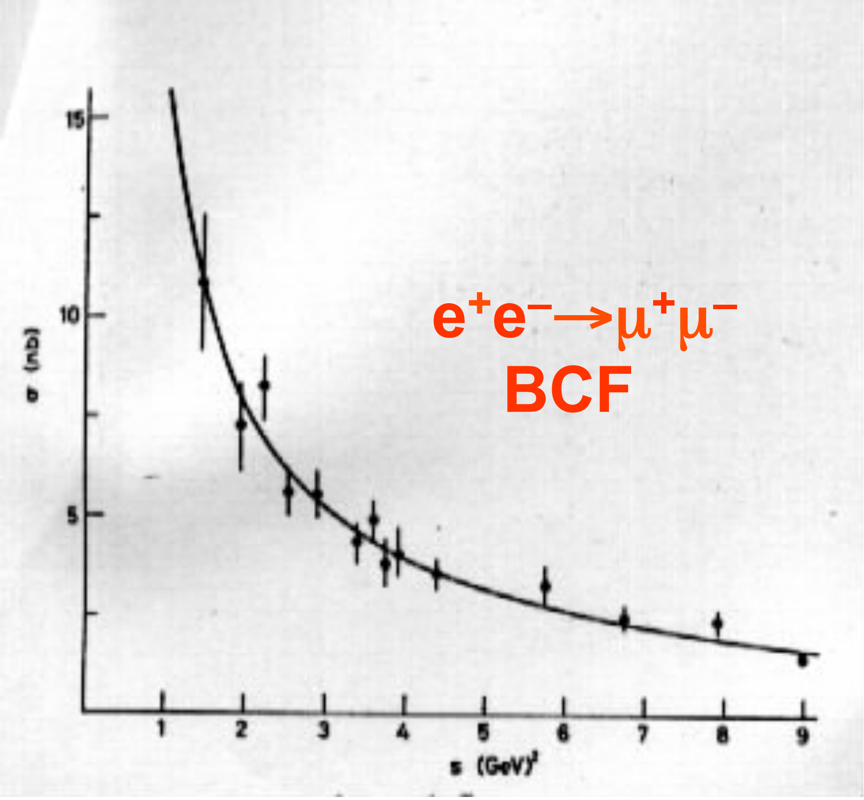
Bhaba scattering fitted to Adone data

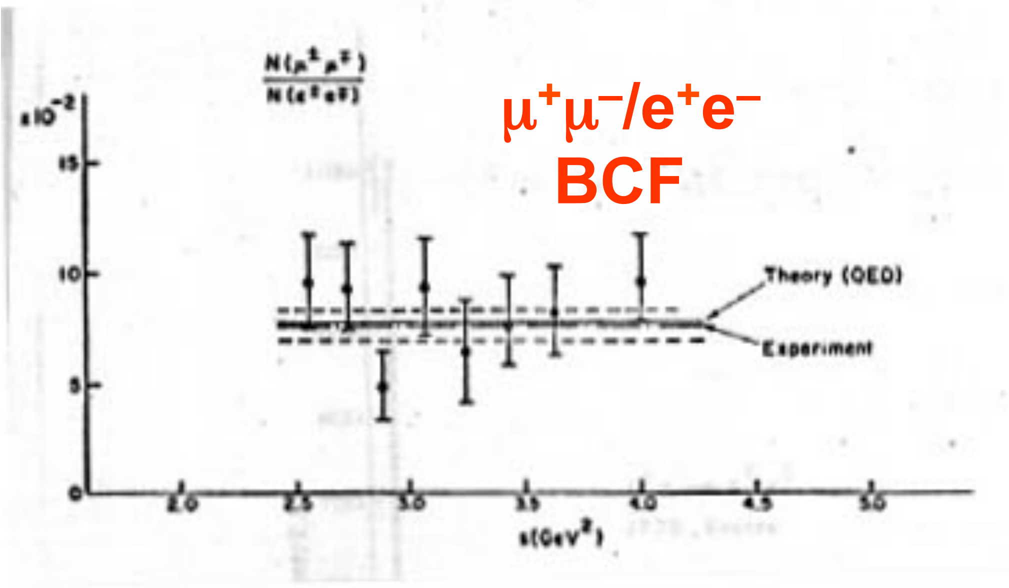






Annihilation into μ pairs was as expected
$e^+e^- \to \mu^+\mu^- / e^+e^- \to e^+e^-$





$R = \sigma_h/\sigma_{\mu\mu}$ around 3 GeV, before the ψ discovery

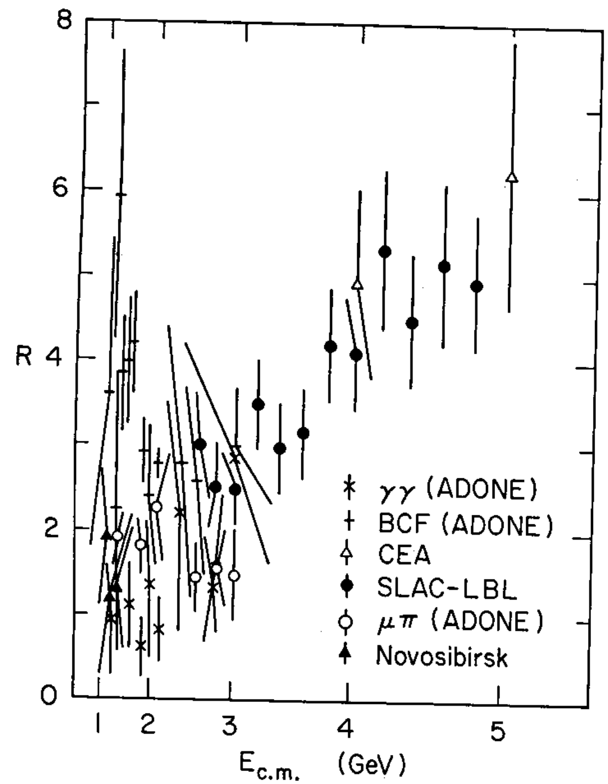


Fig. 3. The ratio *R* as of July 1974.

$e^+e^- \rightarrow$ hadrons was less clear.

R ~ 2 at Adone, but larger above 3 GeV cms at SLAC.

Could we do better?

(translating from Italian):

Giorgio Salvini, *in "Maestri ed Allievi della Fisica Italiana del Novecento", by Luisa Bonolis, Ed. La Goliardica Pavese SRL, 2008, page 127*

"…there was an understandable bitterness…However I do not feel like associating this bitterness to a sense of guilt…nobody, I say nobody could suspect that a few steps beyond the 3 GeV limit there was an Eldorado waiting..."

Giorgiob, *in "Storie di Uomini e Quarks", by Carlo Bemporad and Luisa Bonolis, Ed. La Societa` Italiana di Fisica, 2010, page 25:* "…Frascati did have a machine that could reach the J/ψ…we kept increasing the statistics at 2,8 GeV… the search for narrow resonances was made only after this earthquake…I was the Director and thus I was not innocent…you cannot imagine how many times I ate my fingers!"

Conclusions

Adone did a good job in its energy range.
Since we did not feel like being shooting for a discovery, the machine program was not a hot issue.

A discovery could not come in the course of the current program, but was not impossible.

SPARES

e^+e^- annihilation into hadrons was problematic

Customary view

$e^+e^- \to \gamma \to$ hadrons

Quark model hypothesis

$e^+e^- \to \gamma \to q\bar{q} \to$ hadrons

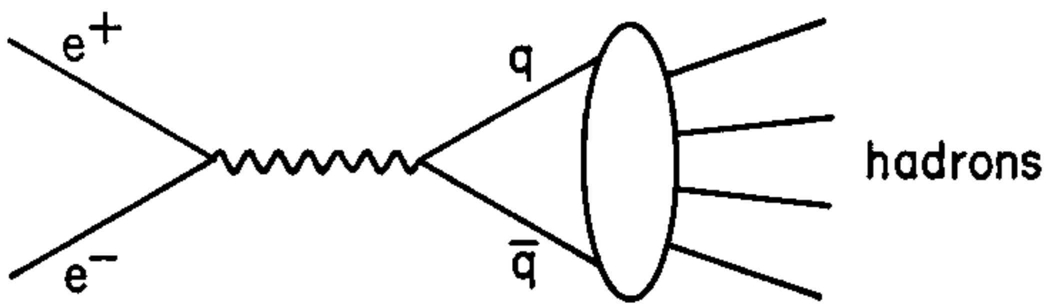
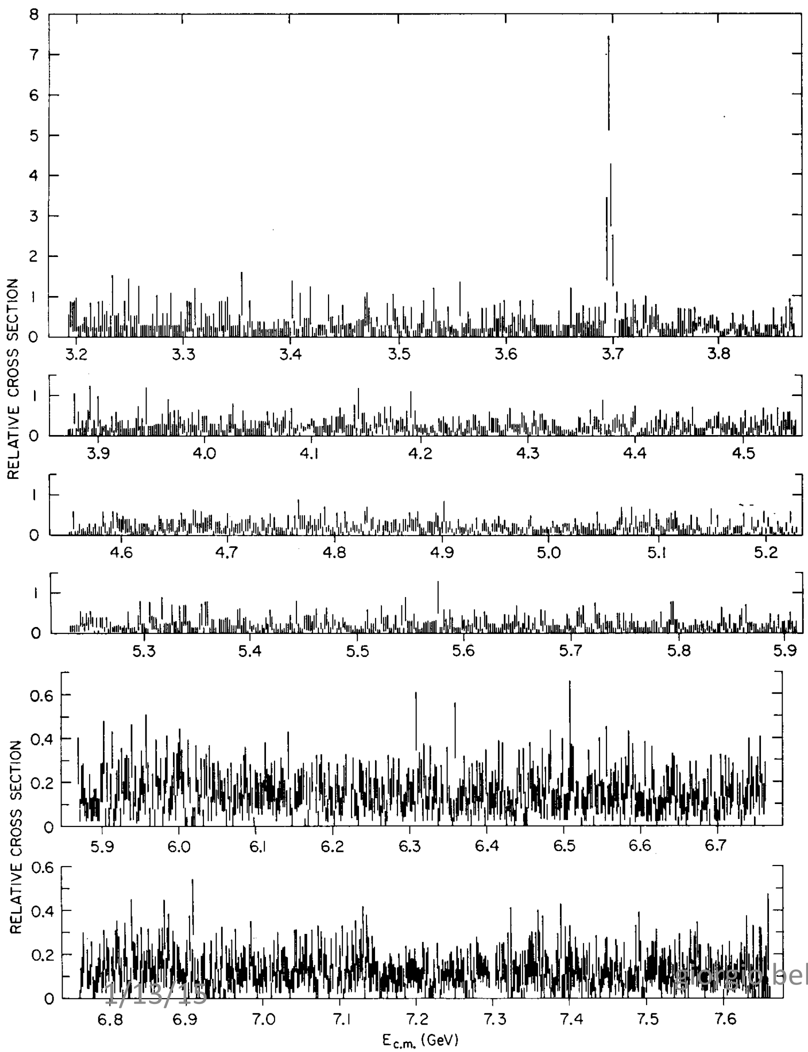


Fig. 16. Hadron production in the quark model.

Simple quark model estimate:

R= $\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-) = 3\sum Q_q^2 = 2$ by u +d + s

More resonances above the Ψ



A recurrence to the Ψ, named Ψ‘, was found just below 3.7 GeV.

Fig. 9. The fine-scan data from our search for other narrow ψ-like states. The signal near 3.7 GeV is the ψ′.

The "charmonium spectrum"

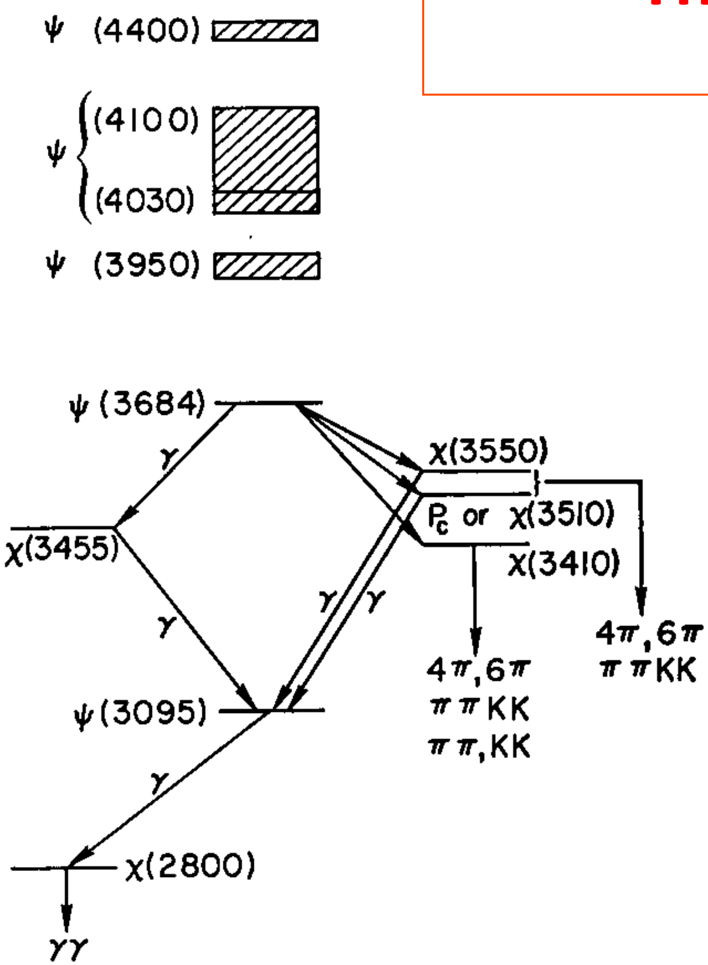


Fig. 15. An energy-level diagram of the new particles. The many observed decay modes of the psi family have been omitted.

In addition to the Ψ' many other excited C-Cbar excited states were found, as well as many final state open charm hadrons above 4 GeV.

R around 4 GeV

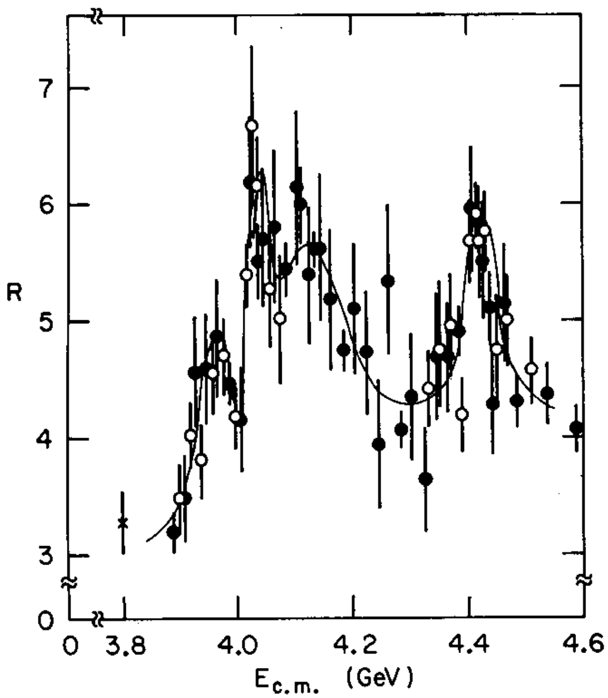
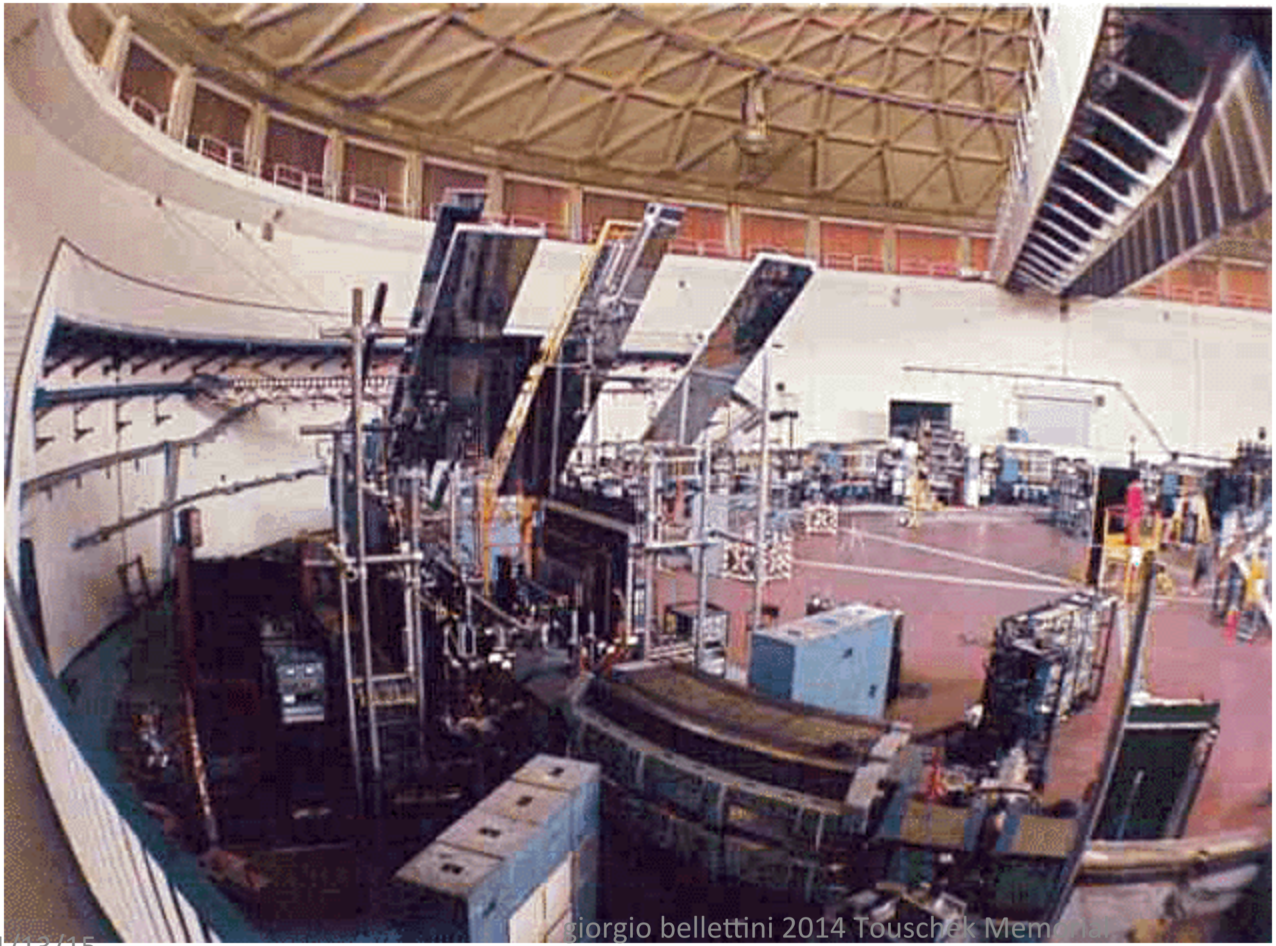


Fig. 14. An expanded view of *R* in the transition region around 4 GeV.

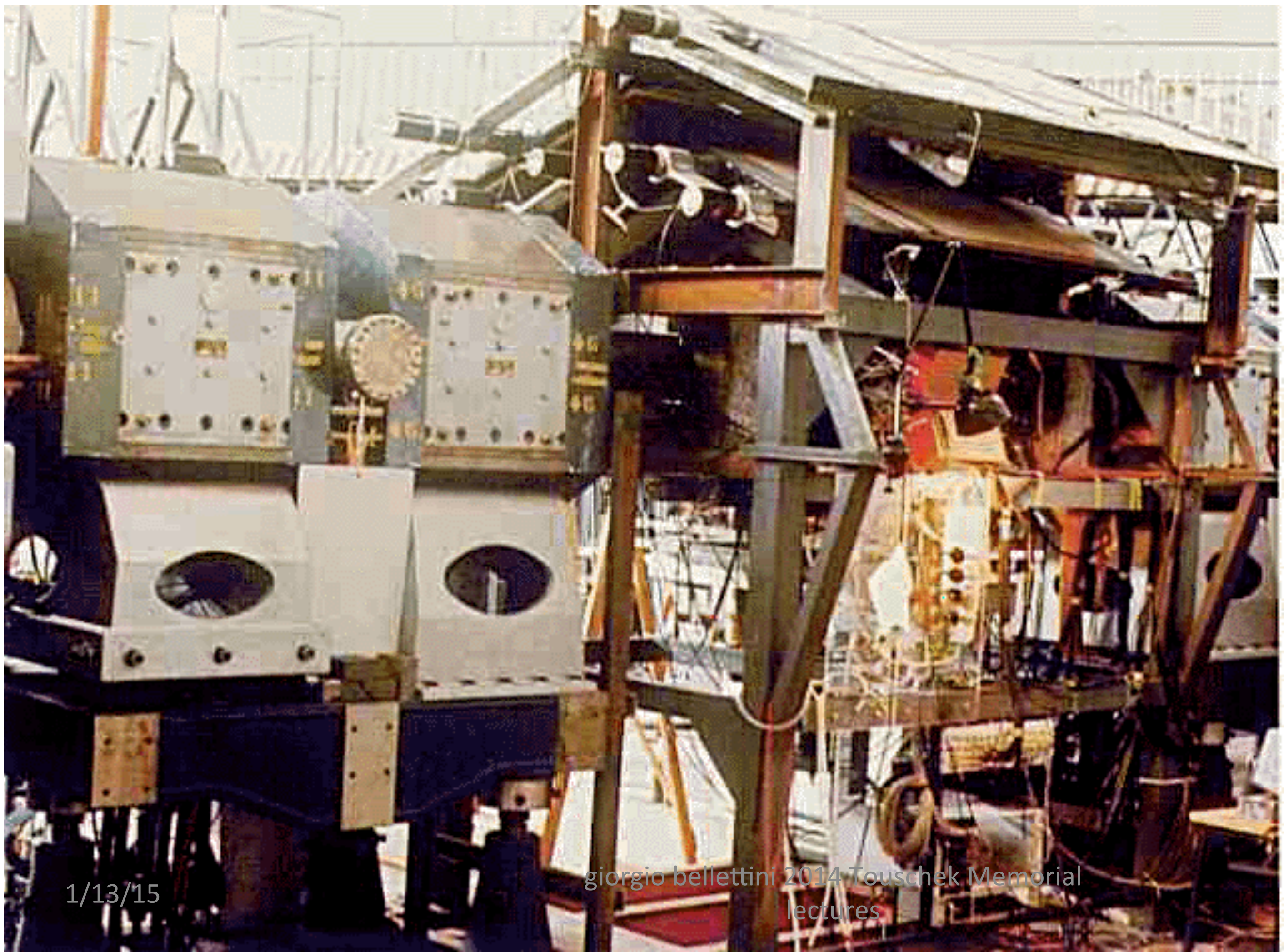
$R = \sigma_{hadrons}/\sigma_{\mu\ pairs}$

In hadron final states a number of wider structures above 3,7 GeV indicated Ψ ststes above open charm production

The $\mu\pi$ detector ad Adone

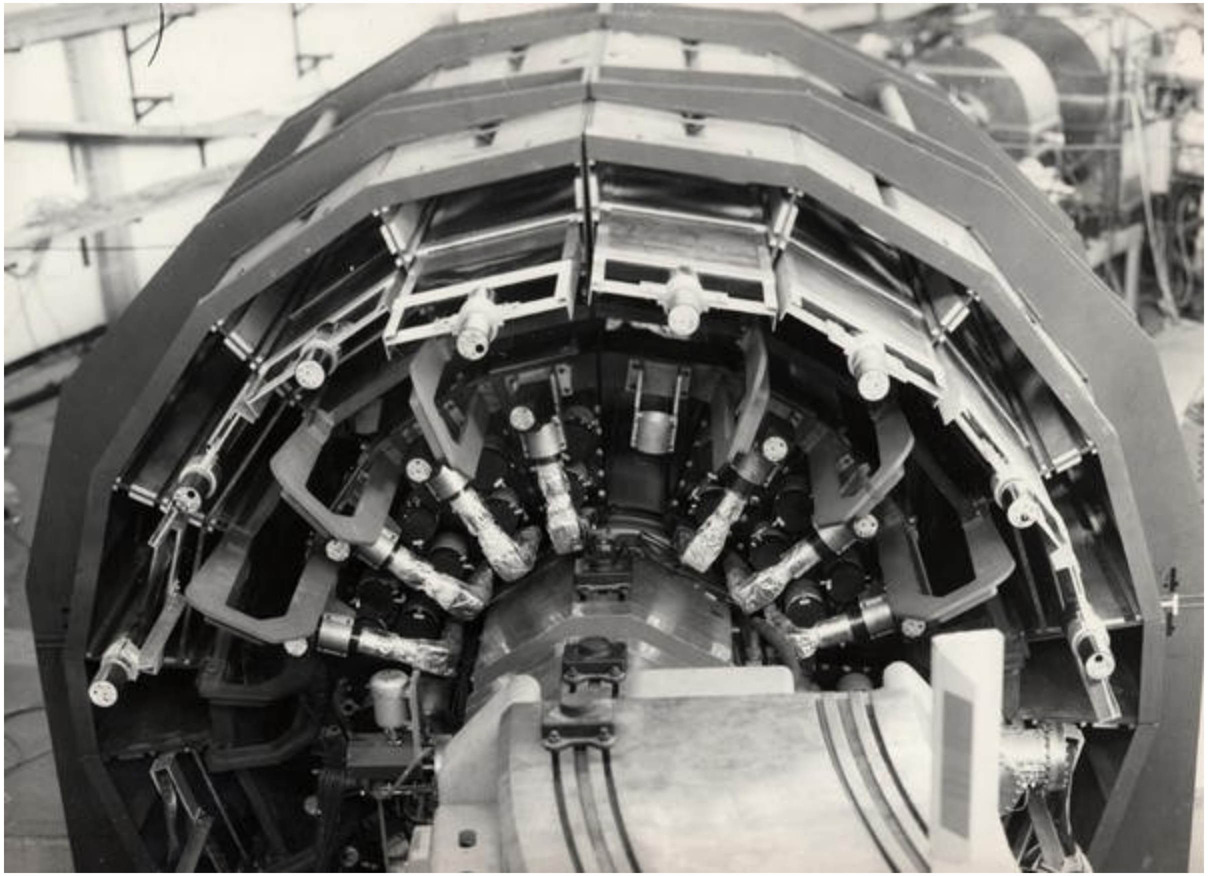


The “Boson” detector



The “Boson” detector was covered with a cosmic muon shield.

The Barion-Antibaryon detector



A cylindrical detector was installed on Adone in 1970, replacing the Boson detector.

SPEAR picture of R without the ψ`s

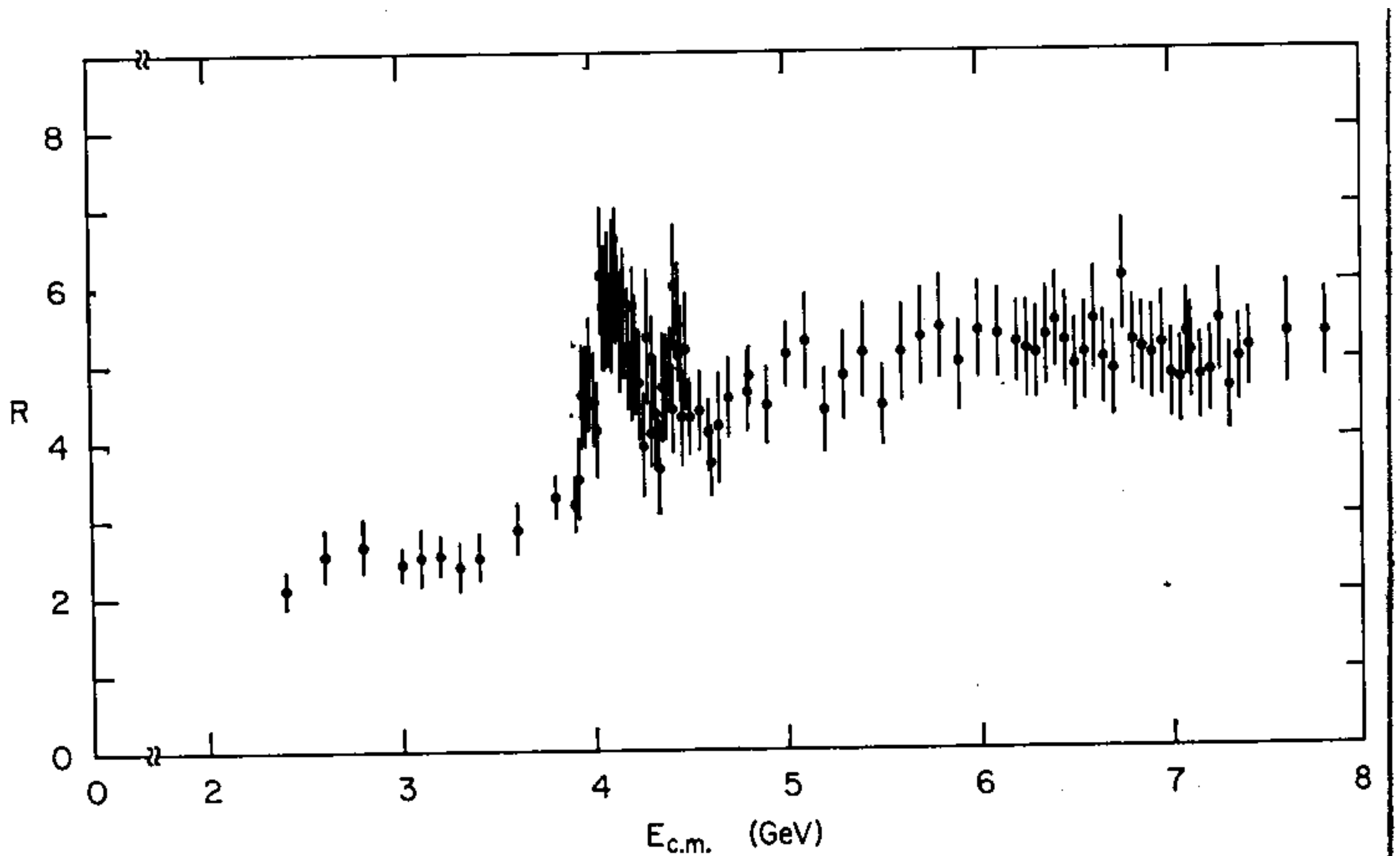


Fig. 13. The ratio *R* with the ψ and ψ′ deleted (including their radiative tails).