The (re)discovery of the "charmed φ" in Frascati

Marcello Piccolo

Laboratori Nazionali di Frascati dell'I.N.F.N.

SLAC 11/8/2024

Today's menu

- Few words concerning the birth of the Frascati Laboratory and the Physics program in the early '70.
- The storage ring operation at that time.
- Second generation experiments running at Adone.
- The night of the (re) discovery.
- The PRL paper.

The Frascati National Laboratory

- Born in 1954 by the effort of (few) Enrico Fermi's co-workers: Edoardo Amaldi, Gilberto Bernardini et. al.

- First operational director G. Salvini.

- First accelerator to be built: electron synchrotron of 1100 MeV.

- The first accelerator started its Physics program in 1959.

- In February 1960 Bruno Toushek proposed on the basis of discussions with Rolf Wideroe (some fifteen years back) the colliding electron-positron ring.

- Such technique, for protons and electrons, was also proposed around the same date by Gerald O' Neil and Burton Richter. Parallel efforts were also carried out in Russia by Gersh Budker and collaborators.

The original proposal to build an e⁺e⁻ storage ring

Laboratori Nazionali di Frascati del C.N.E.N.
Servizio Documentazione

Nota interna: n° 55
25 Ottobre 1960

C. Bernardini, G.F. Corazza, G. Ghigo, B. Touschek: THE FRASCATI STORAGE RING (A.d.A.).

It was decided in February 1960 in Frascati to study the possibility of a colliding beam experiment employing electrons and positrons. The discussion of this proposal lead to the design of the machine which we want to describe briefly in this letter.

Electrons and positrons of 250 MeV each are stored in a DC weak focusing magnet. The electrons and positrons circulate on the same orbit meeting in the gap of the radiofrequency and in the neighbourhood of 3 other points spaced at 90° from one another. The particles are produced by converting the γ -rays of the Frascati electron-synchrotron on two targets alternately exposed to the beam.

The magnet, which weights about 8 tons is shown in the figure. It contains 4 'quasistraights' sections, 18 cms of lenght, accomodating respectively the radiofrequency, pumping and injection ports and the experimental section in which about 1/4 of all the reactions taking place in the acceleration chamber should become observable. The doughnut is made of stainless steel and it is intended to eva

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The name ADA was always thought being the Italian acronym of storage ring (Anello Di Accumulazione), but, if you asked Bruno Toushek, he would tell you the machine was named after his aunt Ada, living in Rome as a dealer of a German company selling submersible pumps.

Here is ADA in one of her first runs
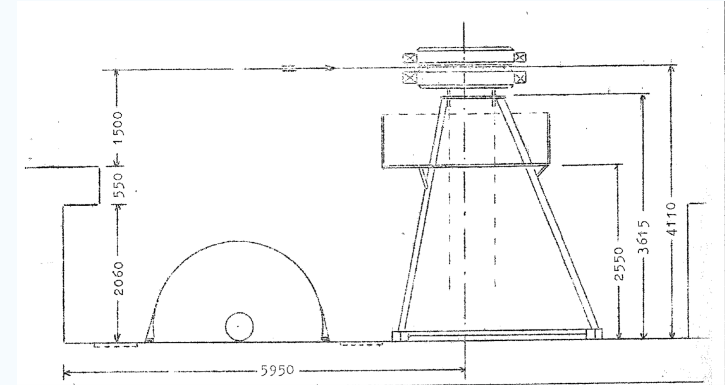
The written version of the presentation at the "International Conference on High Energy Physics Accelerators "(Brookhaven 1961)
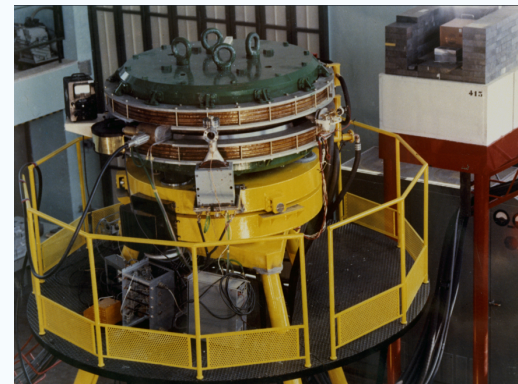
And after ADA there was big ADA -> ADONE

- In Italian when you want to 'enlarge' you add the suffix "one" to the word…. so a big ADA would be ADONE.
- The word (in Italian) is also the name of the mythological lover of Aphrodite and Persephone (ADONIS); and has been always believed to be the standard for male beauty.
- The legend says that the Aphrodite's tears mixed with his blood, when he was mangled by a wild boar, became the anemone flower.

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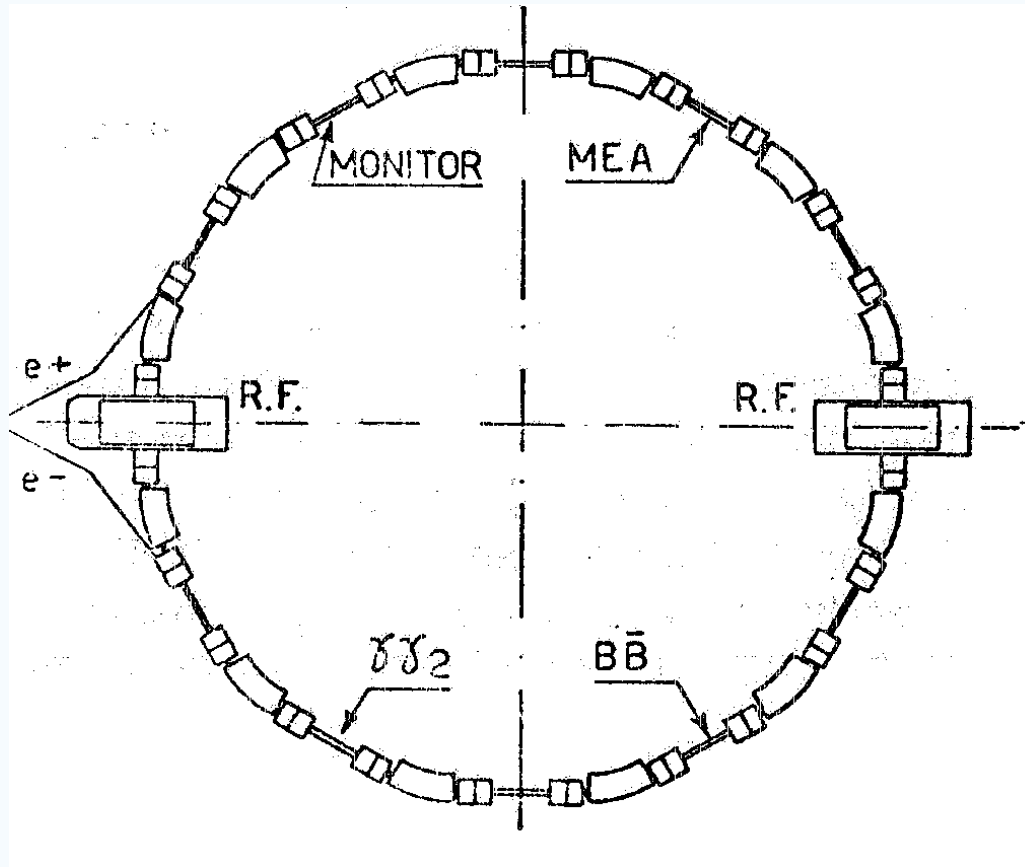
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Laboratori Nazionali di Frascati




LNF-61/65 (7.12.61)




F. Amman: PROPOSTA PER LA REALIZZAZIONE DI UN ANELLO DI
ACCUMULAZIONE, PER ELETTRONI E POSITRONI DA 1.5 GeV.
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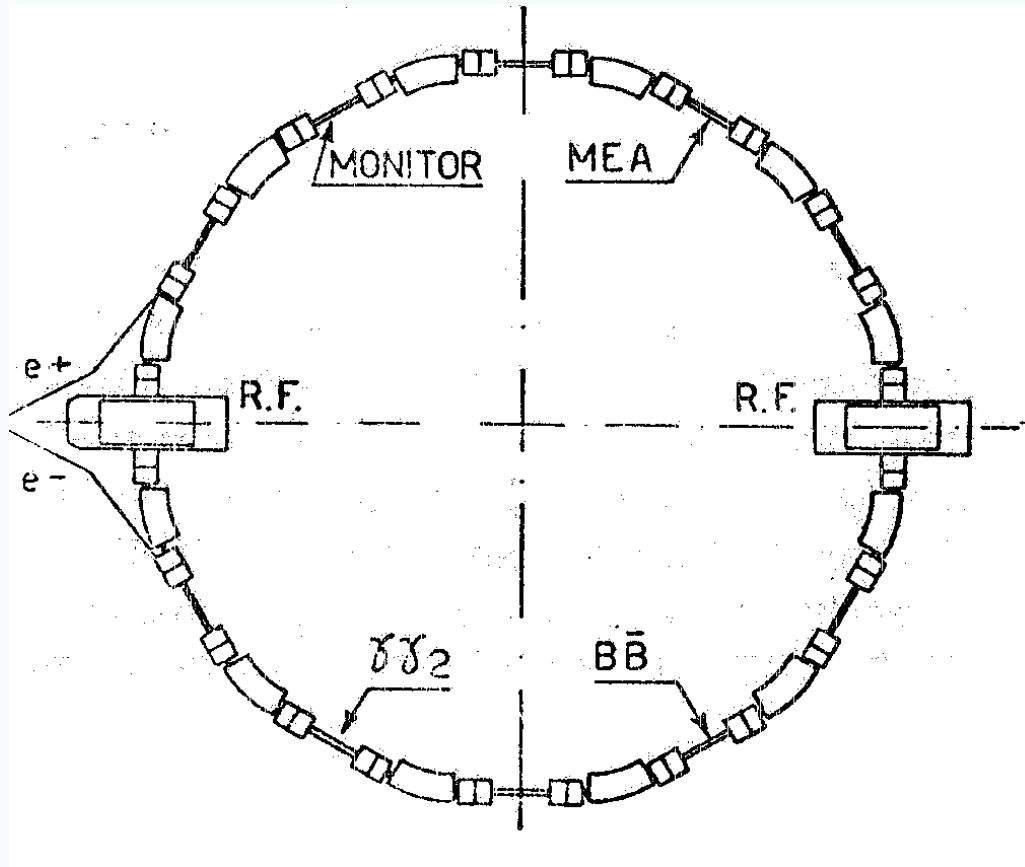
The ADONE physics running

- ADONE started physics runs in 1969, the startup was difficult. The machine was designed with an angle crossing, but a head–tail instability on the electrodes (so interpreted by Claudio Pellegrini) prevented such type of running.

- As a result, the beam spot was a bit less than a meter long reducing substantially the detectors' acceptances.

- Nevertheless, the multi-hadronic production was discovered; the R-ratio measured by three of the four first generation experiments was around 2, substantially higher than expected at that time.

- About at the same time, the second generation experiments were designed and built , three different experiments were installed in the straight sections of the machine :
  - Baryon-antibaryon: as the name says devoted to heavy particles production.
  - Gamma-gamma2 : calorimetric device with good neutral detection.
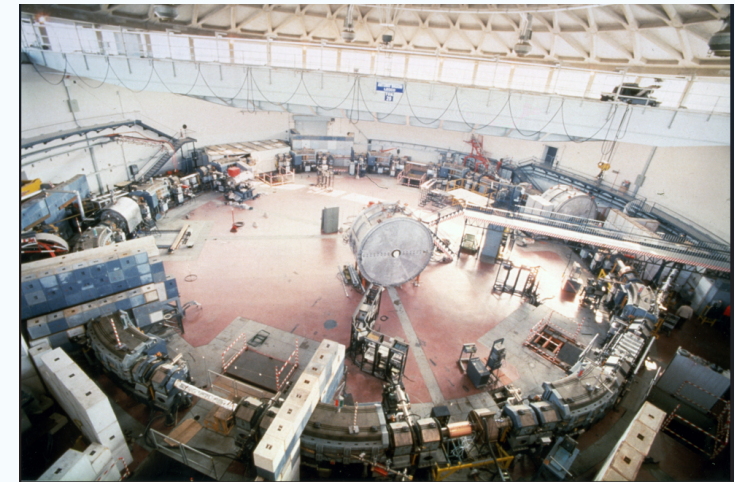 - MEA : a magnetic detector with B-field running perpendicular to the beams' directions.

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Adone parameters (end 1974)

Total length   104. m
Energy (total)   2.2 – 3.1 GeV
Luminosity (@ 3.1 GeV)   ~3* 10^{29}cm^{-2} sec^{-1}
Lum. Region   long. (FWHM)   40* $E^{3/2}_{beam}$ cm

Lum. Region (transv.)   1. x 0.1 cm^2
Lum. Lifetime   few hours
Injection and ramping times   ½ hour
Energy width (σ)   0.3*E^2_{CM} (in GeV)MeV

Energy calibration (abs.)   2 MeV
Energy (re) setting   0.3 MeV
# of bunches/beam   3
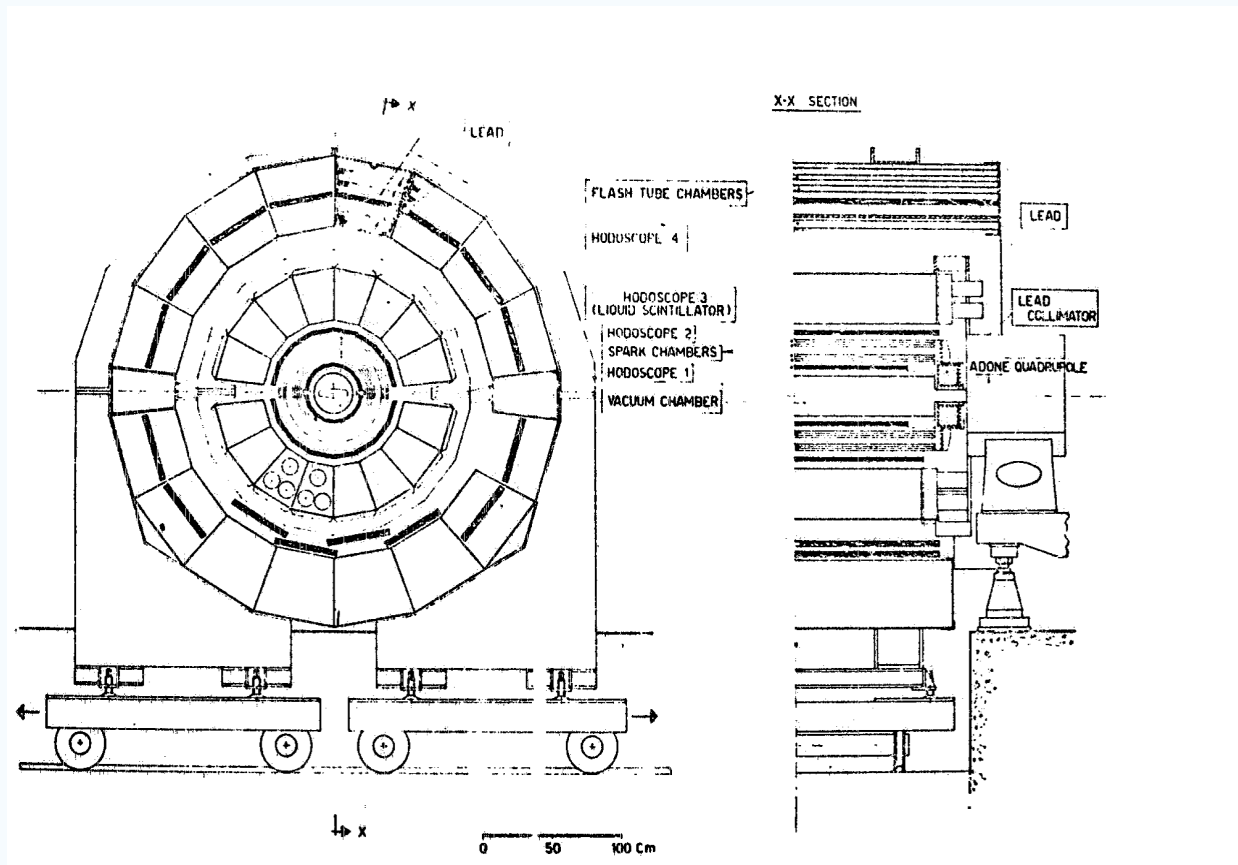Typical integrated luminosity   1 nb^{-1}/day

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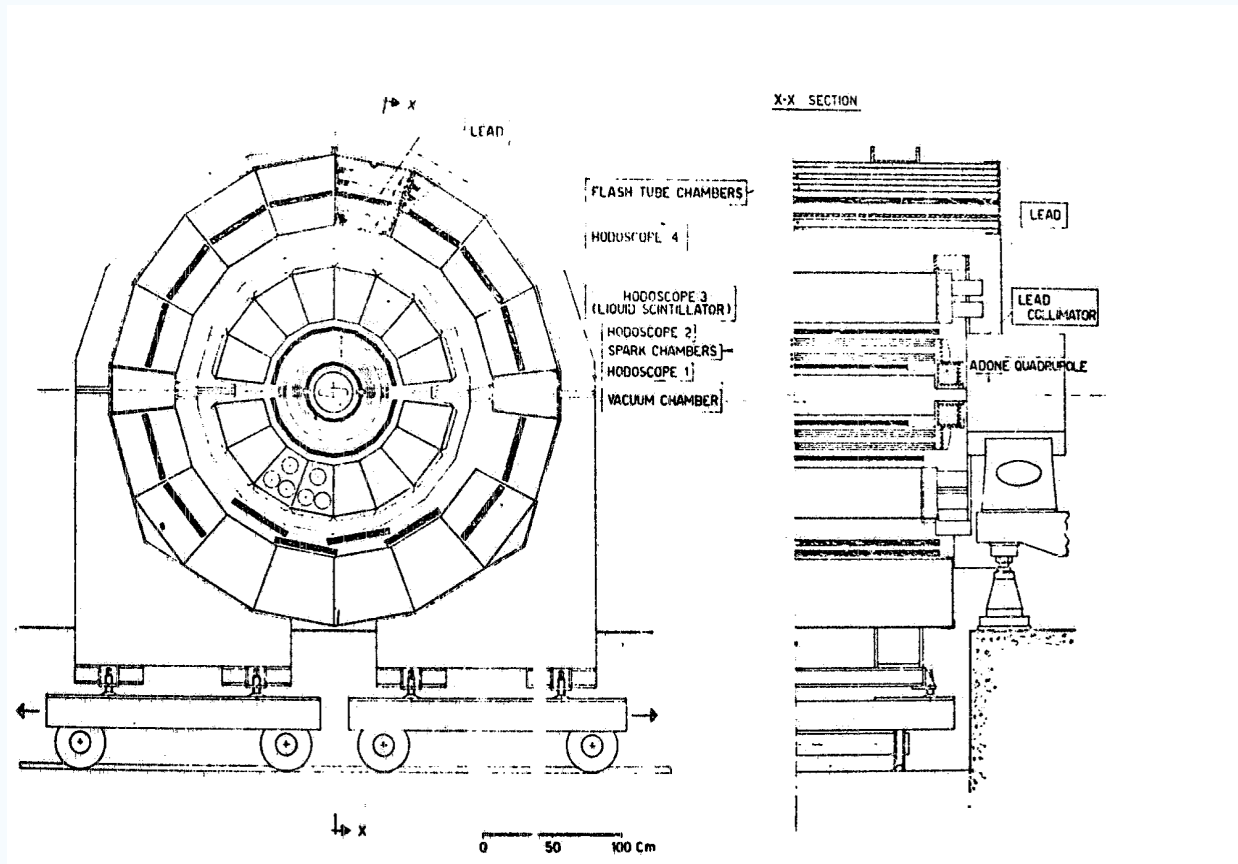# Second generation experiments at ADONE
Baryon-antibaryon

High quality calorimetric apparatus,
Completely digital .
Optimized to detect heavy particles.
Symmetry axis parallel to beam direction.
Solid angle coverage (point source) 70%*4π
 Liquid scintillator for heavy particle energy measurement.
Minimum energy to trigger for a π ~ 60 MeV.
Trigger at least 2 "π"

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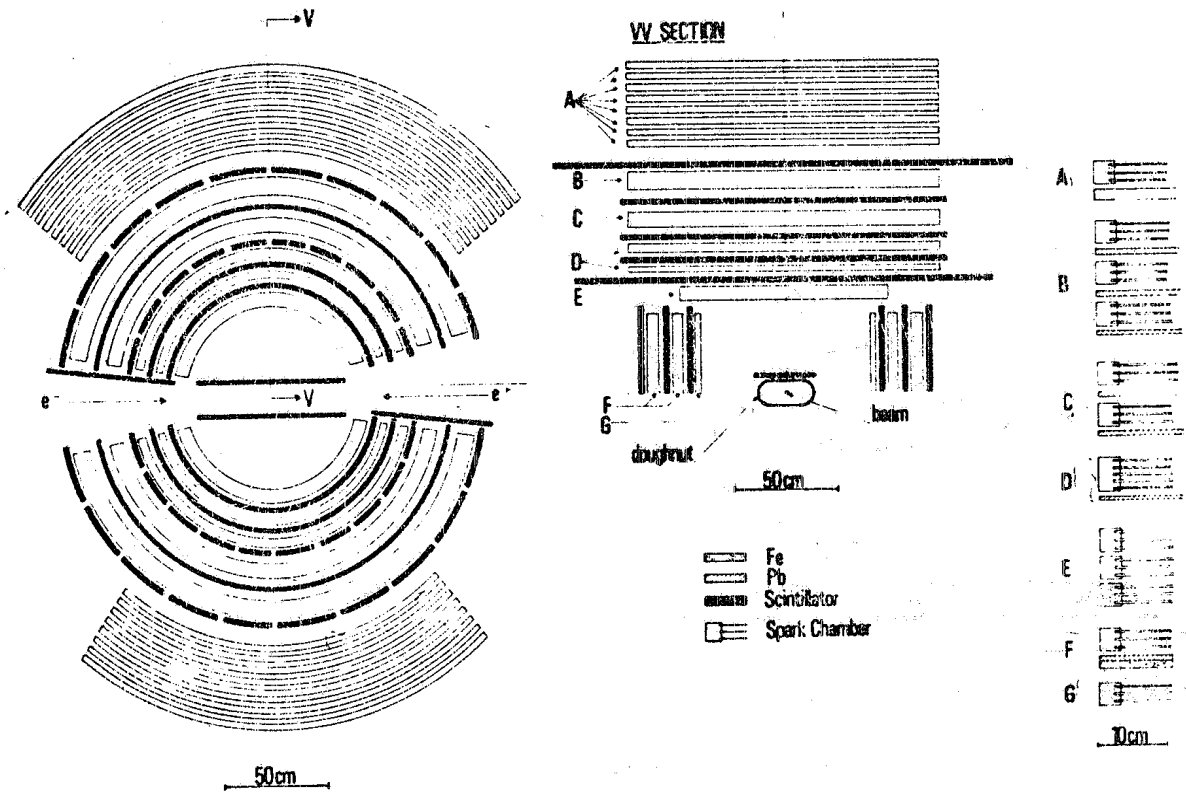# Baryon-antibaryon

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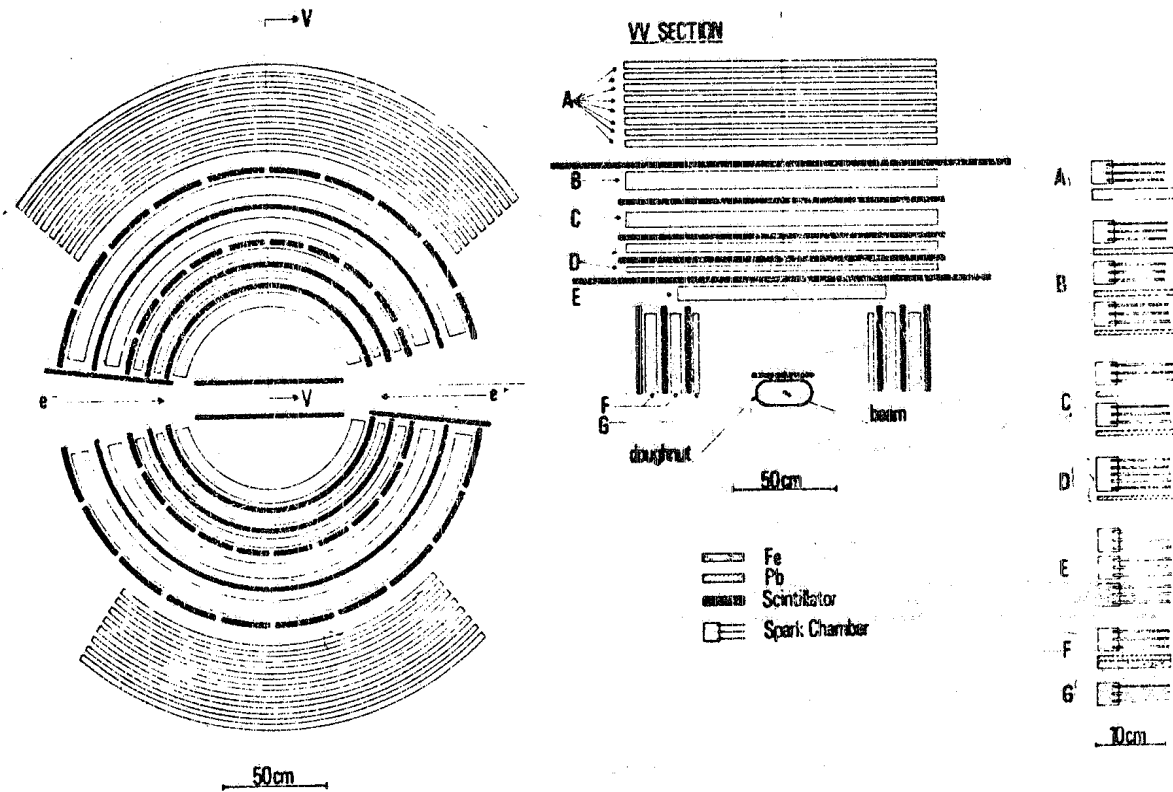Minimum energy to trigger for a π ~ 60 MeV.
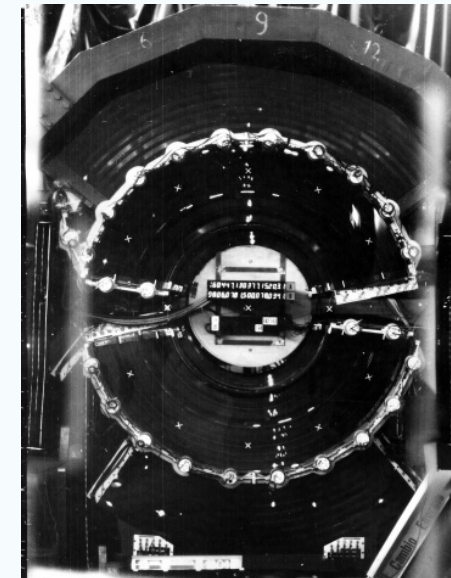Trigger at least 2 "π"

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Calorimetric apparatus optimized to detect neutrals. Symmetry axis perpendicular to beam direction. Such choice dictated by the use of optical spark chambers .
Solid angle coverage (point source) 66%*4π.
Minimum energy to trigger for a π 120 MeV.
Minimum energy to trigger for a γ 40 MeV.
Trigger 1 "π" (120 MeV) or photon(s) with a low energy "p" (40 MeV).

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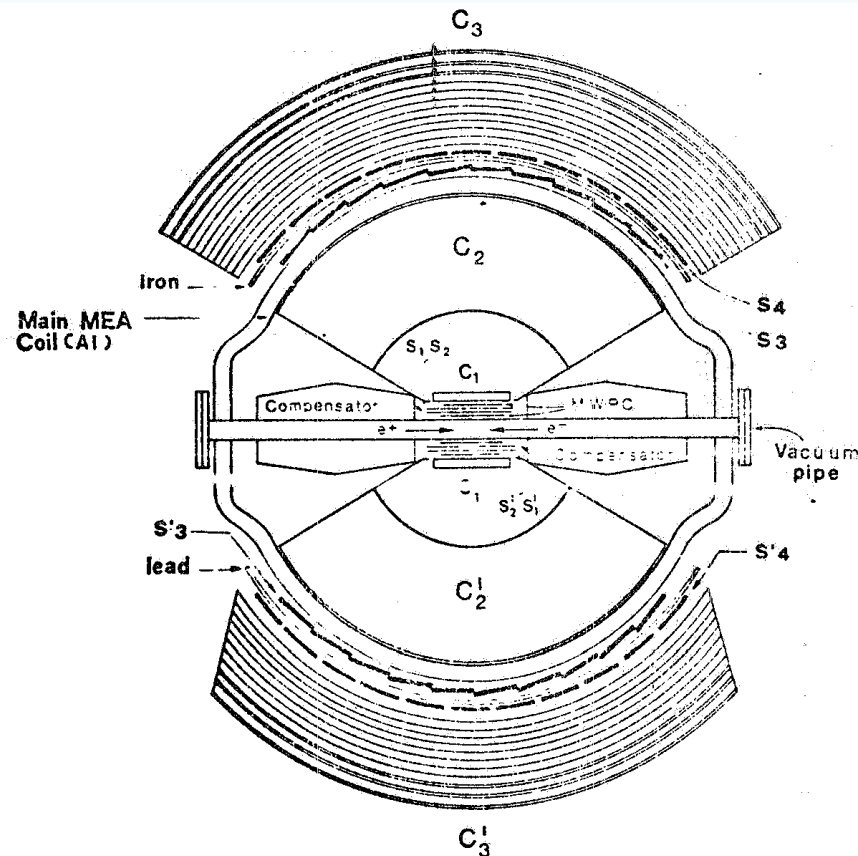Trigger 1 "π" (120 MeV) or photon(s) with a low energy "p" (40 MeV).

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Second generation experiments at ADONE M.(agnete)E.(sperienze)A.(DONE)

Magnetic apparatus: operational B-field 2.5 KG
Symmetry axis perpendicular to beam direction. Such choice dictated by the use of optical spark chambers .
Solid angle coverage (point source) 40%*4π.
(momentum measurement)
Minimum energy to trigger for a π 130 MeV.
Beams interaction with detector B-field somehow critical.
Compensation needed to few parts 10^{-4}.
Trigger 2 "π" 130 MeV each.

COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF – 67/3
20 Gennaio 1967
(ristampa Giugno 1967)

U. Amaldi Jr. , G. K. O'Neill, G. Petrucci, G. Sacerdoti e
E. Schiavuta : RELAZIONE DEL GRUPPO DI STUDIO PER
LA SPERIMENTAZIONE CON CAMPO MAGNETICO PRES
SO ADONE. –

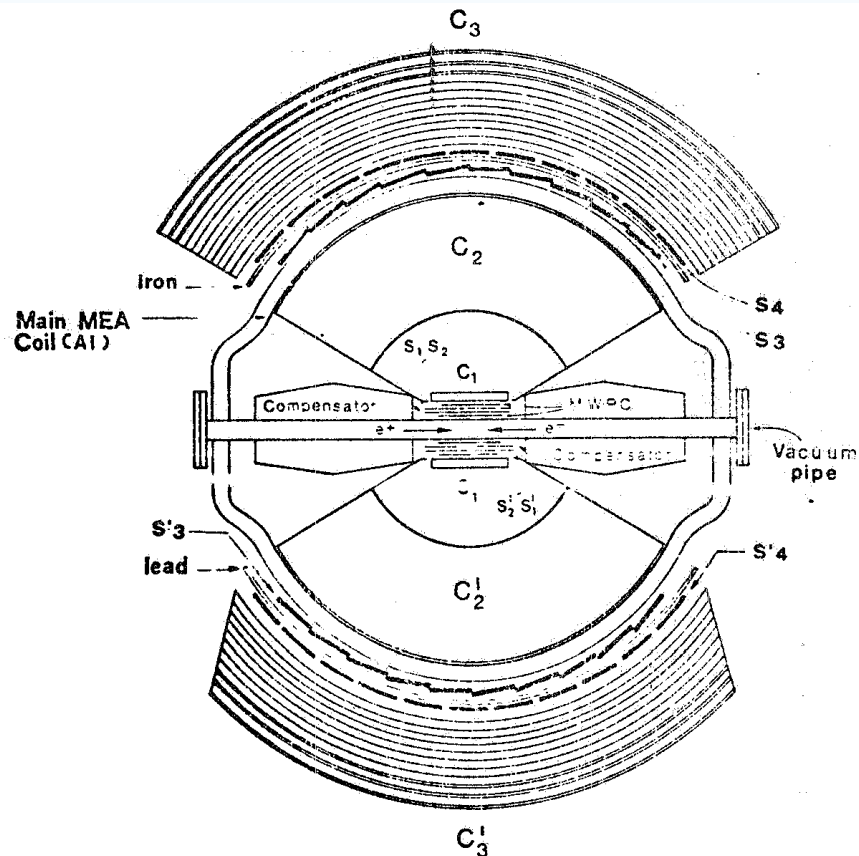# Second generation experiments at ADONE M.(agnete)E. (sperienze)A.(DONE)

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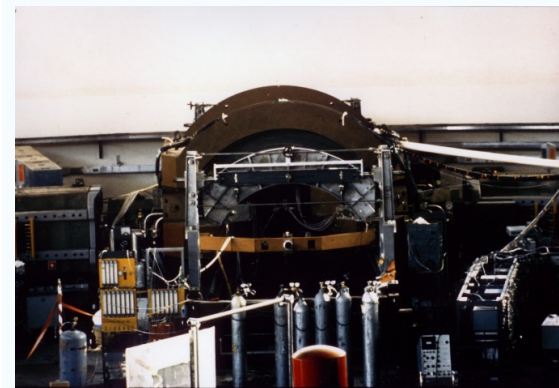Laboratori Nazionali di Frascati

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The news of the "charmed φ "

- On Nov. 11th 1974, in Frascati we were told that a new particle had been found by the S.C.C. Ting group in Brookhaven and by the SLAC-LBL collaboration, Mark I at SPEAR.

- The mass of this new resonance was higher than the nominal max. energy for ADONE (3 GeV), but we set up to look for it pushing the Adone magnet some 100 MeV above the limit.

- It took us three days to find it, as we were having some B-field saturation, but in the night of Nov. 14th we found it.
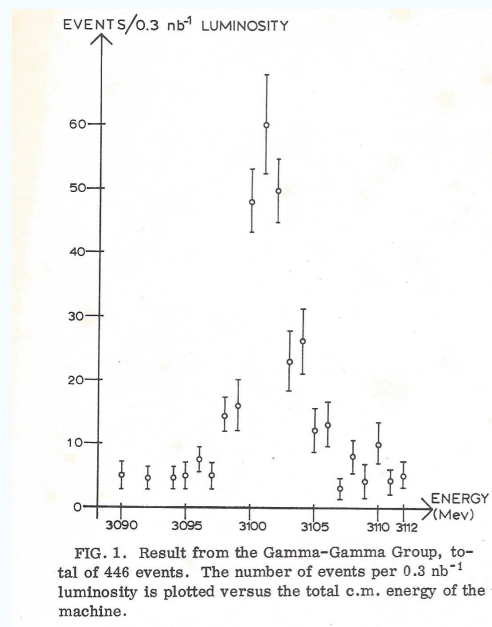
There it was

- Around 11 P.M. I was running the n-th energy scan with my experiment (MEA) when the trigger beeper went berserk….
- We had a typical trigger counting rate of about 1 every couple of minutes: all of a sudden we had 1 trigger every few tens seconds.
- We were almost on top of the resonance.
- Prof. Giorgio Salvini, running his shift on the gamma gamma2 experiment, had the machine operators open the machine access door (the access door for Adone was few meters above the vacuum pipe) and started looking at the spark chambers of his experiment: they looked like a Christmas tree with a counting rate for multi-particles events never seen before.
- We kept logging events all night and, comes the morning, most of the high energy physicists in the Rome area appeared in the ADONE counting rooms.

The results

In few days we recorded and analyzed/scanned few hundred events; on Nov. 18th a joint paper from ADONE experiments was published on PRL.

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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.

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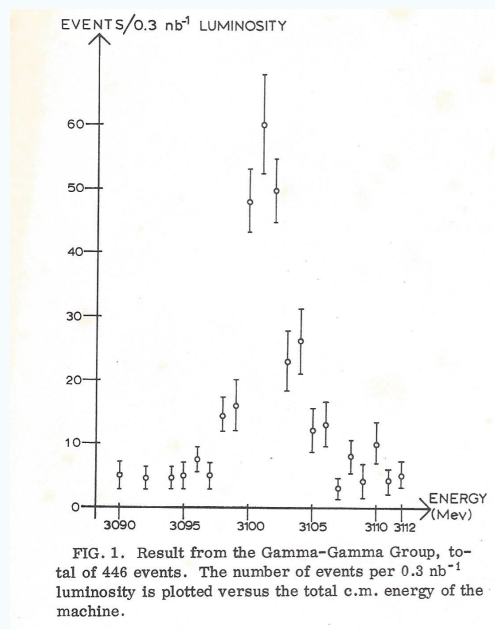

FIG. 1. Result from the Gamma-Gamma Group, total of 446 events. The number of events per 0.3 nb⁻¹ luminosity is plotted versus the total c.m. energy of the machine.

TABLE I. Rate of events as a function of the total energy (MEA Group).

Total energy (MeV)	Total No. of events/0.6-nb⁻¹ luminosity	Hadronic events (noncollinear events)
3090	2 ± 2	0
3092	4 ± 3	2 ± 2
3094.5	4 ± 2	0
3096.5	4 ± 2	3 ± 2
3098.5	4 ± 2	3 ± 2
3100.5	26 ± 5	20 ± 5
3102.5	23 ± 4	15 ± 3
3104.5	10 ± 3	6 ± 2
3106.5	4 ± 2	0
3108.5	5 ± 2	1 ± 1
3110.5	4 ± 2	2 ± 1
3112	4 ± 3	0

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Few odds and ends

- The PRL paper was dictated over the phone by Giorgio Bellettini (then director of the Laboratory).
- It took quite a while, as the words had to be spelled one by one by Giorgio.
- The result was quite a disaster regarding the spelling of the Authors' names…..
- The original paper was dated Nov. 18th ….but a new version with the right authors' names was released on Dec. 2nd

The original (and amended) author list from PRL

- 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

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- 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

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Interpretation(s)

- The end of 1974 was a hectic period for the theoreticians, who were trying to assess the nature of "3.1" particle.
  - A colored state
  - A new quantum number ground state
  - A vector boson (…. careful not the Z_0)
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Is the 3104-MeV Vector Meson the ϕ_c or the W_0 ?

G. Altarelli, N. Cabibbo R. Petronzio (Rome Un.),L. Maiani (ISS), G. Parisi (LNF)
Lett.Nuovo Cim. 11 (1974) 14, 609-612

At the end of the year…..

- Here is what we found :
-       Aver. asymmetry = (49-53)/(49+53) = -.04 ± .1
- **Unfortunately**, we decide to split the measurement vs. energy and we ended up with an unexplainable result:
- In the 2 MeV before the peak we found:
-           Asymmetry = (32-16)/(32+16) = .33 ± .14
- In the 2 MeV after the peak we found:
-           Asymmetry = (12-28)/(12+28) = -.40± .14

Sometimes statistics hit you hard

- ? And this was the case :
- ? It took one year of data taking to smooth out the fluctuation…

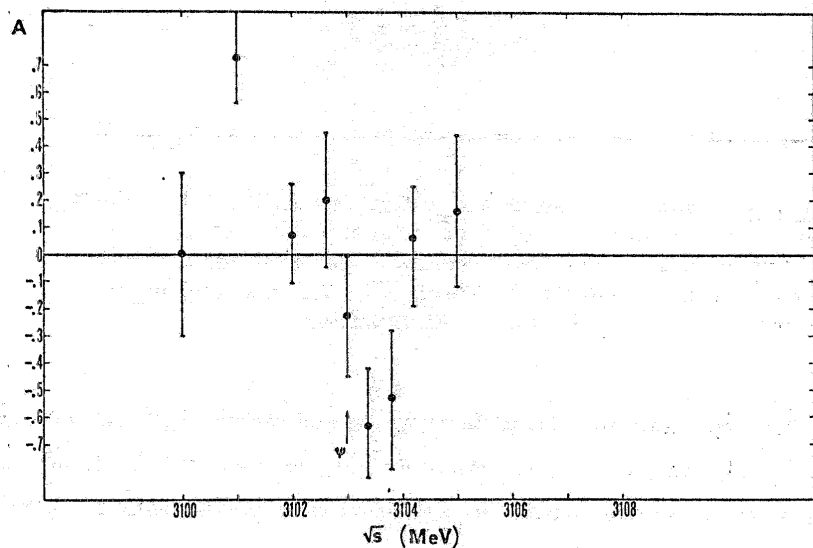End 1974   Beginning 1976

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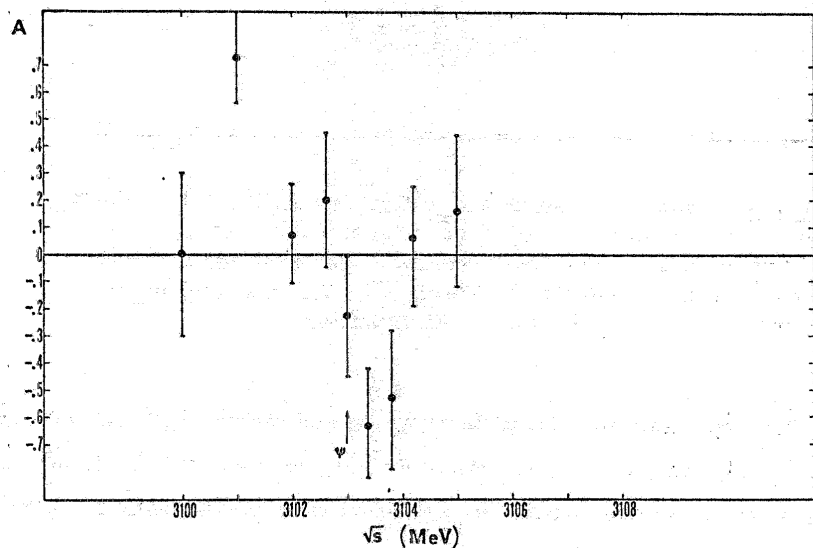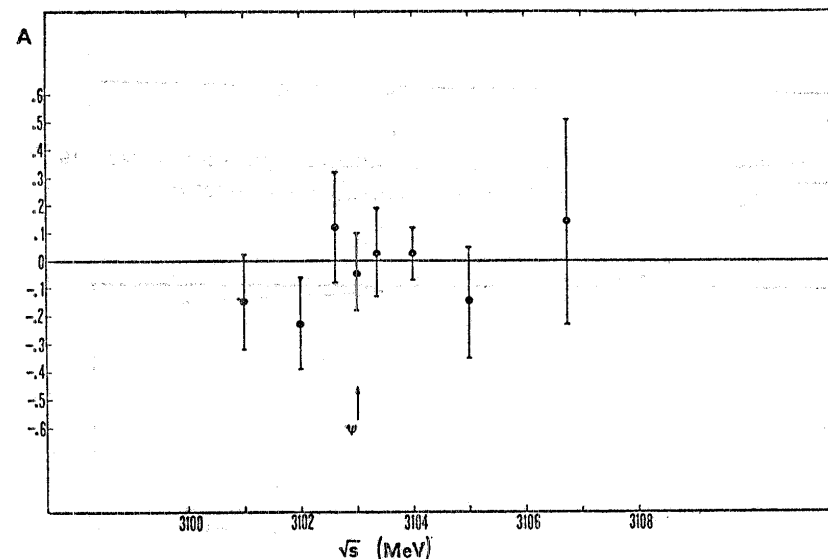Beginning 1976

It was really a revolution

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In the model, the cross section for hadron production has the form

$$\sigma(e^+e^- \rightarrow \text{hadrons}) = \frac{C_1}{S} + C_2 + C_3 S \qquad (14)$$

where the S^{-1} term represents the one photon annihilation, the S term is due to the new interaction, and the constant term is an interference which depends on the form of the direct coupling. In figure 3 the cross section below S=9 is dominated by the one photon term, while between S=9 and S=25 the interference term dominates. The model makes the spectacular prediction that at higher energy the cross section must increase.

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The example here describes a model with a linearly increasing (vs. E2) e⁺e⁻ multi-hadronic cross section…Now we know that thresholds were opening around 4 GeV and the first hint was really the "charmed ϕ ".(confirmation came soon after with the ψ') .

Conclusions

- The generation of physicists that was professionally active at the time of the charm discovery lived through a very exciting time….

- I was one of the lucky bunch.

- I remember my first presentation at an international conference in February1975 (rencontres de Moriond), where I met people with whom I worked for most of my scientific carrier.

- Sadly, several of them are not with us anymore.