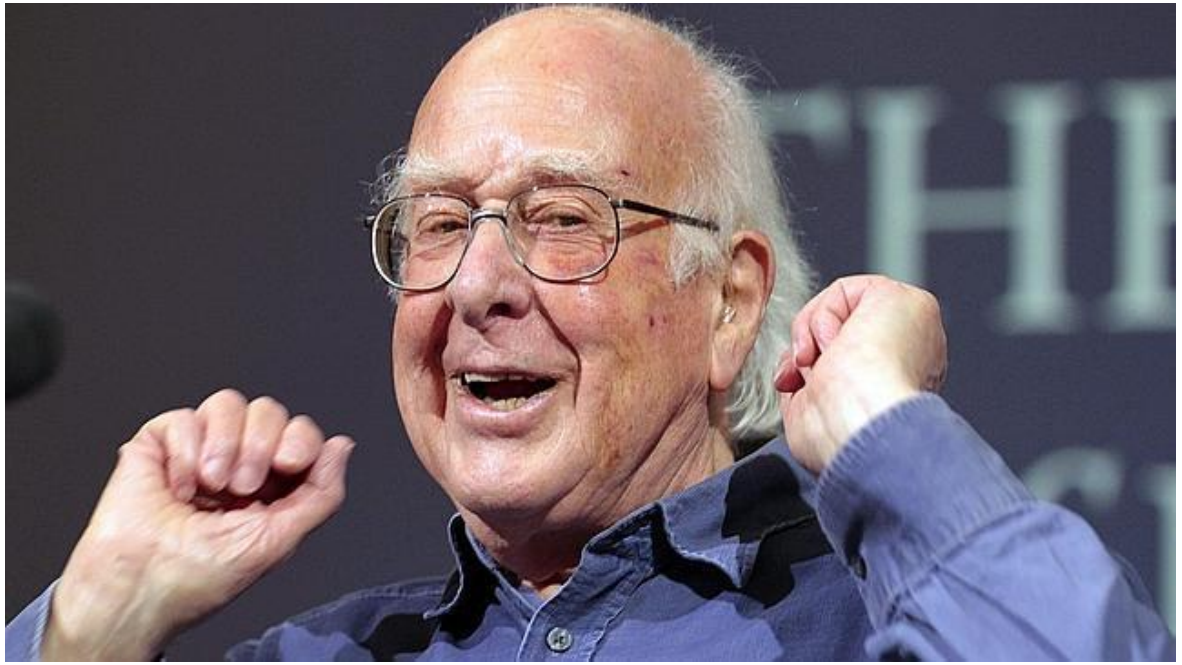
From the Neutral Currents to Higgs Particle discoveries at CERN

André Lagarrigue and André Rousset



Peter Higgs: «El bosón me ha arruinado la vida»

Observation of neutrino-like interactions without muon or electron in the gargamelle neutrino experiment

F.J.Hasert S.Kabe W.Krenz J.Von Krogh D.Lanske J.Morfin K.Schultze H.Weerts
III. Physikalisches Institut der Technischen Hochschule, Aachen, Germany
G.H.Bertrand-Coremans J.Sacton W.Van Doninck P.Vilain
Interuniversity Institute for High Energies, U.L.B., V.U.B. Brussels, Belgium
U,Camerini D.C.Cundy R.BaldiI.Danilchenko W.F.Fry D.HaidtS.Natali P.Musset B.Osculati R.Palmer
J.B.M.Pattison D.H.Perkins A.Pullia A.Rousset W.Venus H.Wachsmuth
CERN, Geneva, Switzerland
V.Brisson B.Degrange M.Haguenauer L.Kluberg U.Nguyen-Khac P.Petiau
Laboratoire de Physique Nucléaire des Hautes Energies, Ecole Polytechnique, Paris, France
E.Belotti S.Bonetti D.Cavalli C.Conta E.Fiorini M.Rollier
Istituto di Fisica dell'Università, Milano and I.N.F.N. Milano, Italy
B.Aubert D.BlumL.M.Chounet P.Heusse A.Lagarrigue A.M.Lutz A.Orkin-Lecourtois J.P.Vialle
Laboratoire de l'Accélérateur Linéaire, Orsay, France
F.W.Bullock M.J.Esten T.W.Jones J.McKenzie A.G.Michette G.Myatt W.G.Scott
University College, London, England
Publication received by Elsevier 25 July 1973

55 collaborators, (usually received question « how can you thrust in a physics result with so many collaborators

Before Gargamelle spanish team included persons from Madrid and Valencia

A study of 10 gev/c k+ nucleus coherent interactions and the q+ nucleon cross-section

- M. Haguenauer W. Michael P. Mine, U. Nguyen-Khac, (Ecole Polytechnique
- A. Haatuft(Bergen U.A. Halsteinslid. K. Myklebost, K. Nordbo J.M. Olsen (Bergen U.
- H. Annoni, R. Arnold, A. Lloret,M. Paty, J.L. Riester, Strasbourg
- B. Escoubes, L. Ferrer P. Ladron De Guevara R.Llosa S. De Unamuno (JEN, Madrid

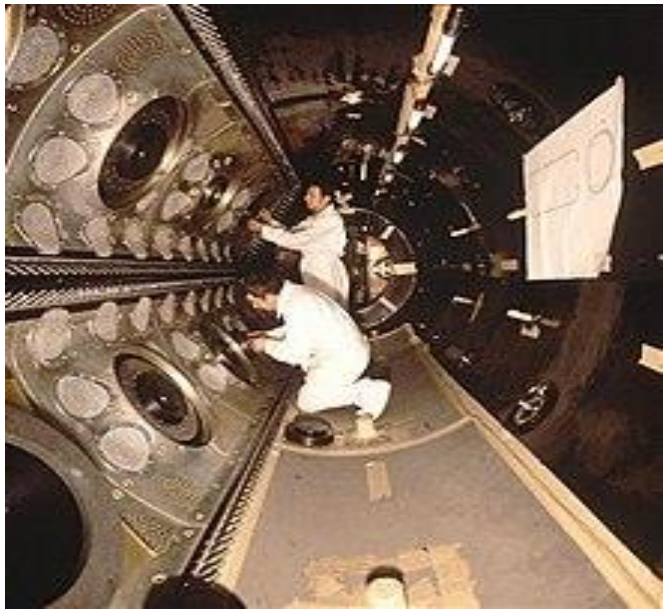
A study of the charge exchange process k+ n ---> k0 p at 10 gev/c

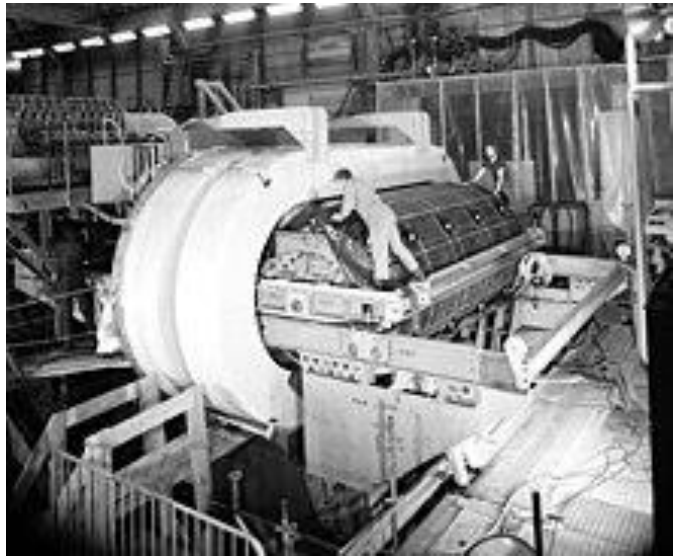
Gargamelle

B.Gregory, L.Leprince-Ringuet, Ch.Peyrou, R.Armenteros,A.Lagarrigue
BG built the 1m hydrogen bubble chamber
moved to CERN and CP in charge of the 2m which followed
AL built the heavy liquid bubble chambers BP2 and BP3

The PS magnet group – which became the Nuclear Physics Apparatus Division in 1961 – turned towards helping to make the PS usable for experiments, and a number of projects took shape under Colin's leadership: a heavy-liquid bubble chamber, magnets and lenses for guiding secondary beams, electrostatic separators, scanning apparatus for bubble-chamber photographs, a fast beam-ejection system, and finally an enhanced neutrino beam.
The Ramm chamber – with a volume of 500 litres – was at the time the largest heavy-liquid chamber in the world operating in a magnetic field. Completed in 1960, it was used in CERN's first neutrino experiments. However, the enhanced neutrino beam quickly became the Division's main preoccupation.

Gargamelle: The chamber



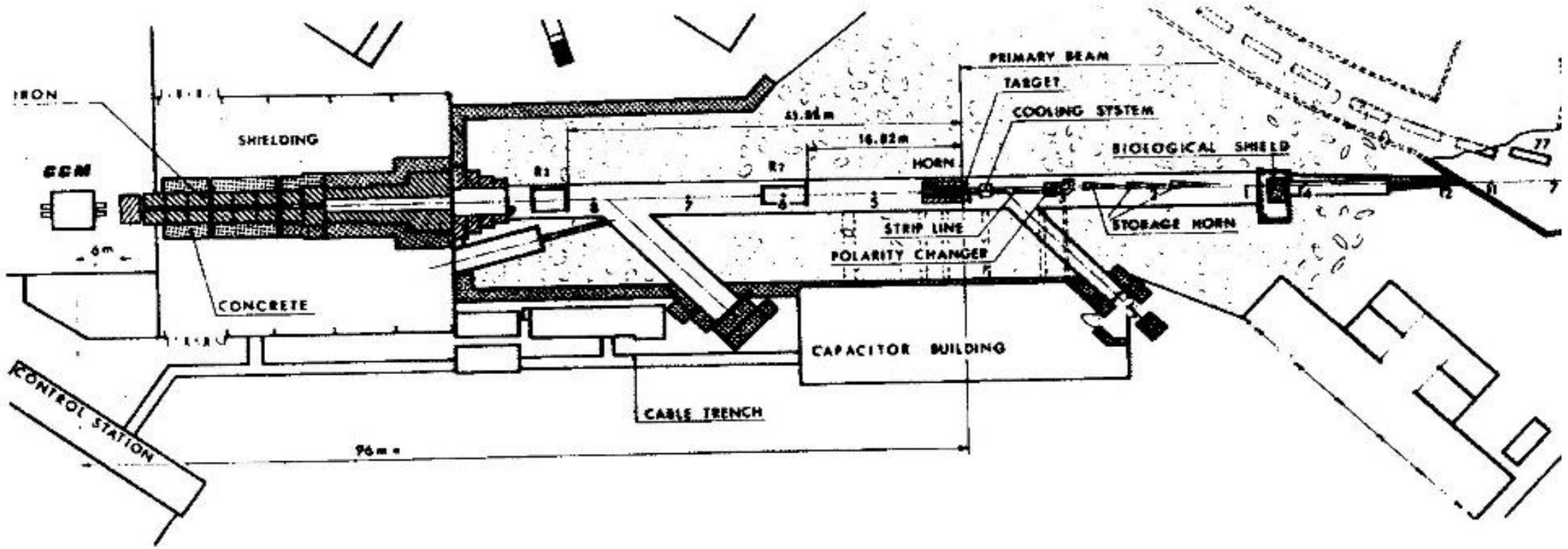


The construction of the chamber was entirely done at Saclay team head J.Lutz, replaced by R,Grégoire for the installation at CERN The chamber was 4.8 meters long and 2 meters in diameter, and held 12 cubic meters of heavy liquid Freon. Gargamelle was surrounded by a magnet providing a 2 Tesla field., installation total weight was 1000 tons.
When recording an event, the chamber was illuminated and photographed. The illumination system emitted light that was scattered at 90° by the bubbles, and sent to the optics. The light source consisted of 21 points disposed on one side of the chamber body and the optics were situated in the opposite half of the cylinder, distributed in two rows parallel to the chamber axis, each rows having four optics design by Pierre Petiau,
The delay between the beam arrival was adjustef to maximize the visibility of the bubbles created by the energy loss of charged paricles going through, using fiducial marks a 3D reconstruction was made,
The software was most in the hand of Francois Jacquet and Jules Six (who even didn't sign the publication)

In memory of Gabriel Setrin (Saclay team) who died accidentally during operation

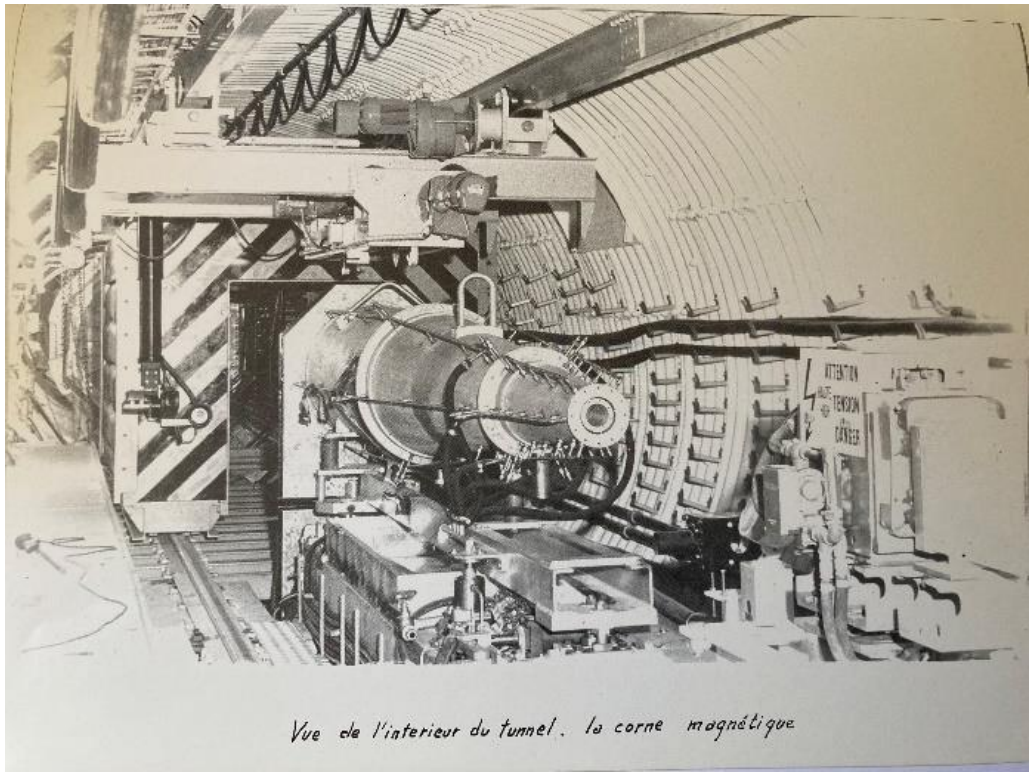
The neutrino beam line

- First of all, the NPA group, head by Colin Ramm stayed in place, giving as many advises as he could André Rousset was new division leader, I never experencied such a smooth transition, Colin's team constructed the previous neutrino beam line; I should mention Simon van der Meer (Nobel prize for W and Z discovery) who optimized the calculation of the magnetic horns, Jean-Marie Mauguin and the whole team taking care of installation and operation, Colin left only in 1972 to his home country Perth/Australia getting head of the university,
- Outside participants, hand work, data acquisition, neutrino end muon flux check: P.Heusse, L.M.Chounet and myself

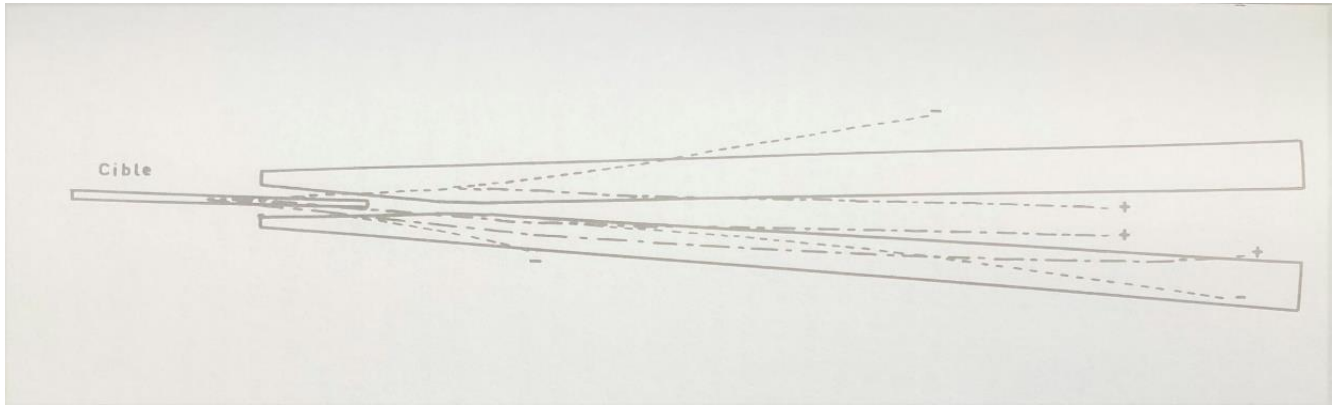


Simon van der Meer: The magnetic horn design

The gain in operational length between Ramm's chamber and GGM was about 5; adding a magnetic horn triplet gained another factor 3



Vue de l'interieur du tunnel. la corne magnétique



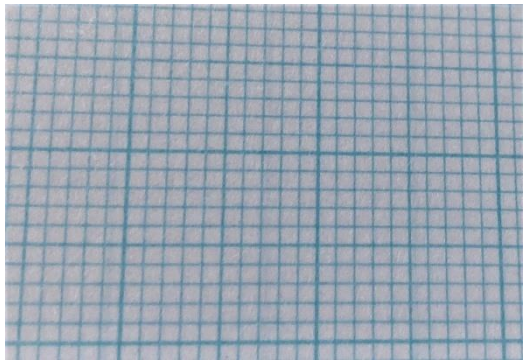
Muon flux monitoring

First aim of GGM, was to measure total neutrino and antineutrino cross sections as a function of ernegy; for that we need the flux as a function of energy; it can only be determined by computer simulation using the measurements by the CERN-Rome collaboration of pion and kaon flux hitting beryllium and cupper targets; they decay along the beam tunnel into neutrinos and muons. By monitoring the muon flux at various radial distances and depths, the validity of the simulation is tested.

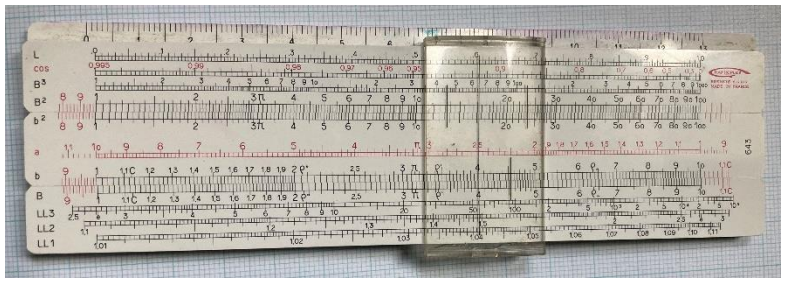
Evolution of the detetors used

1963: ionization chambers

1968: for monitoring online a paper glued on a fluorescent glass + cathodic camera (no data acquisition) check with this type of pocket calculator



+ camera +



- From 1970 on, first time silicon wafers, Erik Heijne and Pierre Jarron

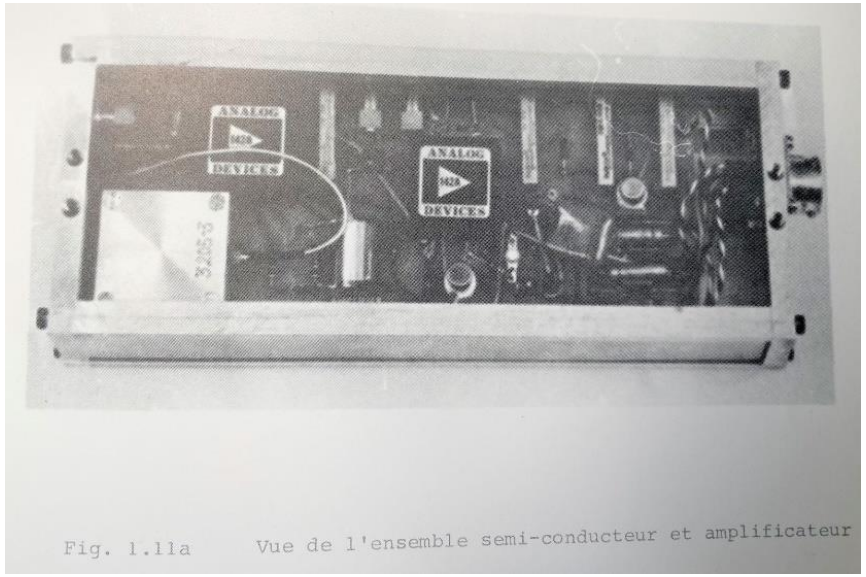
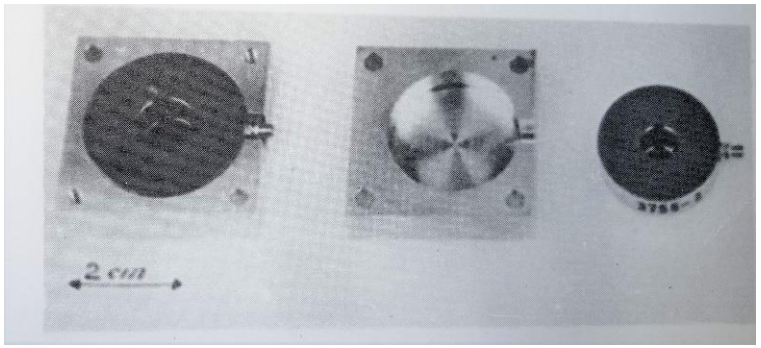
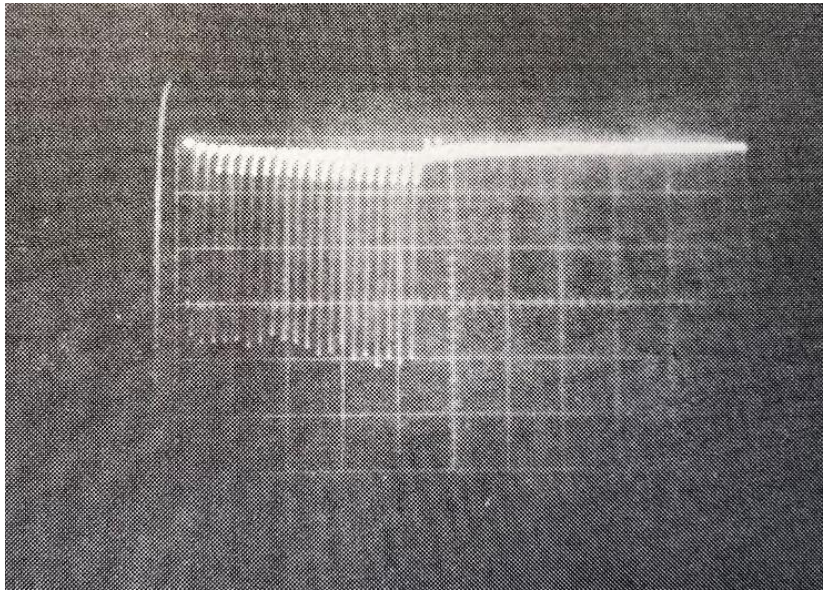


Fig. 1.11a Vue de l'ensemble semi-conducteur et amplificateur

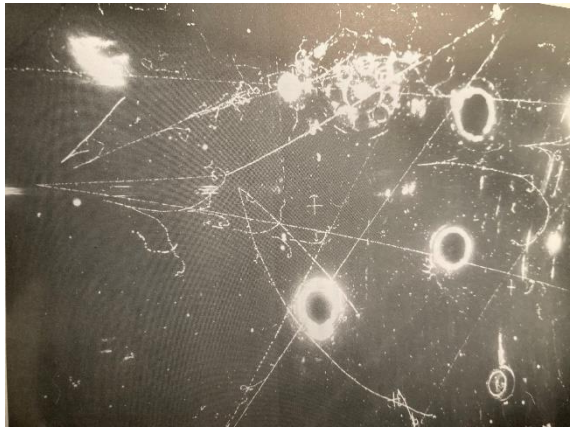




Silicon wafer of 6 mms diameter, prize each 3 000CHF, associated electronics circuit in a box 25x10 cms, « burndy connector » 2cm diameter, all that for one channel.
Expert in the field can compare with actual size and prize

Data analysis system

- Neutrino interaction



Scanning and measuring table

Already online registering of data, computers either CDC 3600/Univac , but data transfer on punched cards
Data transfert by car to CERN and Paris and cleaning by myself,original soft named « savon or soap »; cards brought from building 16 to 510 with a cart,
Analysed by a CDC 6600 at CERN, up load of data in person on a card reader at the allocated day/time (24/24, 7/7)

Output, position , direction, total energy,,on a paper list
Histograms made by hand , most offen by Prof. Sergio Natali , (friendly called le « plotteur du CERN »)

All this details, to show the difference between nowadays

Gargamelle's difficult delivery

The experiment was not approved in 1966, contrary to what was expected. Victor Weisskopf, CERN DG and Bernard Grégory, Scientific Director, decided to commit the money themselves, the latter offering a loan to CERN to cover the instalment due for 1966. The final contract was signed on 2 December 1965, making this the first time in CERN's history that an investment of this kind was not approved by the Council, but by the Director General using his executive authority. BP started as DG in january 1966.

Running in started on Jan 6th 1971, with observation of a neutron rain in GGM, a lot of small recoiling ptons from the reaction n+nucleon>p+nucleon; all forces started to measure evryting visible, the conclusion was that the shielding was not tight. The front onf the shielding was made of iron pyramidal coils on courtsy loan of the swiss army, the insterspace was filled with sand, which could be responsible of it, a fast decision was to remove that part and replace by parallelepipedic shape with perfect surfaces (Europe had still that kind of industry).

Running started again in march, and the background essentially disappeared, the first neutrino interactions were observed and the priority was to evolution of total cross section as a function of neutrino energy (if the W has a mass lover than 40 GeV, it will curve the line), First results in a collabration meeting at CERN but no effect, the data looked like, but I showed that is is due to the gap between neutrino originating from pion and kaon decays,

Second collaboration meting in Paris, and a letter from a senior member saying the neutron background is understood , stop in wasting time by measuring neutron interactions.

But in spring, Jacques Prentki professor at Collège de France spent allmost all the 1971 yearly lessons on the Weinberg Salam theory; his enthusiasm was such that he broke his two pairs of glasses at the same time, as he was also at TH department/CERN, he came to our offices several times per weak

Gargamelle's priorities

1. W search
2. deep inelastic scattering, scaling
3. current algebra sum rules, CVC, PCAC
4. Diagonal Model
5. $\Delta S = 1$ processes, inverse hyperon decay, $\overline{\nu_\mu} + p \rightarrow \Lambda + \mu^+$
6. inverse muon decay, $\nu_\mu + e^- \rightarrow \mu^- + \nu_e$
7. electron–muon universality
8. neutral-current search
9. form factors in exclusive reactions
10. search for heavy leptons

Main results on charged currents

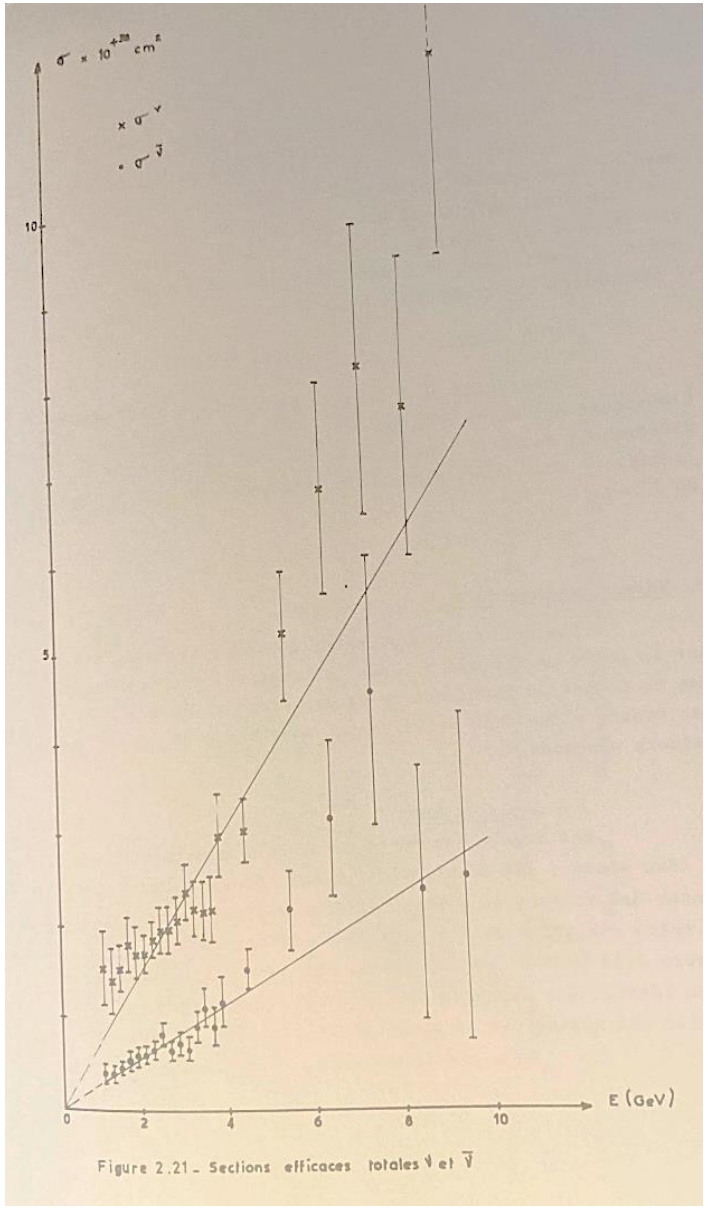


Figure 2.21 - Sections efficaces totales ν et $\bar{\nu}$

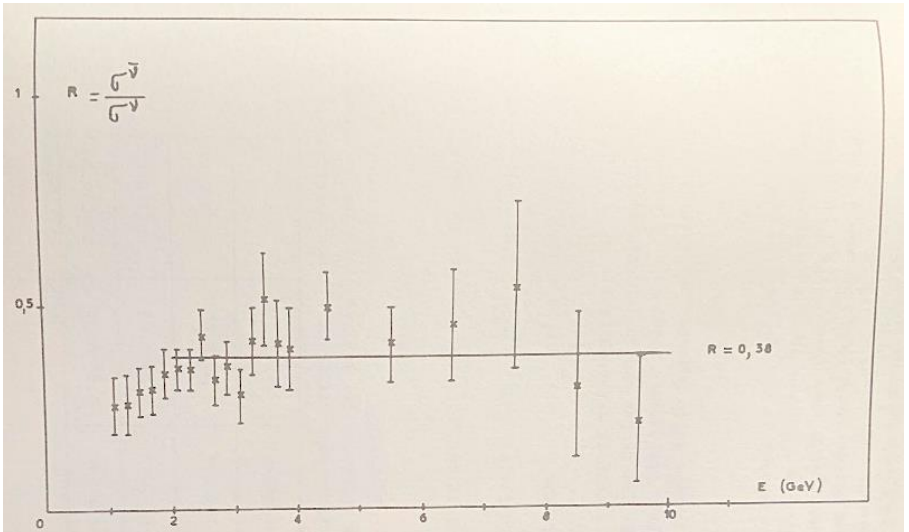


Fig 2.22 Rapport des sections efficaces antineutrino et neutrino

4. - Contribution des différents constituants (Ref. 3.15).

4.a - Contribution de gluons, de quarks non-étranges, de quarks étranges et d'antiquarks.

Dans un modèle où le nucléon serait uniquement formé de quarks et d'antiquarks, la conservation de l'énergie et de l'impulsion implique :

$$U + D + S + \bar{U} + \bar{D} + \bar{S} = 1$$

En utilisant les expressions 3.31 et 3.32 pour évaluer le premier membre de cette équation, nous obtenons :

$$U + D + S + \bar{U} + \bar{D} + \bar{S} = \frac{9}{4(2-9\sin^2\theta_c)} \left[(4-9\sin^2\theta_c)\ (I^{ep} + I^{en}) - (\sigma^{\nu} + \sigma^{\bar{\nu}}) \right]$$

$$= 0.60^{+\ 0.16}_{-\ 0.10}$$

Pour satisfaire à la conservation de l'énergie impulsion, on suppose que le nucléon est aussi formé de partons neutres par rapport aux interactions faibles et électromagnétiques : les "gluons". La fraction ε de l'impulsion du nucléon qu'ils emportent est égale à :

$$\varepsilon = 0.40^{+\ 0.10}_{-\ 0.16}$$

Main results on neutral currents

Purely leptonic event

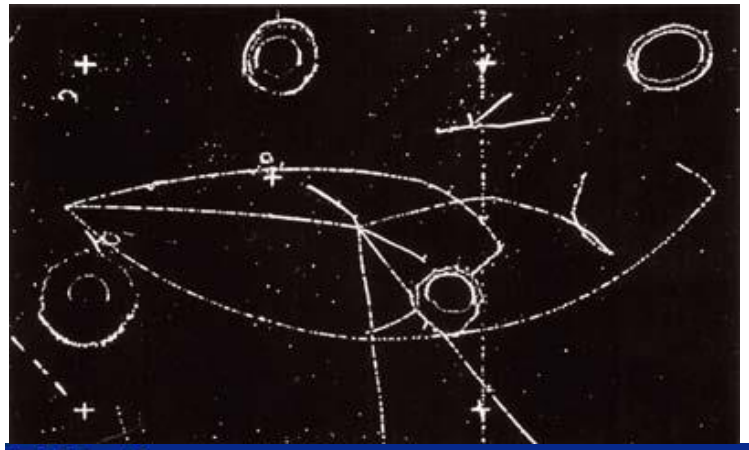
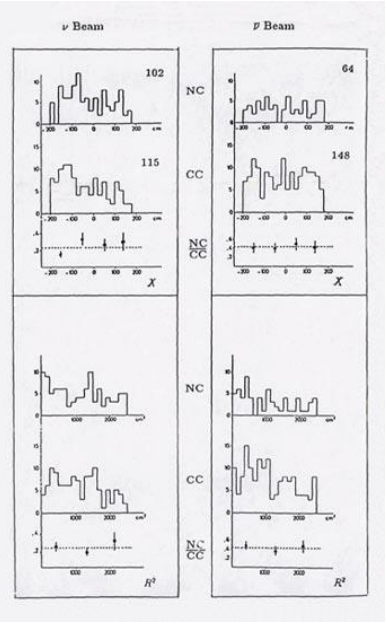


Table 1

	ν-exposure	$\bar{\nu}$-exposure
No. of neutral-current candidates	102	64
No. of charged-current candidates	428	148



Observation of Neutrino Like Interactions Without Muon Or Electron in the Gargamelle Neutrino Experiment

Published in: *Phys.Lett.B* 46 (1973) 138-140

Search for Elastic νμ\nu_\muνμ Electron Scattering

Published in: *Phys.Lett.B* 46 (1973) 121-124

Ome controversy happened on the possibility to be induced by neutrons, but stopped by the equilibrium argument made by A,Rousser, that the number ratio of observed NC events to associated cannot be bigger than 1 , in reality it was close to 3,

In the concluding talk made by C.N.Yang, he said I agree fully with that argument, the neutral currents exist,

Move to SPS

The start of the SPS accelerator and an associated neutrino underground beam line gave the possibilty to move Gargamelle into the new beam, Main argument were a factor 2 more length along the beam, and nearly another factor 2 of liquid density, But the discussions conducted were hard (do you need really double glazing? more modern arguments, do you really need separate toilets,,but it was approved

Behind GGM we added
- before the coil, a free quark detector,
- between the magnet coil a cupper/plasastic scintillator calorimeter to increase energy measurement resolution,
- and 6x8 meters external muon identifier EMI was added also

GGM was not alone along the beam line
- BEPC
- CDHS
- NUMU? (K.Winter)
- GGM
- Prototype to detect neutrino oscillations
- Free quank detector (A.Zichichi)

Failure and Death

In the Gargamelle neutrino experiment, three unambiguous candidates for the reaction ν μ + e − → ν μ e − have been observed corresponding to a cross section for a recoil electron energy within the range 0.3 < E e − < 2.0 GeV of 0.06 × 10 −41 E ν (GeV) cm 2 / electron . The calculated background is 0.44 ± 0.13 events and the probability that all three candidates could be due to this background is 1%.

Break down!

20 years of neutral currents birth elebration 1993

Neutrino oscillations experiment

With the success of neutrino physics, the question of the neutrino mass was starting to be considered.

Under the responsability of F.Jacquet and Charles Grégory, a prototype consisting of

- a water tank (2x1.5x1.5 m)
- a parabolic mirror (1m diameter) mounted downstream, made by the astrophysics laboratory Meudon
- several photomultipliers upstream

The tests were fully conclusive that we can select particles coming along the beam line with a resolution of 1-2 degrees,

A proposal to build a full size detector to be placed in the Jura, for the place (thanks to the survey peoplle) we were lucky the beam came out of the second fold , close to a road, electrical supply,

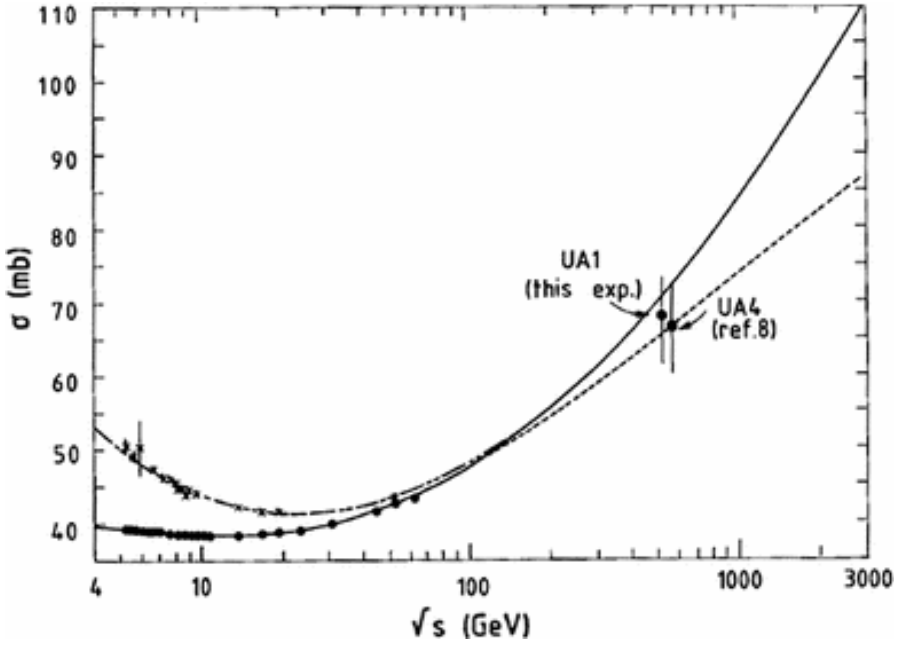
https://www.cernetrou.com/

The proposal could't even be submitted, as the approval of the LEP tunnel was pending, the DG supected opposals when people would take note that a particle beam comes out from CERN,

May be a good deciision, if LEP would have been refused, no LHC too, and no Higgs particle discovery

Elastic scattering , asymptotic cross ssection

- The SPSC collider was in construction and several collaborations UA4-6, where already in good progress,
- Personal choice to join UA4 was motivated by physics as I never got an answer on « what happens at infinite energy/matter density like at the big bang »



Proton-antiproton elastic scattering was measured at the CERN SPS Collider at the centr-of-mass energy s=546 GeV in the Coulomb interference region. The data provide information on the phase of the hadronic amplitude in the forward direction.
The conventional analysis gives for the ratio ϱ of the real to the imaginary part of the hadronic amplitude the result ϱ=0.24±0.04.

Battiston, R ; Bozzo, M ; Braccini, Pier Luigi ; Carbonara, F ; Carrara, R ; Castaldi, R ; Cervelli, F ; Chiefari, G ; Drago, E ; Haguenauer, Maurice ; Köne, B ; Matthiae, Giorgio ; Merola, L ; Napolitano, M ; Palladino, Vittorio ; Sanguinetti, G ; Sciacca, G F ; Sette, G ; Van Swol, R ; Timmermans, J ; Vannini, C ; Velasco, J ; Visco, F

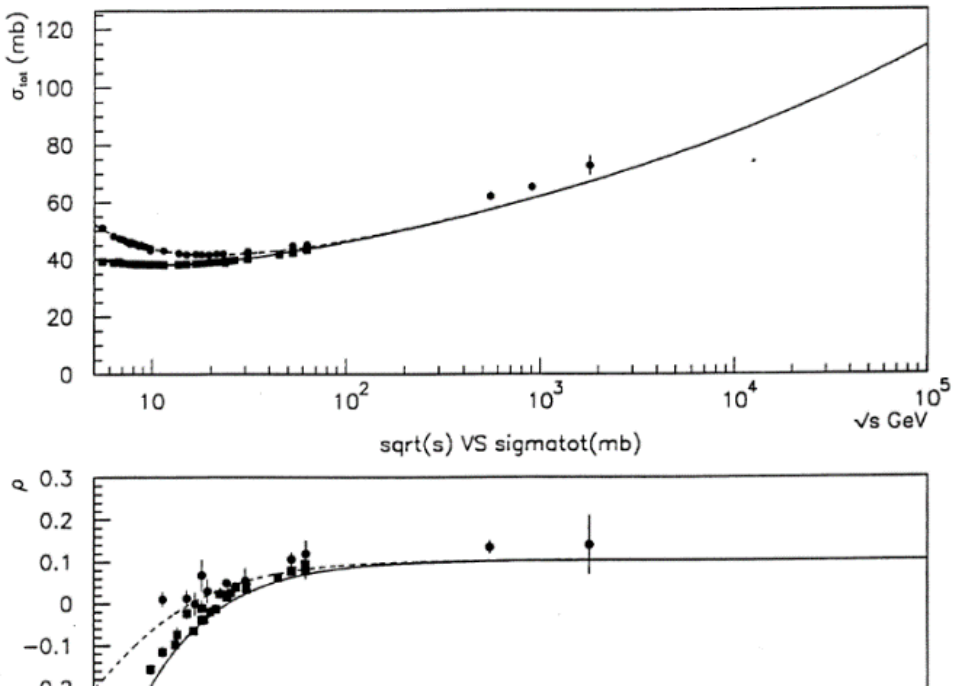
- Collaboration with Valencia on road again
- Small detectors to be used in a series of application among calibration of Aleph and CMS calorimeter, hadrontherapy ,,,

UA4/2

The experiment benefitted fully from the beam-optics design of Angeles Faus-Golfe; reaching so low transfer values is due to her; the optics symetric facilitating the data analysis and allowing such a high precision on the real part, Original article can be find in the IFIC publication

Luminosity determination using Coulomb scattering at the LHC (Angeles Faus-Golfe, J.Velasco (IFIC), MH

The experiment confirmed fully existing theory or models ; close to saturating Froissart-Martin bound



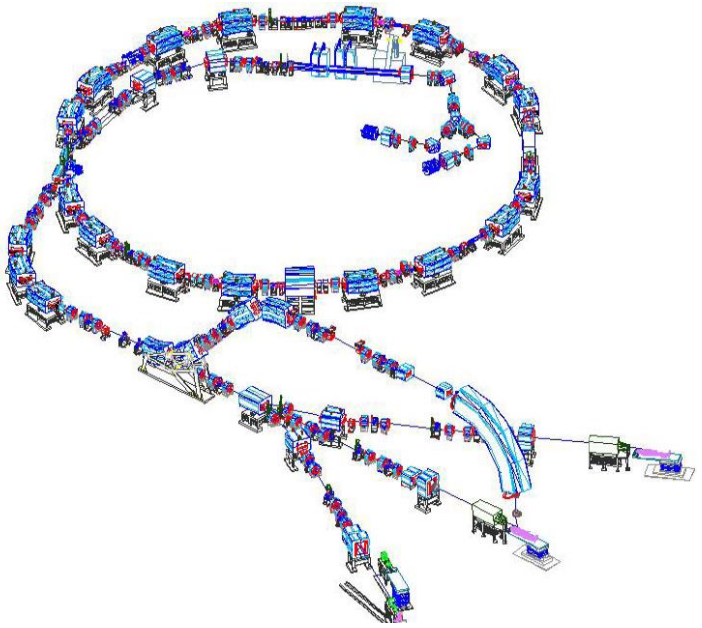
Construction of 12 new detectors by CERN-EP (help from perssons already involved at GGM) gave by-procucts; the optical fiber planes were than used for

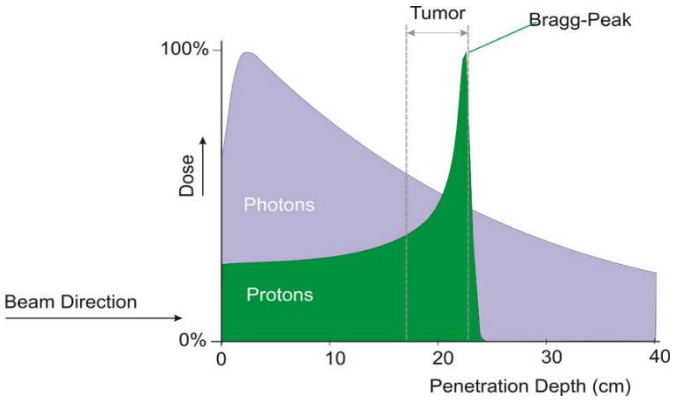
- Hadrontherapy
- CMS calorieter beam tests
- Similar ones in ATLAS/Alfa (CNAO + MedAustron)

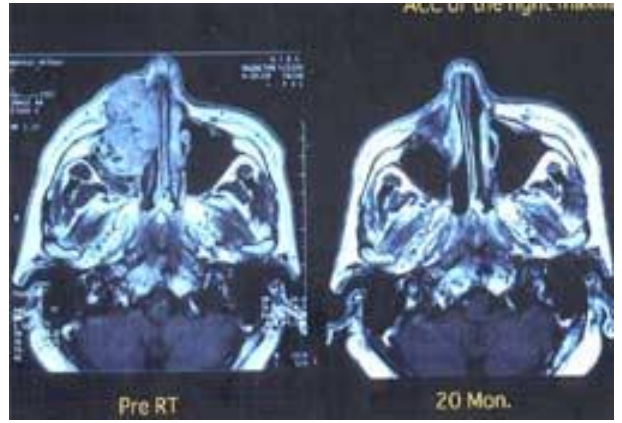
UA7 comparison with Cosmic ray physics

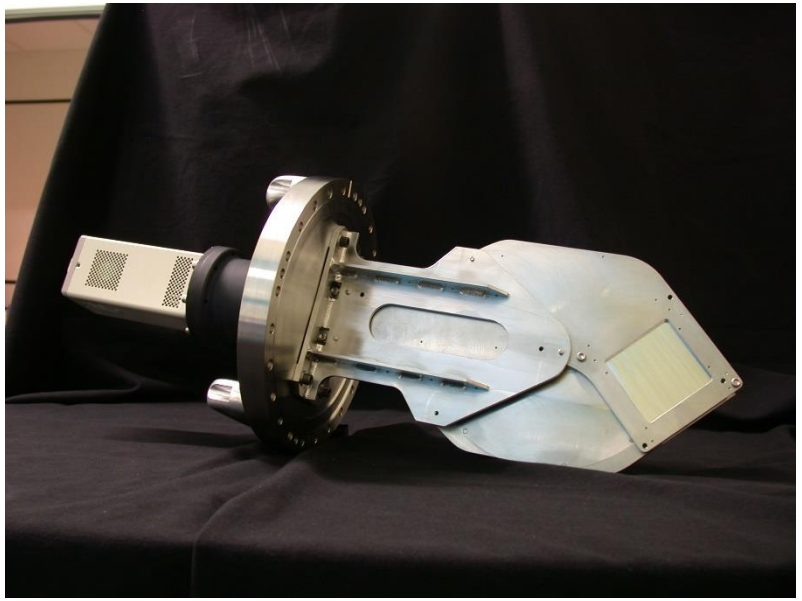
- In paralel in time, a request was made by a group headed by Prof Muraki and Prof Doke (head of Japan space agency) to help for installation of a very forward calorimeter.
- The aim was to normalize observation of terrestrial cosmic observation to reconstruct incoming energy
- As a second service, I was asked to look for the possibility to install a detector close to Aiguille du Midi in the Alps (3800 meters above see level), in order to complete the monitors of the neutron flux on the earth already installed at Chacaltaya (Bolivia) and New Zealand, but the decison to choose Zermatt/Gornergrat instead (Switzerland reacted faster having in mind to attract japanese tourists)

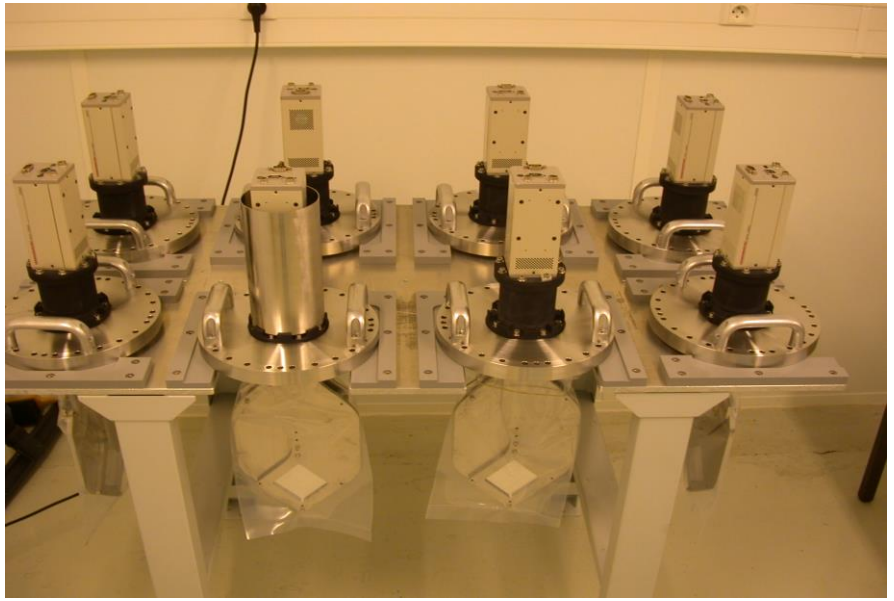
Hadrontherapy CNAO (Pavia) and MedAutron (Wiener Neustadt)





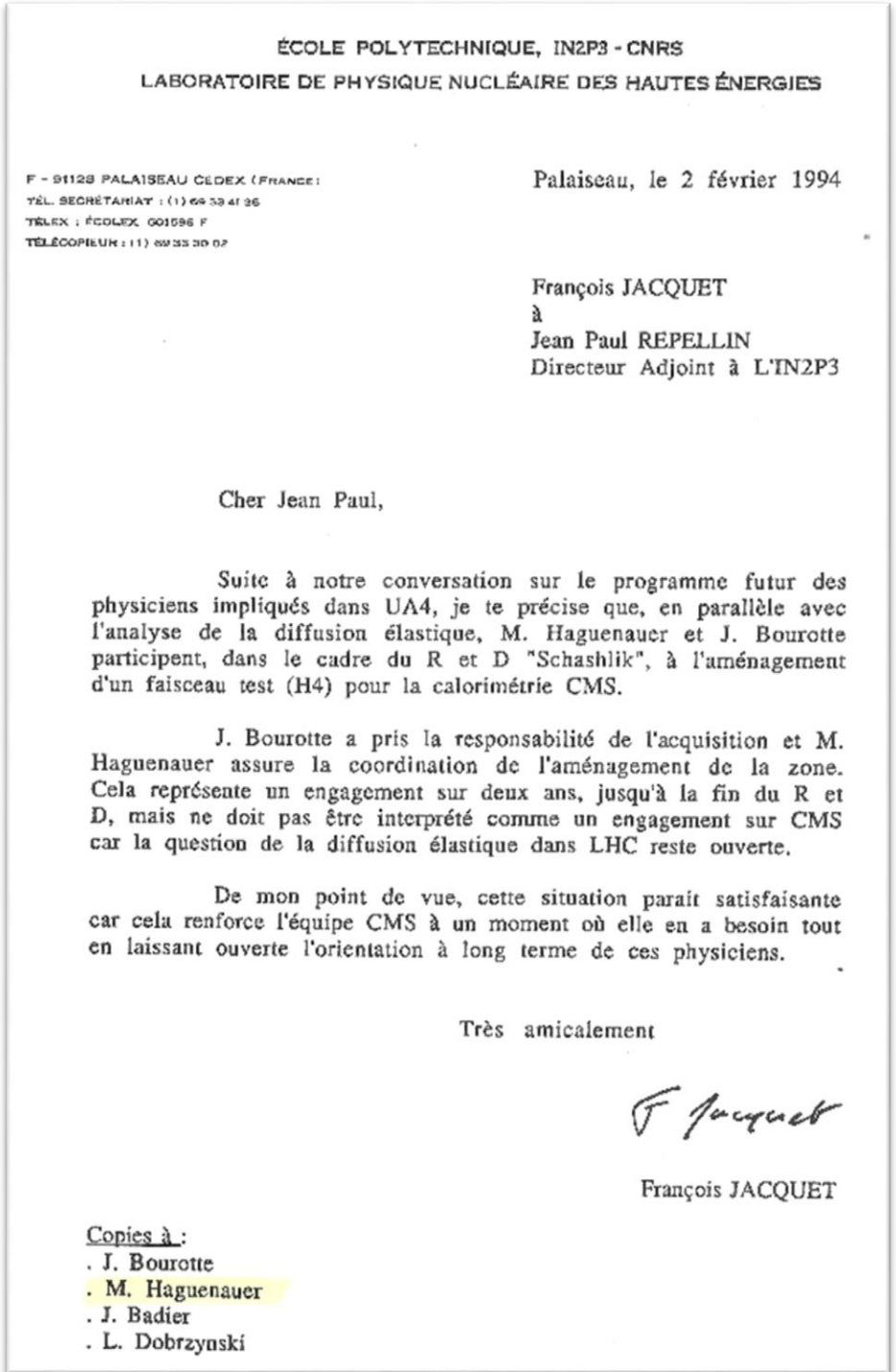






LHC-CMS/ATLAS

- In order to say unambigously, how we (J.Bourotte and myself) joined CMS. We had in mind to join the TOTEM experiment named and supported by IFIC. In the lab, we had two bosses on CMS and that was it. The deal as shown in the adjacent letter was you can continue to work on elastic scattering at the LHC.
- But nevertheless we enjoined and were lucky to sign on the Higgs particle discovery, finally with many others in the lab after Yves Sirois took over
- Also to mention that for elastic scattering, the first study of the beam optics was designed by A.Faus-Golfe; Alfa detector is based on the same fibers used by UA4/2.



ÉCOLE POLYTECHNIQUE, IN2P3 - CNRS
LABORATOIRE DE PHYSIQUE NUCLÉAIRE DES HAUTES ÉNERGIES

F - 91128 PALAISEAU CEDEX (FRANCE)
TÉL. SECRÉTARIAT : (1) 69 33 41 36
TÉLEX : ÉCOLEX 601596 F
TÉLÉCOPIEUR : (1) 69 33 30 02

Palaiseau, le 2 février 1994

François JACQUET
à
Jean Paul REPELLIN
Directeur Adjoint à L'IN2P3

Cher Jean Paul,

Suite à notre conversation sur le programme futur des physiciens impliqués dans UA4, je te précise que, en parallèle avec l'analyse de la diffusion élastique, M. Haguenauer et J. Bourotte participent, dans le cadre du R et D "Schashlik", à l'aménagement d'un faisceau test (H4) pour la calorimétrie CMS.

J. Bourotte a pris la responsabilité de l'acquisition et M. Haguenauer assure la coordination de l'aménagement de la zone. Cela représente un engagement sur deux ans, jusqu'à la fin du R et D, mais ne doit pas être interprété comme un engagement sur CMS car la question de la diffusion élastique dans LHC reste ouverte.

De mon point de vue, cette situation parait satisfaisante car cela renforce l'équipe CMS à un moment où elle en a besoin tout en laissant ouverte l'orientation à long terme de ces physiciens.

Très amicalement

F Jacquet

François JACQUET

Copies à :
. J. Bourotte
. M. Haguenauer
. J. Badier
. L. Dobrzynski

Preparation of CMS calorimeter test set-up

I was asked to take the full responsability of the test set-up of the electromagnetic calorimeter, I applied what is now knowned : « no waste »; we used the UA4 hardware , drift chambers, optical fiber detectors, cables electronics. All was moved to the H4 beam line in the CERN/north hall. We became full support from the « interface group » , conducted by P.Grafstrom and the design office conducted by C.Ferrari, (he drived fast but no accident at all. May be a positive one: Per joined Atlas and proposed « ALFA » the equivalent of TOTEM at ATLAS crossing point.

Testing prototypes is not an easy job, an example, as I was supposed to support the « chashlick » calorimeter built by my lab , but first tests immedialy have shown a rapidly signal decrease by radiation damage. It was cheep in comparison withe the solution proposed by H.Hofer-ETHZurich crystals (200 MCHF for the whole set-up, even made in China).

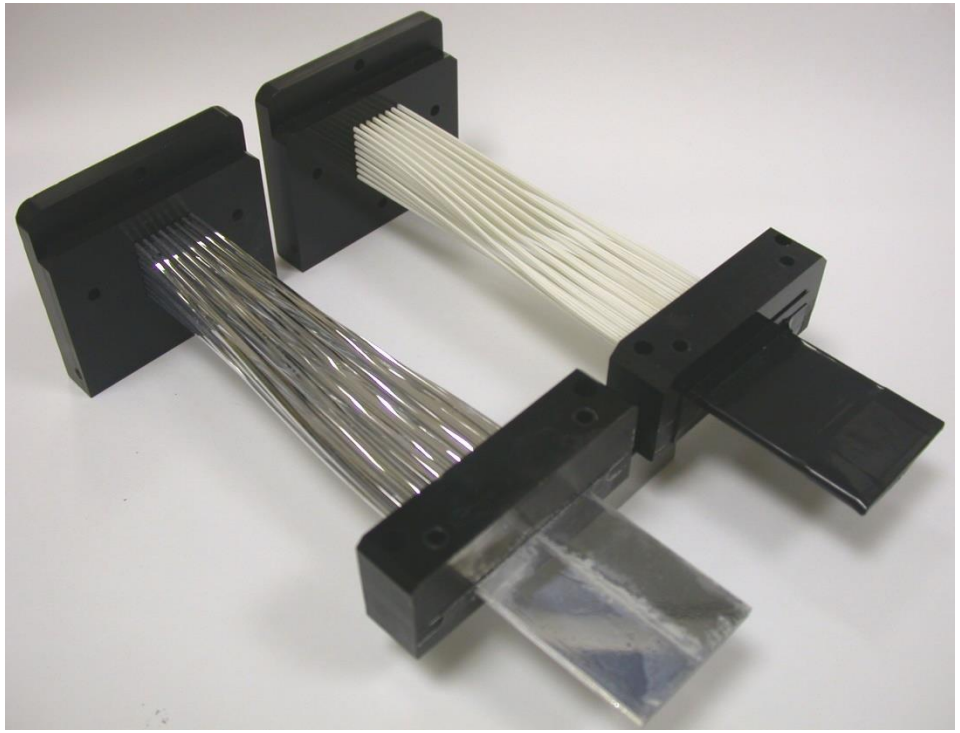
The variation of the energy signal output signal was 1%/ 0.5 degree, we had to build a temperature shielded building, bringing in a rotating table (used before for Aleph, including Jean and myself); total cost for the whole installation 300 kCHF)

Beam size and position monitor

Réalisation de 2 prototypes :
2 couches de 32 fibres décalées
d'une demi fibre : résolution spatiale théorique : 145 µm

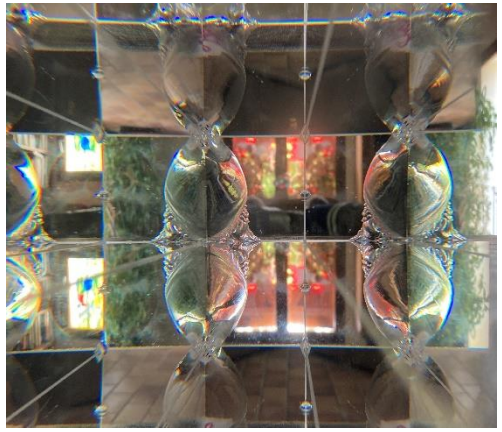
fibres BICRON
section carrée 1×1 mm^2 ;
cœur : PS - "cladding" : PMMA ;
enrobage : peinture blanche
(ep. = 0,02-0,04 mm)

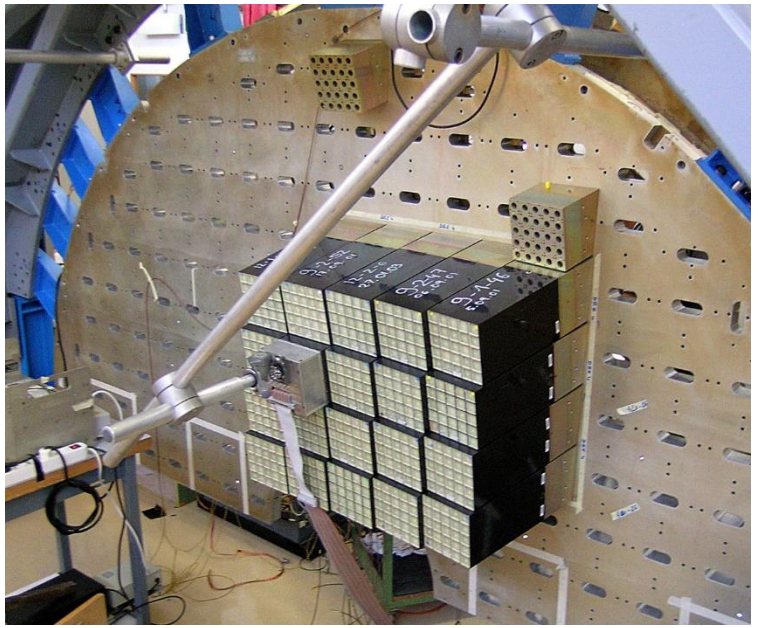
fibres KURARAY
section carrée 1×1 mm^2 ;
cœur : PS - "cladding" : PMMA ;
enrobage : dépôt d'aluminium par "sputtering" (ep. = 0,2 µm)



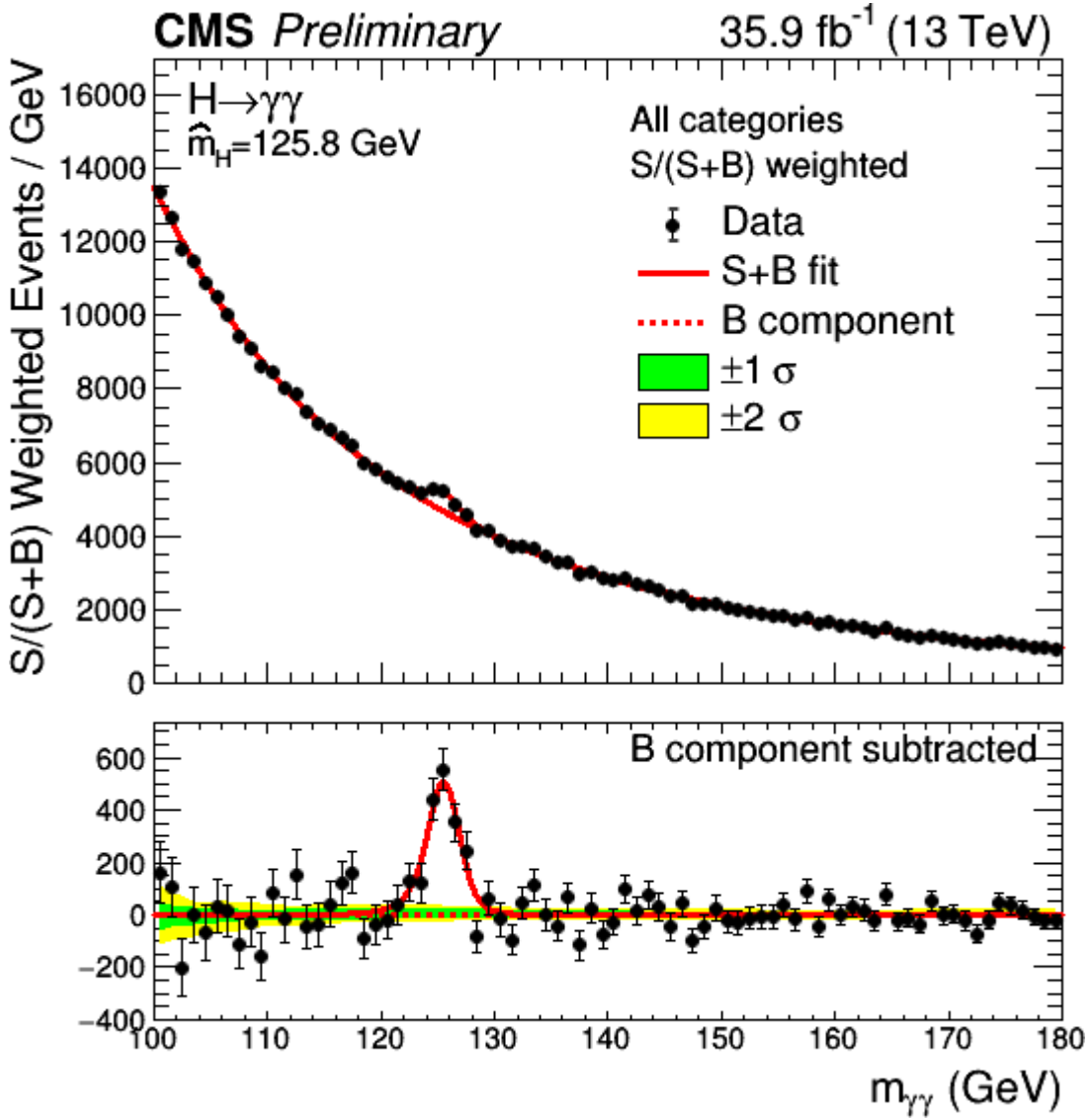
CMS Crystals

- The first prototype arrived in 1993; the essential content was lead tungstate 86%.
- After full validation in the test beam and cooling down, I took it out of the waste
- The beam operation periond took several lasted up to 2003 in cooperation with ETHZurich, (P.Leconte, F.Nessi-Tedaldi, ..
- The first final crystal arrived at CERN on september 1998, the last in 2008 total amount of 75 000; in the lab of E.Auffray each one got a barcode , size check , transparency check, an aluminized bag





Higgs particle discovery



What has change from GGM to Higgs

- Gargamelle was big, but she should not care; she weighted 10 x less
- GGM 55 collaborators ; CMS 2202 collaborators (now more)
  please apologize (including to me) for not quoting all here
- Data transfer, punched cards in the car ot by trailer, we know where the shelters were; now in many places
- Collaboration meetings decided at most one month before after 1 or 2 wire phone call
- Submit software analysis much more easier, but understanding why it it didn't work not so
- Communication of result, GGM drawing by hand, type wrighter, the rich had an IBM; now everydody has at least one in the pocket
- Understanding of basic matter interactions and existence increased a lot, a golden period
- Feedback to daily life exists , on a lot of domains, a good example is hadrontherapy