MACRO at GRAN SASSO
Monopole, Astrophysics, and Cosmic Ray Observatory

INFN
Istituto Nazionale di Fisica Nucleare

The history of MACRO streamer tubes

G. Battistoni

INFN Milano

Introduction

Why this story can be of interest?

- The history of the streamer tubes of MACRO in great part coincides with the history of the birth of the experiment
- At the same time, it is also representative of the history of the birth of Gran Sasso Laboratory and of underground experiments in Italy.
- It is also a history of some innovative concepts in the approach of massive production of detectors, something that might seem obvious today, but wasn't at all in the 80’s
- Last, but not least, it's also the story of many years of work by many people. The evolution of something that started about 10 years before the MACRO proposal was written

Most of what I am going to tell was detailed in a MACRO note that I wrote for the tenth anniversary of the proposal:

MACRO at GRAN SASSO

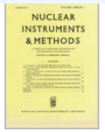
INT. MEMO: 34/94
DATE: November 2, 1994
AUTHOR(S): G.Battistoni
INSTITUTION(S): G.Battistoni

The Development of the Streamer Tubes of MACRO:

a short history

The origin: when the “Streamer mode” was not yet known as such…

Nuclear Instruments and Methods
Volume 117, Issue 1, 1 May 1974, Pages 157-169



Very large proportional drift chambers with high spatial and time resolutions ☆

D.C. Cheng, W.A. Kozanecki, R.L. Piccioni, C. Rubbia, L.R. Sulak, H.J. Weedon, J. Whittaker

Using unusually thick anode wires (r= 50 μm) ➔ large gain

Nuclear Instruments and Methods
Volume 123, Issue 2, 15 January 1975, Pages 225-229

Some observations concerning the construction of proportional chambers with thick sense wires

S. Brehin, A. Diamant Berger, G. Marel, G. Tarte, R. Turlay, G. Charpak, F. Sauli

One year later, Charpak and Sauli group points out that such chambers, operated in that way, exhibit a saturated regime that they think it’s a sort of spatially limited Geiger mode

The next year in Frascati:

LNF-76/58(R)
16 Novembre 1976

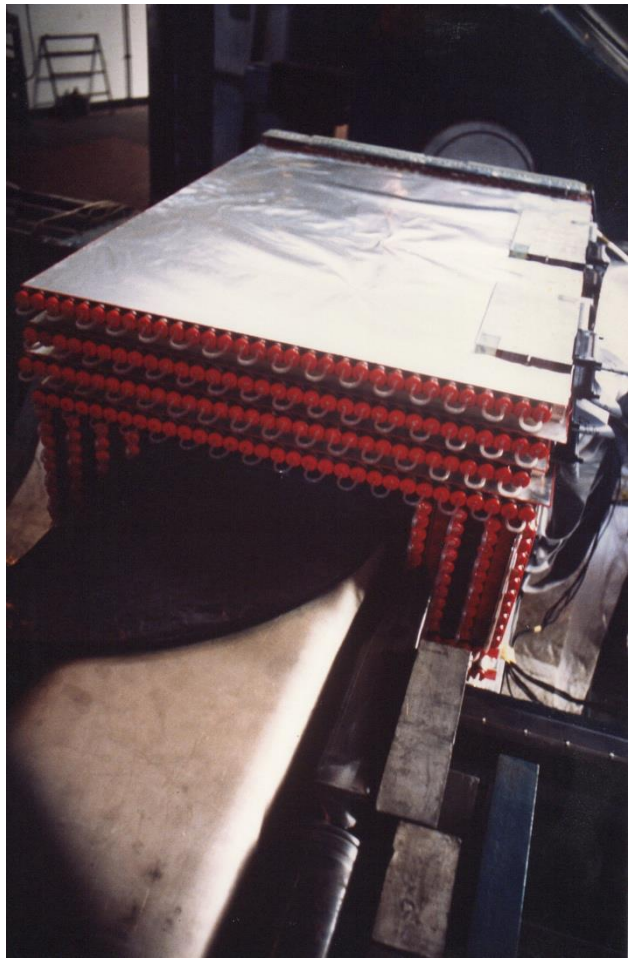
V. Bidoli[x], A. Di Biagio[x], E. Iarocci, G. Nicoletti and L. Tortora[o]: DETECTION OF INDUCED PULSES IN PROPORTIONAL WIRE DEVICES WITH RESISTIVE CATHODES.

Iarocci's idea:
Coupling large gain wires and the idea of resistive cathode, to simplify 2-d readout in large area apparata

(I arrived just in that moment to start my thesis on this subject)

Historical note:
Only few years later it was recognized that the operation mode was not a "limited Geiger" one, but a "limited Streamer" mode (M. Atac, Fermilab)

The very first application



~1978:
A tracking core close to one intersection region of Adone e^+e^- collider, to upgrade the $\gamma\gamma 2$ experiment, based on the use of optical spark chambers

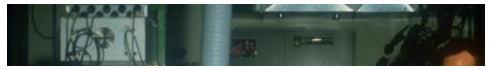
100 μm ∅ wires. Wire and Strip readout

Immediately after:

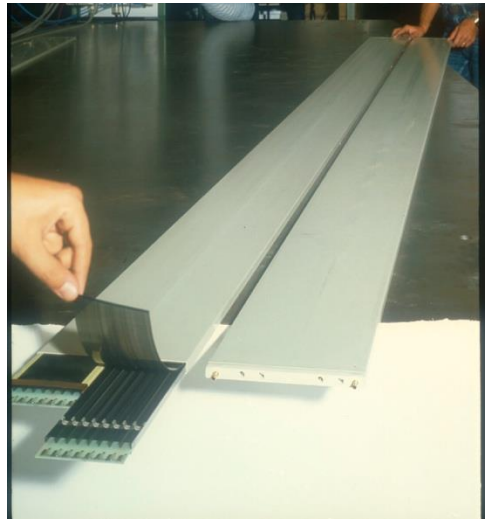
- the idea of digital tracking calorimeters, made of streamer tubes with bidimensional readout
- Application of the technique to large volume detectors in neutrino physics (CHARM)

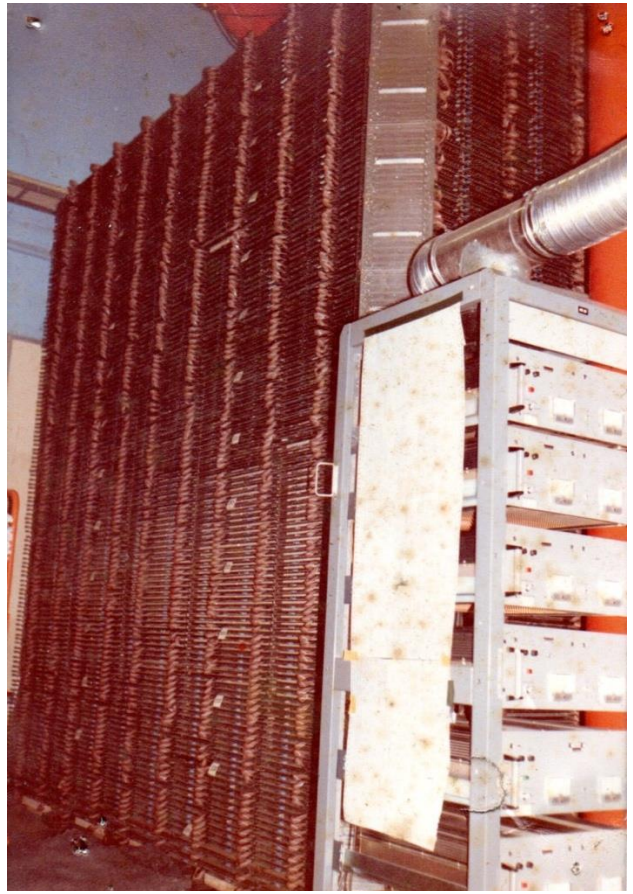
The fundamental turning point: the p-decay NUSEX experiment at the Mont Blanc

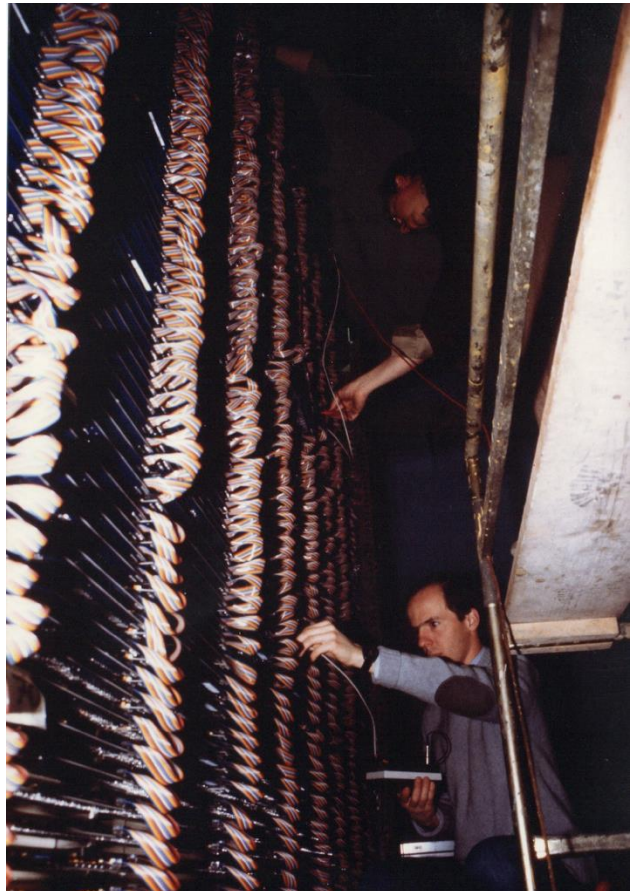
134 planes of ~1 cm^2 cross section streamer tubes with 2-dim readout, 3.5 m long, for a total of 42880 wires (100 μm ∅)



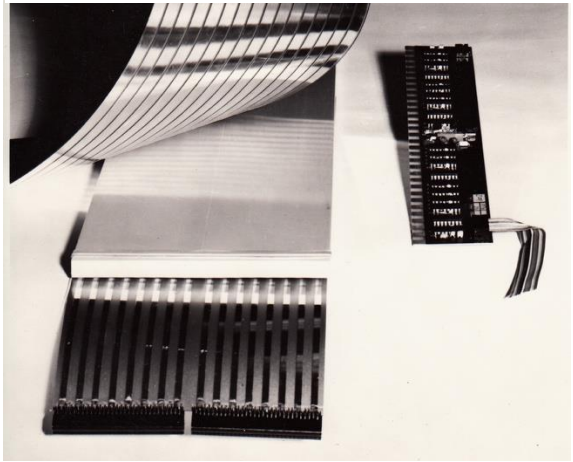
Extruded PVC profiles
Resistive paint coating







2-dim Al strip readout
(no wire readout) ~1 cm pitch.
81472 (X+Y) channels



Ad hoc LeCroy readout electronics:
The MACRO readout will be a better evolution, based on the same basic principle

Similar tubes were almost immediately considered for n – $\overline{n}$ oscillation, then LEP calorimeters and muon detection systems (Aleph, Opal…)

Towards a Gran Sasso experiment

- As soon as NUSEX started operation in 1982, it was already clear that a new proposal for Gran Sasso had to be conceived
- We (Italian side, mainly Frascati) were initially oriented towards a larger nucleon decay detector
- Only during 1983, after IMB results and the appearing of Icarus idea, we gradually switched from "Large Volume" to "Large Area" detector, in view of the emerging fields of Monopole search and Muon Astronomy
- Main technical concerns:
  - Reduce as much as possible costs (no. of readout channels, amount of material…)
  - Increase reliability and stability of operation
  - Simplify construction process

Main solution: a larger cell

From all the lab studied performed since 1978 we learned:

- The wider the cell, the stabler the operation
- With a wider cell, a gas mixture with a reduced content of hydrocarbons could be used (increase of safety)

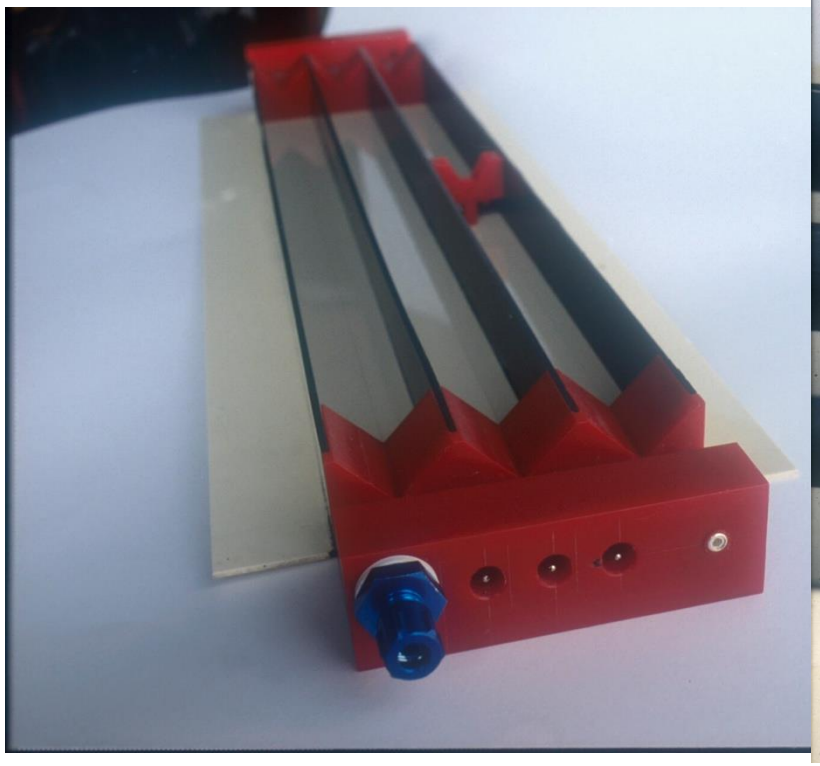
Iarocci very soon (well in advance of MACRO proposal) suggested to go to 3x3 cm^2.
Worries:

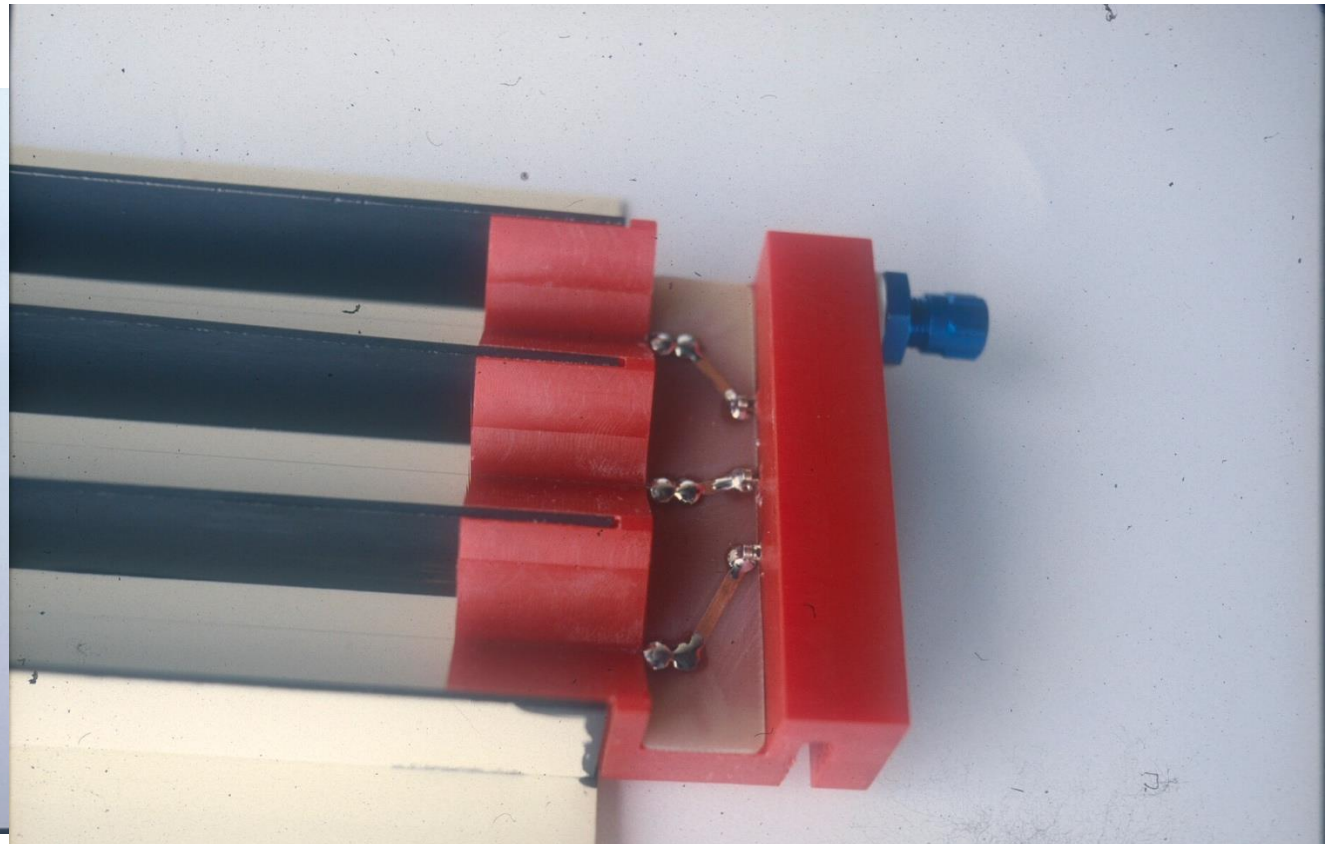
- Is the space point accuracy enough?
- Patter recognition capability(*)?
- What about the time jitter?

(*) notice that at that time we were not considering multiple muon physics as a fundamental topic, even in MACRO proposal. Only much later it acquired relevance in our activity

The first 3 cm prototype (hand machined)

1983-84





You may notice that we were experimenting a solution with only the graphite coating of vertical walls, so to have a field shaping similar to that of a drift chamber, but it was more difficult than having 3 side coated, different from NUSEX, where all 4 sides were coated, but of simpler construction! We called this configuration “coverless”

Which gas mixture? Which operation mode? Which length?

When monopoles became the main goal, there was the issue of Drell effect, at that time calculated only for Helium, but He in plastic tubes was a nightmare: it took a long series of tests to learn how to deal with He-based mixtures…

Should we keep a sensitivity to ionization loss? At the beginning it seemed important, so we opened to the idea of going back from streamer mode to proportional mode, reducing the wire diameter with respect to our standard of 100 μm (see the proposal!)

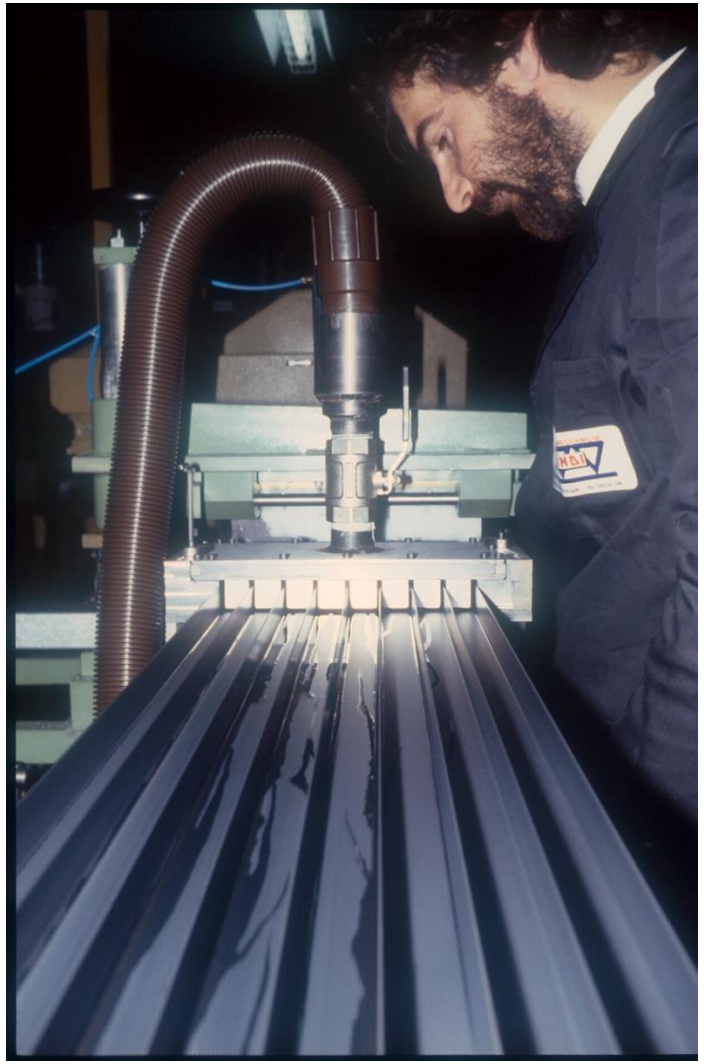
It took time to finalize all this… The final solutions will be achieved within 2 years of work since the writing of MACRO proposal.

Length: that was easy! The maximum transportable length without requiring special permissions was 12 m.

The challenge of mass production

- The experience of NUSEX tube construction was exciting, involving Frascati, Milano, Torino with many technicians and CERN, but it soon appeared that it could not be replicated any more.
- Main intuition (a new insight at that time!), again by Enzo Iarocci: large commitment to industry, not only for the production of raw material, but also for assembling.
- Machines had to be designed by our laboratory, and only a limited number of our personnel was necessary to supervise and perform quality tests
- It was a real challenge at that time!!

The final optimization: 3 side coating with a rather low resistivity paint (~2 kΩ/□)

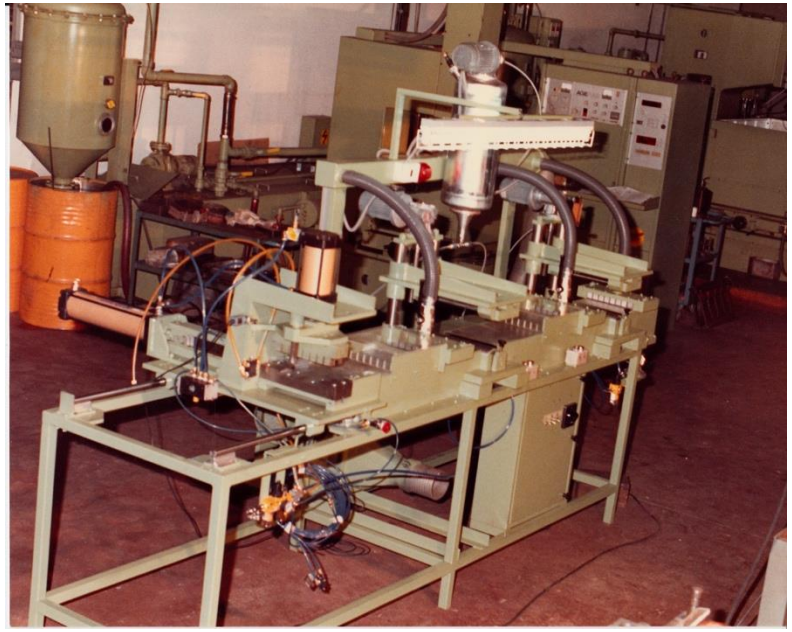


1st innovation step:

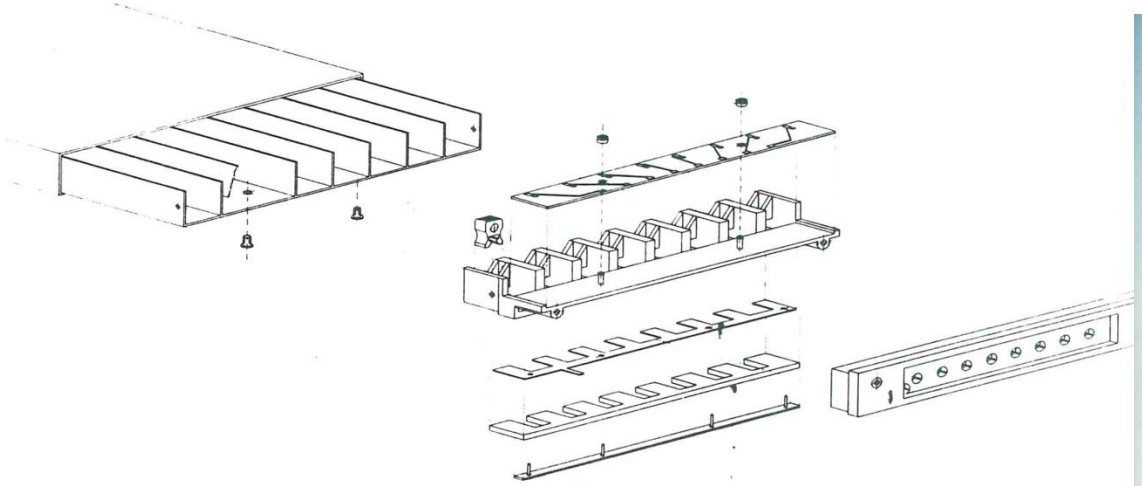
Painting in-line with the PVC extrusion process, directly in the extrusion firm

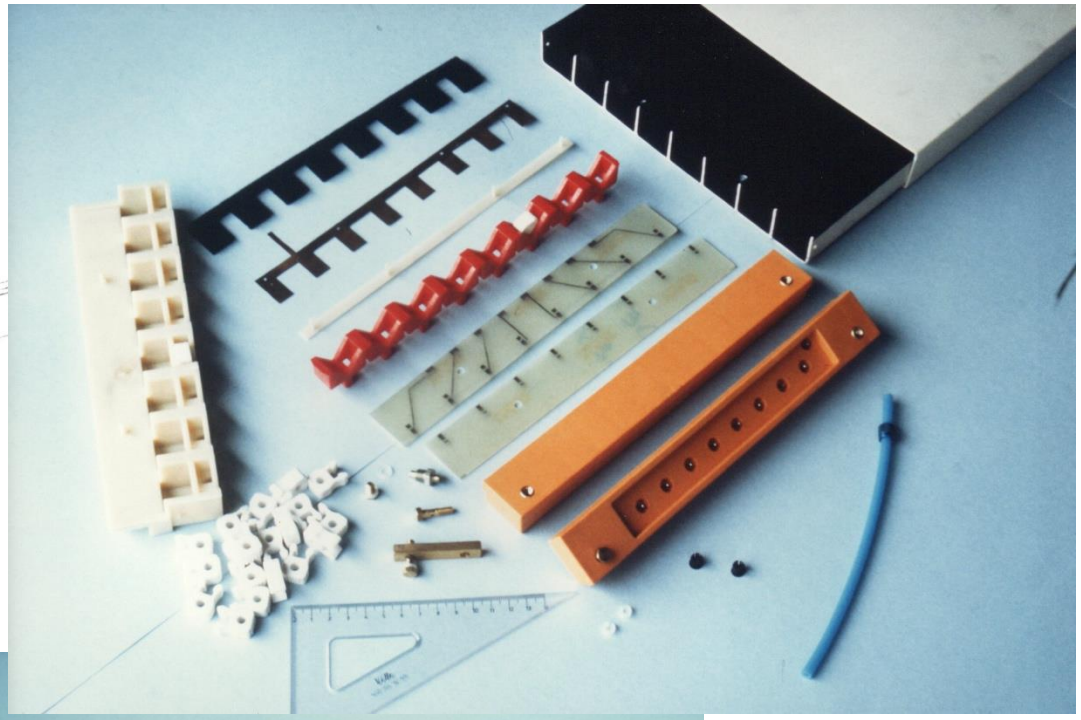
The final solution required a long series of trial-and-error developments.
A patient work carried out mainly by U. Denni

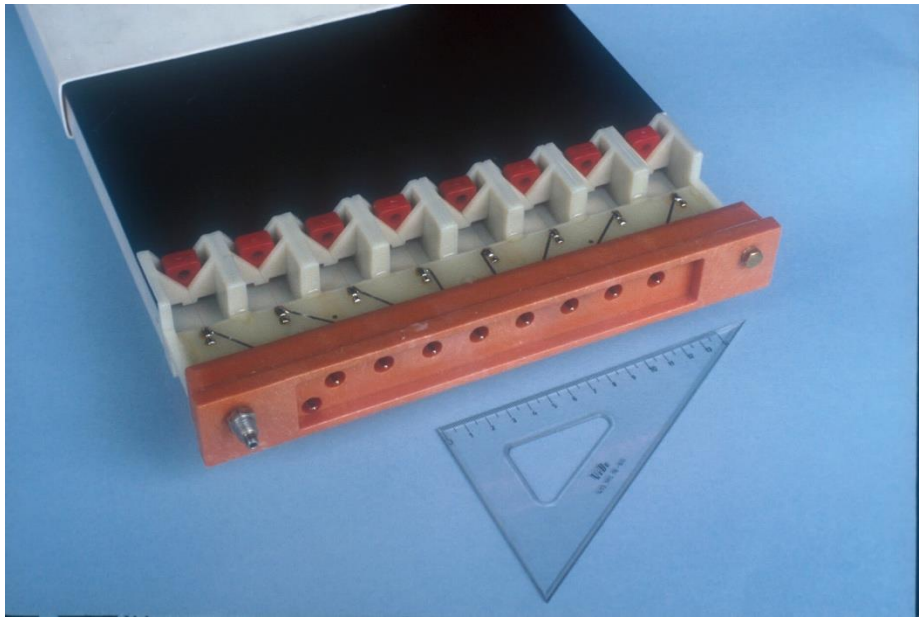
The low resistivity coating was much more reliable with respect to that of NUSEX tubes (where ρ ~100 kΩ/□) and nearly optimal for our strip readout, *if placed on the "coverless" side* (although in some case this could generate cross-talk…)

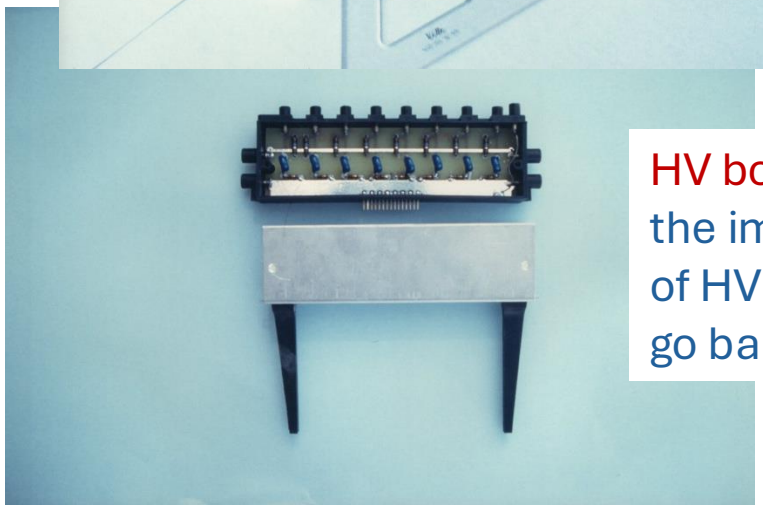


The final design and the different components



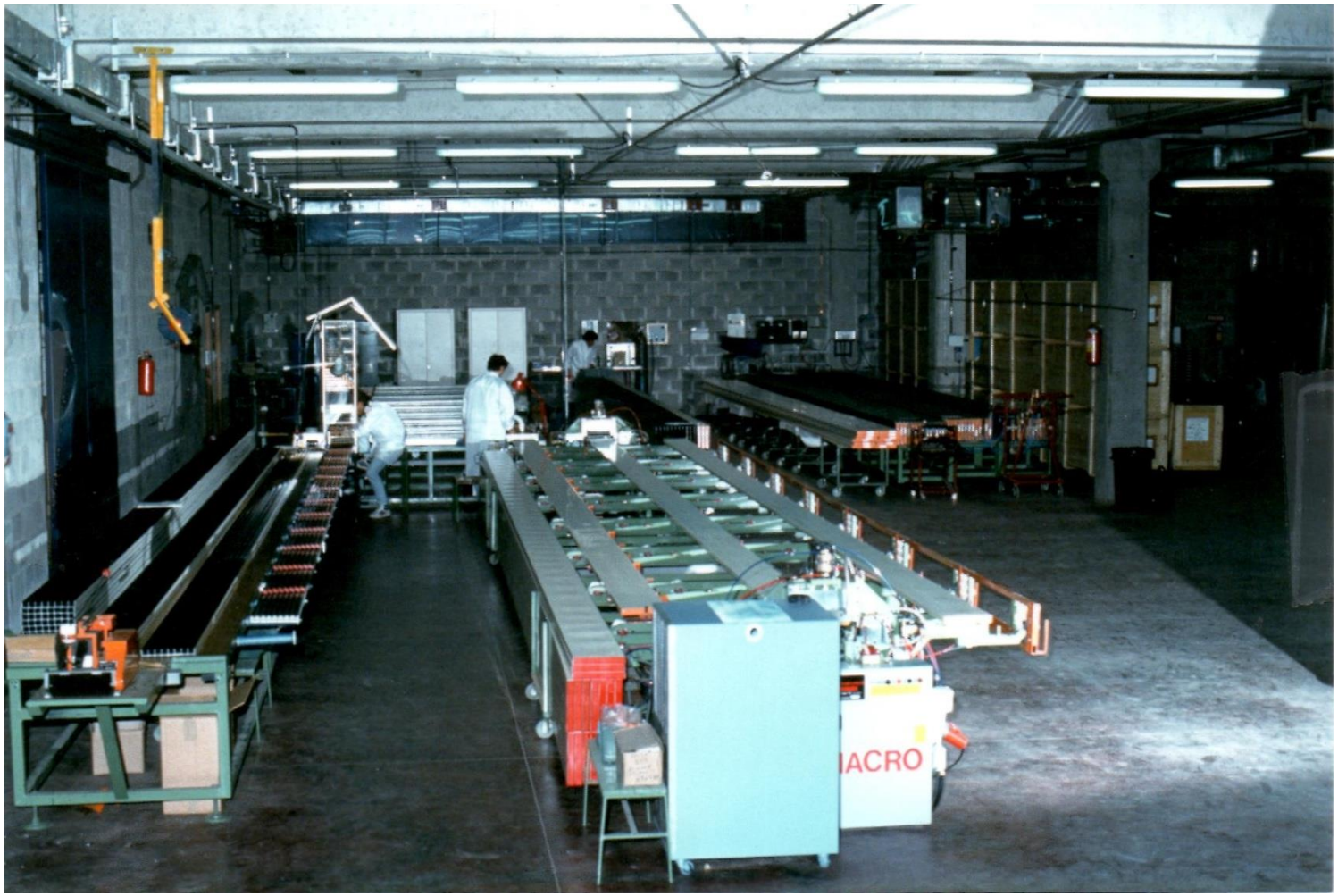


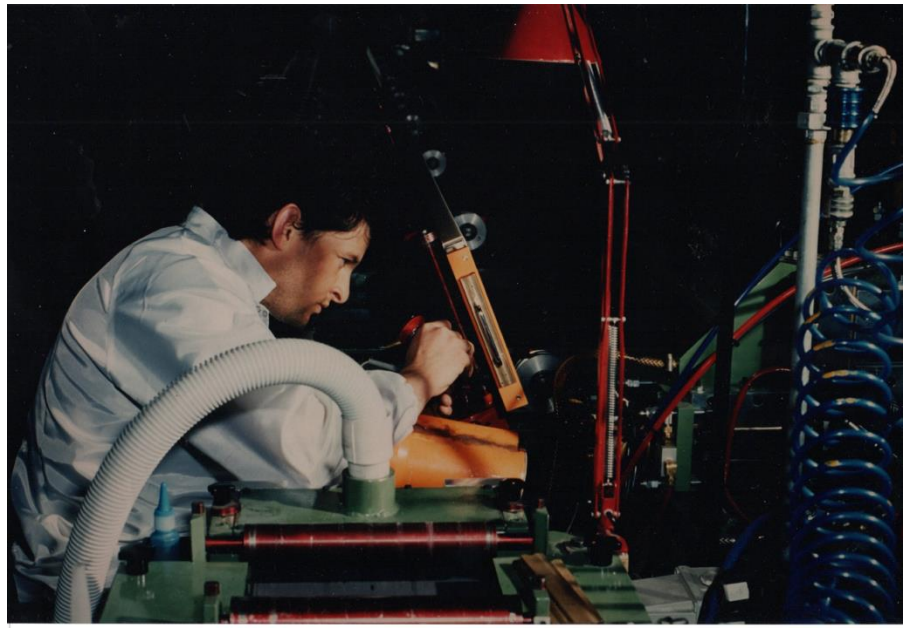


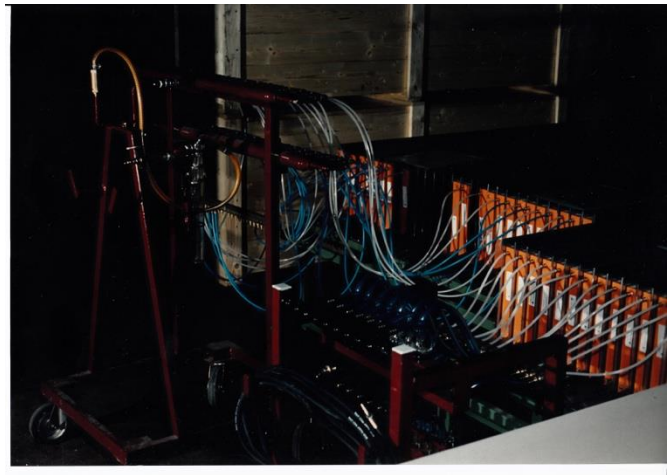


HV box:
the improvement in the quality of HV capacitors allowed us to go back safely to wire readout

2nd innovation step: tube wiring, assembling and test in Politech, Carsoli





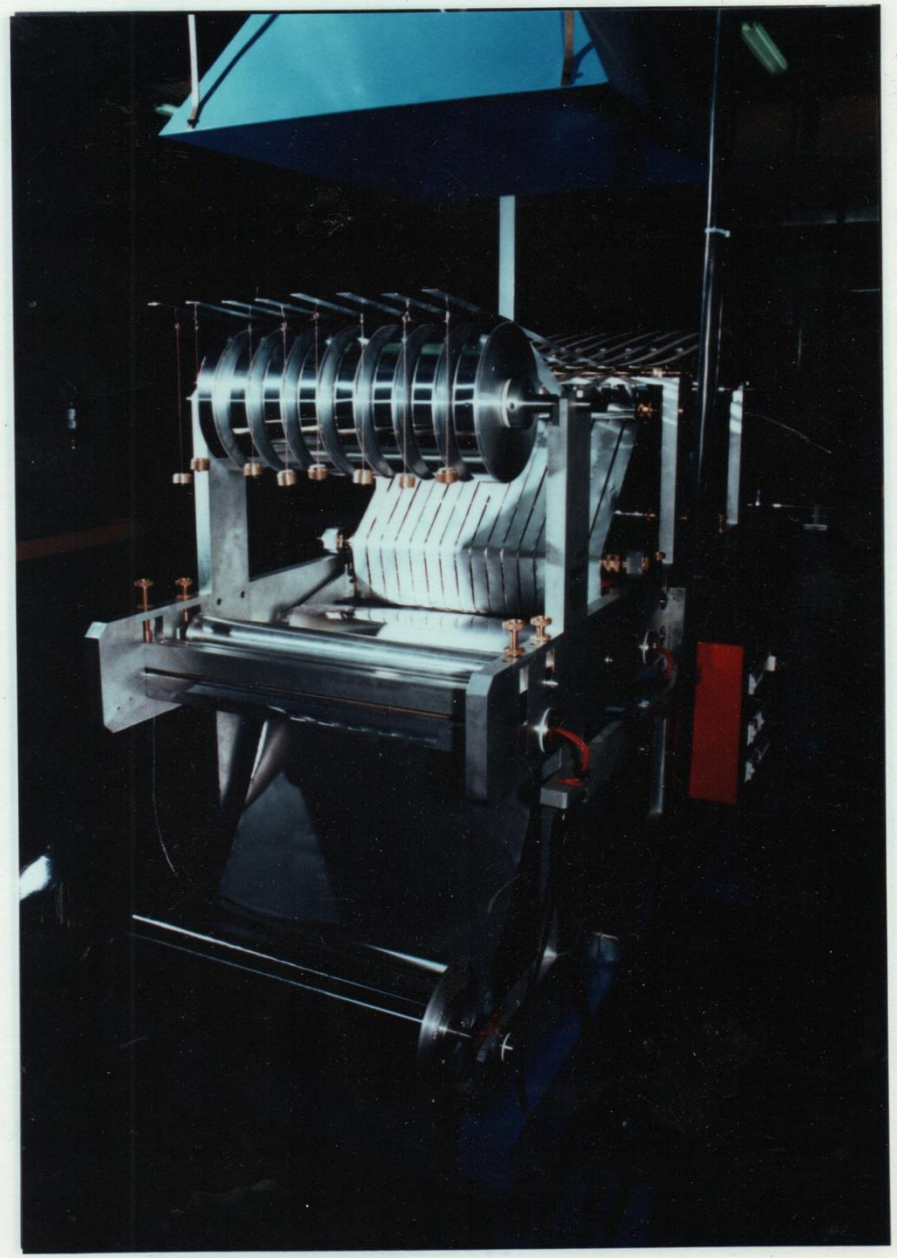


The d-strips

The need for strips at stereo angle was initially motivated only for obvious reasons of access

Only later we realized that diagonal strips could help to solve ambiguities in 3-d reconstruction of multi-track events

The real issue with the 3 cm wide strips of MACRO was given by the very low characteristic impedance. This made not easy the design of their readout electronics



The main 1986 milestones:

- The start of theoretical thesis of V. Patera on Drell effect in Argon: it was possible, but only at higher β threshold. We had to remain with He....

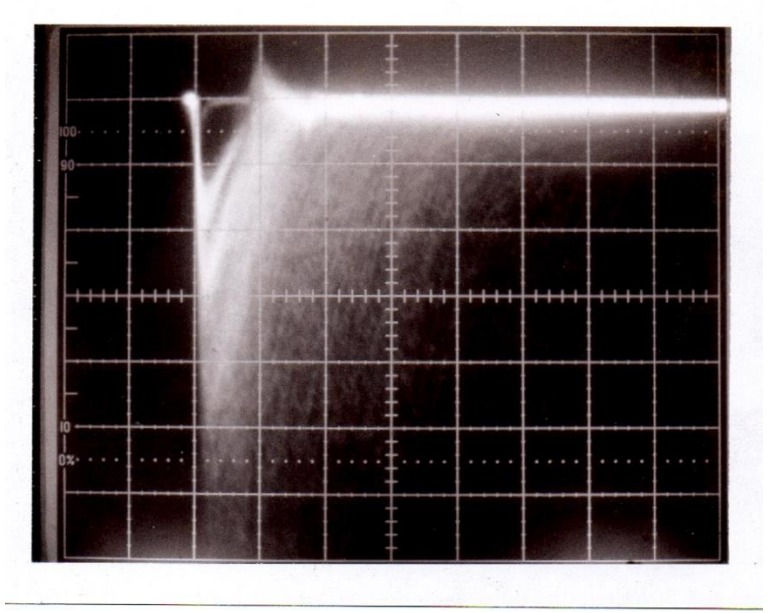
EXCITATION AND IONIZATION IN LOW-*Z* ATOMS BY SLOW MAGNETIC MONOPOLES

V. PATERA
INFN, Laboratori Nazionali di Frascati, P.O. Box 13, 00044 Frascati, Italy

Later published in Phys. Lett A in 1989

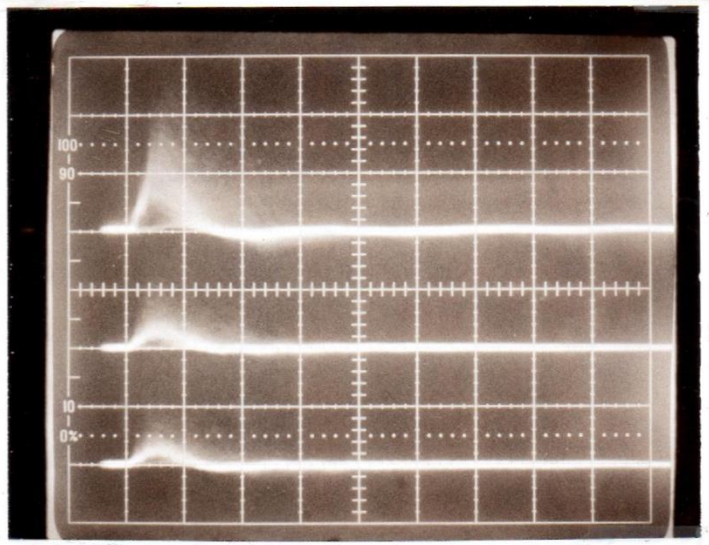
- The measurement of sensitivity of streamer tubes to high ionization after a test with heavy ions in Saclay
- First successful production and delivery of tubes in Carsoli
- The first experimental test of a 12 m long tube together with the test of a long readout strip using low resistivity coating

From my logbook, 11 June 1986



Wire pulse, 12 m long

An Ar+CO_2 1+9 gas mixture was used



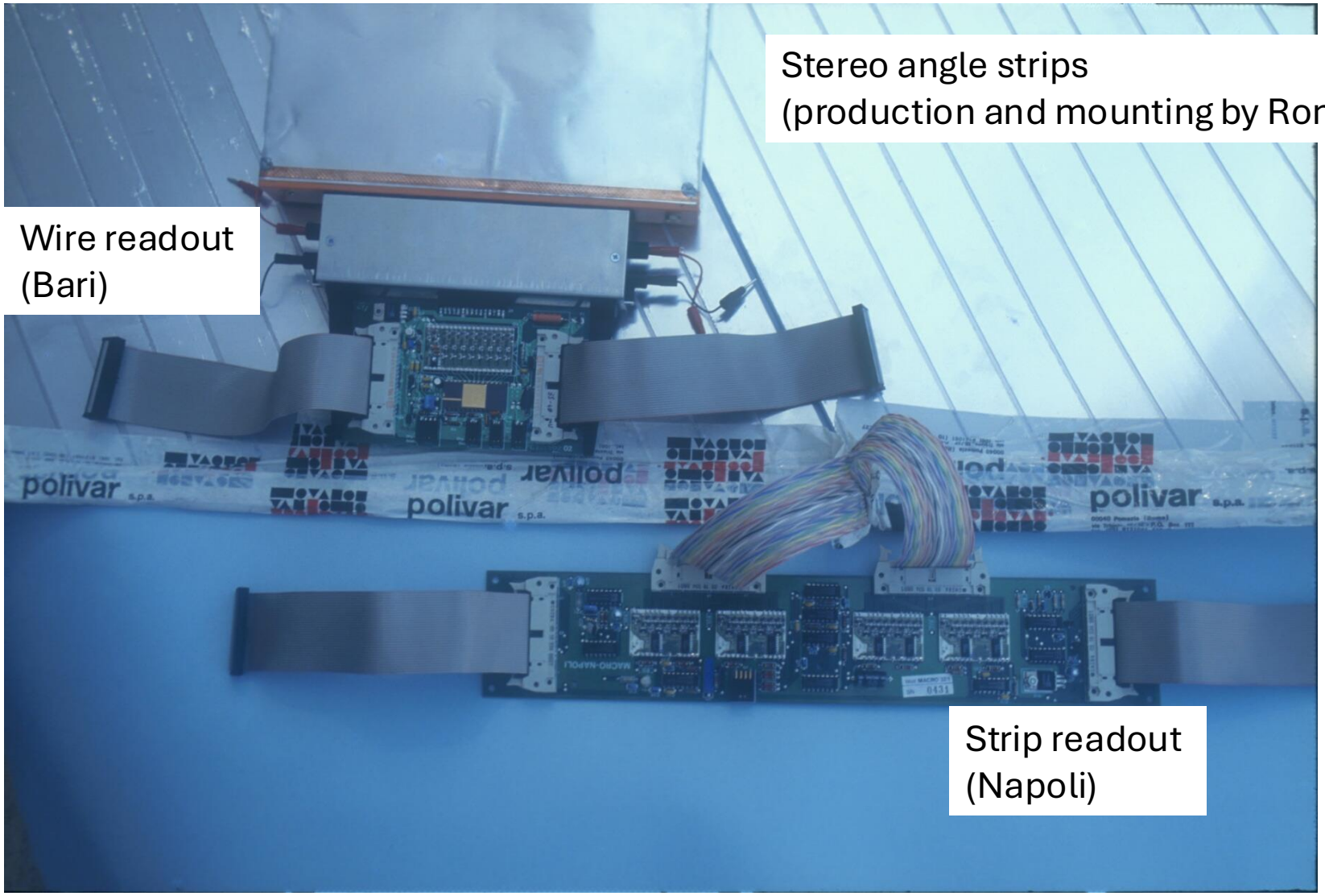
Central strip

1st neighbour strip (right)

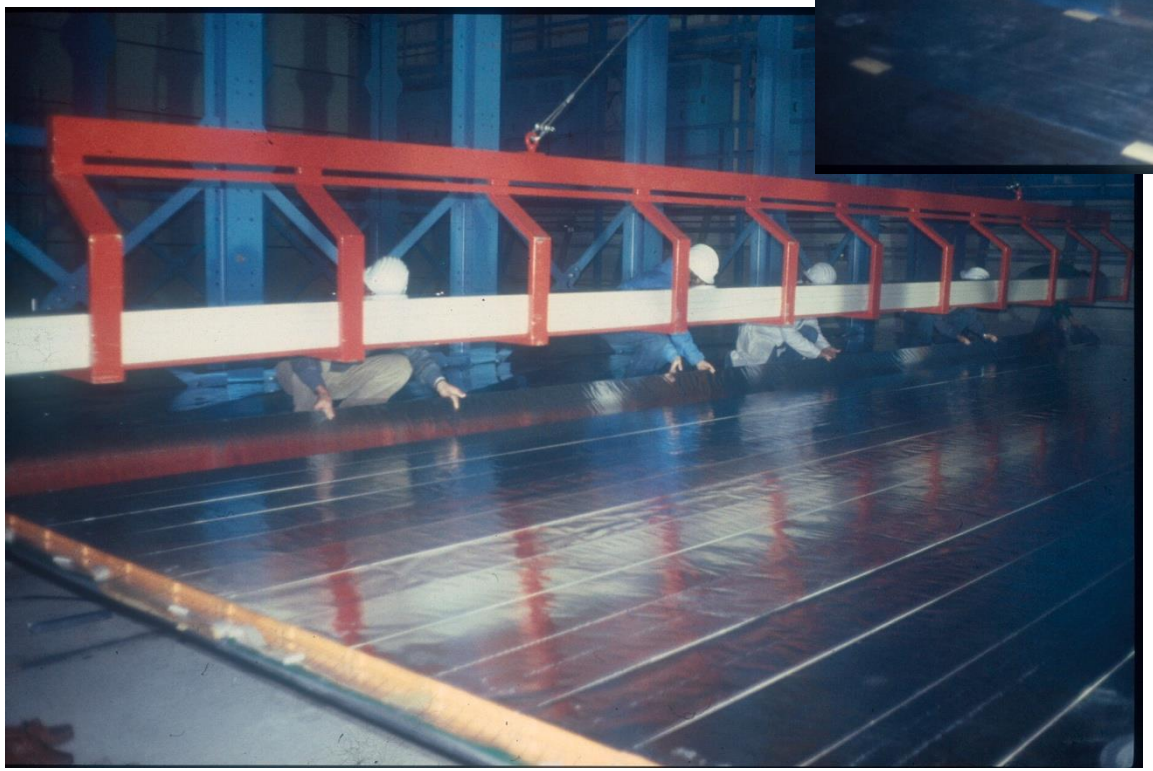
1st neighbour strip (left)

The green light for mass production!

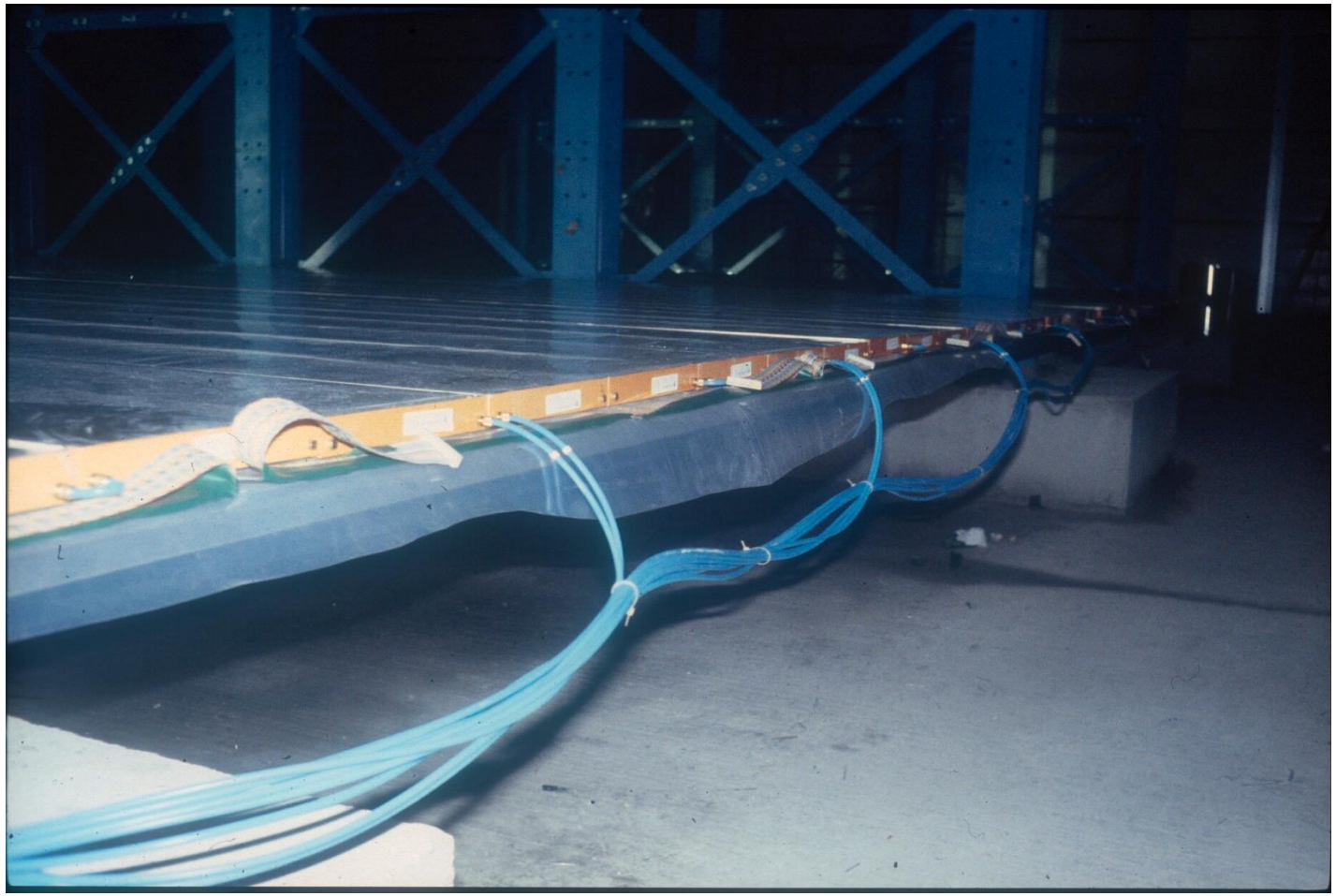
The readout

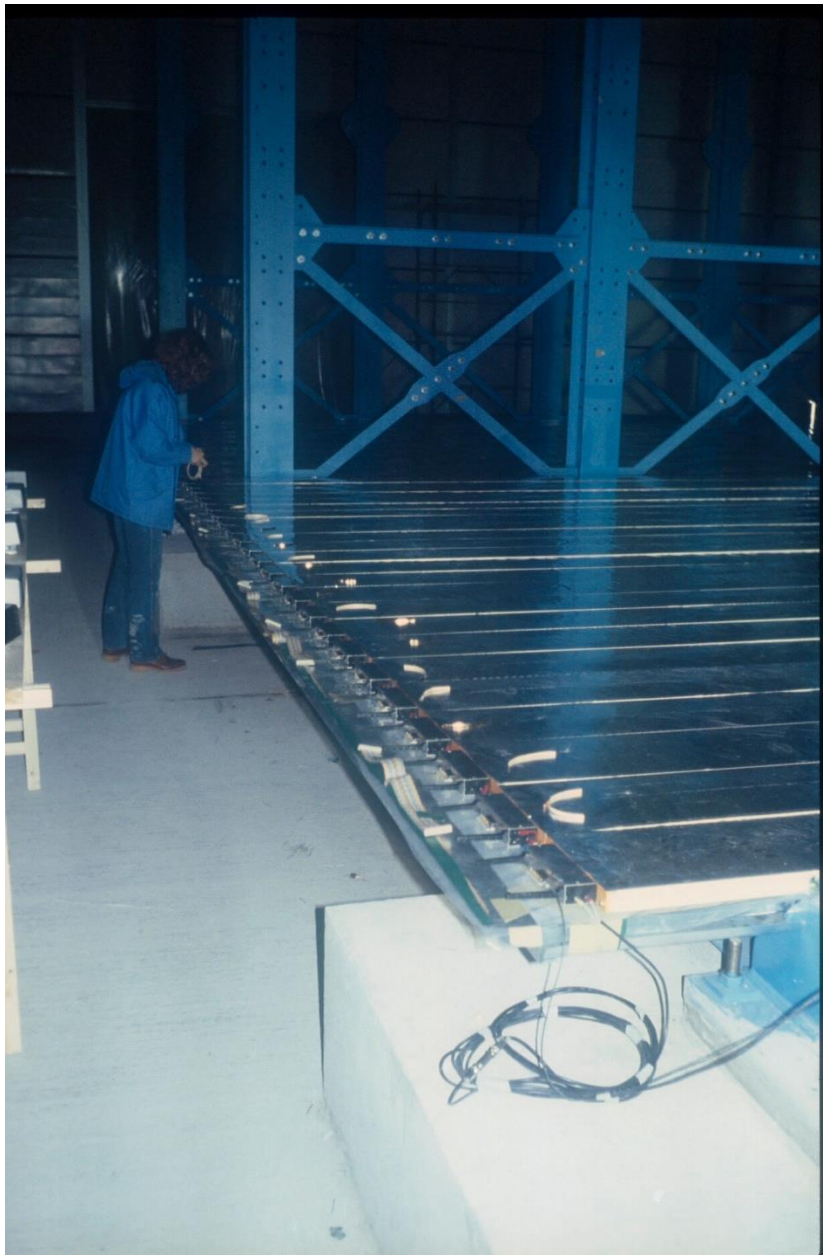

Stereo angle strips
(production and mounting by Roma group)
Wire readout
(Bari)
Strip readout
(Napoli)

Mounting the first plane of tubes of 1st supermodule October 15th 1987



Mounting the first plane of tubes of 1st supermodule
October 1987





Our internal manual for mounting

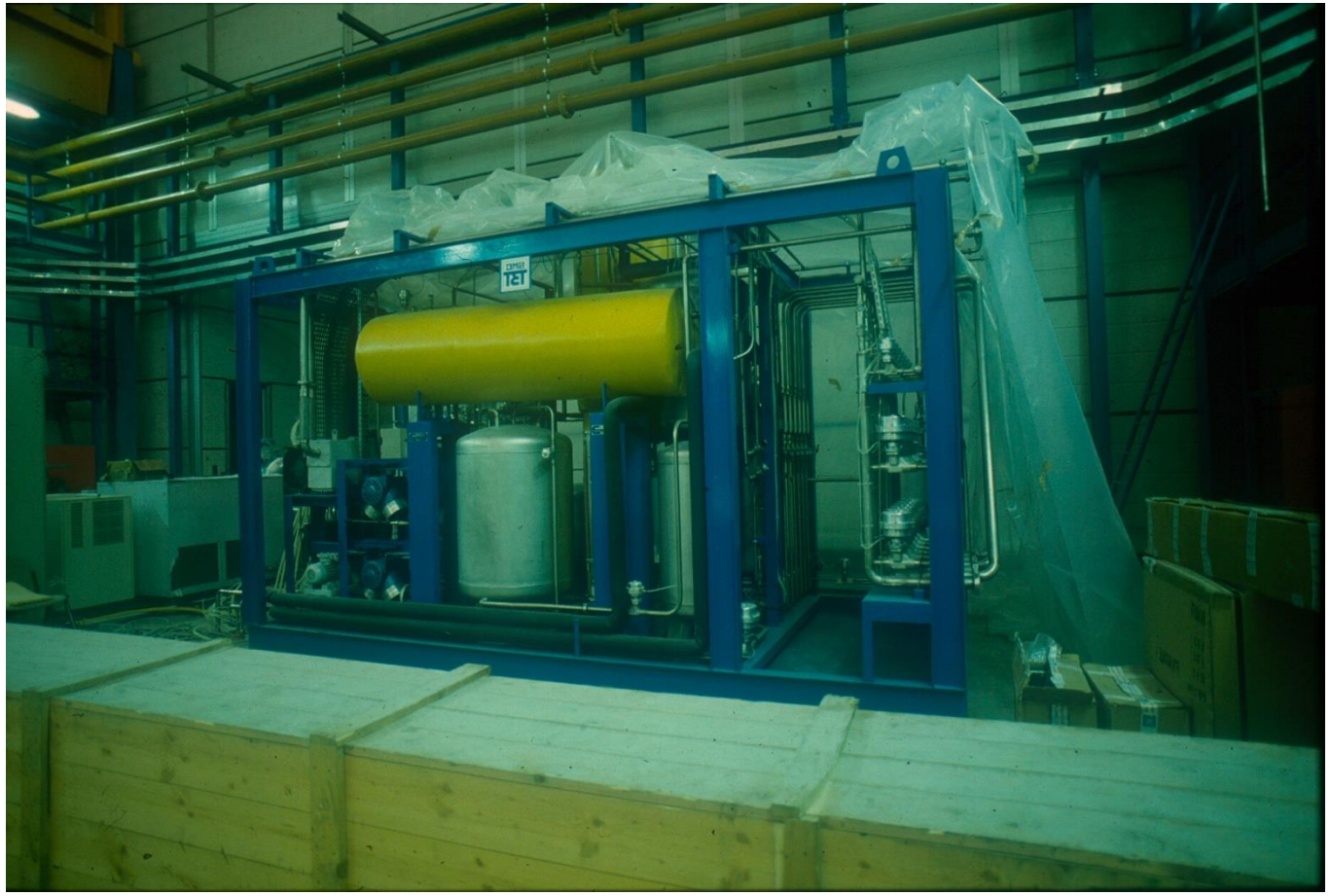
MANUALE PER IL MONTAGGIO DEI PIANI ORIZZONTALI DI TUBI
A STREAMER PER L' ESPERIMENTO MACRO

Release 1.0 - Novembre 1987

G. Battistoni, U. Denni

The gas system

We succeeded to have a stable operation using the He (73%) + n-C_5H_{12} (27%) gas mixture, avoiding a problematic 3-component mixture including CO_2 (too long drift time ➔ inefficiency in readout and trigger system)



The final design and construction of this system required in any case a lot of efforts and time

MACRO was kept under severe scrutiny from the point of view of safety of gas. We made all efforts to keep the fraction of flammable component as low as possible.

If we could have used our standard quenching gas, isobutane (C_4H_{10}), life would have been much much simpler!

However, there was (is?) another experiment in Gran Sasso with streamer tubes allowed to use isobutane… 😡

A test without too much success: burying streamer tubes in the ground at Campo Imperatore, to be used in EAS-TOP

Conclusions:

The MACRO streamer tubes were the final chapter of a successful story of detector development started in INFN, and in particular in Frascati, around 1976.

In the case of MACRO, that system was the result of many efforts, developments, trials and errors, but it can be surely considered a success.

In the 2002 paper we wrote: "*The final fraction of dead channels was 1.70 10^{-3}: These dead channels were almost evenly distributed over the whole detector, although there was some excess in the first SM which had been put into operation in 1988: 21 disconnections in 12 years, 13 of which occurred in the first 3 years of operation*" (the total no. of wires was ~50,000)

The simplicity and reliability of this detection system allowed to achieve a lot of physics results.

Of course, we suffered from some limitations due to some choices dictated by the need of reducing costs as much as possible, but that was really unavoidable. However, we learned to cope with all problems.

Later works with streamer tubes in MACRO

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Nuclear Instruments and Methods in Physics Research A 401 (1997) 309–316

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Response of proportional and streamer tubes to laser induced high ionization tracks

G. Battistoni[a], A. Candela[b], I. De Mitri[c,*], U. Denni[d], A. Frani[d], F. Guarino[e], V. Nassisi[f], A. Sciubba[g,d]

ELSEVIER

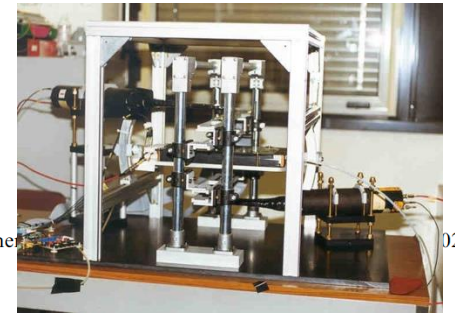
Nuclear Instruments and Methods in Physics Research A 399 (1997) 244–260

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Systematic study of the features of the streamer discharge by means of pulse shape analysis

G. Battistoni[a,*], A. Candela[b], I. De Mitri[c], U. Denni[d], A. Frani[d], F. Guarino[e], L. Nicoletti[d], V. Patera[d,f], A. Sciubba[d,f]

Together with other collaborators in MACRO



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Nuclear Instrume 02) 309–315

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Performance of a large limited streamer tube cell in drift mode

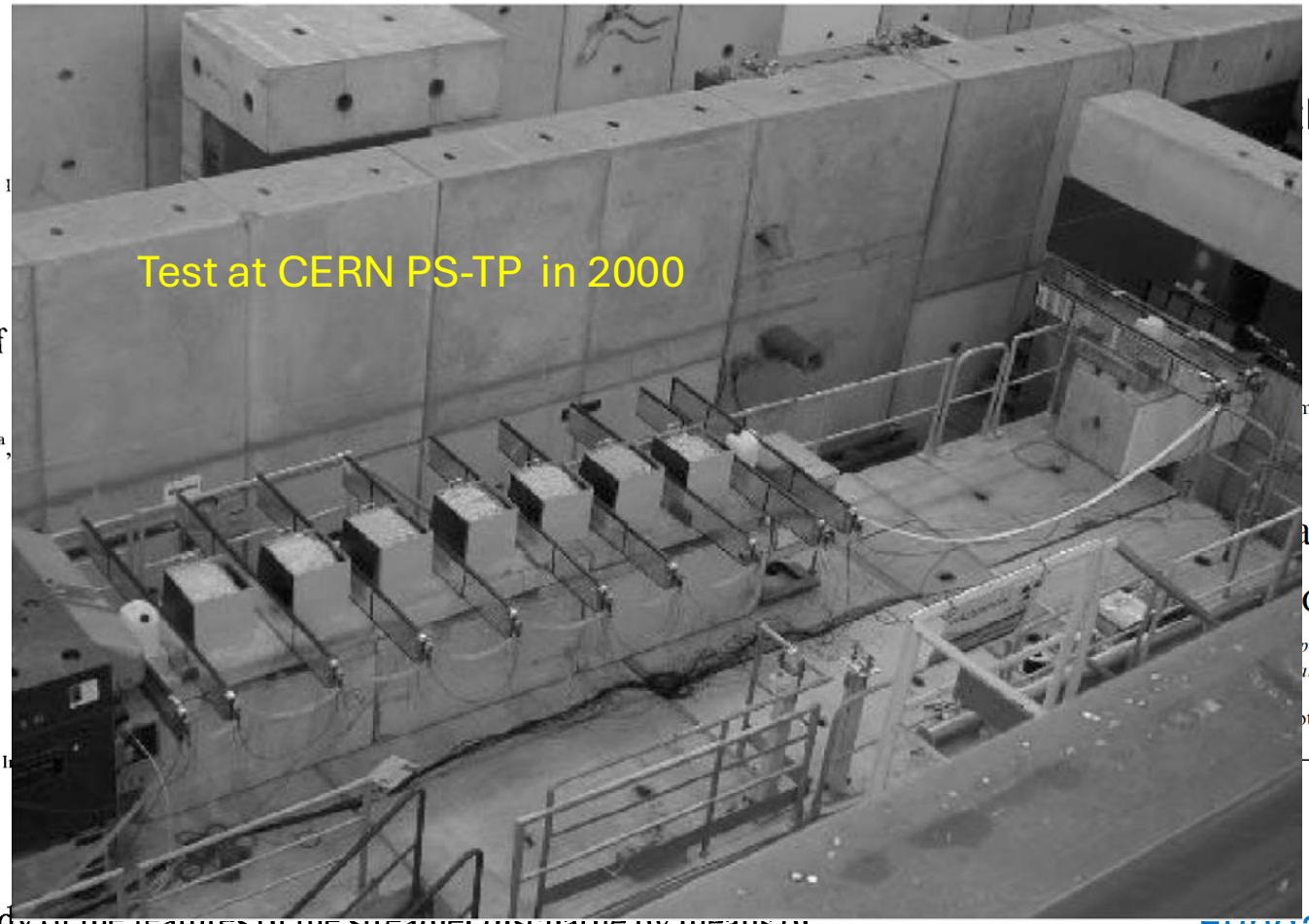
G. Battistoni[a], M. Caccia[a], R. Campagnolo[a], C. Meroni[a], E. Scapparone[b,*]

[a] *Dip. Fisica dell' Università di Milano and INFN Sez. di Milano, Italy*
[b] *INFN, Laboratori Nazionali del Gran Sasso, SS 17 km 18+910, 61070 Assergi (AQ), Italy*

Received 20 September 2000; received in revised form 7 March 2001; accepted 7 March 2001

Fundamental for the evaluation of energy of upward-going muons using multiple scattering

Later works with streamer tubes in MACRO



ELSEVIER Nuclear I

Response of

G. Battistoni[a],

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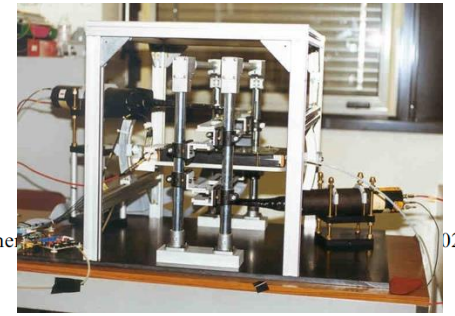
Systematic study of the features of the streamer discharge by means of pulse shape analysis

G. Battistoni[a,*], A. Candela[b], I. De Mitri[c], U. Denni[d], A. Frani[d], F. Guarino[e], L. Nicoletti[d], V. Patera[d,f], A. Sciubba[d,f]

h other collaborators in MACRO



ner 02) 309–315

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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a large limited streamer tube cell in drift mode

Caccia[a], R. Campagnolo[a], C. Meroni[a], E. Scapparone[b,*]

p. Fisica dell' Università di Milano and INFN Sez. di Milano, Italy
tori Nazionali del Gran Sasso, SS 17 km 18+910, 61070 Assergi (AQ), Italy

tember 2000; received in revised form 7 March 2001; accepted 7 March 2001

Fundamental for the evaluation of energy of upward-going muons using multiple scattering

Personally, this work in MACRO represented, maybe, the most important effort in my scientific career, and probably one of the most exciting. I wish to express my sincere gratitude to all those with whom I had the opportunity to live that experience.

In first place: E. Iarocci, U. Denni (engineering),

J. Reynoldson + G. Mazzenga + A. Mengucci (mechanics and technical assistance) + A. Frani (gas system, and much more…)

M. Spinetti + V. Valente ("politics" and administration),

V. Chiarella (gas system design and tender)

G. Satta, P. Campana, C. Gustavino, L. Liberatori, F. Ronga, A. Sciubba, S. Torres, V. Patera (contributions to several tests with MACRO tubes)

And, of course, the Roma group for the strips, the Bari group for the wire readout, and the Napoli group for the strip and analog readout