The MACRO experiment and its legacy: more than three decades of astroparticle and neutrino physics

27-28 Jun 2025

Postcards from MACRO Gran Sasso

... an overview of personal experiences and memories from MACRO experiment

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SEZIONE DI LECCE

Recollection outline

- ✓ 1. Pioneering stage (1987 – 89)
- ✓ 2. Construction stage (1990 - 94)
- ✓ 3. Neutrino search stage (1995 – 98)
- ✓ 4. Closing stage (1999 – 2000)

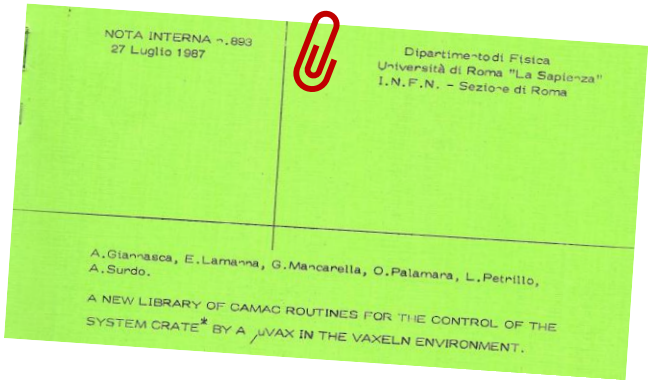
1. Pioneering stage (1987 – 89)

✓ Introduced in 1987 by P. Pistilli to MACRO Collaboration for Master Degree thesis

✓ Activity for the thesis:

- Breaf period of activity on the MACRO DAQ system in the Rome group, supervisor **Ernesto Lamanna**

  - *Internal Note published*


NOTA INTERNA n.893
27 Luglio 1987

Dipartimento di Fisica
Università di Roma "La Sapienza"
I.N.F.N. - Sezione di Roma

A.Giannasca, E.Lamanna, G.Mancarella, O.Palamara, L.Petrillo, A.Surdo.

A NEW LIBRARY OF CAMAC ROUTINES FOR THE CONTROL OF THE SYSTEM CRATE* BY A µVAX IN THE VAXELN ENVIRONMENT.

  - Thanks all people of Rome group …

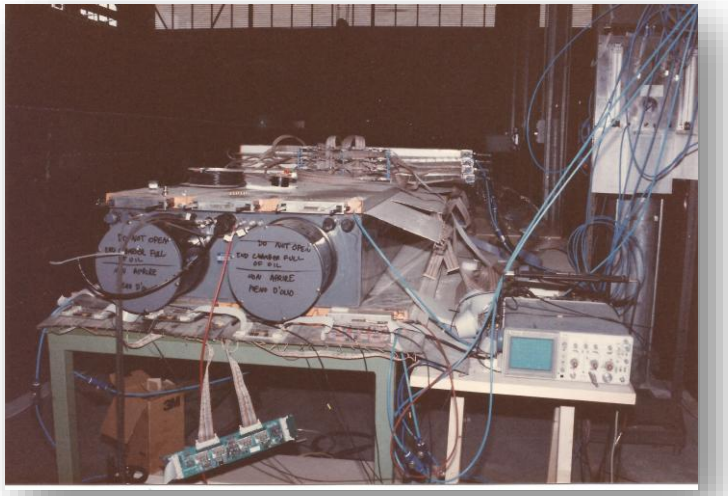
- Continuation of activity in subsequent months at Frascati (LNF)

1. Pioneering stage (1987 – 89)

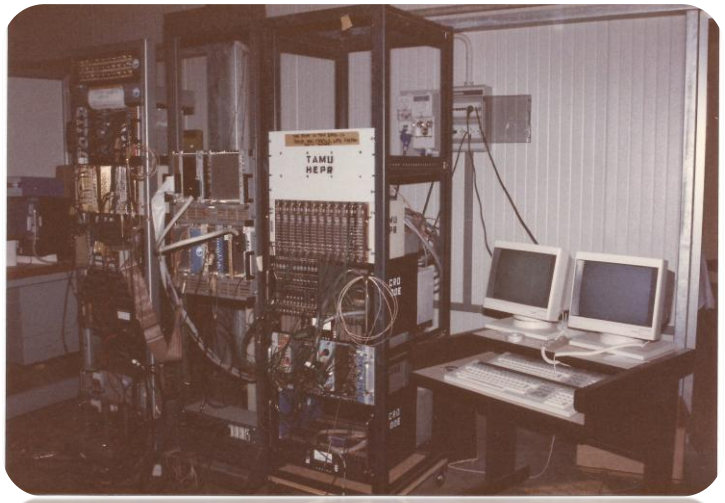
- ✓ Most of activity for degree thesis at Frascati INFN National Laboratory, under the supervision of **Francesco Ronga** (but also with others in the group … thanks a lot!)
- ✓ Stimulating period (contacts with several graduand colleagues / young researchers)
- ✓ Work on MACRO DAQ and slow control, in the lab of the old *High Energy Building*

- At that time, in LNF …

Tests on Streamer Tubes



Tests of the Scintillators



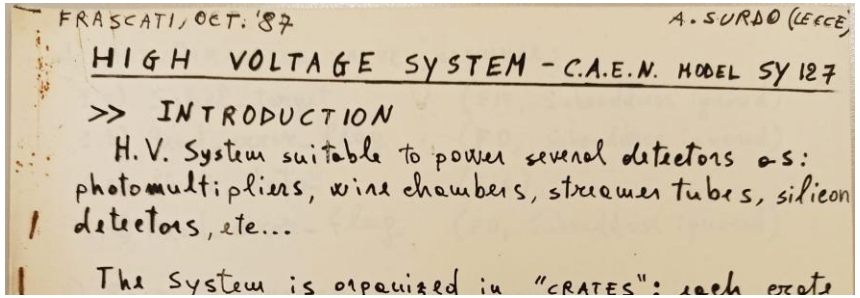
DAQ System test station

1. Pioneering stage (1987 – 89)

✓ Attendance of my **first MACRO Collaboration Meeting (LNF, Oct 1987)**

- **First visit to the under-ground Gran Sasso Laboratory**
- Hall B just completed and ready for the detector intallation
- **Inauguration of the 1st Streamer Tube plane** (Oct 1987)

My first contribution in a
MACRO Collaboration Meeting

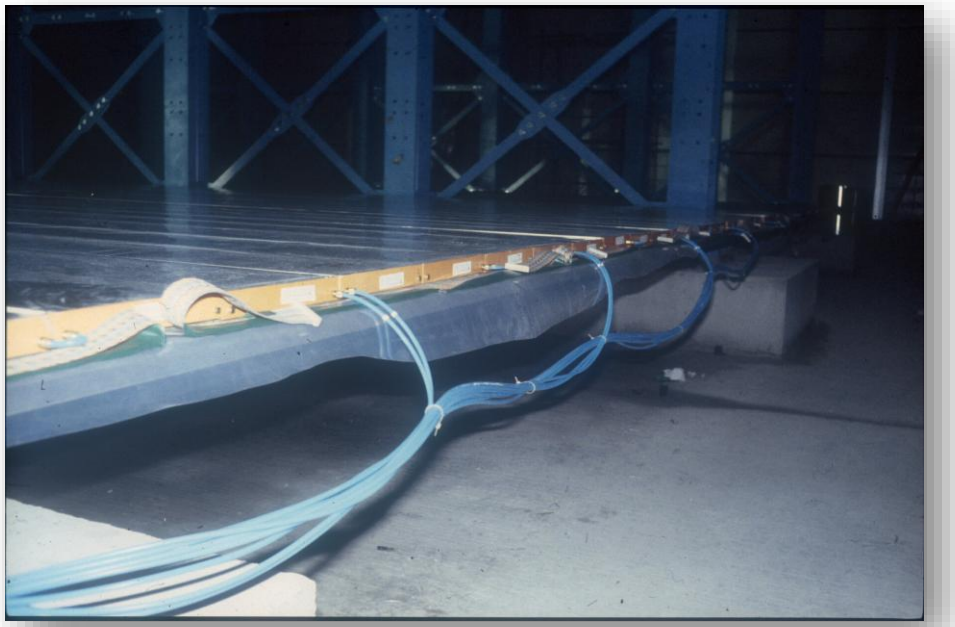

FRASCATI, OCT. '87 A. SURDO (LECCE)

HIGH VOLTAGE SYSTEM - C.A.E.N. MODEL SY 127

>> INTRODUCTION

H.V. System suitable to power several detectors as: photomultipliers, wire chambers, streamer tubes, silicon detectors, etc...

The system is organized in "CRATES": each crate

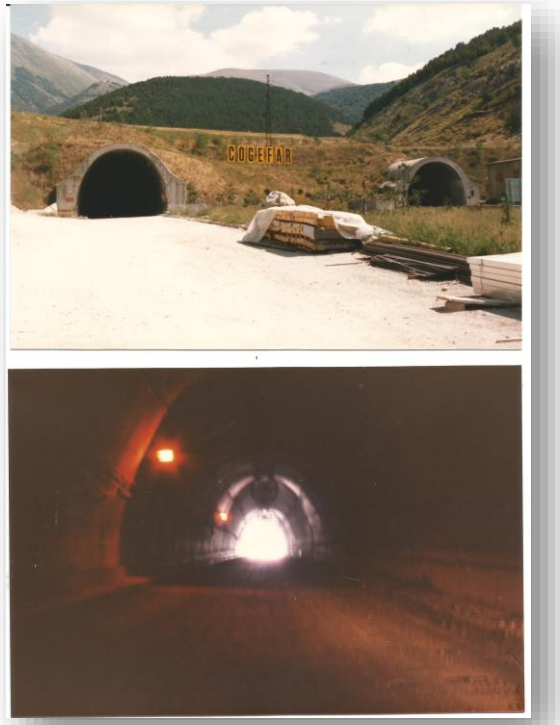


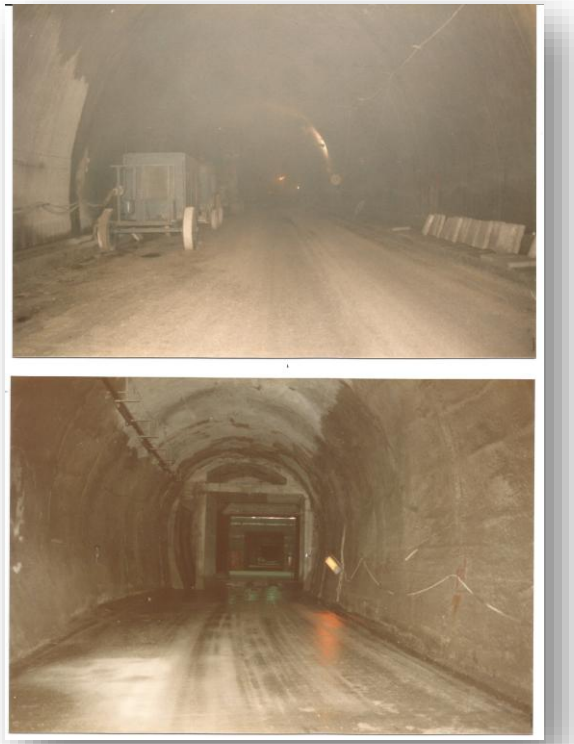
1st Streamer Tube plane installed in Hall B of LNGS

1. Pioneering stage (1987 – 89)

- ✓ Several shifts to the Gran Sasso Lab during detector installation in Hall B
- ✓ Access to underground lab not so easy (dismal road, no lights in the tunnel, ..)
  → … **heroic times!** (for people directly involved in detector installation)

MACRO and electronics room at beginning

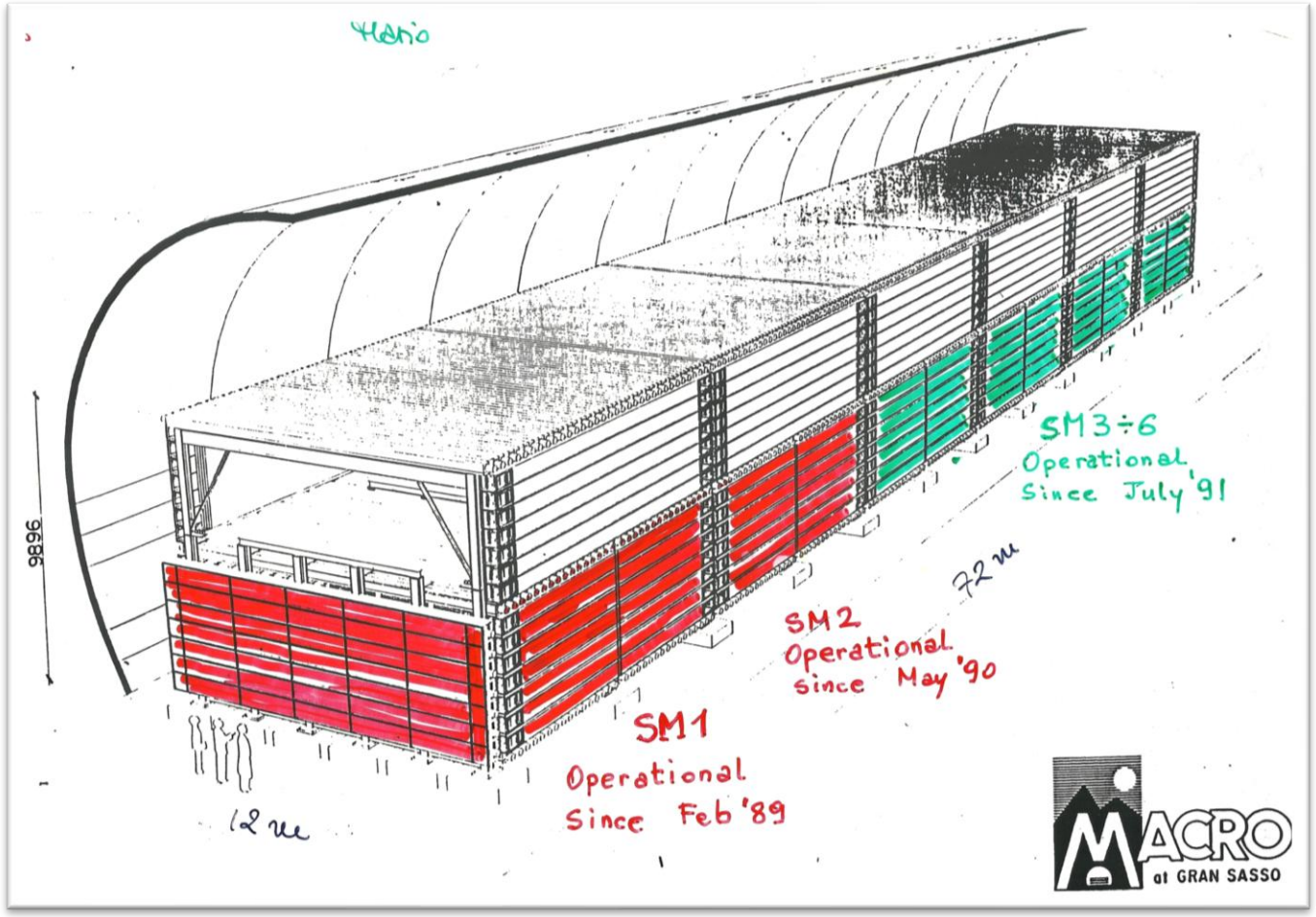




Tunnel and service galleries at beginning of MACRO construction

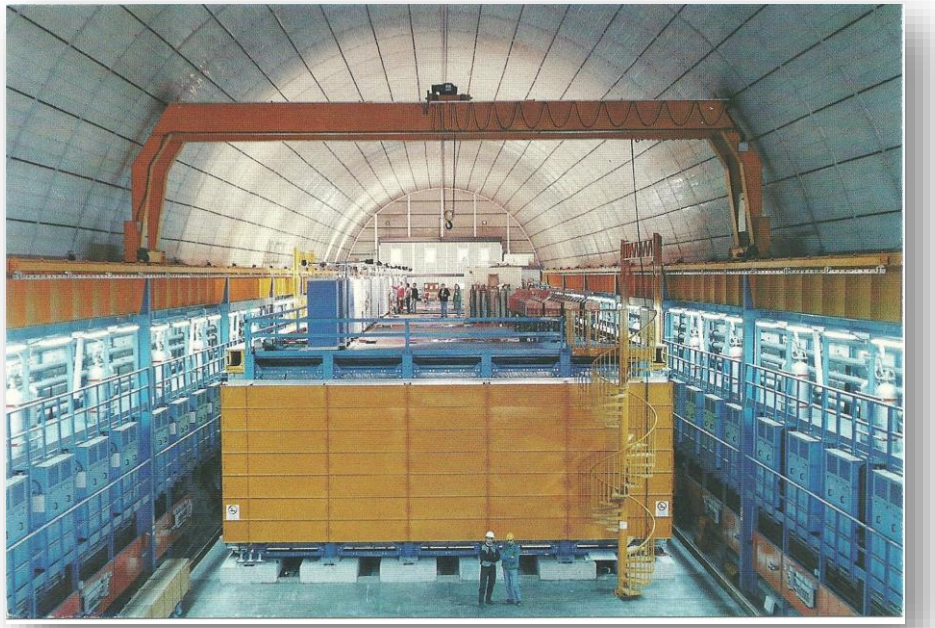
2. Construction stage (1990 – 94)

✓ Several years of Intense work in Hall B, for the **apparatus build-up** and completion



July 1991 –

MACRO lower part completed and (partially) operational



2. Construction stage (1990 – 94)

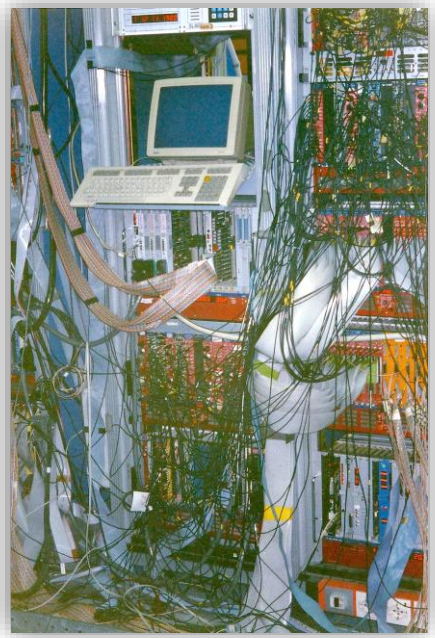
- ✓ Exciting period, with very frequent shifts to Gran Sasso and many contributions to the functional tests and debug of the detector components

Young people team involved in detector tests

- ✓ Tight interactions with many people involved in the ST (STAS, QTP, ..) electronics installation and tests
- ✓ In particular with **Attanasio** and Bari people for STAS debug, Beppe and other Naples people for QTP tests, ...
- ✓ Develpments of several tools for electronics and DAQ system debug (like the «Poor Man Event Display» by F. Ronga)

2. Construction stage (1990 – 94)

- ✓ Also time devoted to installation and debug of the DAQ system with 3 micro-vaxes and related electronics up to commissioning of the 6 Super Modules (Jul ‘91)





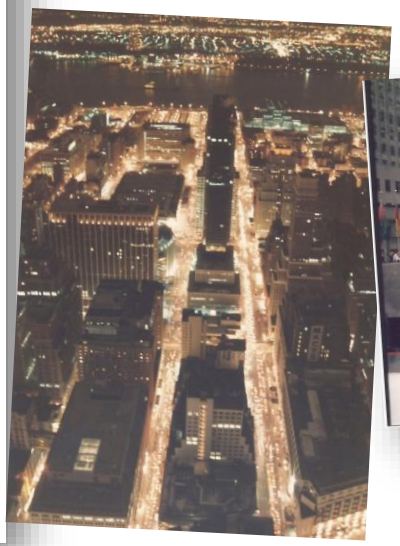


2. Construction stage (1990 – 94)

- Start of Collaboration Meetings in USA …

  ✓ **Bloomington – Indiana (March 1990)**

… trip to **New York** after CM



On top of Twin Towers

2. Construction stage (1990 – 94)

✓ A **contest** was launched by Naples group in **October 1990** with **CM at Capri …**

⇒ **Organizing the Collaboration Meeting in a nice location!**

1990 Naples - Capri
1991 Bologna – Cesenatico
1992 Boston – Cape Cod
1993 Bari - Martina Franca
1994 Texas – Corpus Christi
1996 Drexel – Cape May

1990 - Hotel La Palma, Capri

Wonderful MACRO General Meeting in a unique location!

2. Construction stage (1990 – 94)

✓ **Boston - Cape Cod (1992)**

Boston

Country music pub (Cape Cod)

On boat for Whale watching

2. Construction stage (1990 – 94)

✓ **Caltech – Pasadena (1993)**

… then to Death Valley!

On the road to Death Valley

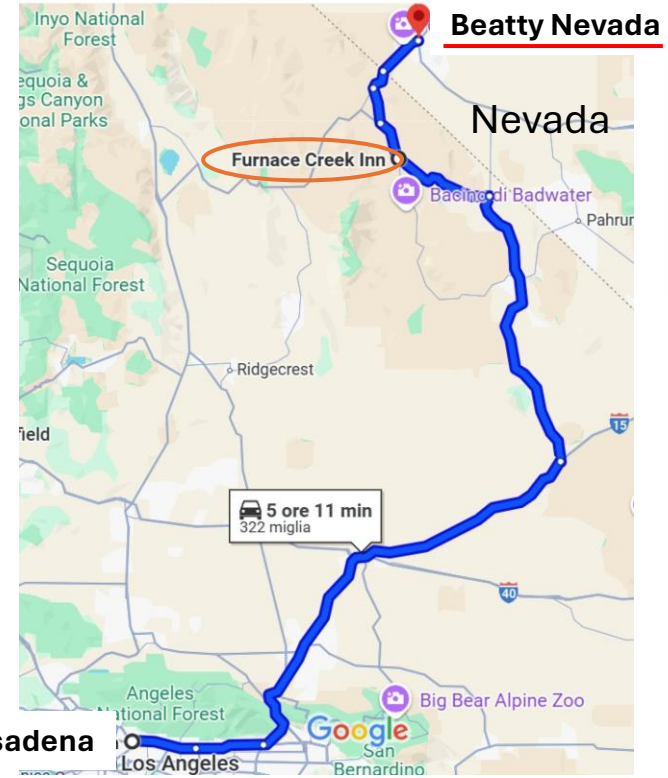
Death Valley: Badwater Basin

2. Construction stage (1990 – 94)

✓ Death Valley trip … a real adventure!

Furnace Creek Inn
NO VACANCY!

Searching for a Motel
in the region ..



Finally to Beatty Nevada

2. Construction stage (1990 – 94)

✓ **Bari – Martina Franca (1993)**

Martina Franca
- Social dinner

✓ **Texas – Corpus Christi (1994)**

Corpus Christi – Ocean seagulls

Corpus Christi – Social dinner

Alamo - San Antonio

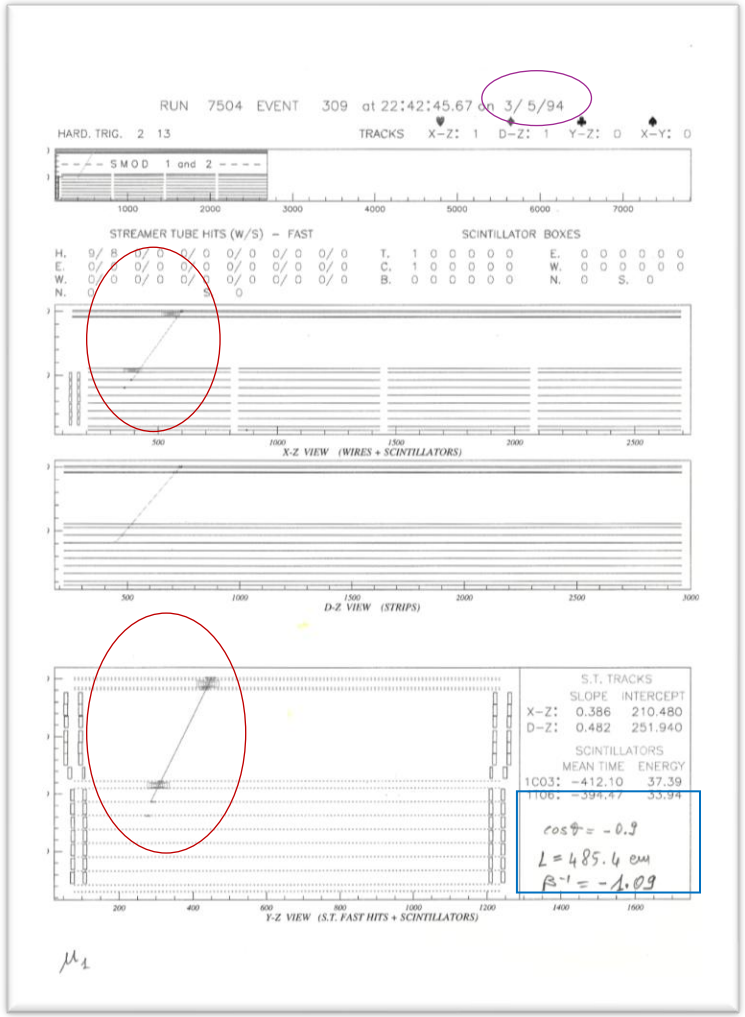
2. Construction stage (1990 – 94)

- ✓ Mar – Oct 1994: my six month period in charge as *Run Coordinator*
- ✓ The **6 MACRO Super Modules**, including **«Attico»**, **completed** and put in data-taking by middle 1994

MACRO during Attico construction

3-May-1994:

1st *In-Up* neutrino event detected!



2. Construction stage (1990 – 94)

- ✓ **October 1994**: MACRO Collaboration Meeting in **Rome**
- ✓ Celebration of **full MACRO data-taking start** and **10 years of MACRO!**

Unforgettable social dinner!

10 years of MACRO celebration …







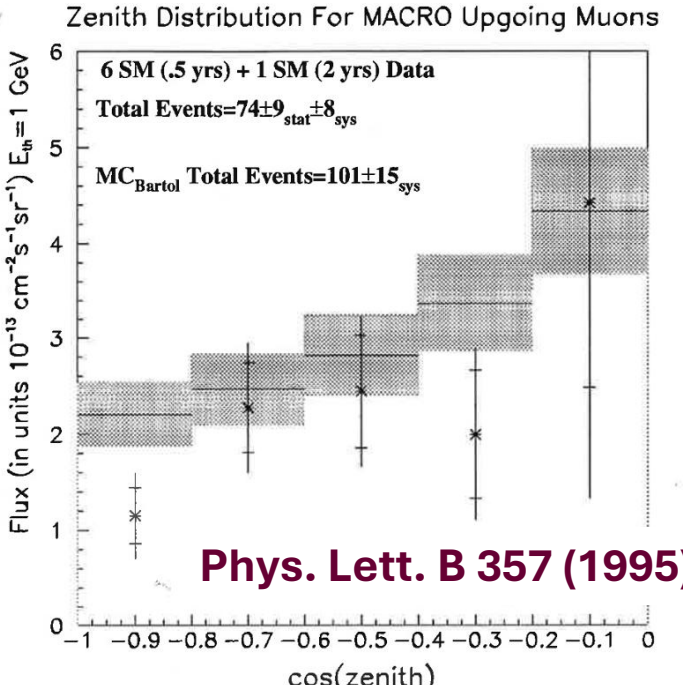
… and a wild dancing night





3. Neutrino search stage (1995 – 98)

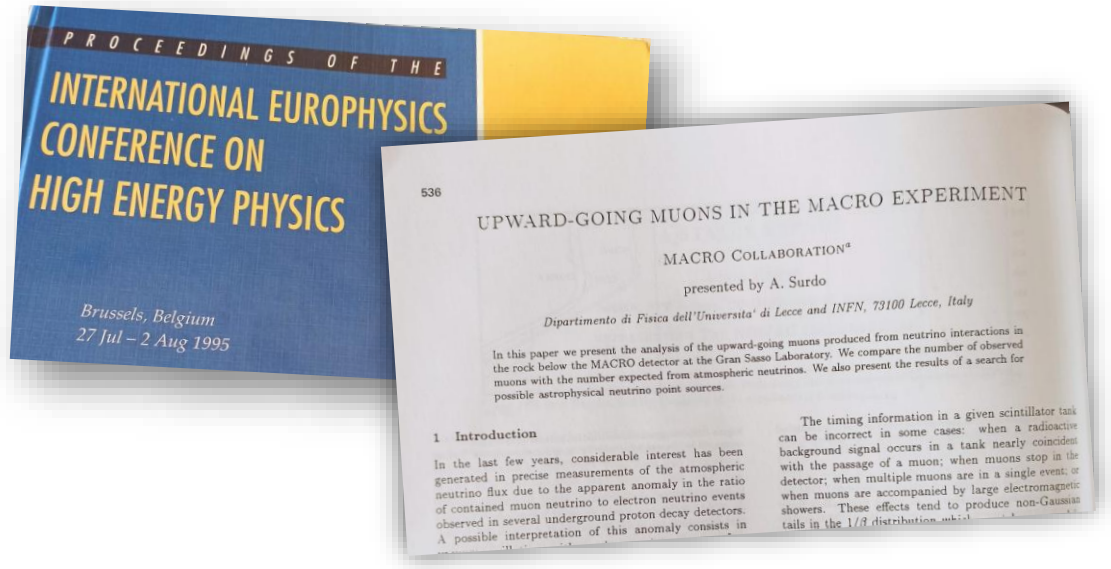
- ✓ Exciting period of analysis activity (after "multi-muon" analysis phase) in a very hot physics item: **atmospheric neutrino flux**
- ✓ Involved in the study of ***Up-Throughging*** muons with the Lecce group (Paolo, ..), then mainly in the search for the ***Internal-Upgoing*** **muons** (*In-Up* events)



Phys. Lett. B 357 (1995)

1st MACRO paper on atm. neutrino flux

My first contribution on that item
(EPS-HEP, Brussels, 1995)



3. Neutrino search stage (1995 – 98)

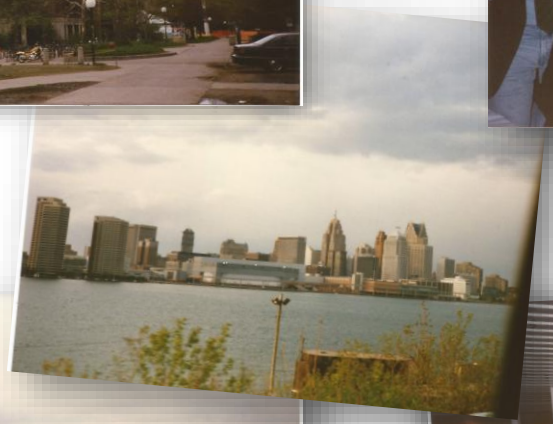
✓ **Drexel – Cape May (1996)**

The social dinner

Sunset at Cape May

3. Neutrino search stage (1995 – 98)

✓ **Michigan – Ann Arbor (1997)**



Social dinner

Trip to the
Niagara Falls

3. Neutrino search stage (1995 – 98)

✓ **1998 - Boston**

MACRO social dinner on the boat

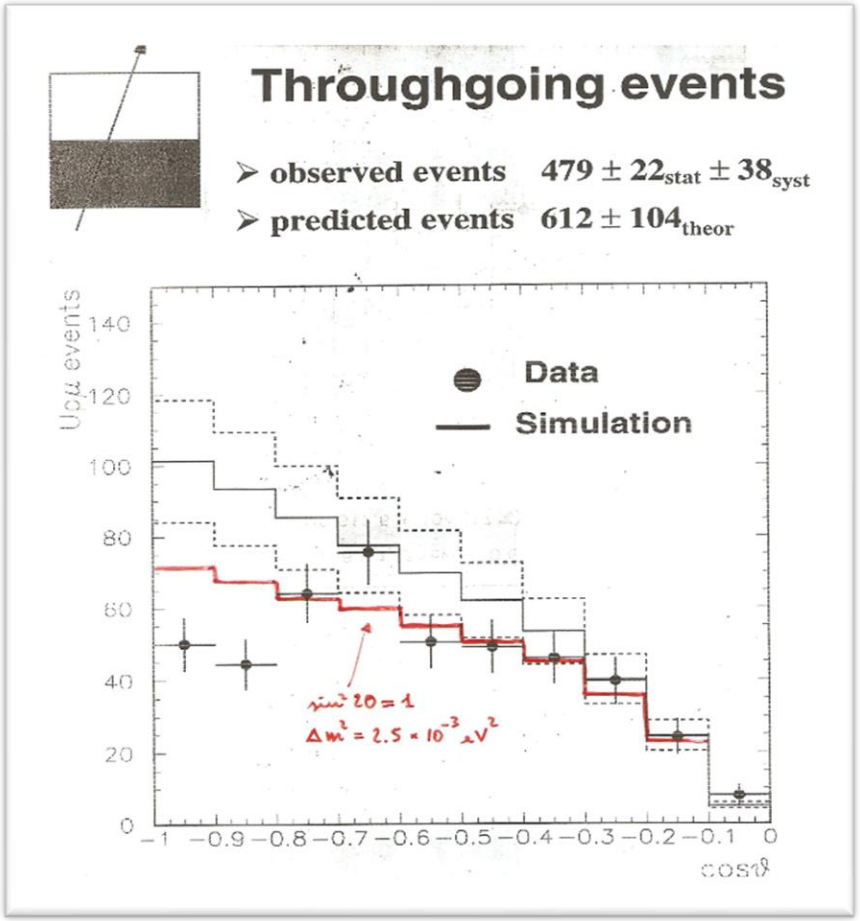
MIT - Cambridge

Marathon

3. Neutrino search stage (1995 – 98)

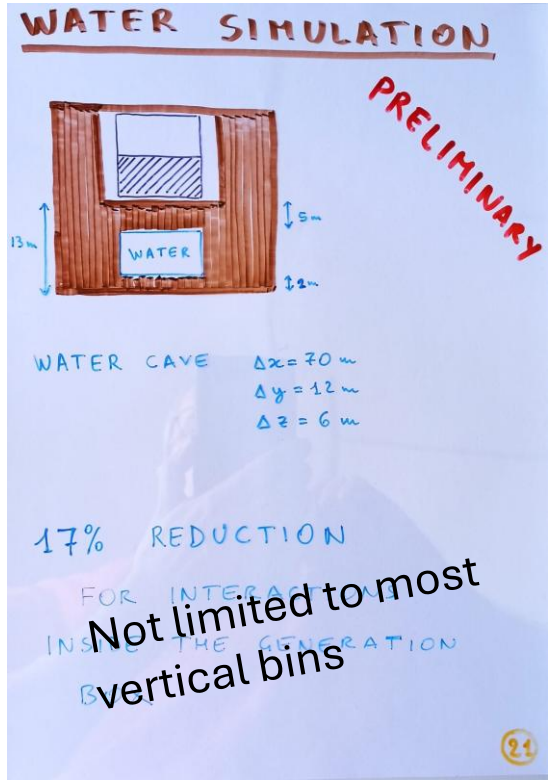
✓ Zenith angle distribution of Up-Throughgoing muons not so smooth …

→ many checks on systematics to try to explain the shape … without results!



.. try to **excavate under MACRO** searching for a water pool ..

Slide by P. Bernardini (CM, Ann Arbor 1997)

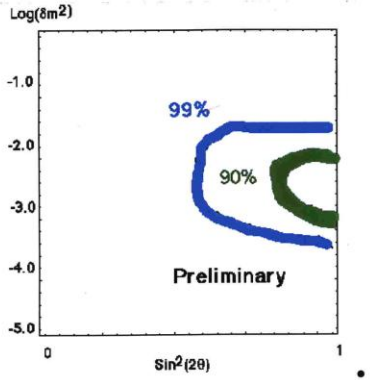


3. Neutrino search stage (1995 – 98)

✓ **Main result from atmospheric ν analyses finally presented at "*Neutrino-98*"**

Slides by F. Ronga

Confidence regions for oscillation parameters (Feldman-Cousins)



- Note : In this kind of plots there is **no information** on the goodness of the agreement of data with the hypothesis You assume that the model is correct (Pbest=17%).
- The regions are smaller than the one expected from the "sensitivity" (statistical fluctuation?)

Conclusions

MACRO **Upgoing Muons** (Through-going) :
Eν≈100 GeV

- Peak probability νμ --> ντ **17%**
- Probability for No oscillations **0.1%**
- Peak Probability νμ --> ν sterile **2%**

Low energy events:
Eν≈5 GeV

	R=data/predict	No oscillations	With oscillations $10^{-3}<\delta m^2<10^{-2}$
Internal Up	0.53±0.15	1	0.56
Internal Down + Stopping Up	0.71±0.21	1	0.73

Conclusion: a νμ --> ντ oscillation with maximum mixing and $\delta m^2 \approx$ a few units in 10^{-3} eV2 is consistent with all the MACRO Data

Only Warning :
The peak probability for the angular distributions of the Upgoing Muons (Through-going) is low (4.6%)
==>> Statistical Fluctuation or Hidden Physics?

$\nu_\mu \rightarrow \nu_\tau$ oscillations clearly favored!

Same results presented by SK

From MACRO proposal ...

In 1984, proposal anticipates MACRO sensitivity and contribution to neutrino oscillations ....

Hence, in two years of operation, our experiment can set a 3σ limit for neutrino oscillations for mass differences in excess of 10^{-3} eV² for maximal mixing. In Fig. (2)13, this limit (shaded region) is compared with the present limits set by other neutrino oscillation experiments. For $\sin^2 2\theta > 0.6$, the experiment should yield nearly an order of magnitude improvement for the limit on Δm^2.

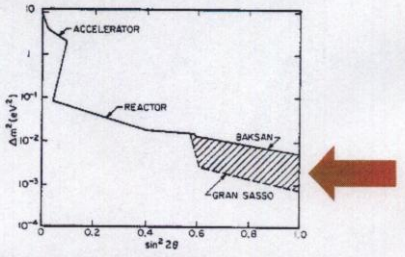


Fig. (2)13 Present best limits on Δm^2 vs. $\sin^2 2\theta$. The shaded region represents the improvement obtainable with our experiment.

4. Closing stage (1999 – 2000)

✓ **Caltech – Pasadena (1999)**

Malibu beach

✓ **Gran Sasso – Last MACRO CM (Jan 2000)**

Villa Dragonetti - Social dinner

Jan 21, 2000

Spokesperson speech

Crying for MACRO end!

4. Closing stage (1999 – 2000)

MACRO main outcomes:

- ✓ Results on **atmospheric neutrino oscillation** established
- ✓ **Cosmic ray** composition studies and many results on muon physics published
- ✓ Most stringent **magnetic monopole** flux limits set
- ✓ …

⇒ main motivation boost to continue the experiment by then axhausted!

✓ **Debate inside the Collaboration:**

"Close the experiment or continue data-taking as a permanent Observatory? "

✓ **Main goals for continue data-taking:**

- Setting more stringent limits on magnetic monopole flux
- Waiting for a stellar collapse in the Galaxy (estimate: ~1/20 years on average)

4. Closing stage (1999 – 2000)

✓ Debate conclusion:

Close MACRO data-taking by end 2000

Stopping MACRO Run!

(since the scientific motivations were not enough strong to continue)

✓ My personal (and several people) prevalent attitude:

MACRO should be continued ..

Looking back, such an attitude not based on robust scientific reasons ...

rather it was of emotional nature ...

... we were too fine within this Collaboration!

December 19-21, 2000: The End!

Thank you!