WORKING WITH ITALO

Luigi Di Lella

CERN and Physics Department, University of Pisa

- Some old memories
- Studying $K^{\pm} \rightarrow \pi^{\pm}\pi^{\circ}\pi^{\circ}$ decays in the NA48/2 experiment
- Measuring the ratio of the $K^{+} \rightarrow e^{+}\nu_{e}$ to the $K^{+} \rightarrow \mu^{+}\nu_{\mu}$ decay rate
- The fast muon veto in the NA62 experiment

Italo's Fest

S.N.S. , Pisa, September 5th, 2018

1953 - 54: first-year physics student
at Scuola Normale Superiore
(ranked first at the entrance examinations)

Italo with fellow students Giorgio Bellettini and Vittorio Silvestrini (physics) and Mario Dall’Aglio (chemistry) while violating Italian traffic rules (1957?)

All S.N.S. students (Spring 1957)
Both Humanities and Sciences, 1st to 4th year

1957: the year when parity violation was first observed

(in β – decay of polarized Co^{60} nuclei and in the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain)

There were suggestions that parity violation would be observed only in final states containing neutrinos (the V – A theory had not been formulated yet)

For his physics degree in 1957, Italo worked on a search for parity violation in $\Lambda \rightarrow p\, \pi^-$ decay (a weak decay with no neutrinos in the final state)

Phys. Rev. **108** (1957) 1353

Demonstration of Parity Nonconservation in Hyperon Decay*†

F. EISLER, R. PLANO, A. PRODELL, N. SAMIOS, M. SCHWARTZ, AND J. STEINBERGER, *Columbia University, New York, New York and Brookhaven National Laboratory, Upton, New York*

P. BASSI, V. BORELLI, G. PUPPI, G. TANAKA, P. WOLOSCHEK, AND V. ZOBOLI, *Istituto di Fisica, Bologna, Italy*

M. CONVERSI, P. FRANZINI, I. MANNELLI, R. SANTANGELO, AND V. SILVESTRINI, *Istituto di Fisica, Pisa, Italy*

AND

D. A. GLASER, C. GRAVES, M. L. PERL, *University of Michigan, Ann Arbor, Michigan*

(Received October 21, 1957)

A bubble chamber exposure to ~1 GeV beams from the 3 GeV proton synchrotron ("Cosmotron") at the Brookhaven National Laboratory.

Event analysis performed in various laboratories including Bologna and Pisa.

$\pi^- + p \rightarrow \Lambda + K^\circ$ produces Λ – hyperons with polarization normal to the Λ production plane.

Result:

$$< P_\Lambda > \alpha = 0.40 \pm 0.11$$

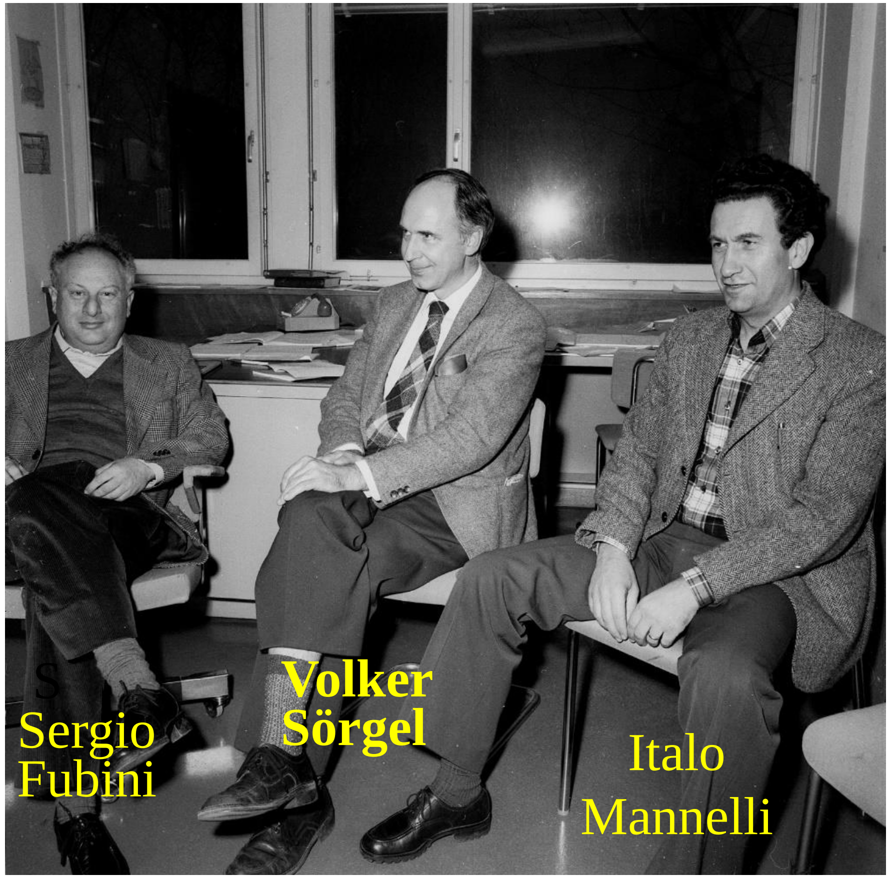
1958: Italo receives a S.I.F. prize for his thesis

(S.I.F.: Italian Physical Society)

1958: Summer School on Particle Physics in Varenna (Lake Como)

Until 2003 Italo and I never worked together on the same experiment, though in the mid 1960s and in the 2nd half of the 1970s we did experiments at the same CERN accelerator (the PS in the 1960s and the ISR in the 1970s).

At the end of the 1970s Italo became a member of the CERN Directorate.
So, while preparing the UA2 experiment at the CERN $\bar{p}$ p collider,
I had a few physics discussions with him



Members of the CERN Directorate, 1979 - 80

2003: the year when I started working with Italo

Following my retirement from CERN, Italo offered me a scientific associateship at S.N.S. to work on the NA48/2 experiment to search for direct violation of CP symmetry in the decay of charged K-mesons to three pions:

$K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ (Branching fraction 5.57%)

$K^{\pm} \to \pi^{\pm}\pi^{\circ}\pi^{\circ}$ (Branching fraction 1.73%)

NA48/2 used the same detector as NA48, with two simultaneous 60 GeV K^{+} and K^{-} beam lines superimposed in space in the decay volume (designed and tuned by Niels Doble **)**

METHOD: search for K^{+} / K^{-} difference of "odd pion" energy distribution

"Odd pion": π^{-} in $K^{+} \to \pi^{+}\pi^{+}\pi^{-}$; π^{+} in $K^{-} \to \pi^{-}\pi^{-}\pi^{+}$; $\pi^{\pm}$ in $K^{\pm} \to \pi^{\pm}\pi^{\circ}\pi^{\circ}$

Matrix element: $|\boldsymbol{M(u,v)}|^2 = \boldsymbol{1 + gu + hu^2 + kv^2}$

$$\left(\begin{array}{l} g \approx -0.215 \text{ for } K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-} \\ g \approx 0.638 \text{ for } K^{\pm} \to \pi^{\pm}\pi^{\circ}\pi^{\circ} \end{array} \right)$$

Kinematic variables: $u = (s_3 - s_0)/m_\pi{}^2$ $\quad v = (s_2 - s_1)/m_\pi{}^2$ $\quad$ (i = 3 : odd pion)

$$s_i = (P_K - P_i)^2 = (m_K - m_\pi)^2 - 2m_K T_i^* \qquad s_0 = \frac{(s_1 + s_2 + s_3)}{3} = \frac{1}{3}\left(m_K{}^2 + \sum_i m_i{}^2\right)$$

(T_i^* : kinetic energy of the i – th pion in the $K^{\pm}$ rest frame)

Violation of CP symmetry: $A_g \equiv \dfrac{g_{K^+} - g_{K^-}}{g_{K^+} + g_{K^-}} \neq 0$

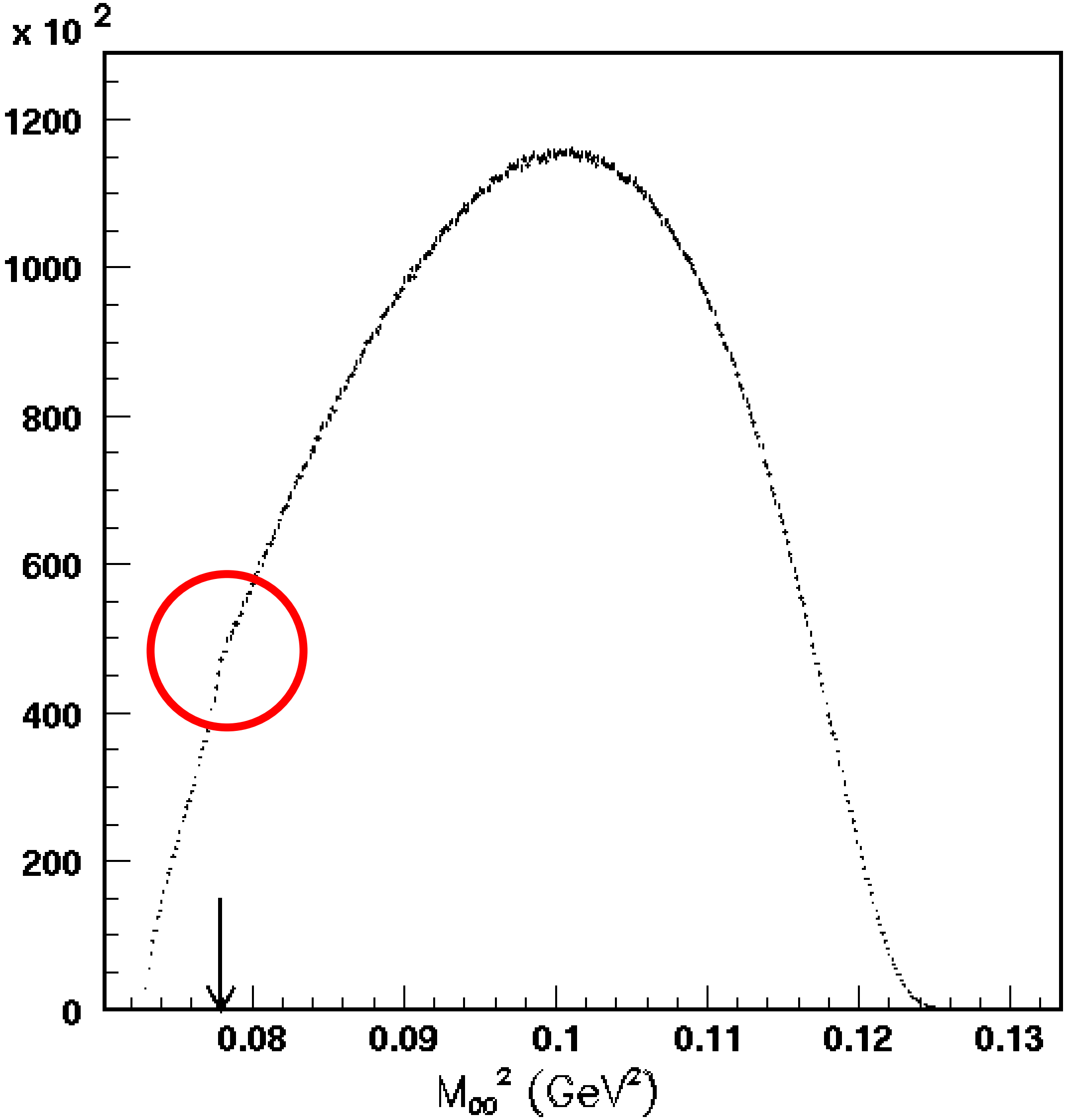
Standard Model predictions on the CP–violating parameter A_g (A_g of the order of 10^{-5}) were lower than the uncertainty on A_g expected from the NA48/2 experiment ($\delta A_g \approx 2 \times 10^{-4}$, mainly limited by statistics).

Indeed, no evidence for direct CP violation was found. However, the large event samples reconstructed by NA48/2 (3.1×10^9 $K^\pm \to \pi^\pm\pi^+\pi^-$ and 9.1×10^7 $K^\pm \to \pi^\pm\pi^\circ\pi^\circ$ events) allowed measurements of other $K^\pm$ decay properties with higher precision than previous experiments.

Before the start of data–taking, Italo had suggested that, when a $\pi^+\pi^-$ pair from $K^\pm \to \pi^\pm\pi^+\pi^-$ decay is produced with invariant mass $M_{\pi\pi} \approx 2m_{\pi+}$ (corresponding to ~ zero relative velocity), $\pi^+\pi^-$ atoms (''pionium'') are formed, soon decaying to $\pi^\circ\pi^\circ$.

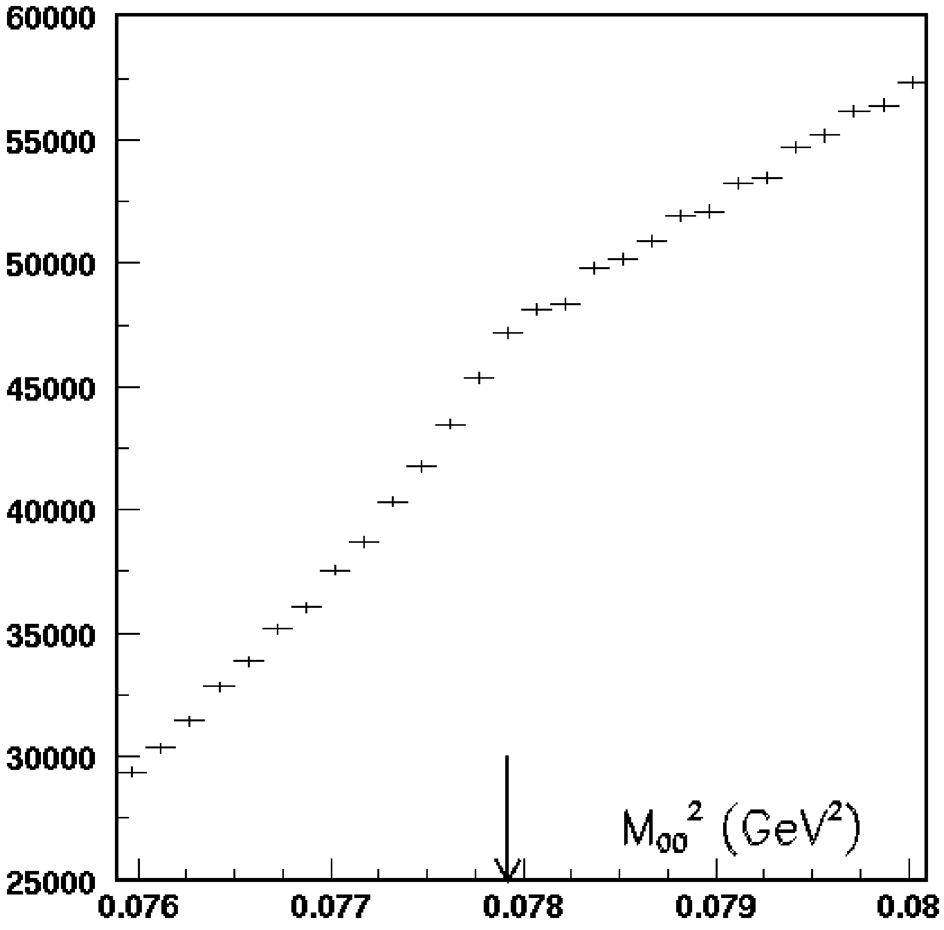
Hence, in the decay $K^\pm \to \pi^\pm\pi^\circ\pi^\circ$, one should observe an excess of $\pi^\circ\pi^\circ$ pairs at $M_{\pi\pi} \approx 2m_{\pi+}$, consistent with the detector $\pi^\circ\pi^\circ$ invariant mass resolution ($\sigma \approx 0.5$ MeV at $M_{\pi\pi} \approx 2m_{\pi+}$, thanks to the excellent energy resolution of the Liquid Krypton calorimeter and to the reconstruction method of $\pi^\circ\pi^\circ$ pairs).

Experimental M_{oo}^2 distribution
for 25.82 x 10^6 $K^\pm \rightarrow \pi^\pm \pi^\circ \pi^\circ$ decays
(after the 1st data-taking year)



A change of slope ("cusp") is visible at $M_{oo} = 2m_+$, associated with a "deficit" of events for $M_{oo} < 2m_+$

Experimental M_{oo}^2 distribution
"Zoom" on the cusp region

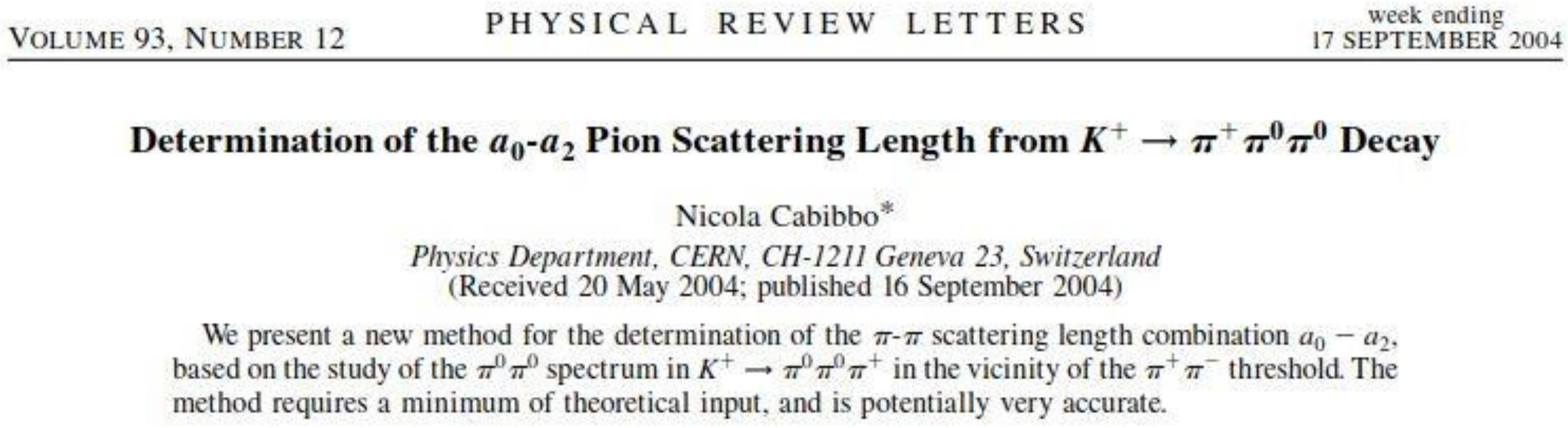


This phenomenon had never been observed before.
Some of us named it ''the Mannelli effect'' .

The origin of the Mannelli effect was mysterious to all of us.

Italo tried to arouse the interest of theorists in Pisa to try to understand it, with no success.

Major progress occurred in 2004, when Nicola Cabibbo came to CERN for a sabbatical year and was assigned an office close to ours. He understood the Mannelli effect and wrote a paper explaining its origin.



VOLUME 93, NUMBER 12 PHYSICAL REVIEW LETTERS week ending 17 SEPTEMBER 2004

Determination of the a_0-a_2 Pion Scattering Length from $K^+ \to \pi^+\pi^0\pi^0$ Decay

Nicola Cabibbo*

Physics Department, CERN, CH-1211 Geneva 23, Switzerland

(Received 20 May 2004; published 16 September 2004)

We present a new method for the determination of the π-π scattering length combination $a_0 - a_2$, based on the study of the $\pi^0\pi^0$ spectrum in $K^+ \to \pi^0\pi^0\pi^+$ in the vicinity of the $\pi^+\pi^-$ threshold. The method requires a minimum of theoretical input, and is potentially very accurate.

The peculiar shape of the $\pi°\pi°$ invariant mass distribution for $M_{\pi\pi} \leq 2m_{\pi+}$ was then renamed ''the Cabibbo – Mannelli effect''.

Nicola Cabibbo's explanation of the phenomenon will be presented by Gino Isidori in the following talk.

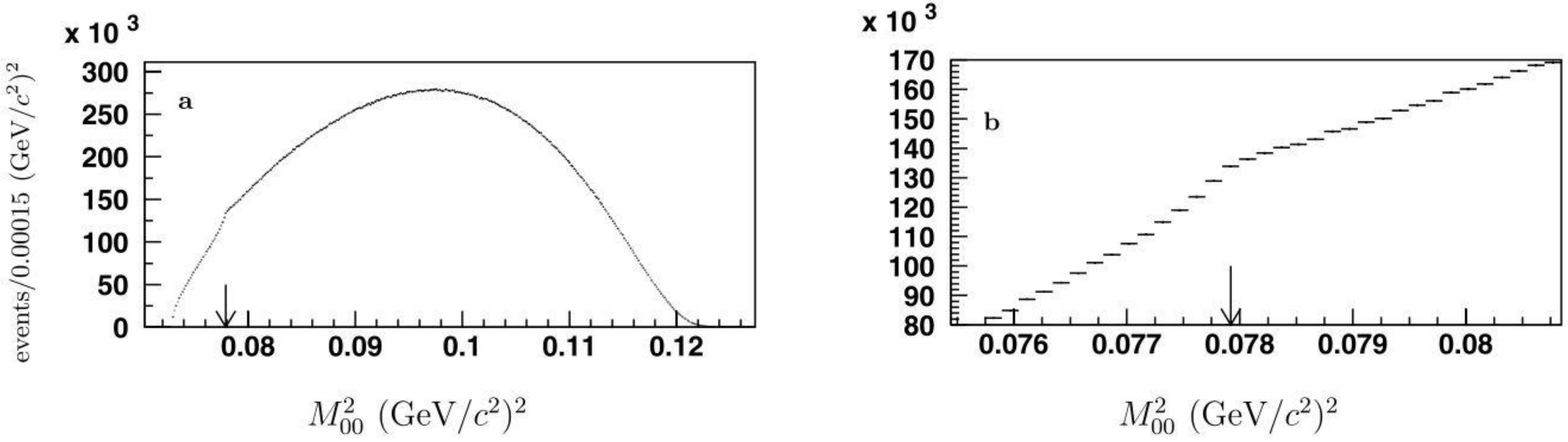
Scattering length ≡ scattering amplitude at zero energy (S – wave only)

$$a(\pi^+\pi^- \rightarrow \pi^0\pi^0) = a_0 - a_2$$

$a_0\,(a_2)$: I = 0 (2) ππ scattering length (I = 1 forbidden by Bose statistics)

In 2005 Nicola Cabibbo and Gino Isidori published a paper which included higher-order terms. We used their formulae to fit the data.

Final result (6 x 10^7 $K^\pm \rightarrow \pi^\pm\pi^\circ\pi^\circ$ decays)

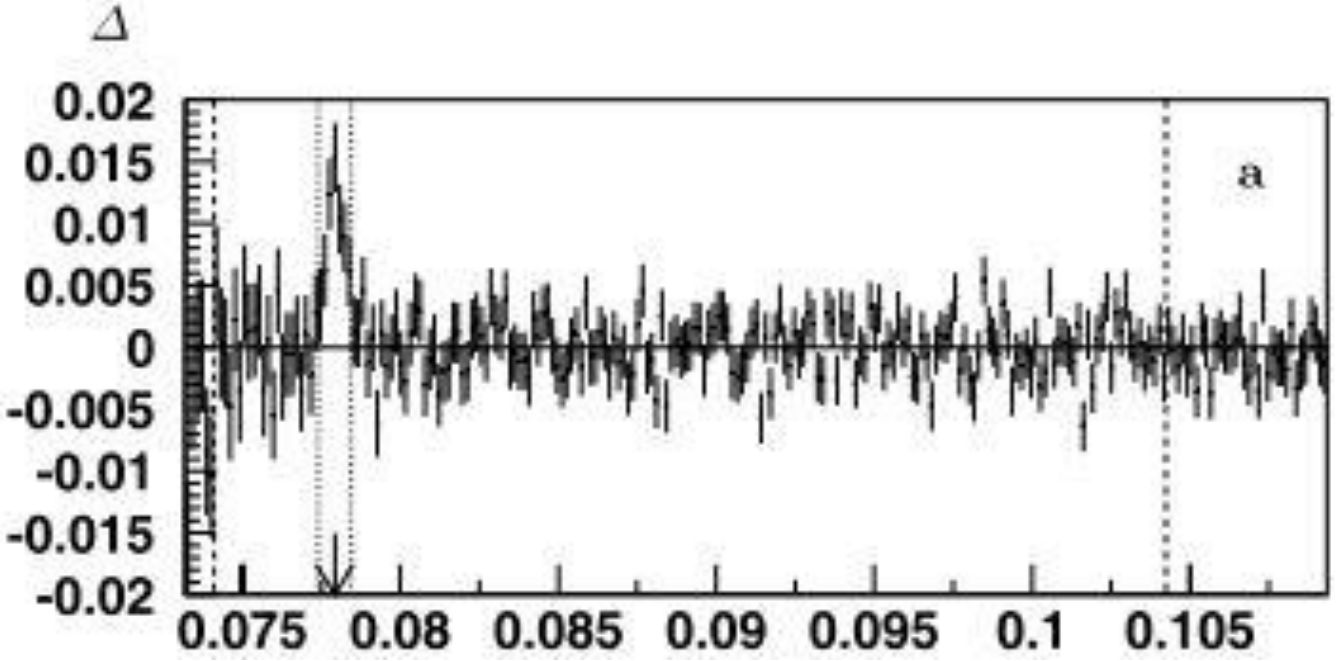


The value obtained by fitting these data, $(a_0 - a_2)m_{\pi^+}$ = 0.2633 ± 0.0034, agrees with other independent determinations (e.g., from Ke4 decays), and is one of the most precise measurements of $(a_0 - a_2)m_{\pi^+}$.

Pionium atoms, as originally suggested by Italo, were also observed

Δ = /data – fit)/data

excluding from the fit 7 points centered at $M_{00}^2 = (2\, m_{\pi+})^2$



$M_{00}^2\ (GeV/c^2)^2$

After submitting to JHEP our final paper on the Cabibbo – Mannelli effect, the JHEP referee pointed out that the effect had been predicted in 1961 !

VOLUME 6, NUMBER 8 PHYSICAL REVIEW LETTERS APRIL 15, 1961

PION-PION INTERACTION FROM THRESHOLD ANOMALIES IN K^+ DECAY

Paolo Budini
Istituto di Fisica dell' Università, Trieste, Italy
and
Luciano Fonda
Istituto di Fisica dell' Università, Palermo, Italy
(Received March 20, 1961)

Most likely, this paper was forgotten because in 1961 K → 3π decay samples were at most few thousand events and the $\pi^o\pi^o$ invariant mass resolution could not be measured with the resolution of modern detectors.

2007 – 2008 : Measurement of $R_K = \frac{\Gamma(K \to e\nu_e)}{\Gamma(K \to \mu\nu_\mu)}$

An experiment proposed by Italo to test μ – e universality with higher precision than previous measurements, using the same detector as NA48/2 and a 74 GeV beam

Standard Model prediction: $R_K = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_K{}^2 - m_e{}^2}{m_K{}^2 - m_\mu{}^2}\right)^2 (1 + \delta_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$

Radiative corrections: δ_{QED} = (-3.79 ± 0.04)%

Previous most precise measurement: $R_K = (2.493 \pm 0.031) \times 10^{-5}$ (KLOE, 13.8 K events)

Expect violation of μ – e universality at the 1% level in some models involving physics beyond the Standard Model with charged Higgs bosons:

PHYSICAL REVIEW D **74,** 011701(R) (2006)

Probing new physics through $\mu - e$ universality in $K \to \ell\nu$

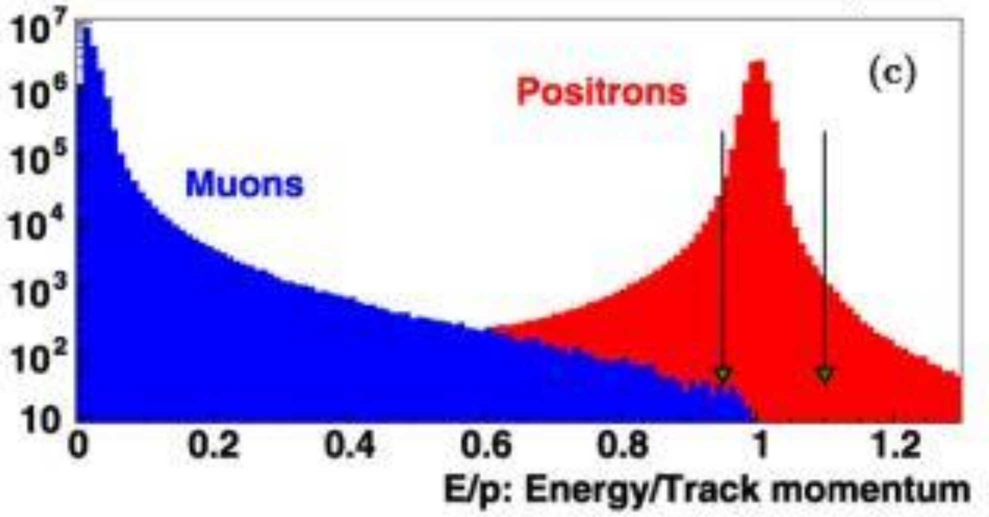
A. Masiero,[1] P. Paradisi,[2] and R. Petronzio[2]
[1]*Dip. di Fisica 'G. Galilei', Univ. di Padova and INFN, Sezione di Padova, Via Marzolo 8, I-35131, Padua, Italy*
[2]*Dip. di Fisica, Università di Roma II "Tor Vergata" and INFN, Sezione di Roma II, Via della Ricerca Scientifica 1, I-00133, Rome, Italy*
(Received 6 December 2005; published 25 July 2006)

Lepton identification based on the ratio E/p of energy deposited in the Liquid Krypton calorimeter to track momentum measured by the magnetic spectrometer.

The condition $0.95 < E/p < 1.1$ selects positrons

+ a small fraction of muons undergoing catastrophic bremsstrahlung in the calorimeter

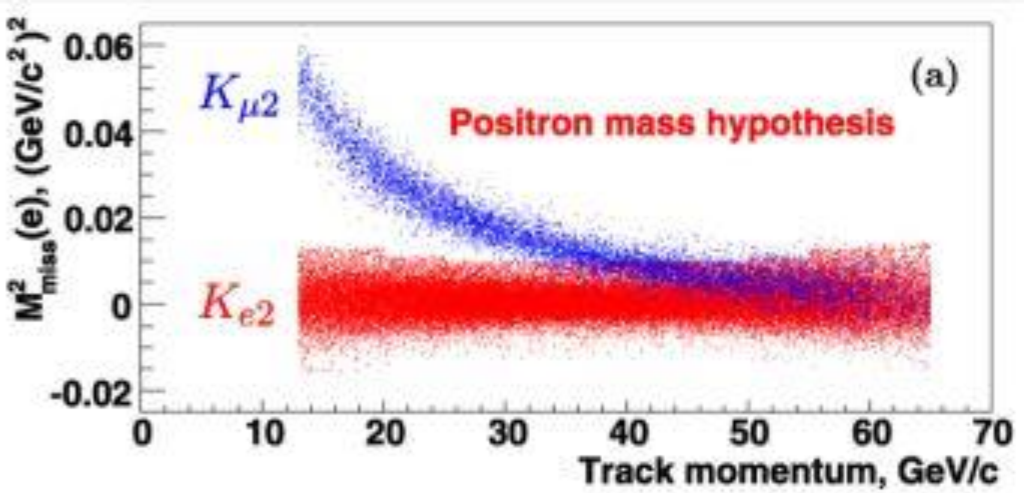
$(3 - 5) \times 10^{-6}$, depending on muon momentum



Kinematic identification requires missing mass consistent with zero from the undetected neutrino.

Genuine Ke2 decays: M^2_{miss} consistent with zero at all lepton momenta;

Kμ2 decays: separation possible only at momenta lower than 25 GeV.

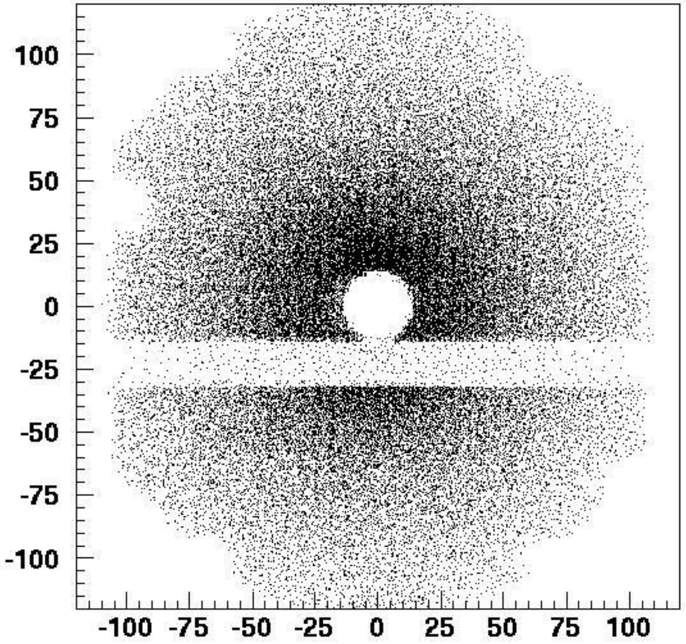


Residual Kμ2 background to the Ke2 sample must be evaluated and subtracted

Italo' proposal:

Let us MEASURE DIRECTLY the Kμ2 background by inserting a thick (9.2 r.l.) Pb wall in front of the Liquid Krypton calorimeter, over part of the acceptance. This wall will absorb all electrons, while producing only a small perturbation to the Kμ2 background.

Photo of the Pb wall before installation



Distribution of positron track coordinates (cm) over the LKr calorimeter front-face

The final Ke2 event sample consisted of 145 958 events in total.
Using data taken with the Pb wall, we measured a Kμ2 background of (6.11 ± 0.22)% .

Our final result, $R_K = (2.488 \pm 0.010) \times 10^{-5}$, agrees with the Standard Model prediction and is the most precise R_K measurement to date.

The Fast Muon Veto (MUV3) of the NA62 experiment

NA62 aims at measuring the fraction of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decays with an uncertainty of ~10% .

Standard Model prediction: $(0.781 \pm 0.080) \times 10^{-10}$

NA62 uses a high-intensity, 75 GeV hadron beam from the CERN 400 GeV SPS:

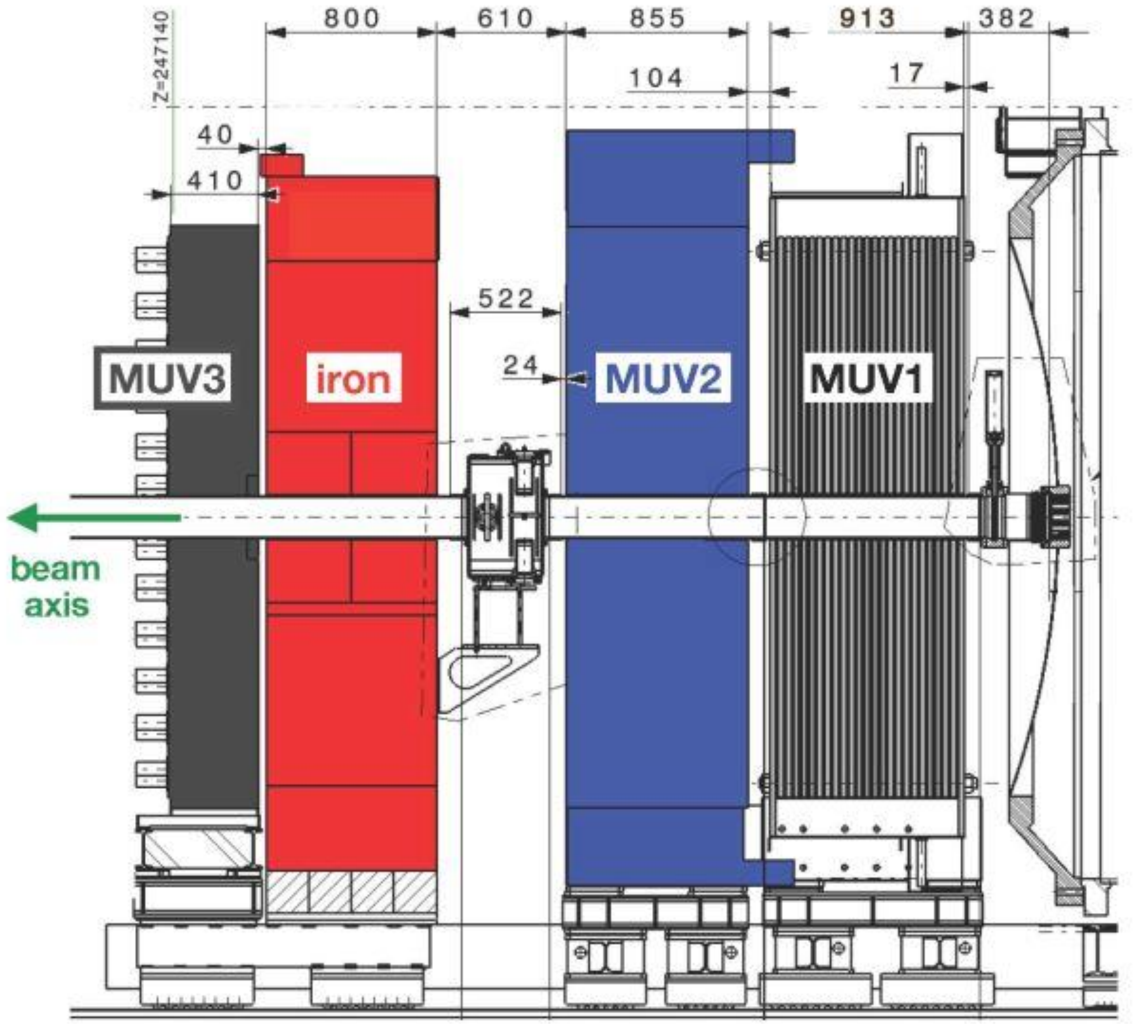
- **Total instantaneous beam rate ~600 MHz;**
- **K^+ : 6% of the total beam flux, of which ~ 10% decay in a 60 m long fiducial region**

(More details in the talk by Augusto Ceccucci)

Near the downstream end of the NA62 apparatus a system of fast scintillation counters (MUV3), located behind 80 cm of iron, provides muon rejection in real time.

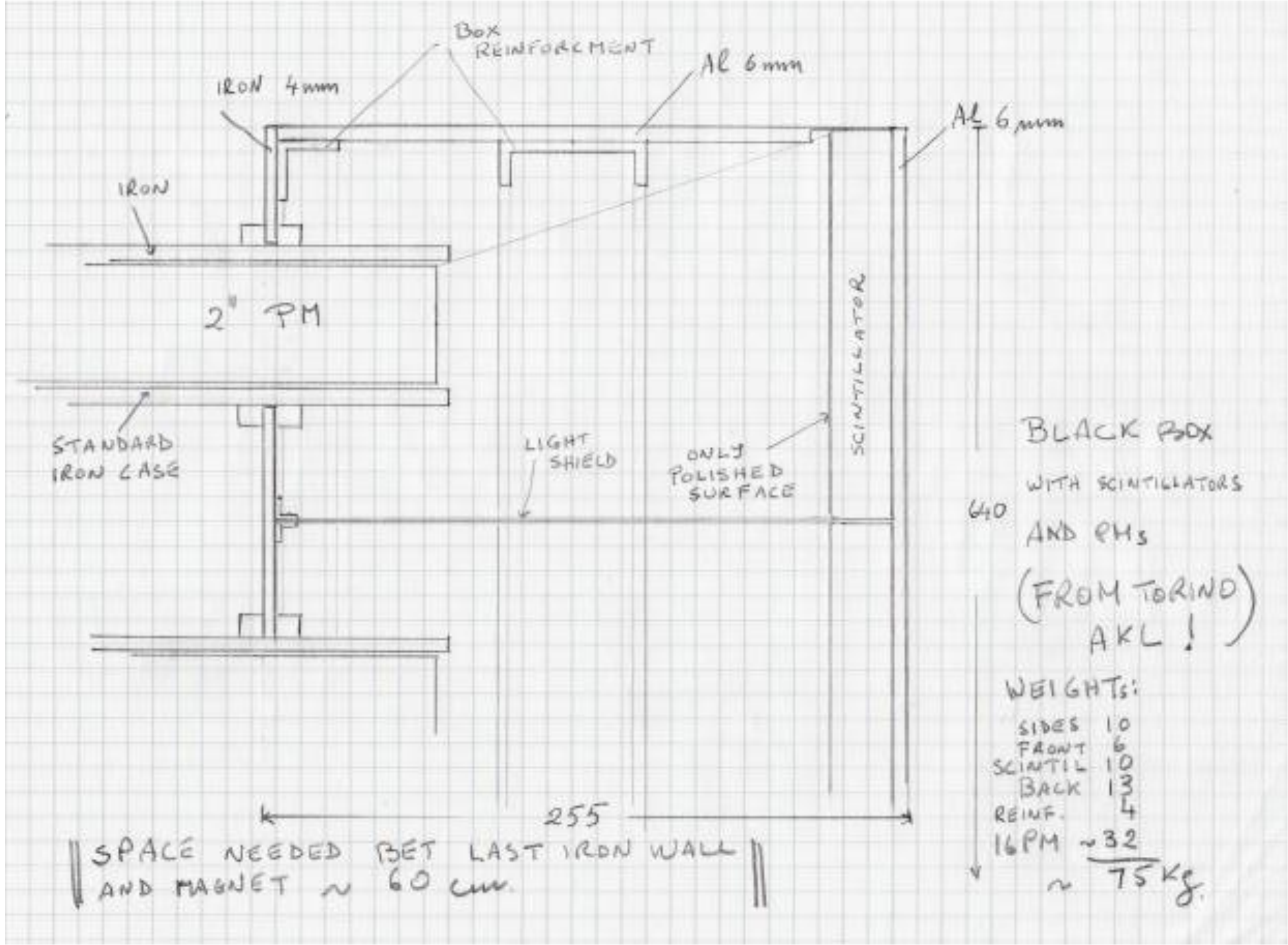
MUV3 transverse dimensions: 2.64 x 2.64 m^2

Instantaneous muon rate: ~8 MHz (mostly muons from Kμ2 decay, "muon halo", $\pi \rightarrow \mu$ decay in the beam)



The main MUV3 requirements were high efficiency and, because of the high muon rate, time resolution (possibly < 1 ns, to minimize random suppression of genuine $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ decays)

Original sketch by Italo Mannelli (end of 2009): independent scintillator tiles in light-tight boxes ("cells")

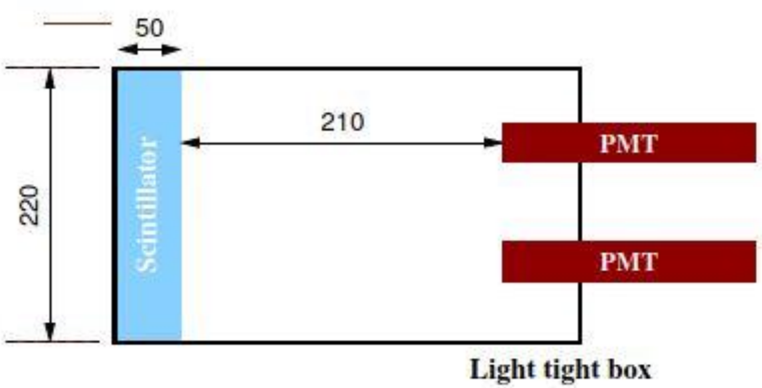


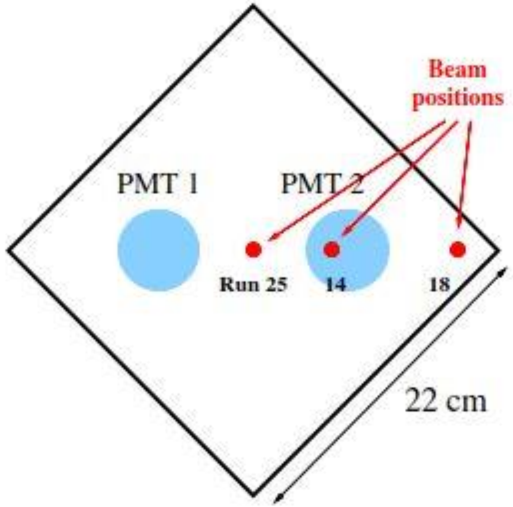
Italo made also computer simulations of light collection by the photomultiplier to validate the design.

The main limitation to time resolution was Čerenkov light in the photomultiplier window produced by muons traversing the photomultiplier. A design with two photomultipliers for each cell was adopted.

With the help of a technician, Italo built the first prototype cell. It was tested successfully on a beam from the CERN PS during the Summer 2010.

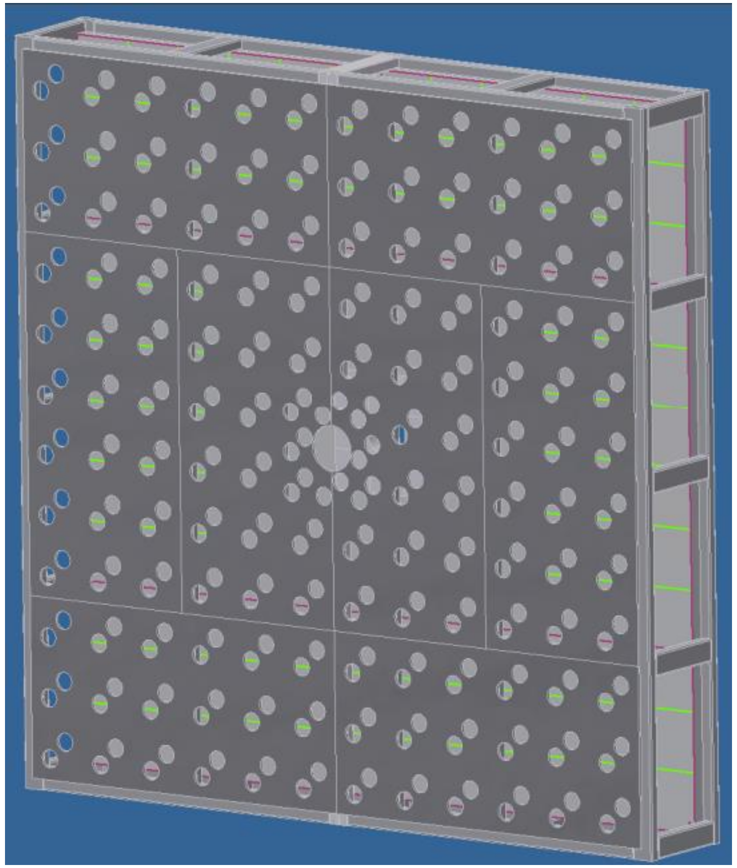
Set-up:





In Pisa, with the help of a technical engineer (Sandro Bianucci), Italo made a detailed design of MUV3

Sketch of the MUV3 detector

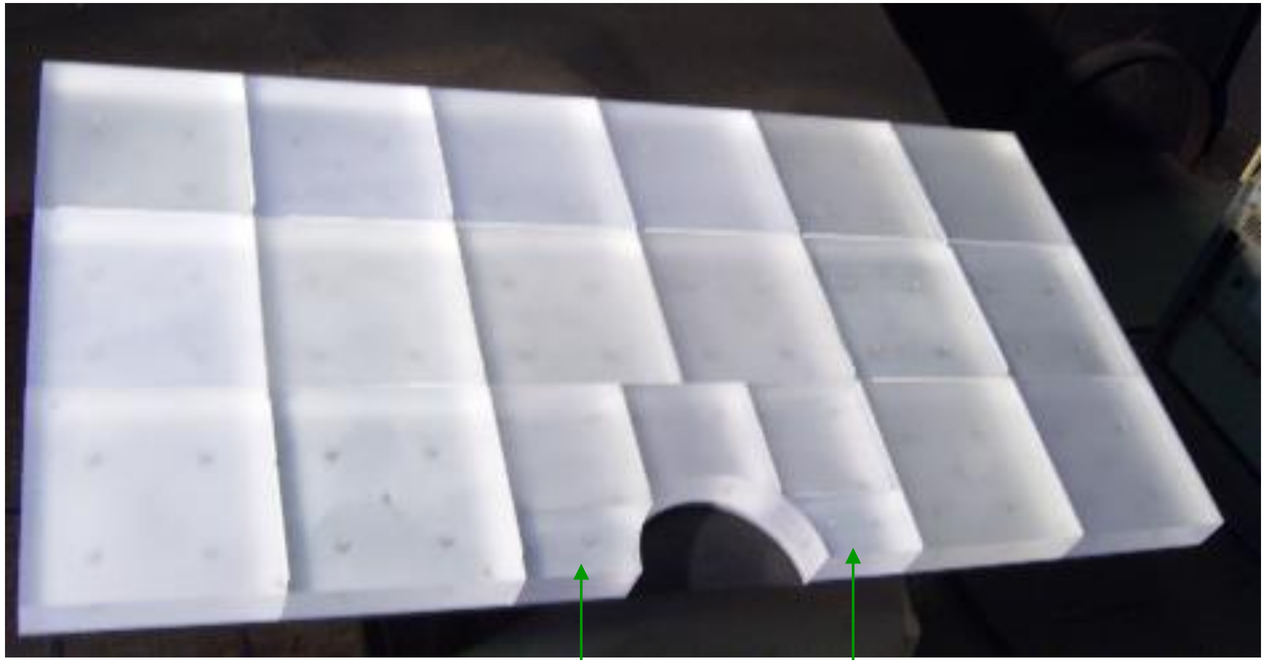


12 x 12 cells with 22 x 22 cm scintillator tiles except for the region near the beam tube where 2 x 2 cells are replaced by 8 smaller cells:
in total, 148 cells (296 PMTs)

Structures of commercially available, light Al tubes (manufactured by Bosch): two frames connected together for each MUV3 half-module

MUV3 was assembled at CERN in 2011 – 12 by a team of technicians from CERN, Pisa and Russia (Protvino).
The scintillator tiles, and other mechanical components, were made in Protvino.

Scintillator tile configuration near the beam axis



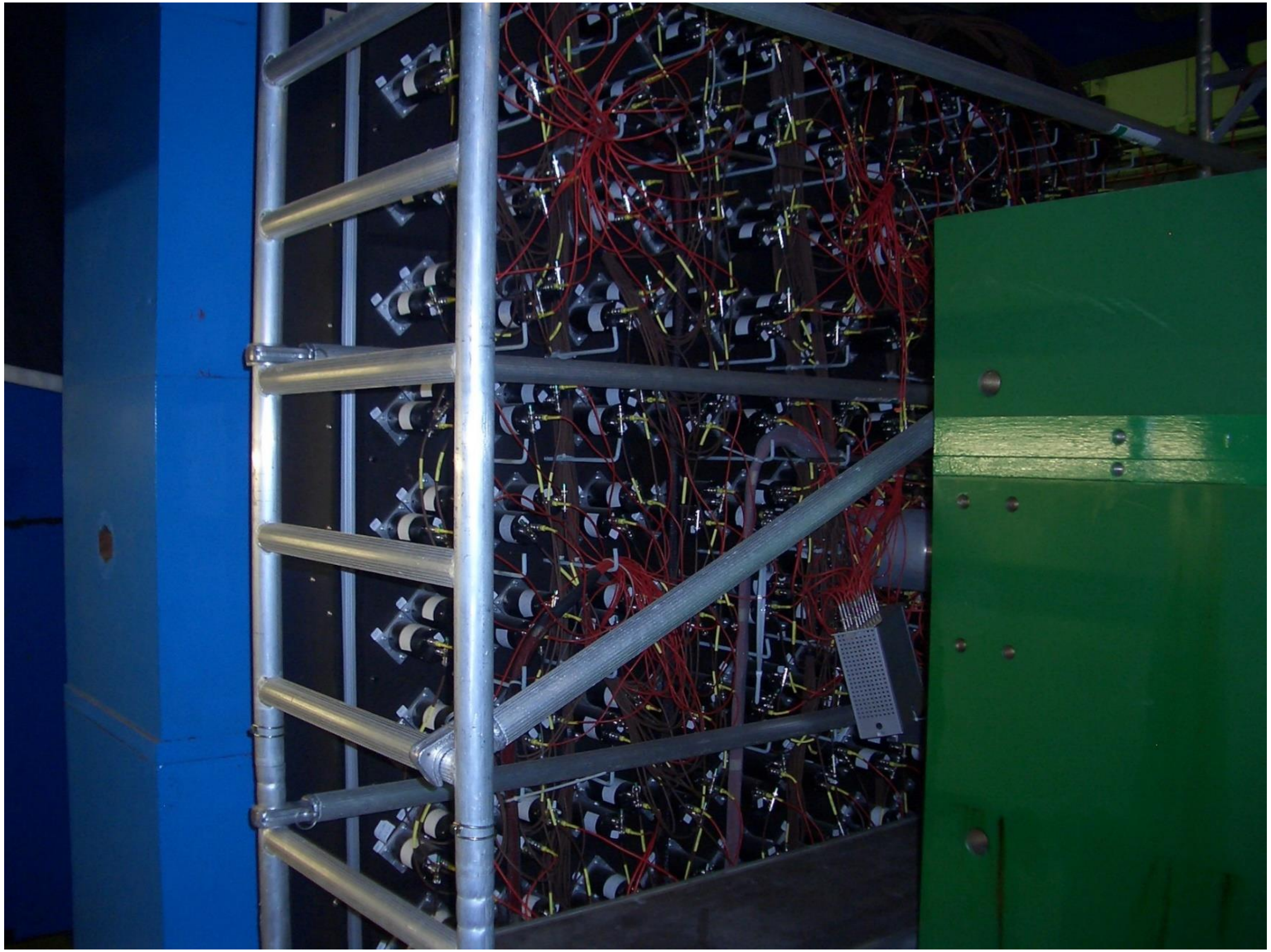
Half tiles → half cells
become full cells when the two half modules are joined together

Photomultiplier supporting plates and light septa before installation and connection to the scintillator tile support

The two halves of MUV3 finally assembled together in the Experimental Hall (not yet on the beam line)

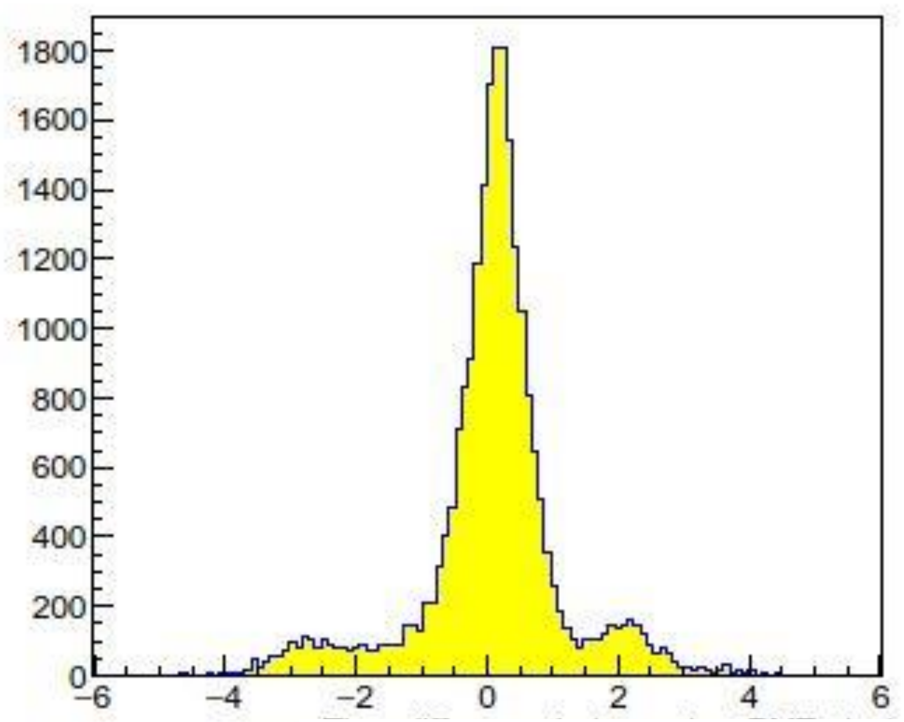
Back face

Front face



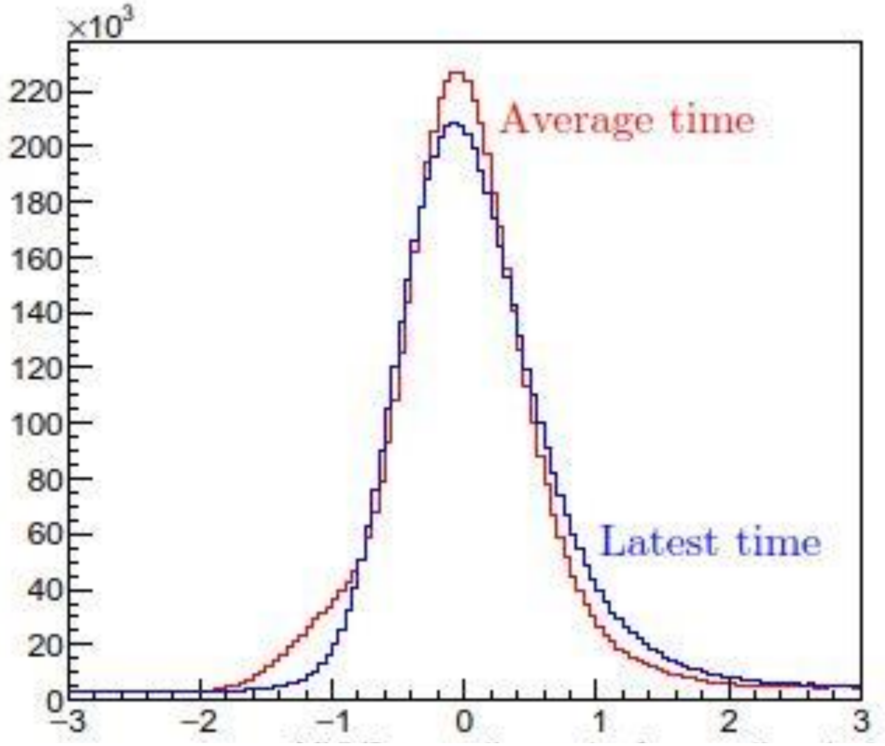
MUV3 in its final position

MUV3 time resolution



t(PMT1) – t(PMT2)

Note side peaks from muons traversing a PMT window.
Central peak corresonds to a resolution σ = 0.41 ns



MUV3 muon time with respect to reference time

σ = 0.41 ns

σ = 0.48 ns

A few concluding words

Among Italo's many talents as an experimental physicist,
I have presented only three:

- Proposing a new experiment which leads to an unexpected, important result;
- Conceiving an original and elegant method to measure a background in a precision experiment;
- Designing in detail a new detector which, once completed, is found to fulfill all required properties.

My best wishes to Italo for many more active years in particle physics. Working with Italo has been, is and will be a source of inspiration and also a great pleasure.