L'esperimento NA62 al CERN sui decadimenti rari dei mesoni K

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Sommario

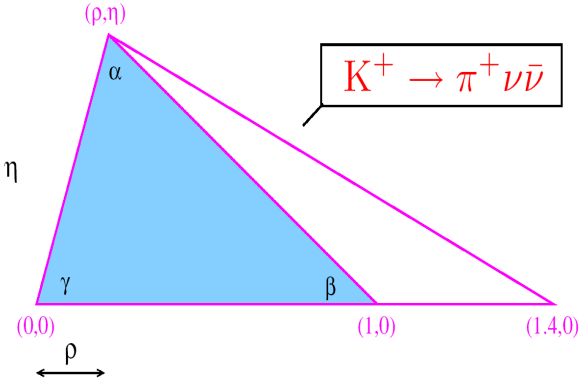
- L'importanza fisica $K^+ \rightarrow \pi^+ \nu\nu$
- Il fascio di protoni dell'SPS
- I canali principali di fondo
- L'apparato sperimentale di NA62
- Accettanza del segnale e rapporto segnale/rumore
- NA62 a Firenze: il rivelatore RICH

Fisica dei K

~~CP~~

$K_L \to \pi^0 \nu\bar{\nu}$

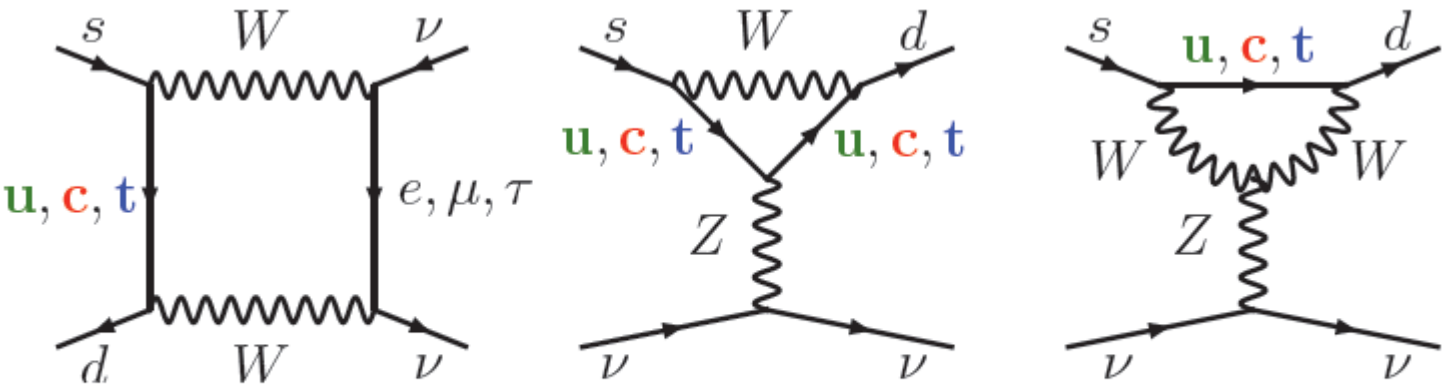
$K_L \to \pi^0 e^+ e^-$ $\begin{cases} K_S \to \pi^0 e^+ e^- \\ K_L \to \pi^0 \gamma\gamma \\ K_L \to ee\gamma\gamma \end{cases}$



$K_L \to \mu^+ \mu^-$ $\begin{cases} K_L \to \gamma\gamma,\ K_L \to e^+ e^- \gamma \\ K_L \to e^+ e^- e^+ e^-,\ e^+ e^- \mu^+ \mu^- \end{cases}$

Il triangolo di unitarietà usando solo i K

K→πνν

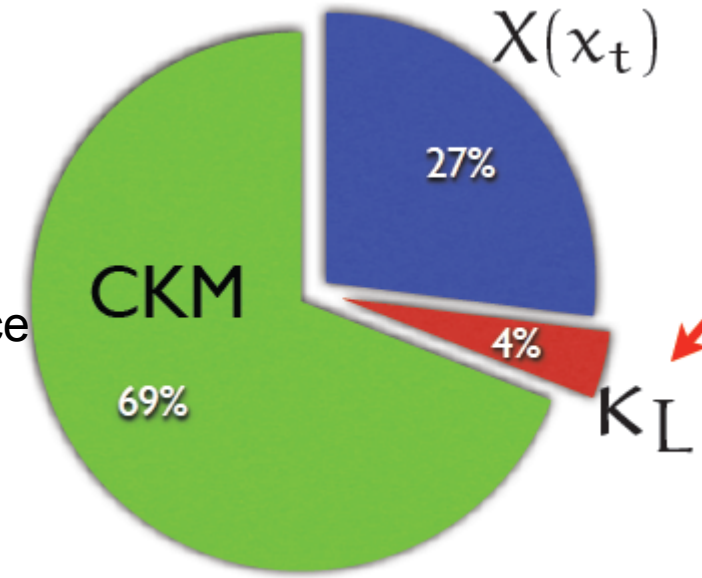


- **Dominant Operator:** $Q_\nu = (\bar{s}_L \gamma_\mu d_L)(\bar{\nu}_L \gamma^\mu \nu_L)$

Grazie ad una rotazione di isospin tutta la parte adronica è nota dalla misura di K→πeν

Incertezza teorica: $K_L \to \pi^0 \nu\nu$

Solo il Top contribuisce

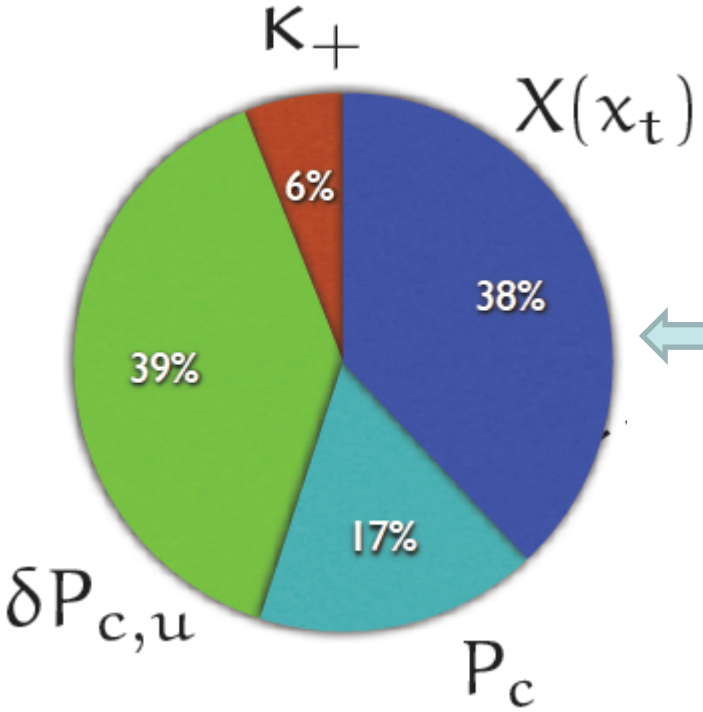


Elemento di matrice da K_{l3}

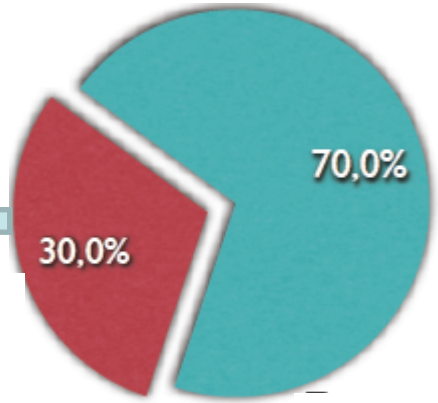
$$\mathcal{B}r(K_L \to \pi^0 \bar{\nu}\nu) = \kappa_L \left(\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X(x_t) \right)^2$$

$$\mathcal{B}r_{K_L} = (2.6 \pm 0.4) \times 10^{-11}$$

Incertezza teorica: $K^+ \to \pi^+ \nu\nu$



Contribuiscono sia il Charm che il Top



$$\mathcal{B}r\left(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)\right) = \kappa_+(1+\Delta_{EM}) \times \left| \frac{V_{ts}^* V_{td} X_t(m_t^2) + \lambda^4 \mathrm{Re} V_{cs}^* V_{cd} \left(P_c(m_c^2) + \delta P_{c,u}\right)}{\lambda^5} \right|^2$$

$$\mathcal{B}r_{K^+} = (0.85 \pm 0.07) \times 10^{-10}$$

Interesse Fisica

- Incertezza teoriche particolarmente basse
- Sensibile a V_{td}
- Molto sensibile a Nuova Fisica (~50 TeV)
- Complementare alla ricerca diretta di Nuova Fisica (LHC)

- Attualmente (E787/949): $\mathbf{BR(K^+ \rightarrow \pi^+ \nu\nu) = 1.73\ ^{+1.15}_{-1.05} \times 10^{-10}}$

con 7 eventi (in realtà solo 3 pesano veramente)

Occorre una misura al 10% (100 events): NA62

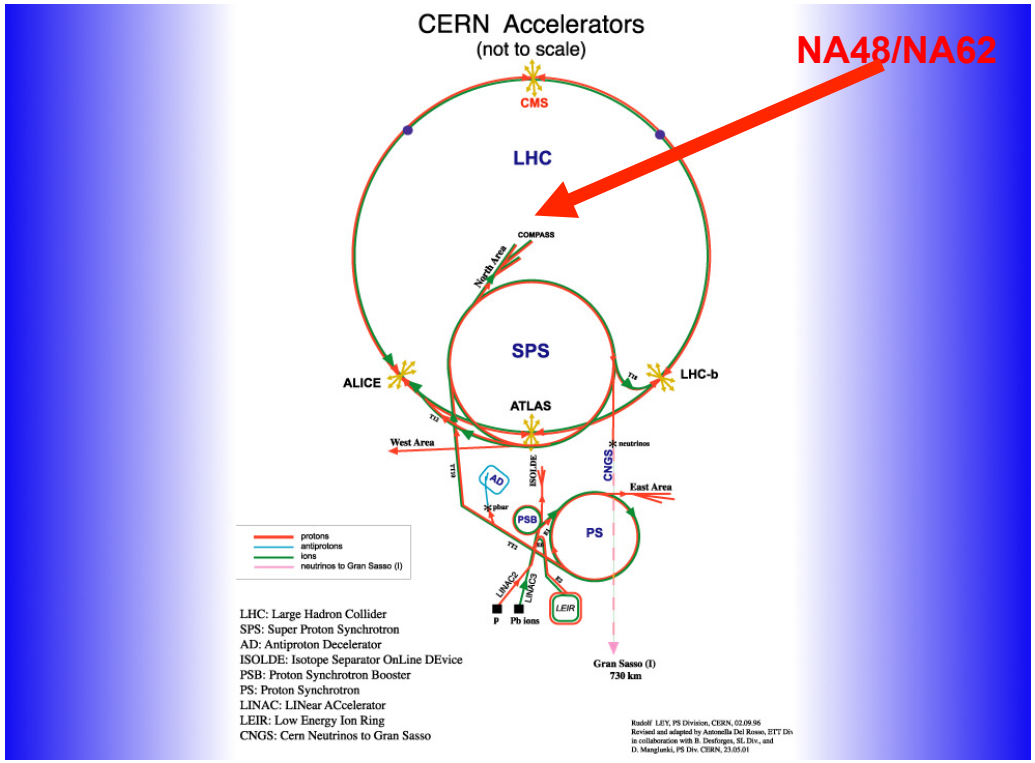
Quanti decadimenti K^+?

- $BR(K^+ \rightarrow \pi^+ \nu\nu) \sim 8\times10^{-11}$
- ~100 eventi di segnale
- Accettanza ~ 10%

→ **~10^{13}** decadimenti K^+

Acceleratore: CERN SPS (ora usato come iniettore di LHC)

Sala sperimentale: "caverna" di NA48 (ECN3)



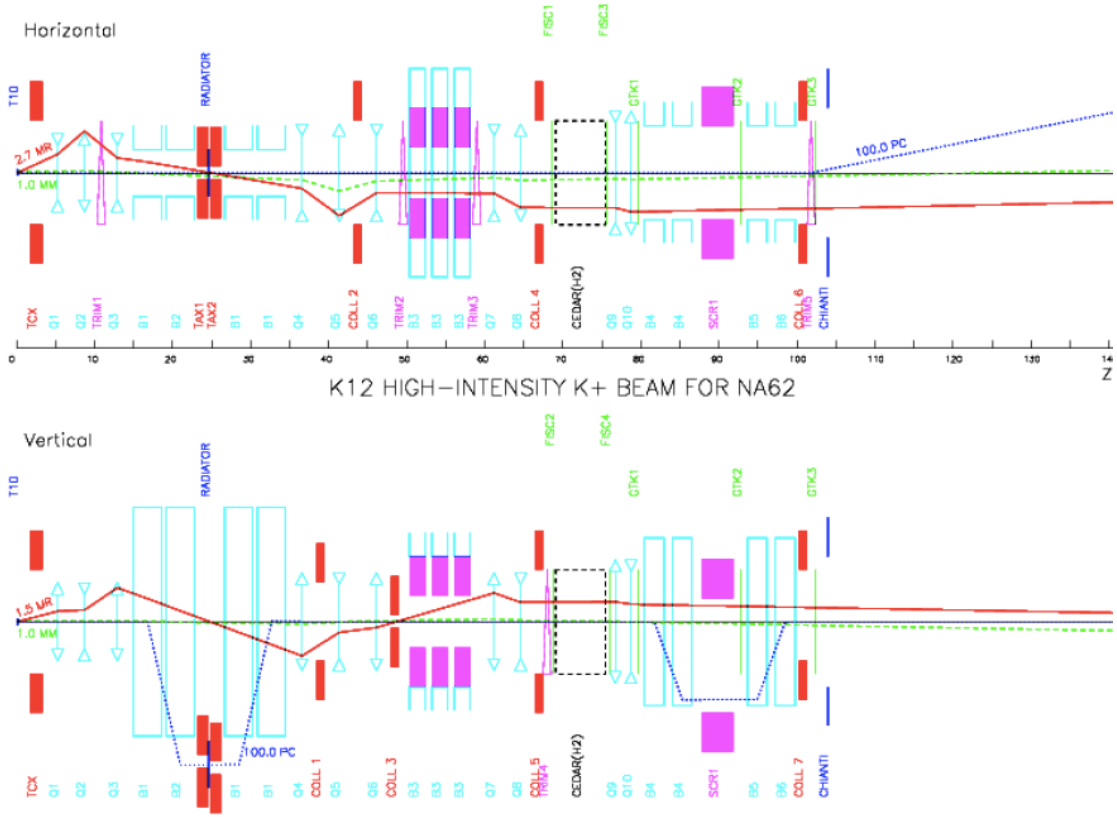
Il Fascio

Fascio Primario (SPS):

- 400 GeV/c (protoni)
- 3×10^{12} protoni/spill (3×NA48/2)
- 4.8/16.8 s duty cycle

Fascio Secondario (K12):

- p = 75 GeV/c ($\Delta p/p\sim1\%$)
- Accettanza.: 12.7 μstr (32×NA48/2)
- Rate totale: 800 MHz
- $K^+ \sim 6\%$
- 4.5×10^{12} K^+ decadimenti/anno (45×NA48/2)



La “purezza” del fascio secondario

Solo il 6% di K^+ ma:

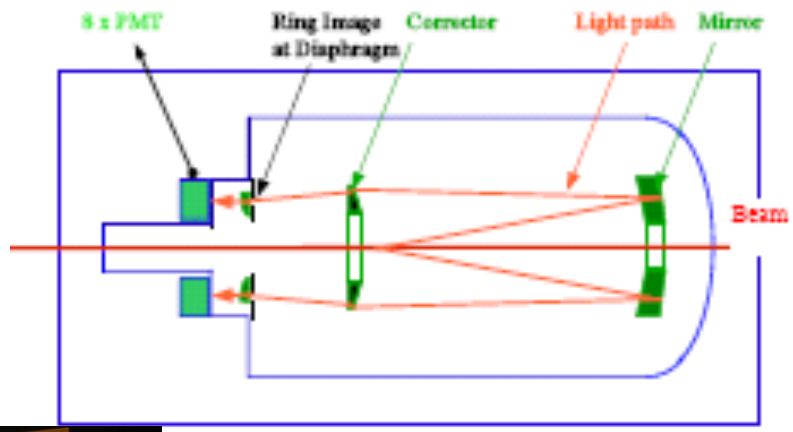
- protoni e positroni non decadono...
- decadimenti di pioni e muoni non possono sembrare decadimenti K^+
- problema: interazioni beam-gas

Si utilizza un tubo a vuoto (10^{-6} mbar) recuperato da NA48

I K^+ sono “taggati” nel fascio:
Si usa un CEDAR

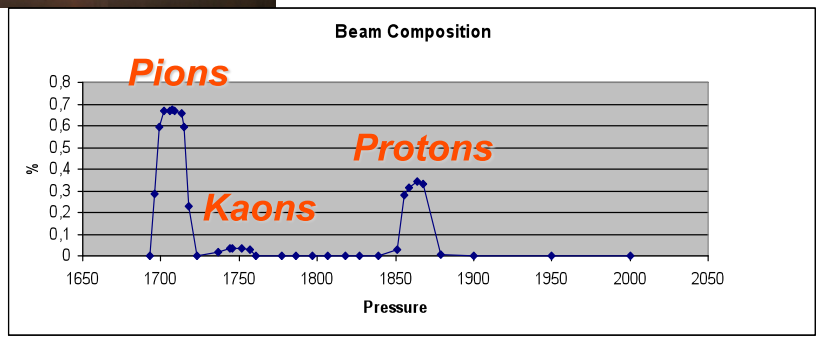
Il CEDAR

Il CEDAR è un contatore Cherenkov usato al CERN dagli anni 80 del XX
Variando la pressione del gas e l'apertura del diaframma si selezionano i K^+



<u>Novembre 2006</u>:
test beam con un CEDAR
P=100 GeV/c beam
Riempito con Azoto

Primo test del gruppo di Firenze per scegliere i PM per il RICH

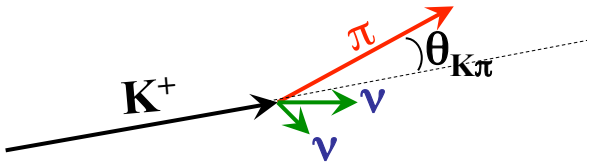


Fondi: tutti i decadimenti del K^+

Decay	BR
$\mu^+\nu$ $(K_{\mu 2})$	63.5%
$\pi^+\pi^0$ $(K_{\pi 2})$	20.7%
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0 e^+\nu$ (K_{e3})	5.1%
$\pi^0\mu^+\nu$ $(K_{\mu 3})$	3.3%
$\pi^+\pi^0\pi^0$	1.8%
$\mu^+\nu\gamma$ $(K_{\mu 2\gamma})$	0.62%
$\pi^+\pi^0\gamma$	2.7×10^{-4}
$\pi^+\pi^- e^+\nu$ (K_{e4})	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$ (K_{e4}^{00})	2.2×10^{-5}
$e^+\nu$ (K_{e2})	1.5×10^{-5}
$\pi^+\pi^-\mu^+\nu$ $(K_{\mu 4})$	1.4×10^{-5}

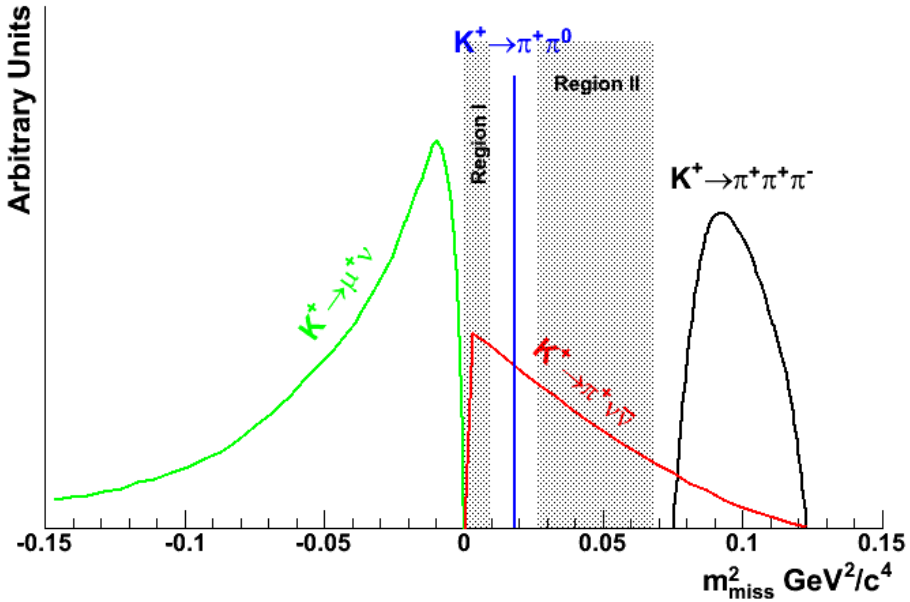
Discuterò in dettaglio solo di questo…

Cinematica

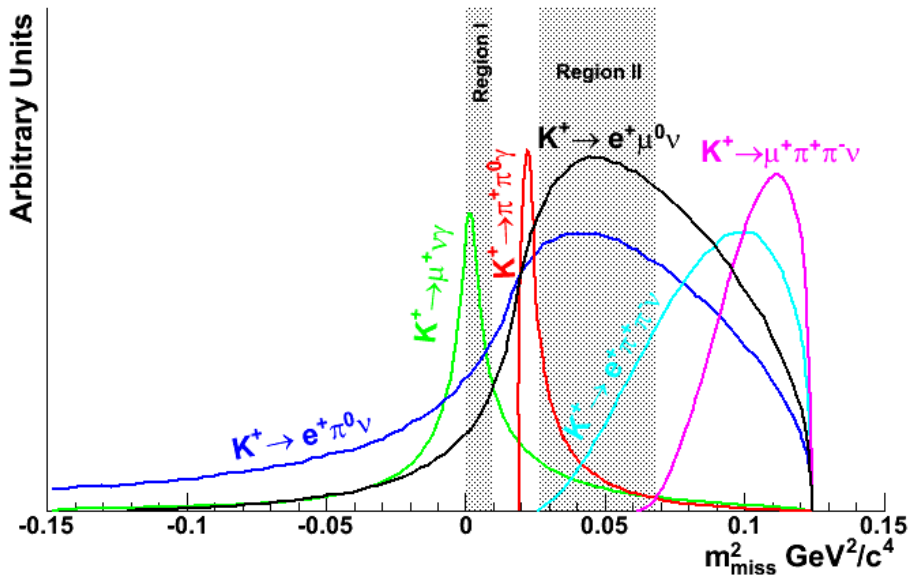


$$m^2_{miss}=(P_K-P_\pi)^2$$

92% decadimenti K^+



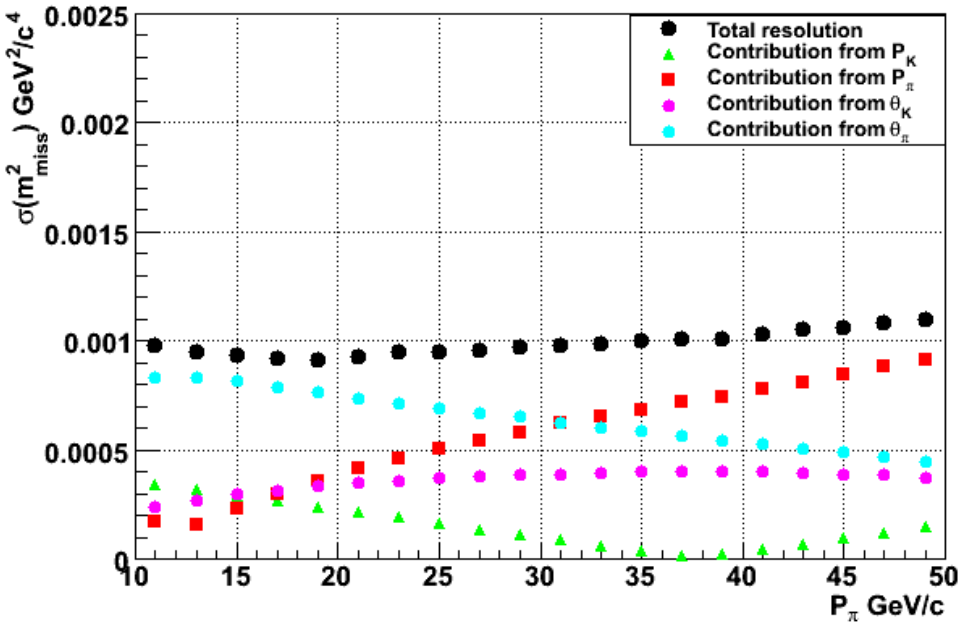
8% decadimenti K^+

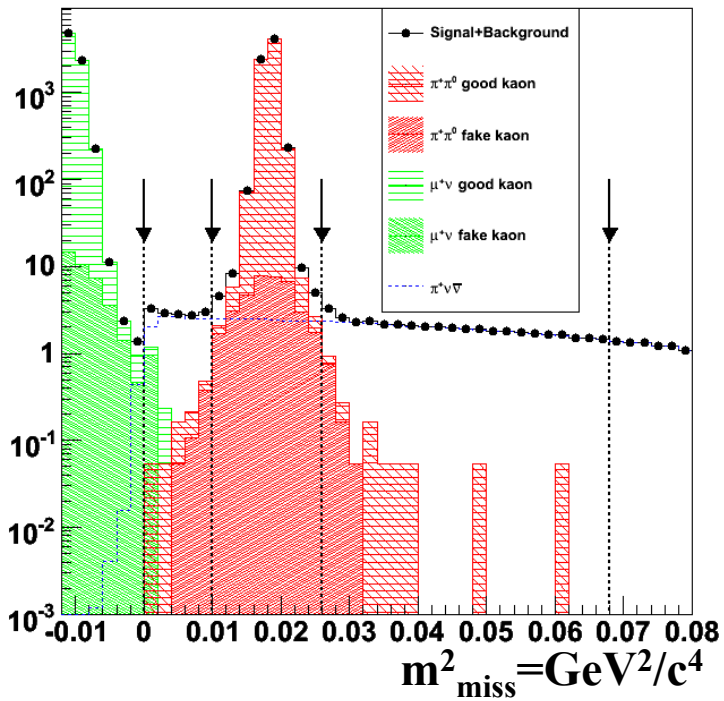


P_K : spettrometro sul fascio (pixel di silicio)

P_π : spettrometro con camere a straw

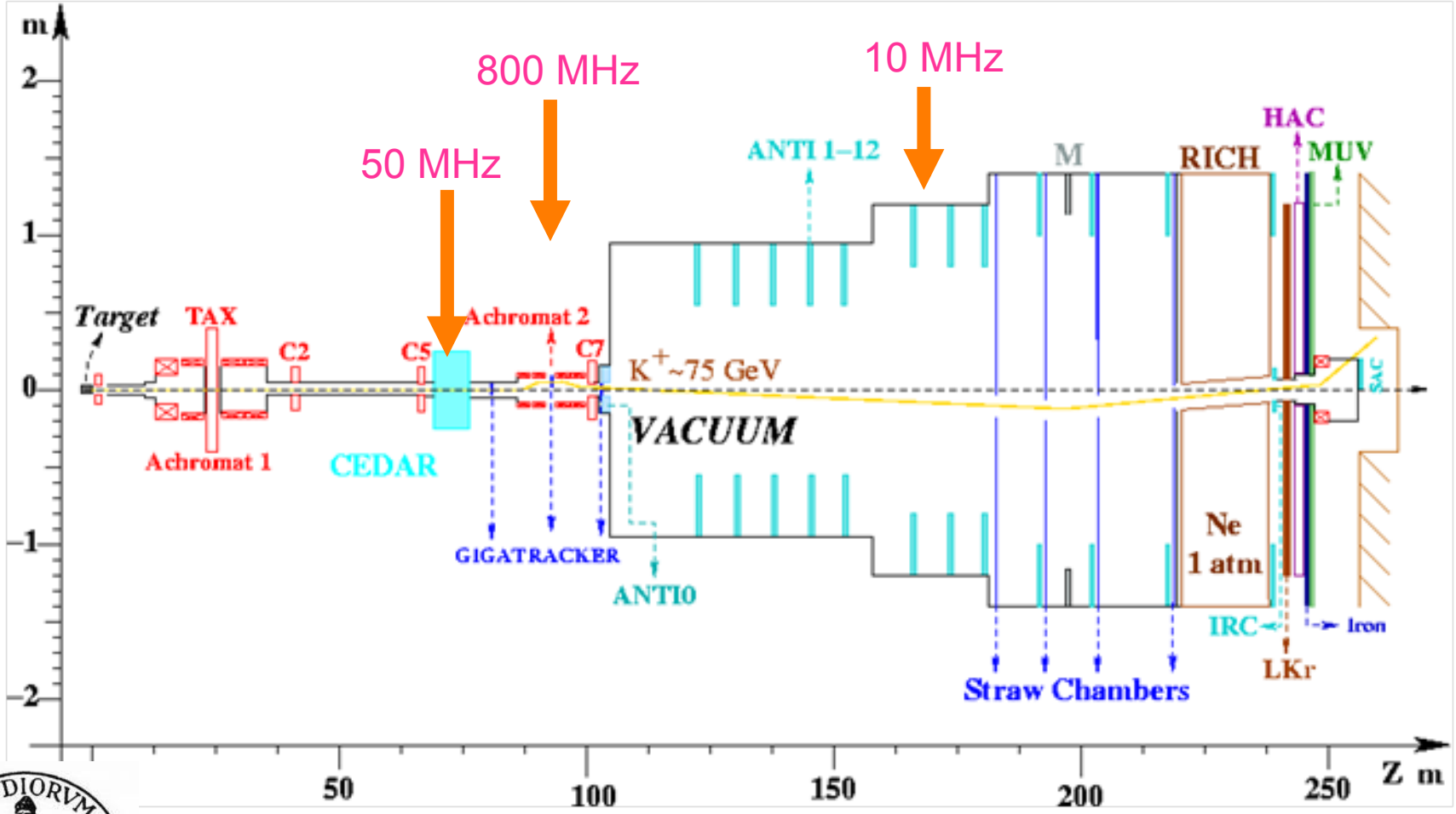
Ricostruzione Cinematica.



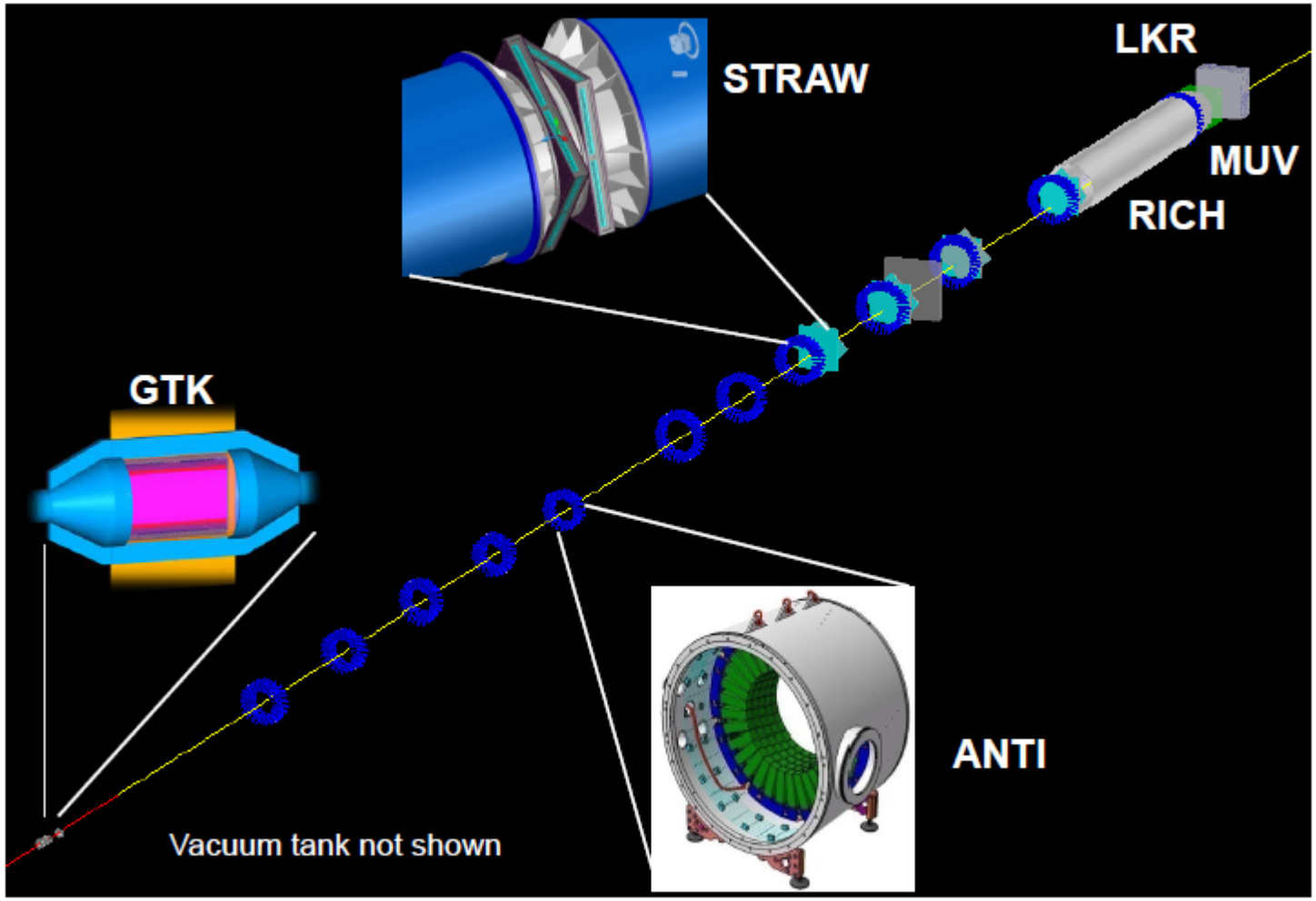


L'errore sulla misura della Massa Mancante è dominato dall'angolo tra mesone K e pione

L'esperimento NA62

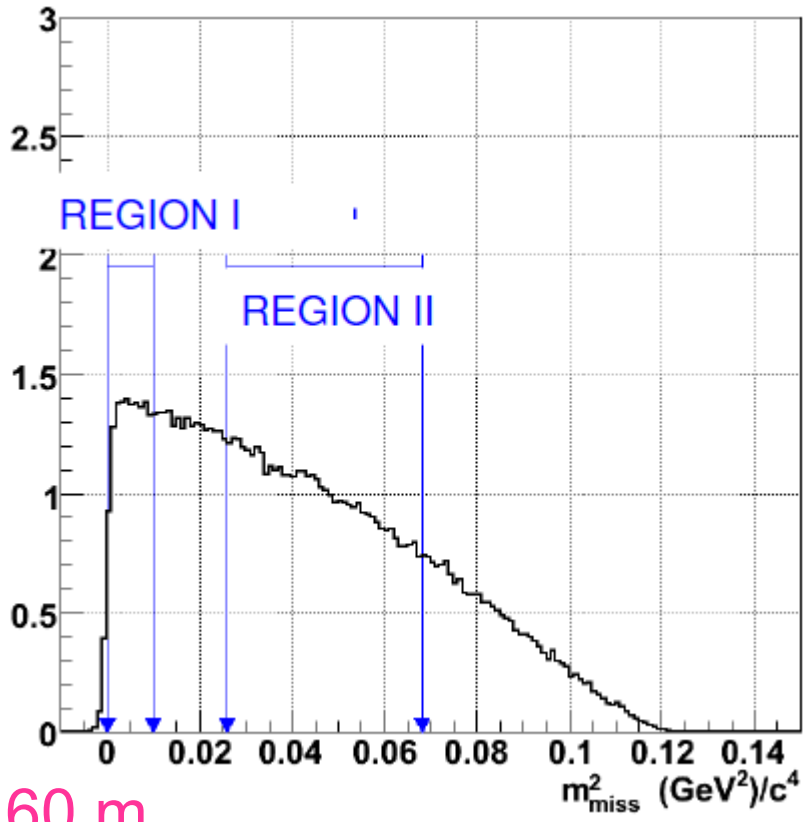


NA62 Event Display



Accettanza del Segnale

Regione I:
$0<m_{miss}^2<0.01$ GeV^2/c^4
Regione II:
$0.026<m_{miss}^2<0.068$ GeV^2/c^4



Nota Bene:
$K_{\mu 2}$ $m_{miss}^2 < 0$
$K_{\pi 2}$ $m_{miss}^2 = 0.0182$ GeV^2/c^4

$15 < p_\pi < 35$ GeV/c
Zona Fiduciale di decadimento: 60 m

Accettanza: 3.5% (Regione I), 10.9% (Regione II): 14.4% (I+II)

Segnale/Fondo

Decay Mode	Events
Signal: $K^+ \to \pi^+ \nu\nu$ [*flux* = 4.8×10^{12} *decay/year*]	55 *evt/year*
$K^+ \to \pi^+ \pi^0$ [$\eta_{\pi 0} = 2\times10^{-8}$ (3.5×10^{-8})]	4.3% (7.5%)
$K^+ \to \mu^+ \nu$	2.2%
$K^+ \to e^+ \pi^+ \pi^- \nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+ \to \pi^+ \pi^0 \gamma$	~2%
$K^+ \to \mu^+ \nu \gamma$	~0.7%
$K^+ \to e^+(\mu^+)\ \pi^0 \nu$, others	negligible
Expected background	≤13.5% (≤17%)

Fondo n.1: $K^+ \rightarrow \mu^+ \nu$

$K_{\mu 2}$:BR più grande di tutti: 63.4%

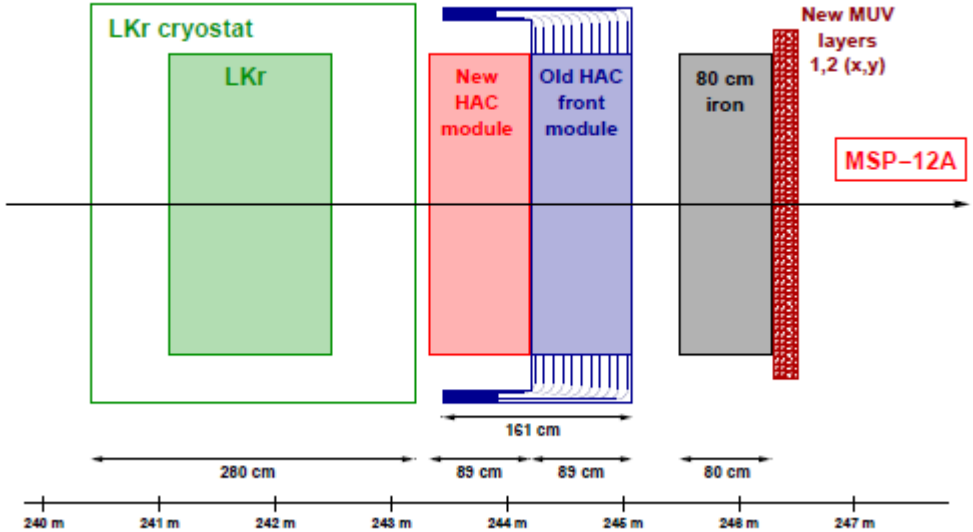
Occorre un fattore di soppressione ~10^{-12}

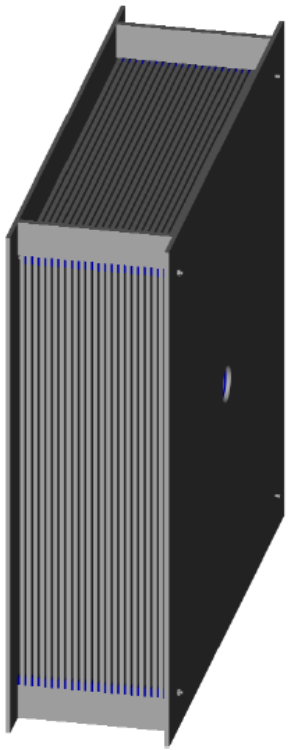
- Cinematica: 10^{-5}
- Veto per Muoni: 10^{-5} → MUV
- Particle ID: 10^{-2} → RICH

Veto per Muoni: MUV

- Riuso del Front Module del Calorimetro adronico di NA48
  - ➢Nuovo modulo
  - ➢Piano Veloce per il trigger

Inefficienza sui μ: 10^{-5}



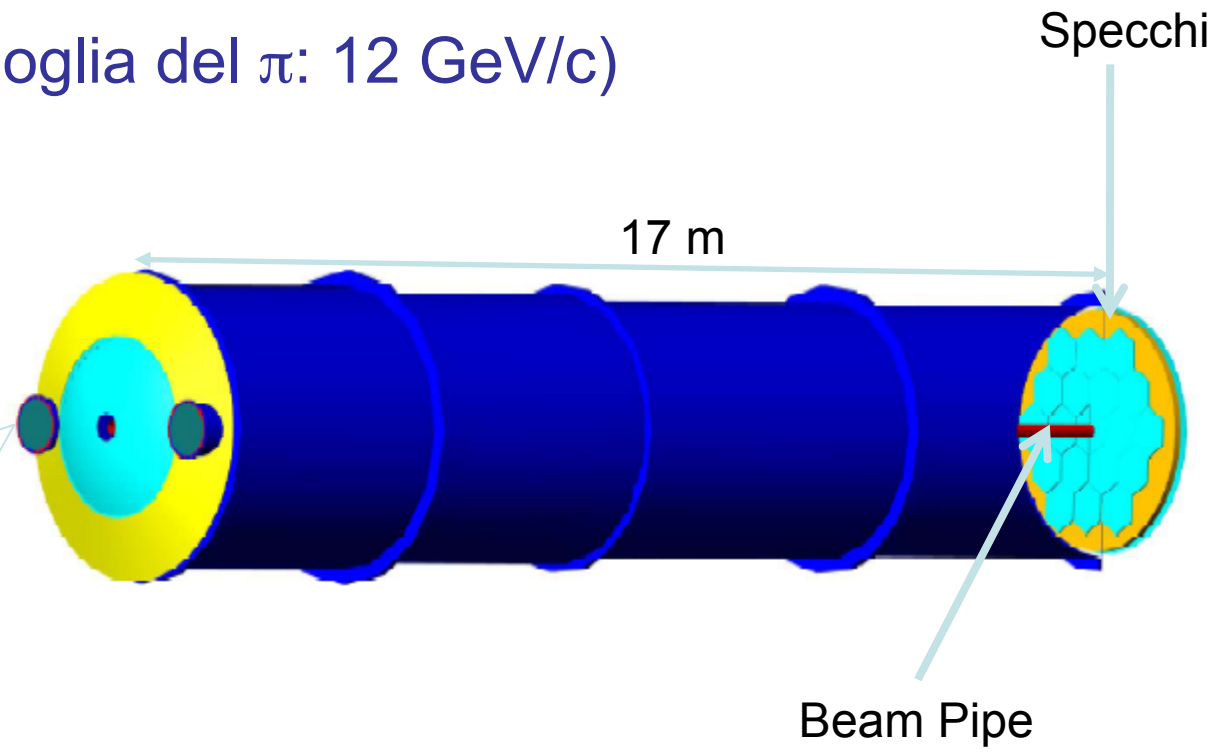


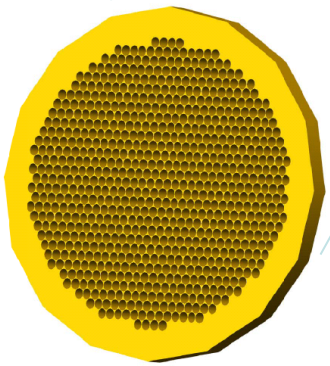
Nuovo modulo: sandwich di piastre di ferro e strip di scintillatore

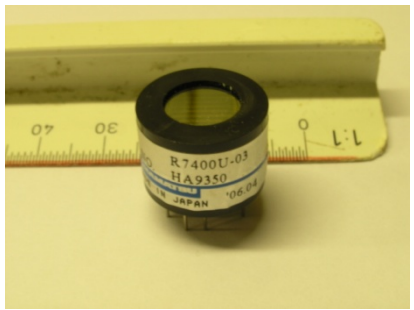
RICH (resp.: Firenze)

Separazione a 3σ π-μ (15-35 GeV/c)

- Neon ad 1 atm (soglia del π: 12 GeV/c)
- 2000 PMT
- 18 mm pixel
- 100 ps

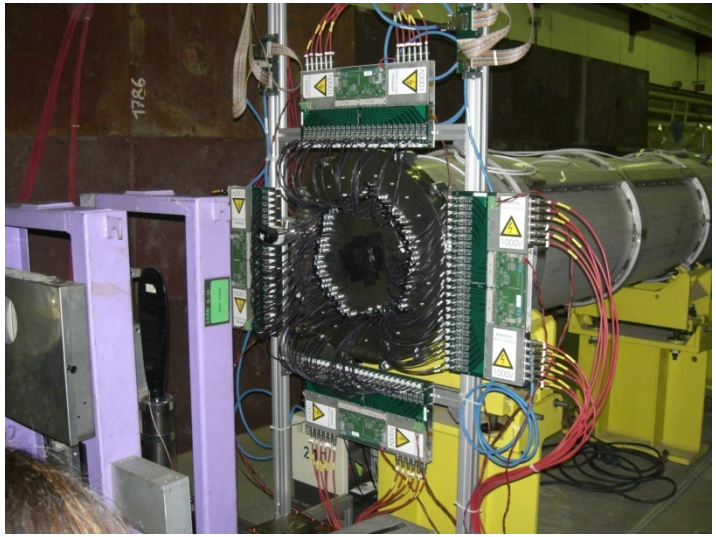






PMT: Hamamatsu R7400 U03

M. Lenti



Prototipo RICH-100 2007 Test Beam

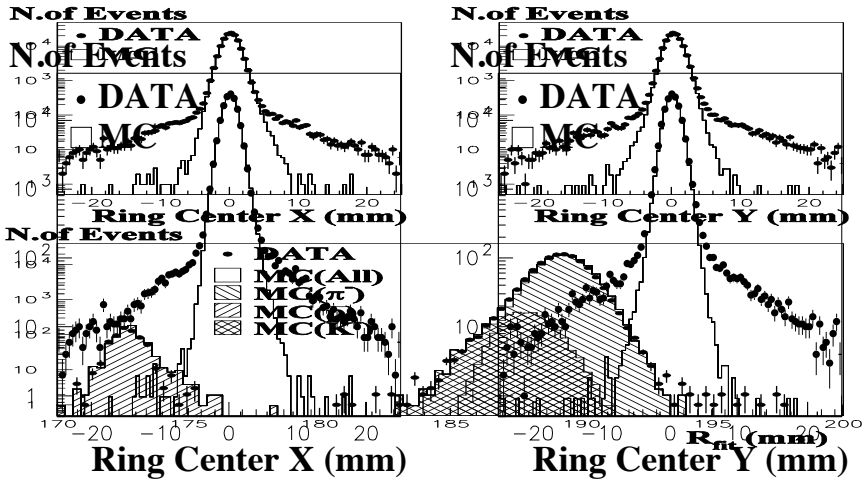
Elettronica fatta a Firenze

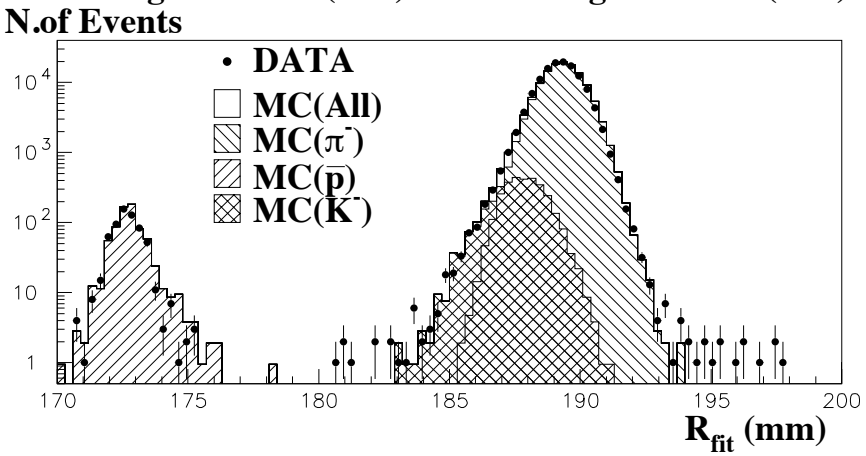
96 PMT:
Supporto
costruito
a Firenze

Specchio f=17 m
Supporto fatto a Firenze

π^- da 200 GeV/c (SPS)
CERN Caverna ECN3

RICH-100: risultati





$\Delta\theta_c \approx 50\ \mu rad$

$\Delta t_{Event} \approx 70\ ps$

Nuclear Instruments and Methods in Physics Research A 593 (2008) 314–318

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Construction and test of a RICH prototype for the NA62 experiment

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ARTICLE INFO

Article history:
Received 16 May 2008
Accepted 19 May 2008
Available online 28 May 2008

Keywords:
RICH
PID
Timing

ABSTRACT

A RICH prototype has been constructed and tested. The detector was cylindrical, 17 m long and 60 cm diameter, filled with neon gas at atmospheric pressure. A spherical mirror with 17 m focal length was used and 96 photomultipliers were placed in the mirror focal plane. The prototype was exposed to a 200 GeV/c momentum negative beam derived from the CERN SPS in the 2007 fall. The performances of the detector in terms of Cherenkov angle resolution, number of photoelectrons and time resolution are presented.

1. Introduction

The NA62 experiment [1] has been proposed at CERN in order to measure the branching ratio of the ultra-rare decay $K^+ \to \pi^+\nu\nu$. The main background is $K^+ \to \mu^+\nu$ which must be suppressed by a factor 4×10^{-13} in order to have a background to signal ratio smaller than 10%: this goal can be accomplished by a combination of kinematical cuts and by pion–muon separation. According to the MC simulation of the experiment, a kinematical suppression of 8×10^{-6} can be reached. A muon rejection factor of 10^{-5} can be achieved exploiting the different penetration probability through matter of the two particles. A further 5×10^{-3} suppression factor can be provided by a Ring Imaging CHerenkov (RICH) detector.

The momentum range over which pions and muons must be identified by the RICH is between 15 and 35 GeV/c; the best pion–muon separation is achieved when the lowest accepted momentum is close to the Cherenkov threshold. As full efficiency is achieved only at a momentum about 20% higher than the threshold, the latter has to be 12.5 GeV/c for a pion, i.e. the index of refraction n must be such that $(n-1) \approx 60 \times 10^{-6}$. Neon gas at roughly atmospheric pressure fulfills this requirement and also guarantees a small dispersion [2]. On the other hand, the tiny $(n-1)$ implies a small number of emitted Cherenkov photons per unit length and therefore a long radiator is mandatory. A 10 m long neon RICH was built and operated by the SELEX experiment [3] and a longer one was proposed by the CKM collaboration [4]. The available space for the RICH in the NA62 experiment setup is about 18 m: a detector of about this size is foreseen.

In a RICH detector [5] the Cherenkov light, emitted at an angle θ_c by a charged particle of velocity βc larger than the speed of light in the crossed medium (c/n), is imaged by means of a spherical mirror onto a ring on its focal plane. The ring radius r is related to the Cherenkov angle as $\theta_c = r/f$ for small n (as it is the case for gas radiators), where f is the mirror focal length. The relation between Cherenkov angle and momentum p of a charged particle of mass m is given by

$$\theta_c^2 = \theta_{c\,MAX}^2 - m^2c^2/(m^2c^2 + p^2) \quad (1)$$

where $\theta_{c\,MAX} = \sqrt{2(n-1)}$ is the Cherenkov angle for $\beta = 1$. The θ_c resolution must be better than 80 μrad in order to achieve the requested pion–muon separation.

Besides pion–muon separation, the NA62 RICH detector must fulfill two other very important tasks: provide the time of pion crossing with 100 ps resolution (in order to suppress accidental

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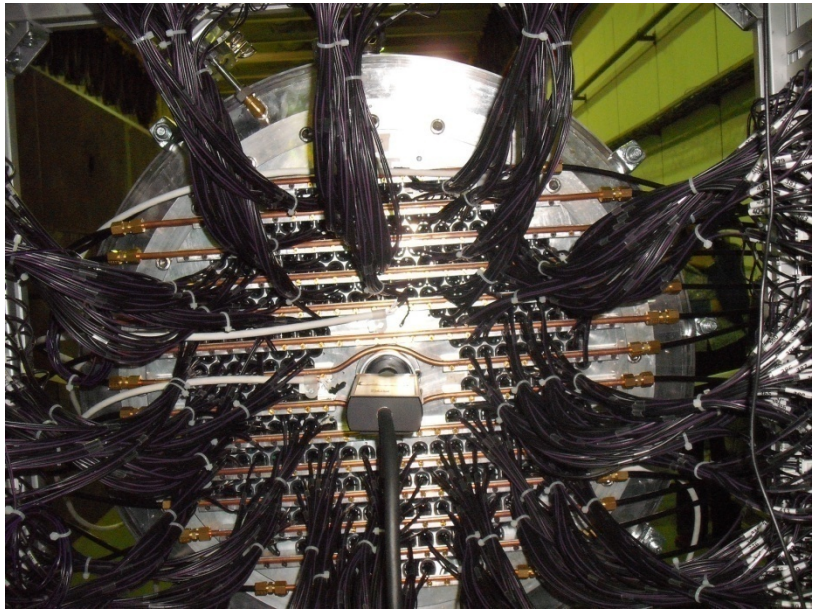
doi:10.1016/j.nima.2008.05.029

RICH-400: 2009 test beam

- 414 PMT + FE e DAQ “finale” (preparati a Firenze)
- Pioni ad energia variabile



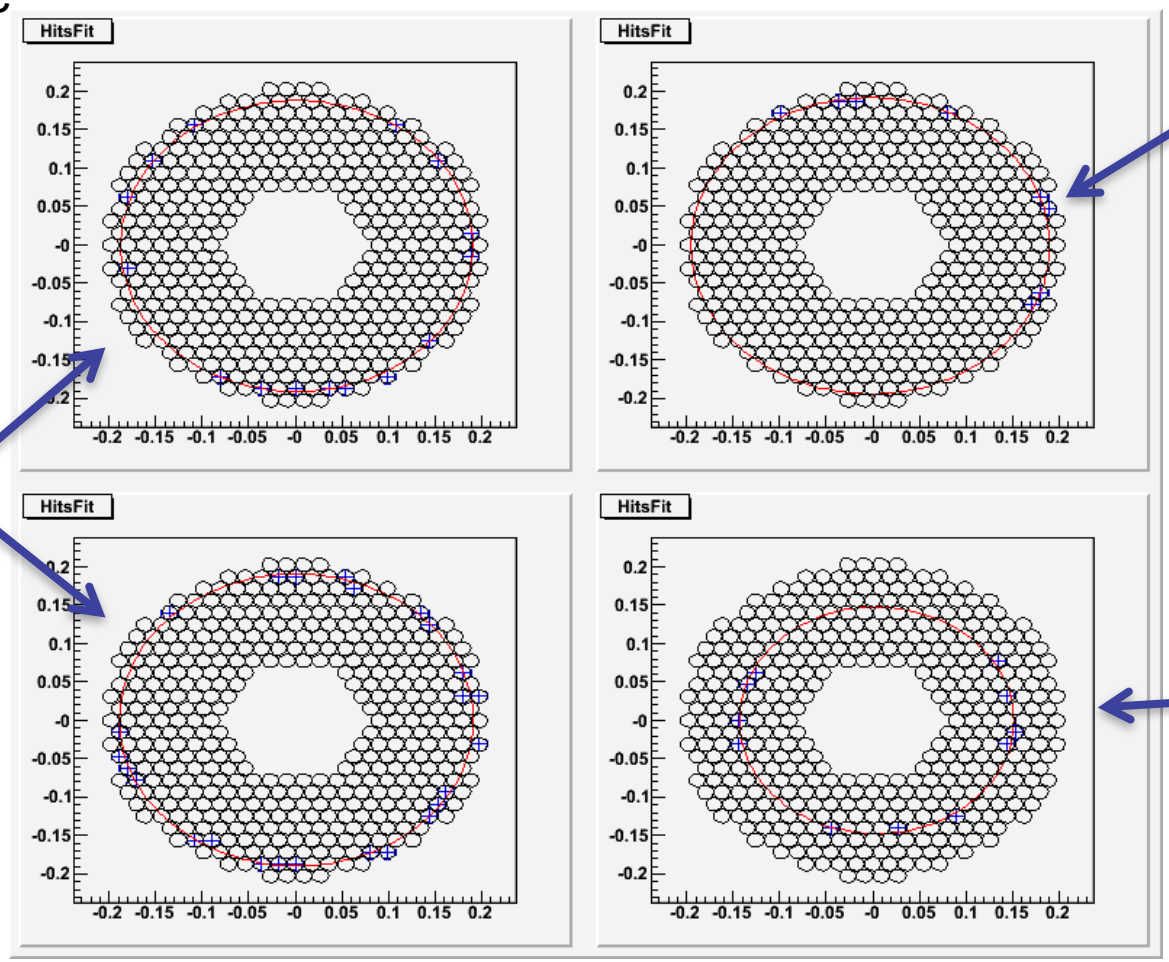
RICH-400

Il servizio di elettronica al lavoro…

Arrivano i dati!

RICH-400: esempi di anelli

20 GeV/c

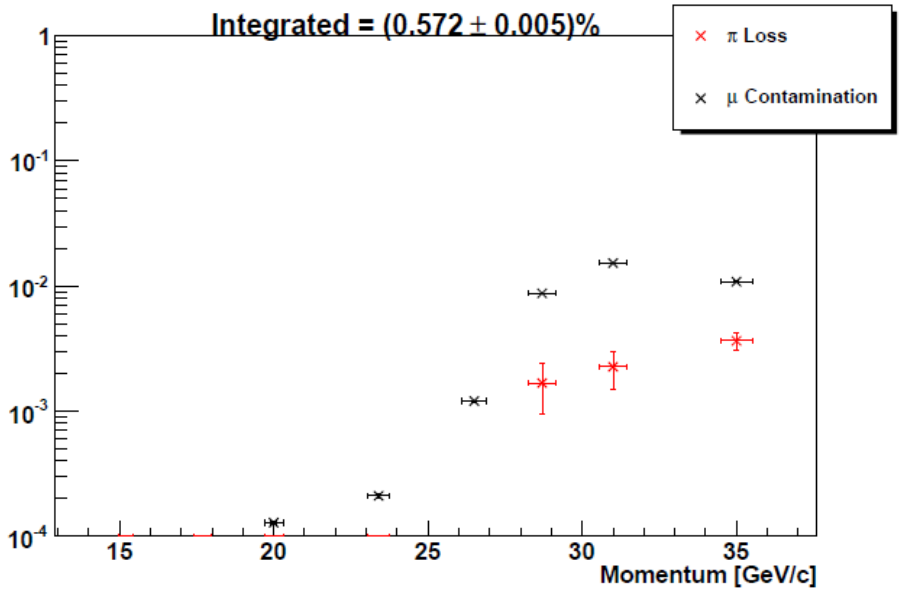


Esempio di anello "patologico"

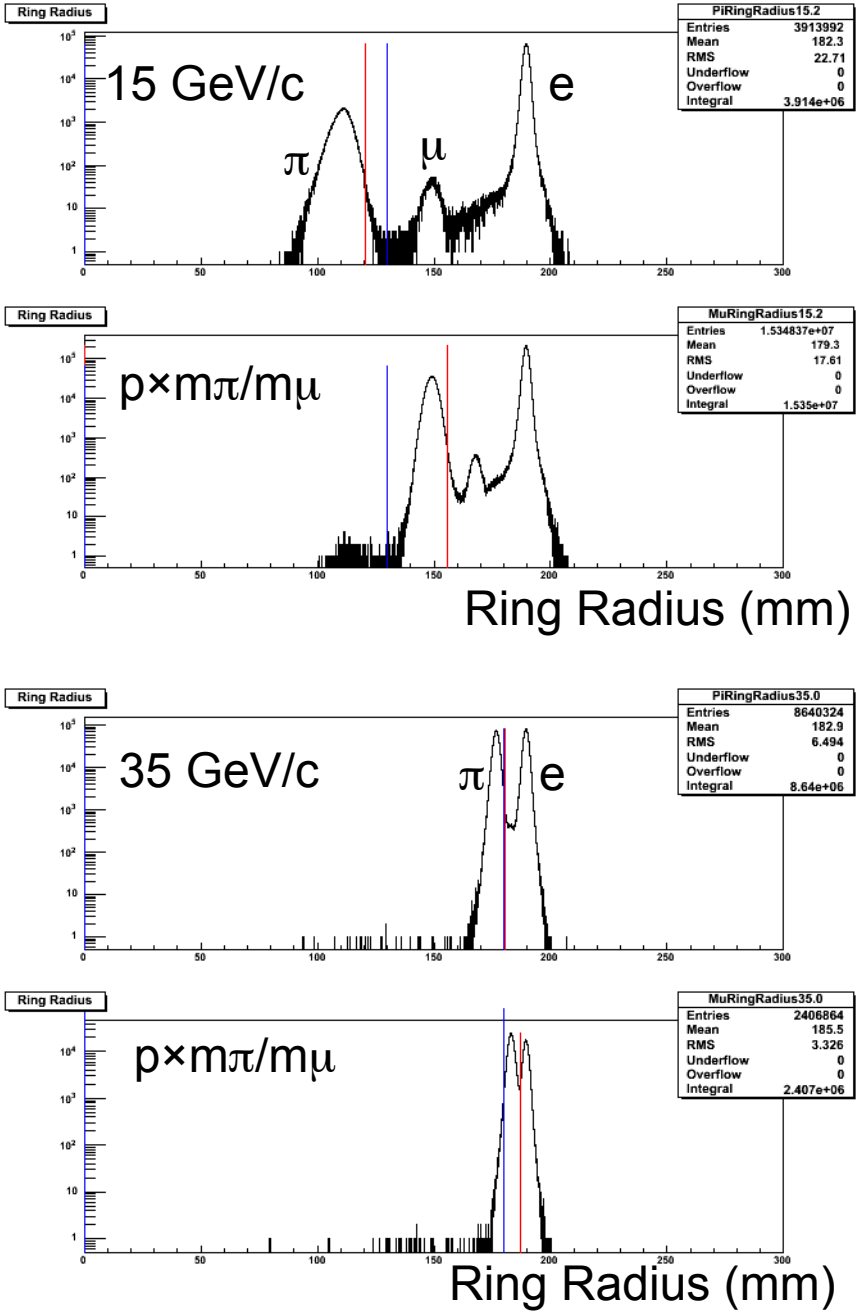
positroni

pione

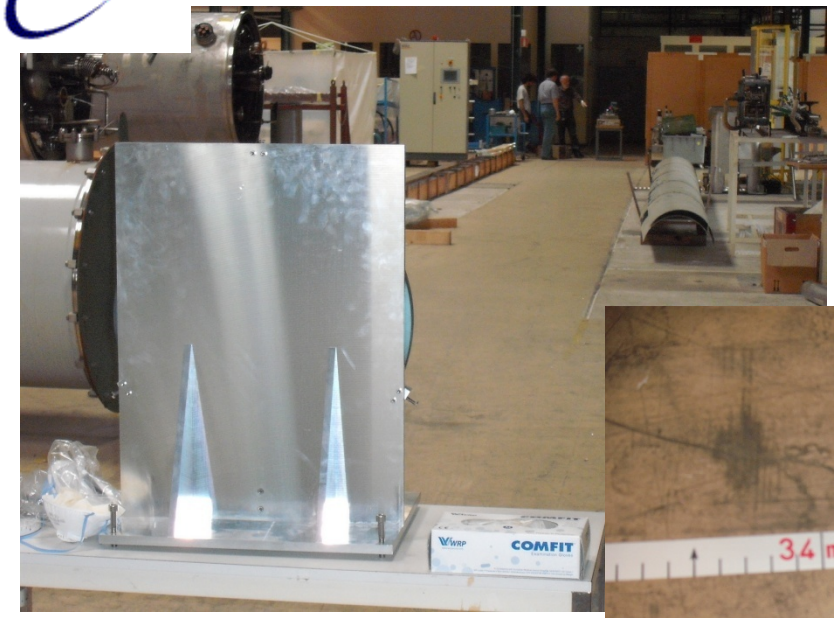
RICH-400: risultati

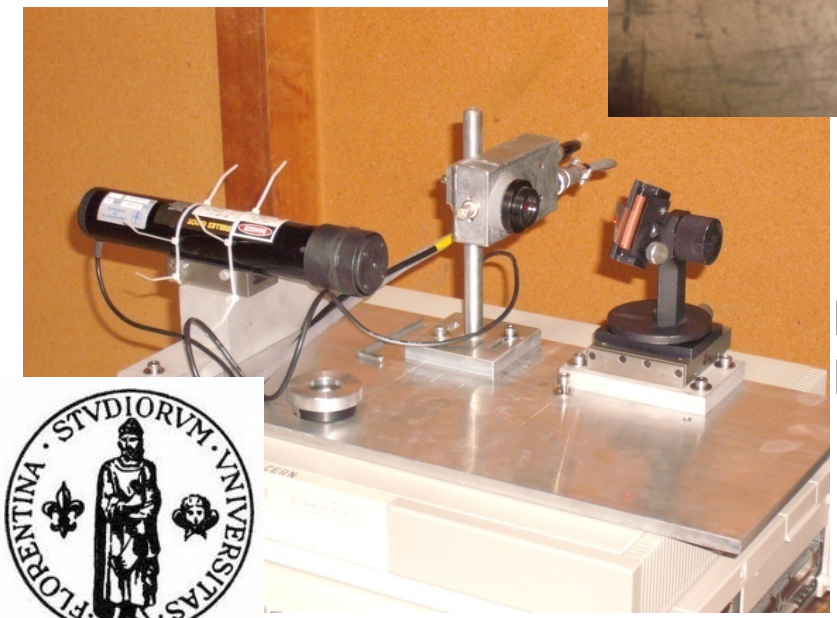


Soppressione dei Muoni (15-35 GeV/c): 0.7%



Test specchi al CERN





D0 = 0.6 mm
R = 34.055 m

M. Lenti

Riassunto: NA62

- 2006-2009: R&D, test beam
- 2009-2011: Costruzione
- 2012: inizio presa dati

- NA62 approvato dal CERN Research Board: 5.12.2008
- NA62 approvato dall'INFN: 24.7.2009 dopo essere stato Giudicato di Primo Livello dal CCS INFN
  - Argomento di fisica "duale" di LHC
  - molti altri canali interessanti

La collaborazioneNA62: ITP Bern, Birmingham, Bristol, CERN, Dubna, INFN (Ferrara, Firenze, Frascati, Napoli, Perugia, Pisa, Rome I, Rome II, Torino), Fairfax, Glasgow, IHEP, INR, Liverpool, Louvain, Mainz, Merced, San Louis Potosi, SLAC, Sofia, TRIUMF

NA62 a Firenze

- A. Bizzeti (P.A.Univ. Modena)
- F. Bucci (Ass.)
- M. Calvetti (P.O.)
- A. Cassese (Dott.)
- E. Celeghini (P.A.)
- R. Ciaranfi (CTER INFN)
- E. Iacopini (P.O., Resp. Nazionale INFN NA62)
- M. Lenti (INFN RIII, Resp. Locale INFN NA62)
- F. Maletta (CTER INFN)
- M. Veltri (R.U.Univ. Urbino)

NA62 a Firenze

- 2 tesi di laurea specialistica
- 1 tesi di dottorato
- 1 assegno di ricerca

NA62: attività a Firenze

- E. Iacopini: coordinatore nazionale NA62
- Il RICH: progettazione, test beams, costruzione (coordinatore del progetto RICH: M. Lenti)
- Test dei 2000 PMT Hamamatsu
- Front-End electronics
- Test di qualità dei 20 specchi
- Sostegno e allineamento degli specchi

NA62: attività a Firenze

- “Fisica Sperimentale”: Lab 26 (PM test, Front-End electronics, etc)
- “Fisica Sperimentale”: Lab 30 (test di ottica, etc)
- “Fisica Sperimentale”: capannone Lab 75C (test degli specchi)
- Officina Univ.: sostegno PMT, sostegno specchi, prototipi, etc
- Servizio Elettronica INFN: Front-end electronics, allineamento specchi, etc.

NA62: finanze

- NA62 qualificato “Primo Livello” dal CCS dell’INFN
- Finanziamento costruzione RICH 2009-2012
- PRIN 2010 (insieme ad altri gruppi italiani di NA62)

NA48-NA62: pubblicazioni

1) **A magnetic spectrometer RICH.** M. Lenti (INFN, Florence) . 2007. 4pp. Published in **Nucl.Instrum.Meth.A574:251-254,2007**.

B1. Presentazioni a Conferenze Internazionali con proceedings (8)

1) **THE NA62 RICH DETECTOR** By Massimo Lenti (INFN, Florence), Oct 2008. 4pp.
Talk given at the XI Topical Seminar on Innovative Particle and Radiation Detectors (IPRD08), Siena, Italy, 1-4 Oct 2008.
To be published on **Nuclear Physics B (Proceedings Supplement).**

2) **$\pi\pi$ SCATTERING LENGTHS FROM KAON KE4 AND 3π DECAYS BY NA48/2** By Massimo Lenti (INFN, Florence), Nov 2007. 8pp.
Talk given at the XII International Conference on Hadron Physics (HADRON 07), Frascati, Italy, 8-13 Oct 2007. Published on **Frascati Physics Series, Volume XLVI (2007),** pp 875-882.

3) **KAONS AND HYPERONS RARE DECAYS BY THE NA48 EXPERIMENT AT CERN.**By Massimo Lenti (INFN, Florence). HEPMAD-2004-011, Nov 2004. 12pp.
Talk given at 2nd High-Energy Physics Conference in Madagascar (HEP-MAD 04), Antananarivo, Madagascar, 27 Sep - 3 Oct 2004.
Published in **Proceedings of 2nd High-Energy Physics Conference in Madagascar (HEP-MAD 04)**, Antananarivo, Madagascar, 27 Sep - 3 Oct 2004, pp 011.

4) **CP-VIOLATION RESULTS ON KAONS BY THE NA48 EXPERIMENT** By Massimo Lenti (INFN, Florence), 2004. 6pp.
Prepared for 10th International QCD Conference (QCD 03), Montpellier, France, 2-9 Jul 2003.Published in **Nucl.Phys.Proc.Suppl.133:227-232, 2004**

5) **A NEW MEASUREMENT OF EPSILON'/EPSILON BY THE NA48 EXPERIMENT AT CERN.**By Massimo Lenti (INFN, Florence). Jul 2001. 10pp.
Prepared for International Europhysics Conference on High-Energy Physics (HEP 2001), Budapest, Hungary, 12-18 Jul 2001. Published in ***Budapest 2001, High energy physics***

6) **A NEW MEASUREMENT OF THE DIRECT CP VIOLATION PARAMETER RE(e'/e) BY THE NA48 EXPERIMENT AT CERN.** By Massimo Lenti (INFN, Florence), XXXVth Rencontres de Moriond QCD, Moriond, March 2000. Published in **"2000 QCD and High Energy Hadronic Interactions", 421-424**.

7) **THE CERN NA48 EXPERIMENT: STATUS AND PERSPECTIVES.**By Massimo Lenti (INFN, Florence). 1999.
Given at International Euroconference on Quantum Chromodynamics (QCD 98), Montpellier, France, 2-8 Jul 1998. Published in **Nucl.Phys.Proc.Suppl.74:193-196,1999**

C1. Pubblicazioni di strumentazione con il gruppo del RICH di NA62 (N.1)

1) **Construction and test of a RICH prototype for the NA62 experiment.**G.Anzivino et al. 2008. 5pp. Published in **Nucl.Instrum.Meth.A593:314-318,2008**.

C2. Pubblicazioni di strumentazione con la collaborazione NA48 (N.2)

1) **The Beam and detector for the NA48 neutral kaon CP violations experiment at CERN.**By NA48 Collaboration (V. Fanti *et al.*). May 2007. 40pp.
Published in **Nucl.Instrum.Meth.A574:433-471,2007**.

2) **The trigger for K0 --> pi0 pi0 decays of the NA48 experiment at CERN.** G. Barr *et al.* CERN-EP-2001-079, Nov 2001. 32pp. Published in **Nucl.Instrum.Meth.A485:676-697,2002**.

D4. Proposal con la collaborazione NA48

1) **Proposal to measure the rare decay K+ ---> pi+ nu anti-nu at the CERN SPS.**
G. Anelli *et al.* CERN-SPSC-2005-013, CERN-SPSC-P-326, Jun 2005. 93pp.

2) **LETTER OF INTENT TO MEASURE THE RARE DECAY K+ ---> PI+ NU ANTI-NU AT THE CERN SPS.**
D. Munday *et al.*. CERN-SPSC-2004-029, CERN-SPSC-I-229, Oct 2004. 56pp.

3) **PRECISION MEASUREMENT OF CHARGED KAON DECAY PARAMETERS WITH AN EXTENDED NA48 SETUP. (ADDENDUM 3 TO PROPOSAL P253/CERN/SPSC).**
R. Batley *et al.*. CERN-SPSC-2000-003, CERN-SPSC-P-253-ADD-3, Dec 1999. 25pp.

4) **A HIGH SENSITIVITY INVESTIGATION OF K(S) AND NEUTRAL HYPERON DECAYS USING A MODIFIED K(S) BEAM. (ADDENDUM 2 TO P253).**
R. Batley *et al.*. CERN-SPSC-2000-002, CERN-SPSC-P-253-ADD-2, Dec 1999. 24pp.

NA48-NA62: pubblicazioni

D1. Pubblicazioni di risultati di Fisica con la collaborazione NA48/2 (N.10)

1) **Determination of the S-wave pi-pi scattering lengths from a study of K+---> pi+ pi0 pi0 decays.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2009-010, May 2009. 16pp. Published in **Eur.Phys.J.C64:589-608,2009**.

2) **Precise measurement of the K+- ---> pi+-e+e- decay.**By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2009-005, Mar 2009. 16pp. Published in **Phys.Lett.B677:246-254,2009**.

3) **New high statistics measurement of K(e4) decay form factors and pi pi scattering phase shifts.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-035, Oct 2007. 24pp. Published in **Eur.Phys.J.C54:411-423,2008**.

4) **First Observation and Measurement of the Decay K+- ---> pi+- e+ e- gamma.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-033, Nov 2007. 13pp. Published in **Phys.Lett.B659:493-499,2008**.

5) **Search for direct CP violating charge asymmetries in K+- ---> pi+- pi+ pi- and K+- ---> pi+- pi0 pi0 decays.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-021, Jun 2007. 28pp. Published in **Eur.Phys.J.C52:875-891,2007**.

6) **Measurement of the Dalitz plot slopes of the K+- to pi+- pi+ pi- decay.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-002, Feb 2007. 14pp. Published in **Phys.Lett.B649:349-358,2007**.

7) **Measurements of Charged Kaon Semileptonic Decay Branching Fractions K+- ---> pi0 mu+- nu and K+- ---> pi0 e+- nu and Their Ratio.**
By NA48/2 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2006-039, Dec 2006. 20pp. Published in **Eur.Phys.J.C50:329-340,2007**.

8) **Search for direct CP-violation in K+- ---> pi+- pi0 pi0 decays.**
By NA48/2 Collaboration (J.R. Batley *et al.*). Jun 2006. 14pp. Published in **Phys.Lett.B638:22-29,2006, Erratum-ibid.B640:297,2006**.

9) **Search for direct CP violation in the decays K+- ---> 3pi+-.**
By NA48/2 Collaboration (J.R. Batley *et al.*). Feb 2006. 14pp. Published in **Phys.Lett.B634:474-482,2006**.

10) **Observation of a cusp-like structure in the pi0 pi0 invariant mass distribution from K+- ---> pi+- pi0 pi0 decay and determination of the pi pi scattering lengths**.
By NA48/2 Collaboration (J.R. Batley *et al.*). Nov 2005. 16pp. Published in **Phys.Lett.B633:173-182,2006.**

D2. Pubblicazioni di risultati di Fisica con la collaborazione NA48/1 (N.8)

1) **Measurement of the polarization of the Xi0 (anti-Xi0) hyperon beam by the NA48/1 experiment.**
By NA48/1 Collaboration (J.R. Batley *et al.*). Nov 2009. 7pp. Published in **Phys.Lett.B681:406-412,2009**.

2) **Determination of the relative decay rate K(S) ---> pi e nu / K(L) ---> pi e nu.**
J.R. Batley *et al.* 2007. 6pp. Published in **Phys.Lett.B653:145-150,2007**.

3) **Measurements of the Xi0 lifetime and the anti-Xi0 / Xi0 flux ratio in a neutral beam.**
By NA48 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-015, Jun 2007. 16pp. Submitted to **Phys.Lett.B**.

4) **First observation and branching fraction and decay parameter measurements of the weak radiative decay Xi0 ---> Lambda e+ e-.**
By NA48 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2007-004, Feb 2007. 20pp. Published in **Phys.Lett.B650:1-8,2007**.

5) **Measurement of the branching ratios of the decays Xi0 ---> Sigma+ e- anti-nu(e) and anti-Xi0 ---> anti-Sigma+ e+ nu(e).**
By NA48/I Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2006-032, Oct 2006. 16pp. Published in **Phys.Lett.B645:36-46,2007**.

6) **A Measurement of the CP-conserving component of the decay K0(S) ---> pi+ pi- pi0.**
By NA48 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2005-037, Jul 2005. 9pp. Published in **Phys.Lett.B630:31-39,2005**.

7) **Observation of the rare decay K(S) ---> pi0 mu+ mu-.**
By NA48/1 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2004-025, Jun 2004. 19pp. Published in **Phys.Lett.B599:197-211,2004**.

8) **Observation of the rare decay K(S) ---> pi0 e+ e-.**
By NA48/1 Collaboration (J.R. Batley *et al.*). CERN-EP-2003-062, Sep 2003. 13pp. Published in **Phys.Lett.B576:43-54,2003**.

NA48-NA62: pubblicazioni

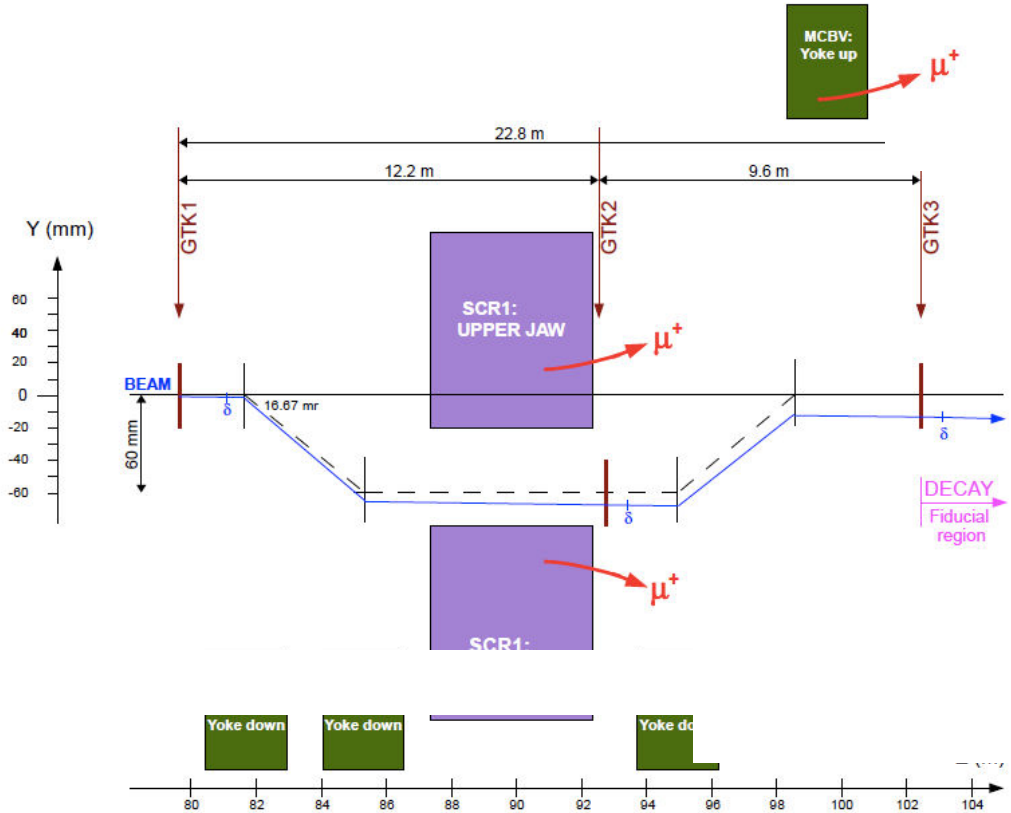
D3. Pubblicazioni di risultati di Fisica con la collaborazione NA48 (N.29)

1) **Measurement of the ratio Gamma(KL ---> pi+ pi-) / Gamma(KL ---> pi e nu) and extraction of the CP violation parameter |eta(+-)|.**
By NA48 Collaboration (A. Lai *et al.*). CERN-PH-EP-2006-034, Oct 2006. 20pp. Published in **Phys.Lett.B645:26-35,2007.**
2) **Measurement of K0(mu3) form factors.** By NA48 Collaboration (A. Lai *et al.*). CERN-PH-EP-2006-033, Oct 2006. 21pp. Published in **Phys.Lett.B647:341-350,2007**.
3) **Measurement of the K(L) e+ e- e+ e- decay rate.**By NA48 Collaboration (A. Lai *et al.*). May 2005. Published in **Phys.Lett.B615:31-38,2005**.
4) **Measurement of the radiative K(e3) branching ratio.**By NA48 Collaboration (A. Lai *et al.*). CERN-PH-EP-2004-054, Oct 2004. 13pp. Published in **Phys.Lett.B605:247-255,2005**.
5) **Measurement of K0(e3) form-factors.**By NA48 Collaboration (A. Lai *et al.*). CERN-PH-EP-2004-048, Aug 2004. 16pp. Published in **Phys.Lett.B604:1-10,2004**.
6) **Measurement of the branching ratio of the decay K(L) ---> pi+- e-+ nu and extraction of the CKM parameter |V(us)|.**
By NA48 Collaboration (A. Lai *et al.*). CERN-PH-EP-2004-047, Oct 2004. 18pp. Published in **Phys.Lett.B602:41-51,2004**.
7) **Search for CP violation in K0 ---> 3 pi0 decays.**By NA48 Collaboration (A. Lai *et al.*). Aug 2004. 18pp. Published in **Phys.Lett.B610:165-176,2005**.
8) **Measurement of the branching ratio and form-factors for the decay K(L) ---> pi+- pi0 e-+ nu(e)(anti-nu(e)).**
By NA48 Collaboration (J.R. Batley *et al.*). CERN-PH-EP-2004-013, Apr 2004. 12pp. Published in **Phys.Lett.B595:75-85,2004**.
9) **Measurement of the Xi0 ---> Lambda gamma decay asymmetry and branching fraction.**
By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2003-078, Jan 2004. 15pp. Published in **Phys.Lett.B584:251-259,2004**.
10) **First observation of the K(S) ---> pi0 gamma gamma decay.**By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2003-052, Aug 2003. 10pp. Published in **Phys.Lett.B578:276-284,2004**.
11) **Investigation of K(L,S) --> pi+ pi- e+ e- decays.**By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2003-006, Jan 2003. 34pp. Published in **Eur.Phys.J.C30:33-49,2003**.
12) **Search for the decay K(S) ---> pi0 gamma gamma.**A. Lai *et al.* CERN-EP-2002-101, Dec 2002. 12pp. Published in **Phys.Lett.B556:105-113,2003**.
13) **Precise measurements of the K(S) ---> gamma gamma and K(L) ---> gamma gamma decay rates.**
A. Lai *et al.* CERN-EP-2002-074, Oct 2002. 10pp. Published in **Phys.Lett.B551:7-15,2003**.
14) **A Precision measurement of direct CP violation in the decay of neutral kaons into two pions.**
By NA48 Collaboration (J.R. Batley *et al.*). CERN-EP-2002-061, Jul 2002. 19pp. Published in **Phys.Lett.B544:97-112,2002**.
15) **Precise measurement of the decay K(L) ---> pi0 gamma gamma.** By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2002-030, May 2002. 17pp. Published in **Phys.Lett.B536:229-240,2002**.
16) **A Measurement of the K(S) lifetime.**By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2002-028, May 2002. 15pp. Published in **Phys.Lett.B537:28-40,2002**.
17) **New measurements of the eta and K0 masses.**By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2002-025, Apr 2002. 17pp. Published in **Phys.Lett.B533:196-206,2002**.
18) **A Precise measurement of the direct CP violation parameter Re(epsilon-prime / epsilon).**
By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2001-067, Oct 2001. 42pp. Published in **Eur.Phys.J.C22:231-254,2001**.
19) **Search for the decay K(S) --> pi0 e+ e-.**By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2001-042, Jun 2001. 12pp. Published in **Phys.Lett.B514:253-262,2001**.
20) **Measurement of the quadratic slope parameter in the K(L) ---> 3 pi0 decay Dalitz plot.**
By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2001-041, Jun 2001. 13pp. Published in **Phys.Lett.B515:261-268,2001**.
21) **Observation of the decay K(S) --> pi+ pi- e+ e-.**By NA48 Collaboration (A. Lai *et al.*). DAPNIA-SPP-00-24, Oct 2000. 13pp. Published in **Phys.Lett.B496:137-144,2000**.
22) **A new measurement of the branching ratio of K(S) --> gamma gamma.**
By NA48 Collaboration (A. Lai *et al.*). CERN-EP-2000-122, Sep 2000. 11pp. Published in **Phys.Lett.B493:29-35,2000**.
23) **A New measurement of direct CP violation in two pion decays of the neutral kaon.**
By NA48 Collaboration (V. Fanti *et al.*). CERN-EP-99-114, Aug 1999. 18pp. Published in **Phys.Lett.B465:335-348,1999**.
24) **Precision measurement of the Xi0 mass and the branching ratios of the decays Xi0 ---> Lambda gamma and Xi0 ---> Sigma0 gamma.**By NA48 Collaboration (V. Fanti *et al.*).
PRINT-99-036, (Received Aug 1999). 8pp. Published in **Eur.Phys.J.C12:69-76,2000**.
25) **Measurement of the decay rate and form-factor parameter alpha(K*) in the decay K(L) ---> e+ e- gamma.**
By NA48 Collaboration (V. Fanti *et al.*). CERN-EP-99-053, CERN-EP-99-53, Apr 1999. 11pp. Published in **Phys.Lett.B458:553-563,1999**.
26) **A Measurement of the transverse polarization of Lambda hyperons produced in inelastic p N reactions at 450-GeV proton energy.**
V. Fanti *et al.* PRINT-99-001, Sep 1998. 5pp. Published in **Eur.Phys.J.C6:265-269,1999**.
27) **Direct search for light gluinos.** By NA48 Collaboration (V. Fanti *et al.*). CERN-EP-98-172, Oct 1998. 11pp. Published in **Phys.Lett.B446:117-124,1999**.
28) **Measurement of the decay rate and the parameter alpha(K*) of the decay K(L) ---> mu mu gamma.**
By NA48 Collaboration (V. Fanti *et al.*). PRINT-97-274, MZ-ETAP-97-9, (Received Dec 1997). 11pp. Published in **Z.Phys.C76:653-657,1997**.
29) **First measurement of the rate K0(L) ---> pi mu nu gamma.**M. Bender *et al.* SI-97-17A, Oct 1997. 20pp. Published in **Phys.Lett.B418:411-418,1998**.

M. Lenti

SPARES

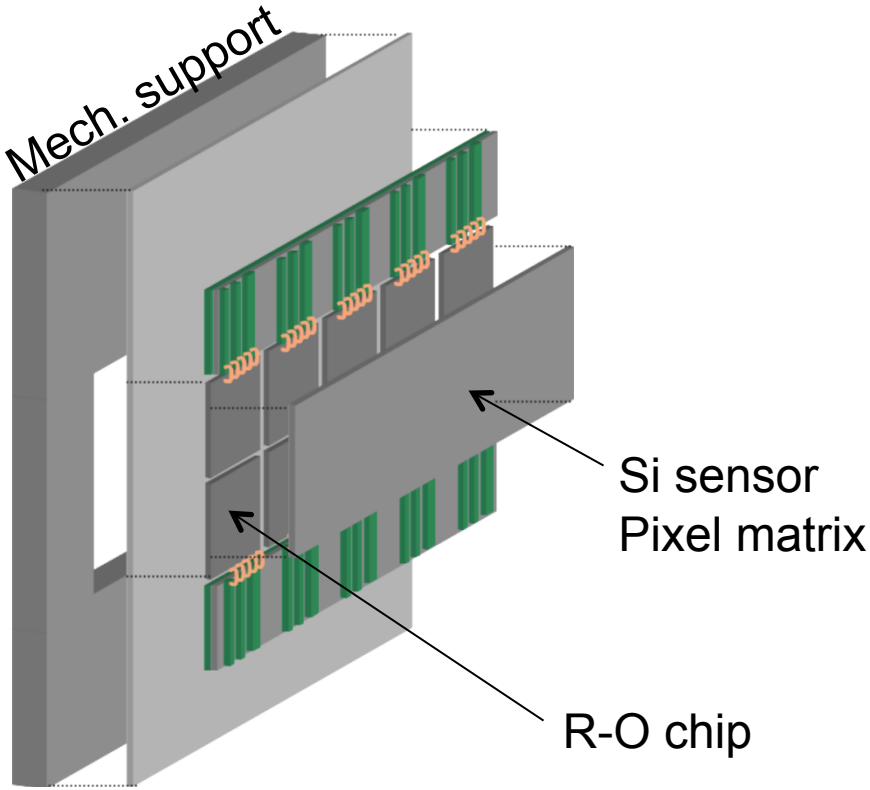
Beam Spectrometer (I)

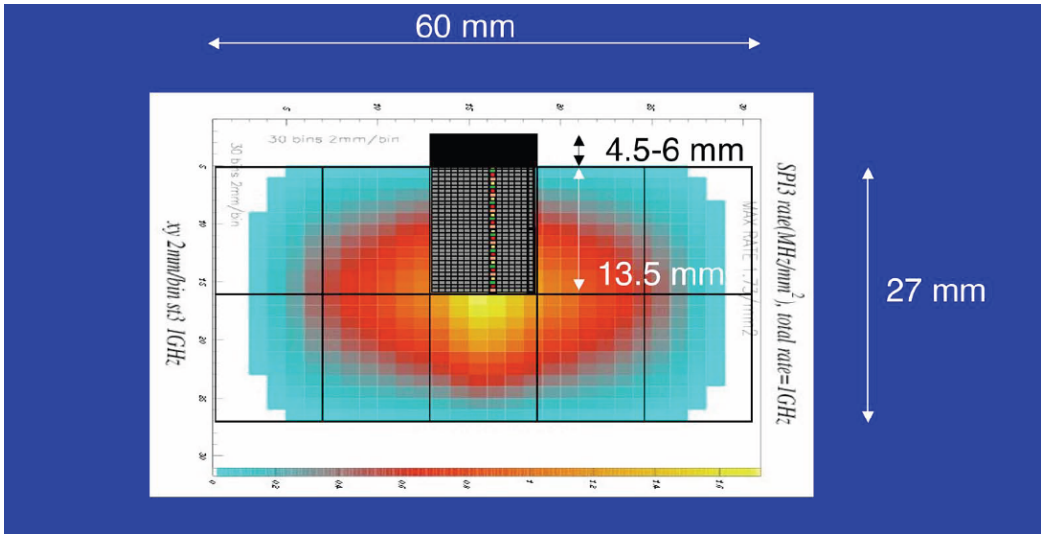


- 3 Silicon Pixels stations across the 2nd Achromat: 60(X) × 27(Y) mm per station (18000 pixel/station)
- Beam rate: 800 MHz ("Gigatracker"), 50 MHz/cm^2

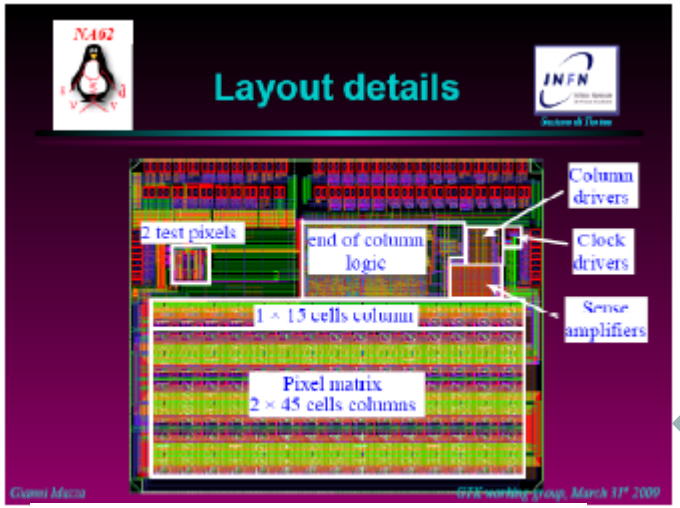
Beam Spectrometer (II)

- 300×300 μm pixels p-in-n (18000 pixel per station) → $\sigma(P_K)/P_K \sim 0.2\%$, $\sigma(\theta_K) \sim 14$ μrad
- 200 μm Si sensor + 100 μm chip → <0.5% X0 /station
- 0.13 μm CMOS technology → $\sigma(t) \sim 200$ ps/station



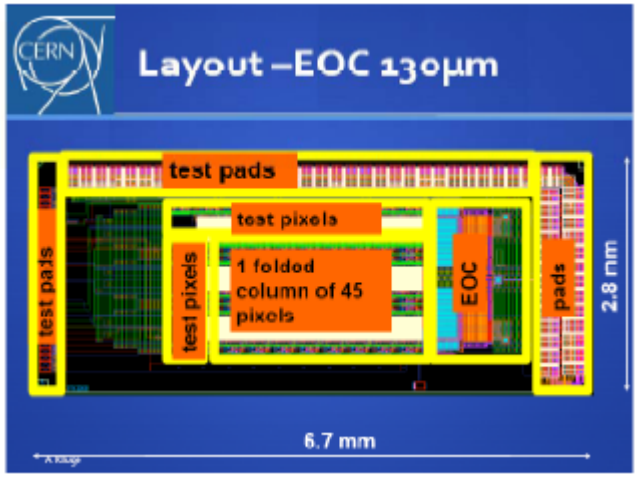


Beam Spectrometer (III)



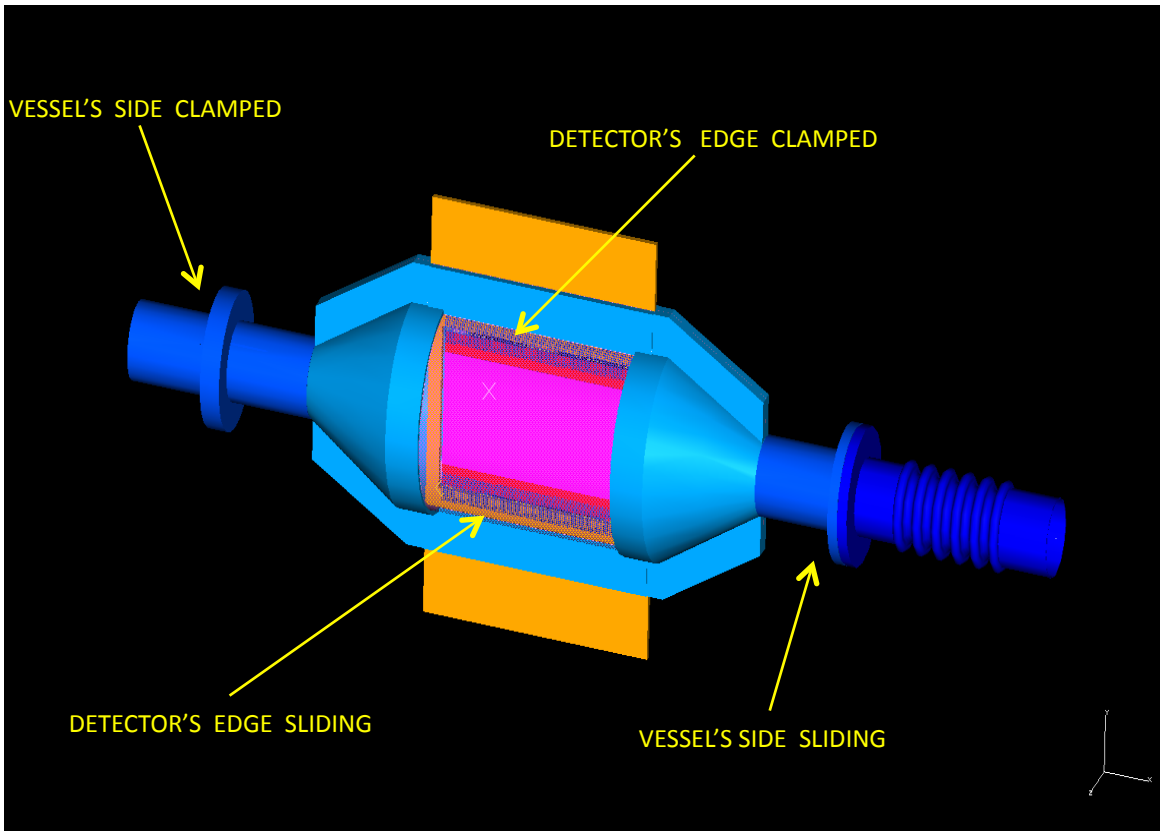
INFN Design: One TDC / pixel

Readout

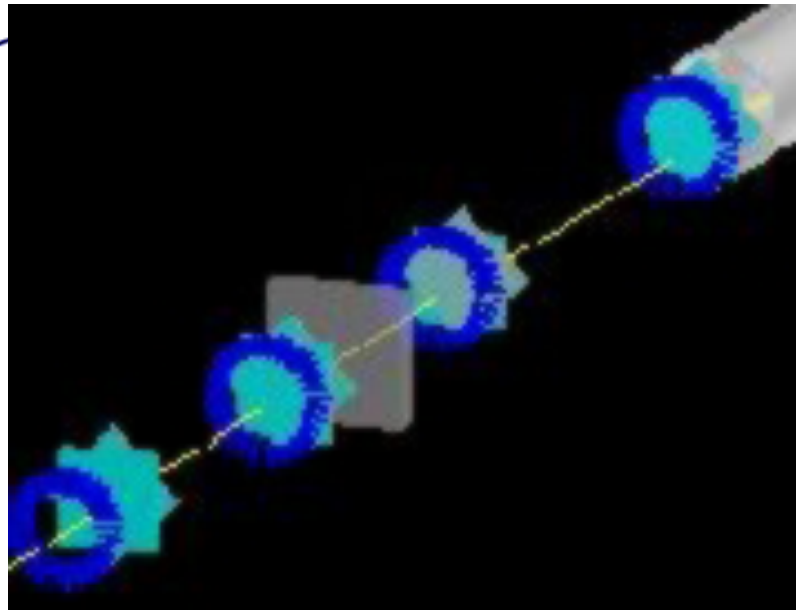


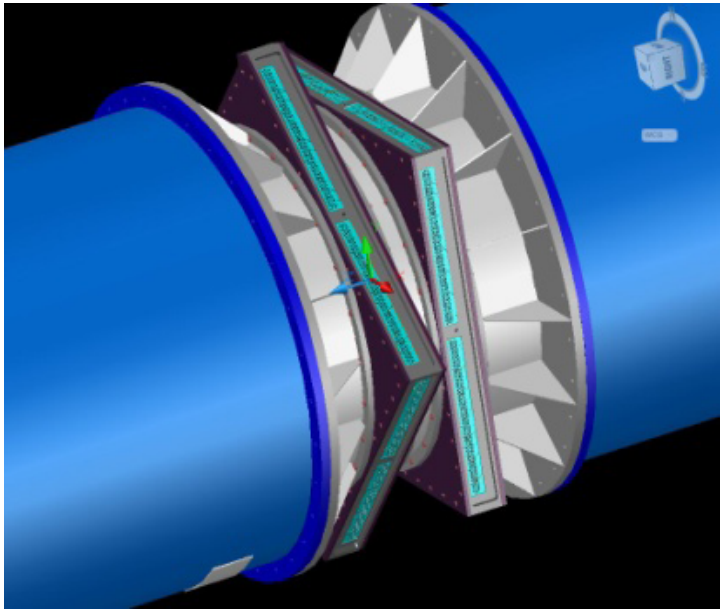
CERN Design: End of Column TDC

The cooling System

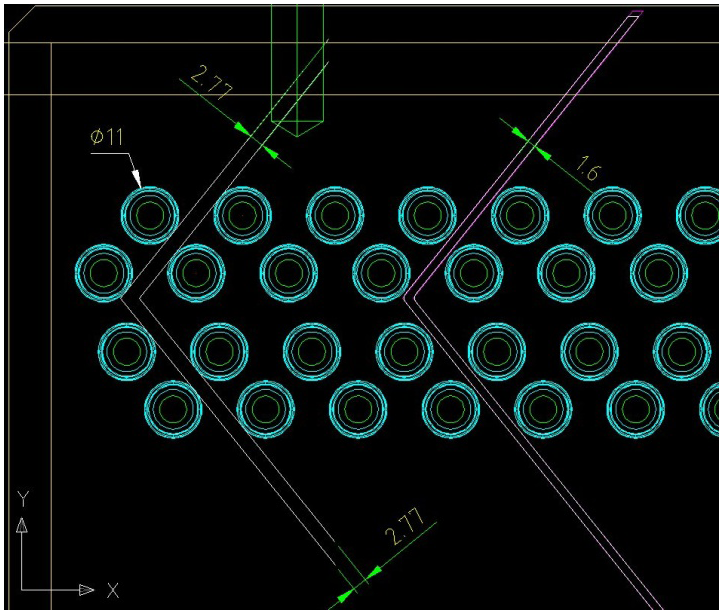


Straw Chambers





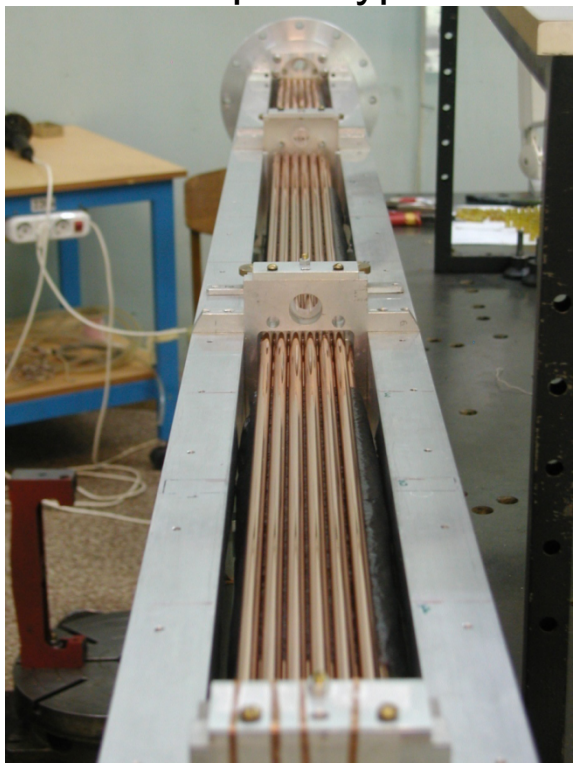
- 4 chambers with 4 layers/view
- Ø 9.6 mm straw tubes in vacuum
- 2.1 m long straws
- 0.1% X_0 per view (4 views)
- 130 μm hit resolution per view
- NA48 magnet (256 MeV/c p_t kick)
- holes follow beam path



M. Lenti

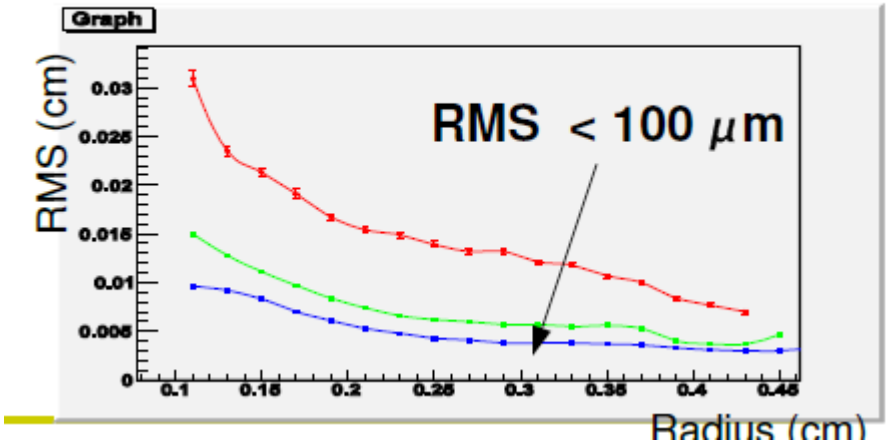
Straws Prototype

2007 prototype



In vacuum

- Resolution from test beam (blue points)



Background 2: $K^+ \rightarrow \pi^+\pi^0$ ($K_{\pi 2}$)

2nd Largest BR: 20.9%

Need ~10^{-12} rejection factor

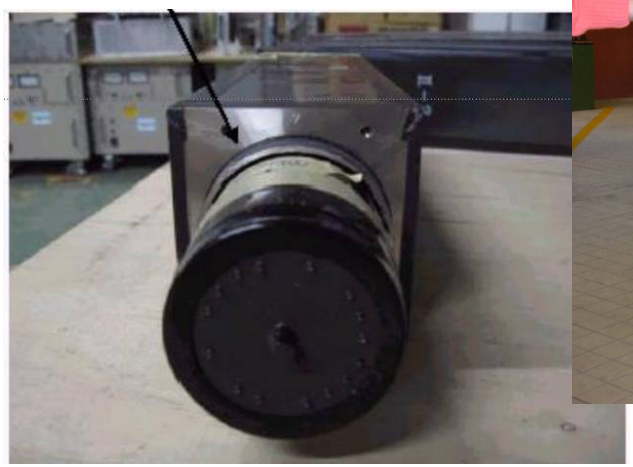
- Kinematics: 5×10^{-3}
- Photon Veto: 10^{-5} per photon (10^{-8} per π^0)

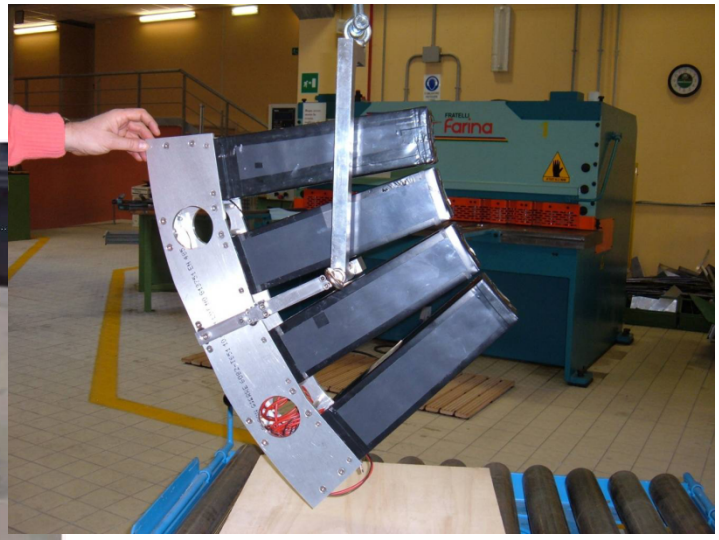
- **Large angle:** **12 ANTIs (10 < acceptance < 50 mrad)**
- **Medium angle:** **NA48 LKr (1 < acceptance < 10 mrad)**
- **Small angle:** **IRC, SAC (acceptance < 1 mrad)**

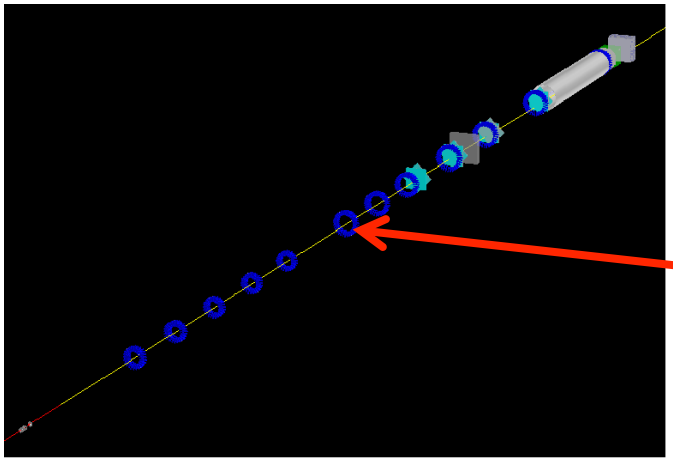
Large Angle Veto

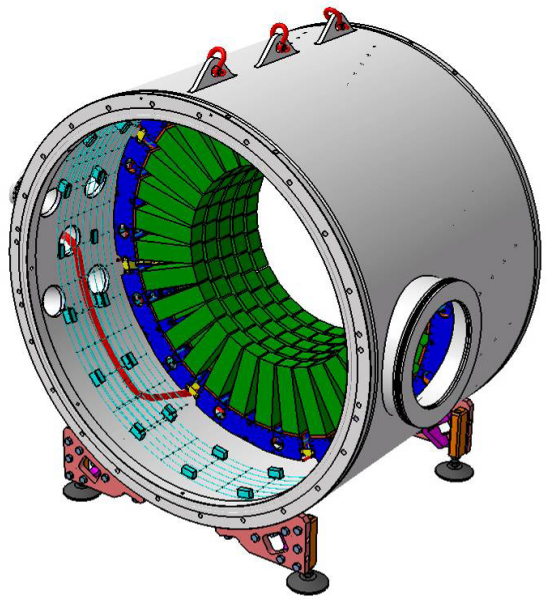
- 12 ring em calorimeters in vacuum
- 5 staggered planes per ring
- inefficiencies:
  - 10^{-4} $.05<E_\gamma<1$ GeV
  - 10^{-5} $E_\gamma>1$ GeV

OPAL Lead Blocks reused







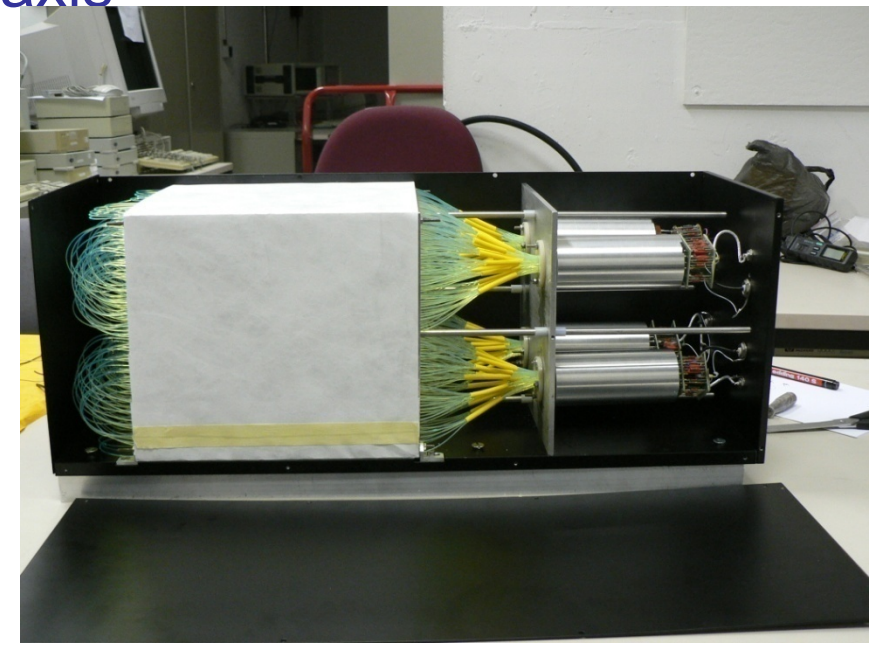


Large Angle Veto: 1° ring

First ring built in Frascati and installed at CERN.
Test beam in mid-october 2009

Small Angle Veto

- shaslyk calorimeter on the beam axis
- 10^{-5} ineff. High energy γ



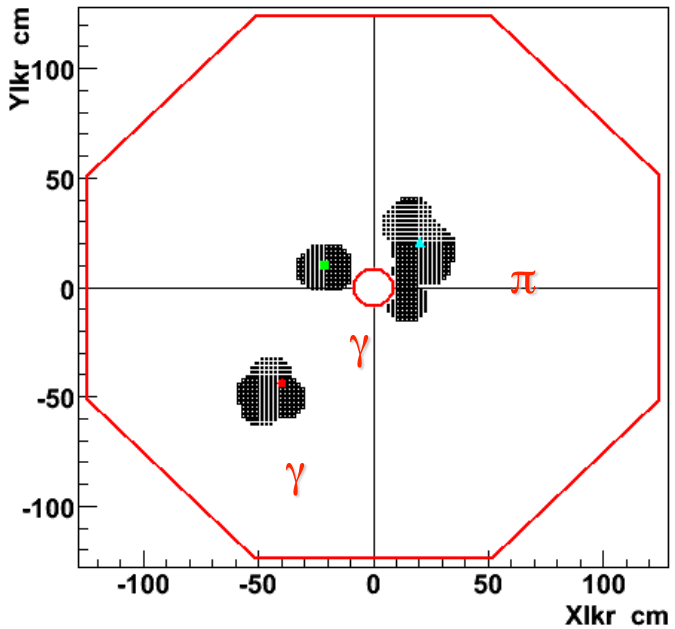
Tested in October 2006
In the NA48 tagged photon beam
(see later)

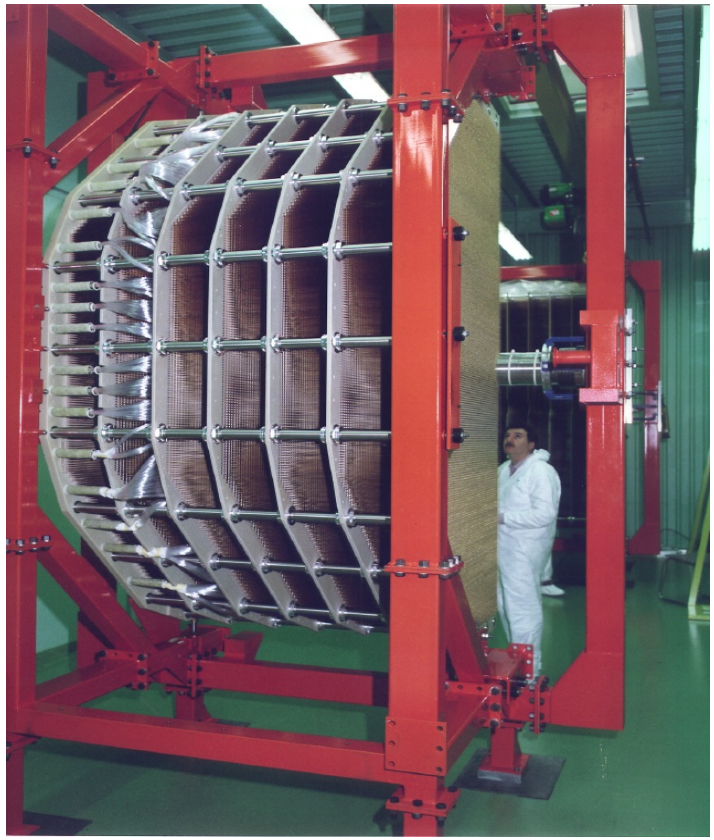
Liquid Kripton Calorimeter

Use the existing NA48 LKr calorimeter

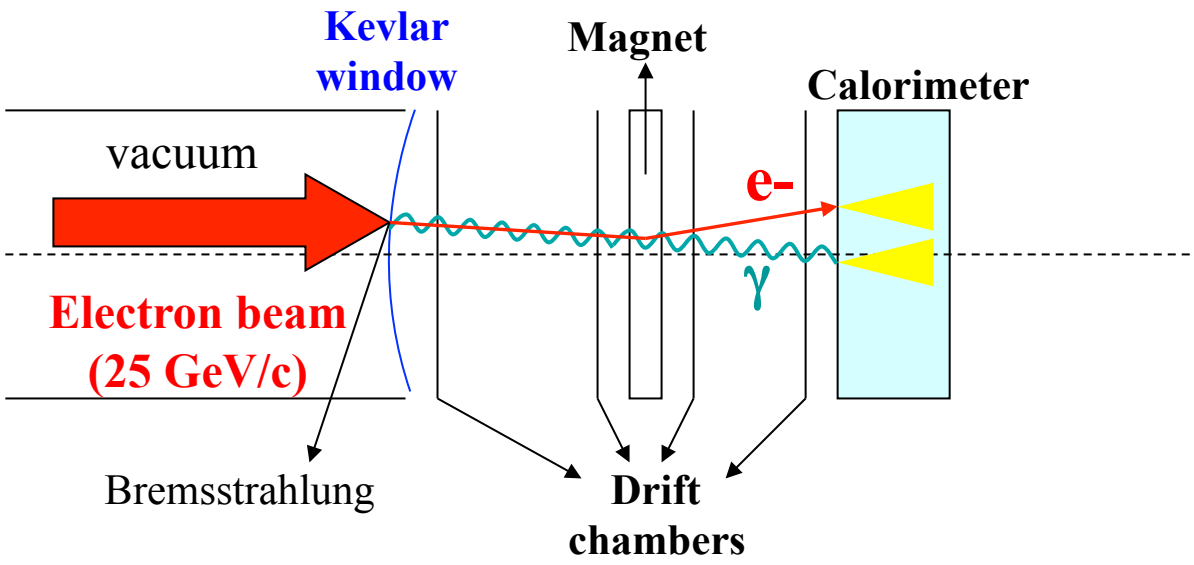
- 10^{-5} ineff. E_γ>5 GeV
- 10^{-4} ineff. 1<E_γ<5 GeV

Ineff. for E_γ>10 GeV tested on data collected by NA48/2 ($K^+ \rightarrow \pi^+\pi^0$)



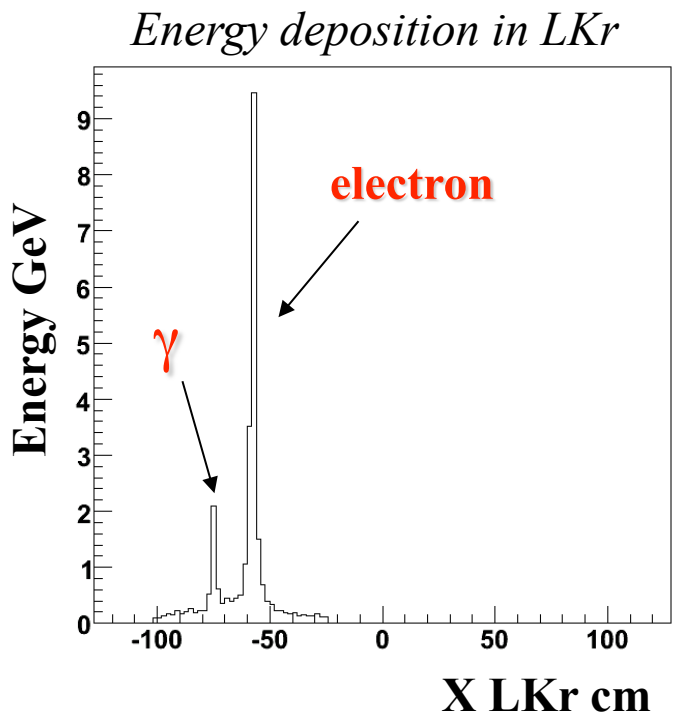


Liquid Kripton Calorimeter



October 2006 test:
Tagged photon beam
Using the existing NA48 setup

- 2×10^{8} electrons collected
- 10^{-5} ineff.sensitivity below 10 GeV

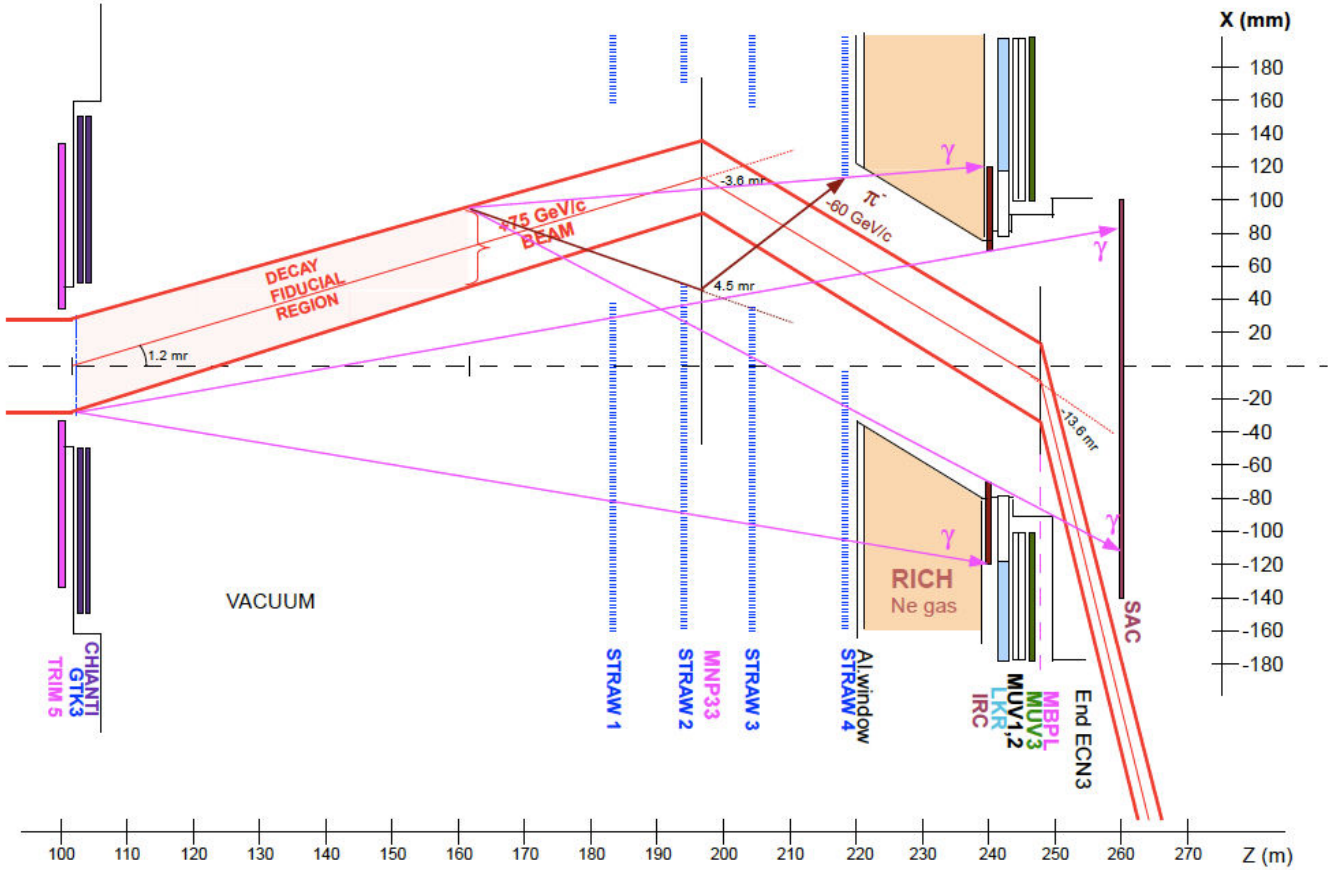


M. Lenti

Multibody Background

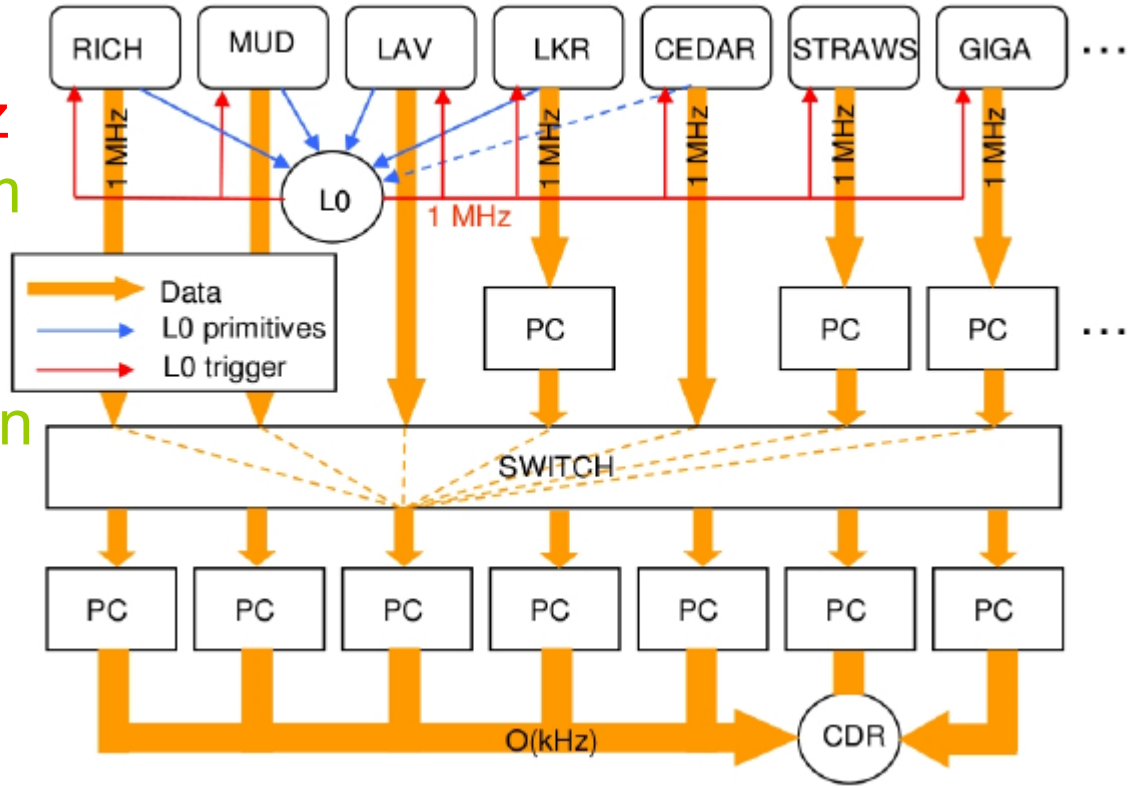
Ex. $K^+ \rightarrow \pi^+\pi^-e^+\nu$

Stagger Straws to be hermetic for π^- up to 60 GeV/c



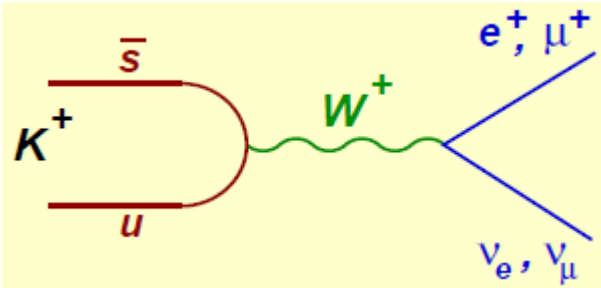
Trigger Levels

- 10 MHz L0 trigger input
- 1track × μ! × γ! → 1 MHz
L1 trigger input → PC farm
- Software trigger reduction
~ 40



R_K: theory

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{rad.corr.})$$

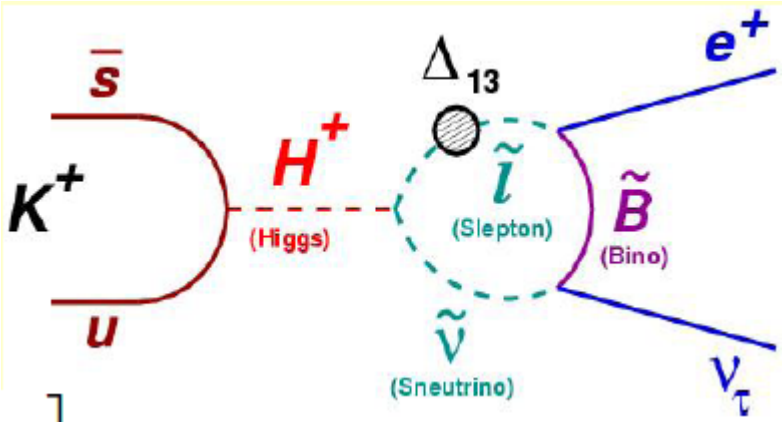


SM uncertainties well below 10^{-3}

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$

V. Cirigliano and I. Rosell, Phys. Lett. 99 (2007) 231801

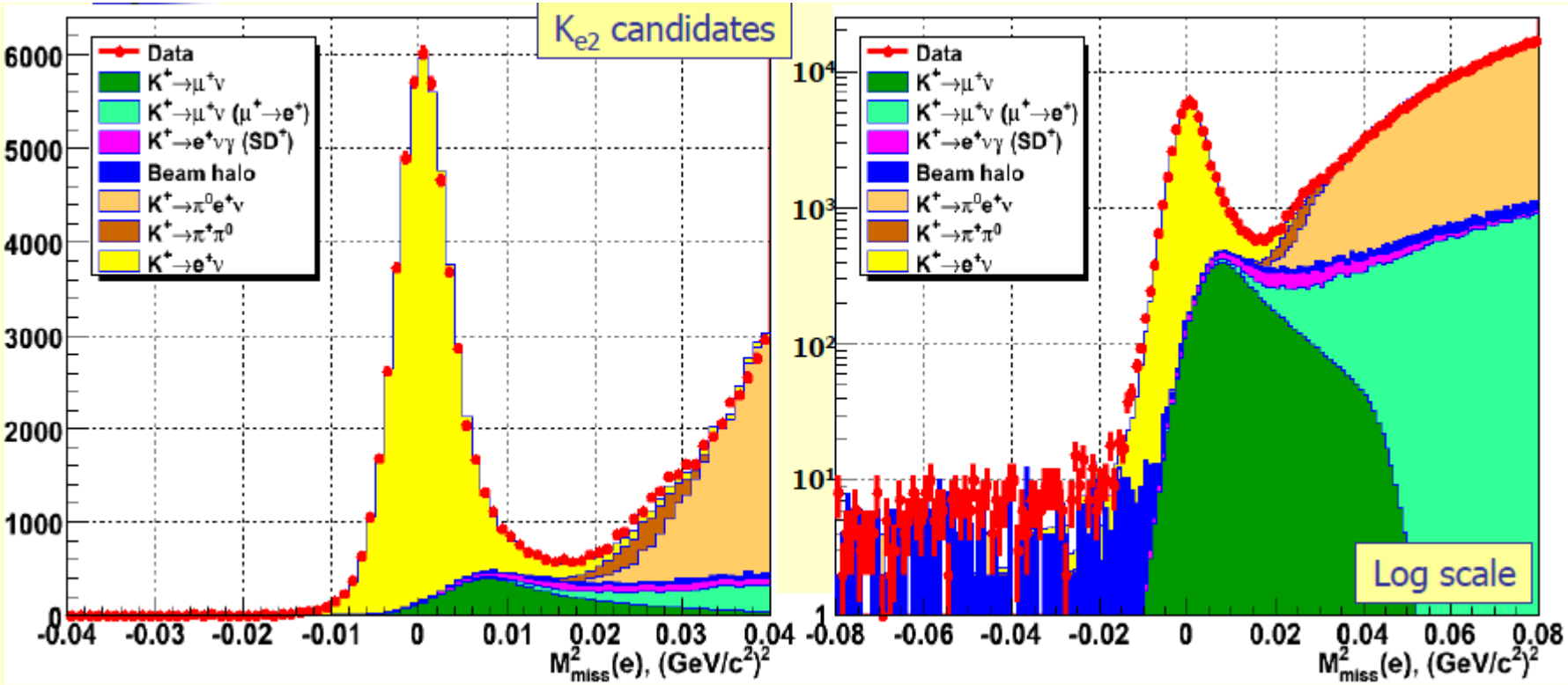


$$R_K^{LFV} \approx R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2 \tan^6\beta\right]$$

A. Masiero, P. Paradisi and R. Petronzio, PRD74 (2006) 011701 and JHEP 0811 (2008) 042

Few % effect possible

R_K: NA62(2007-2008)



40% of data analyzed, 51000 K_{e2} candidates, 8% background

R_K: prelim.results

$$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{syst}) \times 10^{-5}$$
$$= (2.500 \pm 0.016) \times 10^{-5}$$