The NA62 RICH detector

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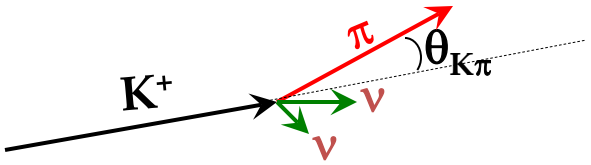
Outlook

- Physics motivations
- The Vessel and the Gas system
- The Mirrors
- The Photomultipliers
- FE and DAQ
- 2007 and 2009 test beams: results
- Construction schedule
- Conclusions

Physics Motivations

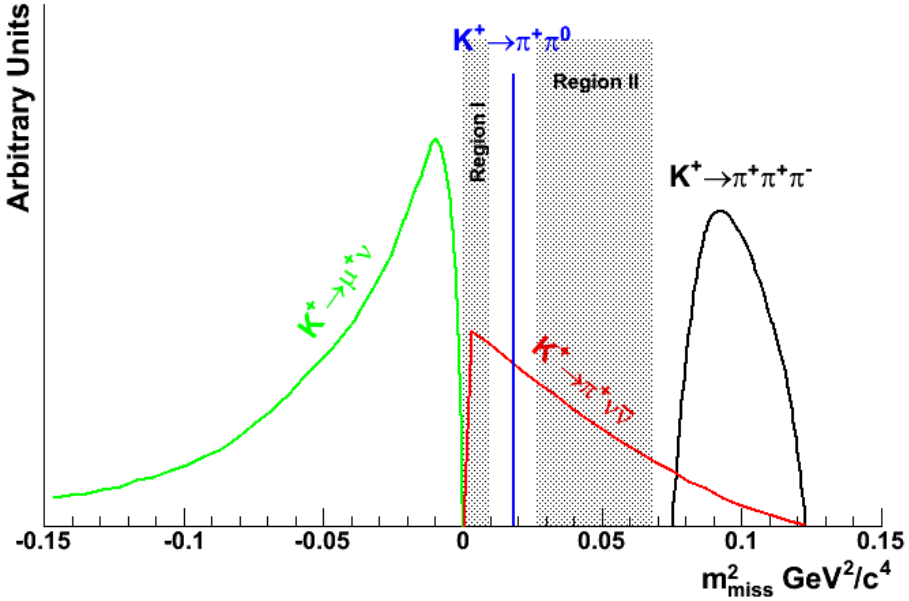
- NA62 aim at a 10% measurement of the BR($K^+ \to \pi^+ \nu\nu$)
- Theory: BR = $(0.85 \pm 0.07) \times 10^{-10}$
- One of the cleanest channel in flavor physics…
- Very hard from an exp. point of view
- Present result: $\mathbf{1.73^{+1.15}_{-1.05} \times 10^{-10}}$ **(BNL E787/E949)**

Kinematics

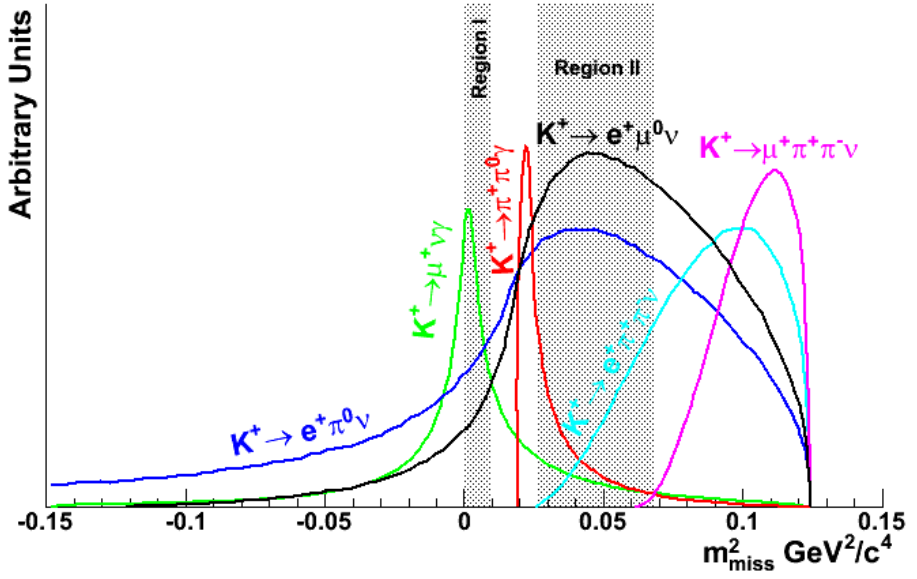


$$m^2_{miss}=(P_K-P_\pi)^2$$

92% K^+ decays



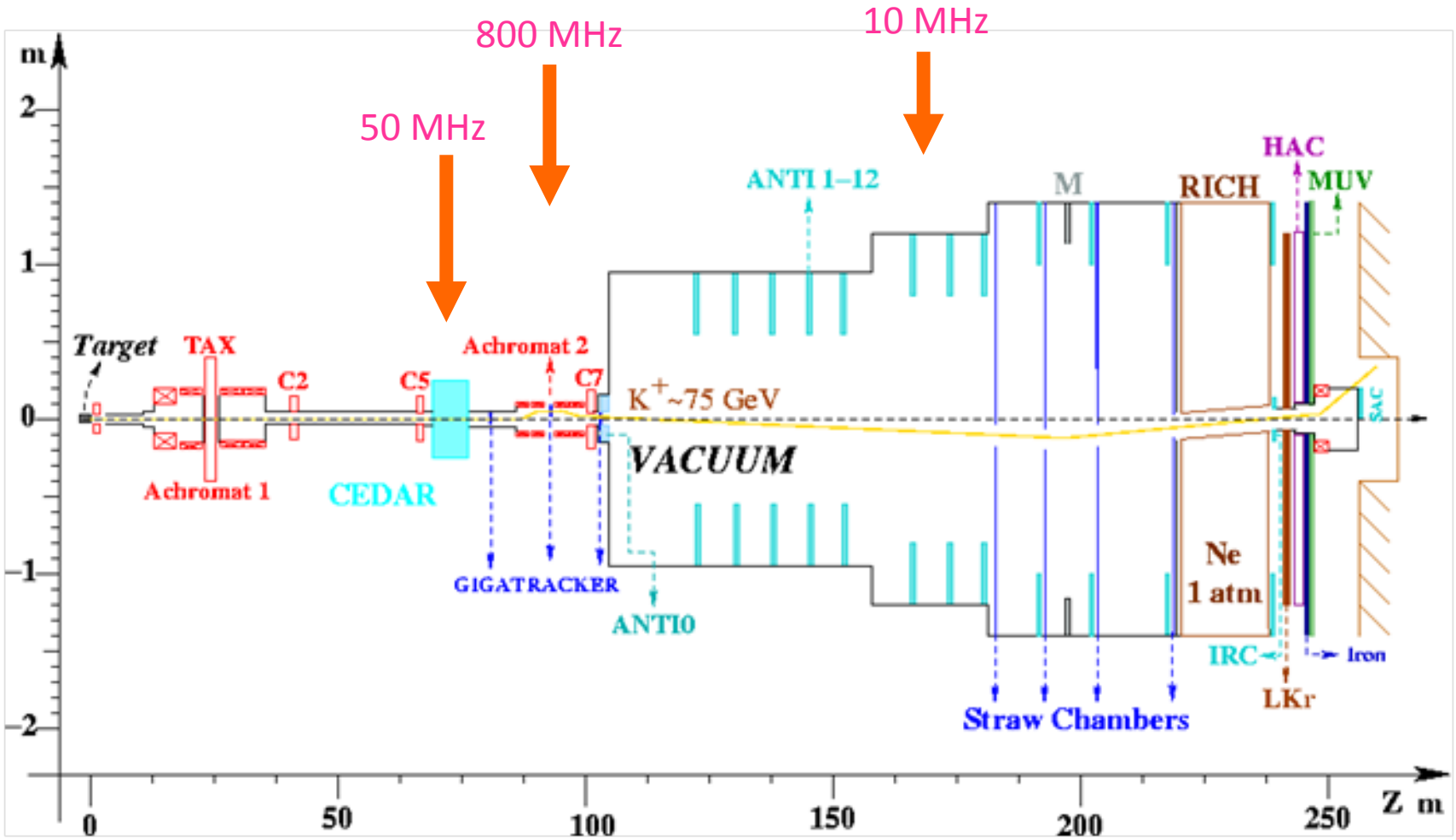
8% K^+ decays



P_K : beam spectrometer

P_π : straw chambers spectrometer

The NA62 Layout



The pile-up problem

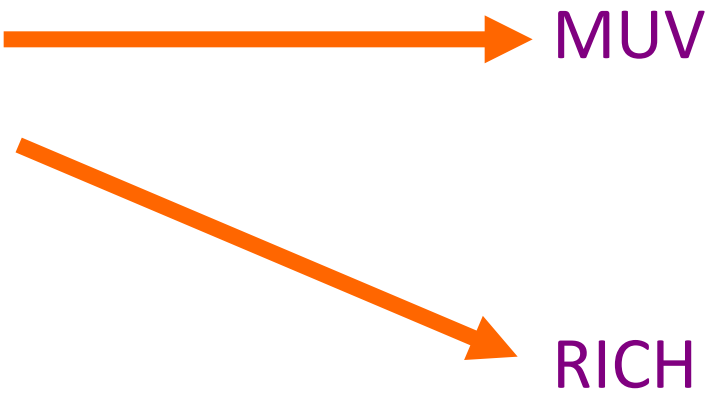
- Need to match a track (pion) seen by the straw spectrometer (rate: 10 MHz)
- with a track (kaon) seen by the beam spectrometer (rate: 800 MHz)
- Wrong matching: wrong missing mass
- Measure the track time, both upstream and downstream at 100 ps level

Background 1: $K^+ \rightarrow \mu^+ \nu$

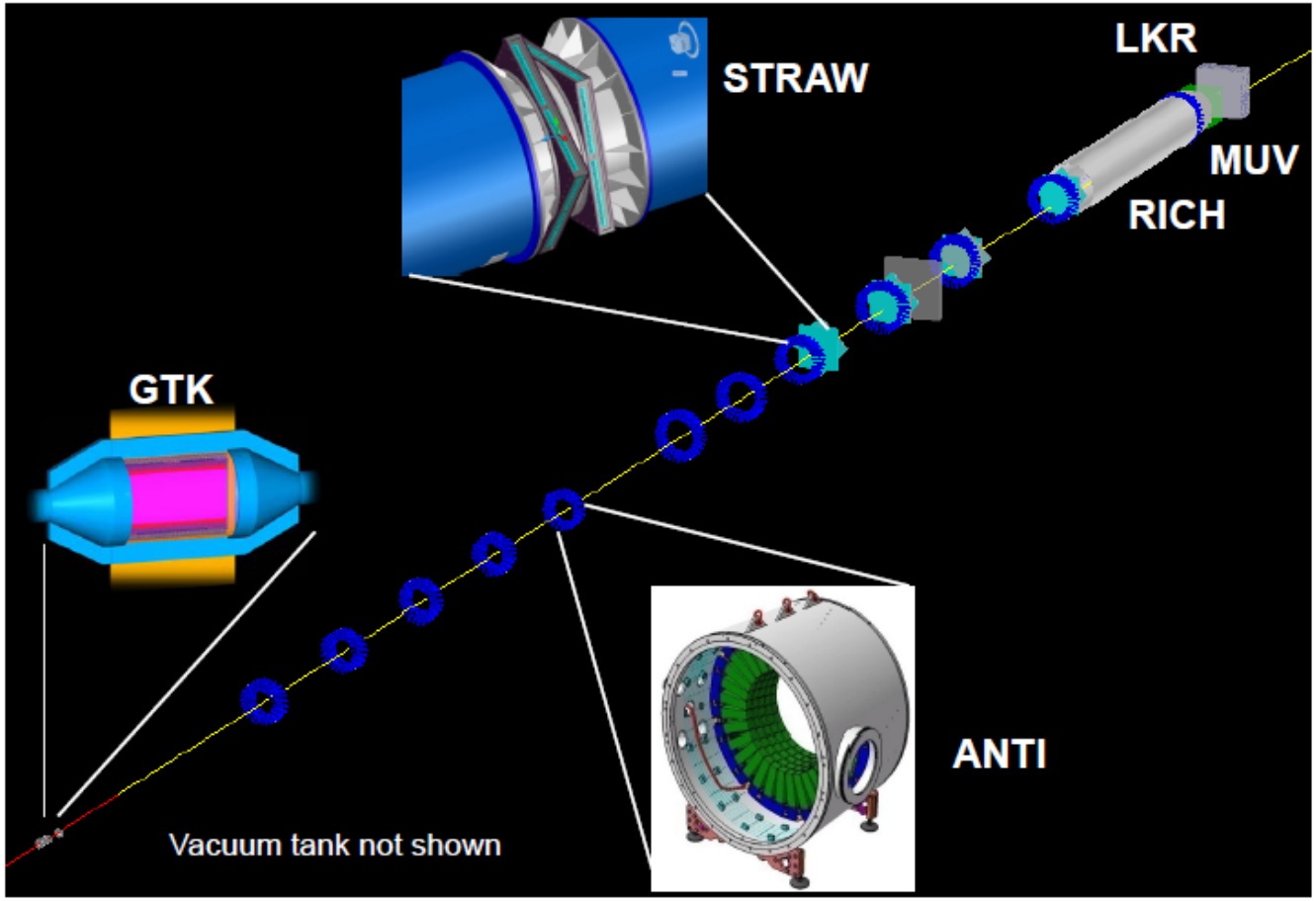
$K_{\mu 2}$:largest BR: 63.4%

Need ~10^{-12} rejection factor

- Kinematics: 10^{-5}
- Muon Veto: 10^{-5}
- Particle ID: 10^{-2}



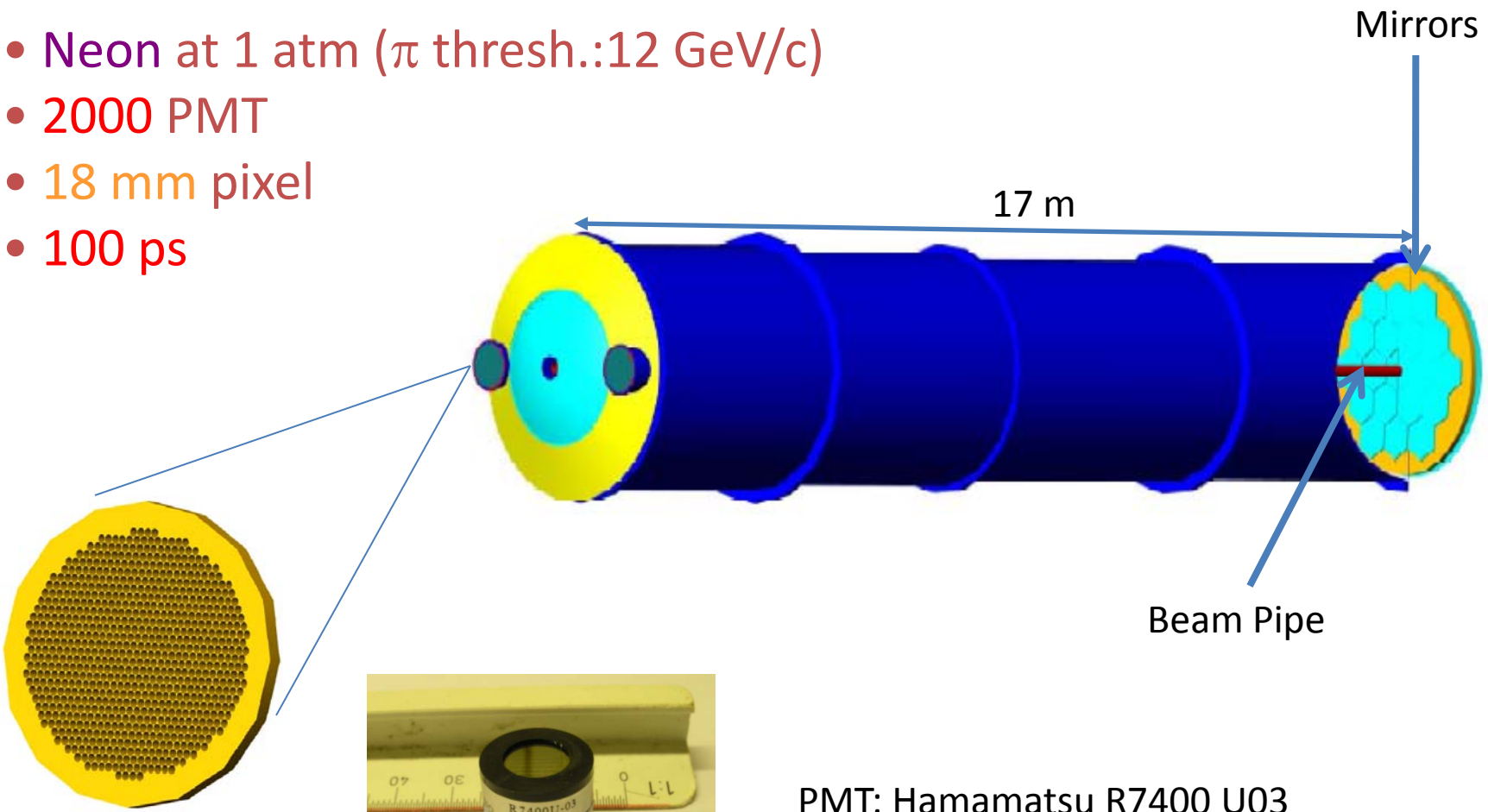
The RICH inside the NA62 layout



The NA62 RICH

3σ $\pi-\mu$ separation (15-35 GeV/c)

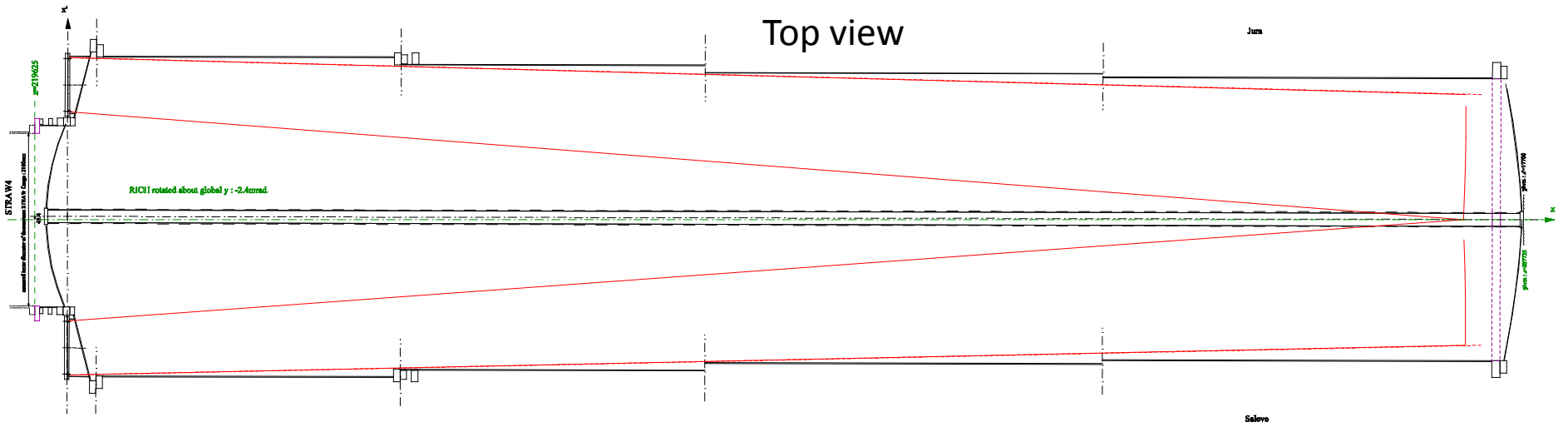
- Neon at 1 atm (π thresh.:12 GeV/c)
- 2000 PMT
- 18 mm pixel
- 100 ps



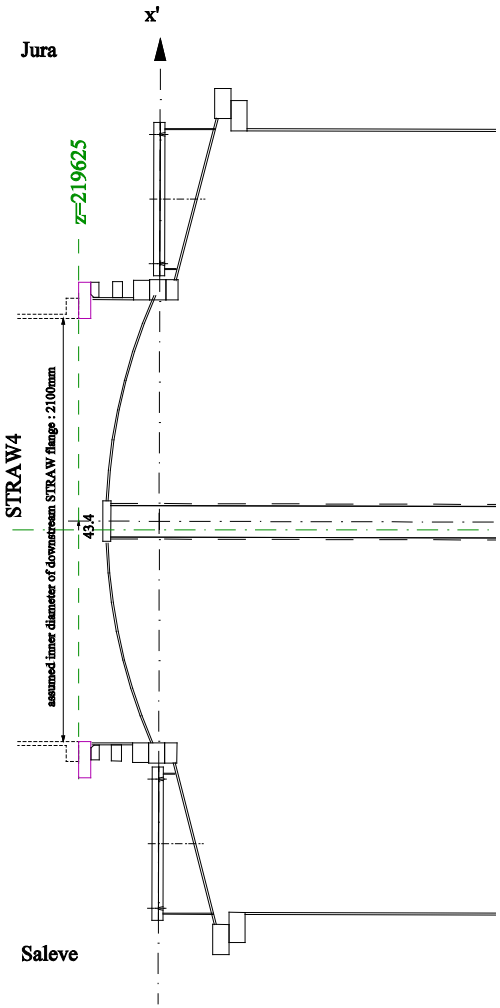
PMT: Hamamatsu R7400 U03

The RICH Vessel

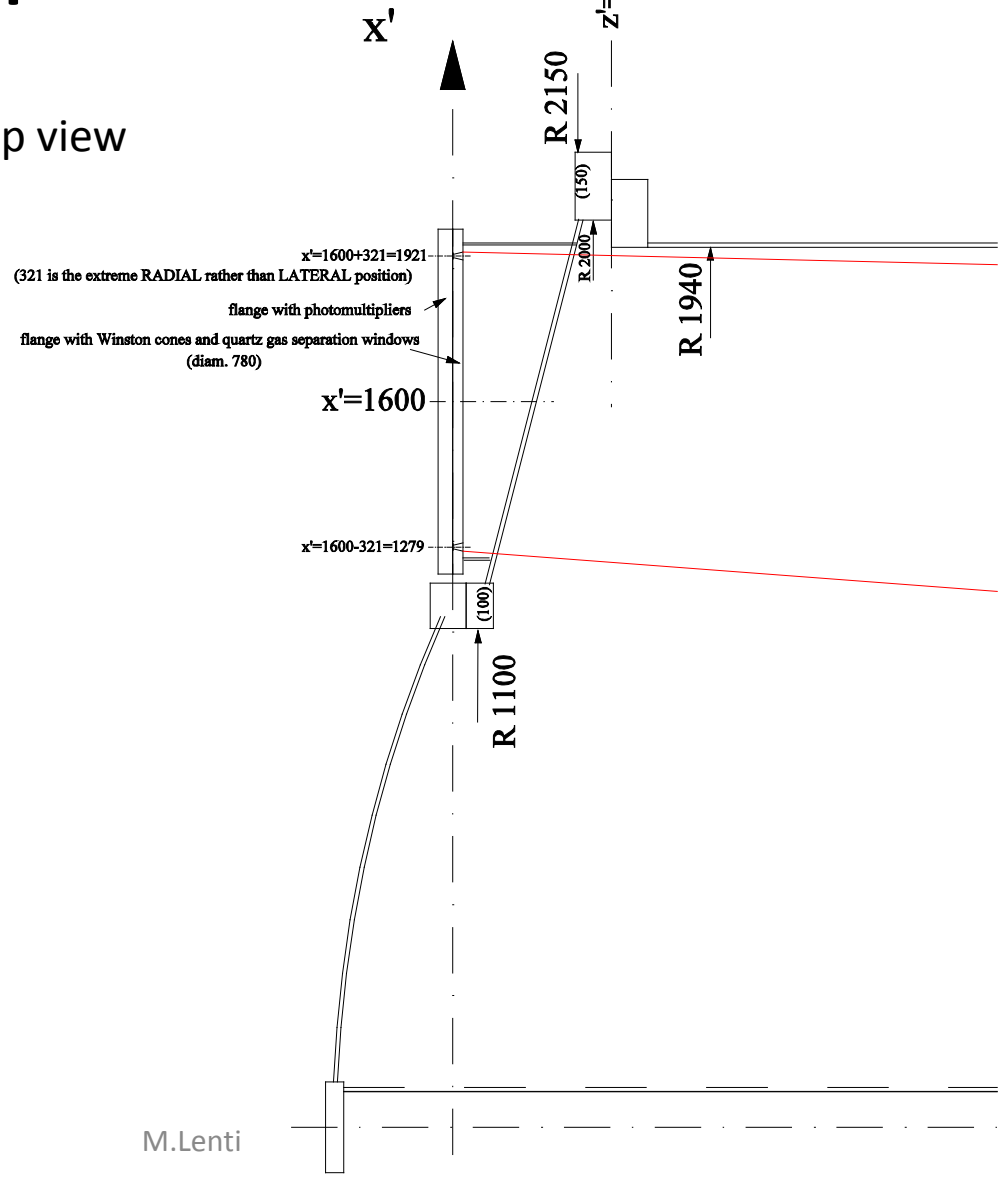
- 17 m long vessel in construction steel, not vacuum proof
- max overpressure: 150 mbar
- 4 m wide (beginning), 3.4 m wide (end)
- beam pipe (Ø 157 mm) going through
- thin aluminium entrance and exit windows
-



The Vessel, upstream



Top view

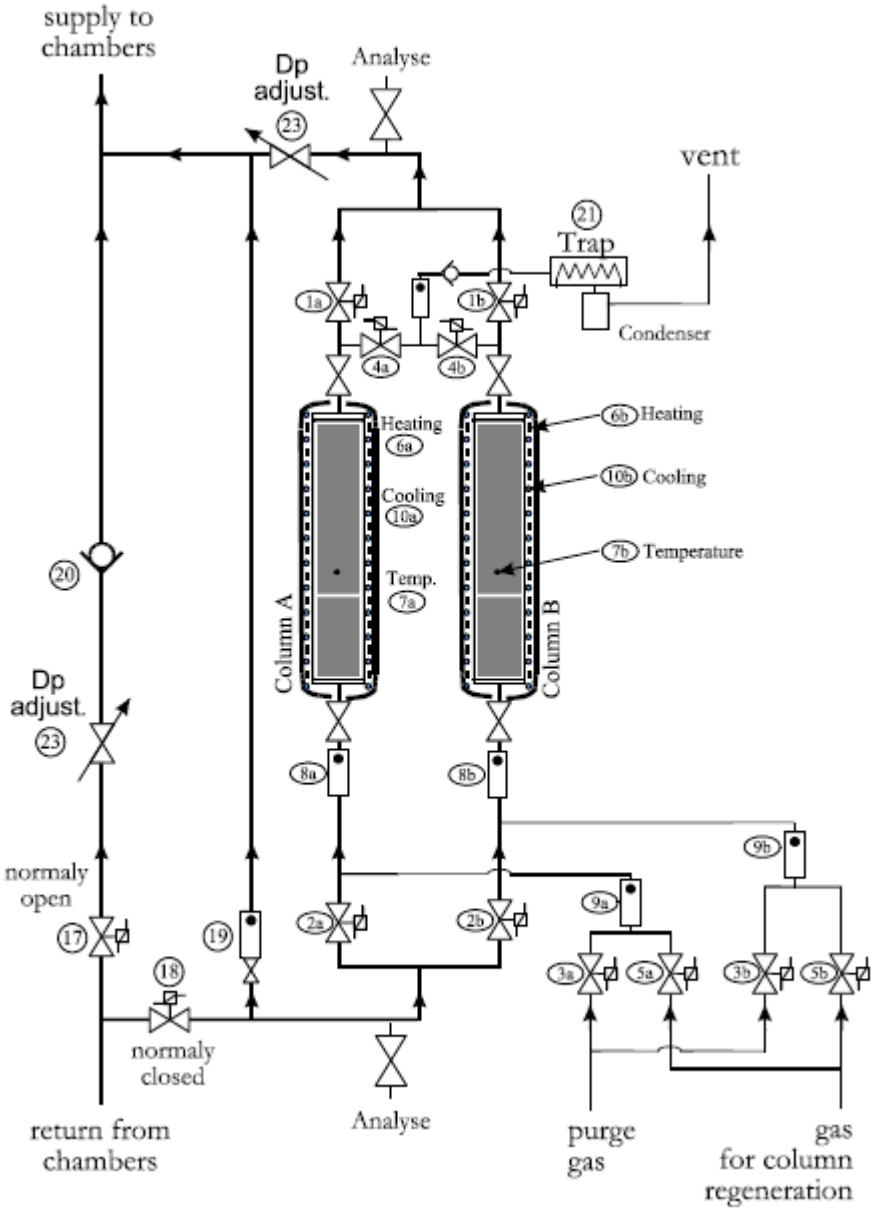


The Gas System

- Vessel volume: 200 m3
- Neon at slightly above atmospheric pressure
- Neon density stability < 1%
- Contaminants < 1%
- CO_2 used to purge the vessel
- The gas is then circulated in closed loop, and the Neon is introduced while absorbing the CO_2 in a molecular sieve filter.
- At the end the vessel is valve closed

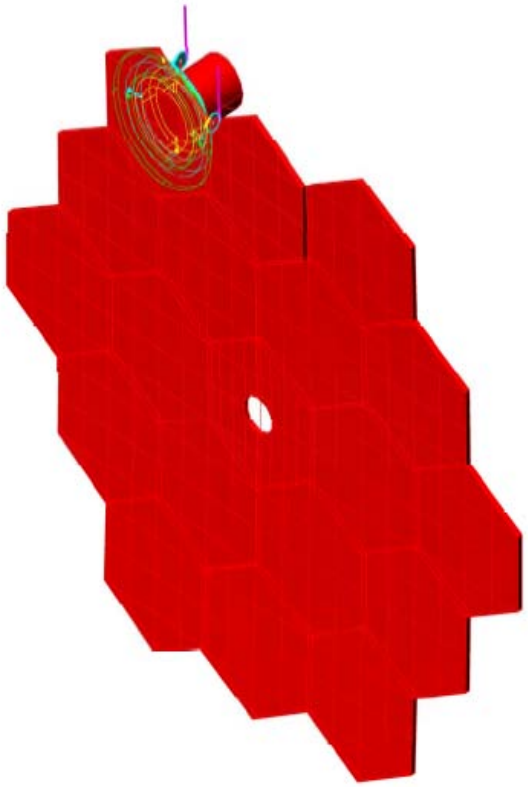
The CO2 absorber

- Two absorbtion cartridges (24 liters)
- One in operation, one in regeneration
- 1° regeneration phase: pressure lowered to few mbar (very fast)
- 2° regeneration phase: heating to 180 degree (slower but higher absorbtion capacity)



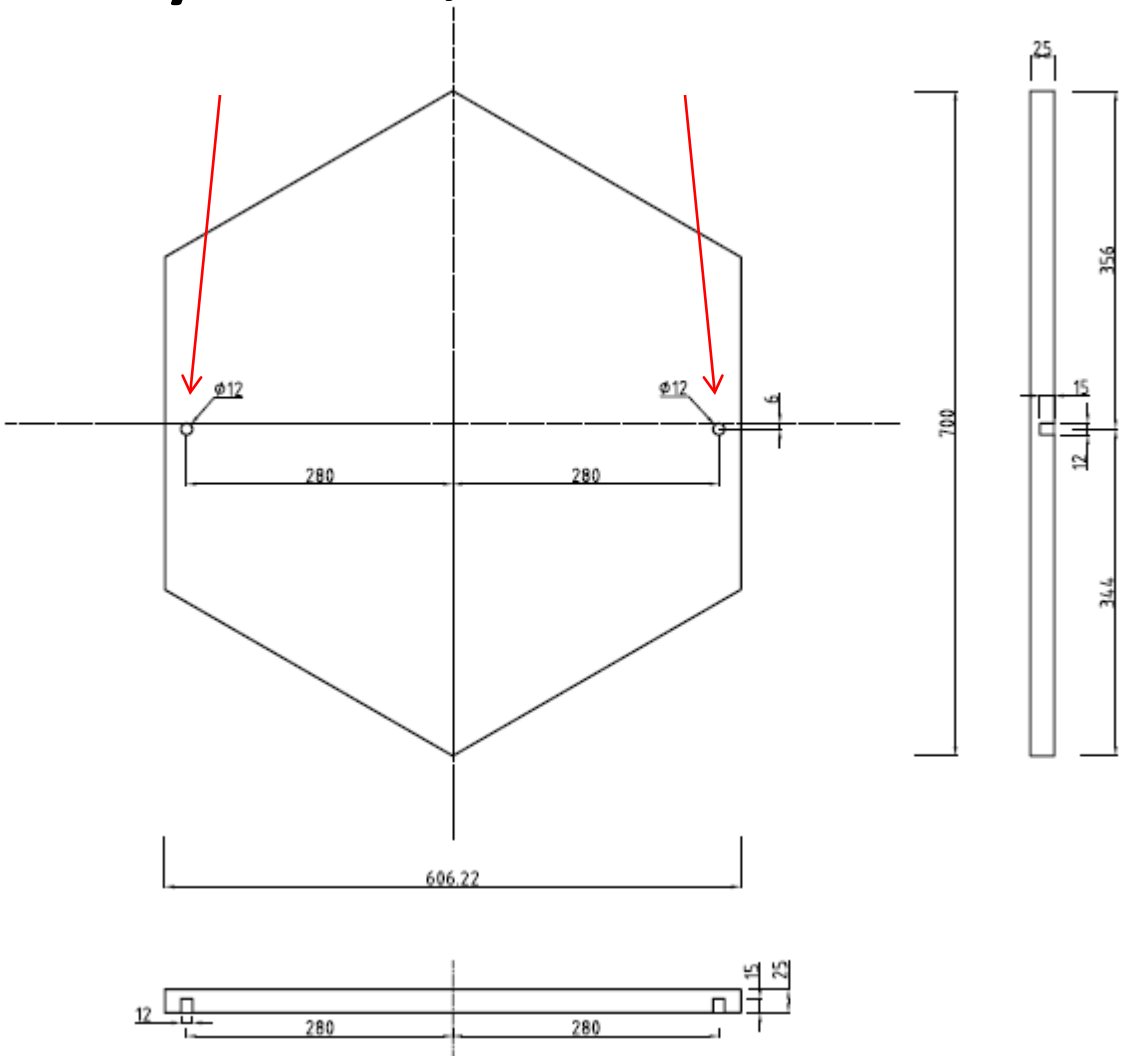
The Mirror system

- 20 mirror pieces
- 18 hexagonal
- 2 semi-hex + pipe hole
- 700 mm wide, 25 mm thick glass
- 17 m focal lenght, D0<1 mm



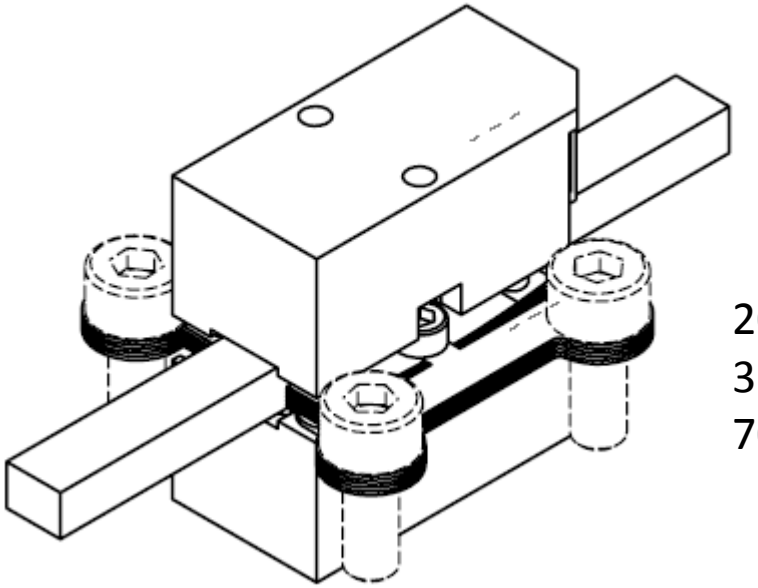
The Mirror system, cont'd

- Two hole drilled in the back
- The mirror is hung inserting rods in the holes
- E.M. calorimeter downstream of the RICH…

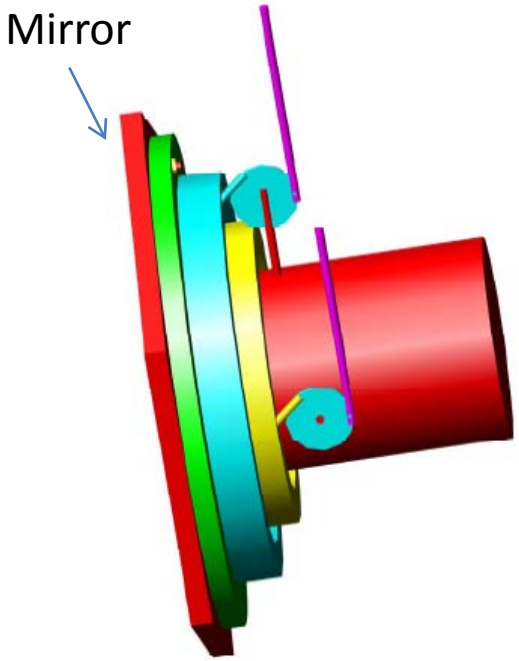


The Mirror System, III

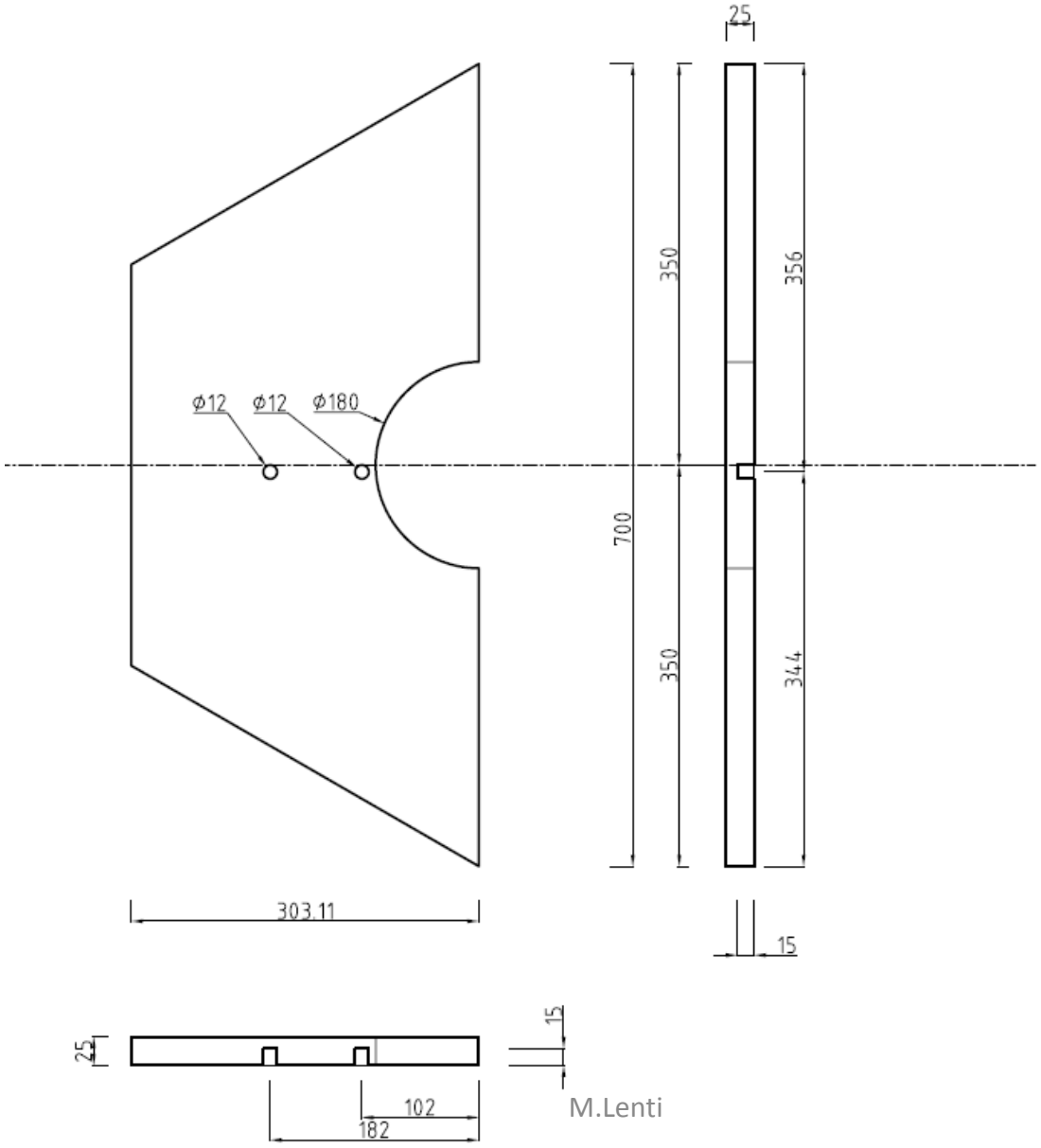
- Two axis movement
- Piezo actuators, outside acceptance



20 Newtons
35 mm range
70 nm resolution

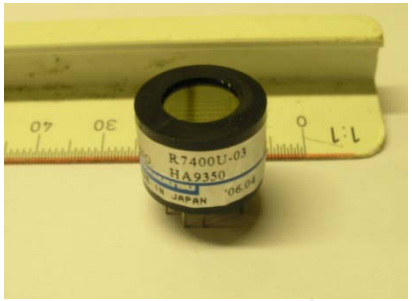


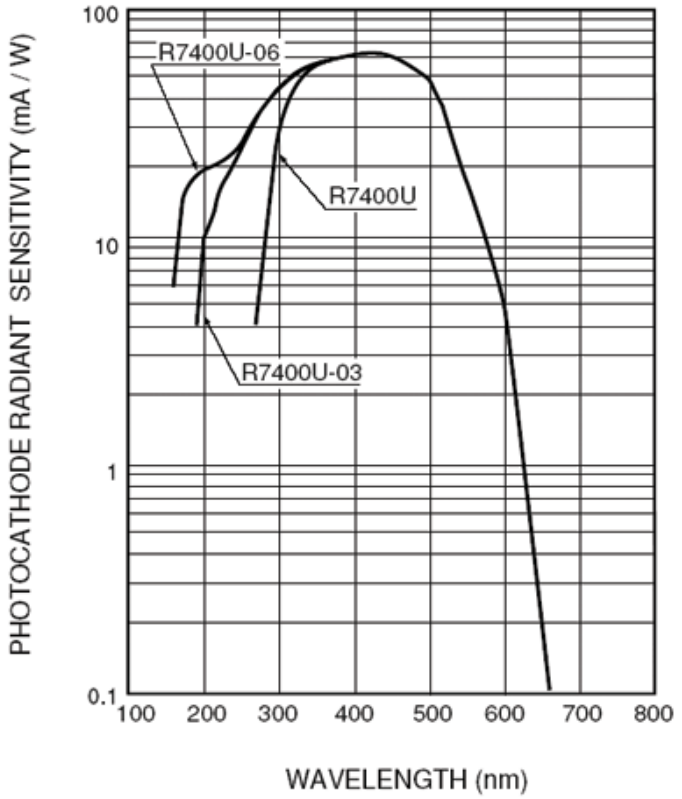
Semi-hex mirrors

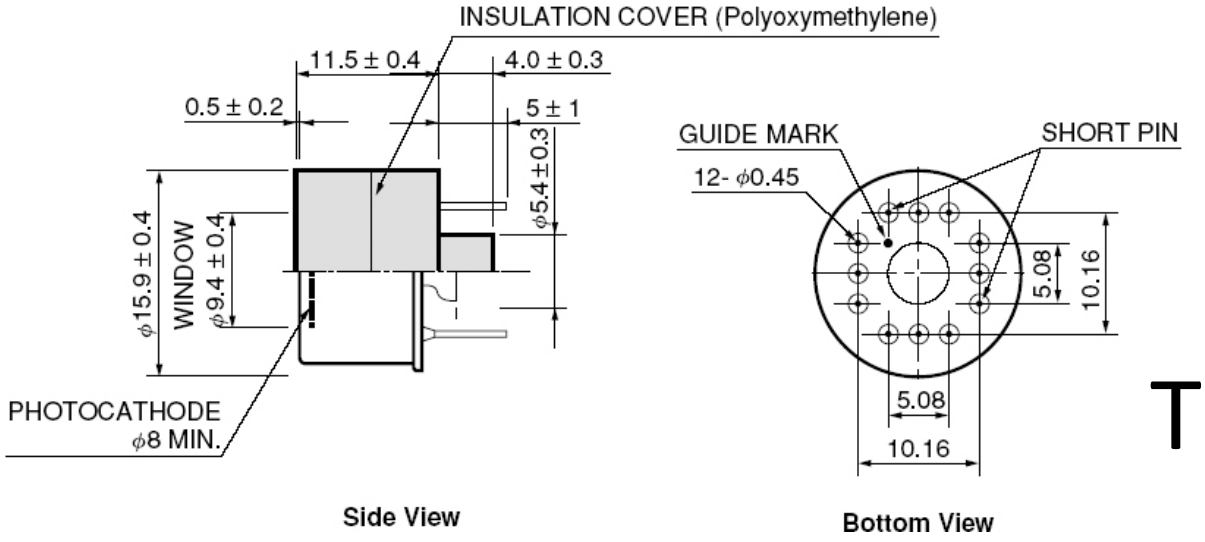


The Photomultipliers

- Hamamatsu R7400U-03
- UV-glass, bialkali, 8 dyn
- 16 mm wide (8 mm active)
- Gain 1.5 10^{+6} @900 V
- 280 ps time jitter (FWHM)
- 185-650 nm response (420 nm peak)
- Q.E. around 20% on peak
- PM output (1 p.e.): 240 fC, peak at 200 μA or -10 mV (50 Ω)
- Rise time: 0.78 ns, fall time~1.6 ns

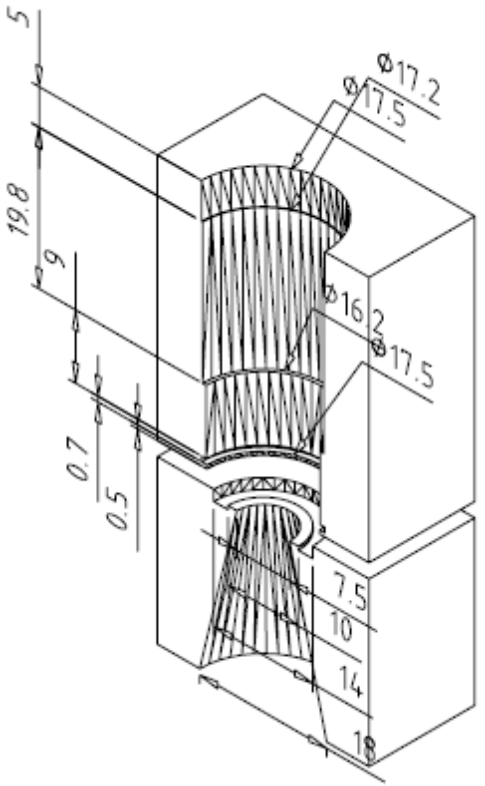


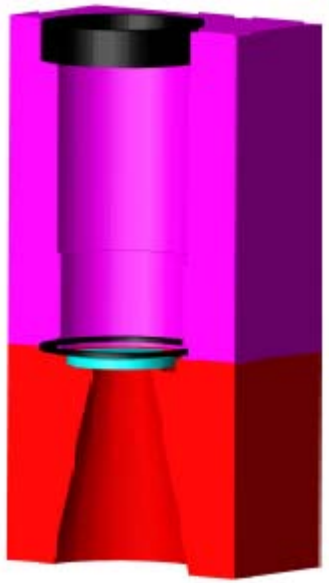




The PMs, cont'd

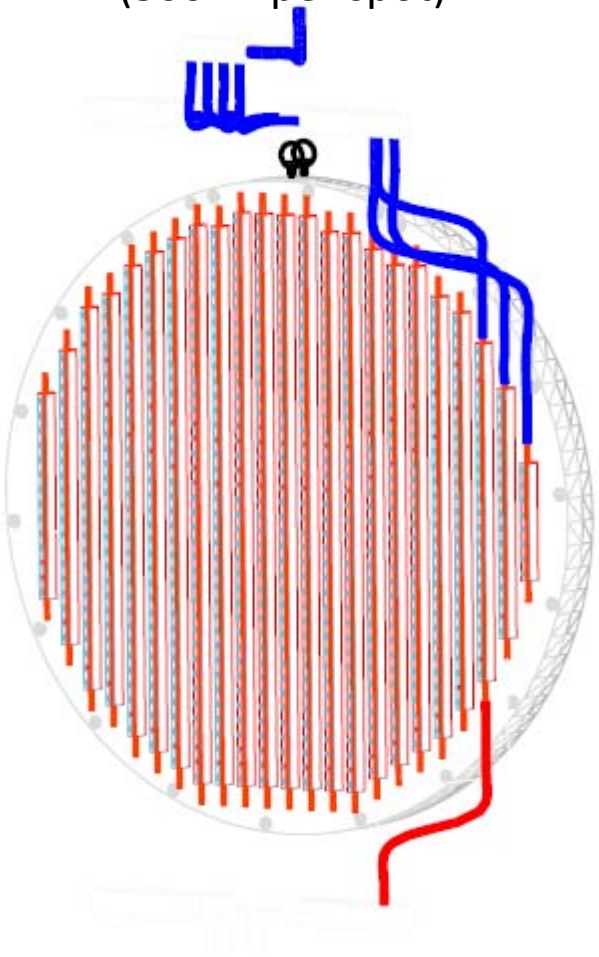
- 1000 PM packed per spot
- Cooling is an issue
- Light collection: Winston cones with aluminized mylar foil
- Quartz window to separate Neon from air
- O-rings for light tightness and thermal contact



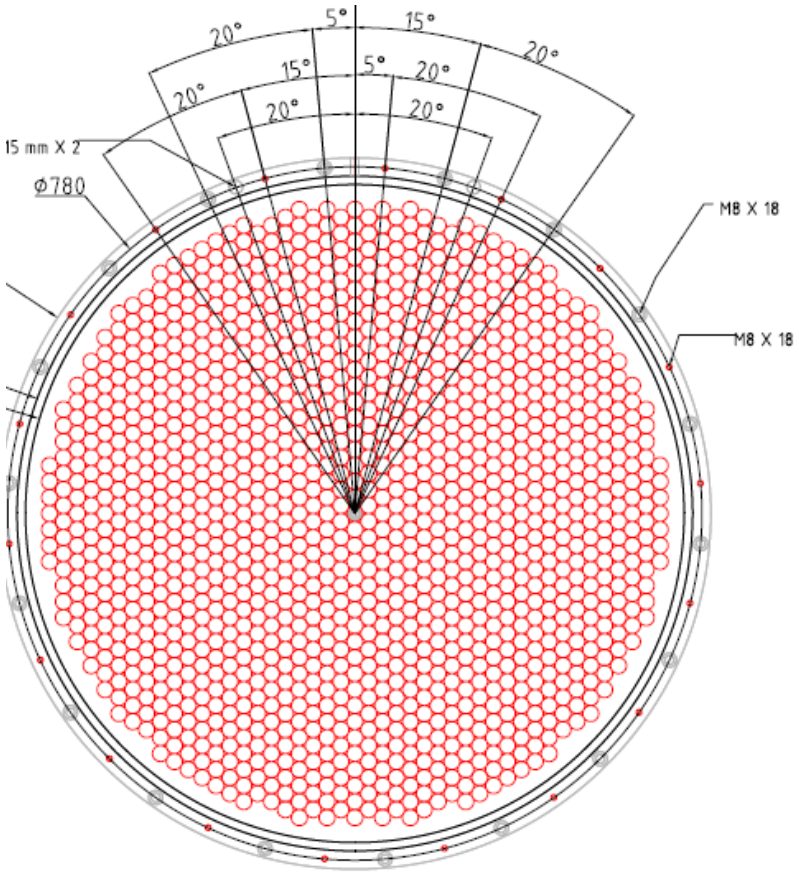


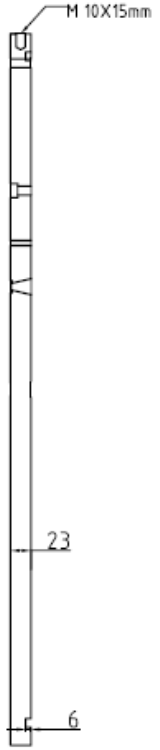
The PM, III

Water cooling
(300 W per spot)



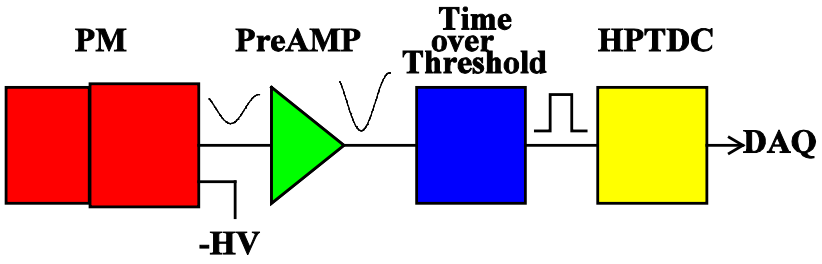
One 1000-PM flange





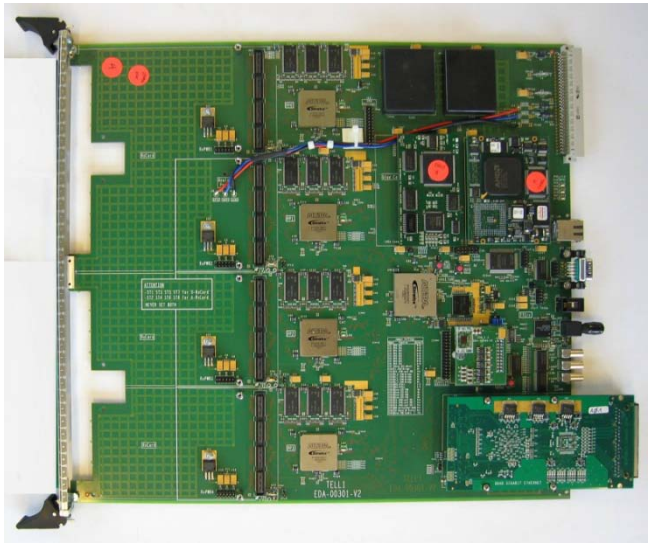
More holes than PM in this picture…

Front-End and DAQ



FE+DAQ contribution < 50 ps

- NINO ASIC (from ALICE) as fast discriminator operated in Time over Threshold
- HPTDC (developed at CERN) embedded on TELL1 (from LHCb)
- Possible use of the RICH as main charged trigger of NA62



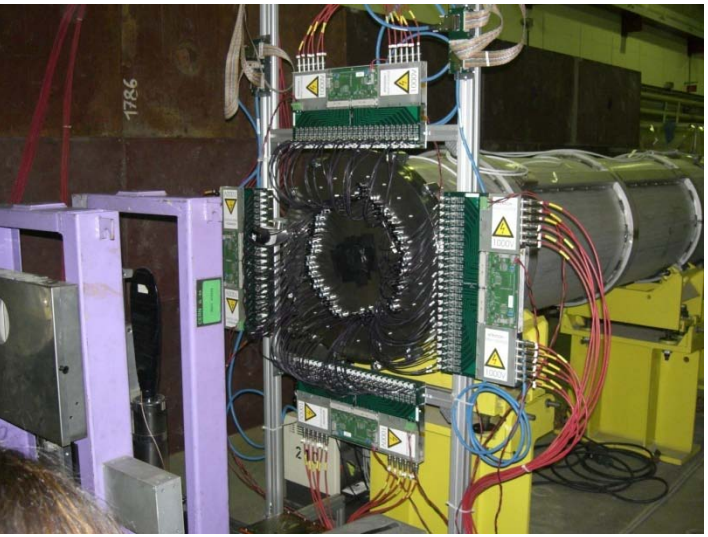
See Poster by Collazuol, Lamanna, Sozzi

Test Beams

- Strong RD to validate the chosen approach
- 2007 Test Beam: RICH prototype with 96 PM (time resolution, n.of p.e.,…)
- 2009 Test Beam: RICH prototype with 414 PM (3σ $\pi-\mu$ separation, n.of p.e., cooling, DAQ,…)

RICH prototype

- 17 m long, 0.6 m wide cylindrical vessel
- 17 m focal, 0.5 m wide mirror
- 96(2007) or 414(2009) PM
- Vessel evacuated, then Neon filled
- Prototype placed along the old NA48 beam line at CERN



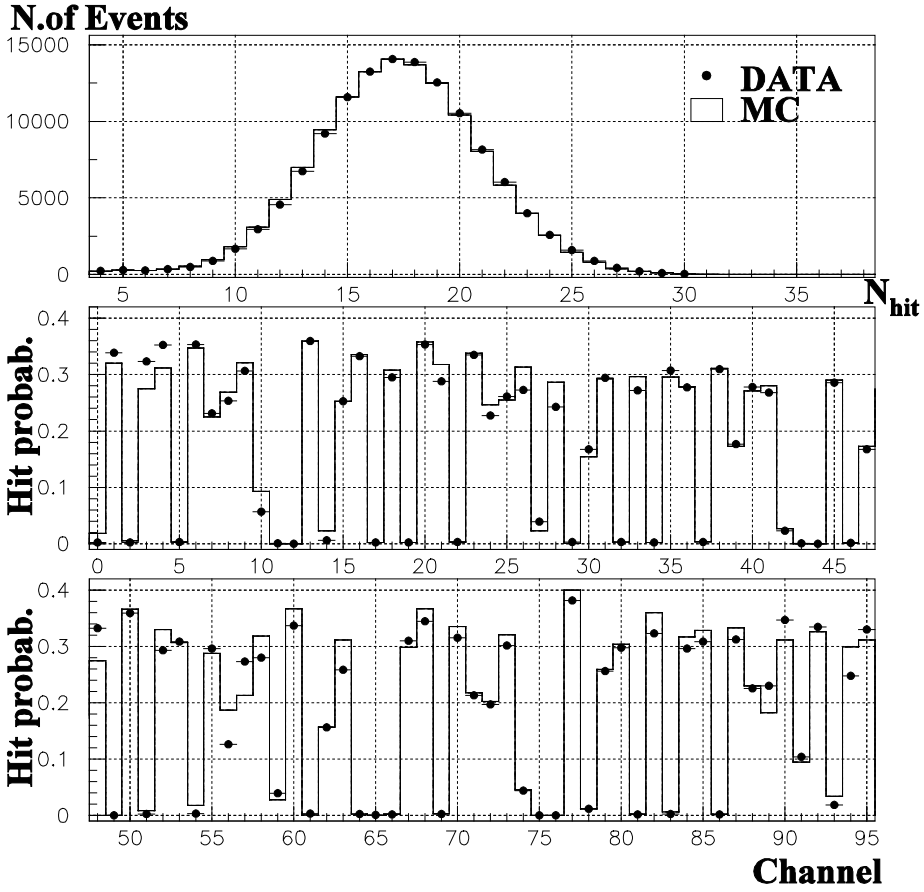
RICH-100 Prototype 2007 Test Beam

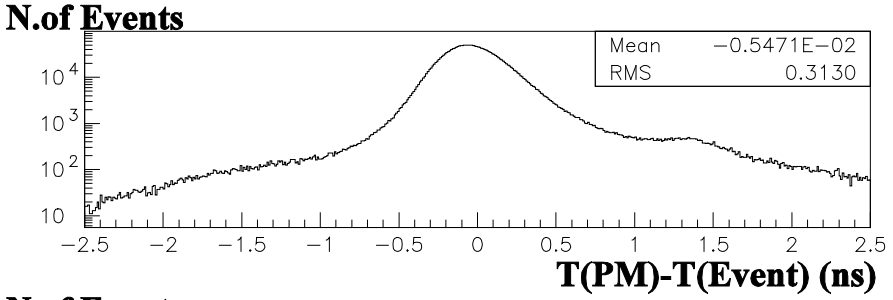
96 PMT

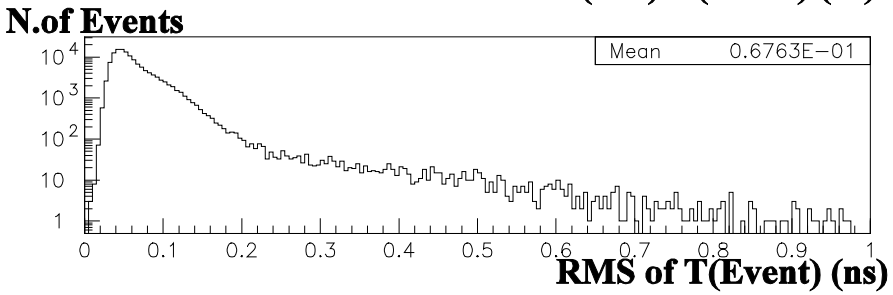
π^- p=200 GeV/c (SPS)
CERN Cavern ECN3

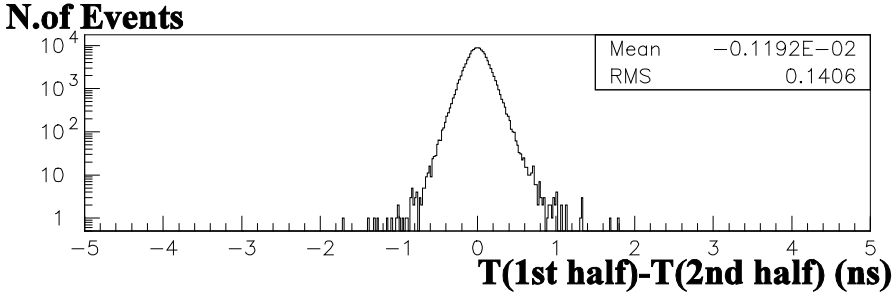
Mirror f=17 m

RICH-100: 2007 Test Beam results





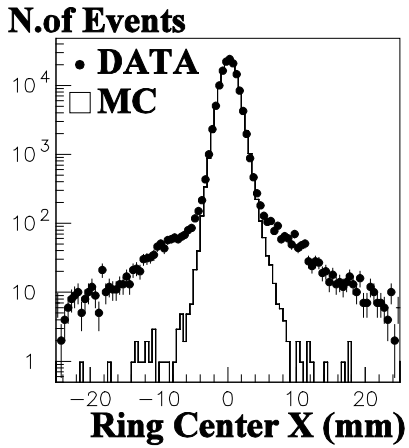


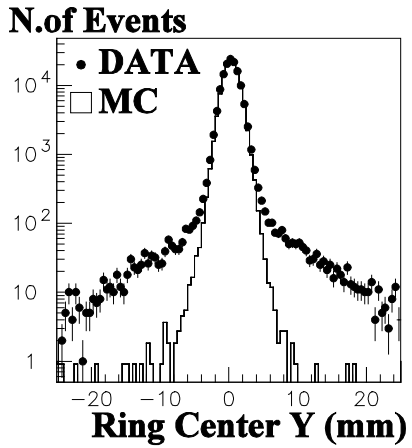


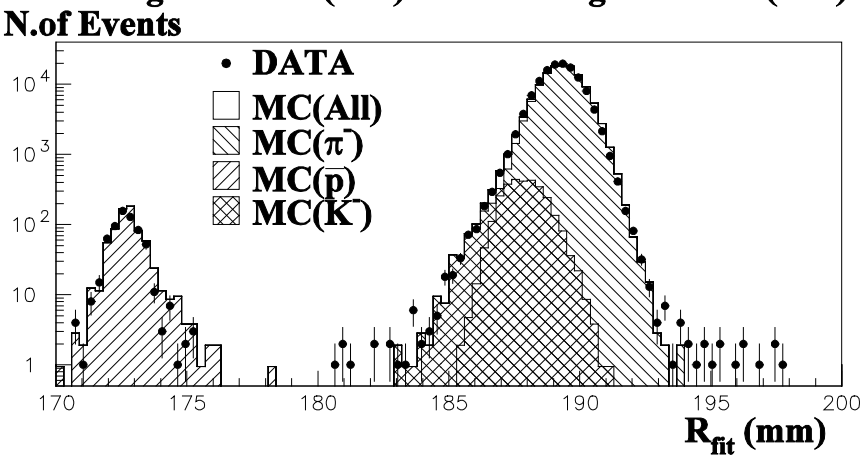
$N_{Hits} \approx 17$

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

RICH-100: results







$\Delta\theta_c \approx 50$ μrad

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

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Construction and test of a RICH prototype for the NA62 experiment

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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 $K^+ \to \pi^+\nu\bar{\nu}$. 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

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

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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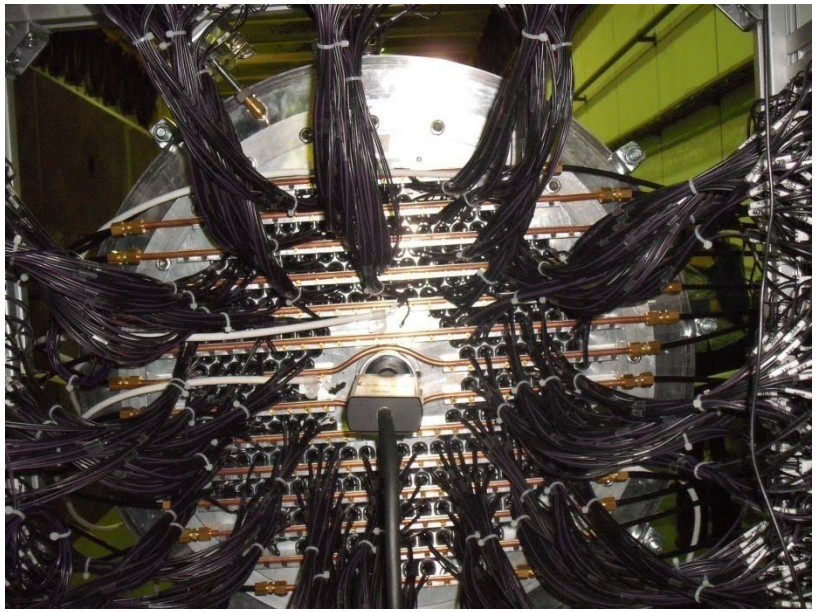
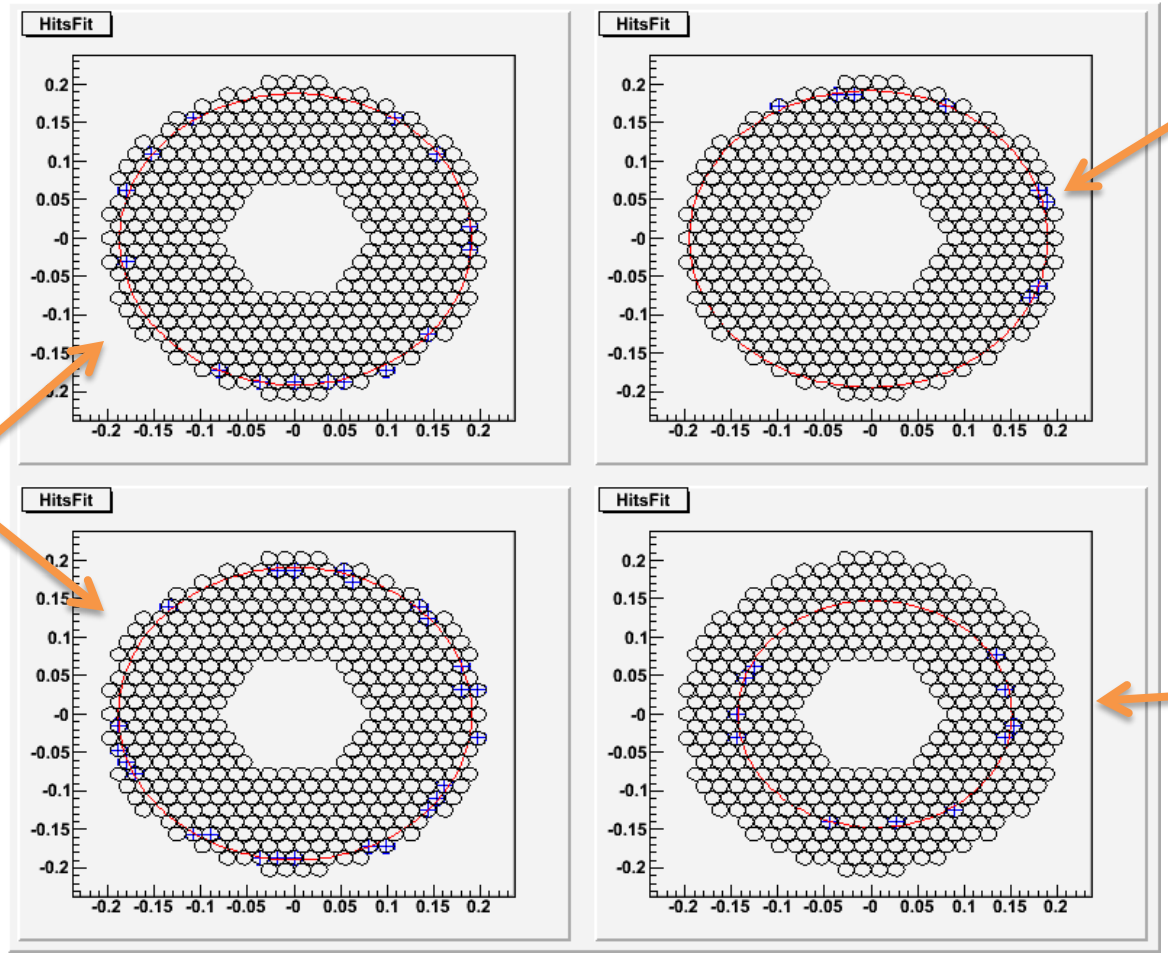
RICH-400:
2009 test beam

- 414 PMT + FE and DAQ , cooling
- Pions at tunable energy



RICH-400: fitted rings

20 GeV/c

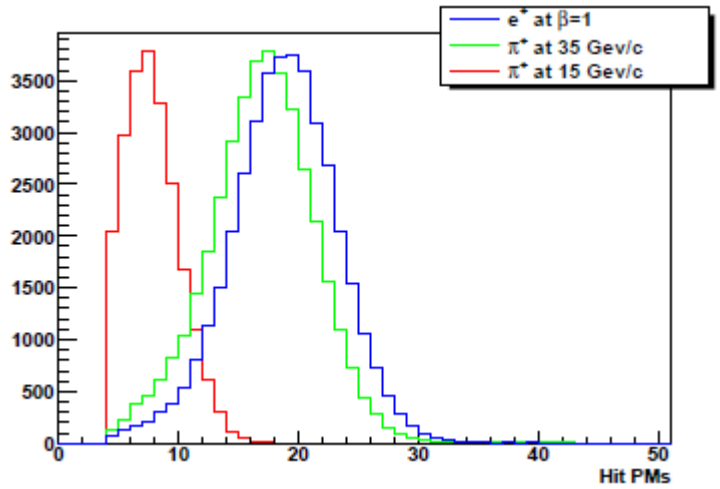


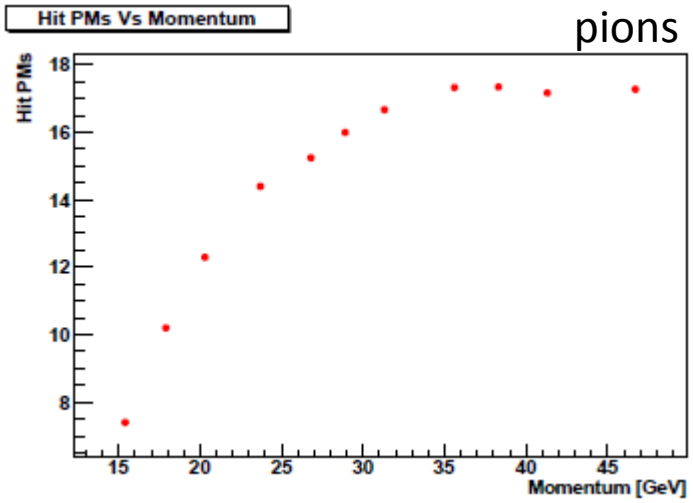
positrons

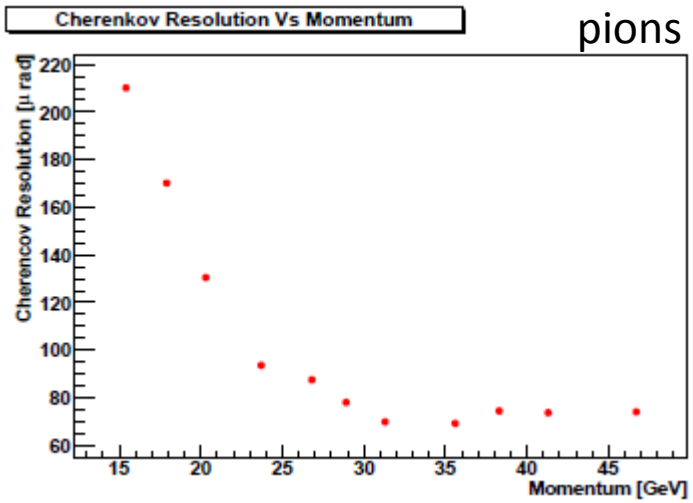
Hard to reconstruct ring…

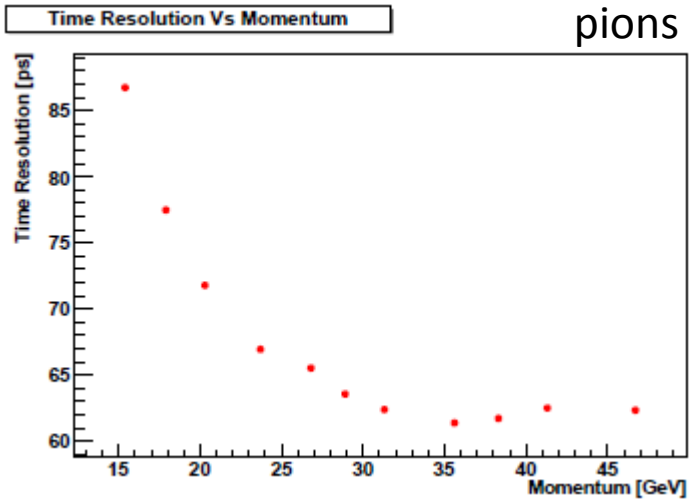
pion

RICH400: performances









RICH-400: $\pi-\mu$ separation

- Easy to have a good pion beam, not a muon one
- For each energy point, take two runs:

➢ One at the same nominal energy

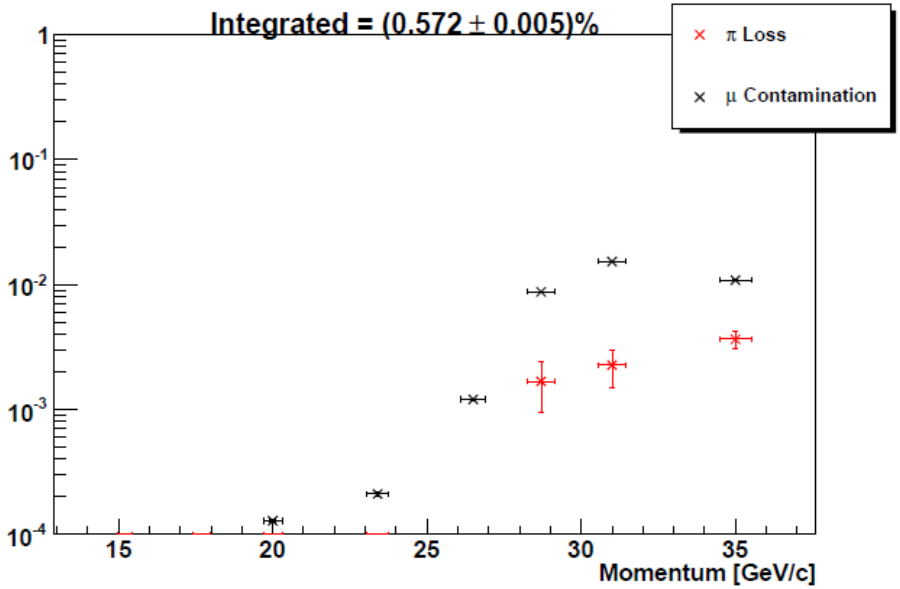
➢ One at energy×mπ/mμ (pion velocity equal to muon velocity at nominal energy)

➢ Compare the two distributions of the fitted Cherenkov Rings

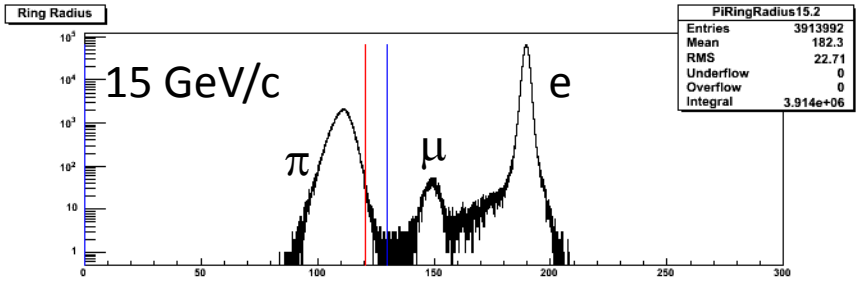
π	15.2	17.7	20.0	23.4	26.5	28.7	31.0	35.0
"μ"	20.0	23.4	26.5	31.0	35.0	38.0	41.0	46.3

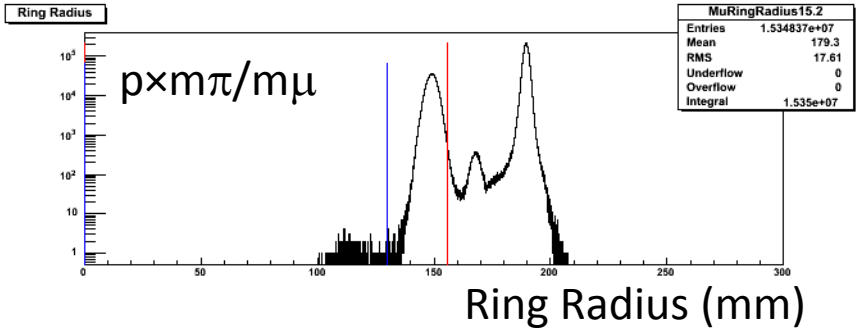
GeV/c

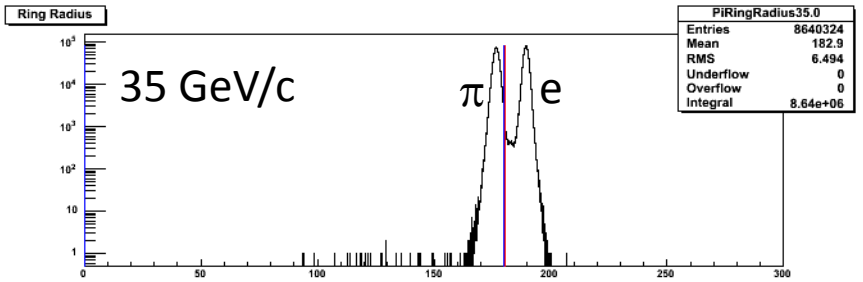
RICH-400: results

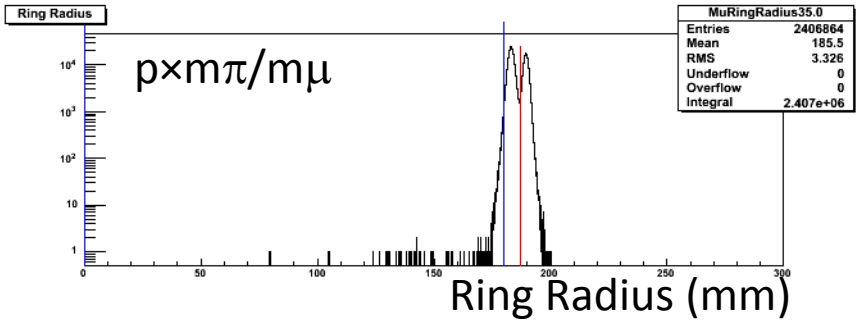


Muon suppression (15-35 GeV/c):
0.7%









RICH 400: results

- Paper submitted to NIM on April 23, 2010

Pion-Muon separation with a RICH prototype for the NA62 experiment

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Abstract

The NA62 experiment at CERN, aimed to measure $K^+ \to \pi^+\nu\bar{\nu}$ branching fraction ($O(10^{-11})$), relies on a Neon based RICH detector for π/μ separation, time measurement and level 0 trigger. The experimental requirements for this detector are: a muon contamination in pion samples lower than 5×10^{-3} in the momentum range 15-35 GeV/c and a time resolution on the charged track better than 100 ps. A prototype of such a detector was built and tested in 2009; it consists of a full length ($\approx$ 18 m) Ne filled vessel equipped with a spherical mirror and 414 PMs on its focal plane, located about 17 m upstream of the mirror. This prototype was tested at CERN SPS on a positive hadron beam, in the required momentum range, to measure the π/μ separation and to confirm the time resolution obtained with a previous prototype; the μ misidentification probability is about 0.7% and the time resolution is better than 100 ps in the whole momentum range.

Keywords: RICH, PID, timing
PACS: 29.40.Ka, 29.30.Aj

1. Introduction

The goal of the NA62 experiment [1] at CERN is a precision measurement (10%) of $K^+ \to \pi^+\nu\bar{\nu}$ branching fraction ($O(10^{-11})$), which provides a rare possibility to test in a stringent way the Standard Model (SM) due to small theoretical uncertainties on the predicted value.

The detector must be able to reject events from decay channels that have branching fraction up to 10 orders of magnitude higher than the signal and with similar experimental signature, such as $K^+ \to \mu^+\nu$. In this framework, NA62 will rely on a gas based RICH detector for π/μ separation, with a μ rejection factor better than 5×10^{-3} in the momentum range 15-35 GeV/c, a level 0 (L0) trigger and event time measurement with a resolution better than 100 ps.

The NA62 RICH [2] is a $\approx$ 18 m long segmented tube ($\varnothing \approx 4$ m) filled with Ne at atmospheric pressure and room temperature, equipped with a segmented mirror (17 m focal length) at the downstream end and about 2000 PhotoMultipliers (PMs) at the upstream end. The mirror(s) orientation defines two regions on the focal plane intersected by Čerenkov light, to avoid the otherwise produced shadow of the beam pipe, placed along the axis of the vessel. The PMs are equally divided to instrument these two regions, using Winston's cones [3] to enhance the ratio between sensitive and instrumented area.

As a first step in the development of a RICH detector capable of fulfilling the experimental requirements, a full length prototype equipped with 96 PMs (Hamamatsu R-7400) and a spherical mirror with 17 m focal length was built in 2007. A test beam was performed [4, 5], with the purpose to check the time resolution, the light collection technique and, even if biased by the small number of PMs, the Čerenkov angle and the track angular resolutions.

An improved version of the prototype was built in 2009, adding to the previous one enough PMs to cover completely the acceptance region for the Čerenkov light, defined by the momentum range, beam composition and direction; this configuration, with 414 PMs (Fig. 1) allows to measure the actual rejection factor for μ.

2. Experimental setup

The detector response was tested using an hadron beam of variable momentum (freely selectable in the range 10 – 75

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Conclusions

- The NA62 RICH is a far demanding object
- Strong RD validated our approach
- Very “aggressive” construction schedule:

➢ Nov 2011: vessel ready to be closed

➢ May 2012: PM installation complete

➢ Jul 2012: Gas filling complete

➢ Jul 2012: first technical run (all NA62)

➢ Nov 2012: first physics run (all NA62)