The NA62 RICH detector

Construction and performance

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on behalf of the NA62 RICH working group

1. The NA62 experiment
2. The RICH detector
3. RICH performances
4. Summary

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The NA62 experiment

at CERN SPS

ECN3 experimental hall

The NA62 collaboration: $\sim$ 200 participants, 30 Institutes

The NA62 goal

Measurement of the Branching Ratio of the decay $K^+ \to \pi^+ \nu\bar{\nu}$

- Theoretically very clean FCNC loop process, sensitive to physics beyond the Standard Model
- SM prediction: $\mathrm{BR_{TH}}(K^+ \to \pi^+ \nu\bar{\nu}) = (0.84 \pm 0.10) \times 10^{-10}$
  [Buras et al., JHEP11 (2015) 033; Brod et al., PRD83 (2011) 034030]
- Experiments: $\mathrm{BR_{EX}}(K^+ \to \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$
  [BNL E787/E949 collab., PRD77 (2008) 052003; PRD79 (2009) 092004]
- NA62 goal: $\sim$ 100 events, 10% precision

Schedule:

2012-14	Detector installation
2015	Commissioning run
2016-18	Physics run

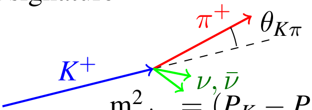
The NA62 experimental principles

- Goal: 10% precision BR measurement
- ≈ 100 $K^+ \to \pi^+ \nu \bar{\nu}$ events in 3 years

• Statistics:	10^2
• $\mathrm{BR}_{\mathrm{SM}} = 0.84 \times 10^{-10}$	
• Acceptance:	10^{-1}
$\Rightarrow$ K^+ decays:	10^{13}

Very challenging experiment

Weak signal signature



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

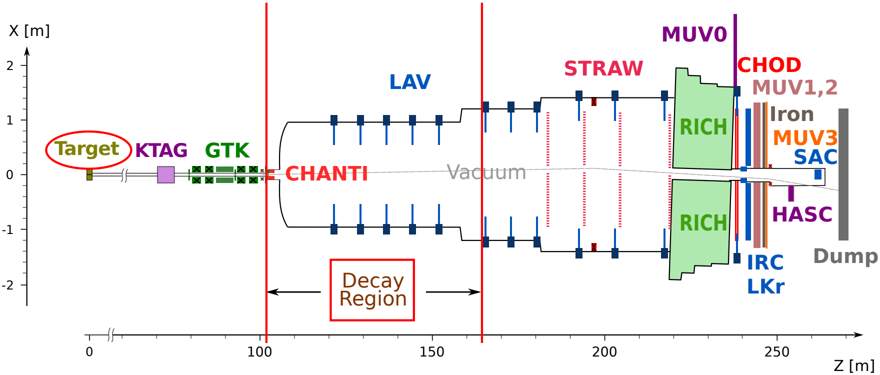
Huge backgrounds

Decay		BR
$\mu^+\nu$	$(K_{\mu 2})$	63.5%
$\pi^+\pi^0$	$(K_{2\pi})$	20.7%
$\pi^+\pi^+\pi^-$	$(K_{3\pi})$	5.6%
$\pi^0 e^+ \nu$	(K_{e3})	5.1%
$\pi^0 \mu^+ \nu$	$(K_{\mu 3})$	3.3%

- Main background: $K^+ \to \mu^+ \nu$ $\longrightarrow$
- Need rejection factor $\lesssim 10^{-12}$
  - kinematics: $10^{-4} \div 10^{-5}$
  - veto for muons: $\sim 10^{-5}$
  - particle identification: $\lesssim 10^{-2}$ $\Rightarrow$ RICH

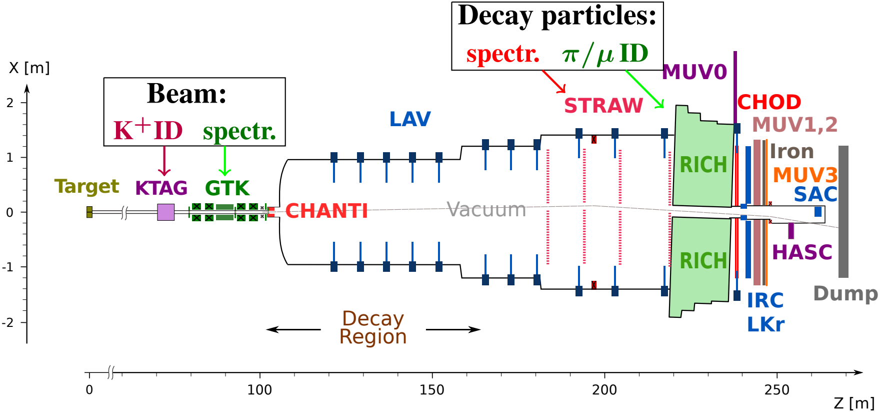
The NA62 beam

- 400 GeV/c SPS primary protons, 10^{12} protons/s, 3.5 s spill
- 75 GeV/c ($\pm 1\%$) unseparated hadron beam, K^+ component $\sim 6\%$
- 750 M hadrons/s $\rightarrow$ 5 MHz K^+ decays $\Rightarrow$ 4×10^{12} K^+ decays/year

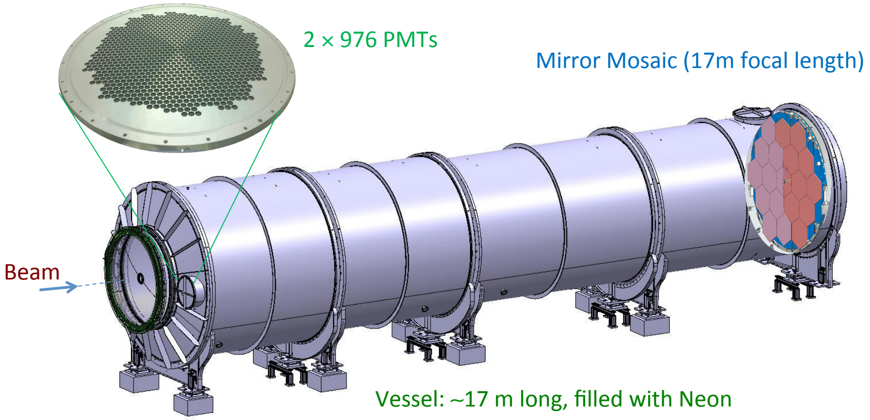


The NA62 detectors

- Beam and decay particle tracking
- Hermetic photon vetoes
- Particle identification



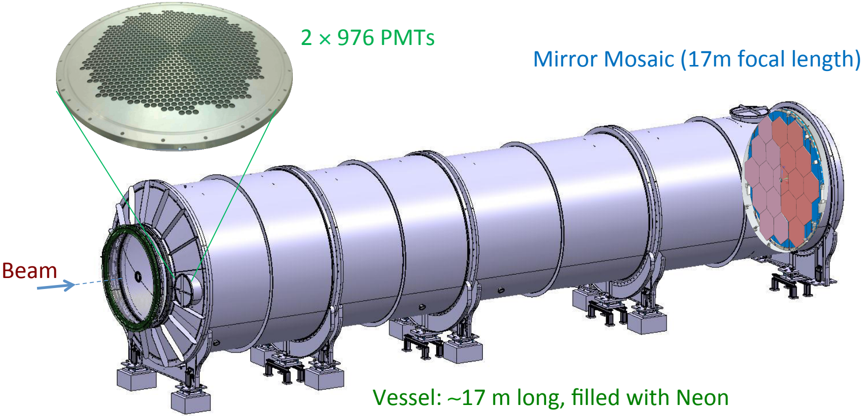
The RICH detector



Requirements:

- μ contamination in π sample [$P = (15 \div 35)$ GeV/c]: $\times(\leq)10^{-2}$
- Time resolution $\sigma_t < 100\,\mathrm{ps}$
- Provide L0 trigger for charged tracks

The RICH radiator [for $P = (15 \div 35)$ GeV/c μ/π separation]

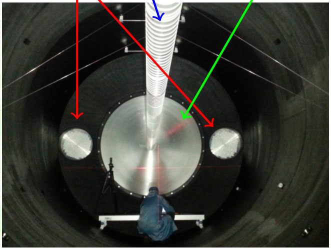


Neon gas slightly above atmspheric pressure

- $(n-1) = 62.8 \cdot 10^{-6}$ at $\lambda = 300\,\mathrm{nm} \rightarrow$ $P_{\mathrm{thr}}(\pi^{\pm}) = 12.5\,\mathrm{GeV/c}$
- Good light transparency, low chromatic dispersion
- Fresh Neon injected in evacuated vessel, no purification/recirculation

The RICH vessel

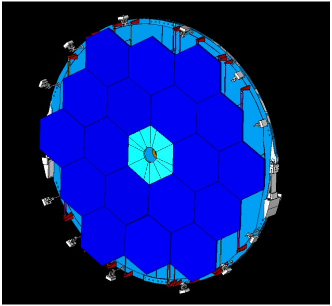
- Vacuum proof steel tank 17m long, $\sim 200\,\mathrm{m}^3$ volume
- 4 cylindrical sections of decreasing diameter
- Thin Al entrance and exit windows for decay particles
- Beam pipe ($\varnothing$ 17 cm) going through

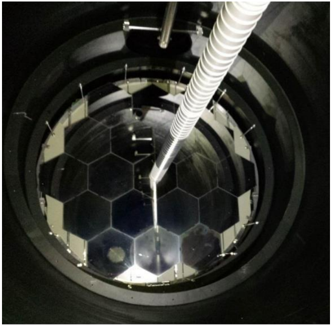


view from inside, looking upstream

Mirror layout

- Mosaic of 20 spherical mirrors to focus Čerenkov light to the PMTs:
  - 18 hexagonal mirrors (350 mm side)
  - 2 semi-hex with hole for beam pipe
- 25 mm thick glass, coated with Al + protective thin dielectric film
- Radius of curvature: (34.0 ± 0.2) m
- Average reflectivity(195-650nm)$\simeq$ 90%
- D_0 (optical quality) < 4 mm

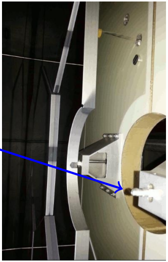




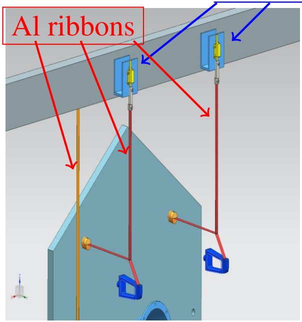
Mirror support and orientation system

Al honeycomb structure,
50 mm thick,
divided in two halves

- Each mirror is supported by a dowel in its back side



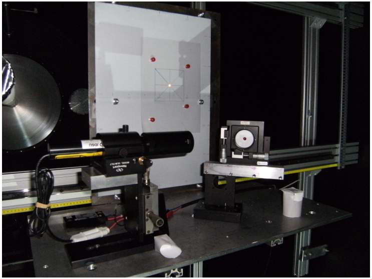
- Two Al ribbons for mirror equilibrium + orientation by rem.controlled piezo-motors



- A third vertical ribbon prevents mirror rotation

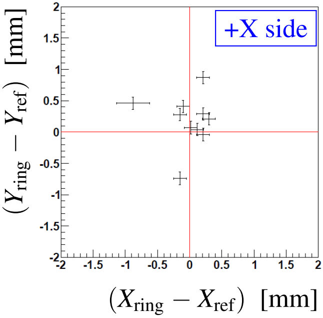
RICH mirror alignment

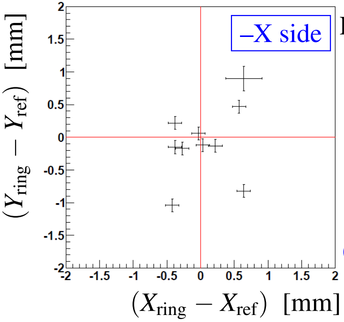
1. Preliminary laser alignment →



2. Final alignment using charged tracks measured by the STRAW spectrometer:

- select particles illuminating a single mirror
- compare the position of the ring centre in the PMT plane with that expected from track flight direction





Each cross = 1 mirror

All mirrors aligned within ± 1 mm ($\approx 30\ \mu$rad) with respect to a reference mirror (semi-hex same side)

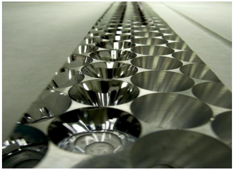
The Photomultipliers

Reflected Čerenkov light collected by 2 arrays of 976 PMTs each
Compact hexagonal packaging, 18 mm pixel size

- Hamamatsu R7400-U03 ⟶
  - 185–650 nm (420 nm peak)
  - Gain 1.5×10^6 at 900V
  - Q.E. $\sim 20\%$ at peak
  - 280 ps time jitter (FWHM)
  - UV-glass window

- Custom made HV dividers
- Al mylar Winston cones ⟶ to optimize light collection

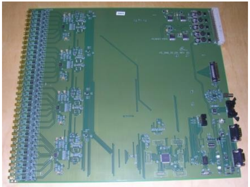
- quartz window between Neon and air
- TDAQ system: custom-made FE boards + TEL62



Front-End and Readout electronics

RICH Front-End:

- 64 custom-made 32-ch boards
- each one with four 8-ch discriminators (NINO chips)



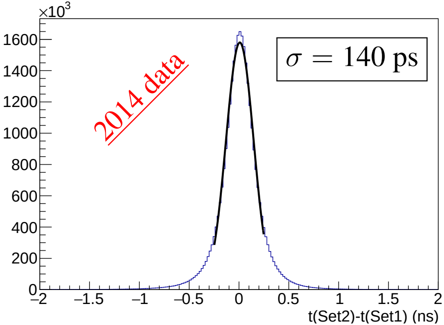
RICH Readout:

- 128-ch TDC daughter boards (TDCB), each housing 4 CERN HPTDC chips

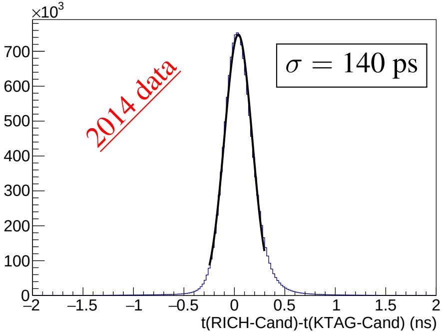
- 5 TEL62 mother boards (each with 4 TDCBs = 512 TDC ch.):
  - 4 for the 1952 PMTs
  - 1 for L0 trigger

Time resolution

Intrinsic RICH time resolution



RICH–KTAG time difference



- Detected photons (hits) of one Čerenkov ring are split in two sets
- Difference between time averages of the two sets is plotted
- Time resolution of the full ring = $\frac{1}{2}\sigma$

- Čerenkov ring average time compared with KTAG time

Time resolution of a full Čerenkov ring $\sim$ 70 ps

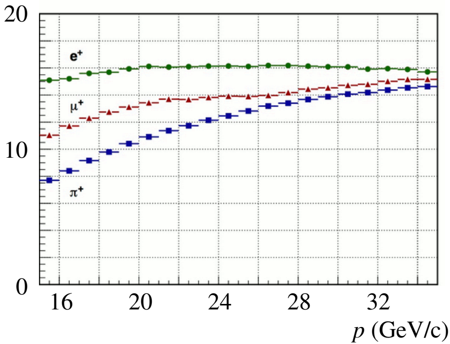
RICH Particle Identification

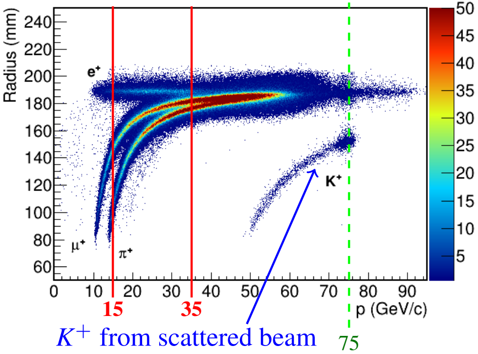
$\pi^{\pm}$, $\mu^{\pm}$ and $e^{\pm}$ selected using calorimeters and spectrometer

Average number of hits $\langle N_{\text{hits}} \rangle$ per Čerenkov ring

2015 data

Čerenkov ring radius (mm) vs p

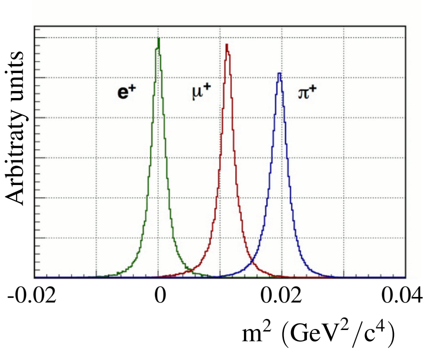




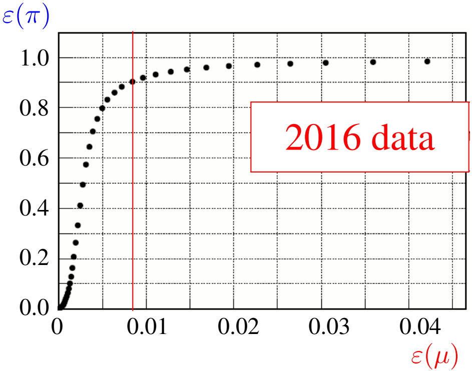
π/μ separation

Squared mass reconstructed using:

- velocity (from RICH ring radius)
- momentum (from spectrometer)



$\pi^{\pm}$ identification efficiency vs.
$\mu^{\pm}$ mis-identification probability



For 90% π ID efficiency a 0.8% μ mis-ID probability is observed

Conclusions

- NA62 RICH detector installed in 2014
- Commissioning run in 2015
- Physics run in 2016–2017–2018
- RICH performances fulfilling expectations:
  - time resolution $\sigma_t \sim 70$ ps
  - μ mis-ID $< 1\%$ for 90% π^+ ID efficiency

Thank you!

Additional information

Kinematical background rejection: missing mass

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

- $\mathrm{m}_{\mathrm{miss}}$(STRAW)
- $\mathrm{m}_{\mathrm{miss}}$(RICH), $\vec{p}_\pi$ assuming m_{π^+}

BKG fractions in
in signal regions:

$K^+ \rightarrow \pi^+\pi^0 \sim 6 \cdot 10^{-4}$

$K^+ \rightarrow \mu^+\nu \sim 3 \cdot 10^{-4}$