Construction and Performance of the NA62 RICH detector

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on behalf of the NA62 RICH working group (CERN, Firenze, Perugia)
Outline

➔ The NA62 experiment at CERN
➔ The RICH design and construction
➔ The RICH performance during the 2015 run
➔ First results from the 2016 run
➔ Summary and Outlook
The NA62 experiment at CERN

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow(INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver(UBC)  ~ 200 participants
Theoretically very clean, sensitive to physics beyond Standard Model

\[ \text{BR}_{\text{TH}}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \times 10^{-10} \quad \text{SM@NLO} \]


\[ \text{BR}_{\text{EX}}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10} \quad \text{E787/949@BNL} \]


Schedule

2012-2014:
Detector Installation & Techn. Run

Oct-Dec 2014:
NA62 Pilot Run

Jun-Nov 2015:
Physics Run @ Low intensity

2016-2018:
Physics Run
NA62 - Experimental principles

- **Goal**: 10% precision Branching Ratio measurement
- **Goal**: \( O(100) \) \( K^+ \rightarrow \pi^+\nu\bar{\nu} \) events in \( \sim \) three years of data taking

Very challenging experiment
Weak signal signature

- **Main background**: \( K^+ \rightarrow \mu^+\nu \ (K_{\mu2}) \) BR = 63.4%
- **Rejection factor at least** \( 10^{-12} \)
  - Kinematics: \( 10^{-4} \div 10^{-5} \)
  - Veto for muons \( \sim 10^{-5} \)
  - Particle Identification: \( \mu \) suppression < \( 10^{-2} \)

Huge background

<table>
<thead>
<tr>
<th>Decay</th>
<th>BR</th>
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<tbody>
<tr>
<td>( \mu^+\nu ) \ (K_{\mu2})</td>
<td>63.5%</td>
</tr>
<tr>
<td>( \pi^+\pi^0 ) \ (K_{\pi2})</td>
<td>20.7%</td>
</tr>
<tr>
<td>( \pi^+\pi^+\pi^- )</td>
<td>5.6%</td>
</tr>
<tr>
<td>( \pi^0e^+\nu ) \ (K_{e3})</td>
<td>5.1%</td>
</tr>
<tr>
<td>( \pi^0\mu^+\nu ) \ (K_{\mu3})</td>
<td>3.3%</td>
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\( m^2_{\text{miss}} = (P_K - P_\pi)^2 \)
**Experiment and beam**

- **Vacuum:** $P < 10^{-5} \text{ mbar}$
- **400 GeV/c SPS primary protons**
- **3 x $10^{12}$ protons/pulse**
- **75 GeV/c unseparated hadron beam ($\Delta p/p \sim 1\%$)**
- **Kaon component $\rightarrow 6\%$**
- **750 MHz $\rightarrow 50 \text{ MHz}$ kaons $\rightarrow 5 \text{ MHz}$ decays**
- **4.5 x $10^{12}$ $K^+$ decays/y $\rightarrow$ SES $\sim 10^{-12}$**
Detector layout

Beam and secondary particle tracking

Hermetic photon vetoes

Particle Identification

GIGATRACKER
3 Si-pixel stations $\sigma_t < 200$

STRAW chambers in vacuum
4 stations + dipole magnet

LAV 8.5 - 50 mrad
LKr 1 - 8.5 mrad
SAV < 1 mrad

Vacuum: P<10^{-5} mbar

Target
protons

beam pipe

Decay Region 65m

Total Length 270m

KTAG - CEDAR
$K^+$ identification

CEDAR

hadron beam

CHANTI

GTK

RICH

$\pi/\mu$ identification

RICH

Straw chambers in vacuum
The NA62 RICH detector

REQUIREMENTS

- Muon contamination in the pion sample ≤ 1% in 15 < p < 35 GeV/c momentum range
- Measure pion crossing time with a resolution < 100 ps
- Provide a L0 trigger for charged tracks

Mirror Mosaic (17m focal length)

2 × ~1000 PMTs

Vessel: ~17 m long
Vessel

✧ Vacuum proof tank 17 m long in structural steel
✧ 4 cylindrical sections of decreasing diameter (4 → 3.4 m) and different lengths
✧ Beam pipe (⌀ 182 mm) going through
✧ Thin Aluminium entrance and exit windows, overall volume ~ 200 m³
Radiator

Neon gas slightly above atmospheric pressure

- full efficiency requires $p_{\text{threshold}} = \frac{m}{\sqrt{n^2-1}} = 12.5 \text{ GeV}/c$ for $\pi$
- appropriate refractive index $(n-1) = 62.8 \times 10^{-6}$ at $\lambda = 300 \text{ nm}$ (small dispersion)
- good light transparency in visible and near-UV, low chromatic dispersion
- low atomic number to minimize radiation length
- $\theta_{\text{max}} = 11.2 \text{ mrad}$

RICH performance rather immune to impurities: no gas renewal
Mirror layout

- Mosaic of 20 spherical mirrors to reflect Cherenkov light
- 18 hexagonal mirrors (35 cm side)
- 2 semi-hexagonal with hole for beam pipe
- Spherical, nominal radius of curvature (34 ± 0.2 m)
- 2.5 cm thick glass, Al coat + thin dielectric film
- Average reflectivity ~ 90% in 195-650 nm
- $D_0 \leq 4$ mm
Mirror support and alignment system

- Al honeycomb structure, 5 cm thick, divided in two halves
- Mirrors supported by a dowel, in the back of the mirror
- Two aluminium ribbons keep the mirror in equilibrium and allow its orientation
- A third vertical ribbon is used to avoid mirror rotations
- Piezo motors, out of the acceptance, allow a remotely controlled orientation for alignment
Photo-detection system

- Reflected light collected by 1952 PMTs, 18 mm pixel size
- PMTs assembled in a compact hexagonal packing on two aluminium disks placed at the upstream endcap
- UV glass window, 16 mm Ø (8 mm active Ø) separate neon from air
- Winston cones to collect light
- Hamamatsu R7400U-03
  - Sensitivity range 185-650 nm (420 nm peak)
  - Gain $1.5 \times 10^6$ at working point = 900 V
  - Q.E. ~ 20% at peak
  - 280 ps time jitter (FWHM)
- Custom made HV divider
Front-end and read-out system

RICH front-end

- Custom-made current amplifiers with differential output
- NINO chips used as discriminators
- 64 boards, 32 channels per board

RICH read-out:

- 128 channels TDC daughter Boards (TDCB), each one housing 4 CERN HPTDC
- 5 FPGA based TEL62 mother boards (4 for the 2000 PMTs, 1 for the multiplicity read-out used to produce the L0 trigger), each one housing 4 TDCBs
- Trigger primitives are built in parallel with the readout on the same TEL62 board
Time resolution

Results from 2014 pilot run

The intrinsic RICH time resolution

- Detected photons of one Cherenkov ring are divided in two groups
- Time difference of each group is plotted
- Time resolution of the full ring is $\sim 0.5 \times \sigma$

Measured event time resolution $\sim 70$ ps

Time difference btw the average time of a Cherenkov ring and the KTAG time

$\sigma = 140 \text{ps}$
Preliminary results from 2015 run

- 2015 run July-November
- Intensity: \((3 - 13) \times 10^{11}\) ppp (10 – 40% of nominal)
- Samples of charged pions, muons and positrons selected using calorimetric and spectrometer information

Number of hits per Cherenkov ring as a function of particle momentum

The Cherenkov ring radius as a function of particle momentum
Pion-Muon separation

Preliminary results from 2015 run

Particle squared mass reconstructed using the velocity from the RICH and the momentum from the spectrometer (particle momentum $15 < p < 35$ GeV/c)

For 80% $\pi$ ID efficiency a 1% $\mu$ mis-ID efficiency is observed

Pion identification efficiency as a function of muon mis-identification
RICH Maintenance

During the 2014 and 2015 runs the RICH mirrors alignment was not optimal need of better performance in the pion-muon separation maintenance carried out in the 2015-2016 winter shutdown

Main interventions:
✔ Replace the two semi-hexagonal central mirrors, partially damaged during the installation of the beam pipe in 2014
✔ Replace some piezomotors
Mirrors alignment

Align mirrors remotely, 2016 data

✓ Semi-hexagonal mirrors chosen as reference, separately for Jura and Saleve side
✓ Tracks reconstructed using the spectrometer and extrapolated to the PM plane
✓ Select rings fully contained in a single mirror
✓ Compare the position of the ring center on the PMT disk with the position predicted by the extrapolation
✓ Measured misalignment corrected using piezomotors, 2 - 3 iterations

All mirrors aligned within ± 1 mm with respect to the reference
2016 preliminary results

For 90% $\pi$ ID efficiency a 0.8% $\mu$ mis-ID efficiency is observed.
Summary and Outlook

✓ Construction, installation and commissioning of the RICH detector completed in time to meet the NA62 data taking schedule

✓ Pilot run in 2014 and run in 2015 at low intensity
  ✓ Excellent time resolution from the first data
  ✓ Good overall performance for physics analysis

✓ Physics run in 2016
✓ All mirrors aligned within 1 mm wrt reference
✓ The measured performance fulfill all the requirements
  ❖ Time resolution ~ 70 ps
  ❖ Muon mis-ID efficiency < 1% for 90% pion ID efficiency

✓ Data taking will continue in 2017 and 2018
Thank you!
Additional information
Background and kinematics

92% Bkg separated from signal by kinematic cuts

8% not separated

$m^2_{\text{miss}} = (P_K - P_\pi)^2$ defines low bkg signal regions separated by $K^+ \rightarrow \pi^+\pi^0$

- high resolution $m^2_{\text{miss}}$ reconstruction
- measure precisely kaon and pion momenta
- keep multiple scattering as low as possible

Gigatracker (kaon)
Straw chambers (pion)

Photon veto system
Particle Identification

missing mass

Veto and PID

extend in the signal region, kinematics doesn’t help

✓ Suppress $K^+ \rightarrow \pi^+\pi^0$ background
✓ Reject offline decays with $\gamma$
✓ $K^+$ identification in the had beam
✓ $10^{-3} \pi-\mu$ separation

5-9-2016

Giuseppina Anzivino@RICH 2016
**Mirrors pre-alignment**

- Before beam pipe installation and vessel closing
- All mirrors pre-aligned using a laser
- The laser is placed in the Center of Curvature, C, of the mirror mosaic
- The reflected laser beam must come in the same position as the source
- Changing the laser beam angle with C as pivot, all the mirrors of one mosaic half can be illuminated and aligned
- If C is not accessible
- Put in C the optical image of the laser