Performance of the RICH detector of the NA62 experiment

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Outline

1. NA62 experiment
2. RICH requirements
3. RICH construction
4. RICH performance
5. Conclusions
$K^+ \rightarrow \pi^+ \nu\nu$ decay:

- Theoretically very clean, sensitive to physics beyond Standard Model
- $\text{BR}_{\text{TH}}(K^+ \rightarrow \pi^+ \nu\nu) = (0.84 \pm 0.10) \times 10^{-10}$ SM@NLO
  
- $\text{BR}_{\text{EX}}(K^+ \rightarrow \pi^+ \bar{\nu}\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ E787/949@BNL
  

**NA62 at CERN SPS:**

- Last generation kaon experiment
- Main NA62 goal: measurement of the BR of the $K^+ \rightarrow \pi^+ \nu\nu$ decay with ~10% precision (~100 events in ~3 years of data taking)

**NA62 timeline:**

- 2012-2014: detector installation
- 2014: Commissioning Run
- 2015: Physics Run at low intensity
- 2016-2018: data taking
NA62 setup

beam particles:
- CEDAR/KTAG (PID, time)
- GTK (tracking, time)

Secondary charged particles:
- STRAW (tracking)
- RICH (PID, time)
- MUV, LKr (PID)

Photon veto:
- LAV (8.5 – 50 mrad)
- LKr (1 – 8.5 mrad)
- SAC (<1 mrad)

NA62 beam:
- 400 GeV/c primary protons from SPS
- 75 GeV/c secondary hadron beam
- ~6% kaon component
- Beam rate: 750 MHz
- Kaon rate: ~50 MHz
- Decay rate in the fiducial volume: ~5 MHz

NA62 setup:
- Decay-in-flight technique
- Decay region 65 m
- SES ~10^{-12}
NA62 and RICH requirements

NA62 requirements:
- $10^{13}$ kaon decays in the fiducial volume
- ~10% signal acceptance
- O(100) signal events
- ~10% precision

RICH requirements:
- Muon misID probability at the $\sim 10^{-2}$ level in the range $15 \text{ GeV/c} < p < 35 \text{ GeV/c}$
- Measure the pion crossing time with ~100 ps resolution
- Provide L0 trigger for charged tracks

Main kaon decay modes

<table>
<thead>
<tr>
<th>Decay</th>
<th>BR</th>
</tr>
</thead>
<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>$\pi^+\pi^-\pi^0$</td>
<td>5.6%</td>
</tr>
<tr>
<td>$\pi^0\mu^+\nu$ ($K_{\mu3}$)</td>
<td>5.1%</td>
</tr>
<tr>
<td>$\pi^0\mu^+$ ($K_{\mu3}$)</td>
<td>3.3%</td>
</tr>
</tbody>
</table>
RICH layout

Vessel (~17 m long)

Beam pipe

PM flange
(2 flanges x ~1000 PMs)

Mirror mosaic
(17 m focal length)
RICH vessel

Vessel:
- 17m long, ~200 m³
- 4 cylindrical sections with decreasing diameter (4.0 to 3.4 m)
- Beam pipe going through
- Thin Al windows (entrance, exit)
- Vacuum proof

Radiator:
- Ne at ~atmospheric pressure and room temperature
- \((n-1) = 62.8 \times 10^{-6}\) at \(\lambda = 300\) nm
- Pion threshold: \(p = 12.5\) GeV/c
- Low chromatic dispersion
- Good light transparency

Operation:
- Sealed gas volume (without renewal)
RICH mirrors:

- 18 hexagonal mirrors (35 cm side), 2 semi-hexagonal
- Made of 2.5 cm thick glass
- Al coating
- Thin dielectric film to improve reflectivity

Mirror optical properties:

- \( R = 34 \text{ m} \)
- Reflectivity \(~90\%\) \((\lambda = 195-650 \text{ nm})\)
- \( D_0 \leq 4 \text{ mm} \)

Mirror support system:

- 5 cm thick honeycomb panel
- Mirrors are supported by the dowel connected to the support panel
- Two Al ribbons allow for the mirror orientation
- One Al ribbon to prevent mirror rotation
- Two piezo motors to rotate mirrors remotely
Mirror alignment with data (separately for Jura and Saleve):

- Use semihexagonal mirrors as reference
- Select events with rings fully contained in a single mirror
- Extrapolate tracks to the PM plane
- Compare the ring center with the track extrapolation
- Calculate the misalignment and the movement to correct it
- 2-3 movement iterations needed

All mirrors are aligned within ±1 mm wrt the reference (~30 μrad)
Light detection

Hamamatsu R7400 U03 PMs:

- External diameter 16 mm
- Active diameter 8 mm
- UV glass window
- Custom-made HV divider
- 185-650 nm sensitive range
- Peak sensitivity @ 420 nm
- Gain $1.5 \times 10^6$ (HV = 900 V)
- QE ~20% (@ 420 nm)
- Transit time spread 0.28 ns (FWHM)
FE electronics

64 FE boards x 32 channels per board

**FE board:**

- Custom-made amplifiers
- NINO chips (discrimination, signal stretching)
- multiplicity output (for the L0 trigger)
- ELMB (embedded local monitor board) for remote control and monitoring

**NINO:** developed by ALICE experiment (CERN)

**ELMB:** developed by ATLAS experiment (CERN)
Readout system

Data readout: 4 mother boards x 4 daughter boards x 128 channels per board
L0 trigger: 1 mother board with 1 daughter board

Mother board (TEL62):
- development of TELL1 (LHCb experiment at CERN)
- Houses up to 4 daughter boards
- Buffers data
- Produces L0 trigger primitives

Daughter board (TDCB):
- FPGA-based TDC board
- Contains 4 CERN HPTDC (high performance TDC)
RICH performance

RICH direct measurements:
- Time
- Ring center (redundant measurement of the track slope)
- Ring radius $R$ (PID)
- $N_{\text{hits}}$

Performance measurements (2016 data):
- Time resolution
- Ring radius resolution
- Single hit resolution
- Muon-pion separation (PID)

Samples for performance measurements:
- Electrons from $K^+ \to e^+ \nu_e \pi^0$ decay
- Muons from $K^+ \to \mu^+ \nu_\mu$ decay
- Pions from $K^+ \to \pi^+ \pi^0$ decay
- Selection: kinematical cuts + calorimetric PID
Independent time resolution measurement:
- Select $\pi^+$ sample
- Split hits into two groups [Set1] and [Set2]
- Calculate the average time for each group
- Plot the difference of average times
- Fit with the gaussian
- RICH event time resolution is $\sim 0.5\sigma$

RICH event time resolution $\sim 70$ ps

Time difference between two sets of hits

RICH time – KTAG time

$\sigma \sim 140$ ps
Ring radius and single hit resolution

- Select electron sample
- Plot R distribution
- Plot Pull distribution; Pull = (R - \( R_{\text{exp}} \))\(\sqrt{N_{\text{hits}} - 3} \)

\( R_{\text{exp}} \): expected ring radius \( R(m, p) \) predicted from momentum, \( N_{\text{hits}} \): number of hits
- Ring radius resolution: width of the R distribution
- Single hit resolution: width of the Pull distribution

Electron ring radius

- \( \chi^2 / \text{ndf} = 298.7 / 67 \)
- Prob \( \geq 5.403 \times 10^{-31} \)
- Constant \( 1282 \pm 10.9 \)
- Mean \( 189.5 \pm 0.0 \)
- Sigma \( 1.49 \pm 0.01 \)

Pull (electron sample)

- \( \chi^2 / \text{ndf} = 110.7 / 22 \)
- Prob \( \geq 8.39 \times 10^{-14} \)
- Constant \( 3292 \pm 27.2 \)
- Mean \( -0.04943 \pm 0.03015 \)
- Sigma \( 4.684 \pm 0.024 \)

Ring radius resolution 1.5 mm

Single hit resolution 4.7 mm
Select muon and pion samples

- Split the momentum range 15-35 GeV/c into 20 p-bins (1 GeV/c width)
- Put a cut on R or $M^2$ in each p-bin to separate muons and pions
- Calculate Pion ID efficiency and muon misID probability
- **R-based PID**: ring radius used
- **$M^2$-based PID**: reconstructed particle mass $M(p, R)$ used

Reconstructed particle mass $M(p, R)$:
- Velocity from RICH (function of R)
- Momentum $p$ from the spectrometer
**PID with RICH**

**R-based PID in p-bins**
- Muon misID (90% pion ID)
- Pion ID (1% muon misID)

**M$^2$-based PID in p-bins**
- Muon misID (90% pion ID)
- Pion ID (1% muon misID)

**M$^2$-based PID, 15-35 GeV/c:**
- Pion ID efficiency vs muon misID probability

- Standard cuts on the ring quality
  - ~80% pion ID @ 1% muon mis ID

- Tight cuts on the ring quality
  - ~90% pion ID @ 1% muon mis ID

-V.Duk, INFN Perugia
Conclusions

RICH performance fits the experiment requirements:

- Mirrors aligned within 1 mm
- Time resolution ~70 ps
- Ring resolution ~1.5 mm
- Single hit resolution ~4.7 mm
- 1% of muon misID probability is achieved at 80-90% pion ID efficiency

Outlook:

- Take data until 2018
- Improve muon-pion separation (optimization of the R-based algorithm, use of likelihood method etc.)
Thank you!