Particle identification with the NA62 RICH

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RICH-2022 workshop, 12-16.09.2022, Edinburgh, UK
Outline

• NA62 experiment
• RICH detector
• PID in single-track final states
• PID in multi-track final states
• Conclusions
NA62 experiment

**NA62:** fixed target experiment at CERN SPS

**Technique:**
Kaon decays in flight

**Timeline:**
- 2015: commissioning
- 2016-2018: physics runs
- 2021-2025: physics runs

**Primary goal:**
Measure BR($K^+ \rightarrow \pi^+ \nu \nu$)

**NA62 collaboration:** ~300 participants, ~30 institutions
Primary beam:
- 400 GeV/c protons
- $3 \times 10^{12}$ protons per spill

Secondary beam:
- 75 GeV/c (±1%)
- Divergency < 100 µrad
- 70% pions, 6% $K^+$, 24% protons

Key detectors:
- PID: KTAG, RICH, LKr, MUV1-2, MUV3
- Momentum: GTK, STRAW
- Time: GTK, KTAG, RICH, CHOD
- Photon veto: LAV, LKr, IRC, SAC
Gas vessel
- 17 m long, 200 m$^3$
- Neon @ atmospheric pressure

Mirrors
- Mosaic of 20 mirrors
- 18 hexagonal, 2 semihexagonal
- 2 groups (Jura and Saleve)

Light sensors
- 1952 Hamamatsu R7400-U03 PMTs
- Arranged in two disks
- Sensor position optimized for positively charged tracks
- Not optimal for negatively charged tracks due to the acceptance

All details in the talk by F. Bucci (12.09.2022)
R-based PID
• Only single-track final states
• Momentum P from spectrometer
• Ring radius R from the single ring (or track-seeded) fit
• Calculate \( m(RICH) \)
• PID = cut on \( m(RICH) \)

Likelihood-based PID
• Any final states
• P for each track from spectrometer
• Expected R calculated for each mass hypothesis
• Calculate likelihoods for several mass hypotheses (e, \( \mu \), \( \pi \), K, bkg)
• PID = select the highest likelihood and/or cut on likelihood ratio

General approach:
• Measure PID with the data as a function of momentum
• Apply to MC as an event weight

\[ m^2(RICH) = p^2 \cdot \left( \frac{E^2 - m^2}{F^2 + R^2} - 1 \right) \]
NA62 recent results

• \( K^+ \rightarrow \pi^+ \nu \nu \)
  
  BR measurement, Search for \( K^+ \rightarrow \pi^+ X \)  JHEP 06 (2021) 93; JHEP 03 (2021) 58

• LFV/LNV decays
  
  \( K^+ \rightarrow \pi^- l^+ l^- \)  PRL 127 (2021) 131802
  
  \( K^+ \rightarrow \pi^- \pi^0 e^+ e^- \)  PLB797 (2019) 134794; PLB830 (2022) 137172
  
  \( K^+ \rightarrow \mu^- \nu e^+ e^- \)  PLB830 (2022) 137172
  
  \( K^+ \rightarrow \mu^- \nu e^+ e^- \)  Paper in preparation

• Precise measurements
  
  \( K^+ \rightarrow \pi^+ \mu^+ \mu^- \)  Paper in preparation
  
  \( K^+ \rightarrow \pi^0 e^+ \nu \gamma \)  Paper in preparation

• HNL production in \( K^+ \rightarrow l^+ N \)  PLB 807 (2020) 135599; PLB 816 (2021) 136259

• Search for \( \pi^0 \rightarrow \text{invisible} \)  JHEP 02 (2021) 201
NA62 recent results

- $K^+ \rightarrow \pi^+ \nu \nu$
  
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- LFV/LNV decays
  
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  $K^+ \rightarrow \mu^- \nu \pi^0 \nu$  
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- Search for $\pi^0 \rightarrow invisible$  
  JHEP 02 (2021) 201
RICH PID in a single-track final state
Run 1 (2016-2018) fully analyzed

<table>
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<th>Data</th>
<th>N(K decays)</th>
<th>N(K$^+\to\pi^+\nu\bar{\nu}$ candidates)</th>
<th>publication</th>
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<td>2016</td>
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<td>PBL 791 (2019) 156</td>
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<td>JHEP 11 (2020) 042</td>
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<td>2018</td>
<td>4x10$^{12}$</td>
<td>17</td>
<td>JHEP 06 (2021) 093</td>
</tr>
</tbody>
</table>

Combined result:

$$\text{BR}(K^+\to\pi^+\nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9|_{\text{syst}}) \times 10^{-11} \text{ at } 68\% \text{ CL}$$

Statistical significance: $p = 3.4 \times 10^{-4}$ (3.4 $\sigma$)

First evidence of the decay
One of main backgrounds: $K^+ \rightarrow \mu^+ \nu$ (K\(\mu\)2)

- $\text{BR}(K\mu2) = 0.63$
- $O(10^{12})$ suppression needed

✓ Kinematics: $O(10^4)$
✓ PID with hadron calorimeters: $O(10^5)$
✓ PID with RICH: $O(10^3)$
PID in the $K^+ \rightarrow \pi^+ \nu \nu$ analysis

R-based PID

Likelihood-based PID
PID in the $K^+ \rightarrow \pi^+ \nu \nu$ analysis

- Both algorithms used
- Pion efficiency $\epsilon(\pi) = 85\%$
- Muon misID probability $\epsilon(\mu) = 0.2\%$
RICH PID in a multi-track final state
Search for $K^+ \rightarrow \pi^- e^+ e^+$

Data:
- Run 1 (2016-2018)

Main features
- blind analysis
- $A(\text{sig}) = 4.23\%$
- $N_K = 9.79(31) \times 10^{11}$
- SES = $2.4 \times 10^{-11}$

Normalisation:
- $K^+ \rightarrow \pi^+ e^+ e^-$
- $N(K^+ \rightarrow \pi^+ e^+ e^-) = 9483$

Expected bkg:
- $N = 0.43(9)$

$\text{SM: } M(\pi^+ e^+ e^-)$

$\text{LNV: } M(\pi^- e^+ e^+)$

$\text{BR}(K^+ \rightarrow \pi^- e^+ e^+) < 5.3 \times 10^{-11} \text{ (90\% CL)}$

Factor of 12 improvement wrt previous limit: $\text{BR} < 6.4 \times 10^{-10} \text{ (90\% CL)}$
PID in the $K^+ \rightarrow \pi^- e^+ e^+$ selection

Bkg from $K^+ \rightarrow \pi^+ \pi^0, \pi^0 \rightarrow e^+ e^- \gamma$
- $\pi^+$ misidentified as $e^+$
- $e^-$ misidentified as $\pi^-$

RICH PID
- Applied only for positively charged tracks
- misID probabilities measured on $K^+ \rightarrow \pi^+ \pi^+ \pi^- \gamma$ sample

RICH provides additional rejection factor up to $10^3$
PID in the $K^+ \rightarrow \pi^+ e^+ e^-$ selection

Normalization selection $K^+ \rightarrow \pi^+ e^+ e^-$

Bkg from $K^+ \rightarrow \pi^+ \pi^+ \pi^-$
- One $\pi^+$ misidentified as $e^+$
- $\pi^-$ misidentified as $e^-$

$O(10^3)$ reduction due to RICH
• RICH PID is essential for NA62
• RICH PID works well only for positively charged tracks (due to the acceptance)
• $K^+ \rightarrow \pi^+ \nu \nu$ analysis: $O(10^3)$ suppression of $K^+ \rightarrow \mu^+ \nu$ bkg with $(\mu^+ \rightarrow \pi^+)$ misID
• LNV search in $K^+ \rightarrow \pi^- e^+ e^+: O(10^3)$ suppression of bkg with $(e^+ \rightarrow \pi^+)$ and $(\pi^+ \rightarrow e^+)$ misID
Conclusions

- RICH PID is essential for NA62
- RICH PID works well only for positively charged tracks (due to the acceptance)
- $K^+ \rightarrow \pi^+ \nu \nu$ analysis: $O(10^3)$ suppression of $K^+ \rightarrow \mu^+ \nu$ bkg with $(\mu^+ \rightarrow \pi^+)$ misID
- LNV search in $K^+ \rightarrow \pi^- e^+ e^+$: $O(10^3)$ suppression of bkg with $(e^+ \rightarrow \pi^+)$ and $(\pi^+ \rightarrow e^+)$ misID

Thank you!
Spare