Particle identification with the NA62 RICH

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on behalf of the NA62 RICH working group

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

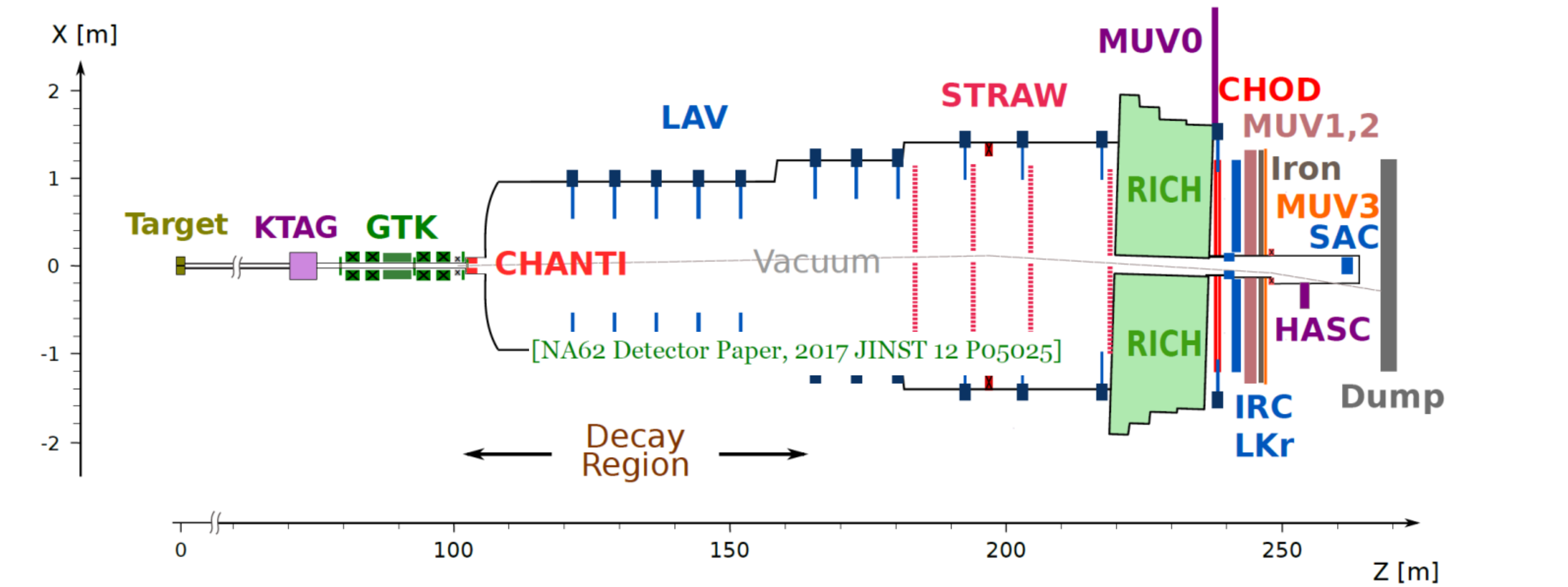
Primary goal:
Measure BR($K^+ \rightarrow \pi^+ \nu\nu$)

ECN3 hall at CERN

NA62 collaboration: ~300 participants, ~30 institutions

NA62 experimental setup

[NA62 Detector Paper, 2017 JINST 12 P05025]



Primary beam:
- 400 GeV/c protons
- 3×10^{12} protons per spill

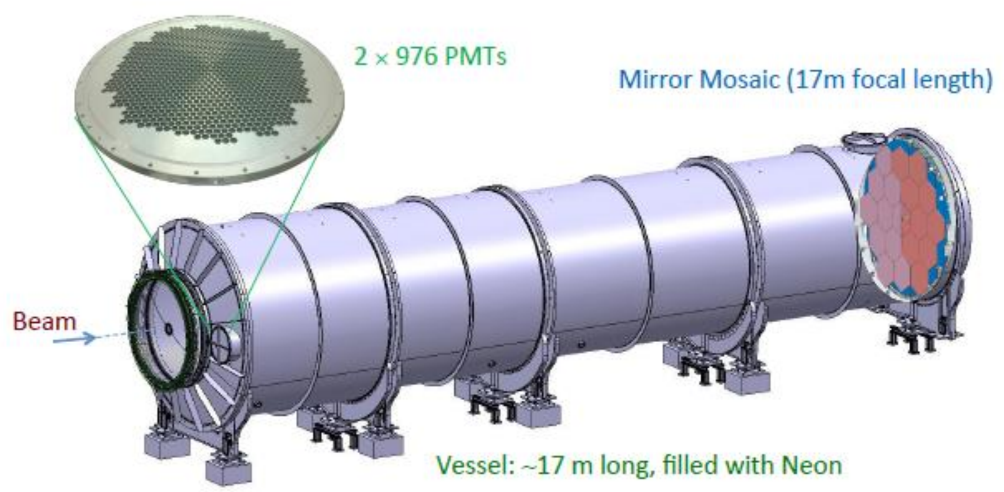
Secondary beam:
- 75 GeV/c (±1%)
- Divergency < 100 μrad
- 70% pions, **6% K^+**, 24% protons

Key detectors:
- PID: KTAG, RICH, LKr, MUV1-2, MUV3
- Momentum: GTK, STRAW
- Time: GTK, KTAG, RICH, CHOD
- Photon veto: LAV, LKr, IRC, SAC

NA62 RICH

Gas vessel

- 17 m long, 200 m^3
- Neon @ atmospheric pressure

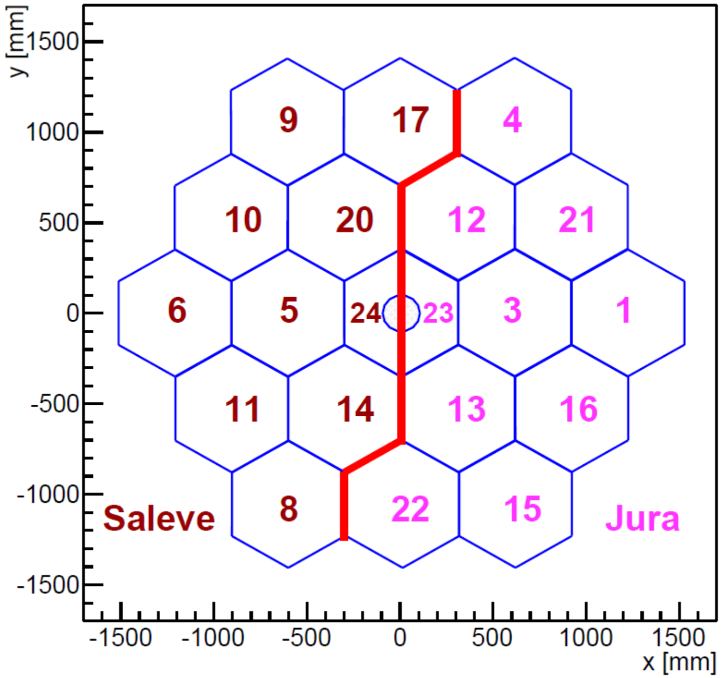


Light sensors

- 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

Mirrors

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

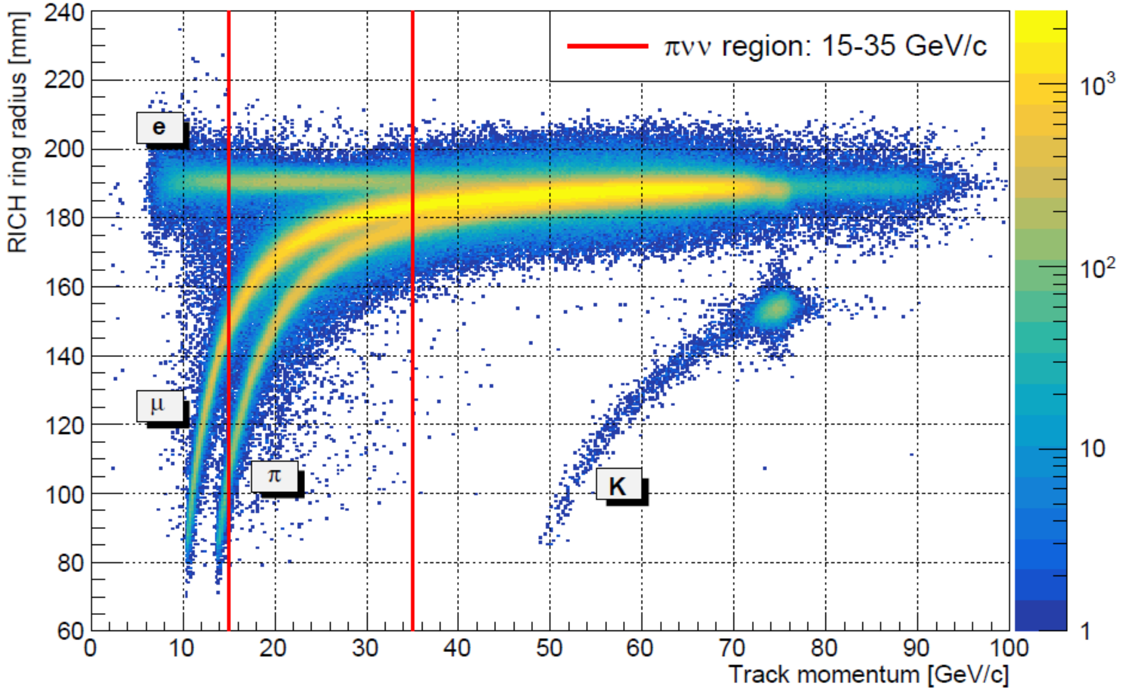


All details in the talk by F. Bucci (12.09.2022)

PID with RICH

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) $m^2(RICH) = p^2 \cdot (\frac{F^2 \cdot n^2}{F^2+R^2} - 1)$
- 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, μ, π, 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

NA62 recent results

- $K^+ \to \pi^+ \nu \nu$

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

- LFV/LNV decays

    $K^+ \to \pi \mu e$ PRL 127 (2021) 131802

    $K^+ \to \pi^- l^+ l^+$ PLB797 (2019) 134794; PLB830 (2022) 137172

    $K^+ \to \pi^- \pi^0 e^+ e^+$ PLB830 (2022) 137172

    $K^+ \to \mu^- \nu e^+ e^+$ Paper in preparation

- Precise measurements

    $K^+ \to \pi^+ \mu^+ \mu^-$ Paper in preparation

    $K^+ \to \pi^0 e^+ \nu \gamma$ Paper in preparation

- HNL production in $K^+ \to l^+ N$ PLB 807 (2020) 135599; PLB 816 (2021) 136259
- Search for $\pi^0 \to$ invisible JHEP 02 (2021) 201

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RICH PID essential (single-track final state)

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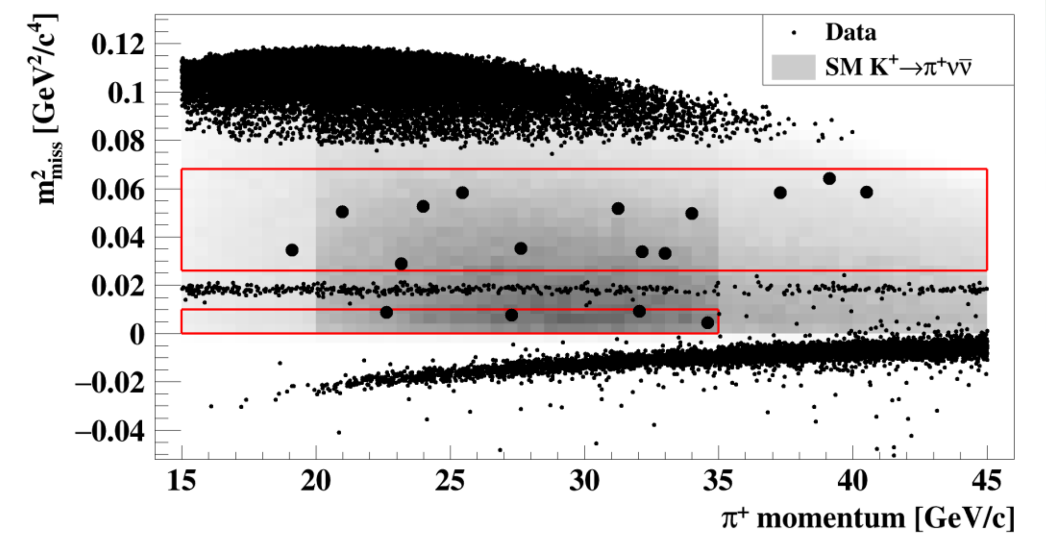
RICH PID in a single-track final state

NA62 main goal: BR($K^+ \to \pi^+ \nu\nu$)

2018 data sample

Run 1 (2016-2018) fully analyzed

Data	N(K decays)	N($K^+ \to \pi^+ \nu\nu$ candidates)	publication
2016	2×10^{11}	1	PBL 791 (2019) 156
2017	2×10^{12}	2	JHEP 11 (2020) 042
2018	4×10^{12}	17	JHEP 06 (2021) 093

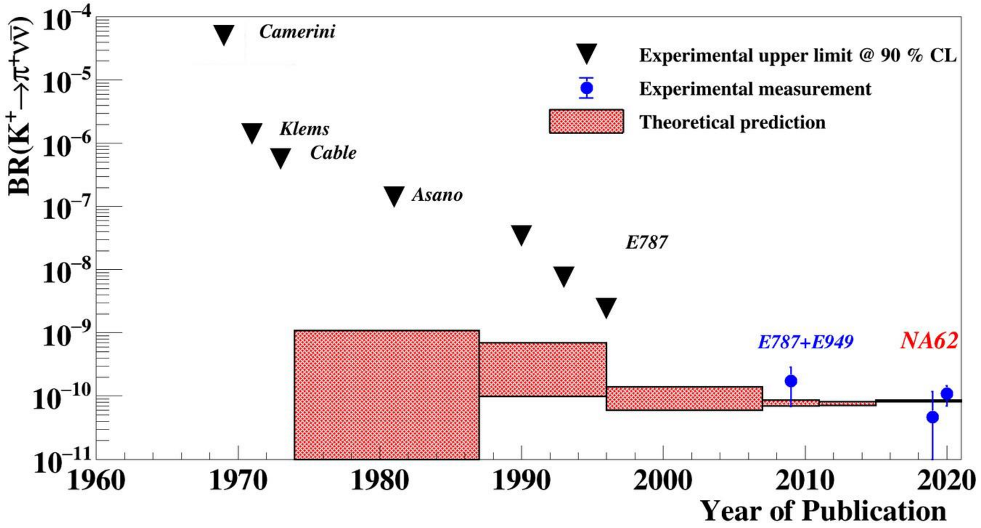


Combined result:

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

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

First evidence of the decay



PID in the $K^+ \to \pi^+ \nu\nu$ analysis

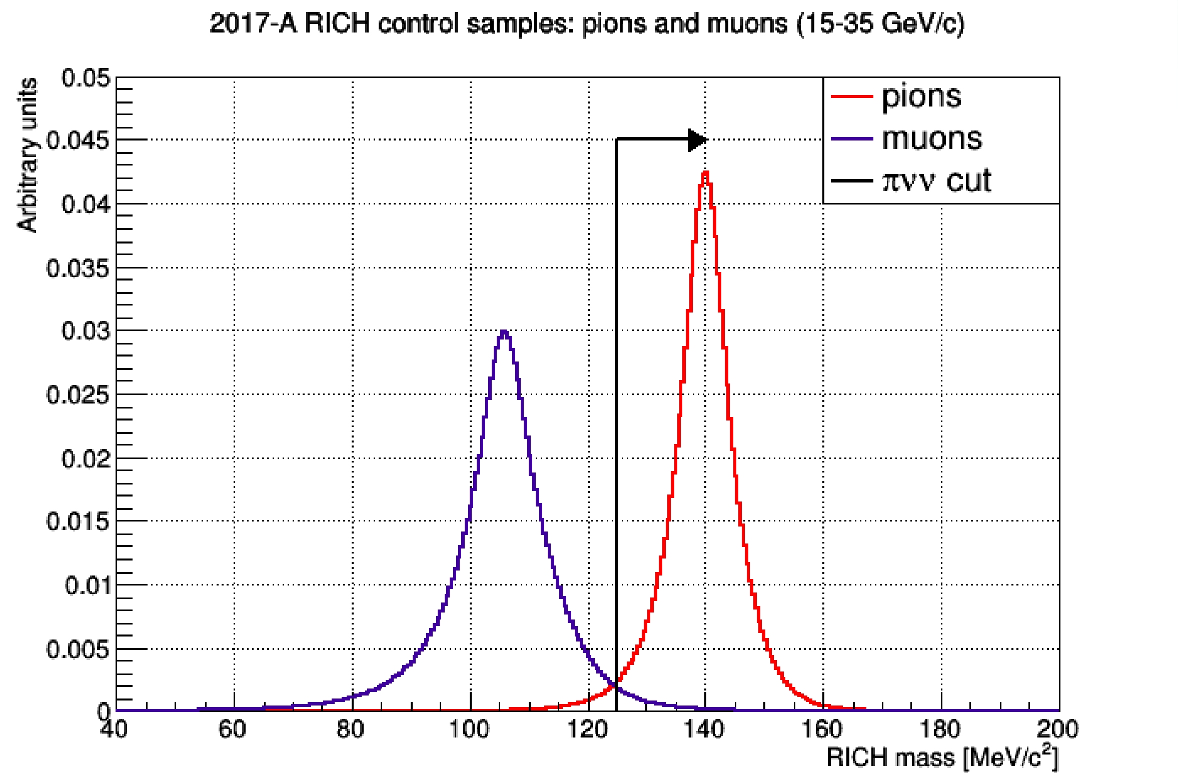
One of main backgrounds: $K^+ \to \mu^+ \nu$ (Kμ2)

- BR(Kμ2) = 0.63
- $O(10^{12})$ suppression needed

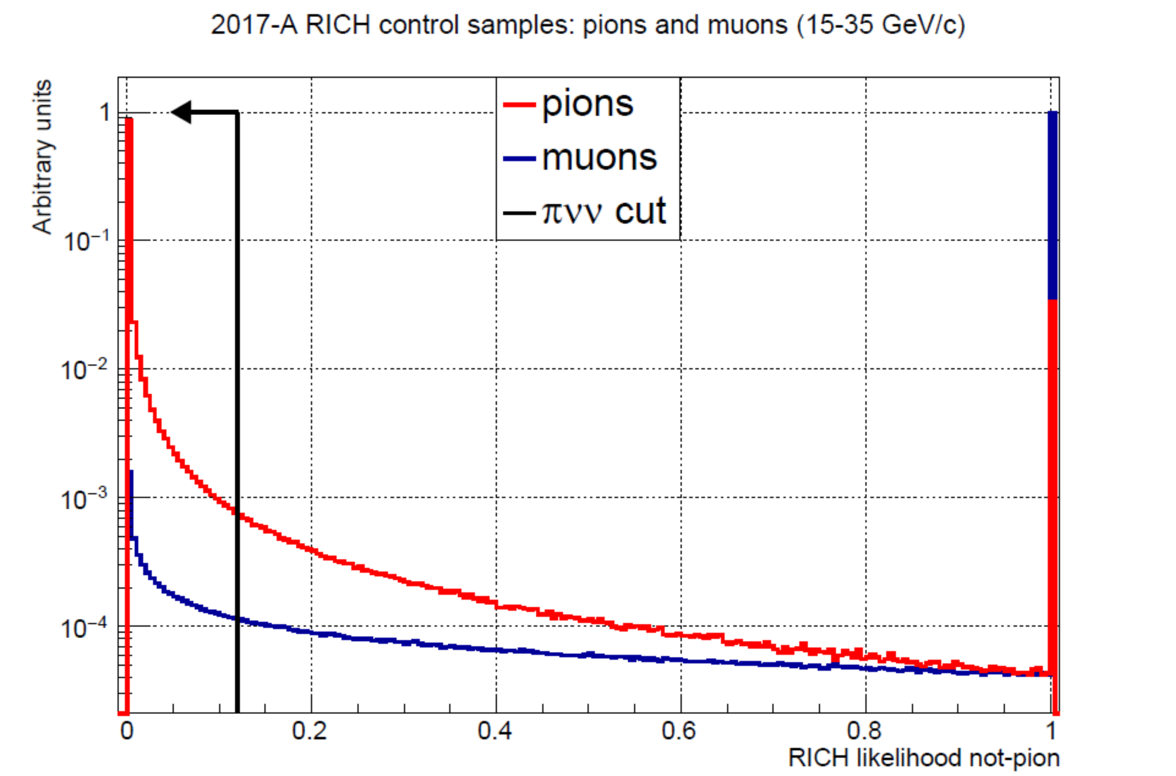
  - ✓ Kinematics: $O(10^4)$
  - ✓ PID with hadron calorimeters: $O(10^5)$
  - ✓ PID with RICH: $O(10^3)$

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

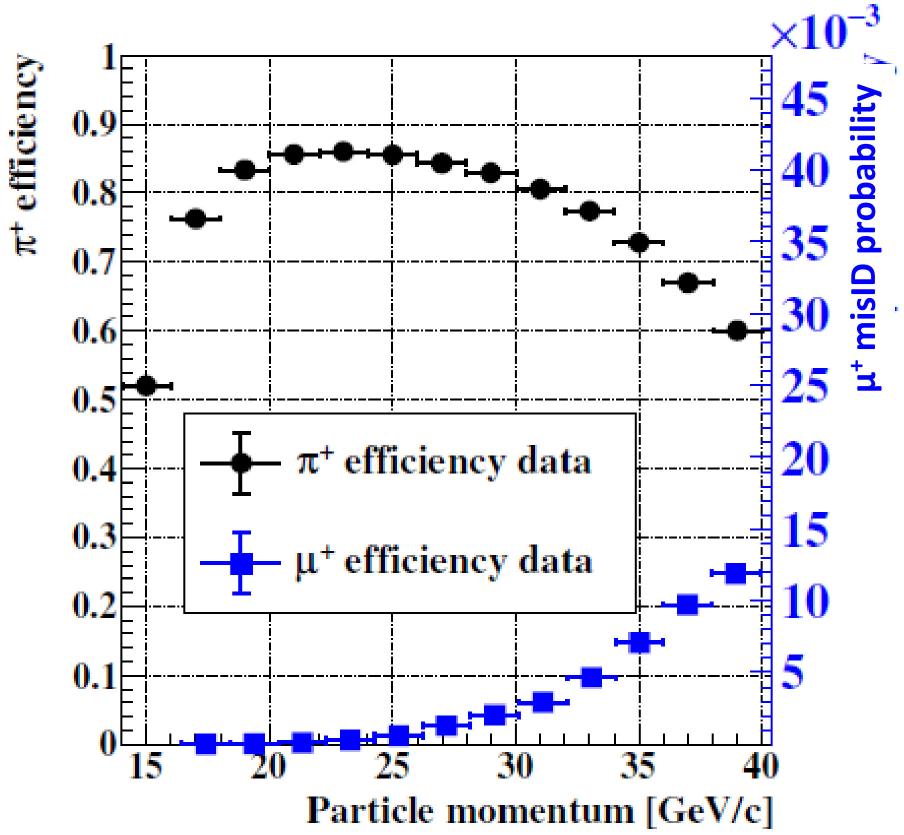
R-based PID



Likelihood-based PID

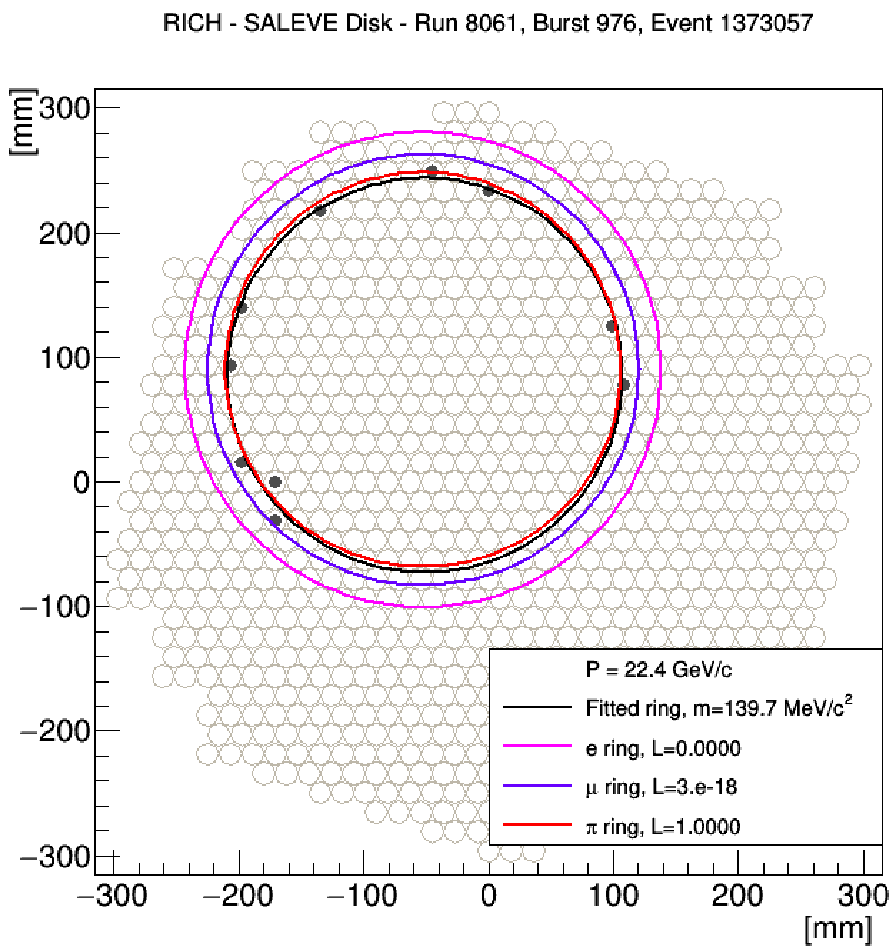


PID in the $K^+ \rightarrow \pi^+ \nu\nu$ analysis



- Both algorithms used
- Pion efficiency $\varepsilon(\pi) = 85\%$
- Muon misID probability $\varepsilon(\mu) = 0.2\%$

Example of a single ring fit and expected rings



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(sig) = 4.23%
- $N_K = 9.79(31) \times 10^{11}$
- SES = 2.4×10^{-11}

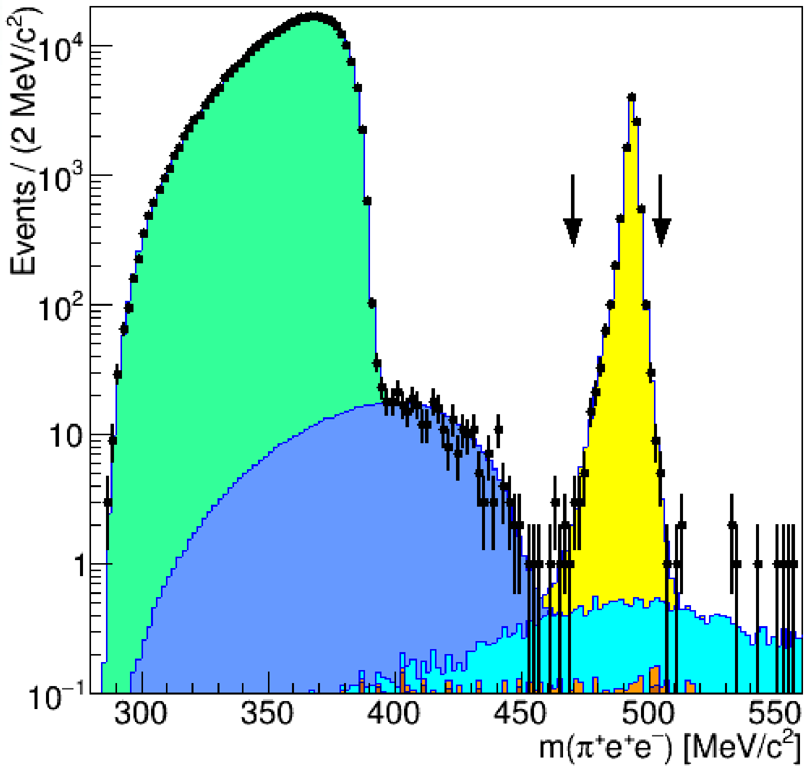
Normalisation:

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

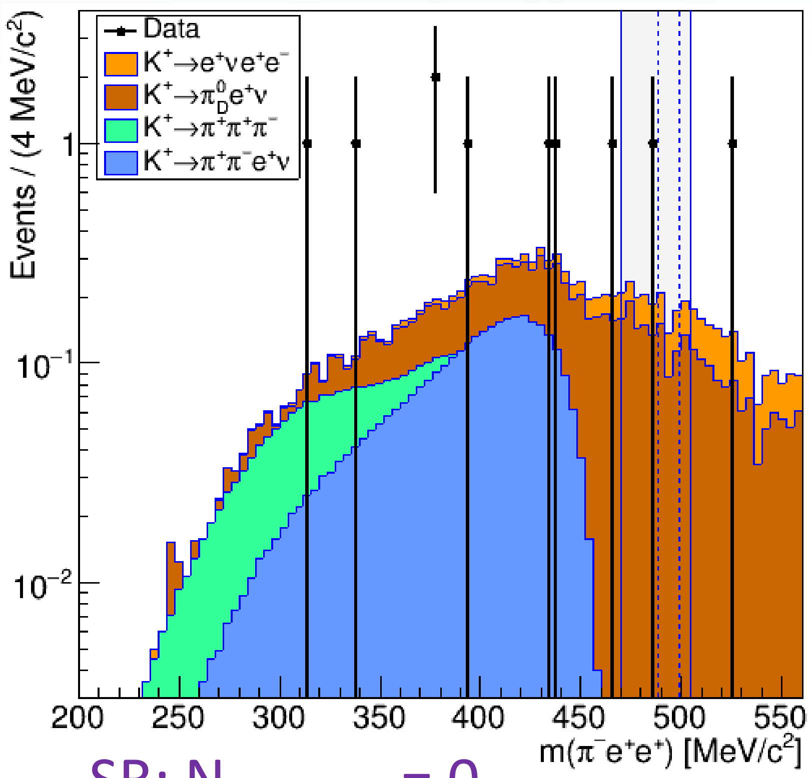
Expected bkg:

- N = 0.43(9)

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



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



SR: $N_{observed} = 0$

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

Factor of 12 improvement wrt previous limit: BR < 6.4×10^{-10} (90% CL)

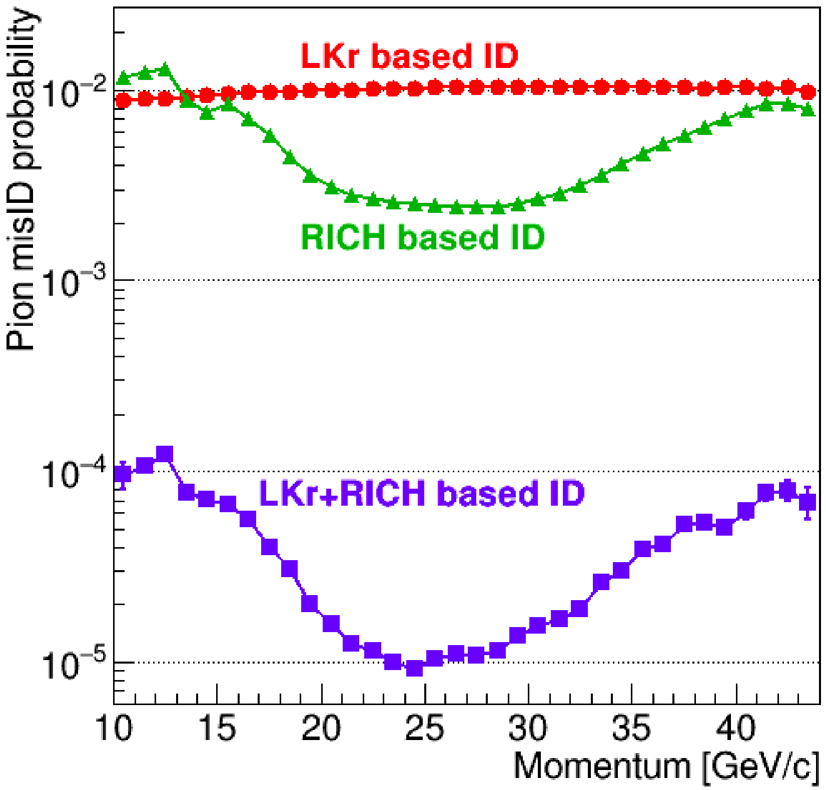
PID in the $K^+ \to \pi^- e^+ e^+$ selection

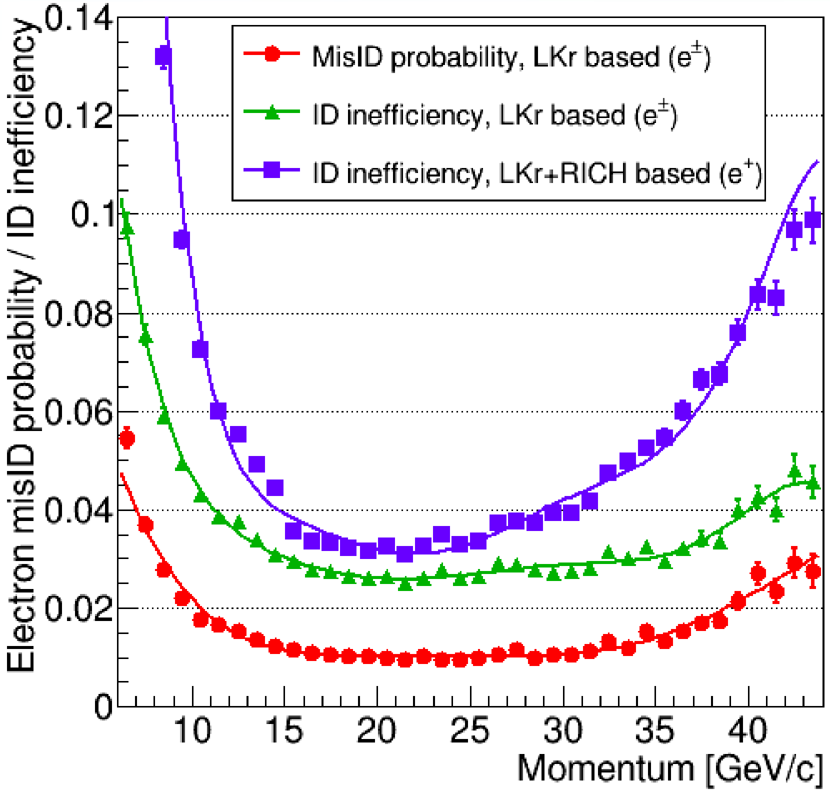
Bkg from $K^+ \to \pi^+ \pi^0$, $\pi^0 \to e^+ e^- \gamma$

- π^+ misidentified as e^+
- e^- misidentified as π^-

RICH PID

- Applied only for positively charged tracks
- misID probabilities measured on $K^+ \to \pi^+ \pi^+ \pi^-$ sample





RICH provides additional rejection factor up to 10^3

PID in the $K^+ \rightarrow \pi^+ e^+ e^-$ selection

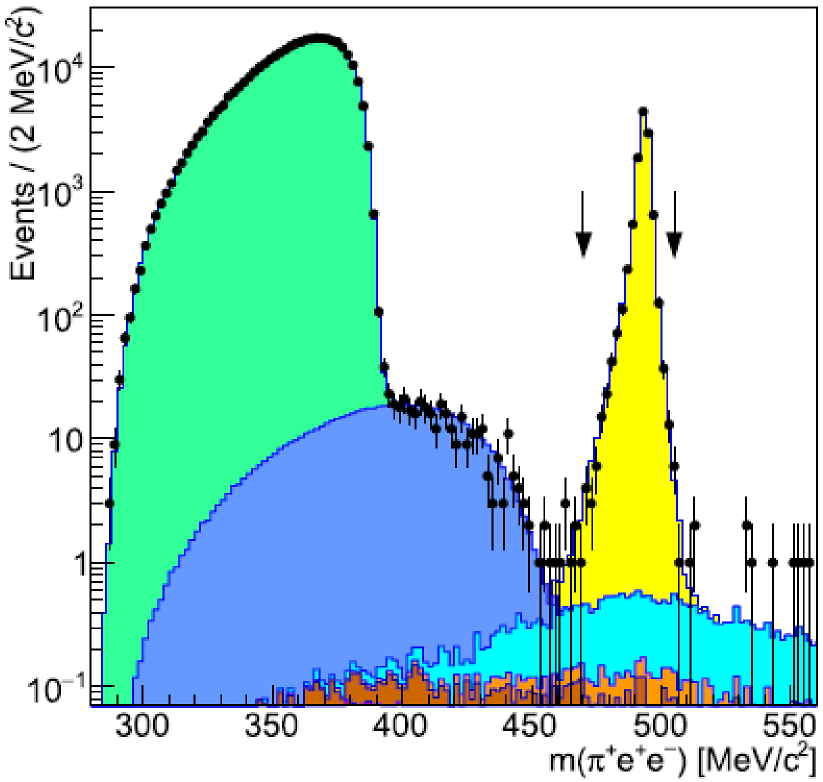
Normalization selection $K^+ \rightarrow \pi^+ e^+ e^-$

Bkg from $K^+ \rightarrow \pi^+ \pi^+ \pi^-$

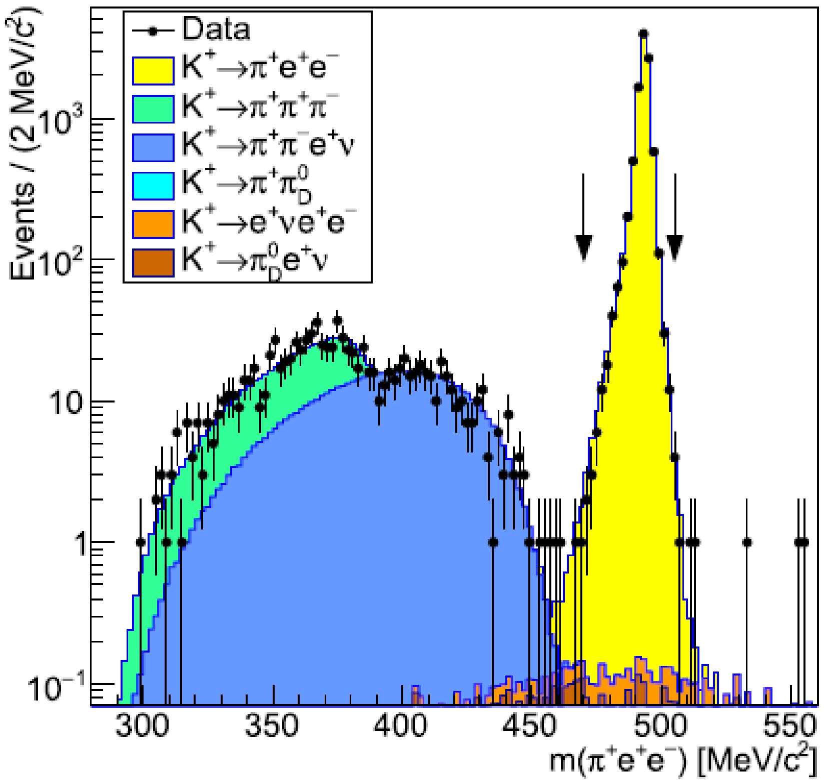
- One π^+ misidentified as e^+
- π^- misidentified as e^-

$O(10^3)$ reduction due to RICH

without RICH PID



with RICH PID



Conclusions

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

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Thank you!

Spare