The kaon identification system in the NA62 experiment at CERN SPS

On behalf of the NA62 collaboration

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The NA62 Experiment

Fixed target Kaon experiment at CERN SPS

The NA62 collaboration
32 Institutes ~250 participants
13 Countries

Primary goal: Collect $\mathcal{O}(50)$ SM $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events per year of data taking and measure $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with 10% accuracy
Motivations for $K^+ \to \pi^+ \nu \bar{\nu}$

- Ultra rare FCNC decay forbidden at tree level

- CKM suppressed ($\sim |V_{ts}V_{td}|^2$)
  - Dominant short-distance t quark contribution
  - Small c quark contribution
  - Small long-distance corrections
  - Hadronic matrix element extracted from $Br(K^+ \to \pi^+ e\nu)$

  $Br(K^+ \to \pi^+ \nu \bar{\nu})_{SM} = (9.11 \pm 0.72) \times 10^{-11}$

  [A.J. Buras et al., JHEP 1511 (2015) 033]

- Best measurement based on 7 events (E787/E949)

  $Br(K^+ \to \pi^+ \nu \bar{\nu})_{Exp} = 1.73^{+1.15}_{-1.05} \times 10^{-10}$

Motivations for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- Ultra rare FCNC decay forbidden at tree level

- Sensitive to new physics
  - Probe of new physics scenarios
  - Searches complementary/alternative to LHC
  - Accessible mass scales beyond those of LHC
  - Littlest Higgs Model with T-parity
  - Minimal Flavor Violation
  - 4th generation
  - Randall-Sundrum with custodial protection
The NA62 Challenge

Detect $\mathcal{O}(50) K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events ($\mathcal{B}_{SM} \sim 9 \times 10^{-11}$) per year of data taking with Signal/Bckg $\sim 10$. Measure $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with 10% accuracy.

Background known to 10% precision

High Intensity: $4.5 \times 10^{12} K^+$ decays/year
10% detector acceptance

Background rejection $> 10^{12}$

decay-in-flight technique (Vetoes – PID)

Decay-in-flight technique (Vetoes – PID)
The NA62 Challenge

Beam line – Primary from SPS
- 400 GeV/c proton beam
- Impact on Beryllium target

Beam line – Secondary
- Unseparated hadron beam
- 75 GeV/c (±1%)
- $K^+ \sim 6\%, \pi^+ \sim 72\%, p \sim 22\%$
- Particle rate: 750 MHz
- 10% of kaons decays in 60 m fiducial volume

$4.5 \times 10^{12}$ decays/year
The NA62 Challenge

Background rejection

<table>
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<tr>
<th>Decay backgrounds</th>
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<tr>
<td><strong>Decay mode</strong></td>
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<tr>
<td>( \mu^+ \nu(\gamma) )</td>
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<tr>
<td>( \pi^+ \pi^0(\gamma) )</td>
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<td>( \pi^+ \pi^+ \pi^- )</td>
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<td>Upstream interactions</td>
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Kinematic rejection

- Kaon momentum (GigaTracker)
- \( \pi \) momentum (Straw)

\[
m^2_{\text{miss}} \cong m_K^2 \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m_\pi^2 \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}
\]

Other backgrounds

- Beam-gas interactions
- Upstream interactions

PID and high efficiency Veto systems \((< 10^{-5} \text { inefficiency})\)

- Photons vetoes (LAV, LKr, IRC, SAC)
- Leptons vetoes (LKr, MUV)
- Accidentals vetoes (CHANTI)

Time resolution

Matching of upstream-downstream activity \((< 100 \text{ ps time resolution})\)
The Kaon Identification System

Requirements

- 45 MHz Kaon flux
- > 95% Kaon ID efficiency and < 0.1% mis-tagging probability
- < 100 ps time resolution
The Kaon Identification System

- Re-use CEDAR build in the ’80s for CERN SPS beam lines
  - Vessel filled with radiator gas (nitrogen)
  - Internal optics axis precisely aligned with the beam axis
  - Light is transported by internal optics through a diaphragm to PMTs
  - Diaphragm selects light within a range around a fixed angle
  - Gas pressure tuned to select specific particle mass

Not able to withstand rate requirements
The KTAG Upgrade

- Upgrade detector – For each octant
  - Add mirrors to project Čerenkov light to new PMT plane (90°, wider area)
  - Replace old single PMT with a light box
    - Light collection cones (Light Guides) machined in aluminium spherical convex planes
  - Array of 48 PMTs at the exit of the light guide (Hamamatsu R7400U-03 and R9880U-210)
  - HV distribution board
  - Front-end electronics
  - Heat-sink
The KTAG Upgrade

- Upgrade readout

- Custom printed circuit board with differential anode output
- NINO ASIC chip for fast Time-over-Threshold discriminator
- NINO board with Low Voltage Differential Signal (LVDS) output
- Splitter Board (LVDS distribution)
- TEL62 mother board
  FPGA based, integrated trigger and DAQ: buffers data and produces trigger primitives
- CERN HPTDC ASIC for analog to digital time conversion
  TDC board
Simulation

- \(~20\, \gamma/\text{Kaon}\)
- Single PMT rate \(~5\, MHz\)
- Single \(\gamma\) time resolution: \(\sigma_t(\gamma) = 300\, ps\)
- Kaon time resolution: \(\sigma_t(K^+) = \frac{\sigma_t(\gamma)}{\sqrt{\langle N_\gamma \rangle}} \approx 70\, ps\)

Diaphragm aperture of 1.5 mm lead to \(10^{-4}\) \(\pi\) contamination in nitrogen

Čerenkov photon distribution at diaphragm
2012 Technical run @ 1% beam intensity

- Test half-equipped KTAG with nitrogen (4 sectors with 32 R7400U-03 PMT each)

- Estimated pion mis-ID probability from extrapolated contamination of $\pi$ in $K \sim 10^{-4}$

- Measured single photon time resolution $\sigma_t(\gamma) = 280 \text{ ps}$
2014/2015 Physics run @ 5-40% beam intensity

- Almost full NA62 setup in 2014 (GTK, Straw and MUV partially equipped), KTAG fully equipped
- Confirmed performances: $\sigma_t(K) < 70 \text{ ps}$

$K^+ \rightarrow \pi^+ \pi^0$ selection with LKr detector only to tag Kaons

KTAG Efficiency > 95% for N-fold* $\geq 5$

*N-fold = number of fired sectors

Efficiency VS N-fold coincidence

Efficiency VS Burst ID

Number of Hits per Kaon candidate

~20 $\gamma/K$
KTAG - Tests & Results

- 2014/2015 Physics Run @ 5-40% beam intensity
  - Diaphragm aperture and pressure scan performed with periodic and accidental triggers
  - Tune KTAG to the Kaon peak: maximise Kaon ID efficiency

Pressure scan at 1mm diaphragm aperture
Pressure scan at 1.5mm diaphragm aperture
Requirements

- Factor better than $10^2 \mu$ suppression in momentum range $15 < p < 35 \text{ GeV/c}$
- $\pi$ crossing time measurement with $\sim 100 \text{ ps}$ resolution
- L0 trigger for charged tracks
The NA62 RICH Detector

- **Vessel**
  - 17m long, 4 cylindrical sections with decreasing diameter (4 m to 3.4 m)
  - 168 mm beam pipe going through
  - Thin Al entrance and exit windows

- **Radiator gas**
  - 200 $m^3$ of Neon slightly above atmospheric pressure
    - 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
  - $\pi$ momentum threshold of 12 GeV/c
  - Sealed gas volume, low sensitivity to impurities (without renewal)
Mirrors

- 20 hexagonal mirrors (35 cm side) and 2 semi-hexagonal mirrors (around beam pipe)
- 2.5 cm thick glass with Al coating and thin dielectric film
  - Average reflectivity better than 90%
- Supported by a dowel inserted in the back and connected to the support panel.
- Thin aluminium ribbons to keep mirror position and orientation with piezo motors for remote control.
- Preliminary alignment with laser
- Pointed towards left & right detection disks
Photon detection
- 1952 Hamamatsu R7400U-03 PMTs in 2 Al disks placed in upstream endcap on left & right of beam pipe
- Light collection with Winston Cones covered with Mylar foils
- 1mm thick quartz windows to separate neon from air

Front-End and Read-out
- Custom made current amplifiers with differential output
- 64 FE boards of 32 channels each containing NINO chips
- Output to 5 TEL62 equipped similarly to the KTAG ones
  - 4 TEL62 for PMT readout
  - 1 TEL62 for trigger primitive generation
2014 Pilot run @ 5% beam intensity

- No tracking during run
- $\pi^+$ sample selected from $K^+ \rightarrow \pi^+\pi^0$ reconstructed with the LKr
- Split ring hits in two halves and compute difference of average time

$$\sigma_t(track) = 0.5 \times \sigma_t(hits) \sim 70 \text{ ps}$$

- Leak rate below 0.1 mbar l/s

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RICH – Tests & Results

- 2015 Physics Run @10-40% beam intensity
  - Tracking available from Straw detector
  - Track matching between Straw and RICH
    - $p_{fit}$: Fitted ring centre position
    - $p_{track}$: Predicted ring centre from track extrapolation on the RICH mirror

  $d_{fit-track} = |p_{fit} - p_{track}| \leq 20 \text{ mm}$

  - Mirror alignment by minimising $d_{fit-track}$
  - Muon rejection factor of 50
  - Pion efficiency 83%

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Conclusions

- NA62 Beam line fully commissioned
- NA62 Detector installation completed
- During 2012 Technical run and 2014 Pilot Run
  - CEDAR fully commissioned
  - RICH fully commissioned
- Both KTAG and RICH preliminary results shows that the expected performances are reached.
- Physics data taking started in 2015, data are being analysed

To be continued in 2016-2018