Recent results from the NA62 experiment at CERN

Riccardo Aliberti
Johannes Gutenberg Universität - Mainz
(on behalf of the NA62 collaboration)

XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS16)

Hamburg, 14/04/2016
The NA62 Experiment

Fixed Target Experiment

Located at the North Area of CERN

75 GeV/c Secondary Hadron Beam

Carry on the tradition of Kaon experiments at CERN - SPS
NA62 2007 Data Taking

NA48 Apparatus

Beam:
• Simultaneous $K^\pm$
• 74 GeV/c

Main Detectors:
• Magnetic Spectrometer
  $\sigma(P)/P = 0.48\% \oplus 0.009 P(\text{GeV/c})\%$
  $\sigma(P)/P @ 20 \text{ GeV/c} = 0.51\%$

• Hodoscope
  $\sigma(t) \approx 200 \text{ ps}$

• Liquid Krypton Calorimeter (LKr)
  $\sigma(E)/E = 3.2\% / \sqrt{E} \oplus 9\%/E \oplus 0.42\% \,(\text{GeV/c}^2)$
  $\sigma(E)/E @ 20 \text{ GeV/c}^2 = 0.94\%$
Transition Form Factor

\[ \pi^0 \rightarrow \gamma \gamma^* \rightarrow \gamma e^+ e^- \]

\[ \frac{1}{\Gamma (\pi^0_{2\gamma})} \frac{d\Gamma (\pi^0_D)}{dx} = \frac{2\alpha}{3\pi} \frac{(1 - x)^3}{x} \left(1 + \frac{r^2}{2x}\right) \sqrt{1 - \frac{r^2}{x}} \left(1 + \delta(x)\right) \left(1 + ax\right)^2 \]

- Transition Form Factor (TFF) to parameterise low energy QCD in \( \pi^0 \)

- TFF Theoretical models used in the hadronic light-by-light scattering contribution to \((g - 2)_\mu\)

- Missing precise direct measurement of the TFF to test theoretical models
Selection

- Full kinematic reconstruction of $K^\pm \rightarrow \pi^\pm \pi_D^0$ events

- 3 track topology ($\pi^\pm$, $e^+$, $e^-$)
- 1 Photon in the LKr Calorimeter
- $x > 0.01$
Selection

- Full kinematic reconstruction of $K^\pm \to \pi^\pm \pi_D^0$ events

- 1.06 $M$ of $\pi^0 \to \gamma e^+e^-$ candidates selected

- TFF obtained by fitting the simulation to the data $x$ spectrum
Preliminary Results

Theoretical Expectation

\[ a = (2.90 \pm 0.50) \times 10^{-2}, \chi^2_{PT}, [K. Kampf et al. EPJ C46 (2006), 191]\]
\[ a = (3.07 \pm 0.06) \times 10^{-2}, \text{dispersion theory}, [M. Hoferichter et al. EPJ C74 (2014), 3180]\]
\[ a = (2.92 \pm 0.04) \times 10^{-2}, \text{two hadron saturation}, [T. Husek et al. EPJ C75 (2015), 586]\]
The NA62 Experiment

Goal

• Measure $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with 10% precision

Requirement

• Collect around 100 events in the next 2 years (statistics)
  ➡ $10^{13}$ $K^+$ decays in 2 years with 10% acceptance
• Better than 10% precision on background measurement (systematics)
  ➡ $10^{12}$ background rejection (<20% background)

Data

• Runs in 2014 and 2015
• Next Physics run starts end of April
$\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$: Theoretical Motivation

- FCNC loop process, highly suppressed, theoretically very clean

- Well calculated inside the SM [A.J. Buras et al., JHEP 1511 (2015) 033]

\[ BR_{SM} (K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11} \]

- Previous Measurement (only 7 events) [BNL E787/E949: PRL101 (2008) 191802]

\[ BR_{exp} (K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \]

Any deviation from the expected value is a hint of new physics
NA62 Detector

**SPS Protons**
- 400 GeV
- $10^{12}$ protons/s
- 3.5 s spill

**Secondary Beam**
- 75 GeV, $\Delta p/p \sim 1\%$
- K (6%), p (23%), π (70%)
- 750 MHz

**Kaon Decays**
- ~ 5 MHz
- $4.5 \times 10^{12}$ per year
- $10^{-6}$ mbar vacuum

**Beryllium Target**

**Fiducial Region 65m**

**Total Length 270m**

**Hadron Beam 750 MHz**

**Cedar**

**Kaon and Tracking**

**Secondary Beam**

**Kaon ID and Tracking**

**Photons and Muons Veto**

**Pion ID and Tracking**

**Secondary Beam**

**Kaon ID and Tracking**

**Kaon ID and Tracking**

**Photons and Muons Veto**

**Pion ID and Tracking**

**Total Length 270m**
Analysis Strategy

Signal:
✓ one beam $K^+$
✓ one $\pi^+$
✓ nothing else

Background:
× Beam activity
× other $K^+$ decays

- Precise **kinematic** reconstruction
  ➞ 2 signal regions
- PID for kaons and pions
  ➞ $15 < P_{\pi} < 35$ GeV/c
- Hermetic **photon** detection
  ➞ 65 m long fiducial region
Analysis Strategy

Signal:
✓ one beam $K^+$
✓ one $\pi^+$
✓ nothing else

Background:
$x$ Beam activity
$x$ other $K^+$ decays

$M_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$

Expected 45 SM events per year with less than 10 background

- Precise kinematic reconstruction
  ➡ 2 signal regions
- PID for kaons and pions
  ➡ $15 < P_{\pi} < 35$ GeV/c
- Hermetic photon detection
  ➡ 65 m long fiducial region
Signal Topology and Kaon ID

One Track Selection (OTS)
- One downstream track topology
- Beam track matching
- Kaon tag in CEDAR (Kaon ID)
- Energy in the calorimeters
✓ Information from RICH and Calorimeters

✓ Need $O(10^7)$ $\mu$ suppression, mainly for $K^+ \rightarrow \mu^+ \nu$

✓ 80% pion efficiency in RICH with $O(10^2) \pi/\mu$ separation

✓ Simple cut analysis on calorimeters provide $(10^4 \div 10^6) \mu$ suppression, with (90% ÷ 40%) $\pi$ efficiency

⇒ Room for improvement
Exploiting correlation between photons from the same \( \pi^0 \)

Need \( O(10^8) \) rejection of \( \pi^0 \), mainly for \( K^+ \rightarrow \pi^+\pi^0 \) suppression

2015 Measurement statistically limited
Other Physics Program

- Compelling Physics program at NA62

<table>
<thead>
<tr>
<th>Decay</th>
<th>Physics</th>
<th>Present limit (90% C.L.) / Result</th>
<th>NA62</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\mu^+e^-$</td>
<td>LFV</td>
<td>$1.3 \times 10^{-11}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\mu^-e^+$</td>
<td>LFV</td>
<td>$5.2 \times 10^{-10}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-\mu^+e^+$</td>
<td>LNV</td>
<td>$5.0 \times 10^{-10}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-\mu^-e^+$</td>
<td>LNV</td>
<td>$6.4 \times 10^{-10}$</td>
<td>$2 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-\mu^+\mu^+$</td>
<td>LNV</td>
<td>$1.1 \times 10^{-9}$</td>
<td>$0.4 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\mu^-\nu^+e^+$</td>
<td>LNV/LFV</td>
<td>$2.0 \times 10^{-8}$</td>
<td>$4 \times 10^{-12}$</td>
</tr>
<tr>
<td>$e^-\nu\mu^+\mu^+$</td>
<td>LNV</td>
<td>No data</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+X^0$</td>
<td>New Particle</td>
<td>$5.9 \times 10^{-11}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\chi\chi$</td>
<td>New Particle</td>
<td>$-$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\pi^+e^-\nu$</td>
<td>$\Delta S \neq \Delta Q$</td>
<td>$1.2 \times 10^{-8}$</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>$\pi^+\pi^+\mu^-\nu$</td>
<td>$\Delta S \neq \Delta Q$</td>
<td>$3.0 \times 10^{-6}$</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>$\pi^+\gamma$</td>
<td>Angular Mom.</td>
<td>$2.3 \times 10^{-9}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\mu^+\nu_h,\nu_h \rightarrow \nu\gamma$</td>
<td>Heavy neutrino</td>
<td>Limits up to $m_{\nu_h} = 350$ $MeV$</td>
<td>$&gt;&gt;2$ better</td>
</tr>
<tr>
<td>$R_K$</td>
<td>LU</td>
<td>$(2.488 \pm 0.010) \times 10^{-5}$</td>
<td>$&gt;&gt;2$ better</td>
</tr>
<tr>
<td>$\pi^+\gamma\gamma$</td>
<td>$\chi$PT</td>
<td>$&lt; 500$ events</td>
<td>$10^5$ events</td>
</tr>
<tr>
<td>$\pi^0\pi^0e^+\nu$</td>
<td>$\chi$PT</td>
<td>$66000$ events</td>
<td>$O(10^6)$</td>
</tr>
<tr>
<td>$\pi^0\pi^0\mu^+\nu$</td>
<td>$\chi$PT</td>
<td>$-$</td>
<td>$O(10^5)$</td>
</tr>
</tbody>
</table>
Other Physics Program

- Compelling Physics program at NA62

- Search for heavy neutrinos in $K^+ \rightarrow e^+ \nu_h$ and $K^+ \rightarrow \mu^+ \nu_h$ decays

- Sensitive for mass region $100 - 380$ MeV/c$^2$

- Background in the mass search region $\sim 5$ order of magnitude below the $K^+ \rightarrow l^+ \nu_{SM}$ peak
Conclusion

• Preliminary world best measurement of $\pi^0$ Transition Form Factor (TFF) slope performed using NA62 2007 data

\[ a = (3.70 \pm 0.53_{stat} \pm 0.36_{syst}) \times 10^{-2} \]

• Commissioning of the NA62 experiment for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is over

• Preliminary study of the data at low intensity:
  • Physics sensitivity for the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ measurement is close to the design
  • Analysis of higher intensity data is on going
  • A further interesting physics program is going to be addressed

• Data taking will resume on the April 25th with around 200 days of run in 2016
Backup Slides
<table>
<thead>
<tr>
<th>Year Range</th>
<th>Collaboration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'86 - '89</td>
<td>NA31</td>
<td>Hint of direct CP violation in Neutral Kaon decays</td>
</tr>
<tr>
<td>'97 - '01</td>
<td>NA48</td>
<td>$\epsilon'/\epsilon$: Proof of direct CP violation</td>
</tr>
<tr>
<td>'02</td>
<td>NA48/1</td>
<td>$K_s$ rare decays</td>
</tr>
<tr>
<td>'03 - '04</td>
<td>NA48/2</td>
<td>CP violation in Charge Kaons decays</td>
</tr>
<tr>
<td>'07 - '08</td>
<td>NA62 (NA48/3)</td>
<td>Lepton Universality ($R_k$)</td>
</tr>
<tr>
<td>'14 - '18</td>
<td>NA62</td>
<td>$K^+ \rightarrow \pi^+\nu\bar{\nu}$ decay</td>
</tr>
</tbody>
</table>
NA62 2007 Data Taking

Simultaneous $K^{\pm}$ beams

$74 \pm 2$ GeV/c
NA62 Detector

Kaon Tagging - CEDAR
45 MHz rate
time: 100 ps

Kaon Tracking - GTK
time: \(\approx 200\) ps
momentum: \(dp/p < 0.4\%\)
direction : \(\approx 0.016\) mrad

Guard Ring - CHANTI
To detect beam interaction within the last GTK station
NA62 Detector

Pion Tracking - STRAW
momentum: dp/p < 0.33%
direction: ≈10 mrad
extracted vertex: ≈1mm

Pion ID - RICH
π/μ separation: 10^2
time: <100 ps

Pion Timing - CHOD
time: <300ps
Charged Trigger
NA62 Detector

Photon Veto
Hermetic coverage
Large Angle: LAV
Intermediate Angle: LKr
Small Angle: IRC, SAC

Muon veto
Muon rejection $10^5$
Calorimeters: LKr, HAC
Trigger for hadronic showers
Fast Veto: MUV
Status of the Experiment

• Commissioning runs in 2014 and 2015

• Beam commissioned up to nominal intensity

• Beam Detectors:
  • Cedar (K ID) and CHANTI (guard ring) fully commissioned
  • GTK (tracker) partially commissioned (full detector in 2016)

• Downstream detectors:
  • Fully commissioned

• Trigger:
  • L0 fully commissioned
  • L1, L2 partially commissioned

• Analysis:
  • Low intensity data taken with minimum bias trigger for detector performance studies
  • Up to full intensity data taken with calorimetric trigger, work on going
2015 Data Quality: Kinematics

✓ Combine information from GTK and STRAW trackers

✓ Need $O(10^4 \div 10^5)$ suppression for main kaon decay modes

✓ Kinematics studied with $K^+ \rightarrow \pi^+\pi^0$ sample selected using the LKr calorimeter

✓ Resolutions close to design

✓ $O(10^3)$ kinematic suppression factor in 2015
2015 Data Quality: Kinematics

✓ Combine information from GTK and STRAW trackers

✓ Need $O(10^4 \div 10^5)$ suppression for main kaon decay modes

✓ Kinematics studied with $K^+ \rightarrow \pi^+\pi^0$ sample selected using the LKr calorimeter

✓ Resolutions close to design

✓ Best $K^+ \rightarrow \mu^+\nu$ suppression for $P_{\pi} < 35$ GeV/c

✓ $O(10^3)$ kinematic suppression factor in 2015