The NA62 Experiment
Search for Heavy Neutral Leptons
Search for a Dark Photon
Search for Axion Like Particles
The NA62 Experiment

200 participants from 30 institutes
Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, GMU-Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC
Firstly Dedicated to $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- Precise **SM prediction**: $(8.4 \pm 1.0) \times 10^{-11}$ [Buras JHEP11 (2015)033]
- Extraordinary sensitivity to **physics beyond SM**
- Results from **E787-E949**: $(17.3^{+11.5}_{-10.5}) \times 10^{-11}$ [PRD79, 092004 (2009)]
- NA62 Aim: **10% precision** measurement
- **NA62 First Results** at Moriond EW 2018 (R. Marchevski)

**Experimental Challenge**

- With 10% Sig Acceptance: $10^{13}$ $K^+$ decays, $\mathcal{O}(10^{12})$ Bkg rejection
The Detector and Beam Line

Beam

- 400 GeV/c SPS protons, $10^{12}$ POT/sec on spill
- 3.5 s spill, 750 MHz of secondary particles (not bunched)
- 75 GeV/c with $\delta p/p = 1\%$
- Composition: $p$ / $\pi^+$ / $K^+$ = 70 / 24 / 6%
The Detector and Beam Line

Beam Instrumentation

- **Kaon Tagging** (KTAG, Differential Cerenkov $N_2$ or $H_2$)
- **Kinematics** (GigaTracker GTK Silicon hybrid pixels)
- Beam particle **scattering detection** (Guard Ring CHANTI)
- **Arrival time** measurement (100 ps resolution)
Fiducial Region

- 120m tube in vacuum (500 m³ at 10⁻⁶ mbar)
- 10% of $K^+$ decay in the first 60m:

$$5\text{MHz of } K^+ \text{ decay, } 4.5 \times 10^{12}/\text{year}$$
Decay Products Instrumentation

- **Kinematics** (STRAW Spectrometer, in vacuum)
- **Photon Detection** (LAV, IRC, LKr, SAC)
- **π** and **μ** **identification** (RICH, Hadronic Calo MUV’s)
- Arrival **time** measurement (all + CHOD for charged particles),
Decay Products Instrumentation

- **Kinematics** (STRAW Spectrometer, in vacuum)
- **Photon Detection** (LAV, IRC, LKr, SAC)
- $\pi$ and $\mu$ **identification** (RICH, Hadronic Calo MUV’s)
- Arrive **time** measurement (all + CHOD for charged particles),
The NA62 Experiment

Data Taking

Time Line

- **2015** Commissioning, 1% nominal intensity, no GTK
- **2016** Commissioning, **Physics** (30 days), 35-40% nom. intensity
- **2017** **Physics** (160 days), 65% nom. intensity
- **2018** **Physics** (217 days expected), on going

**Dumping 400 GeV/c Beam on 11 \( \lambda_t \) Cu (TAX)**

- \( 10^{18} \) POT / nominal year
- \( (5.5+9.0) \times 10^{15} \) POT collected in few hours in 2016 and 2017
Search for Heavy Neutral Leptons

Outline

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Heavy Neutral Lepton

Neutrino Minimal Standard Model $\nu MSM$

- SM with 3 right-handed heavy neutral leptons
- $N_1$ with a mass of $\mathcal{O}(10\text{keV})$, Dark Matter candidate
- $N_{2,3}$ with masses of $\mathcal{O}(1\text{GeV})$, responsible for baryon asymmetry and $\nu$ masses

Experimental Search

- Production in decays $K^+ \rightarrow \ell^+ N$:
  \[ \Gamma(K^+ \rightarrow \ell^+ N) = \Gamma(K^+ \rightarrow \ell^+ \nu) \times \rho(m_N) \times |U_{\ell 4}| \]
  with $\rho$ a kinematics factor.
- Search for missing mass peaks:
  \[ m_{\text{miss}}^2 = |p_K - p_{\ell}|^2 \]
- Normalisation to $K^+ \rightarrow \ell^+ \nu$
Search for Heavy Neutral Leptons


- **2015 Dataset** 1% nominal beam intensity, no beam tracker
  \[ N_K = (3.01 \pm 0.11) \times 10^8 \text{ for positron channel} \]
  \[ N_K = (1.06 \pm 0.12) \times 10^8 \text{ for muon channel} \]

- **Peaks searched opening mass windows** \[ |m - m_N| \leq 1.5 \sigma_m \]
- **Acceptances and mass resolutions** derived from simulations

**HNL search region**

![Graph showing search region for HNL with mass windows and acceptances](image)
Search for Heavy Neutral Leptons


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  \[ N_K = (1.06 \pm 0.12) \times 10^8 \] for muon channel
  
- Peaks searched opening mass windows \( |m - m_N| \leq 1.5\sigma_m \)
  
- Acceptances and mass resolutions derived from simulations

![Graph showing mass resolution and acceptance vs. HNL mass for different selections](image)

Improved limits on:

- $|U_{e4}|^2$ over 170-488 MeV/c$^2$
- $|U_{\mu4}|^2$ over 300-373 MeV/c$^2$

Prospects

- **2016-2018 Dataset:**
  - 1000 times more $K^+ \rightarrow e^+ \nu$
  - 100 times more $K^+ \rightarrow \mu^+ \nu$

- **Beam Tracker:**
  - better mass resolution, lower background

- **Sensitivity** to $U_{\ell4}$:
  - better than $\mathcal{O}(10^{-8})$
Prospects for HNL search in Beam Dump Mode

- Search for HNL produced in **TAX** and decaying to $\pi$, $\mu$, $e$
- Assuming $10^{18}$ POT (1 year)
- **Two charged tracks** forming a displaced vertex
- Assuming **no background**
- Three scenarios addressed [Shaposhnikov, Gorbunov arXiv:0705.1729v2]
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Dark Photon

SM extension

- SM + extra U(1) gauge symmetry
  - Associated boson $A' = \text{Dark Photon}$
- Interaction via kinetic-mixing with SM EM field
- Free parameters: coupling $\epsilon$ and mass $m_{A'}$

Experimental Searches Possible at NA62

NA62 Standard Operation

- $A'$ from meson decays, decaying to invisible:
  - $K^+ \rightarrow \pi^+ A' \text{ then } A' \rightarrow \text{invisible}$
  - $K^+ \rightarrow \pi^+ \pi^0 \text{ then } \pi^0 \rightarrow A' \gamma \text{ then } A' \rightarrow \text{invisible}$

Dumping Beam on Collimator

- $A'$ from beam primaries or secondary decaying to SM particles:
  - $pN \rightarrow X A' \text{ then } A' \rightarrow \ell^+ \ell^-$
  - $pN \rightarrow X \pi^0 \text{ then } \pi^0 \rightarrow A' \gamma \text{ then } A' \rightarrow \ell^+ \ell^-$
Preliminary Results using $\pi^0$

- Using $K^+\rightarrow\pi^+\pi^0$ then $\pi^0\rightarrow A'\gamma$ then $A'\rightarrow$invisible
- **Dataset:** 4% of 2016 Run: $\sim 1.5 \times 10^{10} K^+$
- Search for peaks in $m_{miss}^2 = |p_{K^+} - p_{\pi^+} - \gamma|^2$
- **Main Background:** $\pi^0\rightarrow\gamma\gamma$ with a lost $\gamma$
  Estimated from the negative $m_{miss}^2$ tail
- **Normalisation** to $K^+\rightarrow\pi^+\pi^0$
- Analysis of the full 2016 dataset on going

**Control Trigger**

$\pi^0\rightarrow\gamma\gamma$ emulating a lost $\gamma$

**MC**

$m_{A'} = 60$ MeV
$m_{A'} = 90$ MeV
$m_{A'} = 120$ MeV

**NA62 Preliminary**

$K\rightarrow\pi\nu\nu$

$\epsilon$

$10^{-2}$

$10^{-3}$

$10^{-4}$

$m_{A'}(\text{GeV})$
Prospects for DP searches in Two Charged Tracks

- Assuming $10^{18}$ 400 GeV/c POT on Be target
- Two charged tracks forming a displaced vertex
- Assuming no background
- Even more sensitive dumping on TAX and including QCD prod
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Axion Like Particles: Prospects at NA62

Experimental Search

- Production via **Primakoff effect** [JHEP 1602 (2016) 018]
- Search for $a \rightarrow \gamma \gamma$
- Prospects assuming no background

- Analysis of 2017 Data ($10^{15}$ POT) on going
Summary

NA62

- NA62 offers several opportunities to search for DM
- Large data sample to be analysed
- More data being collected now

DM Searches Results and Prospects

- Improved limits on DP coupling $\epsilon^2$ using $K^+ \rightarrow \pi^+ A'$ [preliminary]
- Soon results on ALPs searches, stay tuned!

Thank you for your attention