

# Exotics at NA62

The 14th International Workshop **Dark Side Of the Universe**  
Annecy

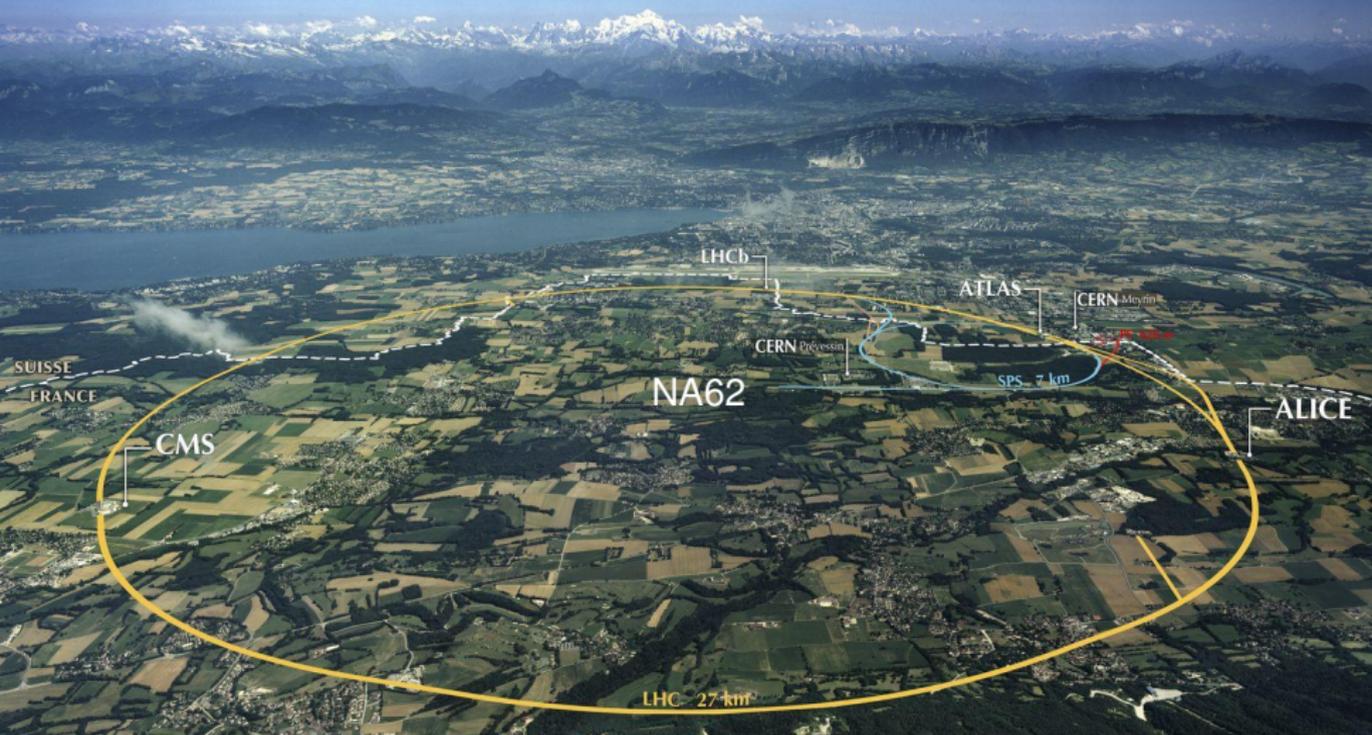
Mathieu PERRIN-TERRIN

Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France  
Université Catholique de Louvain, Belgique.

Tuesday June 26

- ▶ **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

# The NA62 Experiment



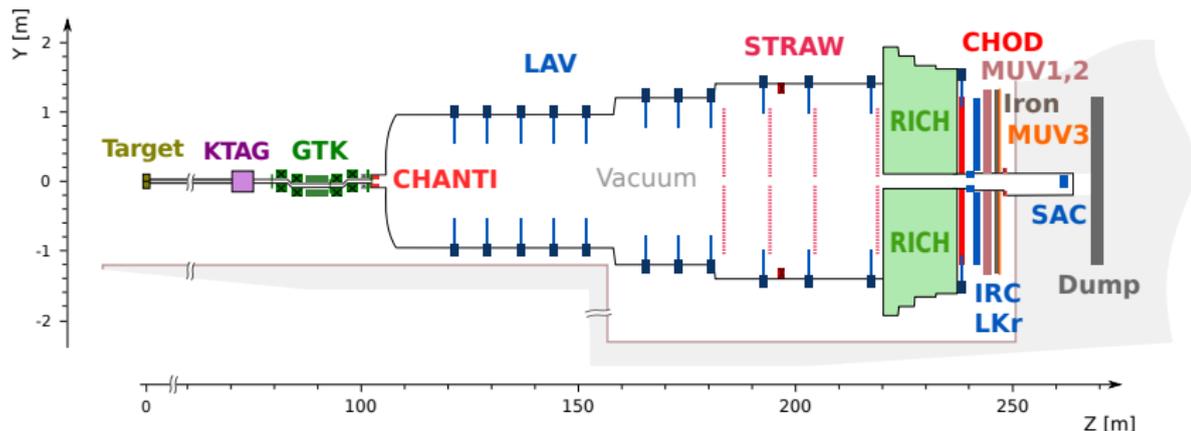
## Firstly Dedicated to $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- ▶ 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 [2017 JINST 12 P05025]

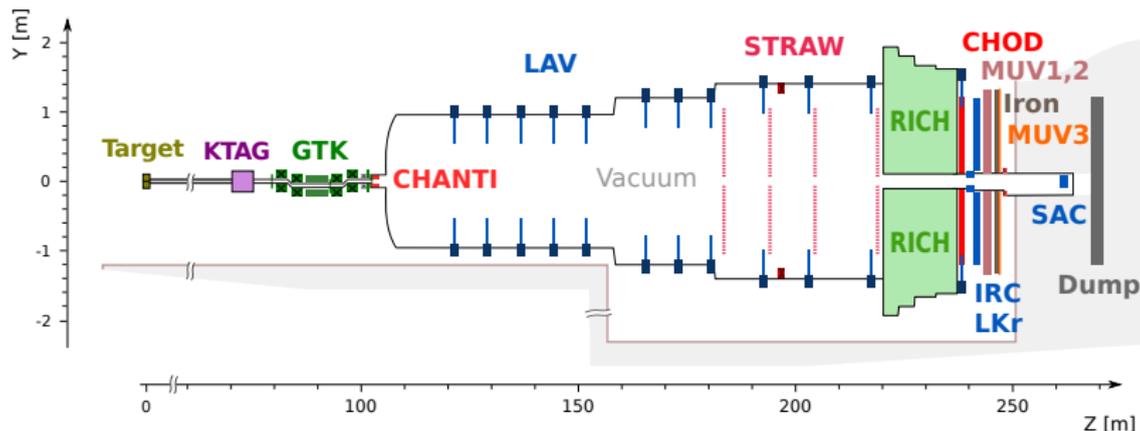


## Beam

- ▶ 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%

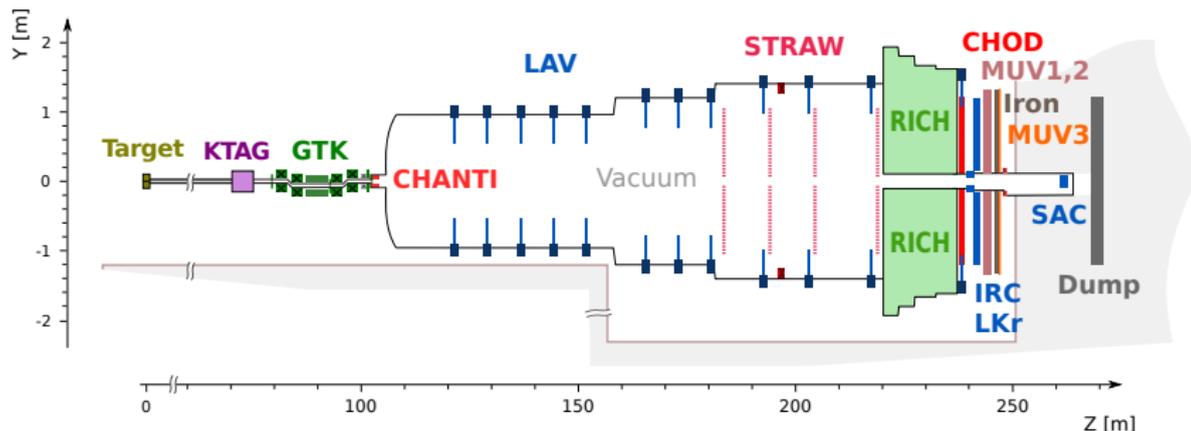
# The Detector and Beam Line [2017 JINST 12 P05025]



## Beam Instrumentation

- ▶ **Kaon Tagging** (KTAG, Differential Cerenkov N<sub>2</sub> or H<sub>2</sub>)
- ▶ **Kinematics** (GigaTracker GTK Silicon hybrid pixels)
- ▶ Beam particle **scattering detection** (Guard Ring CHANTI)
- ▶ **Arrival time** measurement (100 ps resolution)

# The Detector and Beam Line [2017 JINST 12 P05025]

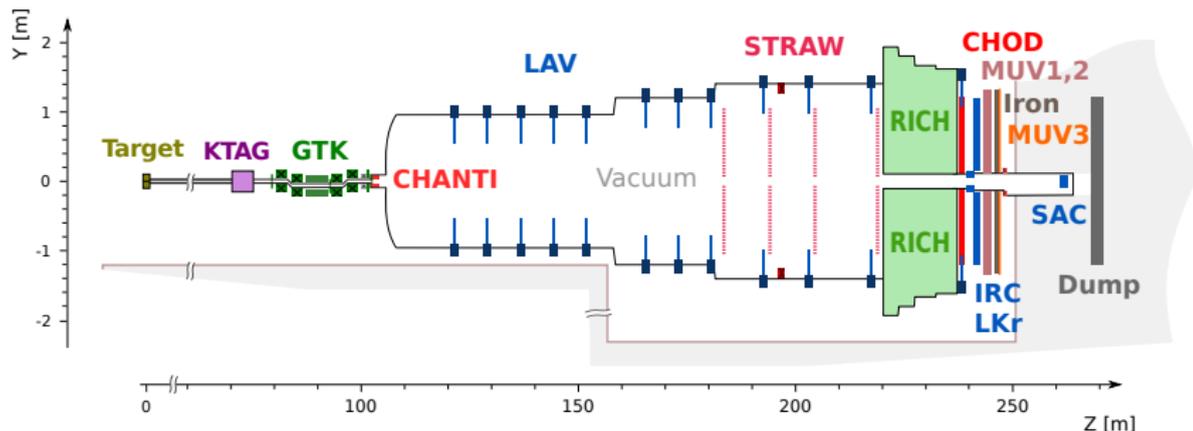


## Fiducial Region

- ▶ 120m tube in **vacuum** ( $500 \text{ m}^3$  at  $10^{-6} \text{ mbar}$ )
- ▶ **10% of  $K^+$  decay** in the first 60m:

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

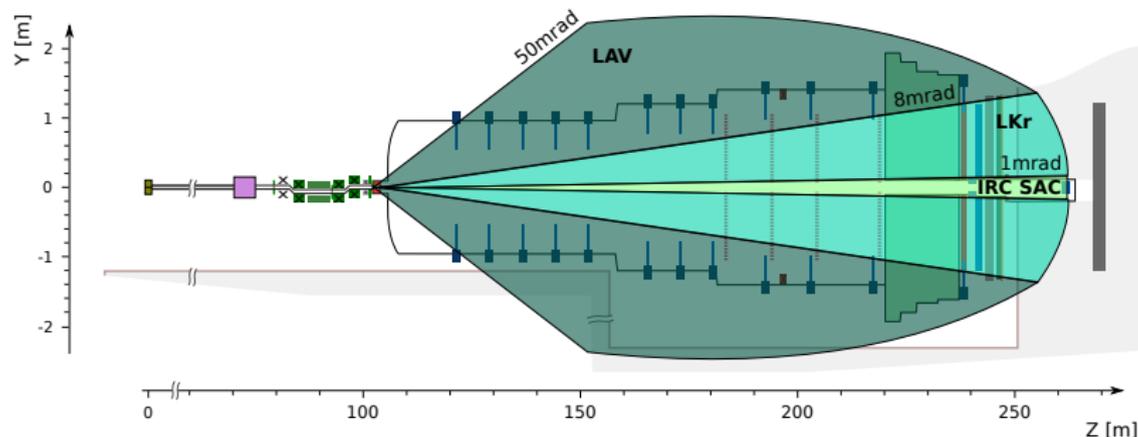
# The Detector and Beam Line [2017 JINST 12 P05025]



## Decay Products Instrumentation

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

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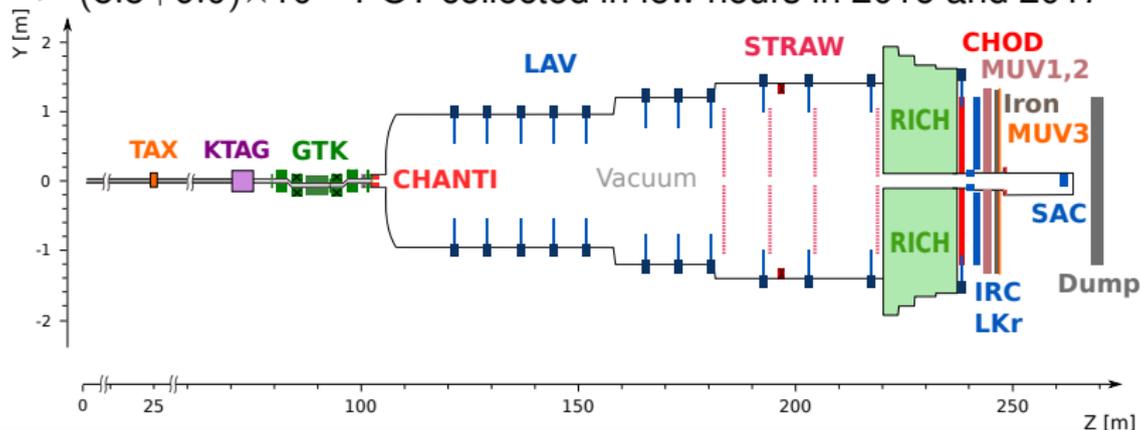
# Data Taking

## 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 $\lambda_1$ Cu (TAX)

- ▶  $10^{18}$  POT / nominal year
- ▶  $(5.5+9.0) \times 10^{15}$  POT collected in few hours in 2016 and 2017



# Outline

- 1 The NA62 Experiment
- 2 Search for Heavy Neutral Leptons**
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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  $K^+ \rightarrow \ell^+ N$ :

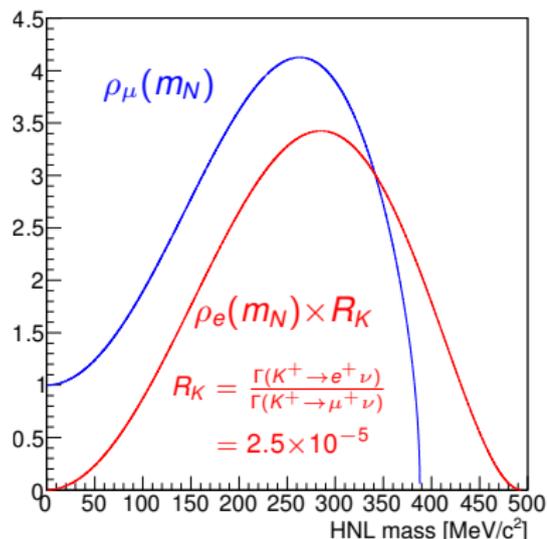
$$\Gamma(K^+ \rightarrow \ell^+ N) = \Gamma(K^+ \rightarrow \ell^+ \nu) \times \rho(m_N) \times |U_{\ell 4}|^2$$

with  $\rho$  a kinematics factor.

- ▶ Search for **missing mass peaks**:

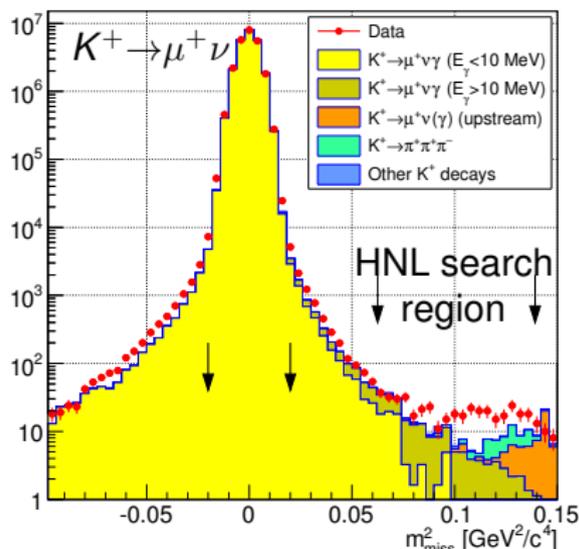
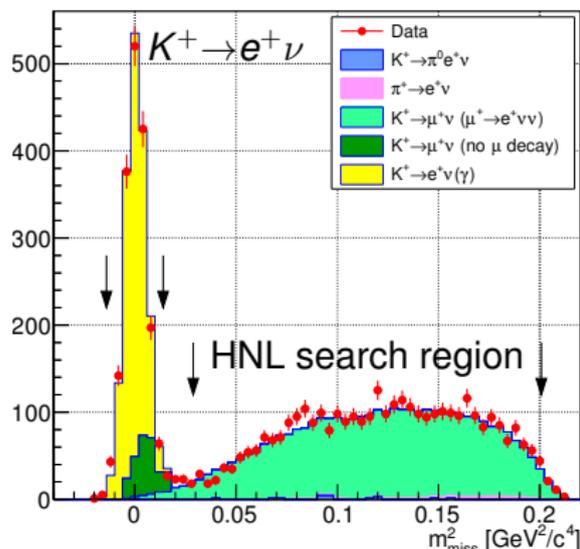
$$m_{\text{miss}}^2 = |p_K - p_\ell|^2$$

- ▶ **Normalisation** to  $K^+ \rightarrow \ell^+ \nu$



# Search for HNL at NA62 [Phys.Lett.B778 (2018) 137]

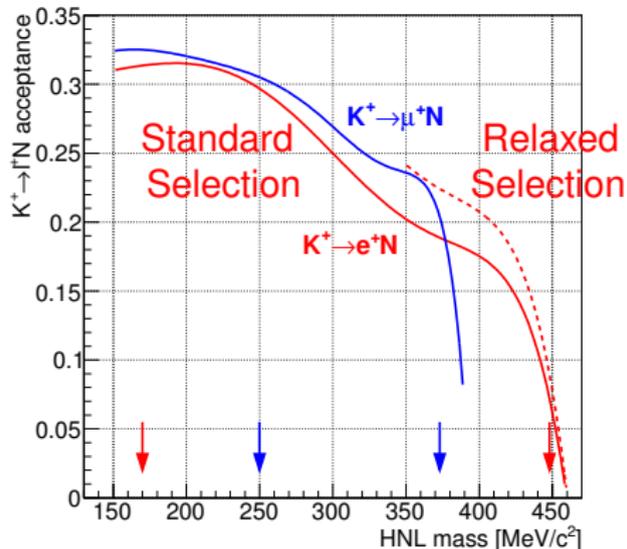
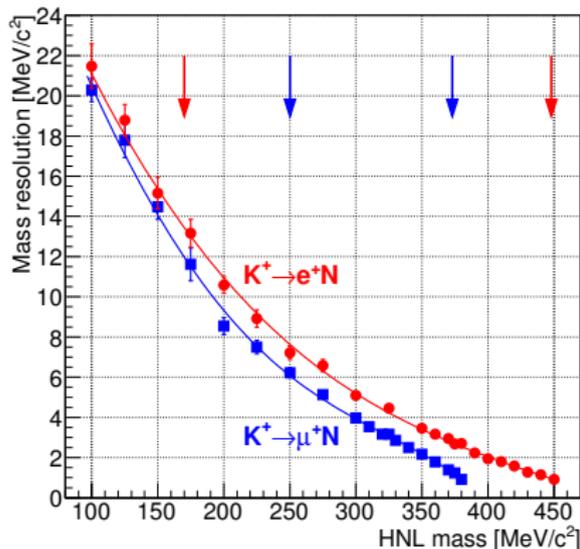
- ▶ **2015 Dataset** 1% nominal beam intensity, no beam tracker  
 $N_K = (3.01 \pm 0.11) \times 10^8$  for positron channel  
 $N_K = (1.06 \pm 0.12) \times 10^8$  for muon channel



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

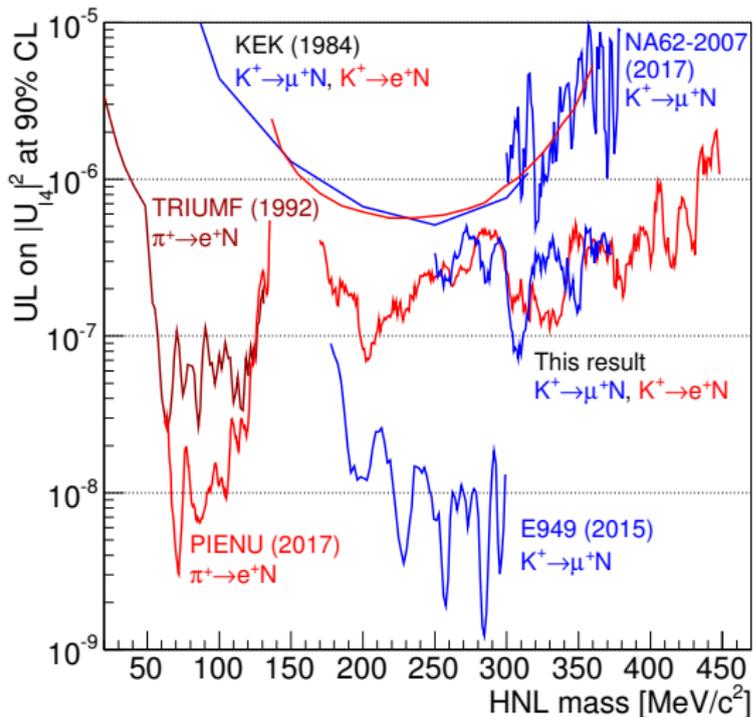
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# HNL Searches Results [Phys.Lett.B778 (2018) 137]



## Improved limits on:

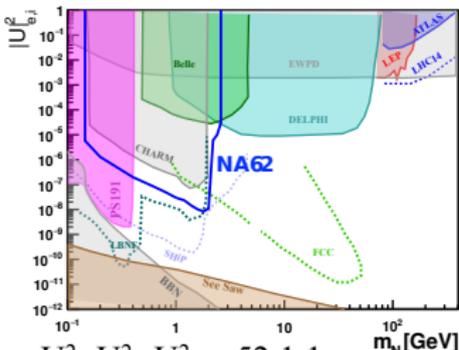
- ▶  $|U_{e4}|^2$  over 170-488 MeV/c<sup>2</sup>
- ▶  $|U_{\mu4}|^2$  over 300-373 MeV/c<sup>2</sup>

## Prospects

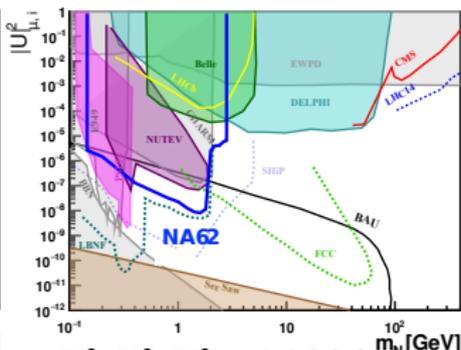
- ▶ **2016-2018 Dataset:**  
1000 times more  $K^+ \rightarrow e^+ \nu$   
100 times more  $K^+ \rightarrow \mu^+ \nu$
- ▶ **Beam Tracker:**  
better mass resolution,  
lower background
- ▶ **Sensitivity to  $U_{l4}$ :**  
better than  $\mathcal{O}(10^{-8})$

# Prospects for HNL search in Beam Dump Mode

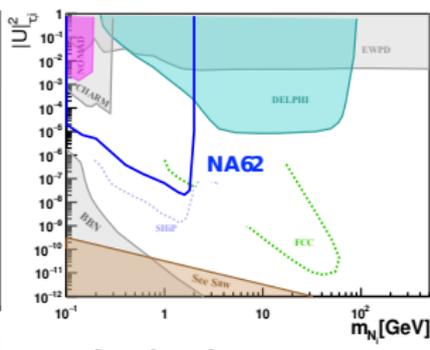
- ▶ Search for HNL produced in **TAX** and decaying to  $\pi, \mu, e$
- ▶ Assuming  $10^{18}$  POT (1 year)
- ▶ **Two charged tracks** forming a displaced vertex
- ▶ Assuming **no background**
- ▶ Three scenarios addressed [Shaposhnikov, Gorbunov arXiv:0705.1729v2]



$U_e^2 : U_\mu^2 : U_\tau^2 = 52:1:1$   
Normal hierarchy of active  $\nu$  masses



$U_e^2 : U_\mu^2 : U_\tau^2 = 1:16:3.8$   
Normal hierarchy of active  $\nu$  masses



$U_e^2 : U_\mu^2 : U_\tau^2 = 0.061:1:4.3$   
Normal hierarchy of active  $\nu$  masses

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# Dark Photon

## SM extension

- ▶ SM + extra U(1) gauge symmetry  
Associated boson  $A' =$  **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

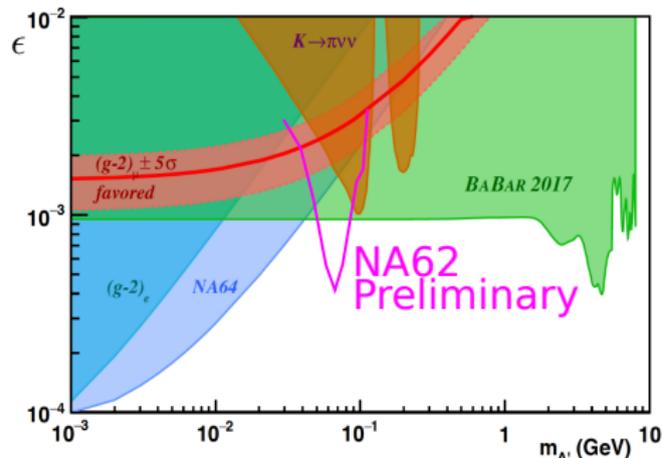
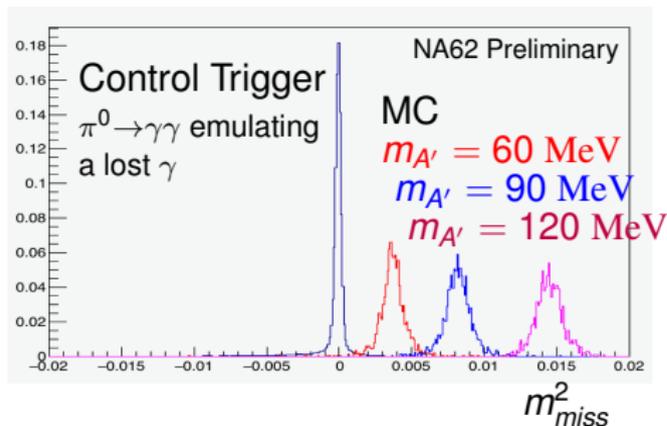
- ▶  $A'$  from meson decays, decaying to invisible:  
 $K^+ \rightarrow \pi^+ A'$  then  $A' \rightarrow$ invisible  
 $K^+ \rightarrow \pi^+ \pi^0$  then  $\pi^0 \rightarrow A' \gamma$  then  $A' \rightarrow$ invisible

### Dumping Beam on Collimator

- ▶  $A'$  from beam primaries or secondary decaying to SM particles:  
 $pN \rightarrow X A'$  then  $A' \rightarrow \ell^+ \ell^-$   
 $pN \rightarrow X \pi^0$  then  $\pi^0 \rightarrow A' \gamma$  then  $A' \rightarrow \ell^+ \ell^-$

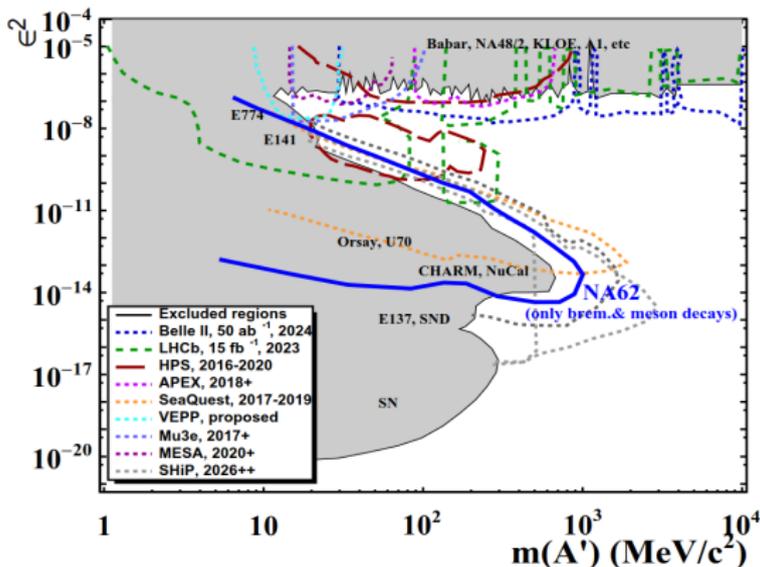
# Preliminary Results using $\pi^0$

- ▶ 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  $m_{miss}^2 = |\mathbf{p}_{K^+} - \mathbf{p}_{\pi^+} - \mathbf{p}_{\gamma}|^2$
- ▶ **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**



# 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



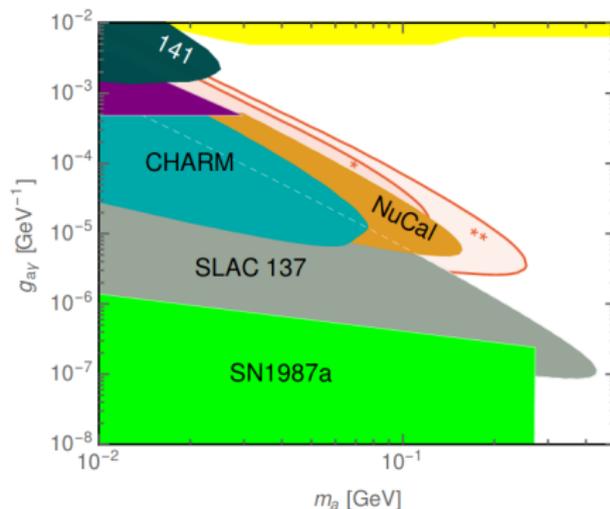
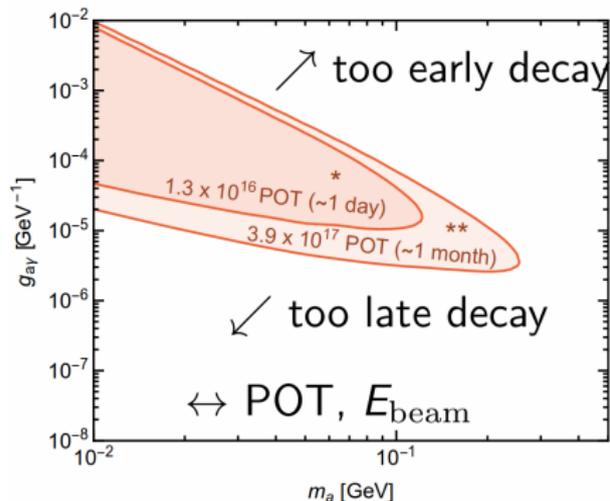
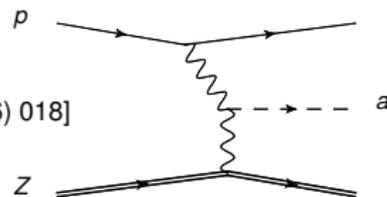
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# Axion Like Particles: Prospects at NA62

## 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

- ▶ **HNL** search using  $K^+ \rightarrow \ell^+ N$  published [Phys.Lett.B778 (2018) 137]
- ▶ 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

# Extra Slides