Search for $K^+ \to \pi^+ \nu\bar{\nu}$ and future searches for exotic processes at NA62

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PARTICLES AND NUCLEI INTERNATIONAL CONFERENCE 2017

Outline

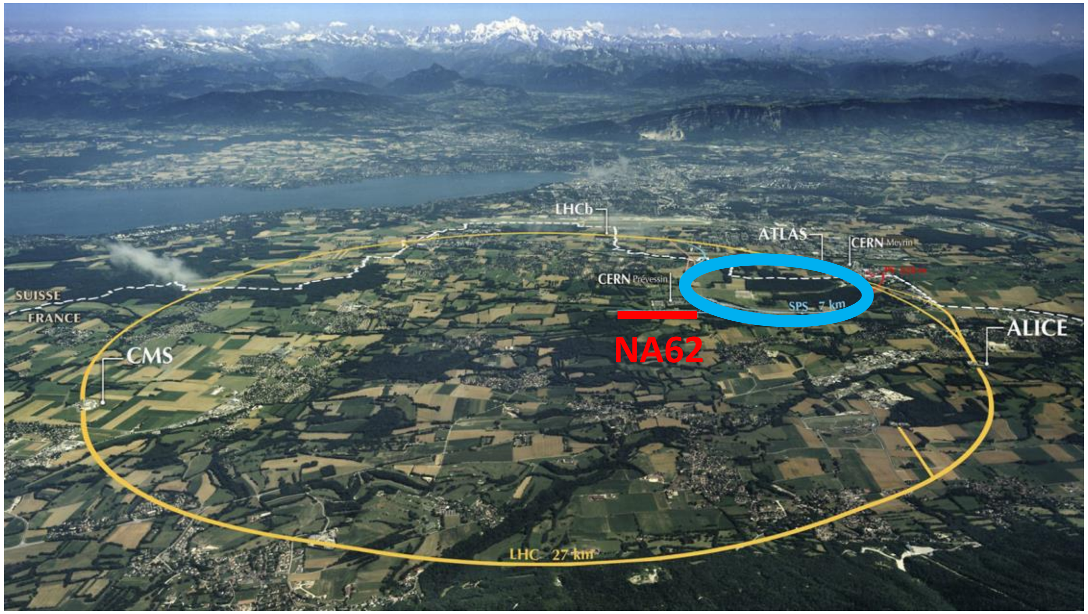
- Introduction: the NA62 experiment at CERN
- $\pi\nu\nu$ search
  - Experimental strategy
  - Data selection
  - First results

- Exotic searches
  - Invisible vector bosons
  - Axion-like particles

  X Heavy neutrinos (L. Bician’s talk)

The NA62 experiment

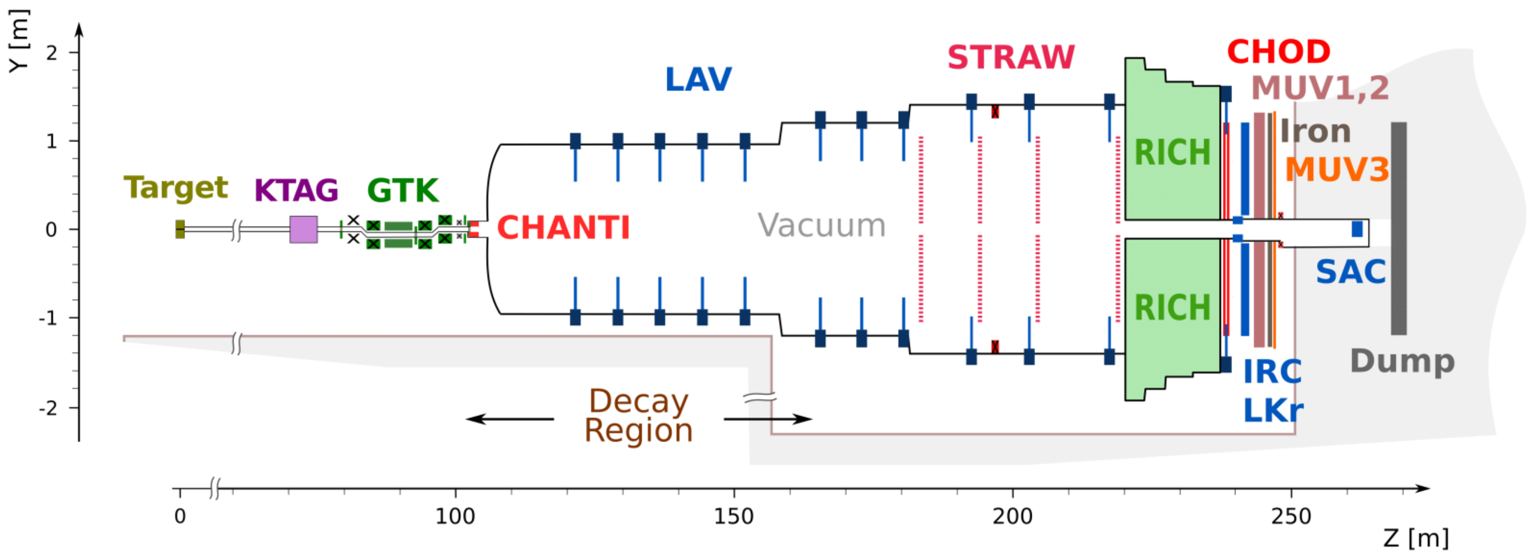
- Fixed target experiment
- Kaon decays in flight
- **Main goal:** measurement of BR($K^+ \to \pi^+ \nu\bar{\nu}$) at 10% precision level



Primary beam of protons from SPS (400 GeV)

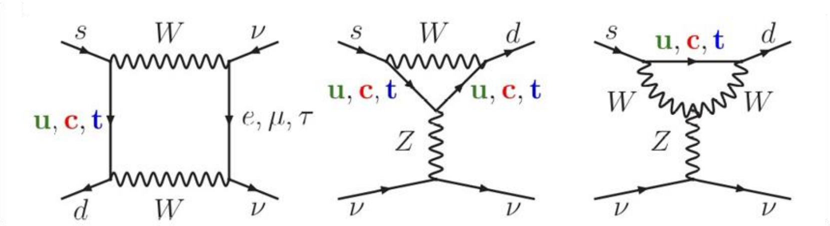
Secondary beam (75 GeV, 800 MHz)
- Pions (70%)
- Protons (23%)
- Kaons (6%)
- Muons (0.7%)

NA62 Schematic layout



Theoretical motivation for $K^+ \to \pi^+ \nu\bar{\nu}$ search

$K^+ \to \pi^+ \nu\bar{\nu}$ is a FCNC process, very suppressed by CKM



Short distance contributions, dominated by t loop

Theoretical prediction [Buras et al. , JHEP 1511 (2015)]:

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

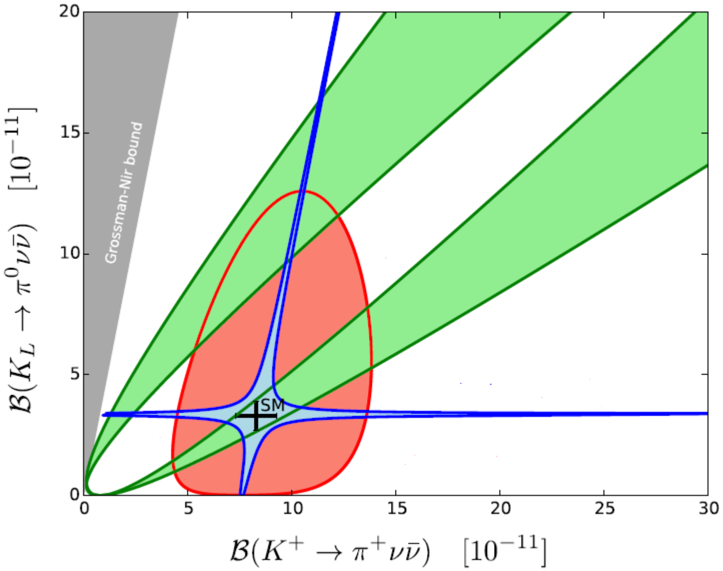
Measured value [Phys. Rev. D 79, 092004 (2009)]:

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11}$$

Theoretical motivation for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ search

$K \rightarrow \pi\nu\bar{\nu}$ decays are very sensitive to New Physics (NP) beyond Standard Model

The correlation between these branching ratios is predicted by different models like:



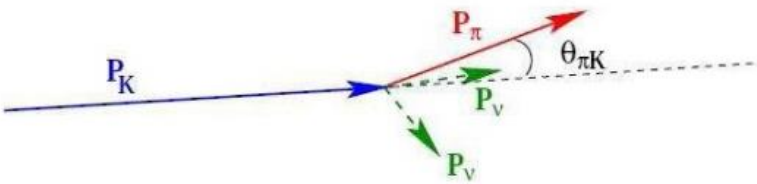
- Randall-Sundrum
- Littlest Higgs with T parity
- Minimum Flavour Violation

$K \rightarrow \pi\nu\bar{\nu}$ decays are very powerful tools to probe NP sector

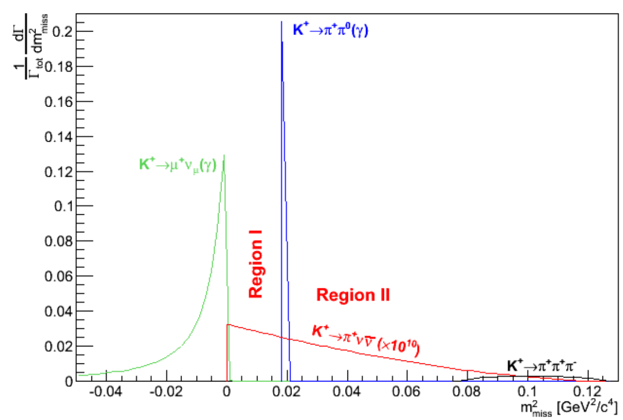
$K^+ \to \pi^+ \nu\bar{\nu}$ search: experimental strategy

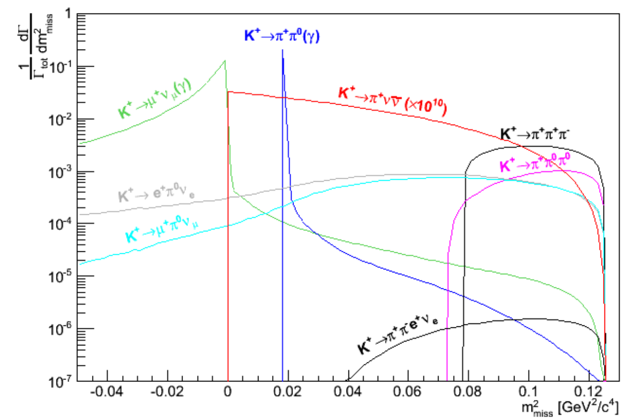
The analysis is based on:

- Kinematic rejection



$$m^2_{miss} = (P_K - P_\pi)^2$$

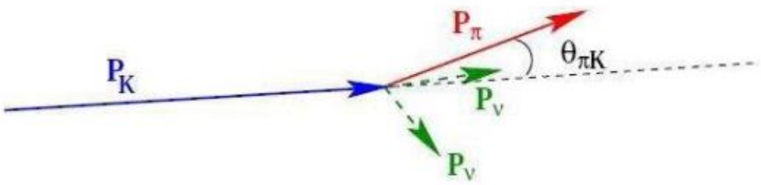




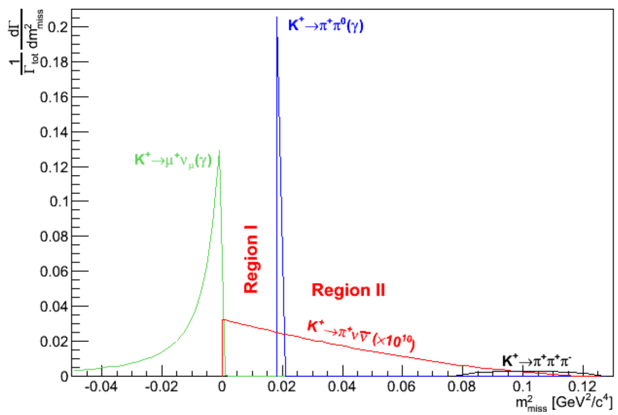
$K^+ \to \pi^+\nu\bar{\nu}$ search: experimental strategy

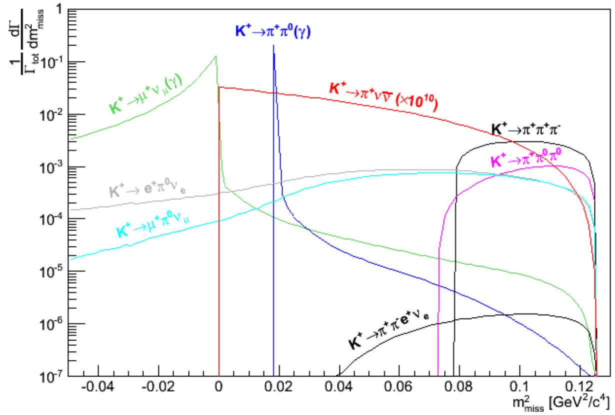
The analysis is based on:

- Kinematic rejection



1. $m^2_{miss} = (P_K - P_\pi)^2$
2. $m^2_{miss}(RICH) = \left(P_K - P_{\pi_{RICH}}\right)^2$
3. $m^2_{miss}(NO\ GTK) = \left(P_{K_{BEAM}} - P_\pi\right)^2$





$K^+ \to \pi^+ \nu\bar{\nu}$ search: experimental strategy

The analysis is based on:

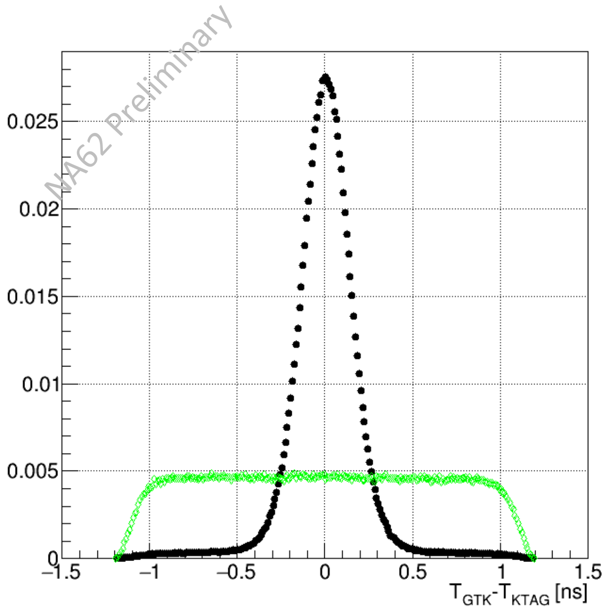
- Kinematic rejection
- Photons and Muons veto

Analysis keystones:

- O(100 ps) timing between sub-detectors
- O(10^4) kinematic background suppression
- $> 10^7$ muon suppression
- $> 10^7$ π^0suppression

The following plots are produced analysing O(5%) of 2016 statistics (~2.3 x 10^{10} K^+ decays)

$K^+ \to \pi^+ \nu\bar{\nu}$ search: K-π matching



Kaon track

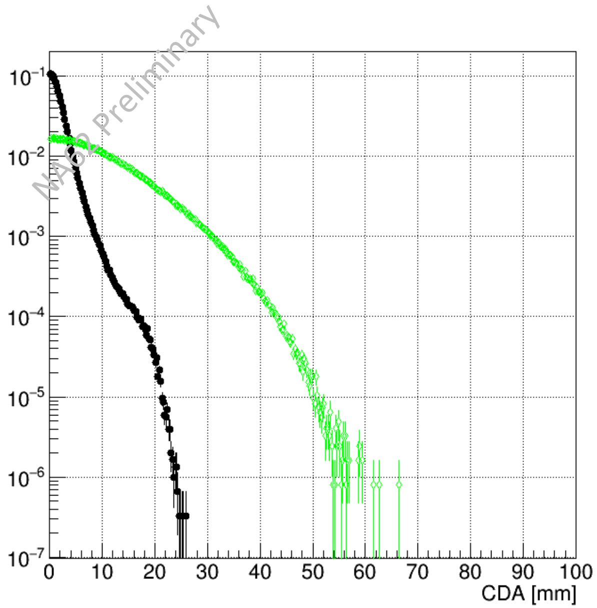
Random beam track

Timing:

π) $\sigma_{t_{CHOD}} = 250\text{ps}$ $\sigma_{t_{RICH}} = 150\text{ps}$

K) $\sigma_{t_{KTAG}} = 80\text{ps}$ $\sigma_{t_{GTK}} = 100\text{ps}$

$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ search: K-π matching

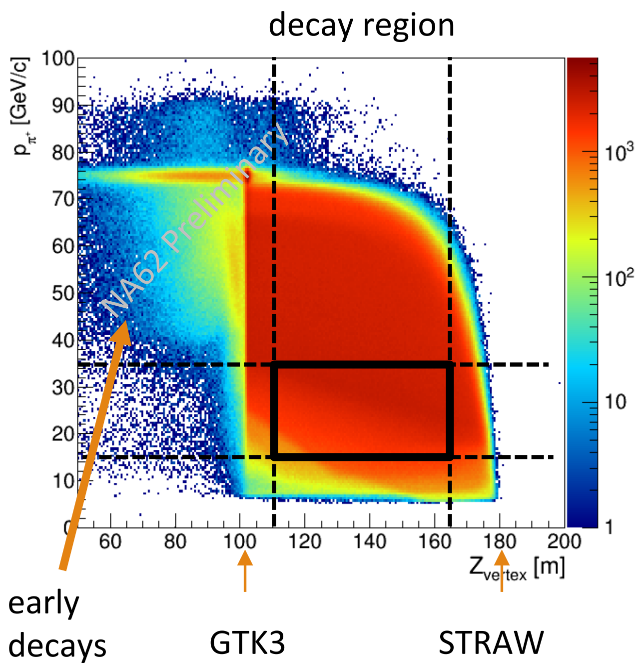


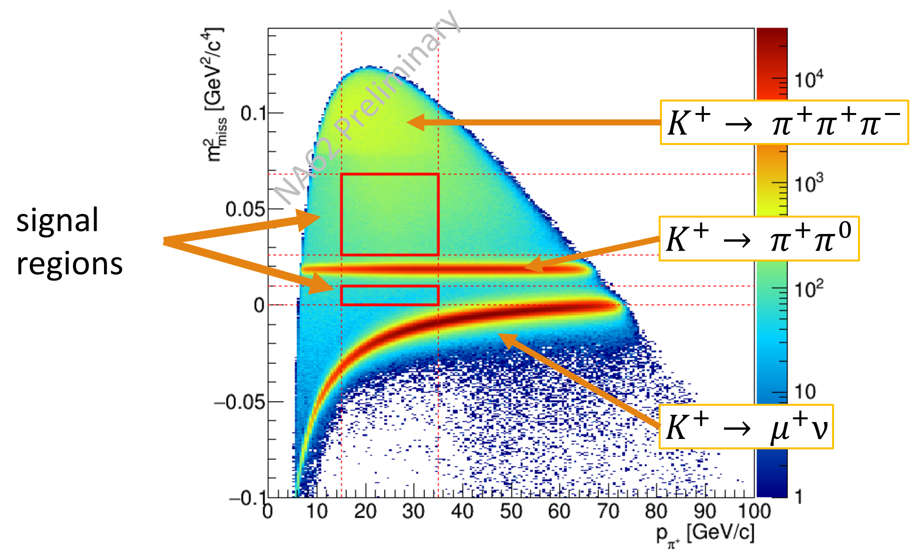
Kaon track
Random beam track

Spatial resolution:
$\sigma_{CDA} = 1.5\text{mm}$

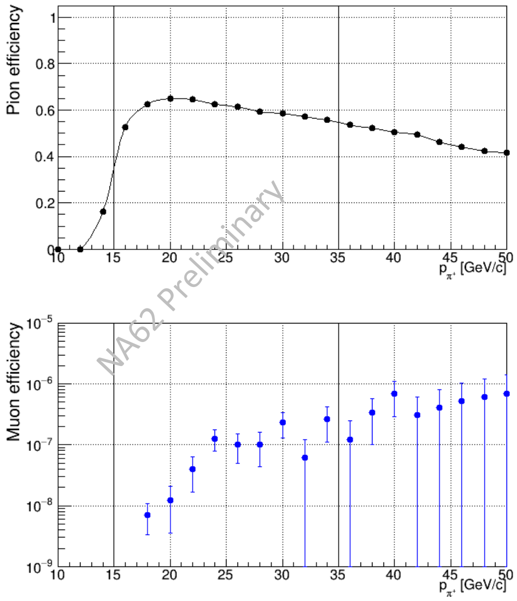
Mis-tagging probability: 1.7%
Efficiency: 75%

$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ search: signal selection



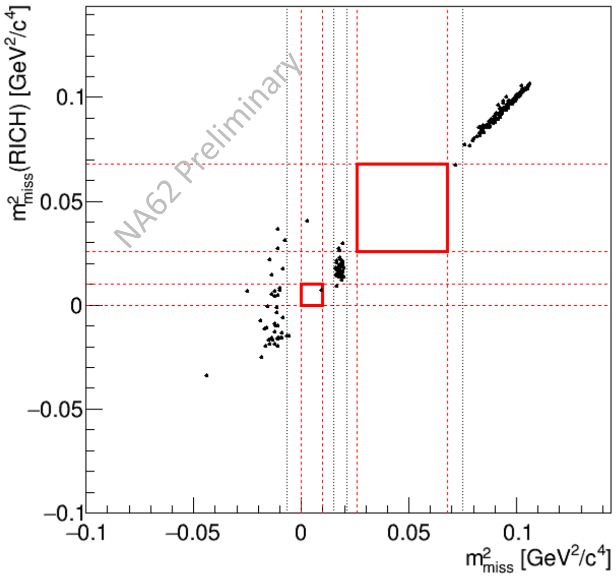


$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ search: particle ID



Particle identification			
Calorimeters		RICH	
ε(π)	ε(μ)	ε(π)	ε(μ)
80%	10^{-5}	80%	10^{-2}

$K^+ \to \pi^+ \nu\bar{\nu}$ search: first results



O(5%) of 2016 statistics
~2.3 x 10^{10} Kaon decays

Expected signal events: 0.064

- Normalization: $K^+ \to \pi^+\pi^0$

Expected backgrounds:

- $K^+ \to \pi^+\pi^0$: 0.024
- $K^+ \to \pi^+\pi^+\pi^-$: 0.017
- $K^+ \to \mu^+\nu$: 0.011
- Beam induced background < 0.005

No events in the three-dimensional signal regions: the remaining event has $m^2_{miss}(NO\ GTK)$ outside the signal region

Analysis optimization is in progress

Exotic searches at NA62

NA62 is particularly suitable for other new physics searches because of its:

- high intensity setup;
- flexible trigger system;
- redundant particle ID;
- very high efficiency photon vetoes.

Exotic searches presented in this talk:

- Invisible vector bosons ("**dark photons**")
- Axion-Like Particles (**ALPs**)

Dark photon

New U(1) gauge symmetry, mediated by a vector boson field A’

A’ couples with the SM photon through a “kinetic mixing” term in the lagrangian:

$$\mathcal{L} = \epsilon A'^{\mu\nu} F_{\mu\nu}$$

This new lagrangian may be accompanied by further interactions, both with SM fields and an hidden sector of dark matter candidates fields.

If these new particles are lighter than A’ it decays “invisibly”, so that missing energy might reveal their presence.

Dark photon search at NA62

NA62 is investigating the decay chain

$$K^+ \rightarrow \pi^+\pi^0 \qquad \pi^0 \rightarrow A'\gamma \qquad A' \rightarrow invisible$$

where:

$$BR(\pi^0 \rightarrow A'\gamma) = 2\epsilon^2\left(1-\frac{m_A^2}{m_{\pi^0}^2}\right)^3 \times BR(\pi^0 \rightarrow \gamma\gamma)$$

Exploiting extreme photon-veto capability and high resolution tracking while sustaining a high-rate environment makes the dark photon analysis synergic with and parasitic to the $K^+ \rightarrow \pi^+\nu\bar{\nu}$ measurement

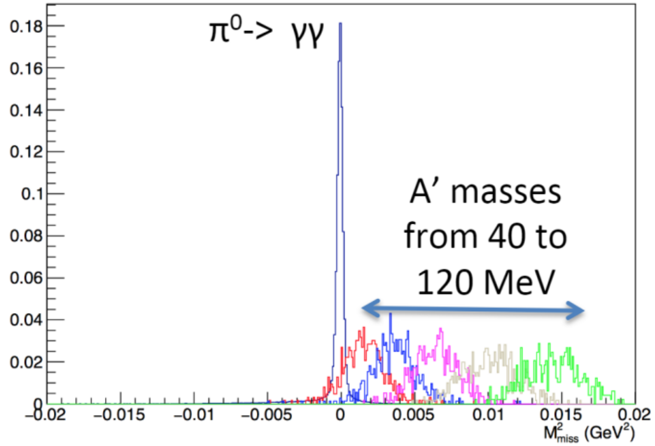
Dark photon search: signal vs background

$$M_{miss}^2 = \left(P_K - P_{\pi^+} - P_\gamma\right)^2$$

The missing mass is expected to have a peak around A' mass and around 0 for SM photon

Dark photon search: signal vs background

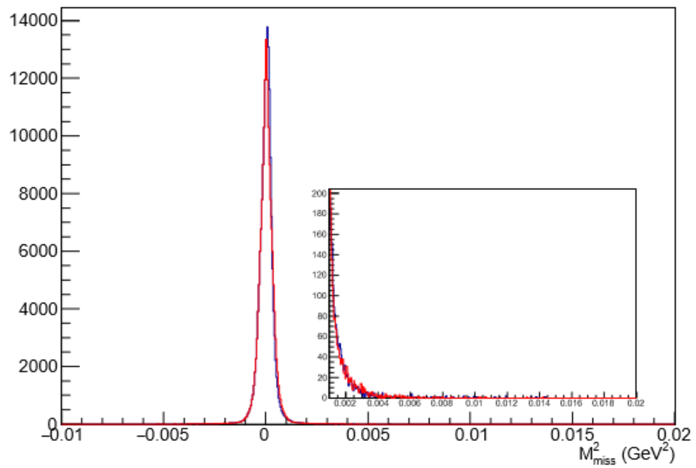
$$M^2_{miss} = \left(P_K - P_{\pi^+} - P_\gamma\right)^2$$



The missing mass is expected to have a peak around A' mass and around 0 for SM photon

Results from MC simulations with different A' masses are superimposed to the contribution from $\pi^0 \to \gamma\gamma$ data in which one photon cluster in the electromagnetic calorimeter has been fictitiously excluded

Dark photon search: strategy



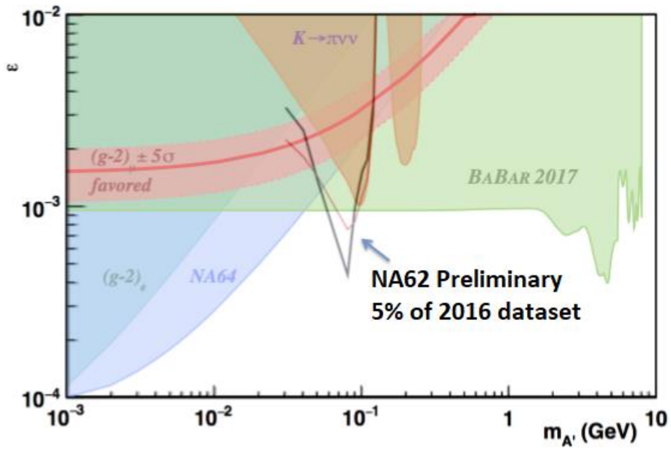
The width of the background peak is due to resolution effects, which are essentially left-right symmetric.

It is possible a data-driven background extimation, using left tail with negative missing mass values

Total number of events:

$$\frac{n_{sig}}{n_{\pi^0}} = \frac{BR(\pi^0 \rightarrow A'\gamma)}{BR(\pi^0 \rightarrow \gamma\gamma)} \varepsilon_{sel} \varepsilon_{trig} \varepsilon_{mass}$$

Dark photon search: results



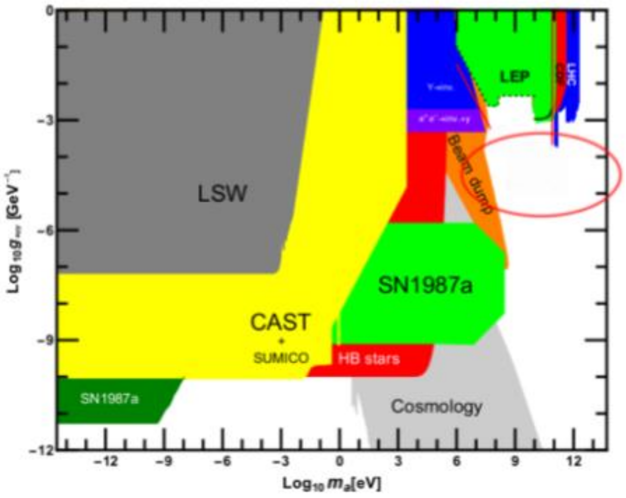
No statistically relevant excess found in ~1.5×10^{10} K^+ decays.

New upper limits at 90% CL in (ε, $m_{A'}$) plane are obtained.

The statistical capability of NA62 allows an improvement on previous recent results. A more refined background evaluation might be needed with larger data samples.

Not only Kaon decays

Fixed target experiments offer a very good discovery potential for **Axion-Like Particles** (ALPs) in the MeV-GeV range



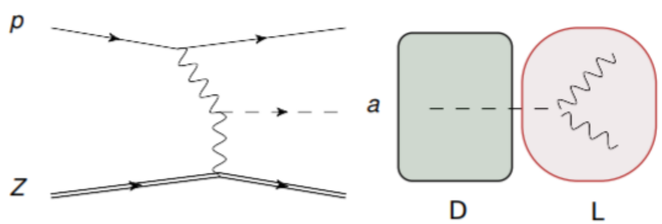
Weak coupling: sufficient energy, high reaction rate, longer lifetimes

ALPs production

NA62 can dump the entire beam by closing TAX (~10^{12} p/s) and removing target

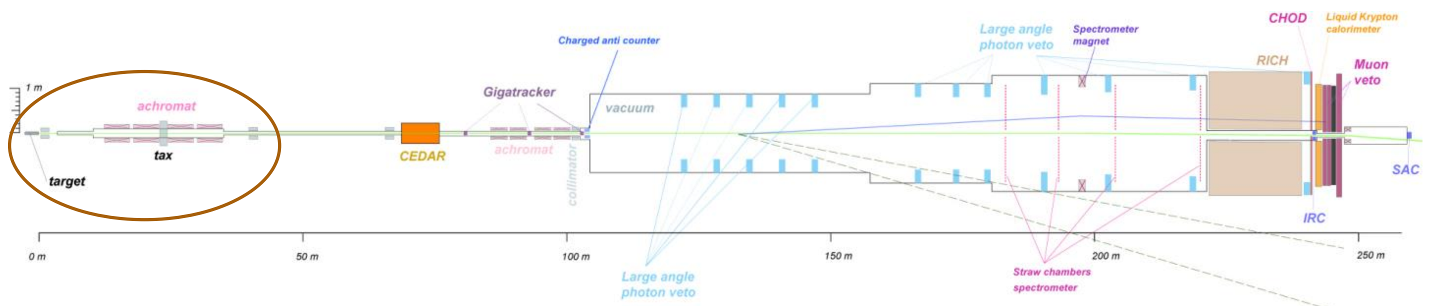
ALPs particles are produced by photon fusion (Primakoff effect)

Decay length $\gamma\beta\tau$, lifetime $\sim 1/(g_{a\gamma}^2 m_a^3)$

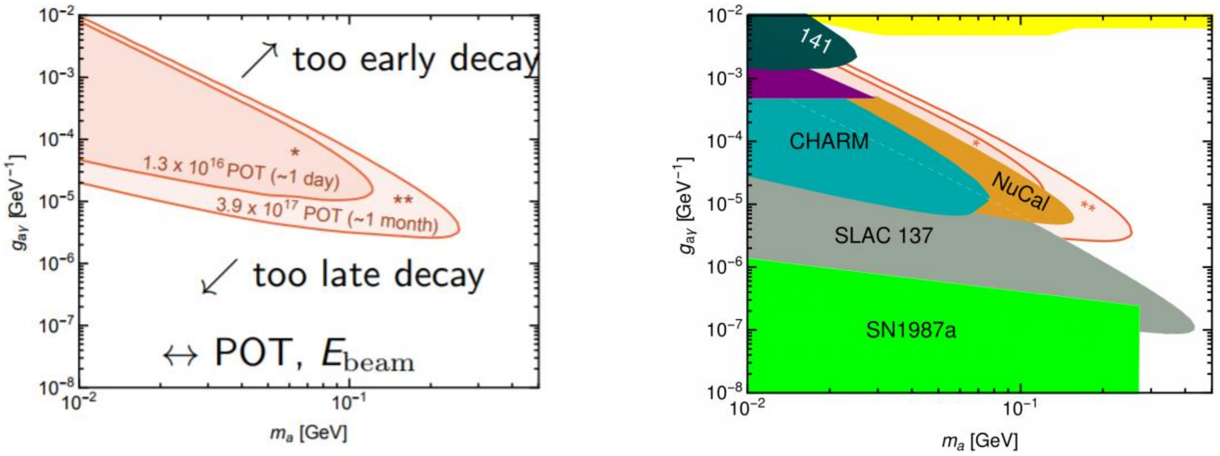


Copper TAX → coherent Z^2 enhancement with charge

~2.5 x 10^{15} POT in dump collected in the end of 2016



ALPs search: projected sensitivity



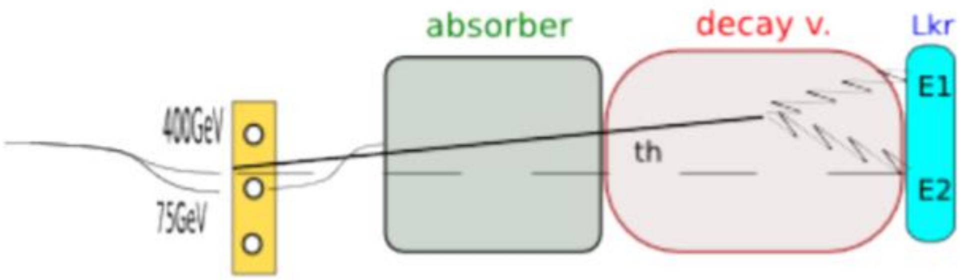
* 1 day
** 1 month

NA62 has small d, large E: one day is sensitive to new physics (90% CL, 0 background)

The projected limits fold as input:

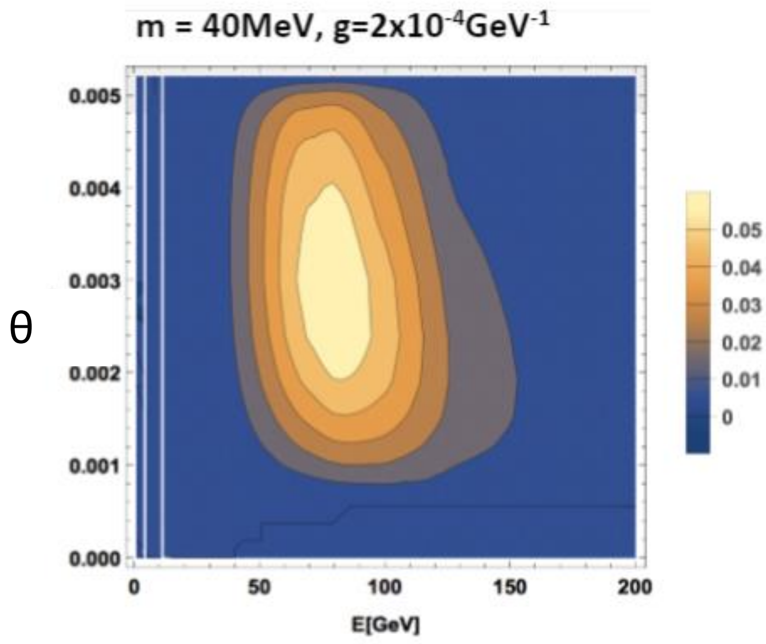
1. differential cross-section for production
2. coincidence and acceptance in EM calorimeter
3. probability to decay within the decay volume

ALPs search: analysis ongoing



- Measured quantities: E_1, E_2 and the distance d between clusters
- Proton is not tracked, need to impose mass or decay point to discriminate
- Baricenter between clusters: non zero angle θ because of the beam hole in LKr

ALPs search: analysis ongoing



- Due to the acceptance, detectable ALPs are highly boosted : only extend beyond existing limits at small decay length

$$l_d = \gamma\beta\tau \sim \frac{E_a}{m_a}\frac{64\pi}{m_a^3 g^2}$$

- Compare charged sample in sideband, deduce expected background in signal region -> optimization of signal efficiency for (g,m) in full MC on the way

Stay tuned!

Conclusions

NA62 is a general purpose experiment, and its physics program is complementary to the collider one.

$\pi\nu\nu$ search:

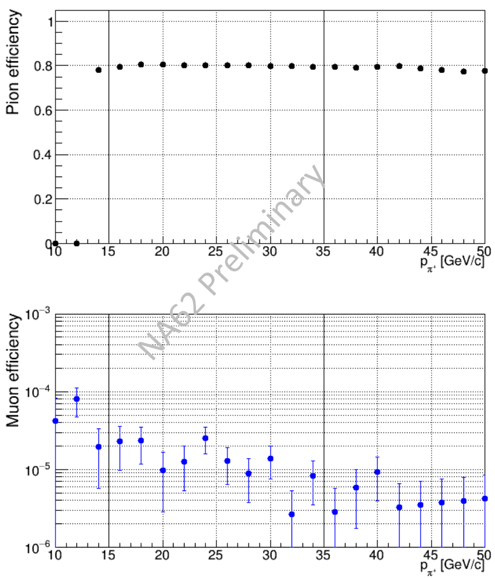
- NA62 expected to reach the SM sensitivity soon;
- BR measurement expected in the next few years.

Exotic searches:

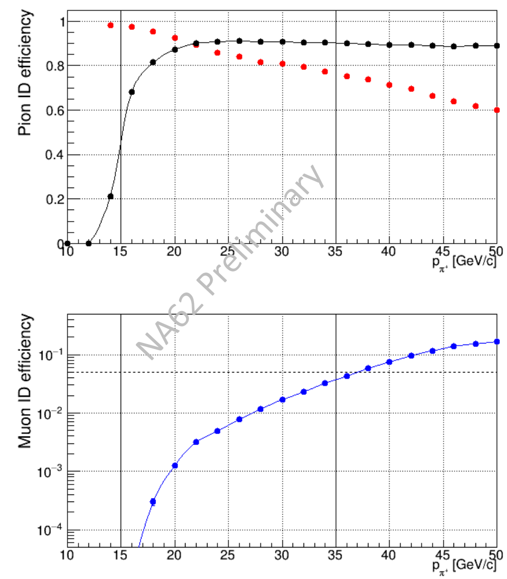
- A prelimary analysis on dark photon search has been shown, new limit on the dark photon production has been presented, with 5% of 2016 data sample;
- Huge improvements both on the statistics and on the analysis are ongoing;
- Analysis for Axion-Like Particles is ongoing.

Particle ID

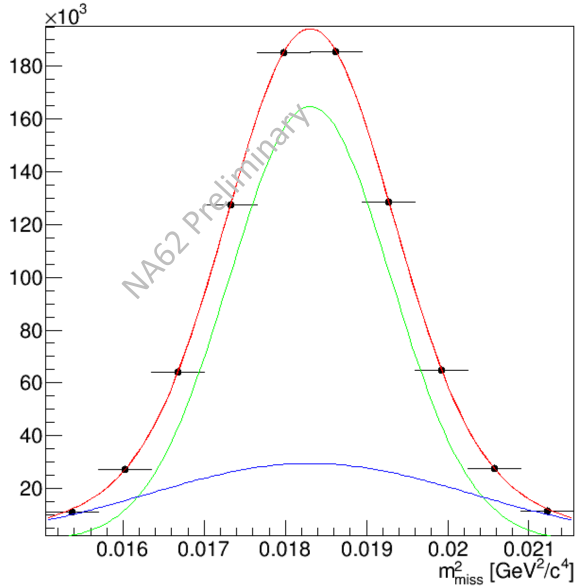
Calorimeters
MV Analysis

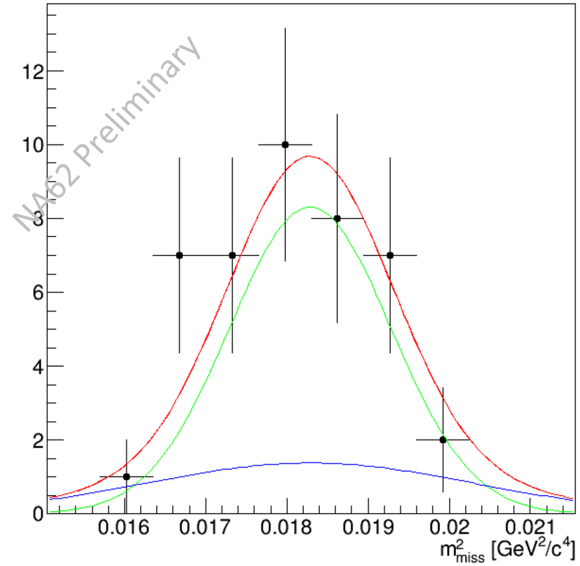


RICH



Pi0 Suppression

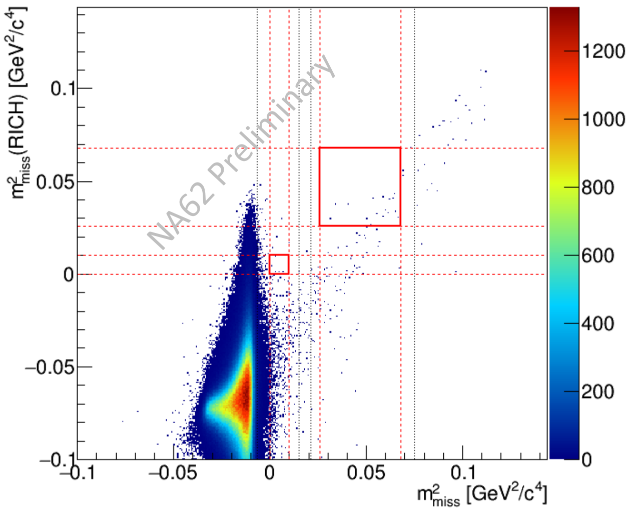


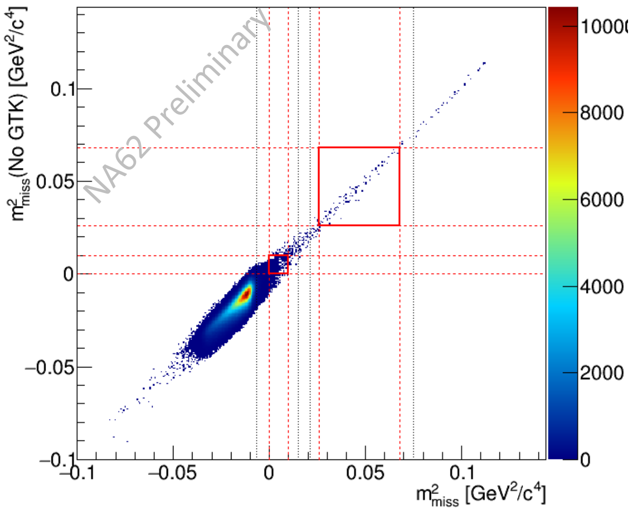


$3.3 \times 10^8 K^+ \rightarrow \pi^+\pi^0$analyzed

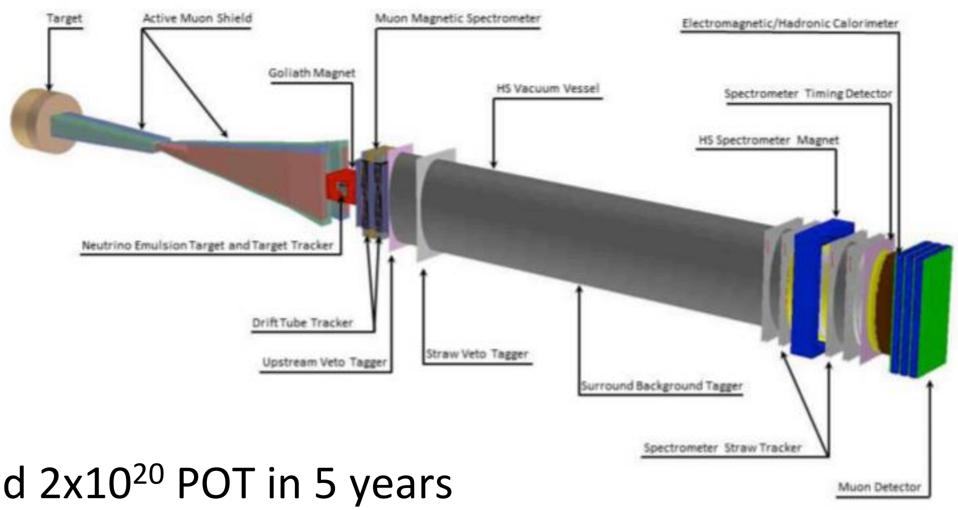
Suppression factor: $\varepsilon_{\pi^0} = (1.2 \pm 0.2) \times 10^{-7}$

Signal regions





SHiP



- Expected $2\text{x}10^{20}$ POT in 5 years
- Target closer to the detector:
  - Angular acceptance up to 20 mrad (NA62 LKr angular acceptance between 1 and 8.5 mrad)

- Molybdenum target (Z=42)
  NA62 uses copper (Z=29)