Marie Skłodowska-Curie Actions

UNIVERSITY OF BIRMINGHAM

Search for hidden sectors in kaon decays at the NA62 experiment at CERN

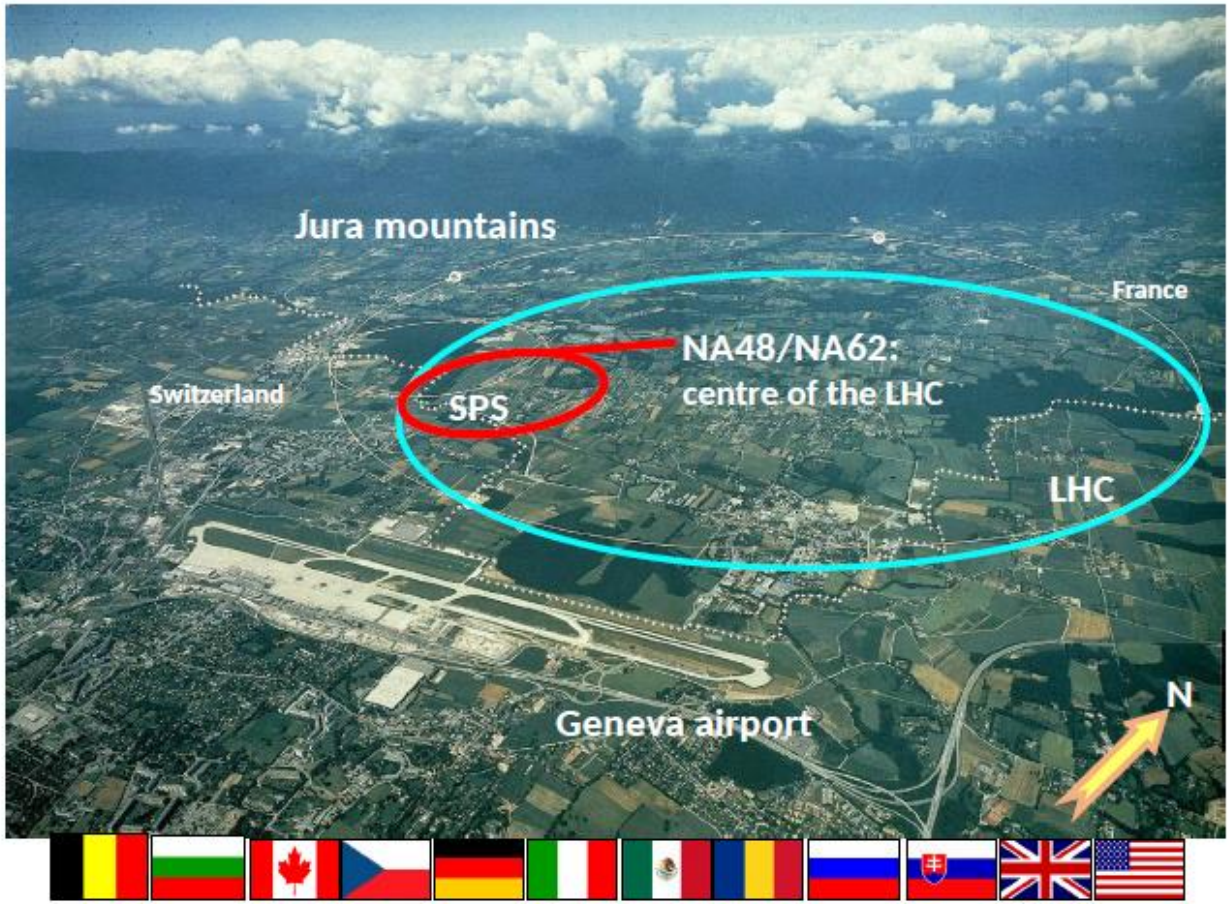
Viacheslav Duk, NA62 collaboration

Joint APP and HEPP Annual conference, Bristol, UK, March 26-28, 2018

Outline

- NA62 experiment
- Hidden sector searches at NA62
- Neutrino portal
- Vector portal
- Scalar portal
- Conclusion

NA62 experiment at CERN SPS



Kaon decay in flight experiments.
NA62: ~200 participants, ~ 30 institutes

NA62 timeline

- ✓ **2015:** commissioning (1% of the nominal beam intensity I_0)
- ✓ **2016:** commissioning + physics (40% I_0)
- ✓ **2017:** physics (60% I_0)

NA62 future

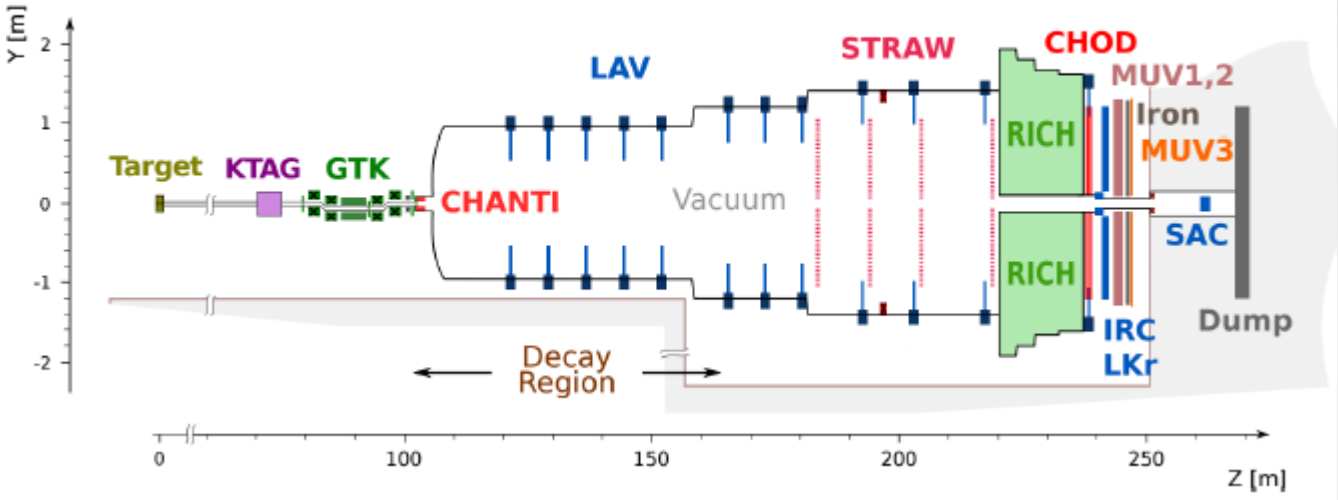
- **2018:** physics
- **2021-2023:** approved

NA62 experiment

- Main goal, 10% precision measurement of: $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$

Technique:
K^+ decays in flight

NA62 collaboration, JINST 12 (2017) P05025



Essential detectors:

- GTK (kaon momentum)
- KTAG (kaon ID)
- STRAW (momentum of secondaries)
- RICH: electron/pion/muon ID
- LKr: electron/photon/pion ID
- MUV1,2: pion/muon ID
- MUV3: muon ID

Essential triggers:

- $\pi\nu\nu$ (RICH, Q1, no muons, CALO)
- **Minimum bias** (hits in hodoscope)
- **Dimuon** (RICH, Qx, 2 muons)

RICH: time reference
Q1: **1-track** signature in hodoscope for charged particles (CHOD)
Qx: **multi-track** signature in CHOD
CALO: <20 GeV in calorimeters

New Physics and hidden sector

New Physics searches at NA62

High masses & sizable couplings to SM (short-lived)

Low masses & feeble couplings to SM (long-lived)

Indirect effects in loops

Hidden sector searches

$K^+ \to \pi^+ \nu\nu$: talk by A. Romano

kaon decays: this talk

upstream decays: talk by L. Iacobuzio

Hidden sector searches at NA62

Neutrino portal:
Search for heavy neutral lepton N in $K^+ \to \mu^+ N$

Vector portal:
Search for dark photon A′ in $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$

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Heavy neutral leptons (HNL): motivation

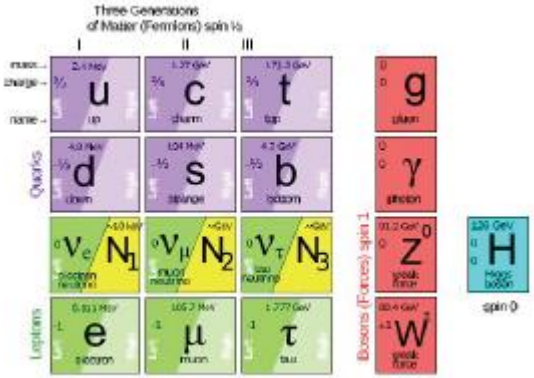
Three major tensions in SM:

- Neutrino oscillations
- Dark Matter
- Baryon asymmetry of the Universe

SM extension resolving all 3 problems: νMSM

- 3 heavy neutral leptons (heavy neutrinos) N_1, N_2, N_3
- m_1~10 keV (DM candidate)
- m_2, m_3 ~ 1 GeV (BAU, neutrino oscillations)

[*Asaka et al., PLB 620 (2005) 17*]



Heavy neutrino searches in kaon decays:

- Kinetic mixing between SM neutrinos and N
- **Production search** in $K^+ \to l^+ N$ (Kl2) ; l=e, μ
- $m(N) < m_K - m_l$
- Signature: peak in $m^2_{miss} = (P_K - P_l)^2$

Search for N_2, N_3 decays:
see talk by L. Iacobuzio

$$\mathcal{B}(K^+ \to \ell^+ N) = \mathcal{B}(K^+ \to \ell^+ \nu) \cdot \rho_\ell(m_N) \cdot |U_{\ell 4}|^2$$

Mixing matrix element

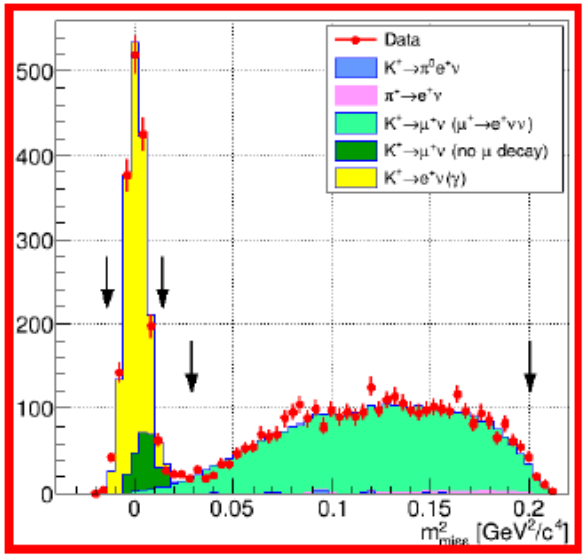
BR(Kμ2) ~0.64
BR(Ke2) ~$1.6*10^{-5}$

HNL search at NA62

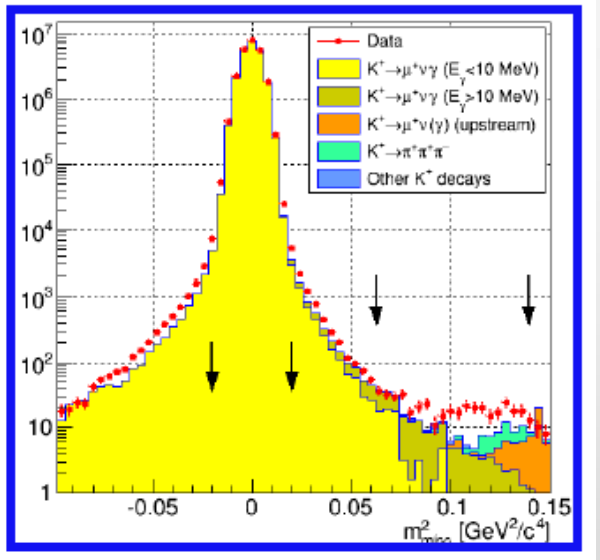
Data sample:

- 2015, $N_K \sim 3*10^8$
- Low intensity
- Beam tracker (GTK) not used

$K^+ \to e^+ N$ (1767 candidates)
Normalization: $K^+ \to e^+ \nu_e$
Mass scan region: 170-448 MeV/c^2



$K^+ \to \mu^+ N$ (24M candidates)
Normalization: $K^+ \to \mu^+ \nu_\mu$
Mass scan region: 250-373 MeV/c^2

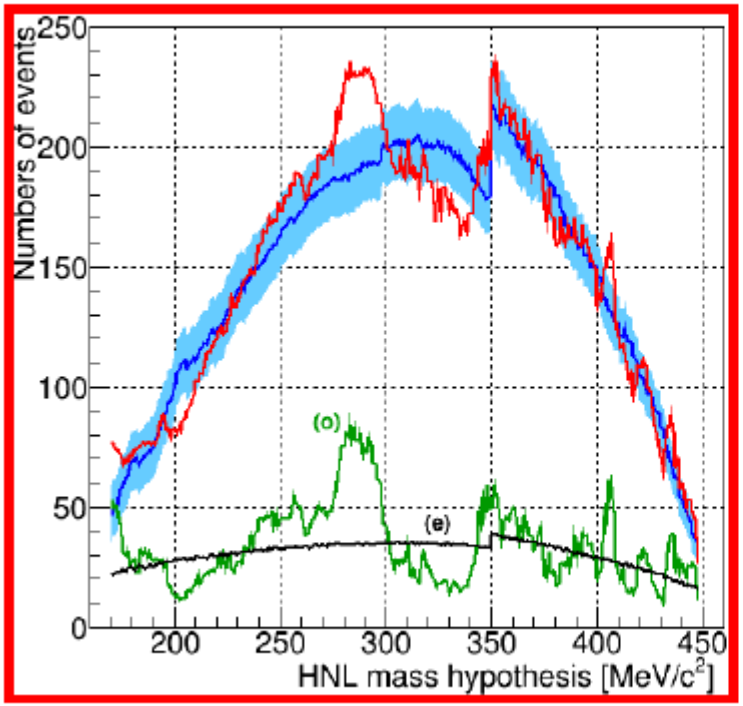


Heavy neutrino search in 2015 data

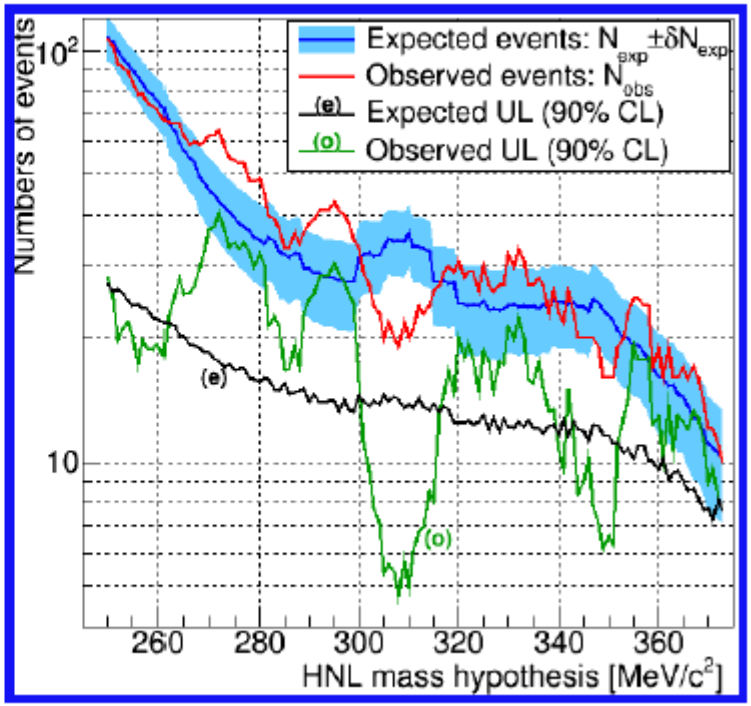
Rolke-Lopez method used to find upper limits on number of signal events

- Heavy neutrino mass step: $1\,\mathrm{MeV}/c^2$
- Search window size for each mass hypothesis: $\pm 1.5\,\sigma(m_N)$

$K^+ \to e^+ N$

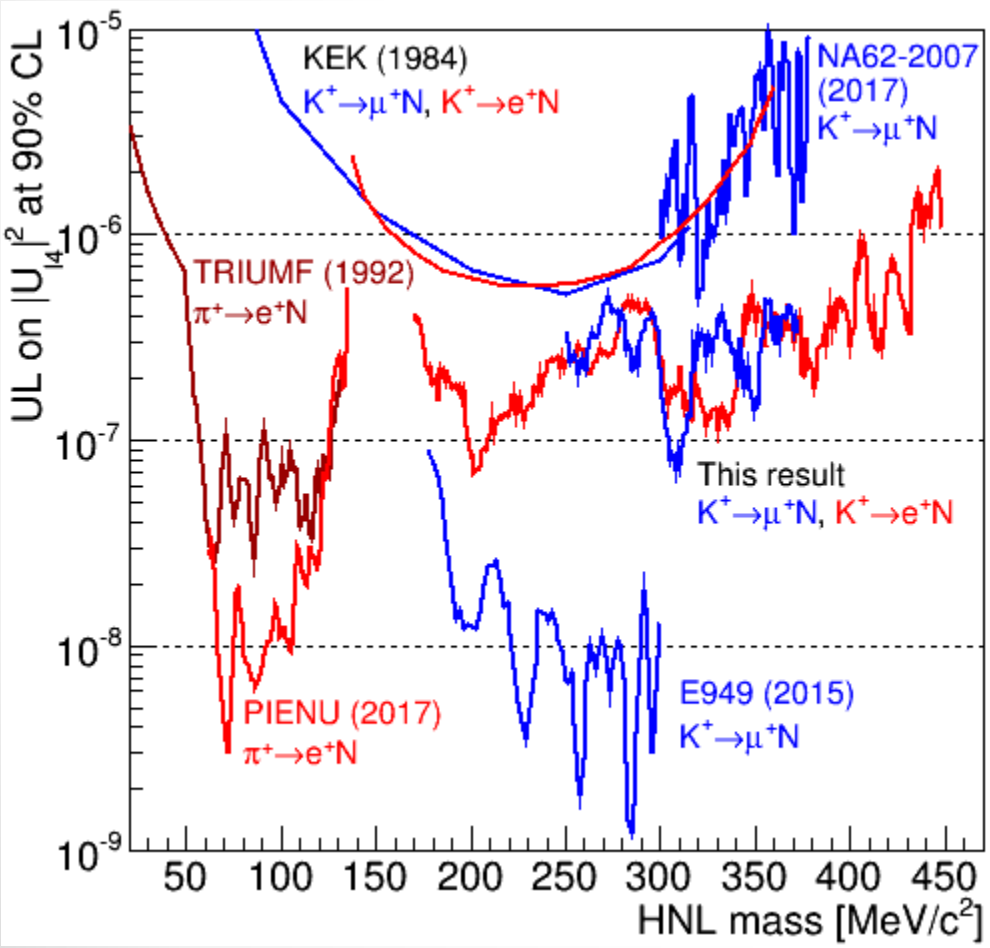


$K^+ \to \mu^+ N$



Upper limits on $|U_{14}|^2$

n^l_{UL} ⇒ $B(K^+ \to \ell^+ N) = \frac{n^\ell_{UL}}{N^\ell_K \cdot A^\ell_N(m_N)}$ ⇒ $|U_{\ell 4}|^2 = \frac{B(K^+ \to \ell^+ N)}{B(K^+ \to \ell^+ \nu)} \times \frac{1}{\rho(m_N)}$



First NA62 physics result !

[*PLB 778 (2018) 137*]

Prospects for 2016-2018 data:

- Better resolution (GTK)
- Much higher statistics

Expected limits: ~10^{-9} on $|U_{e4}|^2$, ~10^{-8} on $|U_{\mu 4}|^2$

Hidden sector searches at NA62

Neutrino portal:

Search for heavy neutral lepton N in $K^+ \to \mu^+ N$

Vector portal:

Search for dark photon A′ in $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$

Scalar portal:

Search for inflaton/sgoldstino S in $K^+ \to \pi^+ S$, $S \to \mu^+ \mu^-$

Dark photons

Models with dark photons (DP):

- Can explain (g-2) anomaly
- DP is a mediator between DM and SM particles
- DP can be light (MeV – GeV)
- DP feebly interacts with γ (kinetic mixing)

Dark photon searches at NA62:

- Production searches in $K^+ \to \pi^+ A'$
- Production searches in $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$ → This talk
- Decay searches in $\pi^0 \to \gamma A'$, $A' \to e^+ e^-$

Dark photon search at NA62

Decay channel: $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$

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

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

Data: 4% of 2016, $N_K \sim 1.5 \cdot 10^{10}$

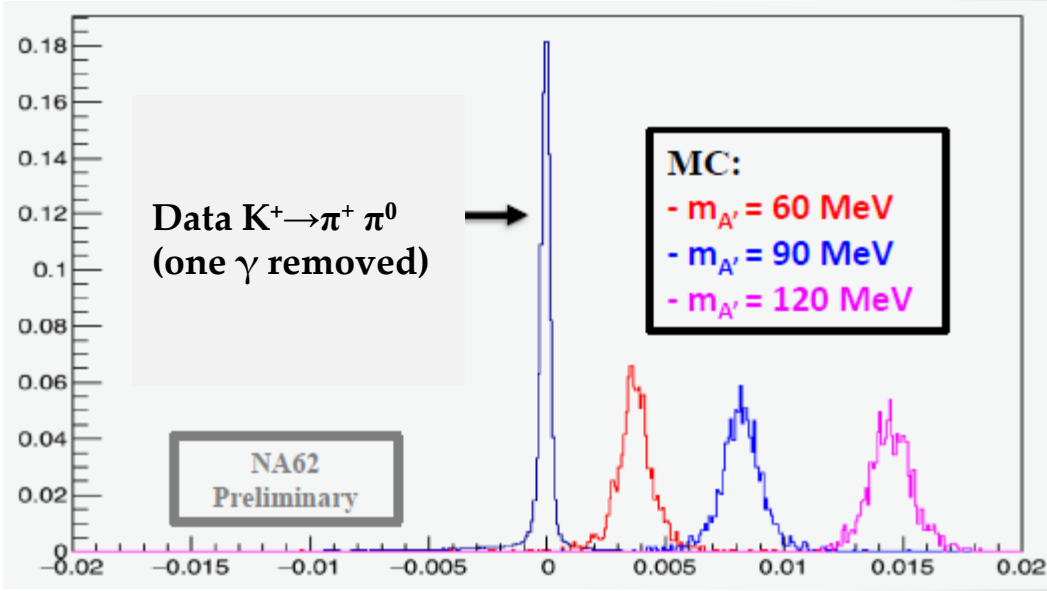
Main variable:

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

Analysis principle:

Look for peaks in M^2_{miss}

Scan over m(A')

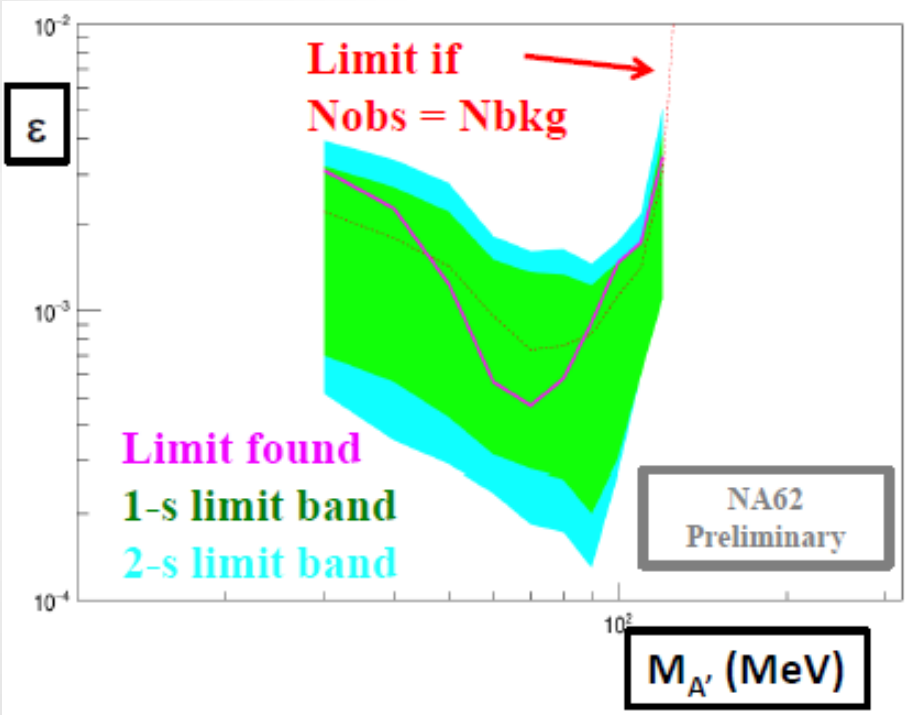


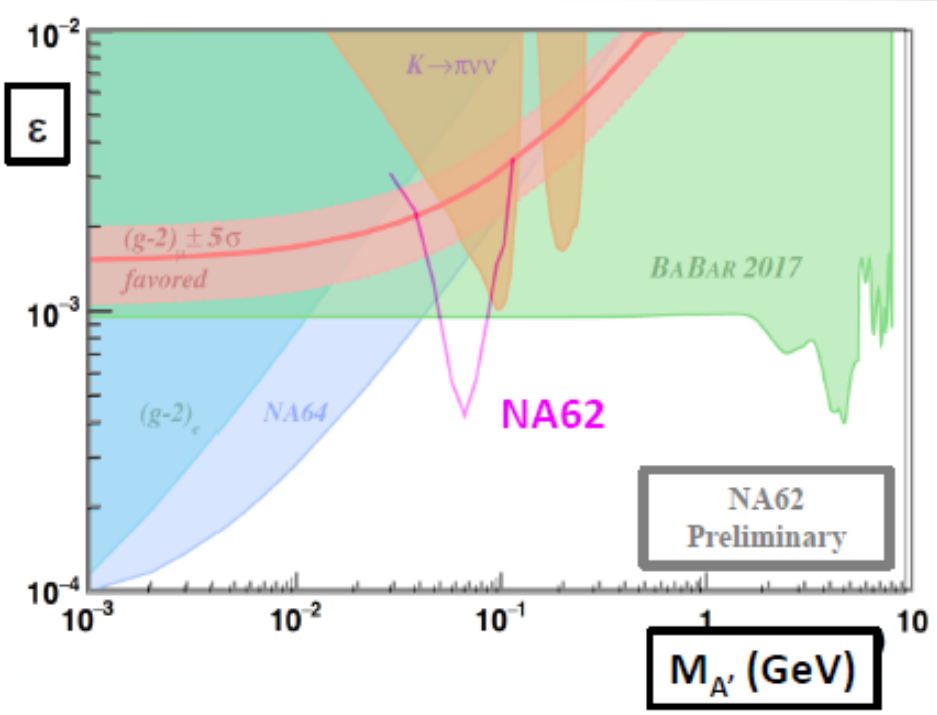
M^2_{miss} [GeV²/c⁴]

Dark photon search at NA62

n_{UL} ⟹ $BR(n_{UL})$ ⟹ ε^2

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





No signal observed
Limits for m=30 to 105 MeV

Hidden sector searches at NA62

Neutrino portal:
Search for heavy neutral lepton N in $K^+ \to \mu^+ N$

Vector portal:
Search for dark photon A′ in $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$

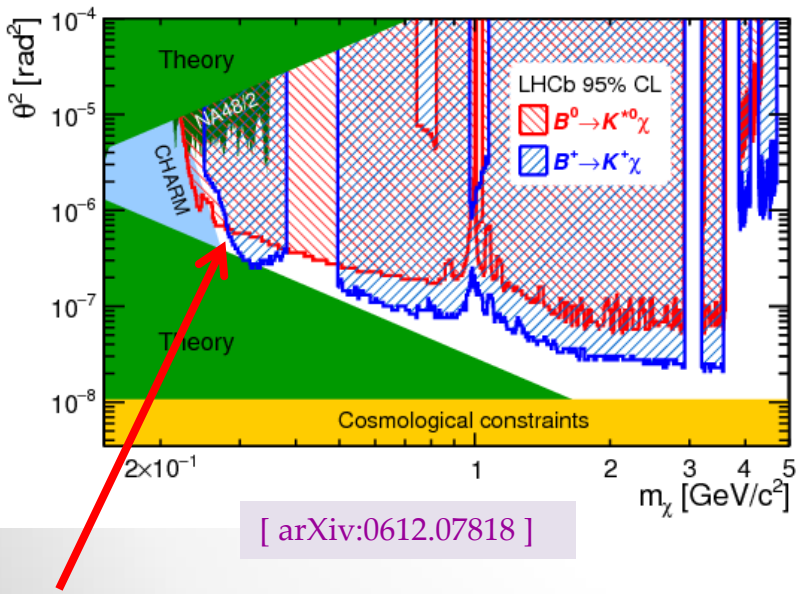
Scalar portal:
Search for inflaton/sgoldstino S in $K^+ \to \pi^+ S$, $S \to \mu^+ \mu^-$

Search for a new scalar in $K^+ \to \pi^+ S$ ($S \to \mu^+ \mu^-$)

Light inflaton model:
- Inflaton **X** is a new scalar
- 3 parameters in the model, 2 free
- Inflaton production: B and K decays are governed by the same parameters
- Inflaton decays to SM particles

Low energy SUSY models :
- Sgoldstinos **P** (pseudoscalar) and **S** (scalar) are superpartners of goldstino
- No strict limits on the mass and lifetime
- Sgoldstino production: K and ∑ decays are driven by the same coupling constants
- P and S can be light and decay to SM particles

Experimental limits (inflaton search):



[arXiv:0612.07818]

Region accessible in $K^+ \to \pi^+ S$, $S \to \mu^+ \mu^-$:
$\theta^2 \sim 4 \cdot 10^{-7}$ (m~270-300 MeV)

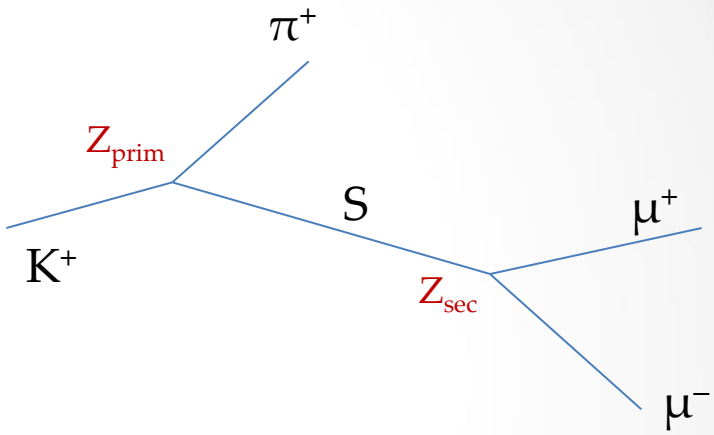
Experimental limits (sgoldstino search):

- Hyperon decays: $\Sigma^+ \to p P^0, P^0 \to \mu^+ \mu^-$
  HyperCP, LHCb [arXiv:hep-ex/0501014] [arXiv:1712.08606]
- K_L decays: $K_L \to \pi^0 \pi^0 X^0 \to \pi^0 \pi^0 \mu^+ \mu^-$
  kTeV [arXiv:1105.4800]
- $K^\pm$ decays: $K^+ \to \pi^+ S,\ S \to \mu^+ \mu^-$
  NA48/2 [arXiv:1612.04723]

Search for a new scalar at NA62 in $K^+ \to \pi^+ S$ ($S \to \mu^+ \mu^-$)

NA62 prospects:

- $O(10^{12})$ K decays in 2016-2017
- Almost background free for long-lived particles
- Acceptance O(1)% for long-lived particles

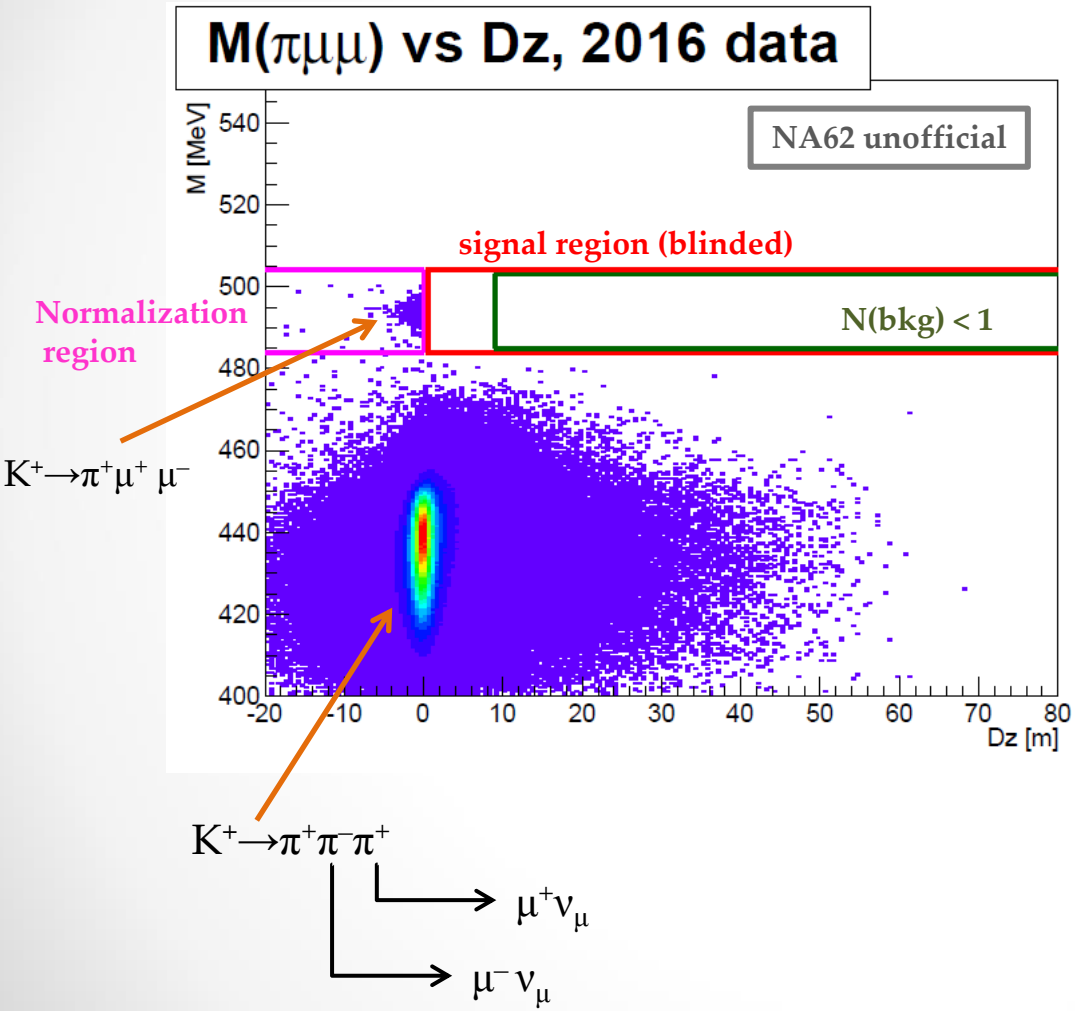


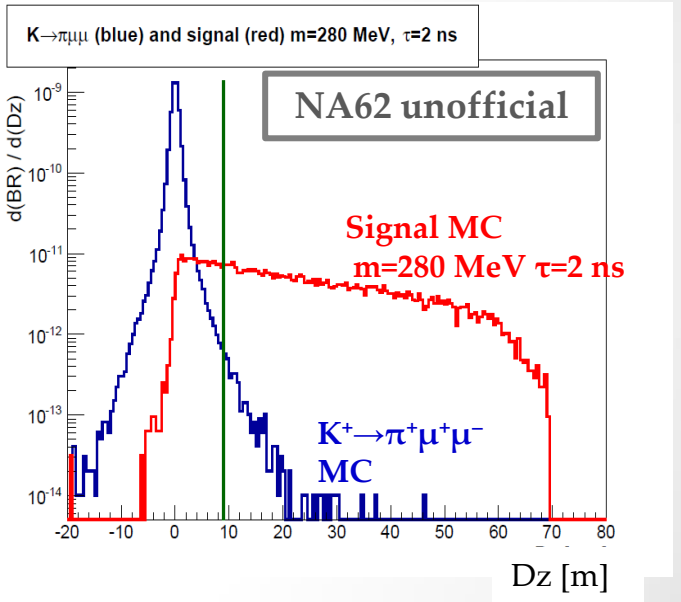
Analysis principles:

- Displaced vertex approach: K-π (primary), μ-μ (secondary)
- Main kinematical variables: $Dz = Z_{sec} - Z_{prim}$ and $M_K = M(\pi\mu\mu)$
- Main backgrounds: $K^+ \to \pi^+ \mu^+ \mu^-$ and $K \to \pi^+ \pi^+ \pi^-$ followed by two $\pi \to \mu \nu_\mu$
- Signal region: $484 < Mk < 504$ MeV, $Dz > 0$
- Normalization: $K^+ \to \pi^+ \mu^+ \mu^-$ in $484 < M_K < 504$ MeV, $Dz < 0$

BR~10^{-7}, see talk by C. Parkinson

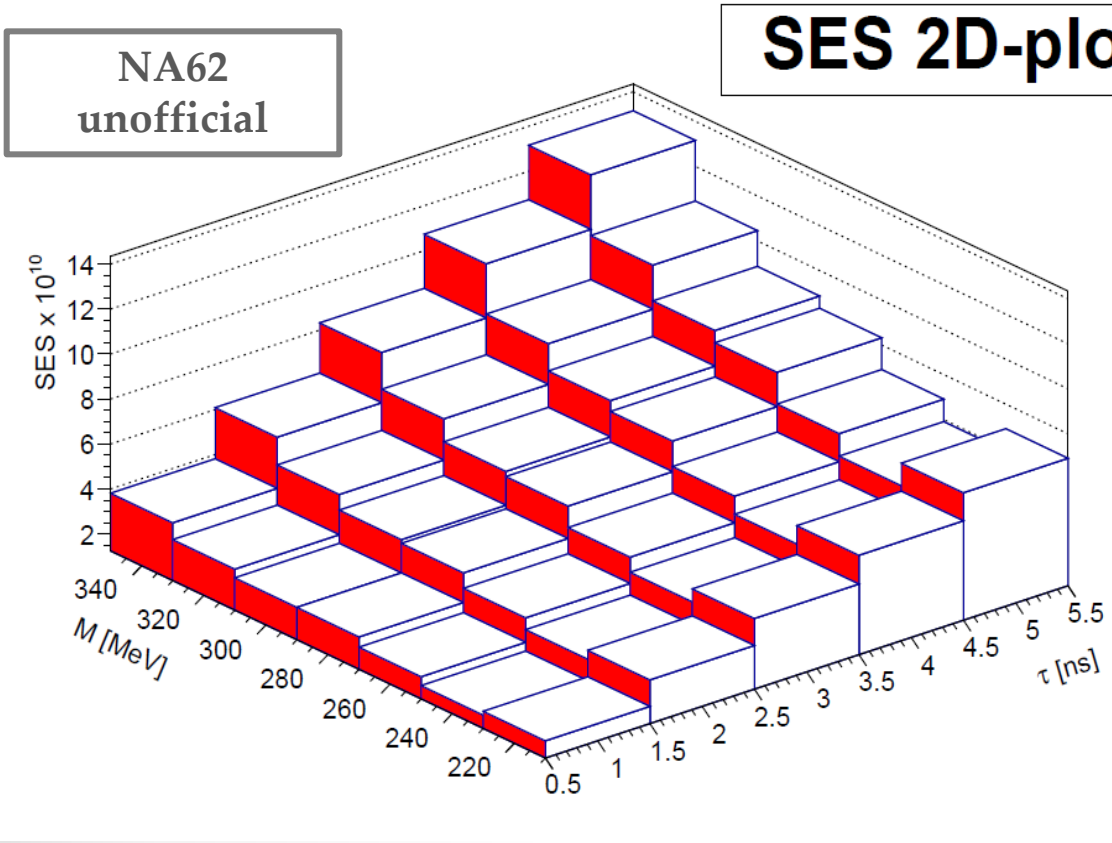
Search for a new scalar at NA62 in $K^+ \to \pi^+ S$ ($S \to \mu^+ \mu^-$)





Search for a new scalar at NA62 in $K^+ \to \pi^+ S$ ($S \to \mu^+ \mu^-$)

SES = 1 / (N_K*Acc)



- $N_K \sim 3.5*10^{11}$
- SES: from $2*10^{-10}$ to $14*10^{-10}$
- Best limits: m~240 MeV

Large τ: acc ~ τ^{-1}
Large m: π at rest ($K^+ \to \pi^+$ S), low acceptance
Small m: parallel muons, bad secondary vertex

Conclusion

Neutrino portal :

- Limits on $|U_{e4}|^2$ from $K^+ \to e^+ N$ @ 10^{-6} to 10^{-7} (170-448 MeV/c^2)
- Limits on $|U_{\mu 4}|^2$ from $K^+ \to \mu^+ N$ @ 10^{-6} to 10^{-7} (250-373 MeV/c^2)
- 2015 data: published
- 2016 data: analysis in progress

vector portal :

- limits on ε from $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \gamma A'$ @ 10^{-3} to 10^{-4}
- 2016 data: analysis in progress

scalar portal :

- SES~10^{-10} for long-lived scalars in $K^+ \to \pi^+ S$, $S \to \mu^+ \mu^-$
- 2016 data: analysis in progress

- ✓ NA62 first physics result published [*PLB 778 (2018) 137*]
- ✓ Good prospects for all analyses with 2016-2018 data