Exotic searches at NA62 Experiment

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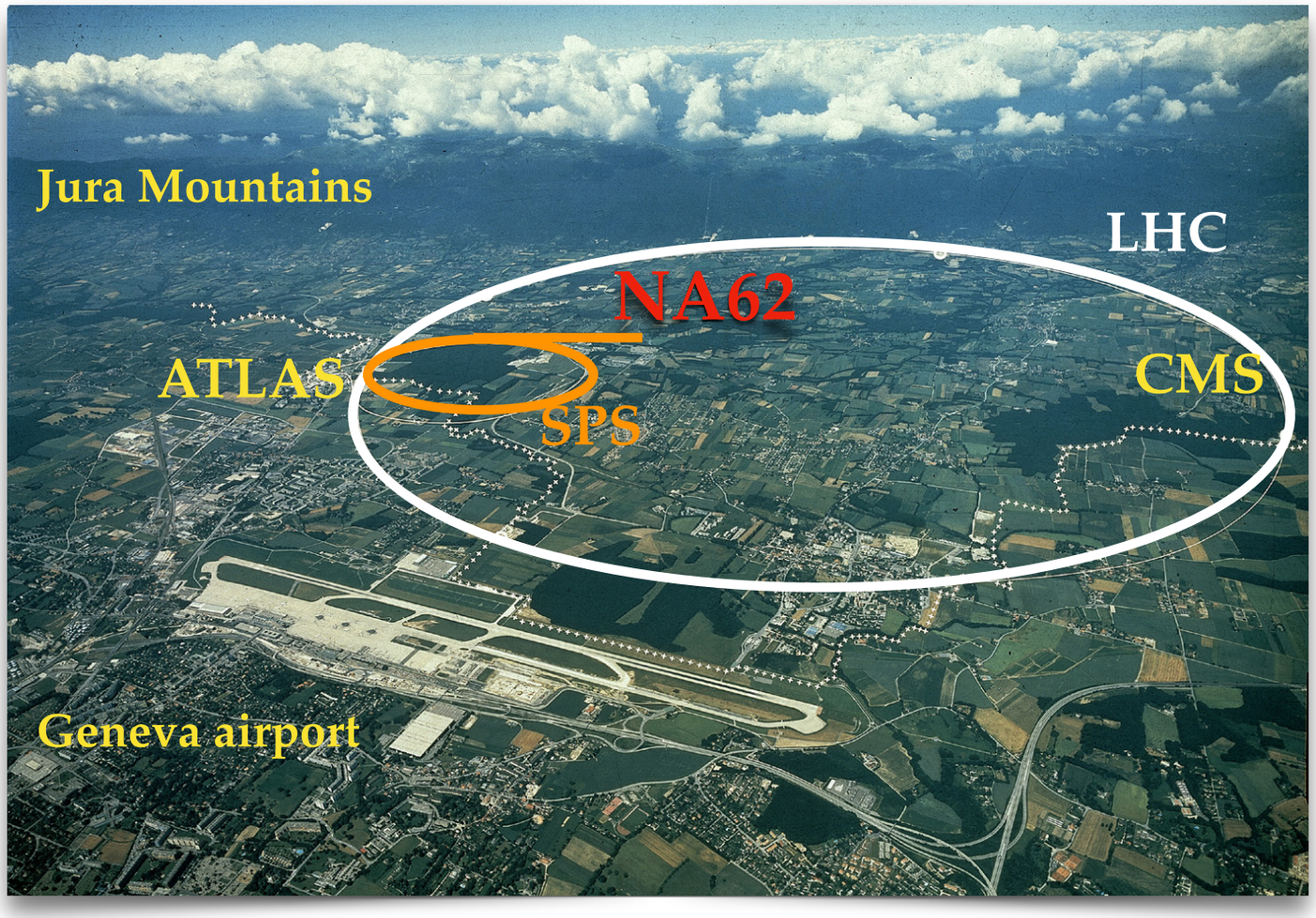
for the NA62 Collaboration

MESON2018, Krakow, 7-12 June 2018

The NA62 experiment at SPS @CERN

Designed ad constructed for the measurement of BR($K^+ \to \pi^+ \nu\nu$) with ~10% precision

But with a larger and various physics program…



~ 200 collaborators

~ 30 Institutions

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax (GMU), Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain-la-Neuve, Mainz, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, Sofia, TRIUMF, Turin, Vancouver (UBC)

NA62 timeline

Talk outline

- ☑ **2014: Pilot Run**
- ☑ **2015: Commissioning Run**

Detector paper:
NA62Collaboration
J. Instrum. 12 (2017) P05025

- ☑ **2016:**
  - ☑ **May-July:** detector commissioning
  - ☑ **July-Sept:** final commissioning and physics
  - ☑ **Sept-Nov: Physics run**
- ☑ **2017: Physics run**
  ~factor 20 larger kaon dataset, analyses ongoing
- ☐ **2018: Physics run** *smoothly ongoing*

First $K^+ \to \pi^+ \nu\nu$ result (see N.Lurkin talk at tomorrow plenary)

Heavy Neutral Lepton (HNL) search
NA62 Collaboration
Phys. Lett. B778 (2018) 137

Preliminary results on dark photon searches

Lepton Flavor and Number Violation (LFV and LNV) searches

Prospects on searches in dump mode

NA62 Apparatus

High intensity proton beam:

- flat top spill 3.5 s
- 10^{12} p/s
- 400 GeV

Secondary beam:

- $\pi^+(70\%)$, p(23%), $K^+(6\%)$
- 75 GeV dp/p~ 1%
- 750 MHz

RICH:

Ring imaging Cherenkov kinematics and particle ID

Photon Veto

IRC, SAC: lead and scintillator plates Shashlyk configuration

Muon Veto

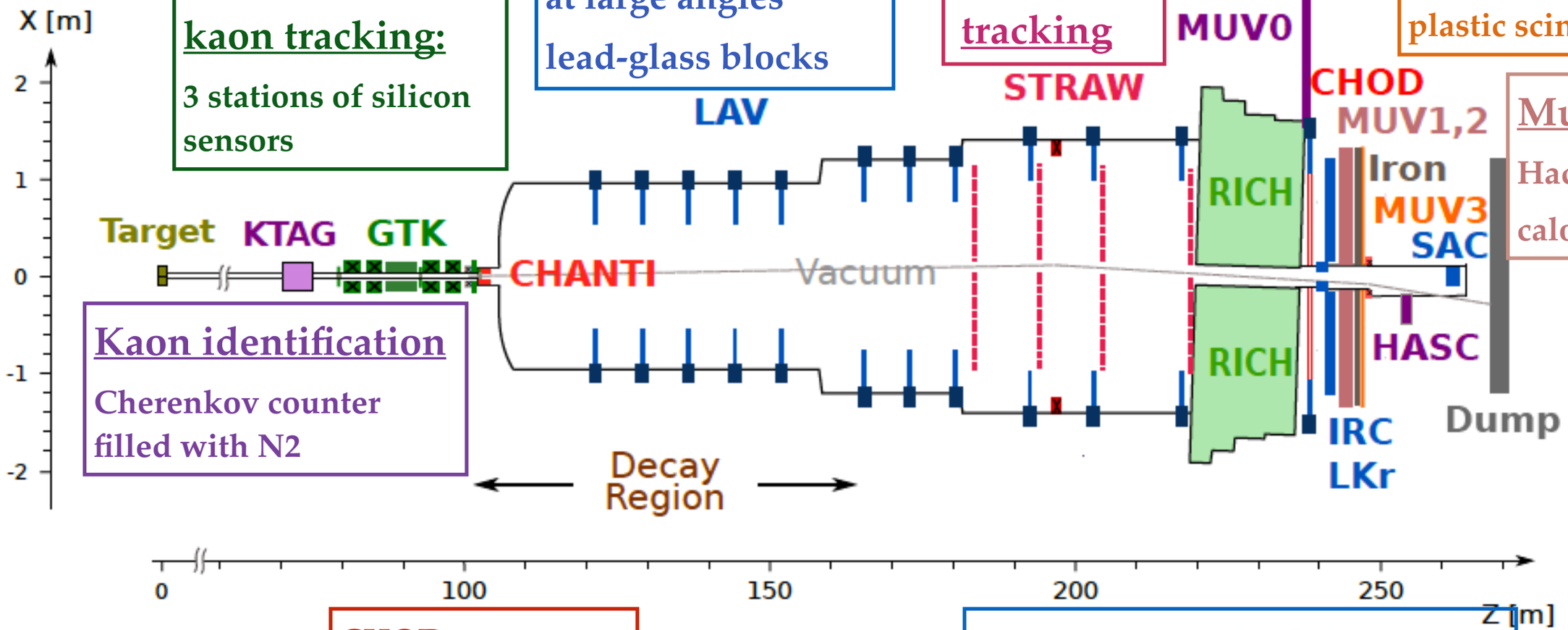
MUV0, MUV3 plastic scintillators

kaon tracking:

3 stations of silicon sensors

LAV: photon veto at large angles lead-glass blocks

Downstream tracking



Muon veto

Hadronic calorimeters

Kaon identification

Cherenkov counter filled with N2

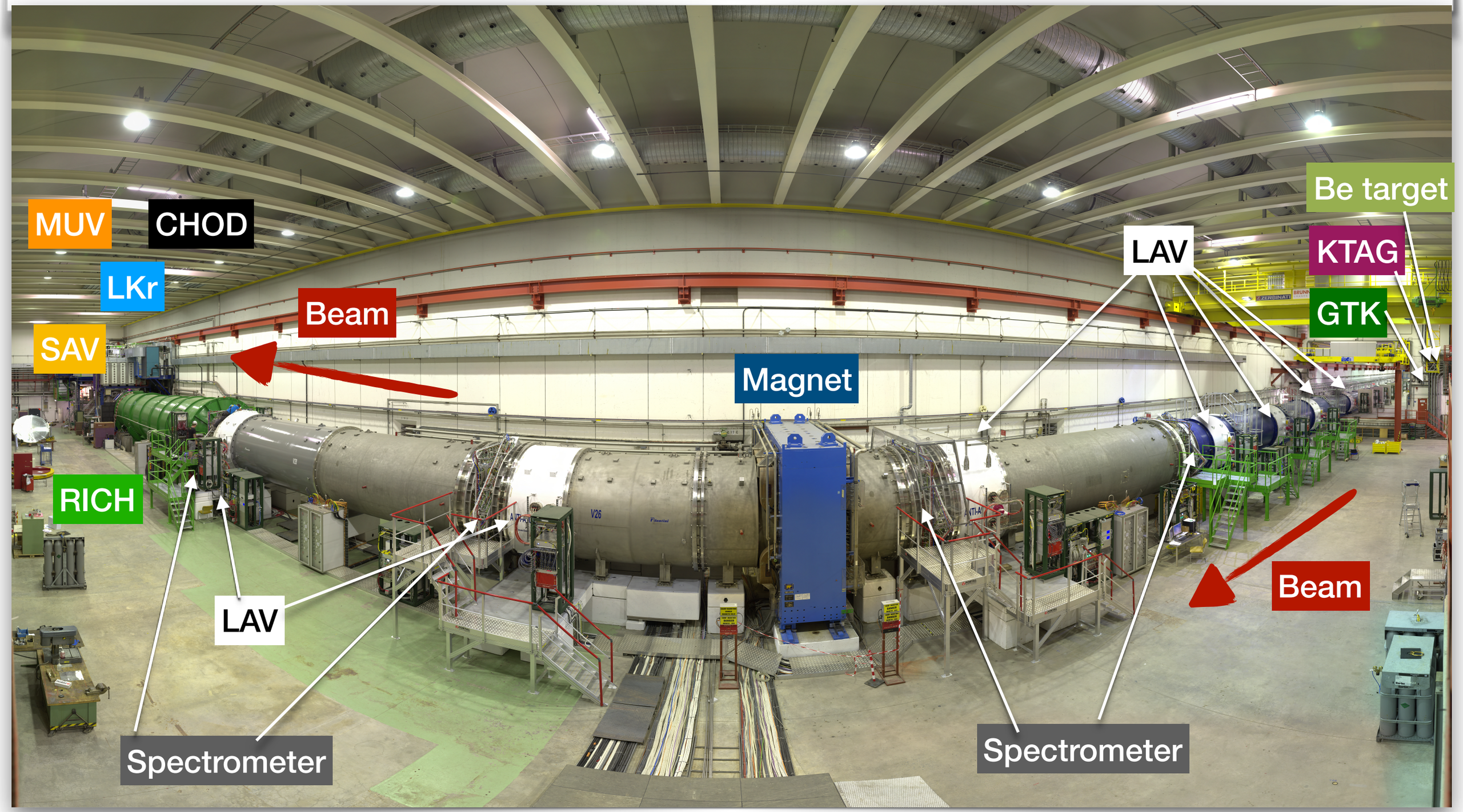
CHOD

charged hodoscope

Electromagnetic Calorimeter

LKr: quasi-homogenous ionization chamber 27X0 deep

NA62 Apparatus

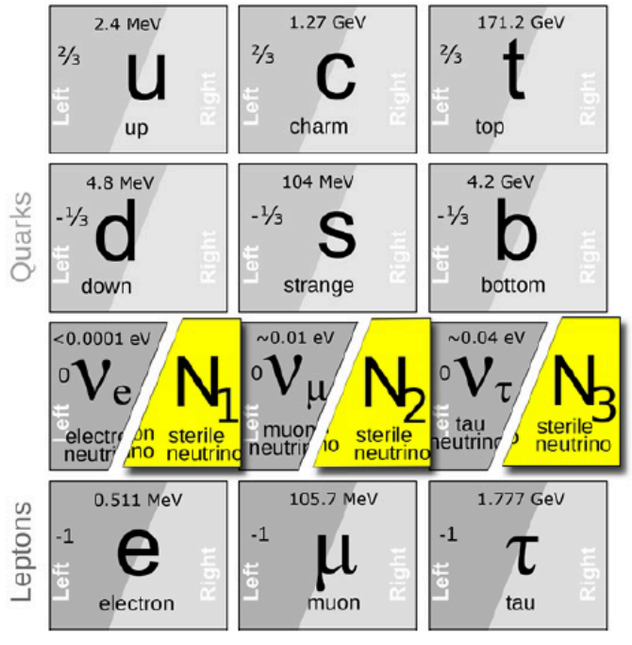


- **High intensity beam**
- **Redondant particle identification**
- **Optimal detectors performance**

It can be employed for several searches for new physics in the intensity frontier

HNL searches motivation

Massive sterile neutrinos generated with low scale seesaw mechanism



νMSM

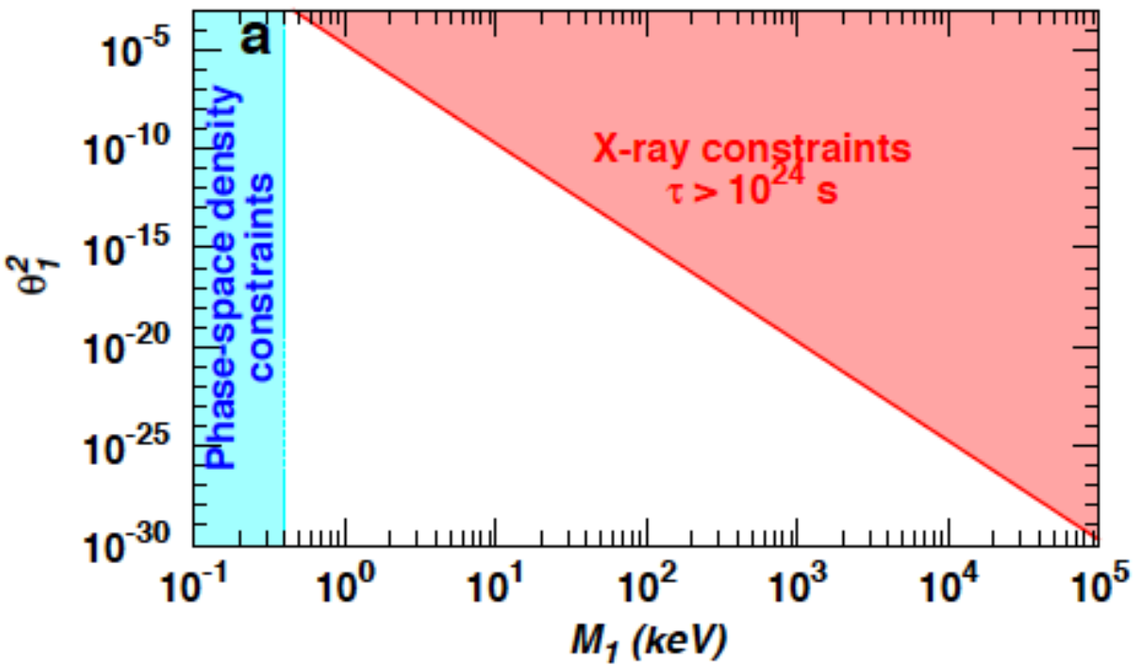
Neutrino Minimal Standard Model

T. Asaka, M. Shaposhnikov, Phys. Lett. B 620 (2005) 17.

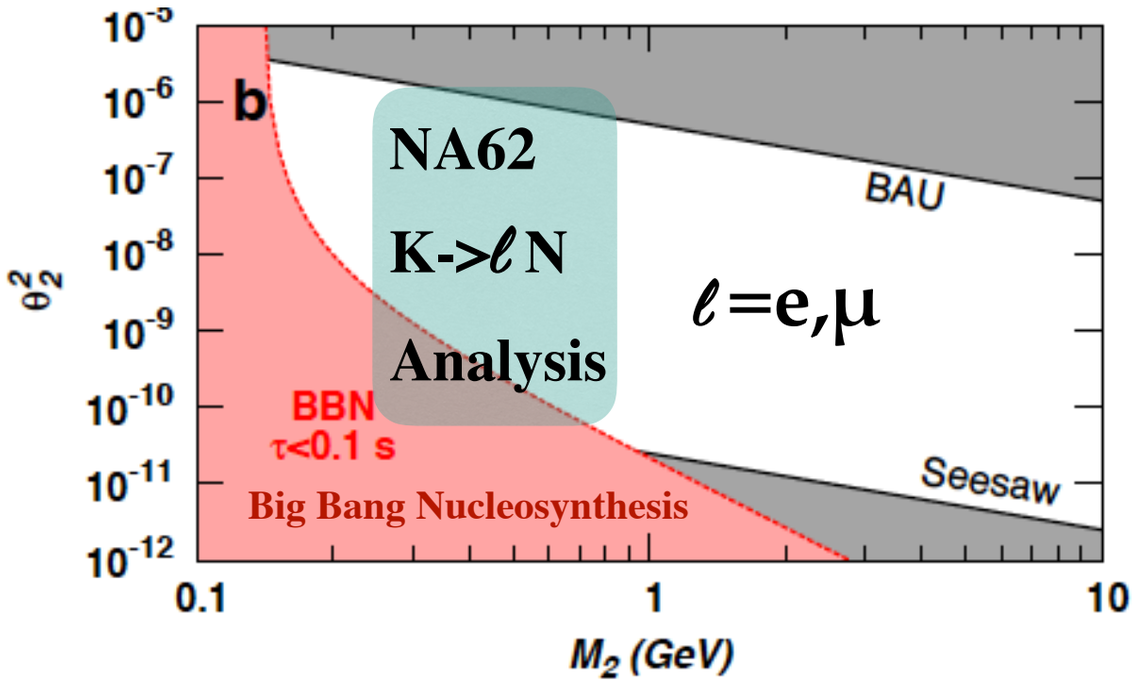
3 right handed neutrinos

Considering the constrains from Neutrinos oscillation, Dark matter amount, Baryon Asymmetry of the Universe (BAU):

M1 ~ O (10 KeV/c2)



M2, M3 ~ O (1 GeV/c2)



Boyarsky et al, Ann. Rev. Nucl. Part. Sci. 59 (2009) 191

HNL search strategy

NA62 Collaboration
Phys. Lett. B778 (2018)

Mixing with SM neutrinos is assumed to be < 10^{-4} → **HNL decaying to SM particles only after ~10 Km** → **The signature is one single track**

Normalization to the SM decay:

Possible discrepancies in data/MC for efficiencies and background yields cancel

ℓ=e,μ

$$N_S^\ell = N_K^\ell \cdot \mathcal{B}(K^+ \to \ell^+ N) \cdot A_\ell^N$$

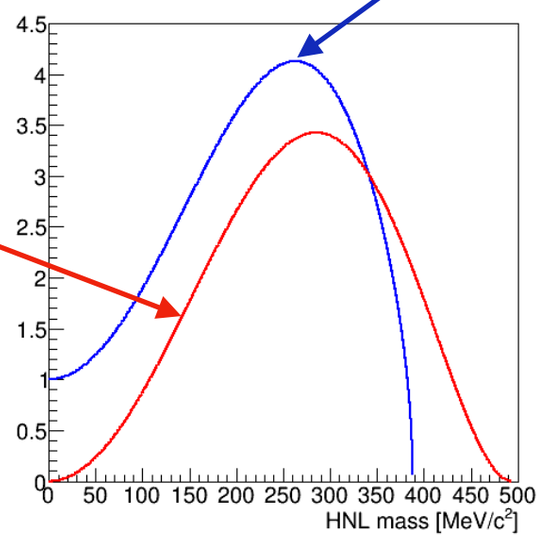
Number of SM decays: $K^+ \to \ell^+ \nu$

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

Mixing with SM neutrinos

$\rho_e(m_N) \times R_K$

$R_K = \Gamma(K^+ \to e^+ \nu) / \Gamma(K^+ \to \mu^+ \nu) \approx \approx 2.5 \times 10^{-5}$



R.R.Shrock(1980)

2015 DATA SAMPLE

Commissioning phase, beam tracker not used

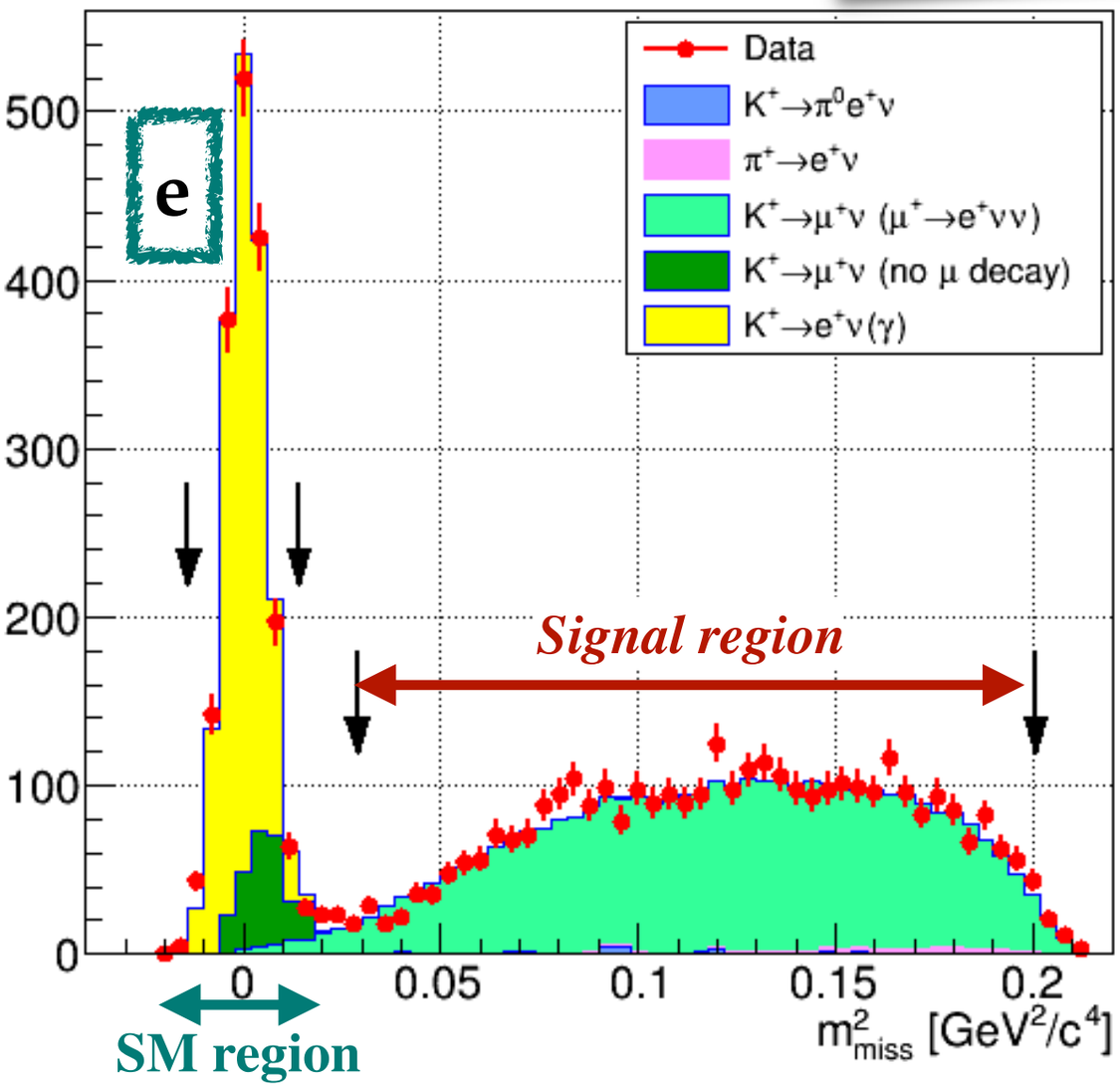
SM and HNL common event selection:

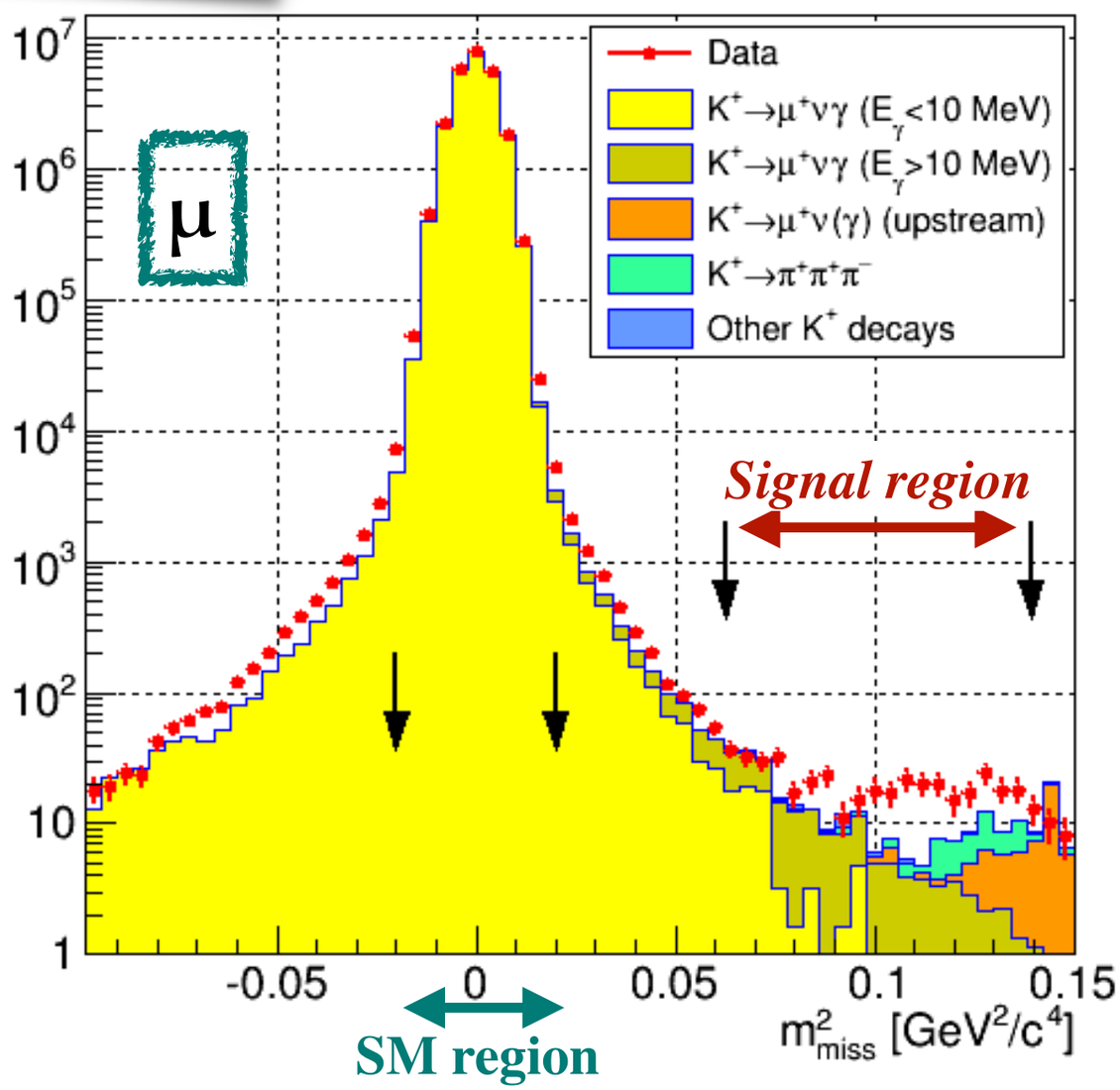
- **Single positive track**
- **Muon and positron identification with:**
  - **E/p**
  - **Muon Veto**
  - **RICH (for p<40 GeV)**
- **Photon vetoes**

HNL search strategy

NA62 Collaboration
Phys. Lett. B778 (2018)

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





$$N_K^e = \frac{N_e}{A_e^e \cdot \mathcal{B}(K^+ \to e^+\nu) + A_e^\mu \cdot \mathcal{B}(K^+ \to \mu^+\nu)}$$

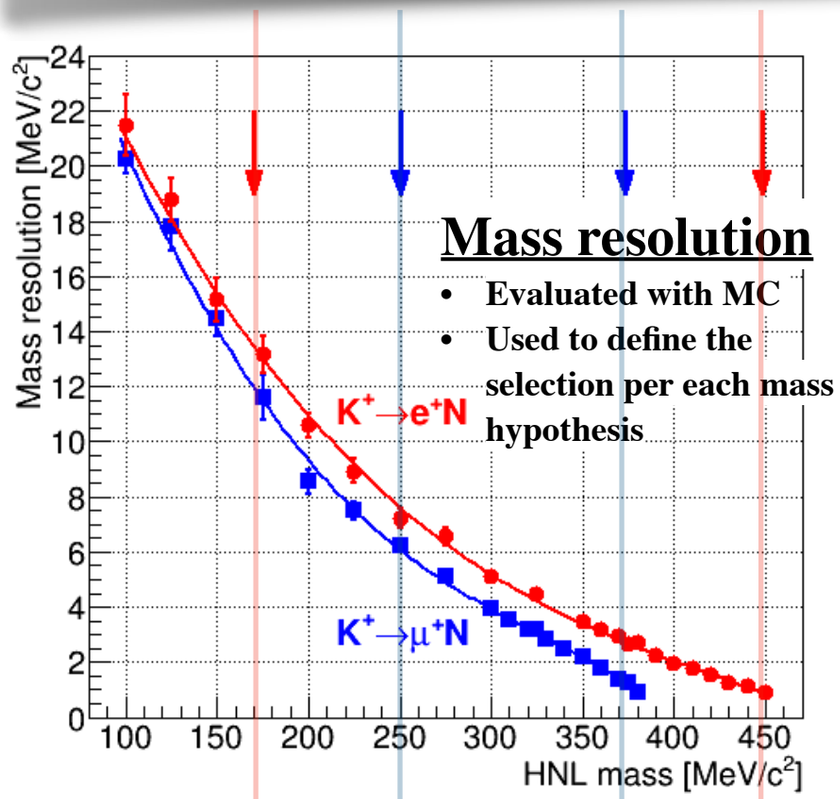
$$N_K^\mu = \frac{N_\mu}{A_\mu^\mu \cdot \mathcal{B}(K^+ \to \mu^+\nu)}$$

N events observed in SM region
Acceptances from MC

Search for peaks over a smooth background in the *signal region*

HNL Results

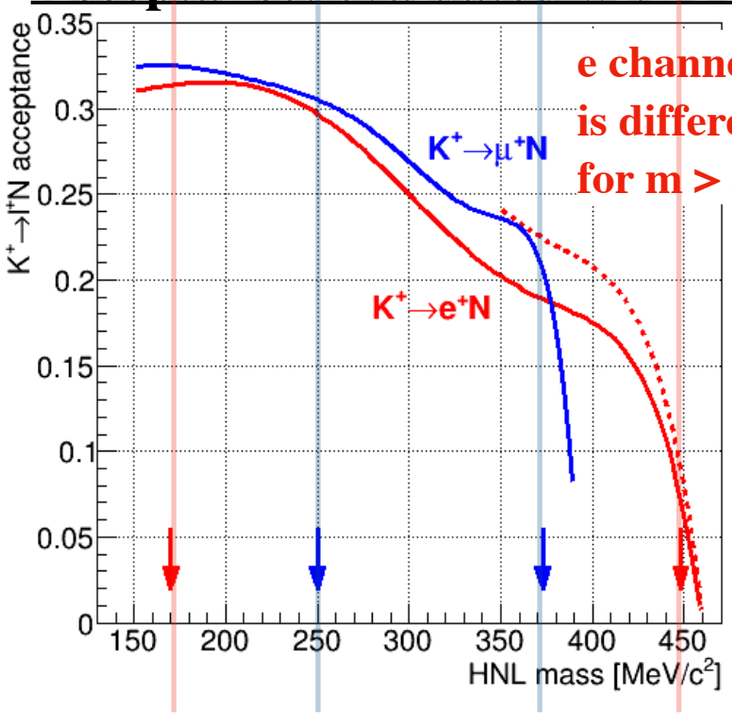
NA62 Collaboration
Phys. Lett. B778 (2018)



Mass resolution

- Evaluated with MC
- Used to define the selection per each mass hypothesis

Acceptance: evaluated with MC

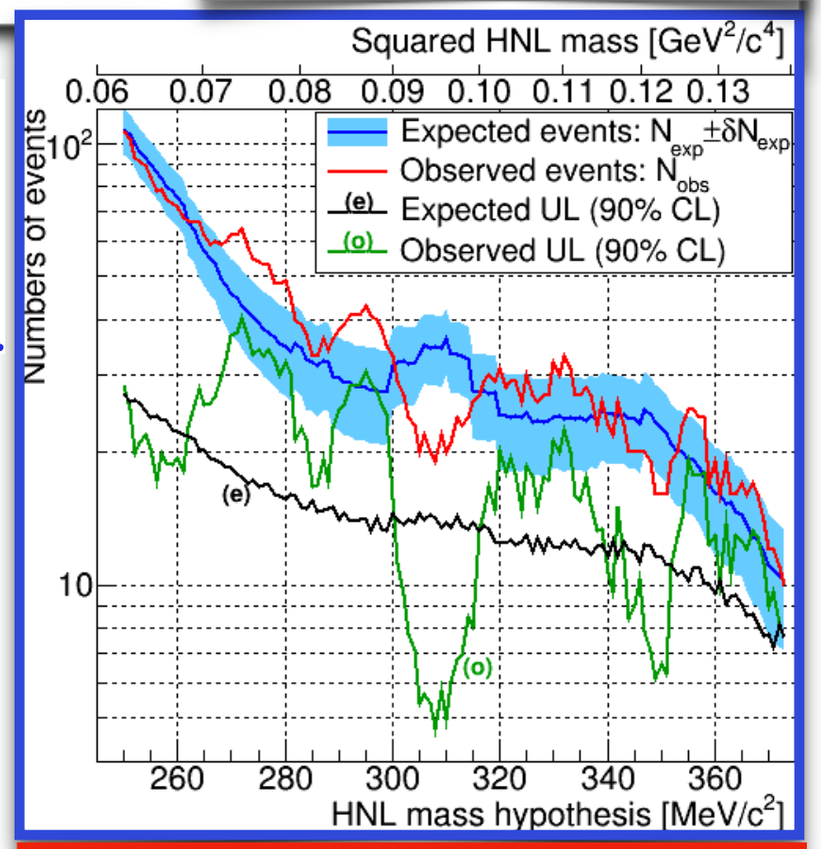


e channel selection is different for m > 350MeV

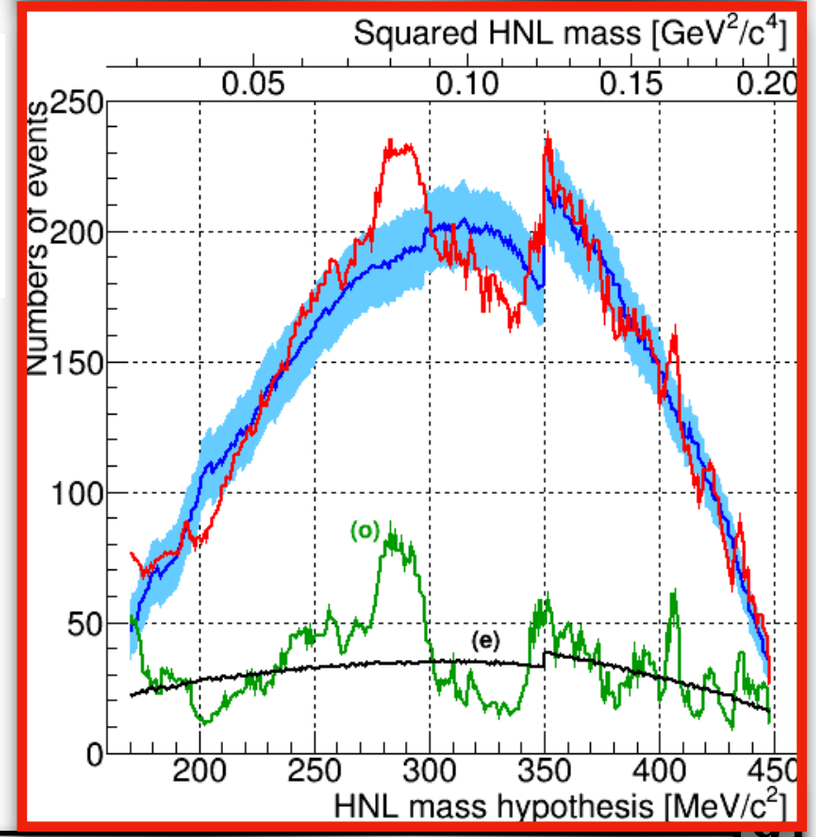
Per each HNL mass hypothesis (1 MeV scan):

- m_{miss} in 1.5 σ (m_{HNL})
- Background evaluated from sidebands in m_{miss} distributions
- MC used only to check that no structures are present in the signal region
- Upper limit @ 90% C.L. computed with counting experiment (Rolke-Lopez)

μ channel

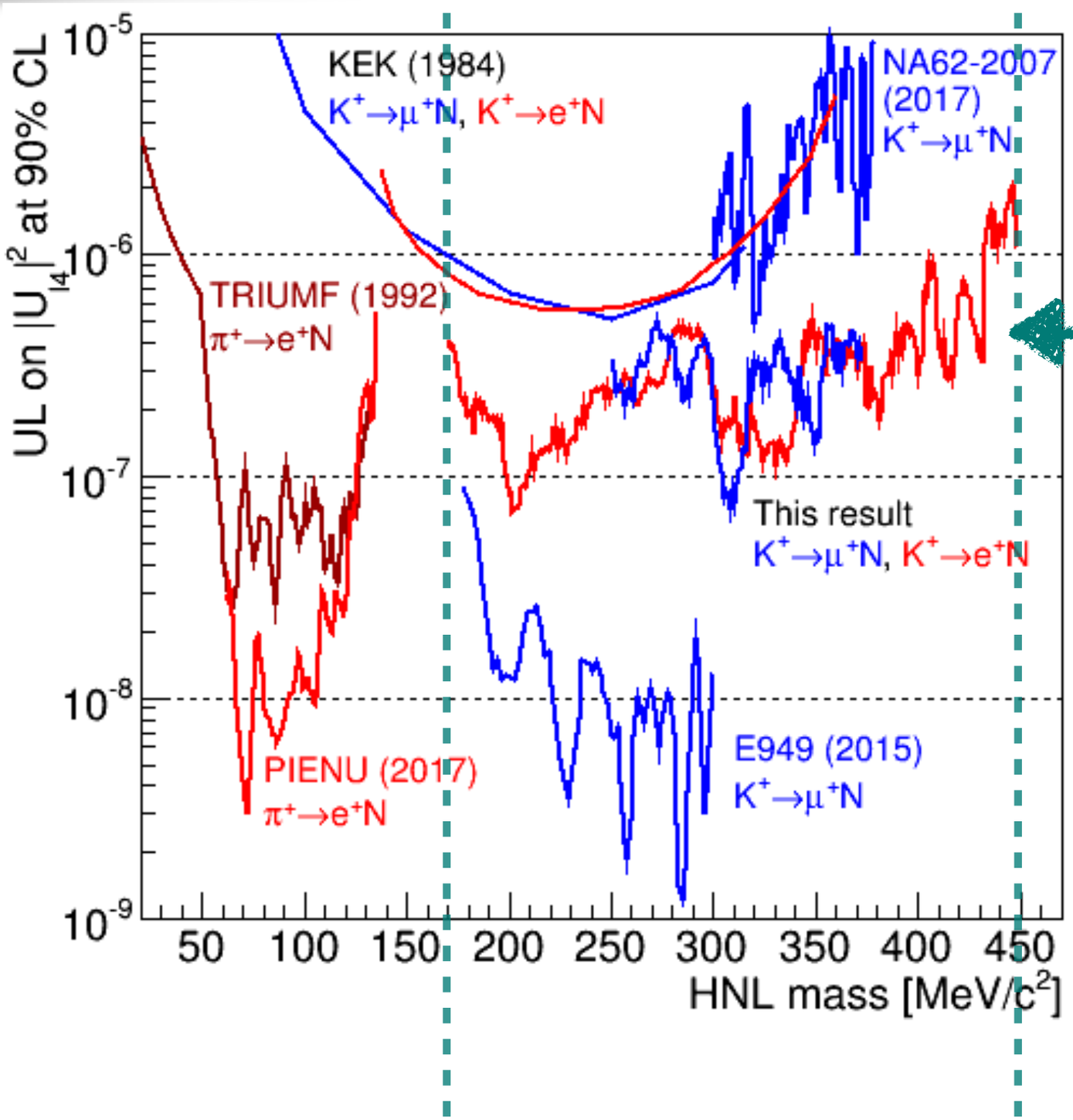


e channel



HNL Results

NA62 Collaboration
Phys. Lett. B778 (2018)



Previous result by NA62-2007

In range 170 - 450 MeV
Upper Limit of ~ 10^{-7} - 10^{-6}
on $|U_{l4}|^2$

The analysis of 2016-2018 data is ongoing

Expected large improvements on the sensitivity

- **Much larger data sample**
- **Kaon tracker (GTK) exploited => better HNL mass resolution and background rejection**

Dark photon

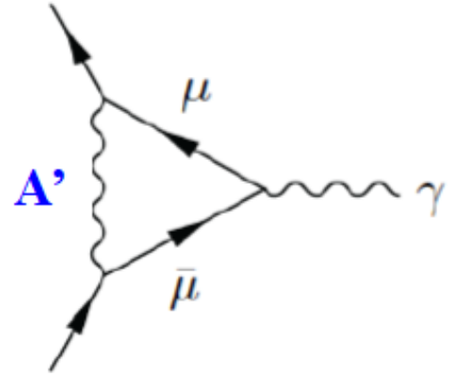
Extra U(1) symmetry Kinematical-mixed portal

$$\mathcal{L} = \mathcal{L}_{\psi,A} + \mathcal{L}_{\chi,A'} - \frac{\epsilon}{2} F_{\mu\nu} F'_{\mu\nu} + \frac{1}{2} m^2_{A'} (A'_\mu)^2$$

Dark U(1)'

$$-\frac{\epsilon}{2} F_{\mu\nu} F'_{\mu\nu} = A'_\mu \times (e\epsilon) J^{\mathrm{EM}}_\mu$$

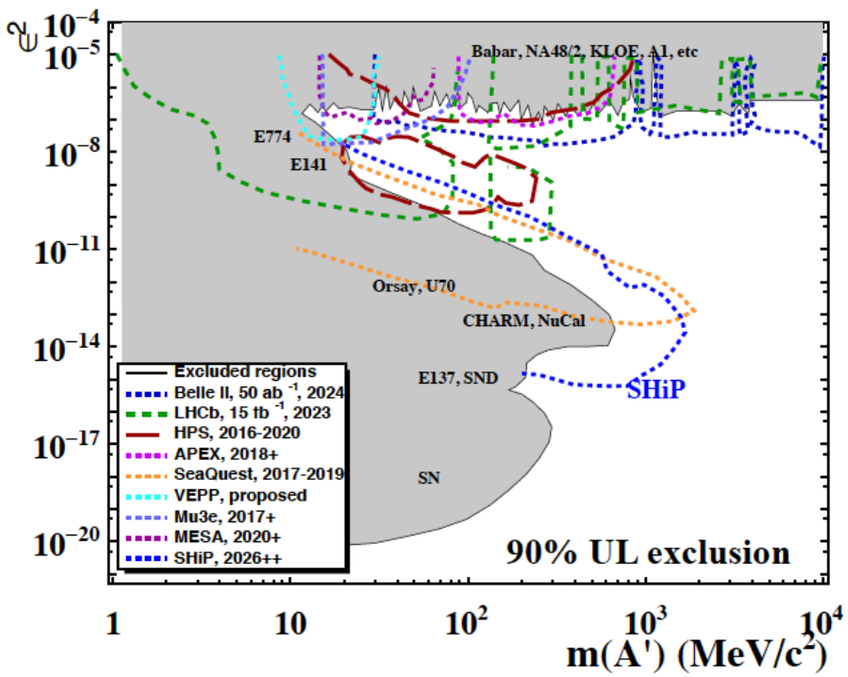
L.B. Okun Sov. Phys. JETP, 56 (1982), p. 502
B. Holdom, Phys. Lett. B 166 (1986) 196

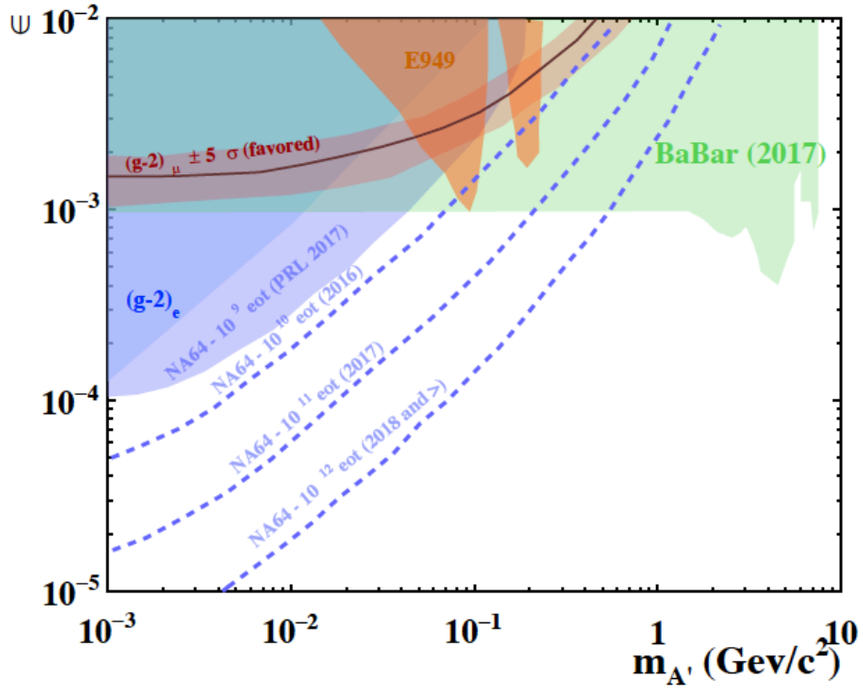


Astrophysical anomalies can be interpreted with this model

g-2, astrophysical positron excess, self-interacting dark matter → light vector new particle (MeV-GeV)

Light (~GeV) vector state with small couplings (not accessible at the energy frontier experiments)





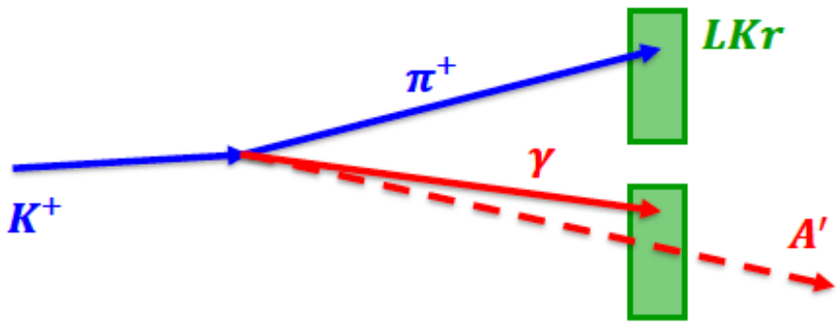
Dark photon to invisible

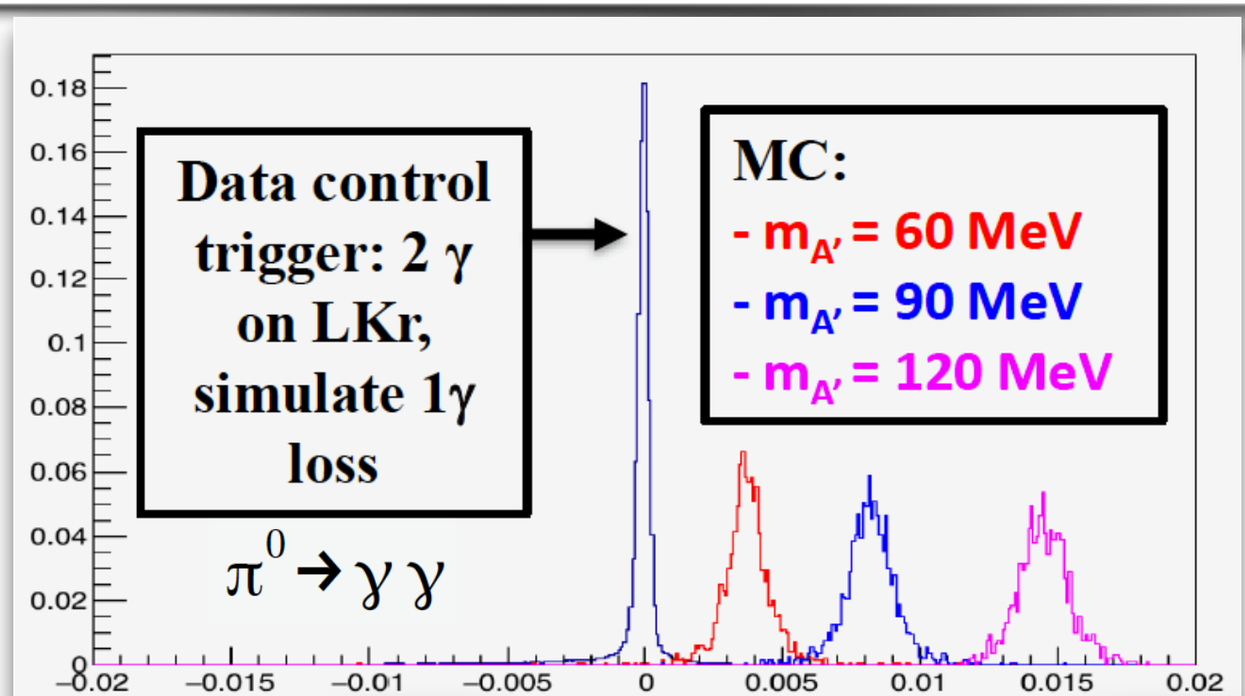
NA62 Preliminary

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

$\pi^0 \to A' \gamma$

$A' \to$ invisible





ε coupling:

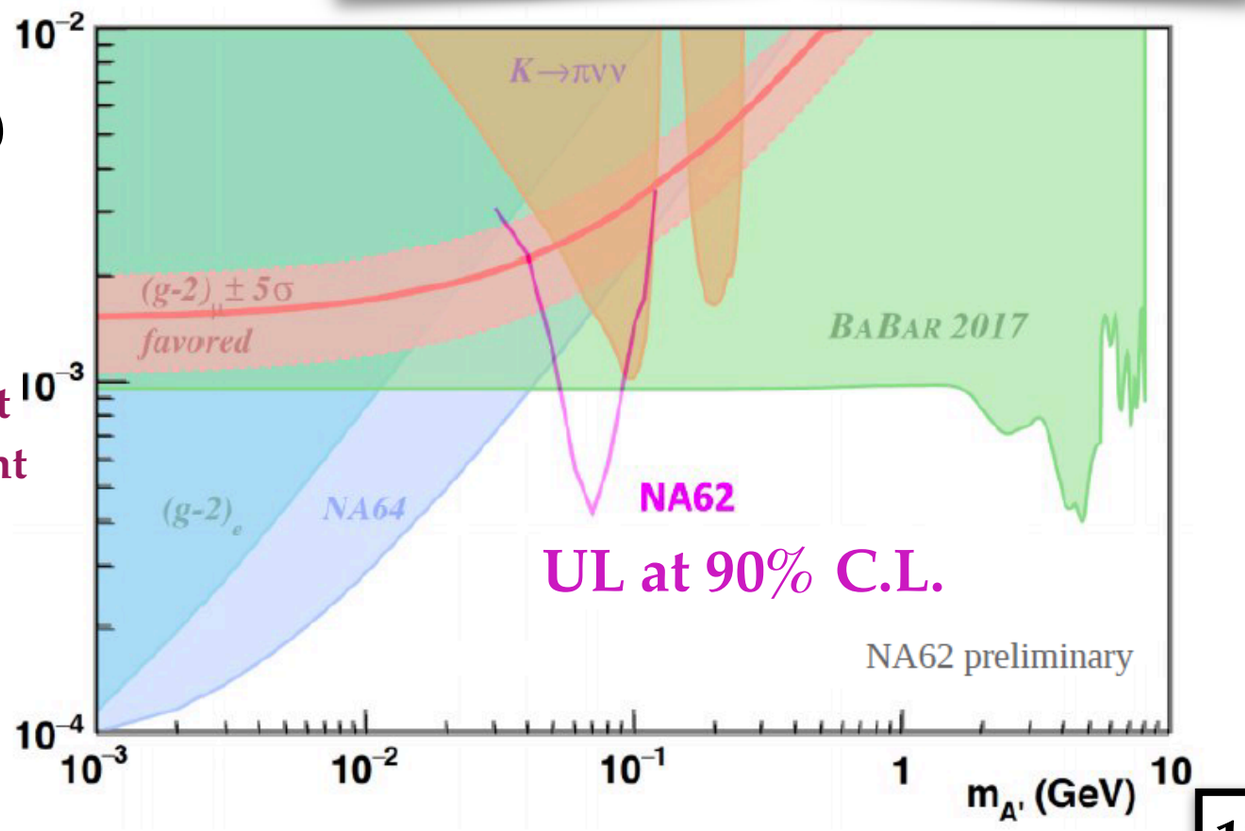
$$\mathrm{BR}\left(\pi^0 \to A'\gamma\right) = 2\epsilon^2 \left(1 - \frac{m_A^2}{m_{\pi^0}^2}\right)^3 \times \mathrm{BR}\left(\pi^0 \to \gamma\gamma\right)$$

$$\frac{n_{\mathrm{sig}}}{n_{\pi 0}} = \frac{\mathrm{BR}(\pi^0 \to A'\gamma)}{\mathrm{BR}(\pi^0 \to \gamma\gamma)} \varepsilon_{\mathrm{sel}} \varepsilon_{\mathrm{trg}} \epsilon_{\mathrm{mass}}$$

Obtained with data-driven and MC methods

Hypothesis mass cut Counting experiment upper limit

Analysis performed with 4% of 2016 data



LFV, LNV, LFUV searches

NA62 Work in progress

- **Lepton Universality test**

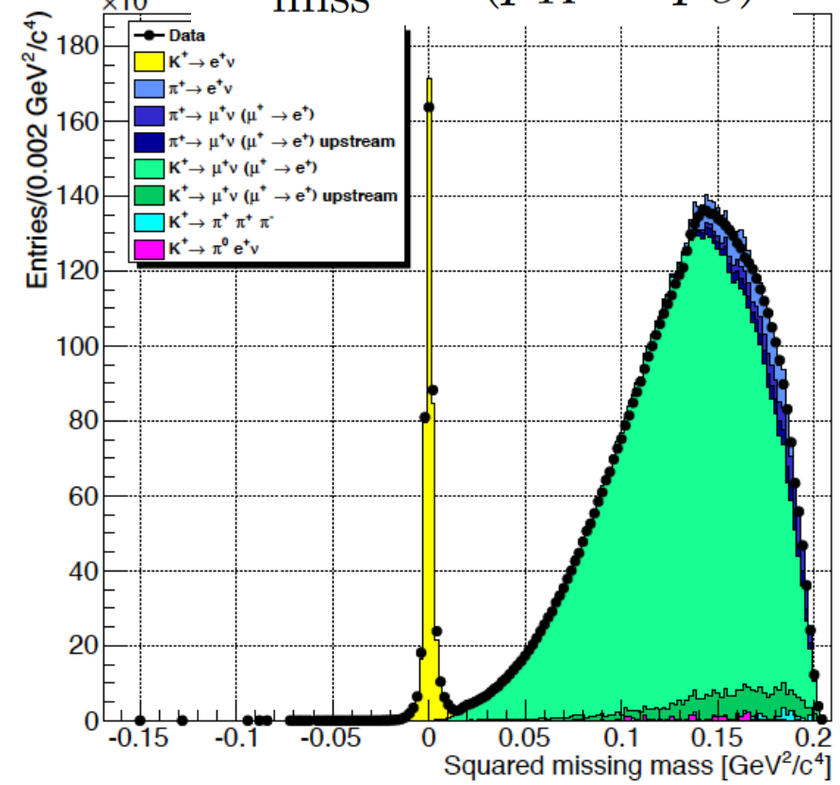
$$R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$$

2017 dataset

World largest sample of $K^+ \to e^+\nu$ candidates

New measurement method gets rid of most of the systematics which limited the 2007 NA62 measurement

$$m^2_{\mathrm{miss}} = (p_K - p_e)^2$$



- **Dedicated multitrack trigger from July 2016**
  - **LNV: $K^+ \to \pi^-\mu^+e^+$**
  - **LFV: $K^+ \to \pi^-\mu^{+/-}e^{-/+}$**

Channel	Br	
$K^+ \to \pi^+\mu^+e^-$	$< 1.3 \times 10^{-11}$	E865, E777
$K^+ \to \pi^+\mu^-e^+$	$< 5.2 \times 10^{-10}$	E865
$K_L \to \pi^0\mu^\pm e^\mp$	$< 7.6 \times 10^{-11}$	KTeV
$K_L \to \mu^\pm e^\mp$	$< 4.7 \times 10^{-12}$	E871

In the next slides: $K \to \pi\mu\mu$ $K \to \pi ee$:

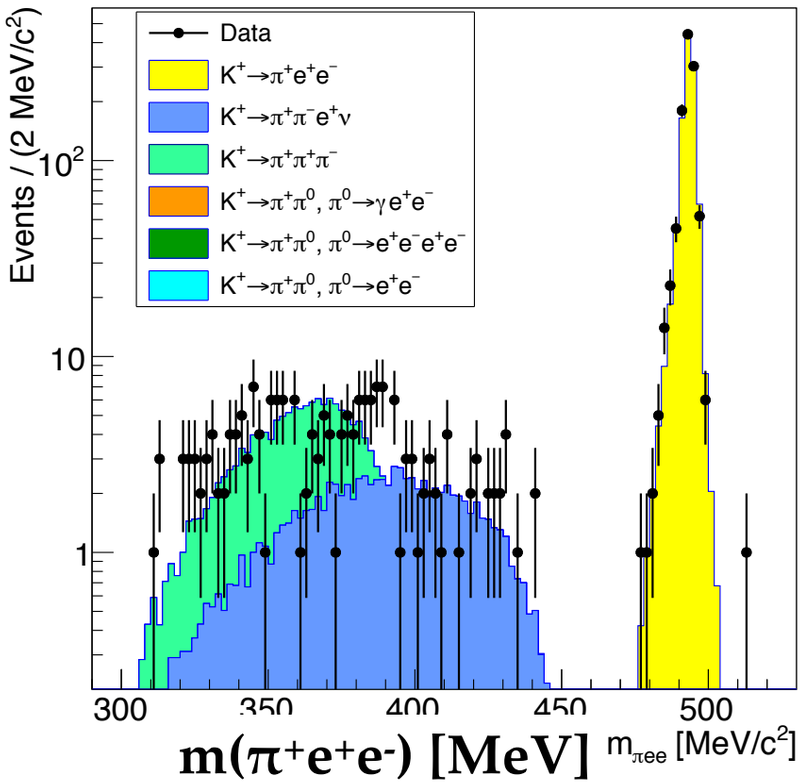
- **Data samples: 50% of 2016 + 25% of 2017**

NA62 will improve the existent upper limit to several forbidden or highly suppressed decays

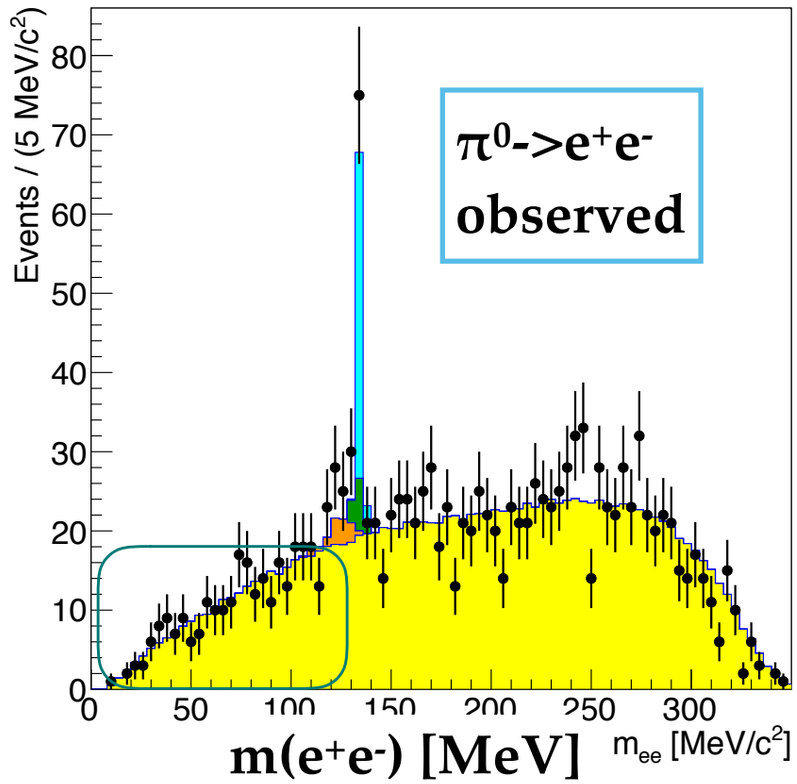
K-> πee data sample

NA62 Work in progress

m($\pi^+e^+e^-$) for m(ee)>140 MeV

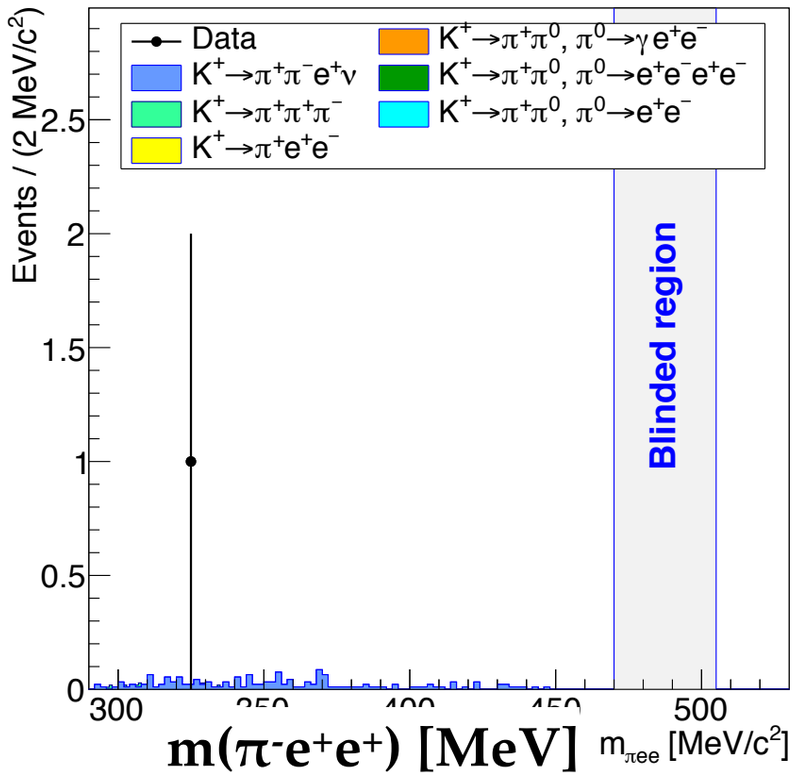


m(e^+e^-) for 488<m($\pi^+e^+e^-$)<150 MeV



<u>Search for $K^+ \to \pi^- e^+ e^+$</u>

m($\pi^- e^+ e^+$)



1.1x10^3 K->πee events
Already large sample

For m(ee)<140 MeV
the process K->πee is observed

<u>10^{-9} sensitivity for BR($K^+ \to \pi^+ X$)</u>

X: new short-lived particle (τ_X<1ns)

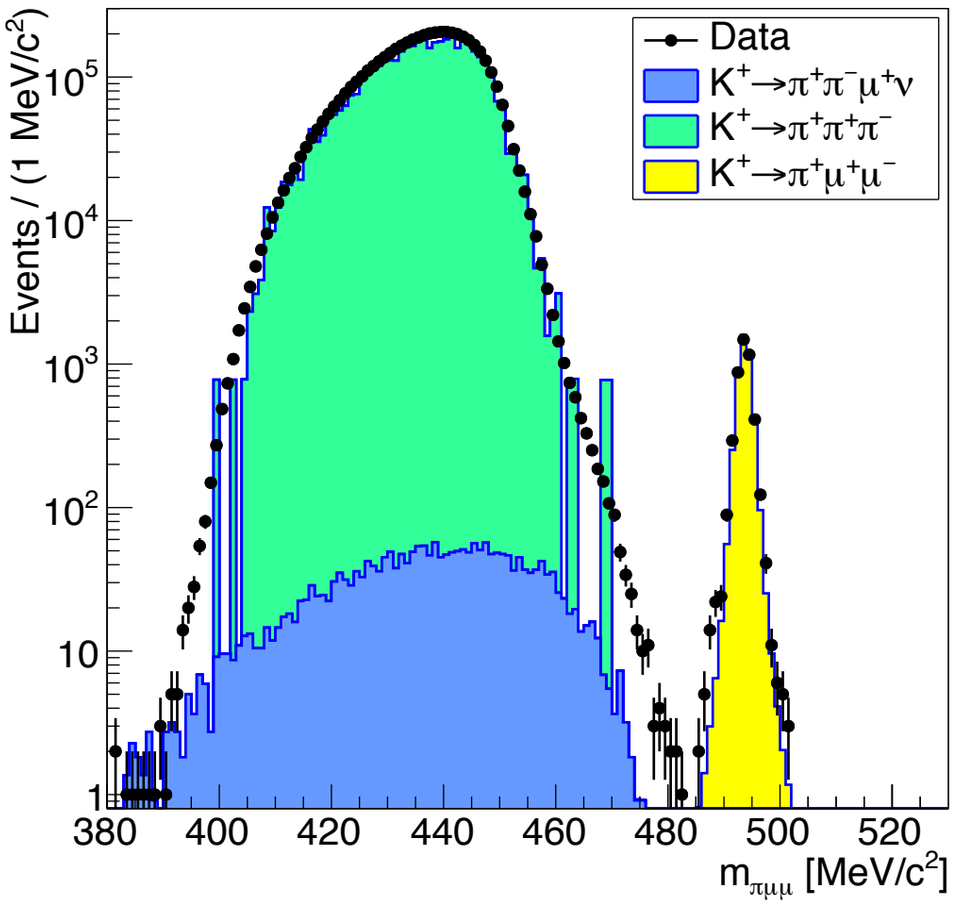
Background free

<u>2 x 10^{-10} sensitivity for BR($K^+ \to \pi^- e^+ e^+$)</u>

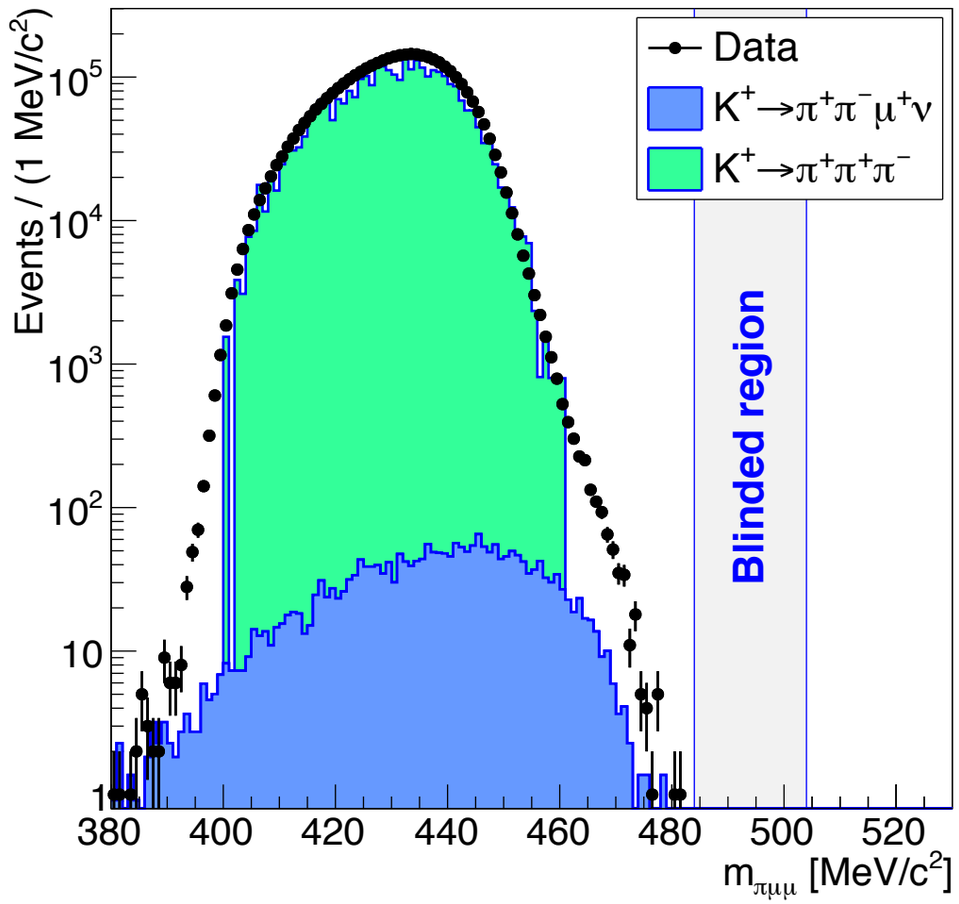
$K^+ \to \pi\mu\mu$ data sample

NA62 Work in progress

$m(\pi^+\mu^+\mu^-)$



$m(\pi^-\mu^+\mu^+)$



- **World largest $K^+ \to \pi^+\mu^+\mu^-$ data sample: 4.6 10^3 events**
- **$m(\pi^+\mu^+\mu^-)$ resolution ~1.2 MeV**
- **With full NA62 dataset 10^4 candidate events are expected**
- **Expected O(10^{10}) sensitivity for search for $K^+ \to \pi^+ S$, $S \to \mu^+\mu^-$ with $\tau <$ O(1 ns)**

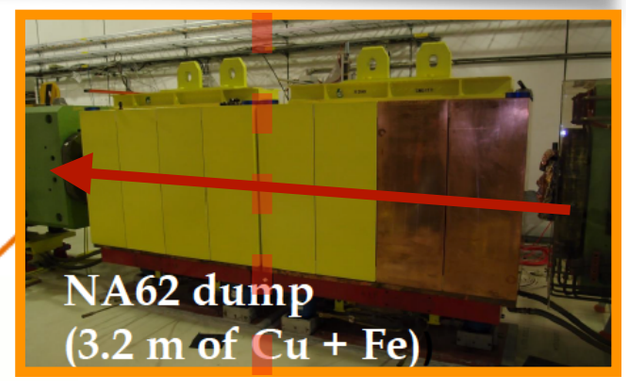
Low statistics in the MC samples

Exotic prospects

NA62 Work in progress

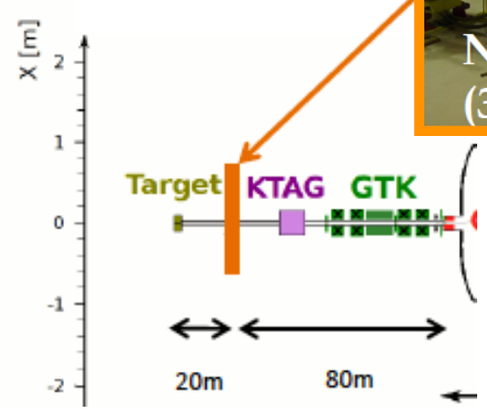
- **High intensity beam**
- **Excellent detector performance**

NA62 can be exploited to search for mediators of several new physics scenarios



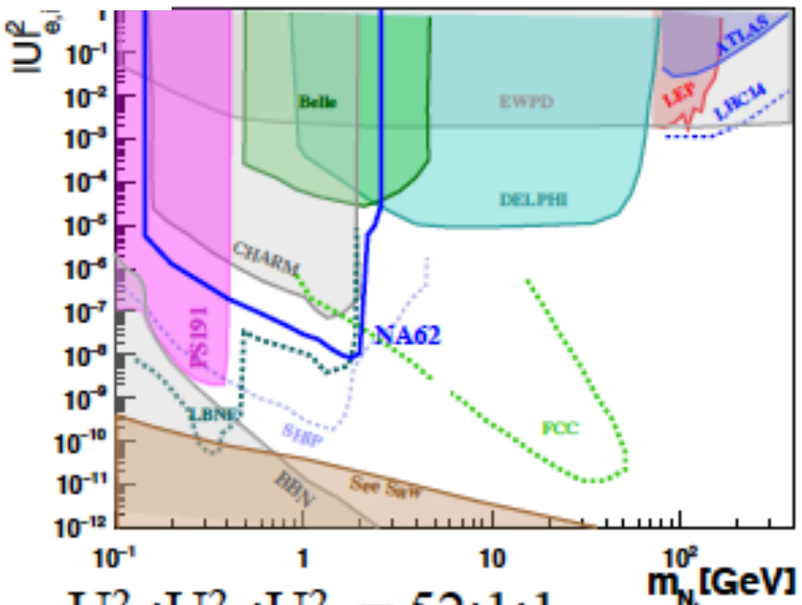
Dump mode: copper collimators can be closed
And target removed

Also D (and B) mesons can be produced
Searches for new particles in D (and B) decays



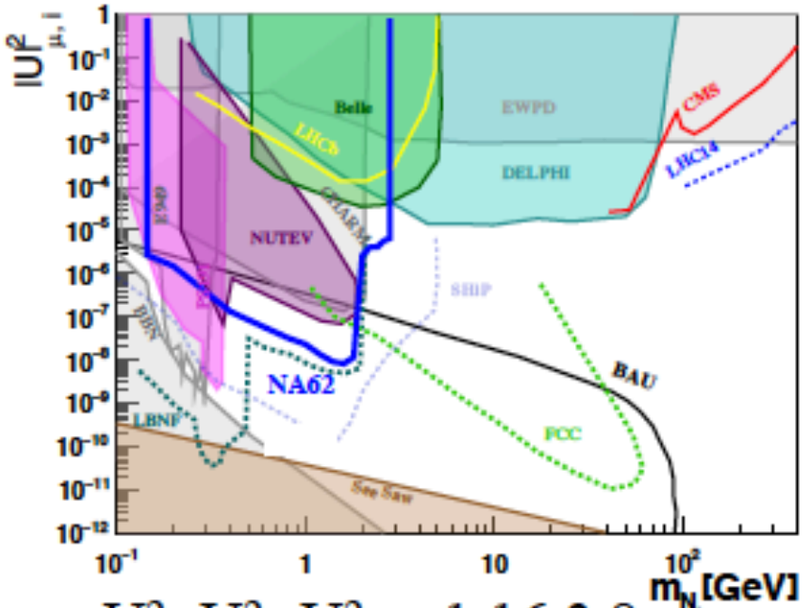
Examples:

✤**HNL:** Search in two tracks final state



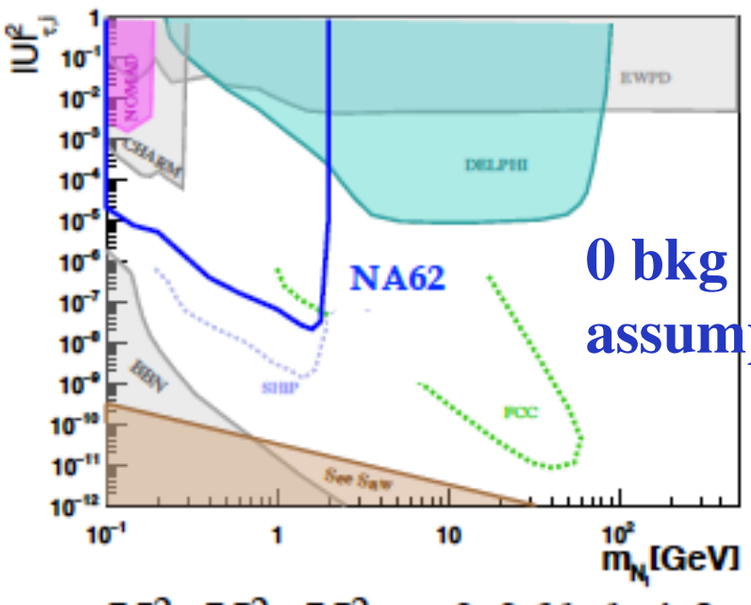
$U^2_e : U^2_\mu : U^2_\tau = 52:1:1$

Normal hierarchy of active ν masses



$U^2_e : U^2_\mu : U^2_\tau = 1:16:3.8$

Normal hierarchy of active ν masses



0 bkg assumption

$U^2_e : U^2_\mu : U^2_\tau = 0.061:1:4.3$

Normal hierarchy of active ν masses

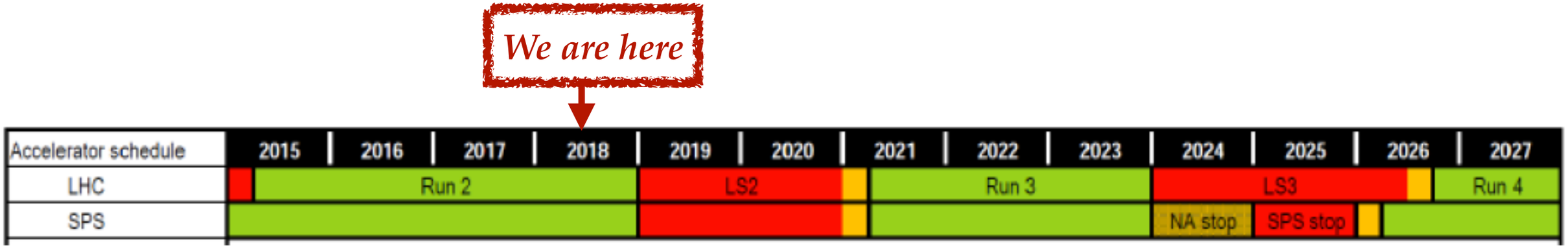
✤**ALPs (Axion Like Particles) :** **JHEP 1602, 018 (2016)**

Analysis of 1 day taken in beam mode is in progress, looking for 2 photons final state

Conclusions

Not only $K^+ \to \pi^+ \nu\nu$

- ☑ **HNL search published with 2015 dataset, large improvements expected with 2016-2018 dataset**
- ☑ **Preliminary results on dark photon decaying to invisible**
- ☑ **First look at the data samples for LFV/LNV searches: expect to improve the existent upper limit for several final states**
- ☐ **Several analyses are ongoing both in kaon and in dump mode**



Target mode

Small sample in dump mode
Special trigger to select 2 tracks (no kaon required)

Target mode and dump mode
(3 months-> 10^{18} pot)

Other experiments dedicated to to hidden sector (SHIP, etc…)

Stay tuned!

Thank you for your attention