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Search for exotics at NA62

A. Shaikhiev
(Institute for Nuclear Research RAS, Université catholique de Louvain)
on behalf of the NA62 collaboration

Outline

- NA62 experiment
- Exotic searches
  - Heavy Neutral Leptons
  - Axion-Like Particles
  - Dark Photon
- Conclusions

NA62 experiment (decay-in-flight)

- Main goal is measure ultra rare kaon decay $K^+ \to \pi^+ \nu\nu$ with 10% precision
- SM prediction:

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$

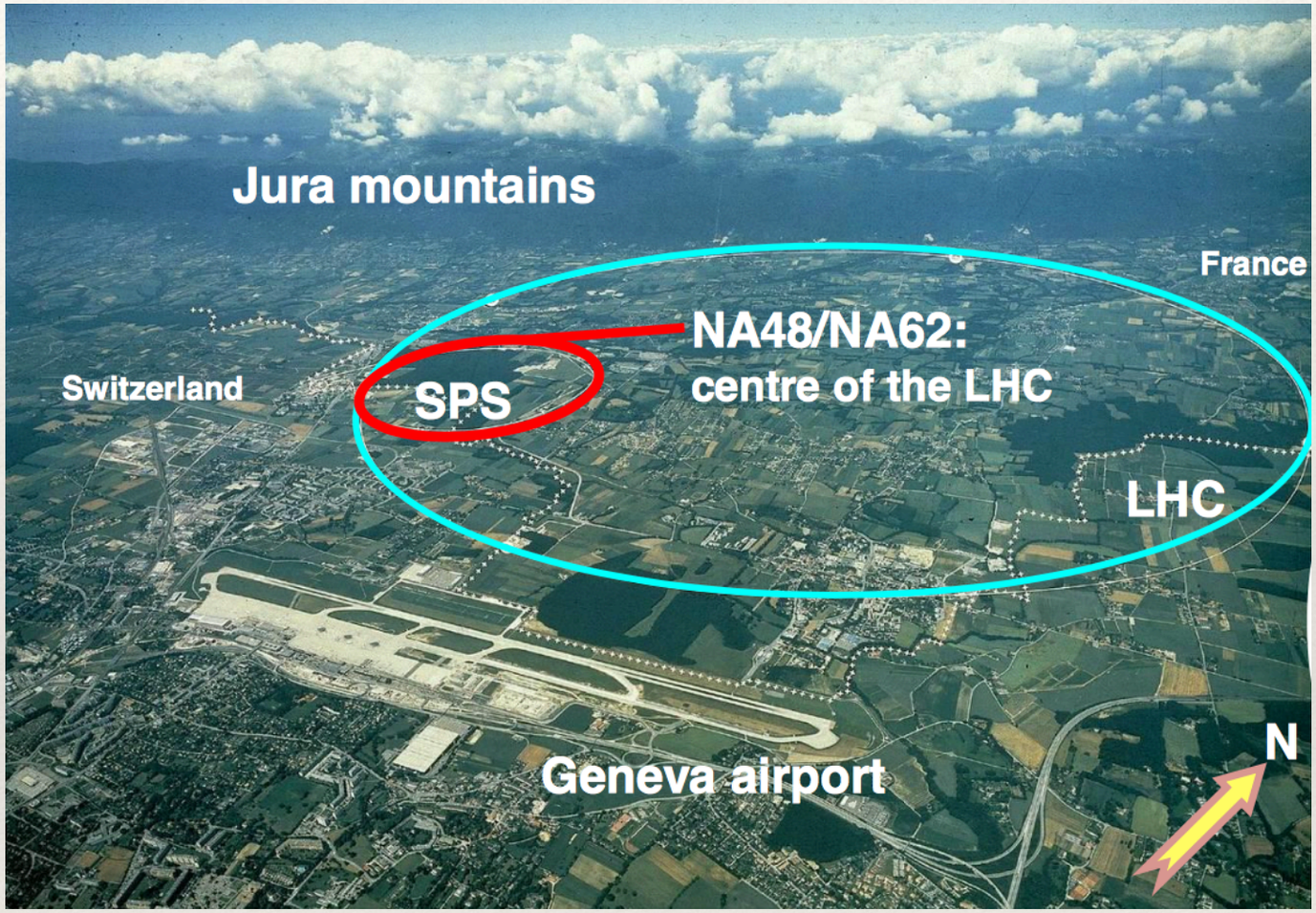
[Buras et al., JHEP 1511 (2015) 033]

- Experimental value

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

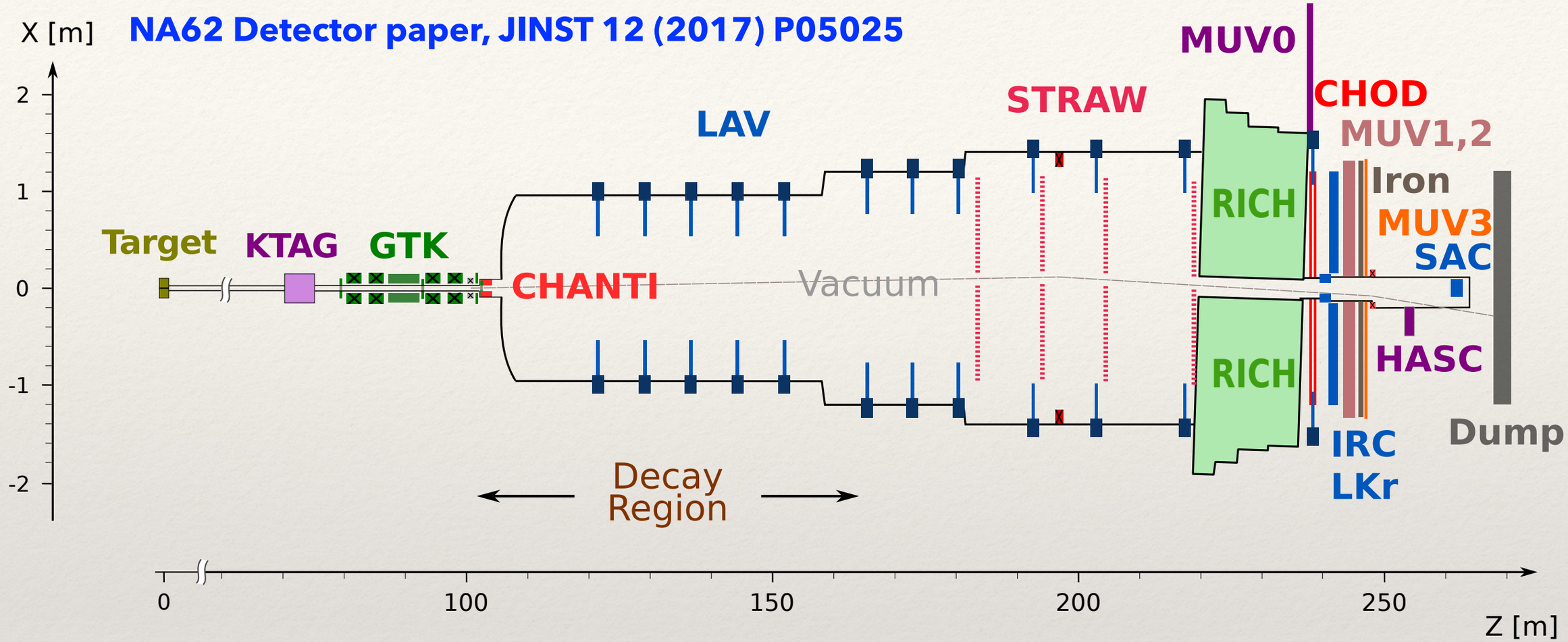
[E949/E787 PRL 101 (2008) 191802]

- See V. Duk talk for details



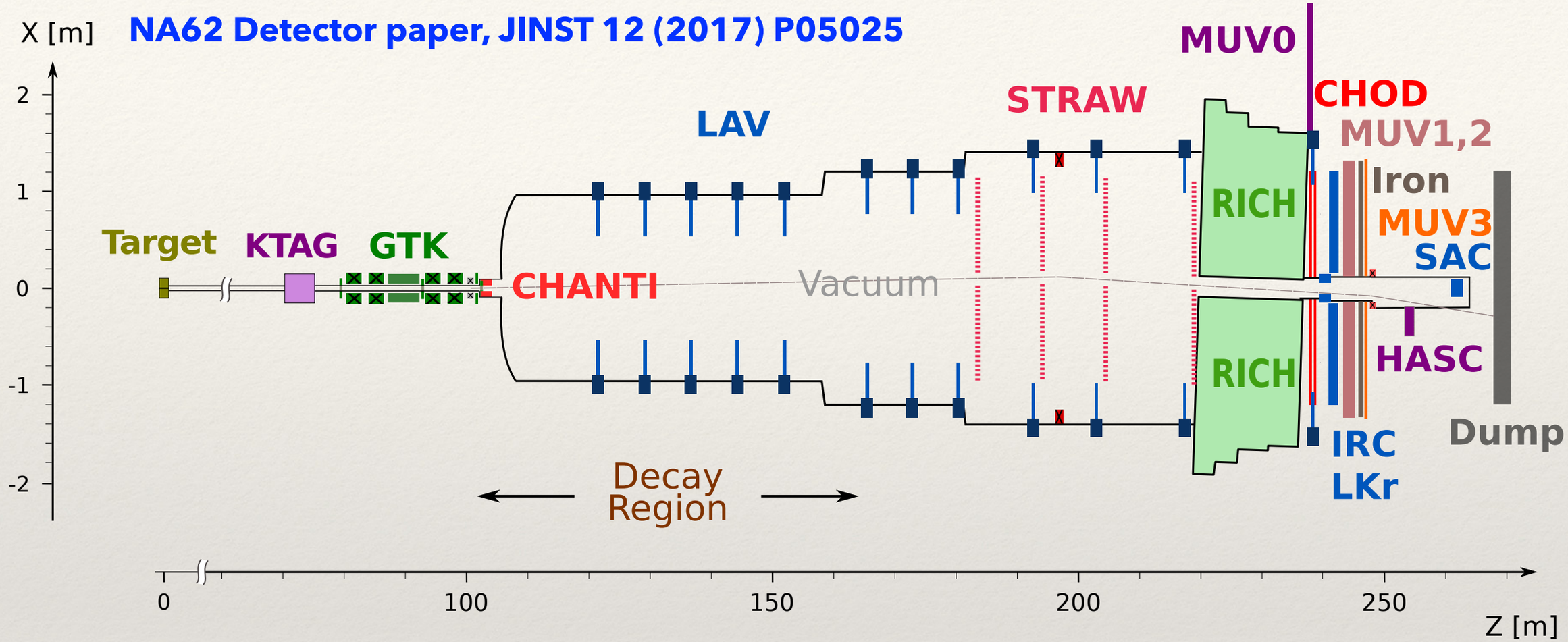
~30 institutes, ~200 participants form: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC

NA62 beam & detector



- SPS beam: 400 GeV/c protons on Be target (POT), ~10^{12} POT/sec, 3.5 sec/spill
- Unseparated secondary hadron beam: π^+(70%)/K^+(6%)/p(24%)
- 750 MHz beam rate @GTK (45 MHz kaon component)
- K^+ beam: 75±1 GeV/c, 60×30 mm^2 transverse size
- 10% of kaons decay in 60 m fiducial volume

NA62 beam & detector



- Kaon ID and direction (KTAG, GTK, CHANTI)
- Pion ID and direction (STRAW, CHOD, RICH)
- Photon veto (Large Angle Veto 12 stations, LKr, Small Angle Veto)
- Muon veto (MUV1,2,3)

Beyond the SM

Neutrino oscillation

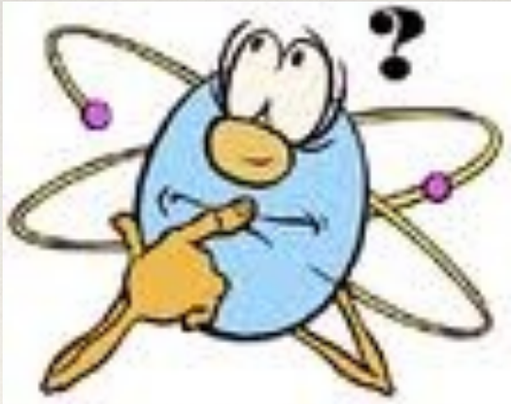
Baryon asymmetry of the Universe

Dark matter and dark energy

There is New Physics beyond the Standard Model, but we don't know exactly what is it

Search for New Physics:

- Study of rare decays of the SM particles
- Search for new particles (HNL, ALP, dark photon etc.)
- Search for forbidden (in the SM framework) processes



Heavy Neutral Leptons (HNL)

- The νMSM (Asaka et al., Phys.Lett.B 620 (2005) 17) is an extension of the SM to explain simultaneously neutrino oscillations, dark matter and baryon asymmetry of the Universe.
  - SM + 3 right-handed sterile neutrinos:
    - N_1: m_1 ~ 10 keV — dark matter candidate
    - $N_{2,3}$: $m_{2,3}$ ~ 100MeV — 100 GeV — baryon asymmetry
- Production in the meson decays, for example $K^+ \to l^+ N$ $(l=e,\mu)$

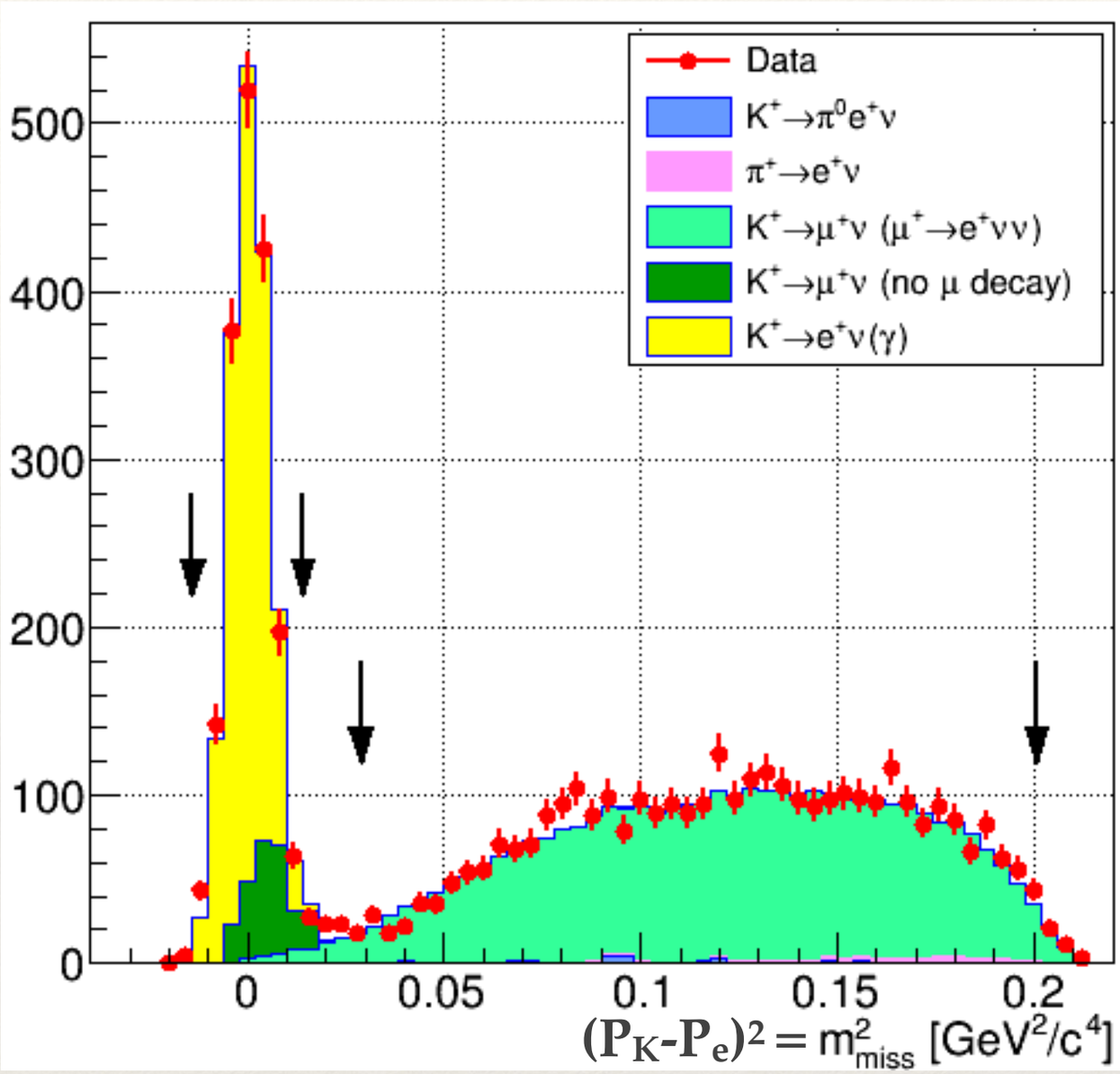
$$\Gamma(M^+ \to l^+ \nu_H) = \rho \times \Gamma(M^+ \to l^+ \nu_l) \times |U_{lH}|^2$$

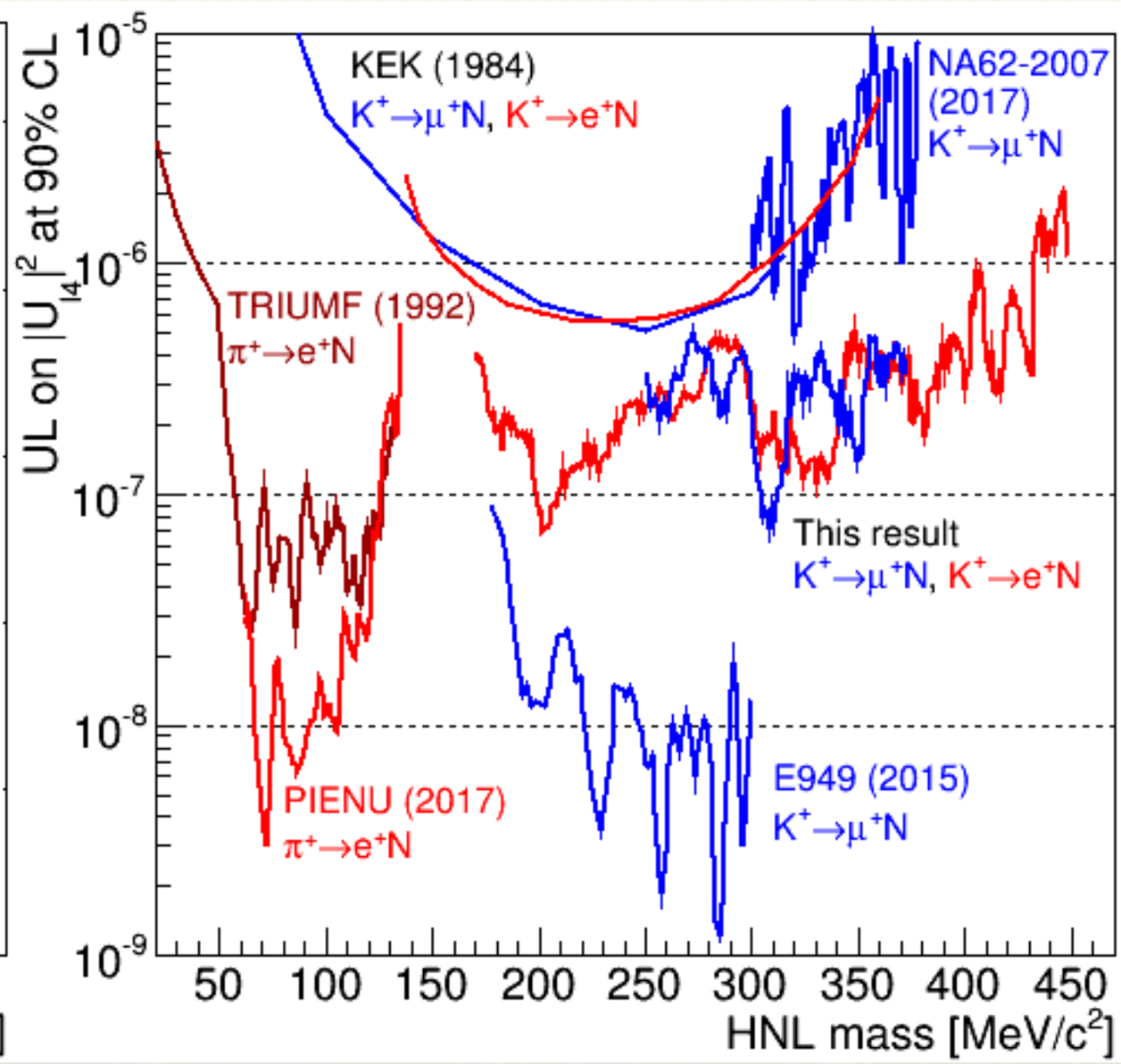
R.E.Shrock, Phys.Rev.D24 1232 (1981)

Heavy Neutral Leptons (HNL)

- Peak search in the missing mass distribution $(P_K\text{-}P_l)^2$, P_K is kaon four-momentum, P_l is lepton four-momentum
- 2015 minimum bias data (~1% of intensity)
- Kaon decays in the fiducial volume: ~3×10^8 $K^+\to e^+\nu$, ~1×10^8 $K^+\to\mu^+\nu$
- Beam tracker (GTK) is not available: kaon momentum is estimated as beam average
- Polynomial fit of the background (data-driven expected background)
- Upper limit for each mass is obtained from numbers of observed and expected events and their uncertainties

Heavy Neutral Leptons (HNL)

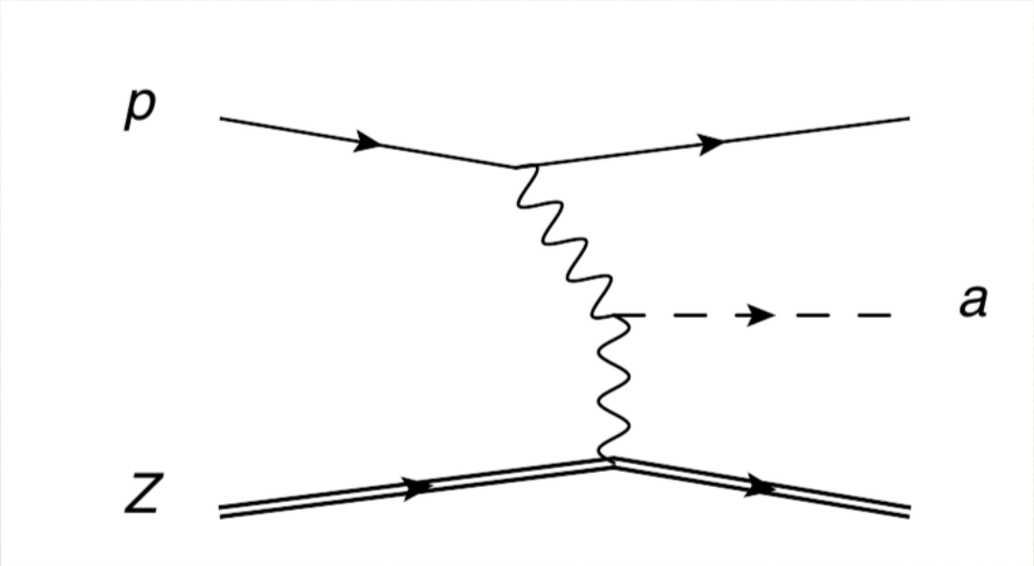


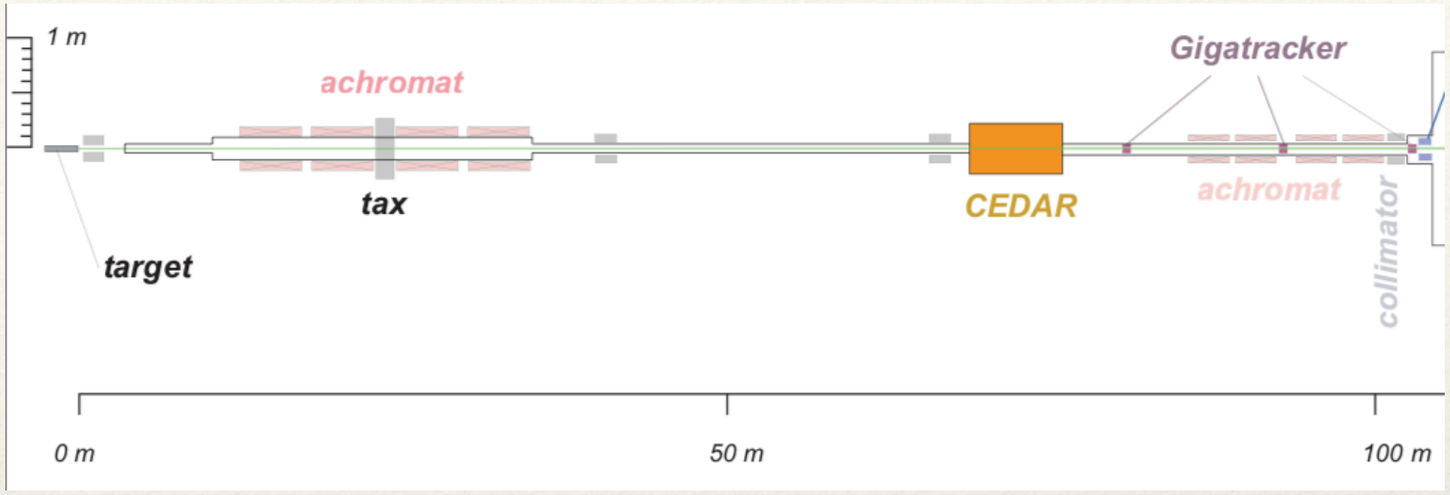


NA62 collaboration, Phys.Lett.B778 (2018) 137

- No signal observed
- Currently analysing 2016—2018 data: expect more strong limits due to using GTK and much more statistics
- Close related study: $K^+ \to l^+ \nu\nu\nu$ and $K^+ \to l^+ \nu X$

Axion-Like Particles (ALPs)

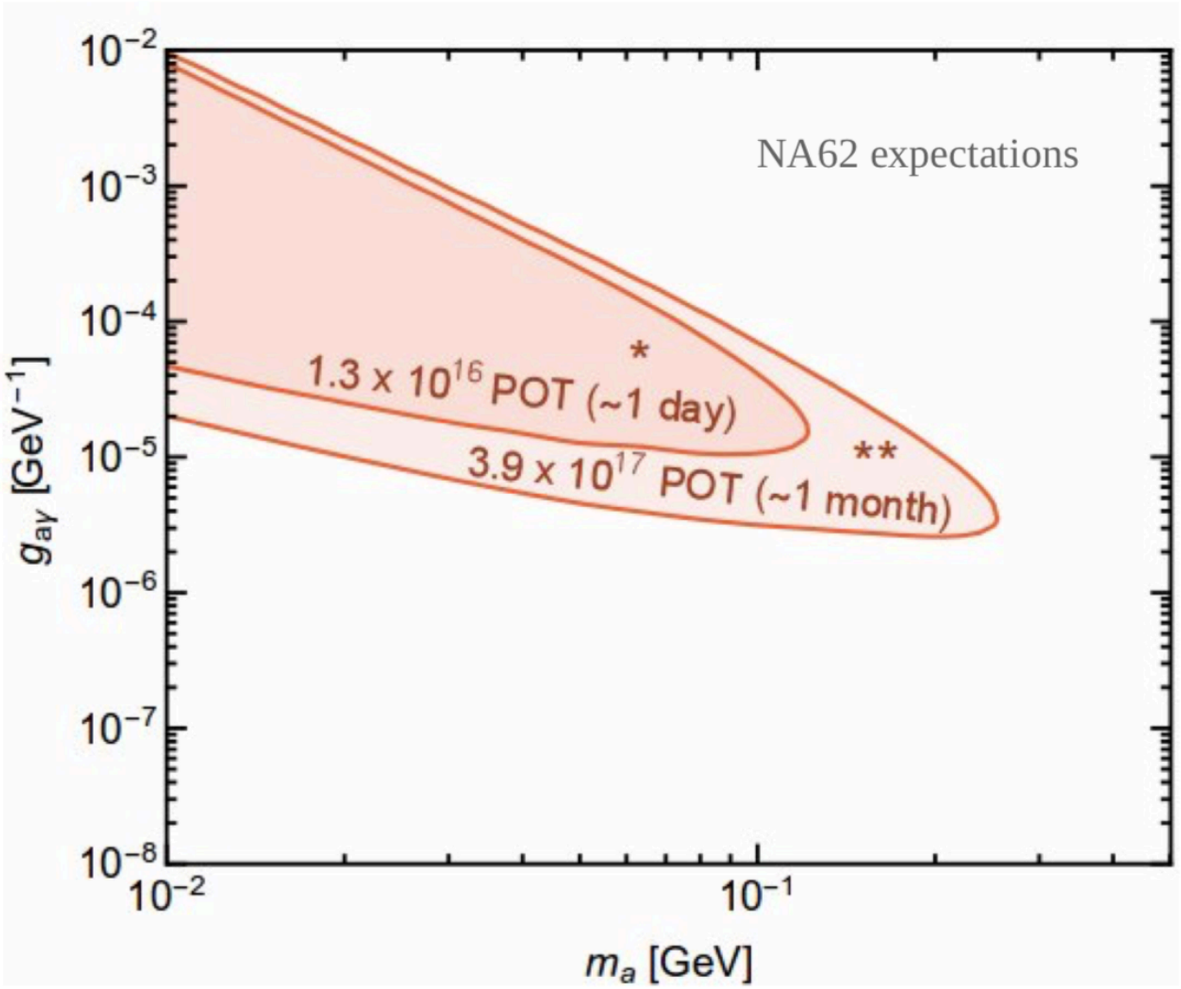


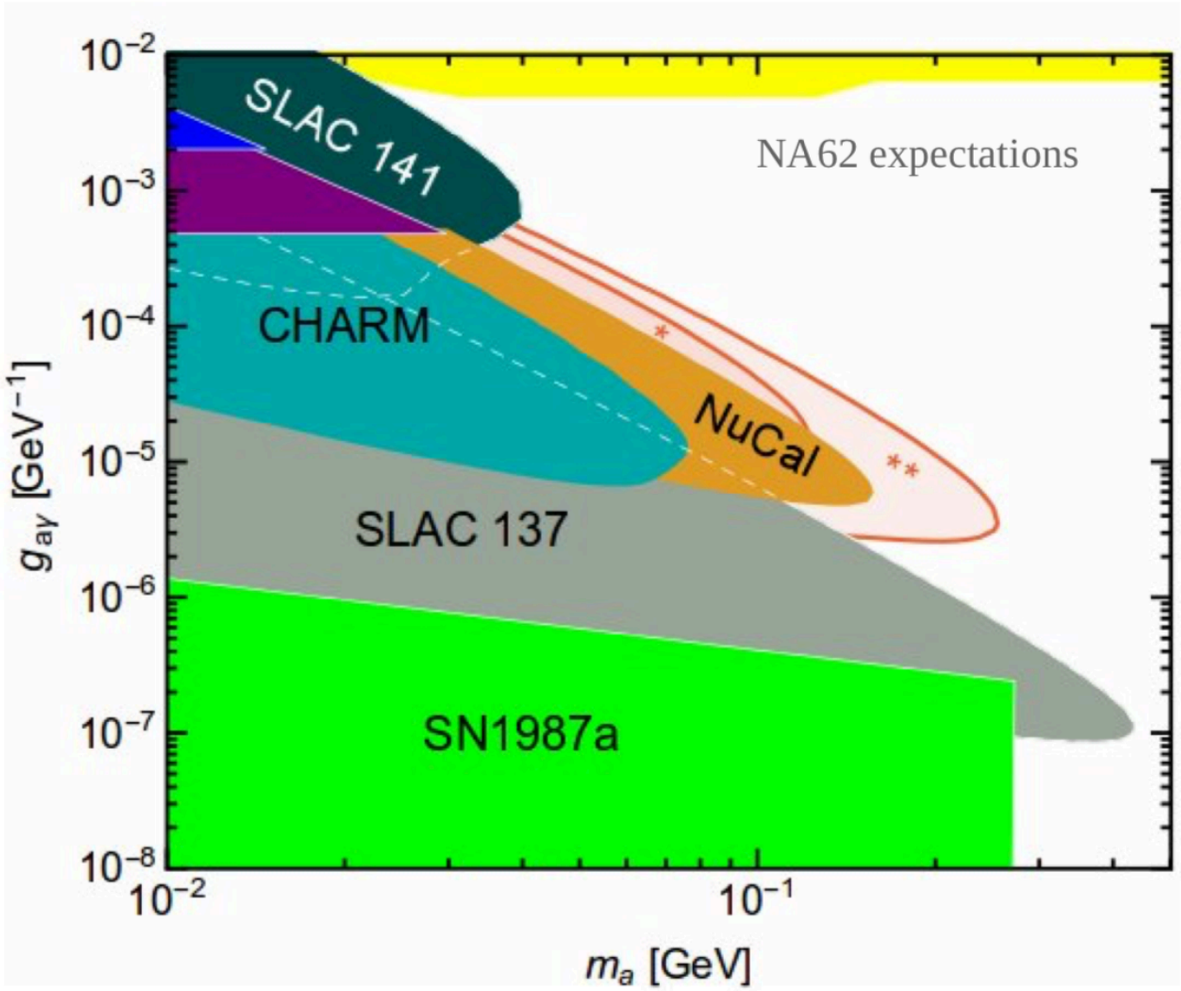


- Cold dark matter candidate
- NA62 can explore ALPs masses in the MeV to GeV range (JHEP 1602 (2016) 018)
- Study ALPs Primakoff production from beam protons interaction on TAXes (copper collimators, 25m after the target, each 1.6m long) + decay to **γ γ**. Search must be performed in the beam dump mode — closed TAXes
- NA62 has hermetic photon veto to reject π^0 to study the "golden" mode $K^+ \to \pi^+ \nu\nu$

Axion-Like Particles (ALPs)

- Significant results are expected with only one day of data taking (~1.3×10^{16} POT)
- Analysis of 2017 data ongoing (~5×10^{15} POT)



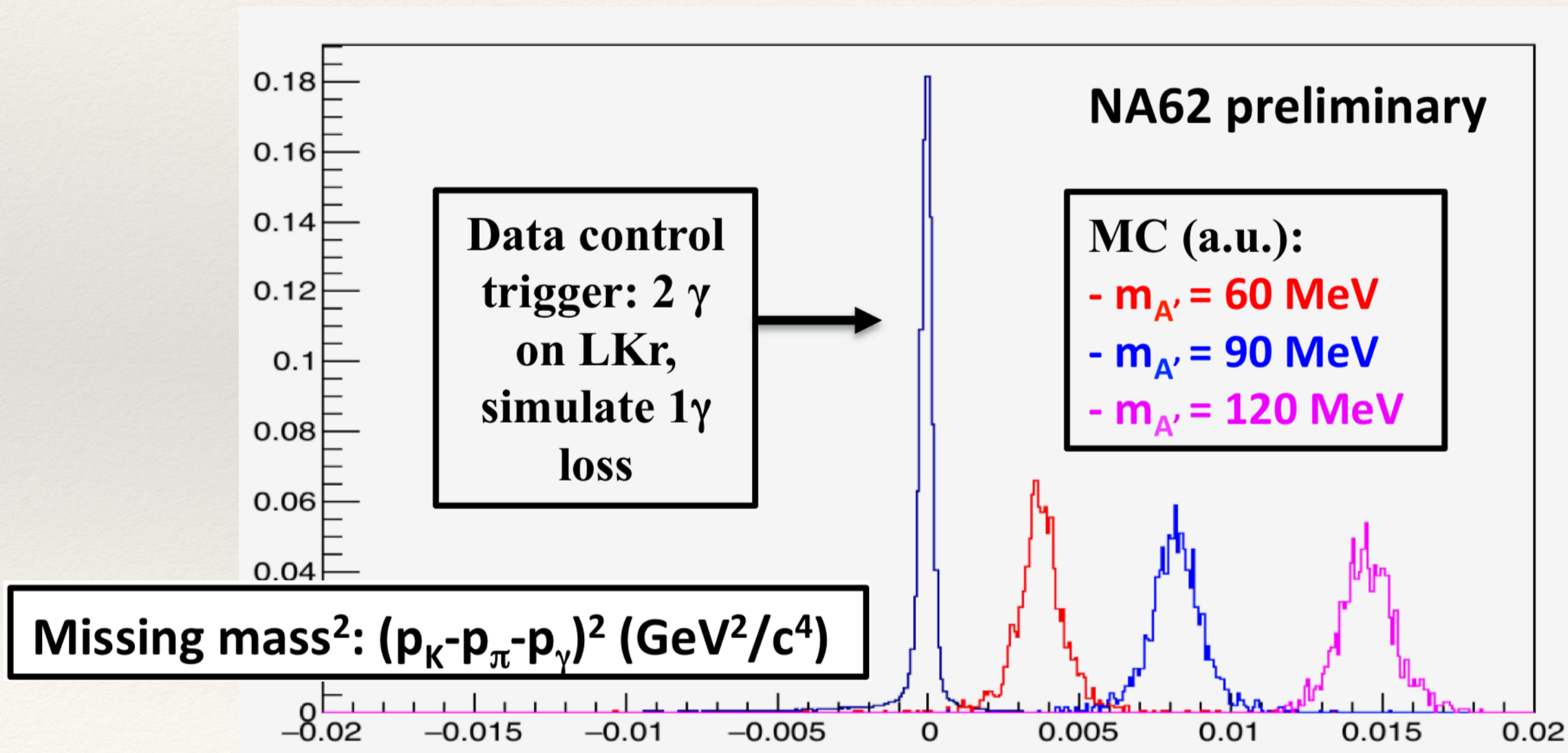


Dark Photon

- Clear sign for New Physics is Dark Matter existence
- Dark photon is a mediator of DM-SM non-gravitational interaction
- Can explain e+ excess in cosmic rays, muon (g-2) anomaly
- NA62 are able to perform DP searches for both visible and invisible modes

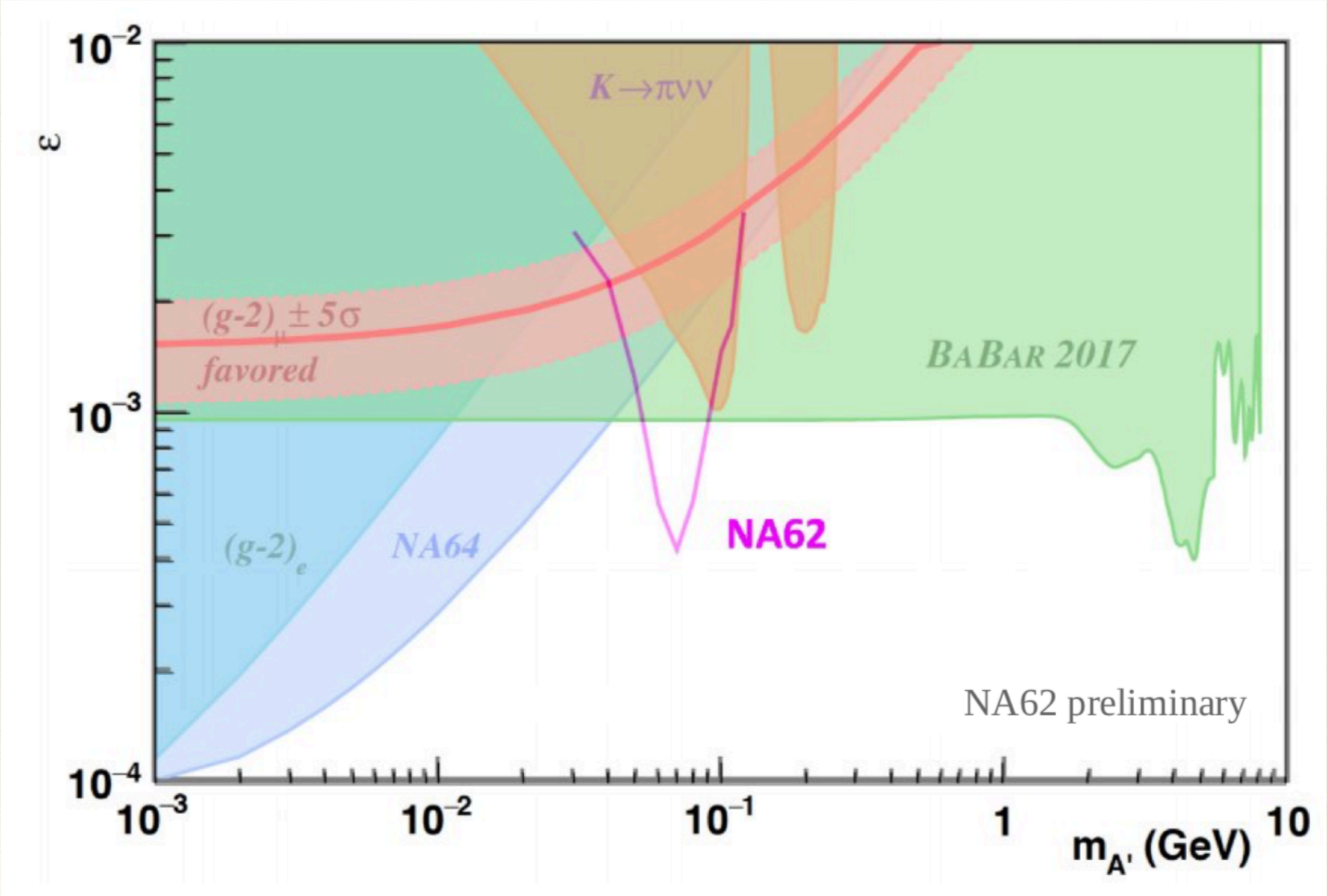
Dark Photon (invisible mode)

- $K^+ \to \pi^+\pi^0$, $\pi^0 \to A'\gamma$, $A' \to$ invisible
- Signal signature: one track, one photon + missing energy
- Search for an invariant mass peak around A′ mass
  - dominant background $\pi^0 \to \gamma\gamma$ with one lost photon



Dark Photon (invisible mode)

- Background from data, symmetrising resolution tails
- Analyzed 2016 data with ~1.5×10^{10} K^+ decays (~4% 2016 data)
- No signal observed, 90%CL upper limit



Dark photon (visible mode)

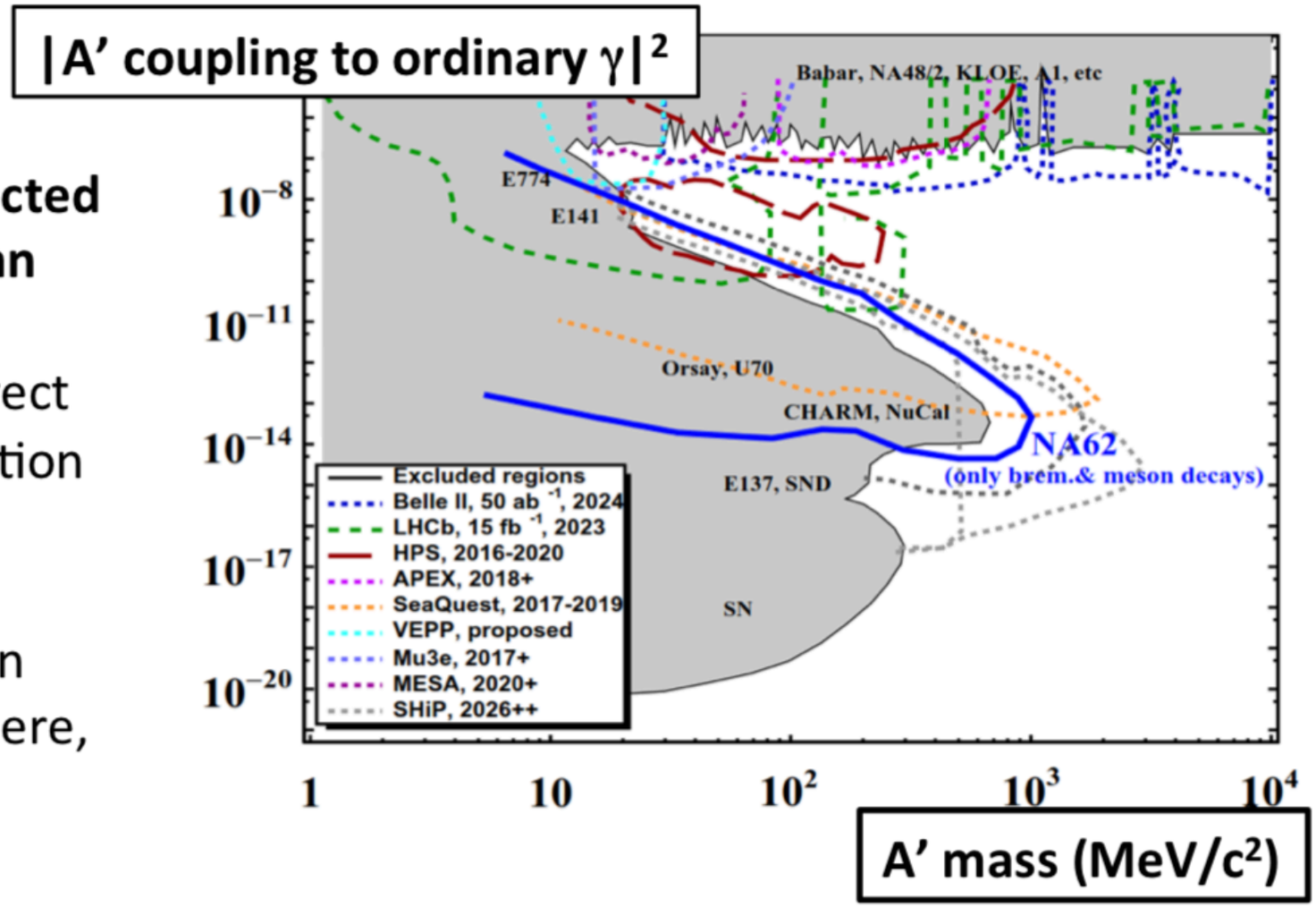
Slide from T.Spadaro talk at
32th Rencontres De Physique De La Vallee D'Aoste

Assume 10^{18} 400-GeV POT :

Study DP production (meson decays, bremsstrahlung) from interaction onto **target**
search for DP-decay to ee, μμ in NA62 fiducial volume, account for geometrical acceptance
assume zero-background, evaluate expected 90%-CL exclusion plot

Sensitivity expected to be higher than shown:

1. including direct QCD production of A'
2. Including A' production in the dump (here, only target)



NA62 evaluation cross-checked with full MC

~3 10^{17} POT acquired in 2016/17 with di-muon parasitic trigger, 5 10^{16} POT with ee trigger

Conclusions

- 2018 data taking ongoing
- HNL: new limits with 2015 data sample. Expect improvements with 2016—2018 data set
- ALPs: analysis of 2017 data ongoing
- Dark Photons: new limits using 4% of 2016 data. New results coming with improved statistics

THANK YOU!