Prospects for exostics and LFV at NA62

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on behalf of NA62

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Introduction

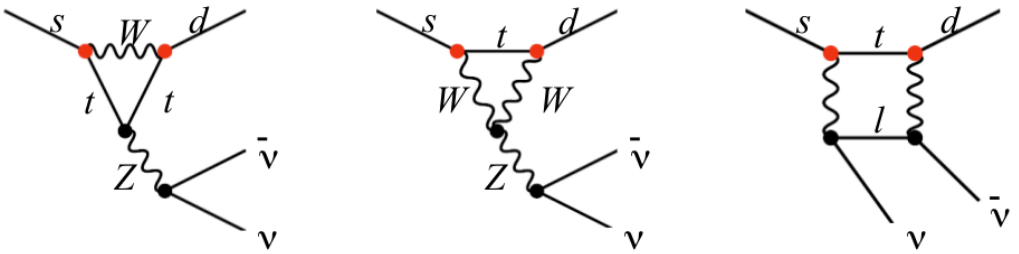
- **NA62 is approved to run until LS2**
- **Main goal:** $BR(K^+ \to \pi^+ \nu \bar{\nu})$ with 10% accuracy

This talk:

- **Broader physics program until LS2 (Run 2):** LNV / LFV modes, heavy neutrinos, π^0 rare decays, …

- **Broader physics program beyond LS2 (Run 3):** LNV / LFV modes, heavy neutrinos, π^0 rare decays, hidden sector particles searches in kaon decays

NA62 experiment: $K \to \pi \nu \bar{\nu}$ decays



- FCNC processes dominated by Z-penguin and box amplitudes, theoretically clean, sensitive to various NP models (**see talk by G.Rugguero, this conference**)
- **SM prediction:** Buras et al., JHEP 11 (2015) 033

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \cdot 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2°}\right)^{0.74} = (8.4 \pm 1.0) \cdot 10^{-11}$$

- **Experimental status:**

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

Stopped K^+, 7 events observed E787/E949, PRL 101 (2008) 191802

- **NA62 goal:** $\mathbf{BR(K^+ \to \pi^+ \nu\nu\text{-bar})}$ with O(10%) total uncertainty (~10^{13} K^+ in 2 yrs)

NA62 detector and beam line

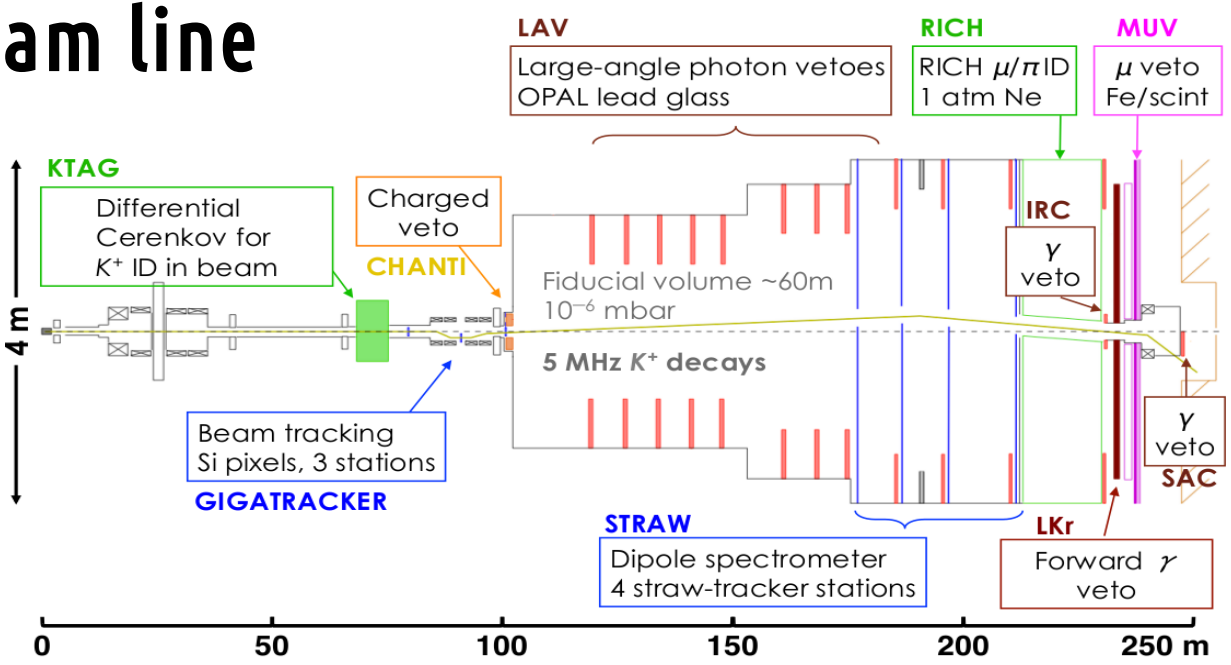
- NA62 is designed to collect **100** $K^+ \to \pi^+ \nu\nu$ events with **only 10 bkg.**

- **~10^{13} K^+** decays in the fiducial volume would be needed.

- This high-intensity and high-performance setup make **NA62 perfectly suited for other NP searches in kaon decays!**

- Trigger bandwidth is limited! The **trigger strategy for exotic processes is critical!**

- The detector and beam line are fully **commissioned and performing as expected (see G. Ruggiero talk).**



	NA48/2	NA62-RK	NA62
Data taking	2003-4	2007-8	**2014-18**
Primary intensity (ppp)	7×10^{11}	7×10^{11}	**3×10^{12}**
Solid angle (μsr)	~0.4	~0.4	**~12.7**
Beam momentum (GeV)	60	74	75
RMS momentum bite (GeV)	2.2	1.4	0.8
Spectrometer thickness, X_0	2.8%	2.8%	1.8%
Spectrometer P_T kick, MeV	120	265	270
$M(K \to \pi^+\pi^+\pi^-)$ resolution, MeV	1.7	1.2	0.8
K decays in fiducial region	2×10^{11}	2×10^{10}	**1.2×10^{13}**

Prospects for NP searches by 2018

- Trigger bandwidth for final states other than $\pi^+ + E_{miss}$ is limited to a **few 100 KHz**
- **LFV/LNV studies** that involve **low-bandwidth triggers for 3-track states** easy to include:

  $K^+ \to \pi^+ \mu^\pm e^\mp$, $K^+ \to \pi^- \mu^+ e^+$, $K^+ \to \pi^- e^+ e^+$, $K^+ \to \pi^- \mu^+ \mu^+$

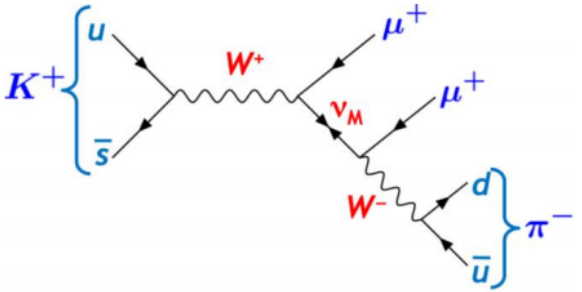
- Possible to do some other studies in parasitic mode with the main trigger:

  HNL in $K^+ \to \mu^+ N$, $K^+ \to e^+ N$
  Rare π^0 decays (Dark photon searches,...**)**

- L0 of the NA62 trigger system is implemented in hardware, **based on FPGA** technology
  Multiple track trigger can be set based on **RICH PMTs multiplicity** and **CHOD quadrants**
  Dielectron trigger: **multiple track + more than 10GeV in the LKr**
  Dimuon trigger: **multiple track + signals in two MUV3 tiles**
  LFV (muon-electron) trigger: **multiple track + more than 10GeV in the LKr + one MUV3 tile**

- Validation of the trigger rates and efficiencies with data is currently underway

NP searches in $K^+ \to \pi\mu\mu$ decays



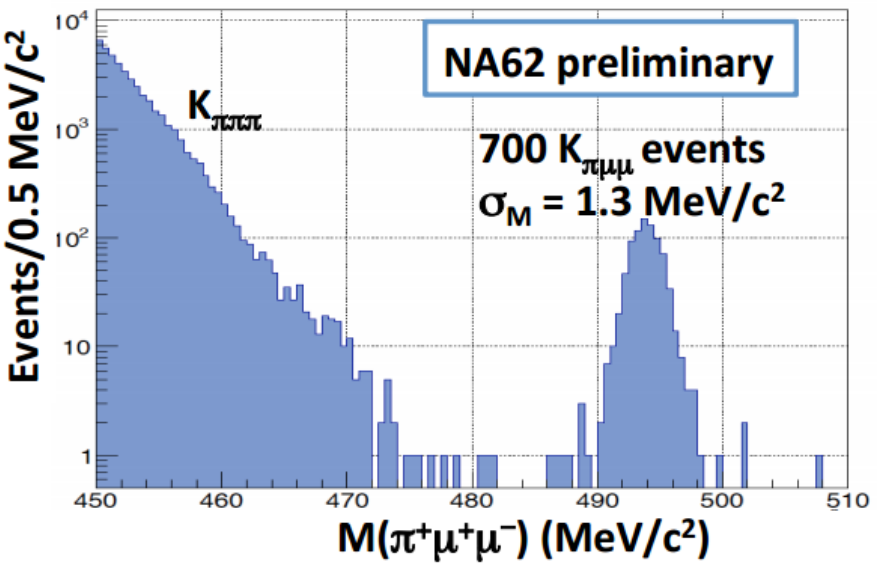
- **Search for Majorana neutrinos** in **LNV** $K^+ \to \pi^- \mu^+ \mu^+$ decays
  Asaka-Shaposhnikov model (vMSM) [PLB 620 (2005) 17]
  Dark Matter + Baryon Asymmetry (BAU) + low mass of SM ν can be explained by adding three sterile Majorana neutrinos to the SM
  Current limits set by NA48/2 (see talk by M. Piccini talk at this conference; paper in prep.)
  $BR(K^\pm \to \pi^\mp \mu^\pm \mu^\pm)$ **$< 8.6 \times 10^{-11}$** @ 90% CL [World Best Limit]
  Same-sign muons sample (decay chain $K^+ \to \mu^+ N$, $N \to \pi^- \mu^+$) Limit set at ~10^{-10} (90% CL) NA48/2

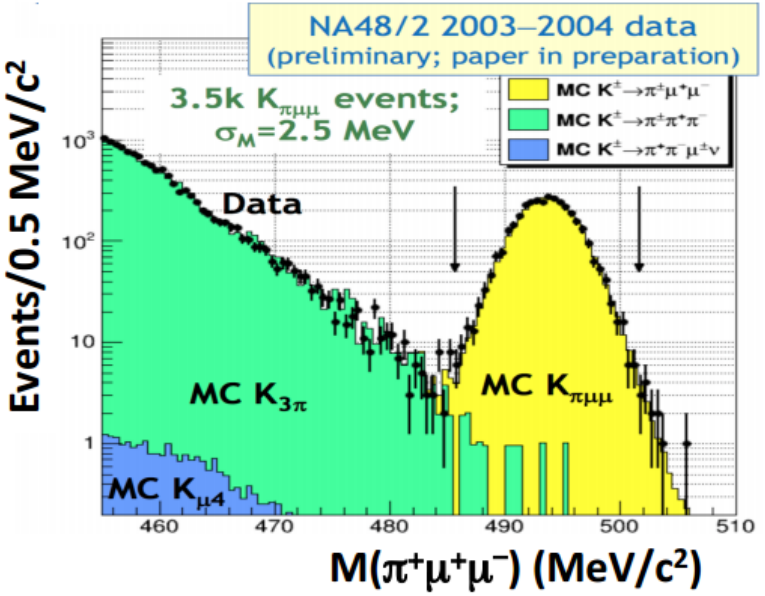
- Search for resonances (N, X, etc.) in the **opposite-sign muons sample**
  Shaposhnikov-Tkachev model [PLB 639 (2006) 414]
  vMSM + real scalar field (inflaton X) with scale invariant couplings
  Explains universe homogenity and isotropy on large scales/structures on smaller scales
  Current limits:
  Heavy neutrinos peak search in $K^+ \to \mu^+ (\pi^+ \mu^-)$
  Inflatons peak peak search in $K^+ \to \pi^+ (\mu^- \mu^+)$ Limits set at ~10^{-9} (90% CL) NA48/2

Dedicated $K^+ \to \pi\mu\mu$ trigger at NA62

- **First look at the 2016 data: ~60K bursts** taken at **18% intensity**
- Dedicated **trigger for three track di-muon events** which runs in parallel with the main trigger
- The **mass resolution at NA62 is better by a factor ~2** as compared to NA48/2

- **NA62 can potentially improve by two orders of magnitude the NA48/2 results**





Other LFV/LNV processes

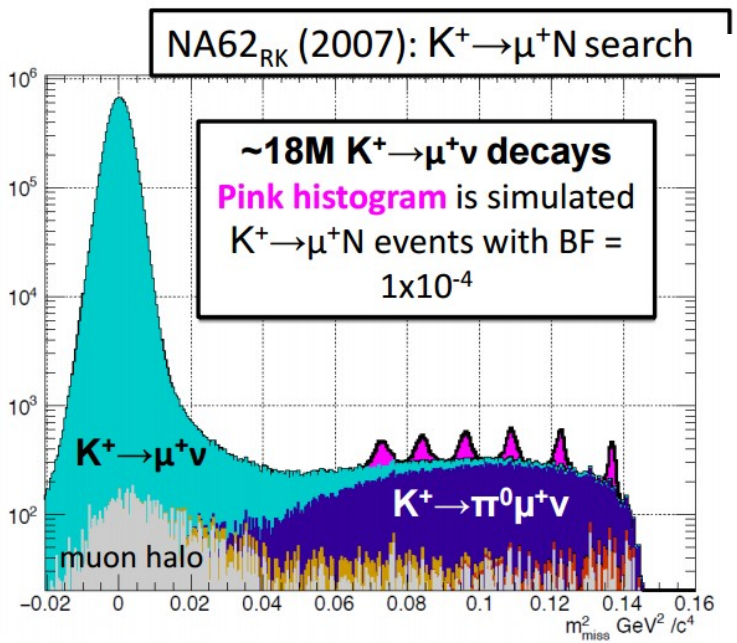
Mode	UL at 90% CL	Experiment	Reference
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	BNL E777/E865	PRD 72 (2005) 012005
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}		
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	BNL E865	PRL 85 (2000) 2877
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}		

Recently observed deviations form SM in semileptonic B-meson decays hint at NP (consistent with MFV) that could produce LFV in K^+ decays
talk by L.Tunstall at this conference

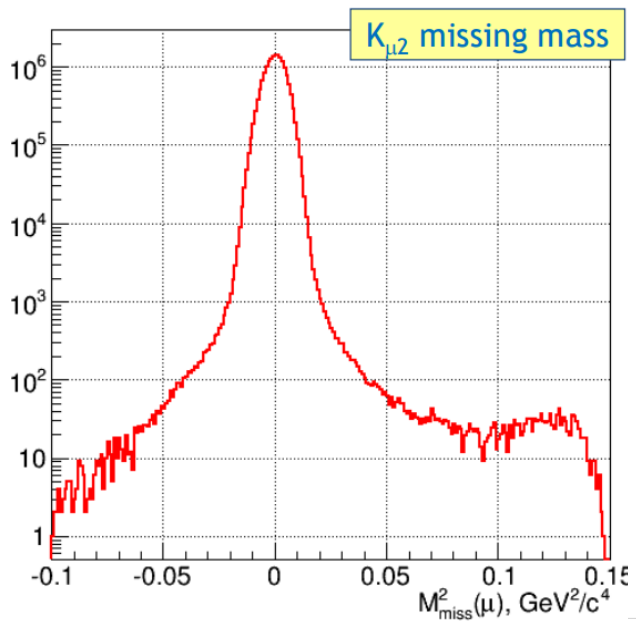
The parameter space relevant for the explanation of the B-meson anomalies lies within the sensitivities of the NA62 experiment. Expected sensitivity ~10^{-12}) (with a dedicated trigger) [hep-ph/1601.00970]

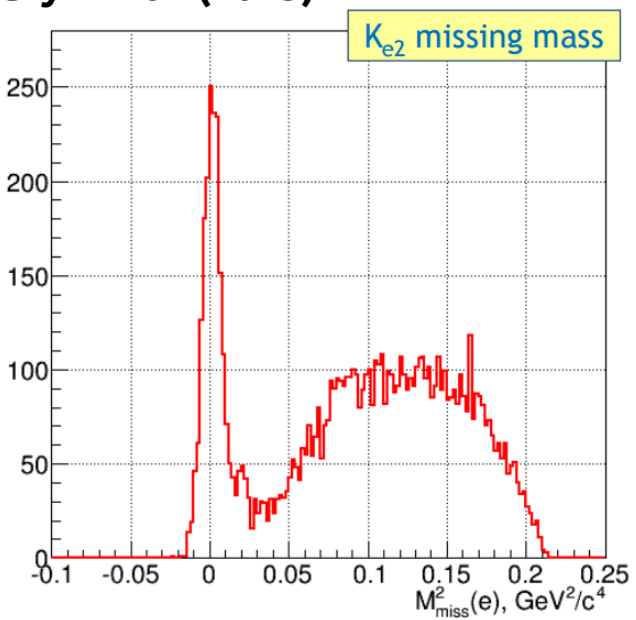
Heavy neutral leptons in $K^+ \to l^+N$

- Can also search for **HNL** in $K^+ \to l^+N$ where N does not decay inside the detector fiducial volume
- $K^+ \to l^+N$ events would appear as peaks in the $K^+ \to l^+\nu$ squared missing mass distribution
- **Searches are model independent**



Preliminary NA62 (2015)

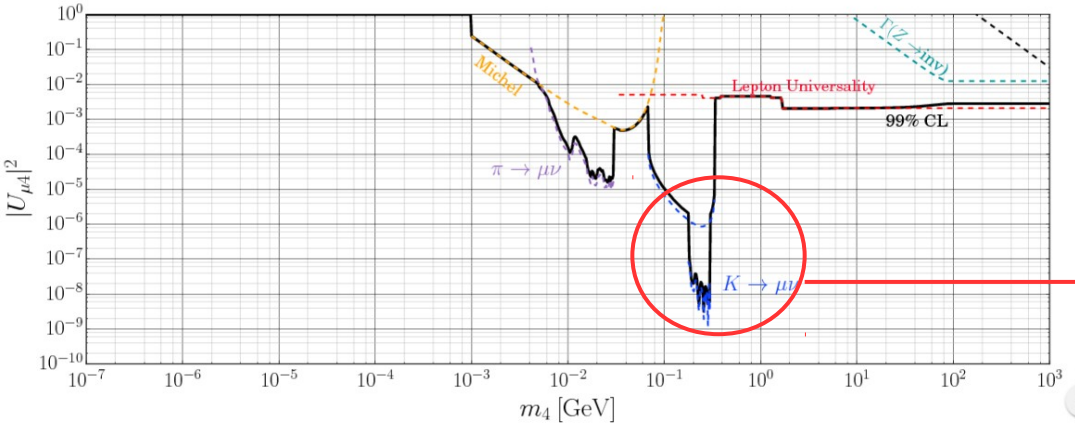


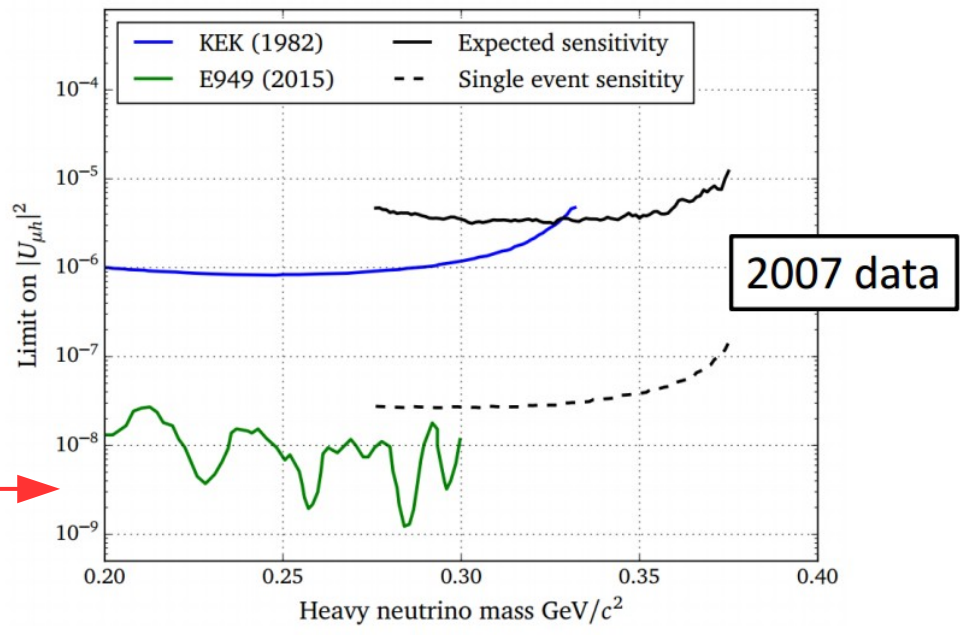


- **Analysis underway with NA62 data from 2015.**

Heavy neutral leptons in $K^+ \to l^+ N$

- Current experimental status: **most stringent constraints from kaon measurements**
- Expected **SES with 2015 NA62 data at the level of 10^{-8}** (similar for **$K \to eN$** and **$K \to \mu N$**)



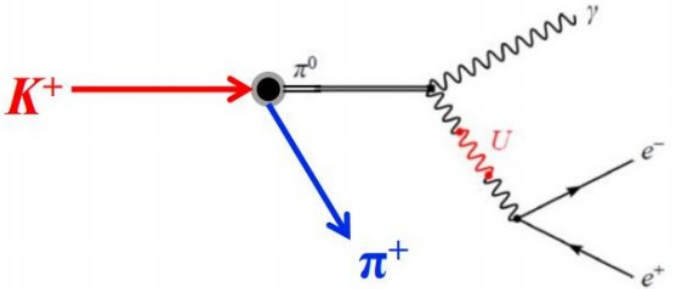


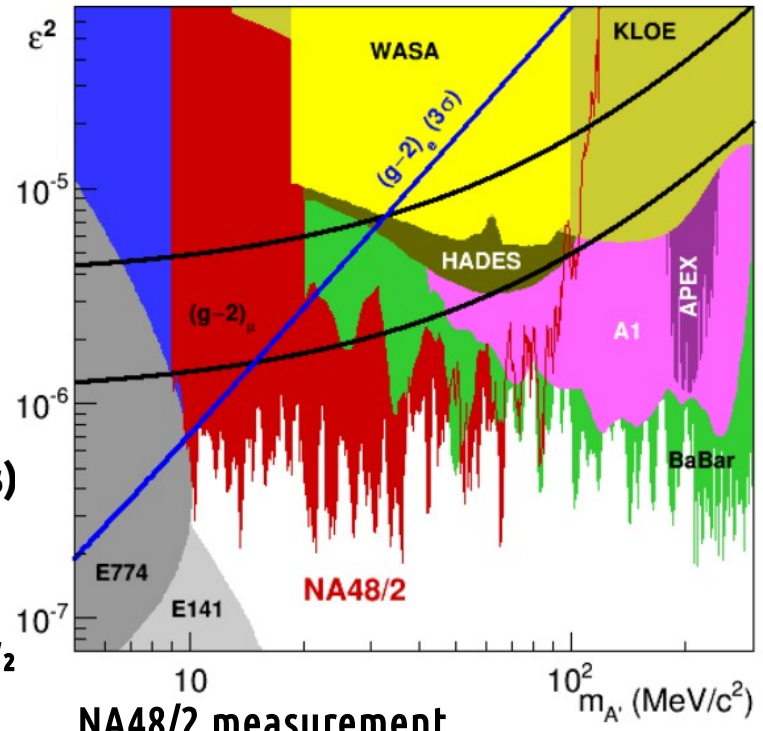
π^0 decays

- With $BR(K^+ \to \pi^+\pi^0) = 20\%$ NA62 is also a π^0 **factory**

- Search for **Dark photon** via the prompt decay chain $\pi^0 \to \gamma A'$, $A' \to e^+e^-$
- Limited by irreducible $\pi^0_D \to \gamma e^+e^-$ background (BR=1.2%)
- Upper limit on ε^2 scales as $\sim(1/N)^{1/2}$
- Modest improvement over the NA48/2 result expected with larger sample at NA62.
- Difficult to set a **ee-trigger** without any downscaling.
- Long lived **A'** search in **"beam-dump" mode (see next slides)**

- Search for $\pi^0 \to \nu\nu$ decay (BR<1.6x10^{-6} @ 90% CL; LSND exp.)
- Sensitive to the neutrino mass. LFV NP modes such as $\pi^0 \to \nu_1\nu_2$
- Fully included in the main trigger for $K \to \pi\nu\nu$





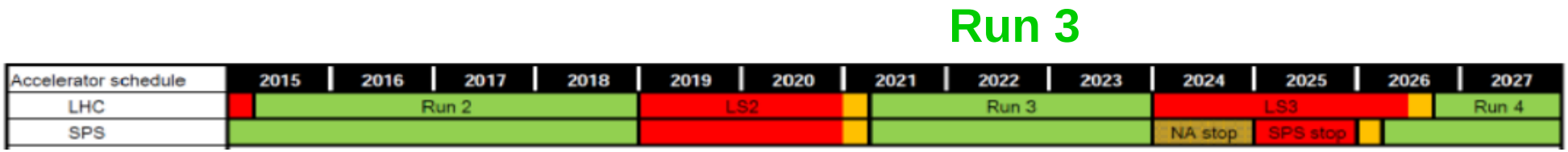
NA48/2 measurement
Phys.Lett. B746 (2015) 178
(see M.Raggi talk at this conference)

NA62 after the LS2 (Run 3)

- Assuming the main goal is fulfilled , **a broad physics program ahead of NA62 in Run 3**
- With **minimal/no upgrades** of the present K^+ beam and detector setup:

  LFV/LNV high-sensitivity studies: $K^+ \to \pi^+ \mu^\pm e$, $K^+ \to \pi^- \mu^+ e^+$, $K^+ \to \pi^- e^+ e^+$, $K^+ \to \pi^- \mu^+ \mu^+$
  ultra-rare/forbidden π^0 decays: μe, 3γ, 4γ, ee, $eeee$

- **Year-long run in "beam-dump" mode:** searches for **MeV-GeV mass hidden-sector candidates** (Dark Photons, Heavy neutral leptons, Axion like particles, etc.)



Hidden sector at NA62

- If DM is a thermal relic from the early universe, can search for non-gravitational DM-SM interactions in particle physics experiments
- **A mediator might exist which let DM and SM fields interact:**
  vector (Dark Photon A'), neutrino (HNL N), axial (ALP a), etc.

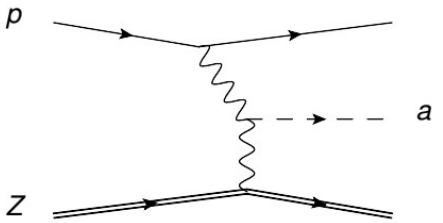
- **Experimental hints** for hidden sector at MeV-GeV masses: e.g. ***g-2*** **3.5σ discrepancy** could be resolved by e.g. light-by-light ALP loop effects [Marciano, et al. arXiv:1607.01022]
  or Dark Photons [B. Holdom Phys.Lett. B166 (1986) 196]

- **Feeble interactions. Long lived states** with **ultra suppressed production rate**

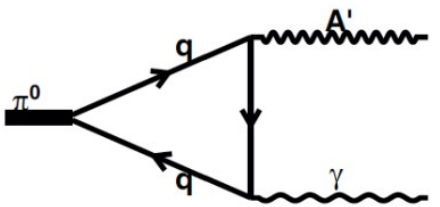
- Each portal can involve different interactions. **Model dependence.**

Hidden sector at NA62

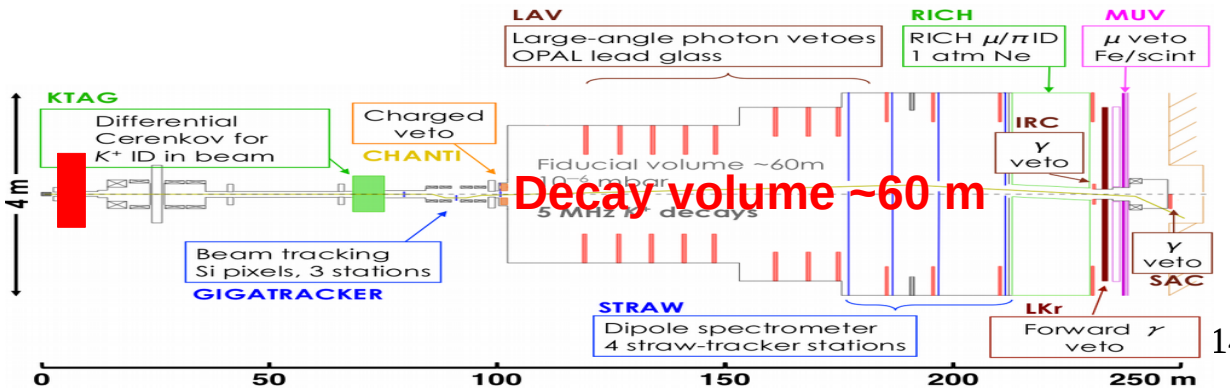
- Proposal: **run in "beam-dump" mode with one of the beam defining collimators (TAX) closed**
- **Production in the TAX**
  e.g ALPs coupled to two photons



- **Production in decays of various mesons coming from the target**
  400 GeV incident proton beam
  10^{18} POT/nominal year
  → 10^{15} D(S), 10^{14} K, 10^{18} $\pi^0/\eta/\eta'/\Phi/\rho/\omega$ with ratios 6.4/0.68/0.07/0.03/0.94/0.95

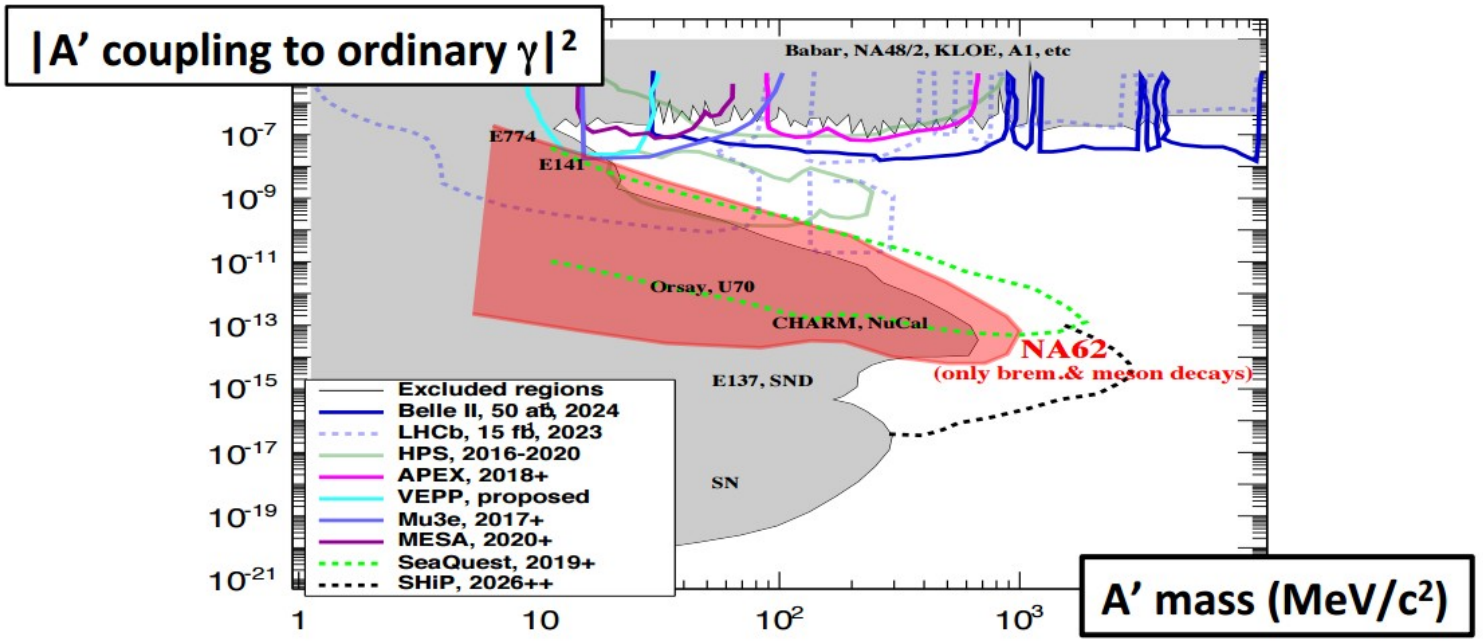


TAX: ~11λ Cu-based
Preferred over **Be** target because of higher **Z**



Search for visible decays of long-lived A’

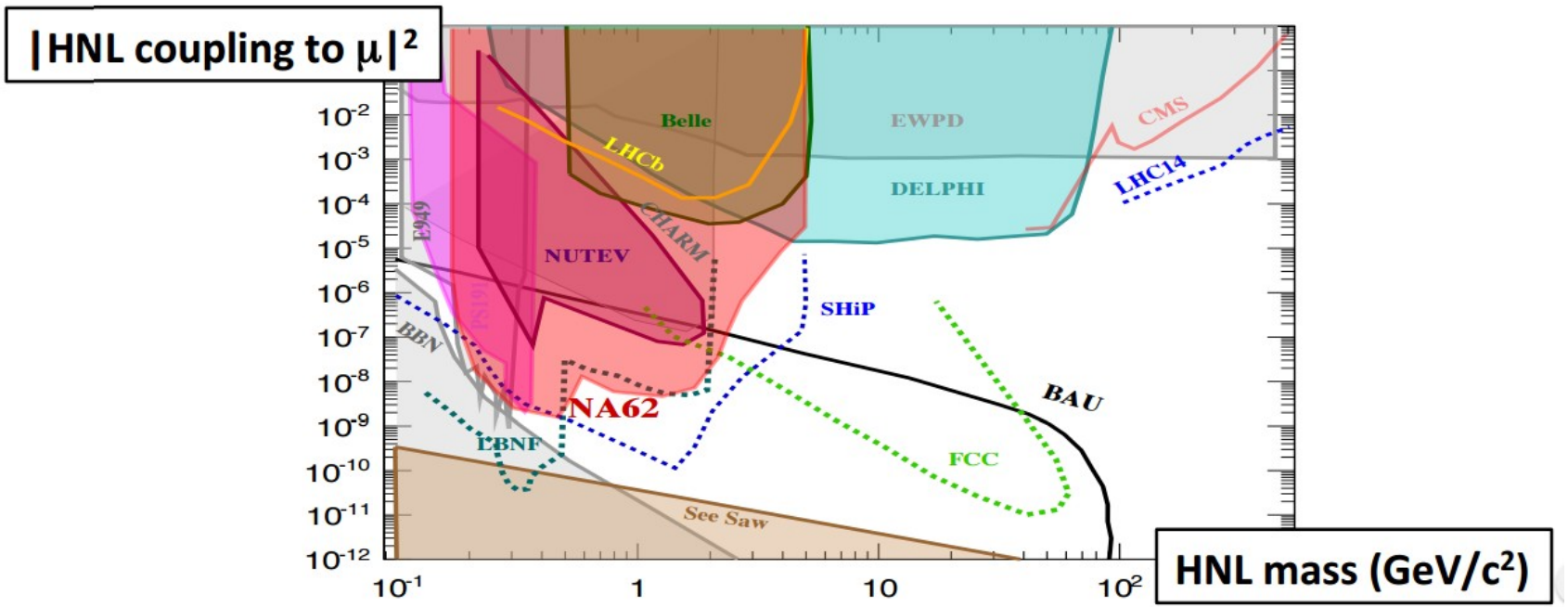
- Search for displaced dilepton decays of dark photons, A’→ee, μμ
- Expected 90% CL plot evaluation:
  assuming 2x10^{18} 400 GeV POT; zero background; trigger, acceptance and selection efficiency



- Sensitivity expected to be even higher: including direct QCD production of A’; production in the TAX (only target considered here)

Search for visible decays of HNL

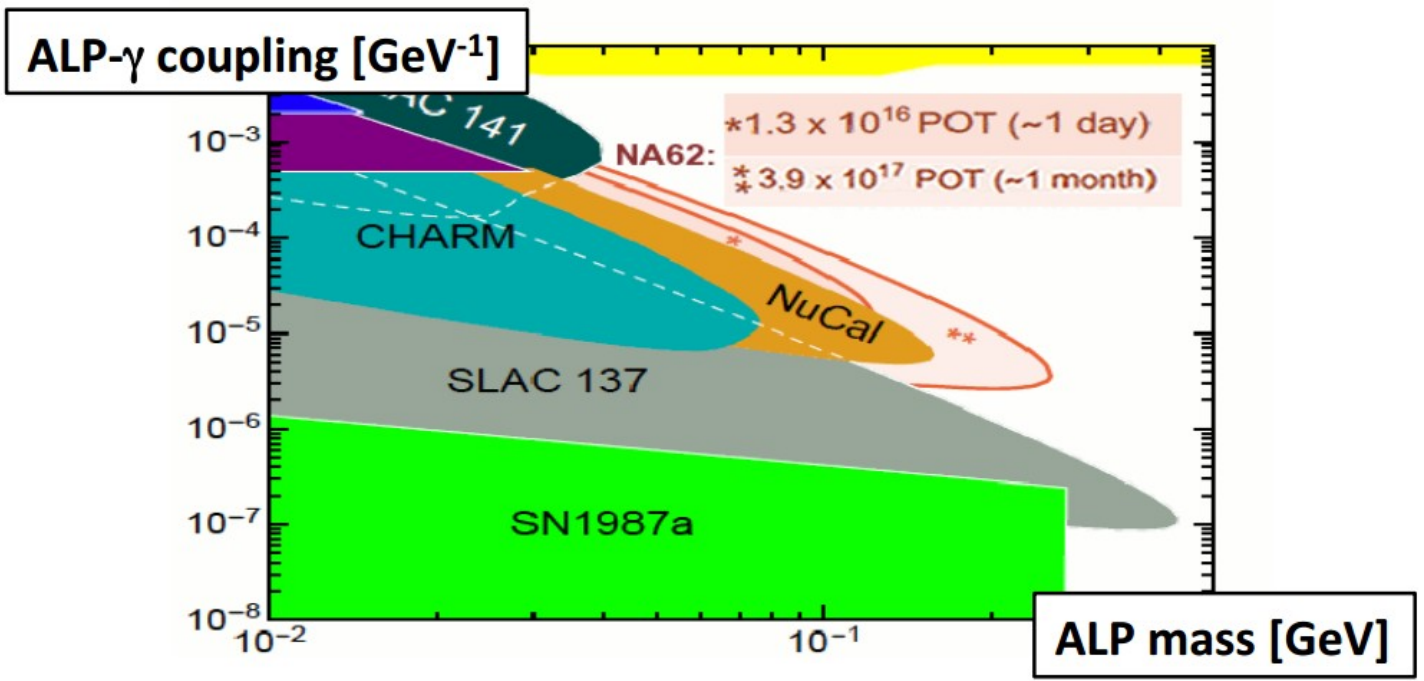
- Search for displaced decays of HNL→πe, πμ
- Expected 90% CL plot evaluation:
  assuming 2×10^{18} 400 GeV POT; zero background; trigger, acceptance and selection efficiency



- Sensitivity expected to be even higher: including other semileptonic and hadronic modes

Search for visible decays of ALPs

- Search for decays of ALP→γγ in the NA62 fiducial volume
- Expected 90% CL plot evaluation:
  assuming 1.3x10^{16} (3.9x10^{17}) 400 GeV POT corresponding to 1 day (1 month) runs;
  zero background; geometrical acceptance;



Test of the zero background assumption

- Sensitivity projections based on the **assumption of zero background**

- Study one of the most important **sources of background at NA62** using data:
  beam halo muons from upstream K, π decays

  expecting **~3 MHz μ^+** and **~150 KHz μ^-** in the detector acceptance
  Talk by T. Spadaro, Physics beyond colliders workshop @ CERN (7 Sep 2016)

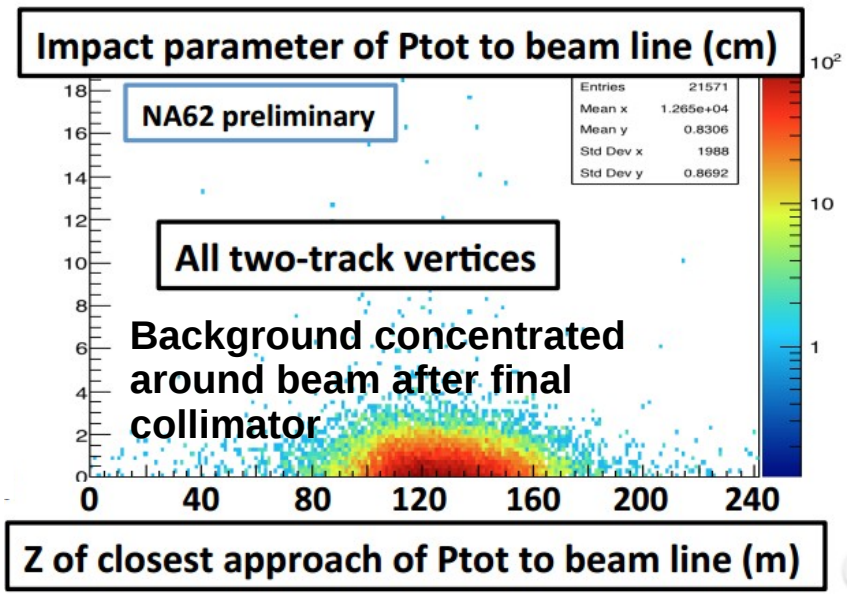
- **Test background rejection capability** with **current data** searching for **A'→μμ**
  background from combinatorial pairing of halo μ's

- Data collected triggering on **2 muons in MUV3 (within 10ns) & LKr energy < 20 GeV**
  The trigger efficiency is included in the sensitivity projections shown previously

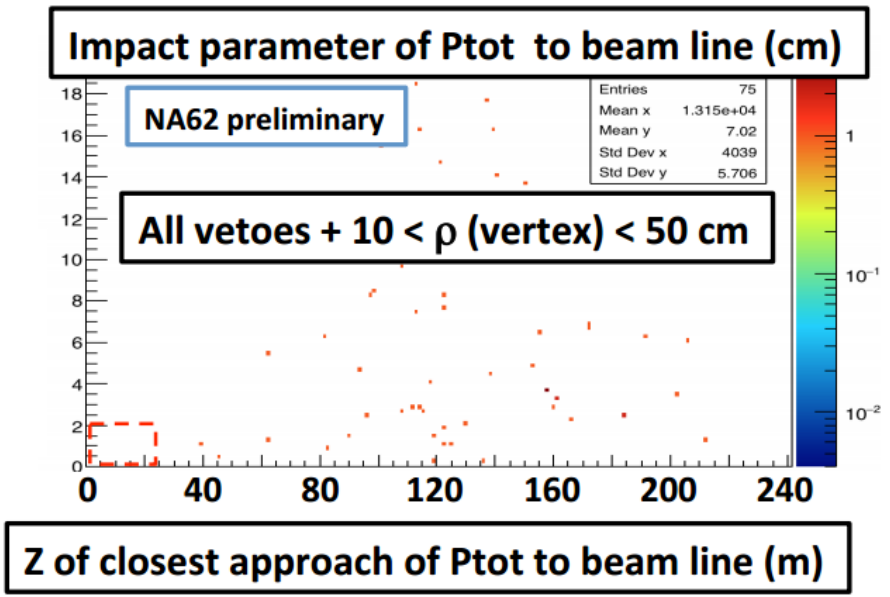
Test of the zero background assumption

- **Event selection: track quality + acceptance cuts**
  - **two track vertex: cda < 1 cm**
  - **position 105 < Z < 165 m**

Stat. corresponds to ~10^{15} POT



- **Event-level veto conditions:**
  - **energy in LKr <2 GeV**
  - **veto on forward/large angle calorimeters**
  - **veto on charged anti-counter**
- **Total momentum stems from target**



No events selected in the signal region!

Conclusions

- **There are planned and current searches for exotic processes at NA62:**

  K^+ decays: LNV/LFV modes, HNL production searches (already under analysis with 2015 data)
  π^0 decays: rare and forbidden LFV, dark photon production

- Assuming fulfillment of main goal, BR(**$K^+ \to \pi^+ \nu\nu$-bar**) at 10% precision, **broad physics program at NA62 after LS2 (to start in 2021)**
- **Current beam and detector setup: LFV/LNV/forbidden π^0/K^+ decays for SES ~10^{-12}**
- **Year-long data-taking in "beam-dump" mode.** Sensitivity to various NP models: **Dark photons, Axions, Heavy neutral leptons, etc.**
- Background rejection power studied for the searches proposed, up to ~10^{15} POTs
- The current NA62 run will be exploited to:
  evaluate the background rejection up to ~10^{18} POTs;
  understand if the current apparatus needs any **optimisations or modifications for a future "beam-dump" operation**

Stay tuned!