Accelerator-based light particles searches with NA62

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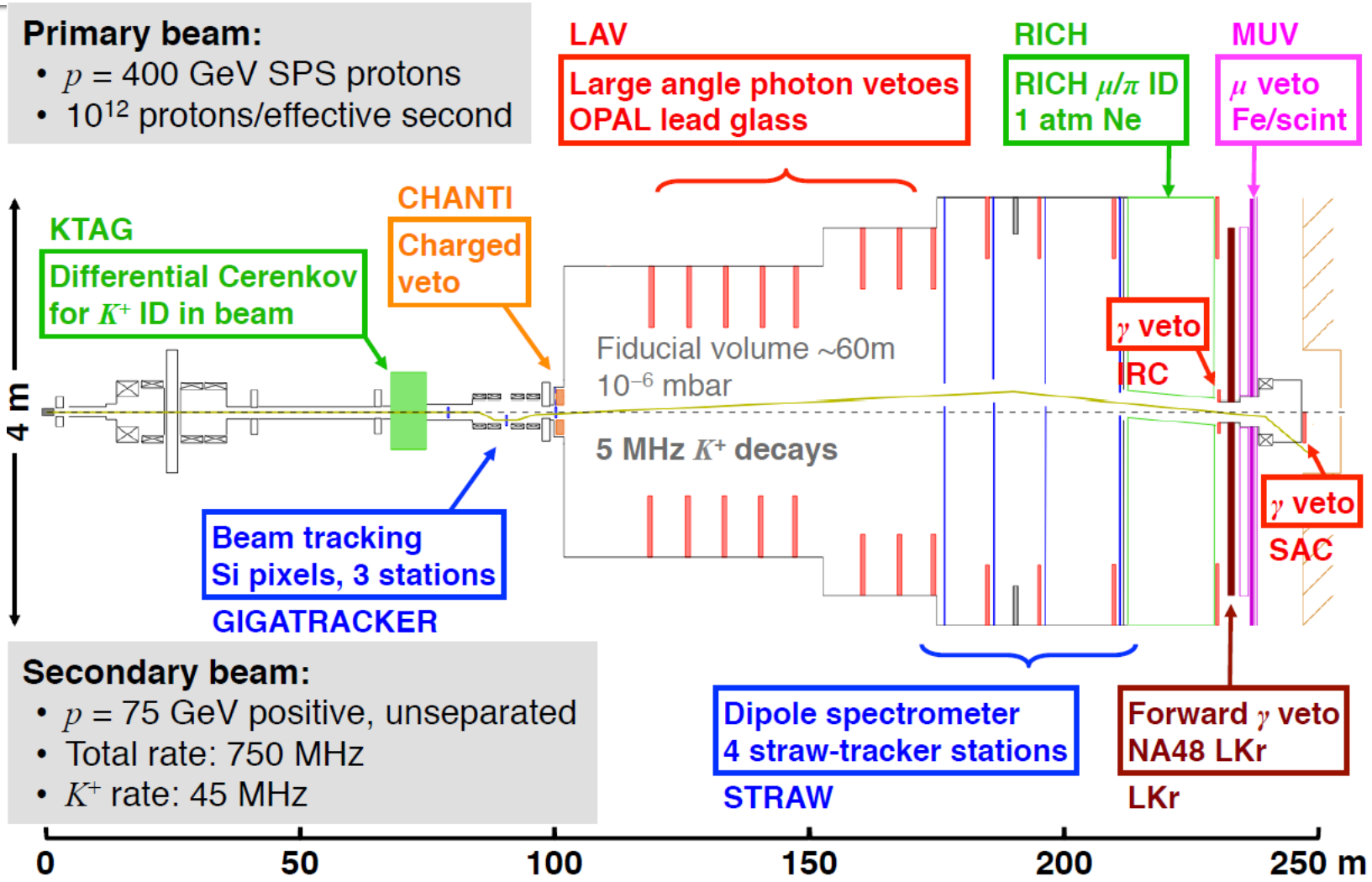
Why light particle searches ?

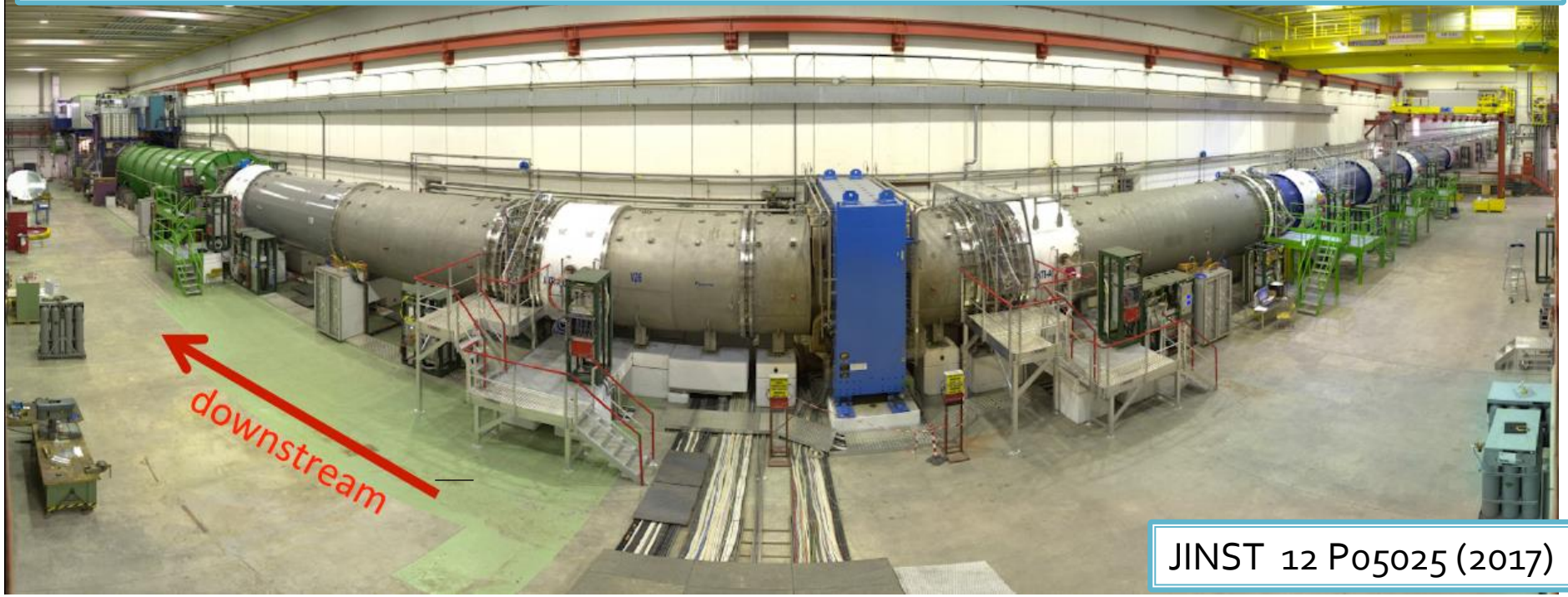
- No evidence so far of NP at $\gtrsim$TeV scale, nor compelling theoretical need for (vacuum «metastable» up to Planck scale…)
- **But** SM uncomplete (neutrino masses & mixing, dark matter, matter-antimatter asymetry, θ_{CP} …)
- NP could be **light** & feebly coupled to SM
- Need both high statistics *and* good mass resolution→ NA62 well suited for searches in the MeV-GeV range

NA62 @ CERN SPS



NA62 @ CERN SPS

- Beam and decay tracking with missing mass resolution **10^{-3} GeV^2/c^4**
- Particle id: O(**10^7**) μ vs π rejection for 15 GeV< p < 35 GeV
- Photon detection: O(**10^8**) π^0 rejection for E(π^0) > 40 GeV
- Primary goal: precision measurement of BR($K^+ \to \pi^+ \nu\nu$) (SM$\approx 8 \cdot 10^{-11}$)



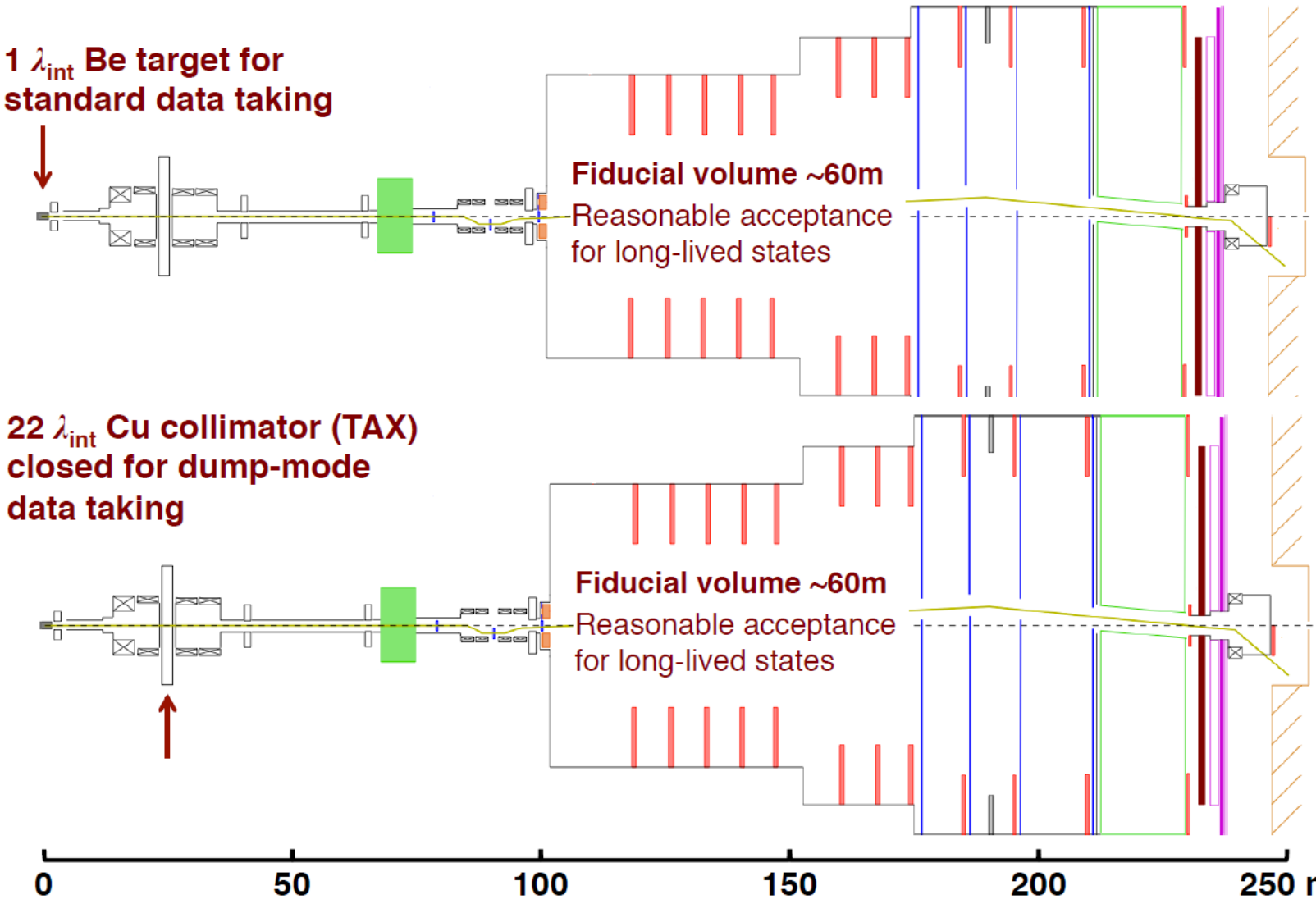
JINST 12 P05025 (2017)

Light particles production at NA62

- **Kaon decays**:
  - K^+ decays in the 60 m decay volume with X in final state
  - Signature: missing mass peaks («invisible» modes)
  - Standard data taking→**O(10^{13}) kaon decays** sample (by 2018)
  - Limited mass range: m_X < m(decaying hadron)

- **400 GeV protons on target** :
  - X produced at beam target (1 λ_{int} Be) or beam dump (22 λ_{int} Cu) Can probe higher m_X range.
  - Signature: visible X decay modes (e.g. ee,μμ,μe,πe,πμ,γγ).
  - Standard beam: N(pot) depending on final state (trigger). **Up to 10^{17} pot collected** for specific triggers
  - Dedicated beam dump runs (closed TAXES) . **10^{18} pot** in Run3 under consideration.

Standard run vs beam dump

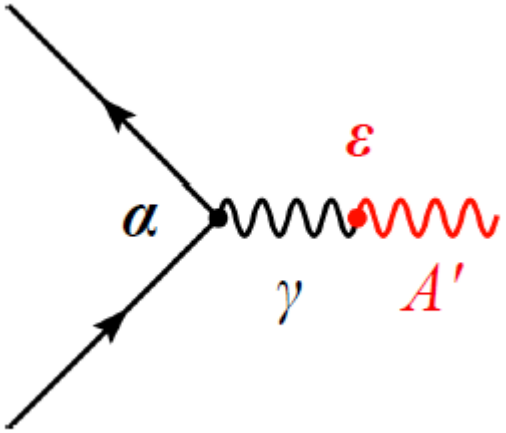


Dark sector searches at NA62

Portal	Coupling
Dark photon	$-\frac{\varepsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Scalar	$(\mu S + \lambda S^2) H^\dagger H$
Axion	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a}\bar{\psi}\gamma^\mu\gamma^5\psi$
Neutrino/HNL	$y_N L H N$

Dark photon @ NA62

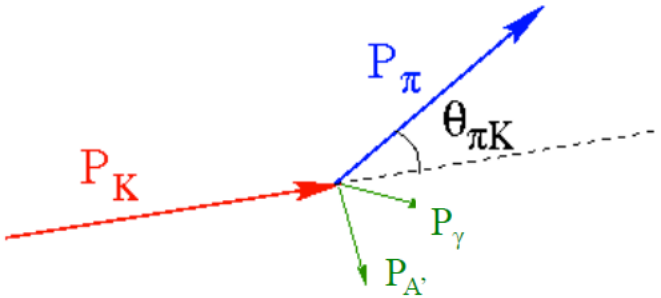
- Extra U(1) massive gauge singlet
- Mixing with SM hypercharge
- ε and $m_{A'}$ are free parameters



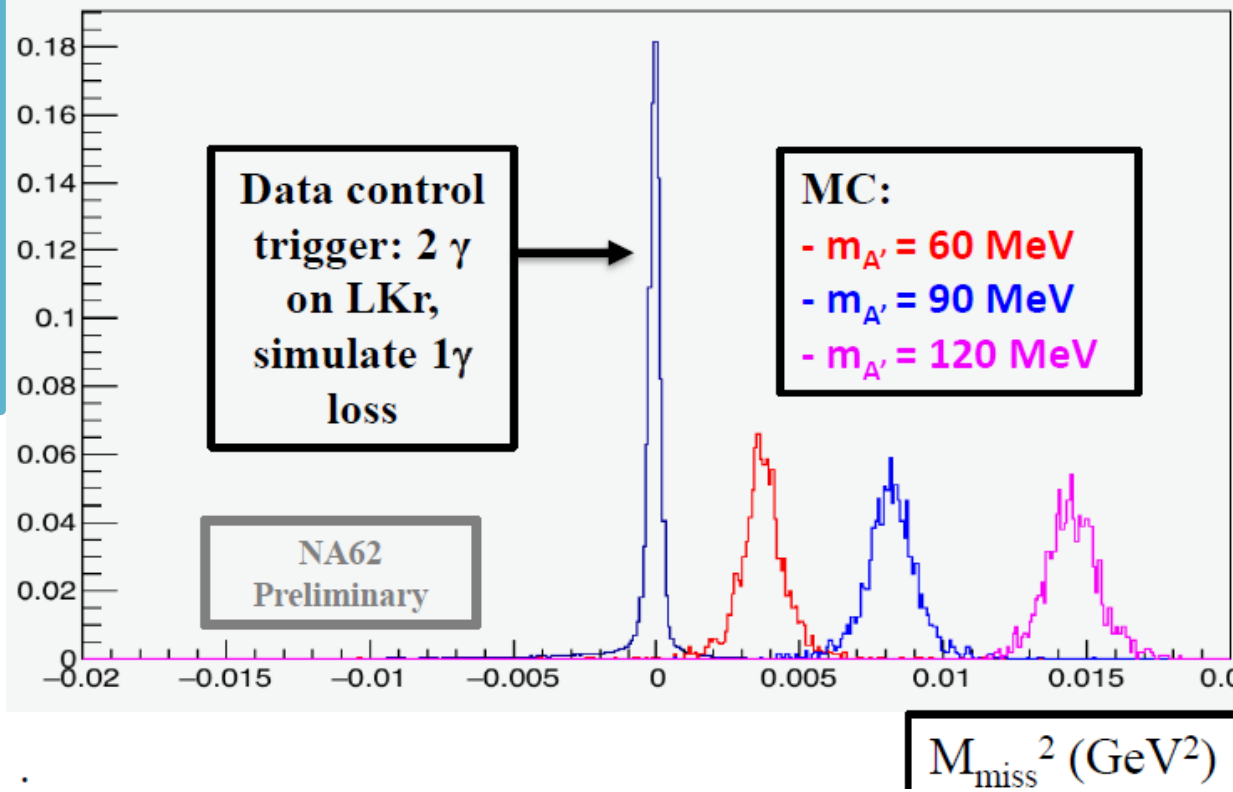
- Searches at NA62 :
  - Invisible modes ($K^+ \to \pi^+ A'$ or $K^+ \to \pi^+ \pi^0$ and $\pi^0 \to \gamma A'$)
  - Production at target/dump and decays like $A' \to ee$ or $A' \to \mu\mu$

Dark photon in π^0 decays

- One π^+ and one γ final state topology
- No need for dedicated trigger
- Data driven background estimation

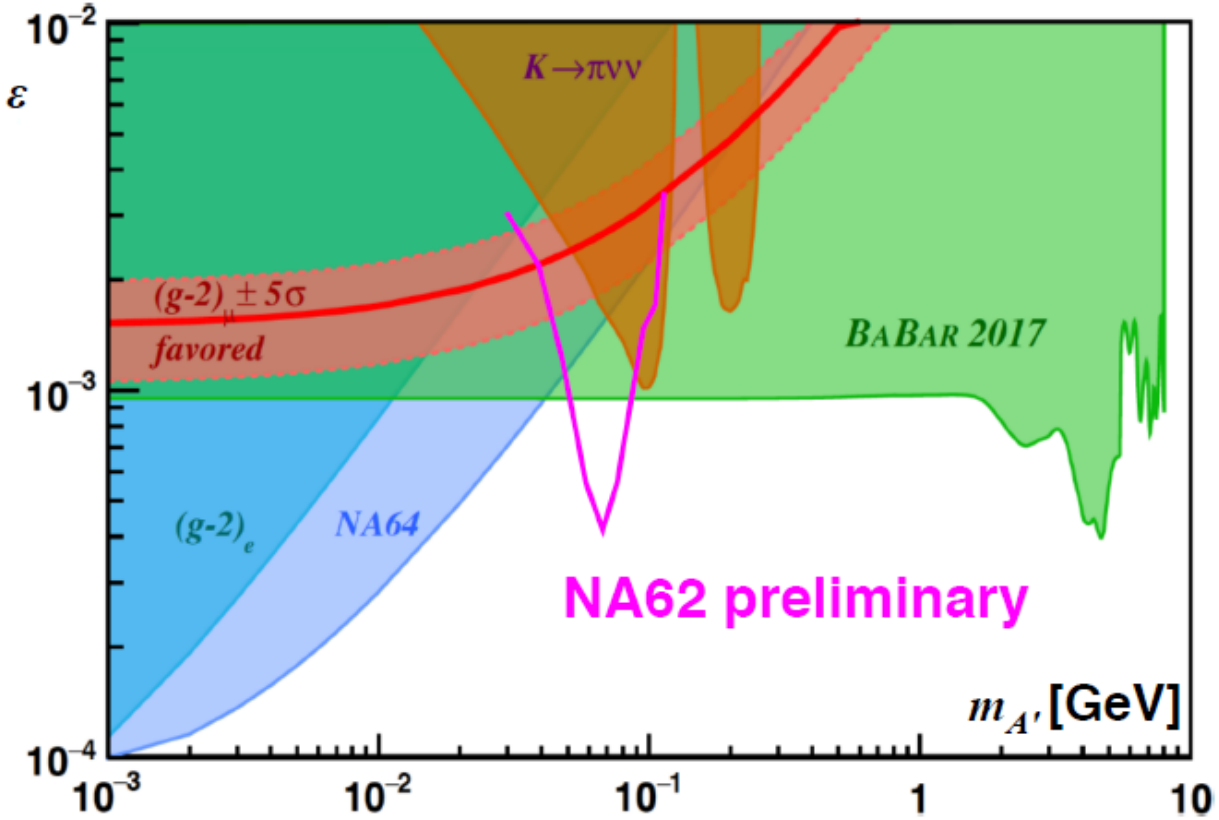


$$M^2_{miss} = (P_K - P_\pi - P_\gamma)^2$$



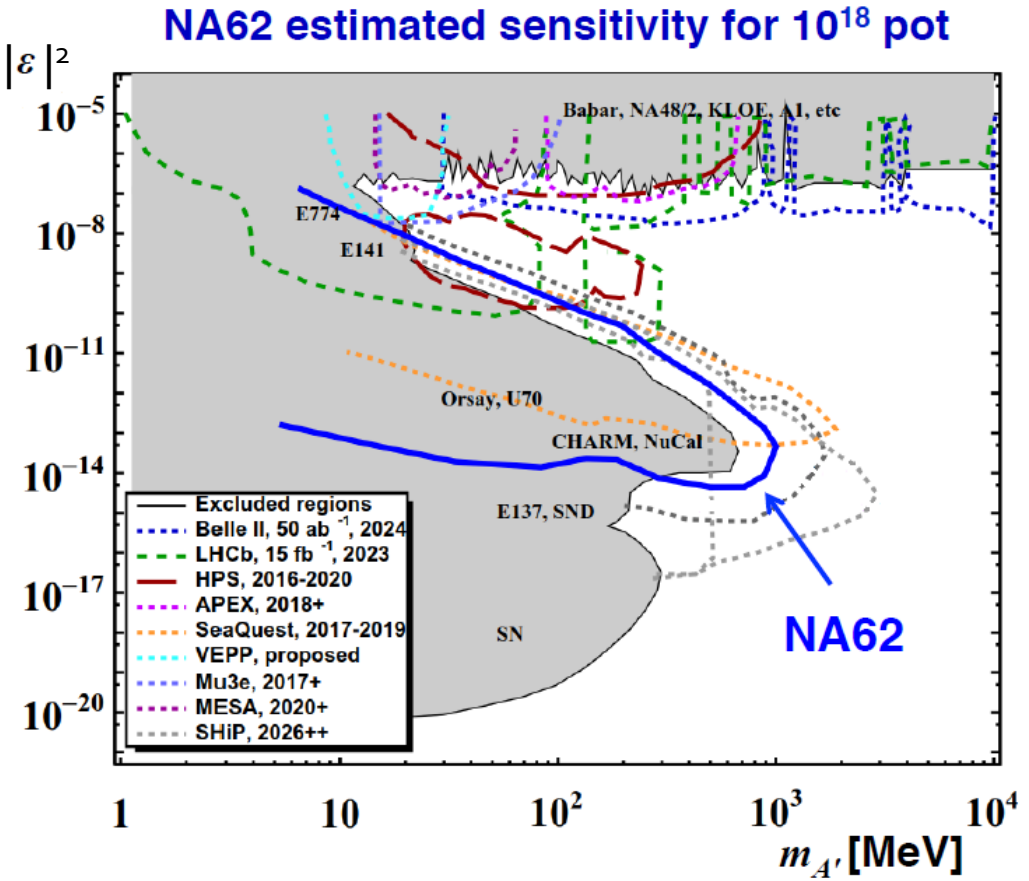
Dark photon in π^0 decays

- Preliminary result using small fraction of 2016 statistics
  ($1.5 \cdot 10^{10}$ K decays)
- 90% CL upper limits statistically compatible with fluctuations in bacgkround-only hypothesis
- Full 2016 analysis in progress



Dark photon from target

- Visible dilepton final states
- 90% CL expected UL for 10^{18} pot (on Be target) using both final states and in zero-background assumption
- Sensitivity does not include A' production in dump and QCD contributions.



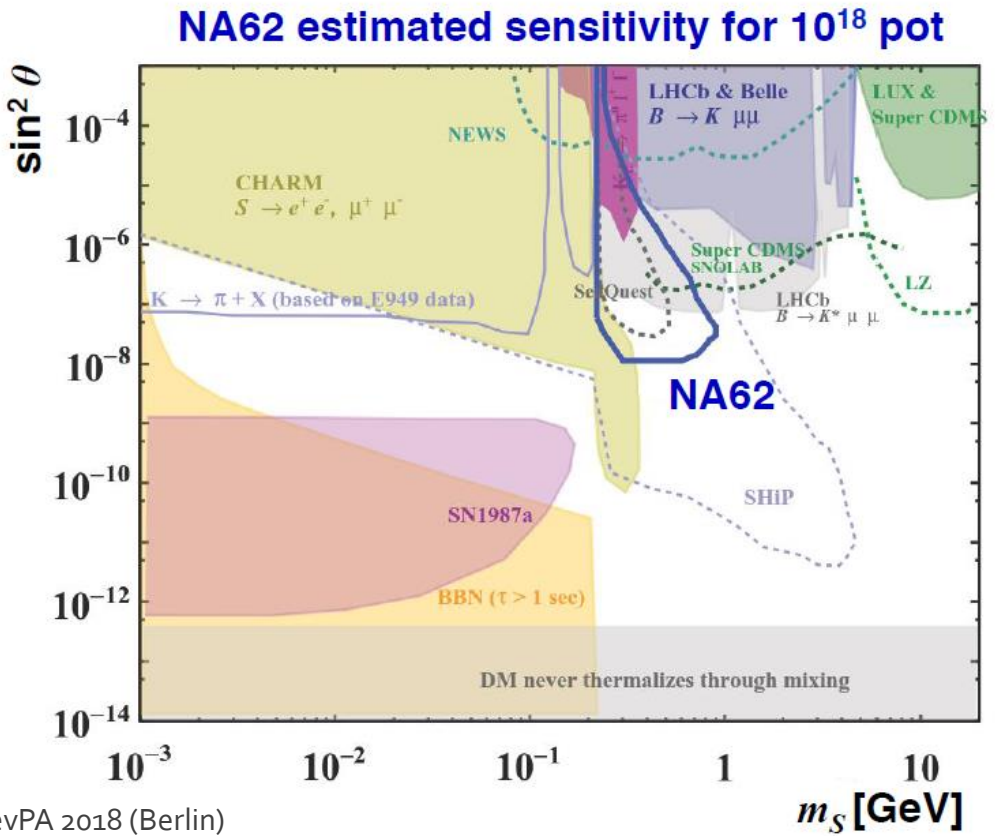
Data from 2016-2017 runs:
$3 \cdot 10^{17}$ pot in μμ
$5 \cdot 10^{16}$ pot in ee

Dark scalar

- Simplified model with λ=0 assumed (single scalar)
- 10^{18} pot assumed
- ee, $\mu\mu$,$\pi\pi$, KK final states
- 90% CL UL sensitivity w zero-bkg assumption

$$\mathcal{L}_{\text{scalar}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} - (\mu S + \lambda S^2) H^\dagger H$$

$$\mathcal{L}_{\text{DS}} = S\bar{\chi}\chi + ... \qquad \theta = \frac{\mu v}{m_h^2 - m_S^2}$$

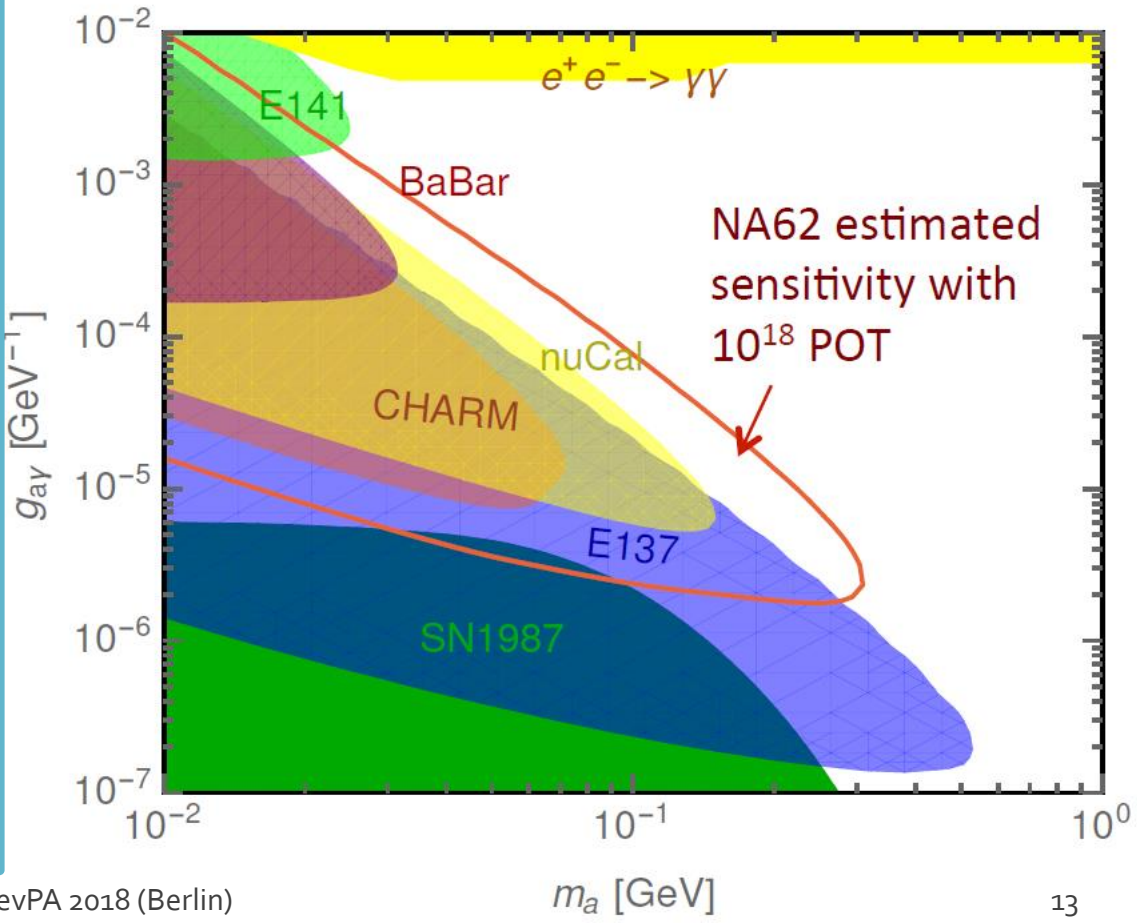


Data from 2016-2017 runs:
$3 \cdot 10^{17}$ pot in $\mu\mu$
$5 \cdot 10^{16}$ pot in ee

Axion Like Particles

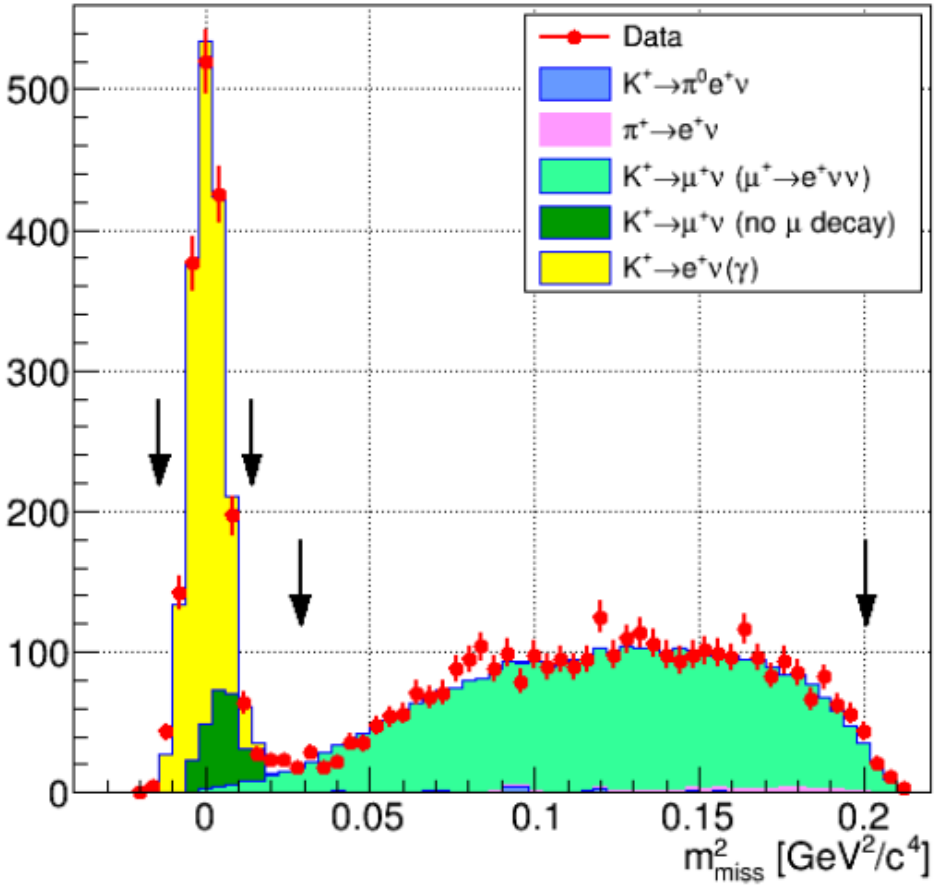
- Axions may solve the strong CP problem while providing a light DM candidate.
- At NA62: $\gamma\gamma$ fusion via Primakoff effect for production and subsequent $\gamma\gamma$ decay
- Need **beam-dump mode** (closed TAXES)
- Significant result already w 10^{16} pot.
- Analysis of $5\cdot 10^{15}$ pot collected in dump mode in 2017 in progress.
- Sensitivity (90% CL UL) estimate for 10^{18} pot in dump mode. Zero-bkg assumption.

$$\mathcal{L}_{\text{axion}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} + \frac{a}{4f_\gamma} F_{\mu\nu}\tilde{F}_{\mu\nu} + \cdots$$



Heavy neutral leptons: K decays

- 3 RH neutrino model could explain neutrino mass hyerarchy, DM and barion asymmetry [Asaka, Shaposhnikov PLB 620 (2005) 17].
- HNL are expected to couple w ordinary SM leptons
- Na62 search for HNL with Minimum Bias data collected in 2015 (**10^8 kaon decays**)
- Search for HNL in both eN and μN final states
- Long lived N → invisible decays
- Search for missing mass peaks on smooth polinomial background.



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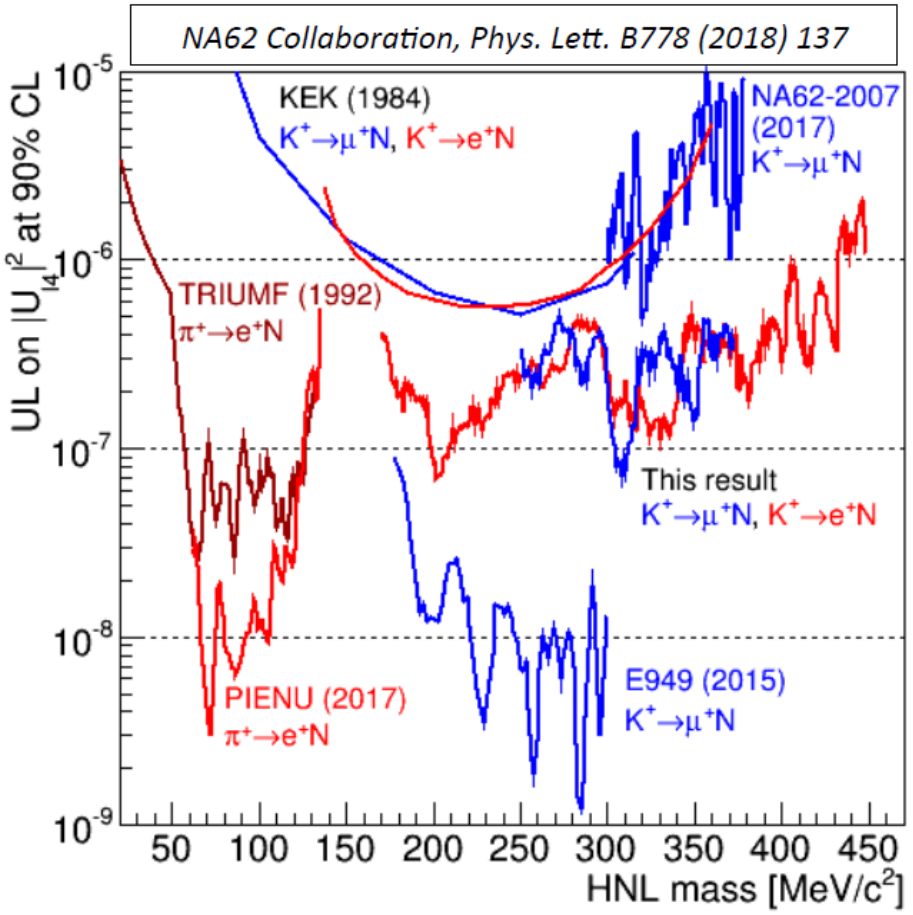
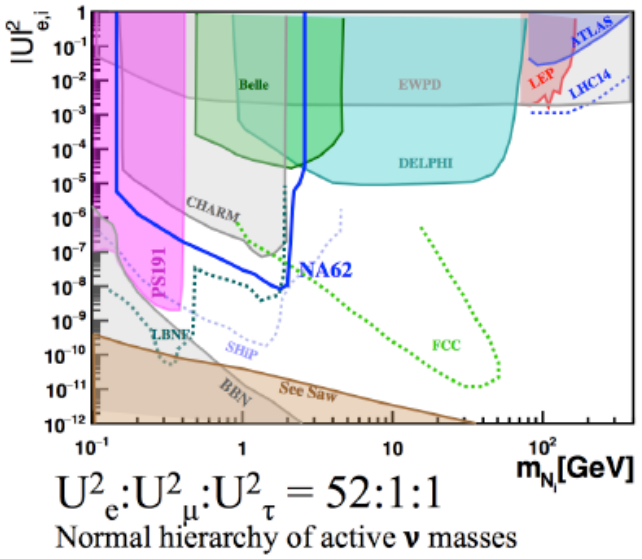
- Long lived N → invisible decays
- Search for missing mass peaks on smooth polinomial background.
- Best world limit above 300 MeV/c^2
- Full 2016- 2018 data set analysis ongoing



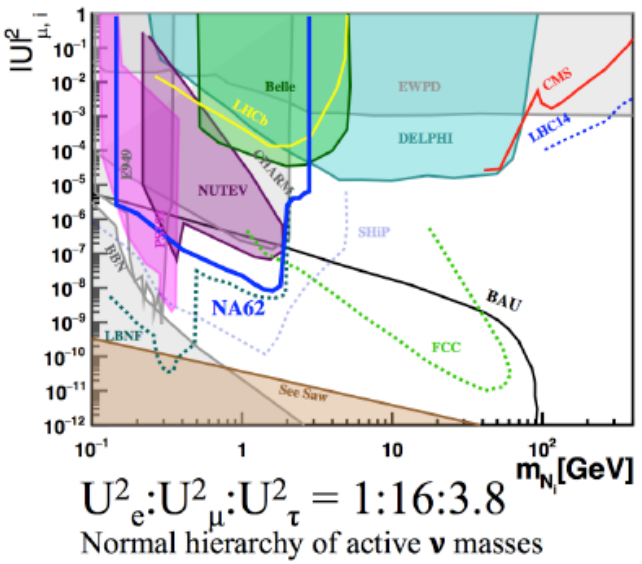
Heavy neutral leptons from dump

- N produced in beam dump
- Two-track final states detected
- Assume 10^{18} pot on TAXES and zero-bkg
- 90% CL upper limit
- 3 scenarios as in Gorbunov ,Shaposhnikov JHEP 10(2007)015



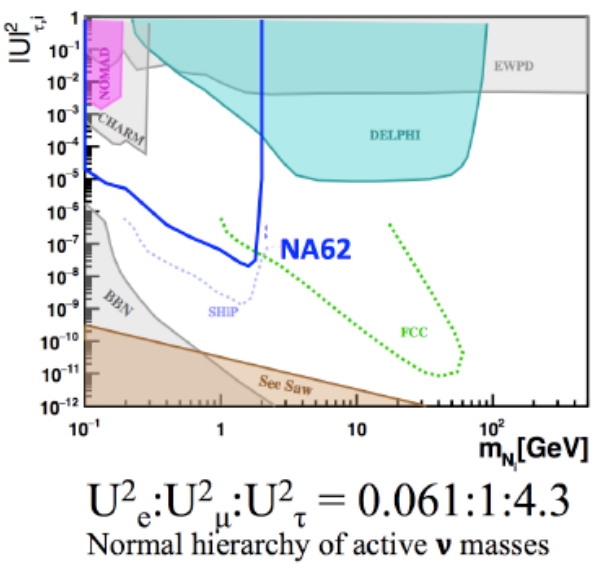
$U^2_e : U^2_\mu : U^2_\tau = 52:1:1$

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



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

Normal hierarchy of active ν masses

Conclusions and perspectives

- NA62 is very well suited to explore the low mass, low coupling region in several NP scenarios
- Analysis is in progress on 2016-2018 data for both kaon decays and target/dump production modes.
- Possibility to collect 10^{18} pot in dump mode in 2021-2023 to fully exploit the NA62 potential for searches and limits.

Additional material

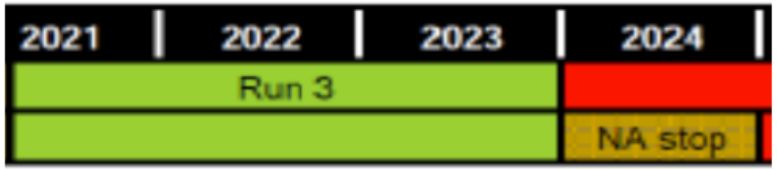
The zero background assumption

- Zero bkg assumed to obtain expected sensitivities for visible modes.
- Checks have been done for $\mu^+\mu^-$ final state at low statistics (10^{15} pot) where no signal is expected and $\mu^+\mu^-$ combinatorial background dominates
- No event survived selection

NA62 beyond LS2

Run 3: many interesting fields to be studied with minimal (or no upgrades at all) of the existing setup

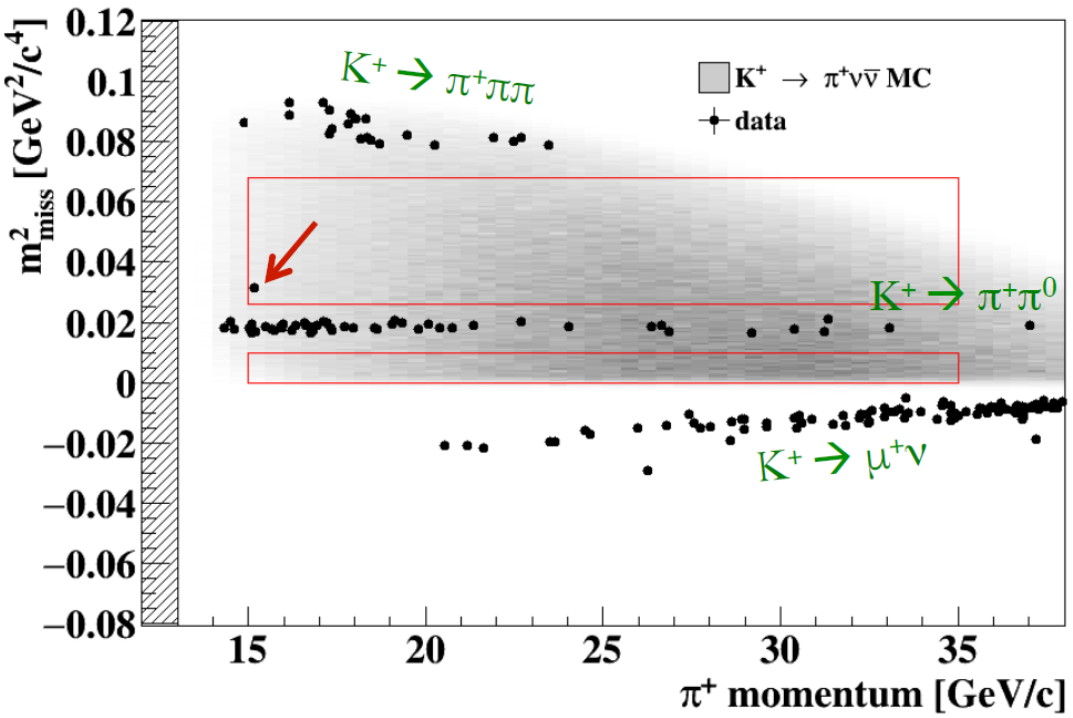
- In K^+ beam mode:
  - If needed improve $K^+ \to \pi^+ \nu\bar{\nu}$, A'→invisible, invisible HNL
    - All benefit from the same trigger signature
- In proton beam dump mode:
  - ALPs, Dark scalar, A', HNL : all in visible decays



1 year of data taking in beam dump mode during Run 3 is under consideration

What about $K^+ \to \pi^+ \nu\bar{\nu}$?

- First results on 2016 data
- Epxected 0.27 SM events and 0.15 bkg events
- 1 signal candidate observed



Results (published soon) →

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10} \ @ \ 95\% \ CL$$

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 2.8^{+4.4}_{-2.3} \times 10^{-10} \ @ \ 68\% \ CL$$

Current best result from E787/949 at BNL (@ 68% CL)

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$