First forum on rare kaon decays (RKF2018)

Search for the hidden sector at NA62

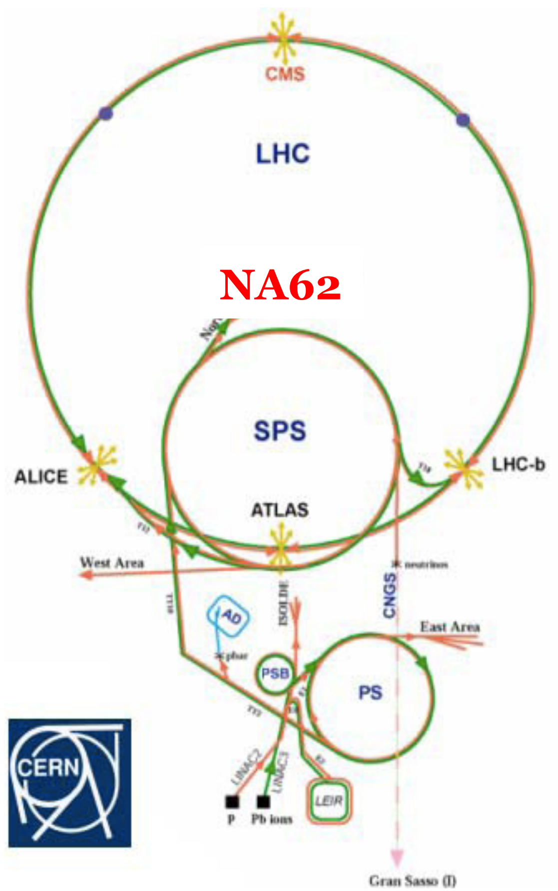
Angela Romano(*), University of Birmingham

Edinburgh, 21 – 23 February, 2018

(*)NA62 Collaboration @ CERN SPS

The NA62 experiment

High precision fixed-target Kaon experiment at CERN SPS



NA62 Timeline

- **Dec 2008 - NA62 Approval**
- **2009 - 2014: Detector R&D, Installation**
- **2015 Commissioning**
- **2016 - 2018: Physics Runs**
- **2021 - 2023 Next Physics Runs**

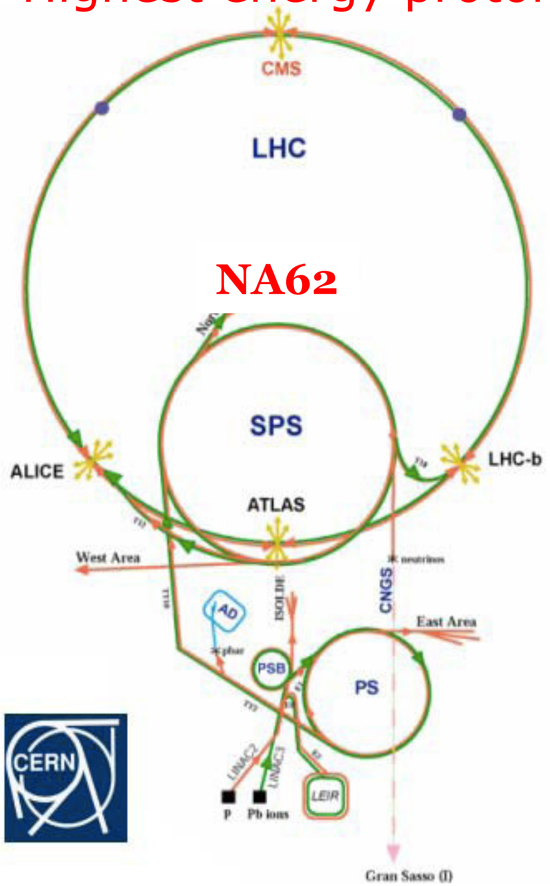
Primary goal: Measure BR($K^+ \to \pi^+ \nu\bar{\nu}$) with 10% accuracy and S/B ~10

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

The NA62 experiment

High precision fixed-target Kaon experiment at CERN SPS

Highest energy proton beam delivered for fixed-target exp in the world



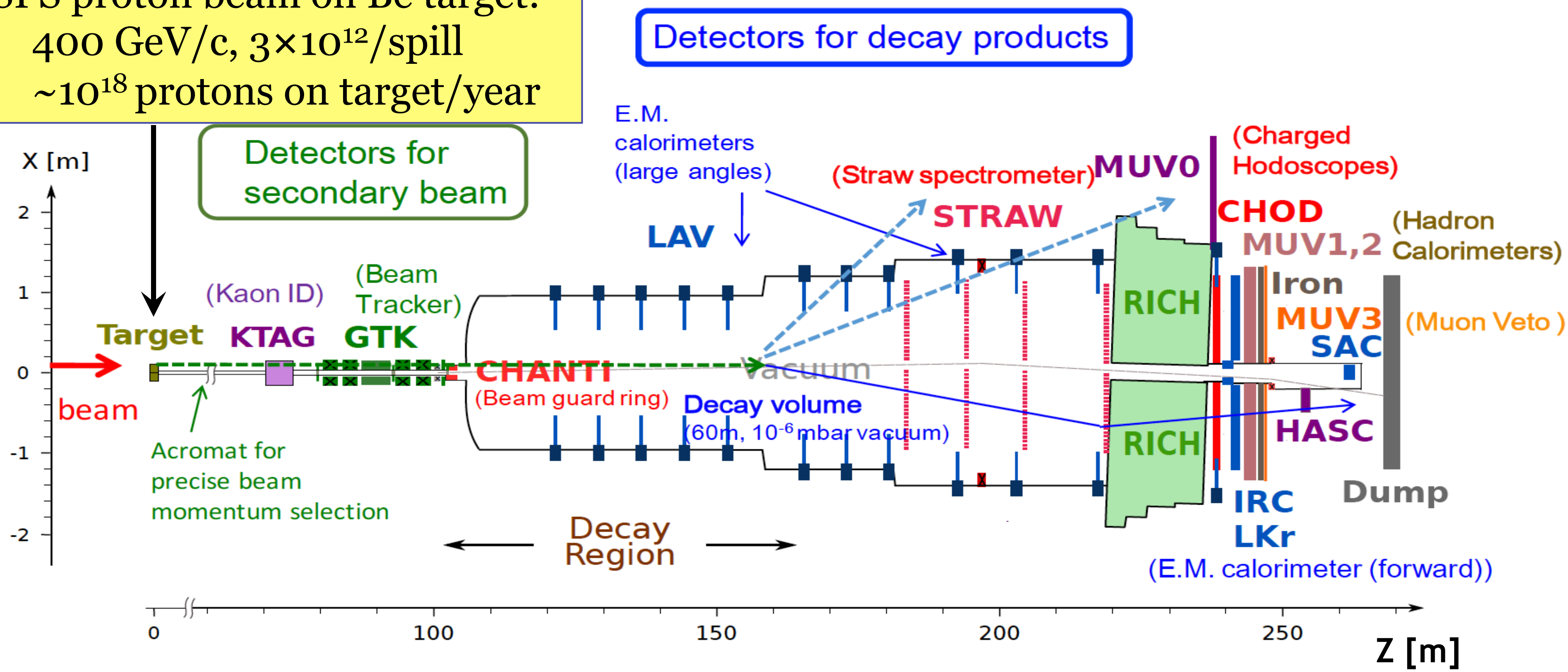
NA62 Beam line & detectors

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

The NA62 Detector

SPS proton beam on Be target:
- 400 GeV/c, 3×10^{12}/spill
- ~10^{18} protons on target/year

[NA62 Detector Paper, 2017 JINST 12 P05025]

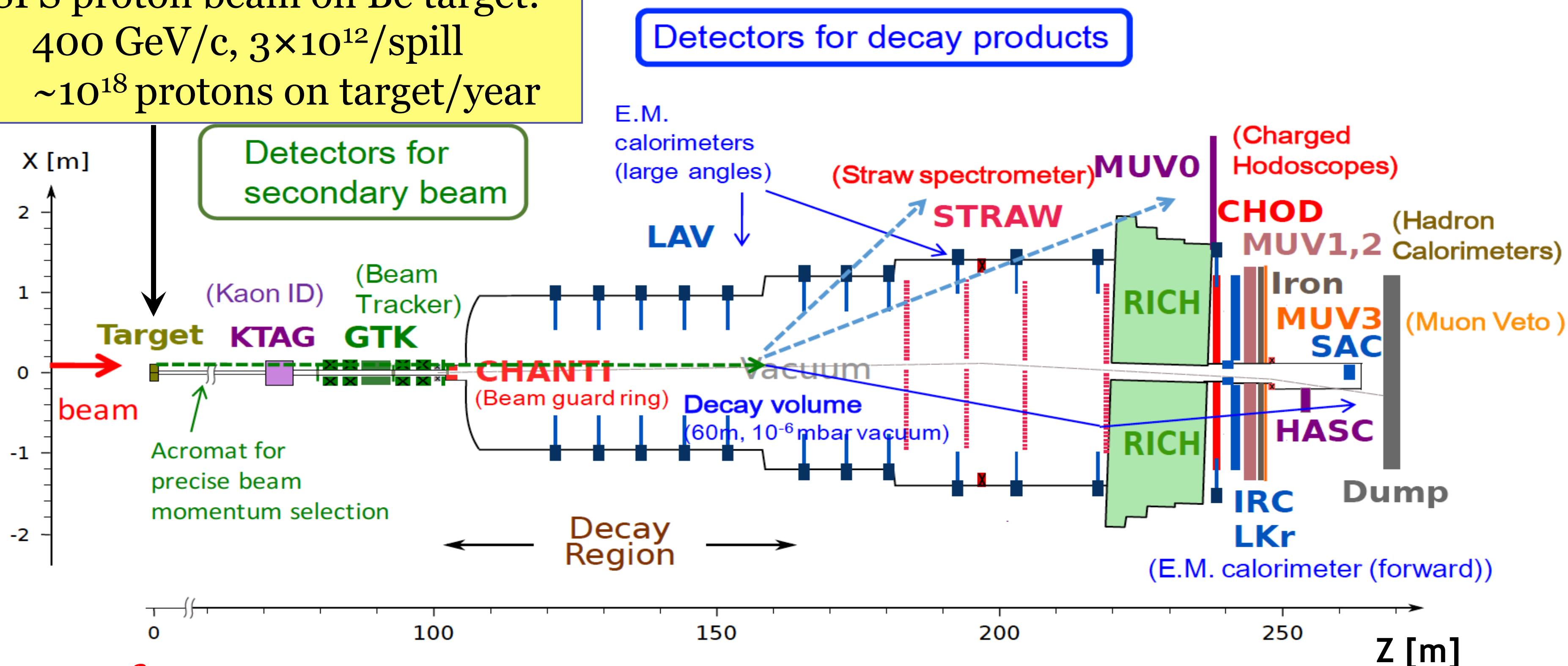


- Secondary **un-separated hadron ($\pi^+/K^+/p$) beam**
- **800MHz** beam rate @GTK (45MHz K^+ component)
- **K^+: 75GeV/c** (±1%), divergence < 100μrad
- Kaon **fiducial decay region ~60 m**

The NA62 Detector

SPS proton beam on Be target:
- 400 GeV/c, 3×10^{12}/spill
- $\sim10^{18}$ protons on target/year

[NA62 Detector Paper, 2017 JINST 12 P05025]



Performances:

- Excellent time resolution **O(100 ps)** to match beam/daugther particle info
- Kinematic rejection factors: $\sim10^{-4}$ for $K^+\to\pi^+\pi^0$, $K\to\mu^+\nu$ bkg channels
- Particle ID: $\sim10^{-7}$ μ suppression for $15 < p(\pi^+) < 35$ GeV/c
- Hermetic photon veto: $\sim10^{-8}$ rejection of $\pi^0\to\gamma\gamma$ for $E(\pi^0)>40$GeV

The NA62 Detector

[NA62 Detector Paper, 2017 JINST 12 P05025]

SPS proton beam on Be target:
- 400 GeV/c, 3×10^{12}/spill
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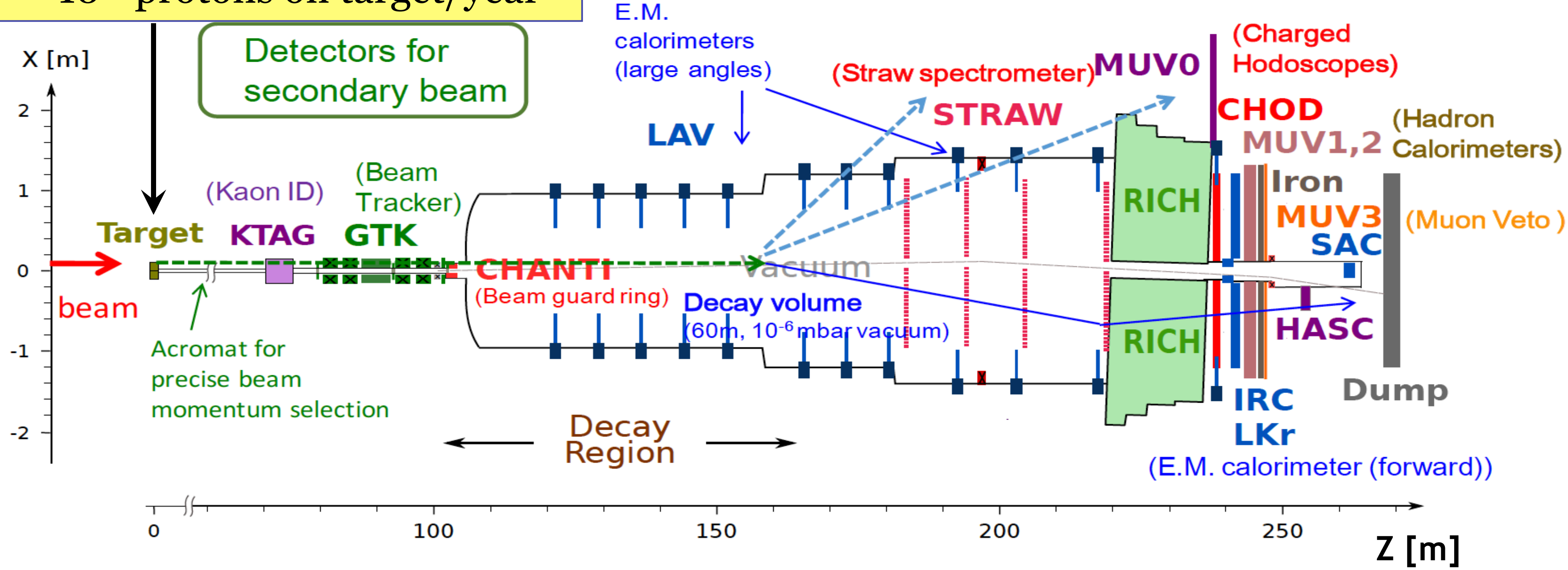


High-intensity setup, trigger system flexibility
and detector performances make

NA62 particularly suitable to search for NP effects from different scenarios

NA62: a general purpose experiment

NA62

- Flavour Physics
  - Search for NP at the EW scale with sizeable coupling to SM particles via indirect effects in loops:
    Golden mode: $K^+ \to \pi^+ \nu\nu$;
    → See G. Ruggiero, 22nd Feb
  - Searches for lepton flavour and number violation (LFV, LNV) - Rare and forbidden decay analysis
    → See E. Goudzovski, today
    C. Parkinson, 22nd Feb
- Hidden Sector
  - Search for NP below the EW scale (MeV-GeV range) feebly-coupled to SM particles via direct detection of long-lived particles:
    HNL, Dark Photon, ALP
    → This talk ☺

Hidden Sector searches at NA62

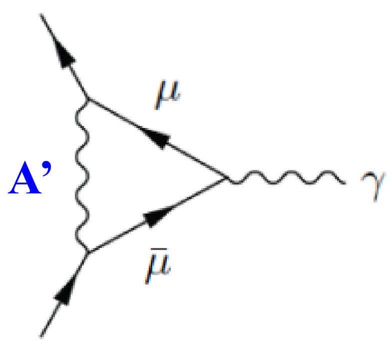
Hidden Sector Motivations

If Dark Matter (DM) is a thermal relic from hot early universe, can hunt for it in particle-physics:
search for non-gravitational interactions DM-SM

- **A mediator of a hidden sector might exist**, inducing DM-SM field **(feeble)** interactions;
- Many possible dynamics: vector (A' dark photon), neutrino (HNL), axial (ALP a), scalar ...

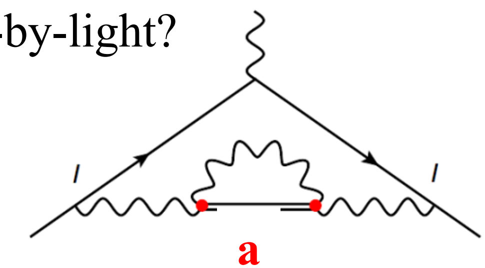
Various experimental hints for hidden sector at MeV-GeV, e.g. a_μ 3.5-σ discrepancy**:**

might be due to a dark photon **A'...**



[*Okun, Holdom*]

…or to an ALP **a** enhancing light-by-light?



[*Marciano et al. arXiv:1607.01022*]

Feeble interaction: ultra-suppressed production rate, **very long-lived states.**
E.g.: 1-GeV mass HNL, $\tau \sim 10^{-5}$-10^{-2} s, decay length ~ 10-10000 Km at SPS energies, suppression at production 10^{-7}-10^{-10}

Hidden Sector at NA62

Feeble interactions: ultra-suppressed production rate, **very long-lived states**

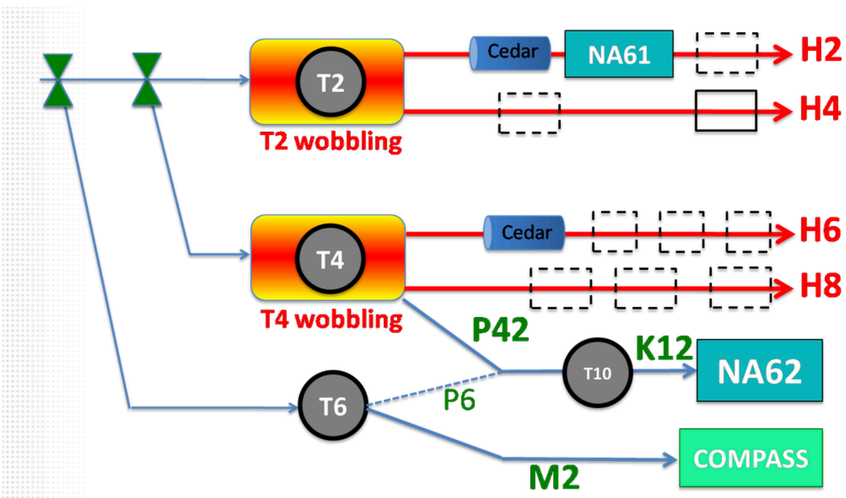
Why searching for hidden sector mediators at NA62?

- **High-intensity, high-energy proton beam**
- To date the world best line to produce high intensity fluxes of beauty and charm hadrons and photons through the interactions of protons on a high-Z target is a 400 GeV/c proton beam line extracted from the CERN SPS

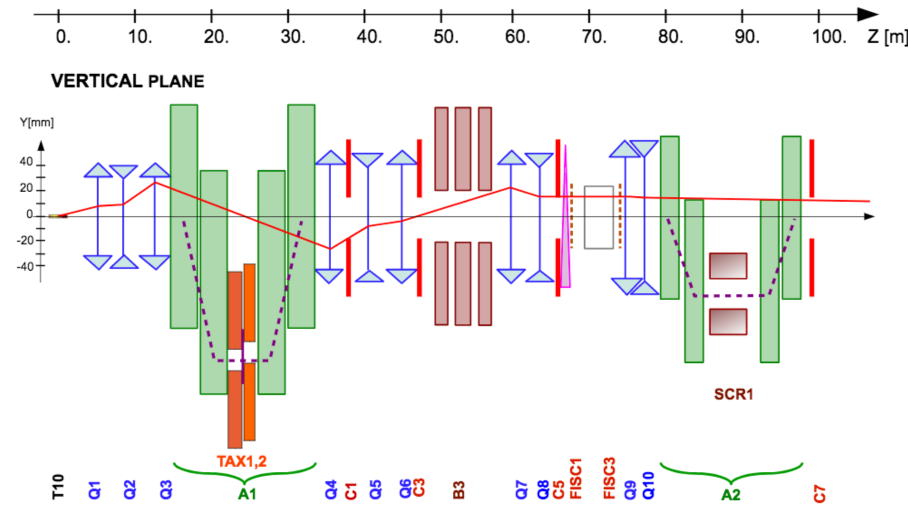
- **Long fiducial decay volume**
- The decays to SM particles can optimally be detected using an experiment with decay volume tens of meters long followed by a spectrometer with particle identification capabilities

The NA62 detector perfectly fits these requirements

NA62 "Kaon" Operation Mode



Schematic of North Area beamlines



K12 beam line layout
(from T10 Be target to entrance of FV)

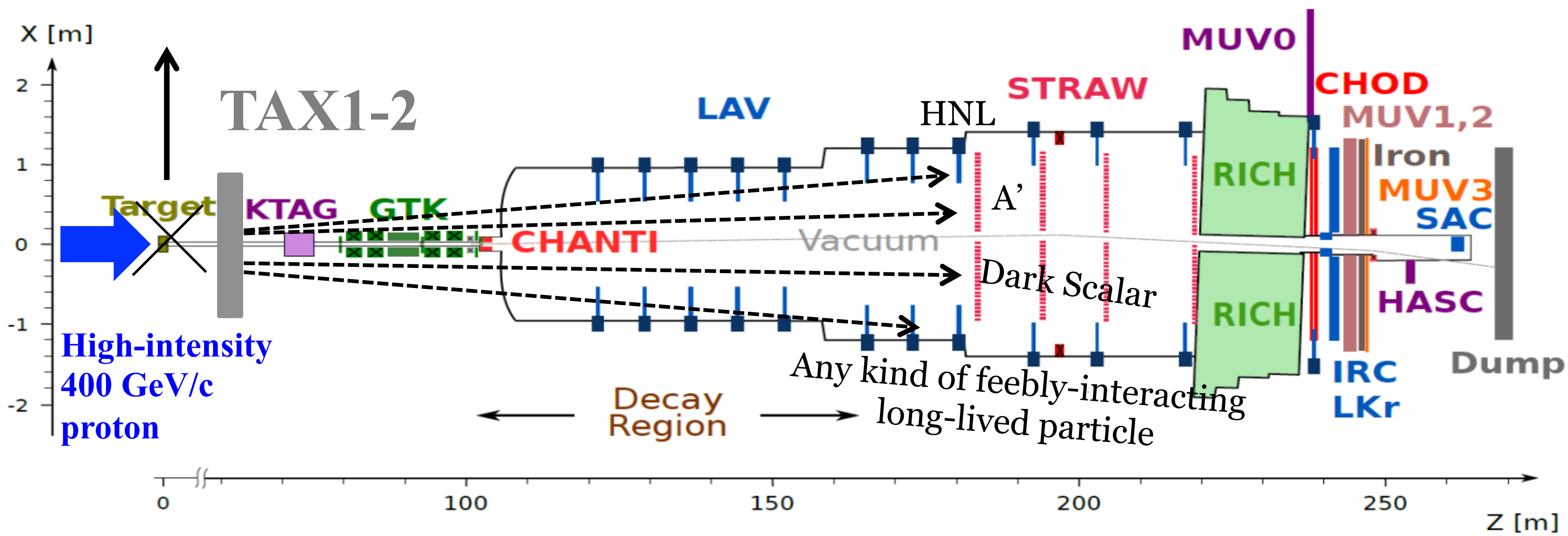
TAX1-2 20m downstream Be target

TAX1-2:

- two 1.6-m long, motorized, water-cooled, copper collimators
- select monochromatic hadron beam (K/π/p) of 75 GeV/c momentum
- dump remaining (40%) primary protons

NA62 “Dump” Operation Mode

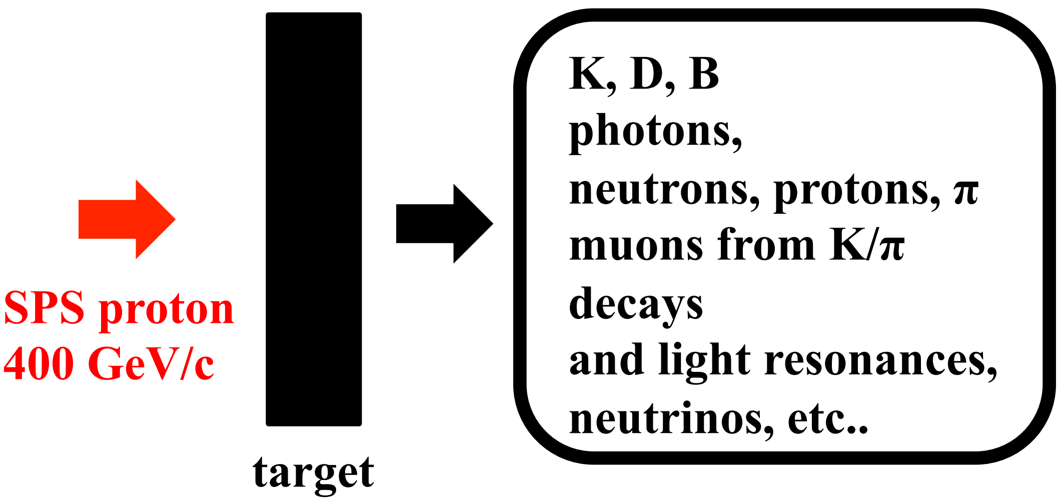
- Be target can be moved away
- Proton beam impinges on TAX1-2 (PoT)
- **TAX1-2 can act as a beam “dump”: 3.2 m of Cu + Fe, ~22λ_I**
- Production of HNLs, Dark Photons, Dark Scalars and ALPs from charm, beauty and photons produced in the interaction of protons with the dump
- **10^{18} PoT/nominal year**: 10^{12} PoT/sec on spill, 100 days/year

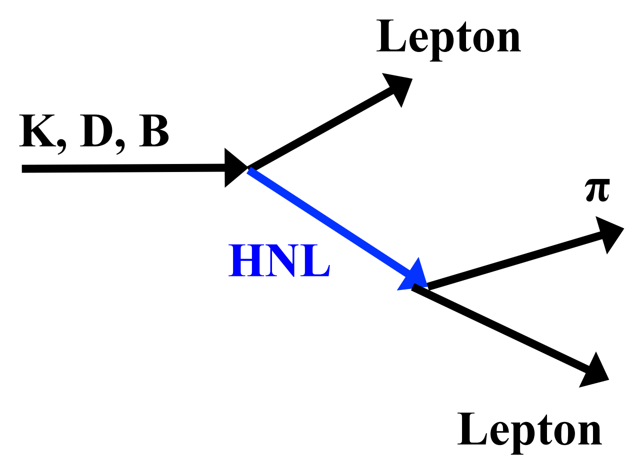


NA62 kaon or proton “dump” modes are easily switchable in current setup

Hidden Sector Particle at NA62

K, B, Bs, D, Ds → lepton HNL
K, B, Bs, D, Ds → semi-leptonic modes



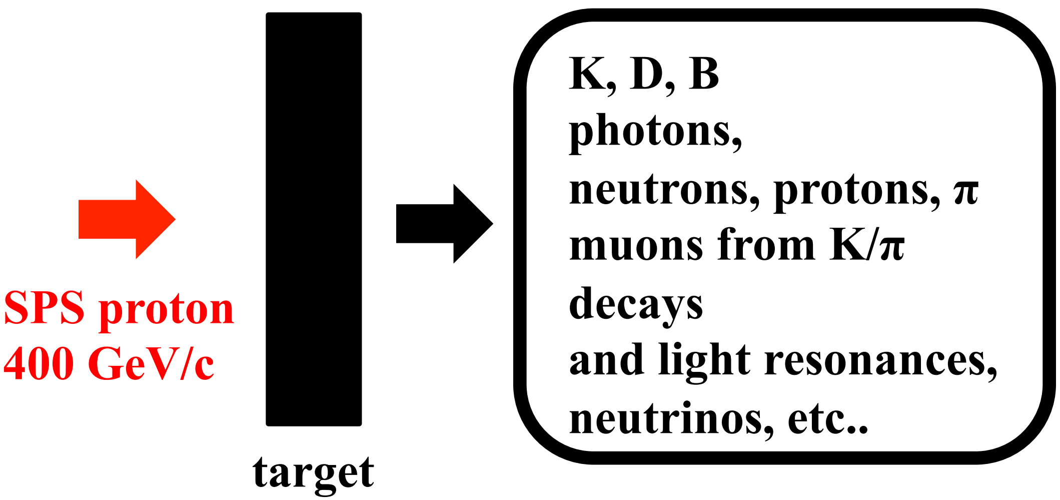


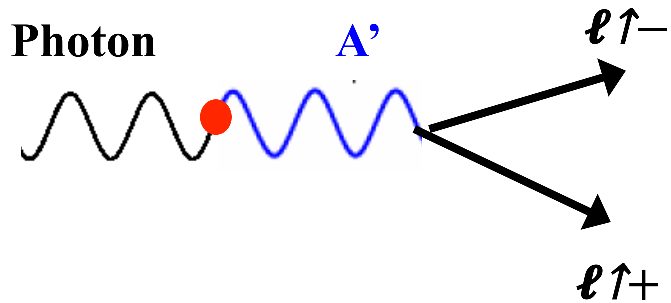
At SPS energies:
σ (pp → s sbar X) ~ 0.15
σ (pp → c cbar X) ~ 2 10^{-3}
σ (pp → b bbar X) ~ 1.6 10^{-7}

Heavy neutrino couplings enter both in production and in decay (~ U^4 process)

Hidden Sector Particle at NA62

Dark photons





At SPS energies:

σ (pp → s sbar X) ~ 0.15

σ (pp → c cbar X) ~ 2 10^{-3}

σ (pp → b bbar X) ~ 1.6 10^{-7}

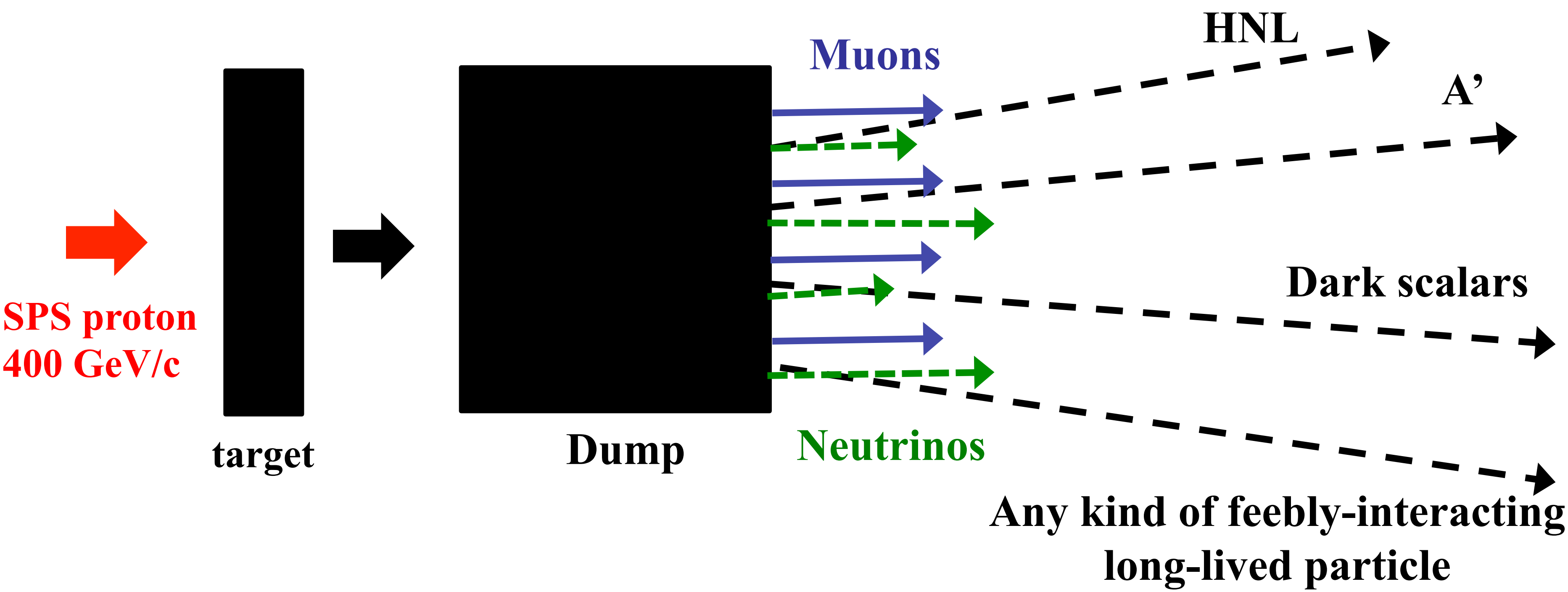
Photon produced in light meson resonances, bremsstrahlung, and QCD processes.

Search for massive particle mixing with the photon and decaying to visible final states ($e^+ e^-$, $\mu^+\mu^-$, etc.)

Hidden Sector Particle at NA62

“Dump” mode

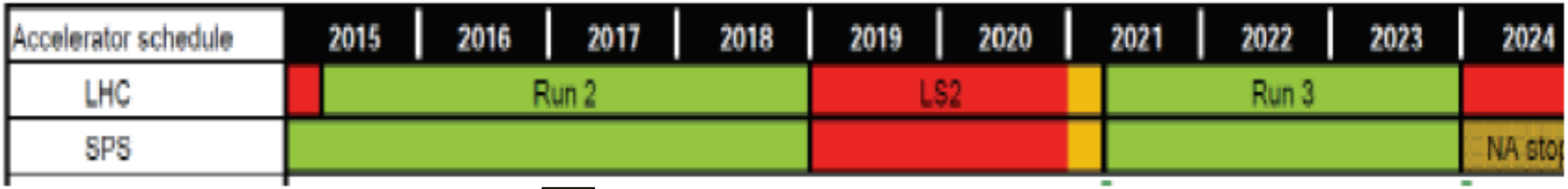
All beam-induced backgrounds are stopped but **muons** and **neutrinos**



A setup with long decay volume allows for probing low values of couplings (as the lifetime of hidden-sector particles ~ 1/coupling^2)

NA62 Timeline – Run 2

NA62 Data taking in 2015-2018 (Run 2)



Data taking in 2016-2017 at 40-60% of nominal beam intensity:

- focused on $\mathbf{K}_{\pi\nu\nu}$ measurement
- limited trigger bandwidth for other physics
- proof of principle for broad LFV/LNV decay programme **(**SES ~ 10^{-10}-10^{-11}**)**
- reached **~10^{17} protons on target**

Prospects for data taking in 2018 → 7 months scheduled

- Keep same goal and beam intensity as in 2016/7;
- Achieve several measurements at SES~10^{-12}: $K^+ \rightarrow \pi^+ A'(A' \rightarrow \text{invisible})$, $\pi^0 \rightarrow \nu\nu$.
- Improve trigger bandwidth for other physics (new HLT for "exotics" lines);
- Might reach **~10^{18} protons on target.**

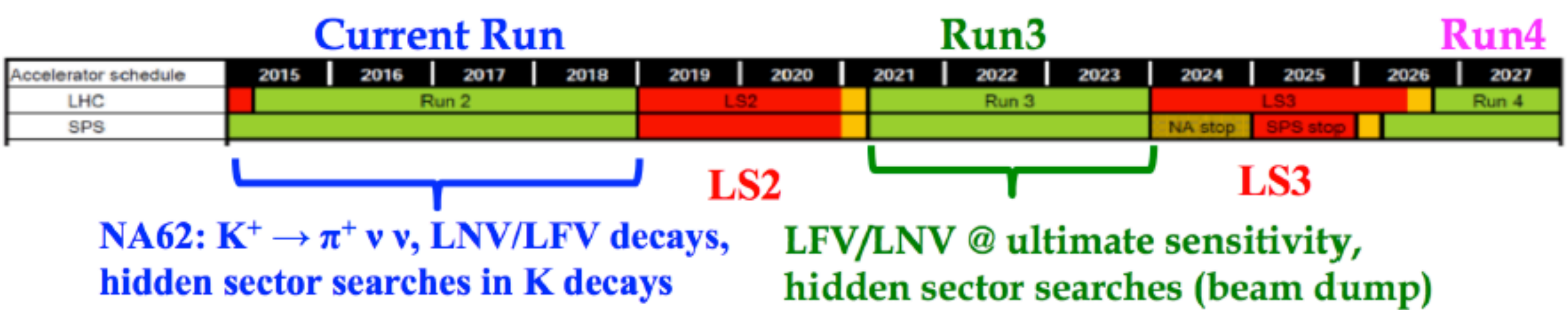
NA62 Timeline – Run 3

NA62 Data taking in 2021-2023 (Run 3)

A rich field to be explored with minimal upgrades to the present setup:

1. **run for refining $K_{\pi\nu\nu}$ measurement**
2. **present K^+ setup: unprecedented LFV/LNV sensitivities from K^+/π^0**
3. **run in "beam-dump" mode with NP searches for MeV-GeV mass hidden-sector candidates: HNLs, Dark Photons, ALPs, etc.**

Run 3 goal: integrate at least 10^{18} PoT in "dump" operation mode(*)



NA62 @ **Physics Beyond Colliders**

(*) "dump" data taking distributed in 3 years, without disruption for the kaon mode operation

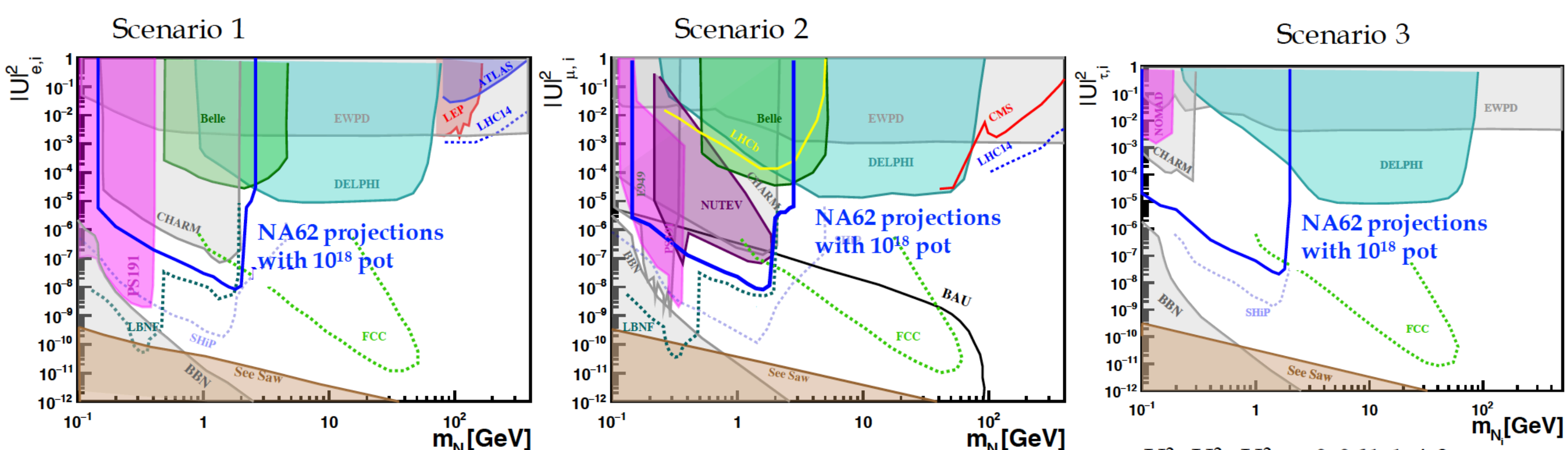
NA62
Expected Sensitivities

DISCLAIMER:
Following sensitivity plots show projections based on toy simulations.
The validation with NA62 fully integrated MC is ongoing.

Heavy Neutral Lepton (HNL)

NA62 sensitivity with **~10^{18} 400-GeV PoT** running in "dump" mode

- Fully reconstructed 2-track final states
- All HNL decays, close and open channels
- Include trigger/acceptance/selection efficiency
- Assume zero-background
- Evaluate expected 90% C.L. exclusion plots



$U^2_e:U^2_\mu:U^2_\tau = 52:1:1$
Normal hierarchy of active **ν** masses

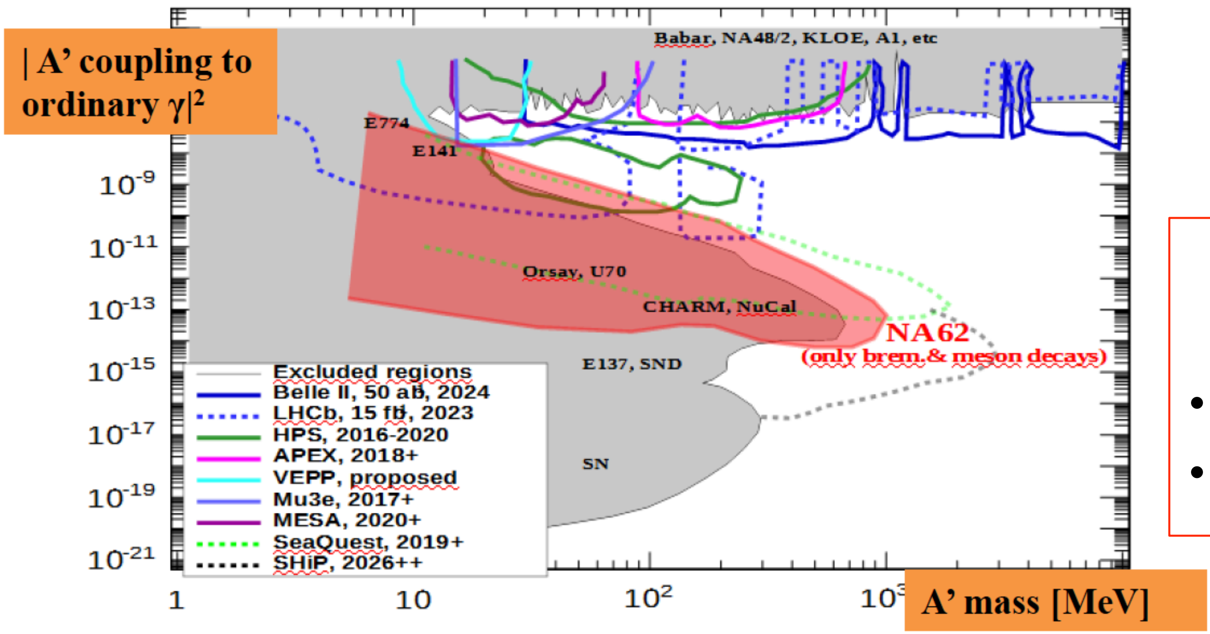
$U^2_e:U^2_\mu:U^2_\tau = 1:16:3.8$
Normal hierarchy of active **ν** masses

$U^2_e:U^2_\mu:U^2_\tau = 0.061:1:4.3$
Normal hierarchy of active **ν** masses

Dark Photon

NA62 sensitivity with **~10^{18} 400-GeV PoT** running in "dump" mode

- Fully reconstructed 2-track final states
- Search for displaced, di-lepton decays of DP (A' → ee,μμ)
- Include trigger/acceptance/selection efficiency
- Assume zero-background
- Evaluate expected 90% C.L. exclusion plots



Projections consider only A' production in Be target

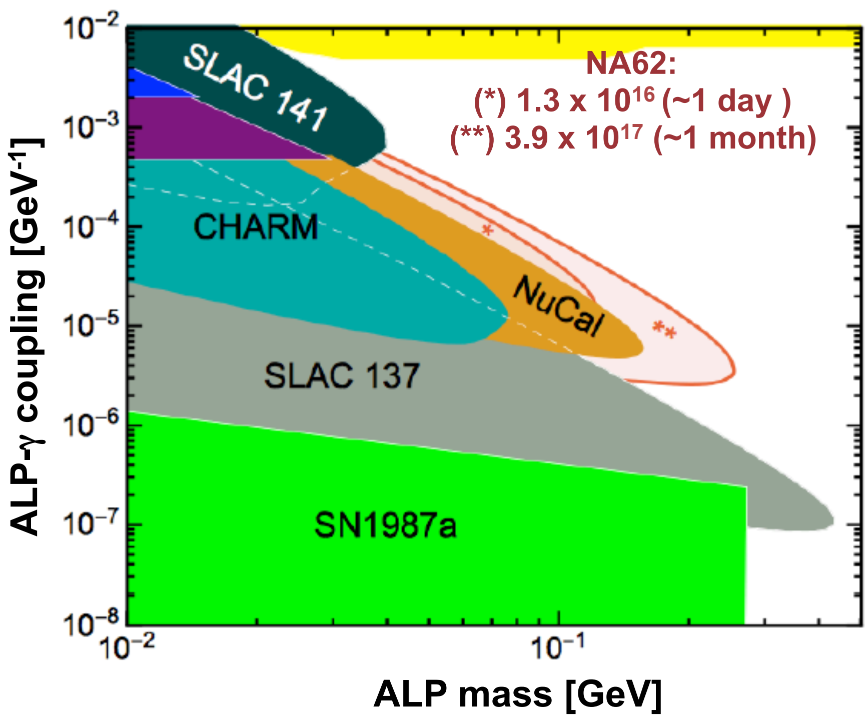
Sensitivity expected to be higher when including:

- Direct QCD production of A'
- A' production in the TAX

Axion-like Particle (ALP)

NA62 sensitivity with **1.3 x 10^{16} (3.9 x 10^{17}) 400-GeV PoT** corresponding to 1 day (1 month) of runs in "dump" mode

- study ALP production via Primakoff effect [*JHEP 1602 (2016) 018*] at target
- search for ALP → γγ in NA62 fiducial volume, account for geometrical acceptance
- Assume zero-background, evaluate expected 90% C.L. exclusion contours



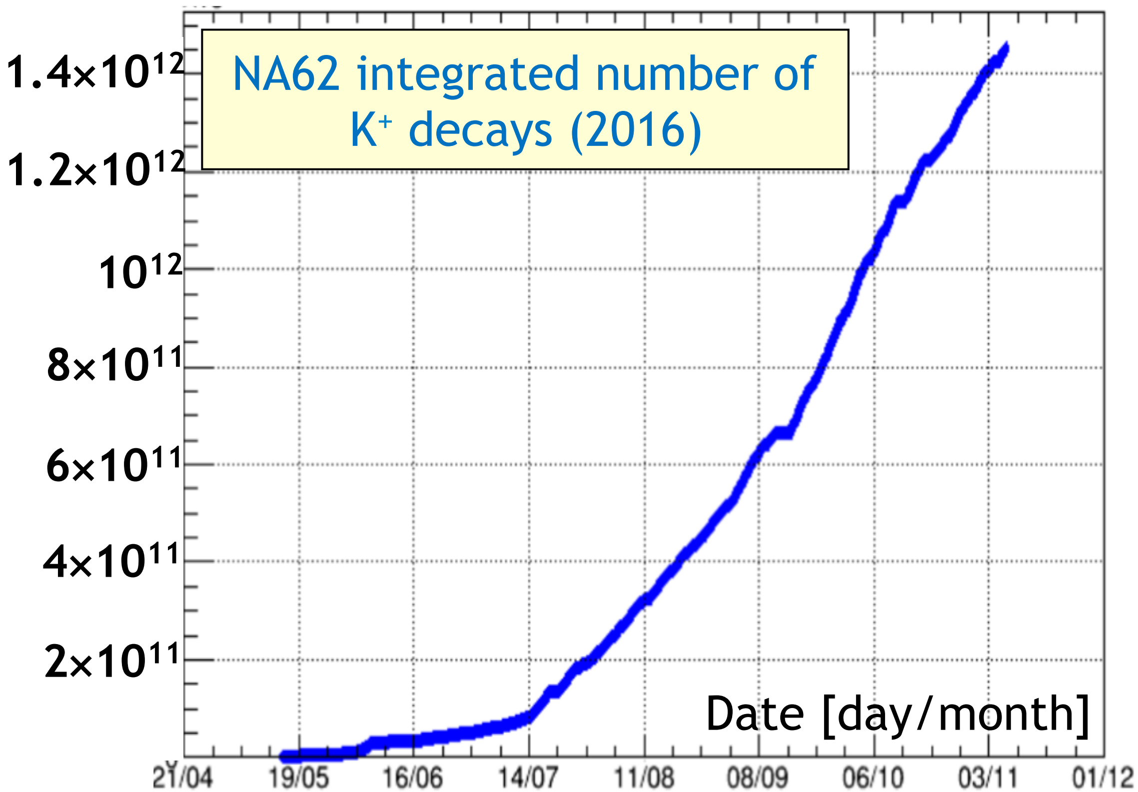
Preliminary studies in "Kaon" & "Dump" operation modes

DISCLAIMER:
The following material is under approval and should not be regarded/presented anywhere as "NA62 preliminary results" or "NA62 prospects" or similar.

Please consult published NA62 papers and official NA62 plots repository for NA62 results.

NA62 2016 Data

- Stable data dating at **~40%** of nominal intensity
- Some exotic searches possible in parasitic mode with the main trigger for $K_{\pi\nu\nu}$
- Search for HNL(ν_h) in $K^+ \rightarrow \mu^+\nu_h$, $K^+ \rightarrow e^+\nu_h$ decays (E. Goudzovski)
- Search for $\pi^0 \rightarrow$ invisible, NA62 sensitive at 10^{-8} or better
- Collected **~3×10^{16}** protons-on-target

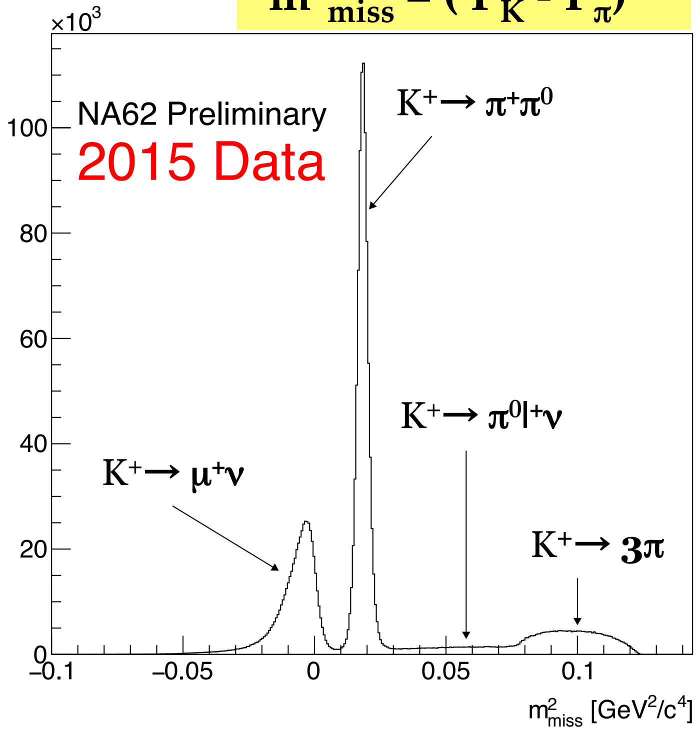


(*) Conversion of POT to number of kaons in FV [JINST 12 (2017) P05025, arXiv:1703.08501]

NA62: Search for $\pi^0 \to$ invisible

Search for $\pi^0 \to$ invisible, NA62 sensitive at 10^{-8} or better…

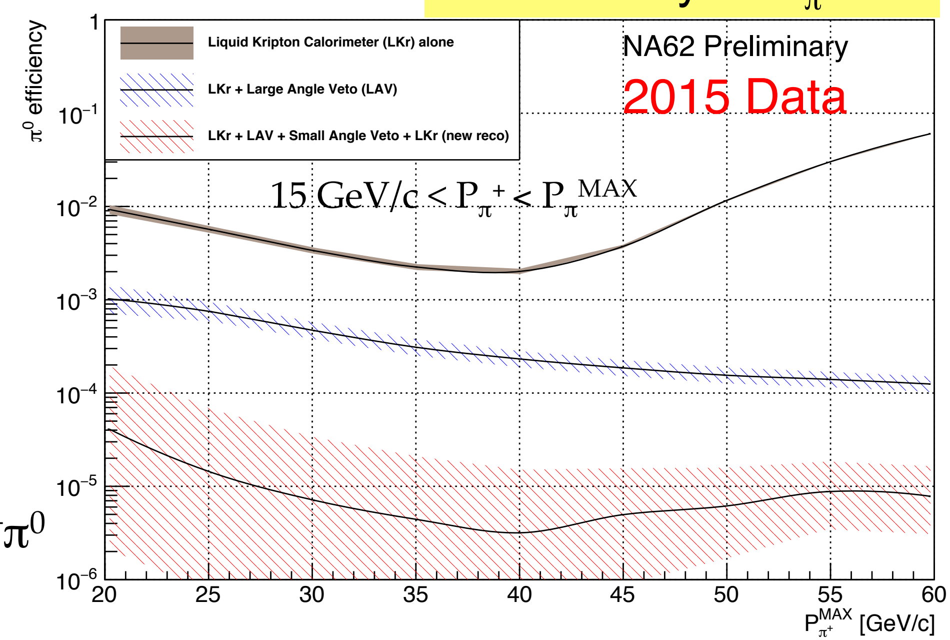
$m^2_{miss} = (P_K - P_\pi)^2$



Photon Rejection (2015 Data):

- Measured $\pi^0 \to \gamma\gamma$ decay suppression = 1.2×10^{-7} in $K_{\pi\nu\nu}$ signal region
- **Goal: $O(10^8)$ π^0 rejection for $K^+ \to \pi^+\pi^0$ bkg**
- $E(\pi^0) > 40$GeV for $P_{\pi^+} < 35$ GeV/c

π^0 efficiency vs P_π^{MAX}



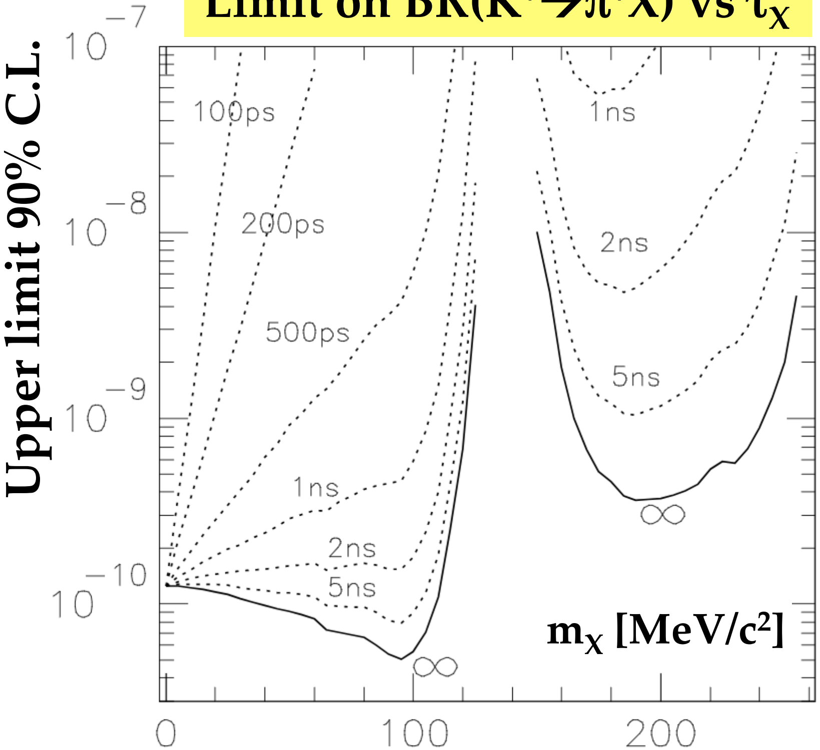
Kinematics (2015 Data):

- Measured bkg rejection: 6×10^{-4} for $K^+ \to \pi^+\pi^0$
- **Goal: $O(10^4)$ for $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu$**

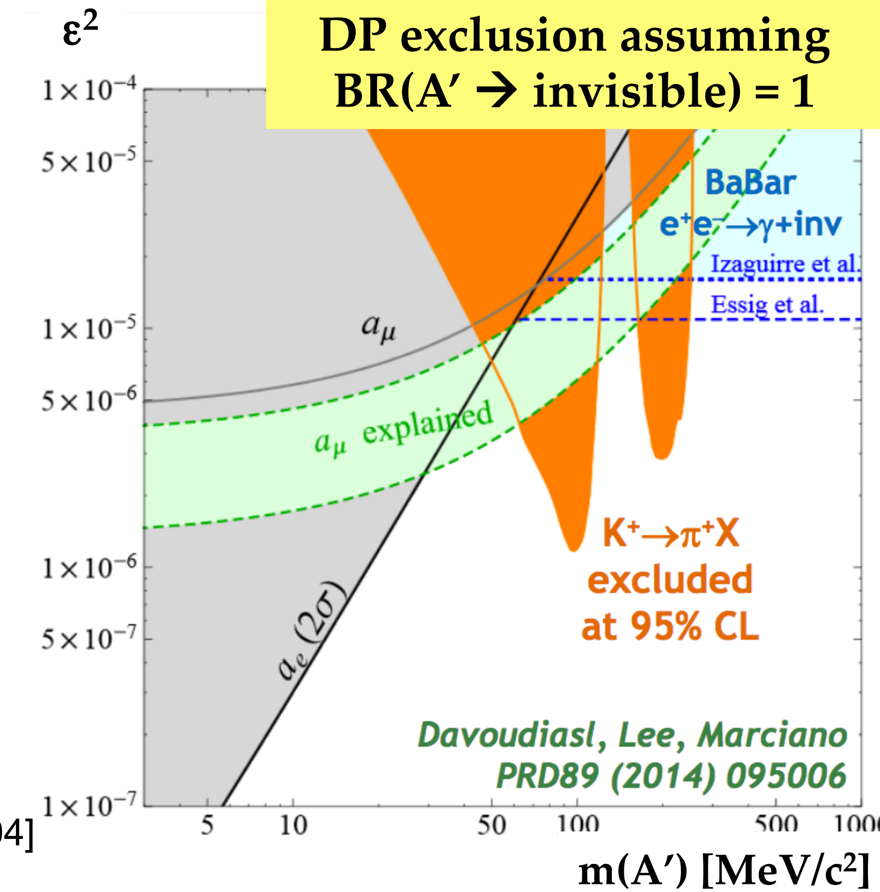
NA62: $K^+ \to \pi^+ A'$, $A' \to$ invisible

NA62 $K^+ \to \pi^+ \nu\nu$ analysis interpreted as $K^+ \to \pi^+ X$ search, X is invisible

Limit on BR($K^+ \to \pi^+ X$) vs τ_X



DP exclusion assuming BR($A' \to$ invisible) = 1



BNL-E949 $K^+ \to \pi^+ \nu\nu$ analysis: [PRD79 (2009) 092004] search for $K^+ \to \pi^+ X$, (X is invisible)

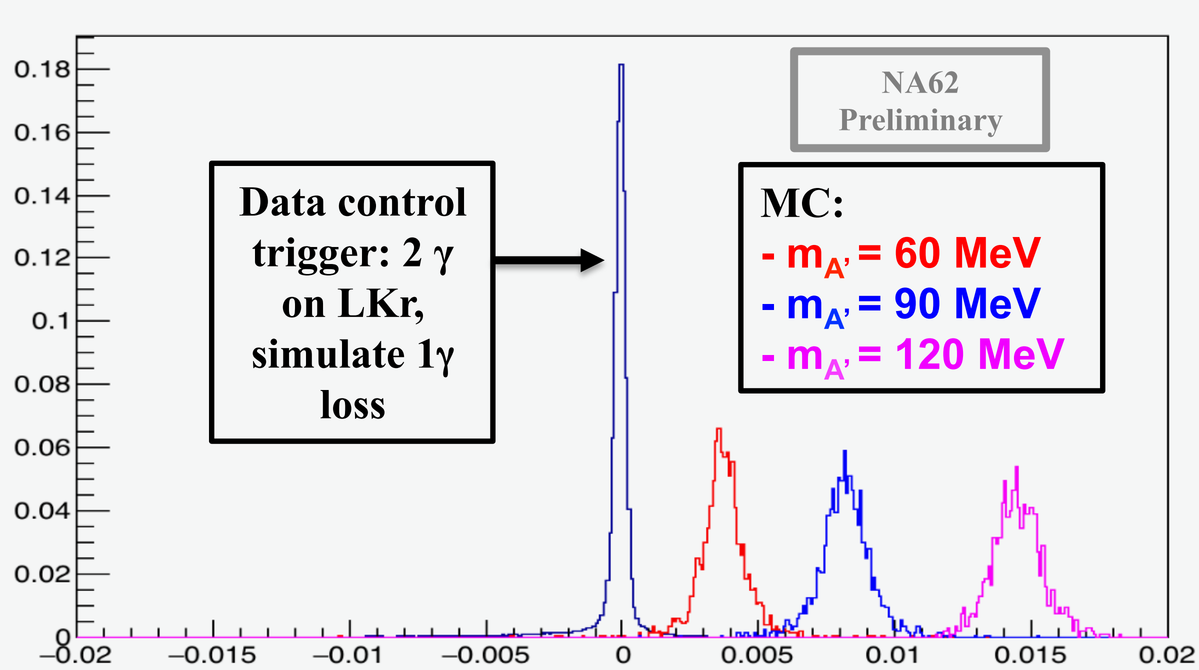
BNL-E949 BR($\pi^0 \to$ invisible) < 2.7×10^{-7} at 90% CL [PRD72 (2005) 091102]

Non-trivial limits on DP phase space including the (g-2)μ favoured band, assuming invisible DP decays.

NA62: expect an order of magnitude improvement

Dark Photon Searches @ NA62

- Search for A' produced via: $K^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma A'$, $A' \to$ invisible
- Sensitivity to DP for $m(A') < m(\pi^0)$
- **NA62 2016 data** (40% nominal beam intensity)
- NA62 main trigger for $K^+ \to \pi^+\nu\nu$
- Search for peaks in $M^2_{miss}(K^+ \to \pi^+\pi^0) = (P_K - P_\pi - P_\gamma)^2$



$M^2_{miss} = (P_K - P_\pi - P_\gamma)^2$ [GeV²/c⁴]

Signature:

- 1 photon + missing energy

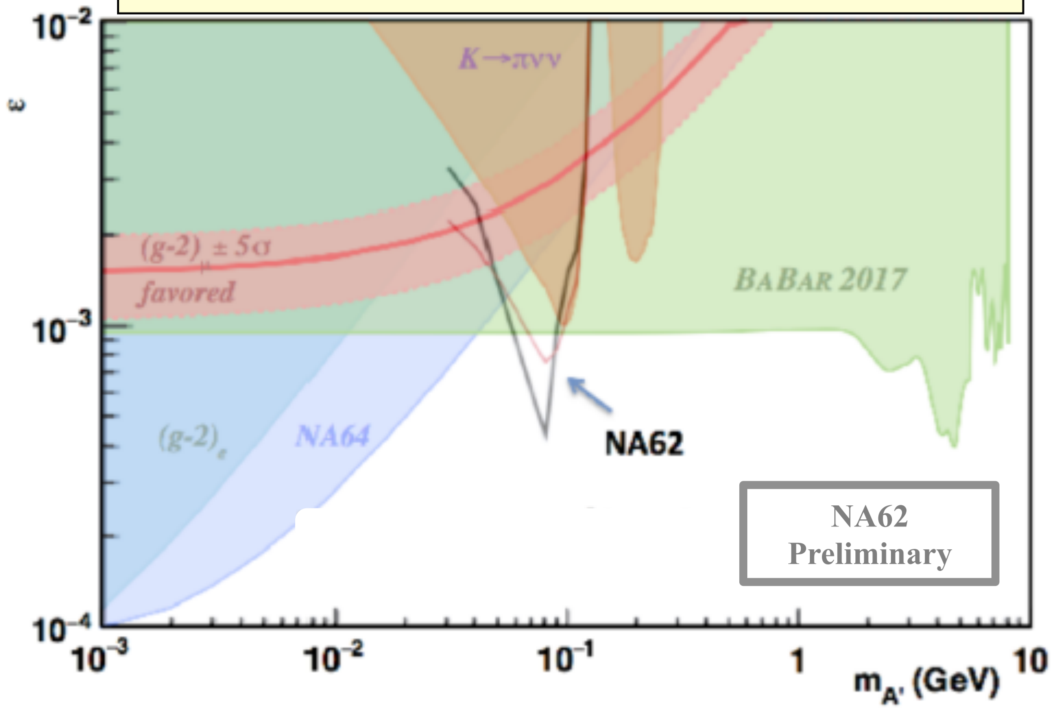
Selection:

- π^+ as in $K^+ \to \pi^+\nu\nu$
- 1 γ in LKr
- Missing momentum in LKr
- Extra γ veto

Dark Photon Searches @ NA62

- Search for A' produced via: $K^+ \rightarrow \pi^+\pi^0$, $\pi^0 \rightarrow \gamma A'$, $A' \rightarrow$ invisible
- NA62 2016 data (40% nominal beam intensity)
- DP mass range: 50 MeV/c² < m(A') < 90 MeV/c²

Expected DP exclusion limits at 90% C.L.



Preliminary results using ~1.5 x 10^{10} K^+ decays [**~4% of 2016 NA62 data**]

Expect improvement over the world data

Improvement on BR($\pi^0 \rightarrow$invisible) over current limit of 2.7×10^{-7} also possible

Search for resonances in $K^+ \to \pi^+ X$ ($X \to \mu^+\mu^-$) decay

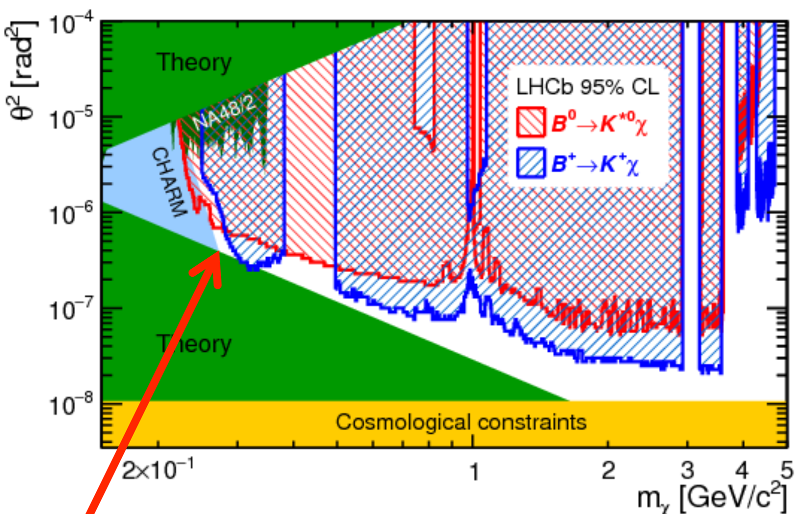
Light inflaton model:

- 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 Σ decays are driven by the same coupling constants
- P and S can be light and decay to SM particles

Experimental limits:



[arXiv:0612.07818]

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

Experimental limits:

○Hyperon decays: $\Sigma^+ \to pP^0, P^0 \to \mu^+\mu^-$
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] → see K.Massri, 22nd Feb

NA62 PROSPECTS:

- O(10^{12}) K decays in 2016-2017
- Displaced vertex approach
- Acceptance up to O(10%)
- Almost background free for long-lived particles

Conclusions

- ✓ NA62 is officially approved to run until LS2 with **the main goal of measuring the Br($K^+ \rightarrow \pi^+ \nu\nu$) with 10% accuracy;**
- ✓ Before LS2 (2018) many searches in the hidden sector will be performed using the kaon beam (**new limits on dark photon investigated**);
- ✓ The list of hidden sector searches presented is not exhaustive;
- ✓ Preliminary studies with data taken in kaon and proton beam "dump" modes show that **background can be kept under control;**
- ✓ After LS2 (2021-2023) there is a window of opportunity to **run NA62 in beam-dump mode to search for hidden sector mediators** from charm and beauty decays and pave the way for the next generation experiments (SHiP/LBNF);
- ✓ **Further improvements in the setup** are currently under study.

Spares

Angela Romano(*), University of Birmingham

Edinburgh, 21 – 23 February, 2018

Dark Photon

Search for an invisible vector boson from π^0 decays

- One of the possible extensions of the SM aimed at explaining the abundance of dark matter in our universe predicts a new U(1) gauge-symmetry sector, with a vector mediator field A′ named "dark photon."
- would (feebly) interact with the SM photon through a "kinetic mixing" lagrangian

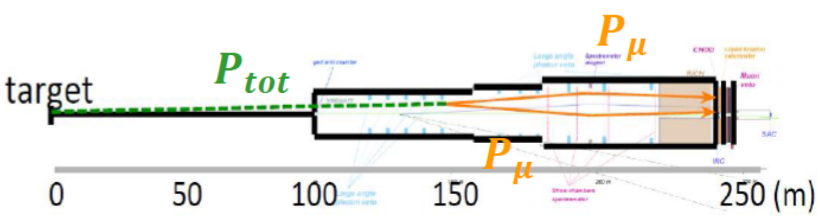
$$\mathcal{L} = \epsilon A'^{\mu\nu} F_{\mu\nu}$$

- where $F_{\mu\nu}$ represents the e.m. field and is a small parameter
- Lagrangian might be accompanied by further interactions, both with SM matter fields and with a secluded, hidden sector of possible dark-matter candidate fields.
- If these are lighter than the A′, the dark photon would decay mostly "invisibly", so that a missing-energy signature might reveal its presence.

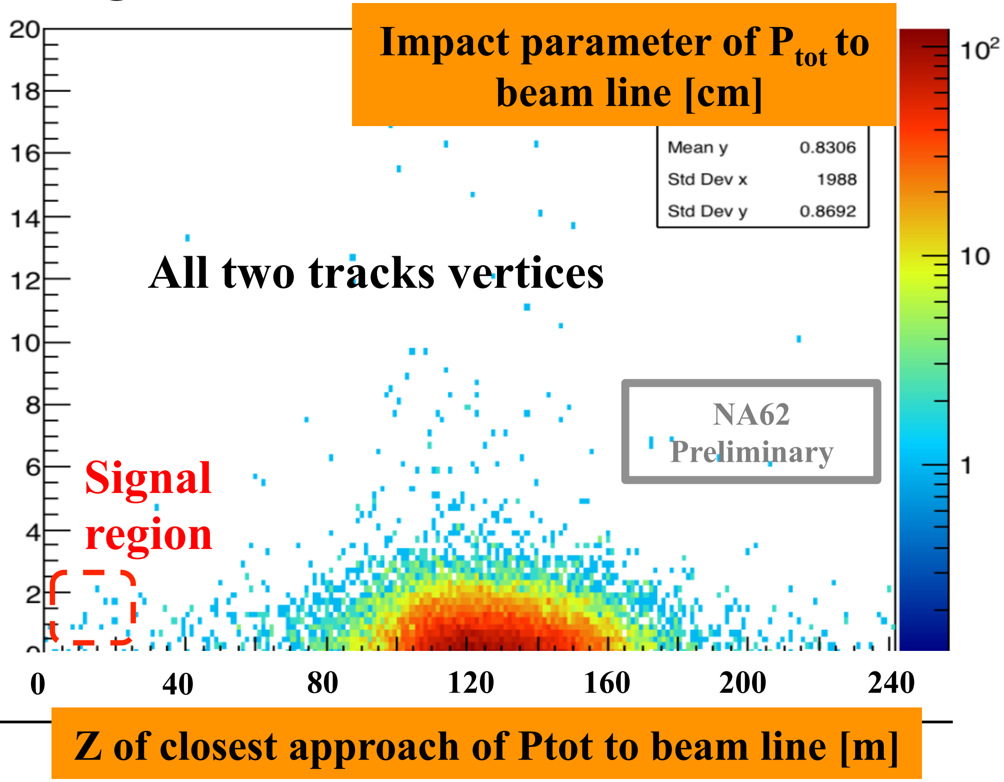
[6] L. Okun, Sov.Phys.JETP 56 (1982) 502;
[7] B. Holdom, Phys.Lett. B166 (1986) 196.

NA62: Study of Long-lived A'→μμ

- **NA62 2016 Data, sub-sample ~10^{15} PoT**
- Event Selection:
  - Track quality & Geometrical acceptance in forward detectors (up to LKr,MUV3)
  - Vertex quality (2-track distance < 1cm) and position in FV (105 m < Zvtx < 165 m)
- Impact parameter of $\mathbf{P_{tot} = P_\mu + P_\mu}$ to beam line used to define the signal region (A' produced at Be target)



Background from K, π decays distributed in area around beam after the final collimator



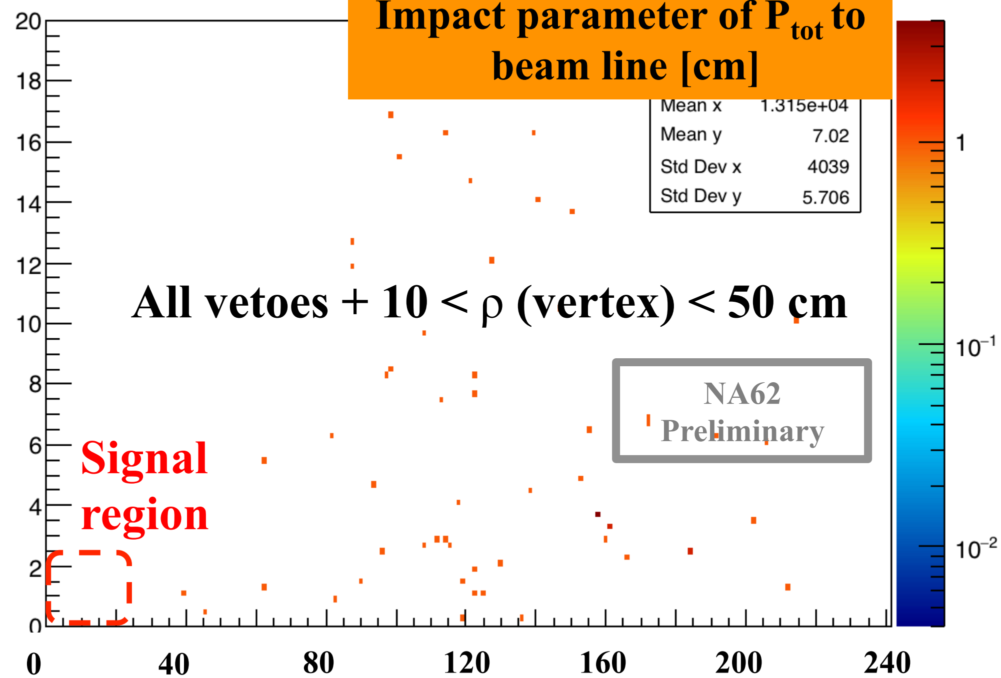
NA62: Study of Long-lived A'→μμ

- **NA62 2016 Data, sub-sample ~10^{15} PoT**
- Add further Veto conditions:
  - Energy deposited in LKr calo < 2 GeV
  - No activity in SAV(forward)/LAV(large) angle calo
  - No activity in CHANTI (upstream charge counter)
- Impact parameter of $\mathbf{P_{tot} = P_\mu + P_\mu}$ to beam line used to define the signal region (A' produced at Be target)

No events selected in the signal region (even with standard K^+ beam)

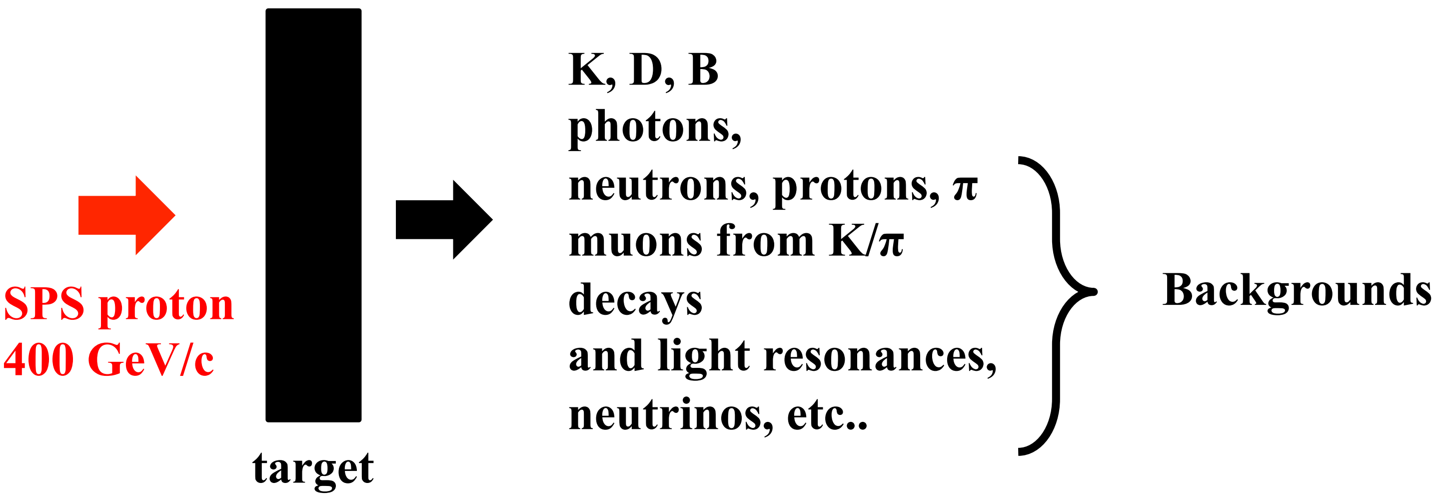
Exploiting extreme photon-veto capability and high resolution tracking while sustaining a high-rate makes the DP analysis synergic with and parasitic to the $K^+ \to \pi^+ \nu\nu$ measurement

Impact parameter of P_{tot} to beam line [cm]



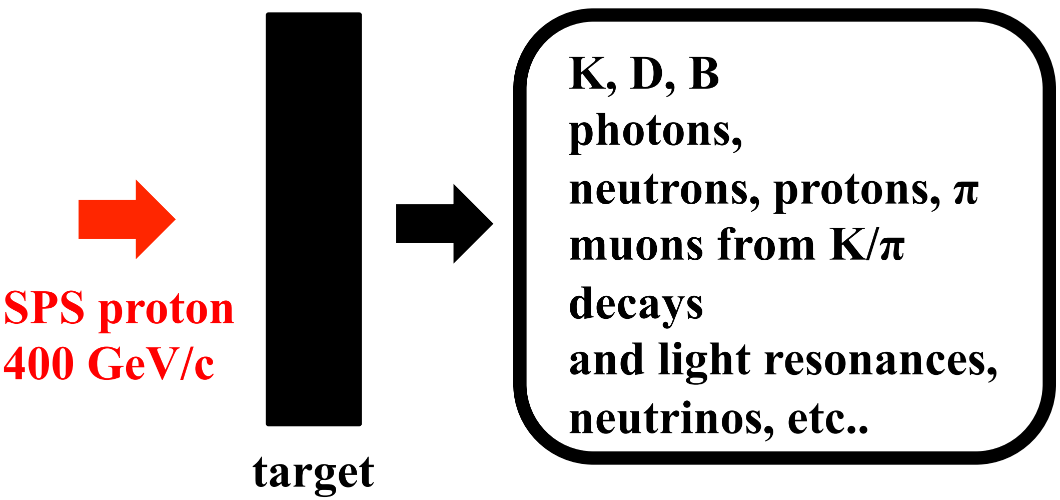
Z of closest approach of Ptot to beam line [m]

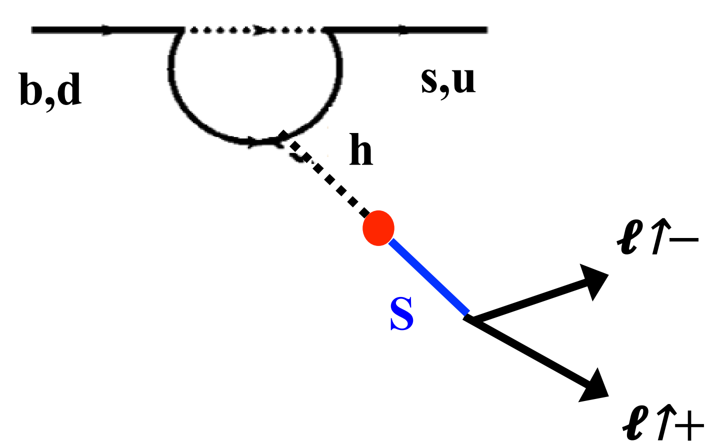
Hidden Sector Particle at NA62



Hidden Sector Particle at NA62

Dark scalars: B →K S, K →π S





At SPS energies:

σ (pp → s sbar X) ~ 0.15

σ (pp → c cbar X) ~ 2 10^{-3}

σ (pp → b bbar X) ~ 1.6 10^{-7}

$\Gamma(K \to \pi\phi) \sim (m_t^2 |V_{ts}^* V_{td}|)^2 \propto m_t^4 \lambda^5$

$\Gamma(D \to \pi\phi) \sim (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$

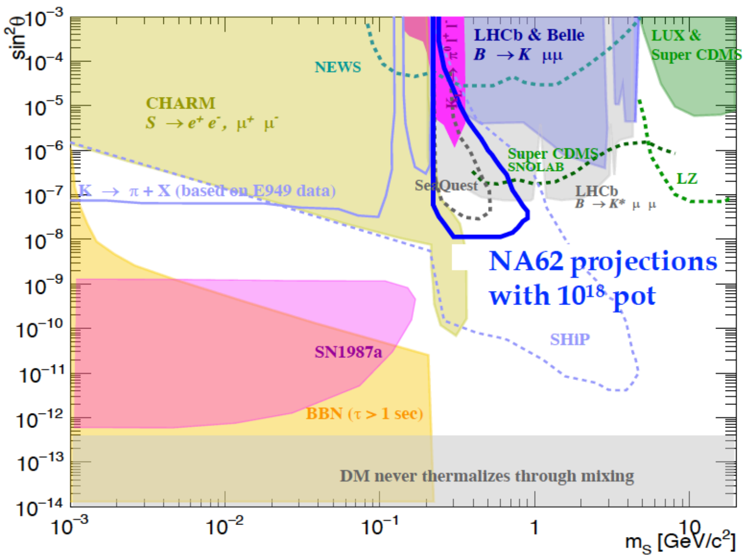
$\Gamma(B \to K\phi) \sim (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$

Dark Scalar & Dark Photon

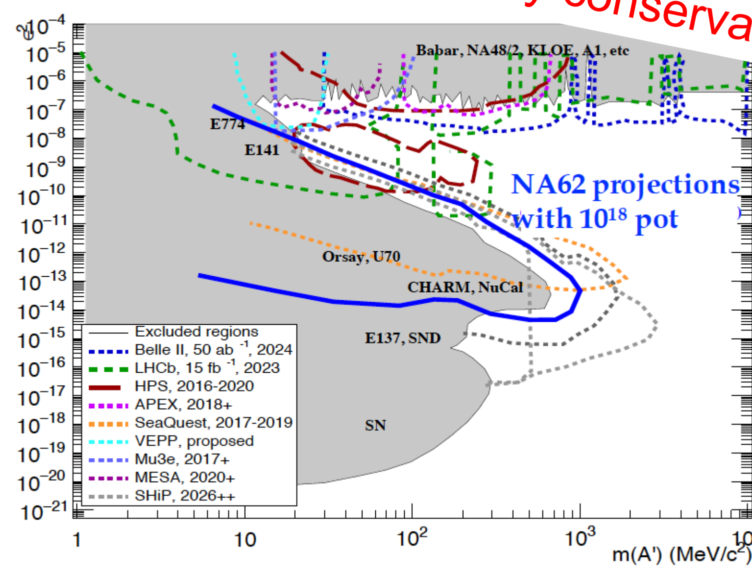
NA62 sensitivity with **~10^{18} 400-GeV PoT** running in “dump” mode

- Dark scalar plot:
  - assume all 2-track fully reconstructed final states
- Dark photon plot:
  - assume di-muon final state only
  - missing the inclusion of two dominant production processes (QED,QCD)
- Assume zero-background

Dark Scalar:



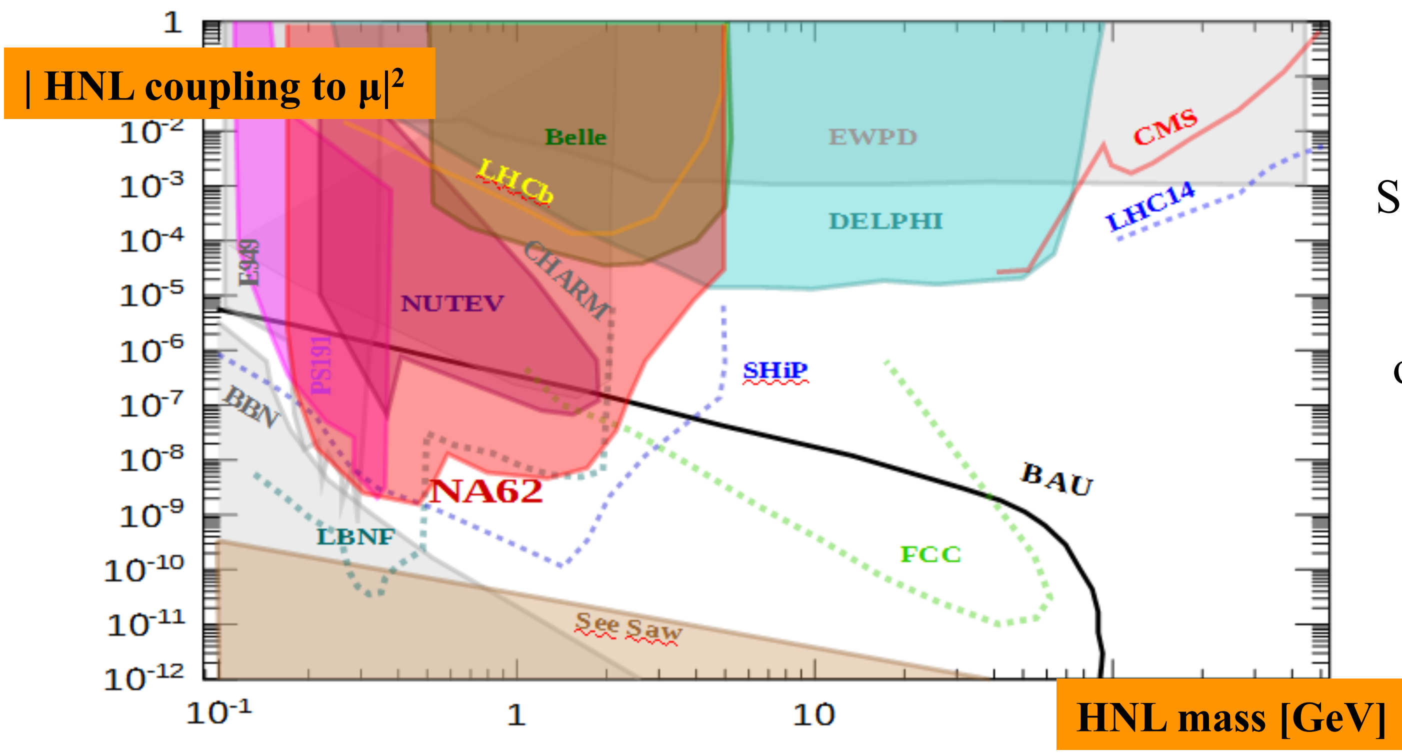
Dark Photon: very conservative!



Heavy Neutral Lepton

Assume 2 × 10^{18} 400-GeV PoT:

- search for displaced, leptonic decays HNL → πe, πμ
- include trigger/acceptance/selection efficiency
- assume zero-background
- evaluate expected 90%-CL exclusion plot



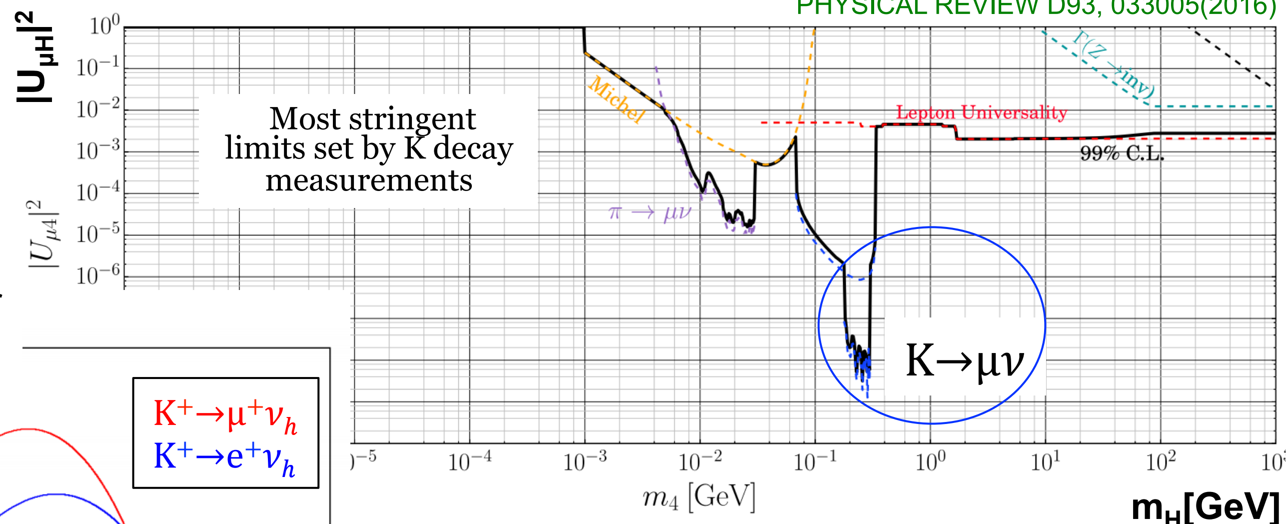
Sensitivity expected to be higher when including search for other decay channels (semileptonic, hadronic modes)

Heavy Neutrino Searches

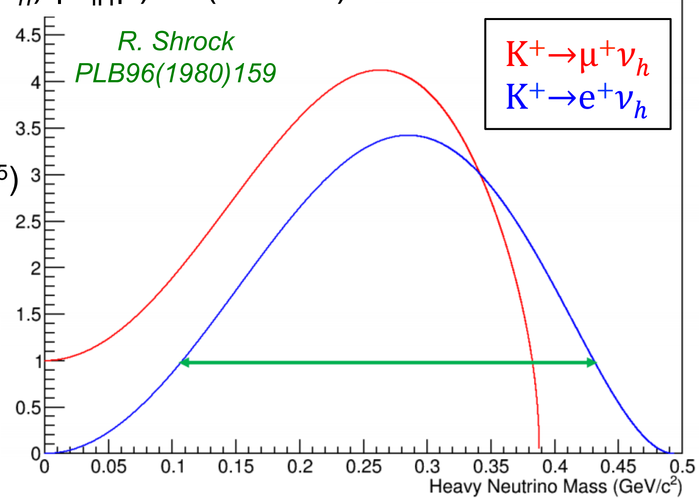
- **νMSM** = **SM** + 3 right-handed HNLs [Asaka et al., PLB 631 (2005) 151]
- Masses: **m_1~10 keV**; **$m_{2,3}$~1 GeV**
- HNLs observable via **production** and **decay**
- Production searches are model-independent
- NA62 searches for HNL produced in $K^+ \to \mu^+ \nu_h$ and $K^+ \to e^+ \nu_h$

PHYSICAL REVIEW D93, 033005(2016)

Global limits on $|U_{\mu H}|^2$ as a function of HNL mass



HNL production, kinematic factor
$(\Gamma(K^+ \to l^+ \nu_h)/|U_{lH}|^2) \,/\, \Gamma(K^+ \to l^+ \nu)$



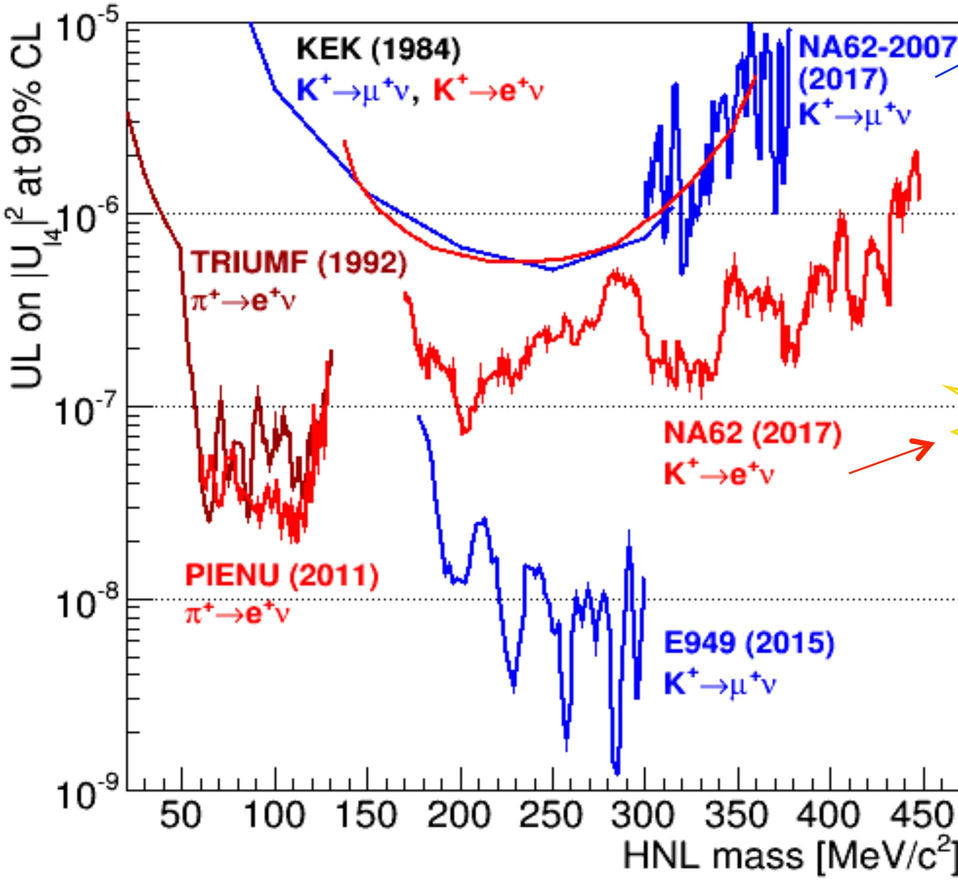
$K^+ \to e^+ \nu_h$ helicity suppressed (~10^{-5}) for $m(\nu_h) \to 0$
PLB698 (2011) 105

Lifting of the suppression by the HNL (for $m(\nu_h)$ ~0.1GeV) means there could be a similar number of $K^+ \to e^+ \nu_h$ events as $K^+ \to \mu^+ \nu_h$

HNL Global Limits

$$|U_{l4}|^2 = \frac{\mathcal{B}(K^+ \to l^+ N)}{\mathcal{B}(K^+ \to l^+ \nu_l)\ \rho_l(m_N)}$$

Limits from heavy neutrino **production** searches



NEW

NA62 2007 Data Analysis:

- Extends the mass range for upper limits on $|U_{\mu 4}|^2$ [arXiv: 1705.07510]
- Most stringent limit in HNL **(300,375) MeV/c²** mass range

NEW

NA62 2015 Data Analysis:

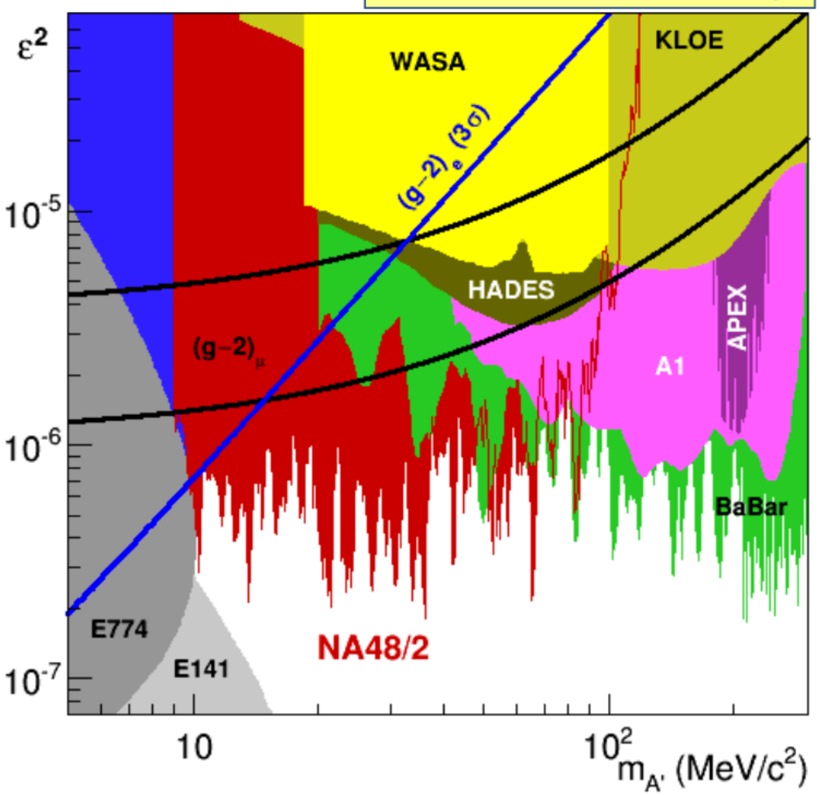
- Reaches **10^{-6}-10^{-7}** limits for $|U_{e4}|^2$ in HNL **(170,448) MeV/c²** mass range

Major improvement foreseen with high intensity NA62 2016 data !

NA48/2: Dark Photon exclusion

Phys. Lett. B746 (2015) 178

DP exclusion summary

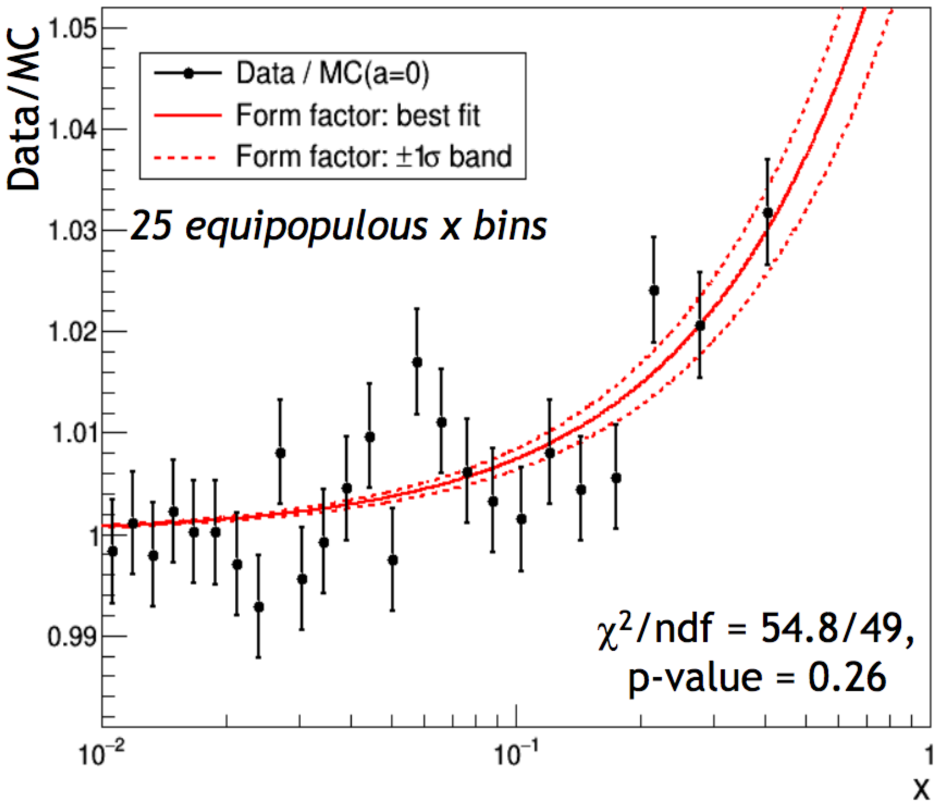


- Improvement on the existing limits in the $m_{A'}$ range **9–70 MeV/c²**.
- Most stringent limits are at low $m_{A'}$ (kinematic suppression is weak).
- Sensitivity limited by irreducible π^0_D background: upper limit on ε^2 scales as $\sim(1/N_K)^{1/2}$, modest improvement with larger data samples.
- If DP couples to quarks and decays mainly to SM fermions, it is ruled out as the explanation for the anomalous $(g-2)_\mu$.
- Sensitivity to smaller ε^2 with displaced vertex analysis: to be investigated.

TFF slope Measurement

NA62-RK 2007 Data

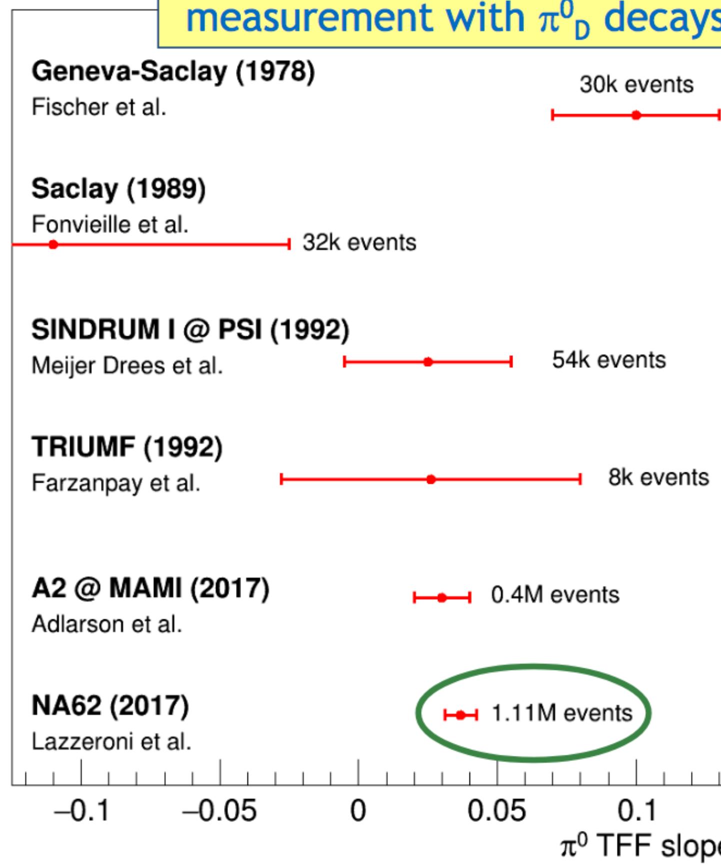
Fit illustration: Data/MC(a=0)



$a = (3.68 \pm 0.51_{stat} \pm 0.25_{syst}) \times 10^{-2}$

[Phys. Lett. B768 (2017) 38]

World data: π^0 TFF slope measurement with π^0_D decays



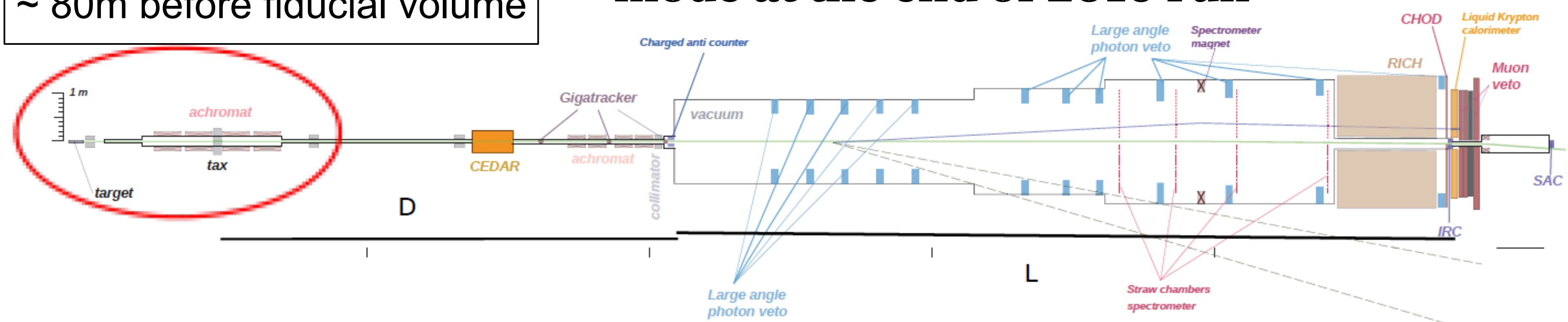
First observation (6.5σ) of *non-zero TFF slope* in the time-like momentum transfer region. [18]

Axion-like particle (ALP) production in NA62

TAX1-2: movable copper + iron made collimators of ~22λ_I total thickness

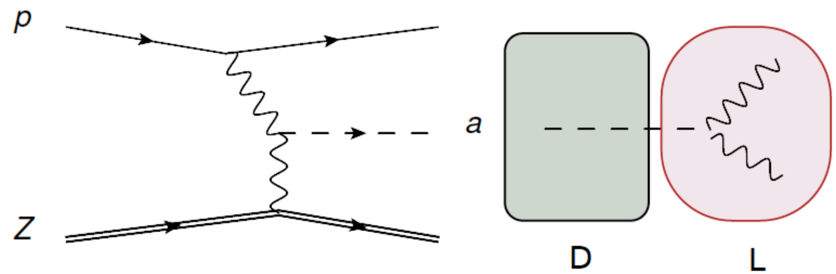
~ 80m before fiducial volume

- K^+ from Be target, large fraction of SPS protons continuously 'dumped'
- long-lived, weakly-interacting particles produced along with nominal beam directly/decay
- possibility to dump entire beam by closing TAX (~ 10^{12} p/sec) and removing Be target
  - Copper TAX → coherent Z^2 enhancement with charge
- **collected ~ 2.5 x 10^{15} PoT in beam "dump" mode at the end of 2016 run**



ALP production from TAX in NA62

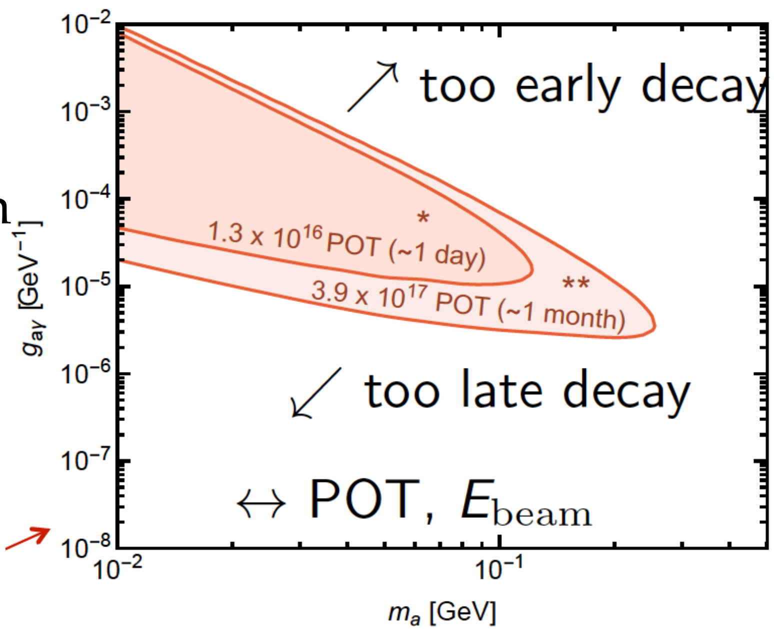
Pseudo-scalar ALP (a) created by photon fusion (Primakoff effect);



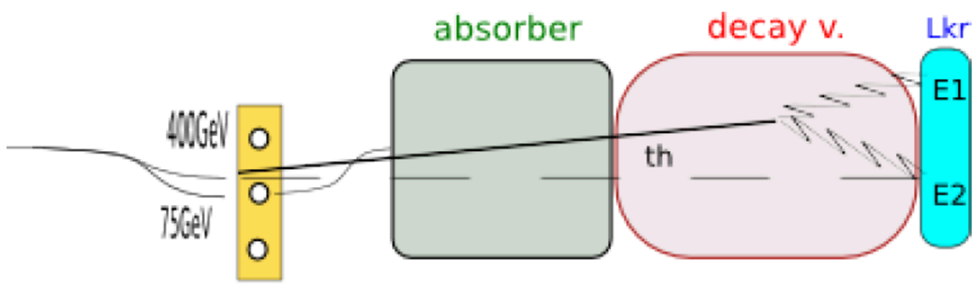
ALP lifetime dependence on its mass and coupling with photon: t ~ $1/(g_{a\gamma}{}^2 m^3{}_a)$

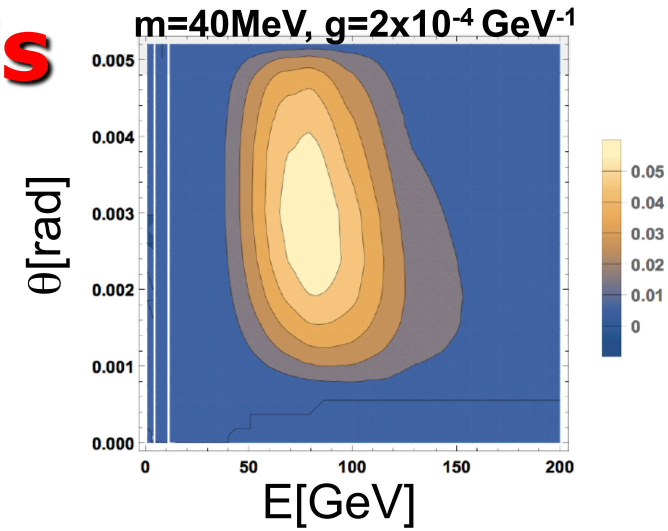
The projected limits fold as input:
1. the differential cross-section for production
2. coincidence and acceptance in EM calo
3. probability to decay within the FV

Expected limits on the mass and coupling assuming (*)1 day/(**)1 month of data taking in "dump" mode



ALP Ongoing Analysis





- **Challenging**:
  - photon is not tracked, know only **E1, E2, d in Ecal** and need to impose mass or decay point to discriminate;
- **Mitigation:**
  - only extend beyond existing limits at small l_d: decay in absorber:

$$\sim \exp(-l_{\text{abs}}/l_d),\ l_d = \gamma\beta\tau \sim \frac{E_a}{m}\frac{64\pi}{m^3 g^2}$$

- yields the **ALPs** in reach **highly boosted** $E_a = E(\gamma 1) + E(\gamma 2)$
- their barycenter enclose a (computable) non-zero angle θ
- compare charged sample in side-band, **deduce expected background** in signal region - optimization of signal efficiency for (g,m) in full MC on the way