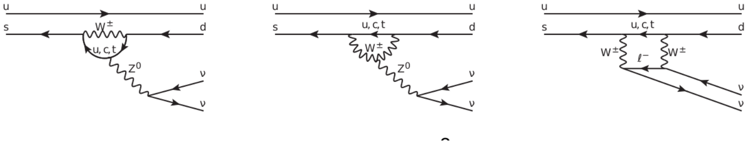
Results and Status of NA62

Babette Döbrich (CERN) for the collaboration

DESY Hamburg, 19/06/18

NA62 at CERN's Prevessin Site

$K \to \pi\nu\bar{\nu}$: motivation and state of art



- ultra-rare FCNC decay, theory prediction:
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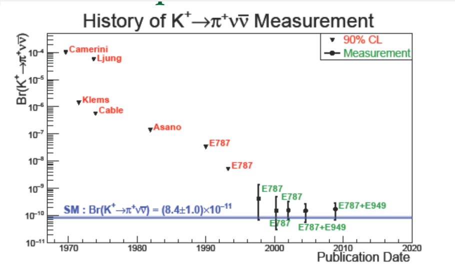

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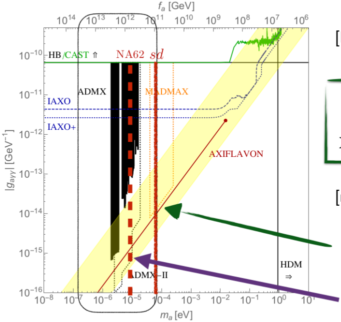
- NA62 primary goal: measurement of $\mathrm{BR}(K \to \pi\nu\bar{\nu})$ with 10% signal acceptance (decay in flight) $\Rightarrow 10^{13} K^+$ in fiducial volume

$K \to \pi\nu\bar{\nu}$:



[R. Ziegler at Annecy, May 3rd 2018]

Natural axion DM window testable at NA62 and ADMX-II!

[note added: and RADES and many others :-)]

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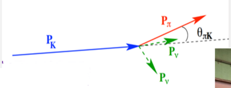
- BR correlated with flavor observables & sensitive to new physics, e.g. **flavored axion models** Phys. Rev. D 95, 095009 (2017)

NA62 rationale

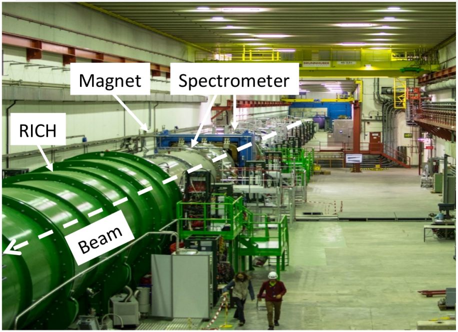


A Kaon's life:

- $BR(K \to \pi^+\pi^0) \simeq 0.21$
- $BR(K \to \mu^+\nu) \simeq 0.64$
- $BR(K \to \pi^+\pi^-\pi^+) \simeq 0.06$

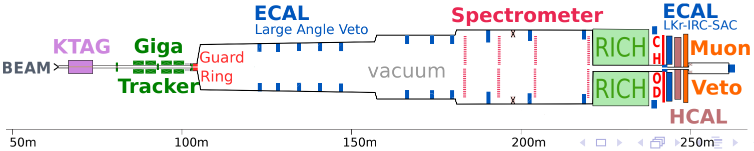
Detector system

- Kaon: KTAG, GTK, CHANTI
- Pion: STRAW, CHOD, RICH
- γ Vetoes: LAV, IRC, SAC, LKr
- MUV system: μ & Hadron



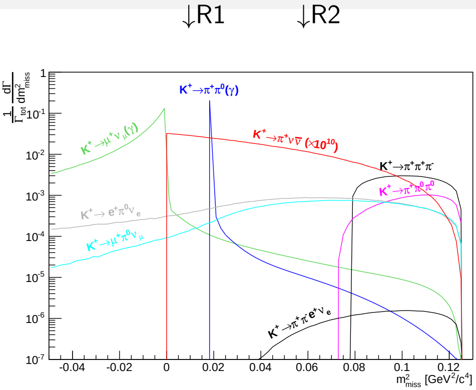
unseparated 750 MHz beam at GTK3

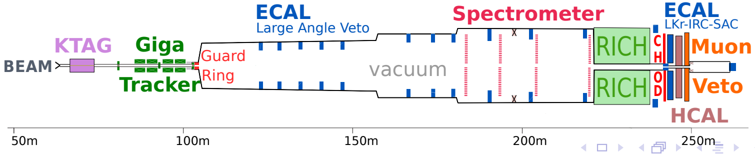
(6.6 % Kaons at 75 GeV, 1 % bite)



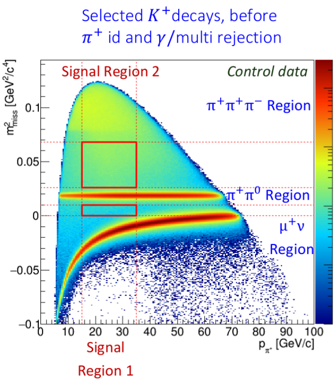
NA62 rationale II & requirements

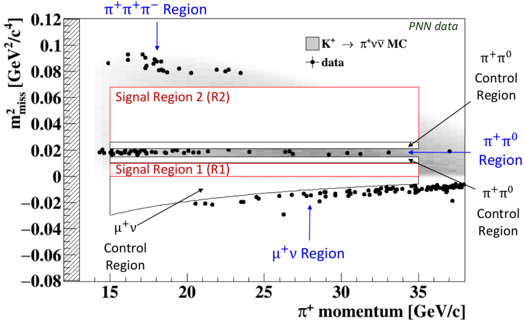
- $m^2_{\text{miss}} = (P_K - P_\pi)^2$
- 10^{12} background rejection!
- kinematic $\mathcal{O}(10^4)$
- high-efficiency veto: $\mathcal{O}(10^8)$ rejection of π^0 for $E(\pi^0) > 40$GeV
- particle ID μ vs π: rejection of $\mathcal{O}(10^7)$ for $15 < p_{\pi^+} < 35$GeV
- timing subdetectors $\mathcal{O}(100\text{ps})$





2016 data: $\sim 10^{11} K^+$ useful for analysis





- K^+ decay into single charged track, π^+ PID, γ & multi-track rejection
- Performances: GTK-KTAG-RICH timing: $\mathcal{O}(100\text{ps})$, γ/multi-track rejection: 3×10^{-8}, overall π^+ ID: 64%,

Single Event Sensitivity and background budget

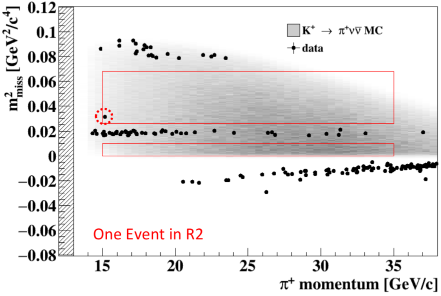
$$SES = \frac{1}{N_K \cdot (A_{\pi\nu\nu} \cdot \epsilon_{RV} \cdot \epsilon_{trig})} \qquad N_K = \frac{N_{\pi\pi} \cdot D}{A_{\pi\pi} \cdot BR_{\pi\pi}}$$

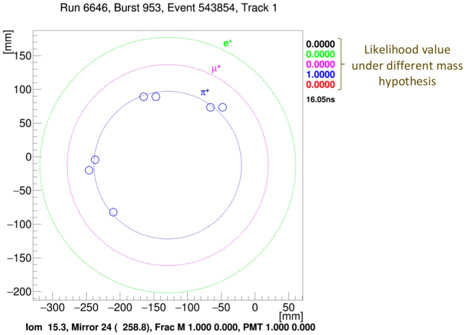
Number of K^+ Decays	$\mathbf{N_K = (1.21 \pm 0.02) \times 10^{11}}$
Acceptance $K^+ \to \pi^+\nu\bar{\nu}$	$A_{\pi\nu\nu} = 0.040 \pm 0.001$
PNN trigger efficiency	$\epsilon_{trig} = 0.87 \pm 0.02$
Random veto	$\epsilon_{RV} = 0.76 \pm 0.04$
SES	$\mathbf{(3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}}$
Expected SM $K^+ \to \pi^+\nu\bar{\nu}$	$0.267 \pm 0.001_{stat} \pm 0.020_{syst} \pm 0.032_{ext}$

Process	**Expected events in R1+R2**
$K^+ \to \pi^+\nu\bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.020_{syst} \pm 0.032_{ext}$
Total Background	$\mathbf{0.15 \pm 0.09_{stat} \pm 0.01_{syst}}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu(\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu$	$0.018^{+0.024}_{-0.017}\vert_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+\pi^+\pi^-$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream Background	$0.050^{+0.090}_{-0.030}\vert_{stat}$

- N_K computed from $K^+ \to \pi^+\pi^0$ on control trigger stream ($D = 400$), w/o γ and multiplicity rejection and modified m^2_{miss}-cut
- Expected number of events from 2016 data: $\mathrm{BR}_{\mathrm{SM\ theory}}/\mathrm{SES}$
- validation of background expectations in control regions, see e.g. `https://indico.cern.ch/event/714178/` for details

Unblinding of signal regions: 1 event observed in 2016 data





Events Observed	1
SES	$(3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \cdot 10^{-10}$
Expected Background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

$BR(K^+ \to \pi^+\nu\bar{\nu}) < 11 \times 10^{-10}$ @ 90% CL

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

Preliminary

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

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

Preliminary

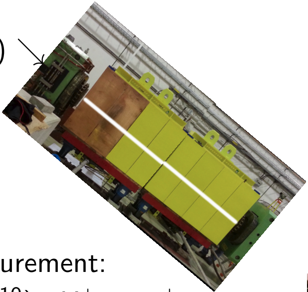
$BR(K^+ \to \pi^+\nu\bar{\nu})_{SM} = (0.84 \pm 0.10) \times 10^{-10}$ SM prediction

$BR(K^+ \to \pi^+\nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$ BNL E949/E787 Kaon Decay at Rest

- Processing of 2017 data ongoing (20-fold present statistics)
- 2018: data taking ongoing → prospect of some mitigation of upstream background

NA62 beyond $\pi\nu\bar{\nu}$

protons on target (POT) ↘



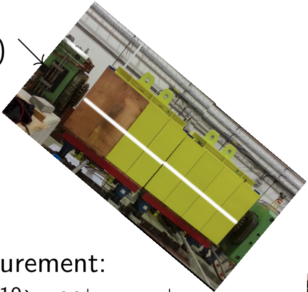
← beam collimator (TAX) ‘open’

$\Rightarrow$ K^+ to detector ↓

main measurement:
BR $\mathcal{O}(10^{-10})$: $K^+ \to \pi^+\nu\bar{\nu}$

NA62 beyond $\pi\nu\bar{\nu}$

protons on target (POT) $\searrow$



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1) Kaon decay
with exotic

NA62 beyond $\pi\nu\bar{\nu}$

protons on
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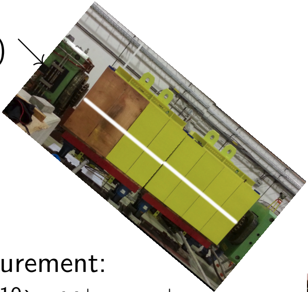
can produce
exotics



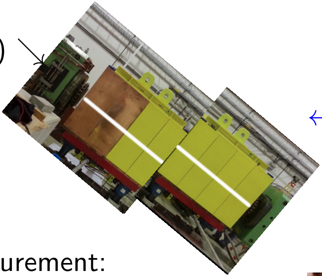
$\leftarrow$ beam collimator (TAX) 'open'

$\Rightarrow$ K^+ to detector $\downarrow$
$+$ exotic away from beamline

main measurement:
BR $\mathcal{O}(10^{-10})$: $K^+ \to \pi^+\nu\bar{\nu}$
1) Kaon decay
with exotic
2) parasitically:
e.g. exotic $\to l^+l^-$

NA62 beyond $\pi\nu\bar{\nu}$

protons on target (POT) ↘ can produce exotics



← beam collimator closed → dump

⇒ exotics to detector ↓ with much reduced backgrounds

main measurement:

BR $\mathcal{O}(10^{-10})$: $K^+ \to \pi^+\nu\bar{\nu}$

1) Kaon decay with exotic

2) parasitically: e.g. exotic $\to l^+l^-$

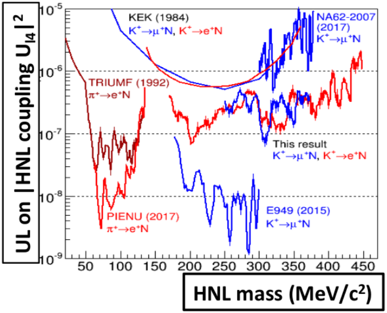
3) dedicated data-taking e.g. axion $\to \gamma\gamma$

some examples will follow!

1) Kaon decay with exotic: results

Trigger band width shared by $\pi^+\bar{\nu}\nu$
$+$ other Kaon & non-Kaon modes
example Kaon: $K^+ \rightarrow N + l^+$,

N: 'stable' Heavy Neutrino
2015 data: PLB 778 137 (2018)
based on $\sim 3 \times 10^8$ Kaon decays



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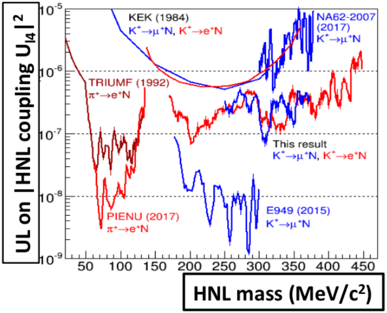
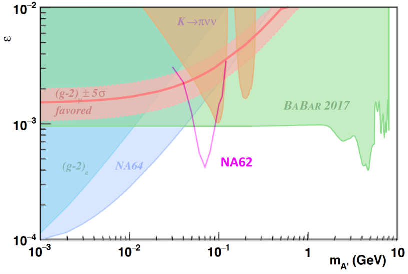


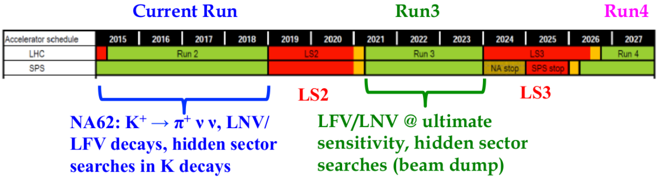


from 2016 data:

invisibly decaying Dark Photon
$K^+ \to \pi^0\pi^+$ with $\pi^0 \to A' + \gamma$
(prelim: paper in preparation)
search peak in missing mass of
$m^2_{\rm miss} = (P_K - P_\pi - P_\gamma)^2$

2+3) Exotic from dumped-beam: prospects

1. Parasitic to $\pi\nu\bar{\nu}$: invisible Dark Photons, heavy Neutrinos… as seen before
2. Trigger Parasitic to $\pi\nu\bar{\nu}$: $\mu\pi + \mu\mu$ away from beamline: 2017: $\mathcal{O}(10^{17})$ POT, sizable statistics $\mathcal{O}(10^{18})$ POT possible this year
3. dump-mode: sizable statistics $\mathcal{O}(10^{18})$ reserved for future, but some channels discovery potential with moderate statistics (e.g. ALP $\mathcal{O}(10^{16})$)



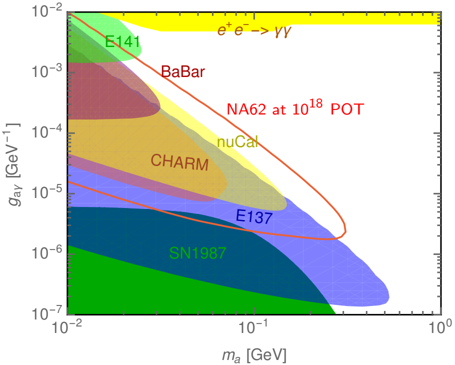
Under study / definition, interaction/synergy with the Physics Beyond Collider CERN initiative

⇒ In the following: "long-lived" prospects at $\mathcal{O}(10^{18})$ POT

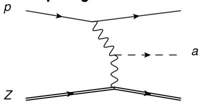
ALPs coupled to photons

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

ALP= Axion-like particle
(name derives from QCD axion)
good properties
as dark matter mediator
see e.g. 1709.00009



- Assume 10^{18} 400-GeV POT
- projection based on Primakov production and 0 background



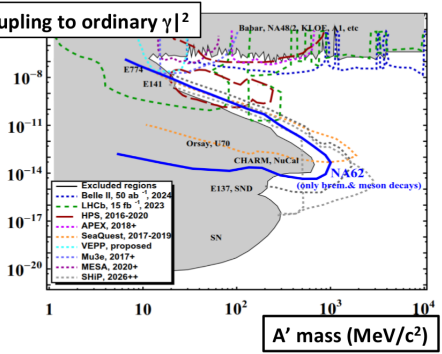
Dark Photons

$$\mathcal{L}_{\text{vector}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} - \frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B_{\mu\nu},$$

minimalistic NP:
Extra U(1)
mixing
kinematically
with EM
or hypercharge

Sensitivity expected to be higher than shown:

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



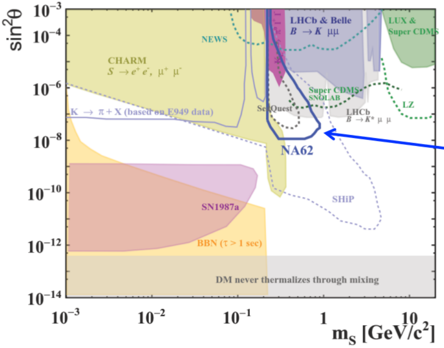
- Assume 10^{18} 400-GeV POT
- Study DP production (meson decays, bremsstrahlung) from interaction on target, search for ee, $\mu\mu$
- assume zero background, expected 90%-CL exclusion plot

Dark Scalars

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

in this model we assume $\lambda = 0$

real
singlet
scalar
coupled
with
Higgs

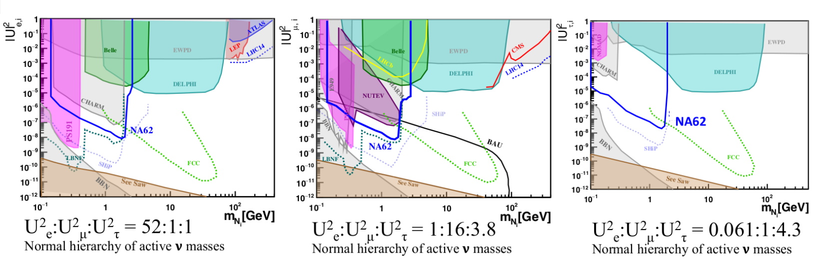


NA62 projected sensitivity
dominated by beauty production

- Assume 10^{18} 400-GeV POT
- sensitivity to hidden scalars charged decays search for ee, $\mu\mu$, $\pi\pi$, KK two-track final states originating at the TAX
- assume zero background, expected 90%-CL exclusion plot

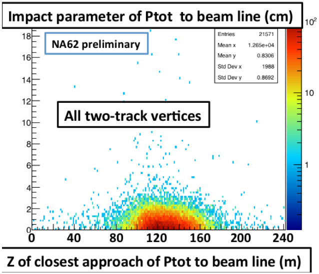
Heavy Neutral Leptons

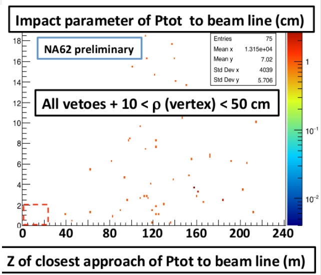
$$\mathcal{L}_{\text{vector}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{DS}} + \sum F_{\alpha I}(\bar{L}_\alpha H)N_I$$



- e.g. νMSM $\rightarrow$ neutrino masses, (warm) DM candidate and baryon asymmetry
- separately address 3 extreme coupling scenarios [Shaposhnikov, Gorbunov arXiv:0705.1729]
- Assume 10^{18} 400-GeV POT: search for two-track final states originating at the TAX sensivity includes open channels, assuming 0 background
- assume zero background, evaluate expected 90%-CL exclusion plot

Background rejection NA62: 2016 data $\mathcal{O}(10^{15})$ POT





- Track quality (association with CHOD, LKr hits in time) + acceptance (CHOD, LKr, MUV3)
- Vertex quality: two-track-distance < 1cm, vertex-position $105 < z < 165$ m
- further veto (rhs): $E_{\mathrm{LKr,additional}} < 2$ GeV; IRC, SAC, LAV no hits with $\pm$ 5ns, CHANTI no candidate within $\pm$ 5ns
- no events in signal region at TAX even with standard K^+ beam at $\mathcal{O}(10^{15})$ POT, background rejection OK for $\mathcal{O}(10^{15})$ POT in standard conditions and $4 \times \mathcal{O}(10^{15})$ in dump

Thanks for listening :-)

- $\pi\nu\bar{\nu}$ expected about 20 SM events from the 2017+2018 sample
- Kaon in-flight-decay technique validated
- methods to improve signal efficiency under study
- 2018: Processing on parallel with data-taking
- the analysis of 2017+2018 sample should provide: ESPP input

In addition,

- before LS2: $\pi\bar{\nu}\nu$-parasitic triggers/searches + short dedicated beam-dump runs
- after LS2, $\mathcal{O}(10^{18})$POT would provide sensitivity to various weakly coupled particles

Additional slides/backup