Rare Decays Searches with NA62

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UCL/CP3

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Belgian Science Policy Office

belspo

Fundamental

.be

Interactions

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- Decays highly suppressed in the SM.
- Fully controlled and calculable

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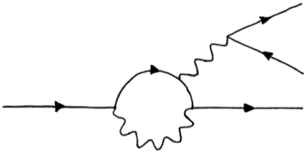

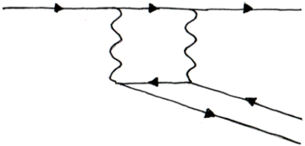

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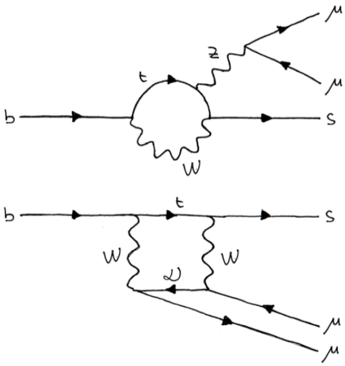

$$\Gamma(B^+ \to K^+ e^+ e^-) = (5.5 \pm 0.7) \times 10^{-7}$$
$$\Gamma(B^+ \to K^+ \mu^+ \mu^-) = (4.43 \pm 0.24) \times 10^{-7}$$

$$\Gamma(B^0 \to K^0 e^+ e^-) = (1.6^{+1.0}_{-0.8}) \times 10^{-7}$$
$$\Gamma(B^0 \to K^0 \mu^+ \mu^-) = (3.39 \pm 0.34) \times 10^{-7}$$
$$\Gamma(B^0 \to \mu^+ \mu^-) = (1.8 \pm 3.1) \times 10^{-10}$$

$$\Gamma(B_s^0 \to \mu^+ \mu^-) = (2.4^{+0.9}_{-0.7}) \times 10^{-9}$$

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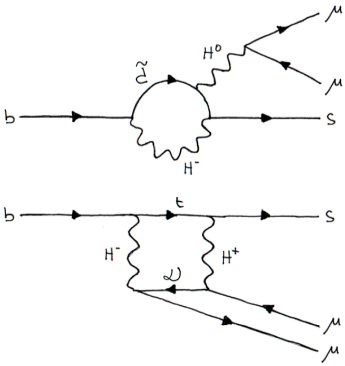

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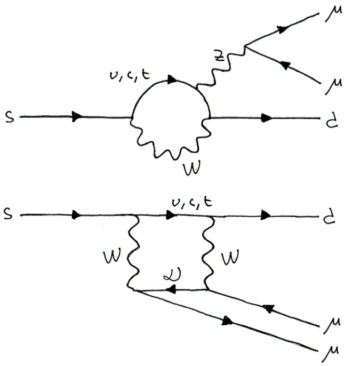

$$\Gamma(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09) \times 10^{-7}$$
$$\Gamma(K^+ \to \pi^+ \mu^+ \mu^-) = (9.4 \pm 0.6) \times 10^{-8}$$

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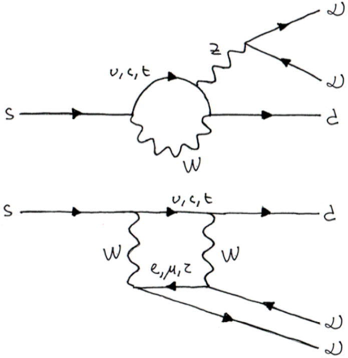

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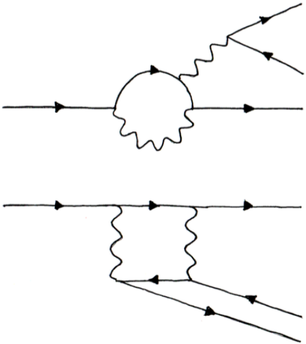
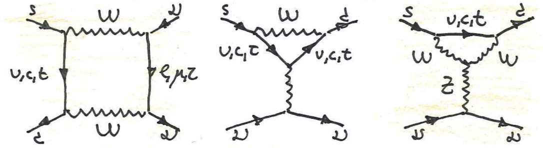


$$\Gamma = 10^{-7} - 10^{-10}$$

- BSM may predict an enhancement/suppression of these decays.
- Indirect test of New Physics at higher energy scales.

$K \to \pi\nu\bar{\nu}$ in the Standard Model

- FCNC processes dominated by Z-penguin and box diagrams

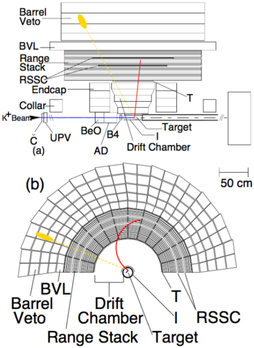


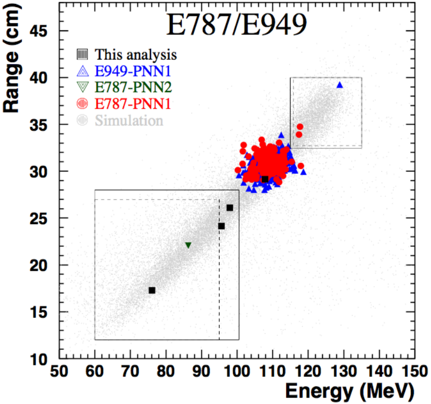
- Very clean theoretically:
  - GIM suppression + CKM suppression ($V_{ts}^{*} V_{td}$)
  - Short distances contributions: NLO (top) NNLO (charm)
  - Long-distance distributions under control:
    - ★ No amplitudes with intermediate photons
    - ★ Hadronic amplitudes from K_{e3} via isospin rotation

$$\mathrm{BR}(K^{+} \to \pi^{+}\nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$
$$\mathrm{BR}(K^{0} \to \pi^{0}\nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}$$

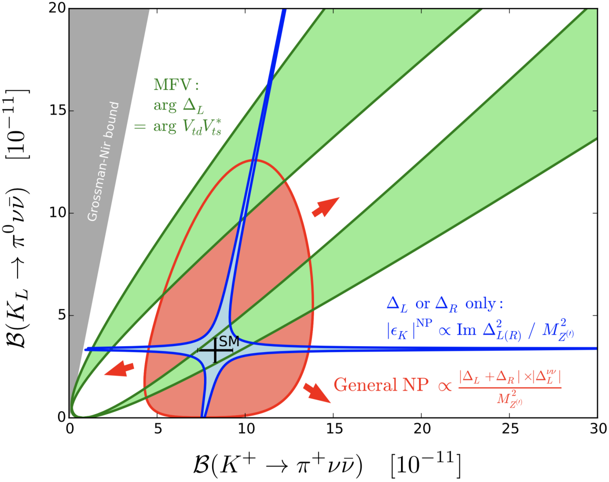
$K \to \pi\nu\bar{\nu}$: experimental status

$$BR(K^+ \to \pi^+\nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$
$$BR(K^0 \to \pi^0\nu\bar{\nu}) < 2.6 \times 10^{-11} \text{ 90\% CL}$$





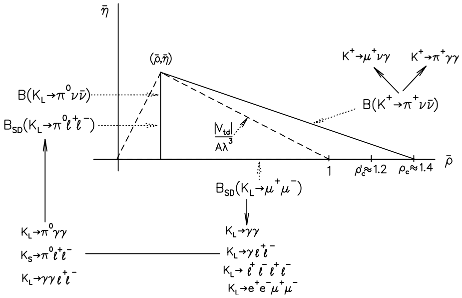
$K^+ \to \pi^+ \nu\bar{\nu}$ and new physics



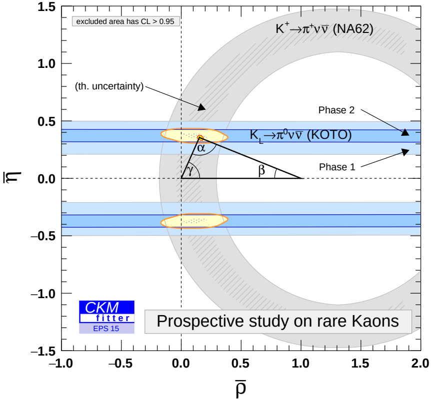
Buras et al. JHEP11(2015).166

$K \to \pi\nu\bar{\nu}$ and CKM

$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) \propto \sigma\bar{\eta}^2 + (\rho_c - \rho)^2$$
$$\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu}) \propto \bar{\eta}^2$$



PDG - Rare Kaon Decays Review



NA62 Experiment

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna(JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, 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)

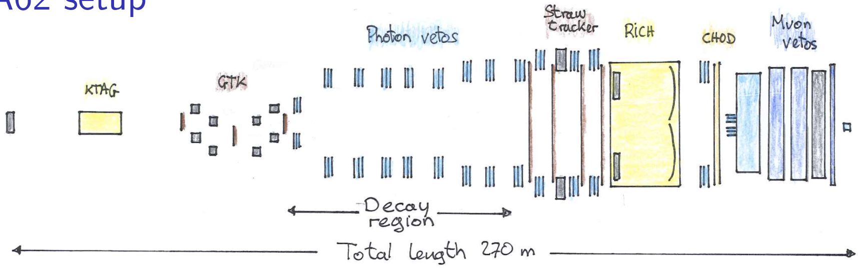
29 Institutes, 230 Collaborators

- NA62: Kaon experiment at CERN SPS
  - Main goal: 10% measurement BR($K^+ \to \pi^+ \nu \bar{\nu}$)
  - Decay in flight technique
- Broader physics program
  - LFV/LNV in K^+ decays
  - Hidden sector particle searches
- Status: NA62 is taking data since 2016

2015	2016	2017	2018
3×10^8	1.0×10^{11}	3×10^{12}	5×10^{12}

  - Approved until LS2
  - Run after LS2 under discussion

NA62 setup



SPS protons

- 400 GeV/c
- 33×10^{11} POT/spill

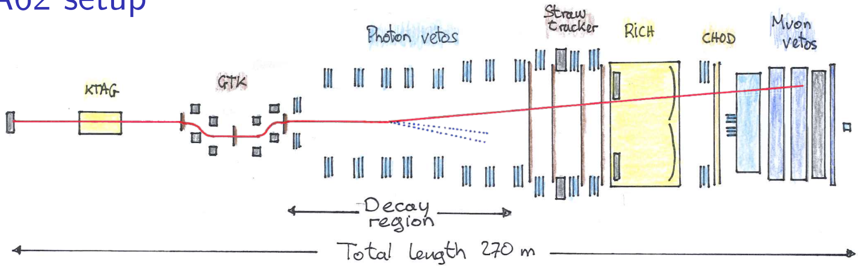
Secondary Beam

- $+75$ GeV/c ($\Delta p/p \sim 1\%$)
- $K(6\%)$,$\pi(70\%)$,p(23%)

Kaon Decays

- $\sim$5 MHz
- 4.5×10^{12}/year

NA62 setup



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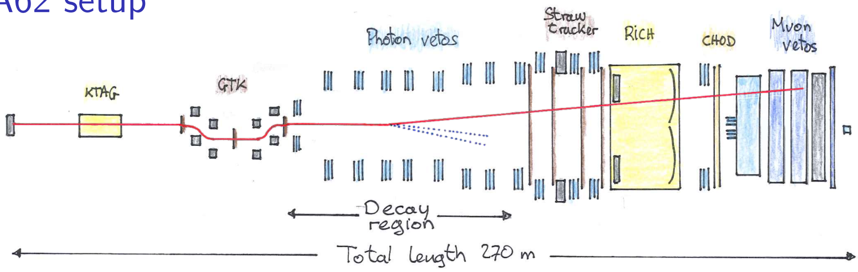

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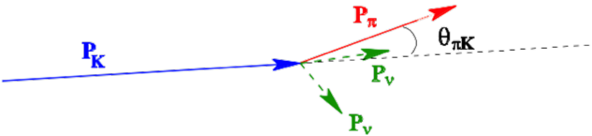
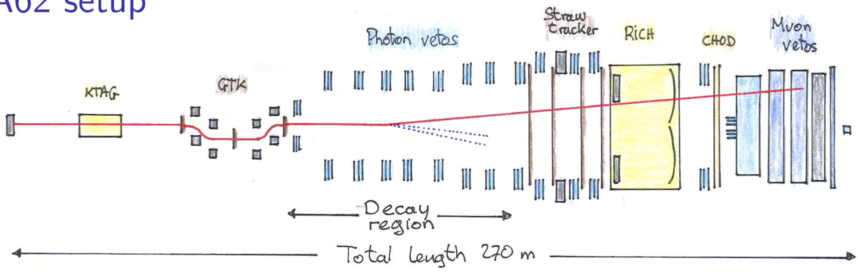


$$m^2_{miss} = (P_K - P_{\pi^+})^2$$
$$\simeq m^2_K \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m^2_\pi \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$

NA62 setup



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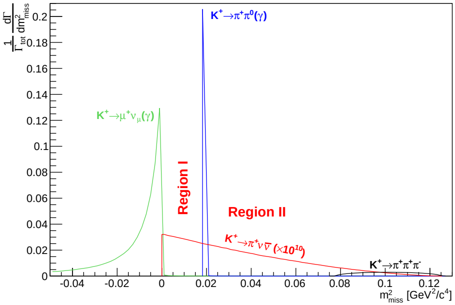

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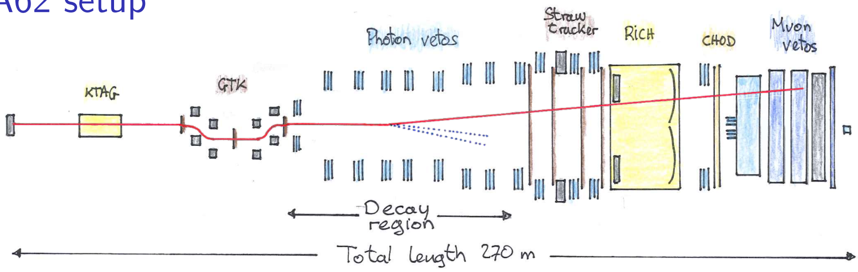

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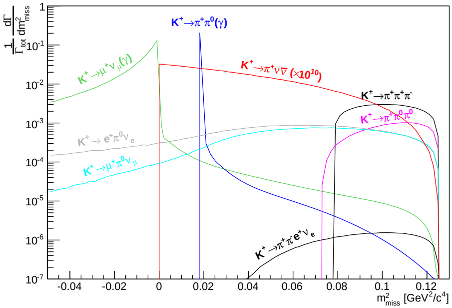

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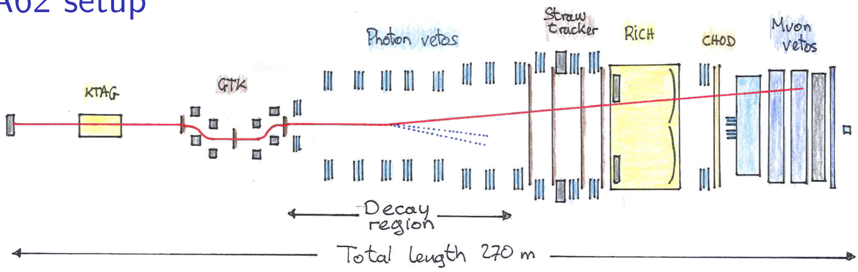

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Experimental principles:

- Precise kinematic reconstruction
- PID: K upstream, $e/\mu/\pi$ downstream
- Hermetic γ detection
- sub-ns timing

NA62 setup

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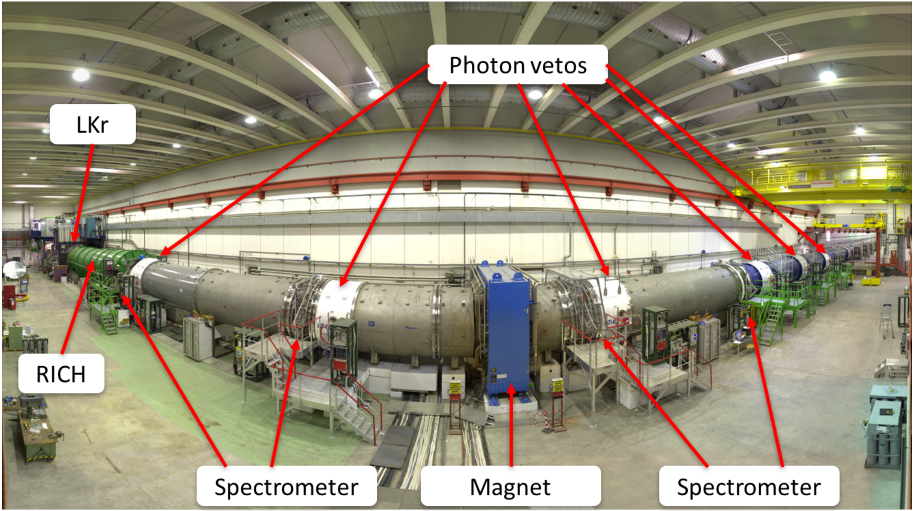
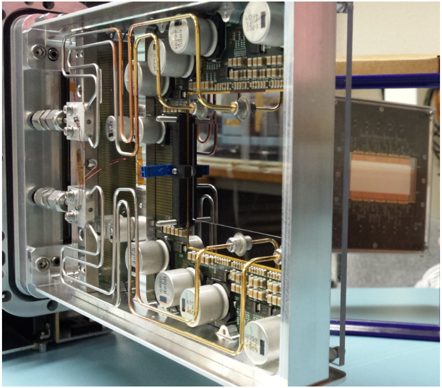
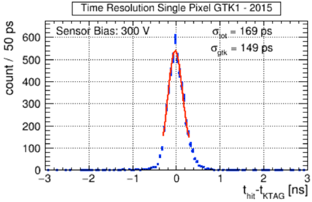
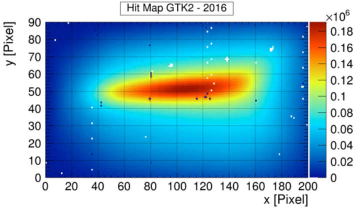


GTK

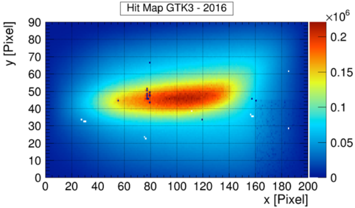




Time Resolution Single Pixel GTK1 - 2015
Sensor Bias: 300 V
σ_{tot} = 169 ps
σ_{gtk} = 149 ps
count / 50 ps
$t_{hit}-t_{KTAG}$ [ns]

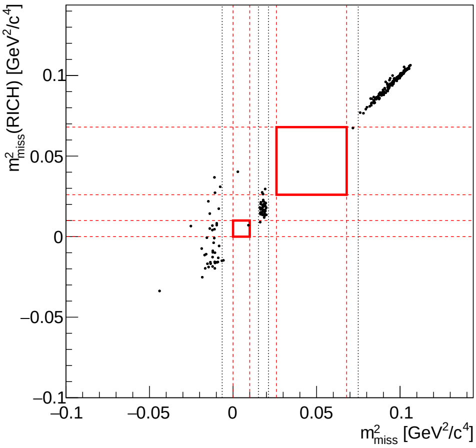


Hit Map GTK2 - 2016
y [Pixel]
x [Pixel]
$\times 10^6$



Hit Map GTK3 - 2016
y [Pixel]
x [Pixel]
$\times 10^6$

$K^+ \to \pi^+ \nu \bar{\nu}$ in 2016



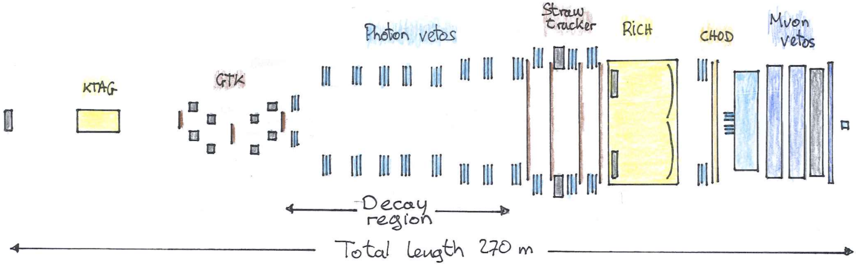
- N(K decays)
  - $\sim 2.3 \times 10^{10}$
  - 5% 2016 statistics
- PNN trigger
- No events in signal region

Event in box has m^2_{miss}(No GTK) outside the signal region

- Data taken at an average intensity of 13×10^{11} POT (40% nominal)

First results will be annouced in Moriond 2018!!!

Decay mode vs Beam Dump mode



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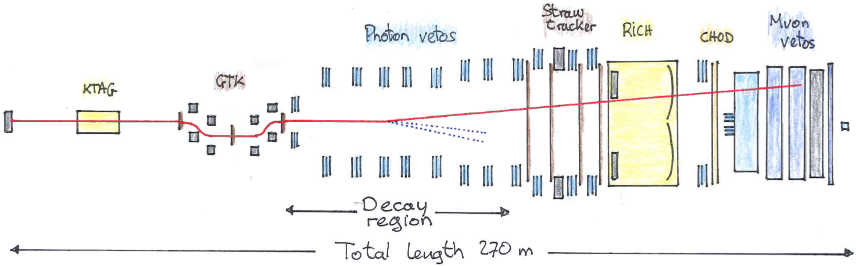

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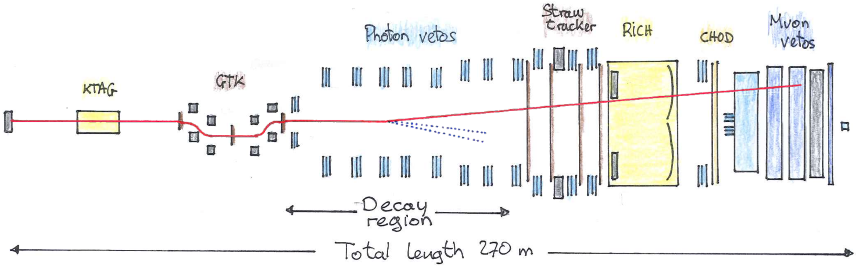

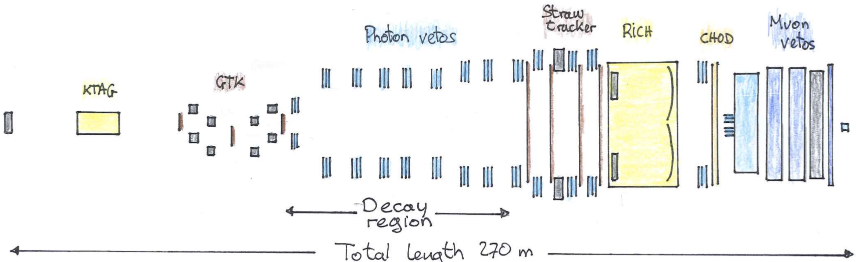

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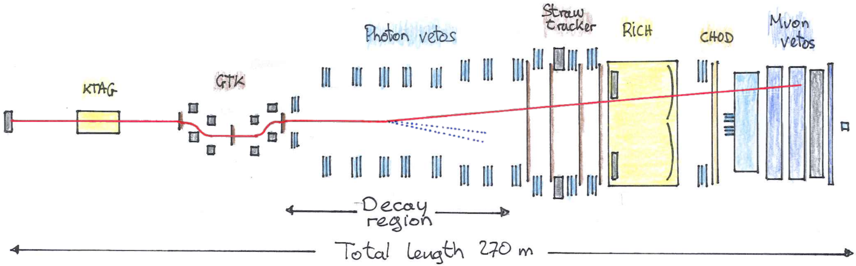

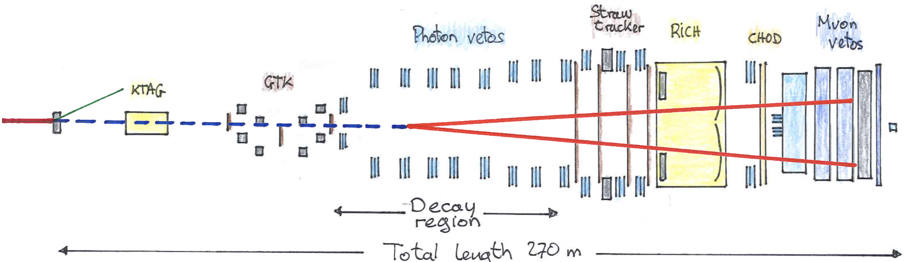

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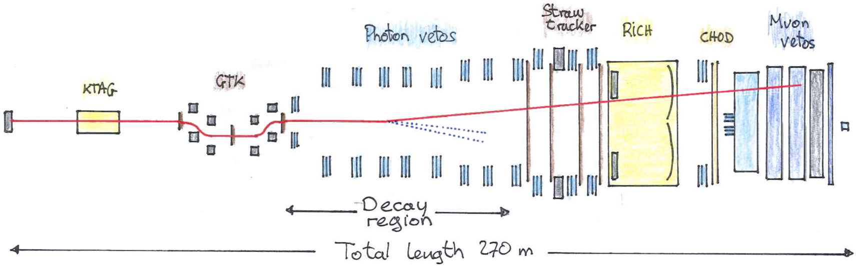

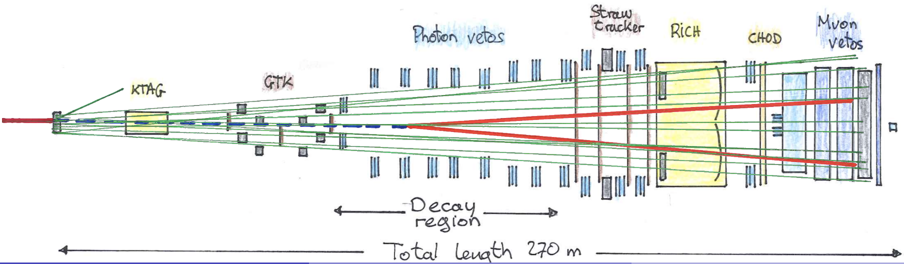

Decay mode vs Beam Dump mode

- "Decay" mode
  Measurement in parallel to $K^+ \to \pi^+ \nu \bar{\nu}$
  - $K^+ \to \pi^+ X$
  - $K^+ \to \ell^+ \nu$: sensitive to HNL
  - LFV/LNV: $K^+ \to \pi^- \ell_1^+ \ell_2^+$
    $K^+ \to \ell_1^- \bar{\nu} \ell_1^+ \ell_2^+$
    $K^+ \to \pi^+ \mu^\pm e^\mp$
  - Dark photon: $K^+ \to \pi^+ \pi^0$, $\pi^0 \to A' \gamma$, $A' \to$invisible
  - Protons on target: A'/HNL $\to \gamma\gamma, \ell^+\ell^-, \ell^\pm \pi^\mp$

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- "Beam Dump" mode
  Special runs with TAXes closed
  - Proton on copper (TAX): A,HNL$\to \gamma\gamma, \ell^+, \ell^-, \ell^\pm\pi^\mp$
  - Few hours in 2016. Few days in 2017-18
  - Improvement of existing limits (CHARM)

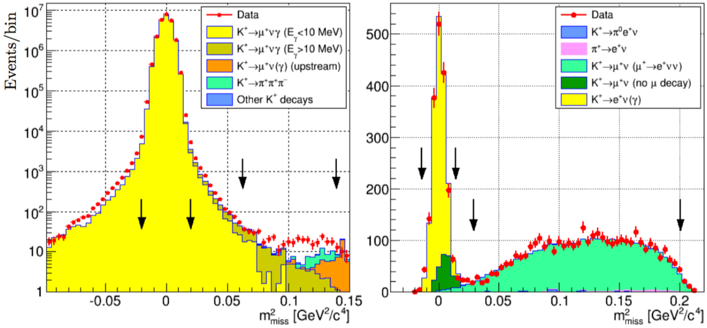
HLN in $K^+ \to \ell^+ N$

arXiv:1712.00297

- HNL should appear as peaks in $K^+ \to \ell^+\nu$ M^2_{miss} distributions

$$\Gamma(K^+ \to \ell^+ N) = \Gamma(K^+ \to \ell^+\nu) \times \rho(m_N) \times |U_{\ell 4}|^2$$

- Model independent searches based on 2015 data ($\sim 10^8$ K^+ decays)



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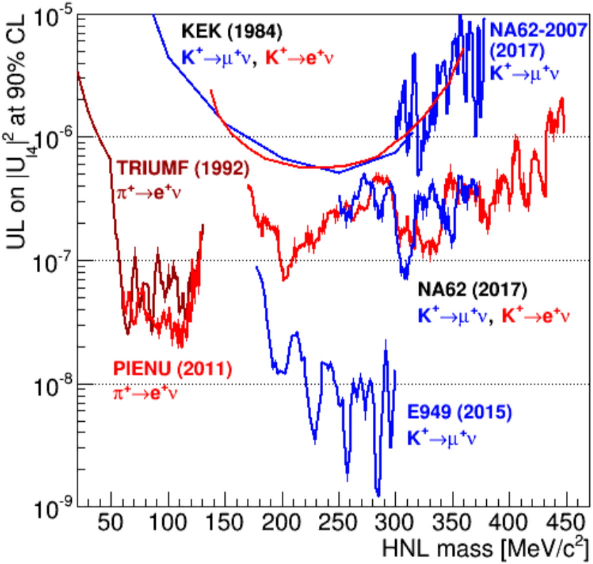

LFV/LNV in K^+ decays

Mode	UL@90% CL	Experiment
$\pi^+\mu^+e^-$	$< 1.3\,10^{-11}$	E777/E865
$\pi^+\mu^-e^+$	$< 5.2\,10^{-10}$	E865/NA48/2
$\pi^-\mu^+e^+$	$< 5.0\,10^{-10}$	E865/NA48/2
$\pi^-e^+e^+$	$< 6.4\,10^{-10}$	E865/NA48/2
$\pi^-\mu^+\mu^+$	$< 8.6\,10^{-11}$	NA48/2

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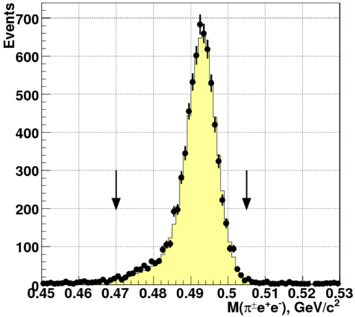

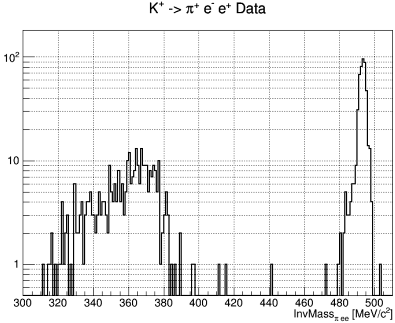

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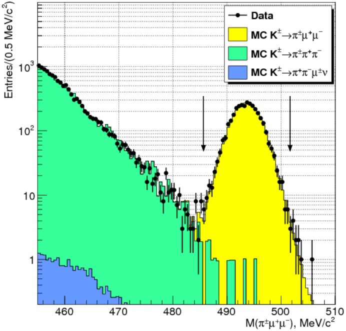
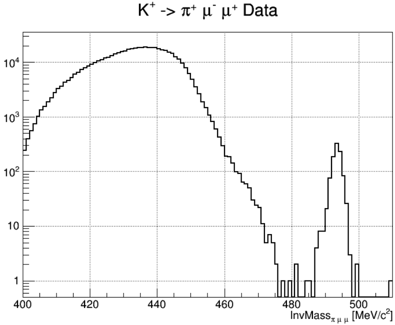
$\pi^-\mu^+\mu^+$	$< 8.6\,10^{-11}$	NA48/2

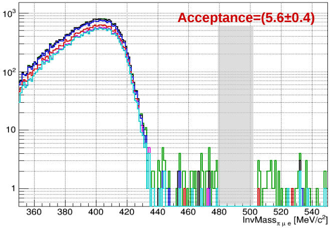




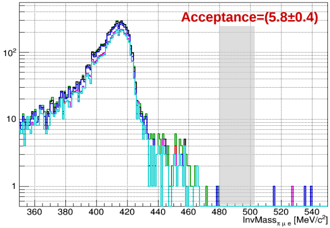
Forbidden decays: LNV & LFV

Blind analysis $M_{\pi\mu e}$=[480,505] MeV/c^2

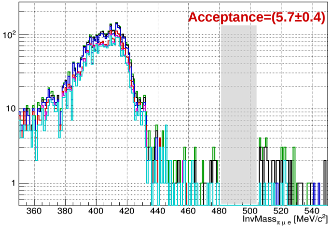
$K^+ \to \pi^+ \mu^+ e^-$ Data



$K^+ \to \pi^+ \mu^- e^+$ Data



$K^+ \to \pi^- \mu^+ e^+$ Data



Single Event Sensitivity: SES=1/N_k* Acc

SES for Sample A 2016 data taking ~ 1.3 10^{-10}

Full 2016 data taking (SampleA+B) possible improvement of the present upper limits for $K^+ \to \pi^+\mu^-e^+$ and $K^+ \to \pi^-\mu^+e^+$

2017 data taking ~ 10^{12} kaon decays → improvement of ULs of 1 order of magnitude

Search Hidden Particles in beam dump mode

- 400 GeV protons on TAXes (Fe-Cu collimators)
- Production of long-lived particles from beauty and charm hadrons.
  - 10^{18} POT: $\sim 2 \cdot 10^{15}$ D mesons, $\sim 10^{11}$ b-hadrons
  - 80 days with nominal NA62 intensity

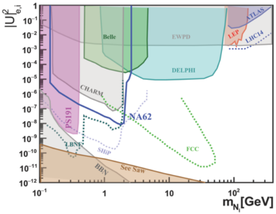
- Minimal changes wrt Decay mode (15 min setup)
- Signal: pair of tracks/photons from the same vertex. Overwhelming background.
- Needed a good understanding of the beam line
  - $\sim$ 30m between target and TAXes
  - Optimisation: obtain maximum intensity in ECN3

- Interplay among phenomenology and experiment

Beam Dump Mode: Heavy Neutral Leptons

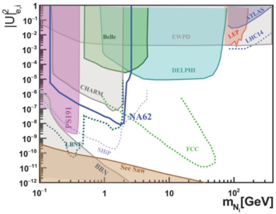
- 2-track final states
- Assumed zero background
- Searches possible in both modes!!!

Scenario 1



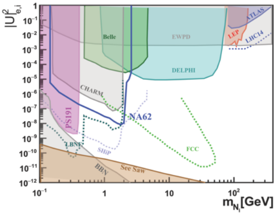
$U_e^2 : U_\mu^2 : U_\tau^2 = 52 : 1 : 1$

Scenario 2



$U_e^2 : U_\mu^2 : U_\tau^2 = 1 : 16 : 3.8$

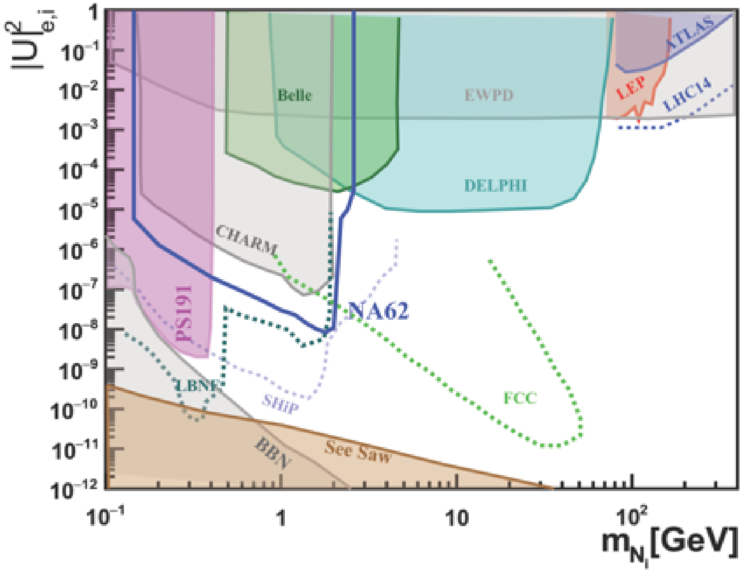
Scenario 3



$U_e^2 : U_\mu^2 : U_\tau^2 = 0.061 : 1 : 4.3$

Asaka, Blanchet, Shaposhnikov, Phys. Lett. B631 (2005) 151
Asaka, Shaposhnikov, Phys. Lett. B620 (2005) 17
Lanfranchi, PoS(EPS-HEP2017)301

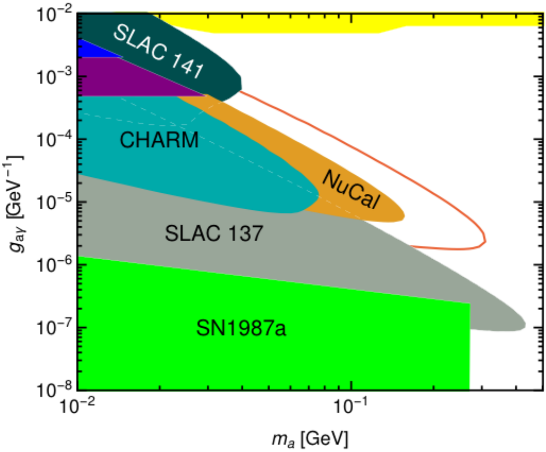
Beam Dump Mode: Heavy Neutral Leptons



ALPs$\to \gamma\gamma$

B. Dobrich et al.,JHEP 02 (2016) 018

- ALP production via Primakoff effect at target
- ALP$\to \gamma\gamma$ decay in NA62 fiducial volume
- Assumed zero background (90% exclusion plots)



Summary

- Rare Decays are an excellent tool to indirectly discover BSM effects.
- NA62 is running and will be exploring Kaon Rare Decays in the following years.
  - Golden channel: $K^+ \to \pi^+ \nu\bar{\nu} \to$ results for the Winter Conferences.
  - Other Rare and Forbidden Decays analysis ongoing.
- Beam Dump mode will provide further insight in Hidden Sector Particles.
- IAP-FI has been instrumental in the development of NA62 in Belgium.


Thanks IAP-FI
Welcome EOS-be.h

BACKUP

Physics scale in effective theories

Any Field Theory can be viewed as an effective theory below a UV cutoff

$$L_{eff} = L^{d=4} + \frac{1}{\Lambda} L^{d=5} + \frac{1}{\Lambda^2} L^{d=6}$$

Λ: maximum energy at which the theory is valid

- Higgs naturalness gives an upper bound on $\Lambda \sim \mathcal{O}(\text{TeV})$

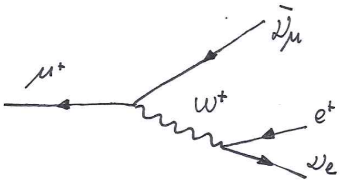
$$\text{B number} \rightarrow \frac{1}{\Lambda^2} qqql \qquad p - decay \rightarrow \Lambda \geq 10^{15}\text{GeV}$$

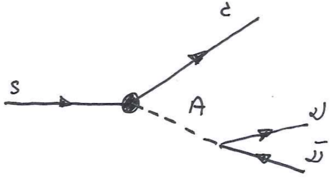
$$\text{L number} \rightarrow \frac{1}{\Lambda} llHH \qquad m_\nu \rightarrow \Lambda \geq 10^{13}\text{GeV}$$

$$\text{quark flavor} \rightarrow \frac{1}{\Lambda^2} \bar{s}\gamma^\mu d \bar{s}\gamma_\mu d \qquad \Delta m_K \rightarrow \Lambda \geq 10^{6}\text{GeV}$$

Adapted from G. Giudice and A. Ceccucci

What energy scale are we testing with $K^+ \to \pi^+ \nu \bar{\nu}$





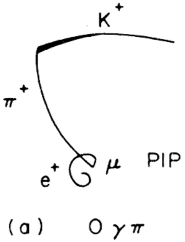
$$BR(\mu^+ \to e^+ \bar{\nu}_\mu \nu_e) \sim 1 \propto \frac{1}{M_W^2} \qquad BR(K^+ \to \pi^+ \nu \bar{\nu}) \sim 10^{-11} \propto \frac{1}{M_A^2}$$

$$\frac{BR(\mu^+ \to e^+ \bar{\nu}_\mu \nu_e)}{BR(K^+ \to \pi^+ \nu \bar{\nu})} = 10^{11} = \frac{M_A^2}{M_W^2}$$

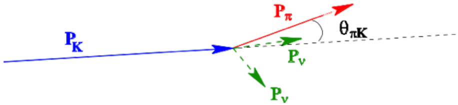
$$M_A \sim 10^5 M_W \to \Lambda \geq 10^4 \text{ TeV} \xrightarrow{MFV} \sim 10\, TeV$$

K^+ beam experiments

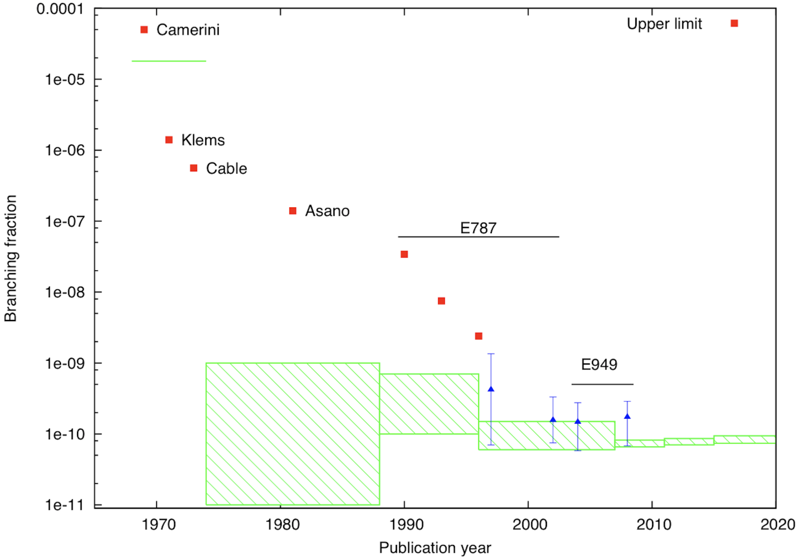
- K^+ decay at rest
  - Low energy photons
  - Hermeticity
  - Compact experiments (ANL,BNL)
  - $p\sim 25$ GeV $\rightarrow K^+\sim 700$ MeV
- K^+ decay in flight
  - Energetic photons
  - Boosted events
  - Long baseline experiments (CERN)
  - $p\sim 400$ GeV $\rightarrow K^+=75$ GeV



Ljung, Cline Phys. Rev (1973)



$K^+ \to \pi^+\nu\bar{\nu}$: History



$K \to \pi\nu\bar{\nu}$ in the Standard Model

$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = \kappa_+(1+\Delta_{EM}) \cdot \left[\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X(x_t)\right)^2 + \left(\frac{\mathrm{Re}\lambda_c}{\lambda}P_c(X) + \frac{\mathrm{Re}\lambda_t}{\lambda^5)}X(x_t)\right)^2\right]$$

$$x_t = m_t^2/M_W^2,\ \lambda = |V_{us}|,\ \lambda_i = V_{is}^* V_{id},\ \Delta_{EM} = -0.003$$

- $\kappa_+ = (5.173 \pm 0.025) \cdot 10^{-11} \left[\frac{\lambda}{0.225}\right]^8$ .... G_F^2+Long Distance
- $X(x_t) = 1.481 \pm 0.005_{th} \pm 0.008_{exp}$ .... top NLO QCD + two loop EW
- $P_c = P_c^{SD} + \delta P_{c,u} = 0.404 \pm 0.024$ .... charm NNLO QCD + EW
  - $P_c^{SD} = \frac{1}{\lambda^4}\left[\frac{2}{3}X_{NNL}^e + \frac{1}{3}X_{NNL}^\tau\right] = 0.365 \pm 0.012$
  - $\delta P_{c,u} = 0.04 \pm 0.02$

$K \to \pi\nu\bar{\nu}$ in the Standard Model

$$\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu}) = \kappa_L \cdot \left(\frac{\mathrm{Im}\lambda_t}{\lambda^5} X(x_t)\right)^2$$

$x_t = m_t^2/M_W^2$, $\lambda = |V_{us}|$, $\lambda_i = V_{is}^* V_{id}$, $\Delta_{EM} = -0.003$

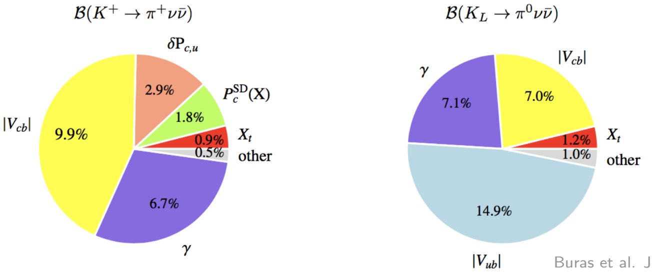
- $\kappa_L = (2.231 \pm 0.013) \cdot 10^{-10} \left[\frac{\lambda}{0.225}\right]^8$ .... G_F^2+Long Distance
- $X(x_t) = 1.481 \pm 0.005_{th} \pm 0.008_{exp}$ ..top NLO QCD + two loop EW

$K \to \pi\nu\bar{\nu}$ in the Standard Model

- QCD and electroweak corrections are under full control
- CKM uncertainties dominates: $|V_{cb}|, |V_{ub}|, \gamma$

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

$$\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu}) = (3.36 \pm 0.05) \times 10^{-11} \cdot \left[\frac{|V_{ub}|}{0.00388}\right]^{2} \left[\frac{|V_{cb}|}{0.0407}\right]^{2} \left[\frac{\sin(\gamma)}{\sin(73.2^o)}\right]^{2}$$



Buras et al. JHEP11(2015)033

$K \to \pi\nu\bar{\nu}$ and new physics

- New physics modify K^+ and K_L decays
- Measuring both channels may allow to discriminate different scenarios

$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = \kappa_+(1+\Delta_{EM}) \cdot \left[\left(\frac{\mathrm{Im}X_{eff}}{\lambda^5}\right)^2 + \left(\frac{\mathrm{Re}\lambda_c}{\lambda}P_c(X) + \frac{\mathrm{Re}X_{eff}}{\lambda^5)}\right)^2\right]$$

$$\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu}) = \kappa_L \cdot \left(\frac{\mathrm{Im}X_{eff}}{\lambda^5}\right)^2$$

$$X_{eff} = V_{ts}^* V_{td}\left(X_L + X_R\right) = V_{ts}^* V_{td} X_L^{SM}\left(1 + \xi e^{i\theta}\right)$$

$$\mathrm{Re}X_{eff} = -\lambda^5\left[\frac{\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu})}{\kappa_+(1+\Delta_{EM})} - \frac{\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu})}{\kappa_L}\right]^{1/2} - \lambda^4 \mathrm{Re}\lambda_c P_c(X)$$

$$\mathrm{Im}X_{eff} = \lambda^4\left[\frac{\mathrm{BR}(K^0 \to \pi^0\nu\bar{\nu})}{\kappa_L}\right]^{1/2}$$

$K \to \pi\nu\bar{\nu}$ and new physics

$$X_{eff} = V_{ts}^* V_{td} \left(X_L + X_R\right) = V_{ts}^* V_{td} X_L^{SM} \left(1 + \xi e^{i\theta}\right)$$

Three classes of NP models:

- CKM-like structure $\to$ $X_R = 0$ and X_L =real
- New Flavor and CP-violating interactions. Strong correlation with ε_K
  - X_L dominates: NP "real". No influence on $K^0 \to \pi^0\nu\bar{\nu}$.
  - X_R dominates: NP "imaginary"
- Left-Right operators are both sizable. No correlation with ε_K
  - Any value for $K^{+,0} \to \pi^{+,0}\nu\bar{\nu}$ possible
  - Subtle cancellations in ε_K parameters $\to$ tuning of parameters

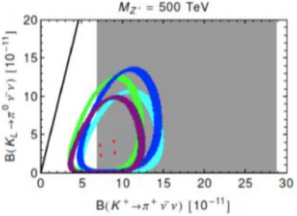
Buras et al. JHEP11(2015).166

$K \to \pi\nu\bar{\nu}$ NP Sensittivity

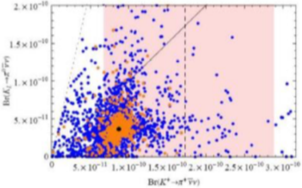
- Simplified Z, Z' models [Buras, Buttazzo,Knegjens, JHEP 1511 (2015) 166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM non-MFV [Tanimoto, Yamamoto arXiv:1603.0796, Isidori et al. JHEP 0608 (2006) 064]

- Constraints from existing measurements (correlations model dependent):
  - Kaon mixing and CPV, CKM fit, K,B rare meson decays, NP limits from direct searches

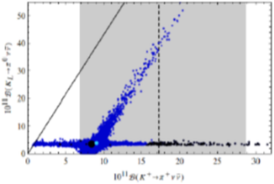
Z' model



Randall - Sundrum



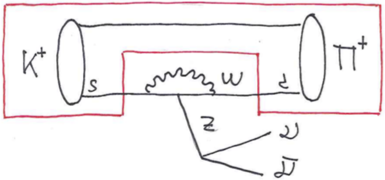
Littlest Higgs

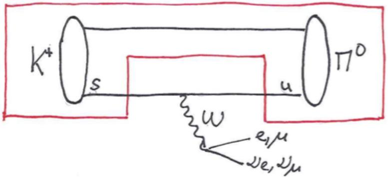


$K \to \pi\nu\bar{\nu}$ in the Standard Model

Buras et al. JHEP11(2015)033

- Complete computations of
  - NLO EW charm quark corrections — Brod,Gorbahn, Phys.Rev.D78 (2008) 034006
  - NLO EW top quark corrections — Brod,Gorbahn,Stamou, Phys.Rev.D83 (2011) 034030
- NLO QCD top quark corrections — Buchalla,Buras, Nucl.Phys.B400(1993)225; Nucl.Phys.B548(1999)309; Misiak,Urban,Phys.Lett.B451(1999)161
- NNLO QCD charm correct. — Buras,Gorbahn,Haisch,Nierste, Phys.Rev.Lett.95(2005)261805; JHEP11(2006)002; Gorbahn,Haisch, Nucl.Phys.B713(2005)291
- Isospin,non-perturbative effects — Isidori,Mescia,Smith, Nucl.Phys.B718(2005)319; Mescia,Smith, Phys.Rev.D76(2007)034017

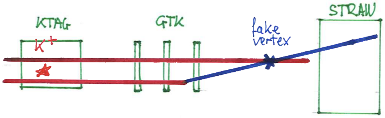




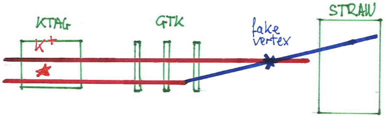
NA62 setup

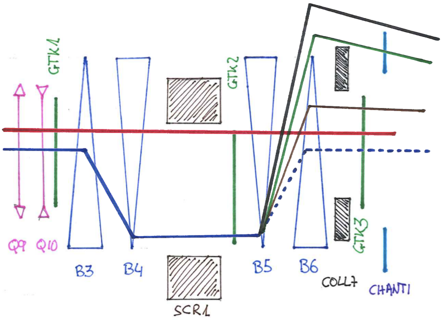
NA62 setup

"Snakes"

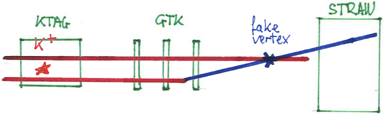


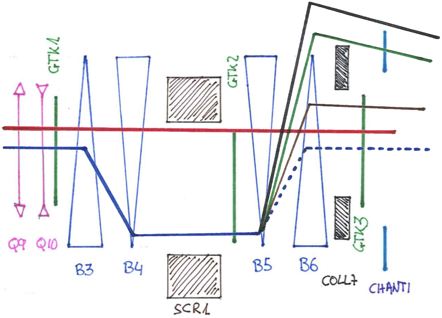
"Snakes"


KTAG
GTK
fake vertex
STRAW
K^+


GTK1
GTK2
GTK3
Q9
Q10
B3
B4
B5
B6
SCR1
COLL7
CHANTI

"Snakes"


KTAG
K+
GTK
fake vertex
STRAW


GTK1
GTK2
GTK3
Q9
Q10
B3
B4
B5
B6
SCR1
COLL7
CHANTI

Expected Signal and Background

N(K decays) $\sim 2.3 \times 10^{10}$ analyzed (5% 2016 statistics)

- Signal

$$N^{exp}_{\pi\nu\nu} = D^{control} \cdot N^{control}_{\pi\pi} \frac{BR_{\pi\nu\nu}}{BR_{\pi\pi}} \cdot \frac{A_{\pi\nu\nu}}{A_{\pi\pi}} \cdot \epsilon^{trig}$$

$N^{control}_{\pi\pi}$	3.3×10^8
$A_{\pi\pi}$	~ 0.07
$A_{\pi\nu\nu}$	~ 0.033
ϵ^{trig}	0.83

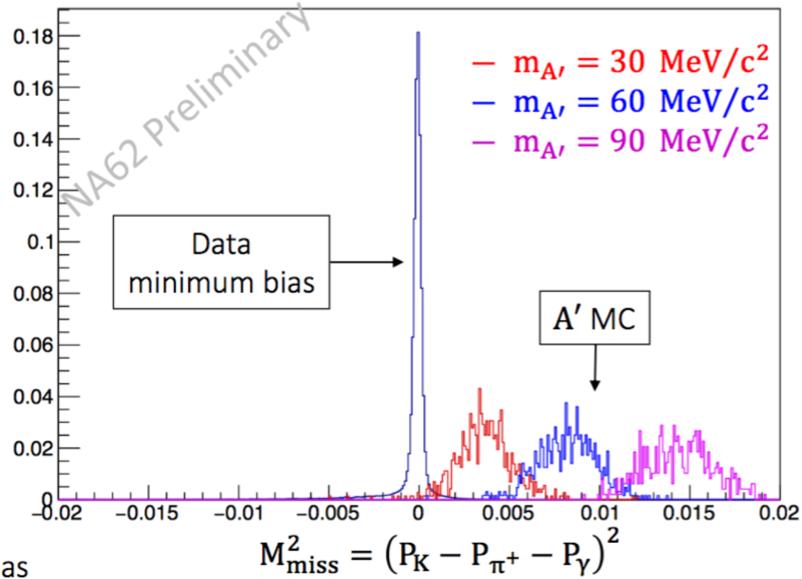
$N^{exp}_{\pi\nu\nu} \simeq 0.064$

- Background

$K^+ \to \pi^+\pi^0$	0.024
$K^+ \to \mu^+\nu$	0.011
$K^+ \to \pi^+\pi^+\pi^-$	0.017

$N^{exp}_{back} \simeq 0.052$

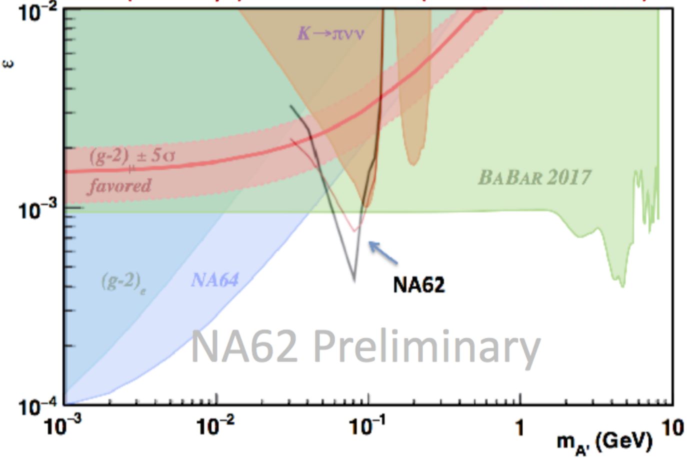
Dark photon



ias

Dark photon

N(K decays) ~ 1.5×10^{10} (4% 2016 statistics)



Forbidden decays: LNV & LFV

LFV $K^+ \to \pi^+\mu^+e^-$ ***B < 1.3 x 10⁻¹¹ (90% CL)*** [A. Sher, et al. Phys. Rev. D, 72 (2005), 012005]

LFV $K^+ \to \pi^+\mu^-e^+$ ***B < 5.2 x 10⁻¹⁰ (90% CL)*** [R. Appel, et al. Phys. Rev. Lett., 85 (2000), 2877]

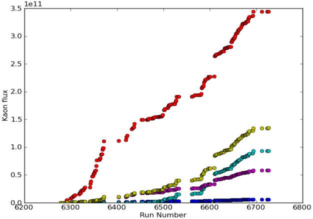
LNV $K^+ \to \pi^-\mu^+e^+$ ***B < 5.0 x 10⁻¹⁰ (90% CL)*** [R. Appel, et al. Phys. Rev. Lett., 85 (2000), 2877]

Data sample:

- 2016 SampleA (162 runs) → $N_K \sim 1.34\ 10^{11}$
- Trigger chain: L0: RICH • Q_x L1: !LAV • $STRAW_{exotics}$ (downscaling between 20 and 150)

  L0: RICH • Qx • MO1 L1: KTAG • !LAV • $STRAW_{exotics}$ (downscaling between 1 and 10)

  L0: RICH • Q_x • E_{LKr}>20GeV L1: !LAV • $STRAW_{exotics}$ (downscaling between 1 and 2)



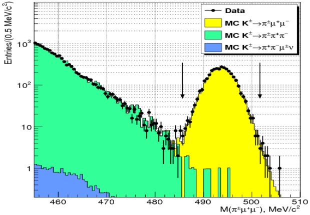
- Control triggers
- Multi tracks trigger
- Muon multi tracks trigger
- Electron multi tracks trigger
- MultiTrack+Muon multi tracks+Electron multi tracks

Kaon flux measured selecting K3π events with control triggers

Rare decays: $K^+ \rightarrow \pi^+\mu^+\mu^-$

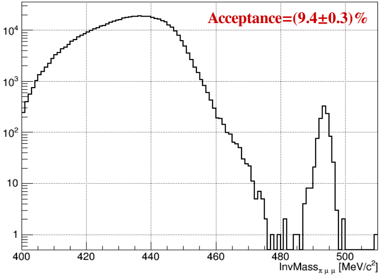
FCNC decay $K^+ \rightarrow \pi^+\mu^+\mu^-$ ***B=(9.62±0.25) x 10^-8***

[J.R. Batley et al.(NA48/2 collaboration), Phys. Lett.B 697(2011) 107]



Data sample:

- 2016 SampleA (162 runs) → N_K~3.44 10^{11} (16/09/2016 - 03/11/2016)
- Dedicated trigger chain: L0: RICH • Q_x • MO2 L1: !LAV • $STRAW_{exotics}$



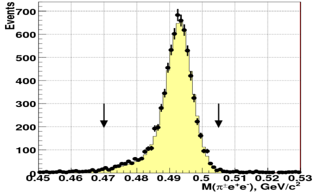
Selection not optimize for $K^+ \rightarrow \pi^+\mu^+\mu^-$ decay

PID procedure optimize for $K \rightarrow \pi\mu e$ selection

Rare decays: $K^+ \to \pi^+ e^+ e^-$

FCNC decay $K^+ \to \pi^+ e^+ e^-$ ***B=(3.11±0.12) x 10^{-7}***

[J.R. Batley et al.(NA48/2 collaboration), Phys. Lett.B 677(2009) 246]

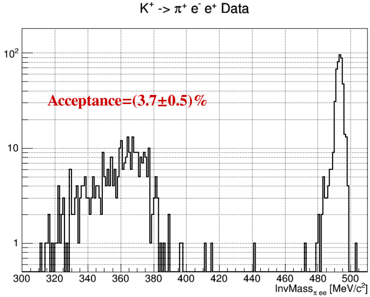


Data sample:

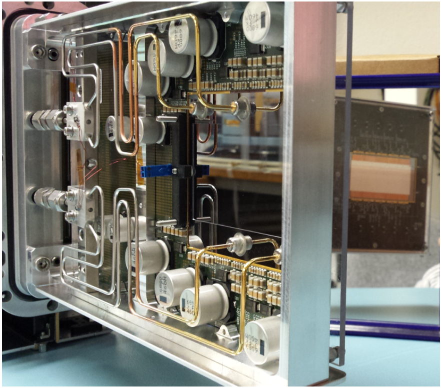
- 2016 SampleA (112 runs) → N_K~5.85 10^{10} (03/10/2016 - 03/11/2016)
- Trigger chain: L0: RICH • Q_x • E_{LKr}>20GeV L1: !LAV • $STRAW_{exotics}$

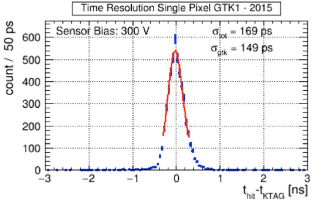
Selection not optimize for $K^+ \to \pi^+ e^+ e^-$ decay

PID procedure optimize for $K \to \pi\mu e$ selection

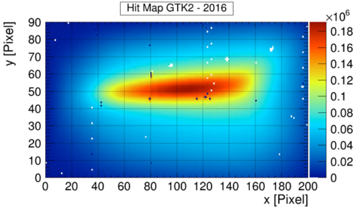


GTK

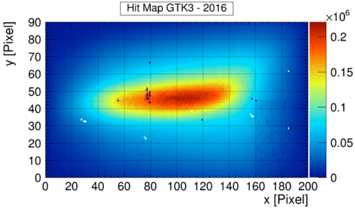




Time Resolution Single Pixel GTK1 - 2015
Sensor Bias: 300 V
σ_tot = 169 ps
σ_gtk = 149 ps
count / 50 ps
t_hit-t_KTAG [ns]

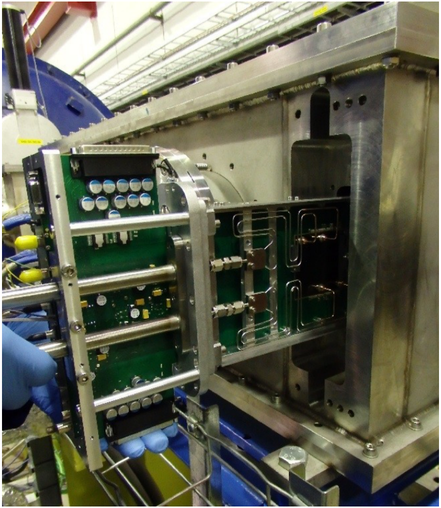


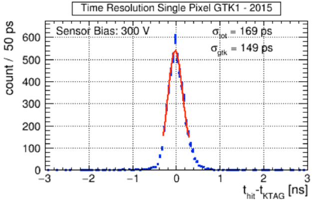
Hit Map GTK2 - 2016
y [Pixel]
x [Pixel]
×10^6



Hit Map GTK3 - 2016
y [Pixel]
x [Pixel]
×10^6

GTK




Time Resolution Single Pixel GTK1 - 2015
Sensor Bias: 300 V
σ_{tot} = 169 ps
σ_{gtk} = 149 ps
count / 50 ps
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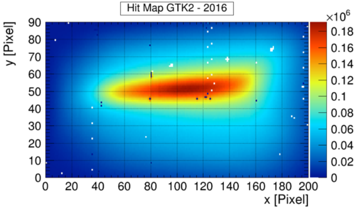
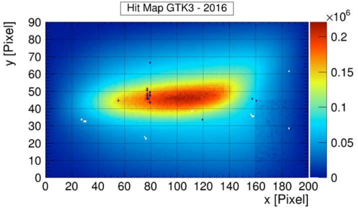
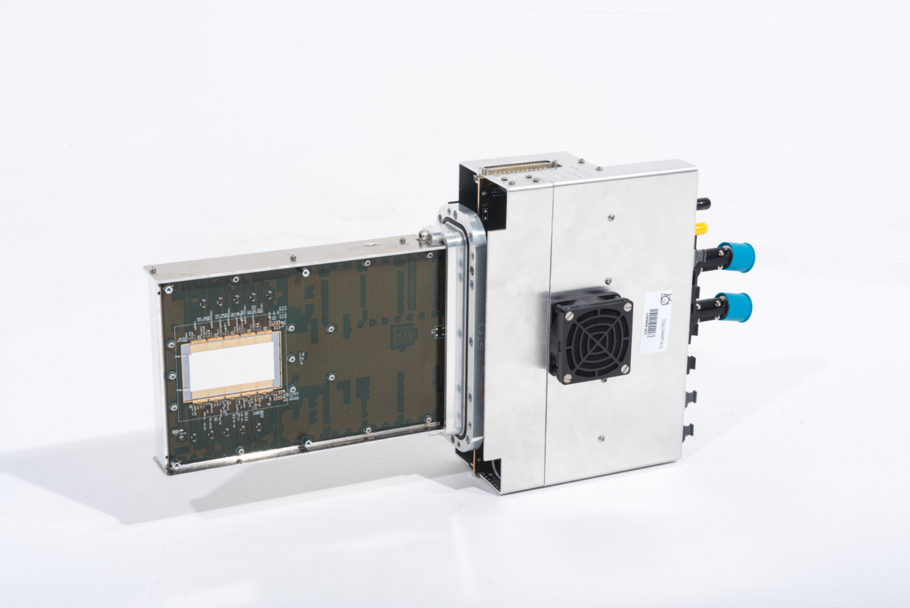

Hit Map GTK2 - 2016
y [Pixel]
x [Pixel]
$\times 10^6$


Hit Map GTK3 - 2016
y [Pixel]
x [Pixel]
$\times 10^6$

GTK



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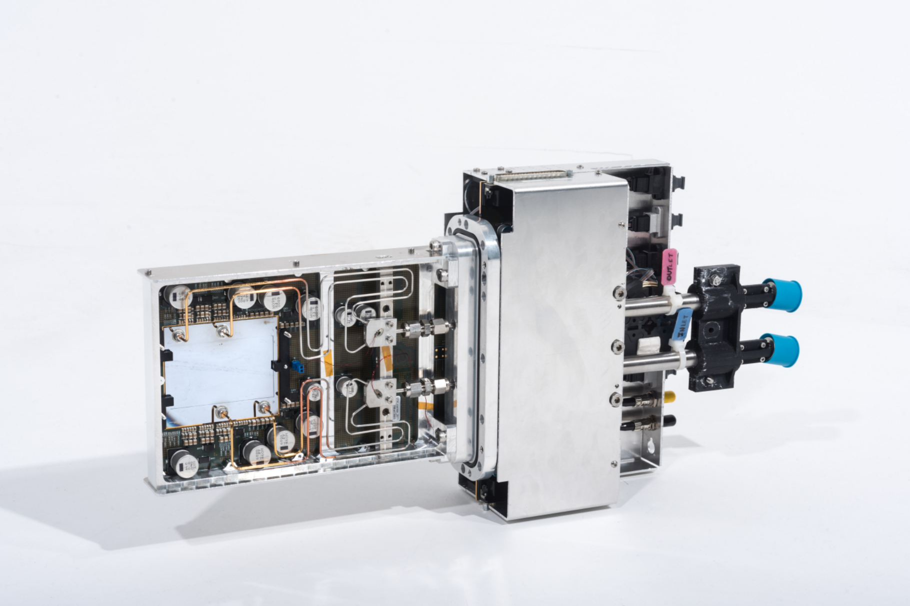
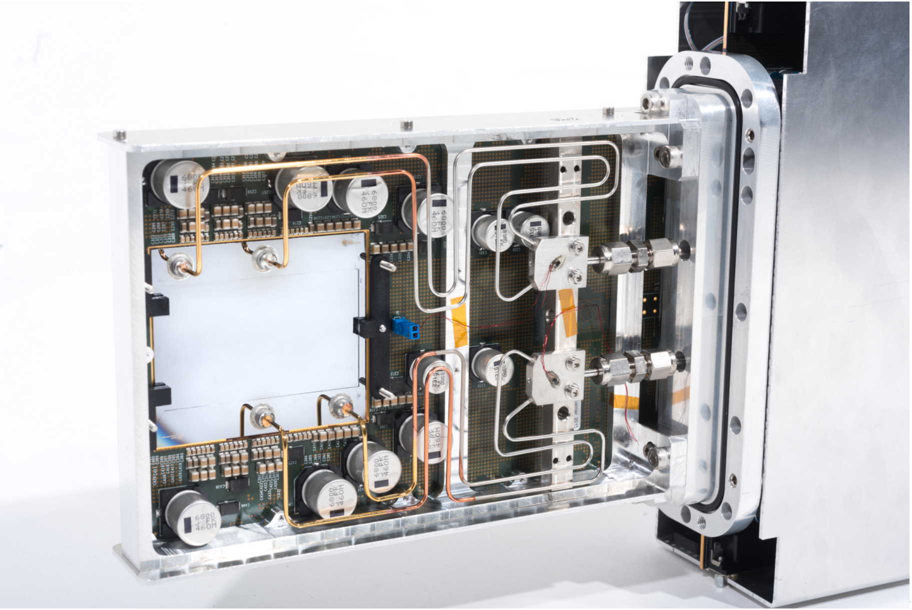
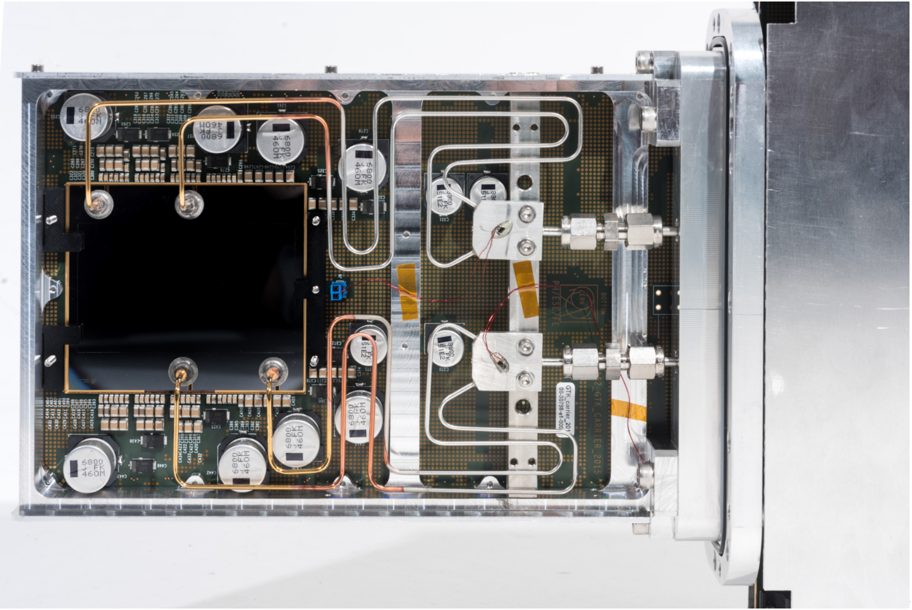


GTK



GTK



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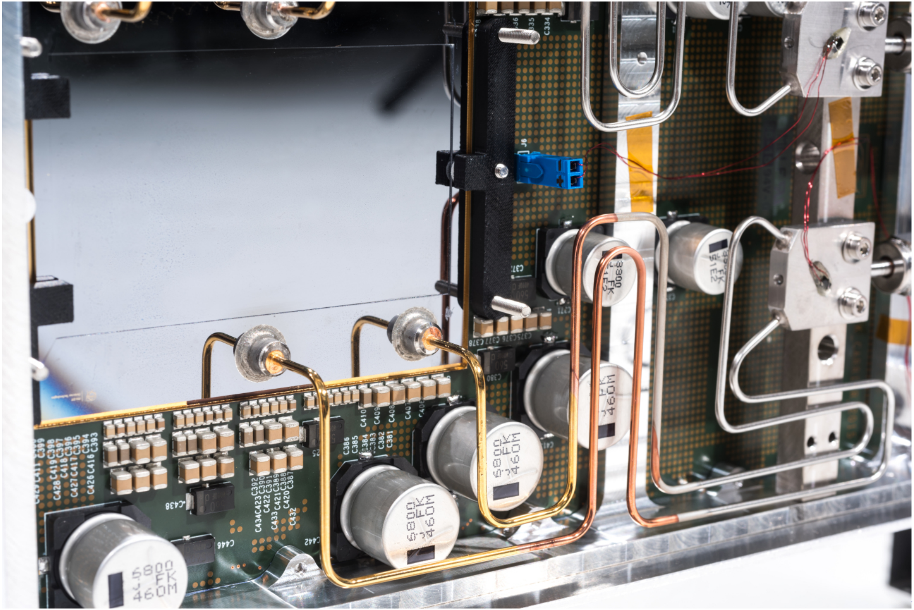

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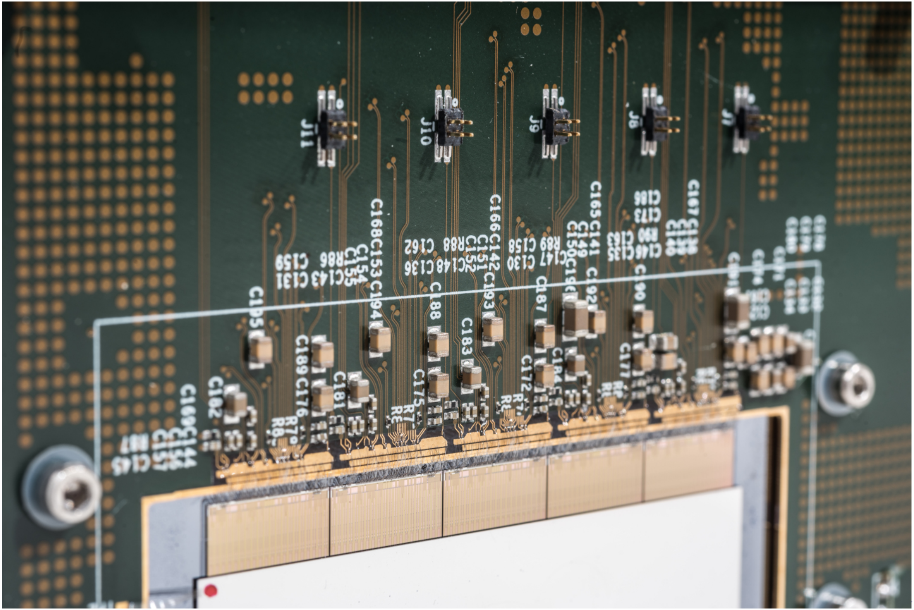

GTK