LFV and exotics at NA62 experiment

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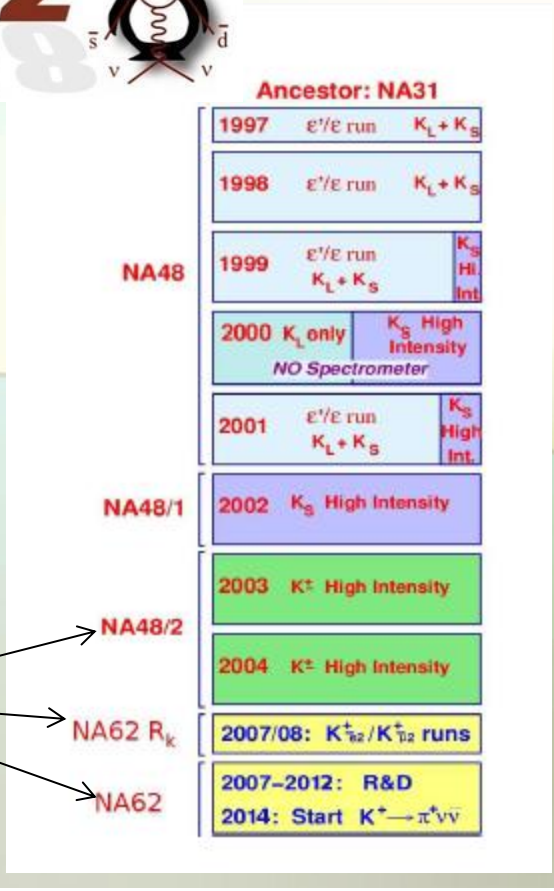
outline

1. NA62 experiment
2. LFV in charged kaon decays
3. $K^+ \to \pi^- \mu^+ \mu^+$ decay
4. Exotic decays
5. Dark photon search
6. Heavy neutrino search
7. Conclusions

NA62 experiment

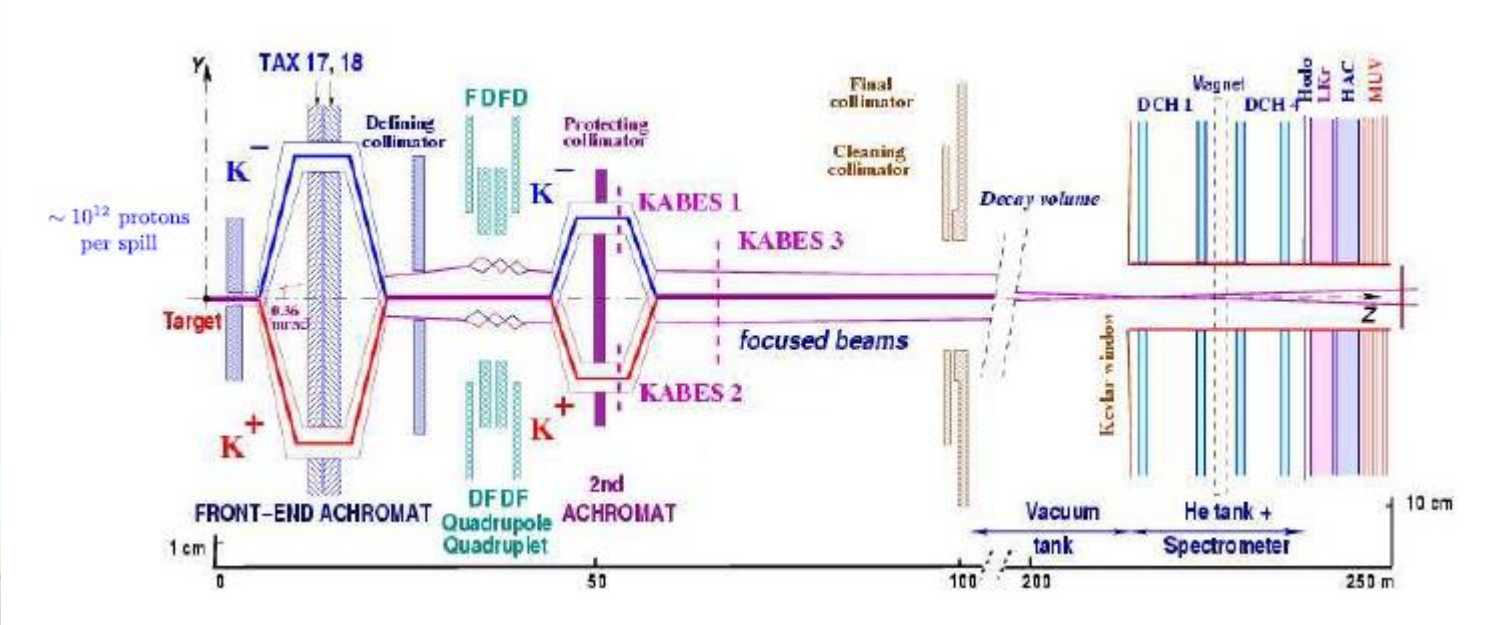
NA62 main goal:
measure $K^+ \to \pi^+ \nu\nu$ decay
(~100 events with S/B~10)

Relevant for LFV and exotics search



NA62 collaboration:
Birmingham, Bratislava, Bristol, Bucharest, CERN, JINR Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Naples, Padua, Perugia, Pisa, Prague, Rome I, Rome II, San Luis Potosí, Sofia, Stanford, Turin

NA48/2 and NA62 beamline



NA48/2 data taking:

- ✓ 4 months in 2003 ($K^{\pm}$)
- ✓ 4 months in 2004 ($K^{\pm}$)

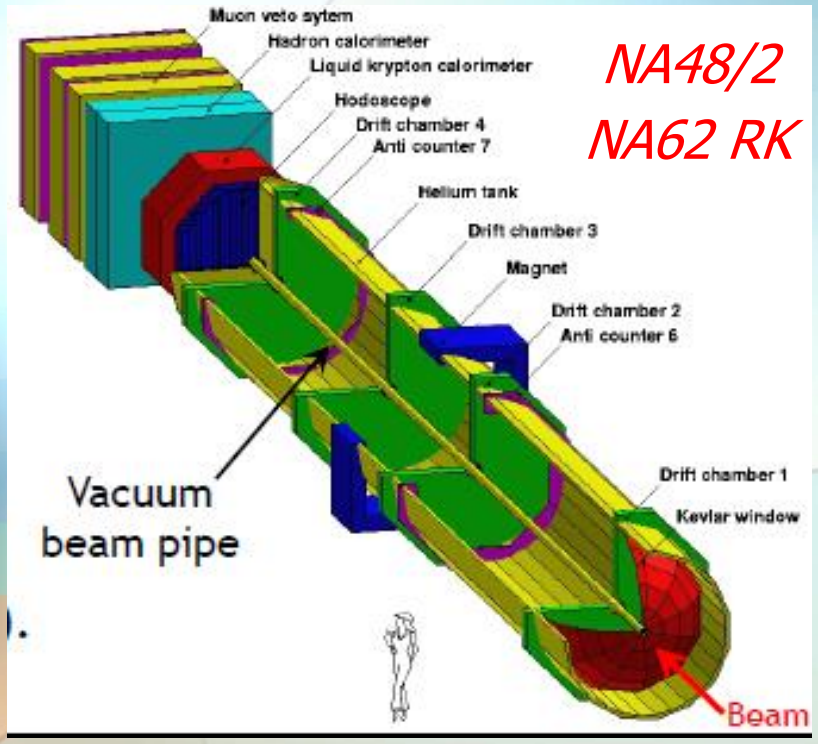
NA62-RK data taking:

- ✓ 2007 (mostly K^{+})

Kaon beam momentum [GeV/c]:

- ✓ NA48/2 (2003-2004): 60.0 ± 2.2
- ✓ NA62-RK (2007): 74.0 ± 1.4
- ✓ NA62 (2014): 75.0 ± 0.8

NA48/2 and NA62 RK detector



NA48/2
NA62 RK

Main detectors:

- ✓ Magnetic spectrometer
- ✓ Scintillator hodoscope
- ✓ Liquid Krypton EM calorimeter (LKr)

Magnetic spectrometer:

- ✓ 4 drift chambers (DCH)
- ✓ 4 views per DCH
- ✓ $\delta p/p = 0.48\% + 0.009\% p$ [GeV/c]

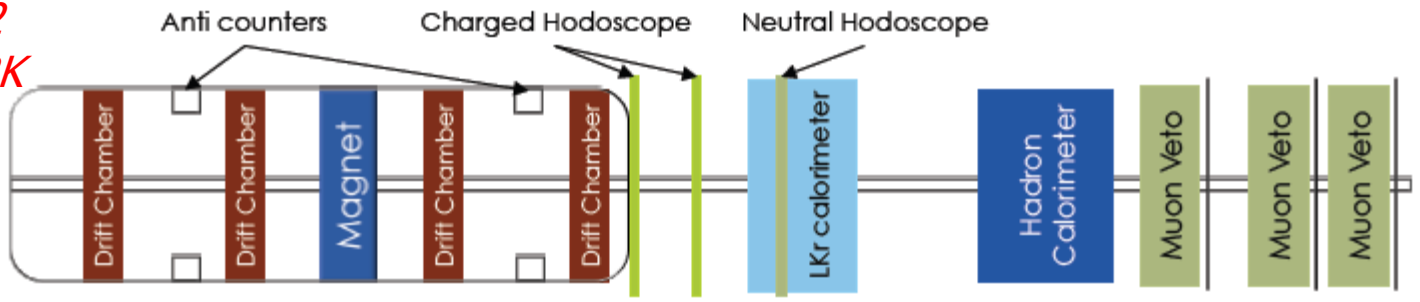
Scintillator hodoscope:

- ✓ Good time resolution (150ps)
- ✓ Fast trigger

LKr:

- ✓ High granularity (13248 cells, 2x2 cm^2)
- ✓ Quasi-homogenious, $7m^3$ liquid Kr ($27X_0$)
- ✓ $\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$ [GeV]

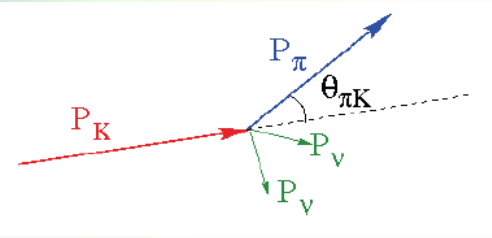
NA48/2
NA62 RK



NA62 experimental setup

From SPS to NA62:

- ✓ SPS primary beam: 400 GeV/c, ~$5 \cdot 10^{12}$ppp
- ✓ Secondary hadron beam: 75 GeV/c, ~6% of K^+
- ✓ ~$4.8 \cdot 10^{12}$ kaon decays per year
- ✓ ~10% signal efficiency
- ✓ ~50 signal events per year



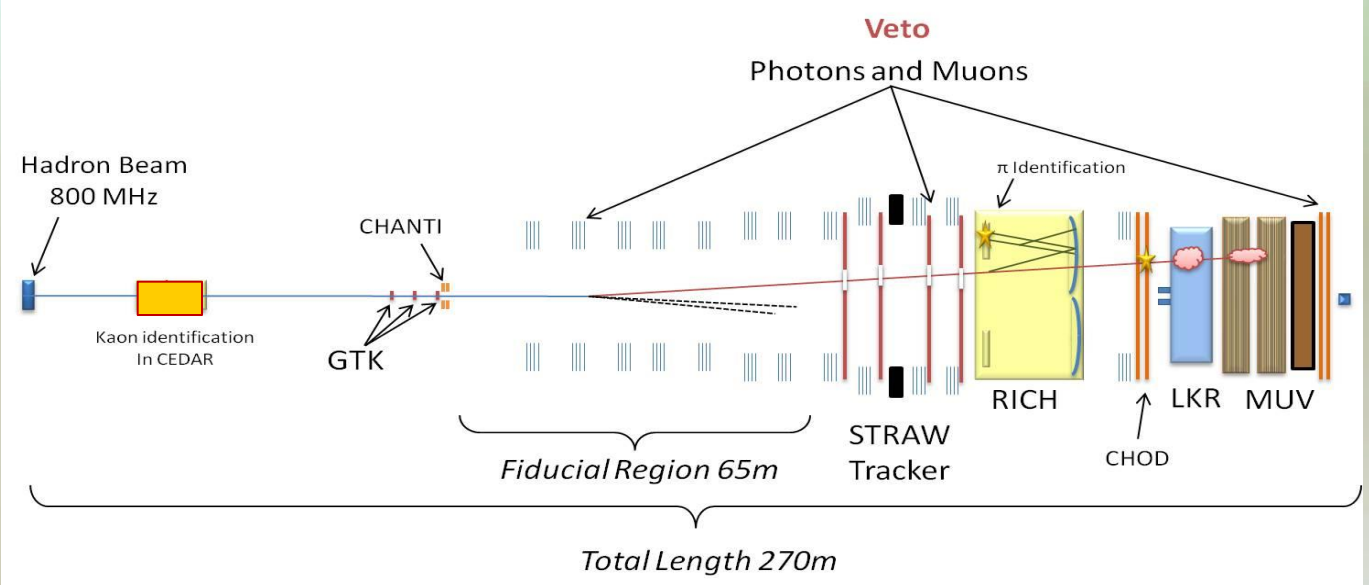
NA62 setup:

- ✓ Decays-in-flight technique
- ✓ Detect K^+ and π^+

NA62 basic principles:

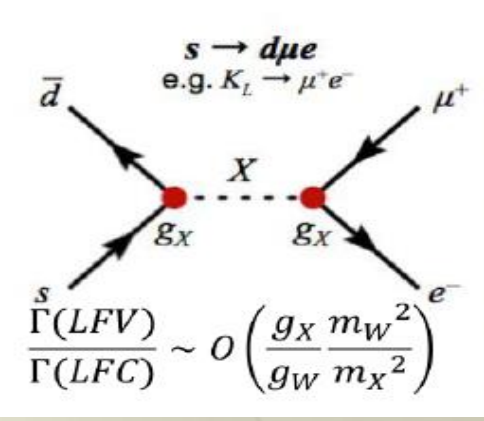
- ✓ High intensity + fast timing
- ✓ Kinematic selection
- ✓ Particle ID
- ✓ Photon rejection

See talk by F. Bucci for details



LFV in kaon decays

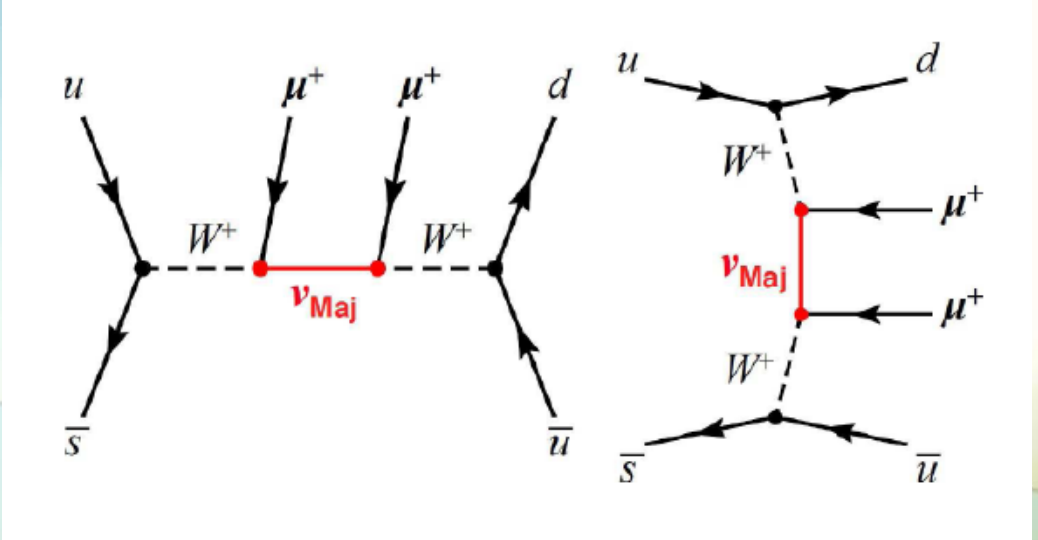
Decay mode	Physics Interest	UL at 90% CL (Experiment)
$K^+ \to \pi^+ \mu^+ e^-$	LFV	$< 1.3 \times 10^{-11}$ (BNL E777/E865)
$K^+ \to \pi^+ \mu^- e^+$	LFV	$< 5.2 \times 10^{-10}$ (BNL E865)
$K^+ \to \pi^- \mu^+ e^+$	LFNV: $\Delta L_\mu = \Delta L_e = -1$	$< 5.0 \times 10^{-10}$ (BNL E865)
$K^+ \to \pi^- e^+ e^+$	LNV: $\lvert\Delta L_e\rvert = 2$	$< 6.4 \times 10^{-10}$ (BNL E865)
$K^+ \to \pi^- \mu^+ \mu^+$	LNV: $\lvert\Delta L_\mu\rvert = 2$	$< 1.1 \times 10^{-9}$ (NA48/2)
$K^+ \to \mu^- \nu_\mu e^+ e^+$	LNV: $\lvert\Delta L_e\rvert = 2$ or LFV	$< 2.8 \times 10^{-8}$ (Geneva-Saclay)
$K^+ \to e^- \nu_e \mu^+ \mu^+$	LNV: $\lvert\Delta L_\mu\rvert = 2$ or LFV	No Data
$\pi^0 \to \mu^\pm e^\mp$	LFV	$< 3.6 \times 10^{-10}$ (KTEV)

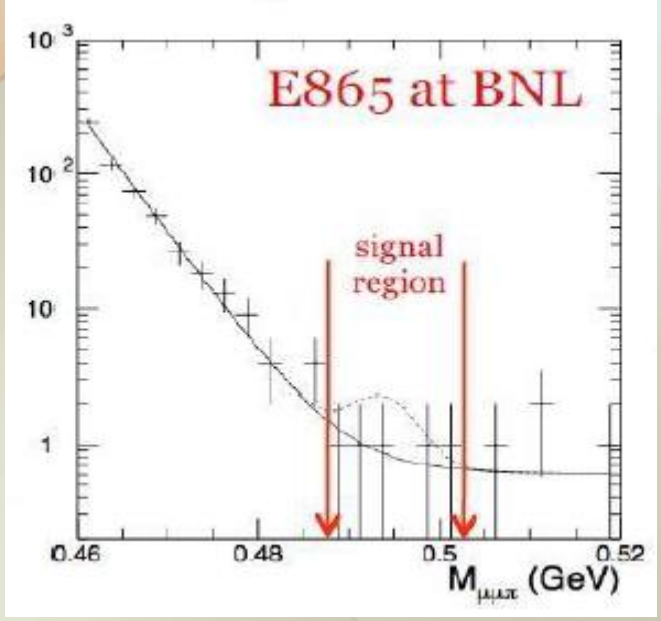


NP probes up to $m_X \sim 100$ TeV
assuming $g_X \sim g_W$, BR~10^{-12}

$K^+ \to \pi^- \mu^+ \mu^+$ decay

- ✓ $|\Delta L|=2$ transition mediated by Majorana neutrino exchange
- ✓ Neutrinoless double-beta decay in the 2nd generation
- ✓ For some models predicted rates are close to experimental limits





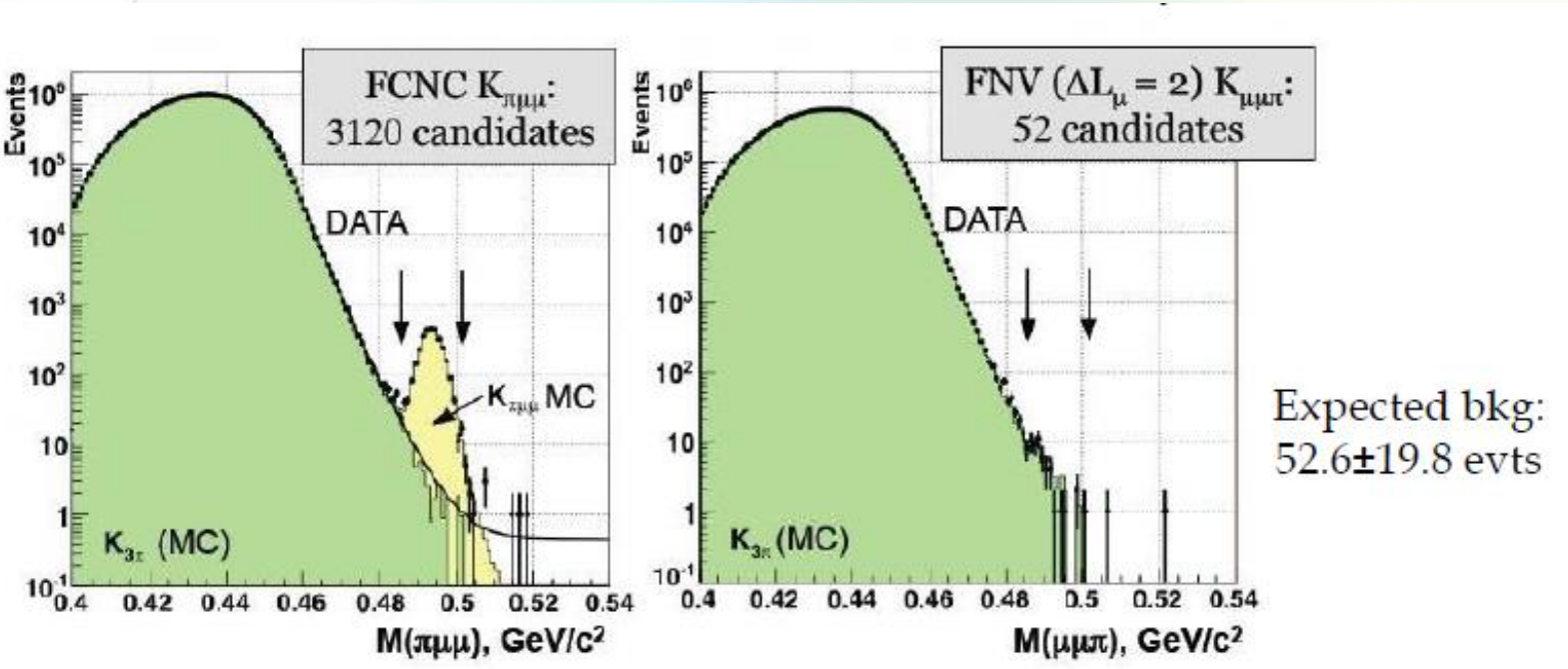
Experiment status before NA48/2:
BNL E865, 5 events in the signal region

Upper limit:
$BR(K^+ \to \pi^- \mu^+ \mu^+) < 3.0 \times 10^{-9}$
(90% CL)

Phys. Rev. Lett. 85 (2000) 2877

$K^+ \to \pi^- \mu^+ \mu^+$ at NA48/2

NA48/2, 2003-2004 data
52 candidates in the signal region



Upper limit:
$BR(K^+ \to \pi^- \mu^+ \mu^+) < 1.1 \times 10^{-9}$ (90% CL)

PLB697 (2011) 107-115

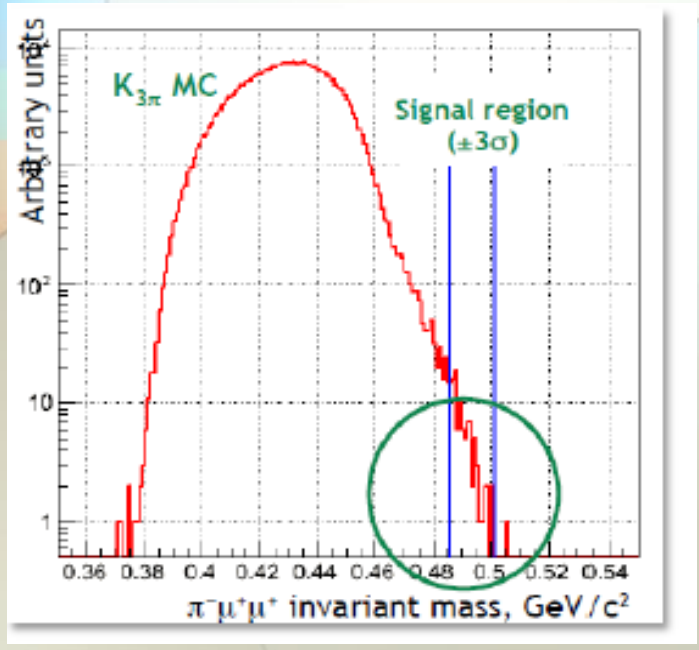
$K^+ \to \pi^- \mu^+ \mu^+$ at NA62

NA62:

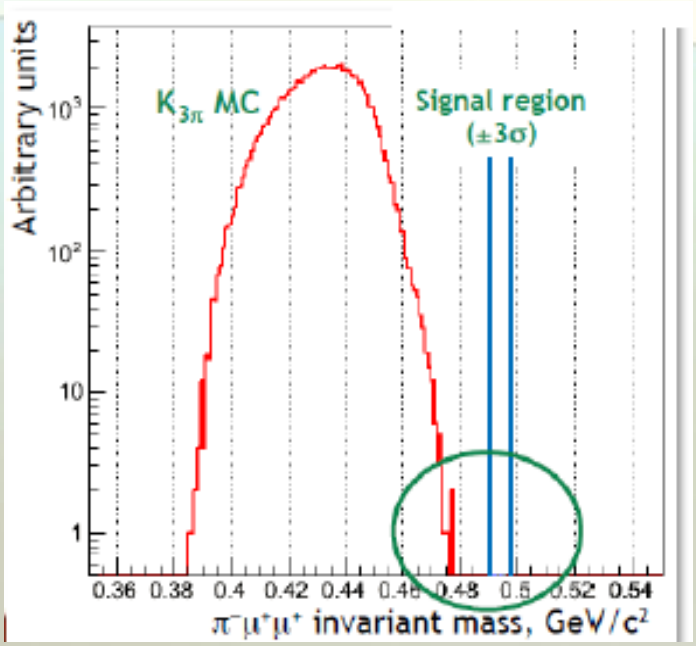
- ✓ Increased kaon flux (x60)
- ✓ Increased $p_\perp$ kick (better invariant mass resolution)
- ✓ up to x1000 improvement in the statistics

Potential sensitivity up to ~10^{-12}

NA48/2 MC



NA62 MC



NA62 sensitivity to LFV decays

Decays in FV in 2 years of data: 1×10^{13} K^+ decays; 2×10^{12} π^0 decays

Single-event sensitivity 1/(decays × acceptance)

Mode	UL at 90% CL	Experiment	NA62 acceptance*
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	BNL 777/865	~10%
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	BNL 865	
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	BNL 865	~10%
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}	BNL 865	~5%
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	~20%
$K^+ \to \mu^-\nu e^+e^+$	2.0×10^{-8}	Geneva Saclay	~2%
$K^+ \to e^-\nu\mu^+\mu^+$	no data		~10%
$\pi^0 \to \mu^+e^-$	3.6×10^{-10}	KTeV	~2%
$\pi^0 \to \mu^-e^+$			

* From fast Monte Carlo simulation with flat phase-space distribution. Includes trigger efficiency.

NA62 single-event sensitivities: **~10^{-12} for K^+ decays**; **~10^{-11} for π^0 decays**

Exotic π^0 decays

NA62 single event sensitivity for π^0 decays: 10^{-11}

Decay mode	Experimental status	Reference	Physics interest
$\pi^0 \to e^+e^-\gamma$	$BR(\pi^0 \to U\gamma) < 10^{-5}$ $30\ MeV < M_U < 100\ MeV$	WASA @ COSY arXiv:1304.0671	Dark forces
$\pi^0 \to e^+e^-e^+e^-$	$BR = 3.34(16) \times 10^{-5}$	KTeV @ FNAL PRL100 (2008) 182001	Off-shell vectors
$\pi^0 \to e^\pm\mu^\mp$	$BR < 3.6 \times 10^{-10}$	KTeV @ FNAL PRL100 (2008) 131803	LFV
$\pi^0 \to 3\gamma$	$BR < 3.1 \times 10^{-8}$	Crystal Box @ LANL PRD38 (1988) 2121	C violation: $BR_{SM} \sim 10^{-31}$
$\pi^0 \to 4\gamma$	$BR < 2 \times 10^{-8}$		$BR_{SM} = 2.6 \times 10^{-11}$ NP: light scalars $\pi^0 \to SS,\ S \to \gamma\gamma$
$\pi^0 \to \nu\bar{\nu}$	$BR < 2.7 \times 10^{-7}$	E949 @ BNL PRD72 (2005) 091102	RH neutrinos, LFV

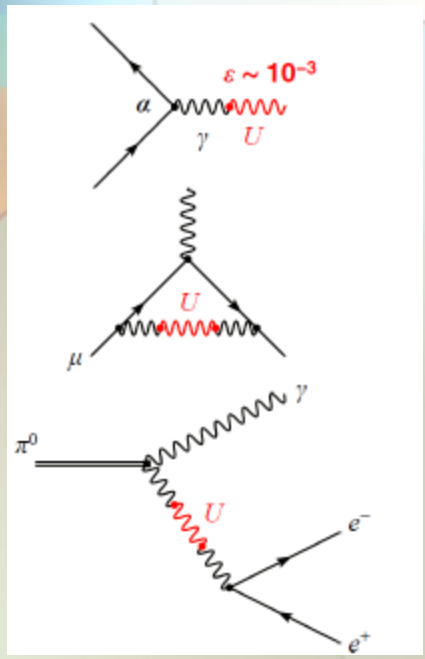
Dark photons

Models with U boson (dark photon):

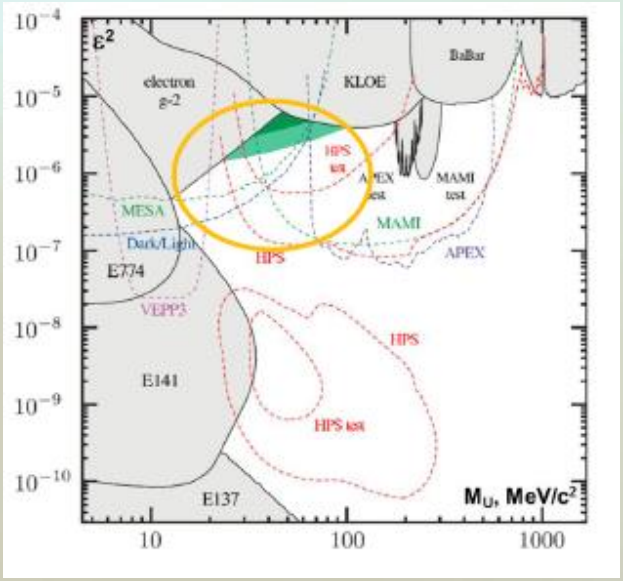
- ✓ U is a new light vector gauge boson (from MeV to GeV)
- ✓ U mediates interactions with DM (hidden sector)
- ✓ Kinetic mixing between U and γ
- ✓ Decays mainly to e^+e^-

Models with U boson (dark photon) can explain several anomalies:

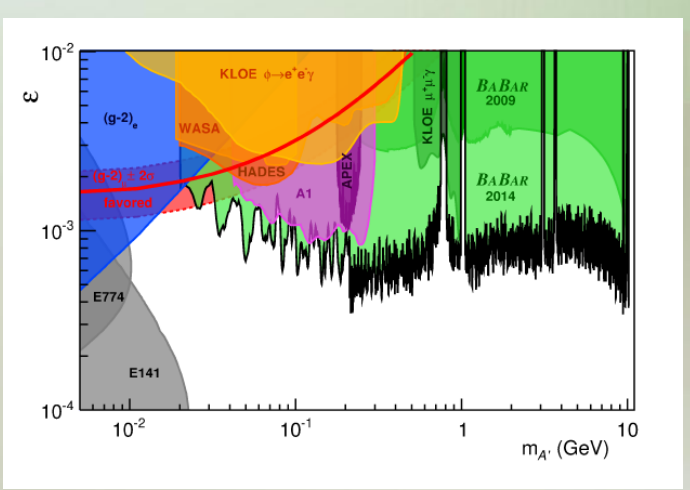
- ✓ PAMELA e^+ excess
- ✓ DAMA/Libra DM signals
- ✓ $(g-2)_\mu$ anomaly



Plot from M.Endo et al., PRD86 (2012) 095029



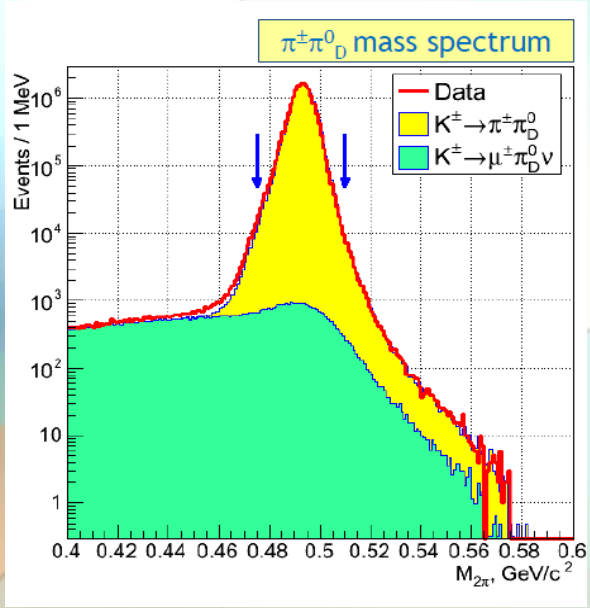
Plot from arXiv: 1406.2980 (with new BaBar data)

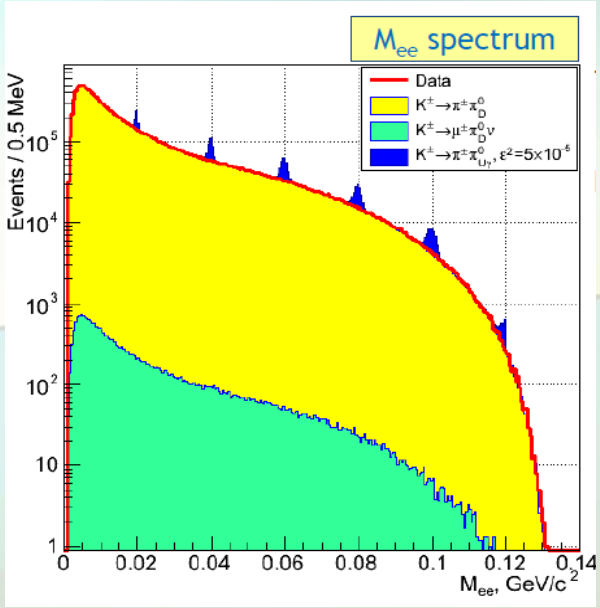


Dark photons in $\pi^0 \to e^+e^-\gamma$

NA48/2
ongoing analysis

blue: signal MC for $\varepsilon^2=5\times10^{-5}$





- An **existing data sample** collected in 2003–2004 with a 3-track trigger. Trigger efficiency: ~98%.
- Large sample of tagged π^0_D decays: ~2×10^7 $K^\pm\to\pi^\pm\pi^0_D$ candidates.
- Further π^0_D samples available from $K^\pm\to\pi^0_D l^\pm\nu$ decays.
- Search for $\pi^0\to U\gamma$, $U\to e^+e^-$. $BR(U\to e^+e^-)=1$ for $M_U<2M_\mu$.

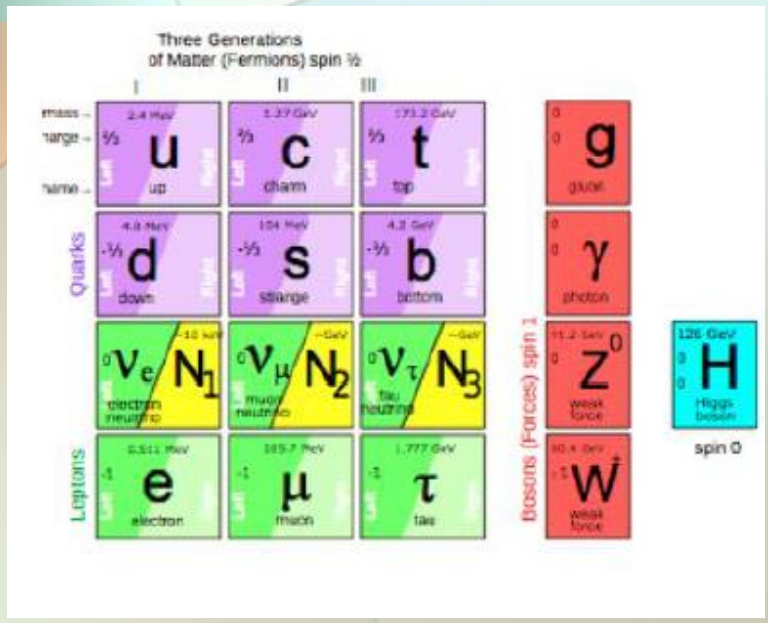
Dark photon search at NA62:

- ✓ ~10^8 $\pi^0\to e^+e^-\gamma$ decays/year can be collected
- ✓ M_{ee} resolution ~1 MeV
- ✓ Sensitivity: $M_U<100$ MeV, $\varepsilon^2\sim10^{-6}$
- ✓ NA62: UL will be improved

Heavy neutrinos

vMSM model:

- ✓ 3 right-handed Majorana neutrinos added (N_1, N_2, N_3)
- ✓ N_1 is the lightest (~keV) and can be a DM candidate
- ✓ N_2, N_3: from 100 MeV to few GeV
- ✓ Standard neutrino masses produced via seesaw mechanism (Yukawa coupling ~10^{-8})

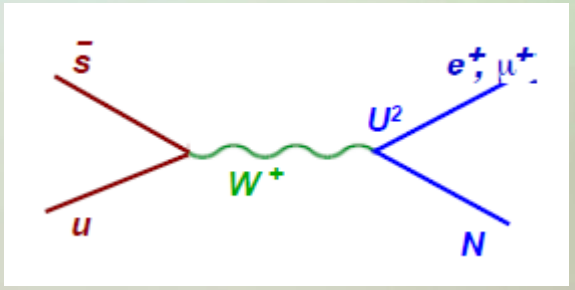


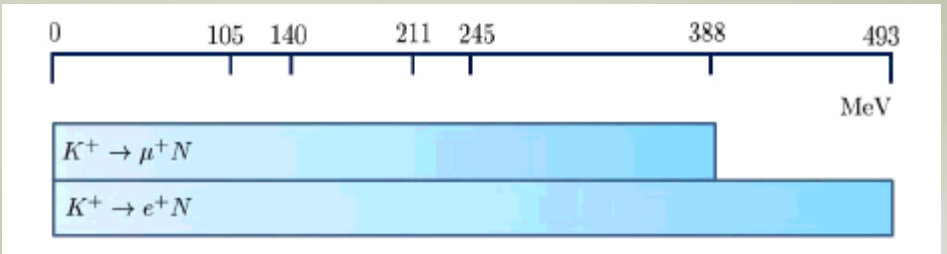
vMSM can explain:

- ✓ Matter/antimatter asymmetry
- ✓ Neutrino mixing
- ✓ Dark matter

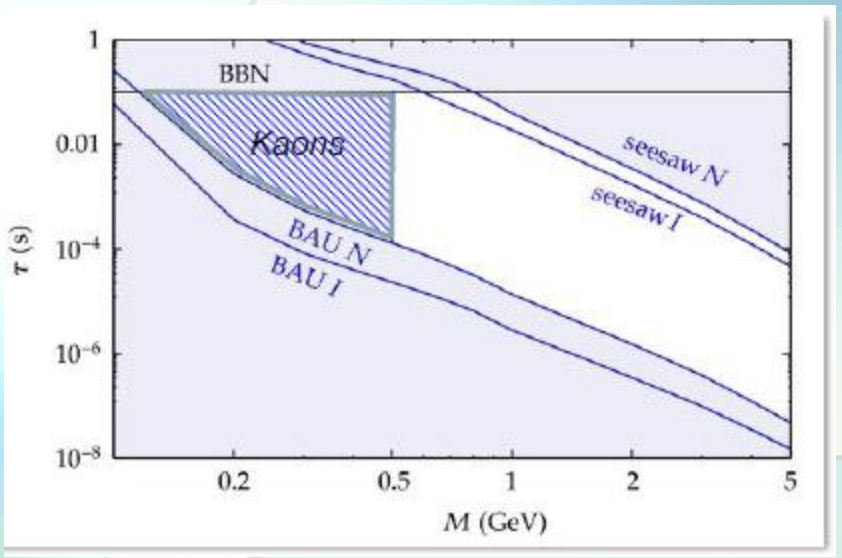
N_2/N_3 search in charged kaon decays:

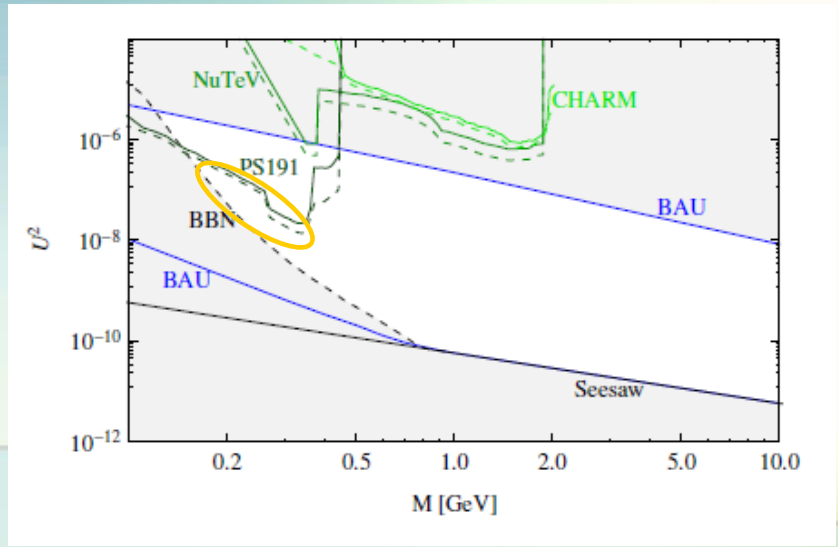
- ✓ $K^+ \to \mu^+ N$, $K^+ \to e^+ N$
- ✓ Sensitivity up to ~300-400 MeV





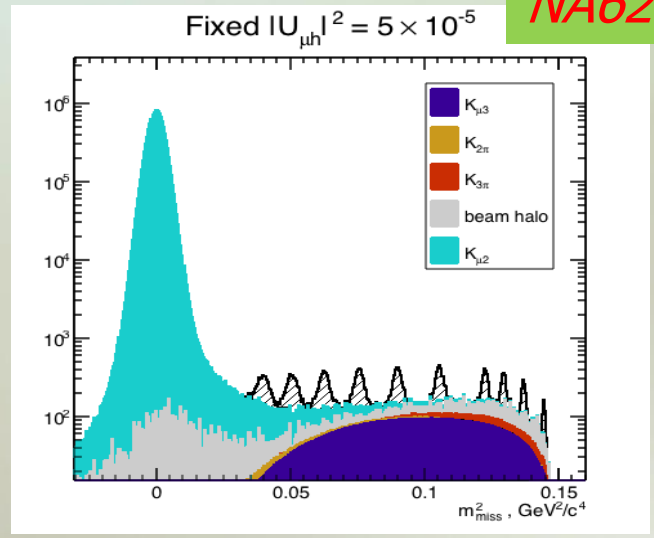
Heavy neutrino search at NA62





Plots from arXiv: 1310.1762

NA62 MC



Ongoing analysis:

- ✓ NA62 RK data (2007)
- ✓ Long-lived neutrino
- ✓ $K^+ \to \mu^+ N$ channel
- ✓ Main variable: $M^2_{miss} = (P_K - P_\mu)^2$
- ✓ NA62: higher statistics, better resolution, better photon veto

More exotics

Process	motivation	90% C.L. limit	Experiment	Year
$K^+ \to \pi^+ X^0$	New particle	$< 5.9 \times 10^{-11}$ $m_{X0}=0$	E787, E949	2002
$K^+ \to \pi^+ \chi\chi$	New particles	(several)	Example: E949	2008
$\pi^0 \to ee(\gamma)$	Dark force	(several)	(several)	--
$\pi^0 \to eeee$	T viol. in SI and EI	C=-0.77+-0.53	Samios et. al.	1962
$\pi^0 \to \gamma\gamma\gamma$	C violation	$< 3.1 \times 10^{-8}$	Crystal Box	1988
$\pi^0 \to \gamma\gamma\gamma\gamma$	light scalar	$< 2 \times 10^{-8}$	Crystal Box	1988
$\pi^0 \to \nu\bar{\nu}$	RH neutrino	$<2.7 \times 10^{-7}$	E949	2005
sgoldstino	New particle	$< 9 \times 10^{-6}$	Hyper-CP, ISTRA+	2004
$K^+ \to \pi^+\pi^+e^-\nu$	$\Delta S!=\Delta Q$	$< 1.2 \times 10^{-8}$	Geneva-Saclay	1976
$K^+ \to \pi^+\pi^+\mu^-\nu$	$\Delta S!=\Delta Q$	$< 3.0 \times 10^{-6}$	Birge et al.	1965
$K^+ \to \pi^+\gamma$	Angular momentum	$< 2.3 \times 10^{-9}$	E949	2005

conclusions

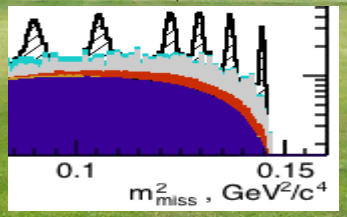
NA62 provides a wide spectrum of studies beyond the baseline:

- ✓ LFV and LNV kaon decays
- ✓ Exotic kaon decays
- ✓ Exotic π^0 decays

These decays allow to probe:

- ✓ Neutrinoless double beta decay in the second generation
- ✓ Dark photons
- ✓ Heavy neutrinos
- ✓ …

October 2014: NA62 starts the data taking



THANK YOU!