Review of Kaon Experiments

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Outline:

1) Introduction to CERN kaon programme
2) The golden decay mode: $K^+ \to \pi^+ \nu \bar{\nu}$
3) Lepton flavour/number violation in K decays
4) Rare π^0 decays
5) Selected recent results, ongoing analyses
6) Summary

UK Flavour 2013

IPPP Durham • 5 September 2013

Kaon physics facilities

BNL
E865, E777, E787, E949

CERN
NA48, NA62

IHEP Protvino
ISTRA+, OKA, *KLOD*

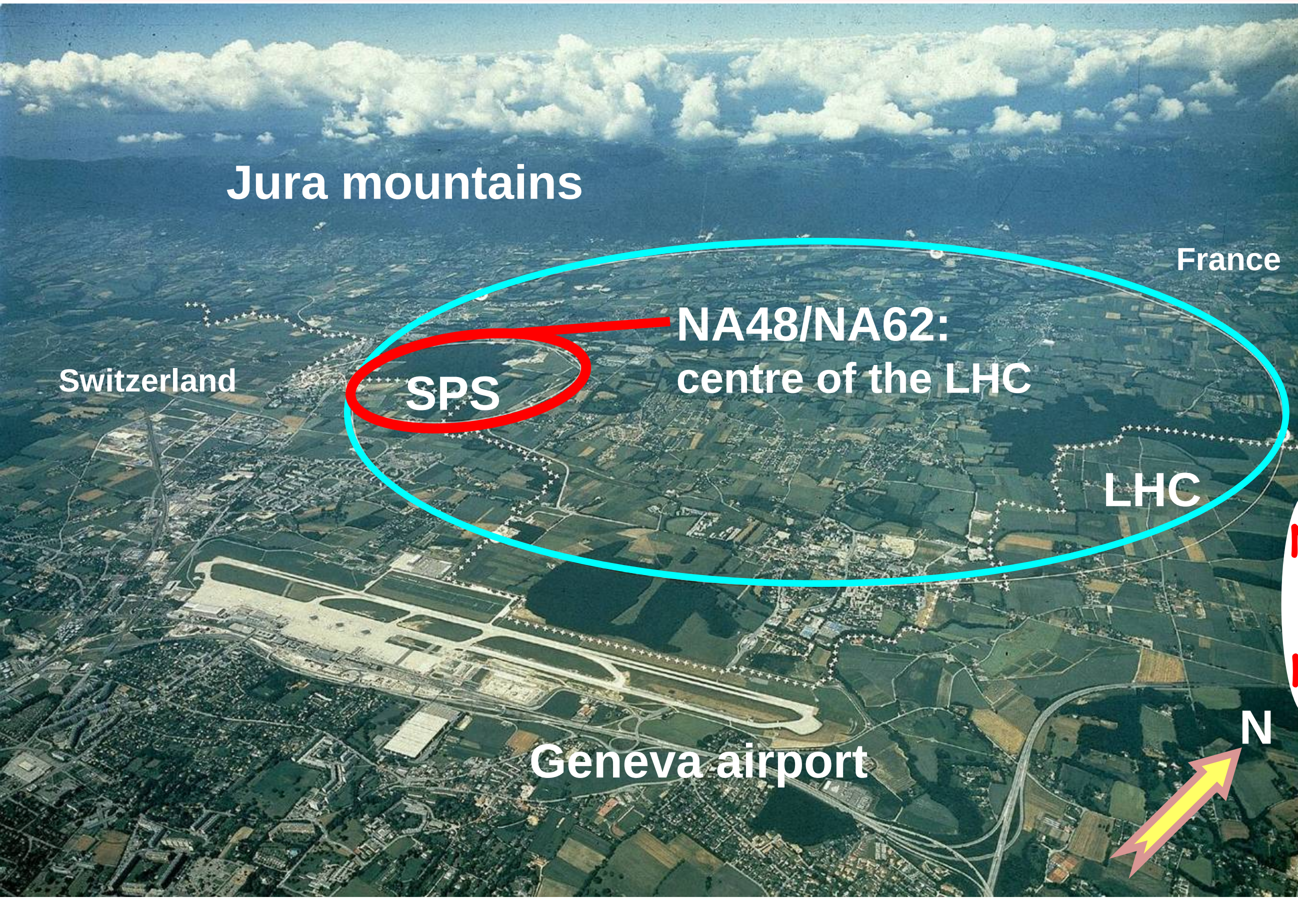
FNAL
KTeV, *ORKA*

LNF
KLOE, KLOE-2

KEK/J-PARC
E391a, KOTO, *TREK*

A variety of experimental techniques:
K decay-in-flight (e.g. CERN), stopped **K⁺**, **ϕ** factory

CERN NA48/NA62 experiments



Earlier: NA31

NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 R_K phase
- 2007: $K^\pm_{e2}/K^\pm_{\mu 2}$ | tests
- 2008: $K^\pm_{e2}/K^\pm_{\mu 2}$ | tests

NA62
- 2012: technical run
- *2014:* 1st $K^+\rightarrow\pi^+\nu\bar{\nu}$ run

Kaon decay in flight experiments.
NA62: currently **~200** participants, **27** institutions

Recent $K^{\pm}$ experiments at CERN

Experiment	NA48/2 ($K^{\pm}$)	NA62-R_K ($K^{\pm}$)	*NA62* *(K^{+}; planned)*
Data taking period	**2003–2004**	**2007–2008**	***2014–2017***
Beam momentum, GeV/c	**60**	**74**	**75**
RMS momentum bite, GeV/c	**2.2**	**1.4**	**0.8**
Spectrometer thickness, X_0	**2.8%**	**2.8%**	**1.8%**
Spectrometer P_T kick, MeV/c	**120**	**265**	**270**
$M(K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-})$ resolution, MeV/c^2	**1.7**	**1.2**	**0.8**
K decays in fiducial volume	**2×10^{11}**	**2×10^{10}**	**1.2×10^{13}**
Main trigger	multi-track; **$K^{\pm}\to\pi^{\pm}\pi^{0}\pi^{0}$**	**$e^{\pm}$**	**$K_{\pi\nu\nu}$ + ...**

Same detector (NA48)

The new NA62 detector:

- beam spectrometer and kaon tagger;
- improved mass reconstruction and particle identification;
- hermetic photon veto.

NA48/2 and NA62-R_K detector

2003–2008: charged kaon beams,
the NA48 detector

Narrow momentum band $K^{\pm}$ beams:

P_K= 60 (74) GeV/c, $\delta P_K/P_K$ ~ 1% (rms).

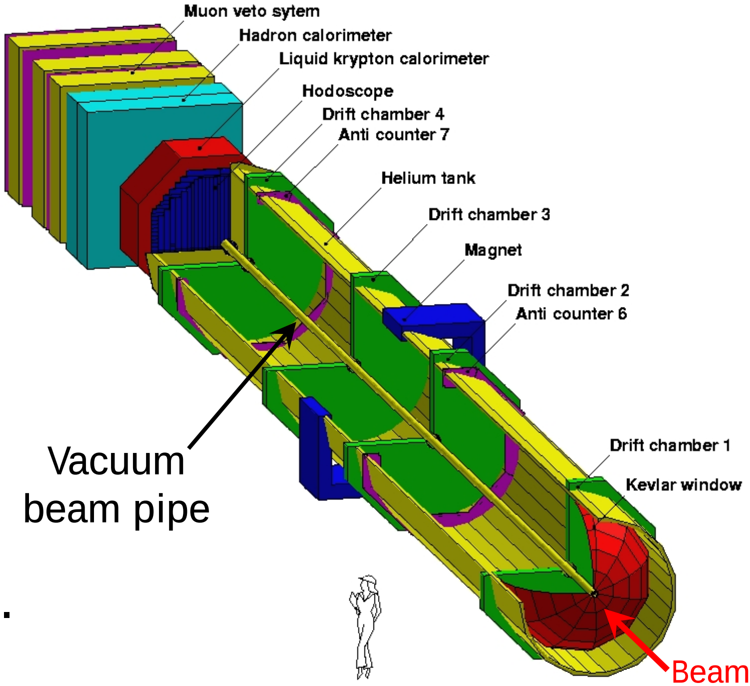
- ❖ Maximum $K^{\pm}$ decay rate ~100 kHz;
- ❖ NA48/2: six months in 2003–04;
- ❖ NA62-R_K: four months in 2007.

Principal subdetectors:

❖ Magnetic spectrometer (4 DCHs)
4 views/DCH: redundancy $\Rightarrow$ efficiency;
$\delta p/p = 0.48\% + 0.009\% p$ [GeV/c] (in 2007)

❖ Scintillator hodoscope
Fast trigger, time measurement (150ps).

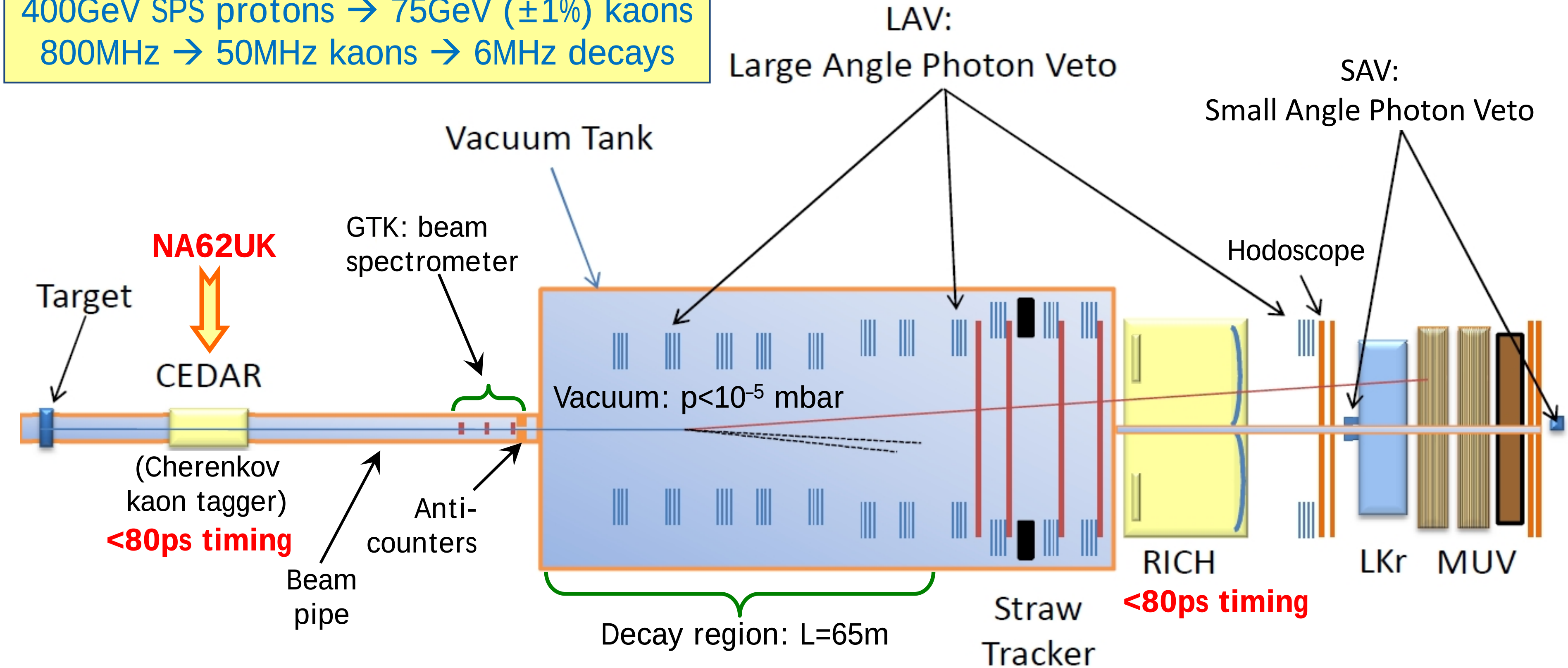
❖ Liquid Krypton EM calorimeter (LKr)
High granularity, quasi-homogeneous;
$\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$ [GeV];
$\sigma_x=\sigma_y=4.2\text{mm}/E^{1/2} + 0.6\text{mm}$ (1.5mm@10GeV).



NA62 detector

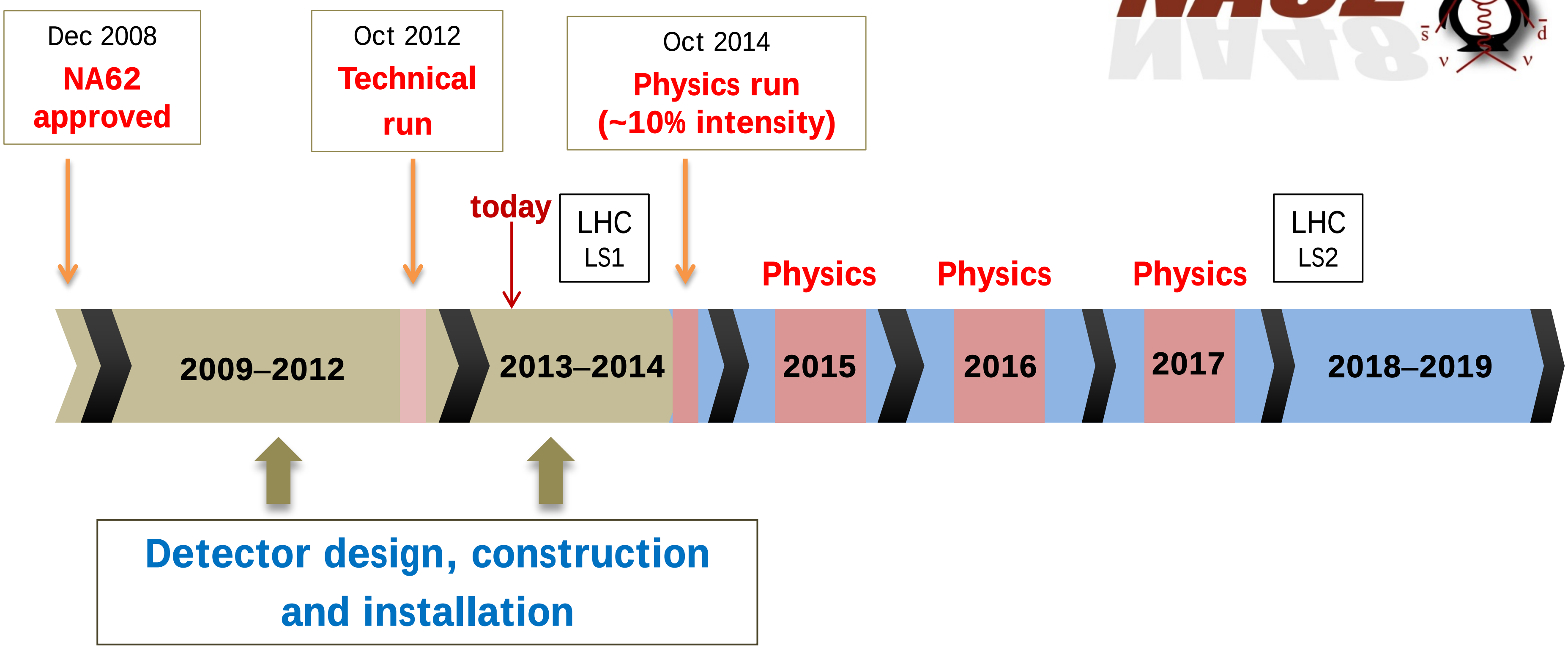
Un-separated hadron ($p/\pi^+/K^+$) beam:
400GeV SPS protons → 75GeV (±1%) kaons
800MHz → 50MHz kaons → 6MHz decays

Total length: ~270m



- Kinematic rejection factors (limited by beam pileup and tails of MCS): 5×10^3 for $K^+\to\pi^+\pi^0$, 1.5×10^4 for $K\to\mu^+\nu$.
- Hermetic photon veto: ~10^8 suppression of $\pi^0\to\gamma\gamma$.
- Particle ID (RICH+LKr+MUV): ~10^7 muon suppression.

NA62 timeline

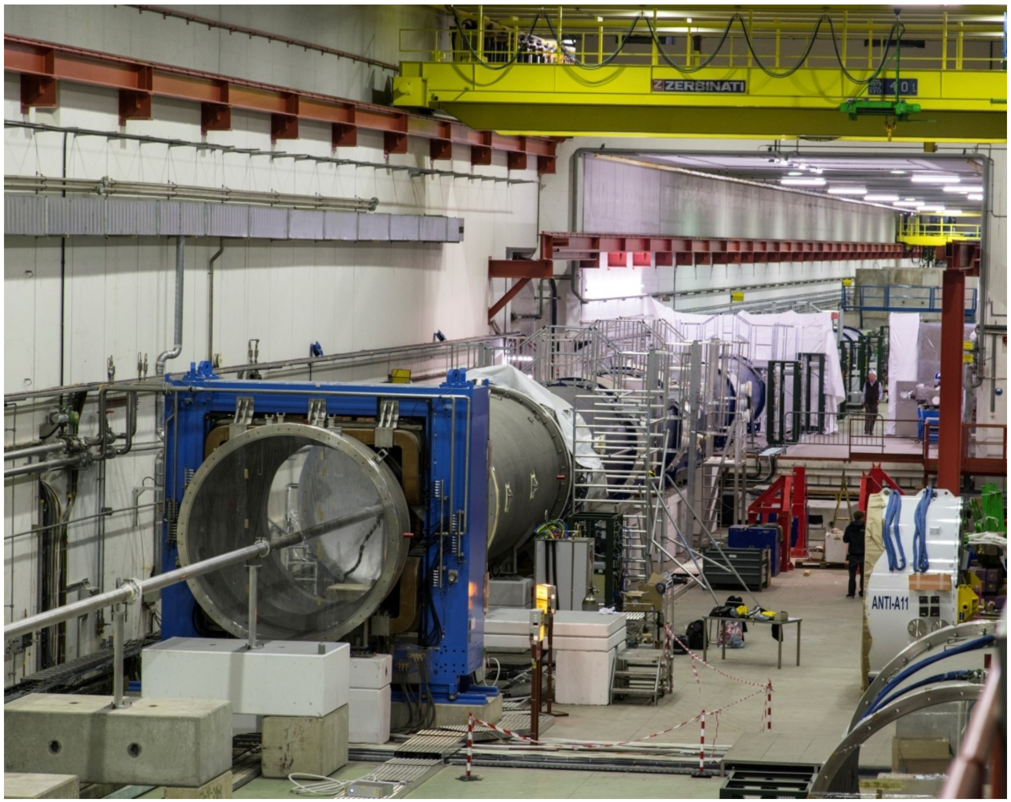


- 5 years of construction interleaved with a technical run in **October 2012**
- First run with full detector: **October–December 2014**
- Physics data taking runs before LHC Long Shutdown 2 (LS2)

NA62 construction & tests

Photon veto (LAV) installation

Vacuum tank view in 2012

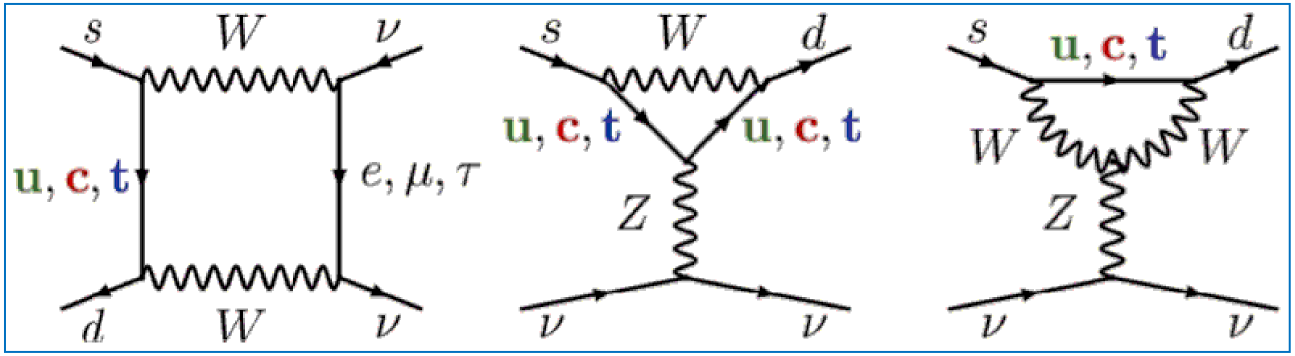


Cherenkov kaon tagger (CEDAR+KTAG)

The golden decay: $K^+ \to \pi^+ \nu\bar{\nu}$

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

SM: box and penguin diagrams



Ultra-rare decays with
the highest CKM suppression:

$$A \sim (m_t/m_W)^2 |V_{ts}^* V_{td}| \sim \lambda^5$$

- Hadronic matrix element related to a measured quantity ($K^+\to\pi^0 e^+\nu$).
- SM precision surpasses any other FCNC process involving quarks.
- Measurement of $|V_{td}|$ complementary to those from B–B mixing or $B^0\to\rho\gamma$.
- Optimal probe for non-MFV *(Gino Isidori, ESPP open symposium 2012)*

SM branching ratios
Brod et al., PRD 83 (2011) 034030

Mode	$BR_{SM}\times10^{11}$
$K^+\to\pi^+\nu\bar{\nu}(\gamma)$	7.81±0.75±0.29
$K_L\to\pi^0\nu\bar{\nu}$	2.43±0.39±0.06

CKM parametric — Intrinsic

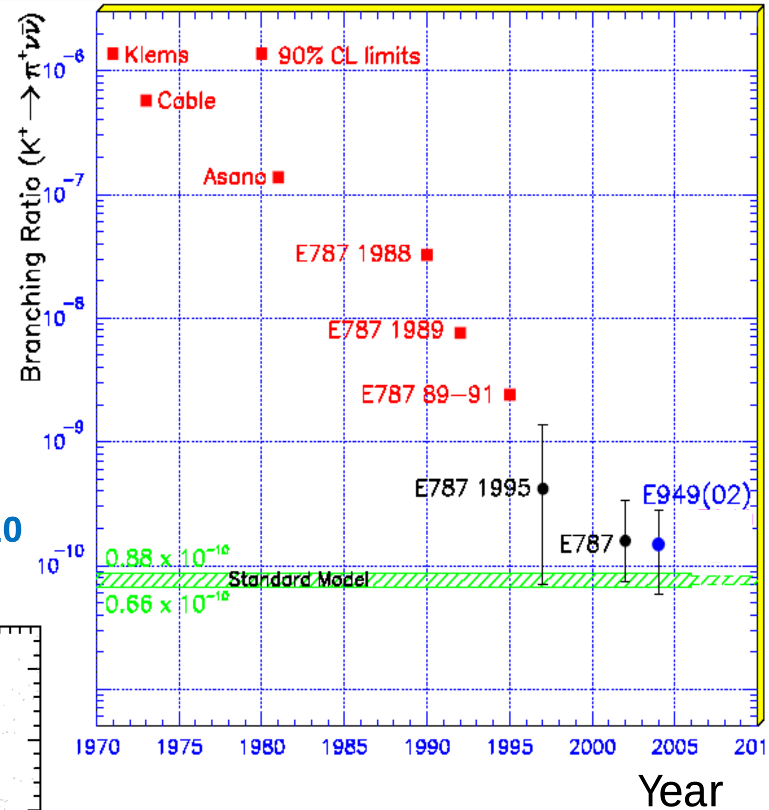
Theoretically clean,
sensitive to new physics,
almost unexplored

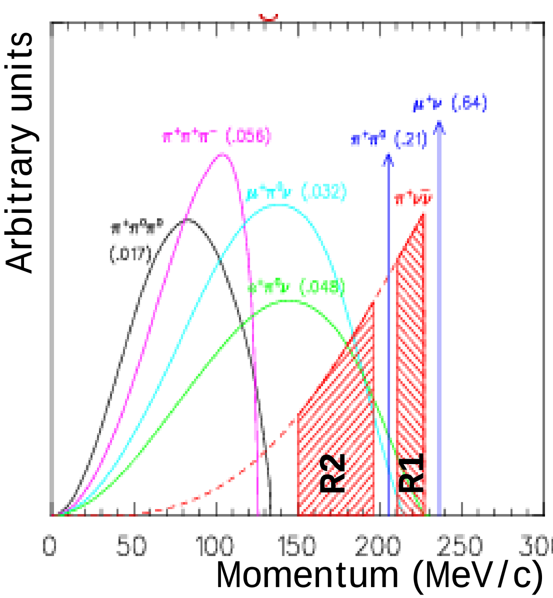
$K^+ \to \pi^+ \nu\bar{\nu}$ at BNL E747/E949

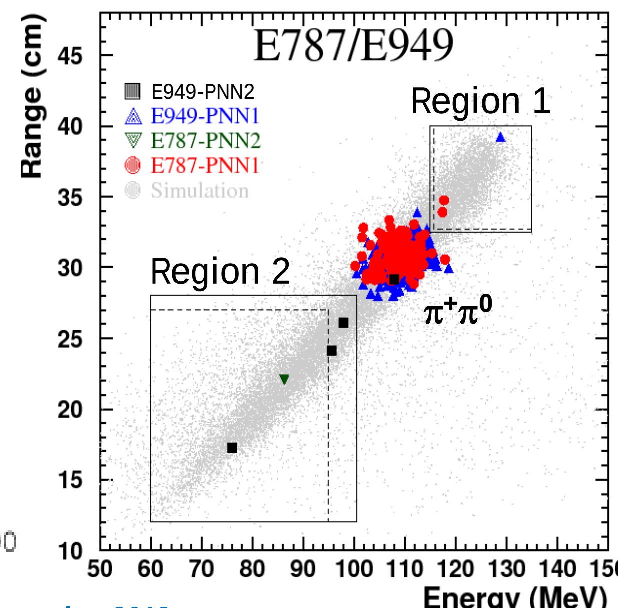
Technique: K^+ decay at rest

Data taking: E787 (1995–98), E949 (2002).
Separated K^+ beam (**710 MeV/c**, **1.6MHz**).
PID: range (entire $\pi^+ \to \mu^+ \to e^+$ decay chain).
Hermetic photon veto system.

Observed candidates: **7**
Expected background: **2.6**
Final result: **$BR = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$**





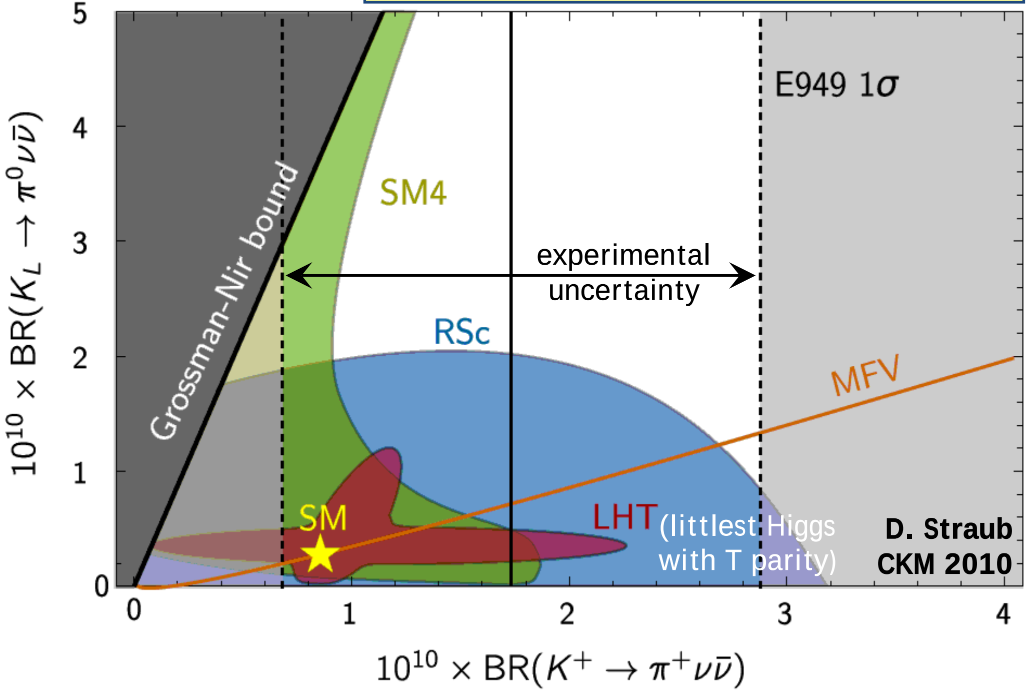


Significant background in Region 2 from the $K_{2\pi}$ decay with π^+ scattering in the target.

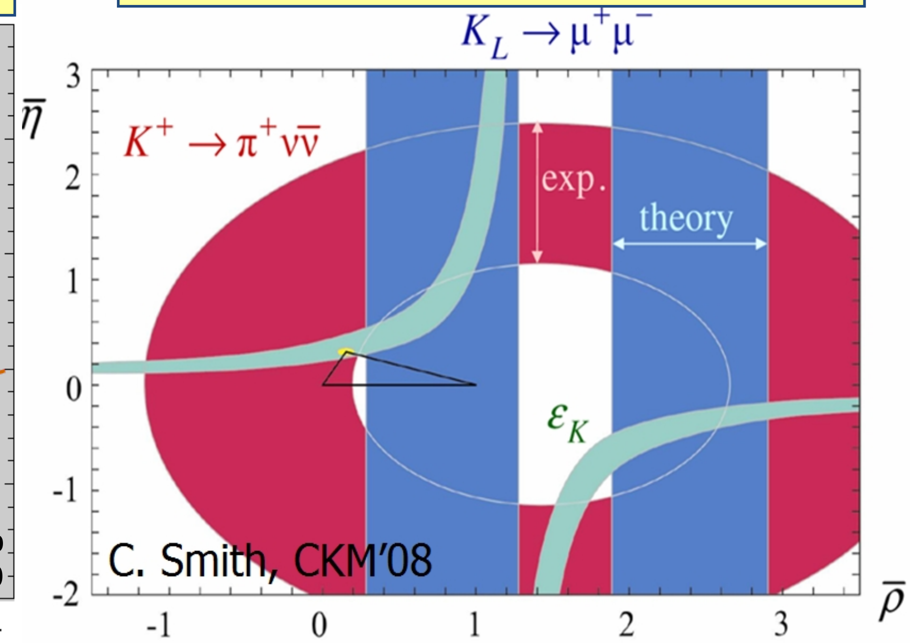
PRL 101 (2008) 191802; PRD 79 (2009) 092004

Experiment vs theory

BR($K_L \to \pi^0 \nu\bar{\nu}$) vs BR($K^+ \to \pi^+ \nu\bar{\nu}$)



CKM unitarity triangle with kaons



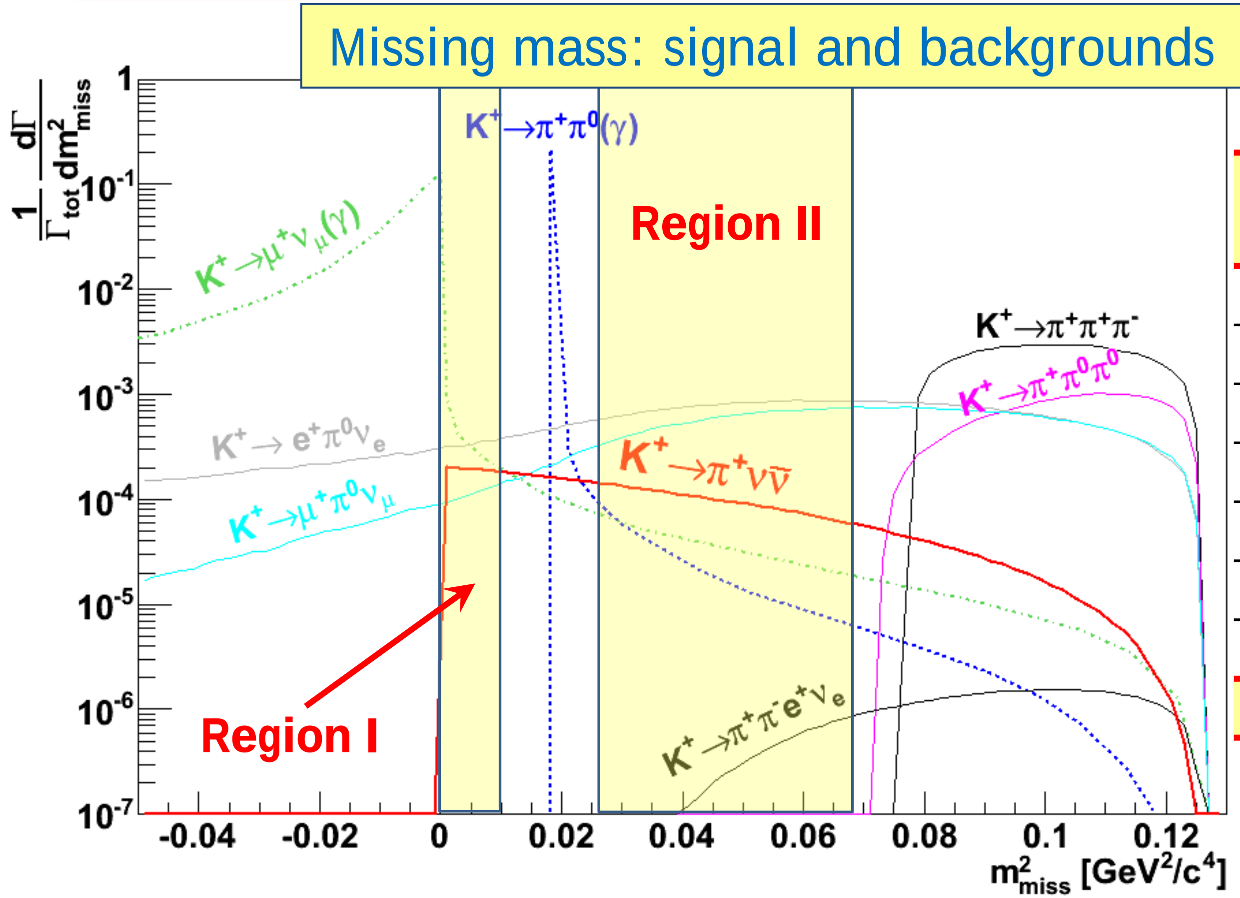
NA62 aim: collect O(100) SM $K^+ \to \pi^+ \nu\bar{\nu}$ decays with <20% background in 2 years of data taking using a novel decay-in-flight technique.

Decay signature: high momentum K^+ (75GeV/c) → low momentum π^+ (15–35 GeV/c).

Advantages: max detected K^+ decays/proton ($p_K/p_0 \approx 0.2$); efficient photon veto (>40 GeV missing energy); good π^+ vs μ^+ identification with RICH.

Un-separated beam (6% kaons) → higher rates, additional backgrounds.

NA62: $K_{\pi\nu\nu}$ signal region



Signal & backgrounds (events/year)	
Signal	45
$K^+\to\pi^+\pi^0$	5
$K^+\to\mu^+\nu$	1
$K^+\to\pi^+\pi^+\pi^-$	<1
Other 3-track decays	<1
$K^+\to\pi^+\pi^0\gamma$ (IB)	1.5
$K^+\to\mu^+\nu\gamma$ (IB)	0.5
Total background	**<10**

92% of total **BR(K^+)**:

- ❖ Outside the signal kinematic region.
- ❖ Signal region is split into **Region I** and **Region II** by the **$K^+\to\pi^+\pi^0$** peak

8% of total **BR(K^+)** including multi-body:

- ❖ Span across the signal region (not rejected by kinematic criteria).
- ❖ Rejection relies on **vetoes**, **PID**.

$K_{\pi\nu\nu}$ measurements worldwide

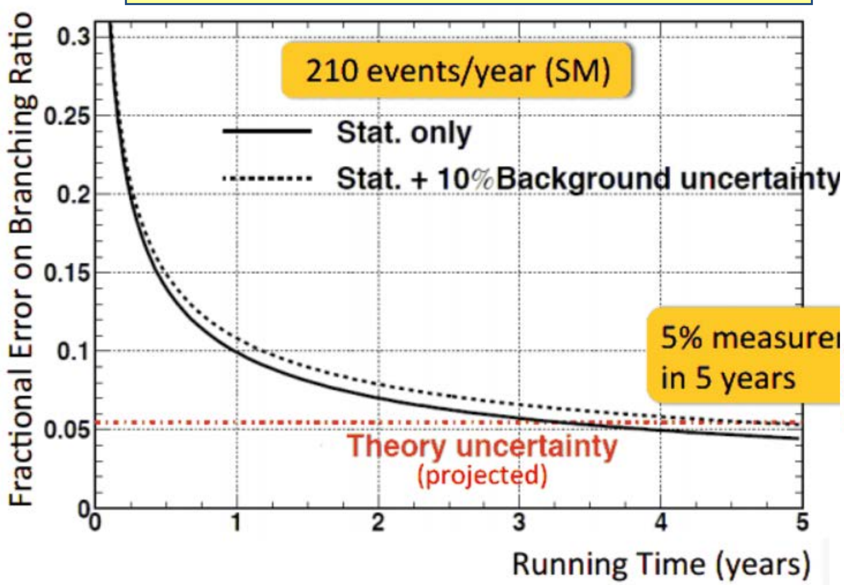
ORKA @ FNAL Main Injector (K^+):

- Builds on BNL stopped-kaon technique.
- Expect **~100** times higher sensitivity.
- Goal: **O(1000)** SM $K^+\to\pi^+\nu\nu$ events.
- Fits inside the CDF solenoid.
- Re-use CDF infrastructure.

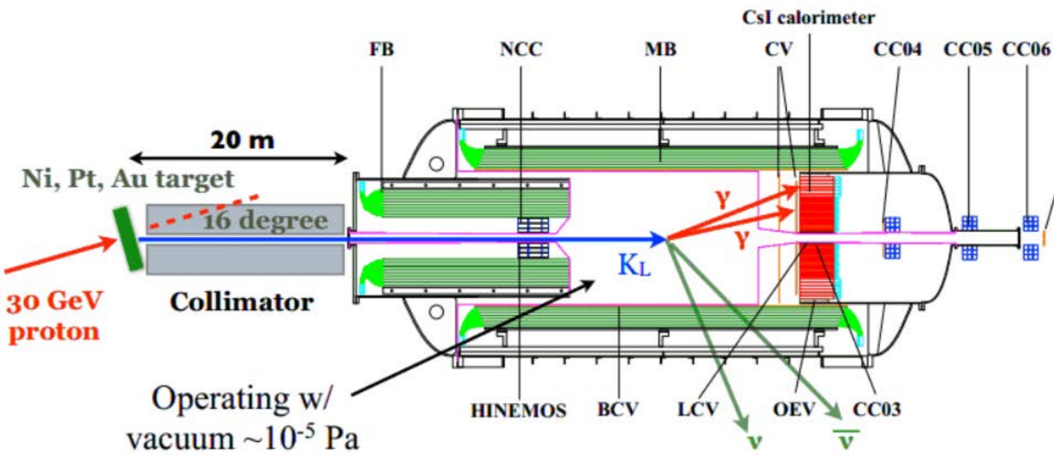
KOTO @ J-PARC (K_L):

- Builds on KEK E391a technique.
- E391a: **$BR<6.8\times10^{-8}$** @ 90%CL.
- Expect **~10^3** times higher sensitivity.
- Goal: **~3** SM $K_L\to\pi^0\nu\nu$ events.
- Data taking: **2013–2017**.
- Possible step 2: **~100** SM events.

ORKA expected sensitivity



"Two photons + nothing"



Lepton Flavour and Lepton Number Violation

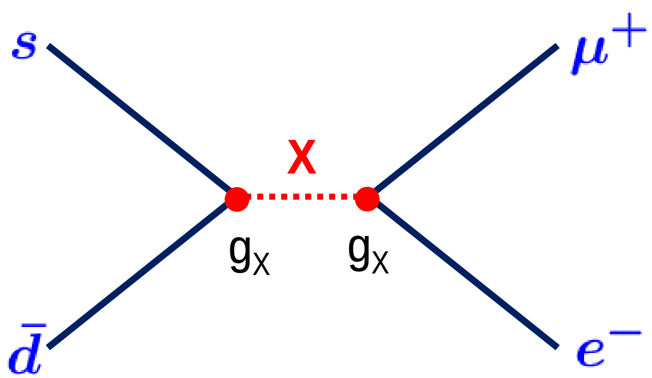
LFV in K decays

Kaons: historically competitive in searches for LFV phenomena

- Copious production: high statistics.
- Simple decay topologies: clean experimental signatures.
- Source of tagged π^0 via $K^+\to\pi^+\pi^0$, $K_L\to 3\pi^0$, ... :
  best limits for LFV π^0 decays.

High NP mass scales accessible for tree-level contributions

Example: $K_L \to \mu^+ e^-$



Dimensional argument:

$$\frac{\Gamma_X}{\Gamma_{SM}} \sim \left(\frac{g_X}{g_W}\cdot\frac{M_W}{M_X}\right)^4$$

For $g_X \approx g_W$ and $\mathcal{B} \sim 10^{-12}$,

$$M_X \sim 100\ \mathrm{TeV}$$

LFV in $K^{\pm}$ and π^0 decays

Mode	UL at 90% CL	Experiment	Reference
$K^+ \to \pi^+ \mu^+ e^-$	1.3×10^{-11}	BNL E777/E865	PRD 72 (2005) 012005
$K^+ \to \pi^+ \mu^- e^+$	5.2×10^{-10}	BNL E865*	PRL 85 (2000) 2877
$K^+ \to \pi^- \mu^+ e^+$	5.0×10^{-10}	BNL E865*	PRL 85 (2000) 2877
$K^+ \to \pi^- e^+ e^+$	6.4×10^{-10}	BNL E865*	PRL 85 (2000) 2877
$K^\pm \to \pi^\mp \mu^\pm \mu^\pm$	1.1×10^{-9}	CERN NA48/2	PLB 697 (2011) 107
$K^+ \to \mu^- \nu e^+ e^+$	2.0×10^{-8}	Geneva-Saclay	PL 62B (1976) 485
$K^+ \to e^- \nu \mu^+ \mu^+$	no data		
$\pi^0 \to \mu^+ e^-$	3.6×10^{-10}	FNAL KTeV	PRL 100 (2008) 131803
$\pi^0 \to \mu^- e^+$	3.6×10^{-10}	FNAL KTeV	PRL 100 (2008) 131803

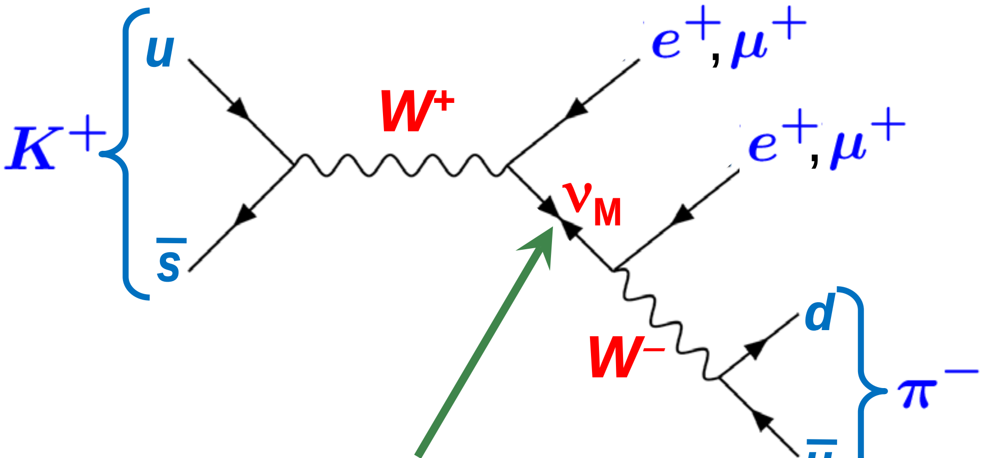
* CERN NA48/2 sensitivities for these 3 modes are similar to those of BNL E865

Expected NA62 single event sensitivities:
~10^{-12} for $K^{\pm}$ decays, **~10^{-11}** for π^0 decays.

- ❖ NA62 is capable of improving on all these decay modes;
- ❖ 2014 run alone: competitive for some modes (e.g. $K^+ \to \pi^- \mu^+ \mu^+$).

Sensitivity to Majorana neutrino

$$K^+ \to \pi^- \ell_1^+ \ell_2^+, \quad \ell = e, \mu$$



Neutrino propagator

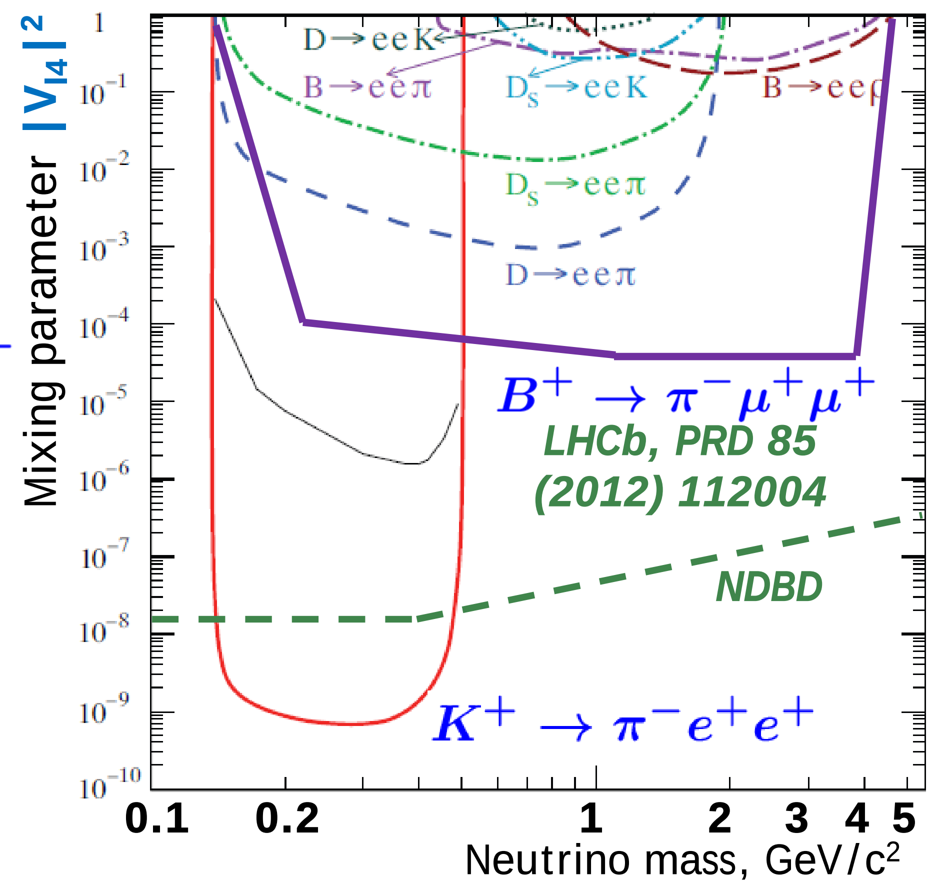
$$\frac{1}{q^2 - m_\nu^2}$$

→ resonant enhancement for

$$m_\pi \lesssim m_\nu \lesssim m_K$$

Littenberg and Shrock, PLB491 (2000) 285

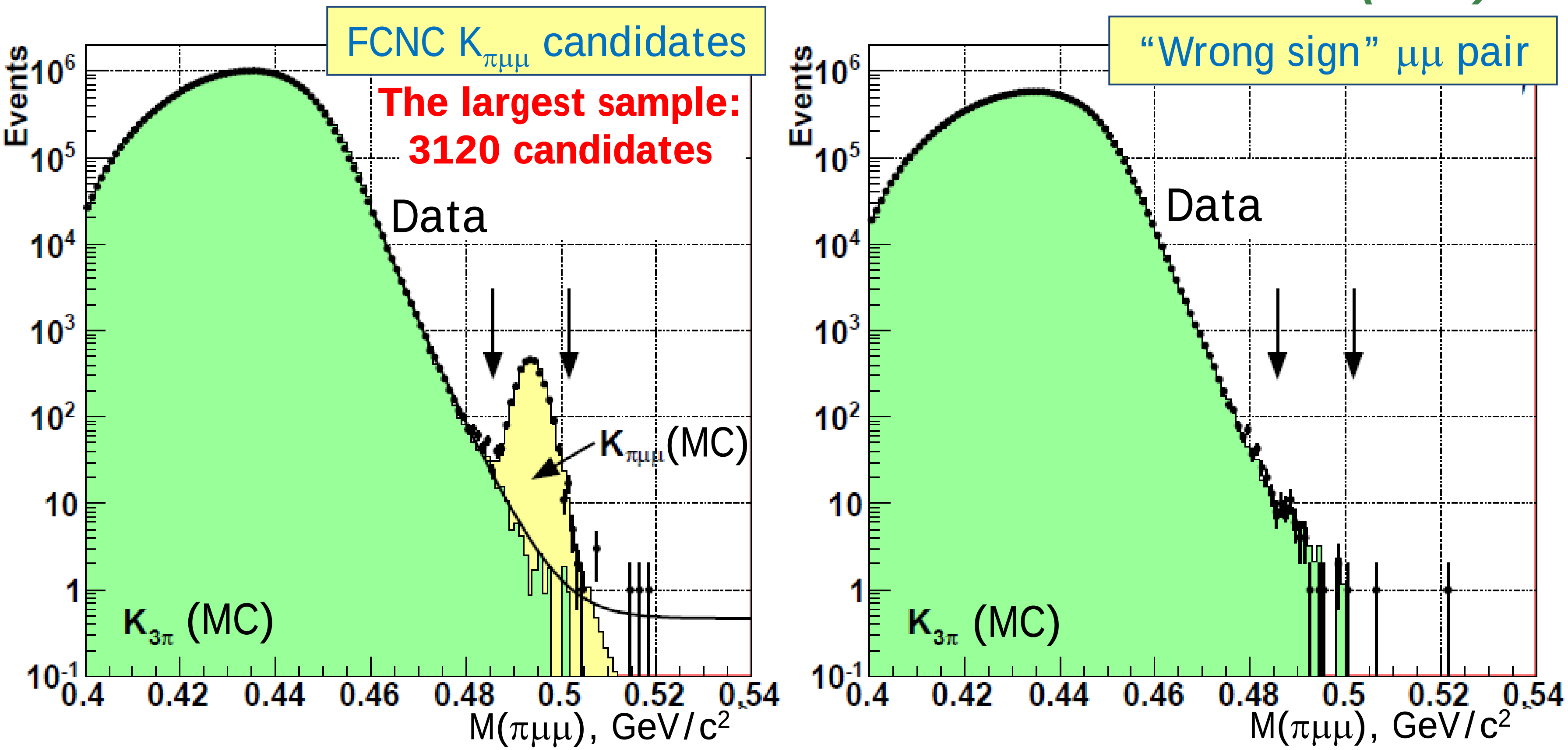
Majorana neutrino exclusion regions from existing data



Plot from Atre et al., JHEP 0905 (2009) 030

NA48/2 $K^\pm \to \pi^\mp \mu^\pm \mu^\pm$ upper limit

PLB 697 (2011) 107



$N_{data} = 52$
$N_{bkg} = 52.6 \pm 19.8_{syst.}$

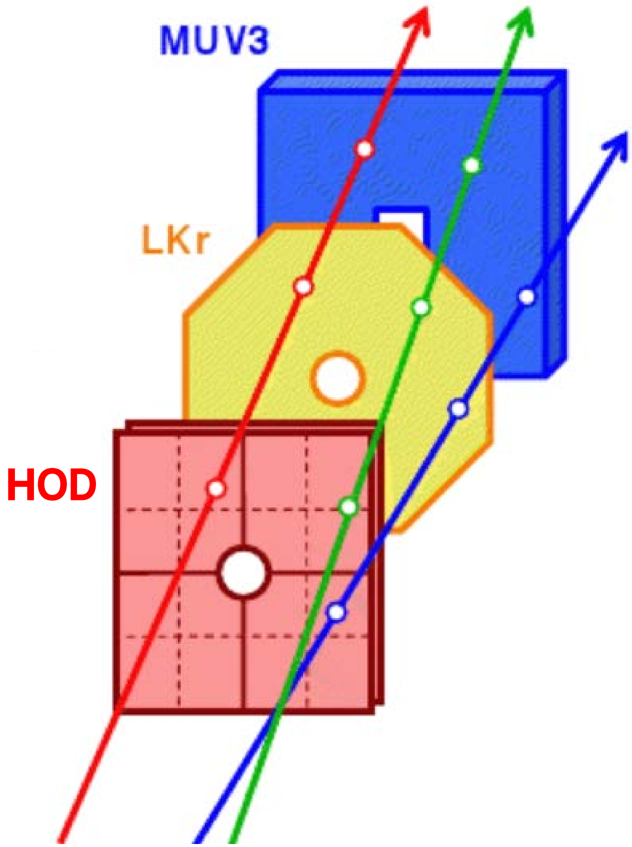
$\Rightarrow$ $\mathcal{B}(K^\pm \to \pi^\mp \mu^\pm \mu^\pm) < 1.1 \times 10^{-9}$ @90% CL

- ❖ Precision limited by background from $\pi^\pm \to \mu^\pm \nu$, despite SES $\approx 3 \times 10^{-11}$.
- ❖ Flat phase space assumed (rather than Majorana neutrino exchange).
- ❖ A dedicated re-analysis has a potential sensitivity of $\sim 10^{-10}$.

NA62: di-lepton trigger

NA62 three-track decay rate upstream HOD: **F_{3track} = 640 kHz**

→ **Too high** to collect all three-track decays (NA48/2 approach)



Available L0 trigger primitives:

- **Q_N**: at least N hodoscope quadrants;
- **$LKR_N(x)$**: at least N LKr clusters with energy E>x GeV;
- **MUV_N**: hits in at least N MUV3 pads;
- **RICH** hit multiplicity.

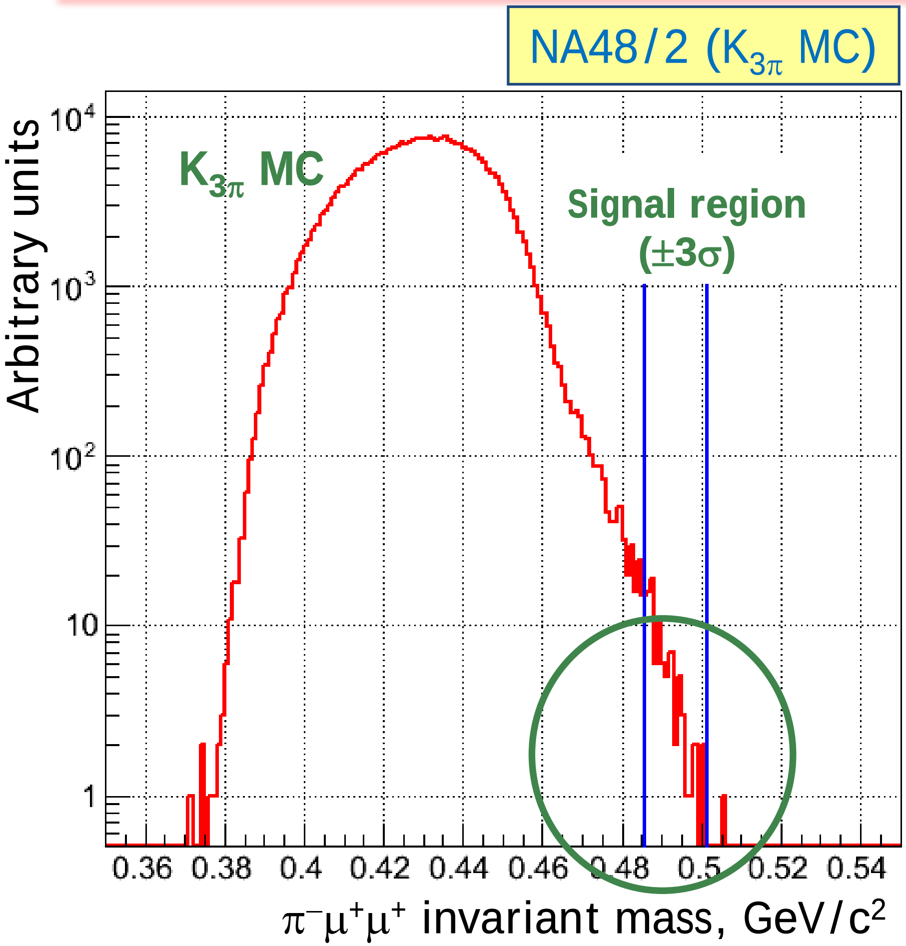
Possible L0 triggers for LFV searches:

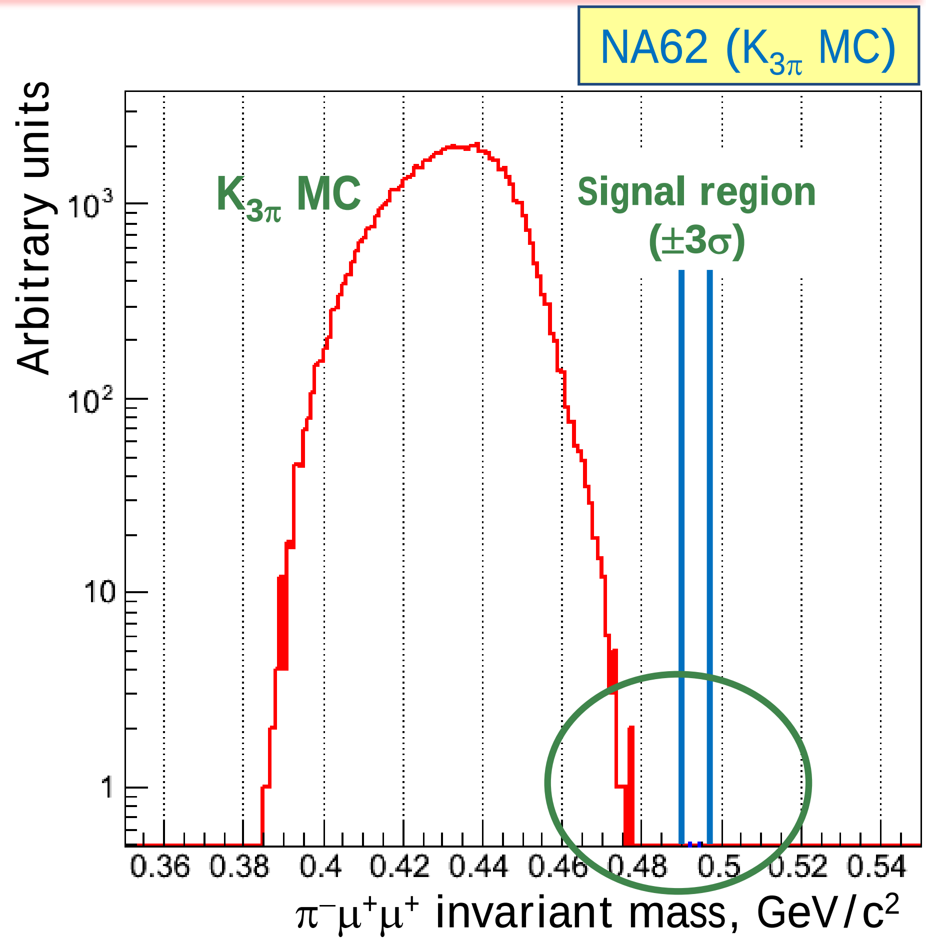
ee pair:	$Q_2 \times LKR_2(15)$
μe pair:	$Q_2 \times LKR_1(15) \times MUV_1$
$\mu\mu$ pair:	$Q_2 \times MUV_2$

Total lepton pair L0 rate (dominated by $K^+ \to \pi^+\pi^+\pi^-$): **F = few × 10 kHz**

→ *Charge-blind lepton pair collection is feasible*

$K^{\pm}\to\pi^{\mp}\mu^{\pm}\mu^{\pm}$ at NA62





NA48/2: $K_{3\pi}$ background to $K_{\pi\mu\mu}$ due to $\pi^{\pm}\to\mu^{\pm}\nu$ decays in the spectrometer

NA62: no $K_{3\pi}$ background expected due to high spectrometer P_T (**270** vs **120 MeV/c**) and improved $\pi\mu\mu$ mass resolution (**1.1** vs **2.6 MeV/c²**)

Rare π^0 decays

Dark photon: experimental status

M.Pospelov, PRD80 (2009) 095002

Secluded U(1) sector with weak admixture to photons: a natural SM extension.

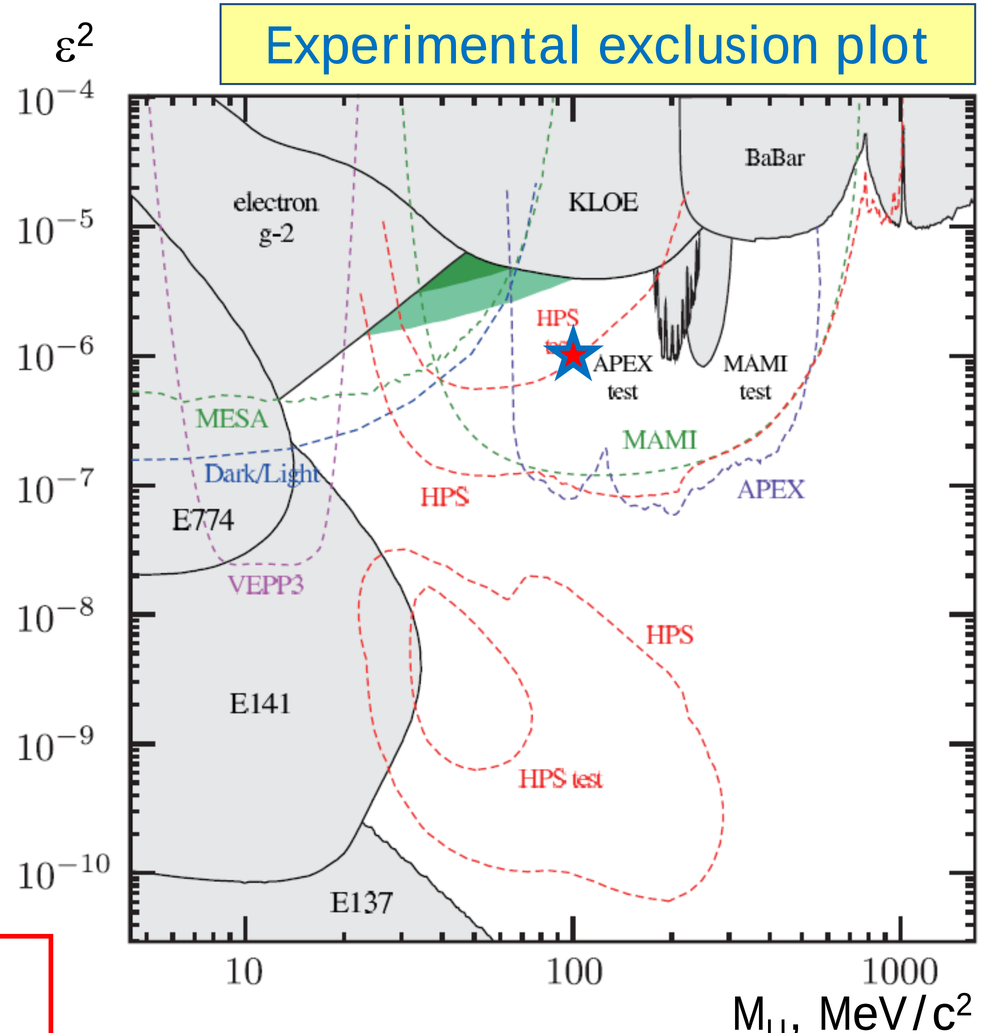
A new light vector boson: the **dark photon**.

Possible parameters:
mixing parameter: $\varepsilon \sim \alpha/\pi \sim 10^{-3}$,
DP mass: $M_U \sim \varepsilon M_Z \sim 100$ MeV/c^2.

Can explain some astrophysical observations as well as the muon **g–2** anomaly.

NA48/NA62 are well suited to explore the favoured region ($\varepsilon^2 \approx 10^{-6}$, $M_U \approx 100$ MeV/c^2)

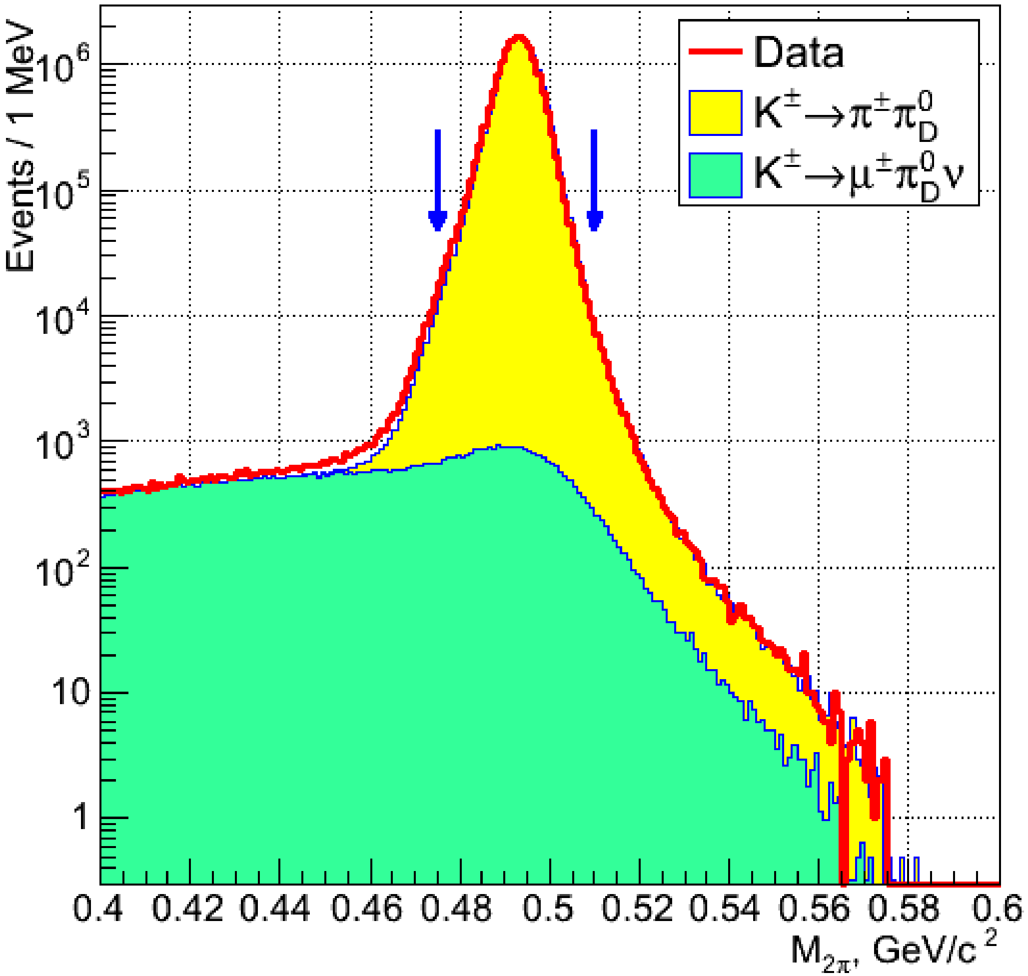
Experimental exclusion plot



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

NA48/2: $\pi^0_D \to e^+e^-\gamma$ sample

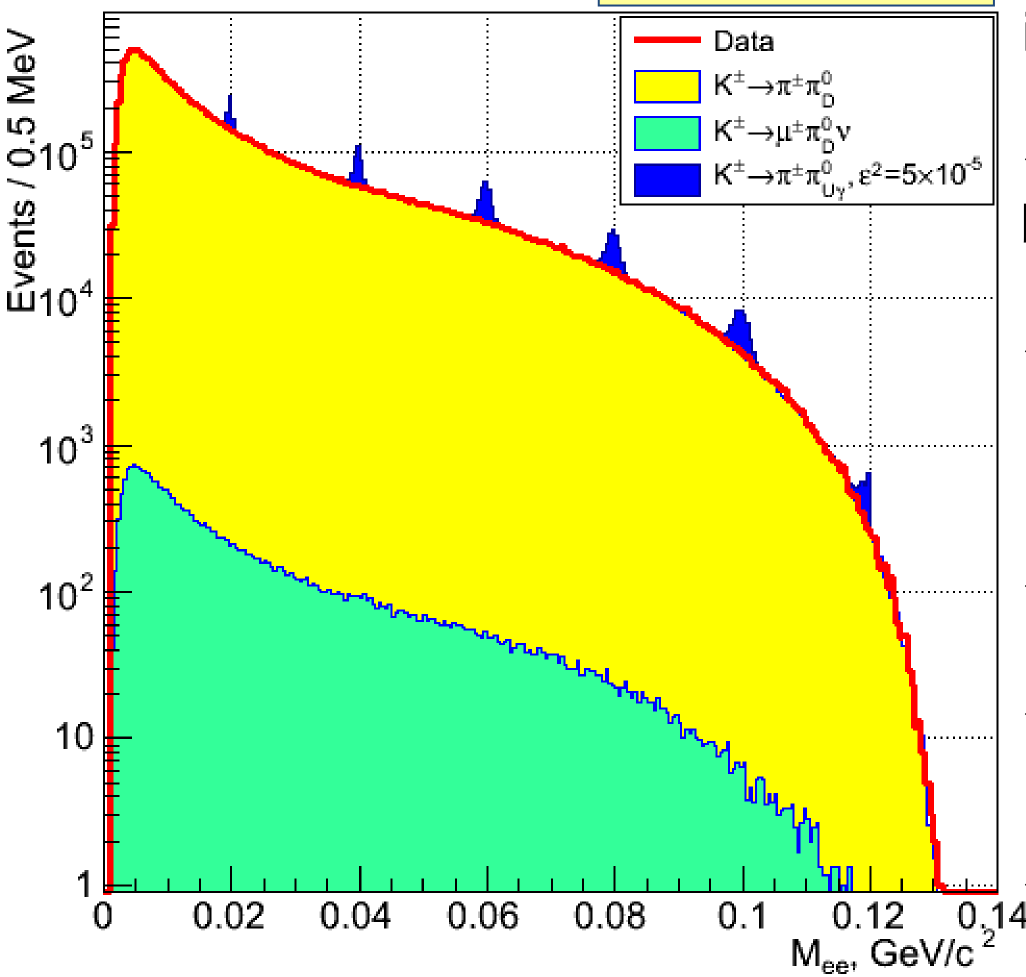
$\pi^\pm\pi^0_D$ mass spectrum



- An **existing data sample** collected in 2003–2004 with a 3-track trigger. Trigger efficiency: **~98%**.
- Large sample of tagged π^0_D decays: **$\sim 2\times10^7$ $K^\pm \to \pi^\pm\pi^0_D$**.
- 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 **$M_U < 2M_\mu$**.

NA48/2: π^0_D M_{ee} spectrum

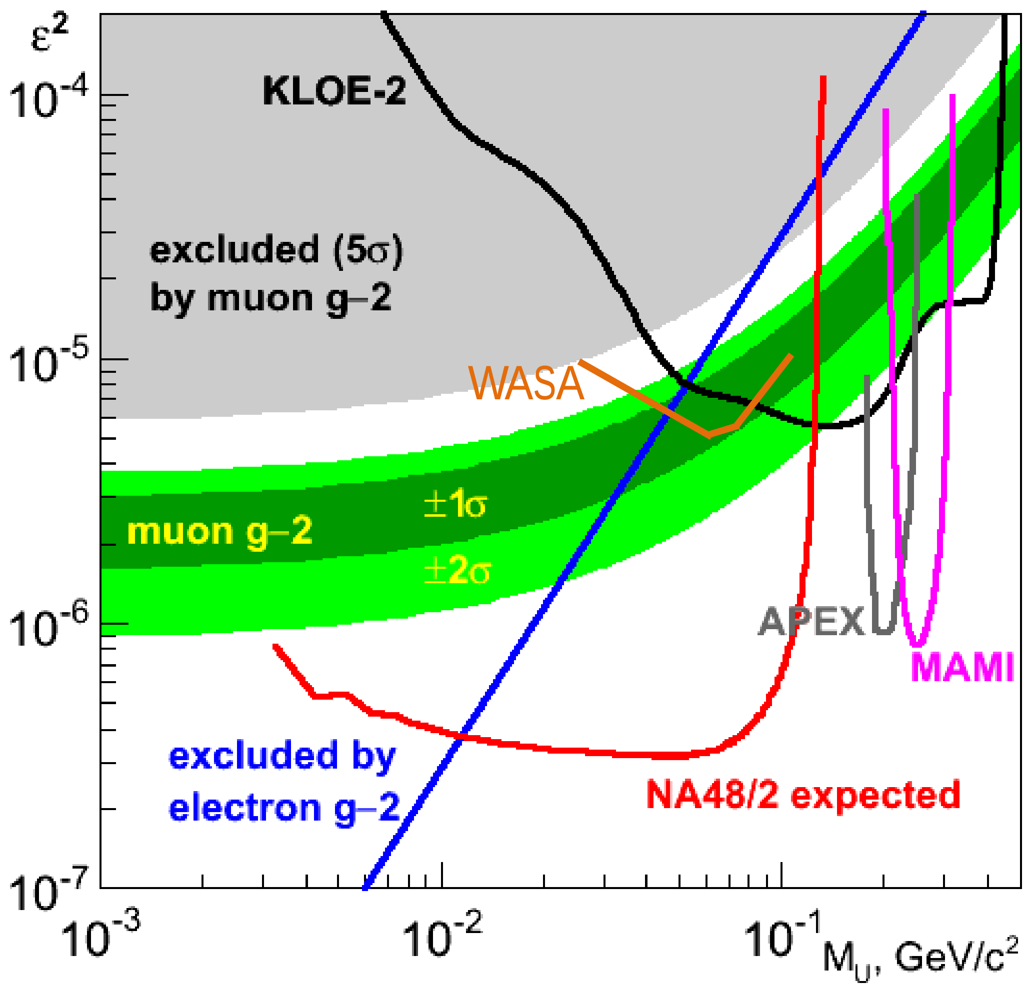
M_{ee} spectrum



π^0 form-factor measurement on-going

- Mean dark photo free path **~1mm**: identical signatures $\pi^0 \to U\gamma$ and π^0_D.
- Sensitivity to dark photon limited by $K_{2\pi D}$ background fluctuation.
- **Upper limit** ~ **(Kaon Flux)$^{-1/2}$** × **(Acceptance)$^{-1/2}$** × **(M_{ee} resolution)$^{-1/2}$**
- Flux **~2×10^{11}**, acceptance **~5%**.
- Spectrometer resolution: $\delta M_{ee} \approx 0.012 M_{ee}$ (<1.4 MeV/c).
- M_{ee} resolution can be improved using the $(P_K - P_\pi)^2$ constraint.

NA48/2 vs other limits at low M_U



<u>Experimental constraints</u>

Electron and muon g–2:
Endo et al., PRD86 (2012) 095029

KLOE-2 [$\phi \to \eta e^+ e^-$]:
Babusci et al., PLB720 (2013) 111

A1 @ MAMI (Mainz Microtron)
Merkel et al.,
PRL106 (2011) 251802

APEX @ J-LAB
Abrahamyan et al.,
PRL107 (2011) 191804

WASA preliminary [$\pi^0 \to \gamma e^+ e^-$]:
Adlarson et al., arXiv:1304.0671

NB: the NA48/2 curve is the expected sensitivity, not a result!

Rare π^0 decays at NA62

Single-event sensitivities for π^0 decays: **$\sim 10^{-11}$**

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

NA62: "neutral" π^0 decays

$\pi^0 \to 3\gamma$

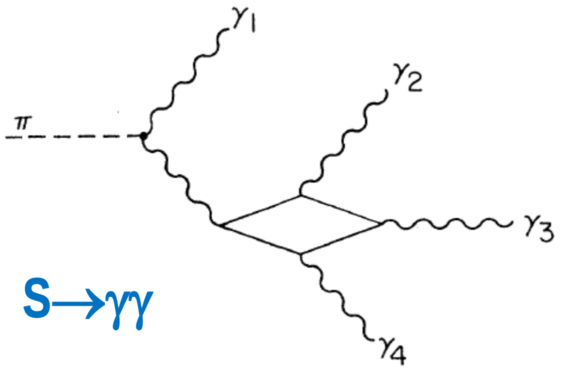
C-violating decay: **$BR_{SM} \sim 10^{-31\pm6}$** *[Dicus, PRD12 (1975) 2133]*

NP not beyond the corner, e.g. non-commutative QED: **$BR_{NP} \sim 10^{-21}$**
[Grosse, Liao, PLB520 (2001) 63]

Experiment: **$BR_{exp} < 3.1\times10^{-8}$** ($\pi^-$ stopped at proton target)
[PRD38 (1988) 2121]

$\pi^0 \to 4\gamma$

SM: dominated by QED electron-loop,
$BR_{SM} = (2.6\pm0.1)\times10^{-11}$
[Bratkovskaya et al., PLB359 (1995) 217]



Deviation: e.g. NP involving light scalars, **$\pi^0 \to SS$**, **$S \to \gamma\gamma$**
$BR_{exp} < 2\times10^{-8}$ *[PRD38 (1988) 2121]*

NA62 may improve these limits to **$BR \sim 10^{-10}$**,
however a dedicated trigger has to be implemented

NA62: the invisible π^0 decay

For a given flavour of massive neutrino (**$m_\nu < m_\pi/2$**),

$$\mathcal{B}(\pi^0 \to \nu\bar{\nu}) \approx 3 \times 10^{-8} k (m_\nu/m_\pi)^2 \sqrt{1 - 4(m_\nu/m_\pi)^2}$$

$$k = \begin{cases} \mathbf{1}, \text{ Dirac type} \\ \mathbf{2}, \text{ Majorana type} \end{cases}$$

From ν_τ mass: **$m_{\nu\tau} < 18.2$ MeV/c^2**, $\mathcal{B}(\pi^0 \to \nu\bar{\nu}) < 5 \times 10^{-10}$

[ALEPH, EPJ C2 (1998) 395]

From primordial nucleosynthesis: $\mathcal{B}(\pi^0 \to \nu\bar{\nu}) < 3 \times 10^{-13}$

[Lam, Ng, PRD44 (1991) 3345; see also Natale, PLB258 (1991) 227]

Possible BR enhancement due to NP with RH neutrino states

Direct experimental limit: **BR<2.7×10^{-7}**,
by-product of the BNL **$K^+\to\pi^+\nu\bar{\nu}$** analysis *[PRD72 (2005) 091102]*

NA62 experimental signature is similar to **$K^+\to\pi^+\nu\bar{\nu}$**.
The limit can be improved to **BR~10^{-10}**.

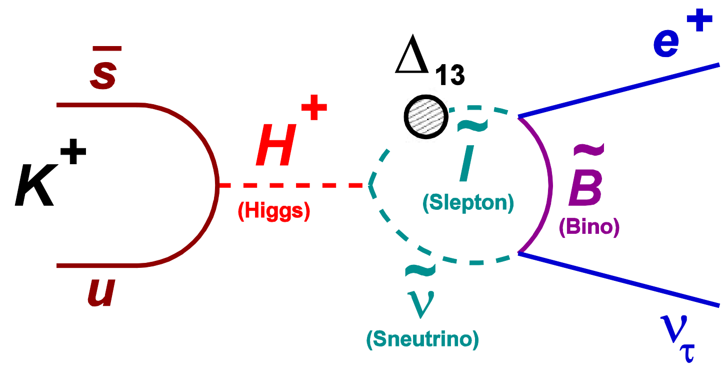
Selected recent results, ongoing analyses

$R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$ beyond the SM

2HDM - tree level

$K^{\pm} \to l^{\pm}\nu$ can proceed via charged Higgs $H^{\pm}$ (in addition to $W^{\pm}$) exchange

→ Does not affect the ratio R_K



2HDM - one-loop level

Dominant contribution to R_K: $H^{\pm}$ mediated LFV (rather than LFC) with emission of ν_τ

→ R_K enhancement can be experimentally accessible

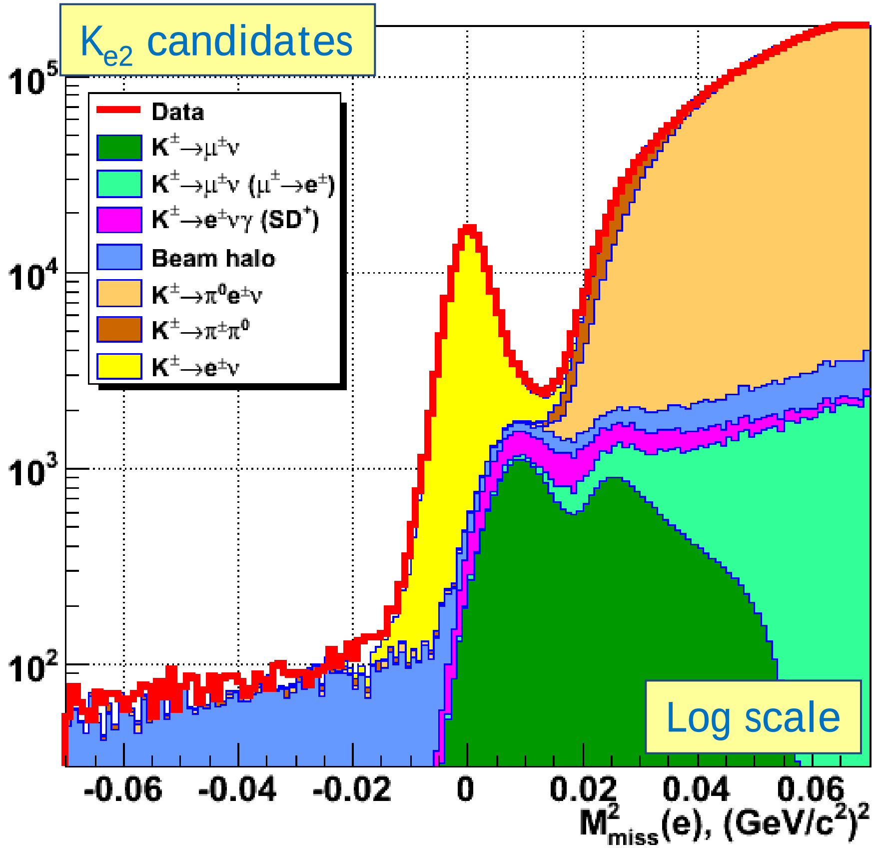
Masiero, Paradisi and Petronzio, PRD 74 (2006) 011701, JHEP 0811 (2008) 042

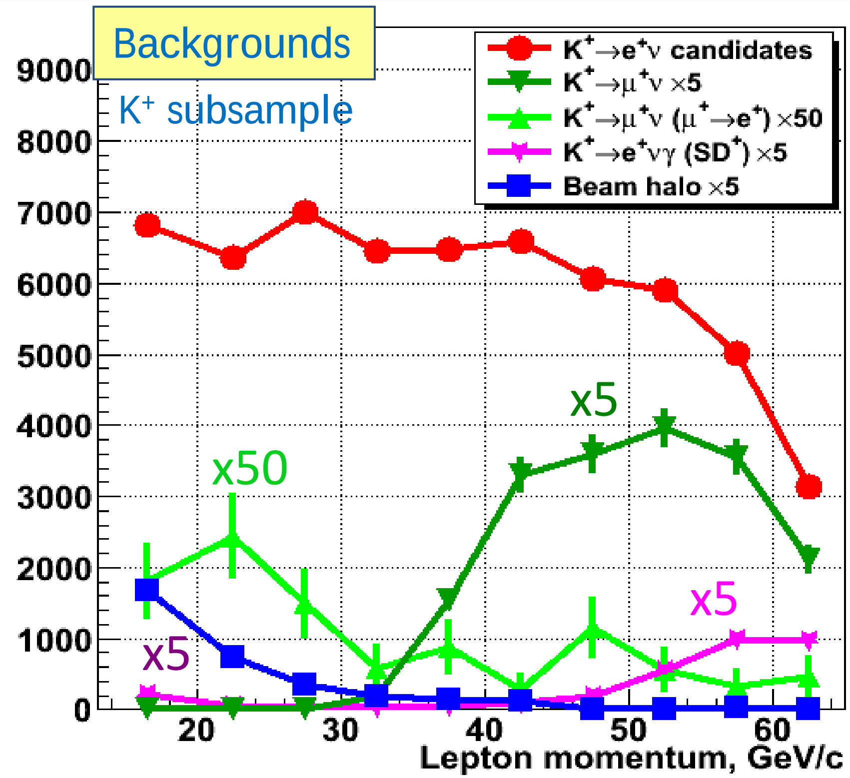
$$R_K^{LFV} \approx R_K^{SM}\left[1 + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2 \tan^6\beta\right]$$

⟹ sensitive to slepton mixing

- MSSM: **~1%** effect possible
  Girrbach and Nierste, arXiv:1202.4906
- However limited by the recent $B_{(S)} \to \mu^+\mu^-$ measurements
  Fonseca, Romão and Teixeira, EPJC 72 (2012) 2228
- Sensitive to SM extensions with 4th generation, sterile neutrinos
  Lacker and Menzel, JHEP 1007 (2010) 006; Abada et al., JHEP 1302 (2013) 048

NA62-R_K data: K_{e2} sample





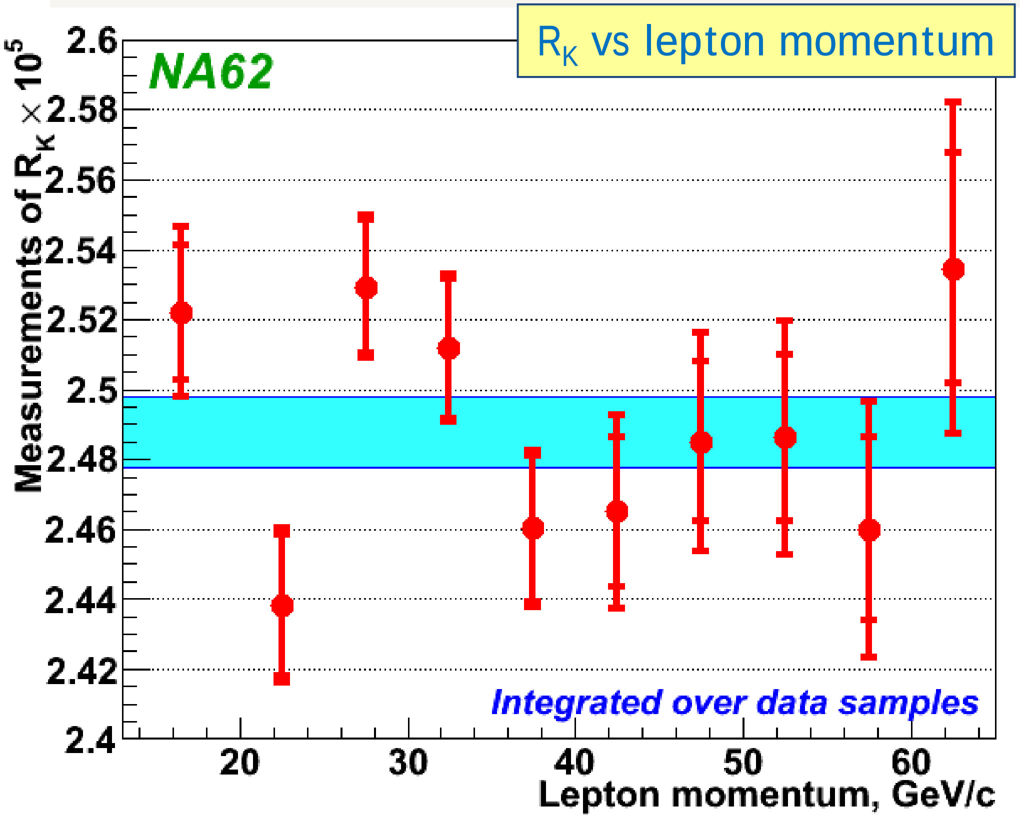
145,958 $K^\pm \to e^\pm \nu$ candidates.
Background: $B/(S+B)=(10.95\pm0.27)\%$.
Electron ID efficiency: $(99.28\pm0.05)\%$.

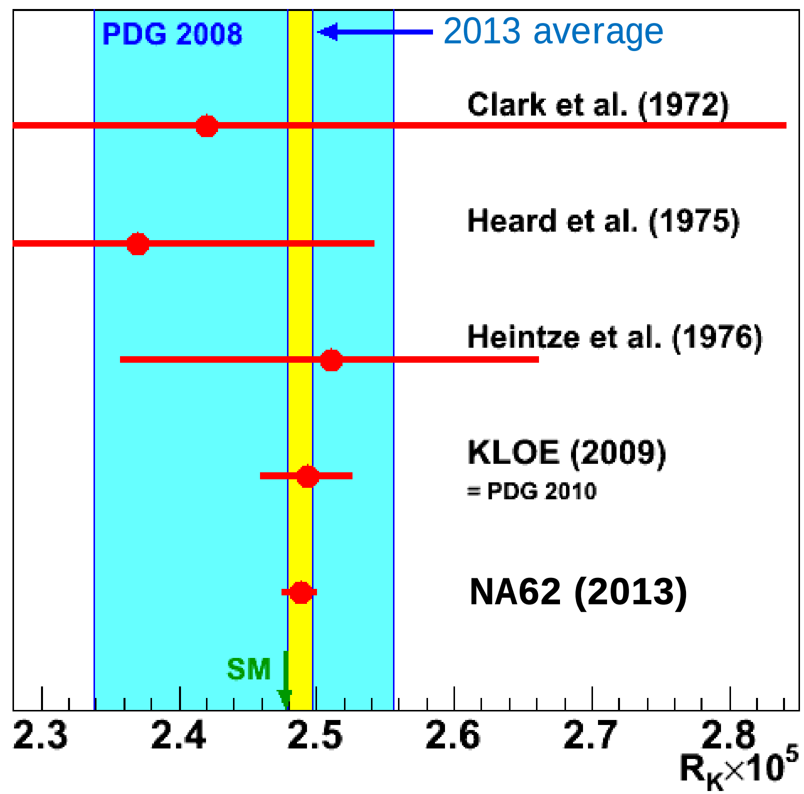
Source	B/(S+B)
$K_{\mu 2}$	$(5.64\pm0.20)\%$
$K_{\mu 2}$ $(\mu \to e)$	$(0.26\pm0.03)\%$
$K_{e2\gamma}$ (SD)	$(2.60\pm0.11)\%$
$K_{e3(D)}$	$(0.18\pm0.09)\%$
$K_{2\pi(D)}$	$(0.12\pm0.06)\%$
Opposite sign K	$(0.04\pm0.02)\%$
Beam halo	$(2.11\pm0.09)\%$
Total	$(10.95\pm0.27)\%$

NA62-R_K final result

PLB 719 (2013) 326

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$$
$$= (2.488 \pm 0.010) \times 10^{-5}$$

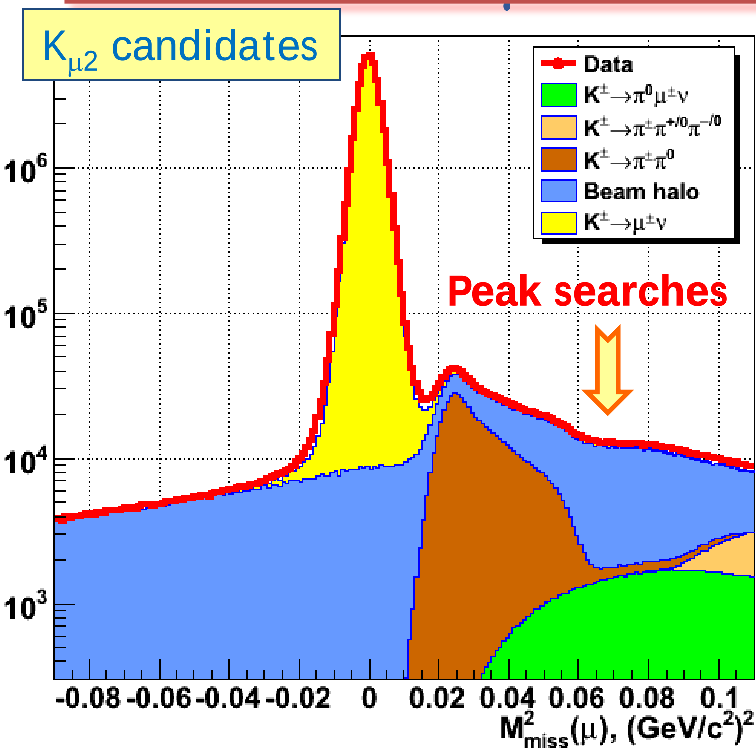


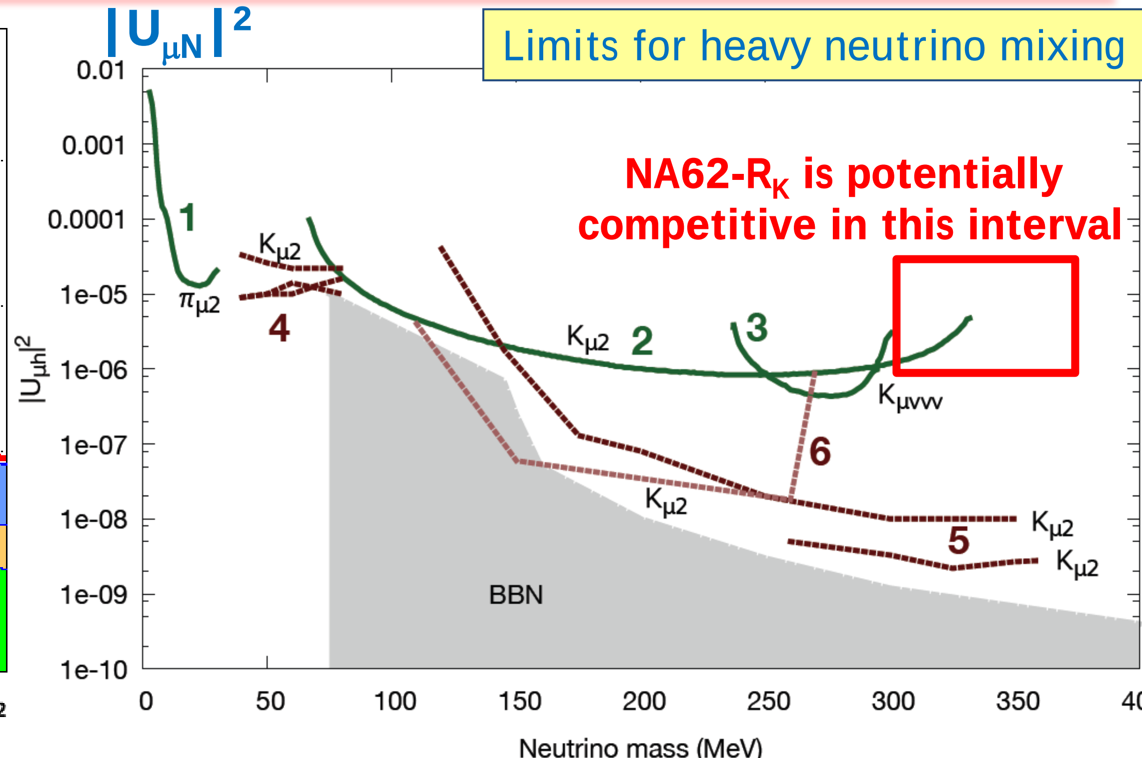


World average	$R_K \times 10^5$	Precision
PDG 2008	2.447±0.109	4.5%
2013	2.488±0.009	0.4%

NA62 prospects:
improve the uncertainty
by a factor ~2

$K_{\mu 2}$: heavy sterile neutrinos





NA62-R_K subsample: 18.0M $K^+ \to \mu^+ \nu_\mu$.

→ Search for heavy sterile neutrino: $K^+ \to \mu^+ N$.

- ❖ NA62-R_K UL if no backgrounds: $|U_{\mu N}|^2 < 10^{-7}$, $100\ MeV/c^2 < M_N < 380\ MeV/c^2$.
- ❖ Sensitivity is limited by background fluctuation (mainly beam halo).
- ❖ NA62-R_K is competitive at high M_N.

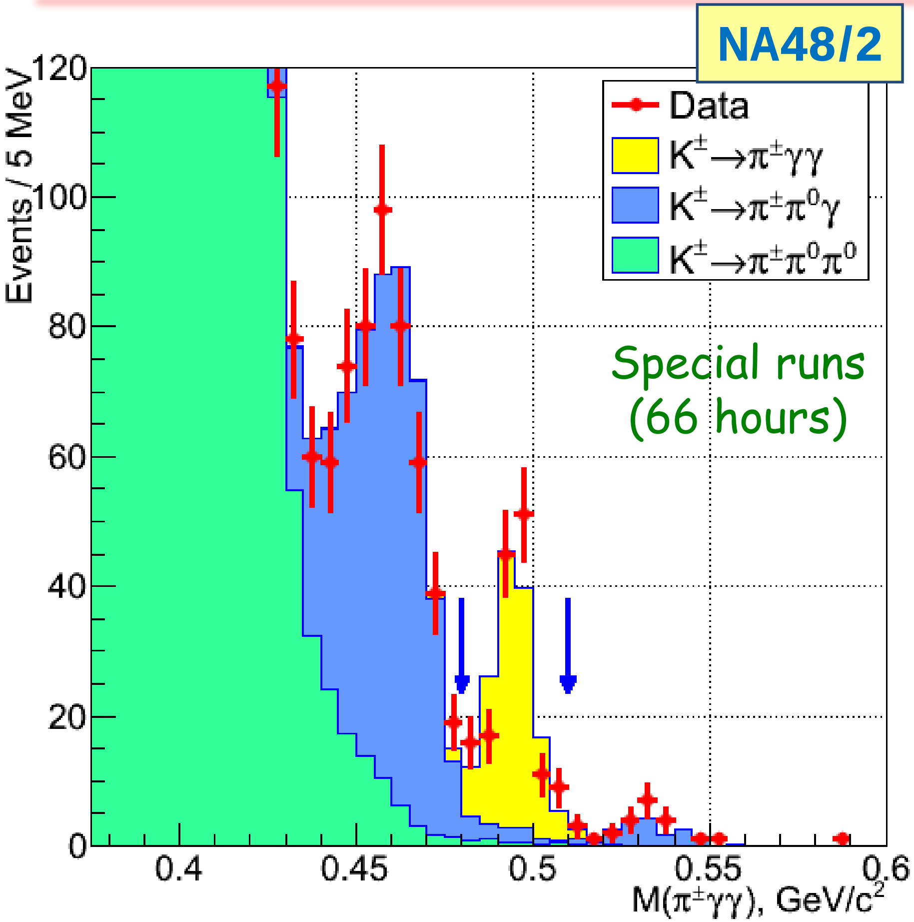
Peak searches (long-lived ν_h)

1. PSI, PLB 105 (1981) 263.
2. KEK, PRL 49 (1982) 1305.
3. LBL, PRD 8 (1973) 1989.

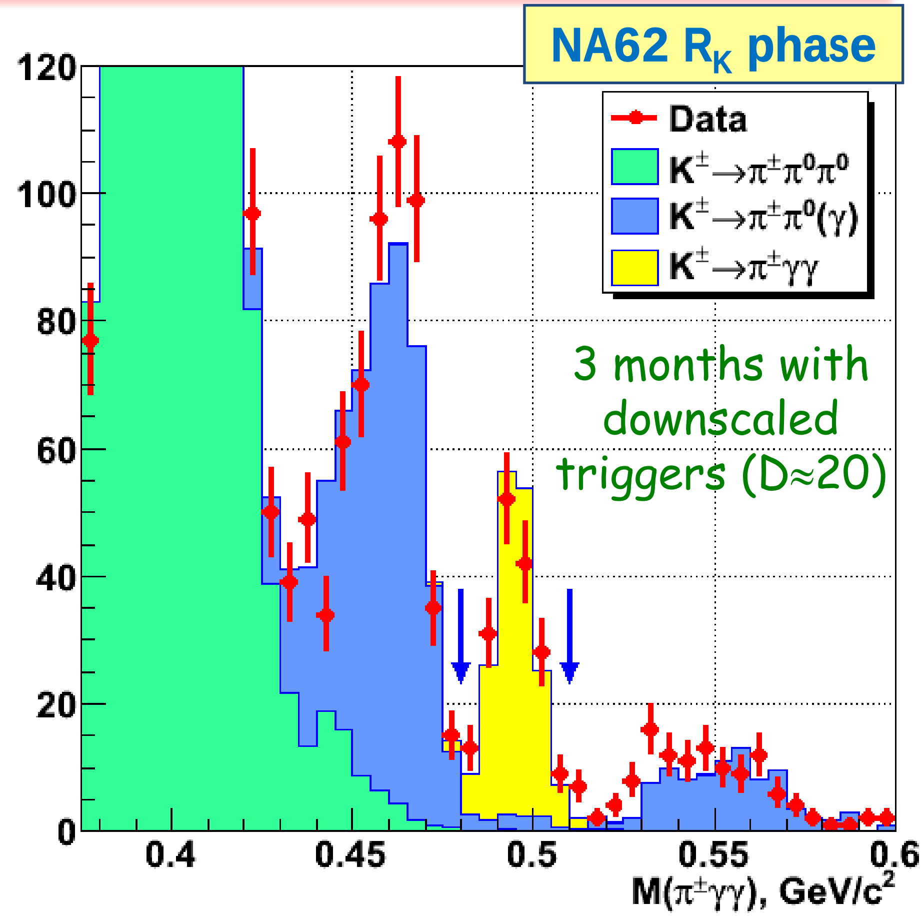
Decay searches (short-lived ν_h)

4. ISTRA+, PLB 710 (2012) 307.
5. CERN-PS191, PLB 203 (1988) 332
6. BNL-E949, preliminary

Minimum bias data: $K^{\pm}\to\pi^{\pm}\gamma\gamma$

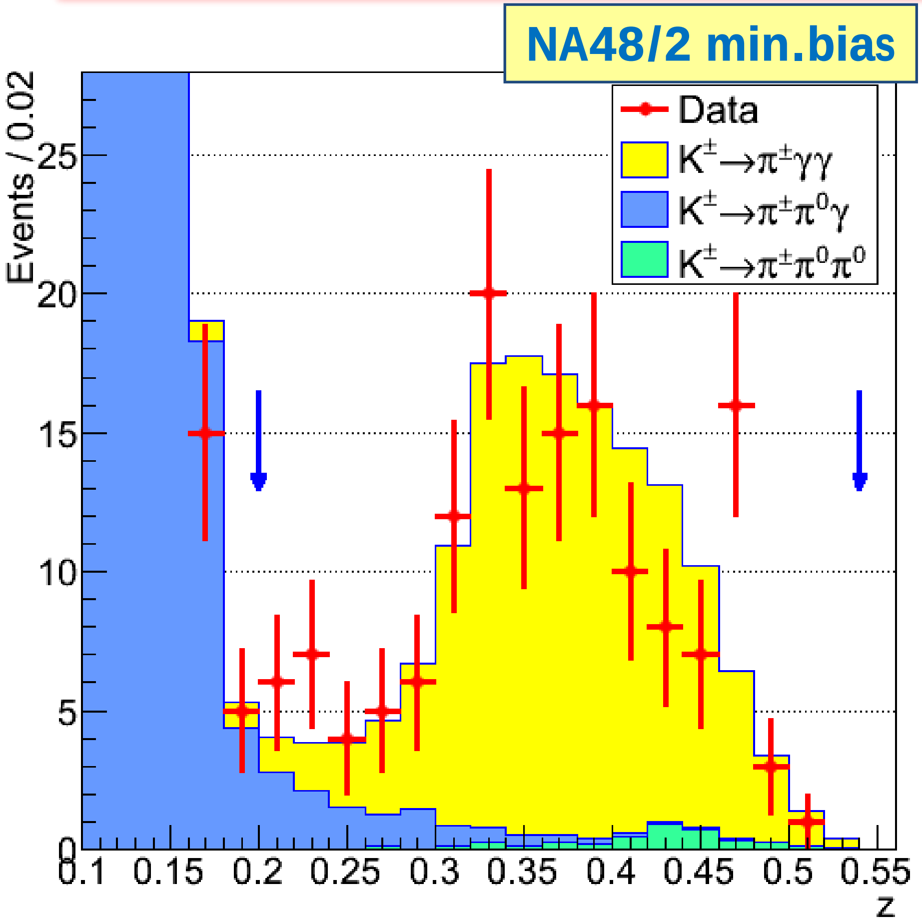


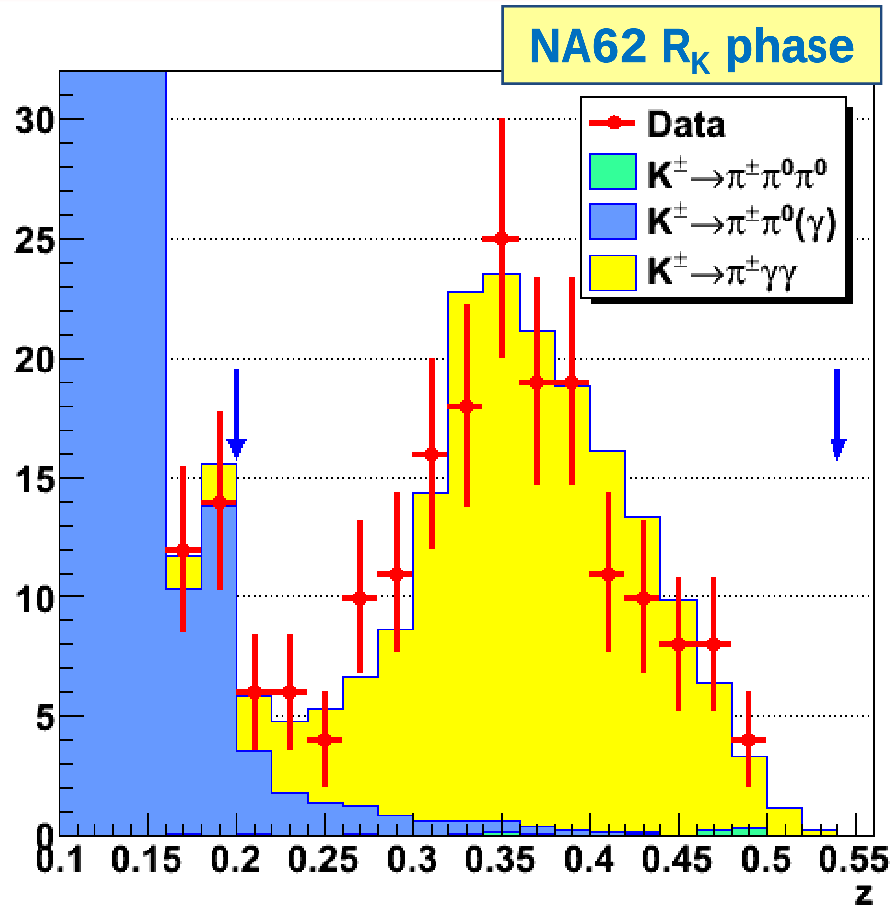
$K_{\pi\gamma\gamma}$ candidates	149
$K_{2\pi(\gamma)}$ background	11.4±0.6
$K_{3\pi}$ background	4.1±0.4
$K_{\pi\gamma\gamma}$ signal	134±12



$K_{\pi\gamma\gamma}$ candidates	175
$K_{2\pi(\gamma)}$ background	11.1±1.0
$K_{3\pi}$ background	1.3±0.3
$K_{\pi\gamma\gamma}$ signal	163±13

Fits to ChPT description





→ Data support the ChPT prediction: cusp at di-pion threshold

NA48/2 final result: $\mathbf{BR_{MI}(z>0.2) = (0.877 \pm 0.087_{stat} \pm 0.017_{syst}) \times 10^{-6}}$

Measurement of the ChPT parameters: publications in preparation

Summary

❖ **NA48/2** (2003–2004): a multi-purpose $K^{\pm}$ experiment.

- ✓ $K^{\pm}$ physics at a new precision level (15 PL, EPJ papers so far);
- ✓ $K^{\pm}$ and π^0 rare decay analyses are on-going.

❖ **NA62-R_K** (2007–2008): minimum bias electron trigger.

- ✓ Lepton Universality test at record **0.4%** precision:
  $\mathbf{BR(K^{\pm}\to e^{\pm}\nu)/BR(K^{\pm}\to\mu^{\pm}\nu) = (2.488\pm0.010)\times10^{-5}}$;
- ✓ rare decays, heavy neutrinos: analyses on-going.

❖ **NA62** (construction/commissioning).

- ✓ expected single event sensitivity for K^+ decays: $\mathbf{\sim10^{-12}}$;
- ✓ preparing for the physics run in 2014 (low intensity);
- ✓ a diverse physics programme is taking shape;
- ✓ friends and competitors worldwide (including J-PARC, FNAL).