Kaon decays: recent results and prospects

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PHYSICS IN COLLISION 2015

XXXV International Symposium on Physics in Collision

University of Warwick, Coventry, UK | September 15-19, 2015

UNIVERSITY OF BIRMINGHAM

European Research Council

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Kaons: “old” laboratory for New Physics

Kaon physics has a long history:
for example discovery of CP violation,
first measurement of direct CP violation

NOW:

Explore New Physics beyond Standard Model
through processes suppressed/prohibited in SM
and precisely calculated in SM
Possible to reach higher mass scale than direct searches

Study flavour structure beyond SM
Complimentary to other flavour physics programs

Dark Photon

$K \to \pi\nu\nu$

Symmetry violations

Where and Who

CERN
LHCb, NA48/NA62

LNF
KLOE,KLOE-2

KEK/JPARC
KOTO, TREK

Dark Photon

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**.

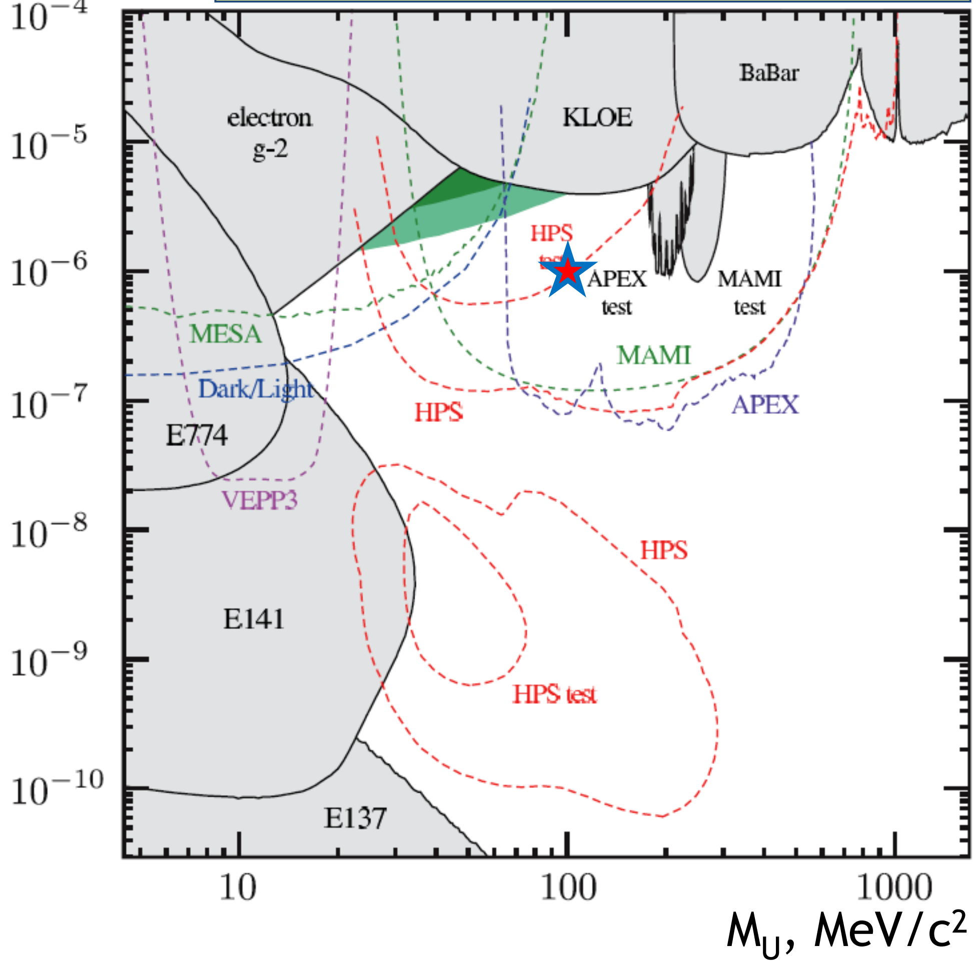
Possible parameters:
mixing parameter: $\varepsilon^2 \sim (\alpha/\pi)^2 \sim 10^{-6}$,
DP mass: $M_U \sim \varepsilon M_Z \sim 100$ MeV/c^2.

Possible explanations for:

Positron excess in cosmic rays (PAMELA, FERMI, AMS-02) by dark matter annihilation

Muon g-2 anomaly

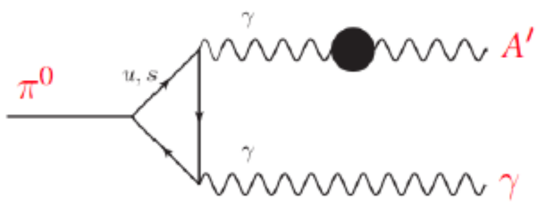
Experimental exclusion plot



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

DP production in π^0 decays

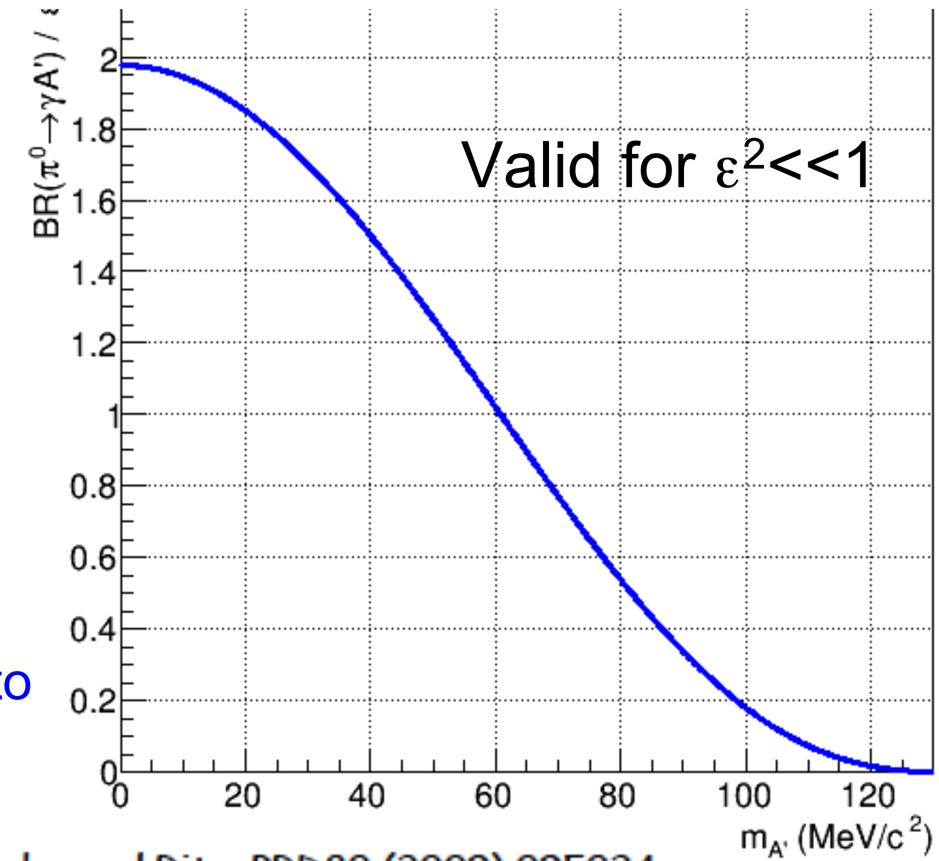
$$B(\pi^0 \to \gamma A') = 2\varepsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 B(\pi^0 \to \gamma\gamma)$$



Two unknown parameters:
mass ($m_{A'}$) and mixing (ε^2)

Sensitivity for $m_{A'} < m_{\pi 0}$

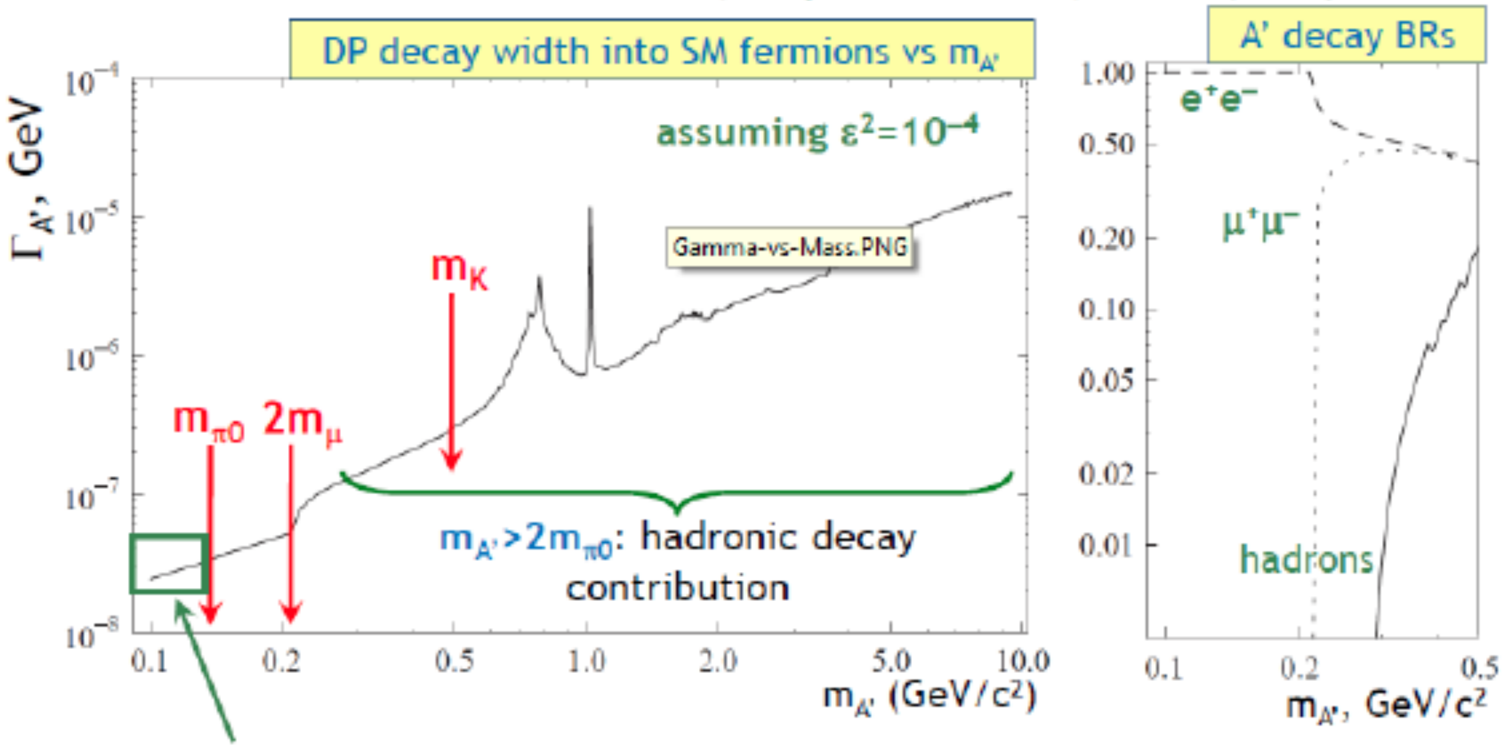
Low sensitivity for near mass, due to kinematic suppression of $\pi^0 \to \gamma A'$



Batell, Pospelov and Ritz, PRD80 (2009) 095024

DP decays into SM fermions

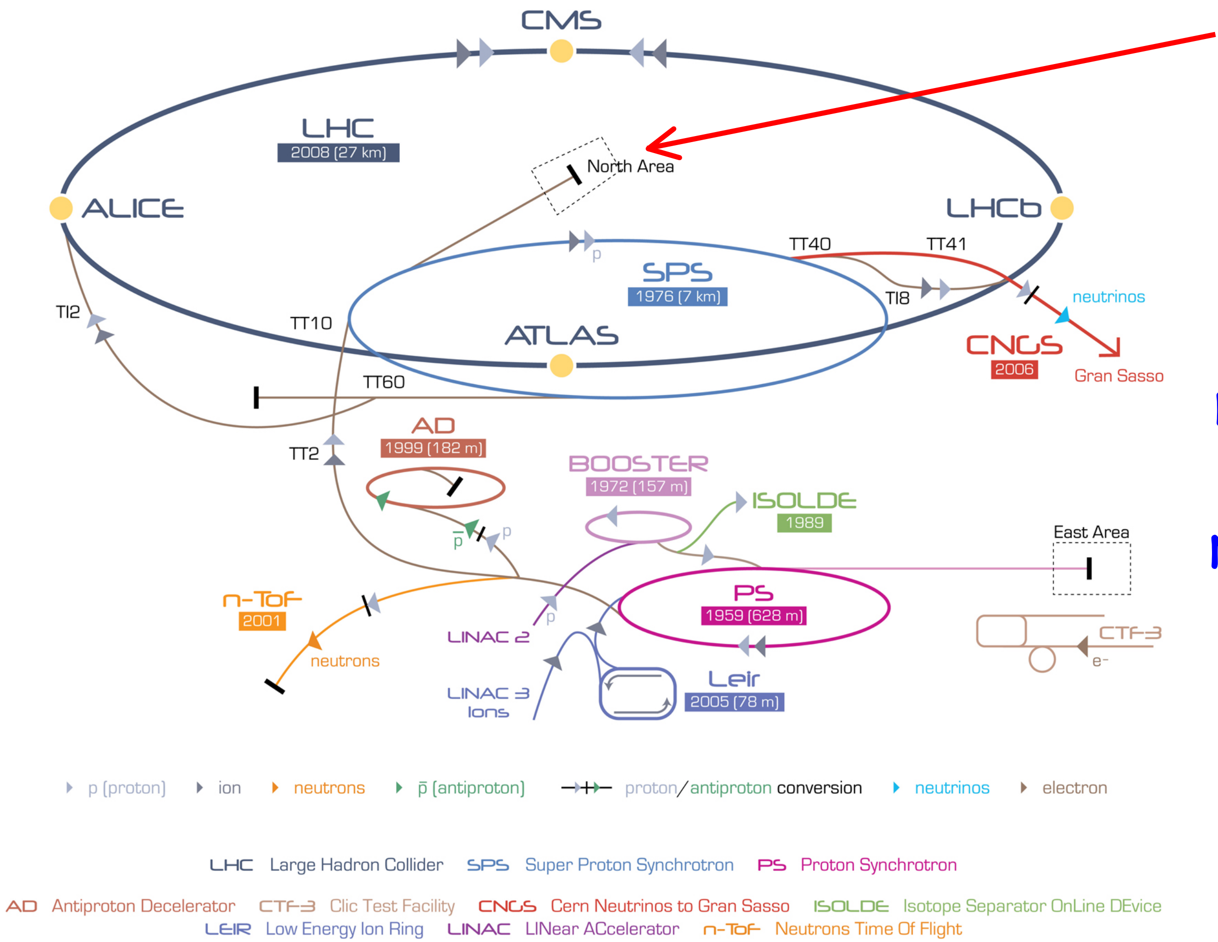
Accessible in π^0 decays: assuming decays only in SM fermions



$$\Gamma_{A'} \approx \Gamma(A' \to e^+e^-) = \frac{1}{3}\alpha\varepsilon^2 m_{A'}\sqrt{1-\frac{4m_e^2}{m_{A'}^2}}\left(1+\frac{2m_e^2}{m_{A'}^2}\right) \approx \alpha\varepsilon^2\,\frac{m_{A'}}{3}$$

Batell, Pospelov and Ritz, PRD80 (2009) 095024

The NA48/NA62 experiment



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^-**

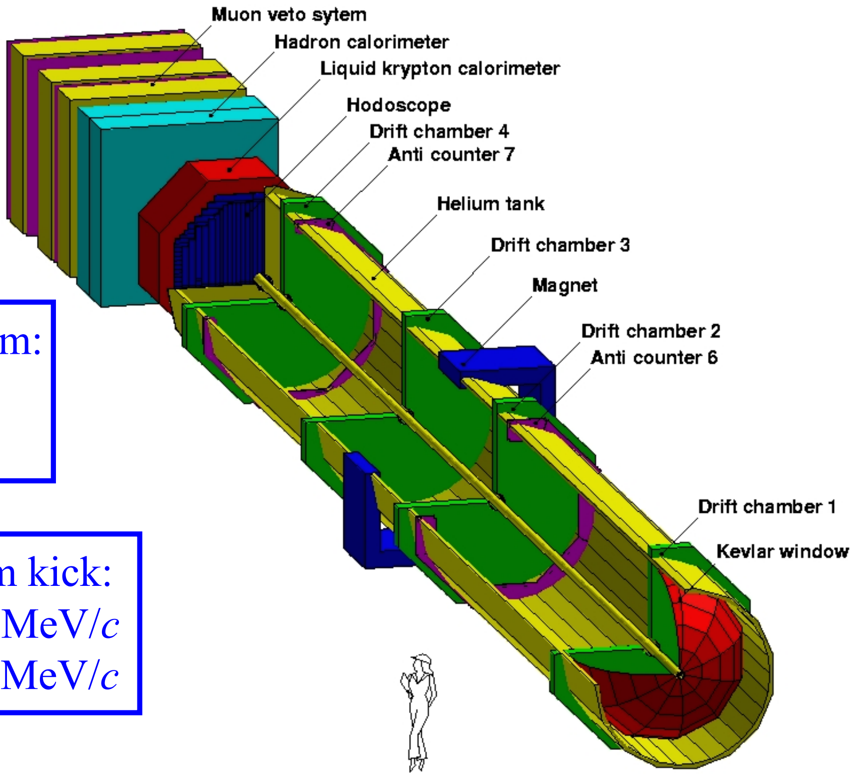
NA62 (R_K)

- **2007: $K^\pm_{e2}/K^\pm_{\mu2}$**
- **2008: $K^\pm_{e2}/K^\pm_{\mu2}$**

NA62

2007–2018: design & construction
2012-4: commissioning
2015-8: physics run

NA48 and NA62-R_K Detector



Magnetic spectrometer:
$\sigma_p/p = (1.0 \oplus 0.044\ p)\%$ [GeV/c] 2004
$\sigma_p/p = (0.48 \oplus 0.009\ p)\%$ [GeV/c] 2007

Beam Momentum:
2004: 60 GeV/c
2007: 74 GeV/c

Trigger Hodoscope:
σ_t=150ps

Momentum kick:
2004: 120 MeV/c
2007: 265 MeV/c

LKr electromagnetic calorimeter:
$\sigma_E/E = (3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42)\%$
(E in GeV)
$\sigma_x = \sigma_y \sim 1.5$mm for E=10 GeV
$\sigma(M_{\pi\pi^0\pi^0}) = 1.4$ MeV/c^2
E/p ratio used for e/π discrimination

- ~100 m long decay region in vacuum
- Similar acceptance between K^+ and K^- beams checked reversing magnetic fields
- Pion decay products, from the hadronic beam, remain into the beam pipe

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

DP lifetime and mean path

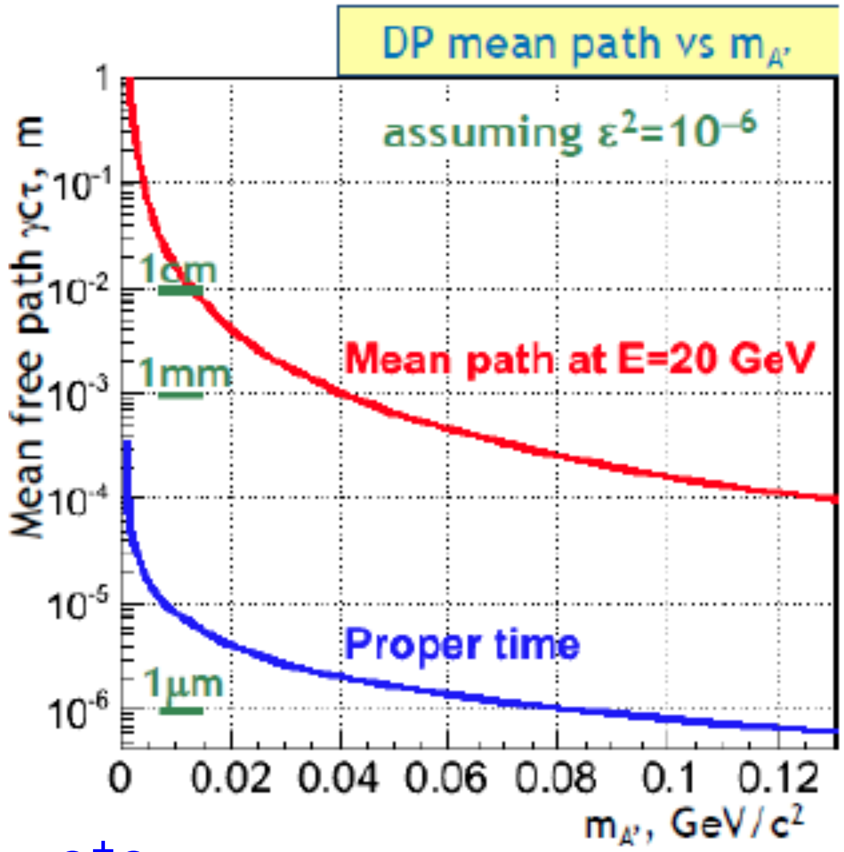
DP proper lifetime below di-muon threshold:

$$c\tau_{A'} \approx 0.8\mu m \cdot \left(\frac{10^{-6}}{\varepsilon^2}\right) \cdot \left(\frac{100 MeV}{m_{A'}}\right)$$

Mean free path at E(A')=50 GeV (maximum energy at NA48/2):

$$L_{\max} \approx 0.4 mm \cdot \left(\frac{10^{-6}}{\varepsilon^2}\right) \cdot \left(\frac{100 MeV}{m_{A'}}\right)^2$$

Assumption of prompt decay:
for $\varepsilon^2 > 10^{-7}$ and $m_{A'} > 10$ MeV
DP path is smaller than resolution on vertex longitudinal coordinate



Signature identical to $\pi^0_D \to \gamma\, e^+e^-$

Batell, Pospelov and Ritz, PRD80 (2009) 095024

Data Sample

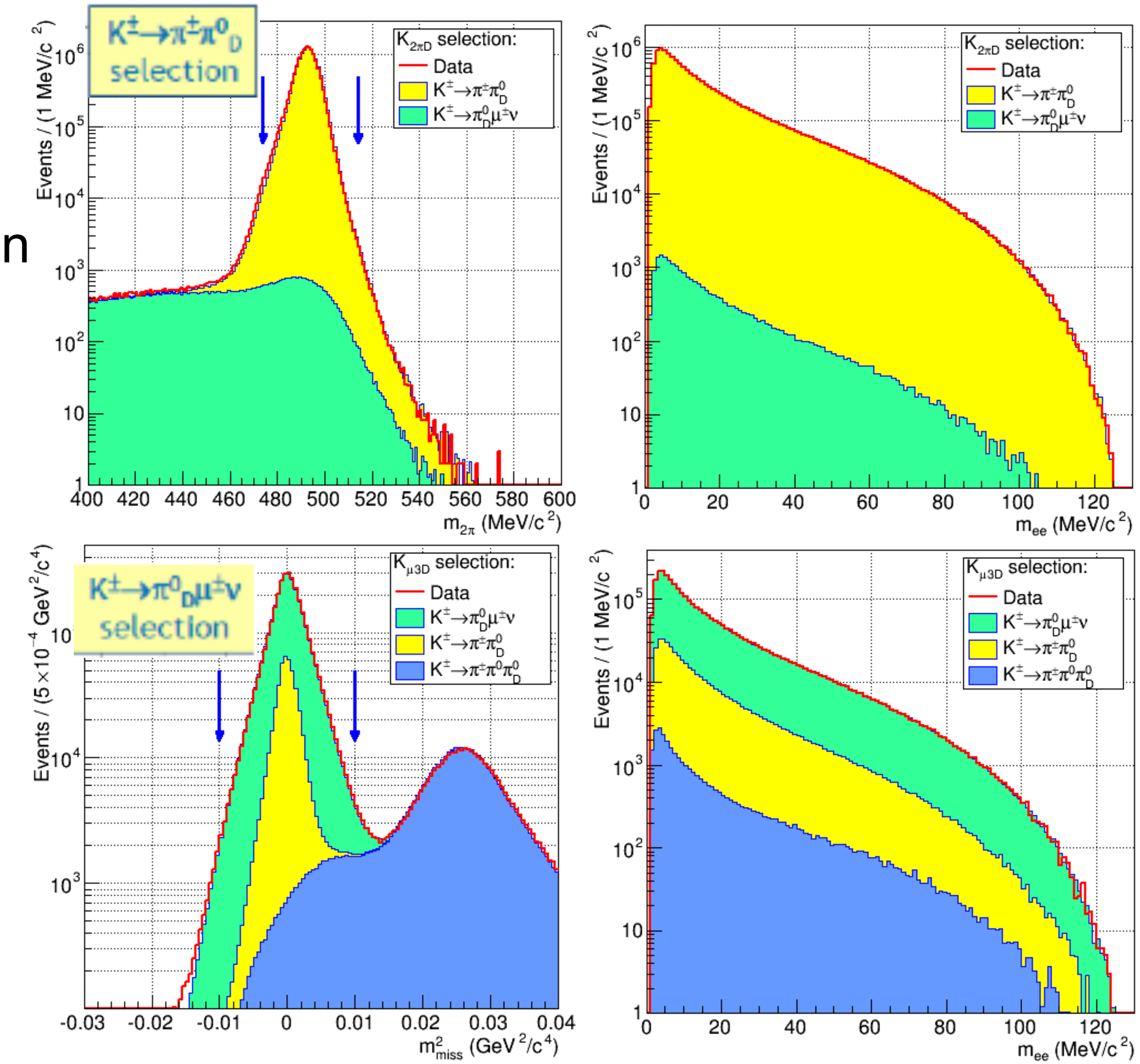
$(1.57 \pm 0.05) 10^{11}$ kaon decays in fiducial volume

$1.7\ 10^7\ \pi^0$ with negligible mean free path

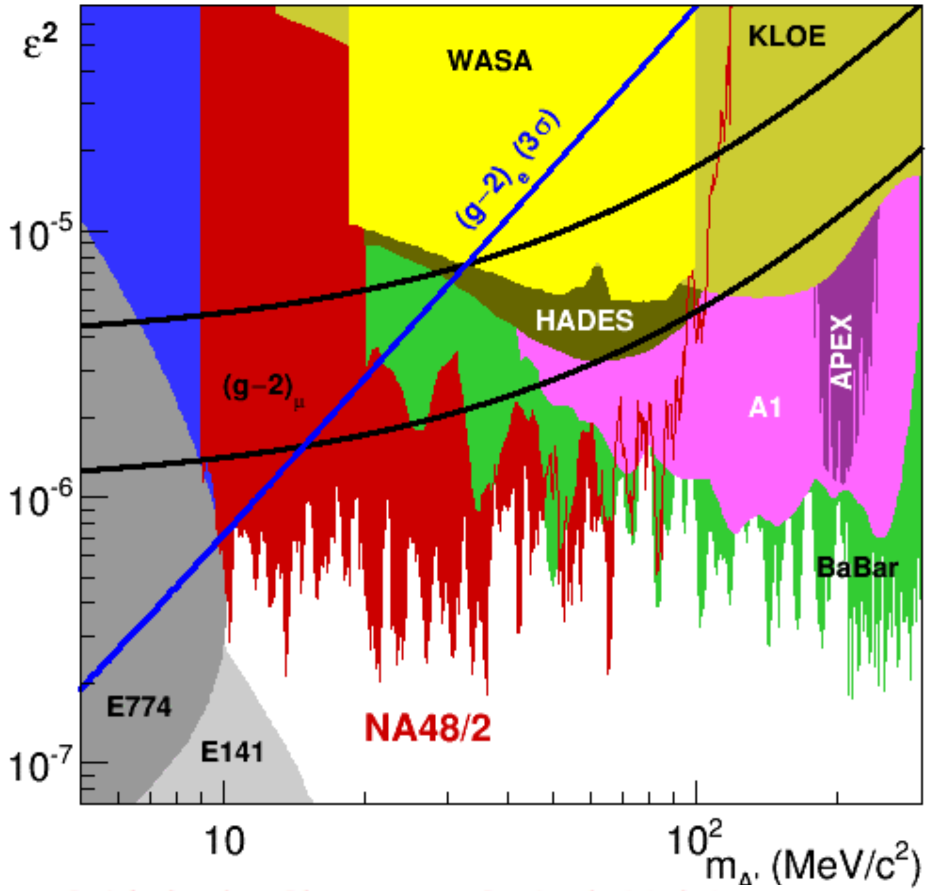
Search for prompt decay chain
$\pi^0 \rightarrow \gamma A' \rightarrow \gamma e^+e^-$
and narrow peak in e+e- mass spectrum
excellent mass resolution
$\sigma_m \sim 0.011\ m_{ee}$

Acceptance depending on $m_{A'}$

Sensitivity determined by irreducible π^0_D background



Dark Photon exclusion: Final NA48/2 result



Published in Phys. Lett. B746 (2015) 178
Numerical UL data for each mass hypothesis available on HepData:
http://hepdata.cedar.ac.uk/view/ins1357601

Improvements on existing limits for 9-70 MeV/c^2

Most stringent limits at low mA'
(weak kinematic suppression)

Sensitivity limited by irreducible π^0_D background
(UL are 2-3 order of magnitude above SES)

Modest improvement on larger samples

If DP couples to quarks and decays mainly to SM fermions, it's ruled out as explanation for anomalous $(g-2)_\mu$

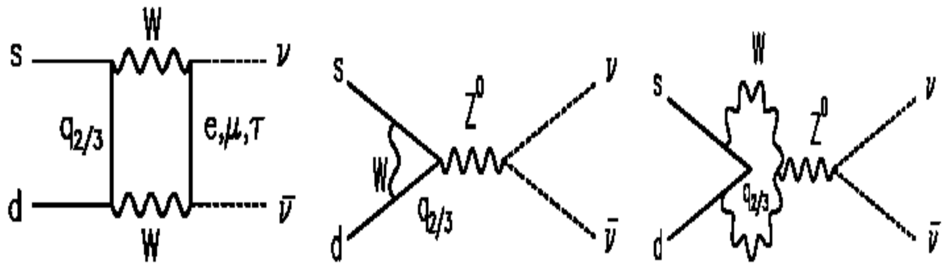
$K \rightarrow \pi\nu\nu$

Theory in the Standard Model

- **FCNC loop processes**
- **SM precision surpasses any other**

FCNC process involving quarks

- **Short distance dynamics dominated**



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$

$$x(q) \equiv \frac{m_q^2}{m_W^2}$$

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

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

Charm contribution

Top contribution

Theoretically clean, sensitive to new physics, almost unexplored

$$\boxed{\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8}$$

The Hadronic Matrix Element is measured and isospin rotated

Mode	$BR_{SM} \times 10^{11}$
$K^+ \to \pi^+ \nu\nu$	9.11±0.72
$K_L \to \pi^0 \nu\nu$	3.00±0.30

[A.J. Buras, D. Buttazzo, J. Girrbach-Noe and R.Knegjens, arXiv:1503.02693]

New Physics Sensitivity

Z' gauge boson mediating FCNC at tree level

[A.J.Buras et al., JHEP 1302 (2013) 116

A.J.Buras et al. Eur. Phys. J. C74 (2014) 039]

Littlest Higgs with T-parity

[M. Blanke et al., Acta Phys. Polon. B 41 (2010) 657]

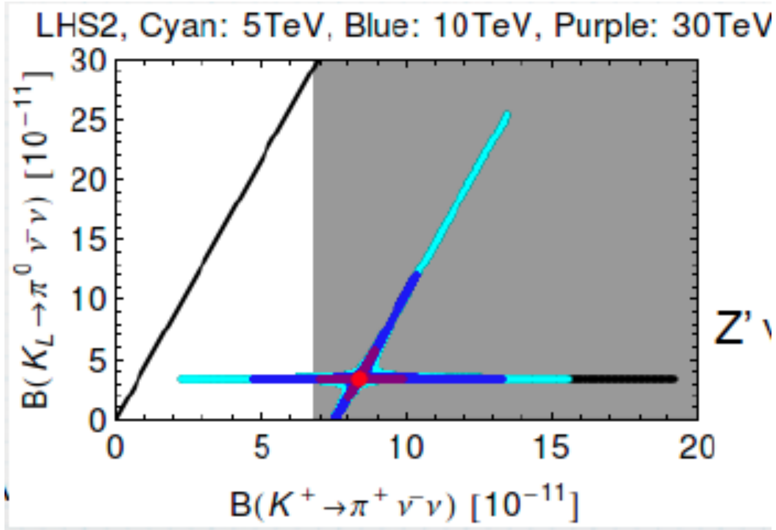
Custodial Randall-Sundrum

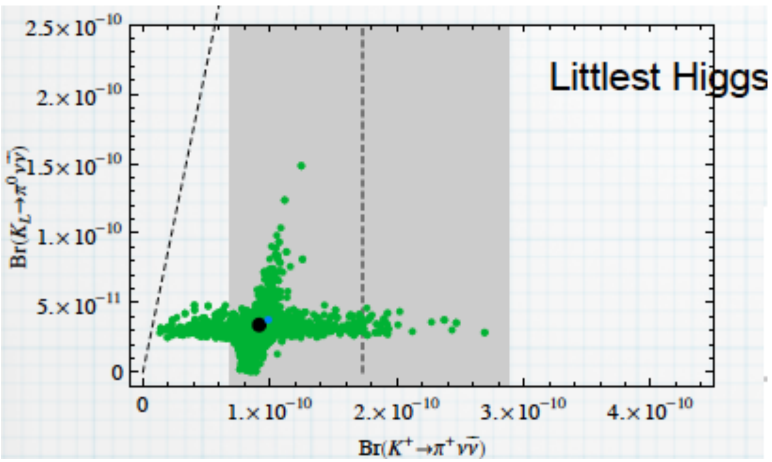
[M. Blanke et al., JHEP 0903 (2009) 108]

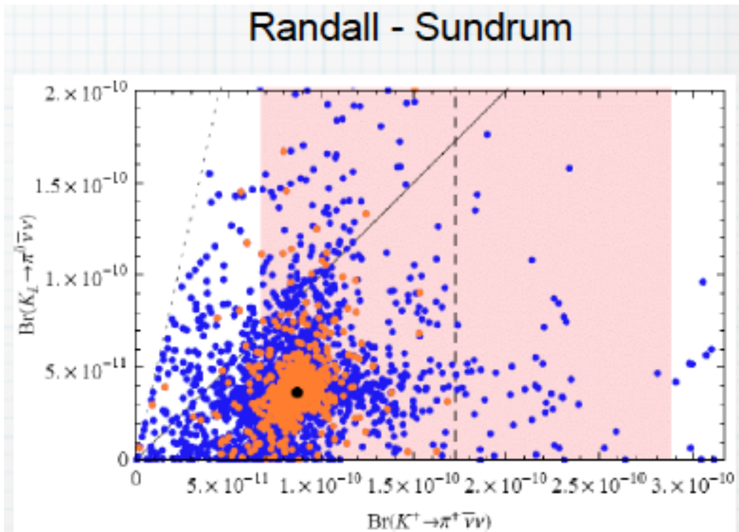
Best probe of MSSM non-MFV

(still not excluded by LHC)

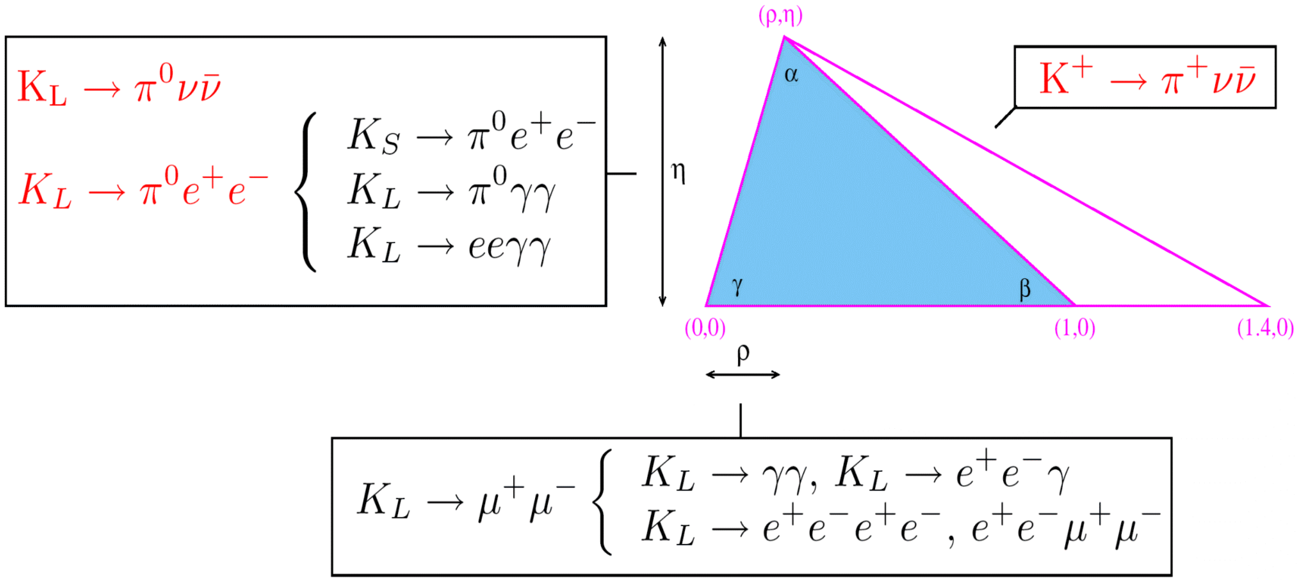
[G. Isidori et al., JHEP 0608 (2006) 088]





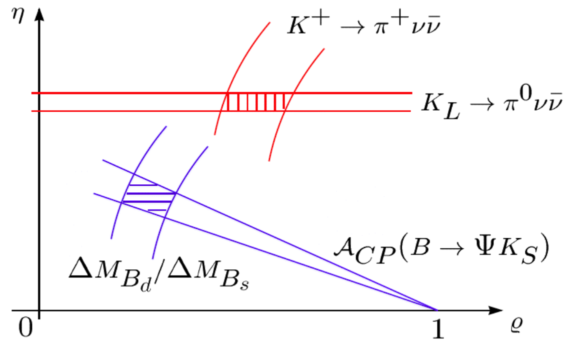


Connection with Flavour Physics



K physics alone can fully constrain the CKM unitarity triangle.

Comparison with B physics can provide description of NP flavour dynamics



Experimental status

Technique: K^+ decay at rest

Data taking: E787 (1995–98), E949 (2002)

Separated K^+ beam (710 MeV/c, 1.6MHz)

PID: range (entire $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain)

Hermetic photon veto system

1.8 x 10^{12} stopped K^+, ~0.1% signal acceptance

$$BR(K^+ \rightarrow \pi^+ \nu\nu) = 17.3^{+11.5}_{-10.5} \times 10^{-11}$$

7 observed candidates, 2.6 expected background

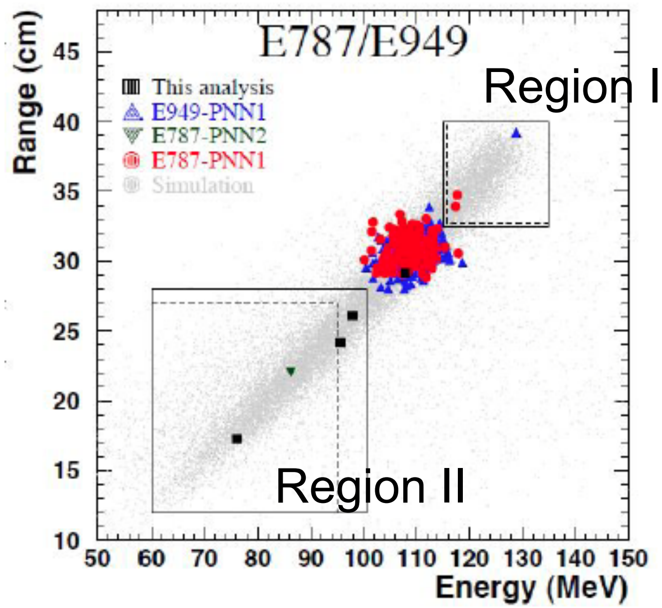
Probability that 7 observed events are all background is 10^{-3}

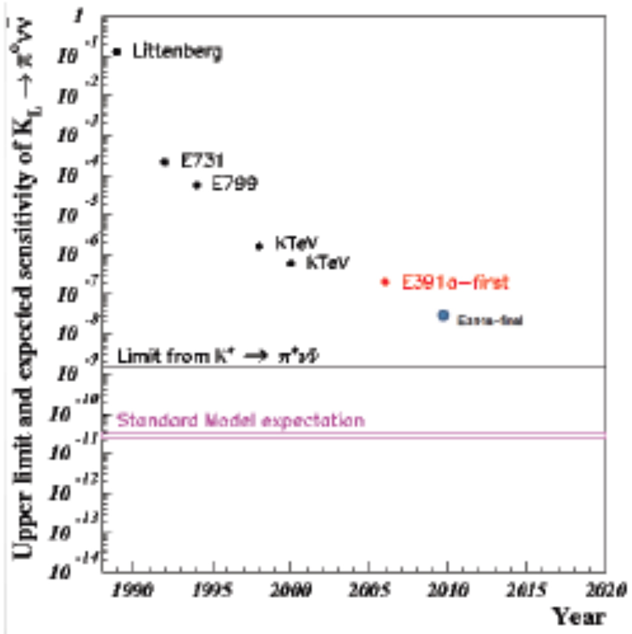
E747/E949 collaborations, Phys. Rev. D 77, 052003 (2008)

Phys. Rev. D 79, 092004 (2009)]

$$BR(K_L \rightarrow \pi^0 \nu\nu) < 2600 \times 10^{-11}$$

[E391a Collaboration , Phys. Rev. 100, 201802 (2008)]



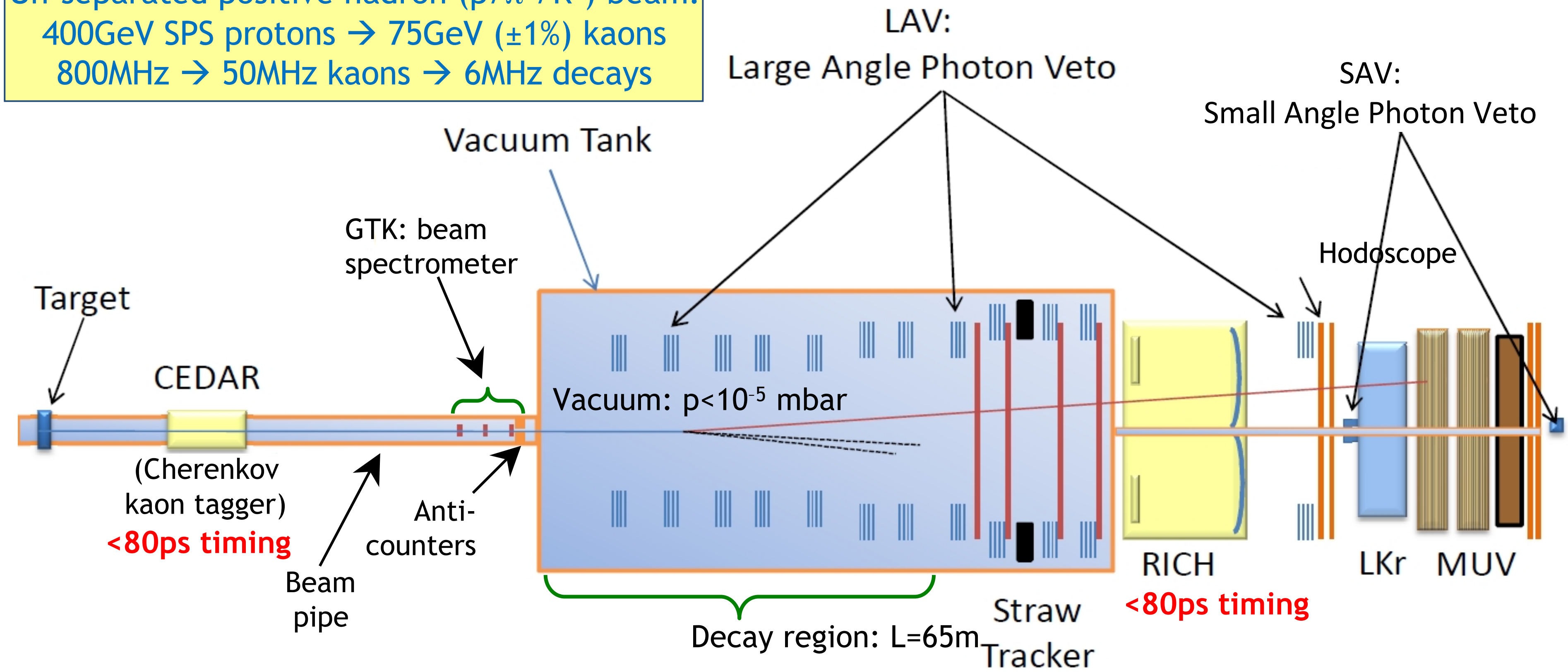


NA62 detector

Kaon decay in flight experiment
10^{13} kaons in 2 years

Total length: ~270m

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



Kinematic rejection factors (limited by beam pileup and tails of MCS):
5×10^3 for $K^+\rightarrow\pi^+\pi^0$, 1.5×10^4 for $K\rightarrow\mu^+\nu$.

Hermetic photon veto: **~10^8** suppression of **$\pi^0\rightarrow\gamma\gamma$**.

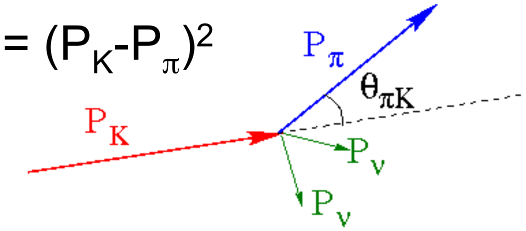
Particle ID (RICH+LKr+MUV): **~10^7** muon suppression.

The Analysis Strategy

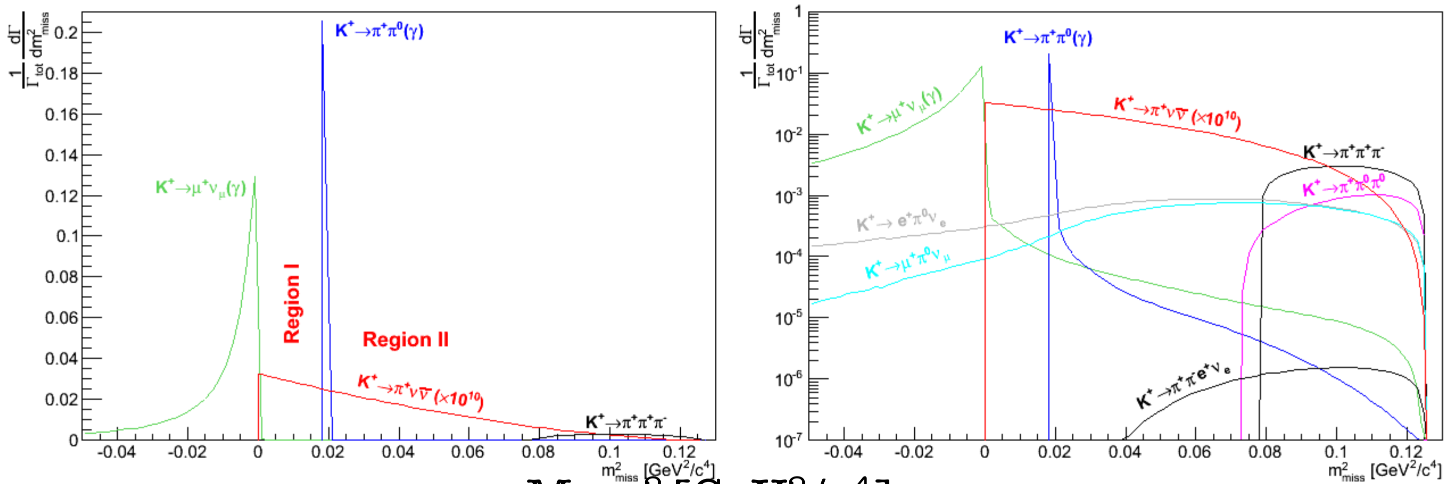
- Signal:
  - Single Pion in the final state matching a beam Kaon (timing and spatial association)

- Background suppression factors:
  - Kinematics $O(10^4\text{-}10^5)$
  - Charged Particle ID $O(10^7)$
  - γ detection $O(10^8)$
  - Timing $O(10^2)$

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



Analytical computation

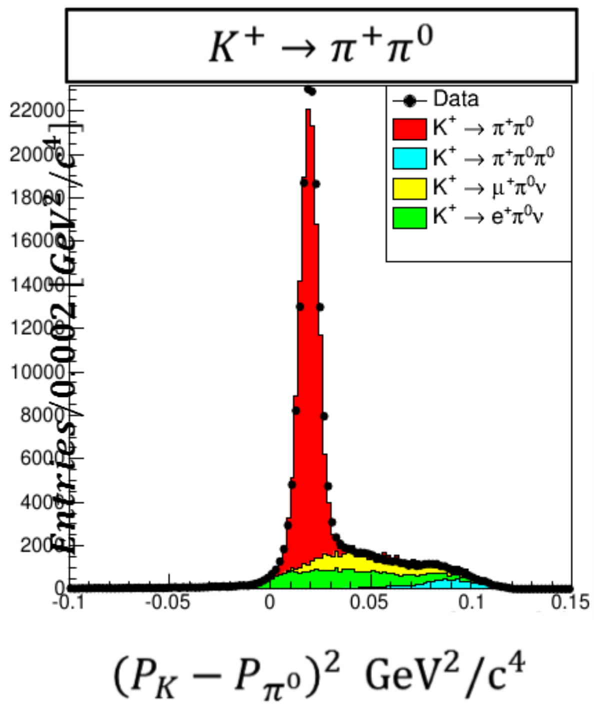


M_{miss}^2 [GeV²/c⁴]

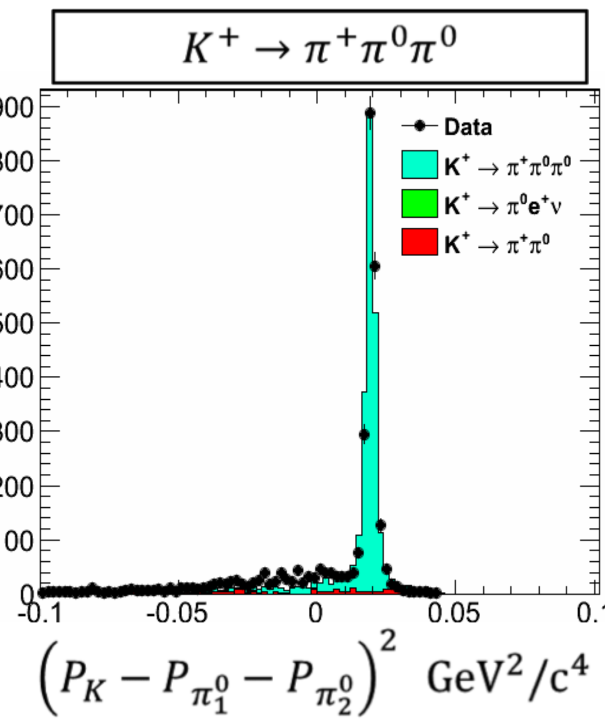
Examples of Control samples

- Kaon decay modes reconstructed with the liquid Krypton calorimeter only (from minimum bias data).
- Useful to measure the kinematic suppression factor, particle ID efficiency …

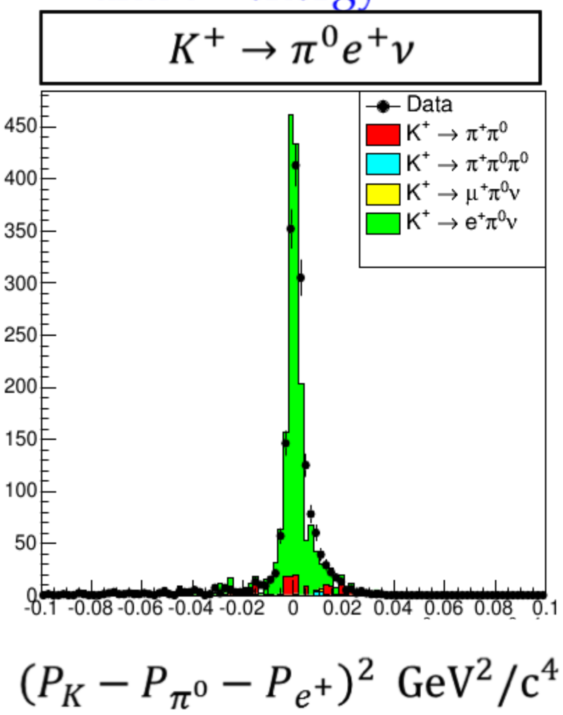
π^0 mass assumed



π^0 mass assumed

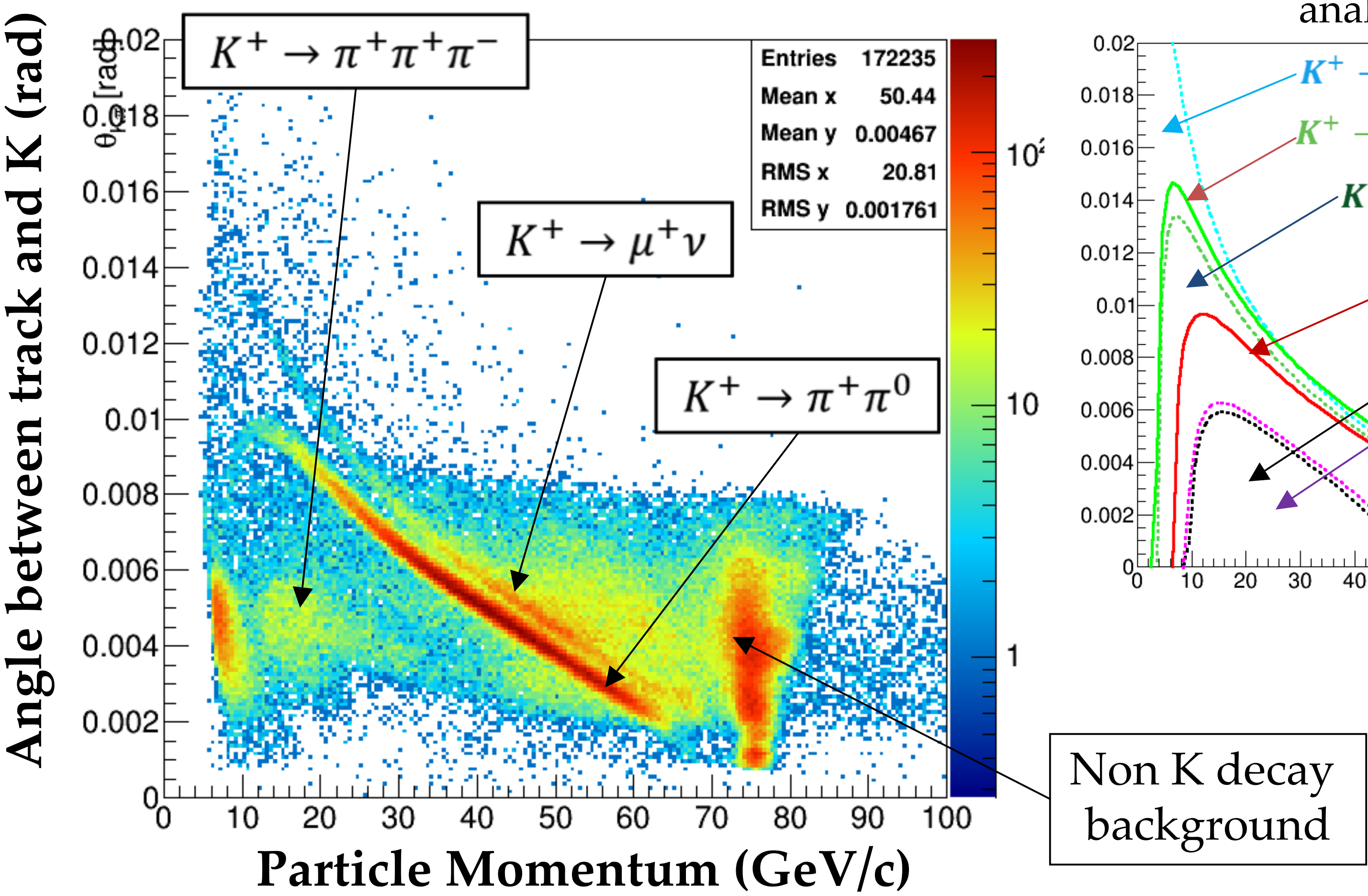


π^0 mass assumed and e^+ energy

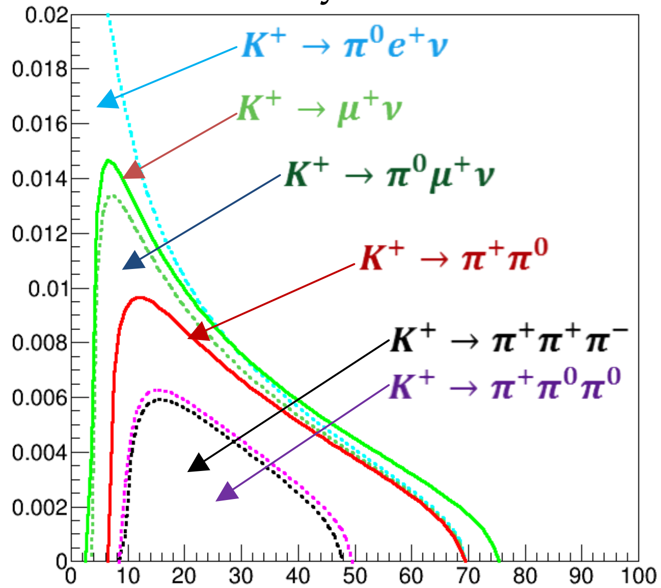


First Look at 2014 Data Quality

- Events with only 1 track in the spectrometer reconstructed (40 ns time window)
- 10^2 muon rejection at trigger level.

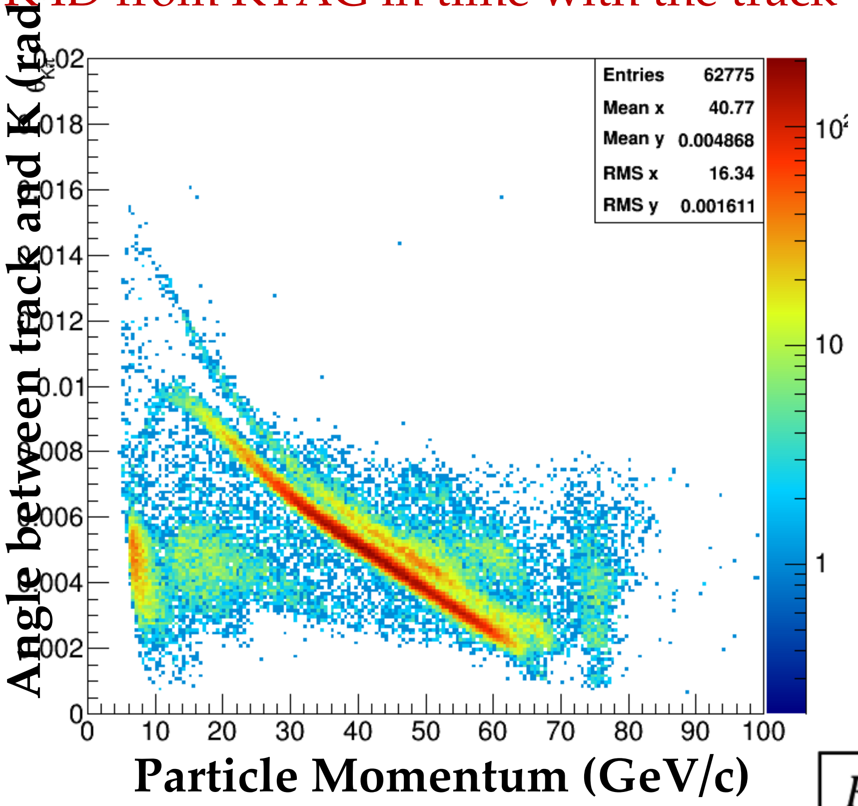


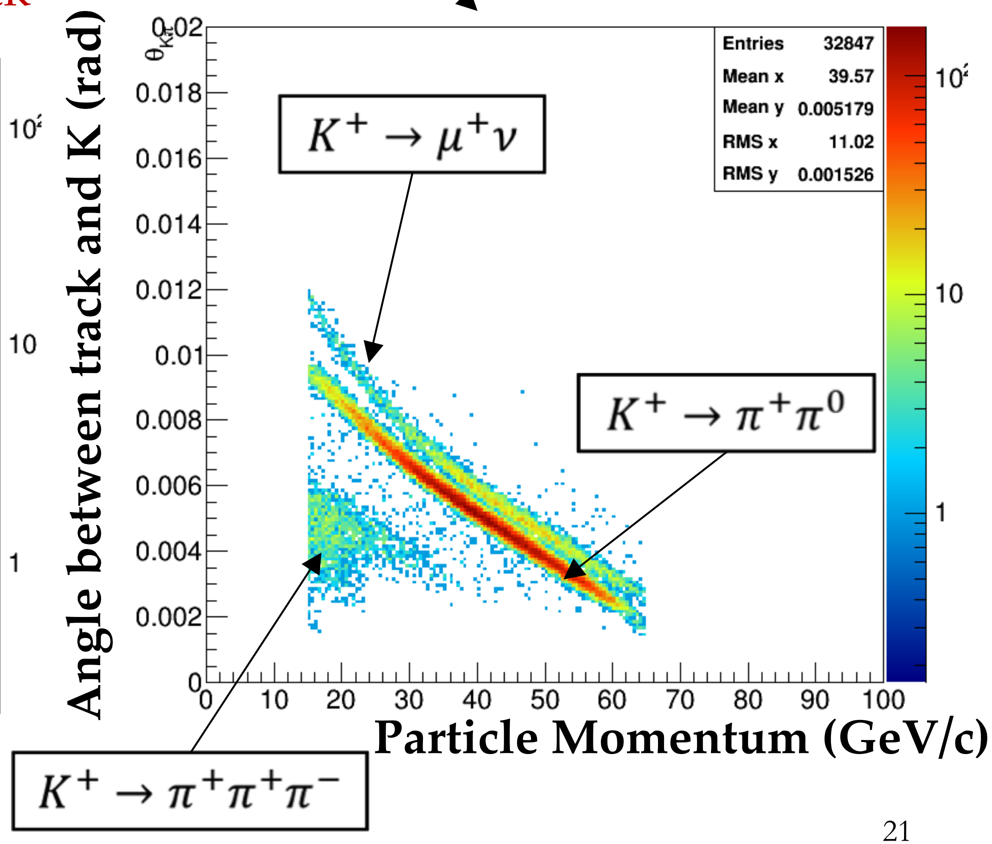
analytical contours

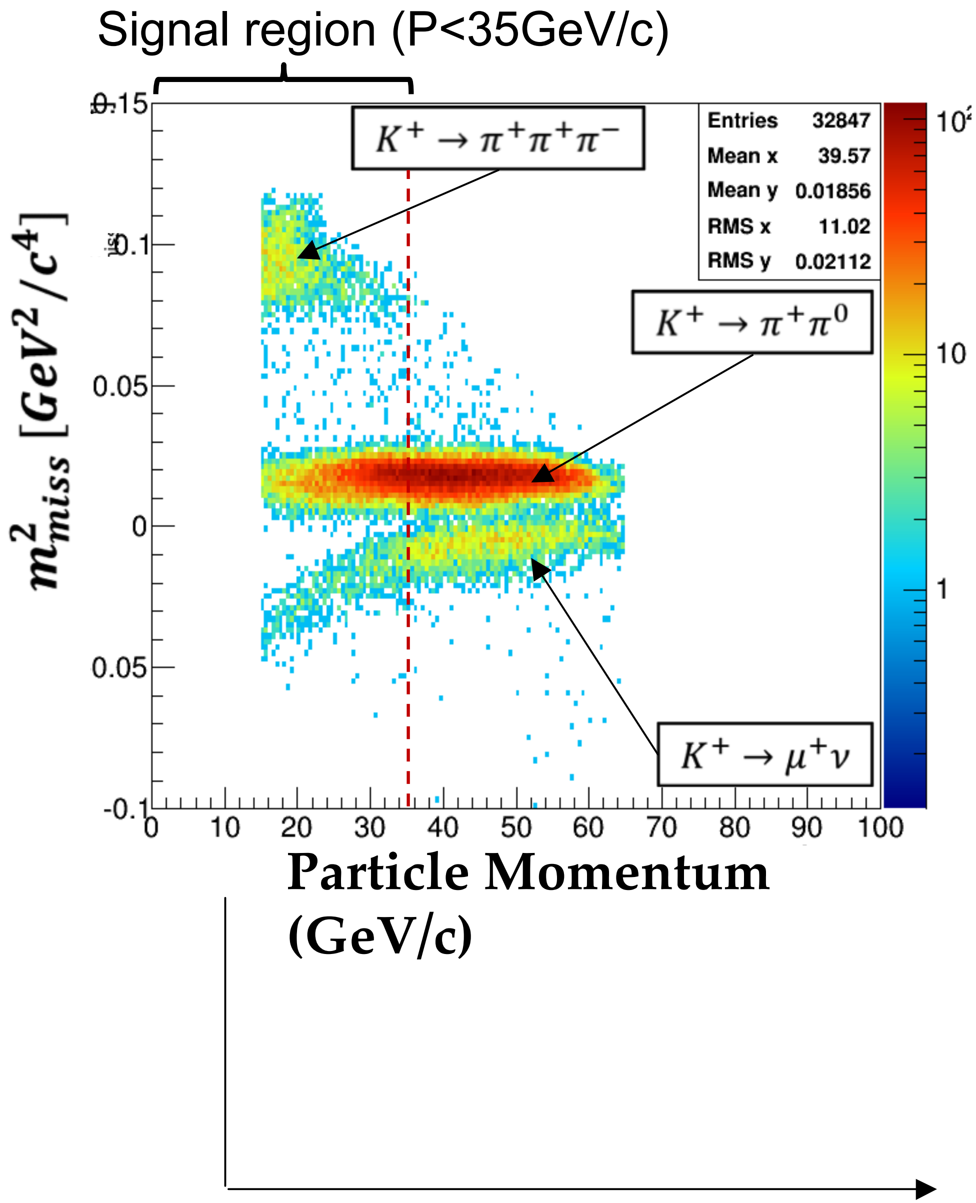


- Apply KTAG for K ID
- Use track origin to suppress the background from kaon interactions
- Decay vertex from the intersection between the track and the nominal K direction to be in fiducial decay region and momentun cut

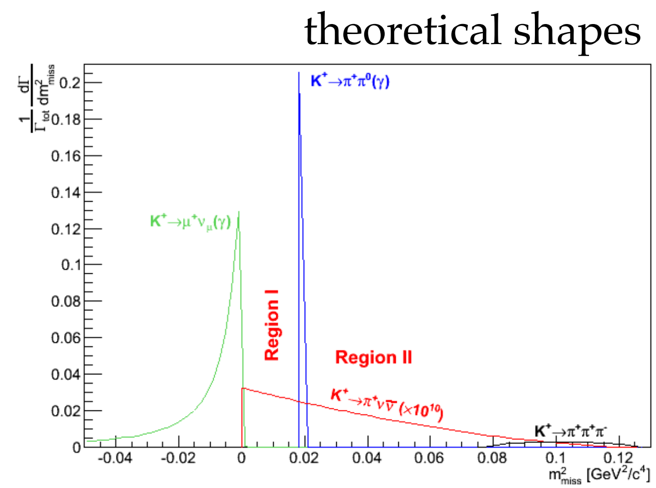
K ID from KTAG in time with the track



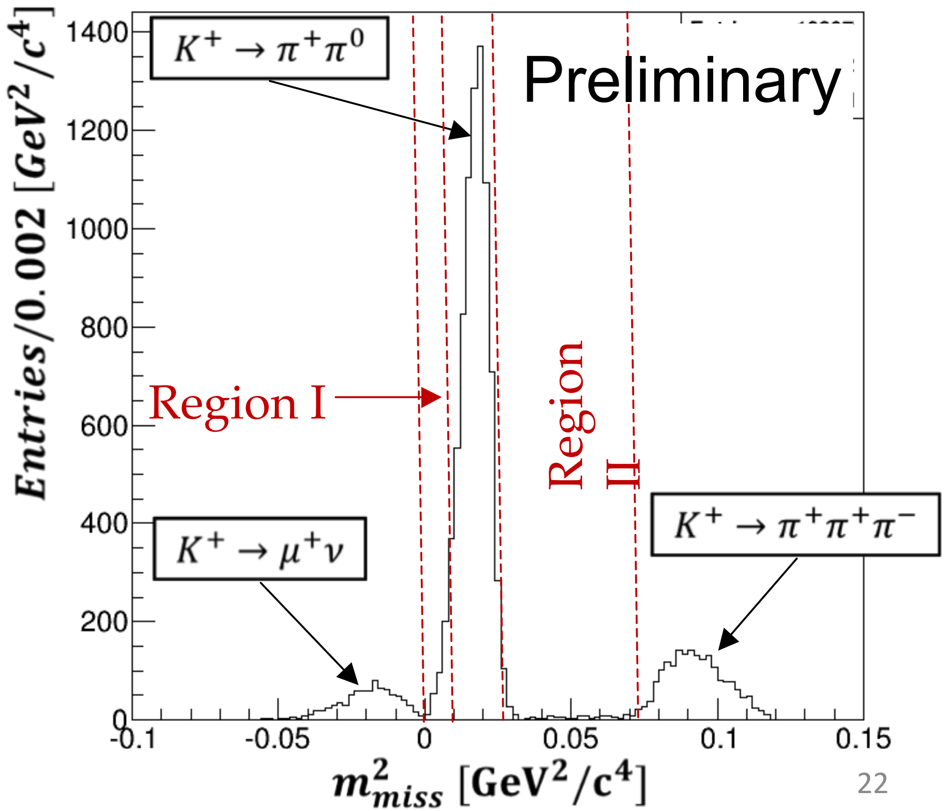




Signal region (P<35GeV/c)
$K^+ \to \pi^+\pi^+\pi^-$
Entries 32847
Mean x 39.57
Mean y 0.01856
RMS x 11.02
RMS y 0.02112
$K^+ \to \pi^+\pi^0$
$K^+ \to \mu^+\nu$
m^2_{miss} [GeV^2/c^4]
Particle Momentum (GeV/c)



theoretical shapes
$K^+\to\pi^+\pi^0(\gamma)$
$K^+\to\mu^+\nu_\mu(\gamma)$
Region I
Region II
$K^+\to\pi^+\nu\bar{\nu}$ ($\times10^{10}$)
$K^+\to\pi^+\pi^+\pi^-$
m^2_{miss} [GeV^2/c^4]

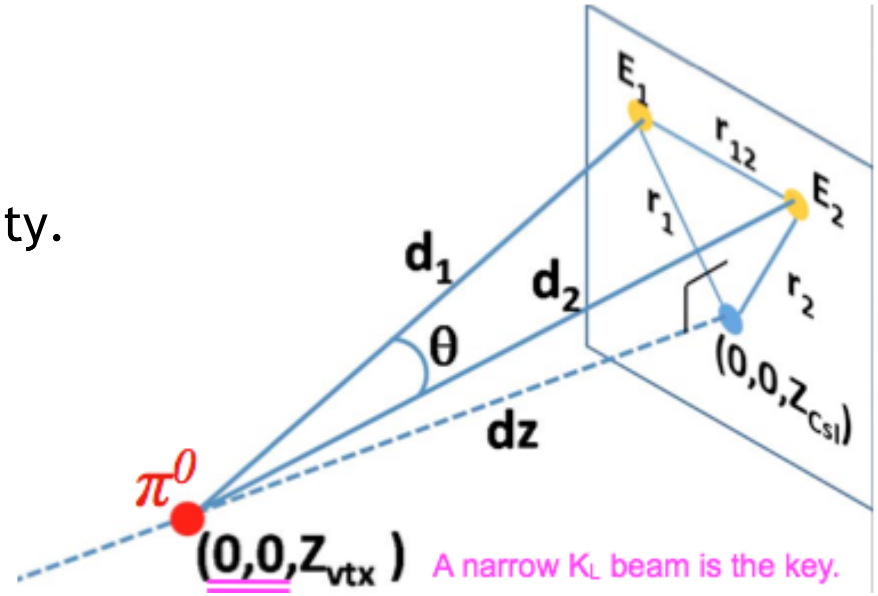


$K^+ \to \pi^+\pi^0$
Preliminary
Region I
Region II
$K^+ \to \mu^+\nu$
$K^+ \to \pi^+\pi^+\pi^-$
Entries/0.002 [GeV^2/c^4]
m^2_{miss} [GeV^2/c^4]

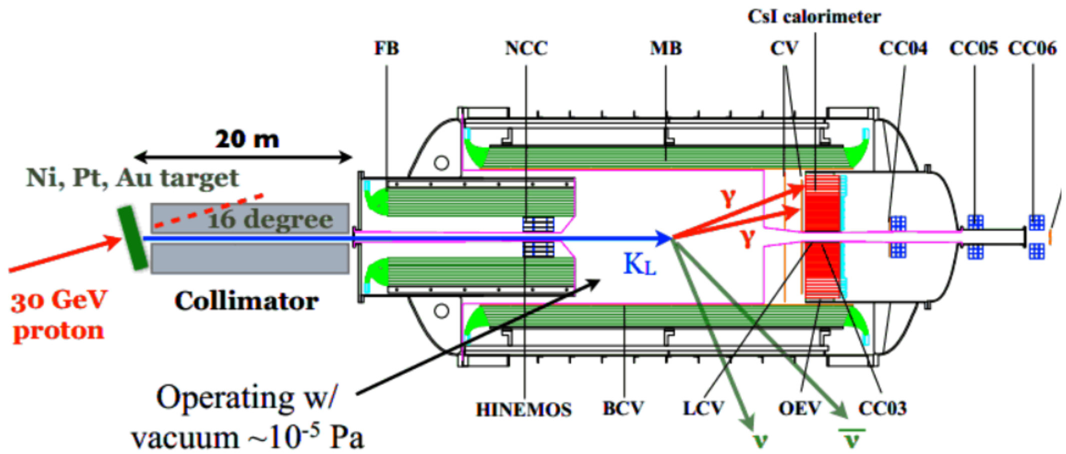
$K_L \to \pi^0 \nu\nu$

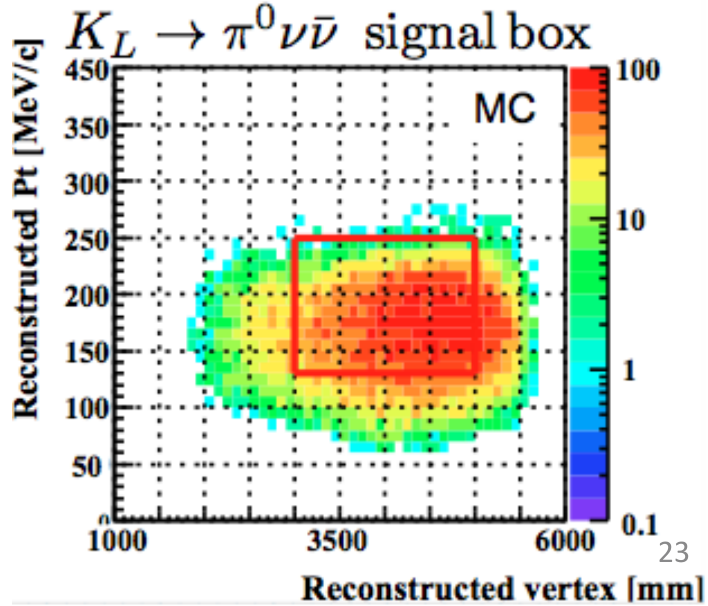
KOTO @ J-PARC (K_L):

- Builds on KEK E391a technique.
- E391a: **BR<6.8×10^{-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.

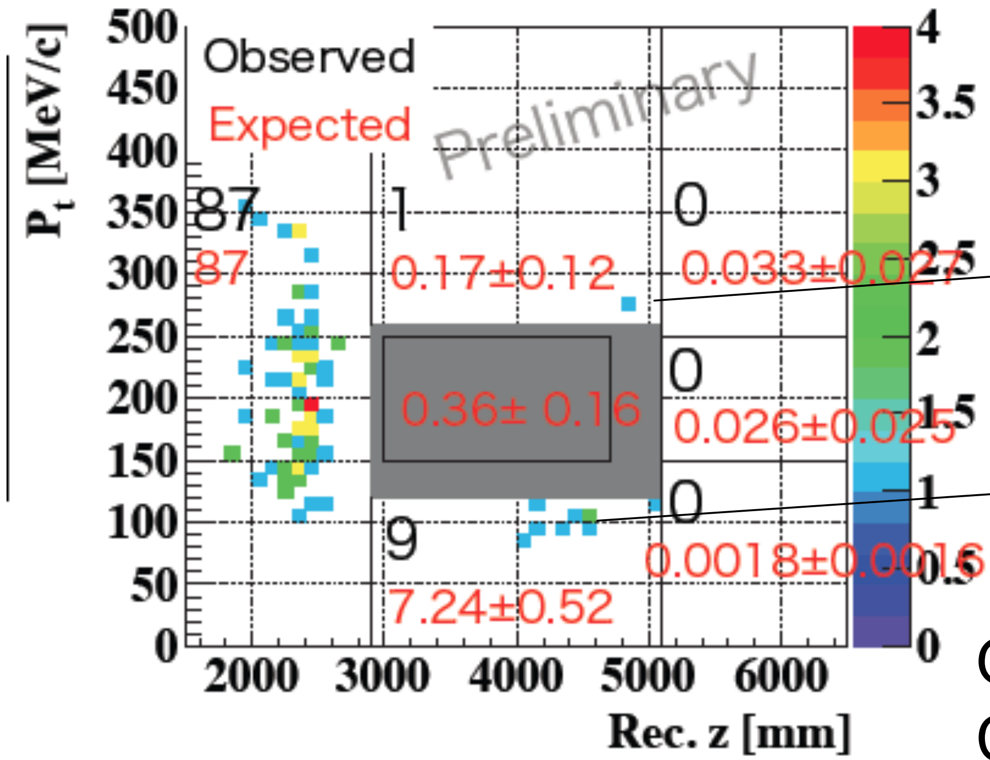


"Two photons + nothing"





KOTO Physics Run in 2013



100 hours, May 2013

Sensitivity = 1.29 10^{-8}

Single neutron makes 2 clusters in calo

$\pi 0 \pi + \pi -$ with charged pions disappearing
Due to interactions in beam pipe

Observed 1 event in box,
Consistent with SM expectations

Inside signal box:

BG source	#BG
Hadron interaction events	0.18±0.15
Kaon decay events	0.11±0.04
Upstream events	0.06±0.06
Sum	0.36± 0.16

KOTO Physics Run in 2015

Upgrade to reduce backgrounds:
- thinner vacuum window
- removable Al target inside the beam for cross-checks
- upgrade downstream detectors (beam pipe charged veto, beam hole charged veto, beam hole photon veto)

Restarted physics run in April 15
About twice 2013 data already collected,
Analysis is ongoing

Another run in Fall 15

Target sensitivity is 2015 is $O(10^{-9})$

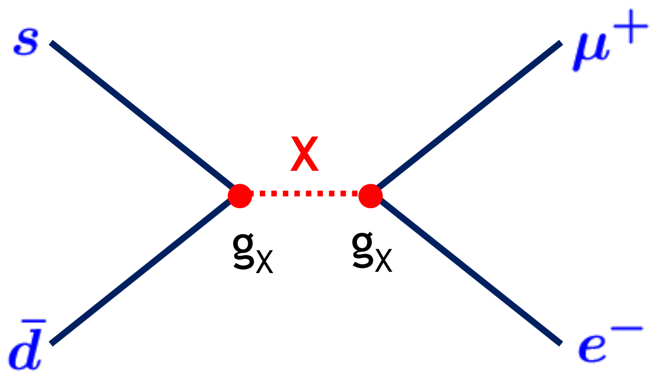
Symmetries

LFV in kaon decays

Copious production: high statistics
Simple decay topologies: clean experimental signatures

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 $\mathcal{B} \sim 10^{-12}$:

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

Lepton Flavour Violation in K 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		

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

NA48/2 2003-4 data:

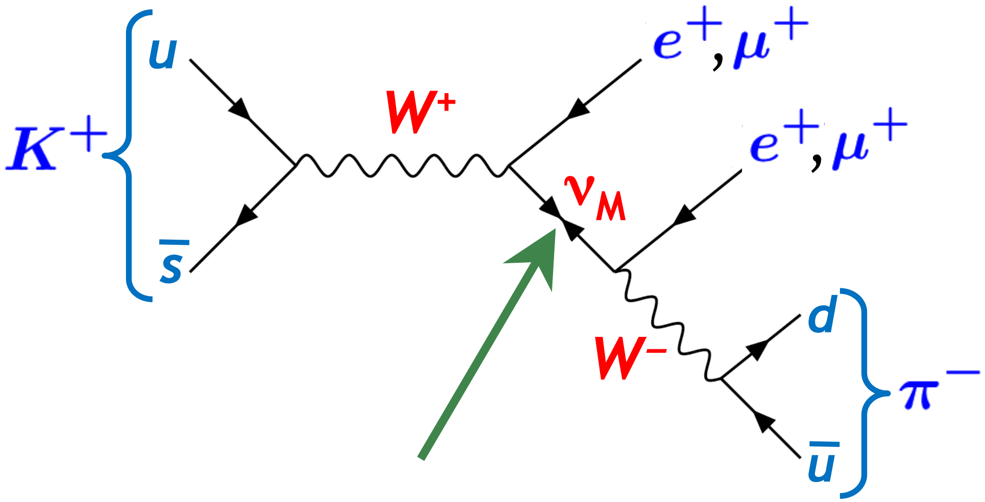
$$\boxed{\mathcal{B}(K^\pm \to \pi^\mp\mu^\pm\mu^\pm) < 1.1 \times 10^{-9} \text{ @90\% CL}}$$

Expected NA62 single event sensitivities: $\sim 10^{-12}$ for $K^\pm$ decays

NA62 is capable of improving on all these decay modes

Sensitivity to Majorana neutrino

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

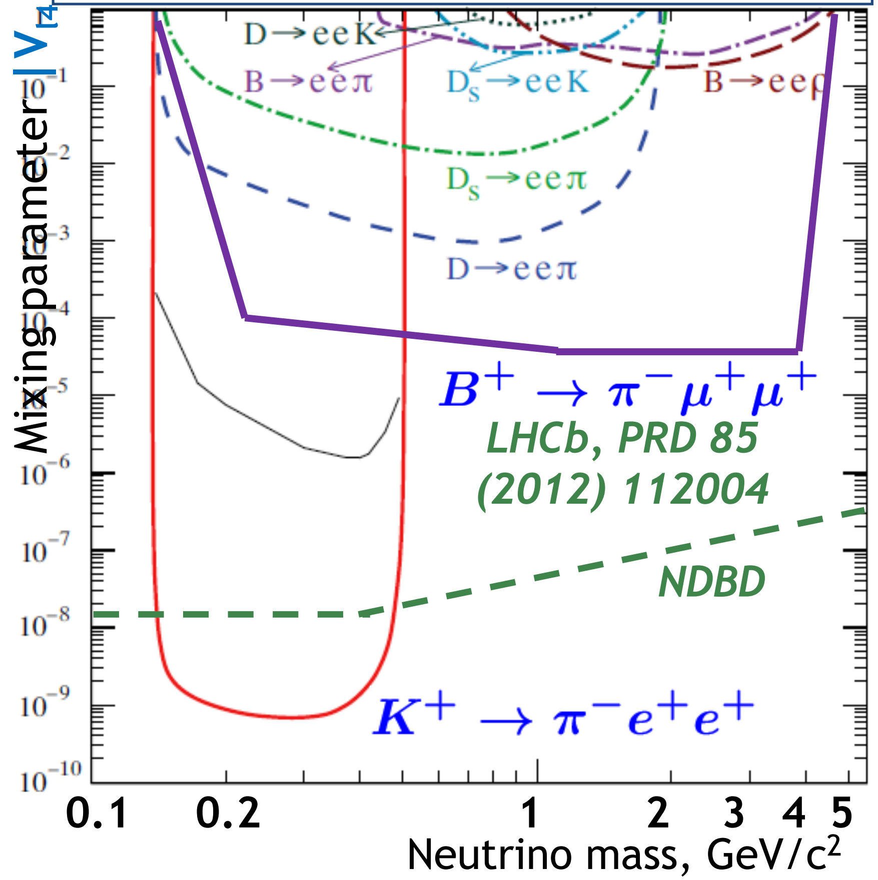


resonant enhancement for

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

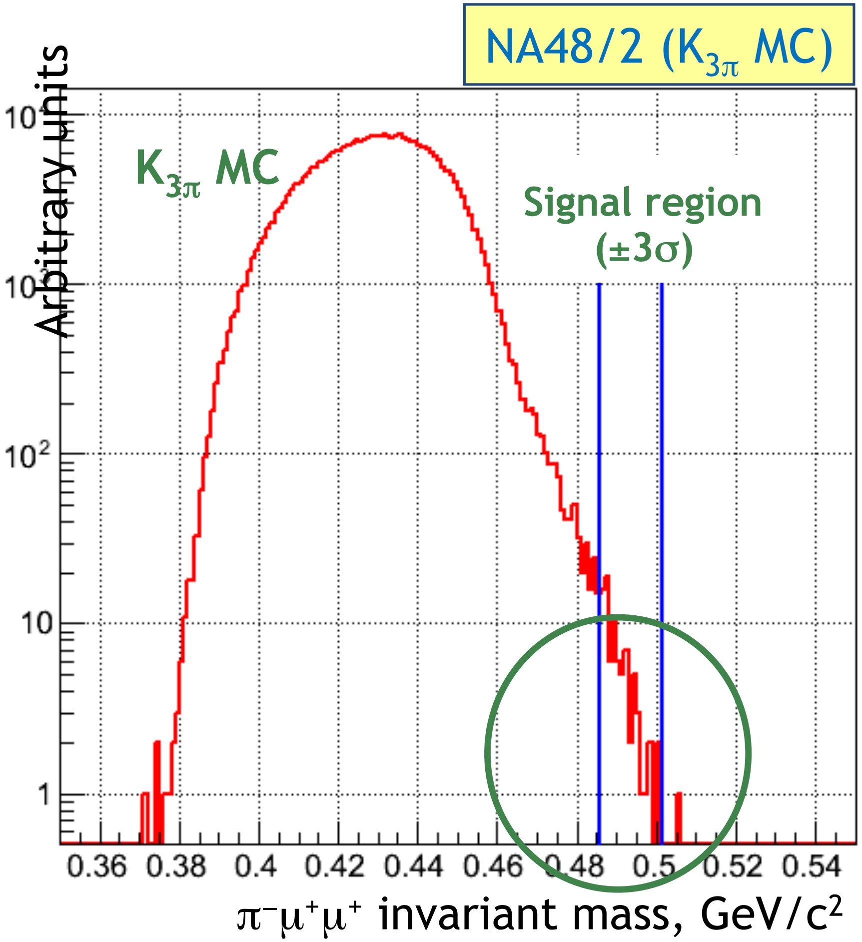
Littenberg and Shrock, PLB491 (2000) 285

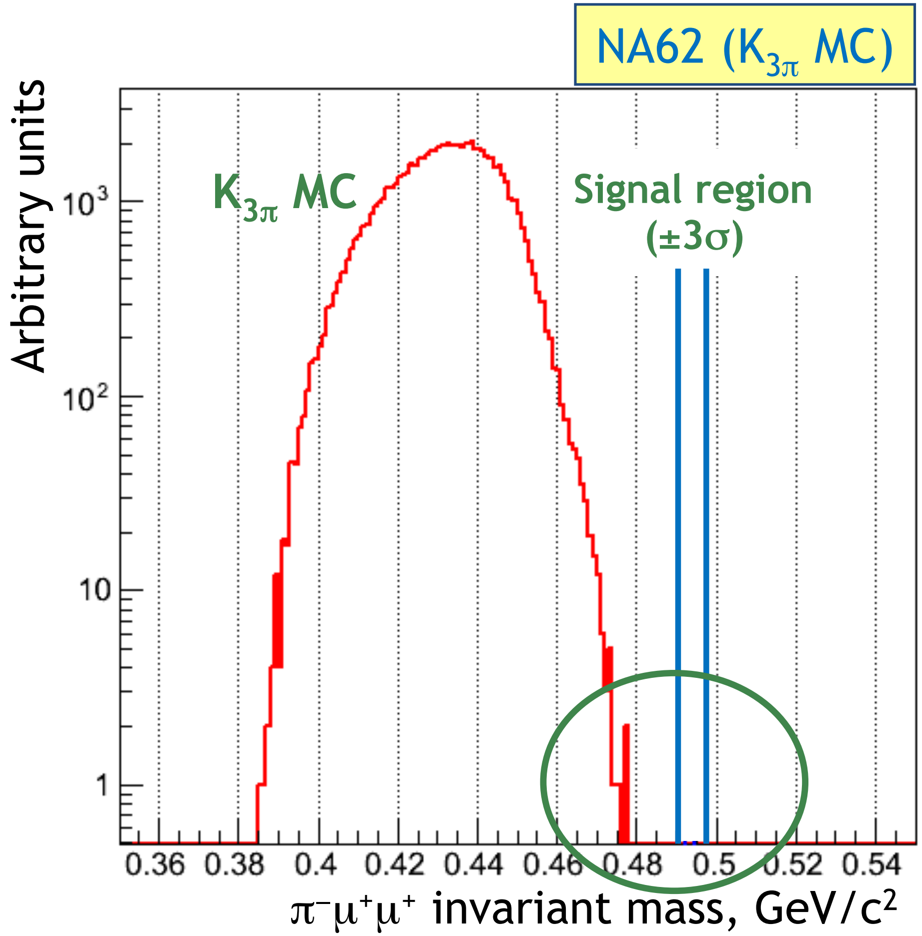
Majorana neutrino exclusion regions from existing data



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

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



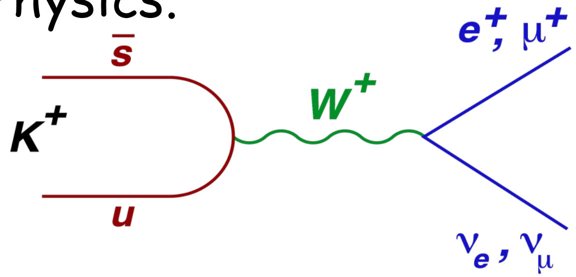


NA48/2: $K_{3\pi}$ background to $K_{\pi\mu\mu}$ due to $\pi^\pm \to \mu^\pm \nu$ decays in the spectrometer

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/c^2)

Lepton Universality: R_K

A precise measurement of the ratio of $K \to l\nu_l$ leptonic decays provides an ideal test of SM and indirect search for New Physics.



Hadronic uncertainties cancel in the ratio $K_{e2/K\mu2}$
SM prediction: excellent sub-permille accuracy

R_K is sensitive to lepton flavour violation and its SM expectation:

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \underbrace{\frac{m_e^2}{m_\mu^2}}_{\text{Helicity suppression: } f\sim 10^{-5}} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \underbrace{(1 + \delta R_K^{\mathrm{rad.corr.}})}$$

Helicity suppression: $f \sim 10^{-5}$

helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

Radiative correction (few %)
due to $K^+ \to e^+\nu\gamma$ (IB) process,
by definition included into R_K
[V.Cirigliano, I.Rosell JHEP 0710:005 (2007)]

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$
Phys. Rev. Lett. 99 (2007) 231801

NA62-R_K:
$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$R_K = (2.488 \pm 0.010) \times 10^{-5}$

[Phys. Lett. B 719 (2013) 326]

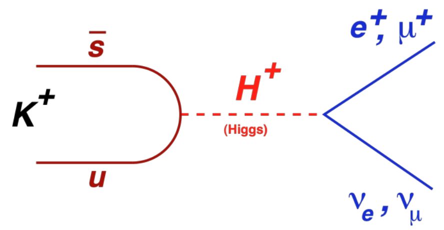
R_K beyond the SM

In the MSSM large tanβ scenario, the presence of LFV terms (charged Higgs coupling) introduces extra contributions to the SM amplitude ~1% effect
Girrbach and Nierste, arXiv:1202.4906

2HDM - tree level

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

→ Does not affect the ratio R_K

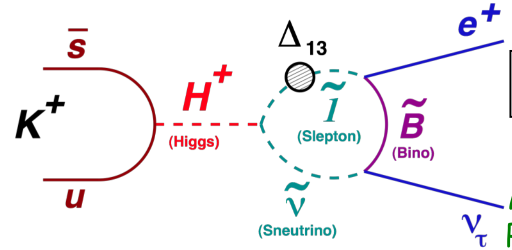


Tree level

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



One-loop level

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

$$R_K^{LFV} = \frac{\Gamma_{SM}(K \rightarrow e\nu_e) + \Gamma_{LFV}(K \rightarrow e\nu_\tau)}{\Gamma_{SM}(K \rightarrow \mu\nu_\mu)}$$

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

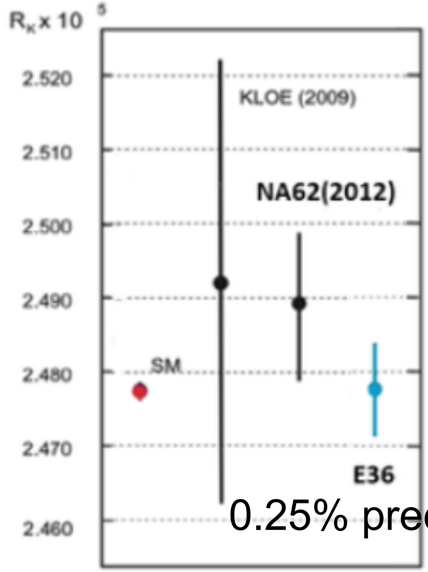
Limited by the recent B and τ measurements
Fonseca, Romão and Teixeira, EPJC 72 (2012) 2228

Sensitive to SM extensions with 4th generation, sterile neutrinos, unconstrained MSSM
Lacker and Menzel, JHEP 1007 (2010) 006;
Abada et al., JHEP 1302 (2013) 048

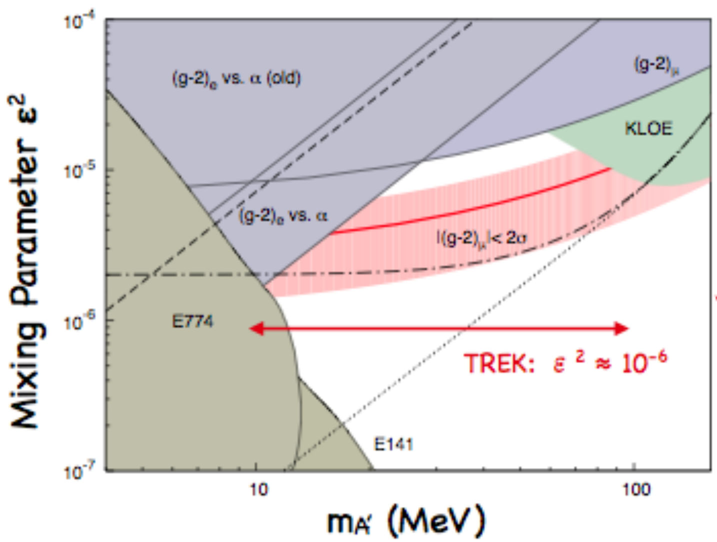
TREK (E36)

TREK detector: Upgrade of E246 detector for the study of various Kaon decay channels at **J-PARC**.

Engineering run: April 15
Physics Run: Fall 15



0.25% precision



T. Beranek and M. Vanderhaeghen, Phys. Rev. D **87**, 015024 (2013)

Search for lepton universality violation in a measurement of the ratio of the K_{e2} and $K_{\mu 2}$ decay widths	$K^+ \to e^+\nu$ $K^+ \to \mu^+\nu$
Search for a heavy sterile neutrino	$K^+ \to \mu^+ N$
Search for dark photon	$K^+ \to \pi^+ A' \to \pi^+ e^+ e^-$ $K^+ \to \mu^+ \nu A' \to \mu^+ \nu e^+ e^-$

$|U|<2\ 10^{-8}$ for M<200 MeV

SM extensions with massive gauge boson A'
Sensitivity: mixing parameter ~10^{-6} for 10<M(A')<100 MeV

M. Abe et al., Phys. Rev. D **73**, 072005 (2006)

R_K: NA62 Future prospects

NA62-R_K: $R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$R_K = (2.488 \pm 0.010) \times 10^{-5}$

[Phys. Lett. B 719 (2013) 326]

Future NA62:
Hermetic veto (large-angle and small-angle veto counters) will strongly decrease the background.
Beam spectrometer (beam tracker plus beam Cherenkov) will allow time correlation between incoming kaons and decay products (improved PID).

Only the $K_{\mu 2}$ ($\mu \rightarrow e$) background will remain: well known ~0.1% contamination.

Assuming an analysis at low lepton momentum and not using electron ID, measurement of R_K with improved systematic precision is feasible.

Further NA62 K Physics Program

Decay	Physics	Present limit (90% C.L.) / Result	NA62 **Potential**
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	
$e^-\nu\mu^+\mu^+$	LNV	No data	
π^+X^0	New Particle	5.9×10^{-11} $m_{X^0}=0$	10^{-12}
$\pi^+\chi\chi$	New Particle	–	10^{-12}
$\pi^+\pi^+e^-\nu$	$\Delta S\neq\Delta Q$	1.2×10^{-8}	10^{-11}
$\pi^+\pi^+\mu^-\nu$	$\Delta S\neq\Delta Q$	3.0×10^{-6}	10^{-11}
$\pi^+\gamma$	Angular Mom.	2.3×10^{-9}	10^{-12}
$\mu^+\nu_h, \nu_h\rightarrow\nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h}=350\ MeV$	
R_K	LU	$(2.488\pm0.010)\times10^{-5}$	>×2 better
$\pi^+\gamma\gamma$	χPT	< 500 events	10^6 events
$\pi^0\pi^0e^+\nu$	χPT	66000 events	$O(10^7)$
$\pi^0\pi^0\mu^+\nu$	χPT	-	$O(10^6)$

Summary

- Recent measurements/limits for rare kaon decays and exotic searches

- Challenging experiments reaching physics data stage

- Updates and new analyses will come soon also from LHCb and KLOE

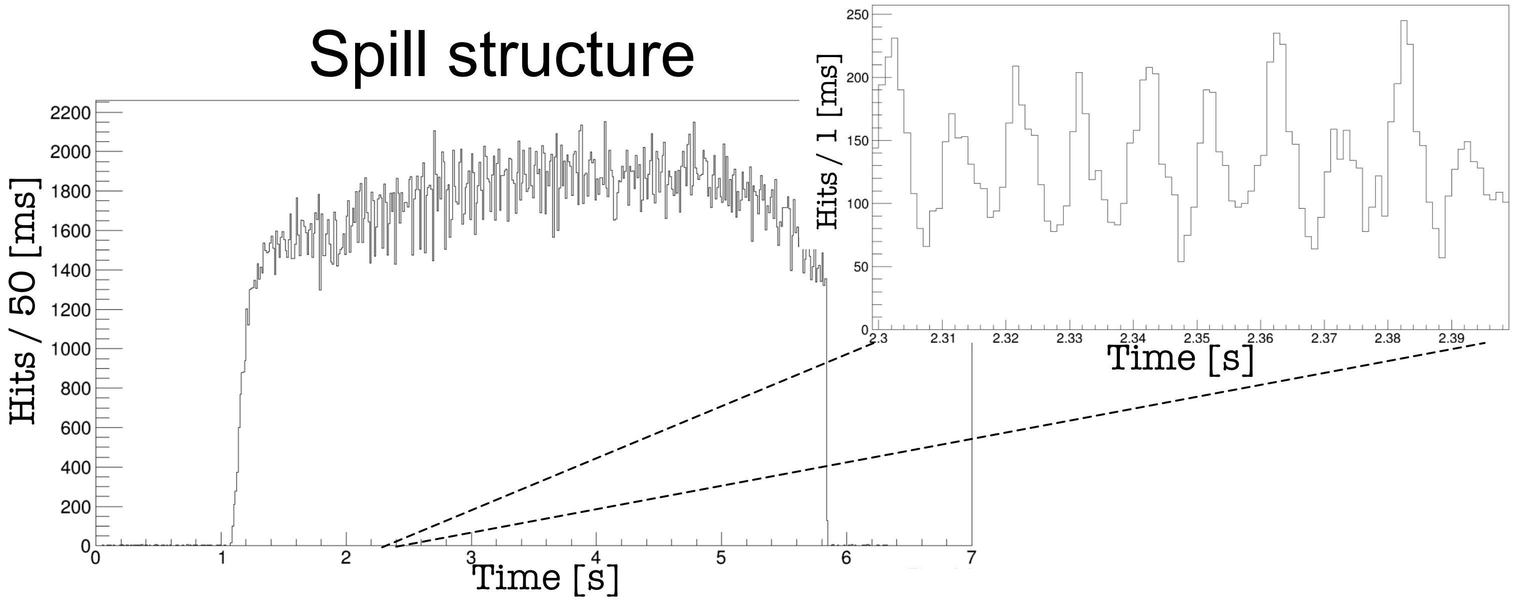
- Important interplay between K, D and B physics in flavour sector to constrain the SM and search for New Physics

Spares

NA62 Goal

- The Experiment aims at
  - ~10% precision measurement of the BR($K^+ \rightarrow \pi^+ \nu\nu$) in 2 years of data taking
- Requirements:
  - Statistics: O(100) events
  - 10^{13} Kaon decays
  - Systematics: <10% precision background measurement
  - >10^{12} background rejection
- Technique:
  - In flight K-decay

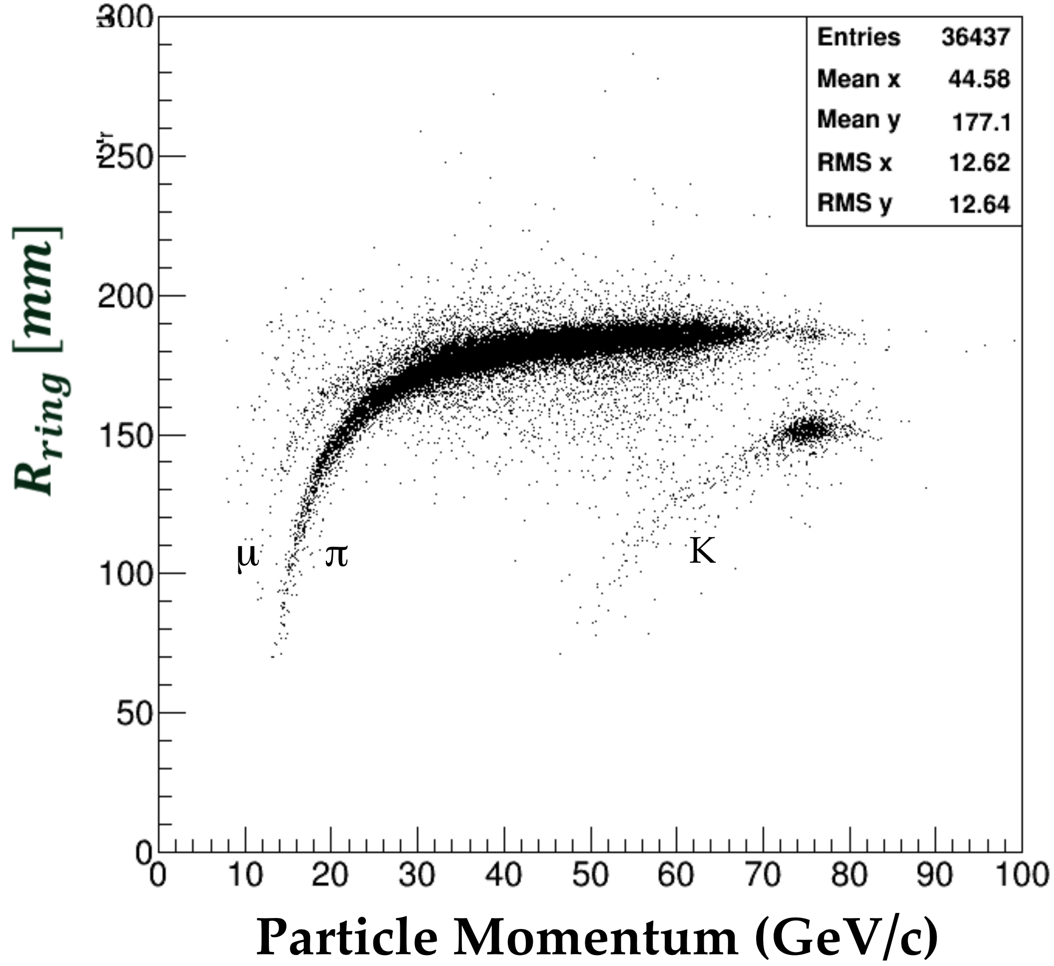
Pilot Run Conditions



- Duty cycle: 4.8/16.8 s spill
- 5% nominal beam intensity (0.025MHz K-decays)
- 2 weeks dedicated to physics studies

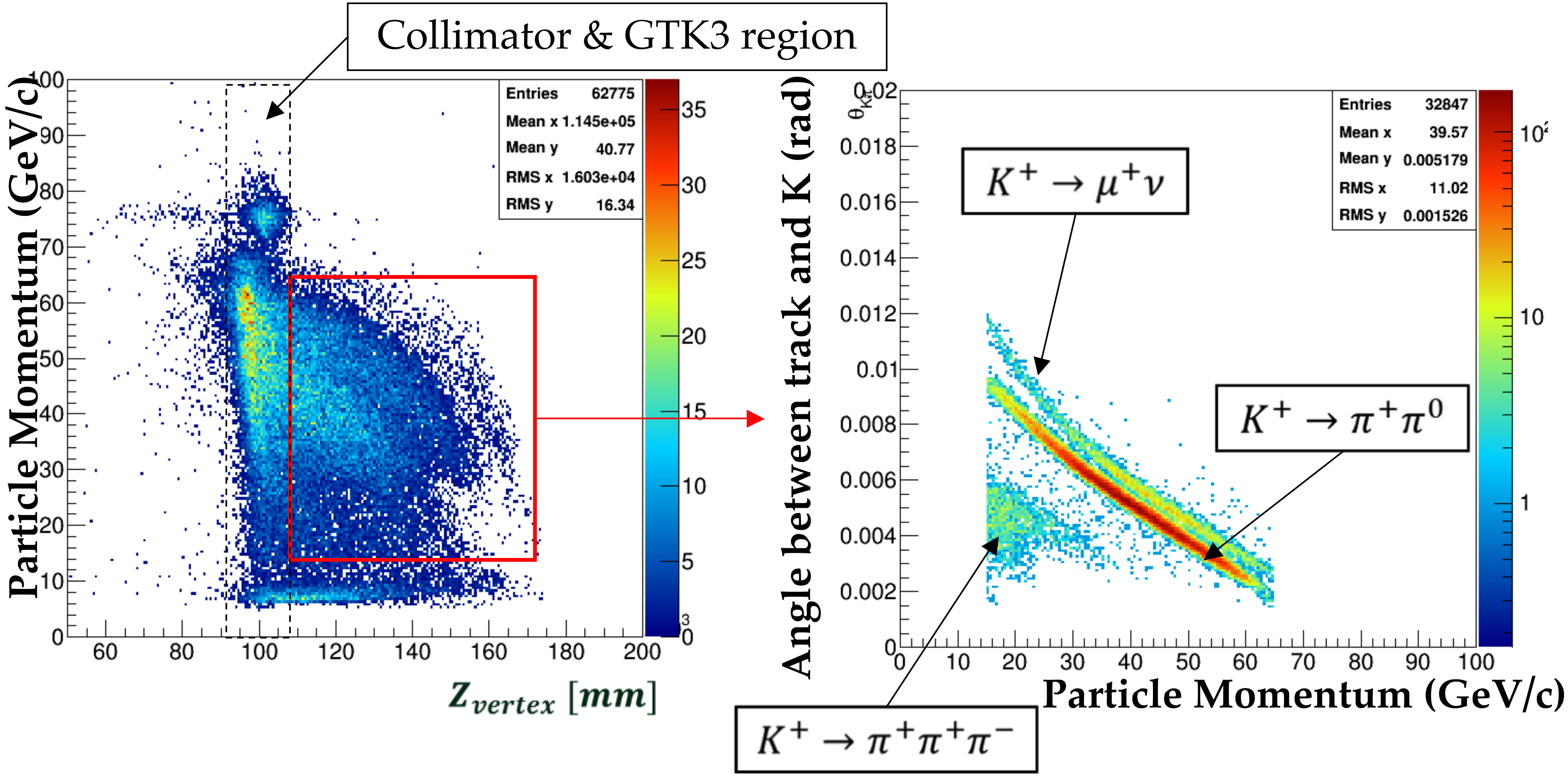
First Look at 2014 Data Quality

- Matching between track and RICH ring to study the particle content
- Positrons suppressed by the trigger



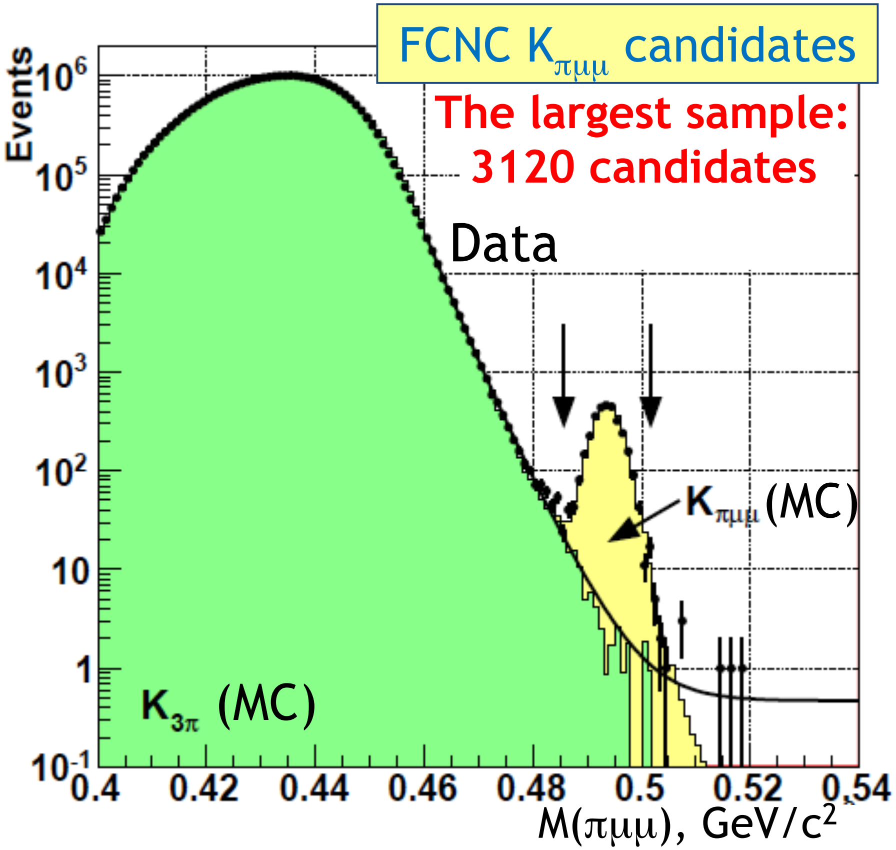
First Look at 2014 Data Quality

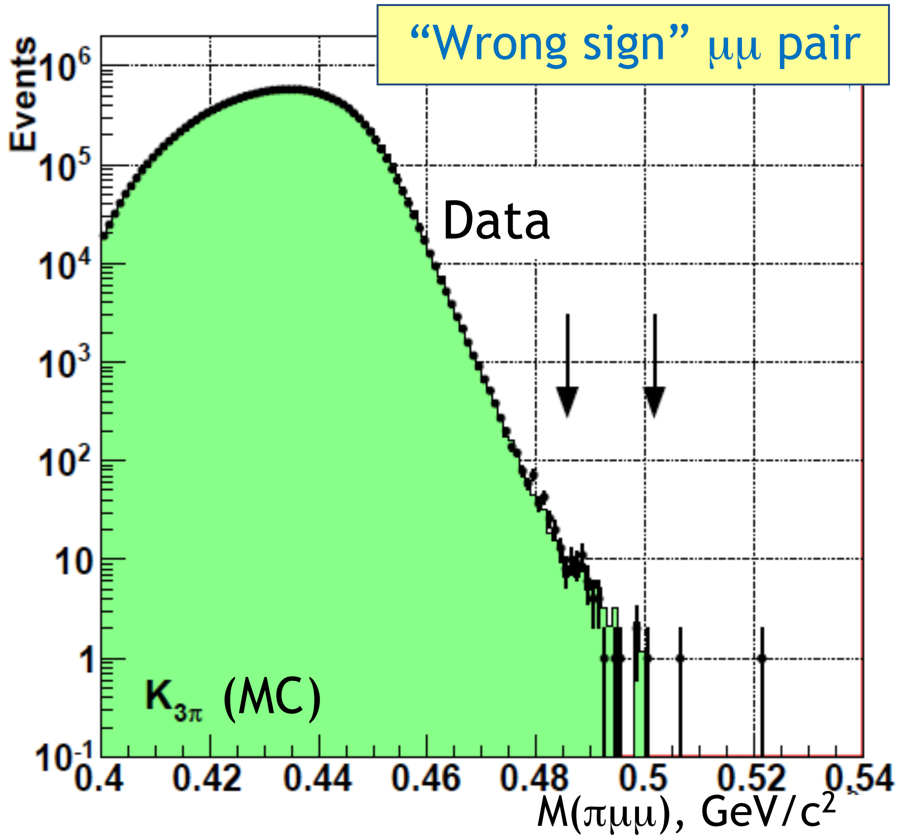
- Use track origin to suppress the background from kaon interactions
- Decay vertex from the intersection between the track and the nominal K direction



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

PLB 697 (2011) 107



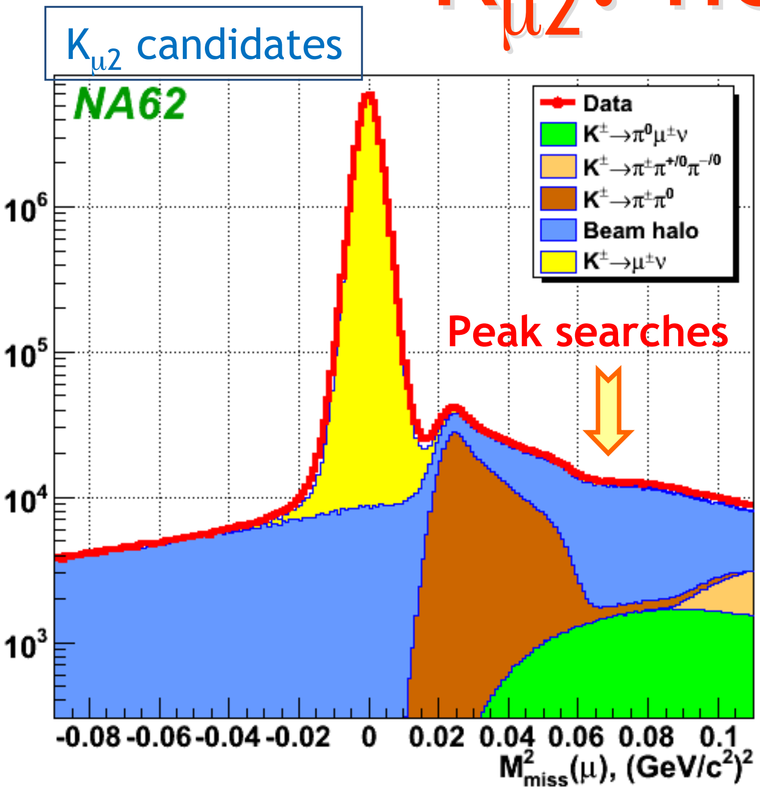


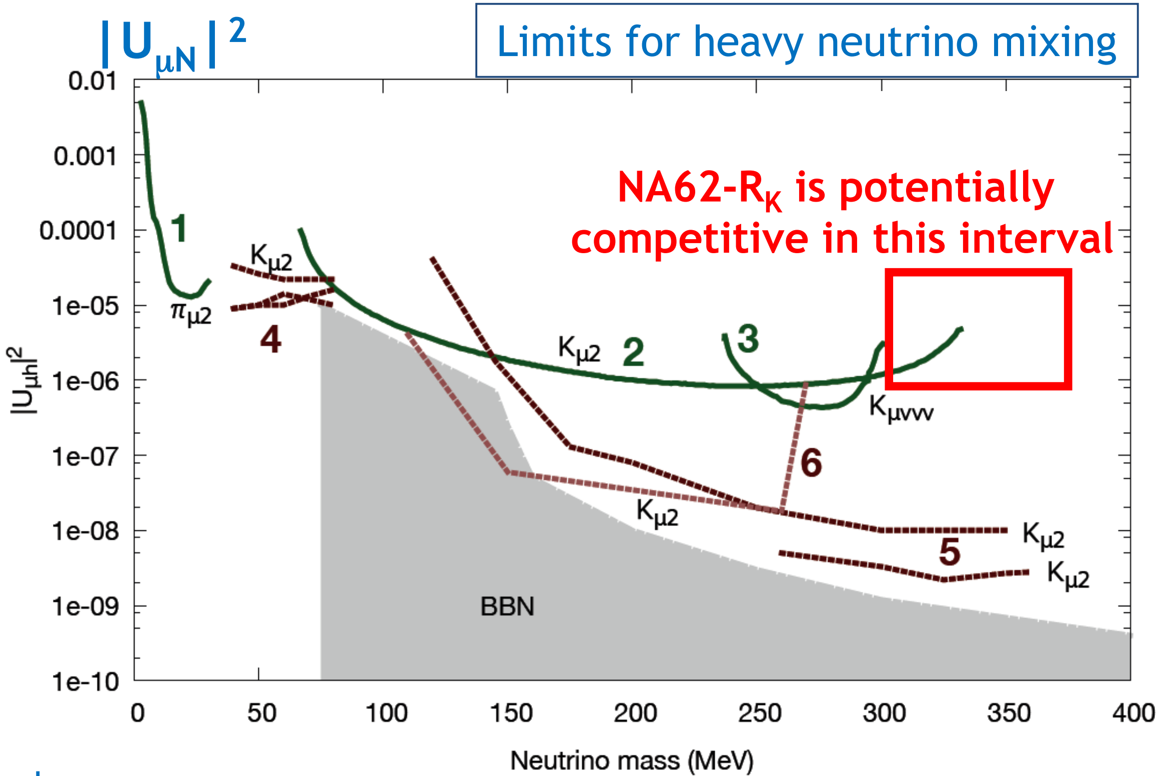
$N_{data} = 52$
$N_{bkg} = 52.6 \pm 19.8_{syst.}$

Sensitivity limited by background from $\pi^{\pm} \to \mu^{\pm}\nu$

Flat phase space assumed (rather than Majorana neutrino exchange)

$K_{\mu 2}$: 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 Upper Limit 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)

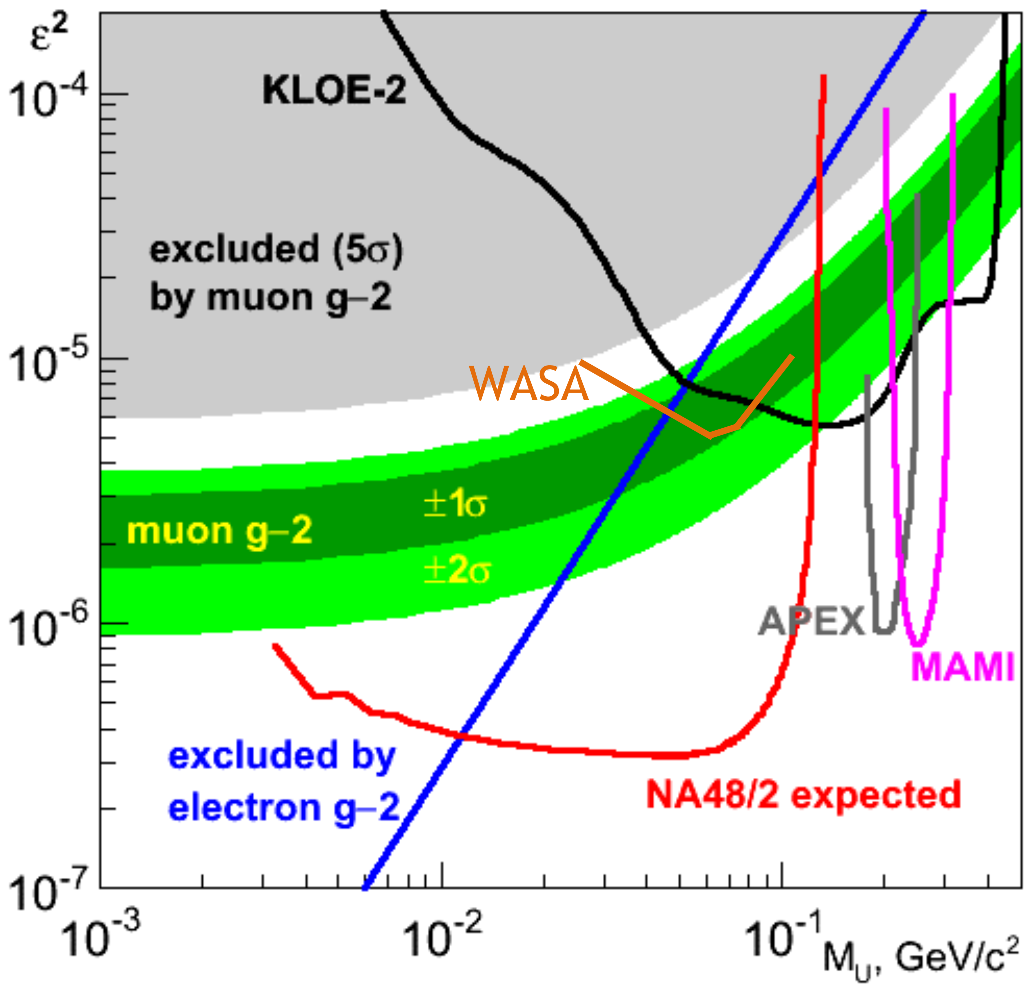
1. PSI, PLB 105 (1981) 263.
2. KEK, PRL 49 (1982) 1305.
3. LBL, PRD 8 (1973) 1989.

Decay searches (short-lived ν_h)

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

Analysis in progress

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

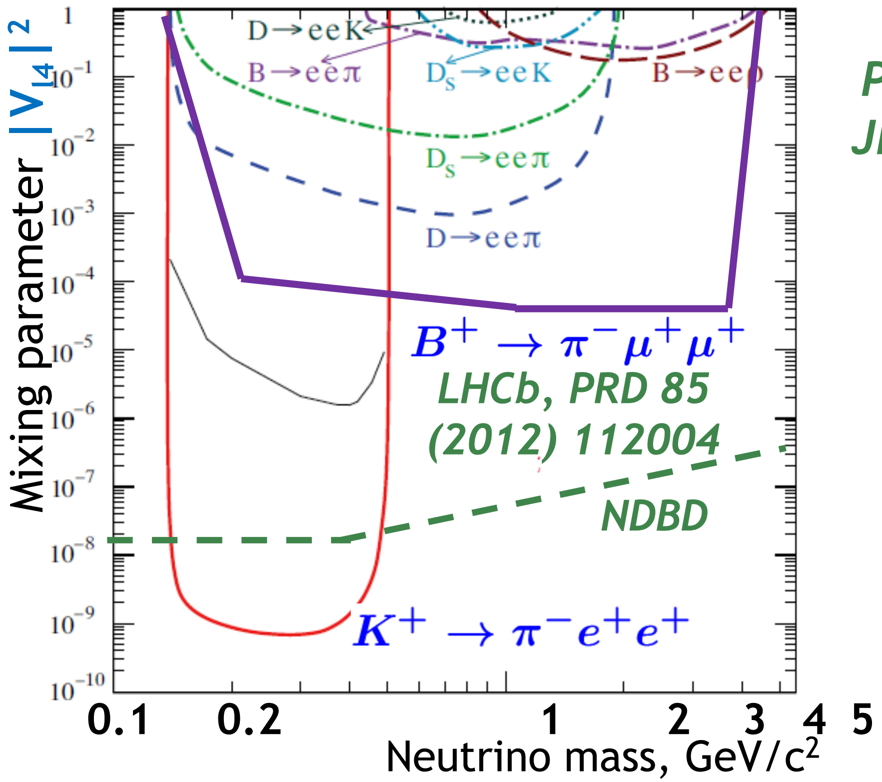
A1 @ MAMI (Mainz Microtron)
Merkel et al.,
PRL106 (2011) 251802

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

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

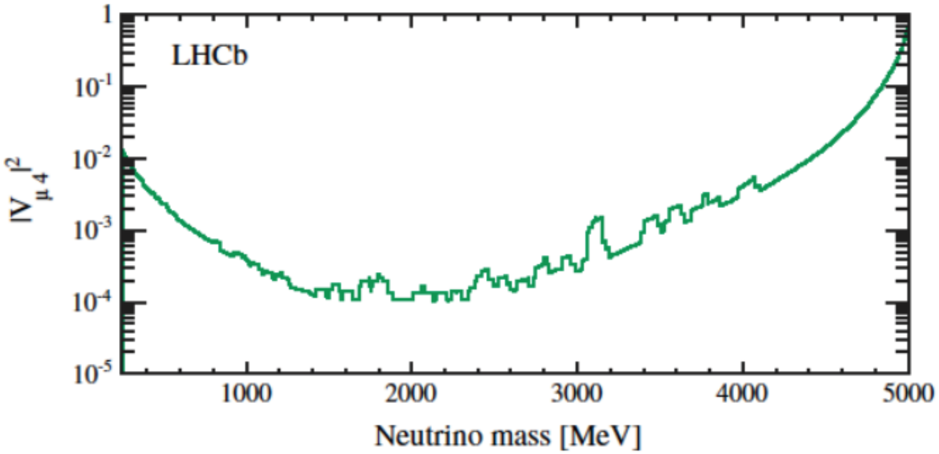
NB: the NA48/2 curve is the expected sensitivity, not a result!

Sensitivity to Majorana neutrino

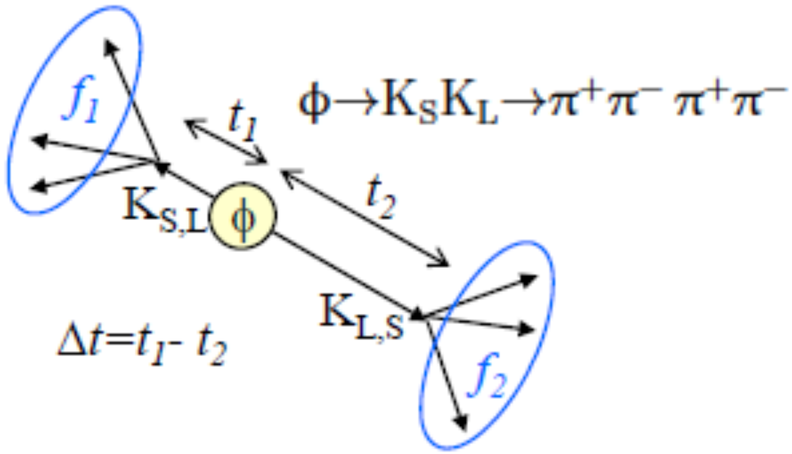


Plot from Atre et al., JHEP 0905 (2009) 030

[JHEP 05 (2009) 030]



KLOE: CPT test



Entangled pair of neutral kaons

$$|K_{S,L}\rangle \propto (1+\epsilon_{S,L})|K^0\rangle \pm (1-\epsilon_{S,L})|\bar{K}^0\rangle$$

$$\epsilon_{S,L} = \epsilon_K \pm \delta_K$$ CP impurities

T CPT

Kaon boost Kaon velocity

$$\delta_K \approx i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a})/\Delta m$$

$$\phi_{SW} = \arctan(2\Delta m/\Delta\Gamma)$$ Δm, $\Delta\Gamma$ mass and width differences

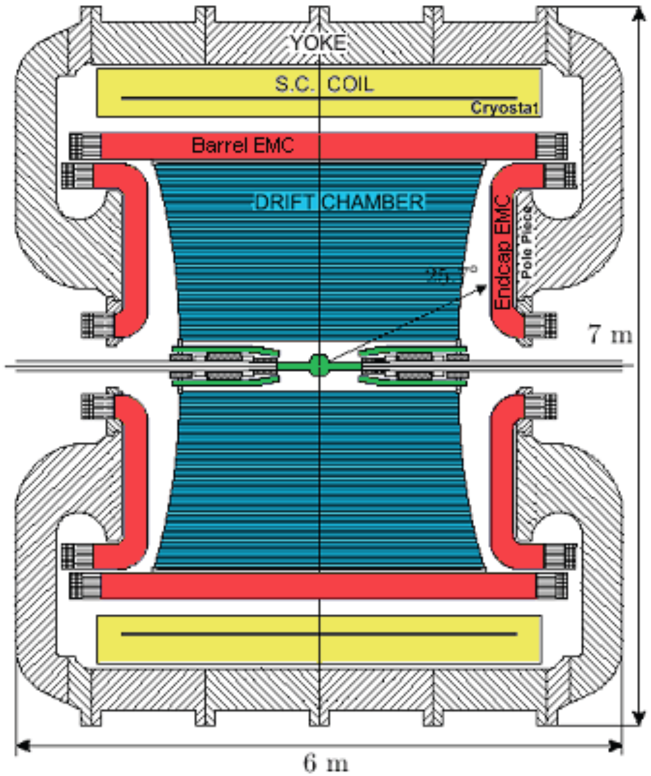
1.7 fb^{-1} of the KLOE data sample [arXiv:1312.6818v2]

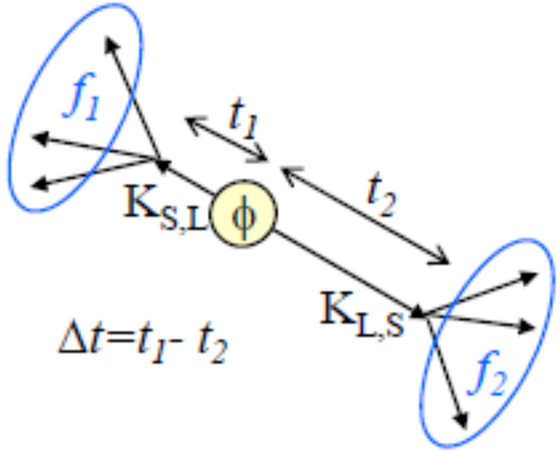
$$\Delta a_0 = (-6.0 \pm 7.7_{stat} \pm 3.1_{syst}) \times 10^{-18}\ \text{GeV},$$
$$\Delta a_X = (\ 0.9 \pm 1.5_{stat} \pm 0.6_{syst}) \times 10^{-18}\ \text{GeV},$$
$$\Delta a_Y = (-2.0 \pm 1.5_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV},$$
$$\Delta a_Z = (\ 3.1 \pm 1.7_{stat} \pm 0.5_{syst}) \times 10^{-18}\ \text{GeV}.$$

Limited by statistics: KLOE-2

KLOE, KLOE-2

KLOE





Entangled pair of neutral kaons

$$|K_{S,L}\rangle \propto (1+\epsilon_{S,L})|K^0\rangle \pm (1-\epsilon_{S,L})|\bar{K}^0\rangle$$

In progress

$\phi \to K_L K_S \to \pi^+\pi^-\pi^+\pi^-$ CPT, Lorentz tests

$\phi \to K_L K_S \to (crash)\pi e\nu$ CP, CPT

$\phi \to K_L K_S \to 3\pi^0\pi l\nu$ T

Limited by statistics: KLOE-2
keeps running for 2-3 years of data taking up to 10 fb^{-1}