Estudios de decaimientos raros del K^{+} en el experimento NA62

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Introduction and Motivation

Two approaches to test New Physics Scenarios:

- Brut Force: Highest Energy Collisions to produce new heavy particles
- Elegant: High Precision experiment to measure indirect effects of new particles.

The two approaches are complimentary and both a necessary to disentagle what really is the new physics.

Introduction and Motivation

Some examples:

- Masses of $W^\pm$, Z^0, top-quark, Higgs, . . . , known before real production
- $B_s^0 \to \mu\mu$, $\mathcal{B} = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$ excludes most of SUSY (MSSM) phase space
- Smallest $\mathcal{B}$ measured: $K_L^0 \to e^+e^-$, $\mathcal{B} = (9^{+6}_{-4}) \times 10^{-12}$
- Null measurements (upper limits) also provide a lot a information on new physics scenarios.

History of Kaon Experiments

Since the first accelerators

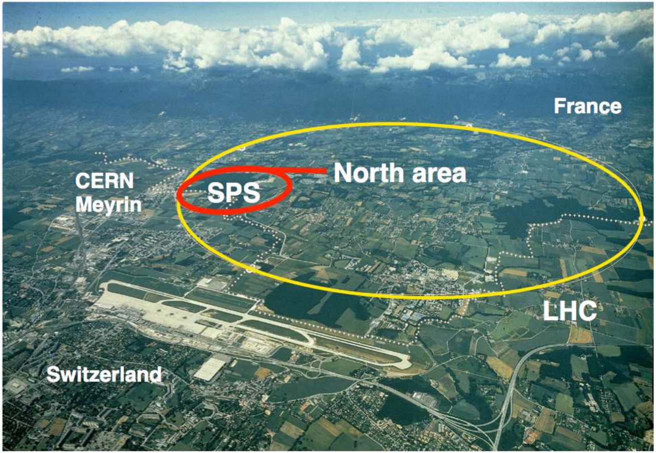
- CERN PS: Precision measurements
- Brookhaven: Several experiments, rare dcays.
  Most famous: Indirect CP Violation $K^0_{\pi 2}/K^0_{\pi 3}$ (Cronin, Fitch)
- Fermilab (E732, KTeV), CERN SPS (NA32, NA48): Direct CP Violation
- KEK, J-PARC: Rare Kaon decays
- In last 15 years several proposals in the US:
  CKM, K0PI0, KPLUS, ORKA.
  All killed by different P5 processes.
- CERN SPS: Continuation of NA48: NA62

Outline

The NA62 Collaboration

- University of Birmingham
- CERN
- Dubna
- George Mason University
- Ferrara
- Firenze
- Frascati
- Mainz
- University of California, Merced
- INR Moscow
- Napoli
- Perugia
- Pisa
- Protvino
- Roma
- Saclay
- San Luis Potosí
- SLAC
- Sofia
- Torino
- TRIUMF

approx 200 collaborators


France
CERN
Meyrin
SPS
North area
LHC
Switzerland

Recent history of CERN North Area experiments

1997–2001	NA48 (K_S/K_L)	Re(ϵ'/ϵ) Discovery of direct CPV
2002	NA48/1 (K_S/hyperons)	Rare K_S and hyperon decays
2003–2004	NA48/2 (K^+/K^-)	Direct CPV, Rare $K^{\pm}$ decays
2007–2008	NA62 R_K-phase (K^+/K^-)	$R_K = K^{\pm}_{e2}/K^{\pm}_{\mu 2}$
2009–2017	NA62 (K^+)	$K^+ \to \pi^+\nu\bar{\nu}$ Rare K^+ and π^+ decays

NA62

- Uses (most of the) beamline, and some detector from NA48
- Adds new detectors: GigaTracker, Straw, Photon Veto (Leadglass), RICH, muon veto, . . .
- Data Taking with the available detectors before all detectors ready for Fall of 2014
- Physics Topics up to now:
  - R_K: Lepton Universality
  - $K^{\pm} \to \pi^{\pm}\gamma\gamma$: Test of Chiral Pertubation Theory
  - not yet: $K^{\pm} \to e^{\pm}\gamma\gamma$
  - not yet: $K^{\pm} \to \ell^{\pm}\nu$: Heavy Neutrino
- Main Goal: $K^{+} \to \pi^{+}\nu\bar{\nu}$, 100 events (40/year)
- A long list of other rare K^{+} and π^{+} decays (see later)

R_K: $K^{\pm} \rightarrow e^{\pm}\nu_e$, $K^{\pm} \rightarrow \mu^{\pm}\nu_{\mu}$

- Fermi's Golden Rule for decay of particle with mass M:

$$d\Gamma = \frac{(2\pi)^4}{M} \cdot |\mathcal{M}_{fi}|^2 \cdot \mathrm{PS}$$

- $\mathcal{M}_{fi}$: describes the physics of the decay (weak interaction, helicity suppressed) and “should” be identical for both decay modes:
  “Lepton Universality”: μ and e are identical except for the mass.
- PS: Phase Space, describing the density of final states.
- for 2-body decays: PS simple to calculate

R_K: $K^\pm \to e^\pm\nu_e$, $K^\pm \to \mu^\pm\nu_\mu$

SM width of $P^\pm \to \ell^\pm\nu$ ($P = \pi, K, D, B$)

$$\Gamma^{\mathrm{SM}}(P^\pm \to \ell^\pm\nu) = \frac{G_F^2 M_P M_\ell^2}{8\pi}\left(1 - \frac{M_\ell^2}{M_P^2}\right)^2 f_P^2 |V_{qq'}|^2,$$

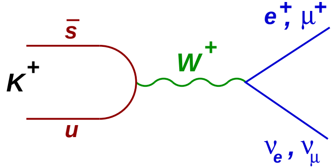
G_F: Fermi constant; M_P, M_ℓ: meson and lepton masses
f_P meson decay constant; $V_{qq'}$: CKM matrix element

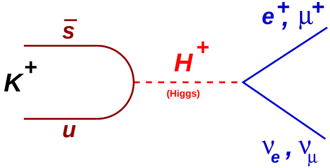
$$\frac{\Gamma(K^\pm \to e^\pm\nu_e)}{\Gamma(K^\pm \to \mu^\pm\nu_\mu)} = R_K^{\mathrm{SM}} = \left(\frac{M_e}{M_\mu}\right)^2 \left(\frac{M_K^2 - M_e^2}{M_K^2 - M_\mu^2}\right)^2 (1 + \delta R_{\mathrm{QED}}) =$$

$$= (2.477 \pm 0.001) \times 10^{-5}$$

$\delta R_{\mathrm{QED}} = (-3.79 \pm 0.04)\%$ EM (radiative) correction.

R_K beyond the Standard Model

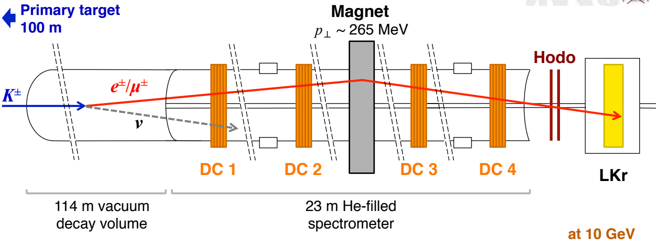




- Charged Higgs boson exchange
- MSSM: R_K enhanced by $\sim 1\,\%$.
  But also constraint by $B_s \to \mu^+\mu^-$ and $B^+ \to \tau^+\nu_\tau$.
- R_K also sensitive to 4. generation and sterile neutrinos.

$\Rightarrow$ Need to measure R_K to better than $1\,\%$

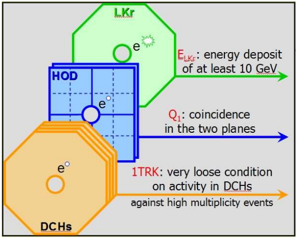
NA48 setup used by NA62 for R_K



		at 10 GeV
Drift chambers	$\sigma(p)/p = 0.48\% \oplus 0.009\%\, p$ [GeV] $\sigma_{x,y} = 90$ µm	0.48%
LKr calorimeter	$\sigma_E/E = 3.2\%/\sqrt{E}$ [GeV] $\oplus$ $9\%/E$ [GeV] $\oplus$ 0.42% $\sigma_x = \sigma_y = 4.2$ mm$/\sqrt{E} \oplus 0.6$ mm	1.4% 1.5 mm
Hodoscope	Fast trigger, good time resolution (150 ps)	

Kaon beam: 74 GeV$/c$, $10^5/sec$

R_K Trigger Logic



Electron Trigger:

- Hodoscopes
- low multiplicity in DCH
- $>$ 10 GeV in LKr

Muon Trigger:

- Hodoscopes
- low multiplicity in DCH
- Downscale by 150

Data Samples, Backgrounds

- $\sim 2 \times 10^{10}$ K decays collected over 4 months
- Main backgrounds for K_{e2}:
  - Beam halo muons
  - Miss-Id of μ as e (also: $\mu \to e\nu_e\nu_\mu$)
  - Strategy: Block one of the beams, measure the background
- Backgrounds for $K_{\mu 2}$:
  - Miss-Id of μ as e (also: $\mu \to e\nu_e\nu_\mu$)
  - Strategy: Clean sample of μ to measure Miss-Id in LKr add Pb block in front to absorb e.

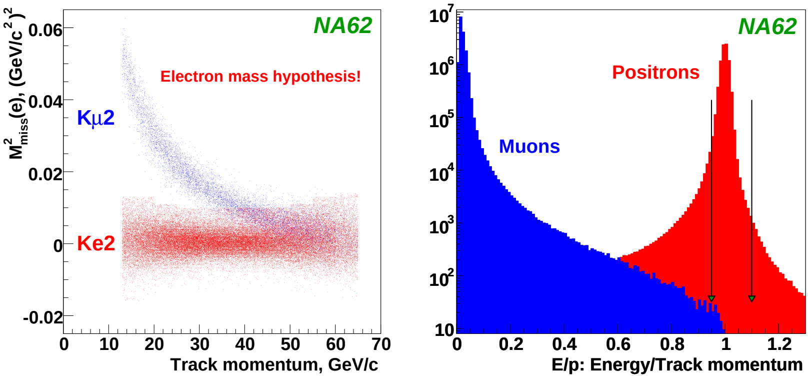
Analysis Strategy

Acceptances different for K^+, K^-, with/without Pb, function of lepton momentum
$\Rightarrow$ 40 independent measurements of

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_{\mathrm{B}}(K_{e2})}{N(K_{\mu 2}) - N_{\mathrm{B}}(K_{\mu 2})} \cdot \frac{A(K_{\mu 2})}{A(K_{e2})} \cdot \frac{f_\mu \times \epsilon(K_{\mu 2})}{f_e \times \epsilon(K_{e2})} \cdot \frac{1}{f_{\mathrm{LKr}}}$$

$N(K_{\ell 2})$: selected candidates; $N_{\mathrm{B}}(K_{\ell 2})$: background events; $A(K_{\mu 2})/A(K_{e2})$: ratio of the geometrical acceptances; f_ℓ; lepton identification efficiencies; $\epsilon(K_{\ell 2})$ trigger efficiencies; f_{LKr}: Global efficiency of the LKr readout; $D = 150$: $K_{\mu 2}$ trigger downscaling factor.

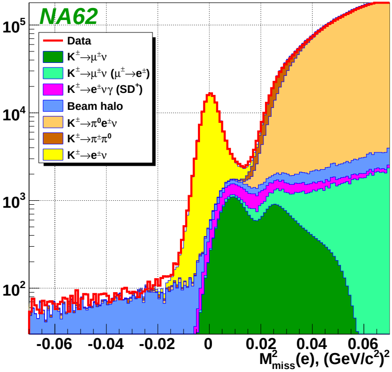
Signal Events

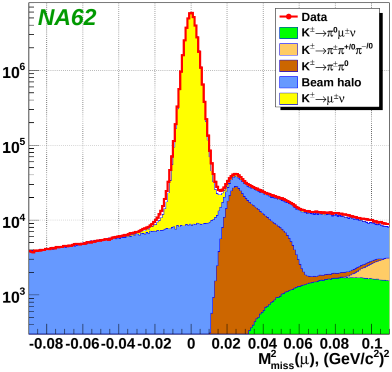


Backgrounds

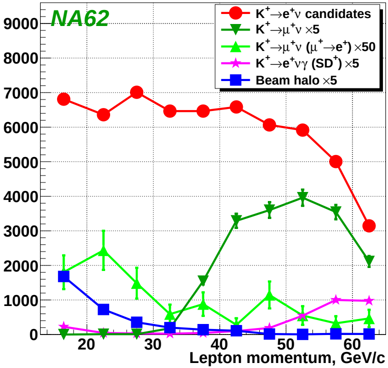
- $K_{\mu 2}$ in K_{e2} sample: Measured via Pb
- $K^{\pm} \to e^{\pm}\nu\gamma$ in K_{e2} sample: Determined via MC based on NA48 measurement
- $K^{\pm} \to \pi^{0}e^{\pm}\nu$, $K^{\pm} \to \pi^{\pm}\pi^{0}$: Missing mass, measured missid of an $\pi^{\pm}$ as $e^{\pm}$
- $K^{\pm} \to \pi^{0}\ell^{\pm}\nu$, $K^{\pm} \to \pi^{\pm}\pi^{0}$, with $\pi^{0} \to \gamma e^{+}e^{-}$: MC simulations.

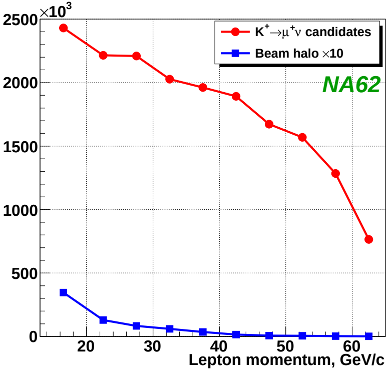
Missing Mass Spectra



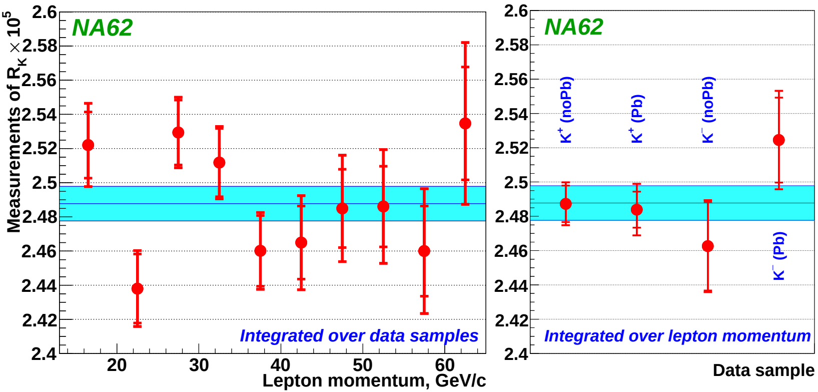


Number of Events





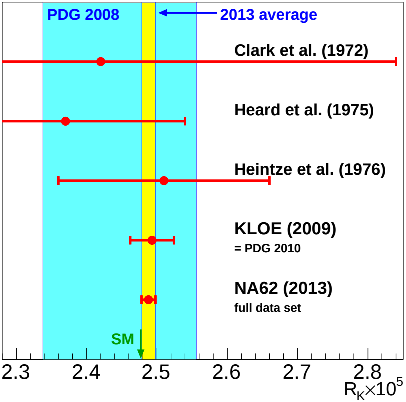
Systematics of R_K



Final result

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

Published: PLB 719, 326
Precision 0.4 %,
still factor 10 more than theory precision.
$\Rightarrow$ New measurement with improved statistics



$K^{\pm} \to \pi^{\pm}\gamma\gamma$

$K^{\pm} \to \pi^{\pm}\gamma\gamma$

Test of Chiral Pertubation Theory.
Kinematic Variables:

$$z = \frac{(q_1 + q_2)^2}{m_K^2} = \left(\frac{m_{\gamma\gamma}}{m_K}\right)^2, \quad y = \frac{p(q_1 - q_2)}{m_K^2}$$

q_1, q_2, p: 4-momenta of photons and kaon
$m_{\gamma\gamma}$: two photon invariant mass

$$0 \leq z \leq z_{\max} = (1 - m_\pi/m_K)^2 = 0.515$$

$$0 \leq y \leq y_{\max}(z) = \frac{1}{2}\sqrt{\lambda\left(1, (m_\pi/m_K)^2, z\right)},$$

$$\lambda(a, b, c) = a^2 + b^2 + c^2 - 2(ab + ac + bc)$$

$K^{\pm} \to \pi^{\pm}\gamma\gamma$

- Considerable phenomenological understanding
- Only small samples observed: $\mathcal{B} =\sim 10^{-6}$
  - BNL E787 (1997): 31 candidates
  - NA48/2 (2014): 149 candidates, $z > 0.2$
  - This measurement: 232 candidates, $z > 0.2$

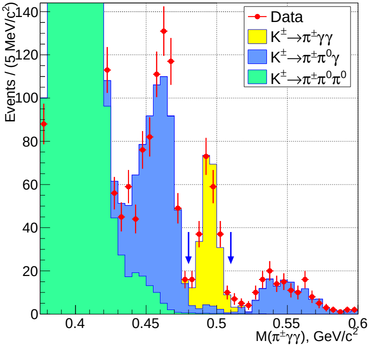
Data sample and trigger

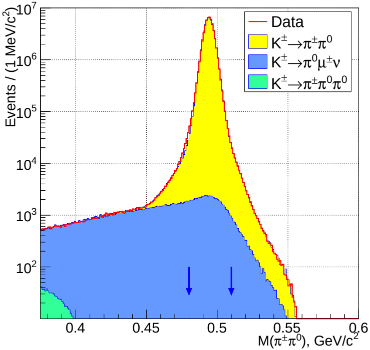
- Parallel datataking with R_K
- Minimum bias trigger, downscaled
- Branching ratio measured relativ to $K^{\pm} \to \pi^{+}\pi^{0}$, $\pi^{0} \to \gamma\gamma$

$$\mathcal{B}(K_{\pi\gamma\gamma}) = \frac{N'_{\pi\gamma\gamma}}{N'_{2\pi}} \cdot \frac{A_{2\pi}}{A_{\pi\gamma\gamma}} \cdot \frac{\varepsilon_{2\pi}}{\varepsilon_{\pi\gamma\gamma}} \cdot \mathcal{B}(K_{2\pi})\mathcal{B}(\pi^{0}_{\gamma\gamma}),$$

$N'_{\pi\gamma\gamma}$, $N'_{2\pi}$ signal and normalization events
$A_{\pi\gamma\gamma}$, $A_{2\pi}$: Acceptances
$\varepsilon_{\pi\gamma\gamma}$, $\varepsilon_{2\pi}$: Trigger efficiencies
$\mathcal{B}(K_{2\pi})\mathcal{B}(\pi^{0}_{\gamma\gamma}) = 0.204 \pm 0.001$

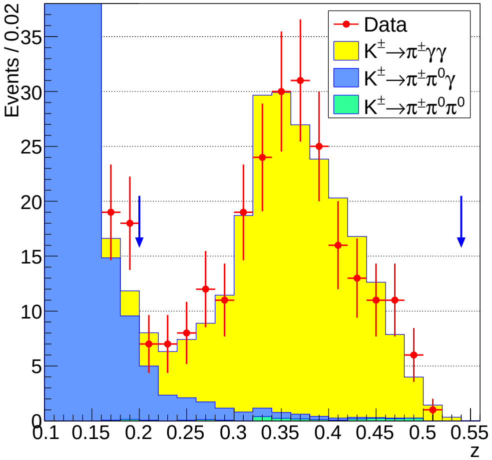
Signal Events





$\pi^{\pm}\gamma\gamma : z > 0.2(m_{\gamma\gamma} > 0.22\text{GeV}/c^2)$
$\pi^{\pm}\pi^{0} : m_{\gamma\gamma} = m_{\pi^0} \pm 10\,\text{MeV}/c^2$

z distribution of signal events



Model Independent Branching Ratio in z-bins

Bin z range	N_j	N_j^B	A_j	$\mathcal{B}_j \times 10^6$
0.20–0.24	14	7.32	0.177	0.024 ± 0.013
0.24–0.28	20	3.83	0.175	0.058 ± 0.016
0.28–0.32	30	1.97	0.169	0.104 ± 0.020
0.32–0.36	54	1.93	0.160	0.204 ± 0.029
0.36–0.40	56	1.00	0.146	0.237 ± 0.032
0.40–0.44	29	0.57	0.124	0.144 ± 0.027
0.44–0.48	22	0.54	0.087	0.155 ± 0.034
$z > 0.48$	7	0.25	0.026	0.162 ± 0.064

$$\mathcal{B}_{\mathrm{MI}}(z > 0.2) = \sum_{j=1}^{8} \mathcal{B}_j = (1.088 \pm 0.093_{\mathrm{stat}}) \times 10^{-6}$$

Chiral Pertubation Theory

Differential decay rate:

$$\frac{\partial\Gamma}{\partial y \partial z}(\hat{c}, y, z) = \frac{m_K}{2^9\pi^3}\Big[z^2\left(|A(\hat{c}, z, y^2) + B(z)|^2 + |C(z)|^2\right) + \left(y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z)\right)^2 |B(z)|^2\Big].$$

$A(\hat{c}, z, y^2)$, $B(z)$, $C(z)$ from $\mathcal{O}(p^4)$ and $\mathcal{O}(p^6)$ ChPT
Fit to z-distribution:

$$\hat{c}_4 = 1.93 \pm 0.26_{\text{stat}}, \quad \hat{c}_6 = 2.10 \pm 0.28_{\text{stat}}.$$

Results

This measurement:

$$\mathcal{B}_{\rm MI}(z > 0.2) = (1.088 \pm 0.093_{\rm stat} \pm 0.027_{\rm syst}) \times 10^{-6}.$$

$$\hat{c}_4 = 1.93 \pm 0.26_{\rm stat} \pm 0.08_{\rm syst}, \quad \hat{c}_6 = 2.10 \pm 0.28_{\rm stat} \pm 0.18_{\rm syst}$$

$$\mathcal{B}_{\rm ChPT} = (1.058 \pm 0.066_{\rm stat} \pm 0.044_{\rm syst}) \times 10^{-6}.$$

Combined with NA48/2 results:

$$\mathcal{B}_{\rm MI}(z > 0.2) = (0.965 \pm 0.061_{\rm stat} \pm 0.014_{\rm syst}) \times 10^{-6}.$$

$$\hat{c}_4 = 1.72 \pm 0.20_{\rm stat} \pm 0.06_{\rm syst}, \quad \hat{c}_6 = 1.86 \pm 0.23_{\rm stat} \pm 0.11_{\rm syst},$$

$$\mathcal{B}_{\rm ChPT} = (1.003 \pm 0.051_{\rm stat} \pm 0.024_{\rm syst}) \times 10^{-6} = (1.003 \pm 0.056) \times 10^{-6}.$$

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

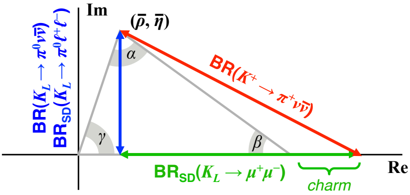
- An “old” dream: CKM finally. . .

Rare kaon decays

FCNC processes dominated by Z-penguin and box diagrams

Short-distance amplitudes related to V_{CKM} with minimal non-parametric uncertainty

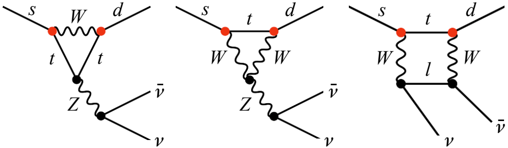
Rate measurements overconstrain V_{CKM} and may provide evidence for new physics



Decay	Γ_{SD}/Γ	Theory err.*	SM BR × 10^{-11}	Exp. BR × 10^{-11}
$K_L \to \mu^+\mu^-$	40%	20%	681 ± 32	684 ± 11
$K_L \to \pi^0 e^+e^-$	40%	10%	35 ± 10	< 28†
$K_L \to \pi^0\mu^+\mu^-$	30%	15%	14 ± 3	< 38†
$K^+ \to \pi^+\nu\bar{\nu}$	90%	4%	7.8 ± 0.8	17 ± 12
$K_L \to \pi^0\nu\bar{\nu}$	>99%	2%	2.4 ± 0.4	<26000†

*Approx. error on LD-subtracted rate excluding parametric contributions †90% CL

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



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$
$$x_q \equiv m_q^2 / m_W^2$$

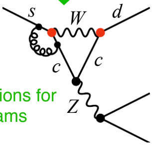
Loop functions favor top contribution

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

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 \quad \leftarrow \not{C}\not{P}$$

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

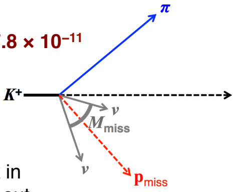
Hadronic matrix element obtained from $\mathrm{BR}(K_{e3})$ via isospin rotation



QCD corrections for charm diagrams contribute to uncertainty

$K^{+} \to \pi^{+}\nu\bar{\nu}$: Signal and background

Signal:
$BR_{SM} \sim 7.8 \times 10^{-11}$



K track in
π track out
No other particles in final state
$M^2_{miss} = (p_K - p_\pi)^2$

NA62 goal:
Measure BR to 10% → **100 signal events**
S/B ~ 10

10^{13} K decays with:
- Acceptance ~10%
- Background rejection ~10^{12}
- Background known to ~10%

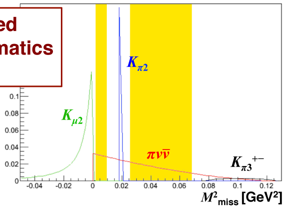
Decay backgrounds

Mode	BR
$\mu^{+}\nu(\gamma)$	63.5%
$\pi^{+}\pi^{0}(\gamma)$	20.7%
$\pi^{+}\pi^{+}\pi^{-}$	5.6%
$\pi^{0}e^{+}\nu$	5.1%
$\pi^{0}\mu^{+}\nu$	3.3%
$\pi^{+}\pi^{-}e^{+}\nu$	4.1×10^{-5}
$\pi^{0}\pi^{0}e^{+}\nu$	2.2×10^{-5}
$\pi^{+}\pi^{-}\mu^{+}\nu$	1.4×10^{-5}
$e^{+}\nu(\gamma)$	1.5×10^{-5}

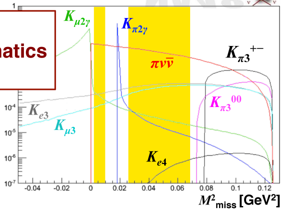
Other backgrounds
- Beam-gas interactions
- Upstream interactions

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

Closed kinematics 92%



Open kinematics 8%



$m^2_{miss} = 0$ or m_π^2 to reject $\mu\nu$, $\pi\pi^0$ ➔ 2 fiducial regions in m^2_{miss}

- High resolution m^2_{miss} reconstruction
- Precise measurement of p_K and p_π
- Minimize multiple scattering

High-rate beam tracker
Low-mass spectrometer in vacuum

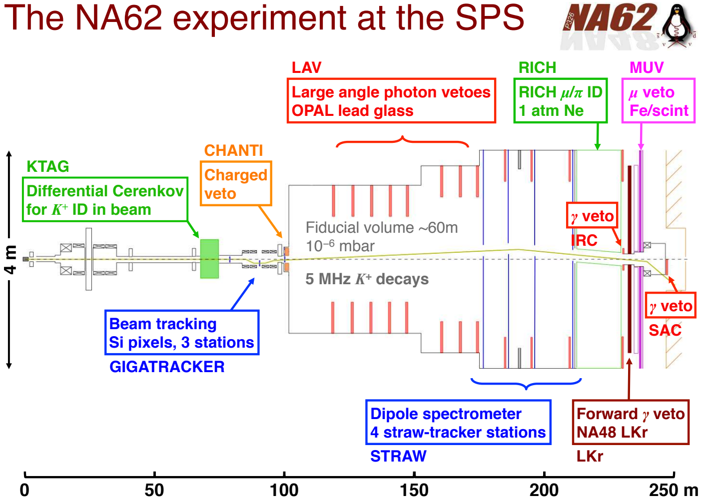
Rejection from kinematics alone: 10^{-4} at best

(Further) rejection relies on PID and vetoes

- Veto detectors for π^0 rejection
- K^+ identification in hadron beam
- Detectors for π/μ separation

Hermetic γ vetoes
Non-destructive beam ID
Secondary particle ID
Muon vetoes

The NA62 experiment at the SPS



K12 high-intensity K^+ beamline

Primary SPS proton beam:

- p = 400 GeV protons
- 3 × 10^{12} protons/pulse (3× NA48/2)
- Duty factor ~ 0.3
  Expect similar to 4.8s/16.8 s duty cycle for NA48/2
  Simultaneous beam delivery to LHC

High-intensity, unseparated secondary beam

- Momentum selection chosen to optimize K decays
- p = 75 GeV (1.4× more K^+ than NA48/2)
- $\Delta p/p$ ~ 1% (3× smaller than NA48/2)
- Beam acceptance 12.7 μstr (32× NA48/2)

Total rate 750 MHz { **525 MHz π**, **170 MHz p**, **45 MHz K** }

Decay volume

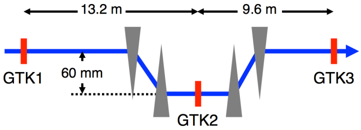
- 60 m long, starting at z = 102 m from target
- 10% of K^+ decay in FV ($\beta\gamma c\tau$ = 560 m)

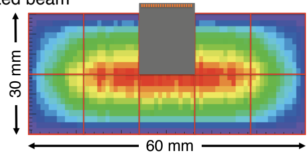
4.5 × 10^{12} K^+ decays/yr = 45× NA48/2

High-rate, precision tracking

Beam tracking: Gigatracker

3 planes of hybrid Si pixel detectors: 1 sensor, 10 bump-bonded readout chips
Tracks individual particles in 750 MHz unseparated beam





Pixel size 300 × 300 µm² → σ_p/p **~ 0.2%,** σ_θ **= 16 µrad**

Secondary tracking: 4 straw chambers in vacuum

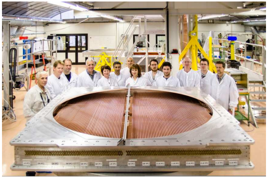
4 chambers, 2.1 m in diameter
16 layers (4 views) of straws per chamber

$\sigma \leq 130$ µm (1 view)
0.45X_0 per chamber

➡

σ_p/p **= 0.32% ⊕ 0.008%** p
$\sigma_{\theta(K\pi)}$ **= 20-50 µrad**

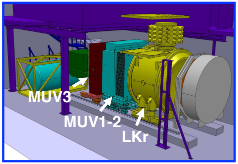
MNP33 dipole: 0.36T ($\Delta p_\perp$ = 270 MeV)



Particle identification

NA62

Primary μ/π separation from downstream muon vetoes (MUV)



MUV1-2: Fe/scintillator hadron calorimeter

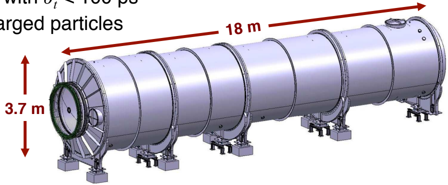
- Used offline to provide principal veto for $K \to \mu\nu$
- Rejects μ to 10^{-5}

MUV3: Fast μ identification for trigger

- Vetoes μ online at 10 MHz with $\sigma_t < 1$ ns

RICH provides additional 10^{-2} μ rejection to exclude $K \to \mu\nu$

- μ/π separation to better than 1% for $15 < p < 35$ GeV
- Measures π crossing time with $\sigma_t < 100$ ps
- Provides L0 trigger for charged particles
- Ne gas at 1 atm
  $p_{\text{thresh}} = 12$ GeV for π
- 2000 8-mm PMTs on upstream flanges



Beam timing and PID

Gigatracker (750 MHz) ← **Must precisely match events** → **Downstream detectors (~10 MHz)**

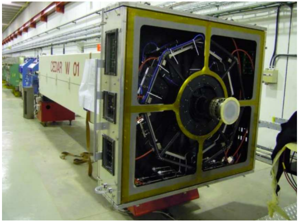
Matching downstream π track to wrong beam particle leads to 3× increase in $\sigma(m_{\text{miss}})$
Use detectors with good time resolution to avoid mismatching:

Gigatracker: σ_t **< 200 ps/station**
KTAG: σ_t **= 100 ps**
RICH: σ_t **< 100 ps**

Mismatch probability < 1%
Still accounts for half of kinematic rejection inefficiency

Non-destructive beam PID using KTAG differential Cerenkov counter

- Identifies 45 MHz of K^+ in 750 MHz of unseparated beam
- Beam ID fundamental to suppress background from beam-gas interactions
  Without KTAG, need 10^{-6} mbar vacuum in decay tank!
- Original CEDAR-W design, now running with H_2 at 3.85 bar
- Completely new, high segmentation readout



Hermetic photon vetoes

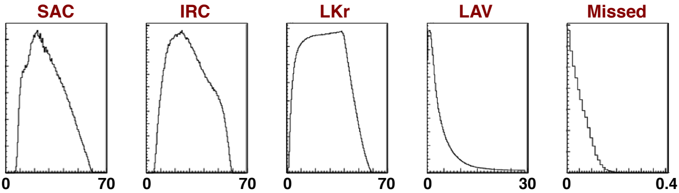
BR($K^+ \to \pi^+\pi^0$) = 21%

- Kinematic rejection (M^2_{miss}) = 10^{-4}
- Cut $p_{\pi+} < 35$ GeV gives $\pi^0 \to \gamma\gamma$ with 40 GeV
- Remaining events have 2γ in one of three configurations:

81.2%	Both γ in forward vetoes
18.6%	1γ in forward vetoes, 1γ in LAVs
0.2%	1γ in LAVs, 1γ undetected

Detector	θ [mrad]	Max. $1-\varepsilon$
LAV	8.5 - 50	10^{-4} at 200 MeV
LKr	1 - 8.5	10^{-3} at 1 GeV 10^{-5} at 10 GeV
IRC+SAC	< 1	10^{-4} at 5 GeV

Photon energy deposited in detector [GeV]



Photon veto detectors

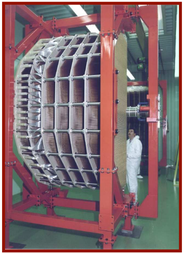
Large-angle vetoes (LAV)
$8.5 < \theta < 50$ mrad

12 stations at intervals of ~10m along vacuum decay volume

4-5 rings/station of lead glass blocks salvaged from OPAL EM barrel calorimeter

$1-\varepsilon$ for e^- at 200 MeV: $(1\pm1)\times10^{-4}$
Tagged e^- at Frascati BTF

NA48 liquid krypton calorimeter (LKr)
$1 < \theta < 8.5$ mrad



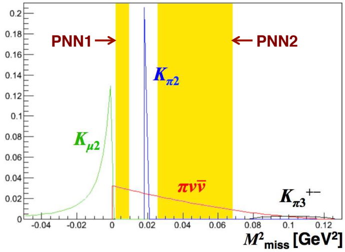
Quasi-homogeneous ionization calorimeter

Readout towers 2×2 cm^2 - 13248 channels

Depth 127 cm = 27 X_0

$1-\varepsilon$ for γ with E > 10 GeV: < 8×10^{-6}
$\pi\pi^0$ and e^- bremsstrahlung events in NA48

Performance for $K^+ \to \pi^+\nu\bar{\nu}$



Acceptance: ~12%

3% in PNN1 region
9% in PNN2 region
50% loss from momentum cut
Detector inefficiencies included

45 signal events/yr

- 1 track with $15 < p_\pi < 35$ GeV and π PID in RICH
- No γs in LAV, LKr, IRC, SAC
- No μs in MUVs
- 1 beam particle in Gigatracker with K PID by KTAG
- z_{vtx} in 60 m fiducial volume

Expected backgrounds	
$K^+ \to \pi^+\pi^0$	10%
$K^+ \to \pi^+\pi^0\gamma_{IB}$	3%
$K^+ \to \mu^+\nu$	2%
$K^+ \to \mu^+\nu\gamma_{IB}$	1%
$K^+ \to \pi^+\pi^+\pi^-$	< 1%
K^+_{e4}, other 3 track decays	< 1%
K^+_{e3}, $K^+_{\mu3}$	negligible
Total	**< 20%**

Prospects to improve on R_K

New detectors for $K \to \pi\nu\bar{\nu}$ will significantly increase background rejection

RICH:
100× more suppression of background from $K_{\mu 2}$ with catastrophic bremsstrahlung

Hermetic photon vetoes:
$K_{e2\gamma}$(SD+) reduced 35× by detecting radiative γ explicitly in LAV, IRC, SAC

Beam spectrometer & CEDAR:
Precise time measurements of incoming kaons and decay products
Reduces beam halo to negligible level

Only significant remaining background: $K_{\mu 2}$ with $\mu \to e$ decay in flight
~0.3%, well understood

NA62 will have abundant statistics

Required statistical uncertainty ~0.05% (~4M K_{e2} candidates)

Required kaon decay flux: $N_K \sim 10^{12}$
Expected NA62 kaon flux: $N_K \sim 10^{13}$
] **~1 month of data taking sufficient**

NA62 sensitivity for LFNV 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.

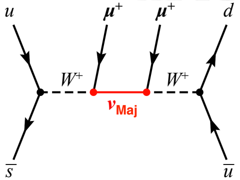
NA62 single-event sensitivities: **~10^{-12} for K^+ decays**; **~10^{-11} for π^0 decays**

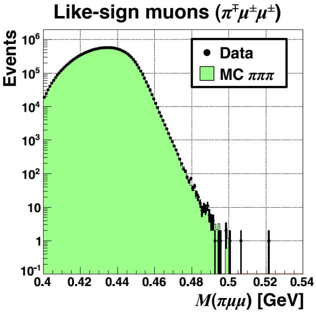
Lepton number violation: $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$

LNV in $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ could provide evidence for Majorana nature of neutrino

NA48/2 (2011) PLB697
BR($\pi^{\mp}\mu^{\pm}\mu^{\pm}$) < 1.1 × 10^{-9} 90%CL

$\langle M_{\mu\mu}\rangle < 0.3$ TeV





NA48/2

52 candidate events with $M(\pi\mu\mu) \sim m_K$

In agreement with MC background prediction

- Unusual $\pi\pi\pi$ topology with 2 $\pi \to \mu$ decays
- 1 of $\pi \to \mu$ between magnet & last DC

NA62

60× increase in kaon flux

Increased $p_{\perp}$ kick in will eliminate $K_{\pi 3}$ background without p_{π} cut

Potential sensitivity ~ 10^{-12}

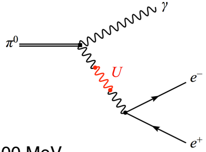
Rare π^0 decays in NA62

2×10^{12} π^0 decays in FV in 2 years of data will allow substantial improvement of results in many channels

Mode	Current knowledge	Experiment	Expectation in SM	Physics interest
Neutral modes				
$\pi^0 \rightarrow 3\gamma$	$BR_{90CL} < 3.1\times10^{-8}$	Crystal Box	Forbidden	Violates C
$\pi^0 \rightarrow 4\gamma$	$BR_{90CL} < 2\times10^{-8}$	Crystal Box	$BR \sim 10^{-11}$	Scalar states $\pi^0 \rightarrow SS$
$\pi^0 \rightarrow$ inv	$BR_{90CL} < 2.7\times10^{-7}$	BNL 949	$BR < 10^{-13}$ (cosm. limit)	N_ν, LFV
Charged modes				
$\pi^0 \rightarrow e^+e^-e^+e^-$	$BR = 3.34(16)\times10^{-5}$	KTeV	$3.26(18)\times10^{-5}$	Off-shell vectors
$\pi^0 \rightarrow e^+e^-\gamma$	$BR_{95CL}(\pi^0\rightarrow U\gamma)$: $< 1\times10^5$, $M_U = 30$ MeV $< 3\times10^6$, $M_U = 100$ MeV	WASA/COSY	Null result	Dark forces

Rare π^0 decays in NA62

Search for U boson in $\pi^0 \to e^+e^-\gamma$ decay



New, light vector gauge boson with weak couplings to charged SM fermions

Could mediate interactions of dark-matter constituents

Expect to collect ~10^8 $\pi^0 \to e^+e^-\gamma$ decays/year

Mass resolution M_{ee} ~ 1 MeV

Potential for ~100× improvement in BR limit for 30 < M_U < 100 MeV

Search for $\pi^0 \to$ invisible

$\pi^0 \to \nu\bar{\nu}$ forbidden by angular momentum conservation if νs are massless
For a given flavor of massive $\bar{\nu}$, BR($\pi^0 \to \nu\bar{\nu}$) directly related to m_ν

Direct experimental limit:

BNL 949 (2005)
BR($\pi^0 \to$ inv) < 2.7 × 10^{-7} 90%CL

Inferred limits on BR($\pi^0 \to \nu\bar{\nu}$) from:

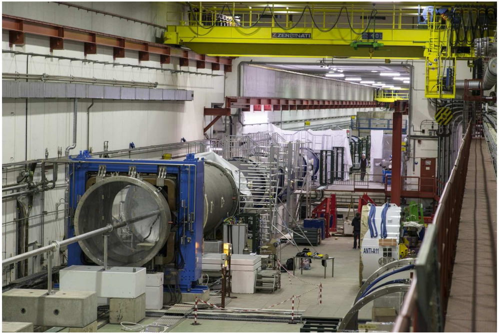
Measured ν_τ mass: < 5 × 10^{-10}
Astrophysics/cosmology: < 3 × 10^{-13}

Experimental signature identical to $K^+ \to \pi^+\nu\bar{\nu}$

Only difference: in $K^+ \to \pi^+\pi^0$, $\pi^0 \to$ invisible, π^+ has 2-body decay kinematics

Limit BR($\pi^0 \to$ invisible) to less than 10^{-9}, ~100× better than present limits

Experimental status



Installing/installed: **KTAG, LAV (9/12), LKr (readout), SAC**

Under construction: **CHANTI, STRAWS, RICH, IRC, MUV**

Advanced design stage: **Gigatracker**

NA62 will take 2 years of data starting late 2014

Conclusions

- NA62 is a new rare kaon decay experiment at CERN SPS.
- Will start full data taking end of 2014
- Took data with existing detectors in 2007/2008
- Published result on Lepton Universitality
- Published result on ChPT tests in $K^{\pm} \to \pi^{\pm}\gamma\gamma$
- working on more results
- Will measure $\sim$ 100 events of $K^{+} \to \pi^{+}\nu\bar{\nu}$
- Will measure a long list of rare and ultrarare K^{+}, π^{0}, and π^{+} decays