R_K and $K^+ \rightarrow \pi^+ \nu\nu$ with NA62 at CERN SPS

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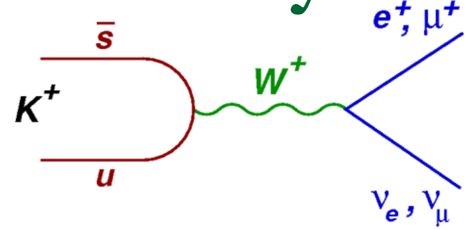
On behalf of the NA62 collaboration

Outline

- R_K measurement with NA62: final result
- $BR(K^+ \to \pi^+ \nu\nu)$ measurement with NA62: status of the experiment

$R_K = \Gamma(K^\pm \to e^\pm \nu)/\Gamma(K^\pm \to \mu^\pm \nu)$: Theory

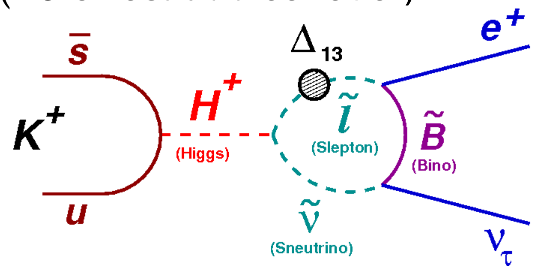
- SM: $$R_K = \frac{\Gamma(K^\pm \to e^\pm \upsilon)}{\Gamma(K^\pm \to \mu^\pm \upsilon)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \cdot \left(1 + \delta R_K^{\text{rad.corr.}}\right)$$



  - Prediction: $R_K = (2.477 \pm 0.001) \times 10^{-5}$ [Phys. Rev.Lett. 99 (2007) 231801]
    - Hadronic uncertainties cancel in the ratio.
    - Strong helicity suppression.
    - Radiative correction (few %) due to $K \to e\nu\gamma$ (IB) included by definition in R_K

- Beyond SM:
  - Model with 2 Higgs doublets (e.g. 2HDM-II MSSM) and LFV sources in the right-handed slepton sector [PRD 74 (2006) 011701].
    - Potentially sizeable effects at 1-loop level at large tanβ (no effect at tree level)

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



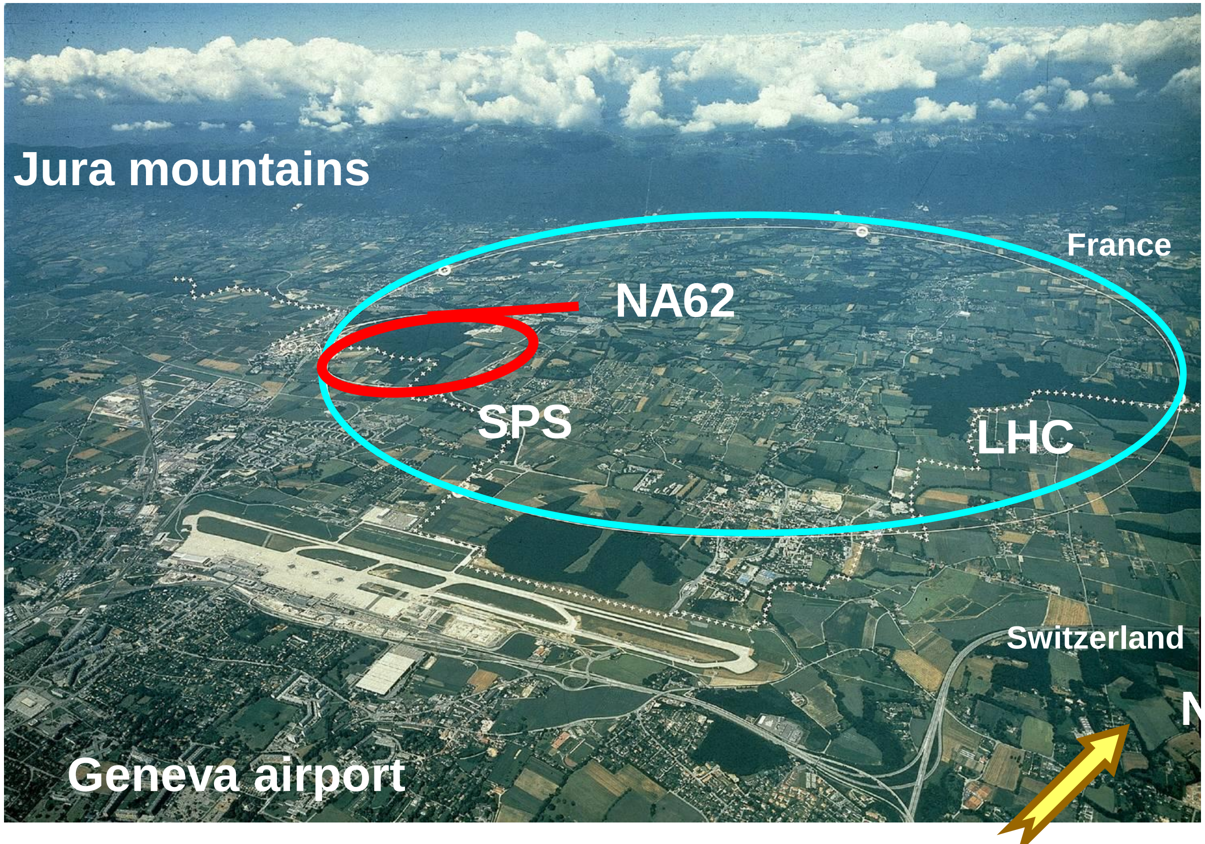
    - Sensitivity: up to % level after tuning of the parameters: experimentally accessible
    - Higher enhancement in B sector , but experimentally challenging

R_K: Experiments

- PDG '08 [1970s measurement] : $R_K = (2.45 \pm 0.11) \times 10^{-5}$
  - $\delta R_K/R_K = 4.5\%$
- KLOE [Eur. Phys, J. C 64 (2009) 627]: $R_K = (2.493 \pm 0.031) \times 10^{-5}$
  - Data collected in 2001-2005
  - 13.8×10^3 $K \rightarrow e\nu$ decays and 16% background
  - $\delta R_K/R_K = 1.3\%$
- NA62:
  - Dedicated 4 months data taking in 2007
  - Goals:
    1. 150×10^3 $K\rightarrow e\nu$ decays
    2. <10% background

$\Rightarrow$ $\delta R_K/R_K < 0.5\%$

NA62 Experiments @ CERN



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

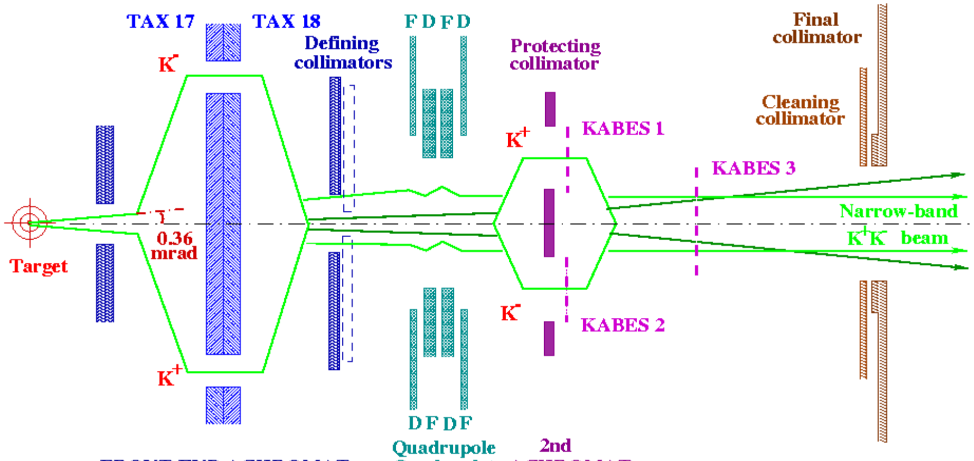
Kaon Physics @ CERN SPS:

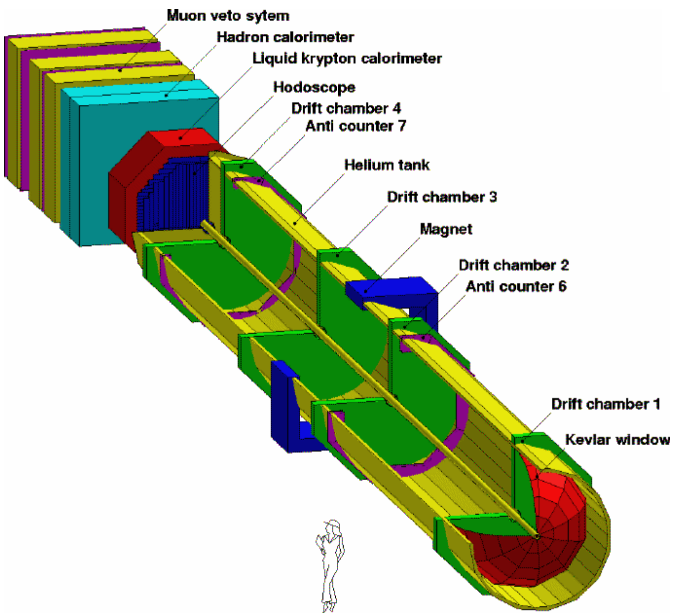
1995-2001: NA48 ε'/ε
2002: NA48/1 $K_S \to l^+l^-$
2003-2004: NA48/2 CPV $K^\pm$
From 2007: NA62

NA62
2007-2008 R_K measurement
2007-2011 R&D for $K^+ \to \pi^+\nu\nu$ 2011-2014 Construction and installation of the new detectors
2012 $K^+ \to \pi^+\nu\nu$ Technical run
2014 $K^+ \to \pi^+\nu\nu$ Physics run

NA62 Layout (R_K measurement)

- $K^{\pm}$ beams:
  - $P_K = 75 \pm 2$ GeV/c





- Main Detectors (NA48):
  - Magnetic Spectrometer: $\sigma(P)/P = 0.48\% \oplus 0.009\, P(\text{GeV/c})\%$
  - Hodoscope: Fast trigger for charged particles and timing for the event ($\sigma(t) = 200$ ps)
  - Liquid Kripton e.m. calorimeter (LKr): $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ (GeV)

R_K: NA62 Measurement Strategy

- $K^\pm \to e^\pm \nu$ (K_{e2}) , $K^\pm \to \mu^\pm \nu$ ($K_{\mu 2}$) collected simultaneously:
  - No dependence on K flux
  - Cancellation of several effects at first order

$$R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \frac{A(K_{\mu 2}) \times f_\mu \times \varepsilon(K_{\mu 2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \frac{1}{f_{LKr}} \frac{1}{D}$$

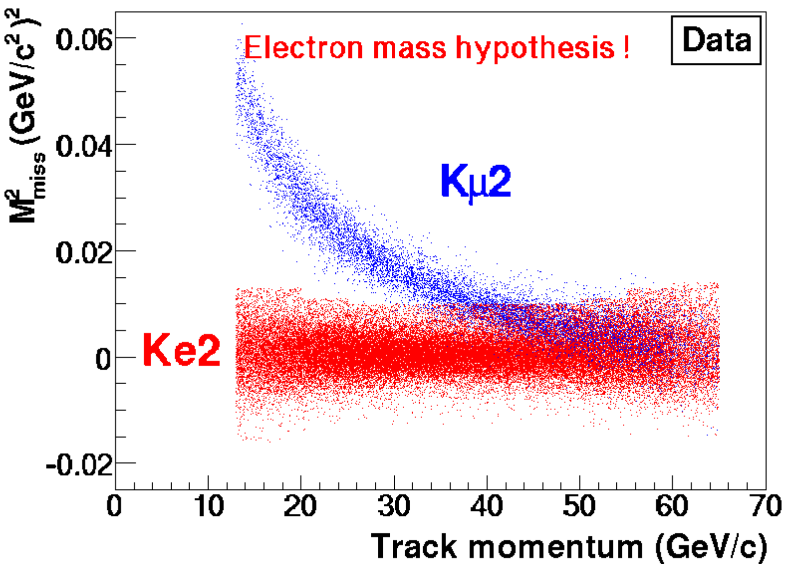
  - $N(K_{e2})$, $N(K_{\mu 2})$: selected candidates
  - $N_B(K_{e2})$, $N_B(K_{\mu 2})$: background, evaluated with data and/or MC
  - $A(K_{e2})$, $A(K_{\mu 2})$: geometrical acceptance (MC), track reconstruction efficiency (MC/data)
  - f_e, f_μ: particle ID efficiency, evaluated with data
  - $\varepsilon(K_{l2})$: trigger efficiency, evaluated with data
  - f_{LKr} : global e.m. calorimetric inefficiency, evaluated with data
  - D : downscaling factor of $K_{\mu 2}$, evaluated with data

- Analysis in 10 lepton momentum bins and 4 data samples.

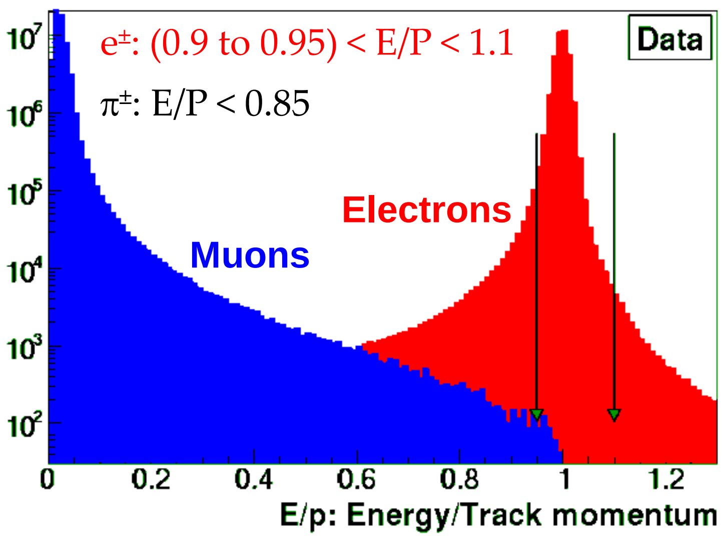
R_K Measurement: K_{e2} and $K_{\mu2}$ Selection

- Common selection criteria:
  - $<P_K>$ reconstructed from $K^\pm \to \pi^\pm \pi^+ \pi^-$
  - 1 track in the acceptance of the subdetectors downstream.
  - Decay vertex in the fiducial region upstream.
  - Photon veto using LKr downstream.

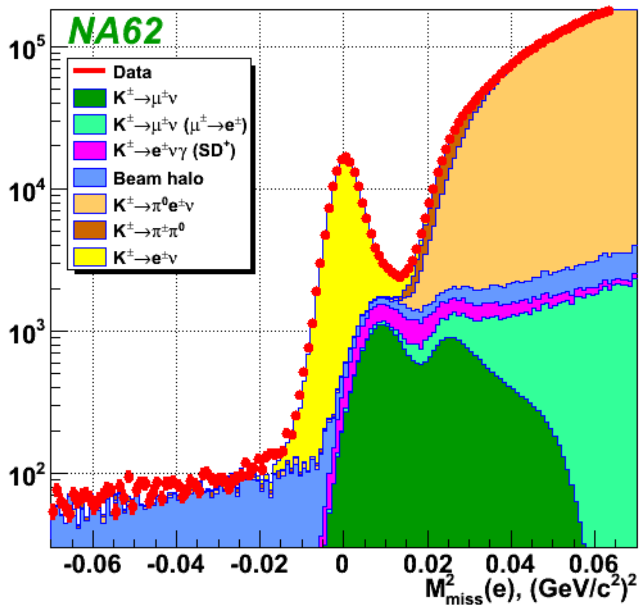
- Kinematic separation:
  - $M^2_{miss} = (P_K - P_l)^2$ (e^+ hypothesis)

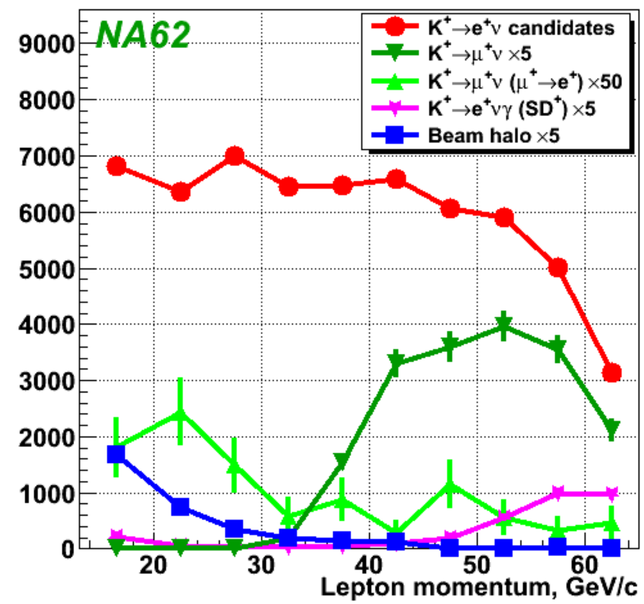


- Lepton identification:
  - E/P = ratio between LKr energy deposit and track momentum measured with the spectrometer



R_K Measurement: Signal and Background



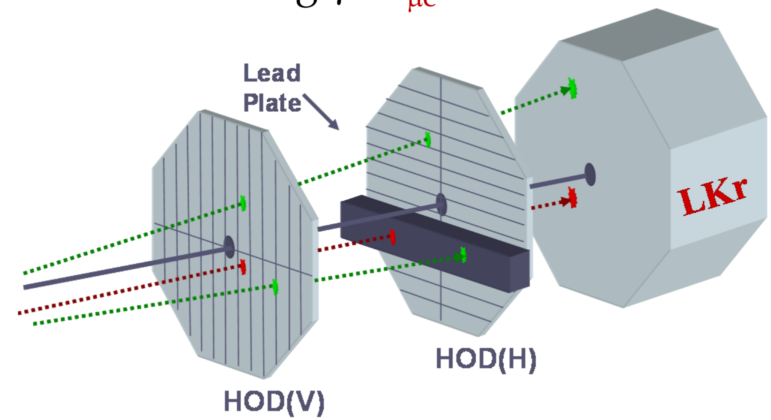


- Full 2007 data sample analyzed:
  - 145'958 $K^\pm \to e^\pm \nu$ (K_{e2}) candidates
  - (99.28 ± 0.05)% e^+ ID efficiency (measured using $K^\pm \to \pi^0 e^\pm \nu$ and $K_L \to \pi^\pm e^\mp \nu$)
  - (10.95 ± 0.27)% B/(S+B) in K_{e2} sample
  - 42.82M $K^\pm \to \mu^\pm \nu$ ($K_{\mu 2}$) candidates
  - (0.50 ± 0.01)% B/(S+B) in $K_{\mu 2}^+$ sample

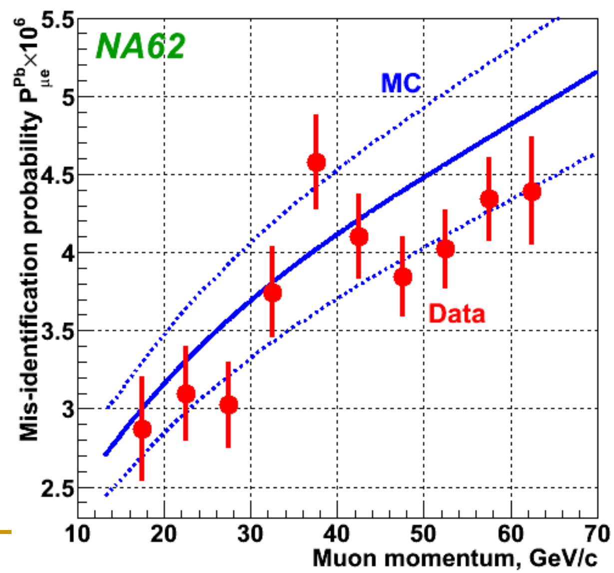
Decay	B/(S+B)
$K^\pm \to \mu^\pm \nu$	(5.64 ± 0.20)%
$K^\pm \to \mu^\pm \nu$ ($\mu \to e$)	(0.26 ± 0.03)%
$K^\pm \to e^\pm \nu \gamma$ (SD+)	(2.60 ± 0.11)%
$K^\pm \to \pi^0 e^\pm \nu$	(0.18± 0.09)%
$K^\pm \to \pi^\pm \pi^0$	(0.12 ± 0.06)%
Wrong Sign K	(0.04 ± 0.02)%
Beam halo	(2.11 ± 0.09)%

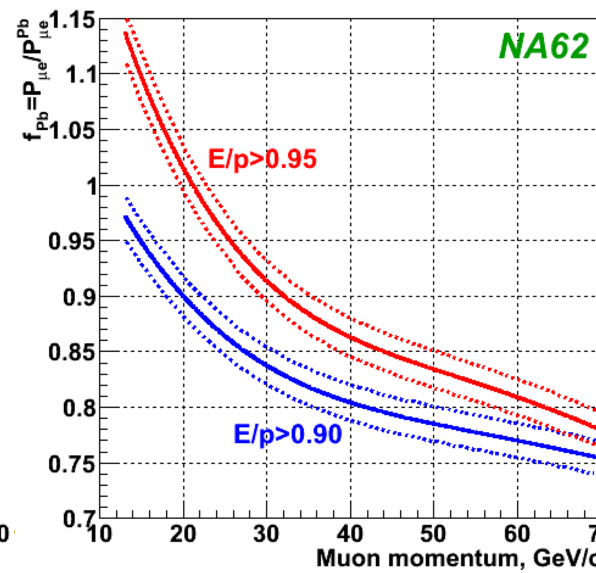
R_K Measurement: Background Analysis

- $K^{\pm}\rightarrow\mu^{\pm}\nu$ background in K_{e2}: source
  - μ catastrophic energy loss in LKr by emission of a bremmstrahlung γ: $P_{\mu e} = 3\text{x}10^{-6}$
- $K^{\pm}\rightarrow\mu^{\pm}\nu$ background in K_{e2}: measurement
  - Lead plate in front of LKr ($9.2X_0$, 20% total area) in order to provide pure μ sample in the LKr.
  - $P_{\mu e}$ measured on the selected pure μ sample
  - $P_{\mu e}$ corrected with Geant4 MC for μ energy loss and bremmstrahlung in the lead plate.

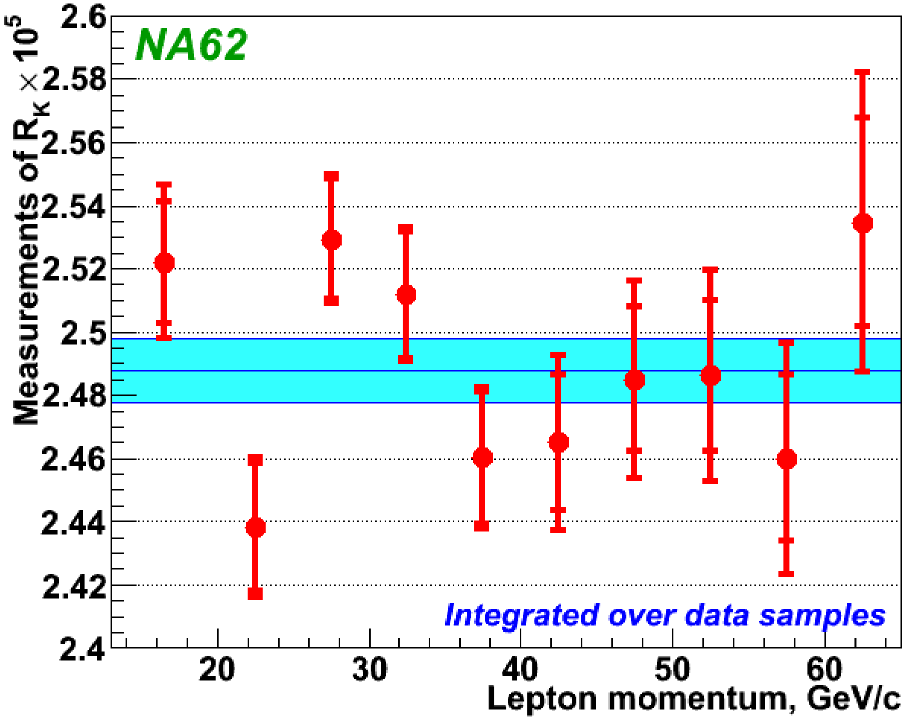


- Result:
  - B/(S+B) = (5.64±0.20)%
    - Uncertainty 3 times smaller than using MC only
    - $(\delta P_{\mu e}/ P_{\mu e})_{MC}$ ~10%
    - $(\delta f_{Pb}/f_{Pb})_{MC}$ ~2%





R_K: Final Result (full 2007 data set)



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

[Full data set: article to be submitted in 2012]

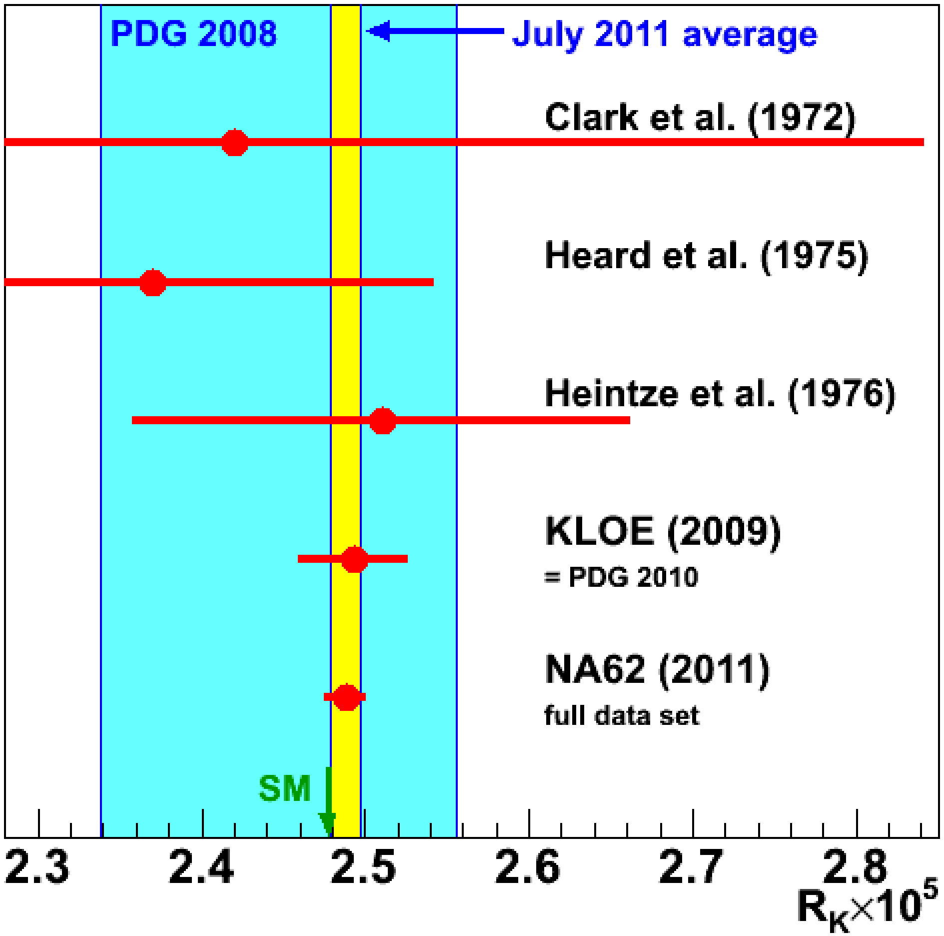
[40% 2007 data set published: Phys. Lett. B 698 (2011) 105]

Uncertainties

Source	$\delta R_K x 10^{-5}$
Statistical	**0.007**
$K_{\mu 2}$ background	0.004
$K^\pm \to e^\pm \nu\gamma$ (SD+) background	0.002
$K^\pm \to \pi^0 e^\pm \nu$,$K^\pm \to \pi^\pm \pi^0$ background	0.003
Beam halo background	0.002
Matter composition	0.003
Acceptance correction	0.002
Spectrometer alignment	0.001
Electron ID efficiency	0.001
1-track trigger efficiency	0.002
LKr readout inefficiency	0.001
Total	**0.010**

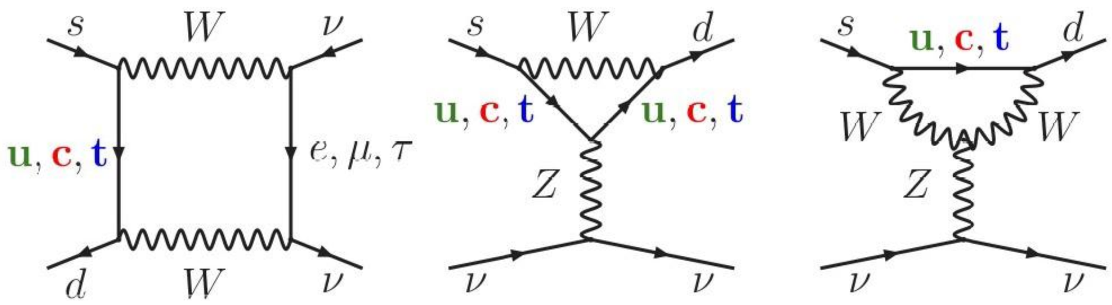
R_K Measurement: Conclusion

- World average: $R_K = (2.488 \pm 0.009) \times 10^{-5}$



The $K \to \pi \nu \bar{\nu}$ decays: a theoretical clean environment

- FCNC loop processes: $s \to d$ coupling and highest CKM suppression



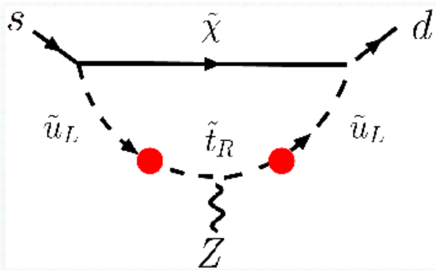
- Very clean theoretically: SD contributions dominate.
  - top quark contribution computed at NLO QCD and 2-loop EW corrections;
  - c quark loop contribution computed at NNLO QCD and NLO EW corrections;
  - correction for LD contributions;
  - hadronic matrix element related to the precisely measured $BR(K^+ \to \pi^0 e^+ \nu)$.
- BR proportional to $|V_{ts}^* V_{td}|^2$ → theoretical clean V_{td} dependence
- SM predictions [Brod, Gorbahn, Stamou, Phys. Rev. D 83, 034030 (2011)] :
  - $BR(K_L \to \pi^0 \nu \nu) = (2.43 \pm 0.39 \pm 0.06) \times 10^{-11}$
  - $BR(K^+ \to \pi^+ \nu \nu) = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$

Parametric error dominated by V_{cb}, ρ

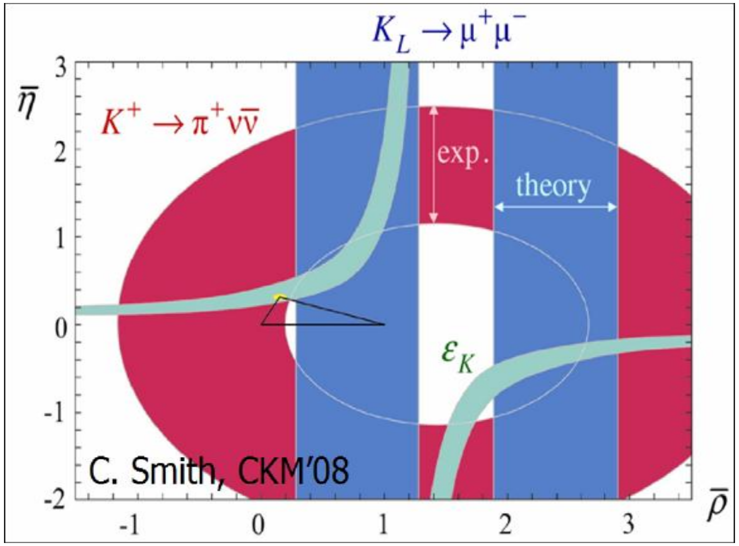
Pure theoretical error, mostly LD corrections

Experimental Measurements and NP Sensitivity

- Sensitive NP probe complementary to LHC
- Best probe of non-MFV (G.Isidori ESPP Open Symposium)
  - E.g. non-MFV in up-squarks trilinear terms.



- Present experimental results:
  - $BR(K^+ \to \pi^+ \nu\nu) = (1.73\,^{+1.15}_{-1.05}) \times 10^{-10}$ [E787, E959]
  - $BR(K_L \to \pi^0 \nu\nu) < 2.6 \times 10^{-8}$ [E391a]



- Upcoming experiments:
  - NA62 @ CERN
  - KOTO @ JPARC
  - ORKA @ Fermilab

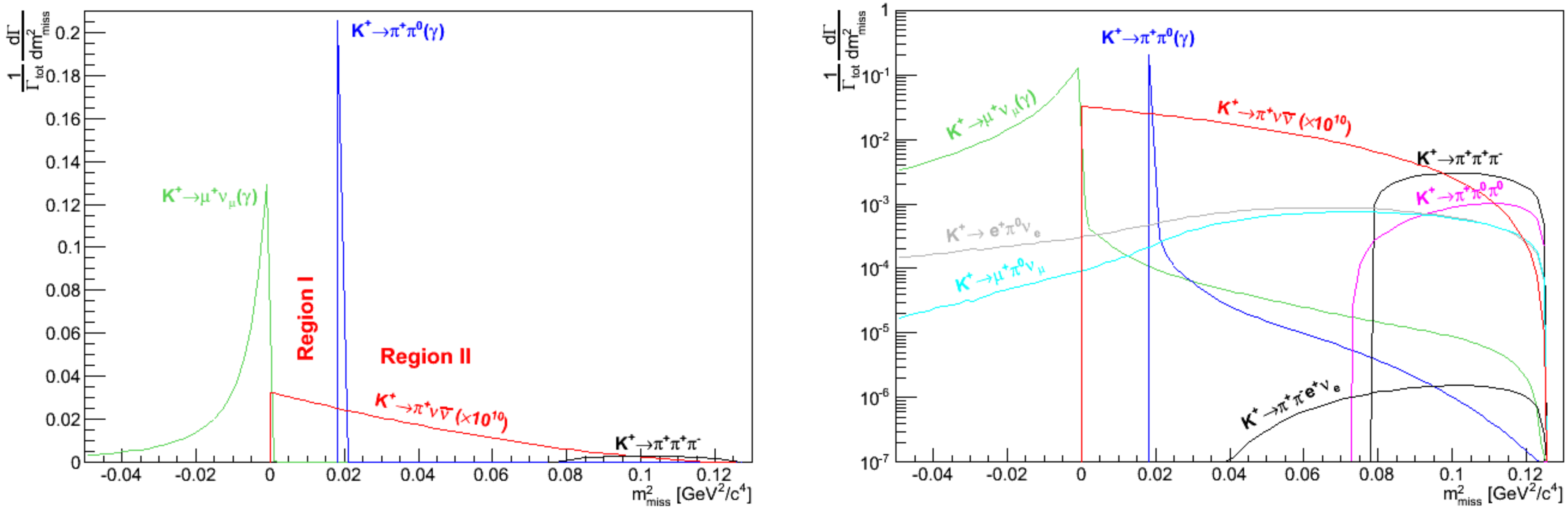
The NA62 Experiment for $K\to\pi\nu\bar{\nu}$: Goals

- Goal: 10% precision branching ratio measurement of $K^+\to\pi^+\nu\nu$
  - O(100) SM $K^+\to\pi^+\nu\bar{\nu}$ events (2 years of data taking)
  - % level systematics
- Requirements
  - Statistics:
    - BR(SM) ~ 8 x 10^{-11}
    - Acceptance: ~ 10%
    - K decays (2 years): 10^{13}

    Kaon intensity   Signal efficiency
  - Systematics:
    - $>10^{12}$ background rejection (i.e. <20% background)
    - <10% precision background measurement

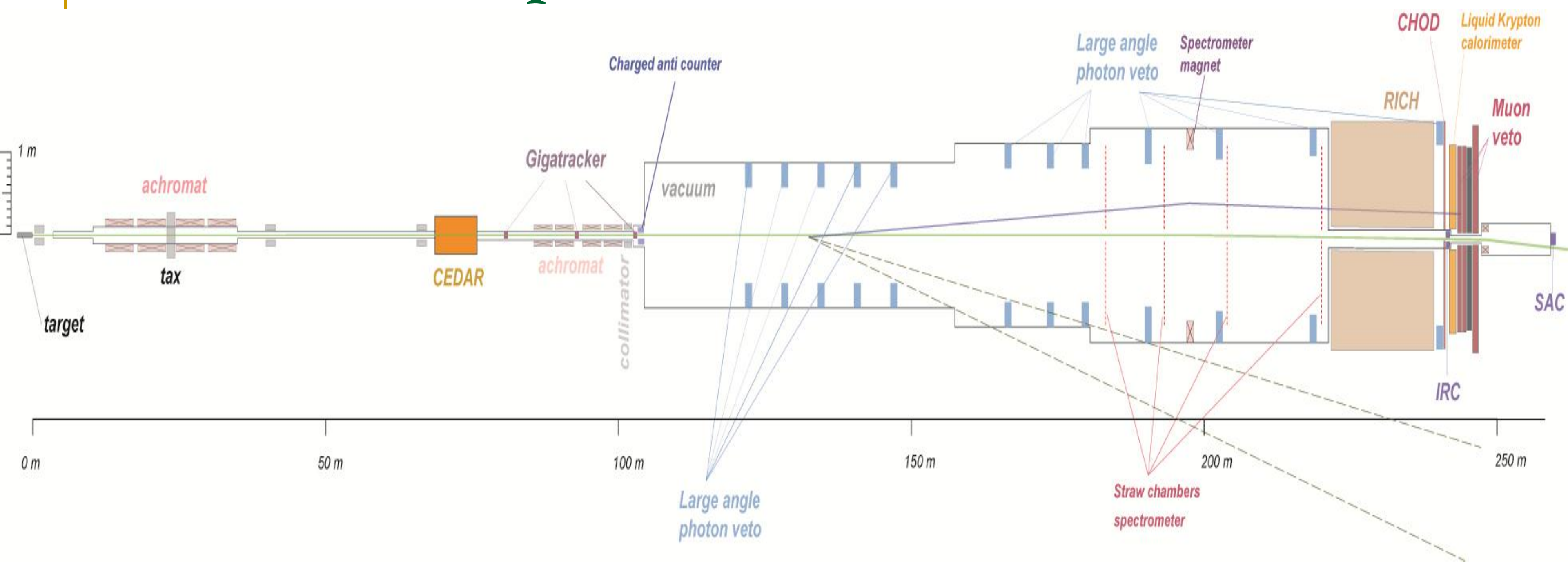
    Signal purity & detector redundancy
- Technique
  - "High" momentum K^+ beam
  - Decay in-flight technique

Signal Definition: $m^2_{miss} = (P_K - P_\pi)^2$



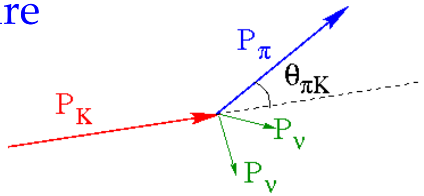
- 90% of K^+ BR well separated from signal: 2 signal regions in the m^2_{miss} spectrum
- Main sources of background contamination:
  - Region I:
    - Physical: radiative tails from $K^+ \to \mu^+\nu$, semileptonics
    - Experimental: resolution tails from $K^+ \to \mu^+\nu$ and $K^+ \to \pi^+\pi^0$ m^2_{miss} reconstruction
  - Region II:
    - Physical: radiative tails from $K^+ \to \mu^+\nu$ and $K^+ \to \pi^+\pi^0$, semileptonics, rare decays
    - Experimental: resolution tails from $K^+ \to \mu^+\nu$, $K+ \to \pi^+\pi^0$, $K \to \pi^+\pi^+(\pi^0)\pi^-(\pi^0)$.

The NA62 Experiment for $K \to \pi \nu \bar{\nu}$: Overview



- SPS proton beam @ 400 GeV/c
- P secondary charged beam 75 GeV/c ($\Delta P/P = 1\%$ unseparated $\to$ 6% K^+)
- Rate @ beam tracker 750 MHz, area 16 cm^2
- Rate downstream 10 MHz (K^+ decays mostly)
- K decay rates / year: 4.8×10^{12}

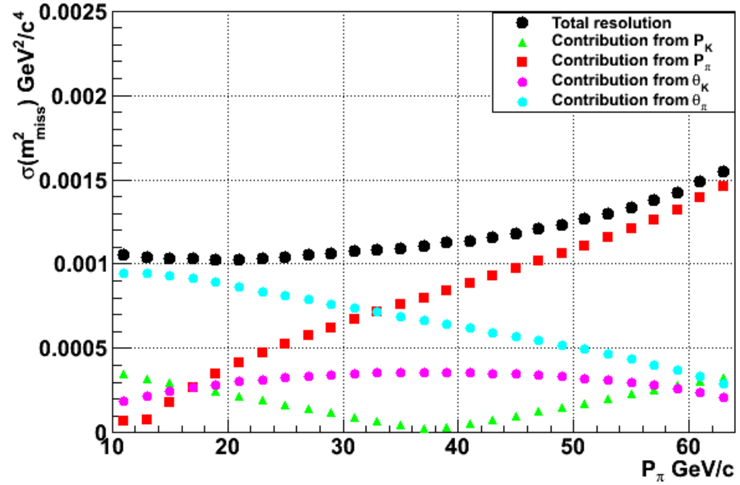
- Signal signature



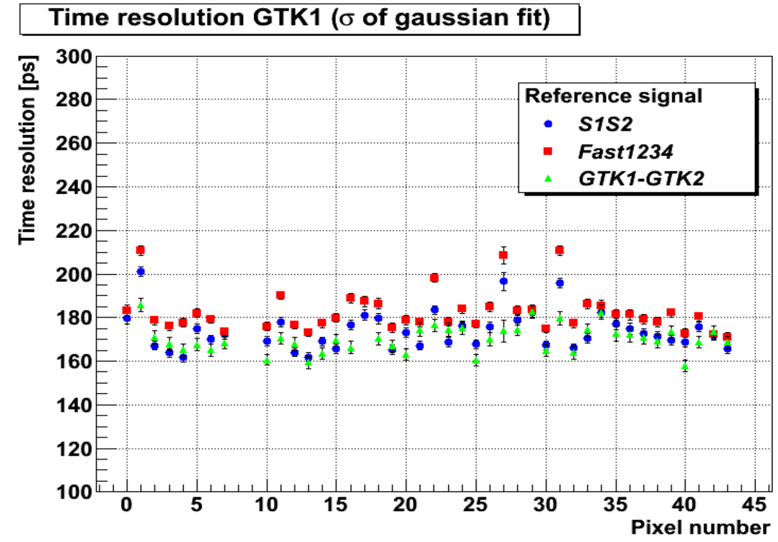
- Background
  - All the K^+ decay modes
  - Accidental single tracks

Experimental Principles

- Kinematic rejection (m^2_{miss}):
  - Minimal amount of material budget:
    - X/X_0 kaon spectrometer (Gigatracker, Si pixel): 1.5% total
    - X/X_0 pion spectrometer (Straw Chambers in vacuum) < 2% total



- Precise timing for K-π matching:
  - Gigatracker time resolution:
    < 200 ps / station
    (beam test results on a prototype)
  - RICH time resolution:
    < 80 ps [NIM A 593 2008]

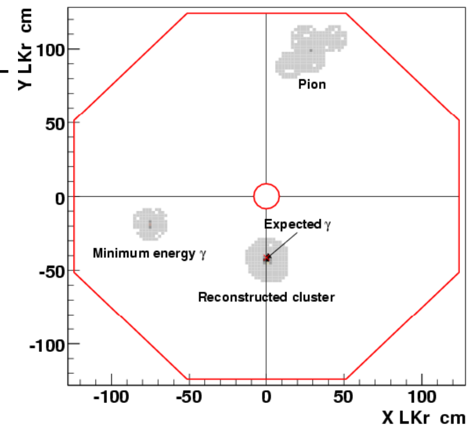


Experimental Principles

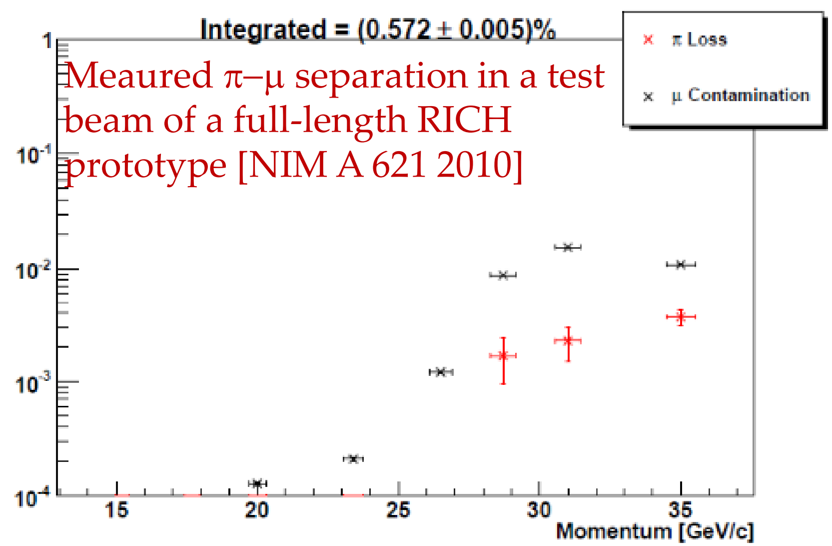
- High efficiency photon veto:
  - 10^{-8} π^0 veto inefficiency in $K^+ \to \pi^+\pi^0$ events
    - Offline analysis trick: $P_{\pi+} < 35$ GeV/c $\to E_{\pi 0} > 40$ GeV
    - 10^{-5} LKr inefficiency for $E_\gamma > 10$ GeV
    - Hermeticity up to 50 mrad and down to 500 MeV photons (LAV detectors)

Intrinsic LKr inefficiency measured using 2004 NA48/2 data

E_γ (GeV)	Inefficiency
2.5 – 5.5	$<10^{-3}$
5.5 – 7.5	$<10^{-4}$
7.5 – 10	$< 5 \times 10^{-5}$
> 10	$< 8 \times 10^{-6}$



- Particle ID
  - MUV and RICH for μ–π separation $\to$ totally independent ID methods
  - LKr and RICH for π–e separation $\to$ totaly indepedent ID methods
  - Cerenkov threshold counter on beam to control the beam induced background



Present Status and Schedule

- Expected sensitivity:
  - Analysis performed using GEANT4-based simulation and data from test beam and NA48/NA62 experiment.
  - 55 signal events/run year, <20% background level.
- Subdetectors construction well advanced

Straw chamber 1 in place

8 LAVs in place

CEDAR + new optics and electronics installed

- Trigger & readout chains under test "in situ"
- Technical run with beam scheduled for november - december 2012
  - Final beam, partial detector set-up
- Overall construction on schedule for the first physics run in autumn 2014.

Conclusions

- K decays are a very appealing laboratory to test NP effects
  - Good sensitivity and precise experimental results.
  - Complementarity to B physics in most of the cases.
- R_K measurement:
  - The NA62 measurement of R_K: 0.4% relative precision reached.
  - The SM precision is still 1 order of magnitude better.
  - NA62 could improve the precision down to 0.2% level (πνν set-up).
- BR($K^+ \to \pi^+ \nu\nu$) measurement with NA62.
  - Compelling physics case thanks to the high sensitivity of this decay to NP.
  - 10% precision BR measurement in 2 years of data taking planned.
  - **First Physics run in autumn 2014.**