Standard Model Tests at the NA62 CERN Experiment

Simone Bifani

University of Bern – ITP

on Behalf of the NA62 Collaboration

Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, IHEP, INR, Louvain, Mainz, Merced, Napoli, Perugia, Pisa, Roma I, Roma II, San Luis Potosi, SLAC, Sofia, Triumf, Torino

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Outline

NA62 Phase I: $R_K = \Gamma(K^{\pm} \rightarrow e^{\pm}\nu) / \Gamma(K^{\pm} \rightarrow \mu^{\pm}\nu)$

- Physics motivations
- Experimental setup
- Measurement strategy and analysis status

NA62 Phase II: $BR(K^{+} \rightarrow \pi^{+}\nu\nu)$

- Theoretical introduction
- Measurement principle
- Detector layout and R&D status

Search for New Physics

New physics effects in Flavour Physics

MFV: helicity suppressed observables are sensible to SUSY with large $\tan\beta$: $B \to ll$, $B \to l\nu$, $K \to l\nu$

The B decays are suppressed ($V_{ub} \ll V_{us}$) while the K_{e2} is $1.5 \cdot 10^{-5}$

Non-MFV: FCNC decays with high suppression in the standard model and clean theoretical prediction

The $K^+ \to \pi^+\nu\nu$ has a very clean SM prediction and has a λ^5 suppression

It's time for a precision measurement in K_{e2} and $K^+ \to \pi^+\nu\nu$!!!

NA62-I (2007-2008)

Lepton universality in kaon decays

NA62-II (2011-2012)

O(100) events measurement of $BR(K^+ \to \pi^+\nu\nu)$

[G.Isidori Capri, Flavianet 2008]

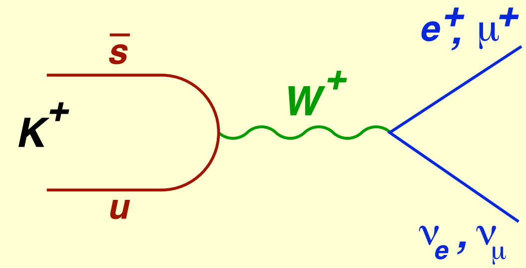
NA62 Phase I:

$R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$

Standard Model

Leptonic decays of light pseudoscalar mesons are the ideal test of SM and search for NP

- Not directly usable due to hadronic uncertainties
- Hadronic uncertainties cancel in the ratio $K_{e2}/K_{\mu2}$
- SM prediction is very accurate ($\delta R_K/R_K \sim 0.04\%$)



$$R_K^{SM} = \frac{\Gamma(K \to e\nu_e)}{\Gamma(K \to \mu\nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) =$$

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

The only difference between electron and muon channel is due to the V-A coupling

K_{e2} is strongly helicity suppressed (V-A coupling) -> Enhanced sensitivity to non-SM effects

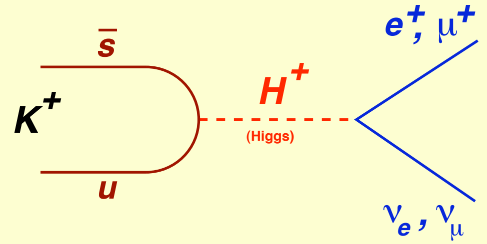
A small correction (few %) has to be included due to the IB radiative decay

[V.Cirigliano, I.Rosell JHEP 0710:005 (2007)]

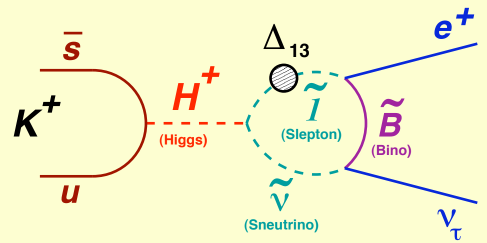
Beyond Standard Model

In the MSSM large $\tan\beta$ scenario, the presence of LFV terms (charged Higgs coupling) introduces extra contribution to the SM amplitude, enhancing the decay rate

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



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



Sizeable effects are predicted for reasonable SUSY parameters

$$\Delta_{13} = 5{\cdot}10^{-4},\ \tan\beta = 40,\ m_H = 500\ \text{GeV} \text{ -> } R_K^{LVF} \cong R_K^{SM}(1 + 0.013)$$

Analogous SUSY effects in pion decay are suppressed by a factor $(m_\pi/m_K)^4 \sim 6{\cdot}10^{-3}$

[Masiero, Paradisi, Petronzio, PRD 76, 2006]

Experimental Status

The **PDG08** value is based on 3 measurements in 70s

$R_K = (2.45 \pm 0.11) \cdot 10^{-5}$ (4.5% error)

but a better precision is needed when comparing with theoretical predictions

Preliminary results by KLOE and NA48/2

$R_K = (2.457 \pm 0.032) \cdot 10^{-5}$ (1.3% error)

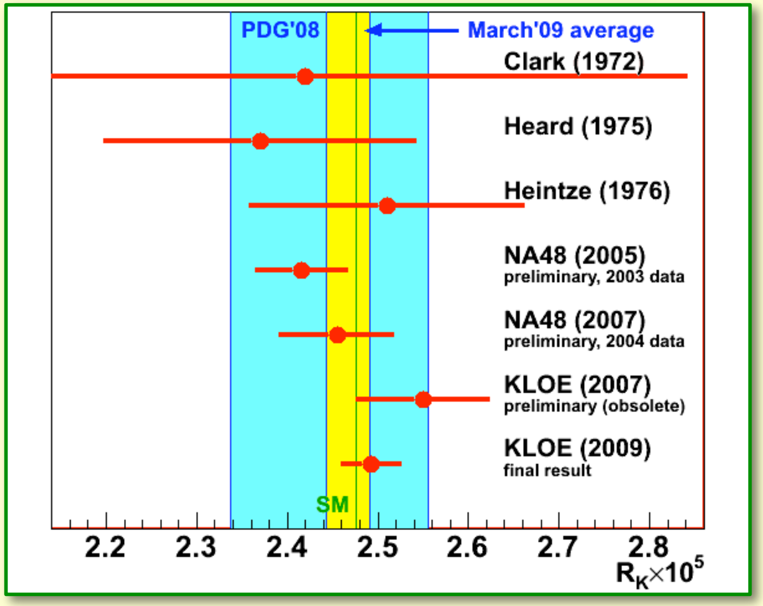
Final result by KLOE (LaThuile09)

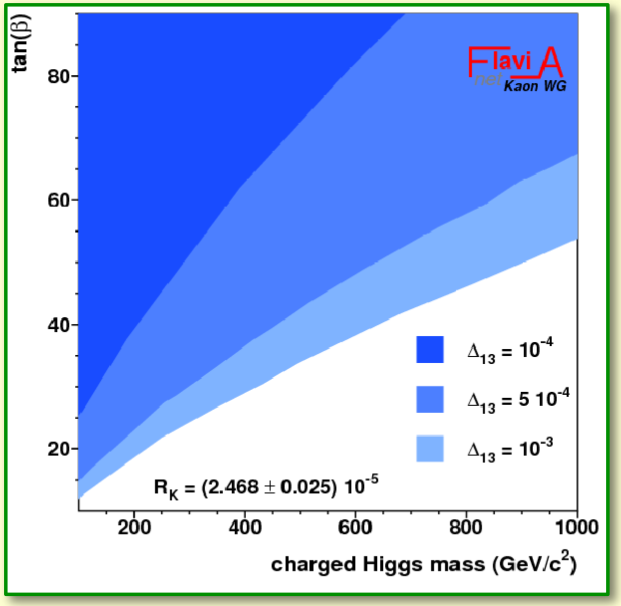
$R_K = (2.493 \pm 0.025 \pm 0.019) \cdot 10^{-5}$

(1.3% with ~13.8k K_{e2} candidates, 16% background)

World average

$R_K = (2.468 \pm 0.025) \cdot 10^{-5}$ (1% error)

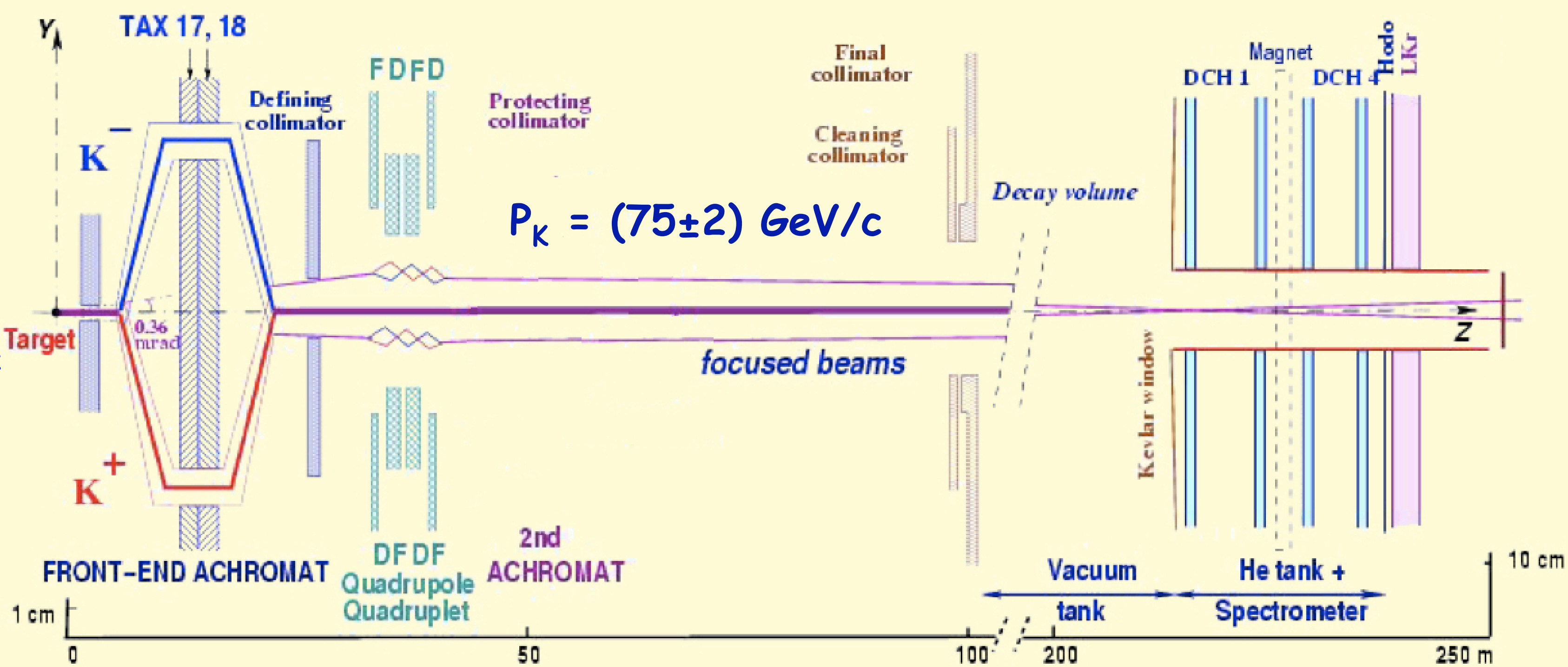




Beam

Beam setup and detector of NA48/2 experiment slightly optimized for K_{e2} measurement

$\sim 2 \cdot 10^{11}$ p/spil
400 GeV/c



> Simultaneous K^+ and K^- beams with narrow momentum band

> High K momentum to better separate K_{e2} and $K_{\mu2}$ events

Detector

Magnetic spectrometer (4 DCHs)

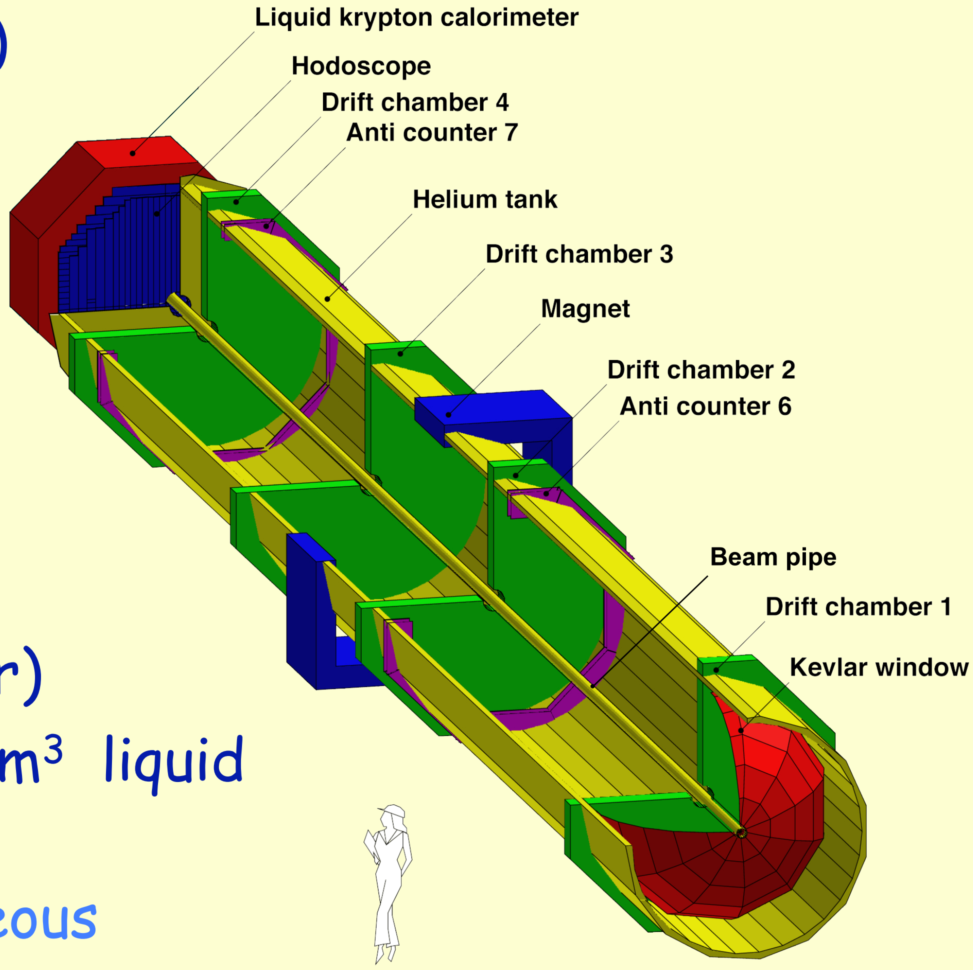
- 4 view / DCH -> high efficiency
- $\sigma_p/p = 1.0\% + 0.044\% \cdot p$ [GeV/c]

Hodoscope

- Fast trigger
- $\sigma_t = 150$ps

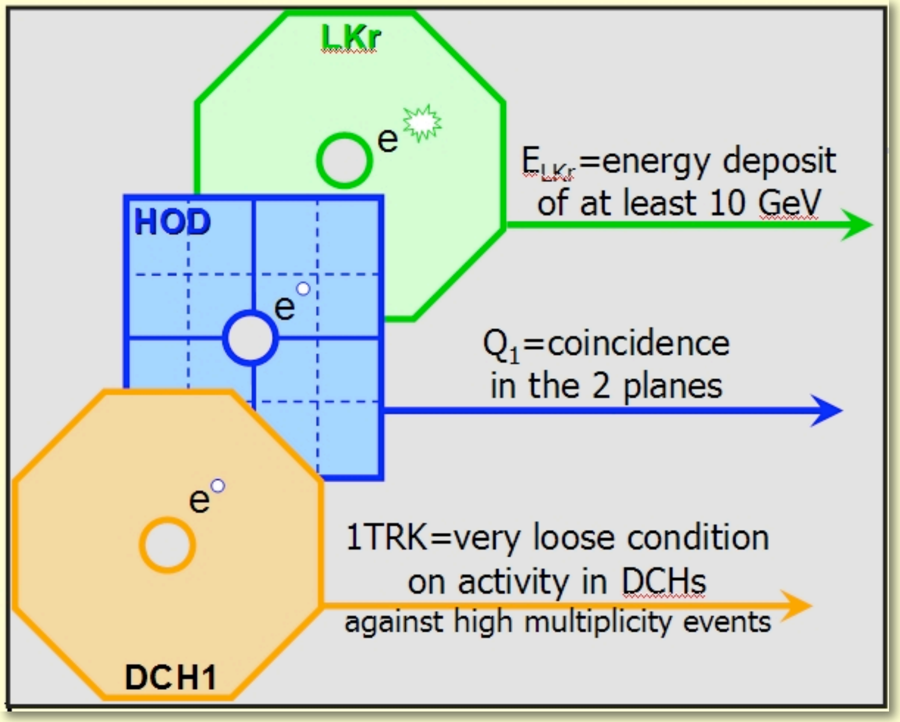
Electromagnetic calorimeter (LKr)

- 13248 cells (2×2 cm^2) in ~10 m^3 liquid krypton (~27 X_0 deep)
- High granularity, quasi-homogeneous
- $\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]
- $\sigma_{x,y}$ ~1 mm (@ 20 GeV)



Trigger

Fast hardware trigger: hodoscope, DCHs multiplicity & LKr energy



K_{e2}: 1TRK * Q_1 * E_{LKr}

$K_{\mu2}$: 1TRK * Q_1

Software trigger: on-line processing of DCHs & LKr information

- $p_{DCH} < 90$ GeV/c
- $E_{LKr}/p_{DCH} > 0.6$ (K_{e2} only)
- Auto-pass events & control triggers

Analysis Strategy

K_{e2} and $K_{\mu 2}$ candidates collected simultaneously

- Measurement independent of kaon flux
- Many systematic effects cancel in the ratio (@ first order)

MC simulation used to limited extent

- Acceptance correction (geometry)
- Correction for background from catastrophic energy loss of muons in the LK

Analysis in 10 bins of reconstructed lepton momentum

$$R_K = \underbrace{\frac{1}{D}}_{K_{\mu 2}\ \text{downscaling}} \; \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \; \frac{f_\mu \cdot A(K_{\mu 2}) \cdot \varepsilon(K_{\mu 2})}{f_e \cdot A(K_{e2}) \cdot \varepsilon(K_{e2})} \; \frac{1}{f_{LKR}}$$

Signal events — Particle ID eff — Trigger efficiency

$K_{\mu 2}$ downscaling — Background events — Geometrical acceptance — Global LKr readout eff

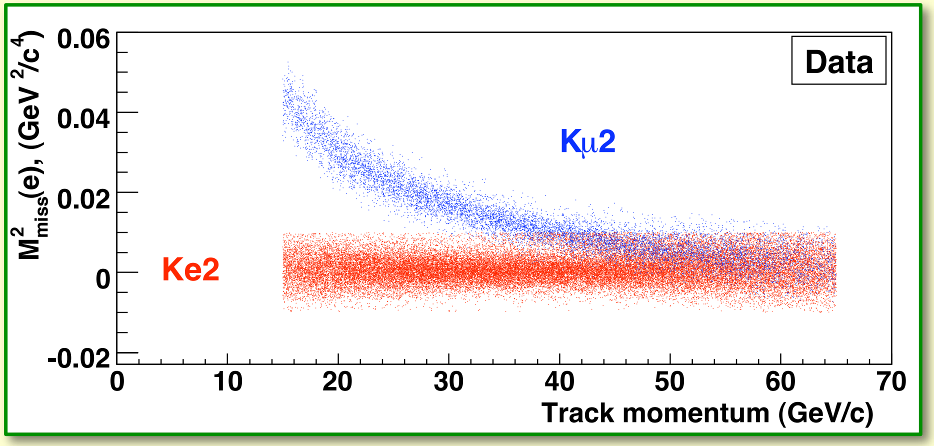
GOAL: Collect 150k K_{e2} events to measure R_K with an accuracy better than 0.5%

Event Selection

Similar kinematics and topology -> Maximize common cuts

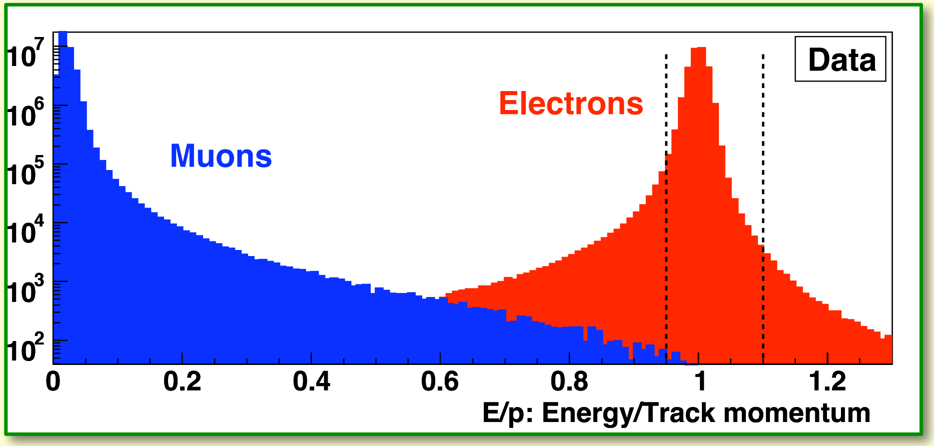
Common selection

- 1 reconstructed track
- common geometrical acceptance
- decay vertex defined as the closest distance of approach between track and kaon axis
- track momentum [15÷65] GeV/c



Kinematical identification

- 2 body decay $M^2_{miss} = (P_K - P_l)^2$ (kaon momentum measured with $K_{3\pi}$)
- $|M^2_{miss}| < 0.015$ GeV^2/c^4



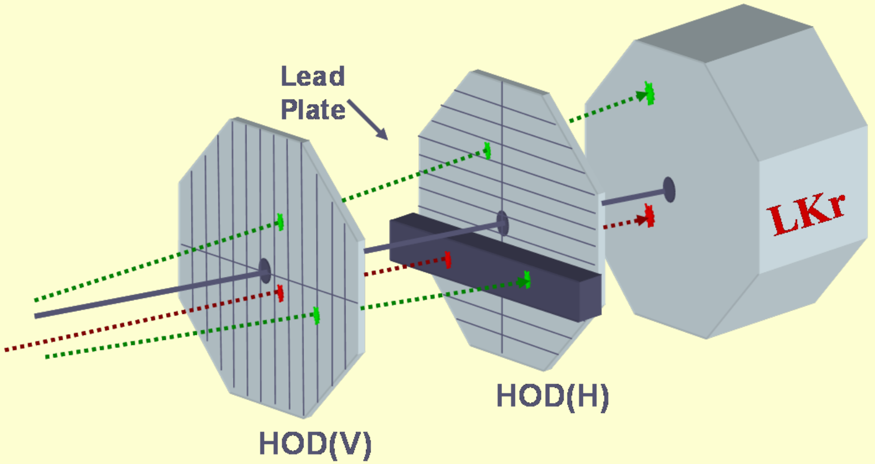
Particle identification

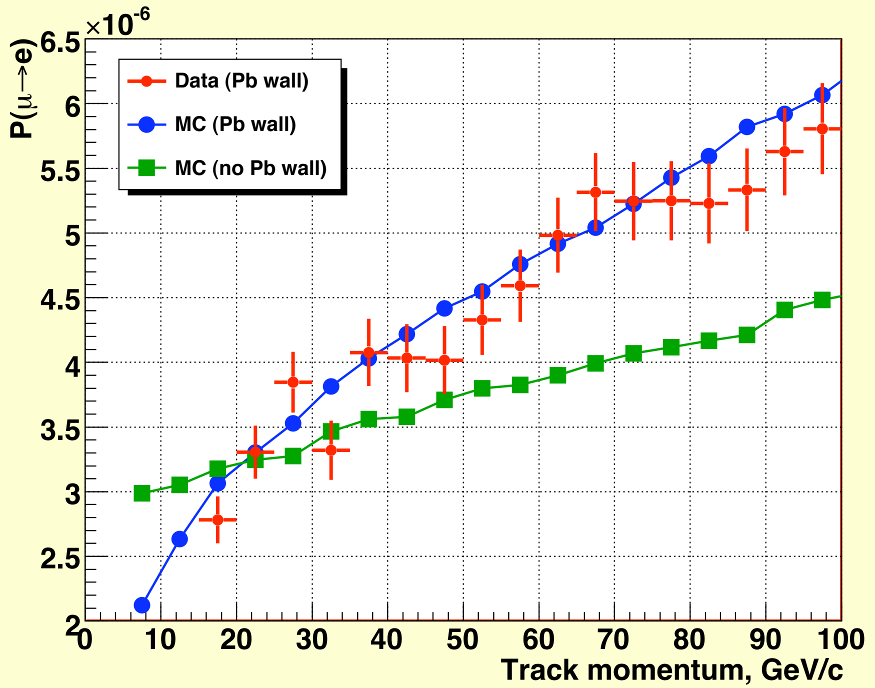
- e ($0.95 < E_{LKr}/p_{DCH} < 1.10$)
- μ ($E_{LKr}/p_{DCH} < 0.85$)

Background - I

- The main background in the K_{e2} sample comes from catastrophic energy loss of muons in the LKr ($E_{LKr}/p_{DCH} > 0.95$ -> tag events as K_{e2})
- It's important at high momentum where the missing masses are indistinguishable
- To measure directly $P(\mu\text{->}e)$ a "lead wall" (~8.9 X_0) has been installed on ~18% LKr surface for ~50% of the run time
- Tracks traversing the lead are pure muon samples (contamination < 10^{-7})
- The reliability of these technique has been studied in special "muon runs"
- The result agrees perfectly with GEANT4 simulation (p dependence)

$$P(\mu\text{->}e) \sim (3\div5)\cdot10^{-6}$$





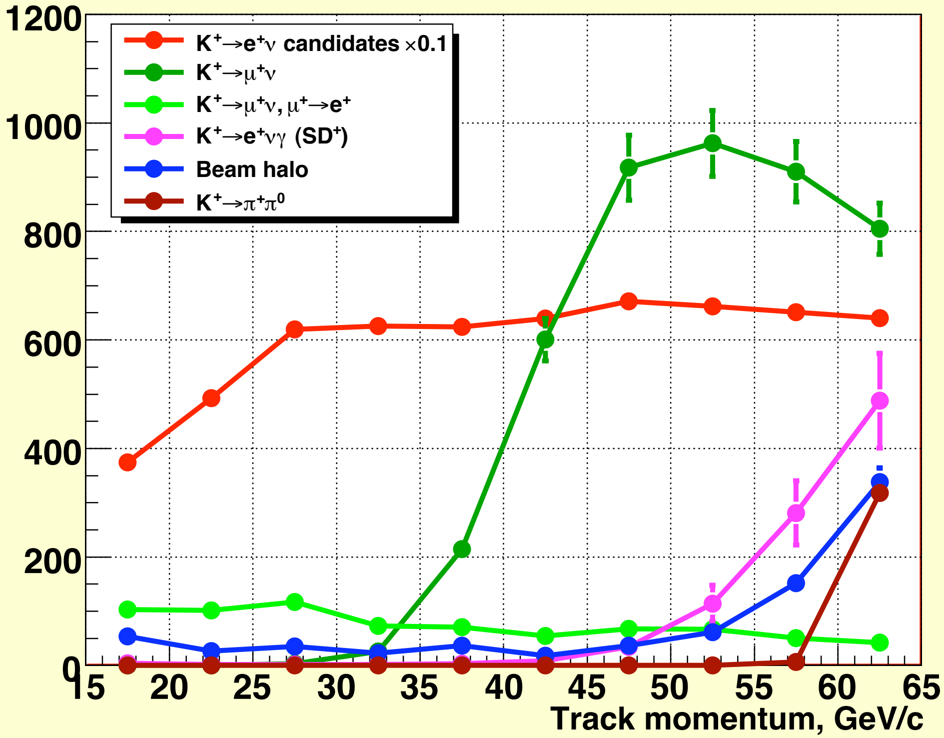
Background - II

K_{e2} background sources

- $K_{\mu 2}$ (CB) $(7.4 \pm 0.2)\%$
- $K_{\mu 2}$ (μ->e) $(1.3 \pm 0.1)\%$
  measured with MC (including also the contribution of μ decay in spectrometer)
- $K_{e2\gamma}$ (SD^+) $(1.6 \pm 0.3)\%$
  limited by the error on the measured BR (20%) (strong improvement expected by our new measurement)
- Beam halo $(1.3 \pm 0.1)\%$
  directly measured on data (special runs)
- $K_{2\pi}$ $(0.6 \pm 0.1)\%$
- K_{e3} ~0.1%

$K_{\mu 2}$ background sources

- Beam halo ~0.2%

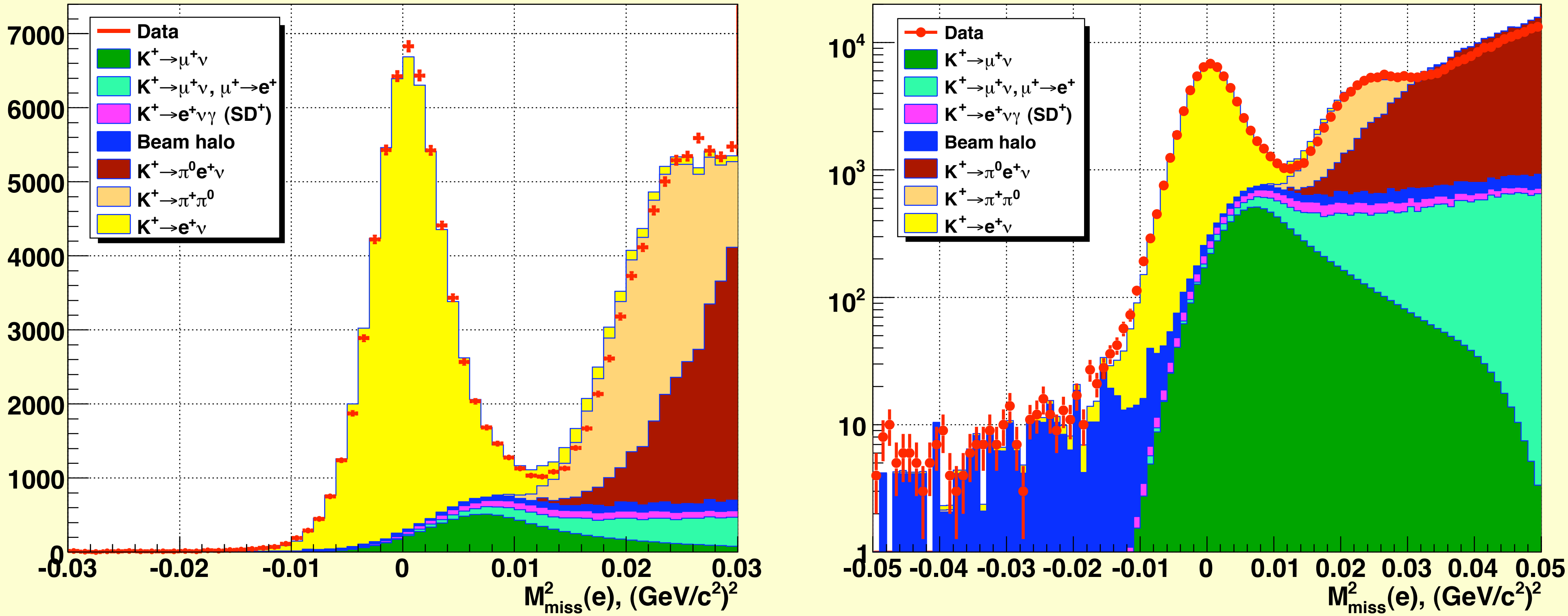


- Largest background fraction at high momentum
- Systematic effect due to background: $\delta R_K/R_K = 0.4\ \%$
- Improvement in precision for each background source is foreseen

Analysis Status - I

40% of data sample

K_{e2} candidates (B/S = 12.3%)

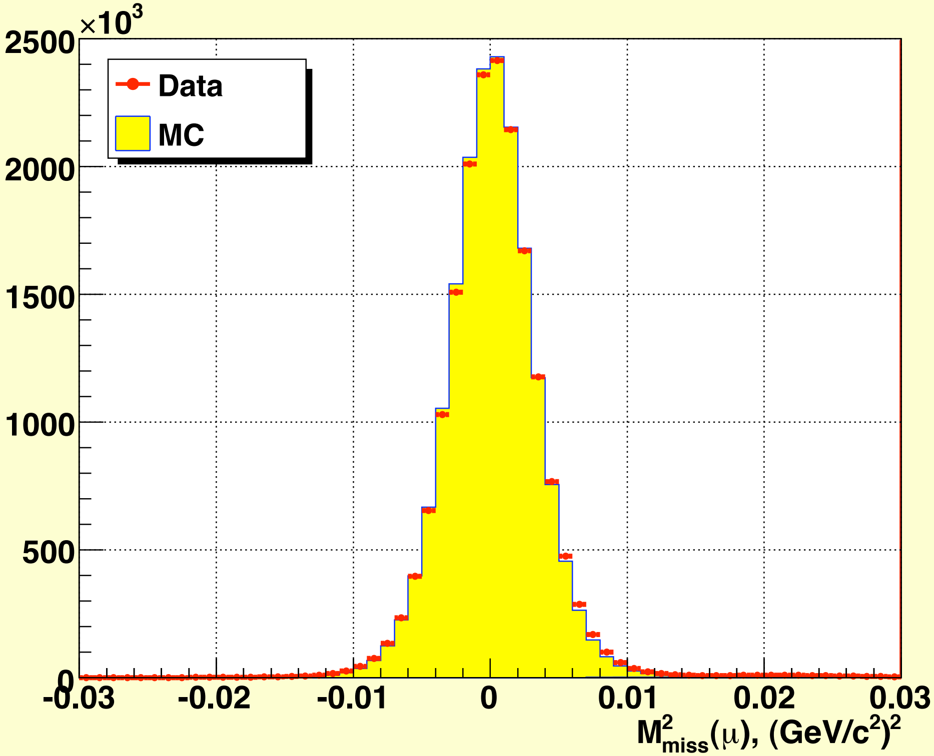


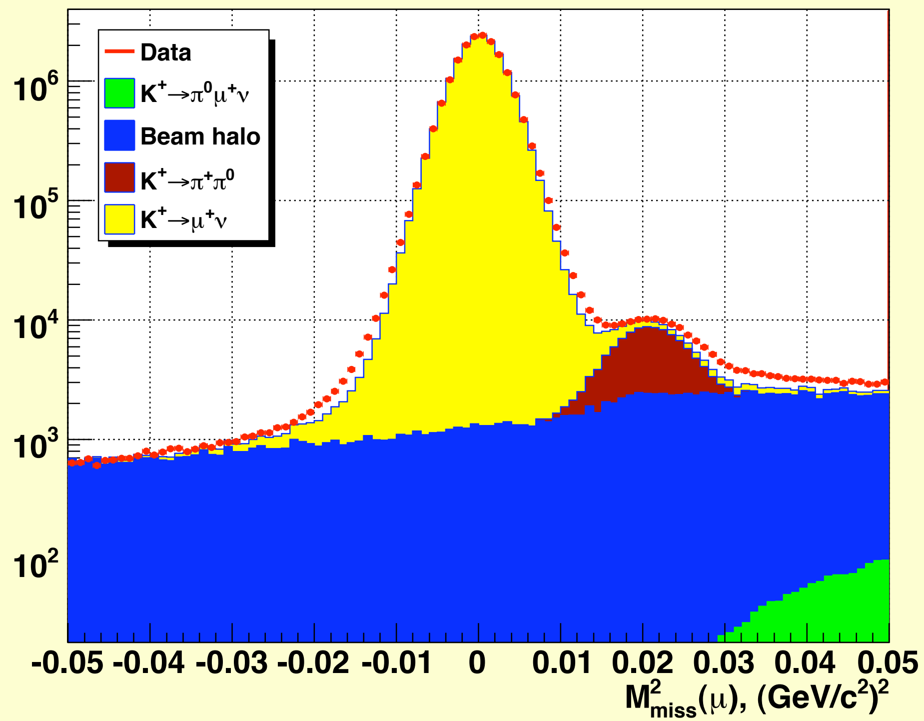
Estimated total K_{e2} sample: 140k K^+ and 20k K^-

(K^+ statistics ~90% of the total sample due to a larger halo background in K^- beam)

Analysis Status - II

$K_{\mu 2}$ candidates (B/S ~ 0.2%)





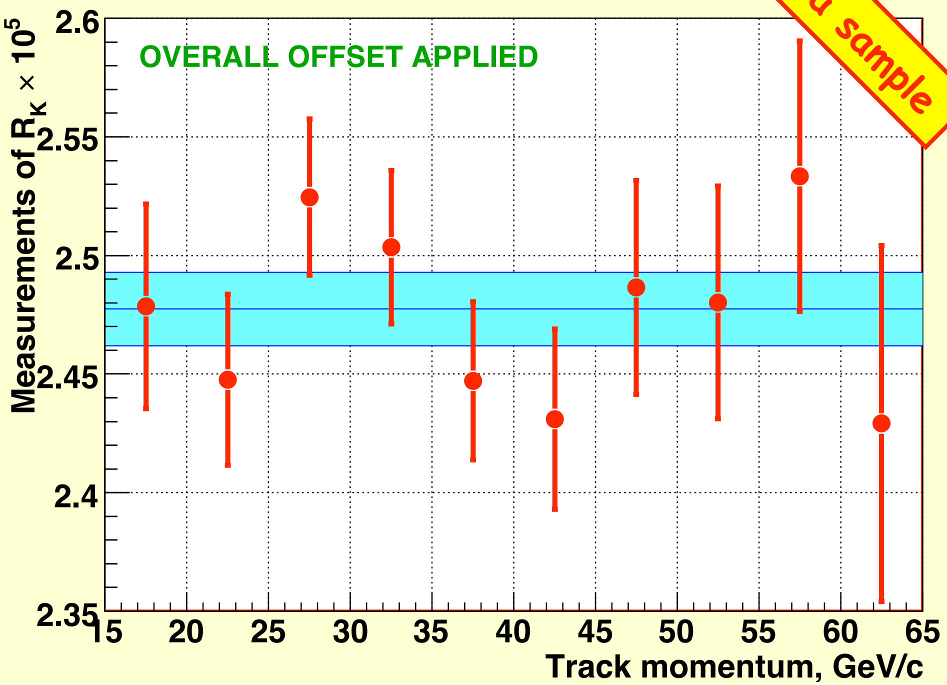
Summary and Prospects

40% of data sample

Main uncertainties

- Statistics 0.4%
- $K_{\mu 2}$ 0.2%
- $K_{e2\gamma}$ (SD^+) 0.3%
- Beam halo 0.2%

- Expected total (0.6÷0.7)%



With the total sample of ~160k candidates

- statistical error <0.3%
- total uncertainty <(0.4÷0.5)%
  (in agreement with proposal)

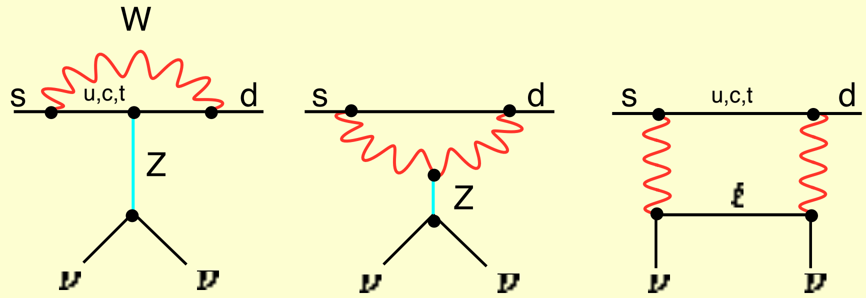
- Stability wrt momentum & main systematic effects understood
- The free space for MSSM LFV model parameters will be very tiny!

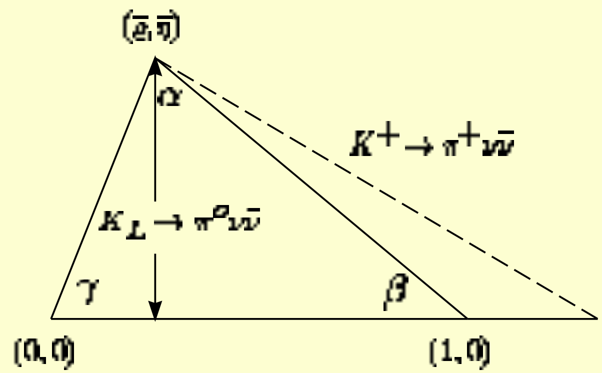
Preliminary NA62 R_K result @ KAON09

NA62 Phase II: $BR(K^{+} \rightarrow \pi^{+}\nu\nu)$

Motivation

- $K^+ \to \pi^+ \nu\nu$ FCNC process is forbidden at tree level
- Only one loop contributions: boxes and penguins
- Top contribution is dominant: small coupling in CKM between t and d,s -> λ^5
- Clean theoretical environment: small contribution by hadronic matrix element and long distance terms
- Cleanest way to extract V_{td} and to give independent determination of the unitarity triangle
- Complementarity with B physics
- Very sensitive to New Physics

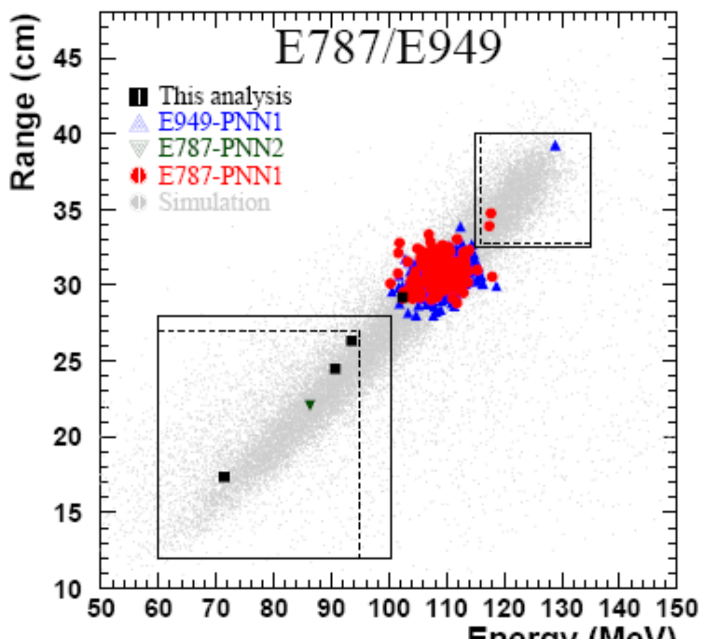




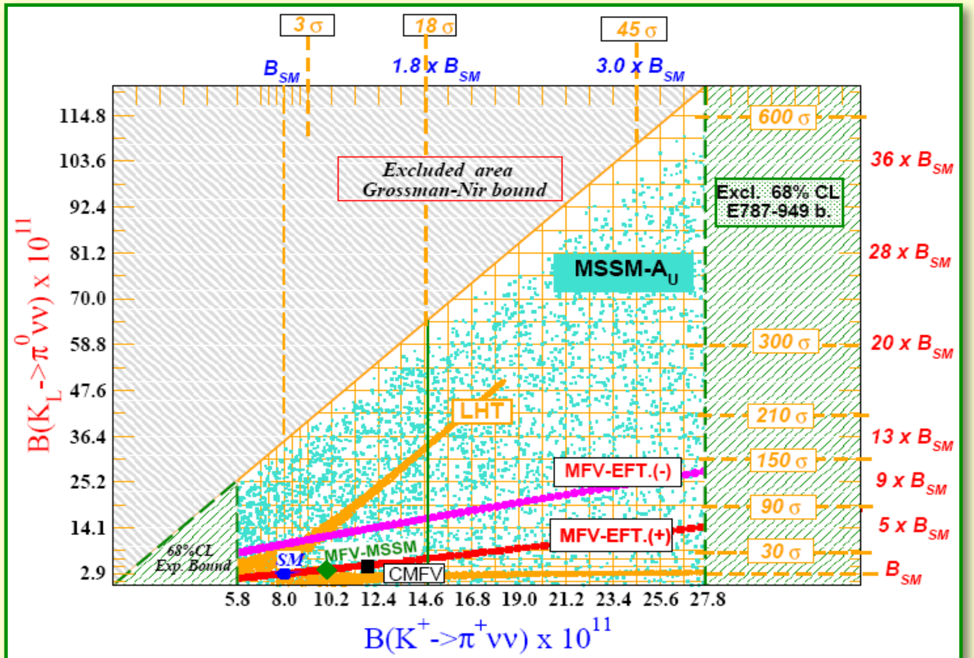
	Short distance	Irreducible error	BR_{SM}
$K_L \to \pi^0 \nu\nu$	>99%	1%	$3 \cdot 10^{-11}$
$K^+ \to \pi^+ \nu\nu$	***88%***	***<3%***	***$9 \cdot 10^{-11}$***
$K_L \to \pi^0 e^+ e^-$	38%	15%	$3.5 \cdot 10^{-11}$
$K_L \to \pi^0 \mu^+ \mu^-$	28%	30%	$1.5 \cdot 10^{-11}$

Experimental Status

- Several NP models: SUSY, MSSM (with or without new sources of CPV or FV), 5-dim split fermions, topcolor, multi Higgs, light sgoldstino, extra-dimensions …
- Possibility to distinguish among different models



(7 candidates E787+E949)



$$BR(K^+ \to \pi^+ \nu\nu)_{th} = (8.5 \pm 0.7)\cdot 10^{-11}$$

$$BR(K^+ \to \pi^+ \nu\nu)_{exp} = (1.73\ ^{+1.15}_{-1.05})\cdot 10^{-10}$$

$$BR(K_L \to \pi^0 \nu\nu)_{th} = (2.8 \pm 0.4)\cdot 10^{-10}$$

$$BR(K_L \to \pi^0 \nu\nu)_{exp} < 6.7\cdot 10^{-7}\ (90\%\ CL)$$

[J.Brod, M.Gorbahn, PRD78, arXiv:0805.4119]
[AGS-E787/E949 PRL101, arXiv:0808.2459]
[c.f. CKM 08 procs.]
[KEK-E391a PRL 100, arXiv:0712.4164]

Experimental Principles - I

Kaon decay in flight to avoid scattering and backgrounds induced by the stopping target (long decay region)

High momentum to improve background rejection (unseparated hadron beam)

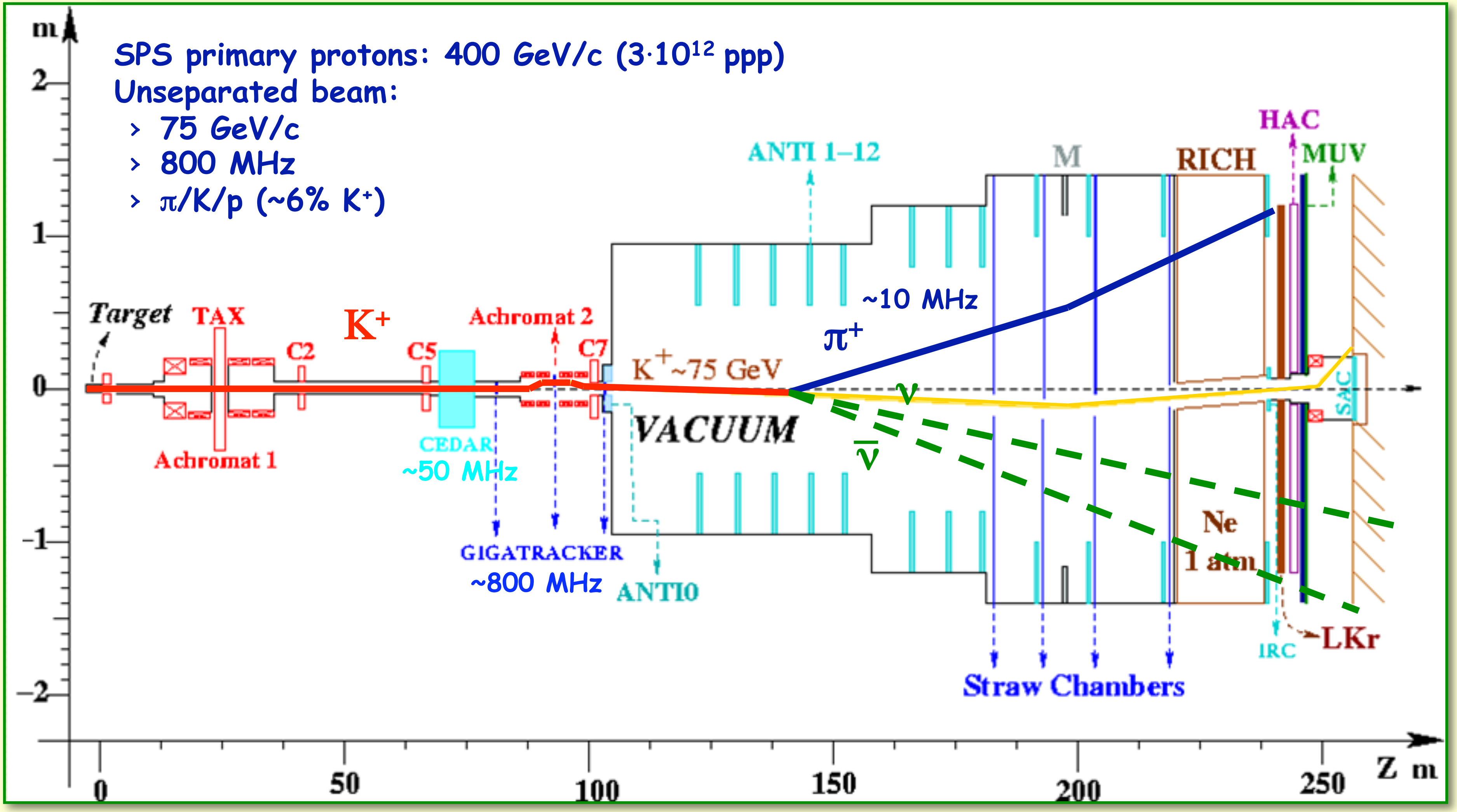
Precise timing to associate the decay to the correct incoming parent particle (K^+) in a ~800 MHz beam (beam tracker with $\sigma_t \sim 100$ ps)

Signature

- Incoming high momentum (75 GeV/c) K^+
- Outgoing low momentum (< 35 GeV/c) π^+

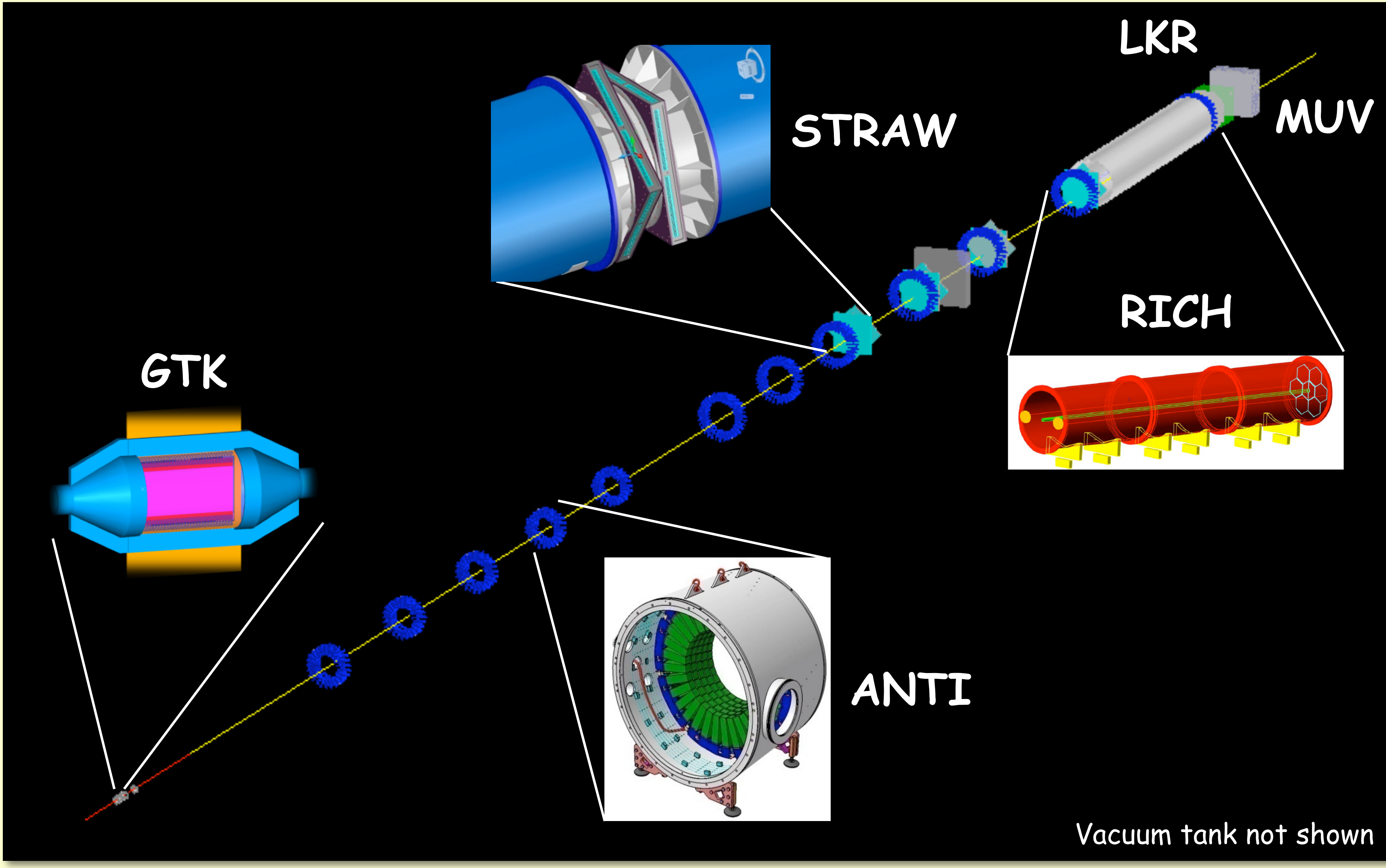
For $K_{\pi 2}$: p_{π^0} > 40 GeV/c -> It can hardly be missed

Detector Layout



Sensitivity is NOT limited by protons flux
Needs ~same amount of protons on target as NA48

Event Display



Experimental Principles - II

Kinematical Rejection

- Low mass tracking (GTK + STRAW)

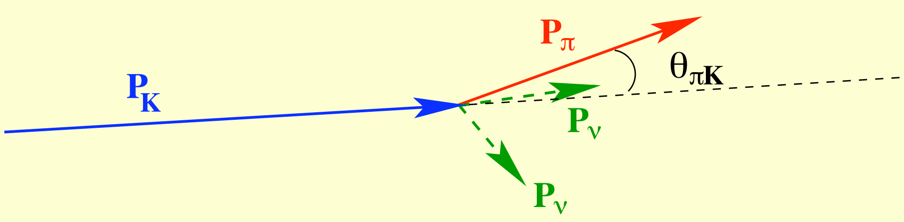
Particle Identification

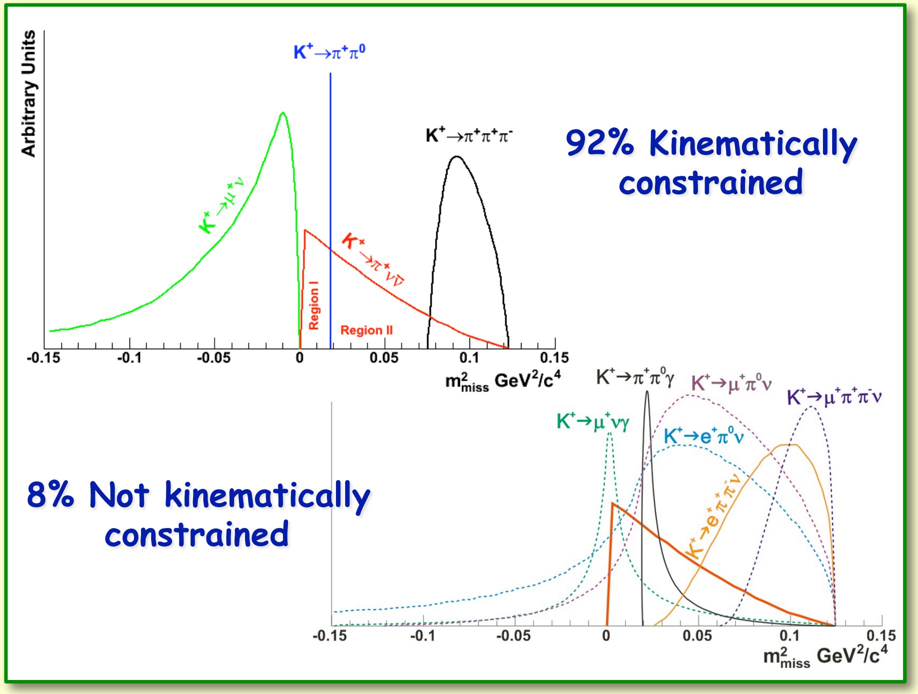
- K/π (CEDAR)
- π/μ (RICH)

$$m^2_{miss} \cong m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\theta^2_{\pi K}$$

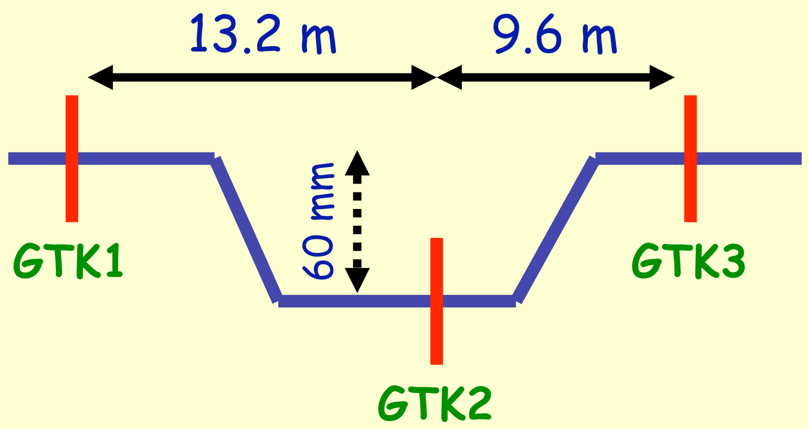
Vetoes

- γ (LAV (OPAL) + LKR (NA48))
- μ (MUV)





GigaTracker



Requests

- Beam spectrometer
- Good space resolution
- Low material budget
- Very high intensity hadron beam: 800 MHz
- Excellent time resolution: 200 ps

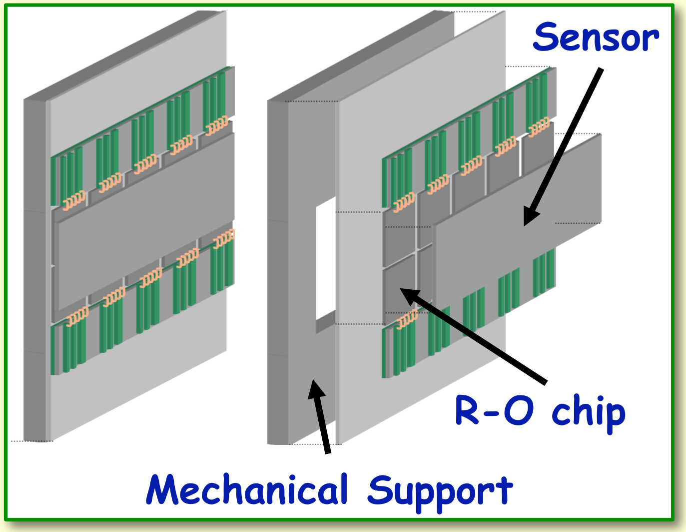
Technology

- 3 stations
- Very thin silicon sensor and readout chip (200+100 μm ~ 0.5 X_0)
- Bump bonded readout chip 0.13 μm CMOS
- 60x27 mm^2 per station
- 300x300 μm^2 pixels

-> 18k pixels / station

R&D

- Readout chip and sensor prototypes under construction
- Bump bonding tests



Straws

Requests

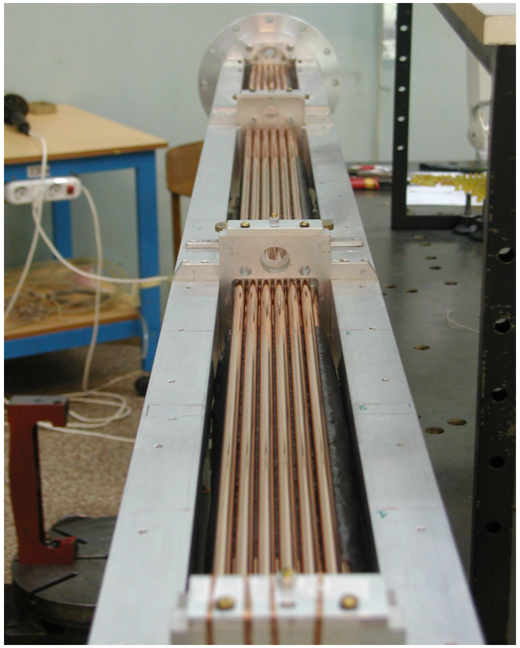
- Secondary particles tracking
- Good space and momentum resolution
- Low material budget: $X/X_0 < 0.5\%$ per chamber
- Operation in vacuum
- Small inactive area around beam

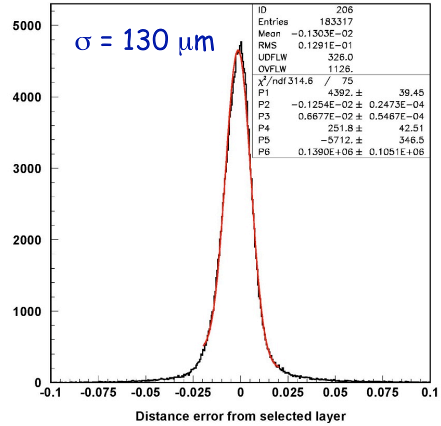
Technology

- 4 chambers
- 4 views with staggered planes
- Straw tubes in aluminum ultrasonic welded (no glue)
- Measured resolution: 130 μm per hit
- Gap between two straws: 1.2 cm (0.1 mm tolerance)

R&D

- Prototypes tested on vacuum with hadronic beam, muons and electrons
- Readout under definition
- Detector in construction



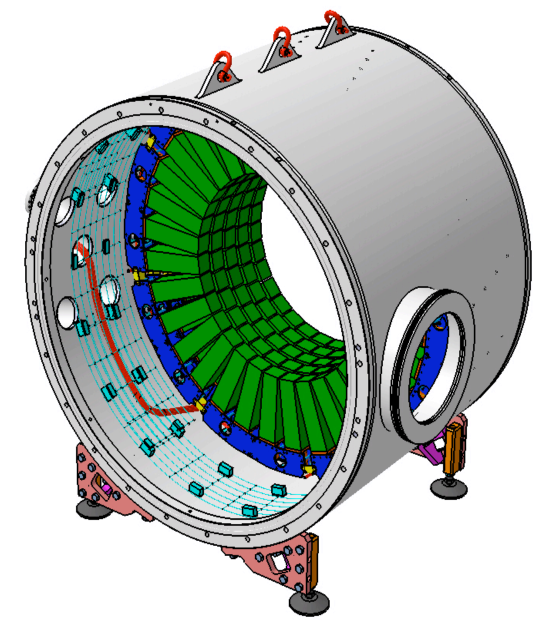


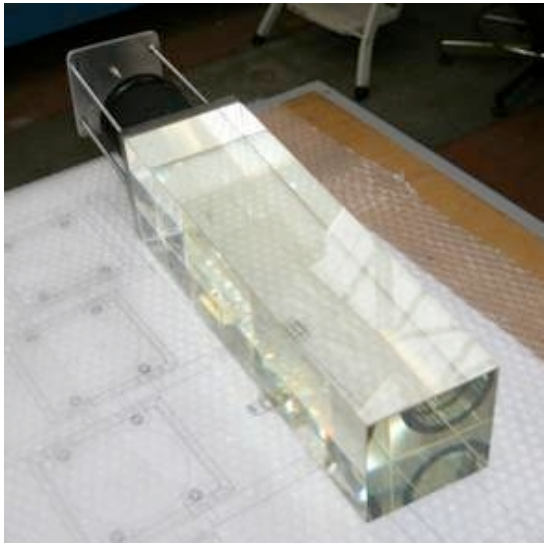
LAV

Requests
- Vetoes for gammas with large angle ([10÷50] mrad)
- Efficient covering along the decay region
- Inefficiency below 10^{-4} for E > 200 MeV

Technology
- Three technology investigated (lead & scintillating fibers, lead & scintillator, lead glass)
- OPAL lead glass solution
- Phototubes operating in vacuum
- 12 rings along the decay region

R&D
- Several test beam to chose the technology
- Characterization with hadrons and muons of a 4x5 blocks real scale prototypes
- Module-0 prototype in construction for test beam in summer





LKr

Requests

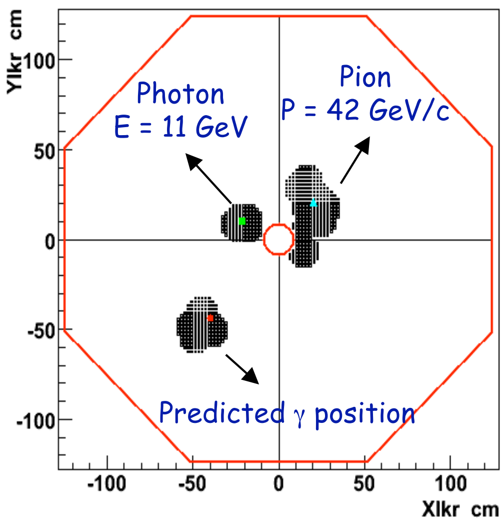
- Very high efficiency to veto forward photons (acceptance range [1÷10] mrad)
- Good time resolution

Technology

- NA48 LKr calorimeter
- The inefficiency has been measured with a special run in 2006:
  - $\eta < 10^{-5}$ for E > 10 GeV
  - $\eta < 10^{-3}$ for E [2.5÷5.5] GeV

R&D

- New cryogenics system and new FE readout already done
- New electronics to allows faster triggering in construction



RICH

Requests

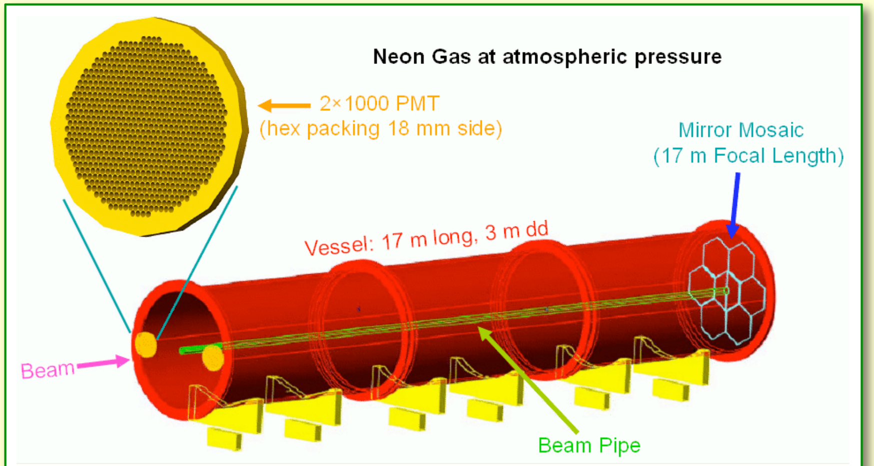
- Provide π/μ separation at $5 \cdot 10^{-3}$ in the range [15÷35] GeV/c
- Measure track time with σ_t ~100 ps
- Provide the main trigger for charged particle

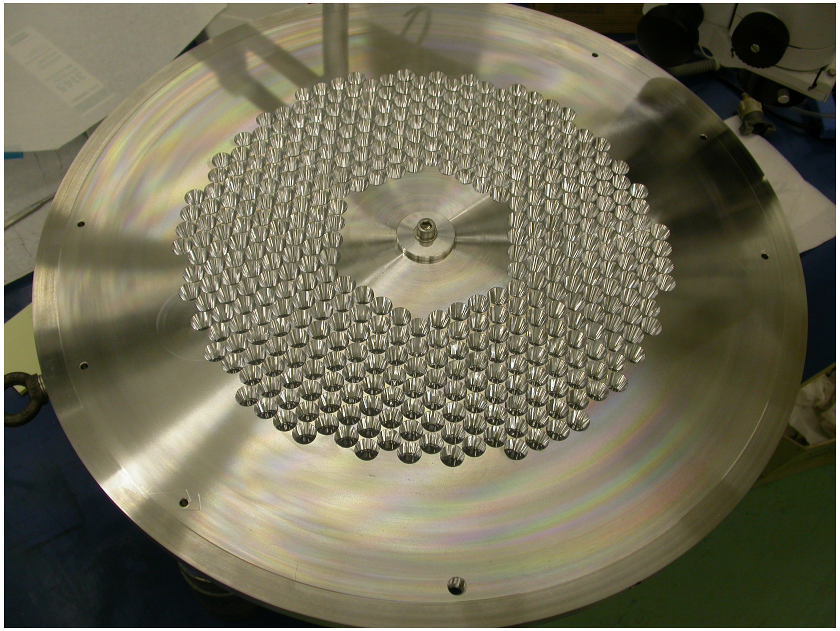
Technology

- 18 m long tube filled with Neon
- Mirrors with f = 17 m
- 2000 single anode PMTs, 1 cm in diameter
- 18 mm "pixel" with Winston cones

R&D

- 100 PMTs full length prototype already tested
- 400 PMTs prototype with new readout electronics currently being tested





Trigger & DAQ

Requests

- Quasi-trigger less paradigm: L0 hardware and L1 software
- High trigger efficiency (>95%)
- Acquisition losses < 10^{-8}
- Fully monitored system: inefficiency, dead time and XOFF recording
- Readout without zero suppression for candidates
- As uniform as possible for most detectors

Technology

- Most of the readout based on TDC -> TELL1 boards (LHCb)

R&D

- A board with 128 channels of TDC has been built
- The FPGA based TELL1 board will house 4 TDCBs
- Currently being tested as RICH prototype DAQ system

Detector	Rate [MHz]
CEDAR	50
GTK	800
LAV (total)	9.5
STRAW (each)	8
RICH	8.6
LKR	10.5
MUV	9.2
SAC	1.5

L0 input rate: ~10 MHz

Conditions on LKr, MUV and RICH multiplicity can reduce the rate to ~1 MHz

Summary

NA62 Phase I: $R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$

- The R_K precise measurement is a very powerful tool to constraint new physics parameters in case of presence of LFV mediators
- The NA62-I experiment will reach a sensitivity of 0.5% exploiting the NA48/2 detectors in a dedicated run
- Preliminary result @ KAON09

NA62 Phase II: $BR(K^+ \to \pi^+\nu\nu)$

- The study of the $K^+ \to \pi^+\nu\nu$ decay could be a good opportunity to found NP and to distinguish among different models
- NA62-II is a challenging experiments aiming to collect O(100) events with S/B = 10
- The detectors R&D will be completed this year
- The data taking should start in 2011-12