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A stringent test of $\mu - e$ universality in $K \rightarrow l\nu$ decays by NA62 at CERN

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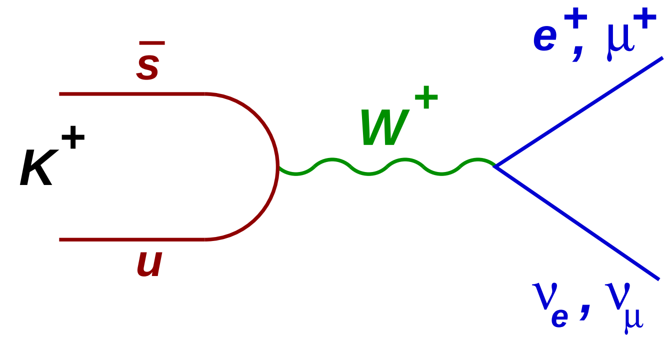
for the NA62 collaboration

Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP, INR, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, San Luis Potosí, SLAC, Sofia, Triumf, Turin

Rencontres de Moriond EW 2009

$\mathrm{R_K} = \Gamma(\mathrm{K} \to e\nu)/\Gamma(\mathrm{K} \to \mu\nu)$ in the SM

- Excellent sub-permille accuracy due to cancellation of hadronic uncertainties in the ratio $\mathrm{R_K}$
- Strong helicity suppression of electronic mode enhances sensitivity to non-SM effects



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

$$= (2.477 \pm 0.001) \times 10^{-5}$$ (V. Cirigliano, I. Rosell, JHEP 0710:005 (2007))

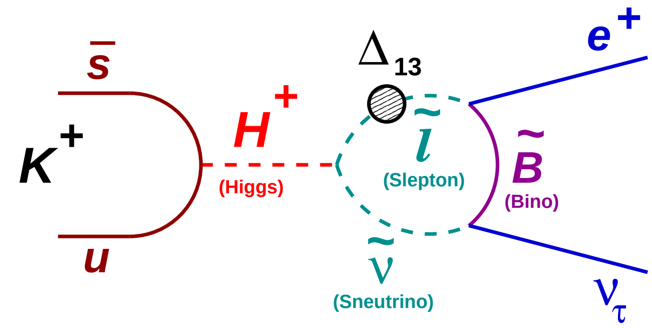
- Radiative corrections $\delta R_K^{\mathrm{rad.corr.}}$ (few $\%$) due to the IB part of the radiative $\mathrm{K} \to e\nu\gamma$ process
- $\mathrm{K} \to e\nu\gamma$(IB) by default included in $\mathrm{R_K}$

$\mathrm{R_K}$ beyond the SM

Possible scenario in MSSM:

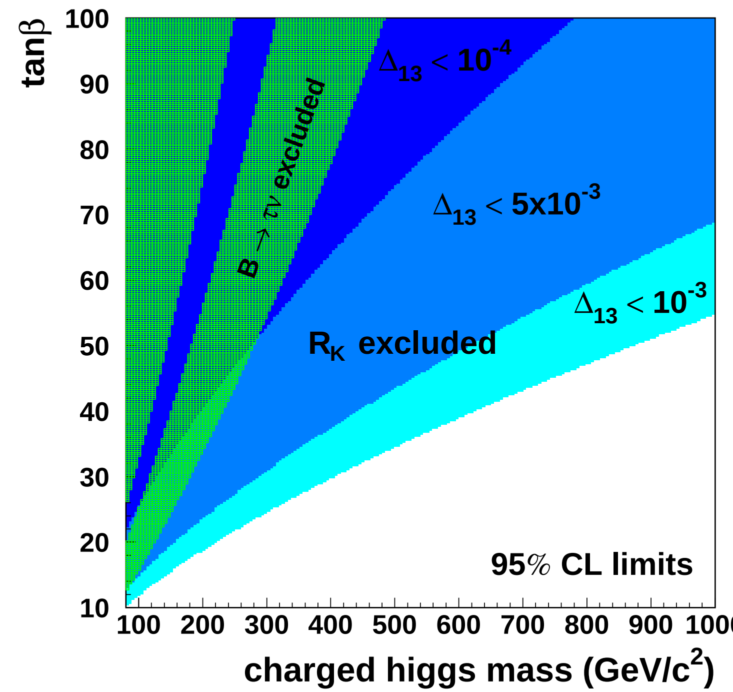
(Masiero, Paradisi, Petronzio, PRD 74, 2006)

’Charged Higgs mediated SUSY LFV contributions can be strongly enhanced, in particular in kaon decays into an electron or a muon and a tau neutrino’



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

A few percent effect possible in large (not extreme) $\tan\beta$ regime with relatively massive charged Higgs



Example:

$\boldsymbol{\Delta}_{\mathbf{13}} = 5 \times 10^{-4}$, $\mathrm{M_H} = 500\,\mathrm{GeV}$, $\tan\beta = 40$:

$R_K^{\mathrm{LFV}} \approx R_K^{\mathrm{SM}}(1 + 0.013)$

NB: Analogous SUSY effects in pion decay are suppressed by a factor $(\mathrm{m_\pi/M_K})^4 \approx 6 \times 10^{-3}$

Experimental situation

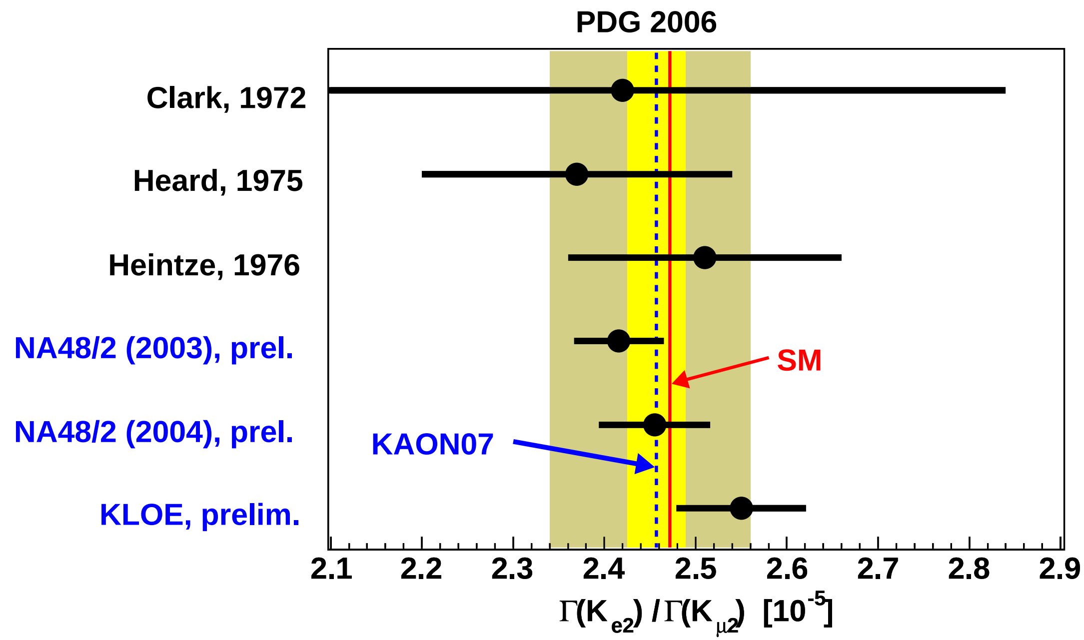
PDG2008: based on three measurements from the 1970's

- $\mathrm{R_K} = (2.45 \pm 0.11) \times 10^{-5}$
- $\delta\mathrm{R_K}/\mathrm{R_K} = 4.5\,\%$

Recent preliminary results by NA48/2 and KLOE:

- $\mathrm{R_K} = (2.457 \pm 0.032) \times 10^{-5}$
- $\delta\mathrm{R_K}/\mathrm{R_K} = 1.3\,\%$

$\rightarrow$ significant improvement

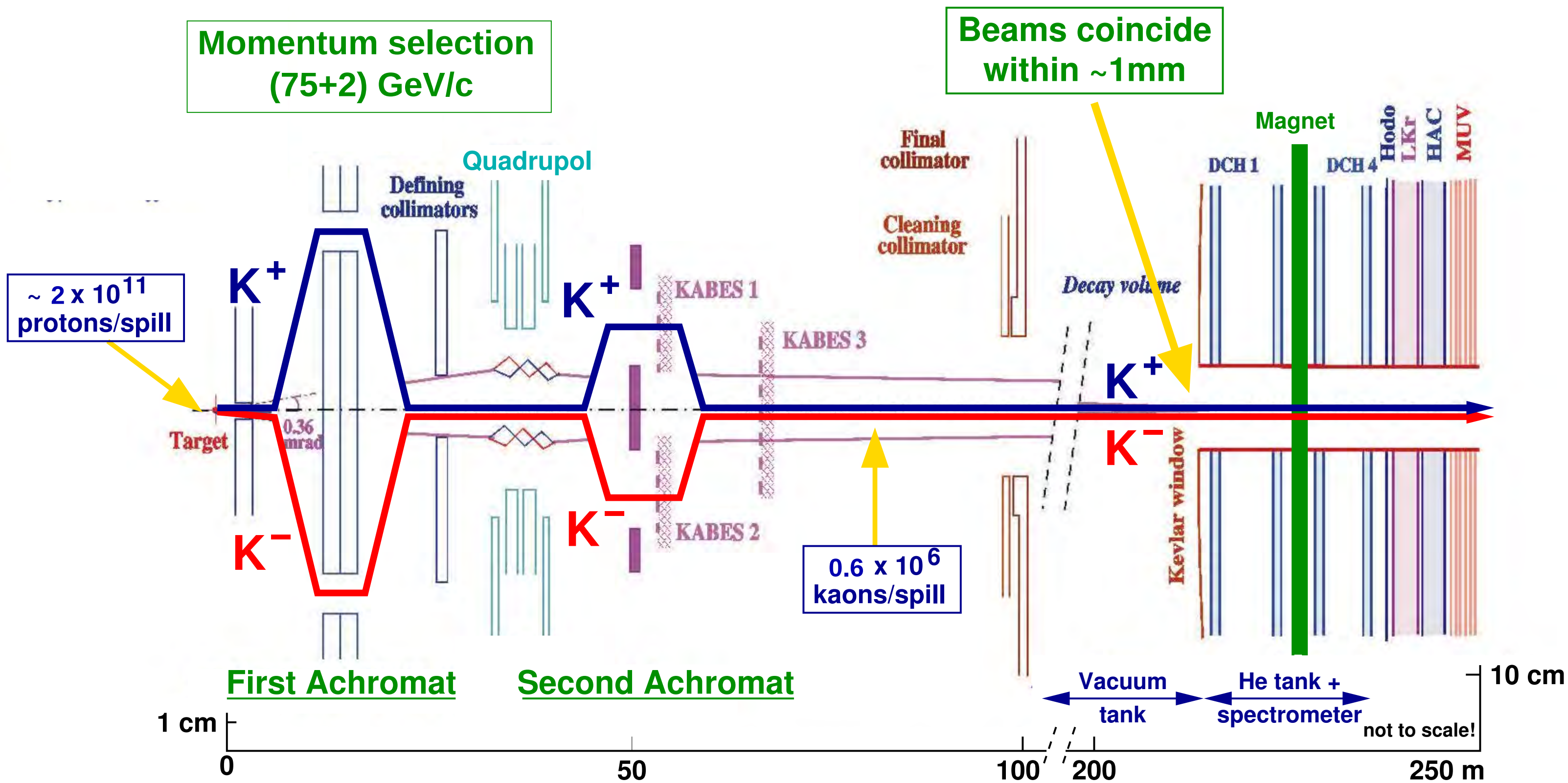


Final result by KLOE announced last week: (La Thuile 2009)
$\mathrm{R_K} = (2.493 \pm 0.025 \pm 0.019) \times 10^{-5}$ ($1.3\,\%$ accuracy with ~10000 $\mathrm{Ke2}$ candidates)

Goal of NA62 for a stringent test of the SM

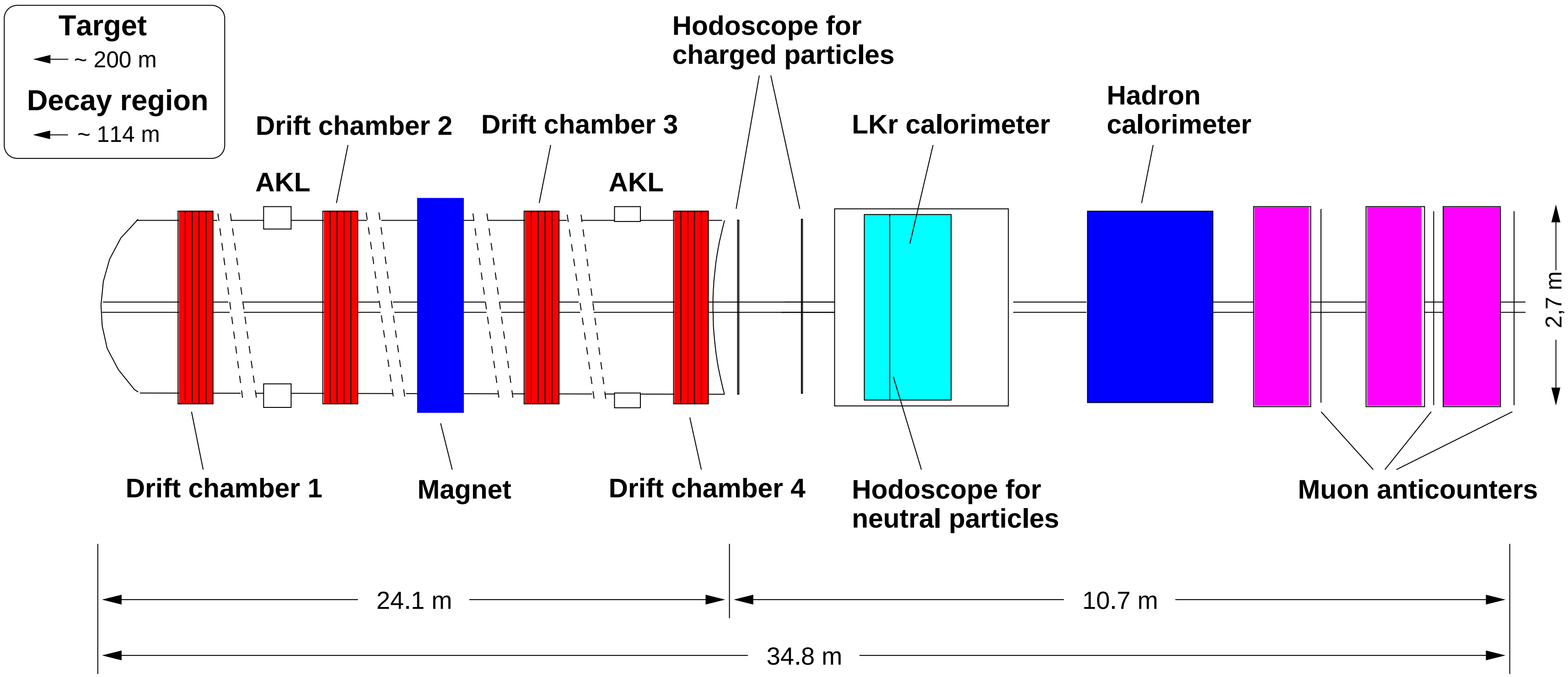
- Collect ~150000 $\mathrm{Ke2}$ decays
- Measure $\Gamma_{Ke2}/\Gamma_{K\mu2}$ with accuracy better than 0.5%!

The NA62 beam line 2007



- Beam setup and detector of NA48/2 experiment slightly optimized for $\mathrm{Ke2}$ measurement
- Simultaneous K^{+} and K^{-} beams with narrow momentum band (75 ± 2 GeV/c)
- Nominal momentum kick of spectrometer magnet doubled

The NA48 detector for NA62



Magnetic spectrometer

- 4 drift chambers with central dipole magnet, 4 views/chamber
- $\Delta p/p = 0.47\,\% + 0.020\,\% \times p$

Scintillator Hodoscope

- Fast trigger + good time resolution

Electromagnetic calorimeter

- Structure: 13248 cells of $2 \times 2\mathrm{cm}^2$ along beamline in $\sim 10\,\mathrm{m}^3$ liquid krypton (27 X_0 deep)
- Energy resolution $\sim 1\,\%$ and spatial resolution ~ 1 mm (at 20 GeV)

Data taking 2007 and 2008

Four months in 2007:

Minimum Bias trigger condition, ~400k SPS spills, 90 TB data recorded, reprocessing and data preparation finished

Two weeks in 2008:

Special data sets allowing reduction of systematic uncertainties

Kaon sign:

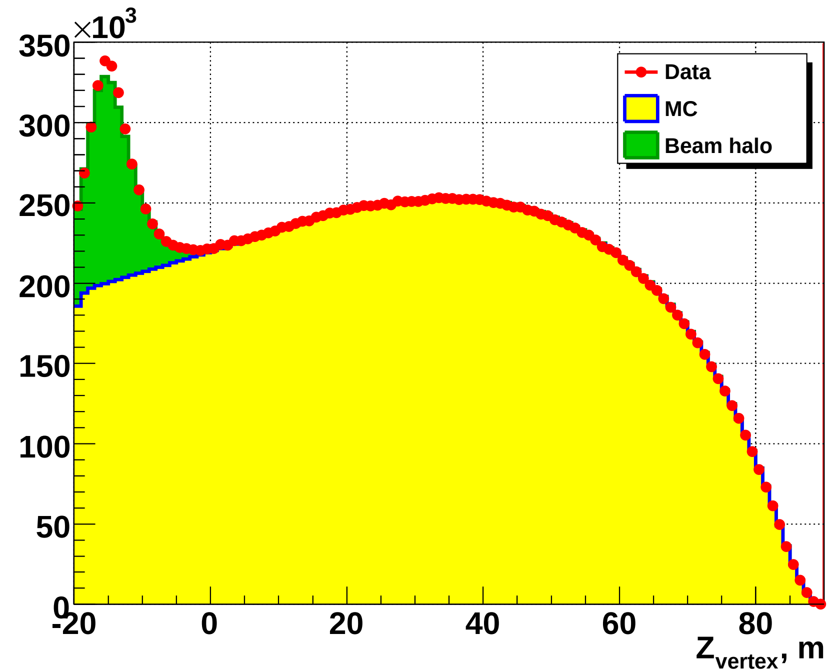
Beam halo background much higher for K^-_{e2} ($\sim 20\,\%$) than for K^+_{e2} ($\sim 1\,\%$)

$\sim 90\,\%$ of data sample: K^+ only

$\sim 10\,\%$ of data sample: K^- only

$\longrightarrow$ Collection of K^+ ONLY and K^- ONLY sets allow direct 'cross-measurements' of beam halo background with excellent precision

Distribution of $K^+_{\mu 2}$ decay vertex



Note: The following results presented in this talk are based on a partial data sample ($\sim 40\,\%$) with pure K^+ beam !

Measurement method

$\mathrm{Ke2}$ and $\mathrm{K\mu2}$ candidates collected simultaneously

- Measurement independent of kaon flux
- A number of systematic effects cancel in the ratio $\mathrm{R_K}$

MC simulation used only to limited extent

- Geometric acceptance correction
- Simulation of catastrophic bremsstrahlung by muon

A counting experiment in track momentum bins

$$\mathbf{R_K = \frac{N(Ke2) - N_B(Ke2)}{N(K\mu2) - N_B(K\mu2)} \cdot \frac{A(K\mu2) \times f_\mu \times \epsilon(K\mu2)}{A(Ke2) \times f_e \times \epsilon(Ke2)} \cdot \frac{1}{f_{LKr}}}$$

$\mathbf{N(Ke2), N(K\mu2)}$:	numbers of selected $\mathbf{Kl2}$ candidates
$\mathbf{N_B(Ke2), N_B(K\mu2)}$:	numbers of background events
$\mathbf{A(Ke2), A(K\mu2)}$:	geometric acceptances (from MC)
$\mathbf{f_e, f_\mu}$:	measured particle ID efficiencies (from data)
$\mathbf{\epsilon(Ke2)/\epsilon(K\mu2) > 0.999}$:	$\mathbf{E_{LKr}}$ trigger efficiency
$\mathbf{f_{LKr}}$:	global LKr readout efficiency

$\mathrm{Ke2}$ and $\mathrm{K}\mu 2$ selection

Large common part (topological similarity)

- One reconstructed track
- Geometrical acceptance cuts
- Track momentum 15 - 65 GeV/c
- Decay vertex defined as closest approach of track + nominal kaon axis

Kinematic separation

Missing mass $M^2_{miss} = (P_K - P_l)^2$

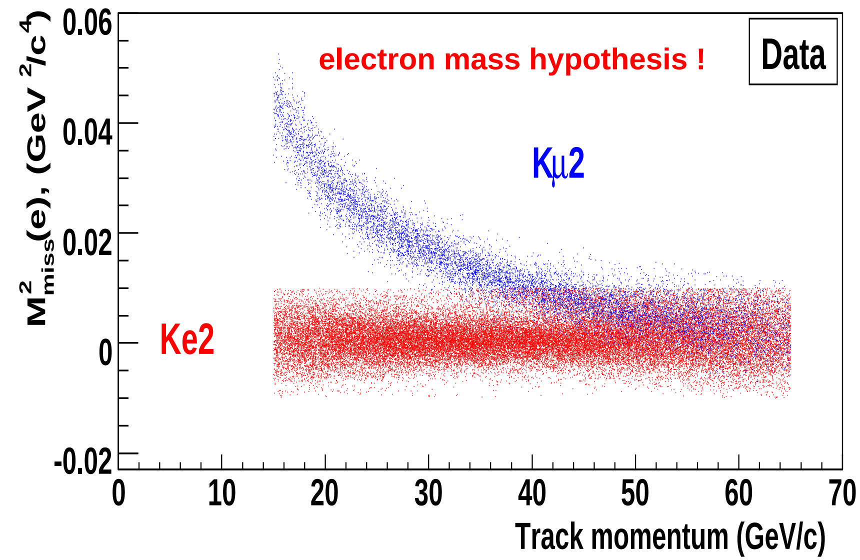
$\mathbf{P_K}$ measured with $\mathbf{K^\pm \rightarrow 3\pi}$ decays

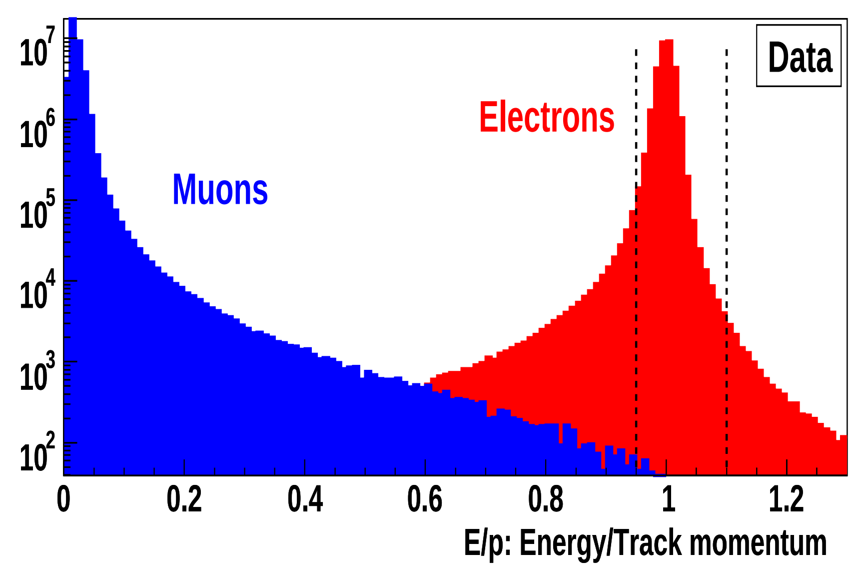
$\Rightarrow$ No $\mathbf{K\mu 2}$ background in $\mathbf{Ke2}$ for momenta < 25 GeV/c (15 % of data)

Particle identification

E/p LKr energy deposit / track momentum

(< 0.85 for muons, 0.95 < E/p < 1.10 for electrons)





Muonic background in $\mathrm{Ke2}$ sample

Problem:

'Catastrophic' energy loss of muons in LKr ($\mathrm{P}(\mu \to \mathrm{e}) \sim 3 \times 10^{-6}$ and momentum-dependent) $\Rightarrow$ Muons with E/p > 0.95 identified as electrons

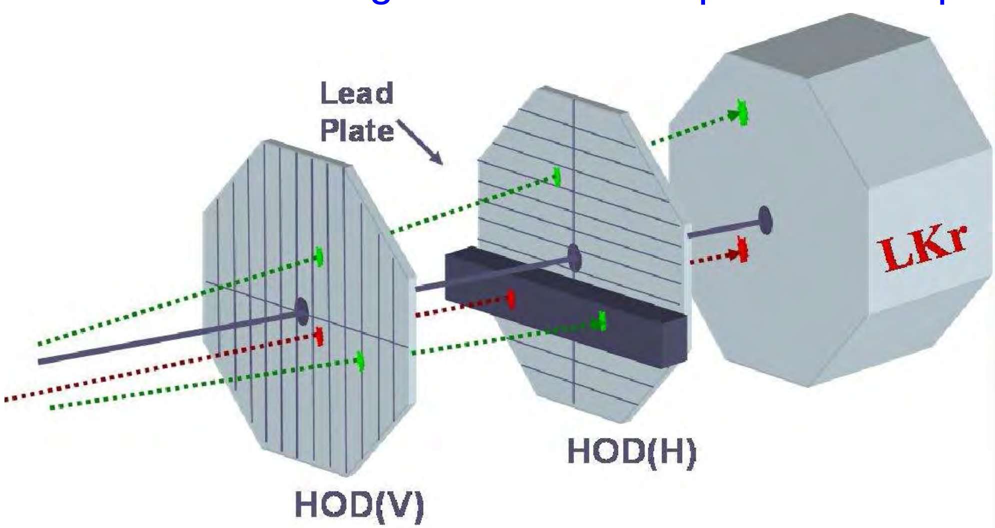
$\Rightarrow$ $\mathrm{K}\mu 2$ decays represent a major background

$\Rightarrow$ Need direct measurement of $\mathrm{P}(\mu \to \mathrm{e})$ with pure muon sample to validate theoretical bremsstrahlung cross-section in the very special high E_γ region

Solution: Lead wall ($9X_0$) between the hodoscope planes

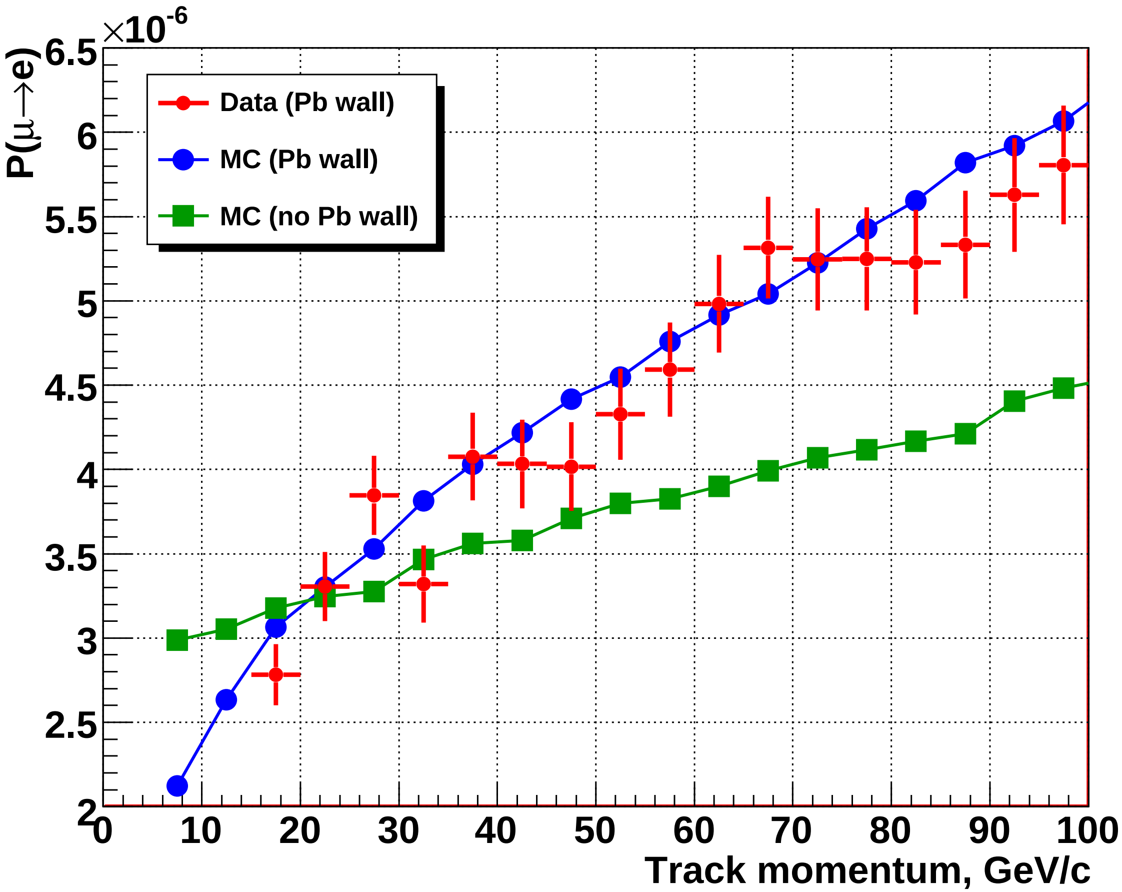
- During $\sim 50\,\%$ of data taking
- Special muon runs with hadron beam absorbed (2007 + 2008), 2007 sample analyzed

$\Rightarrow$ Tracks traversing the wall with E/p > 0.95 are pure muon samples (contamination $< 10^{-7}$)



Muonic background (2)

$\mathrm{P}(\mu \to \mathrm{e})$: measurement (2007 muon sample) vs Geant4-based simulation



- Excellent data/MC agreement for the Pb wall case !
- $\mathrm{P}(\mu \to \mathrm{e})$ is modified by the Pb wall, mainly due to:
  - muon ionization losses (low p)
  - bremsstrahlung in Pb (high p)

Result: $\mathrm{B/S} = (7.4 \pm 0.2)\,\%$

(uncertainty due to the limited size of the data sample used to validate the simulation)

Prospects:

- The 2008 muon sample is twice as large as the 2007 one
- Muons from $\mathrm{K}\mu2$ decays in clear $\mathrm{Ke2/K}\mu2$ separation region (p < 25 GeV/c)

Other background sources in $\mathrm{Ke2}$

Beam halo

Electrons produced by beam halo muons via $\mu \to \mathrm{e}$ decay, kinematically and geometrically compatible to a genuine $\mathrm{Ke2}$ decay

$\longrightarrow$ Directly measured with K^- Only sample $\boxed{\mathrm{B/S} = (1.3 \pm 0.1)\,\%}$

$\longrightarrow$ Uncertainty due to limited size of control data sample

$\longrightarrow$ 2008 K^- sample will improve precision

$\mathbf{Ke2\gamma}$ (SD$^+$)

Background by definition of $\mathrm{R_K}$ (includes only IB part), rate similar to $\mathrm{Ke2}$

Theory: $\mathrm{BR} = (1.12 - 1.34) \times 10^{-5}$ (form factor model-dependent)

Experiment: $\mathrm{BR} = (1.52 \pm 0.23) \times 10^{-5}$

$\longrightarrow$ BR known with a poor precision ($\sim 20\,\%$) $\boxed{\mathrm{B/S} = (1.6 \pm 0.3)\,\%}$

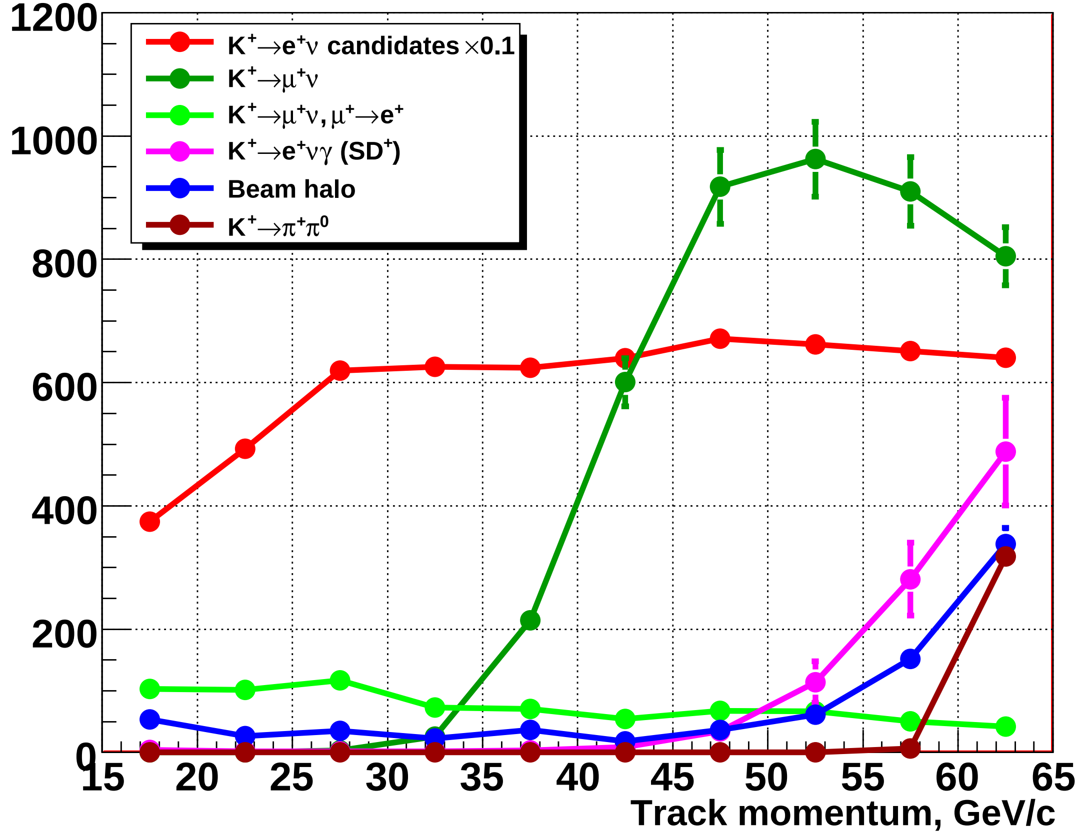
$\longrightarrow$ NA62 analysis with 2007 data started, strong improvement expected !

$\mathbf{K\mu 2}$ with $\mu \longrightarrow e$ decay

$\longrightarrow$ muon decay included in MC simulation $\boxed{\mathrm{B/S} = (1.3 \pm 0.1)\,\%}$

Backgrounds summary

Number of background events in data sample, p-dependent



- Largest background fraction at high momenta
- Systematic effect due to background: $\delta \mathrm{R_K}/\mathrm{R_K} = 0.4\,\%$
- Improvement for each background source foreseen

Other systematic effects

Electron ID efficiency fe

Select samples of pure electrons from

- $K^{\pm} \rightarrow \pi^0 e^{\pm} \nu$ decays, collected during main K data taking (limited momentum range p < 50 GeV/c)
- $K_L \rightarrow \pi^{\pm} e^{\mp} \nu$ decays, collected in a special 15h K_L run (whole track momentum range due to broad K_L momentum spectrum)

$\rightarrow$ Good agreement between the measurements, $\mathrm{fe} = 99.15\,\%$, uncertainty < 0.1 %

Acceptance correction

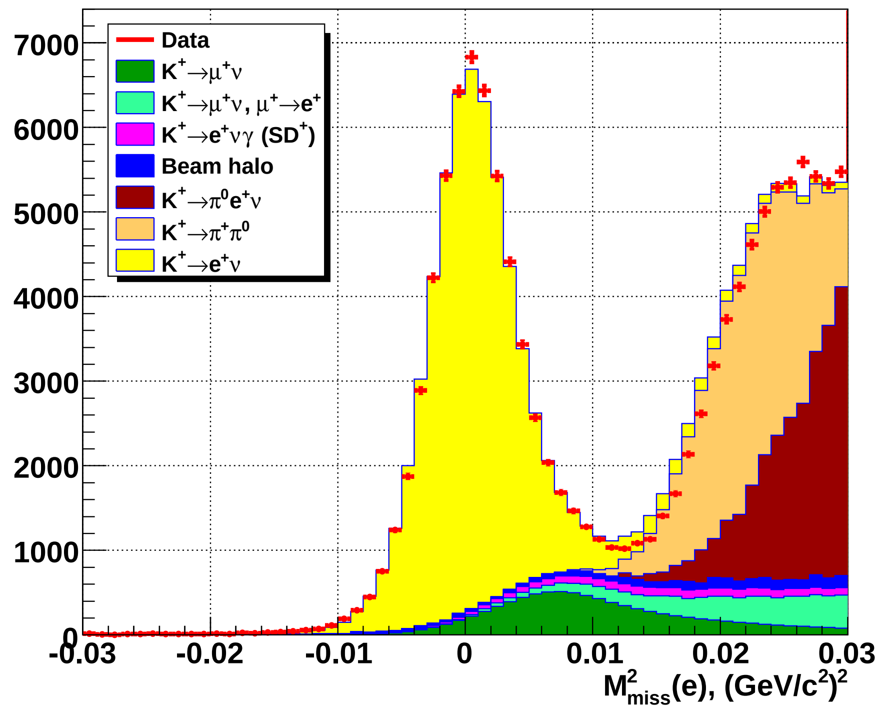
- momentum-dependent
- $\mathrm{Ke2}$ radiative (IB) corrections strongly affect the acceptance

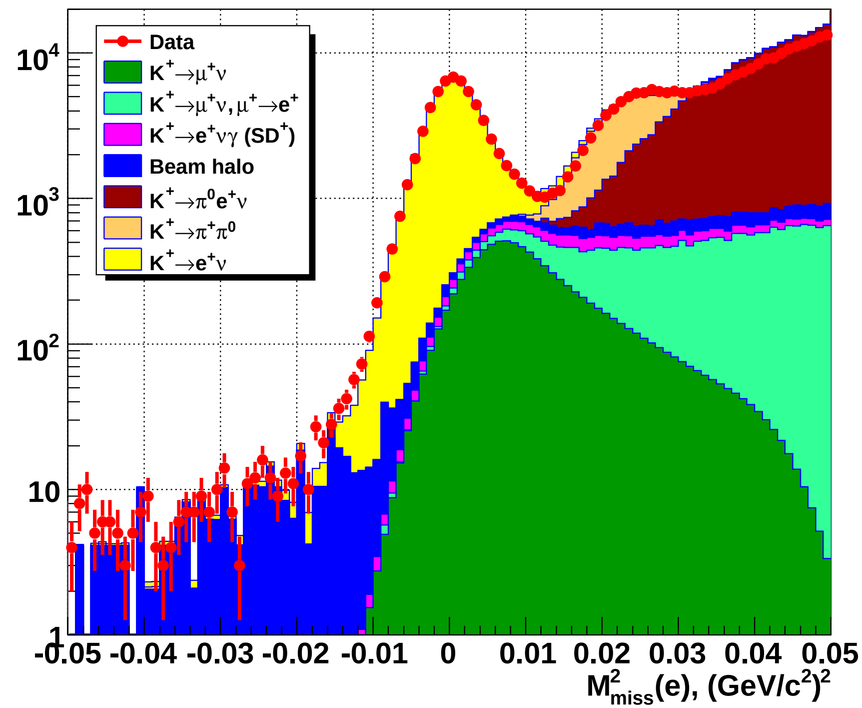
Trigger efficiency correction

- monitored using control trigger samples

$\rightarrow$ uncertainty < 0.1 %

$\mathrm{Ke2}$ candidates: $40\,\%$ of data set





$\mathrm{Ke2}$ background sources:

$\mathrm{K}\mu 2$	$(7.4 \pm 0.2)\,\%$
$\mathrm{K}\mu 2,\ \mu \to e$	$(1.3 \pm 0.1)\,\%$
$\mathrm{Ke2}\gamma$ (SD$^+$)	$(1.6 \pm 0.3)\,\%$
Beam halo	$(1.3 \pm 0.1)\,\%$
$\mathrm{Ke3}$	$0.1\,\%$
$K_{2\pi}$	$(0.6 \pm 0.1)\,\%$

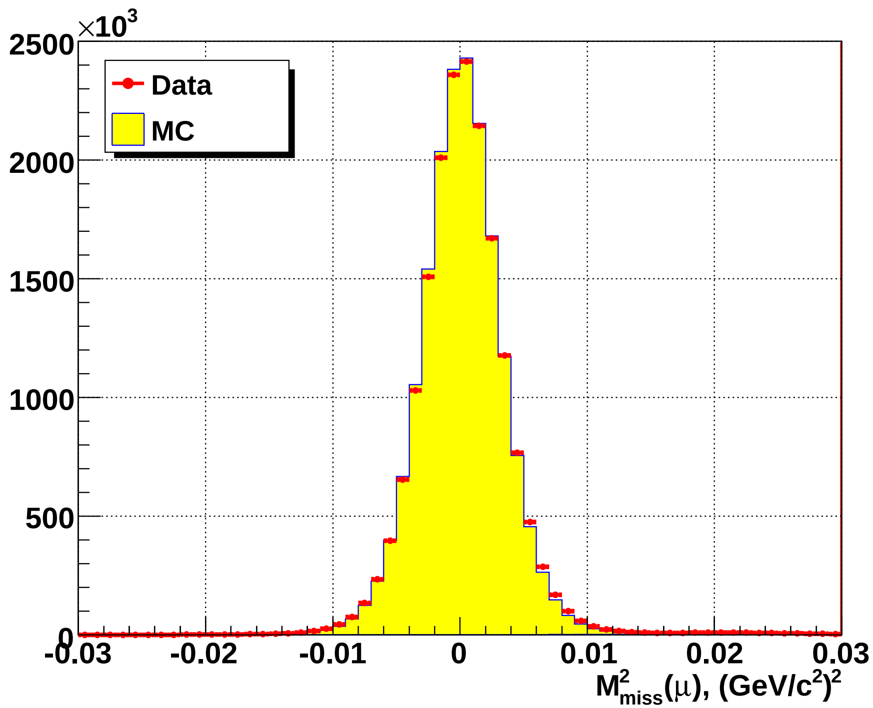
Total $\mathrm{Ke2\ B/S} = 12.3\,\%$

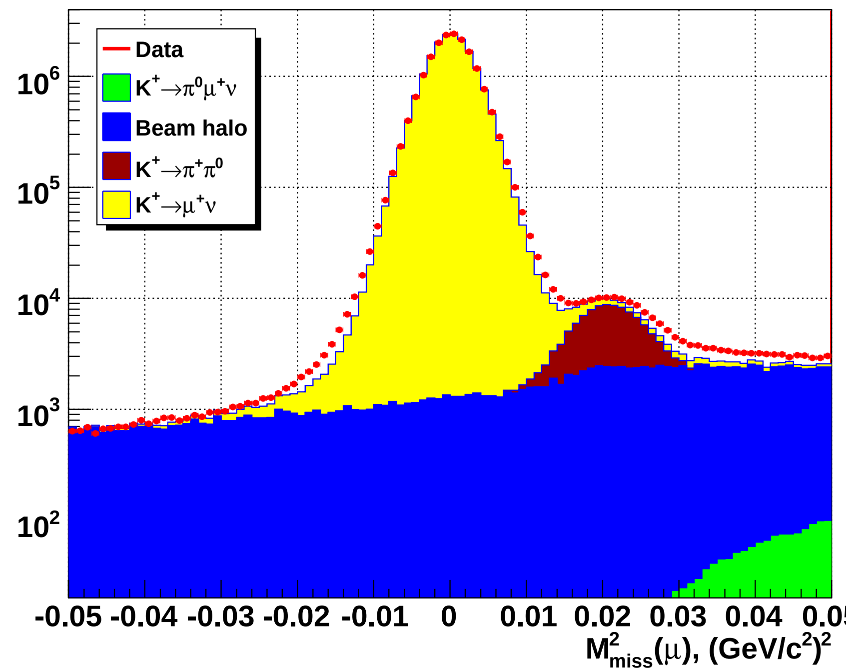
Estimated NA62 total $\mathrm{Ke2}$ sample:

140k K^+ and 20k K^- candidates

Proposal: 150k candidates

$K\mu 2$ candidates: $40\ \%$ of data set



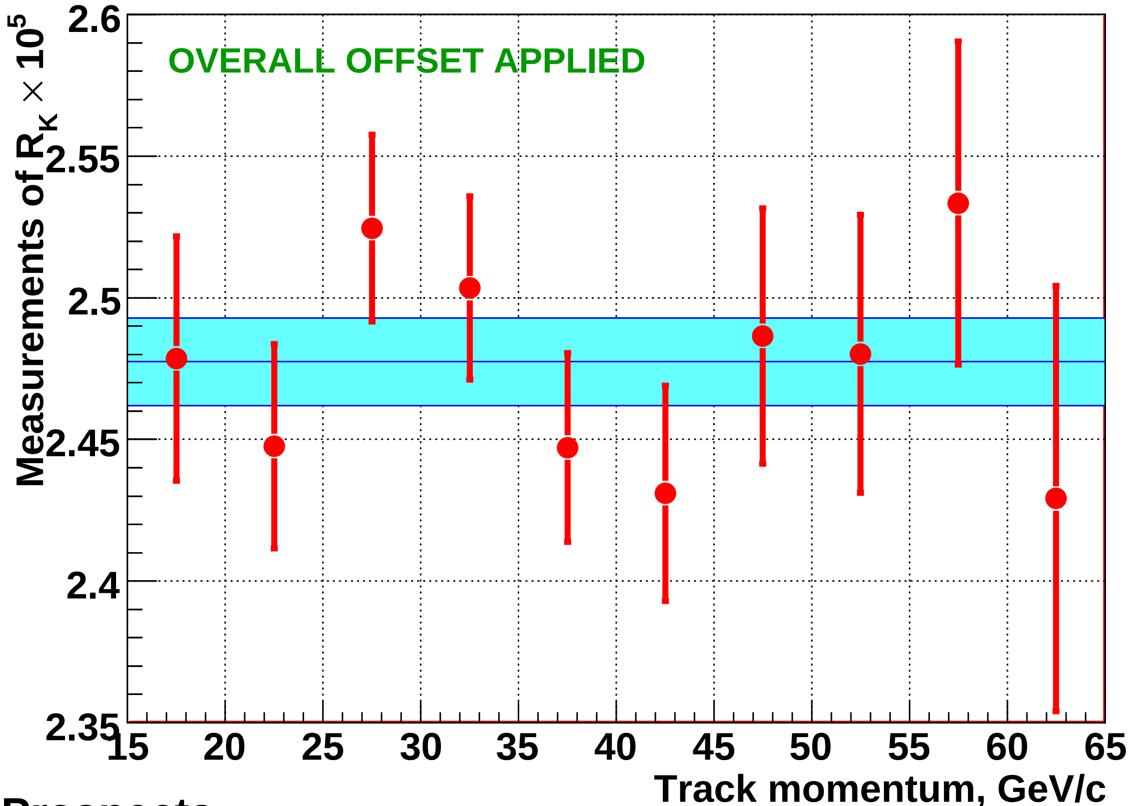


Only relevant $K\mu 2$ background:

Beam halo $\sim 0.2\,\%$

Analysis summary and prospects

10 Independent measurements in track momentum bins



Stability wrt p-dependent main systematic effects understood!

Main uncertainties:

($40\,\%$ of data sample)

Statistical	$0.4\,\%$
$K\mu 2$	$0.2\,\%$
$Ke2\gamma$ (SD$^+$)	$0.3\,\%$
Beam halo	$0.1\,\%$
IB simulation	$0.3\,\%$

Expected total uncertainty from the partial $40\,\%$ sample:

$0.6 - 0.7\,\%$

Prospects:

- Still room for improvements of the systematic errors
- With the whole sample of $\sim$160k candidates:
  $\longrightarrow$ statistical uncertainty pushed below $0.3\,\%$
  $\longrightarrow$ total uncertainty of $0.4 - 0.5\,\%$ is within reach

Conclusions

- Due to the helicity suppression of $\mathrm{Ke2}$, the measurement of $\Gamma_{Ke2}/\Gamma_{K\mu2}$ is well-suited to a stringent test of lepton universality
- The NA62 2007 run has increased the world $\mathrm{Ke2}$ sample by more than an order of magnitude. Data taking had been optimized for $\mathrm{Ke2}$
- The 2007 data sample is reprocessed and fully ready for analysis. After a successfull two weeks $\mathrm{Ke2}$ systematics run in 2008, the data set became fully sufficient for a precise $\mathrm{R_K}$ measurement
- Analysis of a partial data sample ($\sim 40\,\%$) is well advanced. It demonstrates that the overall uncertainty of 0.4 $\%$, as declared in the proposal, is within reach