NA62/P-326: $K_{e2}/K_{\mu 2}$ status report

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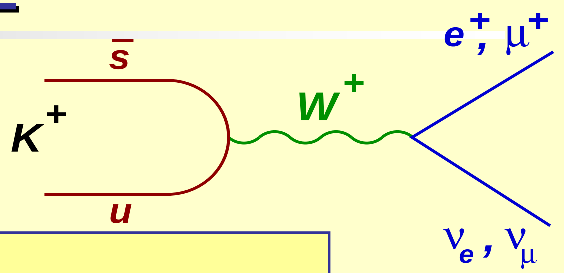
for the collaboration:
Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Louvain, Mainz, Merced, Moscow, Naples, Perugia, Pisa, Protvino, Rome I, Rome II, Saclay, San Luis Potosí, Stanford, Sofia, Triumf, Turin

Outline:

1) Motivation for $R_K=\Gamma(K_{e2})/\Gamma(K_{\mu 2})$ measurement
2) Beams, setup and data taking
3) Background and other systematic effects
4) Summary and prospects

Meeting with NA62 referees
CERN • November 4, 2008

K_{l2} and π_{l2} in the SM



Standard Model: excellent sub-permille accuracy due to cancellations of hadronic uncertainties

$$R_M = \frac{\Gamma(M\to e\nu(\gamma))}{\Gamma(M\to\mu\nu(\gamma))} = \underbrace{\left(\frac{m_e}{m_\mu}\right)^2}_{\text{helicity suppression}} \left(\frac{m_M^2-m_e^2}{m_M^2-m_\mu^2}\right)^2 \underbrace{(1+\delta R_{QED})}_{\text{radiative correction}}$$

Latest SM predictions: V. Cirigliano and I. Rosell, Phys. Lett. 99 (2007) 231801

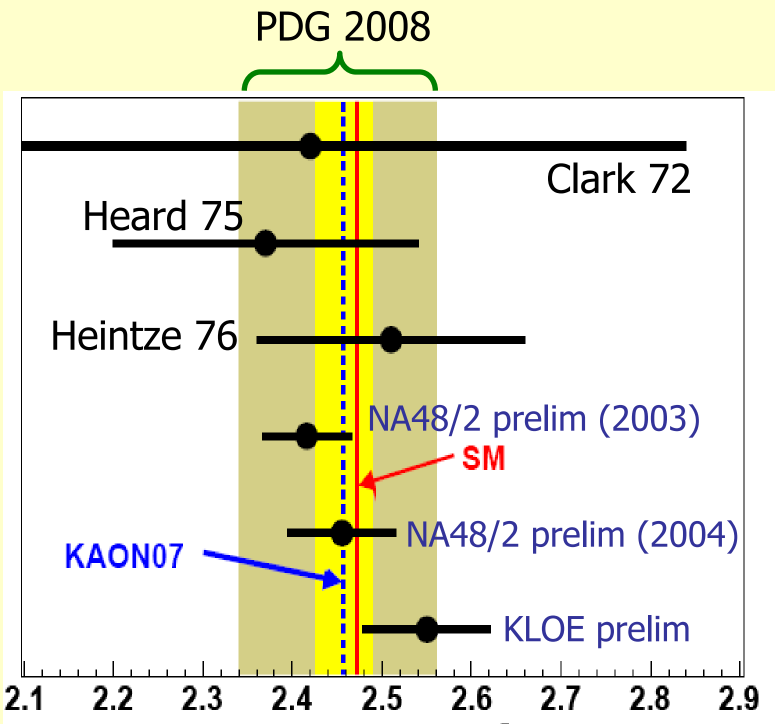
$R_K^{SM} = (2.477\pm0.001)\times10^{-5}$

$R_\pi^{SM} = (1.2352\pm0.0002)\times10^{-5}$

R_K experimental status:

→ PDG'08 (based on 1970s experments):
$R_K=(2.45\pm0.11)\times10^{-5}$ $(\delta R_K/R_K=4.5\%)$

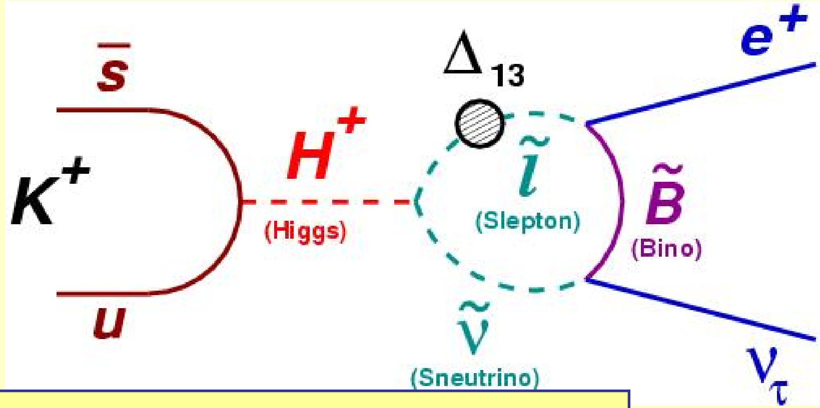
→ Including recent NA48/2 and KLOE preliminary results:
$R_K=(2.457\pm0.032)\times10^{-5}$ $(\delta R_K/R_K=1.3\%)$



R_K outside the SM

Minimal SUSY: LVF contribution dominated by emission of tauonic neutrinos enhances the decay rate

A.Masiero, P.Paradisi, R.Petronzio
Phys. Rev. D74 (2006) 011701



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

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

Example ($\Delta_{13}=5\times10^{-4}$, $\tan\beta=40$, $M_H=500$GeV):
$R_K^{LVF} = R_K^{SM}(1+0.013)$.

A similar SUSY effect in pion decay is suppressed by a factor $(m_\pi/M_K)^4 \approx 6\times10^{-3}$

NA62 goal: accuracy better than 0.5% to provide a stringent SM test

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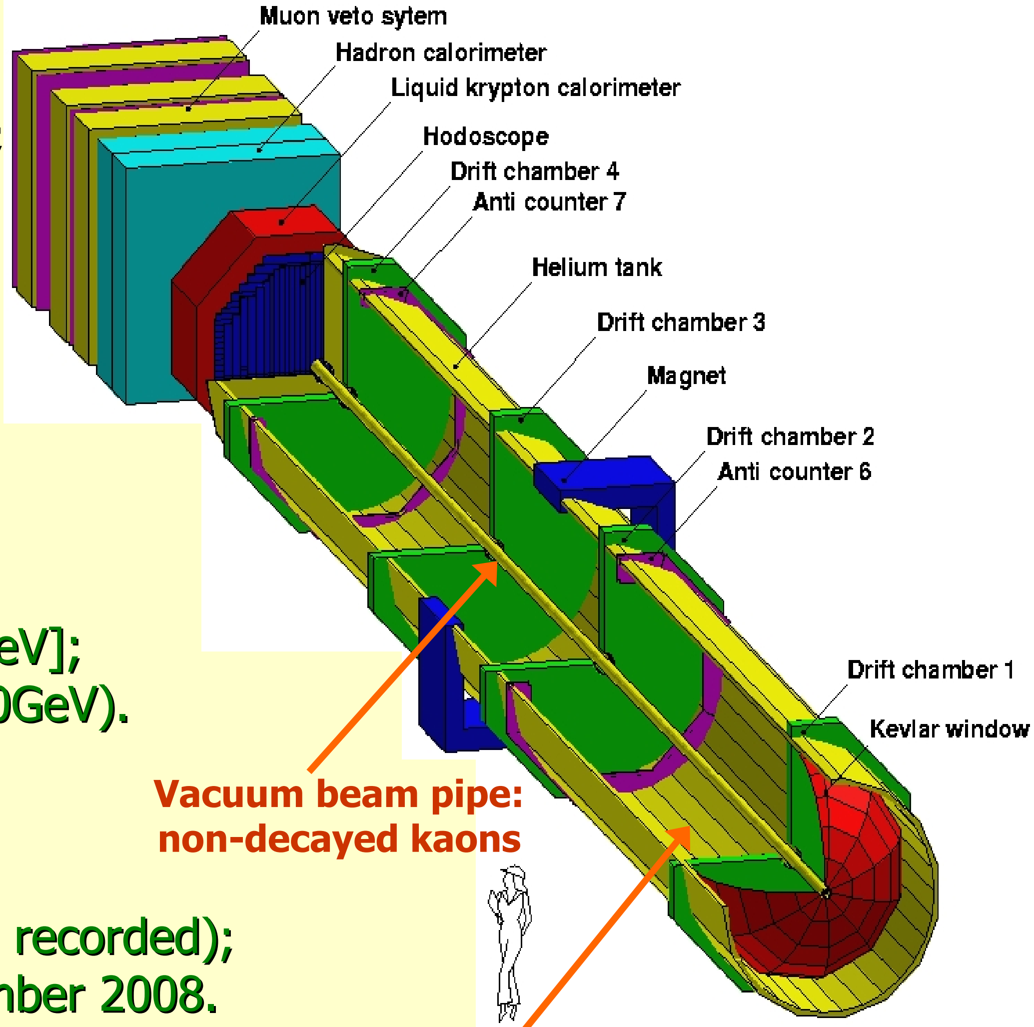
Dedicated data taking strategy + 160K K_{e2} sample with ~10% background

Data taking: 2007 and 2008

Principal subdetectors for R_K:

- Magnetic spectrometer (4 DCHs):
  4 views/DCH: redundancy ⇒ efficiency;
  used in trigger logic;
  $\Delta p/p = 0.47\% + 0.020\%*p$ [GeV/c]
- Hodoscope
  fast trigger;
  precise time measurement (150ps).
- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogenious;
  $\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$ [GeV];
  $\sigma_x=\sigma_y=0.42/E^{1/2} + 0.6\text{mm}$ (1.5mm@10GeV).



Vacuum beam pipe: non-decayed kaons

He filled tank, atmospheric pressure

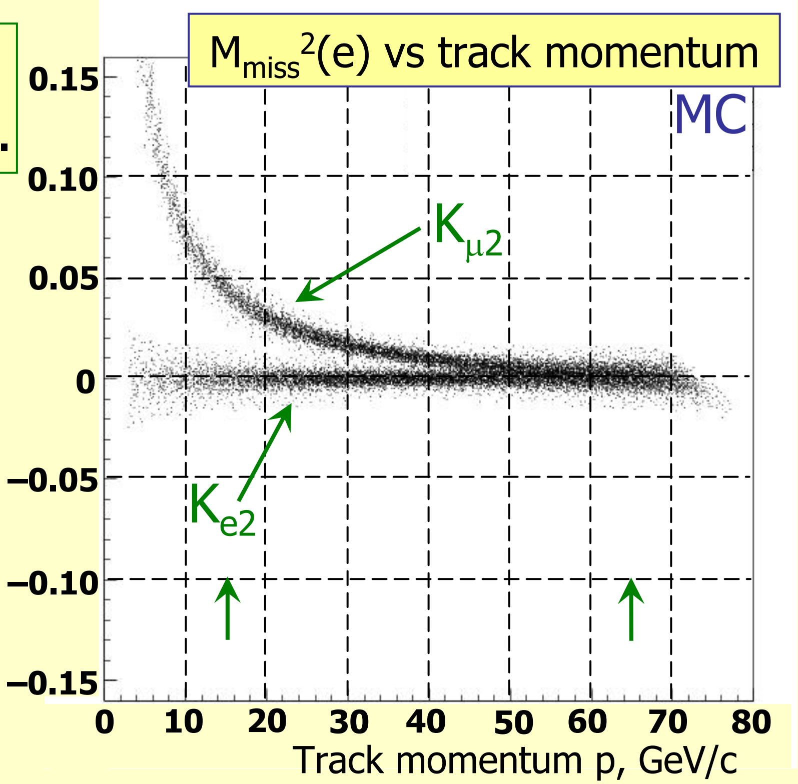
Decay volume is upstream

Data taking:

- Four months in 2007 (23/06-22/10):
  ~400K spills, 300TB of raw data (90TB recorded);
  reprocessing mostly finished by September 2008.
- Two weeks in 2008 (11/09-24/09):
  special data sets to reduce systematic uncertainties.

Kaon beams

NA48/2 beam line: capable of delivering simultaneous K^+/K^- beams (75 GeV/c in 2007).



Kinematic ID of the K_{l2} candidates:

$$\mathbf{M_{miss}^2(l)=(P_K-P_l)^2}$$

P_K is not measured in every event

Poor $K_{e2}/K_{\mu2}$ separation at p_{track}>40GeV/c

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Optimization of M_{miss}^2 resolution:

narrow momentum band beams ($\Delta P_K/P_K$=2%)

Kaon sign

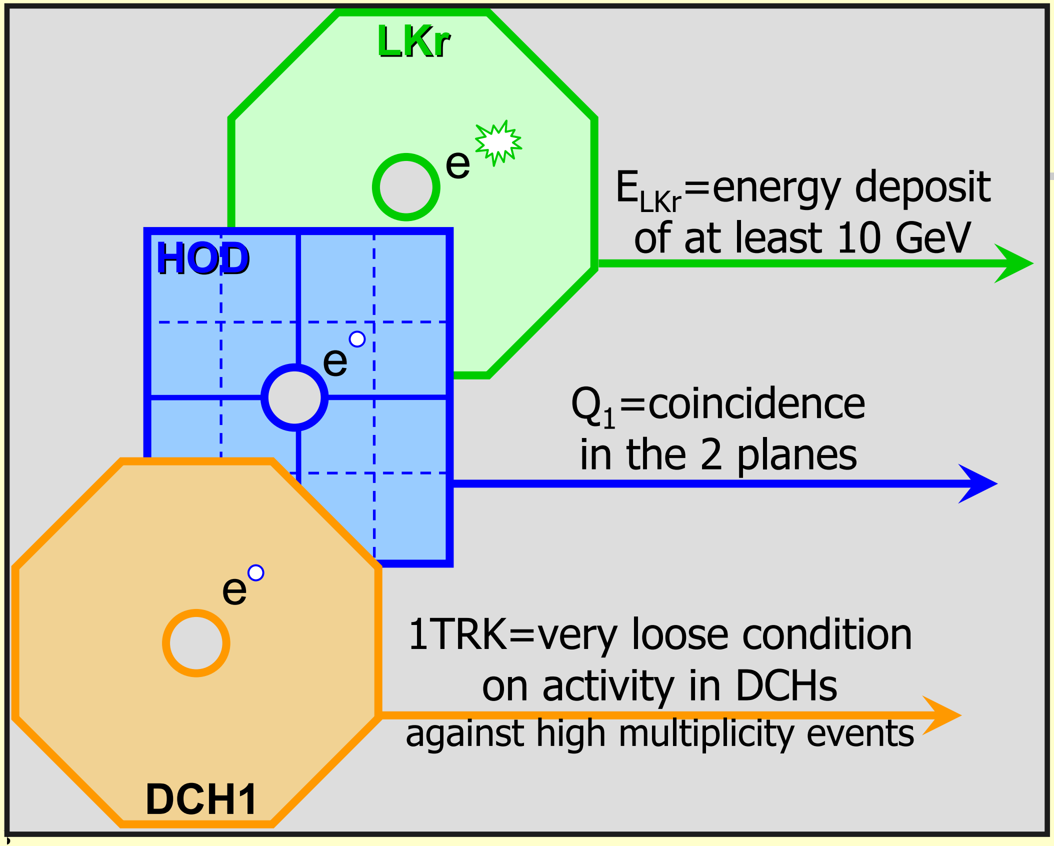
Beam halo background much higher for K^- (~20%) than for K^+ (~1%).

~90% of data sample: K^+ only.

~10% of data sample: K^- only.

K_{l2} samples of charge not present in the beam: direct measurements of the halo background with sufficient precision.

Trigger logic



E_{LKr}=energy deposit of at least 10 GeV

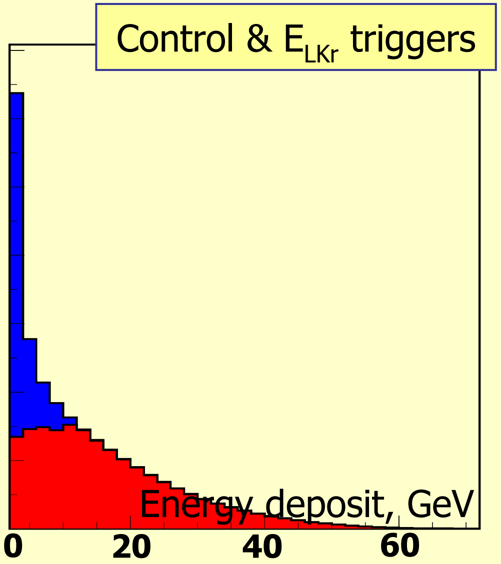
Q_1=coincidence in the 2 planes

1TRK=very loose condition on activity in DCHs against high multiplicity events

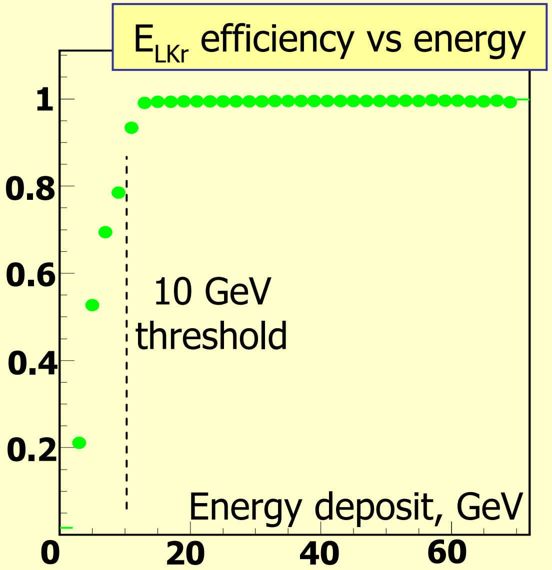
Minimum bias (=high efficiency, low purity) trigger configuration used

K_{e2} condition:
$Q_1 \times E_{LKr} \times 1TRK$.
Purity $\sim 10^{-5}$.

$K_{\mu 2}$ condition:
$Q_1 \times 1TRK/D$, D=50 to 150.
Purity ~2%.



Control & E_{LKr} triggers



E_{LKr} efficiency vs energy

- $K_{\mu 2}$ trigger is used to monitor the efficiency of the K_{e2} trigger.
- E_{LKr} inefficiency is below 0.1% and is directly measured.

Measurement method

$K_{e2}/K_{\mu2}$ candidates collected simultaneously:

- result does not rely on K flux measurement;
- cancellation of certain systematic effects
  (e.g. parts of reconstruction/trigger efficiencies)

MC simulations used to a limited extent:

1) geometric acceptance correction; 2) energetic bremsstrahlung by muon.

A counting experiment in track momentum bins:

$$R_K = \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu2}) - N_B(K_{\mu2})} \cdot \frac{A(K_{\mu2}) \times f_\mu \times \varepsilon(K_{\mu2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \cdot \frac{1}{f_{LKR}}$$

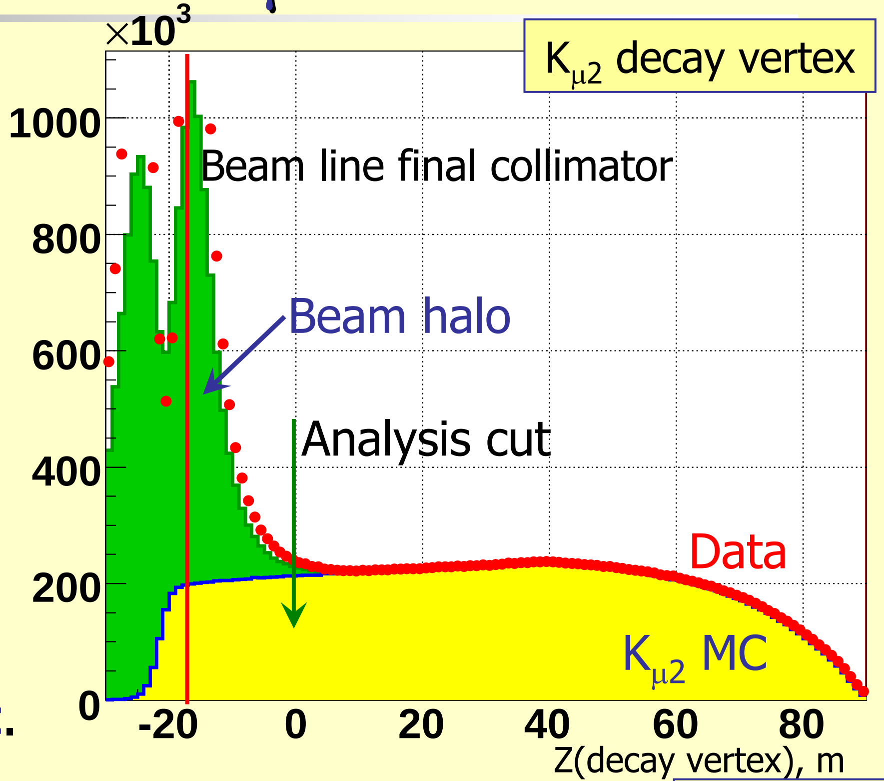
- $N(K_{e2})$, $N(K_{\mu2})$: numbers of selected K_{l2} candidates;
- $N_B(K_{e2})$, $N_B(K_{\mu2})$: numbers of background events;
- $A(K_{e2})$, $A(K_{\mu2})$: MC geometric acceptances (no ID);
- f_e, f_μ: measured particle ID efficiencies;
- $\varepsilon(K_{e2})/\varepsilon(K_{\mu2})>0.999$: E_{LKr} trigger condition efficiency;
- $f_{LKR}\approx0.998$: global LKr readout efficiency.

K_{e2} and $K_{\mu2}$ selection

Large common part for K_{e2} and $K_{\mu2}$

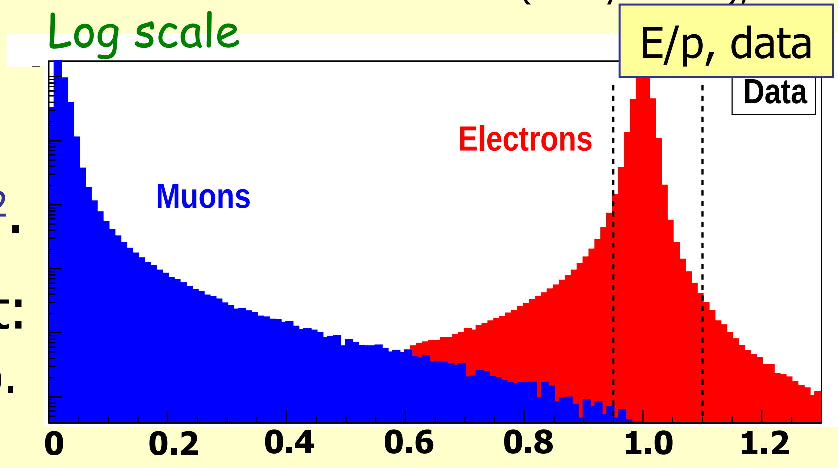
(due to topological similarity)

- One reconstructed charged track;
- Track in geometrical acceptance of the main subdetectors;
- Upper limit on LKr energy deposition not associated to the track;
- Decay vertex: closest approach of track & nominal kaon axis;
- CDA<2cm and $(Z_{vtx}-Z_{coll})>18$m;
- Track momentum: 15GeV/c<p<65GeV/c.

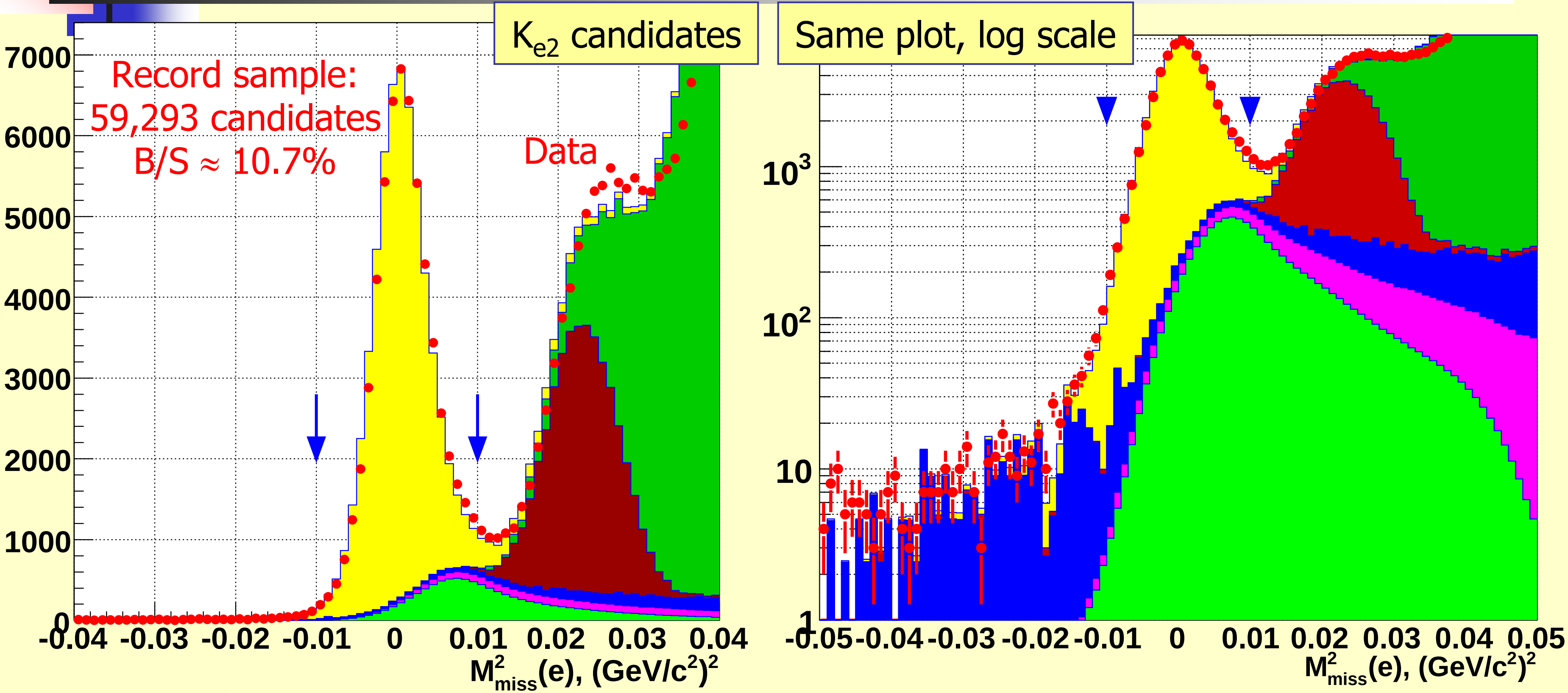


Conditions different for K_{e2} and $K_{\mu2}$

- Kinematic identification by missing mass: $M_{miss}^2(l)=(P_K-P_l)^2$, $|M_{miss}^2(l)|<0.01$ (GeV/c²)².
- Particle identification by LKr energy deposit: $0.95<E/p<1.10$ ($E/p<0.2$) for electron (muon).



K_{e2} and $K_{\mu2}$ (40% of data set)



K_{e2} candidates

Same plot, log scale

Record sample:
59,293 candidates
B/S ≈ 10.7%

Data

K_{e2} background sources

🟩	$K_{\mu2}$	(8.07±0.21)%
🟪	$K_{e2\gamma}$ (SD$^+$)	(1.29±0.32)%
🟦	Beam halo	(1.23±0.07)%
🟥	$K_{2\pi}$	0.11%
🟩	K_{e3}	0.03%

Estimated NA62 total K_{e2} sample:
140K K^+ & 20K K^- candidates.
Proposal (CERN-SPSC-2006-033):
150K candidates

cf. KLOE sample: 8,090 candidates
after background subtraction

Muonic background in K_{e2} sample

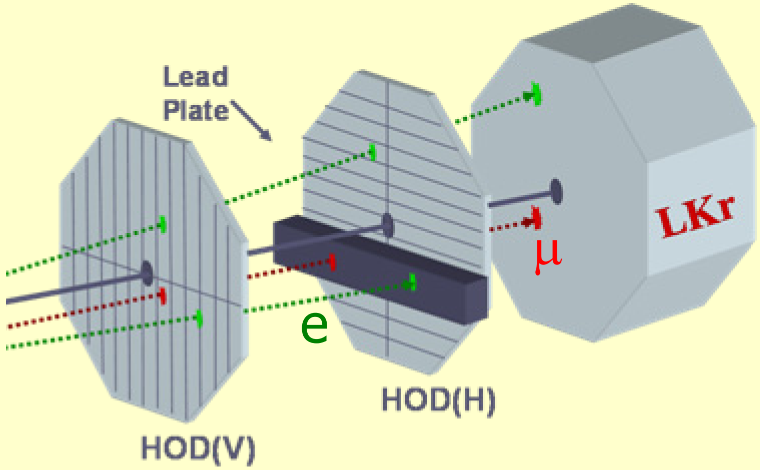
Electron ID is based on LKr energy deposition: $0.95<E/p<1.10$.

Muon mis-identification as electron
due to "catastrophic" bremsstrahung:
$P(\mu\to e) \sim 3\times10^{-6}$ (and p-dependent)

$P(\mu\to e)/R_K \sim 10\%$:
$K_{\mu2}$ decays represent a major background

Direct measurement of $P(\mu\to e)$ is necessary to validate theoretical brems. cross-section computation in the highly energetic γ region.

Pb wall inserted between the HOD planes.
Tracks traversing the wall & with $E/p>0.95$ are pure muon samples (no electrons).



Thickness: ~$10X_0$ (Pb+Fe)
Width: 240cm (=HOD diameter)
Height: 18cm (=3 counters)
Area: 20% of HOD acceptance
Installed: ~50% of running time

Pure muon samples collected:

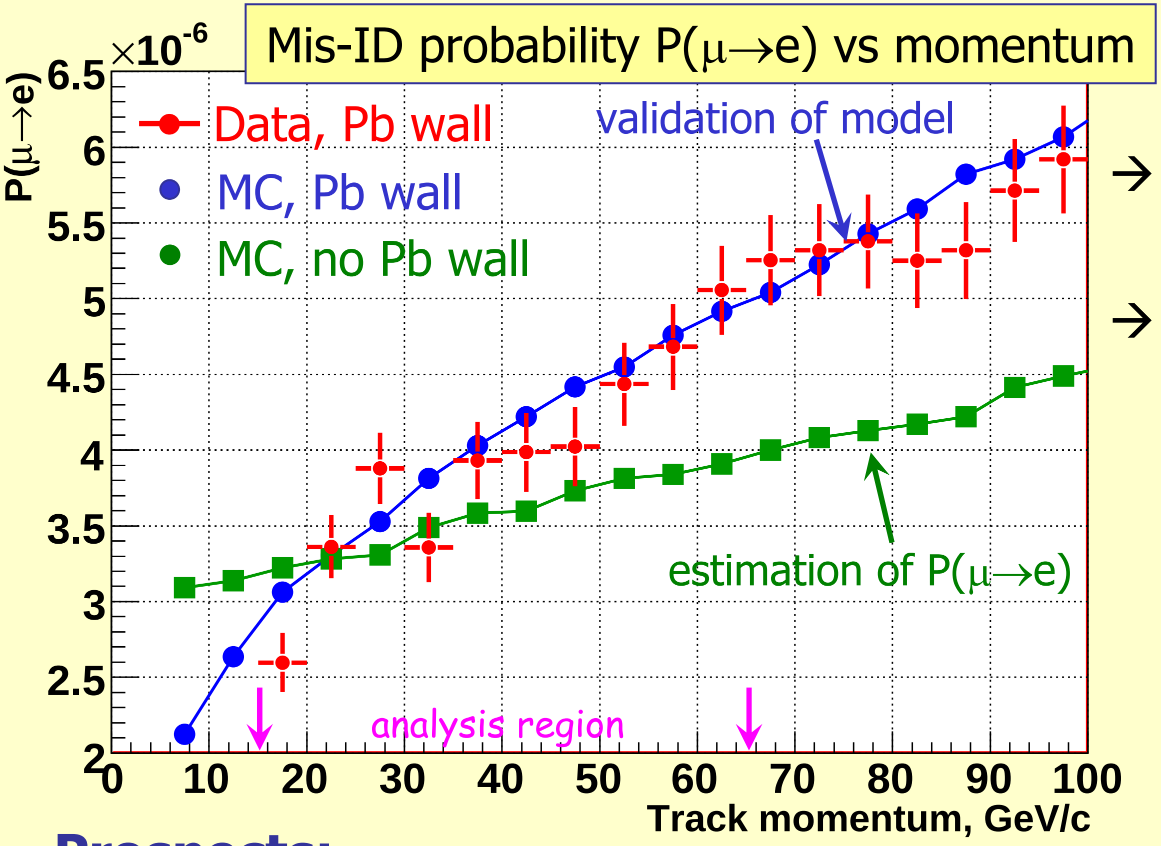
1) From $K_{\mu2}$ decays during main data taking with kaon beams;
2) Special μ runs with hadron beam absorbed (2007+2008).

~1,500 muons with $E/p>0.95$, $35<p<65$(GeV/c) in 2007 special sample.

Muonic background (2)

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

=brems cross-section+
EM shower development in LKr



→ Excellent data/MC agreement for the Pb wall case;

→ $P(\mu\to e)$ appreciably modified by the Pb wall, mainly due to:
1) muon ionization losses (low p);
2) bremstrahlung in Pb (high p).

Result: B/S = (8.07±0.21)%

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

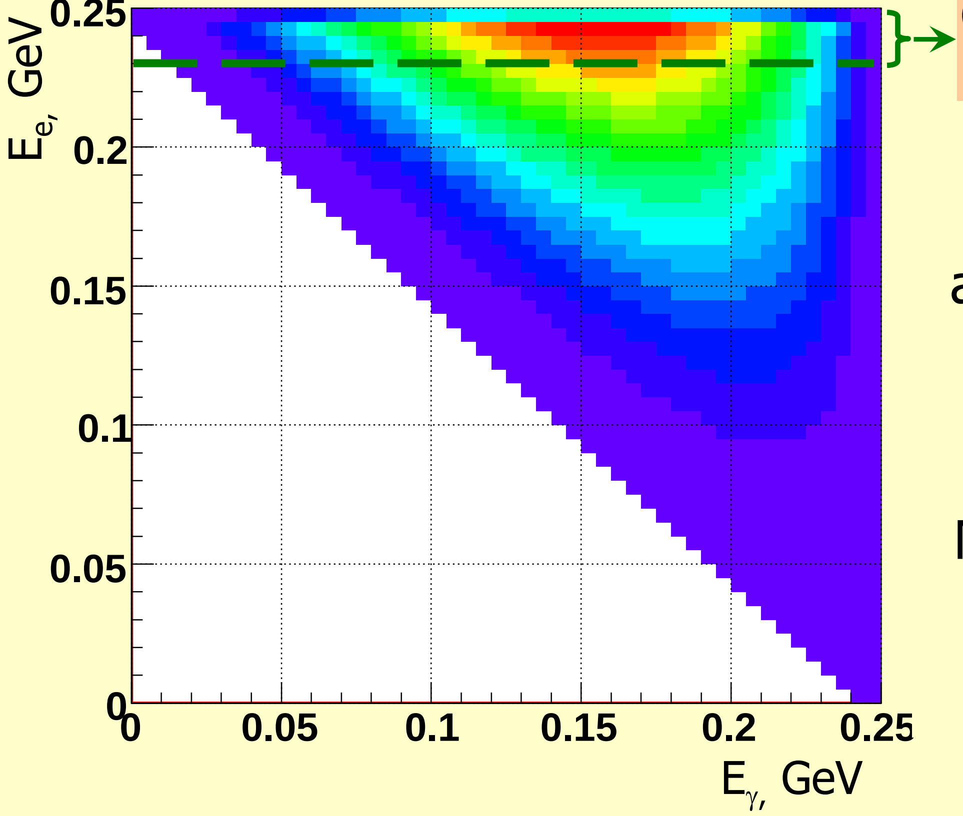
Prospects:

- The 2008 muon sample is twice as large as the 2007 one;
- Another tool: muons from $K_{\mu2}$ decays in $K_{e2}/K_{\mu2}$ separation region (p<25GeV/c).

$K^\pm \to e^\pm \nu\gamma$ background

$K_{e2\gamma}$ (SD+) process: background by definition of R_K, rate similar to K_{e2}.
Theory: BR=$(1.12–1.34)\times10^{-5}$ [model-dependent form-factor]
Experiment: BR=$(1.52\pm0.23)\times10^{-5}$ [1970s measurements]

$K_{e2\gamma}$ (SD+) Dalitz plot distribution



Only energetic electron events (E_e^*>230MeV) are compatible to K_{e2} kinematic ID

⇩

This part of phase space is accessible for direct BR measurement, due to being above K_{e3} background upper limit (E_e^*=227 MeV).

NA62 analysis with 2007 data started.

Current background estimate:

B/S = (1.29±0.32)%

(to be strongly improved)

Beam halo background

Background source in K_{e2} sample:

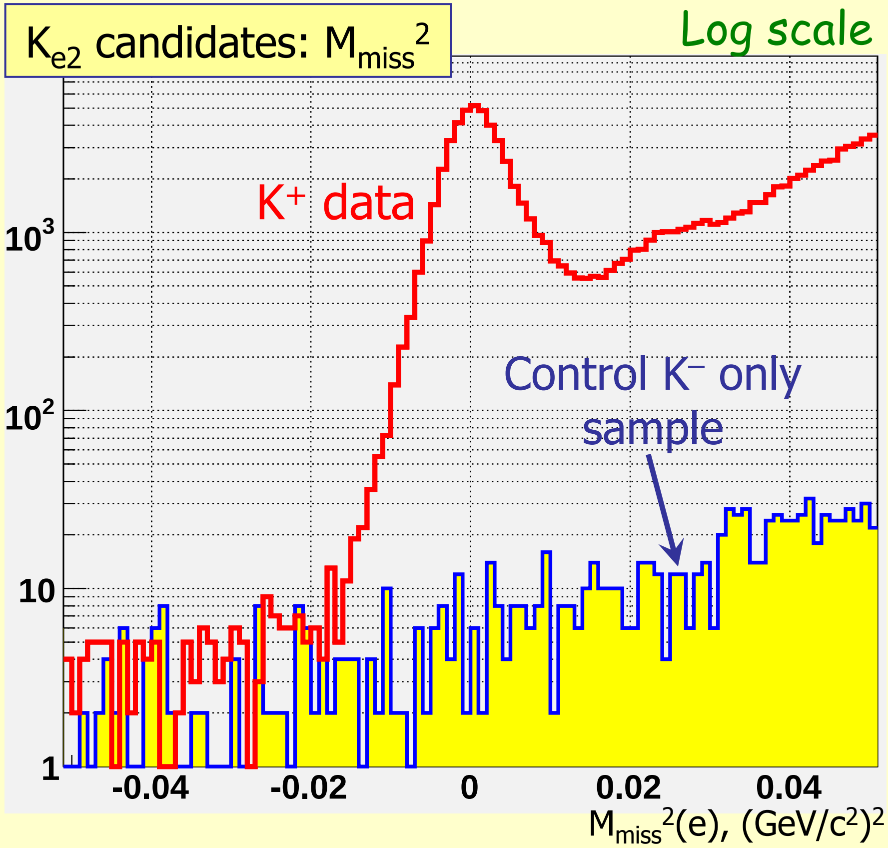
electrons produced by beam halo muons via $\mu \to e$ decay, kinematically and geometrically compatible to a genuine K_{e2} decay

Directly measured with K^- only sample:

$B/S=(1.23\pm0.07)\%$

(uncertainty due to the limited size of control data sample)

Background rate & distribution are fairly well reproduced with beam halo simulation



Prospects:

- 2008 K^- sample will improve precision;
- Smallness of uncertainty potentially allows expanding the analysis fiducial volume further upstream & increase the data sample.

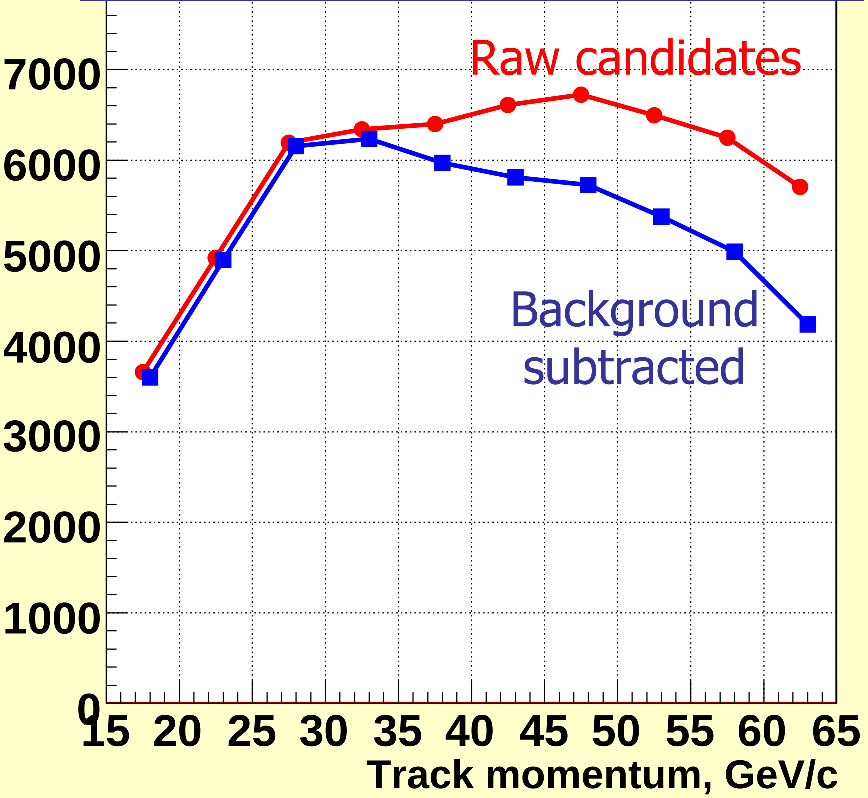
Halo background in $K_{\mu2}$ sample measured with similar technique:

$B/S=0.14\%$ (negligible uncertainty)

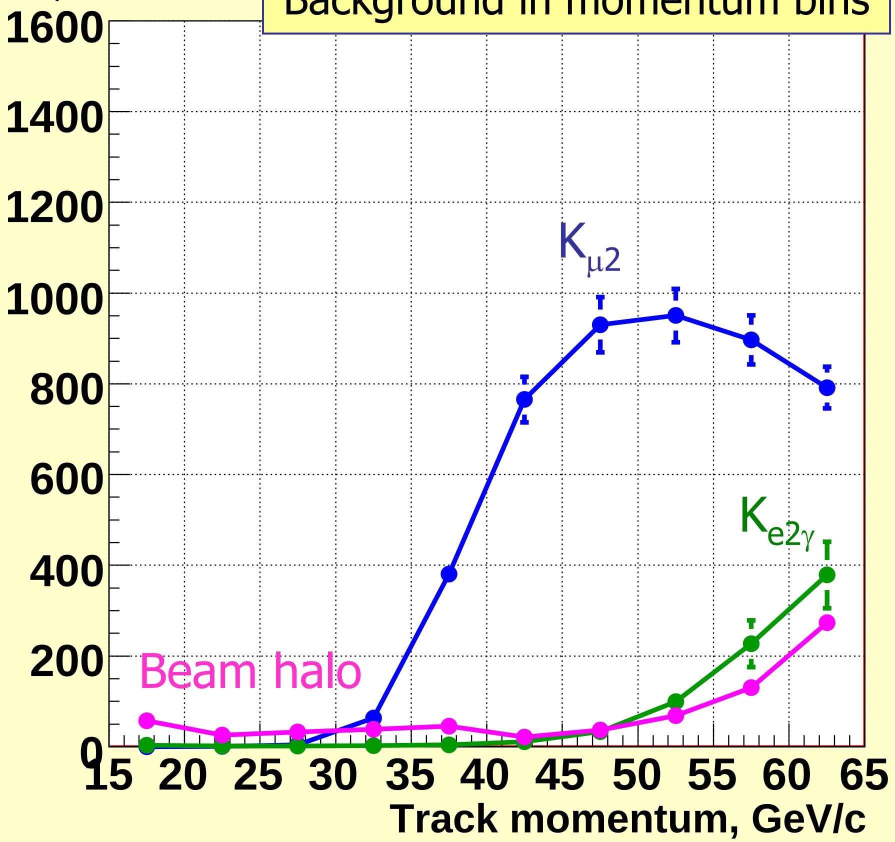
Backgrounds: summary

Scales differ by a factor of 5

K_{e2} candidates in track momentum bins



Background in momentum bins



B/S≈10.7%, mainly at high momentum.
Systematic effect due to BKG: $\delta R_K/R_K=0.4\%$.
Improvement in precision for each
background source is foreseen.

Other identified (minor) backgrounds:

$K^{\pm}\to\pi^0 e^{\pm}\nu$, $K^{\pm}\to\pi^{\pm}\pi^0$ (below 0.1%);
$K_{\mu2}$ + accidental LKr cluster (~0.1%).

Particle ID efficiencies

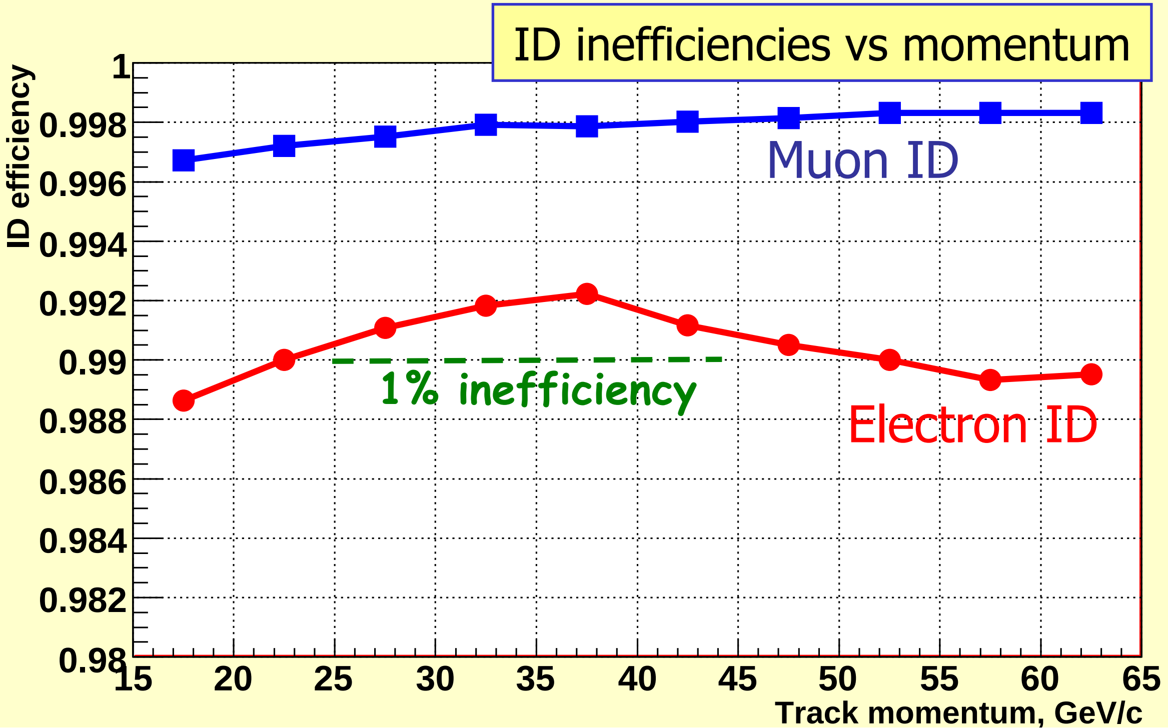
Electron ID efficiency f_e: directly measured by kinematic selection of electrons

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

Precision of f_e measurement: better than 0.1%.

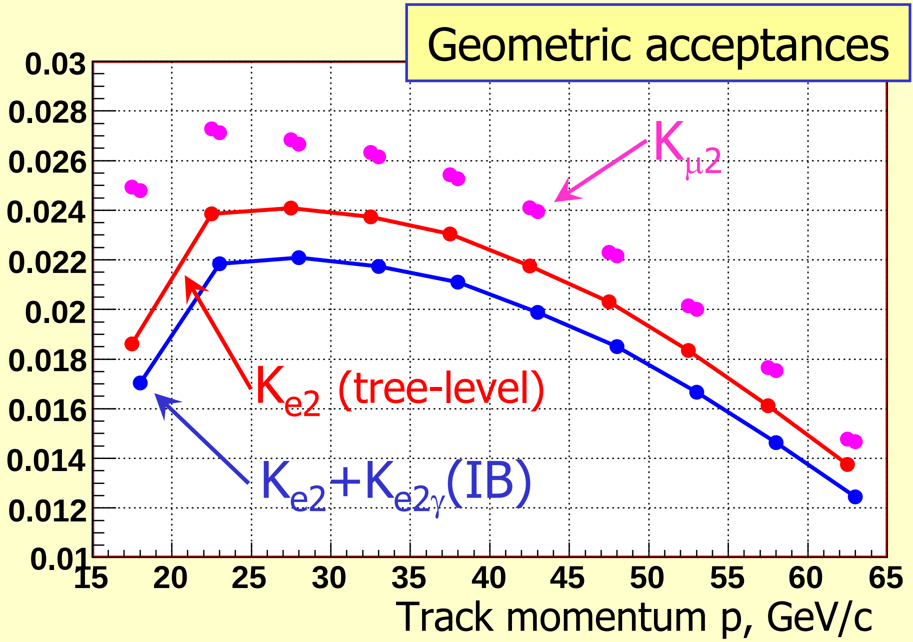
Muon ID efficiency f_μ:

- ID by energy deposit $E/p<0.2$;
- f_μ measured directly to be in the 0.996–0.999 range;
- Uncertainty is much better than $\delta f_\mu=0.1\%$.



ID inefficiencies vs momentum

Other effects



Acceptance correction:

- p-dependent, $A(K_{\mu2})/A(K_{e2})\sim1.2$;
- K_{e2} radiative corrections strongly affect the acceptance;
- Preliminary conclusion: the correction can be evaluated with a 0.1% precision.

Trigger efficiency correction:

- Efficiencies are monitored with control trigger samples;
- Q_1 efficiency mostly cancels in R_K, while E_{LKr} efficiency directly affects R_K.
- E_{LKr} nefficiency measurement: $1-\varepsilon(E_{LKr}) \approx 1-\varepsilon(K_{e2})/\varepsilon(K_{\mu2}) < 0.1\%$;

Other known sources of uncertainies (can be corrected for):

- Trigger afterpulses biasing the Q_1 downscaling factor;
- Global inefficiency of LKr calorimeter readout (preliminary: $f_{LKr}\approx0.998$).

Analysis summary & prospects

Main uncertainties
(40% of the data sample)

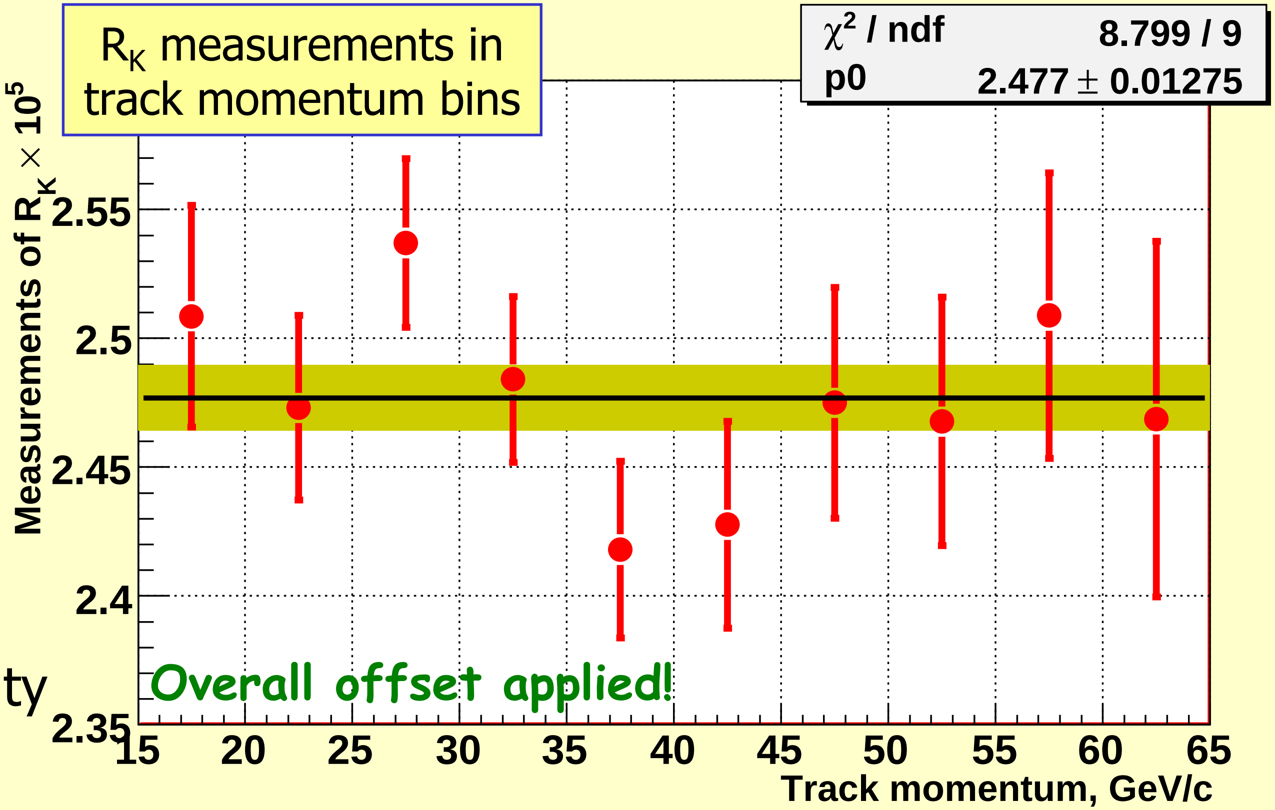
Statistical	0.43%
$K_{\mu2}$	0.25%
$K_{e2\gamma}$ (SD)	0.32%
Beam halo	0.10%
Total	0.60%

Expected total uncertainty with the 40% sample:

0.6–0.7%

(breaking the 1% level for the first time)

Much room for improvement of the systematic errors



R_K measurements in track momentum bins

Overall offset applied!

Using the whole **~160K** candidates: statistical uncertainty pushed below **0.3%**, total uncertainty of **0.4–0.5%** is within reach.

(in agreement with the proposal)

Conclusions

- NA62 has increased the world K_{e2} sample by more than an order of magnitude.

- $R=\Gamma(K_{e2})/\Gamma(K_{\mu 2})$ is sensitive, for instance, to SUSY in the large $\tan\beta$ scenario with broken lepton universality.

- Analysis of a partial data set is quite advanced. It is demonstrated that an overall uncertainty of 0.4% declared in the proposal is within reach.

- The NA62 is going to provide a timely result, as direct searches for New Physics at the LHC are approaching.