A precision test of lepton universality in $K^+ \to l^+\nu$ decays at CERN NA62

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Outline:

1) Purely leptonic meson decays: why interesting?
2) Overview of kaon experiments at CERN
3) Analysis of NA62 dedicated $K^+ \to l^+\nu$ sample
4) Competitors, comparison to world data
5) The future: NA62 phase II
6) Summary

UNIVERSITY OF BIRMINGHAM

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CERN

Leptonic meson decays: physics interest

Flavour physics in the LHC era

Searches for physics beyond the Standard Model

Energy Frontier (LHC)

Determine the energy scale of NP by direct production of NP particles

Rarity (High Intensity) Frontier

Determine the flavour structure of NP via virtual effects in precision observables: deviations from precise SM predictions in rare or forbidden processes.

CP violation in B and K systems

Universality tests in B and K

Rare B and K decays

LVF in μ and τ decays

Neutron EDM

$(g-2)_\mu$

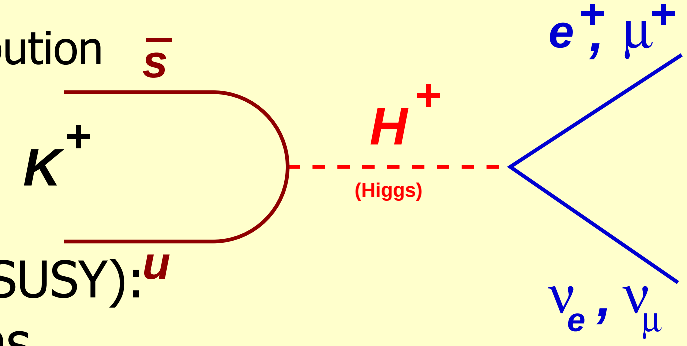
Improved CKM fits

Physics programme at the Rarity Frontier is complementary to direct searches for new physics at the Energy Frontier

Leptonic meson decays: $P^+ \to l^+ \nu$

Angular momentum conservation → suppressed SM contribution

$$\Gamma(P^+ \to l^+\nu) = \frac{G_F^2 M_P M_l^2}{8\pi}\left(1 - \frac{M_l^2}{M_P^2}\right)^2 f_P^2 |V_{qq'}|^2$$



Models with two Higgs doublets (2HDM-II including SUSY):
sizeable charged Higgs ($H^\pm$) exchange contributions
PRD48 (1993) 2342; Prog.Theor.Phys. 111 (2004) 295

(numerical examples for M_H=500GeV/c^2, $\tan\beta$ = 40)

$\pi^+ \to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_\pi/m_H)^2\, m_d/(m_u+m_d)\, \tan^2\beta \approx -2\times10^{-4}$
$K^+ \to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_K/m_H)^2 \tan^2\beta \approx -0.3\%$
$D^+_s \to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_D/m_H)^2\, (m_s/m_c) \tan^2\beta \approx -0.4\%$
$B^+ \to l\nu$: $\Delta\Gamma/\Gamma_{SM} \approx -2(m_B/m_H)^2 \tan^2\beta \approx -30\%$

$R = Br(K\to\mu\nu)/Br(K_{e3})$:
$(\delta R/R)_{exp} = 1.0\%$

BaBar, Belle: $Br_{exp}(B\to\tau\nu) = (1.42\pm0.43)\times10^{-4}$
Standard Model: $Br_{SM}(B\to\tau\nu) = (1.33\pm0.23)\times10^{-4}$

(SM uncertainties: $\delta f_B/f_B$=10%, $\delta|V_{ub}|^2/|V_{ub}|^2$=13%)

⇒ $\Delta\Gamma/\Gamma_{SM} = 1.07\pm0.37$

(JHEP 0811 (2008) 42)

Not hopeless, but obstructed by hadronic uncertainties

$R_K = K_{e2}/K_{\mu 2}$ in the SM

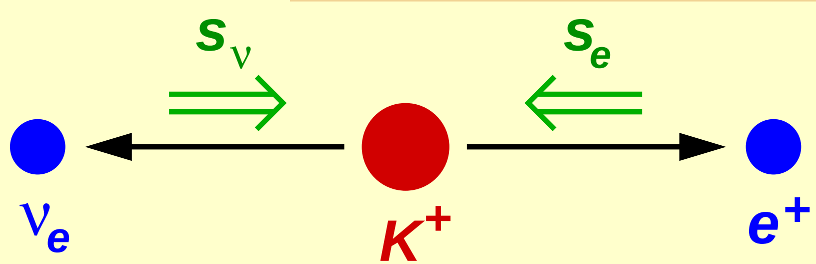
Observable sensitive to lepton flavour violation and its SM expectation:

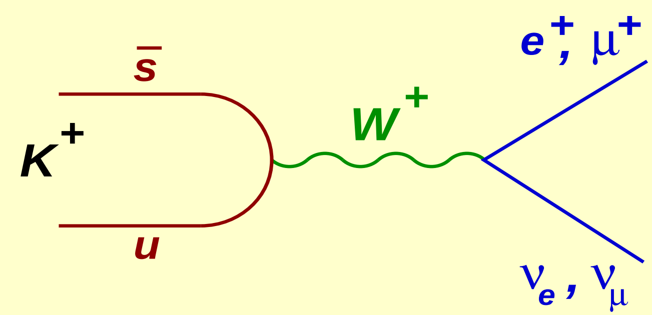
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 \cdot \left(1 + \delta R_K^{\text{rad.corr.}}\right)$$

(similarly, R_π in the pion sector)

Helicity suppression: $f \sim 10^{-5}$

Radiative correction (few %) due to $K^+ \to e^+ \nu \gamma$ (IB) process, by definition included into R_K



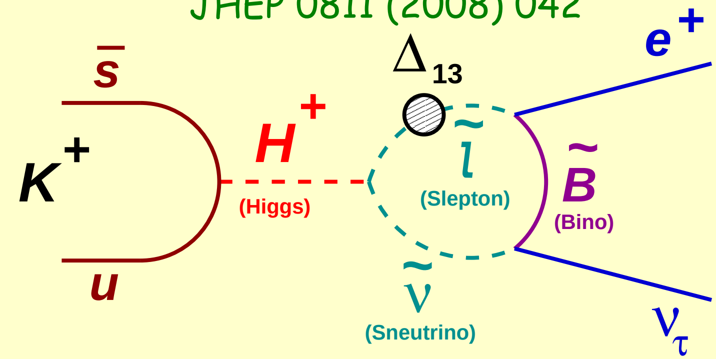


- SM prediction: excellent sub-permille accuracy due to cancellation of hadronic uncertainties.
- Measurements of R_K and R_π have long been considered as tests of lepton universality.
- Recently understood: helicity suppression of R_K might enhance sensitivity to non-SM effects to an experimentally accessible level.

$$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$$
$$R_\pi^{SM} = (12.352 \pm 0.001) \times 10^{-5}$$

Phys. Lett. 99 (2007) 231801

$R_K = K_{e2}/K_{\mu 2}$ beyond the SM



2HDM-II: tree level (including SUSY)

The charged Higgs $H^\pm$ exchange contribution is flavour-independent

→ Does not affect the ratio R_K

2HDM-II: one-loop level

Dominant contribution to ΔR_K: $H^\pm$ mediated LFV (rather than LFC) with emission of ν_τ

→ R_K enhancement can be experimentally accessible

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

~1% effect in large (but not extreme) $\tan\beta$ regime with a massive $H^\pm$

Example:
($\Delta_{13}=5\times10^{-4}$, $\tan\beta=40$, $M_H=500$ GeV/c^2)
lead to $R_K^{MSSM} = R_K^{SM}(1+0.013)$.

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

(see also PRD76 (007) 095017)

Large effects in B decays due to $(M_B/M_K)^4 \sim 10^4$:

$B_{\mu\nu}/B_{\tau\nu}$ → ~50% enhancement;

$B_{e\nu}/B_{\tau\nu}$ → enhanced by ~one order of magnitude.

Out of reach: $Br^{SM}(B_{e\nu}) \approx 10^{-11}$

R_K & R_π: experimental status

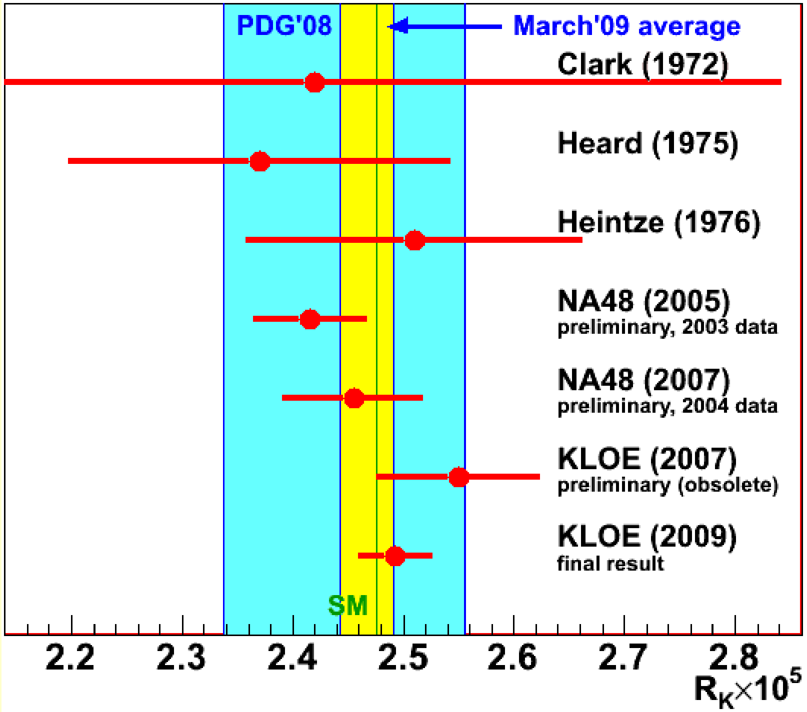
Kaon experiments:

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

→ Recent improvement: KLOE (Frascati).
Data collected in 2001–2005,
13.8K K_{e2} candidates, 16% background.
$R_K=(2.493\pm0.031)\times10^{-5}$ ($\delta R_K/R_K=1.3\%$)
(EPJ C64 (2009) 627)

→ NA62 current goal:
dedicated data taking strategy,
~150K K_{e2} candidates, <10% background,
$\delta R_K/R_K<0.5\%$: a stringent SM test.

R_K world average (March 2009)



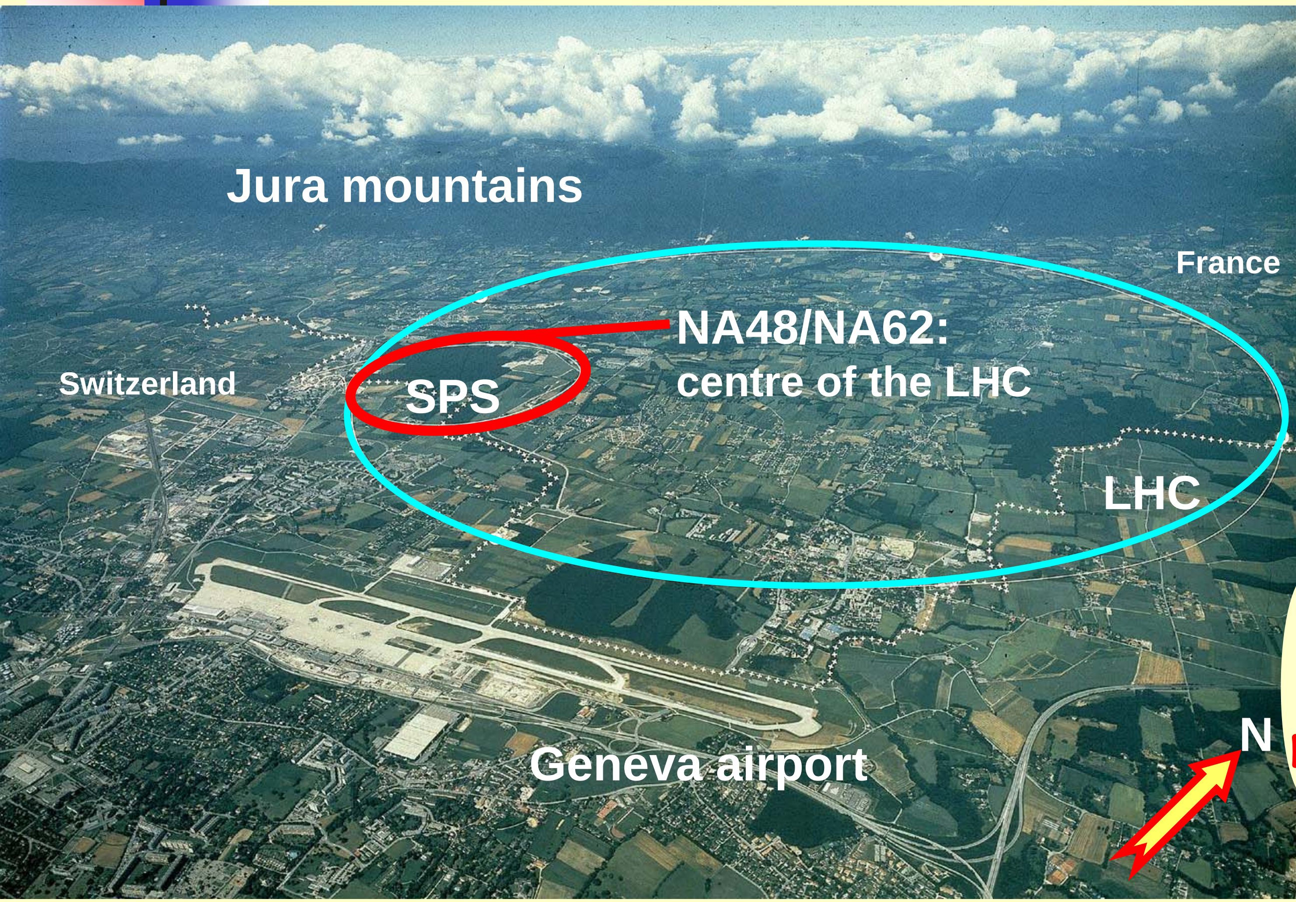
Pion experiments:

→ PDG'08 average (1980s, 90s measurements):
$R_\pi=(12.30\pm0.04)\times10^{-5}$ ($\delta R_\pi/R_\pi=0.3\%$)

→ Current projects: PEN@PSI (stopped π) running (arXiv:0909.4358)
PIENU@TRIUMF (in-flight) proposed (T. Numao, PANIC'08 proceedings, p.874)
$\delta R_\pi/R_\pi$~0.05% foreseen (similar to SM precision)

Kaon experiments at CERN: NA48 and NA62

CERN NA48 and NA62



Earlier: NA31

NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 (phase I)
- 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests
- 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests

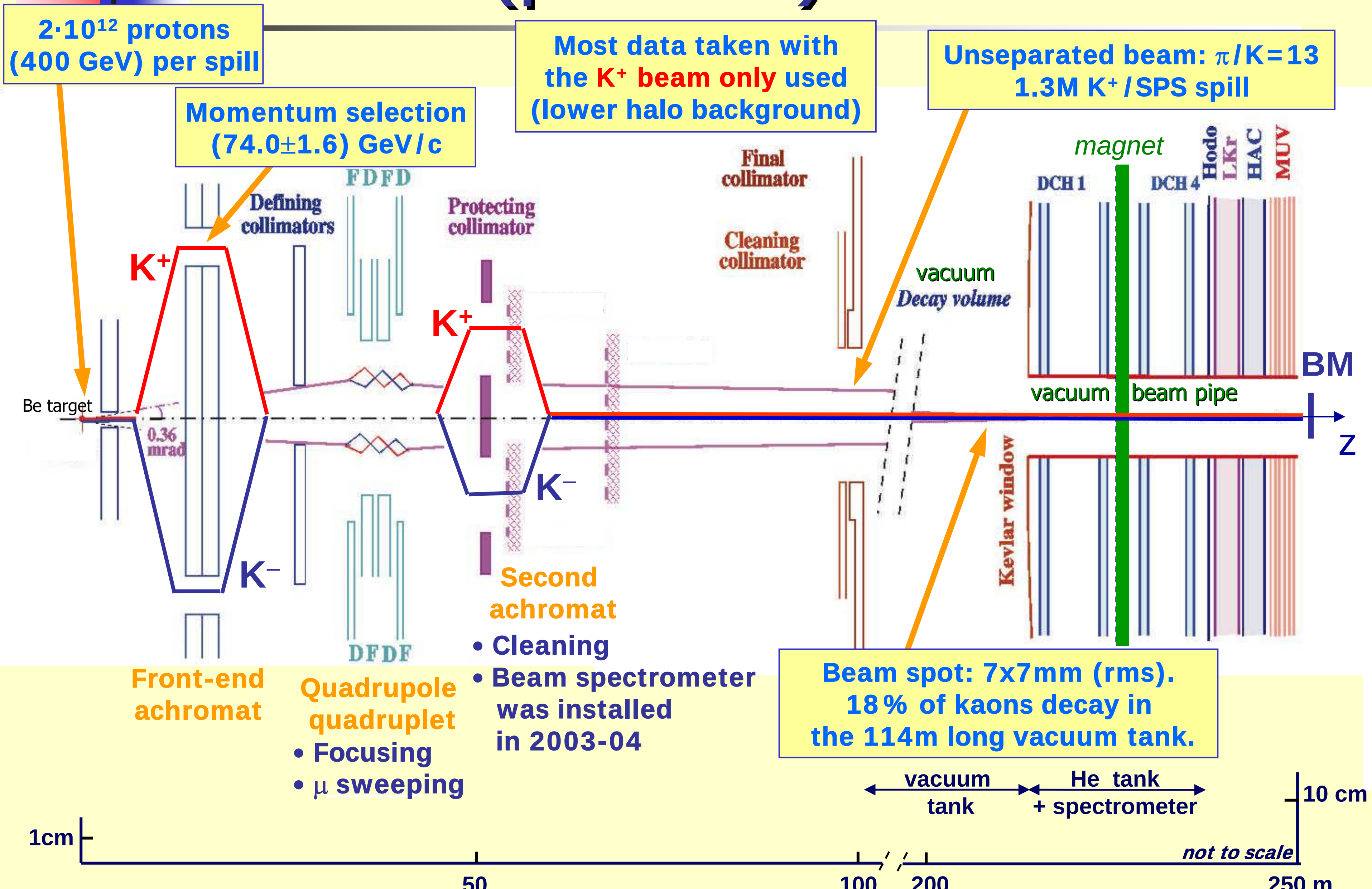
NA62 (phase II)
- 2007–2012: design & construction
- 2013–2015: $K^+\to\pi^+\nu\bar{\nu}$ data taking

NA62 phase I: Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP Protvino, INR Moscow, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin

NA48/NA62 $K^{\pm}$ beam line

Kaon decays in flight: beamline+setup are ~700 feet long

NA62 (phase I) K^+ beam line



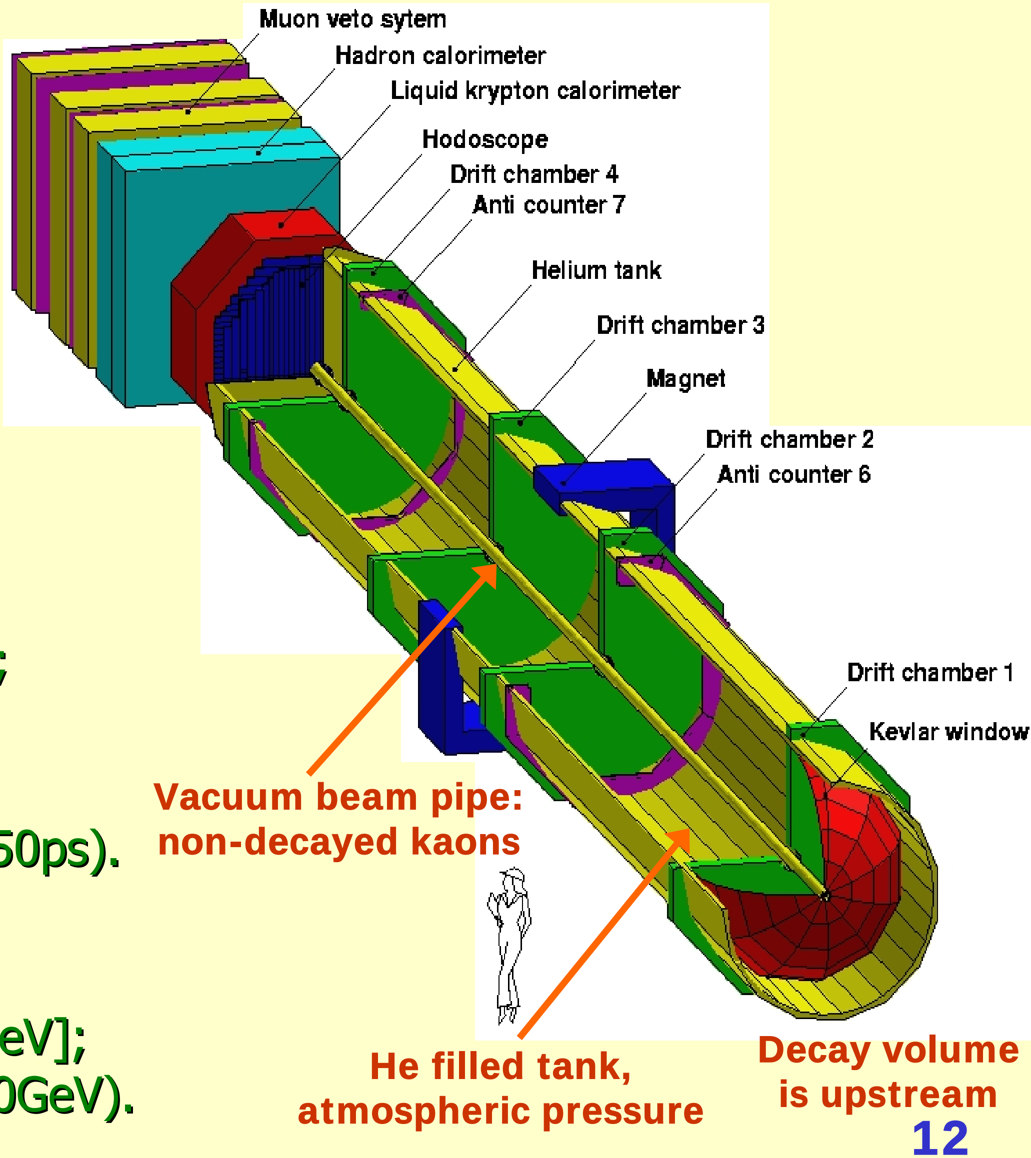
Data taking & detector: 2007/08

Data taking

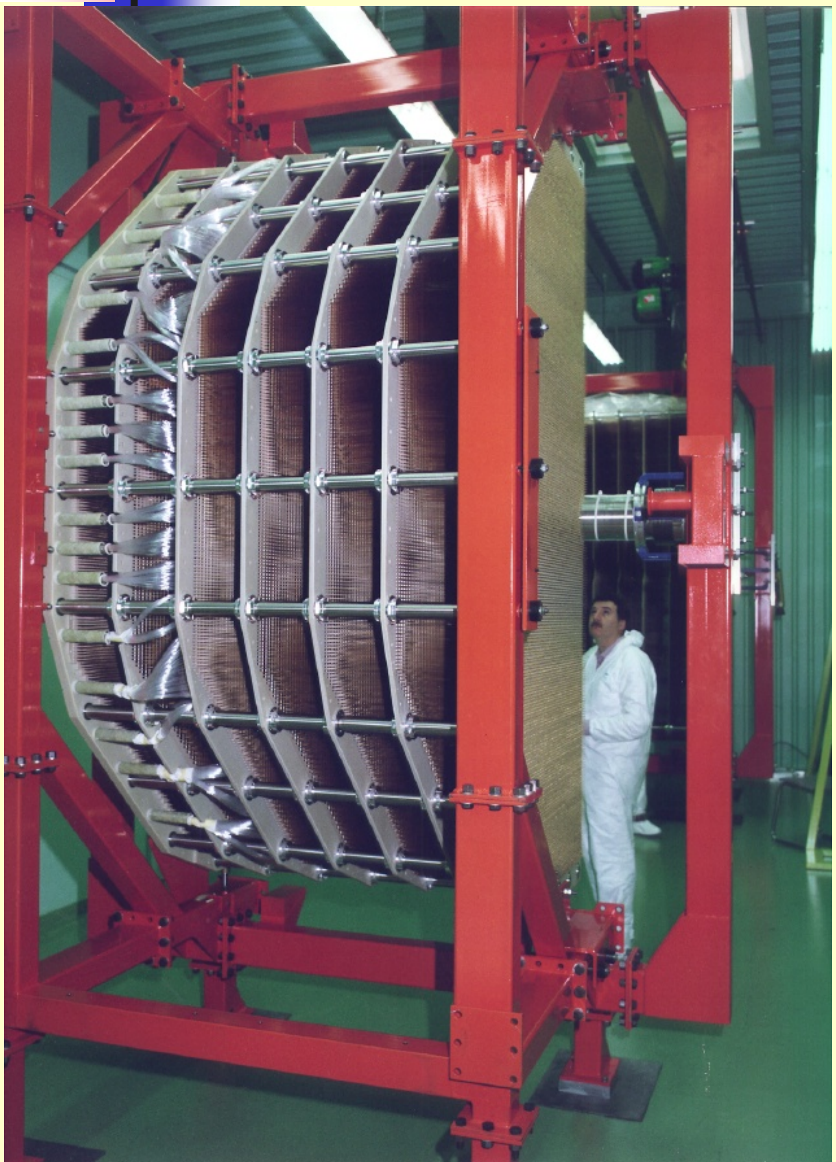
- Four months in 2007:
  ~400K SPS spills,
  ~300TB of raw data handled
- Two weeks in 2008:
  dedicated data sets allowing reduction of the systematic uncertainties.

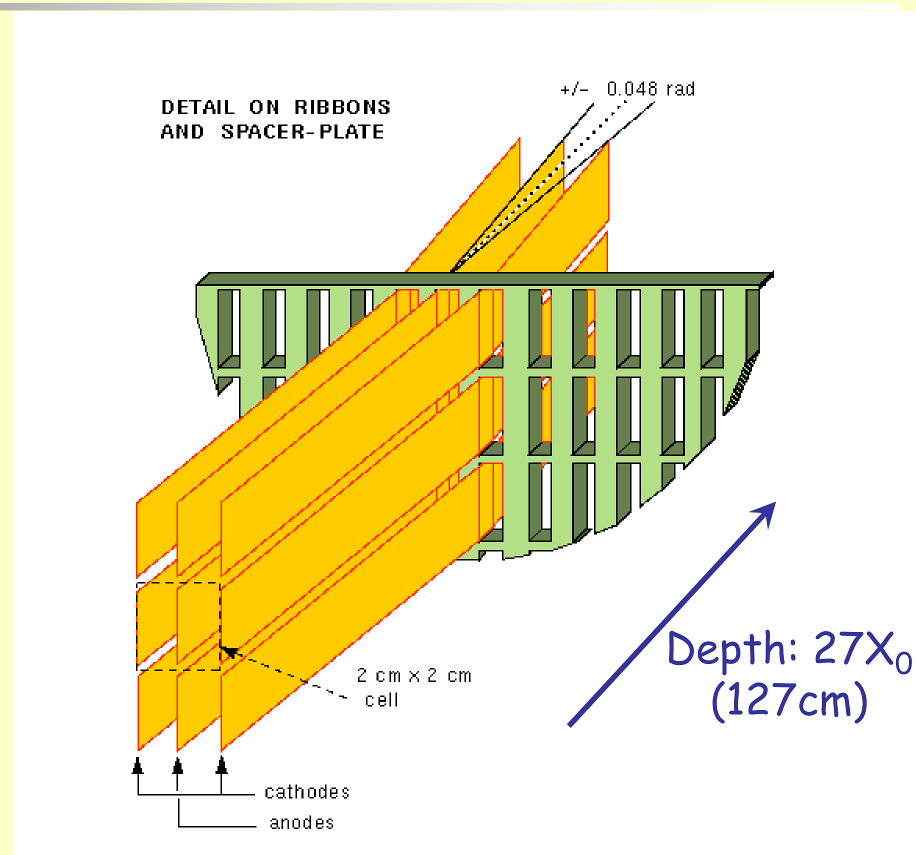
Principal subdetectors for R_K:

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



Electromagnetic LKr calorimeter

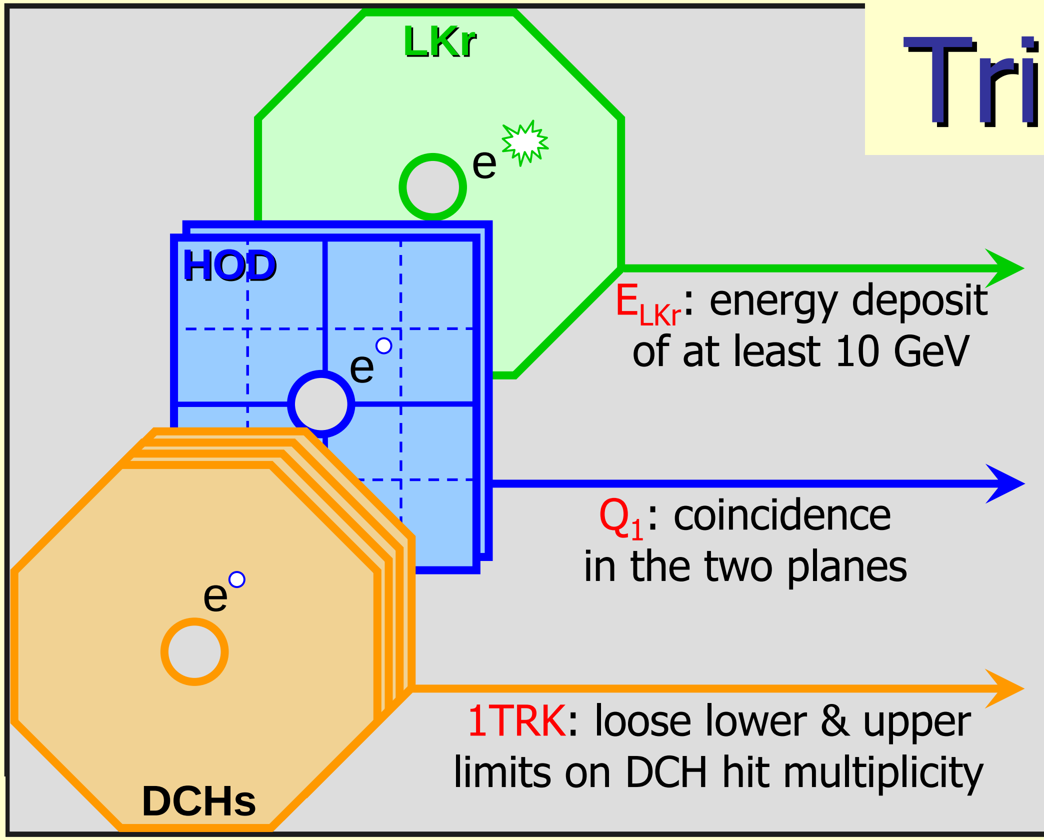




Transversal segmentation: 13,248 cells ($2\times2cm^2$), no longitudinal segmentation.

Essential for the present analysis:
(1) positron/muon identification
(2) photon veto.

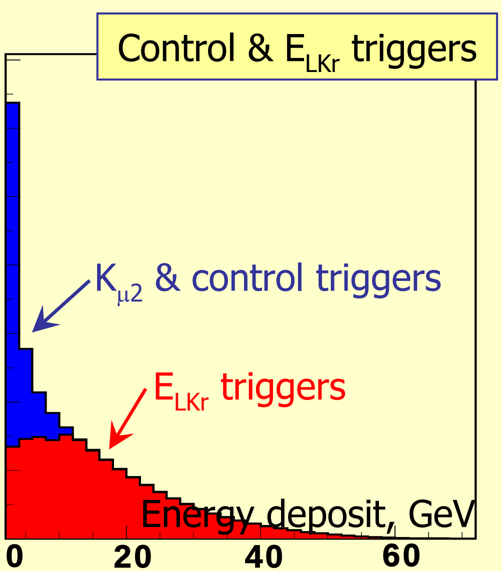
Trigger logic 2007

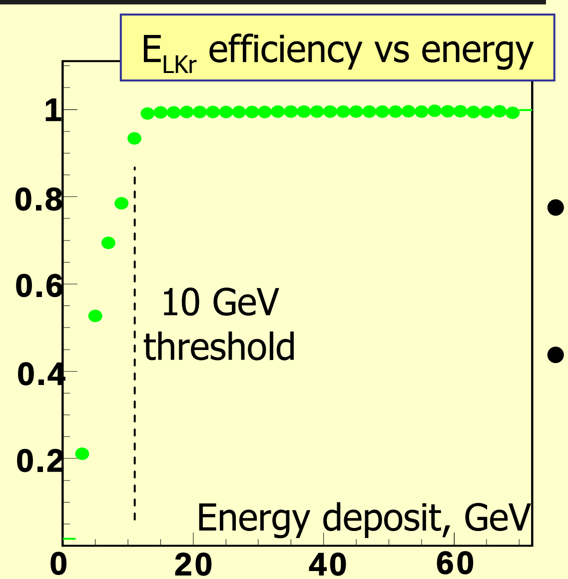


Minimum bias trigger in 2007:
(high efficiency, but low purity)

$K_{\mu2}$ condition: $Q_1 \times$1TRK/D, downscaling (D) 50 to 150.
Purity ~2%
(rate dominated by the beam halo).

K_{e2} condition: $Q_1 \times E_{LKr} \times$1TRK.
Purity $\sim 10^{-5}$
(same order as R_K).





- Efficiencies of the trigger components are monitored using control triggers.
- Measured E_{LKr} inefficiency for electrons: <0.05% for in the relevant momentum range.

Dedicated $K^+ \rightarrow l^+ \nu$ sample: data analysis

Measurement strategy

(1) $K_{e2}/K_{\mu 2}$ candidates are collected simultaneously:

- the result does not rely on kaon flux measurement;
- several systematic effects cancel at first order
  (e.g. reconstruction/trigger efficiencies, time-dependent effects).

(2) counting experiment, independently in 10 lepton momentum bins
(owing to strong momentum dependence of backgrounds and event topology)

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

$N(K_{e2})$, $N(K_{\mu 2})$: numbers of selected K_{l2} candidates;

$N_B(K_{e2})$, $N_B(K_{\mu 2})$: numbers of background events; ⇒ $N_B(K_{e2})$: main source of systematic errors

$A(K_{e2})$, $A(K_{\mu 2})$: MC geometric acceptances (no ID);

f_e, f_μ: directly measured particle ID efficiencies;

$\varepsilon(K_{e2})/\varepsilon(K_{\mu 2})>99.9\%$: E_{LKr} trigger condition efficiency;

$f_{LKr}=0.9980(3)$: global LKr readout efficiency.

(3) MC simulations used to a limited extent:

- Geometrical part of the acceptance correction (not for particle ID);
- simulation of "catastrophic" bremsstrahlung by muons.

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

Large common part (topological similarity)

- one reconstructed track;
- geometrical acceptance cuts;
- K decay vertex: closest approach of track & nominal kaon axis;
- veto extra LKr energy deposition clusters;
- track momentum: 15GeV/c<p<65GeV/c.

Kinematic separation

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

P_K : average measured with $K_{3\pi}$ decays

→ Sufficient $K_{e2}/K_{\mu2}$ separation at p_{track}<30GeV/c

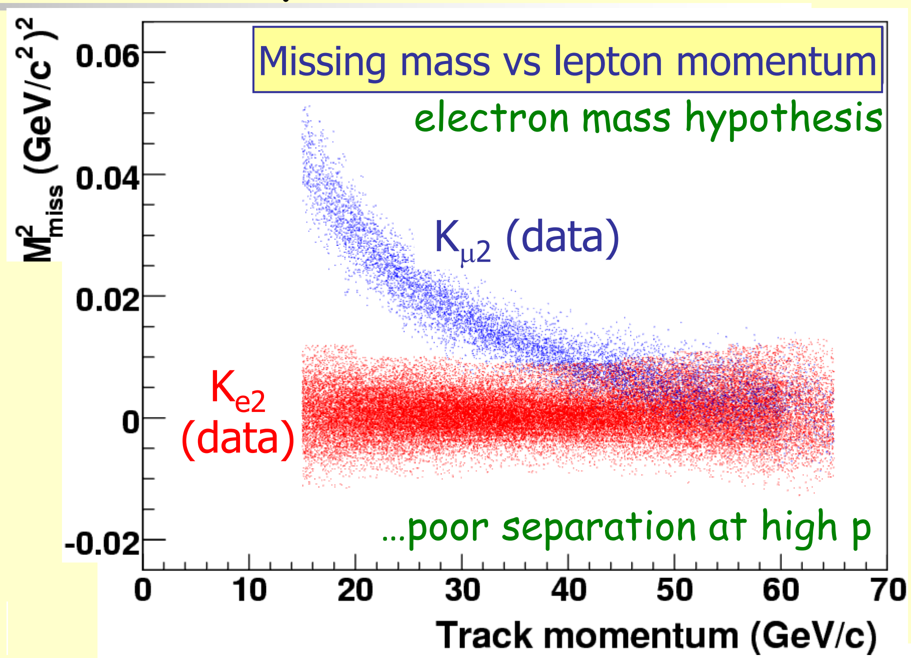
Separation by particle ID

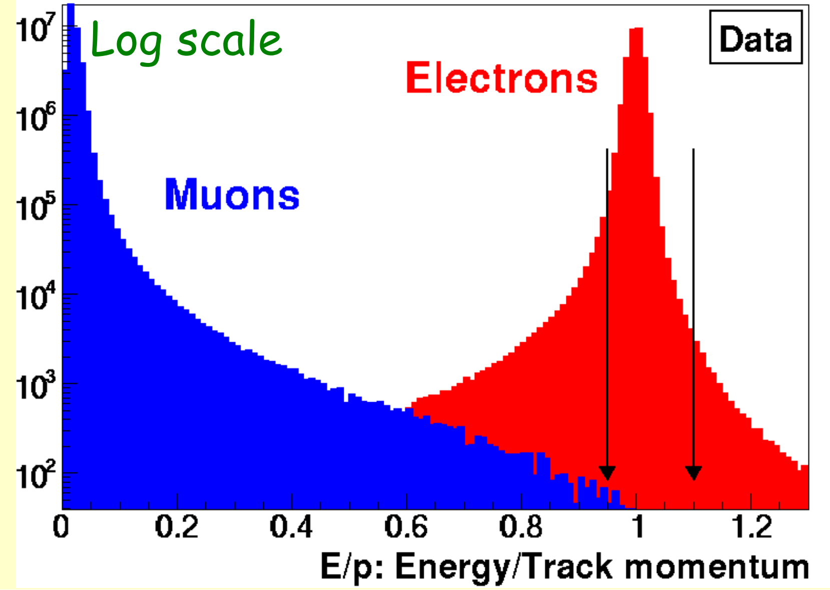
E/p = (LKr energy deposit/track momentum).

0.95<E/p<1.10 for electrons,

E/p<0.85 for muons.

→ Powerful $\mu^\pm$ suppression in $e^\pm$ sample: $f \sim 10^6$





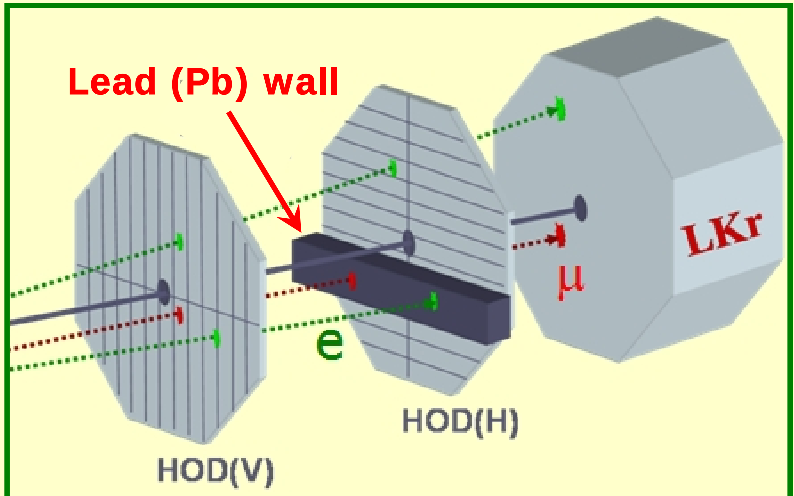
$K_{\mu 2}$ background in K_{e2} sample

Main background source:

muon "catastrophic" energy loss in LKr by emission of energetic bremsstrahlung photons. $P(\mu \to e) \sim 3 \times 10^{-6}$ (and momentum-dependent).

$P(\mu \to e)/R_K \sim 10\%$:
$K_{\mu 2}$ decays represent a major background

Theoretical bremsstrahlung cross-section
[Phys. Atom. Nucl. 60 (1997) 576]
must be validated in the region $(E_\gamma/E_\mu)>0.9$
by a direct measurement of $P(\mu \to e)$
to $\sim 10^{-2}$ relative precision.



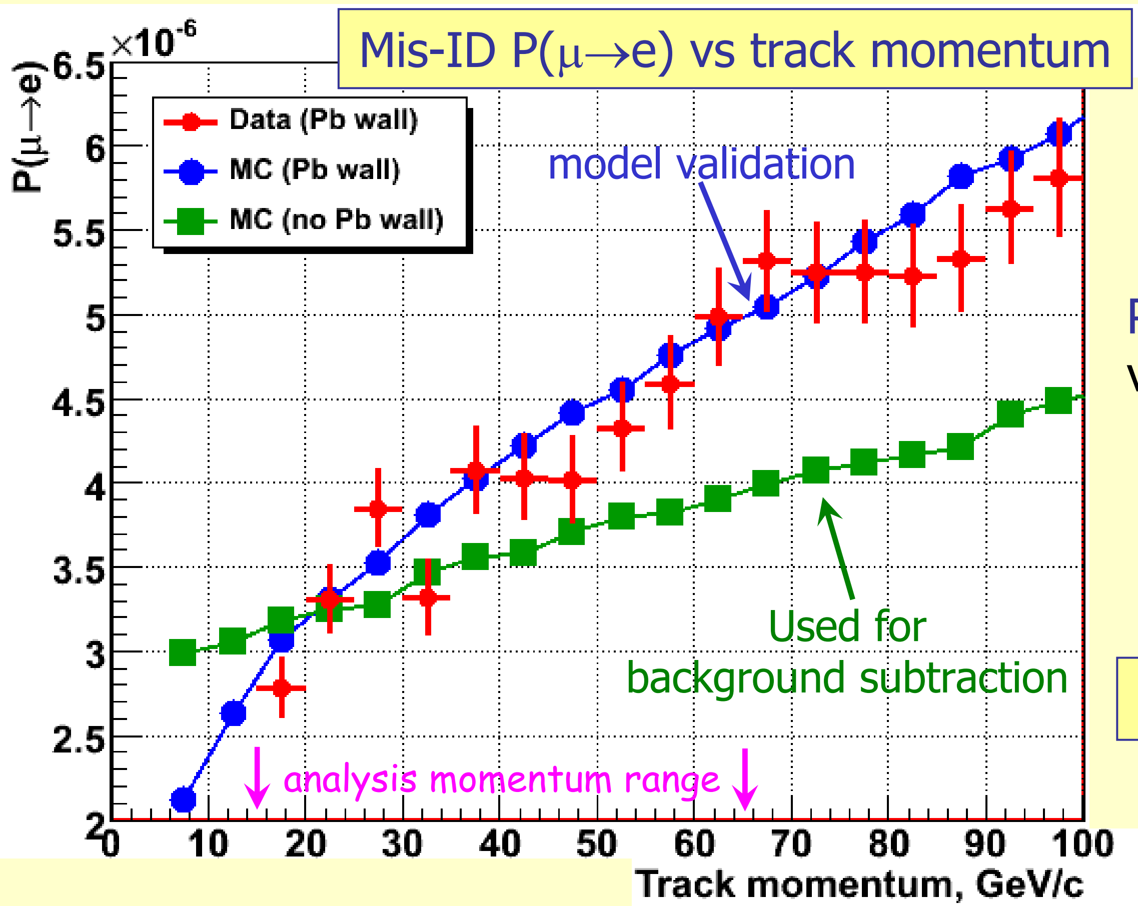
Thickness:	$9.2X_0$ (Pb+Fe)
Width:	240cm (=HOD size)
Height:	18cm (=3 counters)
Area:	~20% of HOD area
Duration:	~50% of R_K runs + special muon runs

Obtaining pure muon samples

Electron contamination due to $\mu \to e$ decay: $\sim 10^{-4}$.
Pb wall ($9.2X_0$) placed between the HOD planes:
tracks traversing the wall and having $E/p>0.95$
are sufficiently pure muon samples (electron contamination $<10^{-7}$).

$K_{\mu 2}$ background (2)

P(μ→e): measurement (2007 special muon run) vs Geant4-based simulation



[Cross-section model:
Phys. Atom. Nucl. 60 (1997) 576]

Good data/MC agreement
for the Pb wall installed

P(μ→e) is modified by the Pb wall
via two competing mechanisms:

1) ionization losses in Pb (low p);
2) bremsstrahlung in Pb (high p).

→ a significant MC correction

Result: B/(S+B) = (6.28±0.17)%

(uncertainty: due to limited size of the data sample used to validate the cross-section model)

Prospects:

- "Measurement (Pb) + MC correction (NoPb/Pb)" approach is less biased than using a validated MC simulation.

$K_{\mu 2}$ with $\mu \to e$ decay in flight

For NA62 conditions
(74 GeV/c beam, ~100 m decay volume),

$N(K_{\mu 2}, \mu \to e \text{ decay})/N(K_{e2}) \sim 10$

$K_{\mu 2}$ ($\mu \to e$) naïvely seems a huge background

Muons from $K_{\mu 2}$ decay are fully polarized:
Michel electron distribution

$$d^2\Gamma/dxd(\cos\Theta) \sim x^2[(3-2x) - \cos\Theta(1-2x)]$$

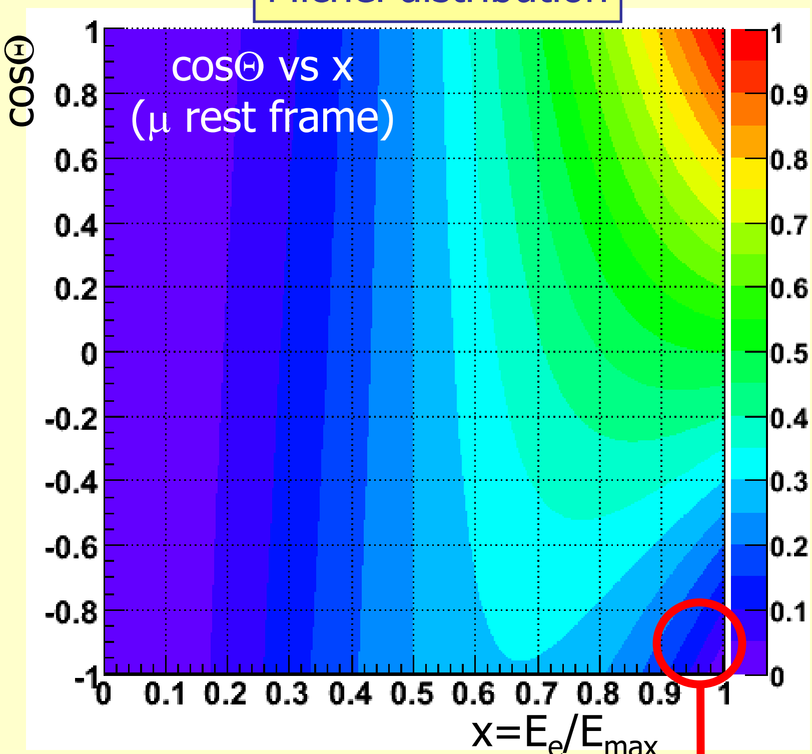
$x = E_e/E_{max} \approx 2E_e/M_\mu$,

Θ is the angle between p_e and the muon spin
(all quantities are defined in muon rest frame).

Result: $B/(S+B) = (0.23 \pm 0.01)\%$

Important but not dominant background

Michel distribution

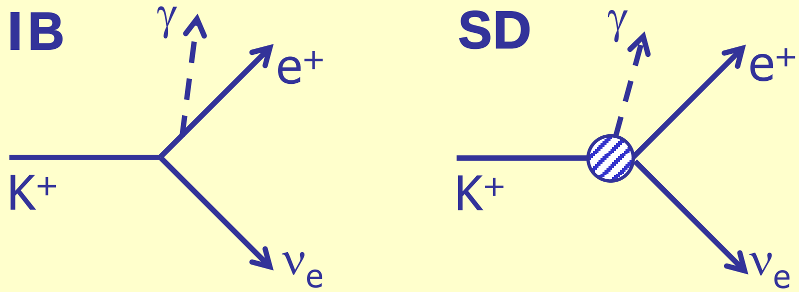


Only energetic forward electrons
(passing M_{miss}, E/p, vertex CDA cuts)
are selected as K_{e2} candidates:
(high x, low $\cos\Theta$).

They are naturally suppressed
by the muon polarisation

Radiative $K^+ \to e^+\nu\gamma$ process

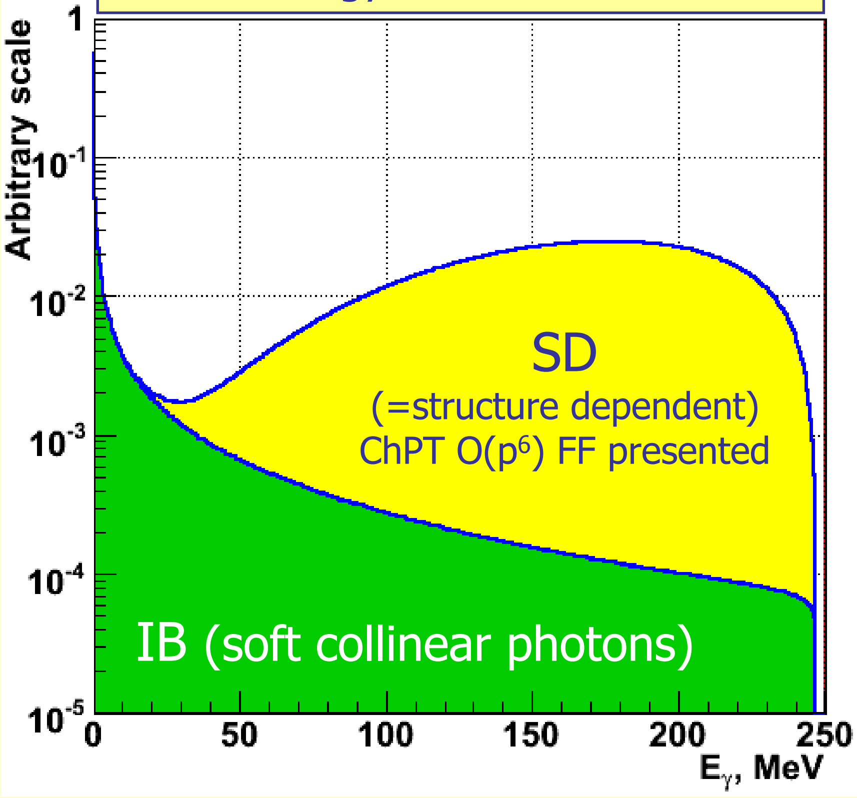
By definition, R_K is inclusive of the IB part of the radiative $K_{e2\gamma}$ process



- The $K_{e2\gamma}$ (SD) process is a background.
- SD is not helicity suppressed, and its rate is similar to that of K_{e2}.
- Known to a limited precision of ~15%.

(NB: a recent 4% precision measurement, EPJC64 (2009) 627, not used in present analysis)

Photon energy in K frame: IB and DE



<u>Experiment:</u> $BR=(1.52\pm0.23)\times10^{-5}$
(average of 1970s measurements)

<u>Theory:</u> $BR=(1.38\text{–}1.53)\times10^{-5}$ [PRD77 (2008) 014004]
(uncertainty due to a model-dependent form factor)

$K^+ \to e^+ \nu\gamma$ (SD) decay

Decay density:

$$\frac{d\Gamma(K\to e\nu\gamma)}{dxdy} = \underbrace{\rho_{IB}(x,y)}_{\text{helicity suppressed}} + \rho_{SD}(x,y) + \underbrace{\rho_{INT}(x,y)}_{\text{negligible}}$$

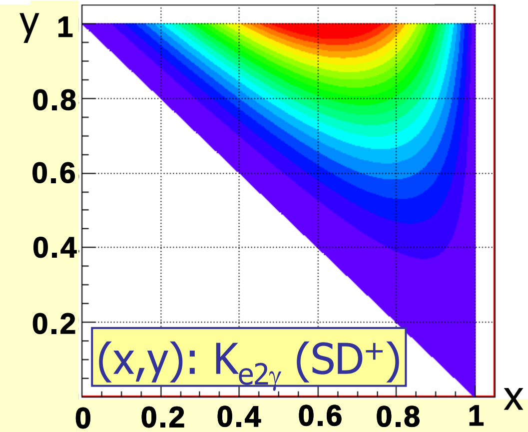
Kinematic variables (kaon frame):

$$x = 2E_\gamma/M_K, \quad y = 2E_e/M_K$$

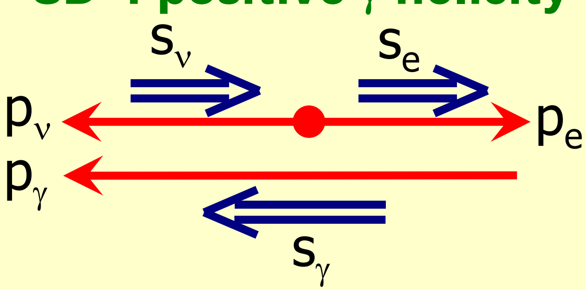
$$\rho_{SD}(x,y) = \frac{G_F^2|V_{us}|^2\alpha}{64\pi^2} M_K^5 \left((f_V+f_A)^2 f_{SD+}(x,y) + (f_V-f_A)^2 f_{SD-}(x,y)\right)$$

Two non-interfering contributions SD^+ and SD^-: emission of photons with positive and negative helicity

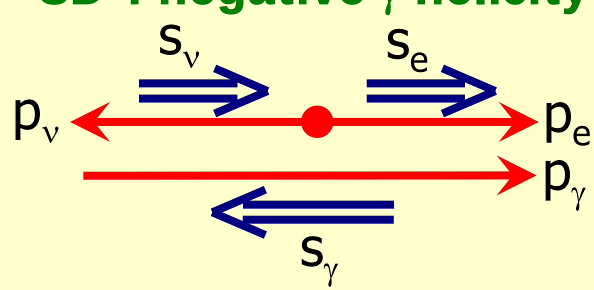
$f_V(x)$, $f_A(x)$: model-dependent effective vector and axial couplings

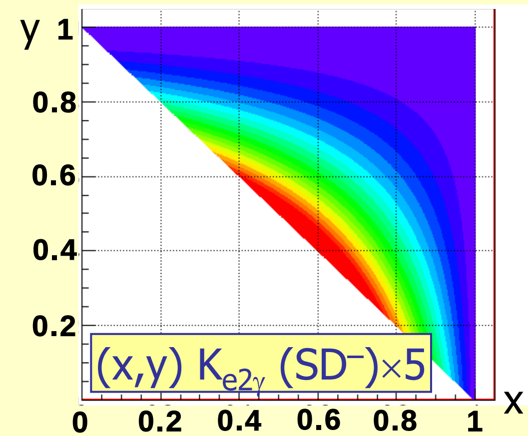


SD^+: positive γ helicity

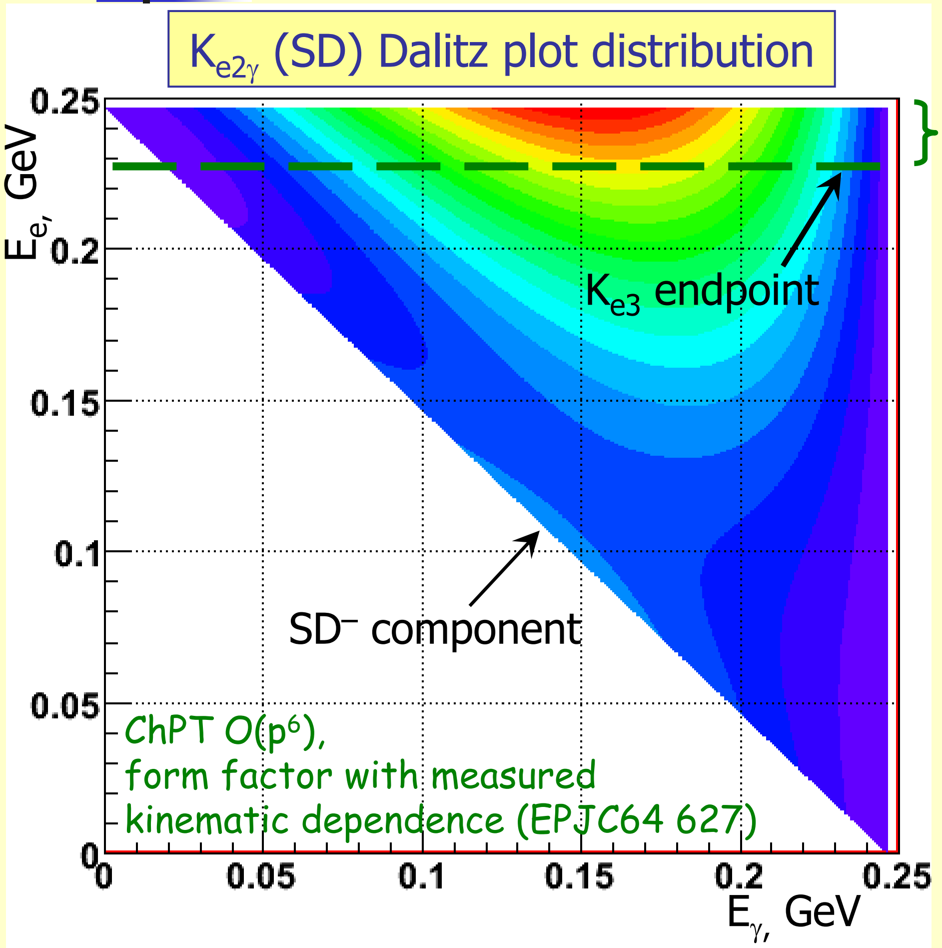


SD^-: negative γ helicity





$K^+ \to e^+ \nu\gamma$ (SD$^+$) background



$K_{e2\gamma}$ (SD$^-$) background is negligible, peaking at $E_e = E_{max}/2 \approx 123$ MeV

Only energetic electrons (E_e^*>230MeV) are compatible to K_{e2} kinematic ID and contribute to the background

⇓

This region of phase space is accessible for direct BR and form-factor measurement (being above the E_e^*=227 MeV endpoint of the K_{e3} spectrum).

SD background contamination

B/(S+B) = (1.02±0.15)%

(uncertainty due to PDG BR, to be improved by NA62 & KLOE)

Beam halo background

Electrons produced by beam halo muons via $\mu \to e$ decay can be kinematically and geometrically compatible to genuine K_{e2} decays

Background measurement:

- Halo background much higher for K_{e2}^- (~20%) than for K_{e2}^+ (~1%).
- Halo background in the $K_{\mu 2}$ sample is considerably lower.
- ~90% of the data sample is K^+ only, ~10% is K^- only.
- K^+ halo component is measured directly with the K^- sample and vice versa.

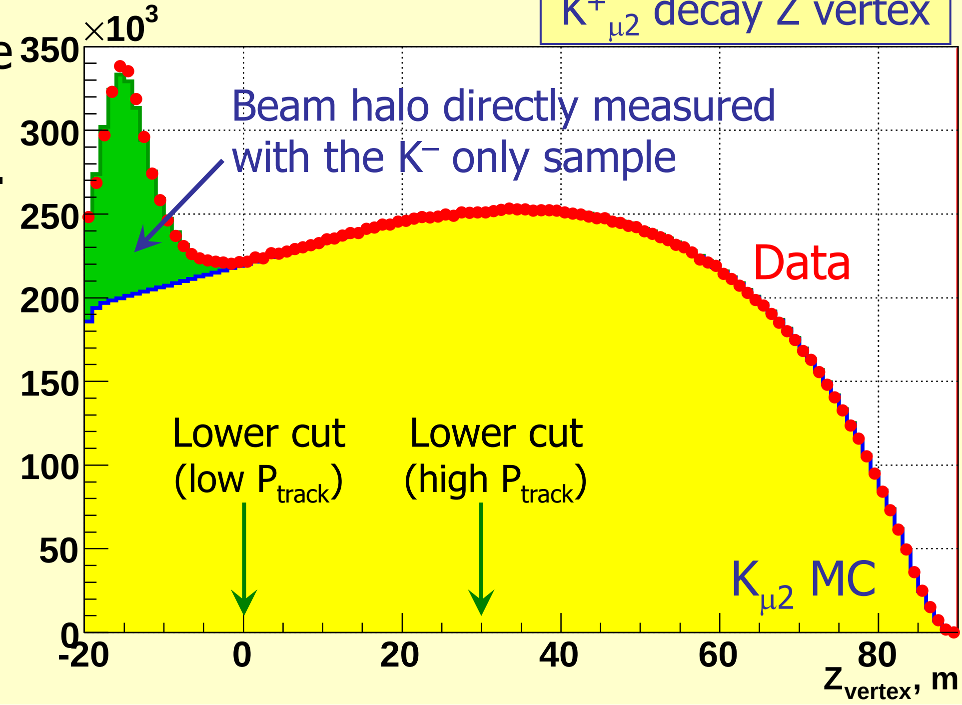
The background is measured to sub-permille precision, and strongly depends on decay vertex position and track momentum.

The selection criteria (esp. Z_{vertex}) are optimized to minimize the halo background.

$B/(S+B) = (0.45 \pm 0.04)\%$

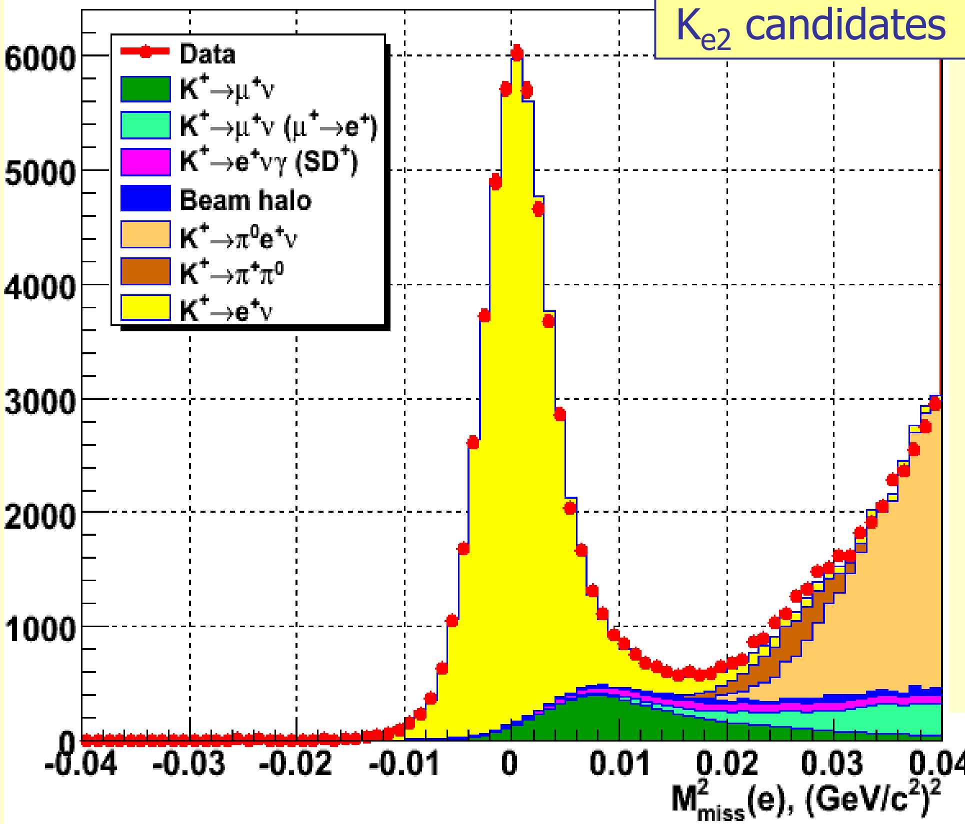
Uncertainty is due to the limited size of the control sample.

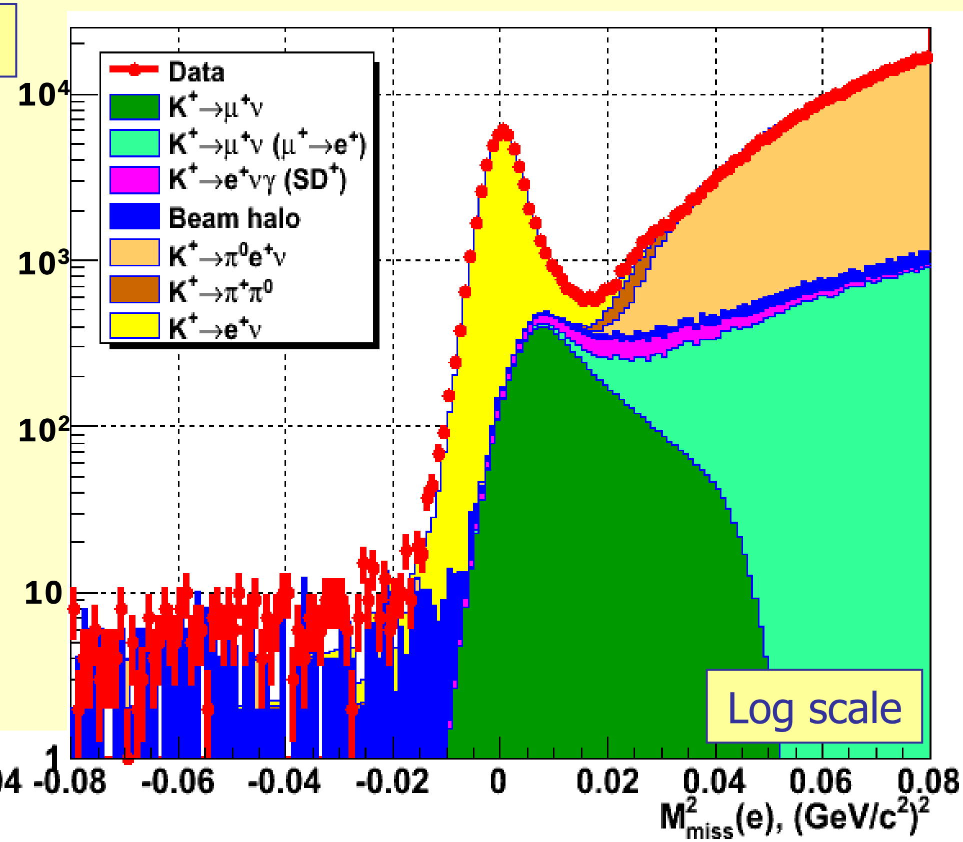
$K^+_{\mu 2}$ decay Z vertex



K_{e2}: partial (~40%) data set

K_{e2} candidates





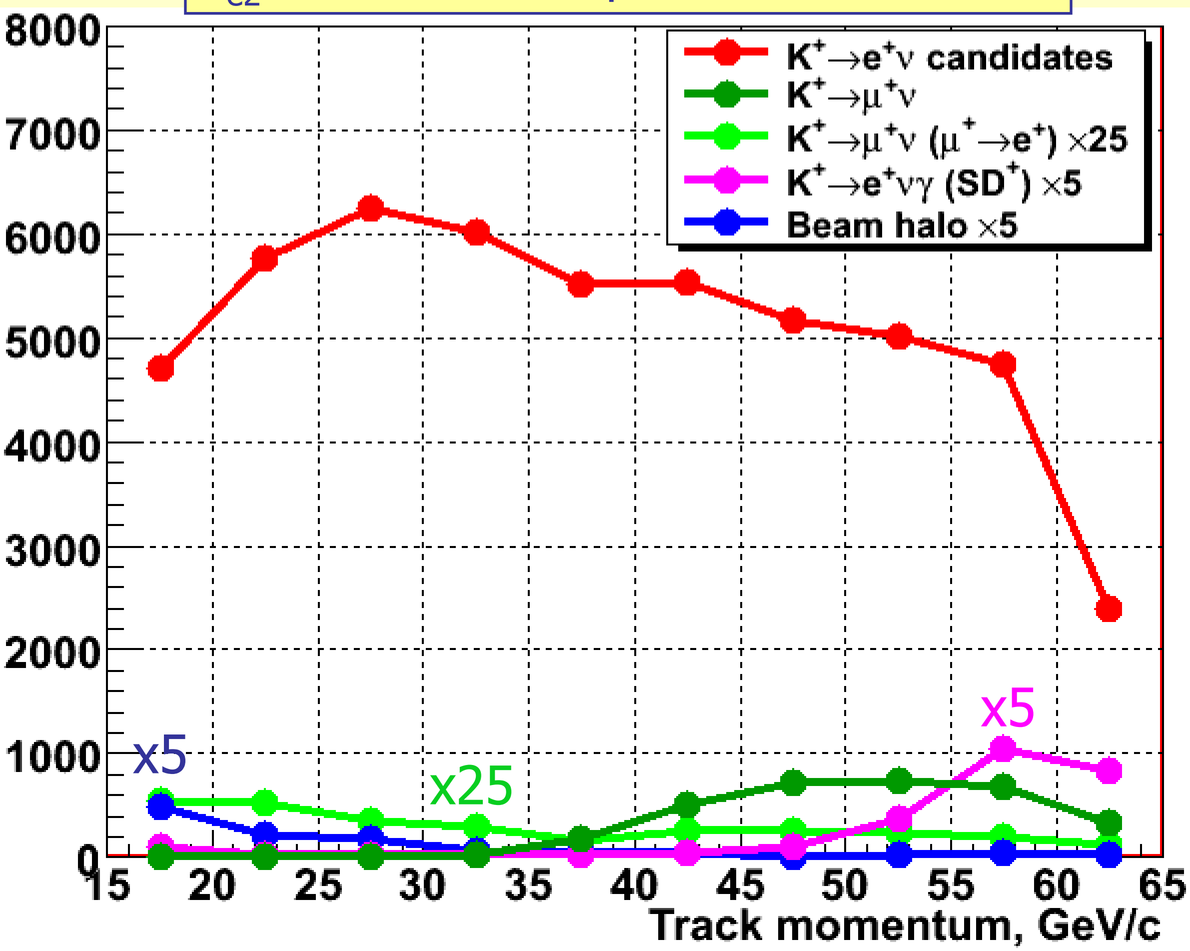
51,089 $K^+ \to e^+\nu$ candidates,
99.2% electron ID efficiency,
B/(S+B) = (8.0±0.2)%

cf. KLOE: 13.8K candidates (K^+ and K^-),
~90% electron ID efficiency, 16% background

NA62 estimated total K_{e2} sample:
~120K K^+ & ~15K K^- candidates.
Proposal (CERN-SPSC-2006-033):
150K candidates

K_{e2} backgrounds: summary

K_{e2} candidates in lepton momentum bins



(selection criteria, e.g. Z_{vertex} and M_{miss}^2, are optimised individually in each P_{track} bin)

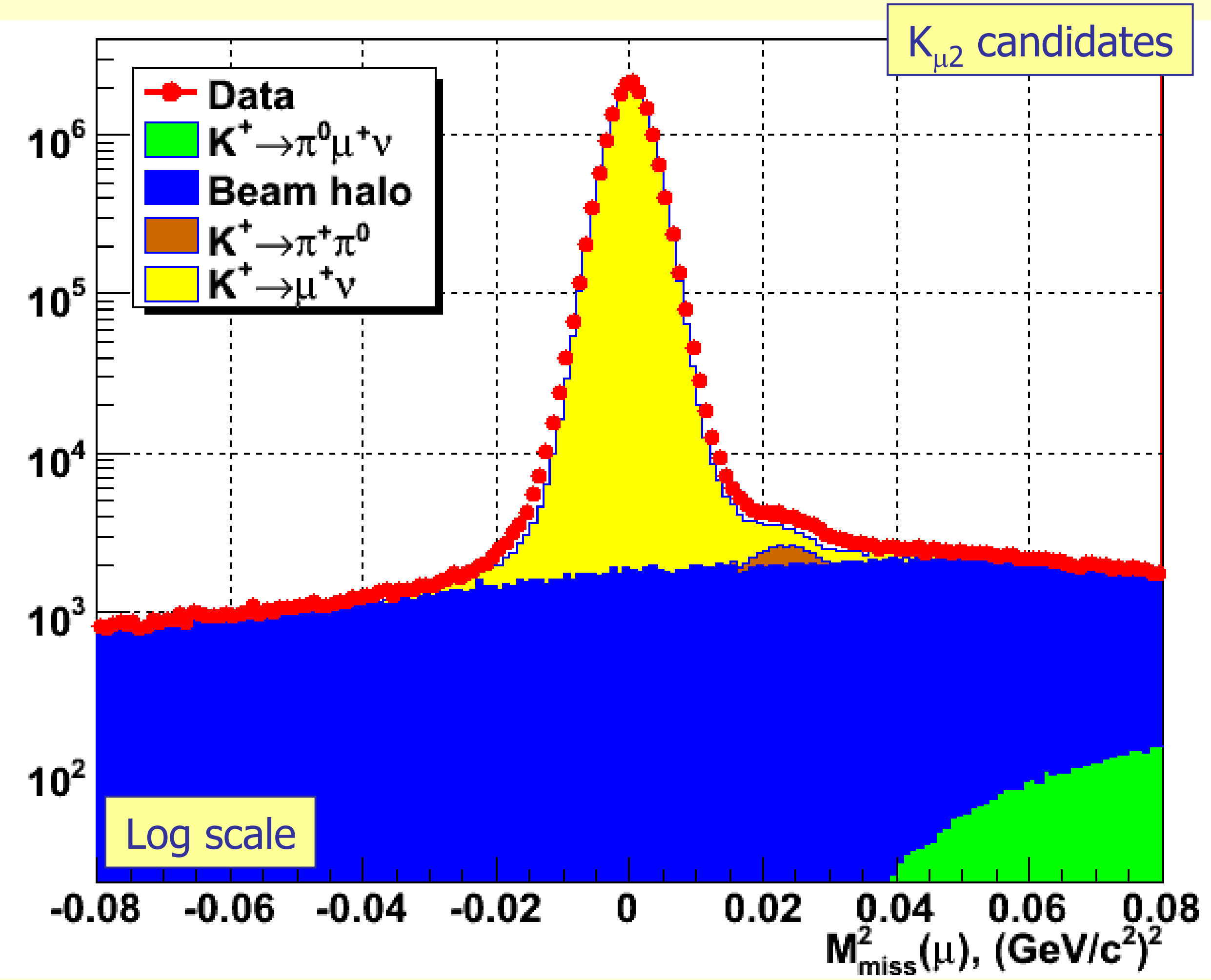
Backgrounds

Source	B/(S+B)
$K_{\mu2}$	(6.28±0.17)%
$K_{\mu2}$ ($\mu \to e$)	(0.23±0.01)%
$K_{e2\gamma}$ (SD^+)	(1.02±0.15)%
Beam halo	(0.45±0.04)%
K_{e3}	0.03%
$K_{2\pi}$	0.03%
Total	(8.03±0.23)%

Record K_{e2} sample:
51,089 candidates
with low background
B/(S+B) = (8.0±0.2)%

Lepton momentum bins are differently affected by backgrounds and thus the systematic uncertainties.

$K_{\mu2}$: partial (~40%) data set



15.56M candidates with low background $B/(S+B) = 0.25\%$

($K_{\mu2}$ trigger was pre-scaled by D=150)

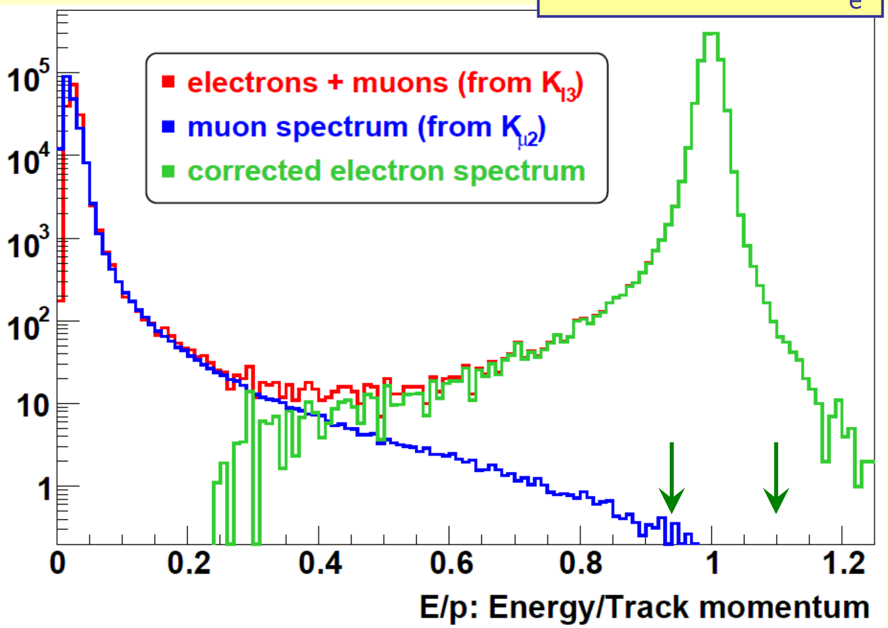
The only significant background source is the beam halo.

Electron ID efficiency (f_e)

Measured directly with samples of pure electrons:

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

Measurement of f_e



Measurement with $K^\pm \to \pi^0 e^\pm \nu$ decays:

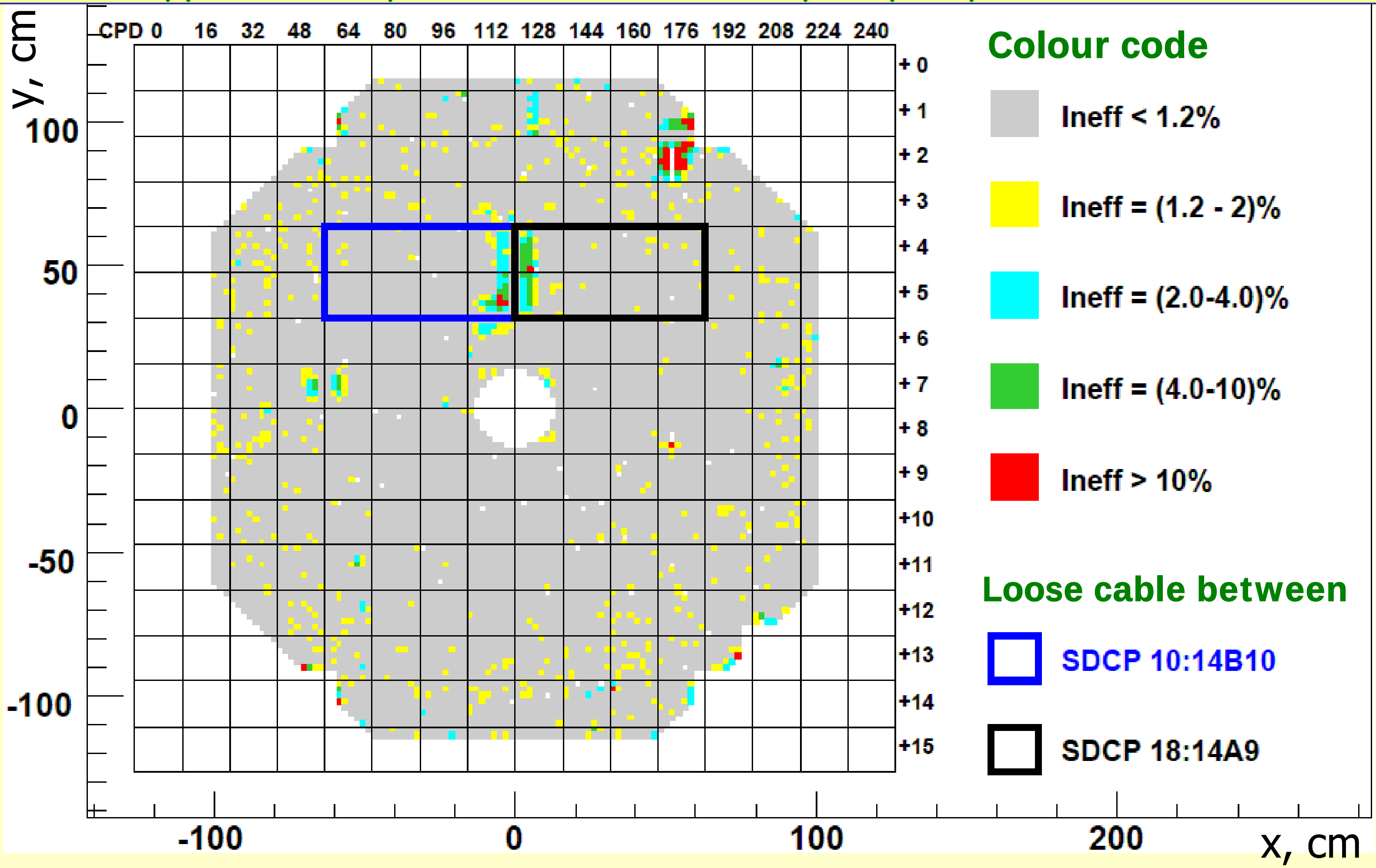
- Selected event sample consists of $K^\pm \to \pi^0 e^\pm \nu$ and some $K^\pm \to \pi^0 \mu^\pm \nu$ events;
- To subtract the muon component, normalised muon E/p spectrum measured using the $K_{\mu 2}$ sample is used.

Measurement with $K_L \to \pi^\pm e^\pm \nu$ is more complicated: the pion component also contributes to the spectrum.

Excellent agreement between $K^\pm$ and K_L methods.
Average f_e=99.15%, precision <0.1%, weak momentum dependence.

LKr inefficiency map

LKr efficiency is monitored vs time for every 2×2cm² cell within acceptance. A typical example of the inefficiency map is presented below.



Higher inefficiency is at low momentum → room for optimization

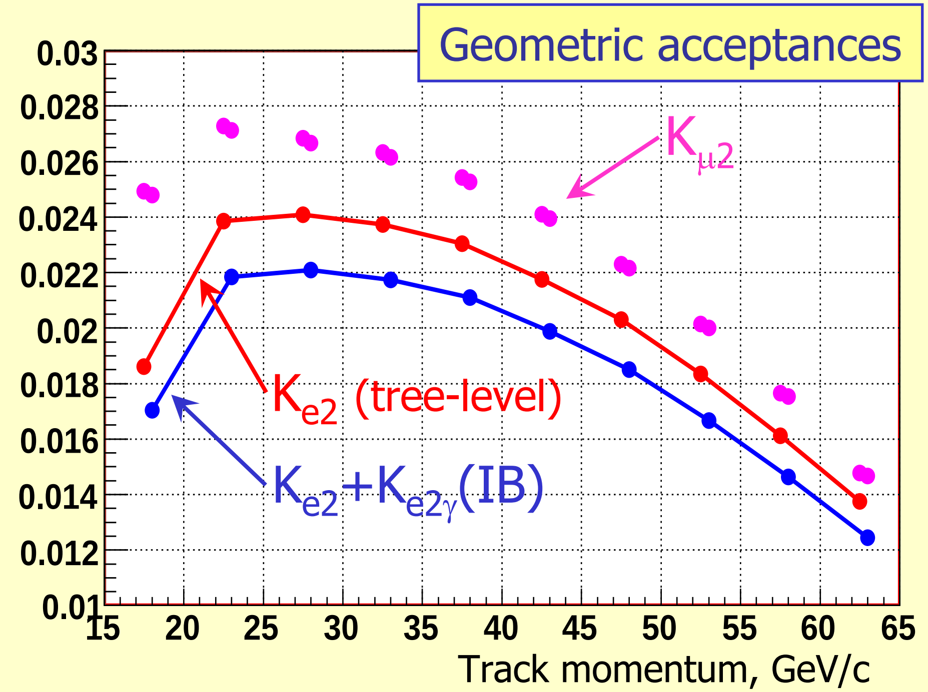
Other systematic effects

Geometric acceptance correction

- p_{track}-dependent, $A(K_{\mu2})/A(K_{e2})\sim1.3$;
- strongly affected by the radiative (IB) corrections to K_{e2};

IB process simulated according to
V. Cirigliano and I. Rosell,
Phys. Lett. 99 (2007) 231801

- conservative systematic uncertainty for prelim. result: $\delta R_K/R_K=0.3\%$, due to approximations used in IB simulation.



Trigger efficiency correction

- E_{LKr} efficiency directly affects R_K;
- monitored with control trigger samples;
- conservative systematic uncertainty for preliminary result: $\delta R_K/R_K=0.3\%$ (due to dead time generated by accidentals).

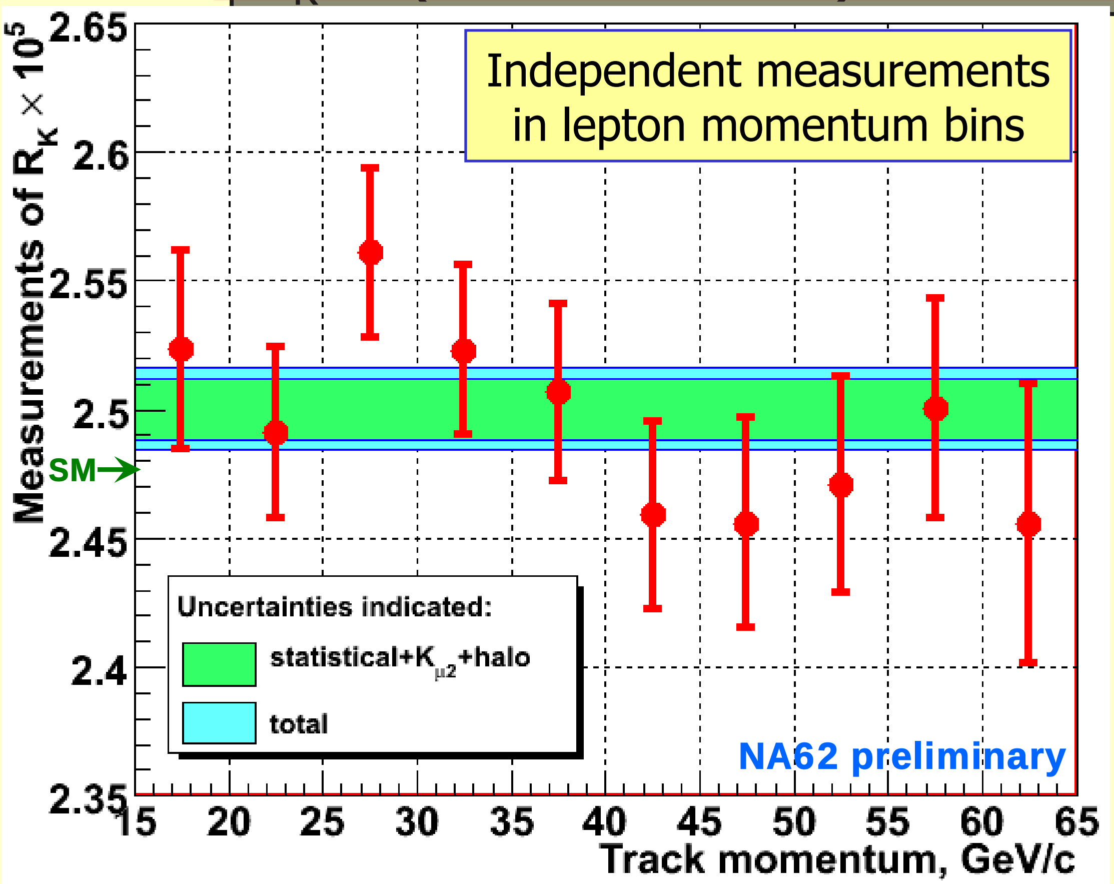
Global LKr efficiency

- Also affects the result directly;
- $f_{LKr}=(99.80\pm0.03)\%$ is measured directly using an independent readout system.

Preliminary result (40% data set)

$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{syst}) \times 10^{-5}$
$= (2.500 \pm 0.016) \times 10^{-5}$

(arXiv:0908.3858)



Uncertainties

Source	$\delta R_K \times 10^5$
Statistical	0.012
$K_{\mu 2}$	0.004
Beam halo	0.001
$K_{e2\gamma}$ (SD^+)	0.004
Electron ID	0.001
IB simulation	0.007
Acceptance	0.002
Trigger timing	0.007
Total	0.016

(0.64% precision)

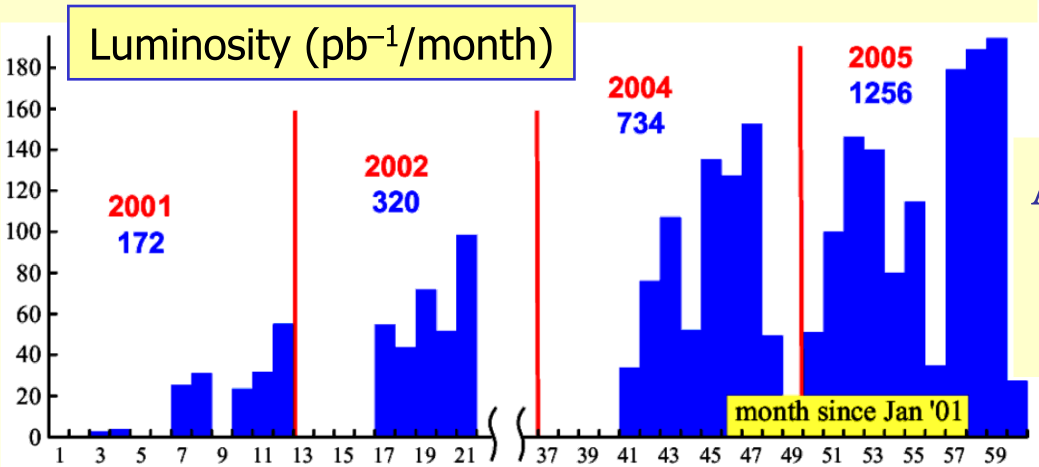
The whole 2007 sample will allow statistical uncertainty ~0.3%, total uncertainty of 0.4–0.5%.

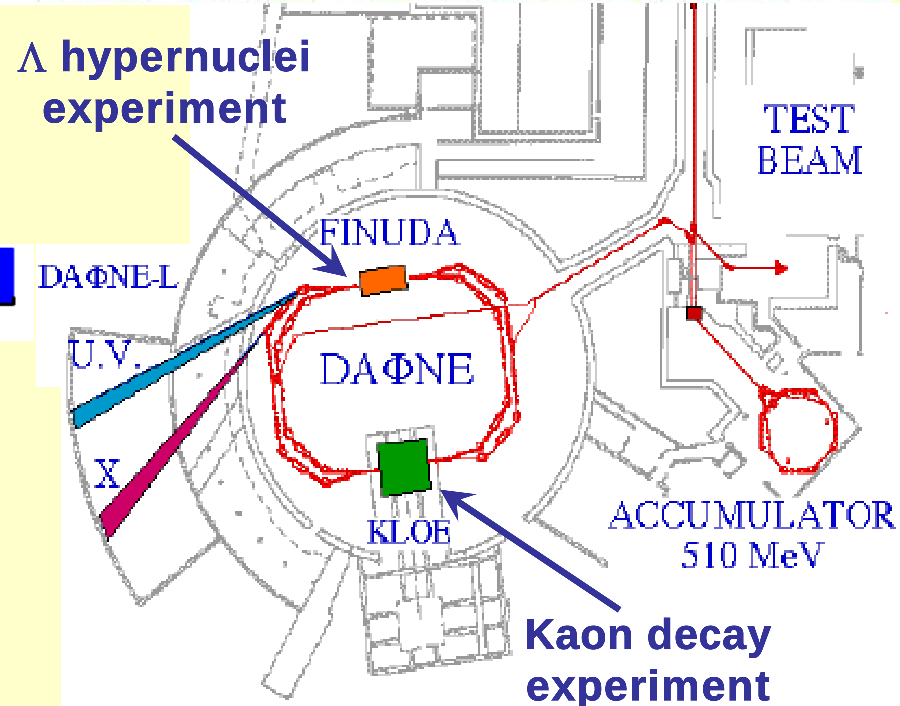
Competitors, comparison to world data

KLOE K_{e2} analysis: decays at rest

DAΦNE: an e^+e^- collider at LNF Frascati

- CM energy ~ m_ϕ = 1019.4 MeV;
- $BR(\phi \to K^+K^-)$ = 49.2%;
- ϕ production cross-section σ_ϕ=1.3μb;
- Data sample (2001–05): 2.5 fb^{-1}.



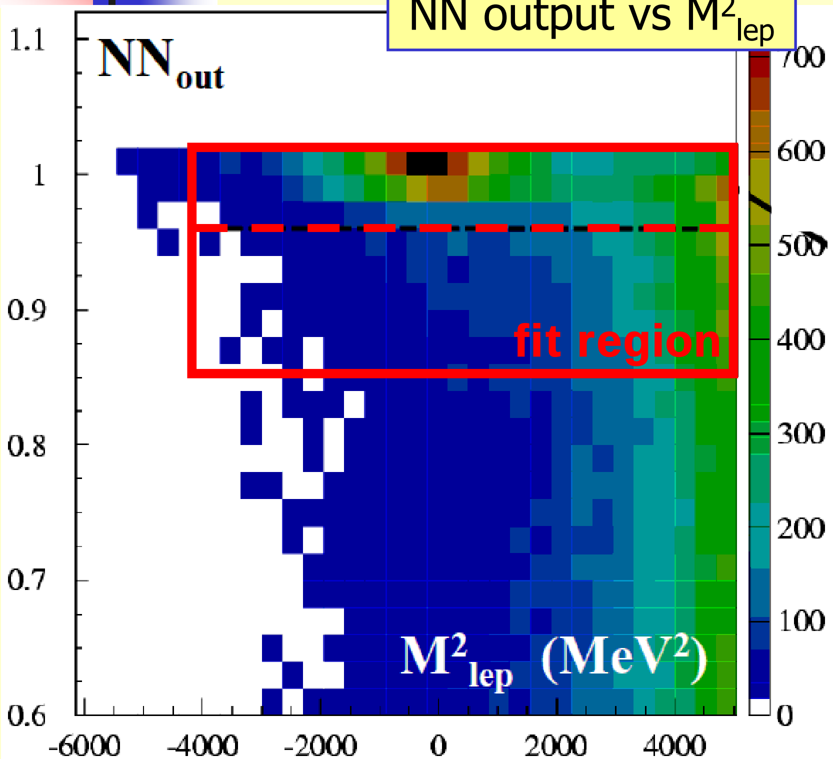


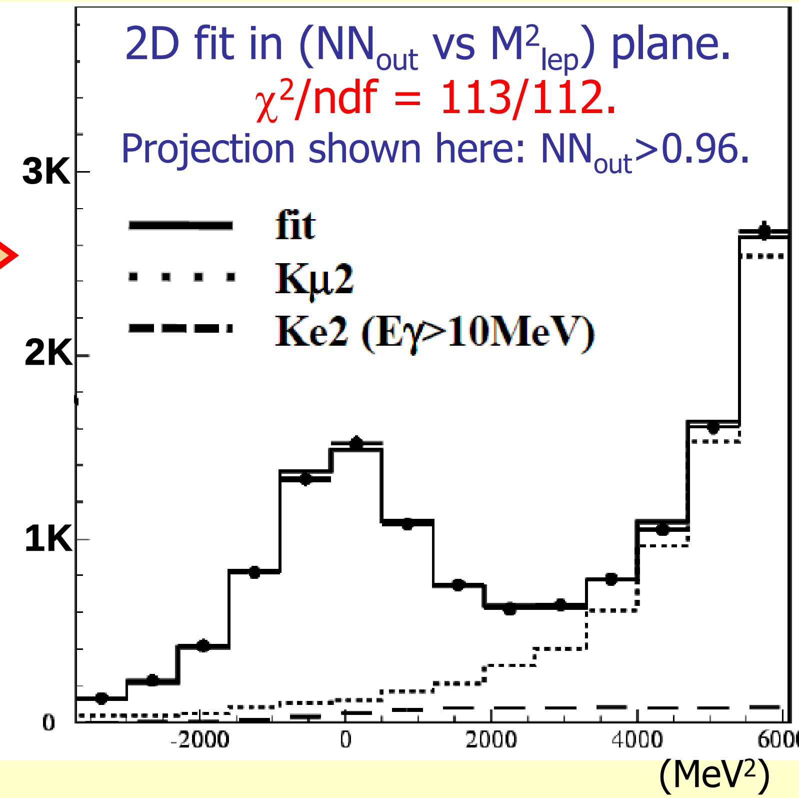
$K_{e2}/K_{\mu2}$ selection technique (vs NA62):

- Kinematics: by M^2_{lep} (equivalent to M_{miss}^2);
- PID: neural network with 12 input parameters (vs E/p for NA62).

KLOE K_{e2} sample

NN output vs M^2_{lep}





Uncertainties	$\delta R_K/R_K$ (%)
Statistical	1.0
$K_{\mu 2}$ subtraction	0.3
$K_{e2\gamma}$ (SD^+)	0.2
Reconstruction efficiency	0.6
Trigger efficiency	0.4
Total	1.3

Full data sample analyzed
[EPJ C64 (2009) 627]

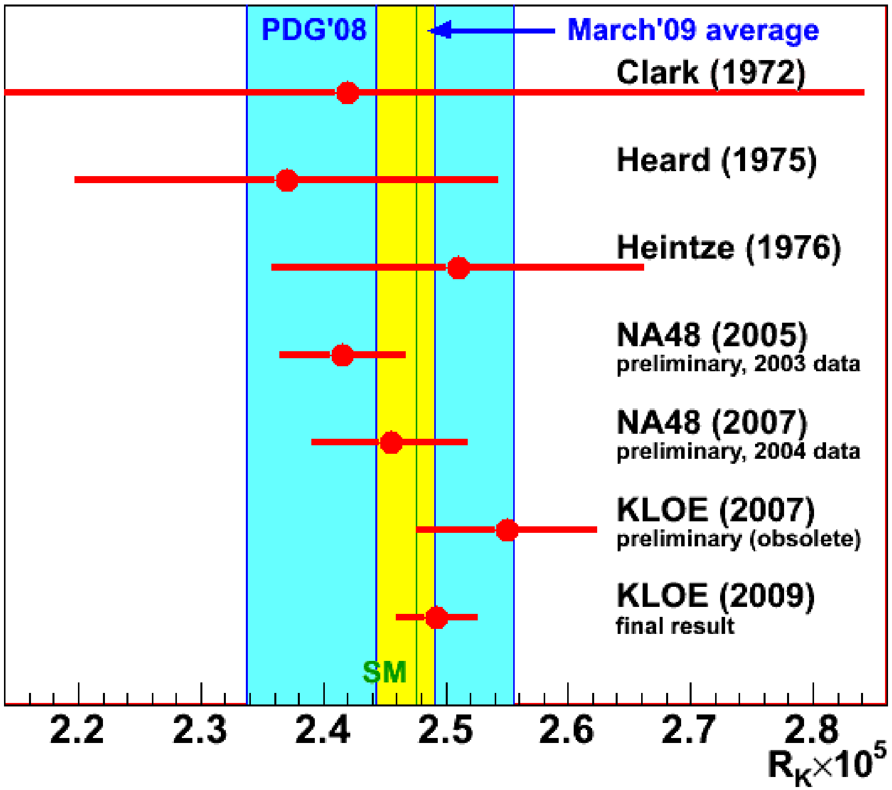
13.8K K_{e2} candidates, 16% background

KLOE-2: expect to start in 2010, $\delta R_K/R_K$=0.4%.
[arXiv:1003.3862]

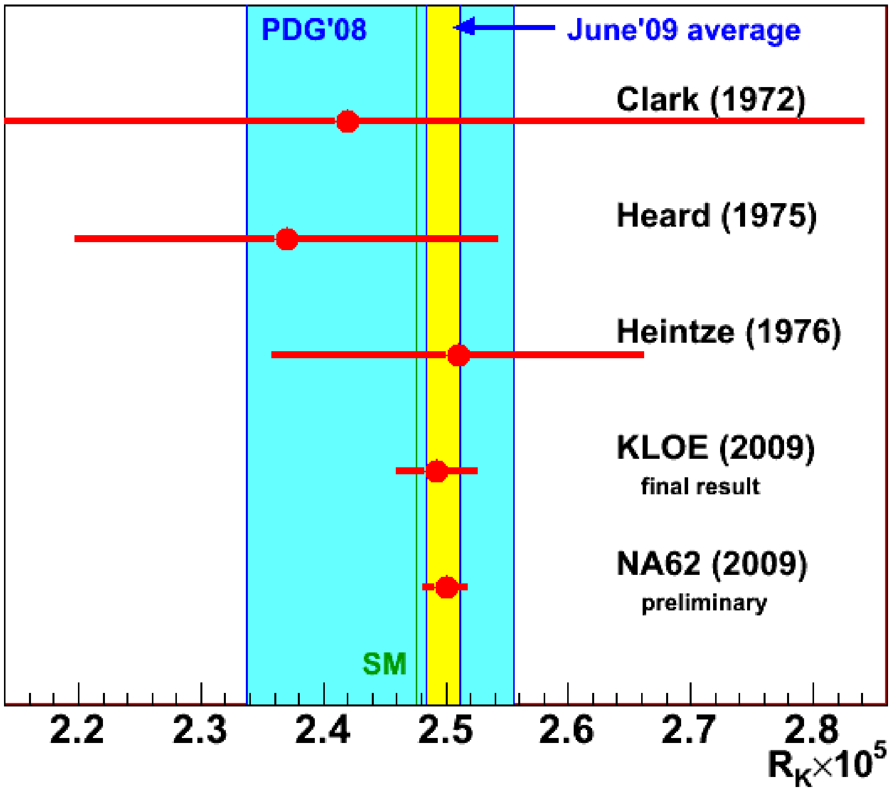
(plots from Barbara Sciascia, KAON 2009)

R_K world average (2009)

March 2009



June 2009



World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467±0.024	0.97%
June 2009	2.498±0.014	0.56%

Updated NA62 results expected in June 2010

⇒ Active development in recent years. New NA62 results are soon to come.

(NA48/2 preliminary results are excluded from the June 2009 fit: they are superseded by NA62)

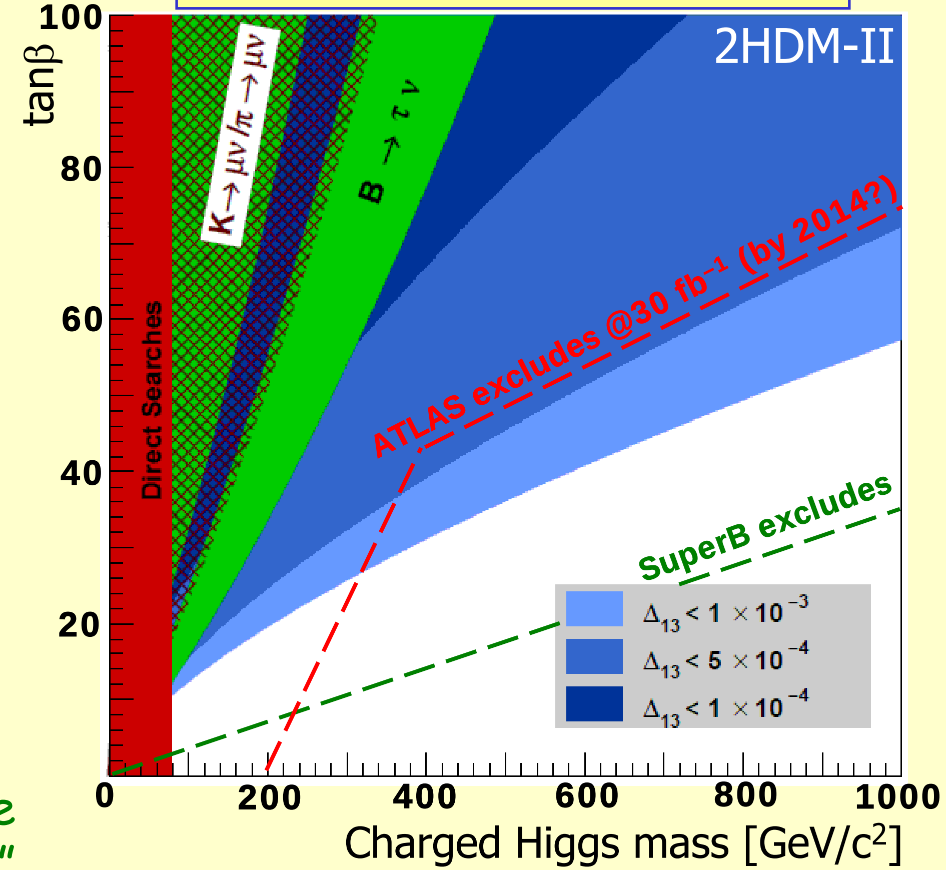
R_K: sensitivity to new physics

R_K measurements are currently in agreement with the SM expectation at $\sim 1.5\sigma$.
Any significant enhancement with respect to the SM value would be an evidence of new physics.

For non-tiny values of the LFV slepton mixing Δ_{13}, R_K sensitivity to $H^{\pm}$ is competitive to the B factories and the LHC

"Maybe NA62 will find the first evidence for a charged Higgs exchange?"
-- John Ellis (arXiv:0901.1120)

(M_H, $\tan\beta$) 95% exclusion limits



Future kaon physics at CERN: NA62 phase II

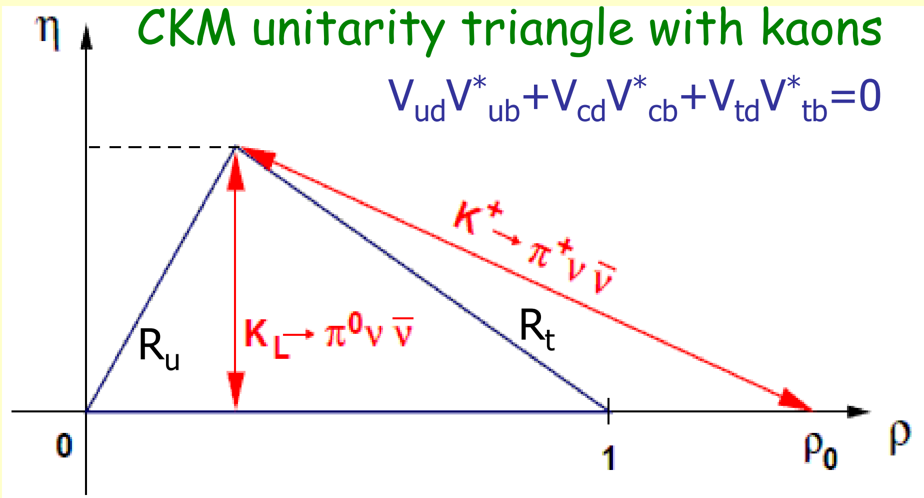
NA62 phase II: $K_{\pi\nu\nu}$

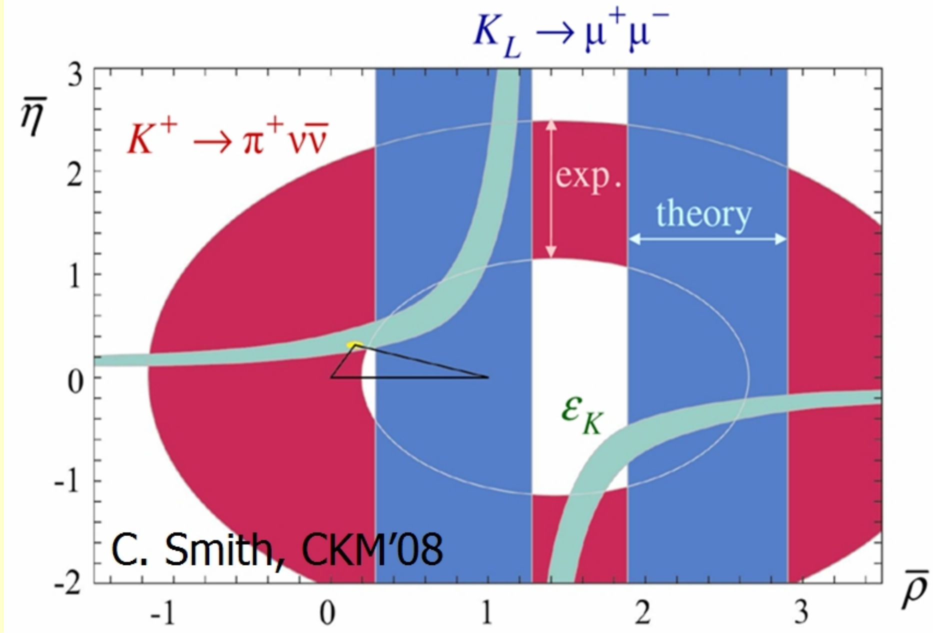
$K\to\pi\nu\nu$: theoretically clean, sensitive to NP, almost unexplored

Branching ratio $\times 10^{10}$

	Theory (SM)	Experiment
$K^+\to\pi^+\nu\nu(\gamma)$	0.82 ± 0.08	$1.73^{+1.15}_{-1.05}$
$K_L\to\pi^0\nu\nu$	0.28 ± 0.04	<670 (90% CL)

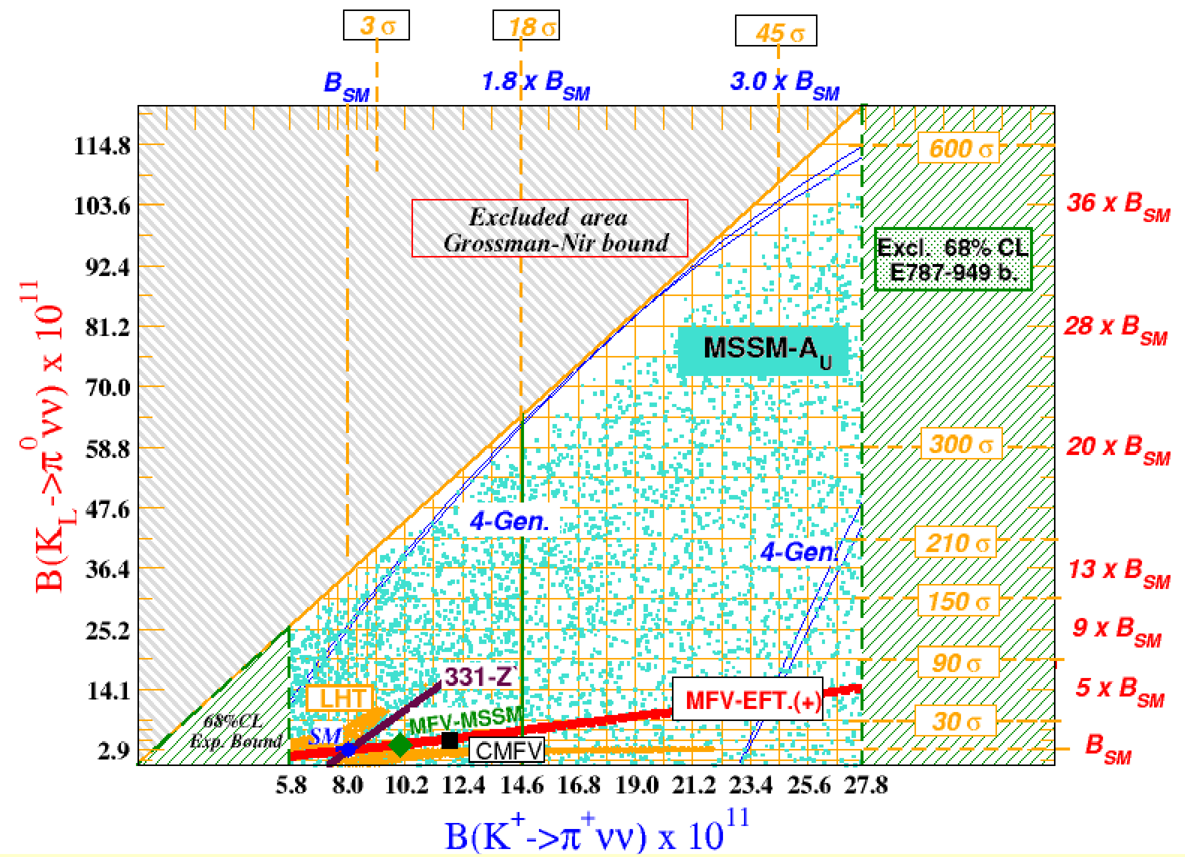
$BR(K^+\to\pi^+\nu\nu) \sim |V_{ts}^* V_{td}|^2$





- Ultra-rare FCNC processes, proceed via Z-penguin and W-box diagrams.
- Hadronic matrix element extracted from precise $K\to\pi e\nu$ measurements.
- Exceptional SM precision not matched by any other loop-induced meson decay.
- Uncertainties mainly come from charm contributions.

Sensitivity of new physics



$BR(K^+ \to \pi^+ \nu\nu) \times 10^{10}$: selected models	
SM	0.82±0.08
MFV (hep-ph/0310208)	1.91
EEWP (NPB697 (2004) 133, hep-ph/0402112)	0.75±0.21
EDSQ (PRD70 (2004) 093003, hep-ph/0407021)	up to 1.5
MSSM (NPB713 (2005) 103, hep-ph/0408142)	up to 4.0

- Large variations in predictions for new physics.
- A 10% precision measurement will provide a stringent SM test.

The NA62 collaboration aims to measure O(100) $K^+ \to \pi^+ \nu\nu$ candidates with ~10% background in 2-3 years of data taking

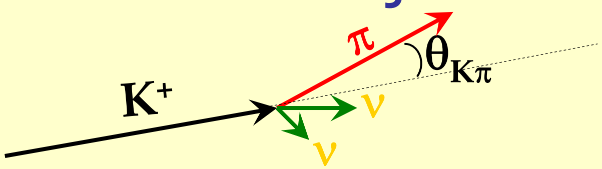
NA62 guidance principles

O(100) $K^+ \to \pi^+ \nu\bar{\nu}$ events, ~10% background @BR(SM) = 8×10^{-11}

N(K decays) ~10^{13}
Acceptance = 10%

- Kaon decay in flight technique;
- 400 GeV proton beam from SPS;
- Unseparated high energy K^+ beam (P_K=75 GeV/c);

Kinematical rejection



Single track signature: $m^2_{miss}=(P_K-P_\pi)^2$

- Kaon momentum: beam tracker;
- Pion momentum: spectrometer;

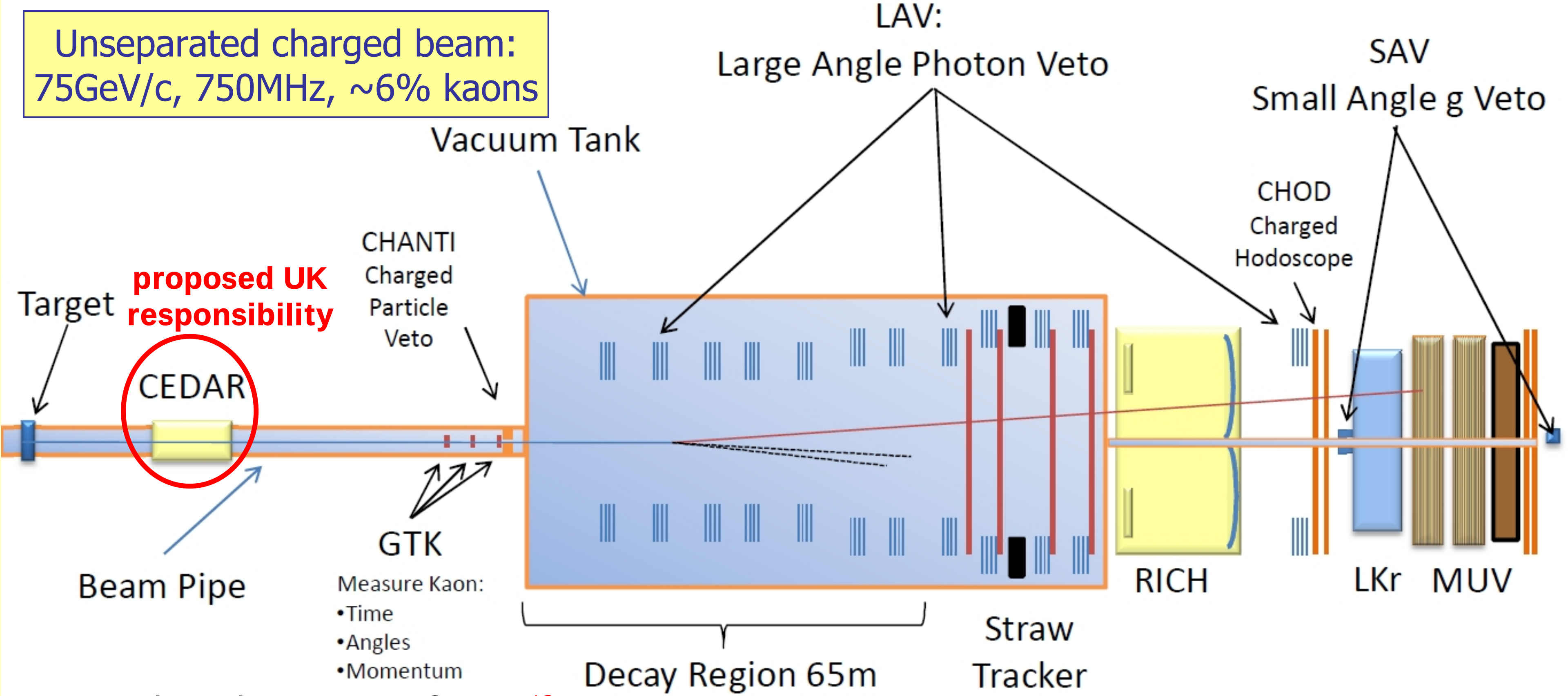
Particle ID and veto
in addition to kinematical rejection

- Charged track veto: spectrometer;
- Photon veto: calorimeters;
- Beam kaon identification: CEDAR;
- $\pi/\mu/e$ separation: RICH;

Budget limitations

- Use of existing NA48 infrastructure: beam line, LKr calorimeter, …

NA62 (phase II) layout

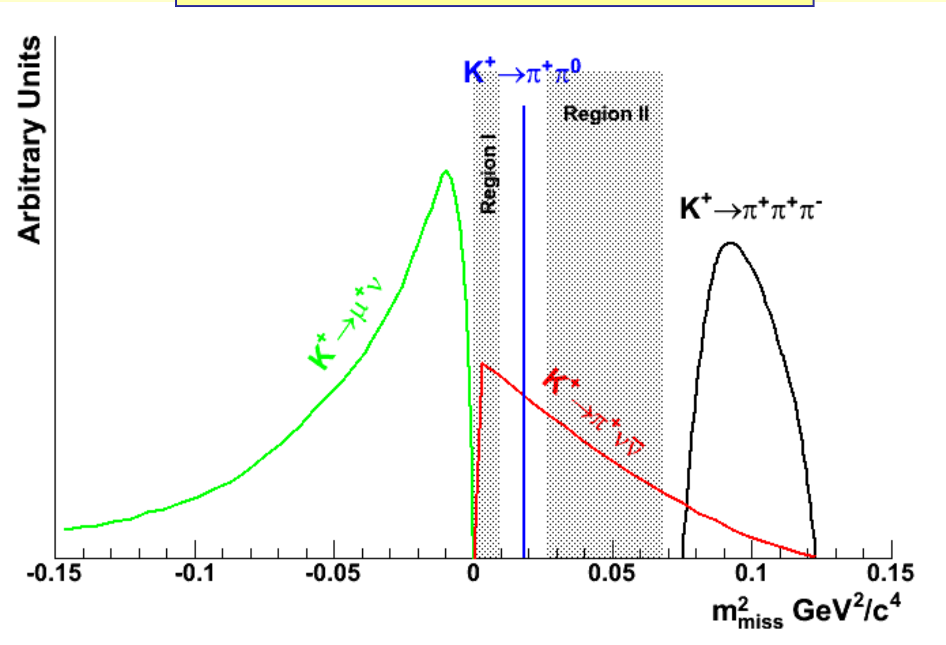


- Record K^+ decay SES of ~10^{-12};
- Hermetic veto & redundant measurements;
- R&D finishing, subdetector construction has started.

- Approved by the CERN research board in December 2008.
- Reviewed by PPAP in July 2009.
- SoI submitted to PPAN in November 2009;
  signed by Birmingham, Bristol, Glasgow, Liverpool.

Kinematics and backgrounds

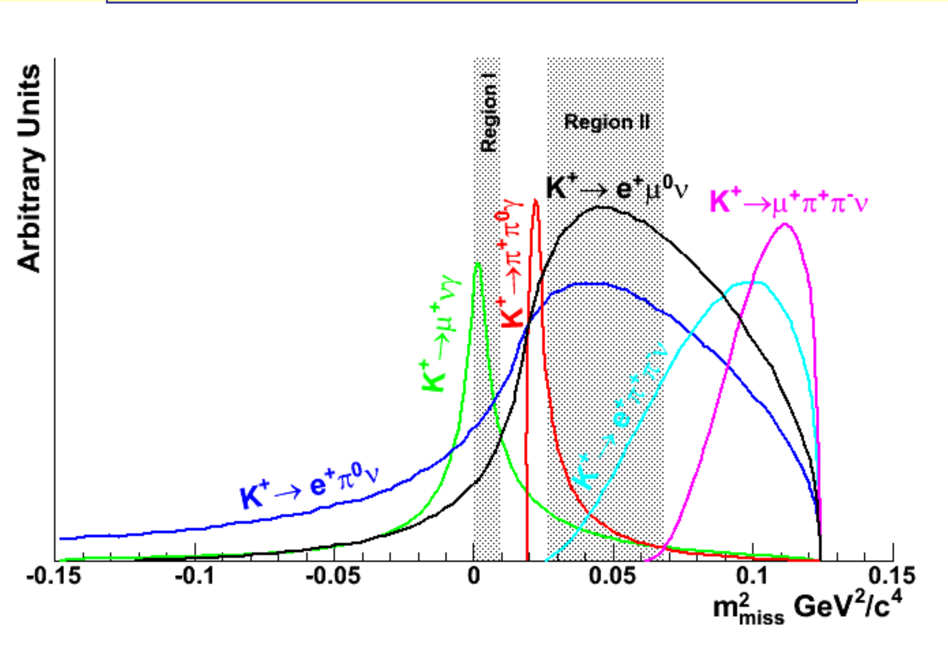
Kinematically constrained



92% of total background

- **Allows us to define a signal region**
- **$K^+\to\pi^+\pi^0$ forces us to split it into two parts (Region I and Region II)**

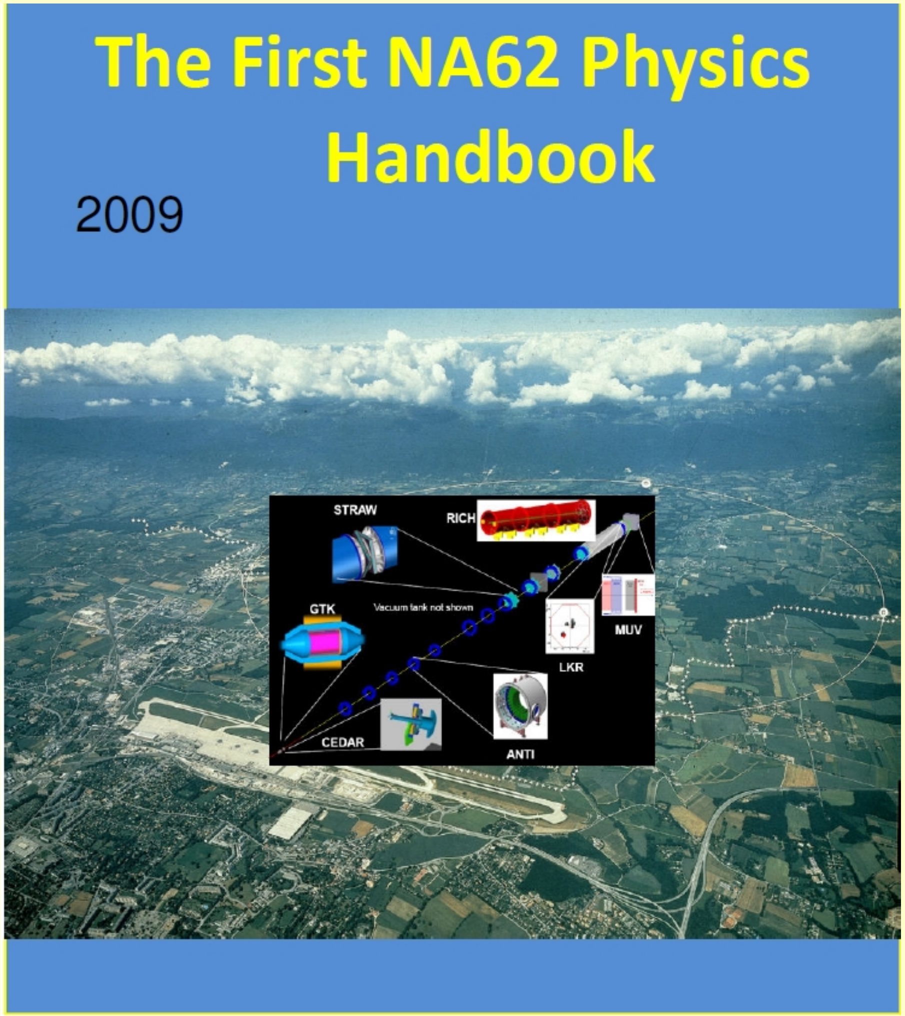
NOT kinematically constrained



8% of total background

- **Span across the signal region**
- **Rejection relies on vetoes/PID**

Other NA62 (phase II) goals



Other physics goals

- Lepton Flavour Violation: measurement of R_K to ~0.2% precision.
- LFV in forbidden decays: searches for $K^+ \to \pi^- l^+ l^+$, $K^+ \to \pi^+ l_1 l_2$.
- Heavy neutrinos (~100MeV), light sgoldstinos ($K^+ \to \pi^+ S$, $K^+ \to \pi^+ \pi^0 P$).
- Hadronic K decays and final-state $\pi\pi$ interactions in $K_{3\pi}$ and K_{e4} decays.
- ChPT tests with rare kaon/pion decays.

1st Physics Handbook workshop:
CERN, 10-11 December 2009
http://indico.cern.ch/conferenceDisplay.py?confId=65927

Summary

- Due to the suppression of the K_{e2} decay in the SM, the measurement of R_K is well-suited for a stringent SM test.

- $P^+ \rightarrow l^+\nu$: active developments of experiment and theory. After recent precise R_K measurements, the R_K world average has a 0.6% precision (and compatible with the SM prediction). Timely result: direct searches for new physics at the LHC are approaching.

- NA62 is a key player: the 2007/08 data taking was optimised for R_K measurement, and increased the world K_{e2} sample by an order of magnitude. Excellent $K_{e2}/K_{\mu 2}$ separation (>99% electron ID efficiency and $\sim 10^6$ μ suppression) leads to a low ~8% background.

- NA62 phase II: stringent SM test by measurement of the ultra rare decay $K^+ \rightarrow \pi^\pm \nu\nu$ with 10% precision, R_K measurement with ~0.1% precision, and much more.