# Search for physics beyond the Standard Model in NA48/2 and NA62 @ CERN

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**on behalf of the NA48 and NA62 collaborations**

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# Outline

- Theory for $K_{l2}$ decay and $R_K$ (SM and beyond SM)
- NA48/NA62: detector and data taking periods
- Preliminary results from NA48/2 (2003-2004)
- NA62: status of the analysis on 2007 data
- Conclusions

# The ratio $R_K$

$R_K$ accurately predicted within the SM:

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu_e)}{\Gamma(K^\pm \to \mu^\pm \nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001)\cdot 10^{-5}$$

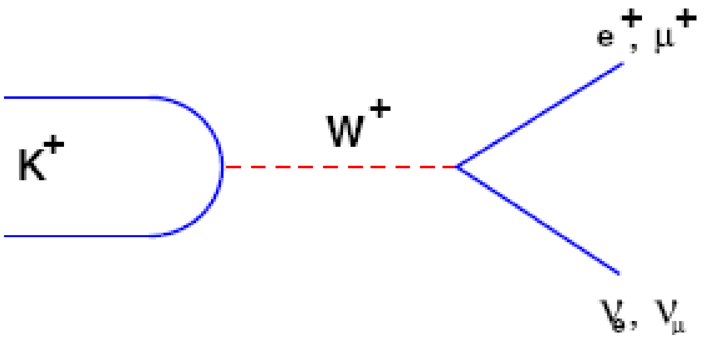
[V. Cirigliano and I Rosell, JHEP 0710:005 (2007)]

ChPT, $O(e^2p^4)$

Helicity suppression

Radiative corrections

Adronic contributions cancel in the ratio



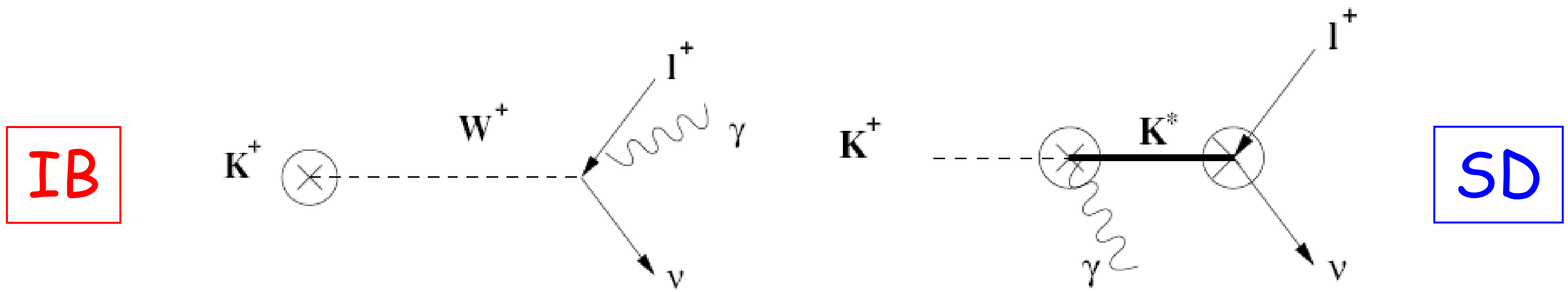

$R_K$ is sensitive to New Physics due to the helicity suppression

A precise measurement of $R_K$ probes μ–e universality and provides a stringent test of the SM.

$\delta R_K = -3.8\%$ compared to $\Delta R_K/R_K \sim 0.04\%$

($K_{\ell 2\gamma}$ and virtual photons)

# Radiative corrections



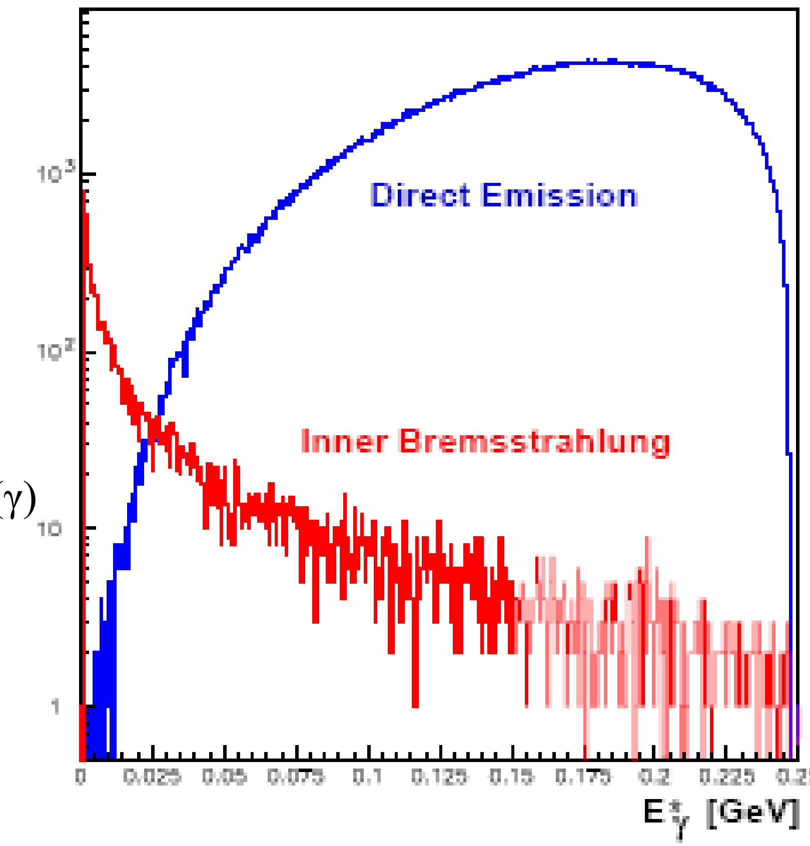

In the $R_K$ computation of SM:

- Inner Bremsstrahlung (IB) contribution is included
- Structure dependent (SD) contribution is not

Experiments measure inclusive $K_{e2(\gamma)}/K_{\mu2(\gamma)}$ and then SD contribution is subtracted

(SD contribution negligible in $K_{\mu2}$, not in $K_{e2}$ )

Effects on the acceptance need also to be taken correctly into account

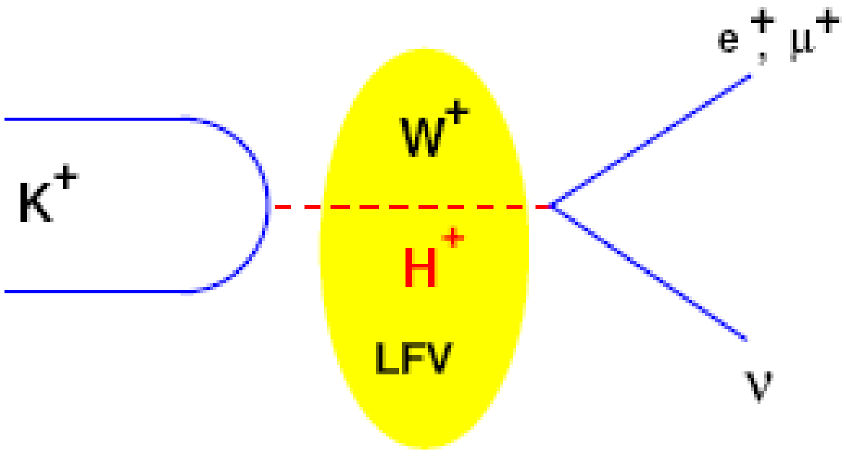


# $R_K$ beyond the SM

SUSY effects (MSSM framework) can modify $R_K$ wrt SM up to 3%

**(Masiero, P. Paradisi, R. Petronzio hep-ph/0511289 PRD74 (2006))**

R-parity is the source of new physics effect on $R_K$




Yukawa LFV effective couplings:

$$lH^{\pm}\nu_{\tau} \rightarrow \frac{g_2}{\sqrt{2}} \frac{m_{\tau}}{M_W} \Delta_R^{3l} \tan^2 \beta \qquad l = e, \mu$$

$\Delta^{31}$ is the LFV term connected to helicity suppression in Ke2

# $R_K$ in SUSY

The measurement of $R_k$ produces limits to the value of $\Delta_{31}=\Delta_{31}(m_{H\pm},\tan\beta)$

$$R_K^{LFV} \approx R_K^{SM}\left[1+\left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_{31}|^2 \tan^6\beta\right]$$

- Loop diagrams mainly contribute
- LFC contributions $O((\tan\beta)^2)$ suppressed
- For large $\tan\beta$ values (still not experimentally excluded) LFV contributions $O(\tan\beta)^6$ dominate producing sizable effects on $R_K$
- Destructive interference between SM and SUSY LFC (arising from double LFV Mass Insertions) can give negative correction to $R_K^{SM}$

$\tan\beta=40$ e $M_H=500$ GeV/$c^2$

$$R_K^{LFV} = R_K^{SM}(1 + 0.013)$$

# NA48 and NA62

| | | | |
|---|---|---|---|
| NA48 | 1997 | ε'/ε run | $K_L + K_S$ |
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| NA48 | 1999 | ε'/ε run $K_L + K_S$ | $K_S$ Hi. Int. |
| NA48 | 2000 | $K_L$ only | $K_S$ High Intensity; NO Spectrometer |
| NA48 | 2001 | ε'/ε run $K_L + K_S$ | $K_S$ High Int. |
| NA48/1 | 2002 | $K_S$ High Intensity | |
| NA48/2 | 2003 | $K^\pm$ High Intensity | |
| NA48/2 | 2004 | $K^\pm$ High Intensity | |

## NA62 phase I

Dedicated 2007 run to measure:

$$R_K = \frac{\Gamma\left(K^\pm \to e^\pm \nu_e\right)}{\Gamma\left(K^\pm \to \mu^\pm \nu_\mu\right)}$$

## NA62 phase II

measurement of the decay

$$K^+ \to \pi^+ \nu \bar{\nu}$$

(2008-2010 R&D
& construction
2011 start of data taking)

# The NA48 detector

Magnet spectrometer (4 DCHs):

4 view: redundancy ⇒ efficiency

$\sigma(p)/p = 1.0\% + 0.044\%\ p$ [GeV/*c*]

Charged Hodoscope:

Fast trigger and good time resolution

(~200ps on single track)

E.m. calorimeter with Liquid Krypton (LKr):

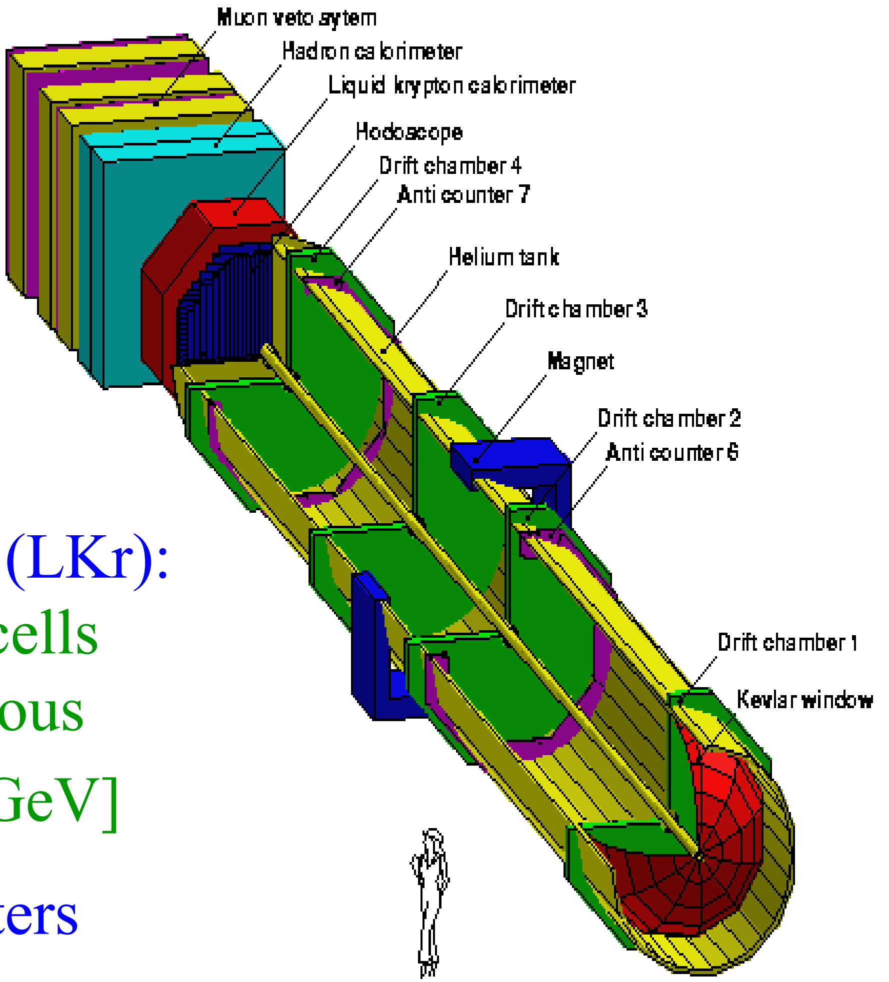
10 $m^3$ (~22 t), 1.25 m (27 $X_0$), 13212 cells

granularity:2x2 $cm^2$, quasi-homogeneous

$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]

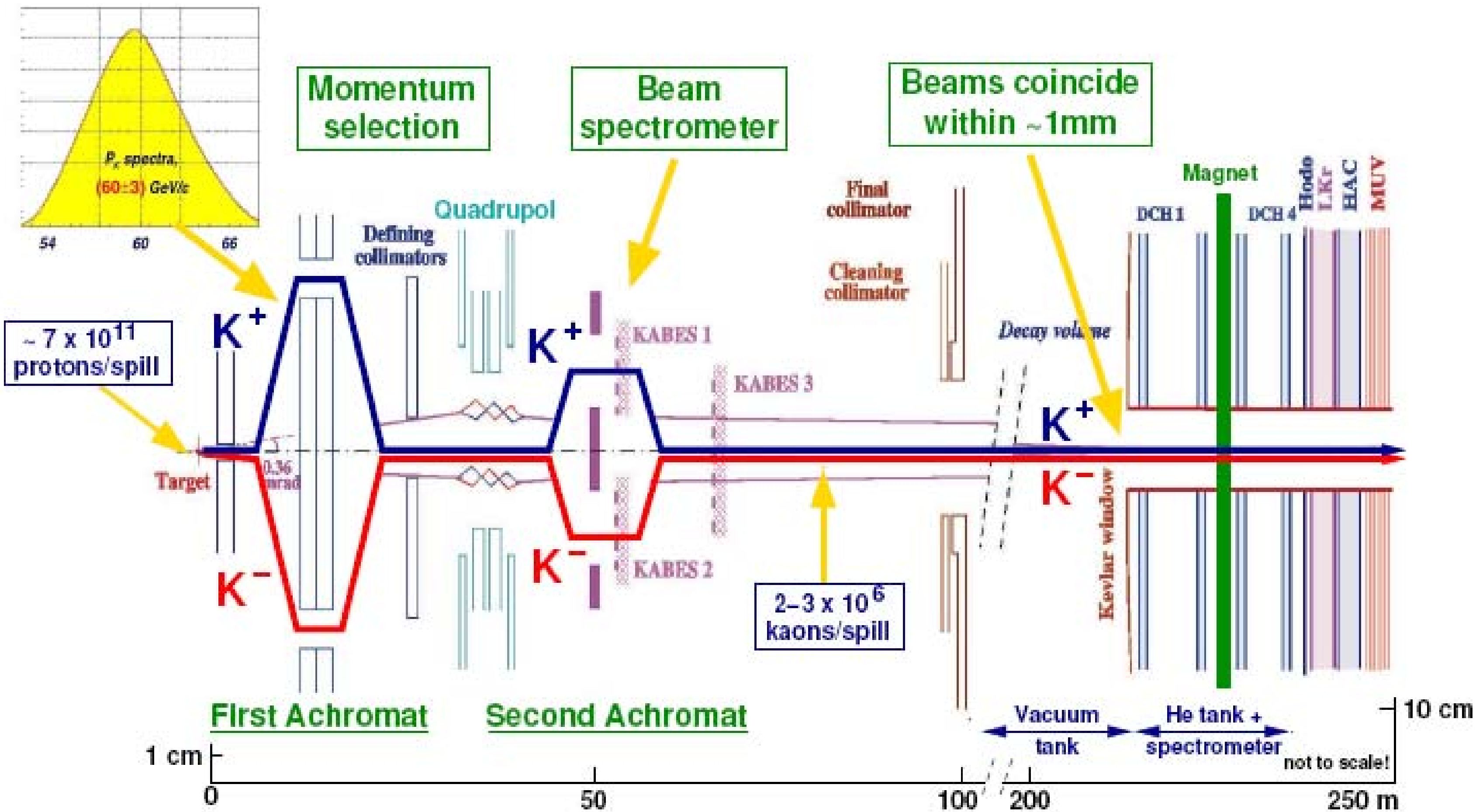
Hadronic calorimeter, large veto counters

and muon veto counters



# The simultaneus $K^+/K^-$ beams

Designed to search for direct CP violation in $K^{\pm} \rightarrow 3\pi$
Quasi-collinear $K^+$ and $K^-$ beams @ 60 GeV ($K^+/K^-$ ~1.8)



# Measurements of $R_K$ from NA48/2

**2003** run

1 month of data taking

trigger: 1 track + energy on LKr + online kinematics

3.4 K $K_{e2}$ candidates collected

High systematic error coming from trigger inefficiency ~ 15 %

**2004** run

56 hours of data taking

trigger: 1 track + energy on LKr

4.6 K $K_{e2}$ candidates collected

Systematic error dominated by $K_{\mu 2}$ background to $K_{e2}$

# Analysis strategy

$$R_K = \frac{N(K_{e2}) - N_{BG}(K_{e2})}{N(K_{\mu 2}) - N_{BG}(K_{\mu 2})} \cdot \frac{1}{D} \cdot \frac{Acc(K_{\mu 2}) \cdot \varepsilon_{TR}(K_{\mu 2}) \cdot \varepsilon_{PID}(K_{\mu 2})}{Acc(K_{e2}) \cdot \varepsilon_{TR}(K_{e2}) \cdot \varepsilon_{PID}(K_{e2})}$$

$N(K_{l2})$ = number of candidates evts

$N_{BG}(K_{l2})$ = number of background evts

$Acc(K_{l2})$ = geometrical acceptance (MC)

$\varepsilon_{TR}(K_{l2})$ = trigger efficiency

$\varepsilon_{PID}(K_{l2})$= selection efficiency (no MC!)

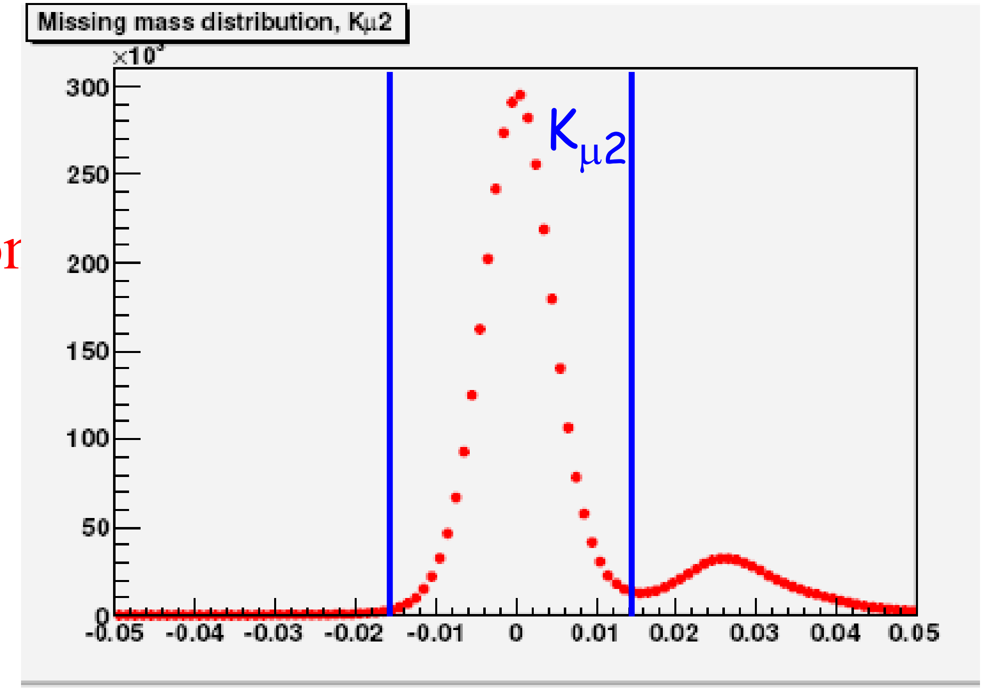
D = trigger downscaling

- $K_{e2}$ and $K_{\mu 2}$ collected simultaneously
  ➡ fluxes cancel in the ratio
- Many time-dependent systematic effects also cancel
- The main contribution to systematic error comes from background subtraction (stat. dependent)

# Event selection

## $K_{e2}$ and $K_{\mu 2}$ decays similar → set of common cuts

- 1 track events
- $15 < p < 50$ GeV/c
- reconstructed decay vertex inside the fiducial decay region
- Geometrical acceptance




Particle ID (E/p):

- e ($E/p > 0.95$)
- μ ($E/p < 0.2$)

Kinematics:

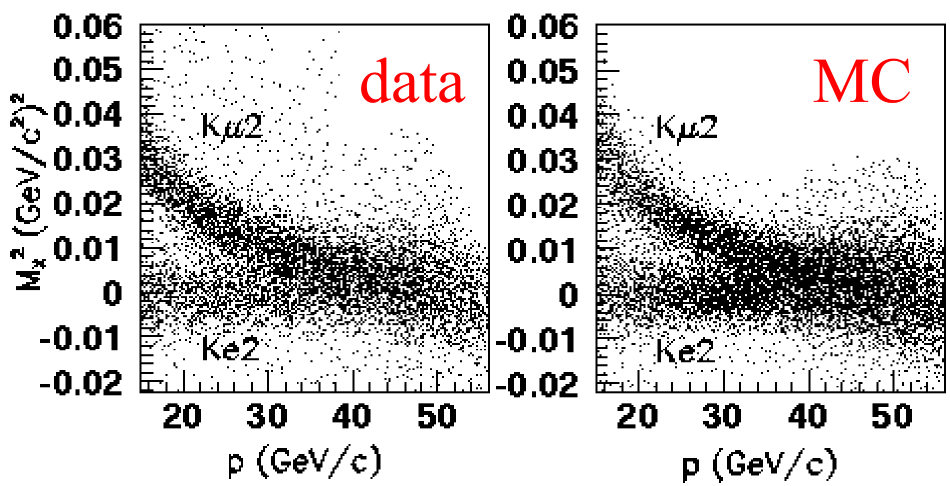
- $M_{miss}^2 = (p_K - p_l)^2$, $-0.015 < M_{miss}^2 < 0.015$

# Background/1

The main systematics come from background subtraction

$K_{\mu 2}$ is the main source of background for $K_{e2}$

- The missing masses for $K_{e2}$ and $K_{\mu 2}$ overlap at high momentum (>35GeV/c)
- The $\mu$ has a probability of ~$4\times10^{-6}$ to produce a catastrophic bremsstrahlung in the LKr and to be misidentified as an electron, giving an E/p bigger than 0.95




- Background from $K^{\pm} \to \pi^0 e^{\pm} \nu$ evaluated with MC simulation

run 2003-2004

$p_K$ = 60 GeV, $p_{kick}$ = 120 MeV/c

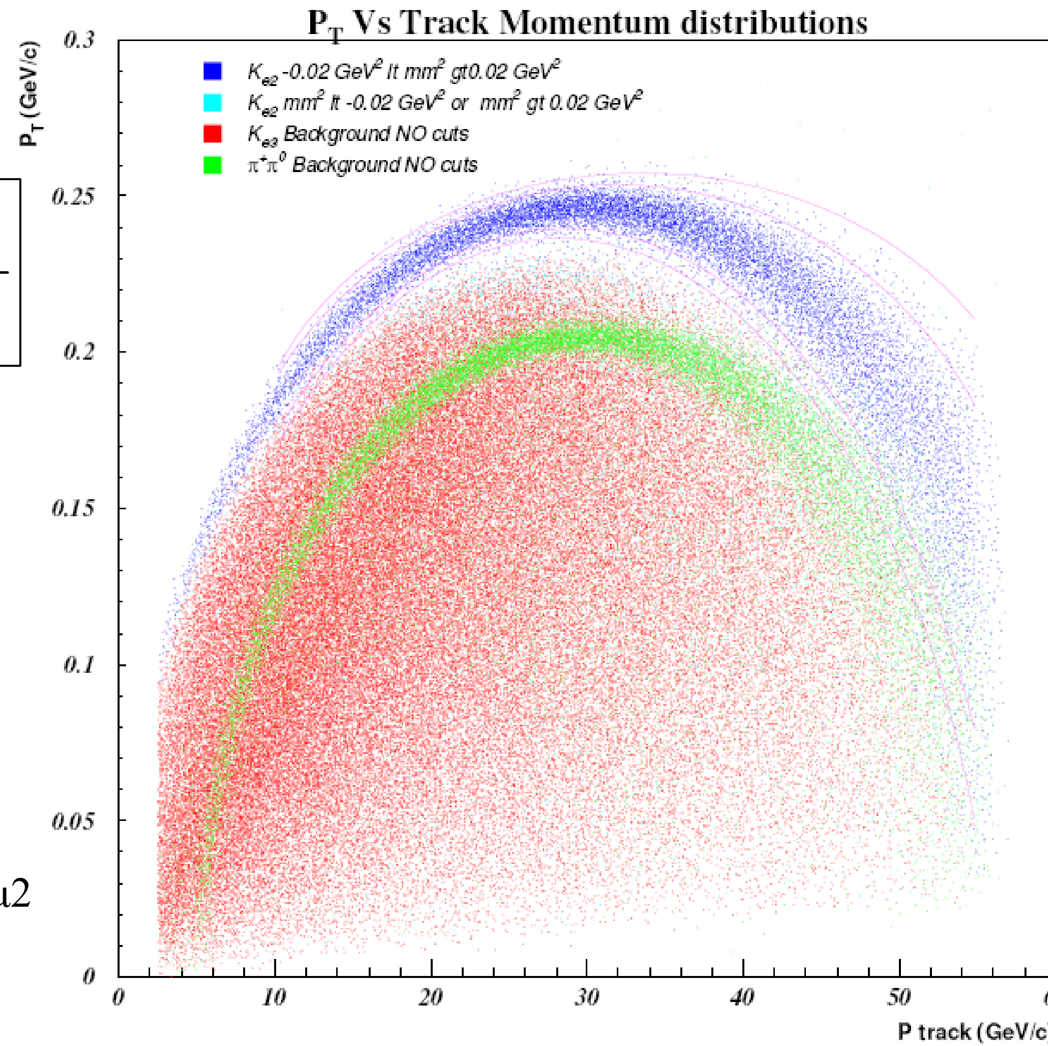
For $K_{\mu 2}$

- Background from $K^{\pm} \to \pi^{\pm}\pi^0$ negligible

# Background/2

$p_t$, $p_{track}$ and $m_{miss}^2$ related with an elliptic equation:

$$m_{miss}^2(e) \cong \frac{m_K^2}{p_K}(p_K - p_e) - p_K \frac{p_t^2}{p_e}$$




$K_{e2}$ decays selected with a cut at 3 $\sigma$ from the average

The same cut was applied to $K_{\mu 2}$

# Results from 2003 and 2004

- Run 2003

final sample: (4670±77$_{stat}$) $K_{e2}$ candidates

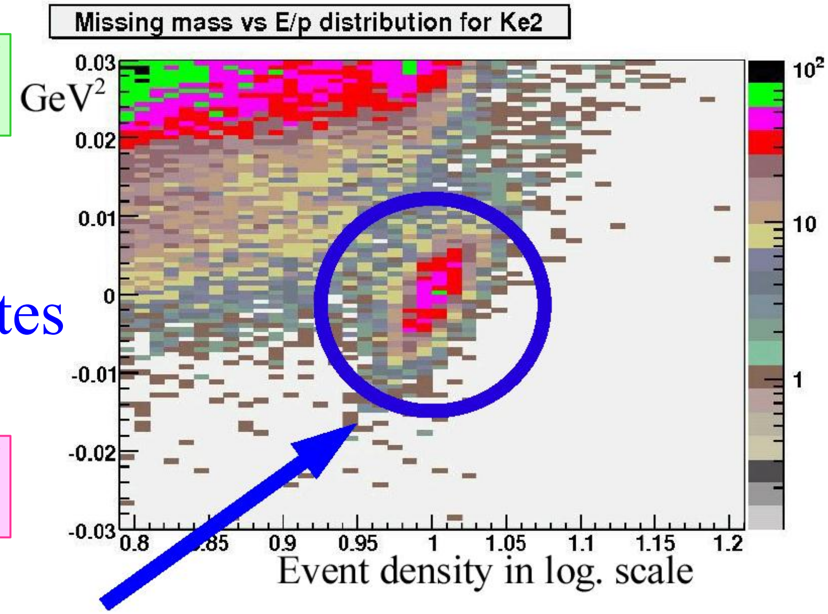
$$R_K = (2.416 \pm 0.043 \pm 0.024) \cdot 10^{-5}$$

- Run 2004

final sample: (3407±63$_{stat}$) $K_{e2}$ candidates

$$R_K = (2.455 \pm 0.045 \pm 0.041) \cdot 10^{-5}$$

$\Delta R_K / R_K \sim 2\%$




preliminary

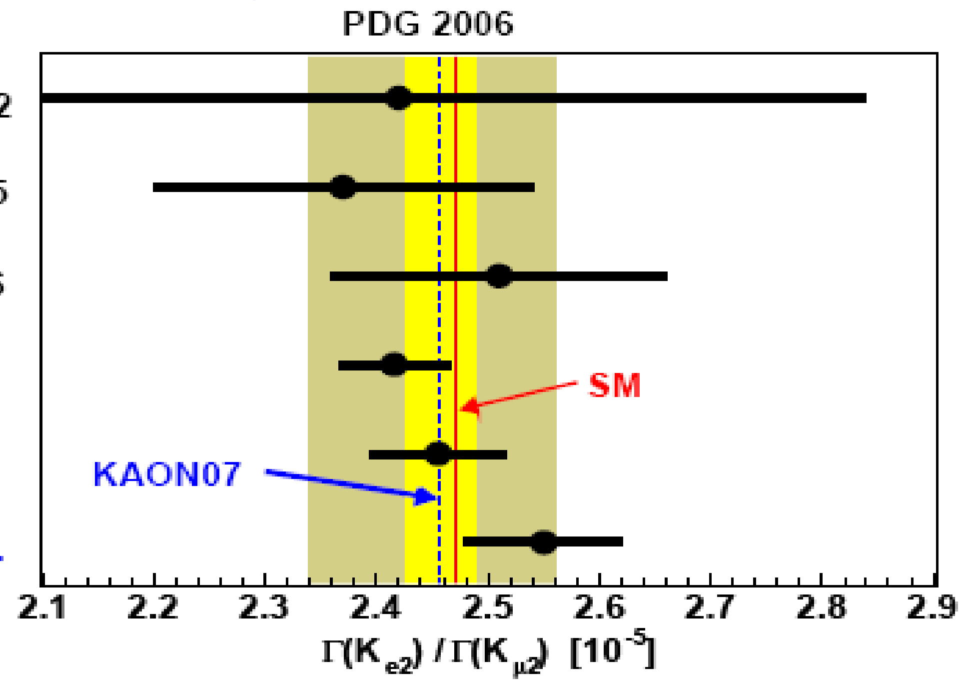
KLOE: $R_K = (2.55 \pm 0.05 \pm 0.05) \cdot 10^{-5}$

~ 8K events published in 2007, error 2.7%,target ~1% [arXiv:0707.4623]

# Flavianet fit to $R_K$

Before NA48/2 and Kloe results → $R_K^{PDG} = (2.45 \pm 0.11) \cdot 10^{-5} \qquad \delta R_K / R_K = 4.5\%$

Flavianet fit to $R_K$ combining PDG 2006, NA48/2 and KLOE results:




$$R_K = (2.457 \pm 0.032) \cdot 10^{-5} \qquad (\chi^2 / ndf = 2.44/3)$$

- ✓ Big improvement wrt PDG → now $\delta R_K/R_K \sim 1.3$ %
- ✓ Good agreement with SM prediction

# Thinking to a new run

At the end of 2006 we started to think how to reduce the error on $R_K$ with the existing NA48 set-up

- Minimum bias trigger (as it was in 2004)
- Then the main source of systematic becomes the $K_{\mu2}$ background to the $K_{e2}$ sample:
  - ⇒ New beam parameters and new spectrometer configuration to improve the resolution on the missing mass
  - ⇒ Direct measurement of the probability for a muon to be misidentified as an electron
- $K^+$ only beam for most of the data taking to reduce the background coming from beam halo from 20% to 1% ($K_{e2}$ channel)

# The new NA62 run

A new run to reduce the error on $R_K$ from 2% to 0.5%

Proposal to the SPSC committee and to CERN Research Board on February 2007 → approved!

**NA62 phase 1**

(Phase II: measurement of the decay $K^+ \rightarrow \pi^+ \nu\nu$)

4 months of data taking for the measurement
(+1 month for the test of prototypes for phase II)

Goal → to collect **$\sim 1 \times 10^5$ $K_{e2}$ candidates**

# The new analysis strategy

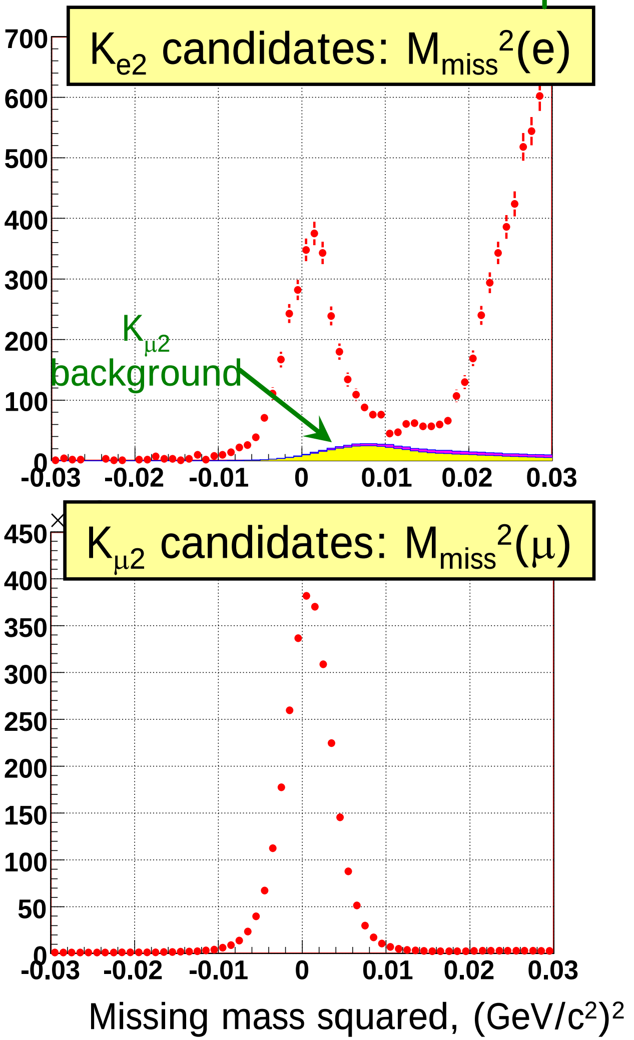
2007 analysis in many aspects similar to the 2003 and 2004 analyses

- $K_{e2}$ and $K_{\mu 2}$ collected simultaneously
- MC used only for geometrical acceptance
- $R_K$ measured in bins of track momentum

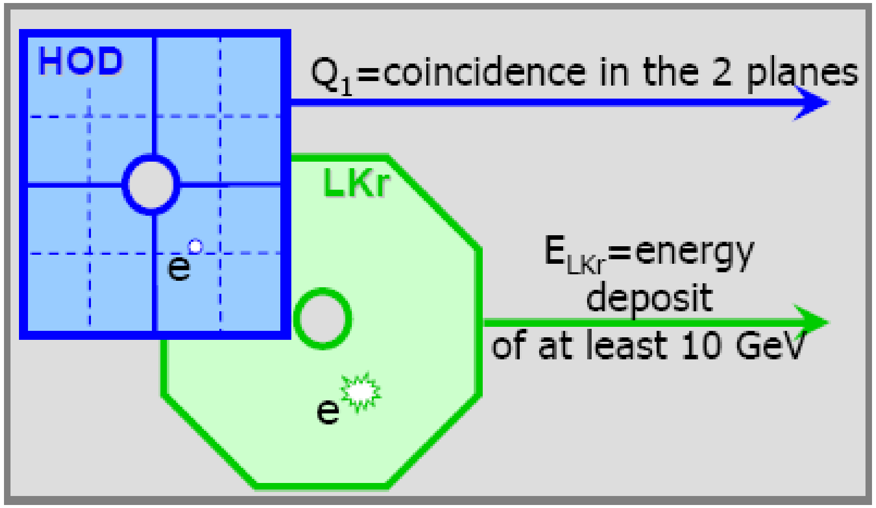
In each beam the following corrections will be applied to the raw ratio:

- Geometrical acceptance
- trigger efficiency
- Particle ID efficiency
- Background subtraction

Express analysis:
~3% of the 2007 $K^+$ sample



# Trigger




Many improvements during data taking to increase the number of $K_{e2}$ collected:

1) Drift chambers multiplicity (1TRK)
2) Optimization of trigger downscaling
3) Beam steering
4) Removal of the lead wall

| Trigger | Condition | | Rates/SPS spill | | Purity | |
|---|---|---|---|---|---|---|
| | Start-up | End-of-run | Start-up | End-of-run | Start-up | End-of-run |
| $K_{e2}$ | $Q_1 \times E_{LKr}$ | $Q_1 \times E_{LKr} \times 1TRK$ | 0.23 | 0.54 | $0.6\times10^{-5}$ | $1.3\times10^{-5}$ |
| $K_{\mu2}$ | $Q_1/50$ | $Q_1 \times 1TRK/150$ | 290 | 160 | 1.8% | 1.8% |

- The $K_{\mu2}$ trigger also used as control trigger for $K_{e2}$ trigger
- Other minimum bias control triggers included
- Small trigger inefficiencies (~0.1%) directly measured from data

# $K_{\mu 2}$ background below 40 GeV/c

**p < 40 GeV/c** ~ 43% events

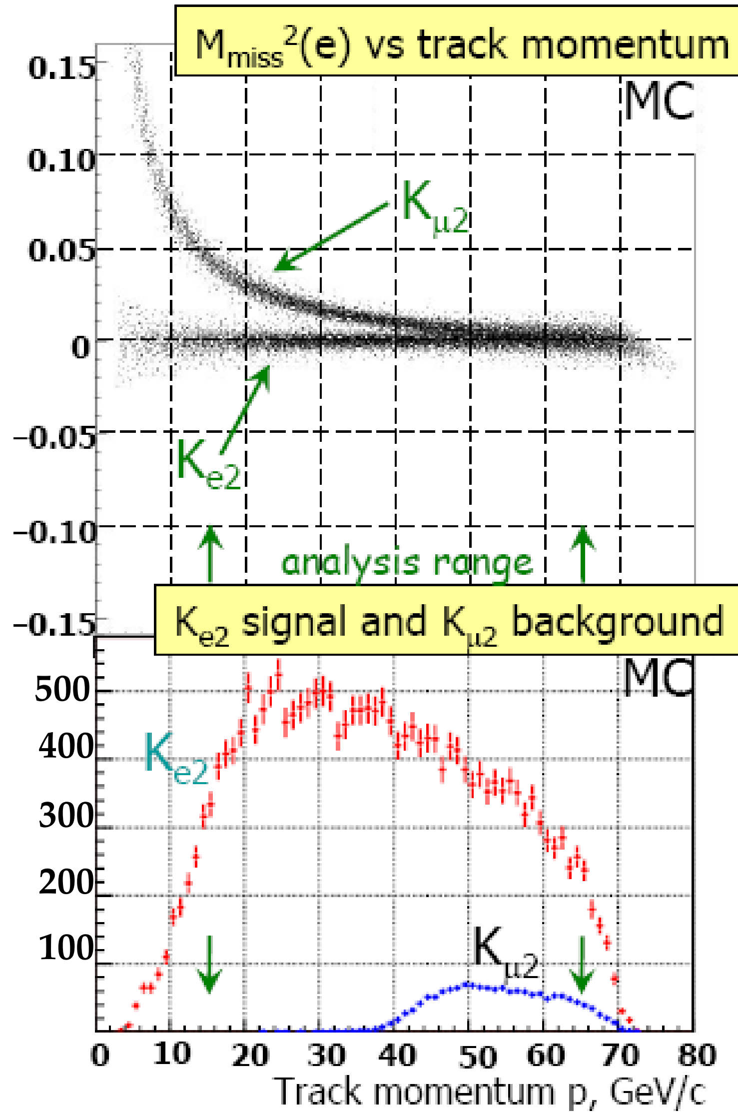
$K_{l2}$ identified with $M_{miss}^2$ (assuming $m_l$)

$$M_{miss}^2\,(l) = (p_K - p_l)^2$$

In 2007 the resolution on $M_{miss}^2$ was improved in the following way:

$p_K$ → Kaon momentum:
(60 ± 3) GeV/c → (75.0 ± 2.5) GeV/c
2003-04 $\Delta p_K/p_K$ 3% vs 2% on 2007

$p_l$ → momentum kick of the magnet
120 MeV/c → 263 MeV/c
$\delta p/p = 0.47\% + 0.020p$ (p in GeV)

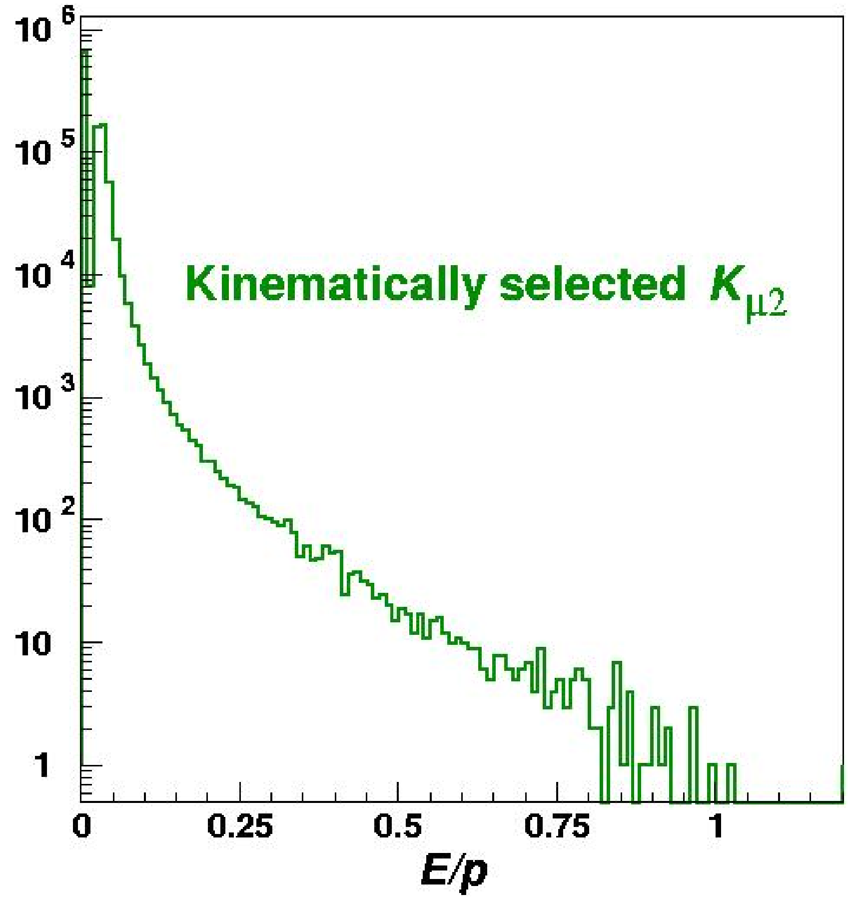


# $K_{\mu 2}$ background above 40 GeV/c

**p > 40 GeV/c** ~ 57% events

Electron identification relays on E/p:

$0.95 < E_{LKr}/p_{tr} < 1.05$




**But:**

A non-negligible fraction of muons has a catastrophic bremsstrahlung in the LKr

→ μ misidentified as electrons

P(μ→e) ~4 $10^{-6}$, depending from p (according to bremsstrahlung cross section)

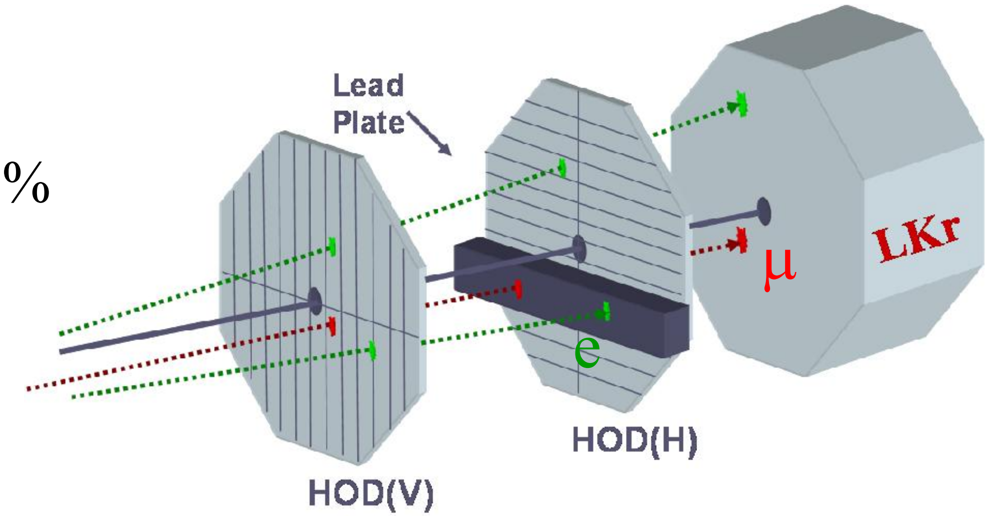
# Measurement of P(μ→e)

## Direct measurement

Lead wall placed in front of the LKr
(between the two planes of the charged hodoscope)

Track crossing the lead wall + 1 MIP in the hodoscope

Pure sample of μ




- The acceptance was reduced by 18%
- E/p distribution for muons can be measured in the desired momentum range

Samples collected:

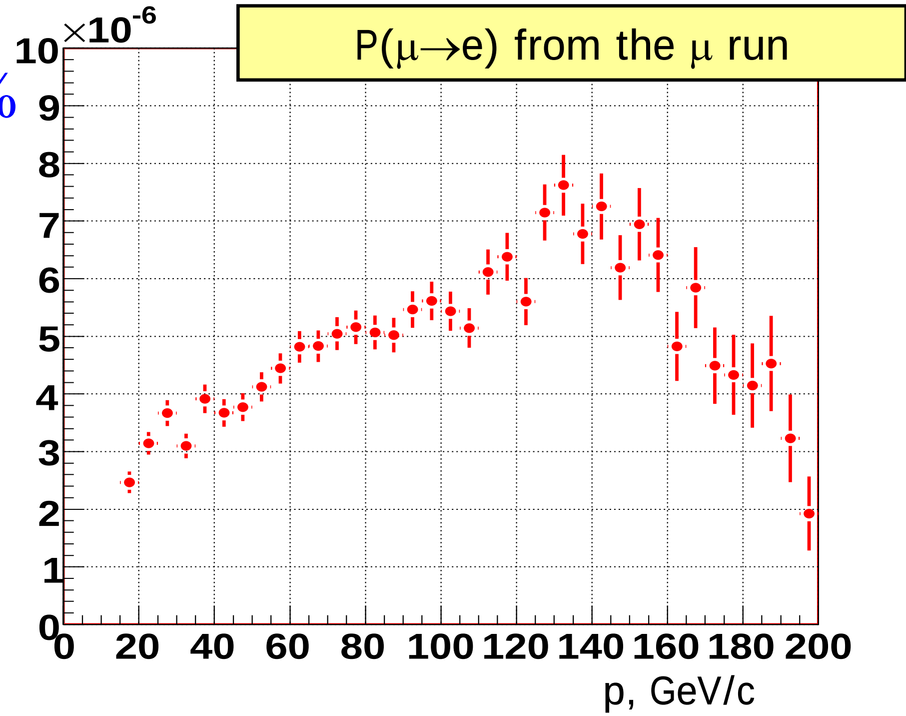
1) $K_{\mu 2}$ from standard data taking
2) Special runs with μ beam

- thickness: Pb(4.5 cm) + Fe (2.0 cm)= $9X_0$
- 18 cm high = 3 hodoscope counters

# Background summary

**sample $K_{e2}$**

1) $K_{\mu 2}$: Evaluated with the direct measurement of P(m→e)
2) Beam halo: (1.3 ± 0.1)% estimated with K-less runs
3) $K_{e2\gamma}$ (SD): Evaluated from MC: (0.7 ± 0.1)%
4) $K_{e3}$: Evaluated with MC: < 1%
5) $K^+ \rightarrow \pi^+\pi^0$:Evaluated with MC: < 1%



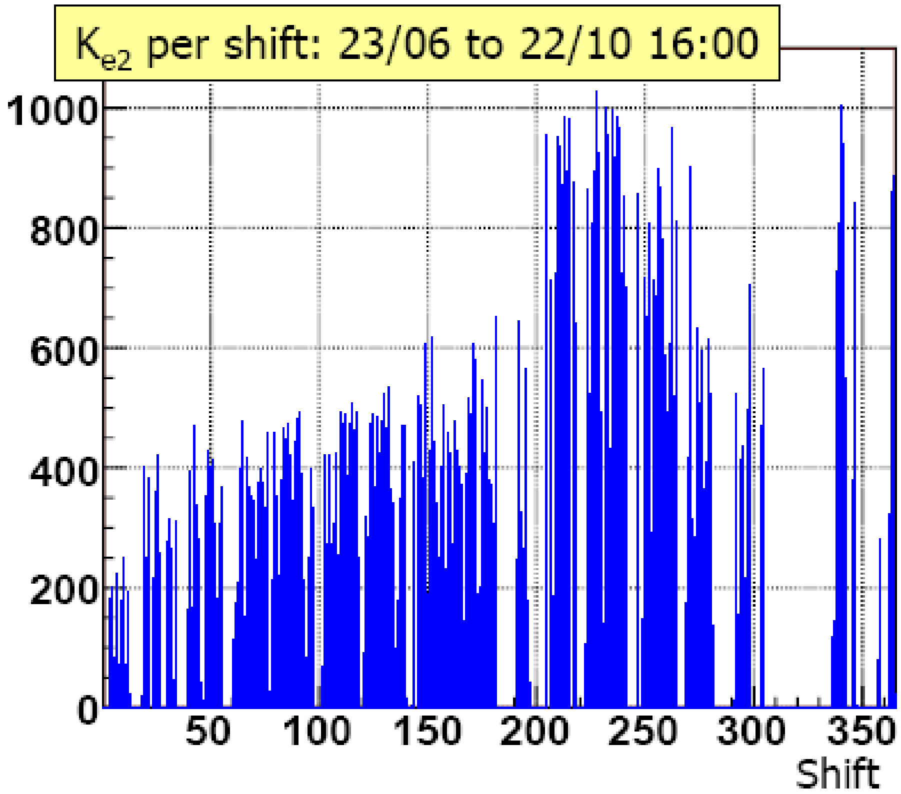

**sample $K_{\mu 2}$**

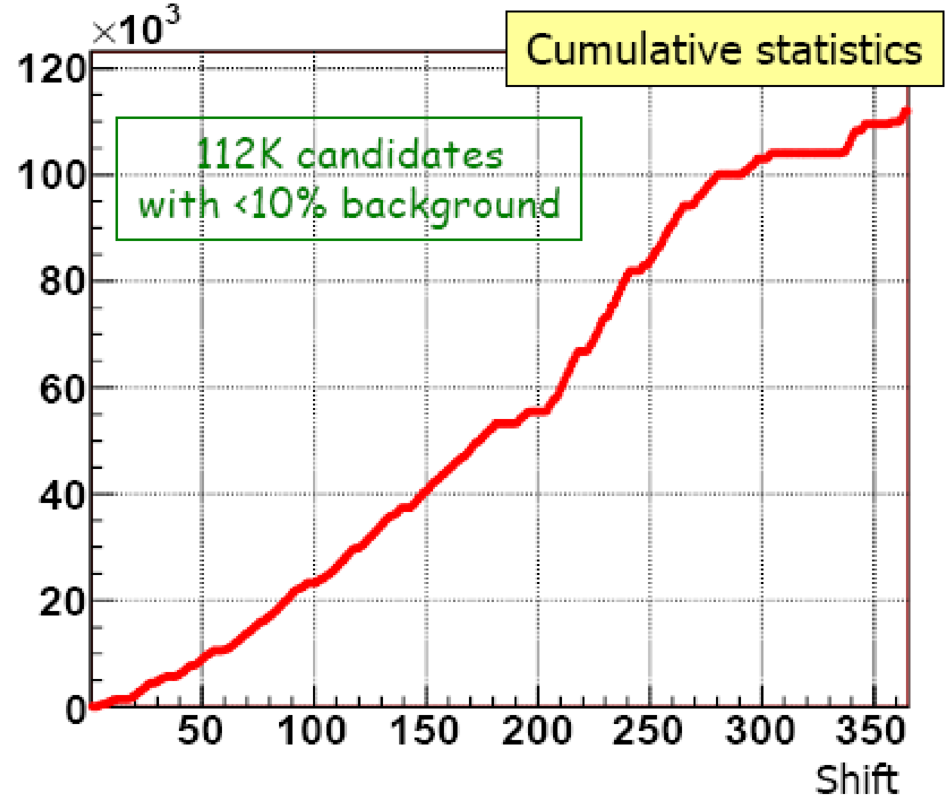
1) Beam halo ~ 0.1%
2) $K^+ \rightarrow \pi^+\pi^0$ < 0.5%

# Data collected

Data taking period: from June, 23th to October,22th in 2007

112 K candidates selected, background < 10%



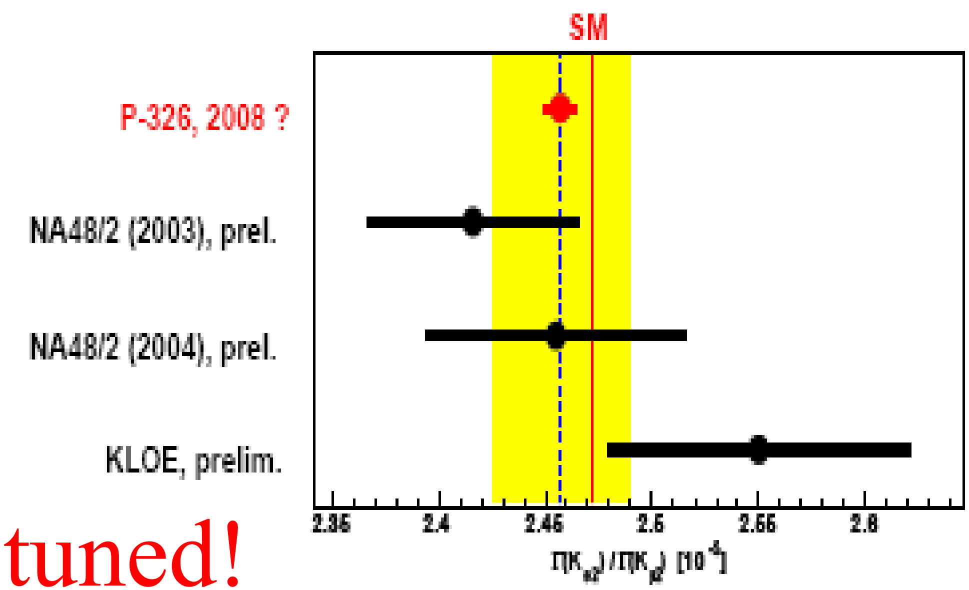




Statistical error on $R_K$ ~ 0.3%, total error < 0.5 %

# Conclusion

- $K_{l2}$ decays represent a good opportunity to test the SM,
- In some SUSY framework, deviation from SM up to 3%
- 2003 e 2004 results from Na48/II has been shown
- During 2007 the NA62 experiment has collected more than 100 K $K_{e2}$ candidates
- The status of the analysis going on on 2007 data has been shown
- Statistical error ~ 0.3%, total error on $R_K$ < 0.5%

Unique opportunity to find New Physics or to strongly constrain SUSY models




Stay tuned!