International Workshop
e+e- Collisions from phi to psi
February 27 - March 2, 2006

Charged kaons at KLOE

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on behalf of the KLOE collaboration

I get it!

СПАСИБО!!!

Outline

- **Vus with charged kaons**
- **TAG mechanism**
- **$K^+ \to \mu^+ \nu (\gamma)$**
- **Semileptonic decays**
- **Charged kaon lifetime**
- **Conclusions**

V_{us} form charged kaons

- From semileptonic decays

Form factor — Radiative corrections

$$\Gamma(K^{\pm}\to\pi^{0}l^{\pm}\nu_{l})=\frac{BR(K^{\pm}\to\pi^{0}l^{\pm}\nu_{l})}{\tau(K^{\pm})}\propto|V_{us}f_{+}(0)|^{2}S_{EW}(1+\delta_{K}^{e})I_{K}^{e}$$

Phase space (λ_+,λ_0)

- From leptonic decay (Marciano, **Phys.Rev.Lett.**93:231803,2004)

$$\frac{\Gamma(K\to\mu\nu(\gamma))}{\Gamma(K\to\pi\nu(\gamma))}\propto\left|\frac{V_{us}}{V_{ud}}\right|^{2}\times\left|\frac{f_{K}}{f_{\pi}}\right|^{2}$$

Lattice QCD

Kaon pair production

The ϕ decays at rest producing a kaon pair: $K_L K_S$ or K^+K^-

The detection of a K guarantees the presence of the $\overline{\text{K}}$ with known momentum $\Rightarrow$ **Tag mechanism**

Normalization to the number of tags allows a precise measurement of <u>absolute BRs</u>

$$\sigma(e^+ e^- \rightarrow \phi) \approx 3\,\mu b$$

$$P_{LAB} = 127\,MeV/c$$

$$BR(\phi \rightarrow K^+ K^-) \simeq 49\,\%$$

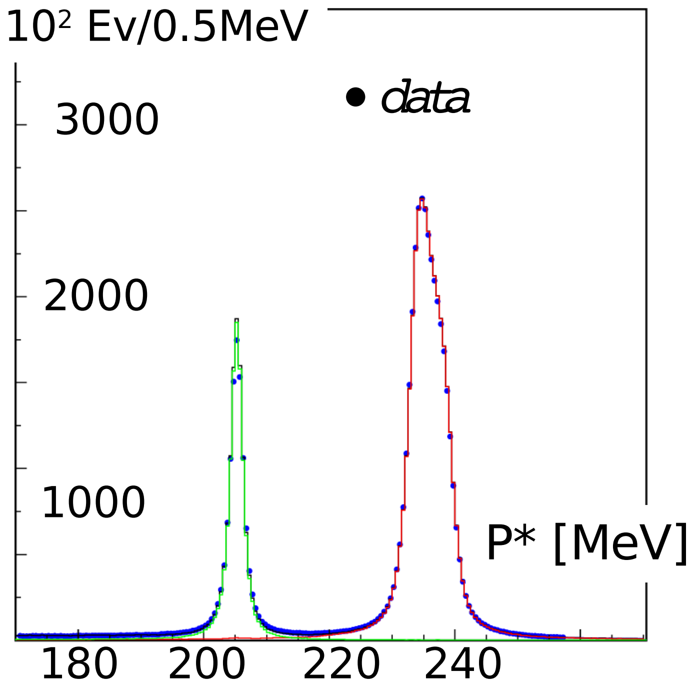
$$\lambda(K^+) = 95\,cm$$

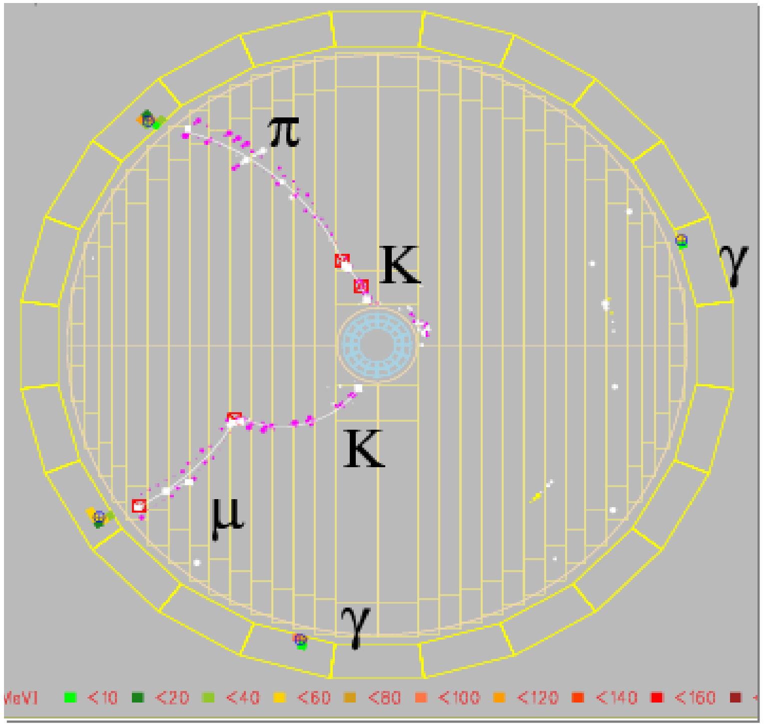
Tag mechanism

$K^{\pm}$ events tagged using two body decays (about 85%):

$K^{\pm} \rightarrow \mu^{\pm} \nu$, $\pi^{\pm} \pi^{0} \approx 1.5 \times 10^{6}$ $K^{+}K^{-}$ ev/pb^{-1}

Two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame $P^*(m_{\pi})$





To minimize the impact of the trigger efficiency tags must provide themselves the Emc trigger of the event: **self-triggering tags**

$N_{\text{self-trg Tag}} \approx 2 \times 10^{5}$ pb^{-1}

Measurement of the absolute branching ratio

$$K^+ \to \mu^+ \nu(\gamma)$$

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Overview $K^+ \to \mu^+ \nu (\gamma)$

- Normalization N_{TAG} given by 175 pb^{-1} from self-triggering $K^- \to \mu^- \bar{\nu}$
- Counting events in the distribution of secondary track momentum in the kaon rest frame p*
- Background subtraction
- Efficiency related to DC reconstruction only (tracking plus vertexing), evaluated on data

Signal $K^{+} \to \mu^{+} \nu (\gamma)$

- Signal given by K⁺ decay in the DC FV (40 cm < ρ < 150 cm)

  Using *~60 pb⁻¹*

- Background given by events

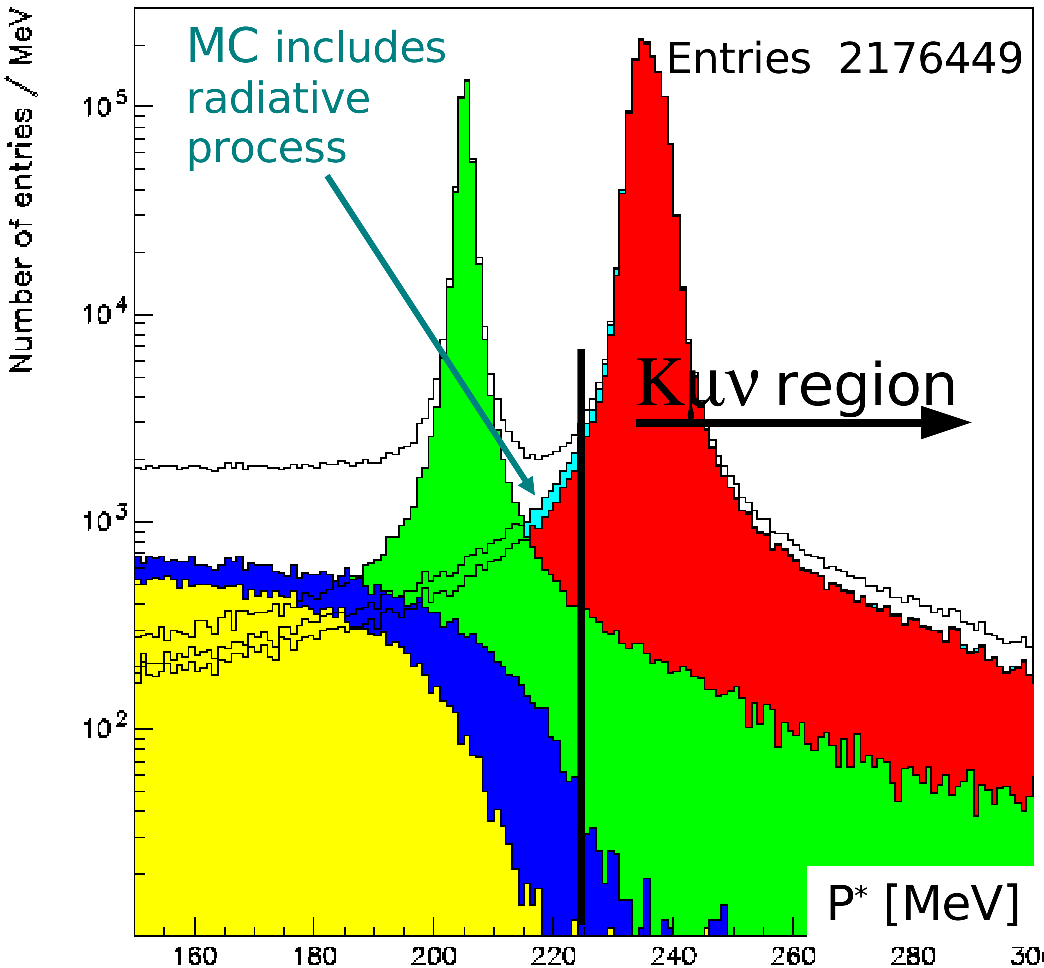
  with π^0 in the final state:

$$K^{+} \to \pi^{+} \pi^{0}$$

$$K^{+} \to \pi^{0} e^{+} \nu_{e}$$

$$K^{+} \to \pi^{0} \mu^{+} \nu_{\mu}$$

$$BR = \frac{N_{K\mu\nu(\gamma)}}{N_{TAG}} \cdot \frac{1}{\epsilon_{DC}}$$



ε_{DC} evaluation

- Efficiency has been evaluated on a second uncorrelated sample of *~115 pb*$^{-1}$ using only calorimeter information
- Double K$\mu\nu$ events have a typical signature in the EMC i.e. 2 isolated clusters with energy in the range $80 < E_{CLU} < 320$ MeV
- A correction O(10^{-4}) to the efficiency has been evaluate from MC:

$$\epsilon_{DC} = \epsilon_{DATA} \times C_{MC} \qquad C_{MC} = \frac{\epsilon_{MC\ \ True}}{\epsilon_{MC\ \ recon.}}$$

Result

$$BR = 0.6366 \pm 0.0009_{stat.} \pm 0.0015_{syst.}$$

Summary table of systematic and statistical uncertainties			
Source of syst. uncert.	**Value**	**Source of stat. uncert.**	**Value**
$\delta_{Low\ Energy\ Cut}$	5×10^{-4}	First estimate	6×10^{-4}
$\delta_{High\ Energy\ radiative\ \gamma}$	7×10^{-4}	Data efficiency	4×10^{-4}
$\delta_{High\ Energy\ Cut}$	2×10^{-4}	MC efficiency	4×10^{-4}
$\delta_{Fiducial\ Volume}$	5×10^{-4}	True MC efficiency	3×10^{-4}
$\delta_{Background}$	3×10^{-4}	Tag bias	1×10^{-4}
$\delta_{p^*\ range}$	3×10^{-4}	**Total stat. uncert.**	9×10^{-4}
δ_{Tag}	1×10^{-4}		
$\delta_{MC\ Lifetime}$	$< 10^{-6}$		
$\delta_{Nuclear\ interactions}$	$< 4 \times 10^{-4}$		
δ_{FILFO}	$< 3 \times 10^{-4}$		
$\delta_{T3\ filter}$	$\mathcal{O}(10^{-6})$		
$\delta_{Trigger}$	9×10^{-4}		
Total syst. uncert.	15×10^{-4}		

Total number of events:
865283

Total accuracy: 0.27%

Result

$$BR = 0.6366 \pm 0.0009_{stat.} \pm 0.0015_{syst.}$$

$$\frac{BR(K\to\mu\nu(\gamma))}{BR(K\to\pi\nu(\gamma))} \propto \left|\frac{V_{us}}{V_{ud}}\right|^2 \times \left(\frac{f_K}{f_\pi}\right)^2$$

Using the updated result from MILC: $f_K/f_\pi = 1.198 \pm 0.003\,^{+0.016}_{-0.005}$

we obtain: $$\left|\frac{V_{us}}{V_{ud}}\right| = 0.2294 \pm 0.0026$$

V_{us} - V_{ud} plane

Inputs:

V_{us} = 0.2248 ± 0.0020 (K_{l3} KLOE)

V_{ud} = 0.97377 ± 0.00027 (Marciano)

V_{us}/V_{ud} = 0.2294 ± 0.0026 ($K_{\mu 2}$ KLOE)

Fit results:

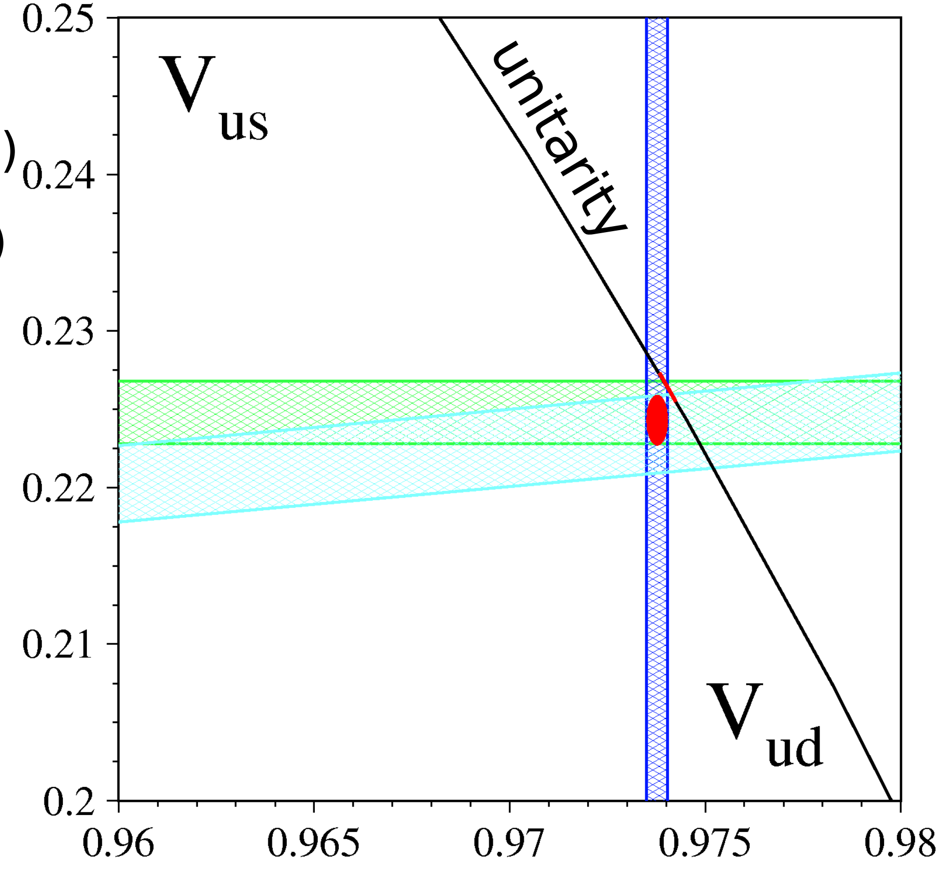
V_{us} = 0.2243 ± 0.0016

V_{ud} = 0.97377 ± 0.00027

Fit results assuming unitarity:

V_{us} = 0.2264 ± 0.0009

$P(\chi^2)$ = 0.43



Measurement of the $K^{\pm}$ semileptonic decays absolute branching ratios

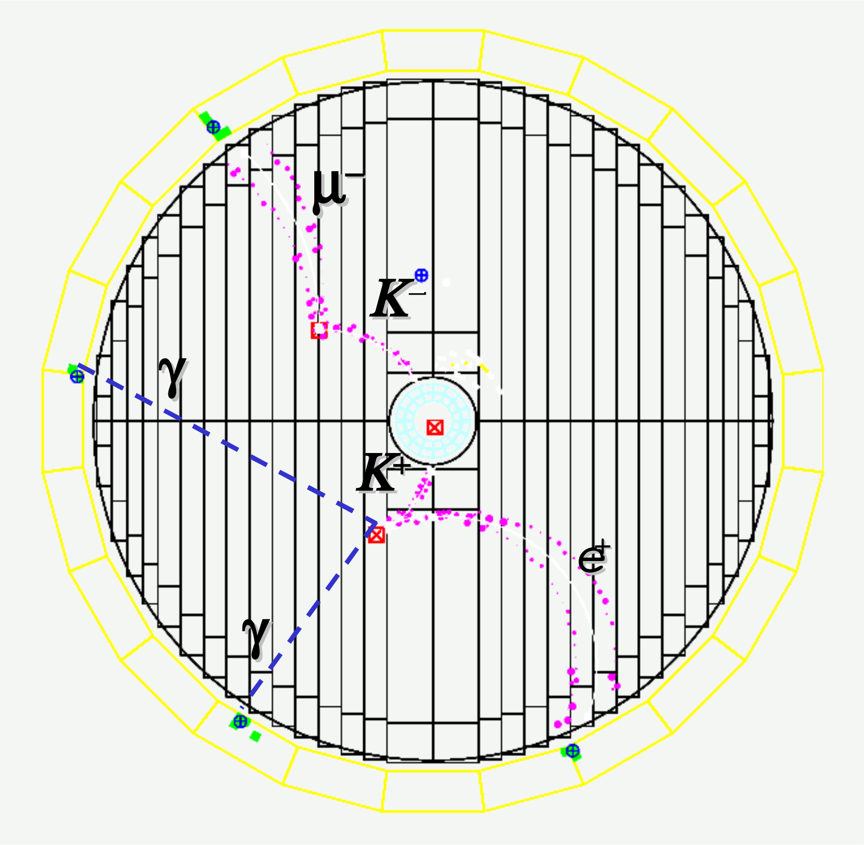
$$K^{\pm} \to \pi^0 e^{\pm} \nu_e \quad \& \quad K^{\pm} \to \pi^0 \mu^{\pm} \nu_{\mu}$$

Semileptonic overview

- 4 independent normalization samples (2 tag x 2 charges)
- 410 pb^{-1} self-triggering tags from 2001 and 2002 data
- Fit of the charged secondary square mass spectrum m^2_{lept}
- $K^\pm \rightarrow \mu^\pm\nu$ and $K^\pm \rightarrow \pi^\pm\pi^0$ rejected cutting on $p^*(m_\pi)$
- Efficiency evaluated from MC and corrected for Data/MC ratio

Signal selection

- Two tracks vertex in the FV:
  40 cm < ρ < 150 cm
- Track of charged secondary extrapolated to EMC
- Two body decays cut:
  $p^*(m_\pi) < 195$ MeV/c
- π^0 reconstruction:
  2 neutral clusters in EMC with TOF matching the kaon decay vertex
- Mass of charged secondary from TOF measurement



$$t_{\pi^0}^{decay} = \frac{(t_1 - L_1/c) + (t_2 - L_2/c)}{2}$$

$$m_{lept}^2 = p_{lept}^2 \cdot \left[\frac{c^2}{L_{lept}^2} (t_{lept} - t_{\pi^0}^{decay})^2 - 1 \right]$$

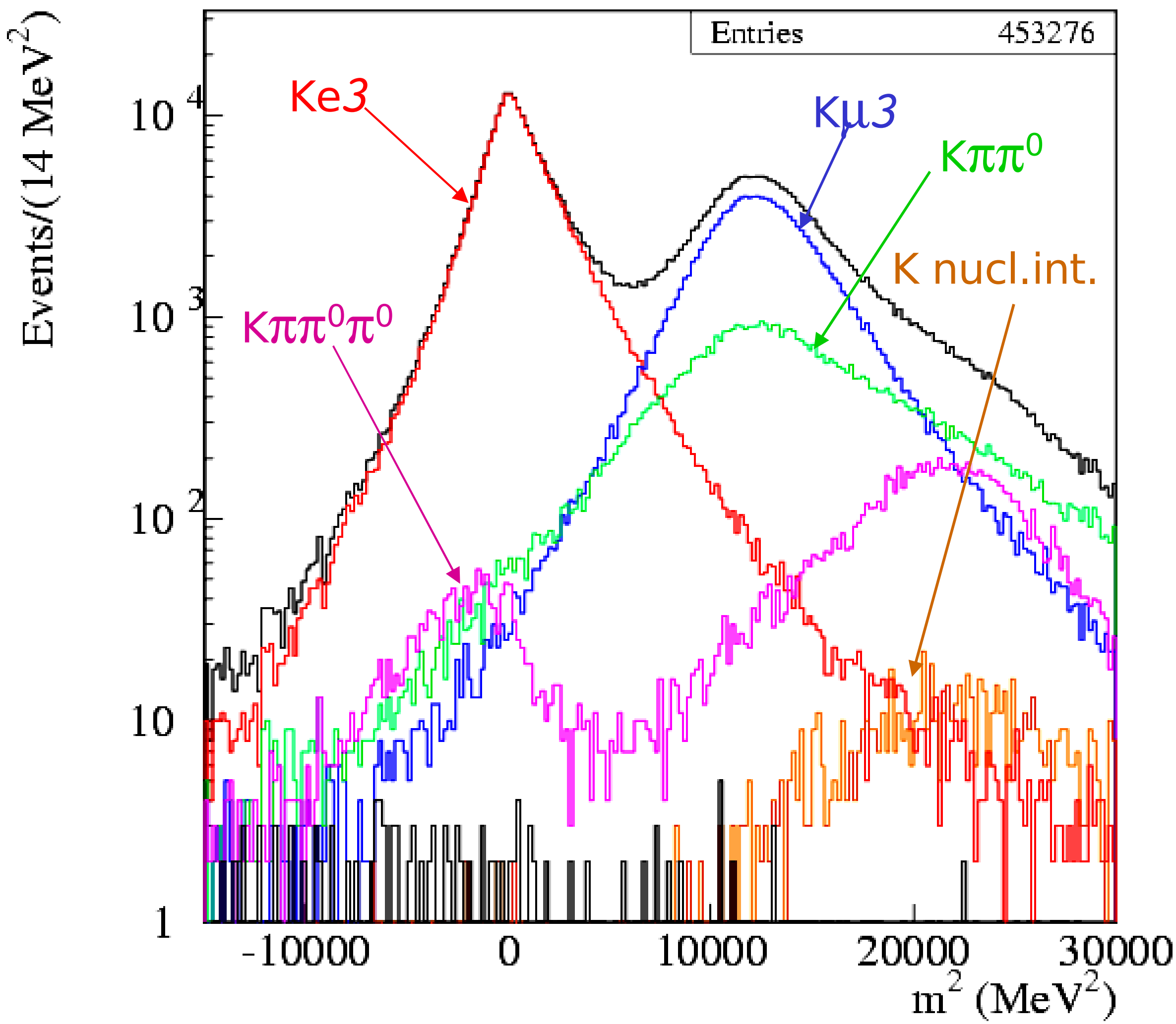
Background (I)

$K^\pm \to \pi^\pm \pi^0 \pi^0$ with a π^0 undergoing a Dalitz decay, or with a wrong cluster associated to $\pi^\pm$, give a m_l^2 under the Ke3 peak

$\Rightarrow$ cut requiring $(E_{miss} - P_{miss}) < 90$ MeV

$K^\pm \to \pi^\pm \pi^0$ with early $\pi^\pm \to \mu^\pm \nu$, give m_l^2 under the Kμ3 peak

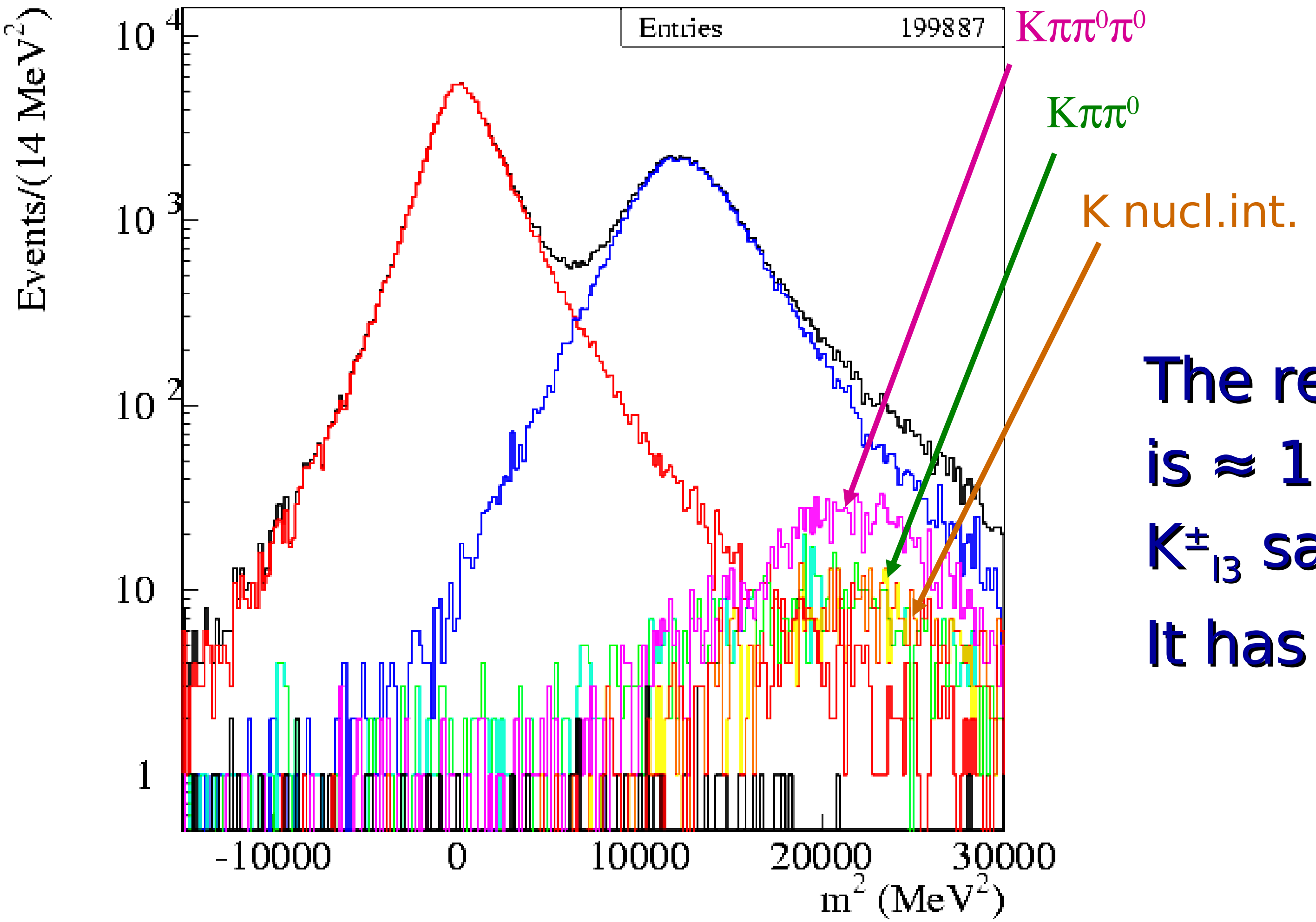
$\Rightarrow$ rejected using the missing momentum of the secondary track in the pion rest frame ($P^*_{sec} < 90$ MeV)



Background (II)

The cuts reject ≈ 96% of the background events

The efficiency on the signal is ≈ 50% for both K_{e3} and $K_{\mu3}$

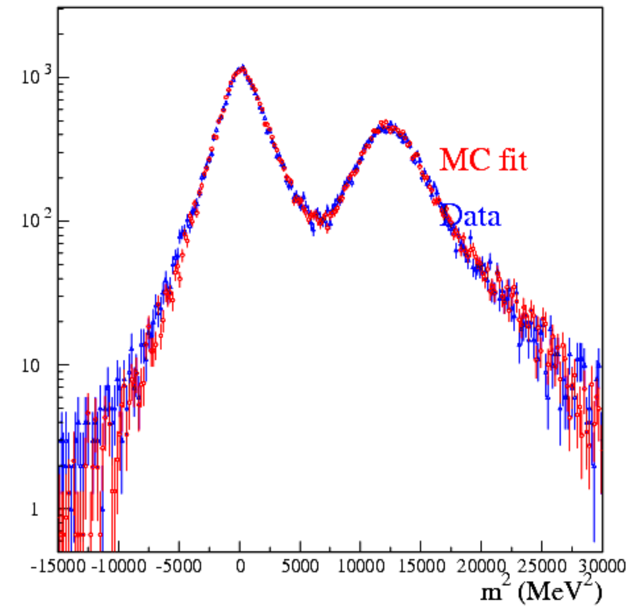


The residual background is ≈ 1.5% of the selected $K^{\pm}_{l3}$ sample.

It has $m_{lept}^2 \approx m_\pi^2$

Event counting

Fit m^2_{lept} spectrum with linear combination of Ke3 , Kμ3 shapes, and bck contribution. Average of the four data samples.



Preliminary

$$BR(K^{\pm} \rightarrow \pi^0 e^{\pm} \nu_e) = (5.047 \pm 0.046)\%$$

$$BR(K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu_{\mu}) = (3.310 \pm 0.040)\%$$

- **Fractional accuracy:**

  0.9% for K_{e3} and 1.2% for $K_{\mu 3}$

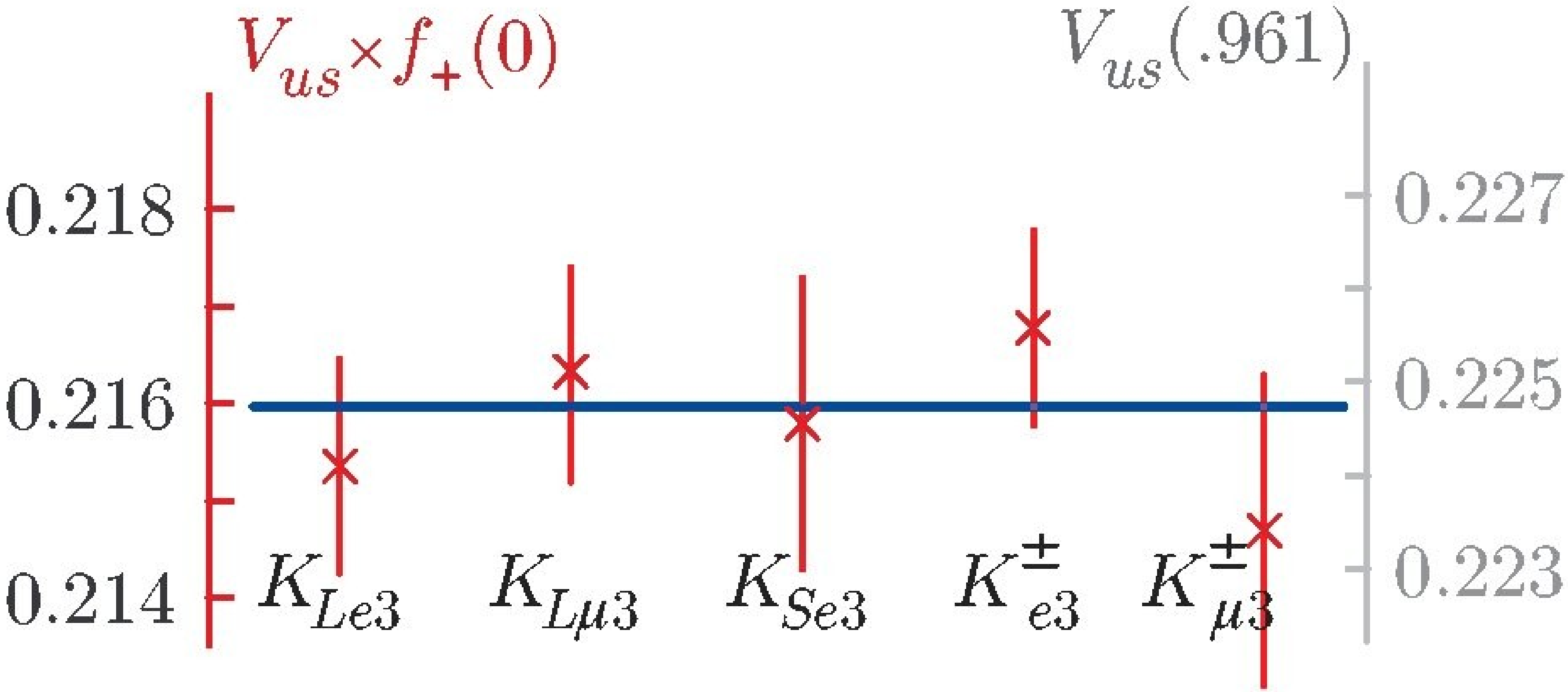
- **Systematic error studies to be completed**
- Dominated by the **knowledge of selection efficiency**

V_{us} from semileptonic decays

$$\tau(K_L) = 50.84 \pm 0.23 \text{ ns}$$

$$\langle V_{us} \times f_+(0) \rangle_{\text{KLOE}} = 0.2160 \pm 0.0005$$

$$\chi^2/\text{dof} = 1.9/4$$



from V_{ud} and unitarity: $V_{us} \times f_+(0) = 0.2187 \pm 0.0022$

Measurement of the charged kaon lifetime

Two different methods to measure τ:

#1: using K decay length

#2: using K decay time

Allow cross check of systematics.

Method #1: using K decay length

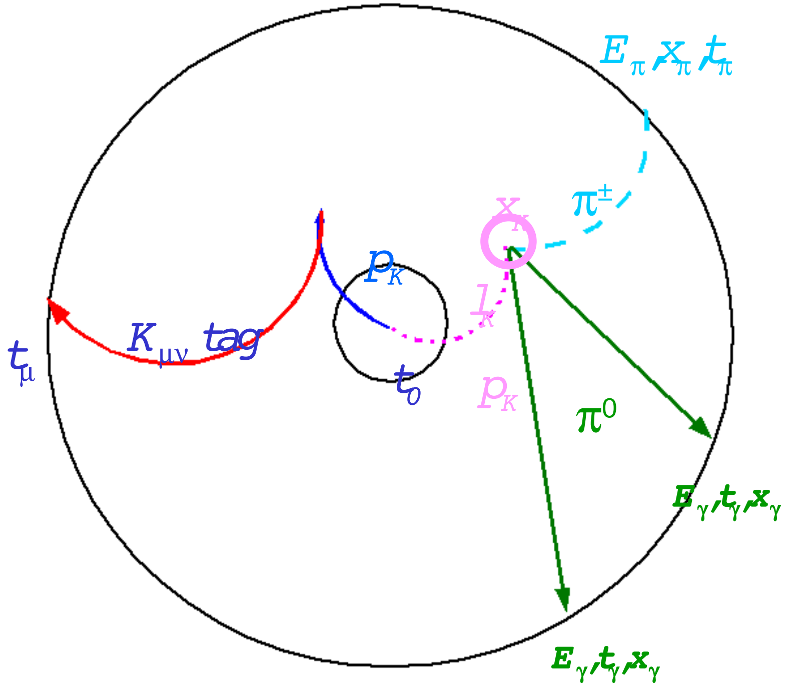
- $K^\pm \to \mu^\pm \nu$ self-triggering tag
- Signal K decay vertex (using DC only)
- Signal K track extrapolated backwards to the IP
- de/dx taken into account $\Rightarrow$ 2mm step

$$\Delta T = \sum_i \Delta T_i = \sum_i \frac{\sqrt{1-\beta^2}}{\beta} \Delta l_i$$

- Efficiency evaluated directly on data

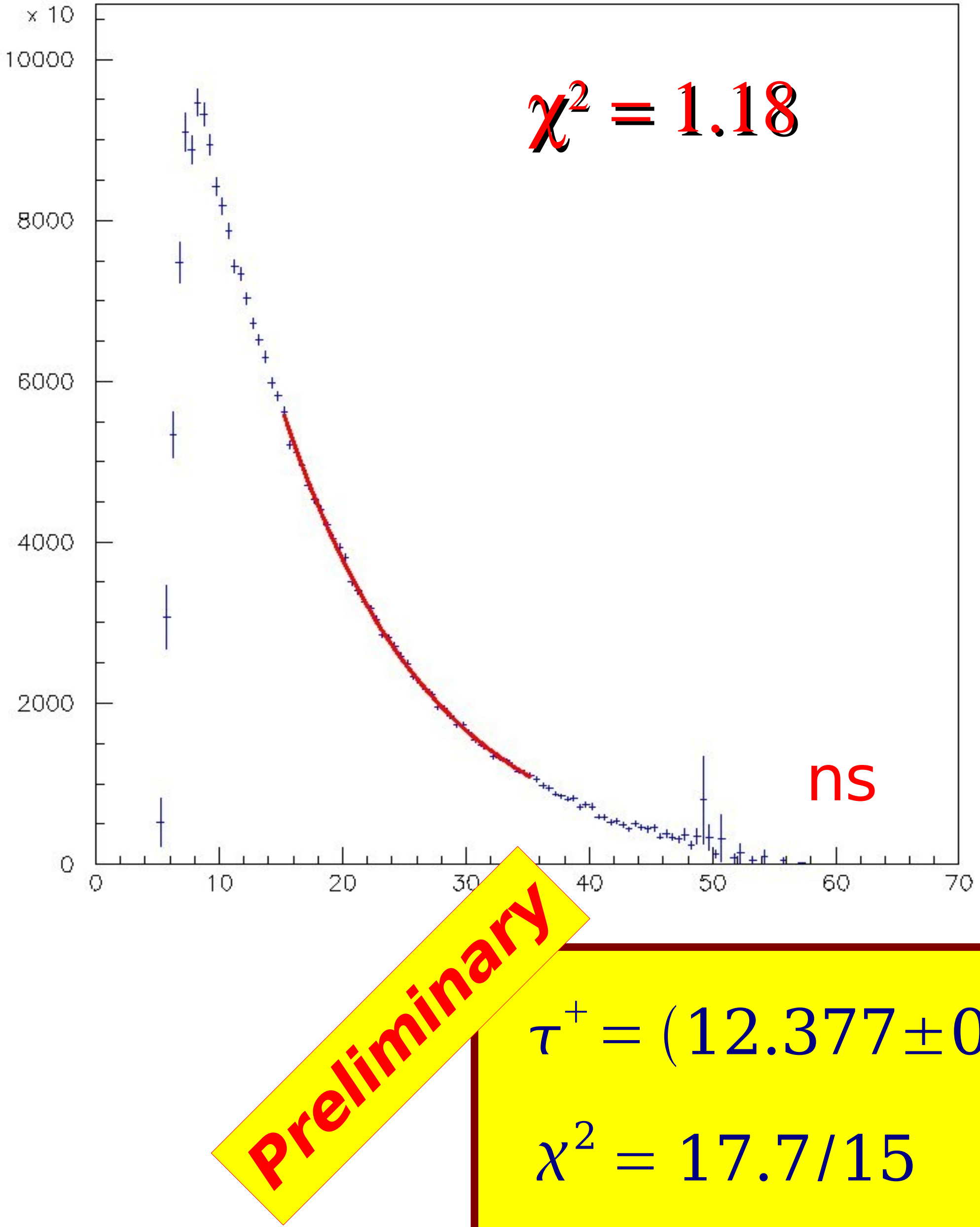
$\varepsilon_{trk+vtx}$ evaluation

- Efficiency has been evaluated directly on data
- Look for a charged vertex on a sample selected requiring a neutral vertex
- Neutral vertex from timing of the neutral clusters fired by the γs from the π^0 decay



$$\epsilon_{DATA} = \frac{DC\ vtx\,(K \to X) \in FV}{\pi^0\ vtx\,(K \to X\pi^0) \in FV}$$

Proper time fit



The proper time is fitted together with the efficiency and taking into account resolution effects too

Fit between 16 and 30 ns

$$\tau^+ = (12.377 \pm 0.044 \pm 0.065)\ ns$$

$$\chi^2 = 17.7/15 \qquad P(\chi^2) = 28.4\%$$

Two different methods to measure τ:

#1: using K decay length

#2: using K decay time

Allow cross check of systematics.

Method #2: using K decay time

- $K^{\pm} \to \mu^{\pm}\nu$ self-triggering tag
- Tag K track extrapolated backwards to the IP
- Second kaon helix extrapolated forwards
- Step along the helix looking for a π^0 decay vertex
- For each photon:

$$\tau = \left(t_{\gamma} - \frac{r_{\gamma}}{c} - t_{\phi} \right) \cdot \sqrt{1 - \beta_K^2}$$

$K^{\pm}$ at KLOE - summary

Absolute BR($K^+ \rightarrow \mu^+\nu(\gamma)$) with 0.27% accuracy

Phys.Lett.B 632:76-80,2006

$K^{\pm} \rightarrow \pi^0 l^{\pm} \nu_l$ absolute branching ratios and lifetime:

preliminary results

BR($K^{\pm} \rightarrow \pi^{\pm} \pi^0$) finalizing

Using 2 fb^{-1} collected KLOE will be able to measure:

$K^{\pm} \rightarrow \pi^0 l^{\pm} \nu_l$ form factors, BR($K^{\pm} \rightarrow \pi^0 \pi^0 l^{\pm} \nu_l$)

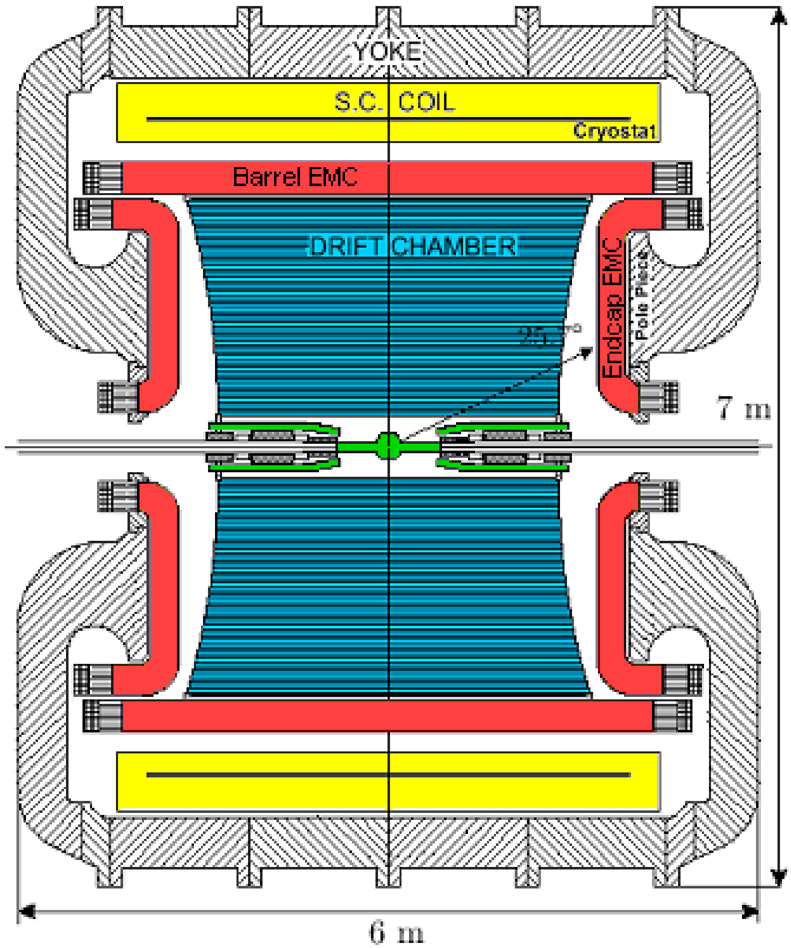
and the ratio BR($K \rightarrow e\nu$)/BR($K \rightarrow \mu\nu$) for e-μ universality

About 5×10^4 Ke2 events produced with 2fb^{-1}

Spare slides

KLOE detector

The KLOE design was driven by the measurement of direct CP parameter ε'/ε



Beam pipe (spherical, 10 cm ∅, 0.5 mm thick) + **instrumented permanent magnet quadrupoles** (32 PMT's)

Drift chamber (4 m ∅ × 3.75 m, CF frame)

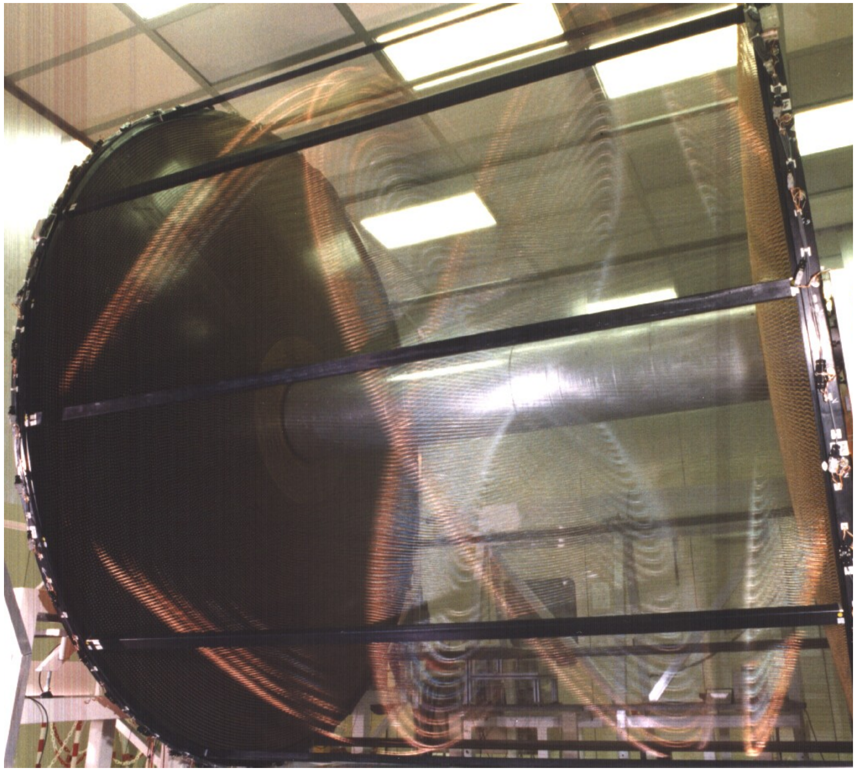
- Gas mixture: 90% He + 10% C_4H_{10}
- 12582 stereo–stereo sense wires
- almost squared cells

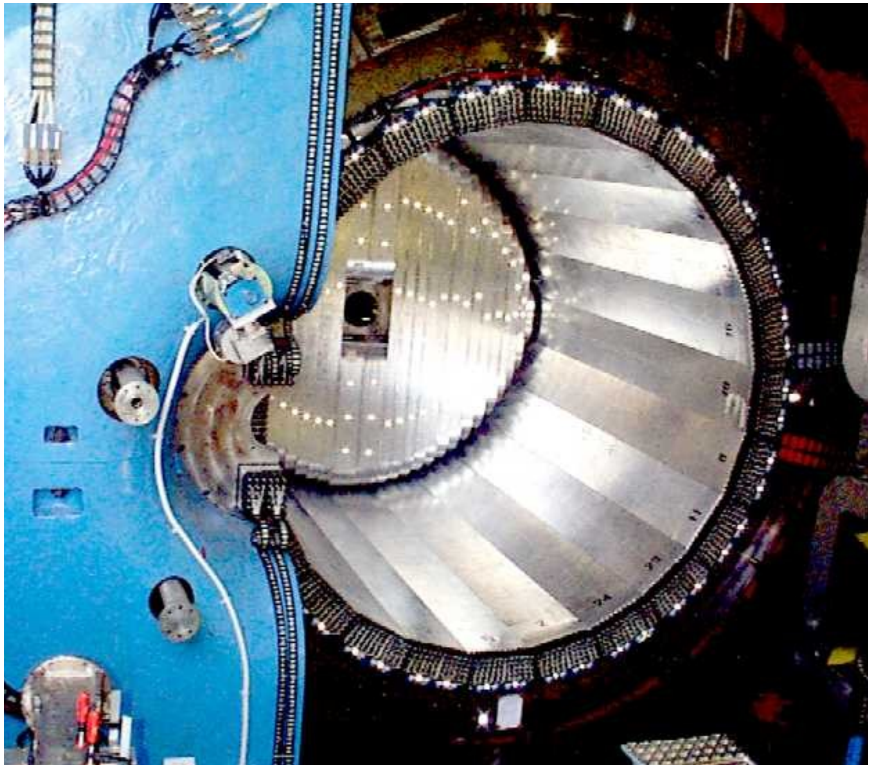
Electromagnetic calorimeter

- lead/scintillating fibers (1 mm ∅), 15 X_0
- 4880 PMT's
- 98% solid angle coverage

Superconducting coil (B = 0.52 T)

KLOE detector





$\sigma_p/p = 0.4\ \%$

(tracks with $\theta > 45°$)

$\sigma_x^{hit} = 150\ \mu m$ (xy), 2 mm (z)

$\sigma_x^{vertex}\ \sim 1$ mm

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$

$\sigma_t = 54$ ps $/\sqrt{E(GeV)} \oplus 50$ ps

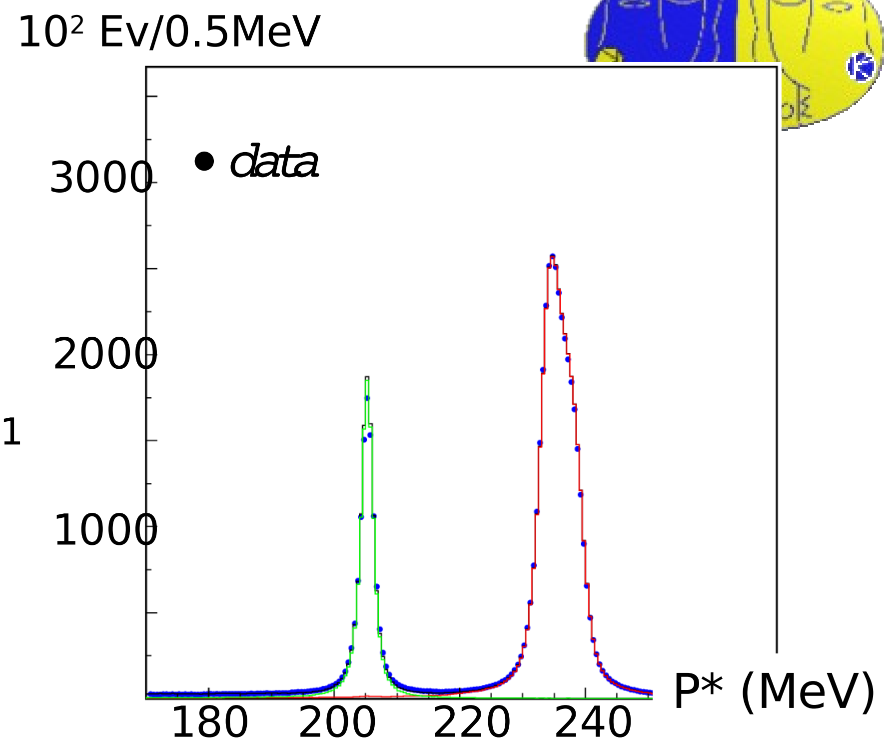
$\sigma_{vtx}(\gamma\gamma) \sim 1.5$ cm

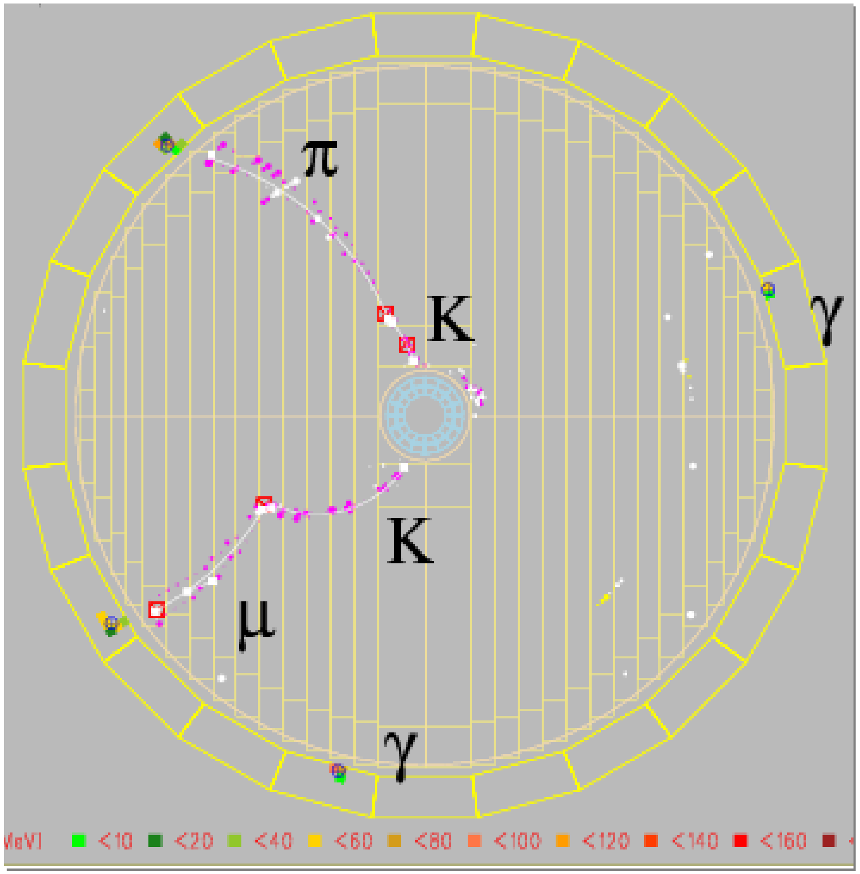
(π^0 from $K_L \rightarrow \pi^+\pi^-\pi^0$)

Tag mechanism (I)

$K^{\pm}$ events tagged using two body decays (about 85%):

$K^{\pm} \rightarrow \mu^{\pm} \nu$, $\pi^{\pm} \pi^{0} \approx 1.5 \times 10^{6}$ $K^{+}K^{-}$ ev/pb^{-1}





Two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame $P^*(m_\pi)$

$$\epsilon_{TAG} \simeq 36\% \Rightarrow \begin{array}{l} \simeq 3.4\times10^{5}\ \mu\nu\ \ tags/pb^{-1} \\ \simeq 1.1\times10^{5}\ \pi\pi^{0}\ \ tags/pb^{-1} \end{array}$$

Tag mechanism (II)

To minimize the impact of the trigger efficiency on the signal side we restrict our normalization sample N_{TAG} to 2-body decays which provide themselves the Emc trigger of the event:

self-triggering tags

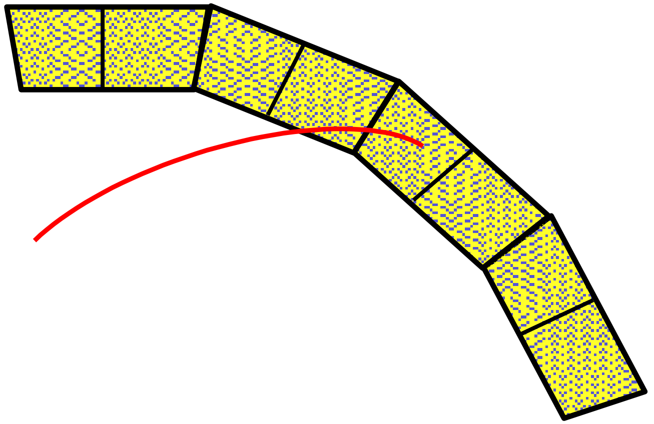
Emc trigger: 2 trigger sectors over threshold ~50 MeV

The μ fires two sectors:

$\varepsilon_{Trigger}$ ~ 35%

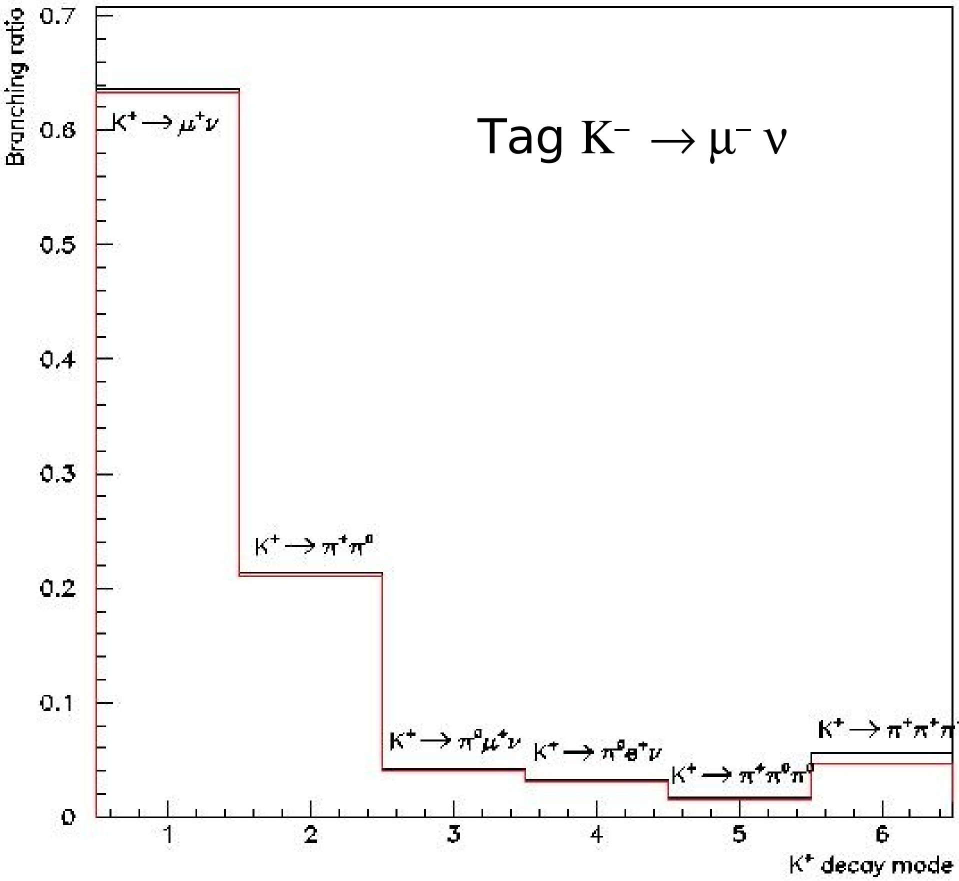
The photons from the π^0 fire two sectors

$\varepsilon_{Trigger}$ ~ 75%



Tag bias

Measuring the BRs we must take into account a correction due to the bias on the signal sample induced by the tag selection **Tag bias**



The correction $\mathbf{C_{TB}}$ is evaluated from MC and is given by:

$$C_{TB} = BR_{MC}(\text{with tag}) \,/\, BR_{MC}(\text{without tag})$$

$K^+ \to \mu^+ \nu(\gamma)$

- Signal given by K^+ decay in the DC FV (40 cm < ρ < 150 cm)
  Using ~60 pb^{-1}
- Background given by events with π^0 in the final state:

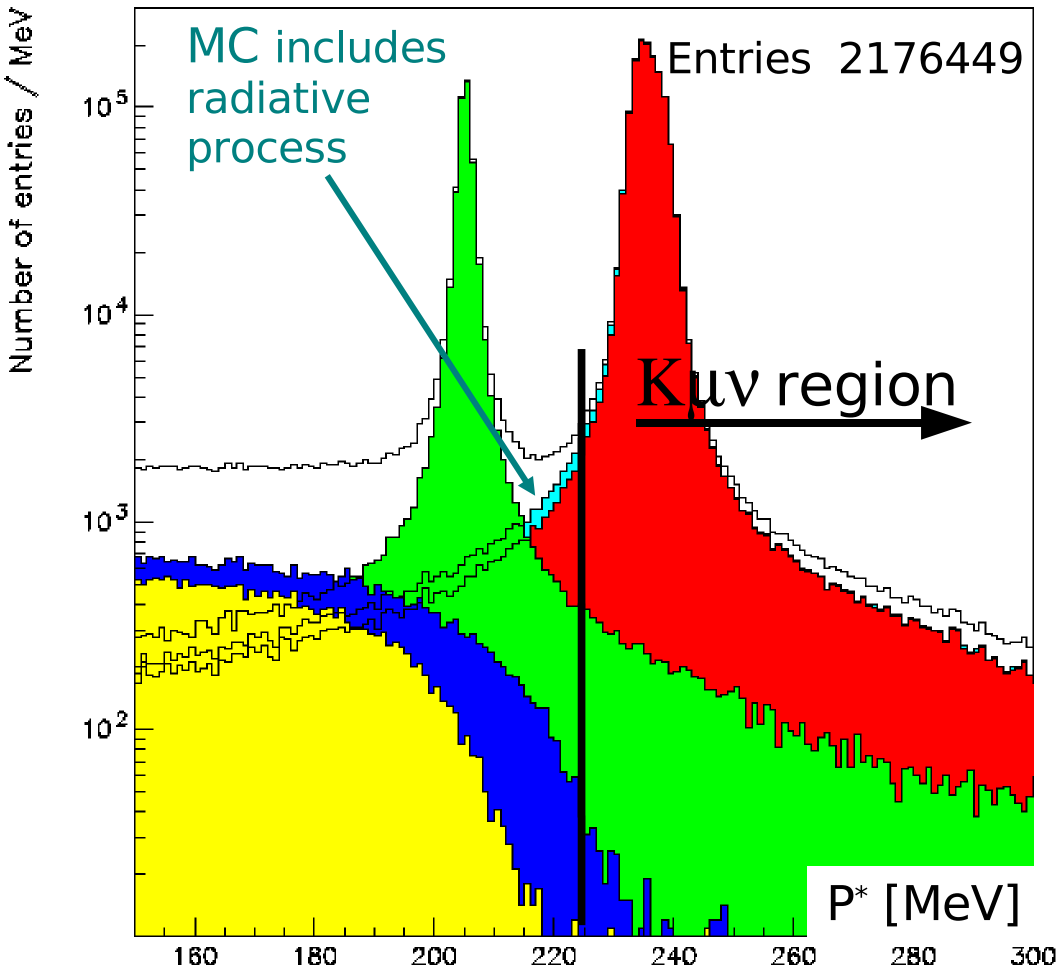
$K^+ \to \pi^+ \pi^0$ $\quad$ $K^+ \to \pi^0 e^+ \nu_e$

$K^+ \to \pi^0 \mu^+ \nu_\mu$

$$BR = \frac{N_{K\mu\nu(\gamma)}}{N_{TAG}} \cdot \frac{1}{\epsilon_{DC}} \cdot \frac{1}{C_{TB}}$$

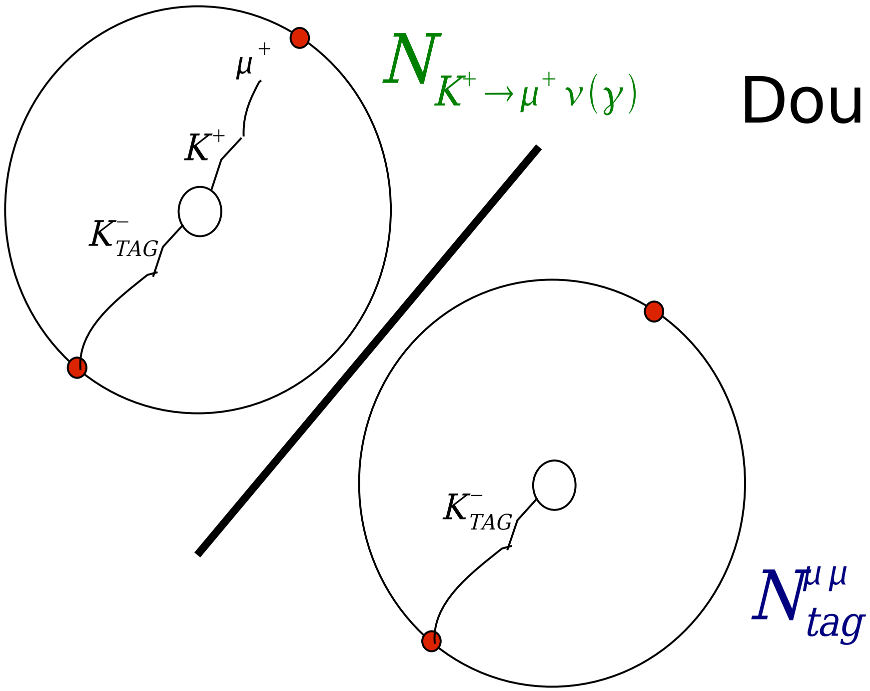
Tag bias estimated from MC:

C_{TB} = 1.0164 +/- 0.0002



ε_{DC} evaluation

Efficiency evaluated on ~*115 pb*$^{-1}$ sample



Double $K\mu\nu$ events selected using Emc

1) Self-triggering $K^- \rightarrow \mu^- \nu$ tag

2) Ask for:

- 1 cluster with $80 < E_{CLU} < 320$ MeV
- no cluster with $20 < E_{CLU} < 80$ MeV

3) No requirements for

$E_{CLU} < 20$ MeV

Low E radiative γ

$$\epsilon_{DC} = \epsilon_{DATA} \times C_{MC}$$

$$C_{MC} = \frac{\epsilon_{MC\ \ True}}{\epsilon_{MC\ \ recon.}}$$

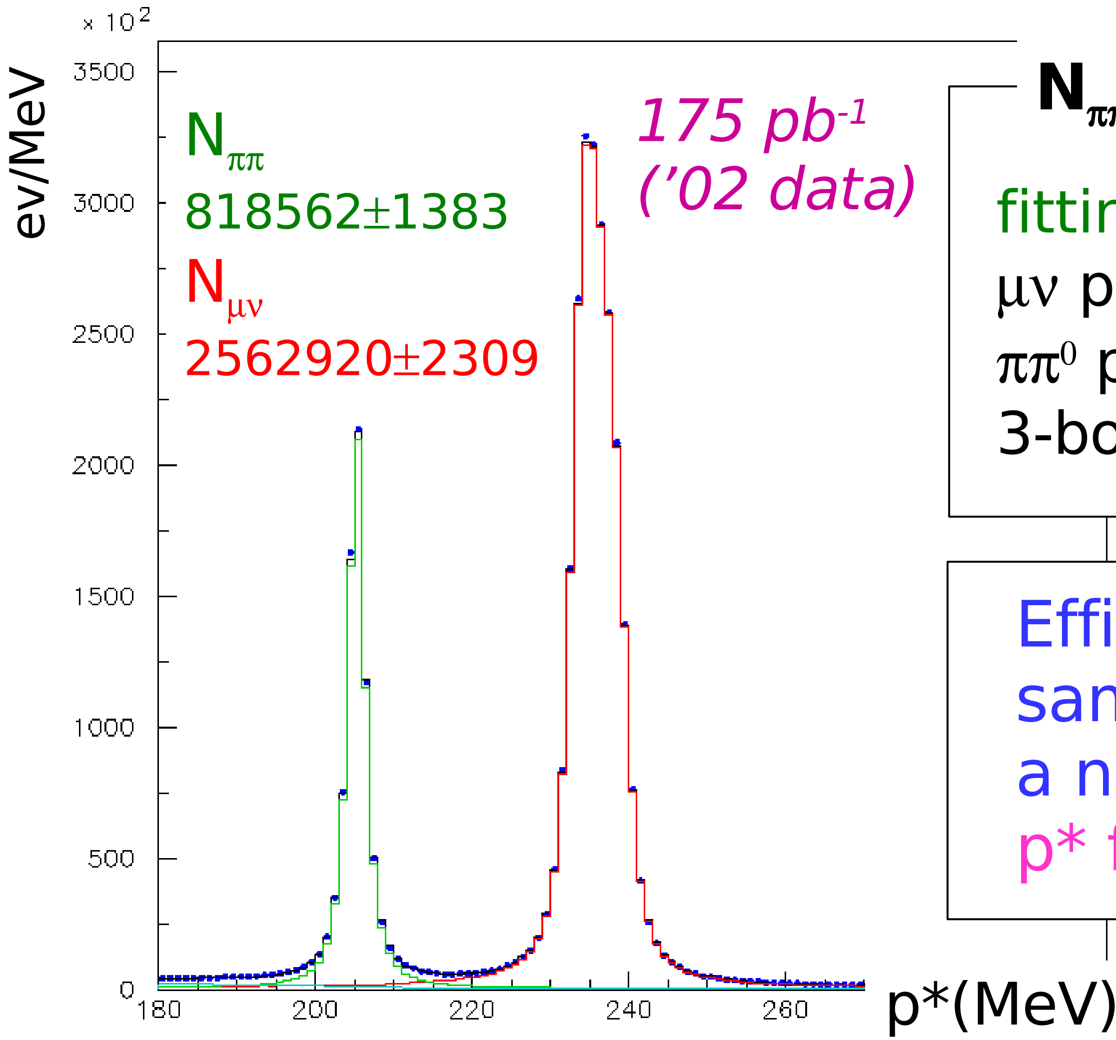
$K^{\pm} \to \pi^{\pm} \pi^{0}$

- Normalization N_{TAG} given by 175 pb^{-1} from 2002's data

  selftriggering $K^{-} \to \mu^{-} \overline{\nu}$
- Counting events in the distribution of secondary track momentum in the kaon rest frame p*
- Fit together signal and backgrounds Km2 and 3-bodies

- Efficiency related to DC reconstruction only (tracking plus vertexing), evaluated on data

$K^{\pm} \to \pi^{\pm} \pi^{0}$



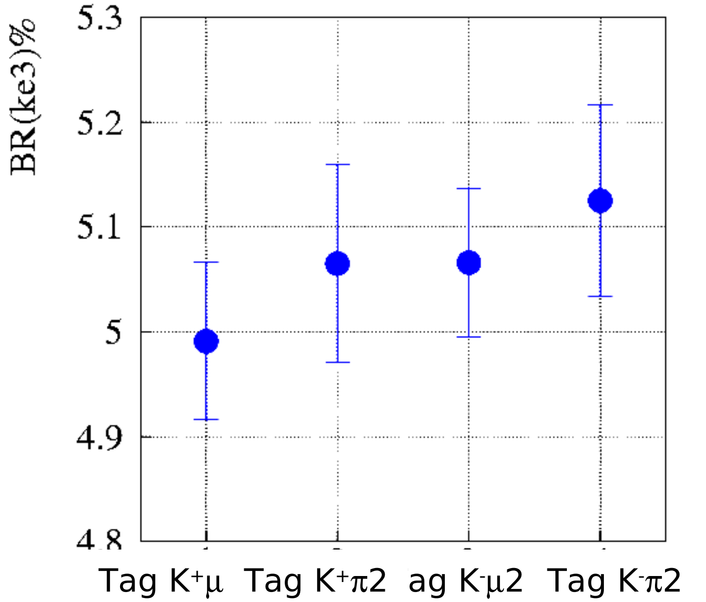
$N_{\pi\pi}$ |FIT

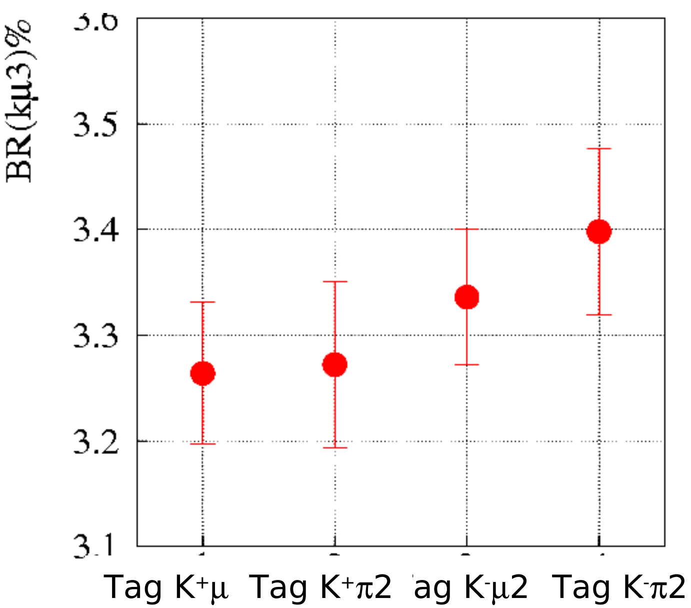
fitting the p* distribution with
$\mu\nu$ peak from EMC sample
$\pi\pi^0$ peak requiring the π^0
3-body decays from MC

Efficency evaluated on a sample selected requiring a neutral vertex
p* fit cut at 180 MeV/c

Status: finalizing

Kl3 preliminary results





- Averages accounting for correlations:

BR(Ke3)	**5.047** ± **0.046**
BR(Kμ3)	**3.310** ± **0.040**

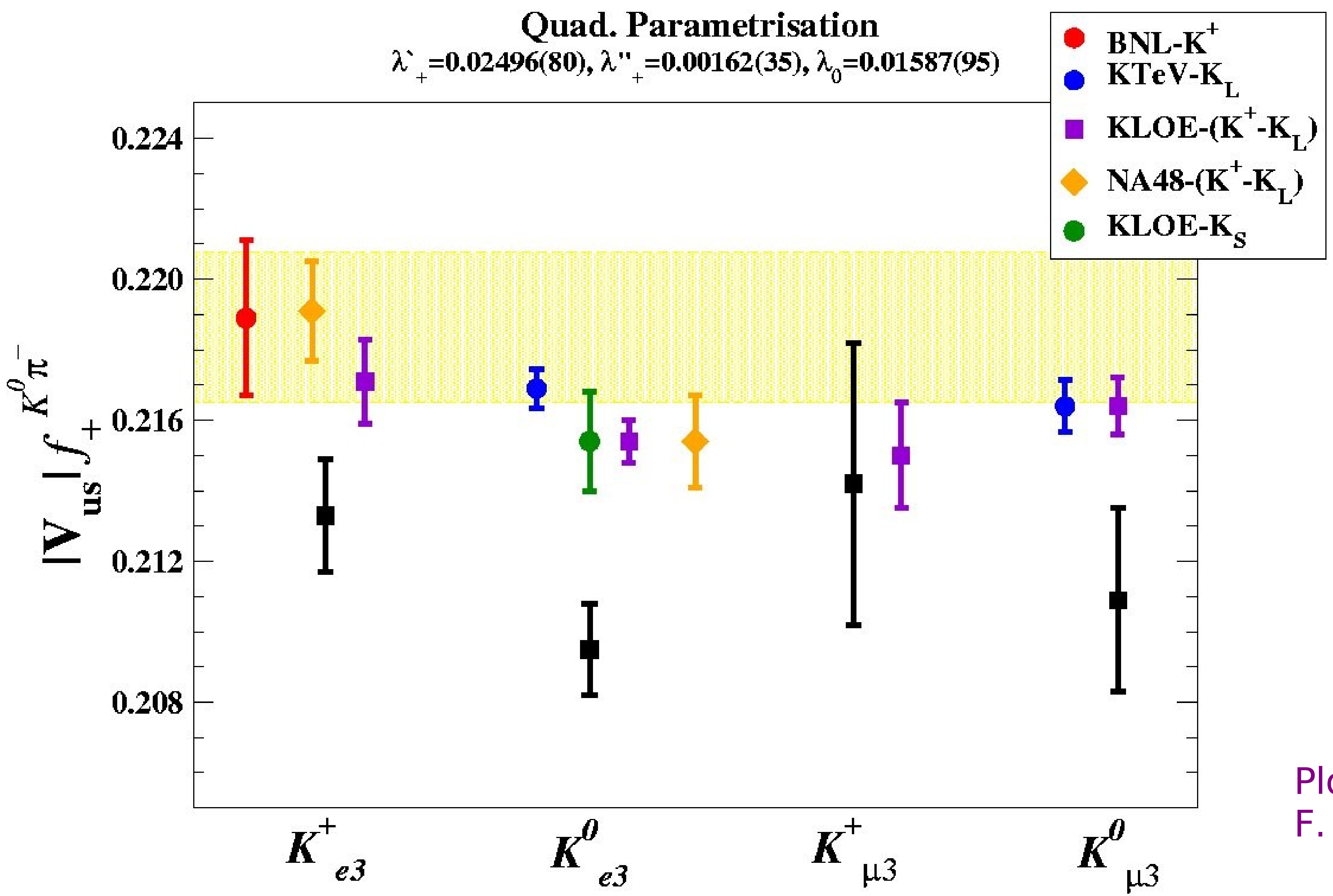
- χ^2/dof for the 4 measurements:

$$Ke3: \quad \chi^2/dof = 3.20/3 \rightarrow P(\chi^2) \simeq 36\%$$
$$K\mu 3: \quad \chi^2/dof = 5.32/3 \rightarrow P(\chi^2) \simeq 15\%$$

- The **error accounts for** the data and Monte Carlo statistics used in the fit, the MC statistics for the efficiency evaluation, the Data/MC efficiency corrections, and the systematics on the tag selection. It is dominated by the error on Data/MC efficiency correction.

- Still to be evaluated the systematics due to the signal selection efficiency, to the nuclear interaction, and to the momentum dependency of the tracking efficiency

V_{us} from semileptonic decays



Plot by
F. Mescia

V_{us} from semileptonic decays

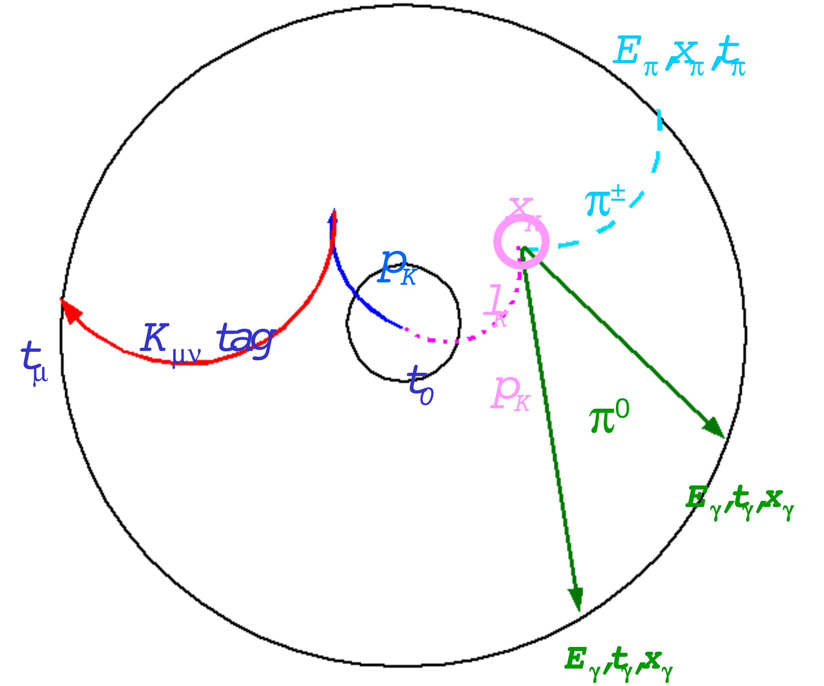
- KLOE τ_L = 50.84(23) ns
  Five KLOE BR(Kl3)
  Form factors quad. param.
  $\lambda_0 = 0.01587(95)$
  $\lambda'_+ = 0.02496(80)$
  $\lambda''_+ = 0.00162(35)$ → $V_{us} \times f_+(0) = 0.2169(5)$

- KLOE + PDG τ_L = 50.99(20) ns
  All available BRs
  Form factors quad. param. → $V_{us} \times f_+(0) = 0.2164(4)$

- Imposing unitarity
  f+(0) = 0.961(8) (Leutwyler, Roos)
  Vud = 0.97377(27) (Marciano) → $V_{us} \times f_+(0) = 0.2187(22)$

$\varepsilon_{trk+vtx}$ evaluation

The K track on the tagging side is extrapolated backwards to the signal hemisphere



Step along the extrapolated kaon looking for the best neutral vertex

Using timing of the neutral clusters fired by the γs from the π^0 decay

$$\epsilon_{DATA} = \frac{DC\ vtx\,(K \to X) \in FV}{\pi^0\ vtx\,(K \to X\pi^0) \in FV}$$

FV $\equiv$ 40 cm $\leq \rho \leq$ 150 cm

$$BR(K \rightarrow e\nu)/BR(K \rightarrow \mu\nu)$$

- Extremely well known within SM:

  R_K^{SM} = (2.472±0.001)x10^{-5}

- Probe μ-e universality:

  non-universal terms from LFV sources in SUSY extensions

- *At KLOE the measurement is extremely challenging,*

  especially the PID due to huge Kμ2 background O(4x10^4)

- *Produced about 5 x 10^4 events with 2fb^{-1}*