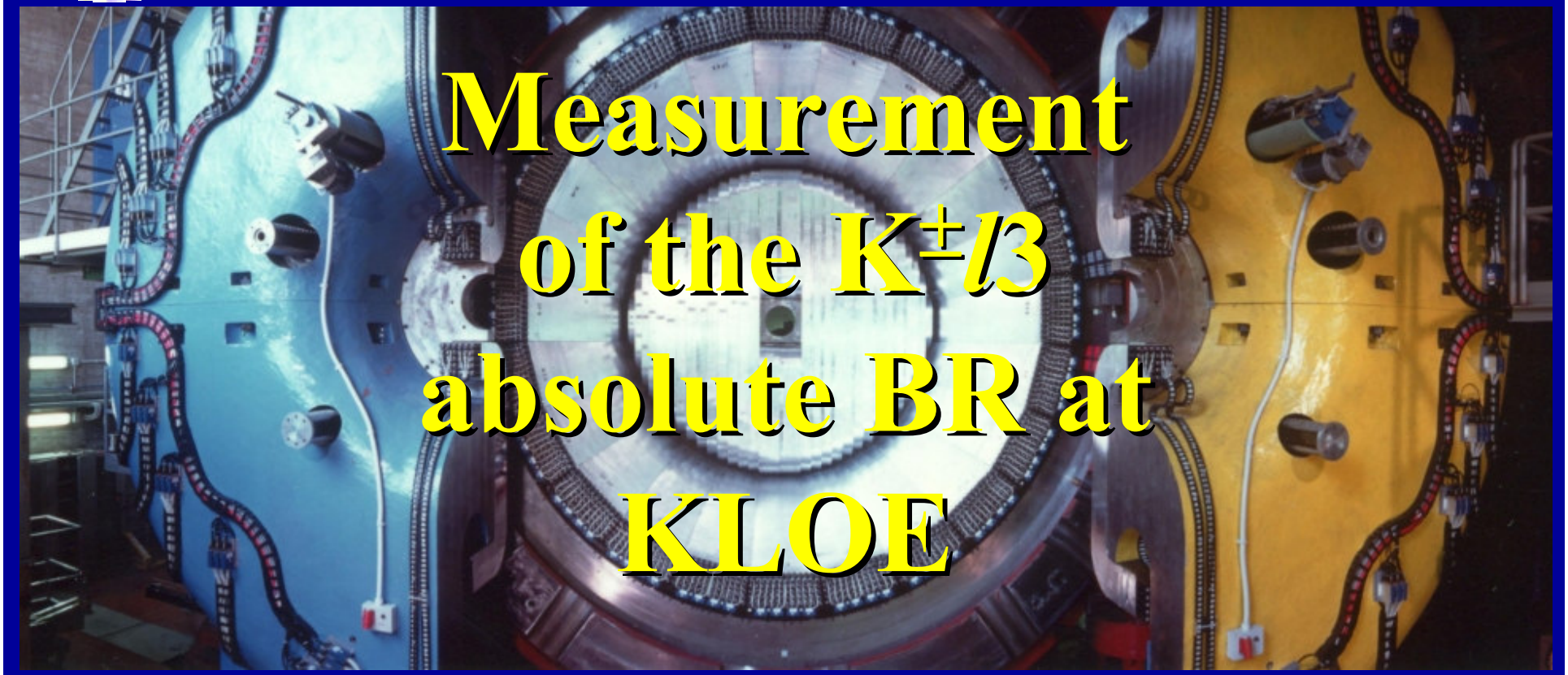
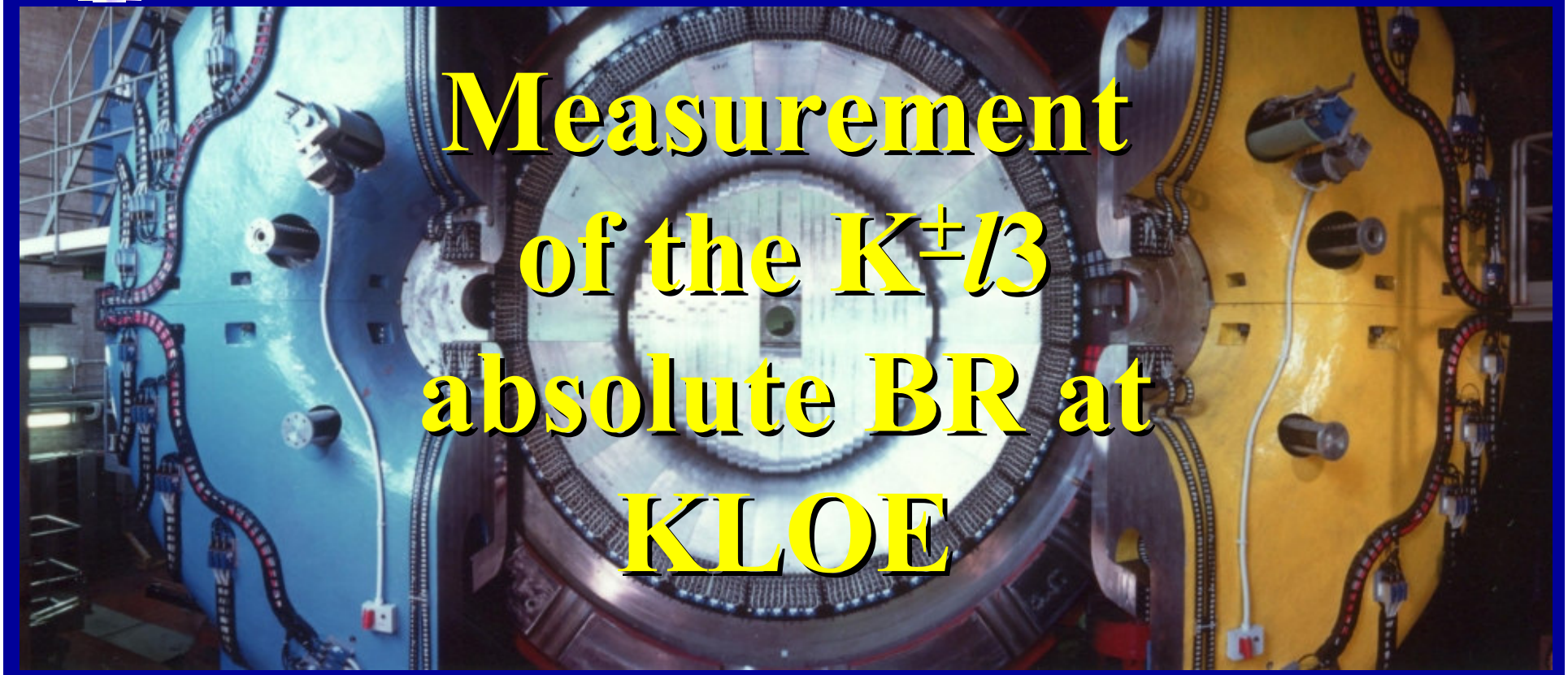


Measurement of the $K^{\pm}l3$ absolute BR at KLOE

B. Sciascia, LNF INFN
for the KLOE collaboration

Kaon 07
Frascati, 21 May 2007



Measurement of the $K^{\pm}l3$ absolute BR at KLOE

Outline:

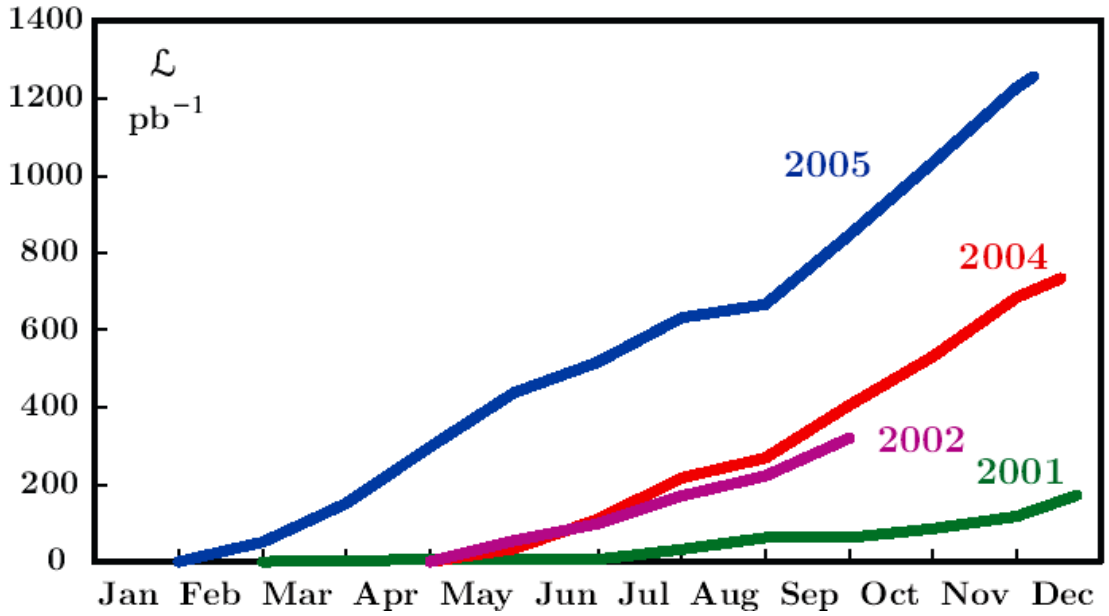
- The KLOE detector at DaΦne
- Measurement of absolute $K^{\pm}l3$ branching ratios
- V_{us} with KLOE BR results

The DAΦNE e^+e^- *collider*

- Collisions at c.m. energy around the ϕ mass: $\sqrt{s} \sim$ **1019.4 MeV**
- Angle between the beams at crossing: $\alpha_{crs} \sim$ **12.5 mrad**
- Residual laboratory momentum of ϕ: $p_\phi \sim$ **13 MeV/c**
- Cross section for ϕ production @ peak: $\sigma_\phi \sim$ **3.1 μb**

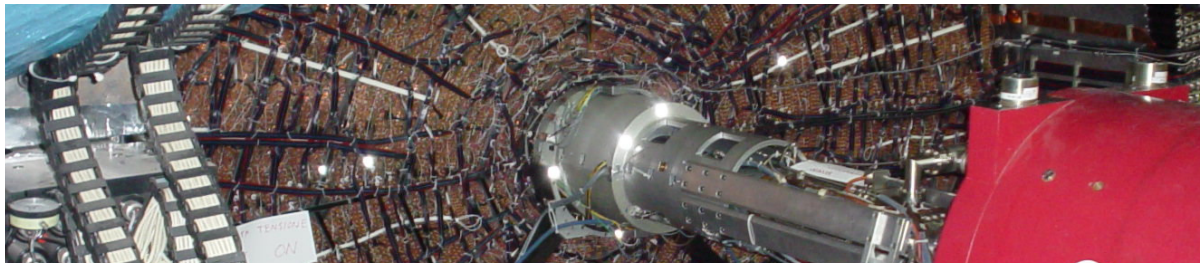
Grand total (2001/5):
$\int \mathcal{L} = 2.5\ fb^{-1}$.
$\mathcal{L}_{peak} = 1.3 \times 10^{32}\ cm^{-2}s^{-1}$.

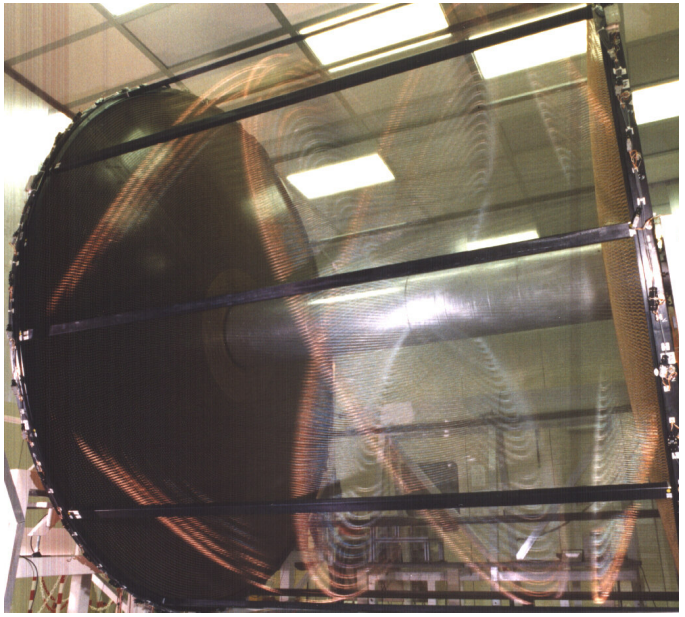
Results presented in this talk from 2001/2 data: $\int \mathcal{L} = 450\ pb^{-1}$.



The KLOE detector

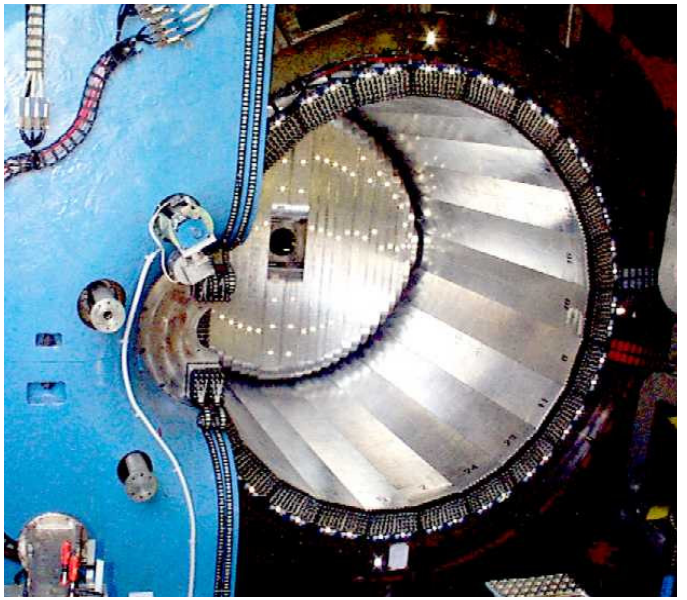
- Large cylindrical drift chamber
- Lead/scintillating-fiber calorimeter.
- Superconducting coil: 0.52 T field.





$He/IsoC_4H_{10}$ 90/10 drift chamber
4m–∅, 3.75m–length, all-stereo
$\sigma_p/p = 0.4$ % (tracks with $\theta > 45°$)
$\sigma_x^{hit} = 150$ μm (xy), 2 mm (z)
$\sigma_x^{vertex} \sim 1$ mm

Lead-Scintillating fiber calorimeter
$\sigma_E/E = 5.7\% /\sqrt{E(GeV)}$
$\sigma_t = 54$ ps $/\sqrt{E(GeV)} \oplus 100$ ps
(relative time between clusters) PID capabilities
$\sigma_L(\gamma\gamma) \sim 2$ cm (π^0 from $K_L \to \pi^+\pi^-\pi^0$)



K physics at KLOE - tagging

K_SK_L (K^+K^-) produced from ϕ are in a pure $J^{PC} = 1^{--}$ state:

$$K_S, K^+ \longleftarrow \phi \longrightarrow K_L, K^-$$

$$\frac{1}{\sqrt{2}}\left(|K_L,\mathbf{p}\rangle|K_S,-\mathbf{p}\rangle - |K_L,-\mathbf{p}\rangle|K_S,\mathbf{p}\rangle\right)$$

ϕ decay mode	BR
K^+K^-	**49.1%**
K_SK_L	**34.1%**

Observation of $K_{S,L}$ signals presence of $K_{L,S}$; $K^{+,-}$ signals $K^{-,+}$

• Allow precise **absolute** branching ratio measurement, by means of a tag technique:

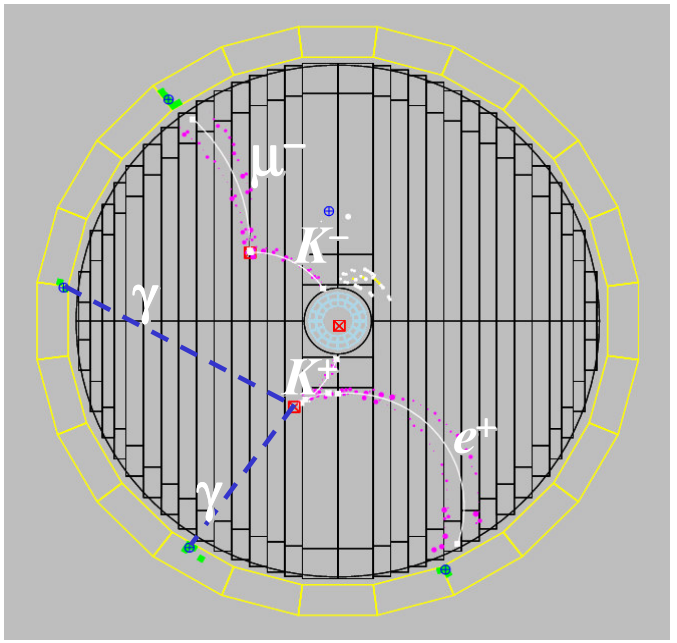
BR = $(N_{sig}/N_{tag})(1/\varepsilon_{sig})$,

• This relies on the capability of selecting a tag kaon independently on the decay mode of the other.

• In fact some dependency on signal mode exists:

BR = (N_{sig}/N_{tag}) $(1/\varepsilon_{sig})$ $(\langle\varepsilon_{Tag}\rangle/\varepsilon_{Tag}(sig))$.

• Tag bias: carefully measured using MC and data control samples.

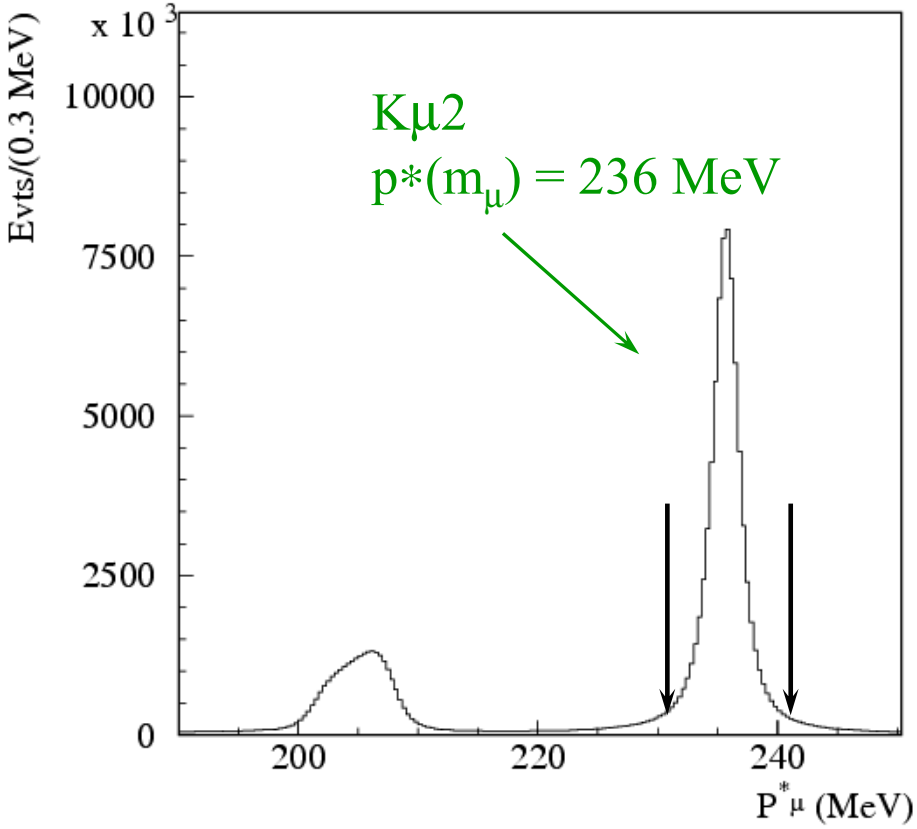


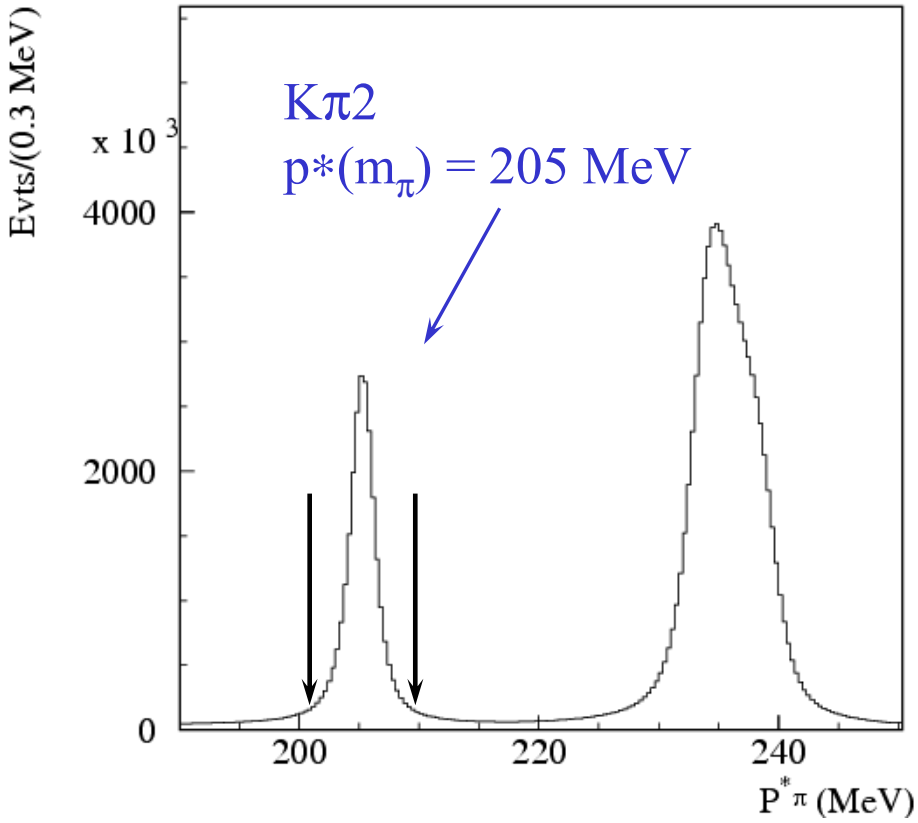
Analysis outline

$$BR(Kl3) = \frac{N(Kl3)}{N_{TAG}\,(1-f_{NI})} \frac{1}{\varepsilon_{FV}} \frac{1}{\varepsilon_{SELE}} \alpha_{TB}$$

- Tag using kaon 2 body decays:
  → 4 independent samples: $\mathbf{K^+\mu 2}$, $\mathbf{K^+\pi 2}$, $\mathbf{K^-\mu 2}$, and $\mathbf{K^-\pi 2}$
  → Keep the systematic effects due to the tag selection under control (Kaon nuclear interaction correction holds for positive tag only).
  → Correct for the tag bias.
- On signal side: selection of semileptonic decays (kinematical cuts to reject dominant backgrounds).
- Obtain number of signal events from a constrained likelihood fit of data distribution.
- Measure selection efficiency on MC and correct for Data/MC differences.
- Perform the BR measurement on each tag sample separately normalizing to tag counts in the same data set.

Tag selection - 1





- Track from IP, momentum cut: 70 MeV≤ p_K ≤ 130 MeV
- Decay vertex in fiducial volume: 40cm ≤ ρ_{VTX} ≤ 150 cm
- 2-body decays identified in kaon rest frame: 3σ cut around p* peak
- For Kπ2 tags, require also π^0 identification.

Tag selection - 2

• To reduce the dependency of the tag selection on signal kaon decay mode, requires the selected tag to satisfy the EMC trigger. For 2001-2002 data set:

Tag	$K^+\mu 2$	$K^+\pi 2$	$K^-\mu 2$	$K^-\pi 2$
N_{TAG}	21 319 804	7 220 354	21 874 232	6 904 949

• Separate measurements for tag channel (Kμ2 and Kπ2) and for charge: allow to keep the systematic effects due to the tag selection under control.

• Measure the dependency of the tag selection efficiency on signal mode using MC. Correct for experimental effects (cosmic veto, machine background filter,…) using MC and downscaled data control samples.

Tag	$K^+\mu 2$	$K^+\pi 2$	$K^-\mu 2$	$K^-\pi 2$
Ke3	0.9694(11)(41)	1.0137(34)(43)	0.9884(10)(38)	1.0328(23)(11)
Kμ3	0.9756(13)(41)	1.0210(36)(44)	0.9963(10)(38)	1.0371(25)(11)

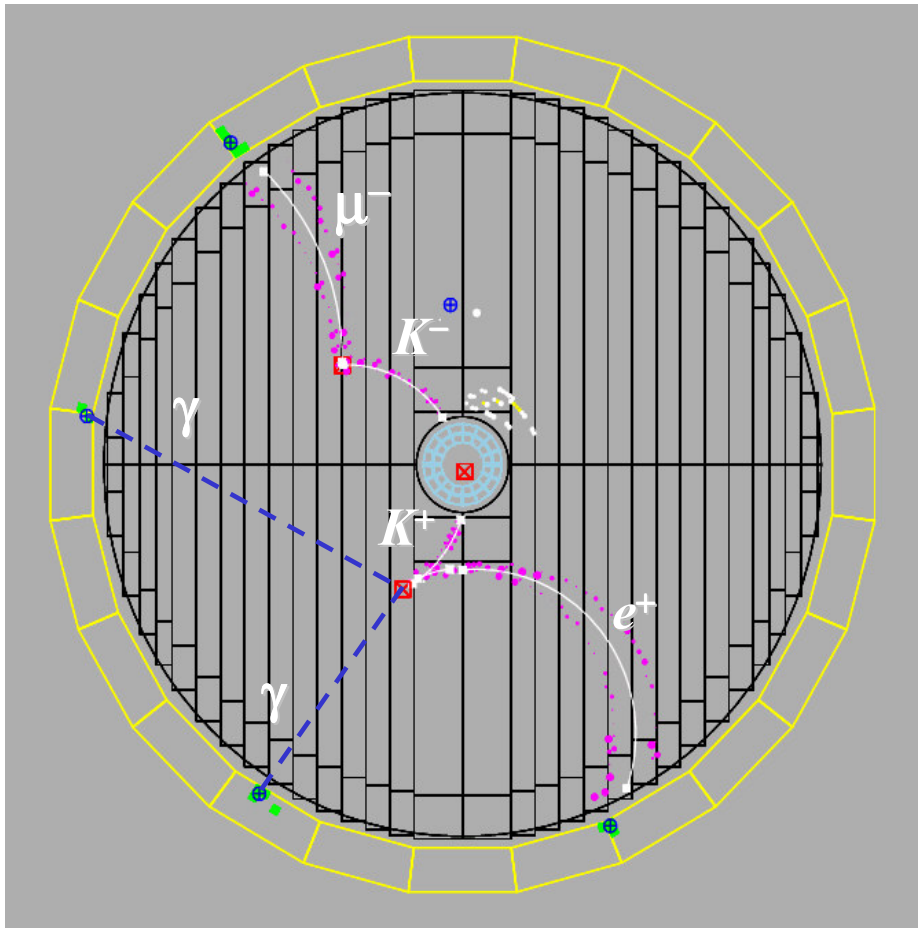
• Corrections range from –3% to +4% following the tag sample.
• For most of the tag bias corrections, the systematic error is the correction itself.

Signal selection

- 1-prong kaon decay vertex in the fiducial volume ($40<\rho_{VTX}<150$ cm).
- Daughter track extrapolated to EMC.
- Search for a π^0: 2 neutral cluster in EMC, with ToF matching the K decay vertex ($\Delta(\delta t)<3\sigma_t$).
- Sample composition: Ke3, Kμ3, and Kπ2.
- Reject the abundant Kπ2 decays:
  $p^*(m_\pi) < 192$ MeV.
- To isolate Ke3 and Kμ3 decays, the lepton is identified by a ToF technique:

$$t^{decay}_K = \langle t_\gamma - L_\gamma/c \rangle = t - L/(\beta c)$$

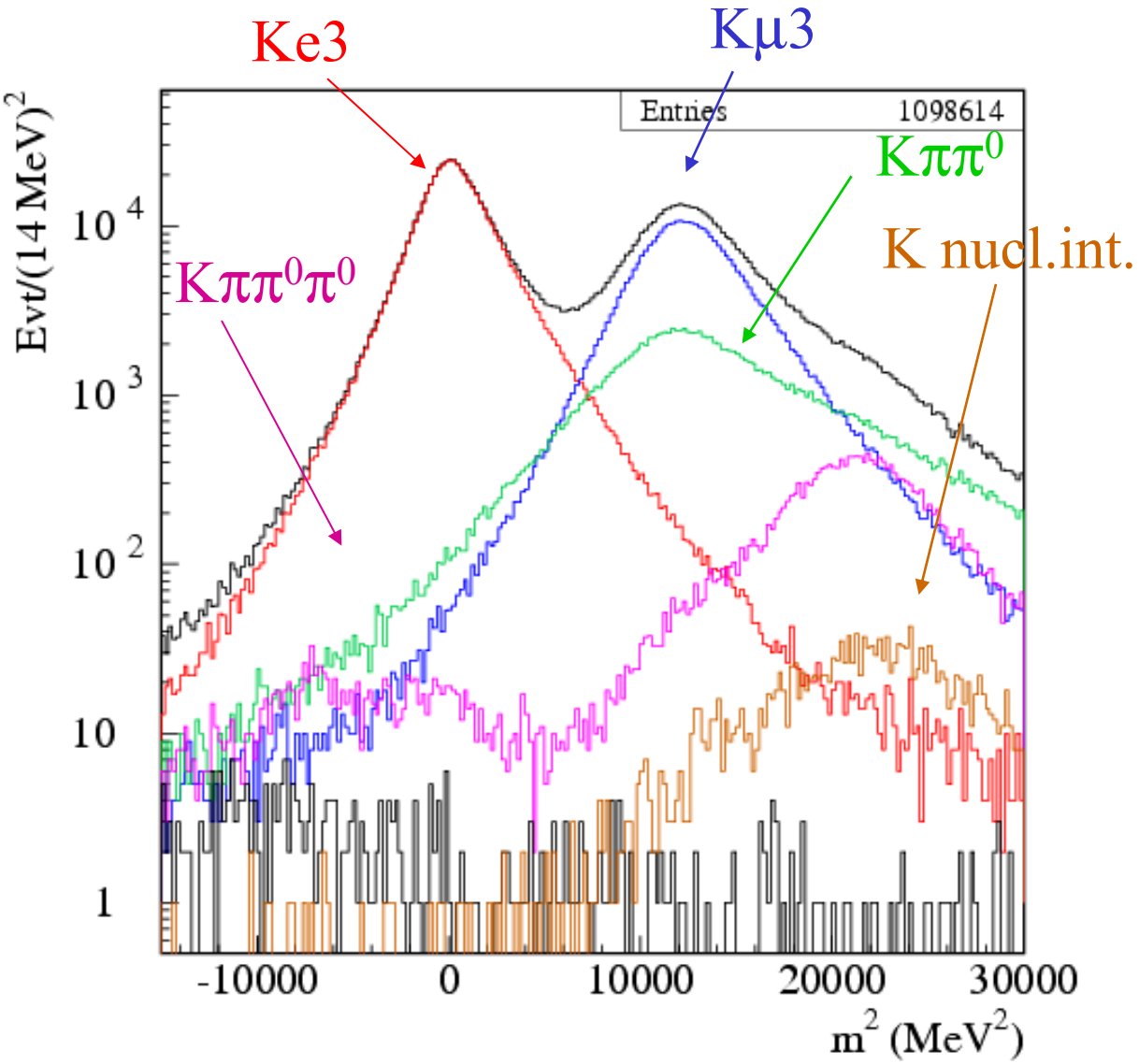
$$(\beta = \mathrm{Sqrt}(p^2 + m_{LEPT}^2)/p)$$



- Spectrum of charged particle mass, m^2_{LEPT}

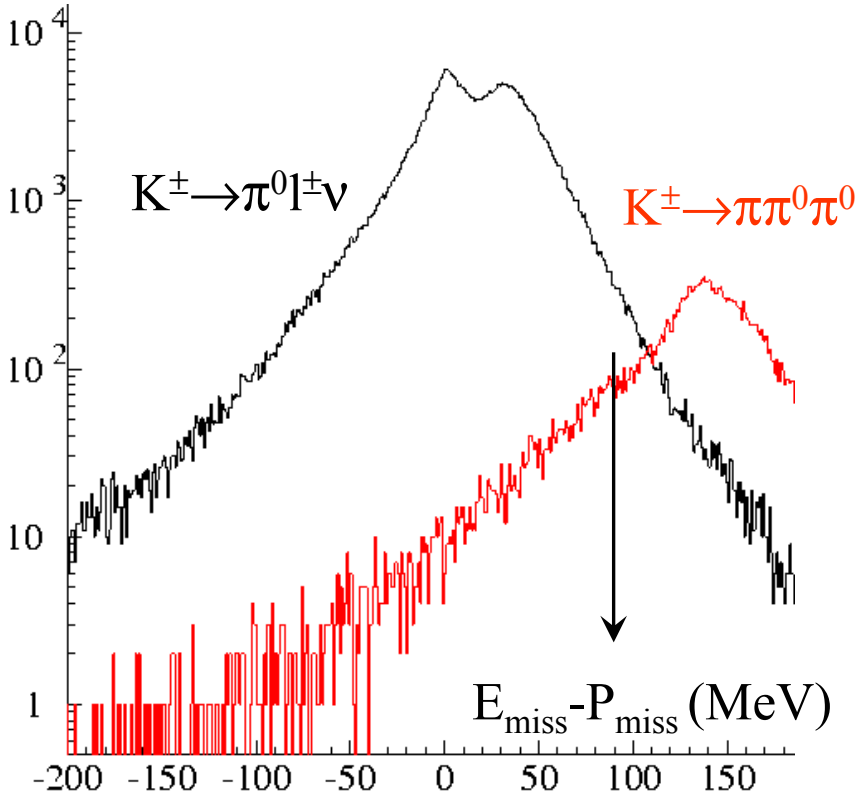
Signal selection: m^2 shapes

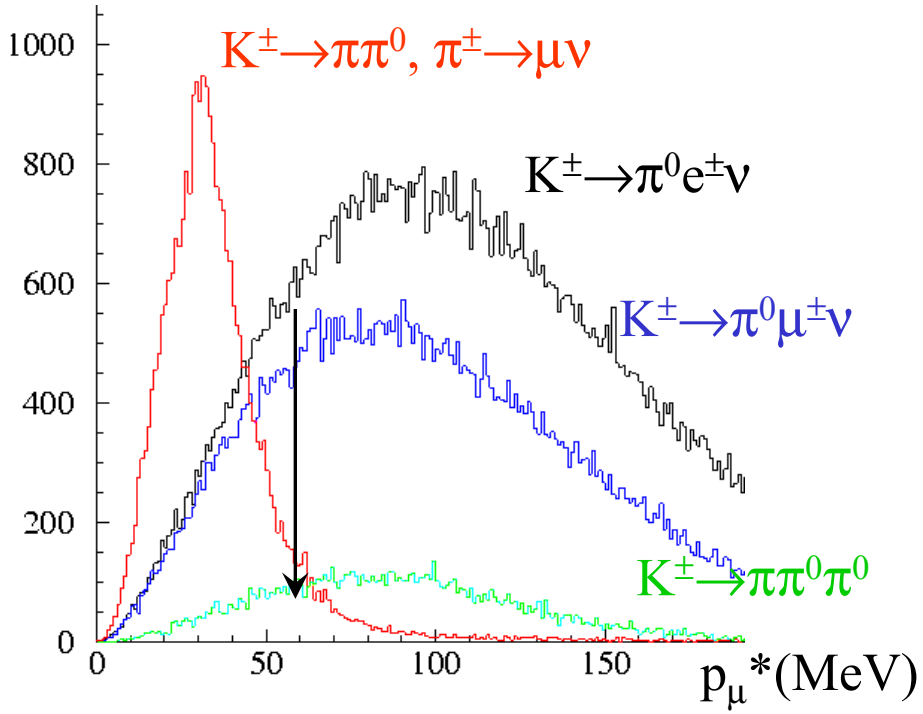
- Evident Ke3 and Kμ3 peaks.
- $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$ – with a π^0 undergoing a Dalitz decay – give a m^2_{lept} under the Ke3 peak.
- $K^{\pm}\to\pi^{\pm}\pi^0$ –with an early $\pi^{\pm}\to\mu^{\pm}\nu$– give a m^2_{lept} under the Kμ3 peak.
- Signals and background have the same signature in m^2.



Background rejection

• $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$ are rejected cutting on E_{miss}-P_{miss} spectrum (<90MeV).

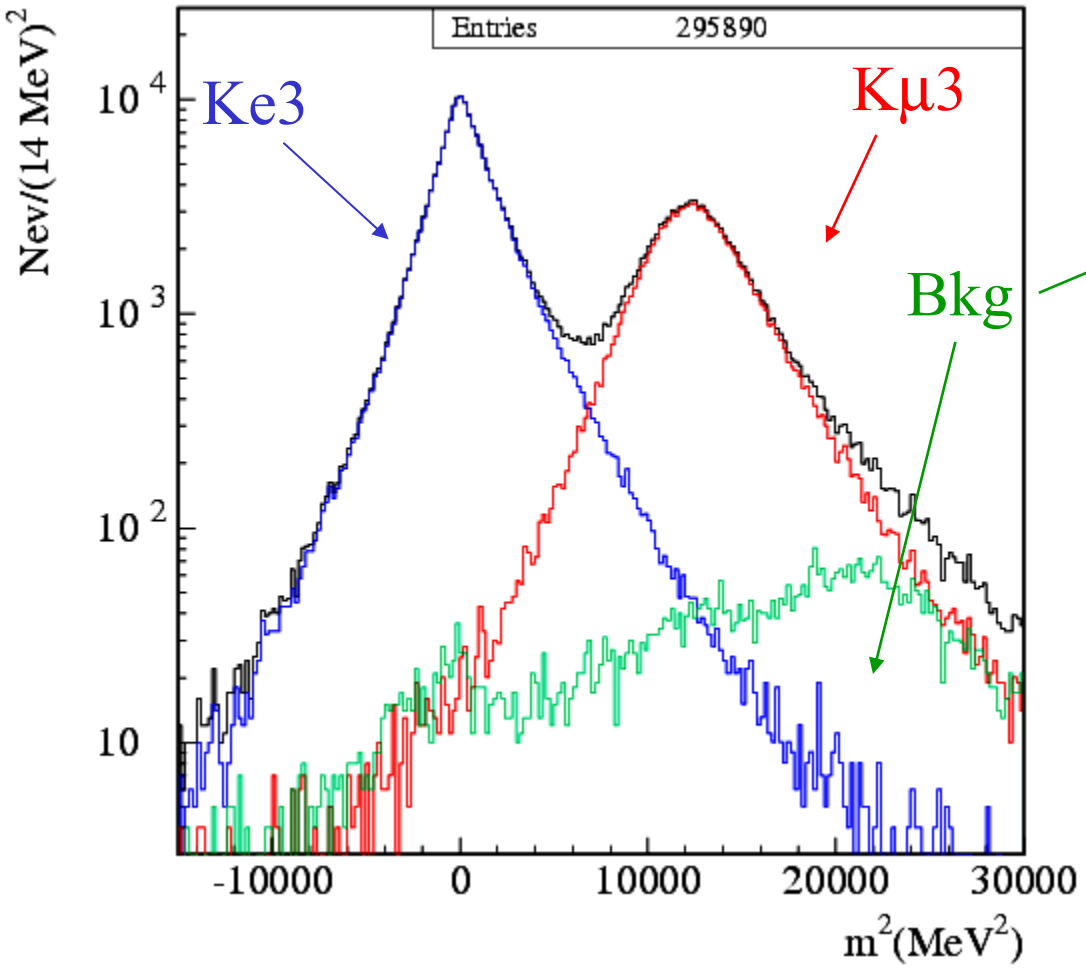


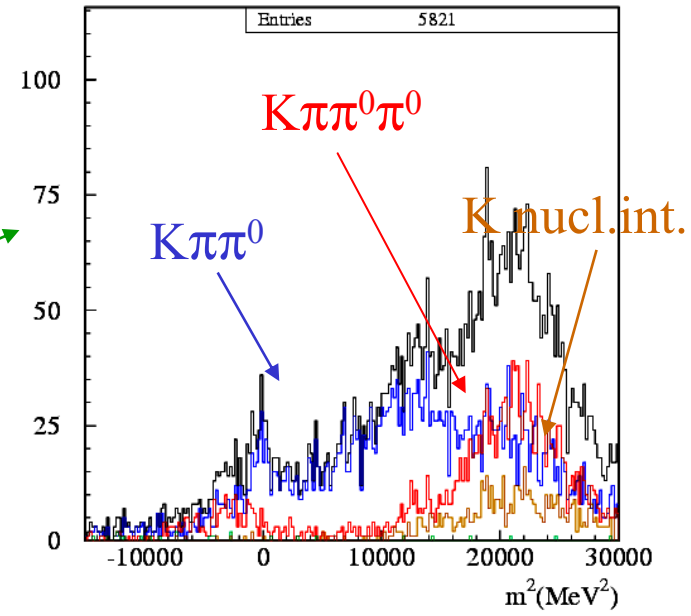


• $K^{\pm}\to\pi^{\pm}\pi^0$ events are rejected evaluating the missing momentum at the decay vertex, and cutting on momentum of the secondary track in the P_{miss} rest frame (p_μ*>60 MeV)

Signal selection: m^2 final shapes

- The previous cuts reject about 95% of background events
- The efficiency on the signal is about 80% for both Ke3 and Kμ3





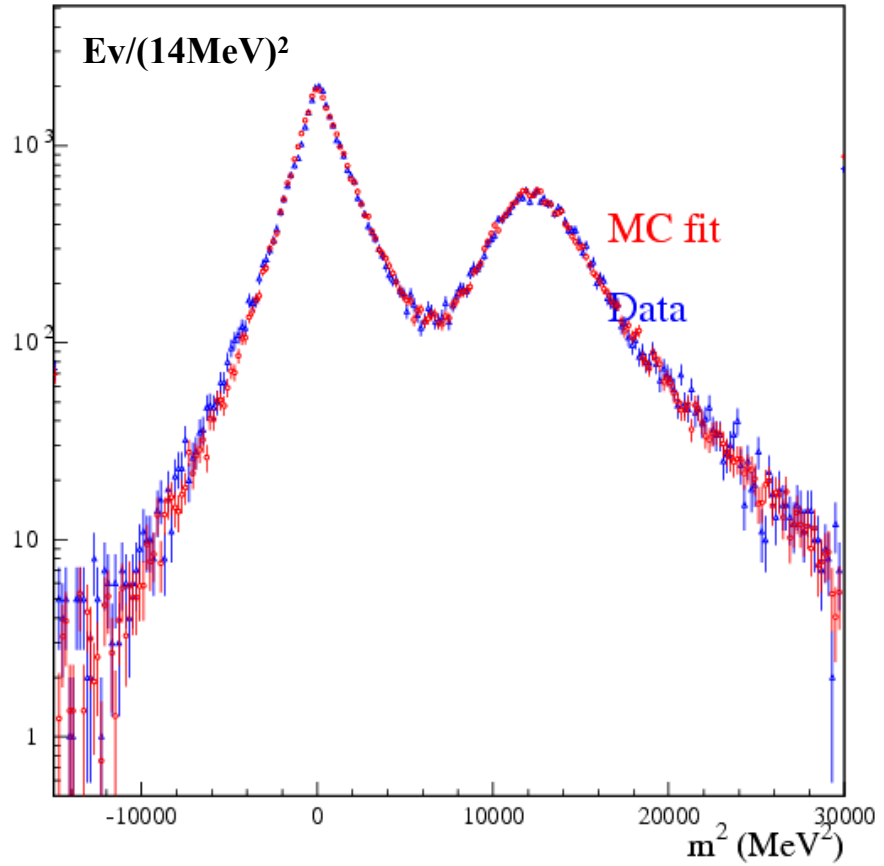
- The residual background is **about 1.5%** of the selected $K^{\pm}l3$ sample, and **has the m_π^2 signature**.

Event counting - 1

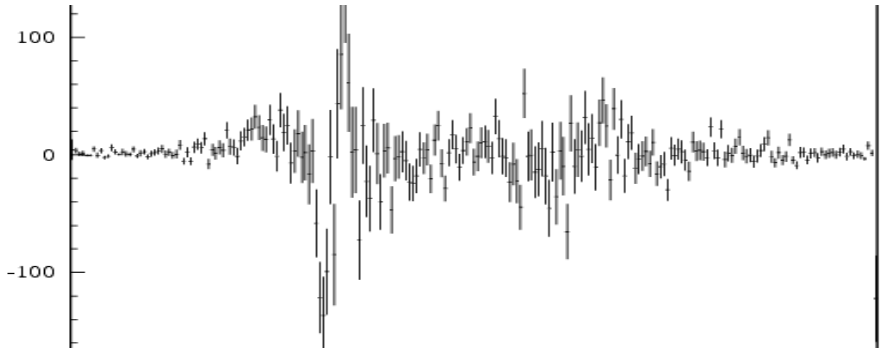
• Obtain number of signal events from a constrained likelihood fit of a **m^2 data spectrum** with a linear combination of Ke3 and Kμ3 shapes, and bkg contribution.
• Correct MC shapes for Data/MC differences on the calorimeter timing.

• The $K^+\pi 2$ tag sample is shown, with χ^2 and fit correlation matrix:

χ^2/DoF	P(χ^2)	$\mathbf{K_{e3}K_{\mu 3}}$	K_{e3}Bkg	$K_{\mu 3}$Bkg
230/222	34%	**−1.9%**	−8.6%	−37%

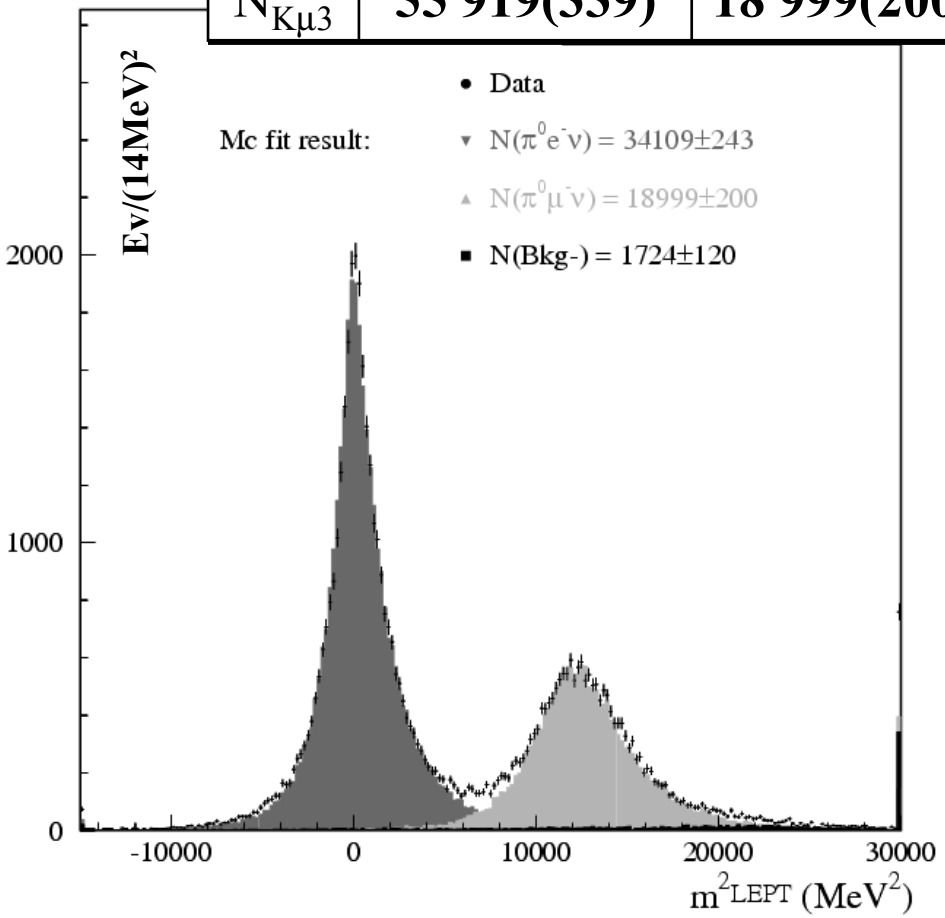


• The residuals distribution and the fit correlation show the same trend for all the tag samples (possible residual different Data-MC resolution).



Event counting - 2

Tag	$K^+\mu 2$	$K^+\pi 2$	$K^-\mu 2$	$K^-\pi 2$
N_{Ke3}	**101 733(411)**	**34 109(243)**	**108 125(430)**	**33 887(243)**
$N_{K\mu 3}$	**55 919(339)**	**18 999(200)**	**59 730(358)**	**18 923(205)**



- Selected signal events in 2001/2002 data set.
- 4 independent measurements for each signal (Ke3 and Kμ3)

Efficiency evaluation

• Measure selection efficiency on MC and correct for relevant Data/MC differences: tracking and EMC clustering (for both photons and leptons).

$$\varepsilon_{SELE} = \varepsilon_{SELE\_MC} \frac{\varepsilon(TRK)_{DATA}}{\varepsilon(TRK)_{MC}} \times \frac{\varepsilon(TCA)_{DATA}}{\varepsilon(TCA)_{MC}} \times \frac{\varepsilon(\gamma_1)_{DATA}\,\varepsilon(\gamma_2)_{DATA}}{\varepsilon(\gamma_1)_{MC}\,\varepsilon(\gamma_2)_{MC}}$$

• For each correction, select control samples in which efficiency can be measured as function of a suitable set of variables:

- **Tracking**: independent $K^{\pm}l3$ sample, plus kinematic fit; correct as a function of K polar angle, decay vertex position, and lepton momentum
- **Photon cluster**: use $K^{\pm}\pi 2$ decays, correct as function of photon energy.
- **Electron cluster**: use a $K_L e3$ sample, correct as a function of lepton momentum and EMC impact angle.
- **Muon cluster**: use a combined $K_L\mu 3$ and $K^{\pm}\pi 2$ plus $\pi \rightarrow \mu\nu$, sample.

• All corrections are stable wrt the variation of the cuts applied in control sample selection.

Ke3 summary

- The systematics have been carefully evaluated for each tag sample and for each decays, taking correlation into account.

- Nuclear interaction corrections affect only negative mmt.

- The final error is dominated by the error of the correction efficiency (tracking).

- Final fractional accuracy ranges from 1.5% to 2.1% following the tag sample.

Source	$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
Statistical				
Tag bias	0.07 %	0.14 %	0.08 %	0.14 %
Cosmic correction to tag bias	0.00 %	0.01 %	0.01 %	0.01 %
FilFo correction to tag bias	0.09 %	0.31 %	0.05 %	0.17 %
f_{NI}	0.32 %	0.57 %	-	-
Fit counting	0.40 %	0.71 %	0.40 %	0.72 %
$\delta\rho_{\pi^0} \oplus \delta\rho_{TRK} \oplus \delta\rho_{TCA}$	1.17 %	1.67 %	1.24 %	1.78 %
Systematics: signal				
ρ_{TRK}	0.54 %	0.54 %	0.53 %	0.53 %
ρ_{TCA}	0.00 %	0.00 %	0.00 %	0.00 %
ρ_{π^0}	0.24 %	0.25 %	0.24 %	0.24 %
Fit	0.13 %	0.19 %	0.35 %	0.15 %
Selection cuts	0.17 %	0.17 %	0.17 %	0.16 %
Systematics: acceptance				
f_{NI}	0.18 %	0.39 %	-	-
$\tau_\pm$	0.09 %	0.09 %	0.09 %	0.09 %
Systematics: tag bias corrections				
FilFo	0.36 %	0.06 %	0.37 %	0.05 %
Cosmic veto	0.04 %	0.02 %	0.03 %	0.04 %
f_{NI}	0.09 %	0.13 %	-	-
Total				
	1.49 %	**2.08 %**	**1.54 %**	**2.03 %**

$K\mu 3$ summary

- The same Ke3 comments hold for Kμ3.
- The final error is dominated by the error of the correction efficiency (tracking and muon track-to-cluster efficiencies).
- Final fractional accuracy ranges from 1.5% to 2.7%.

Source	$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
Statistical				
Tag bias	0.09 %	0.18 %	0.09 %	0.17 %
Cosmic correction to tag bias	0.01 %	0.01 %	0.01 %	0.01 %
FilFo correction to tag bias	0.09 %	0.31 %	0.05 %	0.17 %
f_{NI}	0.32 %	0.57 %	-	-
Fit counting	0.61 %	1.05 %	0.60 %	1.08 %
$\delta\rho_{\pi^0} \oplus \delta\rho_{TRK} \oplus \delta\rho_{TCA}$	1.61 %	2.25 %	1.12 %	2.27 %
Systematics: signal				
ρ_{TRK}	0.44 %	0.43 %	0.43 %	0.43 %
ρ_{TCA}	0.14 %	0.14 %	0.14 %	0.14 %
ρ_{π^0}	0.21 %	0.21 %	0.21 %	0.21 %
Fit	0.03 %	0.16 %	0.19 %	0.06 %
Selection cuts	0.49 %	0.49 %	0.49 %	0.48 %
Systematics: acceptance				
f_{NI}	0.18 %	0.39 %	-	-
$\tau_{\pm}$	0.09 %	0.09 %	0.09 %	0.09 %
Systematics: tag bias corrections				
FilFo	0.36 %	0.06 %	0.37 %	0.05 %
Cosmic veto	0.04 %	0.02 %	0.03 %	0.04 %
f_{NI}	0.09 %	0.13 %	-	-
Total				
	1.95 %	**2.71 %**	**1.52 %**	**2.63 %**

Signal systematics : selection cuts

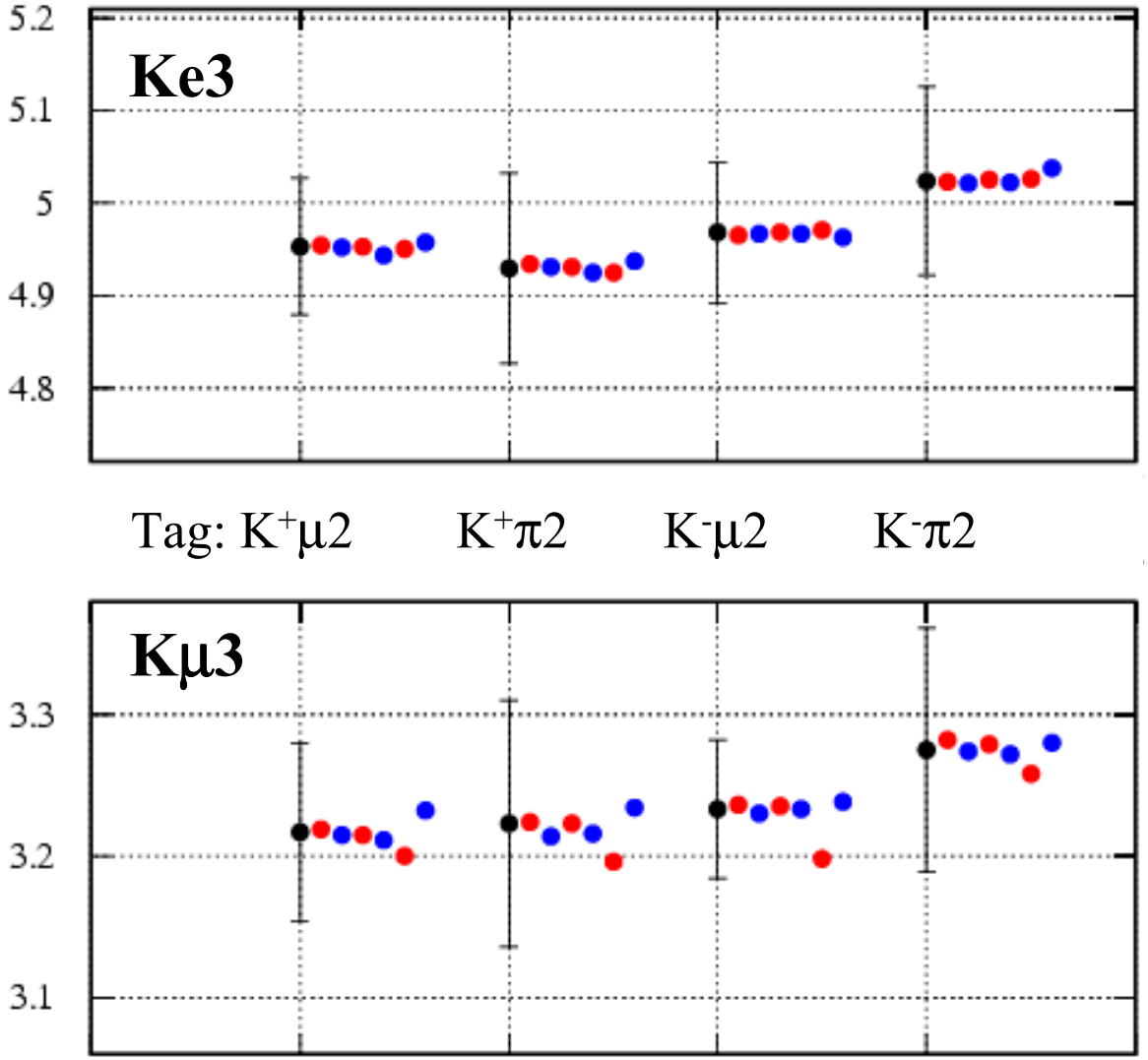
• Selection cuts affect different tag–sample measurements in the same way.

• Estimate the systematic error coming from the cut applied to reject bkg events:

1- $p^*(m_\pi) \leq 192.5$ MeV:
190 MeV-195 MeV

2- E_{miss}-P_{miss} <90MeV:
88 MeV-NoCut

3- p_μ^*>60 MeV:
50 MeV - 70 MeV



Results: BR(Kl3)

- χ^2/ndf for the 4 independent-tag measurements:
  Ke3: 1.62/3, $P(\chi^2 > \chi_M^2) \sim 65\%$
  Kμ3: 1.07/3, $P(\chi^2 > \chi_M^2) \sim 78\%$

- Average of the four results per charge and per decay taking correlations into account.
- χ^2/ndf between the charge measurements:
  Ke3: 0.17/1, $P(\chi^2 > \chi_M^2) \sim 68\%$
  Kμ3: 0.12/1, $P(\chi^2 > \chi_M^2) \sim 73\%$

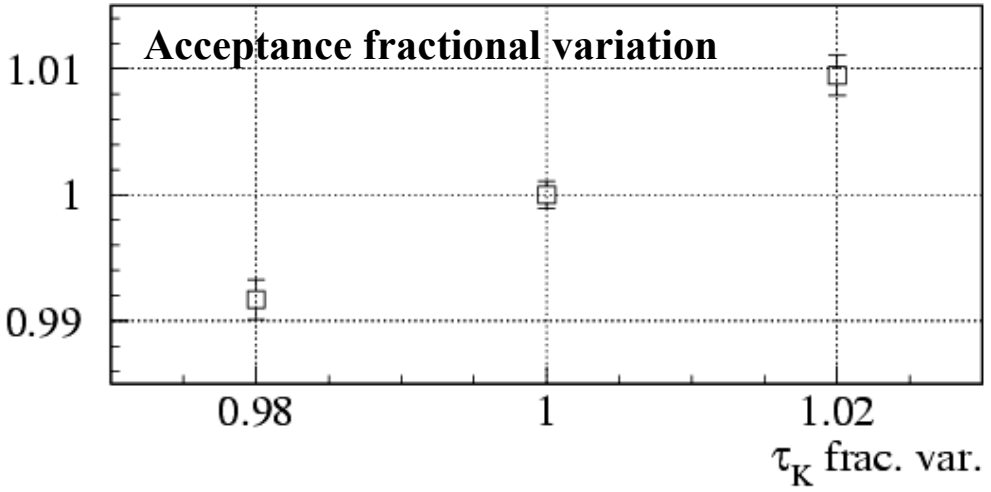
- The errors are dominated by the statistical contribution through the statistic use for TRK correction for Ke3 and TRK+TCA corrections for Kμ3

	Br (Stat) (Syst)%
K^-e3	**4.946 (53) (38)**
K^+e3	**4.985 (54) (37)**
$K^-\mu3$	**3.219 (47) (27)**
$K^+\mu3$	**3.241 (37) (26)**
Ke3	**4.965 (38) (37)**
Kμ3	**3.233 (29) (26)**

- In agreement with KLOE preliminary (05): Ke3 = 5.047(92)%, Kμ3 = 3.310(81)%.

- Efficiency and tag bias corrections, as well as selection cuts induce a **63.02% correlation coefficient** between the Ke3-Kμ3 branching ratio measurements.

τ_K dependency of BR(Kl3)



• τ_K value affects the BR measurement via the geometrical acceptance.

• From the BR=BR(τ_K) dependency:

$BR(Kl3,\tau_K) = BR(Kl3,\tau_K^0)\ (1 - 0.45(\tau_K - \tau_K^0)/\tau_K^0)$

(with τ_K^0 = 12.36 ns, $BR(Ke3,\tau_K^0)$ = 4.968 %, $BR(K\mu3,\tau_K^0)$ = 3.234 %)

BR results are evaluated @ τ_K (PDG 06 fit) = 12.384(24):

$BR(Ke3,\tau_K)$ = 4.965(53) %, **$BR(K\mu3,\tau_K)$ = 3.233(39) %**.

Error matrix (excluding the error coming from τ_K correction):

$$\begin{pmatrix} 0.2780 & 0.1268 \\ 0.1286 & 0.1510 \end{pmatrix} \times 10^{-6}$$

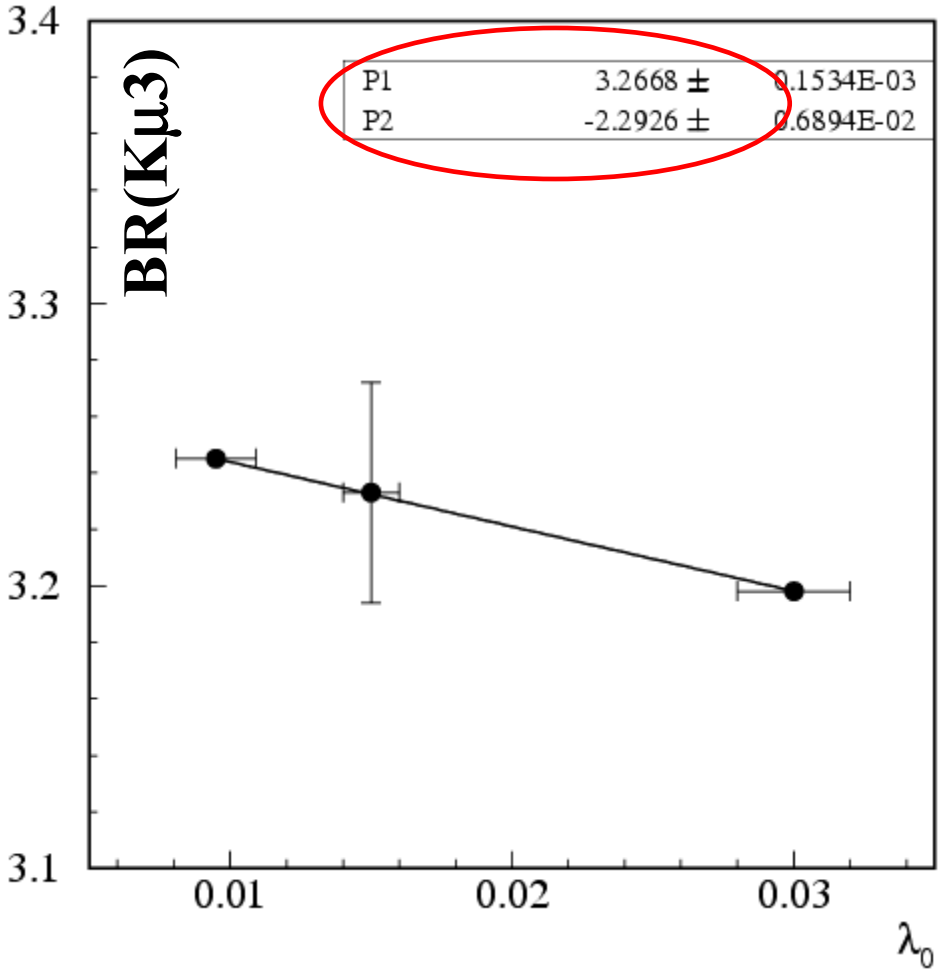
correlation: 62.74%

λ_0 dependency of BR(Kμ3)

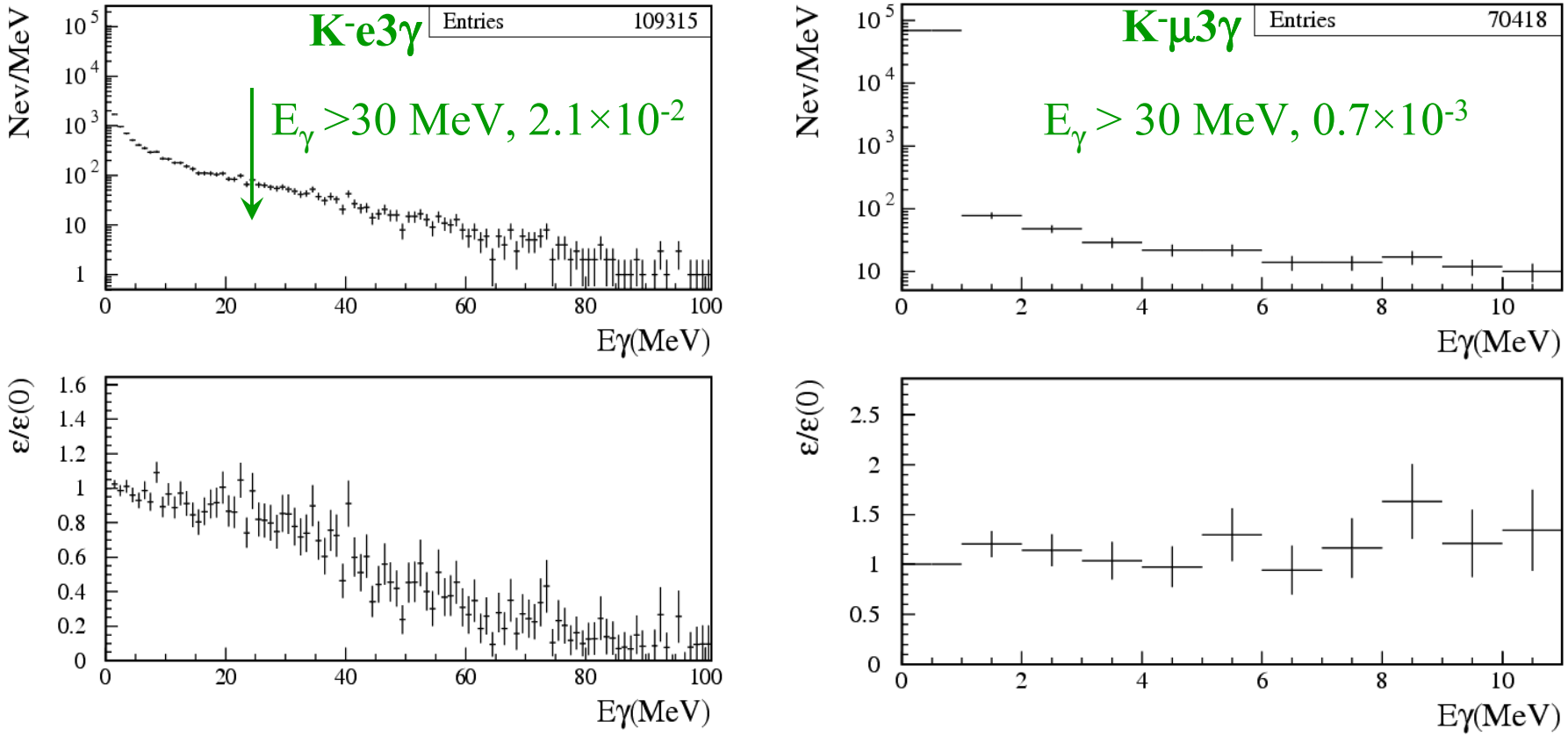
- Wrong/old scalar form factor value in MC ($\lambda_0 = 0.030$).

- Weight MC to obtain BR(Kμ3) at the present value ($\lambda_0 \sim 0.015$).

- Evaluate BR(Kμ3) dependency on λ_0 value:
  $BR(K\mu 3) = P1 + P2*\lambda_0$
- Limited knowledge of λ_0 value, gives negligible contribution to the systematic error.



$Ke3\gamma$ and $K\mu3\gamma$ acceptance



• The acceptance are determined with a generator that uses the soft-photon approximation to sum the amplitudes for real and virtual processes to all orders of α (C.Gatti, *Eur.Phys. J. C*, 45417, 2006).

$R_{\mu e} = \Gamma(K\mu 3)/\Gamma(Ke3)$

- Calculate $R_{\mu e} = \Gamma(K\mu 3)/\Gamma(Ke3)$ in the four tag samples used for BR mmt.
- $R_{\mu e} = (N_{\mu 3}/N_{e3})\ (\varepsilon_{e3}/\varepsilon_{\mu 3})\ \beta_{TB}$
- β_{TB} is the tag bias correction for the ratio, and ranges from 0.4% to 0.8% following the tag sample.

- The correlation between Ke3 and Kμ3 coming from the fit and from the efficiency corrections has been taken into account in calculating $\delta R_{\mu/e}$
- Error dominated by the statistics of the efficiency corrections.

Source	$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
Statistical				
Nke3	0.40 %	0.71 %	0.40 %	0.72 %
Nkμ3	0.61 %	1.05 %	0.60 %	1.08 %
TagBias	0.12 %	0.23 %	0.12 %	0.23 %
$\delta\rho_{\pi^0} \oplus \delta\rho_{TRK} \oplus \delta\rho_{TCA}$	0.94 %	1.09 %	0.59 %	1.36 %
Systematics				
Tag	0.09 %	0.09 %	0.09 %	0.09 %
e3	0.62 %	0.64 %	0.70 %	0.62 %
μ3	0.70 %	0.72 %	0.72 %	0.69 %
Total				
	1.45 %	**1.65 %**	**1.40 %**	**2.02 %**

$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
0.6495	0.6538	0.6508	0.6517
(67)(66)(6)	(80)(72)(6)	(52)(74)(6)	(104)(81)(6)

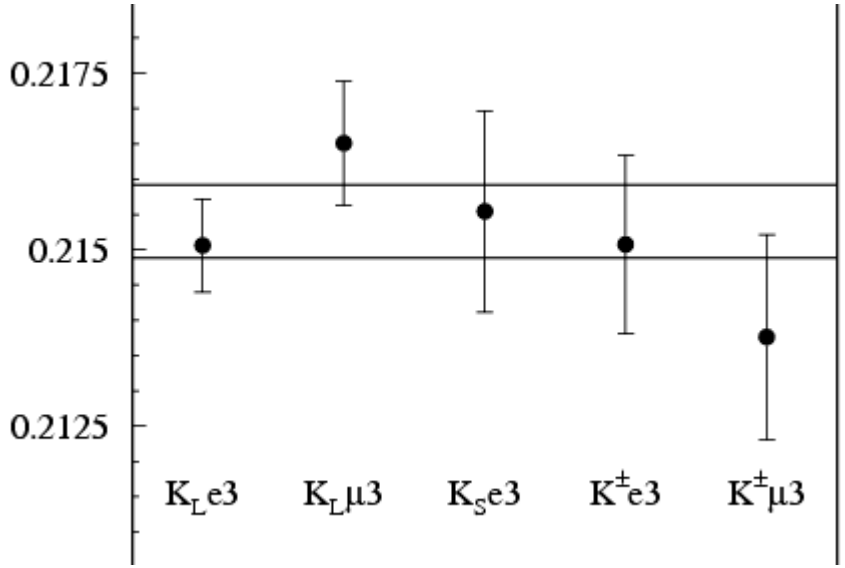
- Average: $\mathbf{R_{\mu e}=0.6511(46)_{Stat}(73)_{Syst}}$
- From theory: $R_{\mu e}=0.6646(61)$

Integrals ($\mathbf{I_{e3}}$ and $\mathbf{I_{\mu 3}}$) and $\delta_{SU(2)}$, δ_{em} corrections from Moulson (FlaviaNet) at CKM06.

V_{us} from KLOE results (BR's)

- All inputs **but branching ratios** are from Moulson (FlaviaNet) at CKM06:

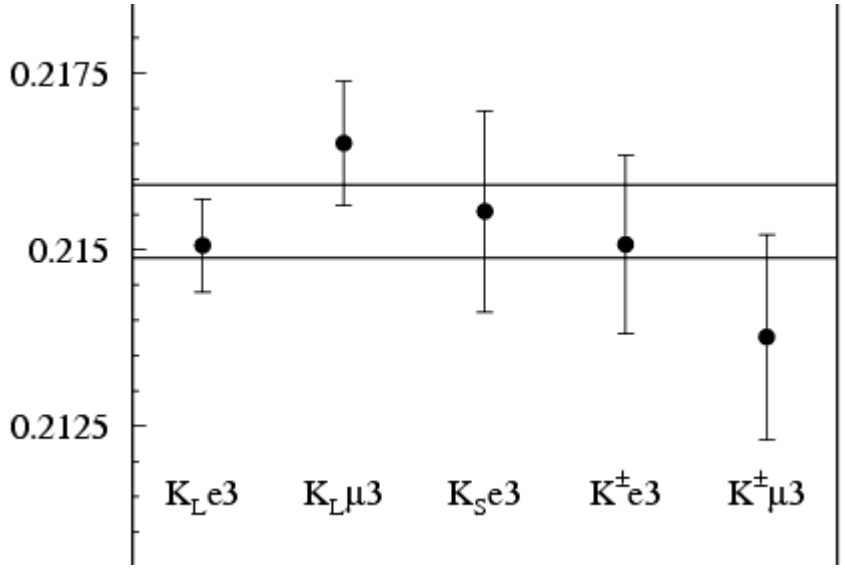
$K_L e3$	$K_L \mu 3$	$K_S e3$	$K^{\pm} e3$	$K^{\pm} \mu 3$
0.4007(15)	**0.2698(15)**	**$7.046(91) \times 10^{-4}$**	**0.04965(53)**	**0.03233(39)**



$V_{us} f_+(0) = 0.2154(5)$

- Taking correlation into account: **χ^2/ndf = 4.37/4** (36% probability).
- Using $f_+(0) = 0.961(8)$ (Leutwyler and Roos), obtain **V_{us} = 0.2241(19)**.
- **$V_{ud}^2 + V_{us}^2 - 1 = -0.0015(10)$**, $V_{ud} = 0.97377(27)$
  compatibile with Unitarity at -1.5σ.

V_{us} from KLOE results (BR's)



$V_{us} f_+(0) = 0.2154(5)$

- Evaluate $V_{us} f_+(0)$ by charge state:
  $K_{L,S} = 0.2155(6)$, $K^\pm = 0.2146(12)$
  Average: 0.2154(5), **χ^2/ndf = 0.48/1** (49% probability).
- Lepton universality: $r_{\mu e} = (R_{\mu e})_{OBS}/(R_{\mu e})_{SM}$
  $r_{\mu e}(K_{L,S}) = 1.013$ (9)
  $r_{\mu e}(K^\pm) = 0.988$ (11)
  Average: **1.003(7),** χ^2/ndf = 3.60/1 (5.8% probability)
- Evaluate empirical **ΔSU(2)** correction: **1.88(58) %**
  to be compared with χ_{PT} prediction **2.31(22) %**

Conclusions

Absolute $K^{\pm}l3$ branching ratio measurements:

- BR measured in 4 independent tag samples: keep tag systematic under control.
- Efficiency corrections carefully checked on Data and MC control samples.
- Completely inclusive measurements: $K\ell 3(\gamma)$.
- Final BR with a fractional accuracy of **1.1%** for Ke3 and **1.2%** for Kμ3.
- $R_{\mu e}$ has been measured on the same sample with **1.3%** of fractional accuracy, and is in agreement within the errors with the theoretical prediction.

$|V_{us}f_+(0)|$ determination with the 5 KLOE semileptonic BR's:

- 0.2% determination of $|V_{us}f_+(0)|$, with $\chi^2/\mathrm{dof} = 4.37/4$.
- Good agreement between charged and neutral determinations: $\chi^2/\mathrm{ndf} = 0.48/1$.

Perspectives for $K^{\pm}l3$ with 2.5 fb^{-1} of KLOE collected data:

- A factor 2 better in the error of BR measurements.
- Measurements of form factors (~2.5 million Ke3, ~1,5 million Kμ3).

Additional information

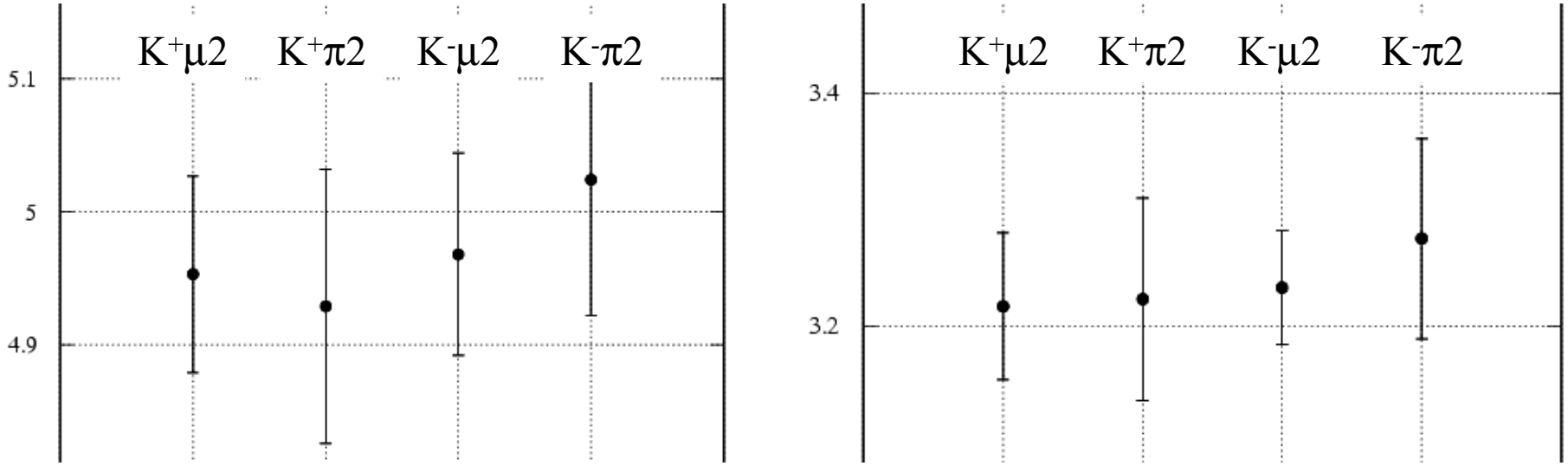
Result: BR(Kl3) - details

	$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
N_{TAG}	21 319 804	7 220 354	21 874 232	6 904 949
N_{Ke3}	101 733 (411)	34 109 (243)	108 125 (430)	33 887 (243)
$1\text{-}f_{NI}$	0.9751(31)	0.9821(59)	-	-
$\varepsilon_{FV}\varepsilon_{Sig}$	0.0957(11)	0.0989(17)	0.0983(12)	0.1008(18)
α_{TB}	0.9694(11)	1.0137(34)	0.98838(94)	1.0328(23)
$BR(K_{e3})$	**4.953(64) %**	**4.929(95) %**	**4.968(65) %**	**5.024(97) %**

	$K^+_{\mu 2}$	$K^+_{\pi 2}$	$K^-_{\mu 2}$	$K^-_{\pi 2}$
N_{TAG}	21 319 804	7 220 354	21 874 232	6 904 949
$N_{K\mu 3}$	55 919 (339)	18 999 (200)	59 730 (358)	18 923 (205)
$1\text{-}f_{NI}$	0.9751(31)	0.9821(59)	-	-
$\varepsilon_{FV}\varepsilon_{Sig}$	0.0815(16)	0.0848(23)	0.0841(11)	0.0867(23)
α_{TB}	0.9756(13)	1.0210(36)	0.9963(10)	1.0371(25)
$BR(K_{\mu 3})$	**3.217(57) %**	**3.223(83) %**	**3.233(42) %**	**3.275(83) %**

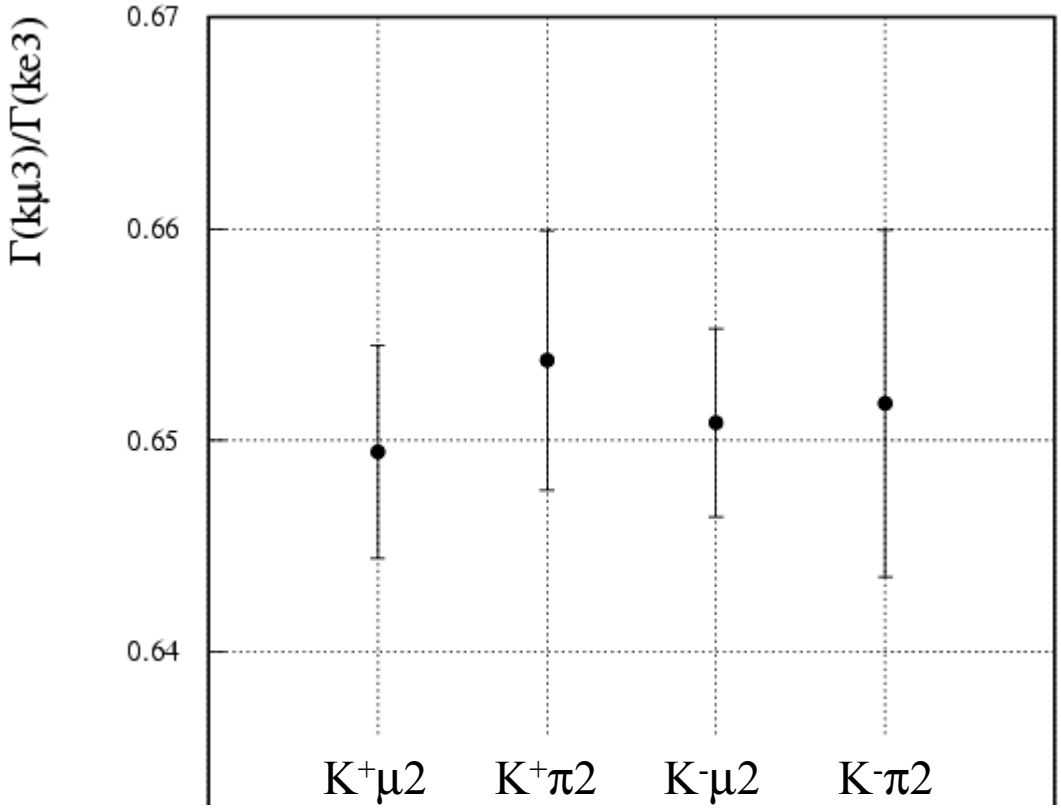
- Only statistical error are show here
- χ^2/DoF for the 4 independent-tag measurements:
  Ke3: 1.62/3, $P(\chi^2 > \chi_M^2) \sim 65\%$
  Kμ3: 1.07/3, $P(\chi^2 > \chi_M^2) \sim 78\%$

Correlation between different tag - Kℓ3



χ^2 between tags:	χ^2/1 DoF	Prob($\chi^2 > \chi^2_{Meas}$)
K_{e3}		
$K^+_{\mu 2}$ and $K^-_{\mu 2}$	0.05	0.82
$K^+_{\mu 2}$ and $K^-_{\pi 2}$	0.68	0.41
$K^+_{\pi 2}$ and $K^-_{\mu 2}$	0.19	0.66
$K^+_{\pi 2}$ and $K^-_{\pi 2}$	0.85	0.36
$K_{\mu 3}$		
$K^+_{\mu 2}$ and $K^-_{\mu 2}$	0.09	0.76
$K^+_{\mu 2}$ and $K^-_{\pi 2}$	0.60	0.44
$K^+_{\pi 2}$ and $K^-_{\mu 2}$	0.02	0.89
$K^+_{\pi 2}$ and $K^-_{\pi 2}$	0.35	0.55

Correlation between different tag - Rμe

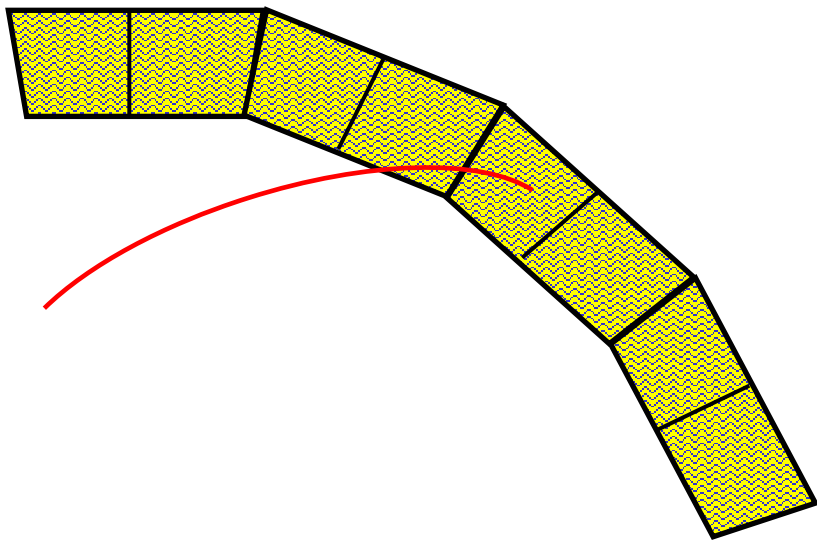


χ2/nDoF	between tags
0.920/3	All
0.094/1	1 and 3
0.143/1	1 and 4
0.330/1	2 and 3
0.096/1	2 and 4

Tag selection - details

- Calorimeter trigger (2 sectors over threshold ~50 MeV) satisfied by tag:

- Tag $K^{\pm}\mu 2$: ask for associated μ-cluster on barrel with energy > 90 MeV. μ-cluster fires at least one sector.
  - μ-cluster fires two sectors (ε~30%)
  - ask for additional fired trigger sectors to satisfy calorimeter trigger (ε~45% for K^+, ε~40% for K^-)



- Tag $K^{\pm}\pi 2$:

a) look for a π^0 from vertex using the $\Delta(\delta t)$ technique and ϕ^* constraint.
b) π^0 clusters satisfy the Emc trigger (ε~90%)

- For each kaon charge, 2+1 different tag samples: Kμ2+μTrg, Kπ2+π^0Trig, and Kμ2+μNoTrg.
- 2 tag × 2 charge = 4 samples for the measurements
- 1 tag × 2 charge = 2 control samples

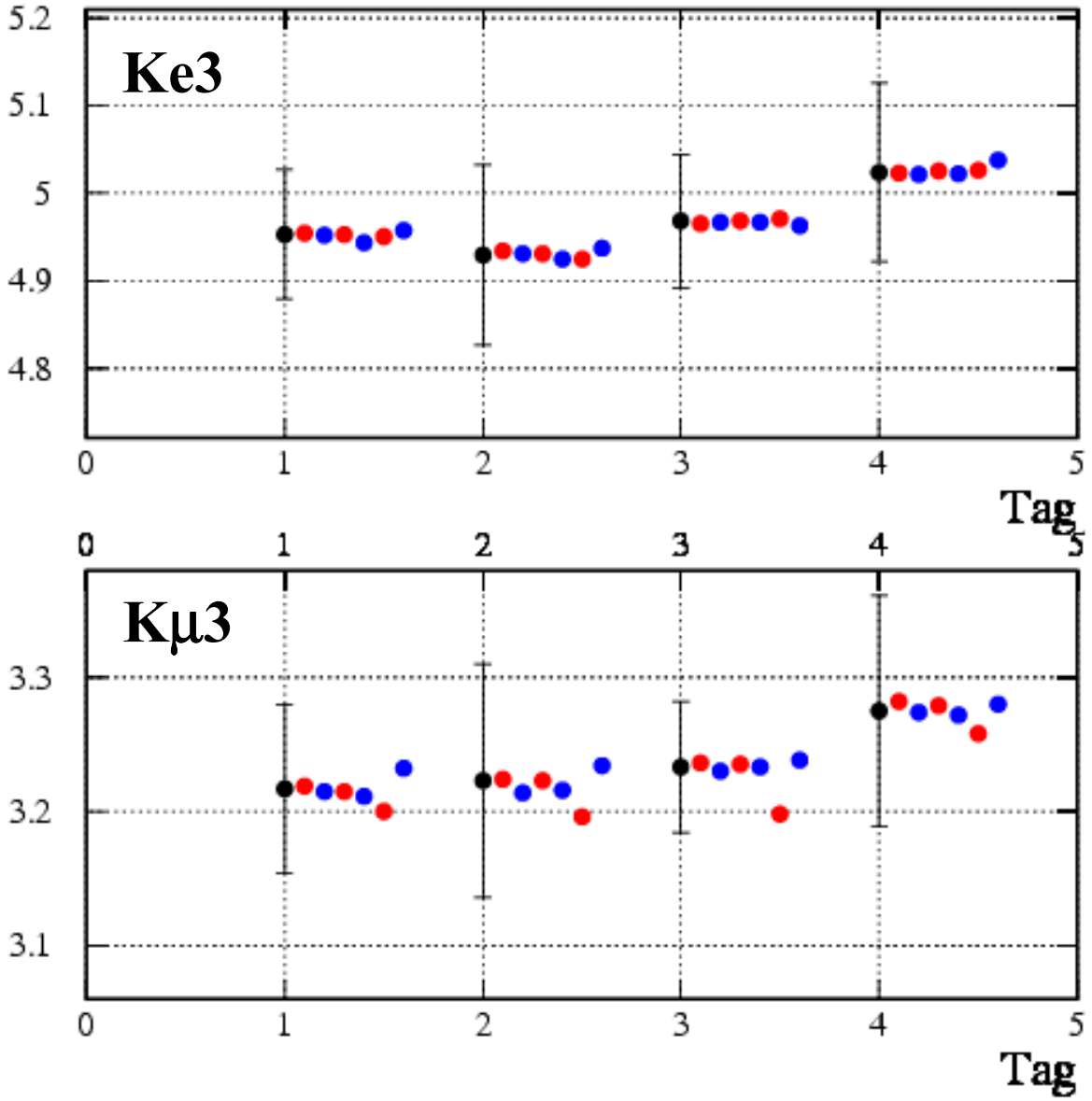
Signal systematics - 1

• Estimate the systematic error coming from the cut applied to reject bkg events:

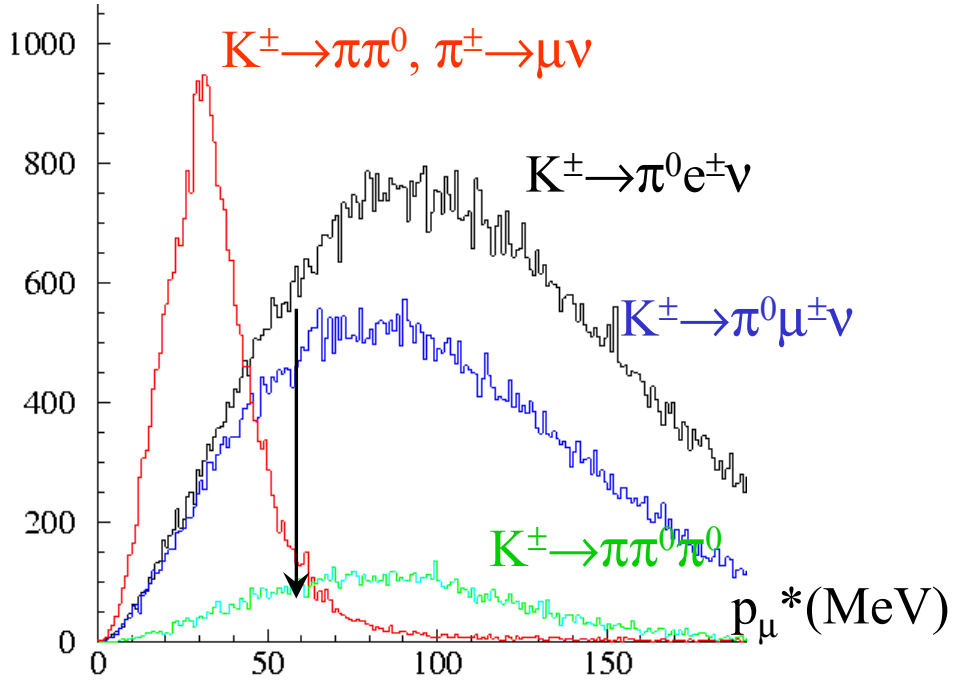
1- $p^*(m_\pi) \leq 192.5$ MeV:
190 MeV-195 MeV

2- E_{miss}-P_{miss} <90MeV:
88 MeV-NoCut

3- p_μ^*>60 MeV:
50 MeV - 70 MeV



Systematic errors from p_μ^* cut

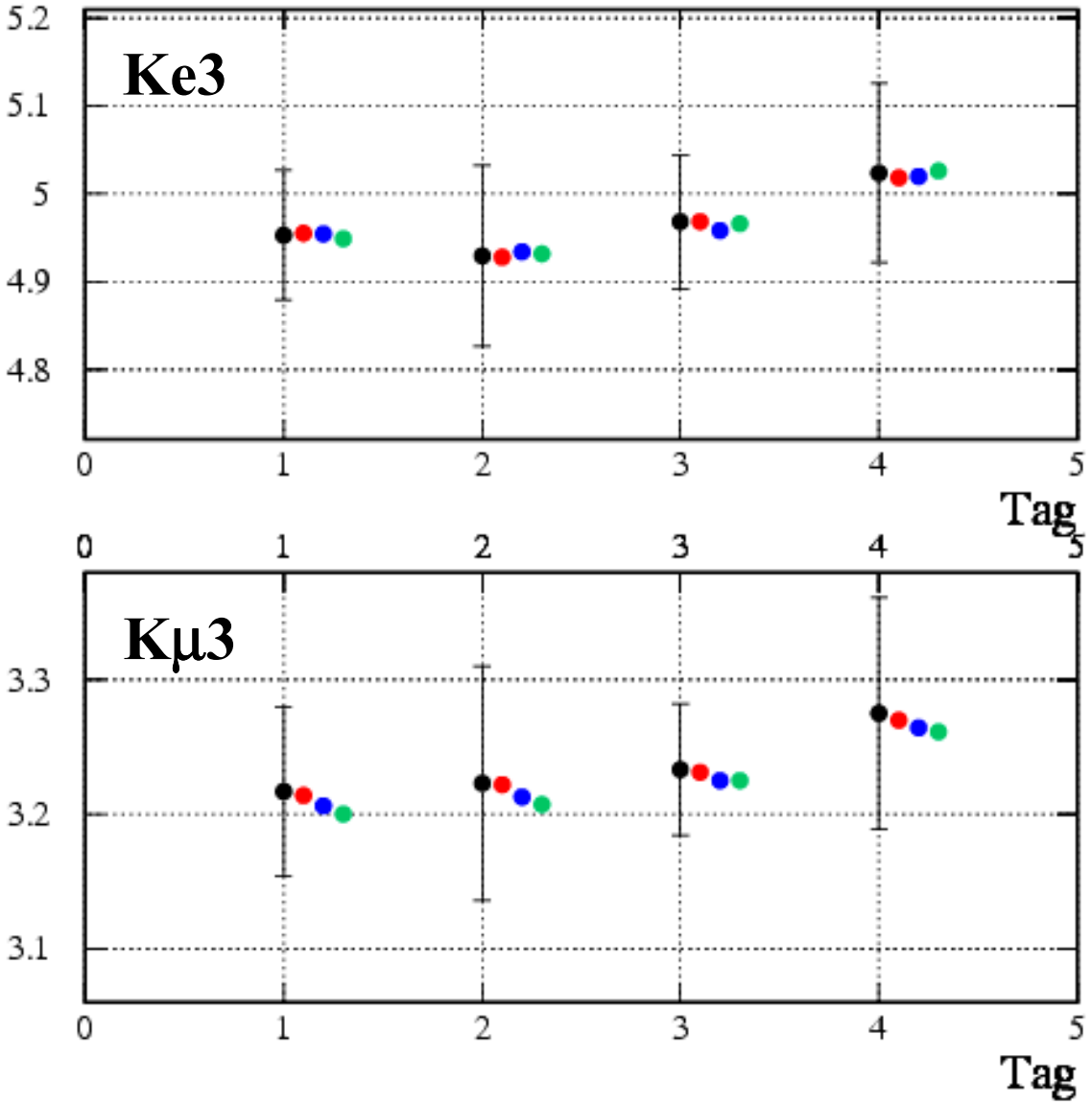


p_μ^* cut MeV)	K_{e3} efficiency (%)	$K_{\mu 3}$ efficiency (%)	Bkg under $K_{\mu 3}$ peak	K_{e3}-$K_{\mu 3}$ correlation	K_{e3}-bkg correlation	$K_{\mu 3}$-bkg correlation
0	100.	100.	56.6	+6.3	-11.4	-80.6
40	93.26	90.52	17.0	+7.2	-15.1	-71.0
50	88.66	86.61	9.1	+4.3	-15.1	-56.7
60	**83.04**	**77.68**	**5.0**	**+1.1**	**-13.6**	**-42.6**
70	76.58	69.95	3.6	-0.9	-11.4	-35.1
80	69.74	61.83	3.0	-1.6	-10.7	-31.9
90	62.46	53.83	2.8	-2.2	-9.2	-29.5

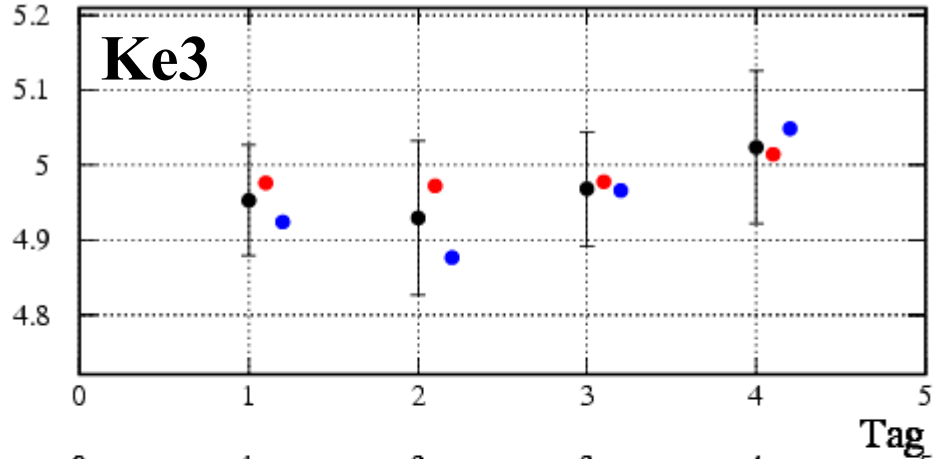
Signal systematics - 2

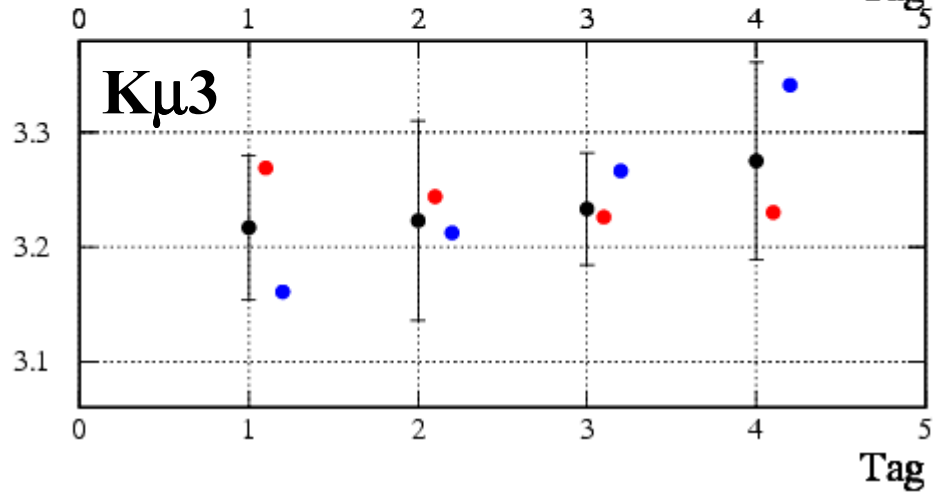
• No cut is applied to P_{LAB} in signal selection; require P_{LAB}> xx MeV to check the stability of the momentum-dependent corrections (TRK and TCA)

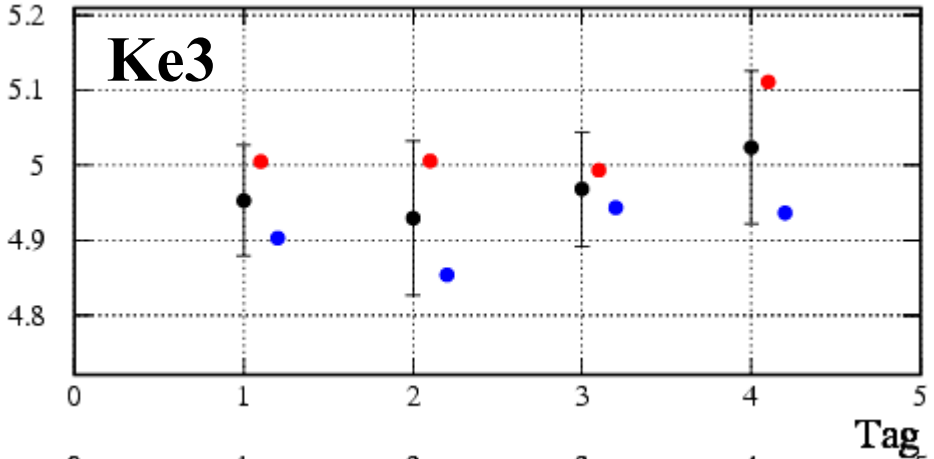
P_{LAB} > 50 MeV
> 70 MeV
> 90 MeV

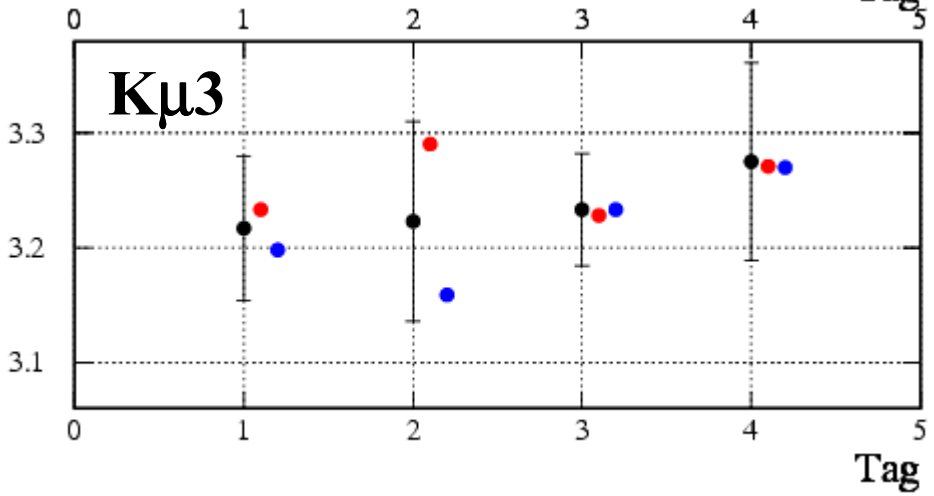


Signal systematics - 3





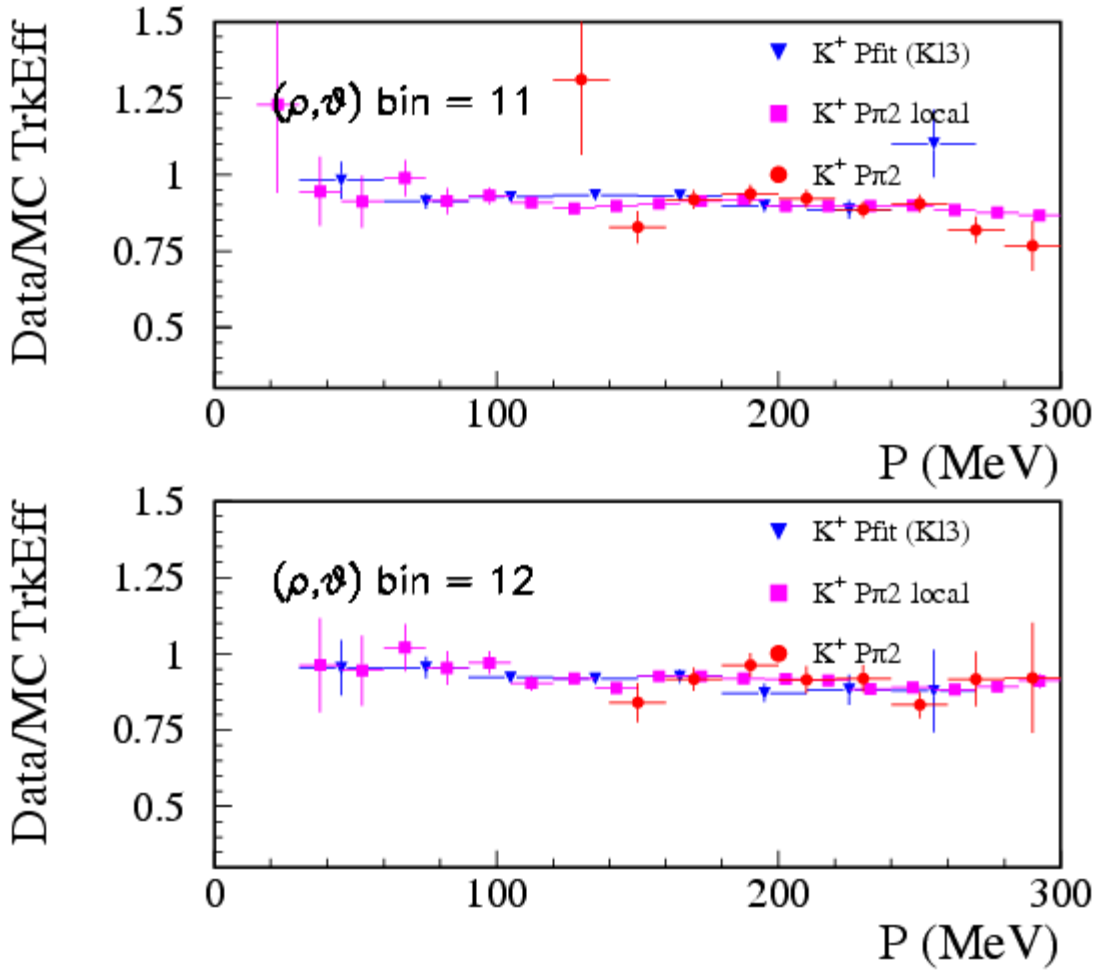


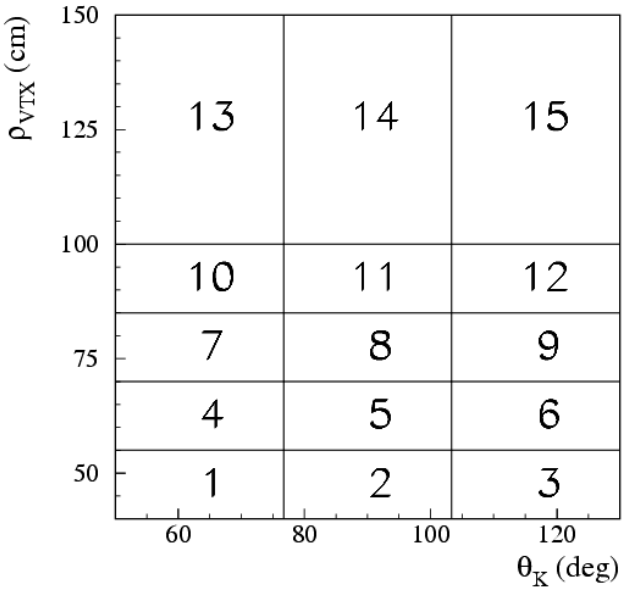


Transversal vertex position (low/high)

Kaon polar angle (vertical or not)

Correction from control sample - TRK





K*l*3 from fit

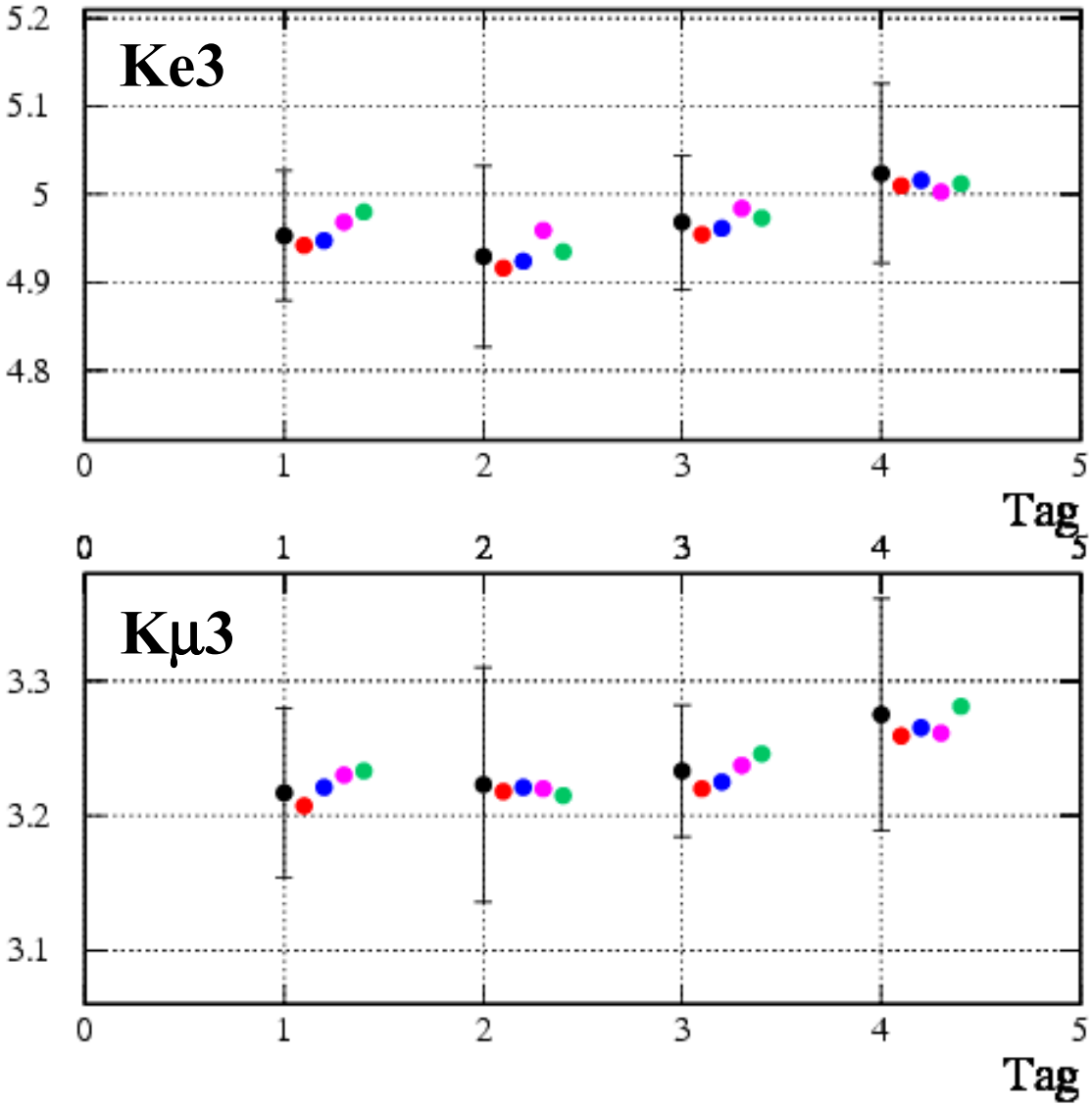
Kπ2 from kinematics (~400 pb^{-1})

Kπ2 (25 pb^{-1}, different selection)

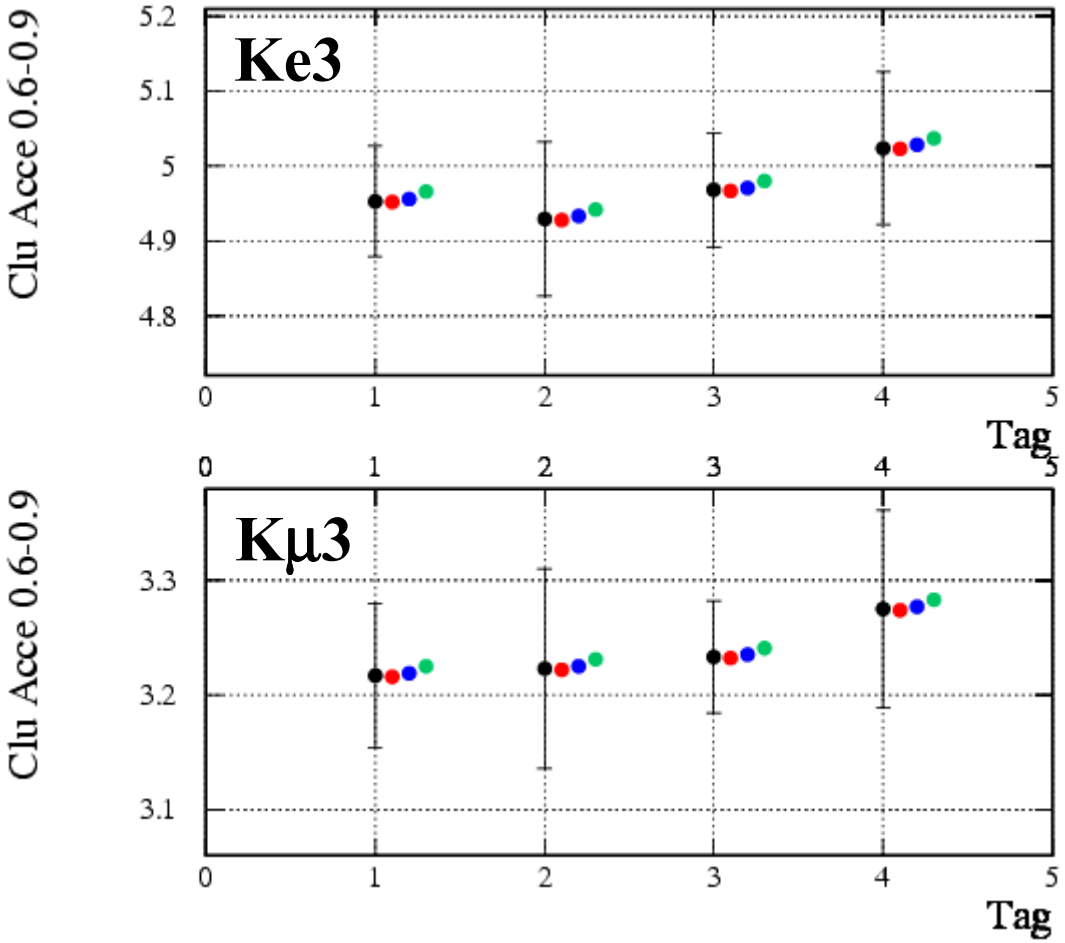
Signal systematics - 4

• To check the correction applied for the cluster efficiency, require a minimum energy to π^0 clusters:

E_{MIN}(Clu) > 0 MeV
> 10 MeV
> 30 MeV
> 40 MeV



Signal systematics - 5



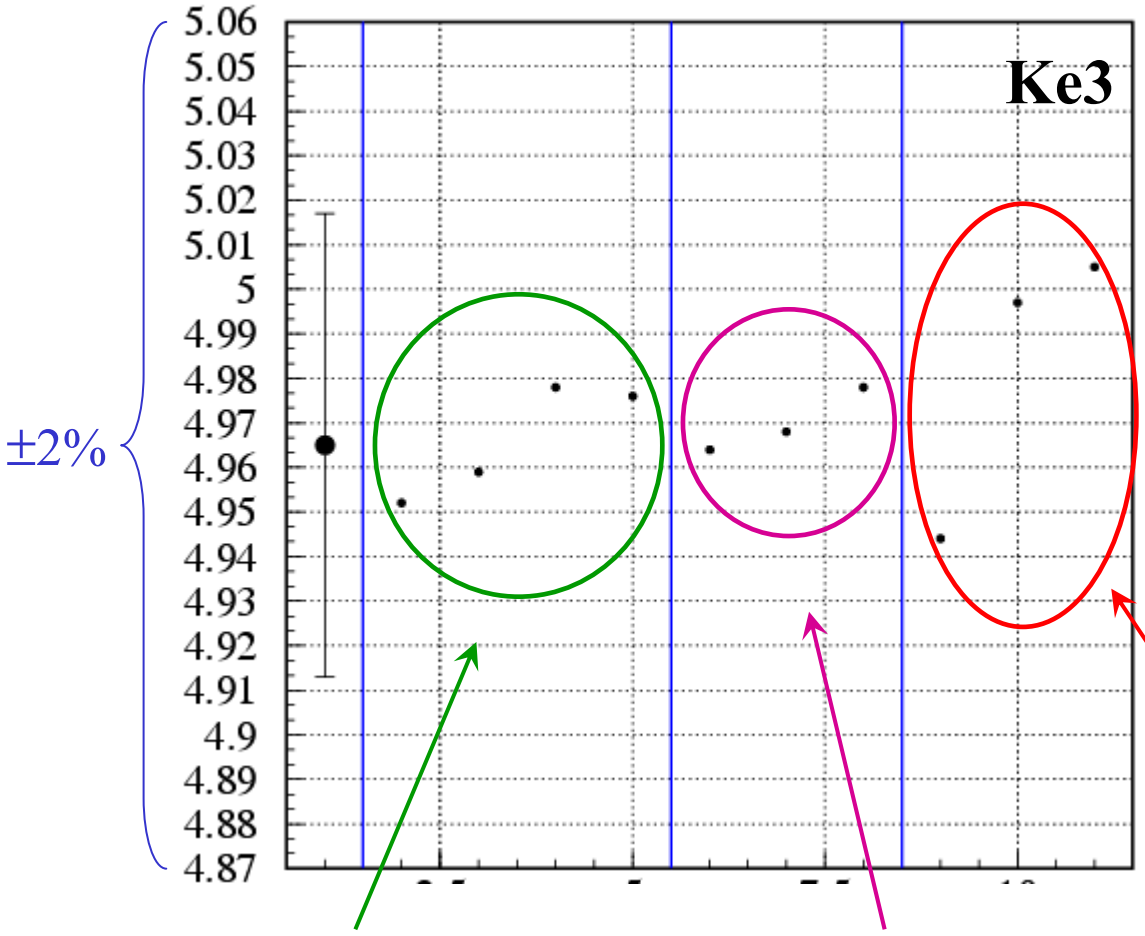
• To check the robustness of the cluster efficiency correction wrt the acceptance cut, vary the opening angle ($\cos(\theta)>0.7$) and use the CLU correction obtained:

$\cos(\theta)$ > 0.6

> 0.8

> 0.9

Signal systematics : CLU correction



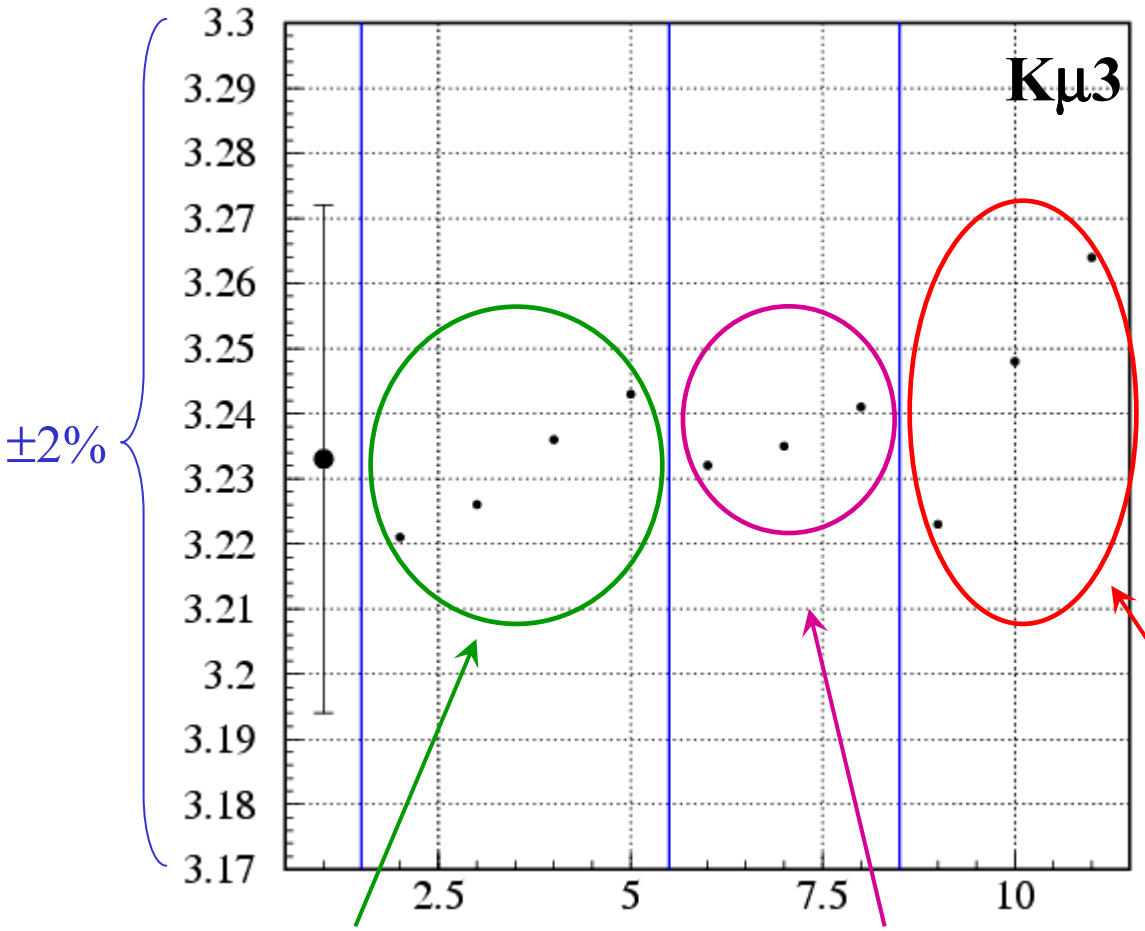
• Assume as systematic error the difference between the 10 and 30 MeV correction and the difference between 0.6-0.8 opening angle @ 20 MeV.

Control sample: $E_{MIN} > x$
Signal selection: $E_{MIN} > x$
x = 0, 10, 30, 40 MeV, cosθ>0.7

Control sample: $E_{MIN} > 20$ MeV
Signal selection: $E_{MIN} > 20$ MeV
cosθ > 0.6, 0.8, 0.9

Control sample: $E_{MIN} > 20$ MeV
Signal selection: $E_{MIN} > x$
x = 10, 30, 40 MeV, cosθ>0.7

Signal systematics : CLU correction



• Assume as systematic error the difference between the 10 and 30 MeV correction and the difference between 0.6-0.8 opening angle @ 20 MeV.

Control sample: $E_{MIN} > x$
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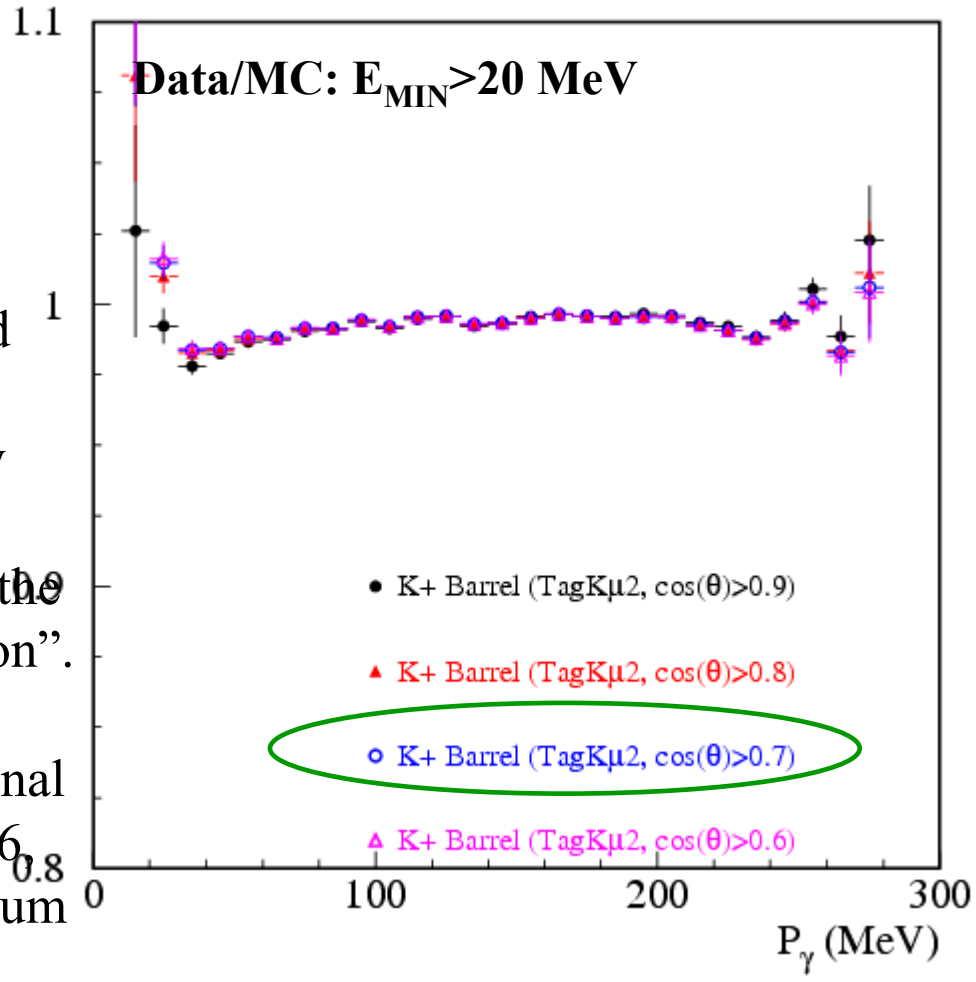
x = 0, 10, 30, 40 MeV, cosθ>0.7

Control sample: $E_{MIN} > 20$ MeV
Signal selection: $E_{MIN} > 20$ MeV
cosθ > 0.6, 0.8, 0.9

Control sample: $E_{MIN} > 20$ MeV
Signal selection: $E_{MIN} > x$
x = 10, 30, 40 MeV, cosθ>0.7

Efficiency from control sample - CLU

- Select events with Kμ2 tag, to unbias the efficiency measurement for the trigger.
- Ask for a Kπ2 selection (p_π^* cut) in the signal side.
- Get $\beta_{\pi 0}$ from the missing momentum at vertex.
- Use the opening angle between estimated and cluster direction Look for a π^0-photon from the vertex, excluding clusters already used by the tag or connected to a track.
- Starting with Kπ2+γ selection, estimate the energy and the position of the "other photon".
- Look for a cluster from the vertex with **Δ(δt) matching** (the one applied for π^0 signal selection), acceptance cut range: cosθ >0.6, >0.7 , >0.8, and >0.9, and require e minimum energy of 0, 10, 20, 30, 40 MeV.
- Use cosθ>0.7 and E_{MIN}=20 MeV for the mmt and use the other as systematic checks.



Correction from control sample - TCA

• The Track-to-cluster association (TCA) efficiency for both electrons and muons is evaluated using $K_L e3$ $K_L \mu 3$ events, identified by tight kinematical selection +NN.

• BR(Kμ3) and Rμe measurements are sensitive to TCAμ correction

• For high momentum muons use also $K^{\pm}\pi 2$, with identified $\pi \rightarrow \mu$ kink, and $K^{\pm}\mu 2$ events. Different corrections in agreement within the errors. Use a "$K_L \mu 3$, $K^{\pm}\mu 2$ combination".

•Correct separately for Barrel and EndCap, and per charge