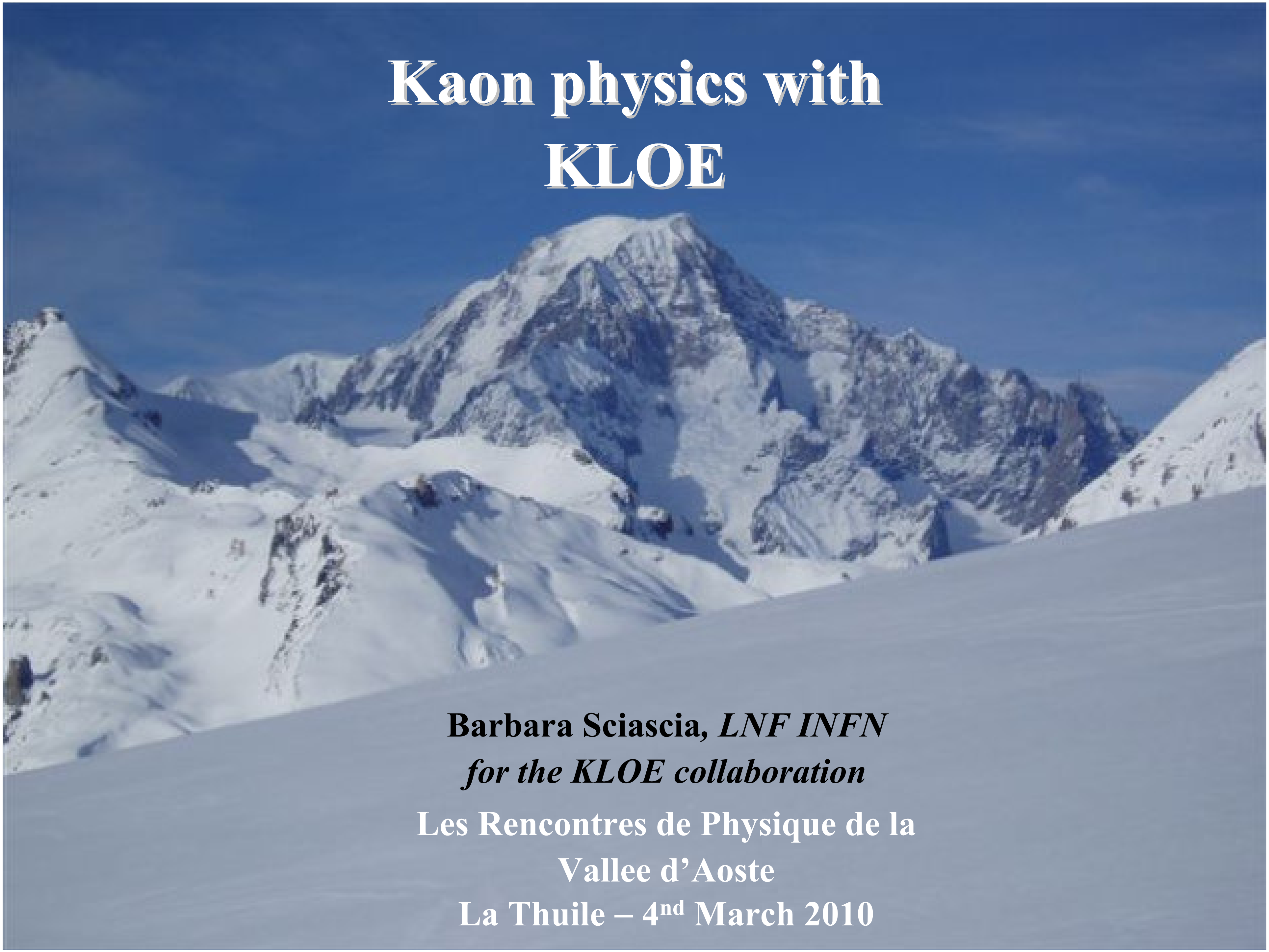
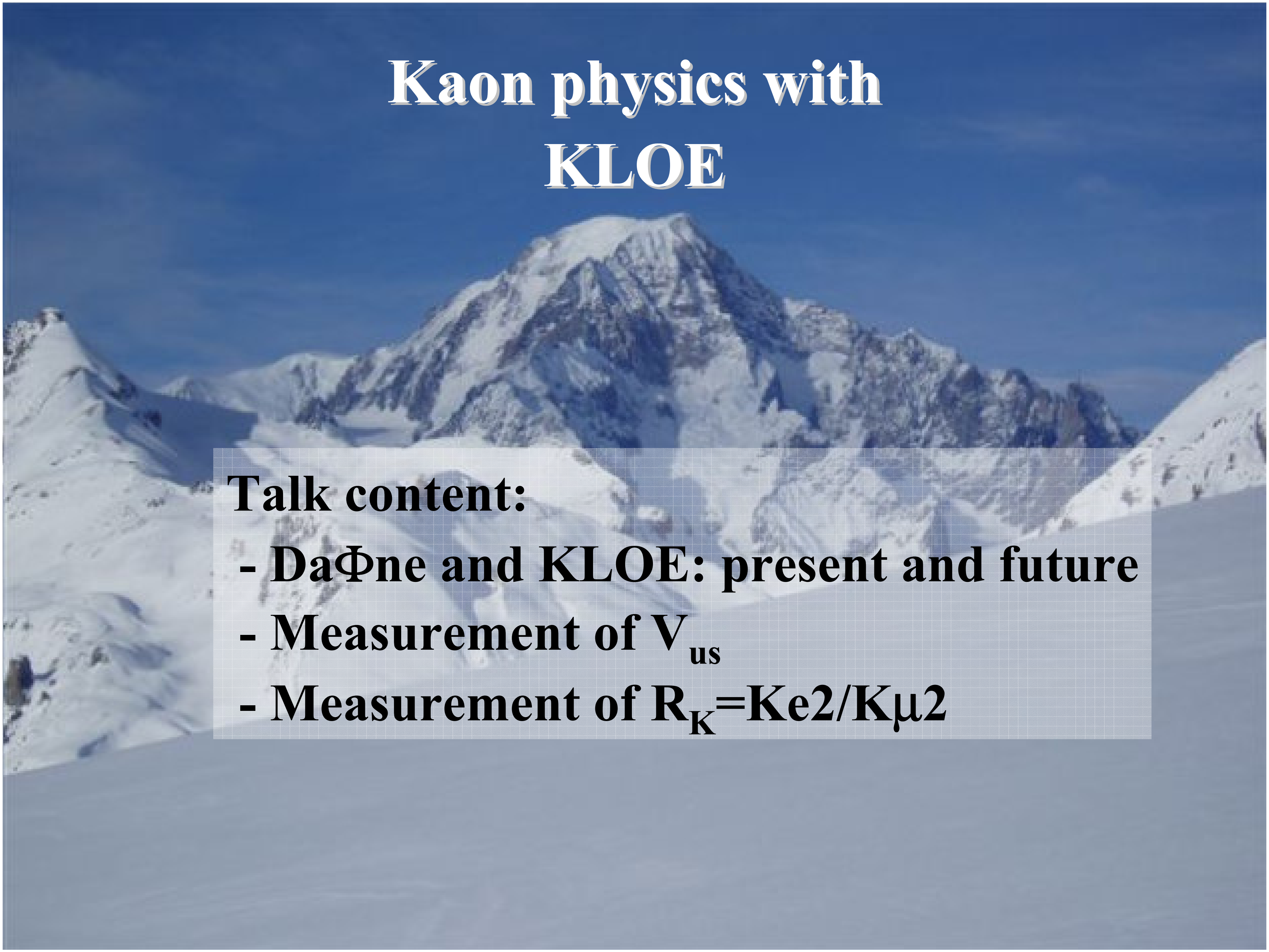


Kaon physics with KLOE

Barbara Sciascia, *LNF INFN*
for the KLOE collaboration

Les Rencontres de Physique de la Vallee d'Aoste
La Thuile – 4nd March 2010



Kaon physics with KLOE

Talk content:

- DaΦne and KLOE: present and future
- Measurement of V_{us}
- Measurement of R_K=Ke2/Kμ2

KLOE and DaΦne

e^+e^- collider, cm energy: **$\sqrt{s} \sim m_\phi$=1019.4 MeV**

Angle between the beams at IP: **$\alpha \sim$ 12.5 mrad**

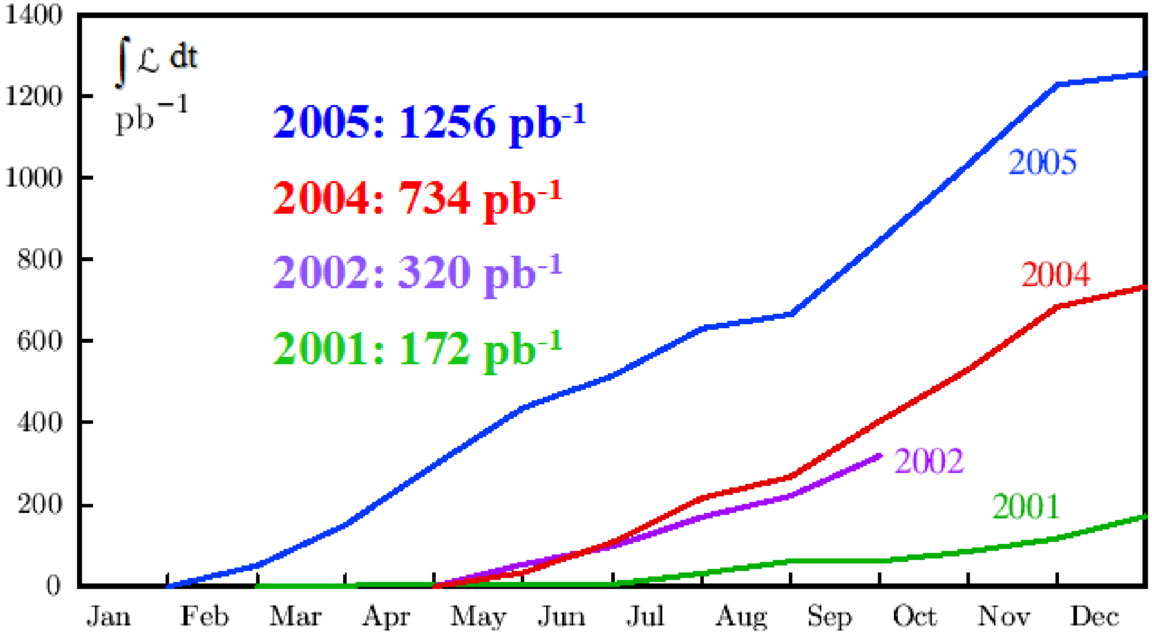
Residual laboratory momentum of ϕ: **$p_\phi \sim$ 13 MeV**

Cross section for ϕ production at peak: **$\sigma_\phi \sim$ 3.1 μb**

KLOE data taking completed (2001/5):

2.5 fb^{-1} integrated at $\sqrt{s}$=M(ϕ);

0.25fb^{-1} at $\sqrt{s}$~1GeV



Best of KLOE run:

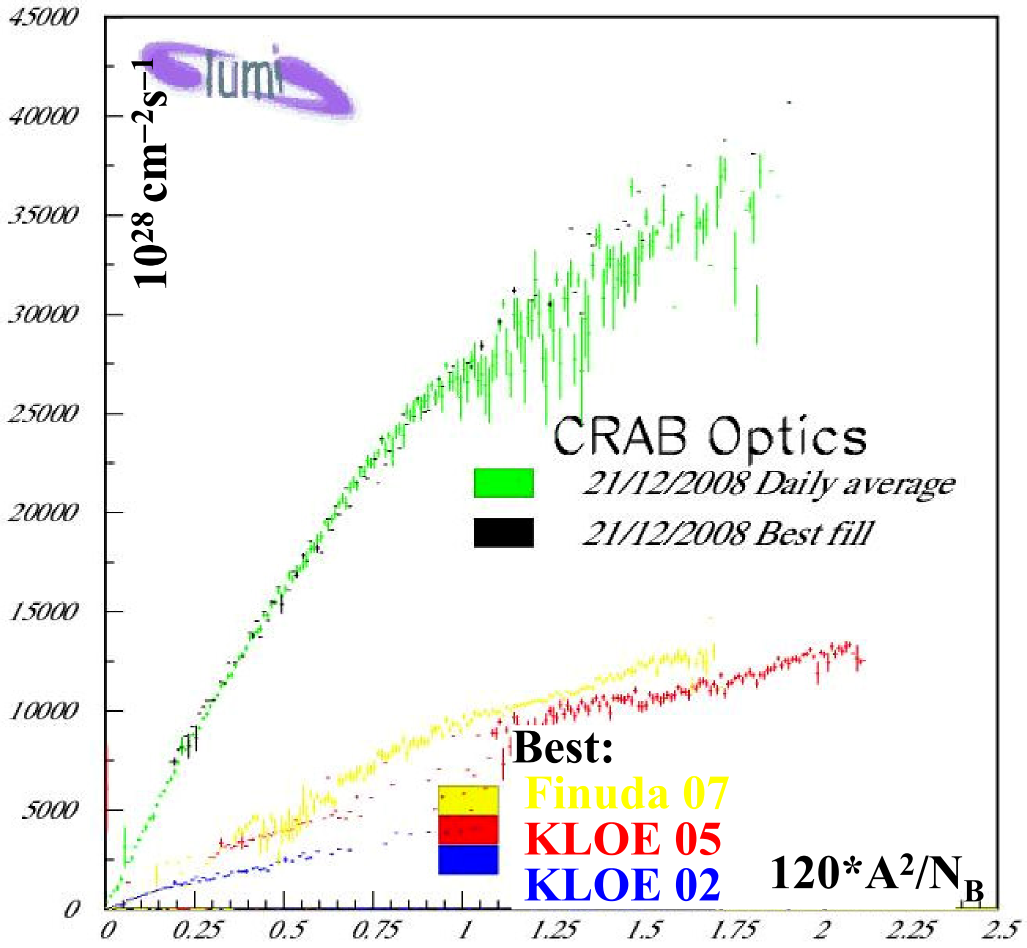
L_{PEAK}=1.4×10^{32} $cm^{-2}s^{-1}$

L_{INT}=8.5 pb^{-1}/day

KLOE and DaΦne

e^+e^- collider, cm energy: **$\sqrt{s} \sim m_\phi$=1019.4 MeV**

KLOE data taking completed (2001/5)



A novel collision scheme “**large Piwinsky angle and crabbed waist**” implemented:

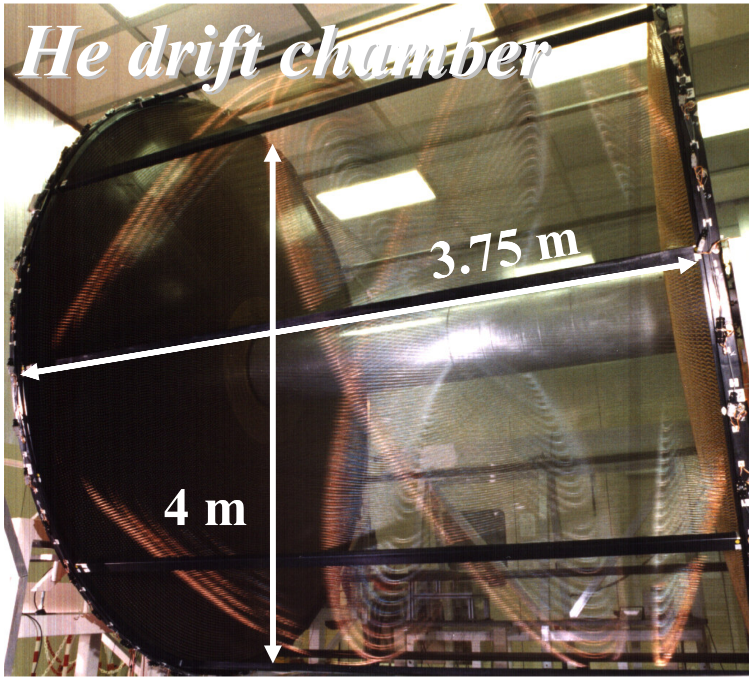
(**at least**) L ~3×

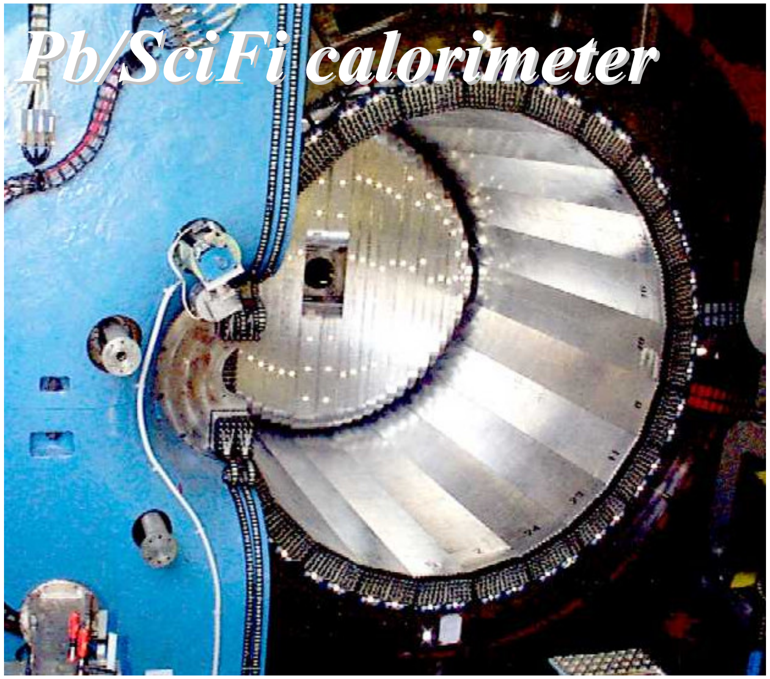
⇒ **Ldt~1pb^{-1}/hour**.

KLOE(2 step0) luminosity goal: 5 fb^{-1} at $\sqrt{s}$=M(ϕ)

The KLOE detector

Large cylindrical drift chamber + lead/scintillating-fiber calorimeter + superconducting coil providing a 0.52 T field





σ_p/p **0.4 %** (tracks with θ > 45°)

$\sigma(\mathrm{m_{KS}}) \leq$ **1 MeV**

σ_x^{hit} **150 µm (*xy*), 2 mm (*z*)**

$\sigma_x^{\mathrm{vertex}}$ **~1 mm**

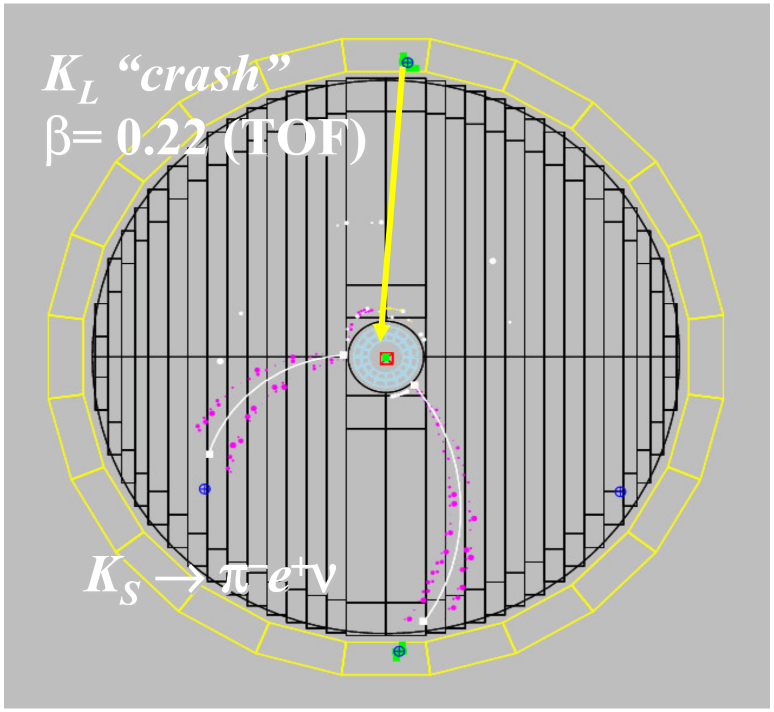
σ_E/E **5.7% /√*E*(GeV)**

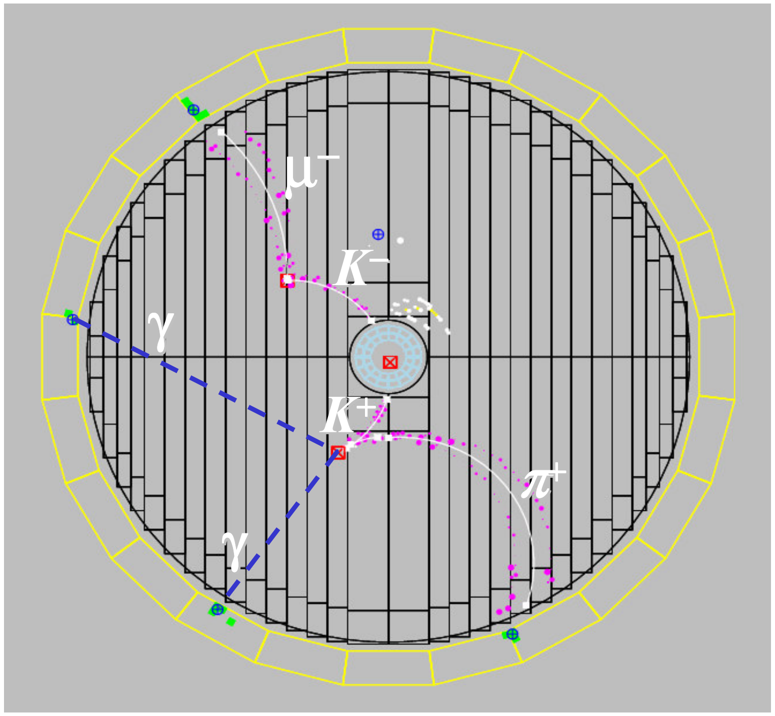
σ_t **54 ps /√*E*(GeV) ⊕ 140 ps**
(relative time between clusters)

$\sigma_L(\gamma\gamma)$ **~2 cm** (π^0 from $K_L \rightarrow \pi^+\pi^-\pi^0$)

Kaon physics at KLOE

- $K_S K_L$ (K^+K^-) pairs emitted ~back to back, p~110 MeV (~127 MeV)
- Identification of $K_{S,L}$ ($K^{+,-}$) decay (interaction) tags presence of $K_{L,S}$ ($K^{-,+}$)
- Almost pure $K_{S,L}$ and $K^{+,-}$ beams **of known momentum** + PID from kinematics and ToF.
- **Measurement of absolute BR, K Form Factors and lifetimes (~0.5 τ acceptance)**

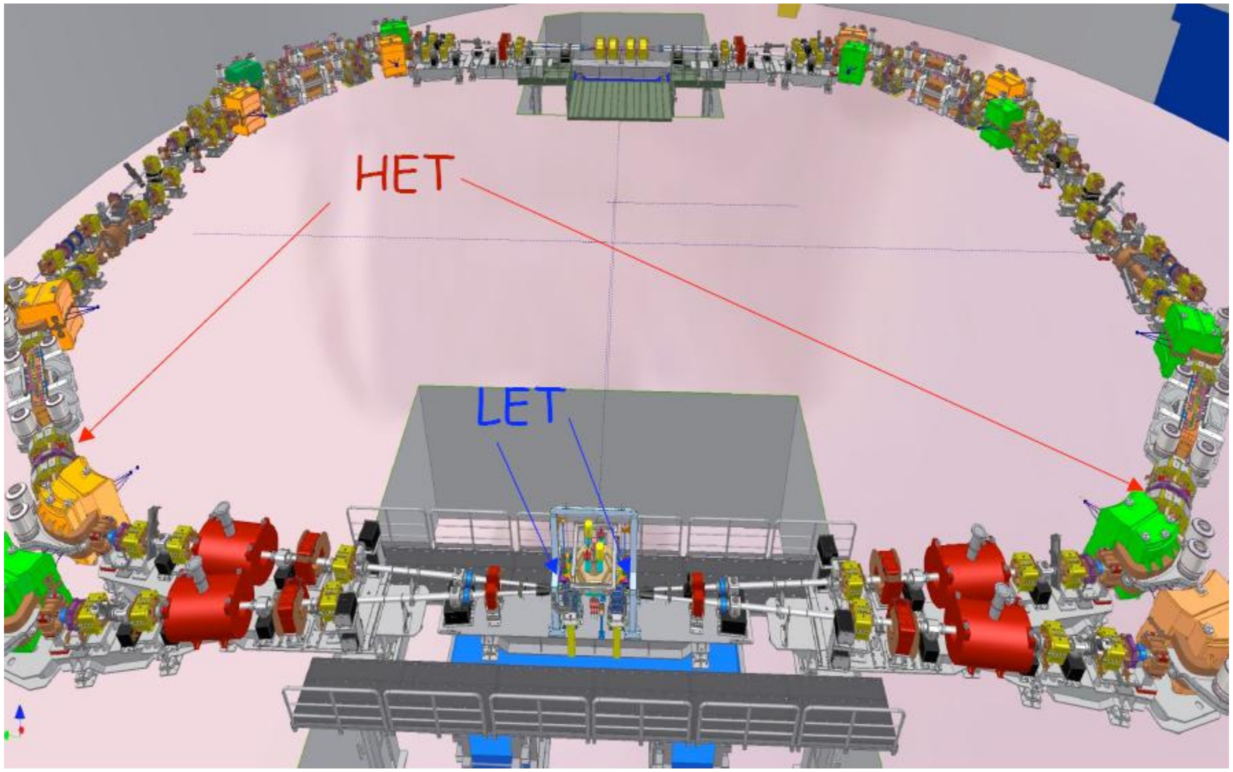




KLOE-2 Step 0

Roll-in (Dec 2009) and alignment (Jan 2010): done

Ready for resume data taking, foreseen for the 4th of May



Minimal **detector** upgrade: tagger for **γγ** physics: detect off-momentum $e^{\pm}$ from $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$ (where X=**ππ**, **π**^{0}, or **η**)

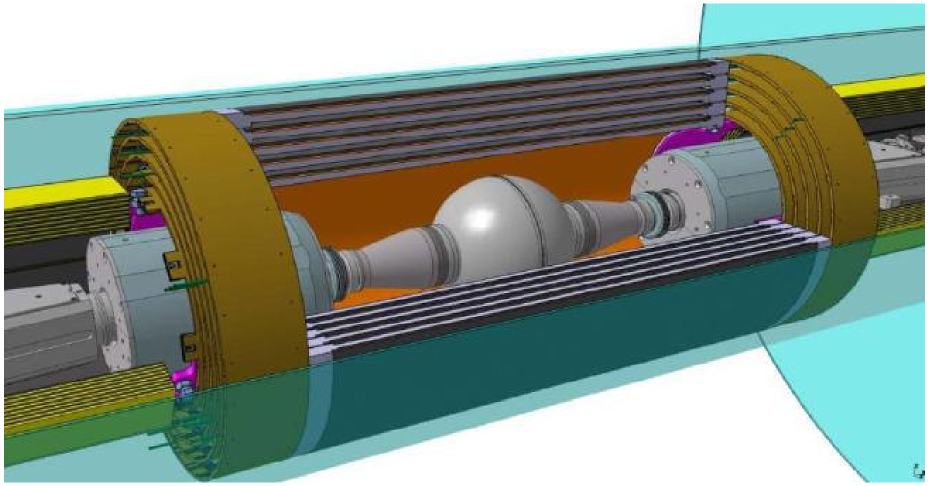
Low Energy Tagger (E_e=130-230 MeV) High Energy Tagger (E_e>400 MeV).

KLOE-2 Step 1

Luminosity goal > 20fb^{-1}.

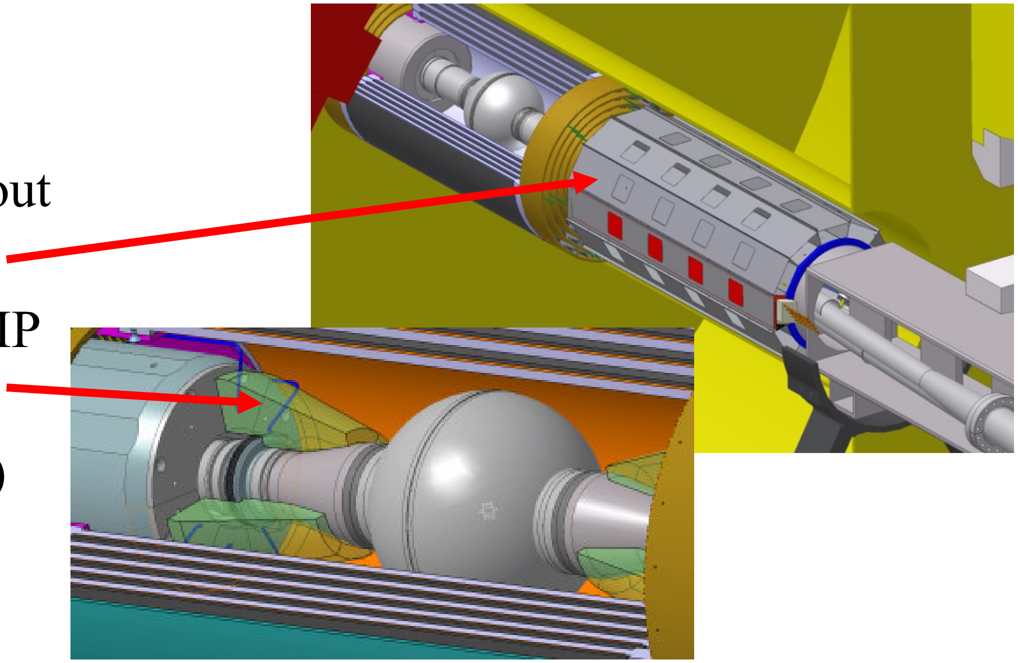
Major detector upgrade;

Inner tracker (IT) between the beam pipe and the DC: 4 layers of cylindrical triple GEM; improve vertex reconstruction efficiency near IP; increase acceptance for low momentum tracks.



QCALT: W plus scintillating tiles, readout by SiPM via WLS fibers

CCAL: LYSO crystals + APD, close to IP to increase the acceptance for photons coming from the IP (θ_{MIN} from 21° to 9°)



Installation: late in 2011

Test of quantum mechanics coherence

Study time evolution of KK decays into ππ–ππ final states, unique at ϕ factory

Test QM coherence: $I(\Delta t) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2(1 - \zeta_{S,L})\, e^{-(\Gamma_S + \Gamma_L)|\Delta\tau|/2} \cos(\Delta m \Delta t)$

$$K_{S(L)} \rightarrow \pi^+\pi^- \text{ at } t_1 \longleftarrow \phi \longrightarrow K_{L(S)} \rightarrow \pi^+\pi^- \text{ at } t_2$$

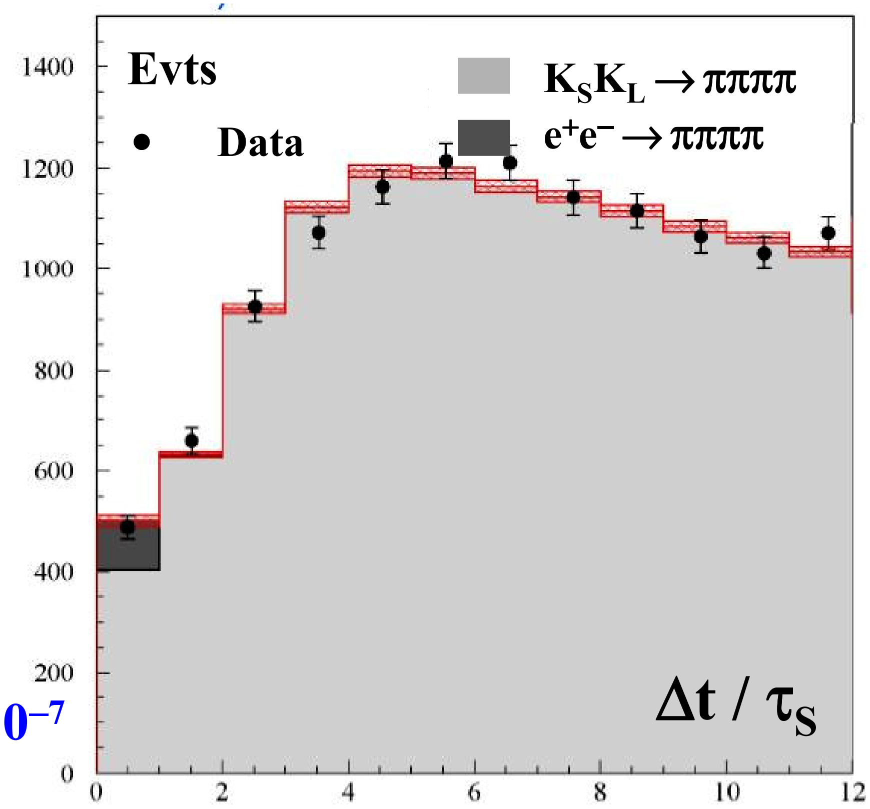
- $K_S K_L$ pairs produced from ϕ decays:

  antisymmetric, 1^{--} state

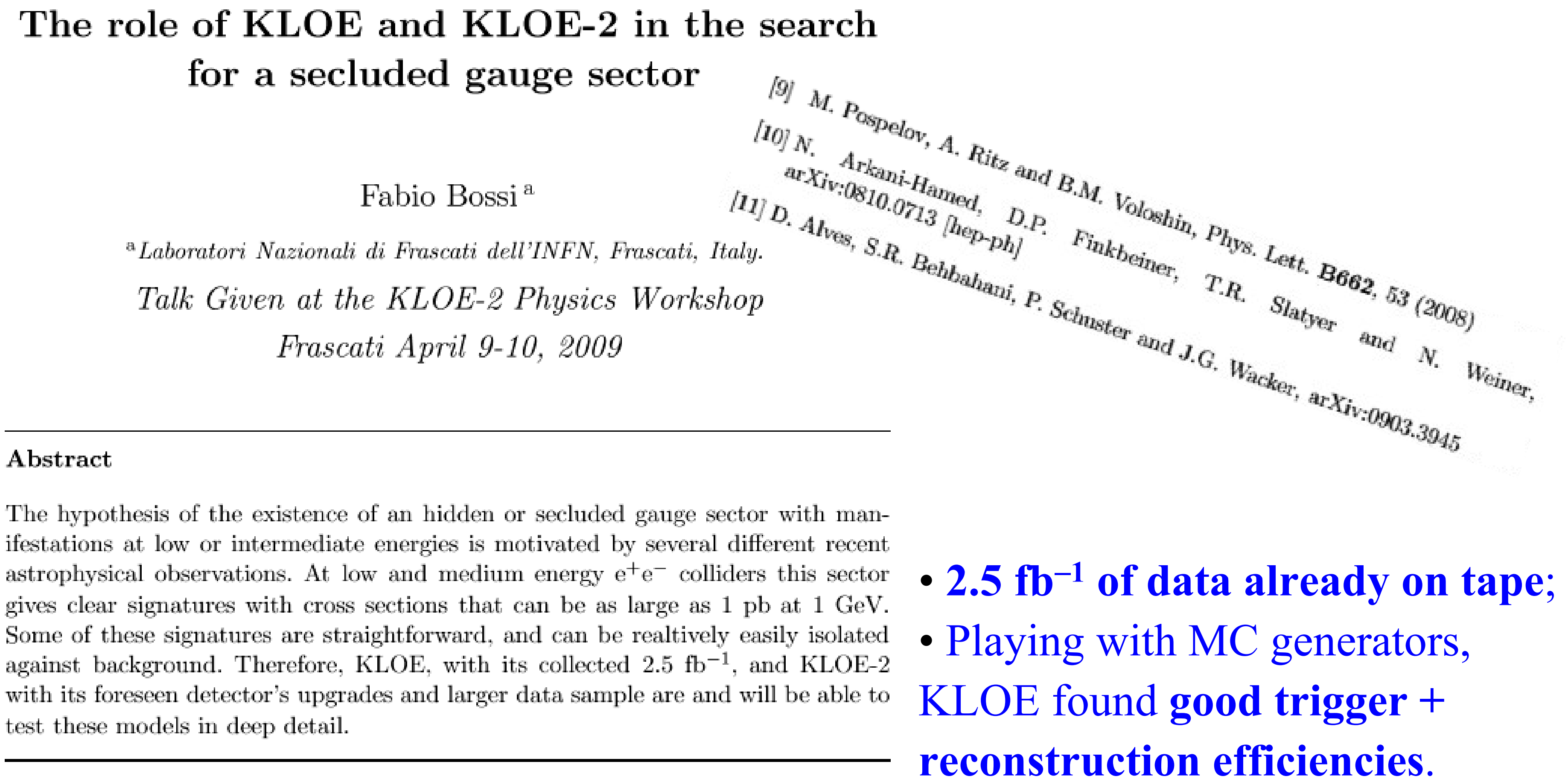
  for a **ππ-ππ** decay expect no events for Δt = 0
- **KLOE final:** $\zeta_{00}=(1.4\pm9.5_{stat}\pm3.8_{syst})\times10^{-7}$

  Compare with B system: $\zeta_{00}=(2.9\pm5.7)\times10^{-2}$

  Compare with quantum optics, $\sigma(\zeta_{00}) \sim 10^{-3}$
- **With IT (and 50 fb^{-1} on tape!) expect ±1× 10^{-7}**



Not only Kaons: Dark Matter search



The role of KLOE and KLOE-2 in the search for a secluded gauge sector

Fabio Bossi [a]

[a] *Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy.*

Talk Given at the KLOE-2 Physics Workshop
Frascati April 9-10, 2009

Abstract

The hypothesis of the existence of an hidden or secluded gauge sector with manifestations at low or intermediate energies is motivated by several different recent astrophysical observations. At low and medium energy e^+e^- colliders this sector gives clear signatures with cross sections that can be as large as 1 pb at 1 GeV. Some of these signatures are straightforward, and can be realtively easily isolated against background. Therefore, KLOE, with its collected 2.5 fb^{-1}, and KLOE-2 with its foreseen detector's upgrades and larger data sample are and will be able to test these models in deep detail.

[9] M. Pospelov, A. Ritz and B.M. Voloshin, Phys. Lett. **B662**, 53 (2008)
[10] N. Arkani-Hamed, D.P. Finkbeiner, T.R. Slatyer and N. Weiner, arXiv:0810.0713 [hep-ph]
[11] D. Alves, S.R. Behbahani, P. Schuster and J.G. Wacker, arXiv:0903.3945

- **2.5 fb^{-1} of data already on tape**;
- Playing with MC generators, KLOE found **good trigger + reconstruction efficiencies**.
- Can profit of many analysis tools developed for already published results (σ_{HAD}, η-ology, …)

First results in near future…

NP test from (semi)leptonic K decays

Measurements of K → πlν, lν decays can shed light on NP BSM

Precise determination of V_{us} from BR's for K → πlν, ff slopes, etc.:

allows most precise test of unitarity of the CKM matrix

translates into a severe constraint for many NP models

Test of SM from $\Gamma(K_{\mu 2})/\Gamma(\pi_{\mu 2})$:

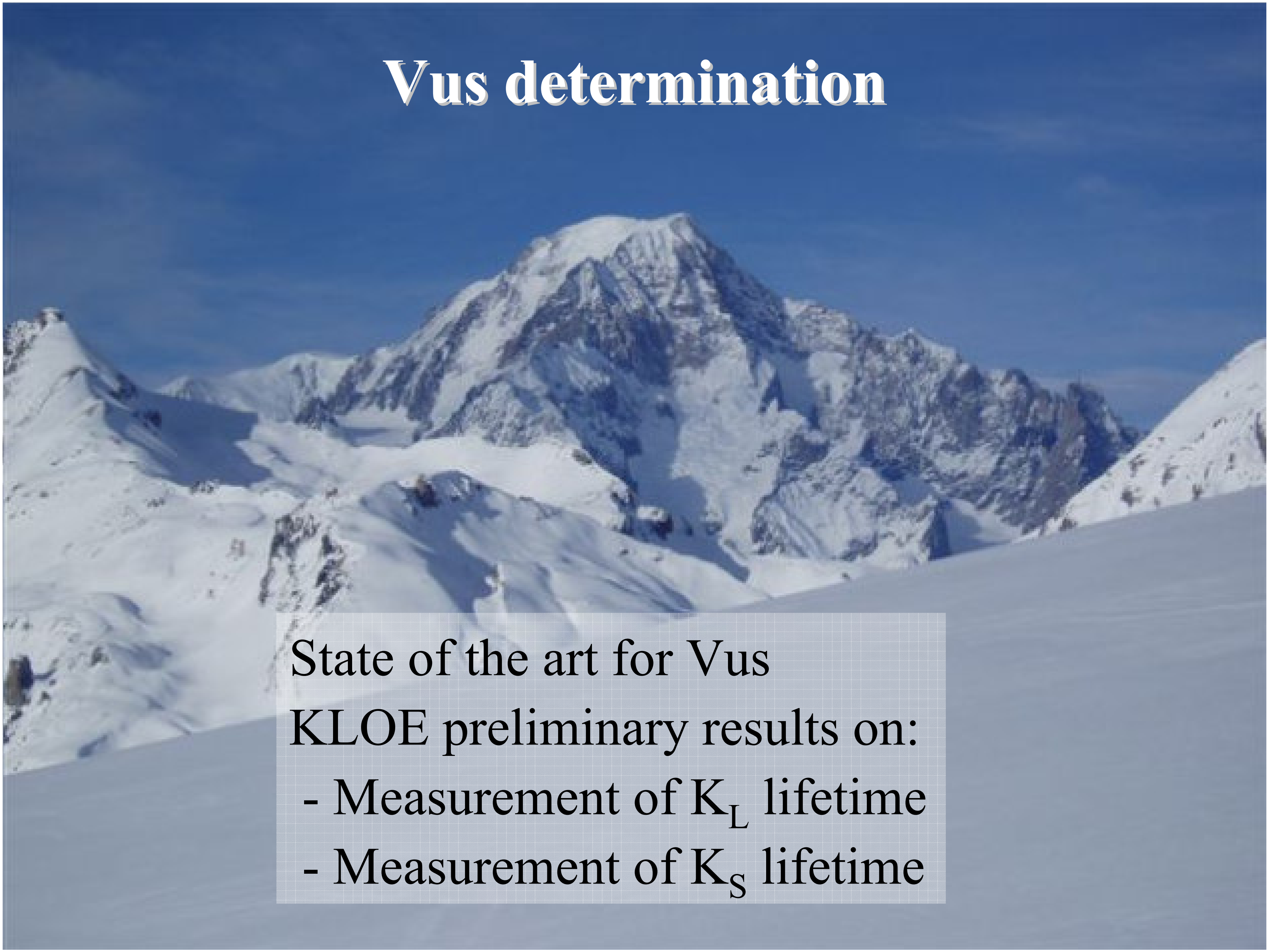
probes NP RH contributions to charged weak currents

probes H^+ exchange in every SM extension with 2 Higgs doublets

LF violation test from $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$:

sensitive to NP effects, which might be at % level wrt SM prediction

Vus determination



State of the art for Vus

KLOE preliminary results on:

- Measurement of K_L lifetime
- Measurement of K_S lifetime

Extraction of V_{us} from K_{l3} decays

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2\, G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2\, |f_+(0)|^2\, I_{K,l}(\lambda)\, (1+\delta_K^{SU(2)}+\delta_{K,l}^{EM})^2$$

(with $K = K^+, K^0$; $l = e, \mu$ and $C_K^2 = 1/2$ for K^+, 1 for K^0)

	Theory			Experiment
Decay Rate				$\Gamma(K_{l3(\gamma)})$ BR and lifetimes
Form Factor	$f_+(0)$ Hadronic matrix element at zero momentum transfer			$I_{K,l}(\lambda)$ Phase space: λ param. form factor dependence on t
Corrections	S_{EW} short distance EW	$\delta_K^{SU(2)}$ strong SU(2) breaking	$\delta_{K,l}^{EM}$ long distance EM	

KLOE measurement of K parameters

$K_{S\,e3}$	**PLB 636 (2006) 173**
$K_S \to \pi\pi$	**EPJC 48 (2006) 767**
$K_S \to \gamma\gamma$	**JHEP 05(2008) 051**

K_S BRs

K_L **decay distribution** (τ)	**PLB 626 (2005) 15**
K_L **decays and lifetime**	**PLB 632 (2006) 43**
$K_L \to \pi^+\pi^-$	**PLB 638 (2006) 140**
$K_L \to \gamma\gamma$	**PLB 566(2003) 61**
K^0 **mass**	**JHEP 12(2007) 073**
$K_{Le3\gamma}$	**EPJC 55 (2008) 539**
$ff\ K_{Le3}$	**PLB 636 (2006) 166**
$ff\ K_{L\mu3}$	**JHEP 12(2007) 105**

K_L BRs

lifetime

FFs

$K^+_{\mu2}$	**PLB 632 (2006) 76**
K^+ **lifetime**	**JHEP 01(2008) 073**
K^+_{l3}	**JHEP 02(2008) 098**
K^+_{τ}	**PLB 597 (2004) 139**
$K^+_{\pi2}$	**PLB666 (2008) 305**

$K^\pm$ BRs

lifetime

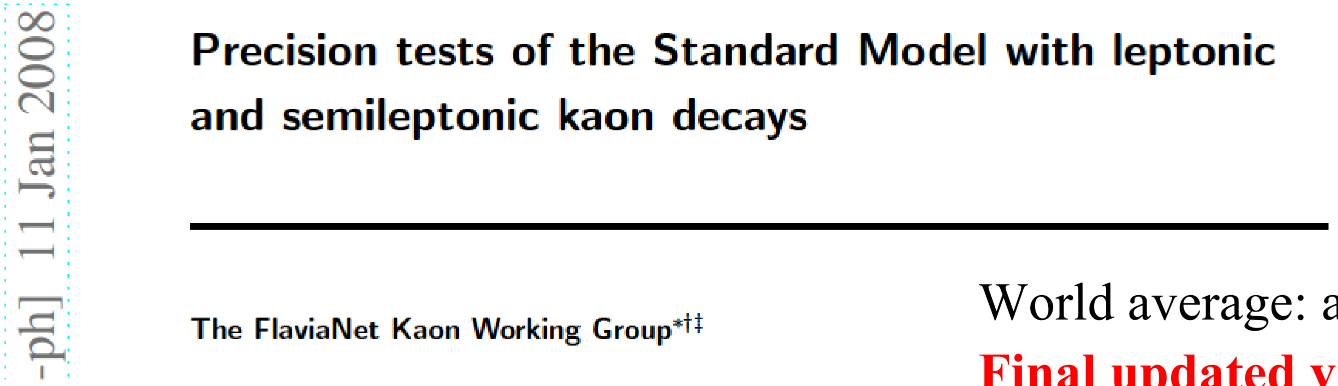
V_{us} and CKM unitarity

Kaon WG

- World data for K→πlν BR's quite satisfactory. determined by experiments with very different techniques:

KLOE@DaΦne: pure K beams, lifetimes, absolute BR
NA48@CERN: intense K^0, K^+ beams from SPS proton beam, ratio of BR's
KTeV@FermiLab: intense K_L beam from Tevatron proton beam, ratio of BR's
ISTRA+@IHEP (Protvino): ratio of K^+l3 BR's

- …and the **theoreticians**!
- **FlaviaNet Kaon Working Group: do the dirty job of putting all together…**



-ph] 11 Jan 2008

Precision tests of the Standard Model with leptonic and semileptonic kaon decays

The FlaviaNet Kaon Working Group*†‡

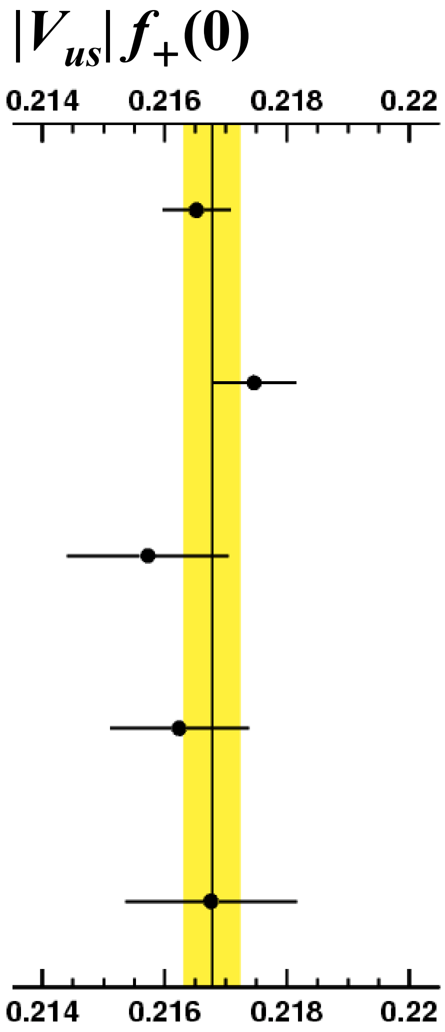
World average: arXiv:0801.1817.

Final updated version ready!

Disclaimer: results on Vus CKM,… are from FlaviaNet Kaon WG, @KAON09

FlaviA net Kaon WG

$|V_{us}|f_+(0)$ *from* K_{l3} *data*



			Approx. contrib. to % err from:			
		% err	**BR**	**τ**	**Δ**	**Int**
K_Le3	**0.21652(56)**	**0.25**	0.11	**0.20**	0.11	0.10
$K_L\mu3$	**0.21746(69)**	**0.32**	0.17	**0.19**	0.11	0.15
K_Se3	**0.21572(132)**	**0.61**	**0.60**	0.03	0.11	0.10
$K^\pm e3$	**0.21624(113)**	**0.52**	**0.31**	0.06	**0.41**	0.09
$K^\pm\mu3$	**0.21676(141)**	**0.65**	**0.48**	0.06	**0.41**	0.15

@KAON09

Average: $|V_{us}|\,f_+(0) = 0.21660(47)$ $\chi^2/\text{ndf} = 3.03/4\ (55\%)$

$|V_{us}| f_+(0)$: $K^\pm$ vs $K_{L,S}$

Fit 5 modes with separate values of $|V_{us}|\, f_+(0)$ for $K^\pm$ and $K_{L,S}$ modes

- Using results of overall fit to form-factor slopes
- With $SU(2)$ corrections for $K^\pm$ modes **[$\Delta^{SU(2)}_{\text{theory}} = 2.9(4)\%$]**

$K^\pm$ modes

$|V_{us}|\, f_+(0) = 0.2163(11)$

↔

$K_{L,S}$ modes

$|V_{us}|\, f_+(0) = 0.2167(5)$

0.3σ difference

$\chi^2/\text{ndf} = 2.9/3\ (41\%)$ $\rho = 0.04$

When fit performed without $SU(2)$ corrections for $K^\pm$ modes, obtain an experimental value for $\Delta^{SU(2)}$

$K^\pm$ modes, no $SU(2)$

$|V_{us}|\, f_+(0) = 0.2226(7)$

$\Delta^{SU(2)}_{\text{exp}} = 2.7(4)\%$

K_{l3} data and lepton universality

For each state of kaon charge, we evaluate:

$$r_{\mu e} = \frac{(R_{\mu e})_{\rm obs}}{(R_{\mu e})_{\rm SM}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{[|V_{us}|\,f_+(0)]^2_{\mu 3,\,\rm obs}}{[|V_{us}|\,f_+(0)]^2_{e3,\,\rm obs}} = \frac{g_\mu^2}{g_e^2}$$

Modes	2004 BRs*	This fit
$K^\pm$	1.016(12)	1.005(9)
$K_{L,S}$	1.056(15)	1.009(6)

*Assuming current values for form-factor parameters and $\Delta^{\rm EM}$; K_S not included

Average *Kl3*

$r_{\mu e} = 1.008(5)$

Without NA48 Kμ3:
$r_{\mu e}$=1.002(5)

To be compared with pure leptonic processes,
$\tau \to l\nu\nu$ decays: $(R_{\mu e})_\tau = 1.000(4)$

[Davier, Hocker, Zhang 06]

and with $\pi \to l\nu$ decays: $(R_{\mu e})_\pi = 1.0042(33)$

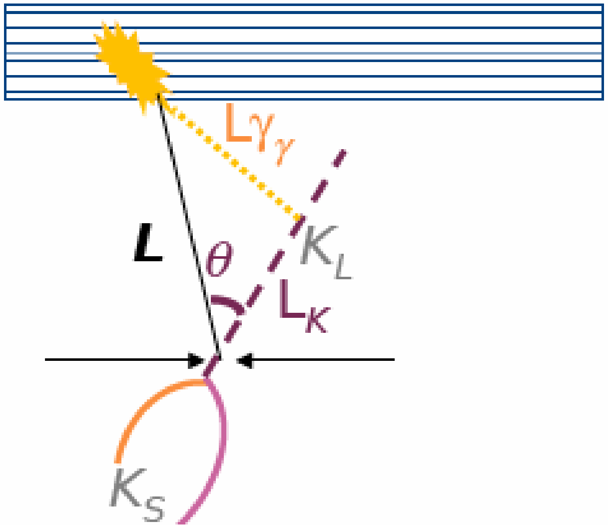
[Ramsey-Musolf, Su, Turlin 07]

K_L lifetime measurement

Previous measurements from KLOE:

- direct ($d\tau/\tau$~0.6%) $\tau_L = 50.92 \pm 0.17 \pm 0.25$ ns
uses 10 M KL→$\pi^0\pi^0\pi^0$ events from 2001-2002 data
[PLB 626(2005)15]

- indirect ($d\tau/\tau$~0.6%) $\tau_L = 50.72 \pm 0.11 \pm 0.35$ ns
uses constraint $\Sigma BR(K_L)=1$ [PLB 632(2006)43]

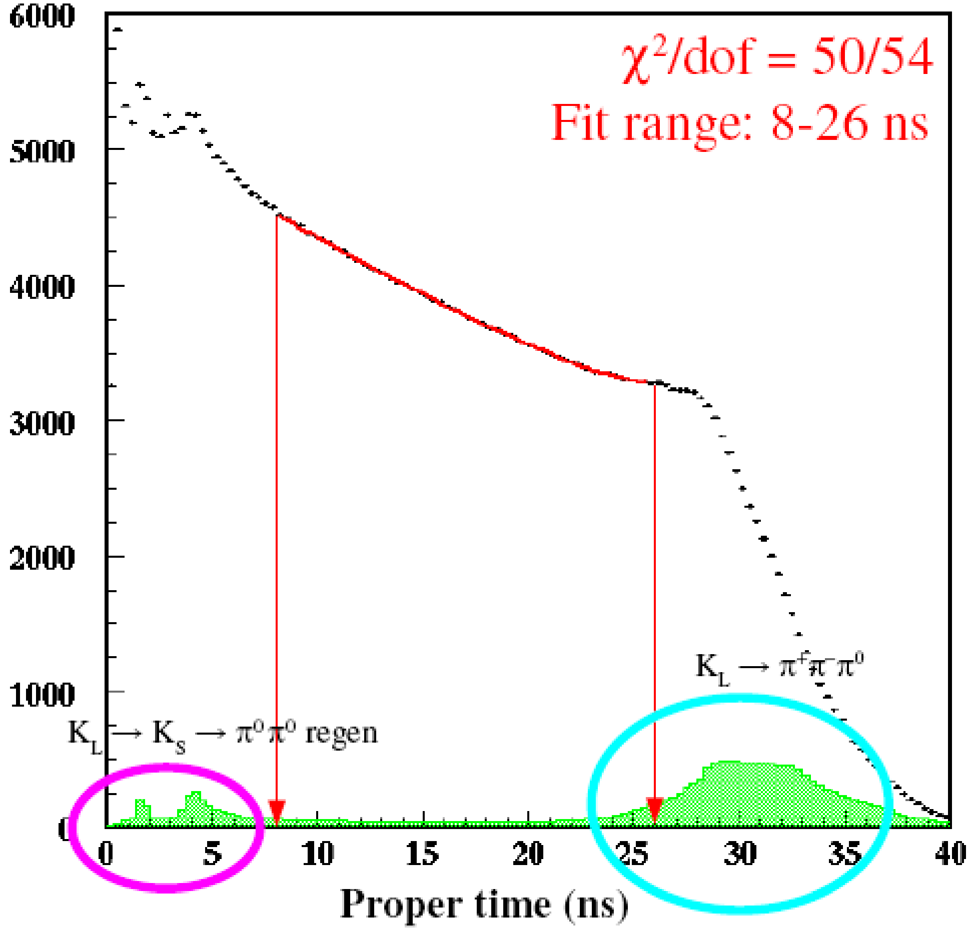


Method (direct measurement):

Reconstruction of $K_S \to \pi^+\pi^-$ determines K_L momentum within 1 MeV and 1°
K_L decay vertex reconstruction from the neutral clusters of the calorimeter

To reconstruct the K_L vertex, require at least 3 photons from the $\pi^0\pi^0\pi^0$ decay.
Reconstruction efficiency for $K_L \to \pi^0\pi^0\pi^0$ with $N\gamma \geq 3$ is high and uniform over a broad interval on L_K.

K_L lifetime measurement



In the fit region:

data events 46 M

background after cuts:1.8%

selection efficiency and

background taken into account

Statistical error can be improved by decreasing the lower limit of the fit region, taking into account the K_L beam losses on the detector material (beam pipe and inner DC wall)

Result for K_L lifetime measurement

Result: τ_L = **$50.56 \pm 0.14_{STAT} \pm 0.21_{SYST}$ ns** **(preliminary)**

Systematics source	$\Delta\tau/\tau_L$(%)	$\Delta\tau$(ns)
Tag efficiency	0.34	0.17
Preselection efficiency	0.10	0.08
Selection efficiency	negligible	negligible
Time scale	0.12	0.06
Nuclear interacions	0.16	0.08
Total		0.21

Compare with previous KLOE results, taking correlation into account:

-1.4σ from direct

-0.4σ from indirect

Way to final result:

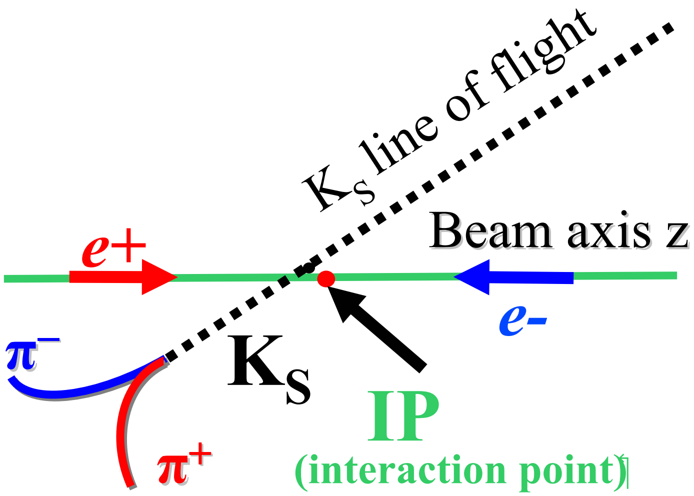
- **whole statistics, →0.11_{STAT} ns**
- **reduce systematic error on tag eff.**

Measurement of the K_S lifetime

First measurement with pure K_S beam and with an event-by-event knowledge of K_S momentum (plus ϕ-position known event-by-event);

Lifetime from fit to proper time t_0 distribution of $K_S \to \pi^+\pi^-$ decay;

$$t^* = \frac{L}{\beta\gamma c} = \frac{LM_K}{pc}$$



Selection:

require good tracking fit for π's;

$|M_{\pi+\pi-} - M_K| < 2$ MeV (~2σ);

Acceptance cuts to improve vertex resolution;

After all cuts, ~25 million decay events.

(data sample: 730 pb^{-1} (2004 data)

Redundant determination of K_S momentum:

from pion tracks: $p_S(\pi\pi)$;

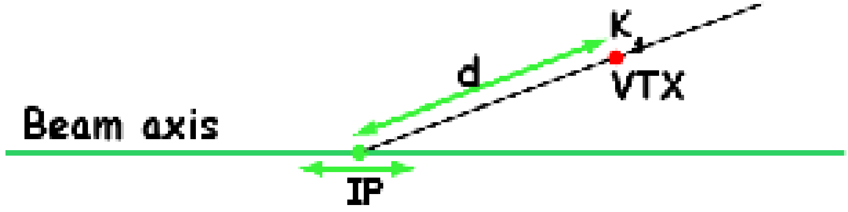
by using information from line of flight and sqrt(s): p_S(boost).

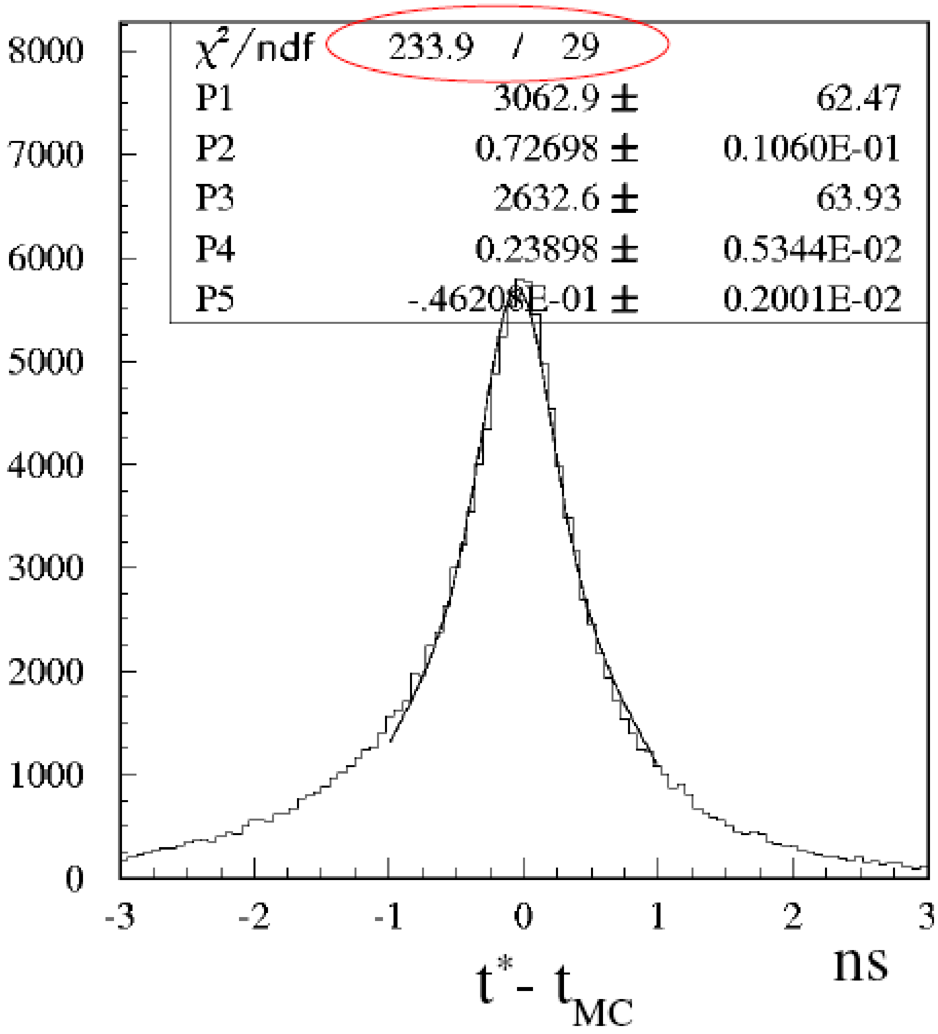
Raw time resolution for K_S sample

Way to improve time resolution:

- Use only well measured tracks: cut on the χ^2 value from the track fit
- Quality cuts on $\pi\pi$ track system.
- Optimize the selection criteria, requiring pions to decay at large angle wrt the K_S line of flight

- Improve reconstruction of IP event-by-event using full geometrical fit





Time resolution for K_S sample

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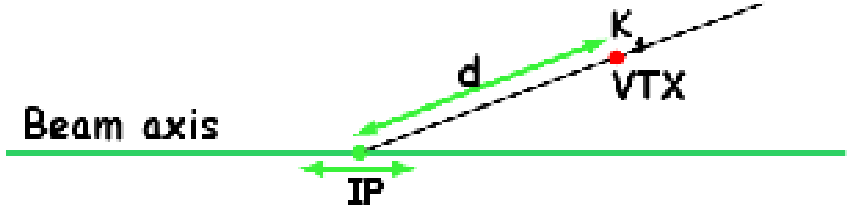
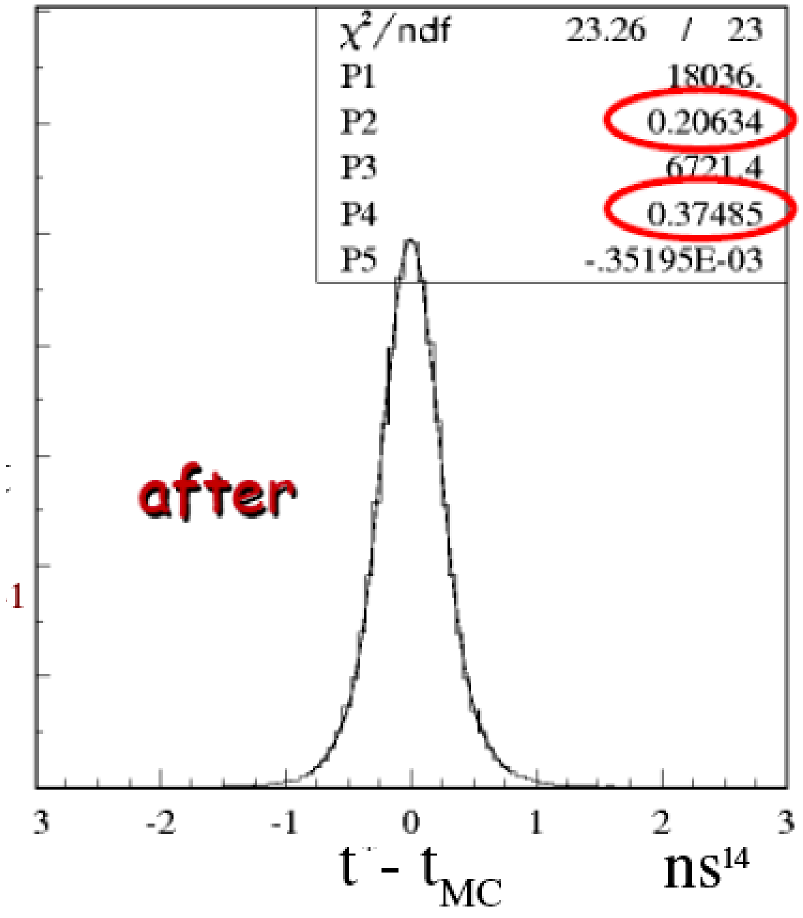
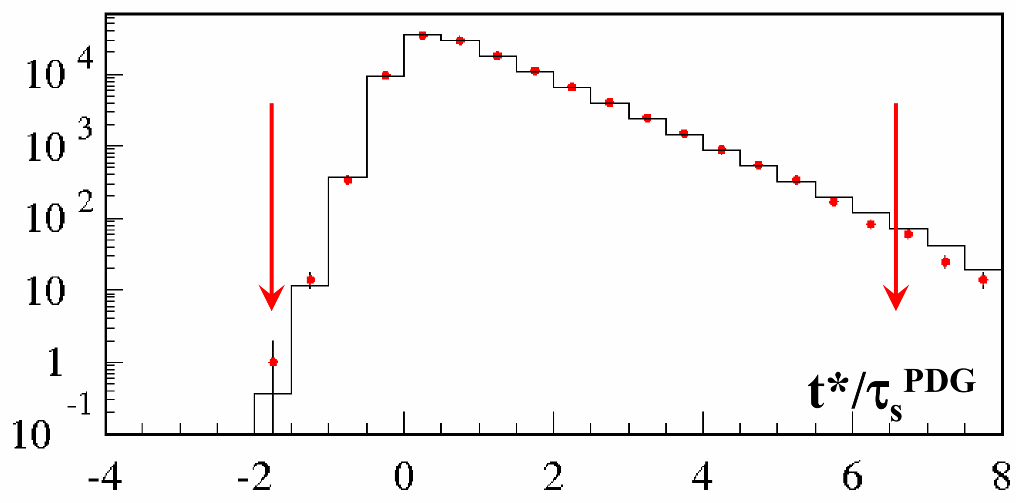


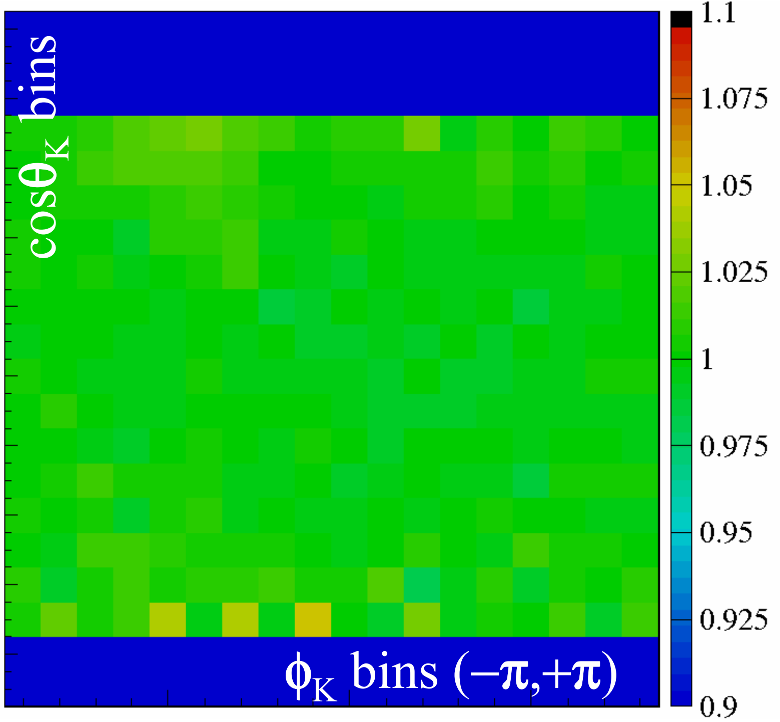


Fit to the K_S lifetime

Resolution depends on K beam direction ⇒
fit done for each of 270 bins in $\cos\theta_K$ and ϕ_K
(this allows **also** to measure τ_S as a function
of sidereal coordinates, interesting to test QM,
CPT and Lorentz invariance).

bin fit results for t^*/τ_s^{PDG}.

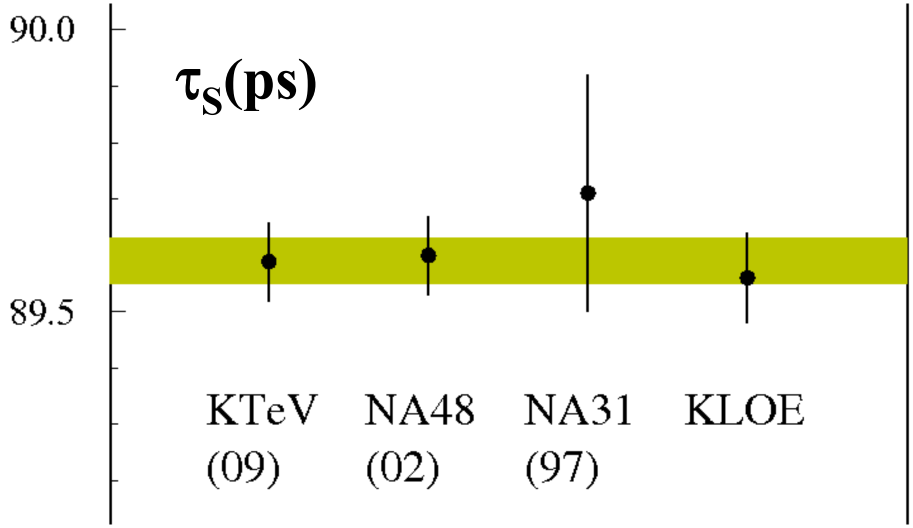




Fit range: from -2 to 7 t^*/τ_s.
Fit function: exponential convoluted with two gaussians (5 parameters: lifetime, 2 normalizations, 2 widths)

Result for K_S lifetime measurement

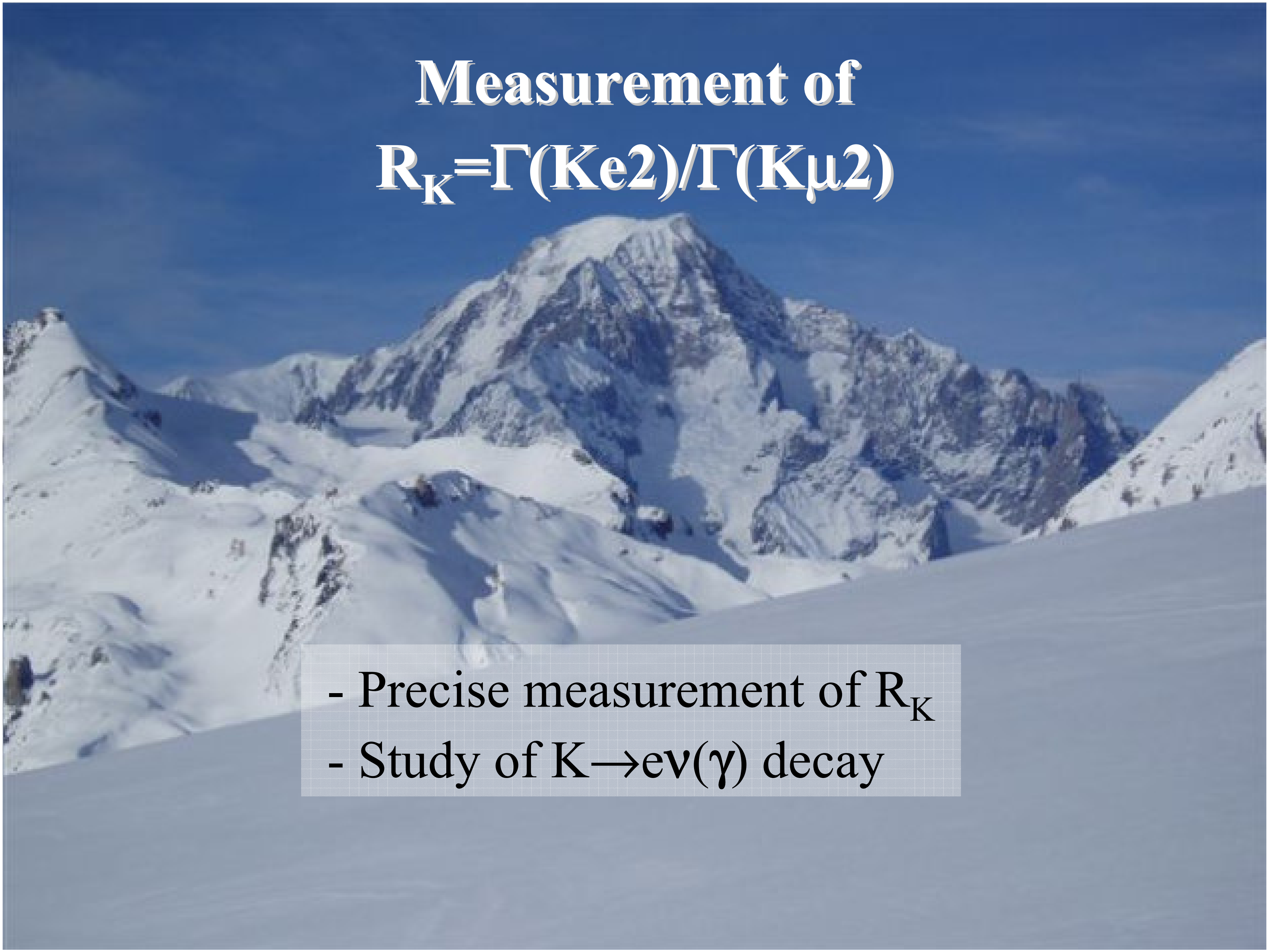
Result: $\tau_S = 89.56 \pm 0.03_{STAT} \pm 0.07_{SYST}$ ps **(preliminary)**



Systematic source	$(\tau/\tau_S \times 10^{-4})$
Selection cuts	3.3
$\cos\theta_K$ cut	5.7
Momentum calibration	0.4
Fit range	5.0

New world average: 89.59(4) ps; 4.6×10^{-4} accuracy, (to be comapred with 5.6×10^{-4}, PDG08)

Way to final result:
- **complete systematic study of selection cuts and fit**



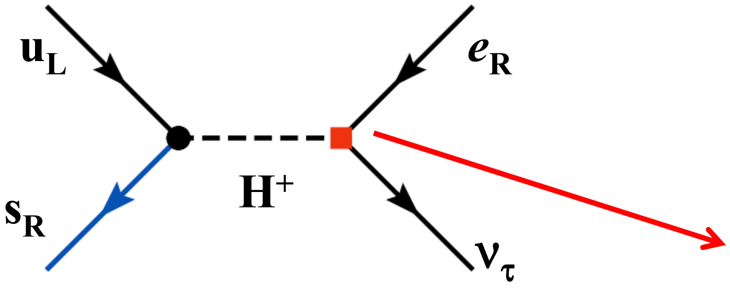
Measurement of $R_K=\Gamma(Ke2)/\Gamma(K\mu2)$

- Precise measurement of R_K
- Study of $K\rightarrow e\nu(\gamma)$ decay

NP potential of $R_K = \Gamma(K^{\pm}_{e2})/\Gamma(K^{\pm}_{\mu2})$

- SM prediction with 0.04% precision, benefits of cancellation of hadronic uncertainties (no f_K): **R_K=2.477(1)×10^{-5}** [*Cirigliano Rosell arXiv:0707:4464*].

- Helicity suppression can boost NP [*Masiero-Paradisi-Petronzio PRD74(2006)011701*].

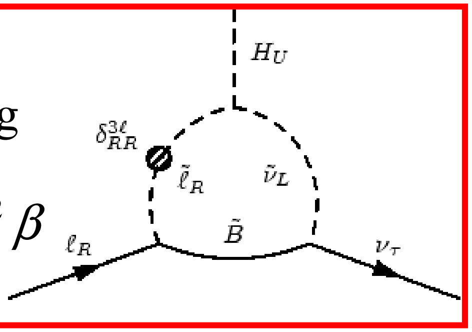


$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \approx \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}$$

$$R_K^{LFV} \approx R_K^{SM}\left(1 + \frac{m_K^4}{m_H^4}\frac{m_\tau^2}{m_e^2}\left|\Delta_R^{31}\right|^2 \tan^6\beta\right)$$

LFV from loop generates an effective $eH^+\nu_\tau$ coupling

$$eH^+\nu_\tau \to \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_R^{31}\tan^2\beta$$

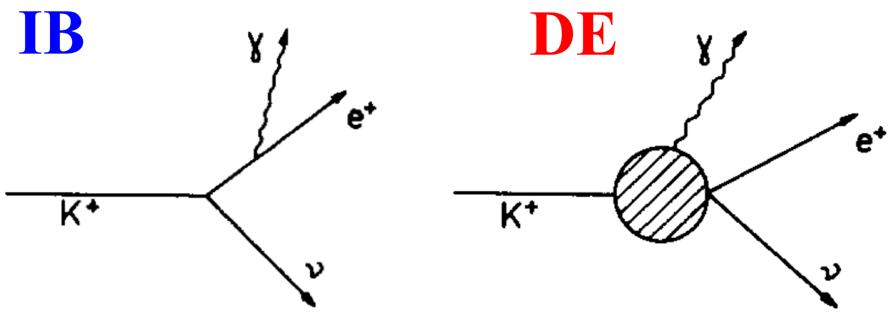


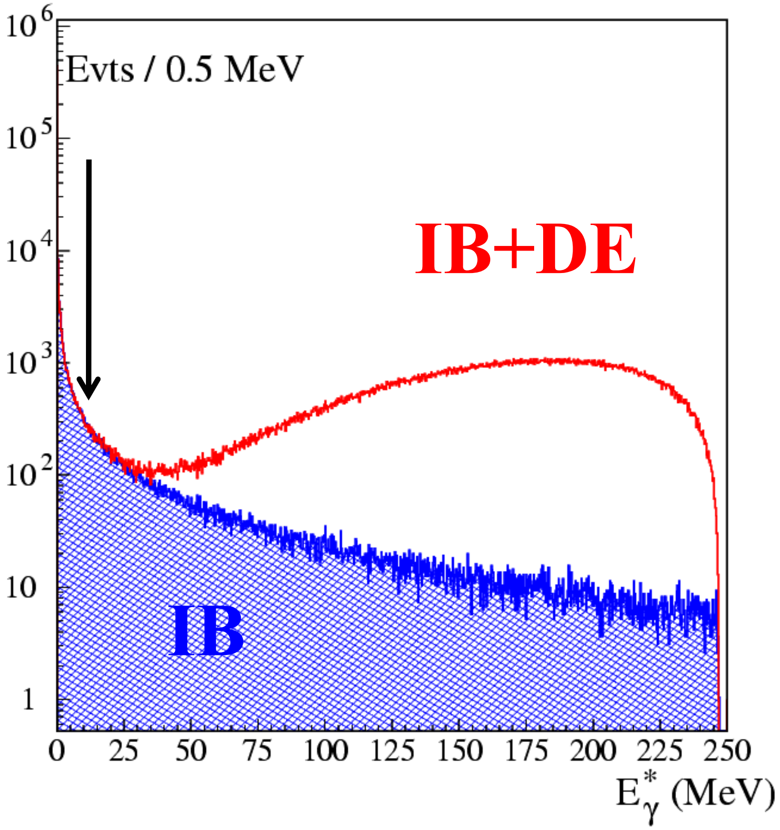
LFV can give **O(1%) deviation from SM (Δ_R^{31}~5×10^{-4}, tanβ ~40, m_H ~ 500 GeV)**

- Experimental accuracy on R_K (before KLOE and NA62 results) at 5% level.
- Measurements of R_K can be very interesting, **if error at 1% level or better**.

Ke2(γ): signal definition

SM prediction is defined to be inclusive of **IB** (ignoring **DE** contributions).





From theory (ChPT) expect **DE** ~ **IB** for Ke2, but experimental knowledge is poor: **δDE/DE~15%**

- **Define as "signal" events with E_γ<10 MeV**.
- Evaluating **IB** spectrum (O(α)+resummation of leading logs) obtain a 0.0625(5) correction for the IB tail.
- Under 10 MeV, the **DE** contribution is expected to be negligible.

Charged kaon at KLOE

ϕ decay at rest provides pure kaon beams of know momentum

$p_K \sim 100$ MeV

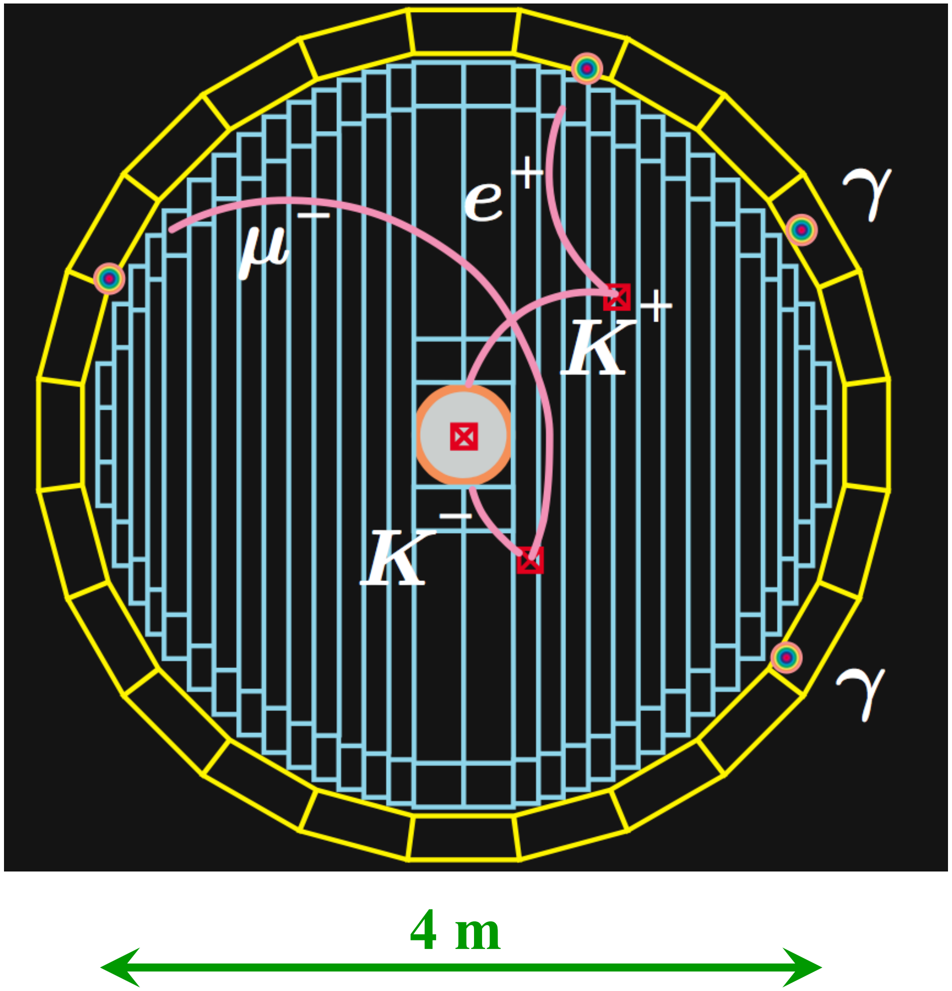
$\lambda \sim 90$ cm (56% of $K^\pm$ decay in DC).

Kaon momentum measured (event by event) with 1 MeV resolution in DC.

Constraints from ϕ 2-body decay.

Particle ID with kinematics and ToF.

Tagging provides unbiased control samples for efficiency measurement.

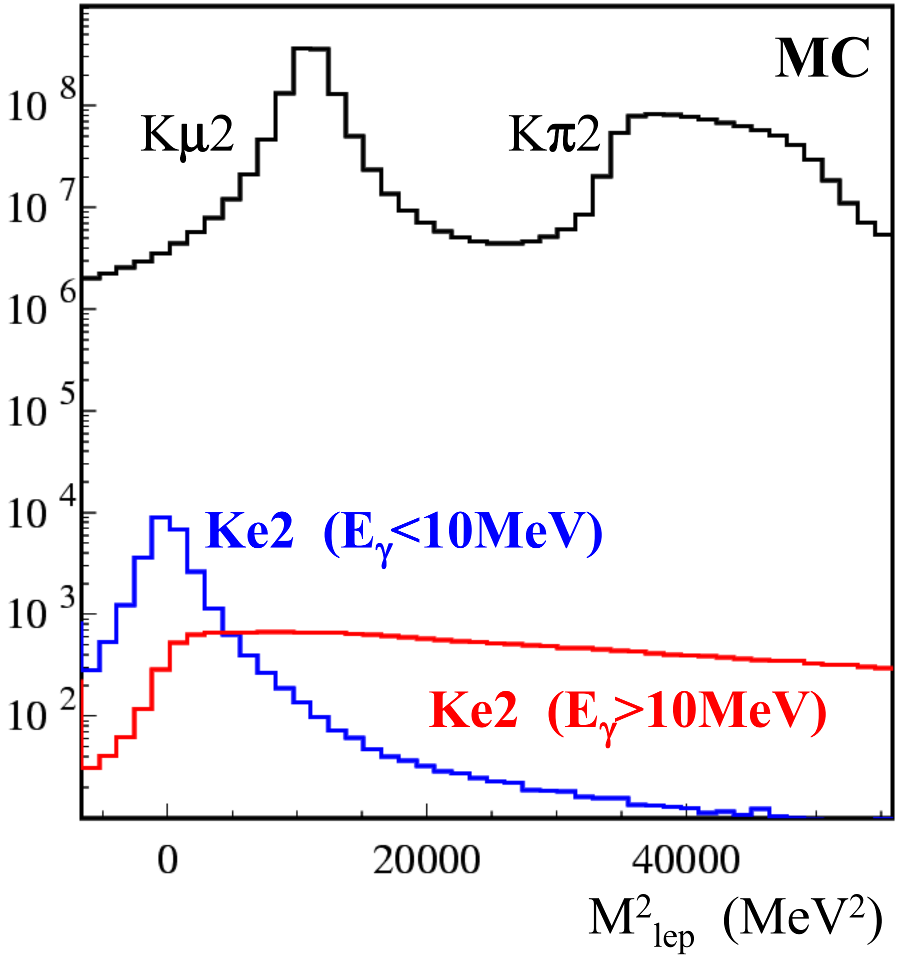


Analysis basic principles

From K and secondary tacks and assuming m_ν=0, get M^2_{lep}:

$$\mathbf{M^2_{lep} = (E_K - p_{miss})^2 - p^2_{lep}}.$$

Around M^2_{lep}=0 we get **S/B ~ 10^{-3}**, mainly due to tails on the momentum resolution of Kμ2 events.



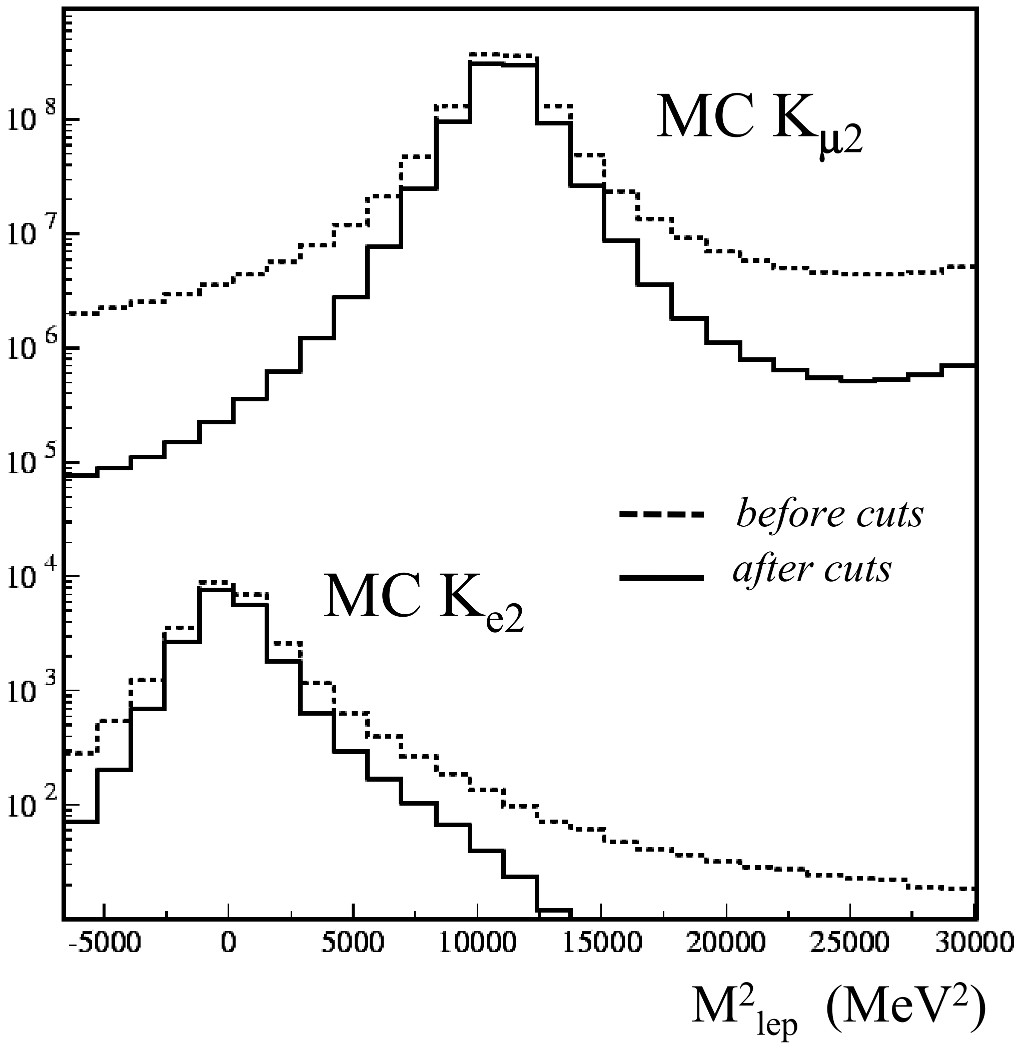
Background rejection (track quality)

- after cuts, we accept ~35% of decays in the FV

- most of Ke2 events lost have bad resolution

- **S/B ~ 1/20**, not enough!

- require the lepton track to be extrapolable to the calorimeter surface and to be associated to an energy release (cluster).



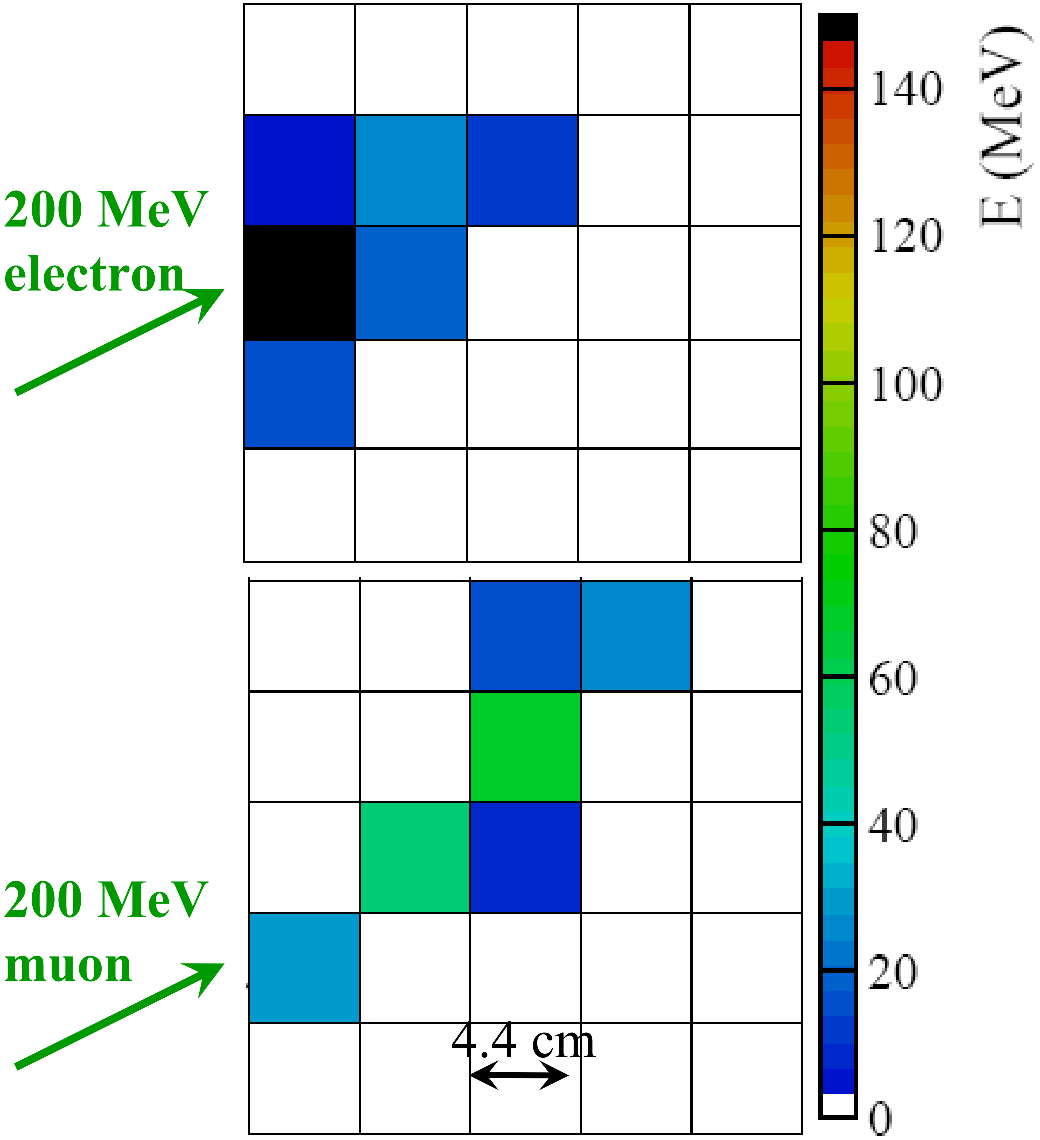
Background rejection (PID)

1) Particle ID exploits EMC granularity (energy deposits into 5 layers in depth):

the energy distribution and the position along the shower axis of all cells associated to the cluster allow for e/μ PID (define 11 descriptive variables).

2) Add E/p and ToF.

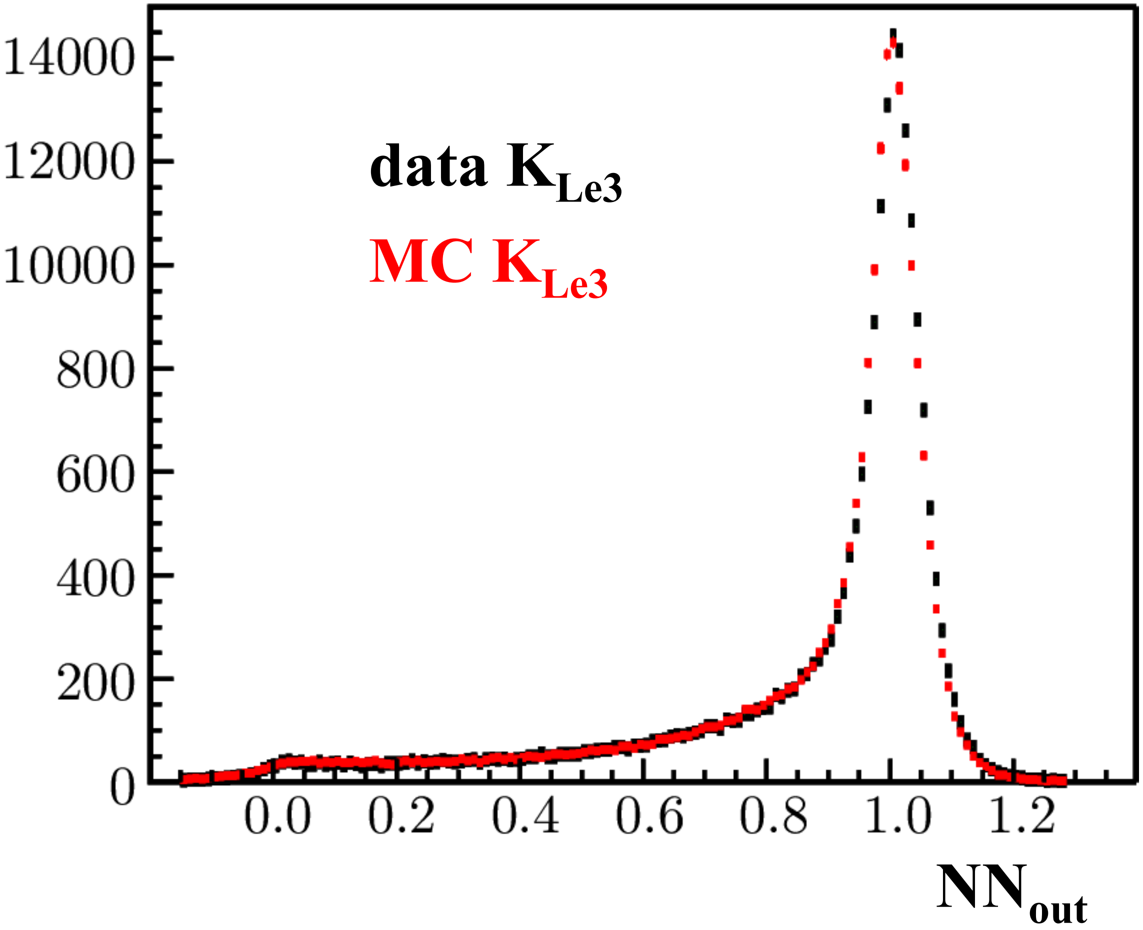
3) Combine all information in a neural network (NN).



Background rejection (PID)

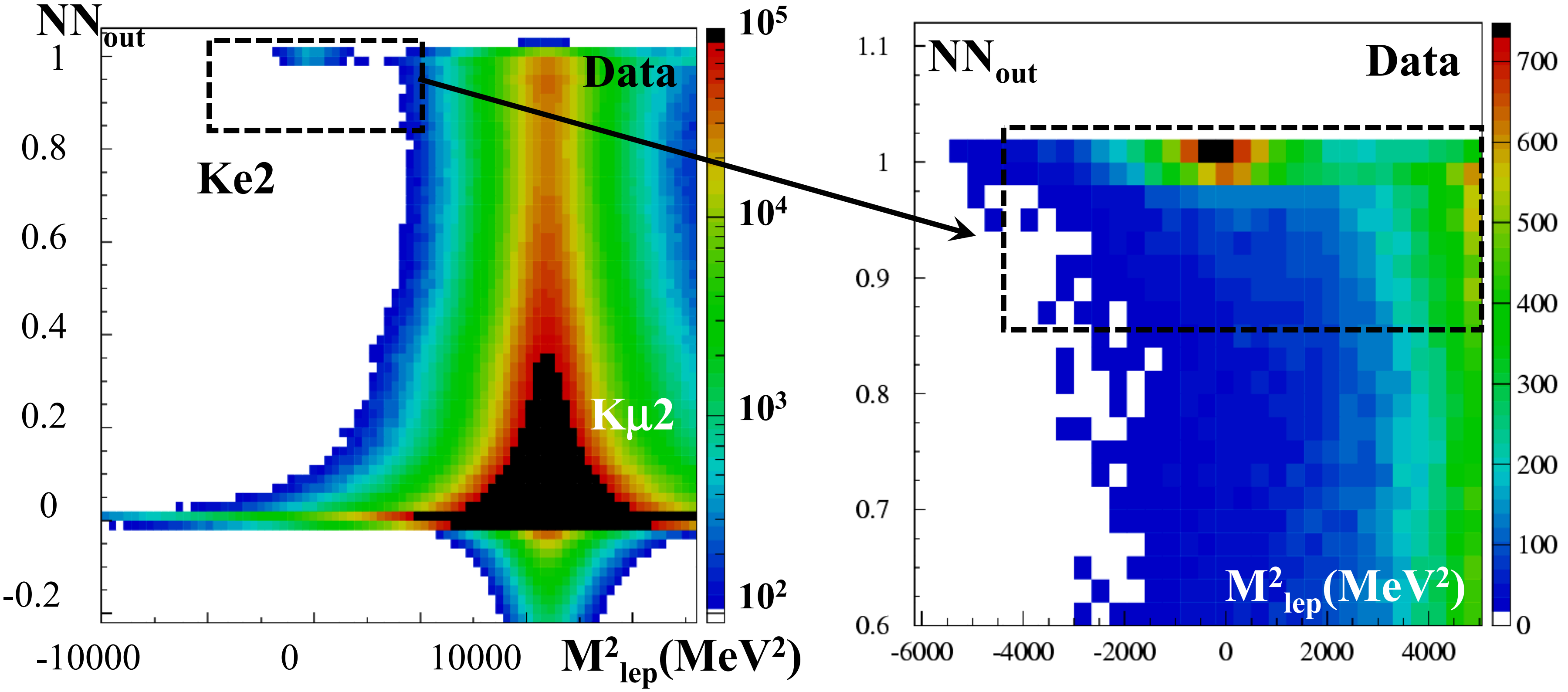
- Use a pure sample of K_Le3 to correct cell response in MC.

- K_Le3 anf Kμ2 for NN training.



Background rejection (PID)

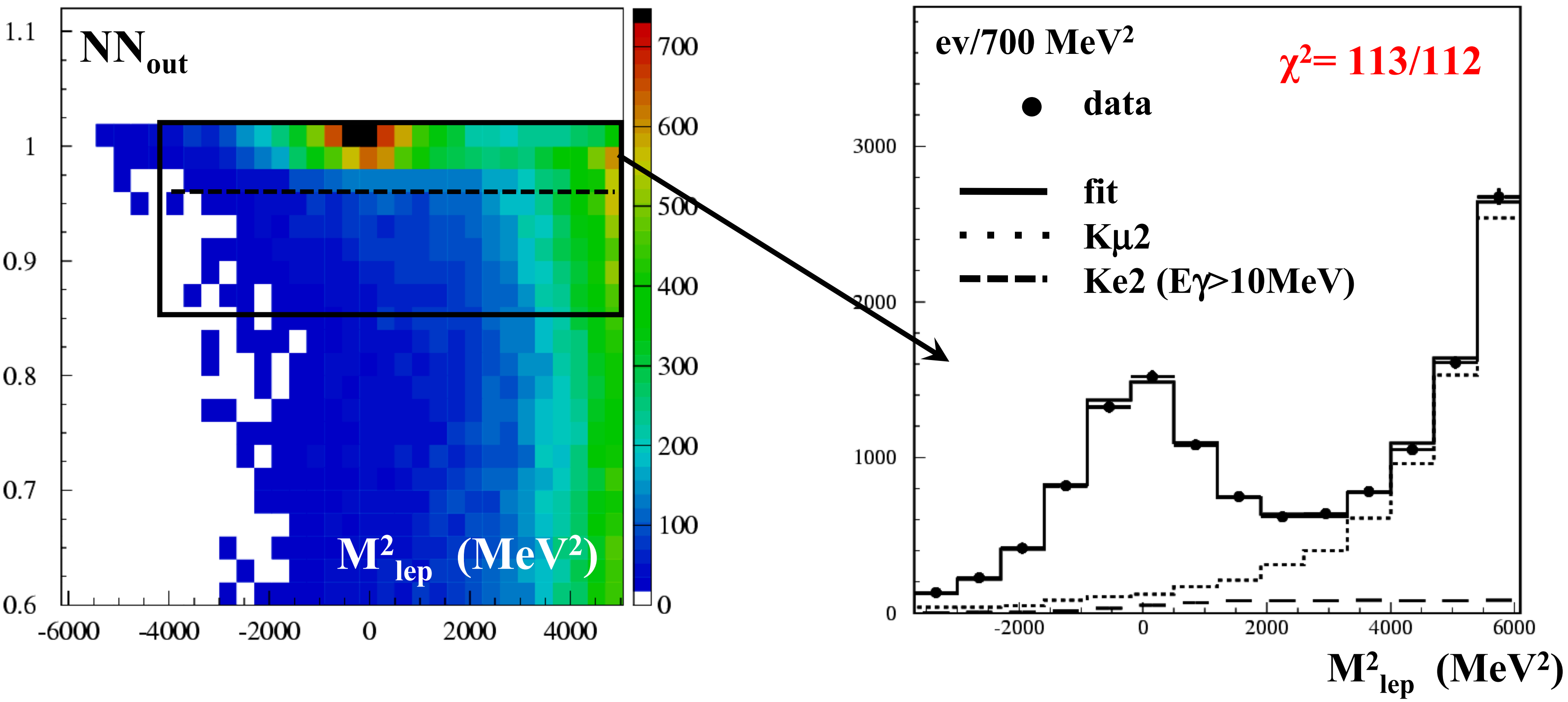
Select a region with good S/B ratio in the $M^2_{lep} - NN_{out}$ plane



after selection: ε~30% (~15,000 K_{e2}) **S/B ~ 5**

K_{e2} event counting

Two-dimensional binned likelihood fit in the M^2_{lep}–NN_{out} plane
in the region **$-4000<M^2_{lep}<6100$** and **$0.86<NN_{out}<1.02$**

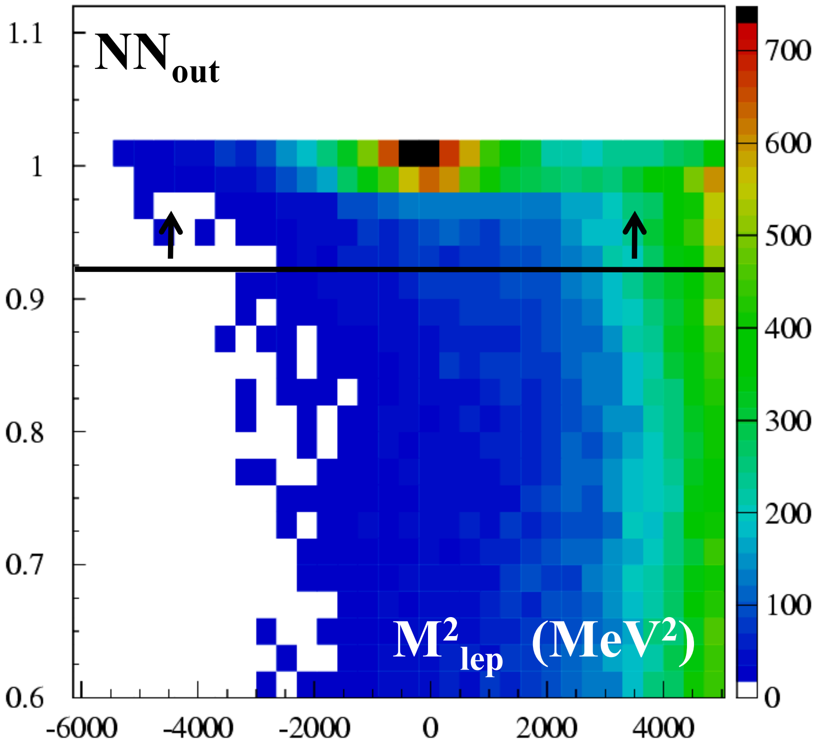


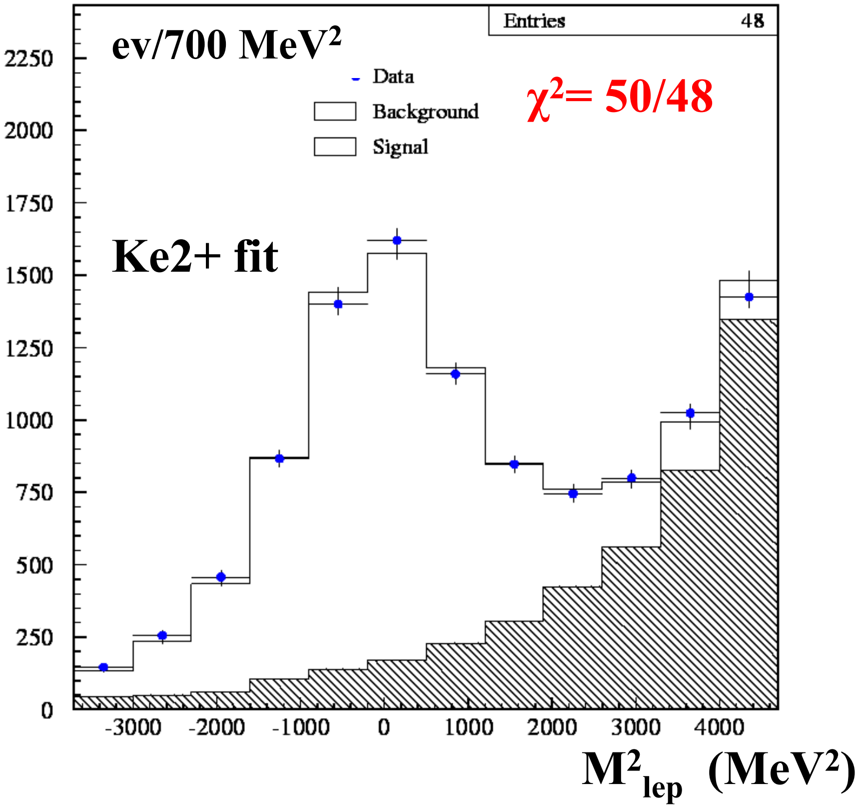
Ke2+ fit; M^2_{lep} proj for $NN_{out}>0.96$

We count **7060 (102) Ke2+** **6750 (101) Ke2–** **(σ_{STAT}=1%, 0.85% from Ke2)**

K_{e2} *event counting: systematics*

Repeat fit with different values of **$\max(M^2_{lep})$** and **$\min(NN_{out})$**:
vary significantly (×20) bkg contamination + lever arm.





minimal bkg with: $-4000 < M^2_{lep} < 4650$ and $0.94 < NN_{out} < 1.02$

maximum bkg with: $-4000 < M^2_{lep} < 7500$ and $0.78 < NN_{out} < 1.02$

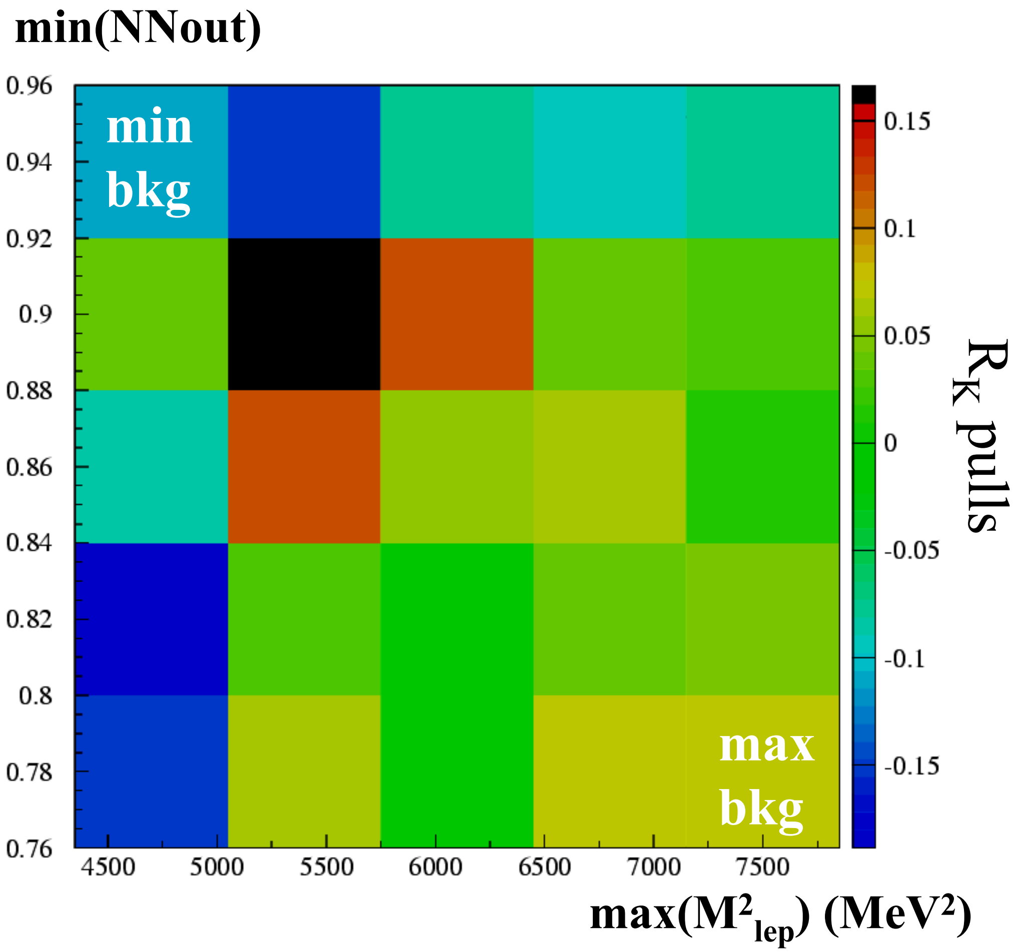
K_{e2} event counting: systematics

We change by a factor of 20 the amount of bkg falling in the fit region by moving

- min(NNout)
- max(M^2_{lep}).

Signal counts change by 15%.

From the pulls of the R_K measurements **we evaluated a 0.3% systematic error**.



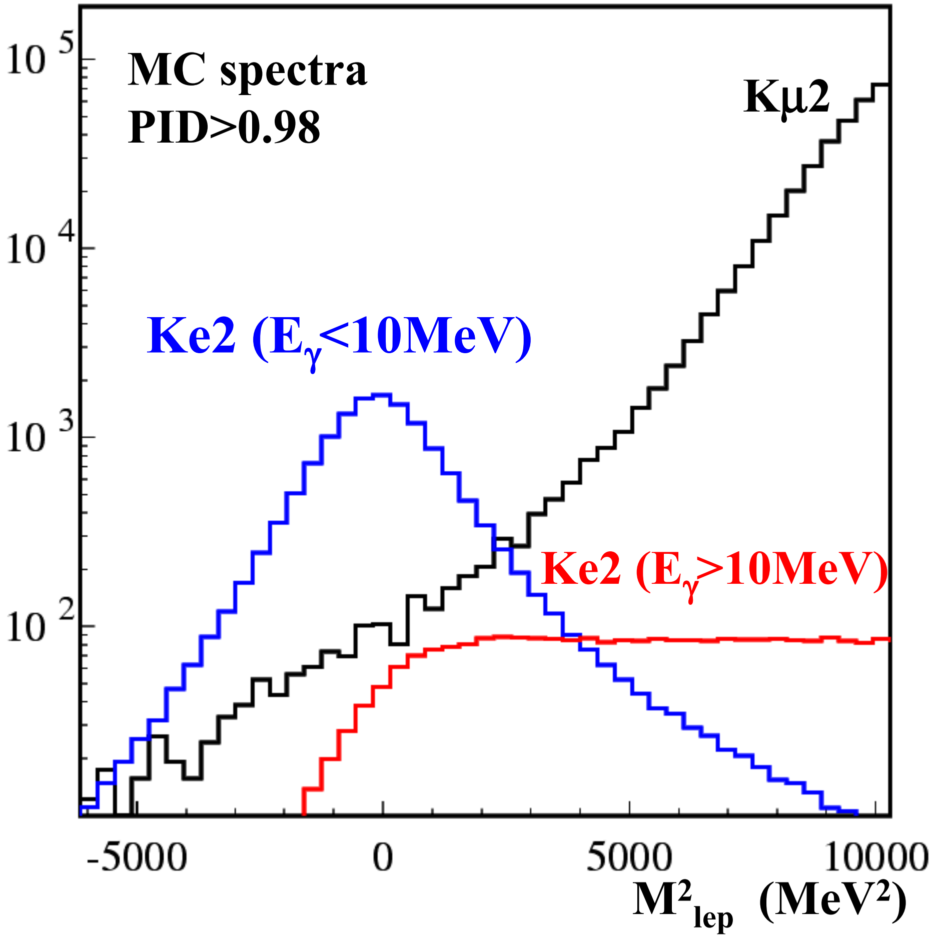
Ke2 fit: radiative corrections

- Analysis **inclusive of photons in the final state**. In our fi region we expect:

$$\frac{\text{Ke2 }(E_\gamma>10\text{MeV})}{\text{Ke2}(E_\gamma<10\text{MeV})} \sim 10\%$$

- Repeat fit by varying Ke2 (E_γ>10 MeV) by 15% (DE uncertainty) **get 0.5% error**.

We performed a **dedicated study of the Ke2γ differential decay rate**



Ke2γ process

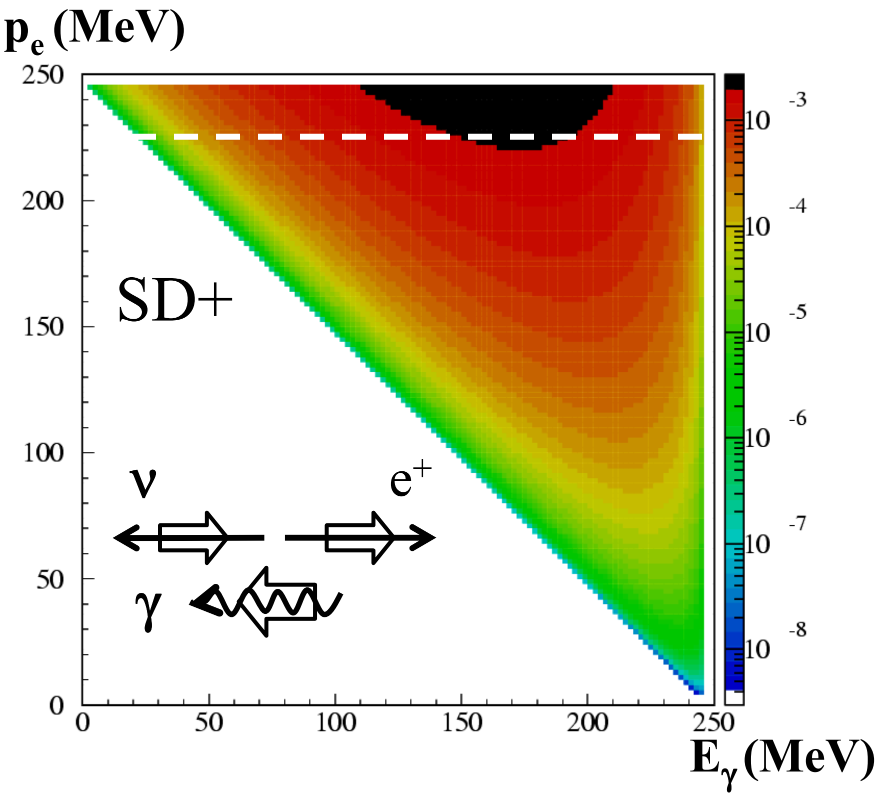
negligible

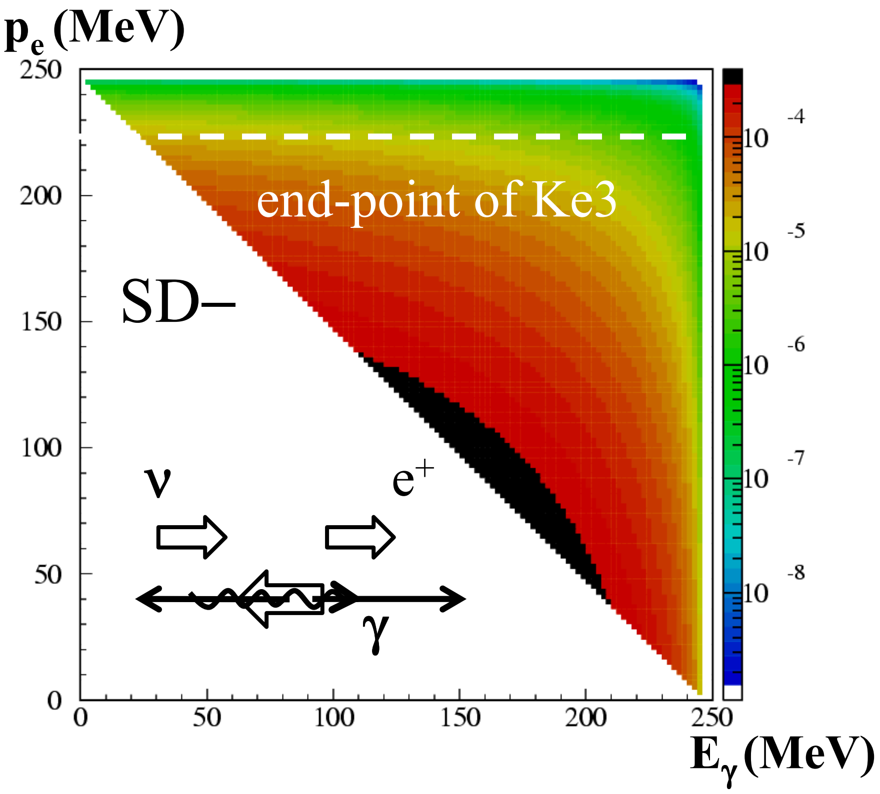
$$\frac{d\Gamma(K \rightarrow e\nu\gamma)}{dx\,dy} = \rho_{\mathrm{IB}}(x,y) + \rho_{\mathrm{SD}}(x,y) + \cancel{\rho_{\mathrm{INT}}(x,y)}$$

$$x = 2E^*_\gamma / m_K$$
$$y = 2E^*_e / m_K$$

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

V, A: effective vector and axial couplings

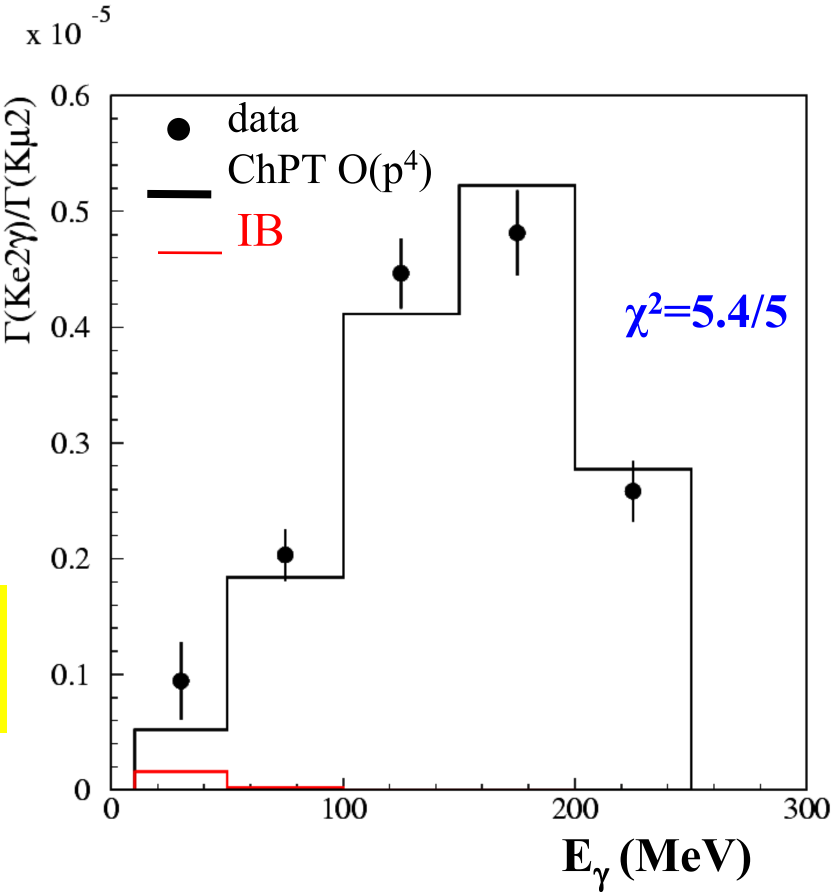




Ke2γ spectrum vs ChPT O(p^4)

Eγ spectrum measured for the first time.
We measure:

$$\frac{1}{\Gamma(K_{\mu2})}\frac{d\Gamma(K_{e2},E_\gamma>10\,MeV,p_e^*>200\,MeV)}{dE_\gamma}$$



Data are **compared** with ChPT O(p^4) calculation. Integrating we obtain:

$$\frac{\Gamma(K_{e2},E_\gamma>10MeV,p_e^*>200MeV)}{\Gamma(K_{\mu2})}=1.483(68)\times10^{-5}$$

in agreement with 1.447 × 10^{-5} of ChPT O(p^4)

This confirm the SD content of our MC, evaluated with ChPT O(p^4), within an accuracy of 4.6% and allows a 0.2% systematic error on Ke2$_{IB}$ to be assessed

Ke2γ spectrum: fit to ChPT $O(p^6)$

- We **fit** our data to extract $\mathbf{f_V+f_A}$ (SD+), allowing for a slope of the vector ff

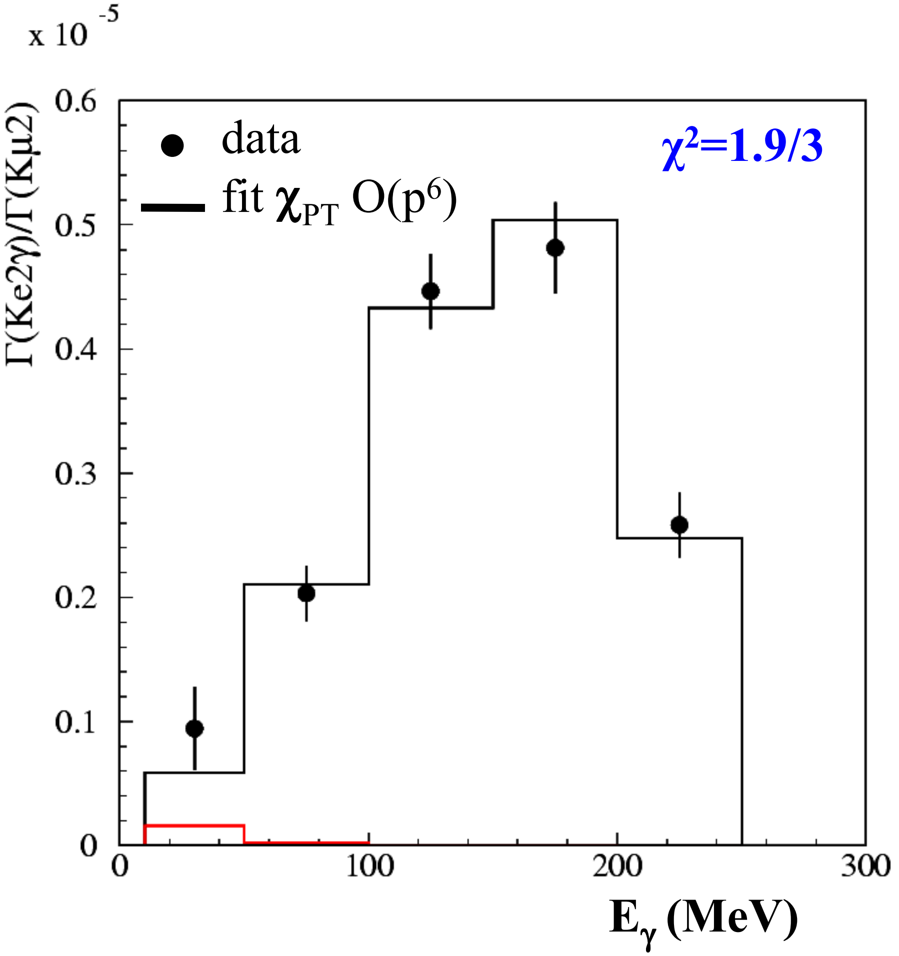
$$f_V = \mathbf{f_{V0}}(1+\boldsymbol{\lambda}(1-x))$$

- Since we are not sensitive to the SD– amplitude (acceptance≈2%) we keep f_V-f_A fixed to the ChPT $O(p^6)$ prediction

We obtain:

$$\mathbf{f_{V0}+f_A = 0.125\pm0.007}$$

$$\boldsymbol{\lambda} \mathbf{= 0.38 \pm 0.21}$$



Compare to χPT $O(p^6)$: $f_{V0}+f_A \approx 0.116$, $\lambda\approx0.4$ (Phys. Rev. D77 (2008) 014004)

R_K measurement

$R_K = (2.493 \pm 0.025 \pm 0.019)\times10^{-5}$

EPJC (2009) 64

Total error:

$1.3\% = 1.0\%_{stat} + 0.8\%_{syst}$

0.9% from 14k Ke2 + bkg subtraction	**dominated by c.s. statistics**

- The result does not depend upon the kaon charge: K^+: 2.496(37) vs K^-: 2.490(38) (uncorrelated errors only)

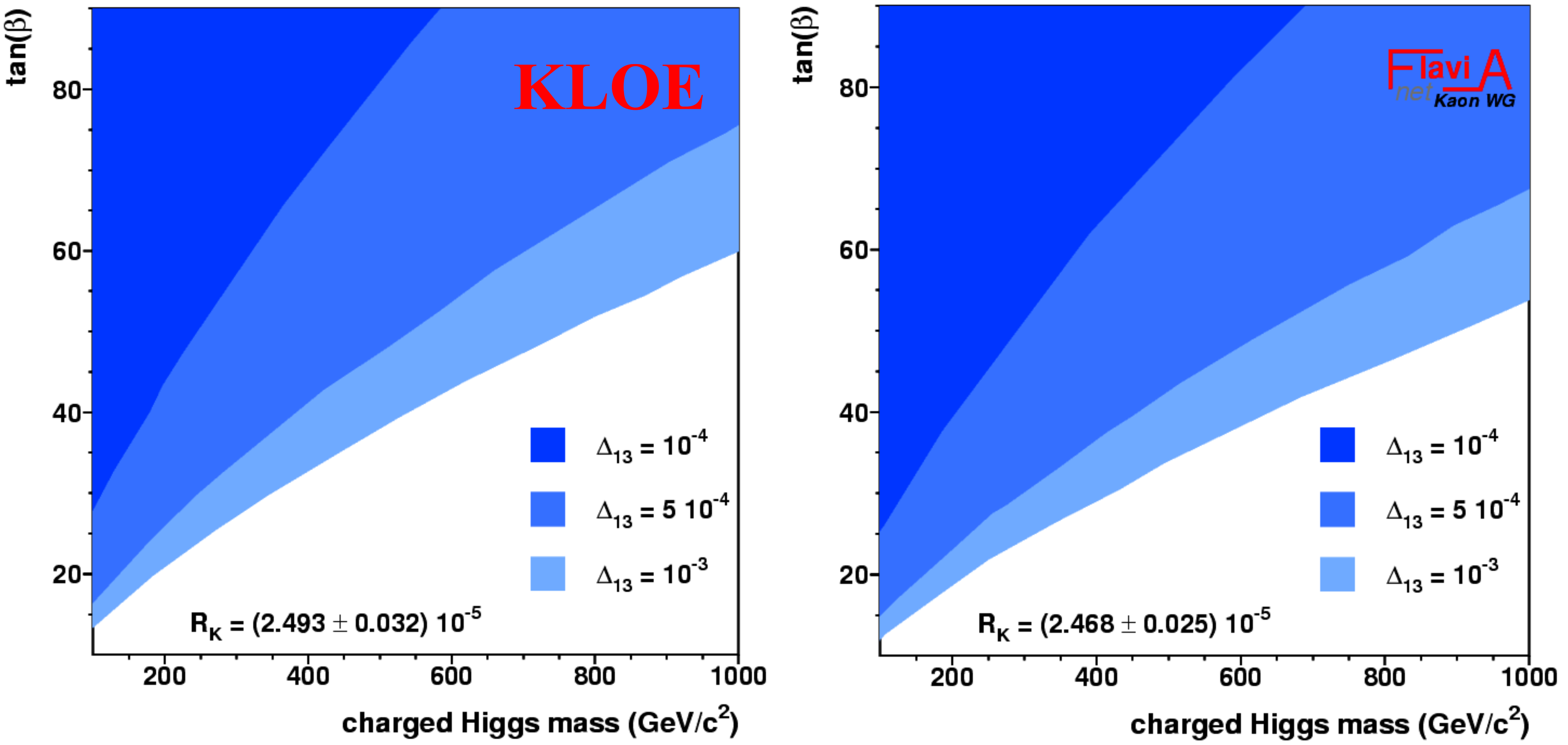
- Agrees with SM prediction: $R_K^{SM} = 2.477(1) \times10^{-5}$

Tracking	**0.6%**	K^+ control samples
Trigger	**0.4%**	downscaled events
syst on Ke2 counts	**0.3%**	fit stability
Ke2γ DE component	**0.2%**	measurement on data
Clustering for e, μ	**0.2%**	K_L control samples
Total Syst	**0.8%**	

- **PDG 2008: $R_K = (2.45 \pm 0.11)\times10^{-5}$ (4.5% accuracy)**
- **New world average at 1% accuracy**

R_K : sensitivity to new physics

Sensitivity shown as 95% CL excluded regions in the tanβ–M_H plane, for different values of the LFV effective coupling, $\Delta_{13} = 10^{-3}, 5 \times 10^{-4}, 10^{-4}$



Summary and perspectives

Recent kaon decay measurements greatly improve knowledge of gauge couplings

- CKM matrix unitarity tested at 0.06%
- effective coupling measured at 0.03% constrains many NP scenarios
- progress from lattice will constrain more severely CKM fits soon

New and interesting tests of NP from kaon 2-body decays

- R_K golden LFV observable (w.a. at 1%)

Kaons pushing findamental principles at severe test

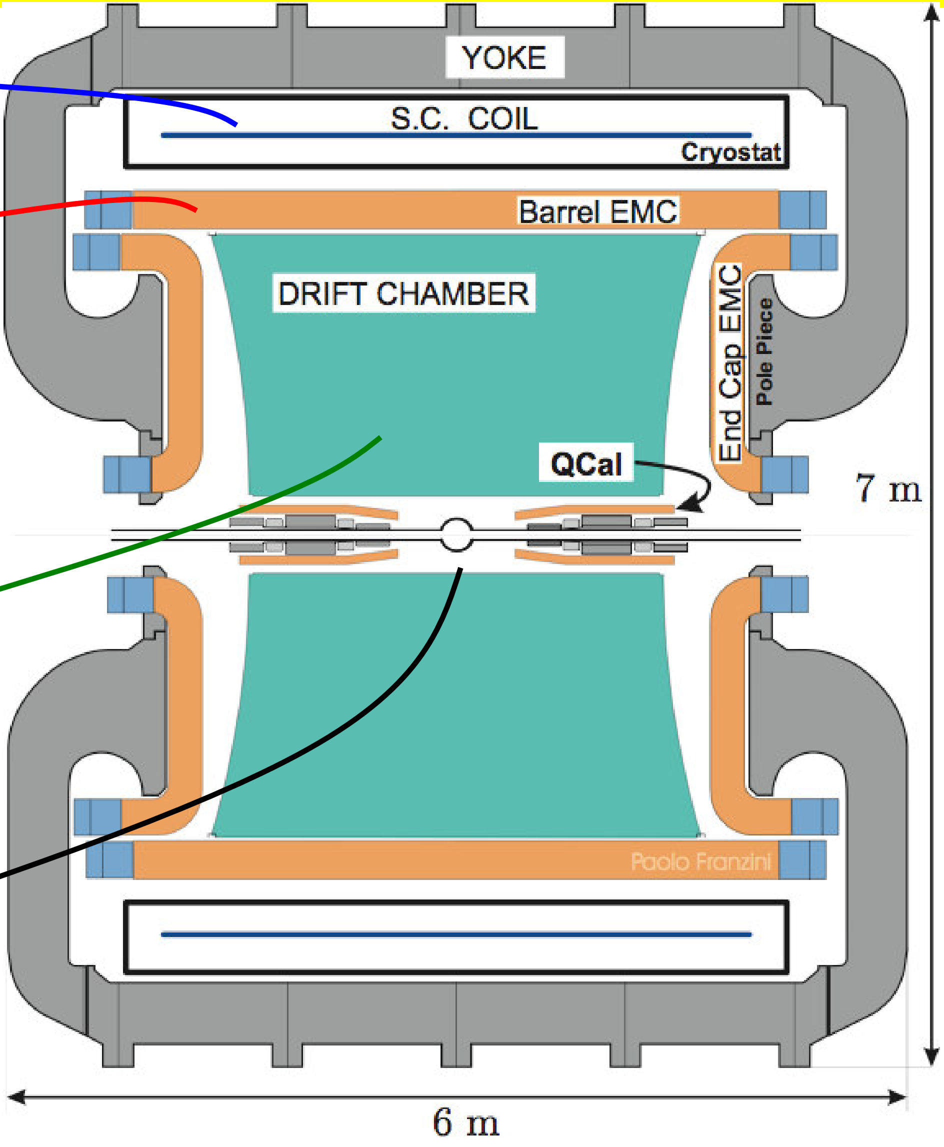
- CPT (and QM decoherence) at state of art

Substantial contributions from KLOE, excellent synergy with other experiments and theoreticians (Flavianet), new results coming in nex years from KLOE-2.

Kaon physics alive and kicking!

Additional information

The KLOE experiment



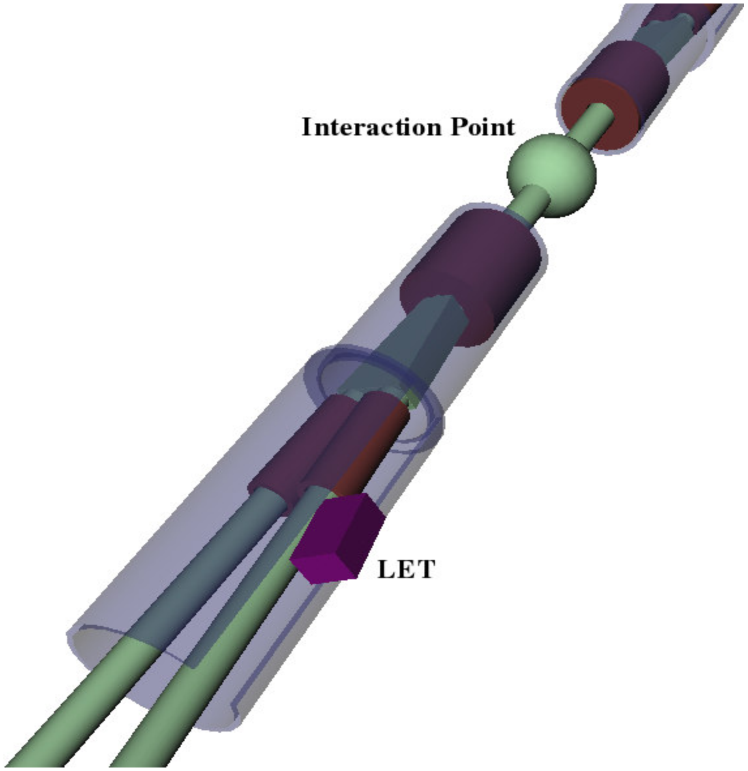
Magnet
SC coil, B = 0.6 T

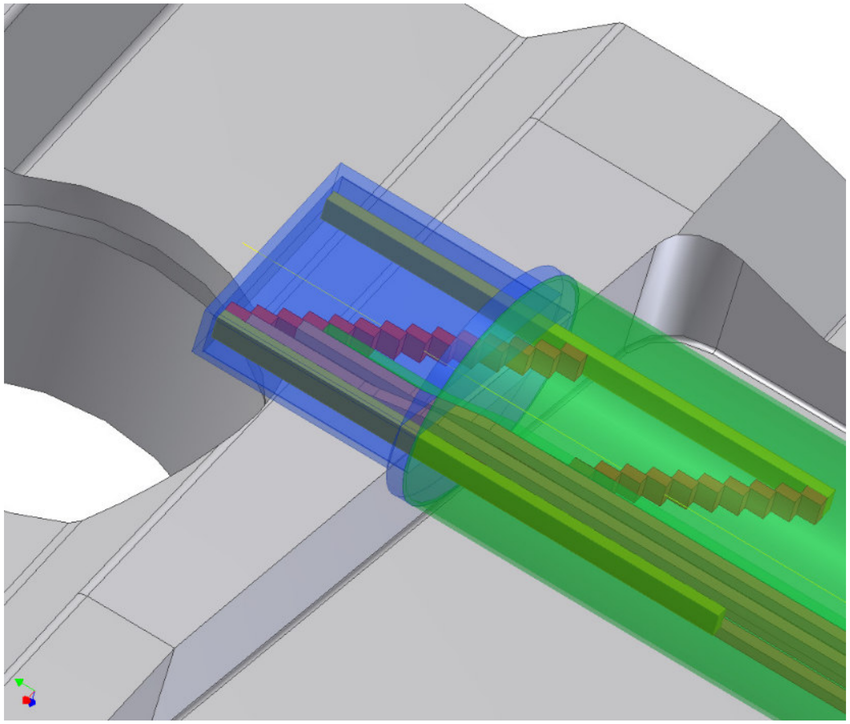
EM Calorimeter
Pb-scint fiber
4880 PMs, 2440 cells

Drift chamber
12582 sense wires
52140 tot wires
Carbon fiber walls

Al-Be beam pipe
r = 10 cm, 0.5 cm thick

KLOE-2 Step 0: LET and HET





Low Energy Tagger (LET)
130-230 MeV
calorimeters LYSO+SiPM

High Energy Tagger (HET) >400 MeV
Position sensitive detectors; strong energy-position correlation ⇒ use DaΦne magnets as $e^{\pm}$ spectrometer

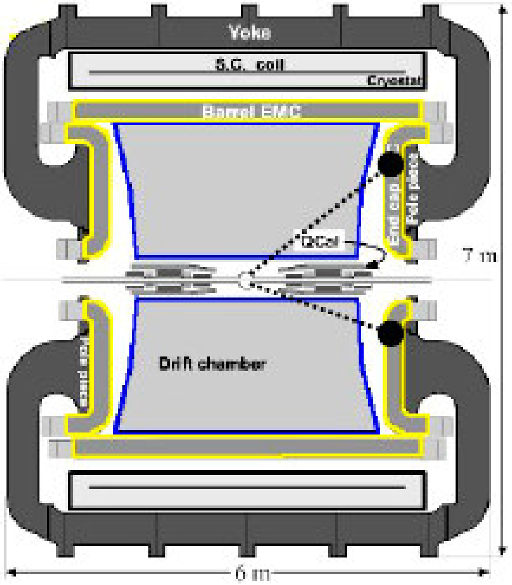
γγ-physics at KLOE: a trigger issue

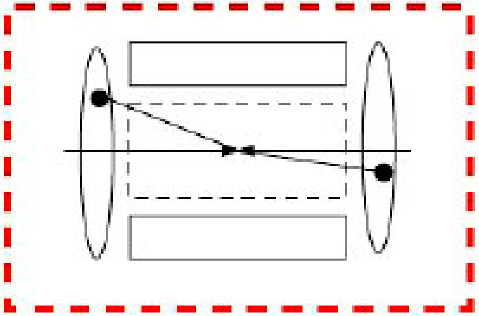
$e^+e^- \rightarrow e^+e^-\pi^0$ at KLOE: trigger issue

✓ look at √s = 1 GeV data

✓ π^0 unbalanced along the beam line

✓ 2 photons emitted in the same Calorimeter End Cap

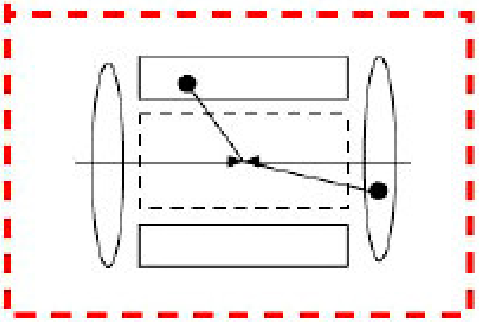




...But Trigger criteria require:

☹ 2 energy deposits (above threshold)

not in the same End Cap



KLOE2: Inner Tracker

For fine vertex reconstruction of **K_s, η and η'** rare decays and **K_s- K_L interference measurements :**

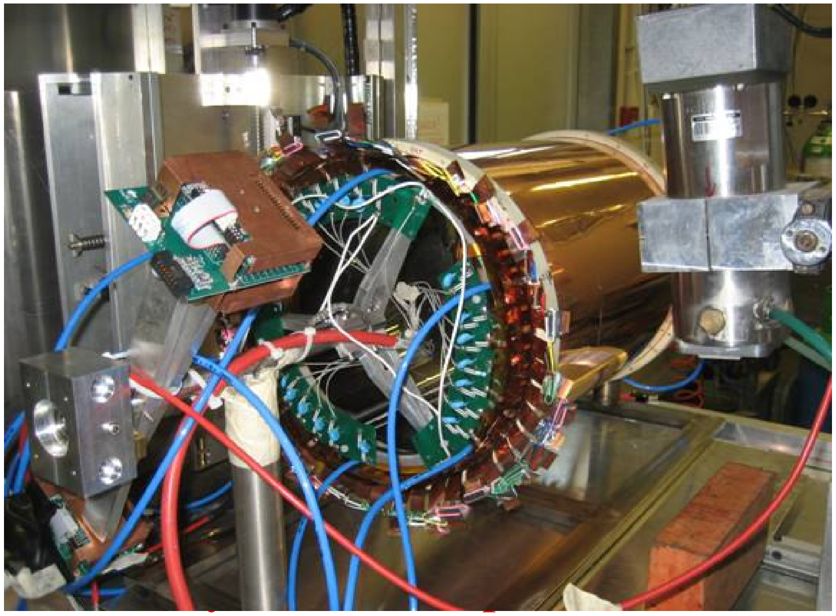
$\sigma_{r\phi}$~ 200 μm and σ_z ~ 500μm
low material budget:<2%X_0
5 kHz/cm^2 rate capability

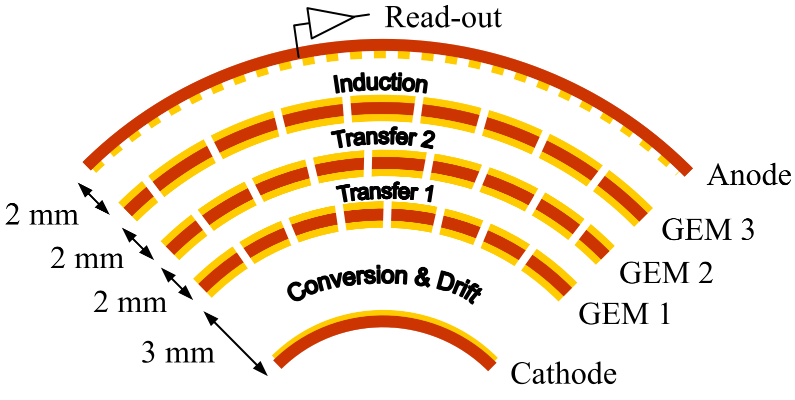
Cylindrical GEM detector is the adopted solution: 5 CGEM layers with radii from **13** to **23** cm from IP and before DC Inner Wall

700 mm active length

XV strips-pads readout (40^o stereo angle)

1.5% X_0 total radiation length in the active region with Carbon Fiber supports





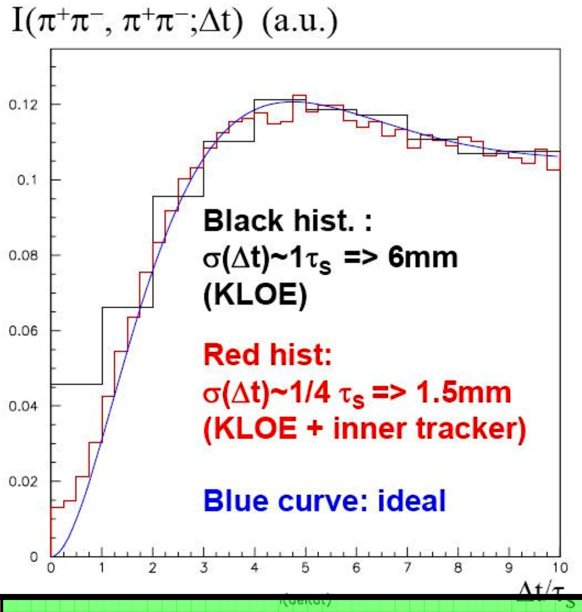
$K_S \rightarrow \pi\pi$ vertex resolution will improve of about a factor 3 from present 6mm

$\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$: *vertex resolution*

Possible signal of decoherence at small Δt

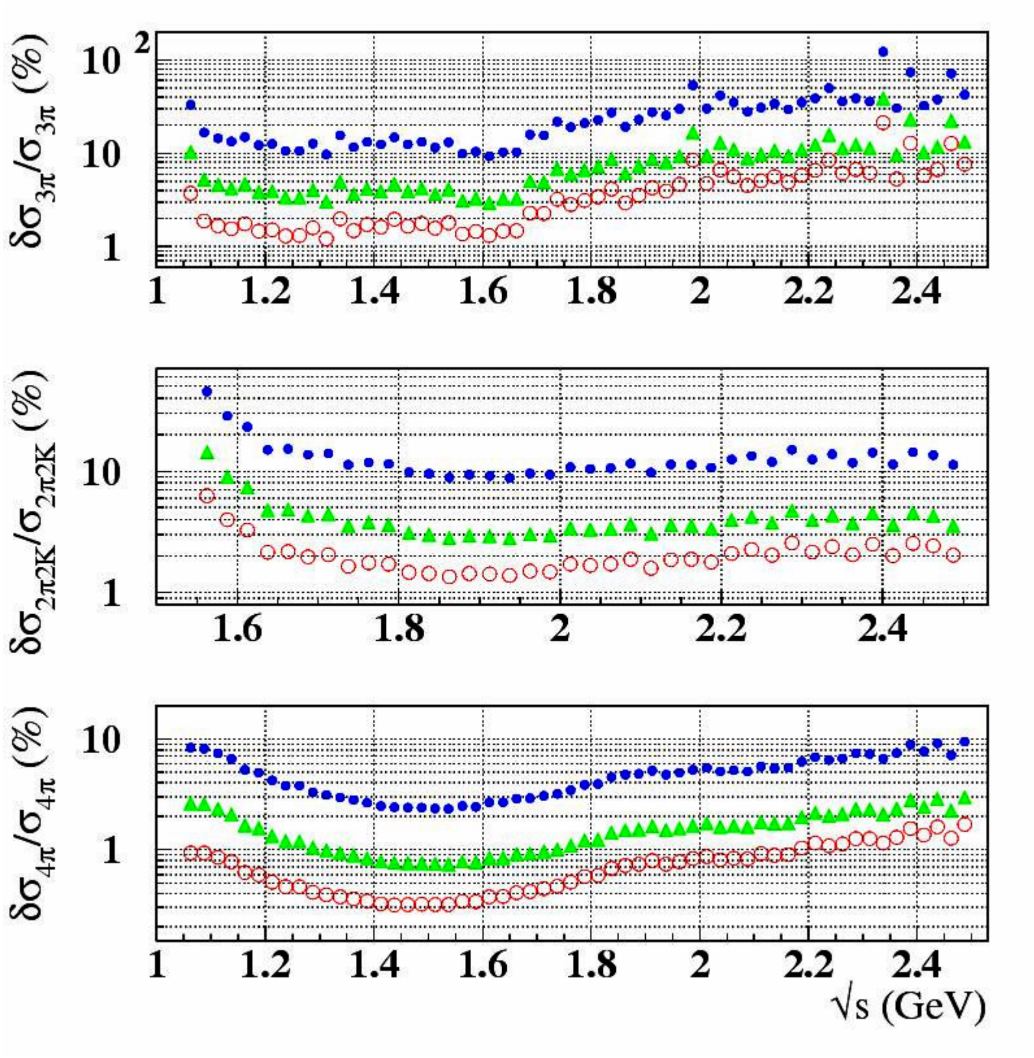
Step 0 (no IT): improvement in stat. uncertainty

Step 1, with Inner Tracker: reduction of systematics



	Best measurement	KLOE-2 L=5 fb^{-1}	KLOE2 L=50 fb^{-1} with IT
ζ_{00}	$(1.4 \pm 10.2) \times 10^{-7}$	$\pm 6.4 \times 10^{-7}$	$\pm 1 \times 10^{-7}$
ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 1.2 \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
γ	$(0.7 \pm 1.2) \times 10^{-21}$ GeV	$\pm 0.7 \times 10^{-21}$ GeV	$\pm 0.1 \times 10^{-21}$ GeV
Re(ω)	$(-1.6 \pm 3.0) \times 10^{-4}$	$\pm 1.7 \times 10^{-4}$	$\pm 2 \times 10^{-5}$
Im(ω)	$(-1.7 \pm 3.5) \times 10^{-4}$	$\pm 2.2 \times 10^{-4}$	$\pm 2 \times 10^{-5}$

Range 1-2 GeV with a scan



Impact of DAFNE/KLOE2 on exclusive channels on the range [1-2] GeV with an energy scan, stat. only:

Babar, published L_{INT} per point (90 fb^{-1})

Babar with ×10

DAFNE/KLOE2 with 20 pb^{-1} per point (<1 week@$10^{32}cm^{-2}s^{-1}$)

Many systematics in KLOE scale with statistics.
ISR can be done as well…

Interest in V_{us} measurement with kaons

In SM, universality of weak coupling dictates:

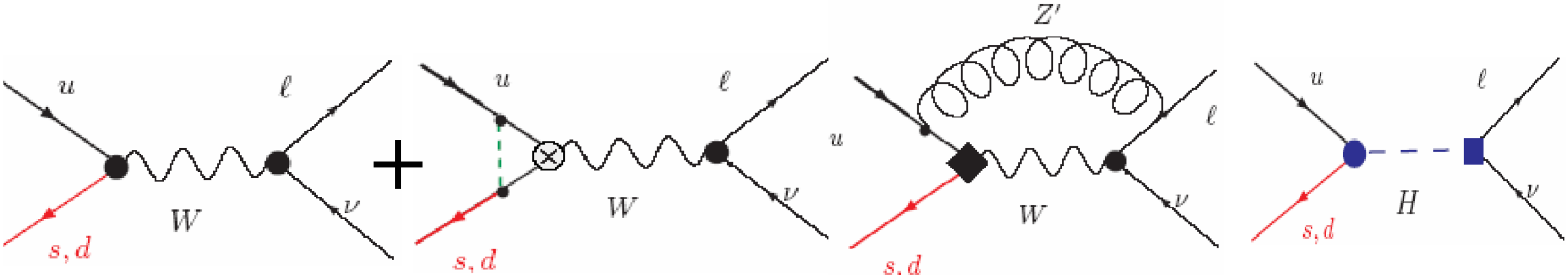
$$G_F^2\,(|V_{ud}|^2 + |V_{us}|^2) = G^2(\text{from } \mu \text{ lifetime}) = (g_w/M_w)^2\ [V_{ub} \text{ negligible}]$$

One can test for possible breaking of one of the two conditions:

CKM unitarity: is $(|V_{ud}|^2 + |V_{us}|^2) = 1$?

coupling universality: is $G_F^2\,(|V_{ud}|^2 + |V_{us}|^2) = G^2(\text{from } \mu \text{ lifetime})$?

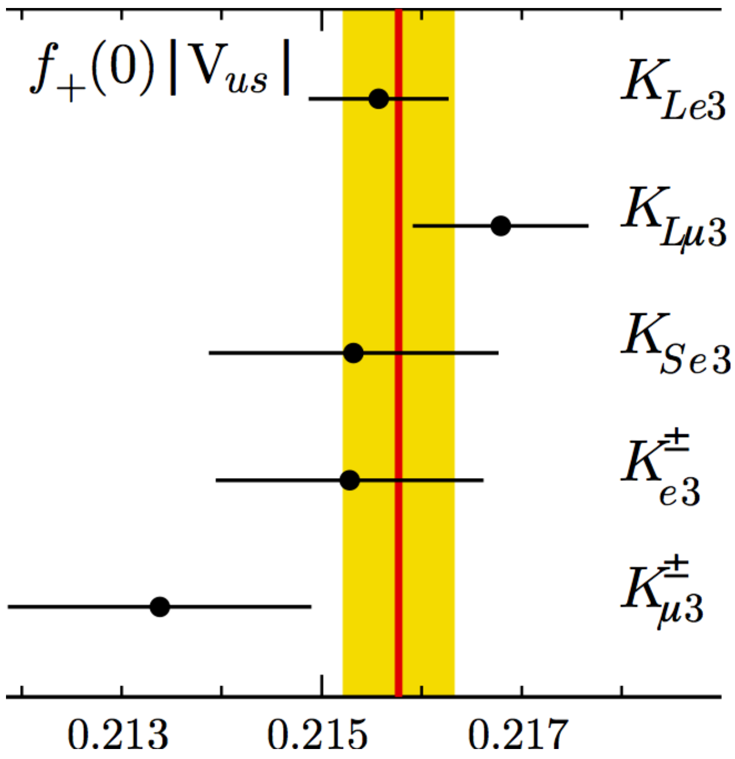
New physics extensions of the SM can indeed break coupling universality:



SM + NP $\propto G_F^2\,|V_{uq}|^2\,(1 + a\,M_W^2/M_{NP}^2)^2$**, naively** $a_{tree} \sim 1$, $a_{loop} \sim g_W^2/16\pi^2$

$f_+(0)|V_{us}|$ from K_{l3} decays

KLOE paper: JHEP 04(2008)059



K_{Le3}	**0.2155(7)**	**0.3%**
$K_{L\mu3}$	**0.2167(9)**	**0.4%**
K_{Se3}	**0.2153(14)**	**0.7%**
$K^{\pm}_{e3}$	**0.2152(13)**	**0.6%**
$K^{\pm}_{\mu3}$	**0.2132(15)**	**0.7%**

$f_+(0)|V_{us}|$

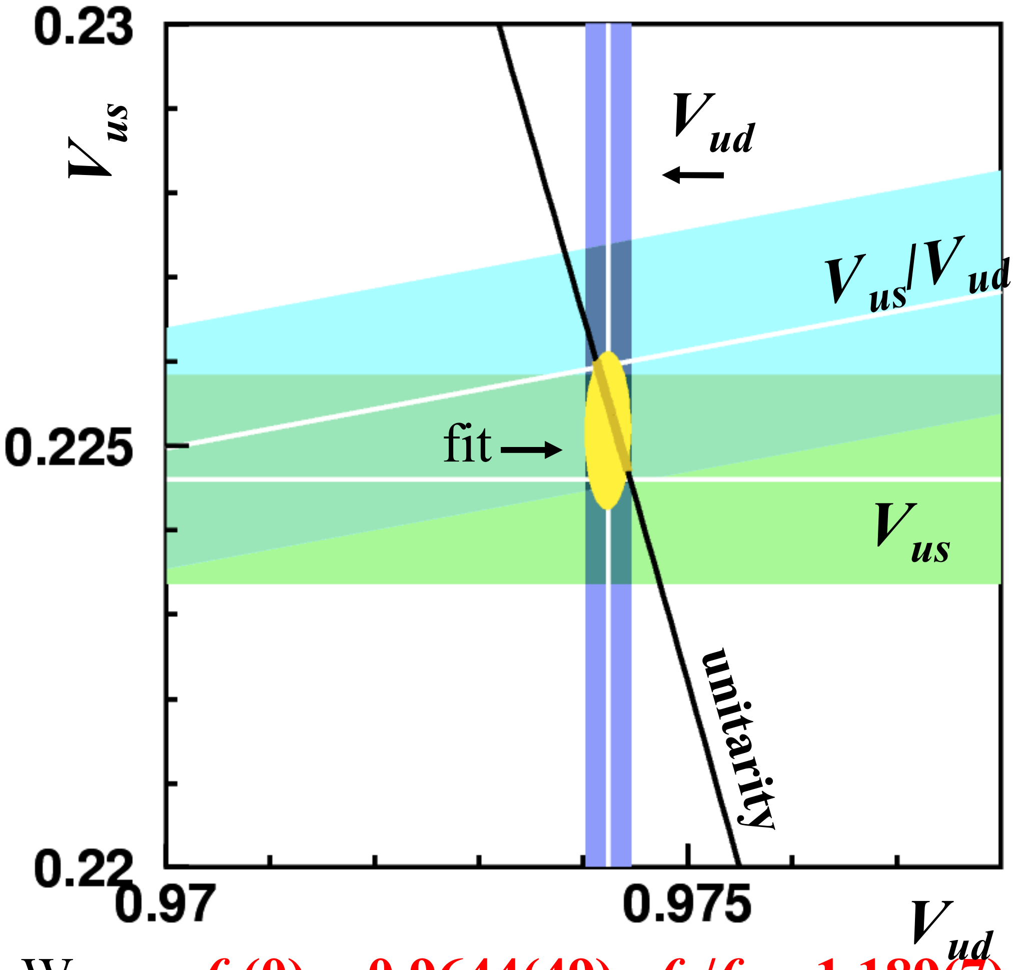
KLOE: 0.2157(6)
χ^2/dof = 7/4 (14%)

World Avg: 0.2166(5)

K^0 *vs* $K^{\pm}$ agree within 1.1σ

alternatively, $K^0 - K^{\pm}$ gives: $\delta^{SU(2)}_{EXP}$=1.7(6)% ⇔ $\delta^{SU(2)}_{THEORY}$=2.36(22)%

CKM unitarity



We use $f_+(0) = 0.9644(49)$, $f_K/f_\pi = 1.189(7)$

Now can fit:

- **V_{us} from *Kl3***
- **V_{us}/V_{ud} from $K_{\mu 2}/\pi_{\mu 2}$**
- **V_{ud} from β decay**

$$V_{ud} = 0.97424(22)$$
$$V_{us} = 0.2252(9)$$
$$\chi^2/\text{ndf} = 0.52/1\ (47\%)$$

$$V_{ud}^2 + V_{us}^2 - 1 = -0.0001(6)$$

Extraction of V_{us}/V_{ud} from K_{l2} decays

Small uncertainties in f_K/f_π from lattice determine V_{us}/V_{ud} from

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K}{f_\pi} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times (1+\alpha(C_K-C_\pi))$$

Inputs from theory:

$f_K/f_\pi = 1.189(7)$ HPQCD/UKQCD 07

- f_K is not protected against SU(3) breaking
- for f_K/f_π profit of cancellation of lattice scale uncertainties
- several solid lattice results are now available, will average soon

$1+\alpha/\pi(C_K-C_\pi) = 0.9930(35)$ Finkemeier Marciano-Sirlin

- uncertainty from SD virtual corrections

Inputs from experiment:

$\Gamma(K_{\mu 2(\gamma)})$ WA (FlaviaNet)

$\Gamma(\pi_{\mu 2(\gamma)})$ PDG

WA: $|V_{us}|/|V_{ud}| = 0.2319(14)$

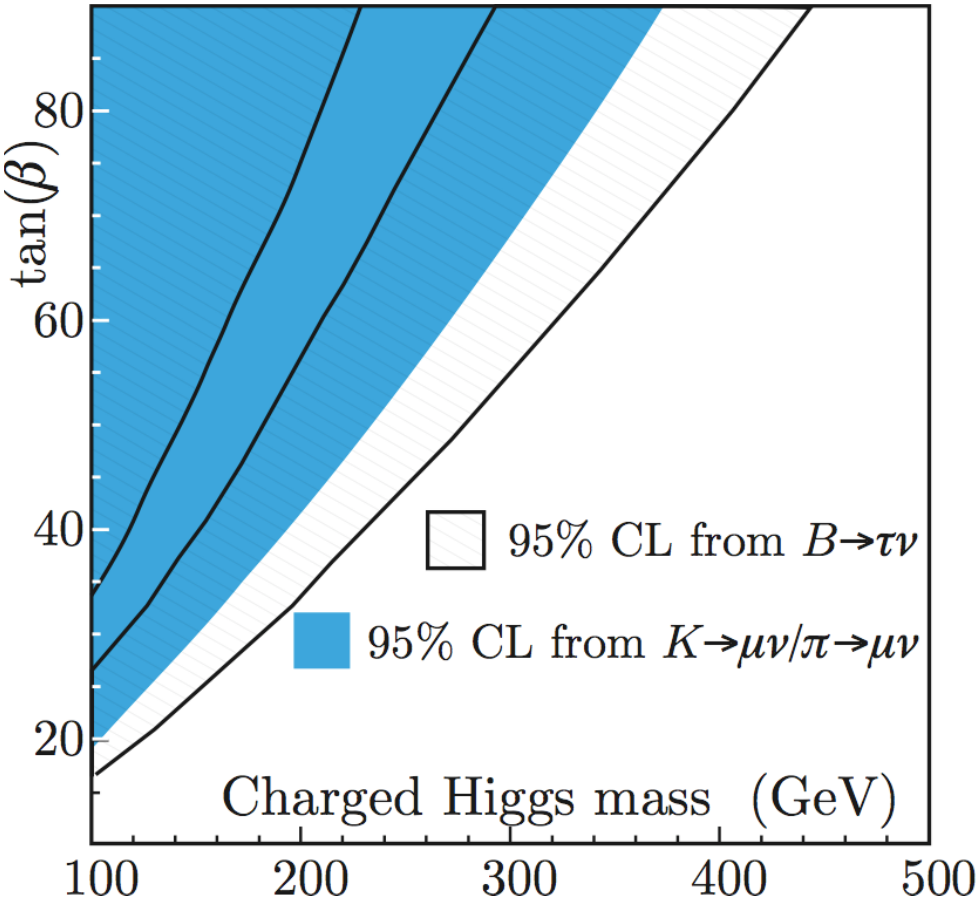
$K_{\mu 2}$: *sensitivity to new physics*

Scalar currents, e.g. due to Higgs exchange, affect $K \to \mu\nu$ width

$$R_{l23} = \left| \frac{V_{us}(K_{\mu 2})}{V_{us}(K_{l3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\mu 2})} \right|$$

$$= \left| 1 - \frac{m^2_{K^+}}{m^2_{H^+}} \left(1 - \frac{m^2_{\pi^+}}{m^2_{K^+}} \right) \frac{\tan^2 \beta}{1 - \varepsilon_0 \tan \beta} \right|$$

[Hou, Isidori-Paradisi]



R_{l23} =1 in SM

we find

$R_{l23} = 1.008 \pm 0.008$

limited by lattice uncertainty on $f_+(0)$ and f_K/f_π

From direct searches (LEP), $M_{H+} > 80$ GeV, $\tan\beta > 2$

$|V_{us}|$ *from* K_{l3} *decays*

From $\dfrac{f_+(0)|V_{us}|_{\text{exp}}}{f_+(0)_{\text{lattice}}}$

WA (Flavianet) $V_{us} = \mathbf{0.2243(12)}$

KLOE $V_{us} = \mathbf{0.2237(13)}$

Using $|V_{ud}| = 0.97425(22)$ from $0^+ \to 0^+$ β decays (Hardy Towner 09)

WA: $1 - |V_{us}|^2 - |V_{ud}|^2 = (5 \pm 5_{Vud} \pm 4_{Vus}) \times 10^{-4} = (5 \pm 6) \times 10^{-4}$

Unitarity verified to 0.6 per mill (KLOE: $8 \pm 7 \times 10^{-4}$)

PDG04 was 0.0031 ± 0.0015

Good agreement with unitarity

also implies observation of short distance radiative corrections (for both β and $Kl3$) at ≈ 40σ level (→ extract M_Z=90± 7 GeV)

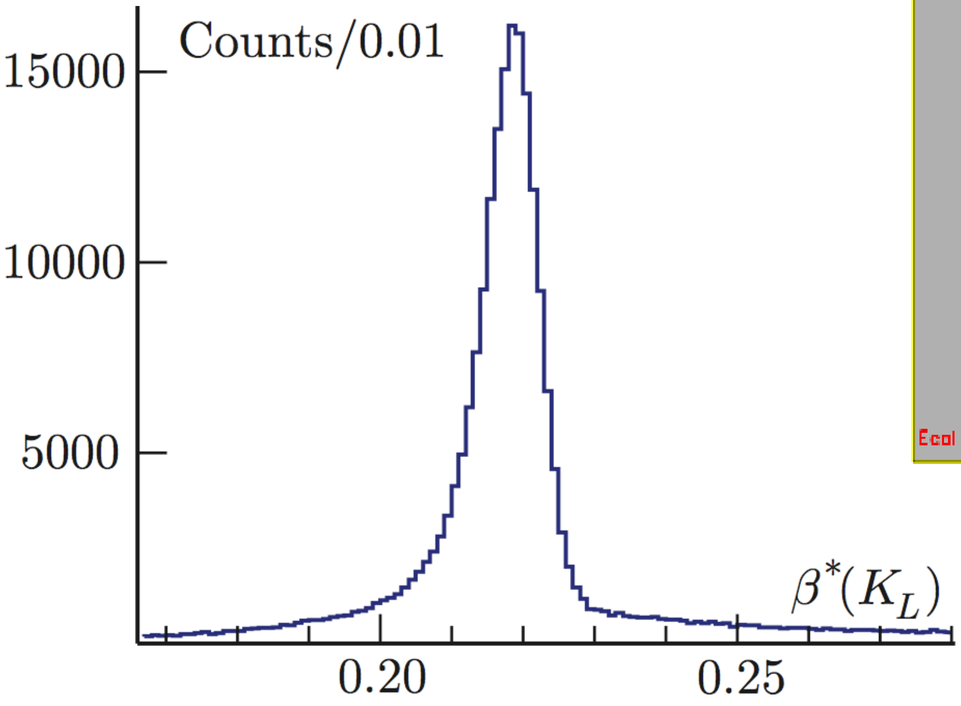
$$\frac{2\alpha}{\pi}\ln(M_Z/M)+\ldots\approx 2.5\%$$

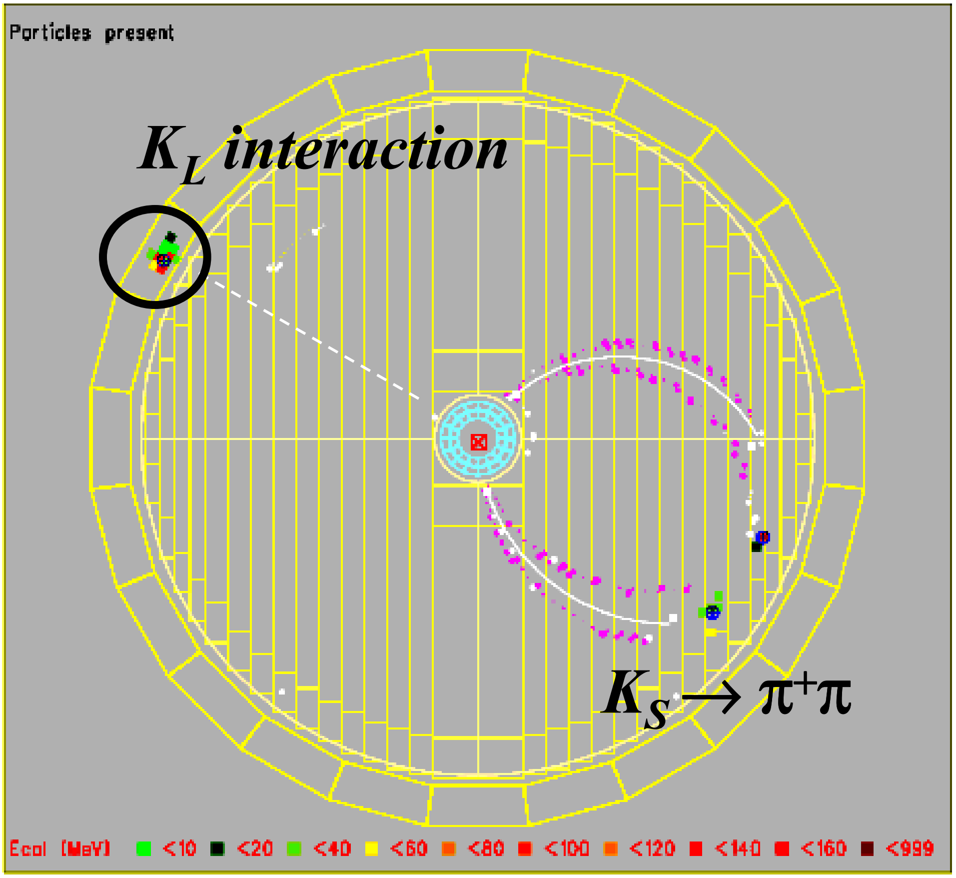
Sirlin 78, Sirlin Marciano 06

K_S "beam"

K_L velocity $\beta \sim 0.2$

K_S tagged by K_L interactions in calorimeter, identified by TOF





K_L *interaction*

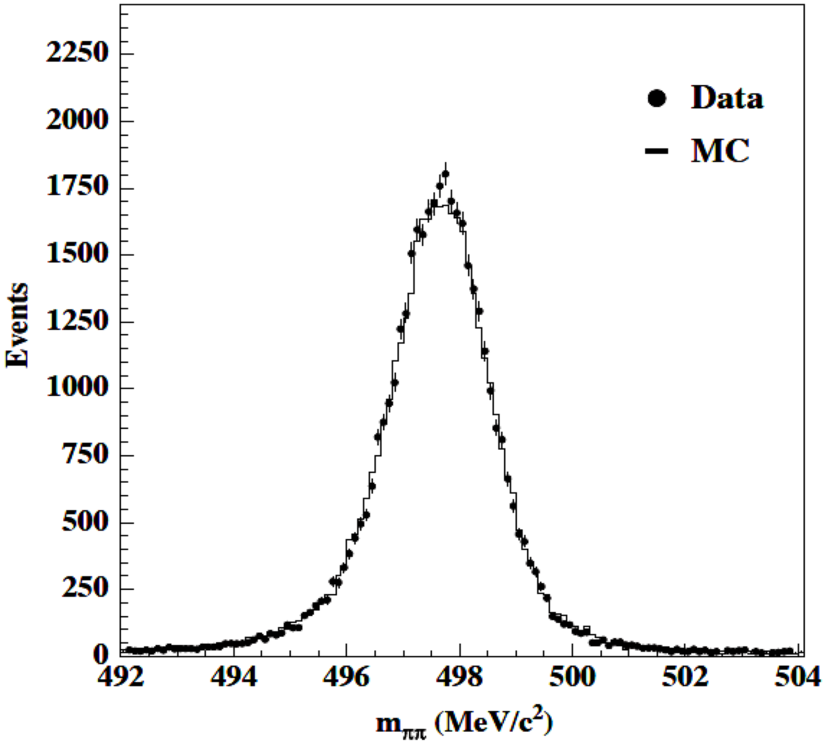
$K_S \rightarrow \pi^+\pi$

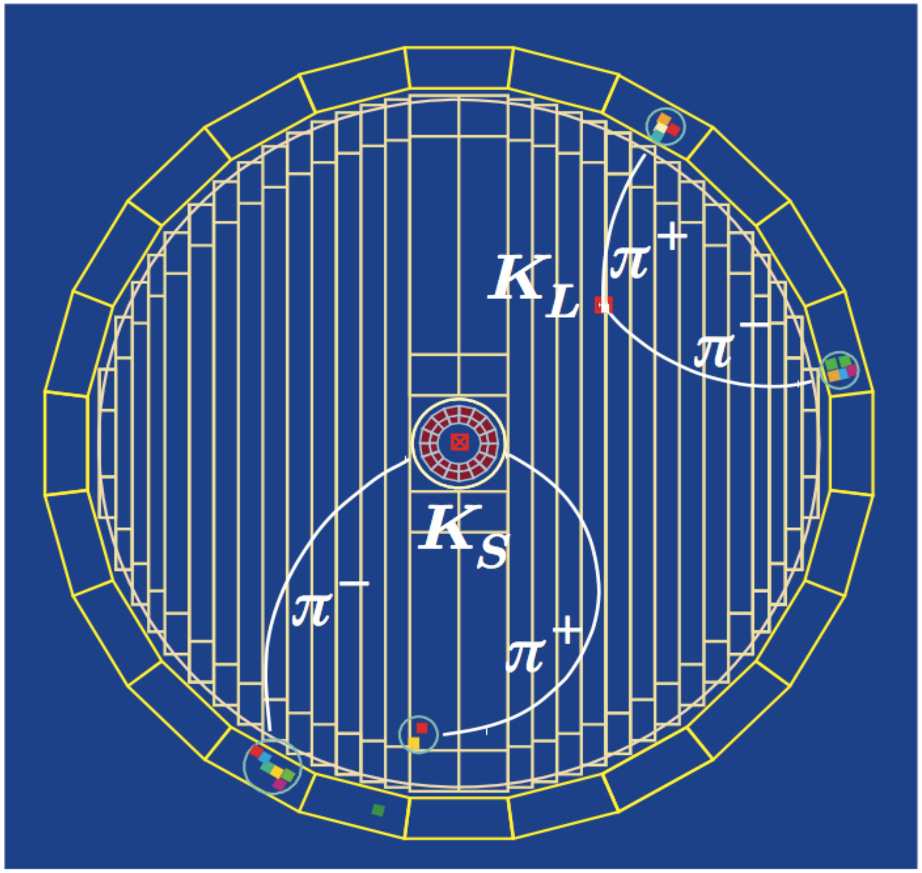
K_S momentum from $p_\phi - p_L$ with 1 MeV resolution

K_L "beam"

K_L tagged by $K_S \to \pi^+\pi^-$ vertex at IP

DC resolution on $\pi\pi$ invariant mass $\sigma \approx$ 1MeV



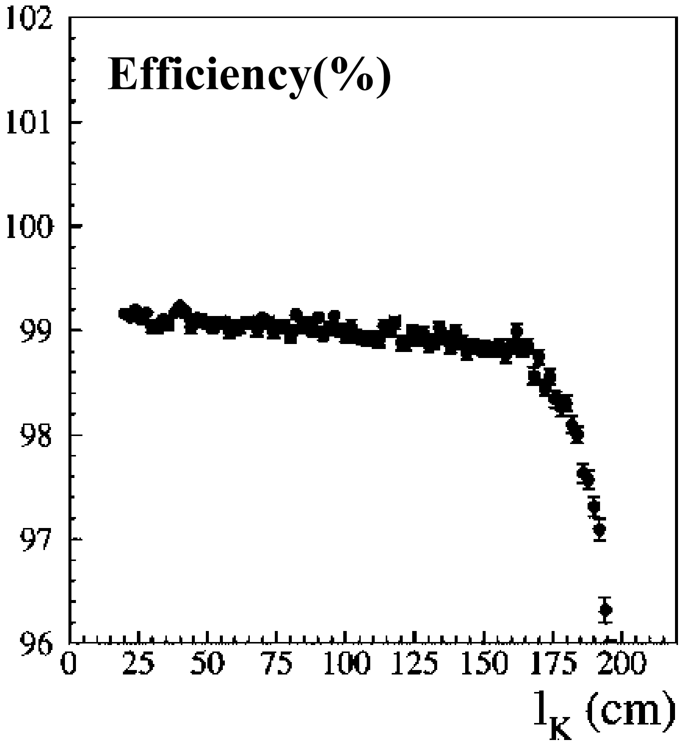


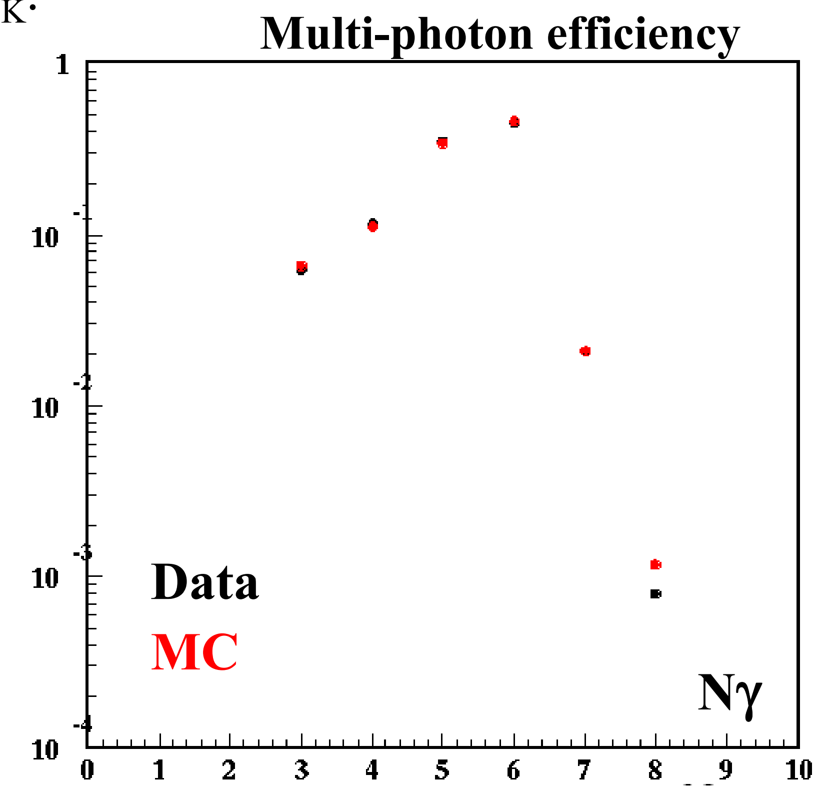
K_L momentum from $p_\phi - p_S$ with 1 MeV resolution

Neutral vertex reconstruction efficiency

Multiphon vertex efficiency evaluated from vertices given by the neutral cluster on the EMC.

Reconstruction efficiency for $K_L \rightarrow \pi^0\pi^0\pi^0$ with $N\gamma \geq 3$ is high and uniform over a broad interval on L_K.





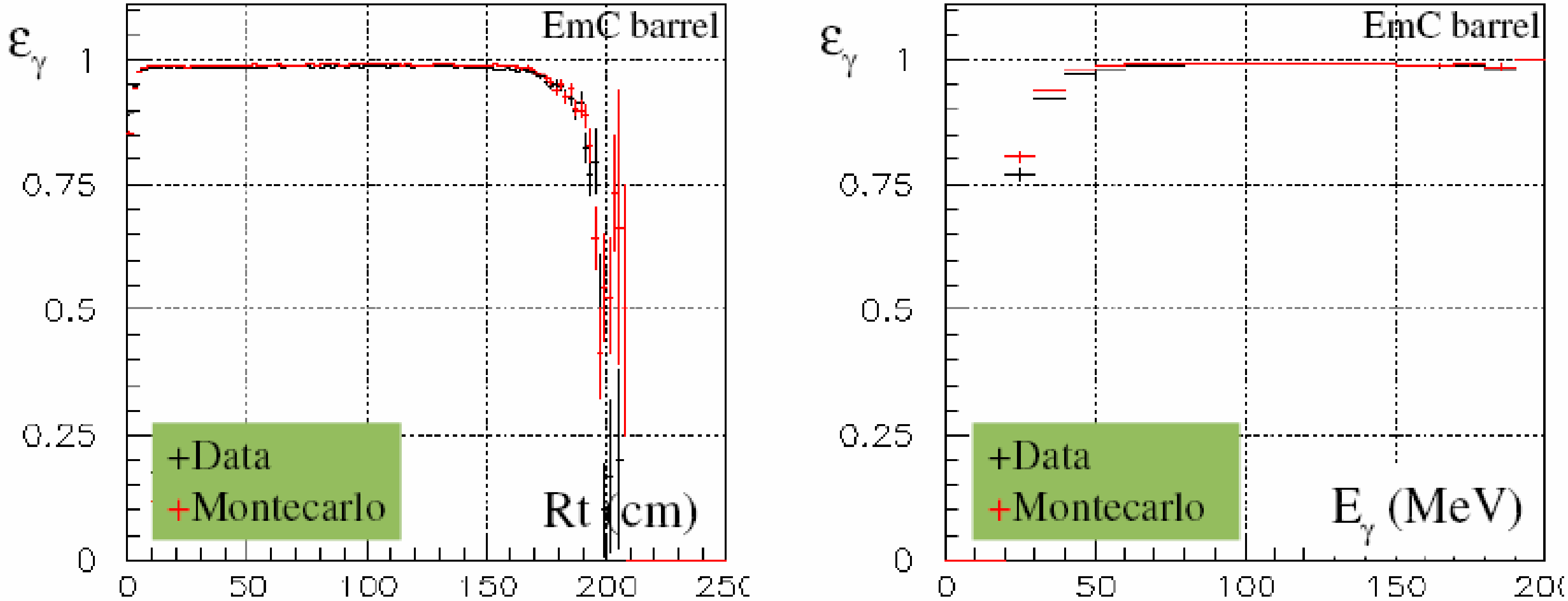
Single γ reconstruction efficiency

Use of the control sample $K_L \rightarrow \pi^+\pi^-\pi^0$ allow to measure the vertex reconstruction efficiency from the single photon

$$\varepsilon_\gamma = \frac{N_{\gamma rec}}{N_{\gamma tag}}$$

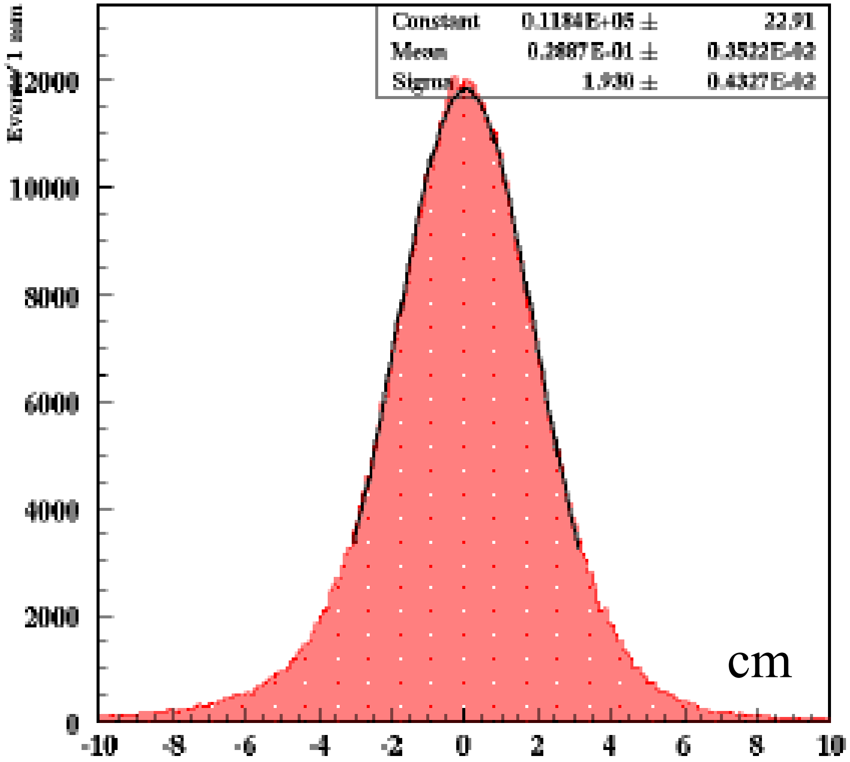
$N_{\gamma rec}$ → Number of events in which a second photon is detected where we expect to find from kinematics

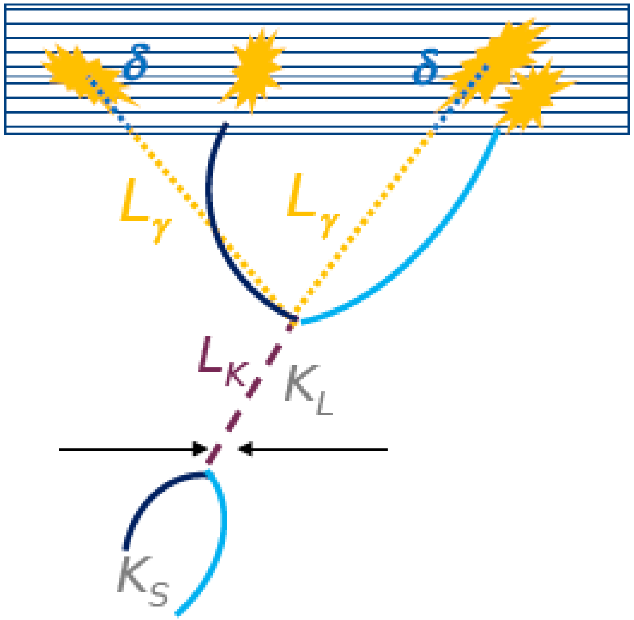
$N_{\gamma tag}$ → Number of events in which at least one photon is detected



We correct the MC efficiency with the ratio $\varepsilon_{data}/\varepsilon_{MC}$

Neutral vertex calibration





To **calibrate the time scale** and study the **neutral vertex resolution**, use of a control sample of $K_L \rightarrow \pi^+\pi^-\pi^0$ decays allows comparison between the vertex given by the reconstructed pion tracks and the neutral vertex.

Entering the precision realm for R_K

Main actors (experiments) in the challenge to push down precision on R_K:

NA48/2: **preliminary** result with 2003 data: **$R_K=2.416(43)_{stat}(24)_{syst}10^{-5}$**, from **~4000 Ke2** candidates (2% accuracy)
NA48/2: **preliminary** result with 2004 data: **$R_K=2.455(45)_{stat}(41)_{syst}10^{-5}$**, from **~4000 Ke2** candidates from special minimum bias run (3% accuracy)

KLOE: **preliminary** result with 2001-2005 data: **$R_K=2.55(5)_{stat}(5)_{syst}10^{-5}$**, from **~8000 Ke2** candidates (3% accuracy), perspectives to reach 1% error after analysis completion.

NA62 (ex NA48): **collected ~150,000 Ke2** events in dedicated 2007 run, aims to breaking the 1% precision wall, possibly reaching <~0.5%

Analysis basic principles

$$R_K = \frac{N_{Ke2}}{N_{K\mu2}} \left[\frac{\varepsilon^{\mathrm{REC}}_{K\mu2}}{\varepsilon^{\mathrm{REC}}_{Ke2}} C^{\mathrm{TRG}} C^{\mathrm{REC}} \right] \frac{1}{\epsilon^{\mathrm{IB}}}$$

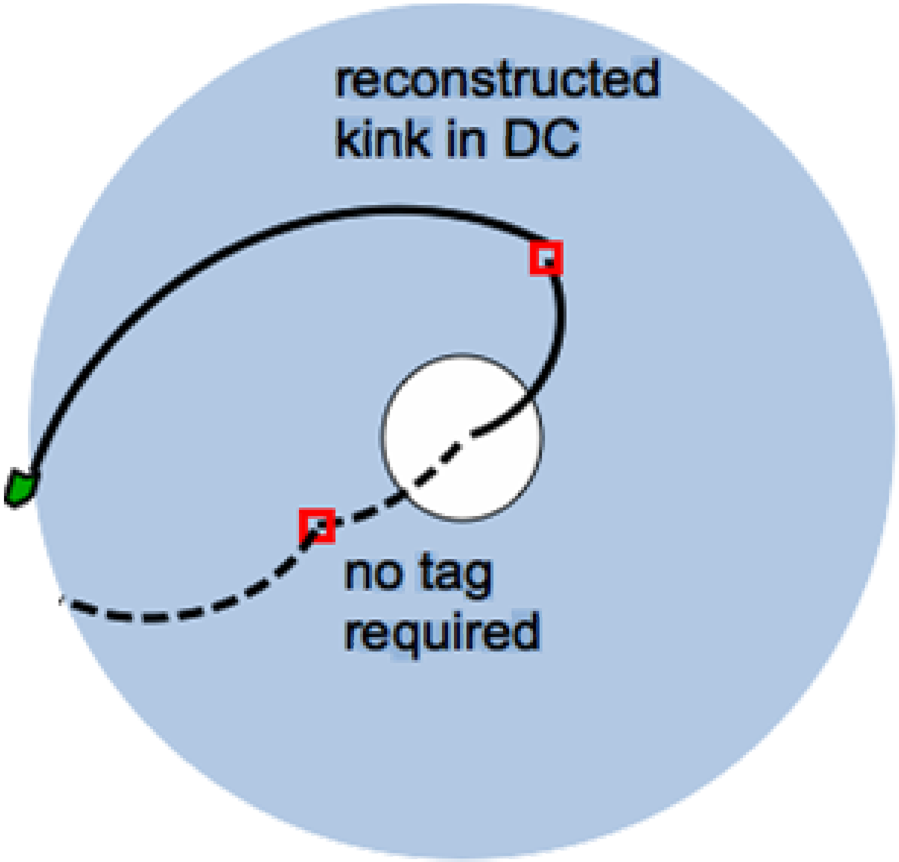
1) Select kinks in DC (~ fiducial volume)

- K track from IP
- secondary with $p_{\mathbf{lep}}$>180 MeV

for decays occurring in the FV;
the reconstruction efficiency is ~51%.

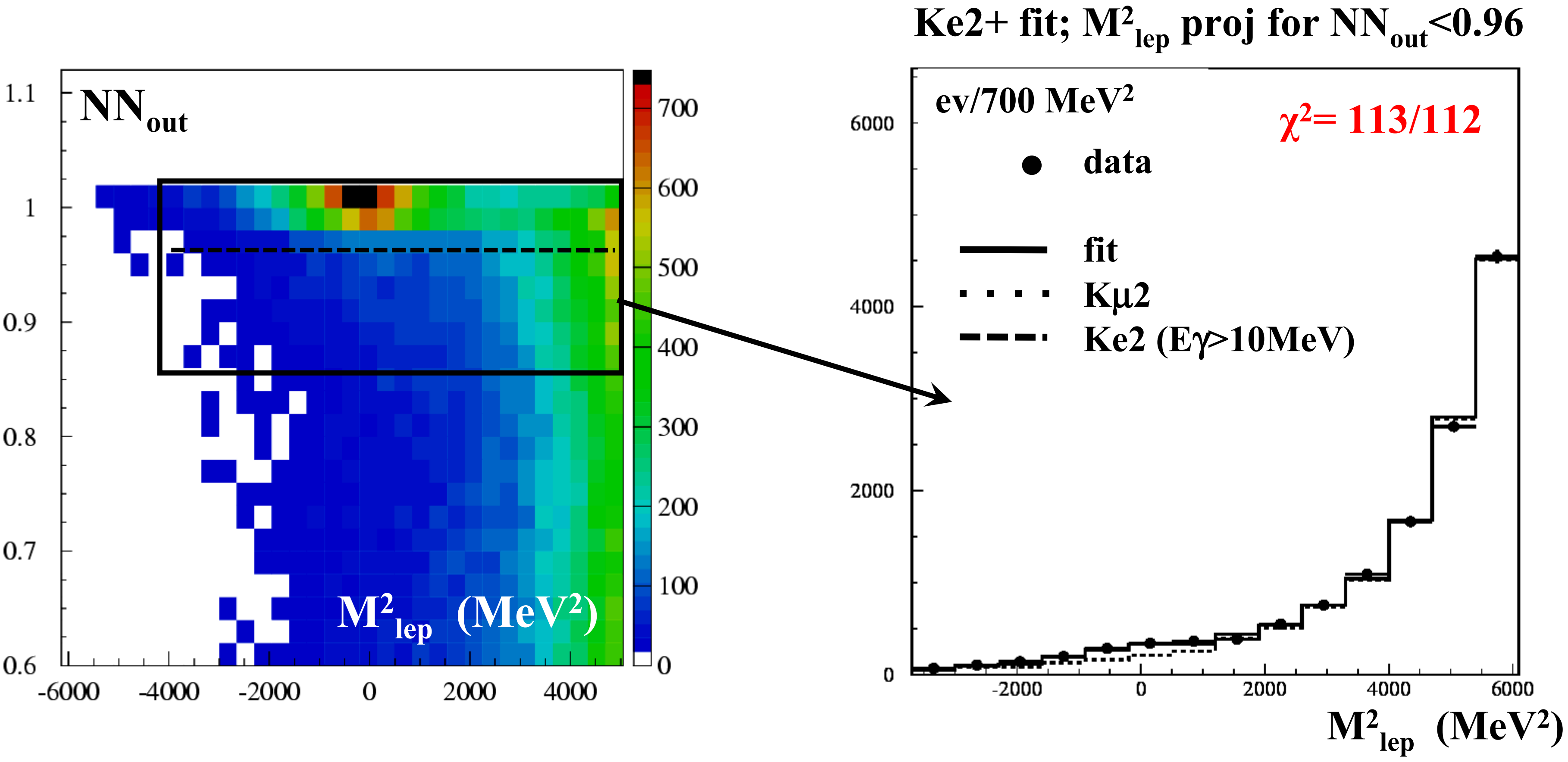
2) No tag required on the opposite "hemisphere" (as we usually do!)

→ gain **×4 of statistics**



K_{e2} event counting

Two-dimensional binned likelihood fit in the M^2_{lep}–NN_{out} plane in the region **$-4000<M^2_{lep}<6100$** and **$0.86<NN_{out}<1.02$**

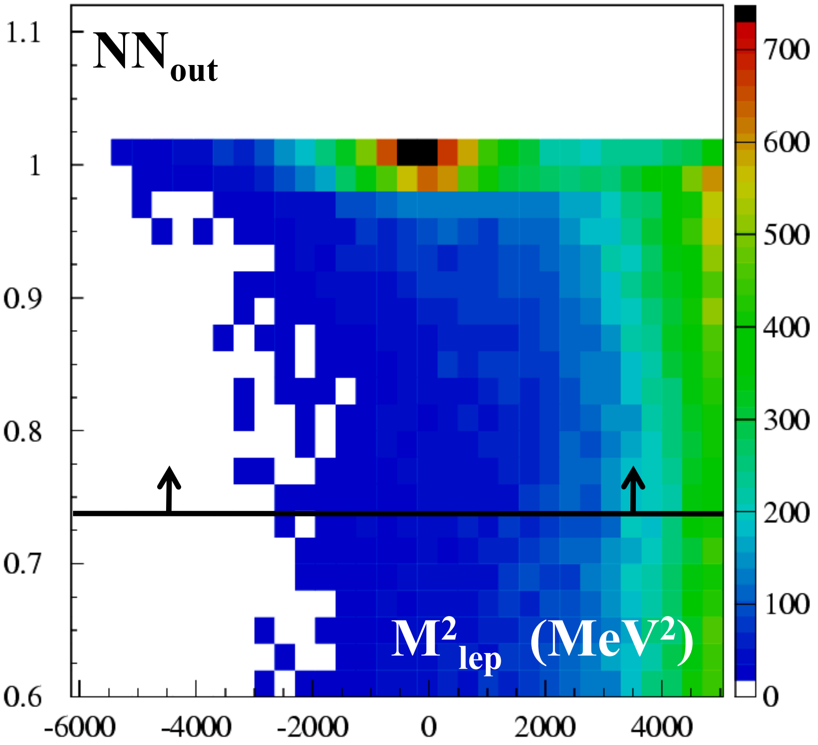


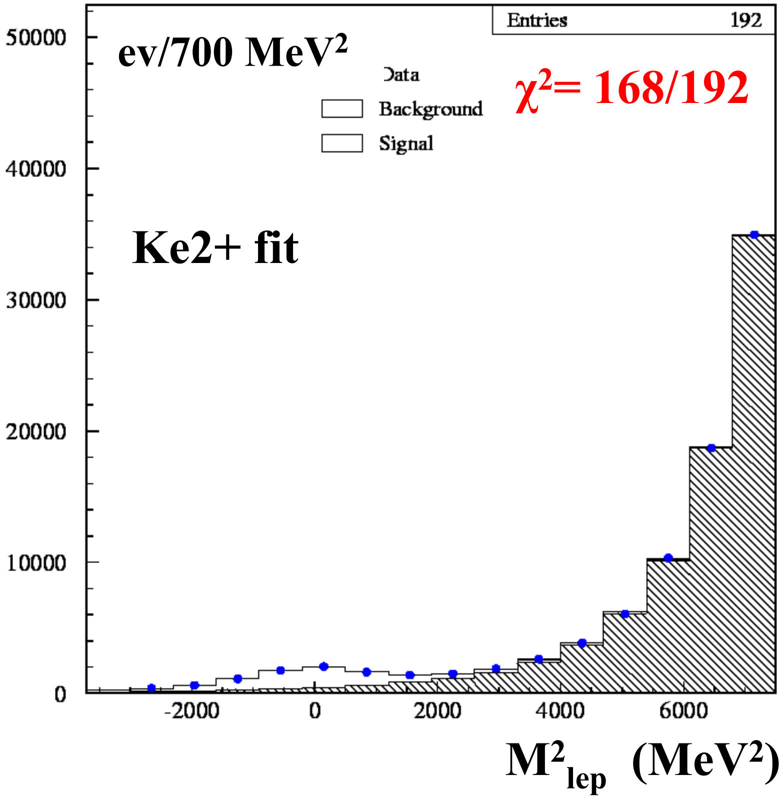
Ke2+ fit; M^2_{lep} proj for $NN_{out}<0.96$

We count **7060 (102) Ke2+ 6750 (101) Ke2–** **(σ_{STAT}=1%, 0.85% from Ke2)**

K_{e2} event counting: systematics

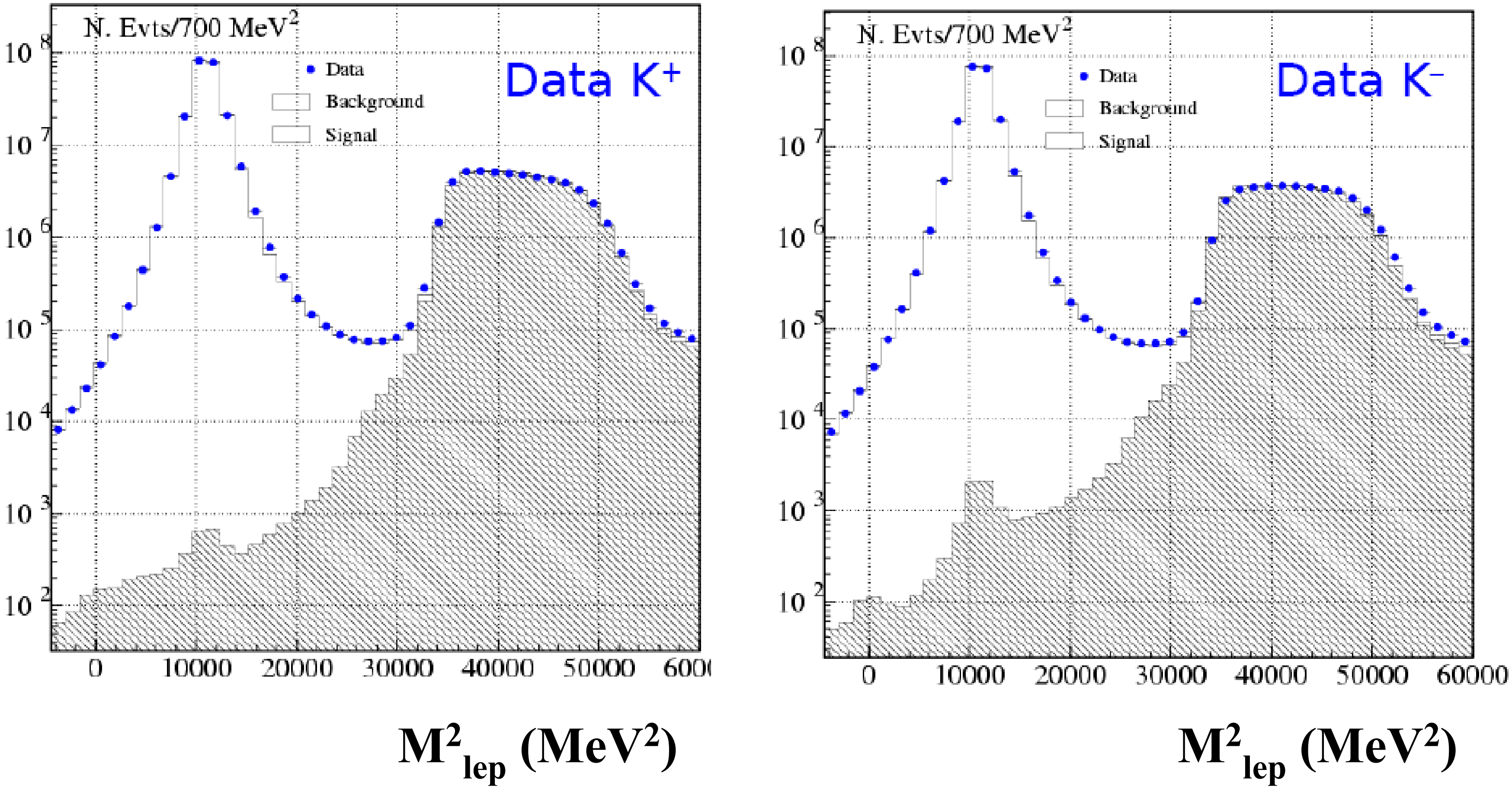
Repeat fit with different values of **max(M^2_{lep})** and **min(NN_{out})**:
vary significantly (×20) bkg contamination + lever arm.





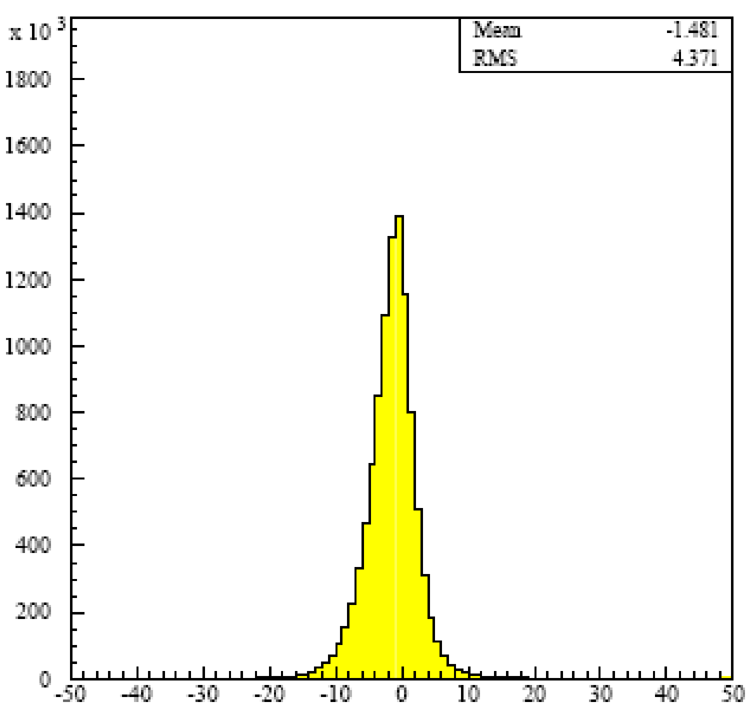
maximum bkg with: $-4000 < M^2_{lep} < 7500$ **and** $0.78 < NN_{out} < 1.02$

Kμ2 event counting

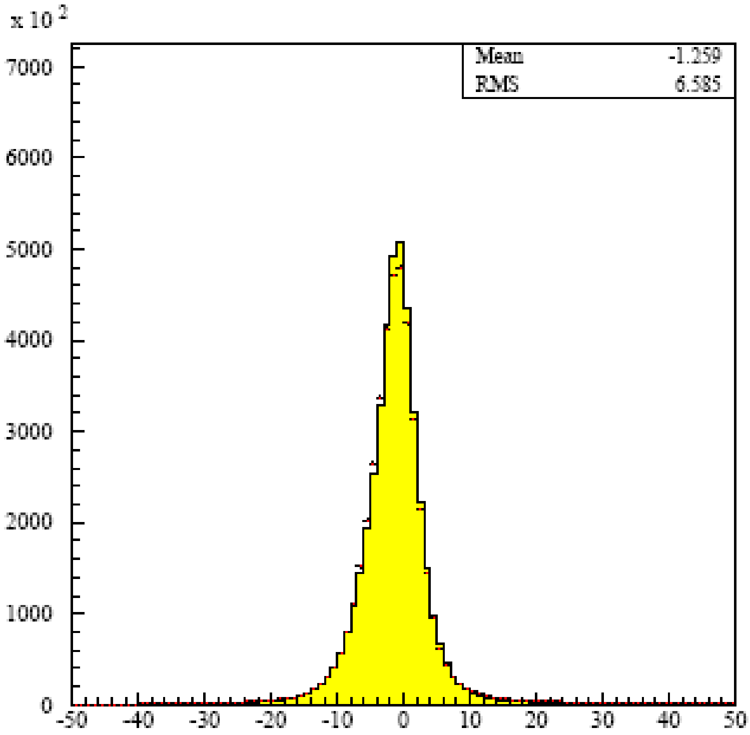


Fit to M^2_{lept} distribution: 300 million Kμ2 events per charge
Background under the peak <0.1%, from MC

Tracking efficiency



p_μ(fit)–p_μ(MC)   (MeV)



p_μ(fit)–p_μ(reco)   (MeV)

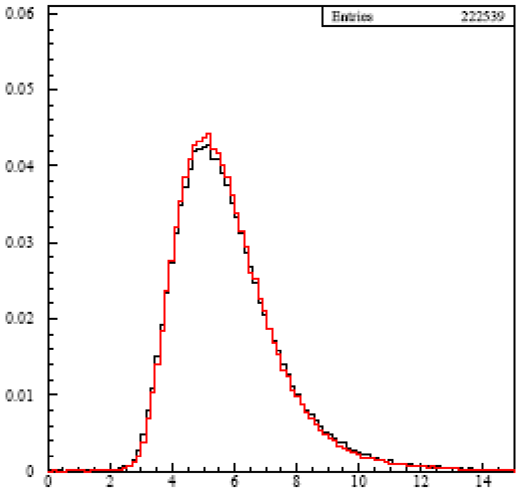
NN details

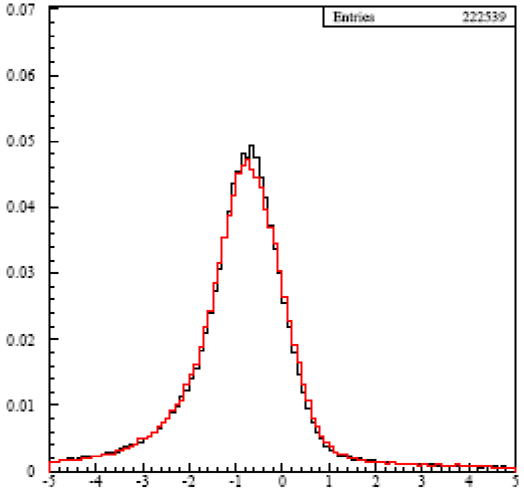
1) E/P;
2) 1st momentum of the distribution of the longitudinal energy path deposition (cluster centroid depth) evaluated at cell level;
3) the 3td momentum of the longitudinal energy path deposistion (skewness);
4,5) asymmetry of energy lost in first two innermost (outermost) planes;
6) RMS of energy plane distribution;
7) energy lost in the 1st plane;
8) number of the plane with larges energy deposition;
9) largest energy deposition in a single plane;
10) slope of the E_int(x) energy distribution;
11) curvature of the E_int(x) energy distribution;
12) de/dx i.e. value of E_int(x)/x|x<15 cm

Additional separation using ToF information: difference δT of the time measured in the EMC with that expected from the DC measurements in electron mass hypothesis has been included in the final version of the NN: 12-25-20-1 becomes 13-25-20-1

NN input distributions: some example

Cluster centroid depth

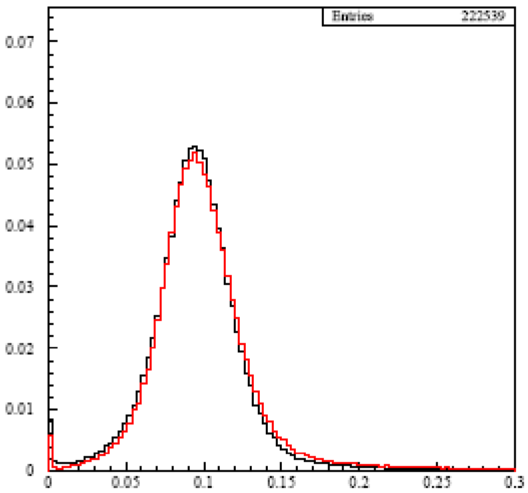


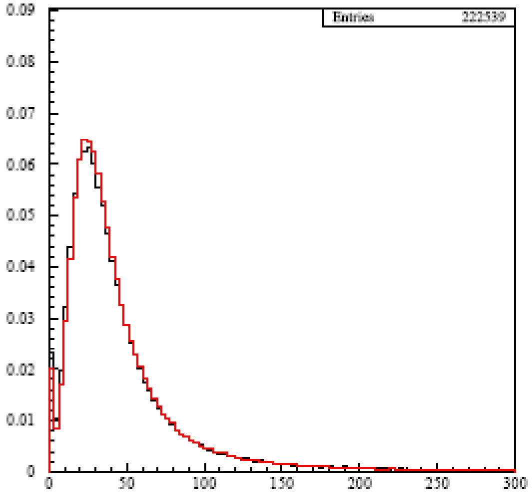


Asymmetry of energy lost in first two innermost planes

Data and **MC**

dE/dx





$E_{INT}(x)$ slope

Control samples for tracking efficiencies

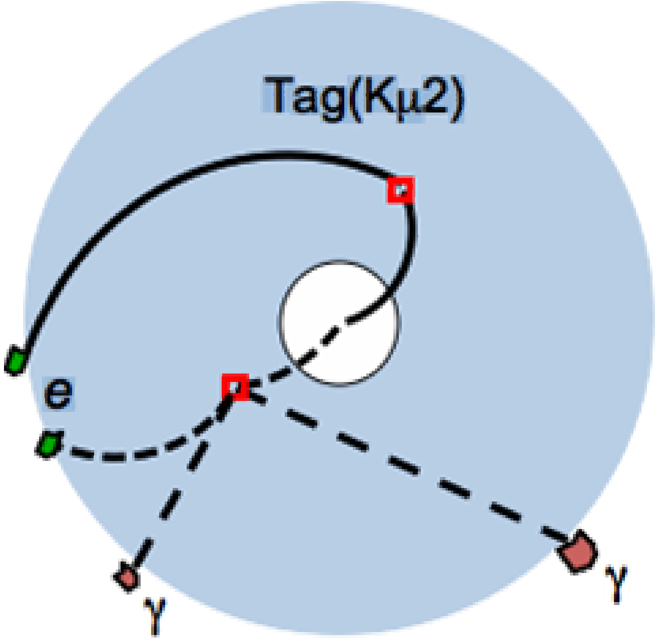
Just an example: selection of K^+e3 control sample to measure tracking efficiency for electrons

0) Tagging decay ($K\mu2$ or $K\pi2$);

1) Tagging decay ($K\mu2$ or $K\pi2$): reconstruction of the opposite charge kaon flight path;

2) Using a ToF technique a $\pi^0 \rightarrow \gamma\gamma$ decay vertex is reconstructed along the K decay path;

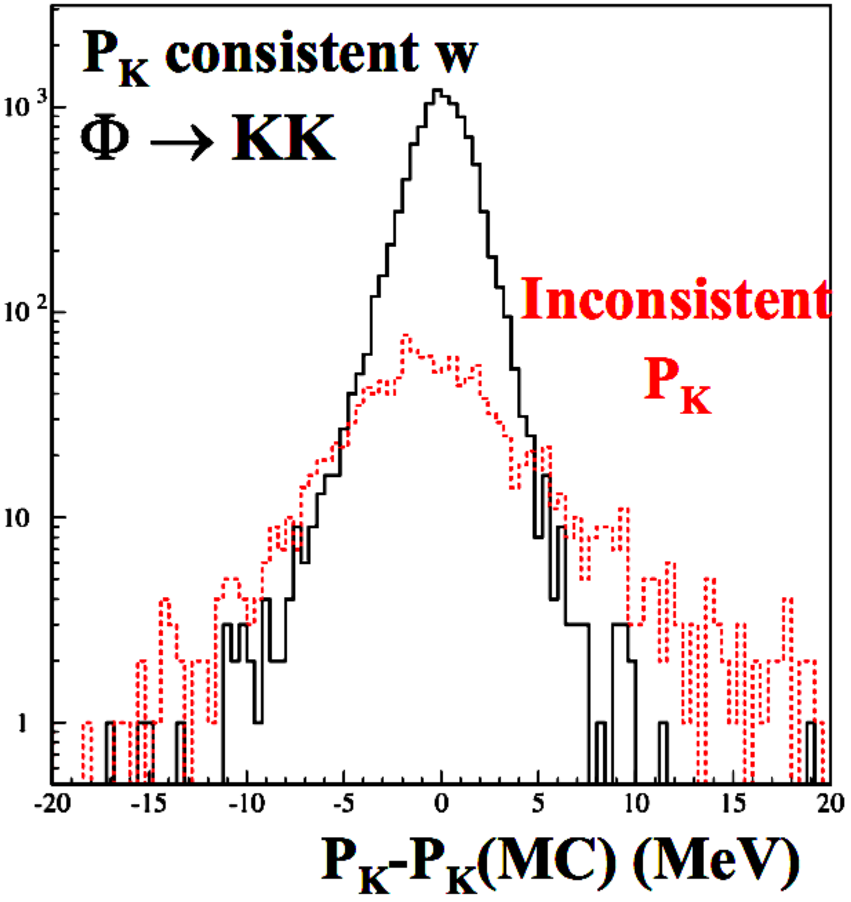
3) Require an electron cluster: p_e estimated from a kinematic fit with constraints on E/p, ToF, cluster position, and $E_{miss} - P_{miss}$.



Evaluate the K + electron kink reconstruction efficiency

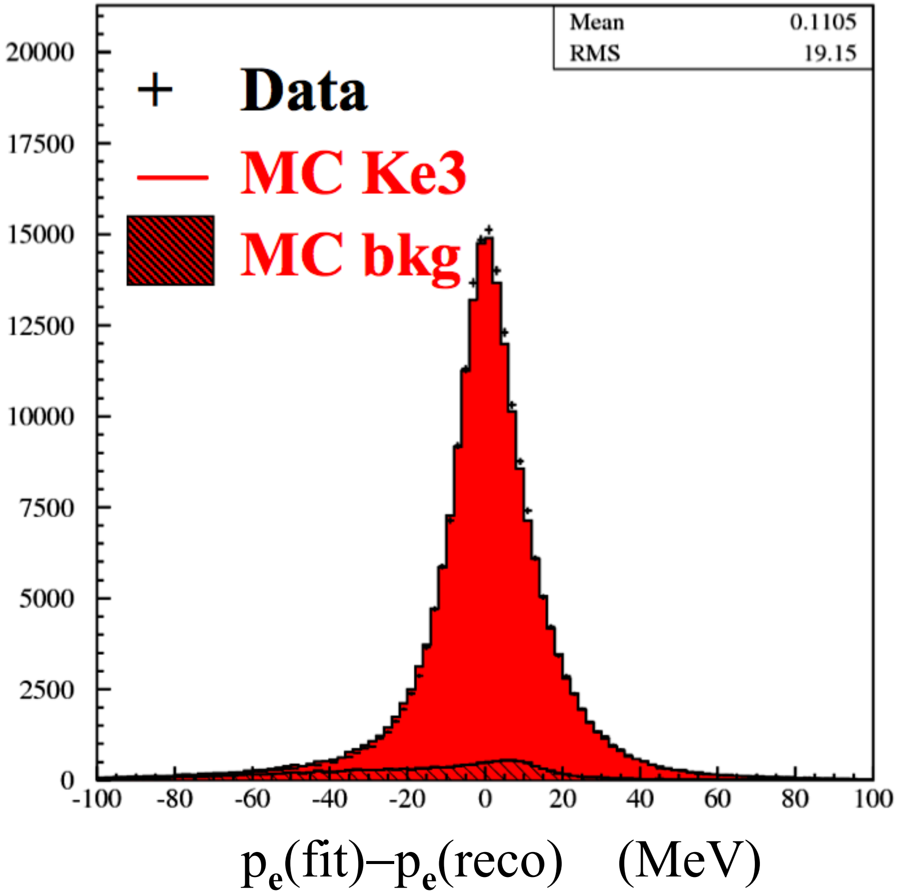
Background rejection (track quality)

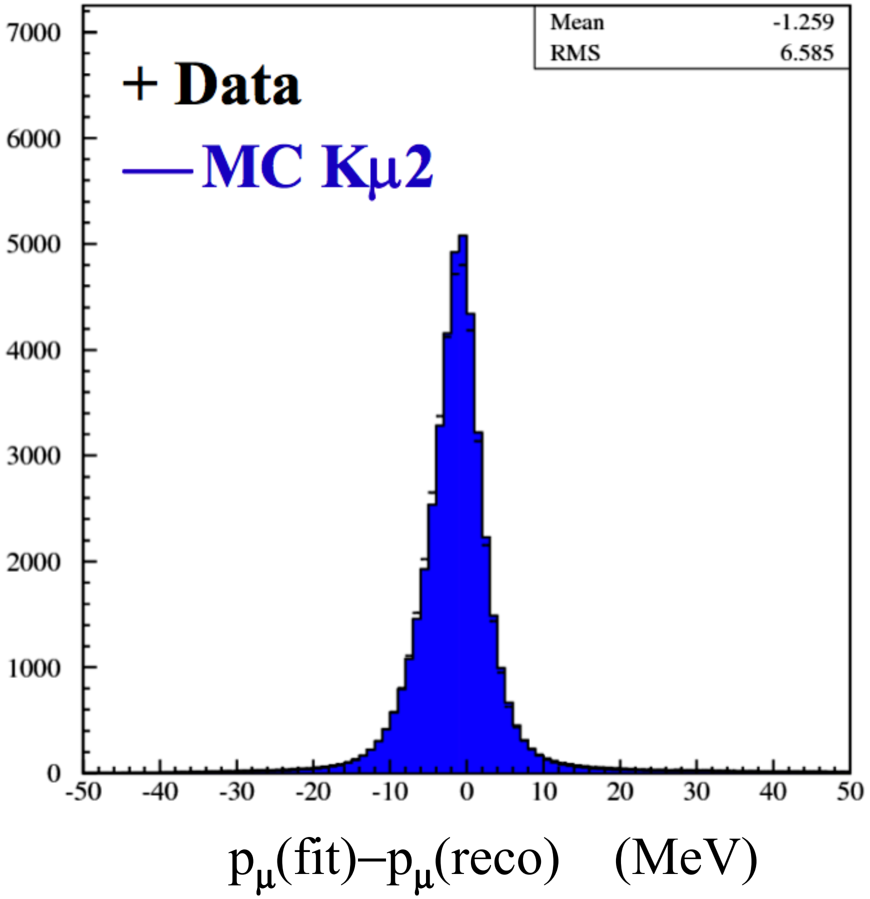
Background composition: Kμ2 events with bad p_K, p_{lep}, or decay vertex position reconstruction



- require good quality vertex and secondary track (χ^2cut);
- reduce $K_{\mu 2}$ tails cutting on the error on M^2_{lep} expected from track parameters;
- quality cuts for K: the kinematic of $\phi \rightarrow K^+K^-$ 2-body decay allows redundant p_K determinartion.

Control samples for tracking efficiencies

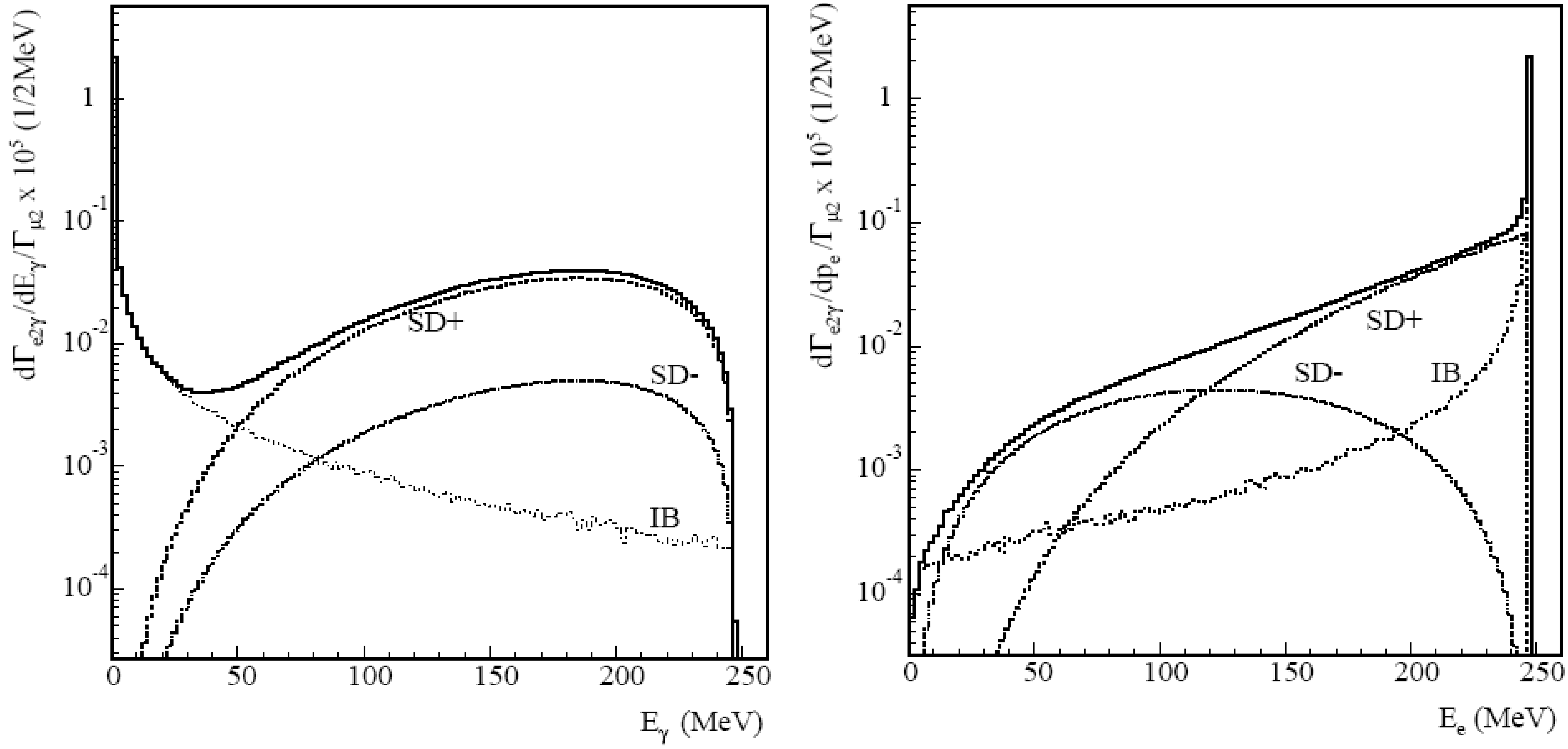




- For electron tracks obtain a resolution σ~19 MeV

- With a similar method, get σ~7 MeV for muon tracks

Distributions for Ke2γ decay



For Ke2**γ** generator, the IB component is described with χ_{PT} at $O(^{e}2p^{2})$ including resummation of leading logaritms, while DE component is described with χ_{PT} at $O(e^{2}p^{4})$.

Ke2(γ) reconstruction efficiencies

The ratio of Ke2 to Kμ2 efficiencies is evaluated with MC and corrected using data control samples

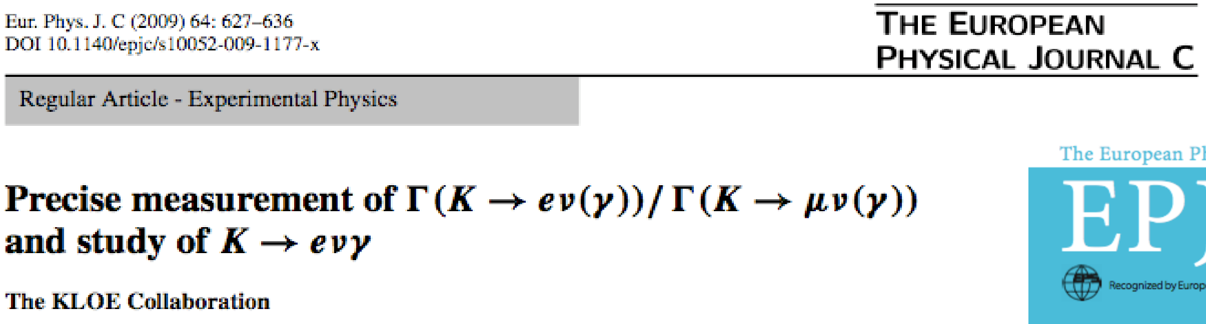
1) **kink reconstruction (tracking):** K^+e3 and $K^+\mu2$ data control samples selected using the tagging and additional criteria based on EMC information only (next slide)

2) **cluster efficiency (*e*, μ):** K_L control samples, selected with tagging and kinematic criteria based on DC information only

3) **trigger**: exploit the OR combination of EMC and DC triggers (almost uncorrelated); downscaled samples are used to measure efficiencies for cosmic-ray and machine background vetoes

We obtain: $\varepsilon(Ke2)/\varepsilon(K\mu2) = 0.946 \pm 0.007$

Measurement of $R_K=\Gamma(Ke2)/\Gamma(K\mu2)$



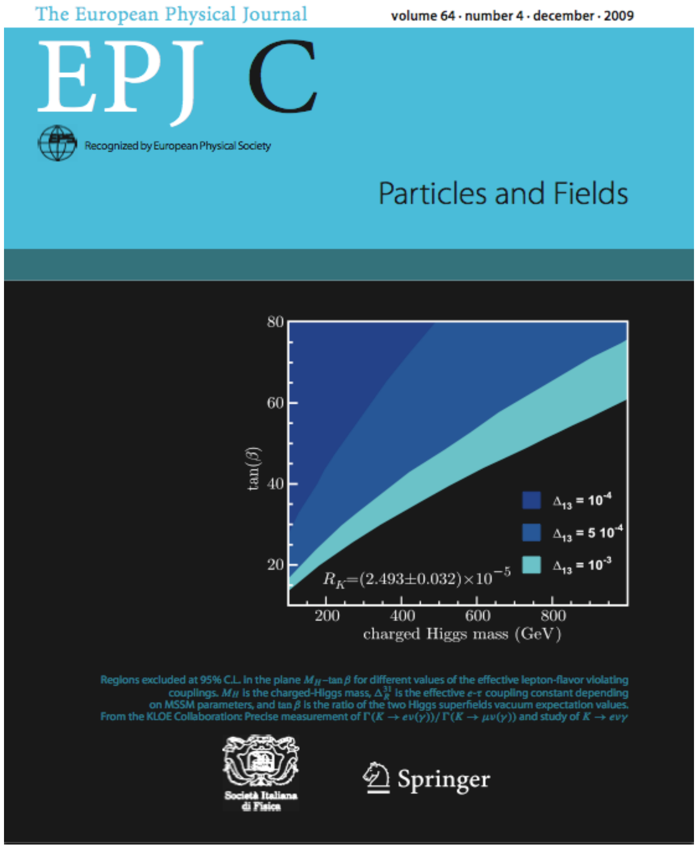
Eur. Phys. J. C (2009) 64: 627–636
DOI 10.1140/epjc/s10052-009-1177-x

THE EUROPEAN
PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Precise measurement of $\Gamma(K \to e\nu(\gamma))/\Gamma(K \to \mu\nu(\gamma))$ and study of $K \to e\nu\gamma$

The KLOE Collaboration



The European Physical Journal volume 64 · number 4 · december · 2009

EPJ C

Recognized by European Physical Society

Particles and Fields

Regions excluded at 95% C.L. in the plane M_H–tan β for different values of the effective lepton-flavor violating couplings. M_H is the charged-Higgs mass, Δ_R^{31} is the effective e-τ coupling constant depending on MSSM parameters, and tan β is the ratio of the two Higgs superfields vacuum expectation values. From the KLOE Collaboration: Precise measurement of $\Gamma(K \to e\nu(\gamma))/\Gamma(K \to \mu\nu(\gamma))$ and study of $K \to e\nu\gamma$

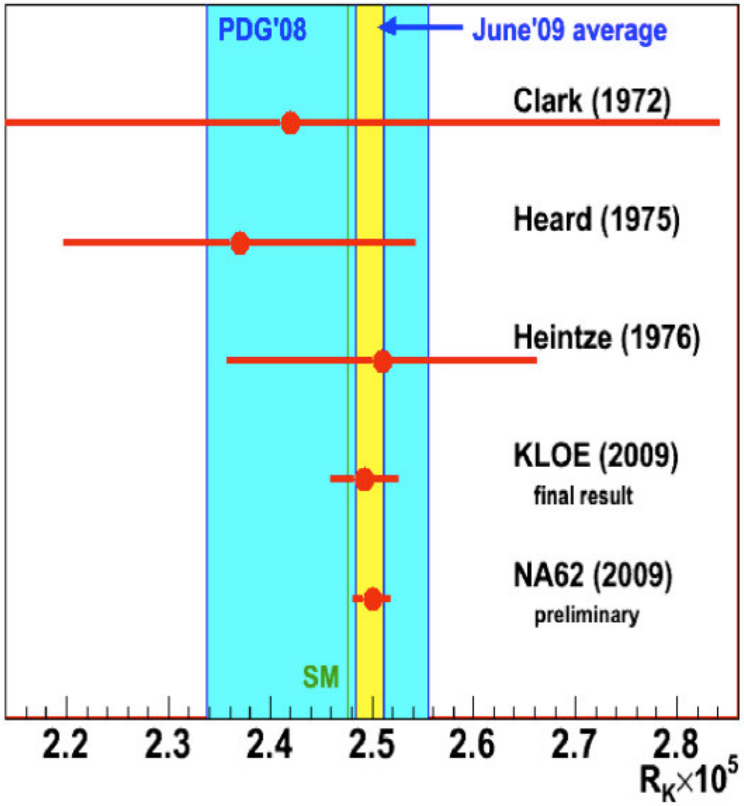
Società Italiana di Fisica

Springer

KLOE paper: EPJC (2009) 64

2009 results for R_K

	KLOE	**NA62**
Ke2's on tape	**30k**	**100k**
Kinematic rejection	**10^3 at ε≈60%**	**10^3-1, p_{lep} in 20-60 GeV**
e/μ rejection	**10^3**	**3-1.5 10^5, p_{lep} in 20-60 GeV**
Bkg to Ke2	**16%**	**8%**
Ke2γ (SD)	**Include as bkg Dedicated meas.**	**Suppress in analysis**
Ke2 counts	**14k**	**50k**
$R_K \times 10^5$	**2.493(25)(19)**	**2.500(12)(11)**
Total error	**1.3%**	**0.64%**
Status	**Published**	**Preliminary**



Ke2γprocess

Dalitz density

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

helicity suppressed

negligible

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

E_γ, E_e in the K rest frame

Structure Dependent

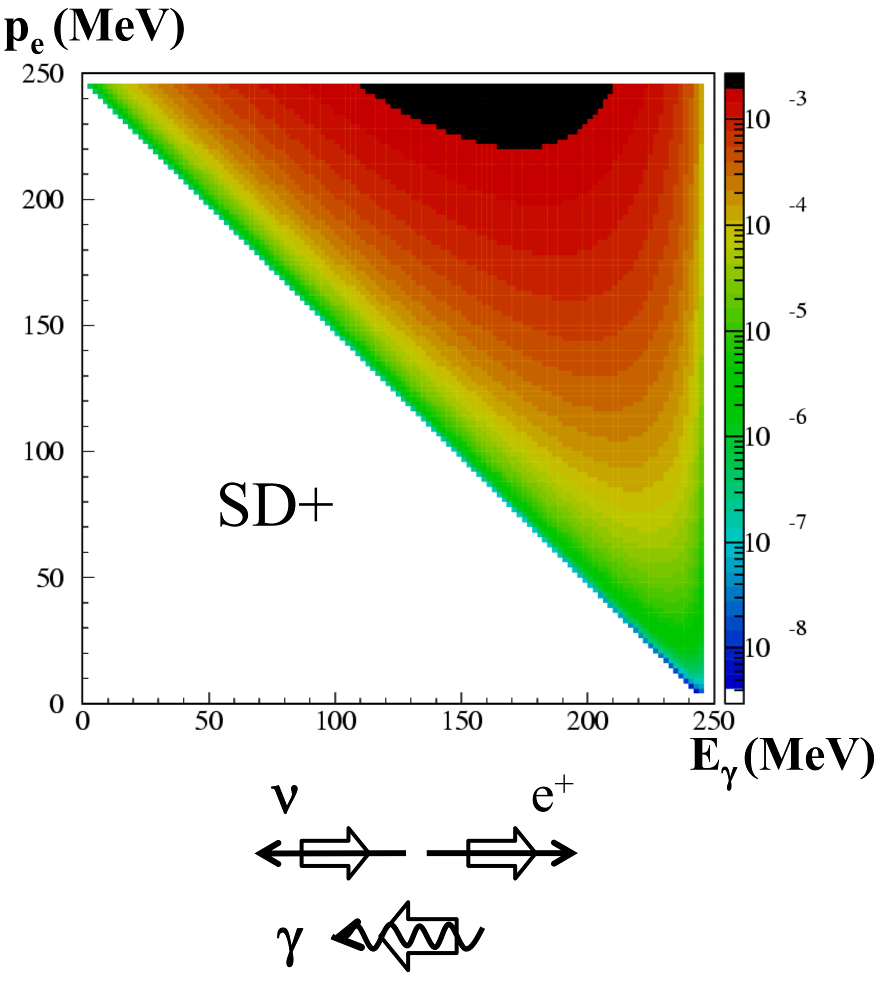
$$\rho_{SD}(x,y) = \frac{G_F^2 |V_{us}|^2 \alpha}{64\pi^2} M_K^5 \left((f_V + f_A)^2 f_{SD+}(x,y) + (f_V - f_A)^2 f_{SD-}(x,y) \right)$$

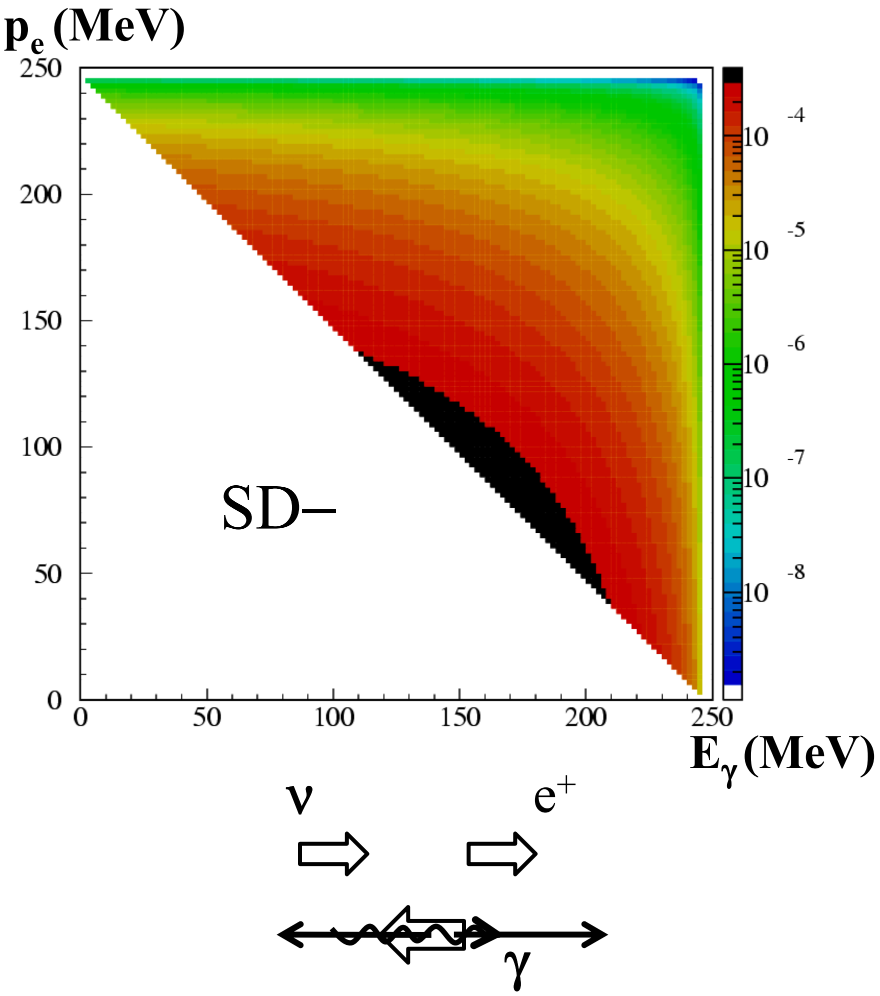
f_V , f_A : effective vector and axial couplings

SD+ = V+A : γ polarization +

SD– = V−A : γ polarization –

Dalitz plots for SD+ and SD–





electron peaks at 250 MeV,
e-γ antiparallel

electron peaks at 100 MeV: **very bad**,
since Ke3 endpoint is 230 MeV

Ke2γ: theory predictions

1) ChPT at O(p^4):

$f_V \approx 0.0945$

$f_A \approx 0.0425$

no dependence on photon energy

Bijnens, Ecker, Gasser 93

2) ChPT at O(p^6):

$f_V \approx 0.082(1+\lambda(1\text{-}x))$

$f_A \approx 0.034$

V linear x dependence ($\lambda \approx 0.4$)

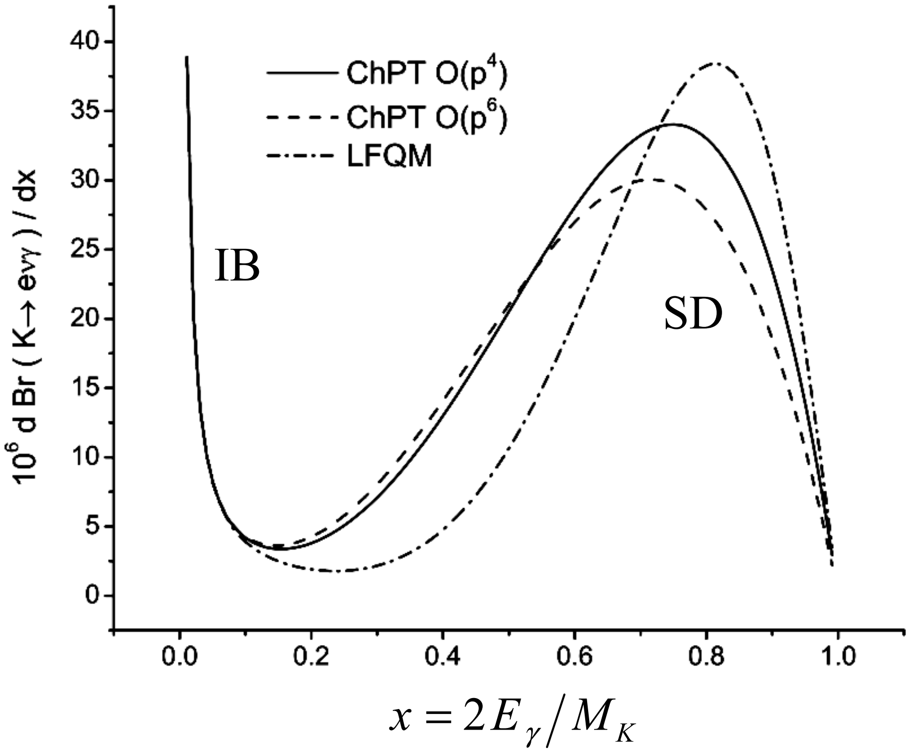
Ametller, Bijnens, Bramon, Cornet 93
Geng, Ho, Wu 04
Chen, Geng, Lih 08

3) LFQM:

non trivial x dependence

$f_V = f_A = 0$ at x=0

Chen, Geng, Lih 08



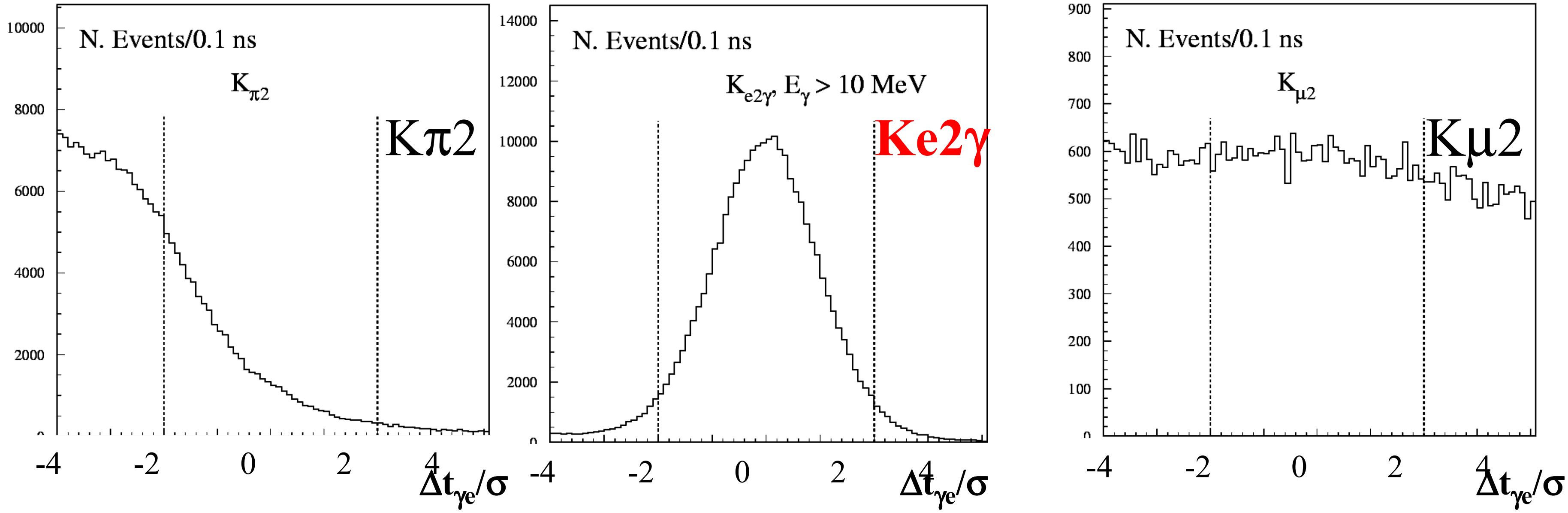
from Phys. Rev. D77 (2008) 014004

Ke2γ selection: photon detection

- A photon is required with energy $E_\gamma^{calo} > 20$ MeV
to reject bkg (we loose Ke2$_{IB}$, too)
- Time of arrival compatible with that of the event (electron):

$$\Delta t_{\gamma e} = \left(t_\gamma - r_\gamma / c\right) - \left(t_e - r_e / c\right) < 2\sigma$$

(r = distance from K decay vtx)



γ from π^0
$\beta(\pi^+) \approx 0.8$ instead of 1

Fake γ from accidental bkg

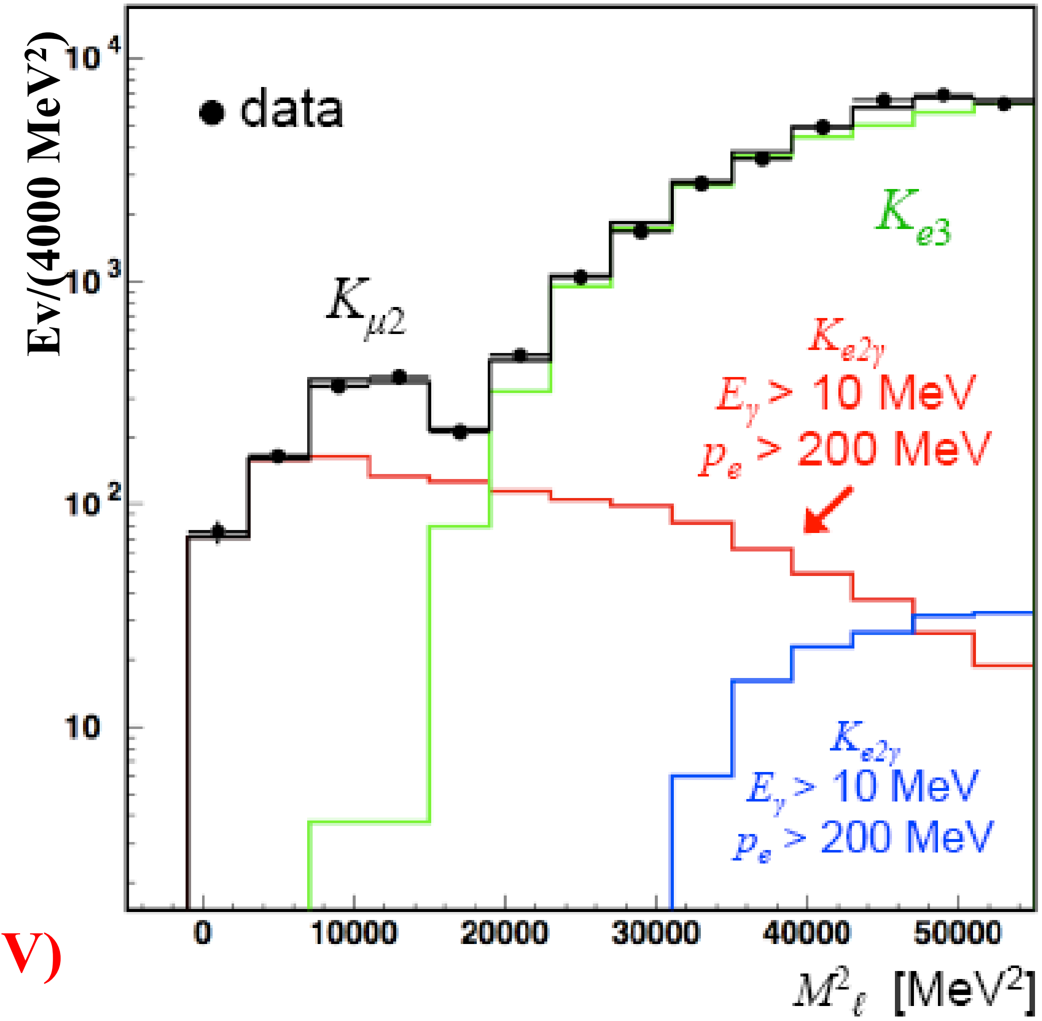
Ke2γ selection

After photon detection
bkg is dominated by

- Kμ2 in the low M^2_{lep} region
- Ke3 for $M^2_{lep} > 20000$

No sensitivity for Ke2γ with
p_e<200 MeV
(SD– amplitude)

We measure
Ke2γ (Eγ>10 MeV, p_e<200 MeV)
→ SD+ amplitude



Ke2γselection: photon matching

$E_\gamma^{\rm lab}$ can be evaluated from $K_{e2\gamma}$ kinematics, using measurements of:

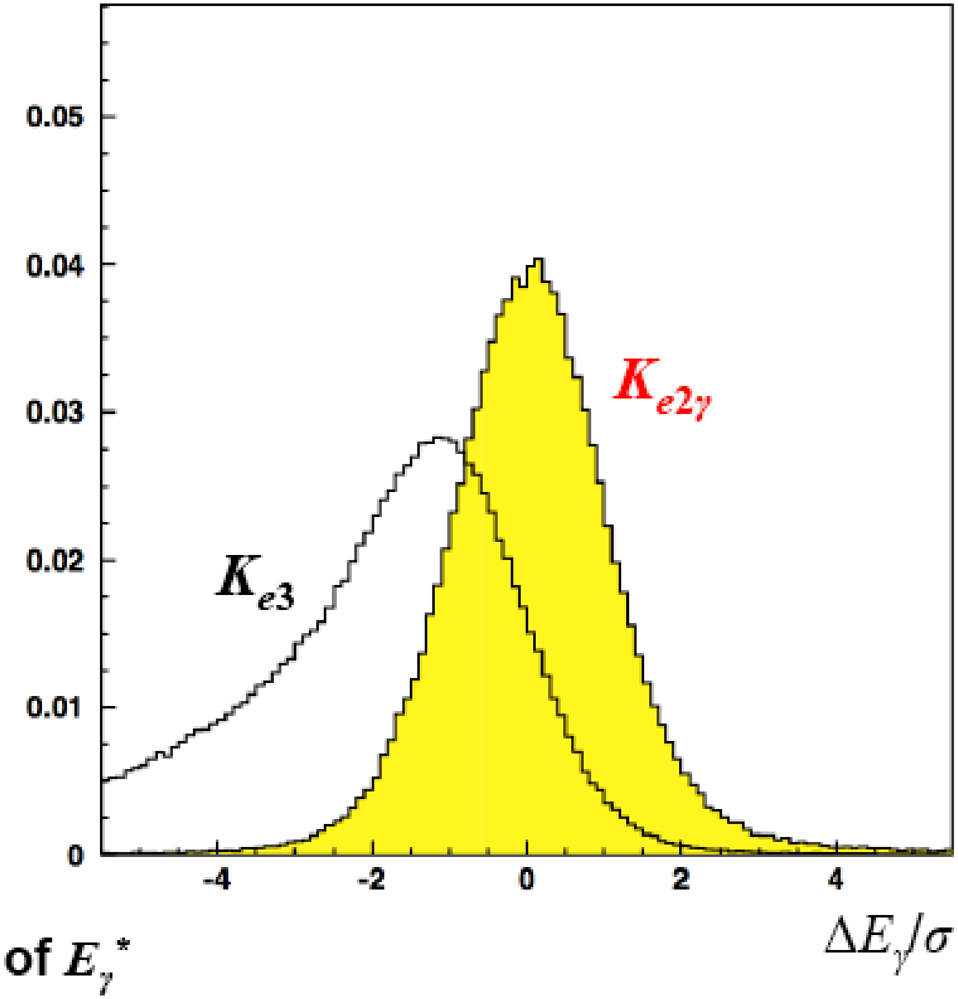
- track momenta $\mathbf{p}_K$, $\mathbf{p}_e$
- photon direction $\mathbf{n}_\gamma$ from cluster and vertex positions

$$E_\gamma^{\rm lab} = \frac{m_K^2 + m_e^2 - 2E_K E_e + 2\mathbf{p}_K \cdot \mathbf{p}_e}{2\left(E_K - E_e - \mathbf{p}_K \cdot \mathbf{n}_\gamma + \mathbf{p}_e \cdot \mathbf{n}_\gamma\right)}$$

$\sigma_E^{\rm lab} \approx$ **12 MeV**

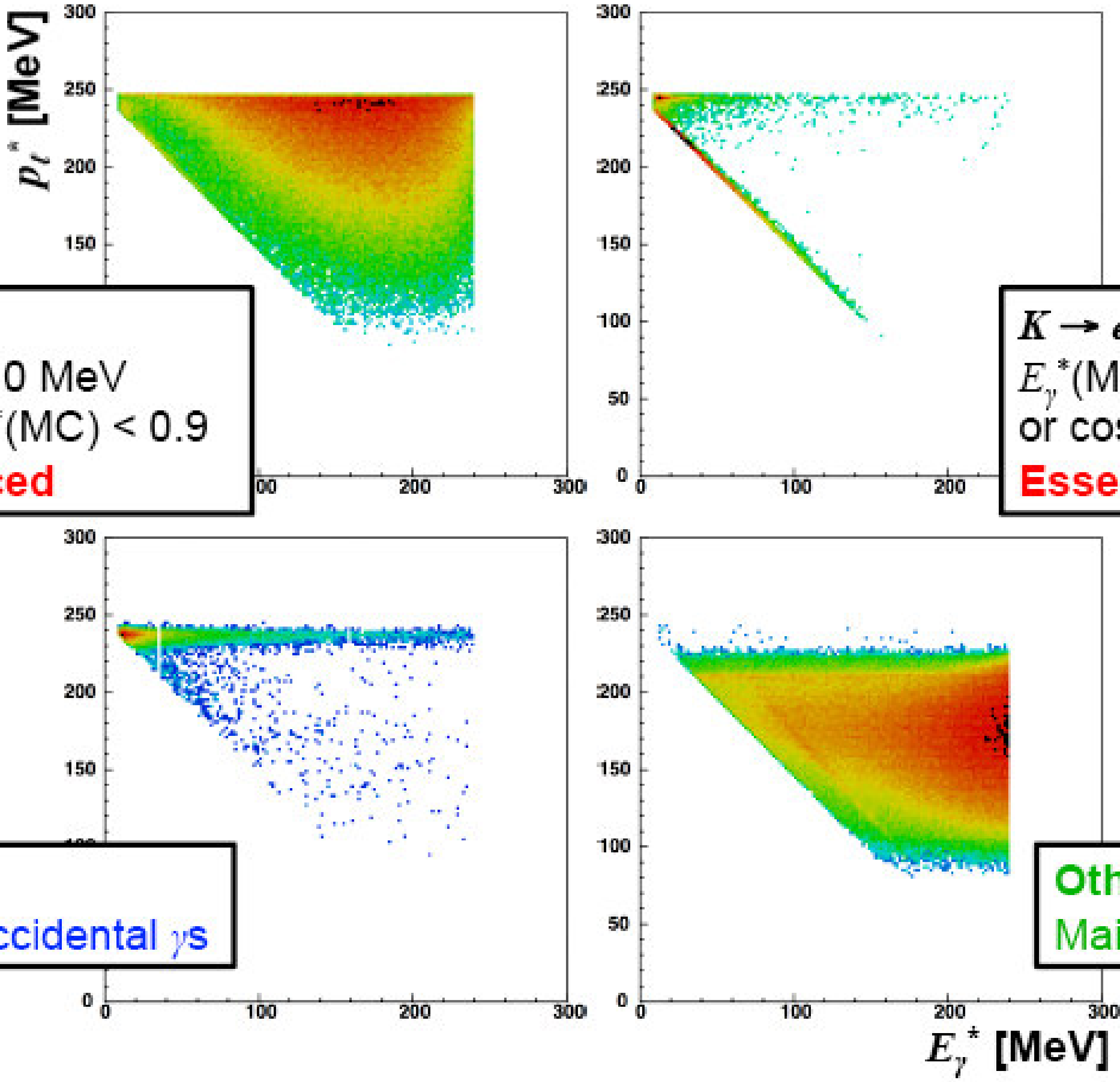
$\sigma_E^{\rm cal} \approx$ **30 MeV**

$\Delta E_\gamma = E_\gamma^{\rm lab} - E_\gamma^{\rm cal}$ useful for signal/ background separation



Perform 2-dimensional binned likelihood fit in M_ℓ^2, $\Delta E_\gamma/\sigma$ in 5 bins of E_γ^*

Ke2γfit: MC samples



$K \to e\nu\gamma$
E_γ^*(MC) > 10 MeV
and cos $\theta_{\gamma\ell}^*$(MC) < 0.9
SD enhanced

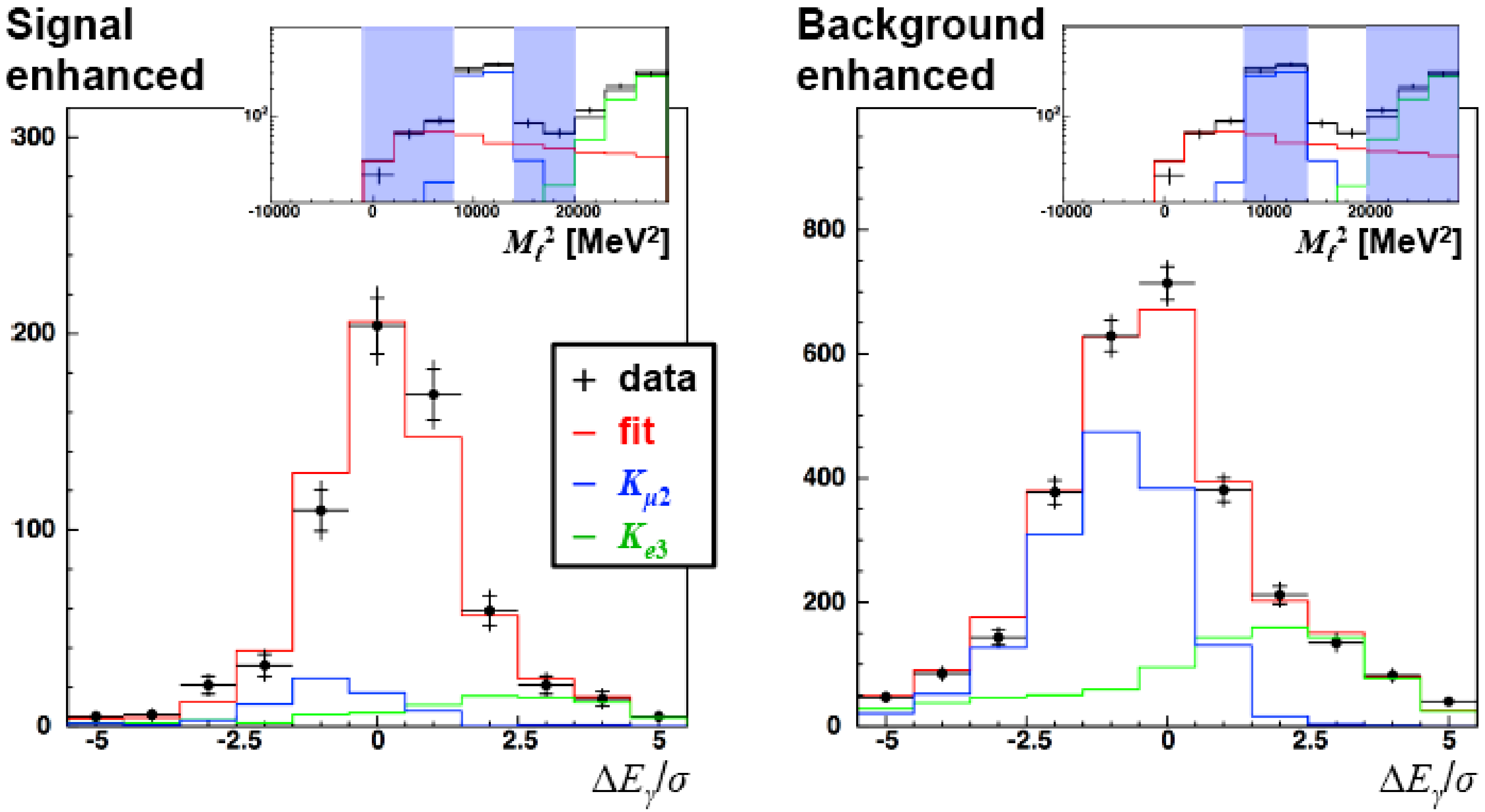
$K \to e\nu\gamma$
E_γ^*(MC) < 10 MeV
or cos $\theta_{\gamma\ell}^*$ (MC) > 0.9
Essentially all IB

$K \to \mu\nu(\gamma)$
including accidental γs

Other background
Mainly K_{e3}

Ke2γ: details on fit results

Projections on $\Delta E_\gamma/\sigma$ axis for all 5 E_γ^* bins, with cuts on M_ℓ^2



Signal enhanced

Background enhanced

Ke2γ event counting

- Two-dimensional binned likelihood fit in the

$M^2_{lep} - \Delta E_\gamma/\sigma$ plane

5 bins of E_γ (from E_γ^{lab} pass in K rest frame):

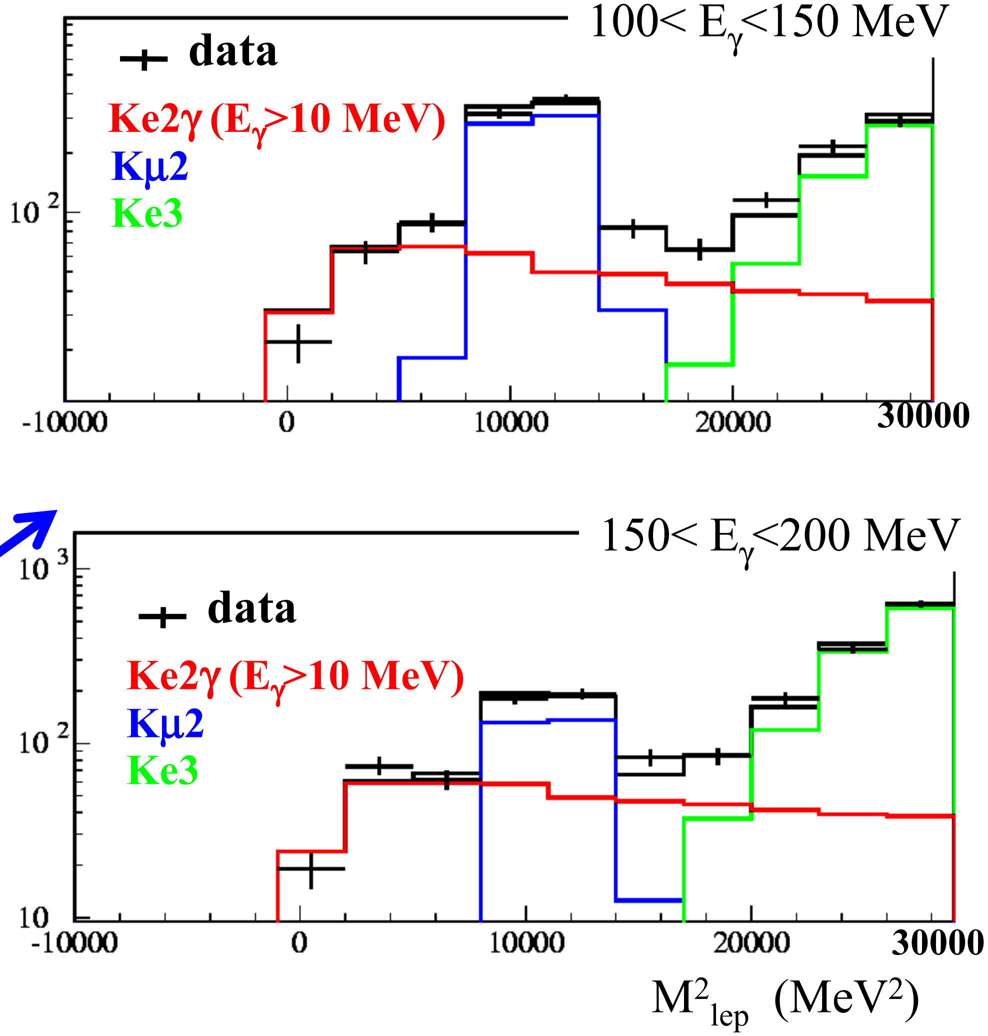
(10, 50) (50,100) (100,150)
(150,200) (200,250)

- Most populated bins

$100 < E_\gamma < 150$ MeV: N = 463 ± 32
$\chi^2 = 87/106$

$150 < E_\gamma < 200$ MeV: N = 494 ± 38
$\chi^2 = 100/106$

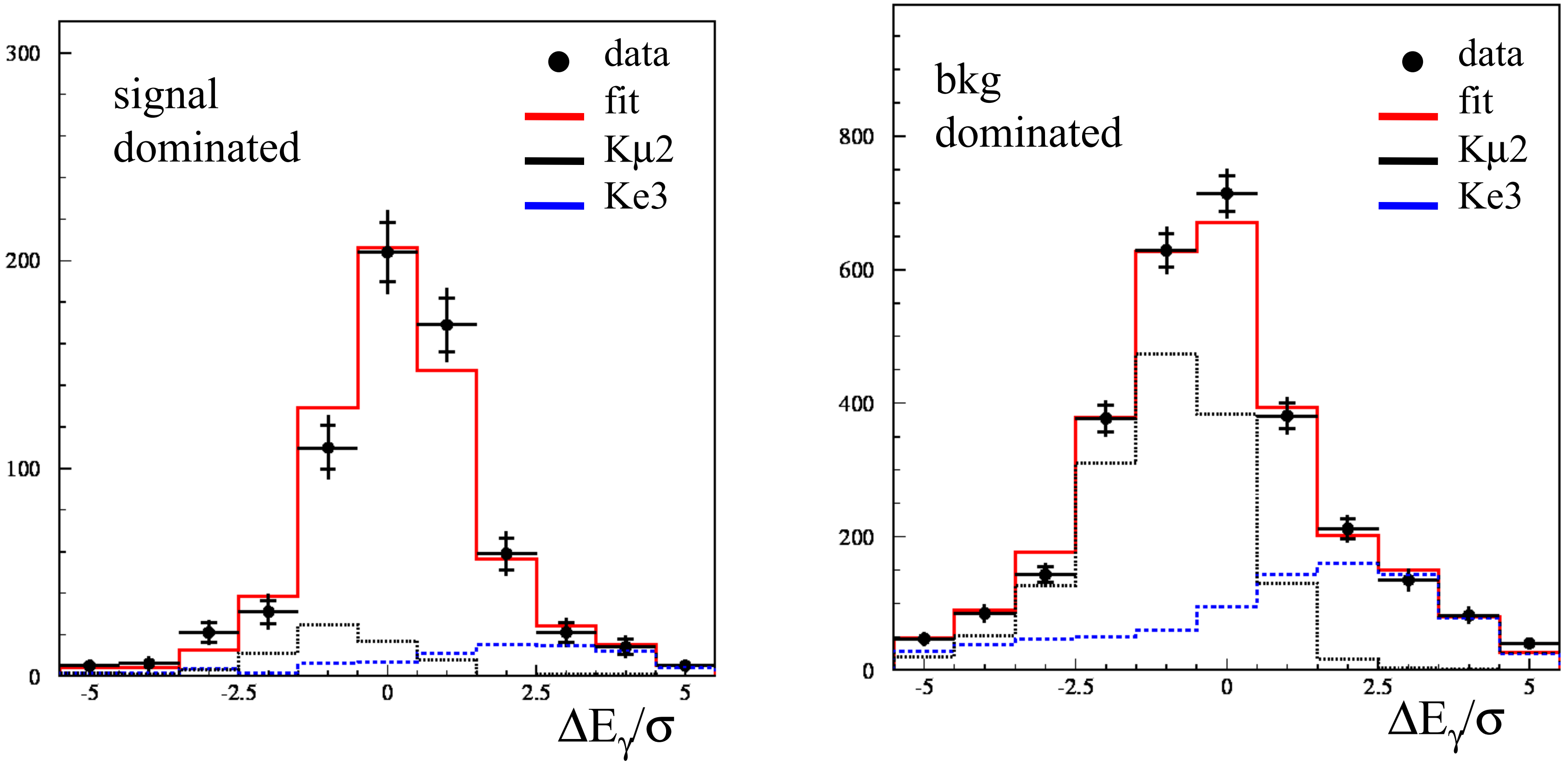
Fit projections on M^2_{lep} axis



Ke2γ event counting

Fit projections on $\Delta E_\gamma/\sigma$ (all E_γ bins together)

(according to M^2_{lep}, we show separately regions dominated by signal and bkg)



In total, we count Ne2γ = 1484 ± 63

Ke2γ spectrum vs LFQM

The spectrum predicted by the
Light Front Quark Model
is excluded by our data, χ^2=127/5