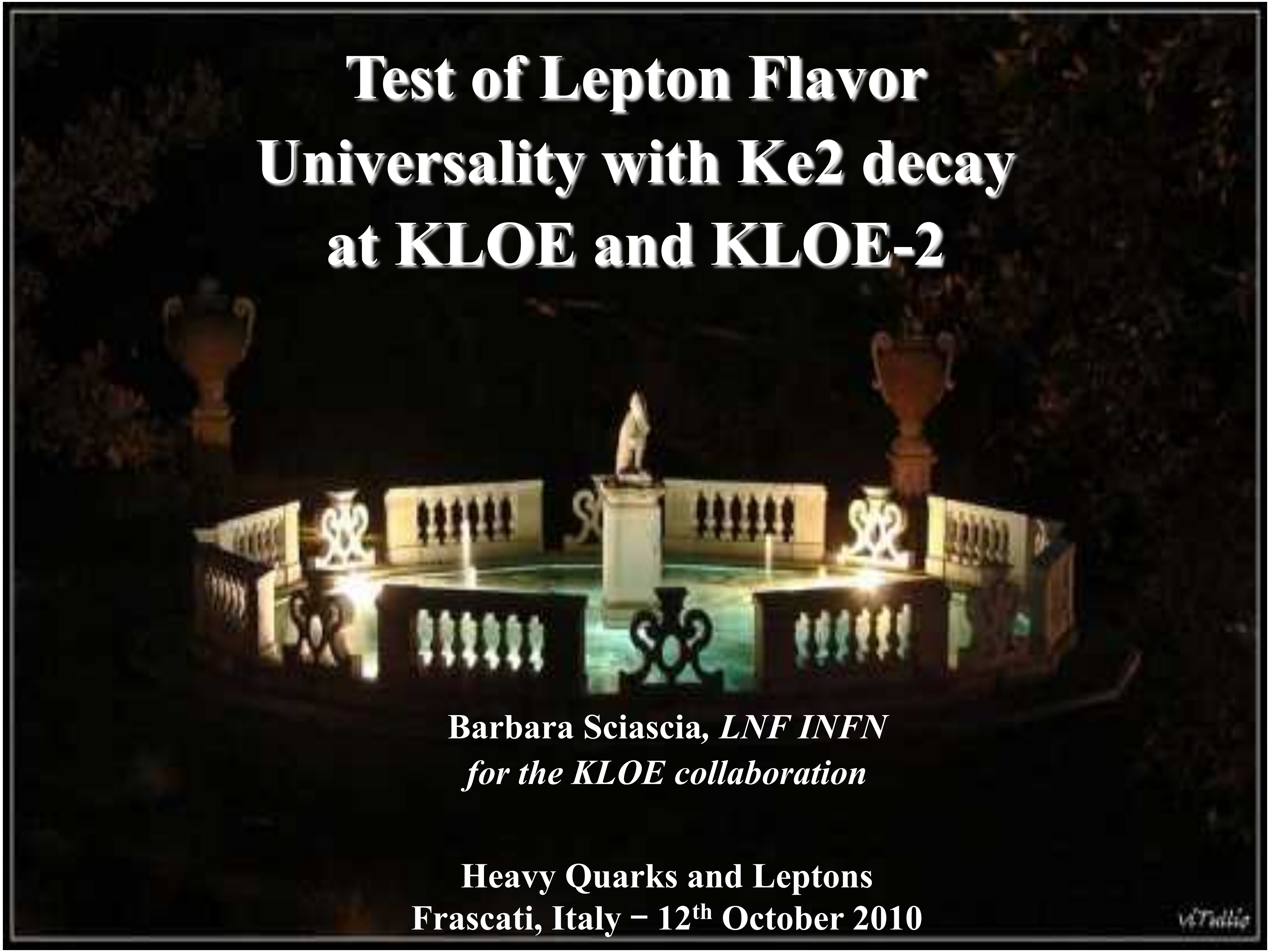


Test of Lepton Flavor Universality with Ke2 decay at KLOE and KLOE-2

Barbara Sciascia, ***LNF INFN***
for the KLOE collaboration

Heavy Quarks and Leptons
Frascati, Italy − 12th October 2010

Test of Lepton Flavor Universality with Ke2 decay at KLOE and KLOE-2

- Daϕne, KLOE, and KLOE-2
- R_K=Ke2/Kμ2 in and beyond the SM
- R_K measurement at KLOE
- Study of radiative process Ke2γ at KLOE
- KLOE-2 prospects for Ke2

KLOE and DaΦne

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

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

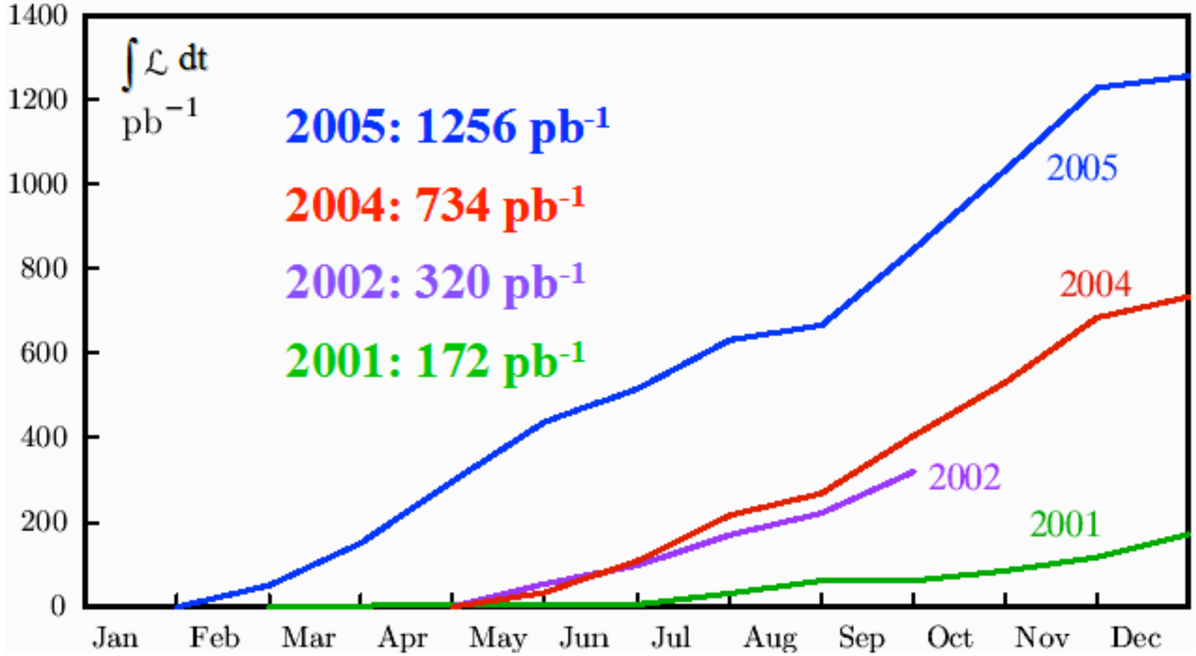
Residual laboratory momentum of ϕ: **$p_\phi \sim$ 13 MeV**

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

KLOE data taking completed (2001/6):

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

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

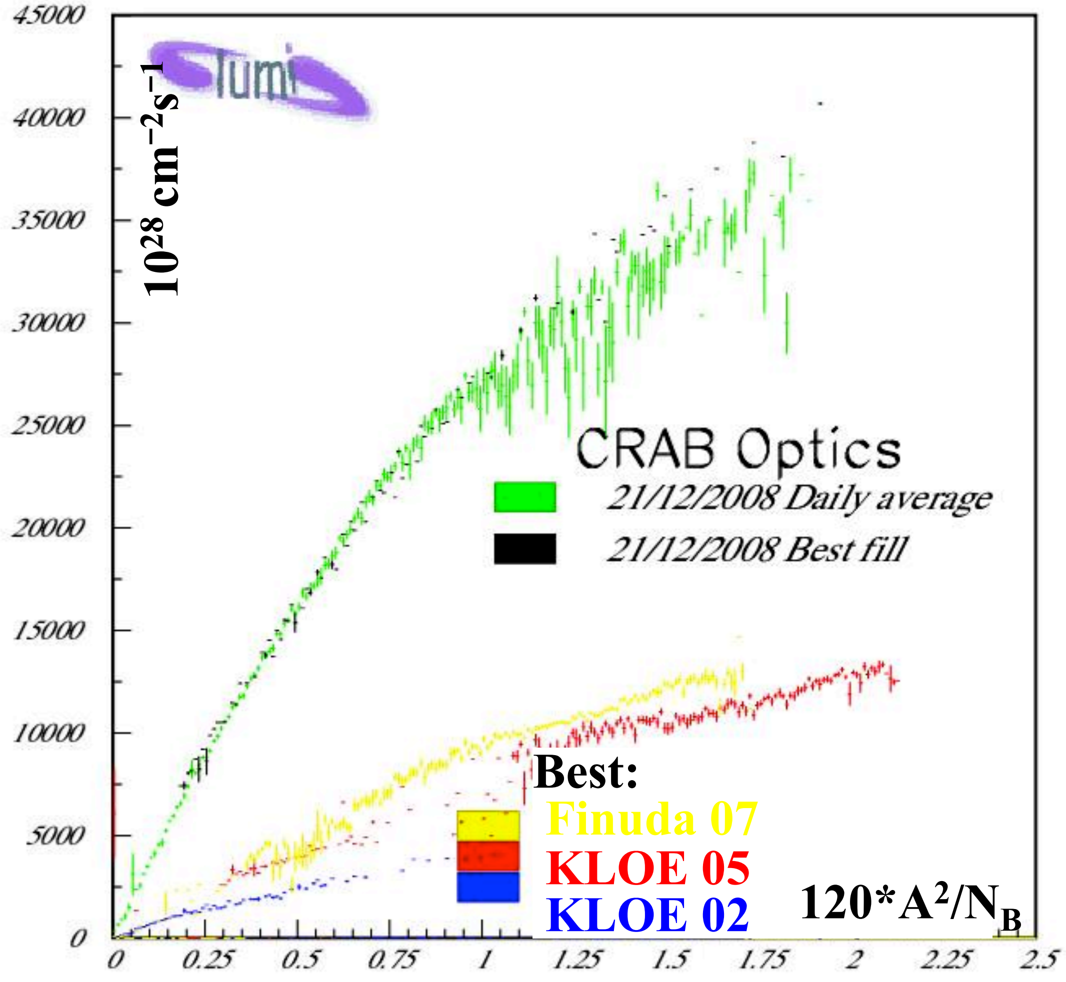


Best of KLOE run:

L_{PEAK}=1.4×10^{32} $cm^{-2}s^{-1}$

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

KLOE and DaΦne



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

(**at least**) L ~3×

⇒ **Ldt~1pb^{-1}/hour**.

KLOE-2 luminosity goal:

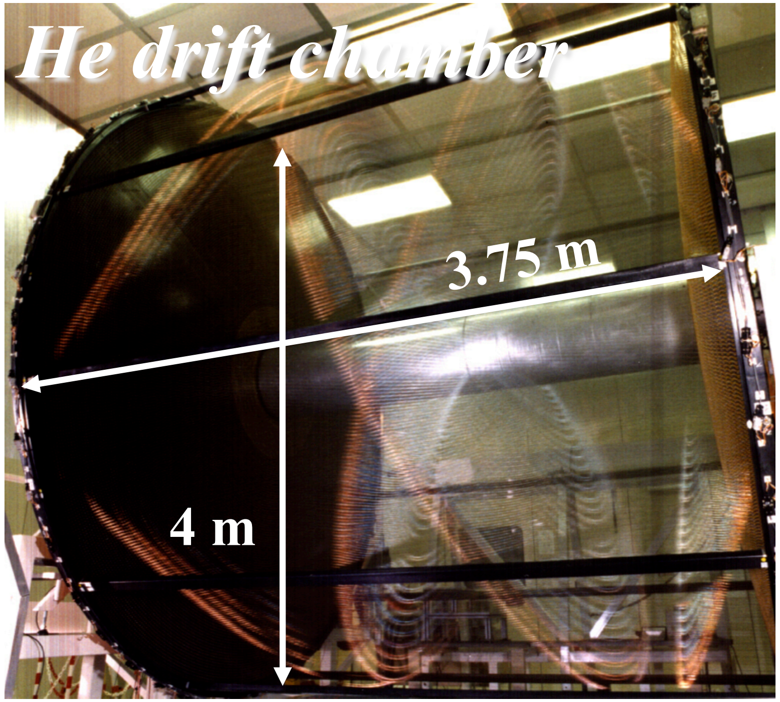
step0, ~5 fb^{-1} at $\sqrt{s}$=M(ϕ)

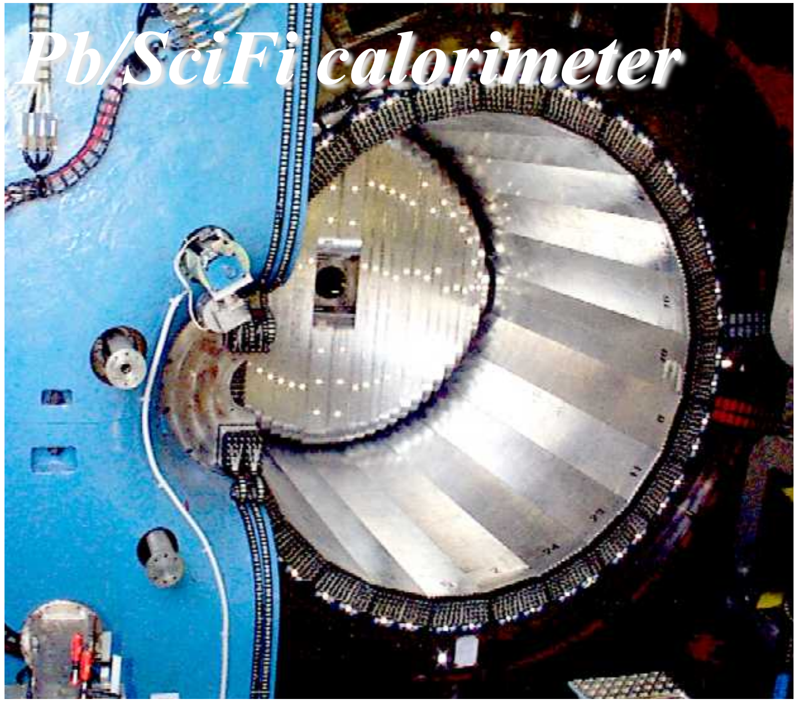
step1, >20fb^{-1} at $\sqrt{s}$=M(ϕ)

More information on KLOE-2:
Wojtek WISLICKI talk's on Friday

The KLOE detector

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





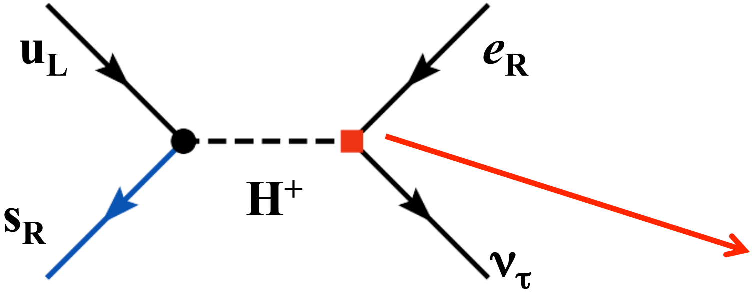
σ_p/p	**0.4 %** (tracks with θ > 45°)
$\sigma(m_{KS}) \leq 1$ MeV	
σ_x^{hit}	**150 µm (*xy*), 2 mm (*z*)**
σ_x^{vertex}	**~1 mm**

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 $K_L \to \pi^+\pi^-\pi^0$)

NP potential of $R_K = \Gamma(K^\pm_{e2})/\Gamma(K^\pm_{\mu 2})$

- 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*].

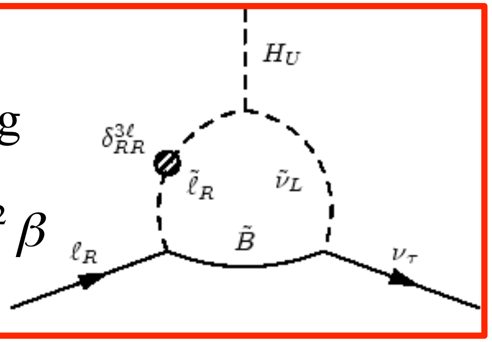
- Helicity suppression can boost NP [*Masiero-Paradisi-Petronzio PRD74(2006)011701*].



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

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

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



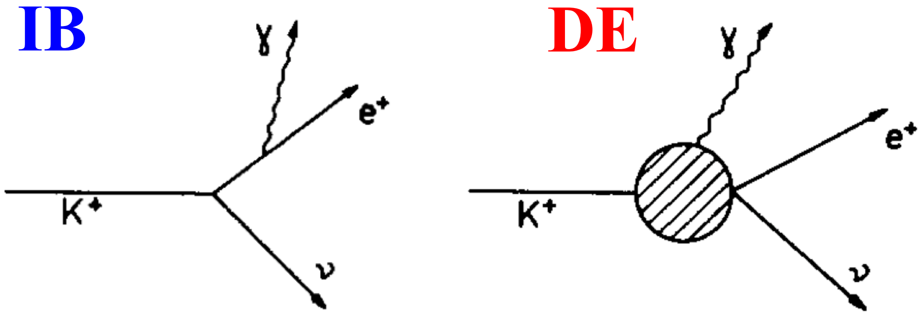
$$R_K^{LFV} \approx R_K^{SM}\left(1 + \frac{m_K^4}{m_H^4}\frac{m_\tau^2}{m_e^2}\left|\Delta_R^{31}\right|^2 \tan^6\beta\right)$$

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

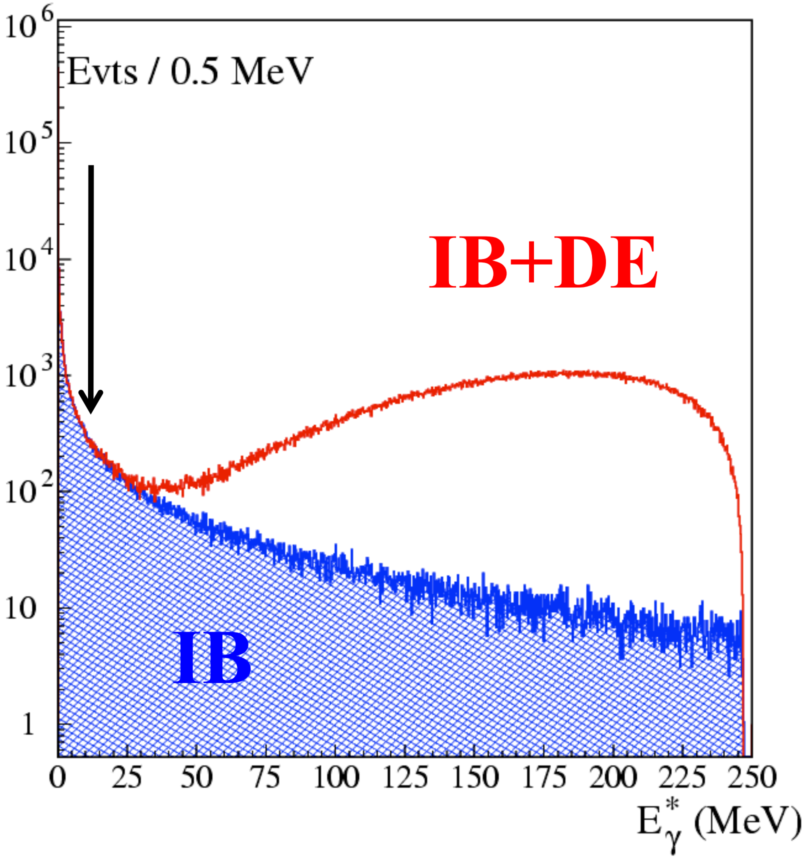
- Exp. accuracy on R_K (before KLOE and NA62 results) at 5% level.
- New measurements of R_K can be very interesting, **if error at 1% level or better**.

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%**



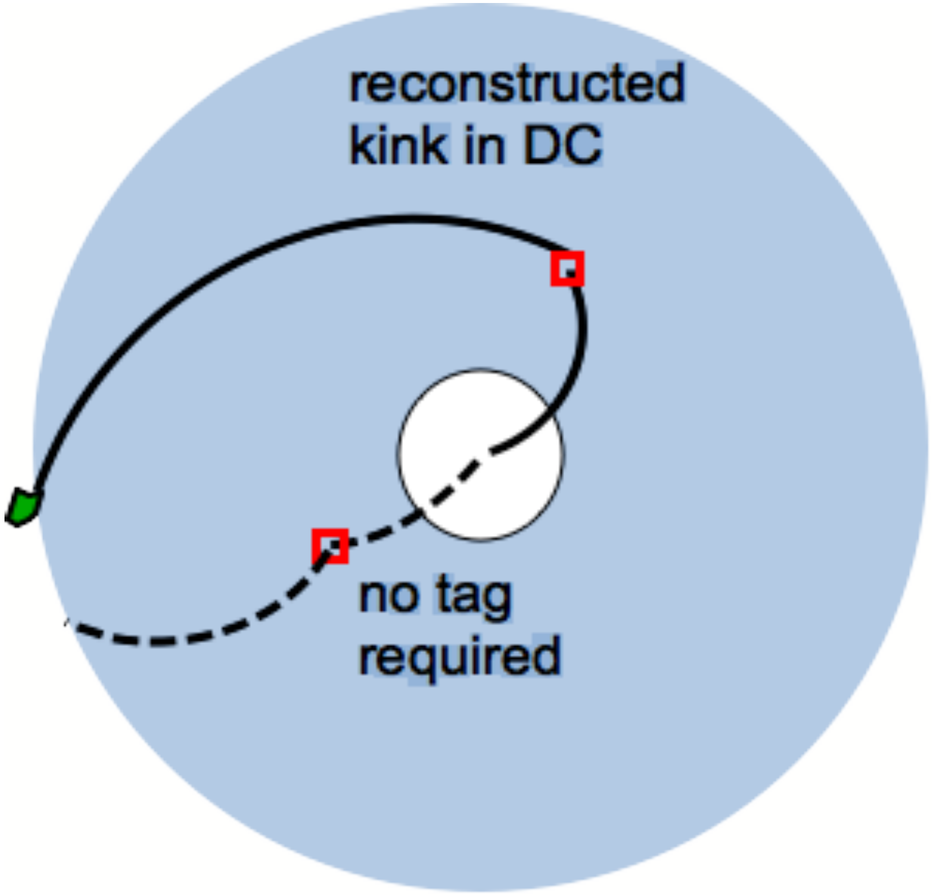
- **Define as "signal" events with E_γ<10 MeV**.
- Evaluating **IB** spectrum (O(α)+resummation of leading logs) obtain a 0.0643(7) correction for the IB tail.
- Under 10 MeV, the **DE** contribution is expected to be negligible.

Analysis basic principles

$$R_K = \frac{N_{Ke2}}{N_{K\mu 2}} \left[\frac{\varepsilon^{\mathrm{REC}}_{K\mu 2}}{\varepsilon^{\mathrm{REC}}_{Ke2}} C^{\mathrm{TRG}} C^{\mathrm{REC}} \right] \frac{1}{\epsilon^{\mathrm{IB}}}$$

1) Select kinks in DC (~ fiducial volume)
- K track from IP
- secondary with p_{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!)

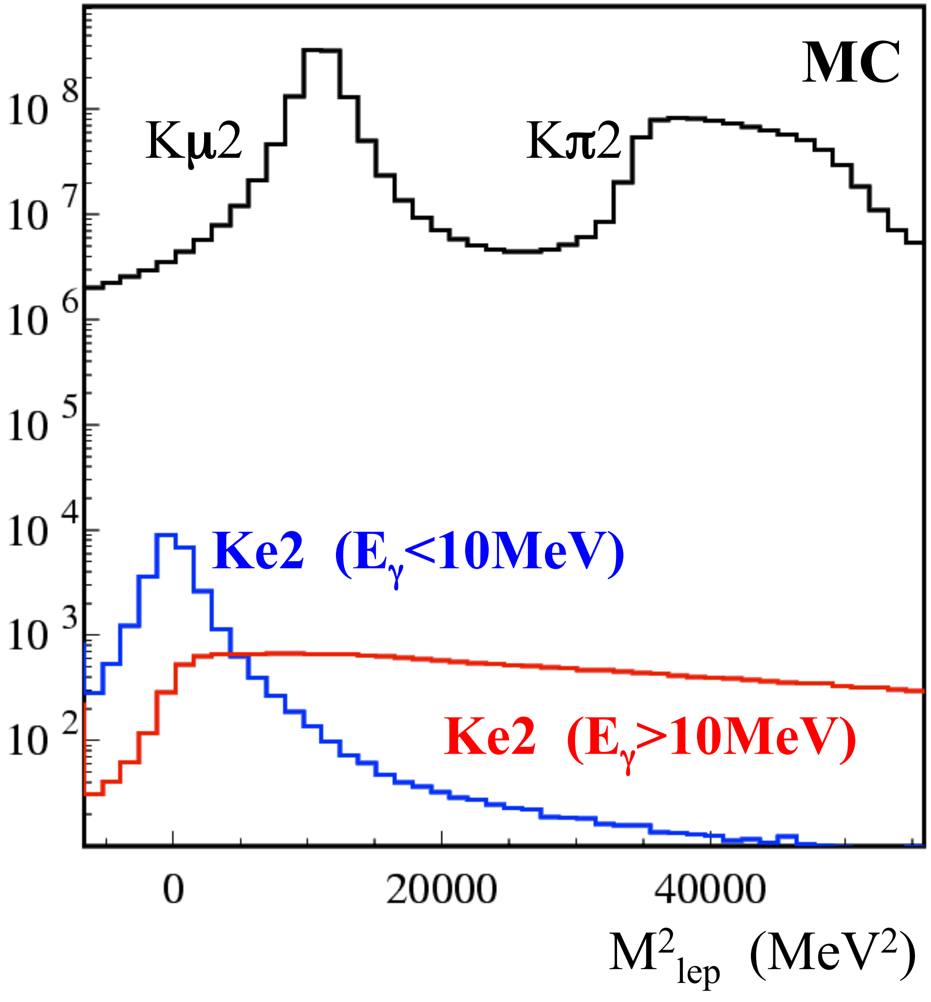
→ gain ×**4 of statistics**

Analysis basic principles

3) Exploit tracking of K and secondary: assuming $m_\nu=0$ get M^2_{lep}:

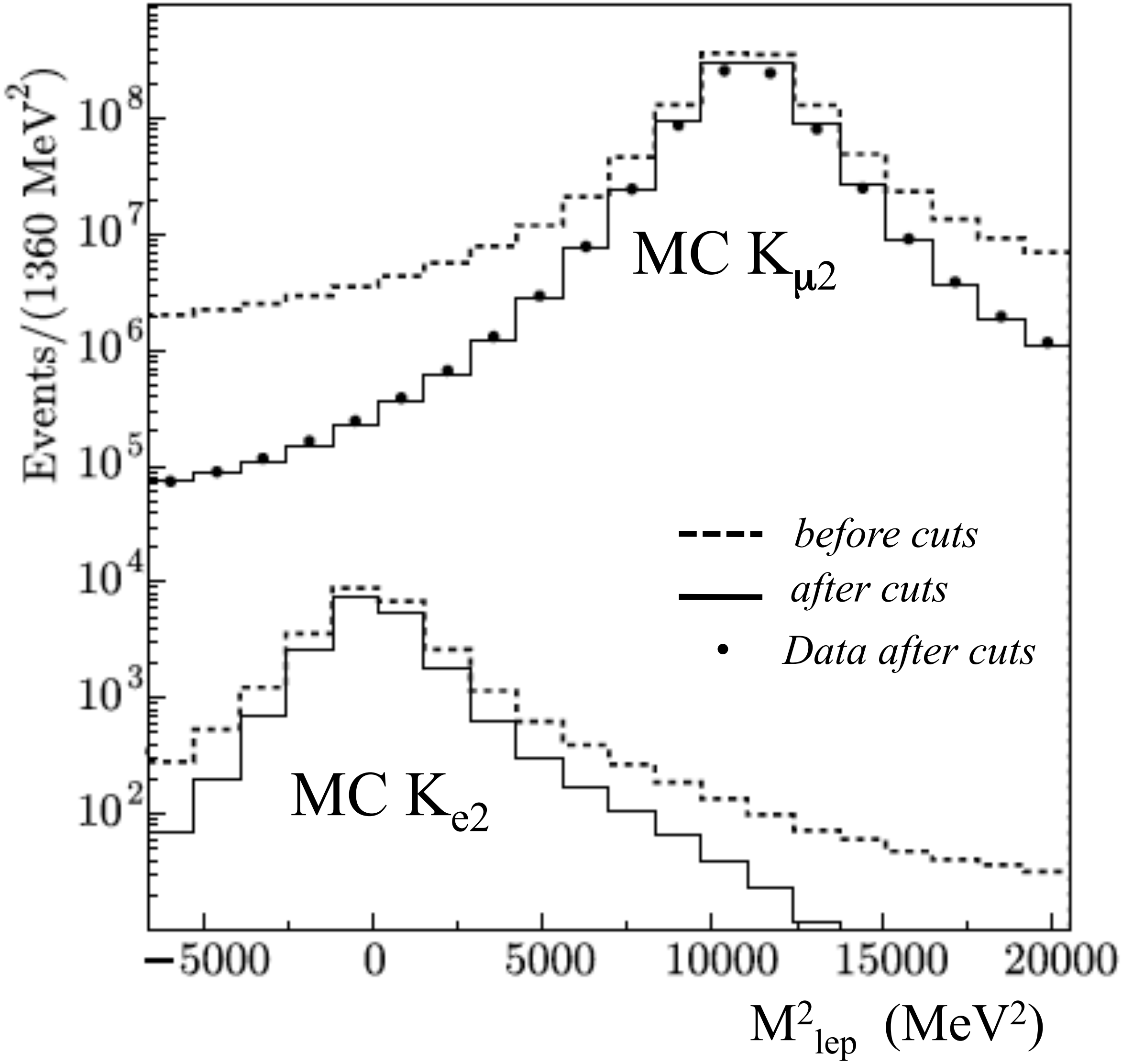
$$\mathbf{M^2_{lep} = (E_K - p_{miss})^2 - p^2_{lep}}.$$

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



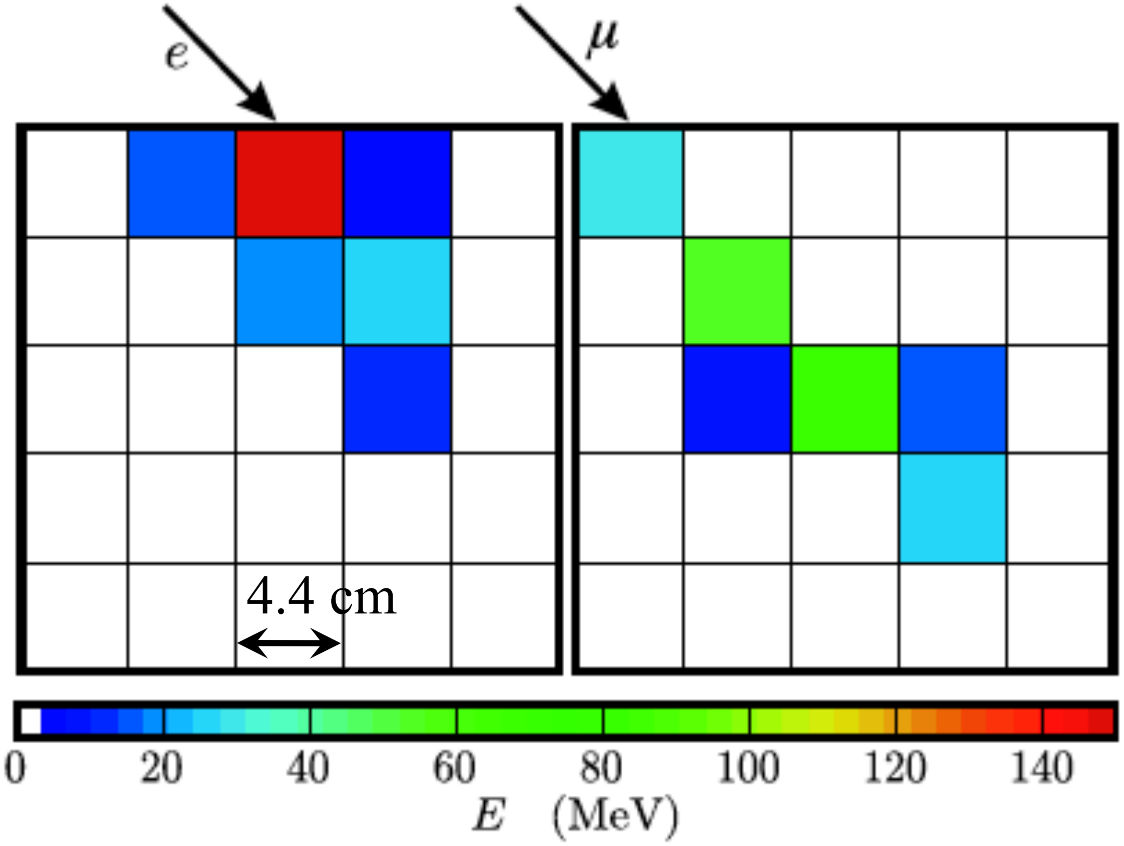
Background rejection (track quality)

- 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).



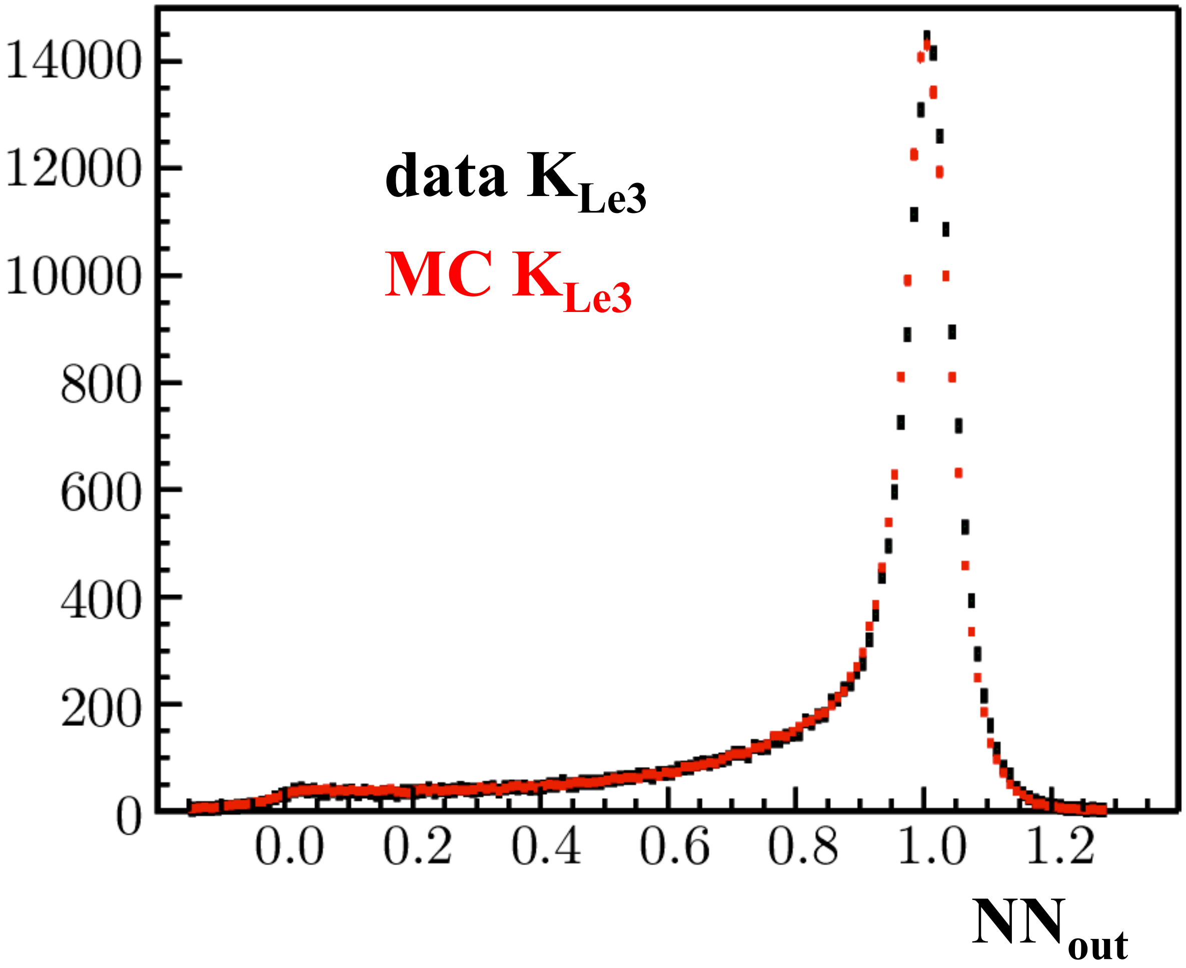
2) Add E/p and ToF.

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

Background rejection (PID)

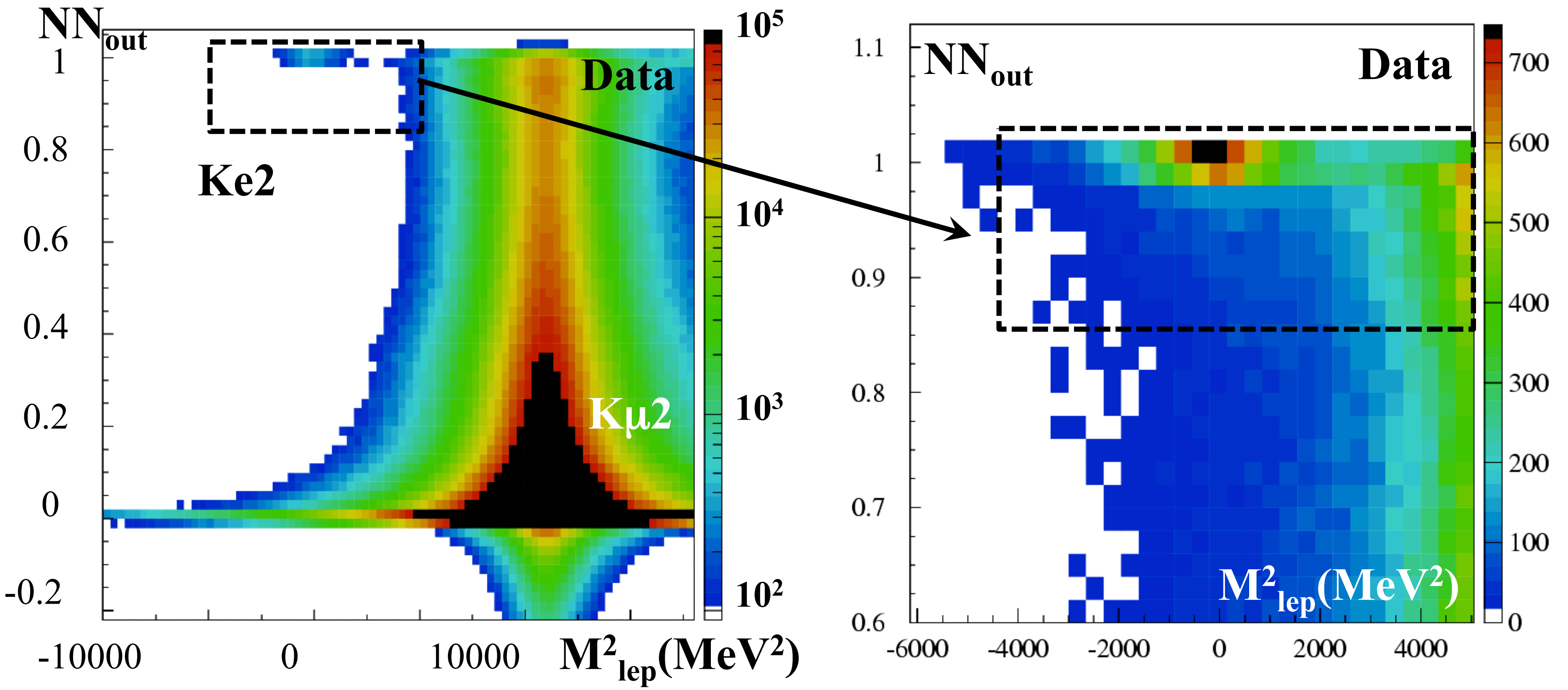
- Use a pure sample of K_Le3 to correct cell response in MC.

- K_Le3 anf Kμ2 for NN training.



Background rejection (PID)

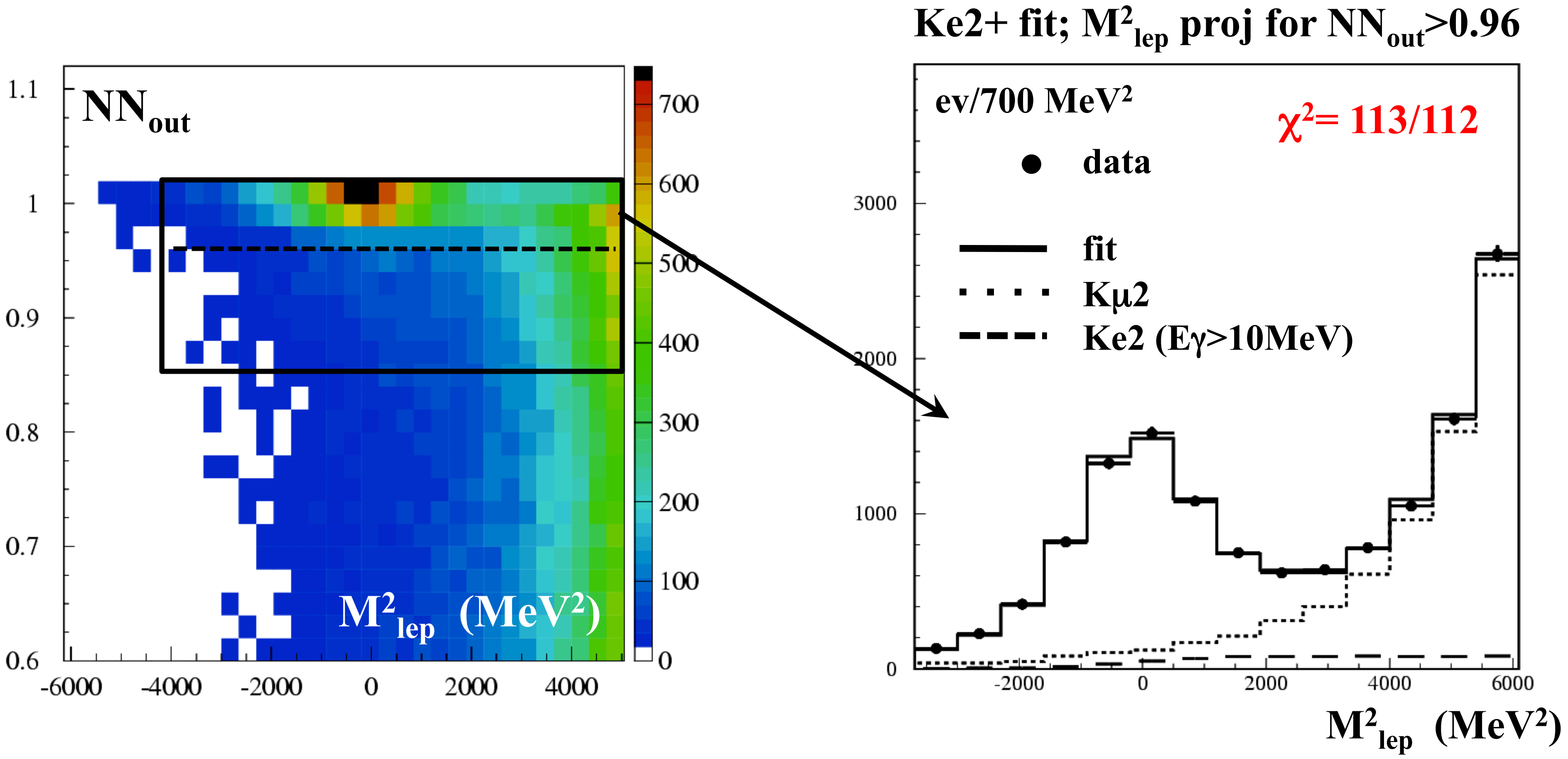
Select a region with good S/B ratio in the $M^2_{lep} - NN_{out}$ plane



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 $0.86<NN_{out}<1.02$**.

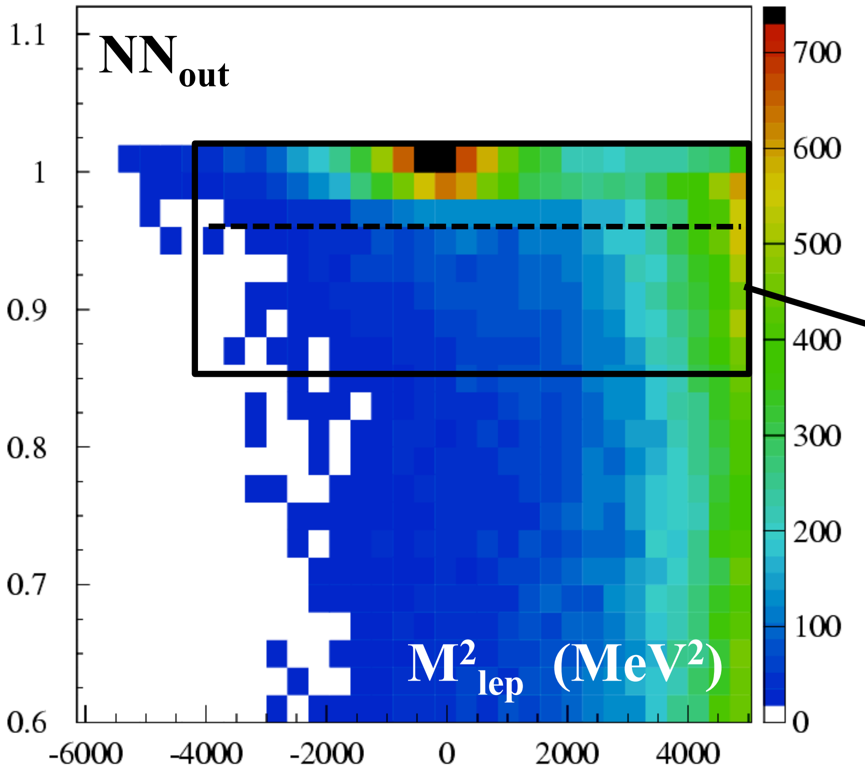


Ke2+ fit; M^2_{lep} proj for $NN_{out}>0.96$

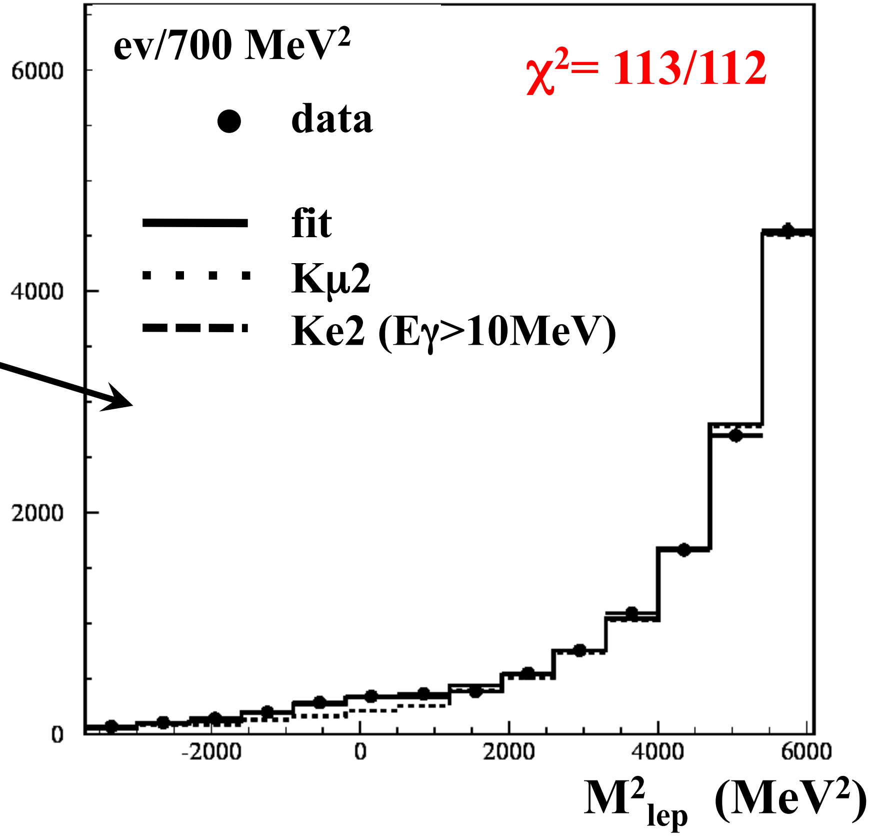
We count **7060 (102) Ke2+ 6750 (101) Ke2−** (**σ_{STAT}=1%, 0.85% from Ke2**)

K_{e2} event counting

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



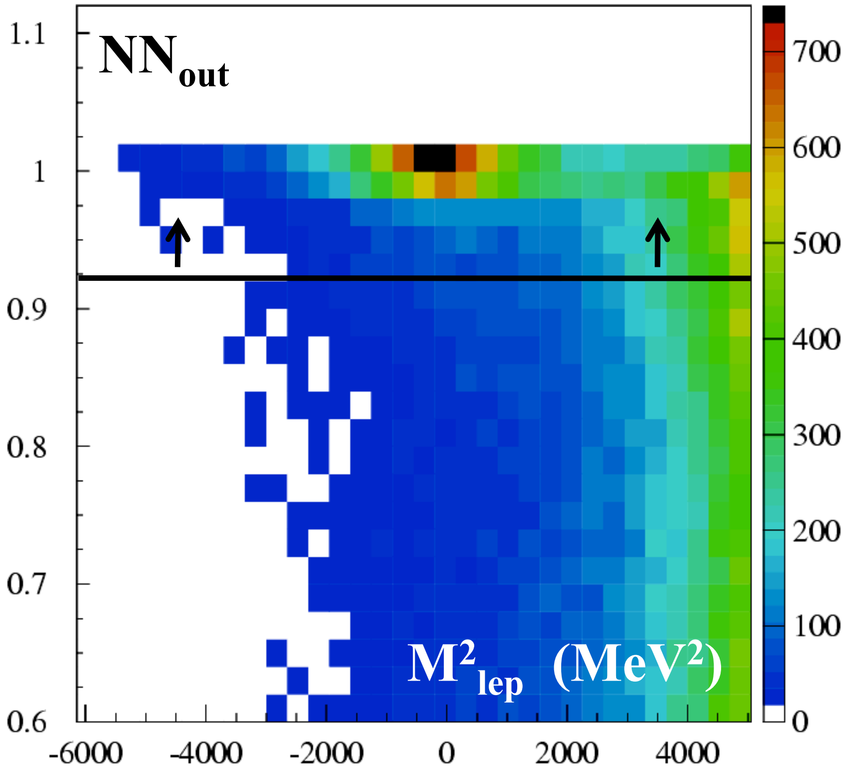
Ke2+ fit; M^2_{lep} proj for NN_{out}<0.96

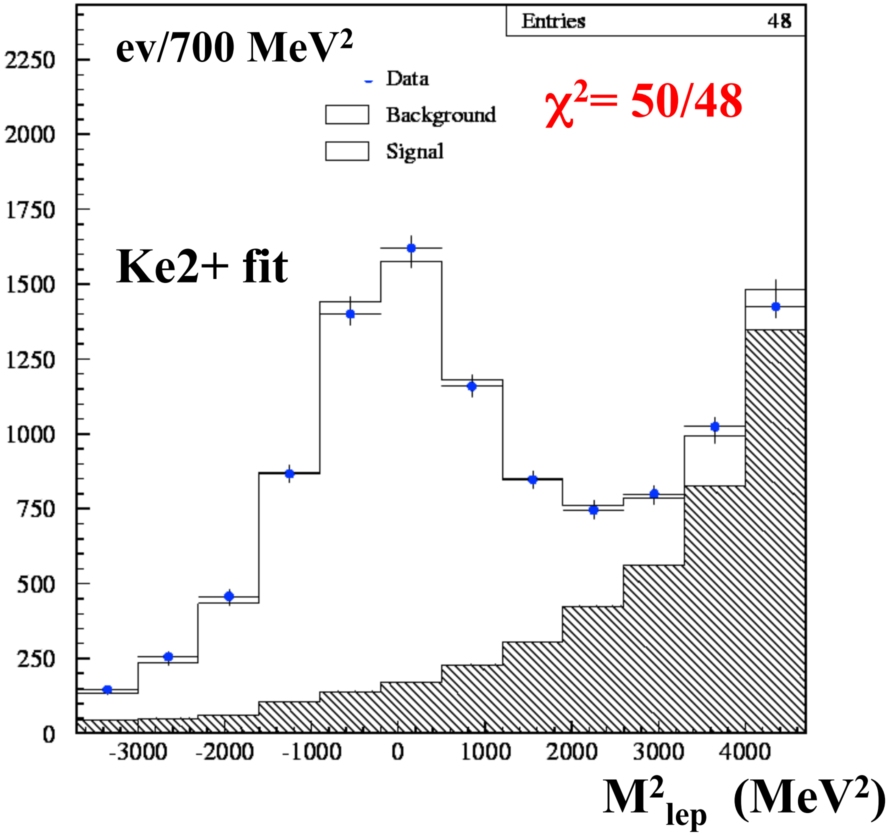


We count **7060 (102) Ke2+** **6750 (101) Ke2−** (σ_{STAT}=1%, **0.85% from Ke2**)

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.

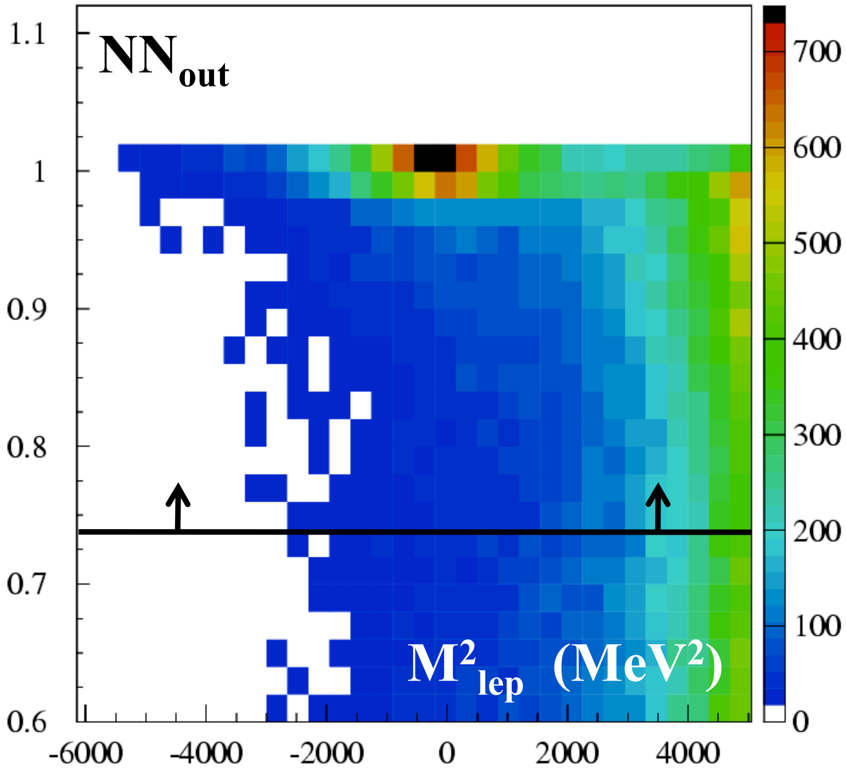


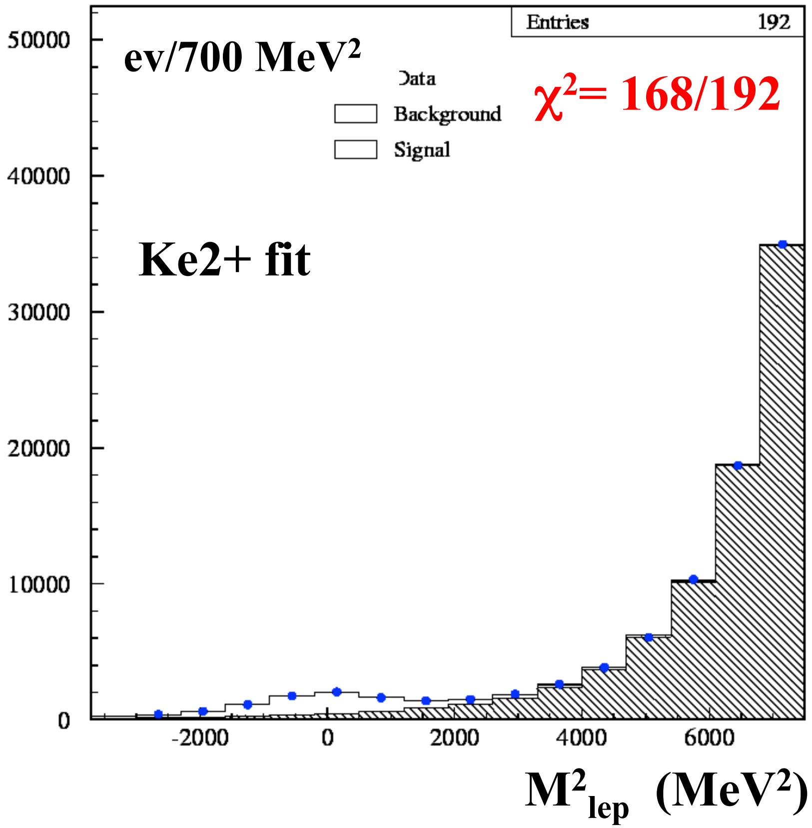


minimal bkg with: $-4000 < M^2_{lep} < 4650$ **and** $0.94 < NN_{out} < 1.02$

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 $0.78 < NN_{out} < 1.02$

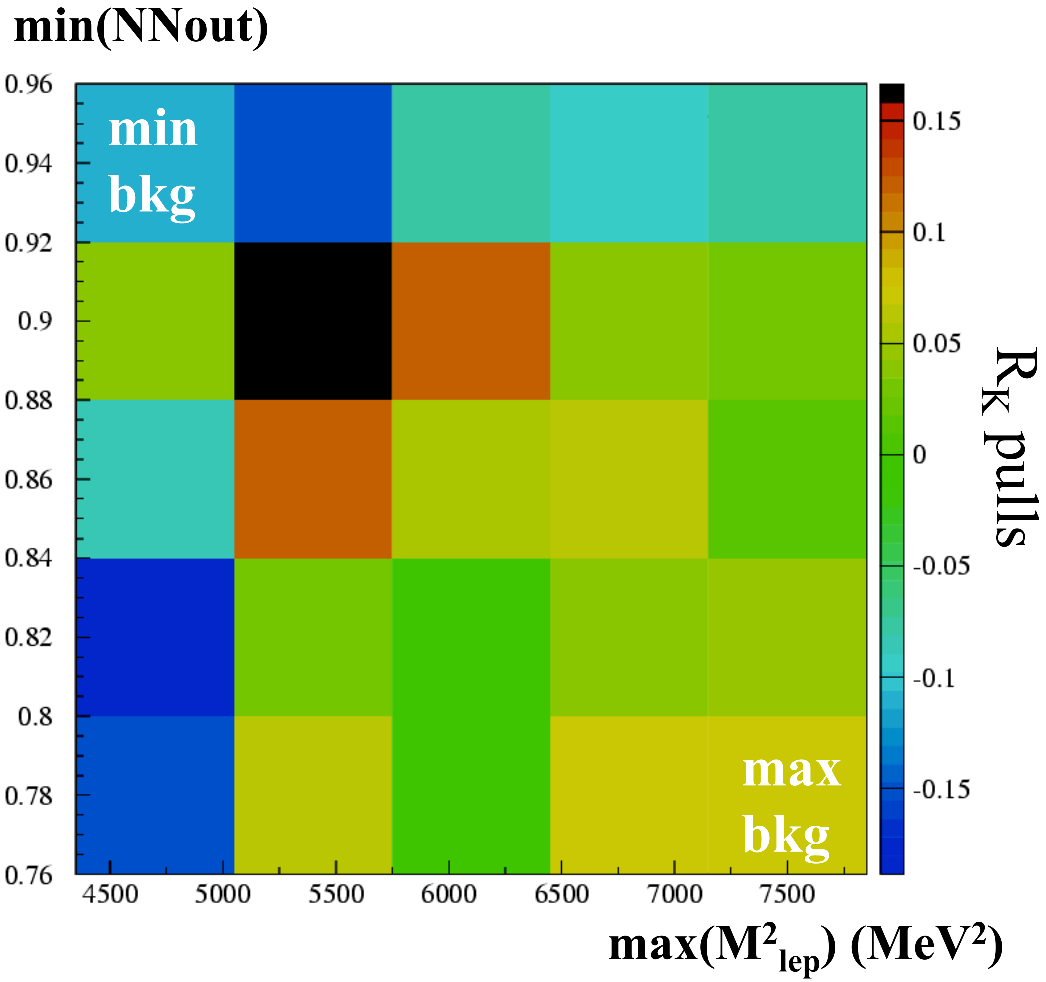
K_{e2} event counting: systematics

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**.



Reconstruction efficiencies

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

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

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: ε(Ke2)/ε(Kμ2) = 0.946±0.007

KLOE result for R_K

Systematics

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

$$R_K = (2.493 \pm 0.025 \pm 0.019)\times 10^{-5}$$

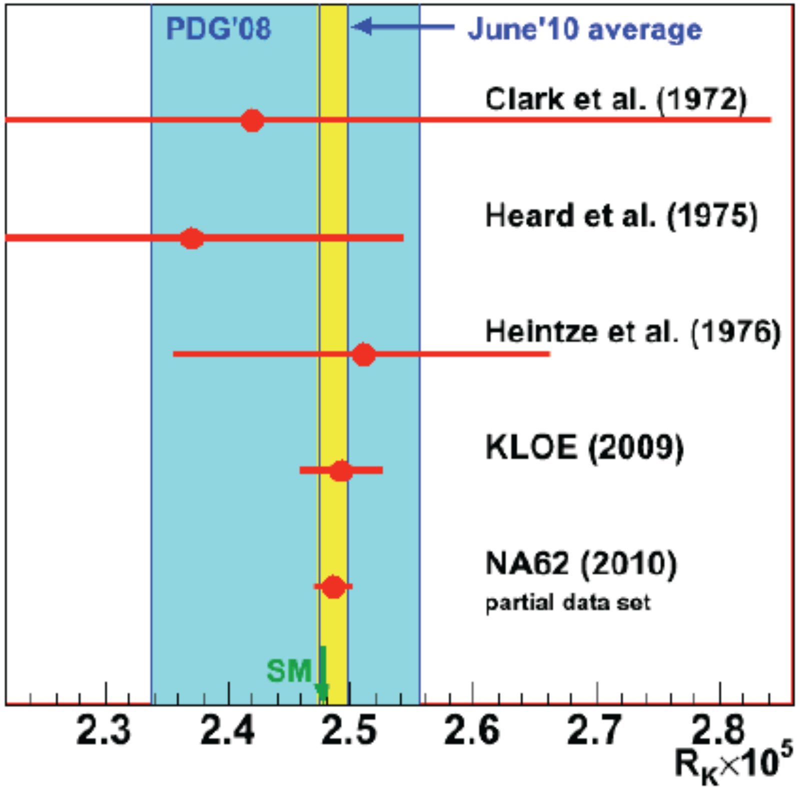
Total error:

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

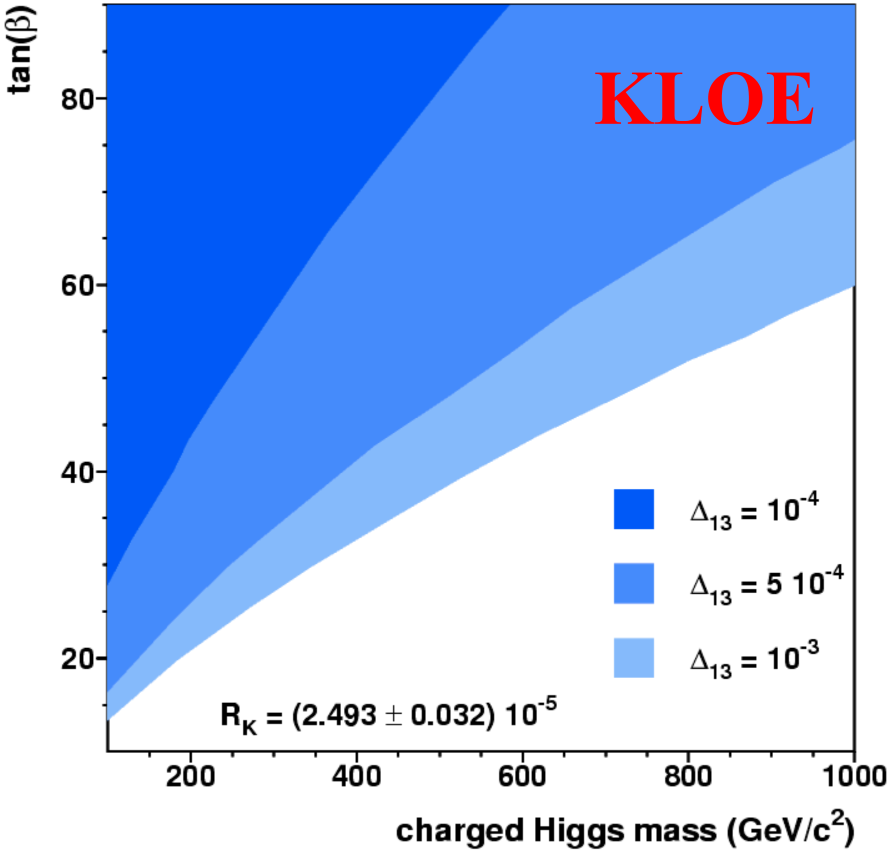
0.9% from 14k Ke2 + bkg subtraction

0.6% from 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 : *sensitivity to new physics*



Sensitivity shown as 95% CL excluded regions in the tan**β**−M$_H$ plane, for different values of the LFV effective coupling, $\mathbf{\Delta}_R^{31} = 10^{-3}, 5\times10^{-4}, 10^{-4}$

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

[A.Masiero, P.Paradisi, R.Petronzio,
J. High Energy Phys. **0811,** 042 (2008)]

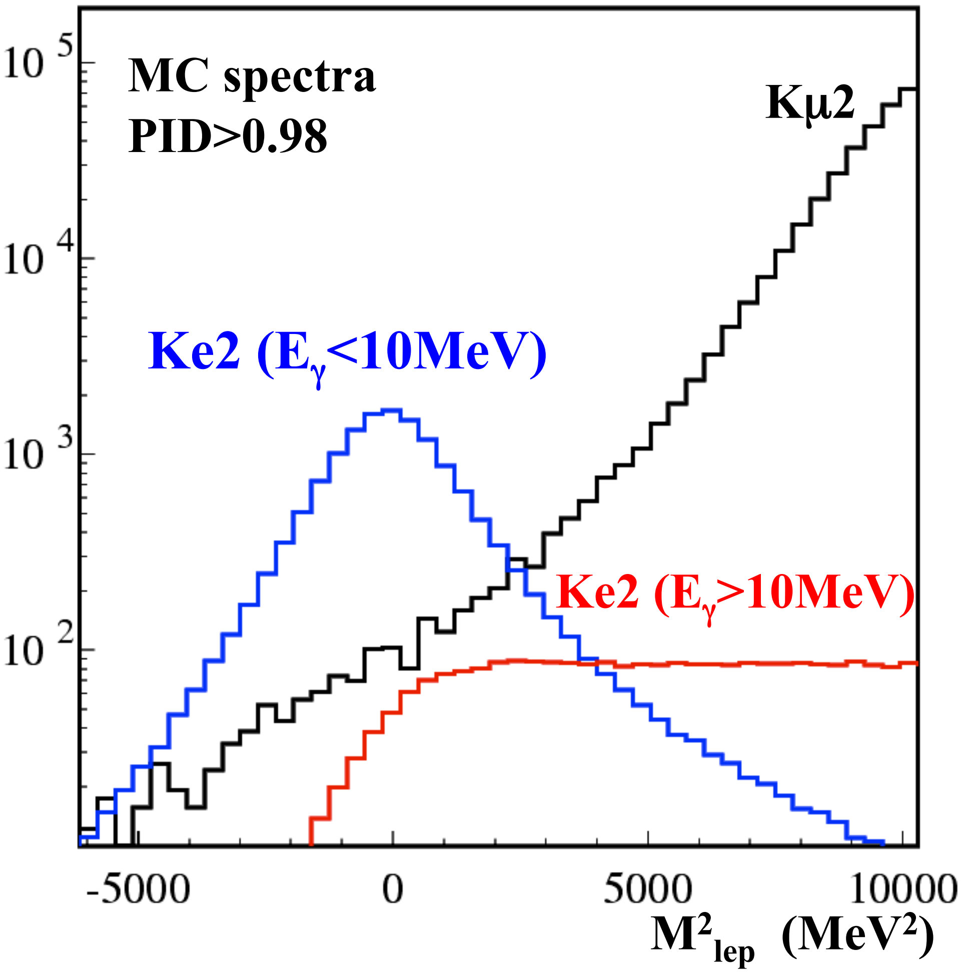
Ke2 fit: radiative corrections

- Analysis **inclusive of photons in the final state**. In our fit 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

Dalitz density:

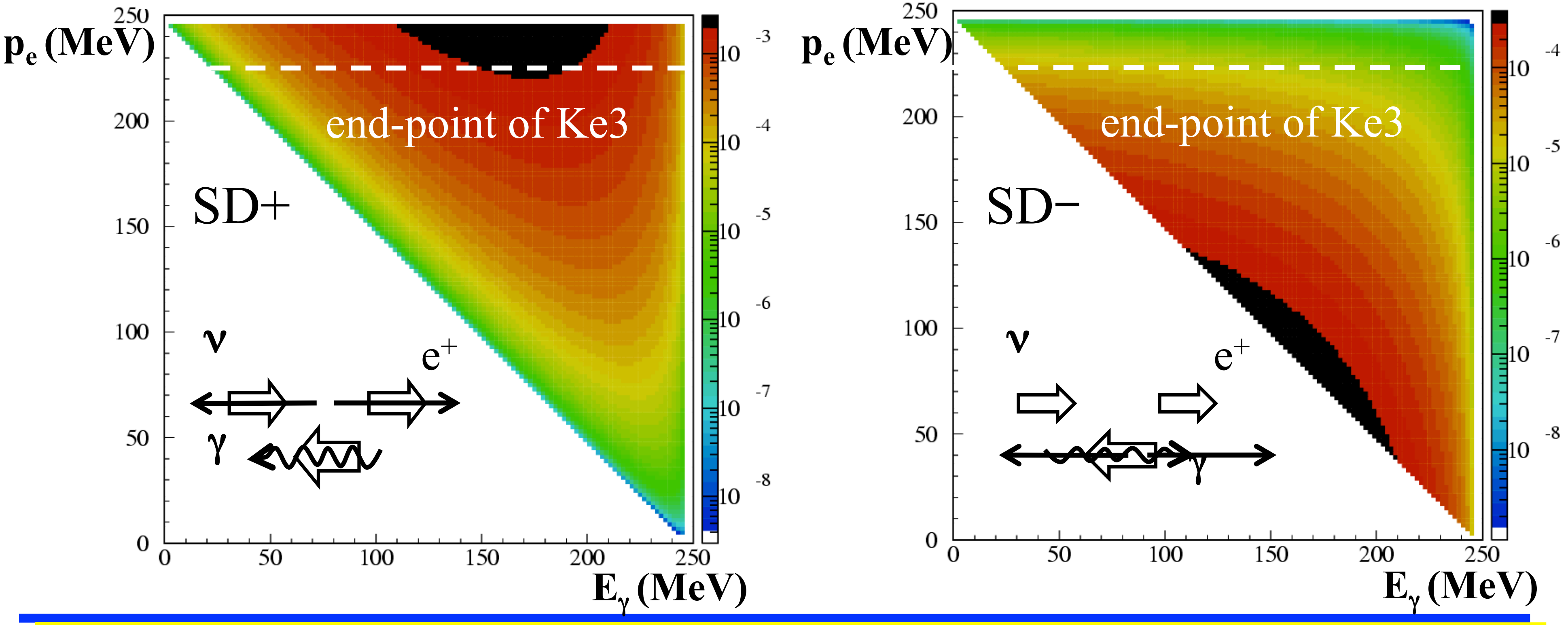
$x = 2E_\gamma / M_K \quad y = 2E_e / M_K$

E_γ, E_e in the K rest frame

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

Structure Dependent ($f_{V\,,}$ f_A : effective vector and axial couplings)

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



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 $O(p^6)$:

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

$f_A \approx 0.034$

V linear x dependence (λ≈0.4)

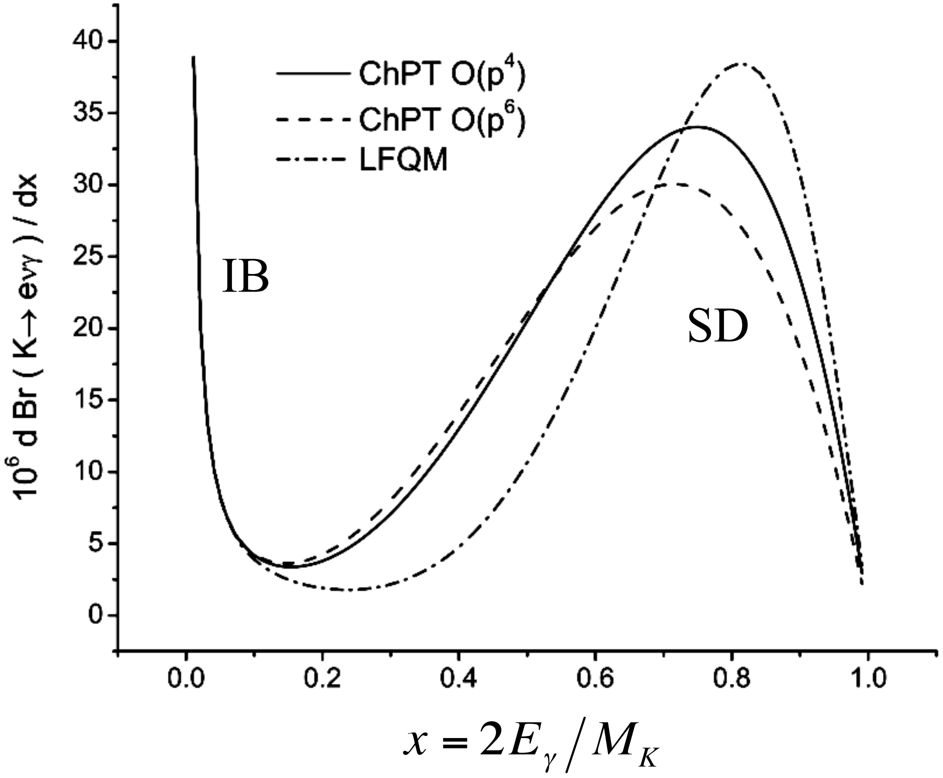
Ametller, Bijnens, Bramon, Cornet 93
Geng, Ho, Wu 04
Chen, Geng, Lih 08

3) LFQM:

non trivial x dependence

$f_V = f_A = 0$ at x=0

Chen, Geng, Lih 08



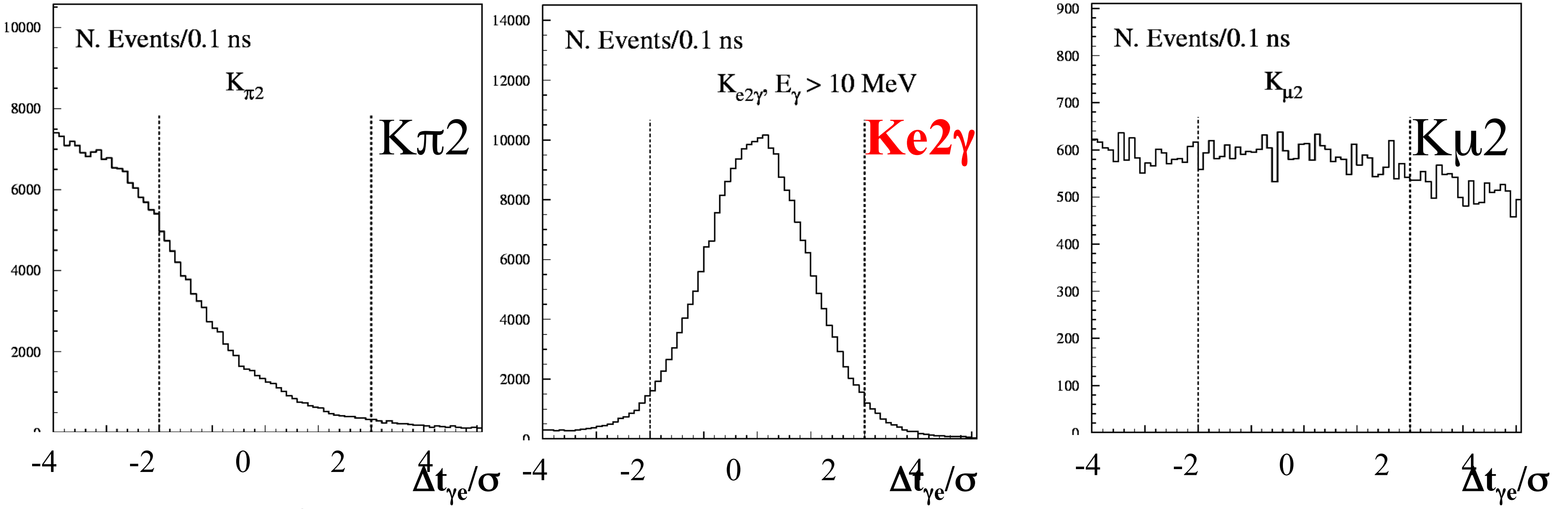
from Phys. Rev. D77 (2008) 014004

Ke2γ selection

- Same selection criteria as for Ke2, but a tighter PID cut, NN>0.98
- 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

Fake γ from accidental bkg

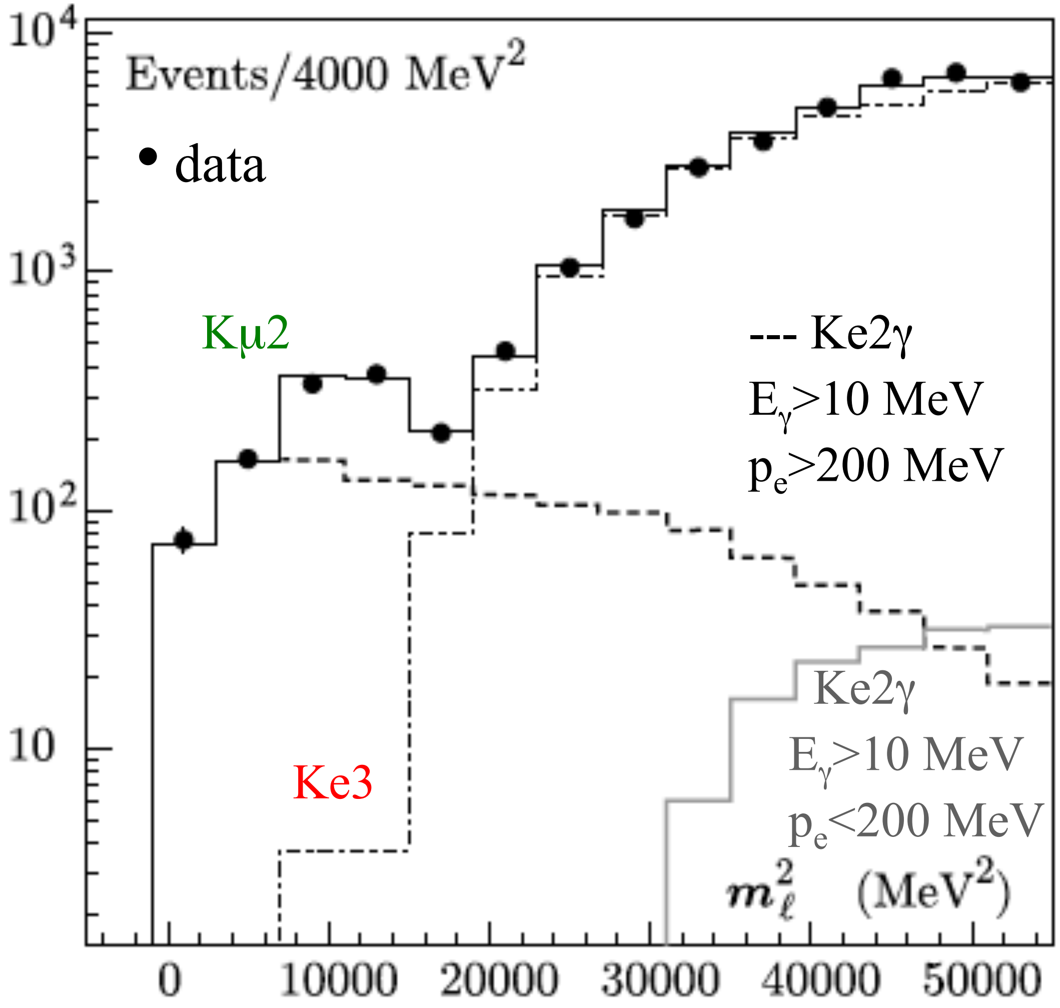
Ke2γ selection

After photon detection bkg is dominated by:

- $K_{\mu 2}$ for $M^2_{lep} < 20000$ MeV^2
- *Ke3* for $M^2_{lep} > 20000$ MeV^2

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

This selection has:
 ~90% acceptance for SD+ events
 ~1% residual IB events



We measure Ke2γ (Eγ>10 MeV, $\cos\theta_{e\gamma}^*$<0.9, p_e>200 MeV) => SD+ amplitude

$K_{e2\gamma}$ photon association

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

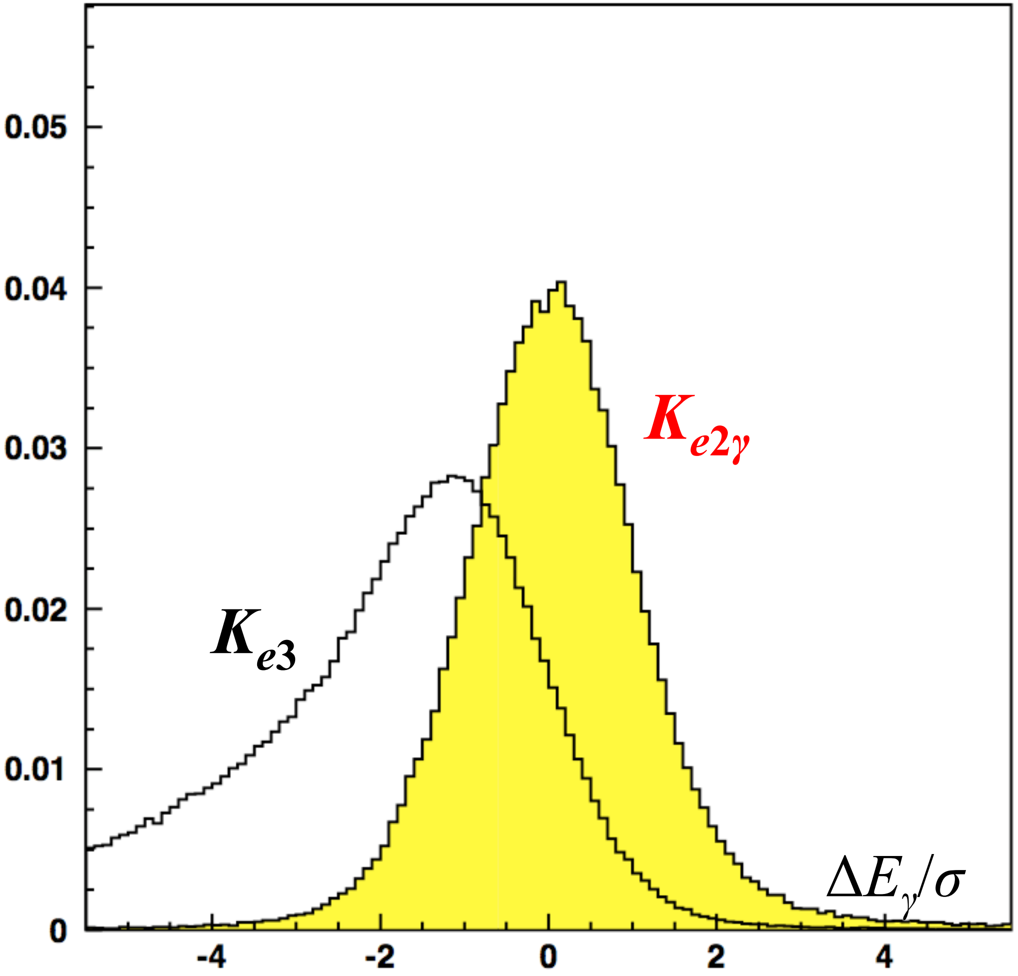
- track momenta $\mathbf{p}_K$, $\mathbf{p}_e$
- photon direction $\mathbf{n}_\gamma$ from cluster and vertex positions

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

$\boldsymbol{\sigma_E}^{\textbf{lab}} \approx$ **12 MeV**

$\boldsymbol{\sigma_E}^{\textbf{cal}} \approx$ **30 MeV**

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

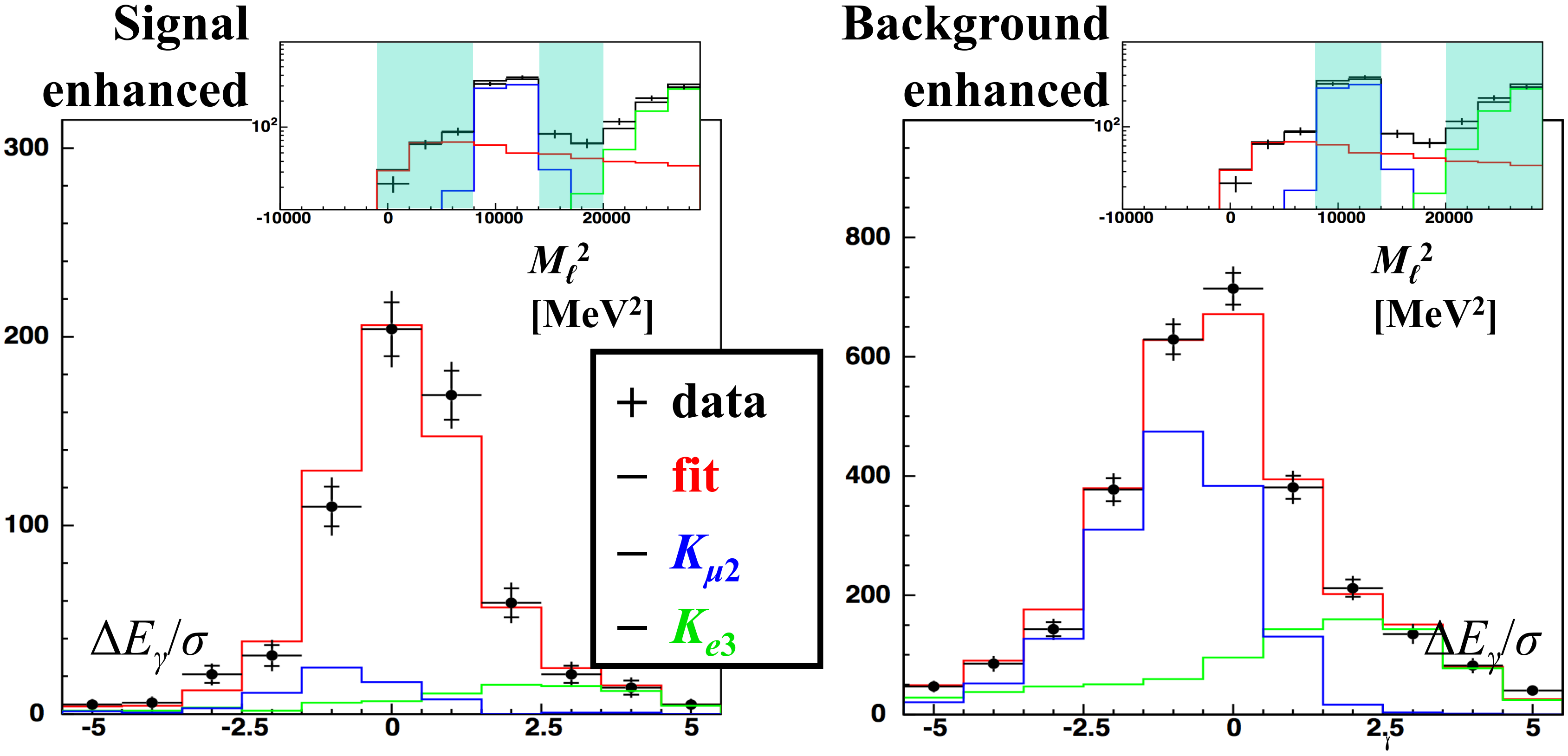


Perform 2-dimensional binned likelihood fit in (M_ℓ^2, $\Delta E_\gamma/\sigma$) plane, in 5 bins of E_γ^*

$K_{e2\gamma}$ fit results

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

E_γ (MeV)	10 to 50	50 to 100	100 to 150	150 to 200	200 to 250
Signal counts	55 ± 16	219 ± 24	463 ± 32	494 ± 38	253 ± 26
χ^2/ndf	80/66	141/105	87/106	100/106	116/102



In total, we count Ne2γ = 1484 ± 63

Ke2γ spectrum vs ChPT O(p^4)

E_γ spectrum measured for the first time

We measure:

$$\frac{1}{\Gamma\left(K_{\mu 2}\right)}\frac{d\Gamma(K_{e2},E_\gamma > 10MeV, p_e^* > 200MeV)}{dE_\gamma}$$

Data are **compared** with:

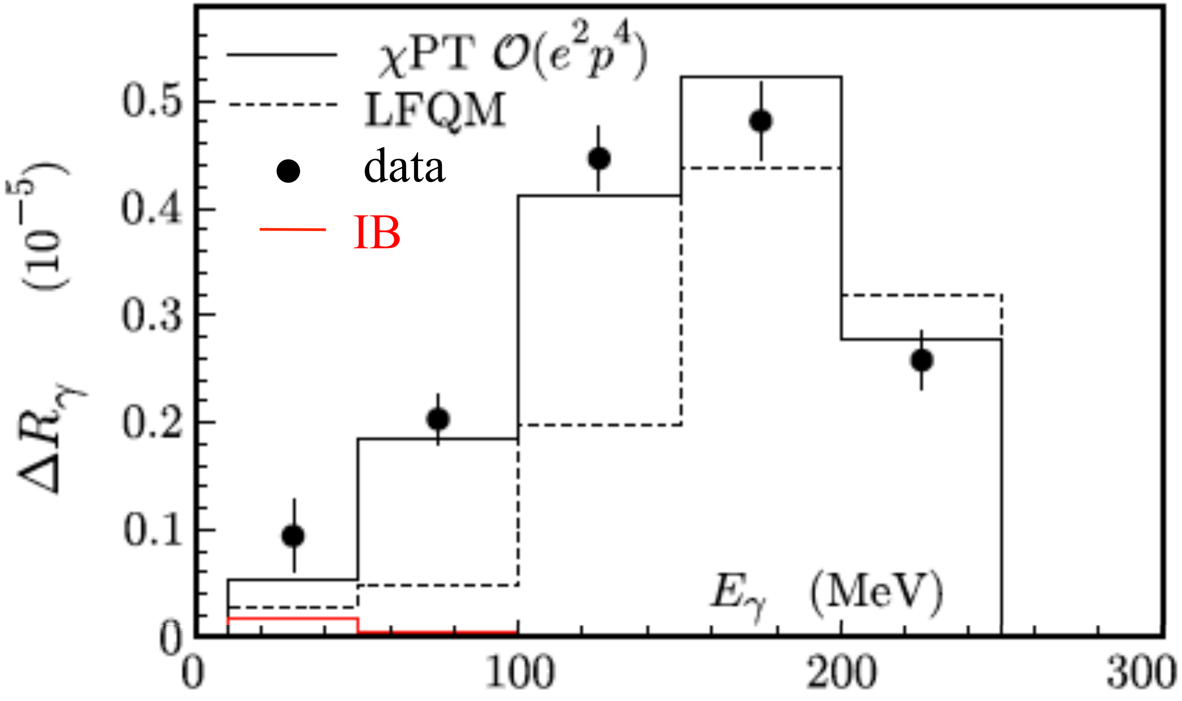
- **ChPT O(p^4)** calculation.

Integrating we obtain:

1.483(68)×10^{-5}

in agreement with1.447×10^{-5} of ChPT O(p^4) [Bijnens, Ecker, Gasser '93]

- **LFQ model**: ruled out



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:

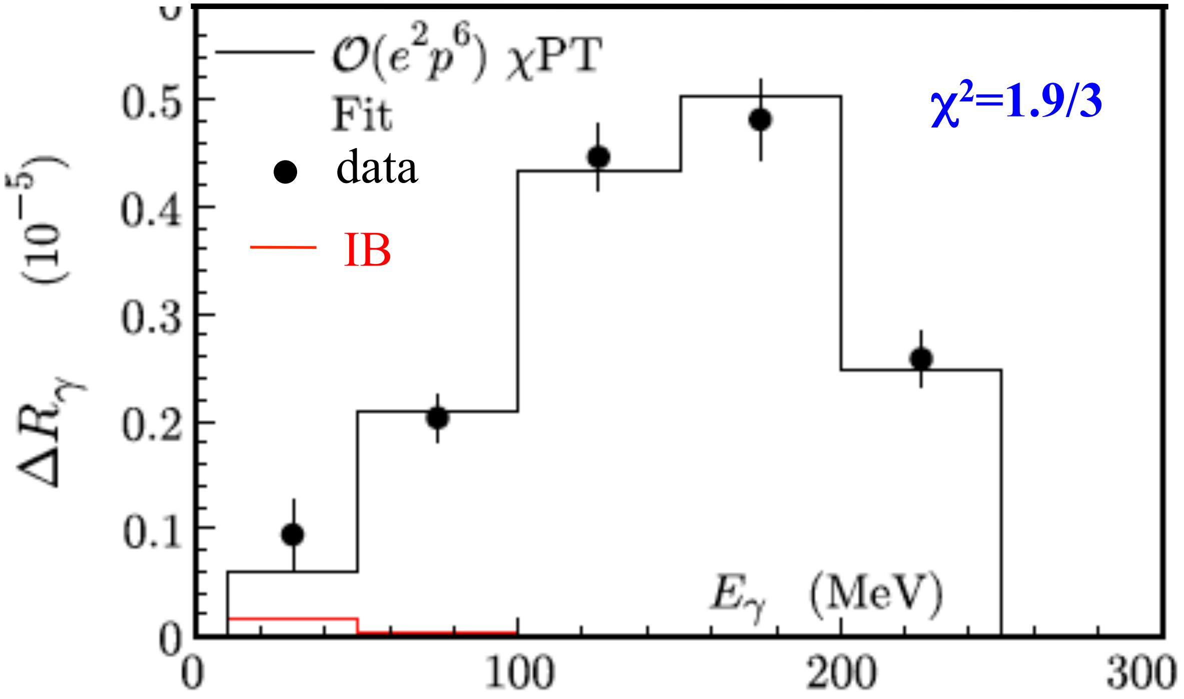
$$f_V = f_{V0}\,(1 + \lambda\,(1\text{-}x)\,)$$

- Since we are not sensitive to the SD− amplitude (acc. ~2%) we keep f_V-f_A fixed to the ChPT $O(p^6)$ prediction

We obtain:

$$\mathbf{f_{V0}+f_A = 0.125 \pm 0.007}$$

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



Compare to χPT $O(p^6)$: $f_{V0}+f_A \approx 0.116$, $\lambda \approx 0.4$ [Phys. Rev. D77 (2008) 014004]

Confirm at ~2σ the presence of a slope in the vector form factor

Conclusions and...

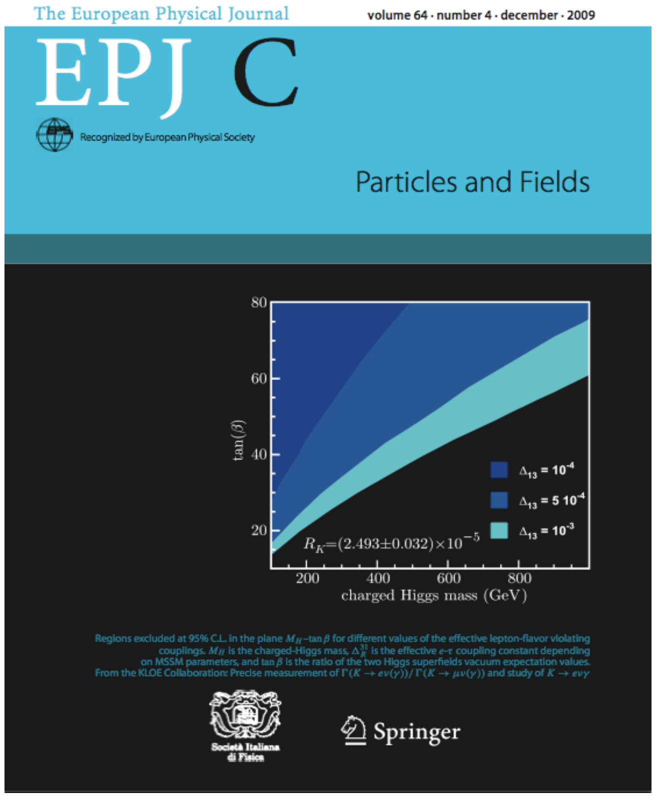
- Using 2.2 fb^{-1} of data acquired at the ϕ peak, KLOE measured:

$$R_K = (2.493 \pm 0.025_{stat} \pm 0.019_{syst}) \times 10^{-5}$$

- This results confirms the SM prediction within its 1.3% accuracy

- Can contribute to set constraints on the parameter space of MSSM with LFV.

- The differential decay width for Ke2γ as a function of E_γ measured **for the first time**.
- SD width in agreement with ChPT expectations and indications of the presence of O(e^2p^6) contributions.



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

…perspectives

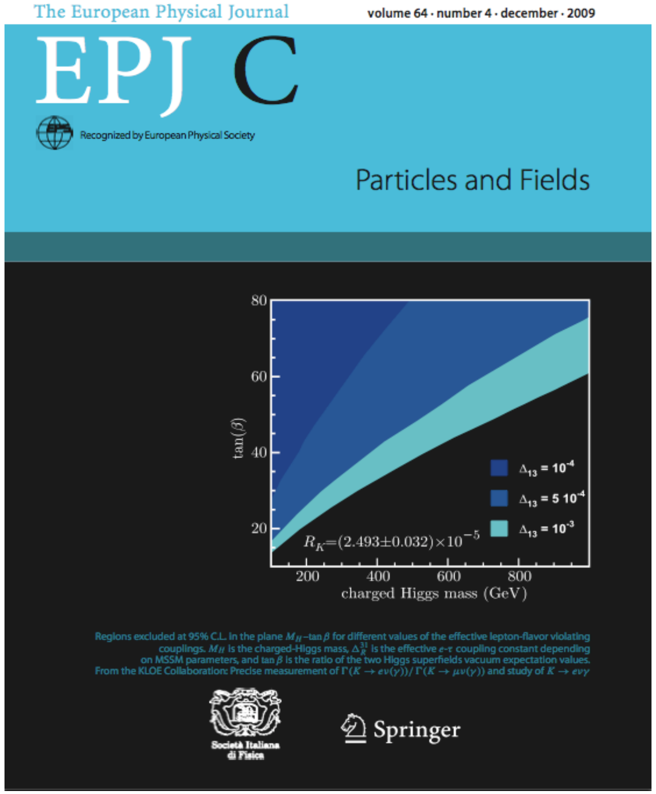
- Using 2.2 fb^{-1} of data acquired at the ϕ peak, KLOE measured:

$$R_K = (2.493 \pm 0.025_{stat} \pm 0.019_{syst}) \times 10^{-5}$$

- KLOE δR_K is dominated by the Ke2 event counting and by the control samples statistics: results can improve with the larger data samples foreseen for the oncoming KLOE-2 run.

- With same analysis strategy, 25 fb^{-1} translate into 0.6% fractional accuracy on R_K.

- Inner Tracker can allow for better performance on K tracking: higher efficiency of Kl2 event selection.


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

Additional information

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

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

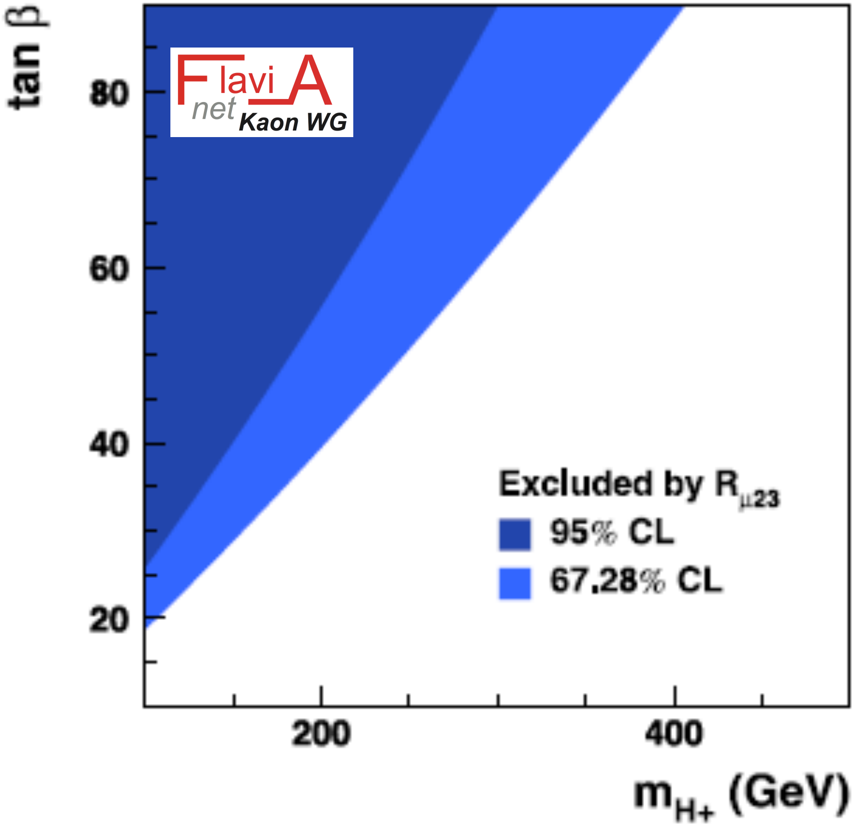
NA62 (ex NA48): **collected ~150,000 Ke2** events in dedicated 2007 run, aims to breaking the 1% precision wall, possibly reaching <~0.5%

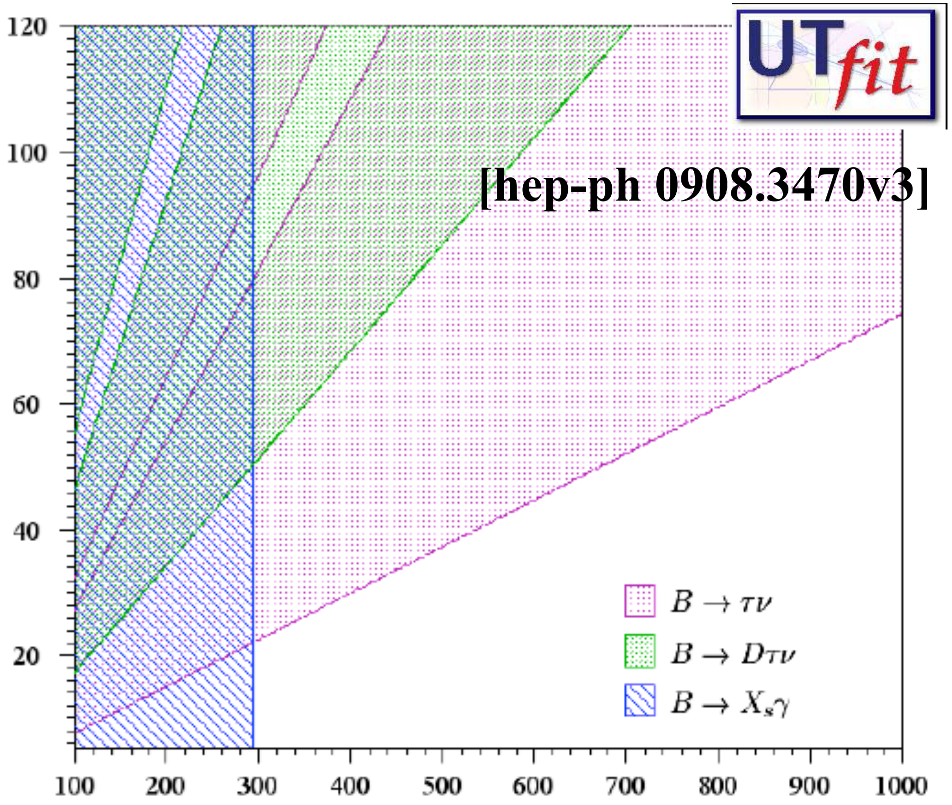
Bounds on non helicity-suppressed amps

With a 3-parameter fit (V_{us} from Kl3, V_{us}/V_{ud} from Kμ2, V_{ud}) with 1 constraint: $[V_{us}(K_{l3})]^2+[V_{ud}(0^+\to 0^+)]^2+[V_{ub}]^2 = 1$, obtains ($\chi^2$/ndf=0.0003/1 P=99%, ρ= −0.55):

$$|V_{us}| = 0.2254(8) \quad [K_{\ell 3}, 0^+ \to 0^+, \text{unitarity}],$$
$$R_{\mu 23} = 0.999(7) \quad [K_{\mu 2}].$$

this excludes the region at low m_{H+} and large tg β favoured by B→τν.

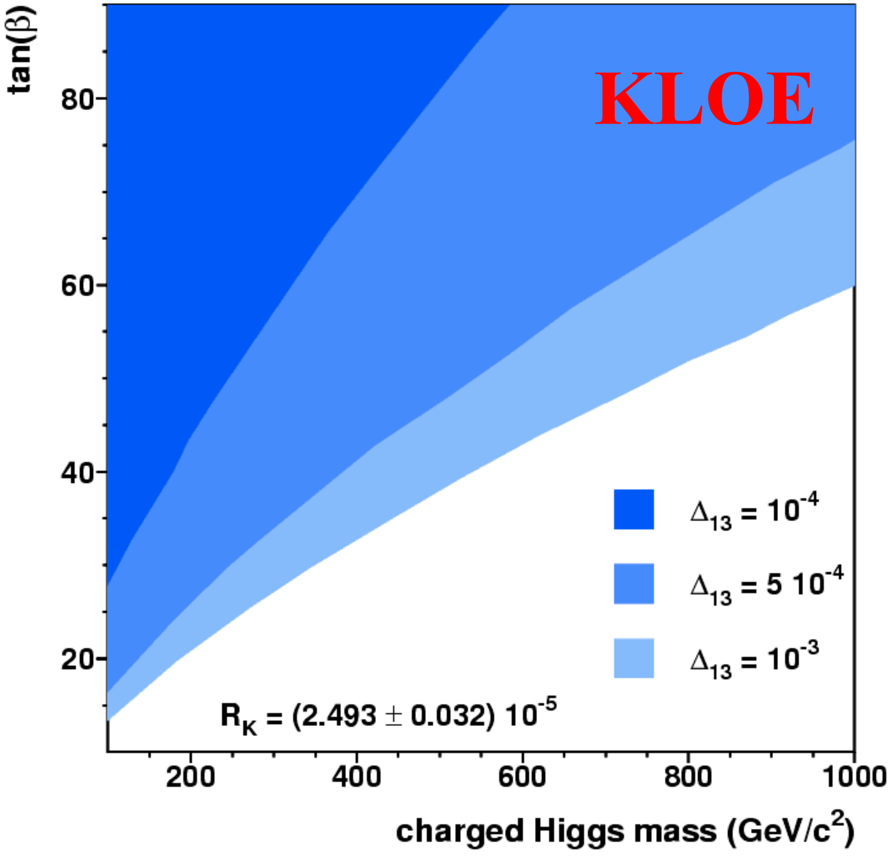


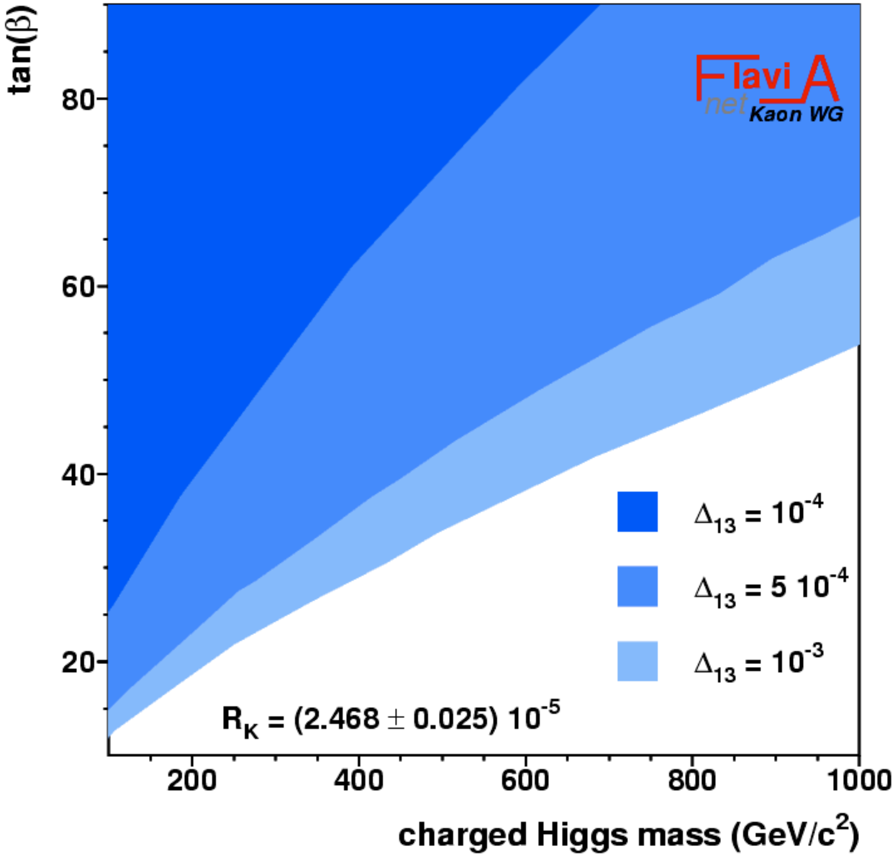


[hep-ph 0908.3470v3]

R_K : sensitivity to new physics

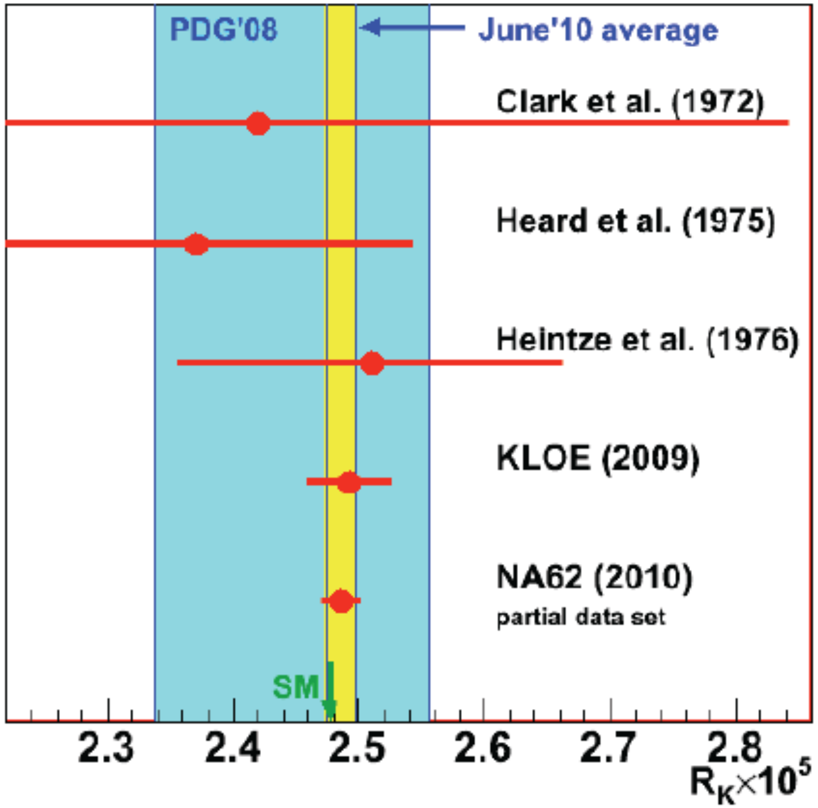
Sensitivity shown as 95% CL excluded regions in the tan**β**−M_H plane, for different values of the LFV effective coupling, $\Delta_{13} = 10^{-3}$, 5×10^{-4}, 10^{-4}





Results for R_K: KLOE vs NA62

	KLOE	NA62 (2010)
Ke2's on tape	30k	150k
Kinematic rejection	10^3 at ε≈60%	10^3-1, p_{lep} in 13-65 GeV
e/μ rejection	10^3	3-1.5 10^5, p_{lep} in 13-65 GeV
Bkg to Ke2	16%	6%
Ke2γ (SD)	Include as bkg Dedicated meas.	Suppress in analysis
Ke2 counts	14k	60k
$R_K \times 10^5$	2.493(25)(19)	2.486(11)(7)
Total error	1.3%	0.52%
Status	Published	Preliminary



Charged kaon at KLOE

ϕ decay at rest provides pure kaon beams of know momentum

$p_K \sim 100$ MeV

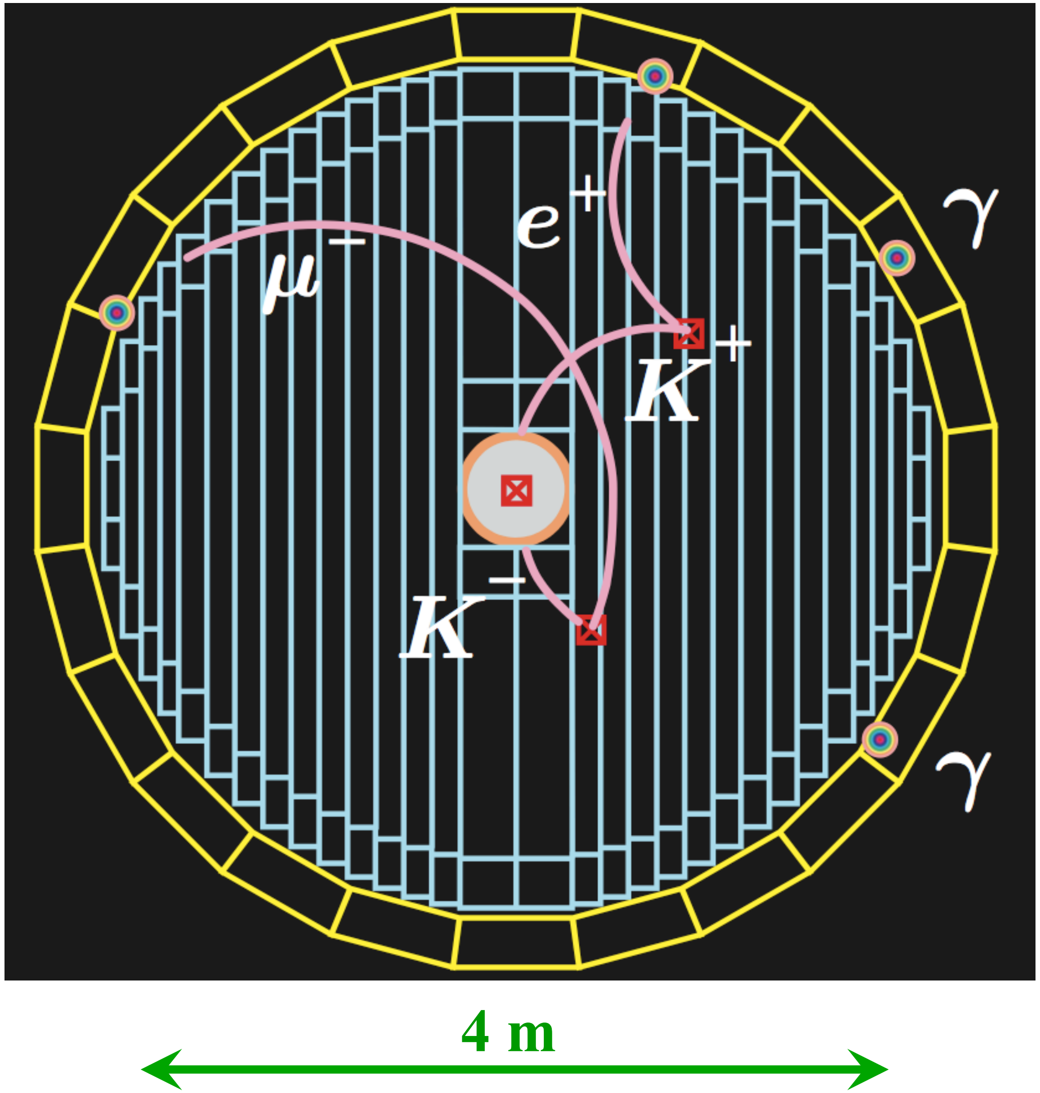
$\lambda \sim 90$ cm (56% of $K^{\pm}$ decay in DC).

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

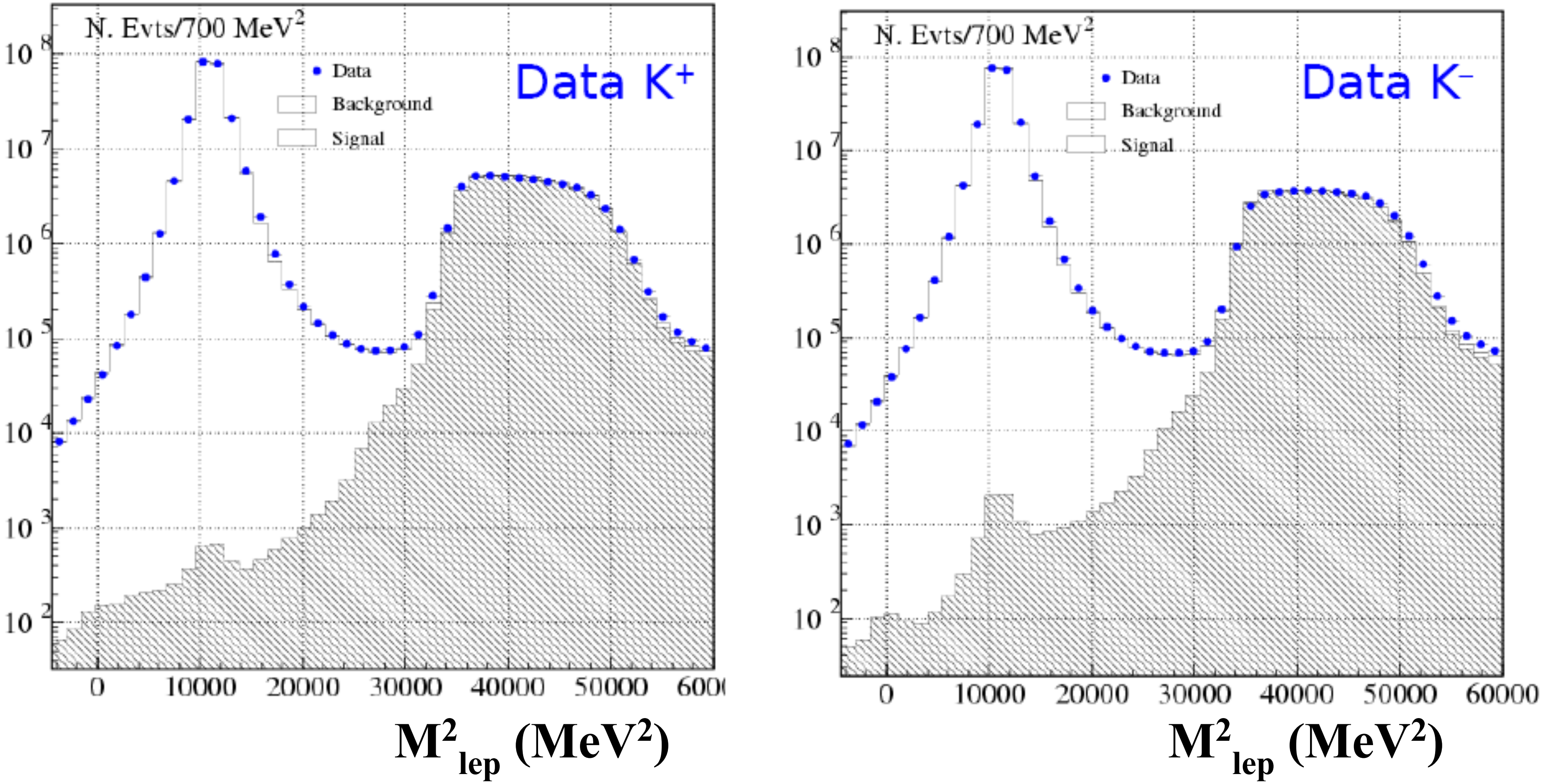
Constraints from ϕ 2-body decay.

Particle ID with kinematics and ToF.

Tagging provides unbiased control samples for efficiency measurement.



Kμ2 event counting

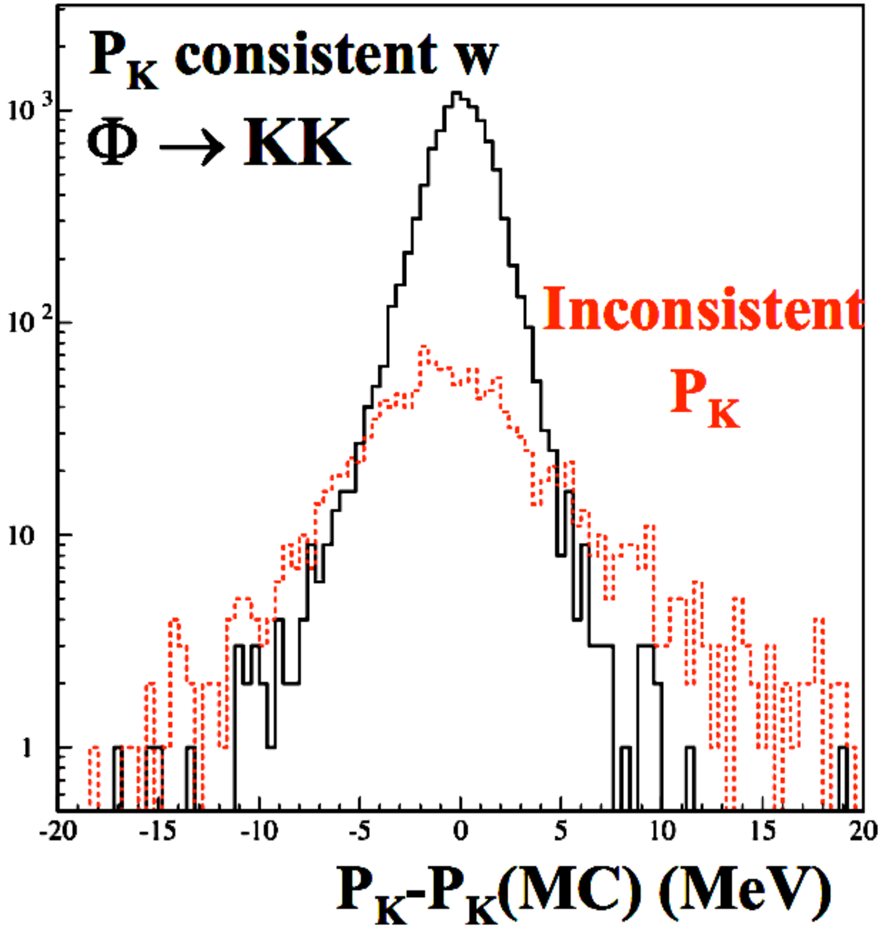


Fit to M^2_{lept} distribution: 300 million Kμ2 events per charge

Background under the peak <0.1%, from MC

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 $\phi \to K^+K^-$ 2-body decay allows redundant p_K determinartion.

Control samples for tracking efficiencies

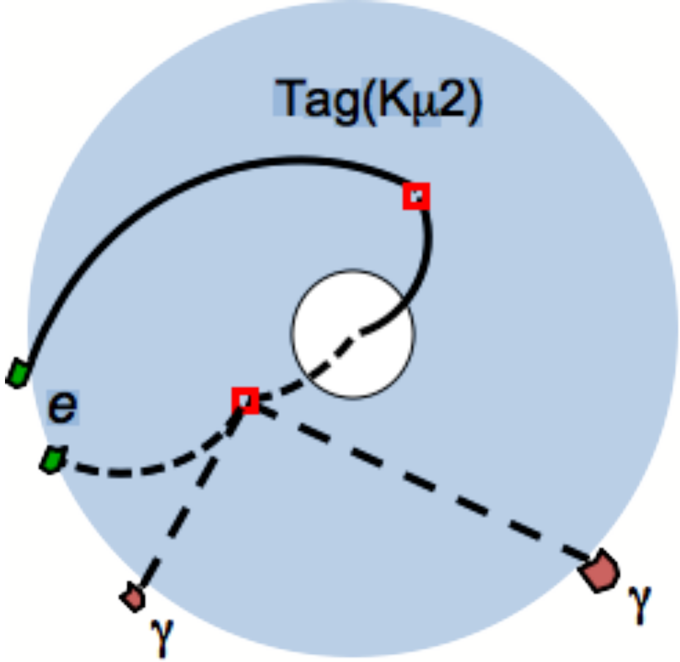
Just an example: selection of K^+e3 control sample to measure tracking efficiency for electrons

0) Tagging decay (Kμ2 or Kπ2);

1) Tagging decay (Kμ2 or Kπ2): reconstruction of the opposite charge kaon flight path;

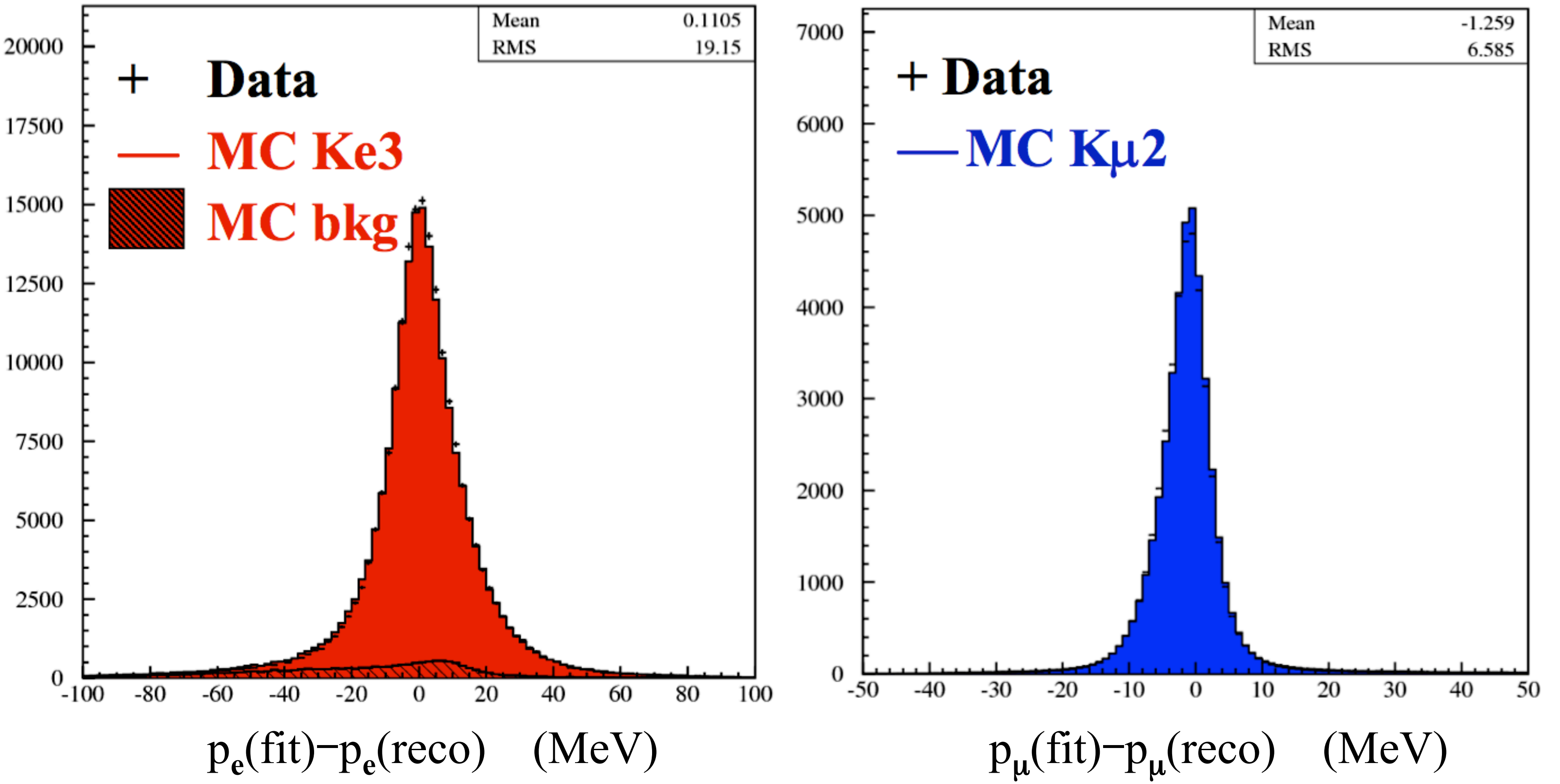
2) Using a ToF technique a $\pi^0 \to \gamma\gamma$ decay vertex is reconstructed along the K decay path;

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

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

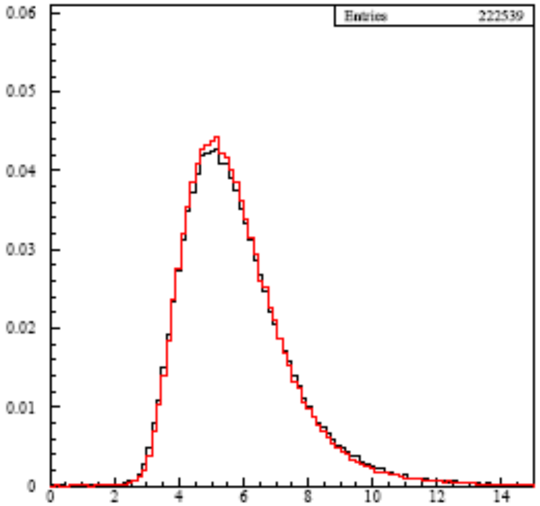
NN details

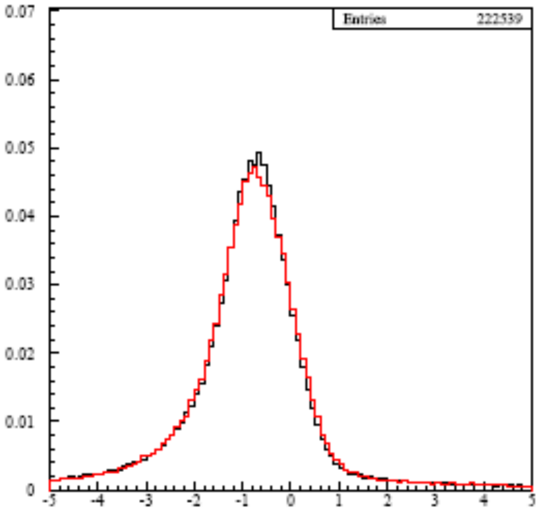
1) E/P;
2) 1st momentum of the distribution of the longitudinal energy path deposition (cluster centroid depth) evaluated at cell level;
3) the 3td momentum of the longitudinal energy path deposistion (skewness);
4,5) asymmetry of energy lost in first two innermost (outermost) planes;
6) RMS of energy 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

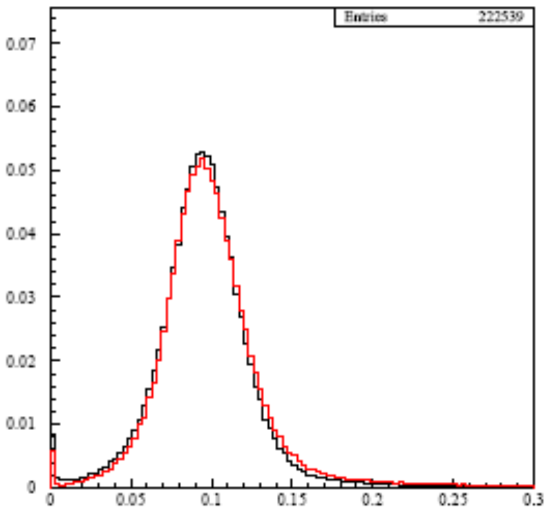


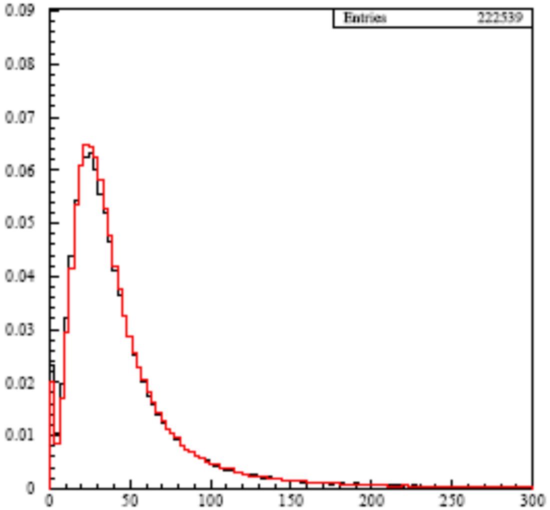


Asymmetry of energy lost in first two innermost planes

Data and **MC**

dE/dx





$E_{INT}(x)$ slope

Systematics and checks

Cross-check on efficiencies: use same algorithms to measure $R_{13} = \Gamma(Ke3)/\Gamma(K\mu3)$

$R_{13} = 1.507 \pm 0.005$ for K^+	SM expectation (FlaviaNet)
$R_{13} = 1.510 \pm 0.006$ for K^-	$R_{13} = 1.506 \pm 0.003$

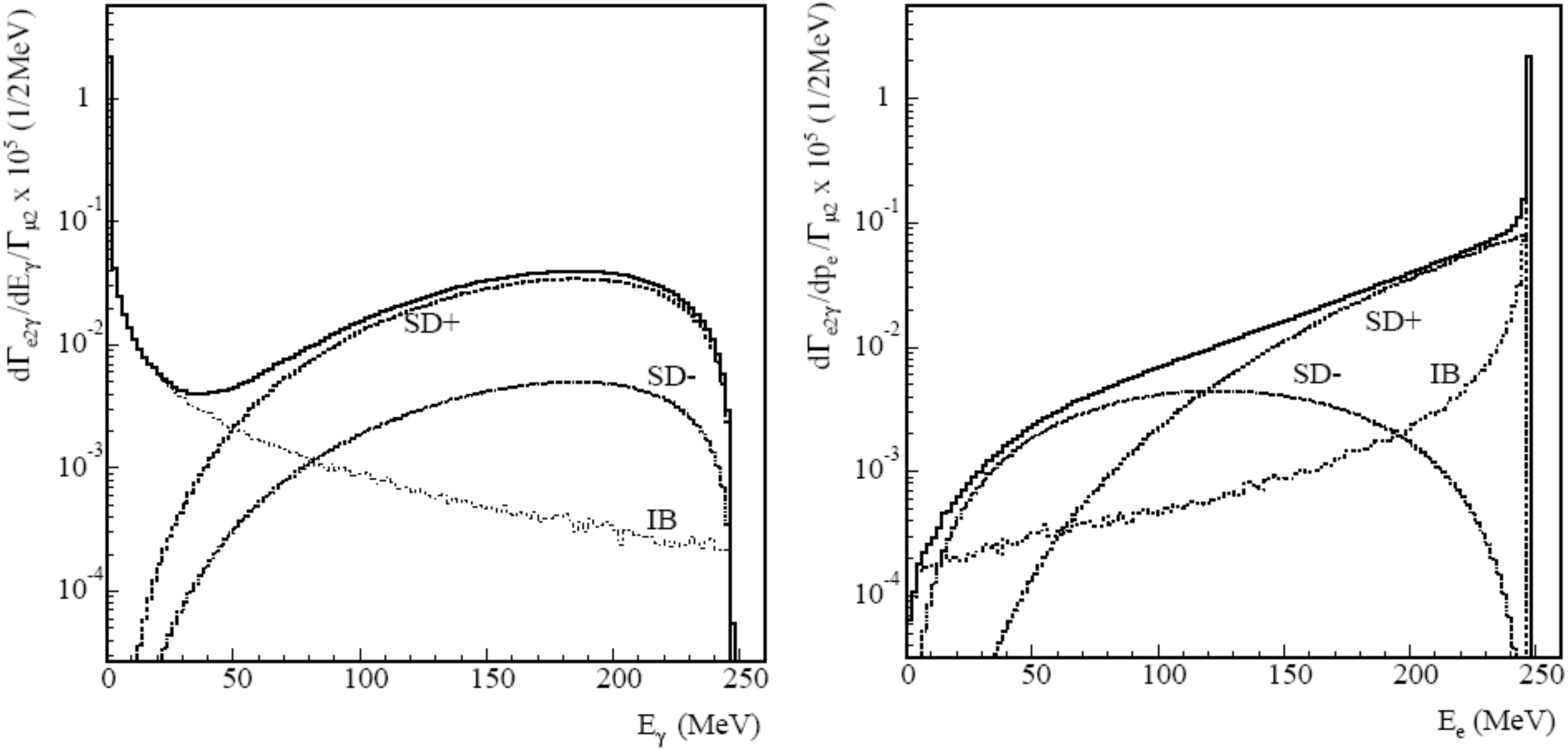
Summary of systematics:

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%**

(0.6% from statistics of control samples)

Distributions for Ke2γ decay



For Ke2γ 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 $O(e^2p^4)$.

Ke2γ process

Dalitz density:

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

E_γ, E_e in the K rest frame

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

helicity suppressed

negligible

Structure Dependent

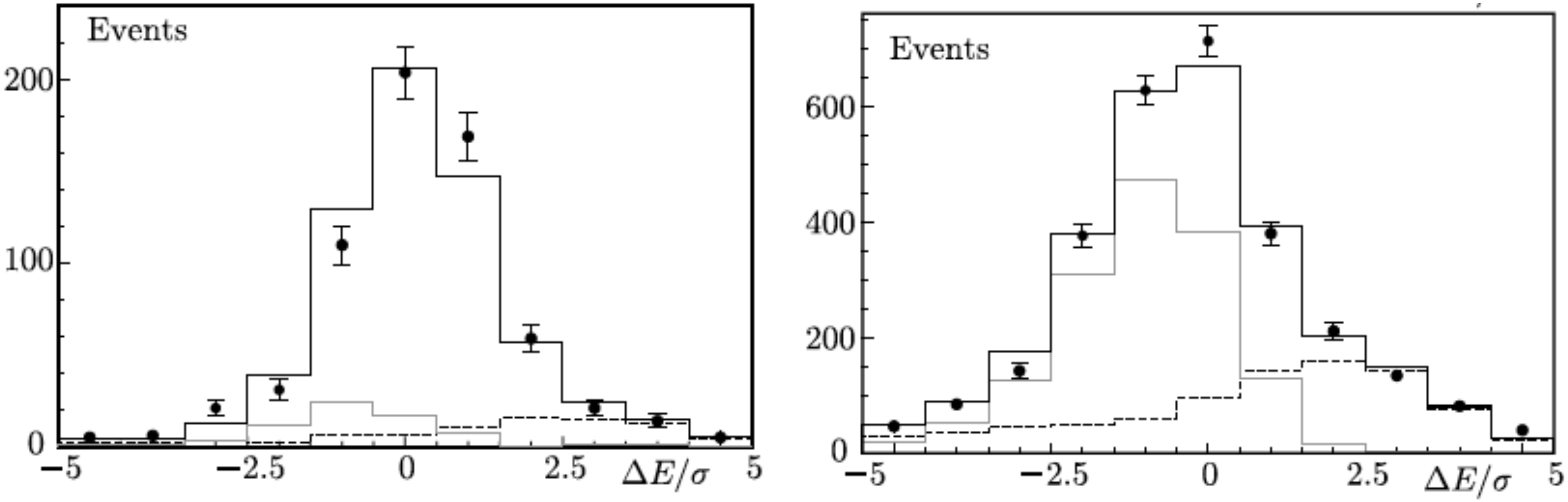
f_V, f_A : effective vector and axial couplings

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

SD+ = V+A (γ polarization +): $f_{DE^+}(x,y) = (x + y - 1)^2 (1 - x),$

SD− = V−A (γ polarization −): $f_{DE^-}(x,y) = (1 - y)^2 (1 - x).$

$K_{e2\gamma}$ fit results



E_γ (MeV)	10 to 50	50 to 100	100 to 150	150 to 200	200 to 250
Signal counts	55 ± 16	219 ± 24	463 ± 32	494 ± 38	253 ± 26
χ^2/ndf	80/66	141/105	87/106	100/106	116/102

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

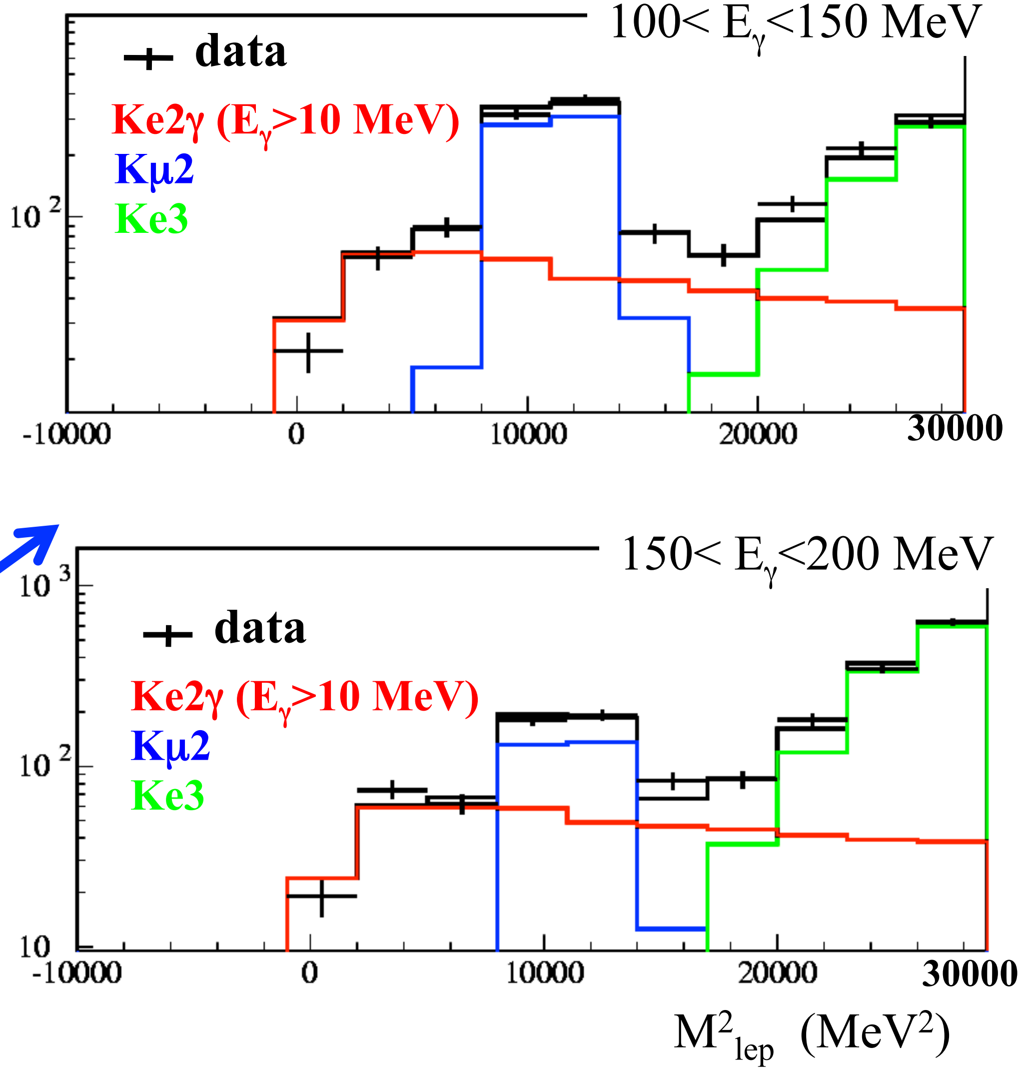
$100 < E_\gamma < 150$ MeV: $N = 463 \pm 32$

$\chi^2 = 87/106$

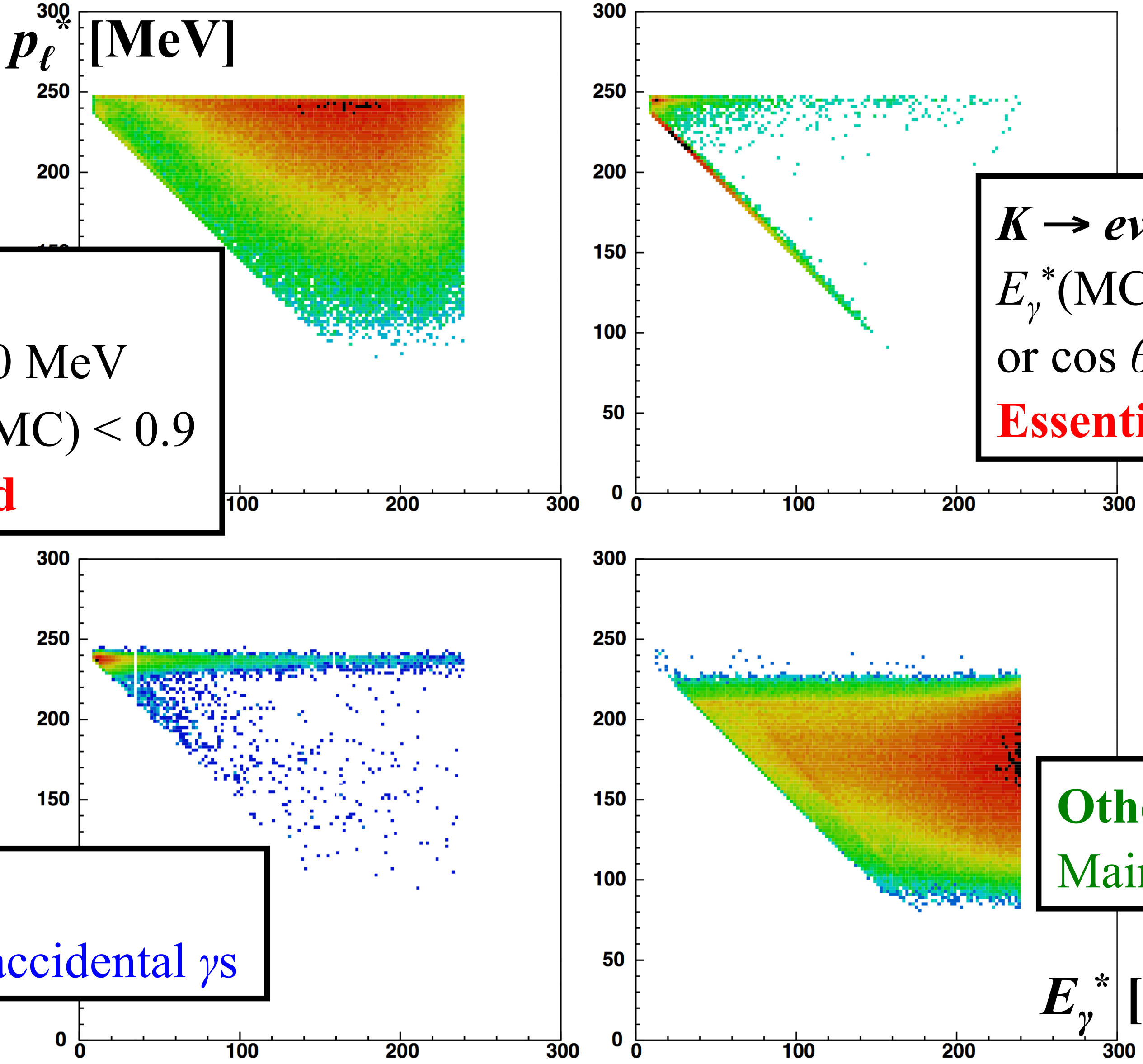
$150 < E_\gamma < 200$ MeV: $N = 494 \pm 38$

$\chi^2 = 100/106$

Fit projections on M^2_{lep} axis



MC kinematics for samples in $K_{e2\gamma}$ fit



$K \to e\nu\gamma$
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

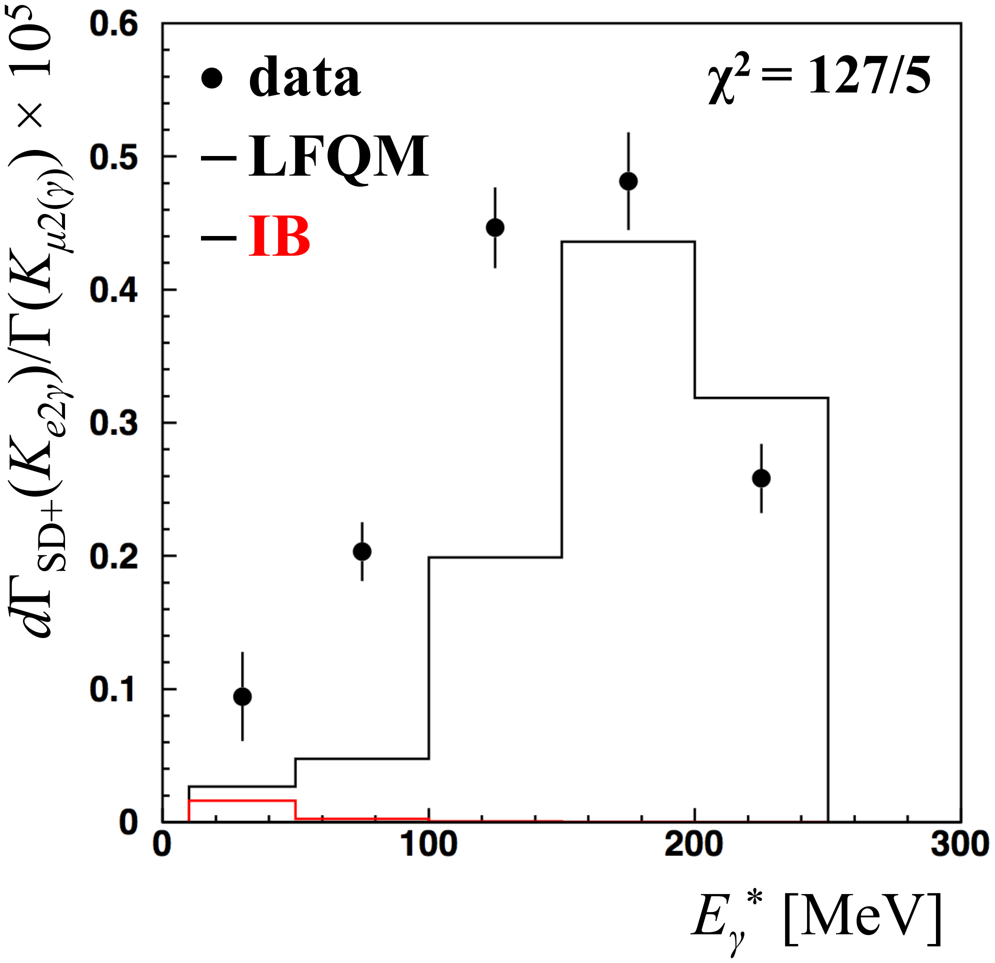
$K \to \mu\nu(\gamma)$
including accidental γs

Other background
Mainly K_{e3}

$K_{e2\gamma}$ spectrum vs LFQM

Light Front Quark Model
with parameters as in
Chen, Geng, Lih, ’08

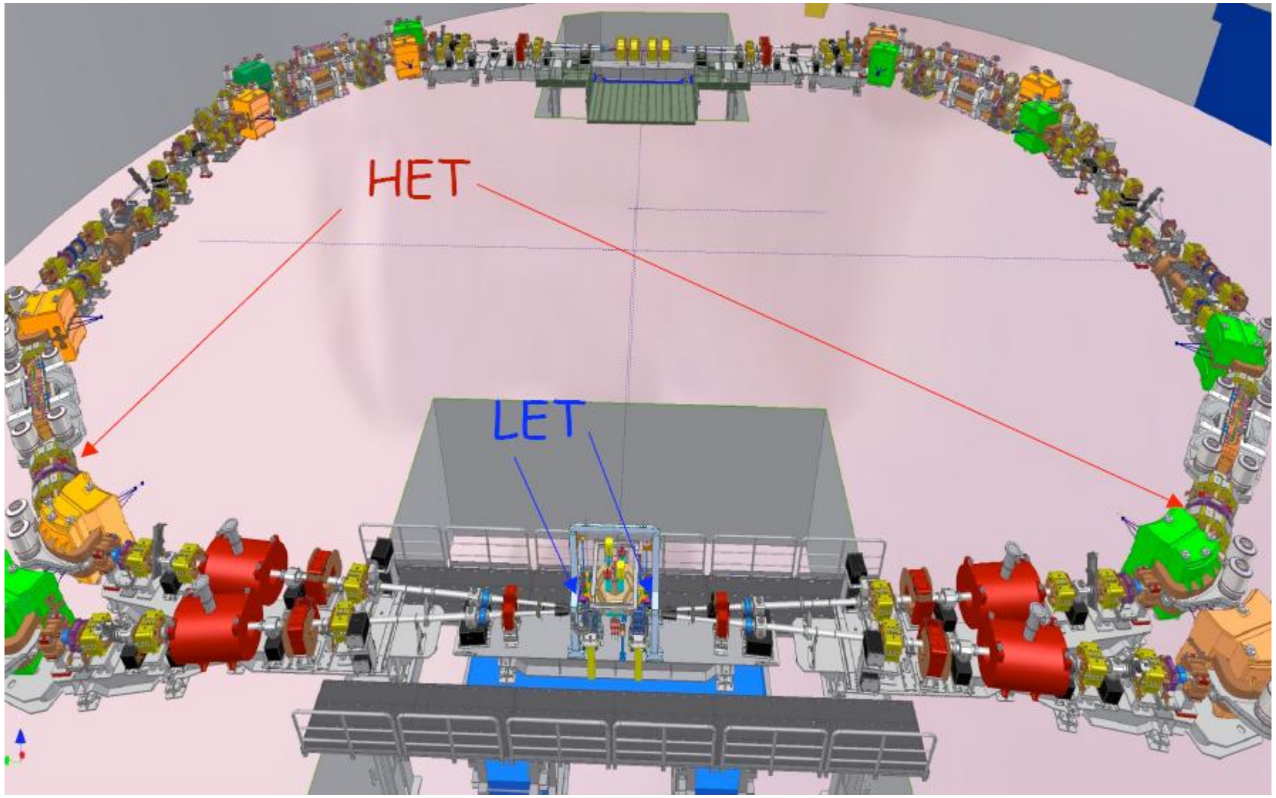
Excluded by our data
$\chi^2 = 127/5$



KLOE-2 Step 0

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

Detector ready for resume data taking.

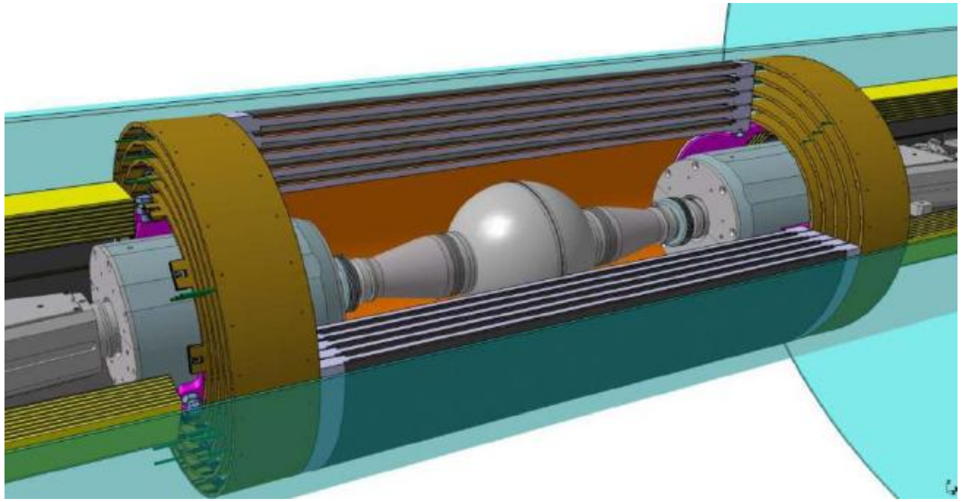


Minimal **detector** upgrade: tagger for **γγ** physics: detect off-momentum $e^{\pm}$ from $e^{+}e^{-}\rightarrow e^{+}e^{-}\gamma^{*}\gamma^{*}\rightarrow e^{+}e^{-}X$ (where X=**ππ**, π^0, or **η**)

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

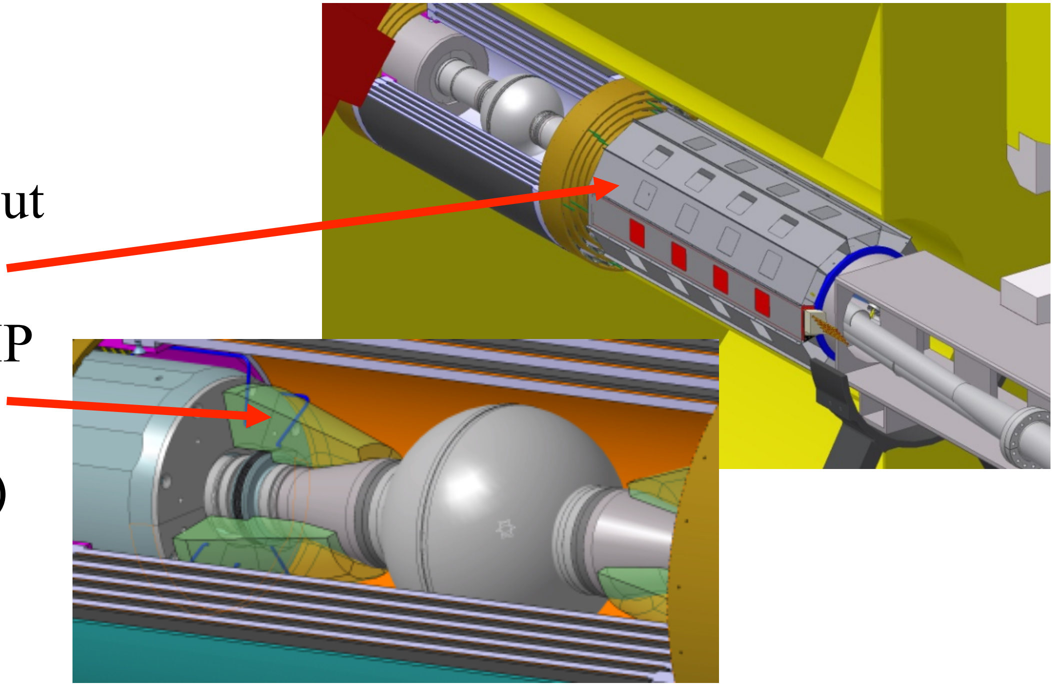
KLOE-2 Step 1

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