KLOE results:
- Hadronic physics
- Kaon physics

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for the KLOE collaboration

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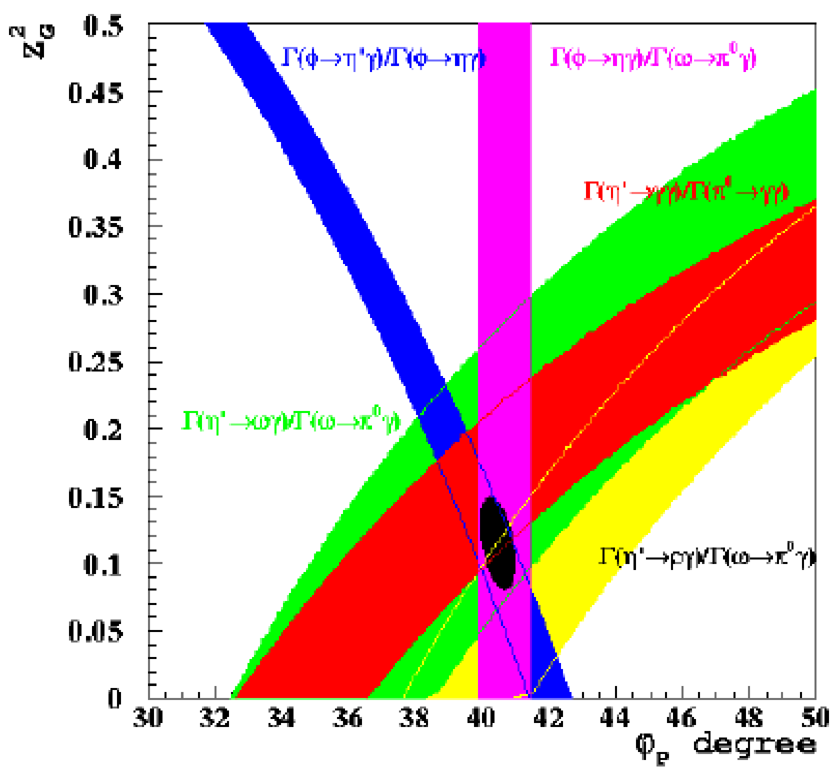
Hadronic physics: state of the art

Hadronic cross section at Large Angle	**published (PLB 670 (2009))**
$\sigma(\pi^+\pi^-\gamma)/\sigma(\mu^+\mu^-\gamma)$	**in progress**
$\eta \to \pi^+ \pi^- e^+e^-$	**PLB, in press**
$\phi \to K_S K_S \gamma$	**submitted to PLB**
$\phi \to$ a0(980) γ	**submitted to PLB**
Gluonium content in η'	**final, paper in writing**
$\eta \to \pi^+\pi^-\gamma$	**in progress**
$\eta \to e^+e^- e^+e^-$	**in progress**
$\eta \to \mu^+ \mu^-$	**new**
$\gamma\gamma \to \pi^0\pi^0$	**in progress**
$\gamma\gamma \to \eta$	**new**

η' gluonium content

A global fit to determine the pseudoscalar mixing angle and the gluonium content of the η' meson.

Paper under the review of the collaboration



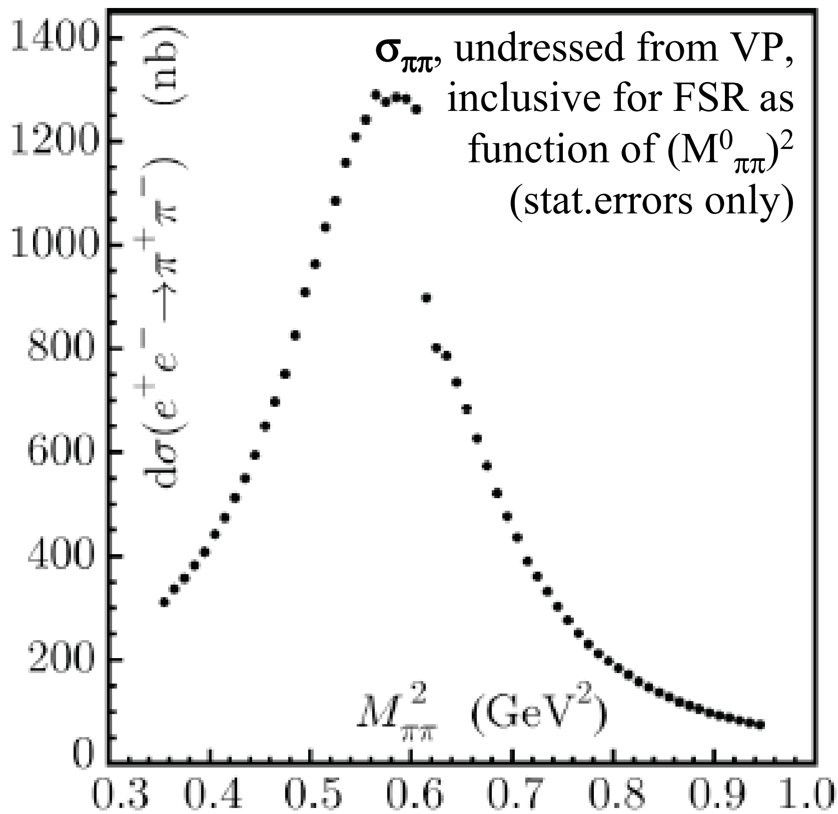
- Use KLOE R_ϕ=BR($\phi\to\eta'\gamma$)/BR($\phi\to\eta\gamma$)
- From a global fit to all measured $V\to P\gamma$ and $P\to V\gamma$ transitions, we extract:
  - gluonium fraction $\mathbf{Z_G^2=0.12(4)}$
  - pseudoscalar mixing angle $\mathbf{\varphi_P=40.4(6)°}$
  - ϕ–ω mixing angle $\mathbf{\varphi_V=3.32(9)°}$

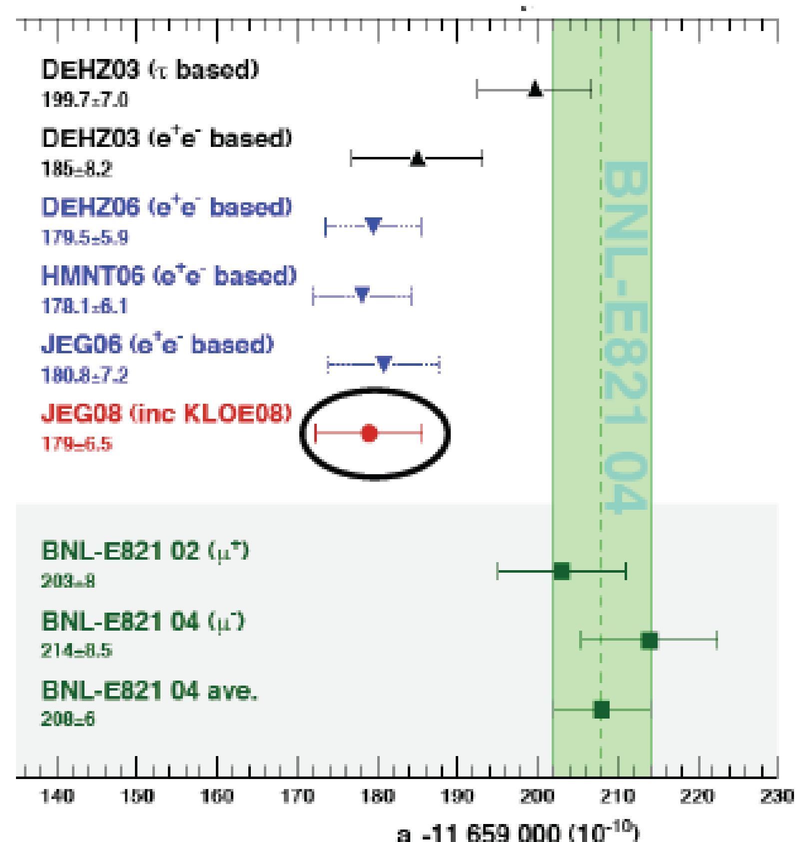
- Fit result slightly different from out previous but **confirms** the presence of significative gluonium contribution in η'.

KLOE result [PLB670(2009)285]

$a_\mu^{\pi\pi}(0.35\text{-}0.95\,\mathrm{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$

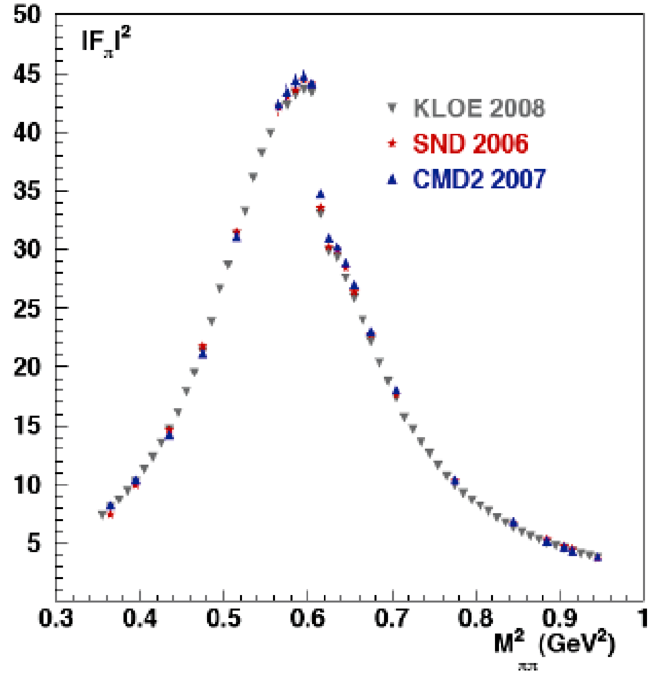
Systematic frac. errors:
exp. 0.6%, th. 0.6%

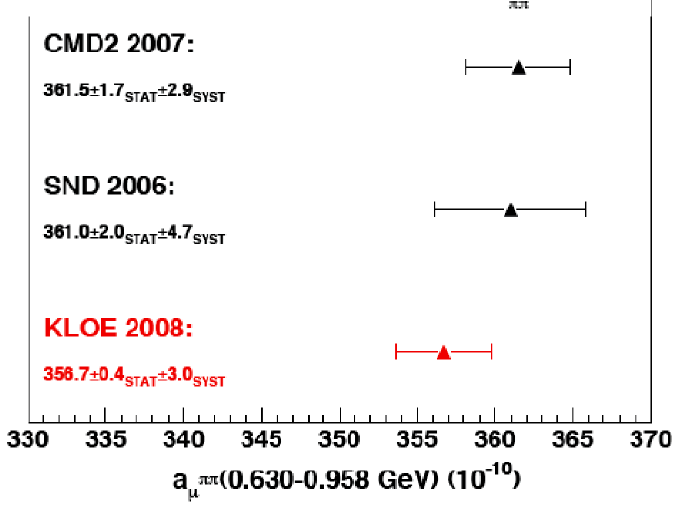




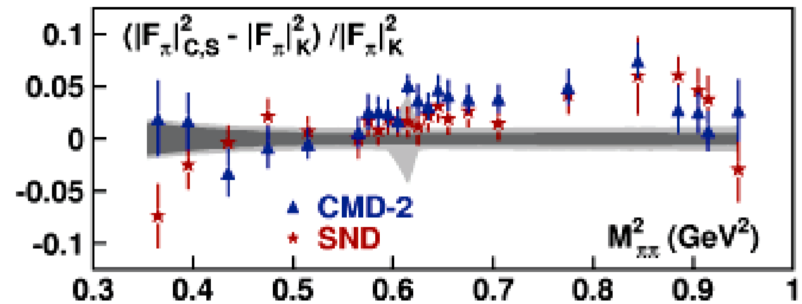
- Th. predictions on $\mathbf{a}_\mu$ vs BNL result.
- KLOE strengthens the discrepancy between SM and experiment (~3.3σ)

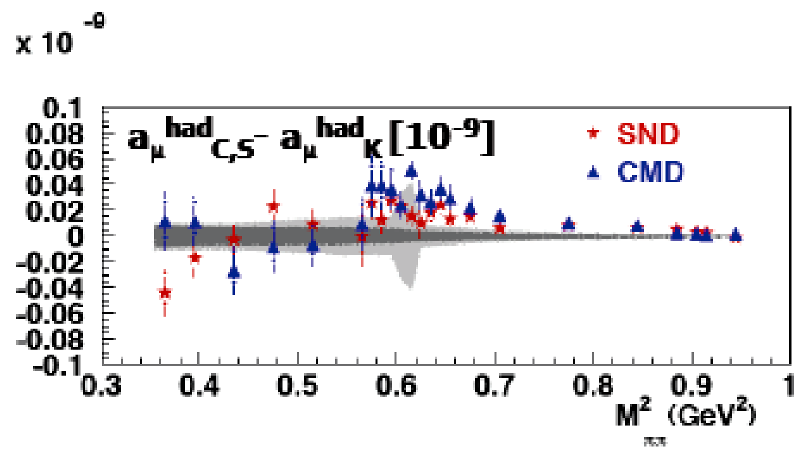
Comparison with CMD2/SND





only statistical errors are shown

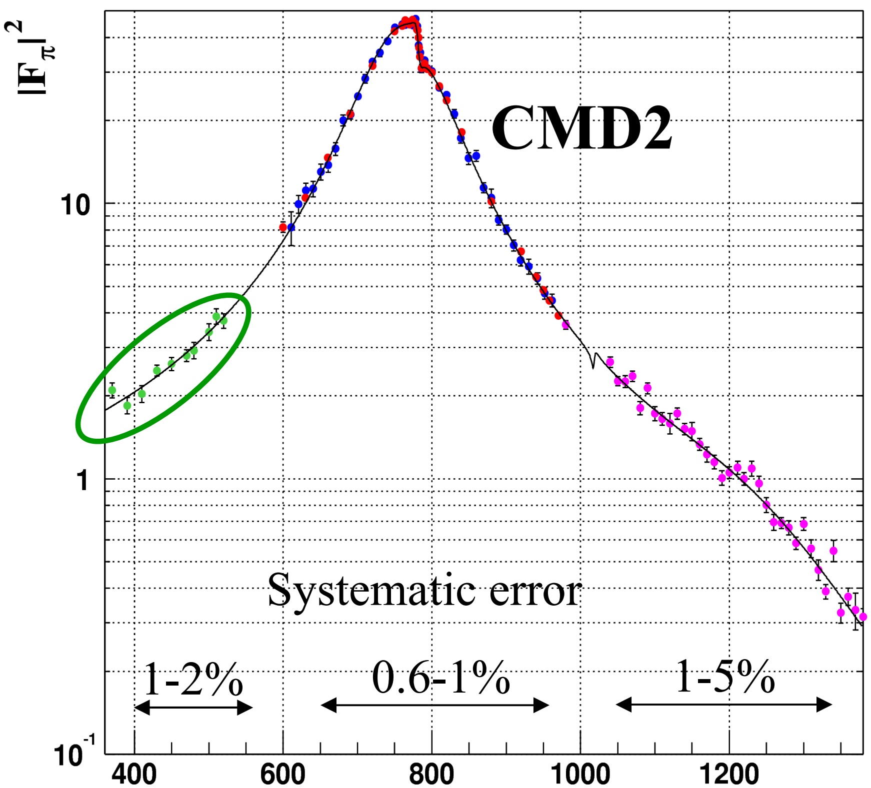




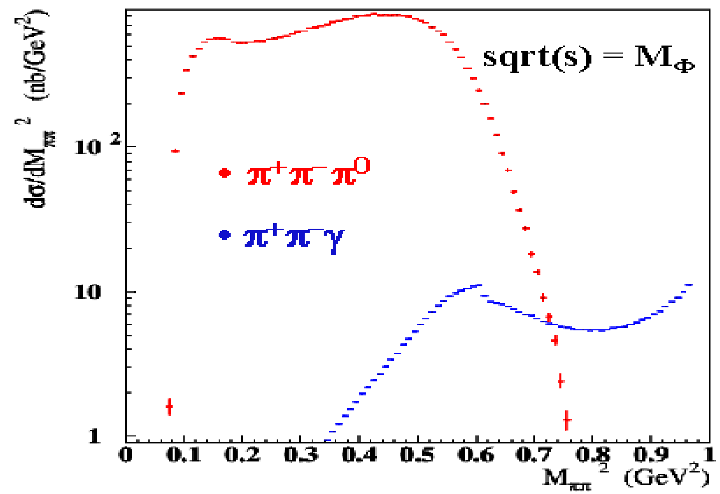
band: KLOE error
data points: CMD2/SND experiments
(CMD-2 and SND data have been averaged over width of KLOE bin (0.01 GeV2))

$\sigma(e^+e^- \to \pi^+\pi^-)$ at threshold

KLOE small angle analysis did not cover the region below 0.35 GeV^2 ($\Delta a_\mu^{\pi\pi}(s<0.35\ GeV^2)$~15% of a_μ^{had})

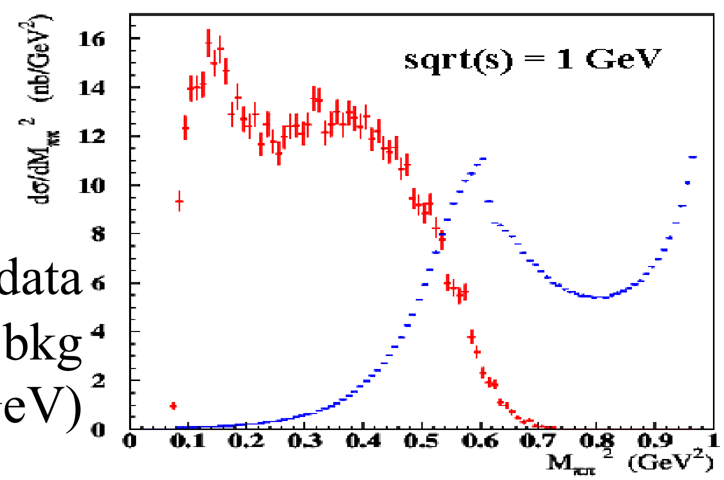


• 10 points between ~375 and 525 MeV **→ ~15 MeV steps**



$\sigma_{\pi+\pi-\pi0}$ = 329.8 nb, $\sigma_{\pi+\pi-\gamma}$ = 4.4 nb

Off peak data (lower ϕ bkg at 1 GeV)



$\sigma_{\pi+\pi-\pi0}$ = 6 nb, $\sqrt{s}$=1003.71 MeV

(from SND, PRD66 (2002) 032001)

New analysis in progress

2 pion tracks at large angles

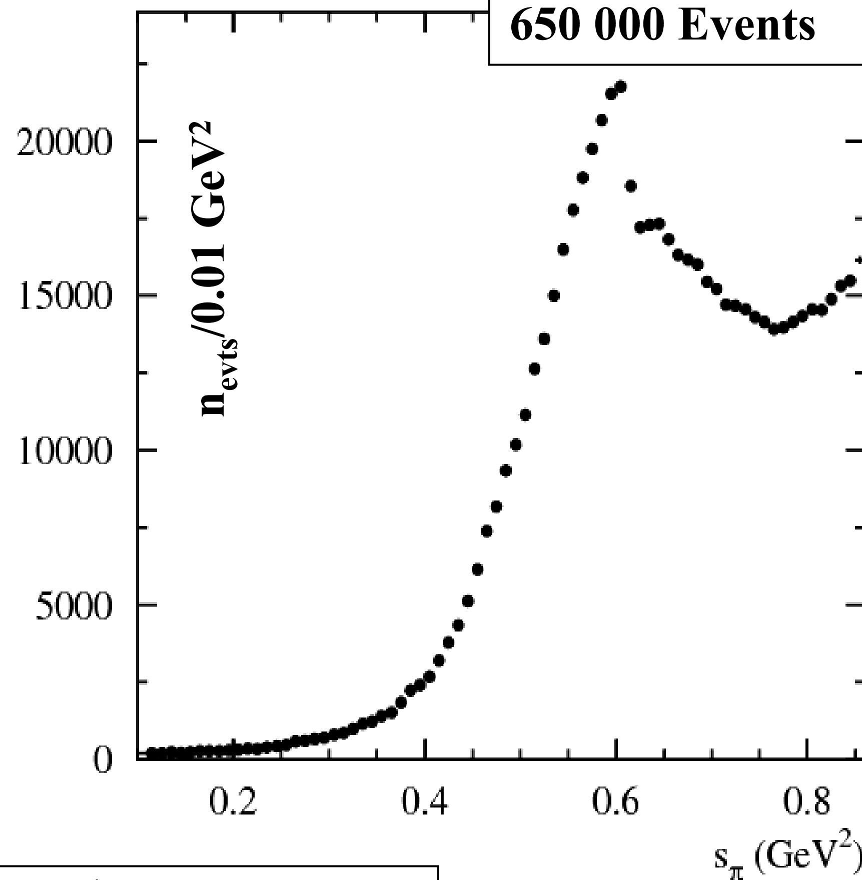
$50^o < \theta_\pi < 130^o$

Photons at large angles

$50^\circ < \theta_\gamma < 130^o$

statistics: 233pb^{-1}

650 000 Events



- independent complementary analysis
- threshold region $(2m_\pi)^2$ accessible
- γ_{ISR} photon detected (4-momentum constraints)
- lower background from ϕ decays ($\phi \to f_0\gamma \to \pi\pi\gamma$, $\phi \to \pi^+\pi^-\pi^0$) off-peak

Use data sample taken at $\sqrt{s} \cong 1000$ MeV, 20 MeV below the ϕ-peak

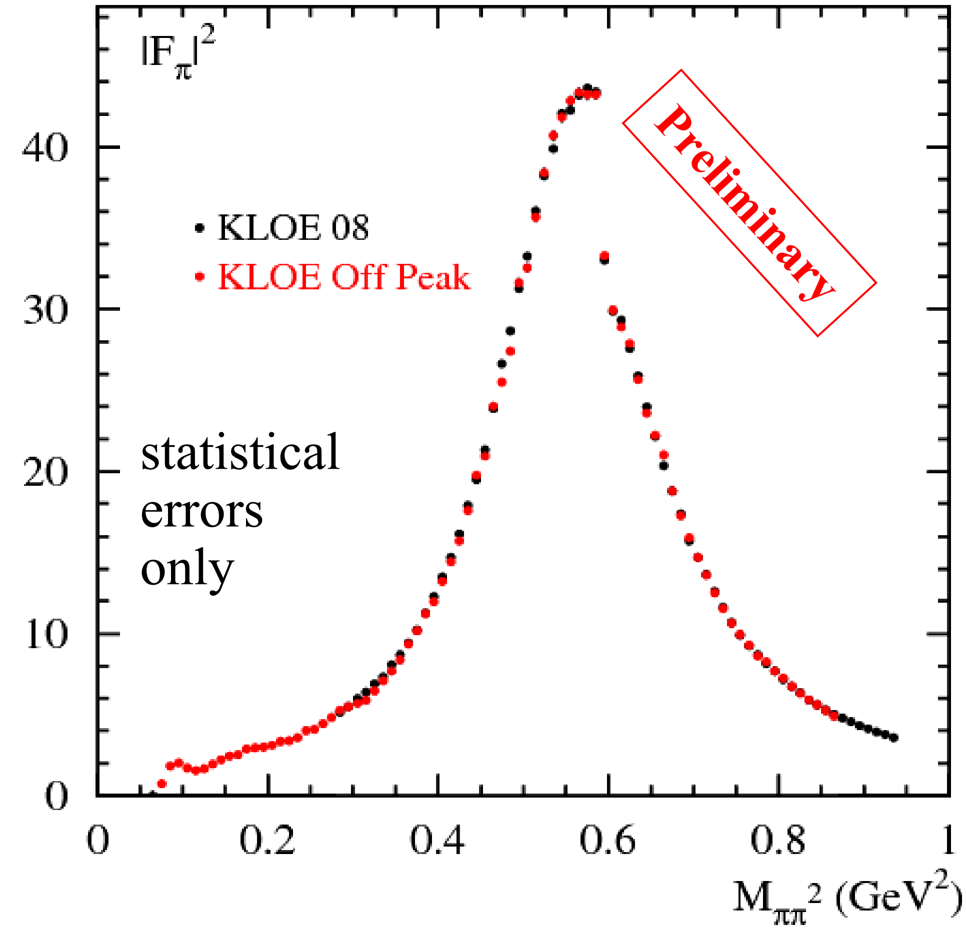
New analysis in progress

• Selection cuts established
• Efficiencies evaluated

• Few systematic uncertainties still under evaluation

• Very good agreement between the spectrum of the preliminary new result and the KLOE 08 published analysis

Analysis very close to final result



Kaon physics: state of the art

$K_S \to e^+e^-$	published
$BR(K^\pm \to e^\pm\nu)/BR(K^\pm \to \mu^\pm\nu)$	final, paper in writing
CPT test from interferometry	1 fb^{-1} update, paper in writing
K_L lifetime with 2004/5 data	in progress
K_S lifetime	in progress
$BR(K^\pm \to \pi^\pm \pi^+ \pi^-)$	in progress

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

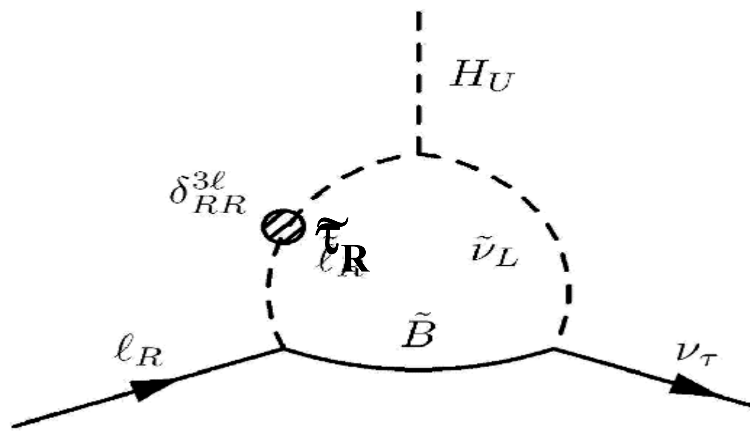
• SM prediction with 0.04% precision, benefits of cancellation of hadronic uncertainties (no f_K): **R_K=2.477(1)×10^{-5}** [Cirigliano Rosell arXiv:0707:4464].

• Helicity suppression can boost NP [Masiero-Paradisi-Petronzio PRD74(2006)011701]. In R-parity MSSM, LFV can give **O(1%) deviation from SM**.

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

NP dominated by contribution of $e\nu_\tau$ final state, with effective coupling (from loop):

$$l\mathbf{H}^{\pm}\nu_\tau \ \rightarrow\ \frac{\mathbf{g_2}}{\sqrt{\mathbf{2}}}\frac{\mathbf{m_\tau}}{\mathbf{M_W}}\,\mathbf{\Delta_{13}}$$



• Present exp. accuracy on R_K at 6% level.

• New measurements of R_K can be very interesting, **if error at 1% level or better**.

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)

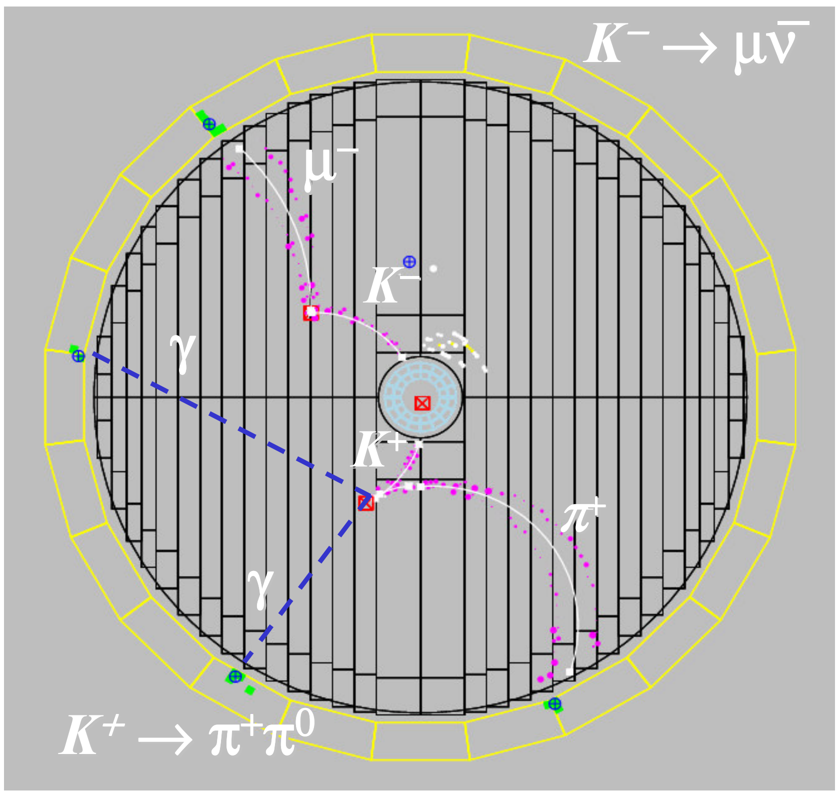
KLOE: **preliminary** result with 2001-2005 data: **R_K=2.55(5)$_{stat}$(5)$_{syst}$10^{-5}**, from **~8000 Ke2** candidates (3% accuracy), perspectives to reach 1% error after analysis completion.

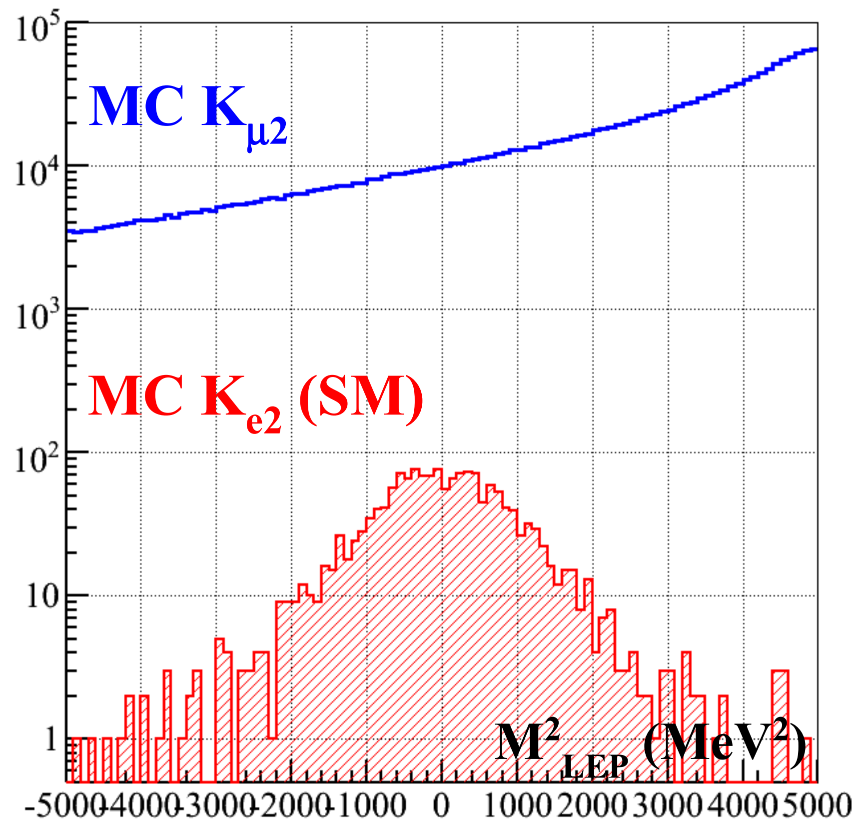
NA62 (ex NA48): **collected ~150,000 Ke2** events in dedicated 2007 run, aims to breaking the 1% precision wall, possibly reaching <~0.5%

Analysis of R_K: basic principles

In KLOE data set (2001/5) expect ~4×10^4 events.

- Perform direct search for Ke2 and Kμ2; no tag: gain ×4 of statistics.
- Selection of $K^\pm$ decays asking for kink in DC.
- Exploit tracking of K and secondary: assuming m_ν=0 get M^2_{LEP}.





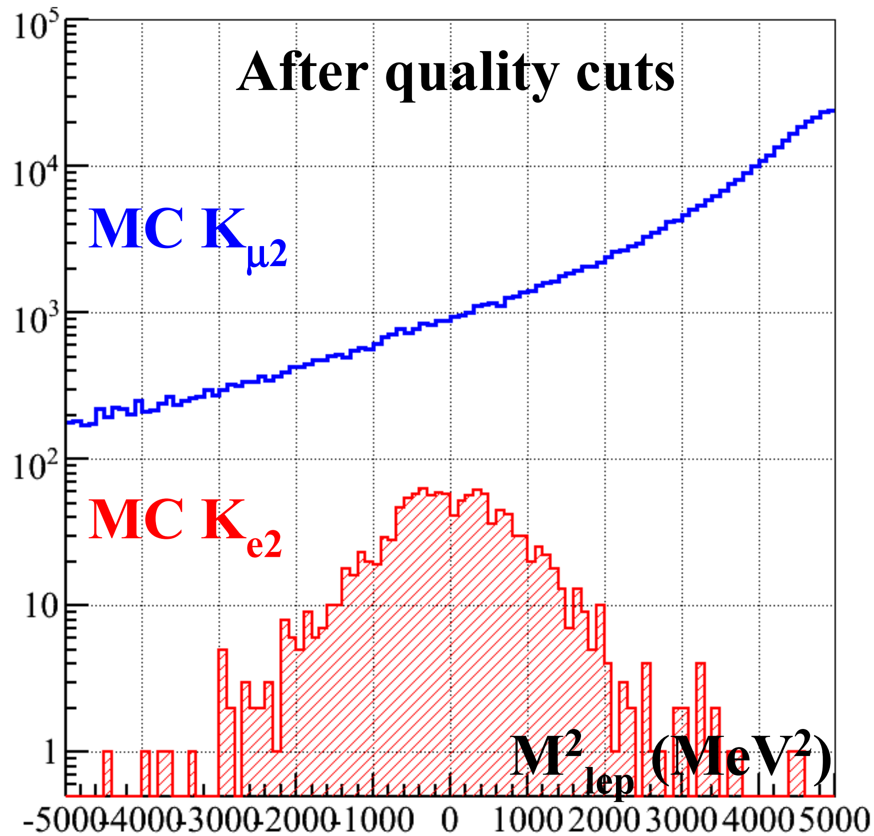
R_K analysis: quality cuts

- Rule of the game: reject Kμ2 by 10^4, with Ke2 efficiency of O(50%).
- Background composition: Kμ2 events with bad P_K, bad P_l reconstruction.
- Apply quality cuts for K and exploit $\Phi \to KK$ two-body kinematics

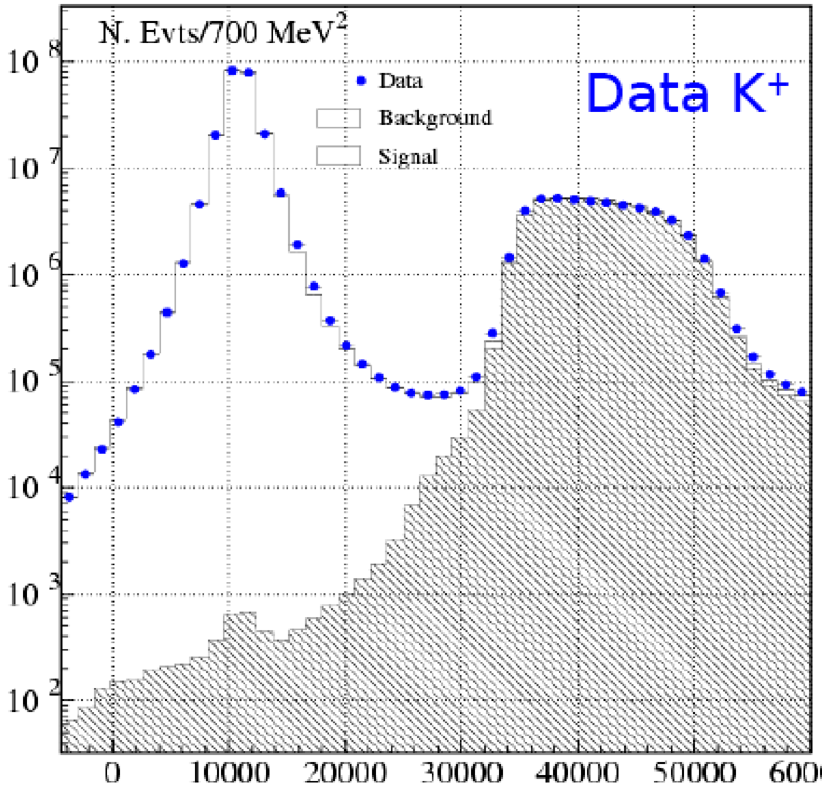
$M_{lep}^2 = f(P_K, P_l, \cos\theta) \to$ a-priori error δM_{lep}^2 is scaled by opening angle.

Achieve cancellation in Ke2/Kμ2 efficiencies, applying cosθ trailing cuts

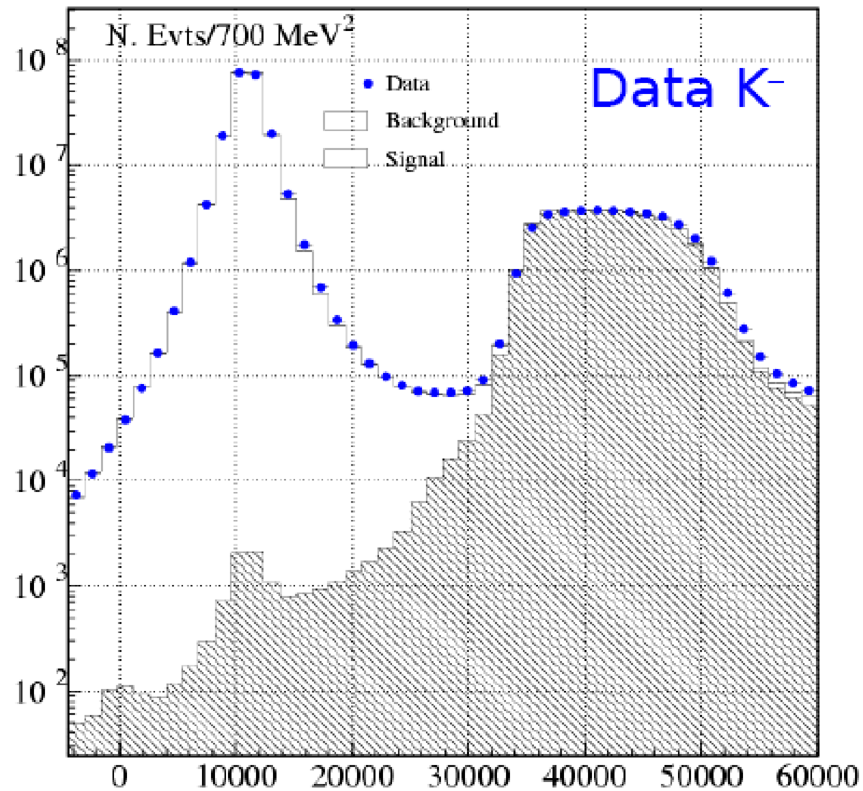
Efficiency ~ 33% at this level



R_K analysis: counting $K\mu2$ events



M^2_{lep} (MeV^2)

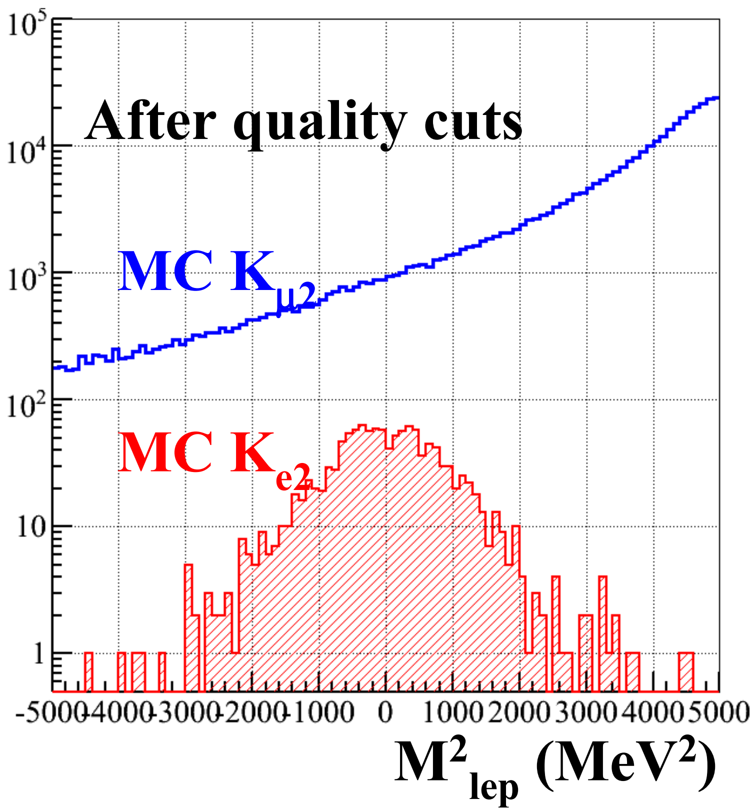


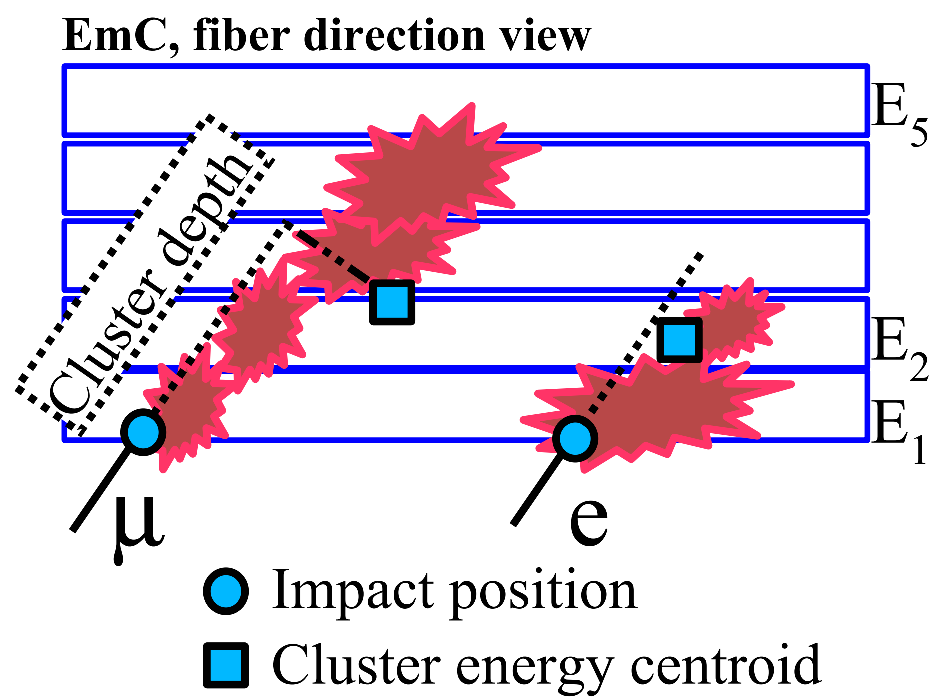
M^2_{lep} (MeV^2)

Fit to M^2_{lept} distribution: 300 million $K\mu2$ events per charge
Background under the peak <0.1%, from MC

R_K analysis: electron identification

- Apply quality cuts, enough to count $K_{\mu 2}$, not for K_{e2} (still Bkg ~ 10×Sig)
- Further rejection for K_{e2}: extrapolate track to EmC, select closest cluster
- PID exploits EmC granularity: energy deposits E_k into 5 layers in depth





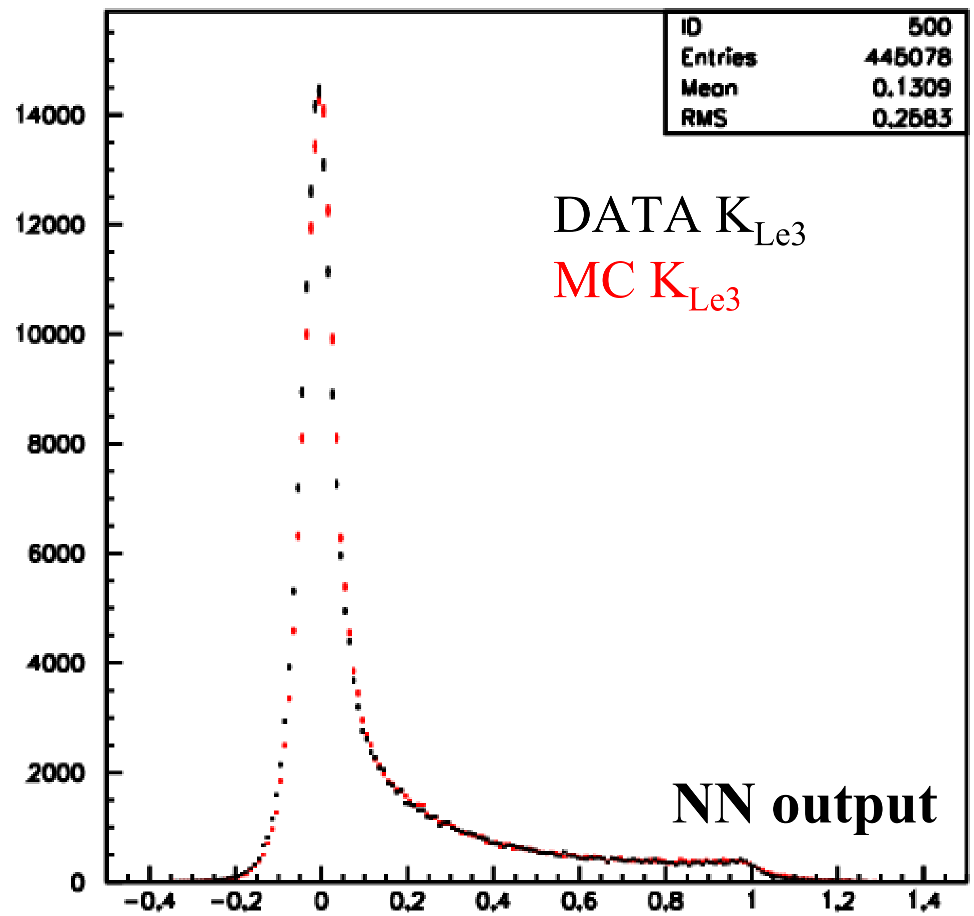
R_K analysis: electron identification

Improve bkg rejection, PID refined

Combine 12 variables using NN

- E/P
- Cluster depth
- Asymmetry of energy lost in first two innermost (outermost) planes
- T2p, Aet (curvature of the fit)
- Energy deposit in first 15 cm
- Skewness of cell-depth distribution
- RMS of plane energies (E_{RMS})
- Plane releases: E1, Nmax, Emax
- TOF

Parametrize with P_{lep}, impact angle



Check Data-MC agreement for NN output: K_{Le3}

R_K analysis: control samples

Check NN output using $K^{\pm}_{e3}$, $K^{\pm}_{\mu3}$

Require π^0 detection

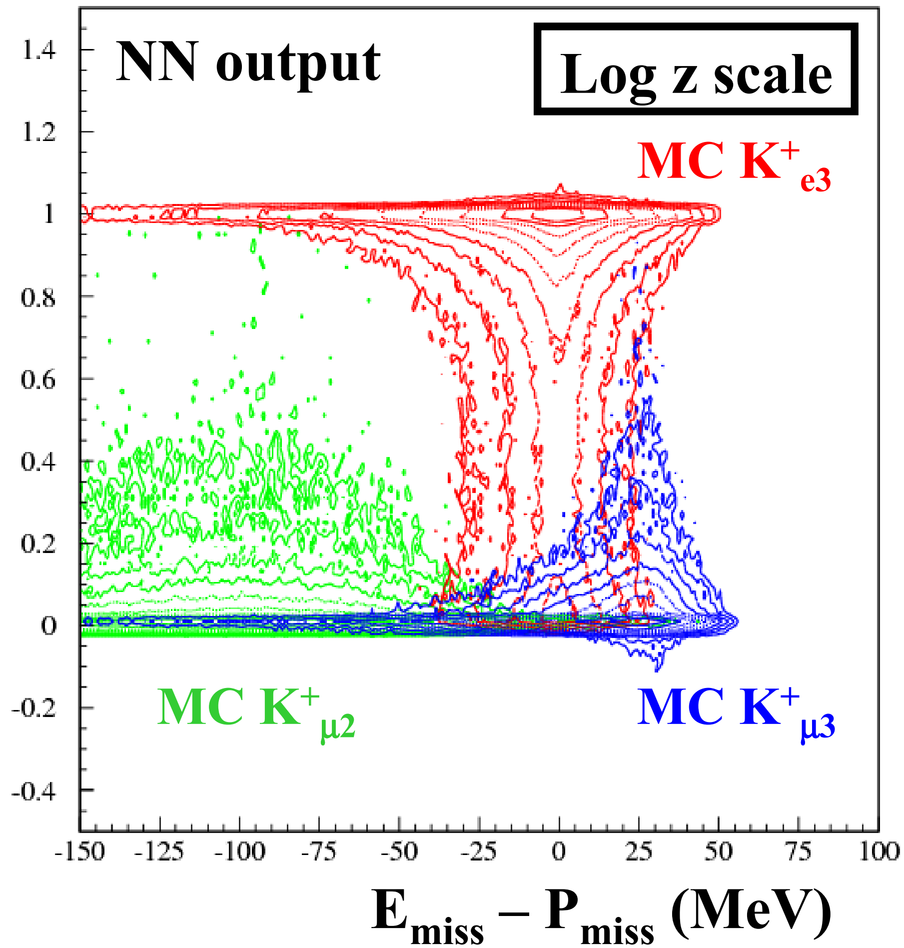
Cut against $\pi\pi^0$ bkg

Use π^0 γ's to evaluate E_{miss}, P_{miss}

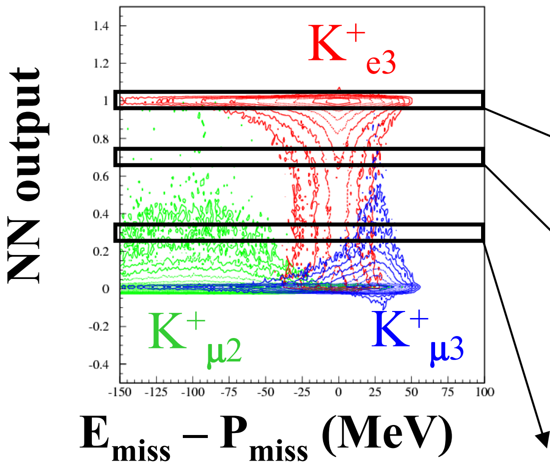
Can select pure $K^{\pm}e3$ sample above 0.2

Can select $K^{\pm}\mu3$ sample below 0.4

Perform 2d fit in entire plane



R_K: control samples



Can select pure $K^\pm_{e3}$ sample above 0.2

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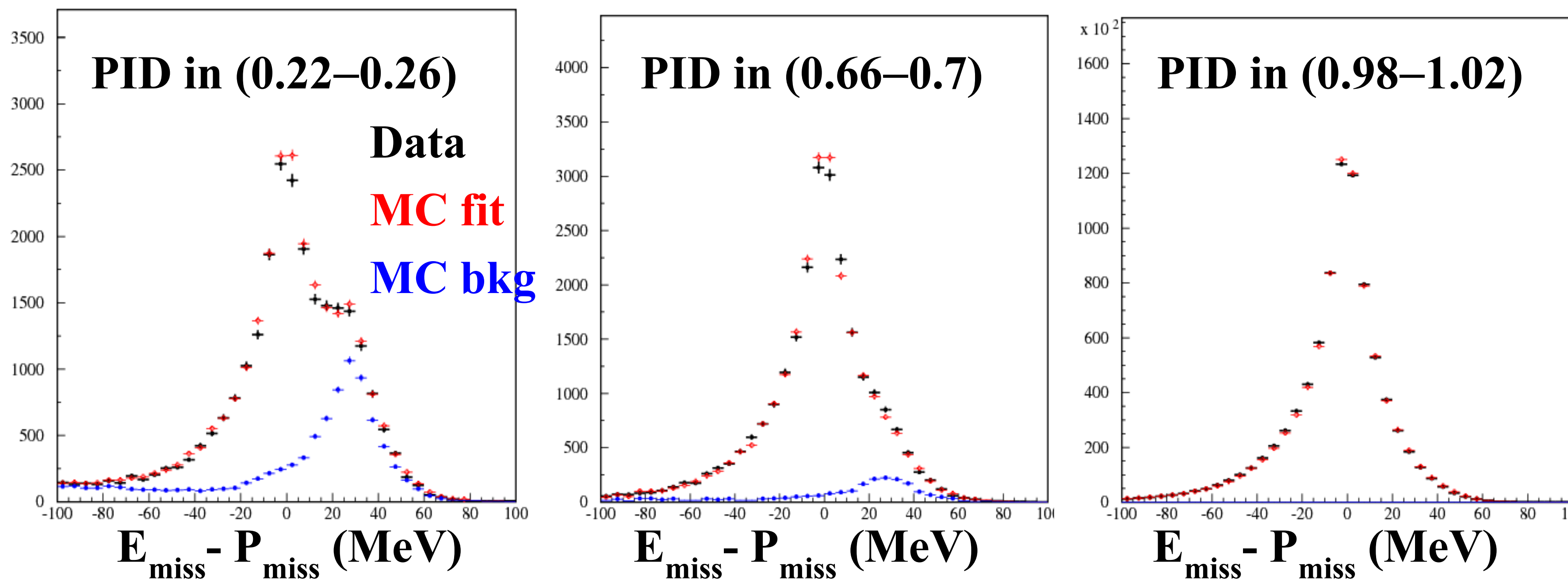
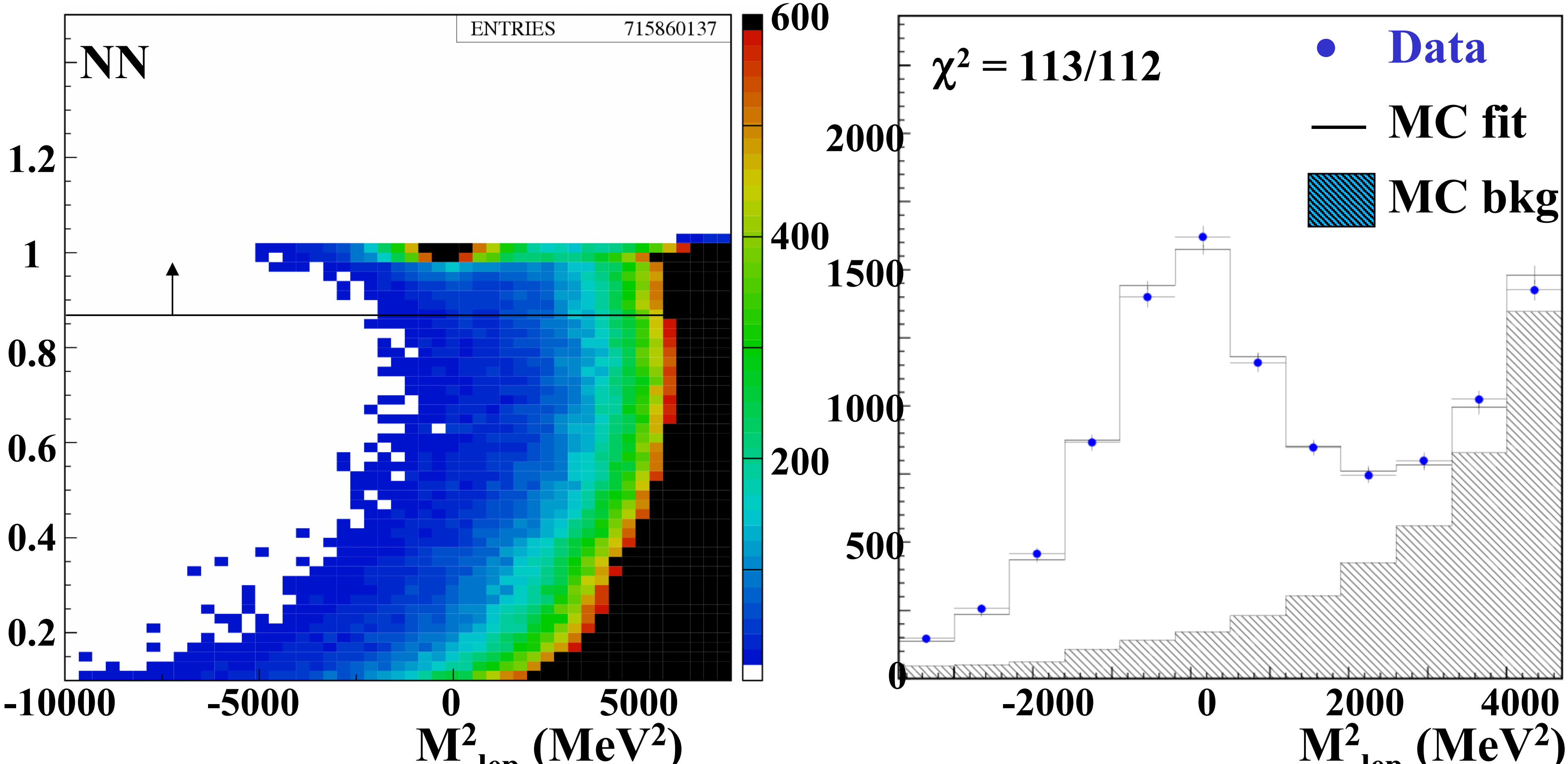


R_K analysis: fitting for Ke2 counting

Two-dimensional binned likelihood fit in the NN- M^2_{lep} plane:

0.86<NN<1.02, –4000<M^2_{lept}<6100 MeV^2.

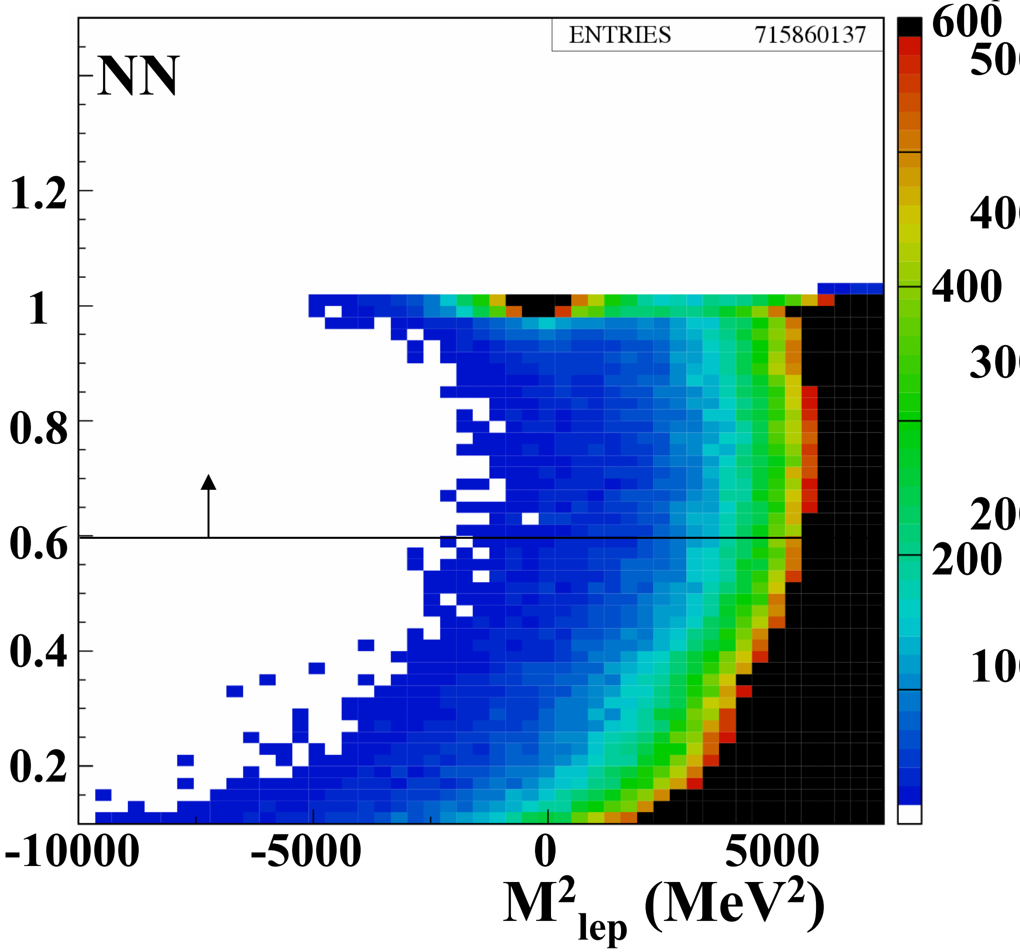


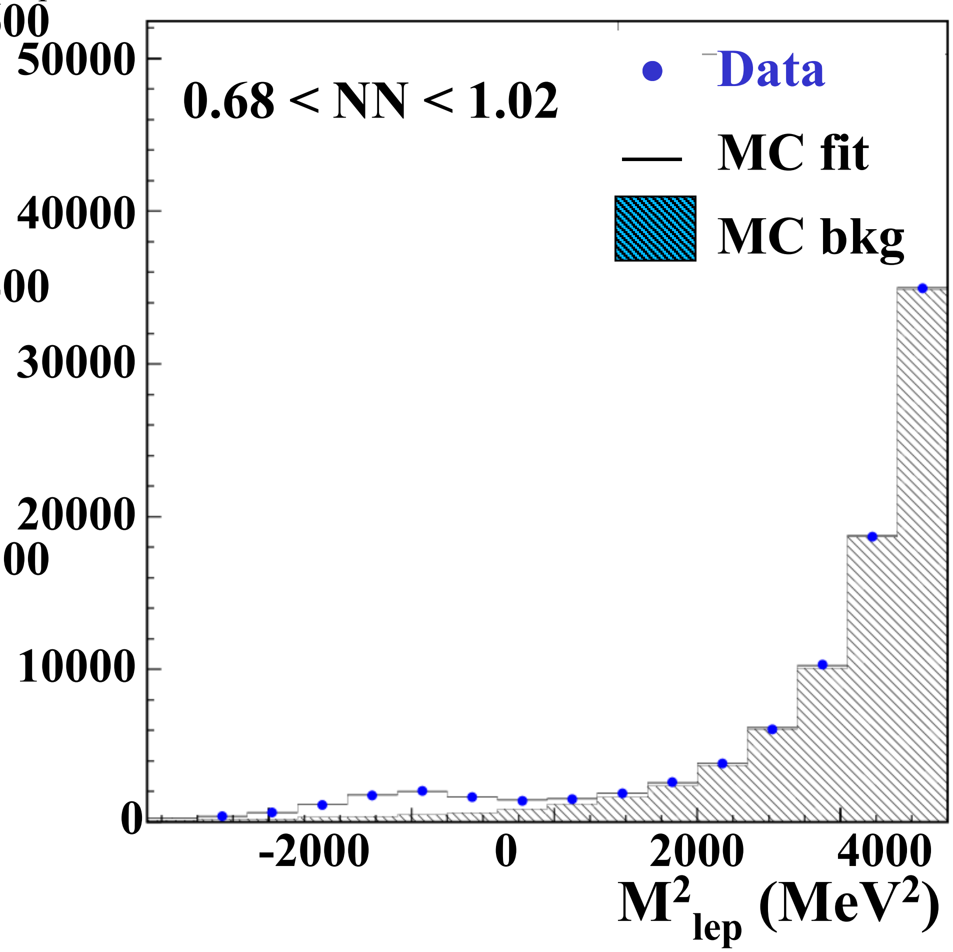
Count in entire statistics: NKe2(e^+) = 7060(98), NKe2(e^-) = 6750(97)

R_K analysis: fitting for Ke2 counting

Assess fit systematic error (**0.3%**) varying fit region:

NN lower limit: 0.78–0.94; M^2_{lept} upper limit: 4500–7500 MeV^2.





Vary significantly contamination + lever arm to assess fit systematics

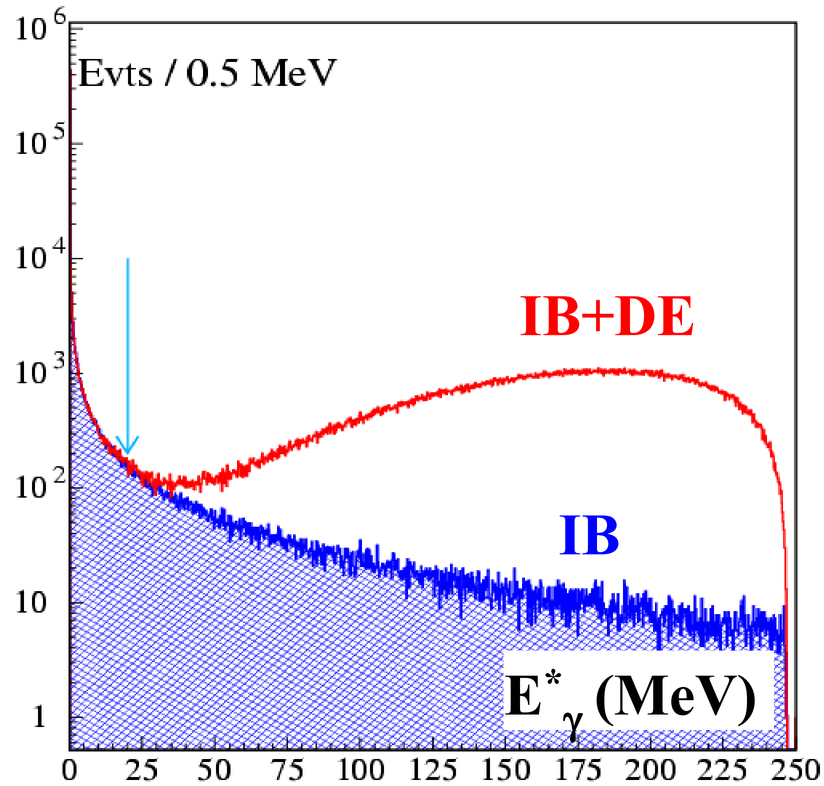
R_K analysis: radiative corrections

To match theory, has to count IB only

Expect DE ~ IB , but we poorly know

δDE/DE ~ 15%

- Fit using IB+DE, count IB by considering as "signal" events those with E^*_γ<20 MeV
- Correct for IB tail, ε^{IB} = 95.28(5)
- Repeat fit varying DE by its 15% uncertainty, **get 0.45% error**…



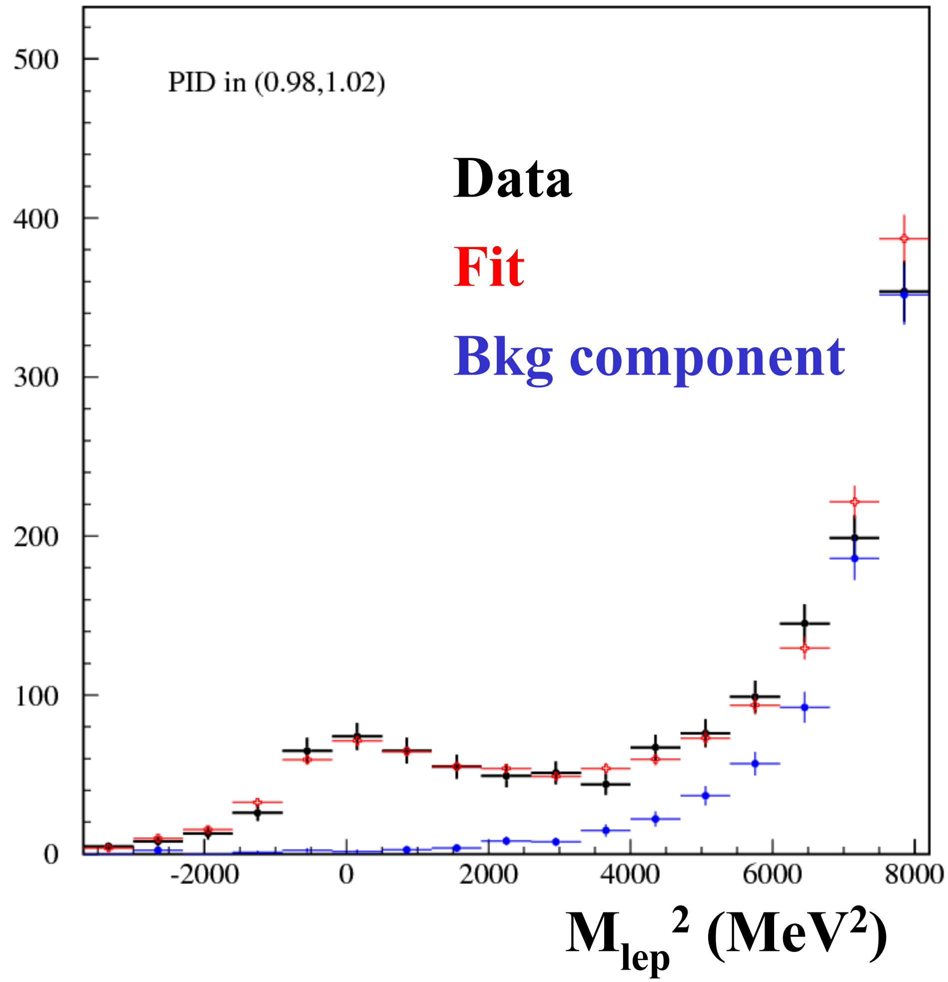
…too bad. Perform a dedicated analysis to measure DE:

- Explicitly detect radiated photon
- Compare DE/IB ratio with expectation from theory

R_K analysis: radiative corrections

- Pass from IB/DE ~ 9 to IB/DE ~ 0.6 by explicitly detecting radiated **γ**
- Count 752(36) + 692(36) events
- Obtain: IB/(IB+DE) = 0.5153(96)

- Agrees with expectation, $IB_{SM}/(IB_{SM}+DE_{mmt}) = 0.509(38)$
- Allow **systematics** from DE to IB measurement to be pushed **down at 0.1%**



Dedicated analysis under the review of the collaboration.

R_K: systematic error budget

Source	Systematic error [%]		Main method
	Stat	Syst	
Reconstruction	0.4	0.4	Control samples
Trigger efficiency	0.4		Downscaled events
Bkg subtraction		0.3	Fit range variation
Ke2(DE) component	0.1		Measurement on data
Clustering for e, μ	0.3		KL control samples
Total	0.6	0.5	

Further systematic check: use same algorithms to measure $R_3 = Ke3/K\mu3$

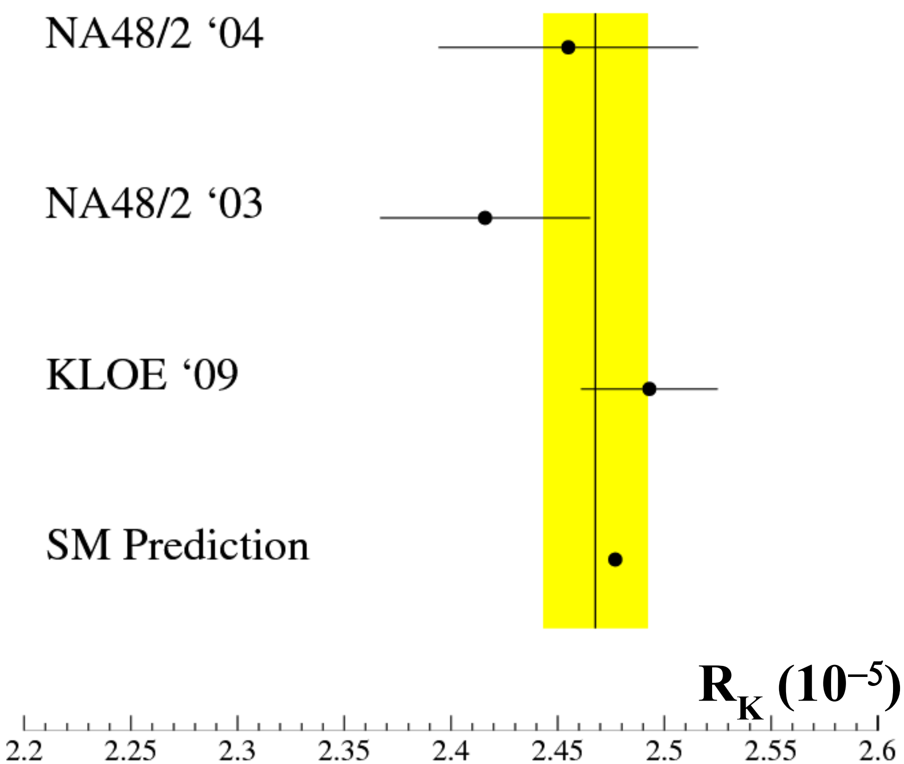
$R_3 = 1.507 \pm 0.005$ for K^+

$R_3 = 1.510 \pm 0.006$ for K^-

world avg $R_3 = 1.506 \pm 0.003$ (FlaviaNet)

R_K: result

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



- Statistical error is 1.1% (0.85 from 14k Ke2 events ⊕ bkg subtraction)
- Systematic error is dominated by statistics again (0.015)

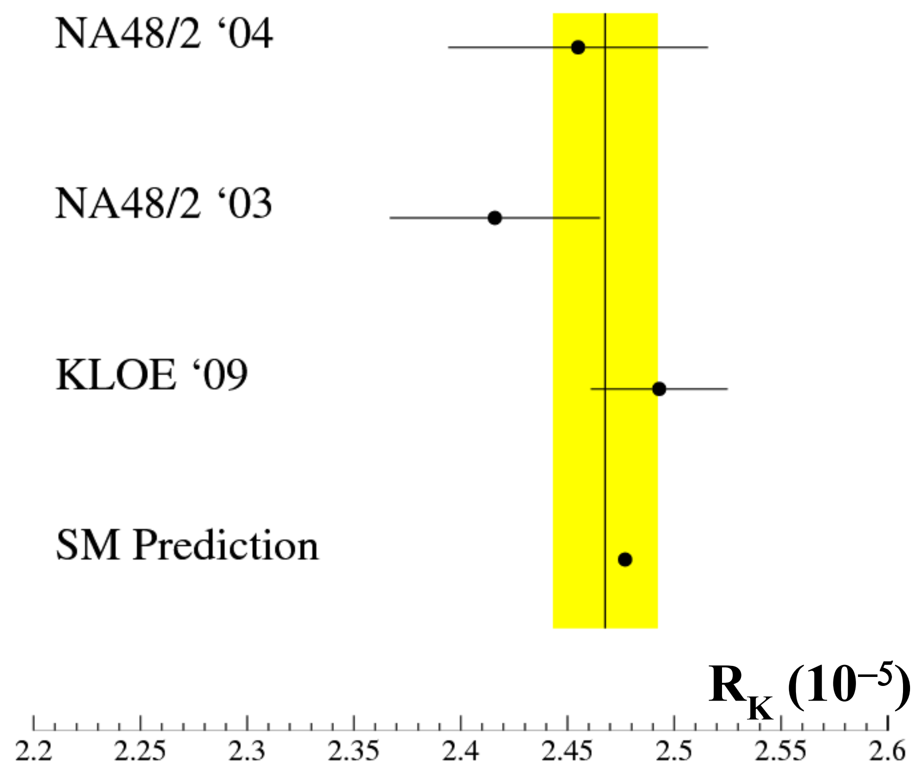
- Measurement do not depend on K charge, good systematic check: K^+: 2.496(37) vs K^-: 2.490(38) (uncorrelated errors only)

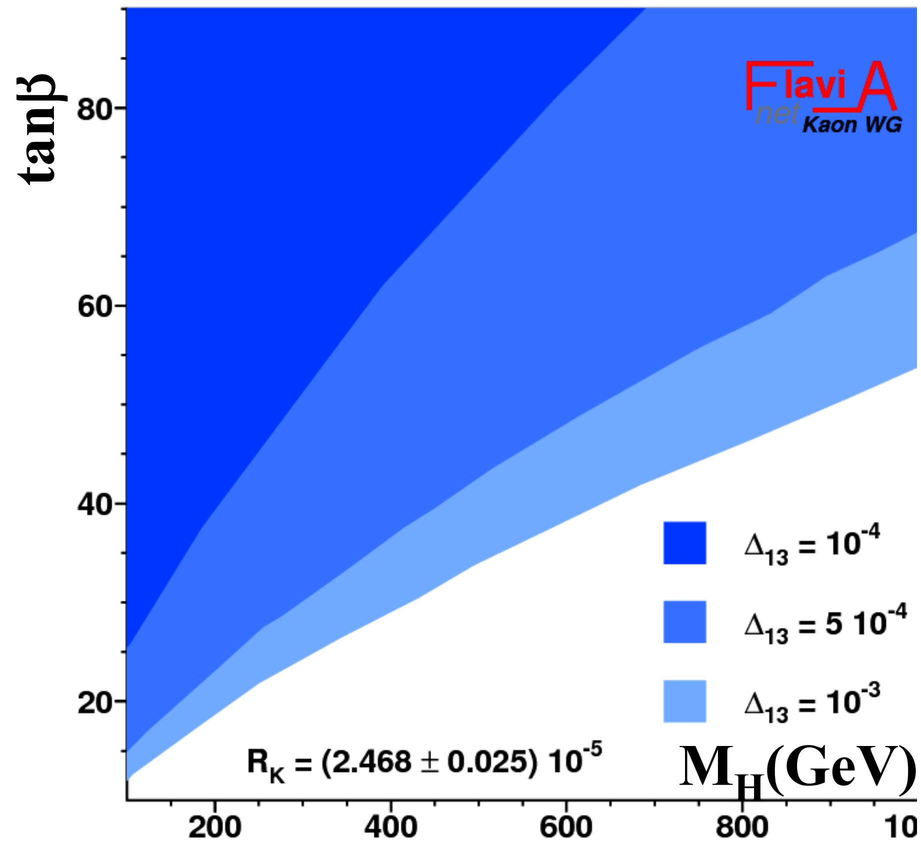
- Measurement agrees with SM prediction, **$R_K = 2.477(1)$**

R_K: sensitivity to NP

Sensitivity shown as 95%-CL excluded regions in the tanβ - M_H plane, for fixed values of the 1-3 slepton-mass matrix element, $\Delta_{13} = 10^{-3}, 0.5\times10^{-3}, 10^{-4}$

WA w new KLOE result: R_K=2.468(25)×10^{-5}





Conclusions and future plans

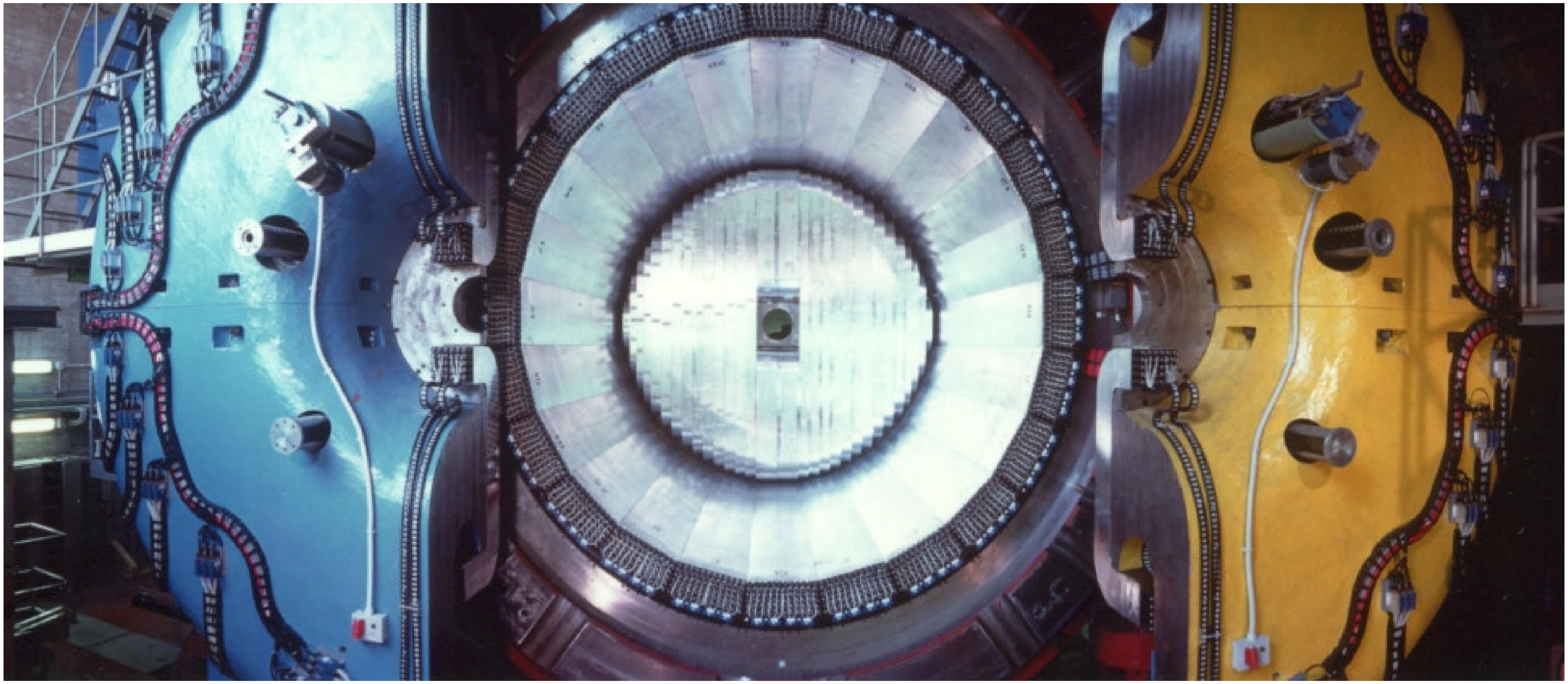
Still a lot of very good physics from the 2.5 fb^{-1} on tape, while preparing for the *xx* fb^{-1} regime.

Hadron physics: $\sigma(e^+e^-\to\pi^+\pi^-)$ published

- F_π from off-peak data, large angle analysis; F_π from ratio of $\pi\pi\gamma$ to $\mu\mu\gamma$ events.
- η-ology
- analysis of $\gamma\gamma\to\pi^0\pi^0$ (search for the σ(600))

Kaon physics: R_K final results

- CPT tests from interferometry
- BR($K^\pm\to\pi^\pm\pi^+\pi^-$), K_S and K_L lifetimes, FF slopes from K_{l3} decays, BR($K_S\to\pi\mu\nu$)
- Rare K_S decays



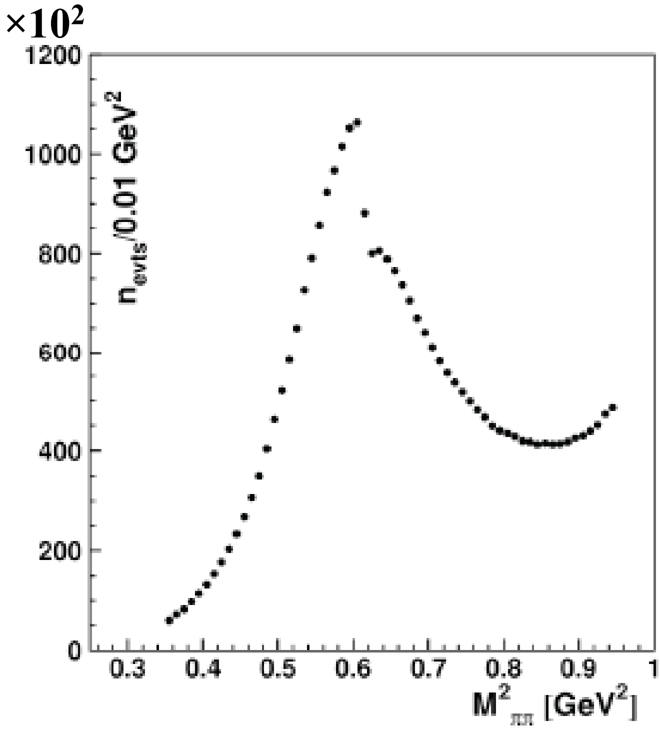
Spare slides

KLOE measurement of $\sigma_{\pi\pi}$

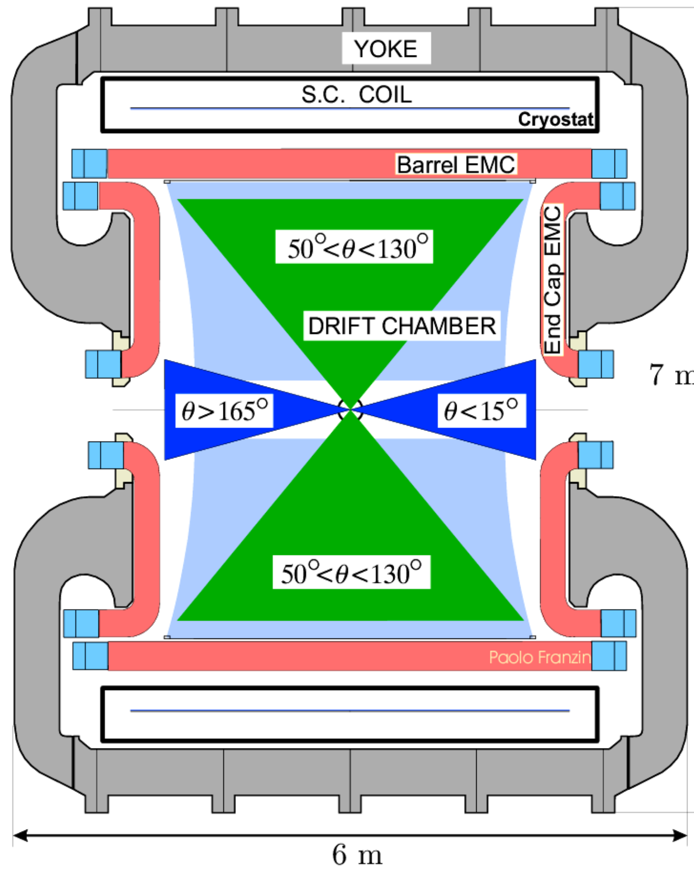
a) 2 tracks with $50^o < \theta_{track} < 130^o$

b) small angle γ ($\theta_{\pi\pi} < 15^o$ or $> 165^o$)

- high statistics for ISR
- low relative FSR contribution
- suppressed $\phi \to \pi^+\pi^-\pi^0$ wrt the signal



kinematics: $p_\gamma = p_{miss} = -(p_+ + p_-)$



Statistics: 242 pb^{-1},
3.1 Mevents between 0.35 and 0.95 GeV^2.

KLOE result [PLB670(2009)285]

Systematic errors on $a_m^{\pi\pi}$:

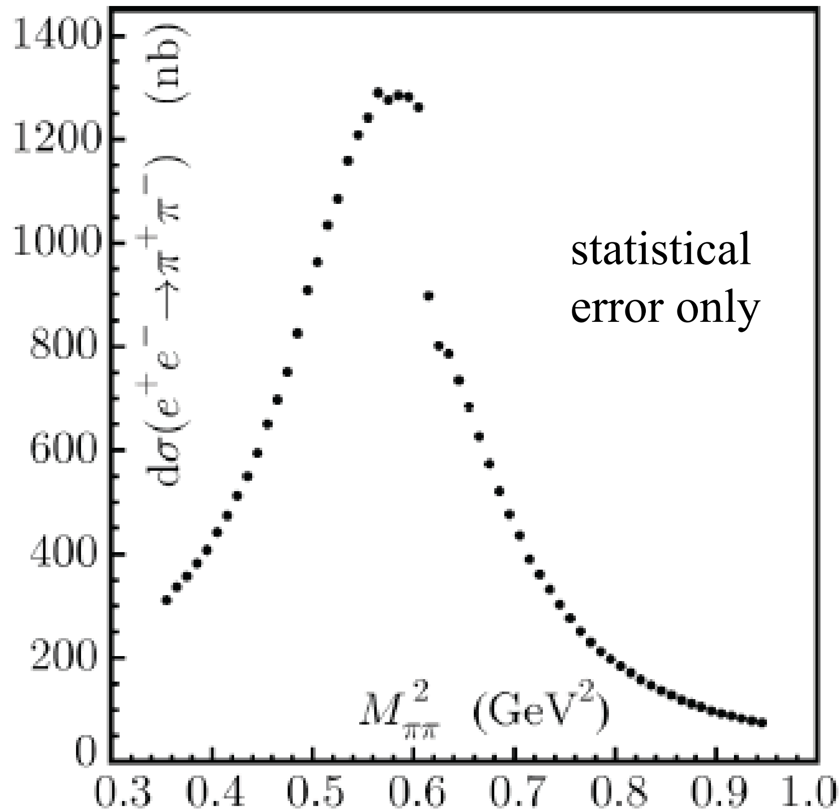
Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
p/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($q_{\pi\pi}$)	0.1%
Acceptance (q_p)	negligible
Unfolding	negligible
Software Trigger	0.1%
√s dep. of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

experimental fractional error on a_μ = 0.6 %

FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	0.1%

theoretical fractional error on a_μ = 0.6 %

$\sigma_{\pi\pi}$, undressed from VP, inclusive for FSR as function of $(M^0_{\pi\pi})^2$



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√s dep. of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

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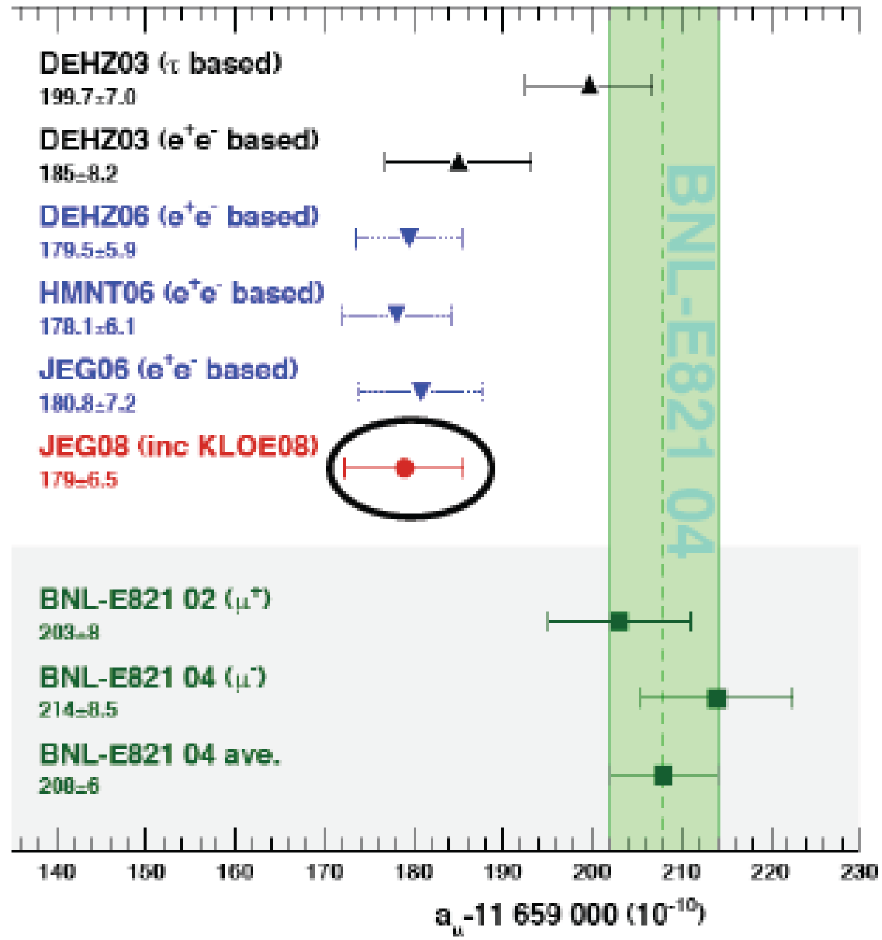
Vacuum polarization	0.1%

theoretical fractional error on a_μ = 0.6 %

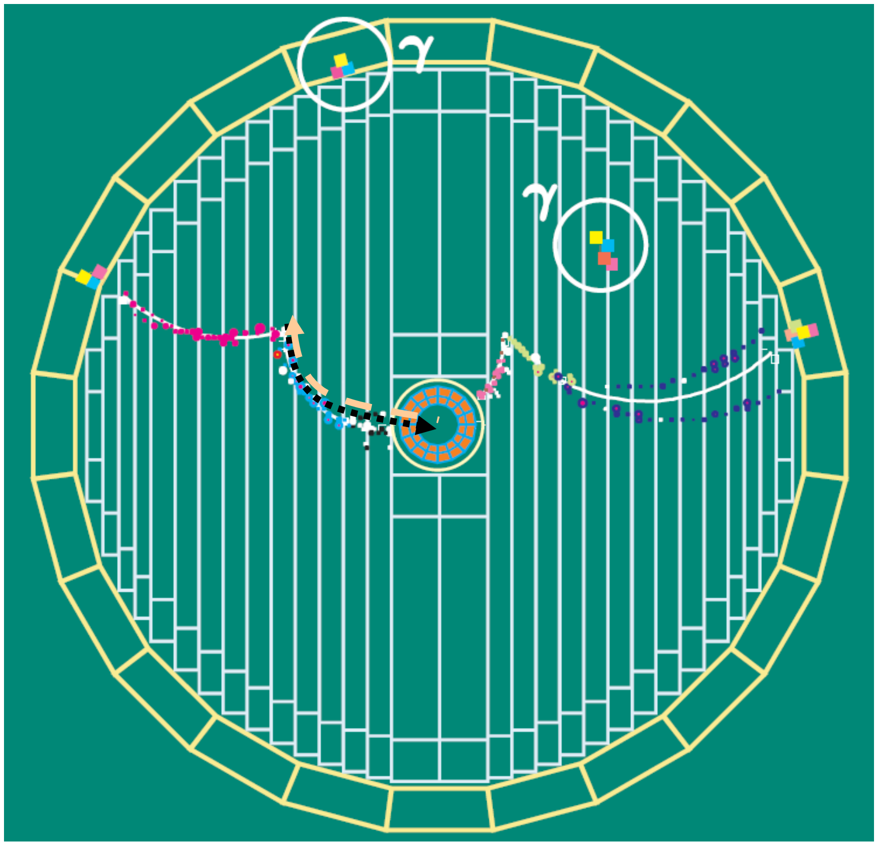
Theoretical predictions on $\mathbf{a_\mu}$ vs BNL result:

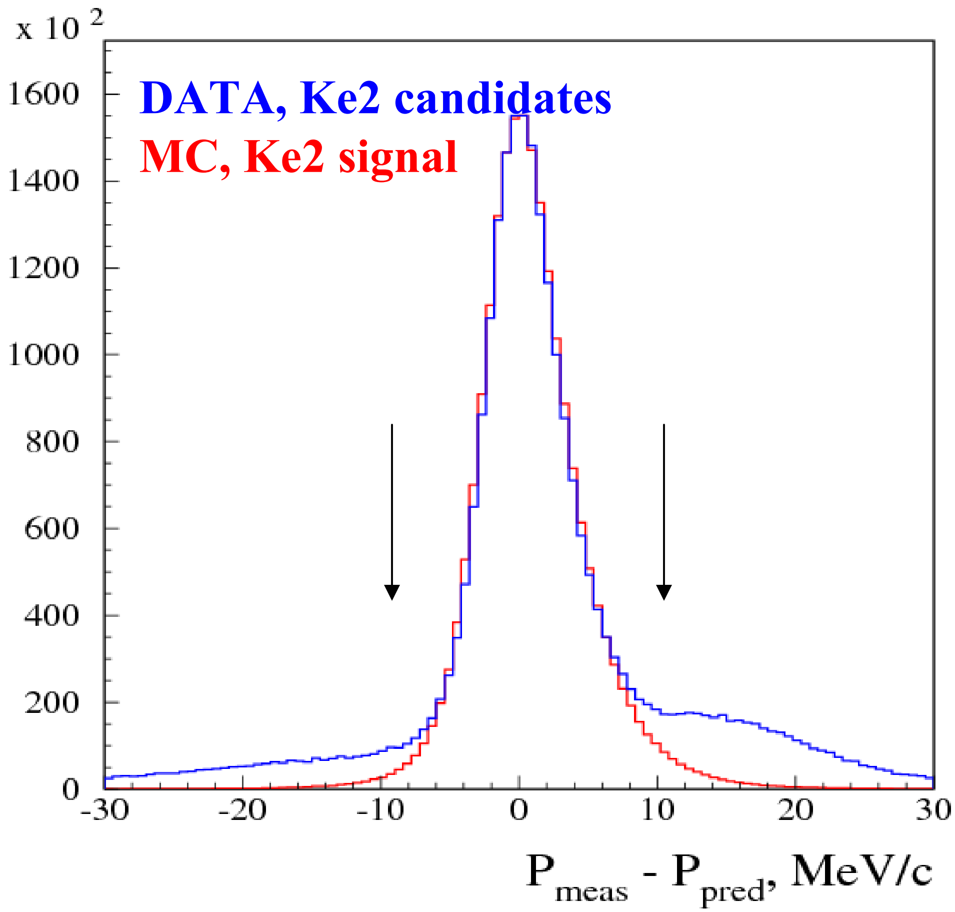


KLOE08 strengthens the discrepancy between SM and experiment (~3.3σ)

R_K at KLOE: p_K determination

Get rid of bad-P_K component using redundant measurement





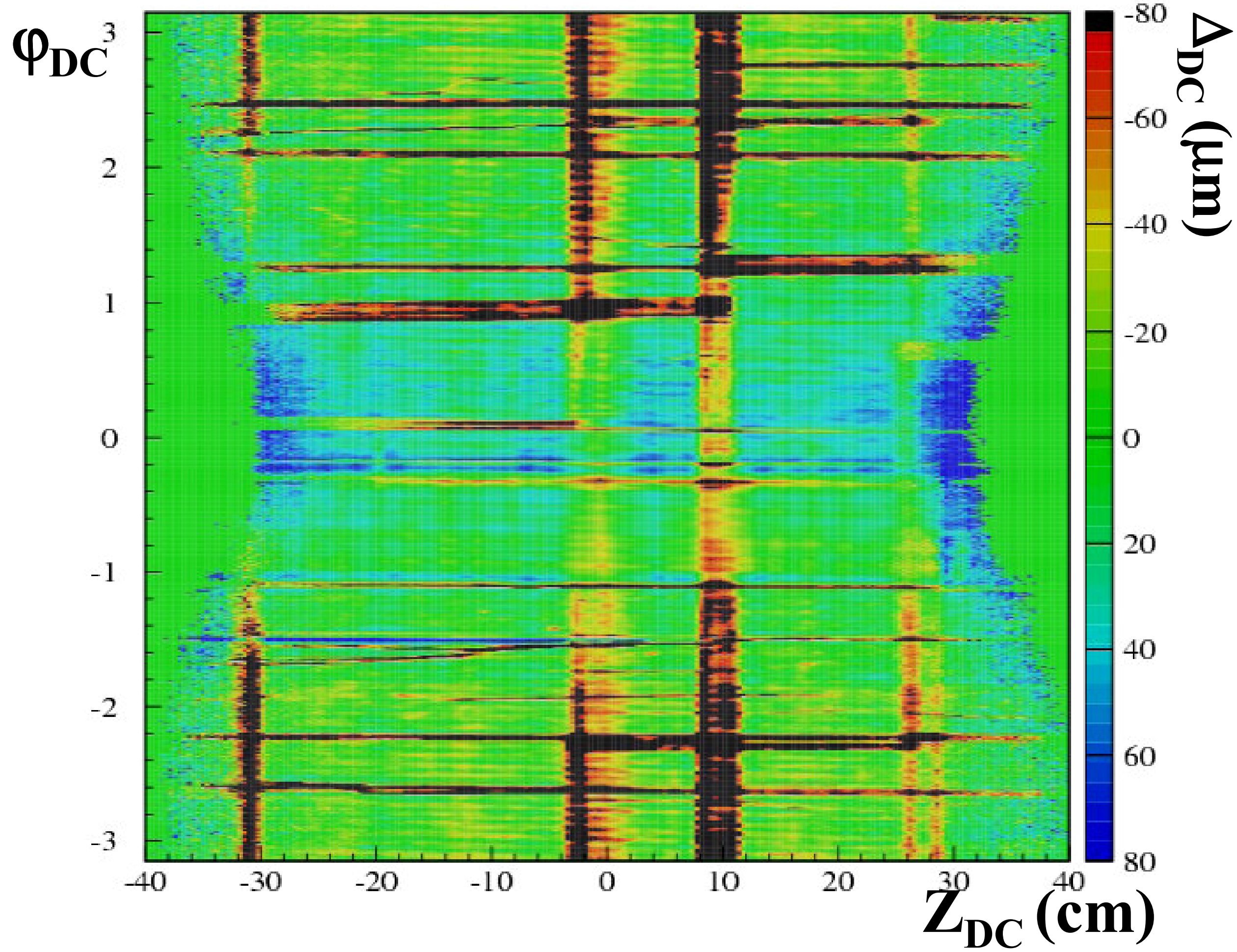
Get rid of bad-P_l's using asymmetry of DC hits in left and right views

R_K analysis, "Kaography"

DC inner wall "Kaography"

In doing extrapolation for K, material budget is a key issue: $\beta_K \sim 0.2$

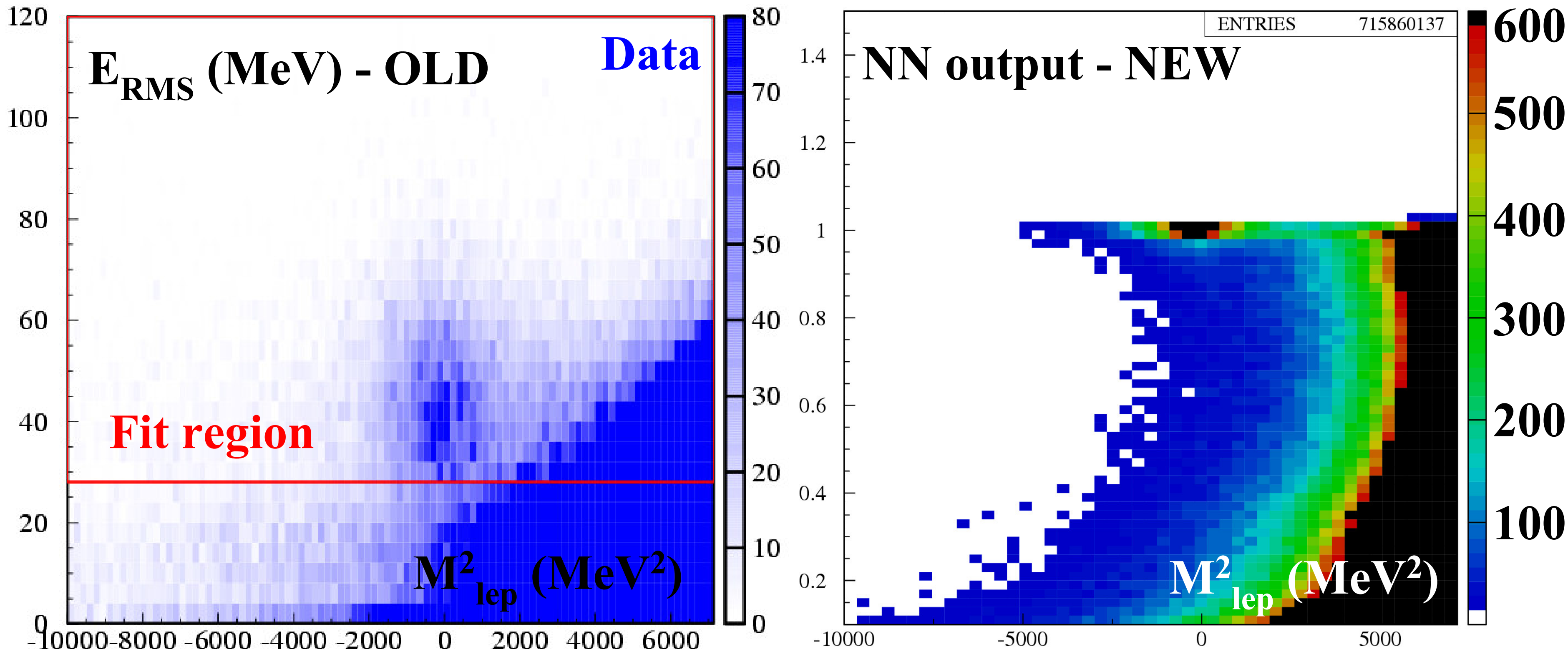
For the Carbon-fiber DC inner wall, sensititivity on thickness difference Δ_{DC} wrt nominal value of 0.9 mm is order of 10 μm



Get rid of bad-P_1's using fit quality + asymmetry of DC hits in L & R views

R_K – PID

- For PID, build variables using essentially cluster information.
- Rejection from PID: now>1000 → loosen kinematic selection criteria



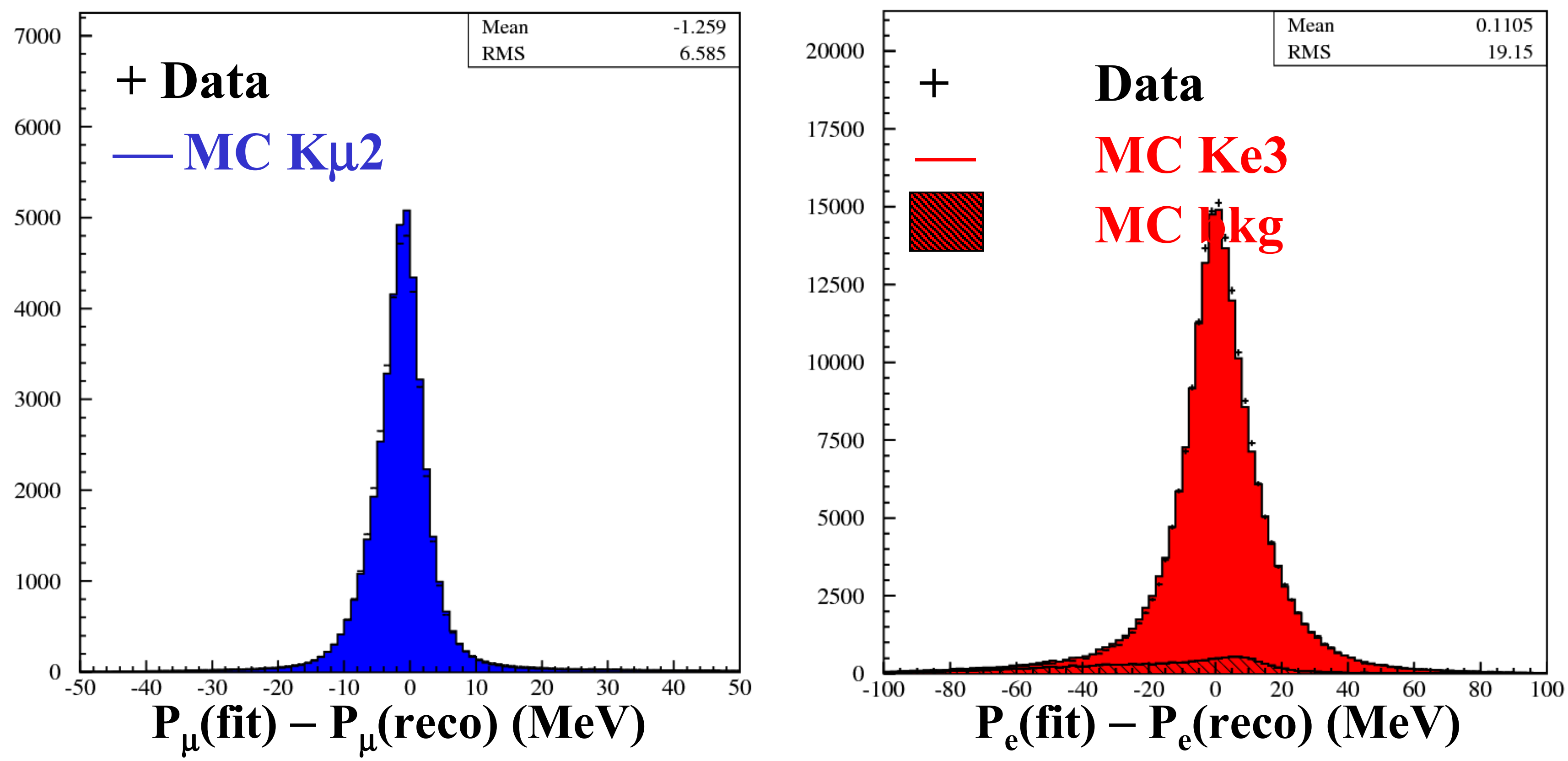
- Ke2 counts: two-dimensional binned likelihood fit in the (NN,M^2_{lep}) plane

R_K analysis: efficiency evaluation

Reconstruction efficiency from MC, corrections from control samples

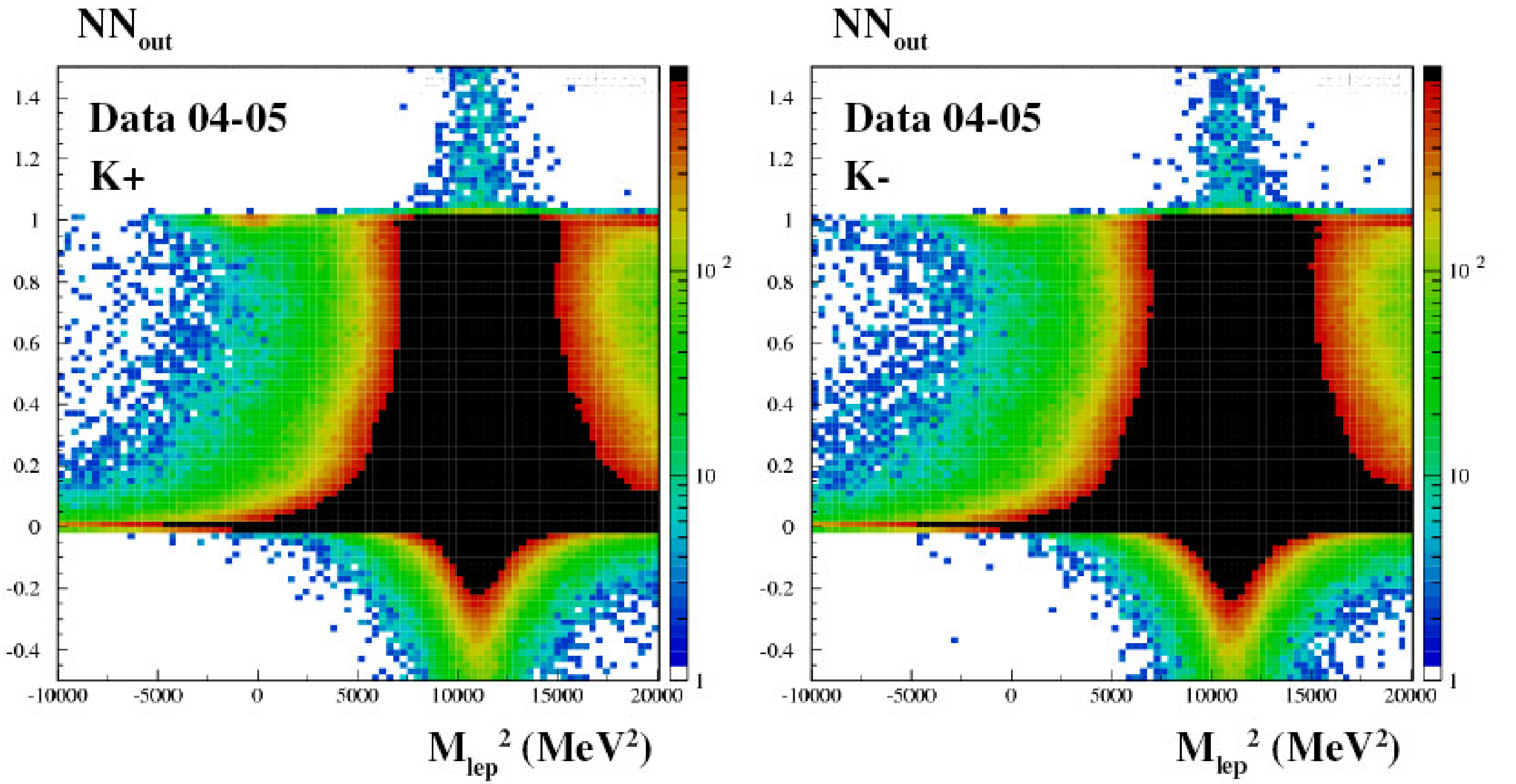
Select $K^{+,-}{}_{\mu 2}$ and $K^{+,-}{}_{e3}$ in events tagged by identification of a $K^{-,+}{}_{\mu 2}$ decay

Fit P_μ(P_e) using μ(e) cluster r,t (& E), kinematics: no K, μ(e) trks required



Analysis of R_K: NN vs M^2_{LEP} plane

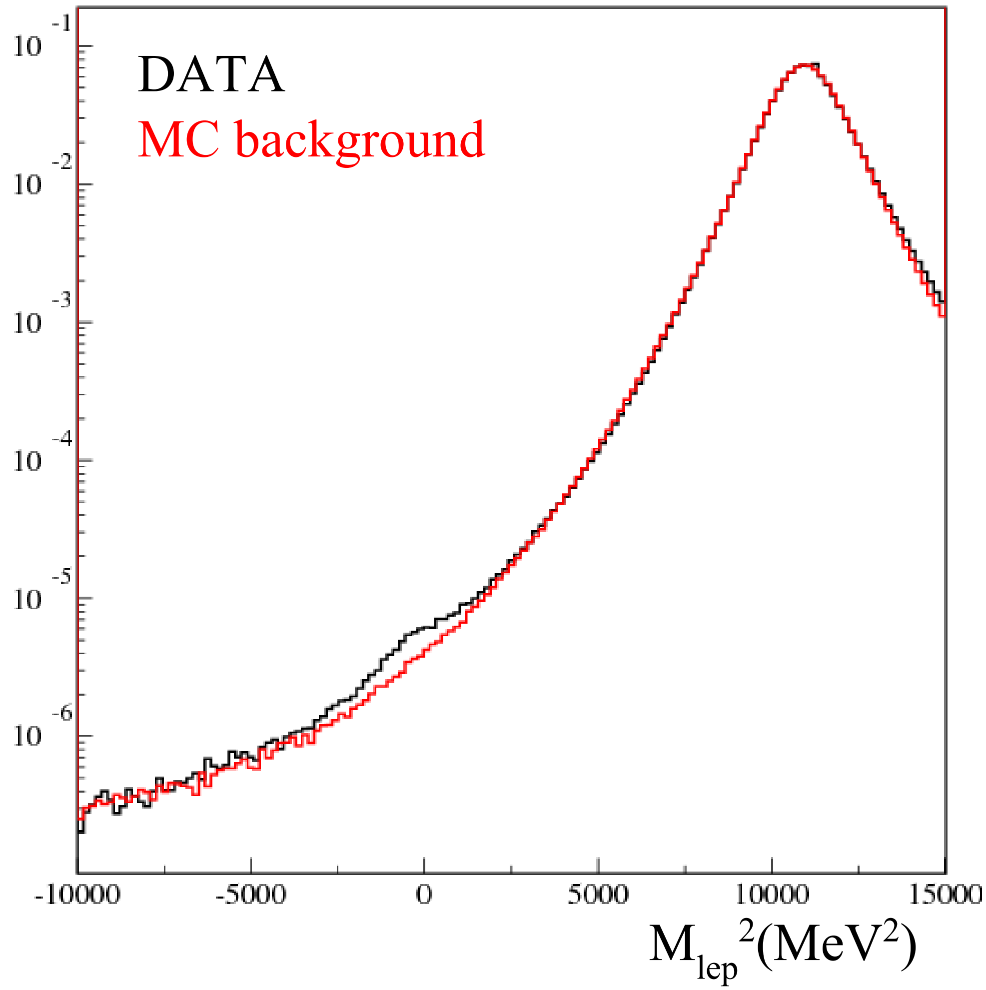
Associate track to EmC clusters for e/μ separation, evaluate PID (NN)



R_K at KLOE: kinematic rejection (old)

Enough bkg rejection from kinematics to see Ke2 w/o any EmC-based PID

MC agrees with data, including very far resolution tails

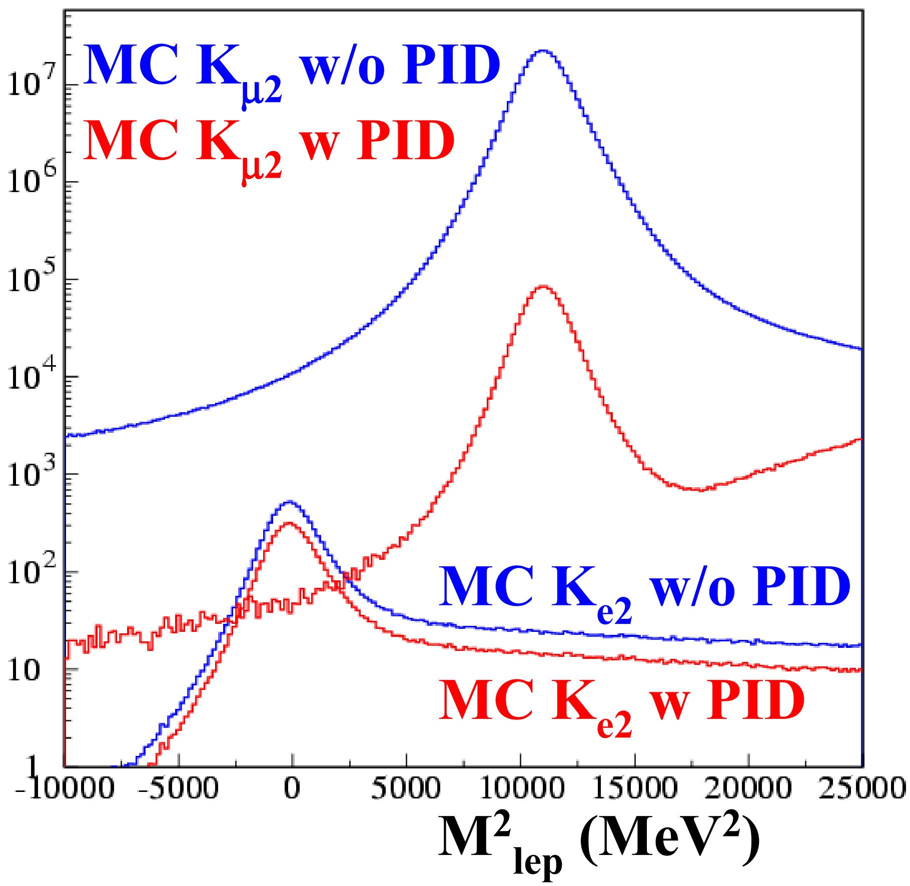


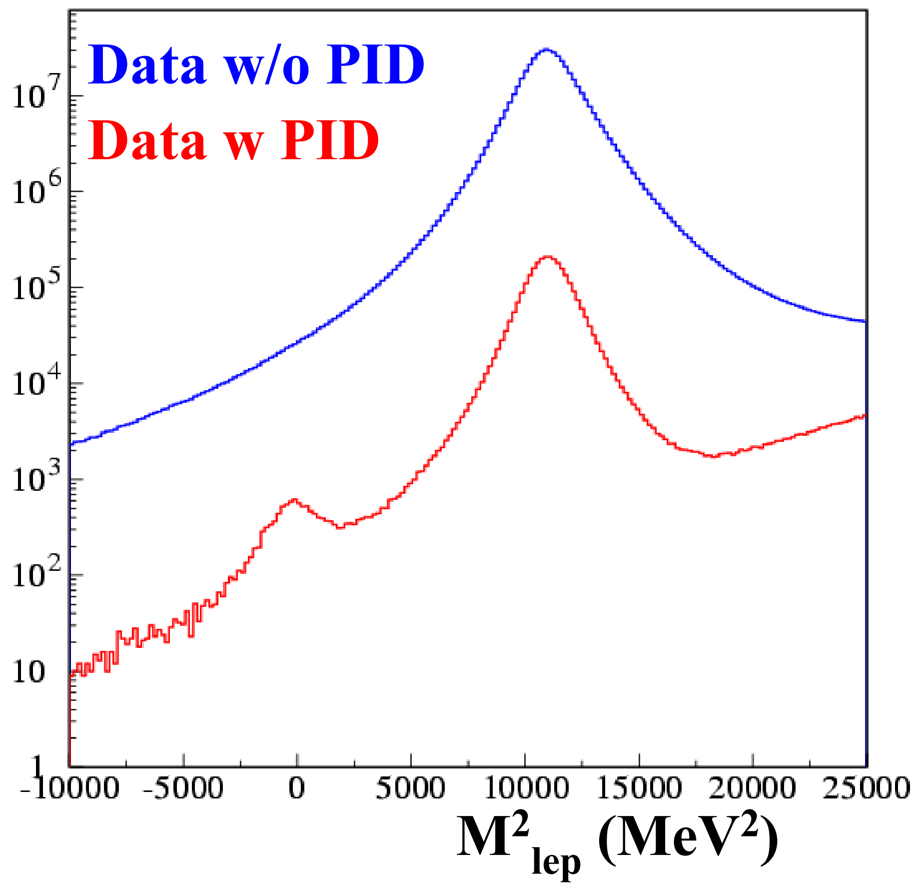
Analysis of R_K – PID via EmC

Impact of PID: retain 60% of signal, reject all but 0.2% of background

Check with K_{Le3} data/MC control samples

After PID (rejection factor is ~500) count Ke2 events



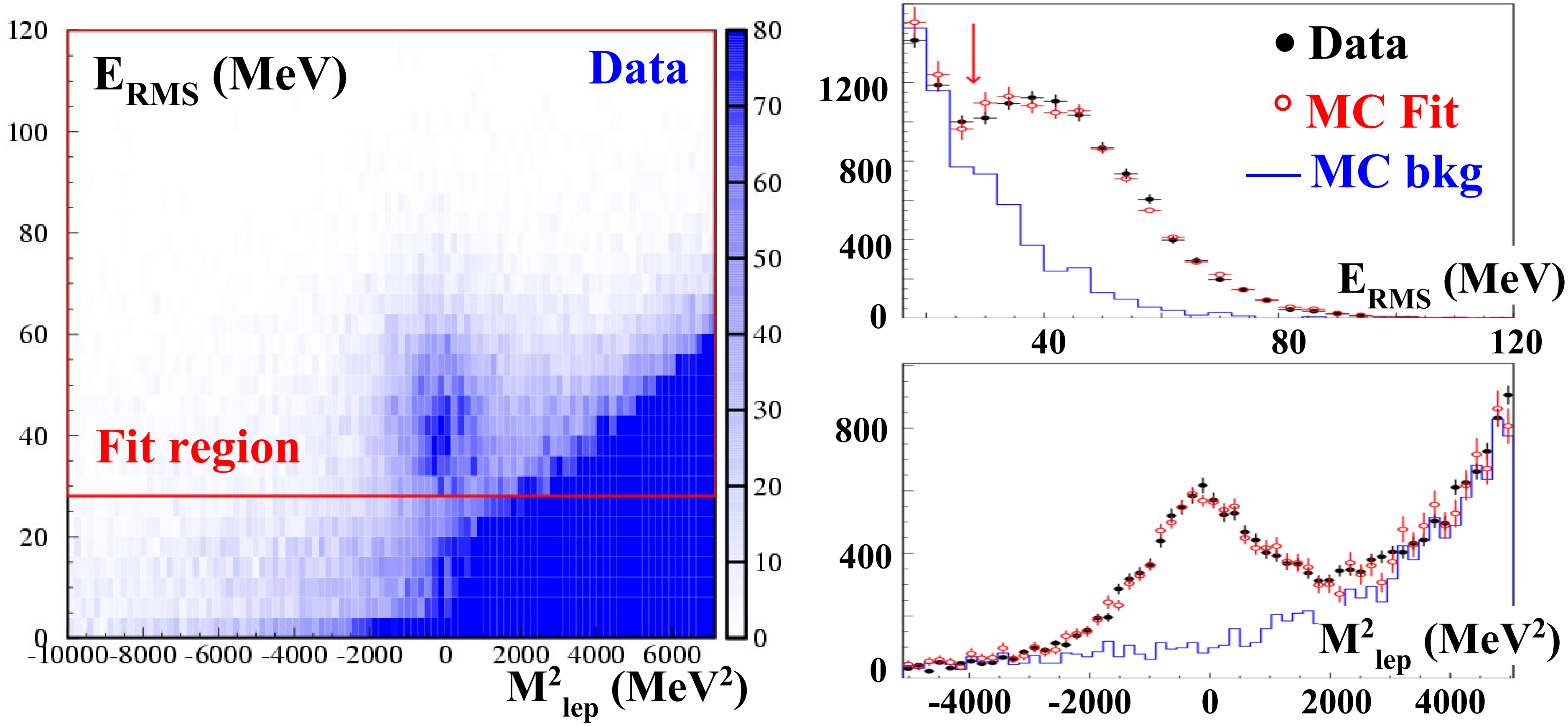


Analysis of R_K: Ke2 event counting (old)

Ke2 event counts: likelihood fit of M_{LEPT} vs E_{RMS}.

Input: MC shapes for Ke2(γ) and background.

Fir parameters: # of Ke2 and bkg; result: 8090±160 observed events.



R_K at KLOE: a-priori error on M^2_{LEP}

Better parametrization of kinematic criteria, better understanding of bkg

$M_{lep}^2 = f(P_K, P_l, \cos\theta) \rightarrow$ a-priori error δM_{lep}^2 is scaled by opening angle

Achieve cancellation in Ke2/Kμ2 efficiencies, applying cosθ trailing cuts