Measurement of FCNC decays $K^{\pm}\to\pi^{\pm}l^{+}l^{-}$ by NA48/2 at CERN

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on behalf of the **NA48/2** collaboration

(Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Florence, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Turin, Vienna)

Outline:

1) Beams, detector and data taking in 2003/04;
2) $K^{\pm}\to\pi^{\pm}e^{+}e^{-}$ analysis: NA48/2 final results;
3) $K^{\pm}\to\pi^{\pm}\mu^{+}\mu^{-}$ analysis: analysis status and prospects;
4) Summary.

Kaon 2009 conference

Tsukuba, Japan • June 9, 2008

NA48/NA62 experiments

NA48	1997:	ε'/ε run K_L+K_S	
	1998:	K_L+K_S	
	1999:	K_L+K_S	K_S HI
	2000:	K_L only	K_S HI
	2001:	K_L+K_S	K_S HI
NA48/1	2002:	K_S/hyperons HI	
NA48/2	2003:	K^+/K^-	
	2004:	K^+/K^-	
NA62 (phase I)	2007:	$K^\pm_{e2}/K^\pm_{\mu 2}$	tests
	2008:	$K^\pm_{e2}/K^\pm_{\mu 2}$	tests

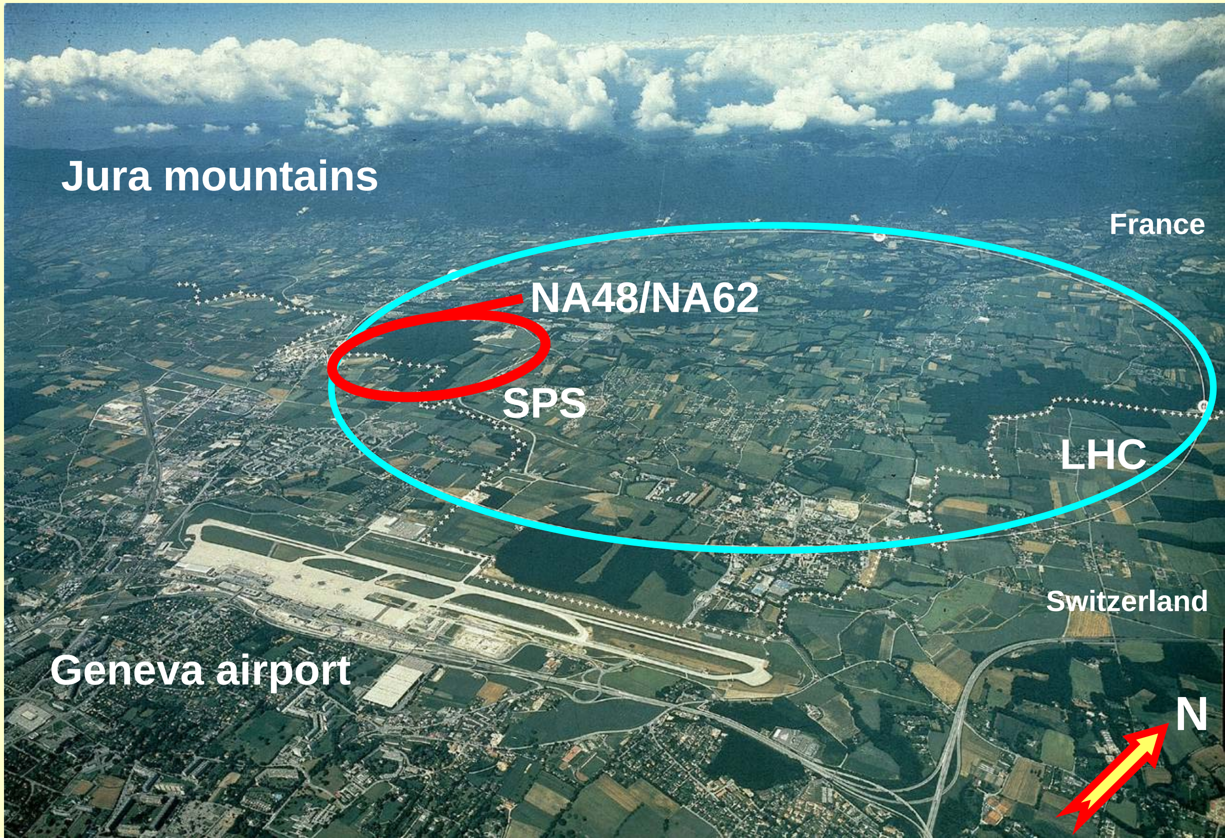
NA62 (phase II)

2006–2010: design & construction

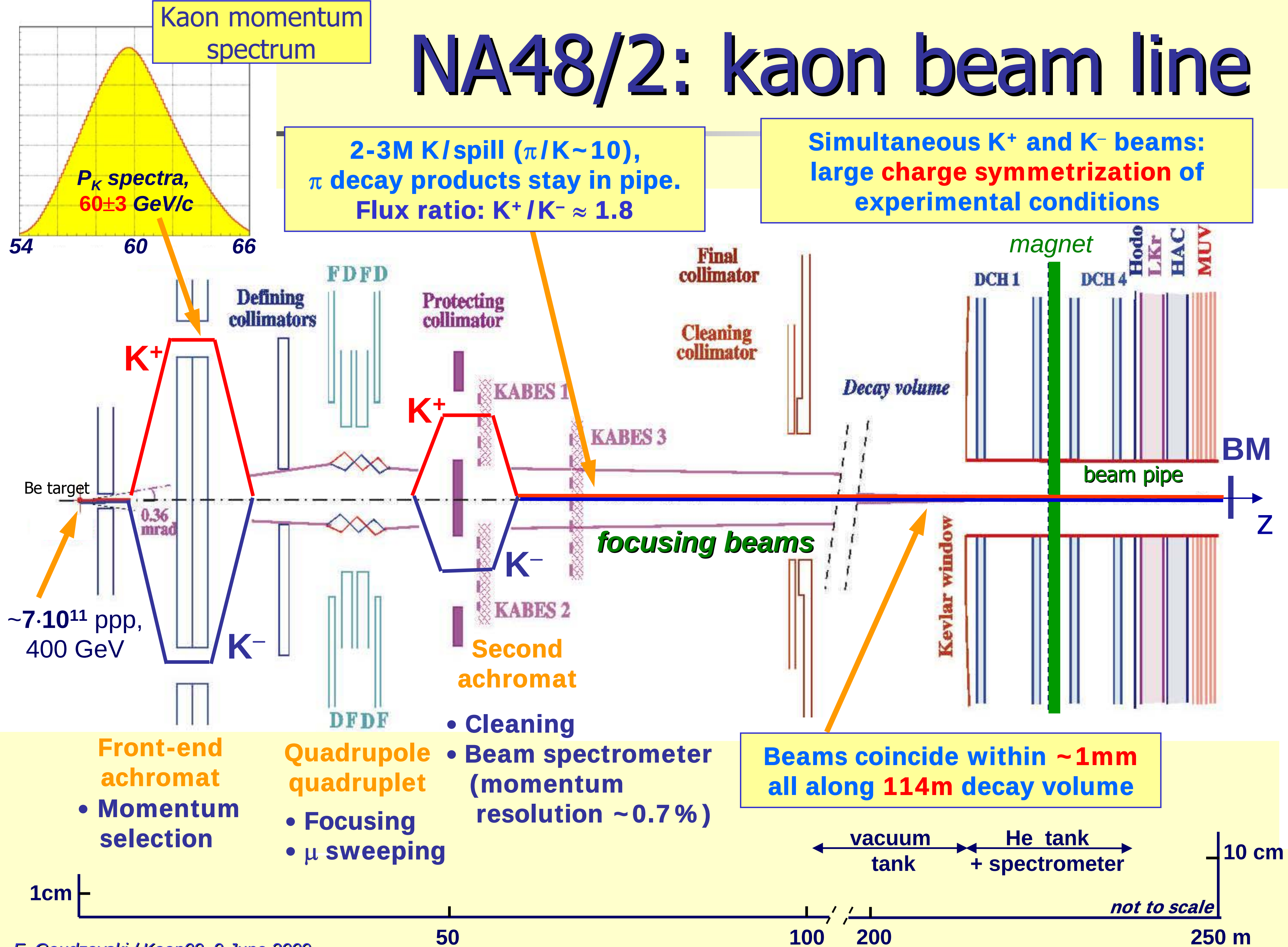
2011: start of $K^+\to\pi^+\nu\bar{\nu}$ run

NA48/NA62: a series of experiments, present-day CERN kaon physics programme

The presented results are based on 2003/04 data



NA48/2: kaon beam line



The NA48 detector

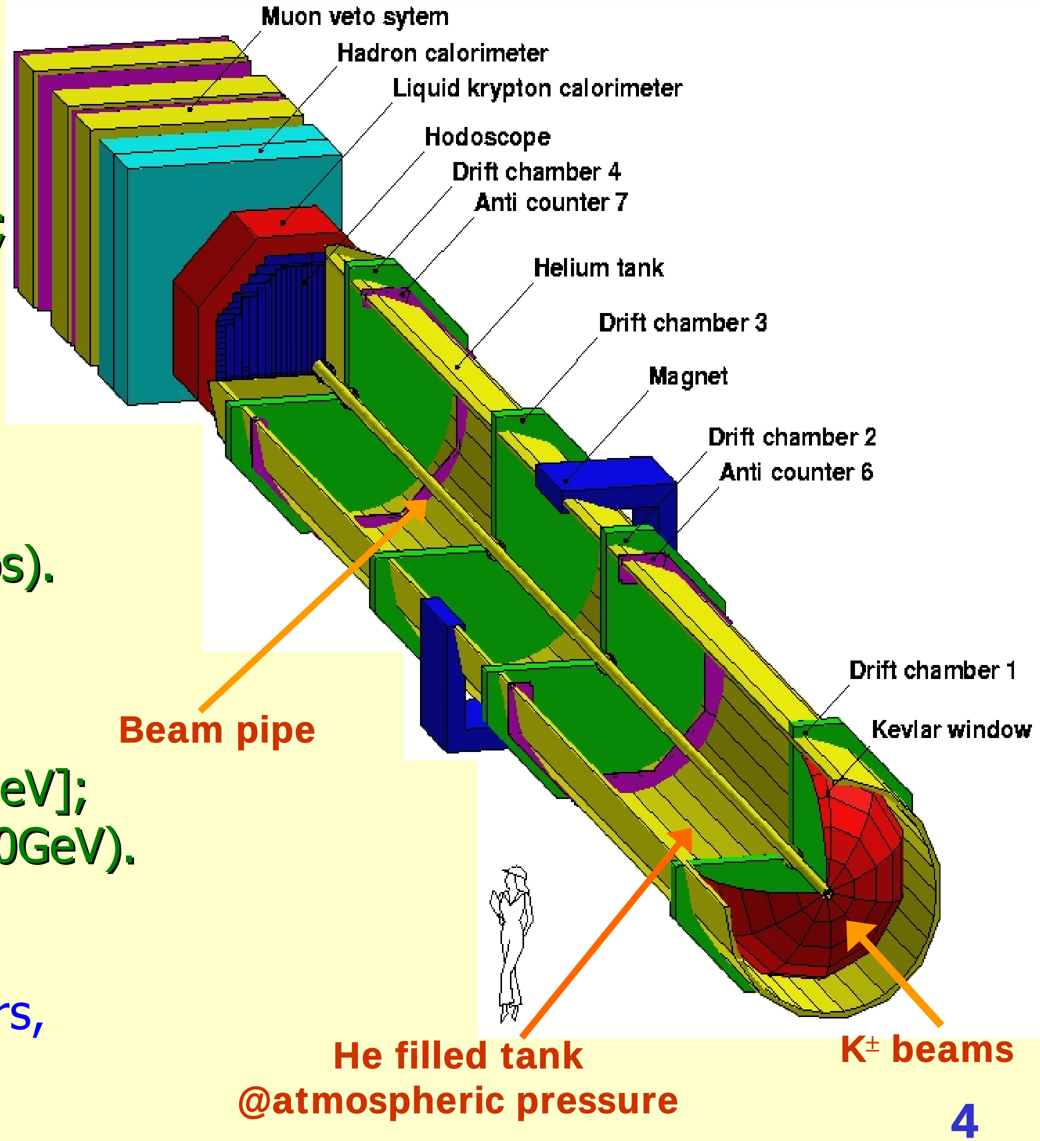
Main detector components:

- Magnetic spectrometer (4 DCHs):
  4 views/DCH: redundancy ⇒efficiency;
  used in trigger logic;
  $\Delta p/p = 1.0\% + 0.044\%*p$ [GeV/c].

- Hodoscope
  fast trigger;
  precise track time measurement (150ps).

- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogenious;
  $\sigma_E/E = 3.2\%/E^{1/2} + 9\%/E + 0.42\%$ [GeV];
  $\sigma_x=\sigma_y=0.42/E^{1/2} + 0.6$mm (1.5mm@10GeV).
  Used for γ detection and particle ID.

- Hadron calorimeter, muon veto counters, photon vetoes.



NA48/2 data taking: completed

A view of the NA48/2 beam line

2003 run: ~ 50 days
2004 run: ~ 60 days

$K_{3\pi}$ statistics in 2 years:
$K^{\pm} \rightarrow \pi^{-}\pi^{+}\pi^{\pm}$: ~$4{\cdot}10^{9}$
$K^{\pm} \rightarrow \pi^{0}\pi^{0}\pi^{\pm}$: ~$1{\cdot}10^{8}$

Rare $K^{\pm}$ decays:
BRs down to 10^{-9}
can be measured

>**200 TB of data recorded**

$K_{\pi ll}$: motivation & theory

$K^\pm \to \pi^\pm\gamma^* \to \pi^\pm l^+ l^-$: suppressed FCNC process proceeding through single virtual photon exchange. Information on weak interactions at low energy.

$d\Gamma_{\pi ee}/dz \sim P(z)\cdot|W(z)|^2$ $z=(M_{ee}/M_K)^2$, $P(z)$ is a phase space factor

Considered models for the form factor:

(1) polynomial: $W(z) = G_F M_K^2 \cdot f_0 \cdot (1+\delta z)$

(2) ChPT $O(p^6)$: $W(z) = G_F M_K^2 \cdot (a_+ + b_+ z) + W^{\pi\pi}(z)$
G. D'Ambrosio et al., JHEP 9808 (1998) 4

(3) ChPT, large-N_c QCD: $W(z) = W(w, \beta, z)$
S. Friot, D. Greynat, E. de Rafael, PLB 595 (2004) 301

(4) "Mesonic" ChPT: $W(z) = W(M_a, M_\rho, z)$
A.Z. Dubnickova et al., Phys. Part. Nucl. Lett. 5 (2008) 76 [hep-ph/0611175]

Goals:
1) $d\Gamma/dz$ and model-independent BR in kinematic range $z>0.08$;
2) parameters of the models + BRs in the full kinematic range;
3) upper limit for CPV charge asymmetry of decay rates.

Principal selection criteria

The $K^\pm \to \pi^\pm e^+e^-$ is measured normalizing to $K^\pm \to \pi^\pm \pi^0_D \to \pi^\pm e^+e^-\gamma$.
Thus particle ID efficiencies cancel in the first order.

Common selection criteria:

3-track vertex [consistent in space/time],
one π candidate, two opposite sign electron candidates.
Electron (pion) ID based on E deposition : $E/p>0.95$ ($E/p<0.85$).

Signal selection:

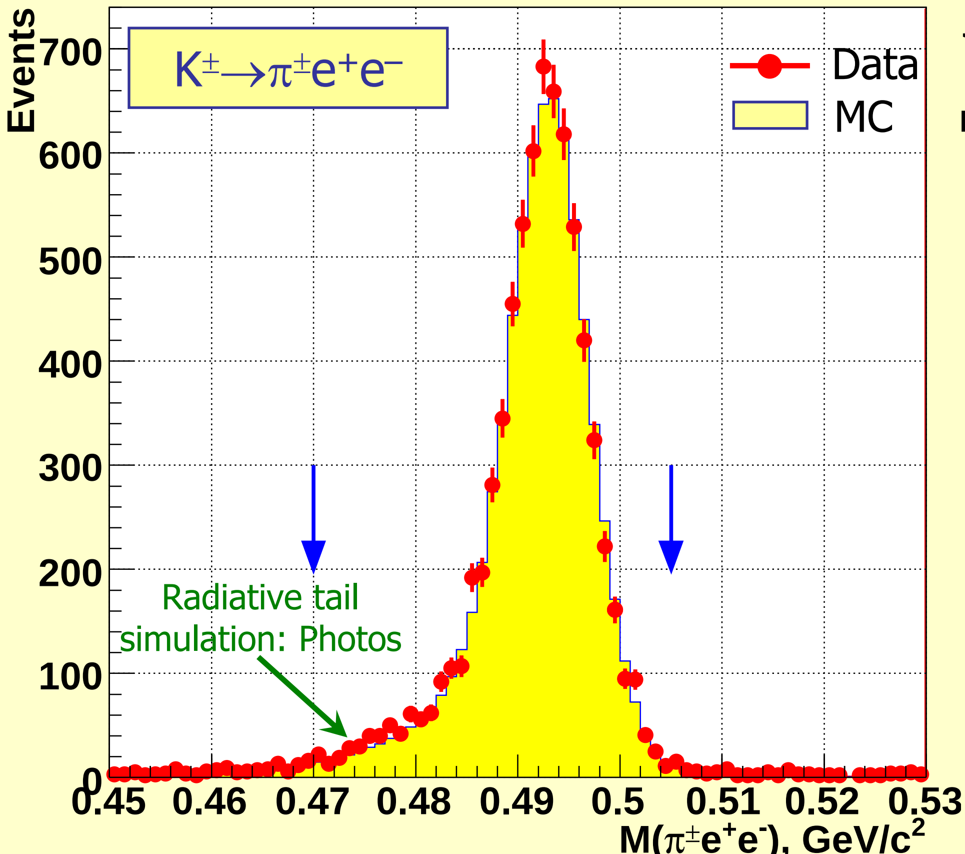
Kinematic suppression of $\pi^\pm\pi^0_D$ background: $M_{ee}>140\text{MeV}/c^2$.
Limitations on reconstructed $\pi^\pm e^+e^-$ invariant mass, total & transverse momentum

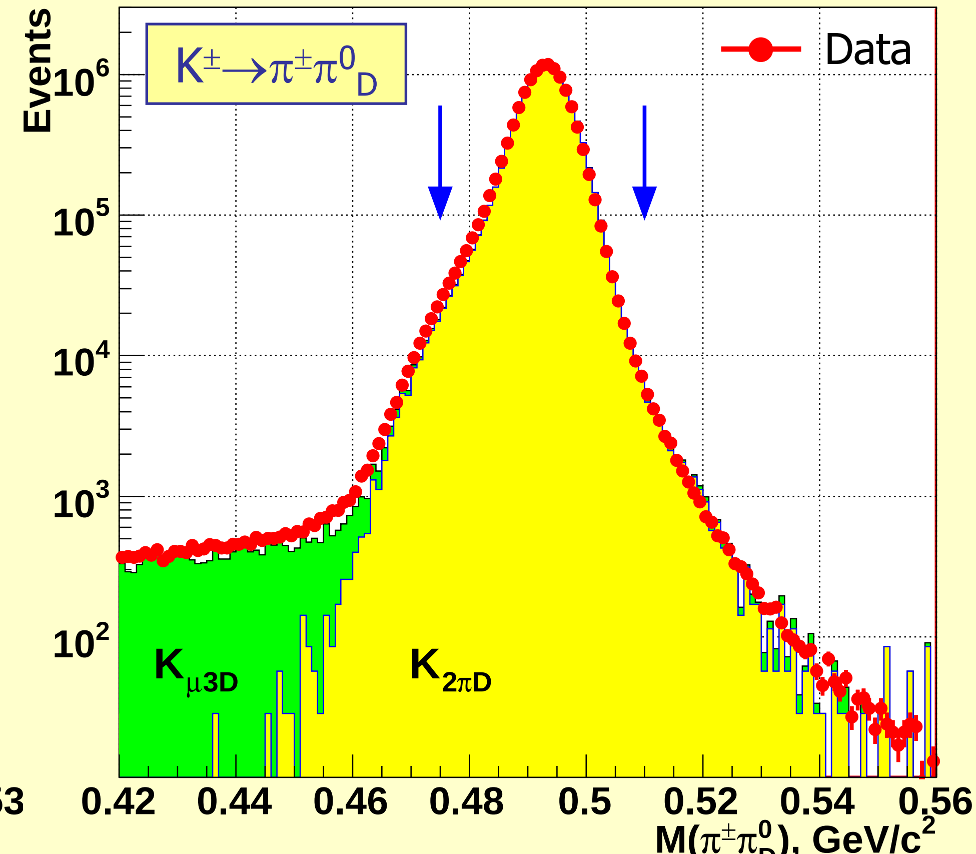
Normalization selection:

Selection of good γ candidate.
Limitations on reconstructed $e^+e^-\gamma$ and $\pi^\pm e^+e^-\gamma$ masses, total & transverse momentum.

Signal & normalisation samples

Total kaon decays in fiducial volume (2003+2004): $N_K=1.7\times10^{11}$





7253 candidates

Background/Signal = 1.0%

($K^\pm\to\pi^\pm\pi^0_D$, $K^\pm\to\pi^0_De^\pm\nu$ + particle misID, two e^+e^- pairs: $\pi^0_{D(D)}$, γ conversions). Subtracted with same-sign lepton candidates.

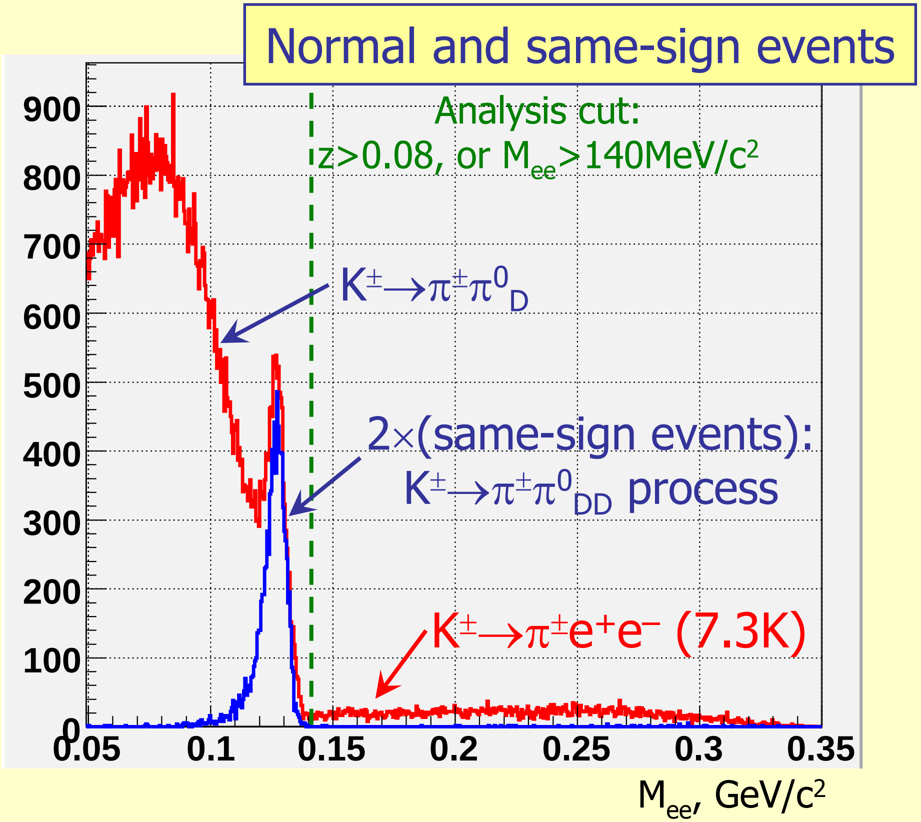
12.12 mln candidates

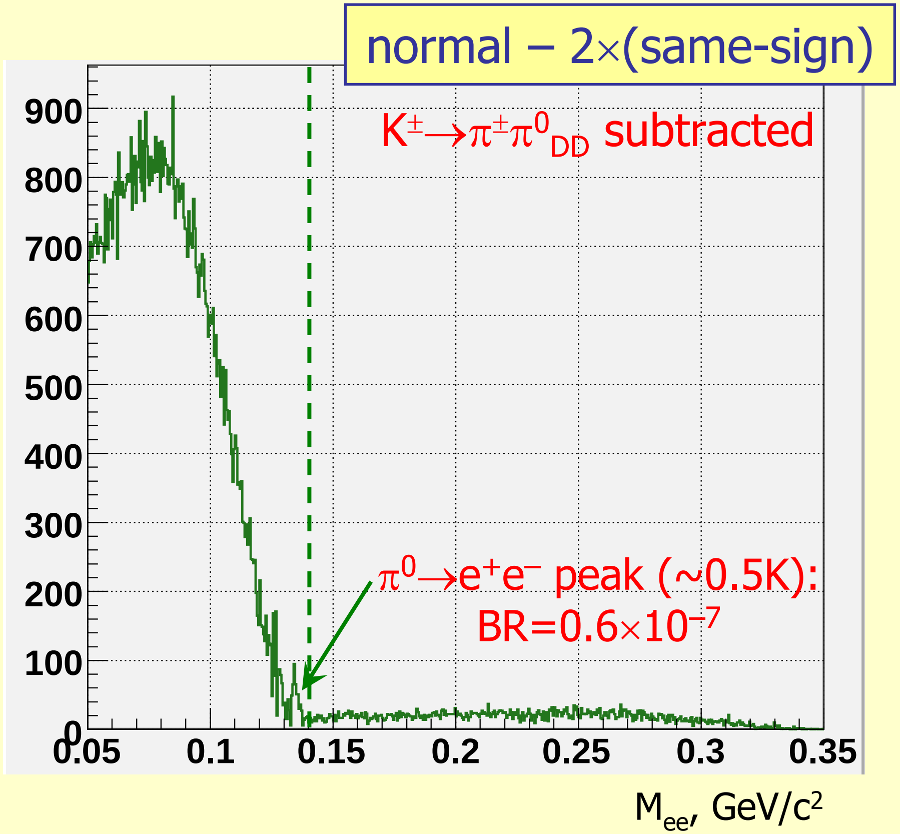
Background/Signal = 0.15%

($K^\pm\to\pi^0_D\mu^\pm\nu$, subtracted with simulation)

The accessible M_{ee} region

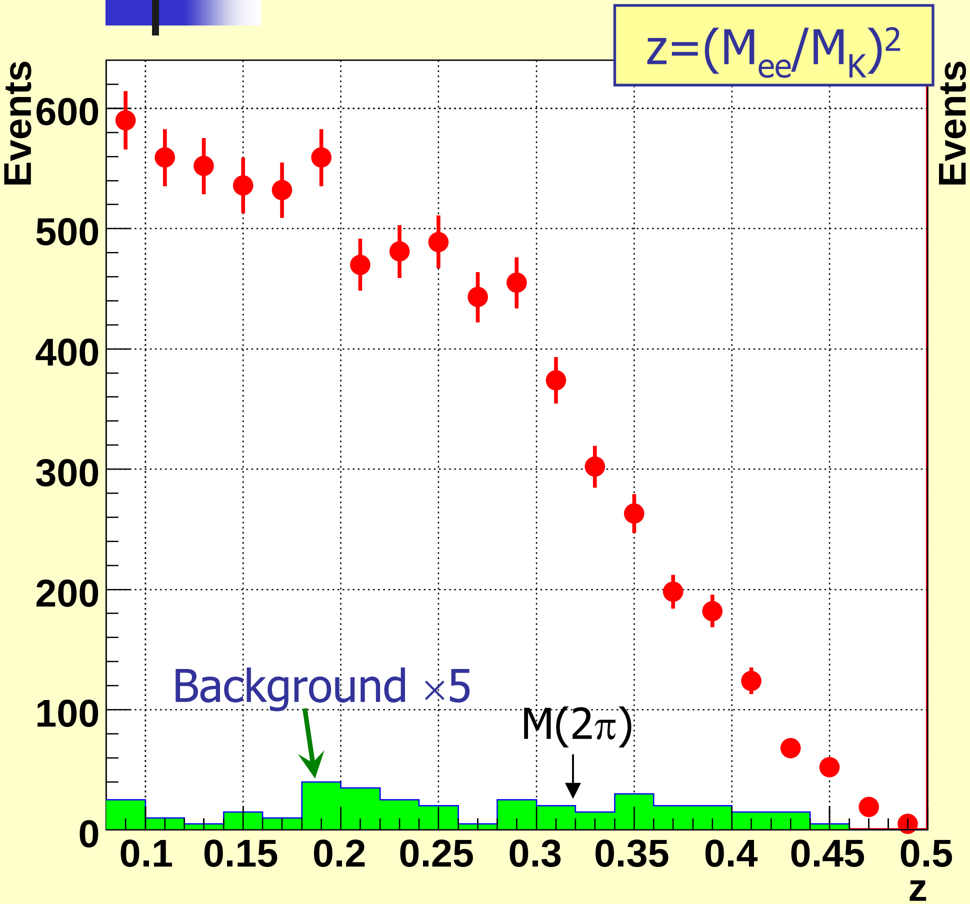
All analysis cuts except the M_{ee} cut are applied

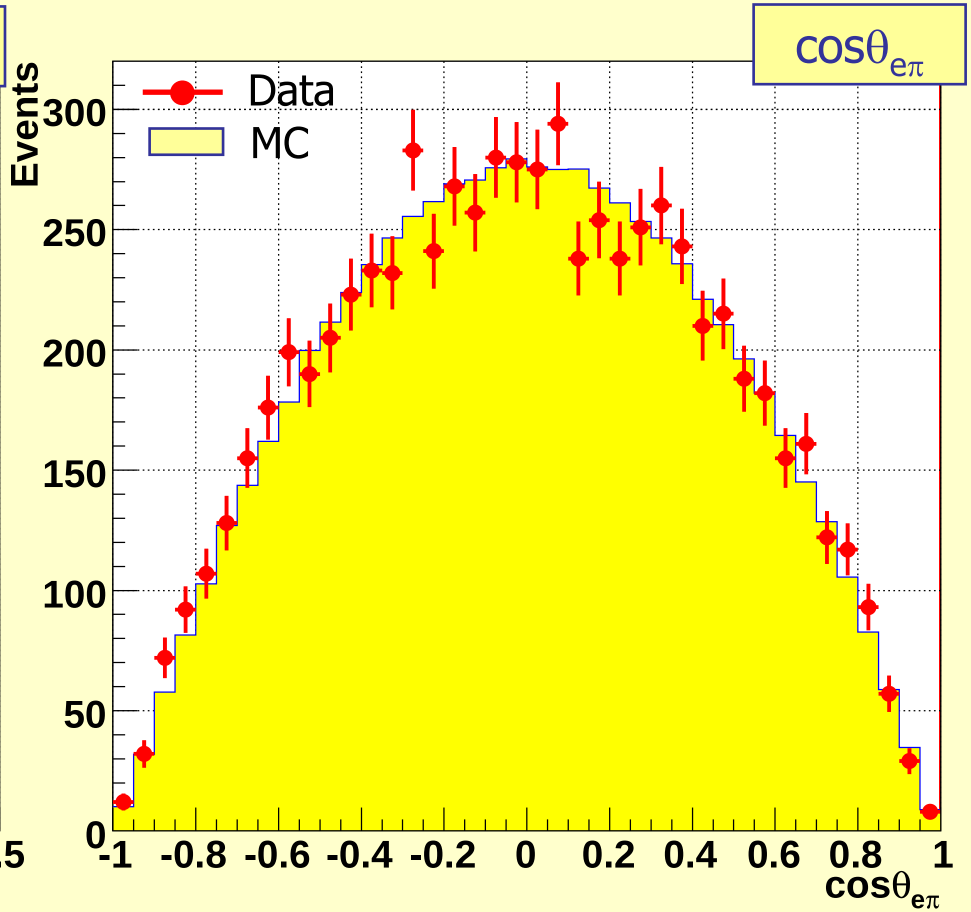




- The region $M_{ee}<140$MeV/c^2 is dominated by background and not accessible;
- Subtraction of the $K^\pm \to \pi^\pm \pi^0_{DD}$ reveals the $\pi^0 \to e^+ e^-$ signal (~500 events).

Kinematic variables: $(z, \cos\theta_{e\pi})$

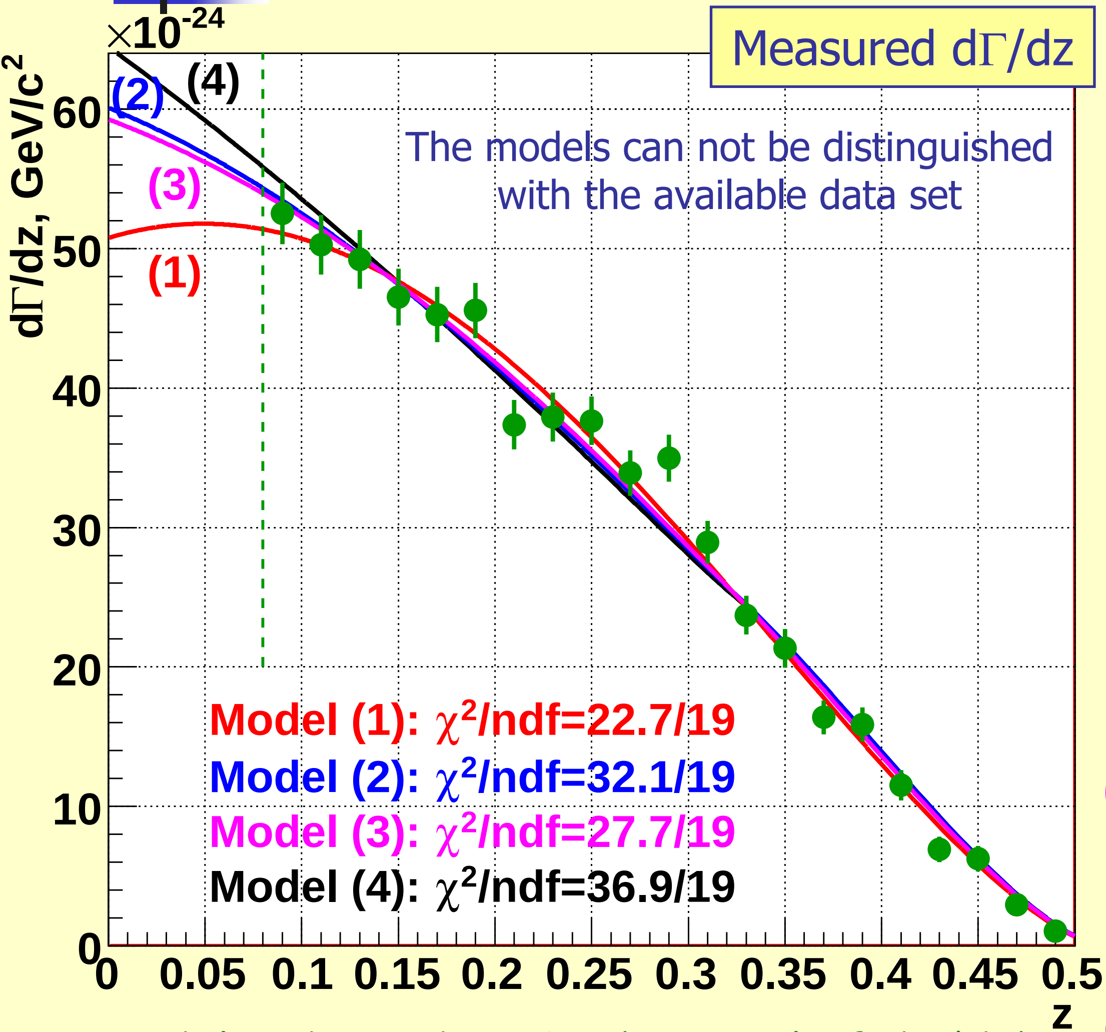




z distribution is sensitive to the form-factor and contains the dynamical information: $d\Gamma/dz \sim P(z) \times |W(z)|^2$.

Decay via one photon exchange: $d\Gamma/d\theta \sim \sin^2\theta = (1-\cos^2\theta)$, θ = angle between (e^+,π) in (e^+,e^-) frame. No dynamical information in this projection.

Fit results (1)



Model-independent BR (integral of dΓ/dz):

$BR_{mi}(z>0.08)=(2.28\pm0.03)\times10^{-7}$

Model parameters with their statistical errors and correlation coefficients:

(1) $f_0 = 0.531\pm0.012$, $\delta = 2.32\pm0.15$, $\rho(\delta, f_0) = -0.962$

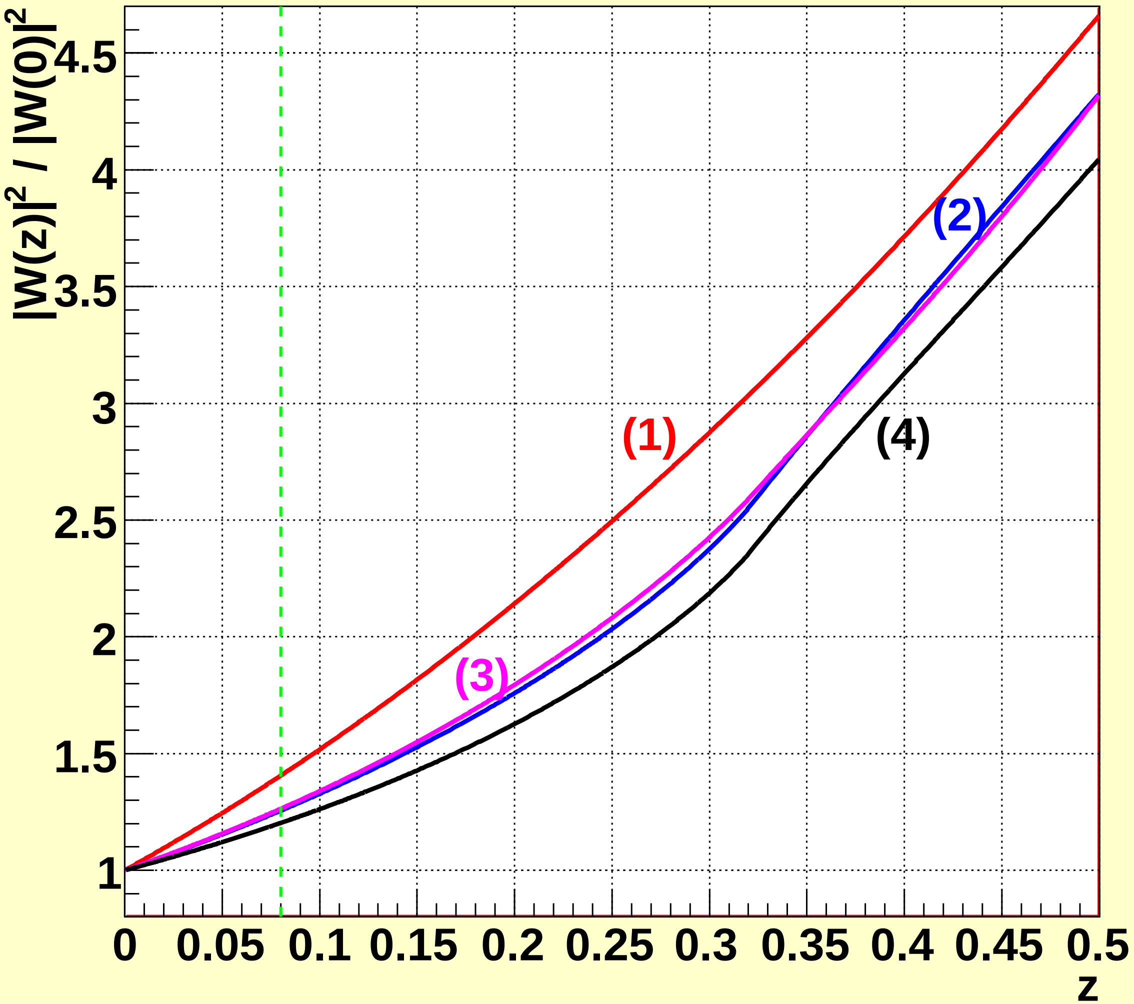
(2) $a_+ = -0.578\pm0.012$, $b_+ = -0.779\pm0.053$, $\rho(a_+, b_+) = -0.913$

(3) $w = 0.057\pm0.005$, $\beta = 3.45\pm0.24$, $\rho(w, \beta) = 0.999$

(4) $M_a = (0.951\pm0.028)$ GeV, $M_\rho = (0.705\pm0.010)$ GeV, $\rho(M_a, M_\rho) = 0.998$

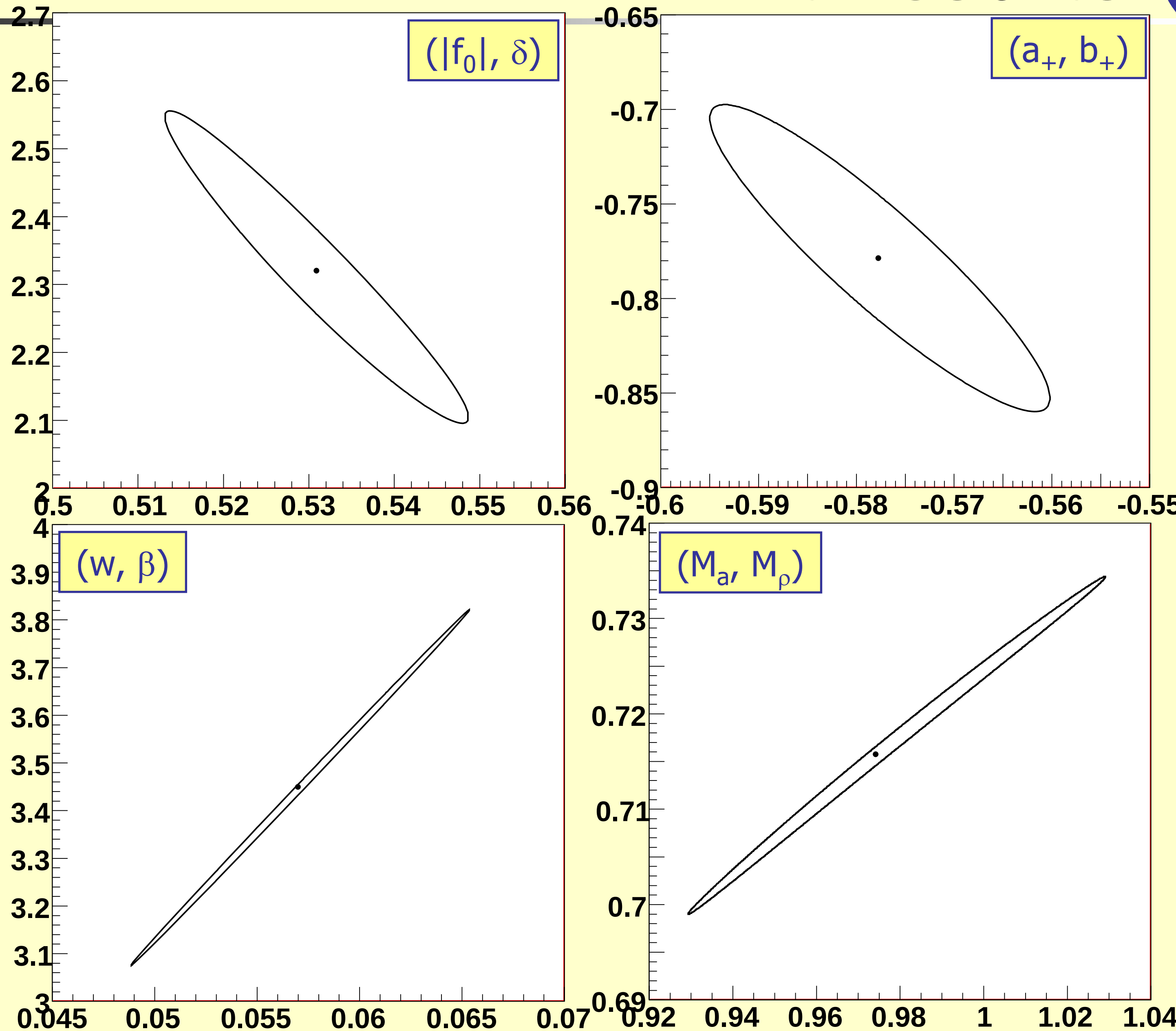
Fit results (2)

Squared form factors normalised by $|W(0)|^2=1$



Fit results (3)

68% CL contours



Fit results (4)

$BR_{mi}\times10^7$ =	2.28 ±	0.03_{stat} ±	0.04_{syst} ±	0.06_{ext}	=	2.28 ± 0.08
f_0 =	0.531 ±	0.012_{stat} ±	0.008_{syst} ±	0.007_{ext}	=	0.531 ± 0.016
δ =	2.32 ±	0.15_{stat} ±	0.09_{syst}		=	2.32 ± 0.18
$BR_1\times10^7$ =	3.05 ±	0.04_{stat} ±	0.05_{syst} ±	0.08_{ext}	=	3.05 ± 0.10
a_+ =	−0.578 ±	0.012_{stat} ±	0.008_{syst} ±	0.007_{ext}	=	−0.578 ± 0.016
b_+ =	−0.779 ±	0.053_{stat} ±	0.036_{syst} ±	0.017_{ext}	=	−0.779 ± 0.066
$BR_2\times10^7$ =	3.14 ±	0.04_{stat} ±	0.05_{syst} ±	0.08_{ext}	=	3.14 ± 0.10
w =	0.057 ±	0.005_{stat} ±	0.004_{syst} ±	0.001_{ext}	=	0.057 ± 0.007
β =	3.45 ±	0.24_{stat} ±	0.17_{syst} ±	0.05_{ext}	=	3.45 ± 0.30
$BR_3\times10^7$ =	3.13 ±	0.04_{stat} ±	0.05_{syst} ±	0.08_{ext}	=	3.13 ± 0.10
M_a =	0.974 ±	0.030_{stat} ±	0.019_{syst} ±	0.002_{ext}	=	0.974 ± 0.035 [GeV/c]
M_ρ =	0.716 ±	0.011_{stat} ±	0.007_{syst} ±	0.002_{ext}	=	0.716 ± 0.014 [GeV/c]
$BR_4\times10^7$ =	3.18 ±	0.04_{stat} ±	0.05_{syst} ±	0.08_{ext}	=	3.18 ± 0.10

Including uncertainty due to the model dependence,

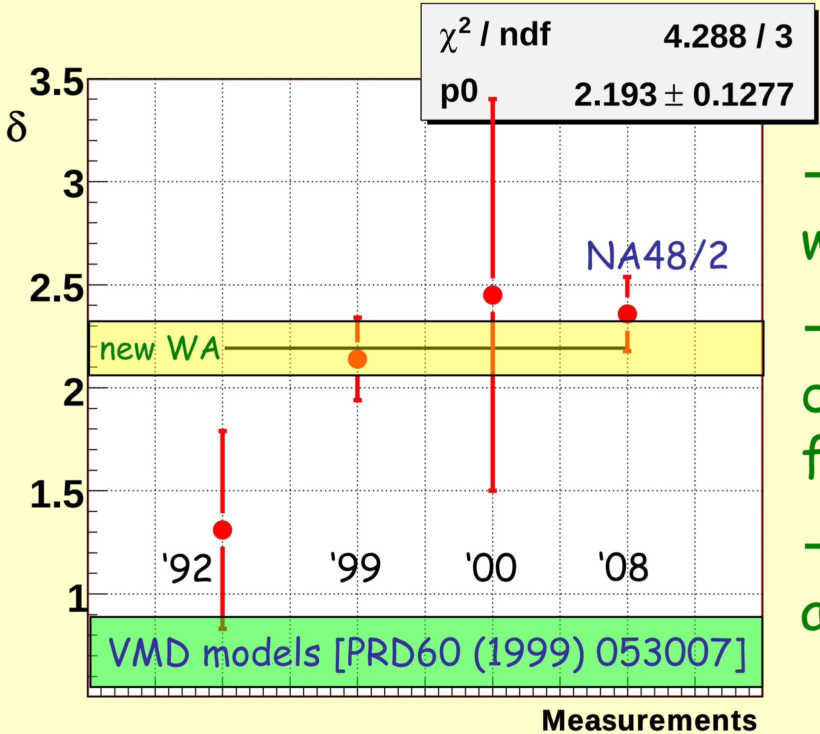
$$BR = (3.11\pm0.04_{stat}\pm0.05_{syst}\pm0.08_{ext}\pm 0.07_{model})\times10^{-7} = (3.11\pm0.12)\times10^{-7}$$

CPV parameter (first measurement; only uncorrelated K^+/K^- uncertainties):

$$\Delta(K^{\pm}_{\pi ee}) = (BR^+-BR^-) / (BR^++BR^-) = (-2.1\pm1.5_{stat}\pm0.6_{syst})\times10^{-2}$$

Comparison: FF slope δ

Measurement	Process	Result
Alliegro et al., PRL 68 (1992) 278	$K^+ \to \pi^+ e^+ e^-$	1.31 ± 0.48
Appel et al. [E865], PRL 83 (1999) 4482	$K^+ \to \pi^+ e^+ e^-$	2.14 ± 0.20
Ma et al. [E865], PRL 84 (2000) 2580	$K^+ \to \pi^+ \mu^+ \mu^-$	$2.45^{+1.30}_{-0.95}$
NA48/2, arXiv:0903:3130 (2009)	$K^\pm \to \pi^\pm e^+ e^-$	2.32 ± 0.18



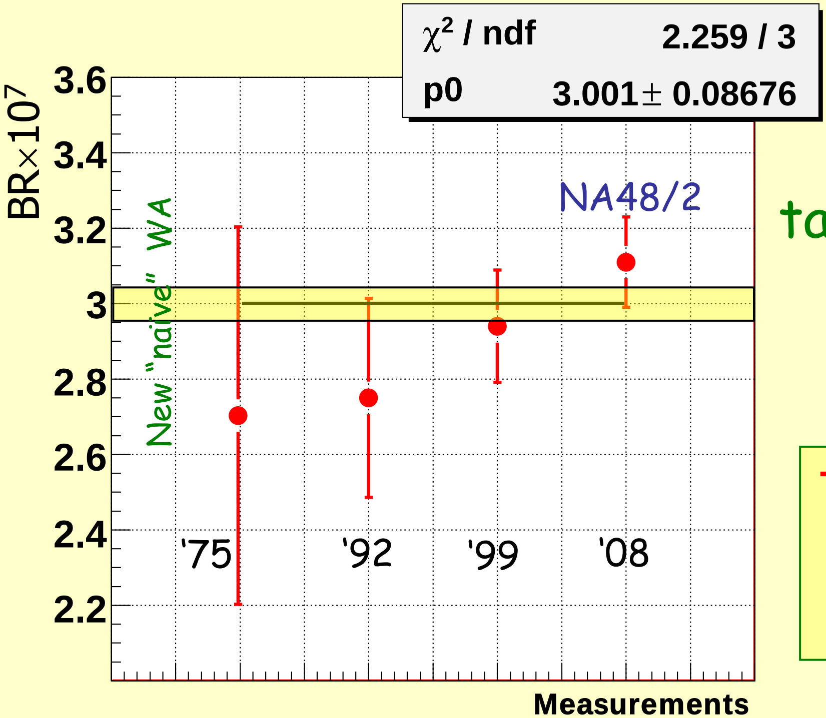
→ NA48/2 measurement of δ is compatible with the earlier results, has good precision;

→ A contradiction of the data to the meson dominance models observed earlier is further confirmed;

→ NA48/2 values of (f_0,a_+,b_+,w, β) are in agreement with BNL E865 ones.

Comparison: BR in full z range

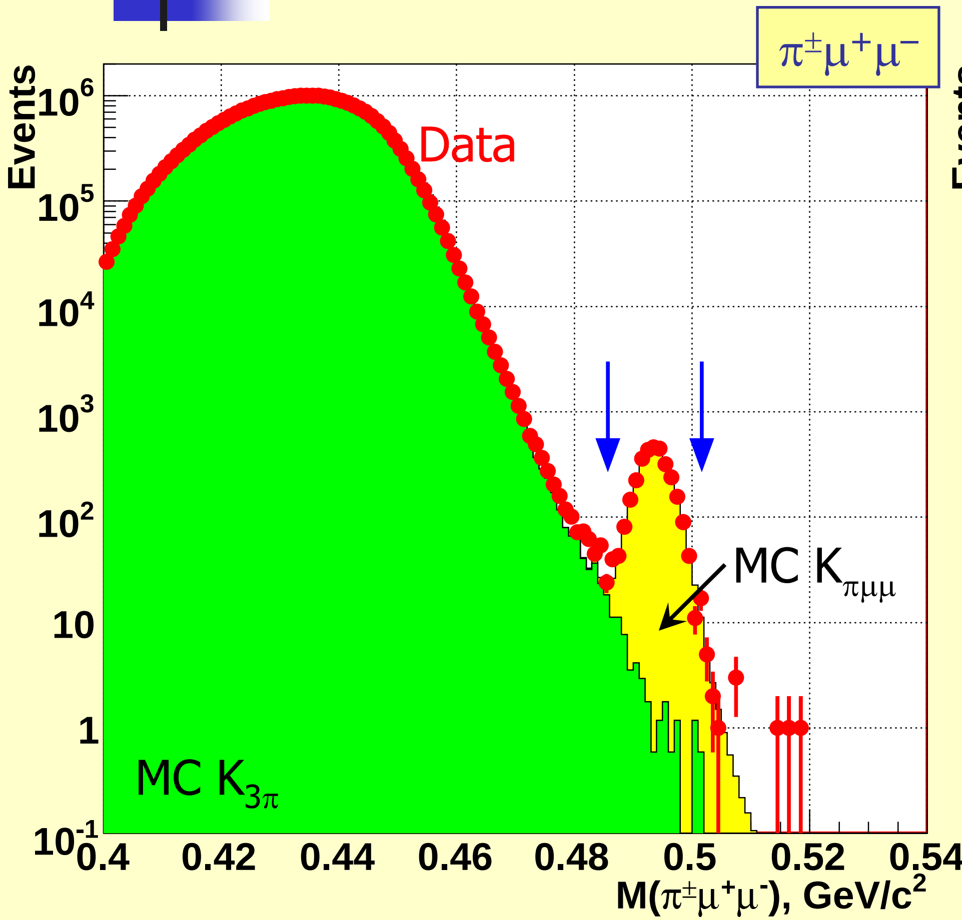
Measurement	Sample	BR×10^7
Bloch et al., PL 56 (1975) B201	41 (K^+)	2.70±0.50
Alliegro et al., PRL 68 (1992) 278	500 (K^+)	2.75±0.26
Appel et al. [E865], PRL 83 (1999) 4482	10,300 (K^+)	2.94±0.15
NA48/2, arXiv:0903:3130 (2009)	7,300 ($K^\pm$)	3.11±0.12

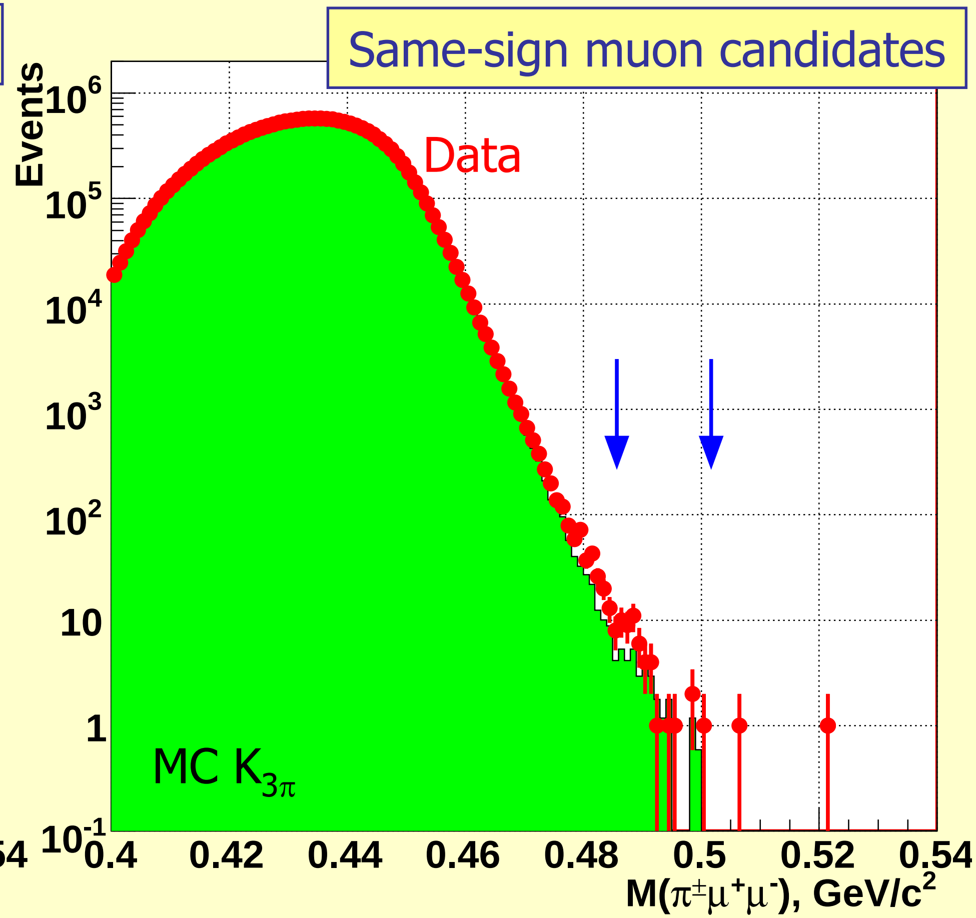


Comparison of E865 vs NA48/2 results taking into account correlated uncertainties (normalization and model dependence): 1.6σ difference.

The NA48/2 results are final and published: CERN-PH-EP-2009-005, arXiv:0903:3130, accepted by Physics Letters B.

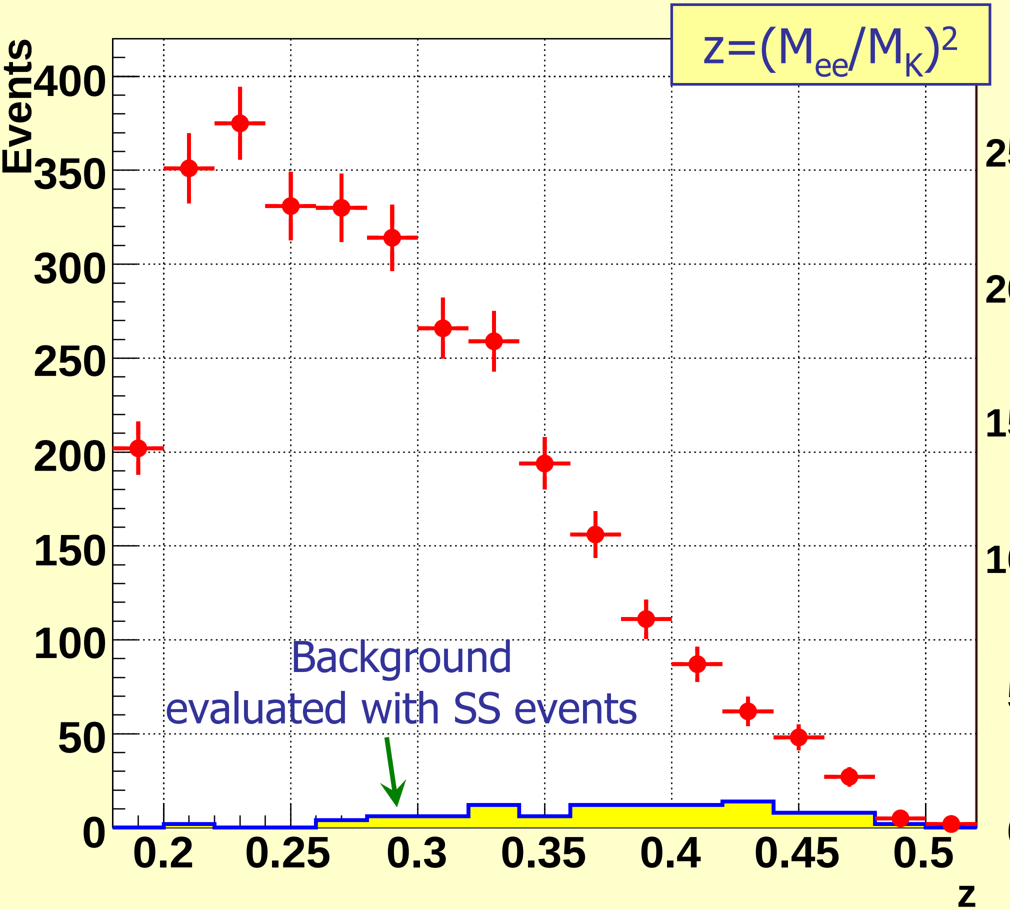
$K^\pm \to \pi^\pm \mu^+ \mu^-$ analysis (1)

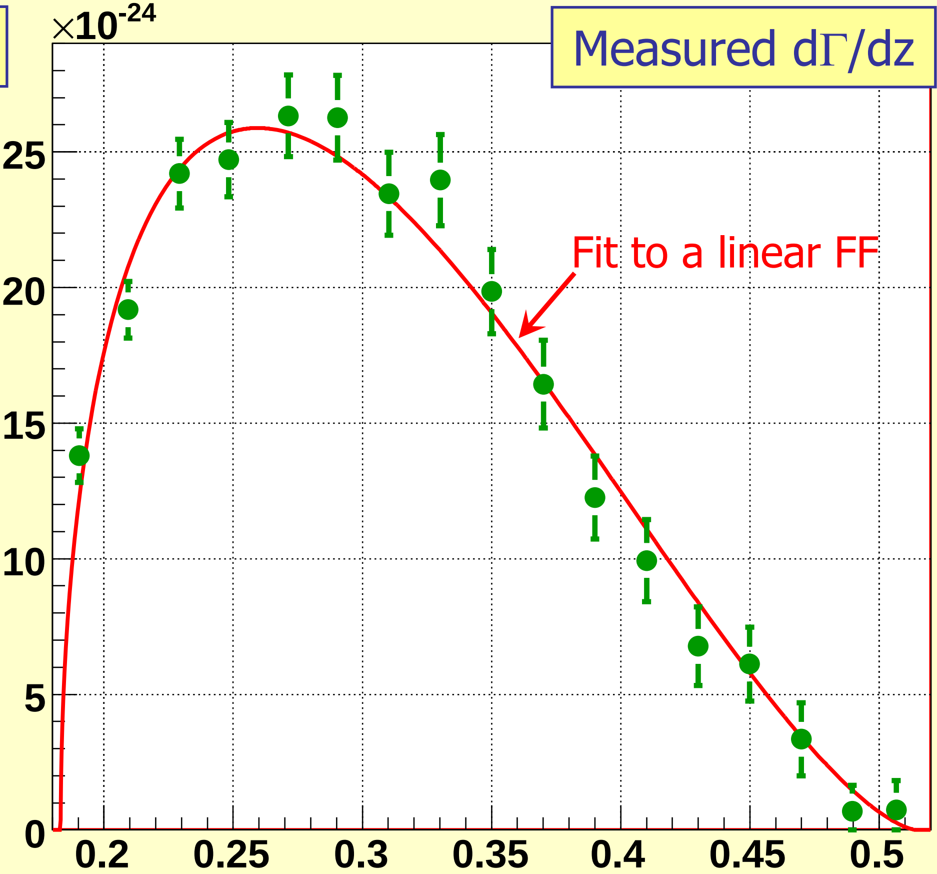




NA48/2: N=3,100 $K^\pm \to \pi^\pm \mu^+ \mu^-$ candidates with 3% background.
Background well described by both $K_{3\pi}$ MC and same-sign muon samples.
Cf. total world sample is ~700 events.

$K^{\pm} \to \pi^{\pm}\mu^{+}\mu^{-}$ analysis (2)





Analysis is well advanced,
we aim to present the preliminary results in 2009.

Summary

- Precise study of the $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}$ decay ($BR\sim3\times10^{-7}$):
  → sample & precision comparable to world's best ones;
  → (BR, FF) agree to theory and earlier measurements;
  → first limit on the CPV charge asymmetry obtained;
  → final results published recently.

- Precise study of the $K^{\pm}\rightarrow\pi^{\pm}\mu^{+}\mu^{-}$ decay ($BR\sim0.8\times10^{-7}$):
  → NA48/2 sample ~4 times larger than total world sample;
  → background is low and under control;
  → aim at preliminary results in 2009 – stay tuned!