Precision measurement of the form factors of the semileptonic decay $K^{\pm} \to \pi^{0} l^{\pm} \nu$ (Kl3)

R.Piandani

University and INFN of Perugia

on behalf of the NA48/2 collaboration

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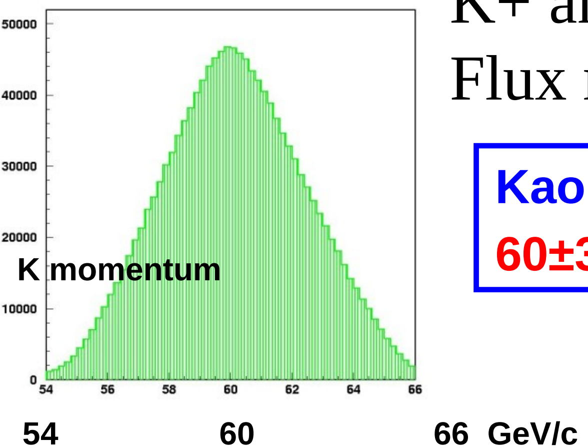
Outline:

- ✗ The NA48/2 Beam and Detectors
- ✗ The theoretical motivations
- ✗ The signal selections and residual background
- ✗ Results
- ✗ Conclusions

The NA48/2 Beam

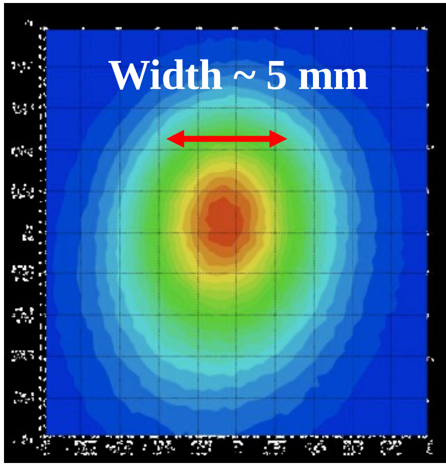


K+ and K- superimposed in space

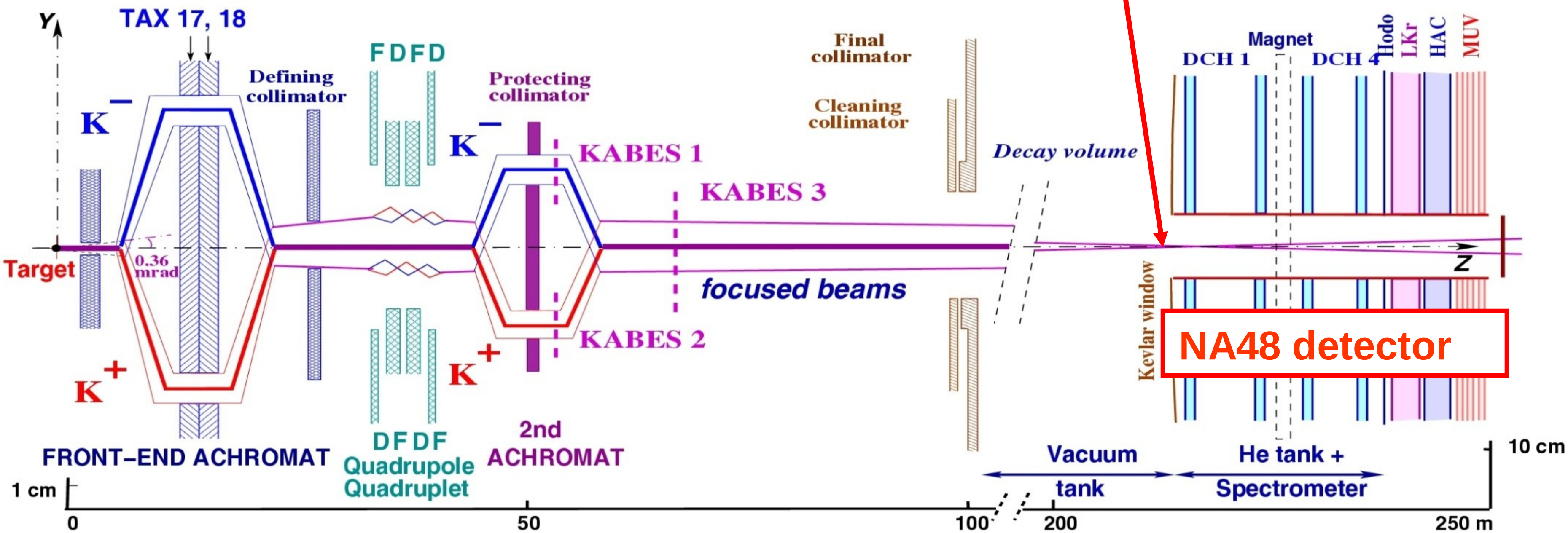
Flux ratio: K+/K- ~1.8

Kaon momentum:
60±3 GeV/c

Data taking:
2003 – 50 days
2004 – 60 days



Beams **coincide within 1 mm**



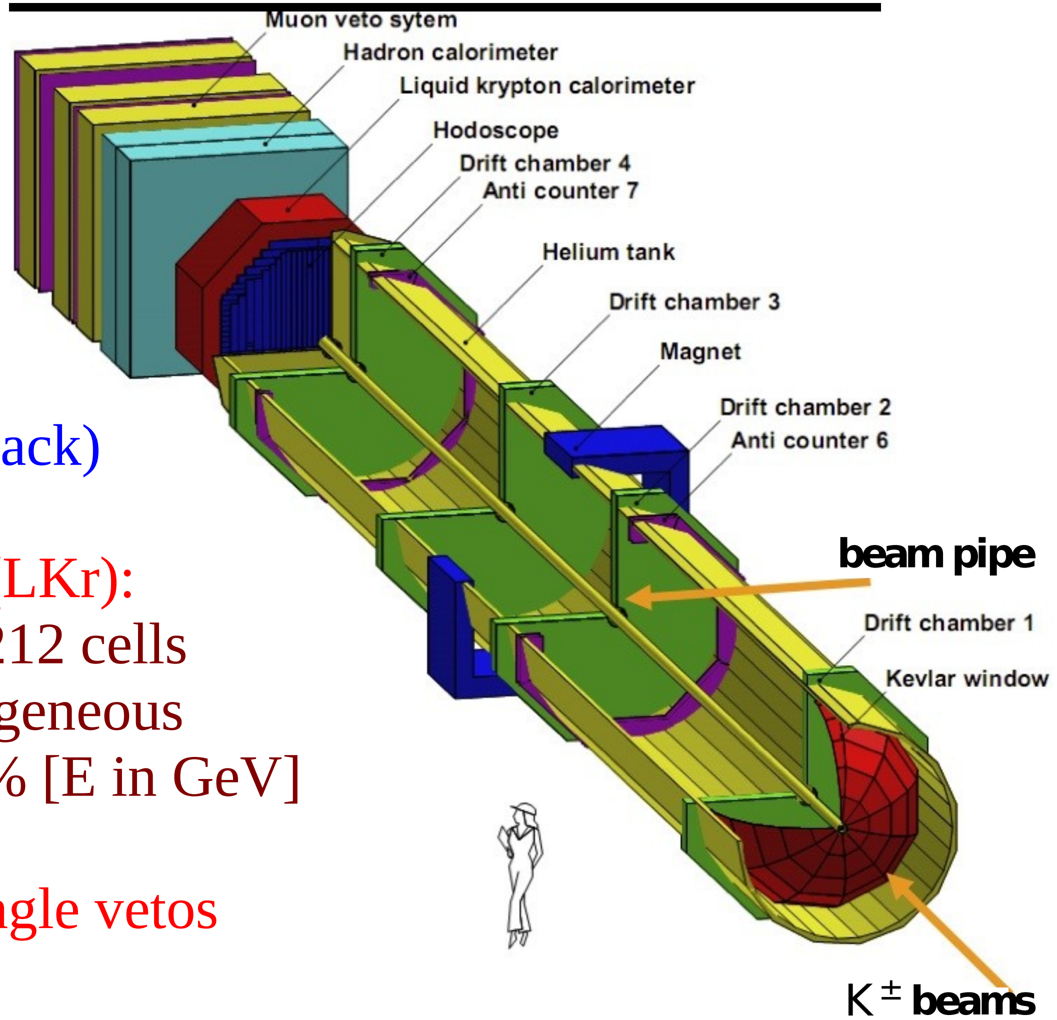
The NA48/2 Detectors

Magnetic spectrometer (4 DCHs):
4 views: redundancy ⇒ efficiency
$\sigma(p)/p = 1.0\% + 0.044\%\ p$ [GeV/c]

Charged hodoscope (scintillators):
Fast trigger and precise time measurement (~200 ps on single track)

Liquid Krypton E.M. Calorimeter (LKr):
10 m3 (~22 t), 1.25 m (27 X0), 13212 cells
granularity: 2x2 cm2, quasi-homogeneous
$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

Then hadronic calorimeter, large angle vetos and muon counter (scintillators)



Min Bias Trigger:
Coincidence of two Hodoscope hits × ELKr > 10 GeV

3 days in 2004

Physics motivation

Kl3 decays are described by **two form factors** $f_{\pm}(t)$, and the **matrix element** can be written as:

$$M = \frac{G_F}{2} V_{us} (f_+(t)(P_K + P_\pi)^\mu \bar{u}_l \gamma_\mu (1+\gamma_5) u_\nu + f_-(t) m_l \bar{u}_l (1+\gamma_5) u_\nu)$$

$t = q^2$ is the square of the four-momentum transfer to the lepton neutrino system

$f_{\pm}(t)$ are the **vector form factors**

$f_0(t)$ the **scalar form factor is** given by:

$$f_0(t) = f_+(t) + \frac{t}{(m_K^2 - m_\pi^2)} f_-(t)$$

$f_-(t)$ can only be measured in Kμ3 decays because of $m_e << m_K$

$f_+(0)$ cannot be measured directly, therefore the form factors are normalised to $f_+(0)$:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)} \qquad \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)}$$

Form Factor Parametrizations

Pole parametrization:

Assumes the exchange of vector and scalar resonances K* with spin-parity $1^-/0^+$ and masses m_V/m_S, $f_+(t)$ can be described by K*(892), for $f_0(t)$ no obvious dominance is seen:

$$\bar{f}_{+,0}(t) = \frac{m_{V,S}^2}{m_{V,S}^2 - t}$$

Linear and quadratic parametrization:

$$\bar{f}_{+,0}(t) = \left[1 + \lambda_{+,0}\frac{t}{m_\pi^2}\right] \quad \text{Linear}$$

$$\bar{f}_{+,0}(t) = \left[1 + \lambda'_{+,0}\frac{t}{m_\pi^2} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m_\pi^2}\right)^2\right] \quad \text{Quadratic}$$

No sensitivity to λ''_0

$\Downarrow$

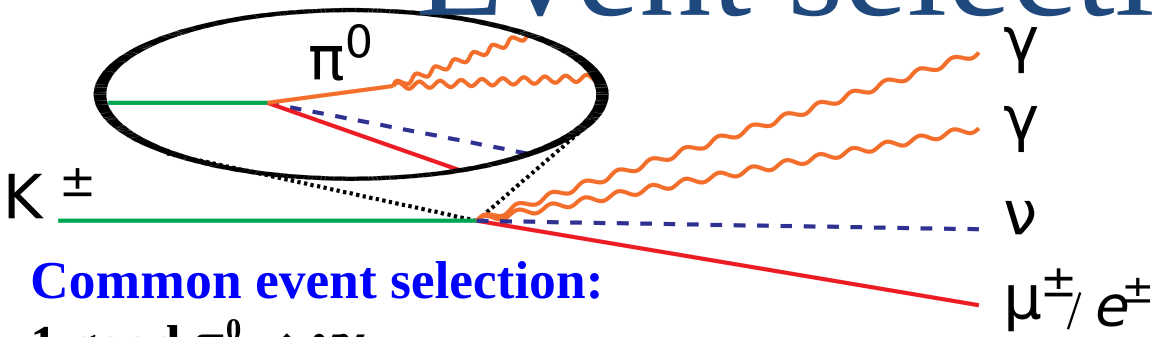
$\bar{f}_0(t)$ linear

Dispersive parametrization: (B. Bernard, M. Oertel, E. Passemar, J. Stern, Phys.Rev.D80(2009) 034034)

$$\bar{f}_+(t) = exp((\Lambda_+ + H(t)t/m_\pi^2)$$

$$\bar{f}_0(t) = exp((ln[C] - G(t))t/(m_K^2 - m_\pi^2)$$

Event selection (1)



Common event selection:

1 good $\pi^0 \rightarrow \gamma\gamma$

2 isolated γ in LKr (D > 20 cm and D_track > 15 cm)

$E(\pi^0) > 15$ GeV

Specific event selection:

$K^{\pm}e3$

1 charged track with p>5 GeV and E/p>0.9

p^{ν}_{T} (beam axis)>0.03 GeV/c

$(p^{\nu}_{L})^2 = (E^{\nu}/c)^2 - (p^{\nu}_{T})^2 > 0.0014 GeV^2/c^2$

$K^{\pm}\mu3$

1 charged track with p>10 GeV and E/p<0.9

An associated signal in the MUV

Cuts to remove $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}$ ($\pi^{\pm}\rightarrow\mu^{\pm}\nu$)

Cuts to remove $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$ ($\pi^{\pm}\rightarrow\mu^{\pm}\nu$ and missing π^{0})

Event selection (2)

Events selected:

$2.91 \cdot 10^6$ $K^{\pm}\mu 3$

$4.28 \cdot 10^6$ $K^{\pm}e3$

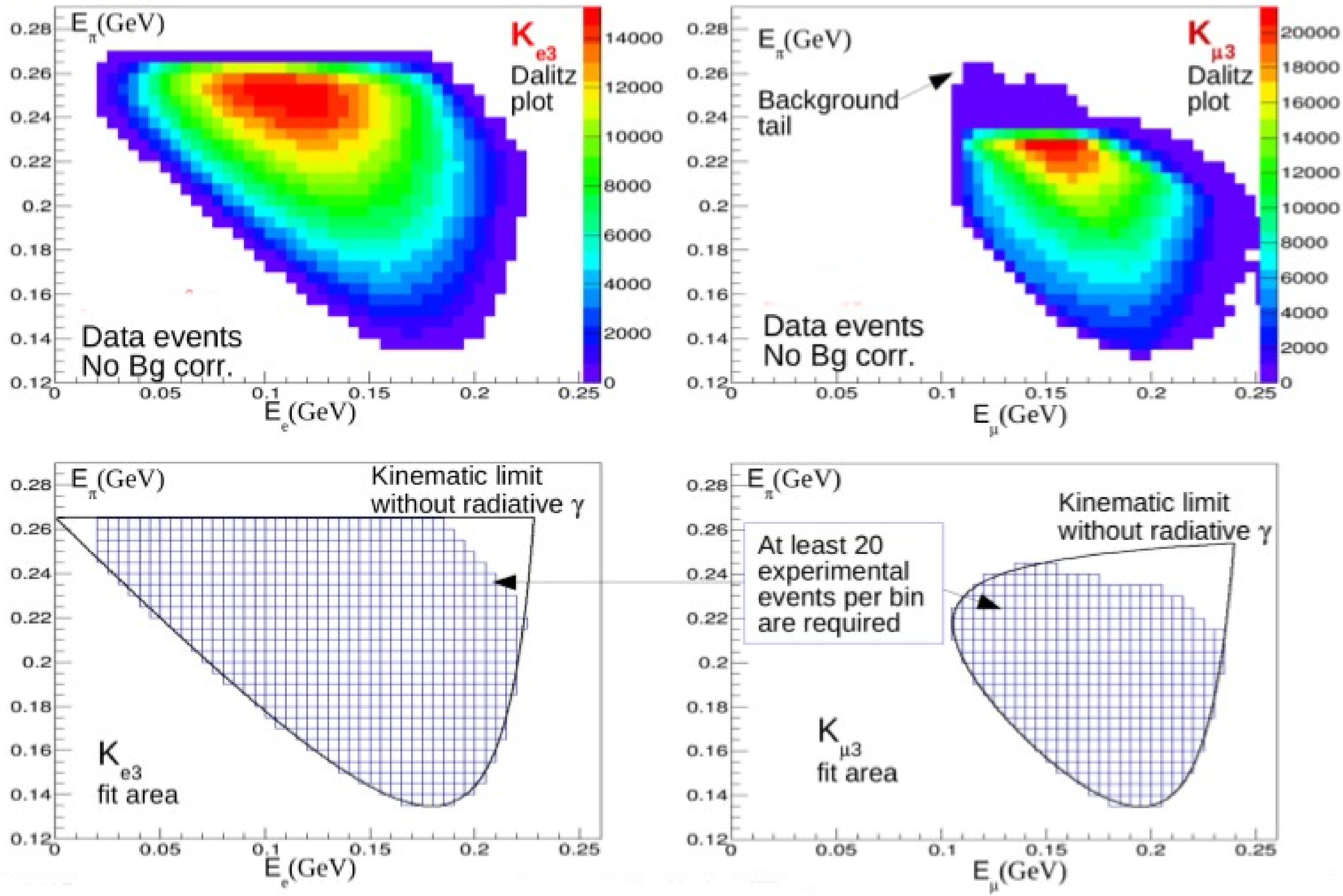
$O(10^{-4} - 10^{-3})$ background contamination

Decay	Br, %	Bkg (e),10^{-3}	Bkg (μ),10^{-3}
$K^{\pm} \rightarrow \pi^{\pm}(\pi^0 \rightarrow 2\gamma)$	20.66	0.270	0.264
$K^{\pm} \rightarrow \pi^{\pm}2(\pi^0 \rightarrow 2\gamma)$	1.761	0.286	1.833

Measured Dalitz plots and fit areas

$$\rho(E_l^*, E_\pi^*) = \frac{d^2N(E_l^*, E_\pi^*)}{dE_\mu^* dE_\pi^*} \propto A f_+^2(t) + B f_+(t)(f_0 - f_+)\frac{m_K^2 - m_\pi^2}{t} + C\left[(f_0 - f_+)\frac{m_K^2 - m_\pi^2}{t})\right]^2$$

(5x5 MeV cells)



Fit procedure

The MC events, generated with a known set of FF (λgen), are weighted using the following formula

$$W(\bar{L}) = W_r \frac{\rho(\bar{L}; E_l^*, E_\pi^*)}{\rho(\bar{\lambda}_{gen}; E_l^*, E_\pi^*)}$$

Where ρ is the Dalitz plot density as a function of the leptons and pion energy in the Kaon rest frame. Wr is different from 1 only for Ke3 in order to take in to account the radiative corrections (V. Cirigliano at all., Eur. Phys. J. C23 (2002) 121–133)

The best value of FF parameters L is found minimizing the χ^2 estimator

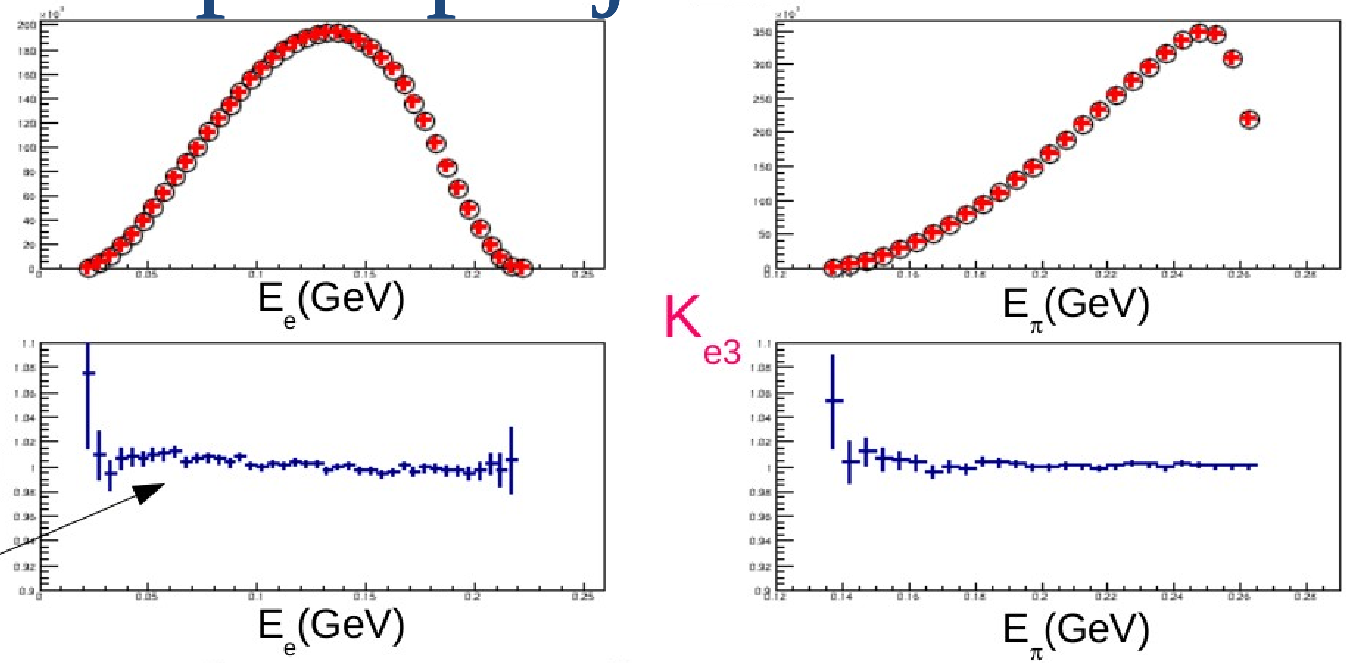
$$\chi^2 = \sum_{celli} \frac{(n_i^{data} - N \cdot n_i^{MC})^2}{\sigma^2_{n_i^{data}} + N^2 \sigma^2_{n_i^{MC}}}$$

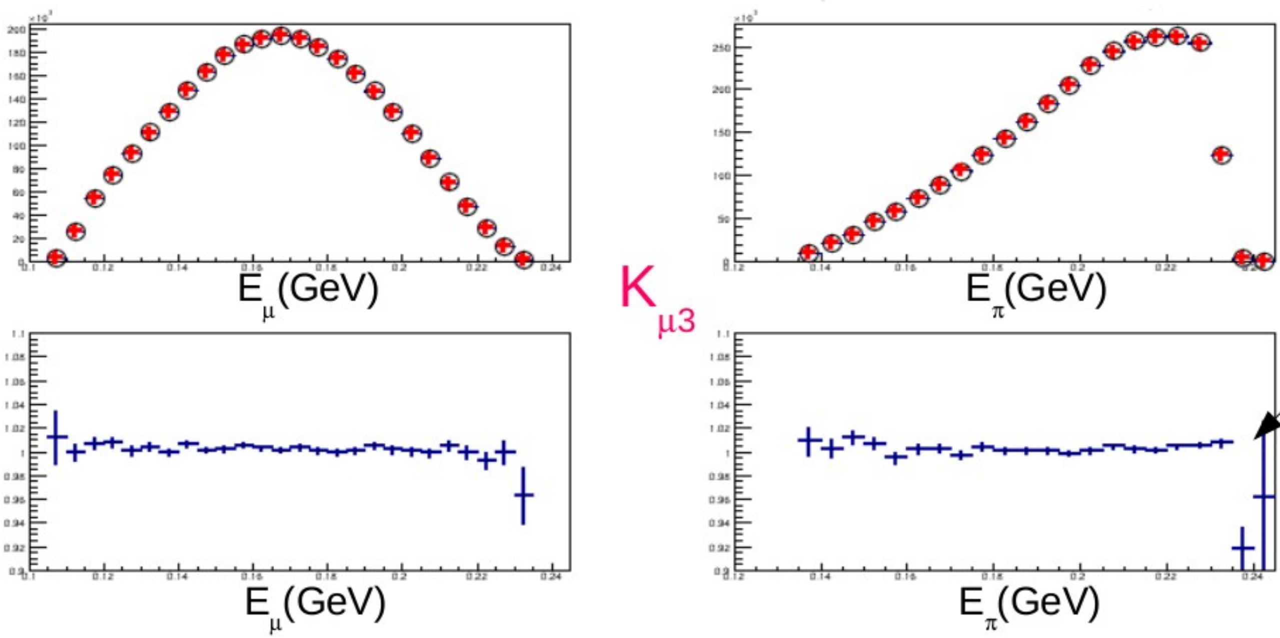
Where n_i^{data} is the population of cell i of reconstructed Dalitz plot of data after background subtraction, n_i^{MC} is the population of the weighted MC Dalitz plot

Dalitz plot projections

○ Data
+ MC fit result (quad.)
+ (Data-Bkg)/MC

Slightly significnat slope, within the radiative correction precision. Radiative effect uncertanty is included in the systematic error





Small deviations in the bkg-affected region
The bkg-related uncertanties are included in the systematic error

Form factors results (1)

Ke3 sample

	Quadratic parameterization (in units of 10^{-3})		Pole parameterization (in MeV)	Dispersive parameterization (in units of 10^{-3})
	λ'_+	λ''_+	M_V	Λ_+
Central value	23.52	1.60	896.8	22.54
Stat. error	0.78	0.30	3.4	0.20
Syst. error	1.29	0.39	7.6	0.62
Total error	1.51	0.49	8.3	0.65
χ^2/ndf	609.4/687		609.3/688	609.1/688
Correlation coefficients	-0.927		-	-

Form factors results (2)

$K\mu 3$ sample

	Quadratic parameterization (in units of 10^{-3})			Pole parameterization (in MeV)		Dispersive parameterization (in units of 10^{-3})	
	λ'_+	λ''_+	λ'_0	M_V	M_S	Λ_+	ln[C]
Central value	23.32	2.14	14.33	879.1	1196.4	23.55	186.68
Stat. error	3.08	1.06	1.11	8.1	18.1	0.50	5.12
Syst. error	3.50	0.96	1.25	13.5	28.8	0.97	9.23
Total error	4.67	1.43	1.67	15.7	34.0	1.10	10.55
χ^2/ndf	391.2/384			388.0/385		385.8/385	

Coorrelation

	λ''_+	λ^0		M_S	ln[C]
λ'_+	-0.969	0.851	M_V	0.320	
λ''_+		-0.810	Λ_+		0.408

Form factors results (3)

Combined K_{l3} sample for the preliminary results

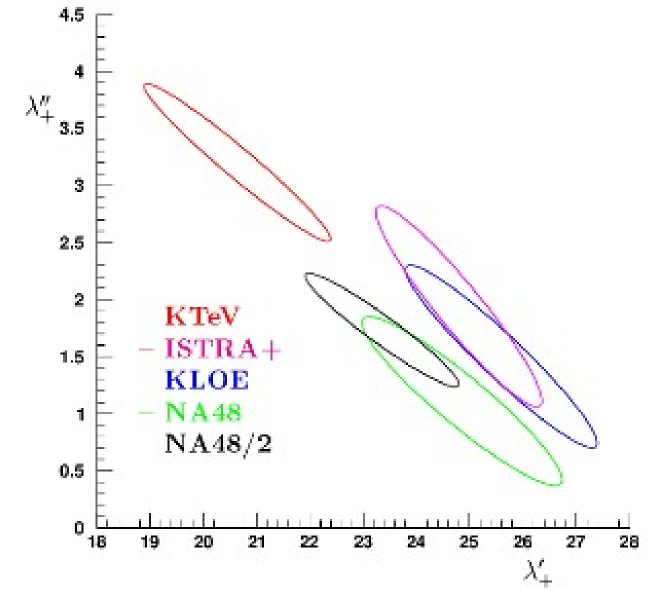
	Quadratic parameterization (in units of 10^{-3})			Pole parameterization (in MeV)		Dispersive parameterization (in units of 10^{-3})	
	λ'_+	λ''_+	λ'_0	M_V	M_S	Λ_+	ln[C]
Central value	**23.35**	**1.73**	**14.90**	**894.3**	**1185.5**	**22.67**	**189.12**
Stat. error	0.75	0.29	0.55	3.2	16.6	0.18	4.91
Syst. error	1.23	0.41	0.80	5.4	35.3	0.55	11.09
Total error	**1.44**	**0.50**	**0.97**	**6.3**	**35.5**	**0.58**	**12.13**
χ^2/ndf	1004.6/1073			1001.1/1074		998.3/1074	

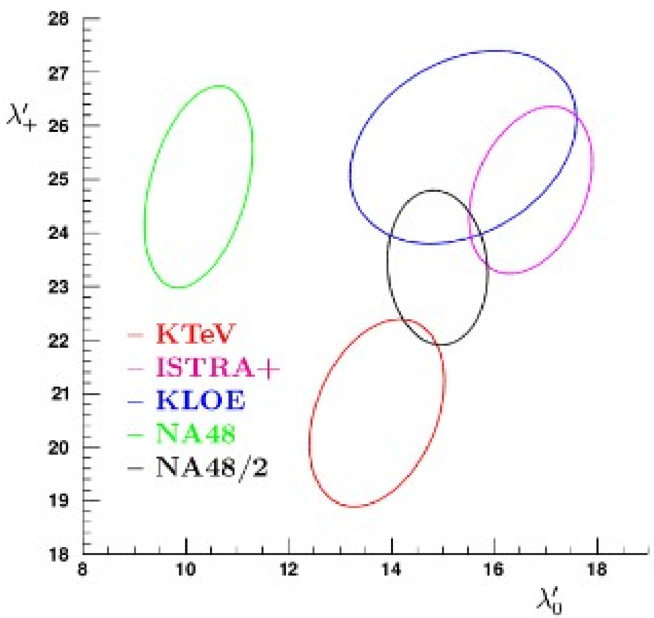
Coorrelations

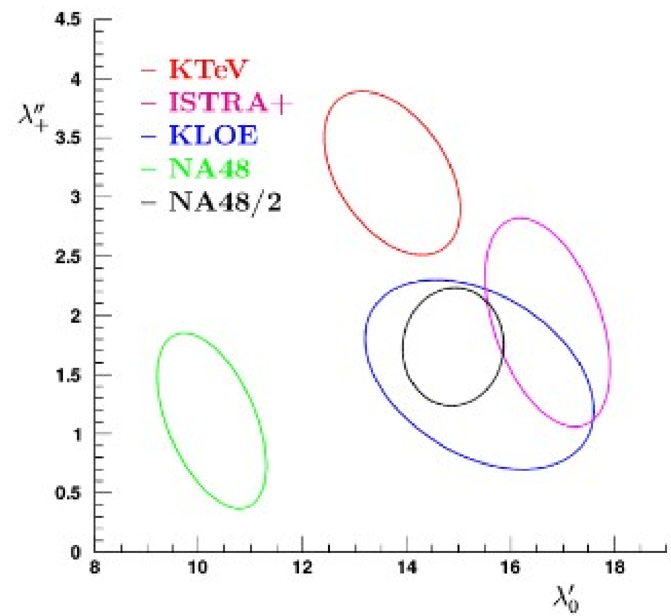
	λ''_+	λ^0		M_S	ln[C]
λ'_+	-0.954	0.076	M_V	-0.278	
λ''_+		-0.035	Λ_+		-0.035

Form factors results (4)

Comparison with other experiments







Summary

~4.3 M Ke3 and ~2.9 M Kμ3 reconstructed with 2004 NA48/2 data taking

Competitive results for Kμ3 and smallest error for Ke3

The combined results are the most precise