Dalitz plot analysis of $D^0 \to K_S \pi^- \pi^+$ using K–matrix formalism

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for the “D^0K Dalitz” group

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RUN 1 – 4 selection (I)

$$D^{*+} \to D^0 \pi^+ \to (K_S \pi^- \pi^+)_D \pi^+$$

$K_S \to \pi^+\pi^-$

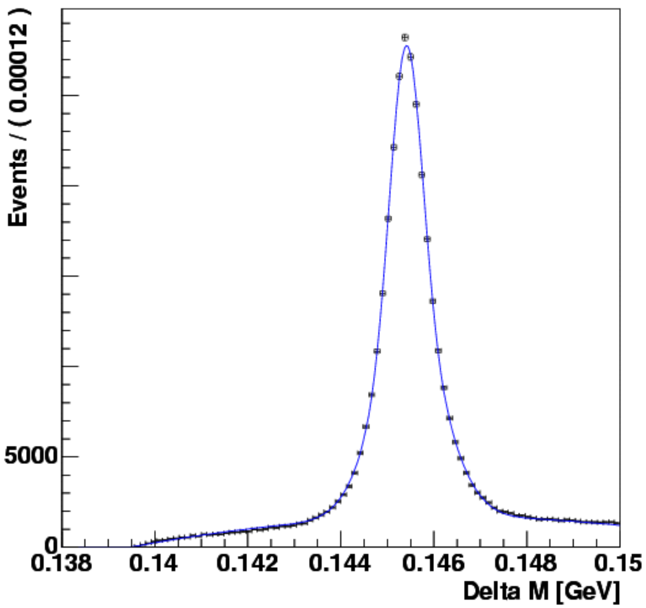
π^+: slow pion

Selection:

- $M(K_S) = [0.35, 0.65]$ GeV/c^2
- K_S vertex fit: χ^2/ndof > 0.001
- K_S mass constraint
- D^0 K_S vtx. distance > 0.4 cm
- $\cos(\alpha(K_S)) > 0.7$
- D^0 vertex fit: χ^2/ndof > 0.001
- D^0 momentum > 2.2 GeV/c
- D^0 mass constraint

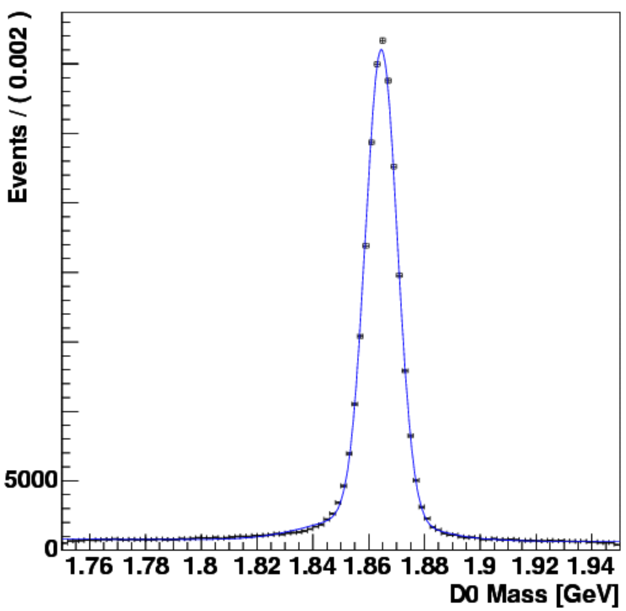
- D^* vertex fit: χ^2/ndof > 0.001
- slow π momentum < 0.6 GeV/c
- ChargedTracks list used for the 2 π from the K_S and for the slow pion
- GoodTracksLoose used for the 2 π from the D^0
- TreeFitter used in all vertex fits

RUN 1 – 4 selection (II)



- Δm fitted with 2 Gaussians (signal) + threshold function (background)
- Cut 1.4 MeV/c^2 ($\sim 2\sigma$) around the mean value

- $M(D^0)$ fitted with 2 Gaussians (signal) + first order polinomial (background)
- Cut 2σ ($\sim$11 MeV/c^2) around the mean value

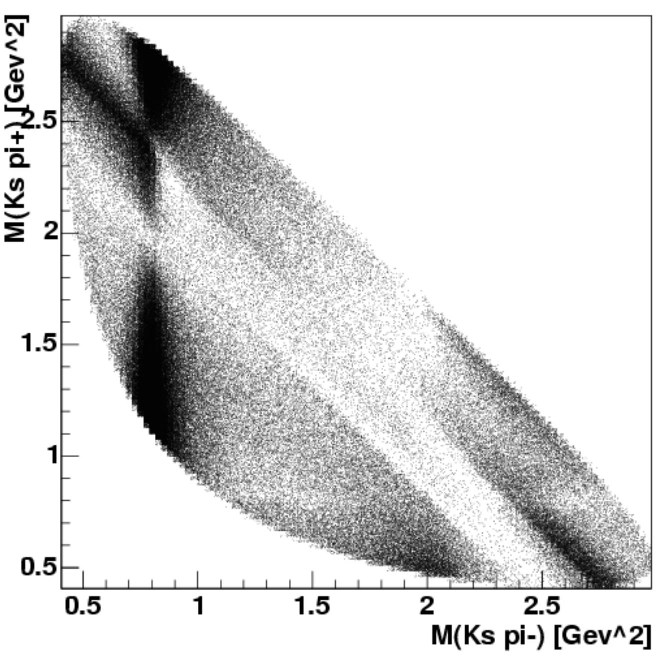


$M(D^0)=1.8646 \pm 1\ 10^{-5}$ GeV/c^2

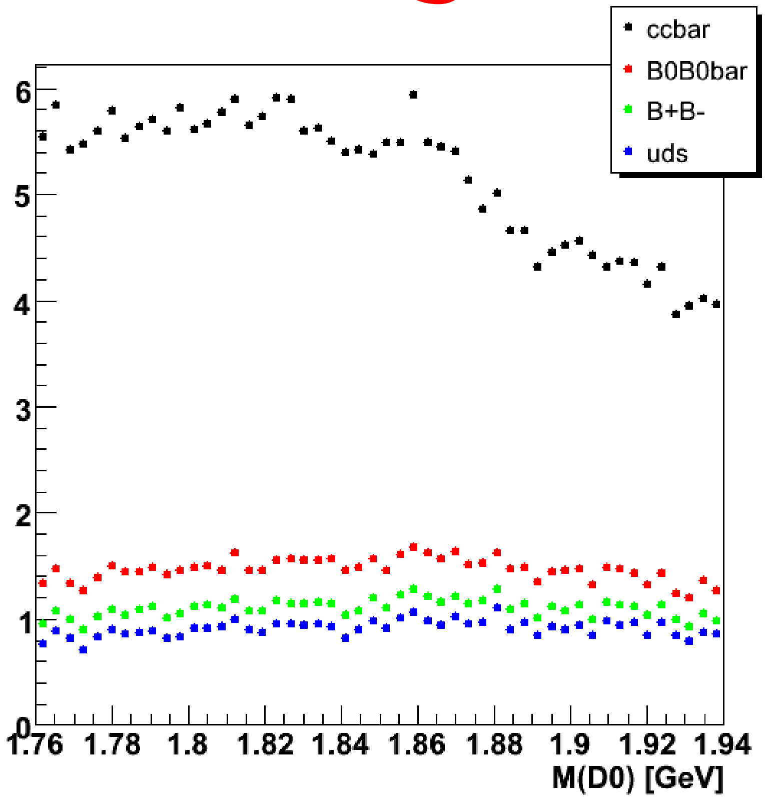
253991 events

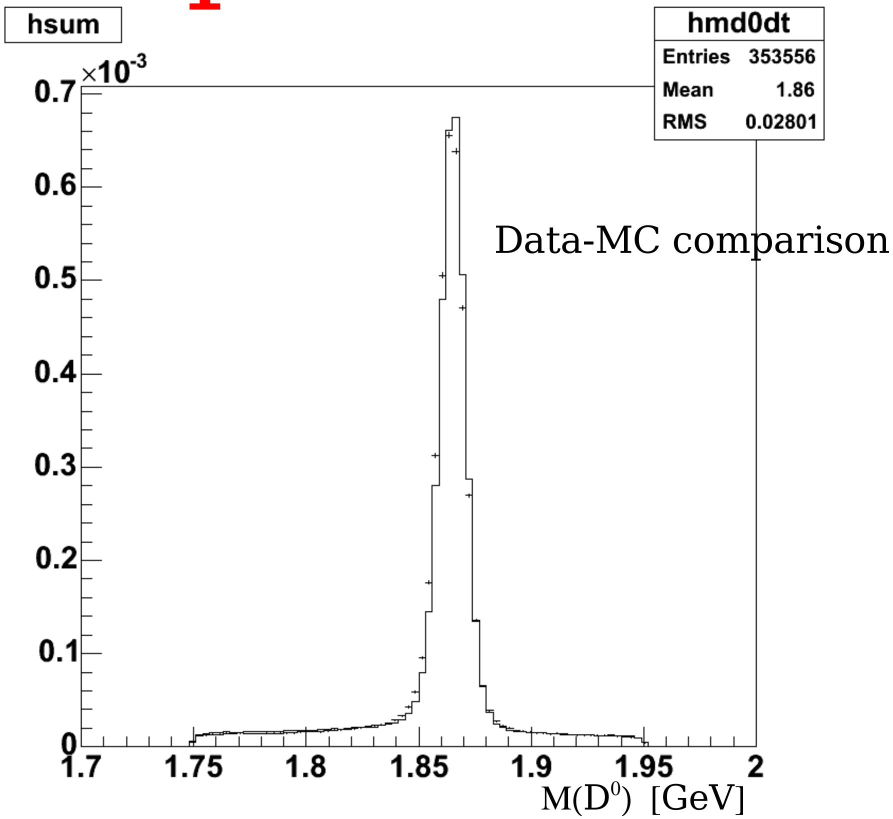
From $M(D^0)$ fit

$$\frac{S}{S+B}=0.977$$



Background composition





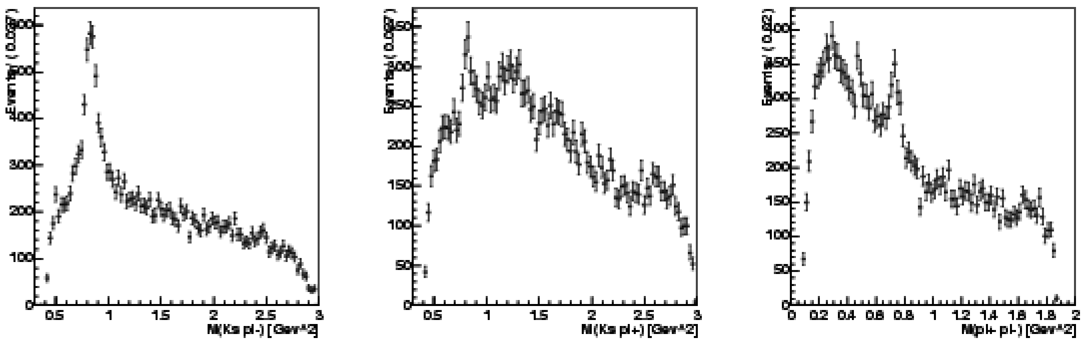
Sample	Selected M_D region	% of events
$D^0 \to K^0_S\pi^+\pi^-$	264228	96.7
$c\bar{c}$	5576	2.0
uds	1513	0.6
$B^0\bar{B}^0$	1484 (895)	0.5 (0.3)
B^+B^-	521 (209)	0.2 (0.1)
$D^0 \to K^0_S\pi^+\pi^-\pi^0$	628	0.2

$() = D^0 \to K_S\ \pi^-\pi^+$

- good Data–MC agreement
- no dominant background
- from MC S/(S+B)=97.1 % close to the one obtained from data (97.7 %)
- we use the value from data

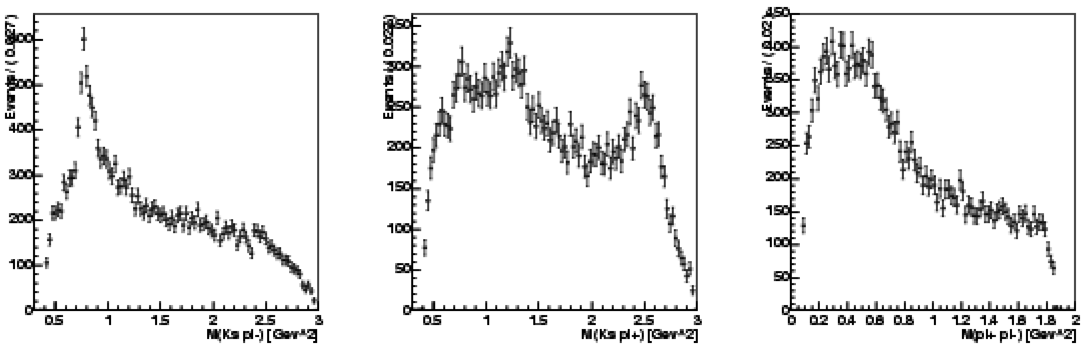
Background parametrization (I)

Use of the M(D^0) sidebands for the background parametrization



"left" sideband

$M(D^0) = [1.7, 1.8] GeV/c^2$



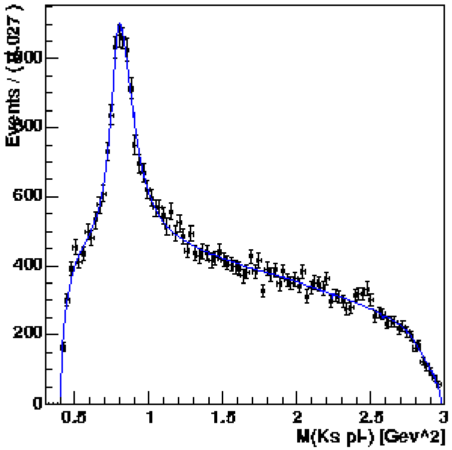
"right" sideband

$M(D^0) = [1.8925, 1.9] GeV/c^2$

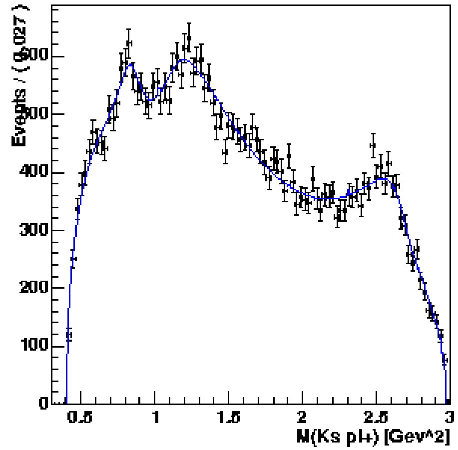
The two distributions are a bit different.

Bkg parametrization and relative systematic still not decided

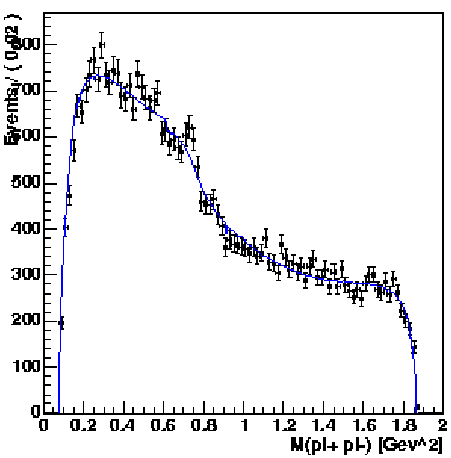
Background parametrization (II)



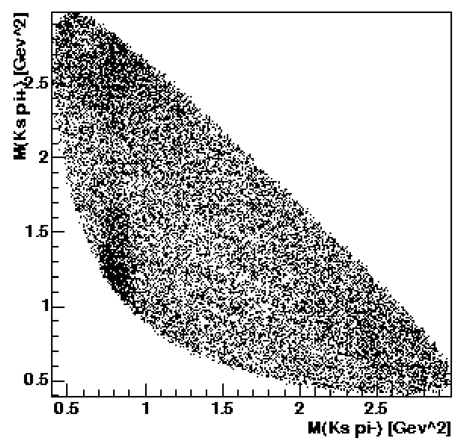
(a) $M^2_{K^0_S\pi^-}$



(b) $M^2_{K^0_S\pi^+}$



(c) $M^2_{\pi^+\pi^-}$



(d) Dalitz plot of the sideband events

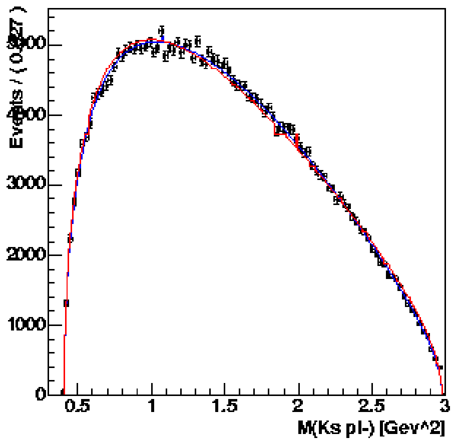
Test the effect on the fit of the bkg parametrization using the sum of the two sidebands

3.5 % of signal events in the sidebands

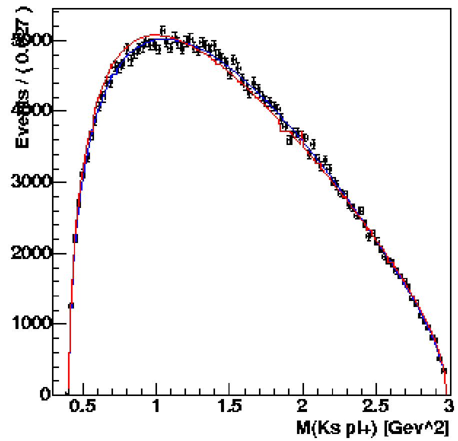
parametrization of the sidebands with a 3rd order polinomial plus $|\Sigma_1^6 \, BW_i|^2$ for background and with the B-W fit (see later) for the signal events

since B/(S+B)=2.3 %
we expect a small systematic

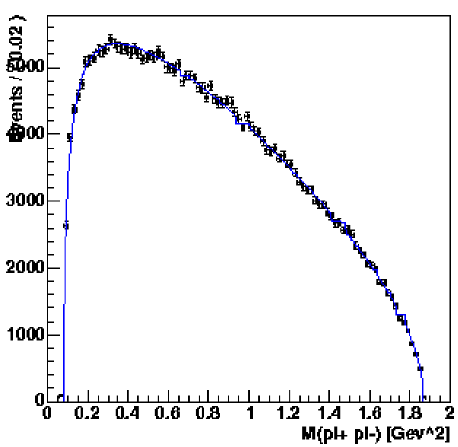
Efficiency map



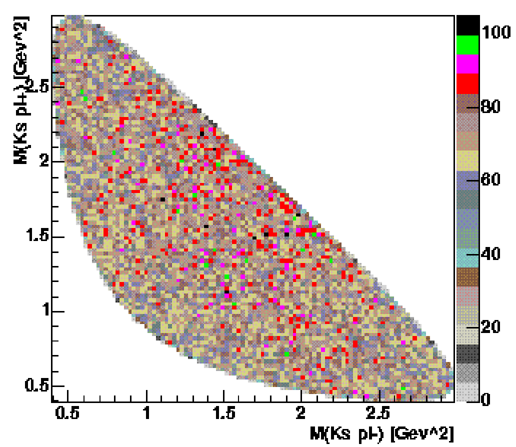
(a) $M^2_{K^0_S\pm}$



(b) $M^2_{K^0_S\pi+}$



(c) $M^2_{\pi^+\pi^-}$



(d) Dalitz distribution

fit result

flat distribution

Phase space signal MC used

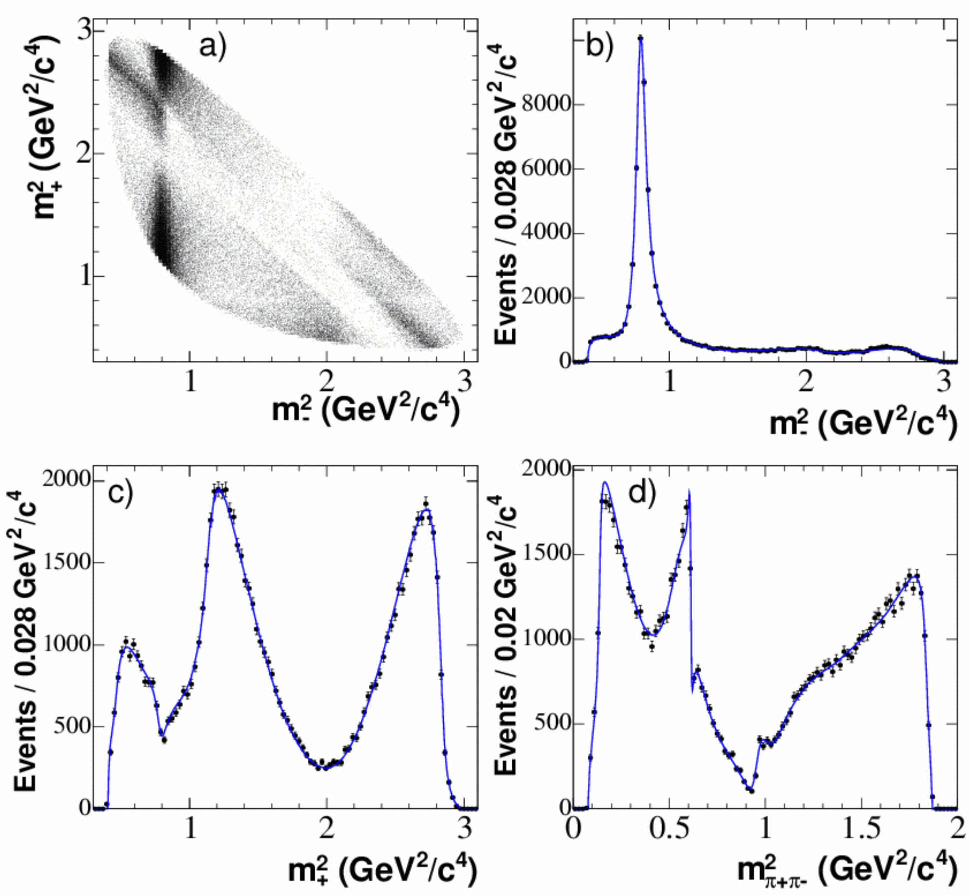
parametrization with a 3rd order polinomial

the efficiency map is very close to a flat distribution

systematic with a flat distribution

Breit Wigner Fit

hep-ex/0504039



Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.781 ± 0.018	131.0 ± 0.82	0.586
$K_0^*(1430)^-$	2.447 ± 0.076	-8.3 ± 2.5	0.083
$K_2^*(1430)^-$	1.054 ± 0.056	-54.3 ± 2.6	0.027
$K^*(1410)^-$	0.515 ± 0.087	154 ± 20	0.004
$K^*(1680)^-$	0.89 ± 0.30	-139 ± 14	0.003
$K^*(892)^+$	0.1796 ± 0.0079	-44.1 ± 2.5	0.006
$K_0^*(1430)^+$	0.368 ± 0.071	-342 ± 8.5	0.002
$K_2^*(1430)^+$	0.075 ± 0.038	-104 ± 23	0.000
$\rho(770)$	1 (fixed)	0 (fixed)	0.224
$\omega(782)$	0.0391 ± 0.0016	115.3 ± 2.5	0.006
$f_0(980)$	0.4817 ± 0.012	-141.8 ± 2.2	0.061
$f_0(1370)$	2.25 ± 0.30	113.2 ± 3.7	0.032
$f_2(1270)$	0.922 ± 0.041	-21.3 ± 3.1	0.030
$\rho(1450)$	0.516 ± 0.092	38 ± 13	0.002
σ	1.358 ± 0.050	-177.9 ± 2.7	0.093
σ'	0.340 ± 0.026	153.0 ± 3.8	0.013
Non Resonant	3.53 ± 0.44	127.6 ± 6.4	0.073

Run1-2 selection
(Run1-4 fit ongoing)

Σ(fit fraction)=124.5 %

σ(m=484±9 MeV, Γ=383±14 MeV) σ'(m=1014±7MeV,Γ=88±13MeV)

K matrix formalism

K-matrix describe the unitarity of the S matrix in processes $a\, b \to c\, d$

$$S = 1 + 2 i \sqrt{\rho}\, T \sqrt{\rho}$$

T = transition operator

ρ = phase space matrix (diagonal matrix)

$$S^{+} S = S S^{+} = 1 \Rightarrow (T^{-1} + i \rho)^{+} = (T^{-1} + i \rho)$$

defining $K^{-1} = (T^{-1} + i\, \rho)$ $K = K^{+}$ (K hermitian)

Use of the isobar model to apply the K-matrix to Dalitz amplitude

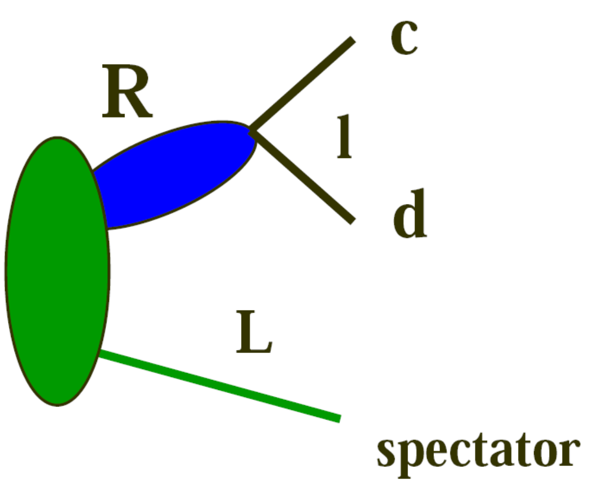
The Lorentz invariant amplitude:

Aitchison, Nucl. Phys. A189, 417(1972)

$$F = (1 - i\, K\, \rho)^{-1}\, P$$

resonance propagation

coupling to the initial state (production vector)



K matrix: ππ S–wave

Parametrize the S-wave component using K matrix formalism

$$F_l = (I - i K\rho)^{-1}_{lj} \; P_j$$

j,l = 1....N   N= number of modes considered

modes(i,j): ππ, KK, 4π, ηη, ηη'

F = amplitude vector

ρ = phase space matrix (diagonal matrix)

P = “initial” production vector

Following the parametrization of:

V.V. Anisovich, A.V. Sarantsev (Eur.Phys.J.A16:229-258,2003)

$$K_{ij}(s) = \left\{ \sum_\alpha \frac{g_i^{(\alpha)} g_j^{(\alpha)}}{m_\alpha^2 - s} + f_{ij}^{scatt.} \frac{1\,GeV^2 - s_0^{scatt.}}{s - s_0^{scatt.}} \right\} \frac{1 - s_{A0}}{s - s_{A0}} \left(s - s_A m_\pi^2 / 2 \right)$$

Pole term   Smooth part   Alder zero term

K matrix poles(α): $f_0(980)$, $f_0(1300)$, $f_0(1200-1600)$, $f_0(1500)$, $f_0(1750)$

F-vector

The $\pi\pi$ component of the F vector:

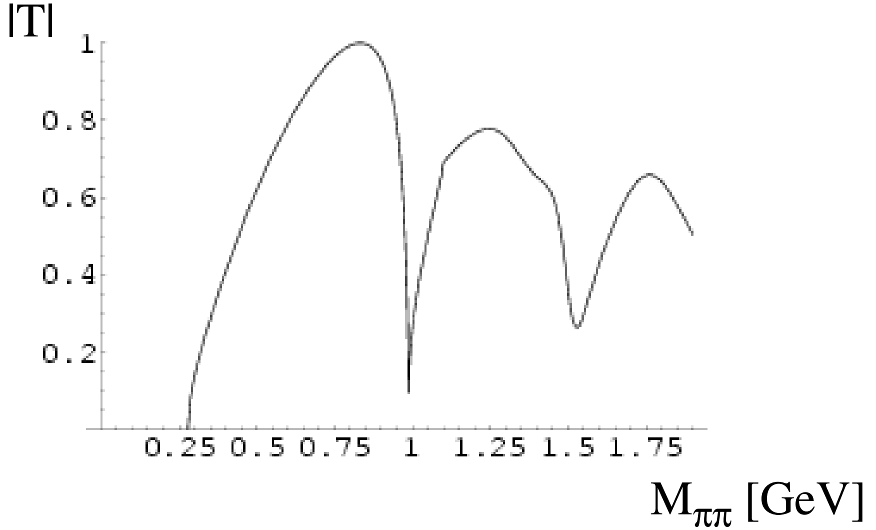
$$F_1 = (I - iK\rho)^{-1}_{1j} \left\{ \sum_\alpha \frac{\beta_\alpha g_j^{(\alpha)}}{m_\alpha^2 - s} + f_{1j}^{prod.} \frac{1\,GeV^2 - s_0^{prod.}}{s - s_0^{prod.}} \right\} \frac{1 - s_{A0}}{s - s_{A0}} (s - s_A m_\pi^2/2)$$

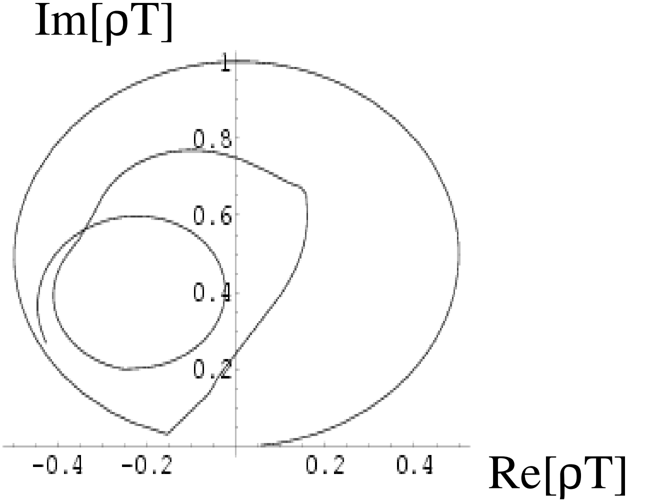
β_α and f_{1j}^{prod} are free parameters in our fit

$s_0^{prod} = s_0^{scatt}$ so far

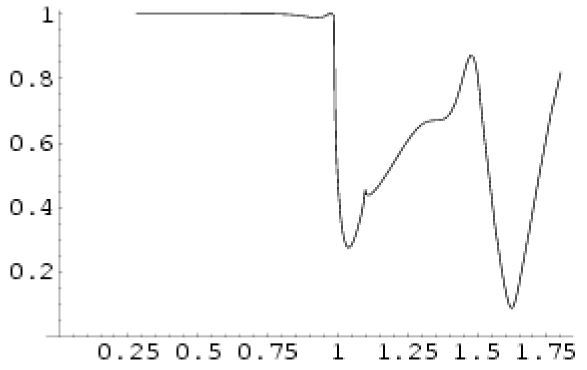
the "zero term" can be omitted in the P vector

The transition matrix: $T = (I - i\,K\rho)^{-1}\,K$

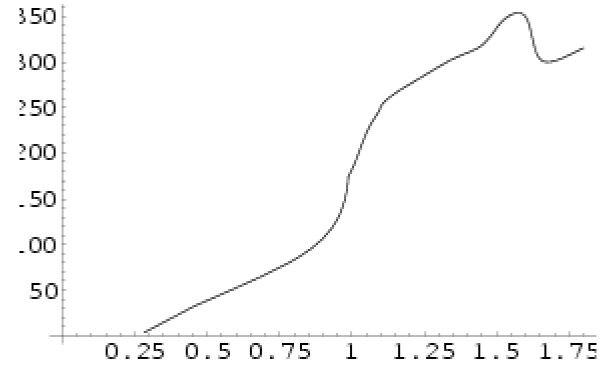




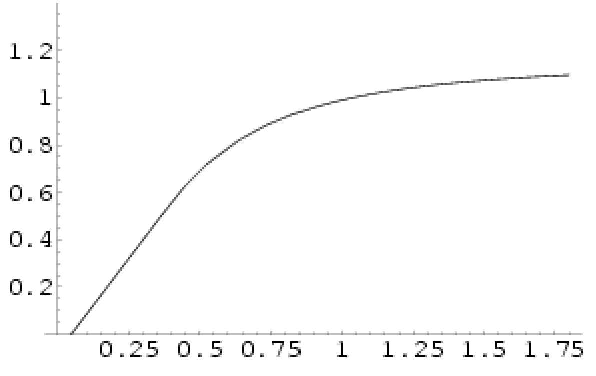
K-Matrix parametrization



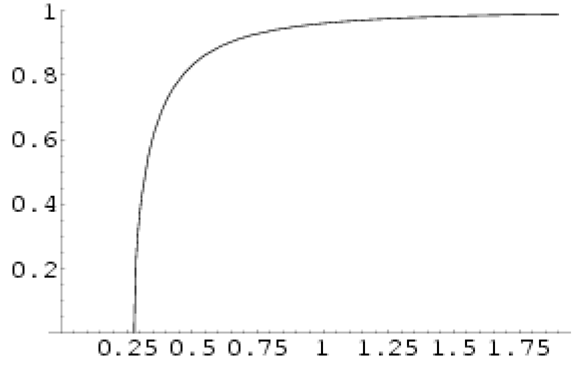
elasticity



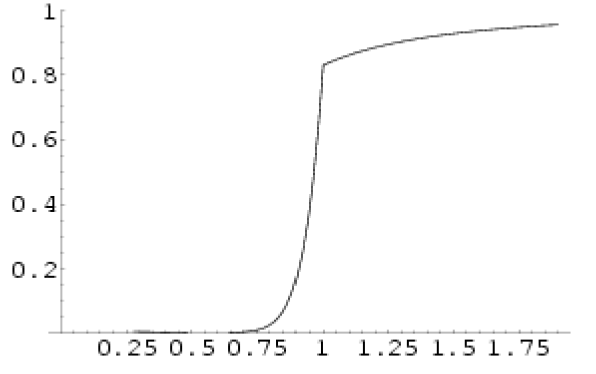
phase shift



Alder zero term suppression near $\pi\pi$ threshold

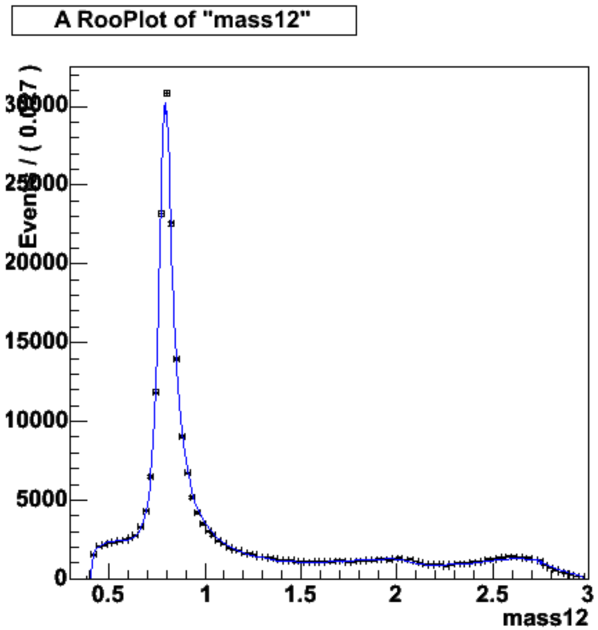


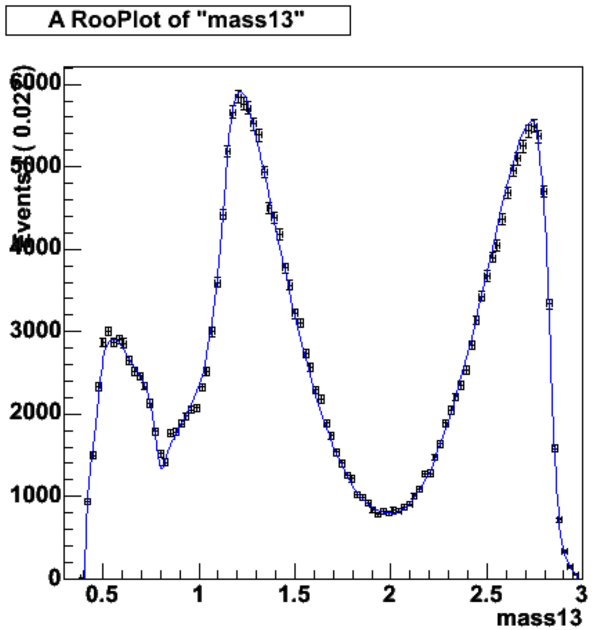
$\pi\,\pi$ phase space

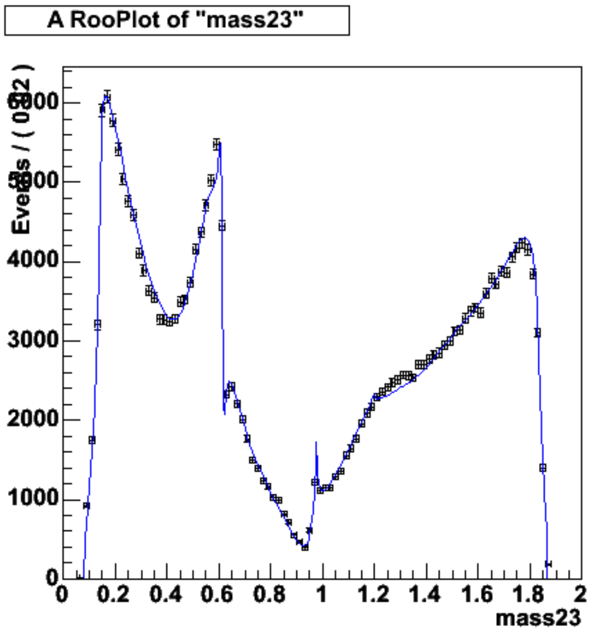


4 π phase space

Fit result (I)

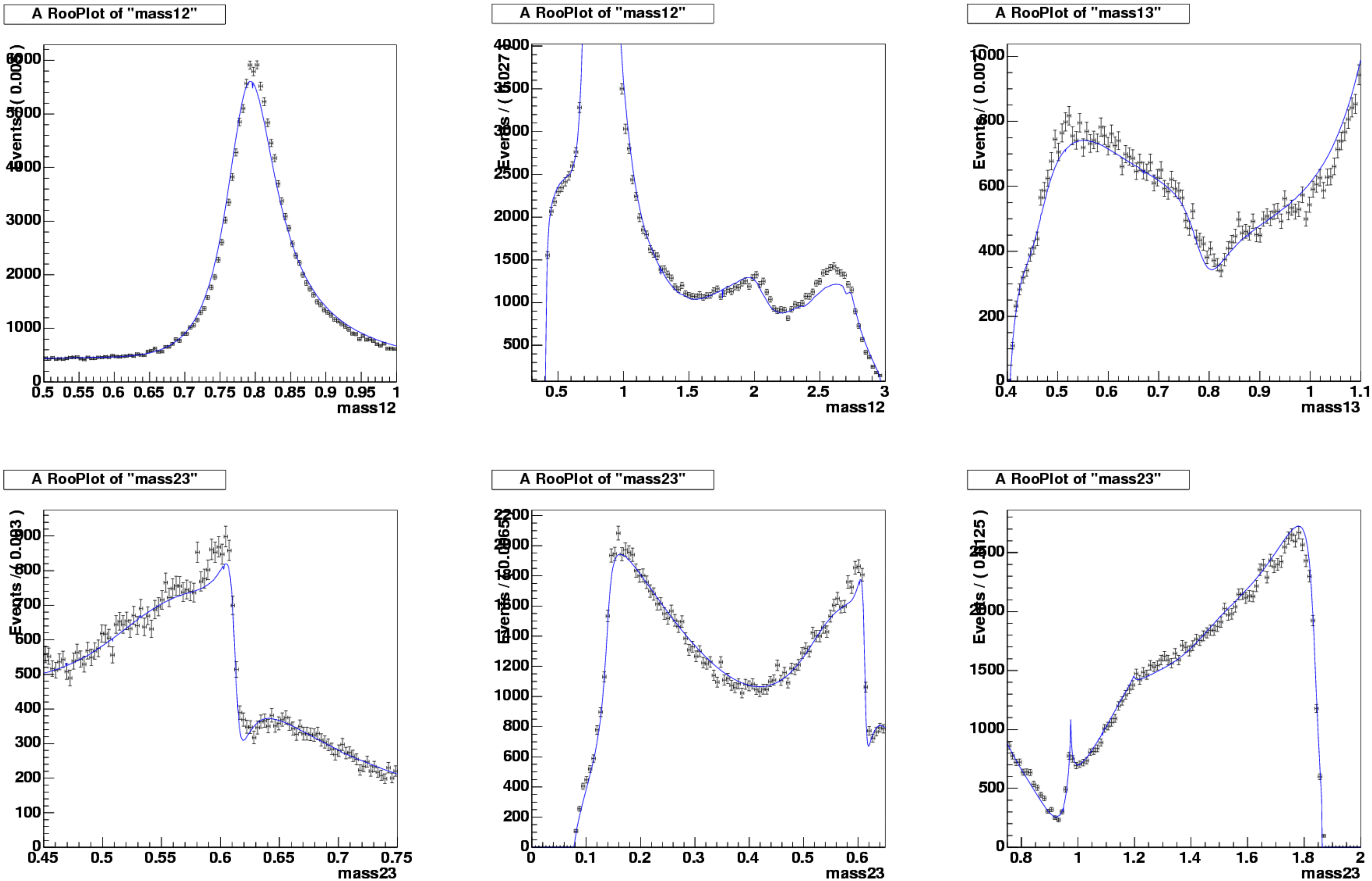






- Values of mass and wight of B.-W. terms fixed to the P.D.G. 2004 values.
- Amplitudes and phases of B.-W. terms floated.
- Parameter of the Production vector floated
- Parameter on the K-matrix fixed.

Fit result (II)



Background effect

	flat bkg val.	flat bkg err	fit bkg val	fit-bkg err	pull
Kst1410_Im	-0.08	0.045	-0.084	0.045	0.130
Kst1410_Re	-0.07	0.050	-0.067	0.049	0.092
K2*1430_DCS_Im	-0.13	0.021	-0.126	0.021	0.115
K2*1430_DCS_Re	0.03	0.022	0.035	0.022	0.118
K2*1430_Im	-0.55	0.029	-0.559	0.029	0.174
K2*1430_Re	0.84	0.022	0.846	0.022	0.301
Kst1430_DCS_Im	-0.17	0.037	-0.190	0.037	0.362
Kst1430_DCS_Re	0.41	0.034	0.422	0.034	0.150
Kst1430_Im	-0.5	0.046	-0.467	0.047	0.433
Kst1430_Re	2.81	0.042	2.808	0.042	0.057
Kst1680_Im	1.13	0.245	1.129	0.244	0.012
Kst1680_Re	-5.04	0.174	-5.023	0.173	0.054
Kstminus_Im	1.33	0.011	1.326	0.011	0.330
Kstminus_Re	-1.1	0.012	-1.101	0.012	0.314
Kstplus_Im	-0.12	0.004	-0.125	0.004	0.154
Kstplus_Re	0.11	0.004	0.110	0.004	0.442
f2_1270_Im	-0.6	0.032	-0.604	0.032	0.197
f2_1270_Re	0.76	0.024	0.769	0.023	0.180
omega782_Im	0.03	0.001	0.031	0.001	0.203
omega782_Re	-0.02	0.001	-0.020	0.001	0.227
rho1450_Im	-0.19	0.087	-0.201	0.086	0.101
rho1450_Re	1.22	0.048	1.194	0.049	0.404
beta1_Im	0.29	0.141	0.32	0.14	0.110
beta1_Re	-2.82	0.119	-2.89	0.12	0.417
beta2_Im	4.22	0.226	4.23	0.23	0.023
beta2_Re	8.29	0.148	8.43	0.15	0.639
beta3_Im	5.05	1.901	5.64	1.91	0.222
beta3_Re	2.69	1.333	3.26	1.34	0.303
beta4_Im	1.44	0.217	1.35	0.22	0.270
beta4_Re	7.5	0.236	7.68	0.24	0.545
fp1_Im	-9.61	0.276	-9.67	0.28	0.146
fp1_Re	-7.13	0.282	-7.28	0.28	0.389

use of cartesian coordinates to better evaluate the low amplitudes component

the value are differs less than 1 σ changing bkg parametrization

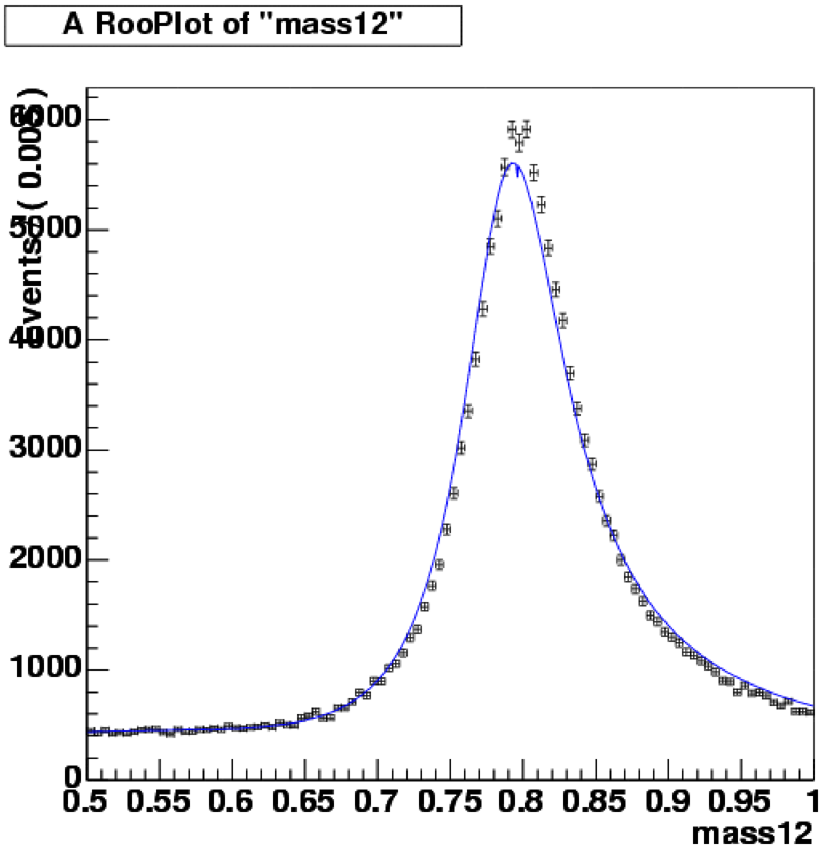
Fit fractions

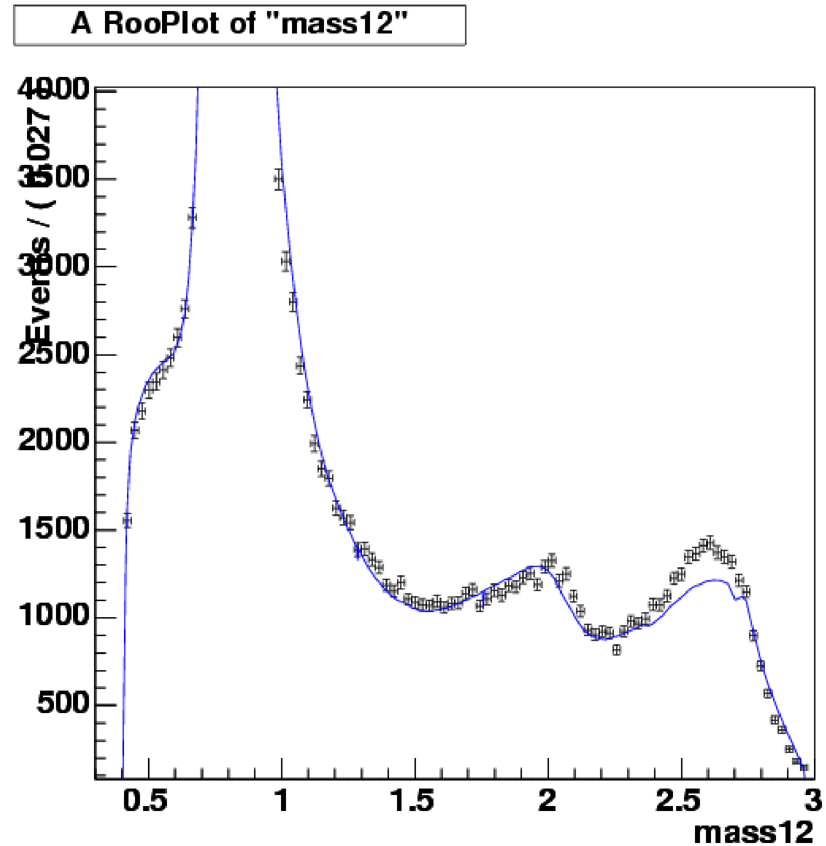
	K-M fit [%]	B-W fit [%]
Rho770	23.28	22.33
Kst1410	0.01	0.39
K2*1430_DCS	0.04	0.01
K2*1430	2.30	2.70
Kst1430_DCS	0.28	0.60
Kst1430	11.46	8.37
Kst1680	6.46	0.35
Kstminus	60.25	58.51
Kstplus	0.54	0.59
F2_1270	2.99	2.95
Omega782	0.52	0.56
Rho1450	1.05	0.28
S-wave	14.20	19.29
NonReson	------------	6.82
SUM	123.39	123.75

the sum of the fit fraction is quite similar in the two fits

The S-wave fit fraction is larger in the BW fit as expected

Fit problems

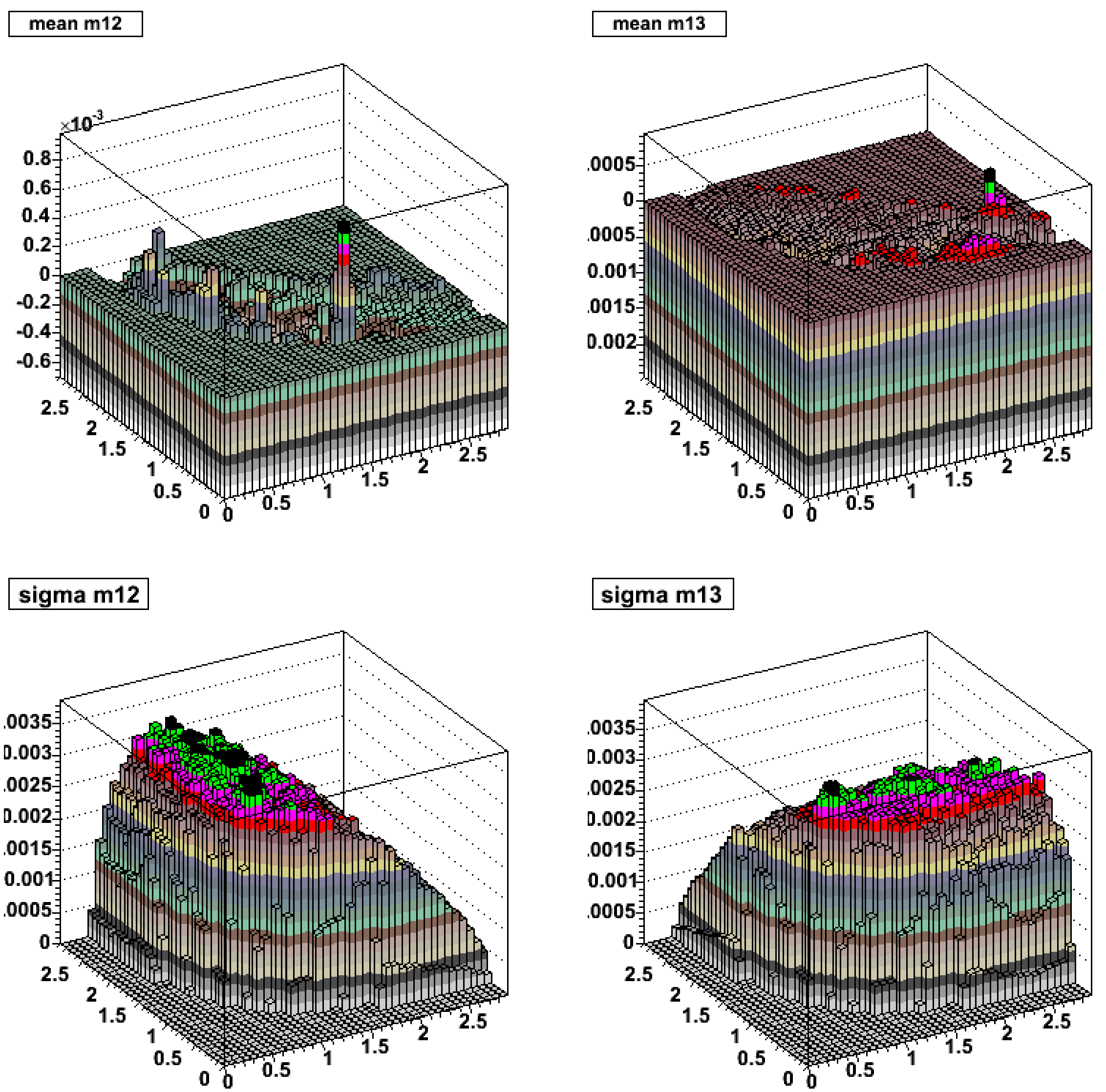




$K^{*}(890)$ shape maybe due to resolution effect

hight $m(K_S\,\pi^{-})$ value maybe due to K–π S–wave (only $K^{*}_{0}(1430)$ in the fit)

Resolution function



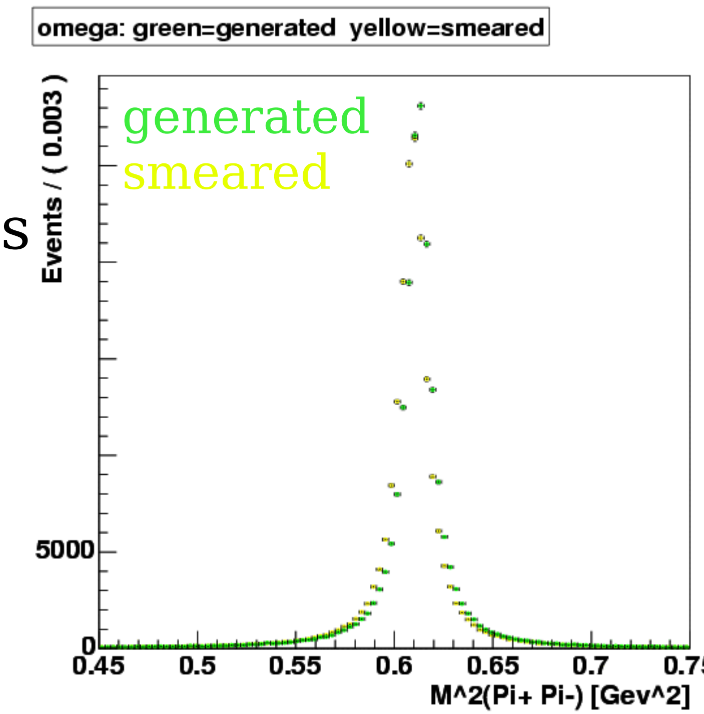
Resolution function evaluated as a function of the Dalitz plot.

m_{ij}(gen.)-m_{ij}(rec.) fitted with 2 gaussians in bins of the Dalitz plot

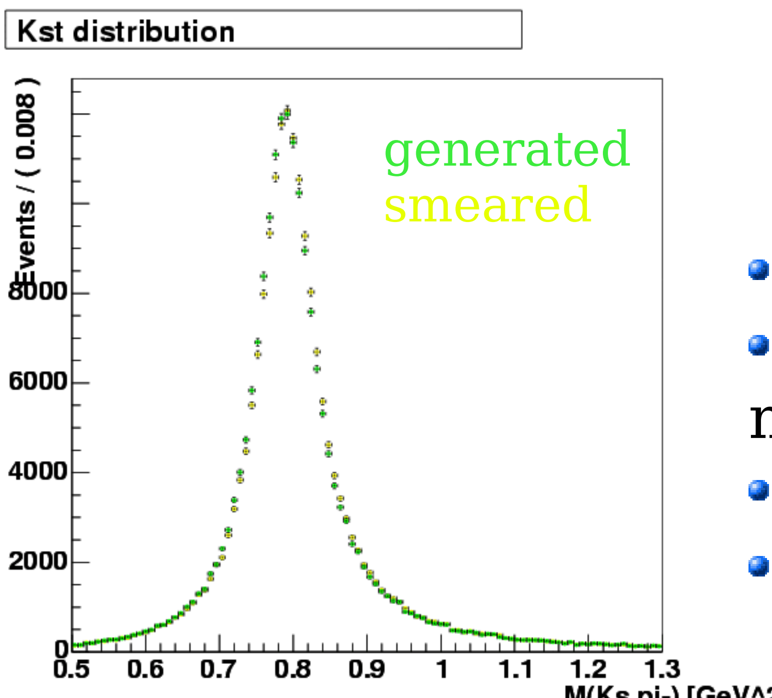
a maximum of the smearing effect is present in the region of $K^{*}(890)$ CA and DCS

Smearing effect

- Generate a sample of K*(892) or ω(782)
- Smear the sample according to the resolution function
- Fit the generated and the smeared samples



parameter	generated	smeared
$K^*(892)$ mass	8.9222e-01 $\pm$ 8.00e-05	8.9348e-01 $\pm$ 8.02e-05
$K^*(892)$ width	5.1208e-02 $\pm$ 1.86e-04	5.1232e-02 $\pm$ 1.86e-04
$\omega(782)$ mass	7.8246e-01 $\pm$ 1.48e-05	7.8053e-01 $\pm$ 1.36e-05
$\omega(782)$ width	8.8380e-03 $\pm$ 2.67e-05	8.8995e-03 $\pm$ 2.93e-05



- Negligible effect on the width
- 1.3 (2.1) MeV/c^2 shift for the K*(892) (ω(782)) mass
- Low ω(782) amplitude, neglect the affect
- Shift the K*(892) mass

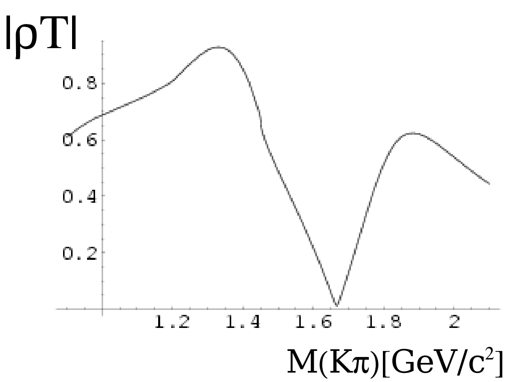
K–π S–wave: K–matrix

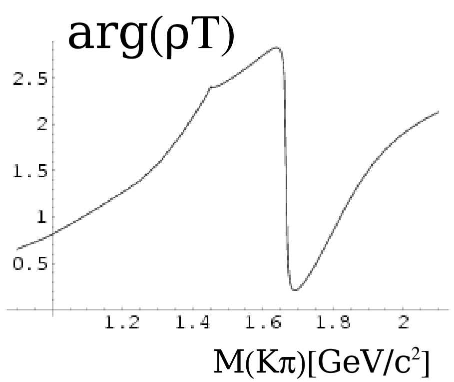
V.V. Anisovich, A.V. Sarantsev (Phys. Lett. B 413 (1997) 137-146)

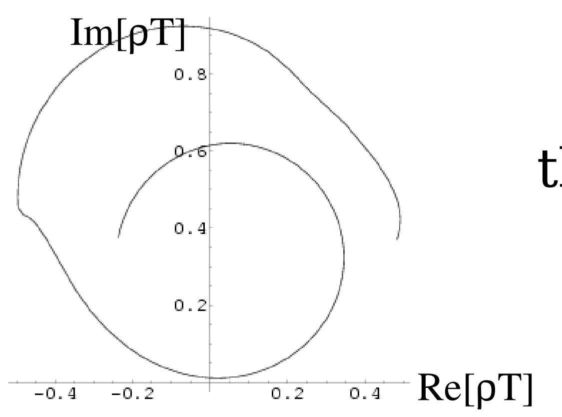
$$K_{ij}(s)=\sum_{\alpha}\frac{g_i^{(\alpha)}g_j^{(\alpha)}}{m_\alpha^2-s}+f_{ij}^{scatt.}\frac{1.5\,GeV^2-s_0^{scatt.}}{s-s_0^{scatt.}}$$

modes(i,j): K π, K η', K 3π
2 poles: 1.16, 1.89 GeV/c^2

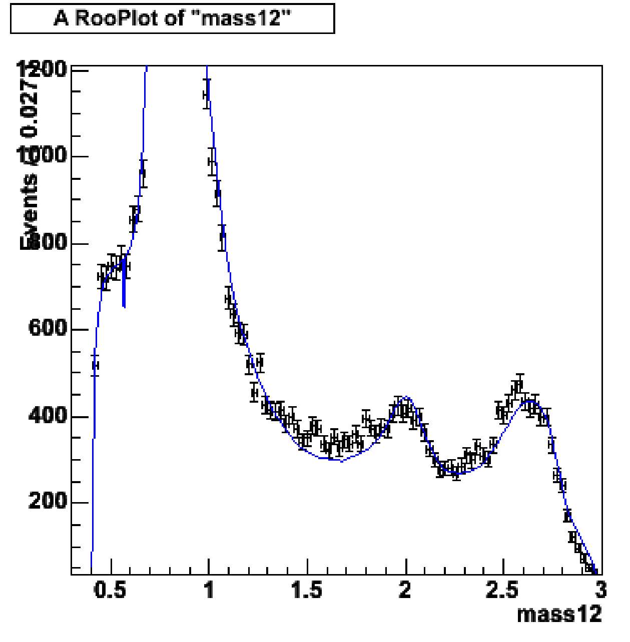
problem: defined in [0.9–2.1] GeV/c^2







we cannot extend the parametrization below 0.9 GeV/c^2

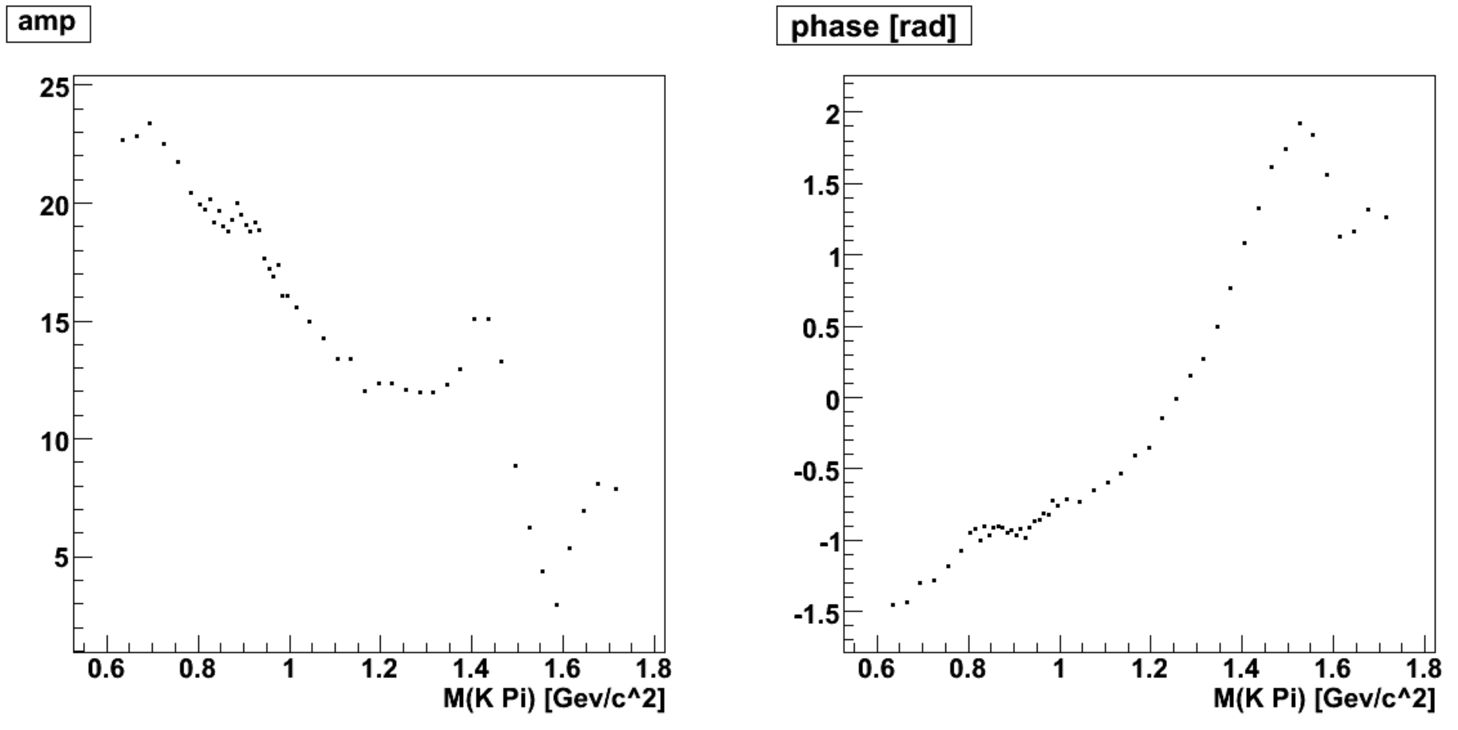


Better hight m(K_S π^-) value description

K–π S–wave from D decays

K–π S–wave extracted from A.Palano in $D^+ \to K^- \pi^+\pi^+$ decay

problems: errors not available, impossible to separate the different production component.



χ^2 evaluation

- The χ^2 value depend from the binning then is impossible to give to the χ^2 a meaning of goodness of fit
- Anyhow the χ^2 can be used to select from different models.

Starting with a 300x300 bins in the Dalitz plot and then merging the bins until having more than 10 events per bin:

for the fit with flat background:

$$\chi^2 = 6640/(3970-32) = 1.69$$

for the fit with sidebands background:

$$\chi^2 = 6593/(3970-32) = 1.67$$

Conclusion

- Run 1-4 selection give more than 25000 events
- Purity of the sample 97.7 %
- Absence of $M(D^0)$ peaking background, it is possible to use the $M(D^0)$ sidebands to parametrize the background
- The indetermination of the background shape can be taken into account with a systematic (2.3 % of background).
- The V.V. Anisovich, A.V. Sarantsev $\pi\pi$ S-wave parametrization works fine for the $D^0 \to K_S \pi^- \pi^+$ decay.
- Problem in the $K^*(890)$ shape, maybe due to resolution effects. Try to shift $K^*(890)$ mass.
- Problem in the hight $m(K_S \pi^-)$ value maybe due to K-π S-wave
- A satisfactory K-π S-wave parametrization not present, work ongoing.
- Final model still not decided, a χ^2 can help to select a model.
- Documentation in BAD #1237