Partial Wave Analysis Activities at Bochum

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RUHR UNIVERSITÄT BOCHUM RUB

Outline

- Status of the PAWIAN software
  - summary of the (new) functionalities

- PWA activities with relevance for PANDA
  - Crystal Barrel @ LEAR data
  - motivation related to PANDA-specific aspects
  - channels of interest

- PWA activities with BESIII data
  - motivation
  - channels of interest

PAWIAN Package

PWA activities for PANDA started in Bochum in spring 2010 with the aims:

- to develop a generic, user friendly and highly modular PWA software package
- to support all physics cases to be studied with PANDA and partly other hadron spectroscopy experiments

Software package PAWIAN (**PA**rtial **W**ave **I**nteractive **AN**alysis) already in a good shape and first analyses are in progress

- Full hypothesis and other input settings defined via configuration files
- Event based maximum likelihood fit
- Minimization with MINUIT2 in multithreaded and networked mode
- qft++: decay amplitudes in various formalisms *(M. Williams (CLAS, GlueX)* Computer Physics Communications, Vol. 180, Issue 10, 2009)

PAWIAN: Status

- Supported reactions
  - $\bar{p}p$: L_{max} unlimited, different L combinations for each production mode possible
  - e^+e^- : initial state described in helicity formalism
- Formalisms (so far for mesons only)
  - helicity and canonical
  - Rarita Schwinger (still to be validated)
- Event generator
  - with obtained fit result and phase space in PAWIAN ASCII-format and HepMC format (so far not implemented in generic part)
- QA and evaluation
  - automated histogramming; trees
  - goodness of fit: logLh+ndf; BIC and AIC (Bayes and Akaike Information Criterion)
  - fractions of the individual waves incl. statistical errors
  - extraction of the spin density matrix incl. statistical error
  - ...

PAWIAN Package: Configuration File

General Settings

Mode for the error logger:
debug, trace, routine, info, warn, alert

```
errLogMode = debug

datFile     = /data/sleipnir1/DataPPPMETA.dat
mcFile  = /data/sleipnir1/McPPPMETA.dat

unitInFile = MEV
orderInFile = Px Py Pz E

ratioMcToData = 3
useEventWeight = true

pdgTableFile = /Particle/pdtNew.table

cacheAmps = true

paramFile  = ./defaultparams.dat

mode = pwa
```

access to the data

access to the particle data table

enable/disable caching of fitted amplitudes

access to initial fit parameter

application mode:
pwa, server, client, dumpDefaultParams, qa, plot, spinDensity

PAWIAN Package: Configuration File

Treating of fit parameter

```
# PwaParamBuddy: Fixing 34 parameters.

# one pbarp singlet and one triplet phase
mnParFix = J0P-1C1L0S0pbarpPhi
mnParFix = J1P-1C-1L0S1pbarpPhi

# productions and decays
mnParFix = J0P-1C1L2S2_J0P-1C1Toa2(1320)_pionMag
mnParFix = J0P-1C1L2S2_J0P-1C1Toa2(1320)_pionPhi
mnParFix = J1P-1C-1L2S2_J1P-1C-1Toa2(1320)_pionMag
mnParFix = J1P-1C-1L2S2_J1P-1C-1Toa2(1320)_pionPhi
mnParFix = J1P1C-1L1S2_J1P1C-1Toa2(1320)_pionMag
mnParFix = J1P1C-1L1S2_J1P1C-1Toa2(1320)_pionPhi
```

fixing

```
replaceParamSuffix  = a0(980)+_pion- a0(980)_pion
replaceParamSuffix  = a0(980)-_pion+ a0(980)_pion
replaceParamSuffix  = a0(980)+Topion+_eta a0(980)Topion_eta
replaceParamSuffix  = a0(980)-Topion-_eta a0(980)Topion_eta

replaceMassKey = a2(1320)+ a2(1320)
replaceMassKey = a2(1320)- a2(1320)
replaceMassKey = a0(980)+ a0(980)
replaceMassKey = a0(980)- a0(980)
```

merging of fit parameter
and replacing of
fit parameter names

PAWIAN Package: Configuration File

Hypotheses and choice of models and formalisms

```
production = rho0 eta
production = omega eta
production = a2(1320)+ pion-
production = a2(1320)- pion+
production = a0(980)+ pion-
production = a0(980)- pion+
production = f2(1270) eta
production = pipiS eta

decay = Cano rho0 To pion+ pion-
decay = Cano omega To pion+ pion-
decay = Cano a2(1320)+ To pion+ eta
decay = Cano a2(1320)- To pion- eta
decay = Cano a0(980)+ To pion+ eta
decay = Cano a0(980)- To pion- eta
decay = Cano f2(1270) To pion+ pion-
decay = Cano pipiS To pion+ pion-
```

Supported formalisms: canonical (“Cano”), helicity (“Heli”) and tensor (“Tensor”)

definition of the decay chain

```
addDynamics = rho0 BreitWigner
addDynamics = omega BreitWigner
addDynamics = a2(1320)+ BreitWigner
addDynamics = a2(1320)- BreitWigner
addDynamics = a0(980)+ Flatte K+ K
addDynamics = a0(980)- Flatte K- K
addDynamics = f2(1270) BreitWigner
addDynamics = pipiS PiPiSWaveAS
```

Supported dynamics: Breit-Wigner, Flatté, K-matrix with $(\pi\pi)_S$- and $(K\pi)_S$-wave

definition of dynamics

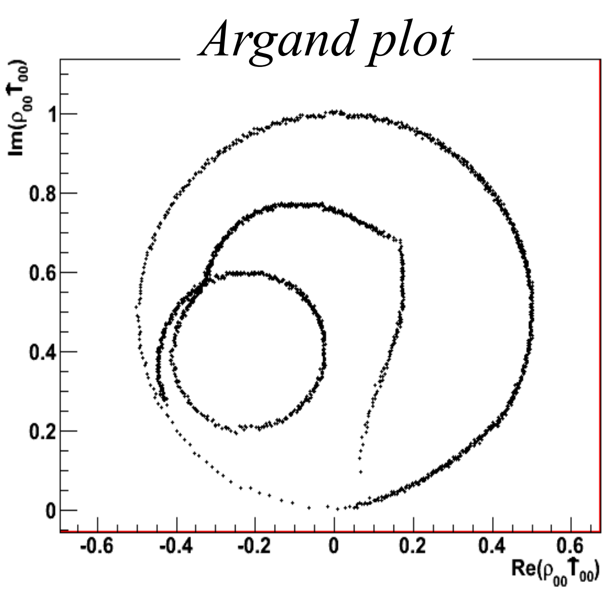
K-Matrix Parametrization: $(\pi\pi)_S$-wave

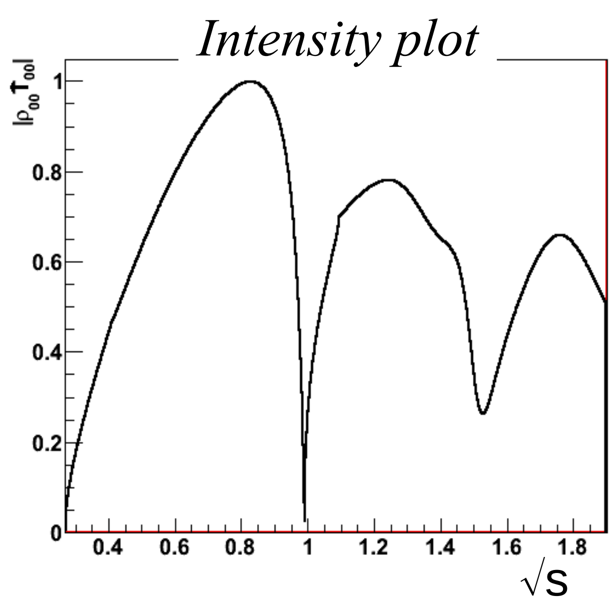
- Parametrization by *Anisovich and Sarantsev, Eur. Phys. J. A16, 229(2003)*
- 5 poles and 5 different channels up to 1900 MeV/c^2

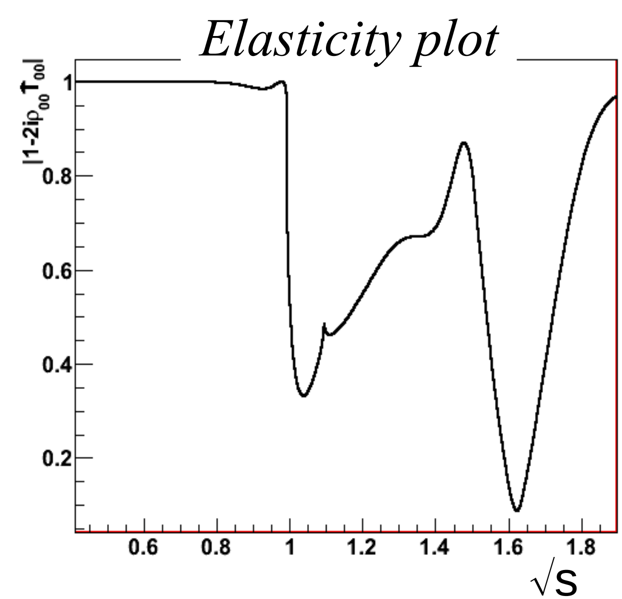
TABLE I. K-matrix parameters from a global analysis of the available $\pi\pi$ scattering data from threshold up to 1900 MeV/c^2 [39]. Masses and coupling constants are given in GeV/c^2.

m_α	$g^\alpha_{\pi^+\pi^-}$	$g^\alpha_{K\bar{K}}$	$g^\alpha_{4\pi}$	$g^\alpha_{\eta\eta}$	$g^\alpha_{\eta\eta'}$
0.651 00	0.228 89	−0.553 77	0.000 00	−0.398 99	−0.346 39
1.203 60	0.941 28	0.550 95	0.000 00	0.390 65	0.315 03
1.558 17	0.368 56	0.238 88	0.556 39	0.183 40	0.186 81
1.210 00	0.336 50	0.409 07	0.856 79	0.199 06	−0.009 84
1.822 06	0.181 71	−0.175 58	−0.796 58	−0.003 55	0.223 58
$s_0^{\rm scatt}$	$f_{11}^{\rm scatt}$	$f_{12}^{\rm scatt}$	$f_{13}^{\rm scatt}$	$f_{14}^{\rm scatt}$	$f_{15}^{\rm scatt}$
−3.926 37	0.233 99	0.150 44	−0.205 45	0.328 25	0.354 12
s_{A0}	s_A				
−0.15	1				

Spectra obtained with PAWIAN

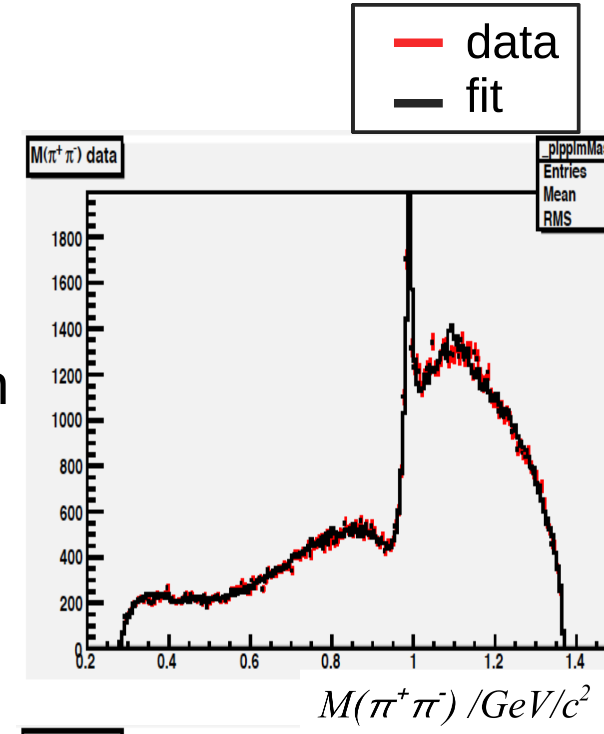


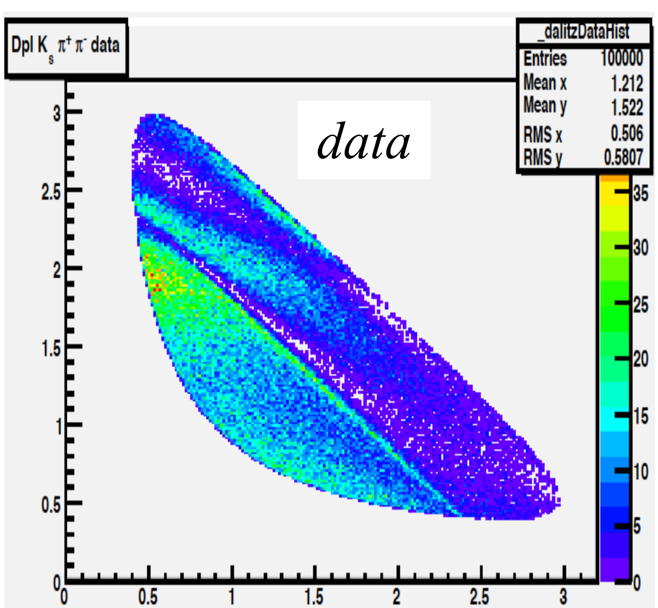


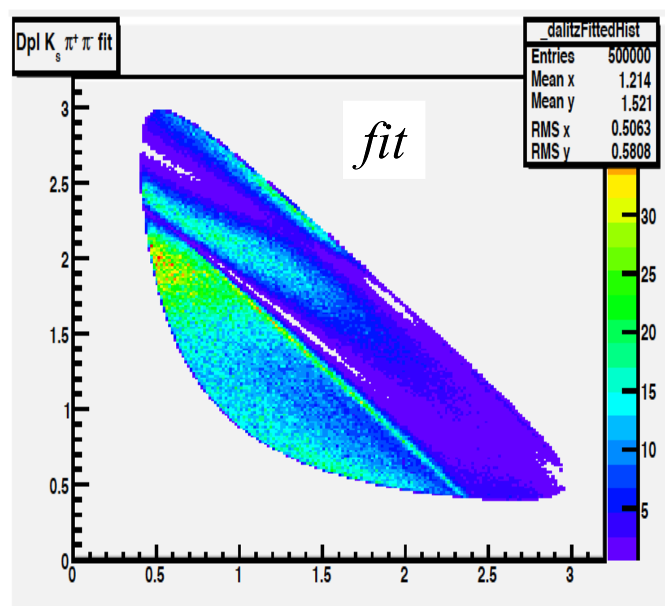


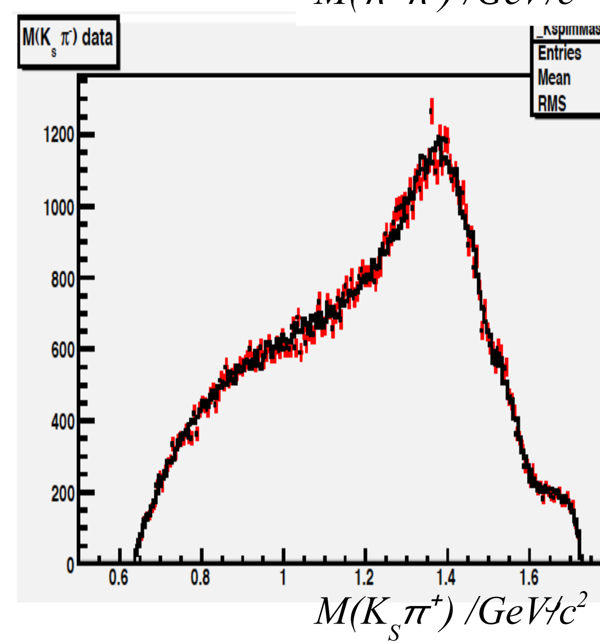
K-Matrix Parametrization: $(K\pi)_S$-wave

- K-Matrix parametrization used by FOCUS
  - *Phys. Lett. B653 (2007) 1-11*
- Test with toy MCs: $D \rightarrow K_S \pi^+ \pi^-$
  - BaBar generator with LASS parametrization for $(K\pi)_S$-wave and Anisovich K-matrix parametrization for $(\pi\pi)_S$- wave provided by *A. Pitka*
  - Good agreement between fit and toy data: χ^2/ndf = 1.03









PAWIAN Package: Configuration File

Histogramming and Parallelization

```
histMass = pion+ pion-
histMass = pion+ eta
histMass = pion- eta

histAngles = pion+ from pion+ pion- eta
histAngles = pion- from pion+ pion- eta
histAngles = eta from pion+ pion- eta
histAngles = pion+ from pion+ pion-
histAngles = eta from pion+ eta
histAngles = eta from pion- eta
```

standard histograms for invariant masses and angular decay distributions

```
noOfThreads = 4
serverPort = 22333
serverAddress = pc14
noOfClients = 8
```

setup for multithreaded and networked mode

PWA Challenges @ PANDA

$\bar{p}p$ production mechanism

- Contributing initial $\bar{p}p$ states rise with increasing beam momentum
  - number of fit parameters rises dramatically
- $p_{\bar{p},max}$ = 1.94 GeV/c @ CB-LEAR → $L_{max} \approx 5$
- $p_{\bar{p},max}$ = 15 GeV/c @ PANDA → L_{max} = ?
  - threshold effects relevant for production of heavy resonances (e.g. charmonia)

J	Singulett $\lambda = 0$	J^{PC}	Triplett $\lambda = \pm 1$	J^{PC}	Triplett $\lambda = \pm 1, 0$	J^{PC}
0	$^1S_0$	0^{-+}			$^3P_0$	0^{++}
1	$^1P_1$	1^{+-}	$^3P_1$	1^{++}	$^3S_1, {}^3D_1$	1^{--}
2	$^1D_2$	2^{-+}	$^3D_2$	2^{--}	$^3P_2, {}^3F_2$	2^{++}
3	$^1F_3$	3^{+-}	$^3F_3$	3^{++}	$^3D_3, {}^3G_3$	3^{--}
4	$^1G_4$	4^{-+}	$^3G_4$	4^{--}	$^3F_4, {}^3H_4$	4^{++}
5	$^1H_5$	5^{+-}	$^3H_5$	5^{++}	$^3G_5, {}^3I_5$	5^{--}
6	$^1I_6$	6^{-+}	$^3I_6$	6^{--}	$^3H_6, {}^3J_6$	6^{++}

Statistics

- Low cross sections for some channels of interest (pb-nb)
- How many events are needed for reliable fits?

PWA related to PANDA

- Analysis of Crystal Barrel @ LEAR data
  - $\bar{p}p$ annihilation with beam momenta up to 1.94 GeV/c $\rightarrow$ overlap with PANDA
  - offline software installed and running
  - raw data available on disk

- Investigation of $\bar{p}p$ annihilation process and production mechanism of vector mesons at various beam momenta (0.6-1.94 GeV/c)
  - $\bar{p}p \rightarrow \omega \pi^0 \rightarrow (\gamma\pi^0)\, \pi^0$
  - $\bar{p}p \rightarrow \omega \pi^0 \rightarrow (\pi^+\pi^-\pi^0)\, \pi^0$
  - $\bar{p}p \rightarrow K^+K^-\pi^0$ with the focus on $\phi\pi^0$ and $K^{*\pm}K^{\mp}$

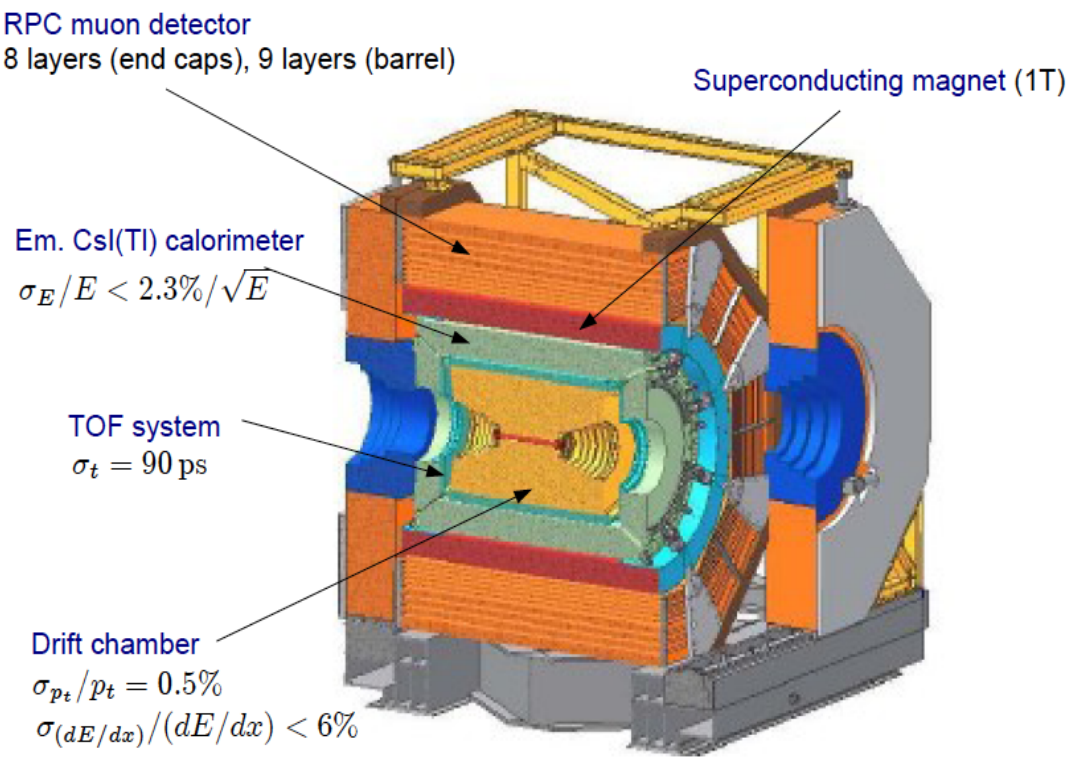
  J. Pychy (PhD Thesis)

- Identification of intermediate resonances in $\bar{p}p$ reactions
  - $\bar{p}p \rightarrow \pi^+\pi^-\eta$ @ 900 MeV/c *E. Köz (Master Thesis)*

PWA of BESIII Data

- Symmetric e^+e^- collider
  - beam energy 1.0-2.3 GeV
  - max. luminosity 10^{33} $cm^{-2}s^{-1}$

- Physics program
  - light meson spectroscopy
  - charmonium spectroscopy
  - open charm physics
  - . . .



- PWA activities focused on search for exotic particles
  - initial states limited to $J^{PC}=1^{--}$ with helicities $\lambda=\pm1$

- Radiative decays from charmonia, especially from J/ψ
  - gluon rich process

J/ψ->$\phi\phi\gamma$

- Glueballs decay flavor blind
  - strong coupling to $\phi\phi$
  - one of the most promising channels: J/$\psi \rightarrow \phi\phi\gamma \rightarrow (K^+K^-) (K^+K^-) \gamma$

- Lightest tensor glueball predicted between 2.0-2.4 GeV/c^2

- Unexpected large cross sections of three f_2 resonances in $\pi^- p \rightarrow n\phi\phi$
  (*Atkin et. al.: Phys.Lett. B201 (1988) 568-572*)

PWA Strategy

- Mass independent fits by scanning the invariant $\phi\phi$ mass
  - identification of the strongest waves

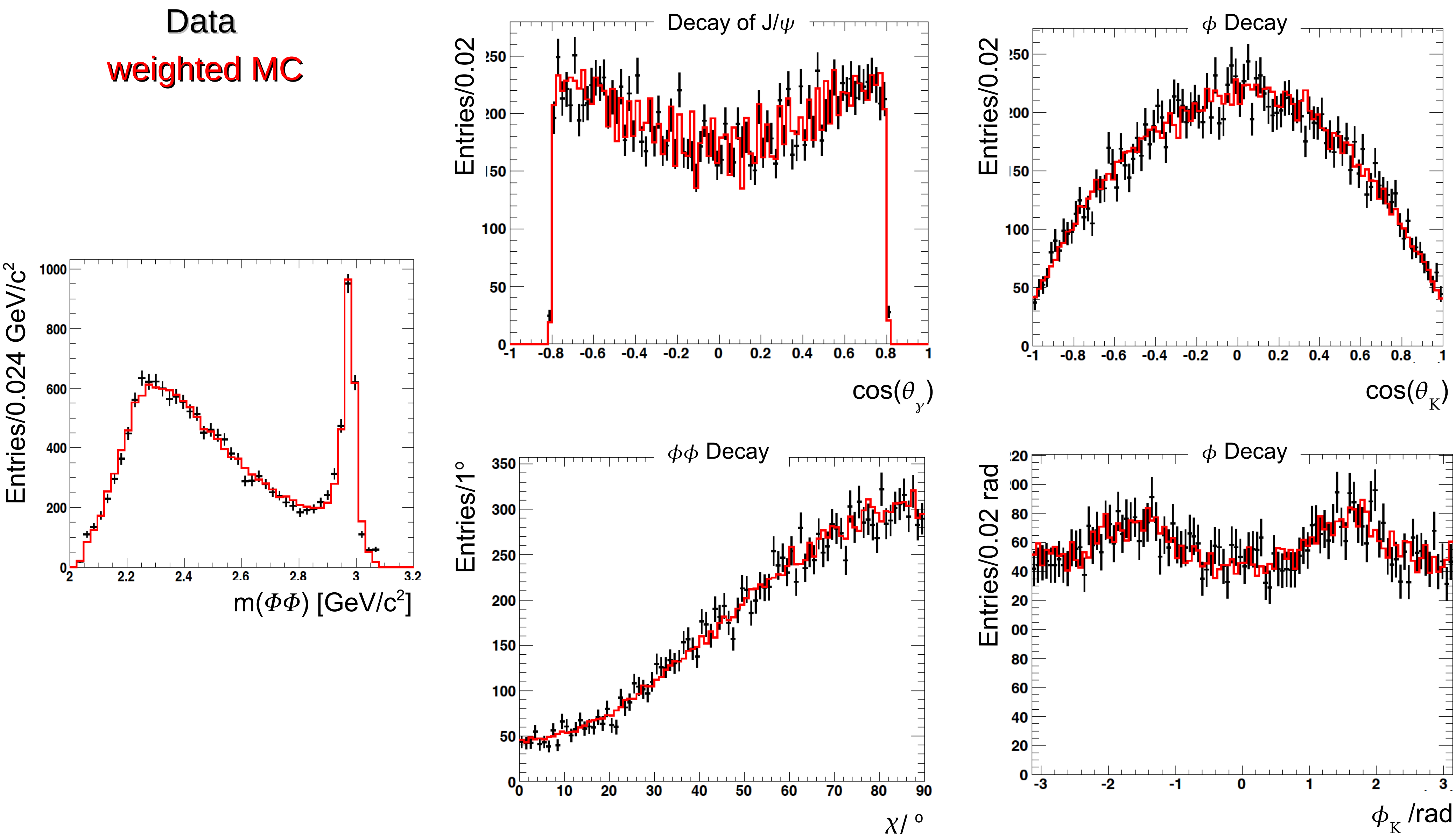
- Mass dependent fits in the complete phase space using Breit-Wigner and Flatté parametrizations

- Helicity formalism

- First results very promising and good description of the data

P. Friedel, PhD thesis, Bochum

Mass dependent fit



PWAs with BESIII-data

$\psi(2S) \rightarrow \chi_{c0}\gamma \rightarrow (K^+ K^- \pi^0 \pi^0)\,\gamma$ *(J. Schulze, PhD Thesis)*

$\psi(2S) \rightarrow \chi_{c0}\gamma \rightarrow (K_S K_L \pi^0 \pi^0)\,\gamma$ *(C. Motzko, PhD Thesis)*

$J/\psi \rightarrow \phi\phi\gamma \rightarrow (K^+K^-)\,(K^+K^-)\,\gamma$ *(P. Friedel, PhD Thesis)*

$J/\psi,\ \psi(2S) \rightarrow \pi^+\pi^-\eta$ *(M. Leyhe, PhD Thesis)*

$J/\psi \rightarrow \omega\phi\gamma \rightarrow (\pi^+\pi^-\pi^0)\,(K^+K^-)\,\gamma$ *(P. Scheffels, Diploma Thesis)*

$J/\psi \rightarrow \omega\omega\gamma \rightarrow (\pi^+\pi^-\pi^0)\,(\pi^+\pi^-\pi^0)\,\gamma$ *(M. Albrecht, PhD Thesis)*

$\psi(2S) \rightarrow \chi_{c1}\gamma \rightarrow (K^+ K^- \eta)\,\gamma$ *(M. Pelizäus)*

$J/\psi \rightarrow \phi\phi\gamma \rightarrow (K^+K^-)\,(K_S K_L)\,\gamma$ *(M. Pelizäus)*