RUB

Production of Vector Mesons in $\bar{p}p$-Reactions

Julian Pychy

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RUHR UNIVERSITÄT BOCHUM RUB

panda

bmb+f Großgeräte der physikalischen Grundlagenforschung

Outline

- Introduction
  - PWA Software
  - Crystal Barrel LEAR
- PWA of CB-LEAR data with relevance for PANDA
  - $\overline{\text{p}}\text{p} \rightarrow \omega\pi^0$
  - $\overline{\text{p}}\text{p} \rightarrow \text{K}^+\text{K}^-\pi^0$
  - $\overline{\text{p}}\text{p} \rightarrow \pi^+\pi^-\eta$
- Summary

Motivations

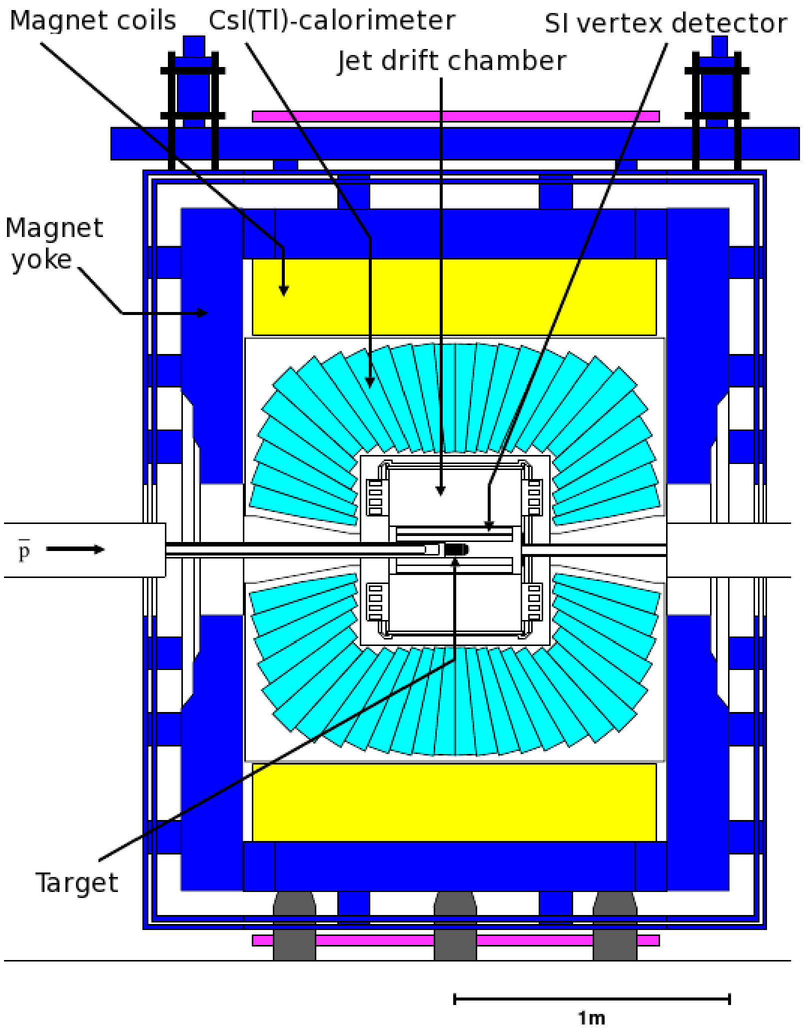
With regard to the upcoming PANDA experiment, analyses of existing p̄p-data are valuable

➡ **Crystal Barrel LEAR**

- Development and test of analysis tools for PANDA, such as the partial wave analysis (PWA) software
- Study of the production of vector mesons and the initial p̄p-states
- Evaluation of the contributing orbital angular p̄p-momenta
  - $p_{\overline{\mathrm{p}},max}$ = 1.94 GeV/c @ CB-LEAR ➡ $L_{max} \approx 5$
  - $p_{\overline{\mathrm{p}}}$ = (1.5 - 15) GeV/c @ PANDA ➡ L_{max} = ?
- Evaluation of the spin density matrix for different mesons
- Modern hardware allows more sophisticated analyses of old data

Crystal Barrel

- Fixed target experiment at LEAR (CERN) data taking 1989 - 1996
- p̄p-annihilation in flight and at rest
- $p_{\overline{\mathrm{p}}}$ = 105 MeV/c ... 2 GeV/c
- $94\% \cdot 4\pi$ detector
- Targets: LH_2, LD_2, GH_2
- Trigger on 0 or 2 charged particles

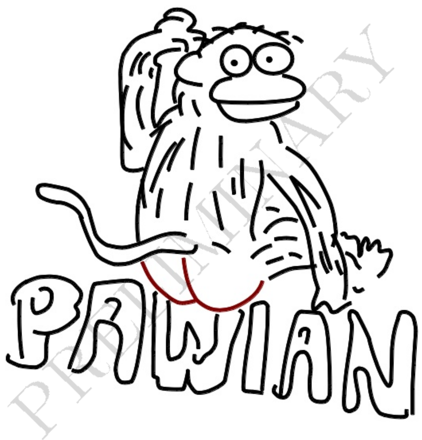


Excellent opportunity for the investigation of specific physics aspects for PANDA

PWA Software Package

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

- To develop a generic 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 have been started

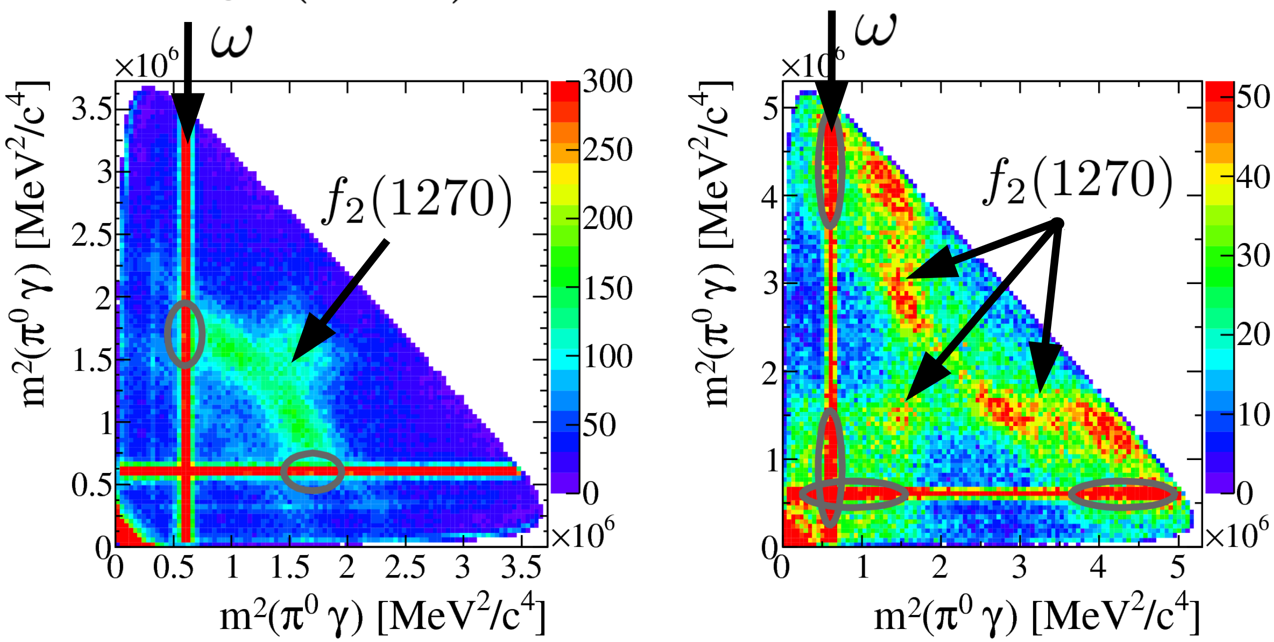
- Full hypothesis and other input settings defined via configuration files
  - Resonances, Decays, ...
  - Formalisms (Canonical, Helicity, Rarita-Schwinger)
  - Dynamics (Breit-Wigner, Flatté, K-Matrix, ...)
- Event based maximum likelihood fit, minimization by MINUIT2
- Multithreading and networking support
- qft++ library for various physical calculations

$\overline{\mathrm{p}}\mathrm{p} \rightarrow \omega\pi^0$ - Data selection

- Relatively simple reaction with easy access to the initial p̄p-system
- Analyzed channels: $\overline{\mathrm{p}}\mathrm{p} \rightarrow \omega(\rightarrow \pi^+\pi^-\pi^0)\pi^0 \rightarrow \pi^+\pi^-4\gamma$
  $\overline{\mathrm{p}}\mathrm{p} \rightarrow \omega(\rightarrow \pi^0\gamma)\pi^0 \rightarrow 5\gamma$
- Various beam momenta between 0.6 and 1.94 GeV/c
- Noticeable background still present after kinematic fit

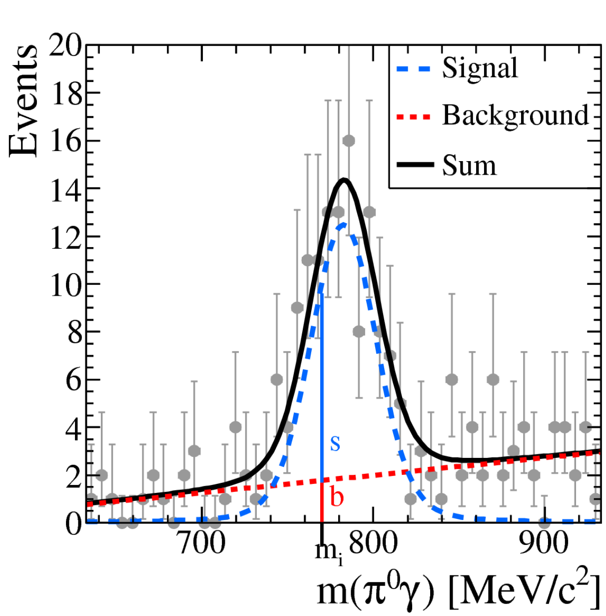
  e.g. from $\overline{\mathrm{p}}\mathrm{p} \rightarrow \pi^0 f_2(1270) \rightarrow \pi^0\pi^0\pi^0$

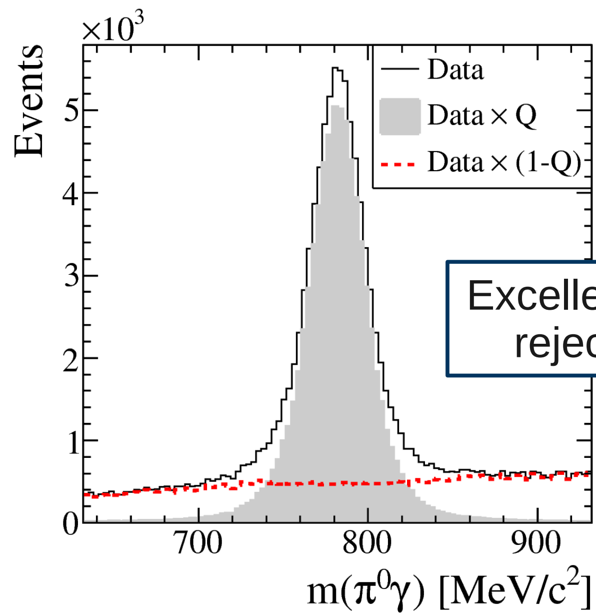
Background crossing the ω-bands!



Background rejection

- New background rejection method based on probabilistic event weights *M. Williams, http://arxiv.org/abs/0809.2548*
- Event weight for each event
  - find n nearest neighbors in phasespace and calculate weight out of signal component in the invariant mass spectrum
- Origin of the background sources not necessarily needed to be known

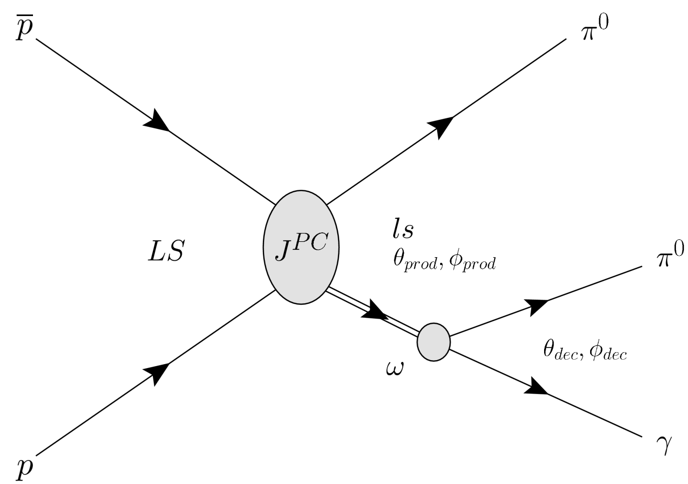




Excellent background rejection power

PWA: $\bar{p}p \to \omega\pi^0$

$$\frac{d\sigma}{d\Omega} \propto \sum_{\substack{\lambda_{\bar p},\lambda_p,\lambda_{\pi^0_r}(=0),\\ \lambda_{\pi^0_d}(=0),\lambda_\gamma}} \left| \sum_{\lambda_\omega} T^{\to\omega\pi^0_r}_{\lambda_{\bar p}\lambda_p\lambda_{\pi^0_r}\lambda_\omega} \cdot A^{\omega\to\pi^0_d\gamma}_{\lambda_\omega\lambda_{\pi^0_d}\lambda_\gamma} \right|^2$$



- Maximum contributing orbital momentum L_{max} is unknown
  - ➡ perform fits for various L_{max} and calculate significance of likelihood improvement

L_{max}	1	2	3	4	5	6	7
Cont. waves	3	7	9	13	15	19	21
Free parameters	4	12	16	24	28	36	40

- Acceptance correction using Monte Carlo events from cbgeant

Fit results and contributing angular momenta

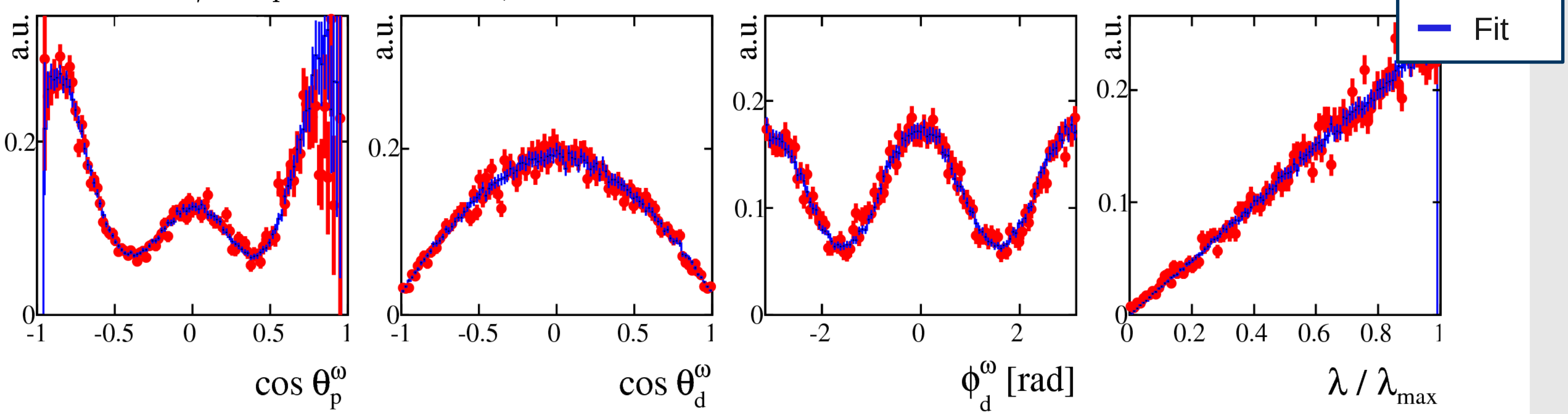
$\omega \to \pi^+\pi^-\pi^0$

$p_{\bar{p}p}$ [MeV/c]	L_{max}	significance of $\mathcal{L}$-ratio $\frac{\ln \mathcal{L}(L_{max})}{\ln \mathcal{L}(L_{max}-1)}$	$\frac{\ln \mathcal{L}(L_{max}+1)}{\ln \mathcal{L}(L_{max})}$	χ^2/ndf
900	4	$4.7\,\sigma$	$0.17\,\sigma$	1.07
1525	4	$13.2\,\sigma$	$0.94\,\sigma$	1.08
1642	5	$3.6\,\sigma$	$0.14\,\sigma$	0.98
1940	5	$13.8\,\sigma$	$0.25\,\sigma$	1.04

$\omega \to \pi^0\gamma$

$p_{\bar{p}p}$ [MeV/c]	L_{max}	significance of $\mathcal{L}$-ratio $\frac{\ln \mathcal{L}(L_{max})}{\ln \mathcal{L}(L_{max}-1)}$	$\frac{\ln \mathcal{L}(L_{max}+1)}{\ln \mathcal{L}(L_{max})}$	χ^2/ndf
600	3	$2.4\,\sigma$	$0.11\,\sigma$	0.91
900	4	$4.9\,\sigma$	$0.01\,\sigma$	1.18
1050	4	$15.1\,\sigma$	$0.86\,\sigma$	0.92
1350	5	$5.8\,\sigma$	$0.02\,\sigma$	1.01
1525	5	$10.3\,\sigma$	$0.1\,\sigma$	1.09
1642	5	$5.6\,\sigma$	$2{\cdot}10^{-3}\,\sigma$	1.09
1800	5	$14.2\,\sigma$	$1.4\,\sigma$	1.14
1940	5	$13.9\,\sigma$	$0.6\,\sigma$	0.96

$\omega \to \pi^0\gamma \quad p_{\bar{p}} = 900\,\mathrm{MeV/c}$



Spin density matrix of the ω

- Provides full information on the production mechanism
- Spin 1 particle: 3x3 complex elements
- Normalization, hermicity and parity conservation yields to only 4 independent parameters

$$\rho = \begin{pmatrix} 1/2(1-\rho_{00}) & \Re\rho_{10} + i\Im\rho_{10} & \rho_{1-1} \\ \Re\rho_{10} - i\Im\rho_{10} & \rho_{00} & -\Re\rho_{10} + i\Im\rho_{10} \\ \rho_{1-1} & -\Re\rho_{10} - i\Im\rho_{10} & 1/2(1-\rho_{00}) \end{pmatrix}$$

$\rho_{00} \neq \rho_{11}$
$\Longrightarrow$ Alignment

- Extraction of the elements via PWA

H. Koch,
Helicity amplitude for pp->ωπ0,
Internal PANDA Note

$$\rho_{\lambda_\omega \lambda'_\omega} = \frac{1}{\sum_{\lambda_{\overline{p}},\lambda_p,\lambda_{\pi^0},\lambda_\omega} |T_{\lambda_{\overline{p}}\lambda_p\lambda_{\pi^0}\lambda_\omega}|^2} \cdot \sum_{\lambda_{\overline{p}},\lambda_p,\lambda_{\pi^0}} T^*_{\lambda_{\overline{p}}\lambda_p\lambda_{\pi^0}\lambda_\omega} T_{\lambda_{\overline{p}}\lambda_p\lambda_{\pi^0}\lambda'_\omega}$$

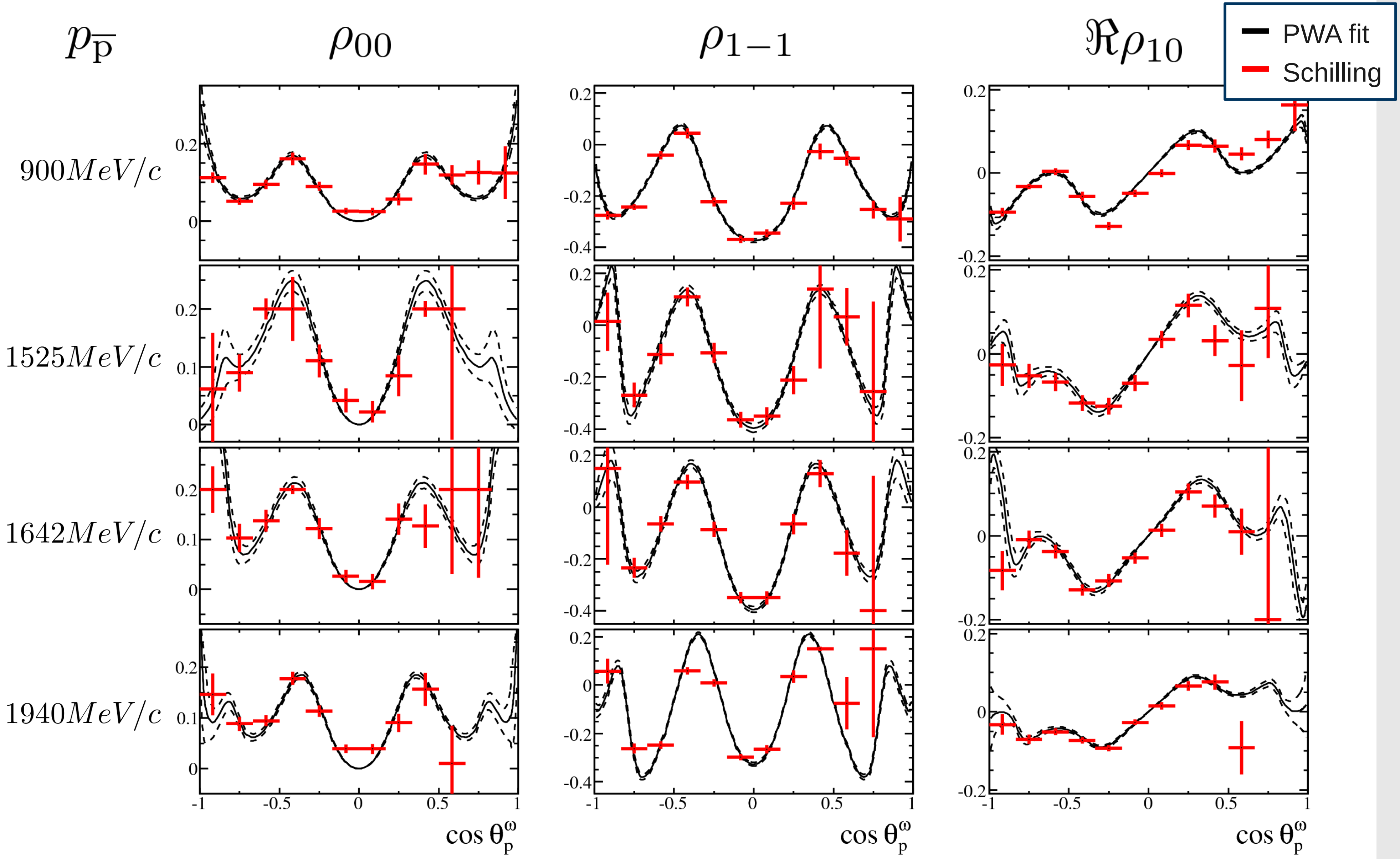
- Or via fit to decay angular distribution

Schilling, Seyboth and Wolf,
Nucl.Phys. B15 (1970) 397-412,
Erratum-ibid. B18 (1970) 332

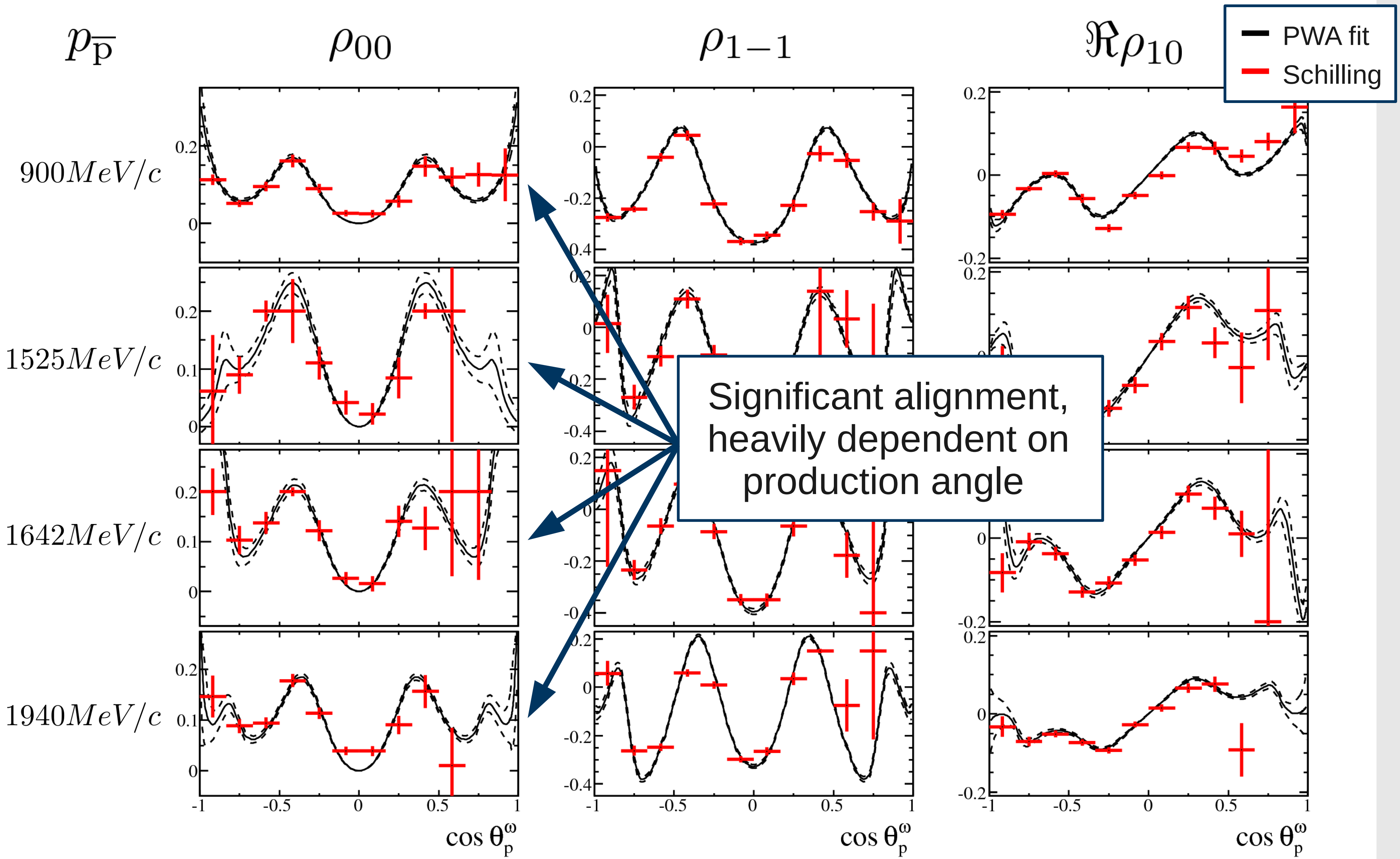
$$W_{\omega\to\pi^+\pi^-\pi^0}(\cos\theta,\phi) = \frac{3}{4\pi}\Big(\frac{1}{2}(1-\rho_{00}) + \frac{1}{2}(3\rho_{00}-1)\cos^2\theta - \sqrt{2}\Re\rho_{10}\sin 2\theta\cos\phi - \rho_{1-1}\sin^2\theta\cos 2\phi\Big)$$

“Schilling's method”

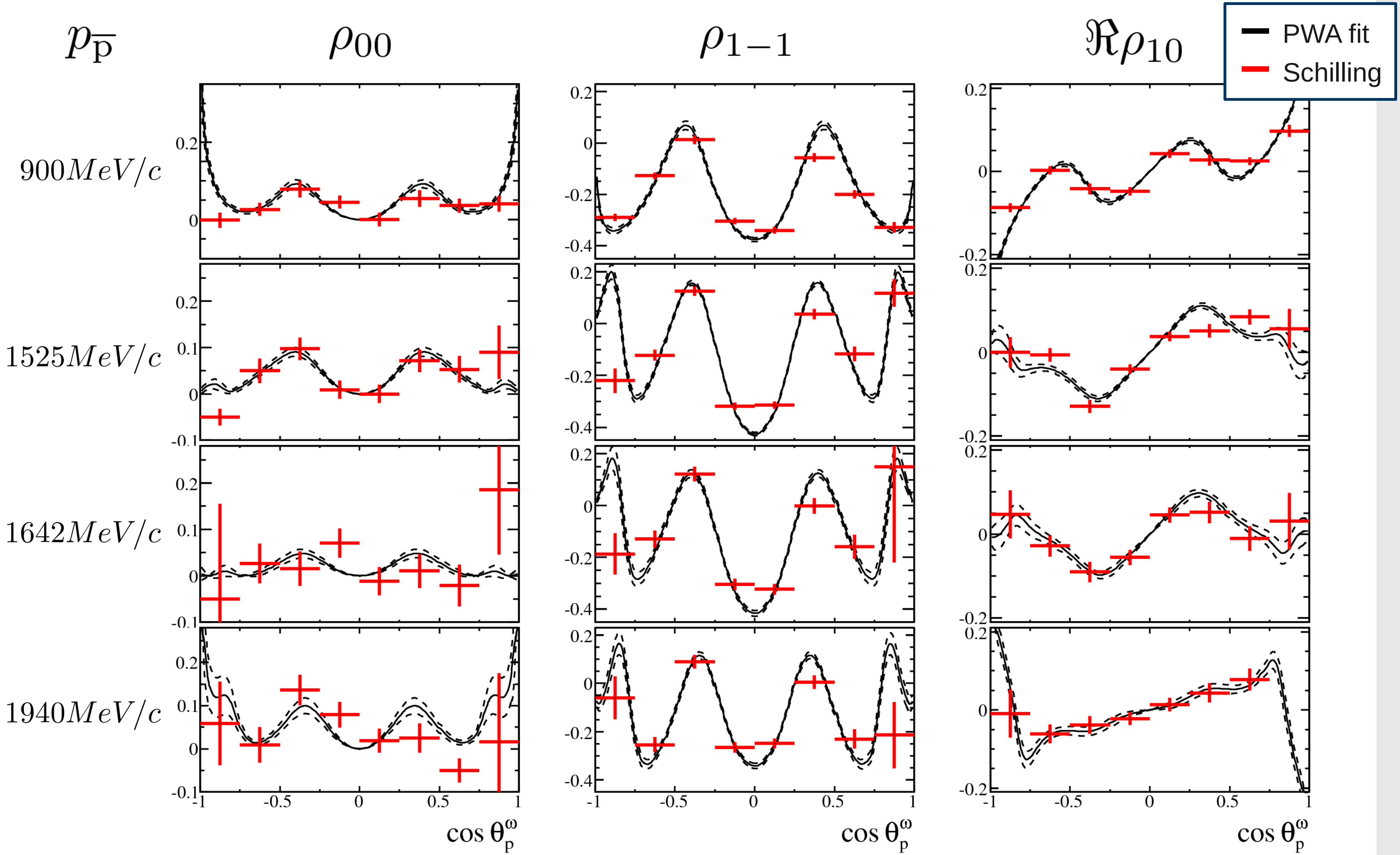
Spin density matrix ($\omega \to \pi^+\pi^-\pi^0$)



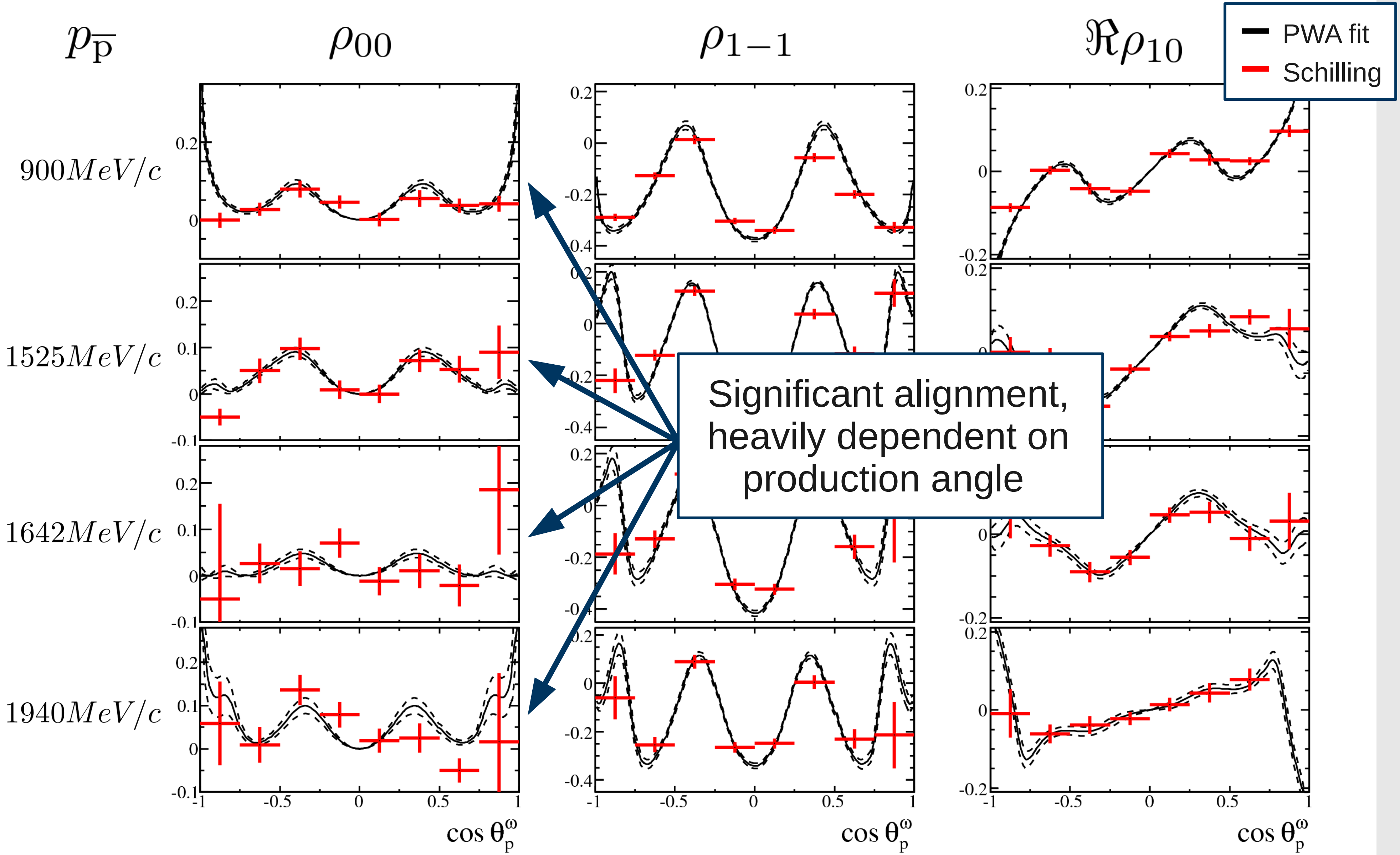
Spin density matrix ($\omega \rightarrow \pi^+\pi^-\pi^0$)



Spin density matrix ($\omega \to \pi^0\gamma$)

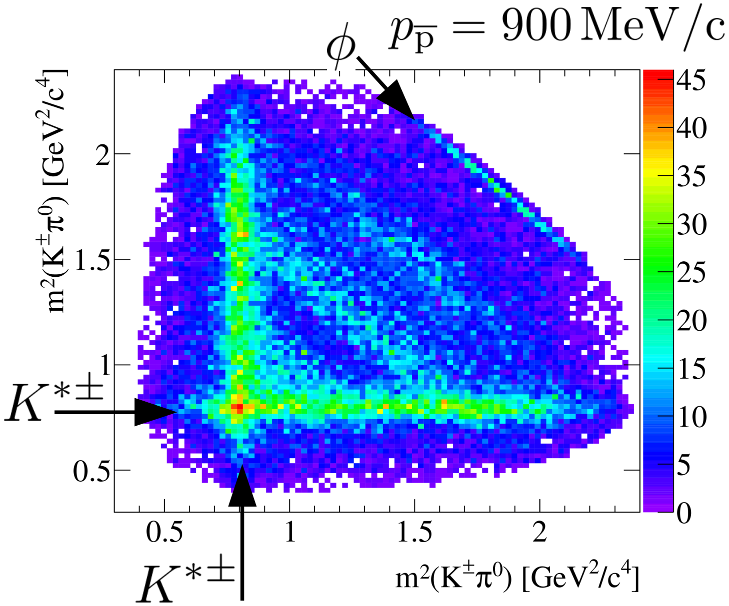


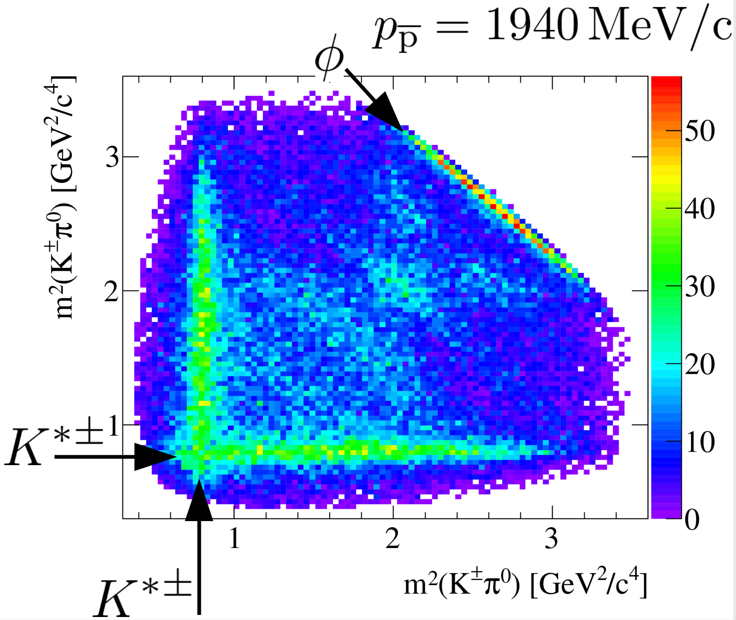
Spin density matrix ($\omega \rightarrow \pi^0\gamma$)



$\bar{\mathrm{p}}\mathrm{p} \rightarrow \mathrm{K}^{+}\mathrm{K}^{-}\pi^{0}$

- Contains $\phi\pi^0$ and $K^{*\pm}K^{\mp}$ events
- Production of vector mesons with strangeness
    - different process in comparison to ω production
    - rearrangement vs. annihilation
- Interference of resonances requires a PWA of the complete channel
- Spin density matrix via extraction of the fitted ϕ and $K^{*\pm}$ amplitudes





PWA : $\bar{\mathrm{p}}\mathrm{p} \rightarrow \mathrm{K}^+\mathrm{K}^-\pi^0$

- Full PWA from the initial to the final state
- L_{max}= 4 @ 900 MeV/c and 1940 MeV/c
- Hypotheses based on previous results (Crystal Barrel: Phys. Lett. B639 (2006) 165)
  - $\phi\pi^0,\ \phi(1680)\pi^0$
  - $f_2(1270)\pi^0,\ f_2^{'}(1525)\pi^0$
  - $a_2(1320)\pi^0$
  - $K^{*\pm}K^{\mp},\ K^*(1680)^{\pm}K^{\mp}$
  - all $f_0\pi^0$-channels via $(KK)_S$-wave
  - all $K_0^{*\pm}K^{\mp}$-channels via $(K\pi)_S(I=1/2)$-wave
  - $K(K\pi)_S(I=3/2)$ -wave

K-matrix parametrization by Anisovich and Sarantsev Eur. Phys. J. A16, 229(2003)

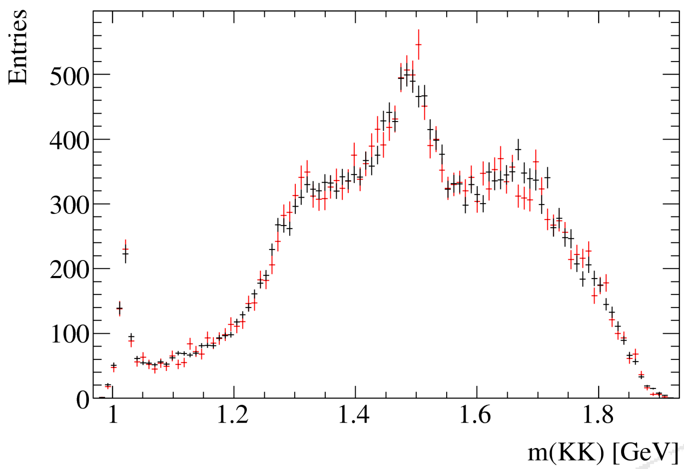
K-matrix parametrization used by FOCUS Phys. Lett. B653 (2007) 1-11

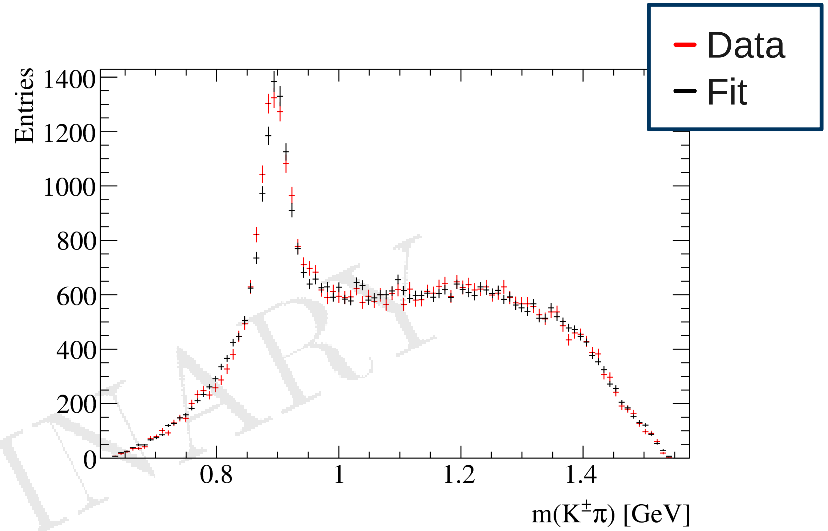
- Many resonances yield in a large number of fit parameters
  - 420 @ 900 MeV
  - 464 @ 1940 MeV

→
- Fit becomes time consuming (weeks)
- Determination of L_{max} difficult

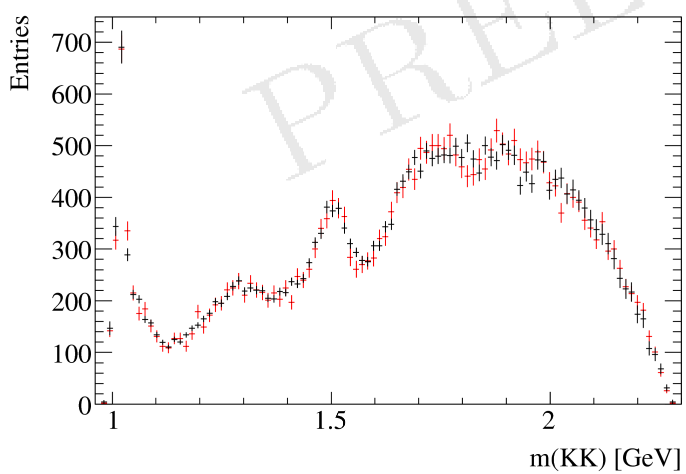
$\bar{\mathrm{p}}\mathrm{p} \rightarrow \mathrm{K}^+\mathrm{K}^-\pi^0$: Fit results

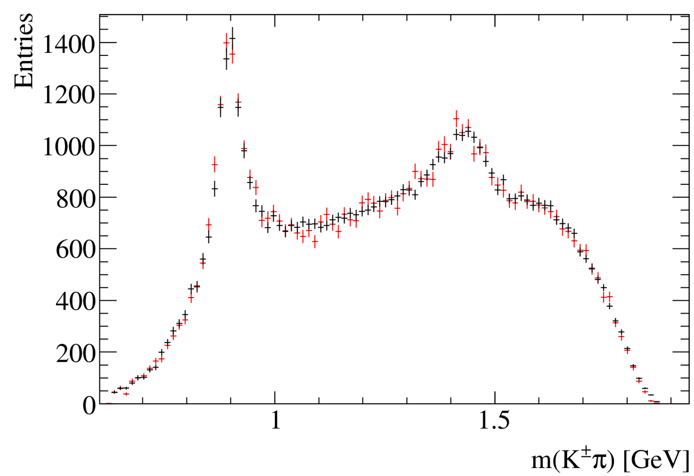
$p_{\bar{\mathrm{p}}} = 900\,\mathrm{MeV/c}$





$p_{\bar{\mathrm{p}}} = 1940\,\mathrm{MeV/c}$





Excellent description of the data

$\bar{\mathrm{p}}\mathrm{p} \to \mathrm{K}^+\mathrm{K}^-\pi^0$: Fit results

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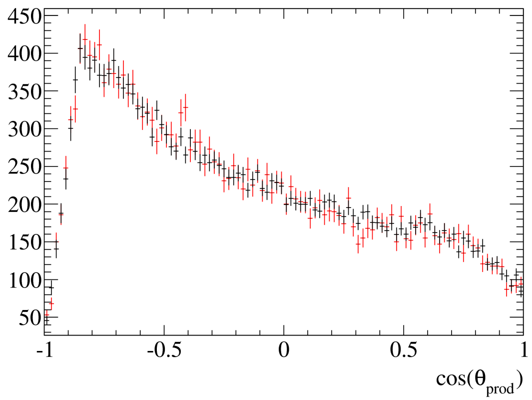
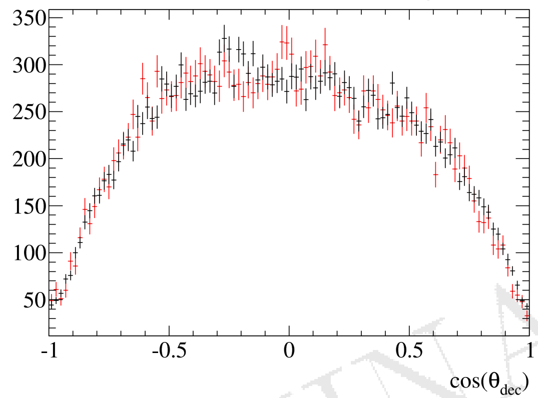
$p_{\bar{\mathrm{p}}} = 900\,\mathrm{MeV/c}$

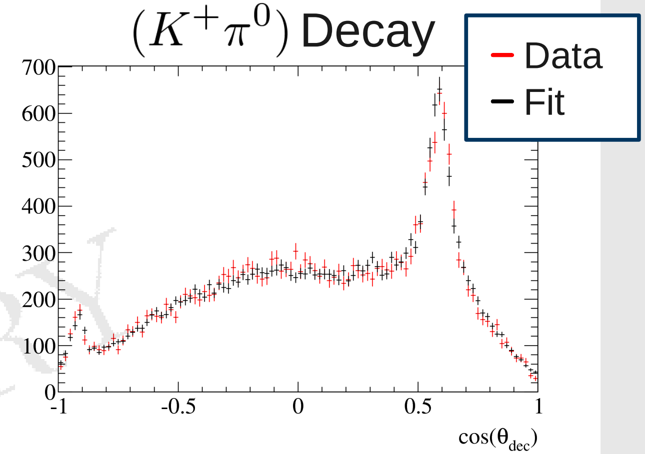
(K^+K^-) Production



(K^+K^-) Decay

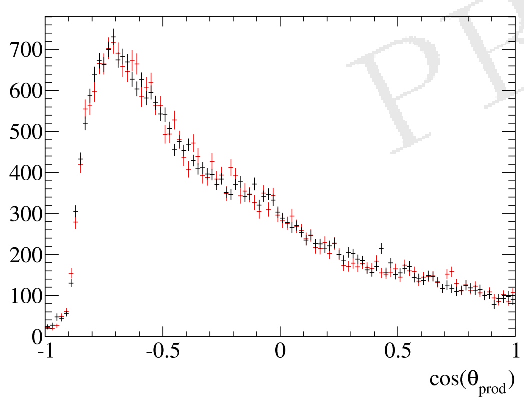


$(K^+\pi^0)$ Decay

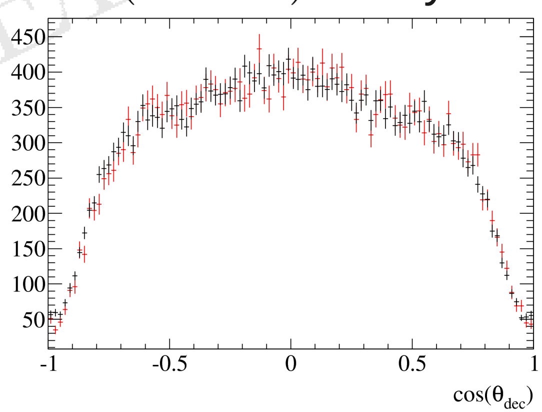


$p_{\bar{\mathrm{p}}} = 1940\,\mathrm{MeV/c}$

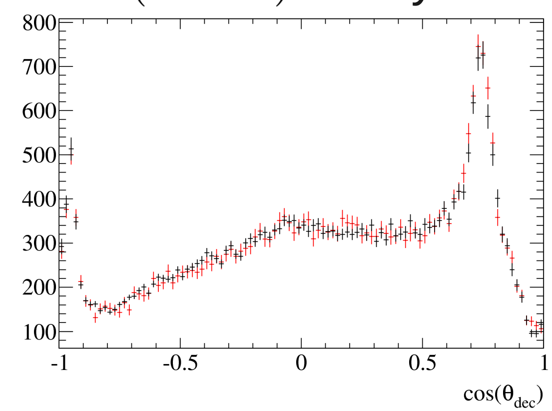
(K^+K^-) Production



(K^+K^-) Decay



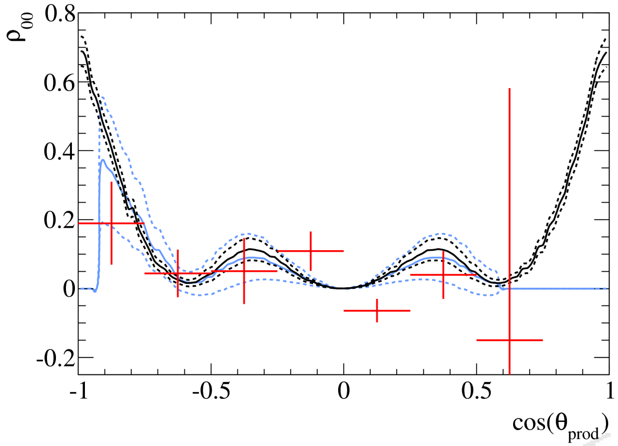
$(K^+\pi^0)$ Decay



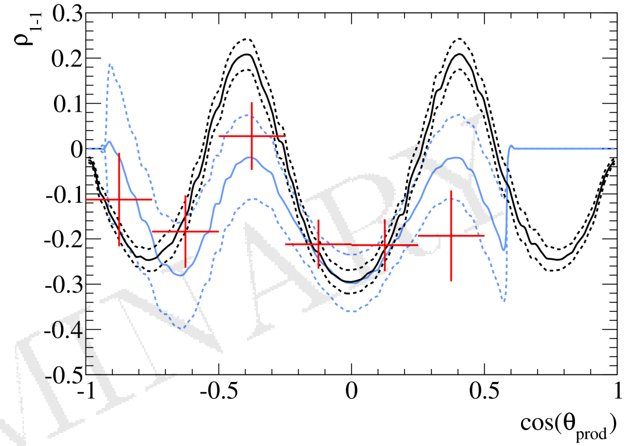
Excellent description of the data

Spin density matrix ($\phi \rightarrow K^+K^-$)

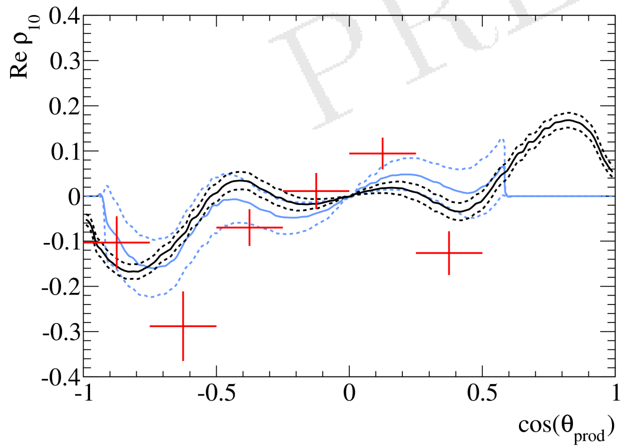
ρ_{00}



ρ_{1-1}



$\Re\rho_{10}$



$p_{\overline{\mathrm{p}}} = 900\,\mathrm{MeV/c}$

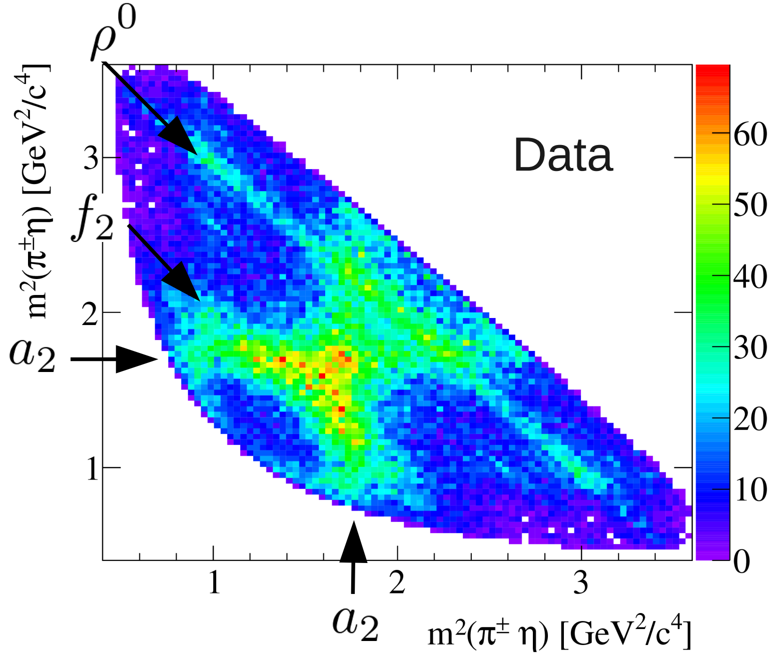
- Full PWA
- PWA of isolated ϕ
- Fit of angular distribution

PWA : $\overline{\mathrm{p}}\mathrm{p} \rightarrow \pi^+\pi^-\eta$

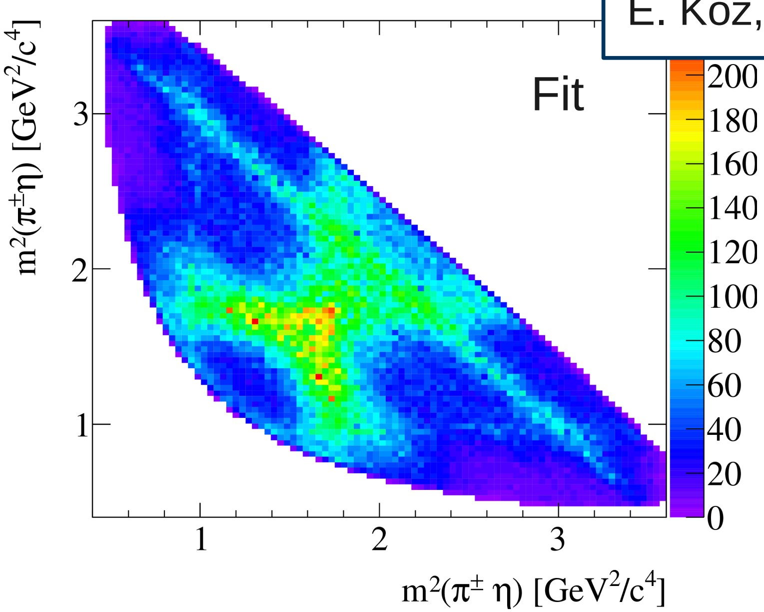
- Hypotheses
  - $\rho^0\eta$, $\omega\eta$
  - $a_2(1320)^{\pm}\pi^{\mp}$
  - $a_0(980)^{\pm}\pi^{\mp}$
  - $\rho(1405)^{\pm}\pi^{\mp}$
  - $f_2(1270)\eta$
  - $(\pi\pi)_S\,\eta$

K-matrix parametrization by Anisovich and Sarantsev Eur. Phys. J. A16, 229(2003)

$p_{\overline{\mathrm{p}}} = 900\,\mathrm{MeV/c}$

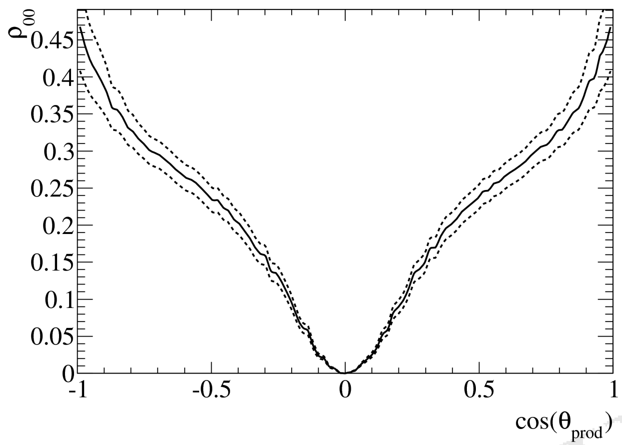


E. Köz, Bochum

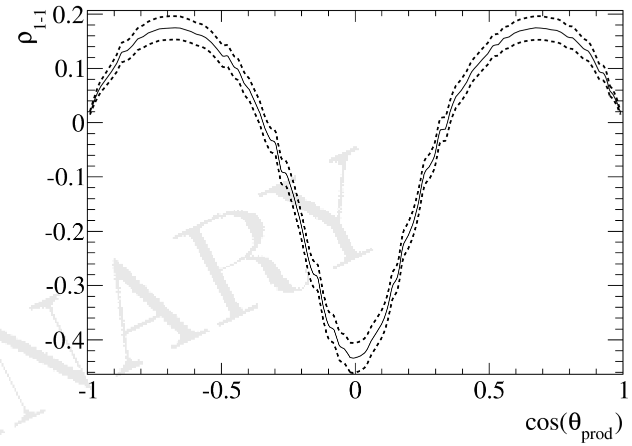


Spin density matrix $(\rho^0 \rightarrow \pi^+\pi^-)$

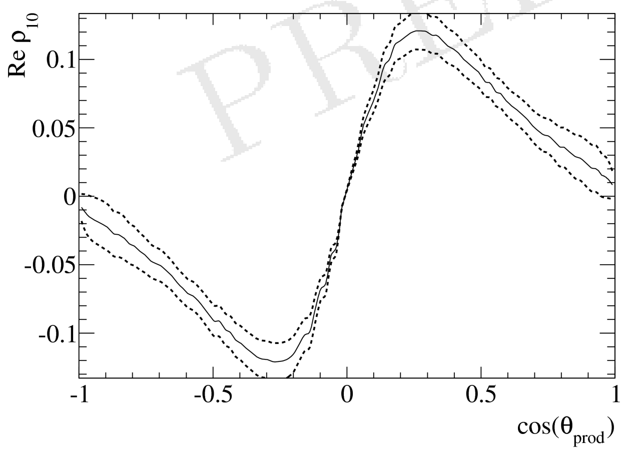
ρ_{00}



ρ_{1-1}



$\Re\rho_{10}$



$$p_{\overline{\mathrm{p}}} = 900\,\mathrm{MeV/c}$$

Summary

- Analyses of Crystal Barrel LEAR data with relevance for PANDA
- $\bar{p}p$ initial states and production of vector mesons
- $\overline{\mathrm{p}}\mathrm{p} \longrightarrow \omega\pi^0$
    - New background rejection method
    - L_{max} rises from 3 @ 600 MeV/c to 5 @ 1940 MeV/c
    - Extraction of the ω-SDM via full PWA
    - Strong alignment and oscillation of ρ_{00} along the production angle
- $\overline{\mathrm{p}}\mathrm{p} \longrightarrow \mathrm{K}^+\mathrm{K}^-\pi^0$ and $\overline{\mathrm{p}}\mathrm{p} \longrightarrow \pi^+\pi^-\eta$
    - Excellent description of the data
    - Extraction of the SDM for ϕ , $K^{*\pm}$, ρ and other resonances possible