Recent results on pi-pi amplitudes at BES III

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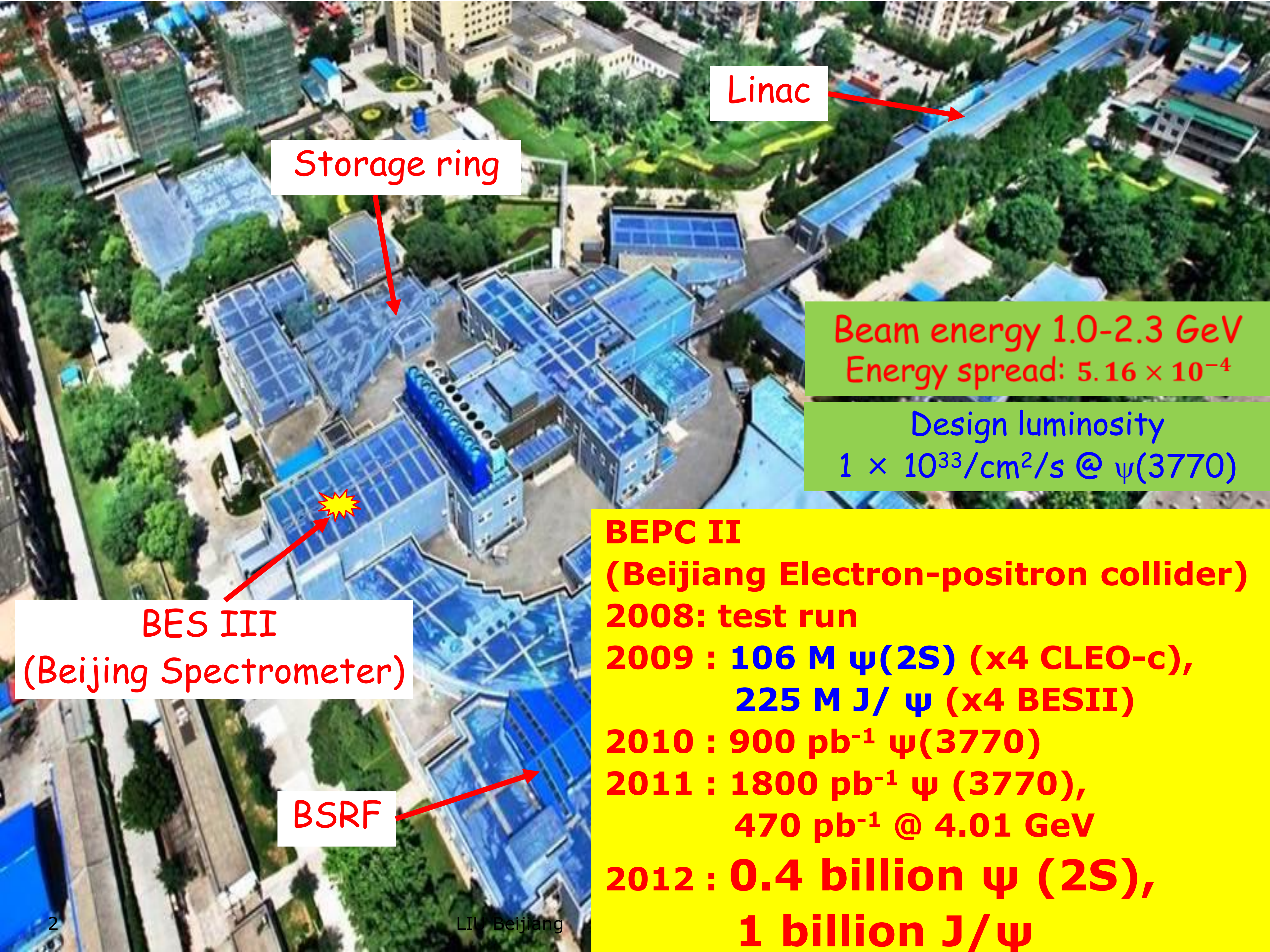
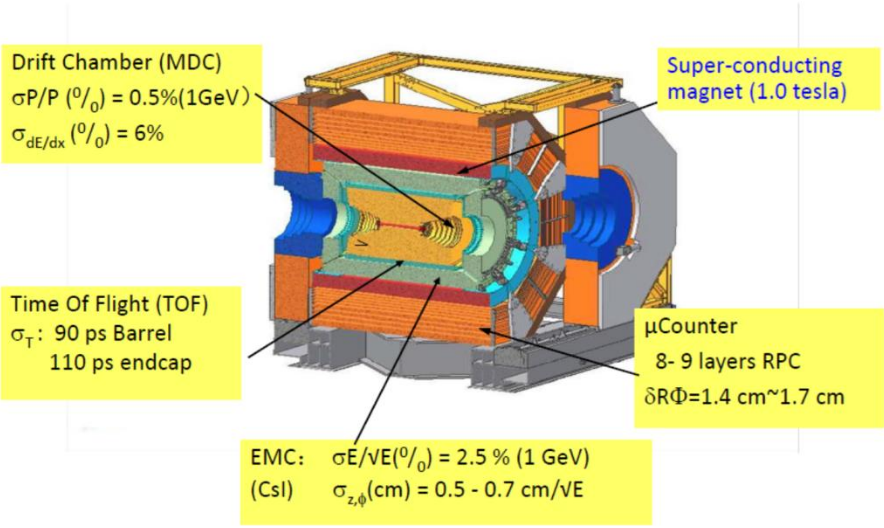


BEPC II
(Beijiang Electron-positron collider)
2008: test run
2009 : 106 M ψ(2S) (x4 CLEO-c),
225 M J/ ψ (x4 BESII)
2010 : 900 pb^{-1} ψ(3770)
2011 : 1800 pb^{-1} ψ (3770),
470 pb^{-1} @ 4.01 GeV
2012 : 0.4 billion ψ (2S),
1 billion J/ψ

Physics Programs @ BESIII

NIM A614, 345 (2010)

The BESIII Detector



Light hadron physics

- meson & baryon spectroscopy
  - multiquark states, glueballs & hybrids
    - Gluon-rich process
    - I, J^{PC} filter
- two-photon physics
- form-factors

Charmonium physics:

- precision spectroscopy
- transitions and decays
- XYZ meson physics:
  - Y(4260): pi pi hc decays

Charm physics:

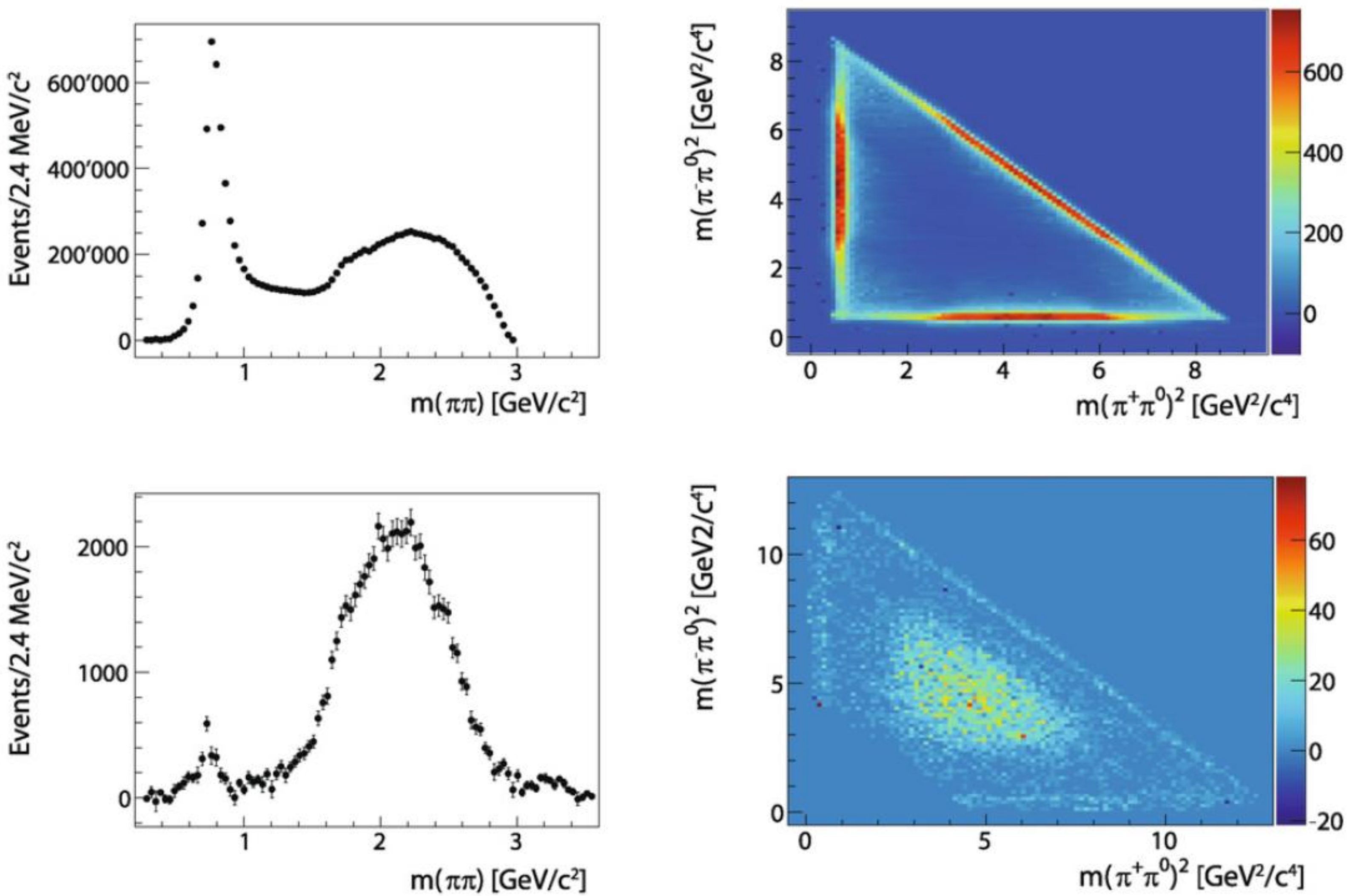
- (semi-)leptonic form factors
- f_D & f_{Ds} decay constants.
- CKM matrix: V_{cd} , V_{cs}
- D0-D0bar mixing and CPV
- strong phases

QCD & tau-physics:

- precision R-measurement
- tau mass / tau decays

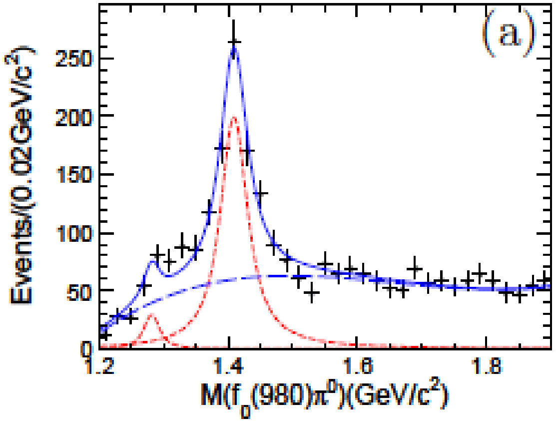
Precision measurement of the branching fractions of $J/\psi \rightarrow \pi^+\pi^-\pi^0$ and $\psi' \rightarrow \pi^+\pi^-\pi^0$

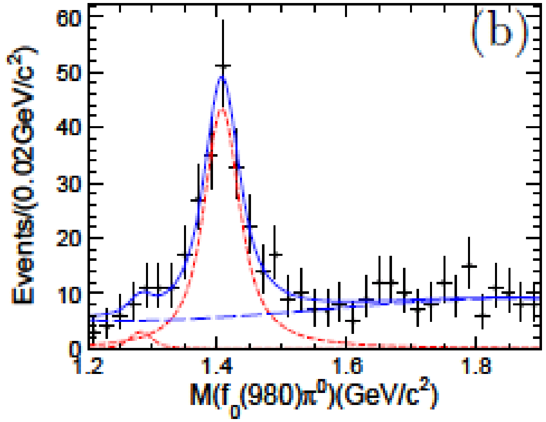
BES III, Phys.Lett. B710 (2012) 594

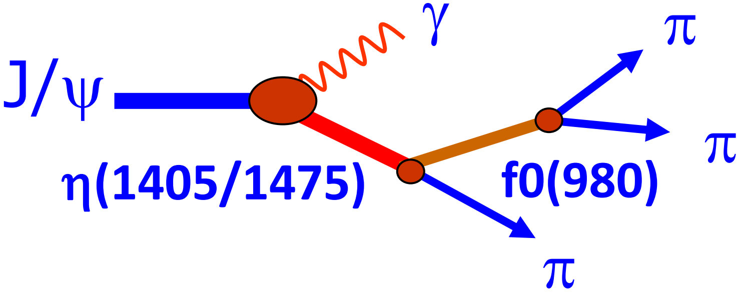


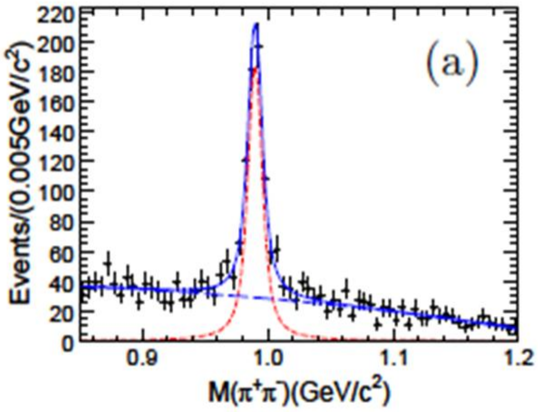
Isospin-violating decay of J/ψ → γπππ

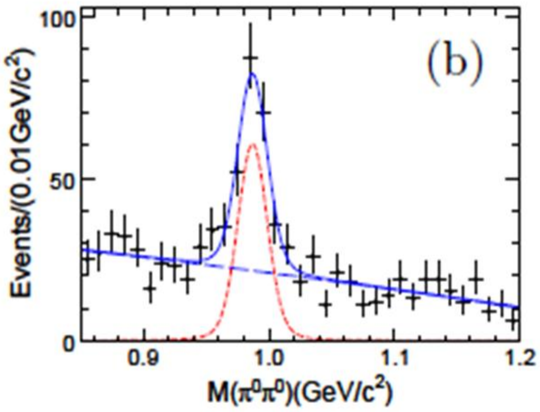
BES III, Phys. Rev.Lett. 108, (2012) 182001



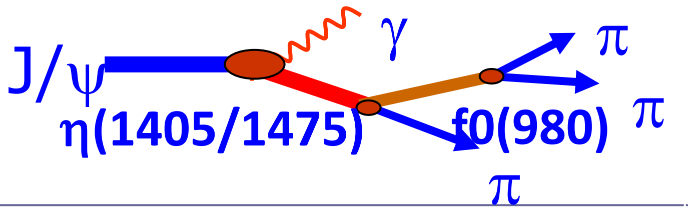








Isospin-violating decay of J/ψ → γπππ



f0(980) is extremely narrow: Γ ≅ 10 MeV.

PDG: Γ(f0(980)) ≅ 40~100 MeV.

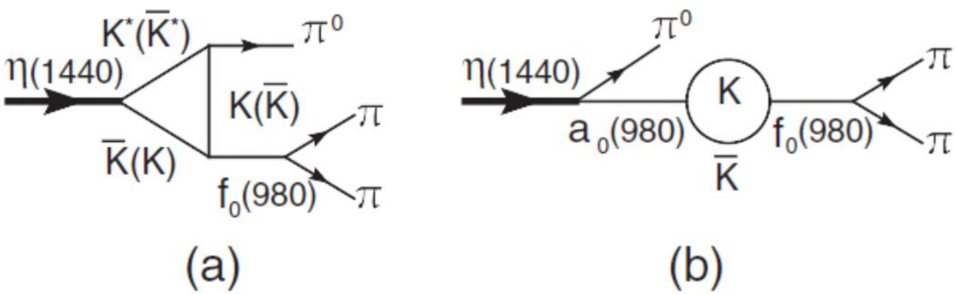
Anomalously large isospin violation:

$$\frac{Br(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\eta(1405) \to a_0^0(980)\pi^0 \to \eta\pi^0\pi^0)} \cong (17.9 \pm 4.2)\%$$

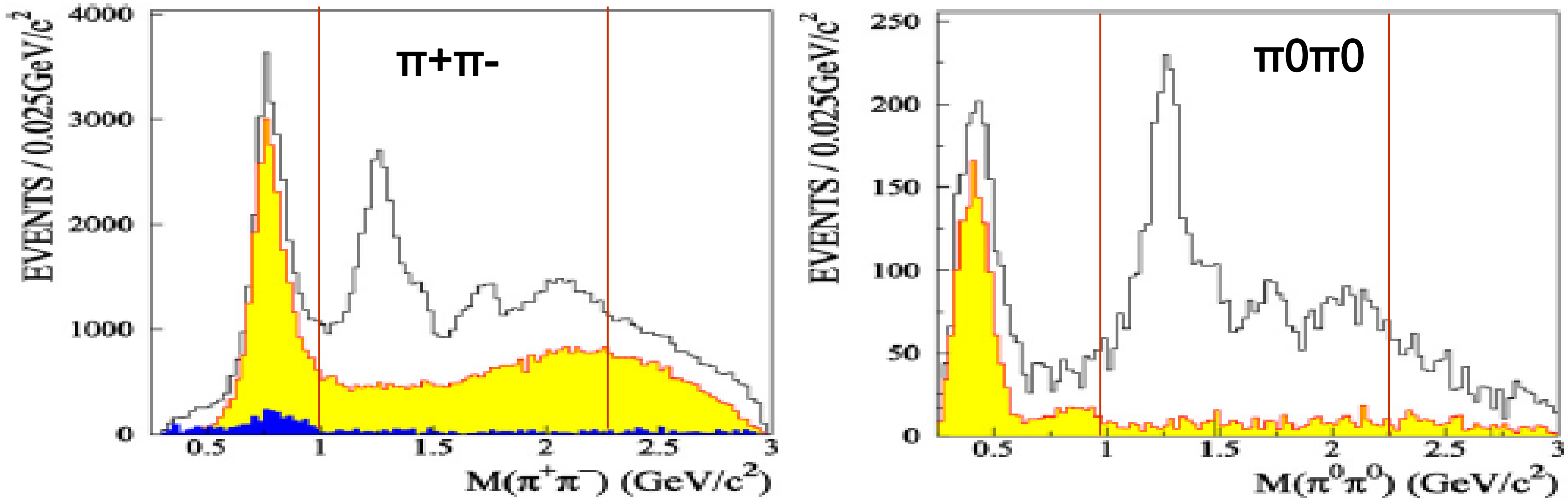
$$\xi_{af} = \frac{Br(\chi_{c1} \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to a_0(980)\pi^0 \to \eta\pi^0\pi^0)} < 1\%(90\%\ C.L.)$$

PRD, 83(2100)032003

J.J. Wu, X.H. Liu, Q.Z. and B.S. Zou, PRL(2012)



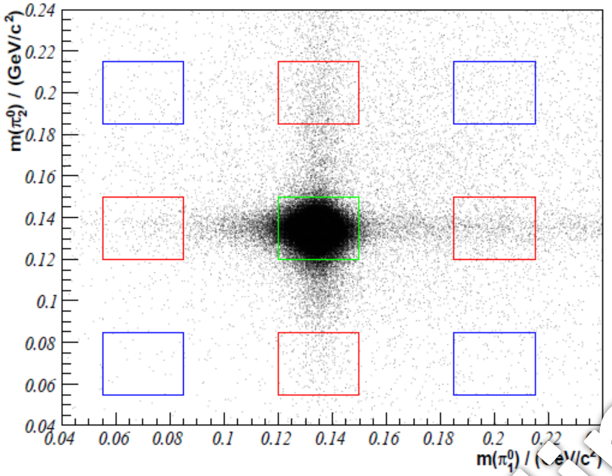
J/ψ→γππ @ BES II , Phys. Lett. B642 (2003) 441

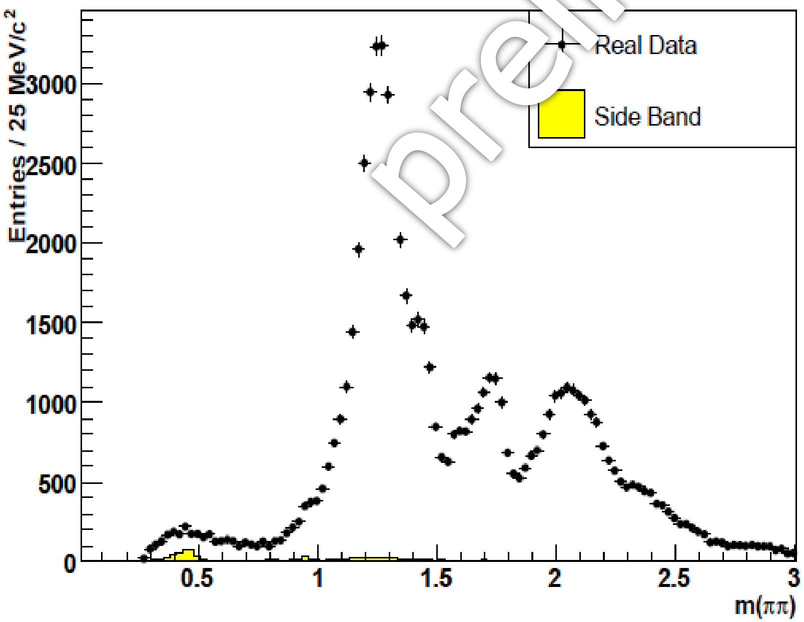


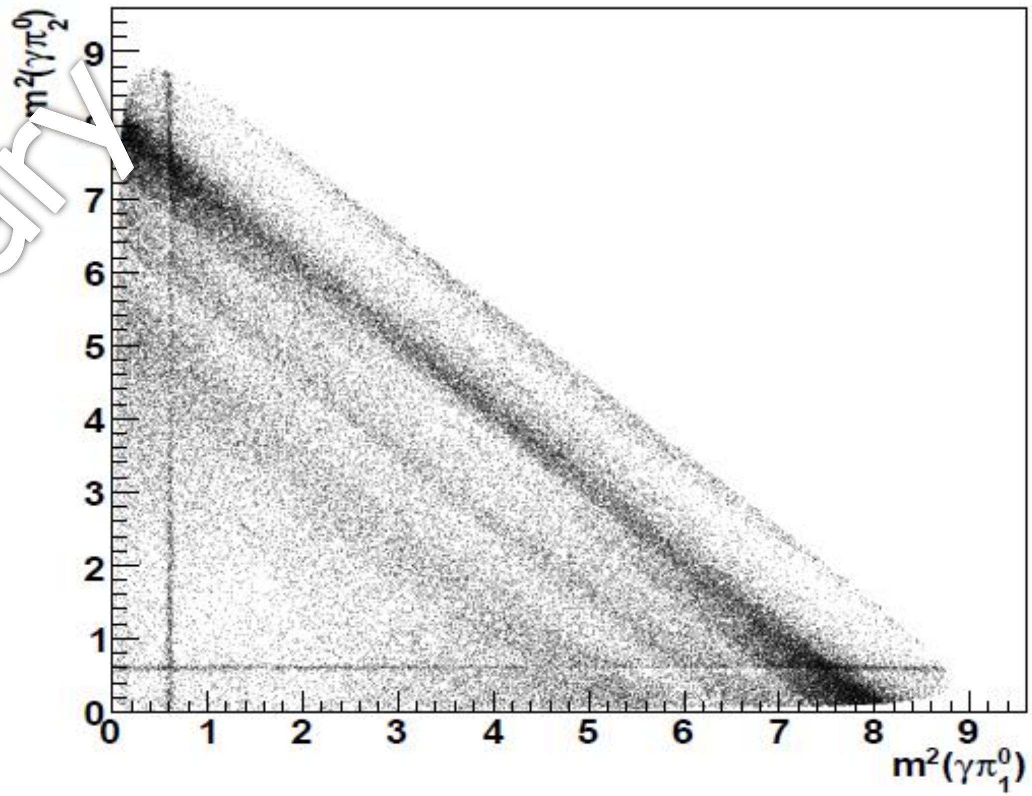
	$J/\psi \to \gamma X, X \to \pi^+\pi^-$		
	Mass (MeV/c^2)	Γ (MeV/c^2)	$\mathcal{B}$ ($\times 10^{-4}$)
$f_2(1270)$	$1262^{+1}_{-2} \pm 8$	$175^{+6}_{-4} \pm 10$	$9.14 \pm 0.07 \pm 1.48$
$f_0(1500)$	$1466 \pm 6 \pm 20$	$108^{+14}_{-11} \pm 25$	$0.67 \pm 0.02 \pm 0.30$
$f_0(1710)$	$1765^{+4}_{-3} \pm 13$	$145 \pm 8 \pm 69$	$2.64 \pm 0.04 \pm 0.75$

	$J/\psi \to \gamma X, X \to \pi^0\pi^0$		
	Mass (MeV/c^2)	Γ (MeV/c^2)	$\mathcal{B}$ ($\times 10^{-4}$)
$f_2(1270)$	same as charged channel		$4.00 \pm 0.09 \pm 0.58$
$f_0(1500)$	same as charged channel		$0.34 \pm 0.03 \pm 0.15$
$f_0(1710)$	same as charged channel		$1.33 \pm 0.05 \pm 0.88$

$J/\psi \rightarrow \gamma\pi^0\pi^0$ @BES III

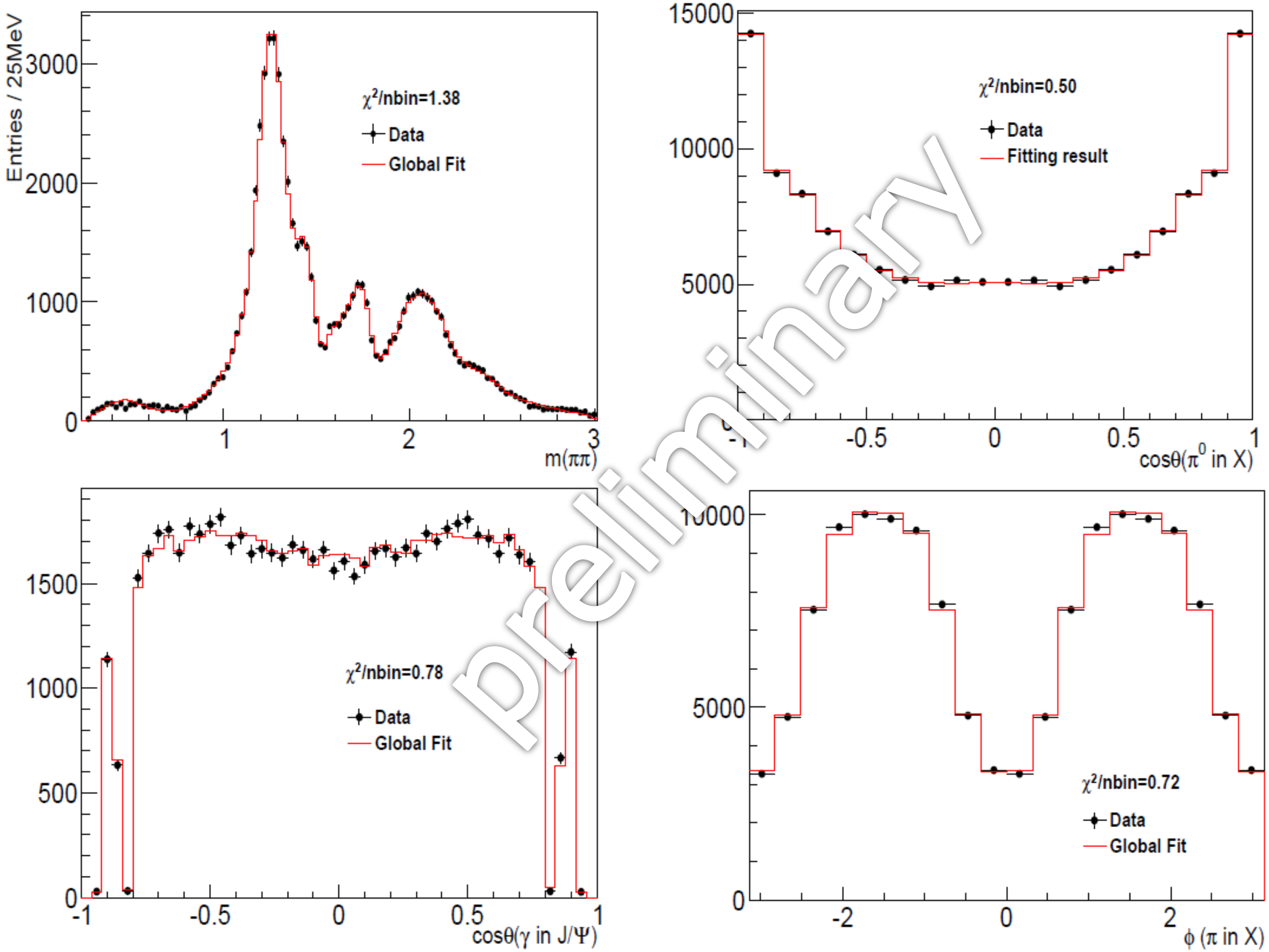






Preliminary PWA results of $J/\psi \rightarrow \gamma\pi^0\pi^0$

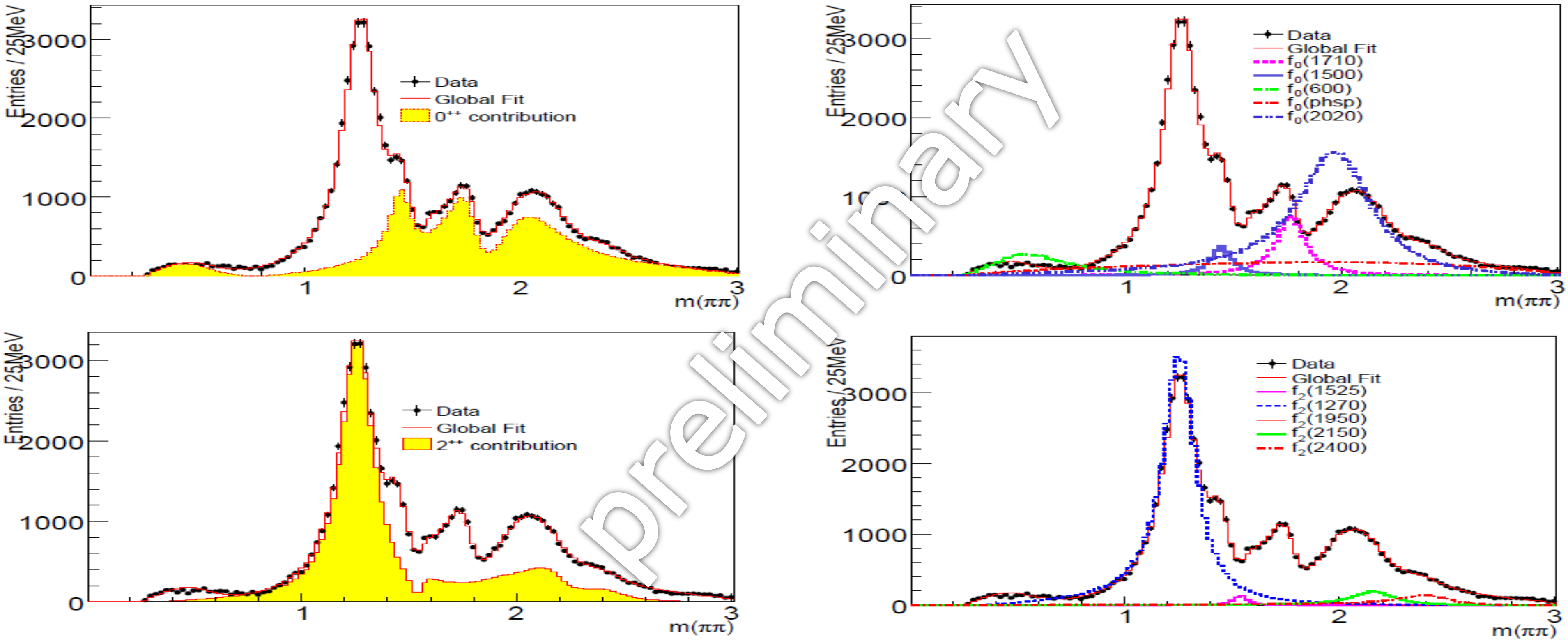
covariant tensor formalism, Zou & Bugg, Eur.Phys.J. A16, 537
event-wise ML fit with isobar model (BW)



Powered by GPUPWA

gpupwa.sourceforge.net

Preliminary PWA results of $J/\psi \rightarrow \gamma \pi^0 \pi^0$



* The parameters of $f_0(600)$ are fixed to “The sigma pole in J / psi --> omega pi+ pi-” PLB 589 149

** Non resonant component: 0+ phsp

Preliminary PWA results of $J/\psi \to \gamma\pi^0\pi^0$

Resonances	Mass(MeV/c^2)	Width(MeV/c^2)	$Br(J/\psi \to \gamma X \to \gamma\pi^0\pi^0)$	Significance
$f_0(600)$	446	578	$0.91^{+0.02+0.32}_{-0.02-0.17} \times 10^{-4}$	$> 40\sigma$
$f_2(1270)$	1255^{+1+4}_{-1-1}	177^{+2+1}_{-2-6}	$5.77^{+0.03+0.42}_{-0.03-0.34} \times 10^{-4}$	$> 40\sigma$
$f_0(1500)$	1445^{+3+9}_{-3-30}	113^{+6+5}_{-6-}[illegible]	$0.44^{+0.01+0.05}_{-0.01-0.08} \times 10^{-4}$	27.6σ
$f_2^{\prime}(1525)$	1539^{+5+5}_{-6-11}	72^{+10+}[illegible] $_{-9}$[illegible]$_{6}$	$0.09^{+0.01+0.08}_{-0.01-0.01} \times 10^{-4}$	13.5σ
$f_0(1710)$	1765^{+3+3}_{-3-4}	159^{+7+3}_{-}[illegible]$_{-13}$	$1.11^{+0.02+0.10}_{-0.02-0.19} \times 10^{-4}$	$> 40\sigma$
$f_2(1950)$	1901^{+22+51}_{-23-5}	313^{+}[illegible]$^{8+65}_{-43-63}$	$0.11^{+0.01+0.06}_{-0.01-0.05} \times 10^{-4}$	11.4σ
$f_0(2020)$	1971^{+6+24}_{-6-4}	409^{+14+9}_{-13-14}	$5.31^{+0.04+0.38}_{-0.04-0.44} \times 10^{-4}$	35.6σ
$f_2(2150)$	2160^{+13+7}_{-13-11}	227^{+22+3}_{-21-31}	$0.32^{+0.02+0.10}_{-0.02-0.08} \times 10^{-4}$	14.2σ
$f_2(2340)$	2419^{+13+7}_{-13-16}	286^{+28+10}_{-26-37}	$0.28^{+0.01+0.04}_{-0.01-0.05} \times 10^{-4}$	17.8σ

* the changes in log likelihood value and in the number of free parameters in the fit with or without a resonance are used as a measure of the significance of the resonance

** the statistical errors are determined by $\Delta \ln L = 0.5$

"Model independent" PWA

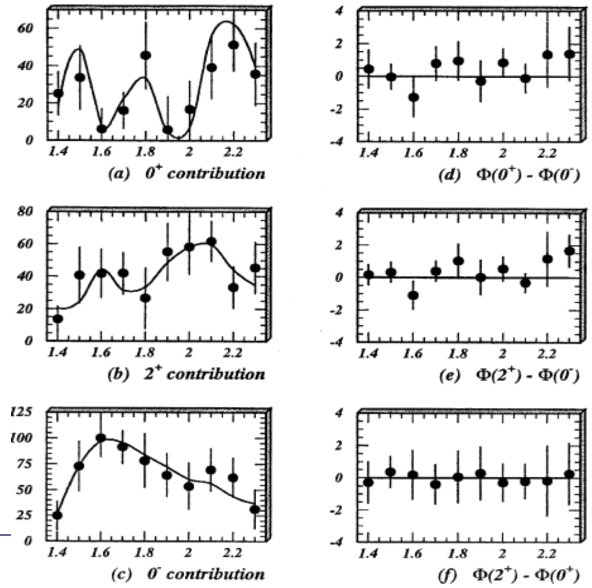
1, Bin-by-bin fit:

Decompose the angular distributions in each mass bin

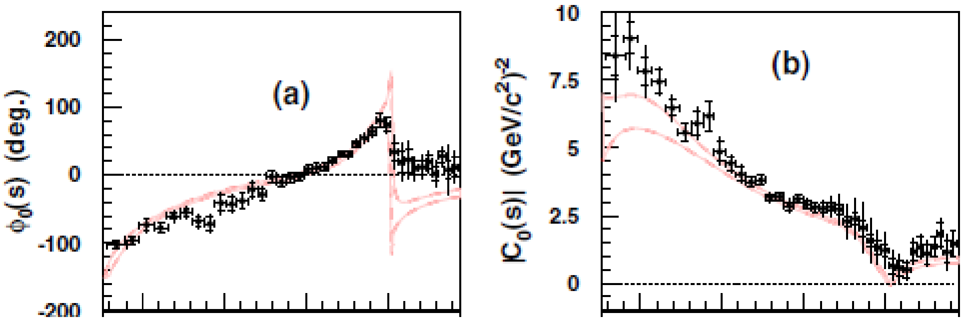
2, MIPWA in Dalitz Plot Analysis:

Using interference to fix the S-wave (parameterize S-wave as a complex spline)

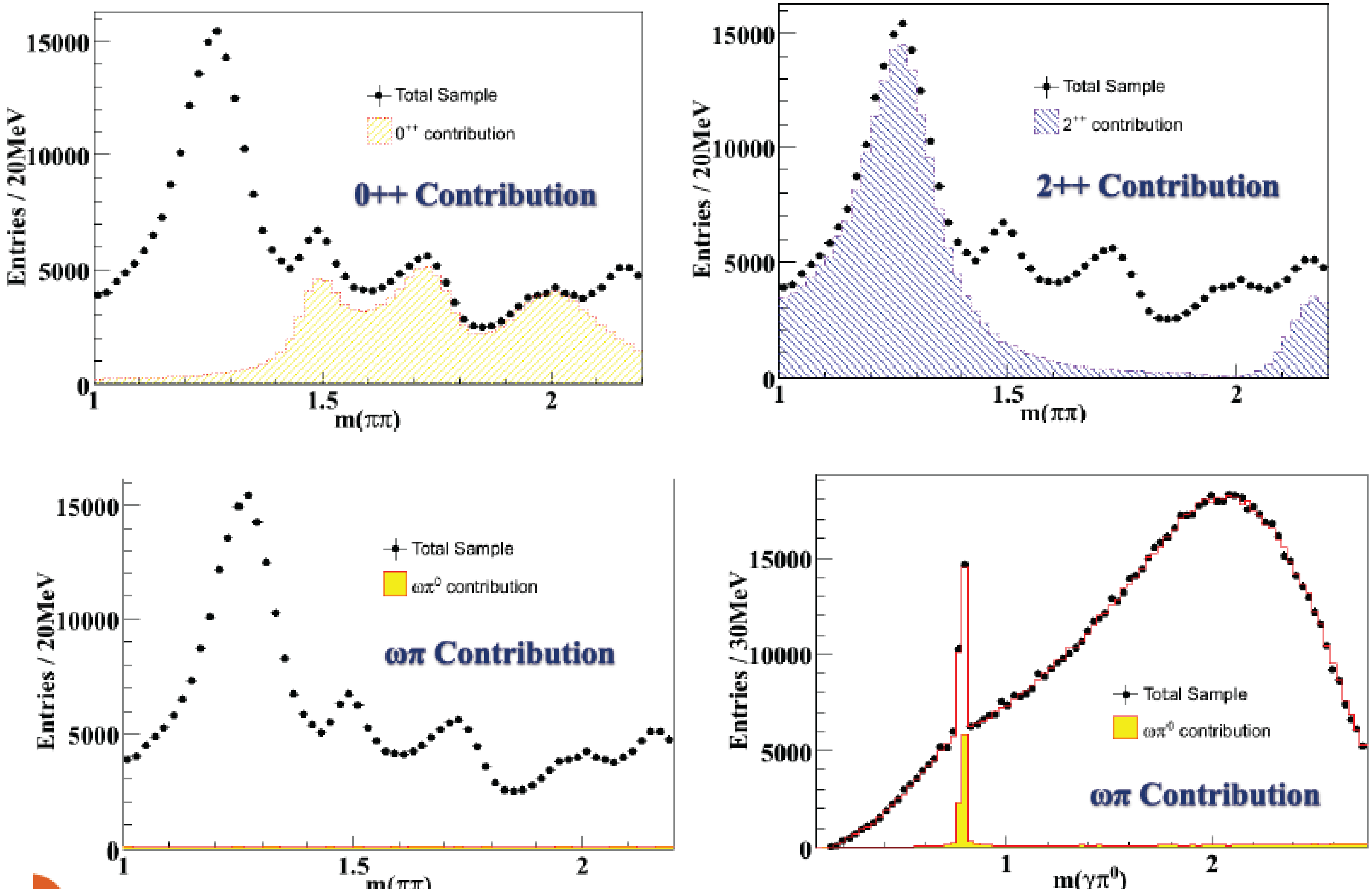
EG1: J/psi→ gamma 4pi @BES I, Phys. Letts. B473 (2000) 207



EG2 : D→Kpipi @ E791, Phys. rev. D73 (2006) 023004

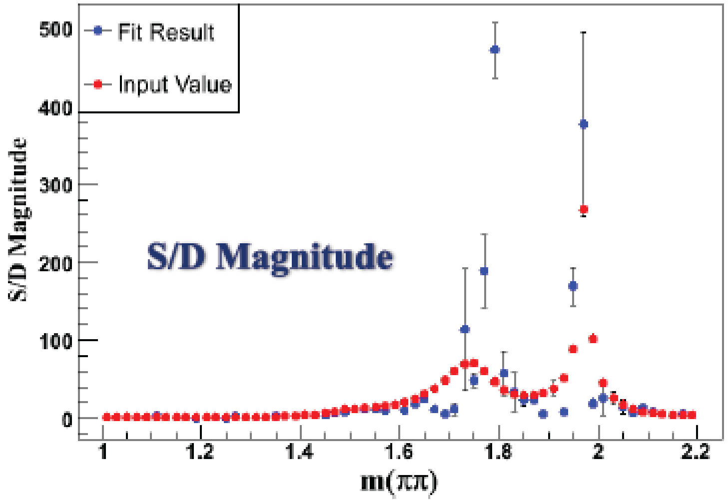


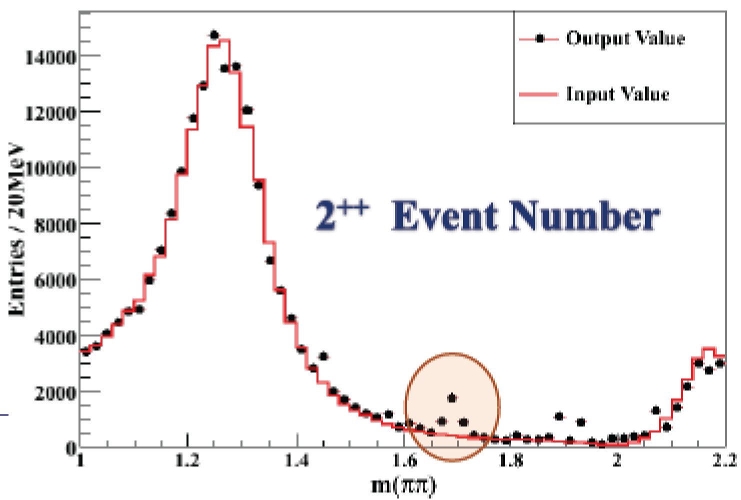
Tests of model independent PWA methods
MC sample: **$J/\psi \rightarrow \gamma\pi^0\pi^0$ (~5% $\omega_{\gamma\pi^0}\pi^0$)**



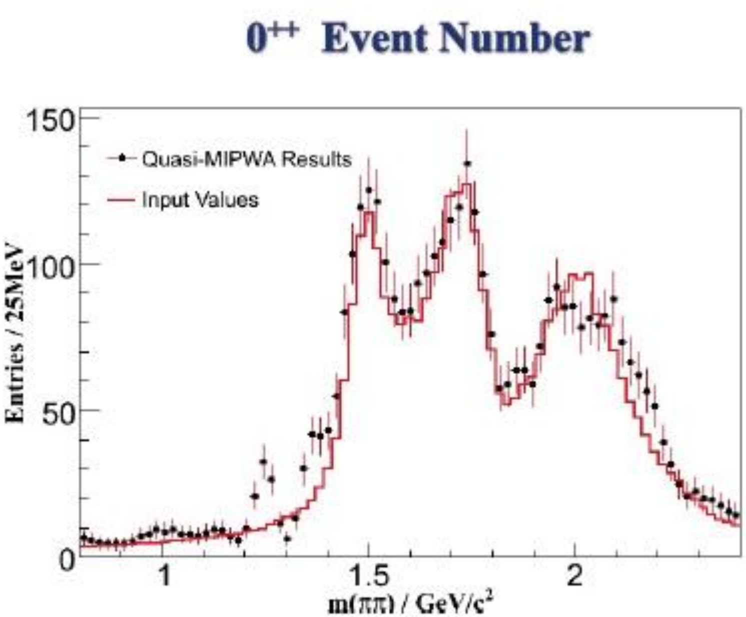
Tests of model independent PWA methods: failed cases: fitting results cannot reproduce inputs

bin-by-bin fit



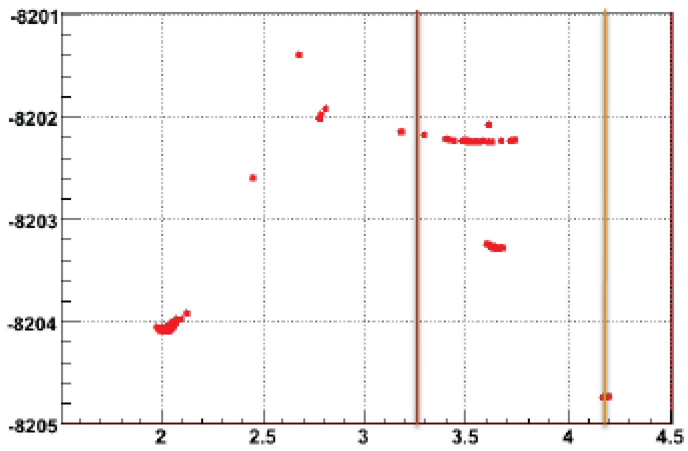


MIPWA fit

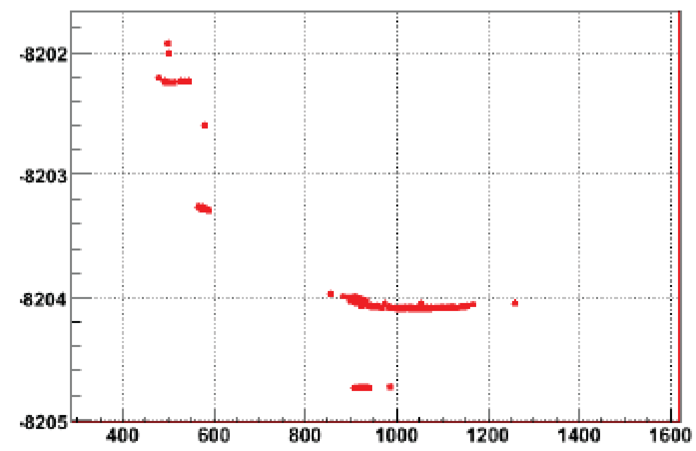


Tests of model independent PWA methods
There're multi solutions

Likelihood profile of one bin in a failed bin-by-bin fit



S-D phase @ 1.66~1.68GeV Bin
Input : 3.26 Output : 4.18



2++ Number @ 1.66~1.68GeV Bin
Input : 417 Output : 929

Some of the solutions provide even better likelihoods than input

Not a summary

Model independent PWA has the attractive advantage.

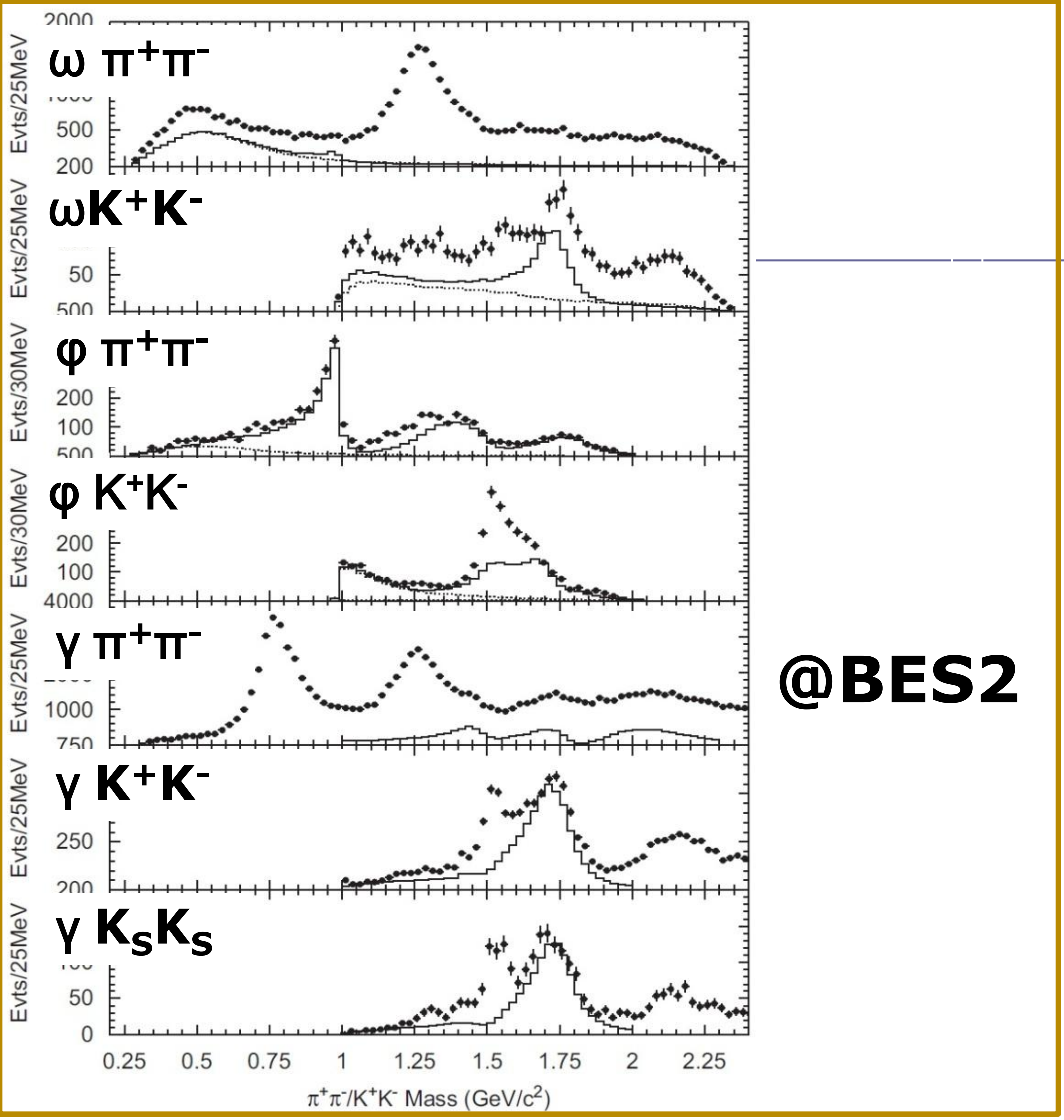
However, there're "multi solution" problems.

- **How to find all the solutions**
- **How to chose the right one**

MIPWA can NOT always provide the correct solution. Nevertheless, it can be employed as a good check whether the model is a good fit to data.

To precisely extract the physics, more efforts are needed.

Outlook



@BES2

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η(')η(')

…

Thank you

Backup

PWA amplitudes
covariant tensor formalism, Zou & Bugg, Eur.Phys.J. A16 537

$$A = \psi_\mu(m_1)e^*_\nu(m_2)A^{\mu\nu} = \psi_\mu(m_1)e^*_\nu(m_2)\sum_i \Lambda_i U_i^{\mu\nu}.$$

$\psi_\mu(m)$ polarization of ψ
$e_\nu(m)$ polarization of γ
Λ coupling strength (complex)

$$\frac{d\sigma}{d\Phi_n} = \frac{1}{2}\sum_{m_1=1}^{2}\sum_{m_2=1}^{2}\psi_\mu(m_1)e^*_\nu(m_2)A^{\mu\nu}\psi^*_{\mu'}(m_1)e_{\nu'}(m_2)A^{*\mu'\nu'}$$

$$= -\frac{1}{2}\sum_{m_1=1}^{2}\psi_\mu(m_1)\psi^*_{\mu'}(m_1)g^{(\perp\perp)}_{\nu\nu'}A^{\mu\nu}A^{*\mu'\nu'}$$

$$= -\frac{1}{2}\sum_{\mu=1}^{2}A_{\mu\nu}g^{(\perp\perp)}_{\nu\nu'}A^{*\mu\nu'}$$

$$= -\frac{1}{2}\sum_{i,j}\Lambda_i\Lambda_j^*\sum_{\mu=1}^{2}U_i^{\mu\nu}g^{(\perp\perp)}_{\nu\nu'}U_j^{*\mu\nu'} \equiv \sum_{i,j}P_{ij}\cdot F_{ij},$$

$$P_{ij} = P^*_{ji} = \Lambda_i\Lambda_j^*,$$

$$F_{ij} = F^*_{ji} = -\frac{1}{2}\sum_{\mu=1}^{2}U_i^{\mu\nu}g^{(\perp\perp)}_{\nu\nu'}U_j^{*\mu\nu'}.$$

Partial wave amplitudes

$$U^{\mu\nu}_{\gamma f_0} = g^{\mu\nu}f^{(f_0)}$$

$$U^{\mu\nu}_{(\gamma f_2)1} = \tilde{t}^{(f_2)\mu\nu}f^{(f_2)},$$

$$U^{\mu\nu}_{(\gamma f_2)2} = g^{\mu\nu}p^\alpha_\psi p^\beta_\psi\tilde{t}^{(f_2)}_{\alpha\beta}B_2(Q_{\Psi\gamma f_2})f^{(f_2)},$$

$$U^{\mu\nu}_{(\gamma f_2)3} = q^\mu\tilde{t}^{(f_2)\nu}_\alpha p^\alpha_\psi B_2(Q_{\psi\gamma f_2})f^{(f_2)},$$

$$U^{\mu\nu}_{(\gamma f_4)1} = \tilde{t}^{(f_4)\mu\nu}_{\alpha\beta}p^\alpha_\psi p^\beta_\psi B_2(Q_{\Psi\gamma f_4})f^{(f_4)},$$

$$U^{\mu\nu}_{(\gamma f_4)2} = g^{\mu\nu}\tilde{t}^{(f_4)}_{\alpha\beta\gamma\delta}p^\alpha_\psi p^\beta_\psi p^\gamma_\psi p^\delta_\psi B_4(Q_{\psi\gamma f_4})f^{(f_4)},$$

$$U^{\mu\nu}_{(\gamma f_4)3} = q^\mu\tilde{t}^{(f_4)\nu}_{\alpha\beta\gamma}p^\alpha_\psi p^\beta_\psi p^\gamma_\psi B_4(Q_{\Psi\gamma f_4})f^{(f_4)},$$

t: orbital tensors
B: barrier factors
f: BW

Likelihood calculation

Likelihood, given n data points at Ω_i

$$\mathcal{L} \propto \prod_{i=1}^{n} \frac{I(\Omega_i)}{\int \eta(\Omega) I(\Omega)\, d\Omega}$$

Product over data events

Detection efficiency

Normalisation integral over phase space

Log likelihood

Independent of fit parameters: precal-culate; memory $\mathcal{O}(N_{event} \times N^2_{wave})$

Independent of fit parameters: precalculate

$$\log \mathcal{L} \propto \sum_{i=1}^{n} \log\Big(\sum_{\alpha,\alpha'} V_\alpha V^*_{\alpha'} A_\alpha(\Omega_i) A^*_{\alpha'}(\Omega_i)\Big) - \sum_{\alpha,\alpha'} \log\Big(V_\alpha V^*_{\alpha'} \Big(\frac{1}{N^{gen}_{MC}} \sum_{i=1}^{N^{rec}_{MC}} A_\alpha(\Omega_i) A^*_{\alpha'}(\Omega_i)\Big)\Big)$$

Sum over data events

Sum over partial waves

Computationally intensive: $\mathcal{O}(N_{iteration} \times N_{event} \times N^2_{wave})$

Normalisation integral as a sum over MC events
Summing only reconstructed events takes into account detection efficiency

GPUPWA
N. Berger, B.J. Liu and J.K. Wang, J.Phys.Conf.Ser., 219, 042031