

Light hadron spectroscopy at BESIII

A. Kupsc

for the **BESIII** Collaboration

Light meson and baryon spectroscopy

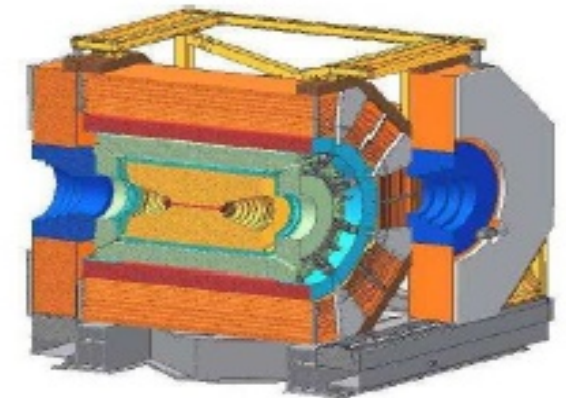
Selected results:

- $J/\psi \rightarrow \gamma \pi^0 \pi^0$ **new**
- $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$ **new** \rightarrow B.Kloss talk 5/20
- $\eta' \rightarrow \gamma \pi^+\pi^-$ **prel**
- $\eta' \rightarrow \gamma e^+e^-$ **new**



UPPSALA
UNIVERSITET

BESIII at BEPCII



CIPANP Vail, CO, May 23, 2015

Light meson spectroscopy at BESIII

X(18??) states:

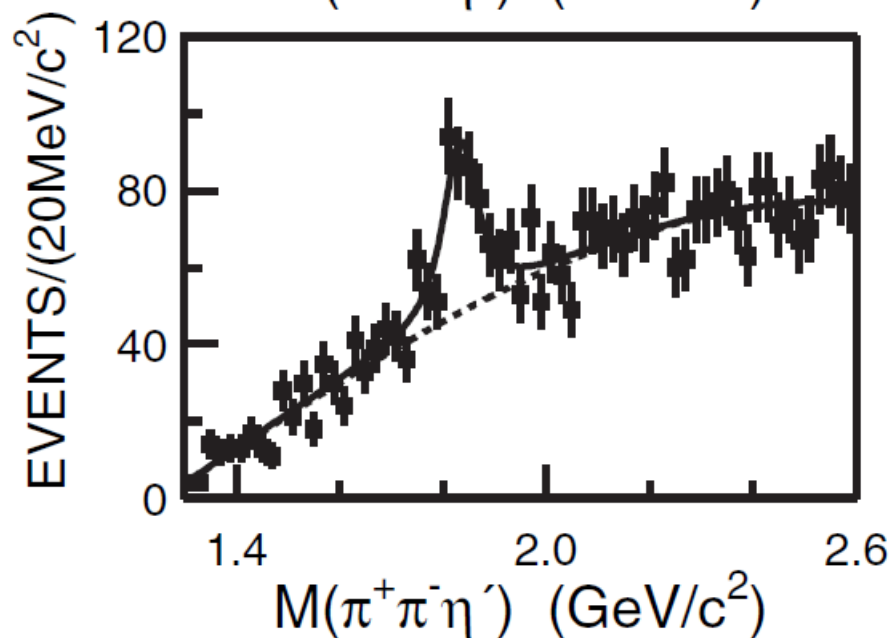
- X(1835) in $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ PRL 106, 072002
- X($\bar{p}p$) in $J/\psi \rightarrow \gamma \bar{p}p$ PRL 108, 112003
- X(1870) in $J/\psi \rightarrow \omega \eta \pi \pi$ PRL 107, 182001
- X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$ PRD 88, 091502
- X(1810) in $J/\psi \rightarrow \gamma \omega \phi$ PRD 87, 032008
- $\eta(1405)$ in $J/\psi \rightarrow \gamma 3\pi, (\omega, \phi) \eta \pi \pi$ PRL 108, 182001; PRD 91, 052017
- $\Upsilon(2175)$ in $J/\psi \rightarrow \phi \eta \pi \pi$
- PWA of $J/\psi \rightarrow \gamma \eta \eta$ PRD 87, 092009

Based on 225 M J/ψ data (now 1.31 M J/ψ)

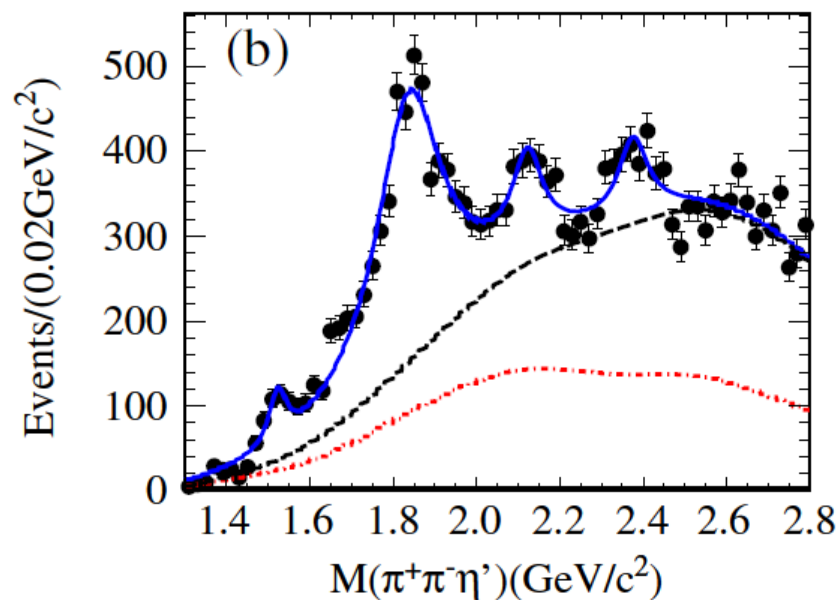


X(1835)

First observed in decay to $\pi^+\pi^-\eta'$ in
 $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$ (BESII PRL95 (2005) 262001)



BESIII PRL106 (2011) 072002



$$M = 1836.5 \pm 3.0(\text{stat})_{-2.1}^{+5.6}(\text{syst}) \text{ MeV}/c^2$$

$$\Gamma = 190 \pm 9(\text{stat})_{-36}^{+38}(\text{syst}) \text{ MeV}/c^2$$

Possible interpretations

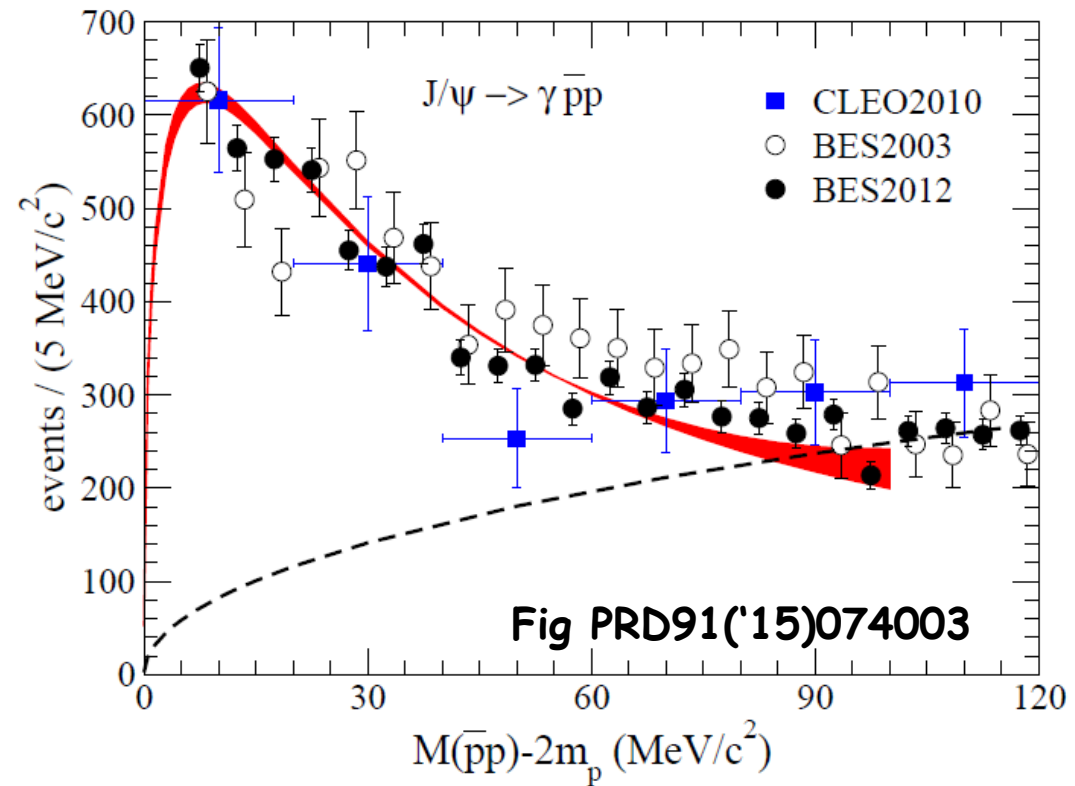
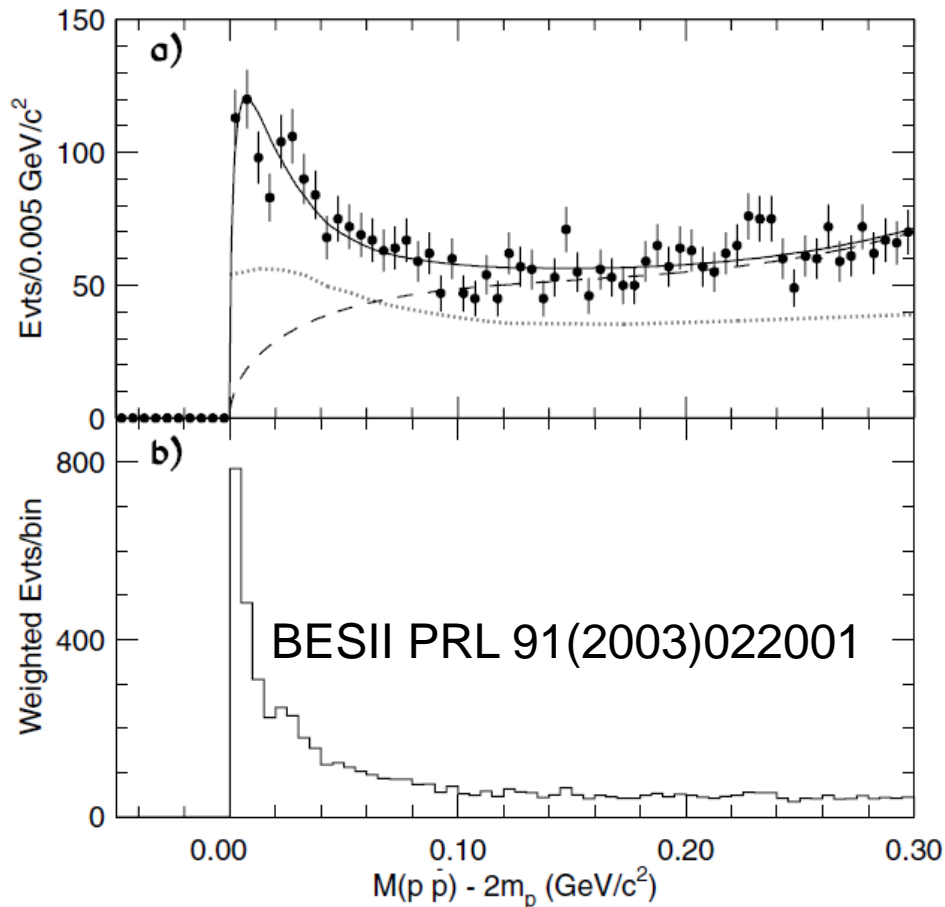
- $\bar{p}p$ bound state
- a second radial excitation of the η'
- pseudo-scalar glueball

Relation to $X(\bar{p}p)$ enhancement,

$X(\bar{p}p)$

Observed by BESII in the decay $J/\psi \rightarrow \gamma \bar{p}p$

(confirmed by BESIII and CLEO).



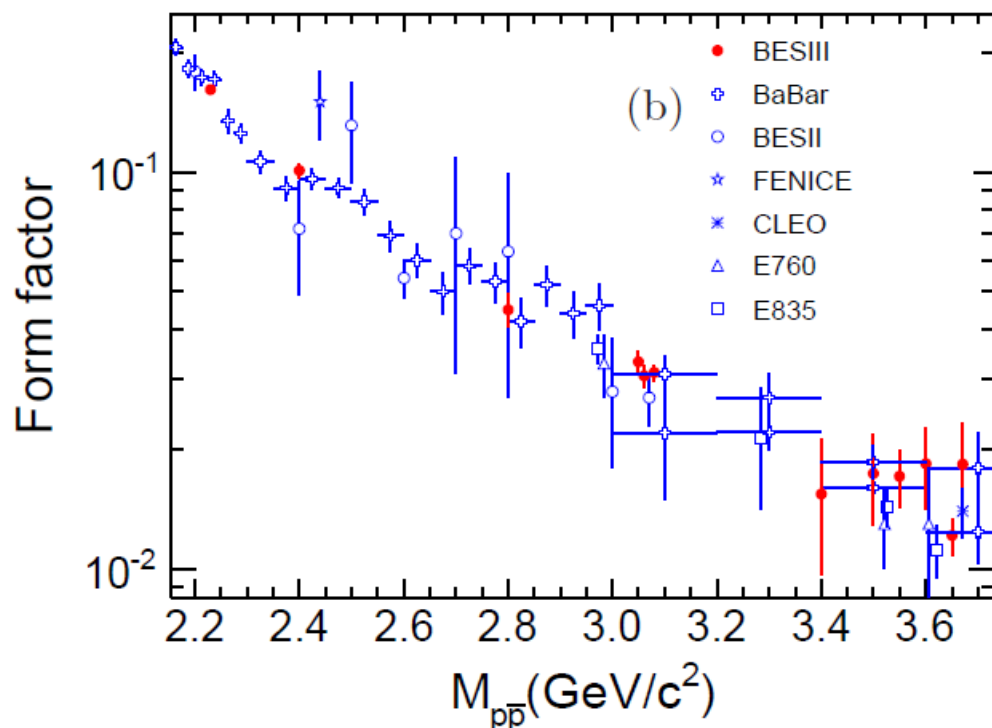
Spin-parity analysis of $J/\psi \rightarrow \gamma \bar{p}p$
performed by BESIII and the $J^{PC} = 0^{+-}$.
 pp FSI ?

Studies of other channels BESIII:
 $\Psi' \rightarrow \gamma \bar{p}p$, $J/\Psi \rightarrow \pi \bar{p}p$,
 $J/\Psi \rightarrow \eta \bar{p}p$, $J/\Psi \rightarrow \omega \bar{p}p$

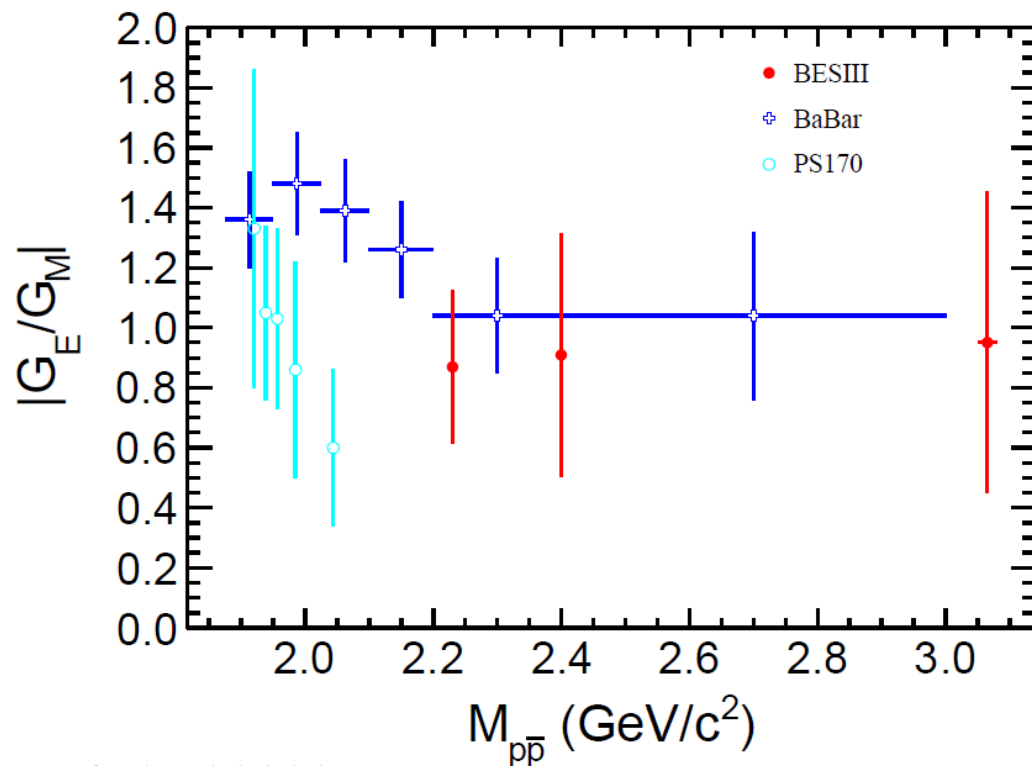
Baryon spectroscopy at BESIII

- PWA of $\psi(3686) \rightarrow \bar{p}p\pi^0$ PRL 110, 022001
- PWA of $\psi(3686) \rightarrow \bar{p}p\eta$ PRD 88, 032010
- Measurement of $\psi(3686) \rightarrow \gamma K^-\Lambda \Xi^+ + c. c.$ arXiv:1504.02025
- Observation of $\psi(3686) \rightarrow \Lambda \Sigma^1 \pm \pi^\mp + c. c.$ PRD 88, 112007

Based on 106 M $\psi(3686)$ data



$e^+e^- \rightarrow p\bar{p}$



arXiv:1504.02680

Amplitude analysis of $\pi^0\pi^0$ system

The light scalar meson spectrum ($J^{PC} = 0^{++}$):

Broad, overlapping states

Lightest glueball state

J/ψ radiative decay to $\pi^0\pi^0$ provides a clean environment to study this spectrum

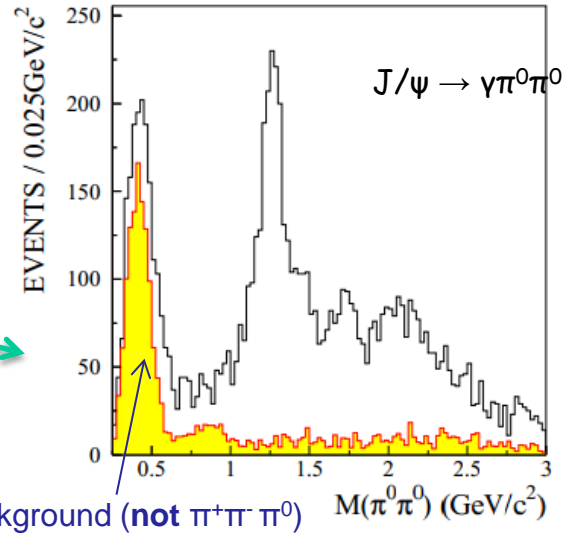
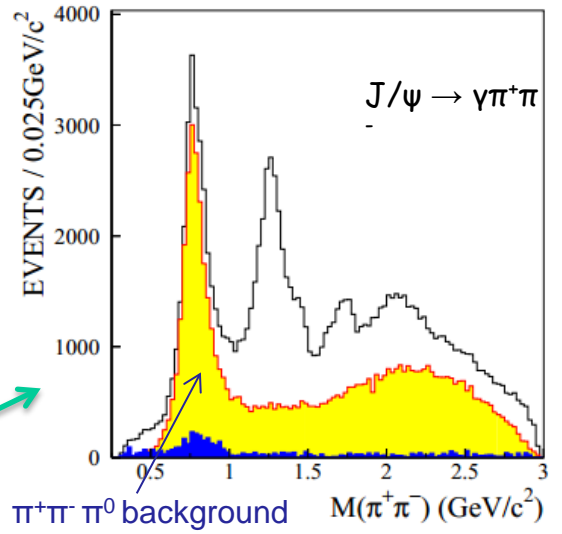
Radiative decays to two pseudoscalars, angular momentum + parity restricts the quantum numbers to $J^{PC}=0^{++}, 2^{++}, 4^{++} \dots$

Neutral channel is cleaner than the charged channel

Amplitude analysis:

Mass independent fits \rightarrow final state interactions of $\pi^0\pi^0$

Mass dependent fits \rightarrow extracting masses, widths, etc. of intermediate states



Event Selection

Initial selection criteria:

No charged tracks

five good photons

25 (50) MeV in the barrel (endcap)

No timing requirement

Perform 6C kinematic fit

If multiple combinations of $\gamma\pi^0\pi^0$,
keep event with smallest χ^2

Additional selection criteria:

6C kinematic fit χ^2

$\chi^2 < 20$ for low mass region ($< 0.99 \text{ GeV}/c^2$)

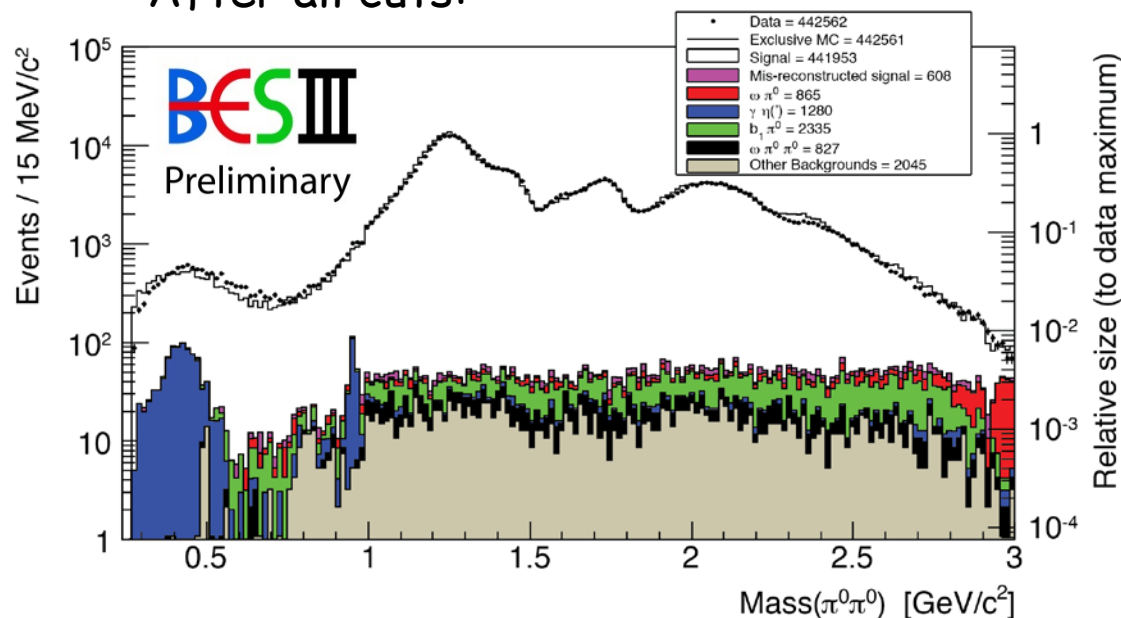
$\chi^2 < 100$ for high mass region ($\geq 0.99 \text{ GeV}/c^2$)

$|M(\gamma\pi^0) - M(\omega)| > 50 \text{ MeV}/c^2$

The invariant mass of the radiative photon
paired with any π^0 daughter photon must
be greater than $150 \text{ MeV}/c^2$

Analysis done at Indiana U
(in coll with JPAC)

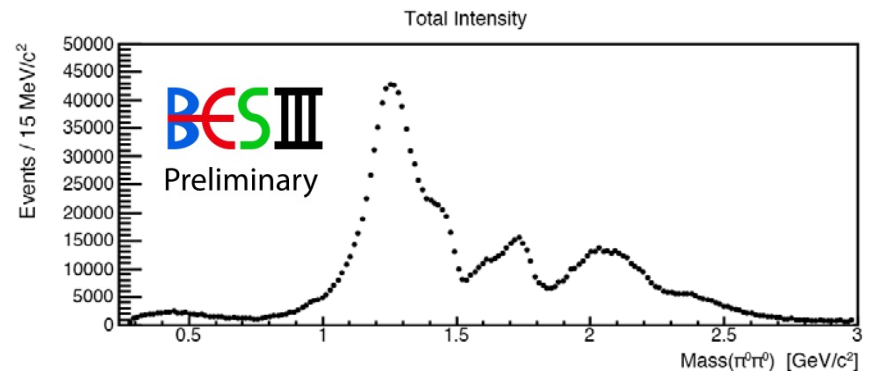
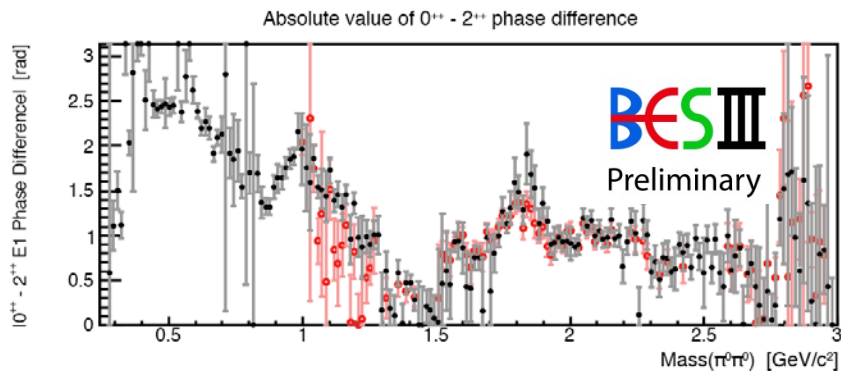
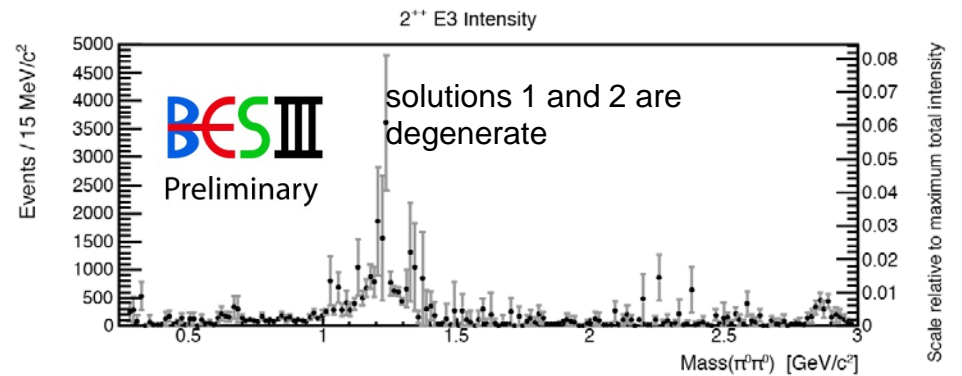
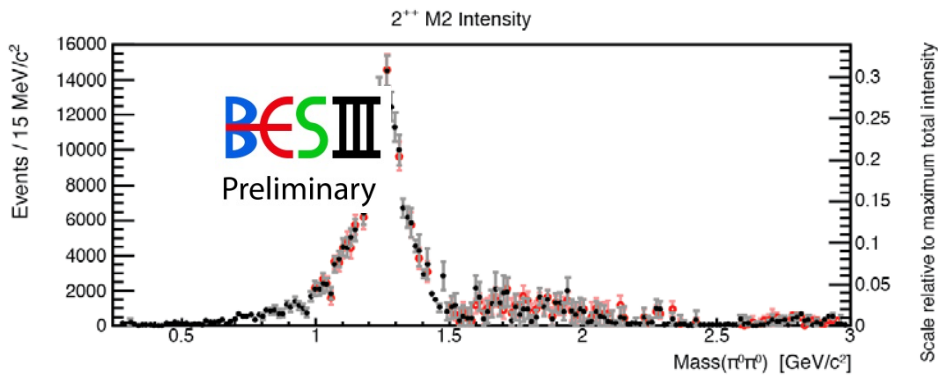
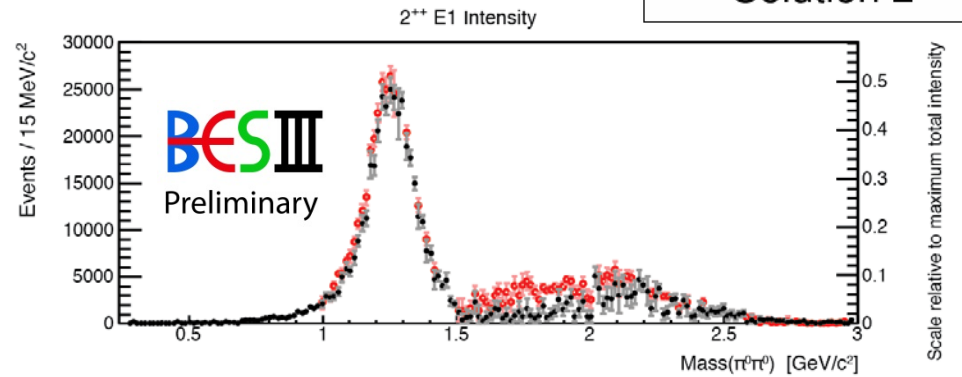
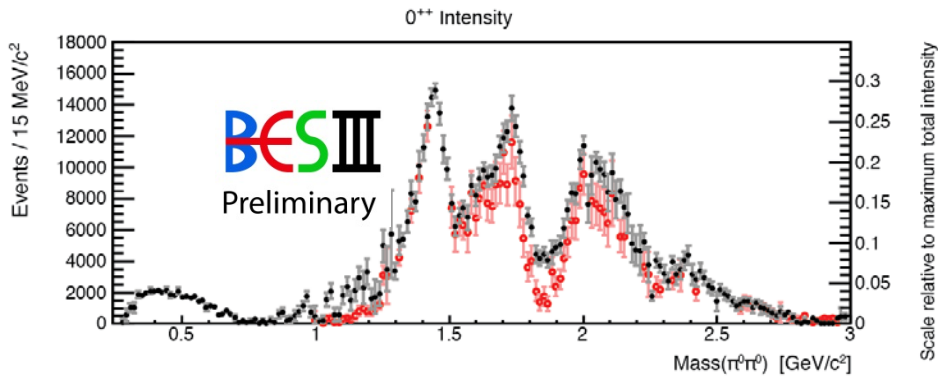
After all cuts:



Decay channel	Number of events
$J/\psi \rightarrow \gamma\pi^0\pi^0$ (data)	475,722
$J/\psi \rightarrow \gamma\pi^0\pi^0$ (MC)	789,801
$J/\psi \rightarrow \gamma\pi^0\pi^0$ (continuum)	277
$J/\psi \rightarrow b_1\pi^0; b_1 \rightarrow \gamma\pi^0$	3,174
$J/\psi \rightarrow \omega\pi^0; \omega \rightarrow \gamma\pi^0$	1,067
$J/\psi \rightarrow \gamma\eta; \eta \rightarrow 3\pi^0$	877
$J/\psi \rightarrow \gamma\eta'; \eta' \rightarrow \eta\pi^0\pi^0; \eta \rightarrow \gamma\gamma$	586
Misreconstructed signal events	2,428
Other backgrounds	6,005
Total Background (MC)	14,141

Results

- Solution 1
- Solution 2
- Solution 2



Conclusions

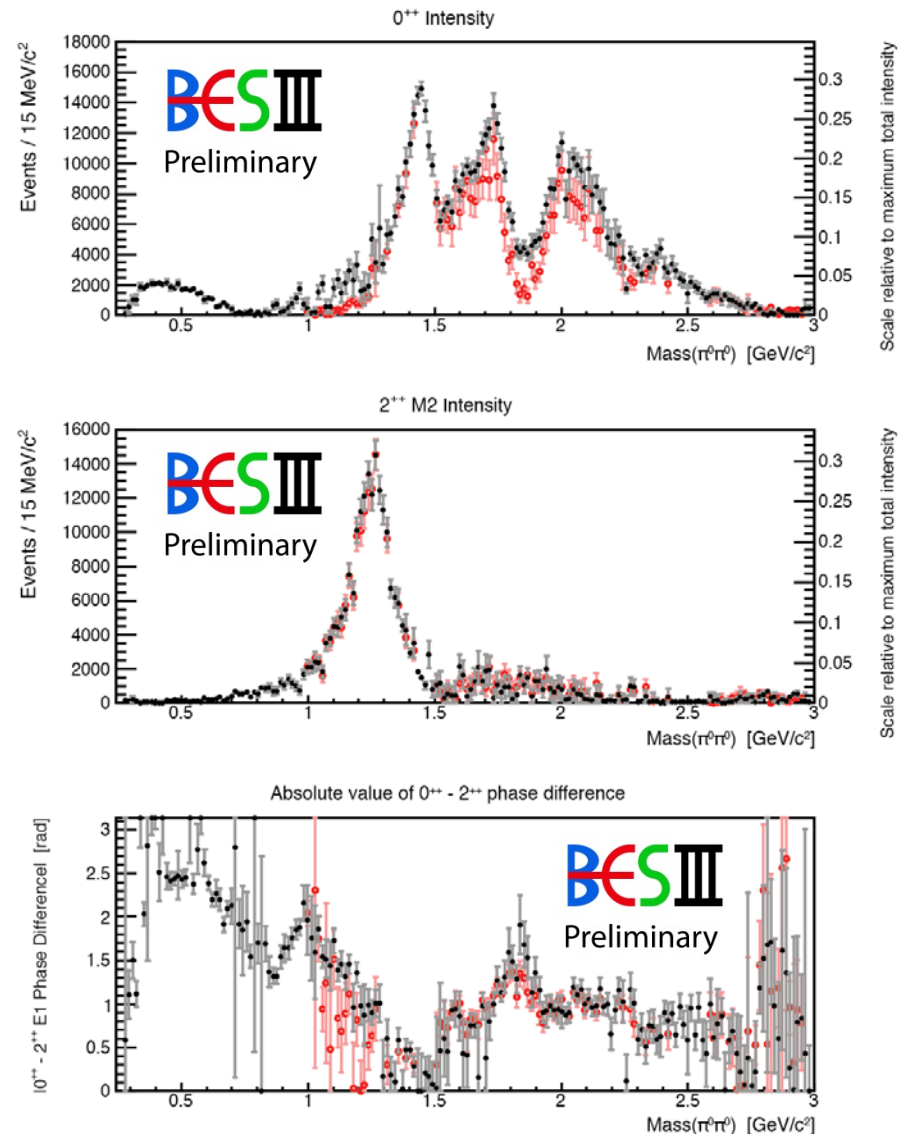
- Solution 1
- Solution 2

A mass independent amplitude analysis is performed

Goal: *Extract the function that describes the dynamics of the $\pi\pi$ interaction*

These results may be integrated with other, related data and fit by any arbitrary model, allowing for studies of $\pi\pi$ dynamics

Significant features of the scalar spectrum include structures near 1.5, 1.7, and 2.0 GeV/c^2



* Error bars are statistical only

Published η/η' results from BESIII:

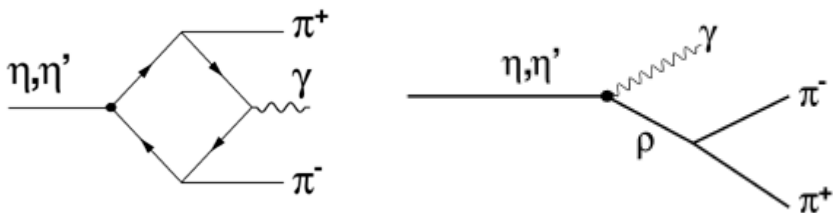
- * $\eta' \rightarrow \pi^+\pi^-\eta$ DP PRD83, 012003('11)
- * $\eta/\eta' \rightarrow \pi^+\pi^-, \pi^0\pi^0$ CPV UL PRD84, 032006('11)
- * $\eta' \rightarrow \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$ BR PRL108, 182001('12)
- * $\eta' \rightarrow \pi^+\pi^-l+l-$ BR PRD87, 092001('13)
- * invisible decays UL PRD87, 012009('13)
- * weak decays UL PRD87, 032006('13)
- $\eta' \rightarrow 4\pi$ BR PRL112, 251801('14)

* These results are based on 226 J/ Ψ



1.31×10^9 J/ Ψ events \rightarrow ca 6×10^6 η'

$\eta/\eta' \rightarrow \pi^+\pi^-\gamma$

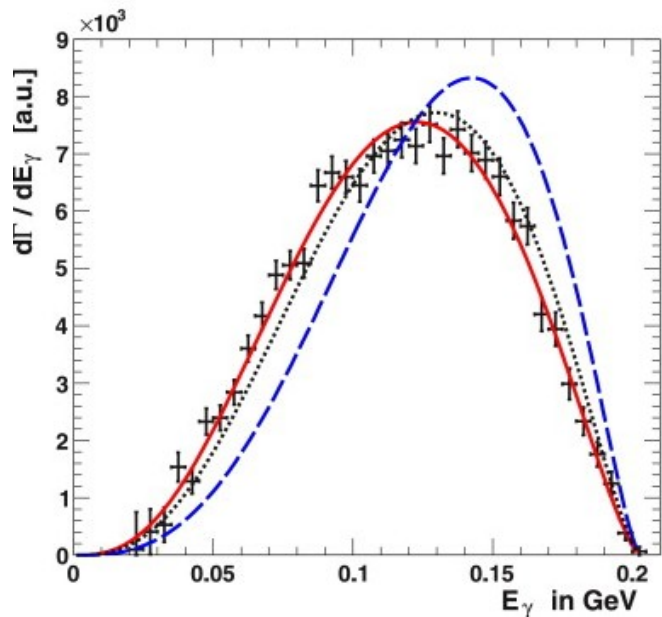


$$\frac{d\Gamma_{\eta(\eta')}}{ds_{\pi\pi}} \propto \left| C + \frac{1}{s_{\pi\pi} - m_\rho^2 - im_\rho\Gamma_\rho} \right|^2$$

$$\frac{d\Gamma}{ds} = |A(1 + \alpha s + \dots)F_V(s)|^2 K_P(s)$$

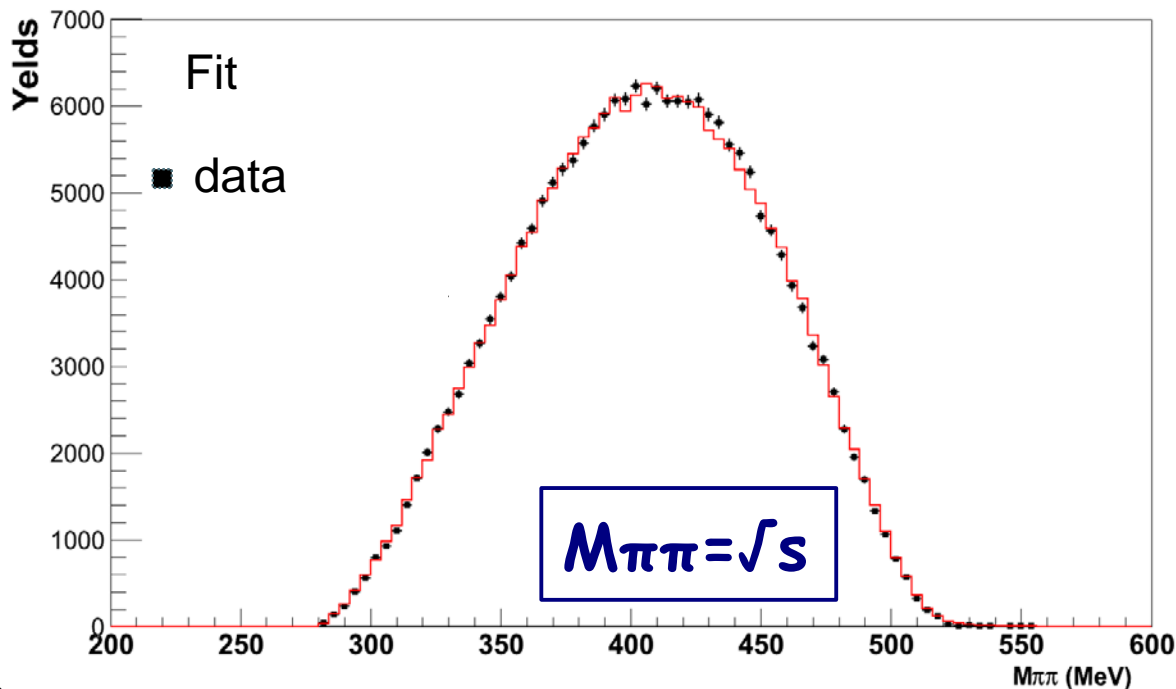
PLB707 (2012) 184

$e^+e^- \rightarrow \pi^+\pi^-$



$$\alpha = 1.89 \pm 0.25_{\text{stat}} \pm 0.59_{\text{syst}} \text{ GeV}^{-2}$$

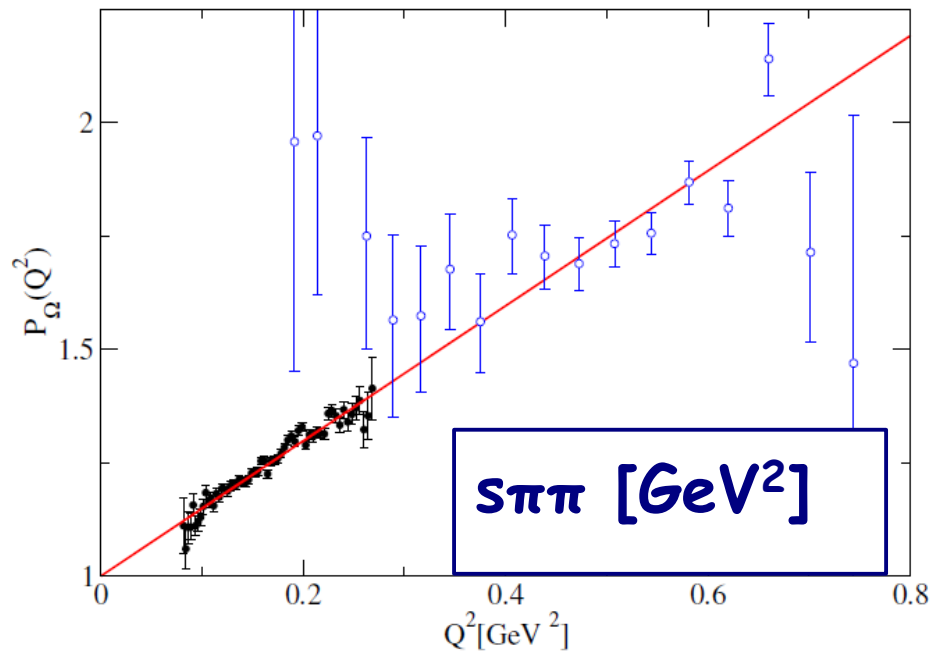
[WASA PLB707 (2012) 243]



$$\alpha = 1.31 \pm 0.08_{\text{stat}} \pm 0.40_{\text{syst}} \text{ GeV}^{-2}$$

[KLOE PLB718 (2013) 910]

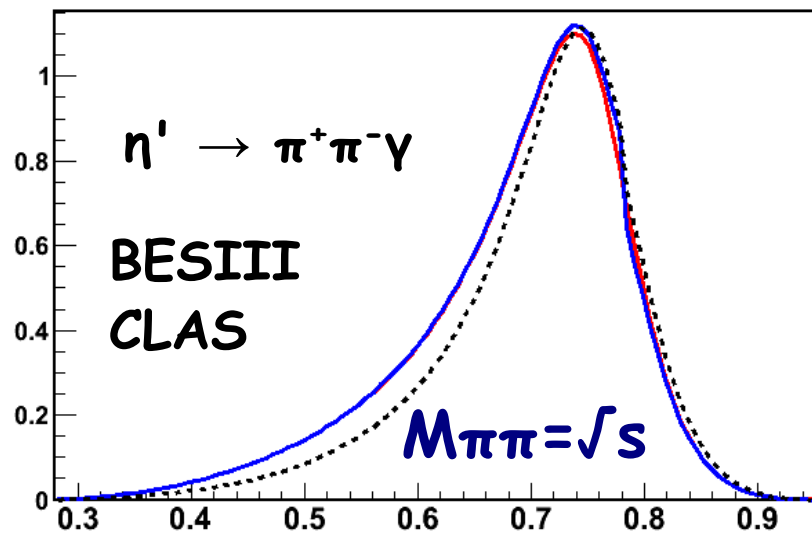
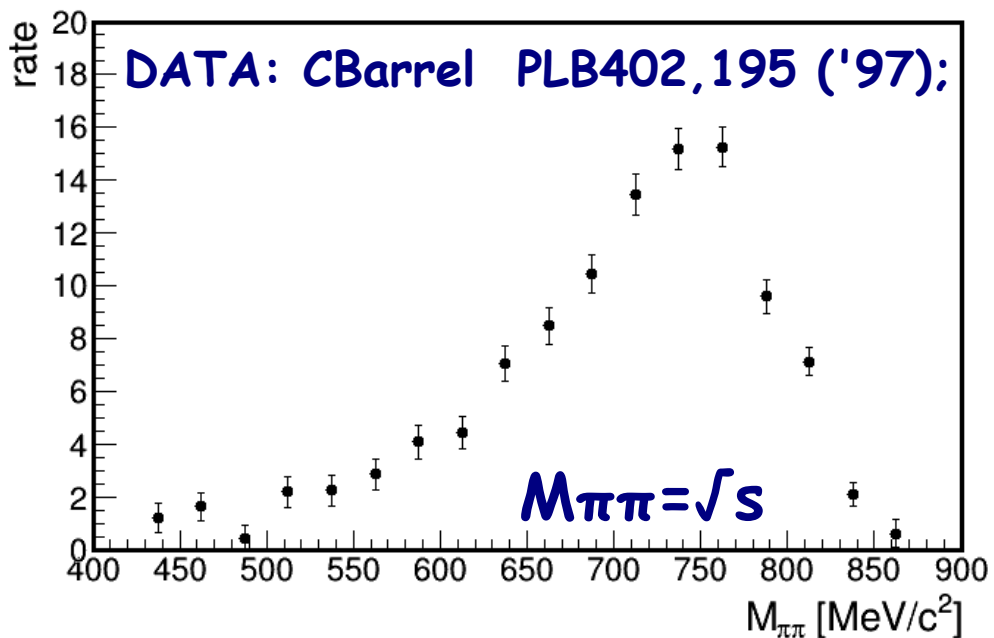
$\eta' \rightarrow \pi^+\pi^-\gamma$



$$P(s_{\pi\pi}) = A_0(1 + \alpha s_{\pi\pi})$$

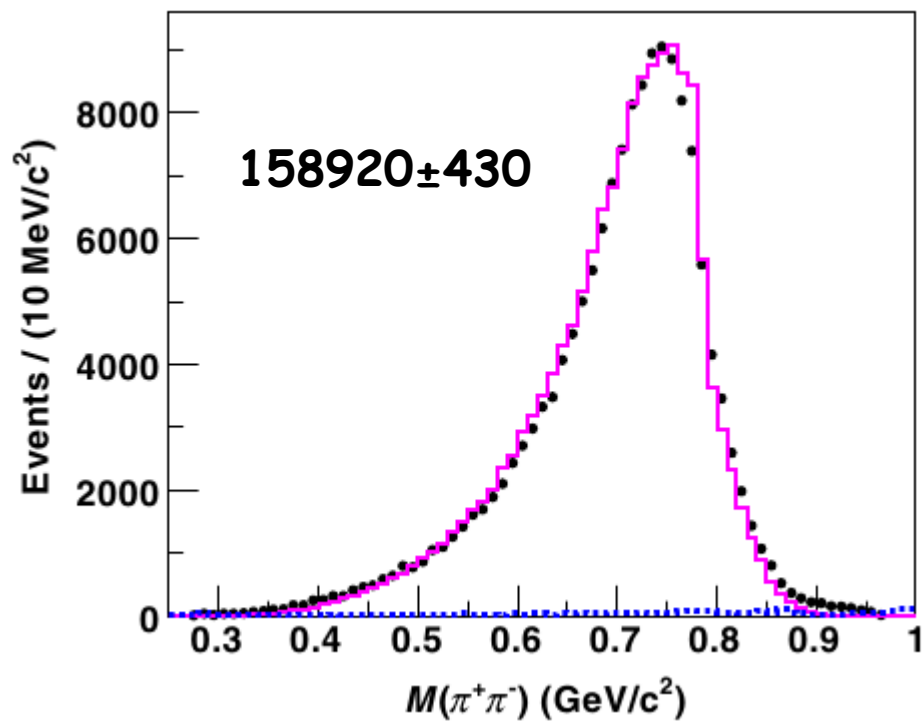
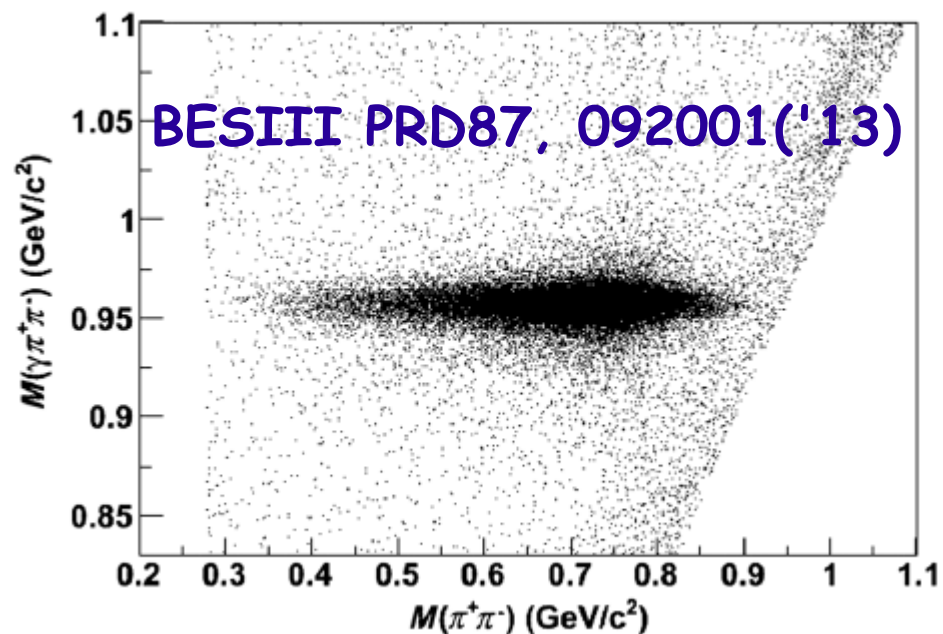
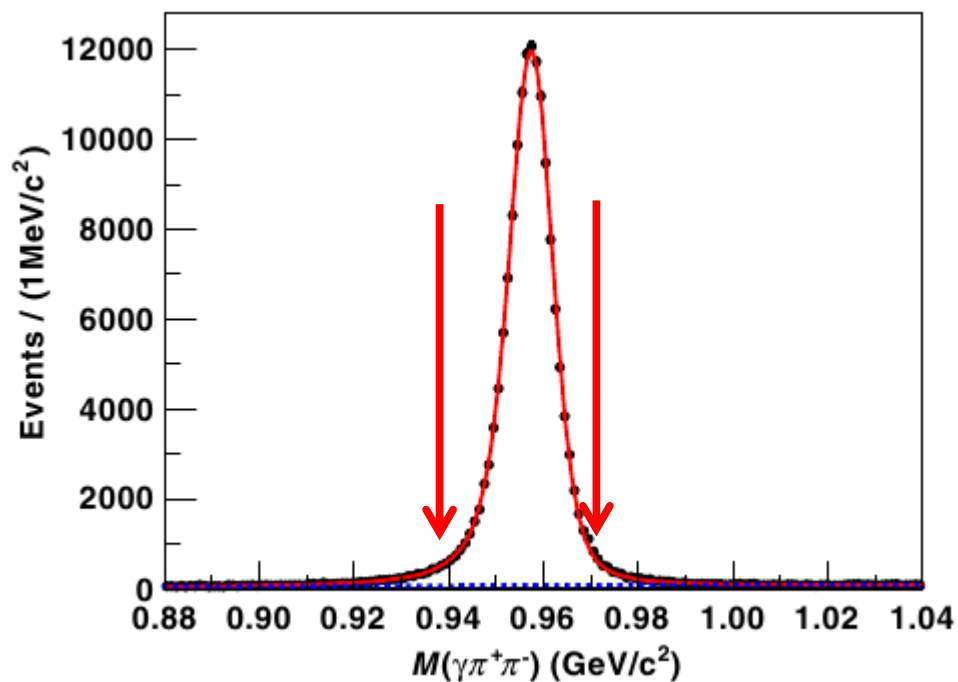
→ α reaction specific

→ $\alpha[\eta] = \alpha[\eta']$ understood
1-loop ChPT + large N_c



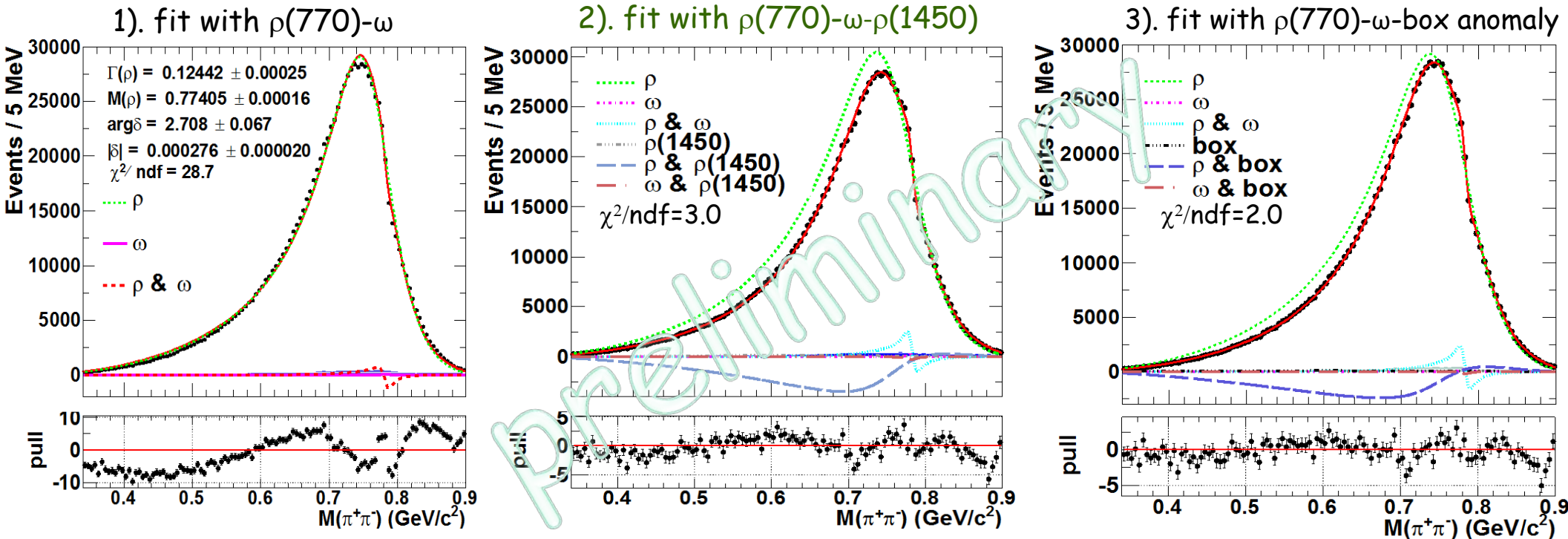
KLOE PL B718, 910 ('13)

BESIII data sample on $\eta' \rightarrow \pi^+\pi^-\gamma$



Now $1.9 \times 10^6 \eta \rightarrow \pi^+\pi^-\gamma$

Model-dependent fit

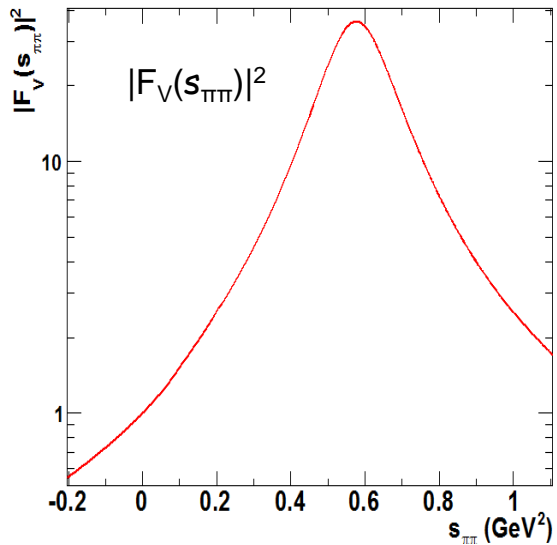


$$\frac{d\Gamma}{dm} \propto k_\gamma^3 q_\pi^3(m) \left| \frac{BW_\rho^{GS} (1 + \delta \frac{m^2}{m_\rho^2} BW_\omega) + \beta \cdot BW_{\rho'}^{GS}}{1 + \beta} + \frac{E_{\eta'}}{F_{\eta'}} \right|^2$$

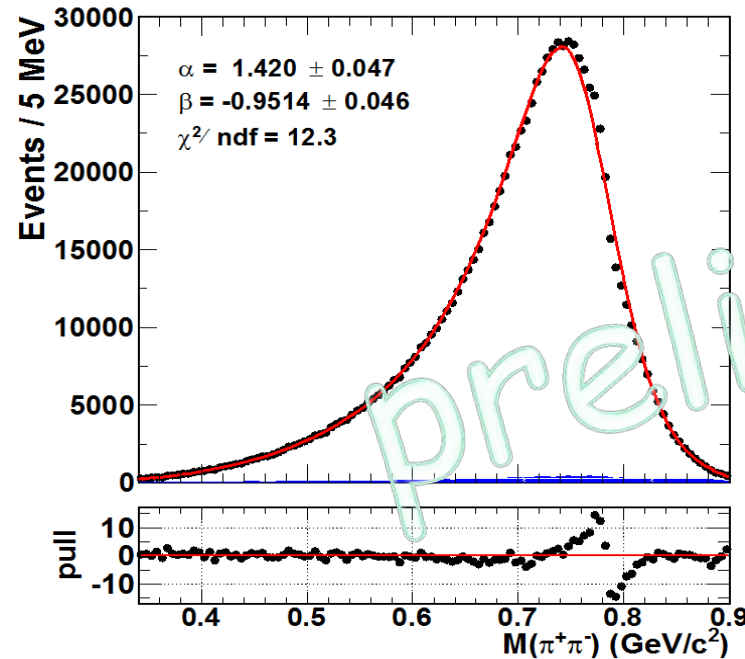
- ✓ Beside $\rho(770)$ resonance, ω is needed
- ✓ $\rho(770)$ - ω is not enough;
- ✓ Extra contribution (maybe $\rho(1450)$ or box-anomaly, maybe both of them) is also necessary

Model-independent fit

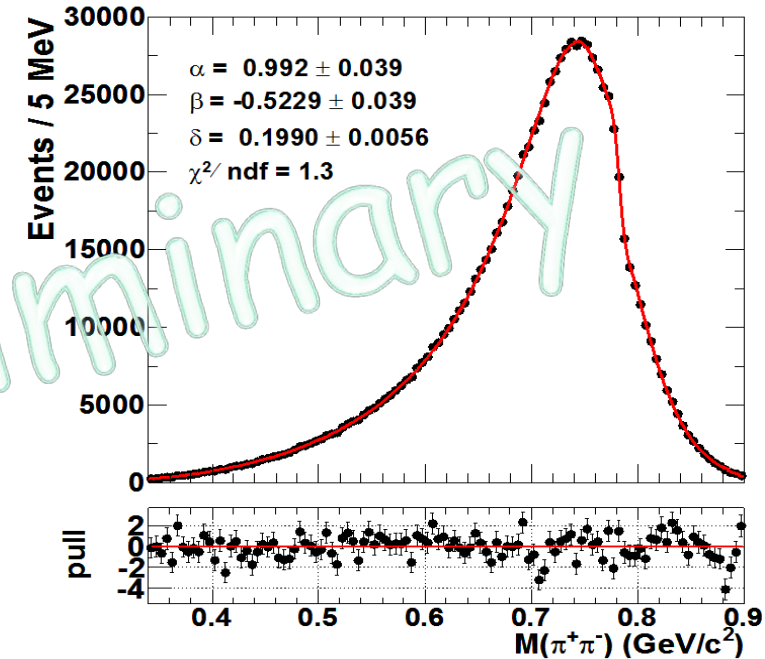
$$\frac{d\Gamma}{ds_{\pi\pi}} = |AP(s_{\pi\pi})F_V(s_{\pi\pi})|^2 \Gamma_0(s_{\pi\pi})$$



$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + \beta s_{\pi\pi}^2$$



$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + \beta s_{\pi\pi}^2 + \delta \text{BW}_\omega$$



Crystal Barrel: $\alpha = (1.80 \pm 0.49 \pm 0.04)\text{GeV}^{-2}$

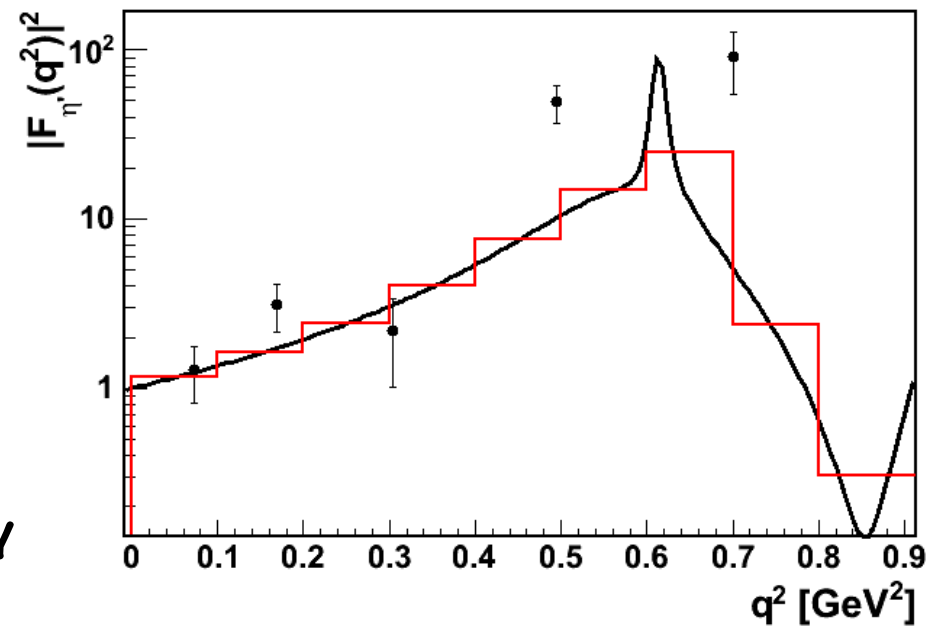
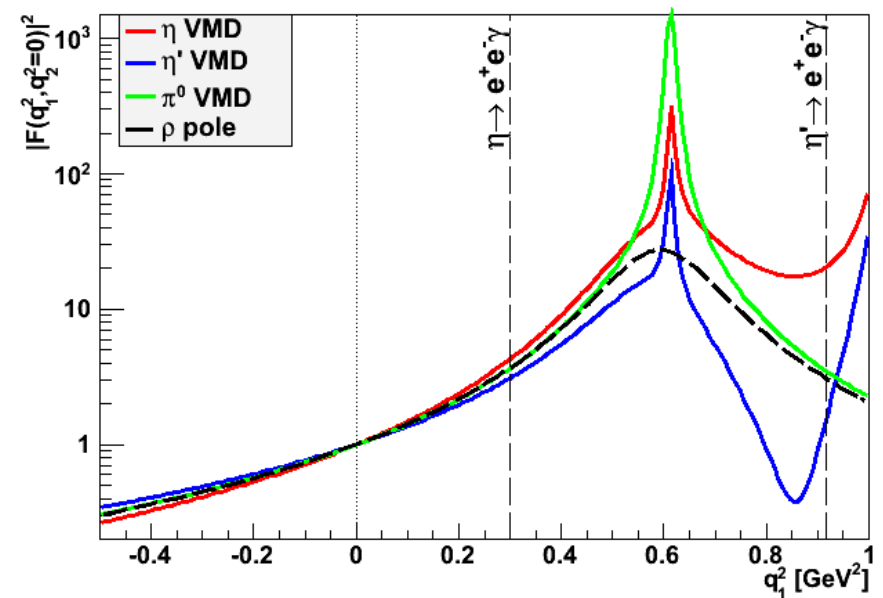
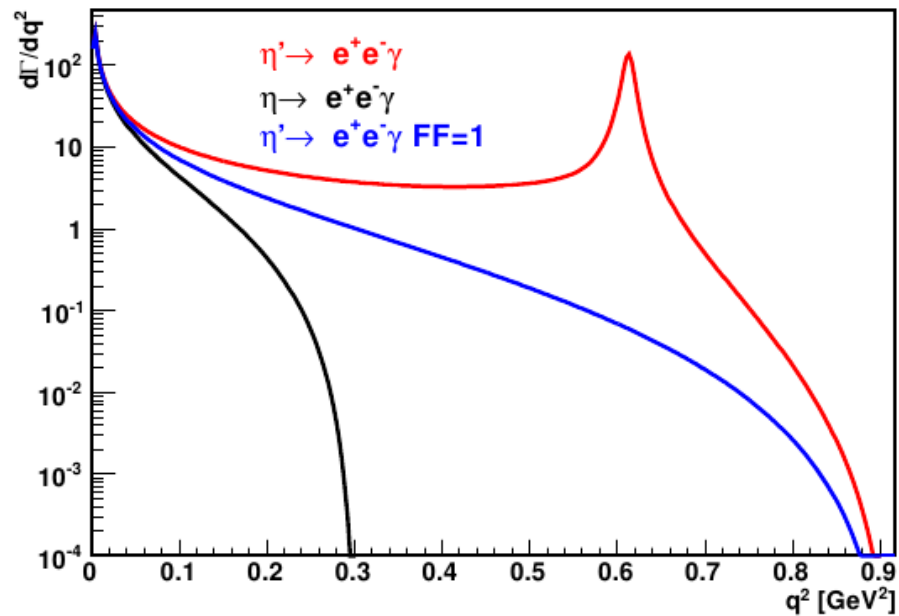
$\beta = (0.04 \pm 0.36 \pm 0.03)\text{GeV}^{-4}$

GAMS-2000: $\alpha = (2.7 \pm 1.0)\text{GeV}^{-2}$

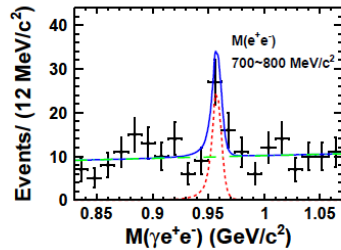
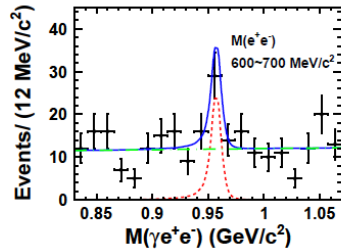
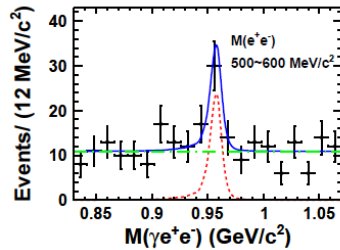
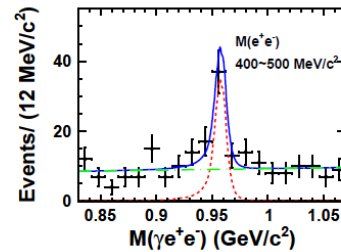
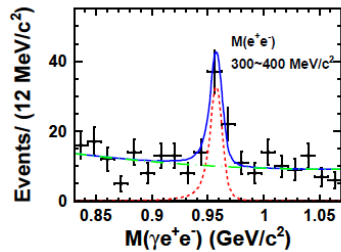
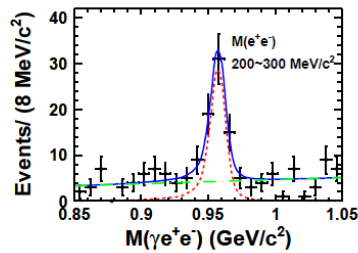
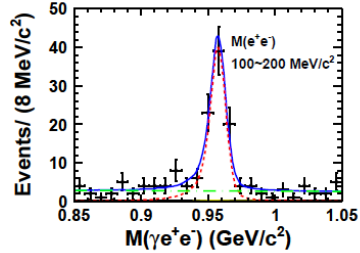
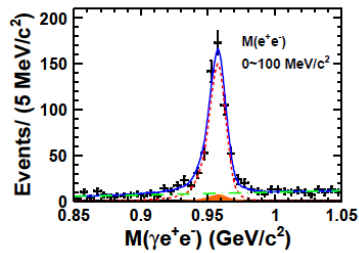
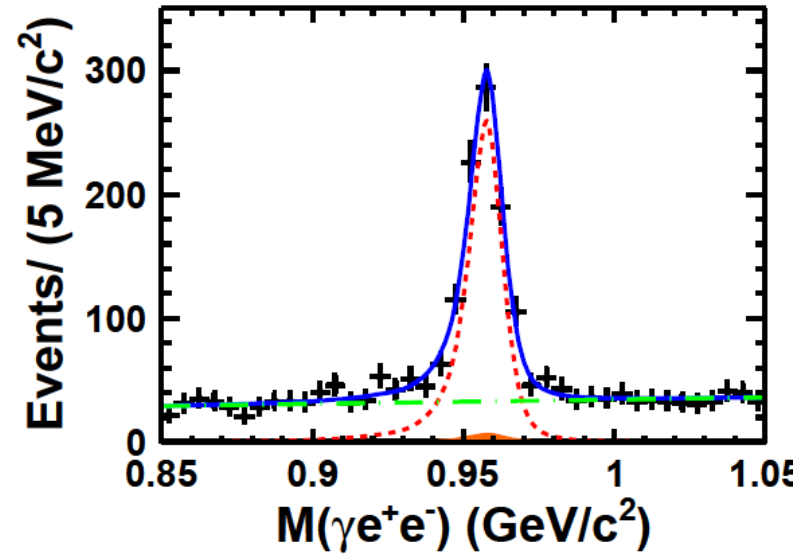
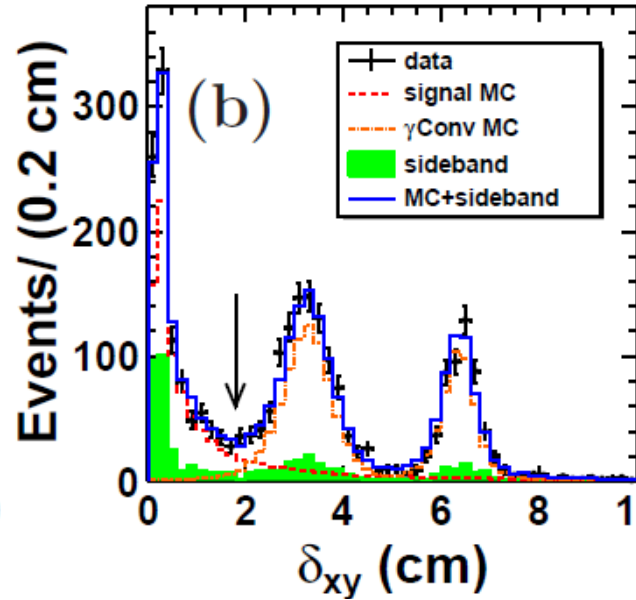
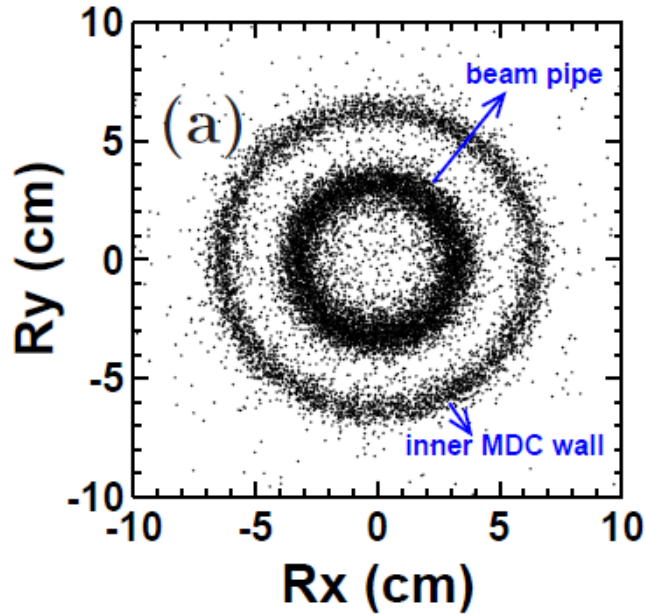
ω contribution is necessary

Linear polynomial is insufficient...

Dalitz decays

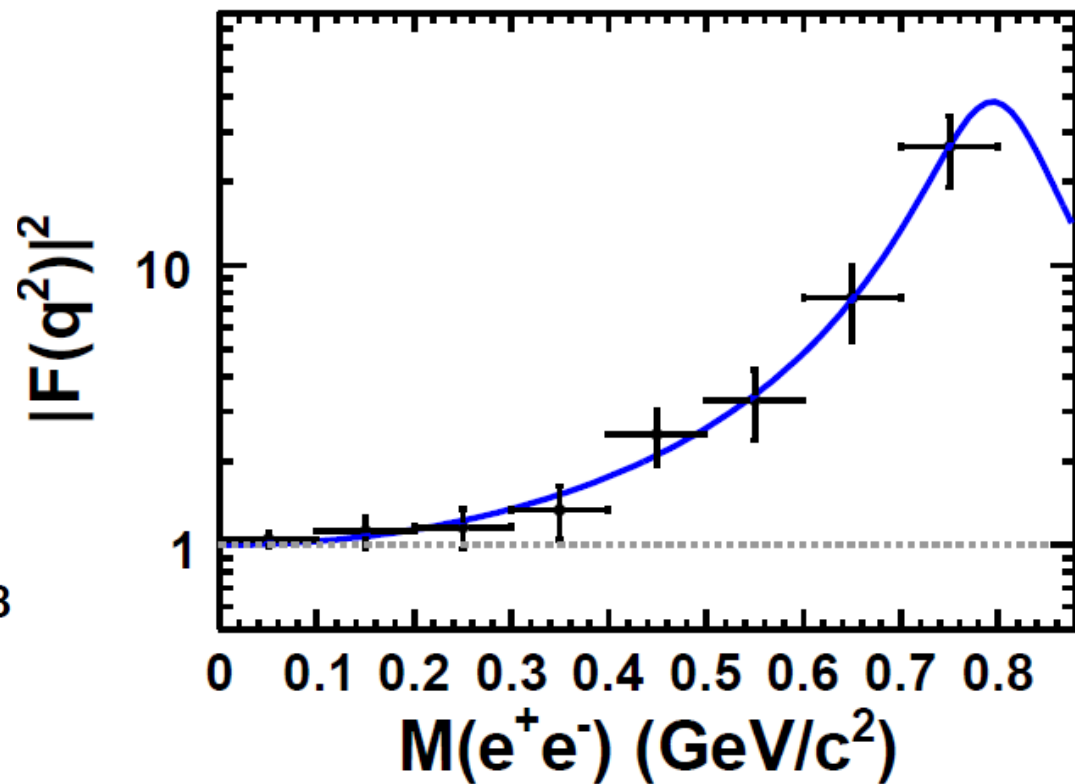
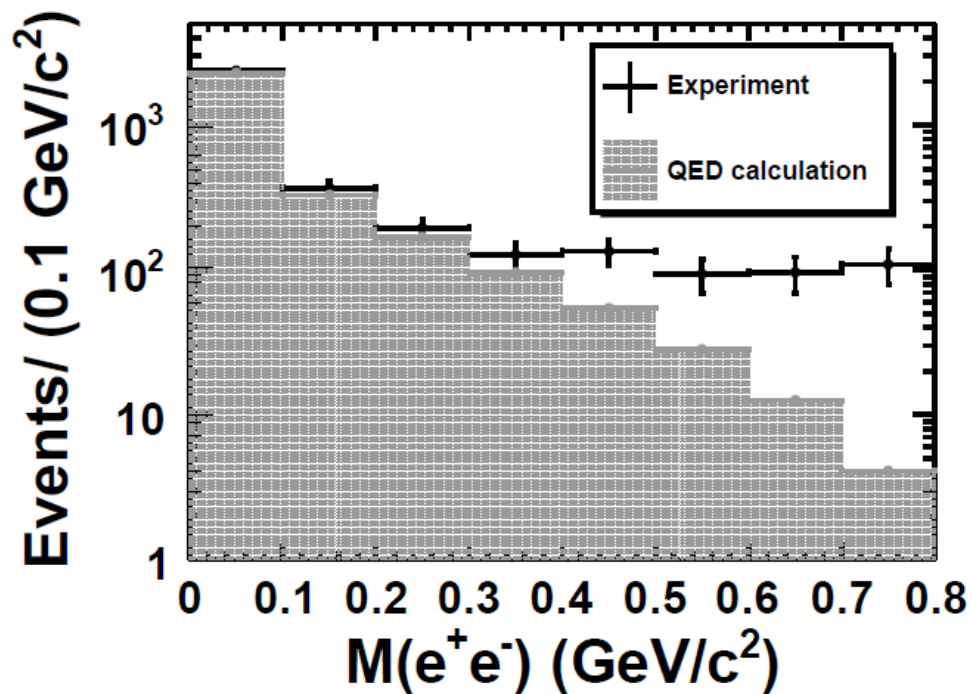


Observation of $\eta' \rightarrow \gamma e^+ e^-$



arXiv:1504.06016

Transition form factor of $\eta' \rightarrow \gamma e^+ e^-$



Summary

- An excellent place to study light hadron spectroscopy (high statistics and low background), complementary to hadro- and photoproduction experiments
- Many interesting results based on 225 M J/ψ and 106 M $\psi(3686)$ data
- Expect much more results with 1.3 B J/ψ and 0.5 B $\psi(3686)$ data
- BESIII is also η' factory



BESIII Collaboration

US (6)
Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Germany (5)
Univ. of Bochum, Univ. of Giessen, GSI, Univ. of Johannes Gutenberg, Helmholtz Ins. In Mainz

Pakistan (2)
Univ. of Punjab
COMSAT CIIT

Italy (3)
Univ. of Torino, Frascati Lab, Univ. of Ferrara

Korea (1)
Seoul Nat. Univ.

North Russia (2)
JINR Dubna; BINP Novosibirsk

Japan (1)
Tokyo Univ

Netherlands (1)
KVI/Univ. of Groningen

Sweden (1)
Uppsala Univ.

Turkey (1)
Turkey Accelerator Center

China (30)
IHEP, CCAST, GUCAS, Shandong Univ., Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll., Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ., Peking Univ., Tsinghua Univ.,
Zhongshan Univ., Nankai Univ., Shanxi Univ., Sichuan Univ., Univ. of South
China, Hunan Univ., Liaoning Univ., Nanjing Univ., Nanjing Normal Univ.,
Guangxi Normal Univ., Guangxi Univ., Suzhou Univ., Hangzhou Normal Univ.,
Lanzhou Univ., Henan Sci. and Tech. Univ., Hong Kong Univ., Hong Kong
Chinese Univ.

~350 members
11 countries
53 institutions
22 outside China

