B E S III

Stato e Risultati

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On behalf of the BESIII Collaboration

*** INFN-Perugia University***

IFAE 2012

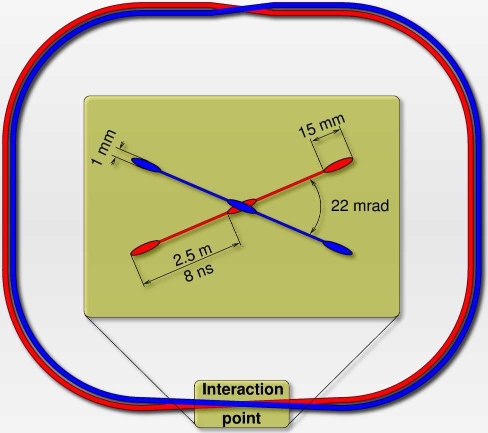
Incontri di Fisica della Alte Energie

11-13 aprile 2012
Ferrara

Agenda

- Propaganda: **BESIII** at BEPCII
- $f_0(980) \sim a_0(980)$ mixing
- $\eta(1405) \longrightarrow f_0(980)\pi^0$
- $J/\psi \longrightarrow p\bar{p}$ and $J/\psi \longrightarrow n\bar{n}$
- New structures
- The zero-degree detector

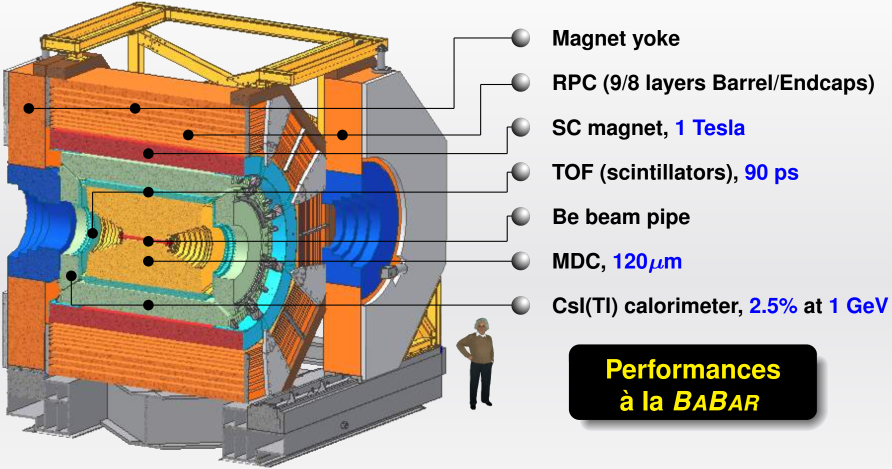
BEPCII: e^+e^- double ring collider



Design Features

- Beam energy: **1.0** - **2.3** GeV
- Crossing angle: **22** mrad
- **Luminosity: 10^{33} cm^{-2}s^{-1}**
- **Optimum energy: 1.89 GeV**
- Energy spread: **5.16** $\times$ **10^{-4}**
- Number of bunches: **93**
- Bunch length: **15** mm
- Total current: **0.91** A
- Circumference: **240** m

The **BESIII** detector

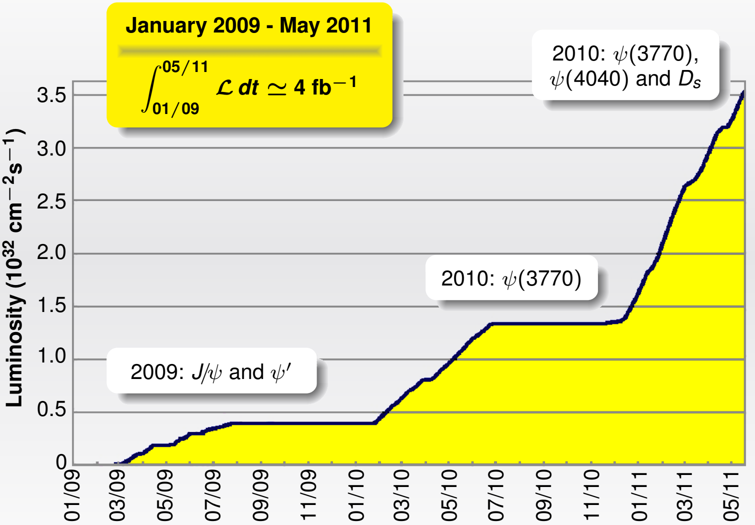


Performances à la *BABAR*

On April 14th 2009 BESIII finished accumulating the first large data set of more than **100 million ψ' events**. This is the world's largest ψ' data set.

BEPCII reached a peak luminosity of **0.65×10^{33} cm^{-2} s^{-1}**

BEPCII luminosity trend since startup



- $R_{\rm had}$ and precision test of Standard Model
- Light hadron spectroscopy ($\phi f_0(980)$, $\phi\pi^0$,...)
- Charm and charmonium physics
- Search for new physics / new particles
- τ physics
- Precision measurements of CKM matrix elements

Physics Channels	Energy (GeV)	Luminosity (10^{33} cm^{-2} s^{-1})	Events/year
J/ψ	3.10	0.6	1.0×10^{10}
$\tau^+\tau^-$	3.67	1.0	1.2×10^{7}
ψ'	3.69	1.0	3.0×10^{9}
$D^*\overline{D}^*$	3.77	1.0	2.5×10^{7}
$D_s\overline{D}_s$	4.03	0.6	1.0×10^{6}
$D_s^*\overline{D}_s$+c.c.	4.14	0.6	2.0×10^{6}

- R_{had} **and precision test of Standard Model**
- **Light hadron spectroscopy** ($\phi f_0(980)$, $\phi\pi^0$,...)
- **Charm and charmonium physics**
- **Search for new physics / new particles**

Nonperturbative Quantum Chromodynamics

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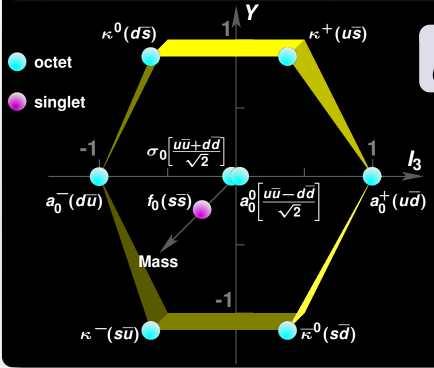
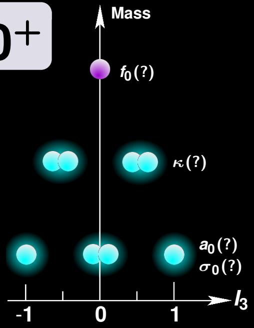
The $f_0(980)$ scalar meson at BESIII

The $q\bar{q}$ scalar nonet

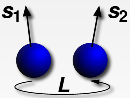
The light quarks ***u***, ***d*** and ***s*** form the ***SU*(3)** flavor nonet: $q^3 \otimes \bar{q}^{\bar{3}} = [\bar{q}q]^1 \oplus [\bar{q}q]^8$



$J^P = 0^+$



Is the $f_0(980)$ an $n^{2S+1}L_J = 1^3P_0$ element of the scalar $q\bar{q}$ nonet of flavor $SU(3)$?



$S = 1,\ L = 1$

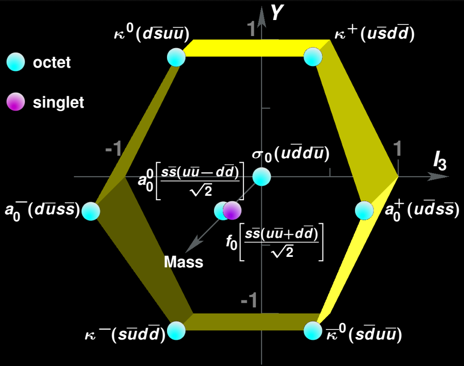
Why its isovector partner $a_0(980)$ has similar mass and width?

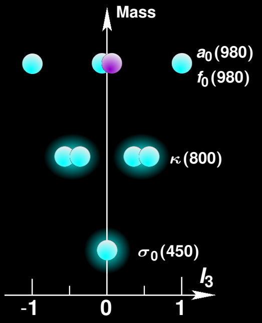
The $q\bar{q}q\bar{q}$ cryptoexotic scalar nonet

States $q\bar{q}q\bar{q}$ include exotics in **27**, **10** and $\overline{\mathbf{10}}$ representations of flavor $SU(3)$

The light states are Q-dominated $\Longrightarrow$
there are only **non-exotic** representations

$$\overline{Q}^{3} \otimes Q^{\bar{3}} = [\overline{Q}Q]^{1} \oplus [\overline{Q}Q]^{8}$$



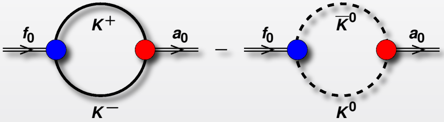


- **The mass hierarchy is inverted**
- **There is $f_0(980)$-$a_0(980)$ mass degeneracy**

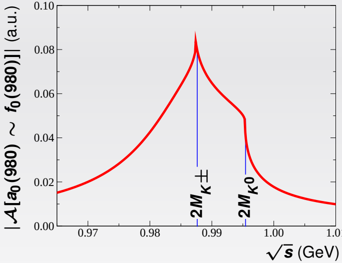
Studying $a_0(980)$ and $f_0(980)$ via their mixing

The isospin-one $a_0(980)$ and isospin-zero $f_0(980)$, degenerate in mass, couple to $K\overline{K}$

The common $K\overline{K}$ intermediate states mediate the isospin violating **$a_0(980)\sim f_0(980)$ mixing**



The proximity of the $K\overline{K}$ thresholds to the $f_0(980)/a_0(980)$ mass enhances the mixing amplitude **$\mathcal{A}[a_0(980)\sim f_0(980)]$** and hence the isospin-violating effect



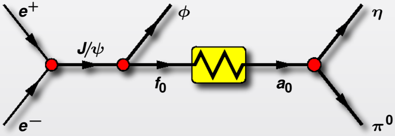
The amplitude **$\mathcal{A}[a_0(980)\sim f_0(980)]$** is highly sensitive to the scalar mesons structure

..... standard $q\bar{q}$ ..... $q\bar{q}q\bar{q}$ tetraquark ..... $K\overline{K}$ molecule ..... $q\bar{q}g$ hybrid .....

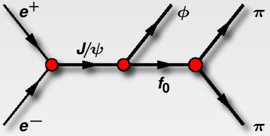
$a_0(980)\sim f_0(980)$ mixing at **BESIII**: the channels

$f_0(980) \to a_0(980)$

Mixing: $|I=0\rangle \to |I=1\rangle$



No mixing: $|I=0\rangle \to |I=0\rangle$

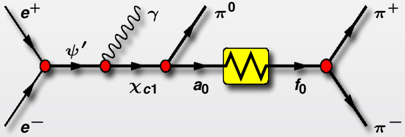


$f_0(980) \to a_0(980)$ transition intensity

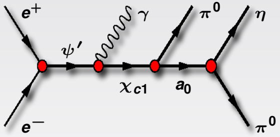
$$T_{a_0}^{f_0} = \frac{\Gamma(J/\psi \to \phi f_0 \sim \phi a_0 \to \phi\eta\pi^0)}{\Gamma(J/\psi \to \phi f_0 \to \phi\pi\pi)}$$

$a_0(980) \to f_0(980)$

Mixing: $|I=1\rangle \to |I=0\rangle$



No mixing: $|I=1\rangle \to |I=1\rangle$



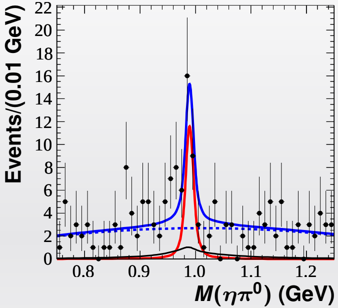
$a_0(980) \to f_0(980)$ transition intensity

$$T_{f_0}^{a_0} = \frac{\Gamma(\chi_{c1} \to \pi^0 a_0 \sim \pi^0 f_0 \to \pi^0\pi^+\pi^-)}{\Gamma(\chi_{c1} \to \pi^0 a_0 \to \pi^0\pi^0\eta)}$$

$a_0(980)\sim f_0(980)$ mixing at **BESIII**: the data

PRD83(2011)032003

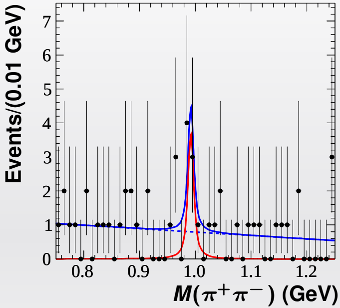
$J/\psi \to \phi f_0 \sim \phi a_0 \to \phi\eta\pi^0$



- Sample of **2.25** $\times$ **10^8** J/ψ
- Backgrounds:
  $e^+e^- \to \gamma^* \to \phi a_0$
  $e^+e^- \to J/\psi \to K^*\overline{K} + \text{c.c.} \to \phi a_0$
- Mixing events: **25.8** $\pm$ **8.6**

$$T_{a_0}^{f_0} = (0.60 \pm \underbrace{0.20}_{\text{stat.}} \pm \underbrace{0.12}_{\text{syst.}} \pm \underbrace{0.26}_{\text{param.}})\%$$

$\psi' \to \chi_{c1}\gamma \to \pi^0 a_0\gamma \sim \pi^0 f_0\gamma \to \pi^0\pi^+\pi^-\gamma$

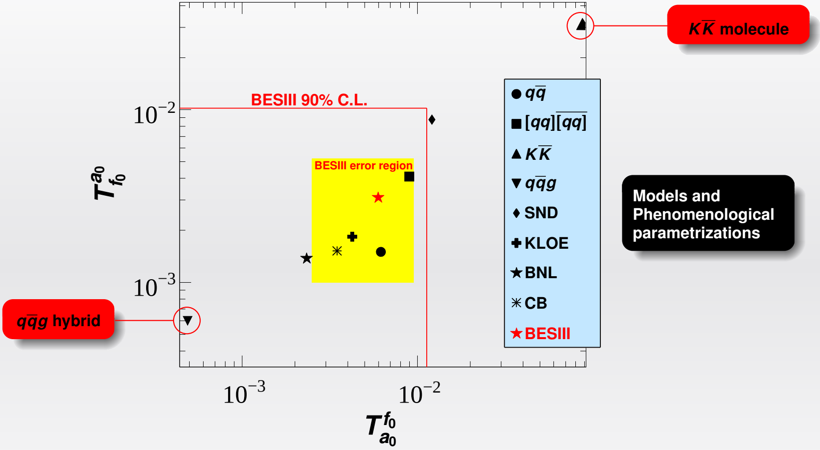


- Sample of **1.06** $\times$ **10^8** ψ'
- No resonant background
- Mixing events: **6.4** $\pm$ **3.2**

$$T_{f_0}^{a_0} = (0.31 \pm \underbrace{0.16}_{\text{stat.}} \pm \underbrace{0.14}_{\text{syst.}} \pm \underbrace{0.03}_{\text{param.}})\%$$

$a_0(980) \sim f_0(980)$ mixing at **BESIII**

PRD83(2011)032003



Models and Phenomenological parametrizations

With higher statistics BESIII will be able to significantly reduce the allowed region

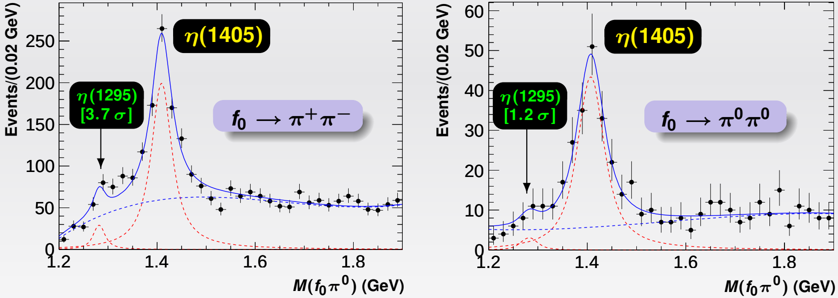
$\eta(1405) \to f_0(980)\pi^0$ for the first time at BESIII

The meson $\eta(1405)$ at **BESIII**

$$e^+e^- \rightarrow J/\psi \rightarrow \underbrace{\eta(1405)\gamma \rightarrow f_0(980)\pi^0\gamma}_{\text{isospin}-\text{violation}} \begin{cases} \pi^+\pi^-\pi^0\gamma \\ \pi^0\pi^0\pi^0\gamma \end{cases}$$

The $\eta(1405)$ nature has been determined by studying the $f_0\pi^0$ angular distribution

First observation of: $J/\psi \rightarrow f_0(980)\pi^0\gamma$ and $\eta(1405) \rightarrow f_0(980)\pi^0$



$$\mathrm{BR}\left[J/\psi \rightarrow \eta(1405)\gamma \rightarrow f_0\pi^0\gamma \rightarrow \pi^+\pi^-\pi^0\gamma\right] = (1.50 \pm 0.11_{\text{stat.}} \pm 0.11_{\text{syst.}}) \times 10^{-5}$$

$$\mathrm{BR}\left[J/\psi \rightarrow \eta(1405)\gamma \rightarrow f_0\pi^0\gamma \rightarrow \pi^0\pi^0\pi^0\gamma\right] = (7.10 \pm 0.82_{\text{stat.}} \pm 0.72_{\text{syst.}}) \times 10^{-6}$$

$\eta(1405)$ and isospin violation

The branching ratio of the J/ψ **isospin-conserving** decay in the $\eta\pi^0\pi^0\gamma$ final state via $\eta(1405)$ and $a_0(980)$ is

$$\mathbf{BR}\left[J/\psi \to \eta(1405)\gamma \to a_0\pi^0\gamma \to \eta\pi^0\pi^0\gamma\right] = (8.40 \pm 1.75) \times 10^{-5}$$

Assuming that the J/ψ **isospin-violating** decay in the $\pi^{0/+}\pi^{0/-}\pi^0\gamma$ final state proceeds mainly through the **$f_0(980) \sim a_0(980)$ oscillation** which occurs with a probability of the order of **0.6%** we expect a branchig fraction

$$\mathbf{BR}\left[J/\psi \to \eta(1405)\gamma \to a_0\pi^0\gamma \sim f_0\pi^0\gamma \to \pi^{0/+}\pi^{0/-}\pi^0\gamma\right] = (5 \pm 1) \times 10^{-7}$$

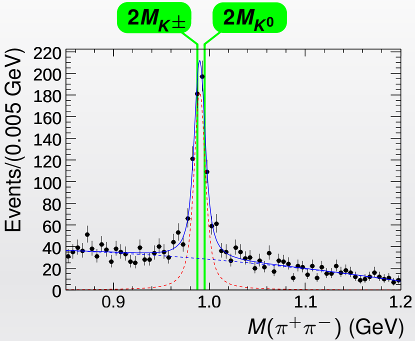
The BESIII measurement gives

$$\mathbf{BR}\left[J/\psi \to \eta(1405)\gamma \to f_0\pi^0\gamma \to \pi^{0/+}\pi^{0/-}\pi^0\gamma\right] = (2.2 \pm 0.3) \times 10^{-5}$$

Large isospin violation: $\dfrac{\mathbf{BR}\left[\eta(1405) \to f_0(980)\pi^0\right]}{\mathbf{BR}\left[\eta(1405) \to a_0(980)\pi^0\right]} \simeq 0.26$

$\eta(1405)$ and the $f_0(980)$ lineshape

arXiv:1201.2737



Parameters of $f_0(980)$ reco. in $\pi^+\pi^-$

$M_{f_0(\pi^+\pi^-)} = 989.9 \pm 0.4$ MeV

$\Gamma_{f_0(\pi^+\pi^-)} = 9.5 \pm 1.1$ MeV

PDG

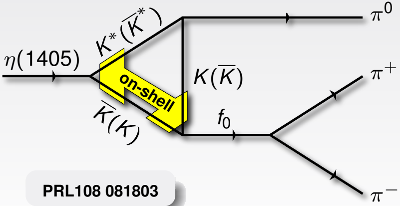
$M_{f_0} = 980 \pm 10$ MeV

$\Gamma_{f_0} = 40 - 100$ MeV

The **$[K^*\overline{K}$+c.c.$]$** loop contribution to the isospin-violating amplitude is enhanced because:

$\eta(1405) \longrightarrow [K^*\overline{K}+\text{c.c.}]_{\text{on-shell}} \longrightarrow \ldots$

$\ldots \longrightarrow [K\overline{K}+\text{c.c.}]_{\text{on-shell}} \longrightarrow f_0(980)$



PRL108 081803

$J/\psi \rightarrow p\bar{p}$ and $J/\psi \rightarrow n\bar{n}$ at BESIII

$J/\psi \to N\bar{N}$
Strong and electromagnetic amplitudes

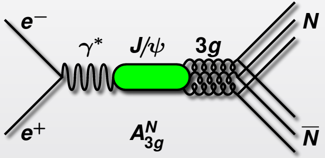
PLB404(1997)362

The $J/\psi \to N\bar{N}$ decay is a very good test of pQCD

The 3 gluons in the **OZI-violating** strong amplitude just match the 3 $q\bar{q}$ pairs of the $N\bar{N}$ final state

The strong amplitudes for $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$ are equal because the J/ψ has isospin zero

The strong amplitude $A^N_{3g} \equiv A_{3g}$ is **real** ($\Leftarrow$pQCD)

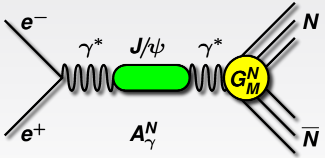


The $J/\psi \to N\bar{N}$ decay has a subdominant electromagnetic (EM) contribution: $J/\psi \to \gamma^* \to N\bar{N}$

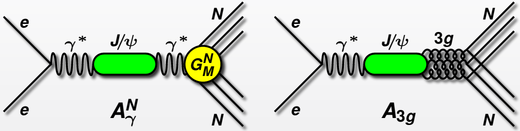
The EM aplitude depends on the electric and magnetic form factors (ff) that describe the $\gamma^* N\bar{N}$ vertex

At the J/ψ mass the main contribution comes from the magnetic ff's that are almost real and:

$$G^p_M(M^2_{J/\psi}) \simeq -G^n_M(M^2_{J/\psi}) > 0$$



$B(J/\psi \to n\bar{n}) / B(J/\psi \to p\bar{p})$



Proton: $B(J/\psi \to p\bar{p}) \sim |A_\gamma^p + A_{3g}|^2 = |A_\gamma^p|^2 + |A_{3g}|^2 + 2\,\mathrm{Re}[A_\gamma^{p*} A_{3g}]$

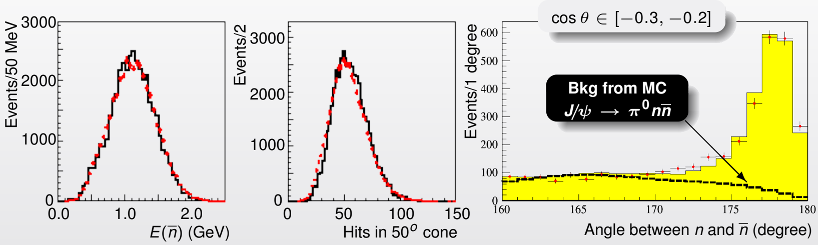
Neutron: $B(J/\psi \to n\bar{n}) \sim |A_\gamma^n + A_{3g}|^2 = |A_\gamma^p|^2 + |A_{3g}|^2 - 2\,\mathrm{Re}[A_\gamma^{p*} A_{3g}]$

Assuming as real both the strong, A_{3g}, and the EM amplitude, $A_\gamma^{p,n}$, the interference is maximum, but with opposite sign for neutron and proton

$$\Downarrow$$

$$\frac{\mathrm{BR}(J/\psi \to n\bar{n})}{\mathrm{BR}(J/\psi \to p\bar{p})} \simeq \frac{1}{2}$$

$n\bar{n}$ identification



BESIII

$$\mathrm{BR}(J/\psi \to n\bar{n}) = (2.07 \pm 0.01 \pm 0.17)\cdot 10^{-3}$$

$$\mathrm{BR}(J/\psi \to p\bar{p}) = (2.112 \pm 0.004 \pm 0.031)\cdot 10^{-3}$$

PDG

$$\mathrm{BR}(J/\psi \to n\bar{n}) = (2.2 \pm 0.4)\cdot 10^{-3}$$

$$\mathrm{BR}(J/\psi \to p\bar{p}) = (2.17 \pm 0.07)\cdot 10^{-3}$$

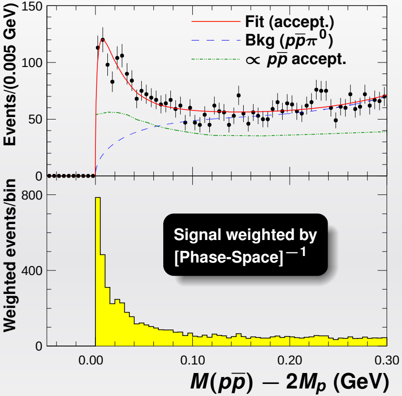
Phase between strong and EM amplitudes

$$\phi = \cos^{-1}\left[\frac{\mathrm{BR}(J/\psi \to p\bar{p}) - A_{3g}^2 - (A_\gamma^p)^2}{2\,A_{3g}\,A_\gamma^p}\right] = (88.7 \pm 8.1)^o$$

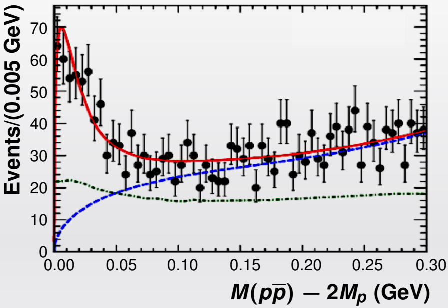
Baryonium and new structures at BESIII

$M(p\bar{p})$ threshold enhancement in $J/\psi \to p\bar{p}\gamma$

BESII [PRL91(2003)022001]



BESIII [CPC34(2010)421]



- $J/\psi \to p\bar{p}\gamma$
- Sample of $\mathbf{5.8 \times 10^7}$ J/ψ
- Resonance in $p\bar{p}$, with

  $M = 1859^{+3}_{-10}(\text{stat.})^{+5}_{-25}(\text{syst.})$ MeV

  $\Gamma < 30$ MeV at 90% C.L.

- $\psi' \to J/\psi\pi^+\pi^- \to p\bar{p}\gamma\pi^+\pi^-$
- Sample of $\mathbf{1.06 \times 10^8}$ ψ'
- Resonance in $p\bar{p}$, with

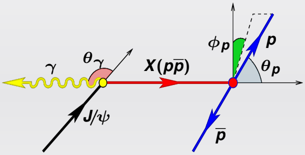
  $M = 1861^{+6}_{-13}(\text{stat.})^{+7}_{-26}(\text{syst.})$ MeV

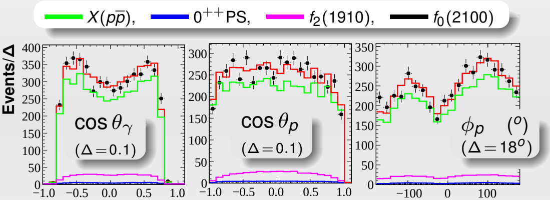
  $\Gamma < 38$ MeV at 90% C.L.

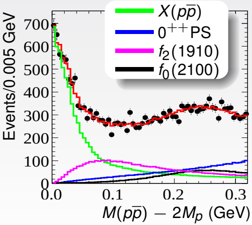
Partial Wave Analysis of the $M(p\bar{p})$ enhancement

arXiv:1112.0942

- Main sample: **2.25×10^8 J/ψ** ($\to p\bar{p}\gamma$). Secondary sample: **1.06×10^8 ψ'** ($\to p\bar{p}\gamma$)
- Four components: **$X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$, 0^{++}-phase-space (PS)**
- Resonances are parametrized as **Breit-Wigner propagators**
- The parameters of the mesons $f_2(1910)$ and $f_0(2100)$ are **fixed to the PDG values**



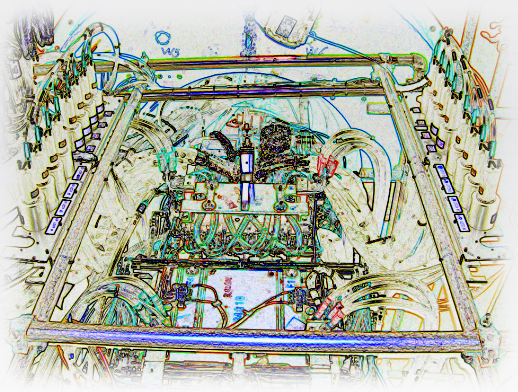




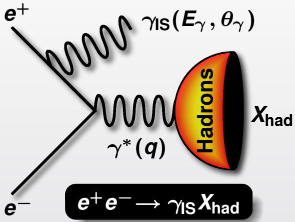
Comp.	J^{PC}	M (MeV)	Γ (MeV)	Sign.
$X(p\bar{p})$	0^{-+}	1832^{+32}_{-26}	13^{+40}_{-41}	$> 30\,\sigma$
$f_0(2100)$	0^{++}	2103_{PDG}	209_{PDG}	$> 5\,\sigma$
$f_2(1910)$	2^{++}	1903_{PDG}	196_{PDG}	$> 5\,\sigma$

($p\bar{p}$-FSI effect included)

The ZDD at BESIII



Initial State Radiation



$e^+e^- \longrightarrow \gamma_{IS} X_{had}$

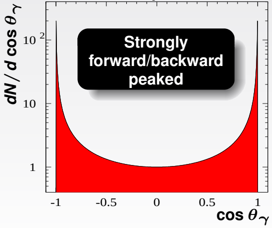
ISR cross section $\displaystyle \frac{d^2\sigma}{dE_\gamma d\theta_\gamma} = \underbrace{W(E_\gamma, \theta_\gamma)}_{\text{radiator function}} \cdot \underbrace{\sigma_{e^+e^- \to X_{had}}(q^2)}_{e^+e^- \text{ cross section}}$

ISR technique at fixed-energy machines yield the same observables of ***e^+e^-* experiments with energy scan**

All q^2 at the same time $\Rightarrow$ better control on systematics

Detected ISR $\Rightarrow$ full X_{had} angular coverage

CM boost $\Rightarrow$ at threshold: $\epsilon \neq$ **0** and $\boldsymbol{\Delta E \sim}$ **1 MeV**



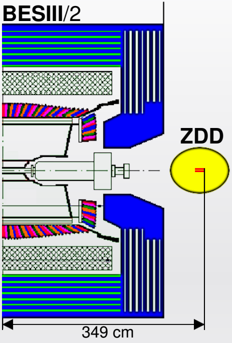
The acceptance at large angle is equivalent to the one, **almost point-like**, in the forward-backward direction

$$\int_{[20^o,\,160^o]} \frac{dN}{d\cos\theta_\gamma} d\cos\theta_\gamma \simeq \int_{2\times[-0.2^o,\,0.2^o]} \frac{dN}{d\cos\theta_\gamma} d\cos\theta_\gamma$$

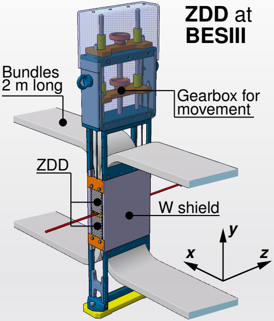
A zero-degree radiative photon tagger will suppress most of the background due to misidentified π^0's

π^0's are produced with high BR's by $c\bar{c}$ resonances

ZDD, the zero-degree detector



- Each section is made of two modules, upper and lower, volume $14 \times 4 \times 6$ cm^3 each
- The empty 10 mm-wide slot between the upper and lower module geometrically suppresses the Bremsstrahlung background
- The calorimeters are arrays of scintillating fibers (60% in volume) embedded in lead
- The fibers are lined up along the y axis and read out from the upper or lower face
- The modules are segmented in the xz plane the first layer has a thinner segmentation to have a better y-resolution
- The signal is extracted and channeled to PM's through bundles of clear optical fibers



The ZDD Chronicles

- 01/2011-06/2011: construction and assembling of a ZDD station (two modules)
- 06/2011-08/2011: tests with cosmic rays and at the Frascati Beam Facility

$$\frac{\sigma_E}{E} = 12.4\% \qquad E = 450 \text{ MeV.}$$

- August 2011: installation of the first ZDD station in the East side region of BESIII

Final comments

Many other analyses:

- Precision measurement of the branching fractions of $J/\psi \to \pi^+\pi^-\pi^0$ and $\psi' \to \pi^+\pi^-\pi^0$
- Search for a light Higgs-like boson A^0 in J/ψ radiative decays
- Search for η_c' decays into vector meson pairs
- Higher-order multipole amplitude measurement in $\psi(2S) \to \gamma\chi_{c2}$
- Search for CP and P violating pseudoscalar decays into $\pi\pi$
- Observation of χ_{c1} decays into vector meson pairs $\phi\phi$, $\omega\omega$, and $\omega\phi$
- Study of χ_{cJ} radiative decays into a vector meson
- Measurement of the matrix element for the decay $\eta' \to \eta\pi^+\pi^-$
- Evidence for ψ' decays into gamma π^0 and $\gamma\eta$
- First observation of the decays $\chi_{cj} \to \pi^0\pi^0\pi^0\pi^0$
- ...

For the future

- J/ψ and ψ' samples will increase by **one order of magnitude or more**
- **Scan measurements** will be performed around $c\bar{c}$ resonances and also at lower energies
- Hadronic cross section measurements with **ISR**

- Many results will be refined
- Rare processes will be accessible at level below 10^{-7}
- More complex channels will be accessible
- ...