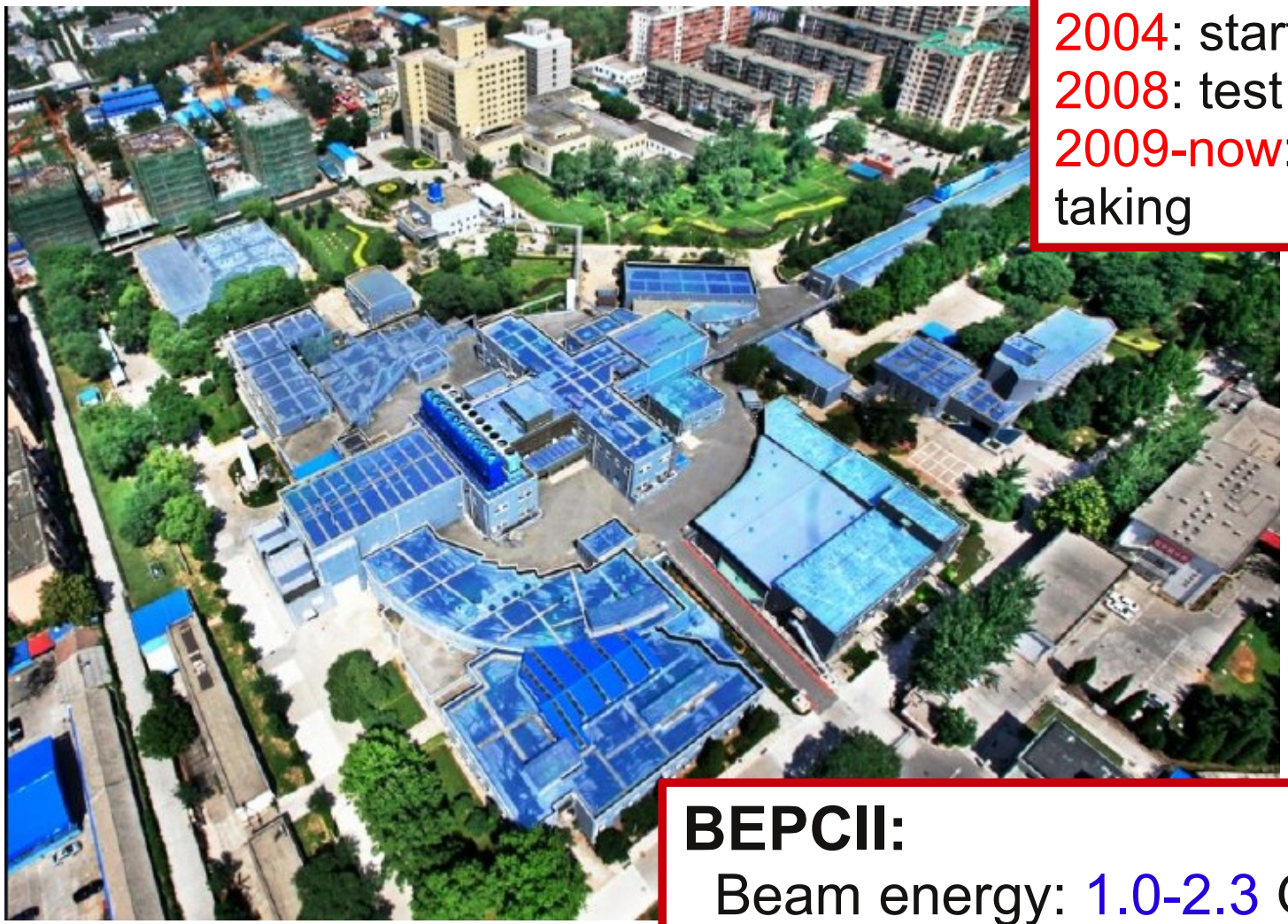
Results of the BES-III experiment

Igor Denysenko
for the BES-III collaboration

JINR Dubna
on leave from BITP, Kiev

NEW TRENDS IN HIGH-ENERGY PHYSICS
September 3-11,2011, Alushta, Ukraine

BEPCII/BESIII at IHEP(Beijing)

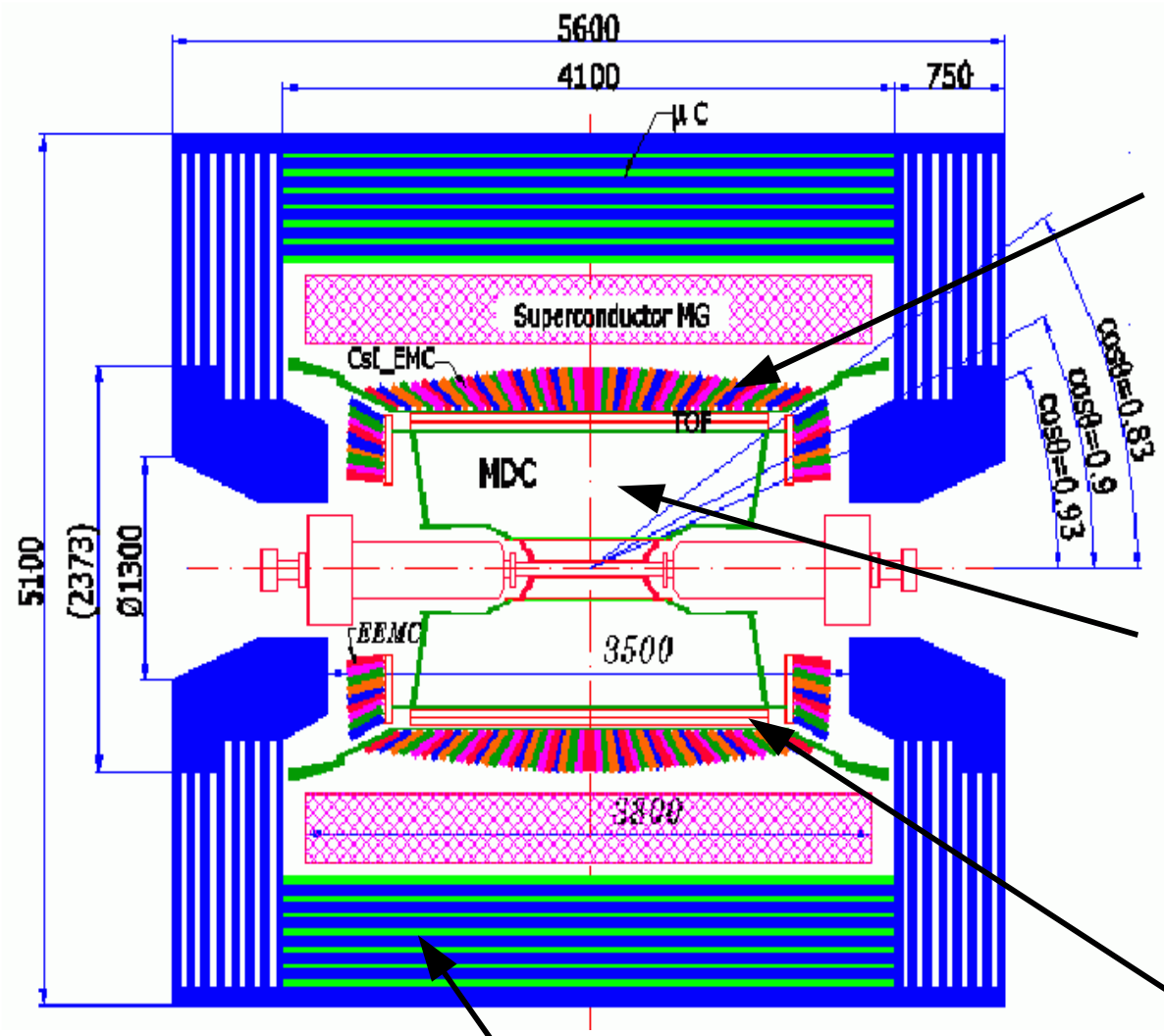


2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BEPCII/BESIII data taking

BEPCII:

Beam energy: 1.0-2.3 GeV
Energy spread: 5.16×10^{-4} GeV
Design luminosity 1×10^{33} /cm^2/s @ψ(3770)
Achieved luminosity: ~0.65×10^{33} /cm^2/s

The BES-III detector



CsI(Tl) EMC:
- Energy resolution: **2.5% @1GeV**
- Spatial resolution: **6mm**

MDC:
- Spatial resolution: σ_{xy} **=120μm**
- Momentum resolution: **0.5%@1GeV**
- Dedx resolution: 6%

TOF:
Time resolution:
- **100ps** (barrel)
- **110ps** (endcaps)

Muon ID:
9 layers RPC, 8 for endcaps

Physics at BES-III

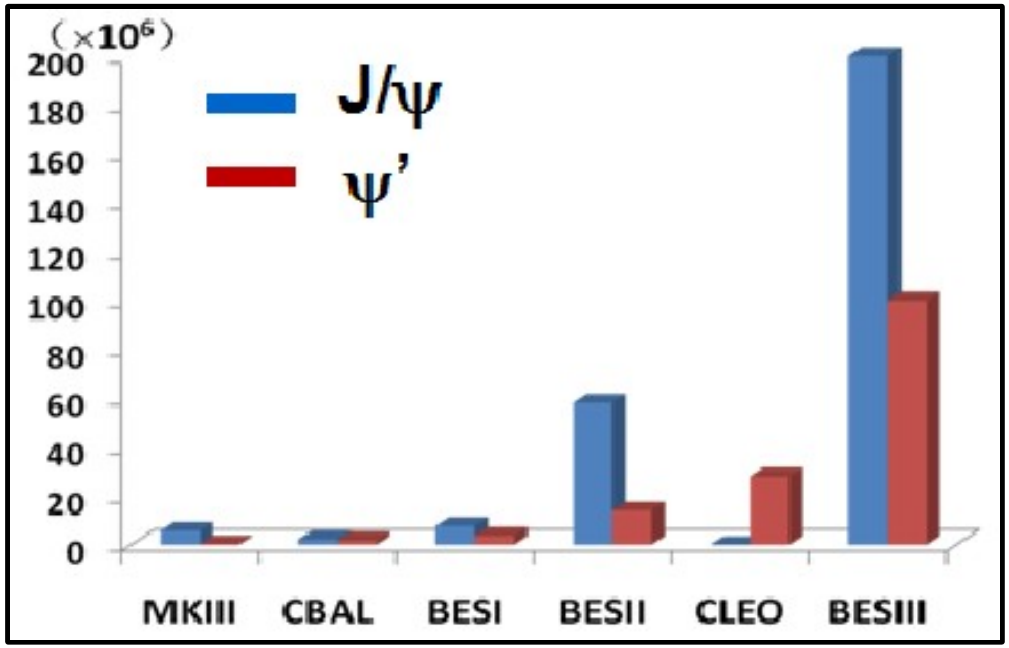
Precision measurements in τ-charm domain

- **Charmonium physics**:
  - **spectroscopy**
  - **transitions and decays**
- **Light hadron physics**
  - **meson and baryon spectroscopy**
  - glueball and hybrid states
  - two-photon physics
  - e.m. formfactors of nucleon
- **τ-physics**
  - τ mass measurement near threshold
- **Charm physics**
  - (semi)leptonic+hadronic decays
  - decay constants, form factors
  - CKM matrix: V_{cd}, V_{cs}
  - D^0-$\overline{D}^0$ mixing and CP violation
- rare/forbidden decays
- many more...

Data samples

So far world largest data samples:

- ~**225** Million J/Ψ
- ~**106** Million Ψ'
- ~**2.9 fb^{-1}** Ψ(3770)
  (3.5 times of CLEO-c data)
- ~**0.5 fb^{-1}** @Ψ(4010)



BES-III data samples compared to other experiments

BESIII will also collect:

- more J/Ψ, Ψ', Ψ(3770)
- data at higher energies (XYZ searches, R scan, D_s physics)

Released results of BESIII

- **Charmonium Spectroscopy and Transitions**
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(submitted soon)*
- **Charmonium Decays**
  - $cJ \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $cJ \to \gamma\rho, \gamma\omega, \gamma\varphi$ *(PRD83,112005(2011))*
  - $cJ \to \omega\omega, \varphi\varphi, \omega\varphi$ *(PRL 107, 092001 (2011))*
  - $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - η, η' and $\eta_c \to \pi\pi$ *(Phys. Rev. D 84, 032006 (2011))*
  - Observation of $\chi_{cJ} \to ppK^+K^-$ *(PRD83,112009(2011))*
- **Light Quark States**
  - $a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (2011))*
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - X(1860) in $J/\psi \to \gamma(pp)$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ *(PRL 106, 072002 (2011))*
  - X(1870) in $J/\psi \to \omega(\eta\pi^+\pi^-)$ *(submitted to PRL)*

More than 20 analyses are under internal review!

Light hadron spectroscopy

- In the last several years, a lot of unexpected experimental evidence for hadron cannot (easily) be explained by the conventional quark model

- Multi-quarks states, glueballs and hybrids have been searched for experimentally for a long time, but none have been established.

Tasks:

- careful study of meson spectra
- search for exotic states, role of the gluon degrees of freedom, search for glueballs and hybrid states
- more...

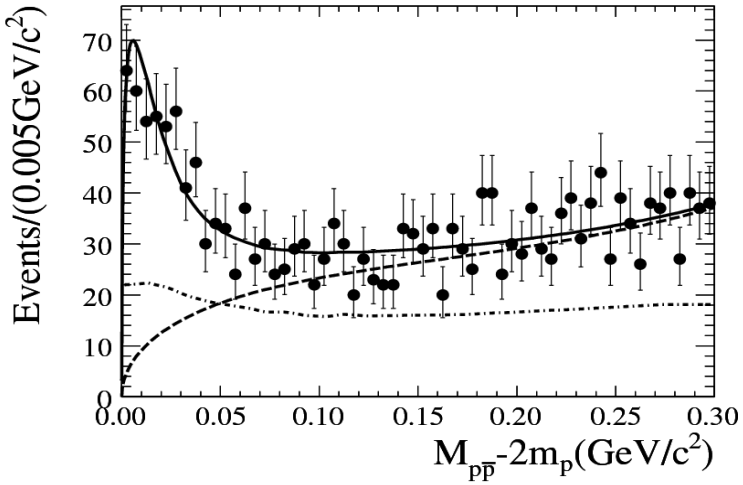
BES-III advantages:

- huge statistics
- well known initial state, powerful J^{PC} and isospin filters
- clean environment

$p\bar{p}$ mass threshold enhancement in $J/\Psi \to \gamma p\bar{p}$

$\Psi' \to \pi^+\pi^- J/\Psi(J/\Psi \to \gamma p\bar{p})$

Chinese Physics C 2010, 34(4)

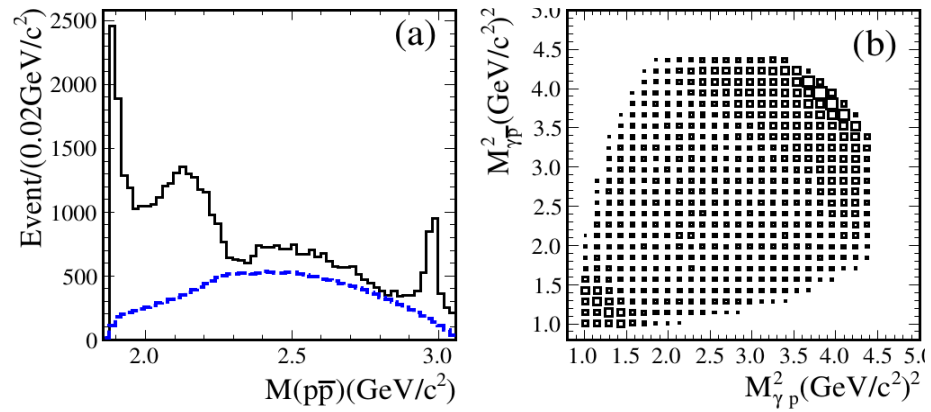


- Unclear nature ($p\bar{p}$ bound state, FSI effect, ...)
- **Not clearly seen at**: **$\psi(2S) \to \gamma p\bar{p}$, $J/\psi \to \omega p\bar{p}$, $\Upsilon(1S) \to \gamma p\bar{p}$**
- If fitted as s-wave resonance:

$$M = 1861^{+6}_{-13}{}^{+7}_{-26}\, MeV$$
$$\Gamma < 38\, MeV\ (90\%\, CL)$$

$J/\Psi \to \gamma p\bar{p}$

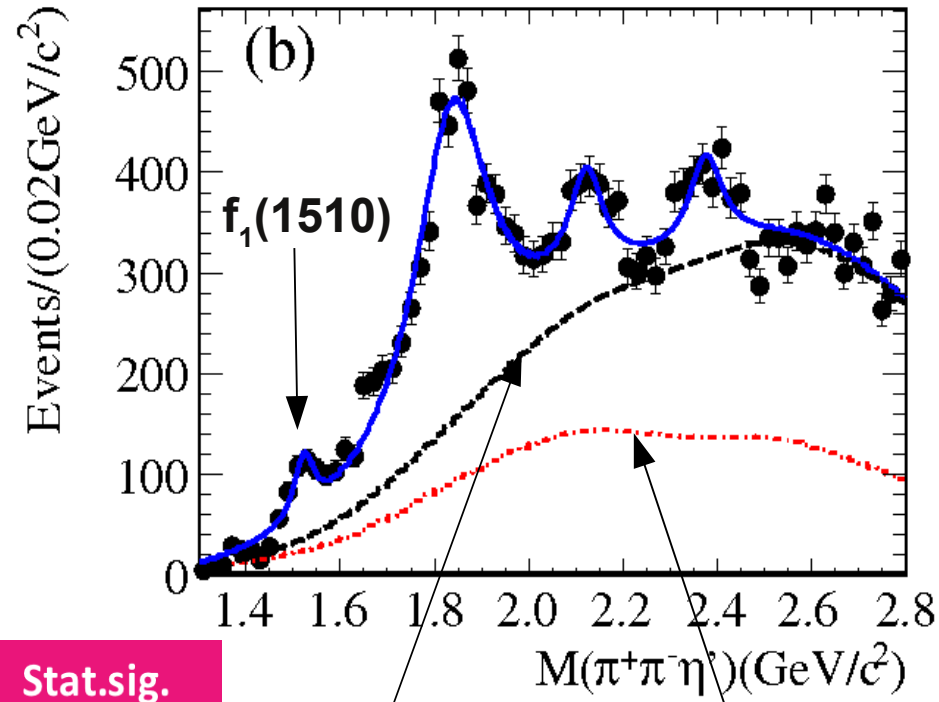
BES-III preliminary partial wave analysis



- $J^{PC} = 0^{-+}$ is preferable
- FSI corrections improve description
- Fit results (with FSI corrections):
  $M = 1832 \pm 5(stat)\ ^{+15}_{-17}(syst) \pm 19(mod)$ MeV
  $\Gamma < 45$ MeV at 90% C.L.
- Can be observed in $\Psi' \to \gamma p\bar{p}$ with the suppression comparable to "12%" rule

X(1835), X(2120), X(2370) in $J/\Psi \rightarrow \gamma\pi^+\pi^-\eta'(\gamma\rho, \pi^+\pi^-\eta)$

- $J/\Psi \rightarrow \gamma\pi^+\pi^-\eta'$ motivated $p\bar{p}$ enhancement, may be good for finding 0^{-+} glueballs
- confirmation of X(1835)
- new states X(2120) and X(2370) found



background: η' sideband and $\pi^0\ \pi^+\pi^-\eta'$

background + non-resonant $\pi^+\pi^-\eta'$(phase space)

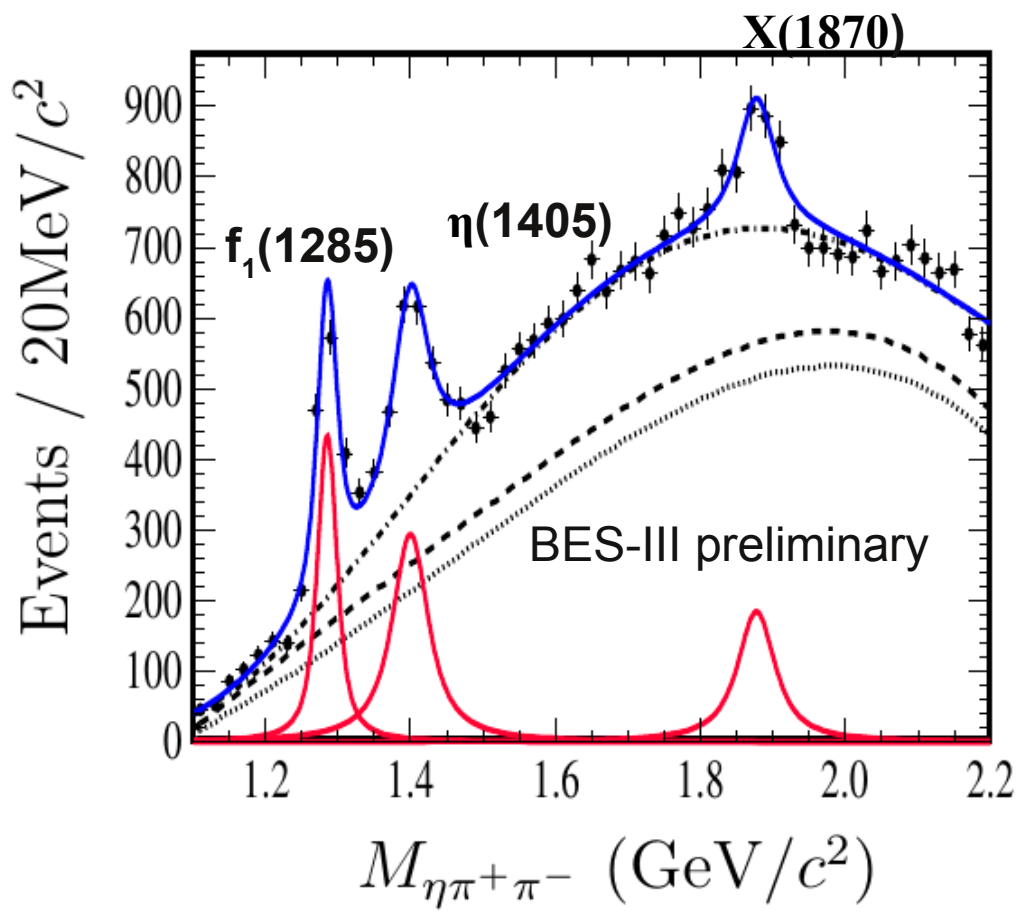
Resonance	M(MeV/c^2)	Γ(MeV)	Stat.sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

Phys.Rev. Lett. 106(2011) 072002

X(1870) in J/Ψ → ω($\pi^+\pi^-\eta$)

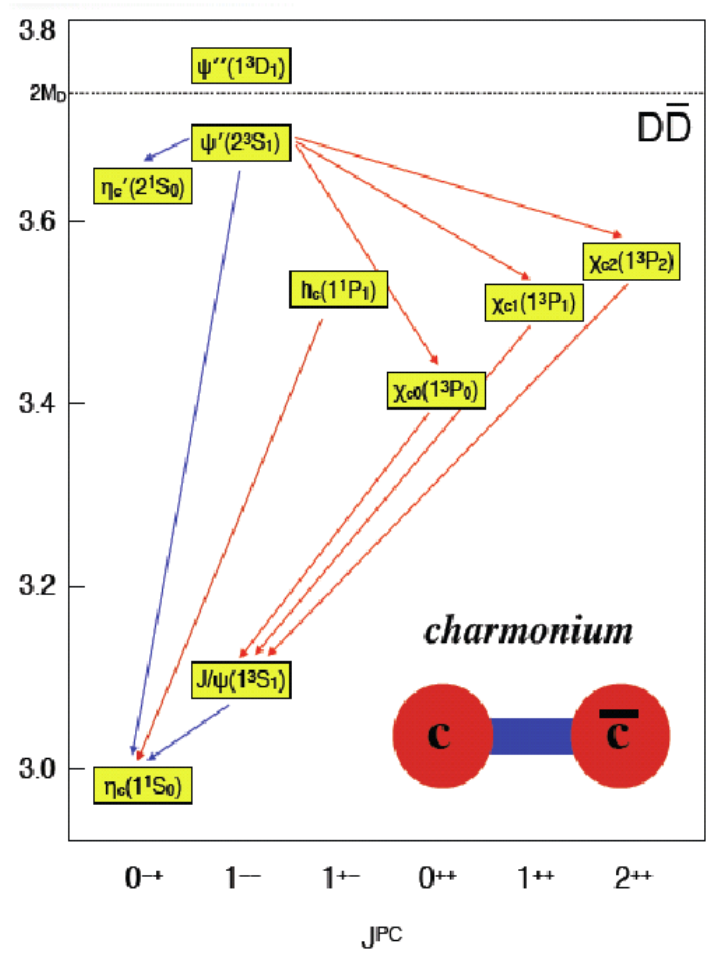
- In the $\pi^+\pi^-\eta$ mass spectra new process $J/\psi \to \omega X(1870)$ and decays $J/\psi \to \omega f_1(1285)$, $J/\psi \to \omega\eta(1405)$ observed.
- X(1870), $f_1(1285)$, $\eta(1405)$ primarily decay to $a_0(980)\pi$
- Fit result for X(1870)
  $M = 1877.3 \pm 6.3$ MeV
  $\Gamma = 57 \pm 12$ MeV

  assuming no interference
- Whether X(1870) is a new state or the signal can be produced from $\eta_2(1870)$ can't be determined from current data
- Branching ratios for the $Br(J/\psi \to \omega X)$ x $Br(X \to a_0(980)\pi)$ x $Br(a_0(980) \to \eta\pi)$ for $X = f_1(1285)$, $\eta(1405)$ measured for the first time



Charmonium physics

- spectra and transitions are a perfect laboratory to test various QCD models and phenomenological mechanisms
- interplay of perturbative and nonperturbative physics



$h_c(^1P_1)$

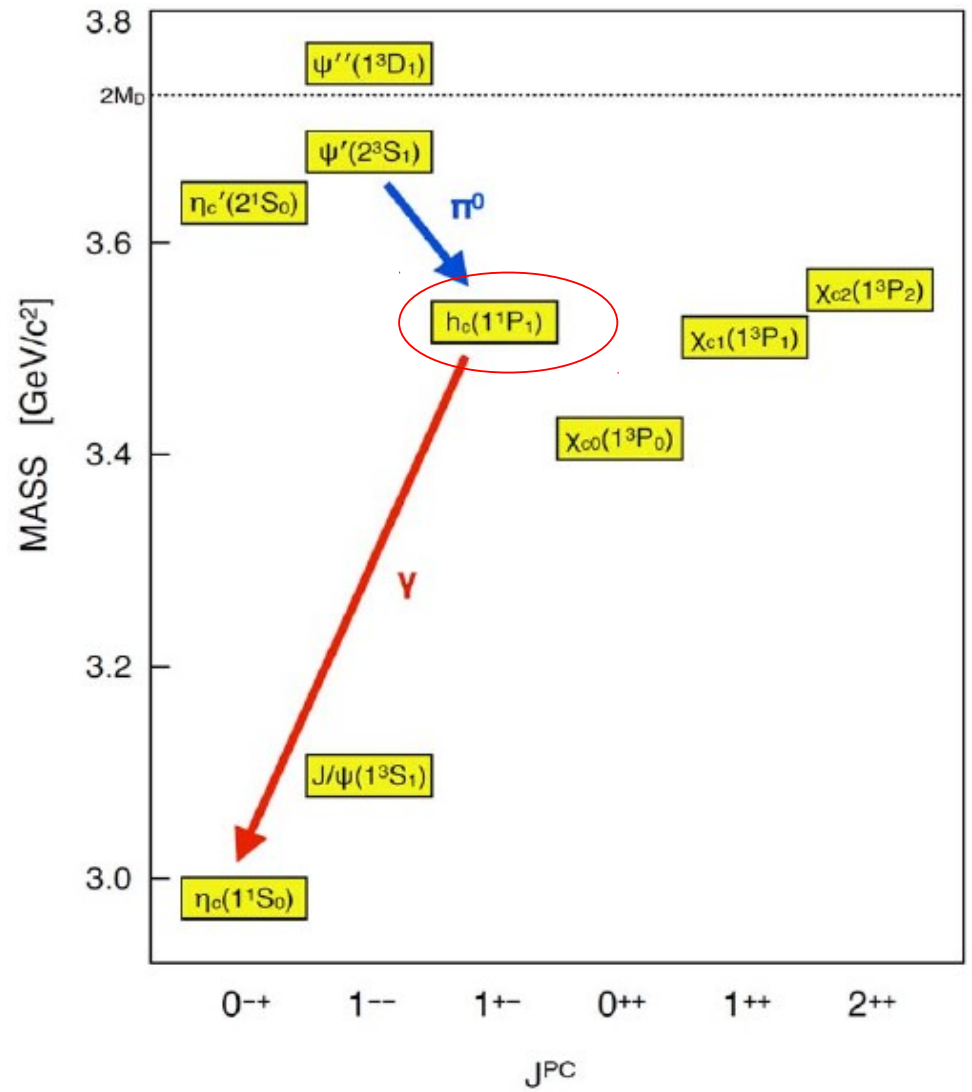
The least studied charmonium state below DD threshold

$Br(\psi' \to \pi^0 h_c)$ is a measure of isospin violation in hadronic charmonium decay

Hyperfine 1P mass splitting
$\Delta M_{hf}(^1P) = \langle M(^3P_J)\rangle - M(^1P_1)$
important to learn about spin-spin interaction of heavy quarks
$\langle M(^3P_J)\rangle = 1/9(M\chi_{c0} + 3M\chi_{c1} + 5M\chi_{c2})$

Large branching of E1 radiation transition

Theory predictions for $B(h_c \to \gamma\eta_c)$ and $B(\psi' \to \pi^0 h_c)$ vary by factor ~2



Properties of h_c at BES-III

Production mode: $\psi' \to \pi^0 h_c$

All measurements from π^0 recoil mass spectra analysis

first measurement

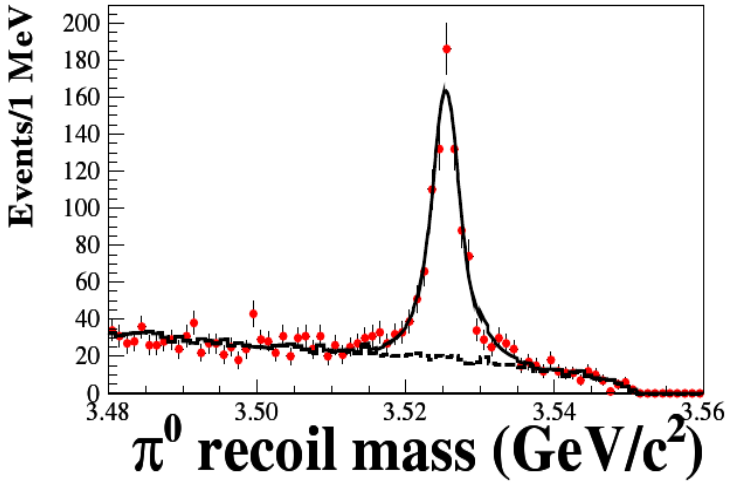
PRL104, 132002 (2010)

Inclusive:
$Br(\psi' \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

Exclusive: Tagging photon from $h_c \to \gamma \eta_c$:
$M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ MeV
$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ MeV
$Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma \eta_c)$
$(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

Combined:
$Br(h_c \to \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2) \times 10^{-2}$

BES-III preliminary



Exclusive: $\psi' \to \pi^0 h_c$, $h_c \to \gamma \eta_c$, η_c reconstructed from 16 hadron mods

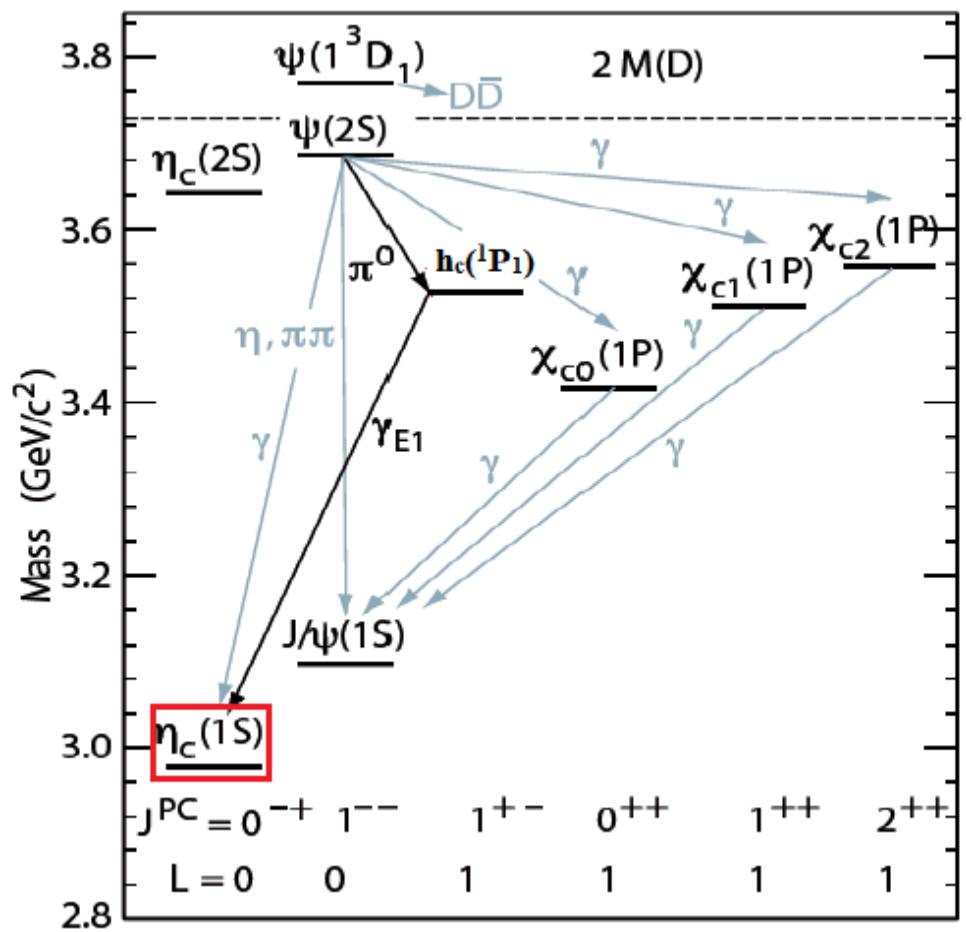
$M(h_c) = 3525.31 \pm 0.11 \pm 0.15$ MeV
$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25$ MeV
$N = 832 \pm 35$

η_c resonance parameters from $\psi' \to \gamma\eta_c$

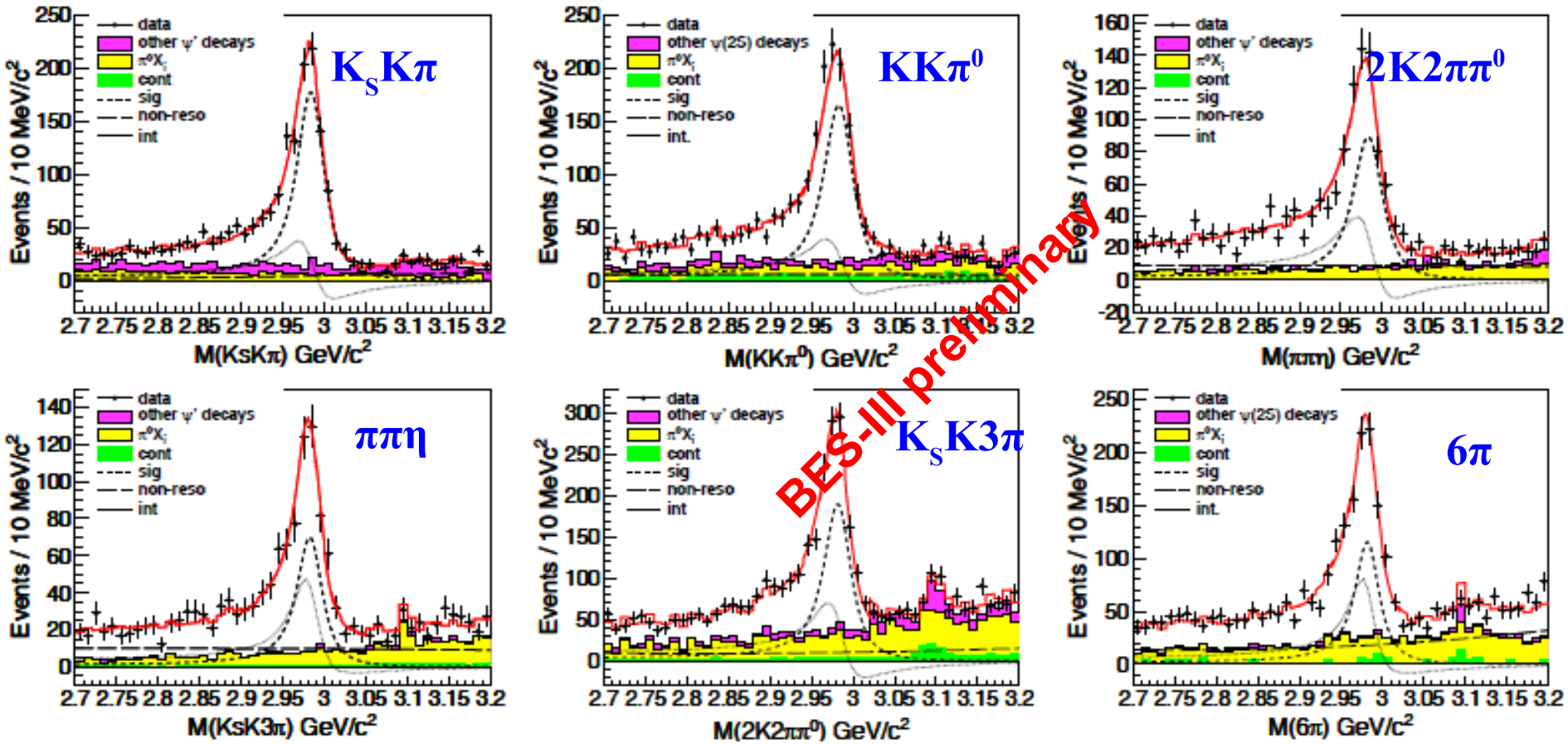
Mass and width are known by an order of magnitude worse then for J/ψ, ψ(2S), χ_{cJ}

- Earlier experiments using J/ψ radiative transition gives $M(\eta_c)$~2978.0 MeV, $\Gamma(\eta_c)$~10 MeV.

- Recent studies using the two-photon processes gives $M(\eta_c)$=2983.1±1.0 MeV, $\Gamma(\eta_c)$=31.3±1.9 MeV.



η_c resonance parameters from $\psi' \to \gamma\eta_c$



Simultaneous fit of shown η_c decay modes.

BES-III preliminary results:

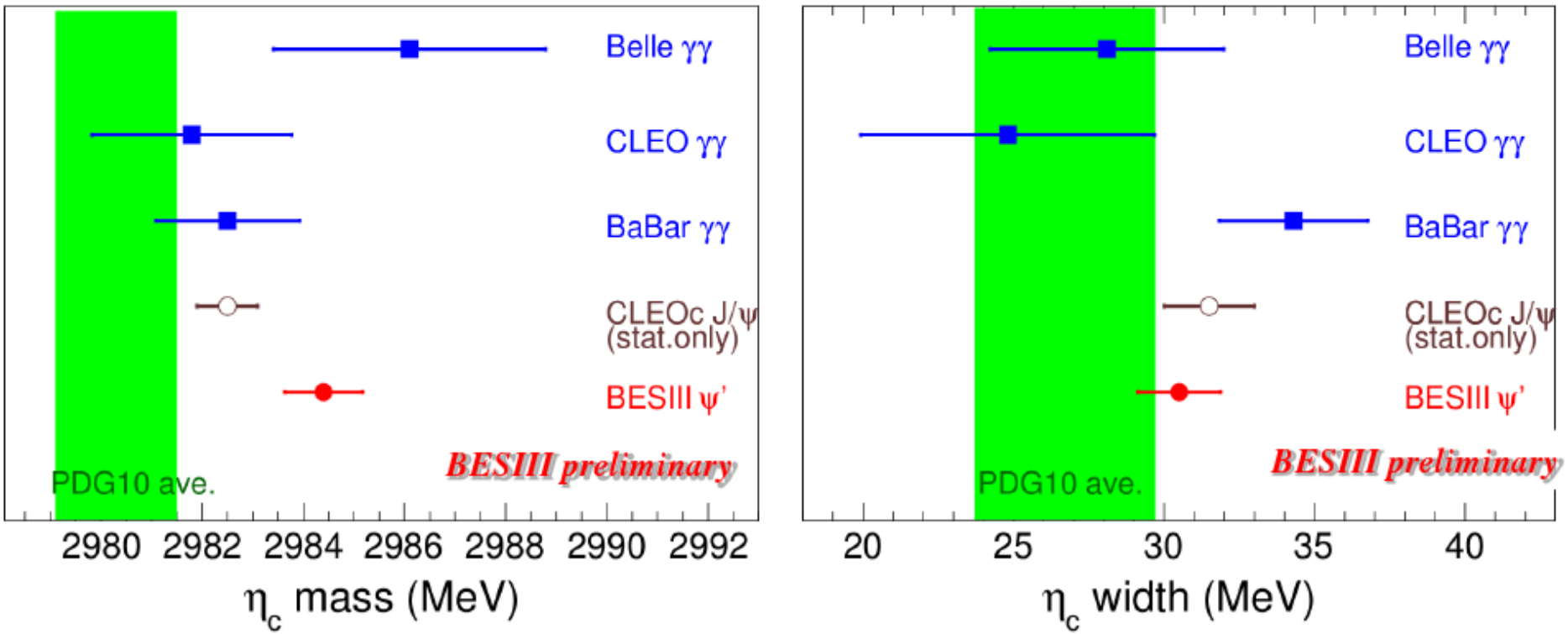
$$M(\eta_c) = 2984.4 \pm 0.5 \pm 0.6\ \text{MeV}$$
$$\Gamma(\eta_c) = 30.5 \pm 1.0 \pm 0.9\ \text{MeV}$$
$$\phi = 2.35 \pm 0.05 \pm 0.04\ \text{rad}$$

φ is a universal phase parameterizing interference between η_c and non-η_c decays

Currently the most precise measurements!

Comparison of BESIII preliminary results with other measurements

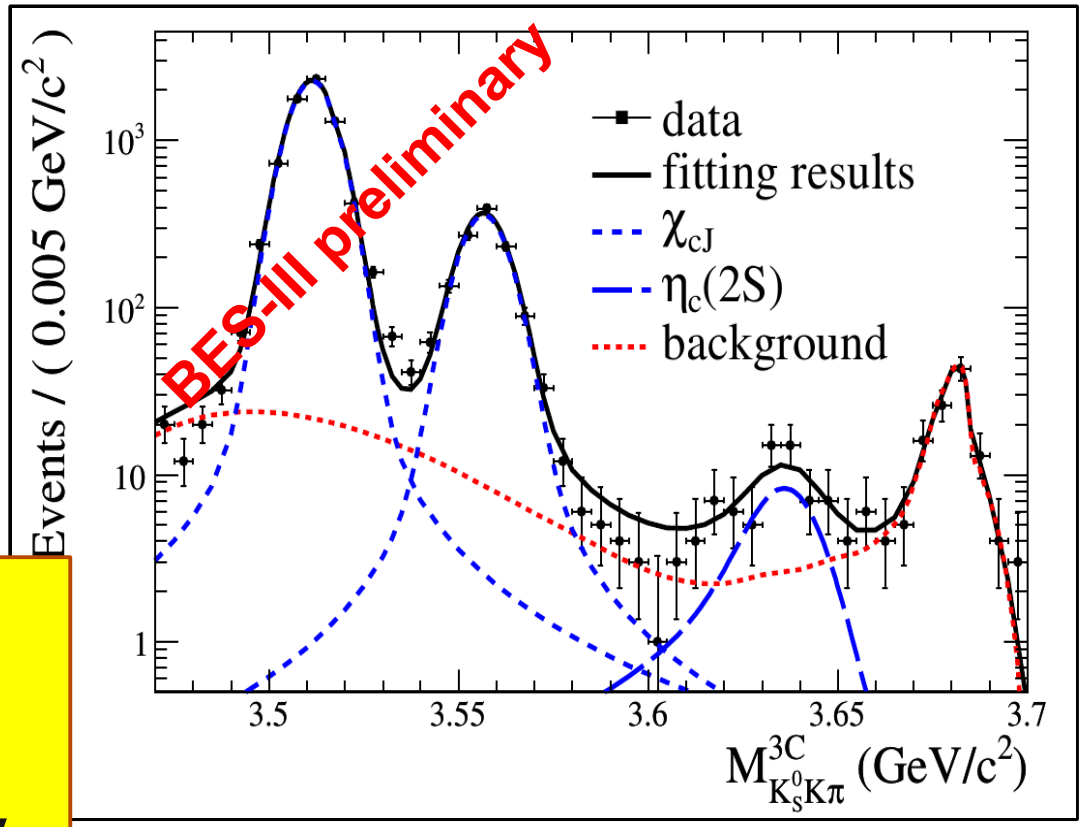
BESIII results include both stat. and syst. errors, which is the most precision measurement, the interference between ηc decay and non-resonance is important.



The world average in PDG2010 was using earlier results

M1 transition $\psi' \to \gamma \eta_c(2S)$

- First $\eta_c(2S)$ observation in charmonia decays
- $\eta_c(2S)$ **reconstructed** from $\eta_c \to K_S K\pi$ (the only observed mode)



BES-III preliminary results:

- Significance with systematic variations greater than 5σ
- $M(\eta_c(2S))$= **3638.5 ± 2.3 ± 1.0 MeV**
- $Br(\Psi' \to \gamma\eta_c(2S) \to \gamma K_S K\pi)$= **$(2.98 \pm 0.57 \pm 0.48) \times 10^{-6}$**

Charmonium decays

- $\psi' \to \gamma P$ ($P=\pi^0, \eta, \eta'$)
- $\chi_{cJ} \to \gamma V$ ($V=\rho, \omega, \varphi$)
- $\chi_{cJ} \to VV$ ($V=\omega, \varphi$)
- $\chi_{cJ} \to p\bar{p}K^+K^-$
- χ_{c0} and $\chi_{c2}, \to \pi^0\pi^0, \eta\eta$, $\chi_{cJ} \to 4\pi^0$

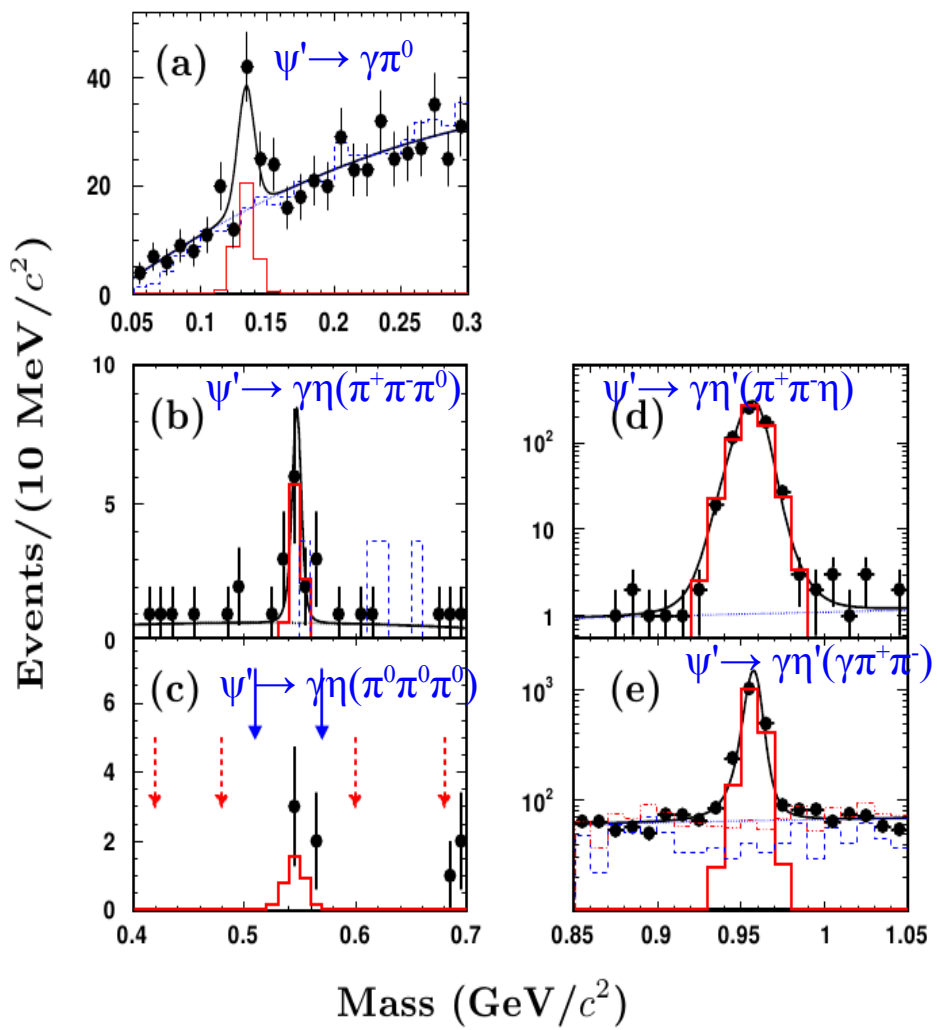
$\psi' \to \gamma P$ ($P = \pi^0, \eta, \eta'$)

PRL 105, 261801 (2010)

Important for testing various phenomenological mechanisms: VMD model, $\eta_c - \eta'$ mixing, 2-gluon couplings to qq states, and final state radiation by light quarks.

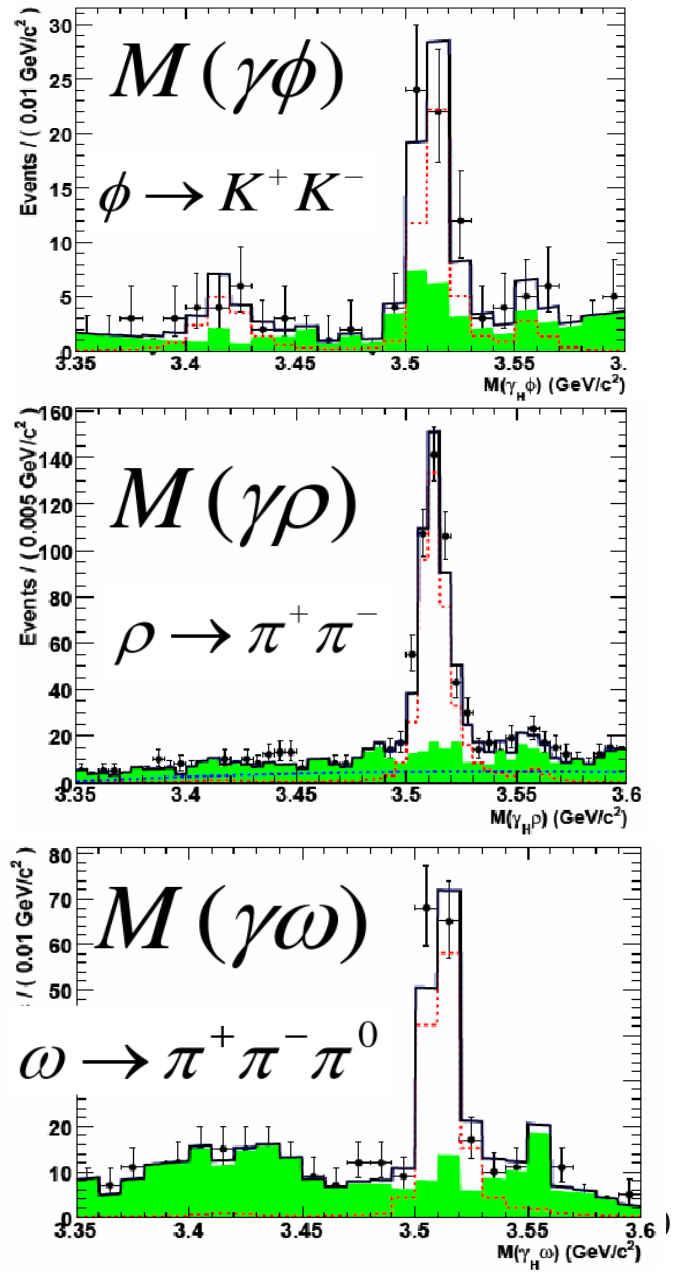
- $\psi' \to \gamma\pi^0$, $\psi' \to \gamma\eta$ measured for the first time
- $R(X) = B(X \to \gamma\eta) / B(X \to \gamma\eta')$
  $R(\psi') = (1.10 \pm 0.38 \pm 0.07)\%$
  measured $R(\psi') << R(J/\psi)$ not predicted by naive theory (confirms CLEO-c)

Mode	Br($\times 10^{-6}$)	PDG	sign.
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	<5	4.6σ
$\psi' \to \gamma\eta$	$1.38 \pm 0.48 \pm 0.09$	<2	4.3σ
$\psi' \to \gamma\eta'$	$126 \pm 3 \pm 8$	121 ± 8	



$\chi_{cJ} \to \gamma V$ (V=ρ, ω, φ)

The recent experimental results (CLEOc: PRL 101, 151801 (2008)) for $B(\chi_{c1} \to \gamma\omega, \gamma\rho^0)$ are by an order of magnitude higher than the corresponding theoretical predictions.



Our measurements:

Mode	Br(x10^{-6})	Stat. sign.
$\chi_{cJ} \to \gamma\varphi$	25.8 ± 5.2 ± 2.3	6σ
$\chi_{cJ} \to \gamma\rho$	228 ± 13 ± 22	>10σ
$\chi_{cJ} \to \gamma\omega$	69.7 ± 7.2 ± 6.6	>10σ

$\chi_{c1} \to \gamma\varphi$ observed for the first time

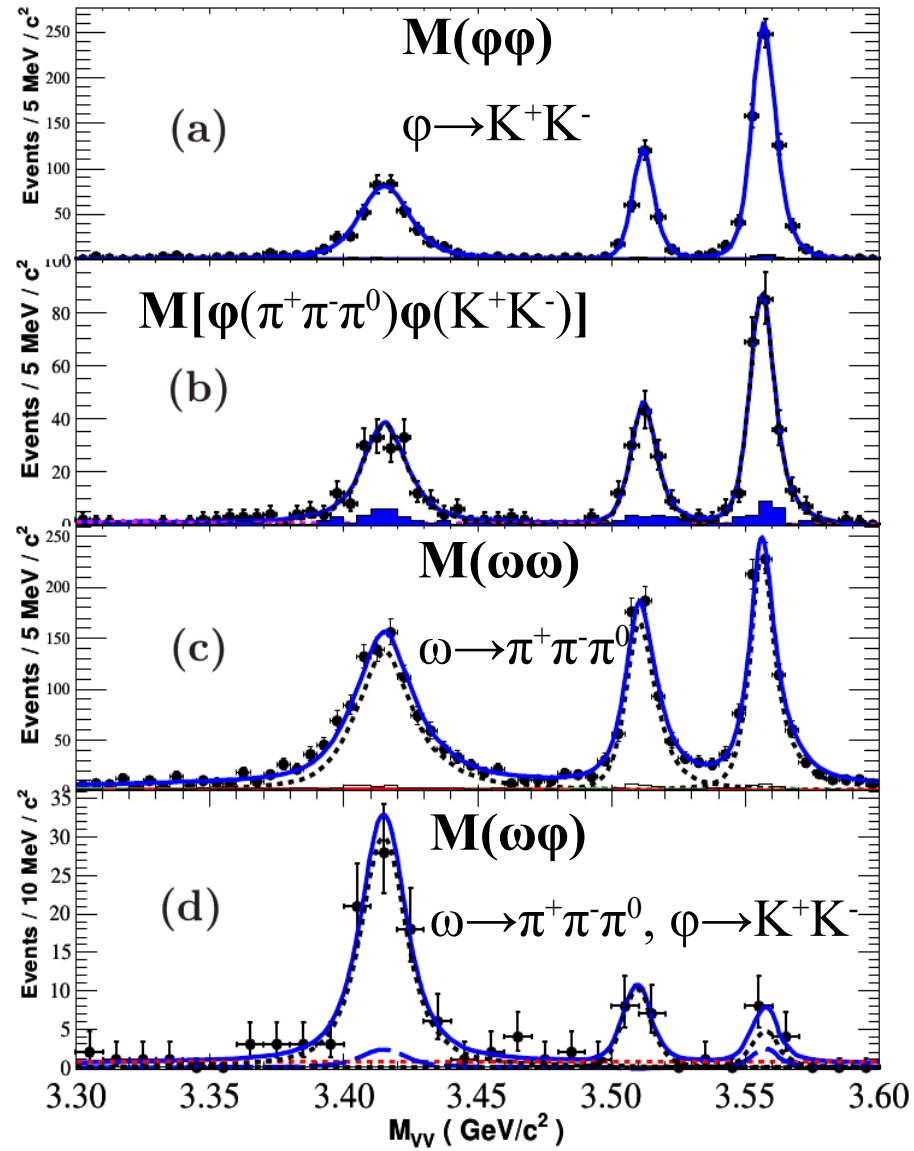
Phys. Rev. D 83, 112005 (2011)

$\chi_{cJ} \to VV$ (V=ω, φ)

PRL 107, 092001 (2011)

- $\chi_{c1} \to \varphi\varphi$, ωω are observed for the first time, branching ratios indicate significant violation of helicity selection rule
- Doubly OZI suppressed $\chi_{cJ} \to \omega\varphi$ decays observed for the first time
- Known branching ratios for χ_{c0} and χ_{c2} measured with improved precision

Channel	Br(x10^{-4})	PDG(x10^{-4})
$\chi_{c0} \to \varphi\varphi$	8.0 ± 0.3 ± 0.8	9.2 ± 1.9
$\chi_{c1} \to \varphi\varphi$	4.4 ± 0.2 ± 0.5	–
$\chi_{c2} \to \varphi\varphi$	10.7 ± 0.3 ± 1.2	14.8 ± 2.8
$\chi_{c0} \to \omega\omega$	9.5 ± 0.3 ± 1.1	22 ± 7.0
$\chi_{c1} \to \omega\omega$	6.0 ± 0.2 ± 0.7	–
$\chi_{c2} \to \omega\omega$	8.9 ± 0.3 ± 1.1	19.0 ± 6.0
$\chi_{c0} \to \omega\varphi$	1.2 ± 0.1 ± 0.2	–
$\chi_{c1} \to \omega\varphi$	0.22 ± 0.06 ± 0.02	–
$\chi_{c2} \to \omega\varphi$	<0.2	–



Future prospects

- More results are coming (more than 20 analysis under internal review)
- 1B J/ψ and 0.7B $\psi(2S)$ are expected in 2012
- The first results in charm are coming
- τ mass measurement (this year)

Year	Running Plan
2012	J/ψ: 1 billion / $\psi(2S)$: 0.7 billion (approved)
2013	4170 MeV: Ds decay R scan (E > 4 GeV)
2014	$\psi(2S)/\tau$ / R scan (E > 4 GeV)
2015	$\psi(3770)$: > 20 fb^{-1} (our final goal)

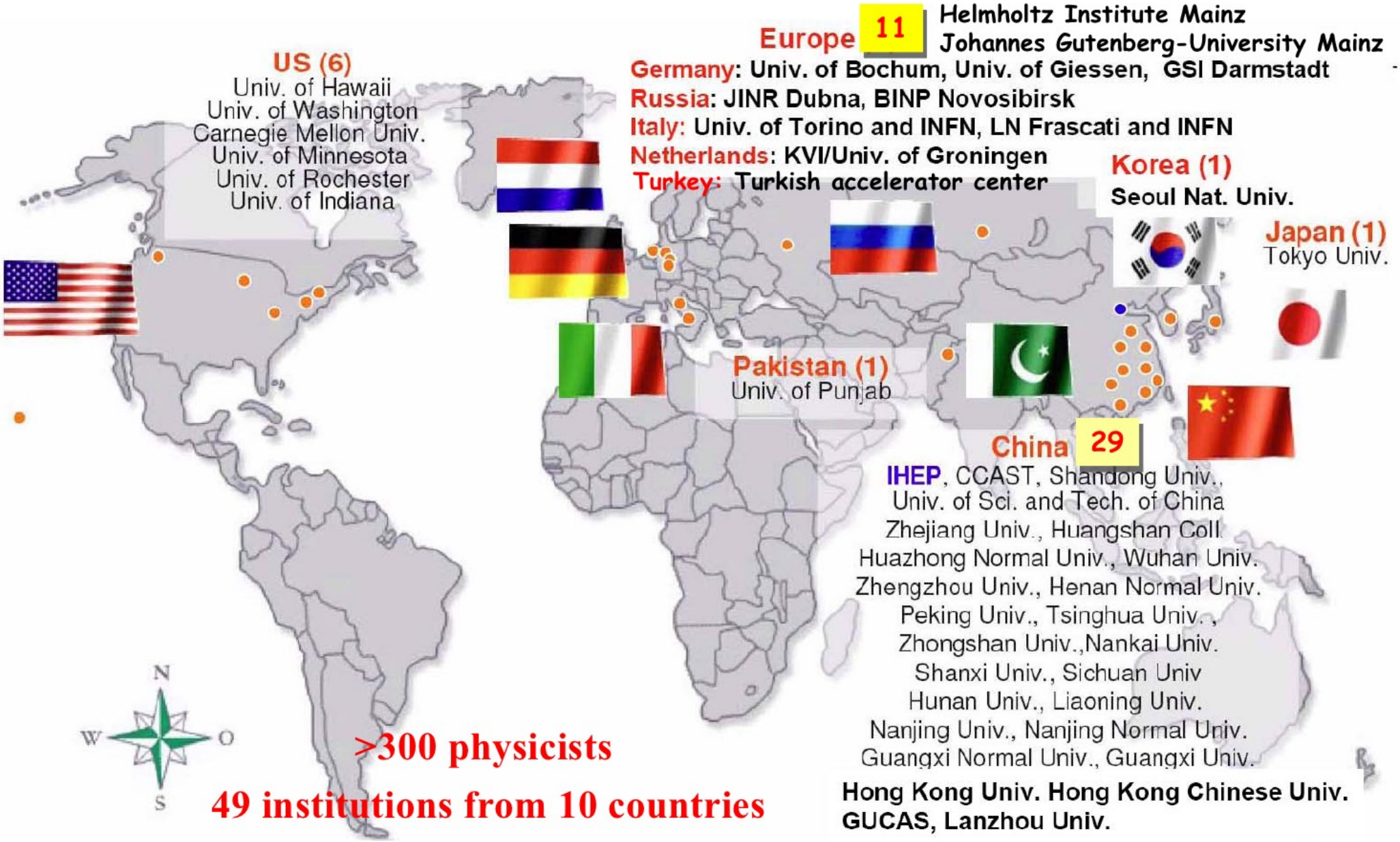
Red: to be approved by BESIII Collaboration

Summary

- BES-III successfully takes data since 2008. It will remain the world leading experiment in the τ-charm domain for the next ten years at least.
- First results are published on:
  - light hadron spectroscopy
  - charmonium spectra
  - charmonium transitions
- Looking forward to much more exciting physics at BES-III in the coming years! .

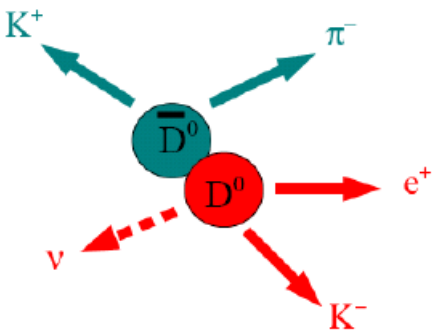
Backup

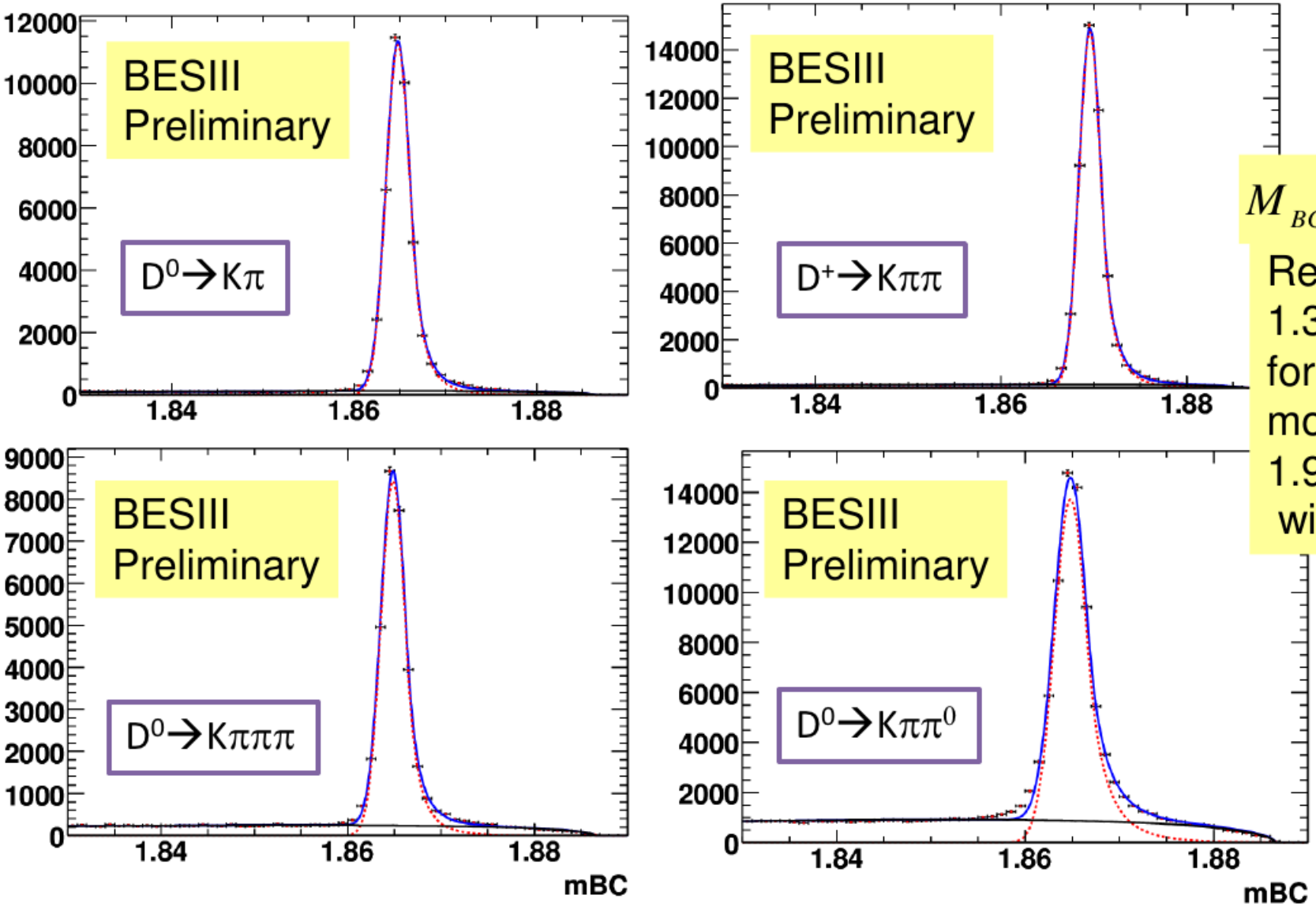
BESIII Collaboration



Clean single tag at BESIII

@ψ(3770) with 420pb^{-1} first clean single tagging sample:



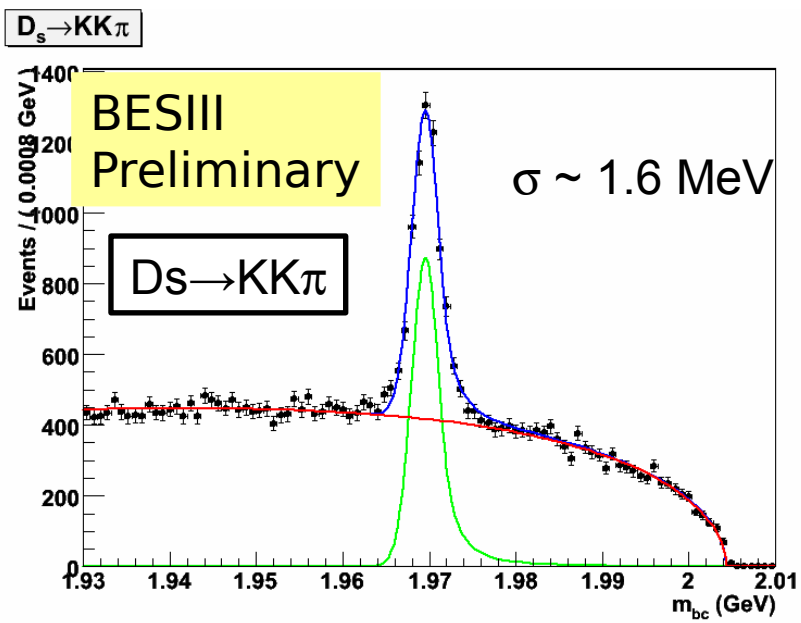


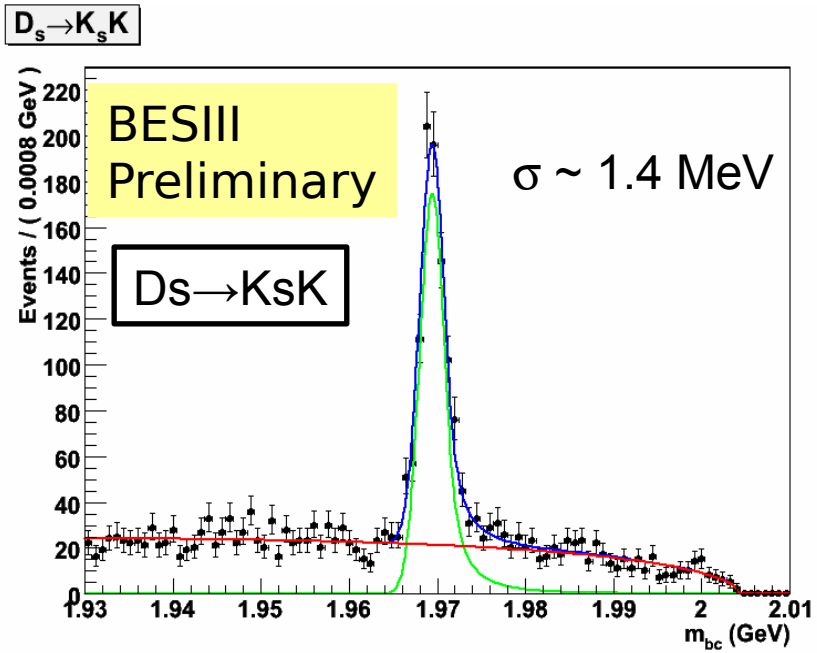
$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV
for pure charged modes;
1.9 MeV for modes with one π^0.

mBC of Ds Single Tag

part of data @ 4010 MeV





$a_0(980)$-$f_0(980)$ mixing

- $a_0(980)$ and $f_0(980)$ are difficult to accommodate in constituent $q\bar{q}$ scenario
- Different suggestions: tetra-quark, hybrids, KK-molecule
- Complimentary modes:
  - $J/\Psi \to \varphi f_0 \to \varphi a_0 \to \varphi\eta\pi$:

$$\xi_{fa} \equiv \frac{Br(J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0)}{Br(J/\psi \to \phi f_0(980) \to \phi\pi\pi)}$$

  - $\chi_{c1} \to a_0\pi^0 \to \varphi a_0 \to \pi^+\pi^-\pi^0$:

$$\xi_{af} \equiv \frac{Br(\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-)}{Br(\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0\pi^0\eta)}$$

PRD 83, 032003 (2011)

$a_0(980)$-$f_0(980)$ mixing

- $a_0(980)$ and $f_0(980)$ are difficult to accommodate in constituent $q\bar{q}$ scenario
- Different suggestions: tetra-quark, hybrids, KK-molecule
- Complimentary modes:
  - $J/\Psi \to \varphi f_0 \to \varphi a_0 \to \varphi\eta\pi$:

$$\xi_{fa} = (0.60 \pm 0.20(\text{stat.}) \pm 0.12(\text{syst.}) \pm 0.26(\text{para.}))\%$$

$$\xi_{fa} < 1.1\% @ 90\, C.L.$$

  - $\chi_{c1} \to a_0\pi^0 \to \varphi a_0 \to \pi^+\pi^-\pi^0$:

$$\xi_{af} = (0.31 \pm 0.16(\text{stat.}) \pm 0.14(\text{syst.}) \pm 0.03(\text{para.}))\%$$

$$\xi_{af} < 1.0\% @ 90\, C.L.$$

First direct measurement

PRD 83, 032003 (2011)