Light hadron spectroscopy at BESIII

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Hadron Structure and Interaction in 2011
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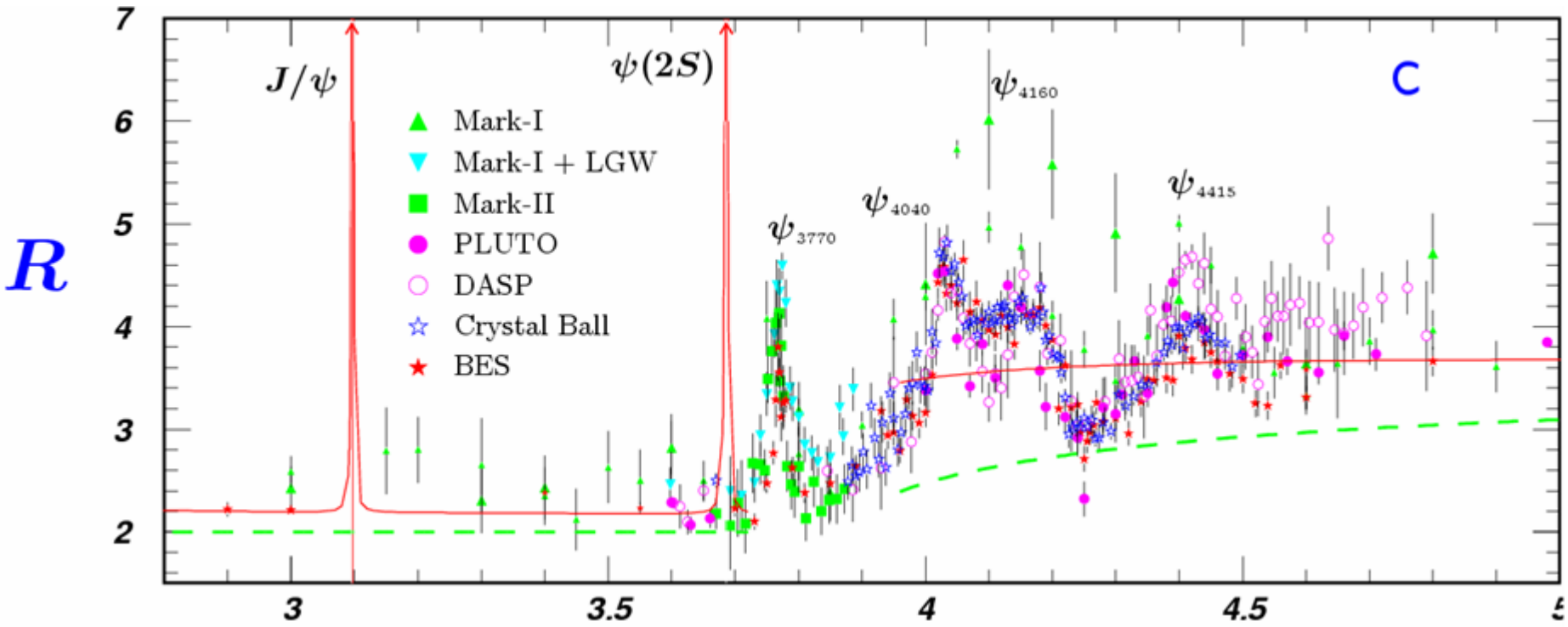
***Osaka*, Japan**

Outline

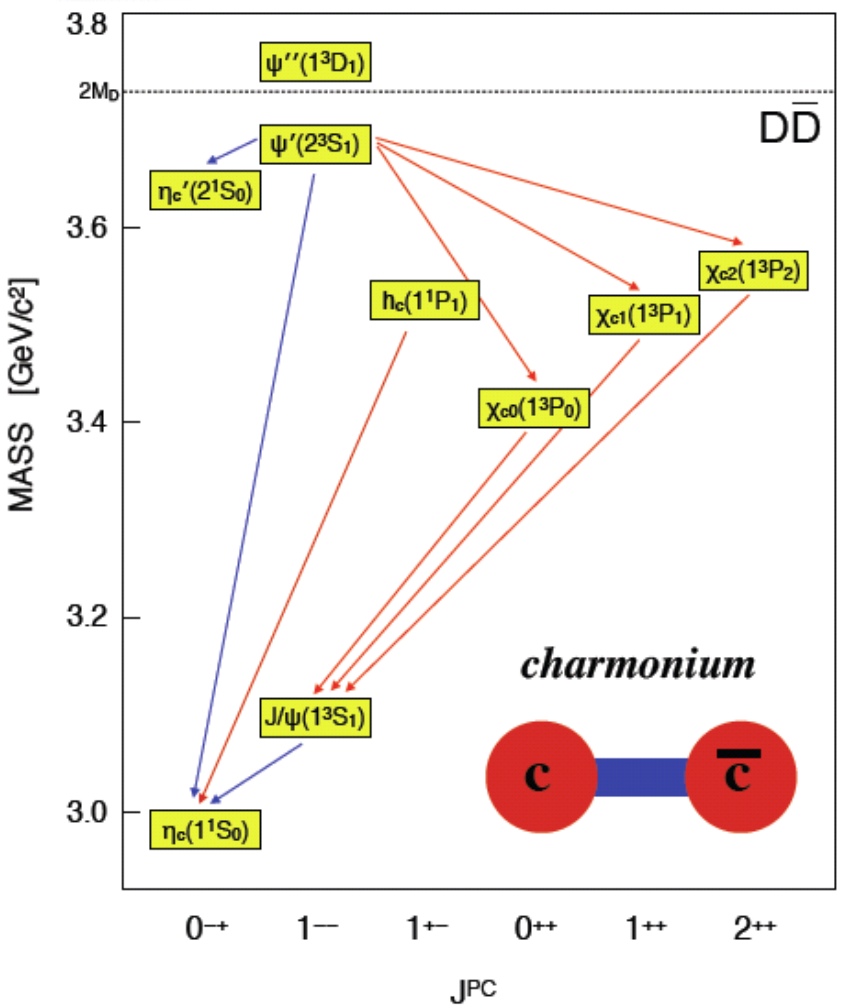
- Status of BEPCII/BESIII
- Light hadron from charmonium decays
- Charmonium transitions and decays
- Charm Physics: advantage near threshold
- Conclusion

Energy range of BEPCII



2.0 – 4.6 GeV

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

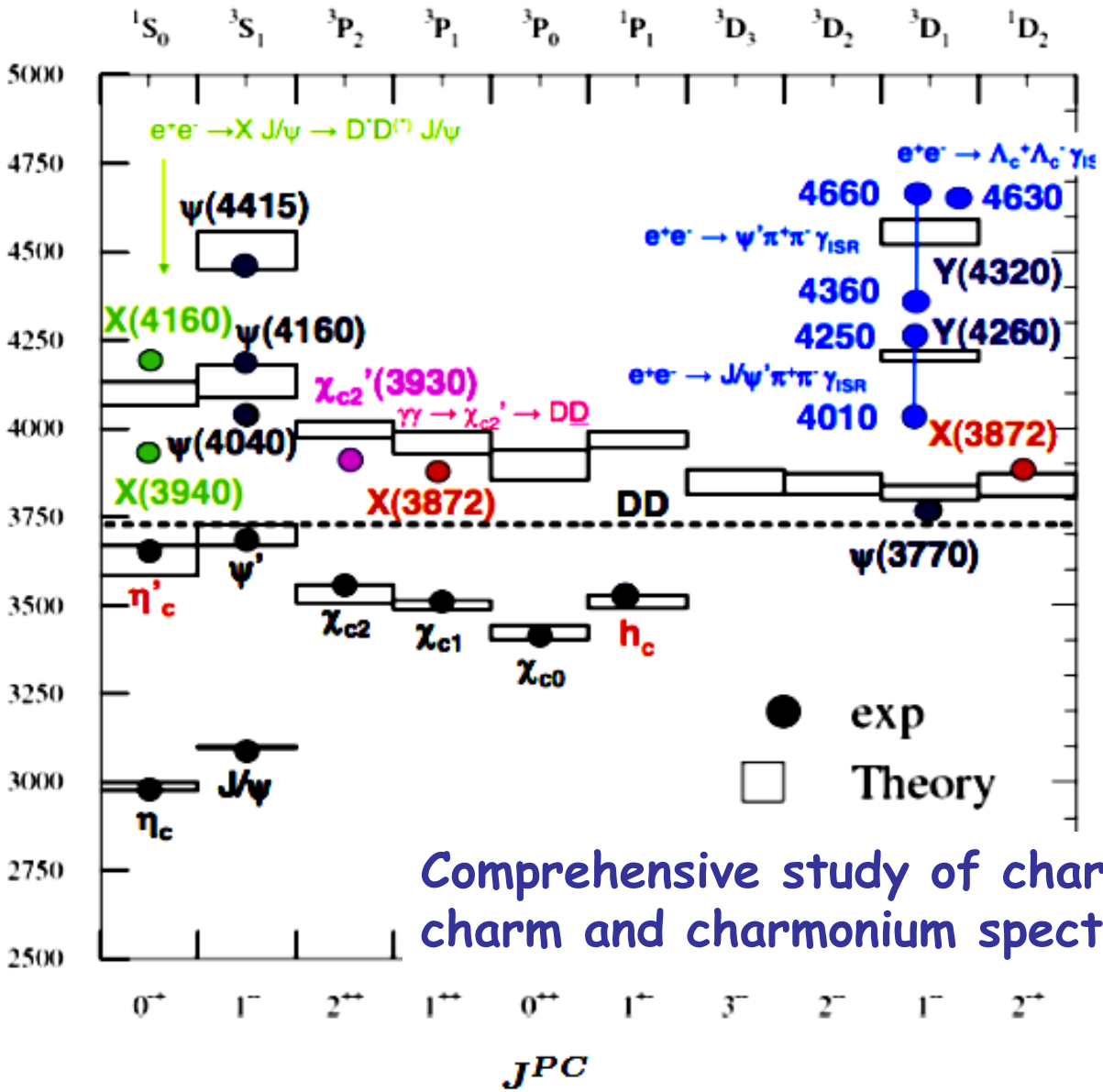
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- Tau decays near threshold
- tau mass scan

…and many more.

Charmonium spectroscopy after the B-factories



BESIII final goal

J/ψ – 10^{10}

$\psi(2S)$ – 3×10^9

$\psi(3770)$ – 6×10^8

Higher ψ's – 10^7

In decays:

$\eta_c(1S)$-10^8

χ_{cJ} – 10^8

h_c – 10^7

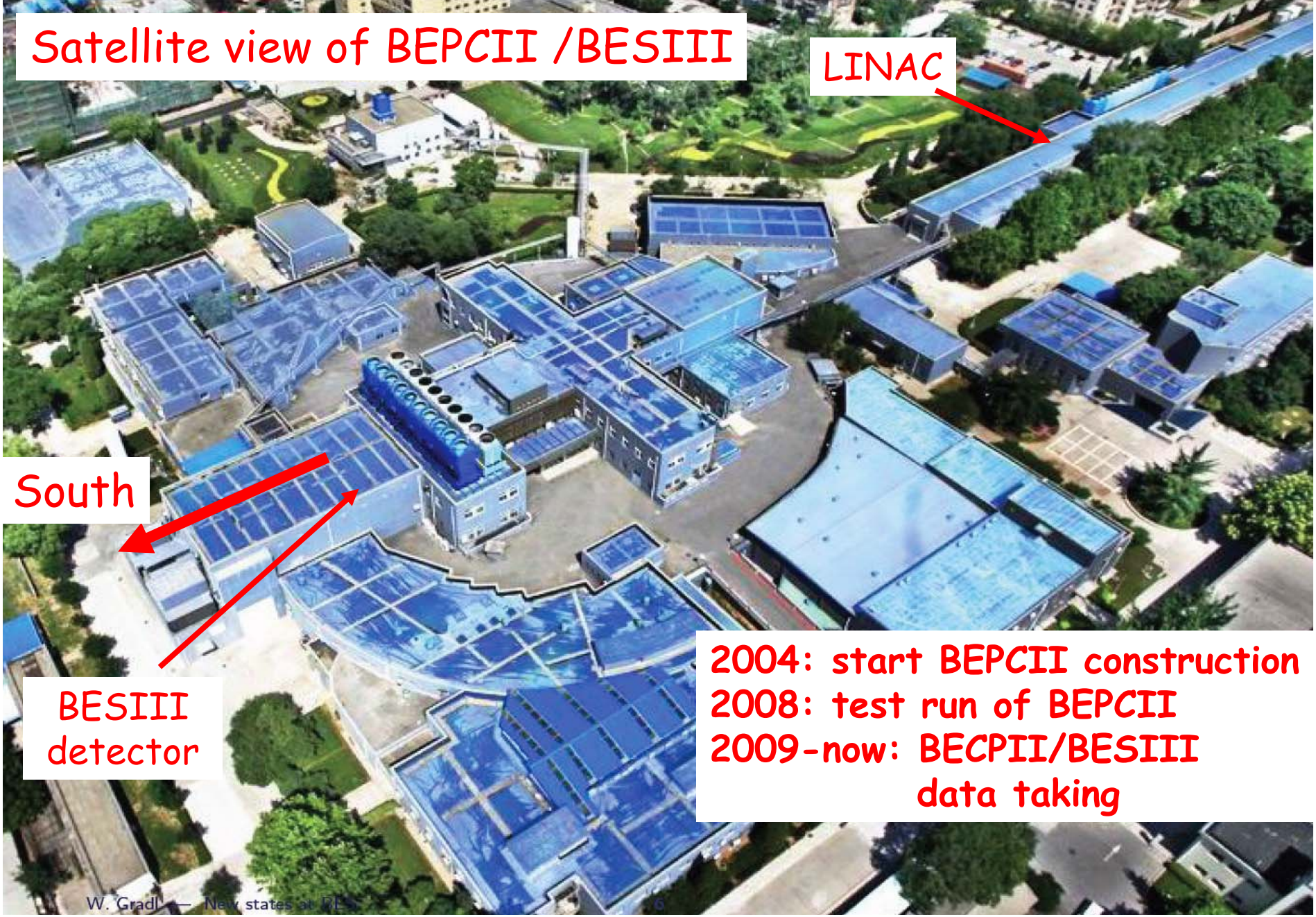
$(\psi(2S)\to h_c\pi^0)$

10^8 η/η' samples

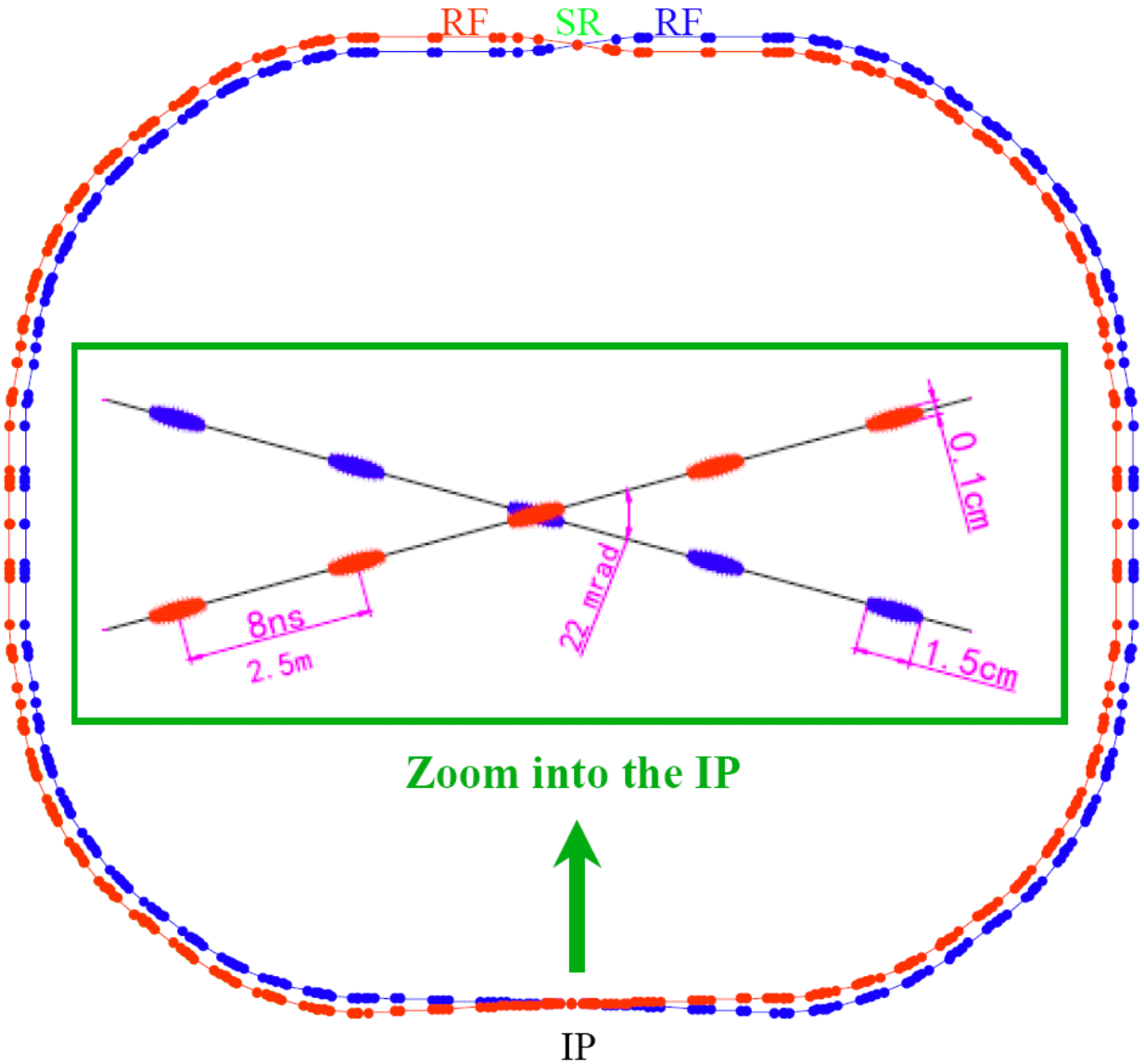
Rare η/η' decays

Comprehensive study of charmonium decays

charm and charmonium spectroscopy


Satellite view of BEPCII /BESIII
LINAC
South
BESIII detector
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

BEPCII storage rings



Beam energy:
1.0-2.3 GeV

Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$

Optimum energy:
1.89 GeV

Energy spread:
5.16×10^{-4}

No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

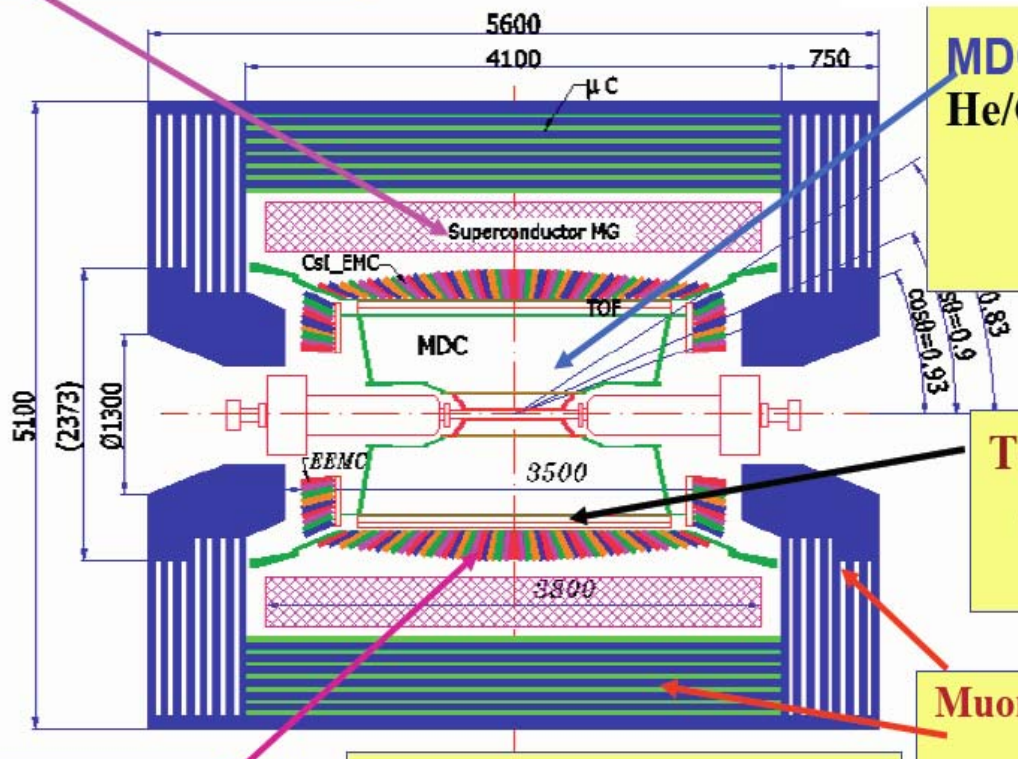
Circumference：
237m

BESIII Detector

BES-III detector: all new !

CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

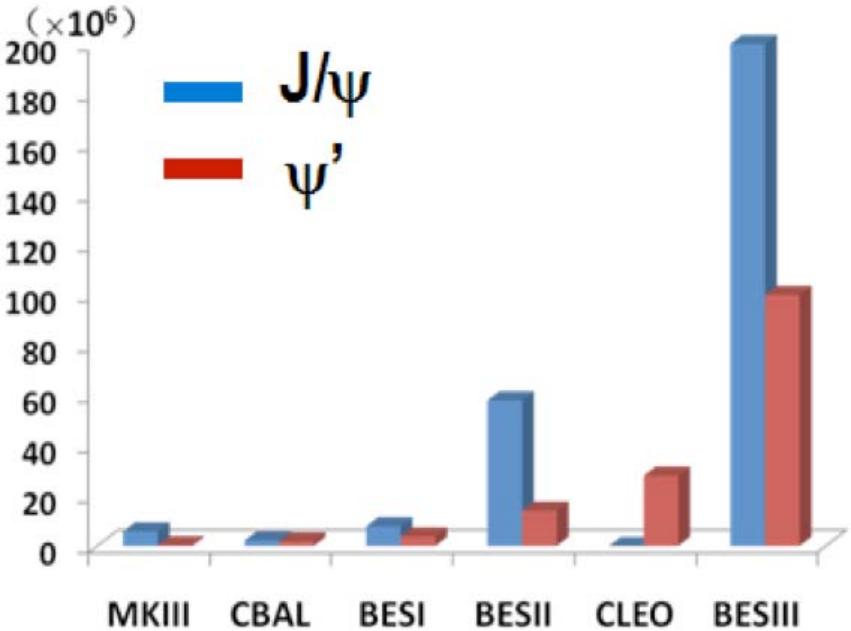
Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
$\sigma z = 0.6\ cm/\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

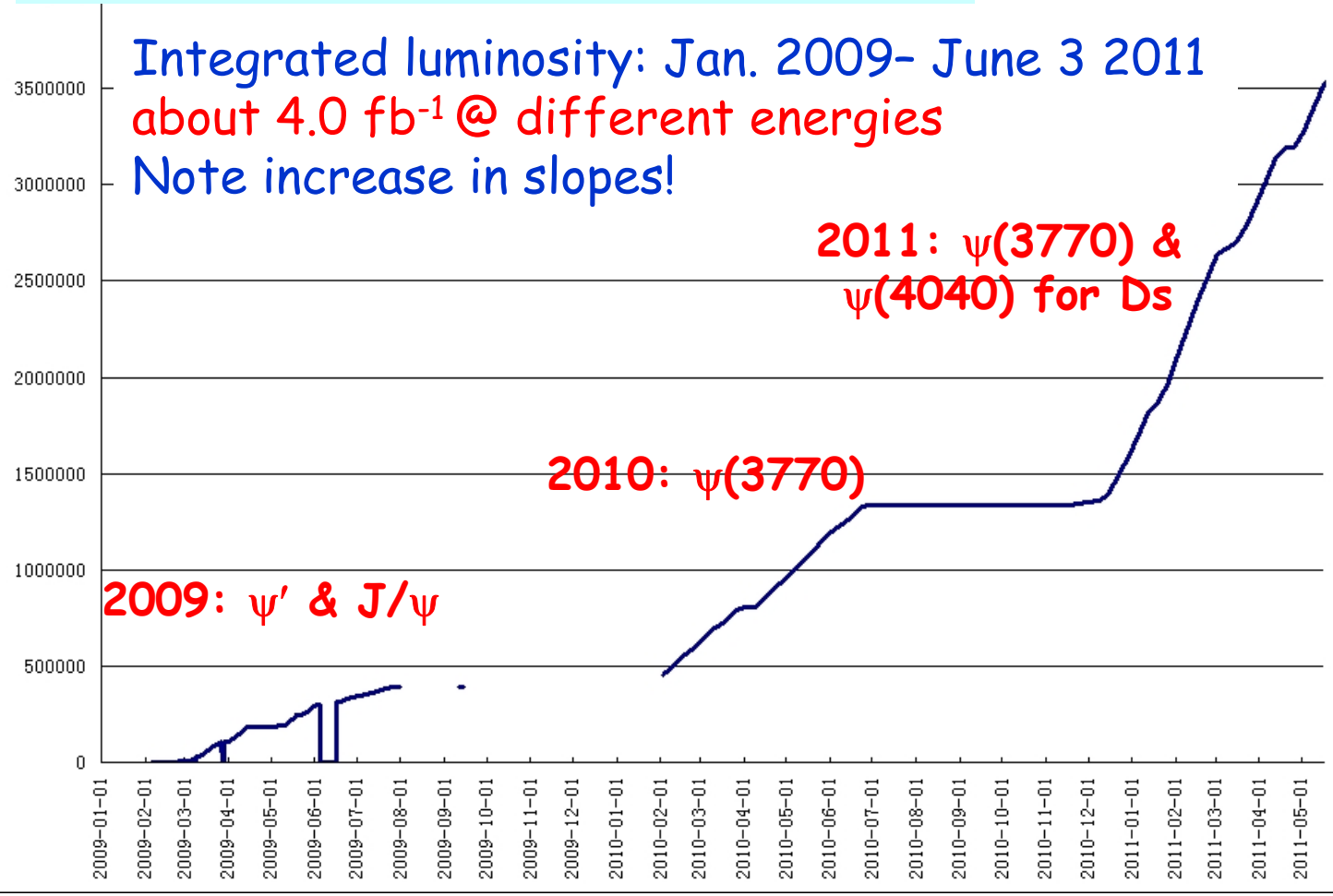
Data samples

- So far BESIII has collected :
  - 2009: 225 Million J/ψ
  - 2009: 106 Million ψ'
  - **2010-11: 2.9 fb^{-1} ψ(3770) (3.5 × CLEO-c 0.818fb^{-1})**
  - **May 2011: 0.5fb^{-1} @4010 MeV (one month) for Ds and XYZ spectroscopy**
- BESIII will also collect:
  - more J/ψ, ψ', ψ(3770)
  - data at higher energies （for XYZ searches, R scan and Ds physics）



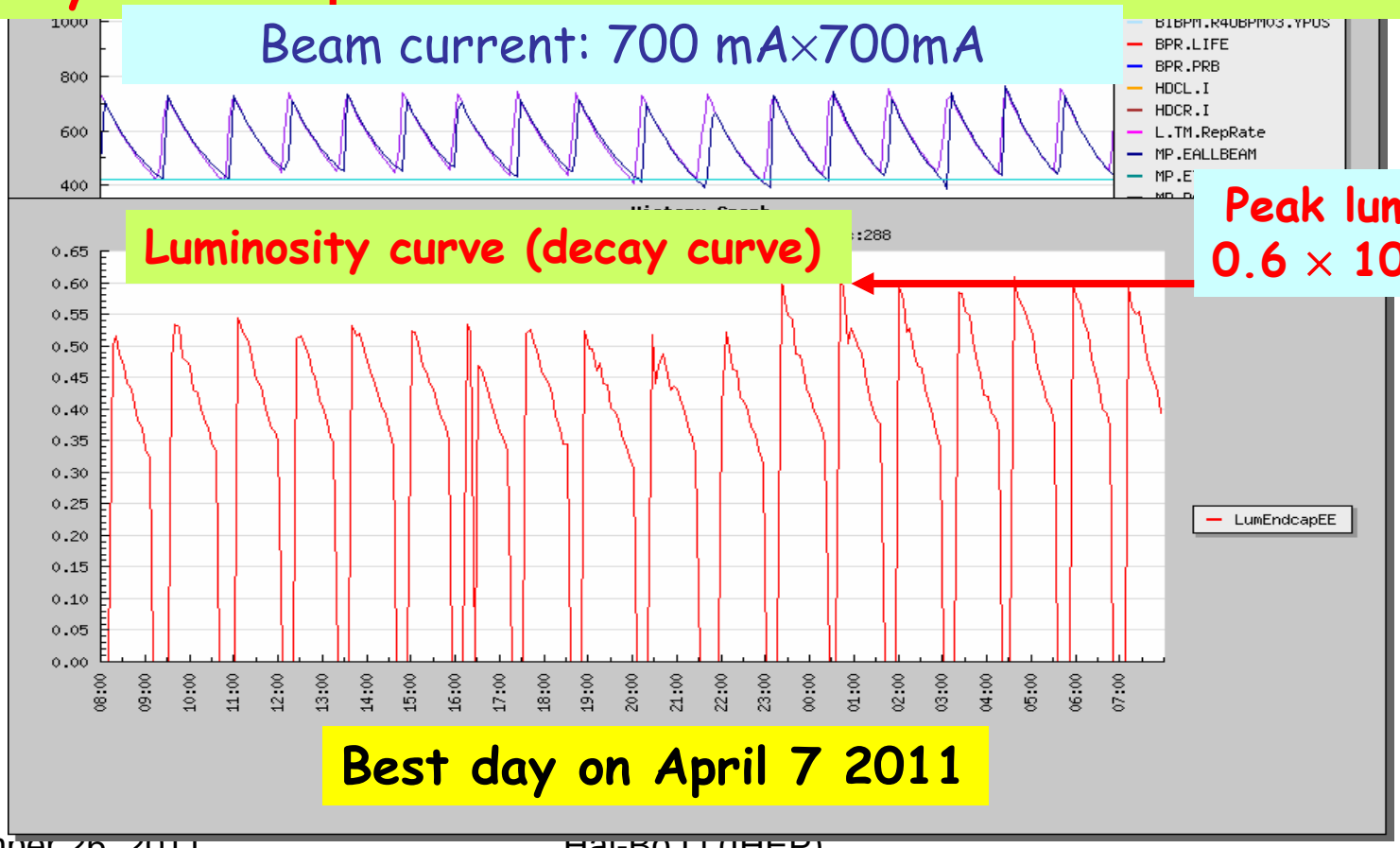
luminosity since startup

Note that luminosity is lower at J/ψ, and machine is optimal near ψ(3770)



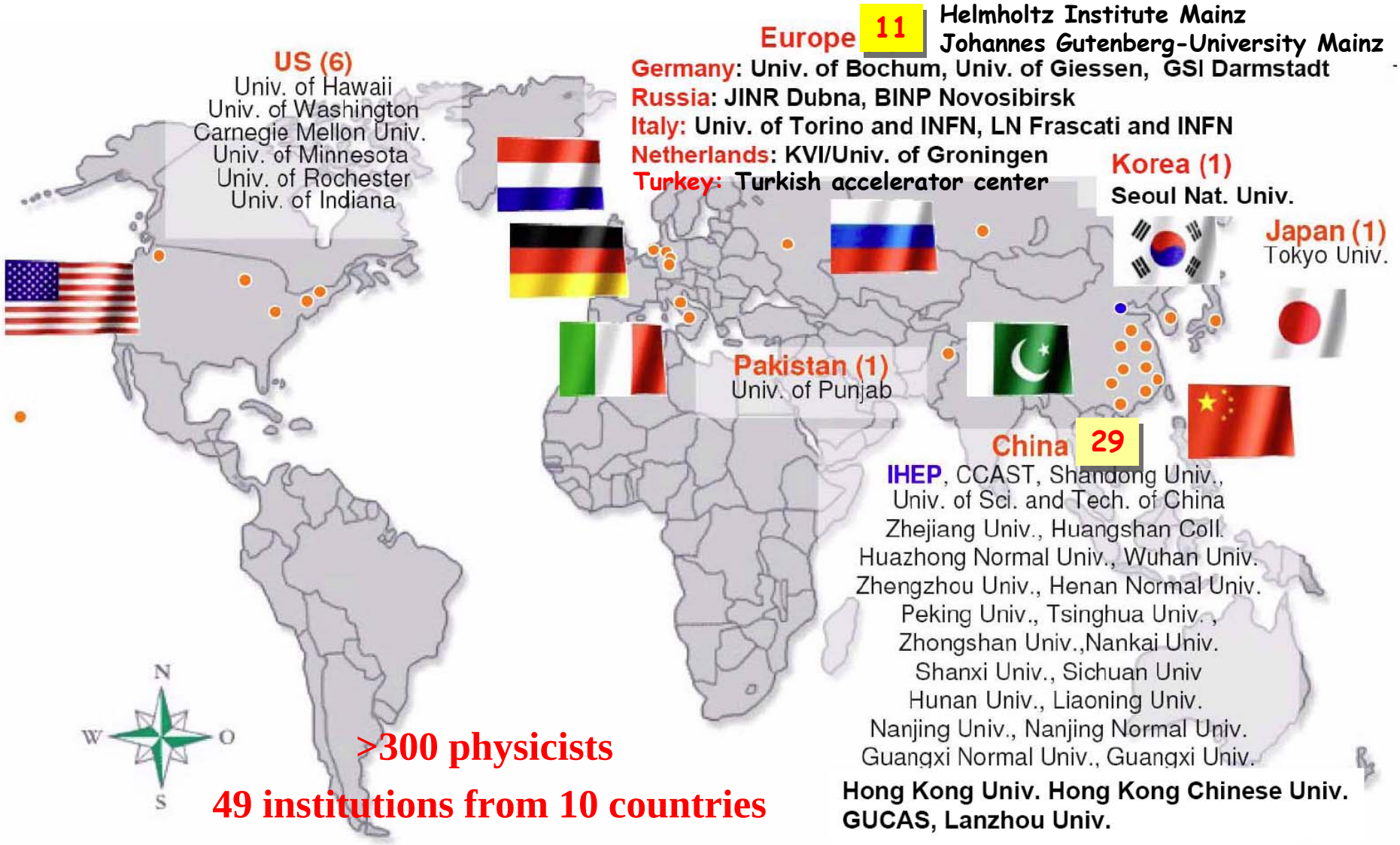
Recent ψ(3770) running

Reference point: $\mathcal{L}$ = 0.5 × 10^{33} /cm^2/s (maximum 0.65 × 10^{33})
theoretically lumi: 43 pb^{-1} /day
But, filling beam, HV ramp, lumi. decay and down time loss 40%
Best week : 160.8 pb^{-1}
Best day : 29 pb^{-1}



Peak luminosity 0.6 × 10^{33}/cm^2/s

BESIII Collaboration



Some results from BESII on light hadrons

Data	BESII	CLEOc
J/ψ	58 M	--
ψ'	14 M	25 M (2006)
ψ''	33 pb^{-1}	~800 pb^{-1} (2006-07)
Continuum	6.4 pb^{-1} ($\sqrt{s}$=3.65 GeV)	21 pb^{-1} ($\sqrt{s}$=3.67 GeV)

Performance of BESII detector

	Performance
$\sigma p/p$	$1.7\%/\sqrt{1+p^2}$
$\sigma E/E$	$22\% /\sqrt{E}$
PartID	dE/dx+TOF
Coverage	80%

More than 100 papers published at BESII experiment

Light scalars

from C.Z.Yuan

- Many scalars found in experiments
- Do the sigma and kappa really exist?
- Have we seen scalar glueball already?

There are many experimental results from BES II--
(theorists (will) give interpretations)

- States in J/ψ decays
  - $\phi\ \pi\pi/\phi K\ K$
  - $\omega\ \pi\pi/\omega\ K\ K$
  - $\gamma\ \pi\pi/\gamma K\ K$
  - $K\ K\ \pi\pi$ (the kappa)
- Sigma in $\psi' \rightarrow \pi^+\pi^- J/\psi$
- χ_c decays
  - Pair production of scalars

$f_0(600)$ or σ

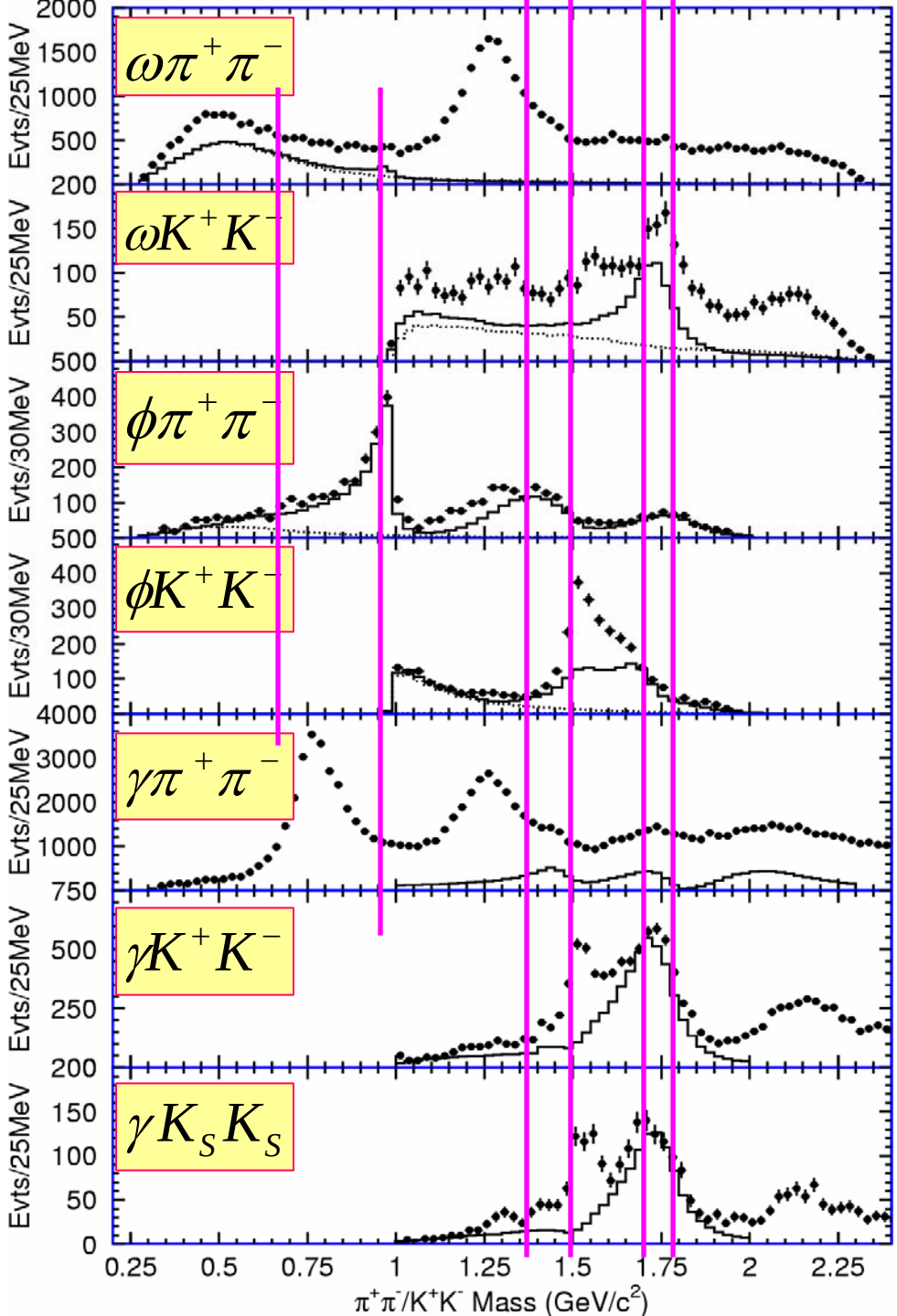
$f_0(980)$

$f_0(1370)$

$f_0(1500)$

$f_0(1710)$

$f_0(1790)$



(IHEP)

The scalars

from C.Z.Yuan

$f_0(600)$ or σ:

$f_0(980)$:

$f_0(1370)$:

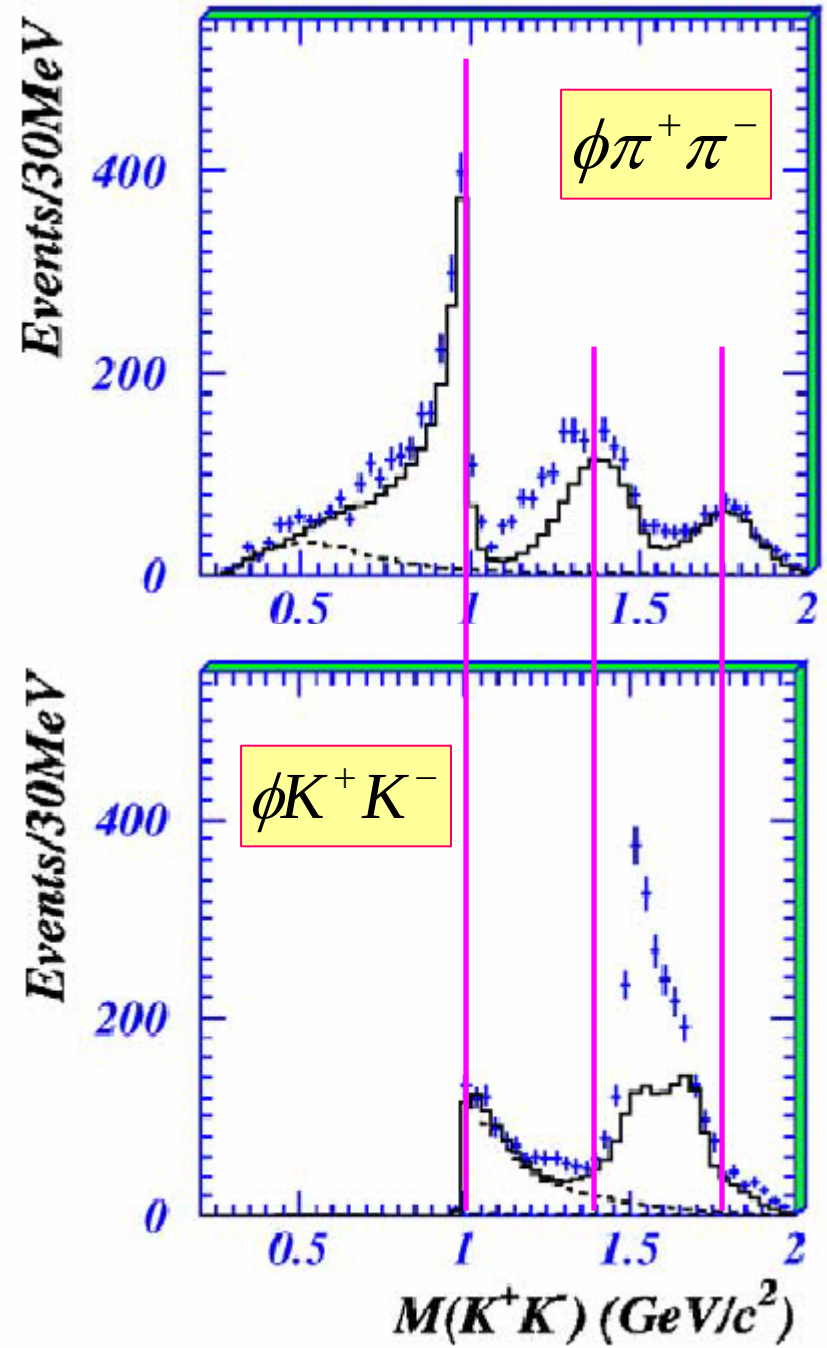
$f_0(1500)$:

$f_0(1710)$:

$f_0(1790)$:

PLB 607 (2005) 243
PLB 603 (2004) 138
PLB 598 (2004) 149
PRD 68 (2003) 052003
PLB 642 (2006) 441

from C.Z.Yuan



PLB 607 (2005) 243

$f_0(980)$ parameters:

$$M = 965 \pm 8 \pm 6 \text{ MeV}$$

$$g_{\pi\pi} = 165 \pm 10 \pm 15 \text{ MeV}$$

$$\frac{g_{KK}}{g_{\pi\pi}} = 4.21 \pm 0.25 \pm 0.21$$

$f_0(1370)$ peak seen!

$$M = 1350 \pm 50 \text{ MeV}$$

$$\Gamma = 265 \pm 40 \text{ MeV}$$

Observation of $f_0(1790)$?

$$M = 1790^{+40}_{-30} \text{ MeV}$$

$$\Gamma = 270^{+60}_{-30} \text{ MeV}$$

Couplings to γ, ω, and ϕ in J/ψ decays, and decays to $\pi^+\pi^-$ and K^+K^- reveal its nature!

BESII: PLB607(2005)243

Scalar	$B(\phi S, S\to\pi\pi)(10^{-4})$	$B(\phi S, S\to KK)(10^{-4})$
$f_0(600)/\sigma$	1.6 ± 0.6	0.2 ± 0.1
$f_0(980)$	5.4 ± 0.9	4.5 ± 0.8
$f_0(1370)$	4.3 ± 1.1	0.3 ± 0.3
$f_0(1500)$	1.7 ± 0.8	0.8 ± 0.5
$f_0(1710)$	--	2.0 ± 0.7
$f_0(1790)$	6.2 ± 1.4	1.6 ± 0.8

$$B(J/\psi\to\gamma f_0(1710)\to\gamma K\bar{K}) = (9.6^{+3.5}_{-1.9})\times10^{-4}$$

$$B(J/\psi\to\omega f_0(1710)\to\omega K^+K^-) = (6.6\pm1.3)\times10^{-4}$$

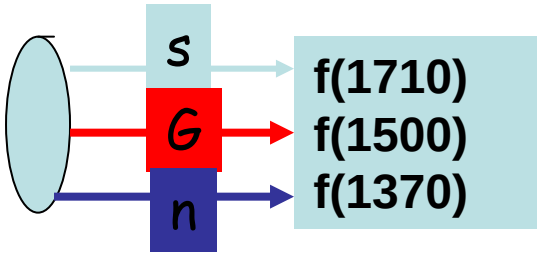
BESII: PRD 68 (2003) 052003

$$\frac{BR(f_0(1710)\to\pi\pi)}{BR(f_0(1710)\to K\bar{K})} < 0.11 \quad @95\%CL$$

BESII: PLB603(2004)138
BESII:PLB598(2004)149

The mixing of the scalars

Idea available long time ago,
a recent analysis in
PRD71, 094022 (2005)
By Frank Close and Qiang Zhao

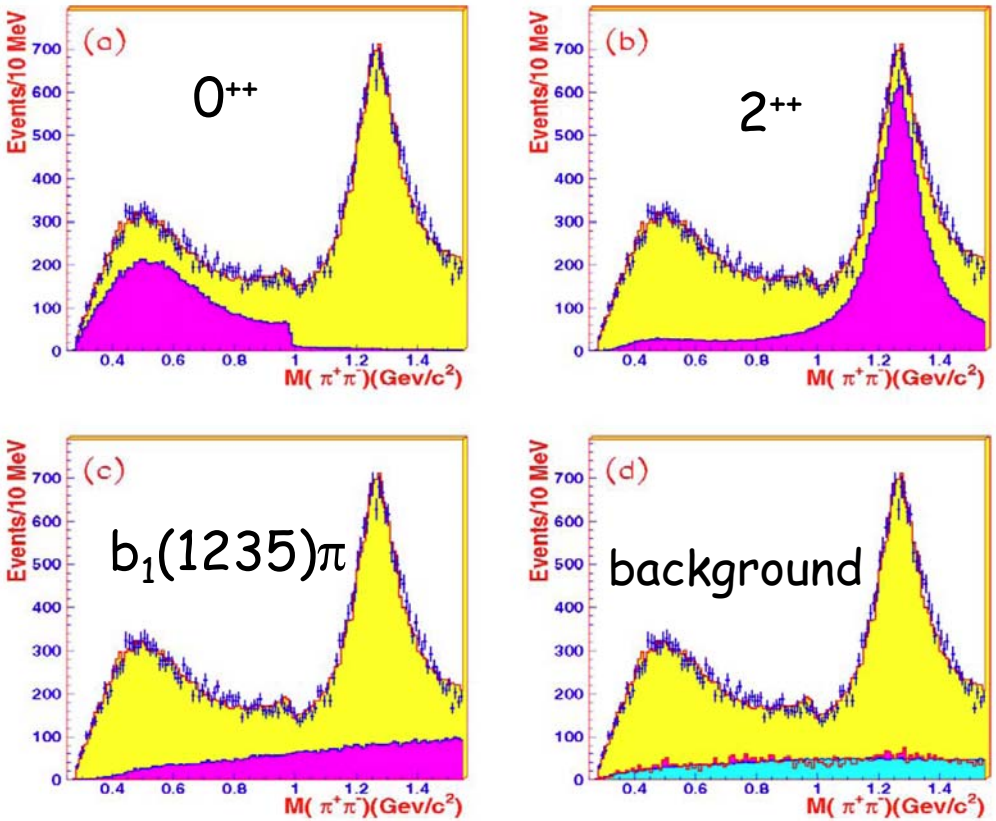


$$
\begin{aligned}
|f_0(1710)\rangle &= 0.39|G\rangle + 0.91|s\bar{s}\rangle + 0.13|n\bar{n}\rangle \\
|f_0(1500)\rangle &= -0.73|G\rangle + 0.37|s\bar{s}\rangle - 0.57|n\bar{n}\rangle \\
|f_0(1370)\rangle &= 0.56|G\rangle - 0.12|s\bar{s}\rangle - 0.82|n\bar{n}\rangle \ ,
\end{aligned}
$$

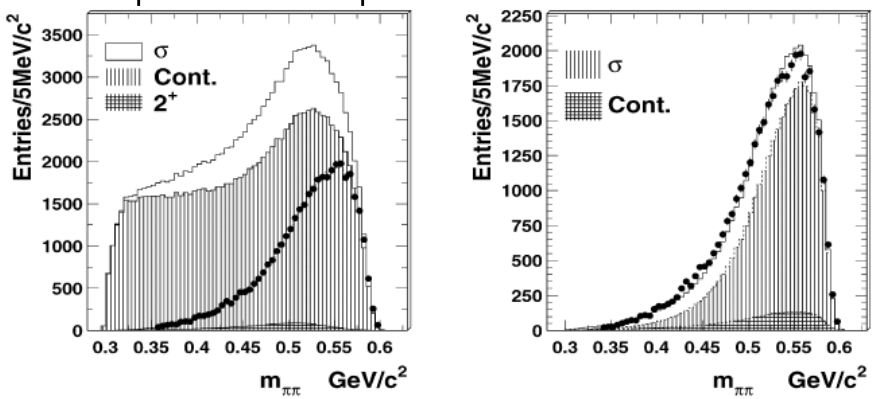
The mass of the scalar glueball is about 1.46-1.52 GeV in the same scheme.

σ and it's pole

$J/\psi \to \omega\pi^+\pi^-$



$\psi' \to \pi\pi J/\psi$



$$(552^{+84}_{-106}) - i(232^{+81}_{-72})\ \mathrm{MeV}/c^2$$

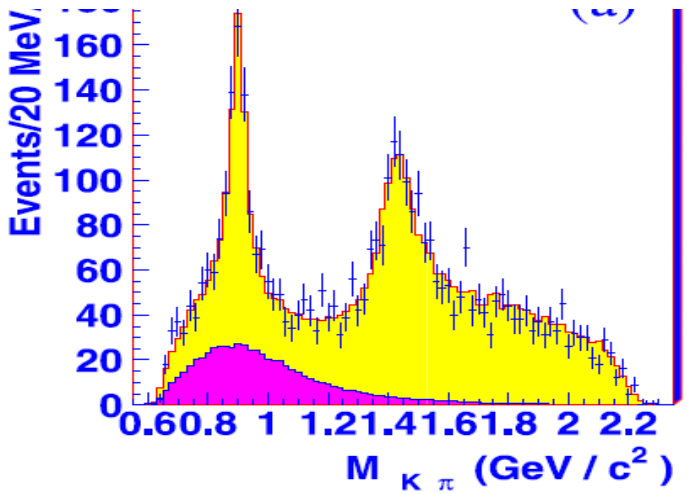
BESII PLB 645(2007)19

$$(541 \pm 39) - i(252 \pm 42)\ \mathrm{MeV}$$

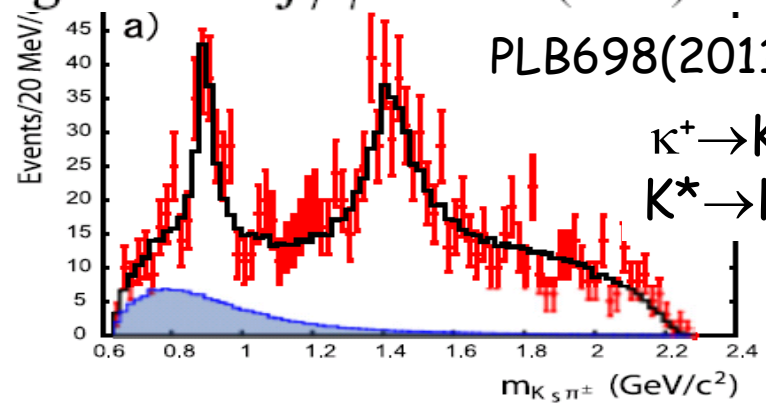
BESII, PLB 598(2004)149

κ and it's pole

κ in $J/\psi \to K^{\pm} K_S \pi^{\mp} \pi^0$



charged κ in $J/\psi \to K^*(892)^{\mp} K_S \pi^{\pm}$



PLB698(2011)183

$\kappa^+ \to K_S \pi^+$

$K^* \to K_S \pi^-$

$(764 \pm 63^{+71}_{-54}) - i(306 \pm 149^{+143}_{-85})$ MeV/c^2

	BW (1)	BW (2)	BW (3)
Mass (MeV/c^2)	$745 \pm 26^{+14}_{-91}$	$874 \pm 25^{+12}_{-55}$	$1140 \pm 39^{+47}_{-80}$
Width (MeV/c^2)	$622 \pm 77^{+61}_{-78}$	$518 \pm 65^{+27}_{-87}$	$1370 \pm 156^{+406}_{-148}$
Pole (MeV/c^2)	$(799 \pm 37^{+16}_{-90})$ $- i(290 \pm 33^{+25}_{-38})$	$(836 \pm 38^{+18}_{-87})$ $- i(329 \pm 66^{+28}_{-46})$	$(811 \pm 74^{+17}_{-83})$ $- i(285 \pm 20^{+18}_{-42})$

Neutral κ

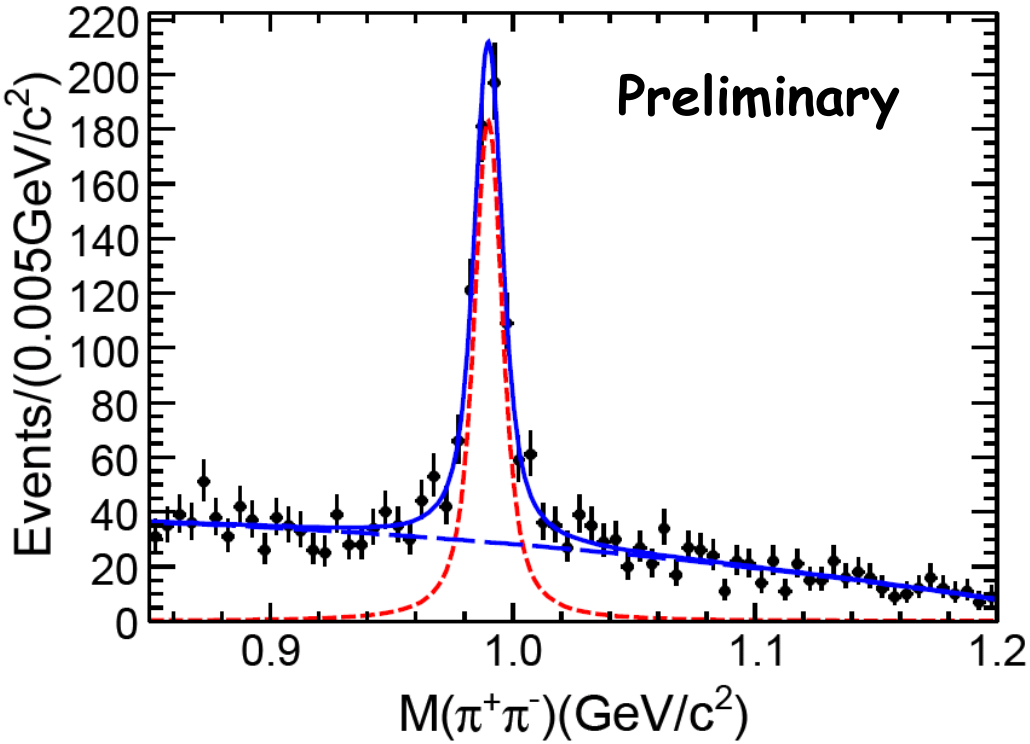
	BW (1)	BW (2)	BW (3)
Mass (MeV/c^2)	$810 \pm 68^{+15}_{-24}$	$884 \pm 40^{+11}_{-22}$	$1165 \pm 58^{+120}_{-41}$
Width (MeV/c^2)	$536 \pm 87^{+106}_{-47}$	$478 \pm 77^{+71}_{-41}$	$1349 \pm 500^{+472}_{-176}$
Pole (MeV/c^2)	$(849 \pm 77^{+18}_{-14})$ $- i(256 \pm 40^{+46}_{-22})$	$(849 \pm 51^{+14}_{-28})$ $- i(288 \pm 101^{+64}_{-30})$	$(839 \pm 145^{+24}_{-7})$ $- i(297 \pm 51^{+50}_{-18})$

Charged κ

BESII PLB693(2010)88

Results at BESIII

Anomalous lineshape of $f_0(980)$ in $J/\psi \to \gamma f_0(980)\pi^0$ decays at BESIII



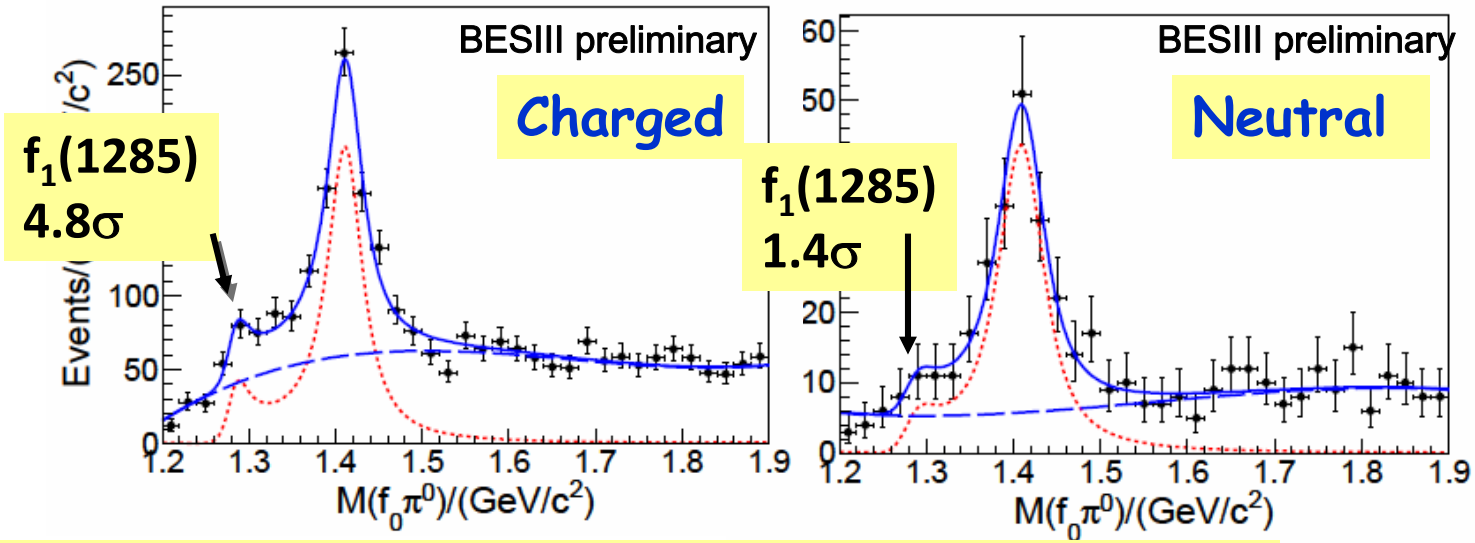
Fitted mass:
M = 989.9±0.4 MeV
Γ= 9.5 ± 1.1 MeV

The width is so narrow!
PDG2010:
Γ=40—100 MeV

Isospin violating decays $J/\psi \to \gamma f_0(980)\pi^0$

$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0, f_0(980) \to \pi\pi$

Charged:
$f_0(980) \to \pi^+\pi^-$
Neutral
$f_0(980) \to \pi^0\pi^0$



Helicity analysis indicates that peak at 1400MeV is from $\eta(1405) \to f_0(980)\pi^0$, not from $f_1(1420)$:

First observation of $\eta(1405) \to f_0(980)\pi^0$ (isospin violating decays) and $J/\psi \to \gamma f_0(980)\pi^0$

Preliminary results:

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}$$

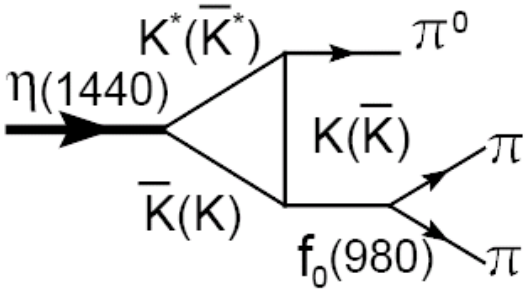
$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^0\pi^0) = (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}$$

Large isospin violation in η(1405) decay

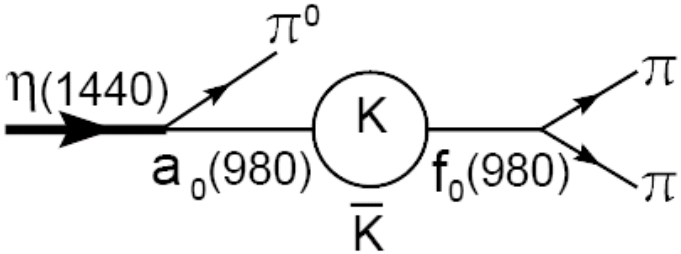
In general, magnitude of isospin violation in strong decay should be less than 1% at 0.1% level. For example:

$$\frac{BR(\psi' \to \pi^0 J/\psi)}{BR(\psi' \to \eta J/\psi)} = 0.2 \times 10^{-2} \times \frac{|P_\pi|^3}{|P_\eta|^3}, \quad \frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} = 0.8 \times 10^{-2}$$

$$\frac{BR(\eta(1405) \to f_0(980)(\pi^+\pi^-)\pi^0)}{BR(\eta(1405) \to \pi^+\pi^-\eta)} \approx 7.5\%, \quad \frac{BR(\eta(1405) \to f_0(980)\pi^0)}{BR(\eta(1405) \to a_0(980)\pi)} \approx 25\%$$



Triangle Singularity (TS)

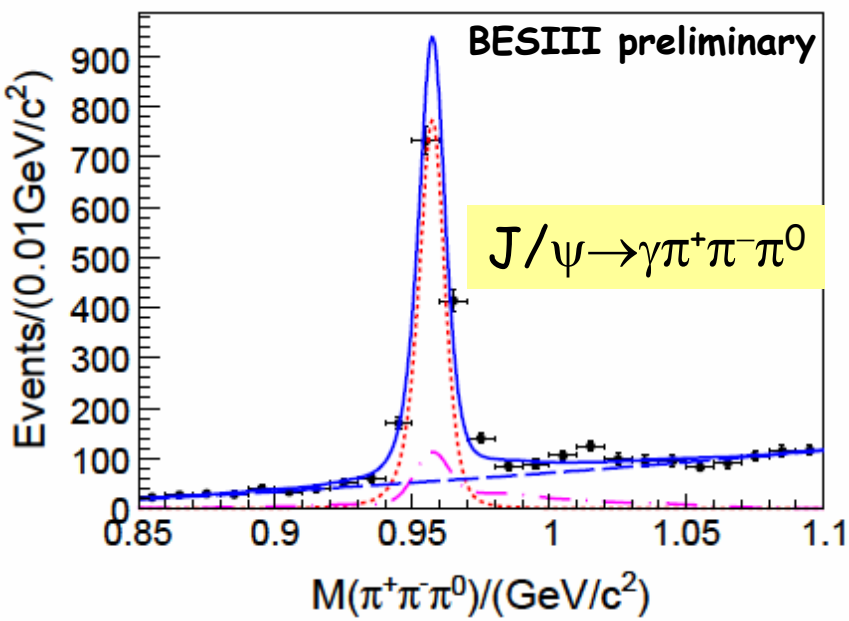


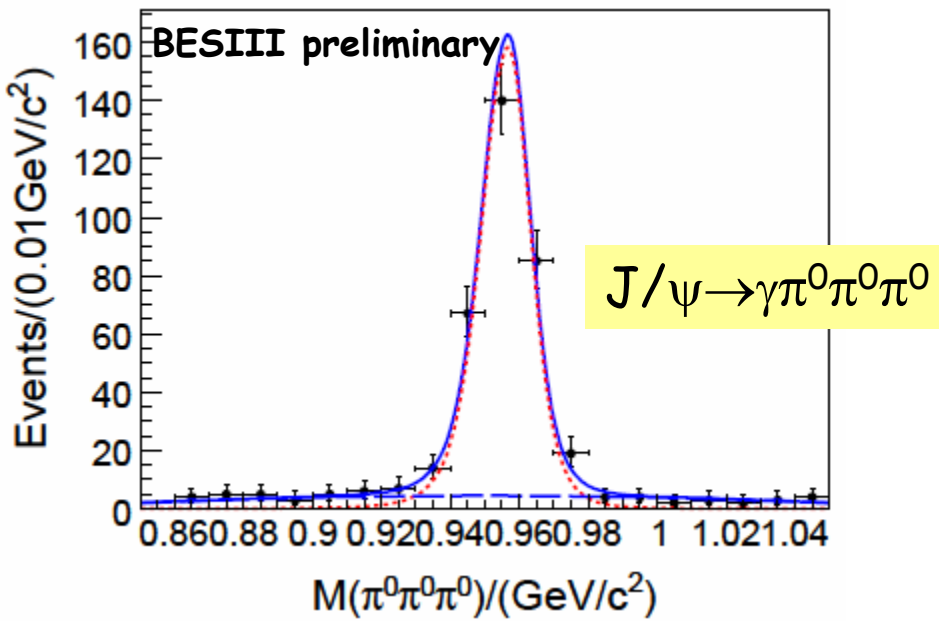
a_0—f_0 mixing

K*K pair in TS is almost on-shell, together with mixing explain the narrow $f_0(980)$, and large isospin violation.

J.J.Wu et al, arXiv:1108.3772

New results on $\eta' \to 3\pi$ in $J/\psi \to \gamma\pi\pi\pi$





Preliminary results:

$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15(stat.) \pm 0.39(sys.)) \times 10^{-3}$$

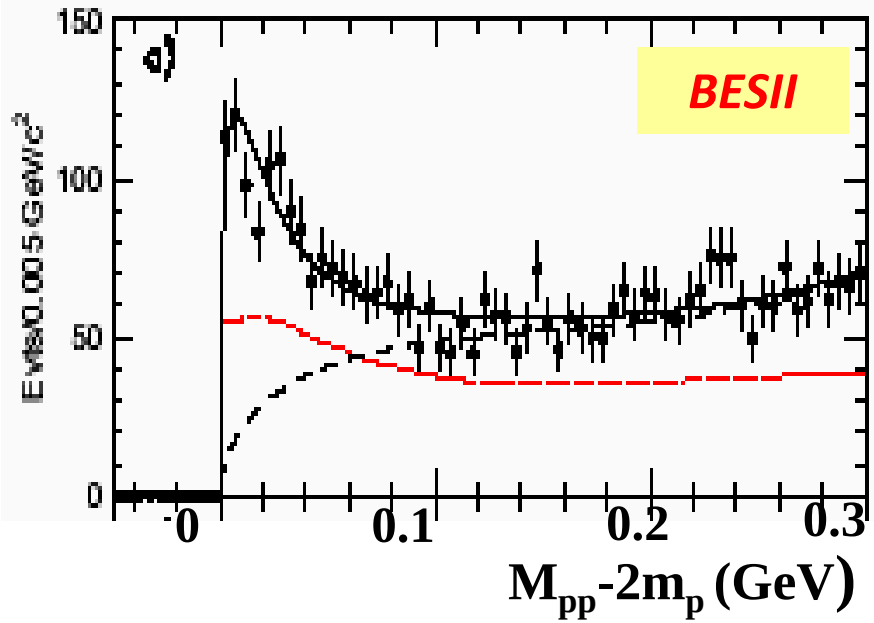
PDG2010: $(3.6^{+1.1}_{-0.9})\times 10^{-3}$ **(2009 CLEO-c)**

$$Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22(stat.) \pm 0.34(sys.)) \times 10^{-3}$$

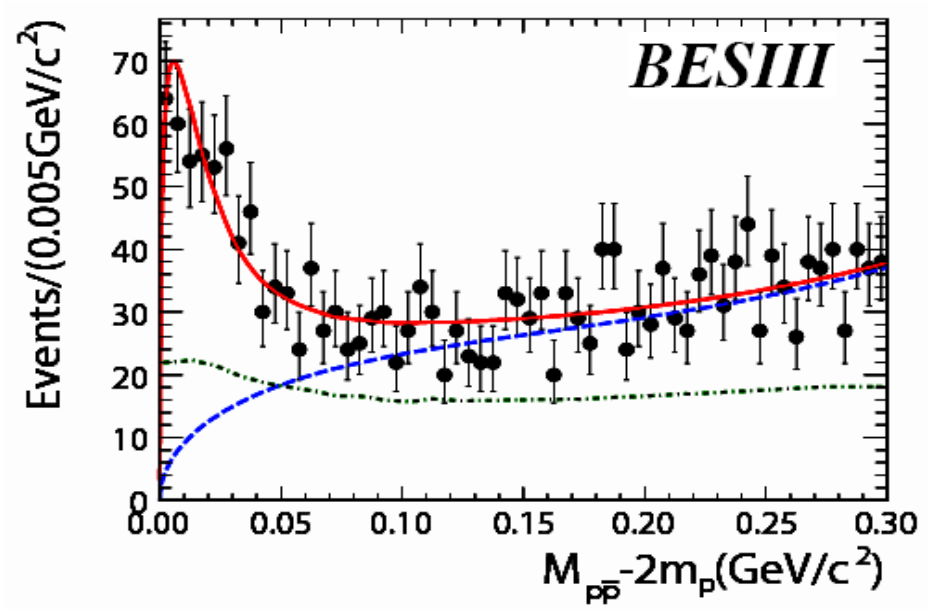
PDG2010: $(1.68\pm 0.22)\times 10^{-3}$ (1984: GAM2)

Observation of $p\bar{p}$ mass threshold enhancement at BESII and BESIII

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



$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$



$M = 1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c^2

$\Gamma < 30$ MeV/c^2 (90% CL)

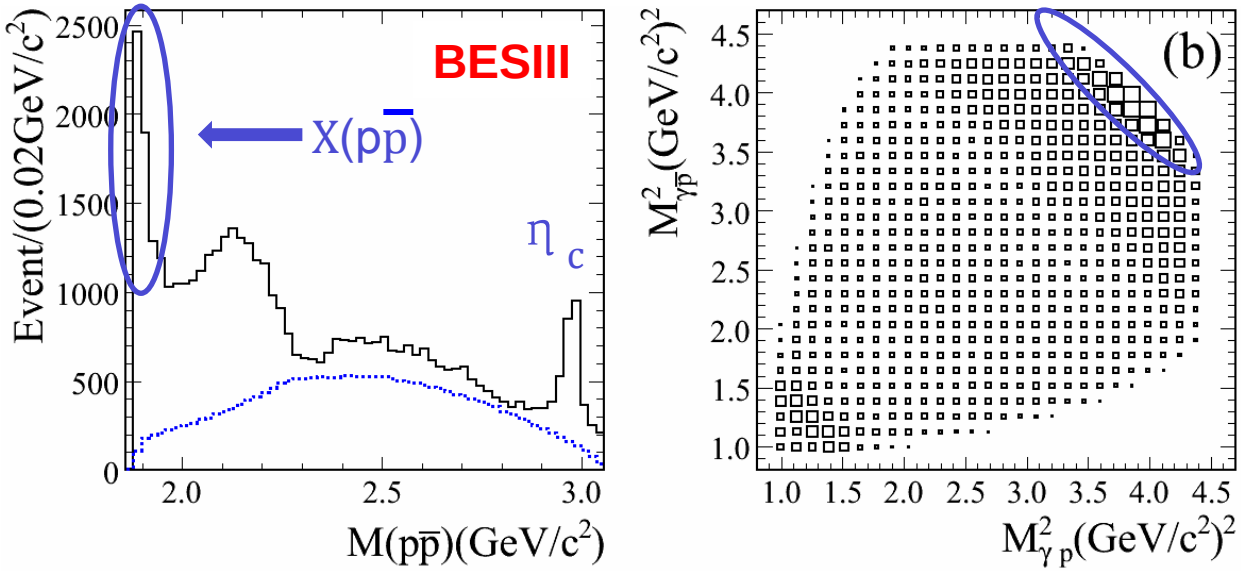
PRL 91 (2003) 022001

$M = 1861^{+6}_{-13}{}^{+7}_{-26}$ MeV/c^2

$\Gamma < 38$ MeV/c^2 (90% CL)

Chinese Physics C 34, 421 (2010)

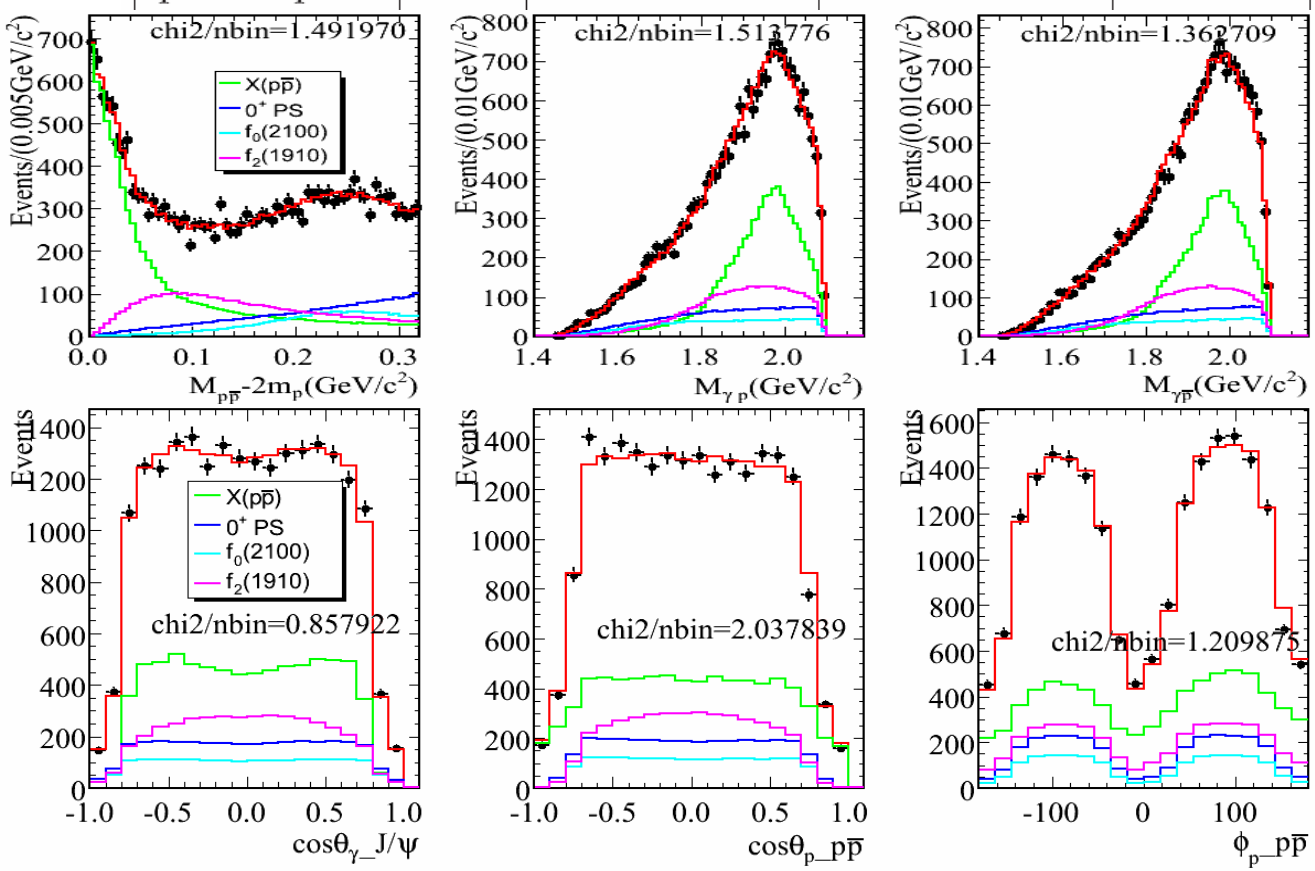
PWA on the $p\bar{p}$ mass threshold structure in $J/\psi \to \gamma p\bar{p}$



- **Evident narrow ppbar mass threshold enhancement in J/ψ decays.**
- **Partial Wave Analysis (PWA):**
  - Concentrate on dealing with the $p\bar{p}$ mass threshold structure, especially to determine the J^{PC}.
  - Convariant tensor amplitudes (S. Dulat and B. S. Zou, Eur.Phys.J A 26:125, 2005).
  - Include the Julich-FSI effect (A. Sirbirtsen et al. Phys.Rev.D 71:054010, 2005).

PWA results and projections in $J/\psi \to \gamma p\bar{p}$

Component	J^{PC}	M (GeV)	Γ (GeV)	Stat.sig.
$X(p\bar{p})$	0^{-+}	1.832 ± 0.005	0.013 ± 0.020	$\gg 30\sigma$
$f_0(2100)$	0^{++}	2.103	0.209	11.2σ
$f_2(1910)$	2^{++}	1.903	0.196	7.7σ
phase space	0^{++}	–	–	6.3σ



- The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.
- It is much better than that without FSI effect, and $\Delta 2\ln L=51 \Rightarrow 7.1\sigma$.

Measurement for X($p\bar{p}$)

- PWA results are carefully checked from different aspects:
  - Contribution of additional resonances
  - Solution with different combinations
  - Different background levels and fitting mass ranges
  - Different BW formula

  All uncertainties are considered as systematic errors.
- Different FSI models → Model dependent uncertainty
- Spin-parity, mass, width and B.R. of X($p\bar{p}$):

$J^{pc} = 0^{-+}$ → >6.8 σ better than other J^{pc} assignments.

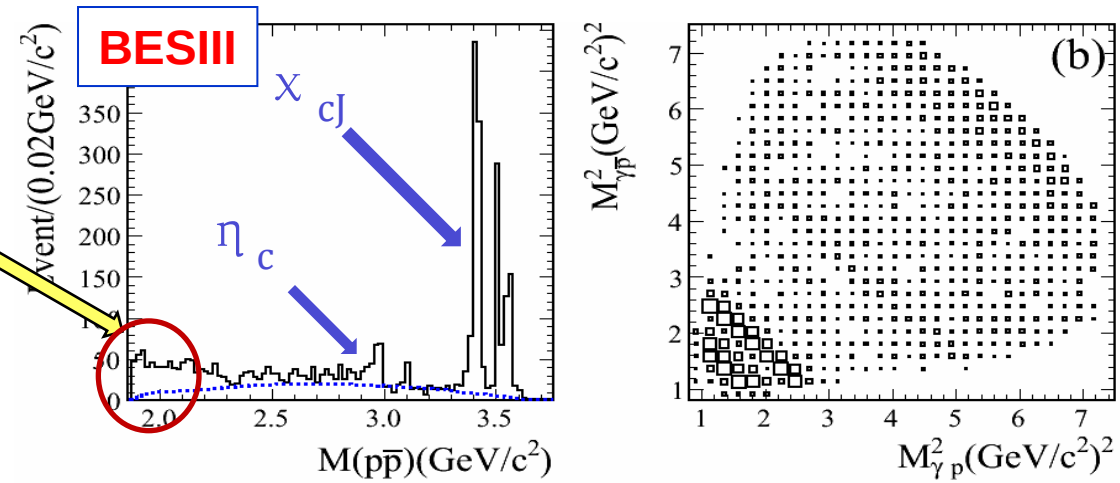
$$M = 1832 \pm 5(\text{stat})^{+19}_{-17}(\text{syst}) \pm 19(\text{mod})\ \text{MeV/c}^2$$

$$\Gamma = 13 \pm 20(\text{stat})^{+11}_{-33}(\text{syst}) \pm 4(\text{mod})\text{MeV/c}^2 \ \text{ or } \Gamma < 48\text{MeV/c}^2\ @90\%C.L.$$

$$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p}) = (9.0 \pm 0.7(\text{stat})^{+1.5}_{-5.1}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$$

PWA on the pp $\bar{m}$ass threshold structure in $\psi' \to \gamma p\bar{p}$

Obviously different line shape of ppbar mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X(pp) is larger than 6.9 σ .
- The production ratio R:

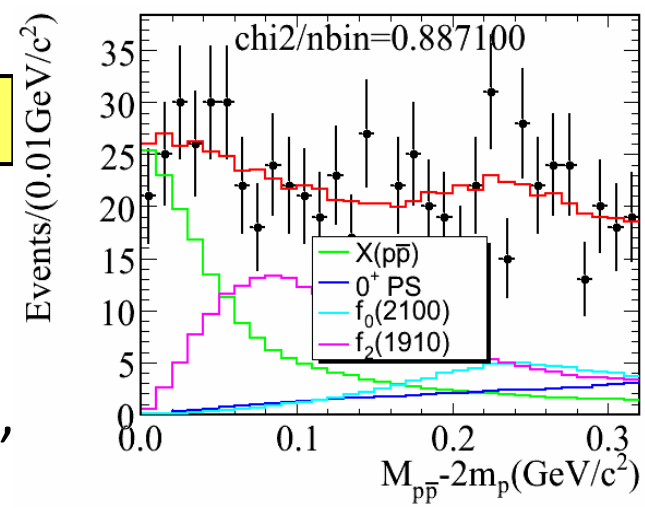
first measurement

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08 \pm 0.56(\text{stat})^{+0.72}_{-3.83}(\text{syst}) \pm 0.12(\text{mod}))\%$$

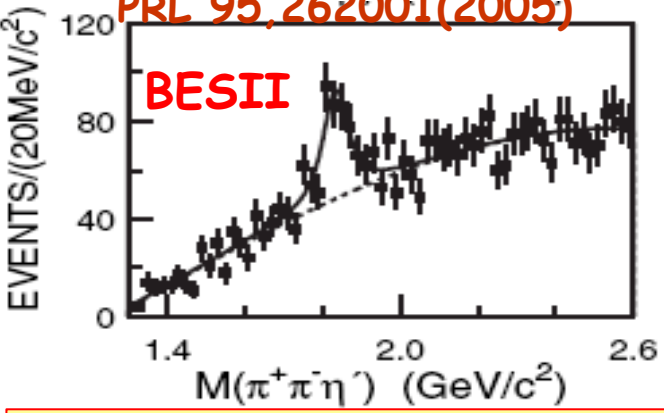
- It is suppressed compared with "12% rule"

PWA Projection:



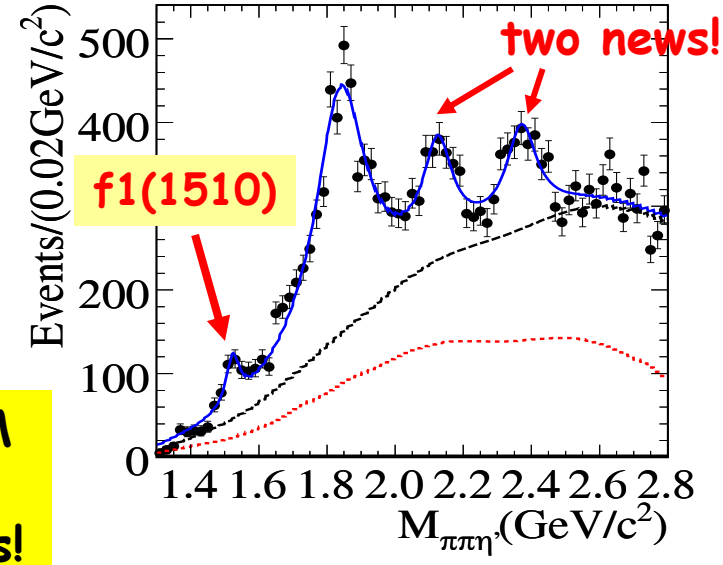
Confirmation of X(1835) and two new structures

PRL 95,262001(2005)



$J/\psi \to \gamma\eta'\pi^+\pi^-$
$\eta' \to \eta\pi^+\pi^-$
$\eta' \to \gamma\rho$

PRL 106, 072002(2011)



BESII result (Stat. sig. ~ 7.7σ):

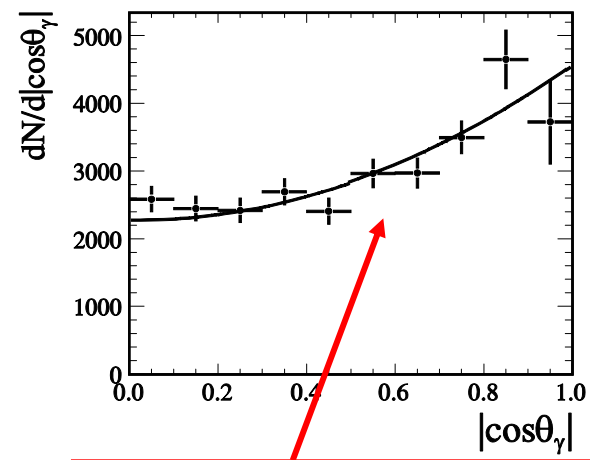
$$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$$

$$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst}) \text{MeV}$$

BESIII: 225M J/ψ events, new structures!

BESIII fit results:

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20 σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2 σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4 σ

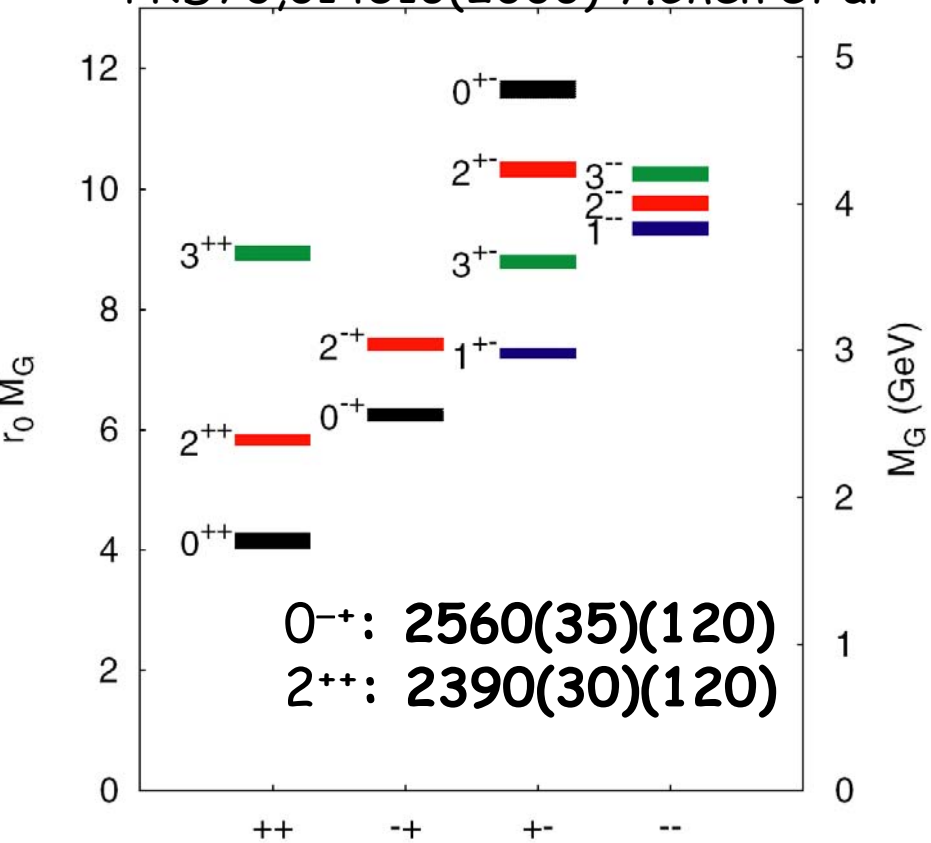


X(1835) consistent with 0^{-+}, but the others are not excluded

An amplitude analysis could help with interpretation for the additional new structures!

What's the nature of new structures?

PRD73,014516(2006) Y.Chen et al



✓It is the first time resonant structures are observed in the 2.3 GeV/c2 region, it is interesting since:

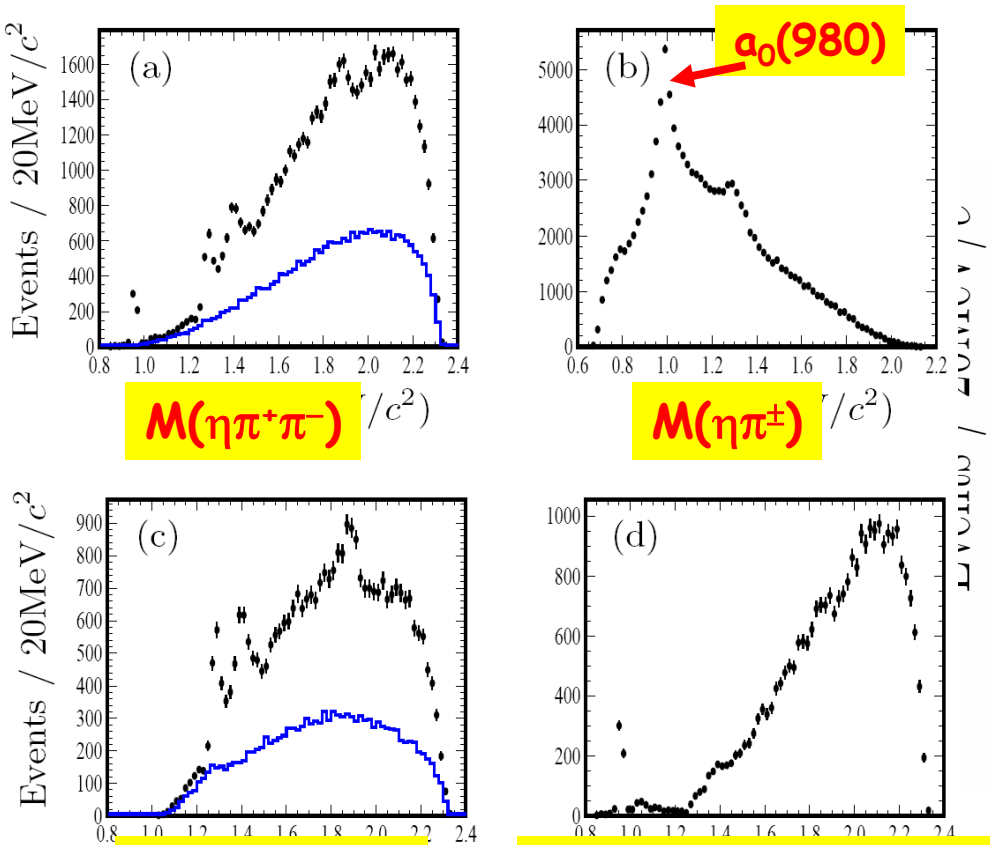
LQCD predicts that the lowest lying pseudoscalar glueball: around 2.3 GeV/c^2.

$J/\psi \to \gamma\pi\pi\eta'$ decay is a good channel for finding 0^{-+} glueballs.

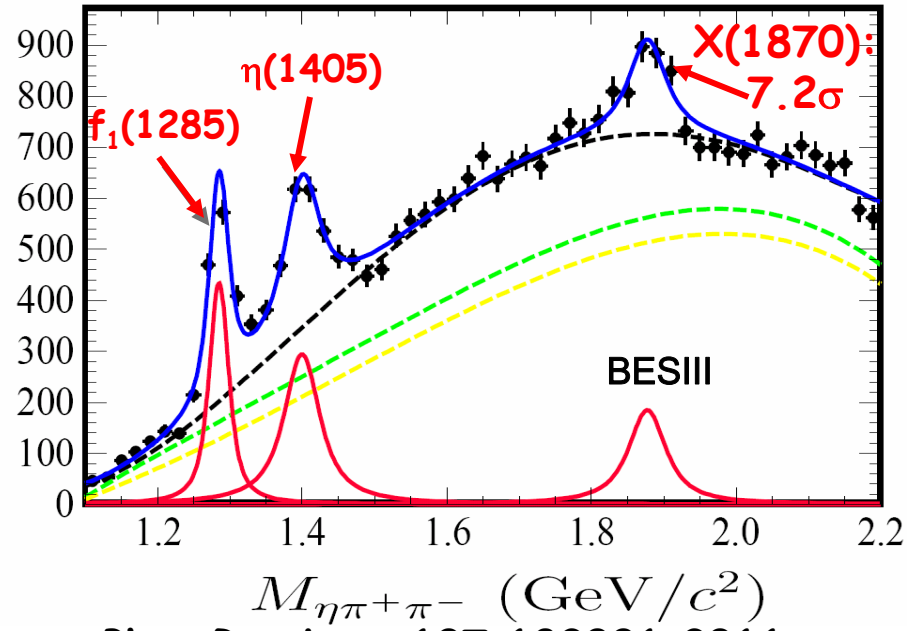
✓Nature of X(2120)/X(2370)
pseudoscalar glueball ?
η/η' excited states?

PRD82,074026,2010 J.F. Liu, G.J. Ding and M.L.Yan
PRD**83:114007,2011** (J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),
and more…

X(1870) in J/ψ→ωX, X→$a_0^{\pm}(980)\pi^{\mp}$



J/ψ→ωηπ⁺π⁻,
a_0(980) reconstructed in ηπ±



Phys.Rev.Lett.107:182001,2011

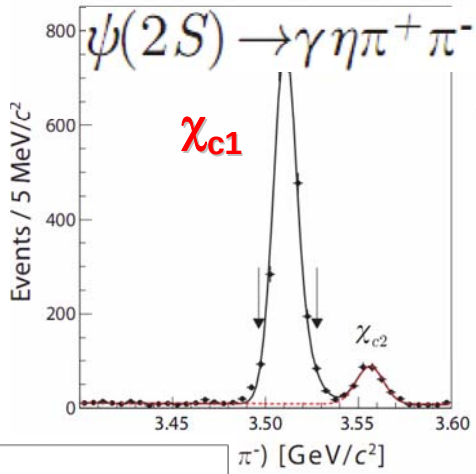
BR(J/ψ→ωX, X→ $a_0^{\pm}(980)\pi^{\mp}$)

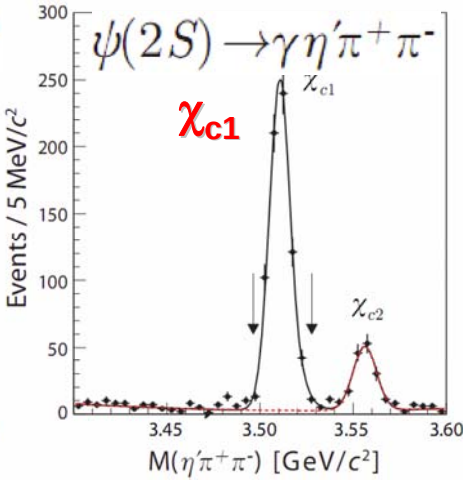
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

Identification of X(1870): 0^{-+}(?)
It is X(1835)?
Need PWA!

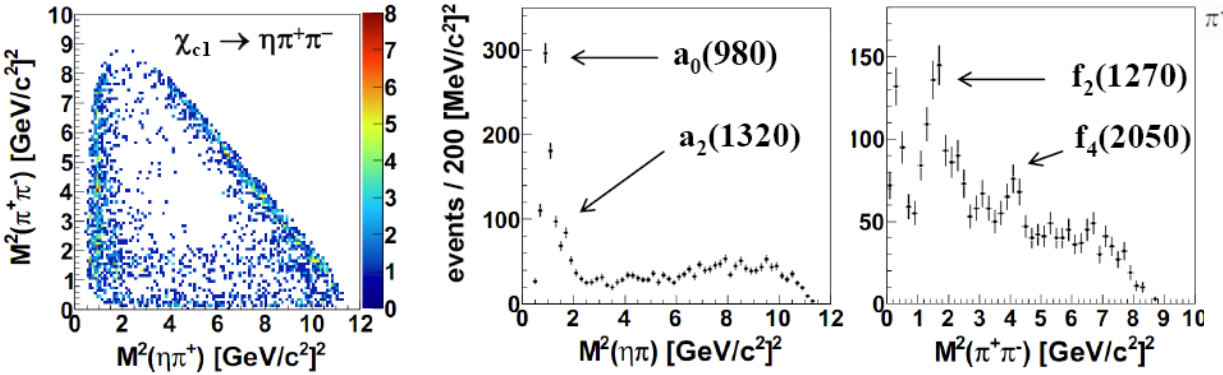
Evidence for $\pi_1(1600)$ in $\chi_{c1}\to\eta'\pi^+\pi^-$ at CLEO-c

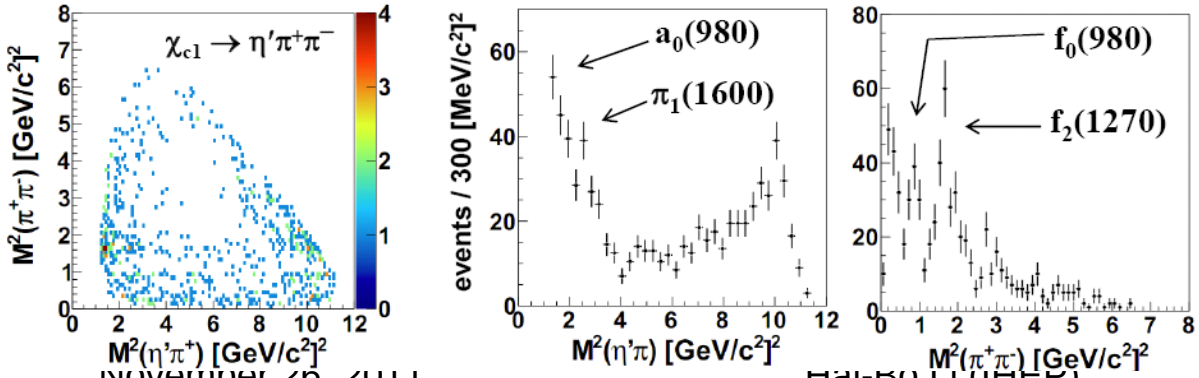
- ✓ Very low background in $\psi'\to\gamma\chi_{c1}\to\eta^{(\prime)}\pi^+\pi^-$
- ✓ Opportunity to study $\chi_{c1}\to\eta^{(\prime)}\pi^+\pi^-$
  - study $(\pi\pi)$-S-wave
  - search for spin exotic, 1^{-+}, $\eta\pi$ or $\eta'\pi$ states





CLEO-c: arXiv:1109.5843





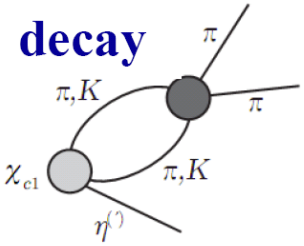
A full amplitude analysis with isobar model :

$\chi_{c1}\to$ isobar + bachelor hadron

BW for most of resonances

Flatte: $a_0(980)$

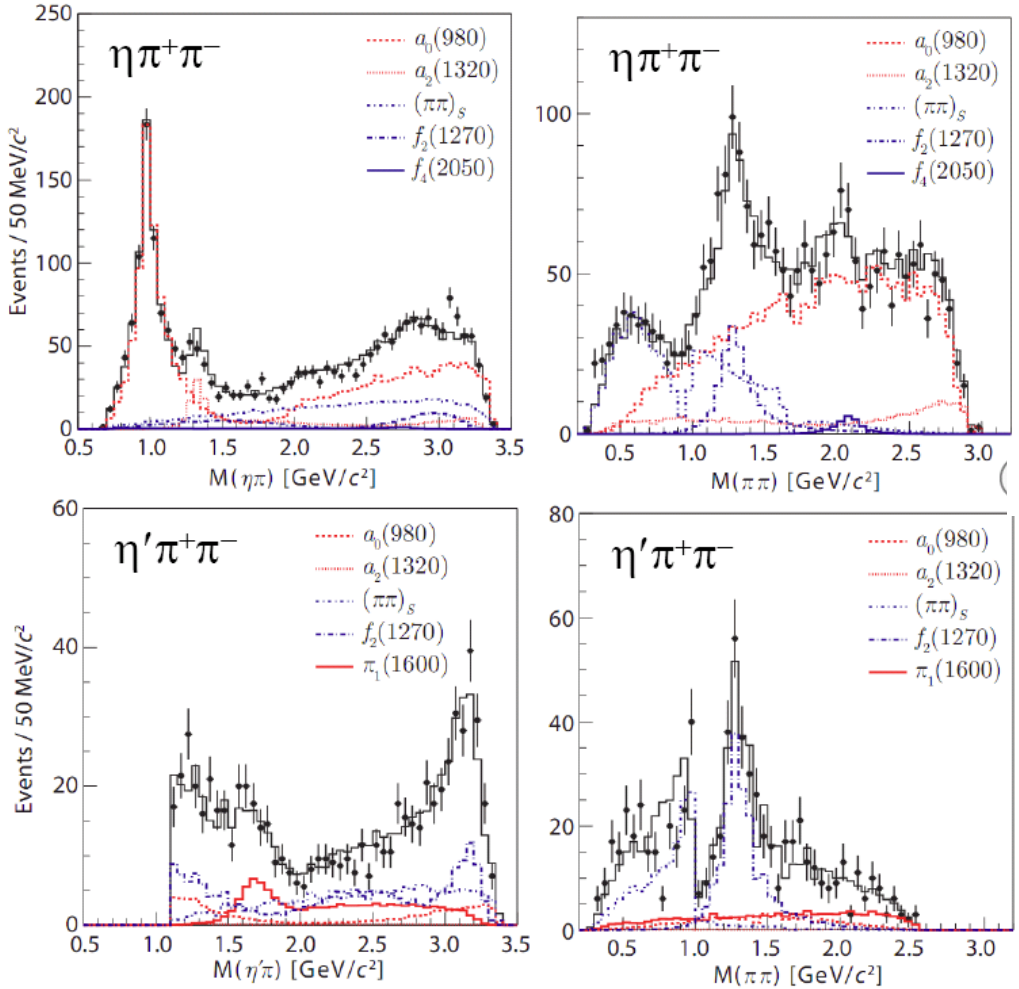
$\pi\pi$ S wave : KK, $\pi\pi$ scattering



M. Kornicer
PANIC11

CLEO-c

Results



$A_\alpha(x)$	F [%]
$a_0(980)\pi$	66.2±1.2±1.1
$a_2(1320)\pi$	9.8±0.8±1.0
$(\pi\pi)_S\eta$	22.5±1.3±2.4
$f_2(1270)\eta$	7.4±0.8±0.7
$f_4(2050)\eta$	1.0±0.3±0.3

CLEO-c: arXiv:1109.5843

$A_\alpha(x)$	F [%]
$a_0(980)\pi$	11.0±2.3±1.8
$a_2(1320)\pi$	0.4±0.5±0.6
$(\pi\pi)_S\eta'$	21.6±2.7±1.4
$f_2(1270)\eta'$	27.0±2.9±1.8
$\pi_1(1600)\pi$	15.1±2.7±3.2

Assuming BW shape for 1^{-+} :
M=1670±30±20 MeV/c²
Γ =240 ±50 ±60 MeV
Significance: 4.4 σ

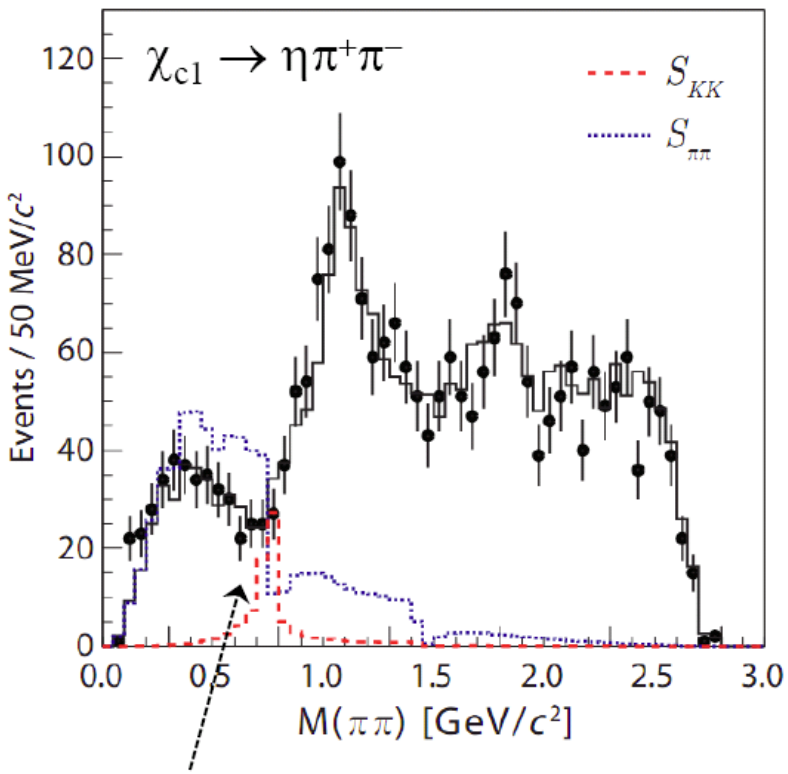
First evidence for $a_0 \to \eta'\pi$:

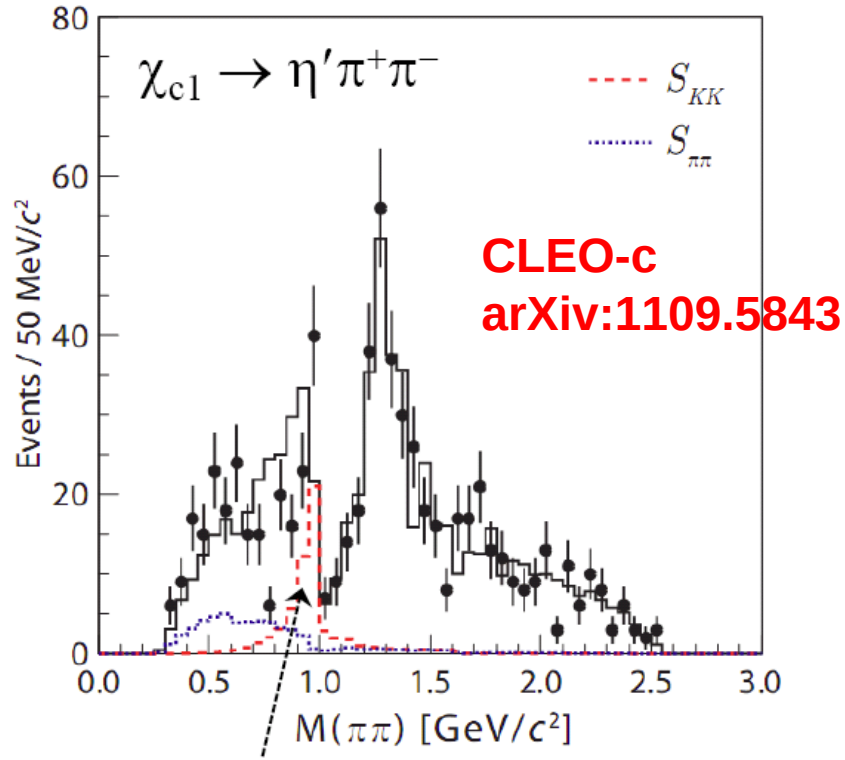
$$\frac{B(a_0(980)\to\eta'\pi)}{B(a_0(980)\to\eta\pi)} = 0.064 \pm 0.013 \pm 0.012$$

First evidence in charmonium decays

M. Kornicer PANIC11

$(\pi\pi)$ S wave in $\chi_{c1}\to\eta^{(\prime)}\pi^+\pi^-$ at CLEO-c

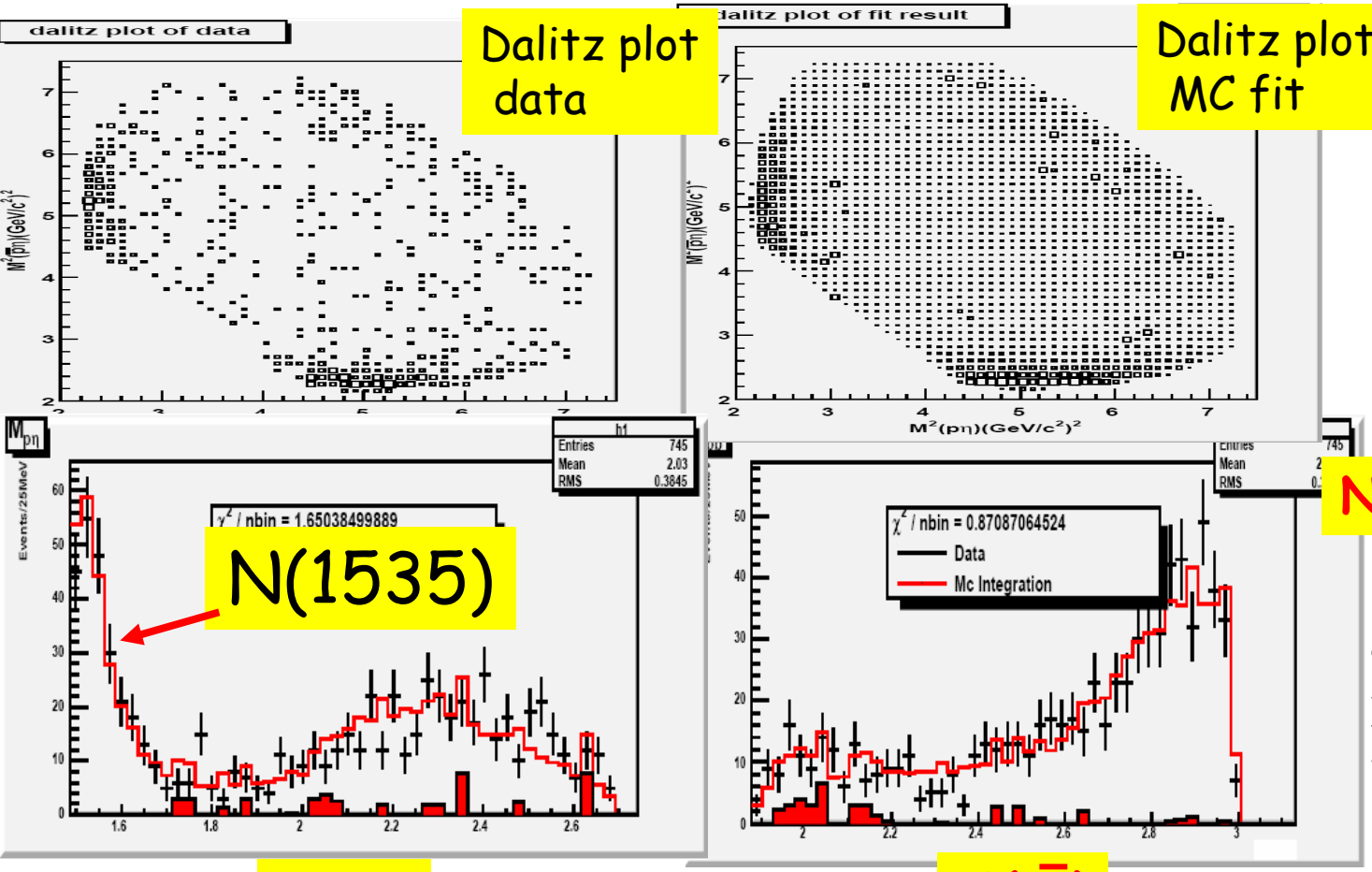




- **dip in $\pi^+\pi^-$ spectra @ 1 GeV**
- **$f_0(980)$-like peak from S-wave $KK\to\pi\pi$ production**

Note: $B(\chi_{c1}\to S_{KK}\eta) \approx B(\chi_{c1}\to S_{KK}\eta')$ while $B(\chi_{c1}\to S_{\pi\pi}\eta')$ is suppressed compared to $B(\chi_{c1}\to S_{\pi\pi}\eta)$

Preliminary results on N* baryon in $\psi' \to \eta p\bar{p}$ decay



A full PWA analysis performed selected in 106 M ψ' events Background clean!

N(1535) is $1/2^-$

Mass:

$1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV/C²

Width:

$0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

$Br(\psi' \to p\bar{p}\eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$

PDG2010: $(6 \pm 1.2) \times 10^{-5}$

$Br(\psi' \to N(1535)\bar{p}) \times Br(N(1535) \to p\eta + c.c.)$

$= 5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

Property of h_c (1p1)

PRL104, 132002 (2010)

Study isospin forbidden transition

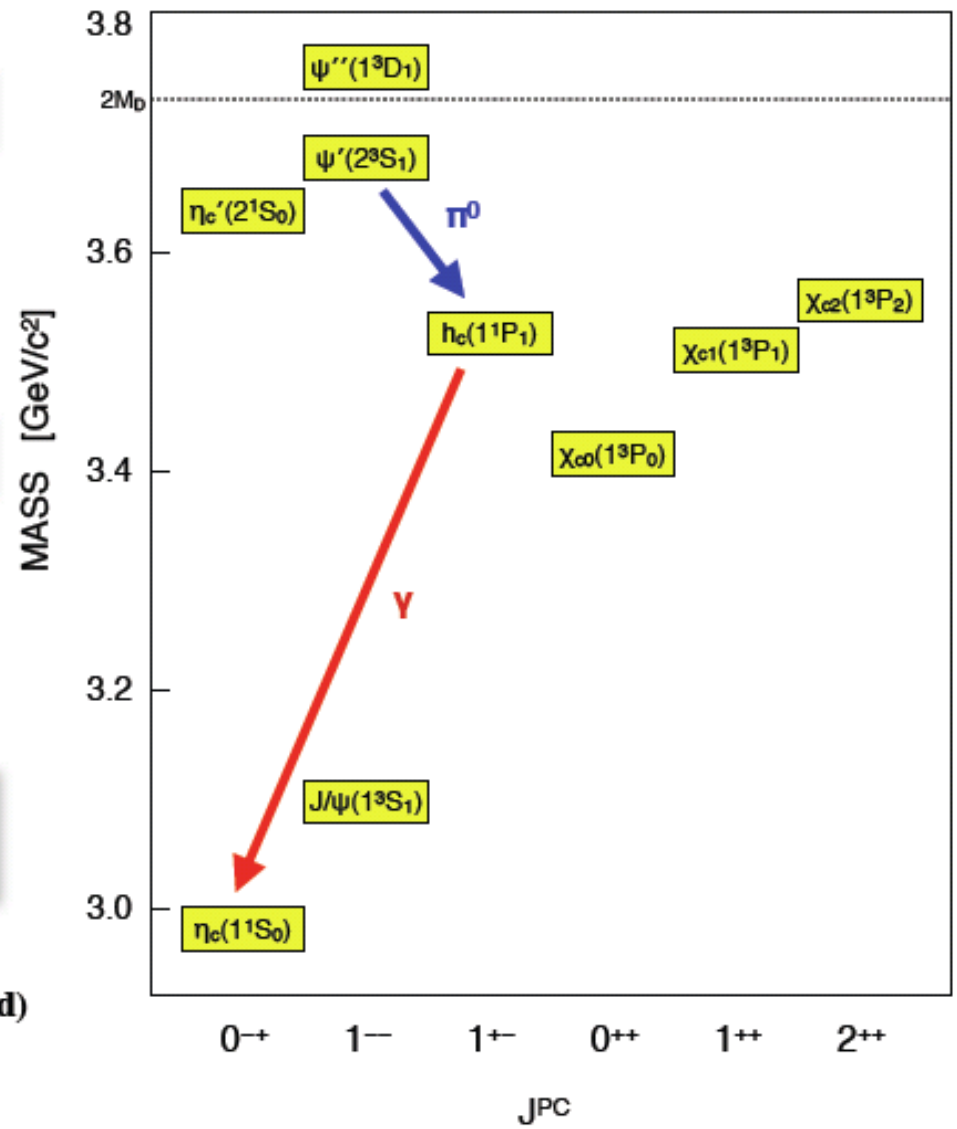
$$B(\Psi' \to \pi^\circ h_c)$$

Measure as well the E1 transition

$$B(h_c \to \gamma \eta_c)$$

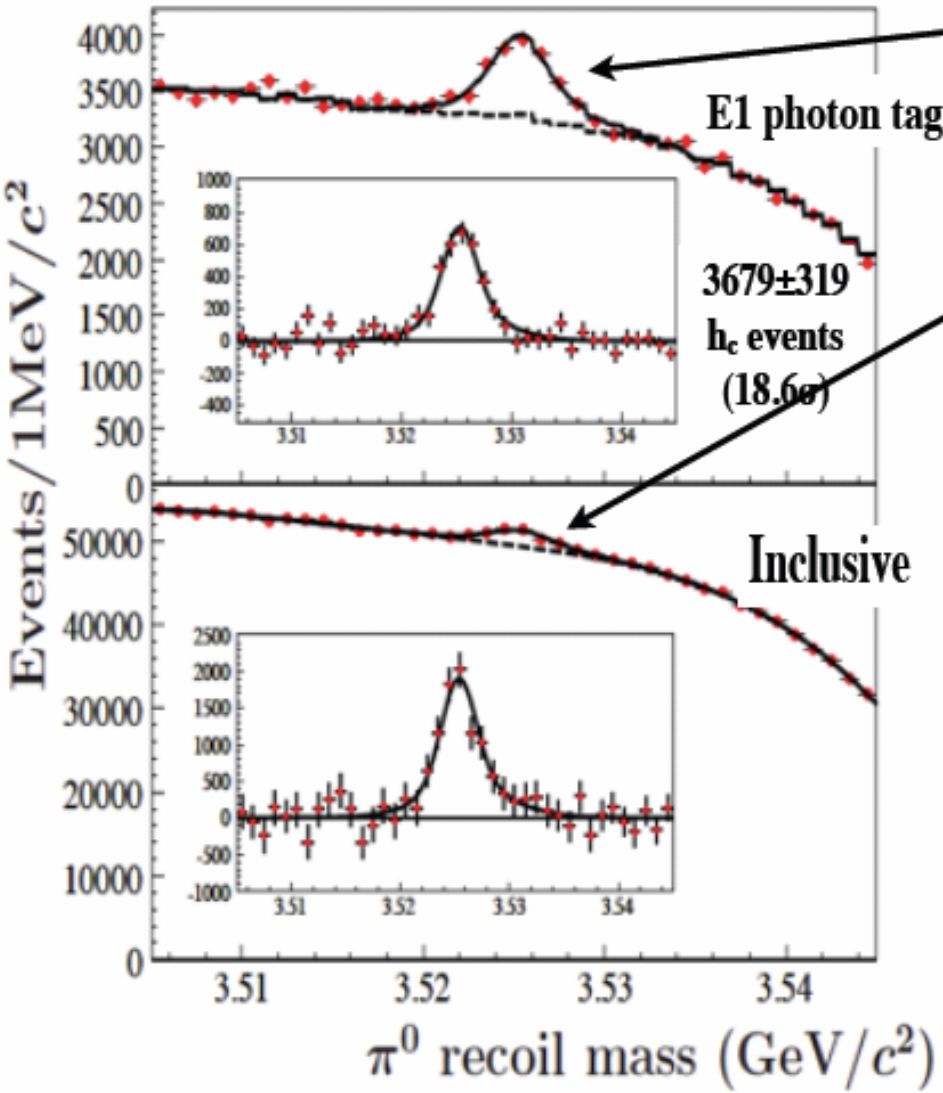
Hyperfine splitting of the 1P states (spin-spin interaction term):

$$M(h_c(1P)) - \langle M(\chi_{cJ}(1P))\rangle_{(\text{spin-weighted})}$$



Observation of h_c in inclusive reaction

PRL104, 132002 (2010)



Tag the E1 photon, yields:

$\psi(2S) \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$
$= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

(consistent with CLEO-c)

Inclusive analysis provides:

$B(\psi(2S) \to \pi^0 h_c)$ (first measurement)
$= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

Combining the two results:

$B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

(first measurement)

Natural width of h_c:

$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28\,\mathrm{MeV}/c^2$

(first measurement)

Hyperfine splitting:

$\Delta M_{hf} = -0.10 \pm 0.13 \pm 0.18\,\mathrm{MeV}/c^2$

(consistent with zero)

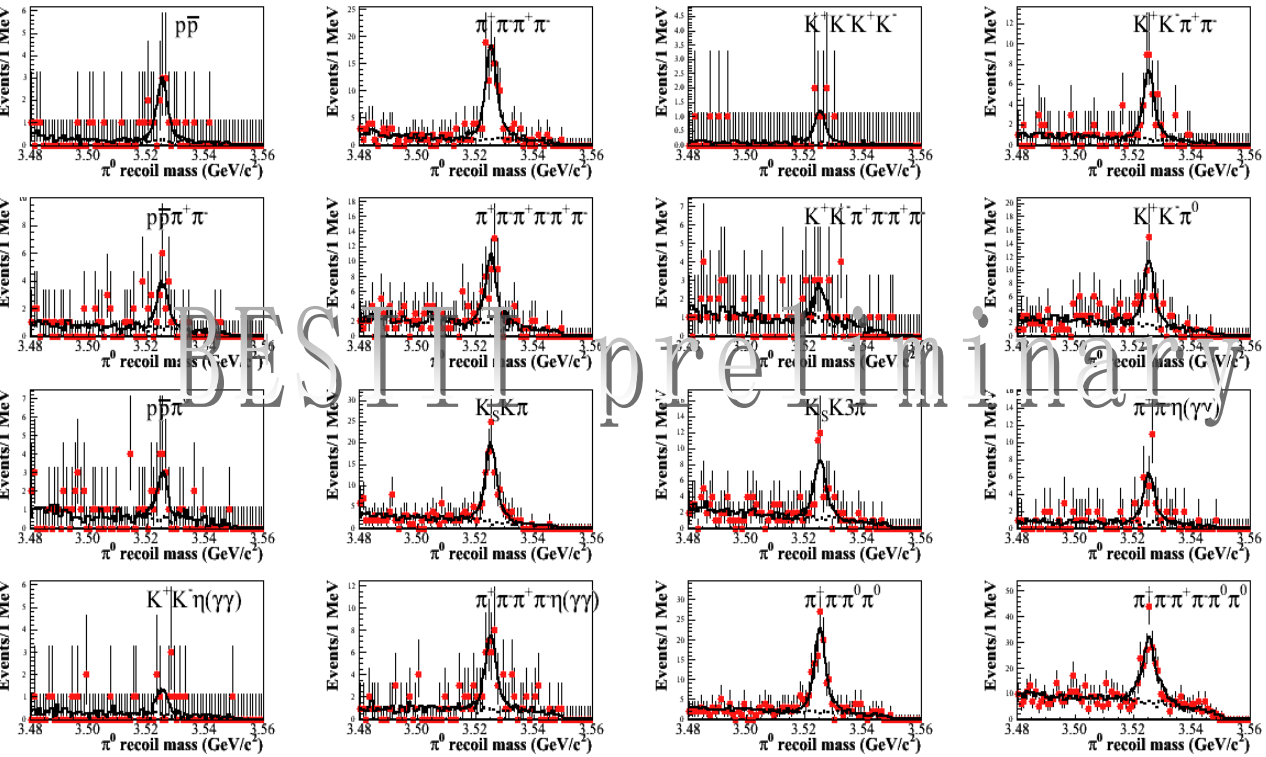
$h_c(1P1)$ in $\psi' \to \pi^0 h_c$, $h_c \to \gamma \eta_c$, $\eta_c \to X_i$ (exclusive)

$\psi' \to \pi^0 h_C$, $h_C \to \gamma \eta_C$, η_C is reconstructed exclusively with 16 decay modes

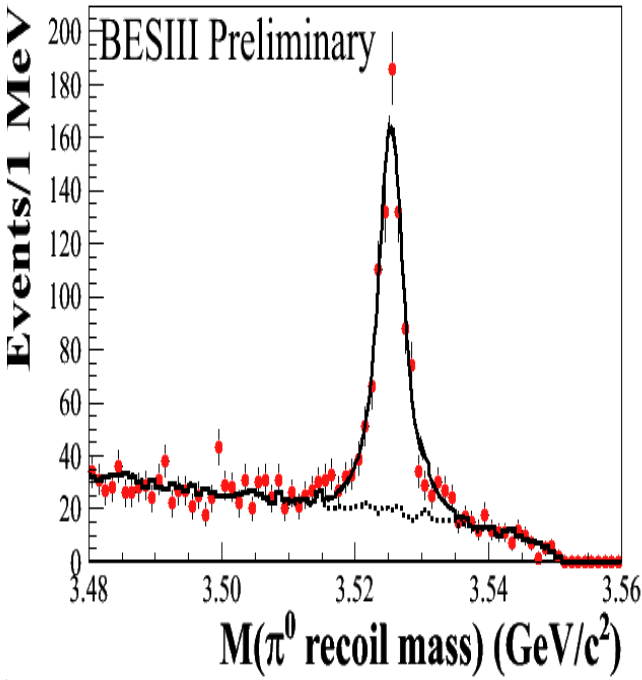
Black from PDG2010,
blue from estimation of $\psi' \to \gamma \eta_c$

16 Decay modes	$BR(\eta_c \to X)$
$\eta_c \to pp^-$	~0.13%
$\eta_c \to \pi^+\pi^- pp^-$	~0.45%
$\eta_c \to 2(\pi^+\pi^-)$	~1.20%
$\eta_c \to 2K^+2K^-$	~0.16%
$\eta_c \to \pi^+\pi^- k^+k^-$	~1.50%
$\eta_c \to 3(\pi^+\pi^-)$	~1.50%
$\eta_c \to K^+K^- 2(\pi^+\pi^-)$	~0.71%
$\eta_c \to k^+k^-\pi^0$	~1.17%
$\eta_c \to pp^{bar}\pi^0$	~0.18%
$\eta_c \to k_s kp;$	~2.33%
$\eta_c \to k_s k3\pi$	~2.40%
$\eta_c \to \pi^+\pi^-\eta;\ \eta \to \gamma\gamma$	~3.27%
$\eta_c \to k^+k^-\eta$	~0.57%
$\eta_c \to 2(\pi^+\pi^-)\eta$	~2.70%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%
$\eta_c \to 2(\pi^+\pi^-)\pi^0\pi^0$	~11.0%

π^0 recoil mass in $h_c \to \gamma\eta_c$, $\eta_c \to X_i$



Sum of π^0 recoil mass



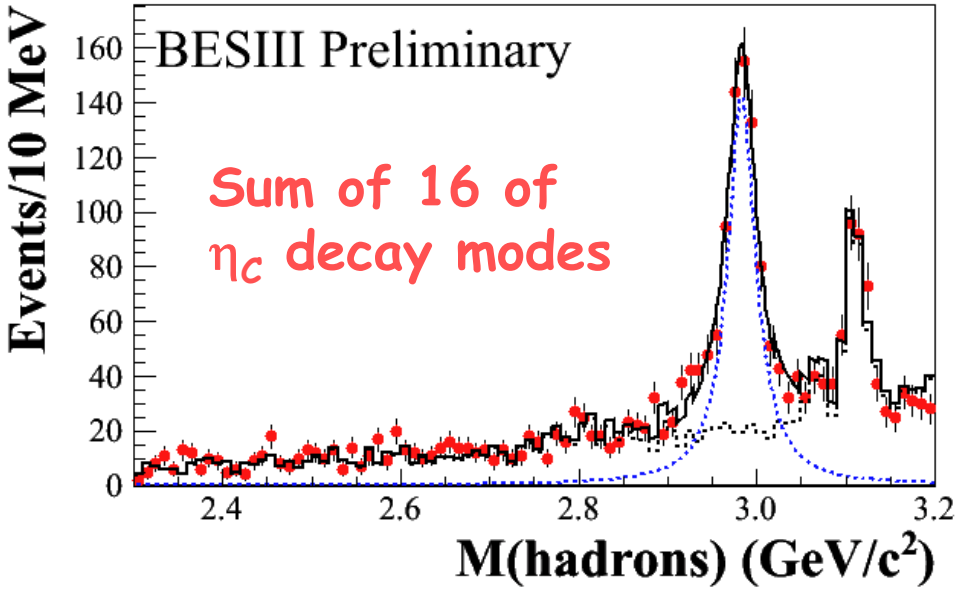
Simultaneous fit to π^0 recoiling mass in 106M ψ' sample (preliminary results):

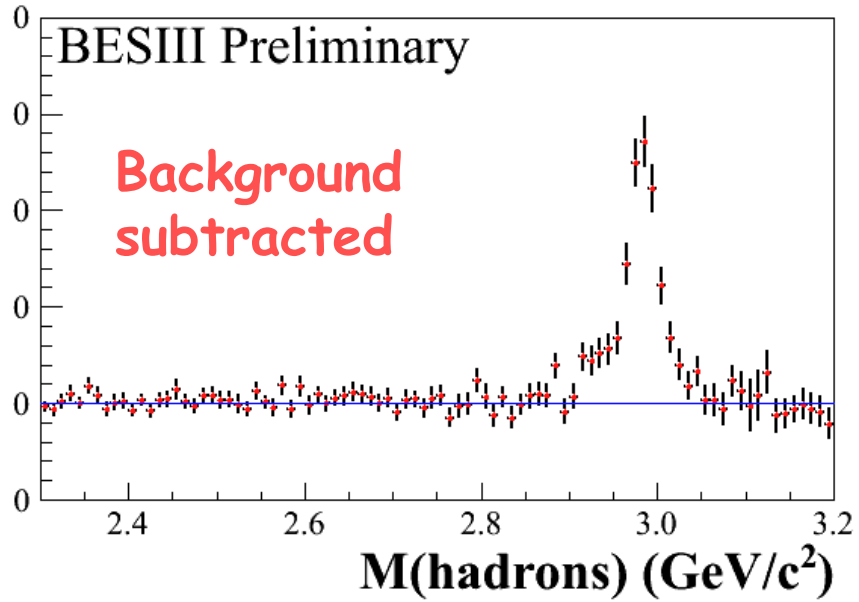
$M(h_c) = 3525.31 \pm 0.11_{(stat)} \pm 0.15_{(sys)}$ MeV/c²
$\Gamma(h_c) = 0.70 \pm 0.28_{(stat)} \pm 0.25_{(sys)}$ MeV

Consistent with BESIII inclusive results PRL104,132002(2010)

CLEOc exlusive results
$M(h_c) = 3525.21 \pm 0.27 \pm 0.14$ MeV/c²
N = 136±14
PRL101, 182003(2008)

η_c lineshape from $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$

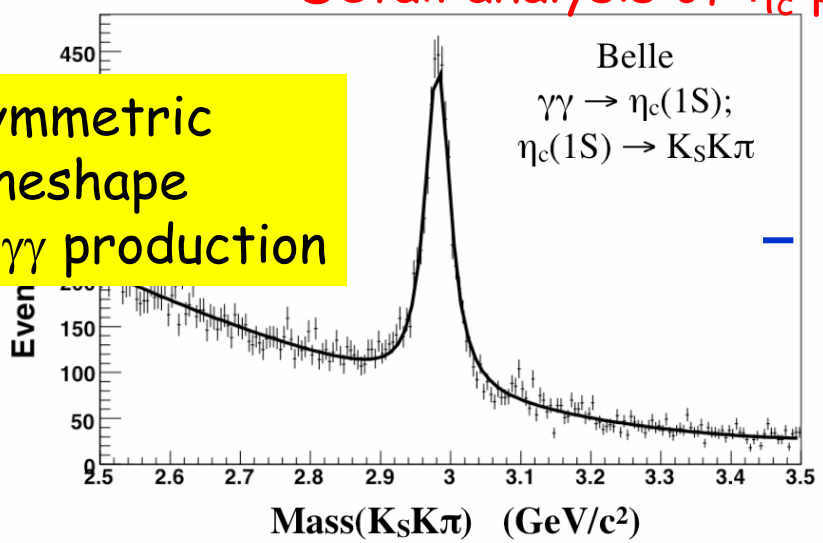


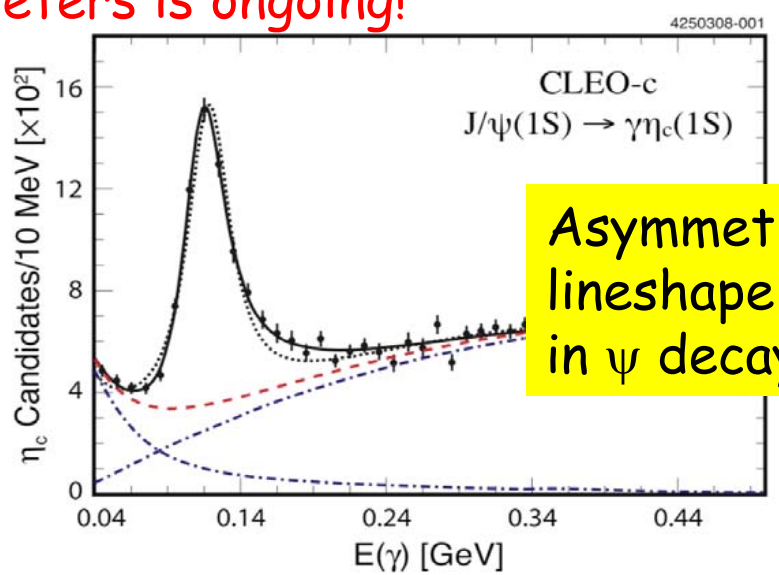


The η_c lineshape is not distorted in the $h_c \to \gamma\eta_c$

Detail analysis of η_c parameters is ongoing!

Symmetric lineshape in $\gamma\gamma$ production

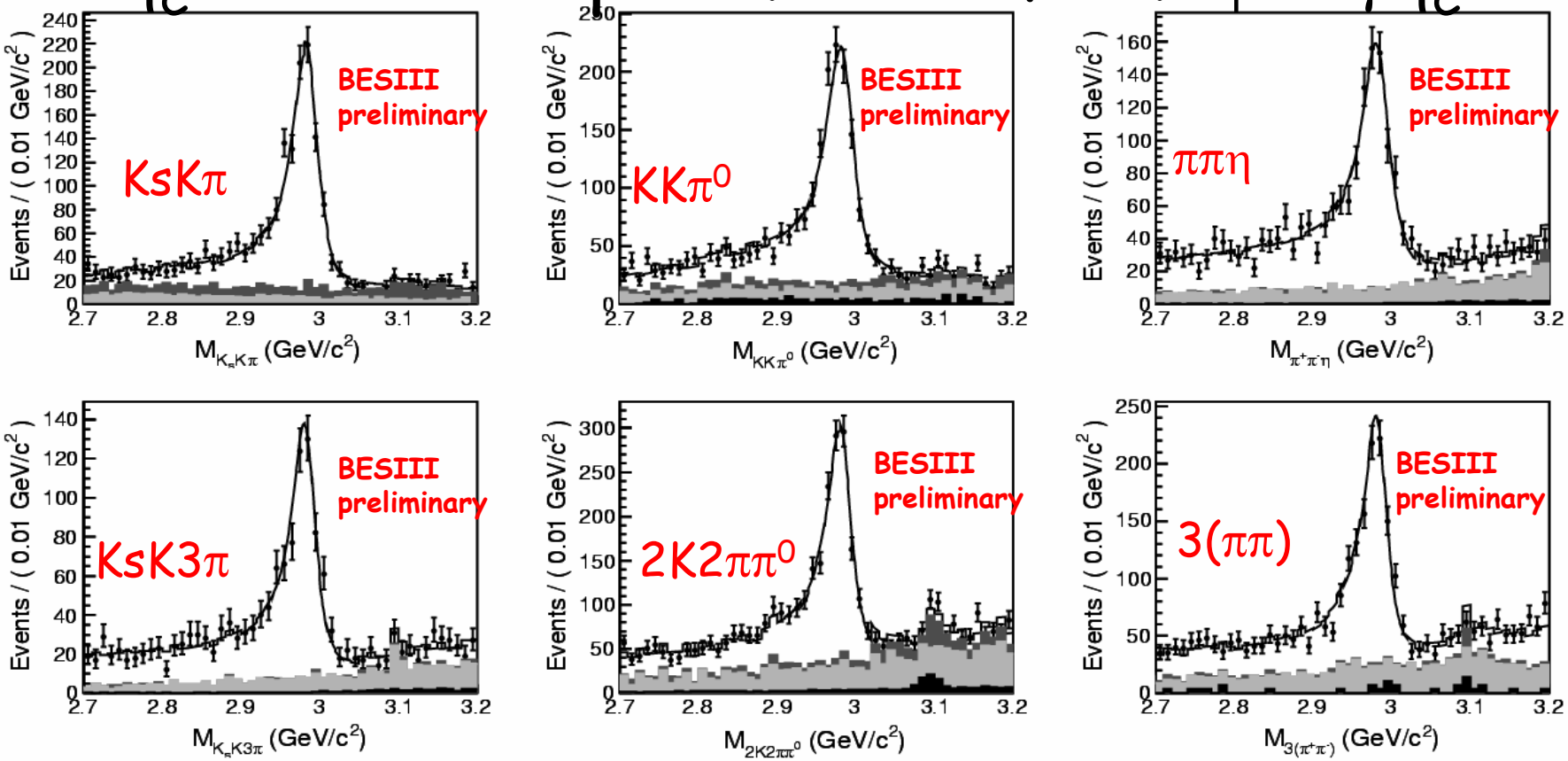




Asymmetric lineshape in ψ decay

Li (IH

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

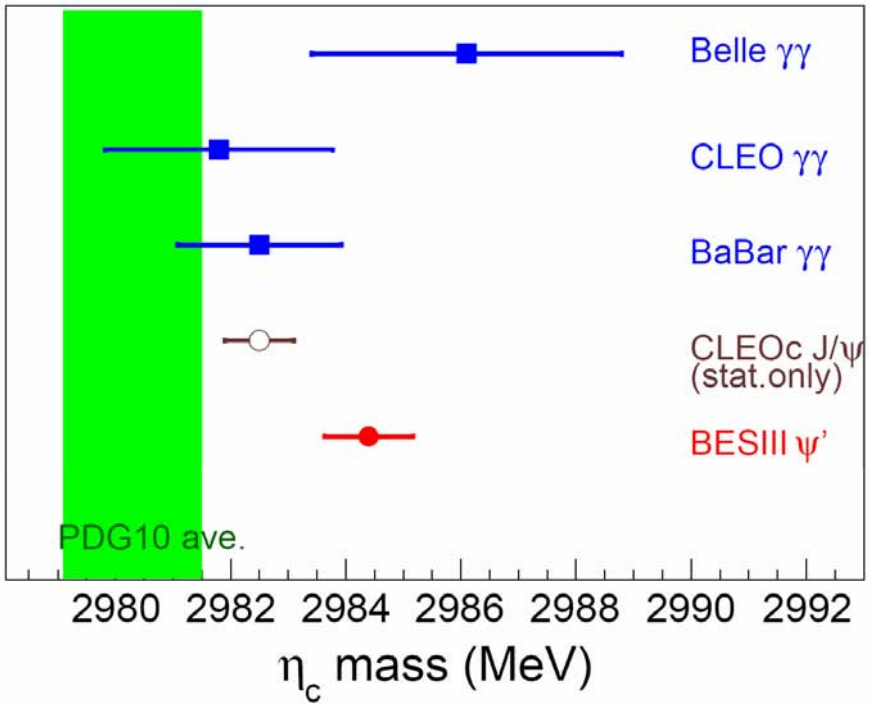


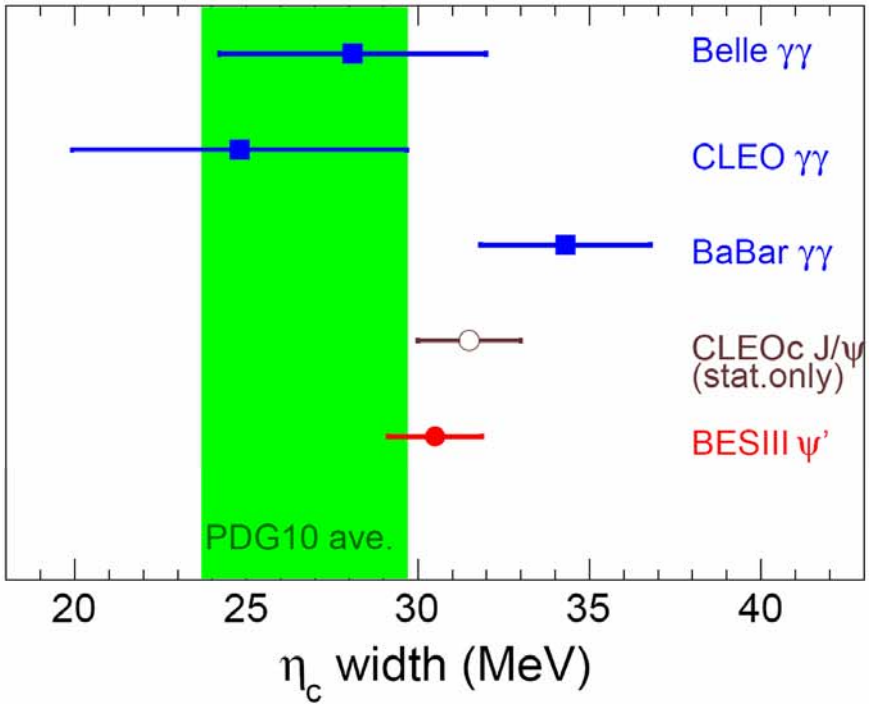
The interference between η_c and non-η_c decays is important

mass: $2984.4 \pm 0.6_{stat} \pm 0.6_{sys}$ MeV/c^2
width: $32.0 \pm 1.2_{stat} \pm 1.0_{sys}$ MeV

BESIII: arXiv:1111.0398

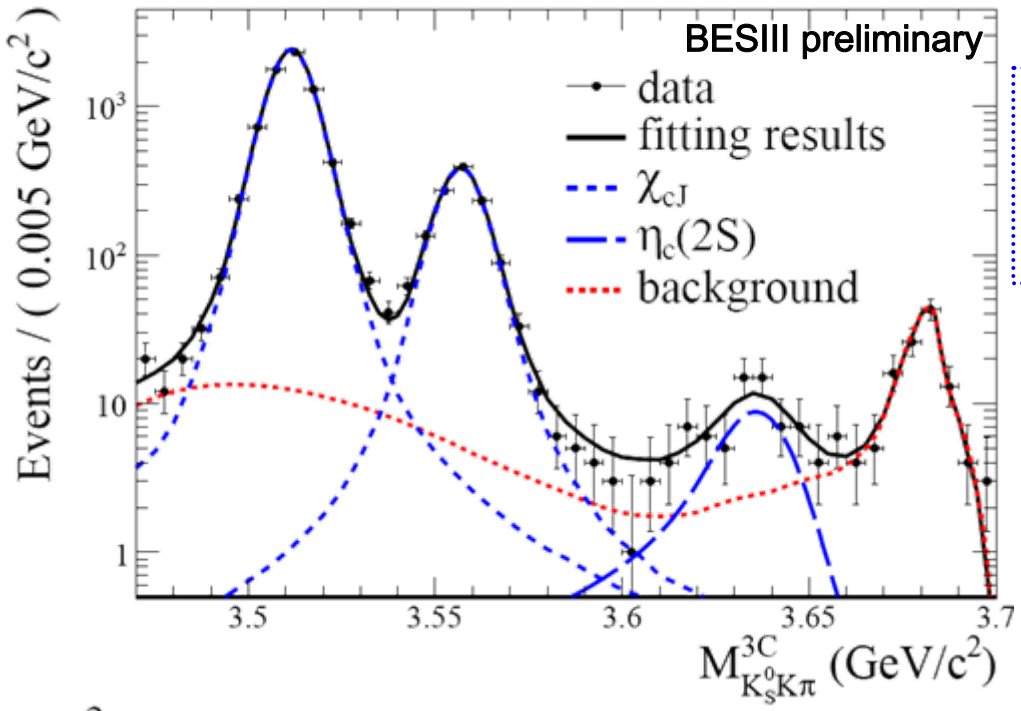
Comparison of the mass and width for η_c





The most precision measurements are from BESIII

Observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to K_s K\pi$



$$(E_\gamma^3 \times BW(m) \times damping(E_\gamma)) \otimes Gauss(0, \sigma)$$

M1 transition

$$\frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$$

$\Gamma(\eta_c(2S))$ fixed to 12MeV (world average)

With 106M ψ' events:

$M(\eta_c(2S)) = (3638.5 \pm 2.3 \pm 1.0)$ MeV/c^2

$N(\eta_c(2S)) = 50.6 \pm 9.7$

Statistical significance larger than 6.0σ!

$Br(\psi' \to \gamma\eta_c(2S) \to \gamma K_s K\pi)$
$= (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$

+

$Br(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$
From BABAR(PRD78,012006)

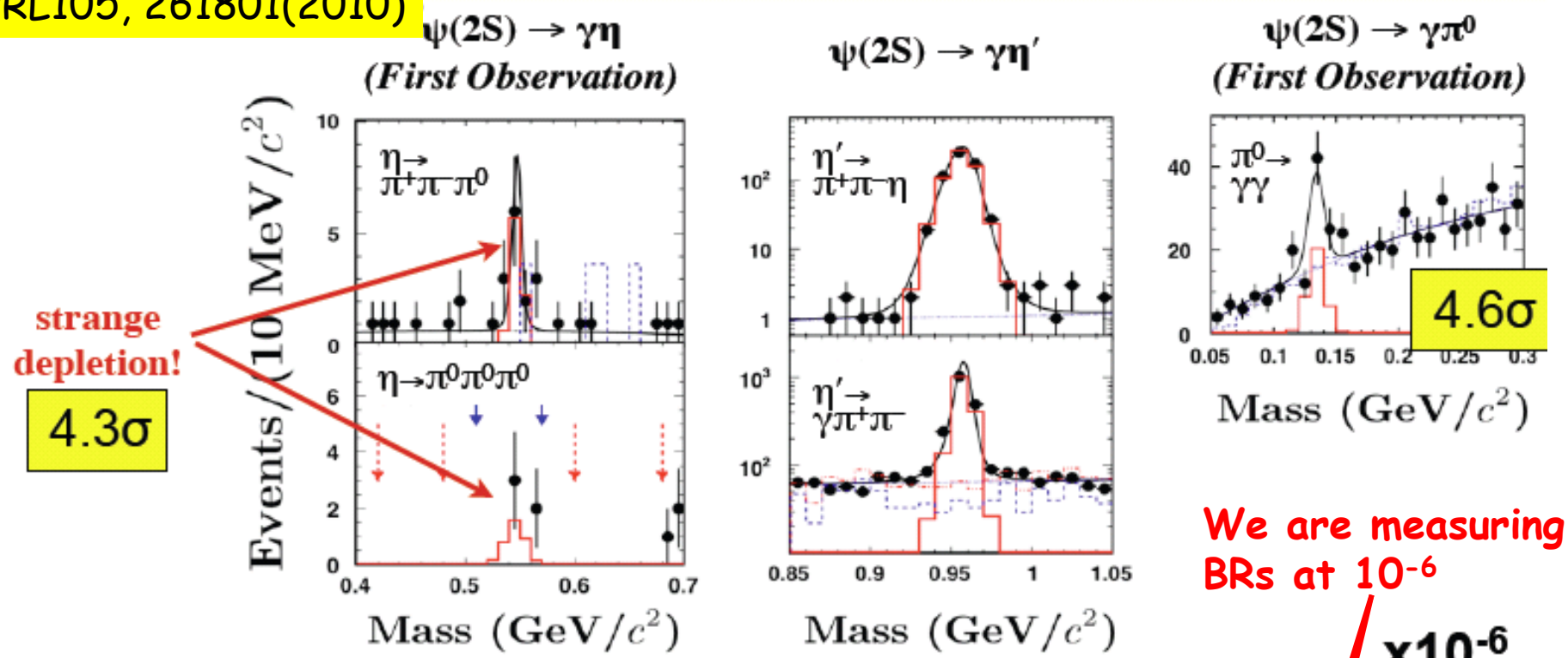
$Br(\psi' \to \gamma\eta_c(2S))$
$= (4.7 \pm 0.9_{stat} \pm 3.0_{sys}) \times 10^{-4}$

CLEO-c: $<7.6\times10^{-4}$ PRD81,052002(2010)

Potential model: $(0.1–6.2)\times10^{-4}$
PRL89,162002(2002)

Evidence for ψ' decays into $\gamma\pi$ and $\gamma\eta$

PRL105, 261801(2010)



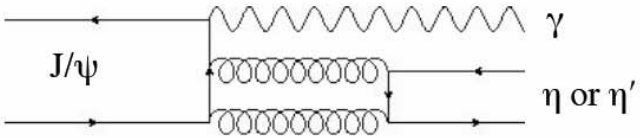
We are measuring BRs at 10^{-6}

x10^{-6}

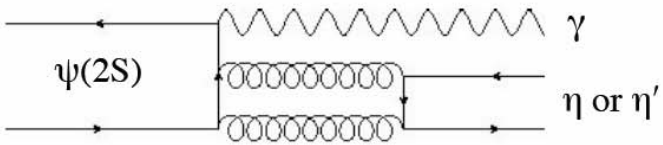
BR $[10^{-6}]$	BESIII	Combined BESIII	PDG10
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^+\pi^0)$	$1.78 \pm 0.72 \pm 0.17$		
$\psi' \to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\eta)$	$120 \pm 5 \pm 8$		
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\gamma)$	$129 \pm 3 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8

Some surprises

PRL105, 261801(2010)



VS



Theory

$$R_{(c\bar{c})} = \frac{Br((c\bar{c})\to\gamma\eta)}{Br((c\bar{c})\to\gamma\eta')}$$

LO-pQCD

$\Downarrow$

$$R_{\psi'} \simeq R_{J/\psi}$$

PRP 112,173 (1984)

Experiment

CLEO-c

PRD79, 111101 (2009)

$$R_{J/\Psi} = \frac{B(J/\psi\to\gamma\eta)}{B(J/\psi\to\gamma\eta')} = (21.1 \pm 0.9)\ \%$$

(consistent with other measurements of η-η′ mixing angle and LO-pQCD)

BESIII

$$R_{\Psi'} = \frac{B(\psi(2S)\to\gamma\eta)}{B(\psi(2S)\to\gamma\eta')} = (1.10 \pm 0.38 \pm 0.07)\ \%$$

(consistent with upper limit from CLEO-c)

$\Rightarrow$ $R_{\psi'} << R_{J/\psi}$

Difference?: Other processes contributing? Related to ρπ puzzle, ... ??

About 480 pb^{-1} @4010 MeV

- Data taking finished June 2011 (one month)
- Study the nature of $\psi(4040)$ [$\rightarrow\pi\pi J/\psi$]
- Understand C=even XYZ:

  Study X(3872) in $\psi(4040) \rightarrow \gamma X(3872)$

  [E_γ=170MeV very narrow peak on the photon spectrum]

  Study XYZ(3940) in $\psi(4040) \rightarrow \gamma XYZ(3940)$

  [E_γ=100-125MeV]
- Ds physics: just above Ds pair threshold

  [0.3 nb DsDs cross section, but CLEAN on the threshold]

Running plan

- **The luminosity of BEPCII is better than expected.**
- **Data taking for open charm:**
  - **$\psi(3770)$: 2.9 fb^{-1} (2010 and 2011)**
  - **4010 MeV : 0.5 fb^{-1} in May 2011 for Ds physics and XYZ**

Year	Running
2012	J/ ψ: 1 billion / $\psi(2S)$: 0.7--1 billion (approved)
2013	4170 MeV: Ds decay + R scan (E > 4 GeV)
2014	$\psi(2S)/\tau$ / R scan (E > 4 GeV)
2015	$\psi(3770)$: 5-10 fb^{-1} (our final goal)

Red: not yet be approved by BESIII Collaboration

Prospects for Charm at BESIII

Look for the size of the statistics/systematic/FSR errors for precision measurements at BESIII after CLEO-c.

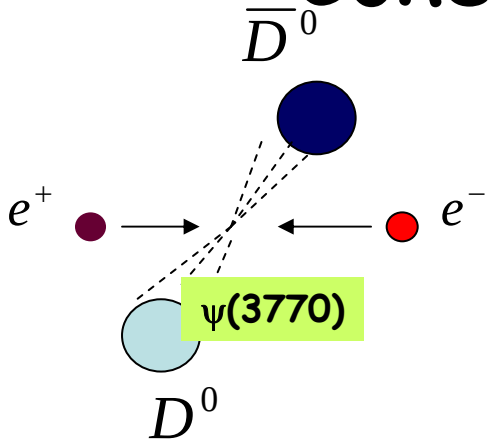
CLEO-c errors for D^0 /D^+ physics with 818 pb^{-1}@3770		BESIII ($5fb^{-1}$)
f_{D+} ($D^+ \to \mu^+ \nu$):	±4.1% (stat.) ± 1.2% (sys.)	±2.0% (stat.)
$f_\pi(0)$ ($D^0 \to \pi l \nu$):	±5.3% (stat.) ± 0.7%(sys.)	±2.3% (stat.)
BR($D^0 \to K \pi$):	±0.9% (stat.) ± 1.8%(sys.)	limited by sys.
BR($D^+ \to K \pi \pi$):	±1.1% (stat.) ± 2.0%(sys.)	limited by sys.

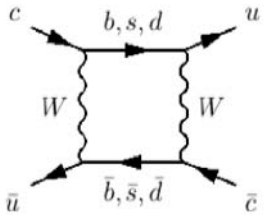
CLEO-c errors for Ds physics with 600pb^{-1}@4170 MeV		
f_{Ds} ($Ds^+ \to \mu^+ \nu, \tau \nu$):	±2.5% (stat.) ± 1.2% (sys.)	±0.8% (stat.)
BR($Ds^+ \to KK \pi$):	±4.2% (stat.) ± 2.9%(sys.)	±2.0% (stat.)

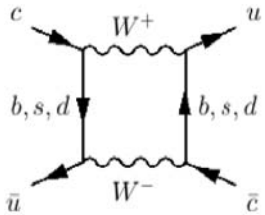
For Ds physics, BESIII is taking data at both 4010 and 4170 MeV:
4010 MeV (clean single tag, lower cross section 0.3 nb) → BESIII 0.5 fb^{-1}
4170MeV (dirty single tag, maximum cross section 0.9 nb) → CLEO-c 0.6 fb^{-1}

Significant gains will be made with increased luminosity at BESIII.

Coherence physics @threshold







$$x \equiv \frac{\Delta m}{\Gamma} = \frac{m_2 - m_1}{\Gamma}$$

$$y \equiv \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

For coherent process:

$$e^+e^- \to \psi'' \to D^0\overline{D}^0$$

The initial state C=-1

$$\psi_- = \frac{1}{\sqrt{2}}\left(\left|D^0\right\rangle\left|\overline{D}^0\right\rangle - \left|\overline{D}^0\right\rangle\left|D^0\right\rangle\right)$$

$$\hat{C}\left|D^0\right\rangle = \left|\overline{D}^0\right\rangle$$
$$\hat{C}\left|\overline{D}^0\right\rangle = \left|D^0\right\rangle$$

The coherent amplitude

$$\Gamma_{ij}^2 = \left|\left\langle i \,|\, D^0\right\rangle\left\langle j \,|\, \overline{D^0}\right\rangle \mp \left\langle j \,|\, D^0\right\rangle\left\langle i \,|\, \overline{D^0}\right\rangle\right|^2$$

$$\frac{\left\langle K^-\pi^+ \middle| \overline{D^0}\right\rangle_{DCS}}{\left\langle K^-\pi^+ \middle| D^0\right\rangle_{CF}} = -\boxed{r_{K\pi}}e^{-i\delta_{K\pi}}$$

~0.06

$\delta_{K\pi}$ connects measurements of y and y'

- ✓ D^0 mixing: $R_M = (x^2+y^2)/2 \sim 10^{-4}$
- ✓ Strong phase can be accessed, will be helpful for mixing measurements at super-B factories:

  Sensitivity on x will be improved by a factor of 3

  Uncertainty of γ due to unknown relative phase on Dalitz decays $D^0 \to K_S h^+h^-$ will be reduced to less than 1^0.
- ✓ CP violation in D sector : 10^{-3}

Sensitivity of rare D decays at BESIII

- Flavor Changing Neutral Current ($c \to u\, l^+ l^-$)
  - $D^0 \to \gamma\gamma$ SM < 3.5×10^{-8}, NP ~ 10^{-6}
    - BABAR: BR < 2.2×10^{-6} (90% CL)
  - $D^0 \to \mu^+\mu^-$ SM <10^{-12} NP ~ 10^{-6}
    - CDF BR< 4.3×10^{-7} (90% CL)
  - $D \to X_u l^+ l^-$ SM <10^{-8} NP ~ 10^{-6}
    - D0 BR($D^+ \to \pi^+\mu^+\mu^-$)< 3.9×10^{-6} (90% CL)
    - CLEO-c BR($D^+ \to \pi^+ e^+ e^-$)< 7.4×10^{-6} (90% CL)
- Lepton Flavor Violation NP ~ 10^{-6}
    - BABAR BR($D^0 \to \mu^+ e^-$) <0.81×10^{-6}
    - BABAR BR($D^+ \to \pi^+ e^+ \mu^-$) <1.1×10^{-5}

With 5-10fb^{-1} @ψ(3770)
BESIII will provide 10^{-6} -10^{-7} sensitivity.

Conclusion

- Huge data samples collected for Charmonium decays at BESIII
- Confirmation of X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$,
- Observation of two new structures X(2120) and X(2370) in $J/\psi \to \gamma\pi\pi\eta'$ decays
- Observation of new structure X(1870) in $J/\psi \to \omega\pi\pi\eta$
- The first observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$ decay
- Precision measurements of $\eta_c(1S)$ parameters in $\psi' \to \gamma\eta_c(1S)$
- η/η' light meson rare decays can also be probed at BESIII
- Charm near threshold undertake complementary studies of D mixing and CPV, and unique test of QCD techniques

Thanks!