

Recent Results on Charmonium Transitions Studied with BESIII

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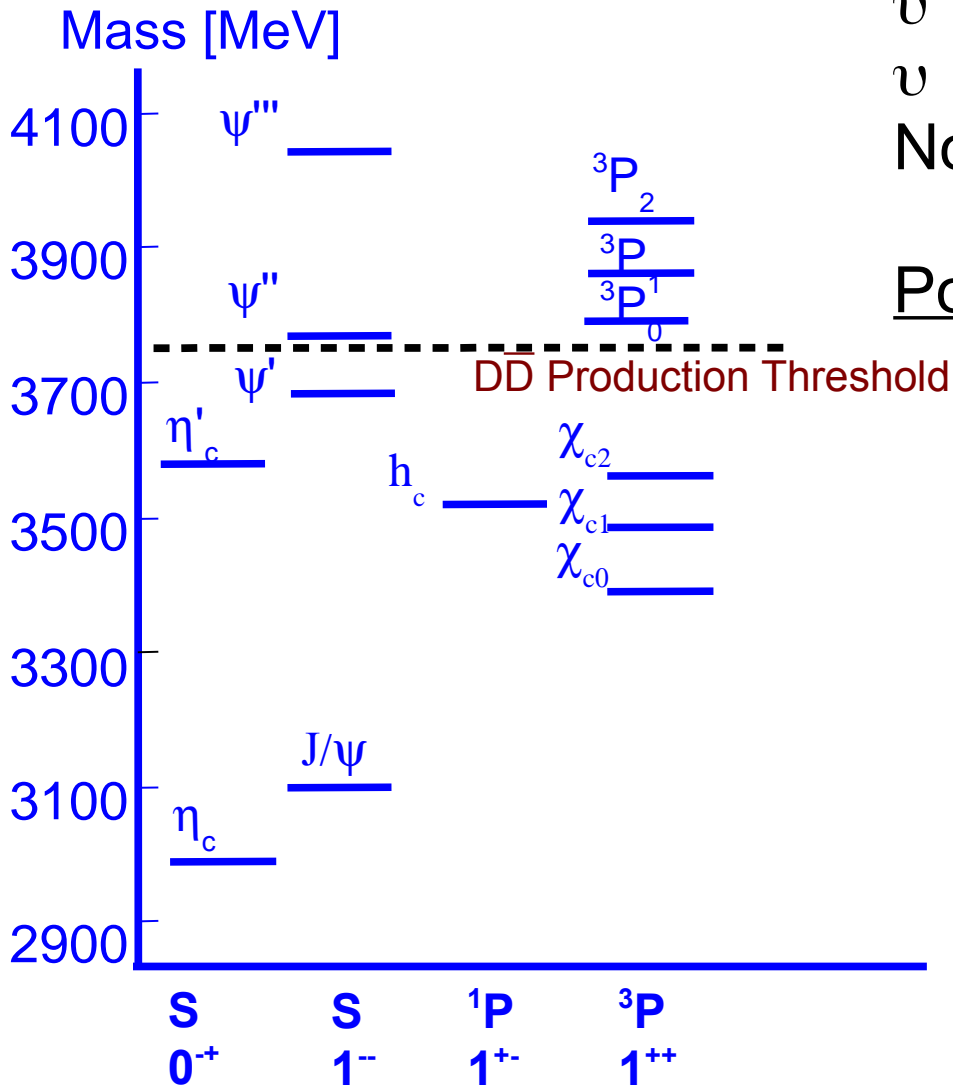
For the BESIII collaboration

18 Sept 2012

EuNPC, Bucharest

Charmonium – positronium of QCD

Charmonium is a bound state of $c\bar{c}$ quarks.



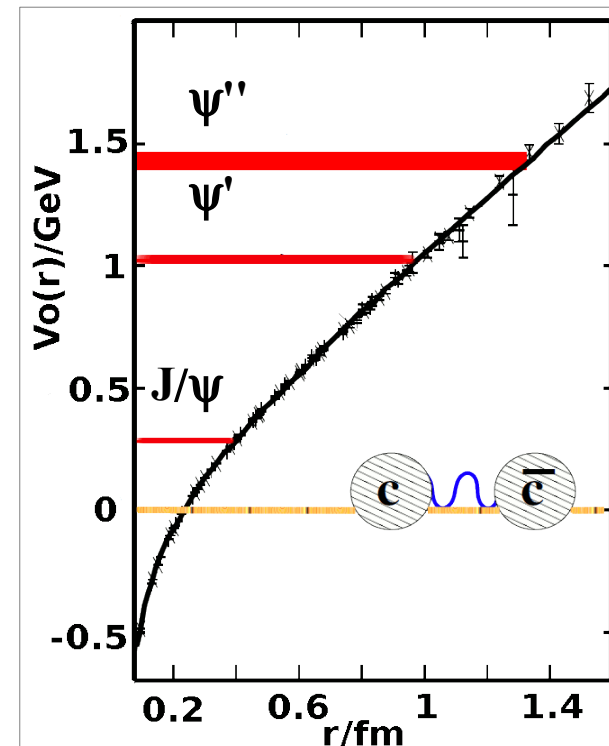
$$v^2 \sim 0.3,$$

v – relative velocity between quarks.

Non-relativistic limit: $v^2 \ll 1$

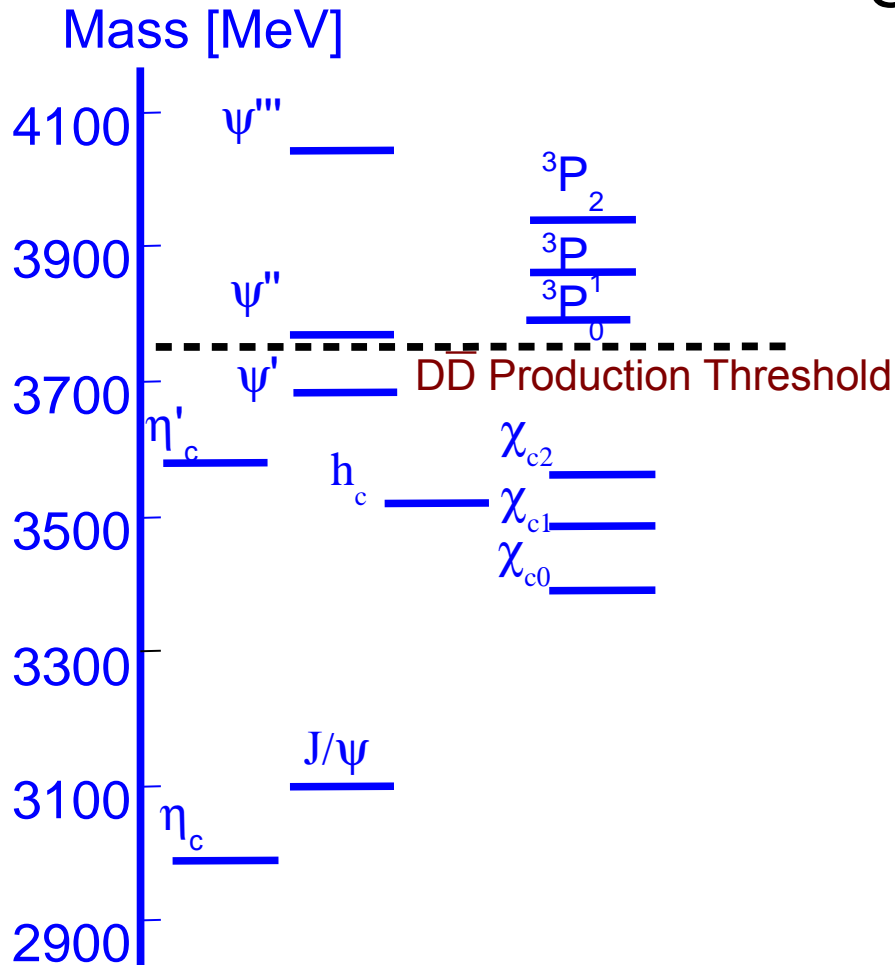
is not unreasonable.

Potential model calculations!



Charmonium – positronium of QCD

States below the $D\bar{D}$ threshold are narrow!
 $D = c\bar{d}, c\bar{u}$

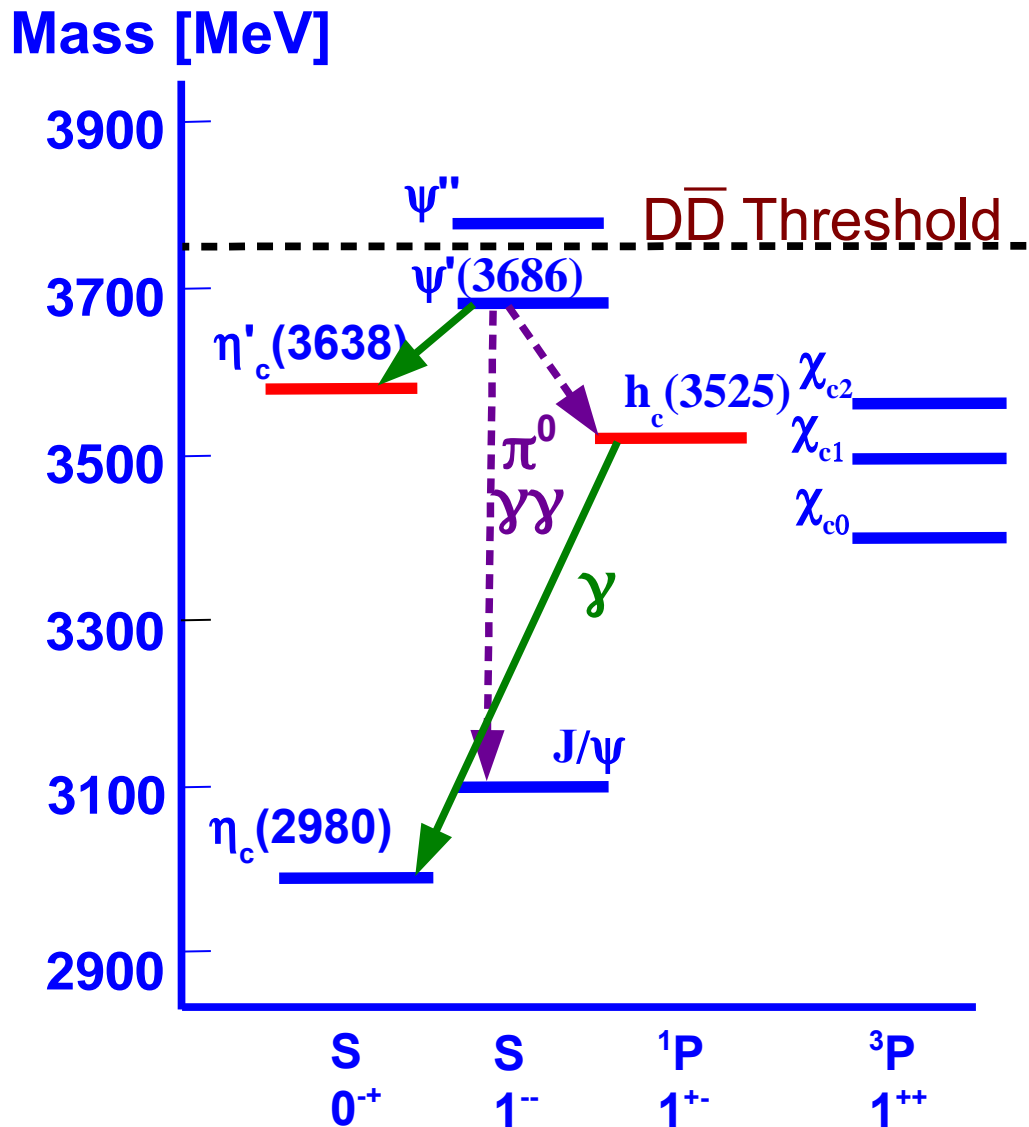


Spectroscopy:

- Ideal tool to study QCD from short to long distance scales;
- Detailed analysis of confinement potential;
- Search for exotic hadronic matter: glueballs, hybrids, tetraquarks, molecules;
- SM and beyond by quark mixing matrix.

Charmonium Transitions @ BESIII

Populating 1^- states directly



Spin singlets η'_c , h_c

Poorly studied due to small branching fractions, difficult to observe!

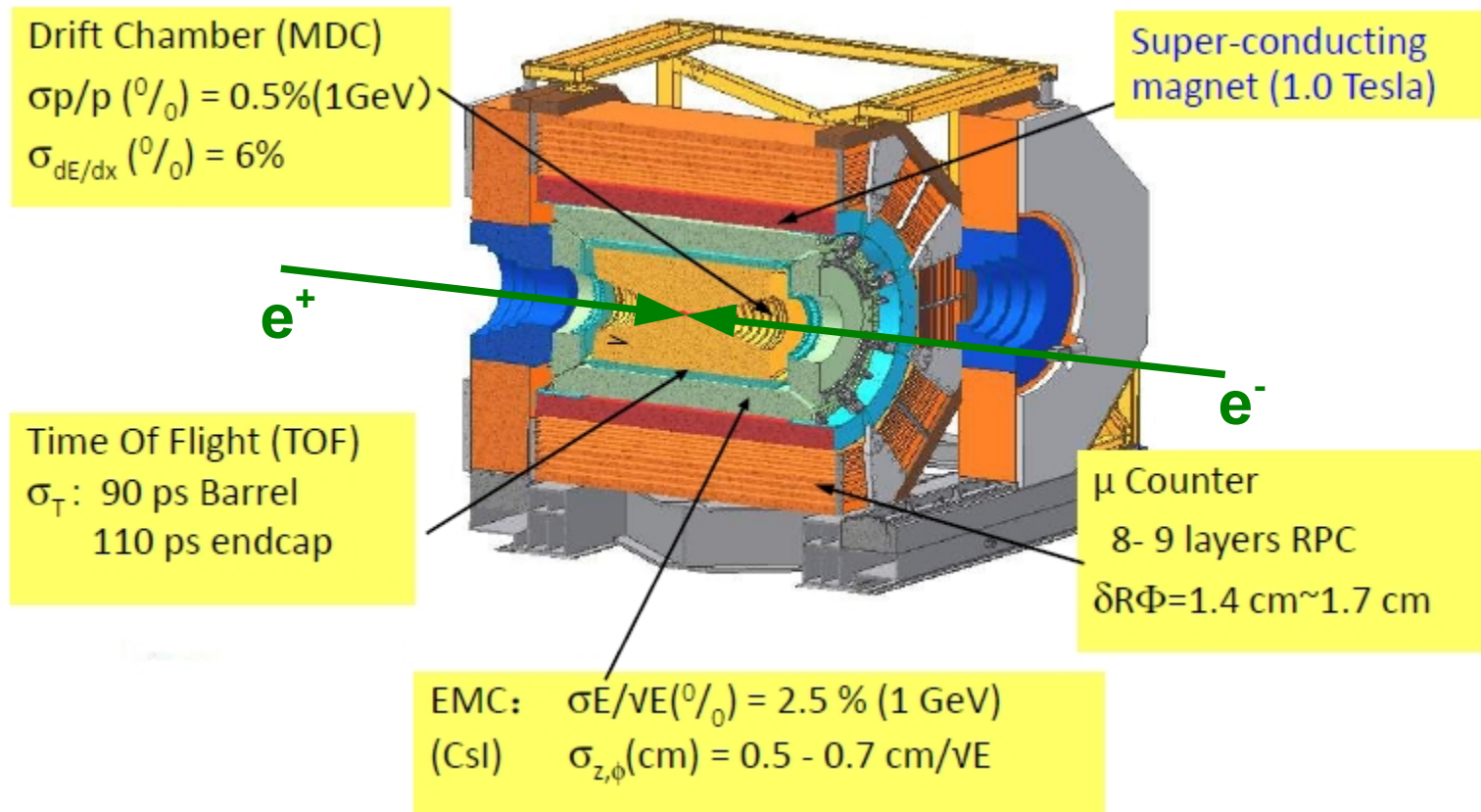
Meson-loop ($D\bar{D}$) studies: require high precision measurements!

A good detector is required!

BESIII is an ideal tool:

- clean environment
- + good performance
- + high statistics
- = better precision!

The BESIII Detector



BESIII Collected by the end of 2011:

J/ψ :	225M	RECORD!
ψ' :	106M	
ψ'' :	2.9 fb^{-1}	(3.5xCLEO-c)
$\psi(4010)$:	0.5 fb^{-1}	

More J/ψ and ψ' data were collected during 2012, not presented in the results yet. 5

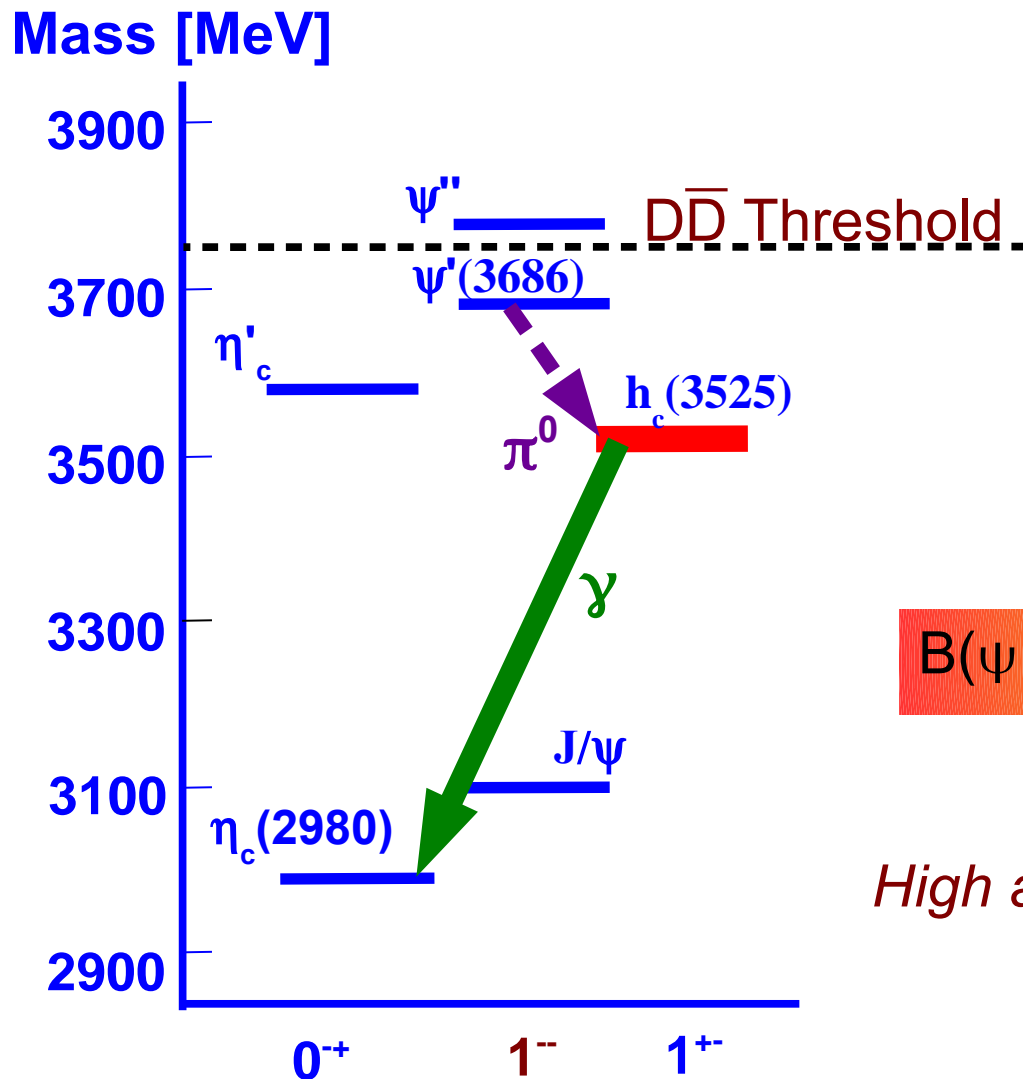
The BESIII Physics Program



- B** (looks like DD for D or charm physics)
- E** (looks like cc for charmonium physics)
- S** (for light hadron Spectroscopy [+exotics])
- T** (for tau physics, looks like a Roman number “III”)

h_c Parameters in $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$

h_c is challenging: small feeding branching fraction



Dominant decay modes!

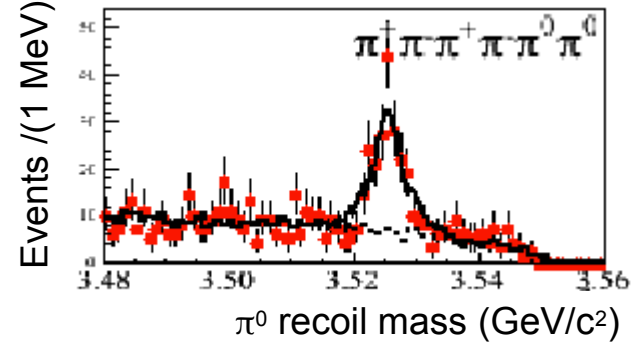
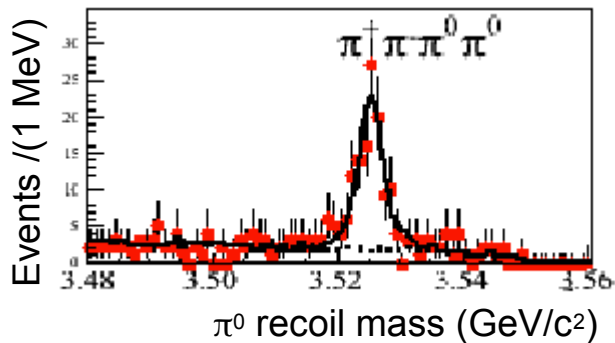
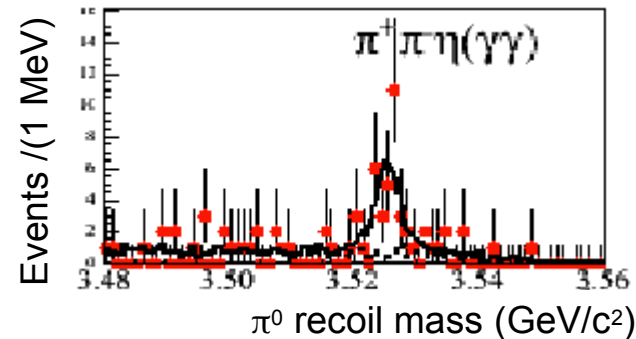
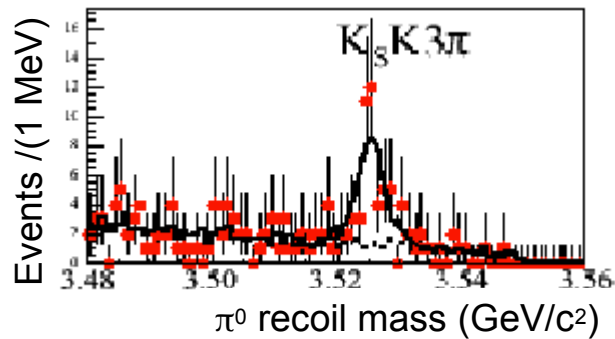
$$B(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \cdot 10^{-4}$$

PRL 104, 132002 (2010)

High accuracy: an excellent detector!

h_c Parameters in $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$

Analyzed 16 decay modes of η_c , some examples:



Simultaneous fit to π^0 recoiling mass

$$M(h_c) = 3525.31 \pm 0.11 \pm 0.15 \text{ MeV}/c^2$$

$$\Gamma(h_c) = 0.70 \pm 0.29 \pm 0.21 \text{ MeV}$$

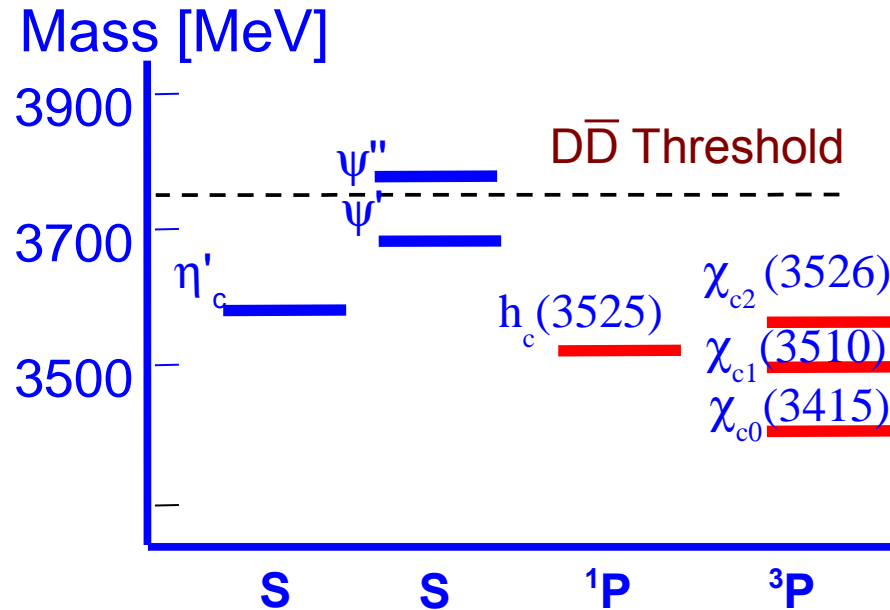
First measurement!

Consistent with previous $E1$ -tagged measurement: **PRL 104, 132002 (2010).**

Consistent with potential model predictions: $M \approx 3526 \text{ MeV}/c^2$, $\Gamma(h_c) = 0.51 \text{ MeV}$

D. Ebert: PRD 67 (2003) 014027, Kuang: PRD 65 (2002) 094024.

h_c Parameters in $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$



Potential model: if P-wave spin-spin interaction is non-zero:

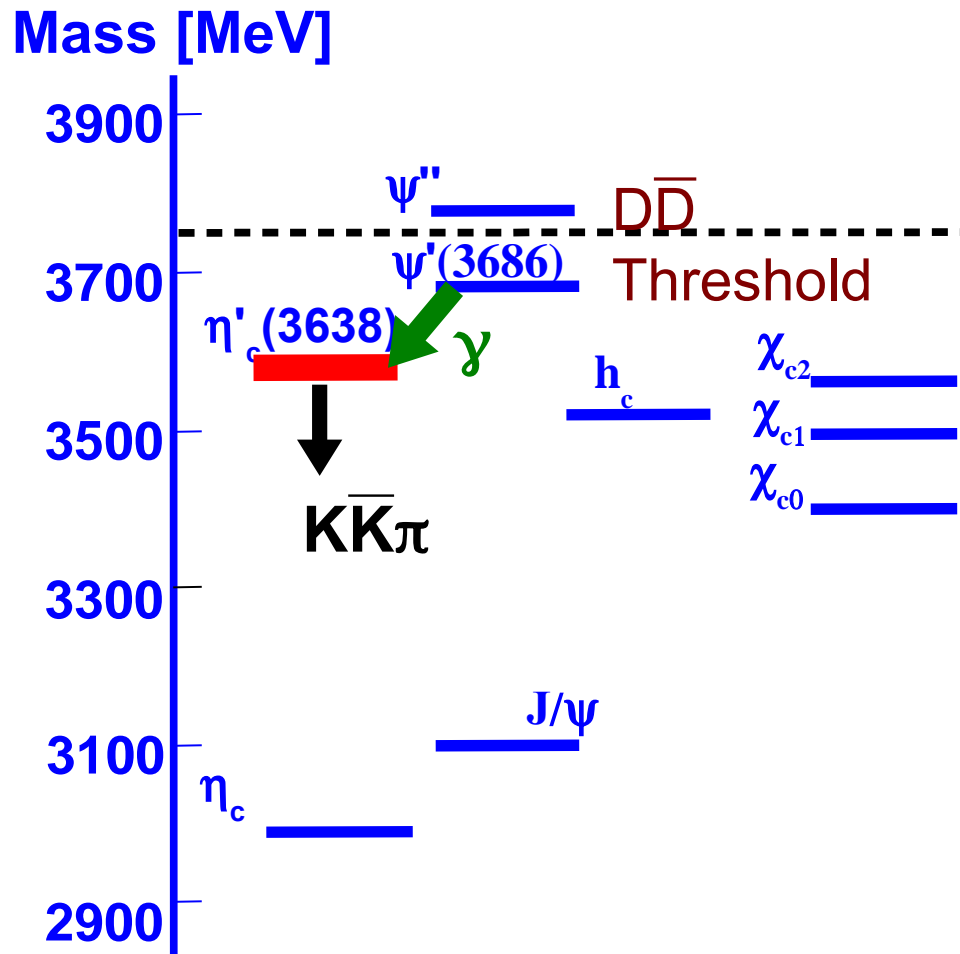
$$\Delta M_{hf}(1P) = M(h_c) - \langle m(1^3P_J) \rangle \neq 0$$

$$\langle m(1^3P_J) \rangle = \sum_{J=0}^2 M_{\chi_{cJ}} (2J+1)/9$$

$$\text{BESIII: } \Delta M_{hf}(1P) = -0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

Consistent with zero

η_c' Parameters



Has not been observed before!

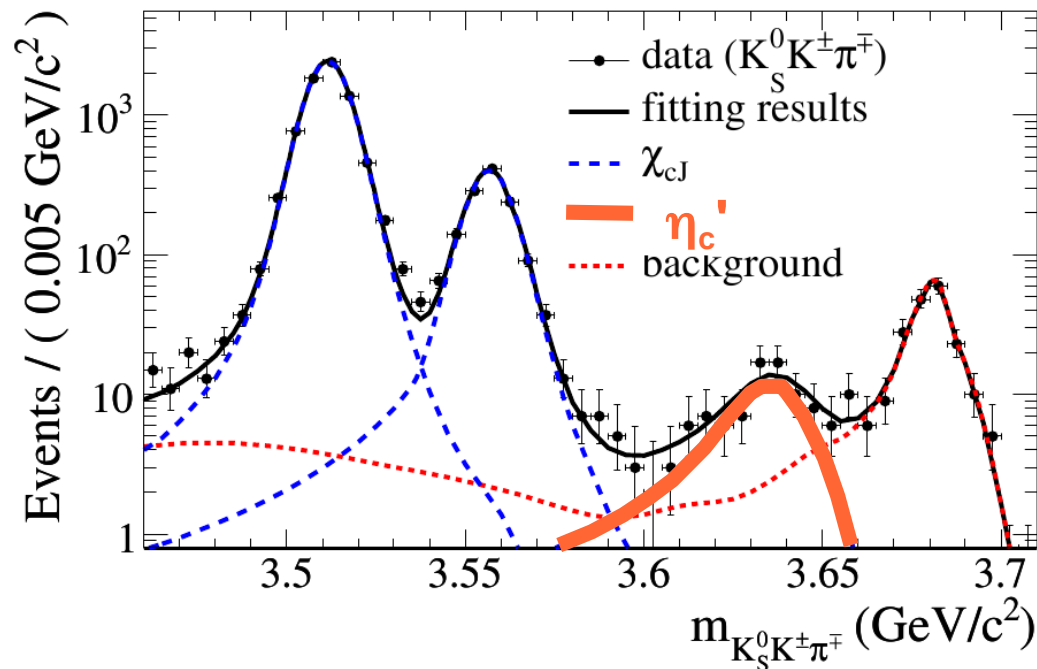
Experimental challenge:

small branching fraction + search for photons with energy ~ 50 MeV

First Observation of $\psi' \rightarrow \gamma \eta_c'$

Phys. Rev. Lett. 109, 042003 (2012)

Decay mode $\eta_c' \rightarrow K\bar{K}\pi$, γ tagging



Mass = $3637.6 \pm 2.9 \pm 1.6$ MeV/c²
Width = $16.9 \pm 6.4 \pm 4.8$ MeV

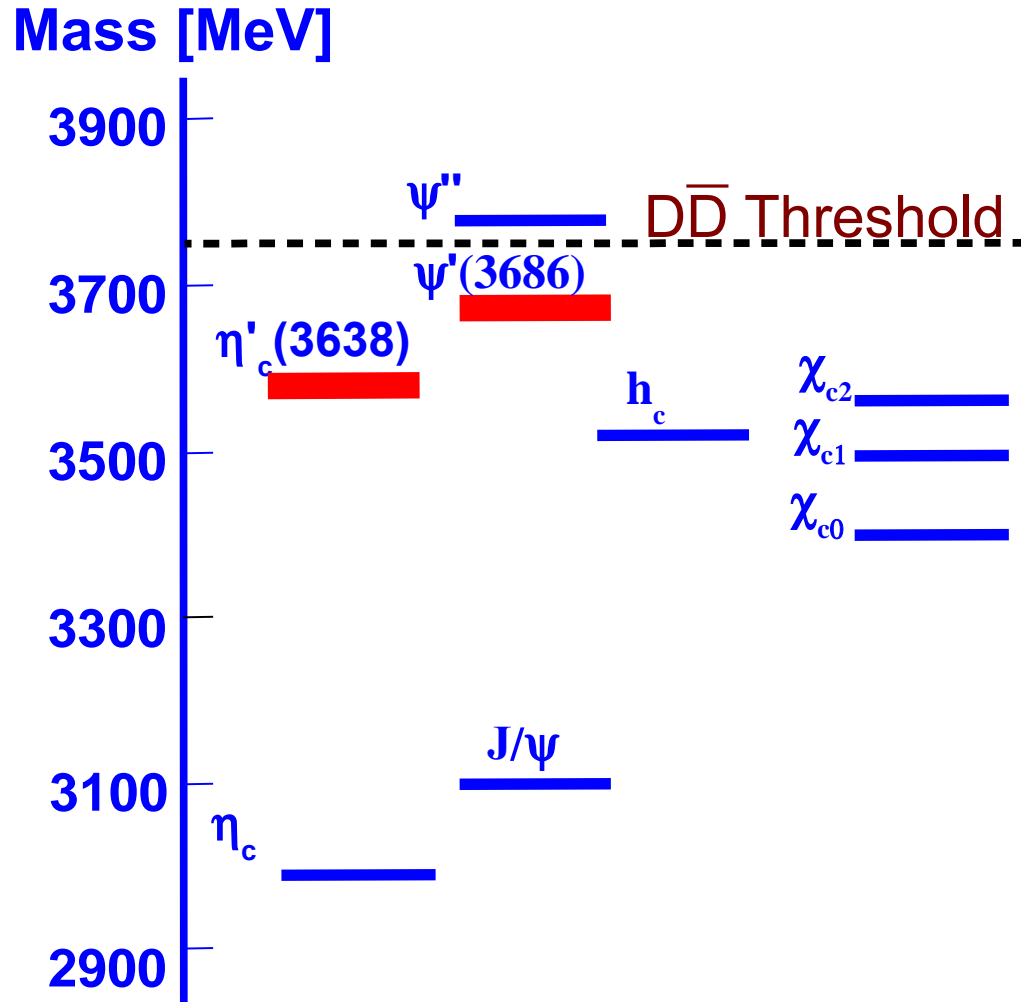
consistent with BaBar results
PRL 92, 142002 (2004).

$$B(\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \cdot 10^{-5}$$

Combined with BaBar measurement of $\eta_c' \rightarrow K\bar{K}\pi$:

$$B(\psi' \rightarrow \gamma \eta_c') = (6.8 \pm 1.1 \pm 4.5) \cdot 10^{-4}$$

Surprises: Meson loops?



η_c' Mass = $3637.6 \pm 2.9 \pm 1.6$ MeV/c²

η_c' Width = $16.9 \pm 6.4 \pm 4.8$ MeV

Potential picture *PRD 69, 094019 (2004)*:

$$M(\psi') - M(\eta_c') = 67 \text{ MeV}$$

Observed:

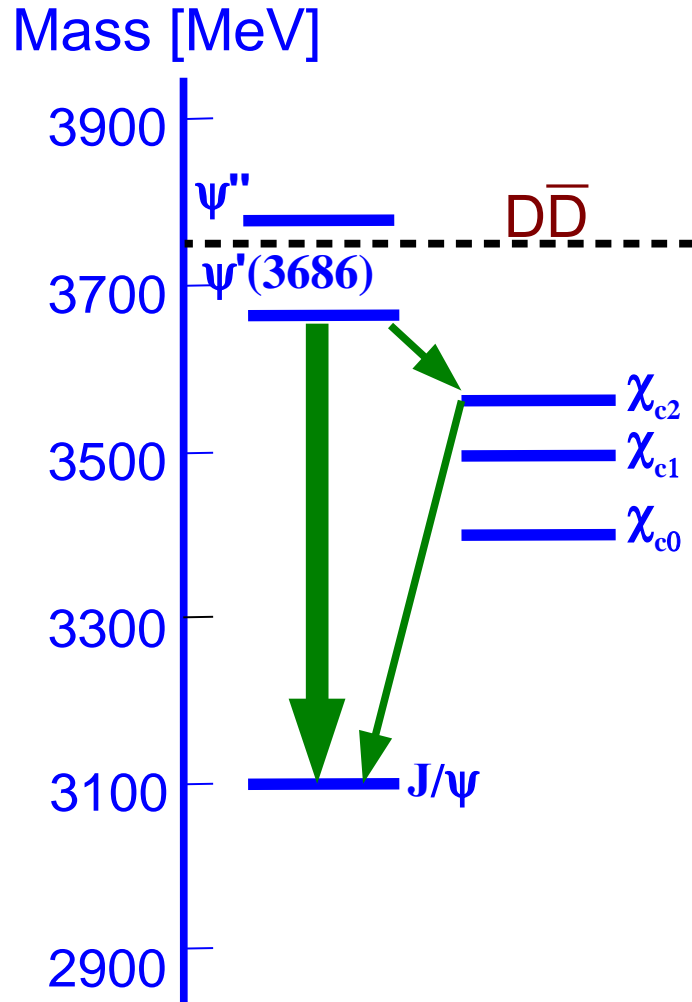
$$M(\psi') - M(\eta_c') = 48.3 \text{ MeV}$$

“Something is rotten in the state of Denmark”?

Influence of virtual decay channels?

cc couples strongly to DD̄!

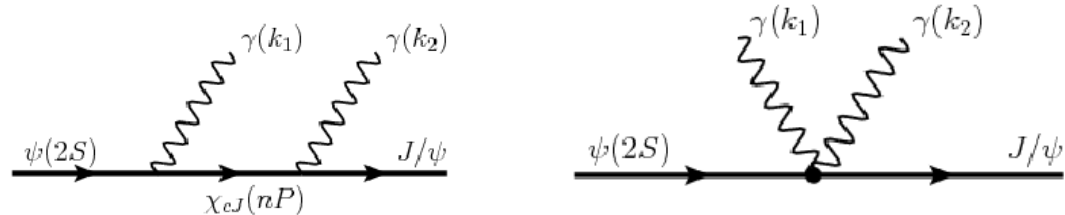
Meson-loop studies in $\psi' \rightarrow \gamma\gamma J/\psi$



Final state $\gamma\gamma J/\psi$ at amplitude level has 2 parts

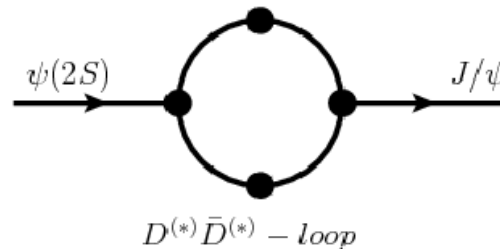
Discrete part: $c\bar{c}$ states only.

On-shell and offshell. $\psi' \rightarrow \gamma\chi_c \rightarrow \gamma\gamma J/\psi$



Continuum part: intermediate off-shell D mesons.

$\psi' \rightarrow \gamma\gamma J/\psi$: **Never observed before!**



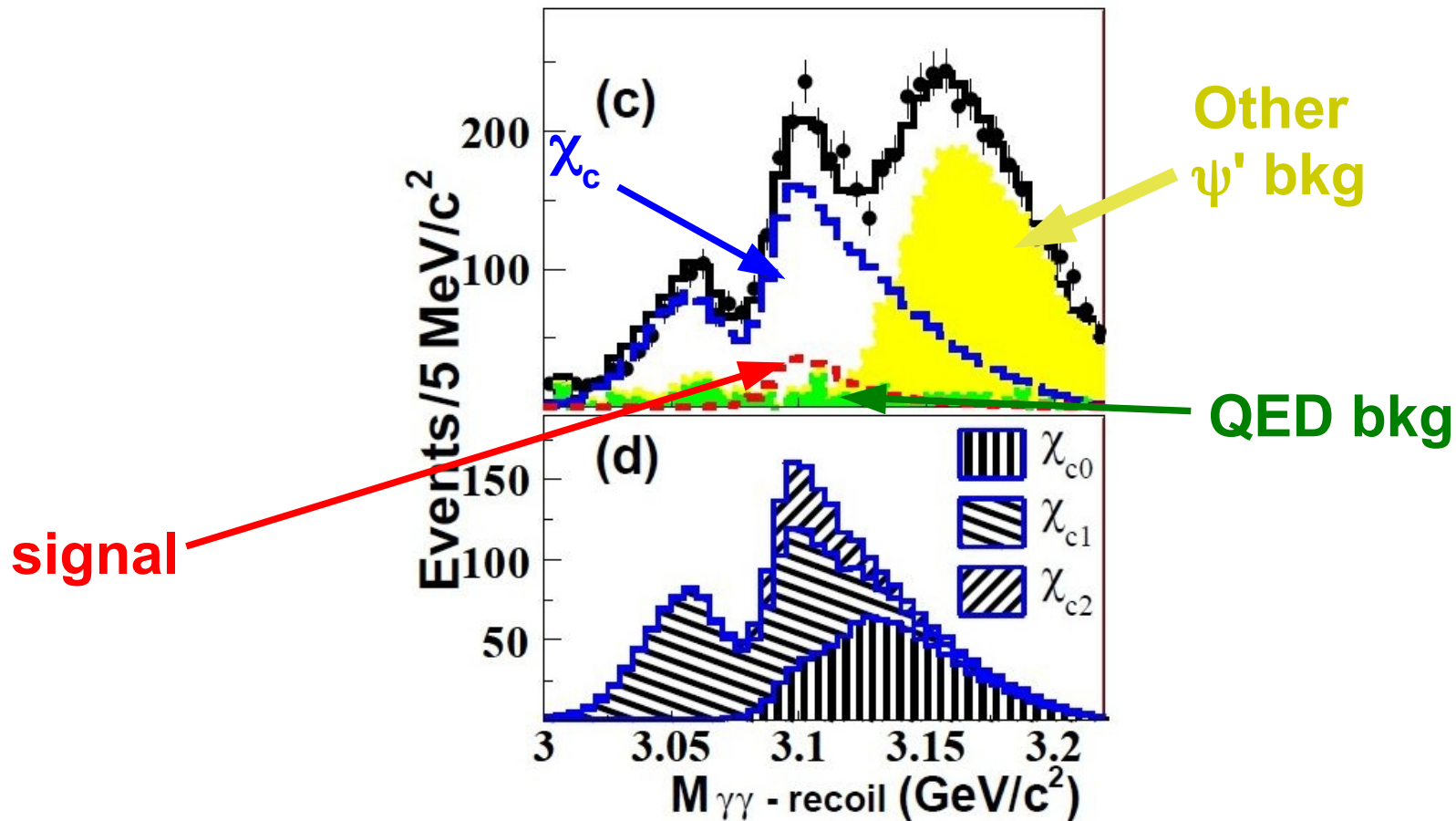
CLEO-c upper limit:

$\text{Br}(\psi' \rightarrow \gamma\gamma J/\psi) < 1 \times 10^{-3}$ **PRD 78,011102(2008)**

Meson-loop studies in $\psi' \rightarrow \gamma\gamma J/\psi$, $J/\psi \rightarrow l+l-$

arXiv: 1204.0246 Accepted by PRL

Background studies are important!



$$B(\psi' \rightarrow \gamma\gamma J/\psi) = (3.1 \pm 0.6 +0.8/-1.0) \cdot 10^{-4}$$

Observed for the first time!

Meson-loop studies: Isospin violating transitions

Sources of symmetry breaking:

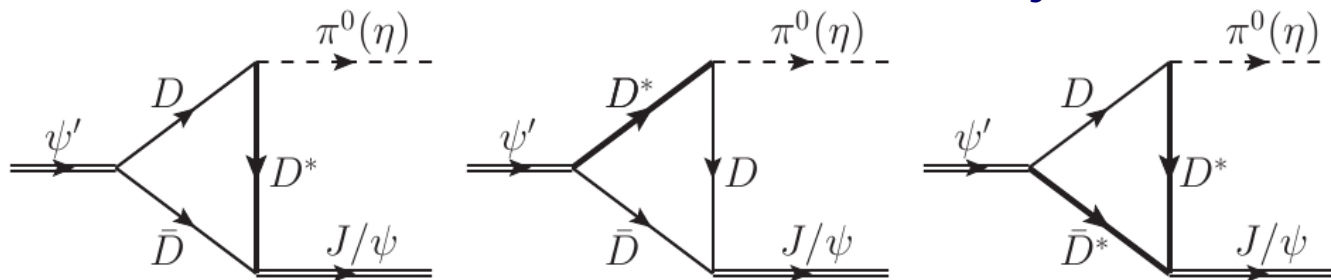
- the up-down quark mass difference
- electromagnetic interaction

J.F. Donoghue (1989), K. Maltman (1991): EM contribution for $\psi' \rightarrow \pi^0 J/\psi$ is much smaller than the quark mass difference.

→ **EFT** (QCD multipole expansion)

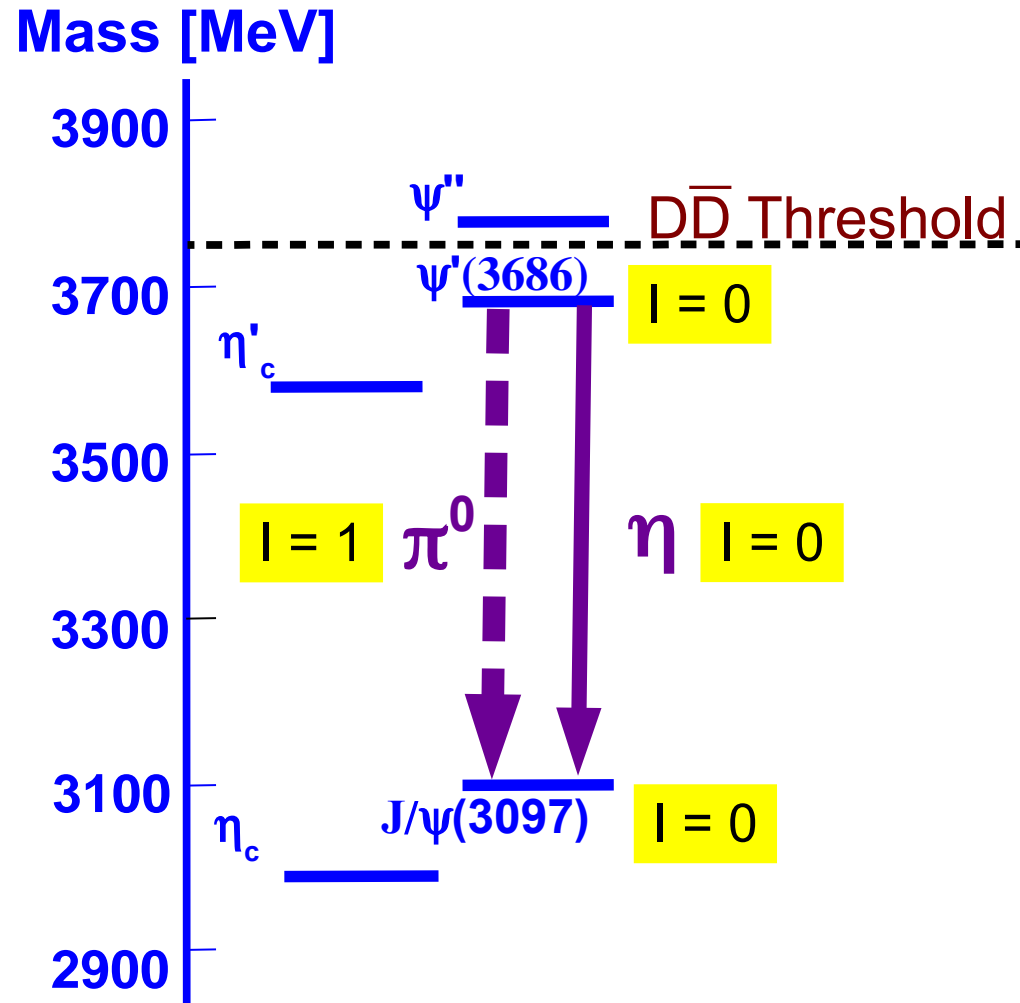
$$\frac{m_u}{m_d} \Leftrightarrow R = \frac{B(\Psi' \rightarrow \pi^0 J/\psi)}{B(\Psi' \rightarrow \eta J/\psi)} + \text{loops!}$$

F.-K. Guo, C. Hanhart: Phys. Rev. Lett. 103, 082003 (2009)

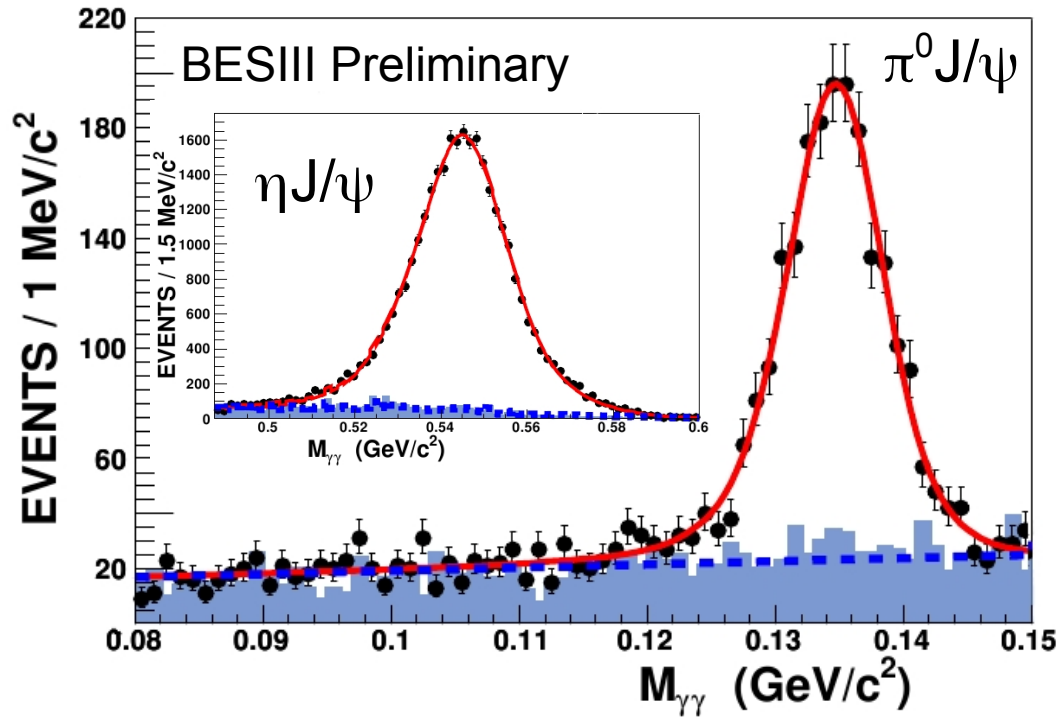


We are interested in π^0 (isospin) transitions between various charmonium states in order to reveal the hadronic-loop contributions to light quark masses (communication with Juelich theory group).

Isospin violating $\psi' \rightarrow \pi^0 J/\psi$ @ BESIII



Isospin violating $\psi' \rightarrow \pi^0 J/\psi$ @ BESIII



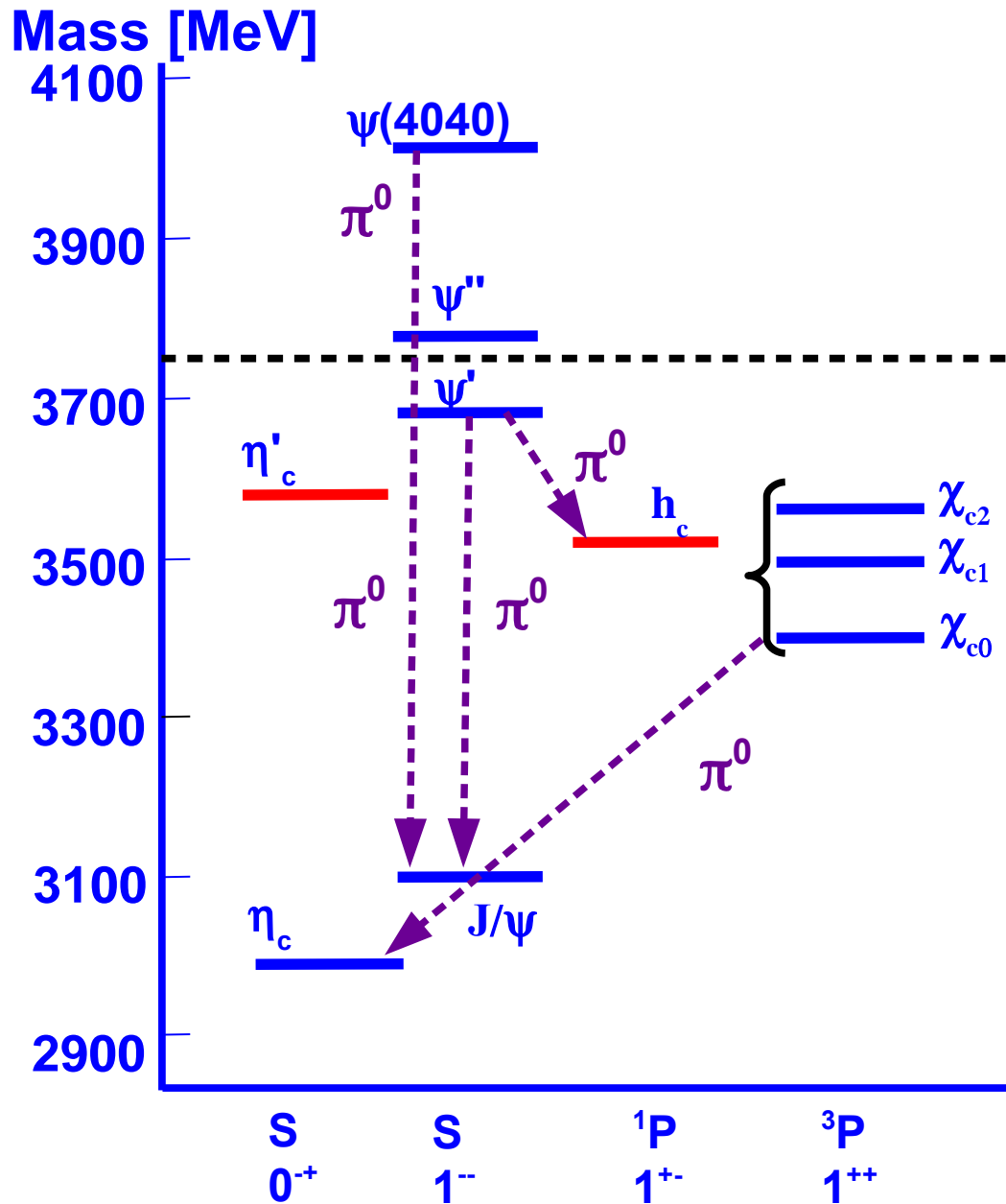
$$\frac{B(\Psi' \rightarrow \pi^0 J/\psi)}{B(\Psi' \rightarrow \eta J/\psi)} (\%)$$

	$J/\psi \rightarrow \mu\mu$	$J/\psi \rightarrow ee$
EFT	11 ± 6 (*)	
This work	$3.76 \pm 0.09 \pm 0.10$	$3.71 \pm 0.09 \pm 0.10$
CLEO-c	$3.88 \pm 0.23 \pm 0.05$	

Best Measurement!

Can constrain EFT!

Isospin violating transitions @ BESIII



$$B(\psi(4040) \rightarrow \pi^0 J/\psi) < 2.8 \cdot 10^{-4}$$

Accepted by PRD

$$B(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \cdot 10^{-4}$$

PRL 104, 132002 (2010)

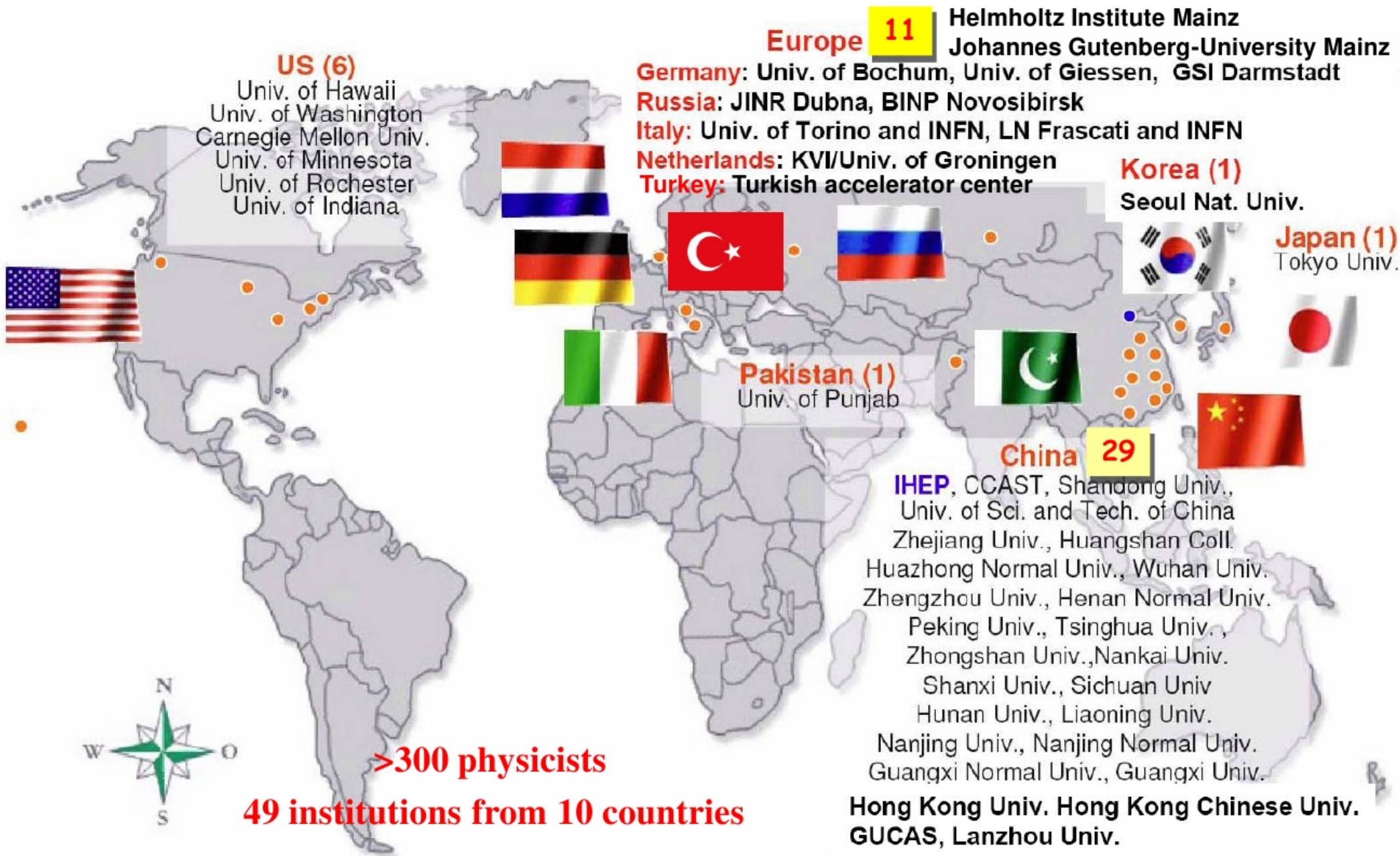
$$B(\psi' \rightarrow \pi^0 J/\psi) / B(\psi' \rightarrow \eta J/\psi) = (3.74 \pm 0.6 \pm 0.04) \cdot 10^{-2}$$

Preliminary

$$B(\chi_{c0,2} \rightarrow \pi^0 \eta_c) < ?$$

In Progress

Thanks to the BESIII Collaboration



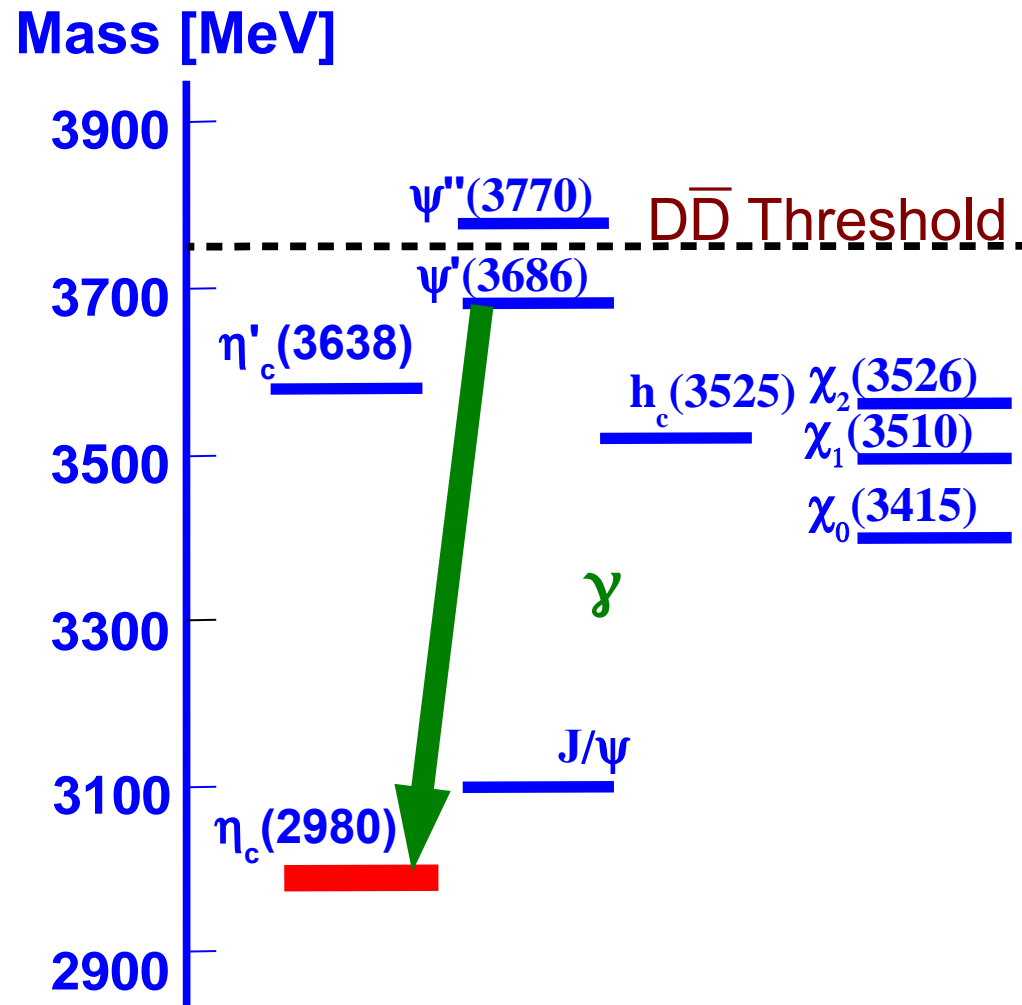
>300 physicists

49 institutions from 10 countries

Summary

- BESIII is operational since 2008:
 - ✓ World's largest data samples of J/ψ , ψ' , ψ'' , $\psi(4040)$ are already collected;
 - ✓ More data will come in future ($D_s^{*+}D_s^-$ at 4170MeV is coming soon).
- A lot of results have been obtained, particularly in charmonium spectroscopy:
 - ✓ Precision measurements of h_c parameters have been performed;
 - ✓ M1 transition $\psi' \rightarrow \gamma \eta_c'$ has been observed for the first time;
 - ✓ Transition $\psi' \rightarrow \gamma \gamma J/\psi$ has been observed for the first time;
 - ✓ Precision measurement of $\psi' \rightarrow \pi^0 J/\psi$ has been performed.
- Many more exciting physics results are obtained but not shown in this talk, and many more will come in the near future!

$\eta_c(1S)$ Parameters



$\eta_c(1S)$ Parameters

The S-wave spin-singlet charmonium ground state, found in 1980

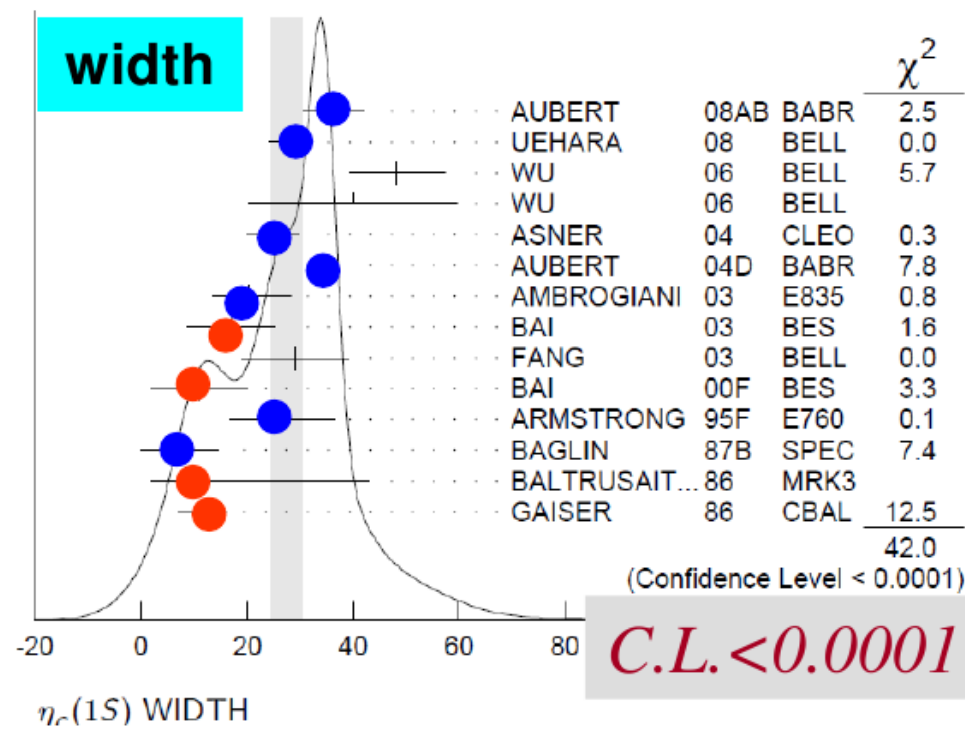
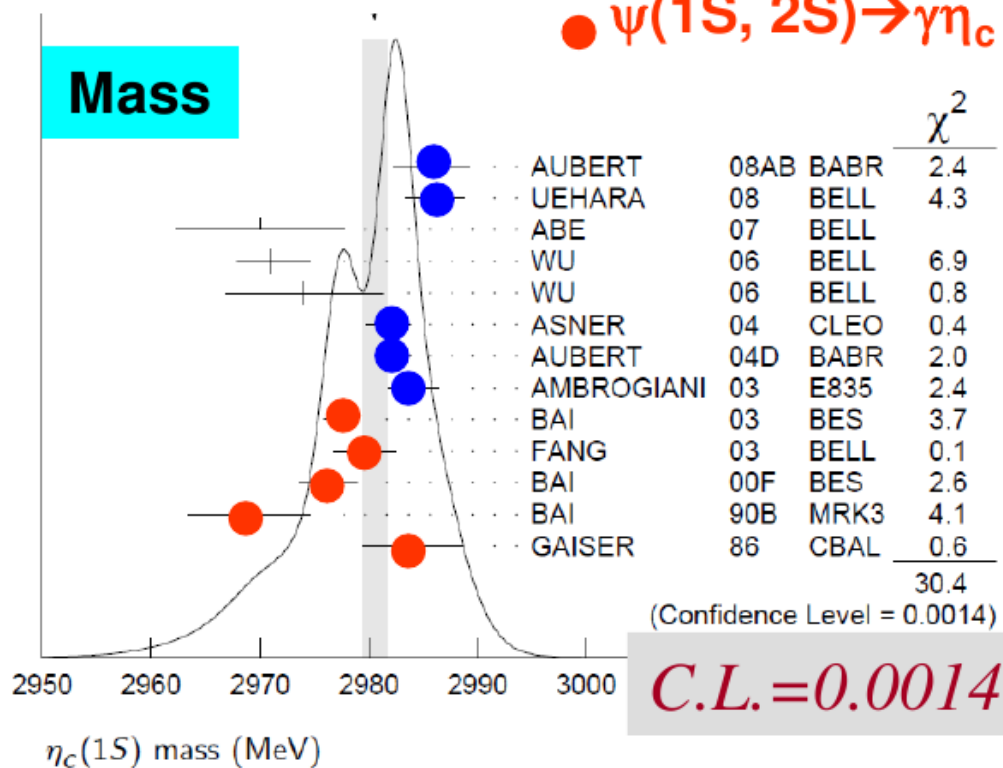
- M & Γ measurements:

- J/ ψ radiative transitions: M \sim 2978.0 MeV, $\Gamma \sim$ 10 MeV

- $\gamma\gamma$ processes /B decays : M = 2983.1 \pm 1.0 MeV/, $\Gamma = 31.3\pm 1.9$ MeV

● $\gamma\gamma$, $p\bar{p}$, B decay

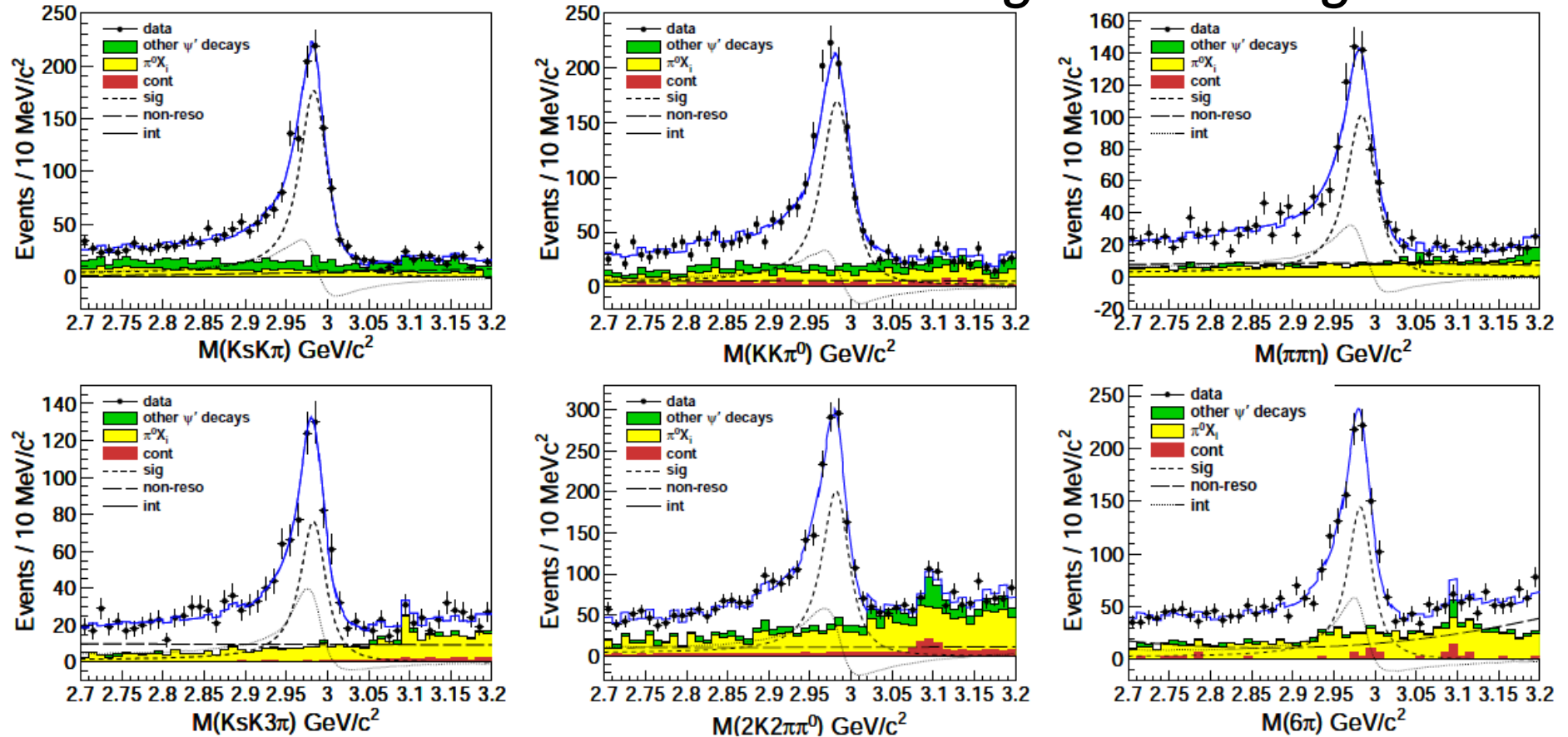
● $\psi(1S, 2S) \rightarrow \gamma\eta_c$



$\eta_c(1S)$ Parameters with $\psi' \rightarrow \gamma \eta_c(1S)$

Phys. Rev. Lett. 108, 222002 (2012)

Interference with non-resonant background is significant!



Mass = $2984.3 \pm 0.6 \pm 0.6 \text{ MeV}/c^2$

Width = $32.0 \pm 1.2 \pm 1.0 \text{ MeV}$

$\phi = 2.40 \pm 0.07 \pm 0.08 \text{ rad}$ (constructive)

$\phi = 4.19 \pm 0.03 \pm 0.09 \text{ rad}$ (deconstructive)