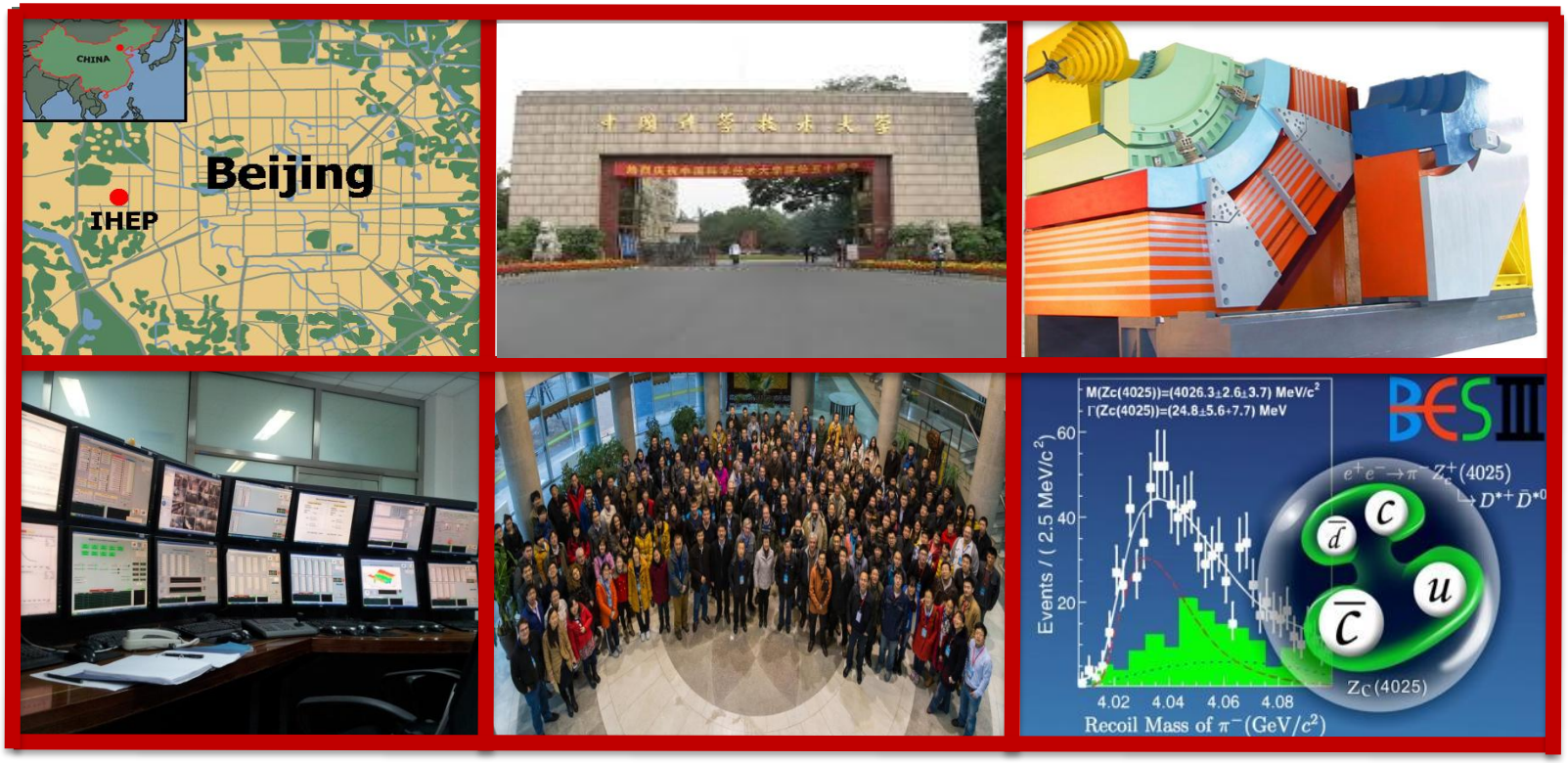
university of groningen

kvi - center for advanced radiation technology

BESIII

Radiative transition studies below the open-charm threshold with BESIII



Zahra Haddadi, KVI-CART (University of Groningen)

for the BESIII collaboration

university of groningen

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BESIII

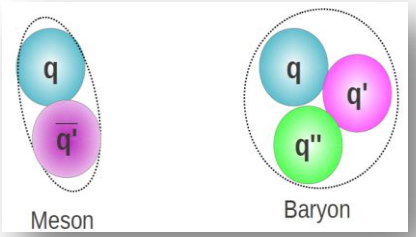
Outline:

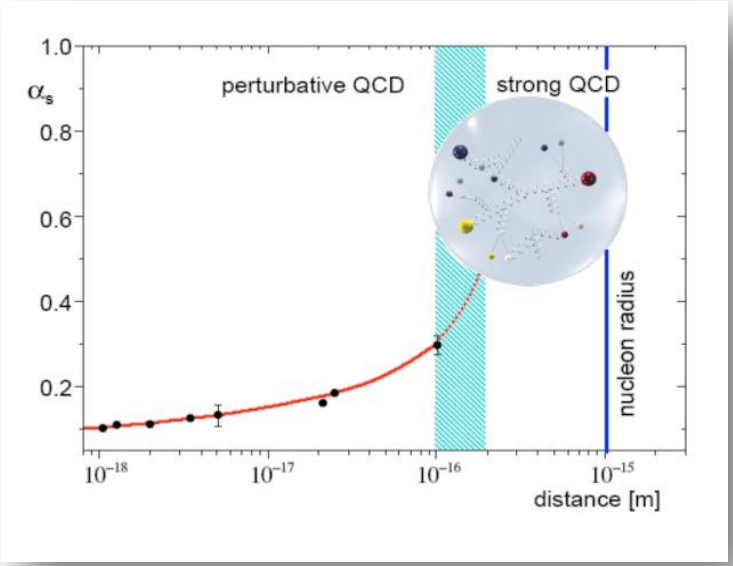
- Charmonium spectroscopy
- spin-singlet states puzzle
- BESIII & precision measurements

QCD bound systems

QCD:

- Is well tested at high energies.
- In low-energy region, many aspects are not understood.

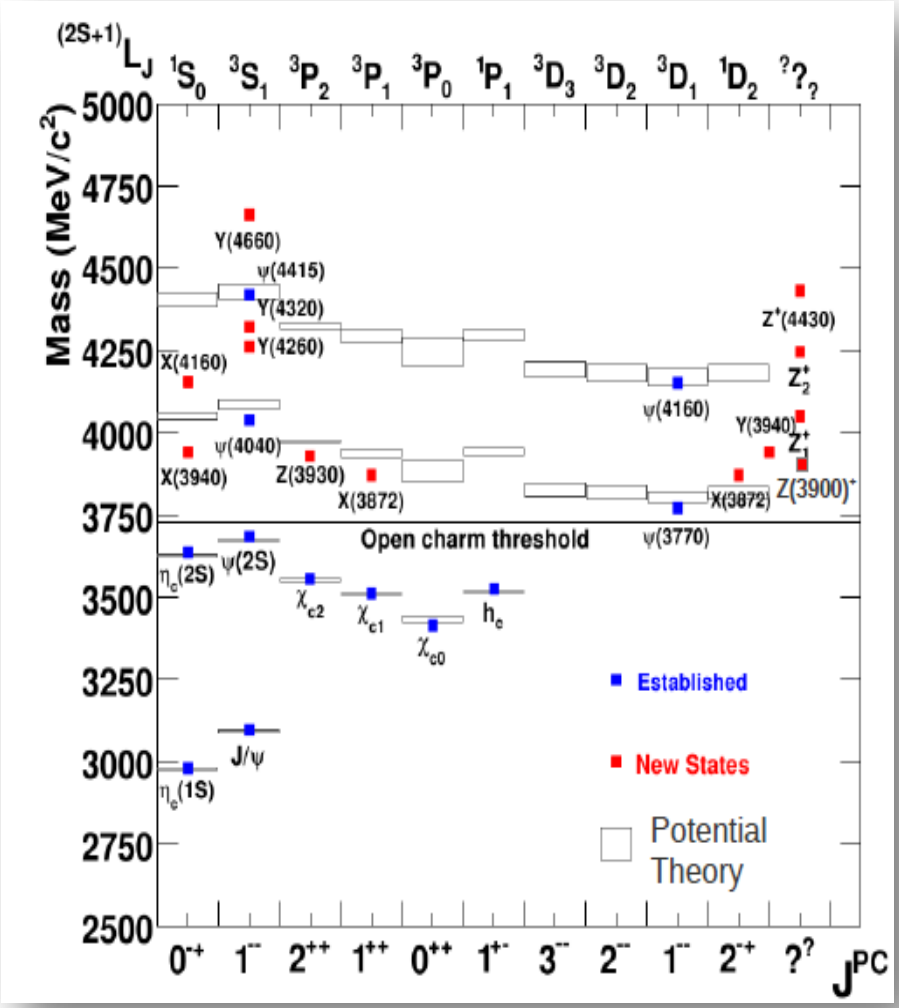




Charmonium:

- The mesonic bound state of $c\bar{c}$.
- Simplest bound state of QCD.
- $m_c \approx 1.4$ GeV: probe transition region from perturbative to non-perturbative region.

Charmonium spectrum



- **Potential model**
  describes spectrum very well;

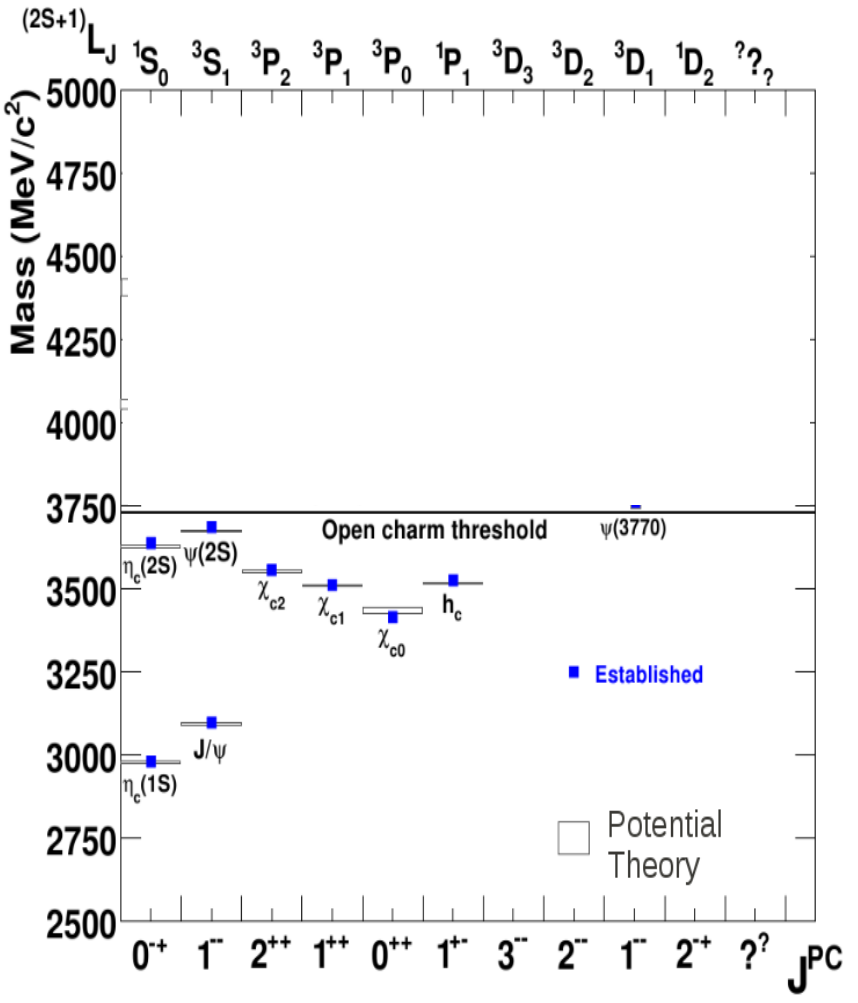
$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + \frac{32}{9}\frac{\pi\alpha_s}{m^2}\delta_\sigma(r)\ \vec{S_c}.\vec{S_{\bar{c}}}$$

$$+\frac{1}{m^2}\left[\left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{L}.\vec{S} + \frac{4\alpha_s}{r^3}T\right]$$

- **Below the open-charm threshold**
  - ✓ Narrow states
  - ✓ Good agreement between theory and experiment

- **XYZ states:**
  Talk by Landdiao Liu
  Hadron Structure, Spectroscopy and dynamics II

Charmonium spectrum



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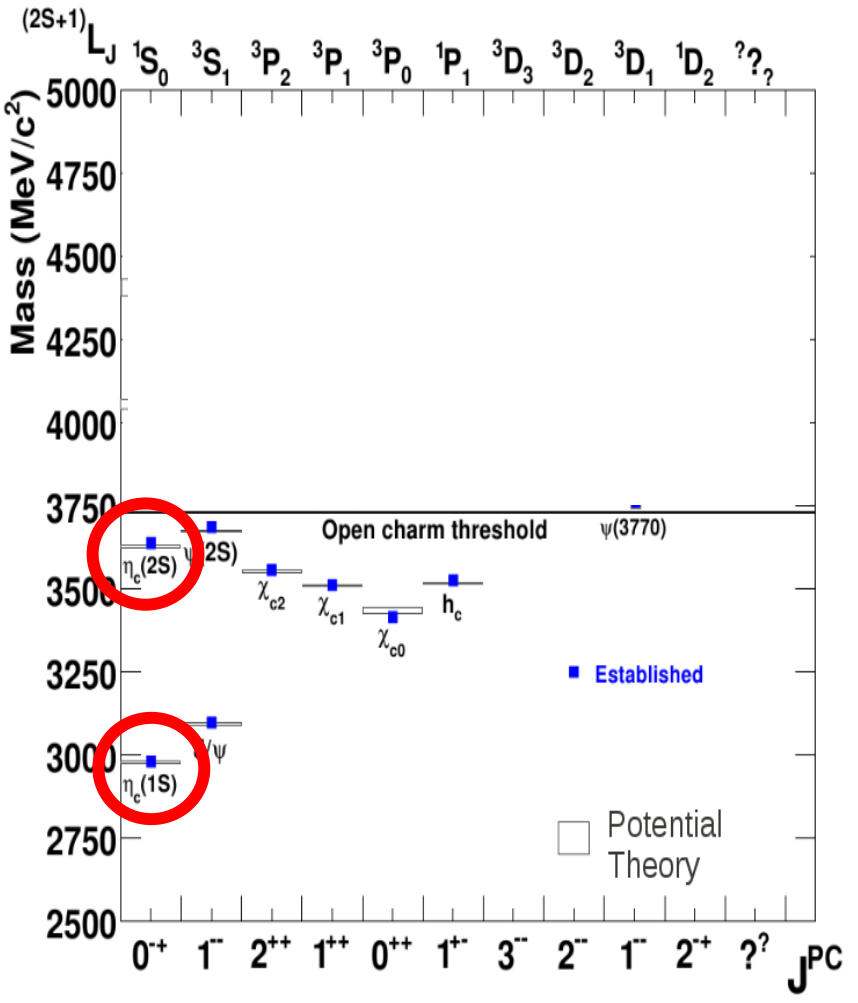

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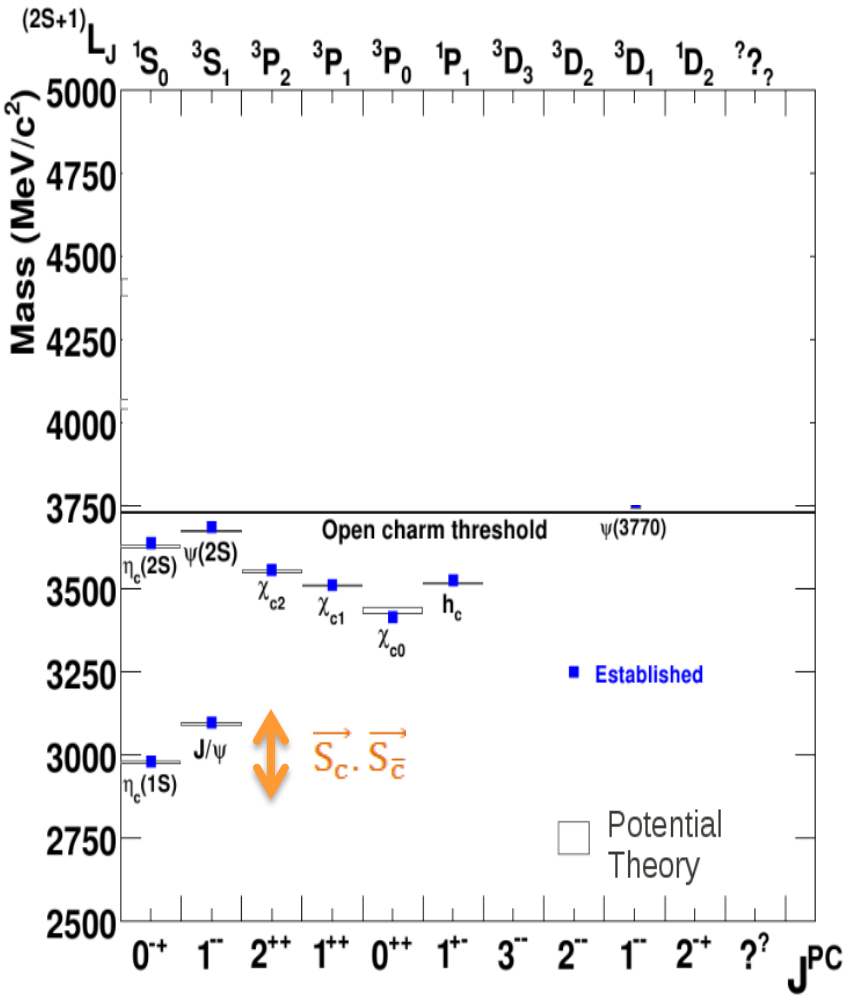

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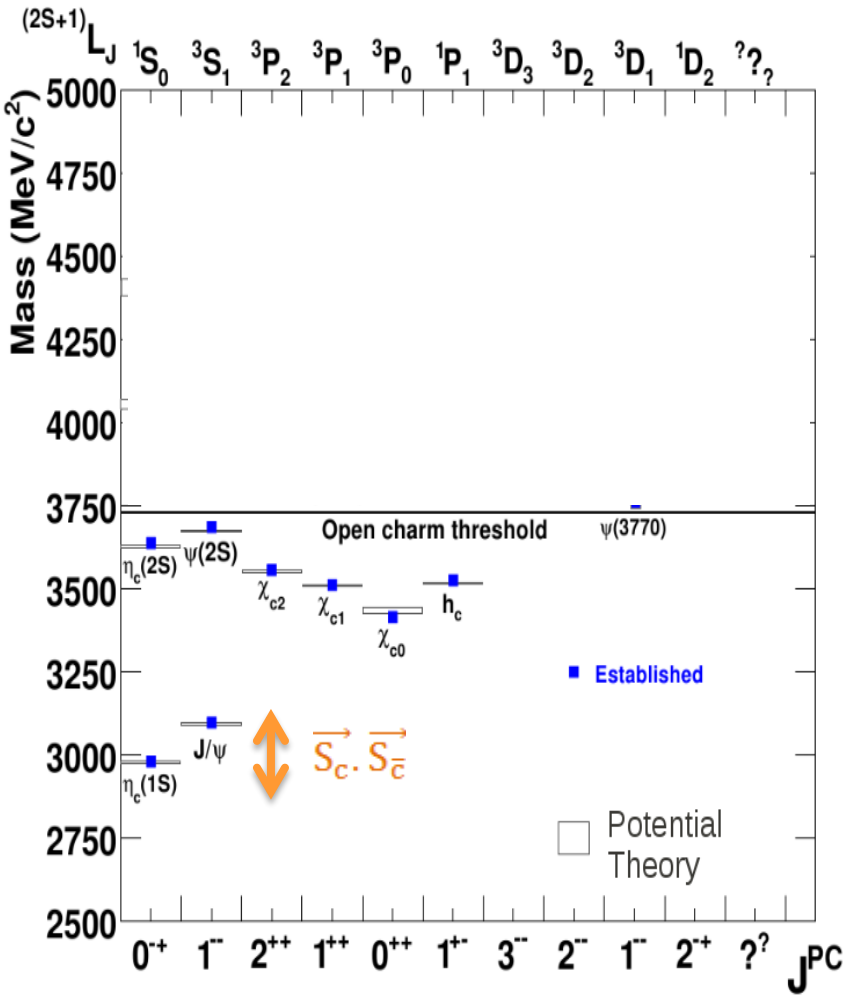

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Experiment

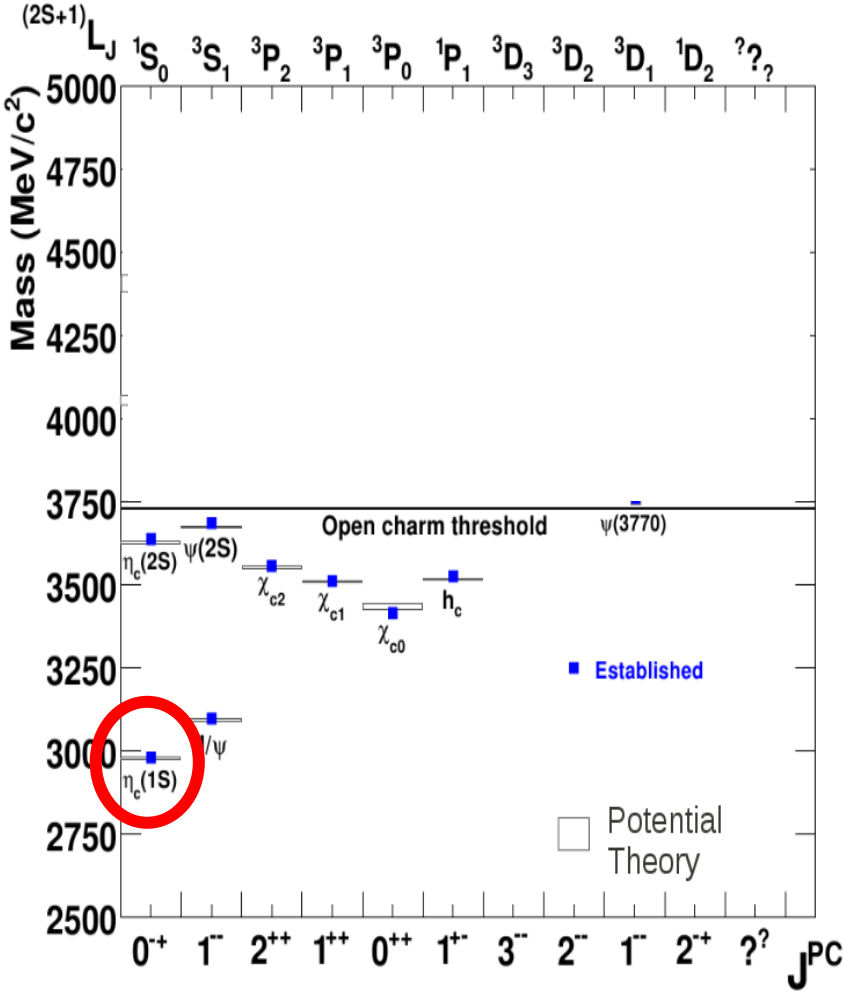
$$\Delta M(1S) = 116.6 \pm 1.0\ \mathrm{MeV/c^2}$$
$$\Delta M(1S) = M(J/\psi) - M(\eta_c)$$

Lattice QCD

$$\Delta M(1S) = 107.9 \pm 0.3 \pm 1.1\ \mathrm{MeV/c^2}$$

Phys. Rev. D 87, 034501 (2013)

Charmonium spectrum



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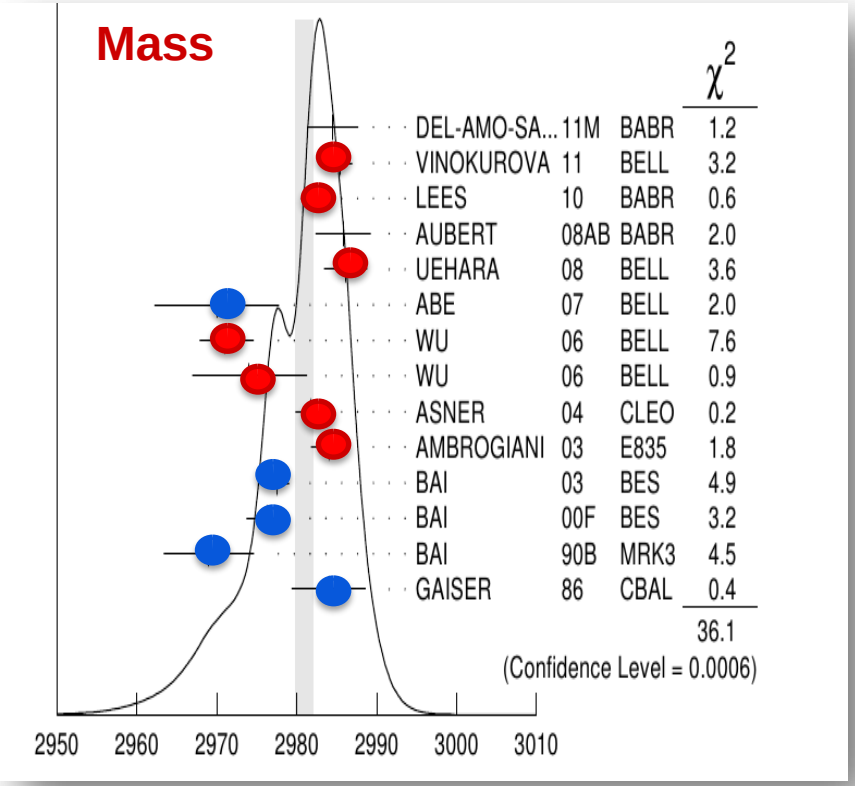
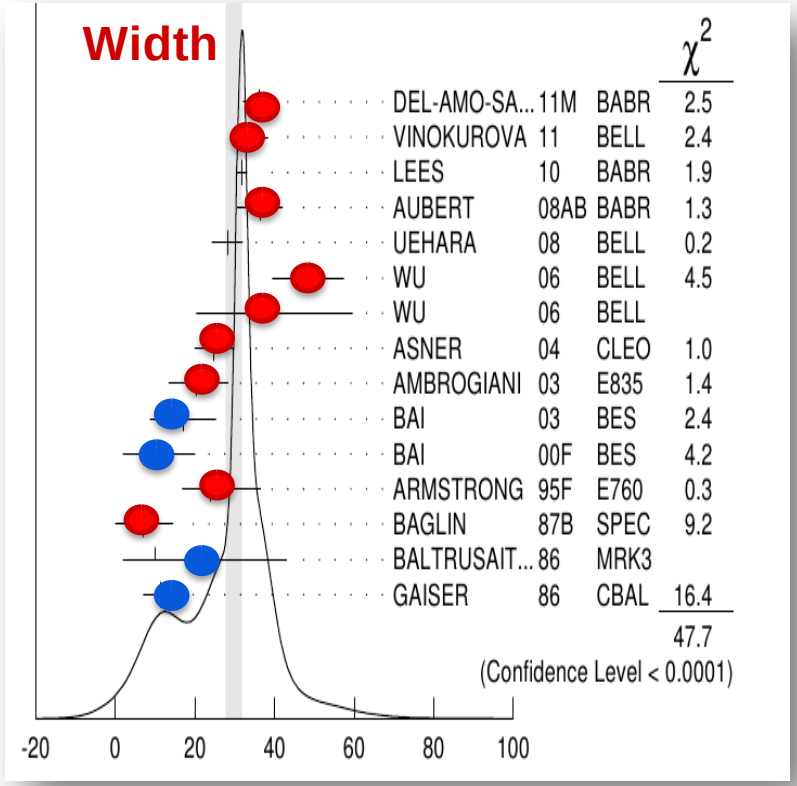
Mass & Width of the ground state: η_c





- radiative transition
- $\gamma\gamma$ processes, $p\bar{p}$, $B \to K\eta_c$

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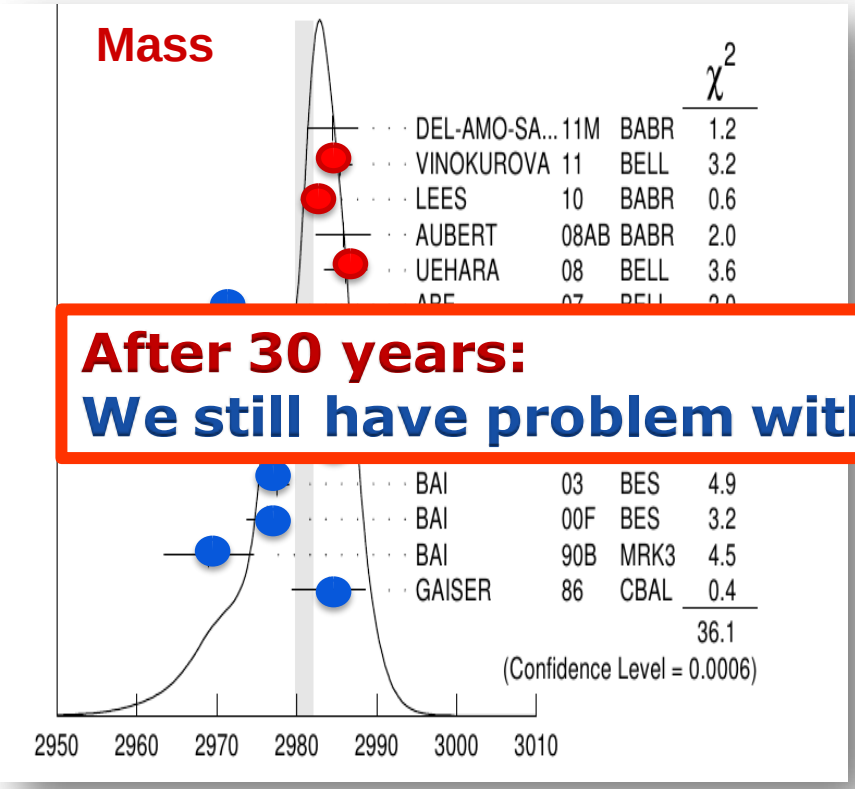
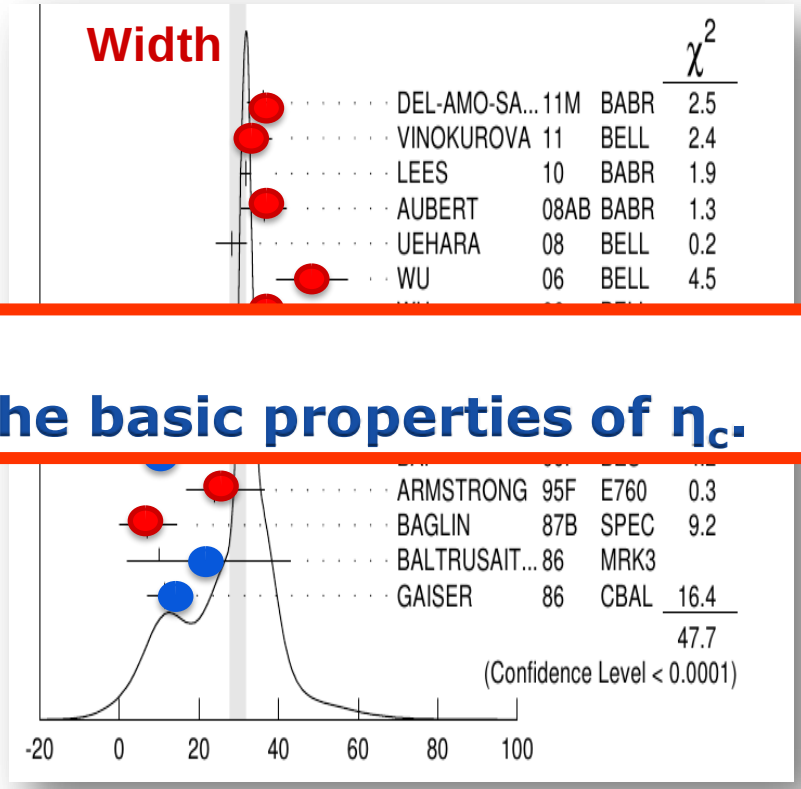
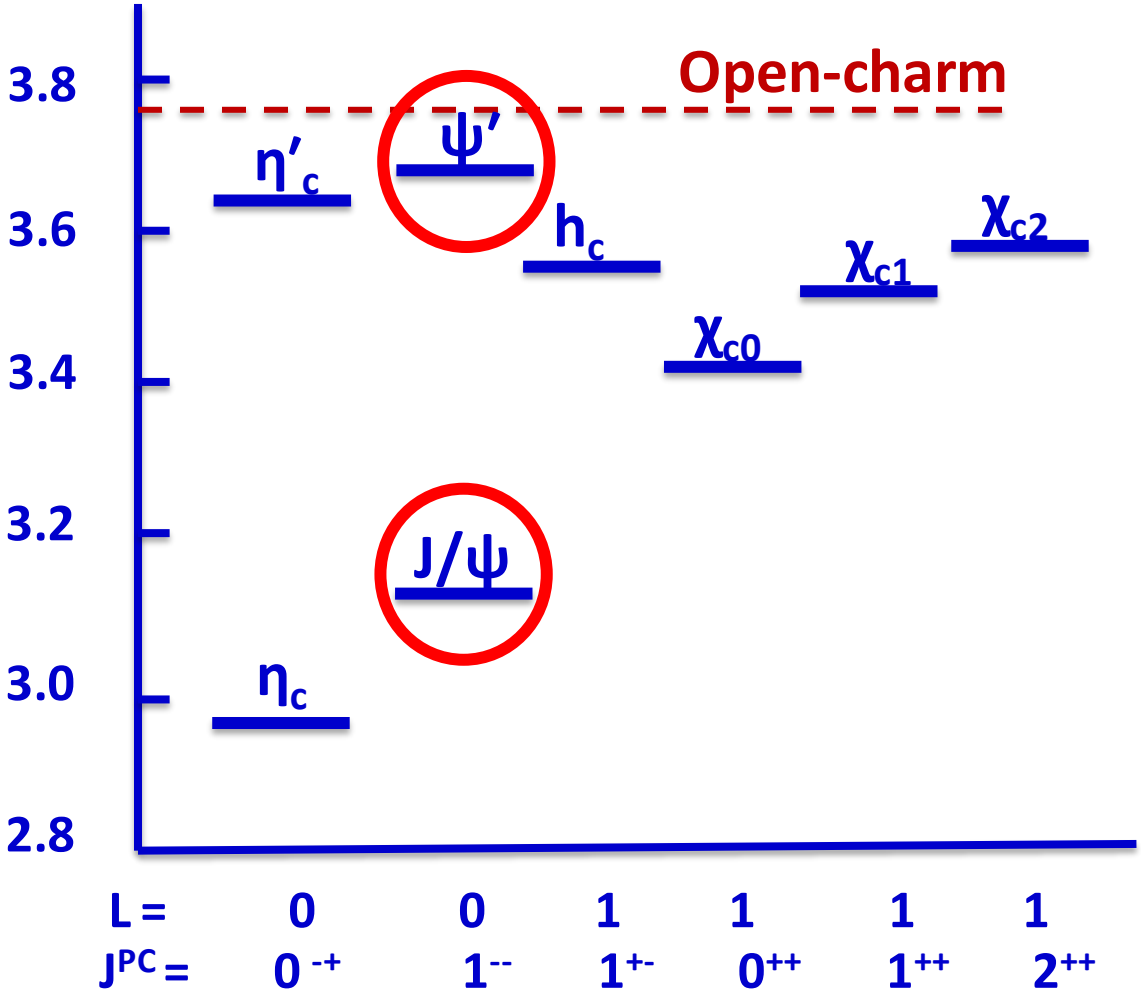




After 30 years:
We still have problem with the basic properties of η_c.

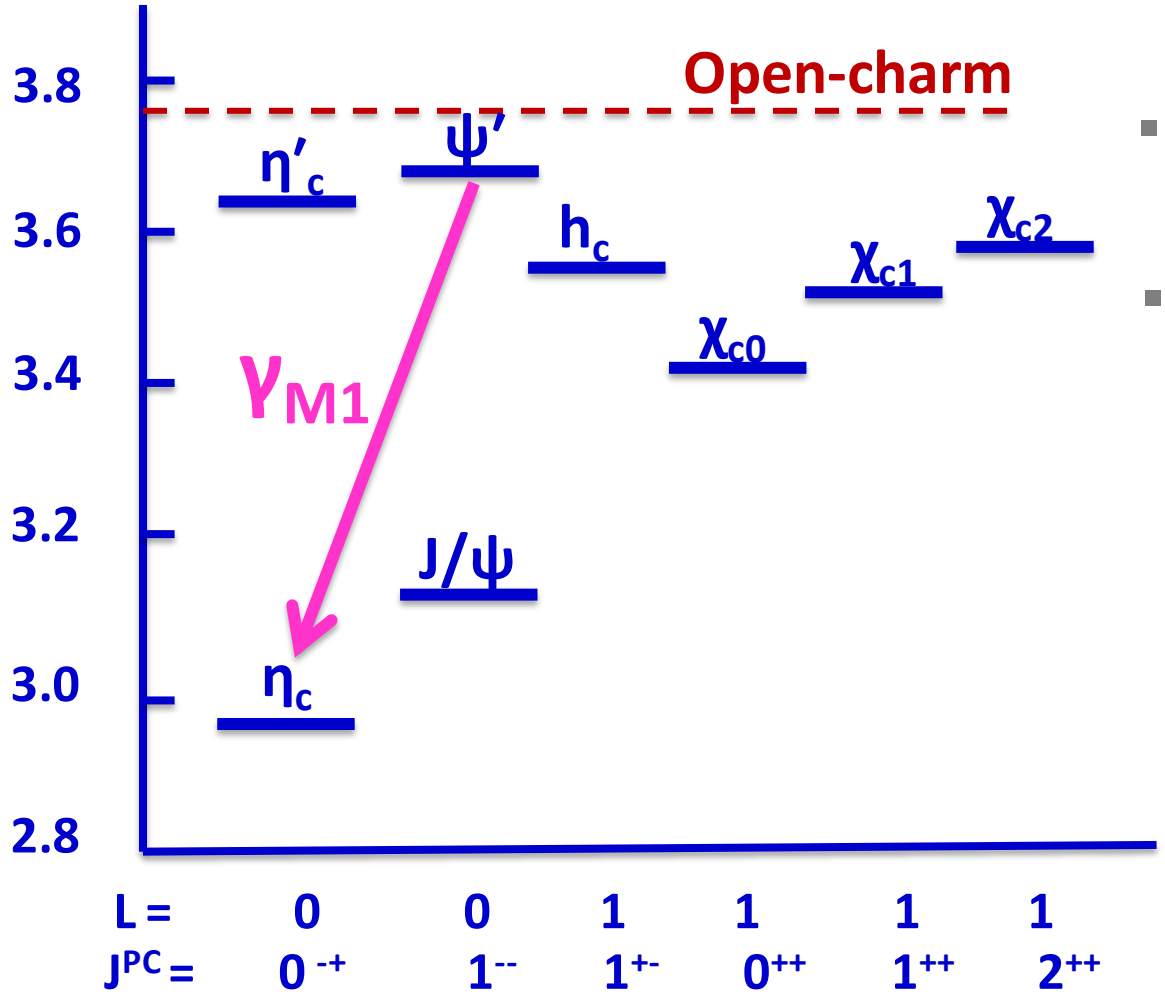
- radiative transition
- $\gamma\gamma$ processes, $p\bar{p}$, $B \to K\eta_c$

η_c studies from e^+e^- annihilation



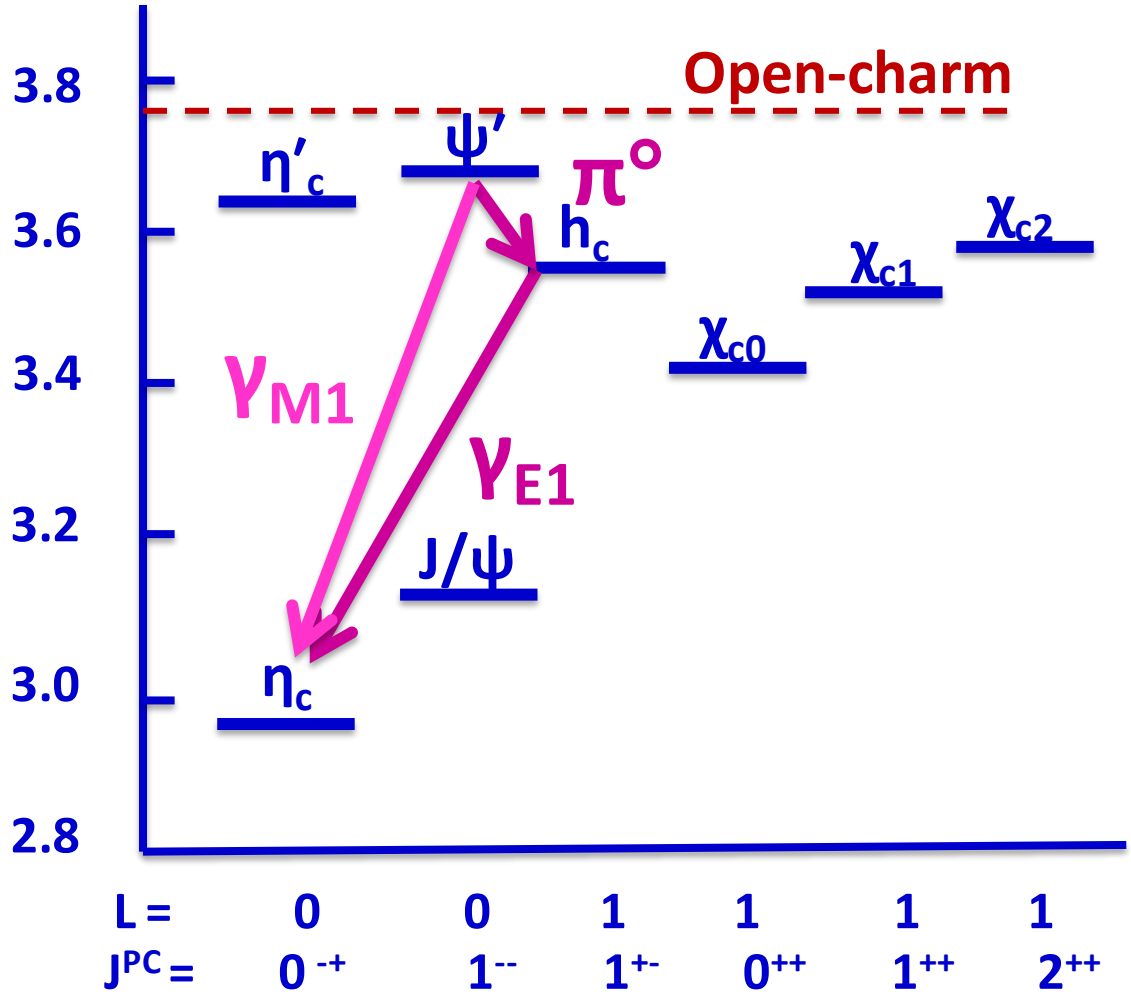
- **e^+e^- annihilation:**
  clean and simple environment

η_c studies from e^+e^- annihilation



- e^+e^- annihilation:
  clean and simple environment
- η_c:
  Mass and width and lineshape
  $\psi' \rightarrow \gamma\eta_c$
  suppressed M1 transition!

η_c studies from e^+e^- annihilation



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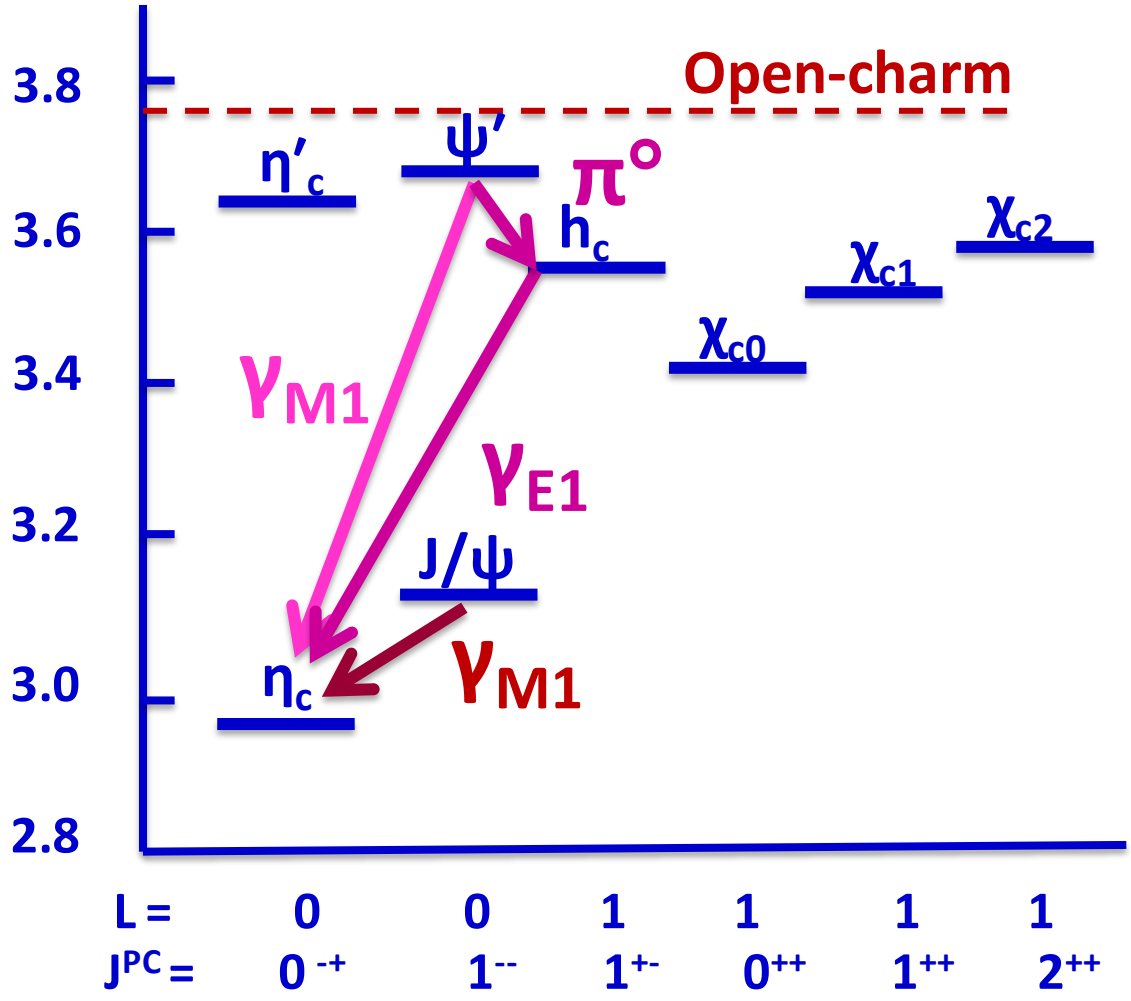
  $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$
  Isospin forbidden!

η_c studies from e^+e^- annihilation



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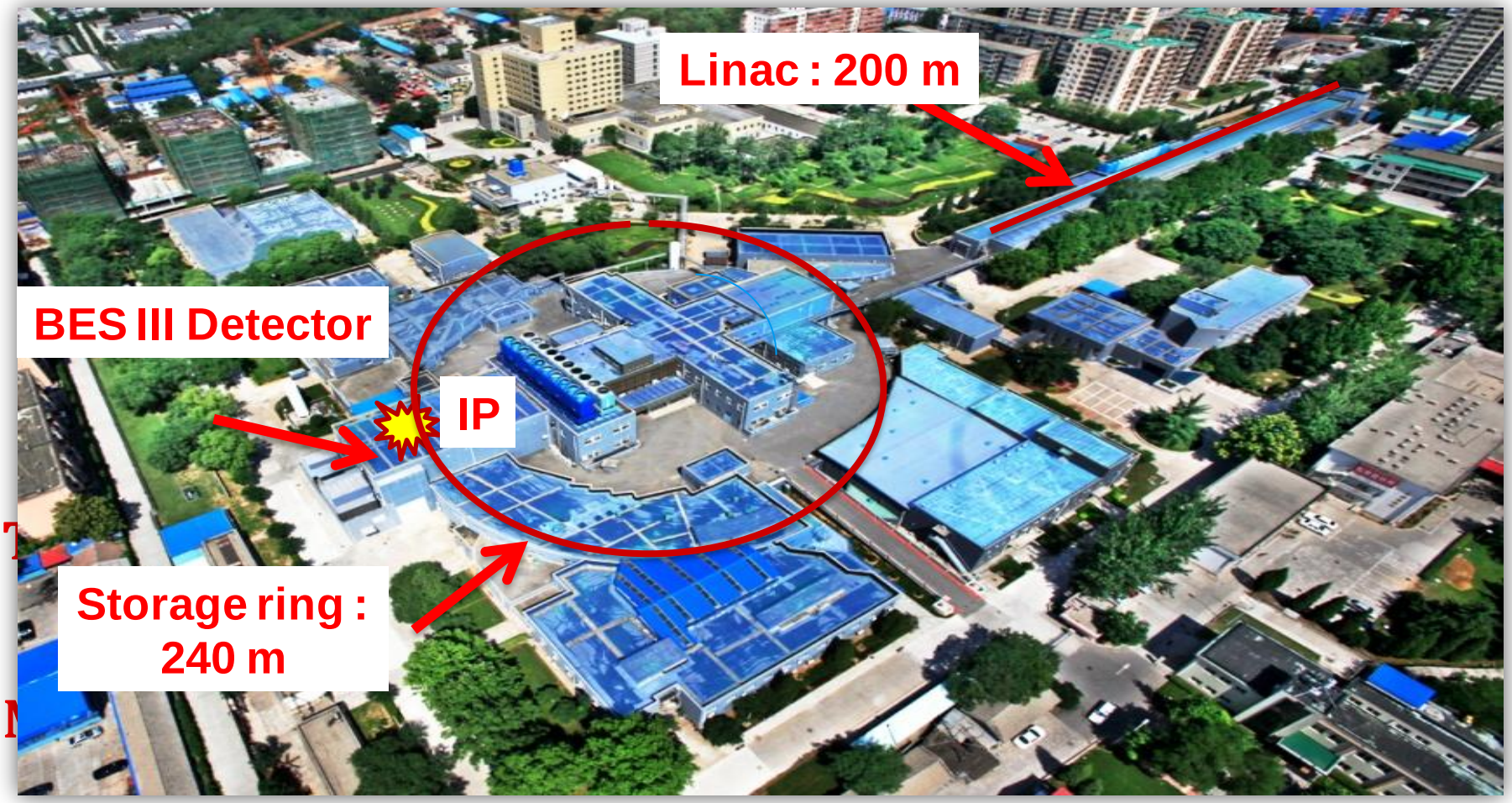
  Isospin forbidden!

  $J/\psi \to \gamma\eta_c$
  Suppressed M1 transition!


Linac : 200 m
BES III Detector
IP
Storage ring : 240 m

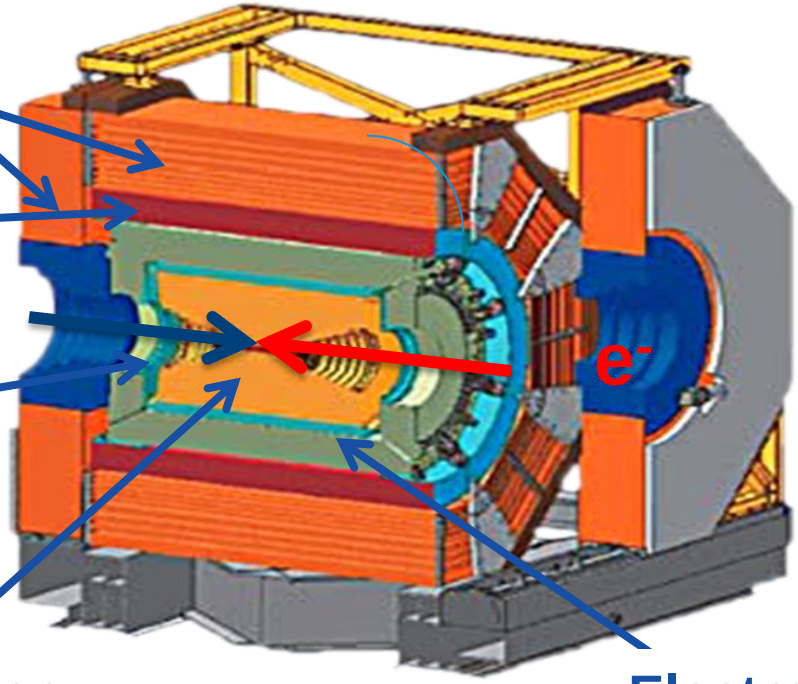
BESIII: BEijing Spectrometer (BES)

Magnet Yoke

SC magnet : 1T

e^+

Time of flight



Main drift chamber

Electromagnetic Calorimeter

Collected data by BESIII

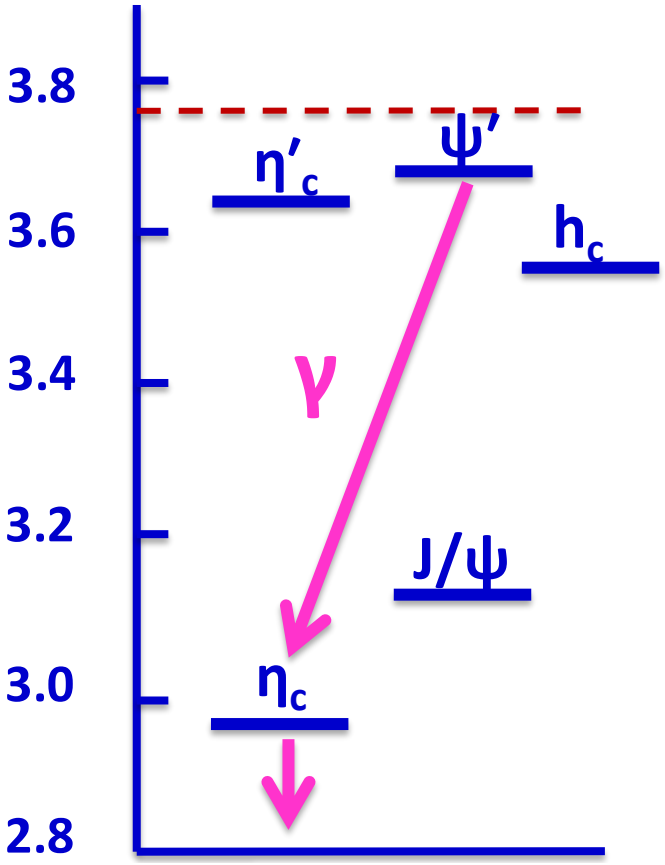
By the end of 2012 :

450×10^6 ψ′

1×10^9 J/ψ

We are well equipped for measuring these transitions.

$\psi' \to \gamma \eta_c$

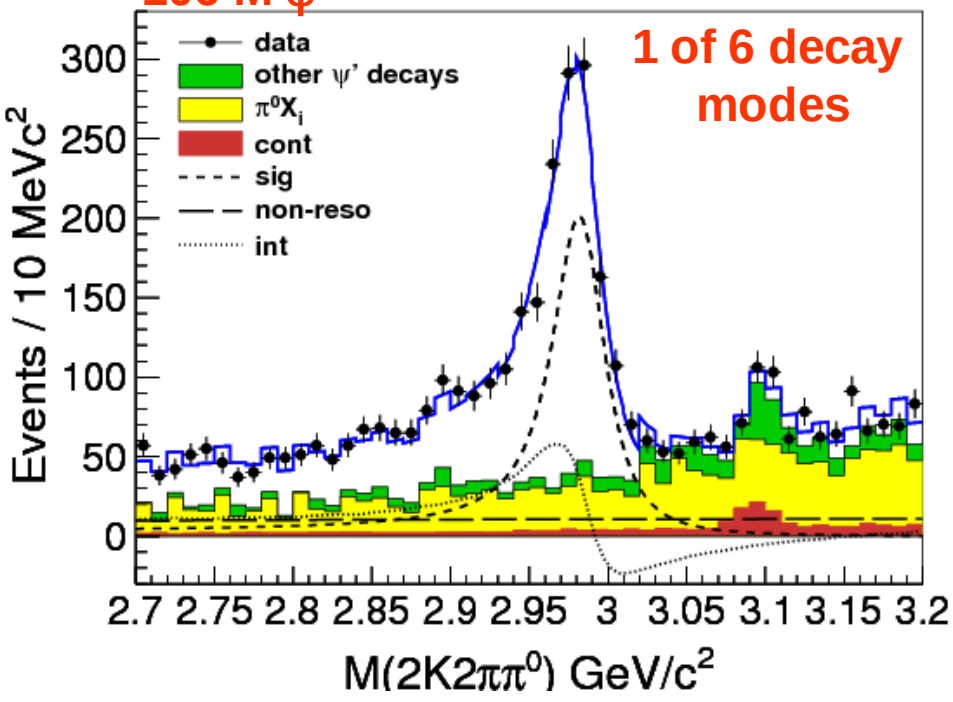


6 exclusive decay modes

BES III (2012)

$\psi' \to \gamma\eta_c, \eta_c \to 2K2\pi\pi^0$

106 M ψ'



- ✓ Simultaneous fit to 6 modes
- ✓ Phases are consistent within **3σ**

- ❑ Obviously asymmetric lineshape:
  - ✓ Long tail on the low mass side.
  - ✓ The signal drops rapidly on the high-mass side.
- ❑ Interference between η_c and non-resonant background is significant:
  - ✓ Interference was found to be **15σ**.

- ❑ $M_{\eta c}$ = 2984.3 ± 0.6 ± 0.6 MeV/c^2
- ❑ $\Gamma_{\eta c}$ = 32.0 ± 1.2 ±1.0 MeV

PRL 108, 222002 (2012)

BES III (2012)

❑ $M_{\eta c}$ = 2984.3 ± 0.6 ± 0.6 MeV/c^2

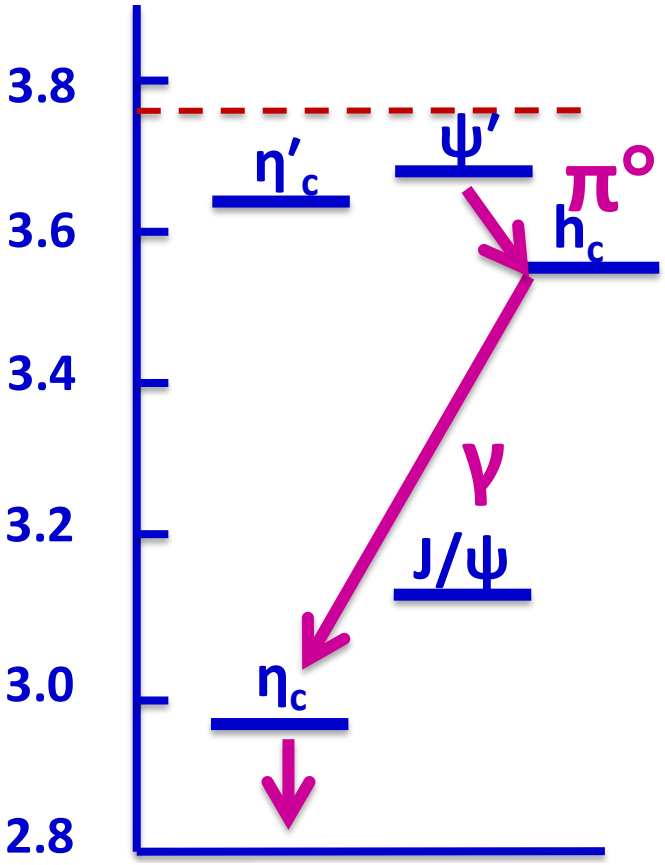
	ΔM(1S) = M(J/ψ)-M(η_c)
Lattice 2012	107.9 ± 0.3 ± 1.1 MeV/c^2
PDG 2012	115.9 ± 1.0 MeV/c^2
BESIII	112.6 ± 0.8 MeV/c^2

✓ **closer to prediction than the earlier results!**

Phys. Rev. D 86, 010001 (2012)
Phys. Rev. D 87, 034501 (2012)

Question : **Can we see this distortion in the other radiative transition like $h_c \rightarrow \gamma\eta_c$**

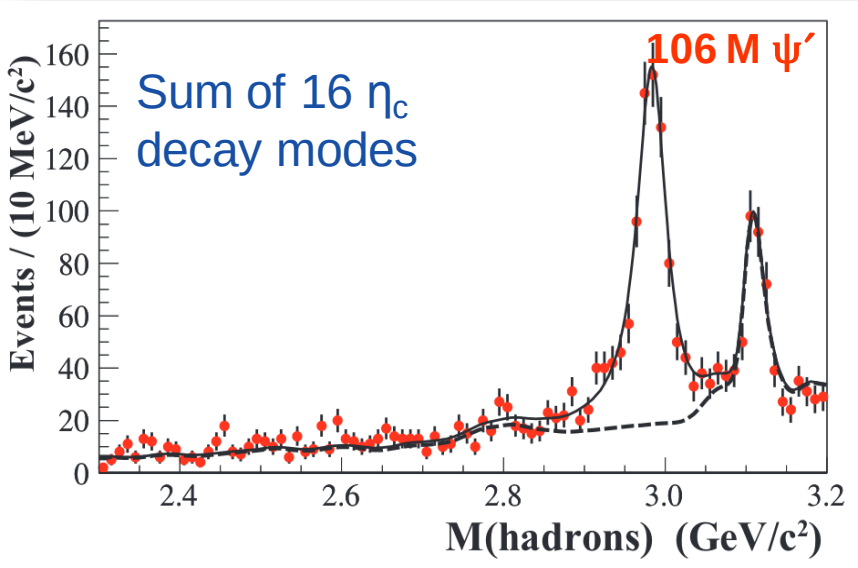
$\psi' \to \pi^0 h_c,\ h_c \to \gamma \eta_c$

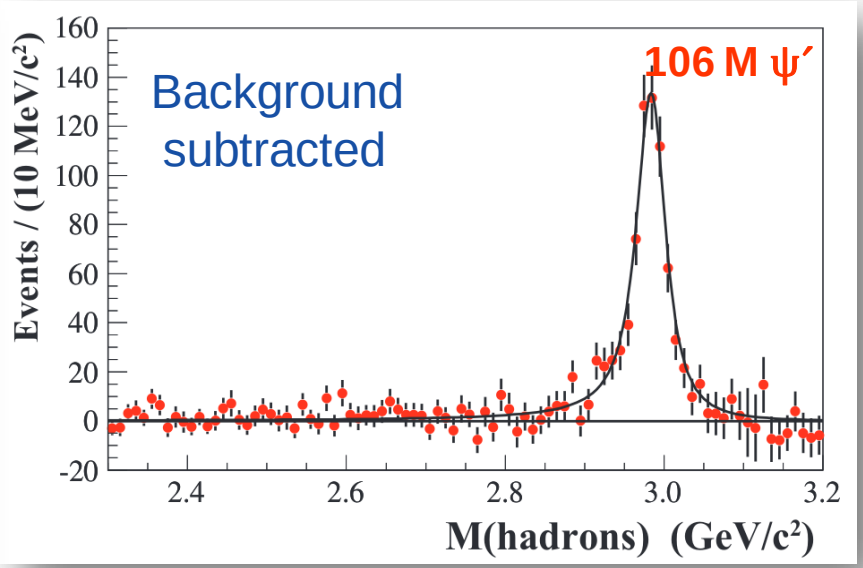


16 exclusive decay modes

η_c lineshape in E1 transition $h_c \to \gamma\eta_c$

- Weaker interference & Larger amplitude: $B(\psi' \to \gamma\eta_c) = 0.3\%$, $B(h_c \to \gamma\eta_c) = 50\%$

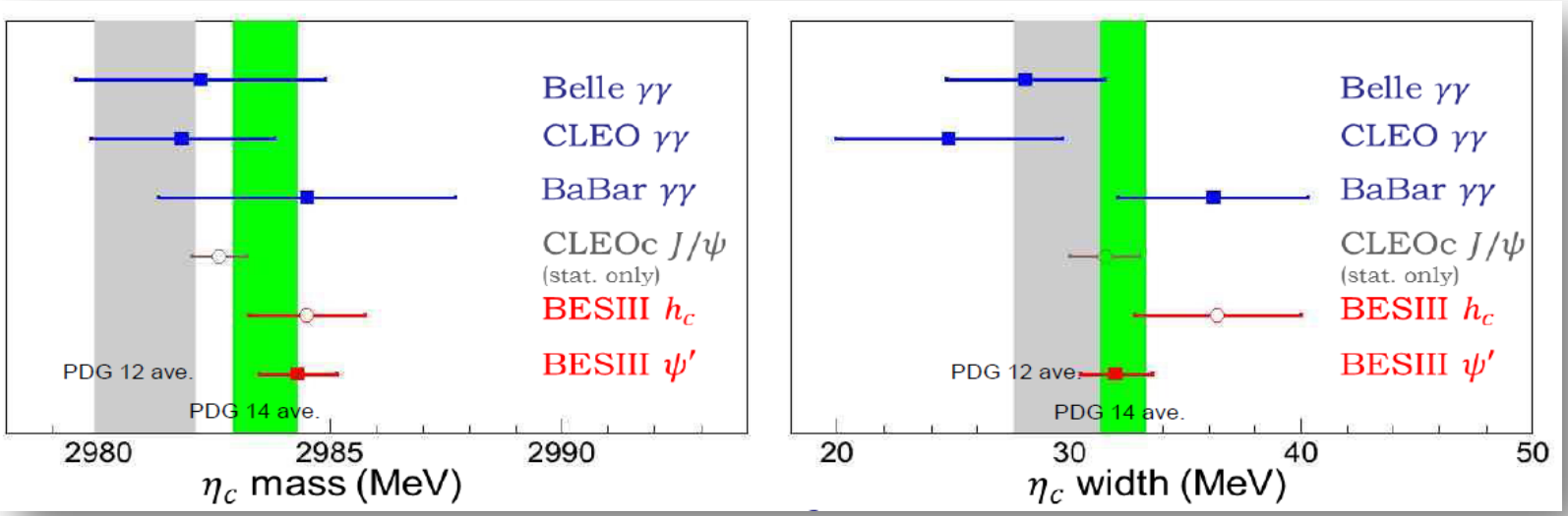




PRD 86, 092009

Signal can be described by a simple Breit-Wigner.

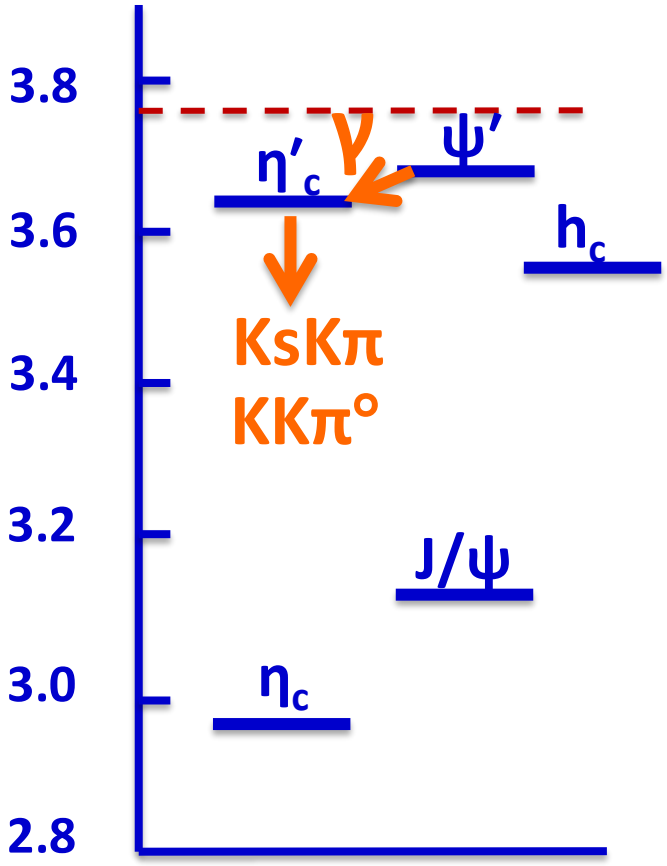
Comparison of the latest results:



Decay Modes	M(GeV/c2)	Width(MeV)
$\psi' \to \gamma\eta_c$	2984.3 ± 0.6 ± 0.6	32.0 ± 1.2 ±1.0
$h_c \to \gamma\eta_c$	2984.40 ± 1.16 ± 0.52	36.4 ± 3.2 ± 1.7

- Statistical error is dominant.
- Ongoing analysis with four times more statistics.

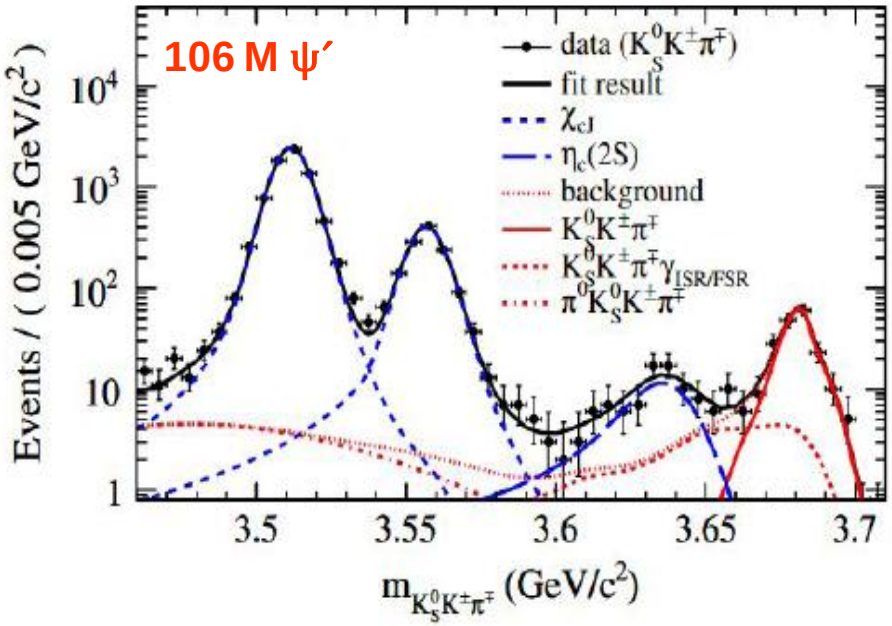
$\psi' \to \gamma \eta_c'$

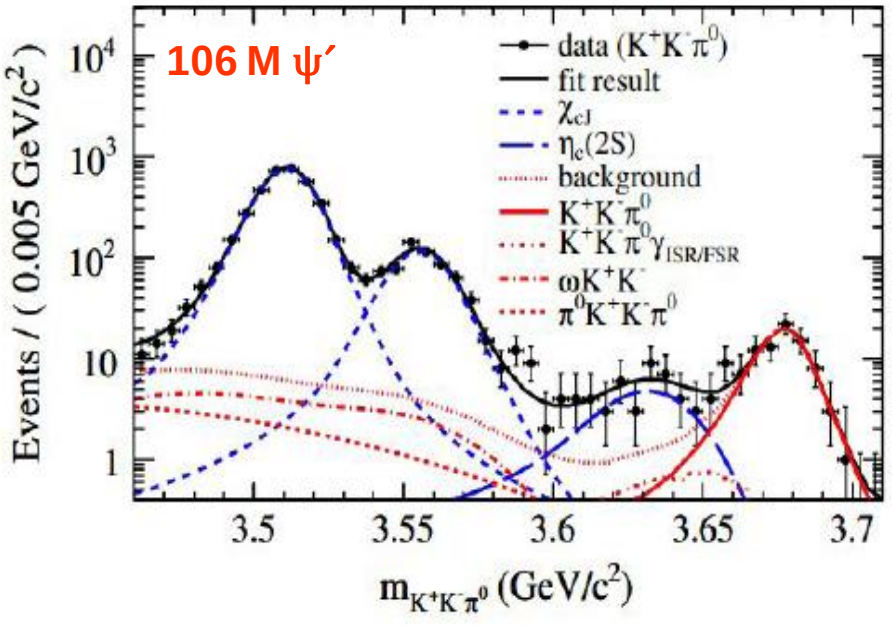


First observation of the ψ′→γη′

Experimental challenge : search for photon of 50 MeV.

CLEO-c : Found no signal (25M ψ′)





Signal : Significance is larger than 10σ

PRL 109, 042003 (2012)

B(ψ′→γη_c′) = $(6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

CLEO-c $< (7.6 \pm 1.1) \times 10^{-4}$

PRD81, 052002 (2012)

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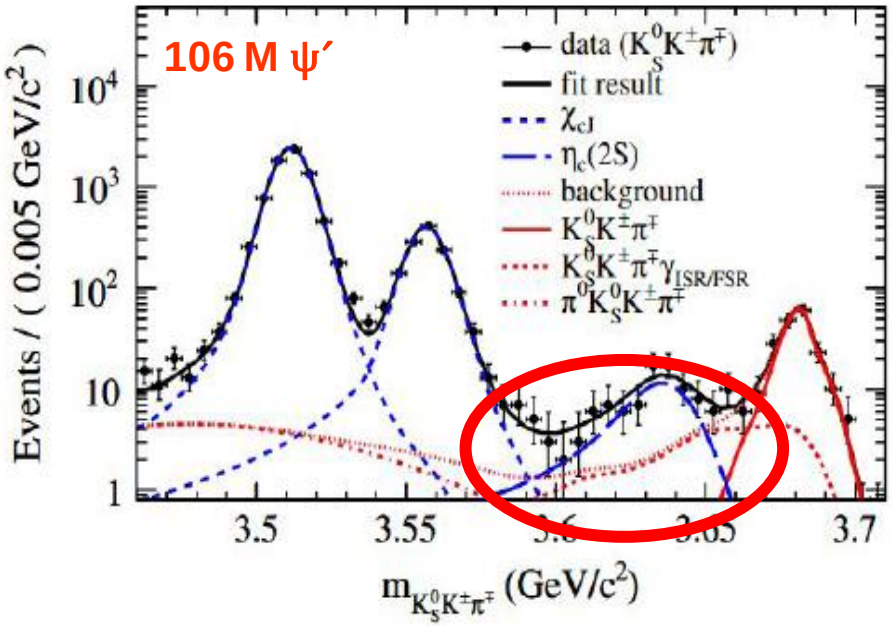

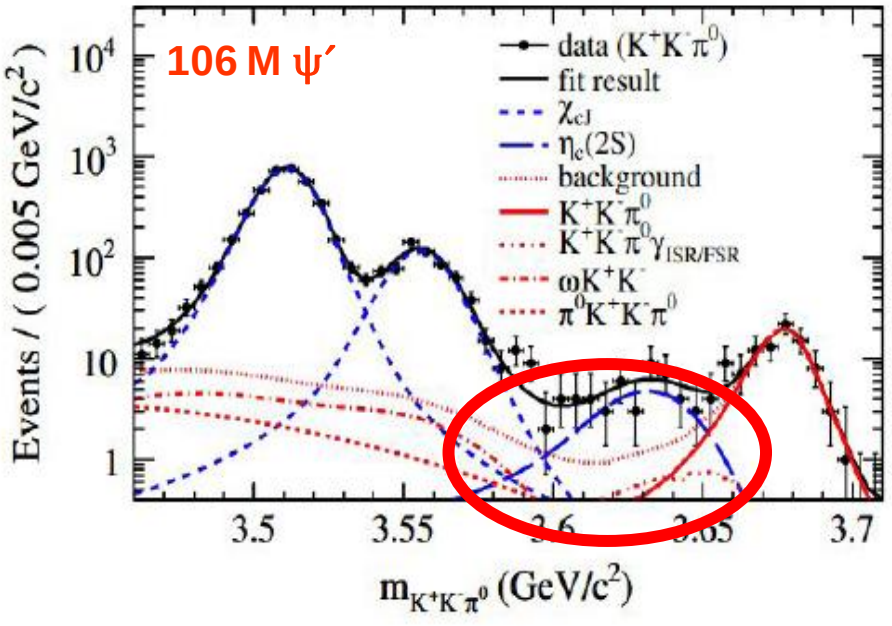

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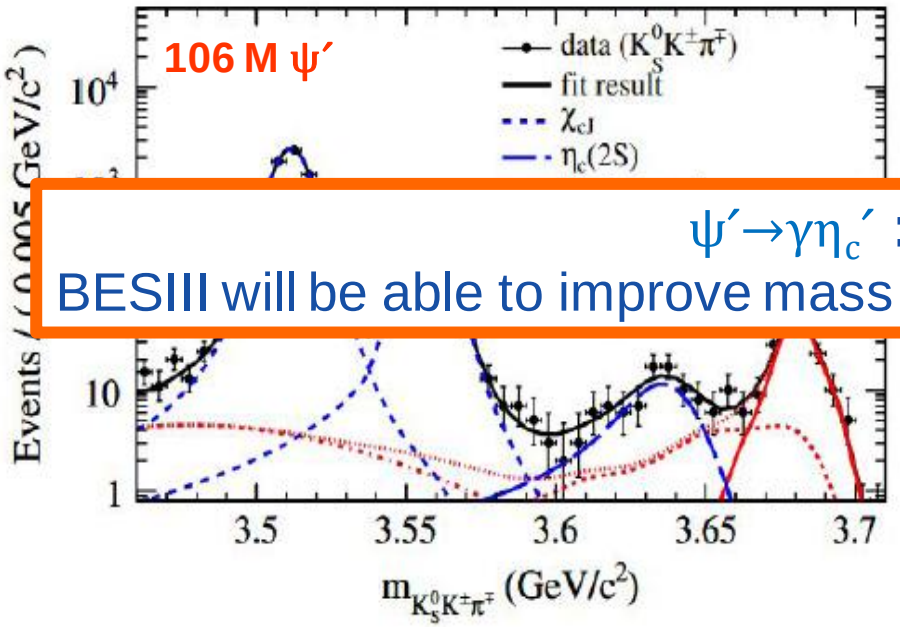
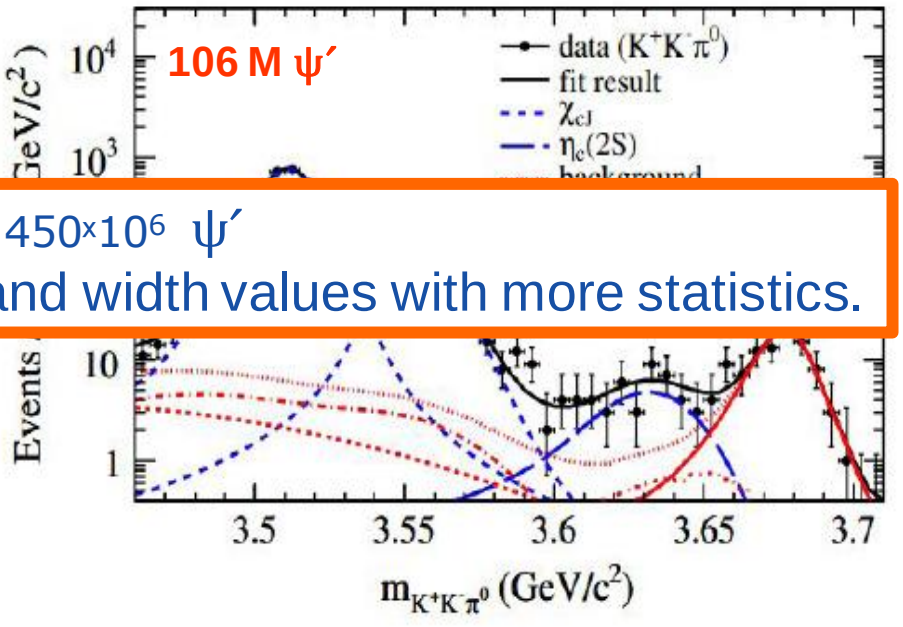




$\psi' \to \gamma\eta_c'$: 450×10^6 ψ′

BESIII will be able to improve mass and width values with more statistics.

Signal : Significance is larger than 10σ

PRL 109, 042003 (2012)

B(ψ′→γη$_c$′) = $(6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

CLEO-c < $(7.6 \pm 1.1) \times 10^{-4}$

PRD81, 052002 (2012)

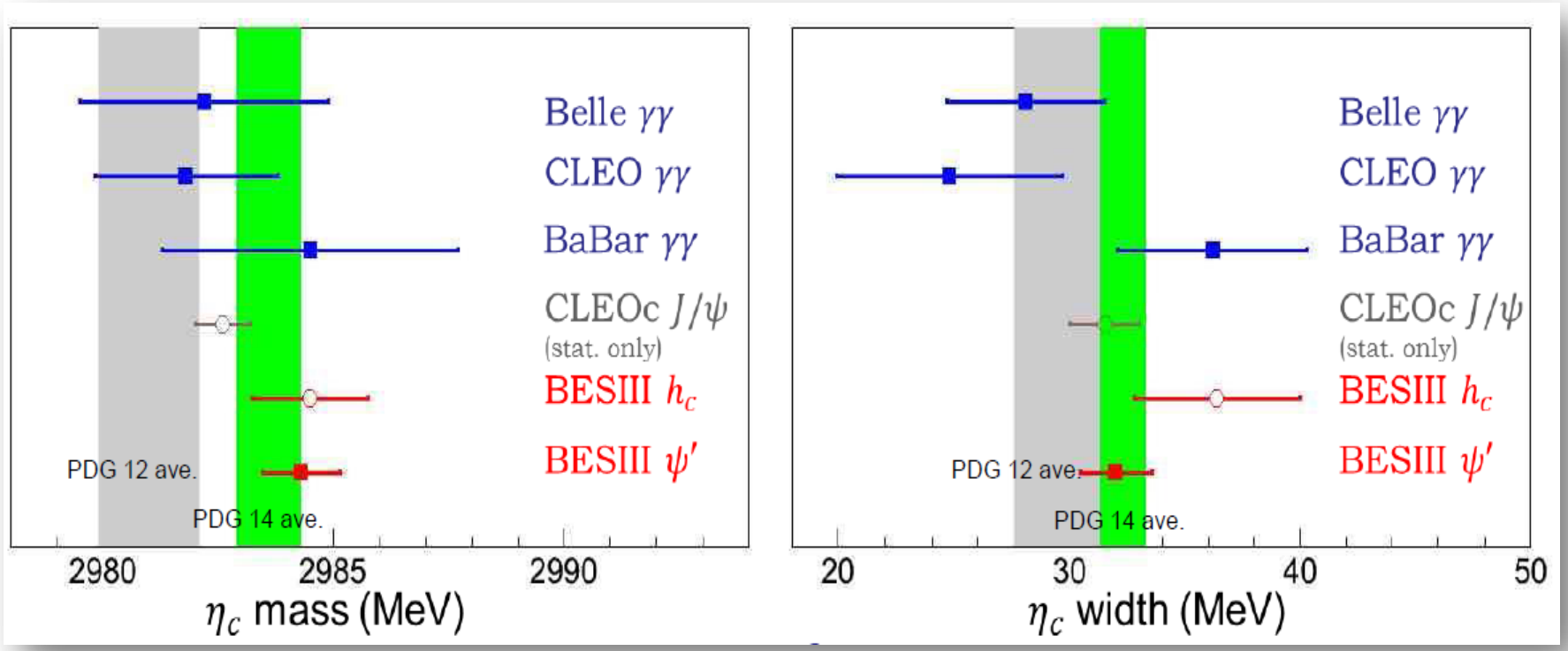
Outlook

- η_c and η_c' studies was done at BESIII:
  - $\psi' \to \gamma\eta_c$
    - precise measurement on basic properties like mass and width
    - improving the hyperfine splitting value
    - considering the interference for the first time
  - $\psi' \to \pi^0 h_c, h_c \to \gamma\eta_c$
    - interference free lab for η_c lineshape
    - promising channel to measure the basic properties of η_c
  - $\psi' \to \gamma\eta_c'$
    - first observation even with 106M ψ'

Lineshape : **More interesting result will come very soon!**

Thanks for your attention

Comparison of the latest results:



Ke Li

Understanding the nature of interference is the key point!

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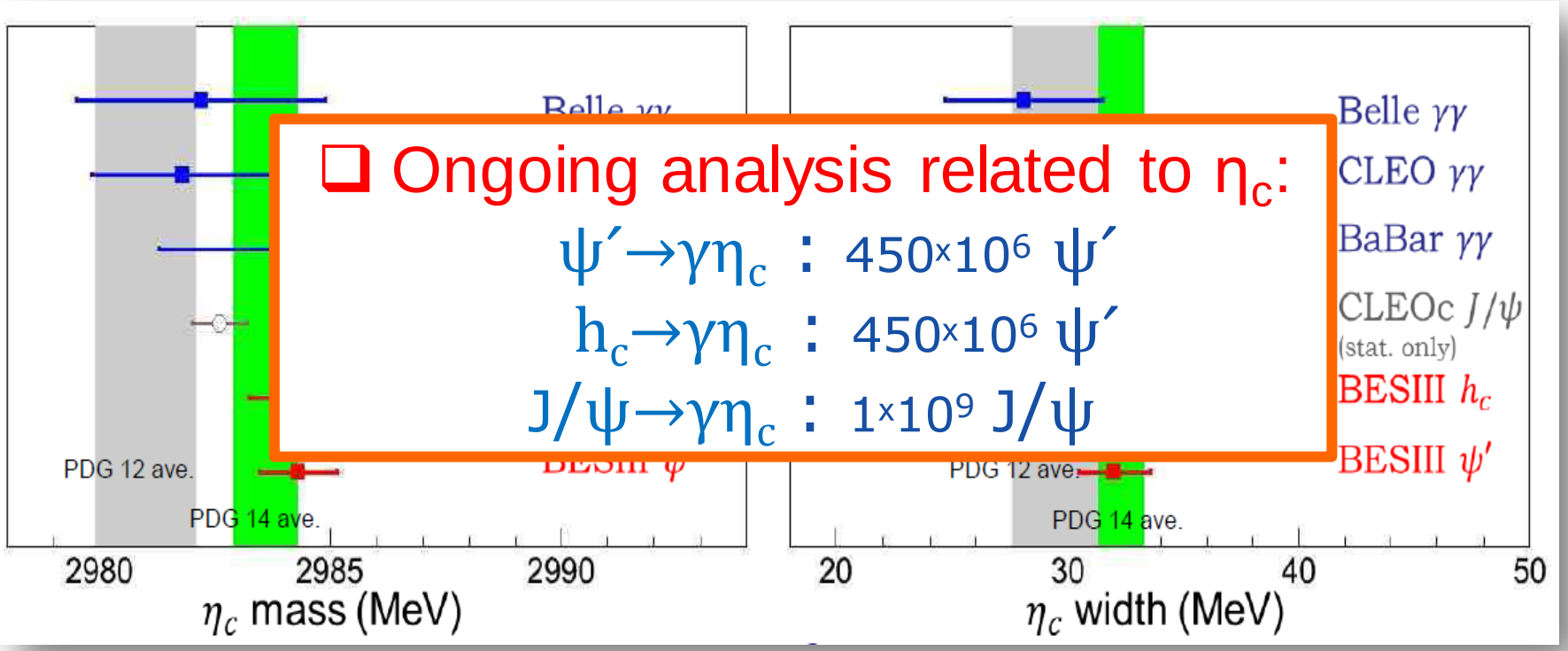
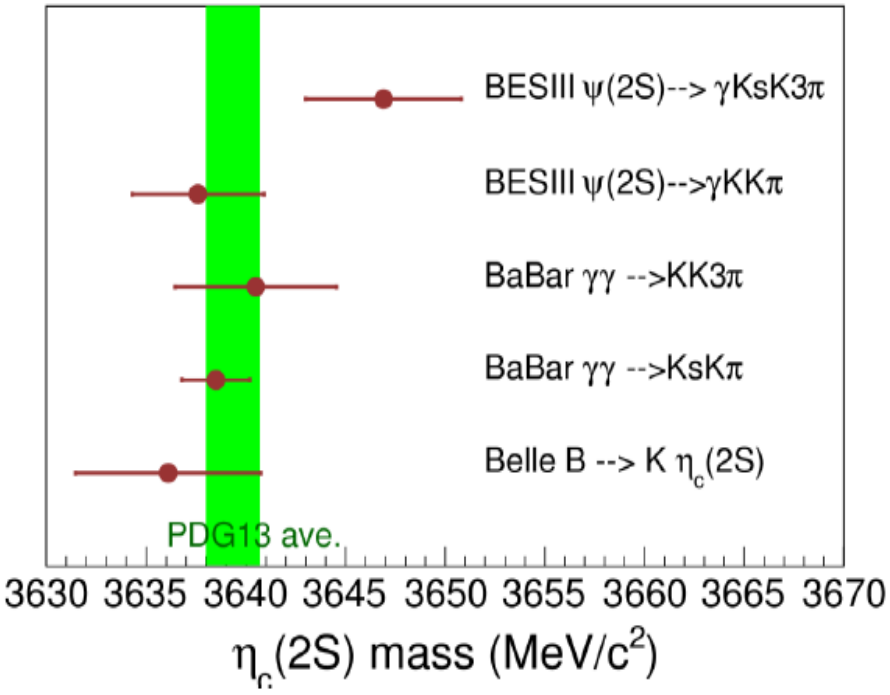


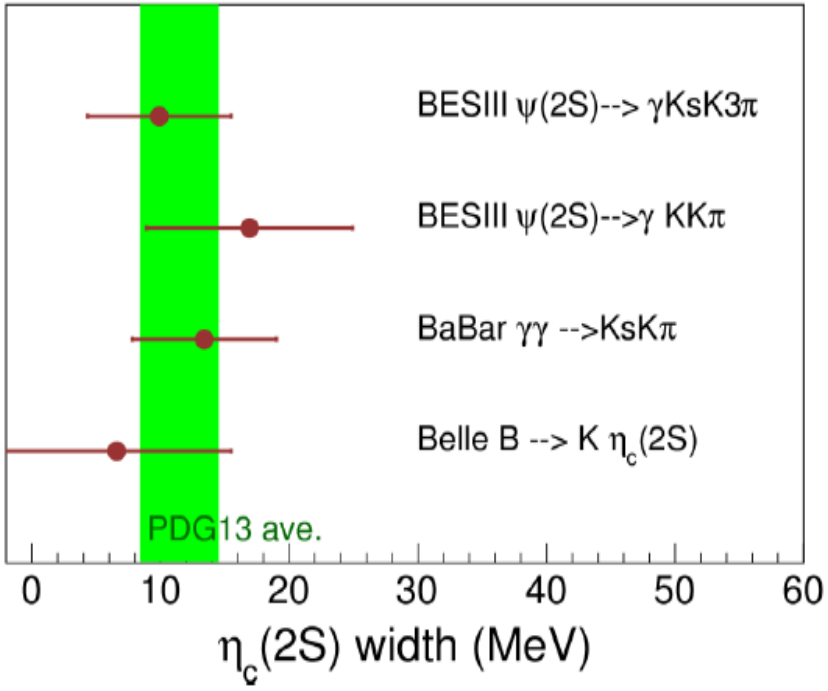
- Ongoing analysis related to η_c:
  - $\psi' \to \gamma\eta_c$: 450×10^6 ψ'
  - $h_c \to \gamma\eta_c$: 450×10^6 ψ'
  - $J/\psi \to \gamma\eta_c$: 1×10^9 J/ψ

Ke Li

Understanding the nature of interference is the key point!

Comparison in different production mechanisms:





BESIII : PRD 87 052005 (2013)

BESIII : PRL 109 042003 (2012)

BaBar : PRD 84 012004 (2011)

Belle : PLB 706 139 (2011)

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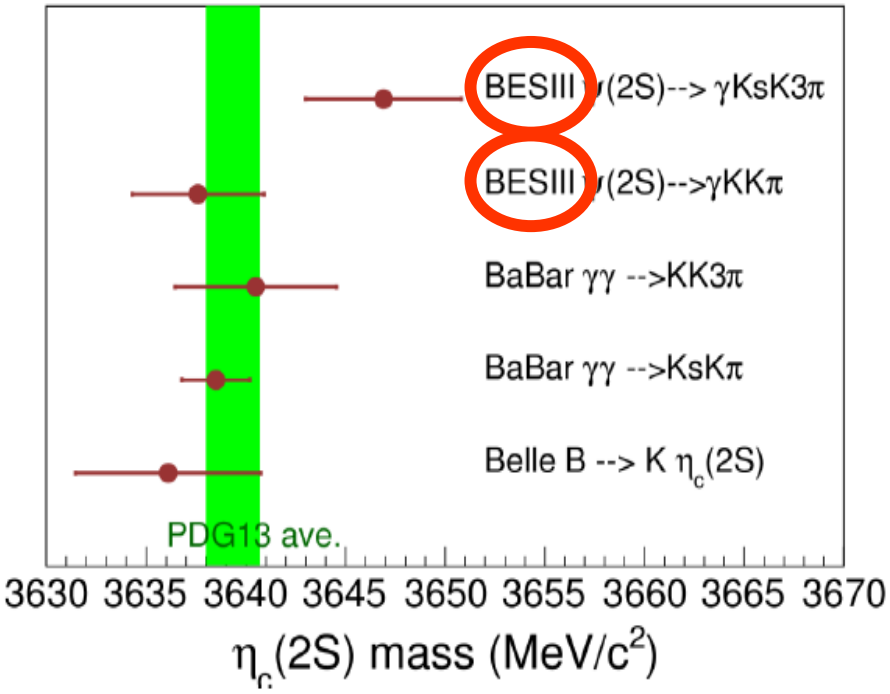
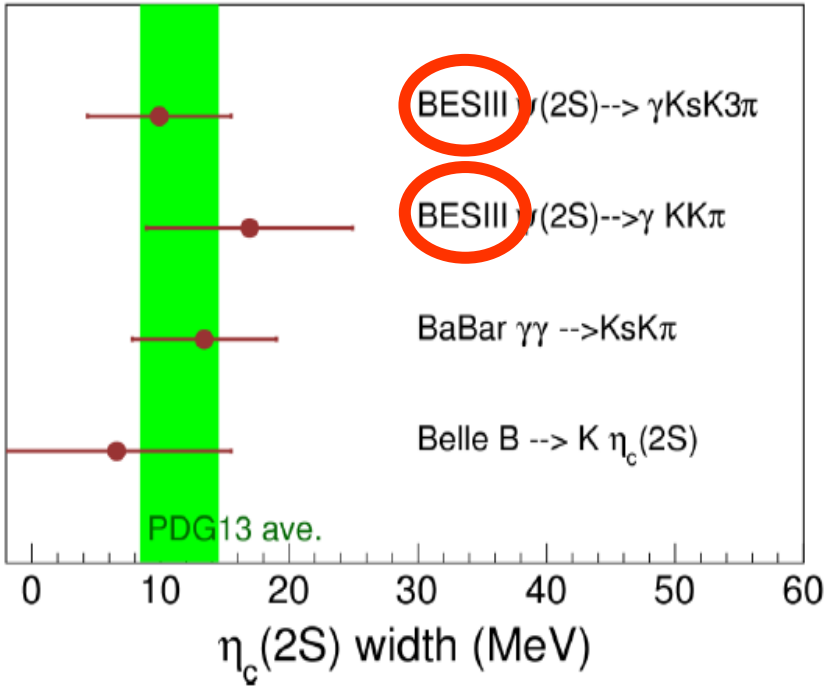
Comparison in different production mechanisms:





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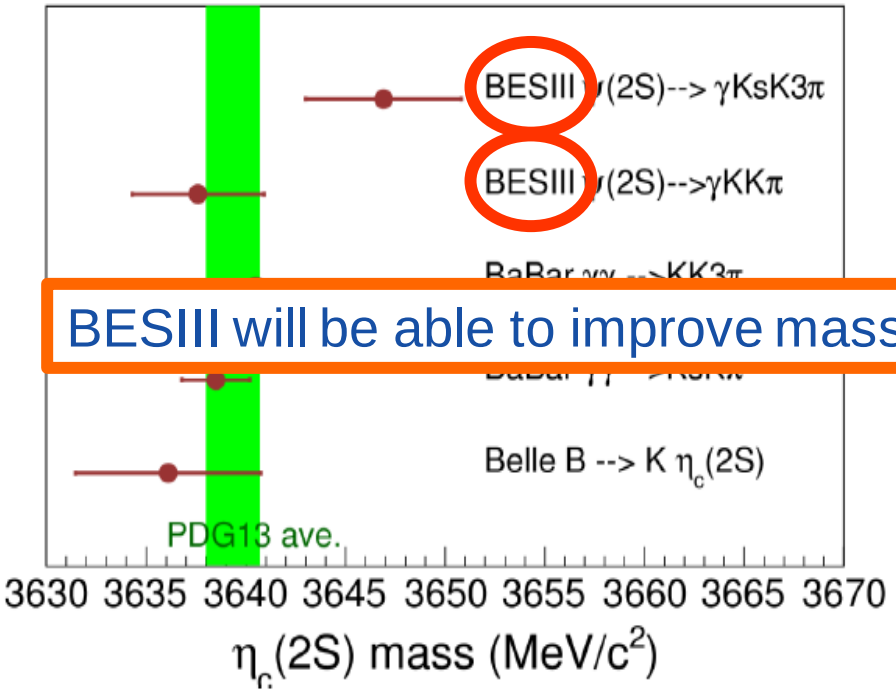

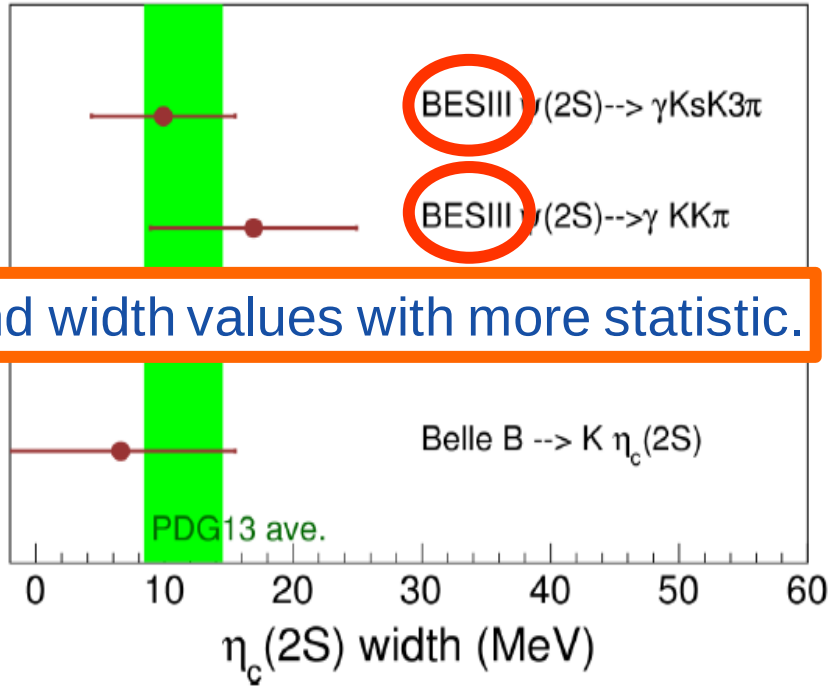

BESIII will be able to improve mass and width values with more statistic.

BESIII : PRD 87 052005 (2013)

BESIII : PRL 109 042003 (2012)

BaBar : PRD 84 012004 (2011)

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BaBar : PRD 72 031101 (2005)

Radiative partial decay widths:

- Long-standing puzzle on the radiative transition rates of J/ψ and ψ′→γη$_c$:

Initial meson	J/ψ	ψ′	ψ′
Final meson	η_c	η_c	η_c'
$\Gamma_{M1}^{NR}\ (KeV)$	2.9	9.7	0.21
$\Gamma_{exp}\ (KeV)$	1.58 ± 0.37 PDG2014	0.97 ± 0.14 CLEO-c	0.143 ± 0.027 ± 0.092 BESIII
$\Gamma_{LQCD}\ (KeV)$	2.51 ± 0.08	0.4 ± 0.8	-------

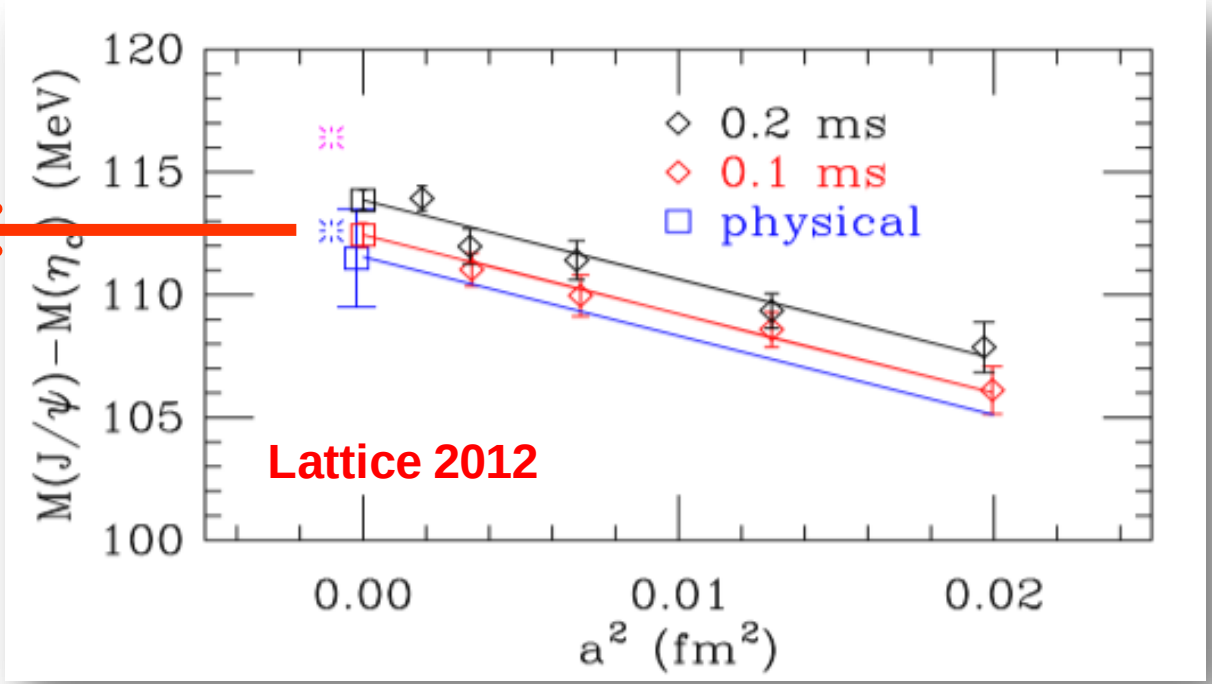
arXiv:1107.2037v2

Finding a procedure to understand interference seems crucial to be able to extract the exact values.

BES III (2012)

- $M_{\eta c}$ = 2984.3 ± 0.6 ± 0.6 MeV/c^2

BESIII



$\Delta M_{hf}(1S)$ = 112.6 ± 0.8 MeV/c^2

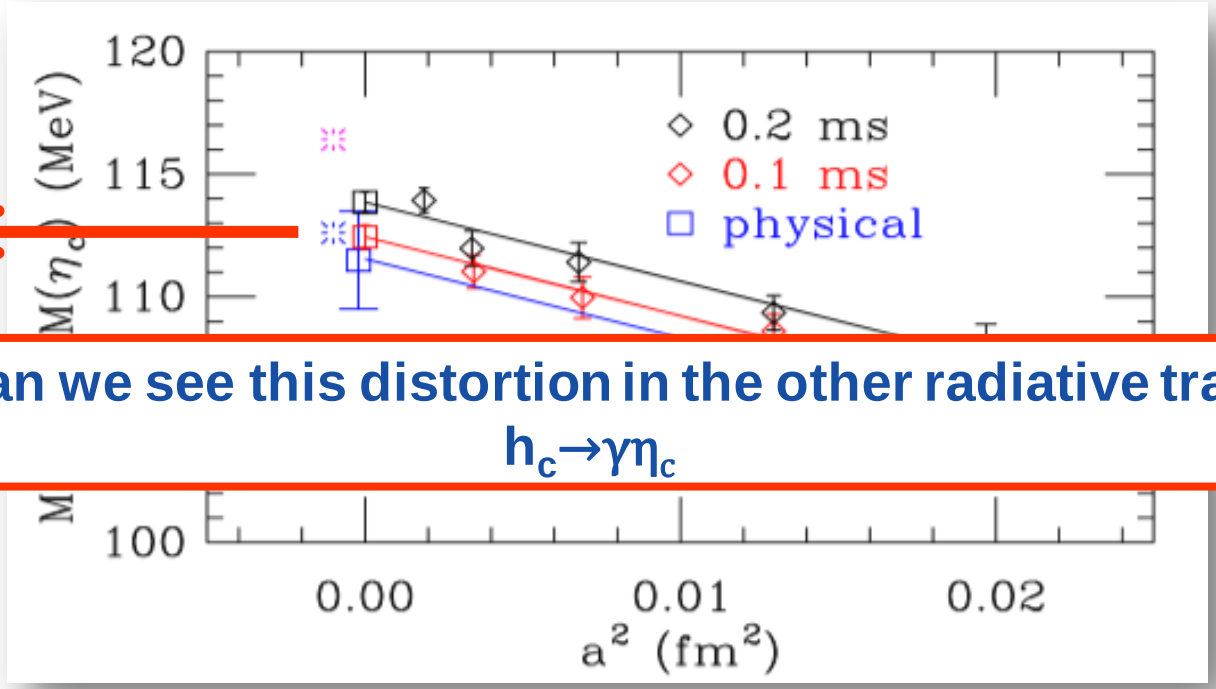
✓ **Agrees well with recent lattice computations!**

arXiv:1211.2253

BES III (2012)

- $M_{\eta c}$ = 2984.3 ± 0.6 ± 0.6 MeV/c^2

BESIII



Question : **Can we see this distortion in the other radiative transition like $h_c \rightarrow \gamma\eta_c$**

$\Delta M_{hf}(1S)$ = 112.6 ± 0.8 MeV/c^2

✓ **Agrees well with recent lattice computations!**

arXiv:1211.2253