university of groningen

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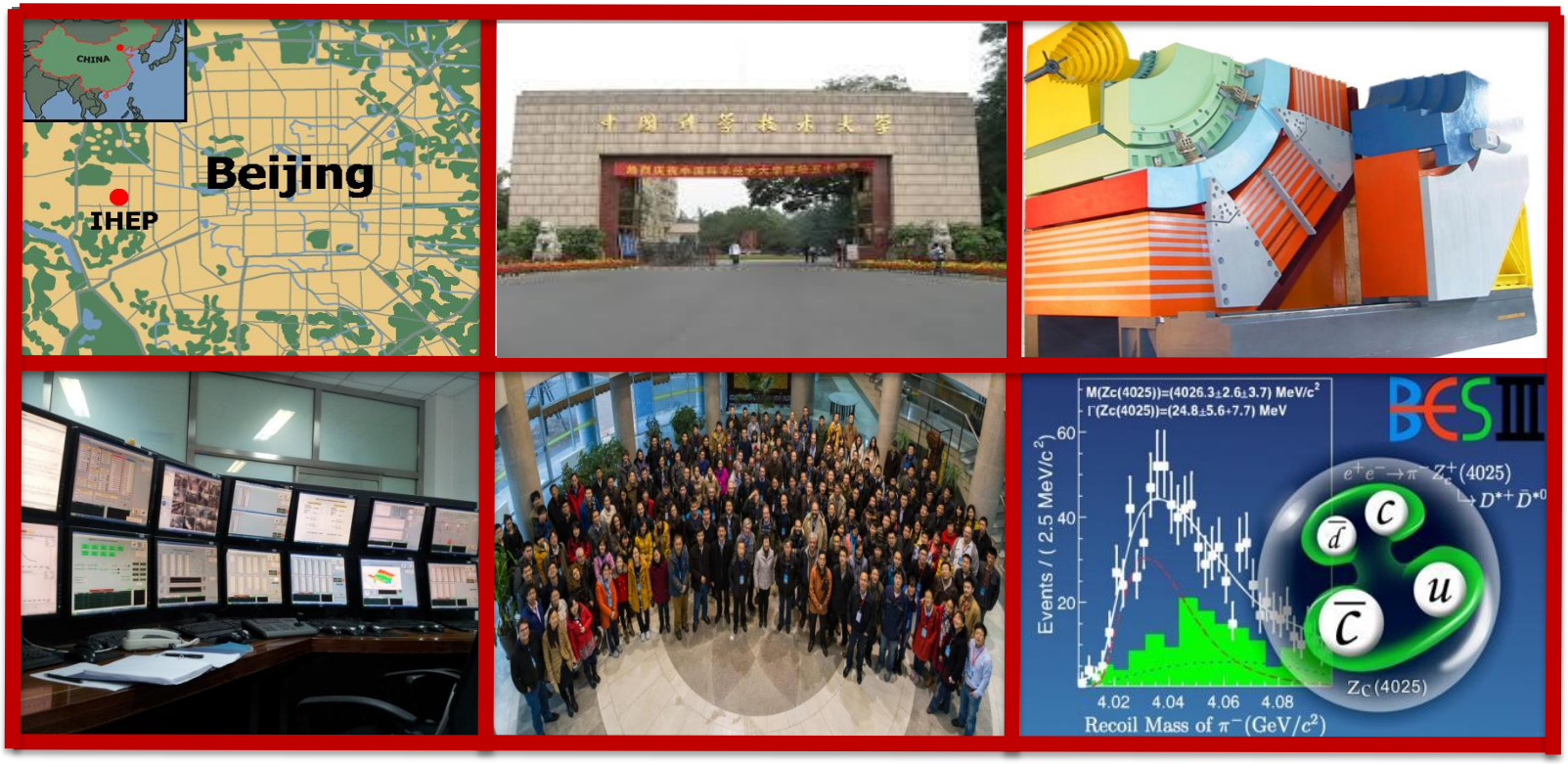
BESIII

Radiative transition studies below the open-charm threshold with BESIII



Zahra Haddadi, KVI-CART (University of Groningen)

for the BESIII collaboration

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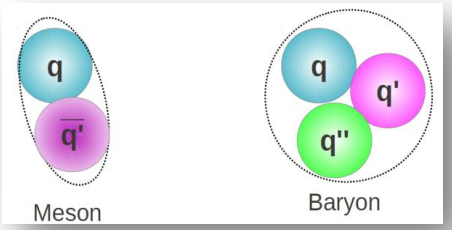
BESIII

Outline:

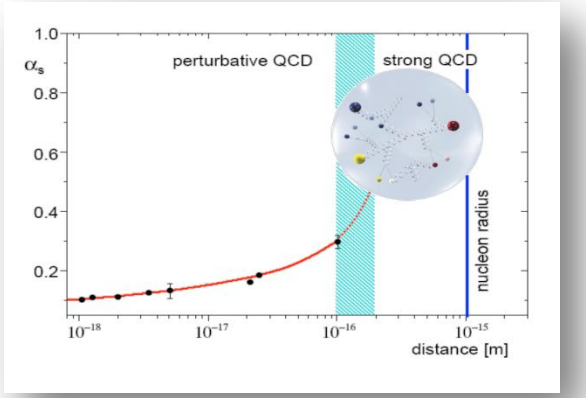
- Charmonium spectroscopy
- spin-singlet states puzzle
- BESIII & precision measurements

QCD bound systems



QCD:

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



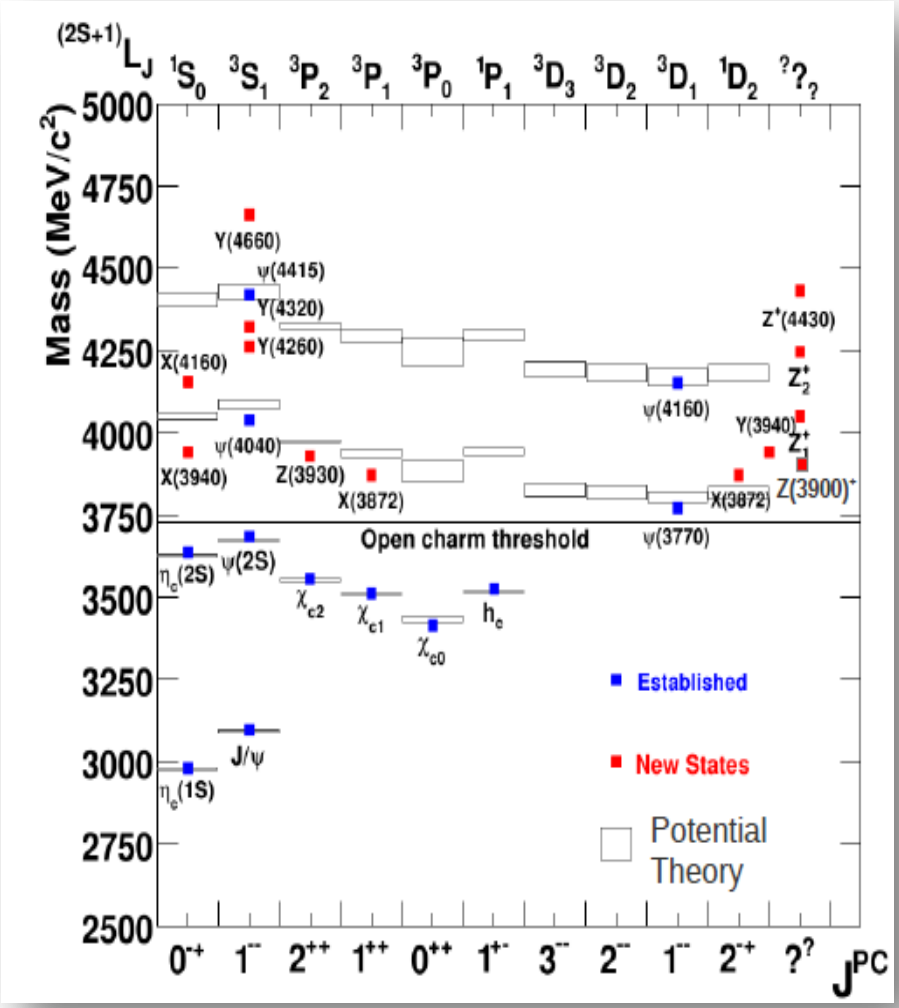
Charmonium:

- The mesonic bound state of $c\bar{c}$.
- Simplest bound state of QCD.
- $m_c \approx 1.4$ GeV : Non-relativistic potential model.

Charmonium spectroscopy:

- Precise measurements on basic properties of known states.
- Clean system to study non-perturbative QCD dynamics.

Charmonium spectrum



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

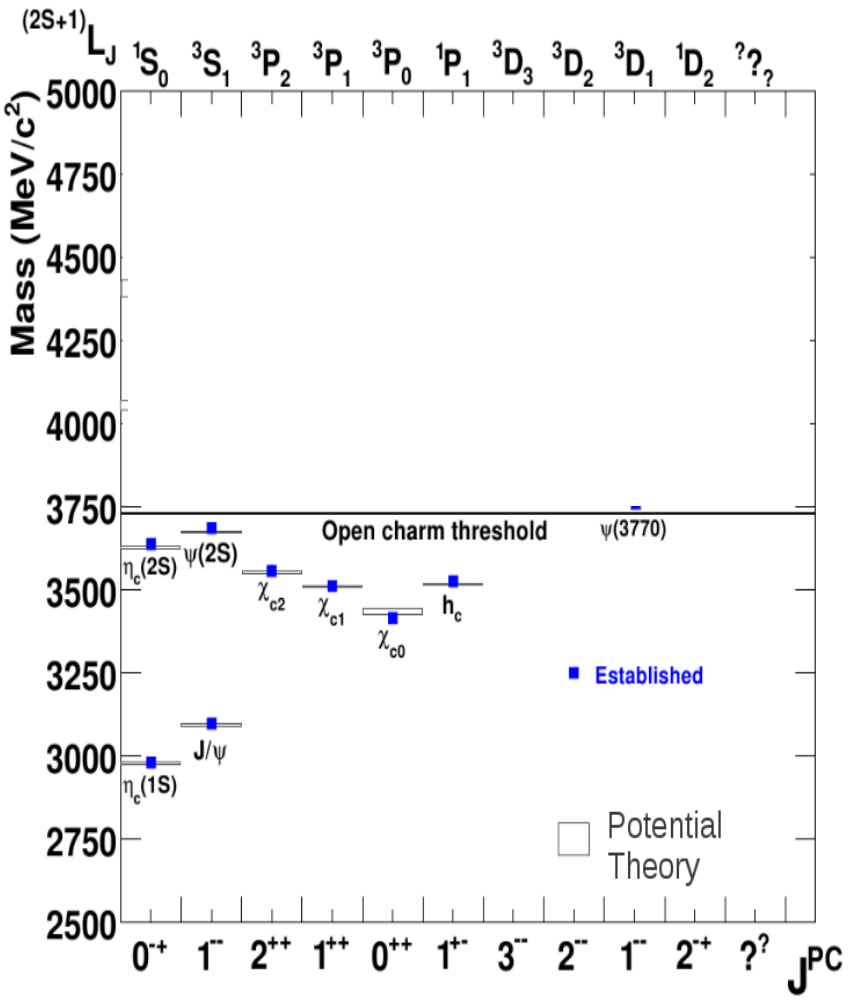
$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + \frac{32}{9}\frac{\pi\alpha_s}{m^2}\delta_\sigma(r)\ \vec{S_c}.\vec{S_{\bar{c}}}$$

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

- **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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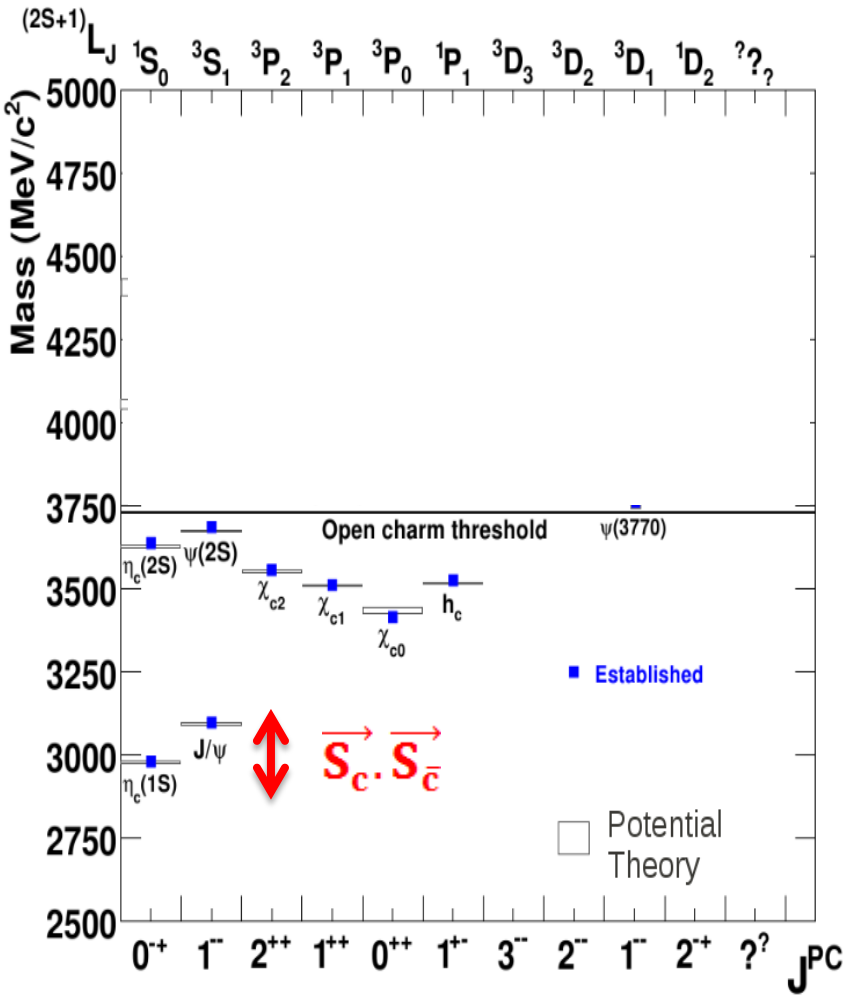

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Experiment

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

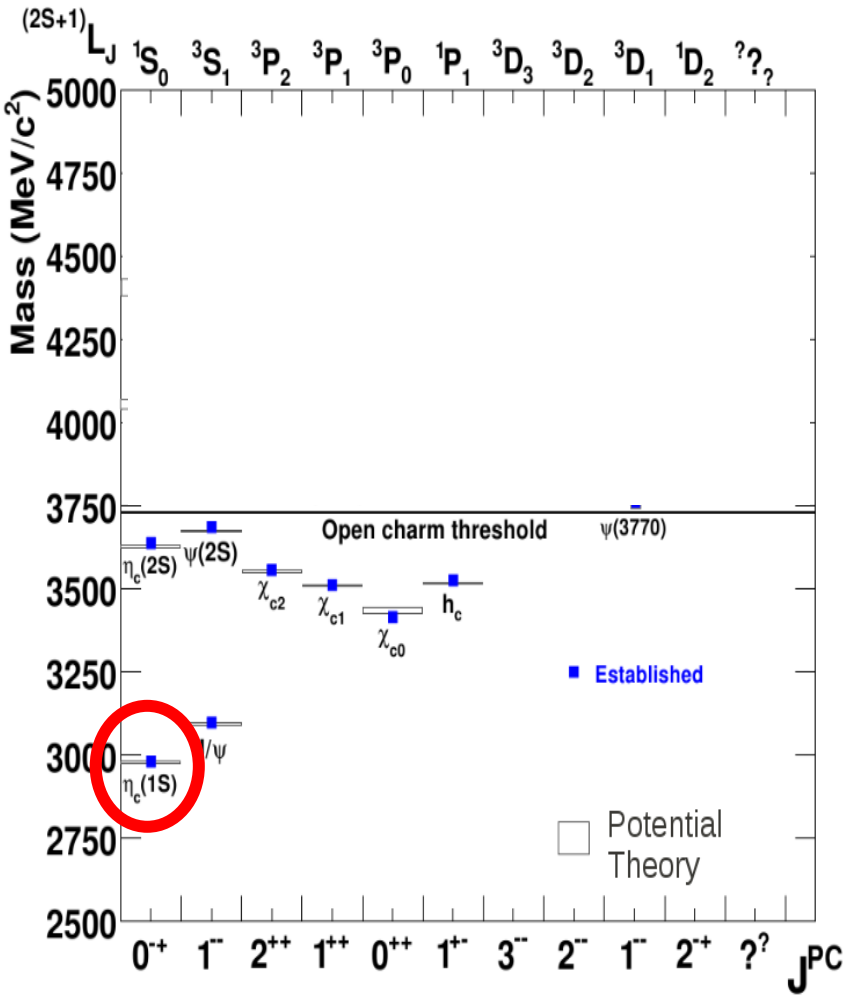
$$\Delta M(1S) = M(J/\psi) - M(\eta_c)$$

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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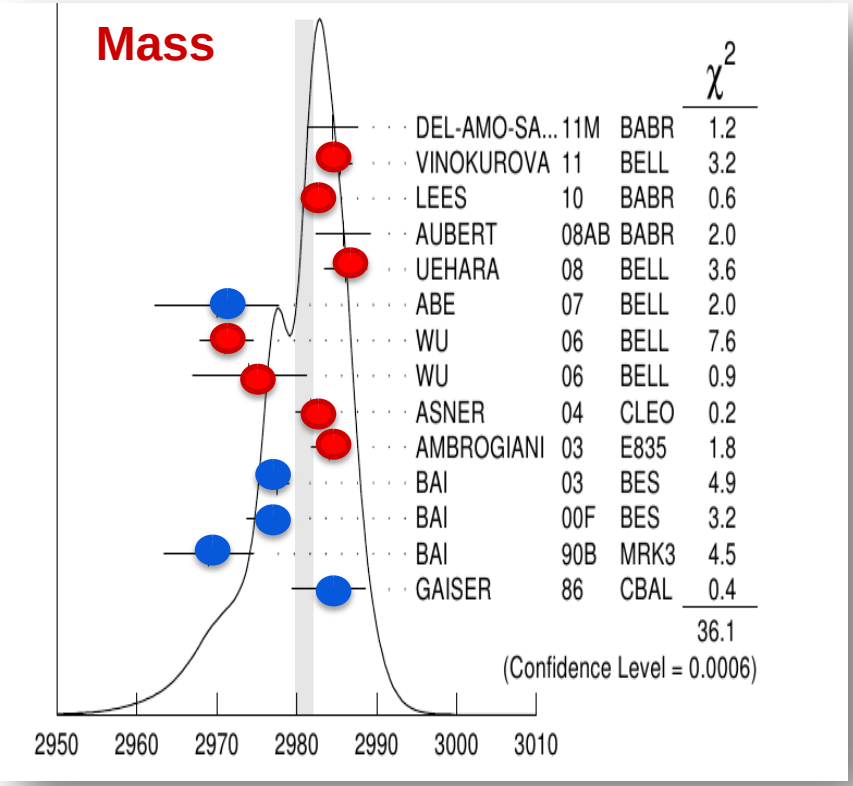
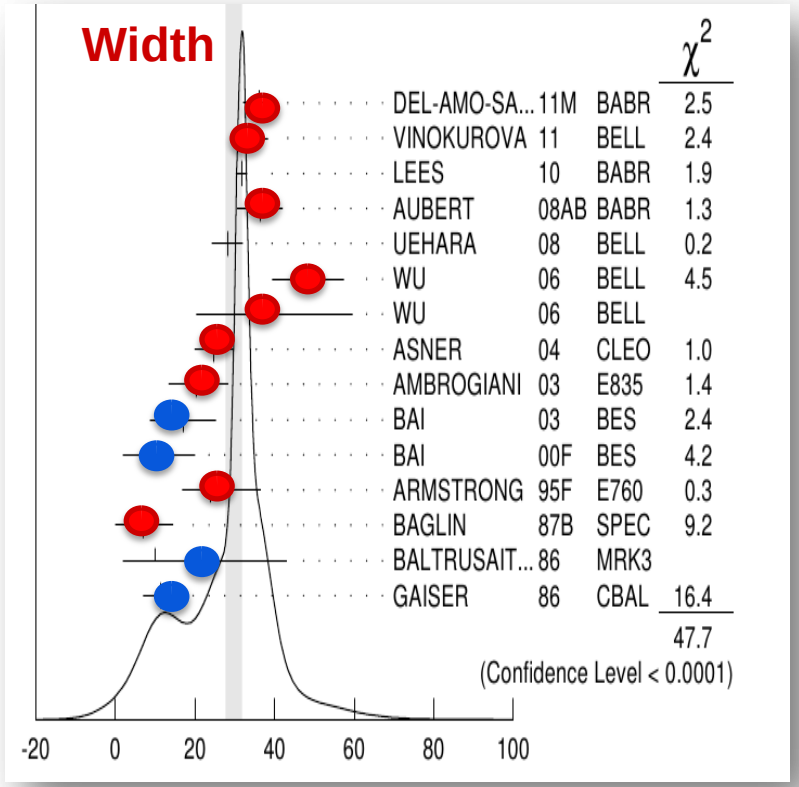
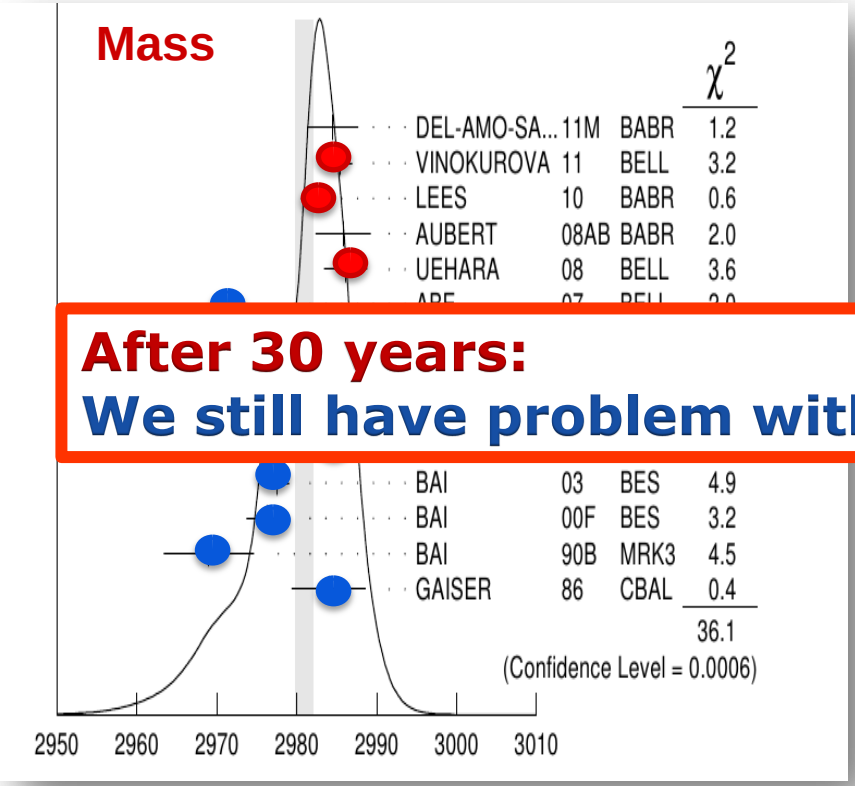
Mass & Width of the ground state: η_c

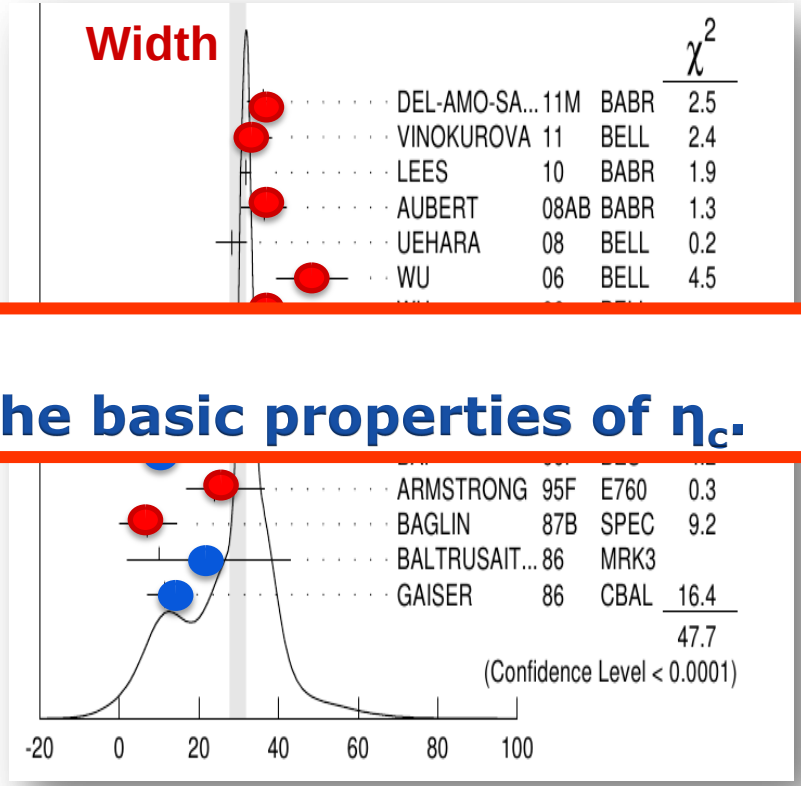




- radiative transition
- $\gamma\gamma$ processes, $p\bar{p}$, $B \to K\eta_c$

Mass & width of the ground state: η_c

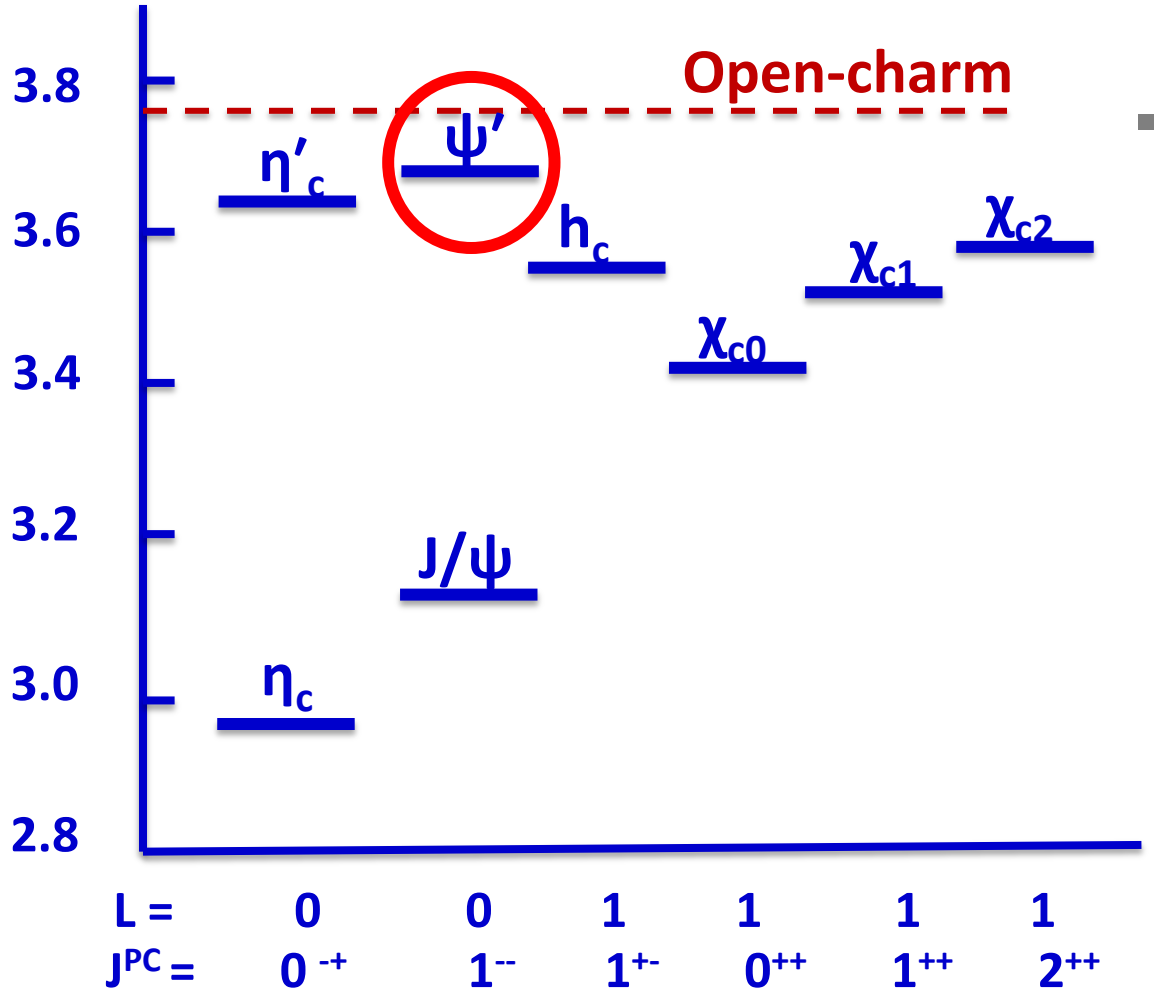




After 30 years:
We still have problem with the basic properties of η_c.

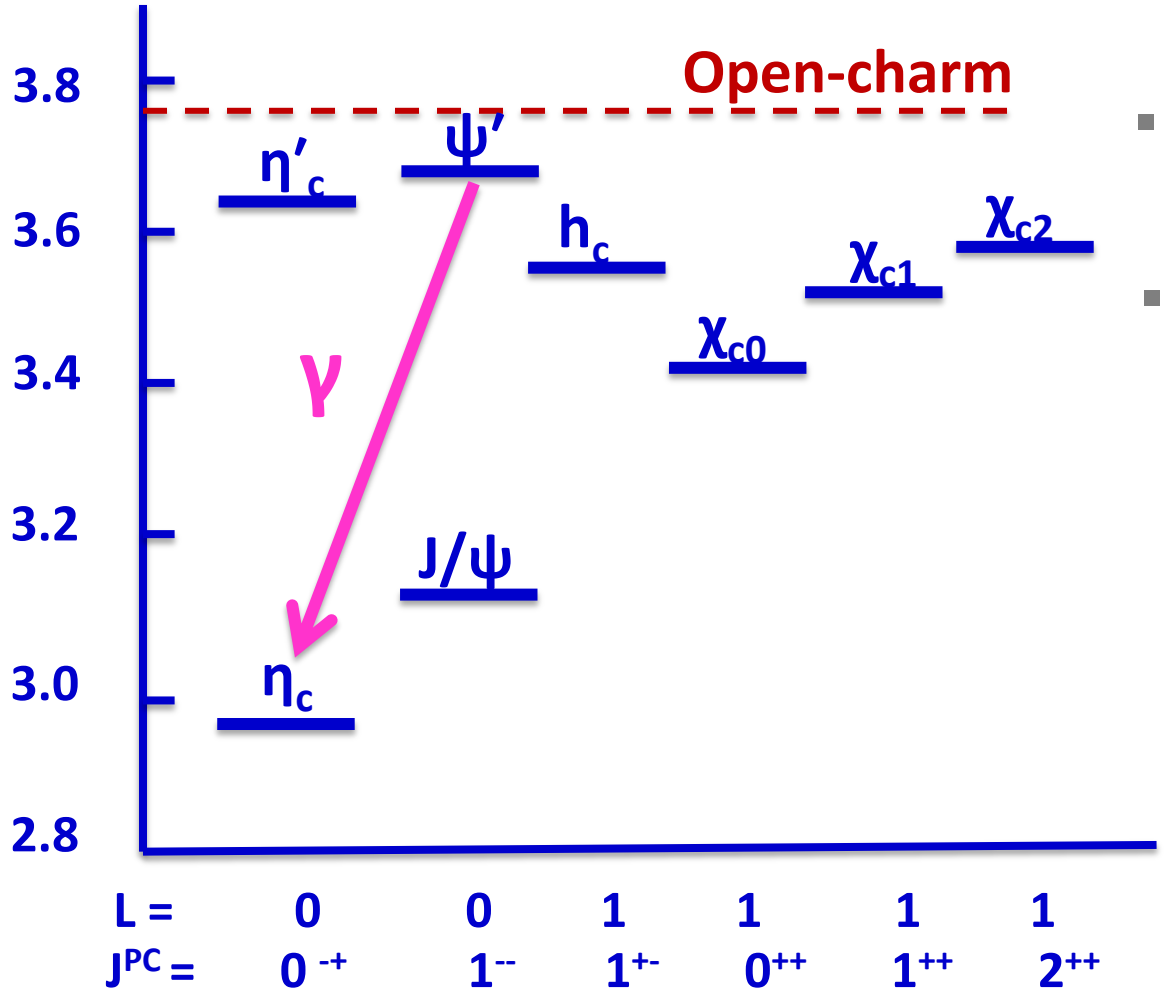
- radiative transition
- $\gamma\gamma$ processes, $p\bar{p}$, $B \to K\eta_c$

η_c studies from e^+e^- annihilation



- **ψ′ decay & e^+e^- annihilation:** clean and simple environment

η_c studies from e^+e^- annihilation

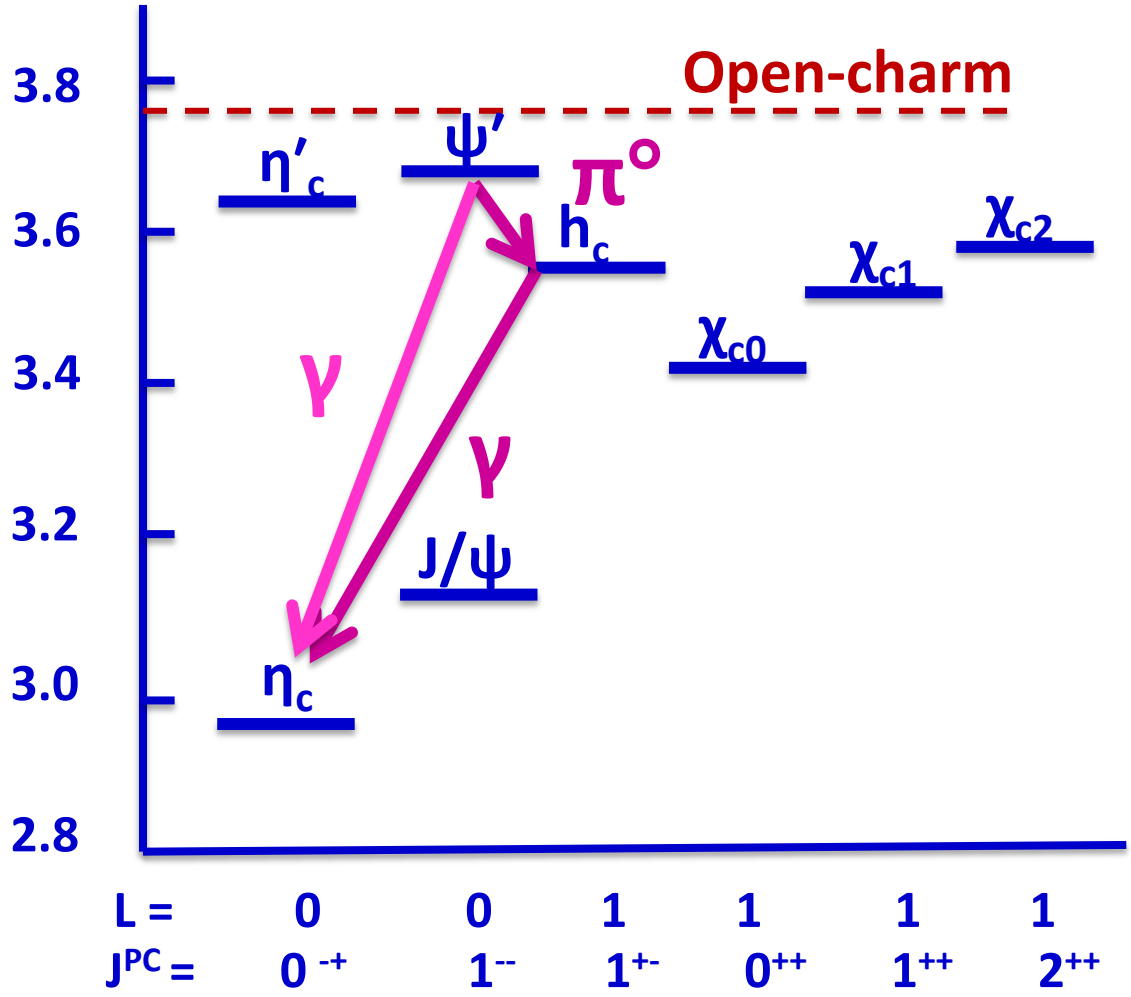


- **ψ' decay & e^+e^- annihilation:** clean and simple environment
- **η_c:** Mass and width and lineshape

  $\psi' \rightarrow \gamma\eta_c$

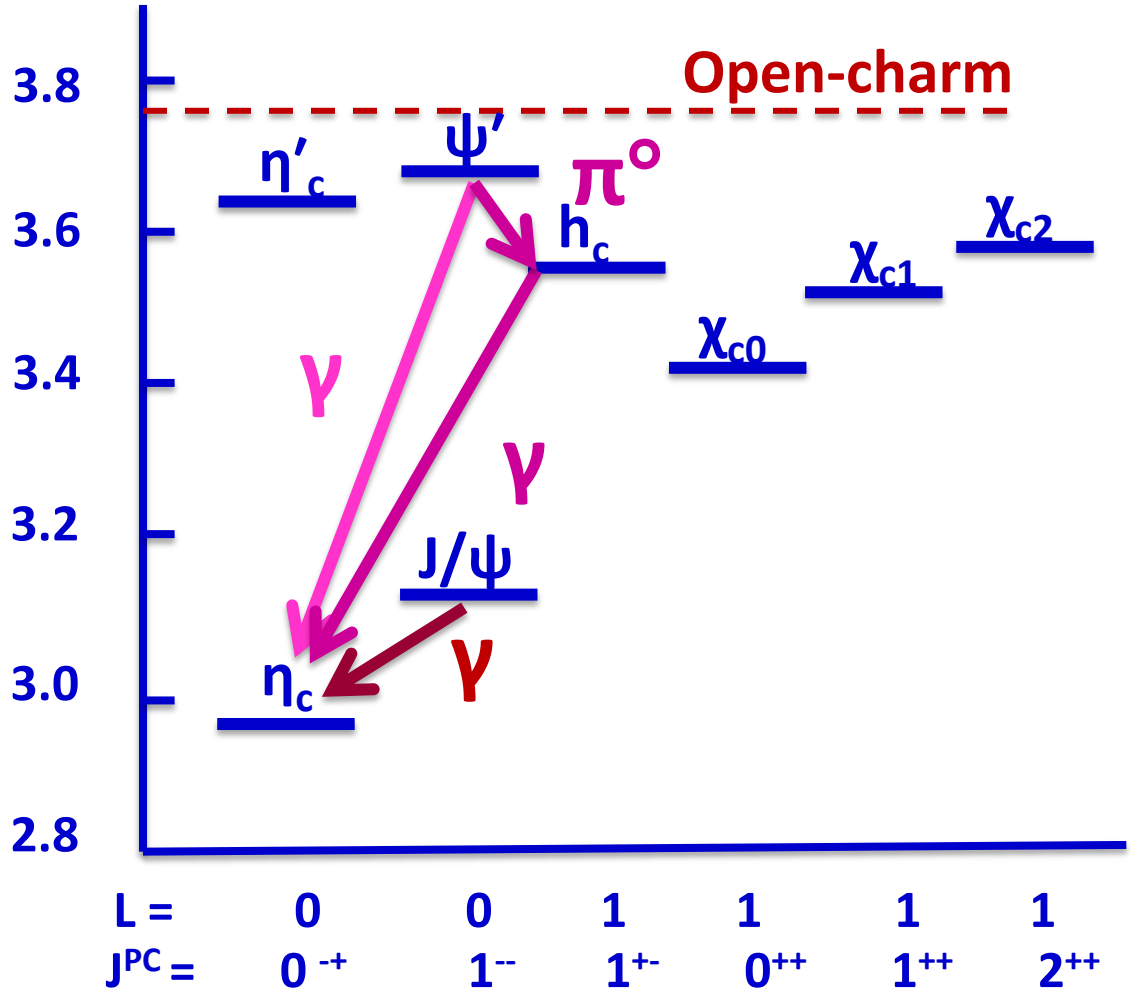
  suppressed M1 transition!

η_c studies from e^+e^- annihilation



- **ψ' decay & e^+e^- annihilation:** clean and simple environment
- **η_c:** Mass and width and lineshape
  - $\psi' \to \gamma\eta_c$ **suppressed M1 transition!**
  - $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ **Isospin forbidden!**

η_c studies from e^+e^- annihilation



- **ψ′ decay & e^+e^- annihilation:** clean and simple environment
- **η_c:** Mass, width and lineshape

  $\psi' \to \gamma\eta_c$

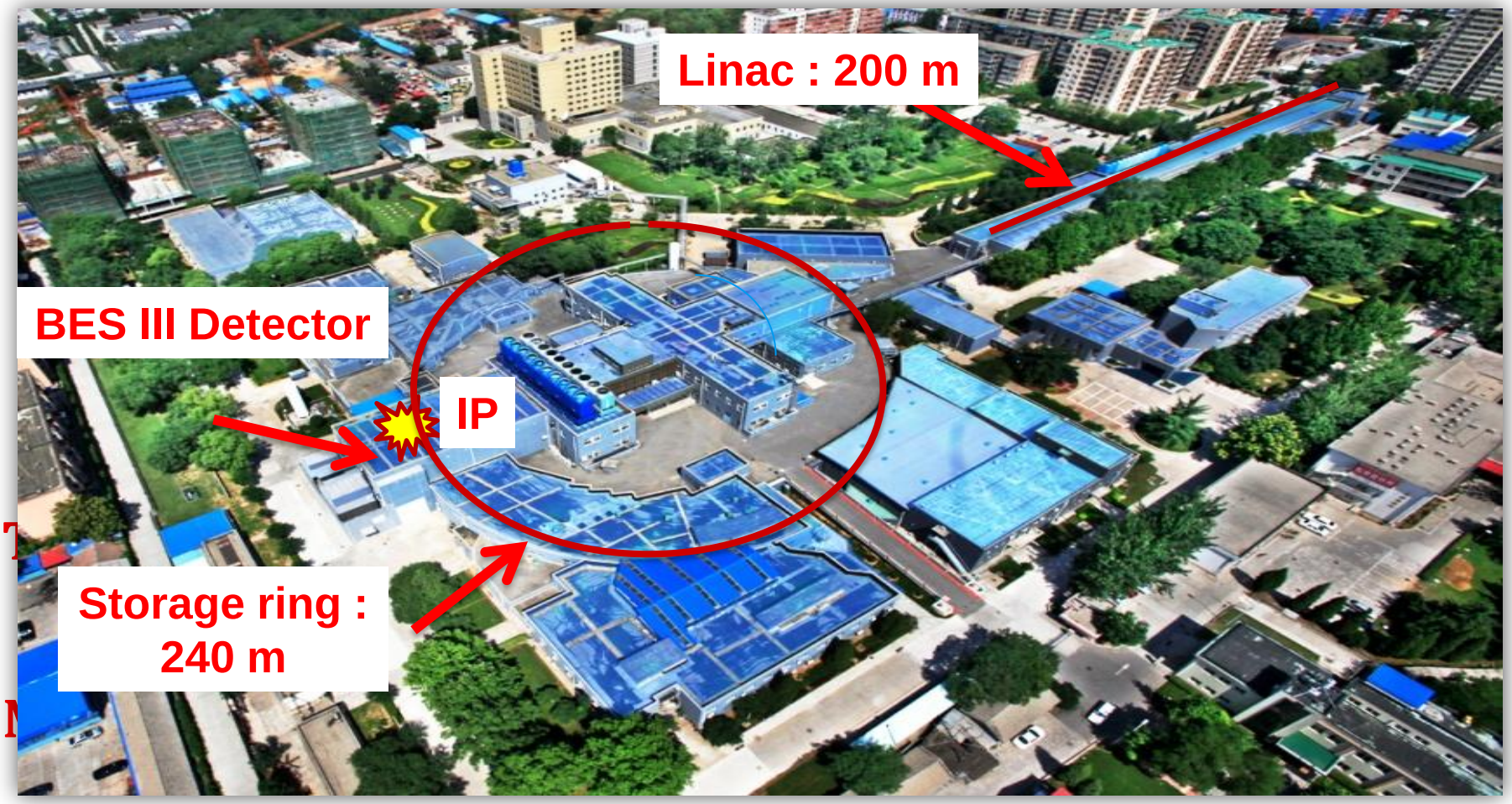
  Suppressed M1 transition!

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

  Isospin forbidden!

  $J/\psi \to \gamma\eta_c$

  Suppressed M1 transition!


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

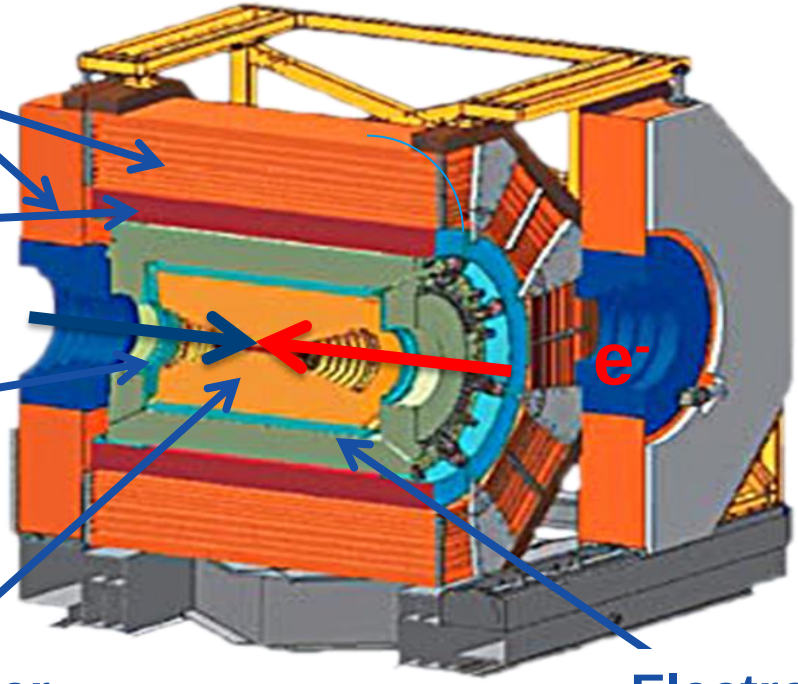
BESIII: BEijing Spectrometer (BES)

Magnet Yoke

SC magnet : 1T

e^+

Time of flight



Main drift chamber

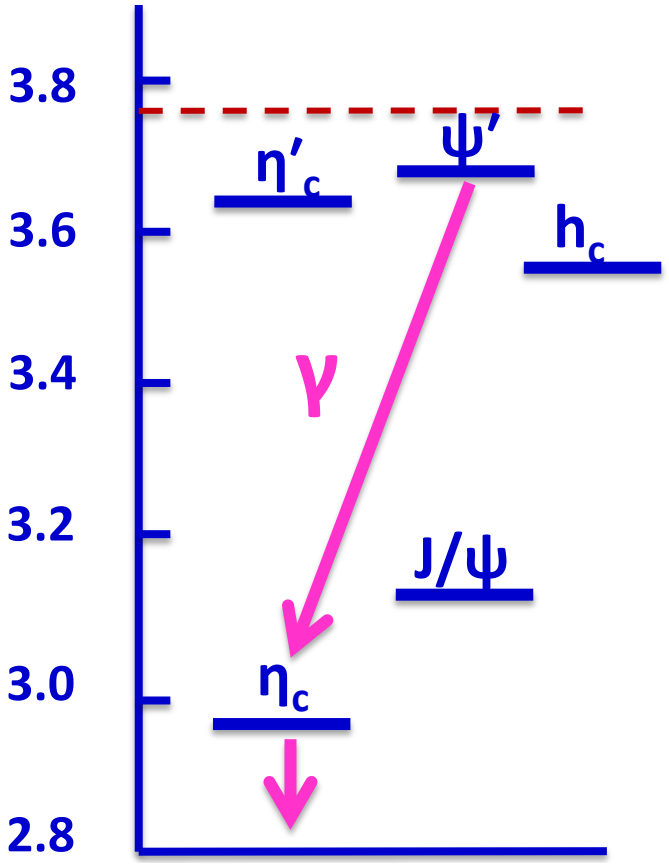
Electromagnetic Calorimeter

Collected data by BESIII

By the end of 2012 :
450×10^6 ψ′

We are well equipped for measuring these transitions.

$\psi' \to \gamma \eta_c$

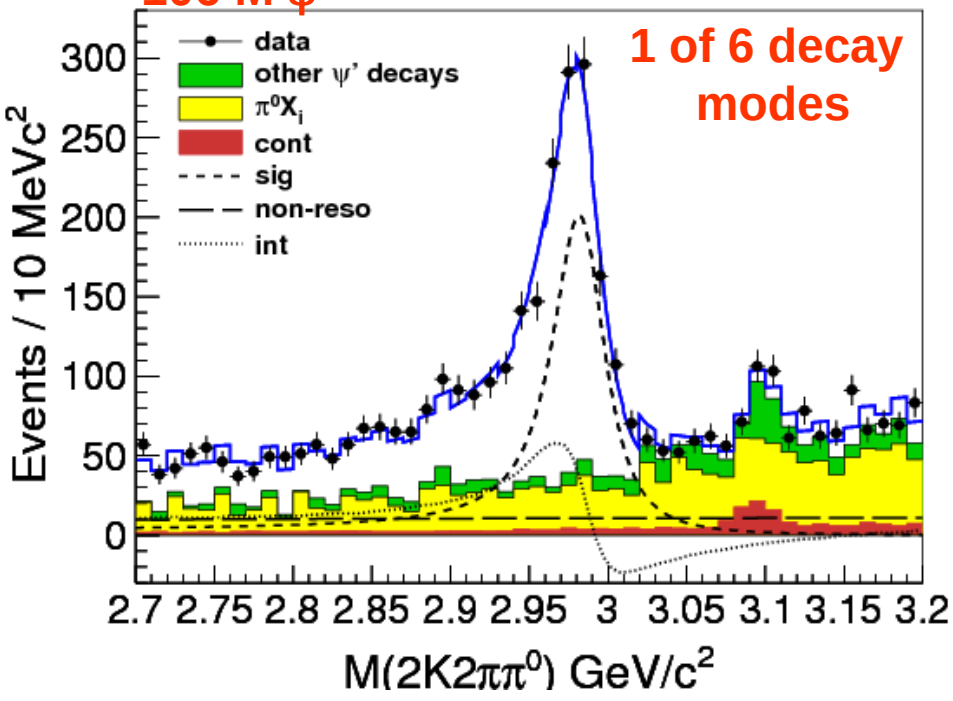


6 exclusive decay modes

BES III (2012)

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

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)

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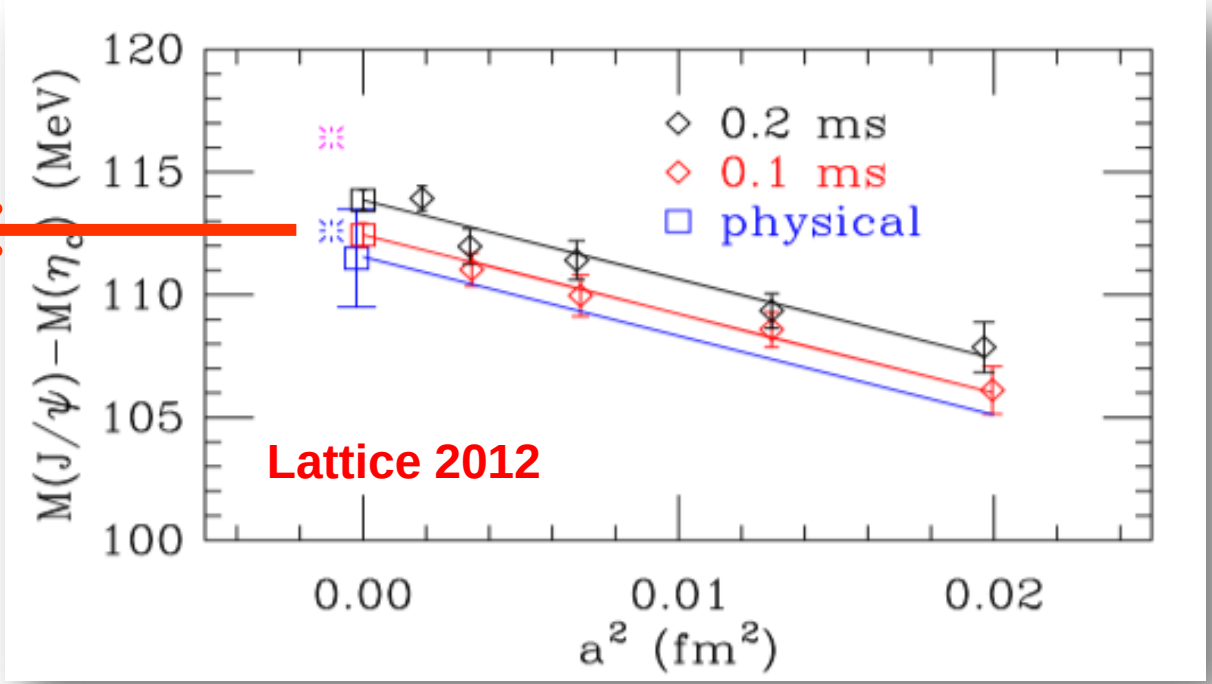
BESIII



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

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

arXiv:1211.2253

BES III (2012)

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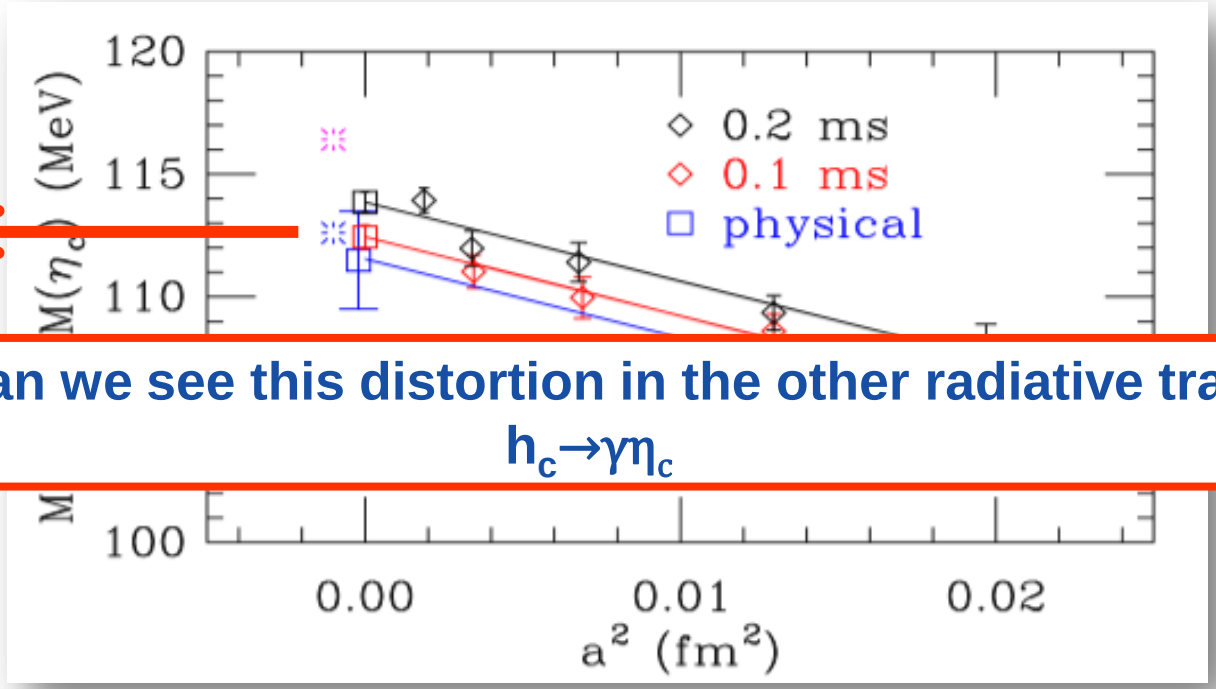
BESIII



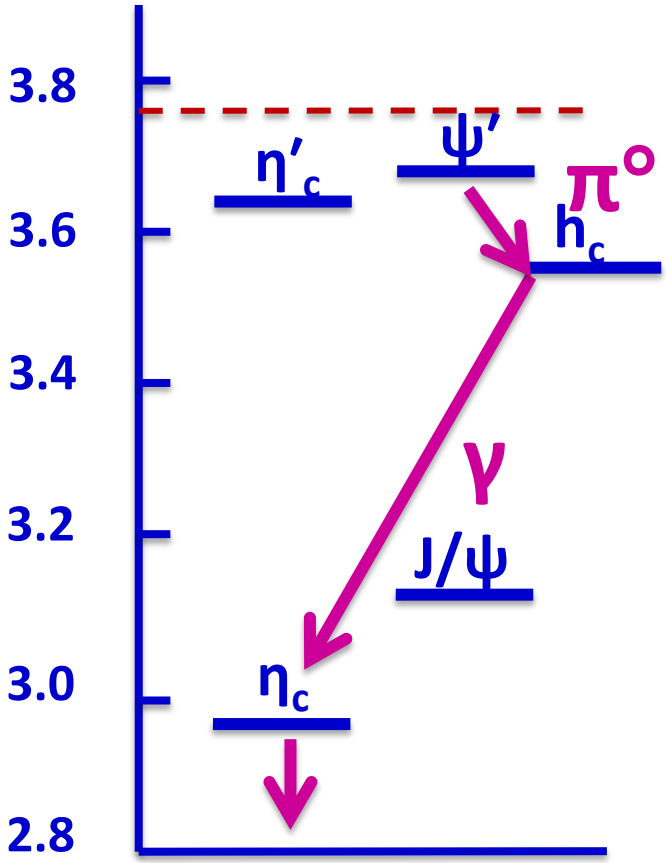
Question : **Can we see this distortion in the other radiative transition like $h_c \rightarrow \gamma\eta_c$**

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

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

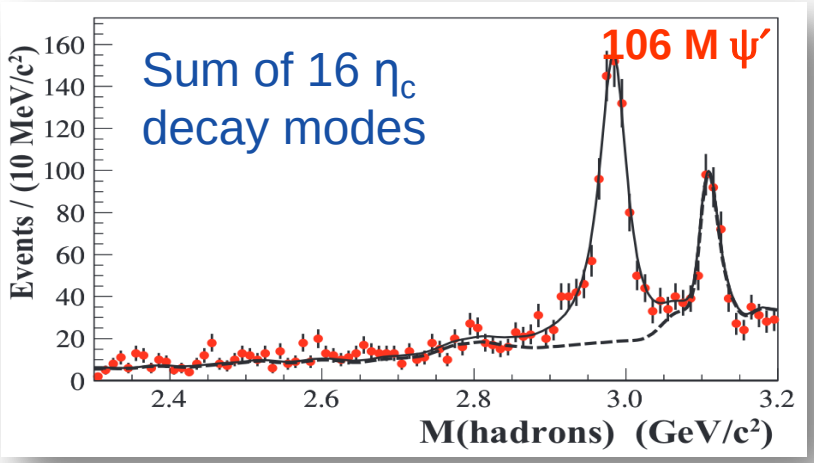
arXiv:1211.2253

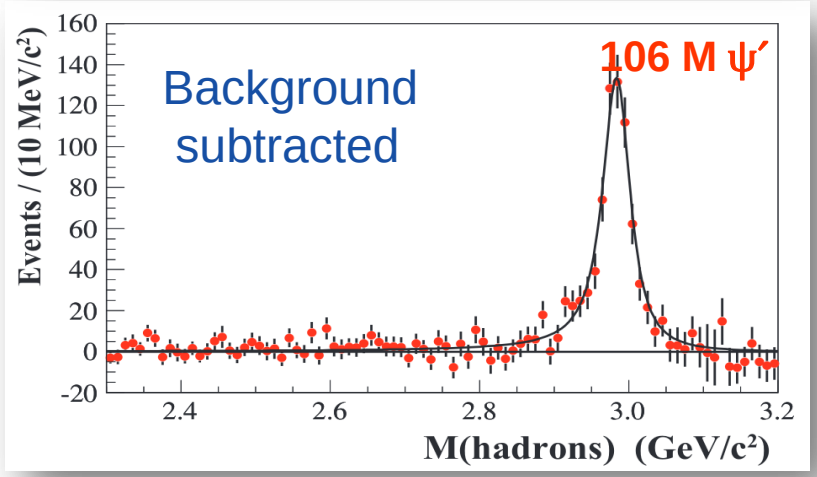
$\psi' \to \pi^0 h_c,\ h_c \to \gamma \eta_c$



16 exclusive decay modes

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





$B(\psi' \to \gamma\eta_c) = 0.3\%$

$B(h_c \to \gamma\eta_c) = 50\%$

- Weaker interference
- Larger amplitude

Signal can be described by a simple Breit-Wigner

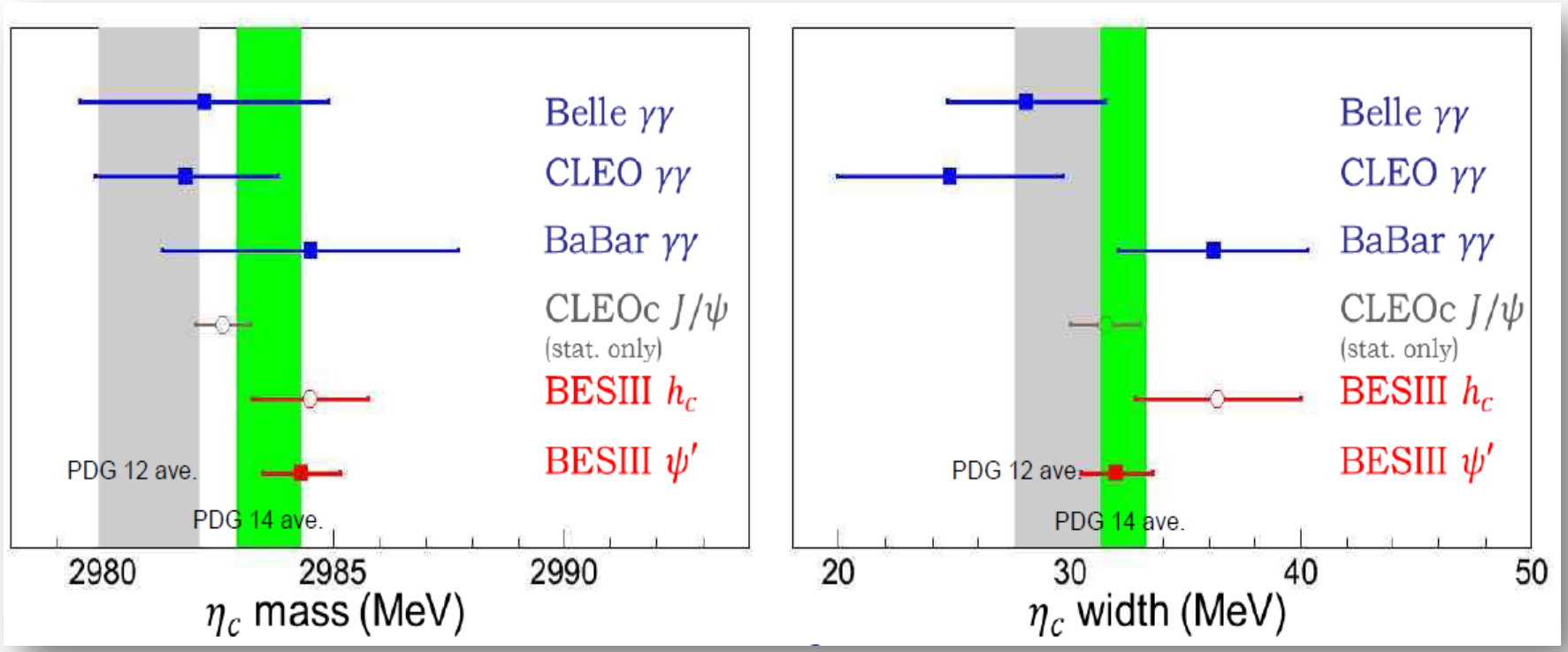
- $M_{\eta c} = 2984.40 \pm 1.16 \pm 0.52$ MeV/c^2
- $\Gamma_{\eta c} = 36.4 \pm 3.2 \pm 1.7$ MeV

PRD 86,092009

- compared with the result from $\psi' \to \gamma\eta_c$:
- $M_{\eta c} = 2984.3 \pm 0.6 \pm 0.6$ MeV/c^2
- $\Gamma_{\eta c} = 32.0 \pm 1.2 \pm 1.0$ MeV

Statistic error is dominated!

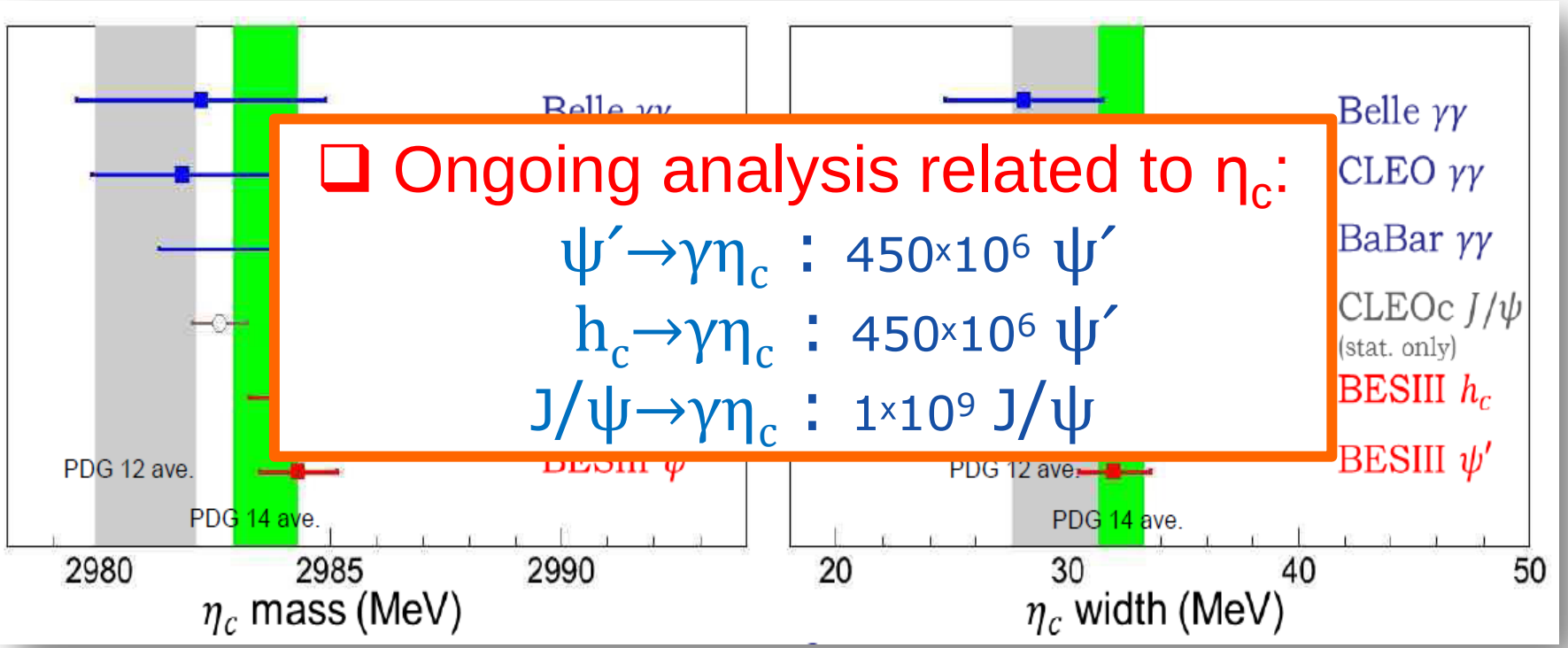
Comparison of the latest results:



Ke Li

Understanding the nature of interference is the key point!

Comparison of the latest results:

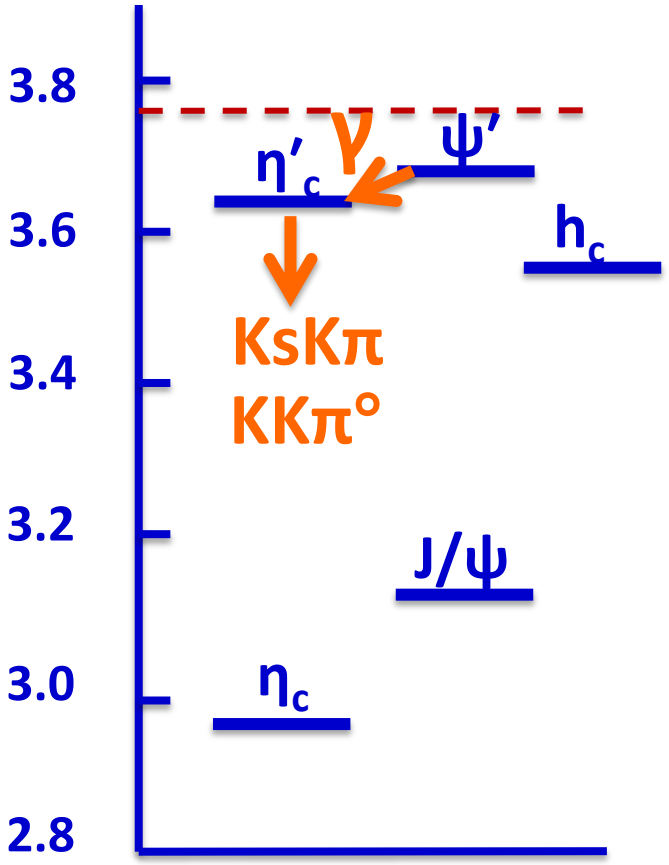


- Ongoing analysis related to η_c:
  - $\psi' \to \gamma\eta_c$: 450×10^6 ψ'
  - $h_c \to \gamma\eta_c$: 450×10^6 ψ'
  - $J/\psi \to \gamma\eta_c$: 1×10^9 J/ψ

Ke Li

Understanding the nature of interference is the key point!

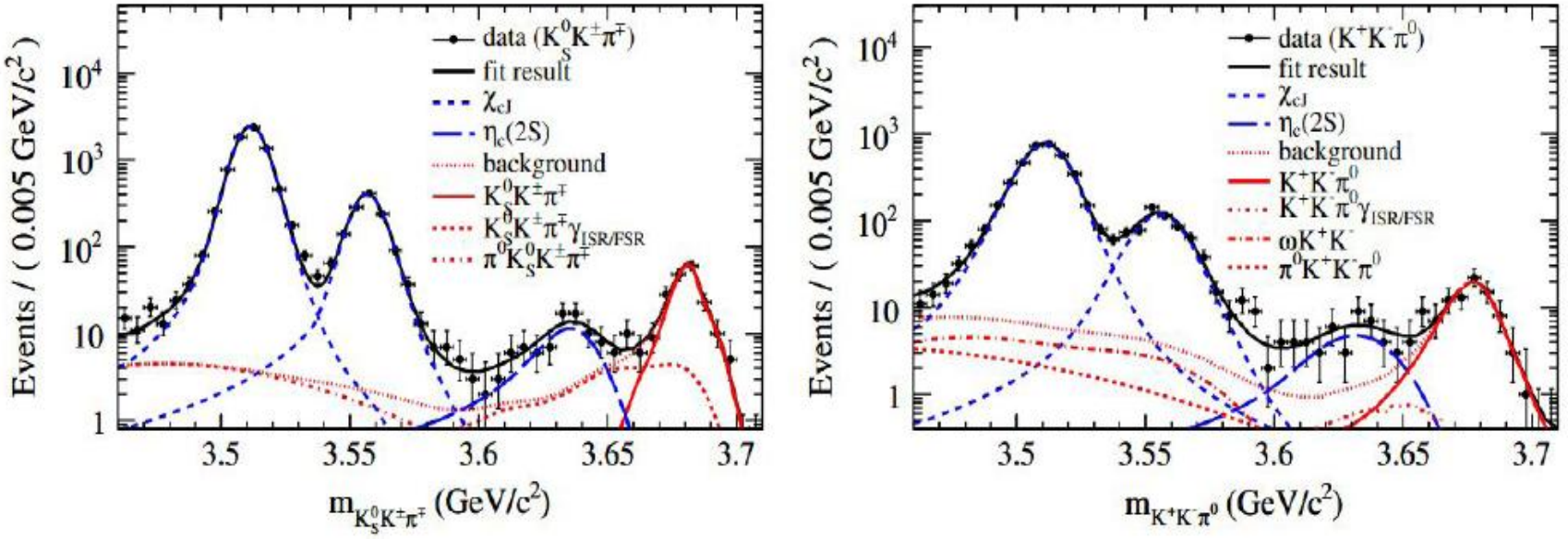
$\psi' \to \gamma \eta_c'$



First observation of the ψ′→γη′

Experimental challenge : search for photon of 50 MeV.

Found no signal : CLEOc (25M ψ′)



Signal : Significance is larger than 10σ

- $M_{\eta c'}$ = 3637.6 ± 2.9 ± 1.6 MeV/c^2
- $\Gamma_{\eta c'}$ = 16.9 ± 6.4 ± 4.8 MeV

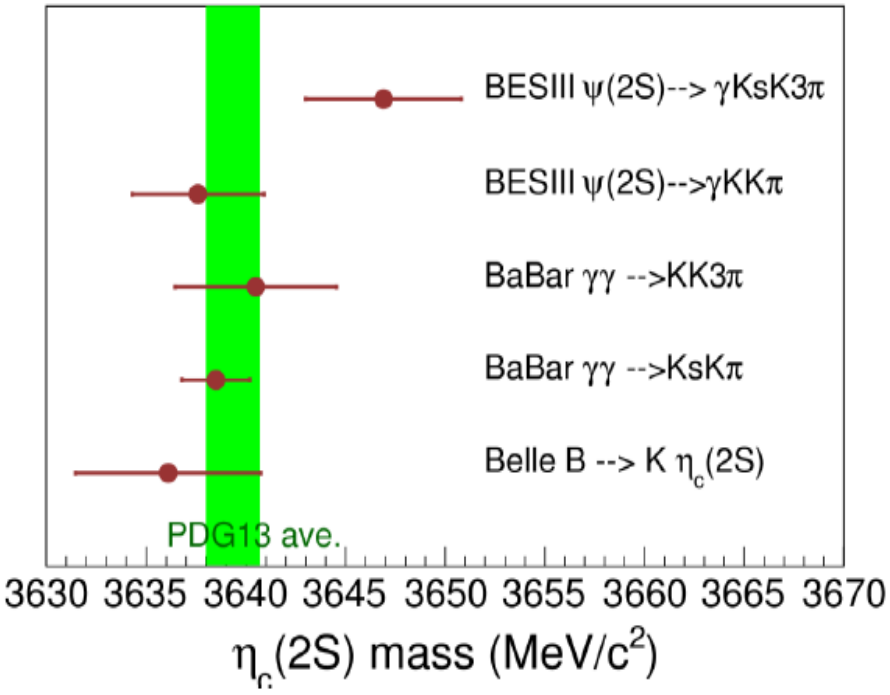
PRL 109, 042003 (2012)

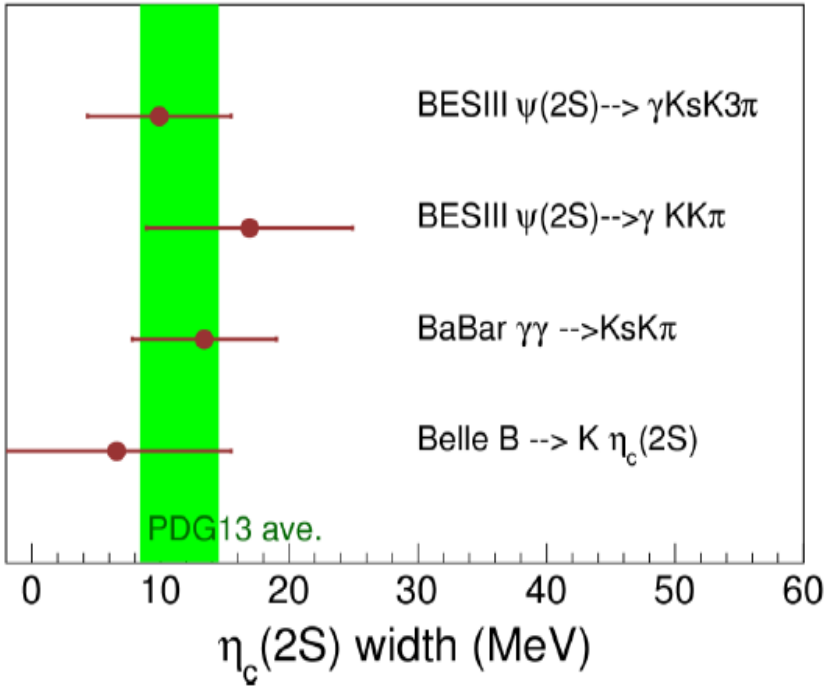
$B(\psi' \to \gamma \eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$

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

PRD81, 052002 (2012)

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)

BaBar : PRD 72 031101 (2005)

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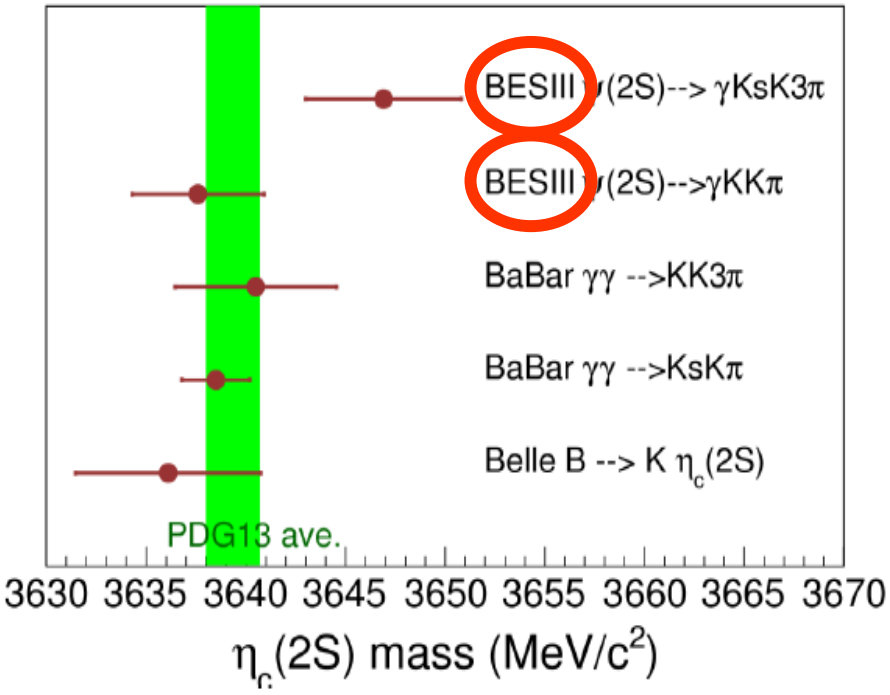

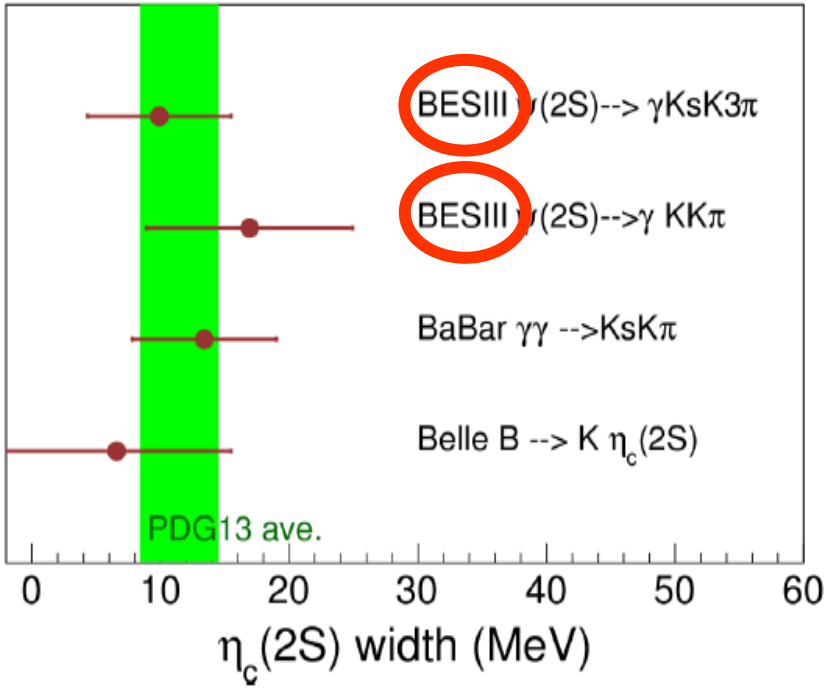

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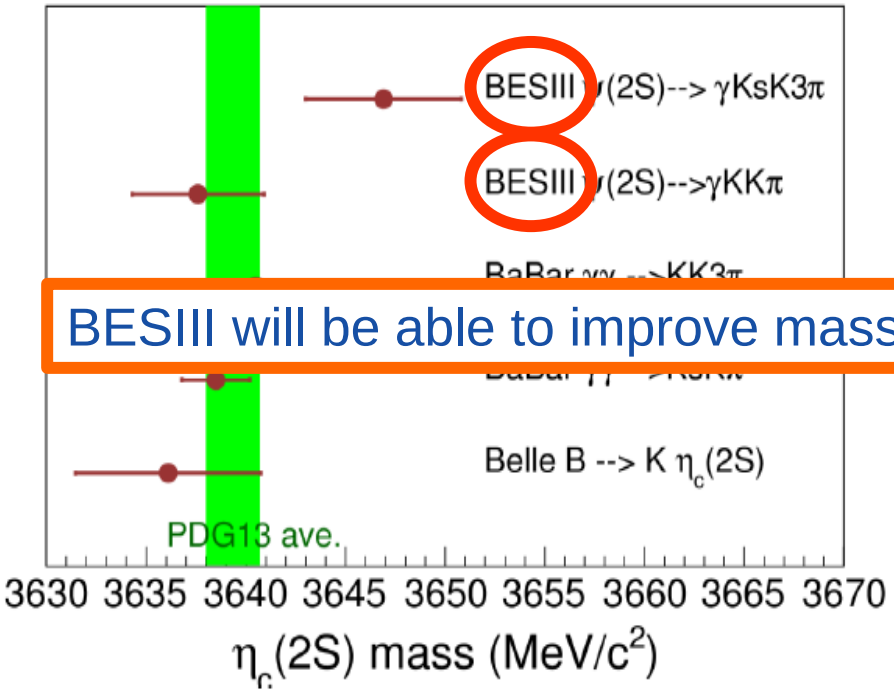

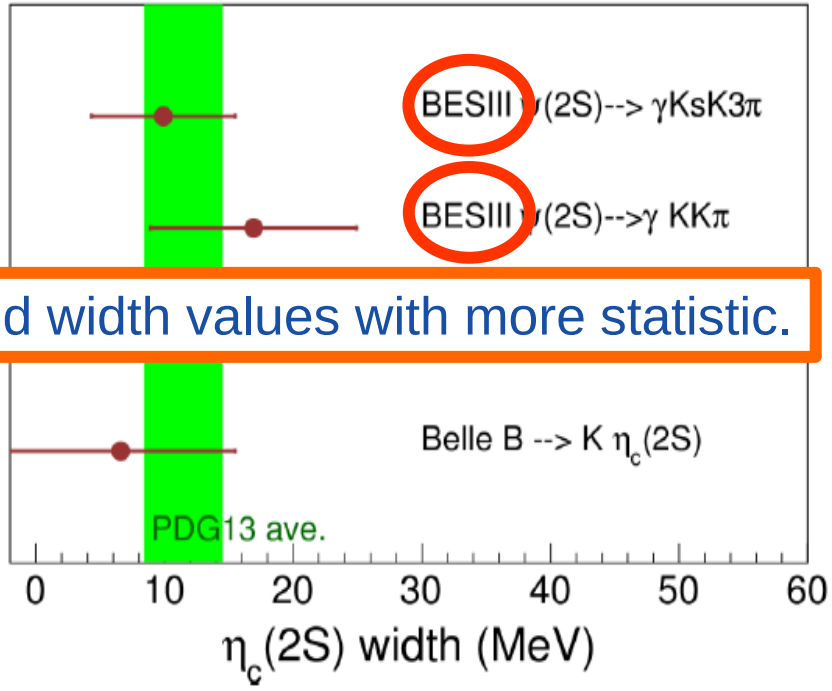

BESIII will be able to improve mass and width values with more statistic.

BESIII : PRD 87 052005 (2013)

BESIII : PRL 109 042003 (2012)

BaBar : PRD 84 012004 (2011)

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Radiative partial decay widths:

- Long-standing puzzle on the radiative transition rates of J/ψ and $\psi' \to \gamma\eta_c$:

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.

Outlook

- precise 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'

Nature of interference : **More interesting result will come very soon!**

Thanks for your attention