Systematic studies of isospin-violating transitions in charmonium with BESIII

university of groningen
kvi - center for advanced radiation technology
GSI

Olga Bondarenko (KVI-CART, University of Groningen)
on behalf of the BESIII collaboration

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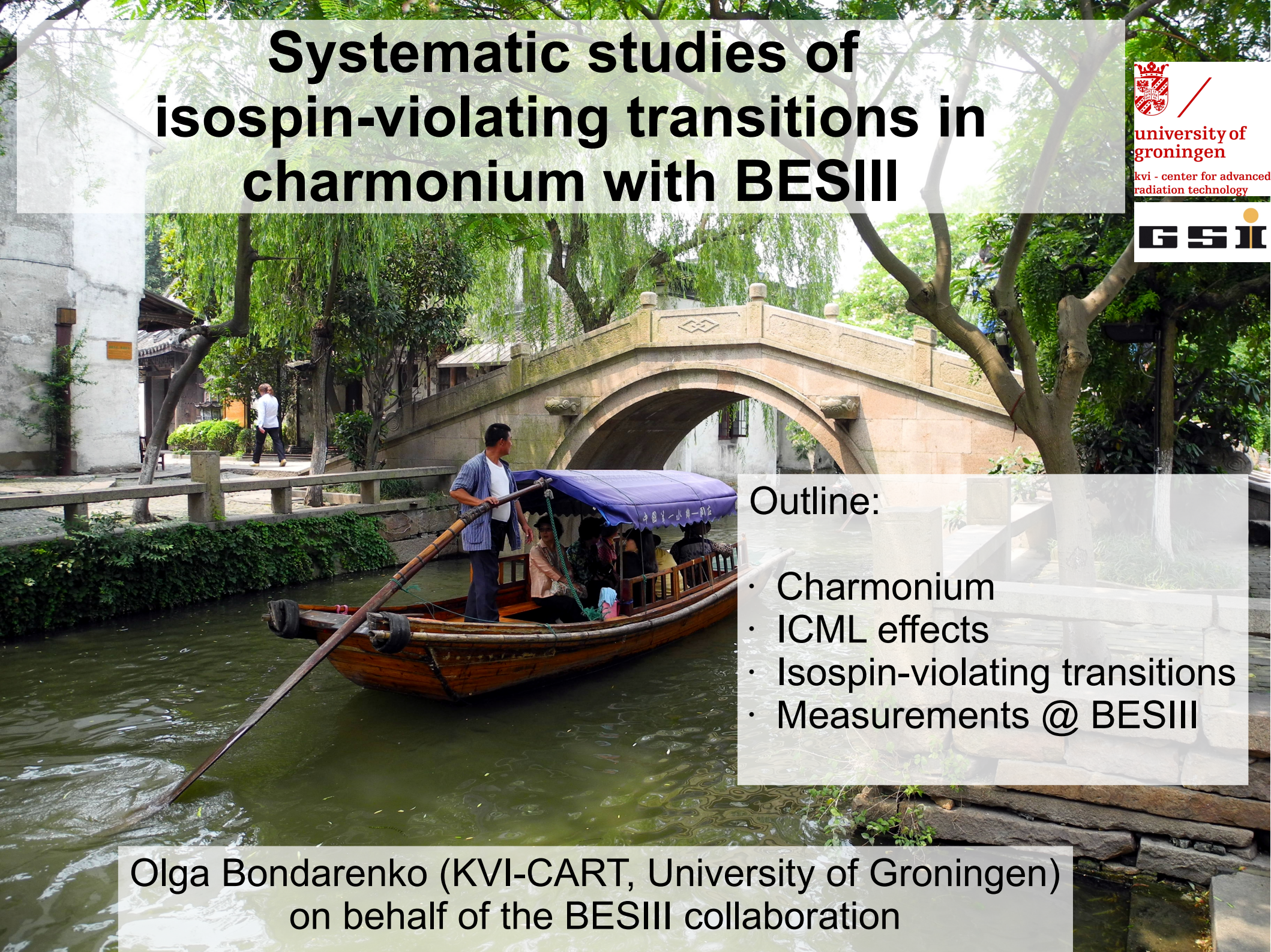

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Outline:

- Charmonium
- ICML effects
- Isospin-violating transitions
- Measurements @ BESIII

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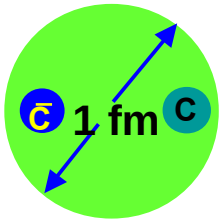
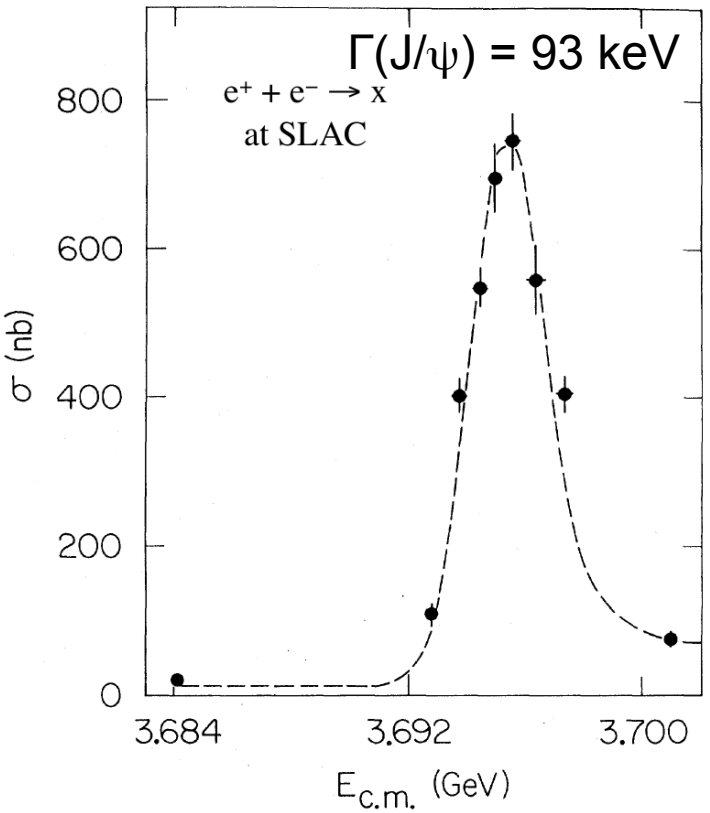
Charmonium – bound state of $c\bar{c}$ quarks

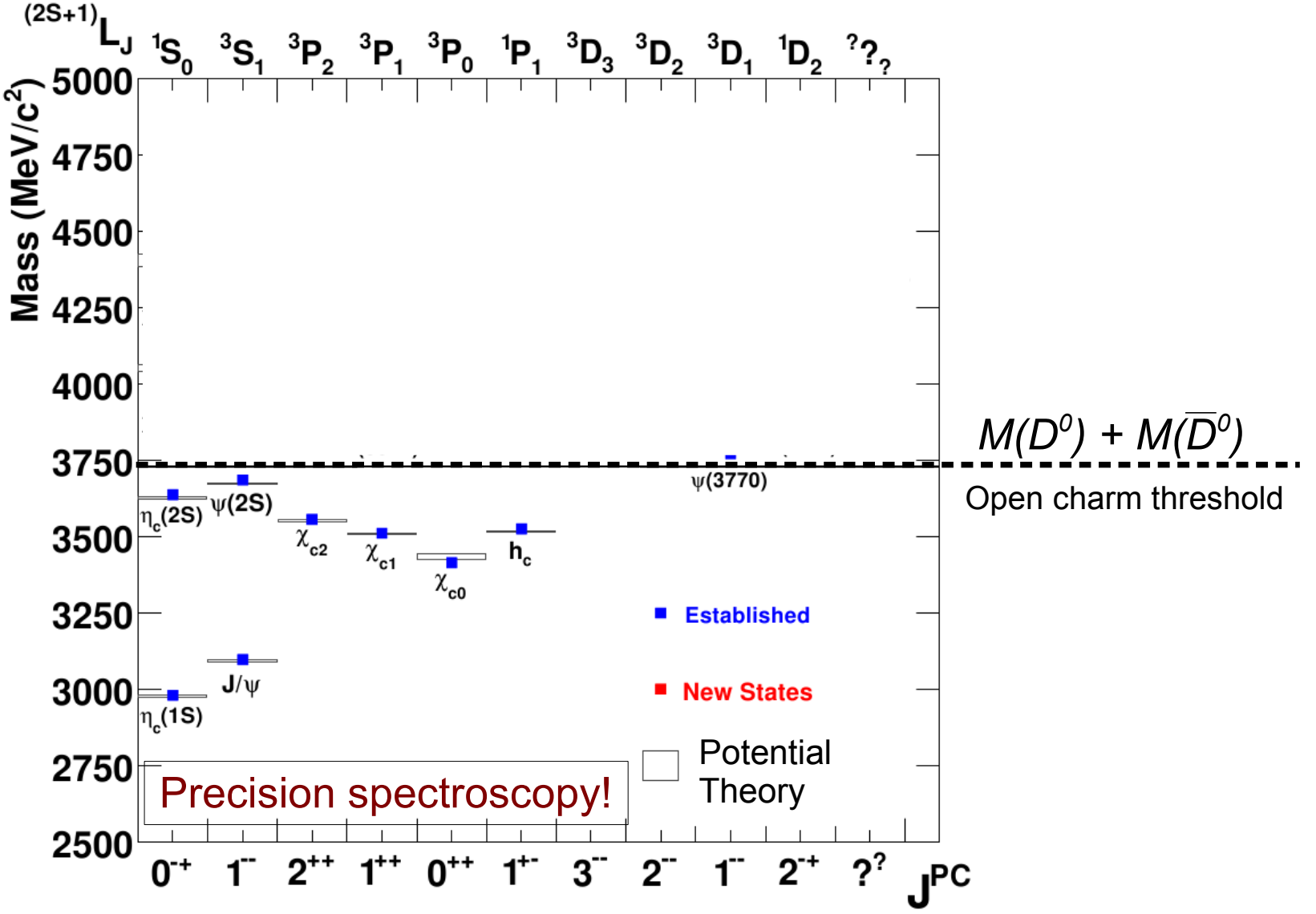




PRL 33, 1453 (1974)

- Simplest two-quark system
  → ideal test of confinement
- The J/ψ is discovered in 1974:
  the 40th anniversary!
- Narrow states below open-charm threshold
  → low-background beacons of QCD!
- Promising energy regime to search for exotic states of QCD!
- Heavy charm quark
  → relative velocity between quarks small
  → allows for non-relativistic framework
  + relativistic corrections

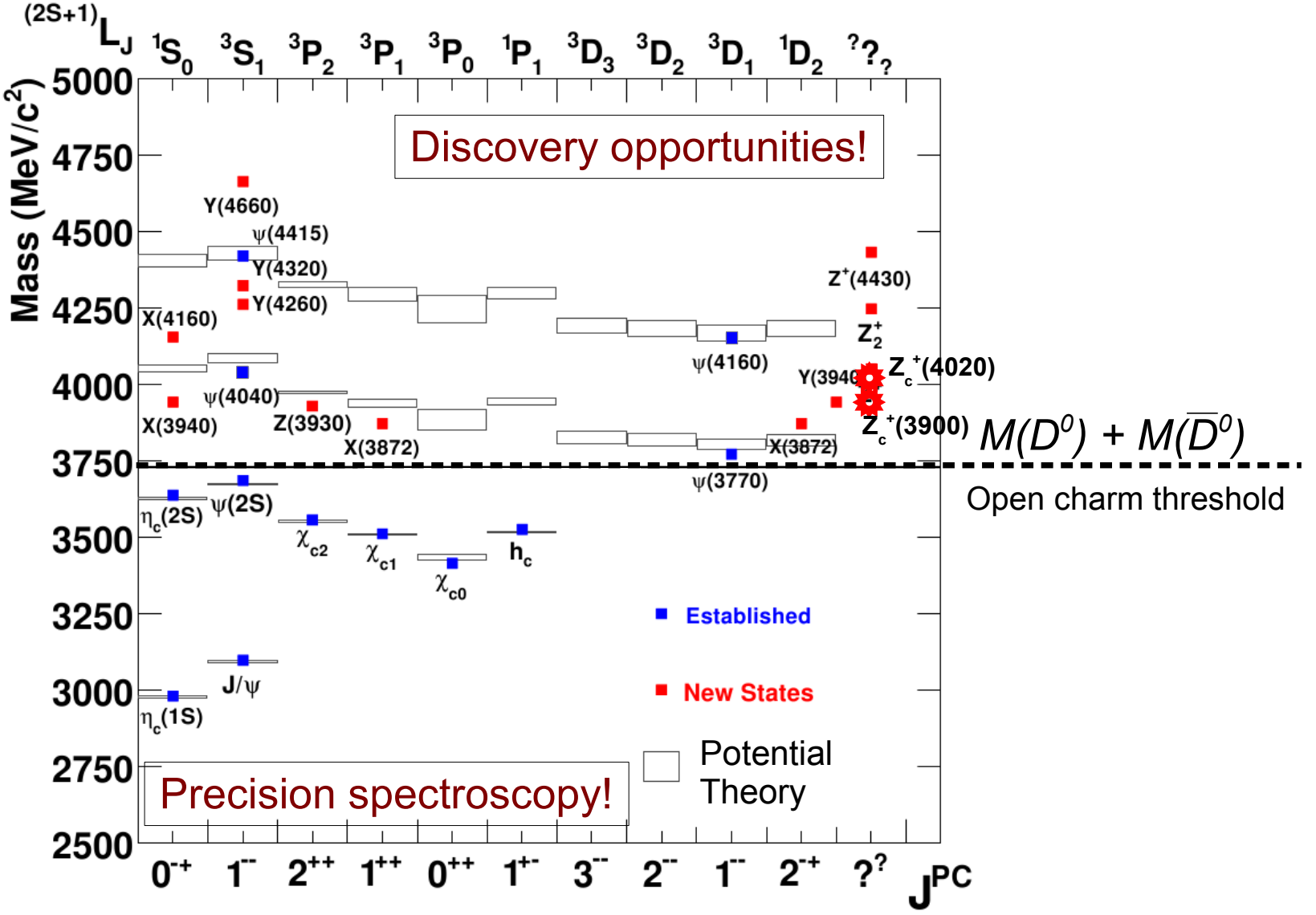
Charmonium: Potential theory vs experiment



CERN Yellow Report, CERN-2005-005(2005)

Charmonium is an excellent laboratory for Standard Model tests

Charmonium: Potential theory vs experiment



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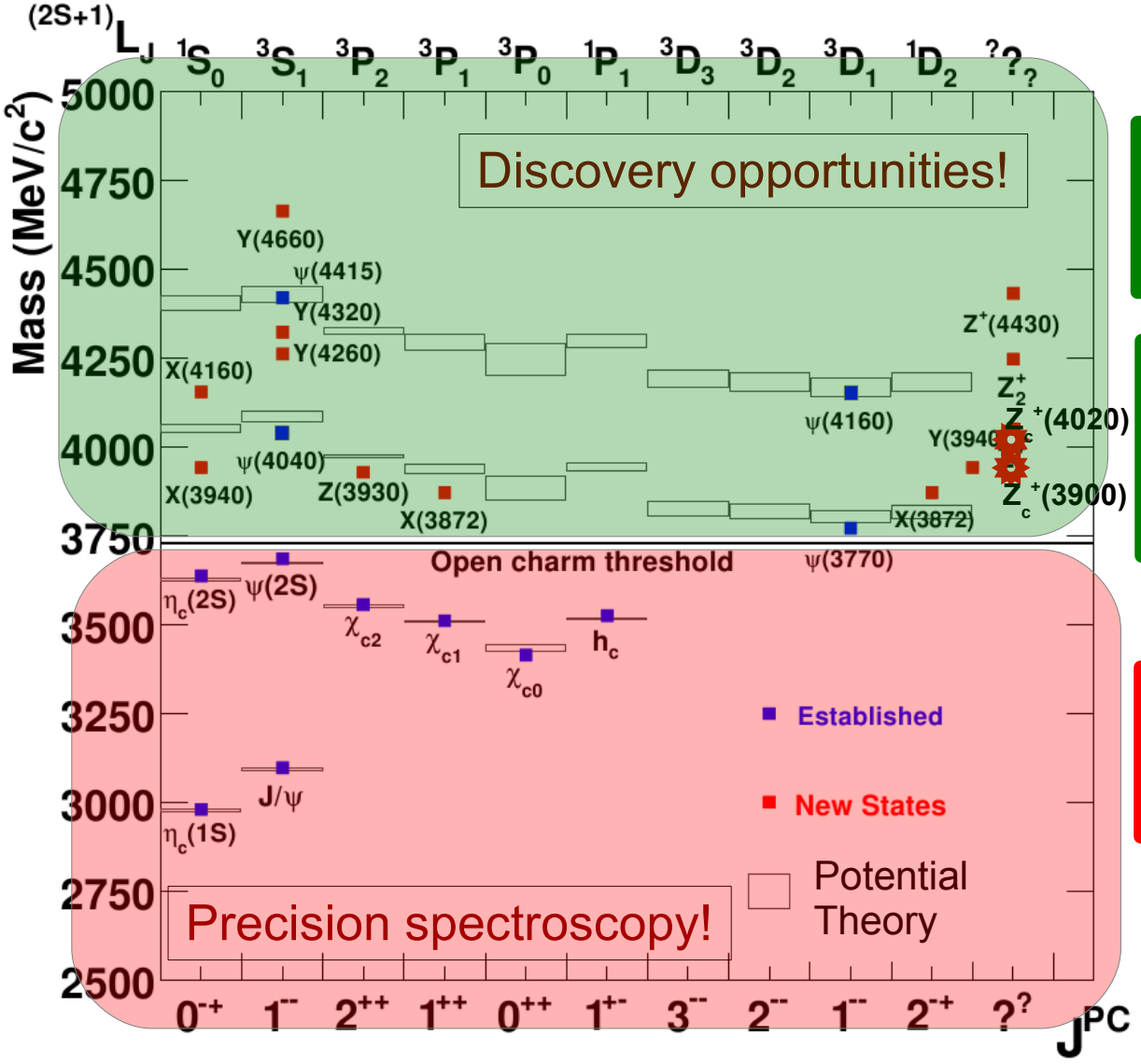


XYZ Studies:
Yuping GUO,
Fri 30 May, 09:30

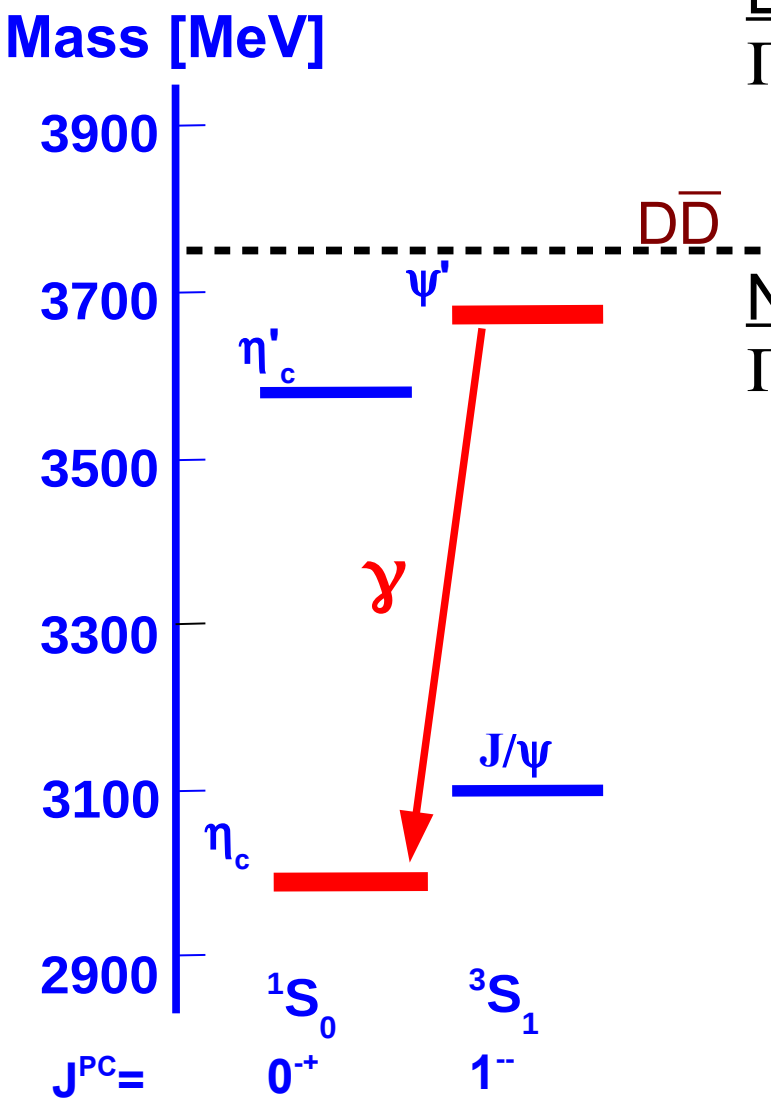
Charm physics:
Peilian LIU,
Fri 30 May, 17:10
Session B

Charmonium physics:
this talk

CERN Yellow Report, CERN-2005-005(2005)

Not to miss!

M1 Radiative Transition



Experiment:

$\Gamma(\psi' \to \gamma\eta_c) = 0.97 \pm 0.14$ keV

CLEOc, PRL 102, 011801 (2009)

Non-relativistic Potential Model

$\Gamma(\psi' \to \gamma\eta_c) = 9.7$ keV ←One order of magnitude difference!

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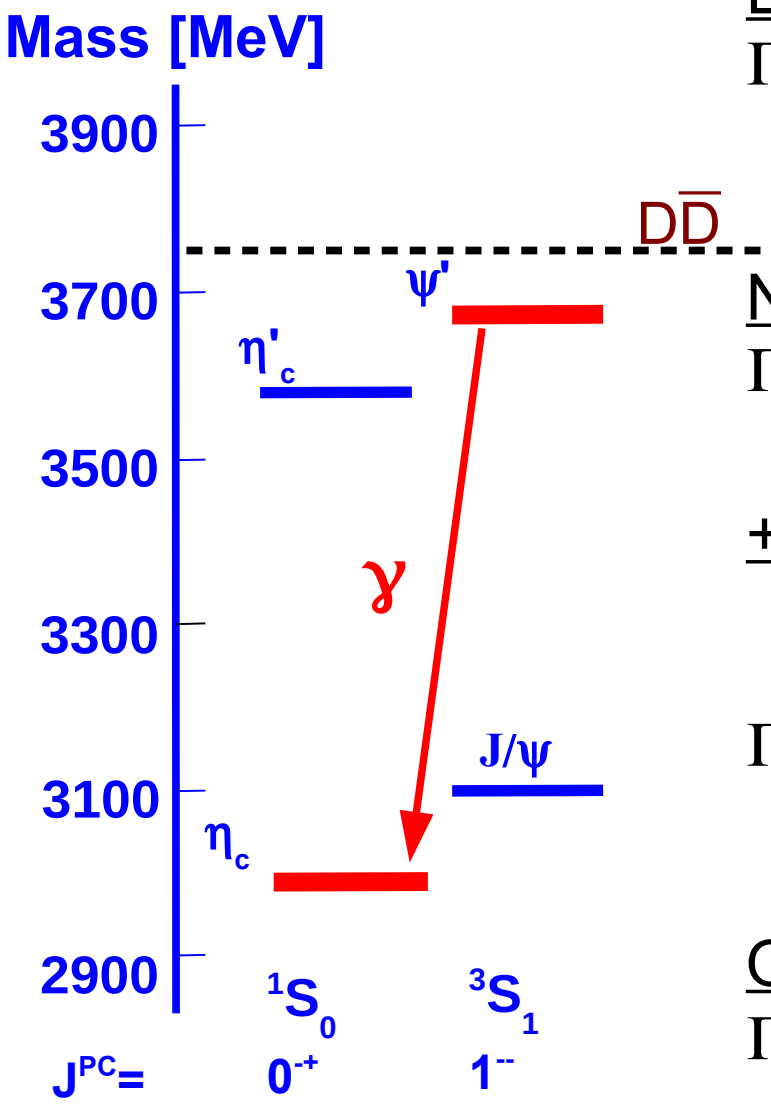

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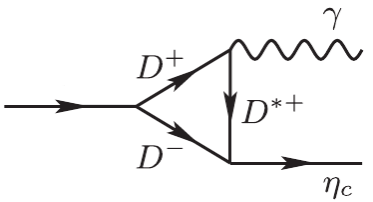
+ Intermediate Charmed Meson Loops (ICML)



$\Gamma(\psi' \to \gamma\eta_c) = 2.05^{+2.65}_{-1.75}$ keV ←Better agreement!

G.Li and Q.Zhao, PRD 84, 074005 (2011)

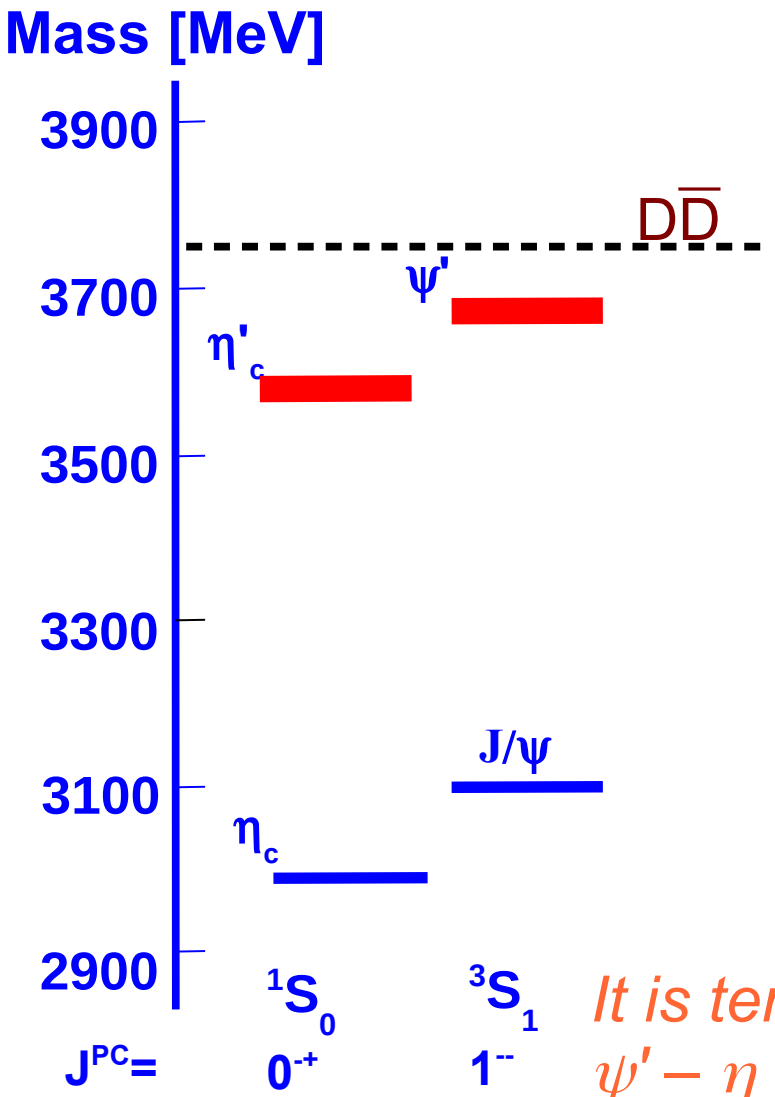
Quenched Lattice

$\Gamma(\psi' \to \gamma\eta_c) = 0.4 \pm \mathbf{0.8}$ keV

J.Dudek et al., PRD 73, 094504 (2009)

Influence of virtual decay channels can be significant

2S Hyperfine Splitting



Experiment:

$M(\psi') - M(\eta_c') = 48.5 \pm 3.3$ MeV

BESIII, PRL 109, 042003(2012)

Potential (Coulomb+linear) Model

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

Potential Model + ICML

$M(\psi') - M(\eta_c') = 46$ MeV

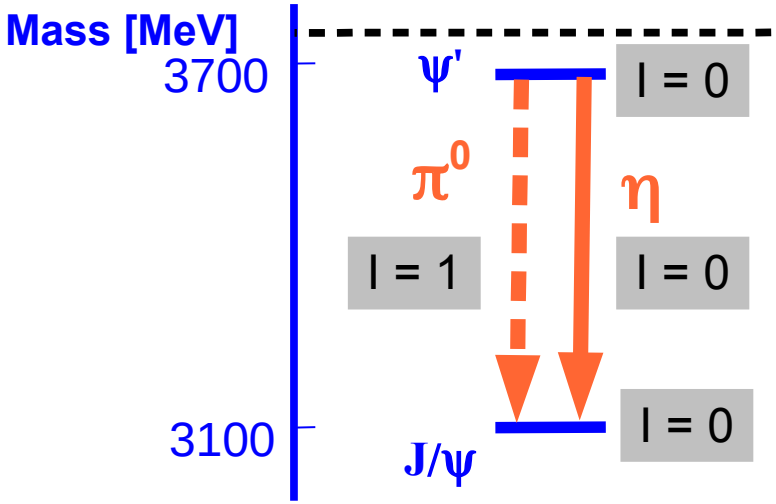
Eichten et al., PRD 69, 094019 (2004)

It is tempting to conclude that the $\psi' - \eta_c'$ splitting reflects the influence of virtual decay channels.

E.Eichten at al., PRD 69, 094019 (2004)

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 $\psi' \to \pi^0 J/\psi$ is much smaller than the quark-mass difference.

➔ Tree-level contribution
(0^{th} order QCD multipole expansion)

$$R = \frac{B(\psi' \to \pi^0 J/\psi)}{B(\psi' \to \eta J/\psi)} \Leftrightarrow \frac{m_u}{m_d} = 0.4 \pm 0.01$$

Using CLEOc data

Isospin violating transitions

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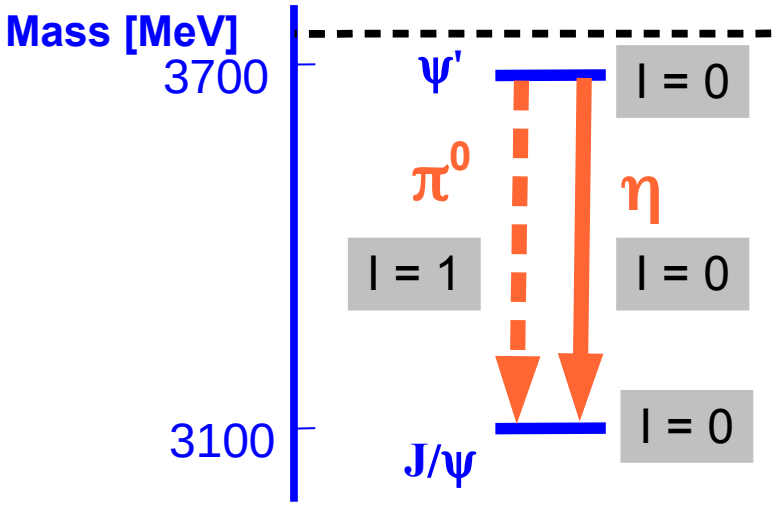

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Result contradicts previous estimates from light-meson mass ratio:

$$\frac{m_u}{m_d} = \frac{M^2_{K^\pm} - M^2_{K^0} + 2M^2_{\pi^0} - M^2_{\pi^\pm}}{M^2_{K^0} - M^2_{K^\pm} + M^2_{\pi^\pm}} = 0.56$$

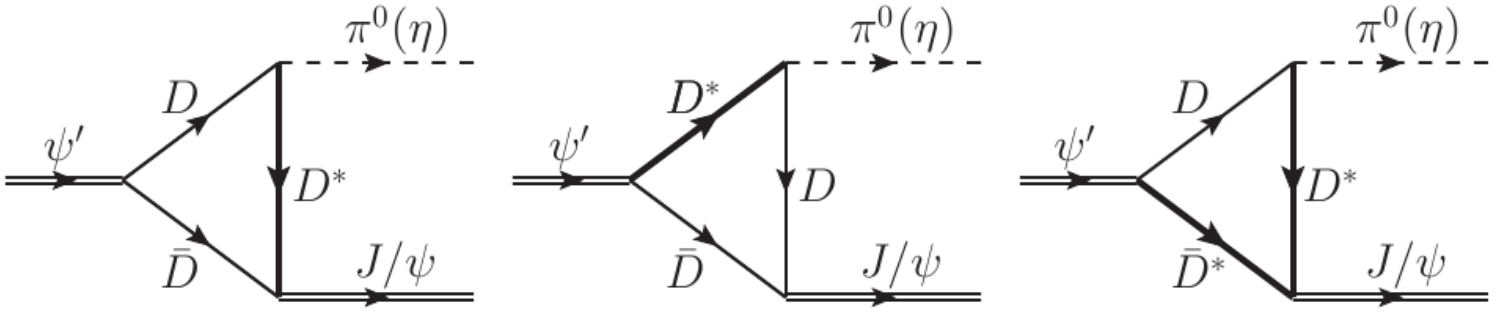
Weinberg (1977); Gasser, Leutwyler (1982); Leutwyler (1996)

Isospin violating transitions: Intermediate Charmed-Meson loops (ICML)

➔ Effective Field Theory
(non-multipole effect)

$$R=\frac{B\left(\psi'\to\pi^0 J/\psi\right)}{B\left(\psi'\to\eta J/\psi\right)}=TreeLevel\left(\Leftrightarrow\frac{m_u}{m_d}\right)+Loops\ !$$

F.-K. Guo: PRL 103, 082003 (2009)



Are these charmed-meson loops important?

Predictions of Non-Relativistic EFT

Phys. Rev. D 83, 034013 (2011)

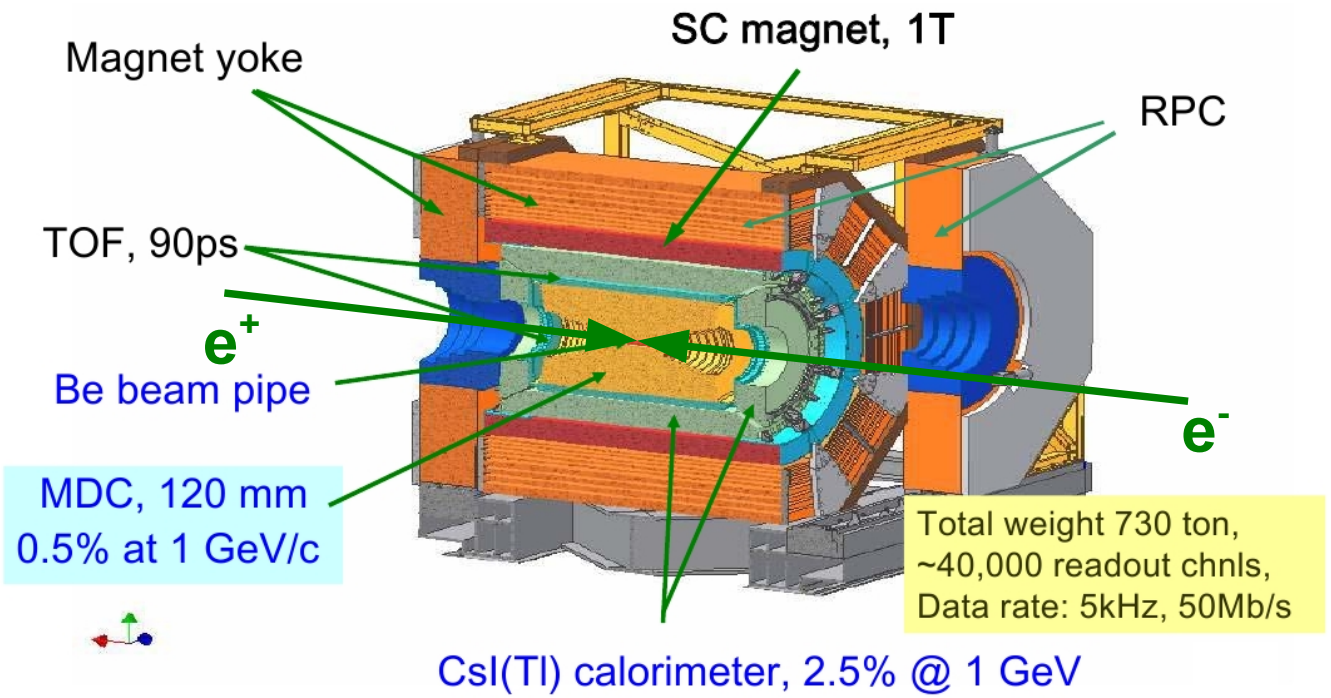
Contributions of ICML in charmonium transitions depend on:

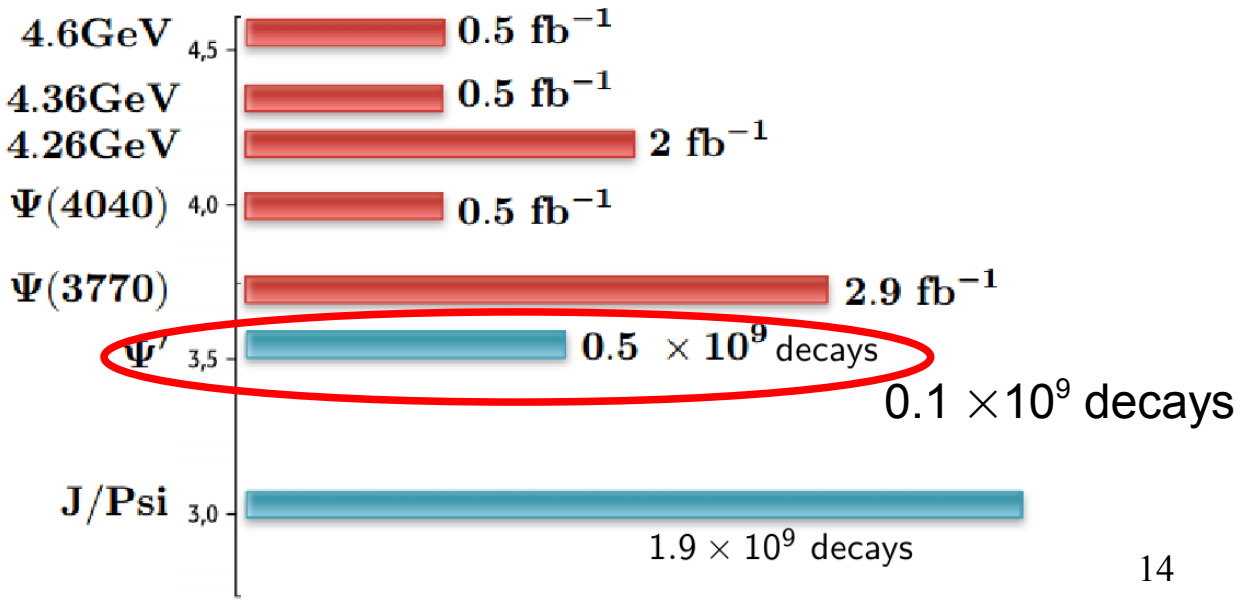
- quantum numbers of the states,
- momentum q of the π^0,
- velocity υ of the heavy meson in ICML: $\upsilon/c \sim \sqrt{(2M_D - M_\Psi)/M_D}$

Transition	Suppression Factor SF = (loops / tree) contributions
SS	$(\upsilon/c)^{-1}$
SP	$\frac{q^2}{(\upsilon/c)^3 M_D^2}$

We are interested in π^0(~~isospin~~) transitions between various charmonium states in order to reveal the hadronic-loop contributions (communication with Juelich+IHEP theory groups).

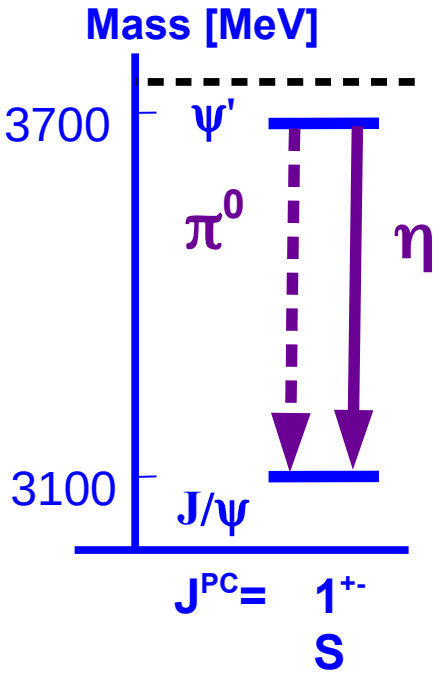
The BESIII Detector & Data Sets

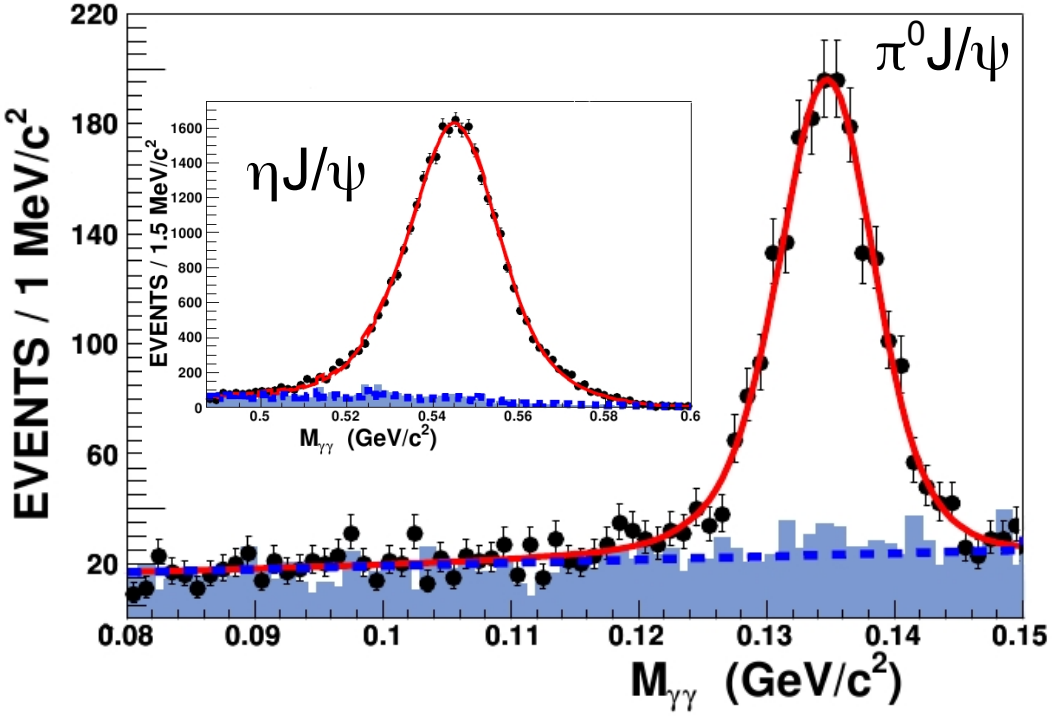




plus 0.8 fb^{-1} R scan, 104 energy points between 3.85 and 4.59 GeV

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





Low background!
A clean probe!

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

EFT	11 ± ***6*** (*)
CLEO-c	3.88 ± 0.23 ± 0.05
BESIII	**3.74 ± 0.06 ± 0.04**

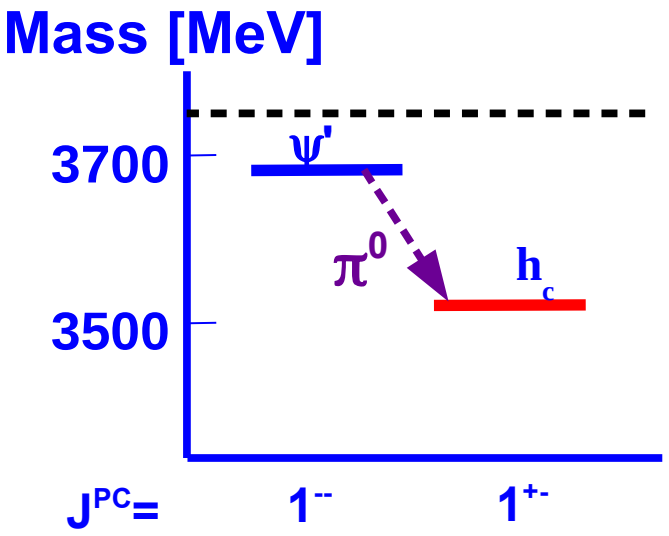
(*) F.-K. Guo, PRL. 104, 109901(E) (2010)

PRD 78, 011102 (2008)

PRD 86, 092008 (2012)

Most accurate measurement to date!

Isospin violating $\psi' \to \pi^0 h_c$ @BESIII



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

PRL 104, 132002 (2010)

Tiny branching fraction! First Measurement!

Theory, NREFT: charmed-meson loops contribution is about 10% → ***tiny!***
Tree-level diagram + dimensional analysis:

$$\Gamma(\psi' \to \pi^0 h_c) = (0.9 \pm \mathbf{0.6}) C^2 \text{ keV}, \; C \approx 1$$

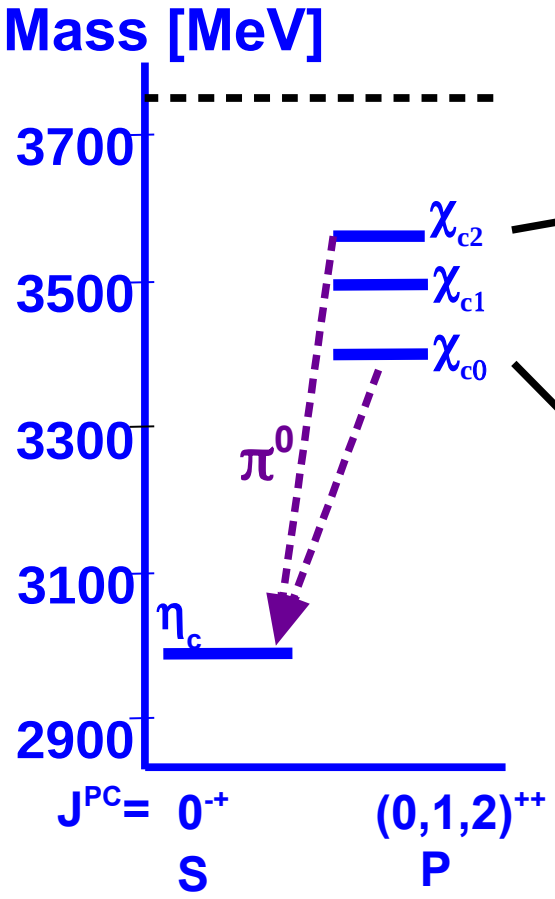
F.-K. Guo, PRD 82, 034025 (2010)

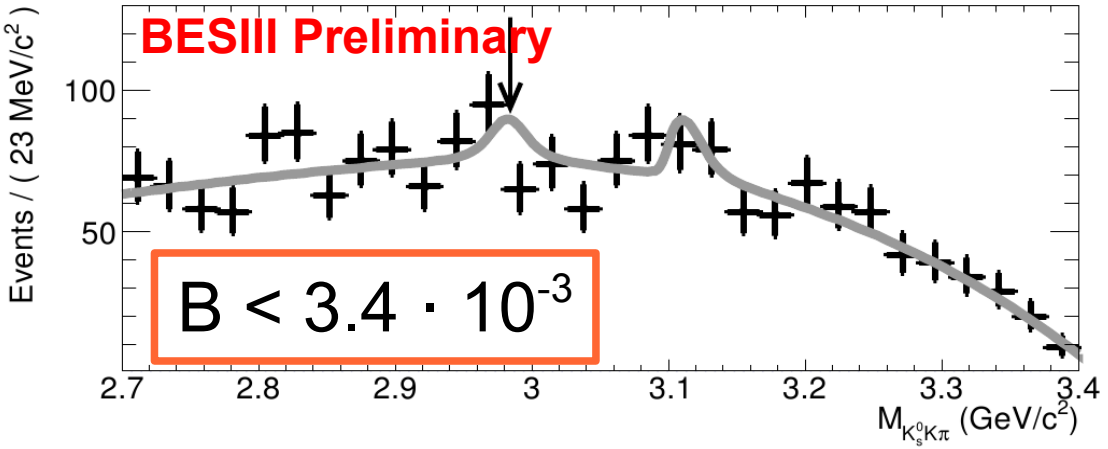
$$\Gamma(\psi' \to \pi^0 h_c) = (0.26 \pm 0.05) \text{ keV}$$

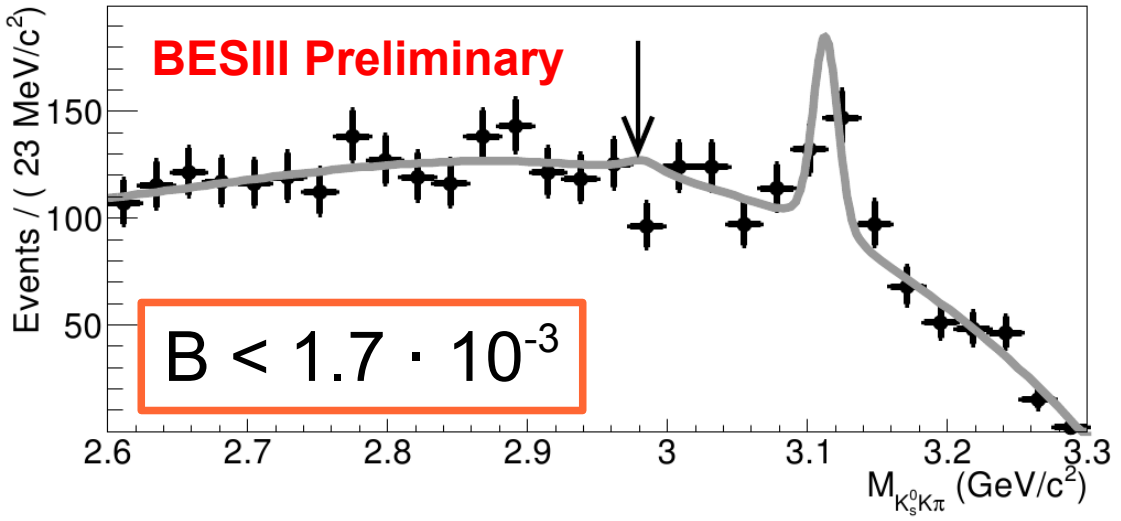
BESIII

Results are in agreement,
the NREFT approach is promising

Isospin violating $\chi_{c0,2} \to \pi^0 \eta_c$ @BESIII

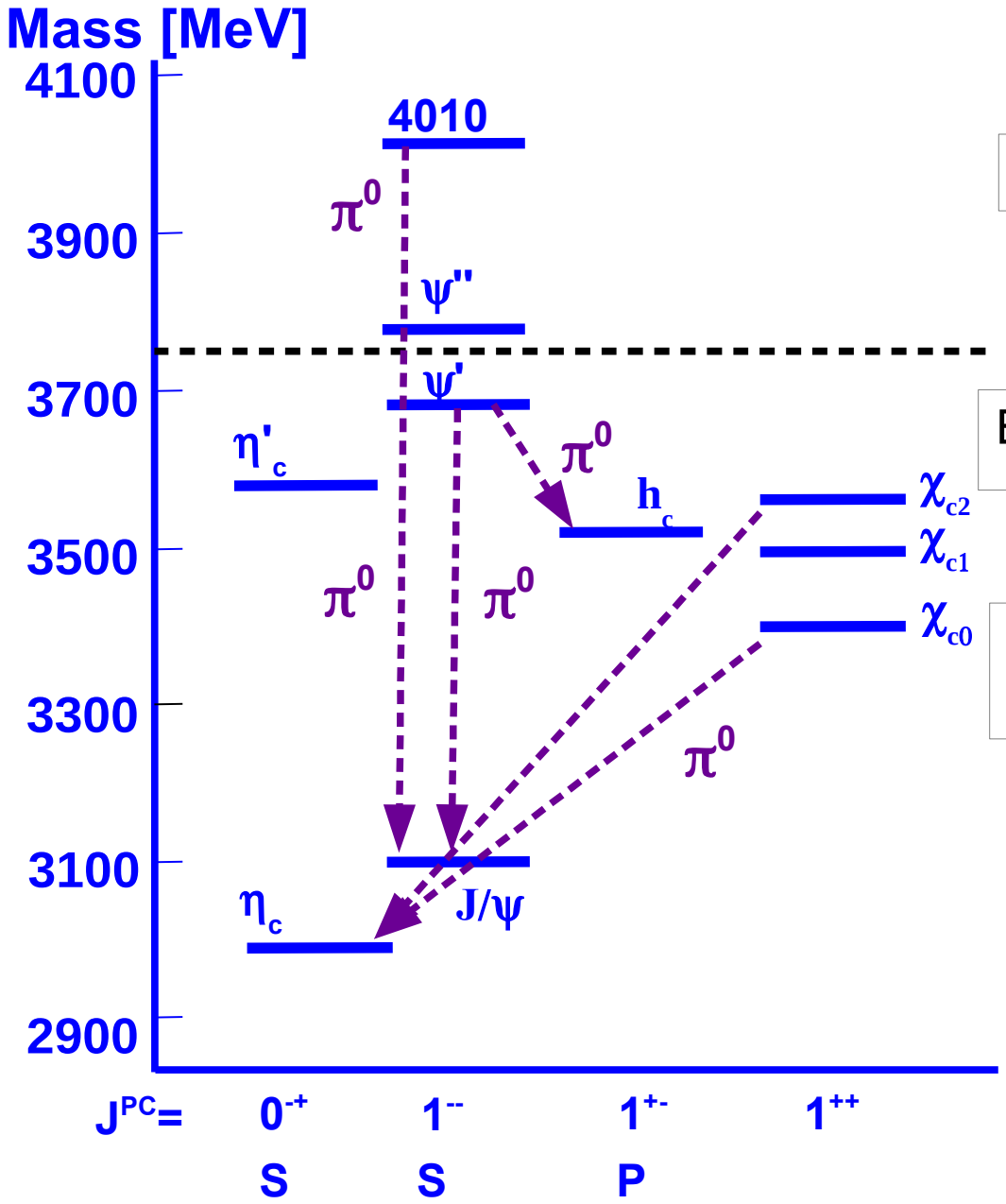






90% CL Upper Limits on the branching fractions are set for the first time

Isospin violating transitions @ BESIII



$B(e^+e^-(4010) \to \pi^0 J/\psi) < 2.8 \cdot 10^{-4}$

Phys. Rev. D 86, 071101(R) (2012)

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

PRL 104, 132002 (2010)

$B(\psi' \to \pi^0 J/\psi)/B(\psi' \to \eta J/\psi) = (3.74 \pm 0.06 \pm 0.04) \cdot 10^{-2}$

PRD 86, 092008 (2012)

$B(\chi_{c0} \to \pi^0 \eta_c) < 1.7 \cdot 10^{-3}$

$B(\chi_{c2} \to \pi^0 \eta_c) < 3.4 \cdot 10^{-3}$

Preliminary

A lot of new results! Are these sensitive results?

Discussion: Theory vs Experiment

	Transition	SF, number	NREFT prediction *Phys. Rev. D 83, 034013 (2011)*	BESIII measurement
SS	$\psi' \to \pi^0 J/\psi$ $\psi' \to \eta J/\psi^a$	0.53^{-1} 0.53^{-1}	$\Gamma = (0.048 \pm 0.025) g_2^2 g_2^{\prime 2}$ keV $\Gamma = (0.43 \pm 0.23) g_2^2 g_2^{\prime 2}$ keV $R = (11 \pm 6)\%$	$\Gamma = (0.38 \pm 0.02)$ keV $\Gamma = (10.26 \pm 0.41)$ keV $R = (3.74 \pm 0.07)\%$
SP	$\psi' \to \pi^0 h_c$	0.03	$\Gamma_{loop} = 2.1 \times 10^{-7} g_1^2 g_2^{\prime 2} \sim 10^{-5}$ keV $\Gamma = (0.9 \pm 0.6) C^2$ keV	 $\Gamma = (0.26 \pm 0.05)$ keV
	$\eta_c' \to \pi^0 \chi_{c0}$	0.1	$\Gamma_{loop} = 1.0 \times 10^{-5} g_1^2 g_2^{\prime 2}$ $\Gamma = 1.5 \pm 0.4$ keV	 -
	$h_c \to \pi^0 J/\psi$	0.2	$\Gamma_{loop} = 1.9 \times 10^{-4} g_1^2 g_2^2 \sim 10^{-2}$ keV	-
	$\chi_{c0} \to \pi^0 \eta_c$	0.2	$\Gamma_{loop} = 3.3 \times 10^{-4} g_1^2 g_2^2 \sim 10^{-2}$ keV $\Gamma \sim 1$ keV *	 $\Gamma < 18.8$ keV
	$\chi_{c2} \to \pi^0 \eta_c$	0.3	-	 $\Gamma < 7.1$ keV

* *private communication*

The NREFT predictions are compatible with the BESIII results

Summary

- Effects of intermediate charmed-meson loops on charmonium transitions below the open charm threshold are subject of extensive experimental and theoretical studies.
- Systematic studies of isospin-violating transitions are performed @ BESIII.
- These studies will help to constrain existing theoretical models.
- The NREFT predictions are compatible with the BESIII measurements.
- A good control of intermediate charmed-meson loops will help to access fundamental parameters (e.g. light-quark masses).

Thanks to the BESIII Collaboration

~350 members
50 institutions from 11 countries

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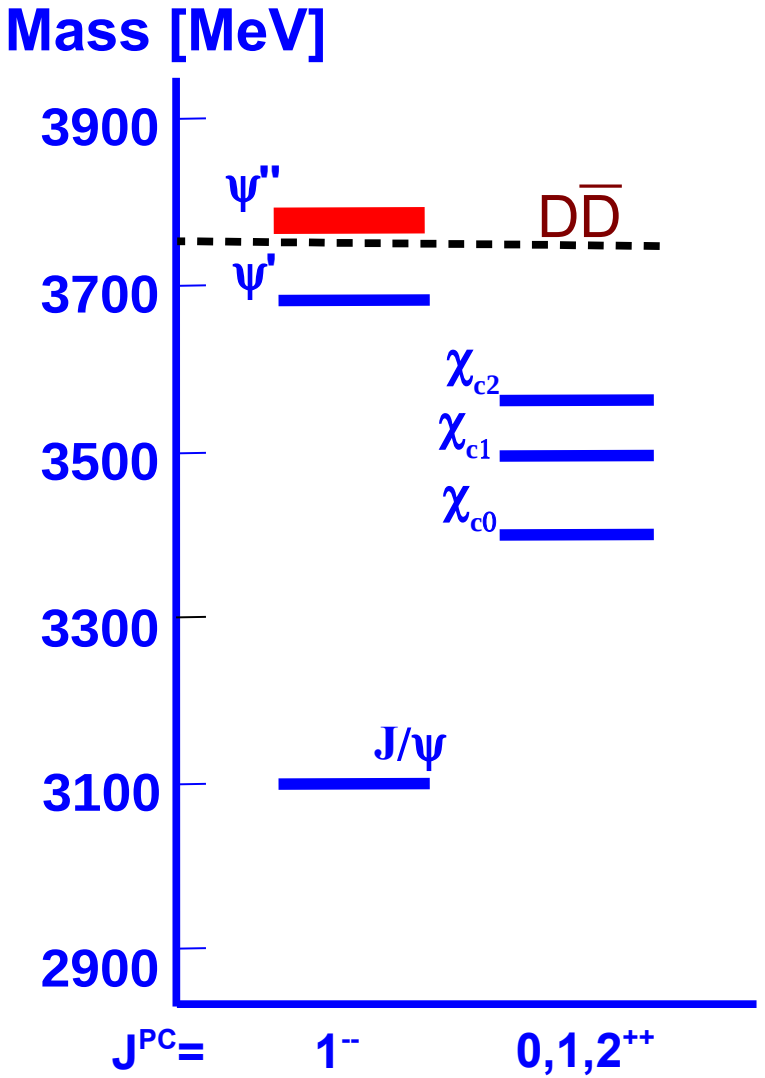
The BESIII Physics Program

DD and charm physics

ψ and charmonium physics

Spectroscopy of light hadrons

Charmonium above the Open-Charm Threshold



Experiment:
M(ψ'') = 3773.2±0.3 MeV

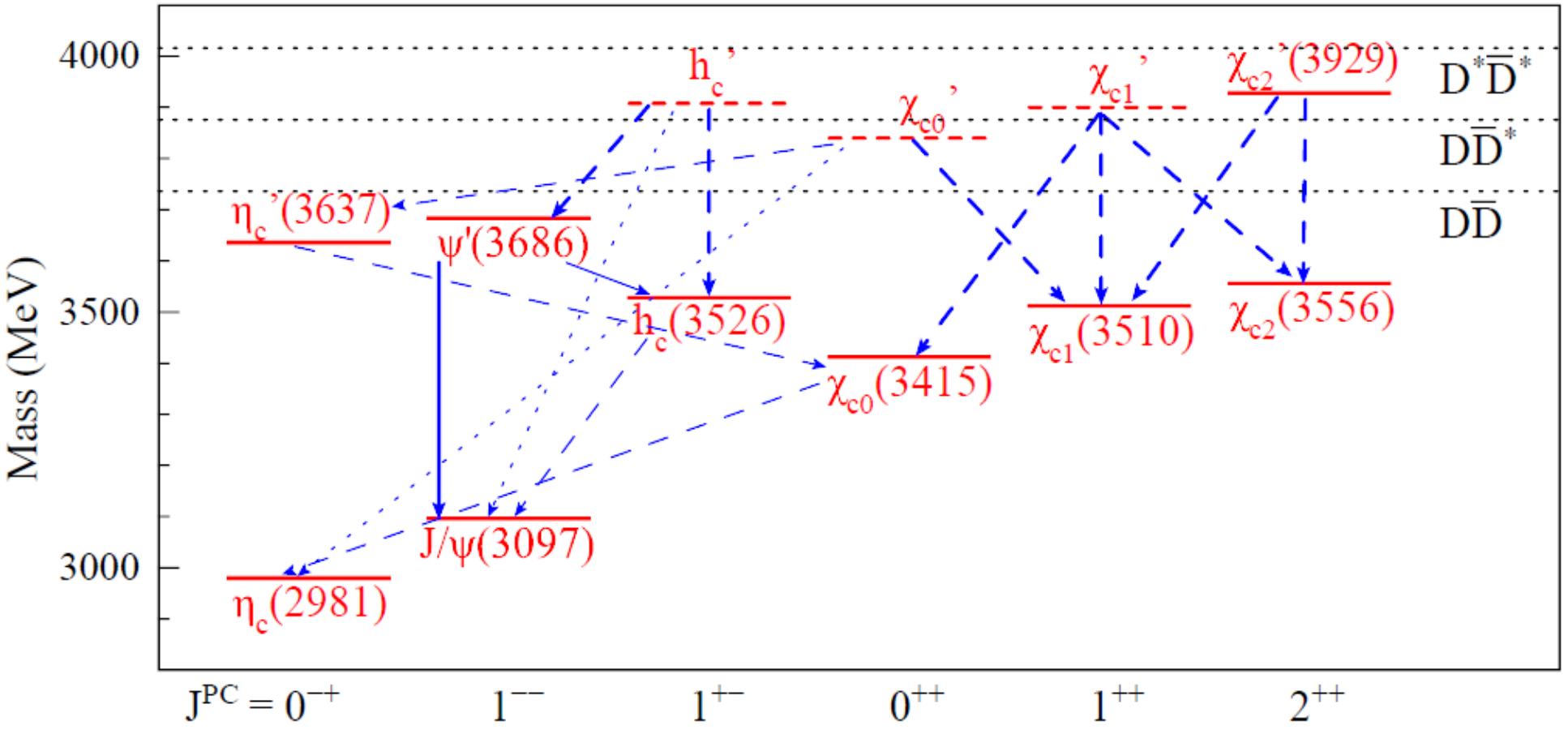
PDG2012

Potential (Coulomb+linear) Model
M(ψ'') = 3810 MeV

Coupled-Channels Model
M(ψ'') = 3755 MeV

Eichten et al., PRD 21, 203 (1980)

Influence of virtual decay channels is significant above the open charm threshold


4000
3500
3000
Mass (MeV)
h_c'
χ_{c0}'
χ_{c1}'
$\chi_{c2}'(3929)$
$D^*\bar{D}^*$
$D\bar{D}^*$
$D\bar{D}$
$\eta_c'(3637)$
$\psi'(3686)$
$h_c(3526)$
$\chi_{c0}(3415)$
$\chi_{c1}(3510)$
$\chi_{c2}(3556)$
$J/\psi(3097)$
$\eta_c(2981)$
$J^{PC} = 0^{-+}$
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}