Recent Results on Charmonium Transitions Studied with BESIII

Olga Bondarenko (KVI/University of Groningen)

Collaboration meeting June 2012 @ Suzhou

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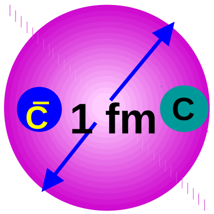
Outline:

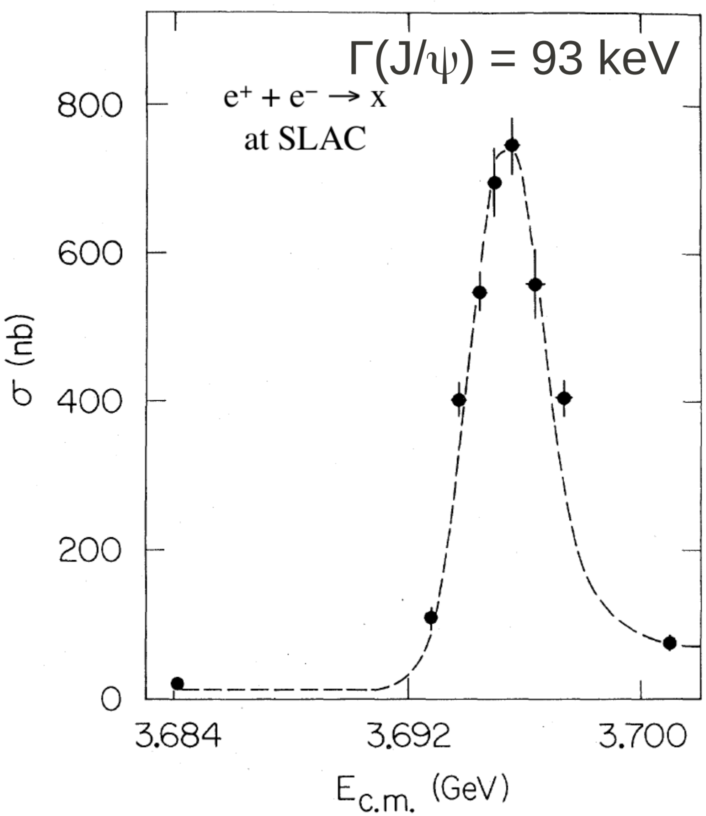
- Charmonium
- Precision measurements
- Discoveries
- Isospin-violating transitions

Collaboration meeting June 2012 @ Suzhou

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

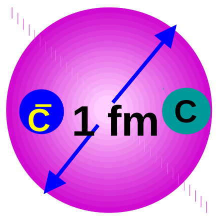


- simplest two-quark system
  → ideal test of confinement
- heavy charm quark
  → relative velocity between quarks small
  → allows for non-relativistic framework
  + relativistic corrections
- narrow states below open-charm threshold
  → low-background beacons of QCD!
- promising energy regime to search for exotic states of QCD!

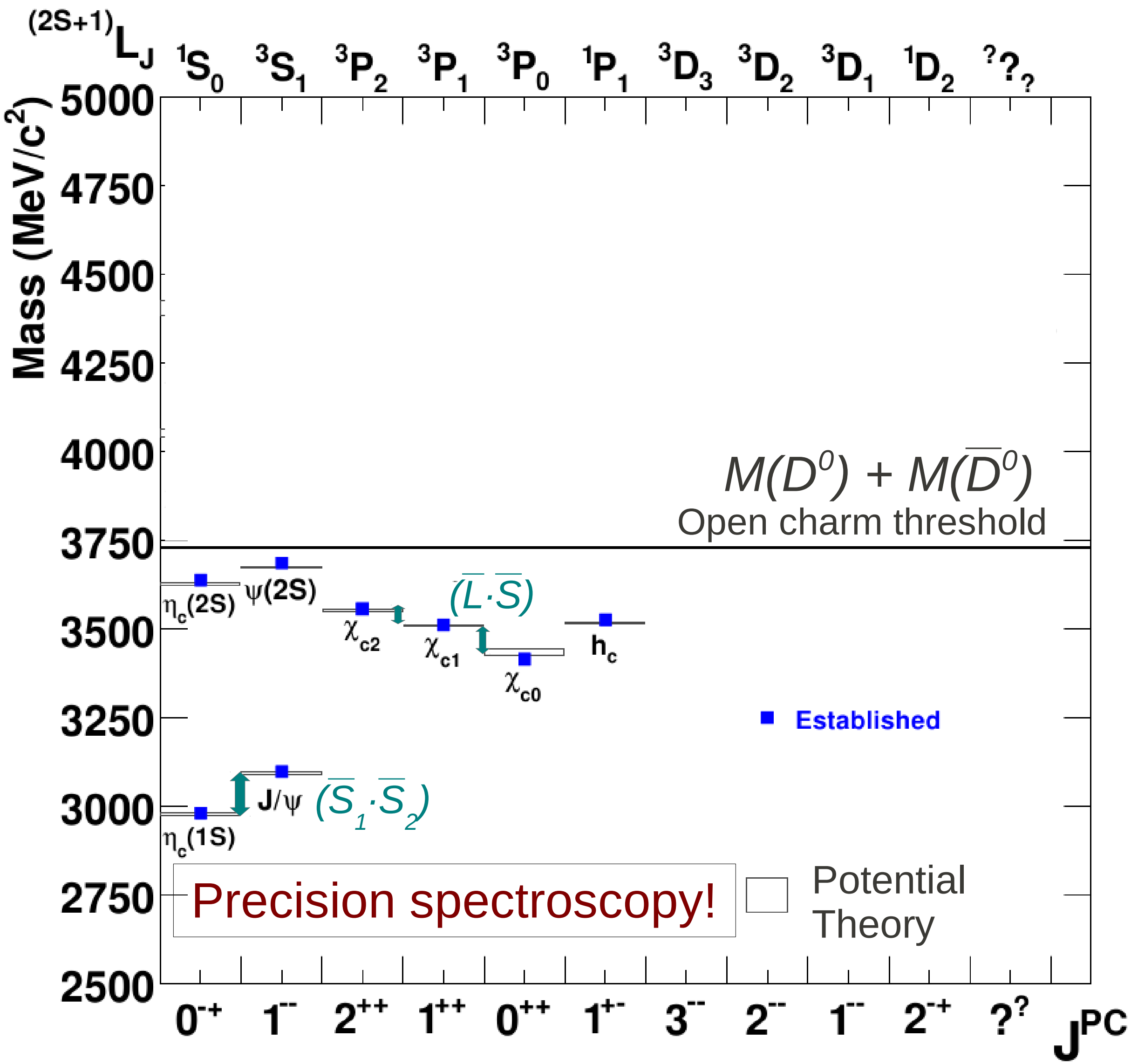


PRL 33, 1453 (1974)

Charmonium below open charm

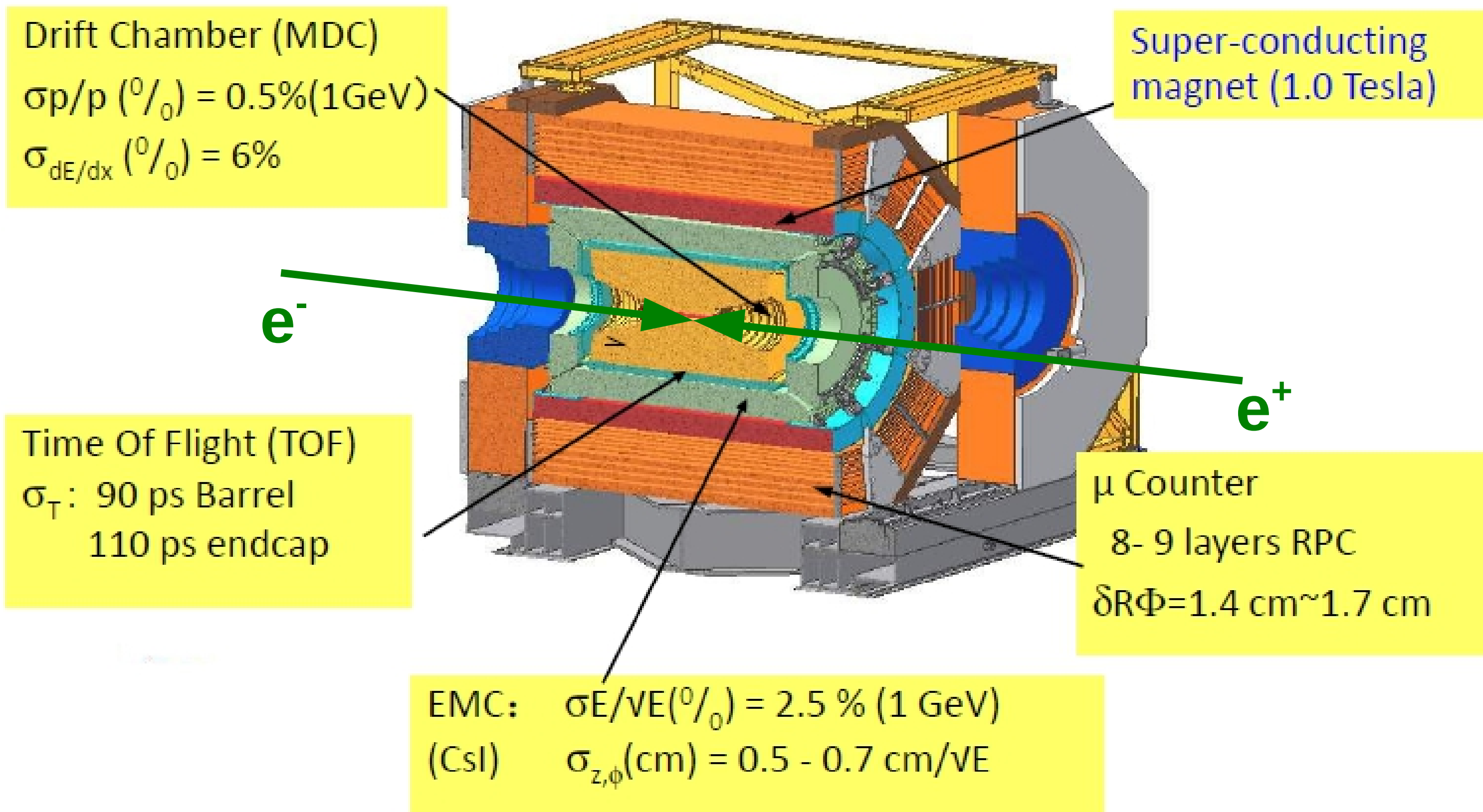


Bound system of 2 fermions



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

The BESIII Detector



BESIII Collected by the end of 2011:

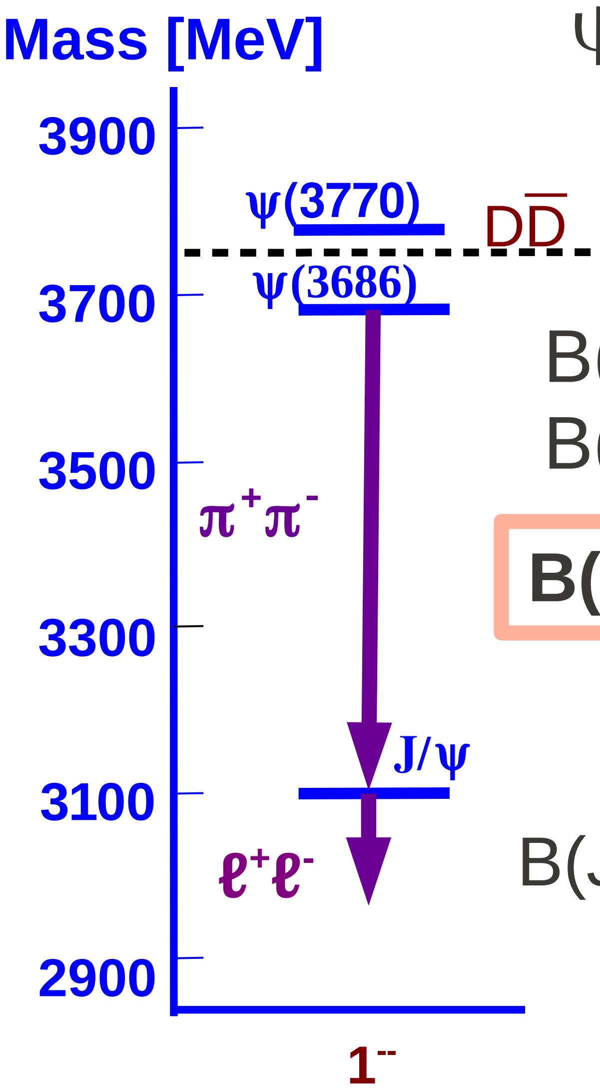
J/ψ:	225M	RECORD!
ψ(3686):	106M	
ψ(3770):	2.9 fb^{-1} (3.5xCLEO-c)	
ψ(4010):	0.5 fb^{-1}	

More J/ψ and ψ(3686) data were collected during 2012, not presented in the results.

NEW!

0.5 fb^{-1} @4010 MeV
0.5 fb^{-1} @4230 MeV
0.8 fb^{-1} @4260 MeV
0.5 fb^{-1} @4360 MeV

Precision measurements:
Test of e-μ universality in $J/\psi \to \ell^+\ell^-$ @BESIII



$\psi(3686) \to \pi^+\pi^- J/\psi$: the cleanest way to identify J/ψ

$B(J/\psi \to ee) = (5.983 \pm 0.007 \pm 0.037)\%$

$B(J/\psi \to \mu\mu) = (5.973 \pm 0.007 \pm 0.038)\%$

$B(J/\psi \to ee)/B(J/\psi \to \mu\mu) = 1.0017 \pm 0.0012 \pm 0.0033$

Preliminary!

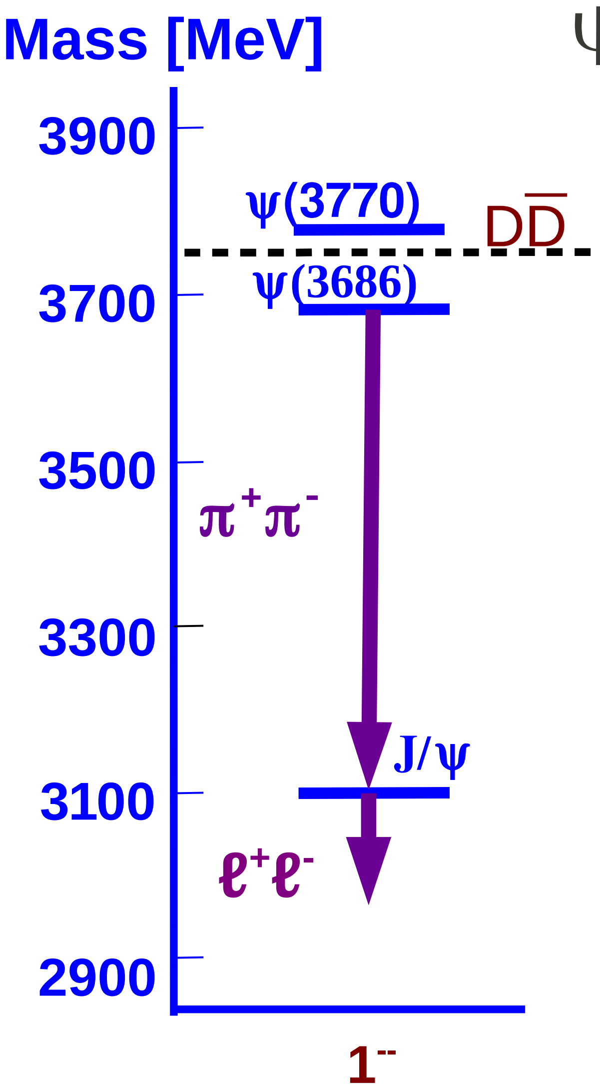
Best measurement!

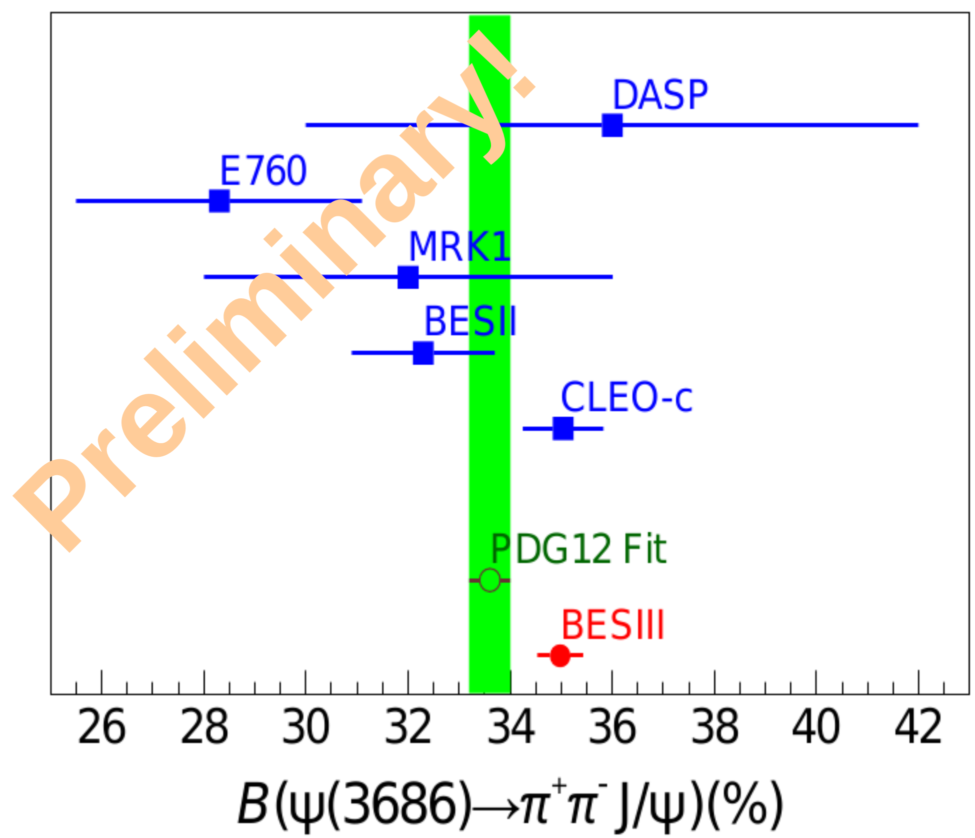
$B(J/\psi \to ee)/B(J/\psi \to \mu\mu) = 0.998 \pm 0.012$ *PDG2012*

High accuracy: an excellent detector!

Precision measurements: $B(\psi(3686) \to \pi^+\pi^- J/\psi)$@BESIII

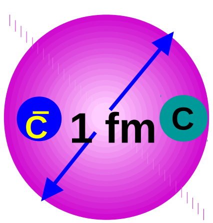
$\psi(3686) \to \pi^+\pi^- J/\psi$: the cleanest way to identify J/ψ

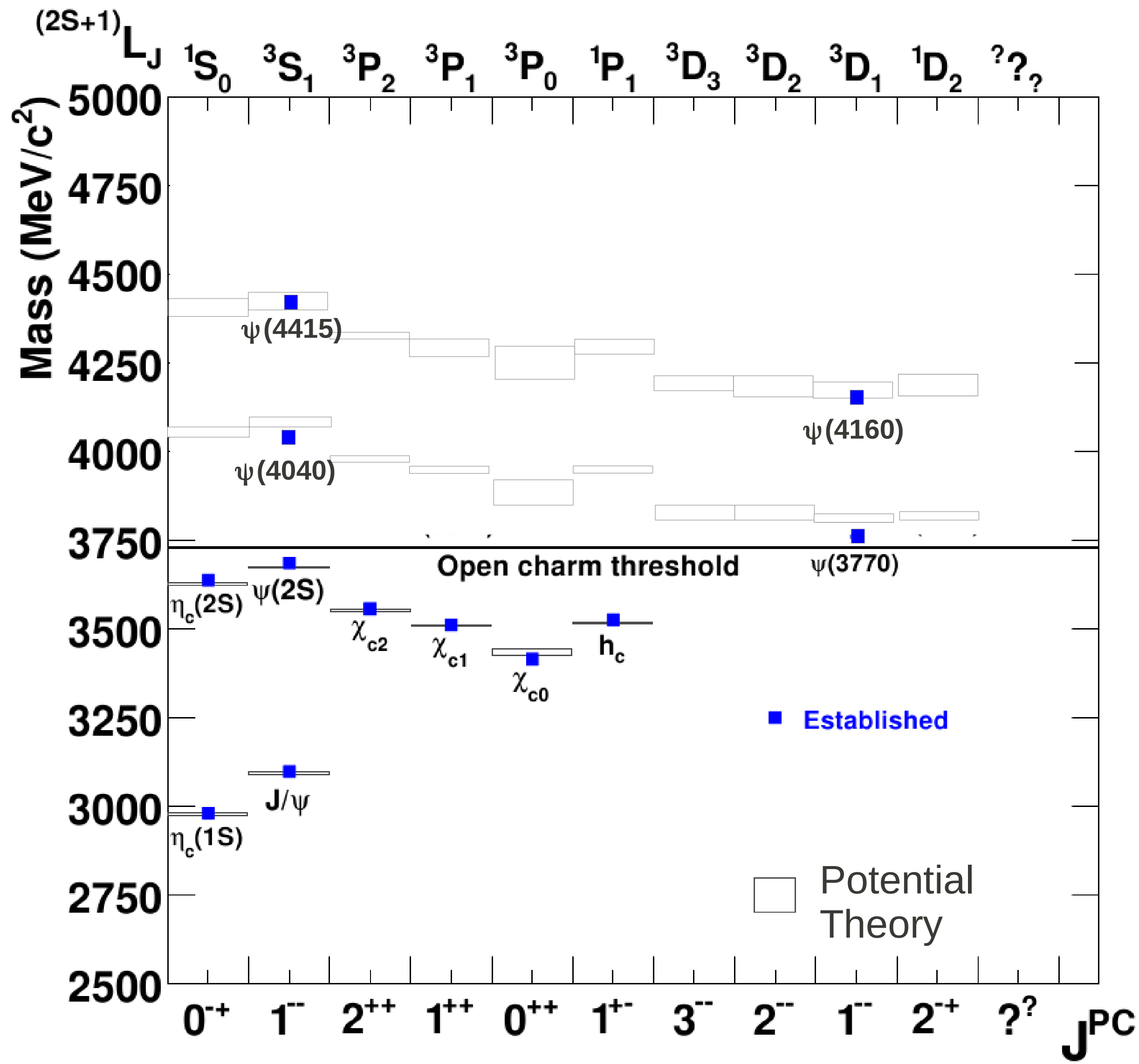




High accuracy: an excellent detector!

Charmonium above open charm

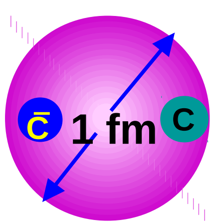


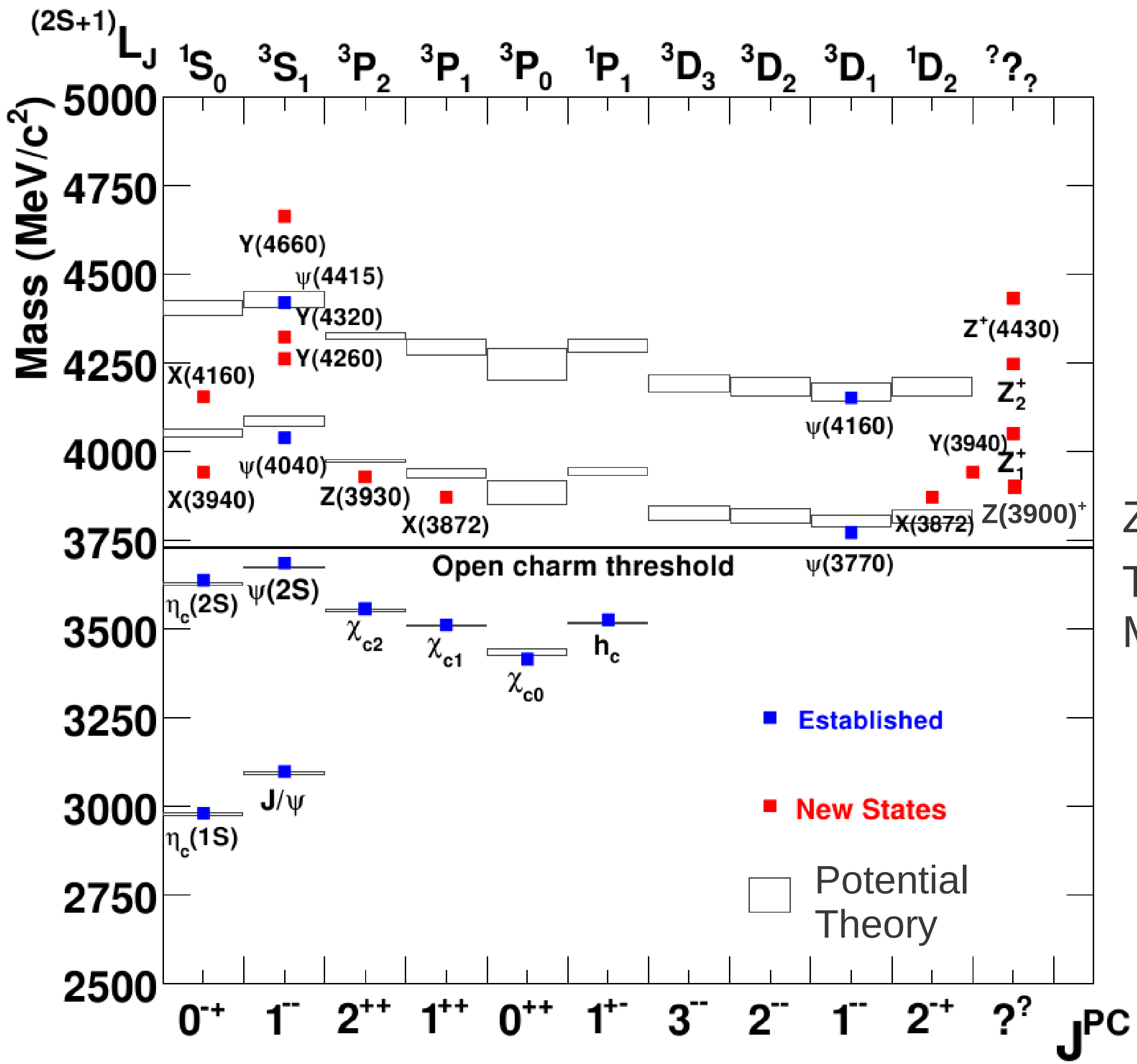


CERN Yellow Report, CERN-2005-005(2005)

Charmonium above open charm

Unexpected states



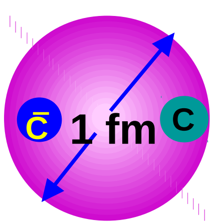


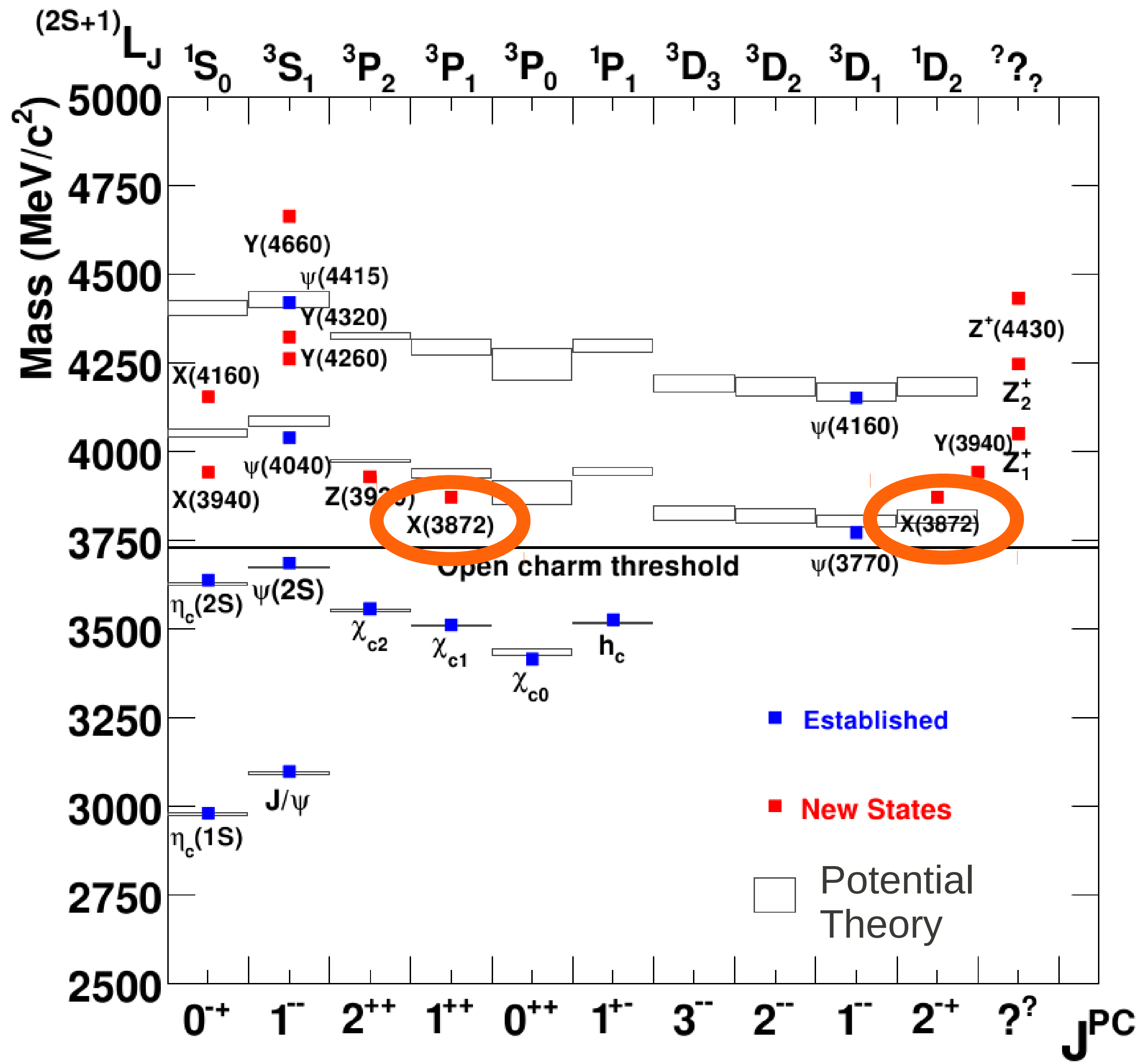
$Z_c(3900)^+$:
Talk by
M.Kavatsyuk

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

Charmonium above open charm

Unexpected states

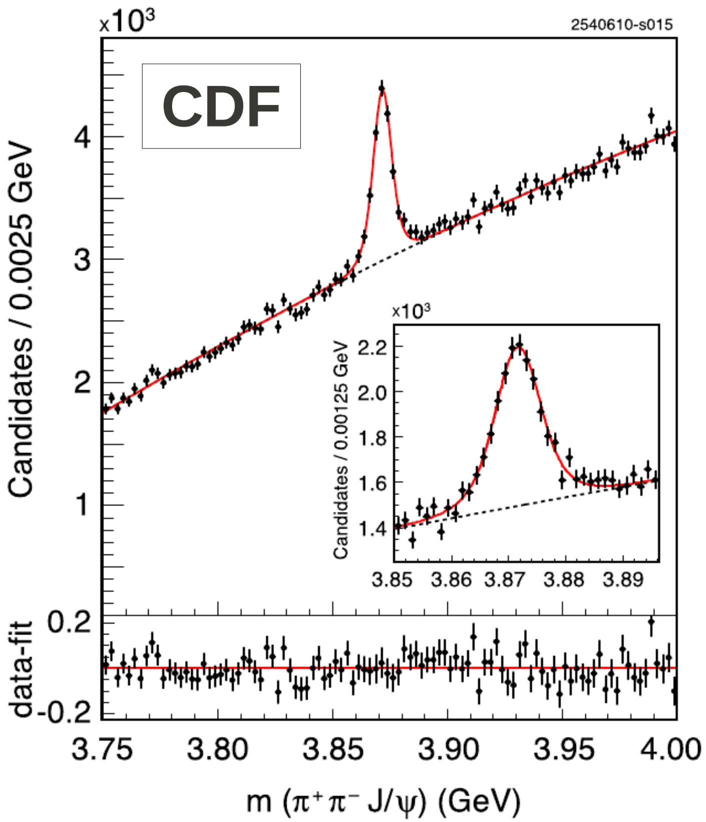




CERN Yellow Report, CERN-2005-005(2005)

X(3872) – what do we know?

Discovered by *Belle in 2003*



- No charged partner found
- Γ < 1.2 MeV – *narrow!* $\Gamma(\psi(3770))$ = 27 MeV
- M = 3871.68 ± 0.17 MeV

  - *suspiciously around the* $D\bar{D}^*$ *threshold*

    $D^0 = c\bar{u}$, $\bar{D}^0 = \bar{c}u$

    $M(D^0) + M(\bar{D}^{0*}) = 3871.81 \pm 0.36$ MeV

- Quantum numbers 1^{++} *(LHCb, March 2013)*
- Large isospin breaking!

$$B(X \to \omega J/\psi)/B(X \to \rho J/\psi) \approx 1$$

Nature is not understood!

X(3872) – what is it?

Models discussed in literature:

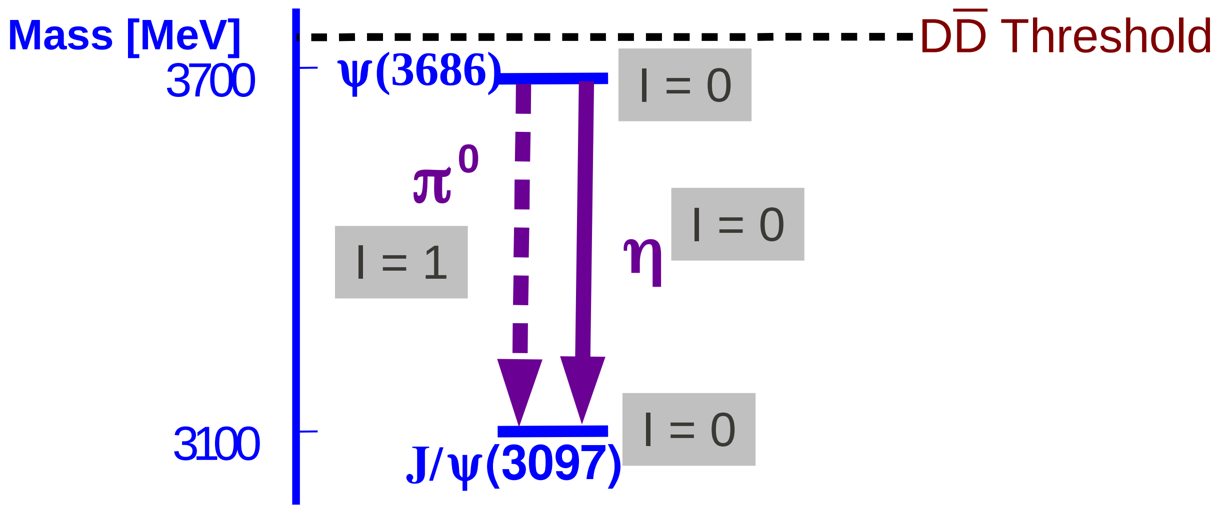
- Charmonium state $|c\bar{c}>$ or a hybrid $|gc\bar{c}>$
- Threshold effects: Virtual states at thresholds.
- Tetraquark: Tightly bound four quarks.
- Molecular state: Loosely bound mesons with a quark/color exchange (short distance) or pion exchange (large distance).

Isospin is an important element determining the nature of X(3872).
Can we learn more from ~~isospin~~ below the $D\bar{D}$ threshold?

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 $\psi(3686) \rightarrow \pi^0 J/\psi$ is much smaller than the quark-mass difference.



➔ Effective Field Theory
(QCD multipole expansion)
zero-order

$$\frac{m_u}{m_d} \Leftrightarrow R = \frac{B(\Psi(3686) \rightarrow \pi^0 J/\psi)}{B(\Psi(3686) \rightarrow \eta J/\psi)}$$

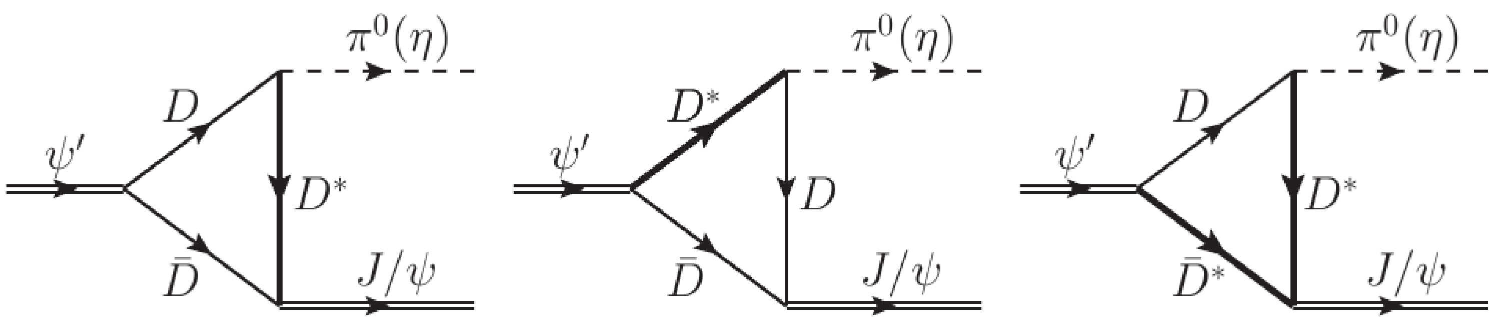
Result contradicts previous estimates from light meson mass ratio

Isospin violating transitions: Meson-loops

➔ EFT (QCD multipole expansion) next approximation

$$\frac{m_u}{m_d} \Leftrightarrow R = \frac{B(\Psi(3686)\rightarrow \pi^0 J/\psi)}{B(\Psi(3686)\rightarrow \eta J/\psi)} + loops!$$

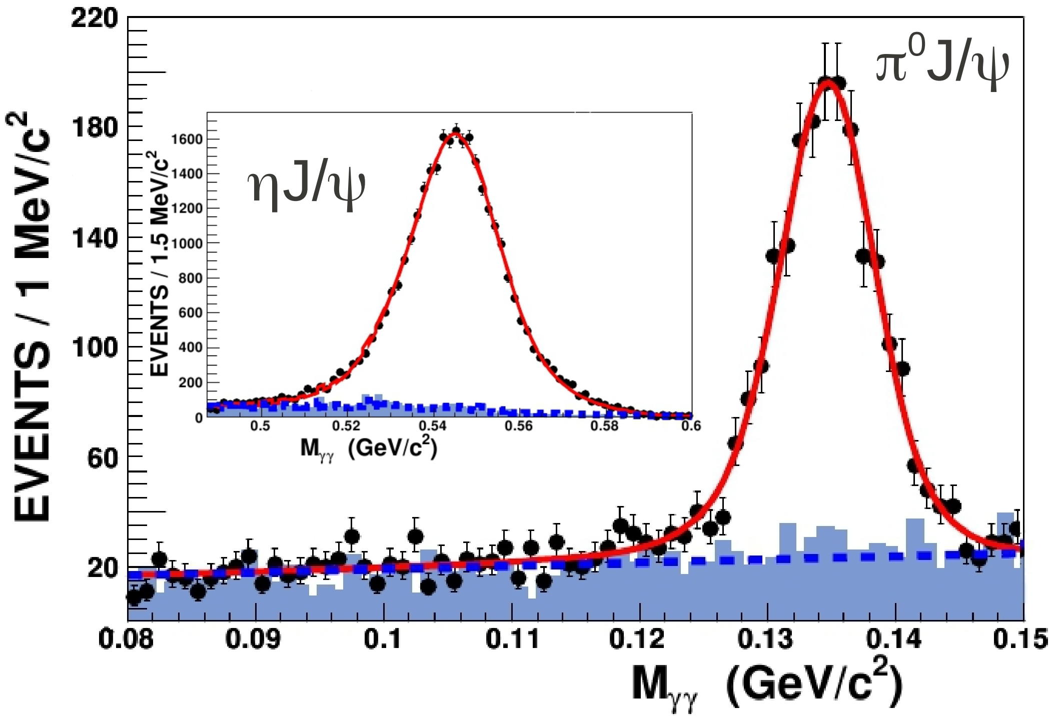
F.-K. Guo, C. Hanhart: PRL. 103, 082003 (2009)



Are these loops important?

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+IHEP theory groups).

Isospin violating $\psi(3686) \to \pi^0 J/\psi$ @BESIII



Low background!
A clean probe!

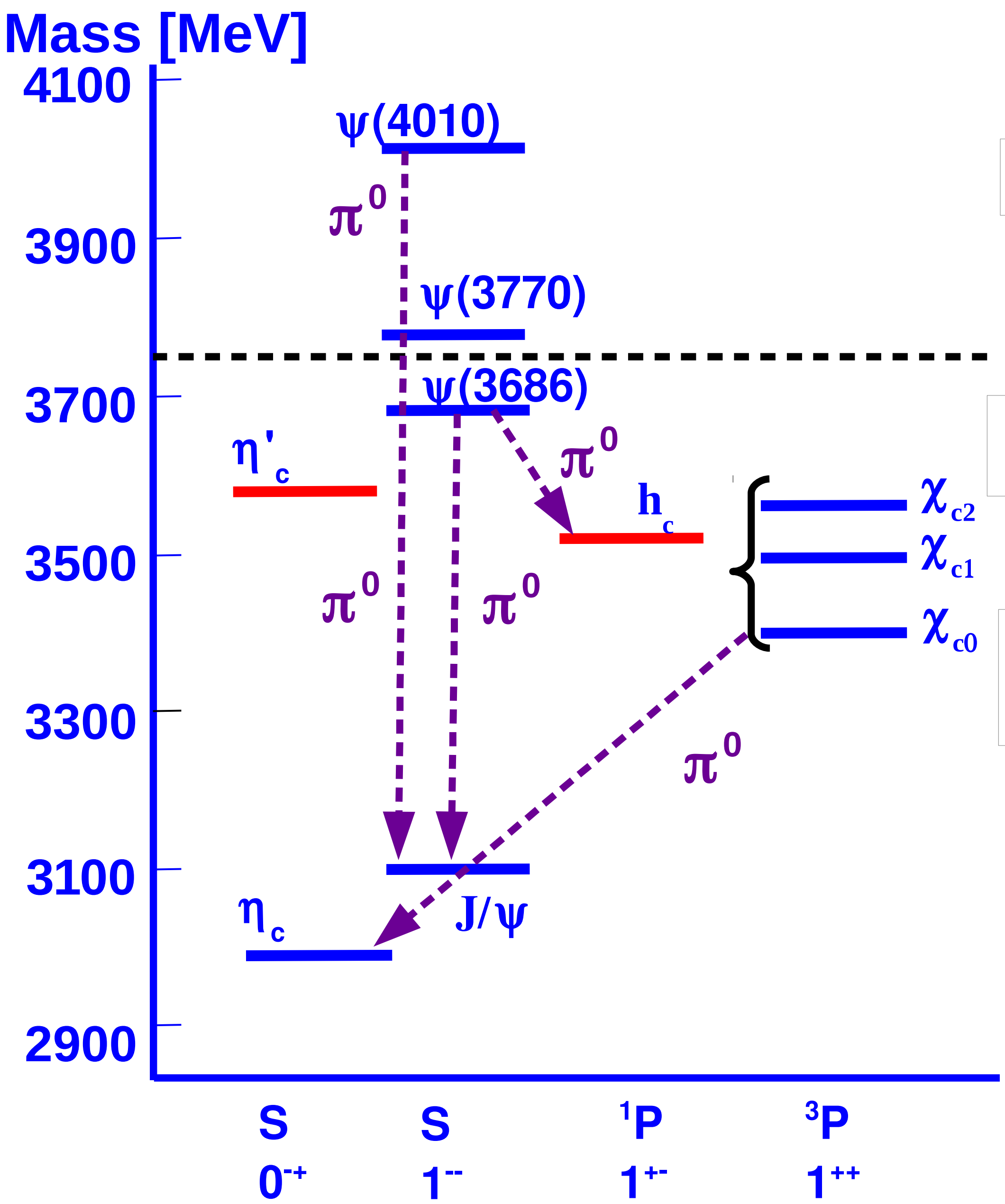
$$\frac{B(\Psi(3686) \to \pi^0 J/\psi)}{B(\Psi(3686) \to \eta J/\psi)} (\%)$$

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

Best Measurement!
Can constrain EFT!

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

Isospin violating transitions @ BESIII



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

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

$B(\psi(3686) \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \cdot 10^{-4}$

PRL 104, 132002 (2010)

$B(\psi(3686) \rightarrow \pi^0 J/\psi)/B(\psi(3686) \rightarrow \eta J/\psi) = (3.74 \pm 0.06 \pm 0.04) \cdot 10^{-2}$

PRD 86, 092008 (2012)

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

In Progress

Summary

- Charmonium below the $D\bar{D}$ threshold: progress by precision.
- Charmonium above the $D\bar{D}$ threshold: progress by discovery.
- Interpretation of XYZ states is a hot topic.
- Understanding of isospin breaking will shed light on the XYZ puzzle.
- Systematic studies of isospin-violating transitions are performed @ BESIII.
- These studies will help to constrain existing theoretical models.
- Many more exciting physics results will come this year with BESIII and in future with $\bar{\text{P}}$ANDA@FAIR!

m_u/m_d Impossible to measure directly!

- **Lattice QCD**: Numerical solution
  Direct, but computation power demanding.
  $m_u/m_d = 0.47(4)$; $m_u = 2.19(15)$ MeV; $m_d = 4.67(20)$ MeV

FLAG working group, 2011

- **Light mesons mass ratio:**

$$\frac{m_u}{m_d} = \frac{M_K^2 - M_{K_0}^2 + 2M_{\pi^0}^2 - M_\pi^2}{M_{K^0}^2 - M_K^2 + M_\pi^2} = \boxed{0.56}$$

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

difficult to estimate the error

discrepancy!

- **Effective Field Theory: (zero-order)**

$$R = \frac{B(\Psi' \rightarrow \pi^0 J/\psi)}{B(\Psi' \rightarrow \eta J/\psi)} \Leftrightarrow \frac{m_u}{m_d} = \boxed{0.40} \pm 0.01$$

Using results from CLEOc