Exotic hadron spectroscopy at Belle and Belle II

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for the Origin of Particles and the Universe

Belle II

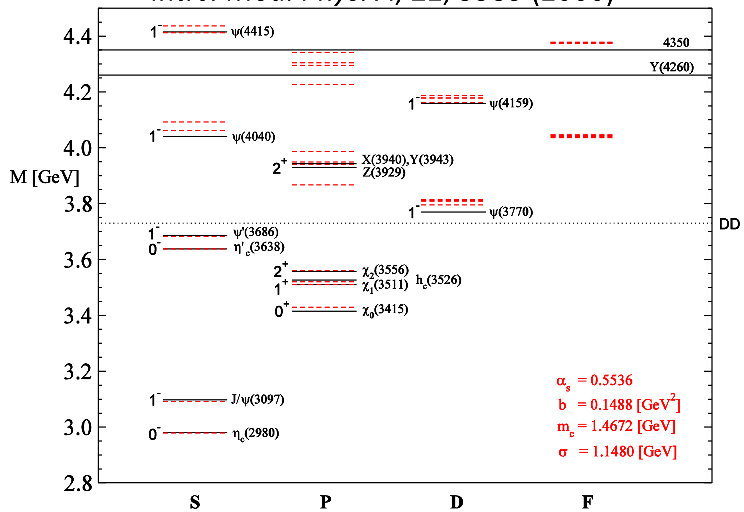
BELLE

Introduction

Success of constituent quark model

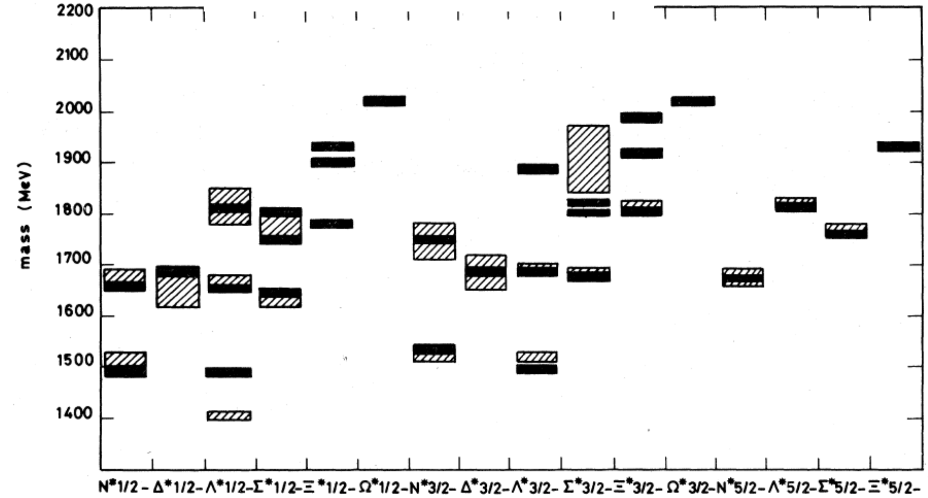
Mesons

Int. J. Mod. Phys. A, **21**, 5583 (2006)



Baryons

Phys.Rev. D18 (1978) 4187



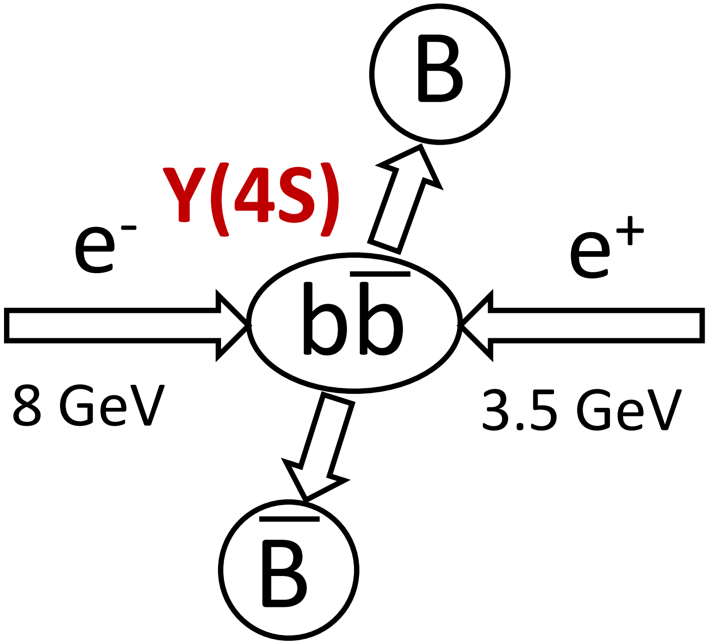
”Constituent quark” must be a good approximation… but not the end.

- Why it works so well?
- What is adaptive limit

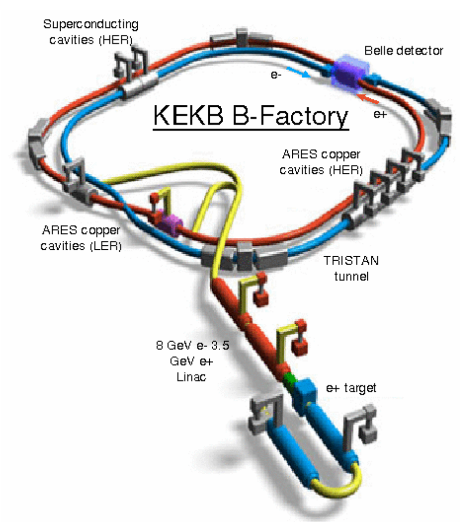
⇒ **Exotic hadrons**

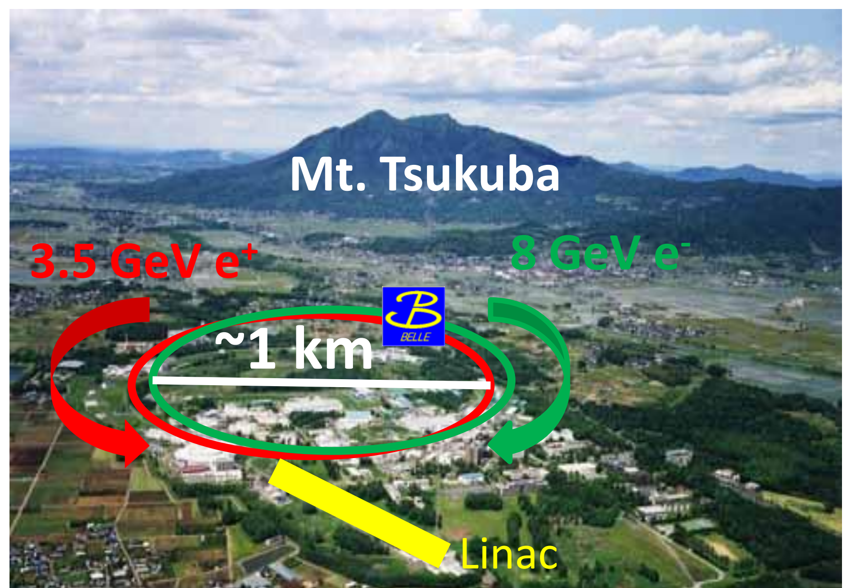
e^+e^- collider (especially B-factory) is a powerful probe!

KEKB accelerator

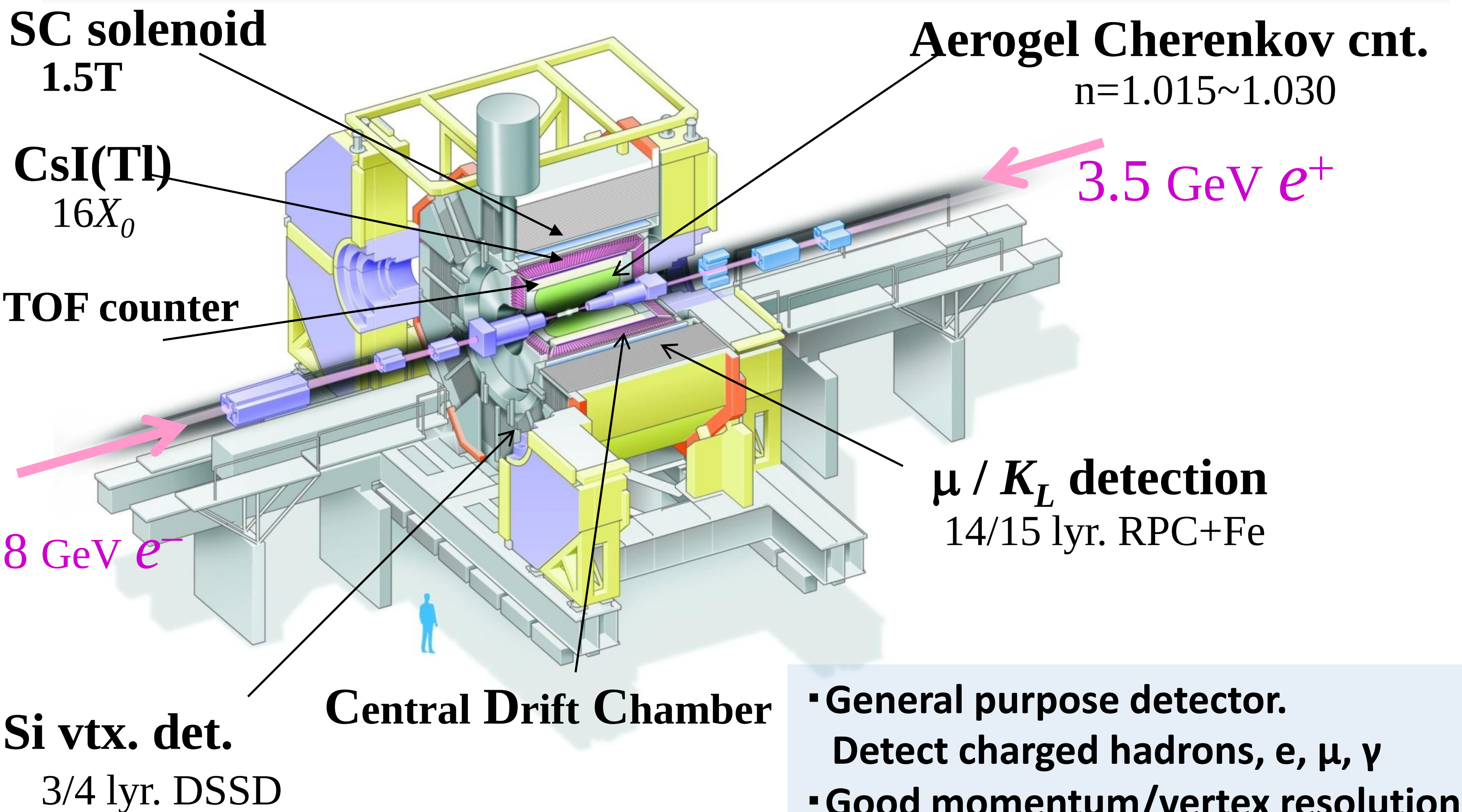


- Asymmetric energy e^+e^- collider constructed to test KM theory for CP violation in the B meson decay. →Nobel prize for them!
- $\sqrt{s}$=10.58 GeV = Y(4S) mass (and other energies) → e^+e^- → Y(4S) → $B\bar{B}$
- Peak luminosity = 2.1×10^{34} $cm^{-2}s^{-1}$ = World highest luminosity!





Belle detector

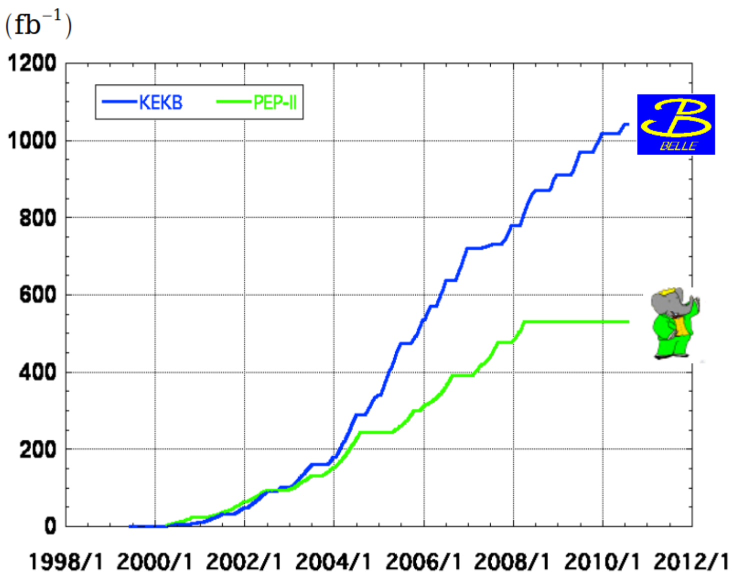


- General purpose detector.
  Detect charged hadrons, e, μ, γ
- Good momentum/vertex resolution.
- K/π separation up to ~3.5 GeV/c

→suitable also for hadron spectroscopy

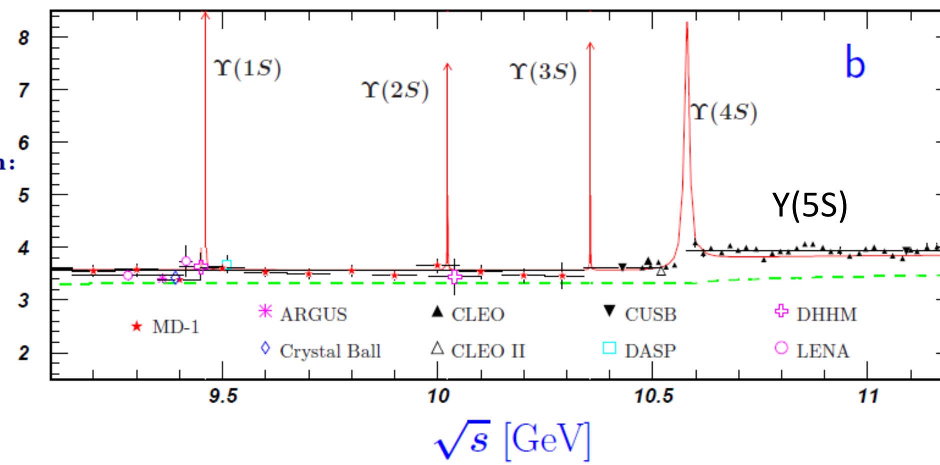
Data accumulated at Belle

Integrated luminosity of B factories



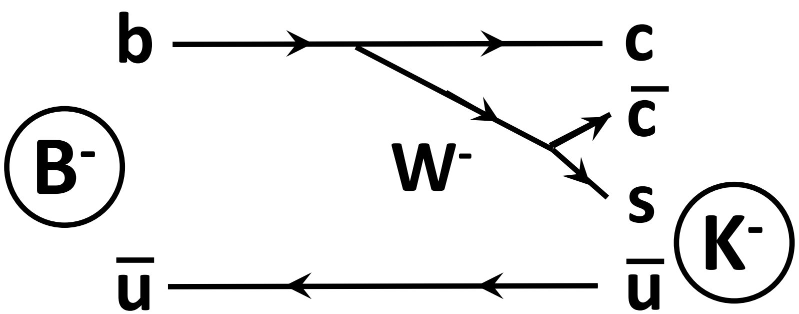
> 1 ab^{-1}
On resonance:
Υ(5S): 121 fb^{-1}
Υ(4S): 711 fb^{-1}
Υ(3S): 3 fb^{-1}
Υ(2S): 25 fb^{-1}
Υ(1S): 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

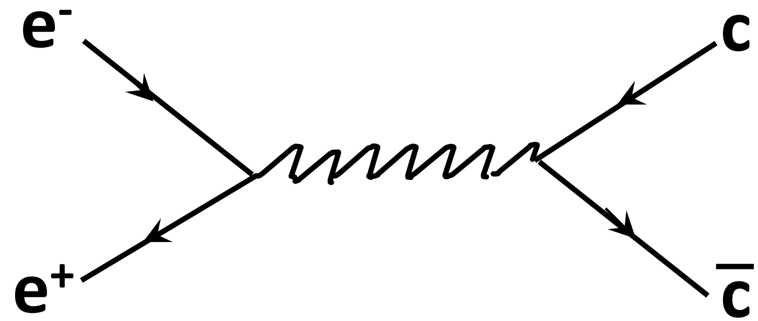
~ 550 fb^{-1}
On resonance:
Υ(4S): 433 fb^{-1}
Υ(3S): 30 fb^{-1}
Υ(2S): 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}



- 10 years operation. Taken at various energies.
- ~70 % of data is taken at Y(4S).
  ~7.7 × 10^{8}B$\bar{B}$ pairs.
- Total inregrated luminosity ~=1000 fb^{-1}.
  ~1 × 10^9 $e^+e^- \to c\bar{c}$.

Hadron production at B-factory





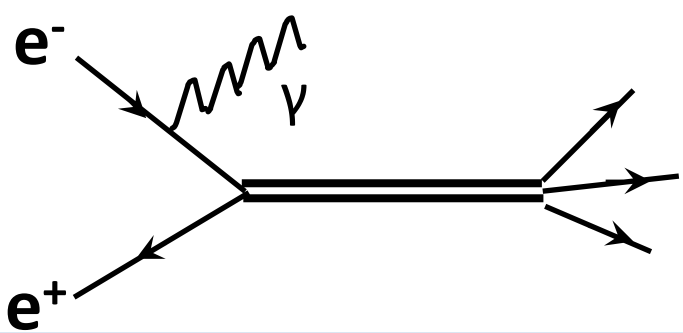
B-decays into charmonium

- Clean "charmonium laboratory".
- X(3872), Z(4430)….

$e^+e^- \rightarrow c\bar{c}$ reaction

- Charmed baryons observed.

- 2-photon process and double charmonium production also contribute.



Initial state radiation

- Produce charmonium with $J^{PC}=1^{--}$
- Y(4260)

- Low multiplicity is common advantage compared with hadron collider (LHC).

- Cross section is not high compared with hadron collider but high luminosity compensate it.

“New hadrons” from B-factories

Belle
BaBar

Unexpected bonus of B-factories！

Hadron type

Reaction

	Charmonium (like)	D(s)	Charmed baryon	Bottomonium
B-decay	$\eta_c(2S)$ X(3872) $Z_c(4050)$ $Z_c(4250)$ $Z_c(4430)$ $Z_c(4200)$	$D_1(2430)$ $D_s(2700)$		
ISR	Y(4260) Z(3900) Y(4008) Y(4360) Y(4660)			
Double charmonium	X(3940) X(4160)			
Two photon	$\chi_{c2}(2P)$			
$e^+e^-\to cc^{bar}$		$Ds_0(2317)$	$\Sigma_c(2800)$ $\Lambda_c(2940)^+$ $\Xi_c(2980)$ $\Xi_c(3080)$ $\Omega_c(2770)$ $\Xi_c(3055)$	
Y(5S) decay				$Z_b(10610)$ $Z_b(10650)$ $h_b(1P)$ $h_b(2P)$ $\eta_b(2S)$

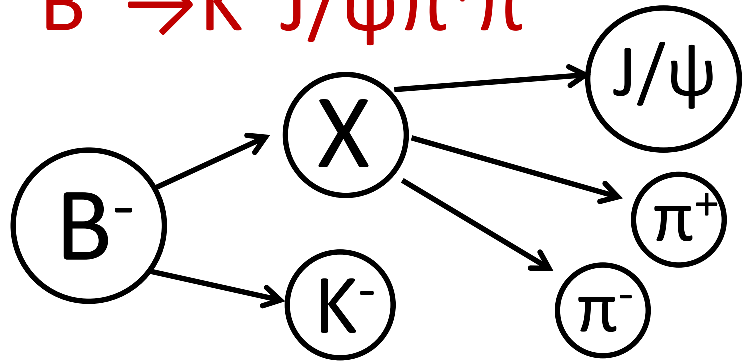
Contents

- X(3872)
- Other Y, Z states
- Prospect at Belle II

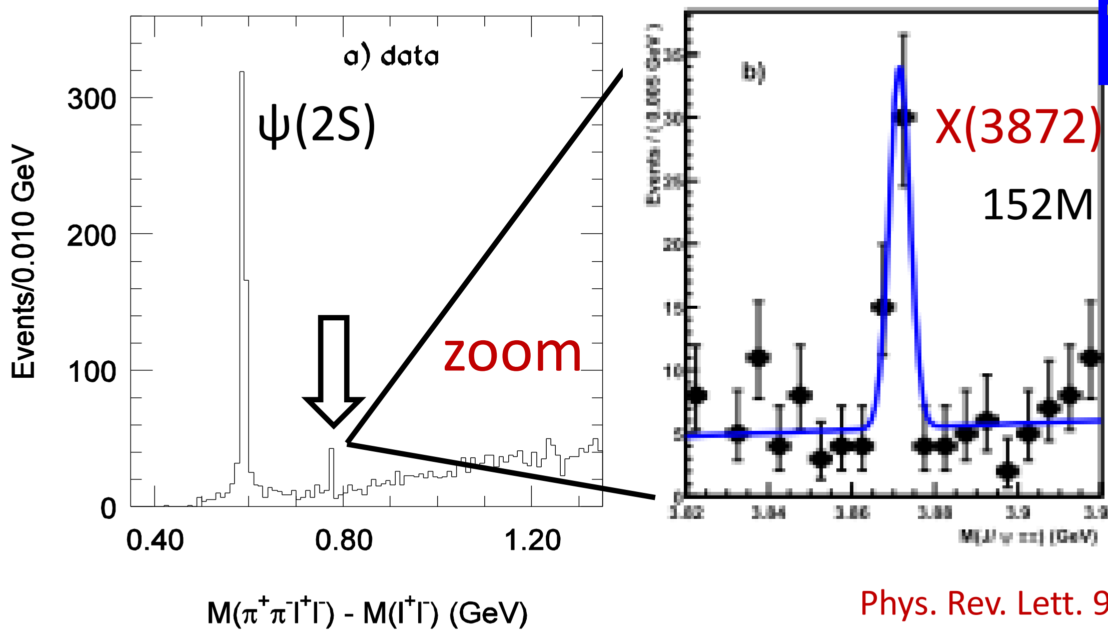
*some states may be missed

X(3872):First observation

$B^- \rightarrow K^- J/\psi\pi^+\pi^-$



$M(\pi\pi J/\psi)-M(J/\psi)$



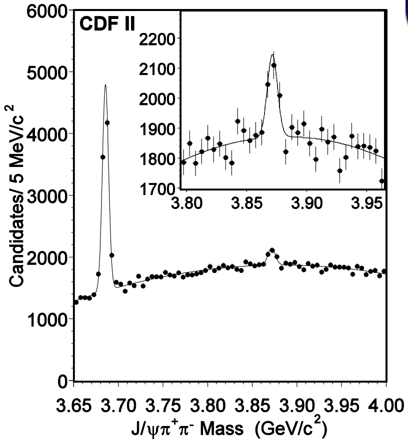
152M BB^{bar} pairs

Phys. Rev. Lett. 91.262001

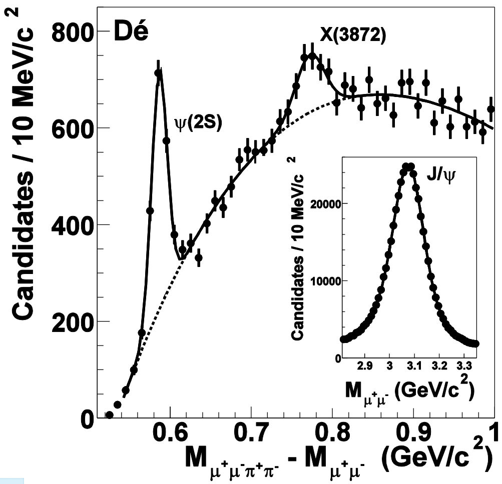
The most cited among ~500 papers in Belle (>1100@INSPIRE)

Confirmed by many experiments

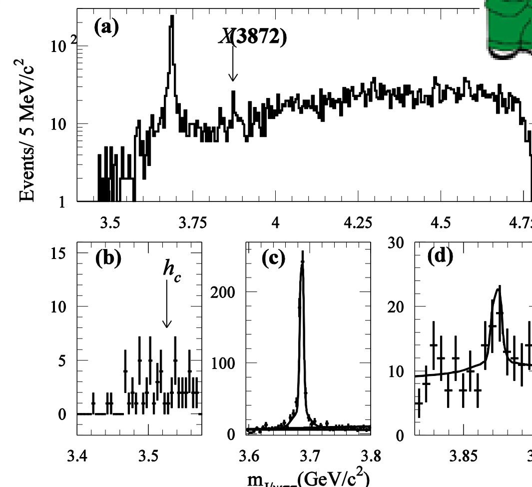
Phys.Rev.Lett.93:072001,2004



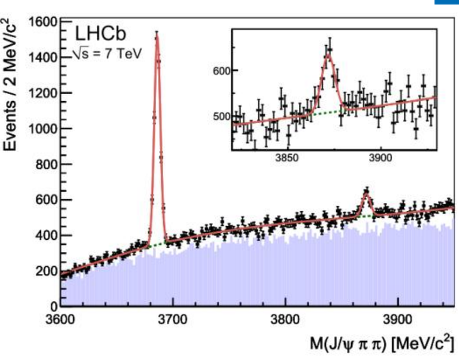
Phys. Rev. Lett. 93, 162002



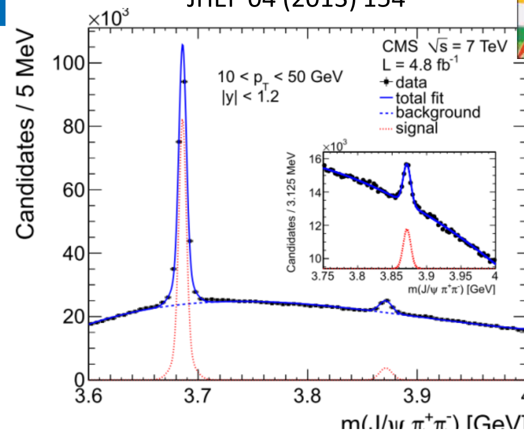
Phys.Rev.D71:071103,2005

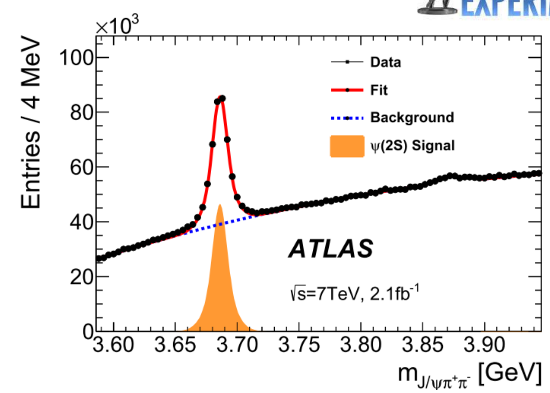


Eur. Phys. J. C. 72 (2012) 1972



JHEP 04 (2013) 154





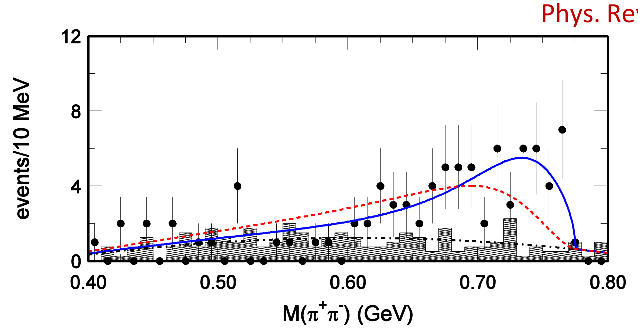
- Existence is established.
- Understanding of the property.

A strange hadron:X(3872)

- No quark model prediction in such mass region
  - Mass of the $\chi_{c1}(2P)$ is the closest but 30 MeV higher.

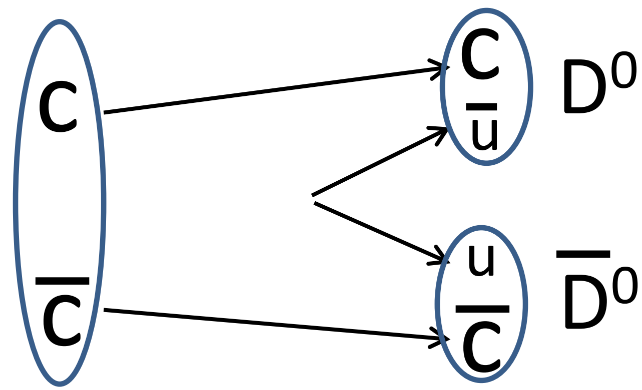
- **Decay breaks Isospin**
  - $J/\psi\pi\pi = J/\psi\rho$. cc^{bar} is I=0   ρ:I=1
  - $J/\psi 3\pi = J/\psi\omega$ is observed ω:I=0

Phys. Rev. Lett. 91.262001



M(ππ)

- Very narrow width though above $D\bar{D}$ threshold
  - Upper limit on the width =1.2 MeV.
  - Ex:Width of ψ(3770) is 27 MeV



- Very close to the $D^0\bar{D}^{*0}$

3871.69 ± 0.17 MeV/c^2 ⇔ 3871.8 ± 0.12 MeV/c^2

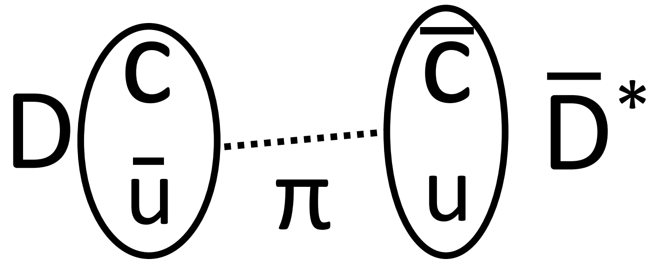
$M_{(X3872)}$ M_{DD*}

$D\bar{D}^*$ Molecular state？(1)

The most natural interpretation is $D\bar{D}^*$ molecular state

D^*: $J^P=1^-$

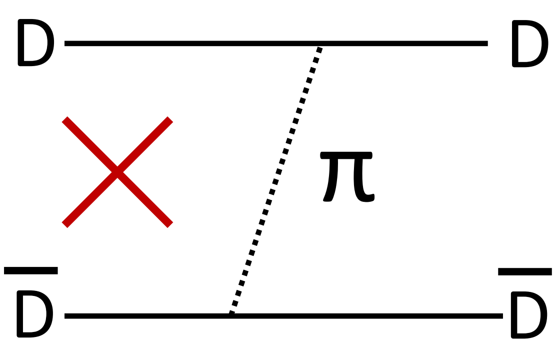
D : $J^P=0^-$



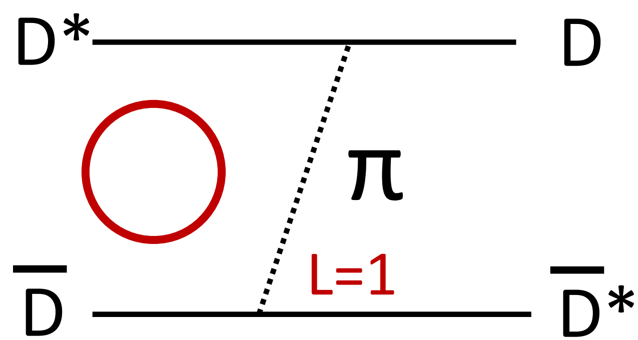
・Narrow width

→$D\bar{D}^*$ has $J^P=1^+$, whereas $D\bar{D}$ has $J^P=0^+$

π exchange is forbidden for DD but allowed for DD*

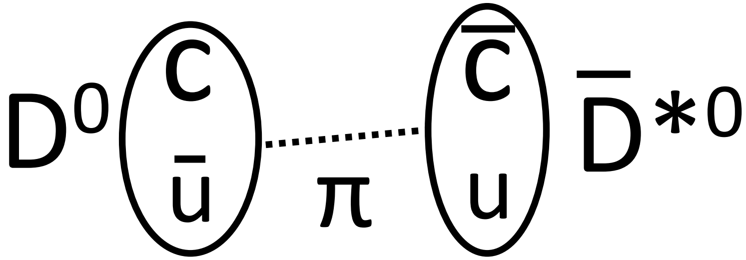


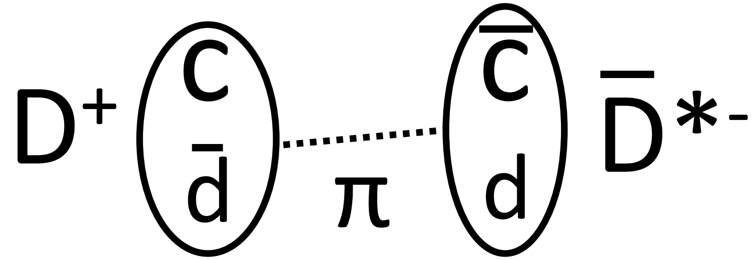
Spin-parity not conserved



Spin-parity can be conserved with orbital angular momentum.

Molecular state? (2)





- Isospin is broken in the decay

I=0 Eigen state is $(|D^0\overline{D^{*0}}>+|D^+\overline{D^{*-}}>)/\sqrt{2}$

*I=0 channel has strong attractive potential. Deuteron has I=0, too.

- **The mass difference of D^0D^{*0} and D^+D^{*-} is around 8 MeV (M_u<M_d)**

- This mass difference is large compared with binding energy. (<1 MeV)

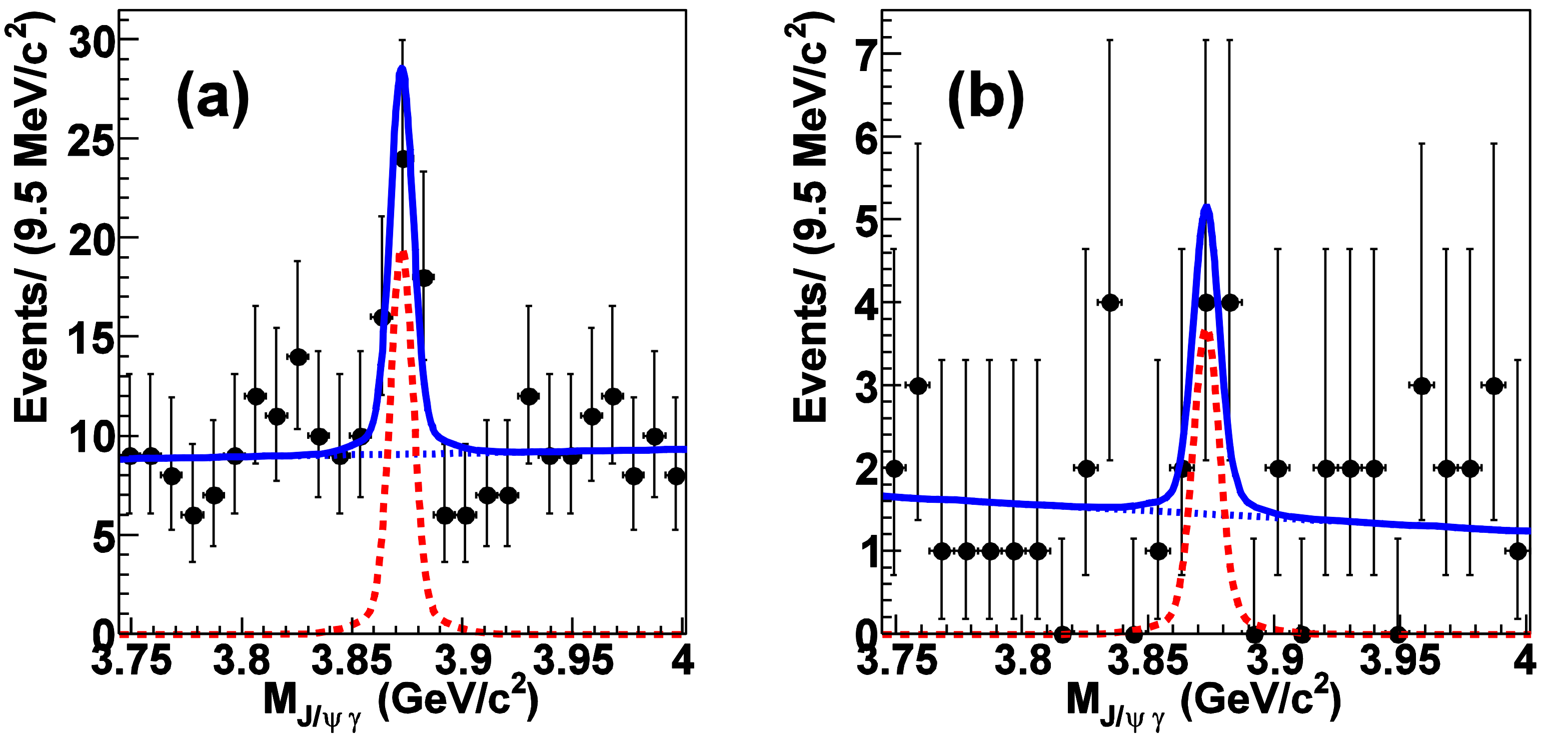
→The contribution of $D^0\overline{D}^{*0}$ becomes large and Isospin 0 and 1 are mixed.

Phys.Lett. B590 (2004) 209-215

The J^{PC} of the X(3872) should be 1^{++} if it is a molecular state.

Determination of C-parity: $J/\psi\gamma$

$B^+ \rightarrow K^+ J/\psi\gamma$ $B^0 \rightarrow K_S J/\psi\gamma$



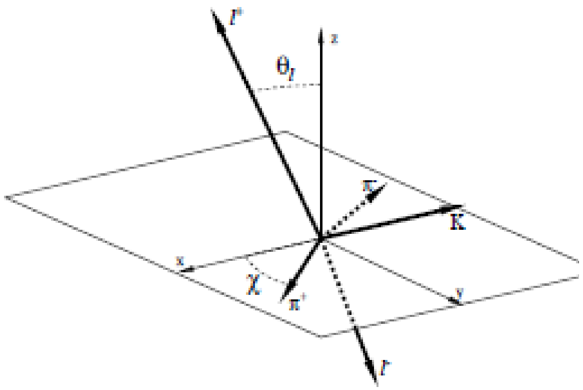
J/ψ: C=-1

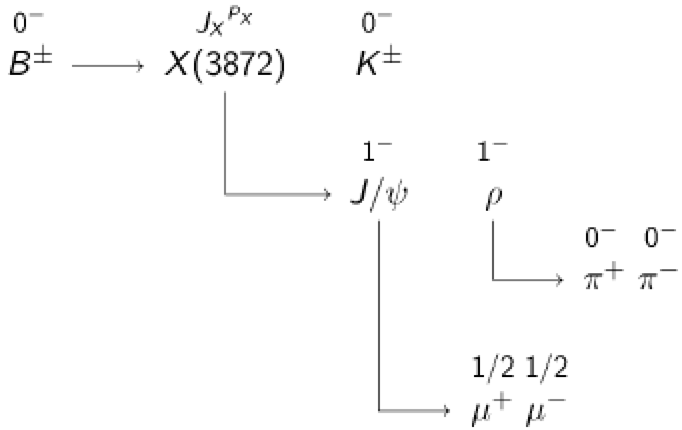
γ: C=-1

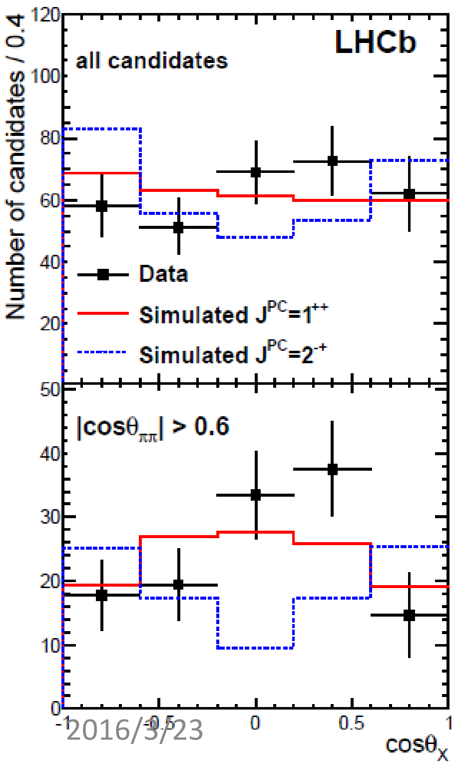
C=-1

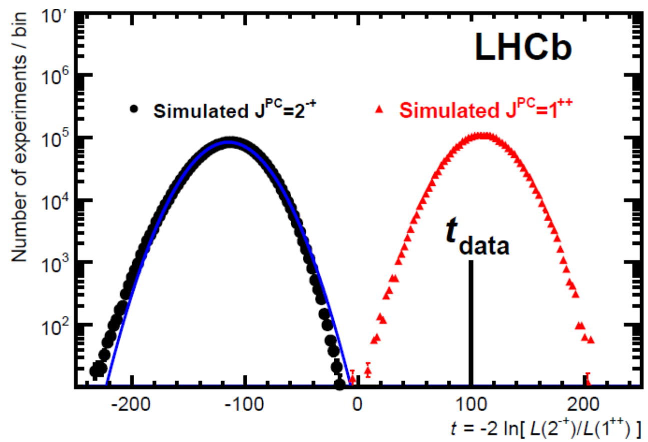
Phys.Rev.Lett. 107:9,2011

Spin-parity determination.









$-2\ln[L(2^{-+})/L(1^{++})]$

Phys. Rev. Lett. 110, 222001 (2013)

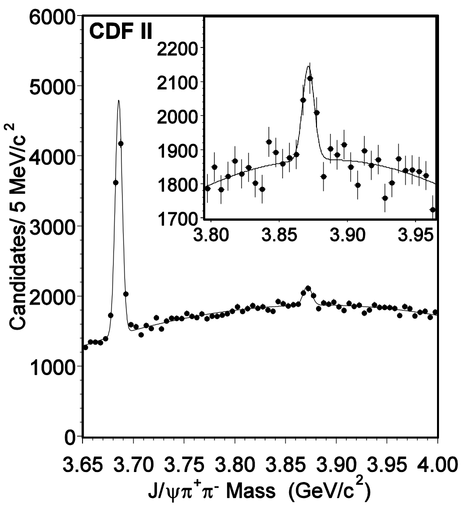
The estimated likelihood ratio for J^{PC}=2-+ and 1^{++}.
Compare with observed likelihood.

→Favor 1^{++} by 8.2σ=Consistent with S-wave DD*

Pure molecular state?

Phys.Rev.Lett.93:072001,2004

$p\bar{p}$ 1.9 TeV



- 80% comes from "prompt production" (not from B decay).
- If X(3872) is pure molecular state, binding energy is small.

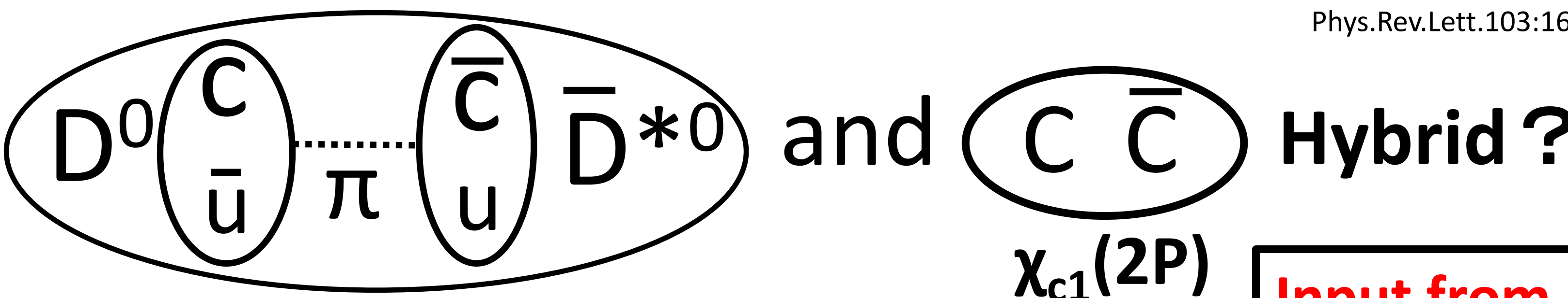
→Size is large: Radius is ~8 fm

→Easy to be broken.

→Prompt production cross section should be small.

Measurement :3.1±0.7 nb ⇔Prediction:0.071-0.11 nb

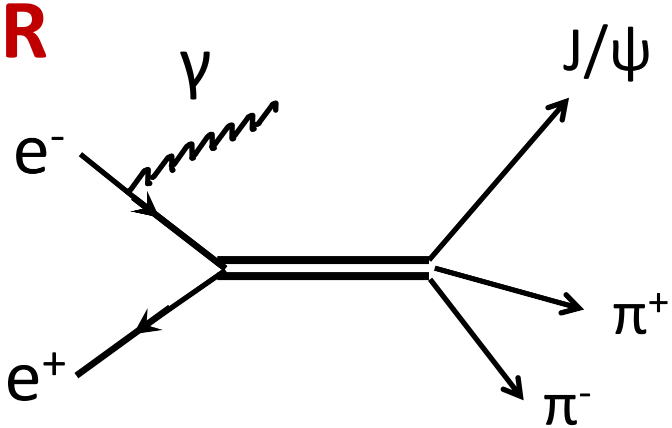
Phys.Rev.Lett.103:162001,2009



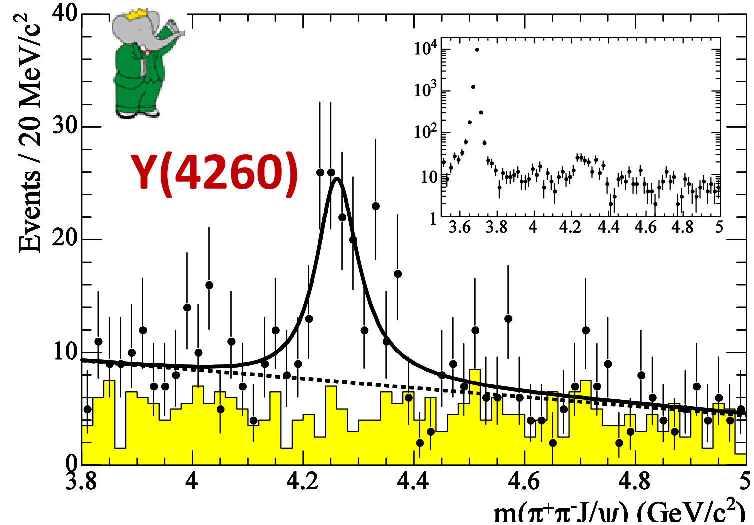
Input from HI should be useful!

Y(4260)

ISR



M(π⁺π⁻ J/ψ)



- Quantum number is the same as photon: 1^{--}
  - Quickly confirmed by CLEO, Belle.
- No prediction in quark model.

- $D\bar{D}$ decay is highly suppressed (spin-parity allows).

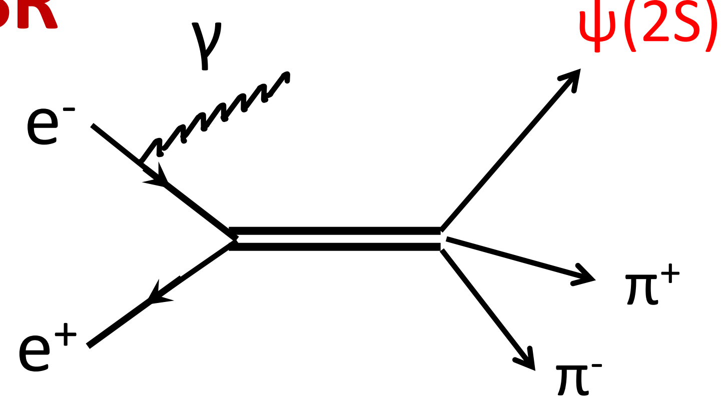
  $Br(Y(4260)\to D\bar{D})/Br(Y(4260)\to J/\Psi\pi\pi)<4.0$

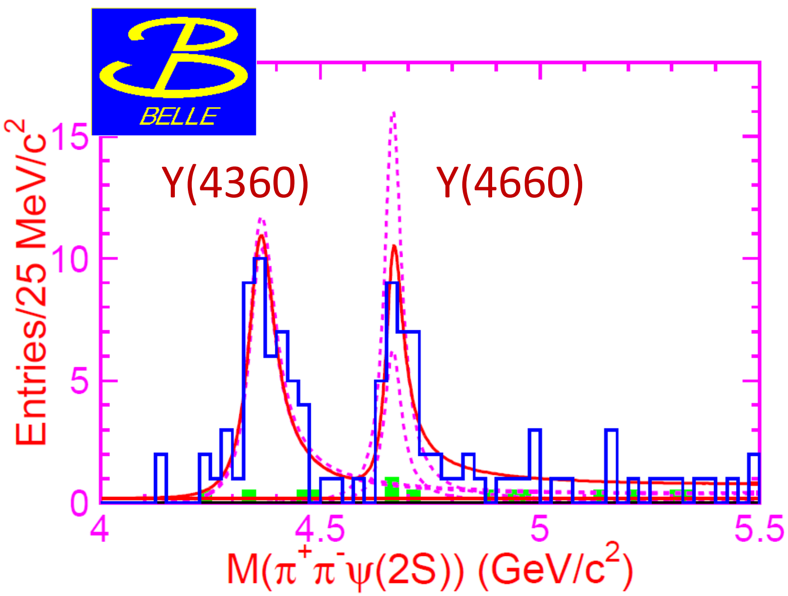
  $\Leftrightarrow Br(\psi(3770)\to D\bar{D})/Br(\psi(3770)\to J/\psi\pi^+\pi^-)\sim=50$

- Hybrid state of charmonium and gluon?

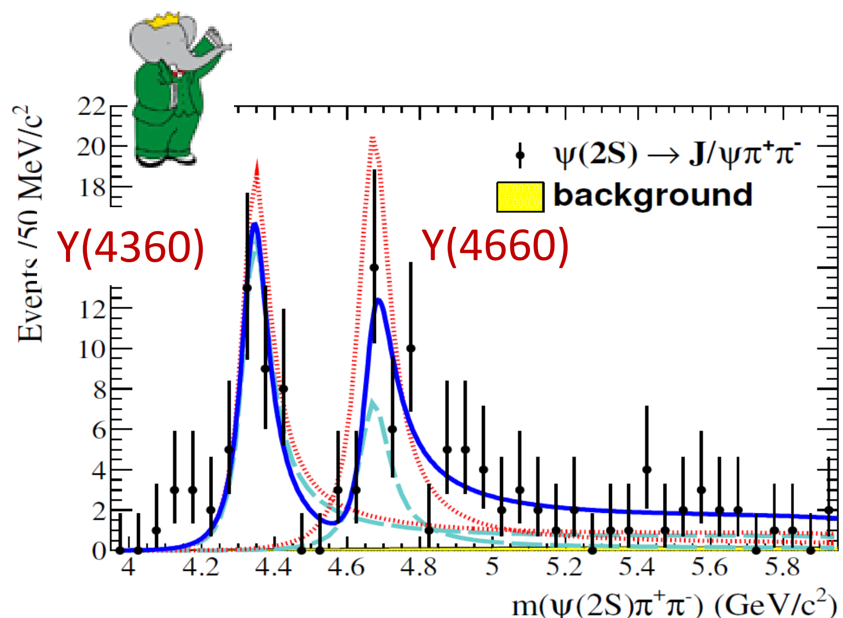
Y(4360), Y(4660) in $\Psi(2S)\pi^+\pi^-$

ISR



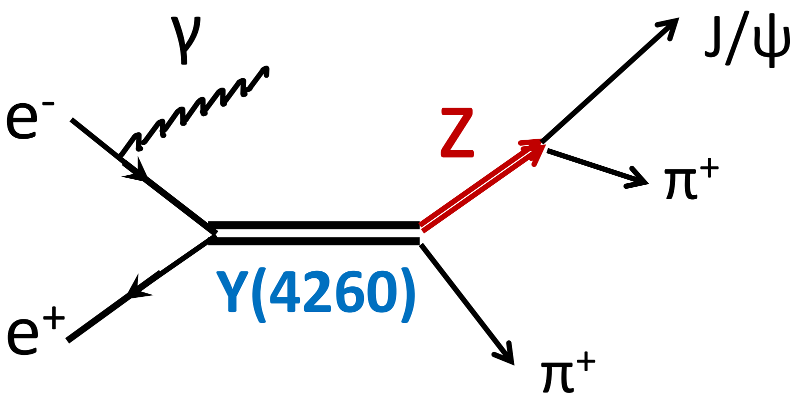


Phys. Rev. Lett. 99, 142002

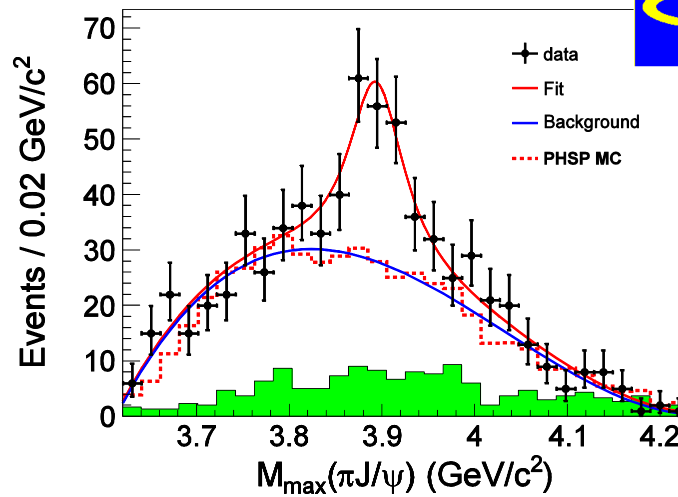


Phys. Rev. D **89**, 111103(R)

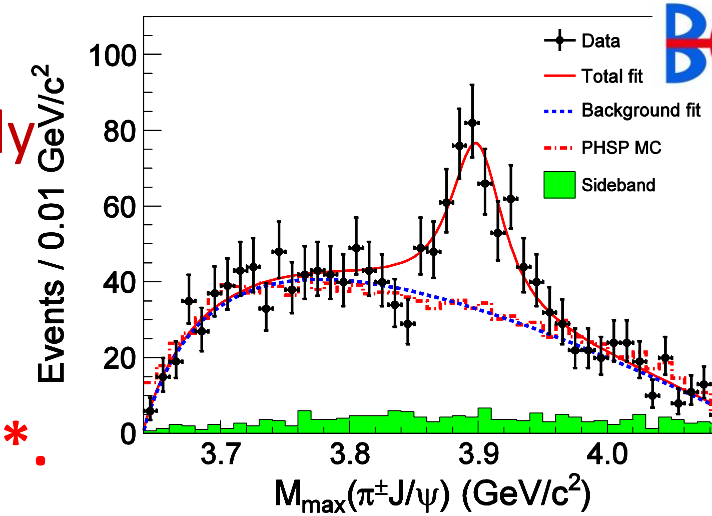
$Z_c(3900)^+$: First established charged charmonium



Phys. Rev. Lett. **110**, 252002 (2013)



Phys. Rev. Lett. **110**, 252001 (2013)

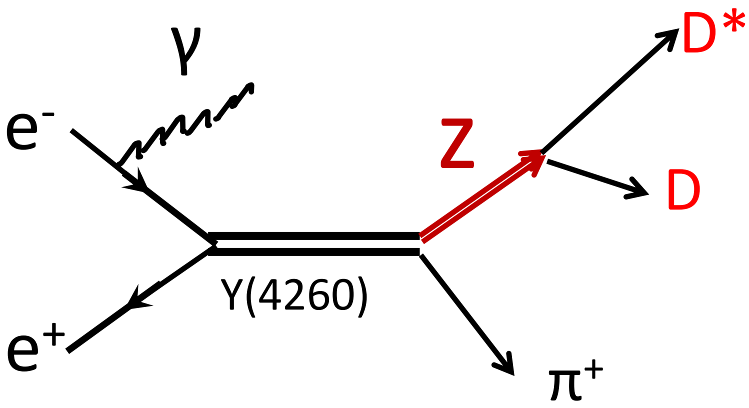


- Decay into $J/\psi\pi^+$ → Contains $c\bar{c}$ (cc^bar)
- The charge of $\psi\pi^+$ is +1 → Not cc^bar only

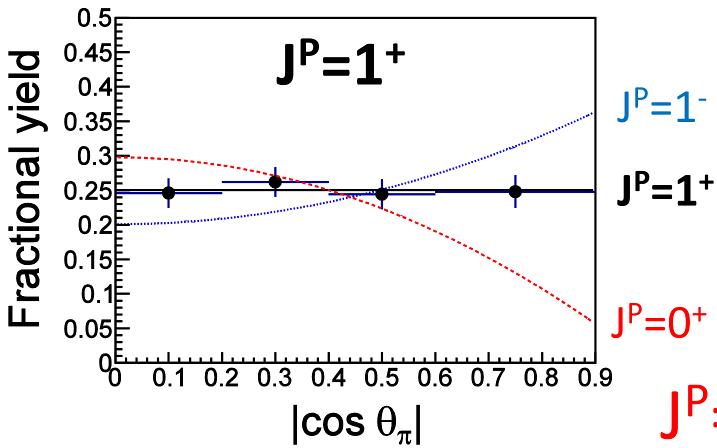
→ Minimal quark content is 4.

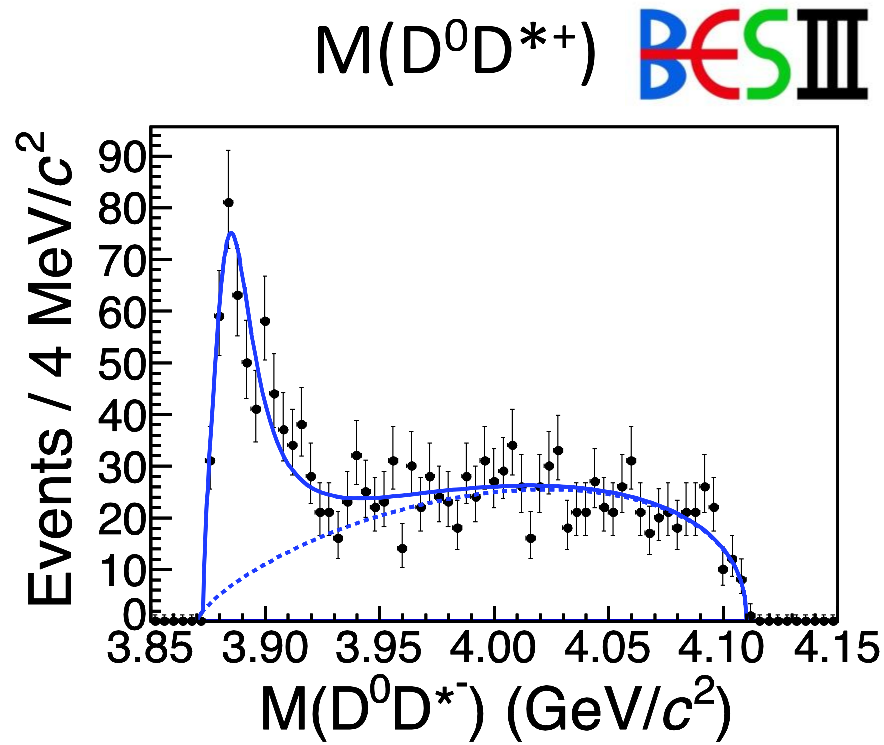
The mass is again close to DD*.

$Z_c(3900) \rightarrow DD^*$ by BES III



π decay angle distribution

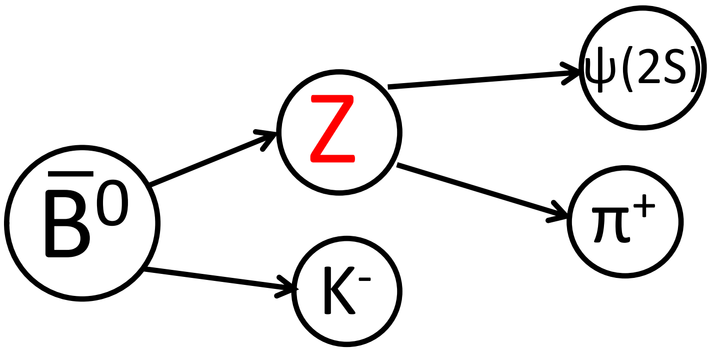




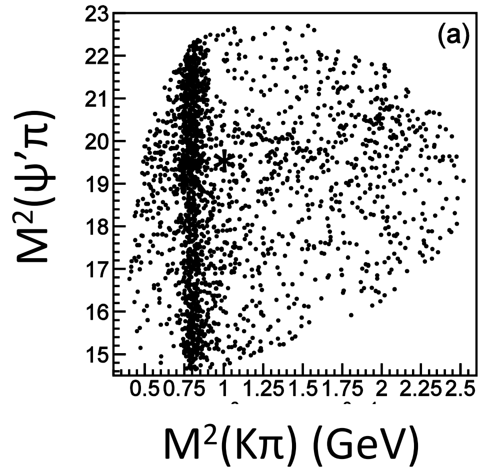
Phys. Rev. Lett. **112**, 022001 (2014)

$J^P = 1^+$: consistent with S-wave DD*

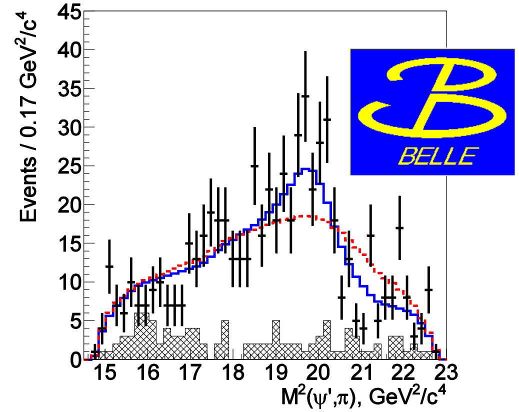
Z(4430)$^+$



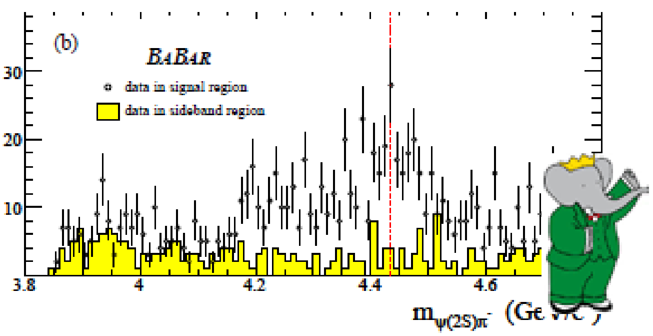
K*



M(ψ(2S)π$^+$) with K* veto

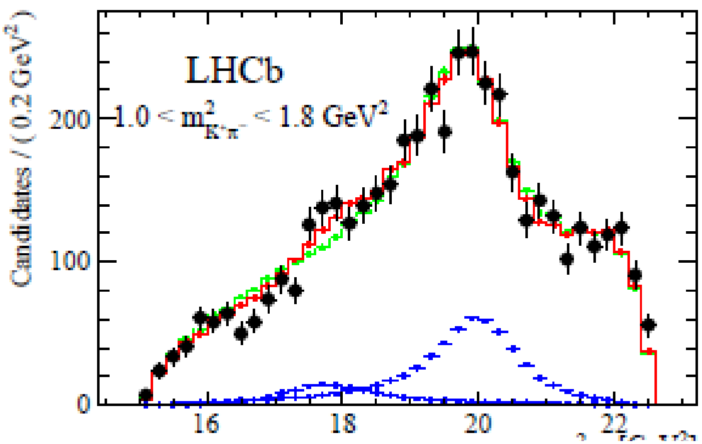


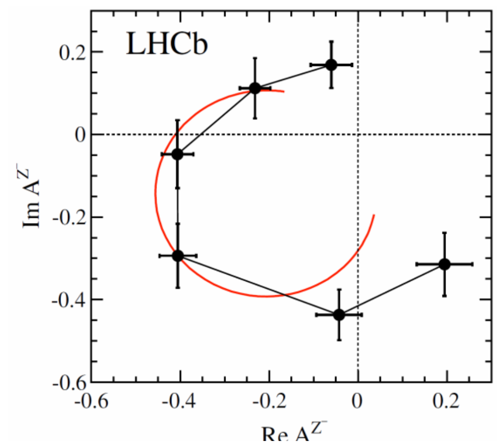
- First "reported" charged charmonium
- Need some time to be "established" as BaBar reported negative result.



Phys.Rev.D79:112001,2009

Confirmation by LHCb experiment





Phys.Rev.Lett. 112 (2014) 222002

- The statistics of $B^0 \to \psi(2S)\pi^+K^-$ is 12 times higher than Belle data.
  2010 ±50± 40 (Belle) ⇔ 25176±174 (LHCb)

- The statistical significance of the $Z_c(4430)^+$ is 13.9σ.
  Argand diagram shows resonance structure.

- $M=4475 \pm 7^{+15}_{-25}$ MeV/c2, $\Gamma=172 \pm 13^{+37}_{-34}$,
  Consistent with Belle result.

- Favor $J^P=1^+$ by 8σ.

Short summary

Z:Charmonium with charge.

Y:Produced with ISR ($J^{PC}=1^{--}$). Not appear in quark model.

X:Other mysterious charmoniums.

Name	J^{PC}	Decay	Production
X(3872)	1^{++}	$J/\psi\pi\pi$ etc	B decay, prompt
Y(4260)	1^{--}	$J/\psi\pi\pi$	ISR
Y(4360/4660)	1^{--}	$\Psi(2S)\pi\pi$	ISR
Z(3900)	1^{+}	$J/\psi\pi$, DD*	Y(4260) decay
Z(4430)	1^{+}	$\psi(2S)\pi$	B decay

Relation between Z(3900) and X(3872)

- Assume Z(3900) and X(3872) are orthogonal state in Isospin space.

X(3872) is close to the $(|D^0\overline{D^{*0}}> + |D^+\overline{D^{*-}}>)/\sqrt{2}$

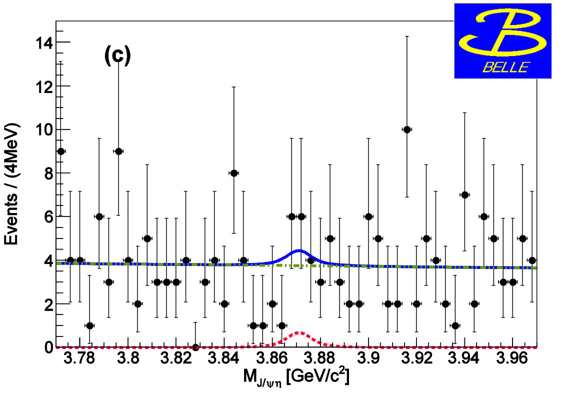
I=0

Z(3900) is close to the $(|D^0\overline{D^{*0}}> - |D^+\overline{D^{*-}}>)/\sqrt{2}$

I=1

- The attractive potential from pion exchange is large for I=0 channel
  →$M_{Z3900} > M_{X3872}$ is qualitatively OK？

M(J/ψη) in B→J/ψηK



10.1093/ptep/ptu043

- The isospin of $J/\psi\pi^+$ is 1

- The isospin breaking decay:J/ψη

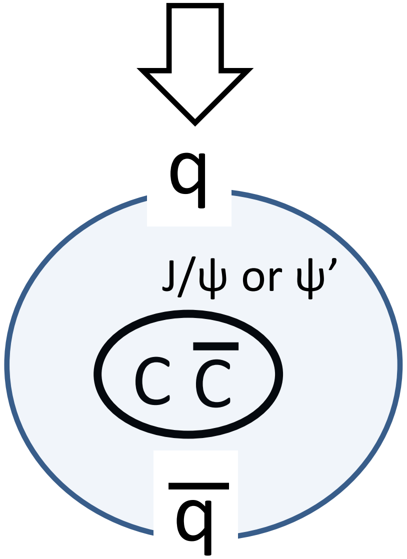
- Already searched for at Belle but no signal.
  Interesting subject at Belle II.

The relation between $Z_c(3900)$ and $Z_c(4430)$?

$Z_c(4430)$:$\psi(2S)\ \pi^+$ decay

$Z_c(3900)$:$J/\psi(1S)\ \pi^+$ decay

- $M(Z_c(4430)) - M(Z_c(3900))$ ~= 580 MeV/c^2 ~= $M(\psi(2S))$-$M(J/\psi)$

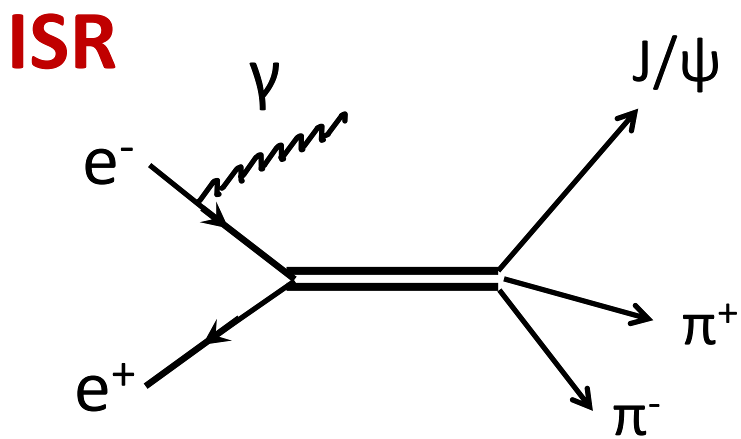


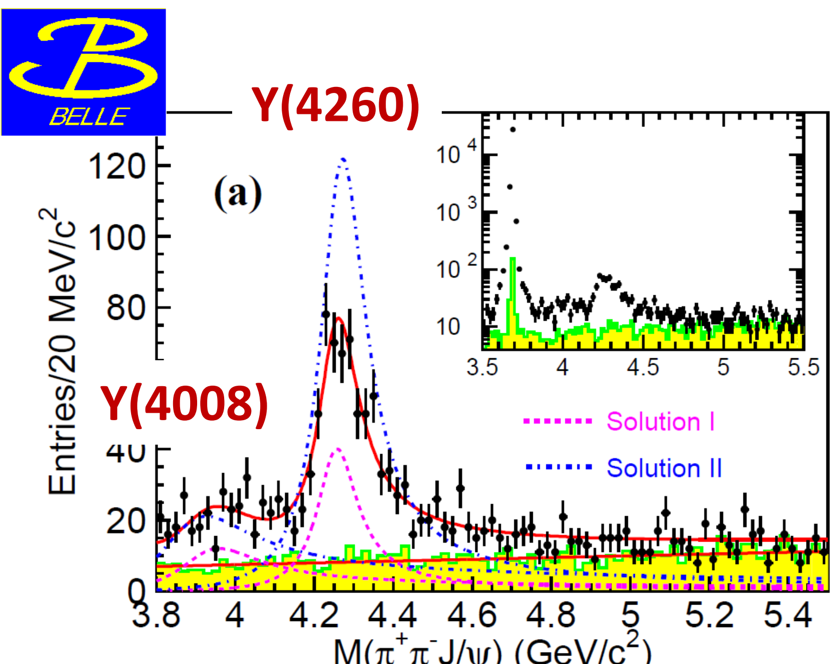
$Z_c(4430)$ produced from B decay

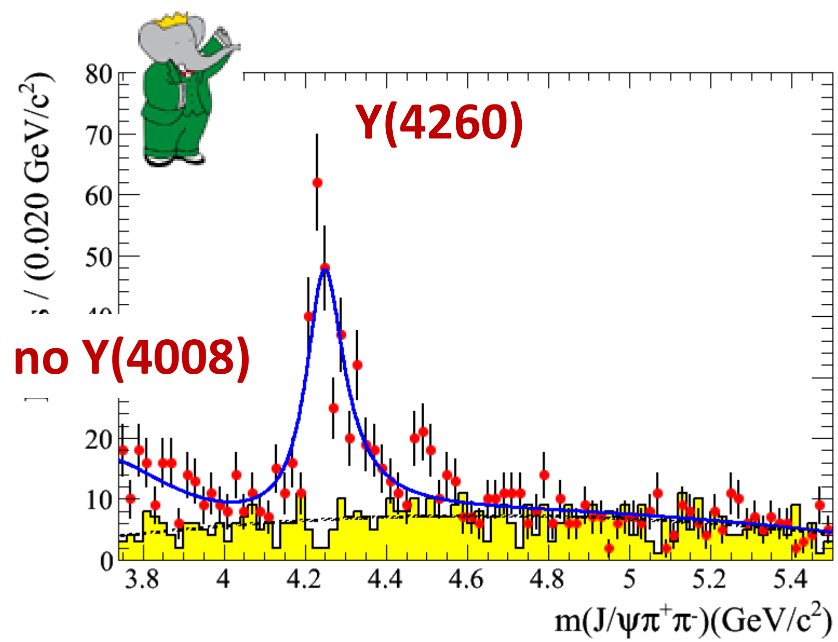
$Z_c(3900)$ produced from ISR (Y(4260) decay).

Origin of the difference?

Controversial states (1): Y(4008)

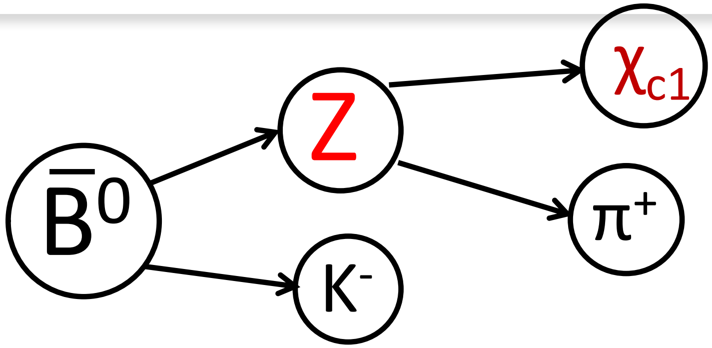




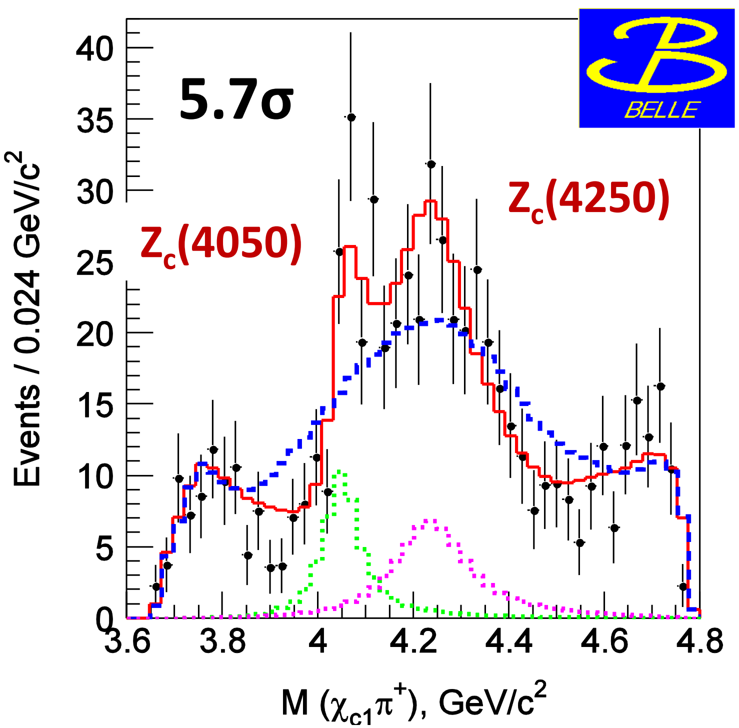


Phys. Rev. Lett. 110, 252002 (2013)

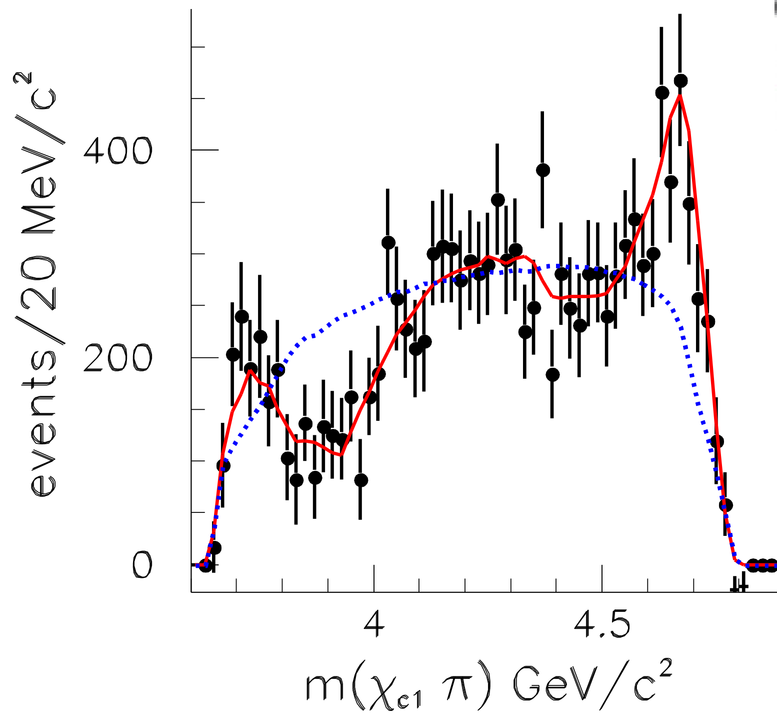
Controversial states (2): Z(4050), Z(4250)



Two resonances



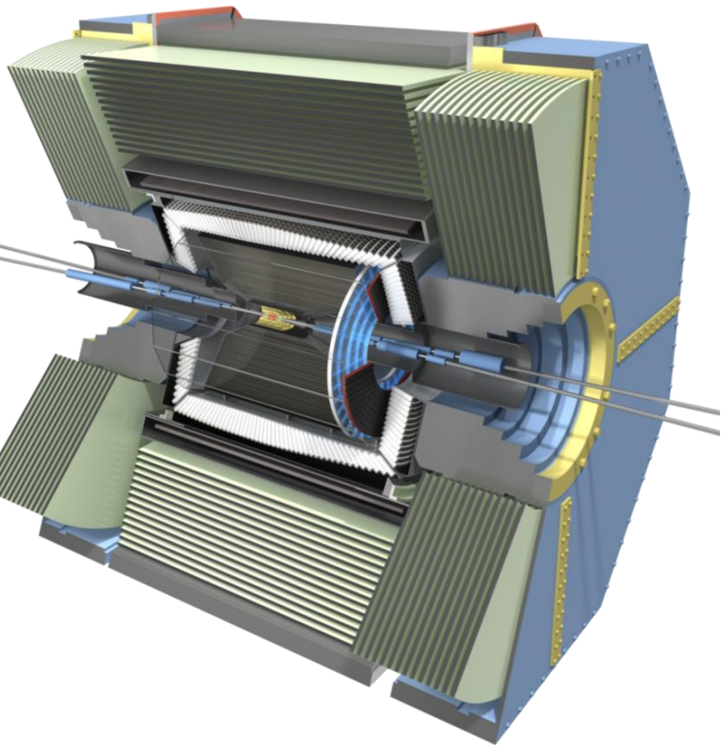
Data can be described by K* resonances.



Phys. Rev. D 85, 052003

Confirmation by independent data →Belle II

Belle II



- KEKB → SuperKEKB
  40 (50) times peak (integrated) luminosity.
- Aim to find physics beyond SM
- Commissioning of the accelerator started.
  Both e^+ and e^- rotated in Feb. 26th
- Physics run w/o vertex detector in 2017.
- Physics run with full detector in 2018.

Hadron spectroscopy with Belle II

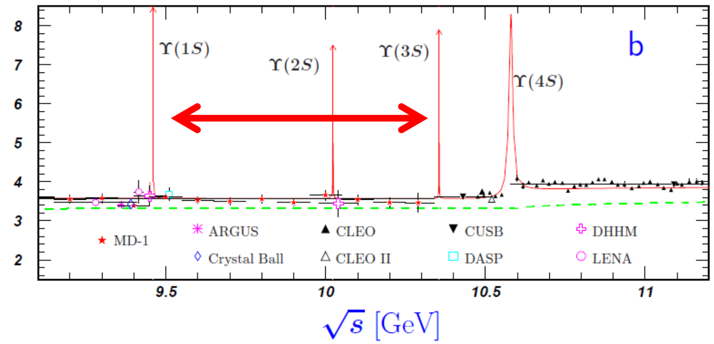
History of hadron spectroscopy at B-factories

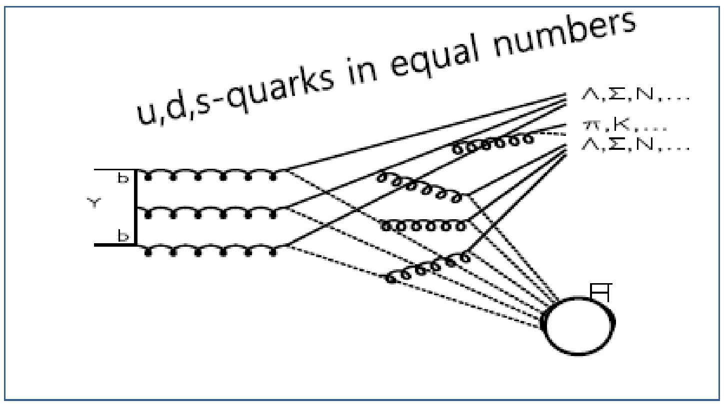
CLEO	→	Belle, BaBar	→	Belle II
~10 fb^{-1}		~ 1000 fb^{-1}		~50000 fb^{-1}
Excited charm meson/baryons		XYZ etc		More exotic!?

Di-baryon search@Υ(1-3S)

Υ(1-3S) decay into **anti-deuteron**
(Br=3 × 10^{-5})

$\bar{p}$ $\bar{n}$





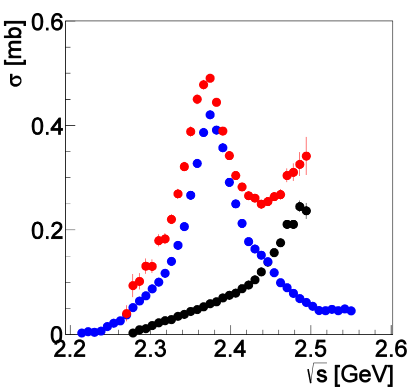
Υ(1-3S) predominantly decay into 3 gluons.
The same fraction for u,d,s.

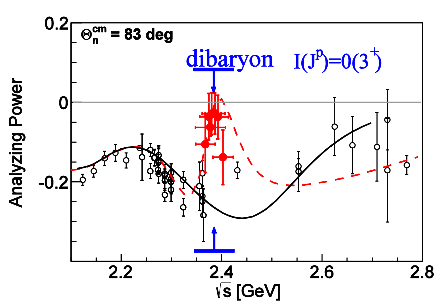
uds
uds

H-dibaryon

Not found in Belle

PhysRevLett.110.222002

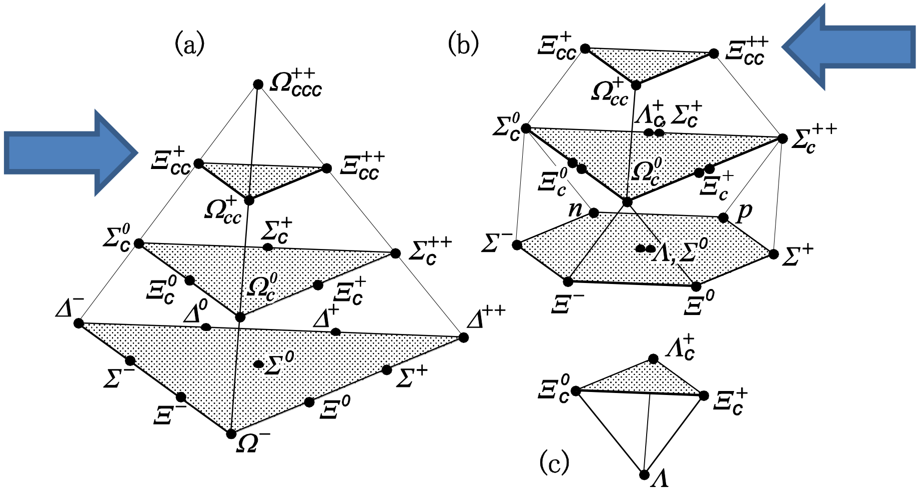




Phys. Rev. Lett. **112**, 202301

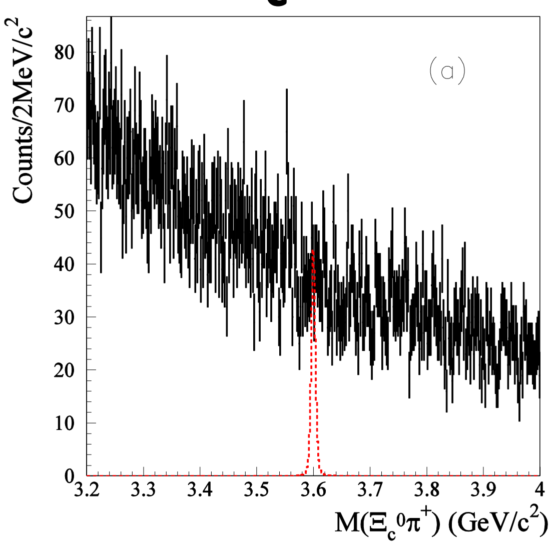
Search for ΔΔ bound state
d*(2380)@COSY
in $d\pi^+\pi^-$ channel is also interesting.

Doubly charmed baryons (not exotic!)



- Useful to extract QQ potential.
- No established doubly charmed baryons even for ground state.
- Selex reported evidence in $\Lambda_c^+ K^- \pi^+$ but not supported by other experiments.

$M(\Xi_c^0 \pi^+)$

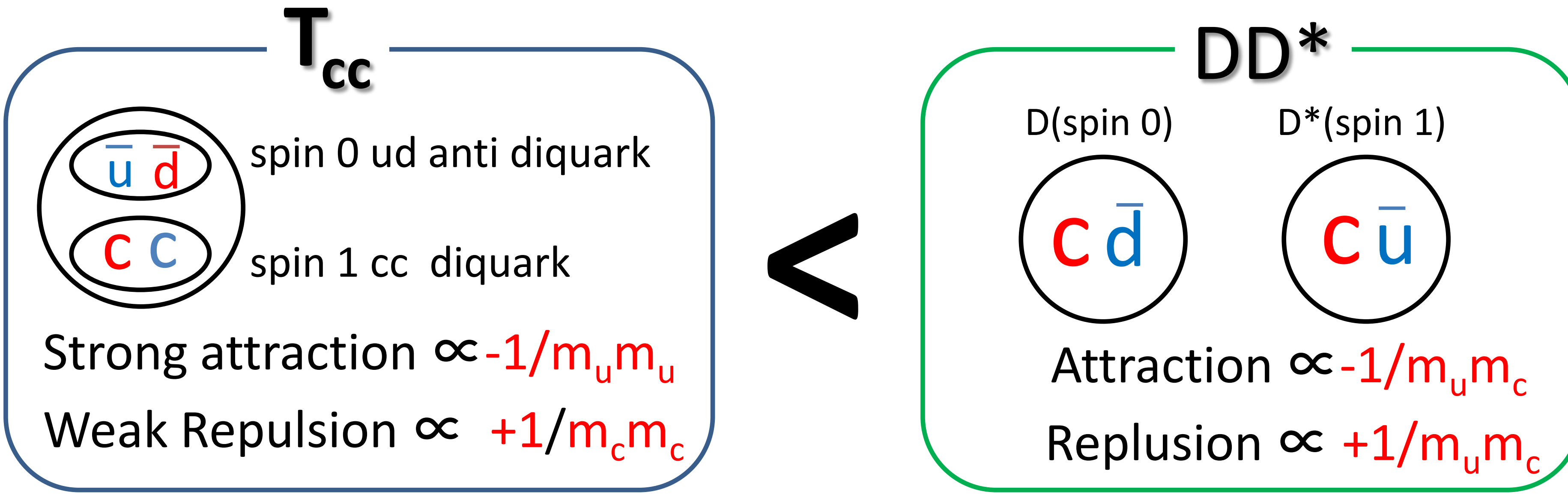


- Belle searched for Ξ_{cc} in the $\Xi_c^0 \pi^+$ and $\Lambda_c^+ K^- \pi^+$ decay modes.
- No significant signals were observed.
- Upper limit on the production cross section is close to the theoretical predictions.
- Good subject in the Belle II.

Phys. Rev. D **89**, 052003

Doubly charmed meson (T_{cc})

The same c-flavor→ Need 4 quarks.



The di-quark configuration is energetically favored.

Bound T_{cc} is a good probe to study the di-quark.

Summary

- Belle is the one of the hottest place for the hadron spectroscopy.

- Discovery of so-called XYZ states opened new era of exotic hadrons.
  - The structure is still not understood yet.
  - Driven by experiments.

  Comprehensive interpretation from theorist awaited!

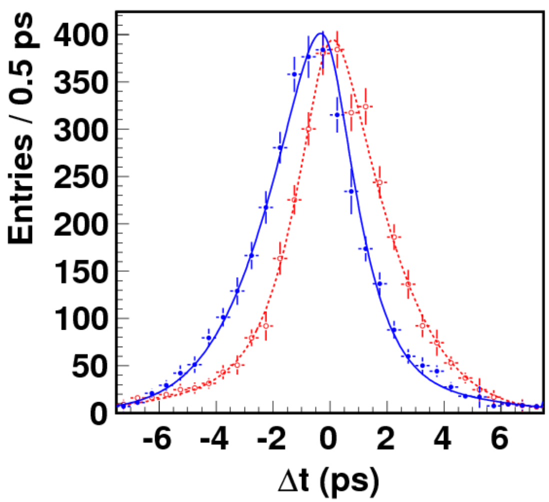
- Belle II will start physics run in 2017.
  - 50 times statistics.
  - Aim to observe physics beyond the SM.
  - Answer to the controversial states.
  - Many interesting hadron physics subjects.

Stay tuned for coming “new hadrons” from Belle II !

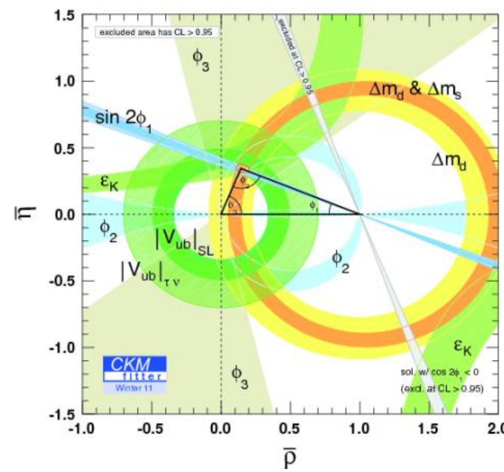
Backup

Belle leads Kobayashi-Maskawa to Nobel prize

Decay time distribution in B(^{bar})→J/ψK_S



Global fit on Unitary Triangle

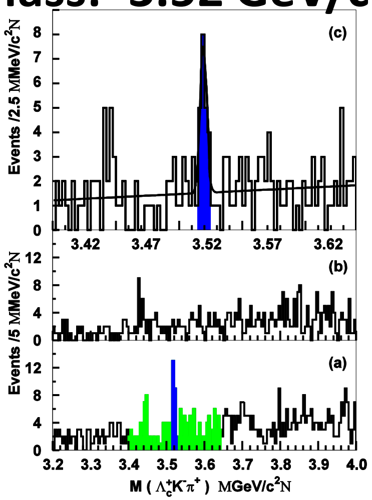


Press release by Nobel foundation (2008)

As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.

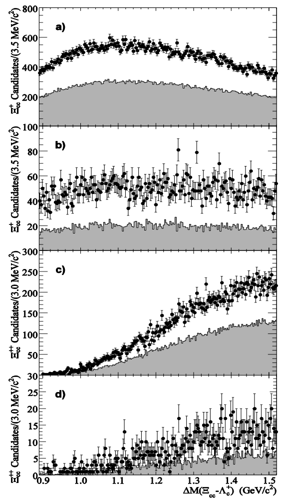
Past experimental search for Ξ_{cc}

Evidence from SELEX
in 2003
Mass:~3.52 GeV/c^2



$M(\Lambda_c^+K^-\pi^+)$
hep-ex/0208014

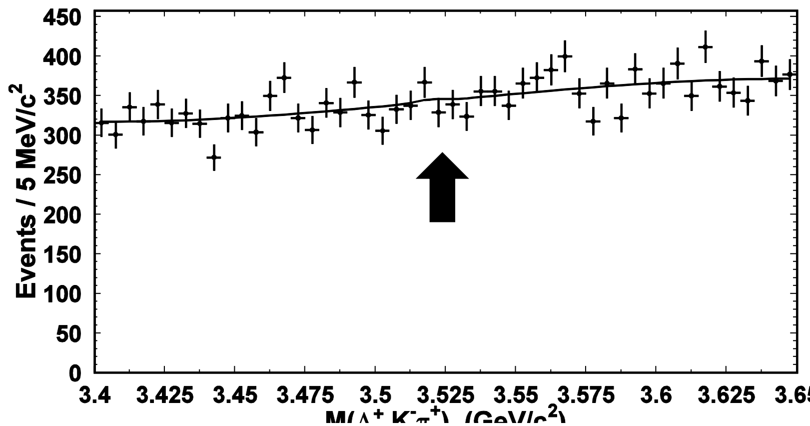
BaBar@232 fb^{-1}



$M(\Lambda_c^+K^-\pi^+)$
hep-ex/0605075

B-factories

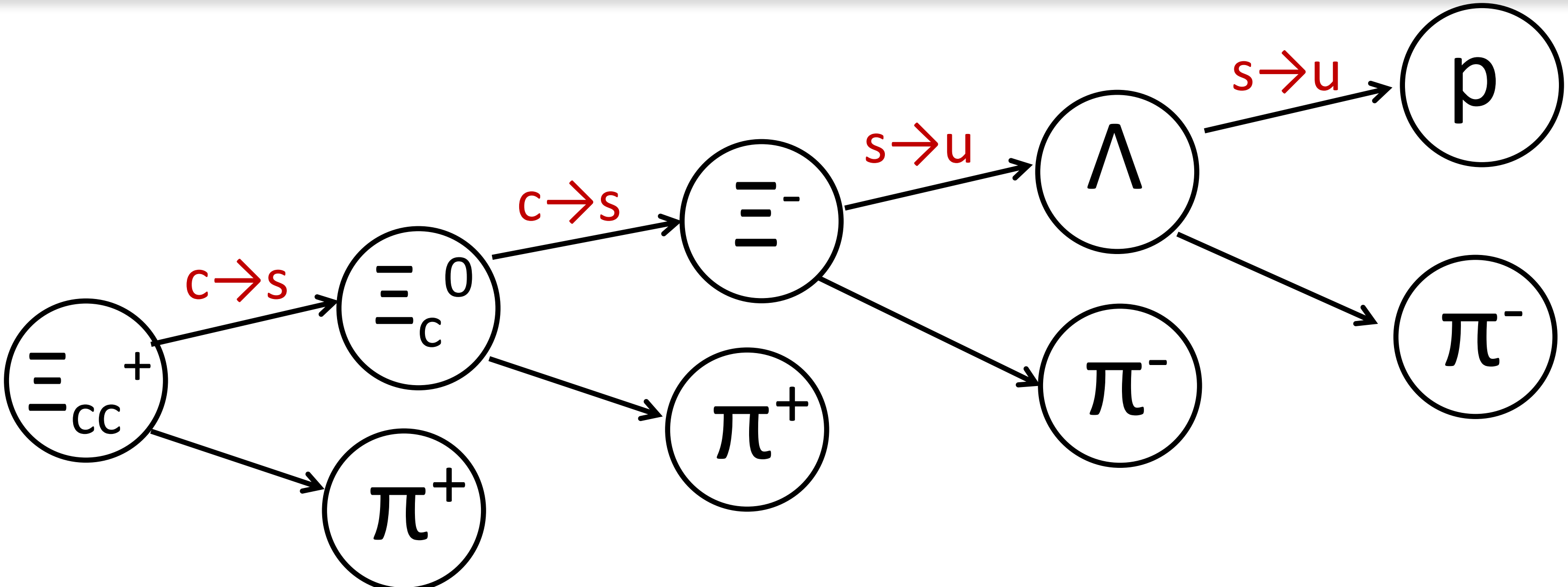
Belle@461.5fb^{-1}



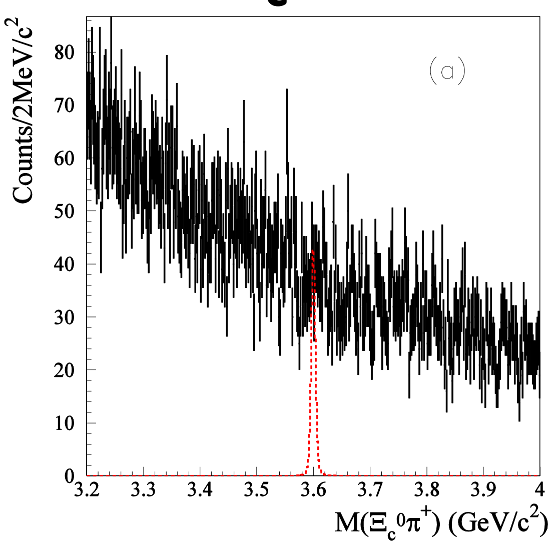
$M(\Lambda_c^+K^-\pi^+)$
hep-ex/0606051

- Evidence by SELEX was not supported by FOCUS, B-factories, and LHCb
- Prediction of the mass: ~3.6 GeV by LQCD
- $\Xi_c^0\pi^+$ decay mode searched by BaBar only.

Doubly charmed baryons at Belle



$M(\Xi_c^0\pi^+)$



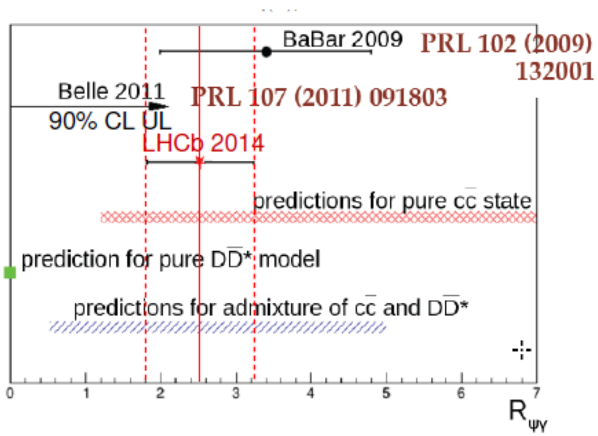
- Belle searched for Ξcc in the Ξc0π+ and Λc+K-π+ decay modes.
- No significant signals were observed.
- Upper limit on the production cross section is close to the theoretical predictions.
- Good subject in the Belle II.

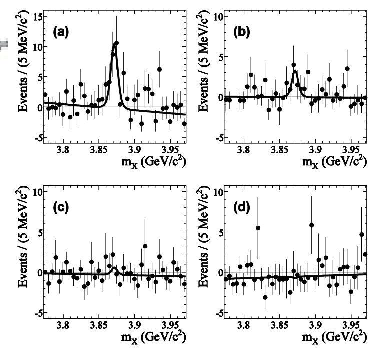
Phys. Rev. D **89**, 052003

X(3872)→ψ'γ

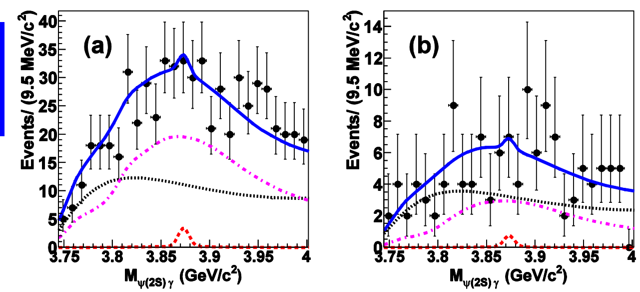
$$R = \frac{Br(X(3872) \to \psi'\gamma)}{Br(X(3872) \to J/\psi\gamma)}$$

Predicted to be small for pure molecular.
Large for charmonium state.

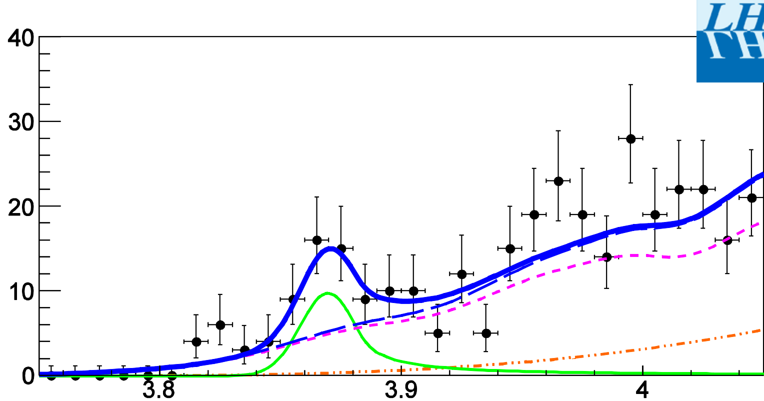




Phys.Rev.Lett.102:132001,2009



Phys.Rev.Lett. 107:9,2011



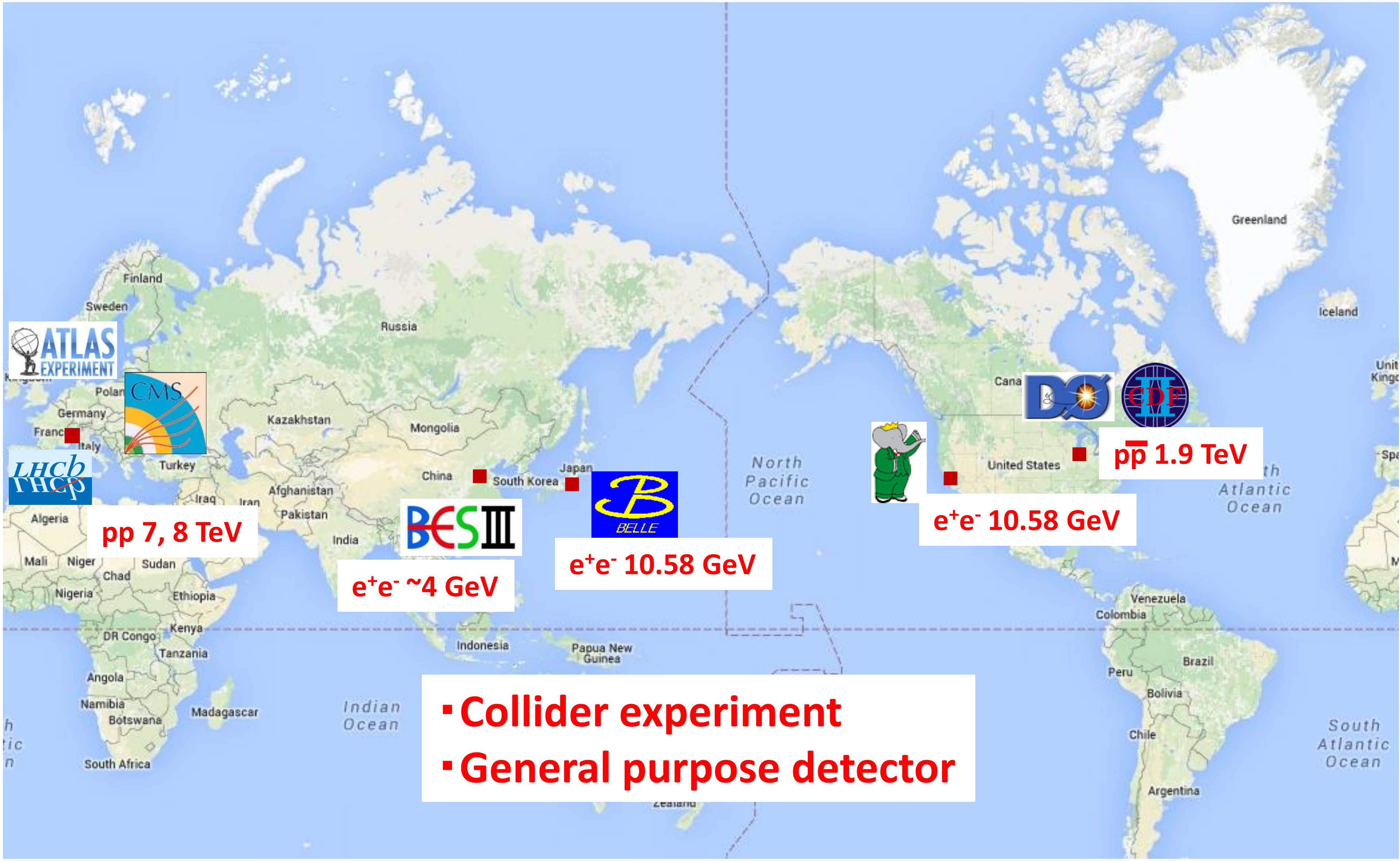
Nucl.Phys. B886 (2014) 665-680

R=2.46±0.64±0.29

Probably not a pure charmonium.

But a large uncertainty on the theoretical predictions.

Other experiments

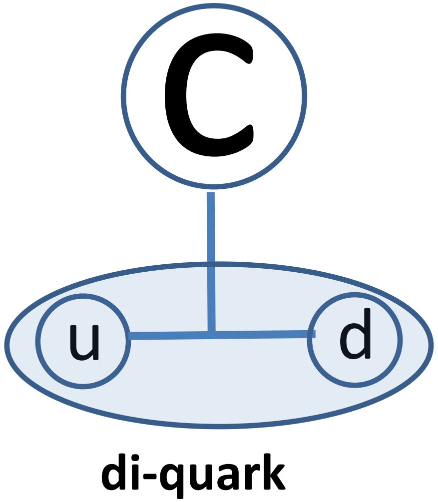


- Collider experiment
- General purpose detector

Charmed baryons

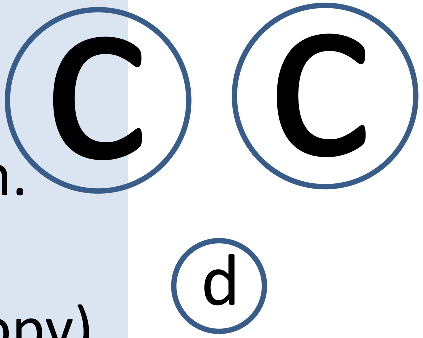
Physics of charmed baryons

Mass of the charm quark is ~1.5 GeV.
This is much heavier than….



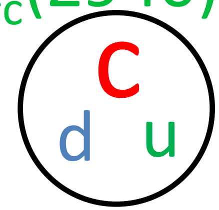
1. Mass of the u,d,s quarks (300-500 MeV)
   spin-spin interaction $\propto 1/m_1 m_2$
   Di-quark correlation in light quarks.
   -More simplified view of the baryon.
   -Di-quark excitaion is a hint of qq potential.

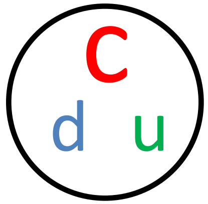
2. Momentum of quarks inside the baryon
   radius ~1fm → 200MeV/c.
   →Non-relativistic quark model is a good approximation.
   Study of QQ potential from doubly charmed baryon.
   (Similar to QQ^{bar} potential by charmonium spectroscopy)

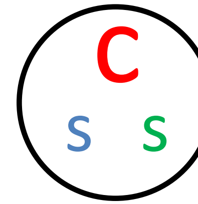


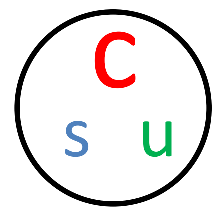
Observed charmed baryons

Λ_c^+	$1/2^+$	$\Sigma_c(2455)$	$1/2^+$	Ξ_c	$1/2^+$	Ω_c	$1/2^+$
$\Lambda_c(2595)^+$	$1/2^-$	$\Sigma_c(2520)$	$3/2^+$	Ξ'_c	$1/2^+$	$\Omega_c(2770)$	$3/2^+$
$\Lambda_c(2625)^+$	$3/2^-$	$\Sigma_c(2800)$	$?^?$	$\Xi_c(2645)$	$3/2^+$		
[$\Lambda_c(2765)^+$	$?^?$]			$\Xi_c(2790)$	$1/2^-$		
$\Lambda_c(2880)^+$	$5/2^+$			$\Xi_c(2815)$	$3/2^-$		
$\Lambda_c(2940)^+$	$?^?$			[$\Xi_c(2930)$	$?^?$]		
				$\Xi_c(2980)$	$?^?$		
				[$\Xi_c(3055)$	$?^?$]		
				$\Xi_c(3080)$	$?^?$		
				[$\Xi_c(3123)$	$?^?$]		







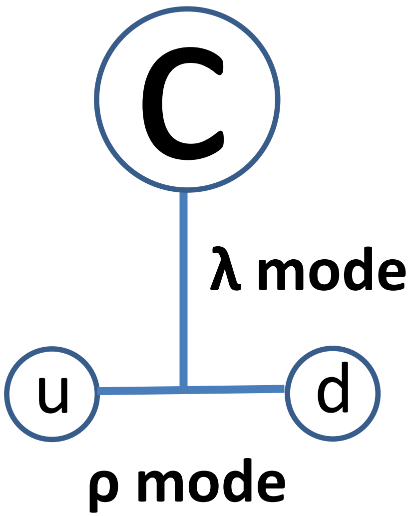


CLEO 8(7) (1995～2001)
BELLE 3 (2006～)
BABAR 5(2) (2007～)

- All the ground state of single charmed baryons are established.
- 16/21 (12/17) charmed baryons are observed in e^+e^- collider experiment.
- Spin-parity measurements only for a few states.
- No doubly (or triply) charmed baryons.

Excitation modes in the charmed baryons

- There are two kind of excitation modes.
  Both states have $J^P=1/2^-$
  - λ mode: excitation between c quark and u-d di-quark.
  - ρ mode: excitation in the di-quarks.
  - In the first excitation, spin-parity should be $1/2^-$



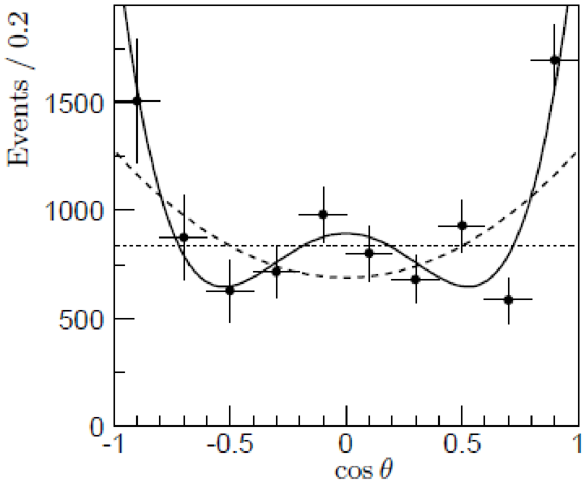
$$\frac{h\omega_\rho}{h\omega_\lambda} = \sqrt{\frac{3m_Q}{2m_q + m_Q}} \sim= \sqrt{3}$$

- $\Lambda_c(2593)^+$ is a candidate of λ mode excitation.

- To find ρ mode excitation is necessary to check the di-quark picture → Spin-parity measurement.

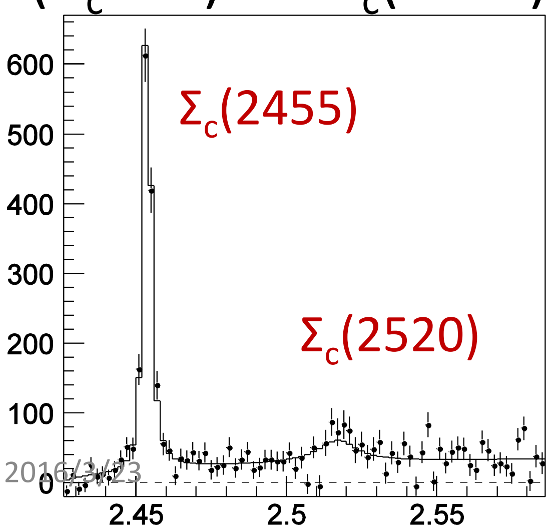
Spin-parity measurement of $\Lambda_c(2880)^+$

- **Spin/parity measurement**
  (hep-ex/0608043)



$\Sigma_c\pi$ decay angular distribution favors **spin 5/2 by 5σ**

$M(\Lambda_c^+\pi^\pm)$ for $\Lambda_c(2880)^+$ events



$$R = \frac{Br(\Lambda_c(2880) \to \Sigma_c(2520))}{Br(\Lambda_c(2880) \to \Sigma_c(2455))} = 0.225 \pm 0.062 \pm 0.025$$

Prediction by **Heavy Quark Spin Symmetry**

R=0.23 for $5/2^+$

R=1.45 for $5/2^-$

On going analysis: $\Lambda_c/\Sigma_c(2765)^+$

$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$ $I(J^P) = ?(?^?)$ Status: *

OMITTED FROM SUMMARY TABLE

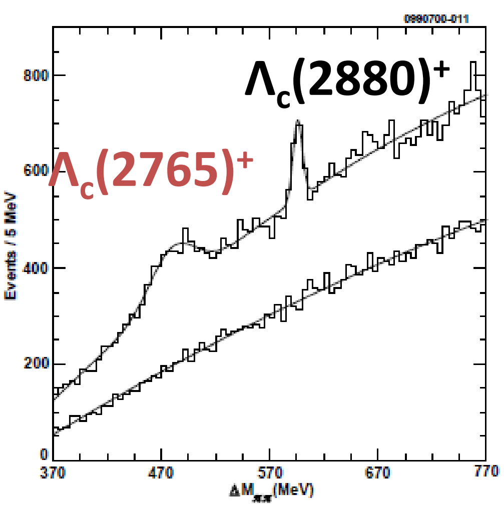
A broad, statistically significant peak (997^{+141}_{-129} events) seen in $\Lambda_c^+\pi^+\pi^-$. However, nothing at all is known about its quantum numbers, including whether it is a Λ_c^+ or a Σ_c, or whether the width might be due to overlapping states.

Most poorly known Λ_c/Σ_c state

- Di-quark excitation ($1/2^-$)?
- pD bound state?
- Roper like ($1/2^+$) state?

hep-ex/0010080

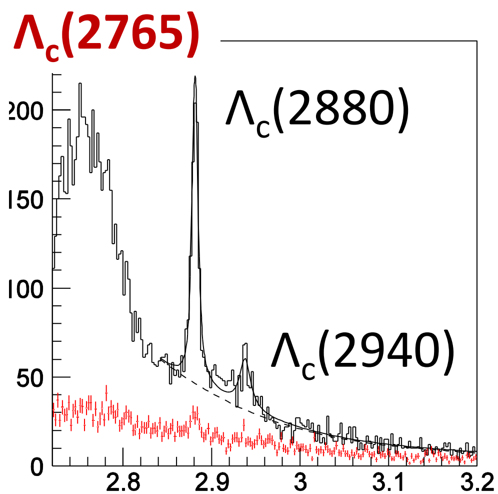
- **First evidence by CLEO**



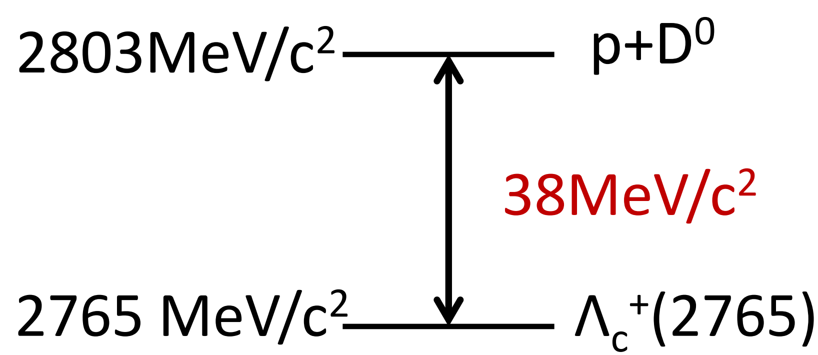
$M(\Lambda_c^+\pi^+\pi^-)$

hep-ex/0608043

- **By Belle**



$M(\Sigma_c\pi)$

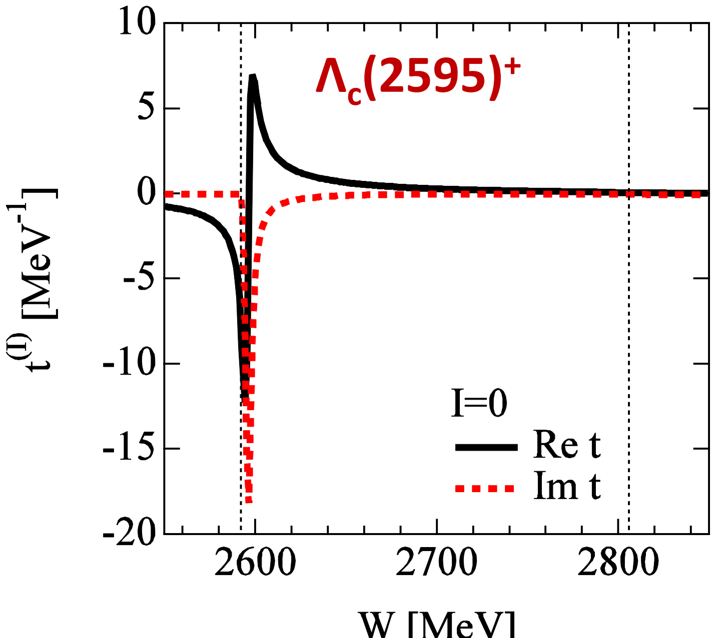


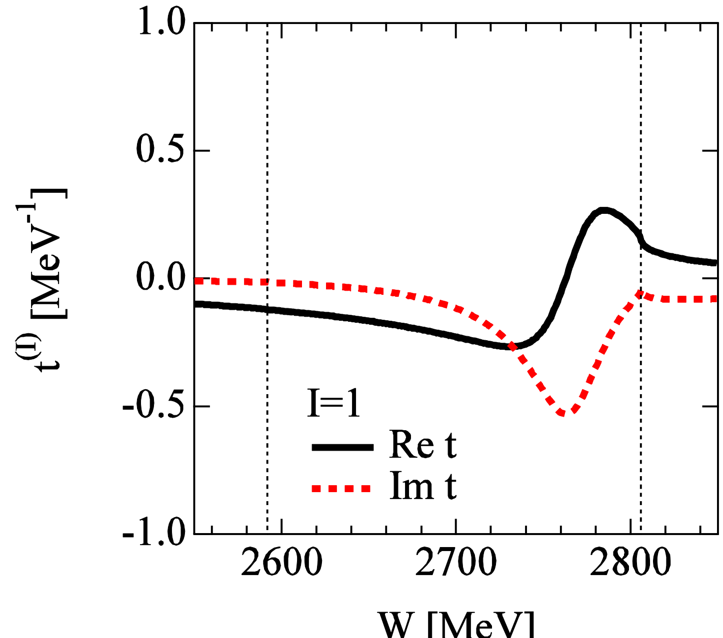
Prediction from coupled channel approach

hep-ph:1205.2275

Coupled channel calculation in I=0 channel. $\Lambda_c(2595)^+$ is clearly seen. Charm partner of $\Lambda(1405)$.

Calculate amplitude in I=1 channel



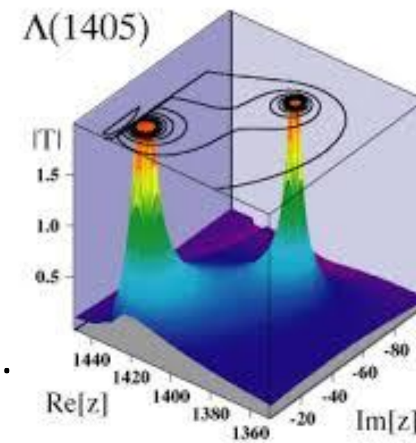


If the scenario is correct, it must be...

- **Isospin = 1 (Σ_c state)**
- **$J^p = 1/2^-$ (S-wave DN scattering)**

Measurement of Σπ scattering length

- Light mass of the Λ(1405) can not be explained by simple quark model.
  → molecule state?

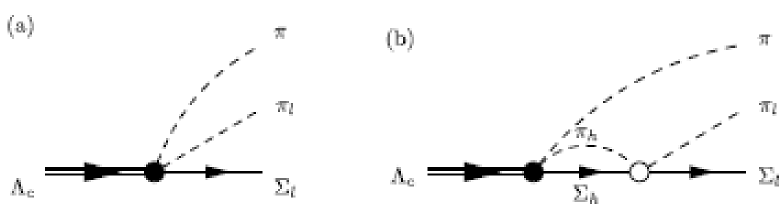


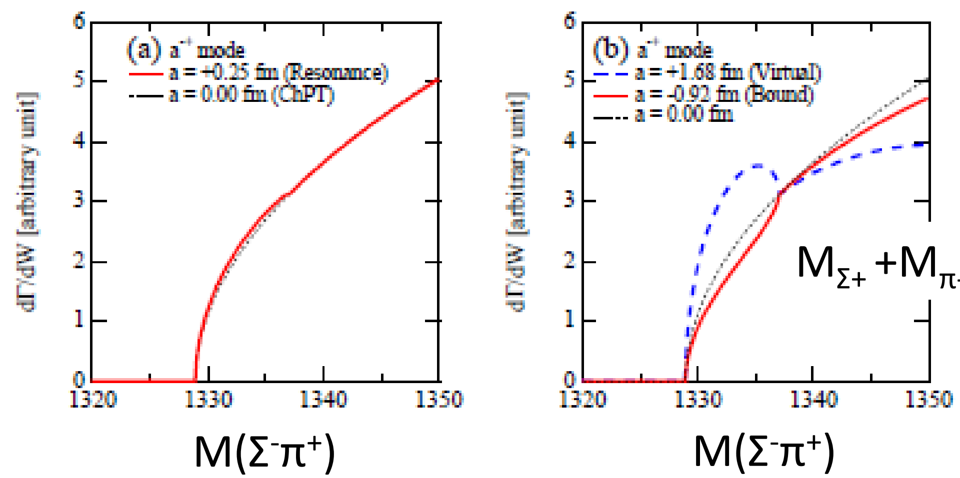
- Chiral unitary model predicts two-pole structure in S-wave meson-baryon scattering near the mass of Λ(1405).
  One couples to KbarN, the other couples to πΣ

D. Jido, et al., Nucl. Phys. A 723, 205 (2003)

- KbarN interaction is relatively known well from scattering experiment.
  However, no data exists for πΣ scattering → Use $\Lambda_c^+ \to \Sigma\pi\pi$ decay.

$M(\pi^+\Sigma^-) > M(\pi^-\Sigma^+)$



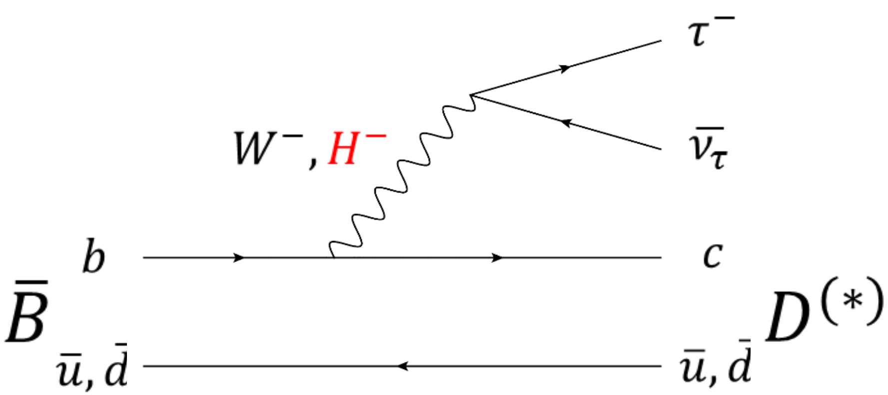


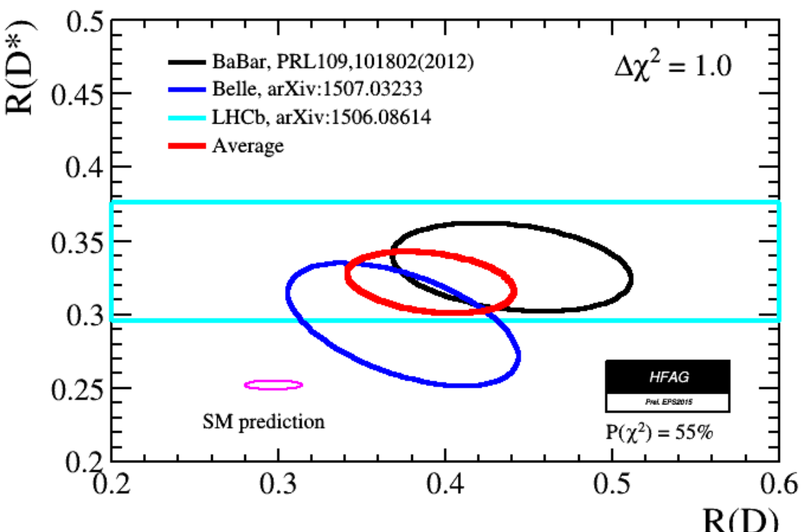
Interference from intermediate $\pi^+\Sigma^-$ creates "cusp" in $M(\pi^-\Sigma^+)$ mass distribution.
Size of the "cusp is sensitive to the scattering length"

Phys. Rev. C **84**, 035201

Physics beyond SM with Belle II

- The semi-leptonic decay B→D(*) τν is mediated by W boson in the SM.
- As the mass of τ is heavy (~1.7 GeV), charged Higgs predicted by SUSY may contribute.
- Taking ratio to the electron, muon: $R(D^{(*)}) = BR(B \to D^{(*)}\tau\nu)/BR(B \to D^{(*)} l\nu)$ cancels various uncertainties like form-factors.
- Current measurement on $R(D^{(*)})$ shows deviation from SM by 3.9σ.





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Belle→Belle II

Aim to find physics beyond the Standard Model