Toward an understanding of the exotic hadron: X(3872)

Y. Kato

Outline

- Introduction

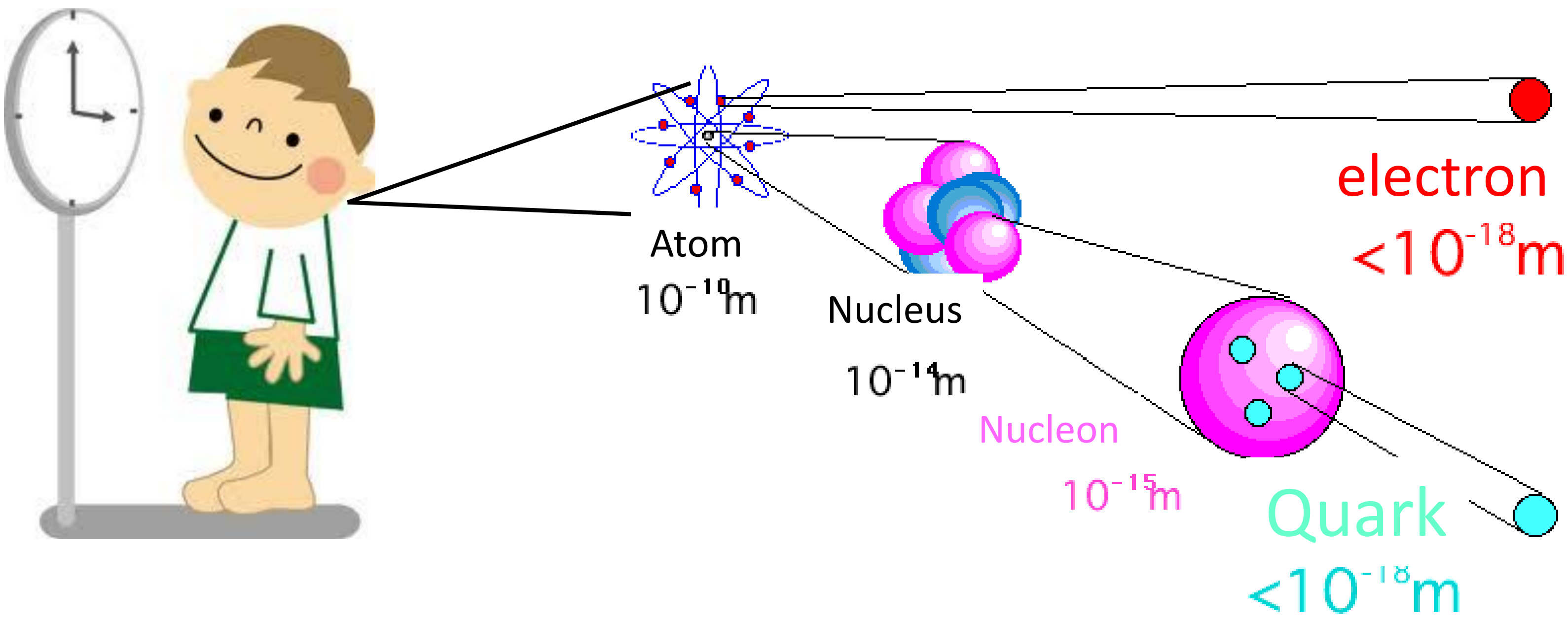
- Belle experiment (focusing on hadron spectroscopy)

- X(3872)
  - Review on X(3872)
  - Measurement of Br(B^+->K^+ X(3872))

    Phys. Rev. D 97, 012005
  - Prospect at Belle II

- Summary

Origin of the mass



Our mass is primary made from
- Atoms ?→ Yes!
- Nucleus ? → Yes!
- Nucleons? → Yes!
- Quarks? → .... ?

Quark and nucleon mass

u $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_u = 1.7$–3.3 MeV Charge $= \frac{2}{3}\,e$ $I_z = +\frac{1}{2}$
$m_u/m_d = 0.35$–0.60

d $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_d = 4.1$–5.8 MeV Charge $= -\frac{1}{3}\,e$ $I_z = -\frac{1}{2}$
$m_s/m_d = 17$ to 22
$\overline{m} = (m_u+m_d)/2 = 3.0$–$4.8$ MeV

*from PDG

p MASS (MeV)

The mass is known much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u = 931.494028±0.000023 MeV/c^2 (MOHR 08, the 2006 CODATA value), involves the relatively poorly known electronic charge.

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
938.272013±0.000023	MOHR	08	RVUE	2006 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •				
938.272029±0.000080	MOHR	05	RVUE	2002 CODATA value
938.271998±0.000038	MOHR	99	RVUE	1998 CODATA value
938.27231 ±0.00028	COHEN	87	RVUE	1986 CODATA value
938.2796 ±0.0027	COHEN	73	RVUE	1973 CODATA value

n

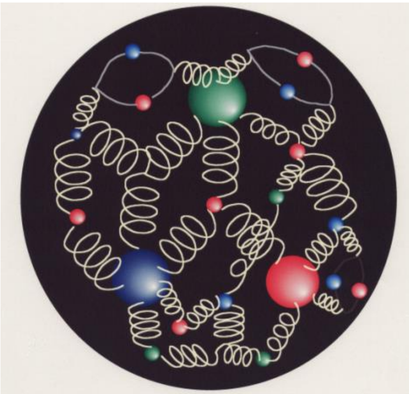
n MASS (MeV)

The mass is known much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u = 931.494028±0.000023 MeV/c^2 (MOHR 08, the 2006 CODATA value), involves the relatively poorly known electronic charge.

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
939.565346±0.000023	MOHR	08	RVUE	2006 CODATA value

- Mass of up, down quarks are several MeV/c^2. (given by Higgs field).
- proton is made from uud.
- Mass of proton is ~ 1000 MeV/c^2
  → quark mass is only ~1% of nucleon mass.
- What is the origin of the mass?

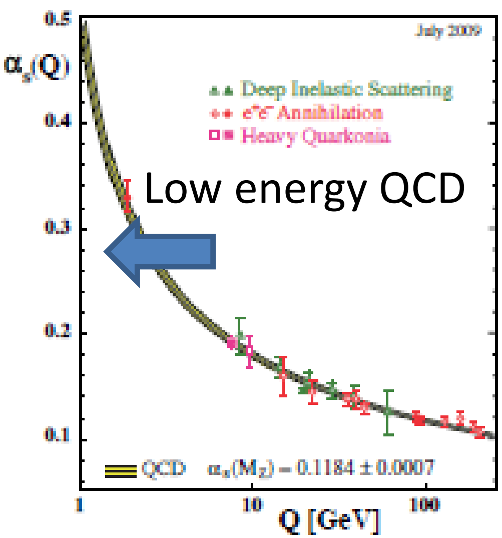
QCD



Proton is not a simple bound state of 3 quark,
but more complicated object.

$$\mathcal{L} = -\frac{1}{2}\mathrm{tr}\left[G_{\mu\nu}G^{\mu\nu}\right] + \bar{q}i\gamma^{\mu}D_{\mu}q - \bar{q}Mq$$

Quantum Chromo dynamics(QCD)
= dynamics of quarks and gluons
Nucleon mass is dynamically generated from QCD



- Non-perturbative in the hadron scale

- Two phenomena in the hadron physics.
  - Mass generation.
  - Quark confinement (isolated quark has never been observed).

- Surprising thing is these two happens simultaneously.
  Generally, bound states makes mass lighter (like nucleus)
  but quark inside hadron acquire mass.

Constituent quark model

QCD can not be solved →effective theory

1. Give mass of ~300 MeV/c^2 to quarks by hand
   = Constituent quark mass

2. Hyper fine interaction.

That's (almost) all!

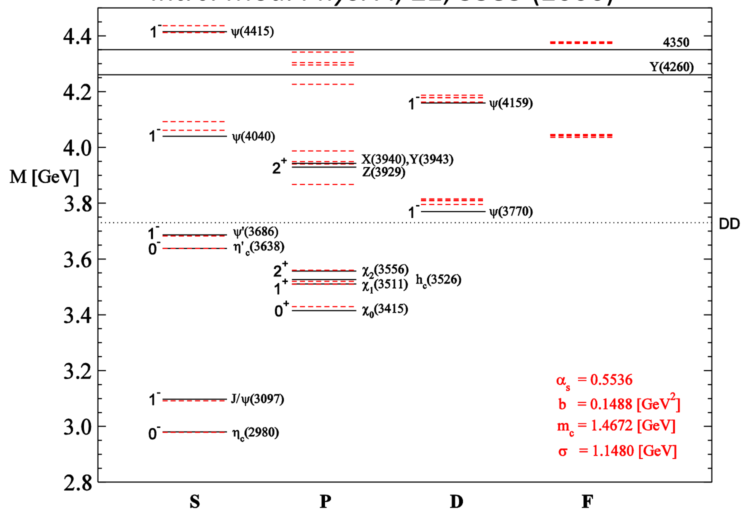
Too simple compared with complex QCD…

Success of quark model and further

Success of constituent quark model

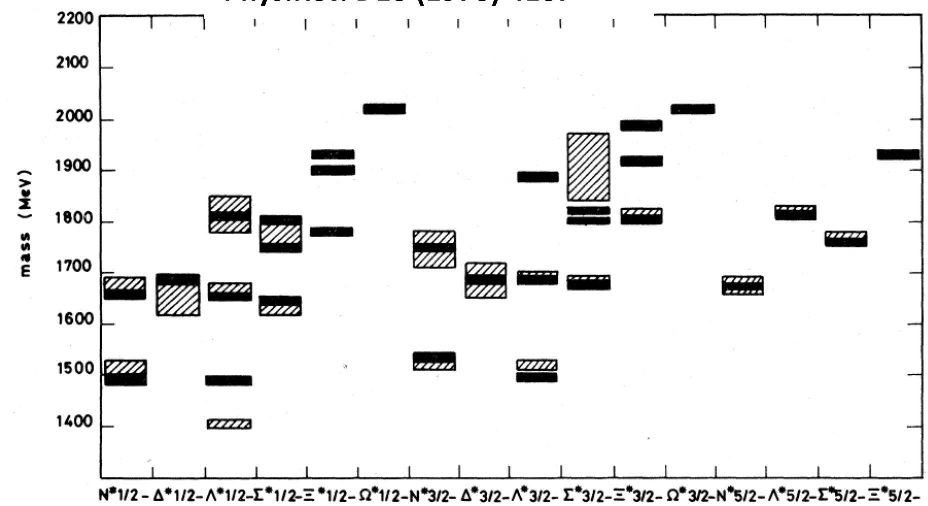
Mesons

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



Baryons

Phys.Rev. D18 (1978) 4187



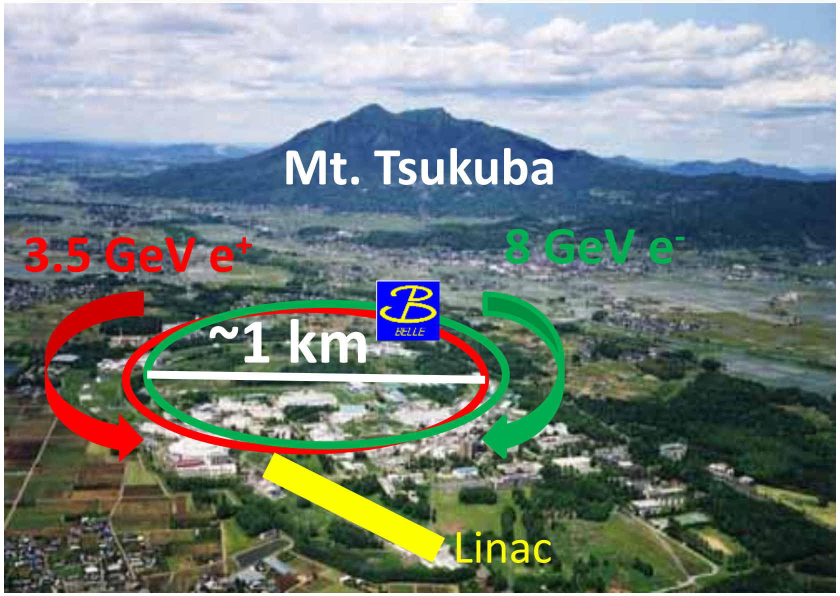
"Constituent quark" must be a good approximation... but not the end..

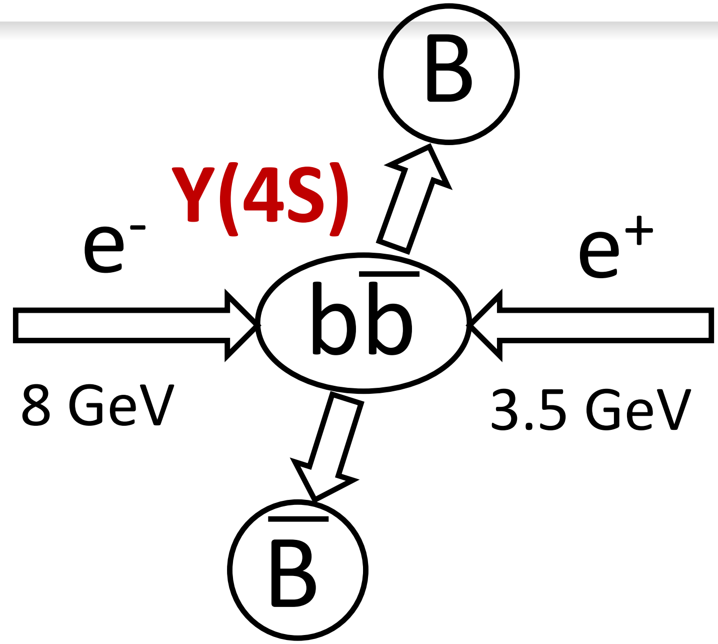
- Why it works so well?
  - What is the adaptive limit?
  - How interaction/constituent quark mass changes in different environment?

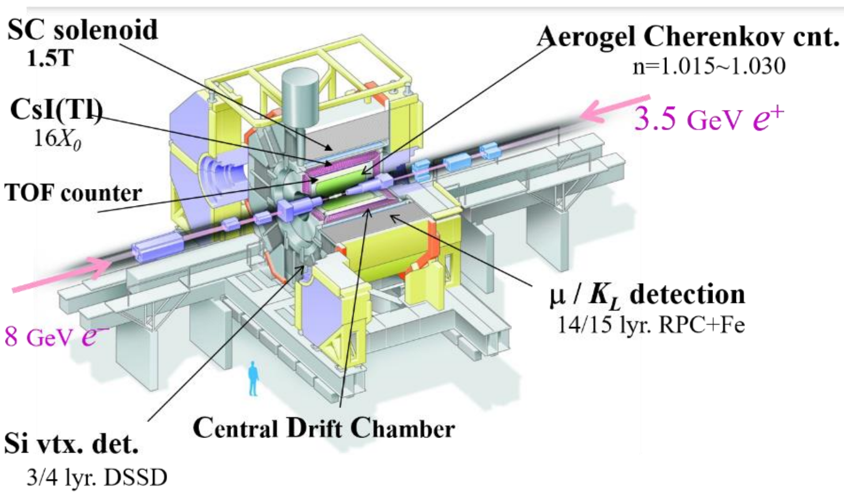
→ **Exotic hadron!**

B-factory is a powerful probe!

Belle experiment







- Asymmetric energy e^+e^- collider to test KM theory in B-meson decays.
- 7.7×10^8 BB^{bar} events are collected.
- Belle: General purpose detector.
- Enabled hadron spectroscopy.

"New hadrons" from B-factories

Hadron Type

Reaction

	Charmonium (like) = cc^{bar}	$D_{(s)}$ = cu^{bar}, cs^{bar}	Charmed baryon = cud, cus, css,…	Bottomonium = bb^{bar}
B-decay	$\eta_c(2S)$ X(3872) X(3915) $Z_c(4050)$ $Z_c(4250)$ $Z_c(4430)$ $Z_c(4200)$	$D^*_0(2400)$ $D_1(2430)$ $D^*_{s1}(2700)$	$\Xi_c(2930)$	
Initial State Radiation	Y(4260) Z(3900) Y(4008) Y(4360) Y(4660)			
Double charmonium	X(3940) X(4160)			
Two photon	$\chi_{c2}(2P)$			
$e^+e^- \to cc^{bar}$		$D_0(2550)$ $D_J^*(2600)$ $D_J^*(2640)$ $D_J(2750)$ $D_{s0}(2317)$ $D_{sJ}(2860)$ $D_{sJ}(3040)$	$\Sigma_c(2800)$ $\Lambda_c(2940)$ $\Xi_c(2980)$ $\Xi_c(3080)$ $\Omega_c(2770)$ $\Xi_c(3055)$	
Y(5S) decay				$Z_b(10610)$ $Z_b(10650)$ $h_b(1P)$,$h_b(2P)$ $\eta_b(1S)$,$\eta_b(2S)$

Belle
BaBar

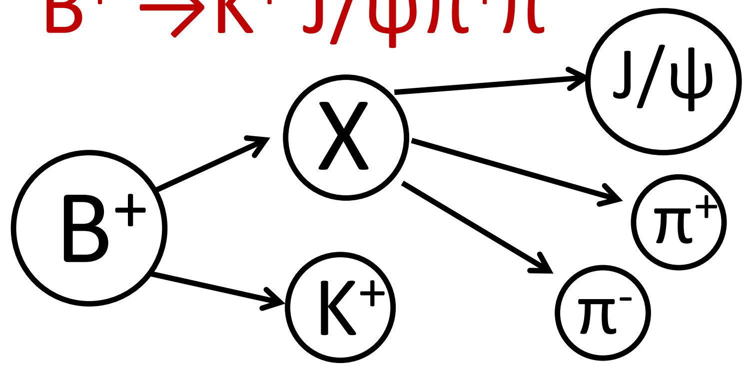
~ 40 new hadrons!
(Some states may be missed)

X(3872)

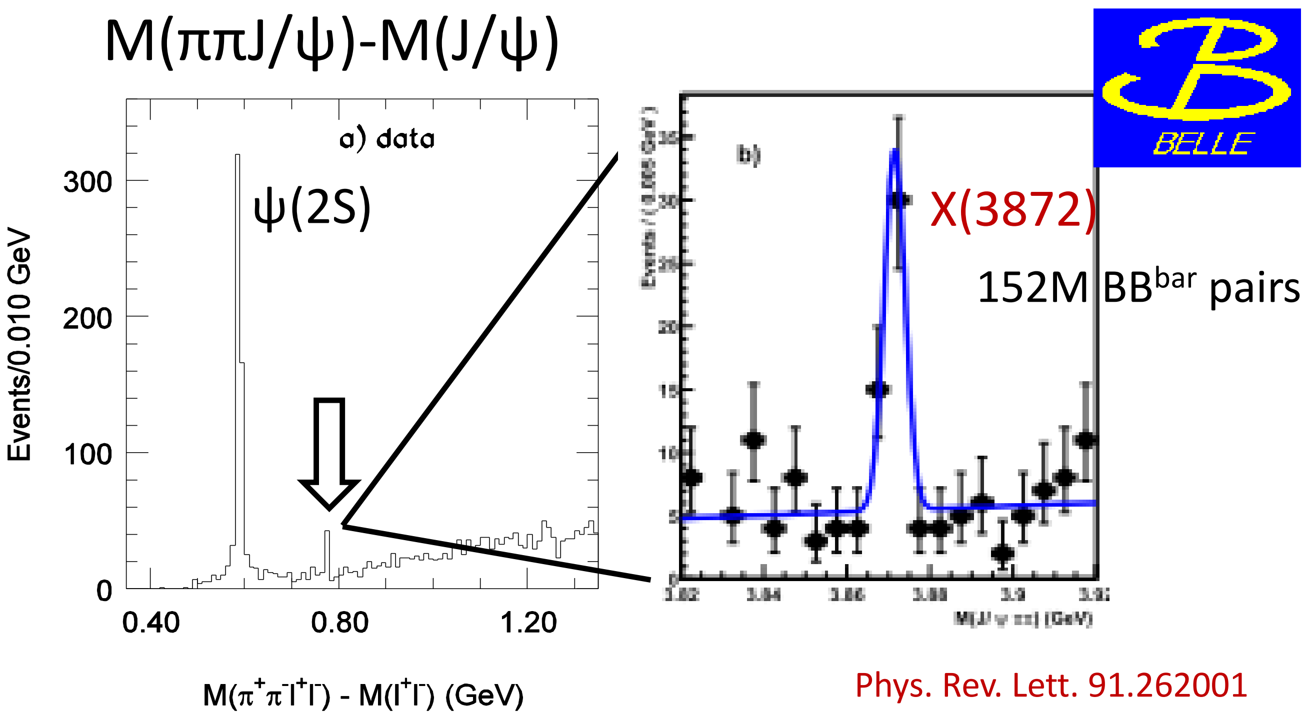
@Virginia

First observation in 2003

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



M(ππJ/ψ)-M(J/ψ)

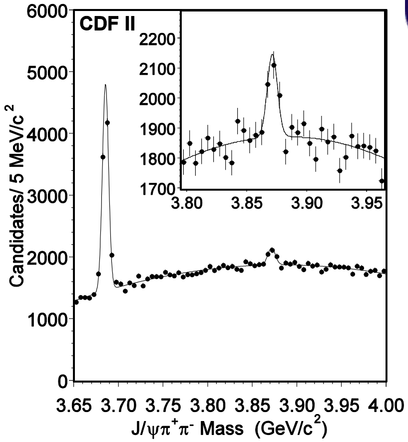


Phys. Rev. Lett. 91.262001

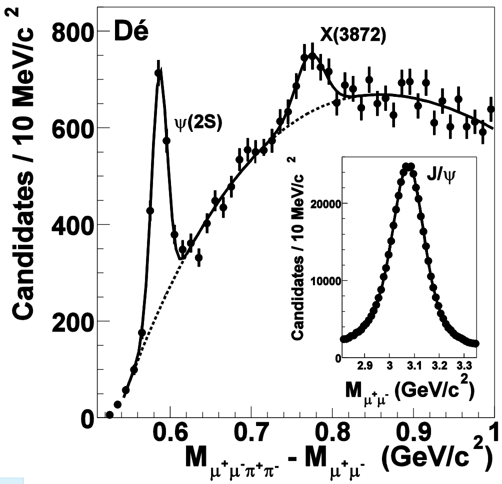
Most cited among ~500 papers in Belle (>1400@INSPIRE)

Confirmed by many experiments

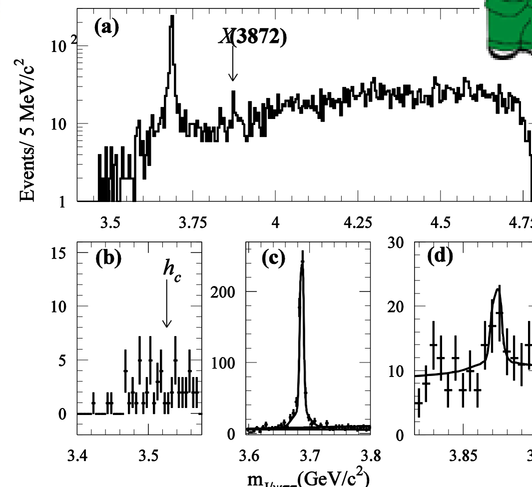
Phys.Rev.Lett.93:072001,2004



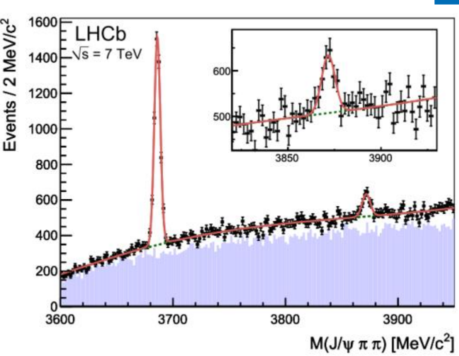
Phys. Rev. Lett. 93, 162002



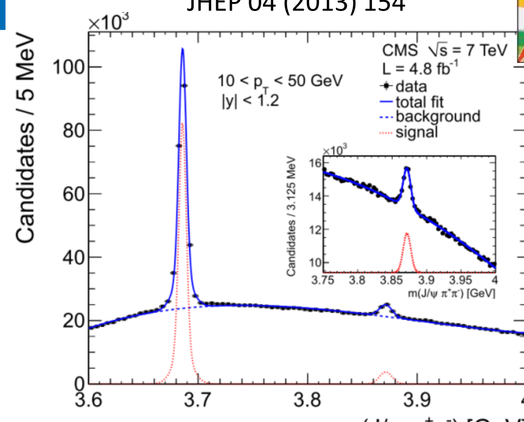
Phys.Rev.D71:071103,2005

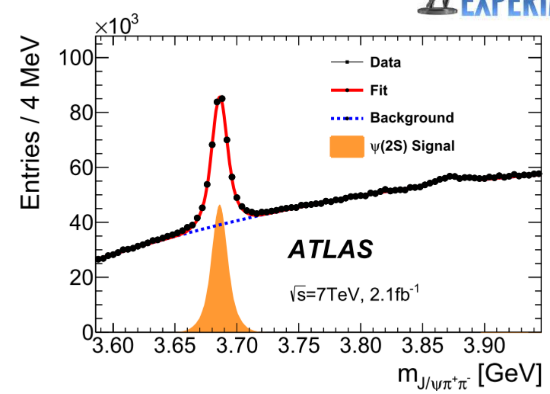


Eur. Phys. J. C. 72 (2012) 1972



JHEP 04 (2013) 154





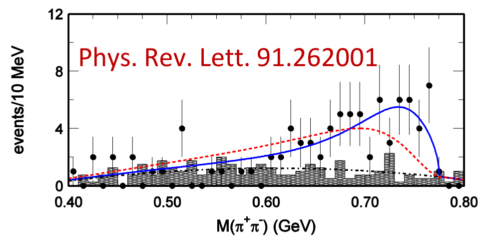
- Existence is established.
- Understanding of the property.

A strange hadron:X(3872)

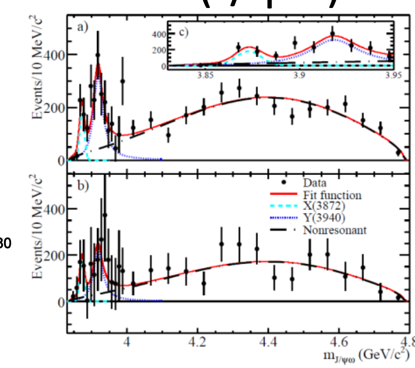
- No quark model prediction in such mass region

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

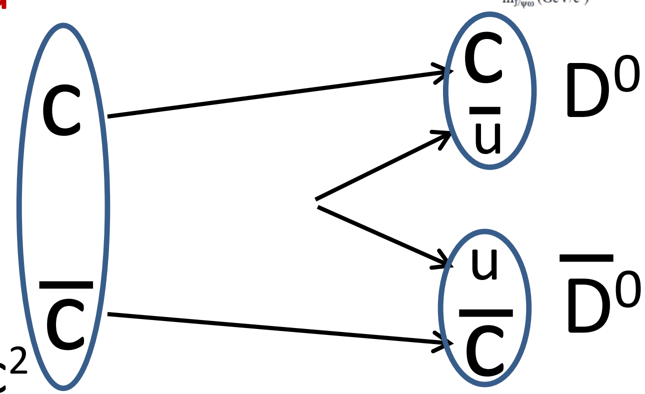
M(ππ) in $J/\psi\pi^+\pi^-$



M(J/ψω)



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



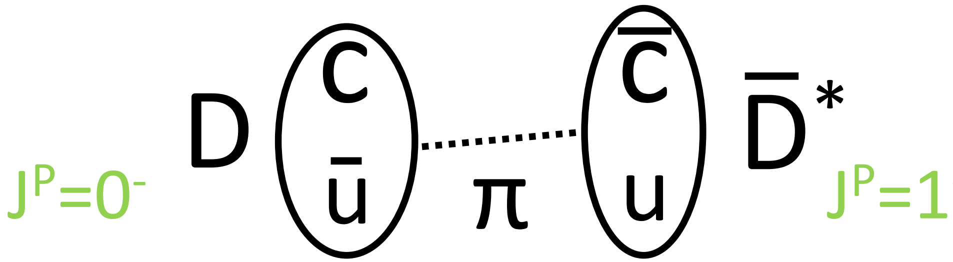
- Very close to $D^0\bar{D}^{*0}$

3871.69 ± 0.17 MeV/c^2 $\Leftrightarrow$ 3871.8 ± 0.12 MeV/c^2

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

$D\bar{D}^*$ Molecular state？(1)

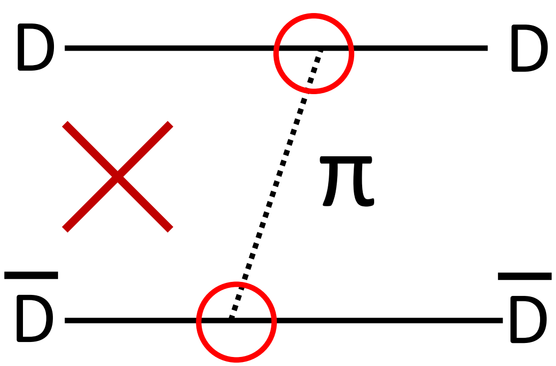
The most natural interpretation is $D\bar{D}^*$ molecular state



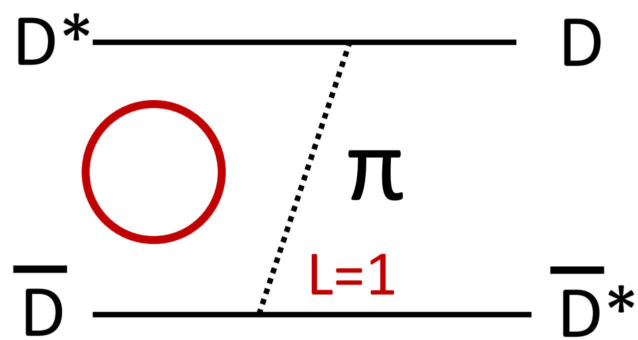
・Narrow width

→$D\bar{D}^*$ 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 $(|D^0\overline{D^{*0}}> + |D^+\overline{D^{*-}}>)/\sqrt{2}$

- **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.

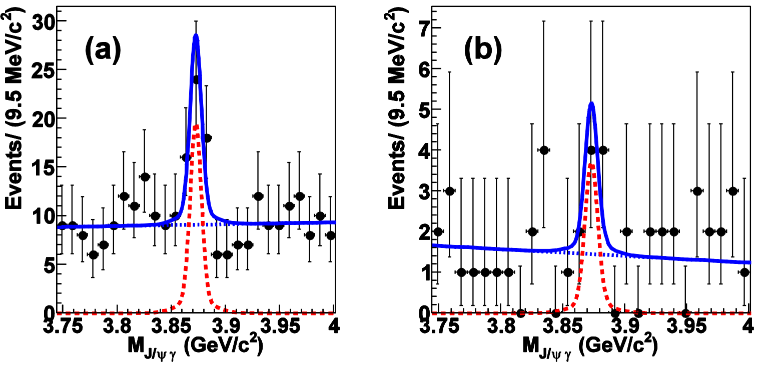
Phys.Lett. B590 (2004) 209-215

J^{PC} of DD* molecule should be 1^{++}

Determination of J^{PC}

C-parity from $J/\psi\gamma$ decay mode

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

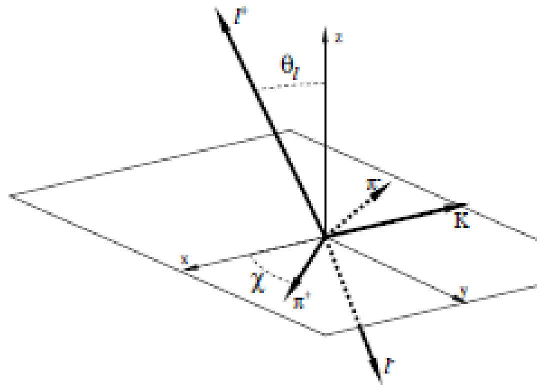


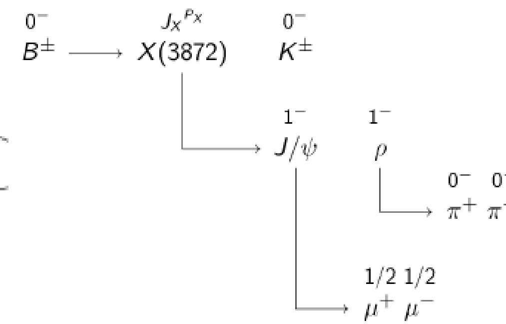
J/ψ:C=-1

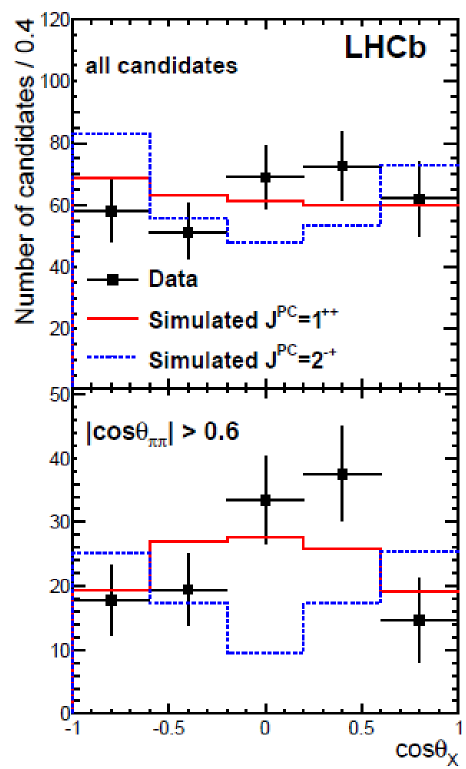
γ: C=-1

C=+1

J^P from $J/\psi\pi^+\pi^-$ decay angular distribution





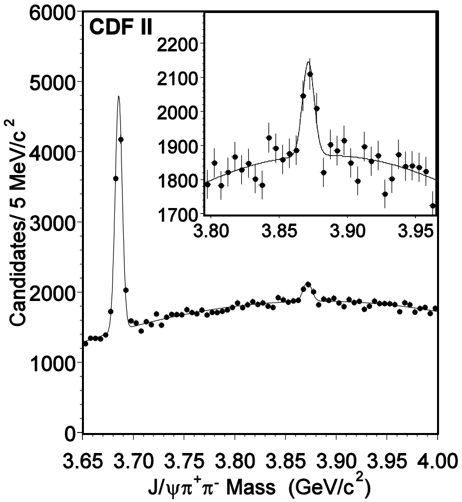


Favor 1^{++} by 8.2σ

Pure molecular state?

Phys.Rev.Lett.93:072001,2004

$p\bar{p}$ 1.9 TeV



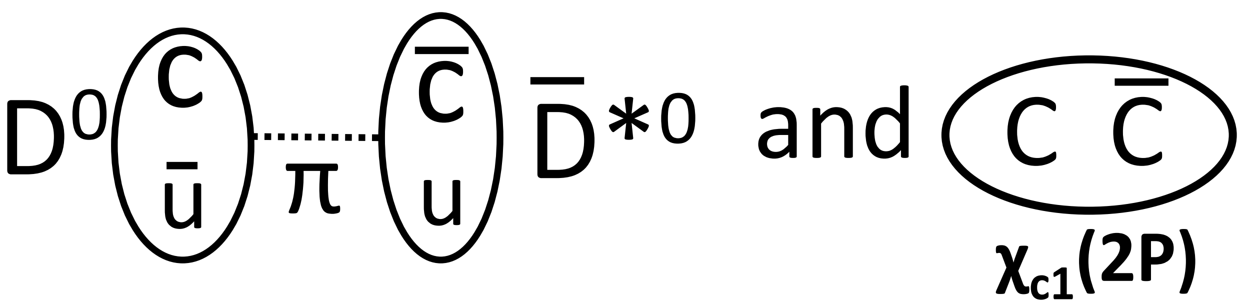
- 80% comes from "prompt production" (not from B decay).
- If X(3872) is pure molecular state, binding energy is small.

→Size is large: Radius is ~8 fm

→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



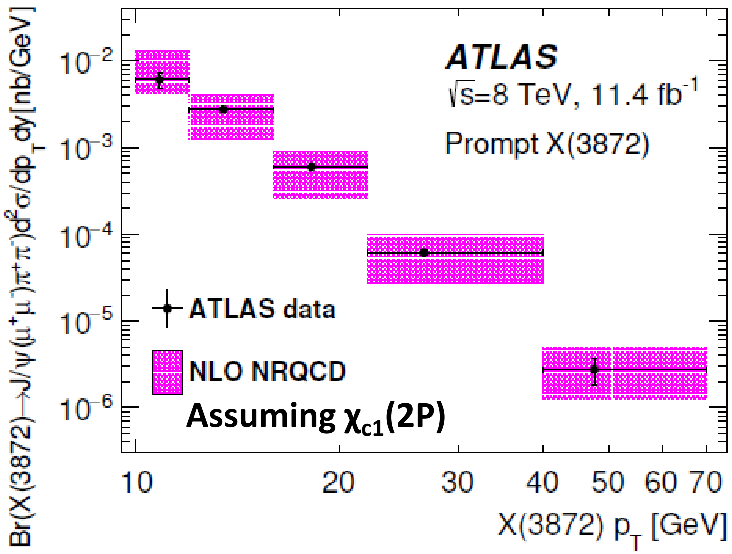
Superposition?

$J^{PC}=1^{++}$, not observed so far.

Measurement by LHC/ATLAS

Cross section × Br(X(3872)→J/ψ π π)

JHEP01(2017)117



- The p_t dependence of prompt production is consistent with theoretical calculation for the production of χ_{c1}(2P).
  (Phys. Rev. D 96, 074014)
  → Suggesting X(3872) has χ_{c1}(2P) component.

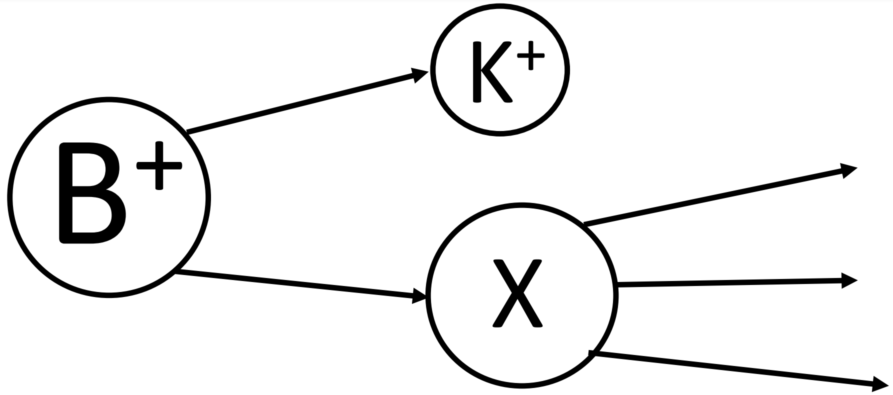
- In the calculation, the product of..
  - Fraction of χ_{c1}(2P) in X(3872)
  - Br(X(3872) -> J/ψ$\pi^+\pi^-$)

  is set to be 0.014 for the normalization.

- **If Br(X(3872)->J/ψ$\pi^+\pi^-$) is determined, the fraction of χ_{c1}(2P) can be determined.**

- **This leads to the cc^{bar}-DD* coupling.**

Why Br(X(3872)→J/ψ π π) not measured?



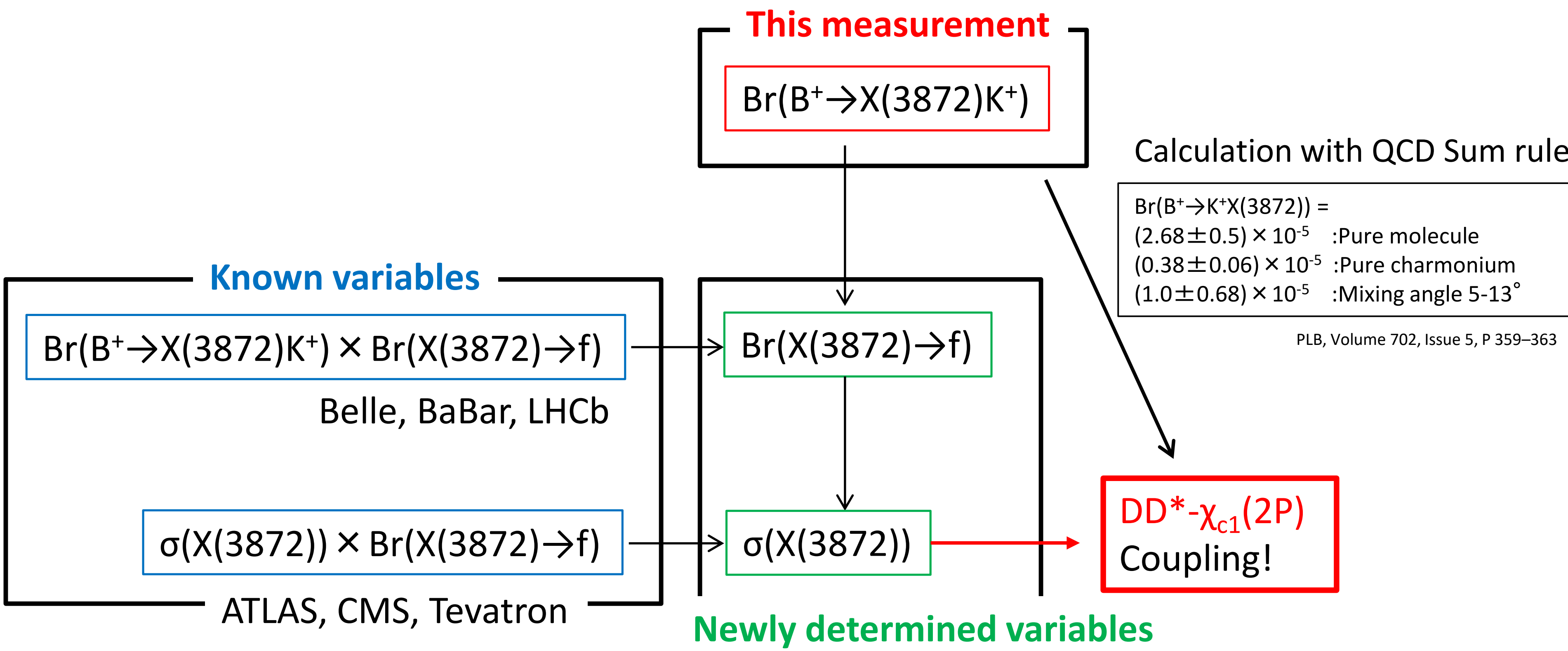
Br(B^+→X(3872)K^+) × Br(X(3872)→J/ψ$\pi^+\pi^-$)

- Usually X(3872) is reconstructed by invariant-mass.
  In other words, detect all the decay object of X

- In this way, only the product of two branching fractions can be measured.

- Both are important (production, decay), but product is less useful.
  → We first need to measure the Br(B^+→X(3872) K^+)
  By measuring it, we can extract Br(X(3872)→J/ψ$\pi^+\pi^-$), too.

Strategy to understand X(3872)



Increase the dynamical information drastically!

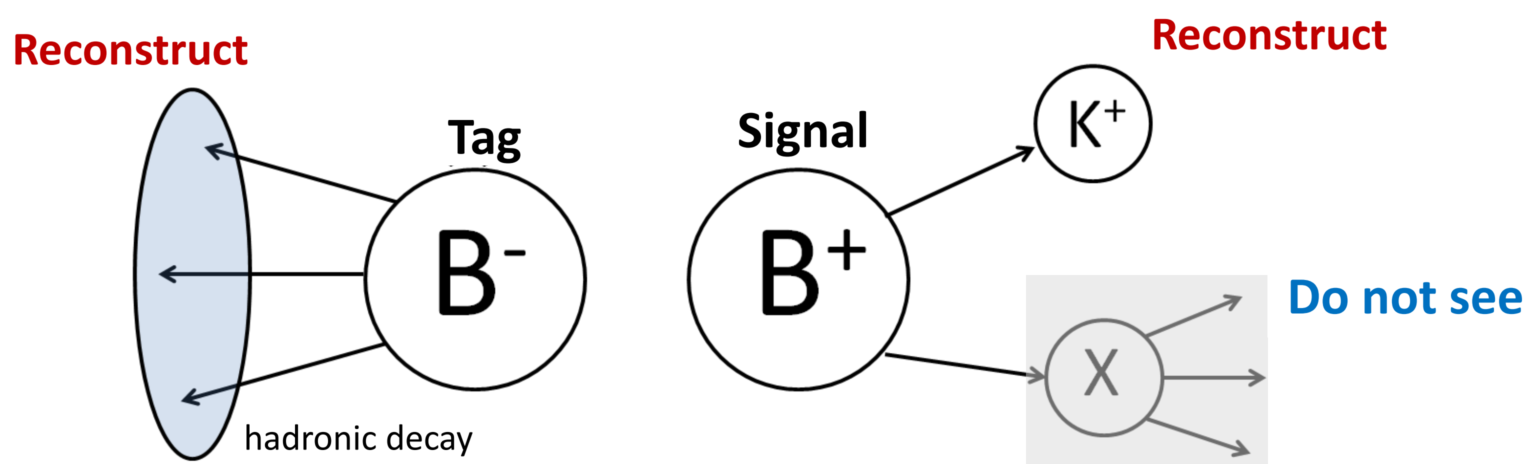
Principle of the measurement

- Extract Br ($B^+ \to X(3872)K^+$) → Do not see X(3872)decays

→Use unique feature of B-factory

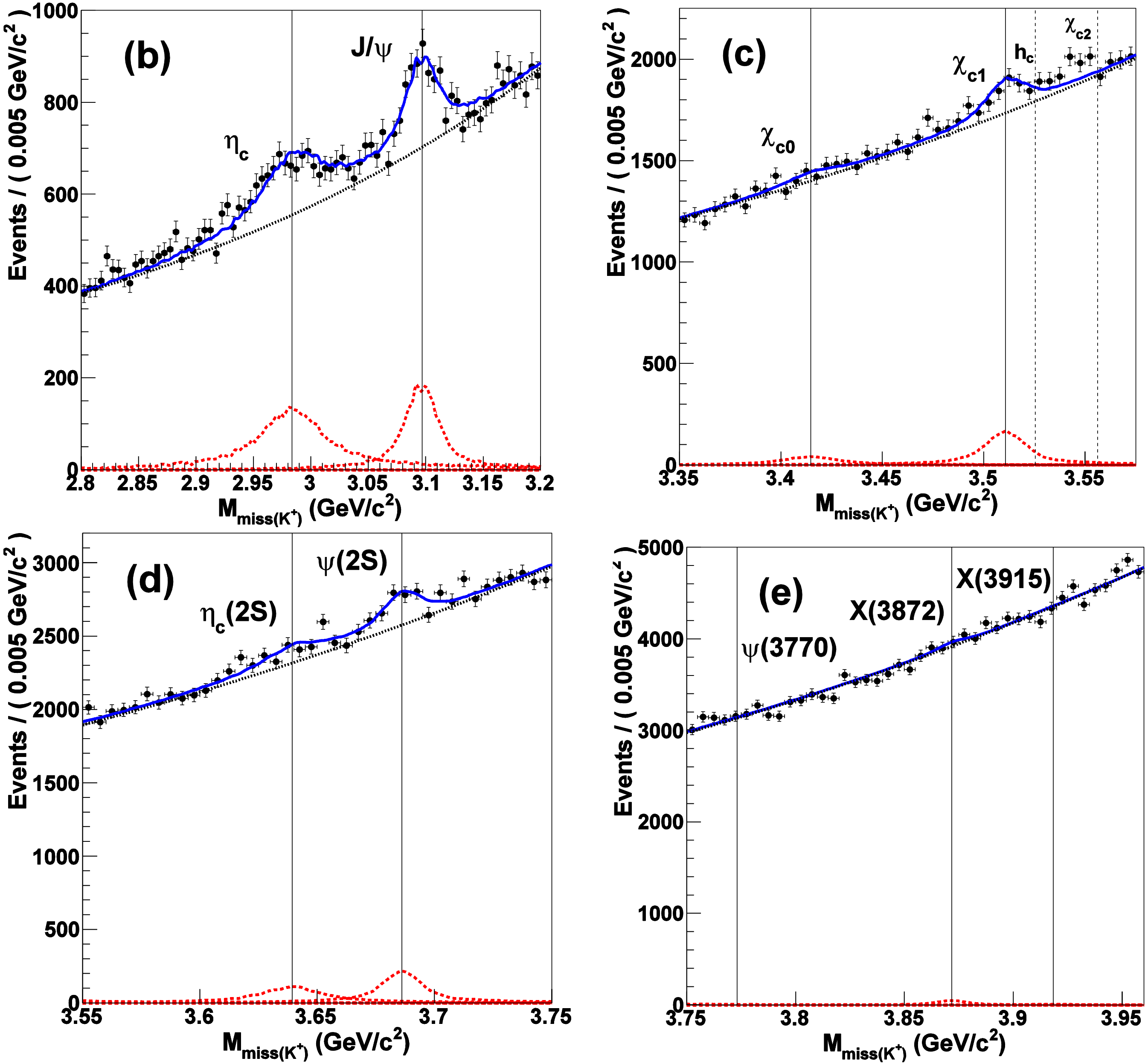
- Reconstruct B mesons hadronically decays (called tag side)
- Reconstruct K^+ mesons from the other B meson.
- Reconstruct X from Missing mass: $M_x^2 = (P_{beam} - P_{BTag} - P_{K+})^2$

- This measurement is impossible at LHCb
  - Final state is not B meson pair.
  - Initial energy not known as it is a collision of partons.



K^+ Missing Mass distribution

Phys. Rev. D 97, 012005



Results

X_{cc}	σ	Br ($B^+ \to X_{cc} K^+$) (10^{-4})	BaBar's (10^{-4})	PDG (10^{-4})
η_c	14.2	12.0±0.8±0.7	8.4±1.3±0.8	9.6±1.1
J/ψ	13.7	8.9±0.7±0.5	8.1±1.3±0.7	10.26±0.031
χ_{c0}	2.2	2.0±0.9±0.1 (<3.3)	<1.8	$1.50^{+0.15}_{-0.14}$
χ_{c1}	6.8	5.8±0.9±0.5	<2.0	4.79±0.23
$\eta_c(2S)$	4.1	4.8±1.1±0.3	3.4±1.8±0.3	3.4±1.8
ψ(2S)	6.6	6.4±1.0±0.4	4.9±1.6±0.4	6.26±0.24
ψ(3770)	-	-0.2±1.4±0.0 (<2.3)	3.5±2.5±0.3	4.9±1.3
X(3872)	1.1	1.2±1.1±1.1 (<2.6)	<3.2	(<3.2)
X(3915)	0.3	0.4±1.6±0.0 (<2.8)	-	-

- The best precision for η_c, $\eta_c(2S)$. First significant measurement for $\eta_c(2S)$
- The most stringent upper limit for X(3872). The first limit for X(3915)
- For other states, the result is basically consistent with world average.

Discussion : X(3872)

- The product of "fraction of $\chi_{c1}(2P)$" and "Br(X(3872) → $J/\psi\pi^+\pi^-$)" is 0.014±0.06 from LHC result (Phys. Rev. D 96, 074014).

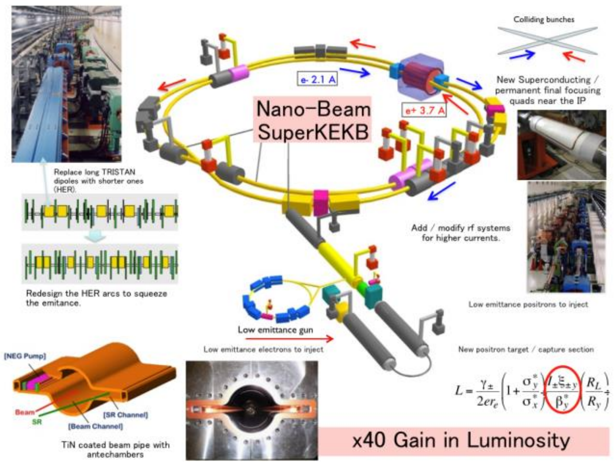
- Br(B^+→X(3872) K^+) × Br(X(3872) × $J/\psi\pi^+\pi^-$) = $(8.6\pm0.8)\times10^{-6}$ (from exclusive measurements).

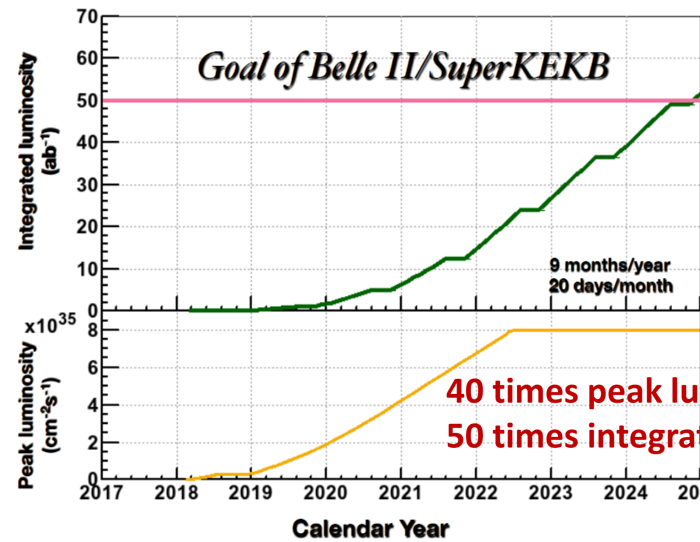
- Br(B^+→X(3872) K^+) < 2.6×10^{-4} (This measurement)
  → Br (X(3872) → $J/\psi\pi^+\pi^-$) > 3.2×10^{-2}
  → The fraction of $\chi_{c1}(2P)$ < ~40%
  (my personal calculations)

- The dominant contribution of X(3872) is coming from DD*

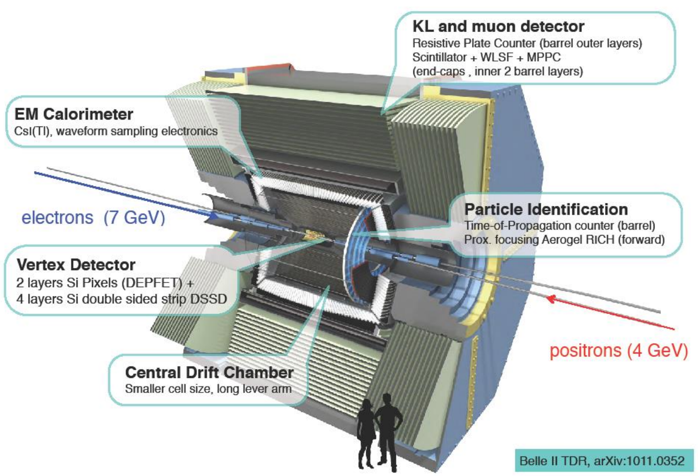
Belle→Belle II

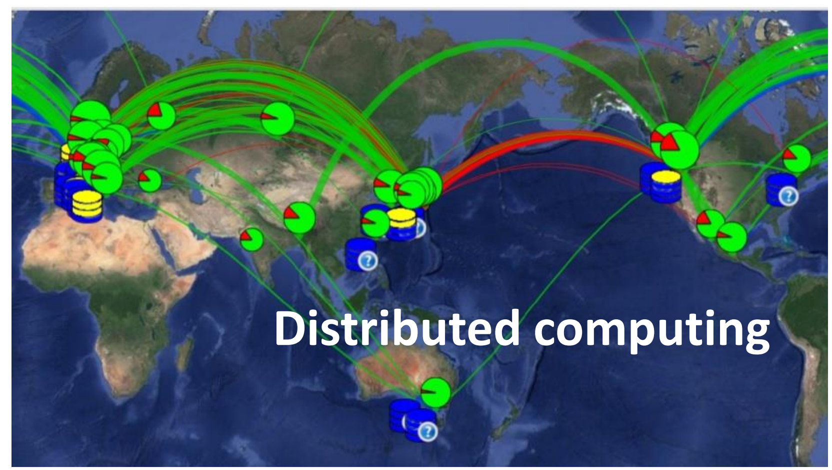
Aim to find physics beyond the Standard Model



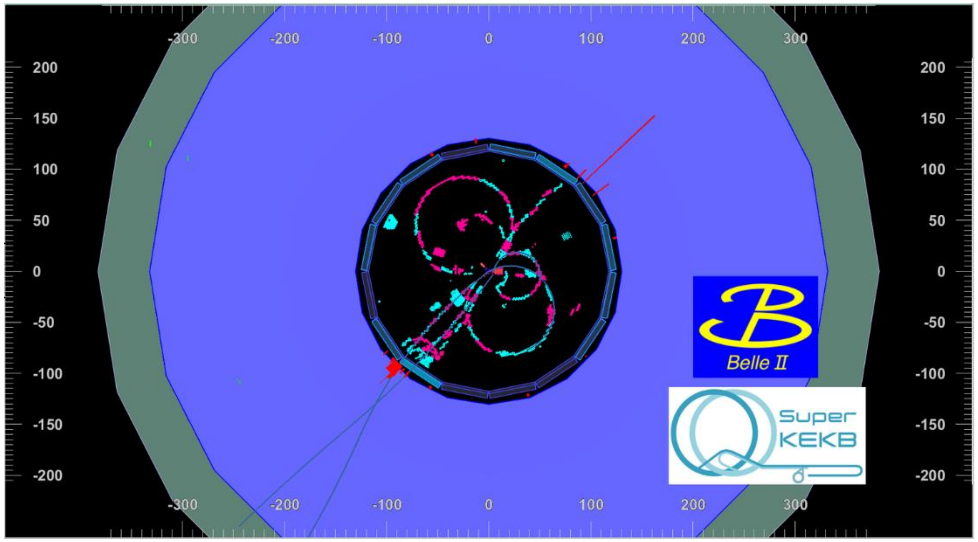


40 times peak luminosity.
50 times integrated luminosity.





First collision happened!



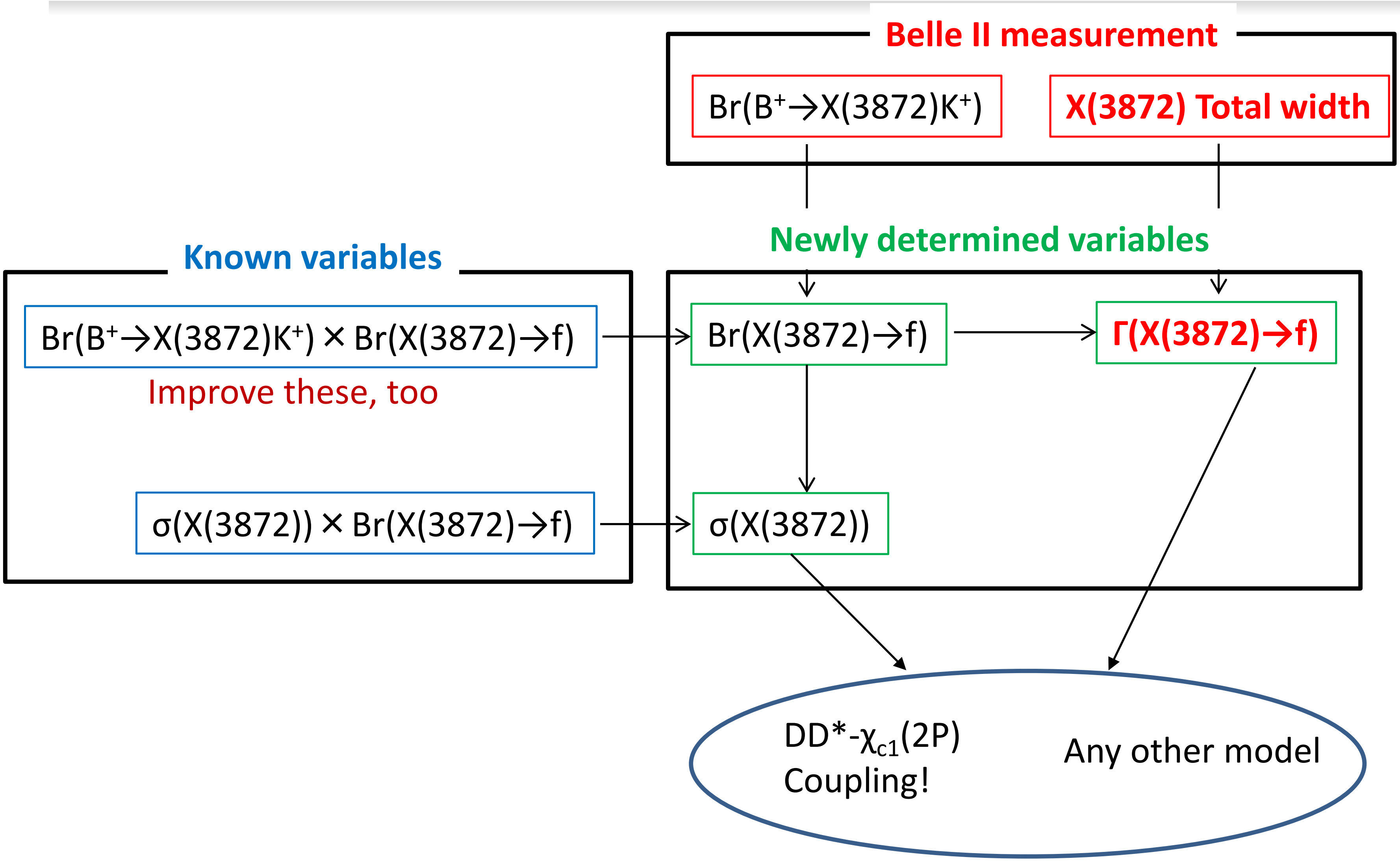
Prospect of X(3872) study at Belle II

- We can determine the $Br(B^+ \rightarrow X(3872)\ K^+)$ with ~7σ with 50 ab^{-1}
  (naïve extrapolation from luminosity)

- The other important variable for X(3872) is total width.
  Only the upper limit of 1.2 MeV is determined.

- From the total width and branching fractions,
  partial width of each X(3872) decay mode can be determined.
  → Compare these with "molecule and $\chi_{c1}(2P)$" picture
  or any other model for X(3872) multidirectionally

Strategy for Belle II



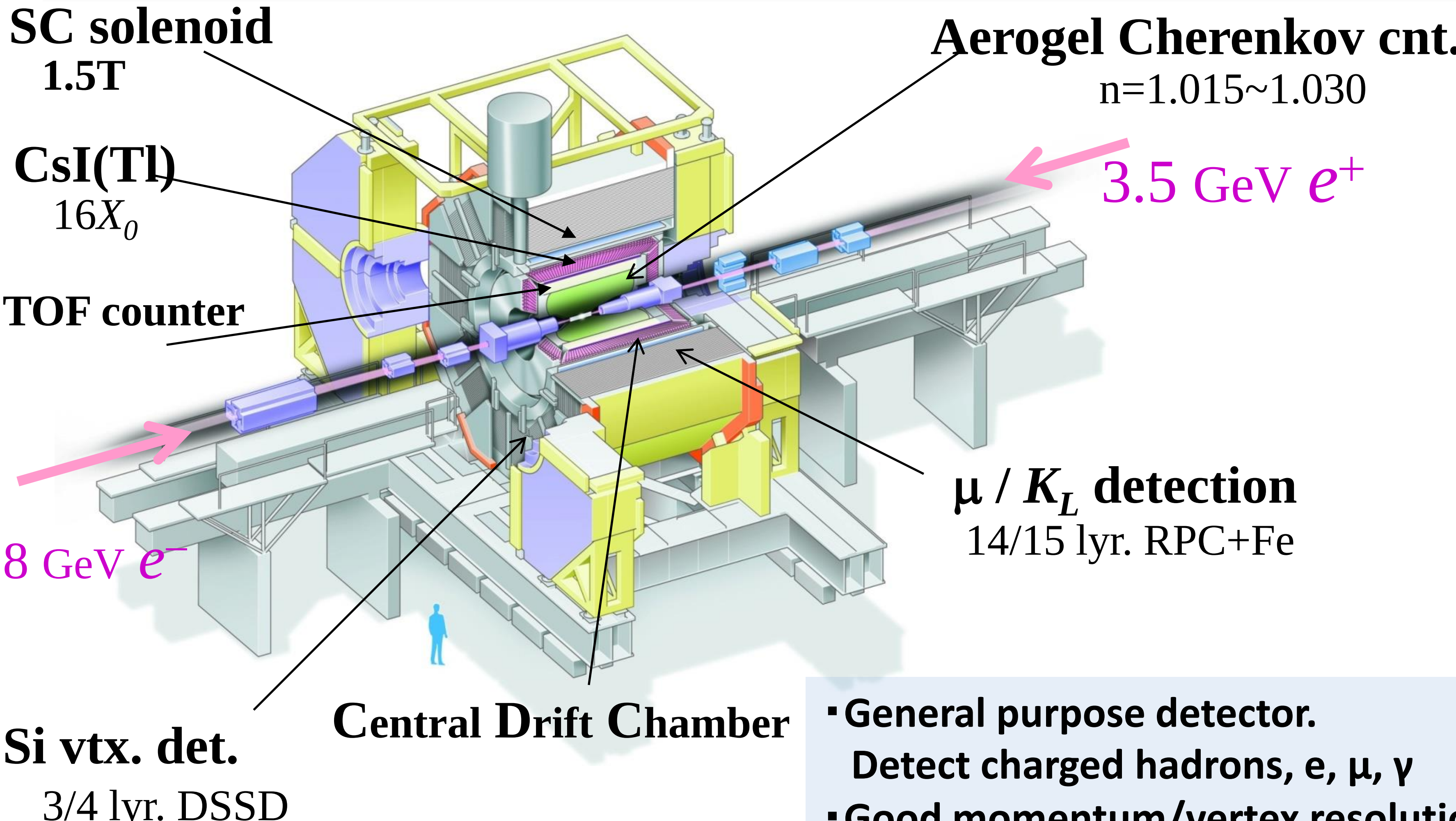
Increase dynamical information more drastically!

Summary

- Belle opened new era in the hadron spectroscopy.
- X(3872) is a candidate of exotic hadron, and studied a lot in this decade.
- Br($B^+ \rightarrow$ X(3872)) is one of the key measurements to understand its nature.
- The most stringent upper limit is set by using missing mass technique.
- Belle II just started!
- Stay tuned for the exciting results from Belle II !!

Backup

Belle detector



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

K^+ Missing Mass distribution (all region)

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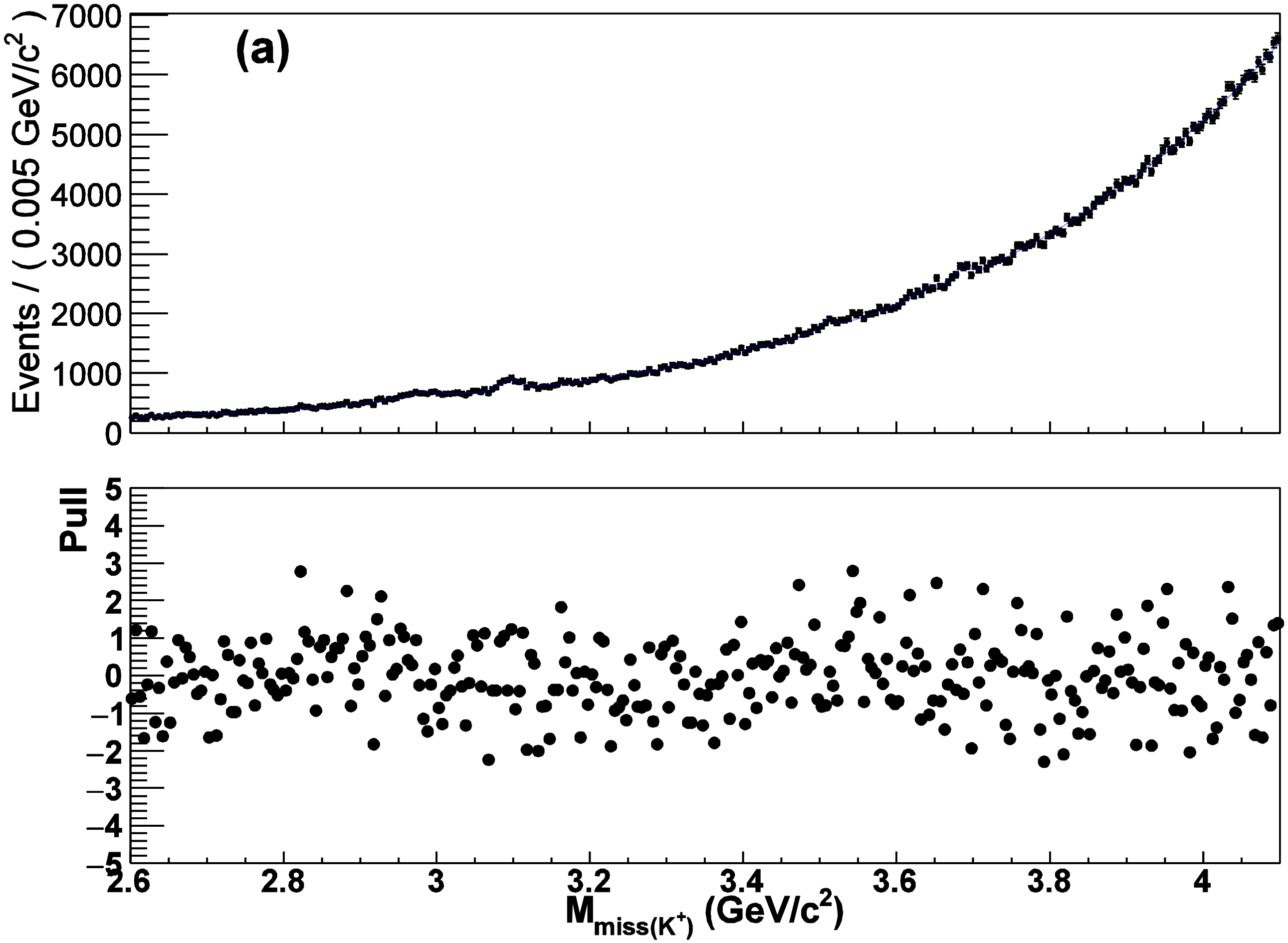

Discussion : X(3872) (2)

*PDG

X(3872) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$e^+ e^-$	
Γ_2	$\pi^+ \pi^- J/\psi(1S)$	> 2.6 %
Γ_3	$\rho^0 J/\psi(1S)$	
Γ_4	$\omega J/\psi(1S)$	> 1.9 %
Γ_5	$D^0 \overline{D}^0 \pi^0$	>32 %
Γ_6	$\overline{D}^{*0} D^0$	>24 %

From BaBar's result $(3.2 \times 10^{-4}<)$

- $Br(B^+ \to K^+ X(3872)) >= \Sigma Br(B^+ \to K^+X(3872)) \times (X(3872) \to f)$
  $\to Br(B^+ \to X(3872) K^+) >= 1.0 \times 10^{-4}$
- The fraction of $\chi_{c1}(2P)$ is roughly 15% - 40% (not small fraction)
- We need more experimental information to check this interpretation can comprehensively explain data (I do not 100% believe $\chi_{c1}(2P)$-DD* molecular scenario).

Discussion on $\eta_c(2S)$

- Firstly observed in the $B^+ \to K^+ \eta_c(2S)$, $\eta_c(2S) \to (K^- K^0 \pi^+)$ decay (Belle: Phys. Rev. Lett. 89, 102001)
- Thought to be the radial excitation of $\eta_c(1S)$.

▪Determination of branching fraction

$$\frac{Br(B^+ \to \eta_c(2S)K^+)\times Br(\eta_c(2S)\to K\bar{K}\pi)}{Br(B^+ \to \eta_c K^+)\times Br(\eta_c \to K\bar{K}\pi)} = (9.6^{+2.0}_{-1.9} + 2.5)\times 10^{-2} \quad ...(1)$$

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$$Br(B^+ \to \eta_c K^+)\times Br(\eta_c \to K\bar{K}\pi) = (6.88 \pm 0.77^{+0.55}_{-0.66})\times 10^{-5} \quad ...(2)$$

This measurement

$$Br(B^+ \to \eta_c(2S)K^+) = (4.9 \pm 1.1 \pm 0.3)\times 10^{-4} \quad ...(3)$$

$$\to Br(\eta_c(2S) \to K\bar{K}\pi) = (1.3 \pm 0.4 \pm 0.4)\times 10^{-2}$$

(neglecting correlation for systematic uncertainty)

▪Determination of two photon width

$$Br(\eta_c(2S) \to K\bar{K}\pi)\times \Gamma(\eta_c(2S) \to \gamma\gamma) = (0.041 \pm 0.004 \pm 0.006) \quad keV$$

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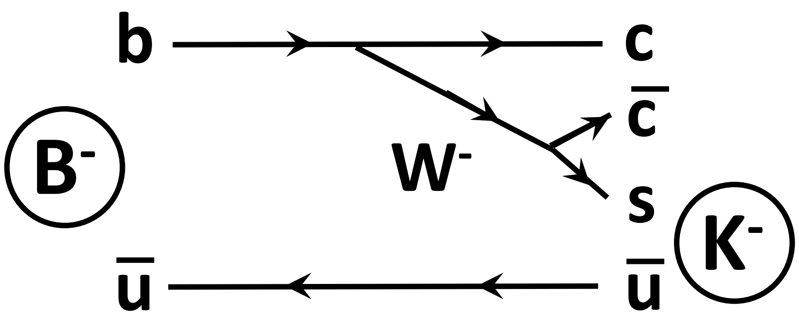
$$\to \Gamma(\eta_c(2S) \to \gamma\gamma) = (3.2 \pm 1.0 \pm 1.0) \quad keV \Leftrightarrow \Gamma(\eta_c \to \gamma\gamma) = (5.0 \pm 0.4) \quad keV$$

$$\frac{\Gamma(\eta_c(2S) \to \gamma\gamma)}{\Gamma(\eta_c \to \gamma\gamma)} = 0.64 \pm 0.28$$

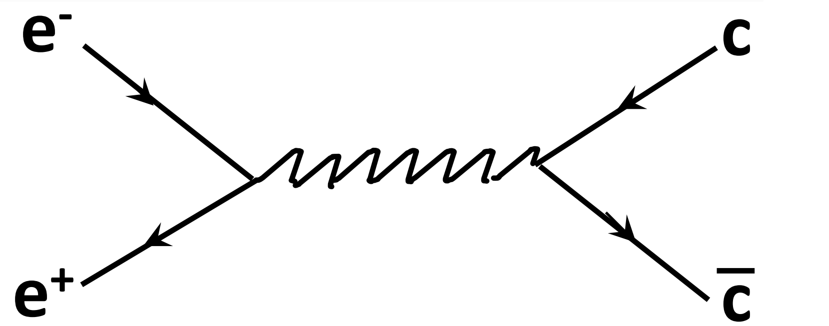
$\Gamma_{\gamma\gamma}$	Experiments	This paper	Ackleh [4]	Kim [5]	Ahmady [6]	Münz [11]	Chao [10]	Ebert [12]
η_c	$7.4 \pm 0.9 \pm 2.1$ (PDG [7])	7.5–10	4.8	7.14 ± 0.95	$11.8 \pm 0.8 \pm 0.6$	3.5 ± 0.4	5.5	5.5
η_c'	1.3 ± 0.6 (CLEO [3])	3.5–4.5	3.7	4.44 ± 0.48	$5.7 \pm 0.5 \pm 0.6$	1.38 ± 0.3	2.1	1.8
η_c'/η_c		0.45	0.77	0.62	0.48	0.39	0.38	0.33

Charmed hadron production at B-factory



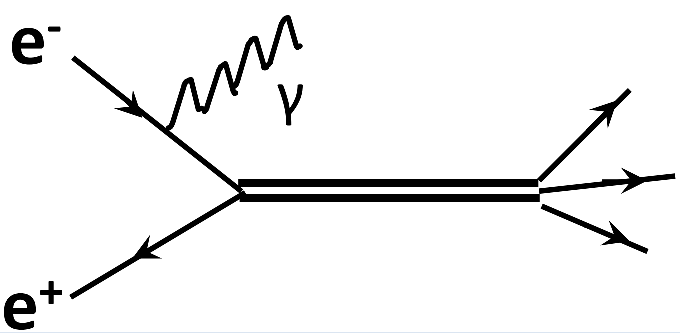
B-decays into charmonium

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



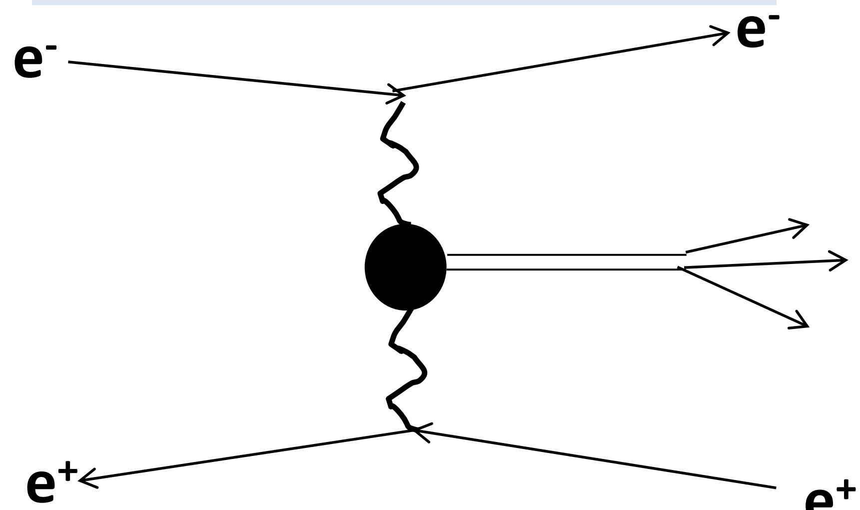
$e^+e^- \rightarrow c\bar{c}$ reaction

- Charmed baryons observed.



Initial state radiation

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

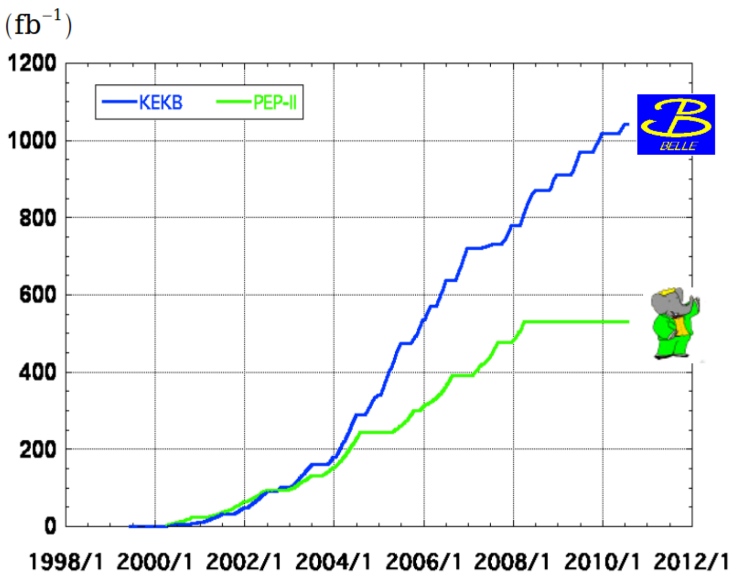


Two photon collision

- Produce charmonium with $J^{PC}=0^{++}$ or 2^{++}
- Two photon width can be measured

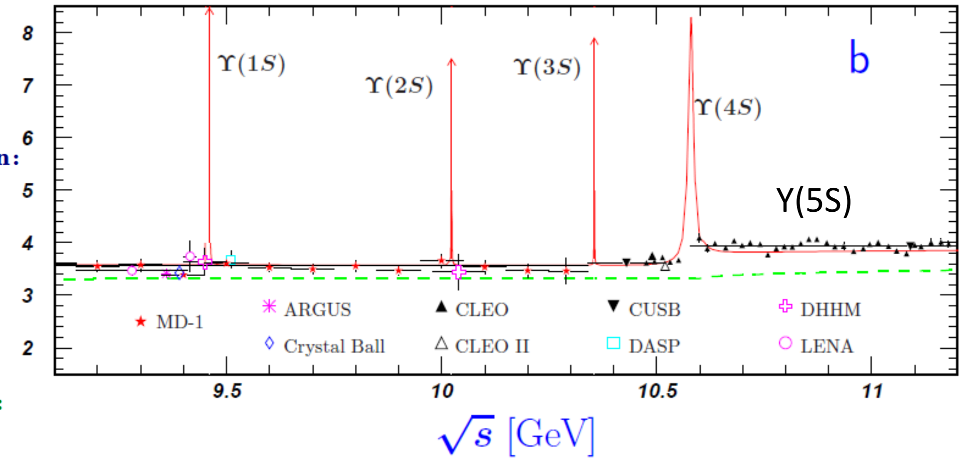
Data accumulated at Belle

Integrated luminosity of B factories



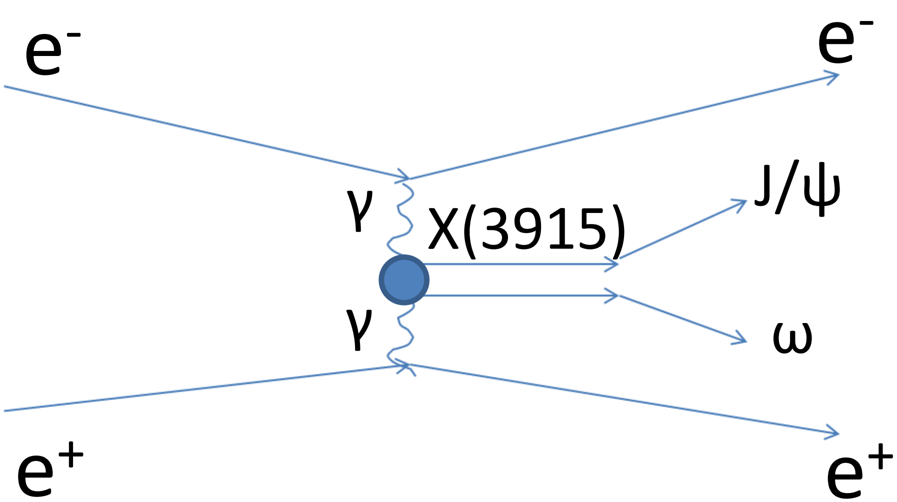
> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 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} $e^+e^- \to c\bar{c}$.
- General purpose feature of Belle detector and large data enable us to study the hadron spectroscopy

X(3915) from two photon collision



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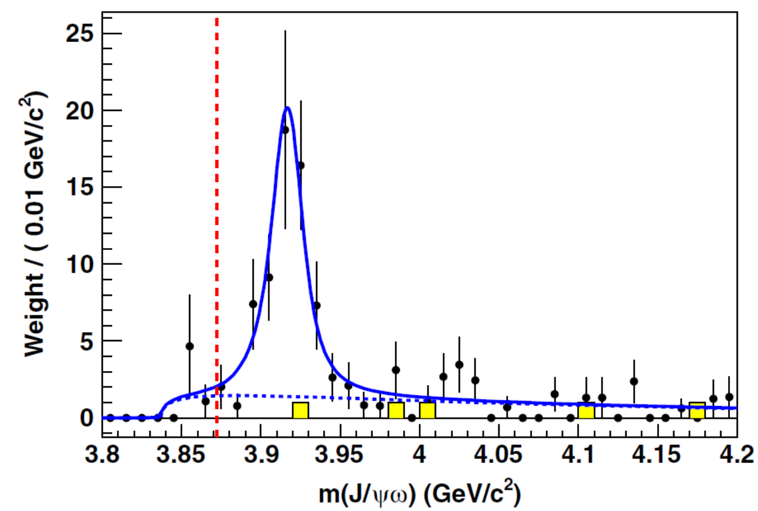
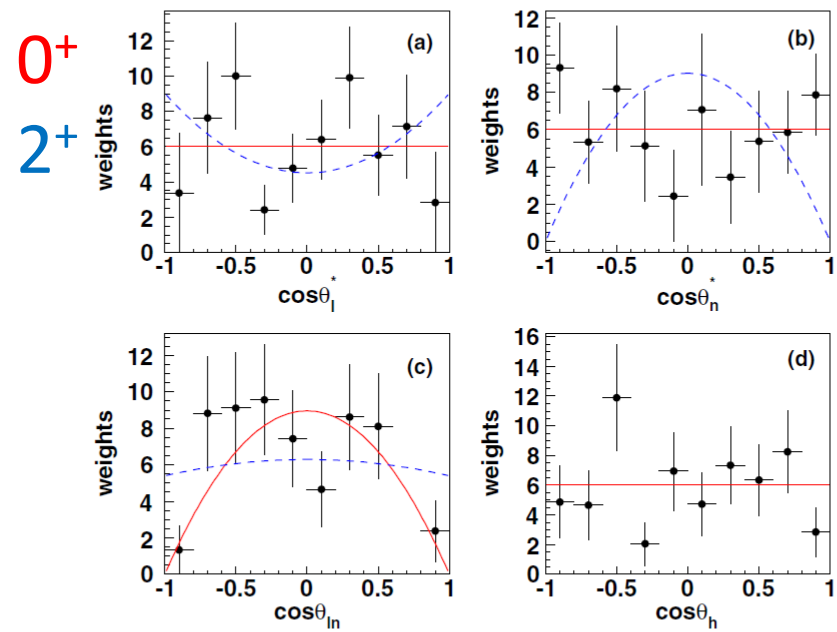




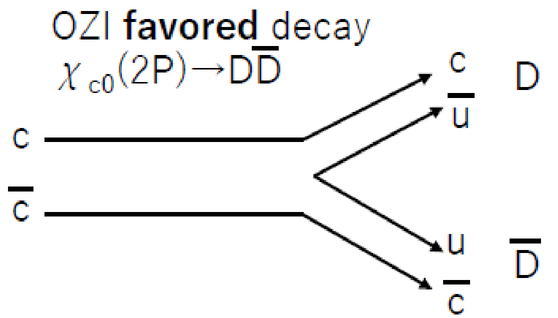
- The angular analysis favors the J^{PC} of 0^{++}
- The unknown charmonium with 0^{++} is $\chi_{c0}(2P)$. However …

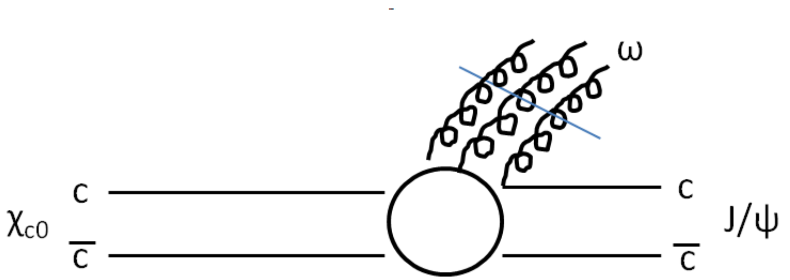
Difficulties to interpret X(3915) as $\chi_{c0}(2P)$

- The mass splitting with $\chi_{c2}(2P)$ is too small (~8 MeV/c^2)
  cf: More than 100 MeV/c^2 for $\chi_{c2}(1P) - \chi_{c0}(1P)$

- The width is too narrow for the state above DD^{bar} (more than 100 MeV is expected)

- It is above DD^{bar}, and 0^+ can decay into DD^{bar}, but
  OZI suppressed decay $J/\psi\omega$ is favored.

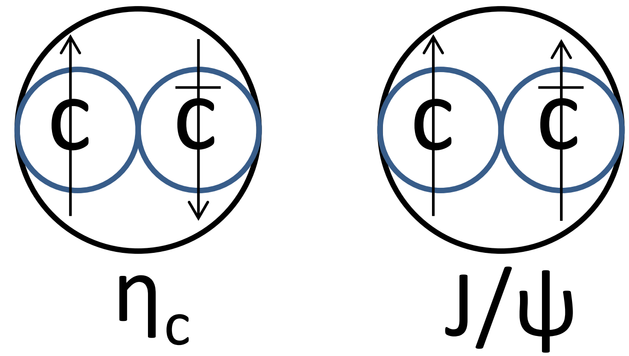




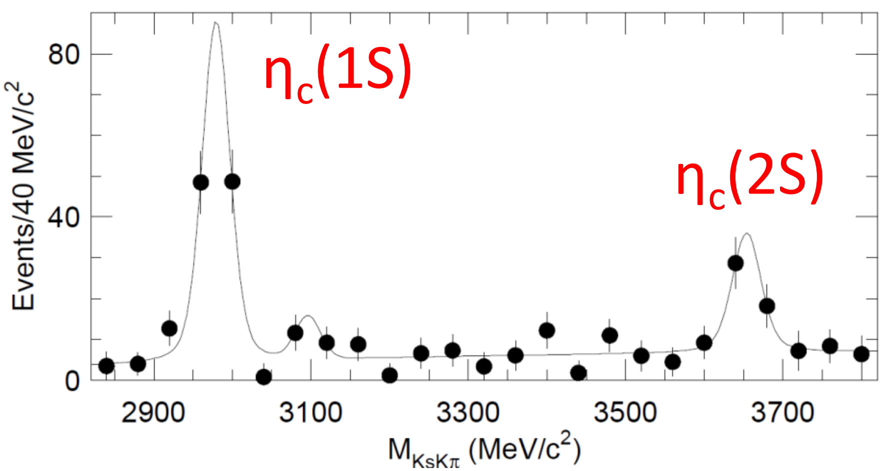
- The width of 20 MeV may be too large as OZI suppressed decay
  (ex: The partial width of $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ is ~ 100 keV)
  Partial decay width of $J/\psi\omega$ is given as $\Gamma_{total} \times Br(X(3915) \rightarrow J/\psi\omega)$
  But the $Br(X(3915) \rightarrow J/\psi\omega)$ is now known..

$\eta_c(2S)$

- Observed at Belle in $B^+ \rightarrow K^+ (K_S K^- \pi^+)$
  - Confirmed by BaBar, BES III, CLEO, and LHCb, in various decays and productions.



- Generally accepted as radial excitation of $\eta_c(1S)$ = ground state of charmonium.



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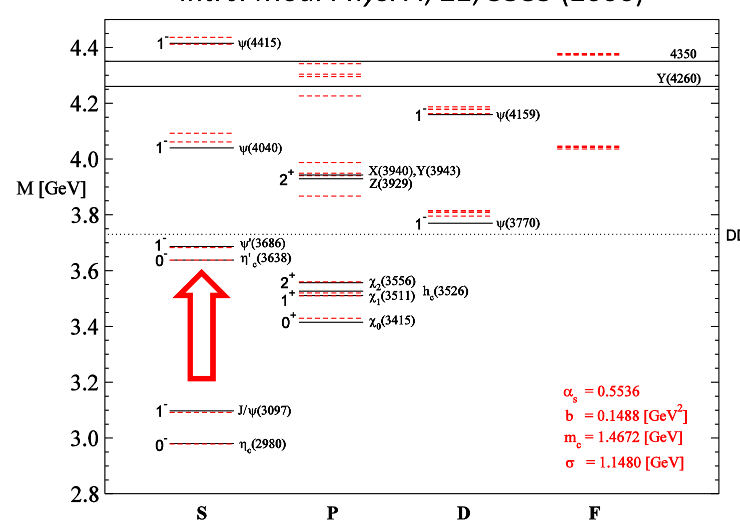
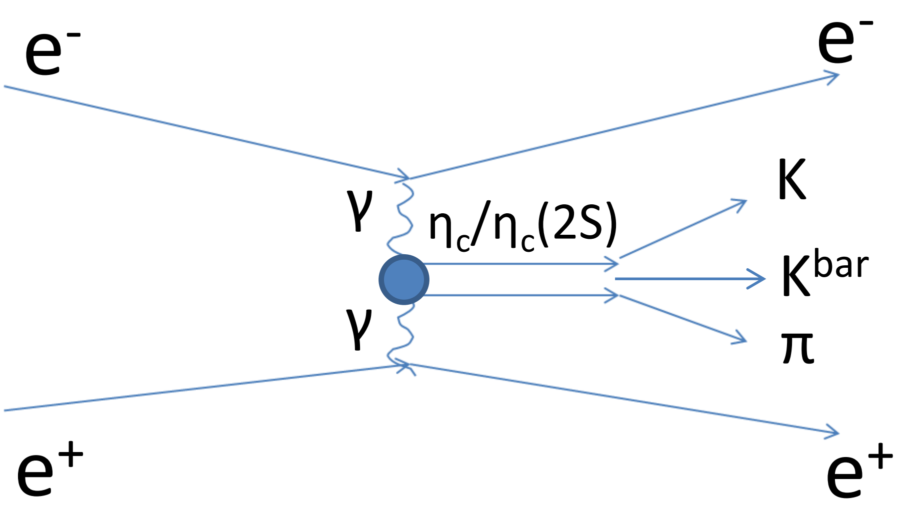
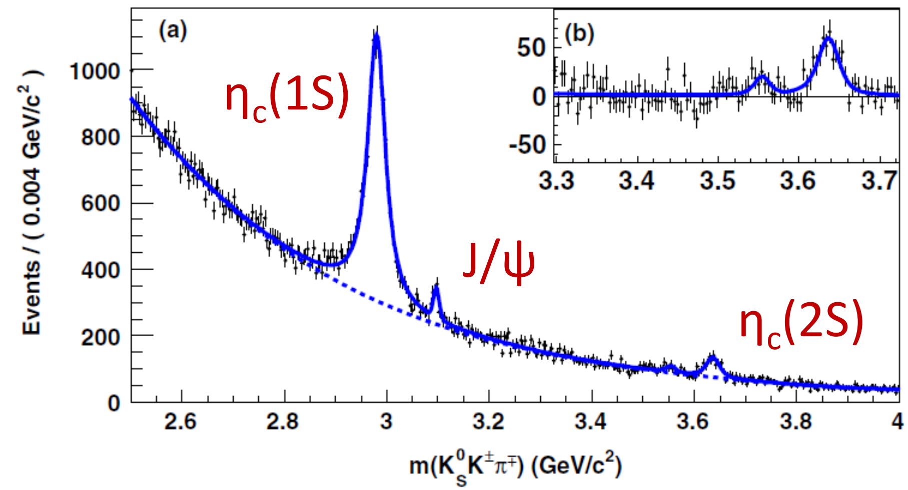


Two photon production of $\eta_c(2S)$





- The two photon collision provides Γ(2γ), which is theoretically clean as it is an electro-magnetic process.

- However, as the Br ($\eta_c(2S) \to KK^{bar}\pi$) is not known, only product Γ(2γ) × Br($\eta_c(2S) \to KK^{bar}\pi$) can be measured.

Comparison with theoretical calculation

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$\Gamma_{\gamma\gamma}$	Experiments	This paper	Ackleh [4]	Kim [5]	Ahmady [6]	Münz [11]	Chao [10]	Ebert [12]
η_c	$7.4 \pm 0.9 \pm 2.1$ (PDG [7])	7.5–10	4.8	7.14 ± 0.95	$11.8 \pm 0.8 \pm 0.6$	3.5 ± 0.4	5.5	5.5
η_c'	1.3 ± 0.6 (CLEO [3])	3.5–4.5	3.7	4.44 ± 0.48	$5.7 \pm 0.5 \pm 0.6$	1.38 ± 0.3	2.1	1.8
η_c'/η_c	0.18 ± 0.1	0.45	0.77	0.62	0.48	0.39	0.38	0.33

- Partial width of ηc(2S) is a bit smaller than theoretical predictions
- Assumed $Br(\eta_c \to KK^{bar}\pi) = Br(\eta_c(2S) \to KK^{bar}\pi)$
- The ratio $\eta_c(2S)/\eta_c(1S)$ is smaller than theoretical calculations.
  - Some problems in understanding of ηc(2S)?
  - Just the assumption is wrong?
- Need to determine $Br(\eta_c(2S) \to KK^{bar}\pi)$

$B^+ \to \pi^+ D^{(*)}$を用いた妥当性検証

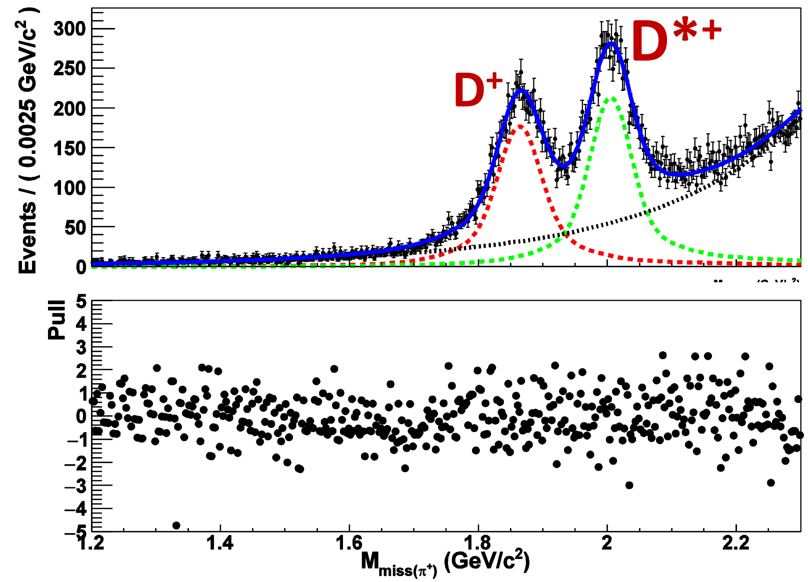
・コントロールサンプルとして最適
- -$B^+ \to K^+X$との違いはK^+とπ^+を交換するだけ。
- -高統計, 低バックグラウンド。
- -Exclusiveな測定による世界平均も高精度 (3-5%)

→MCで求めた信号の形と
解析全体の妥当性の検証に用いる。

・D,D*信号の形はMCの分布を3 Gaussianでフィットすることで決定。

・"$\sigma_{Data}/\sigma_{MC}$" "$\mu_{Data}-\mu_{MC}$"をパラメータとしてフィット。

π^+ missing mass (data)



Preliminary

信号の形のデータとMCの違い

	$\sigma_{Data}/\sigma_{MC}$	$\mu_{Data}-\mu_{M}$(MeV/c²)
D^0	0.994±0.025	-0.5±0.8
D*	1.035±0.029	-0.8±0.8

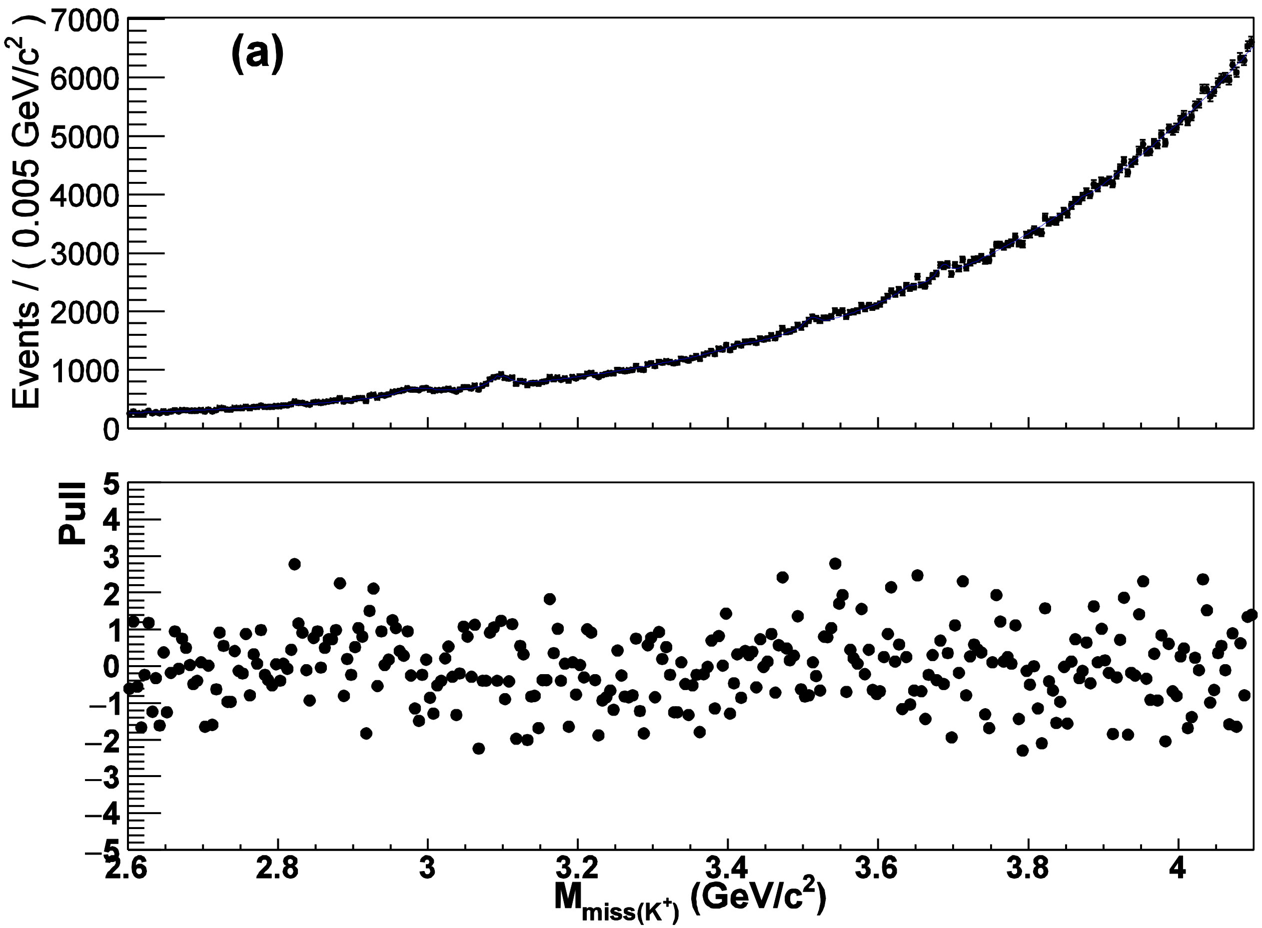
信号の形はデータとシミュレーションで無矛盾

分岐比測定 (10^{-3})

	本測定	PDG
$Br(B^+ \to \pi^+ D^0)$	4.58±0.12±0.34	4.80±0.15
$Br(B^+ \to \pi^+ D^{*0})$	5.07±0.10±0.26	5.18±0.26

崩壊分岐は世界平均と無矛盾。
精度も世界平均に近いものが得られた。
物理結果として論文にも入れる。

K^+ Missing Mass分布 (全領域)



- BGは二次のexponential: $\exp(ax+bx^2)$
- X_{cc}信号はMCから作ったヒストグラムPDF。
- Pull 分布に特にバイアスは見られない。

$\eta_c(2S)$

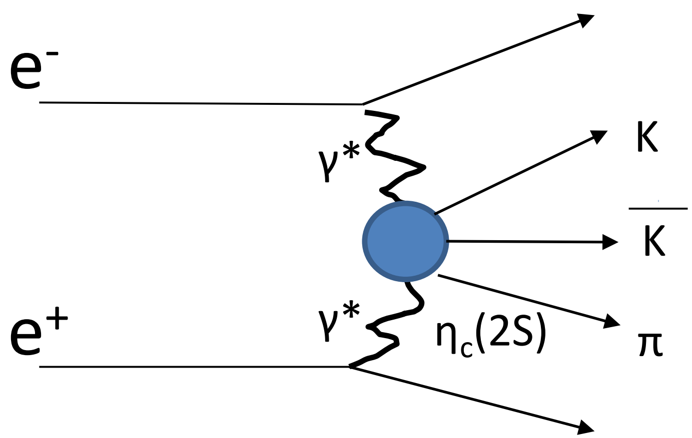
- $B^+ \to K^+$ $(K^- K^0 \pi^+)$ 崩壊で初めて発見 (Belle: Phys. Rev. Lett. 89, 102001)
- $\eta_c(1S)$ (spin=0, L=0)のradial excitation状態と考えられている。
- 2-photonへの崩壊幅は、理論的に精度良く計算できる量。

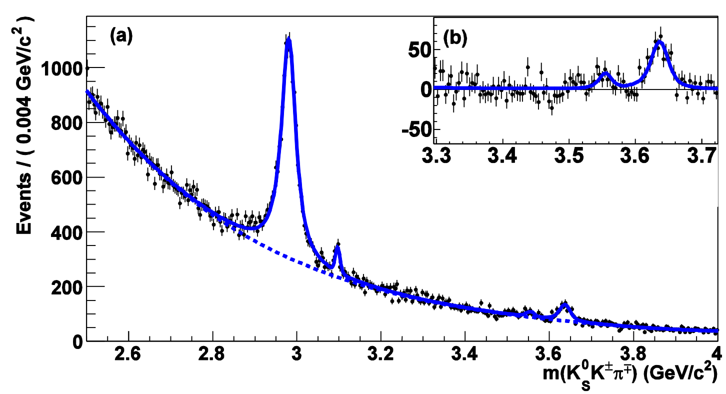
$\Gamma_{\gamma\gamma}$	Experiments	This paper	Ackleh [4]	Kim [5]	Ahmady [6]	Münz [11]	Chao [10]	Ebert [12]
η_c	$7.4 \pm 0.9 \pm 2.1$ (PDG [7])	7.5–10	4.8	7.14 ± 0.95	$11.8 \pm 0.8 \pm 0.6$	3.5 ± 0.4	5.5	5.5
η_c'	1.3 ± 0.6 (CLEO [3])	3.5–4.5	3.7	4.44 ± 0.48	$5.7 \pm 0.5 \pm 0.6$	1.38 ± 0.3	2.1	1.8

- Belle/BaBarによる2-photon生成から、

$$Br(\eta_c(2S) \to KK\pi) \times \Gamma(\eta_c(2S) \to \gamma\gamma) = (0.041 \pm 0.004 \pm 0.006) keV$$

と分かっているので、$Br(\eta_c(2S) \to KK\pi)$が分かれば、理論との比較が出来る。





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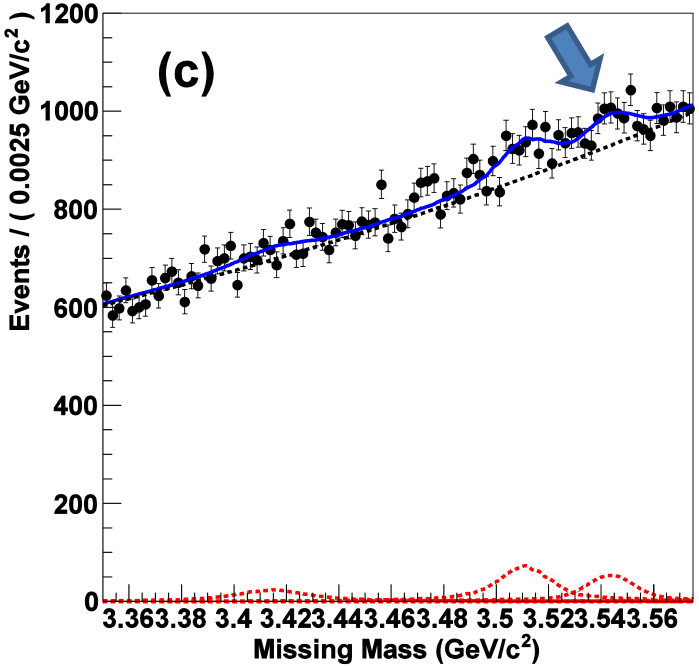
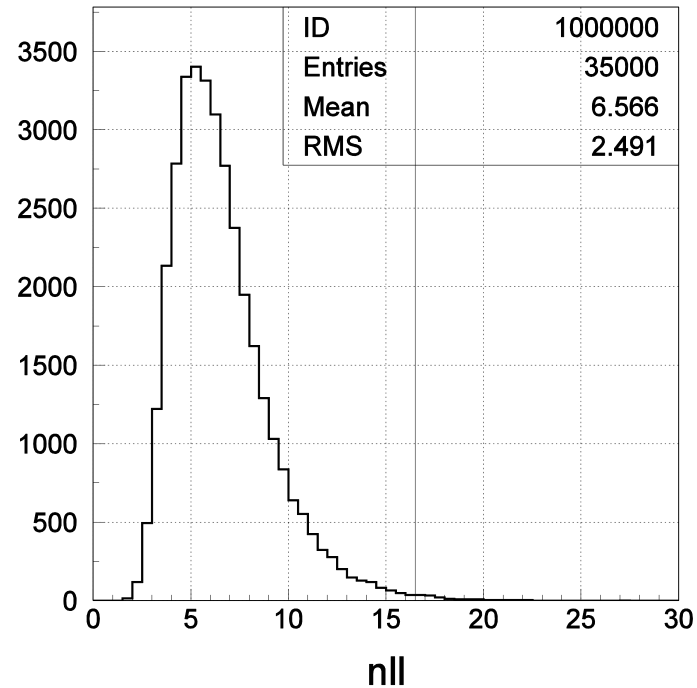
3545 MeV/c²付近のバンプ構造

3545 MeVを入れたフィット



Δ(-2logL)分布



- The peak position is 3544.2±2.8 MeV/c^2
  (χ_{c2}(1P) から4.3σ 離れている)

- The Δ(-2logL) は 16.5→ ローカルな有意度は ~4.1σ

- Pseudo experimentを実施
  BG分布を生成しシグナルを入れたフィットを行い、全領域の中で最大のΔ(-2logL)を抽出。
  Δ(-2logL)が16.5を超える確率は0.43%: 2.8σに対応。有意ではないという結論