Charmed hadron spectroscopy at Belle and Belle II

Y. Kato (KMI, Nagoya University)

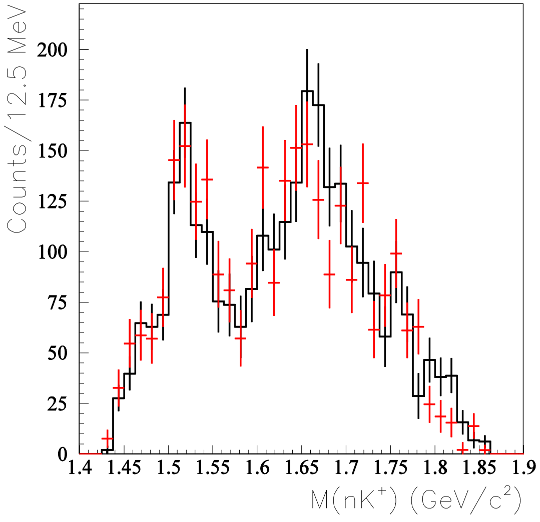
Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

Contents

- Overview of hadron spectroscopy at Belle (~20%)
- Charmed baryons (~30%)
- X(3872) (~20%)
- Prospect of Belle II and distributed computing (~30%)

Self introduction

- ~2012
  Get Ph.D at RCNP, Osaka University (2012).
  Search for pentaquark Θ^+ at SPring-8/LEPS experiment.



Few Body Syst. 54 (2013) 1245-1249

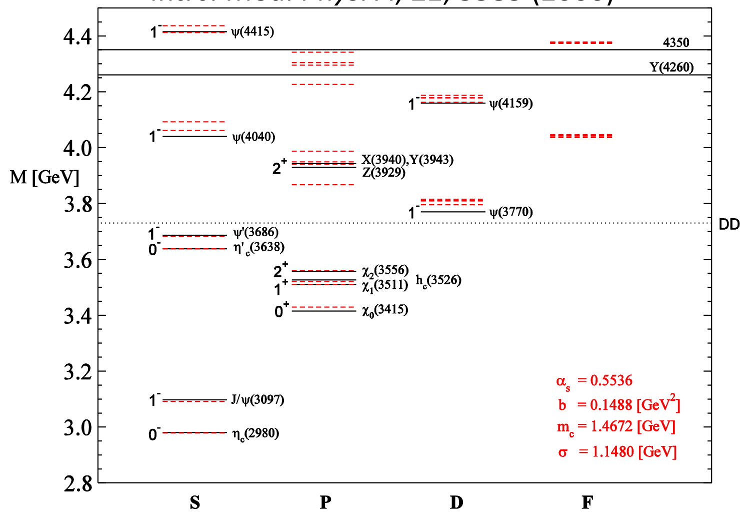
- 2012- Nagoya University（Posdoc until 2015, 特任助教 from 2016FY）
  - Hadron spectroscopy at Belle
  - Development/operation for Belle II distributed computing system.
  - TOP counter (a little).

Introduction (persoanal physics motivation)

Success of constituent quark model

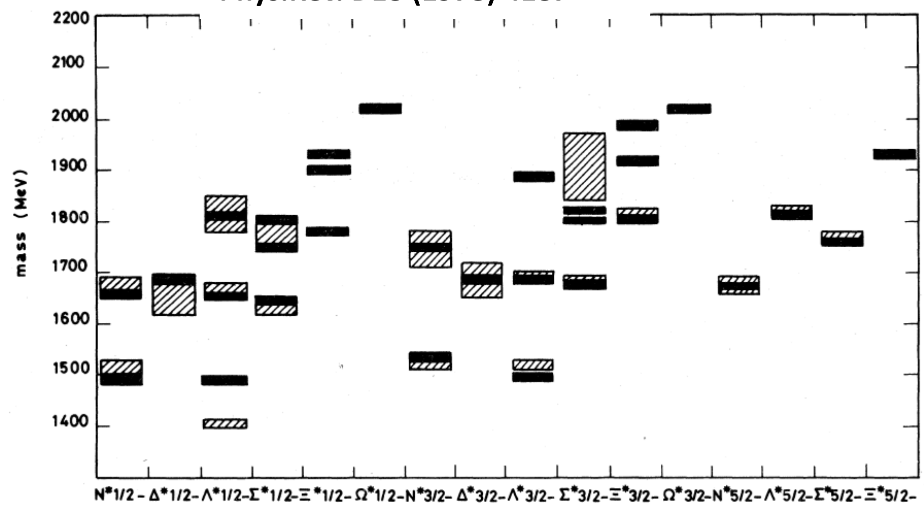
Mesons

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



Baryons

Phys.Rev. D18 (1978) 4187

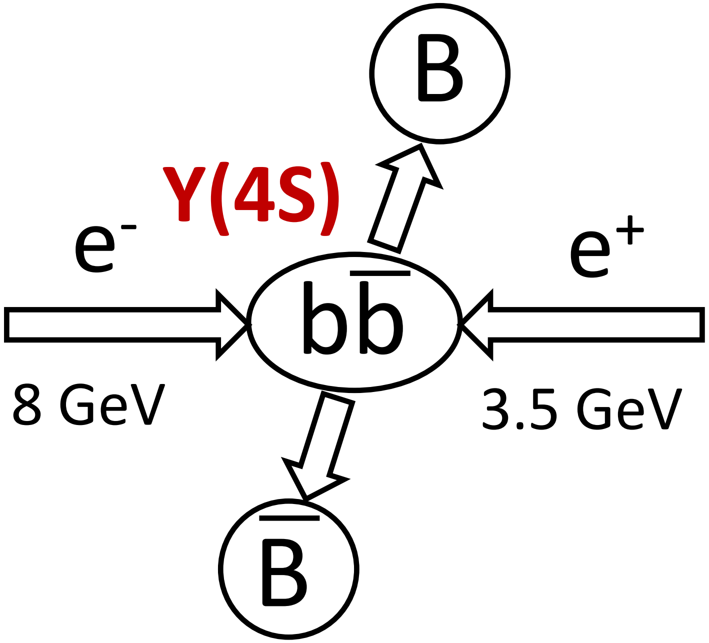


"Constituent quark" must be a good approximation... but not the end

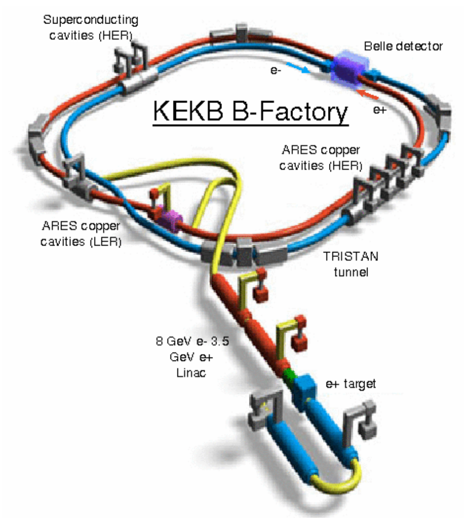
- Why it works so well?
  - Any alternative degree of freedom → (di-quark)
  - What is the adaptive limit? → (exotic hadrons)

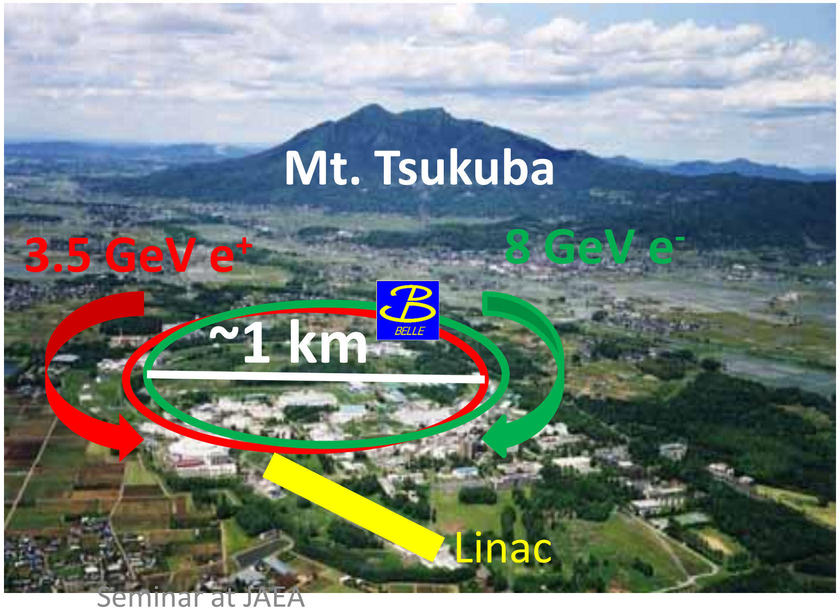
B-factory is a powerful probe!

KEKB/Belle experiment

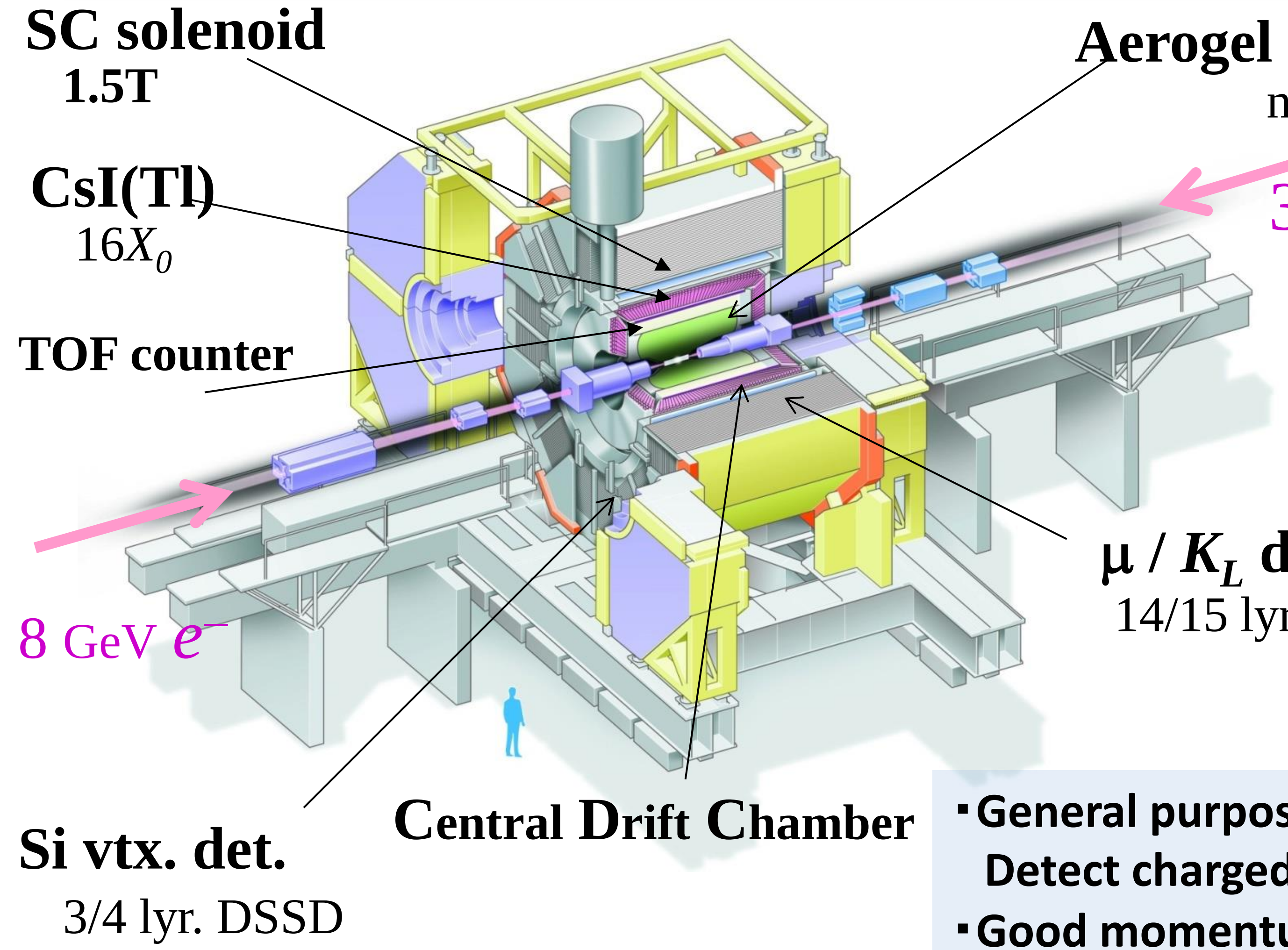


- Asymmetric energy e^+e^- collider constructed to test KM theory for CP violation in the B meson decay.
- $\sqrt{s}$=10.58 GeV = Υ(4S) mass (and other energies) → e^+e^- → Υ(4S) → $B\bar{B}$
- Peak luminosity = 2.1×10^{34} $cm^{-2}s^{-1}$ = World highest luminosity (still higher than LHC)!





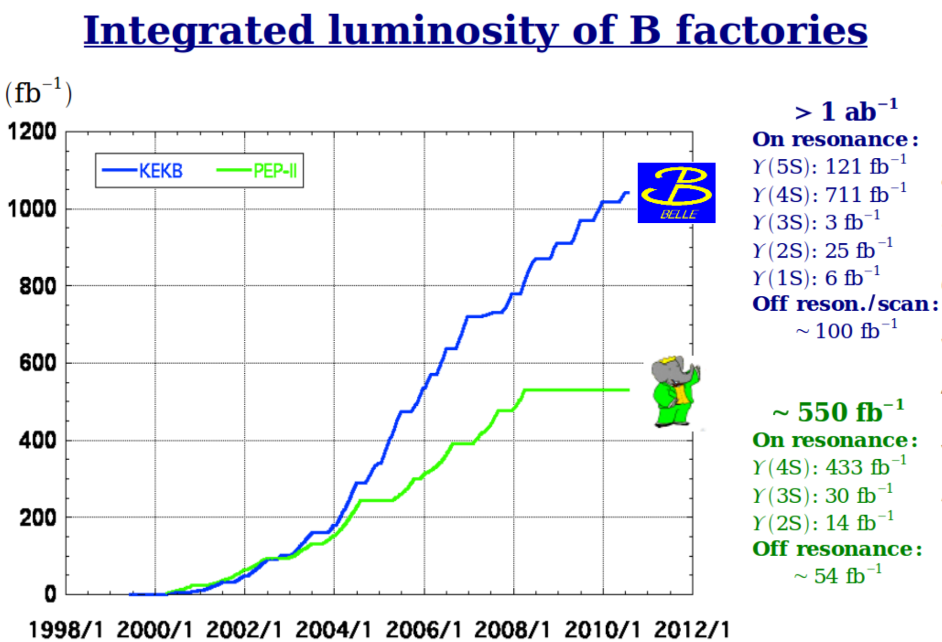
Belle detector

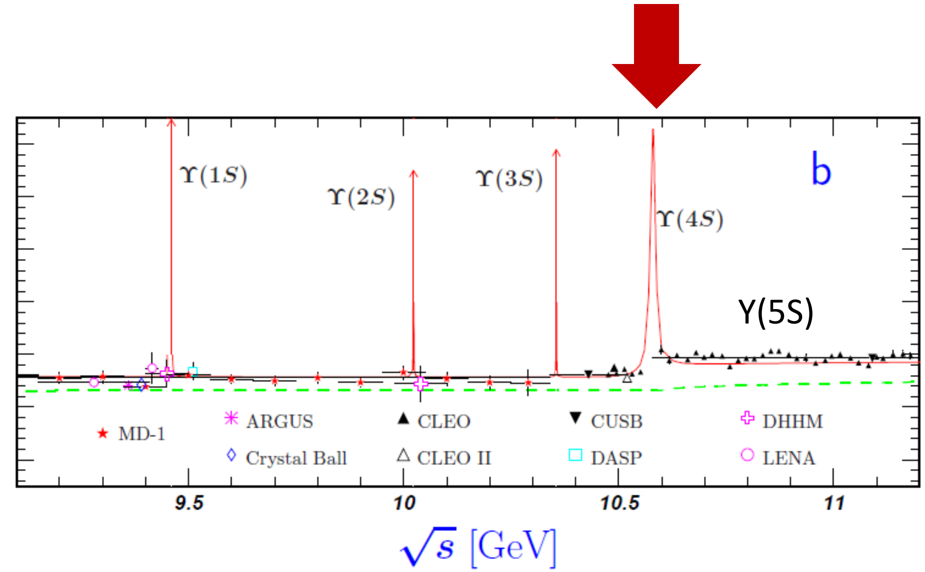


- General purpose detector.
  Detect charged hadrons, e, μ, γ
- Good momentum/vertex resolution.
- K/π separation up to ~3.5 GeV/c

→suitable also for hadron spectroscopy

Data accumulated at Belle (and BaBar)

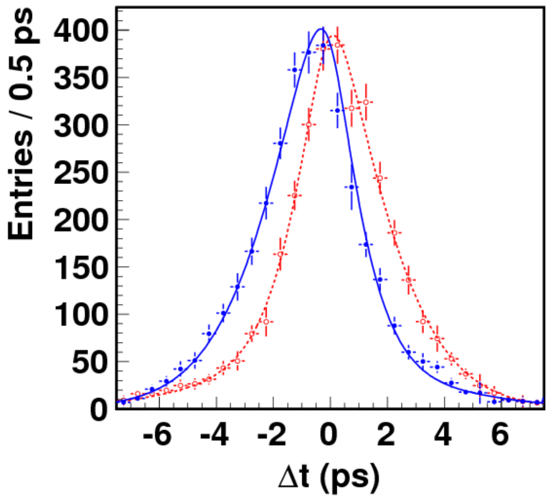




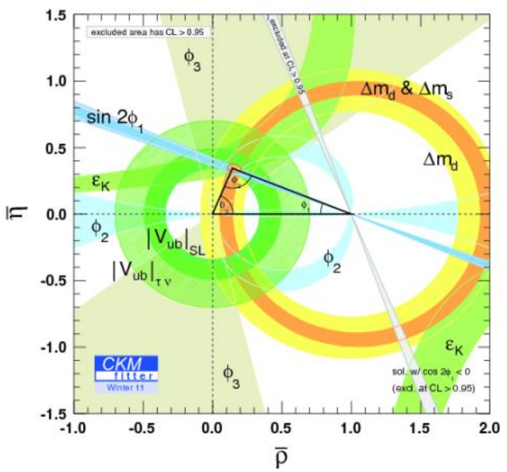
- 10 years operation. Taken at various energies.
- ~70 % of data is taken at Y(4S).
  ~$7.7 \times 10^8 B\bar{B}$ pairs.
- Total inregrated luminosity ~=1000 fb^{-1}.
  ~1×10^9 $e^+e^- \rightarrow c\bar{c}$.

Belle leads Kobayashi-Maskawa to Nobel prize!

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



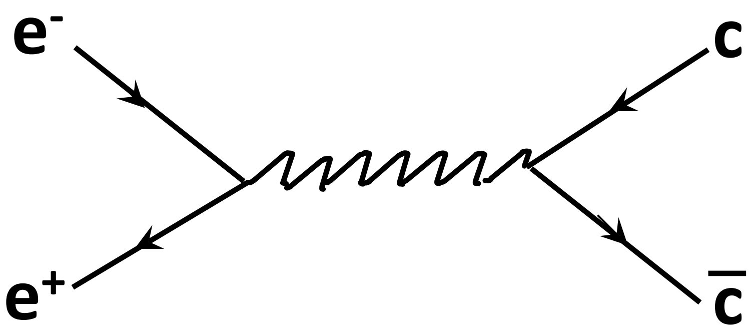
Global fit on Unitary Triangle



Press release by Nobel foundation (2008)

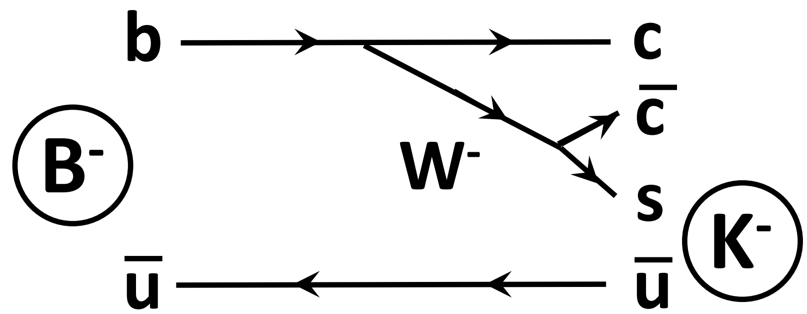
As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.

Hadron production at B-factory



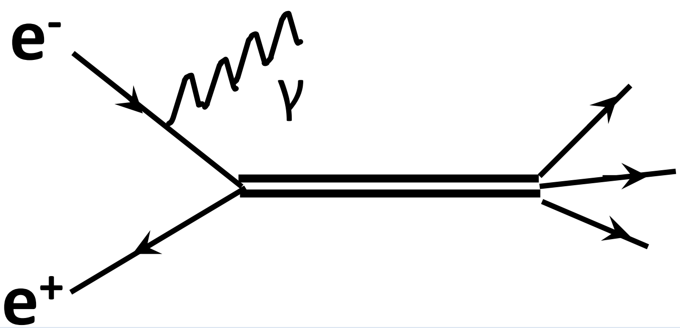
$e^+e^- \rightarrow c\bar{c}$ reaction

- Charmed baryons/mesons.



B-decays into charmonium

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



Initial state radiation

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

- 2-photon process and double charmonium production also contribute.
- Low multiplicity is common advantage compared with hadron collider.
- 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(4660)			
Double charmonium	X(3940) X(4160)			
Two photon	$\chi_{c2}(2P)$			
$e^+e^- \rightarrow cc^{bar}$		$Ds_0(2317)$	$\Sigma_c(2800)$ $\Lambda_c(2940)^+$ $\Xi_c(2980)$ $\Xi_c(3080)$ $\Omega_c(2770)$ $\Xi_c(3055)$	
Y(5S) decay				$Z_b(10610)$ $Z_b(10650)$ $h_b(1P)$ $h_b(2P)$ $\eta_b(2S)$

*some states may be missed

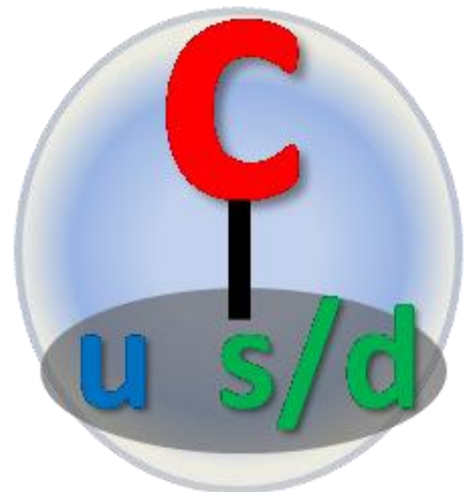
Physics of single charmed baryons

- Charm quark is heavy (1500 MeV/c2) > u,d,s quarks (300-500 MeV/c^2)
- spin-spin interaction $\propto 1/m_1 m_2$

Nucleon

Every pair can not be distinguished.

Charmed baryon

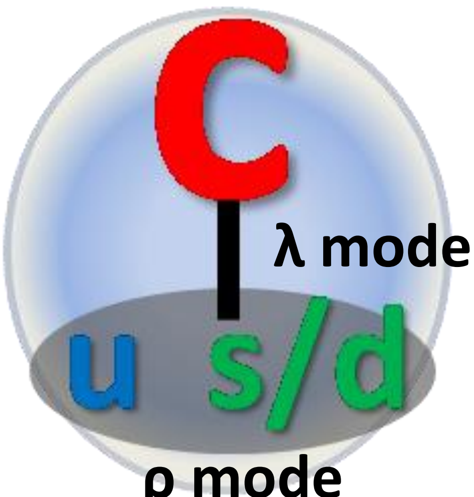


Light di-quark and charm quark.

- Di-quark correlation in light quarks
  - New degree of freedom
  - More simple picture for a baryon.

Theoretical background, Experimental approach

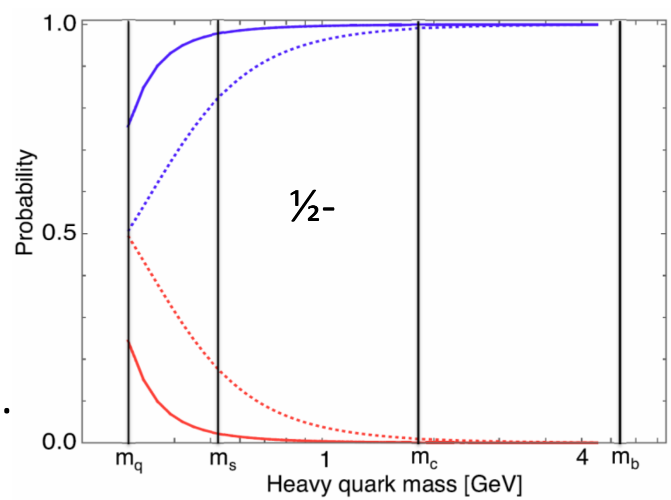
- There are two kind of excitation modes.
  Both states have $J^P=1/2^-$
  - λ mode: excitation between c quark and u-d di-quark.
  - ρ mode: excitation in the di-quarks.



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

The fraction of λ mode for the 1st excited state.

T. Yoshida et al. PRD 92, 114029 (2015)



- The di-quark picture has NOT been confirmed yet.
- Experimentally, we can do..
  - Search for new charmed baryons and measure mass and width.
  - Measure the decay pattern.
  - Determine the spin/parity.
  - Production mechanism.
- Then compare with global consistency with model prediction.

Observed charmed baryons

State	J^P
Λ_c^+	$(1/2^+)$
$\Lambda_c(2595)^+$	$1/2^-$
$\Lambda_c(2625)^+$	$(3/2^-)$
$[\Lambda_c(2765)^+$	$?^?]$
$\Lambda_c(2880)^+$	$5/2^+$
$\Lambda_c(2940)^+$	$?^?$

c d u

State	J^P
$\Sigma_c(2455)$	$(1/2^+)$
$\Sigma_c(2520)$	$(3/2^+)$
$\Sigma_c(2800)$	$?^?$

c d u

State	J^P
Ξ_c	$(1/2^+)$
Ξ'_c	$(1/2^+)$
$\Xi_c(2645)$	$(3/2^+)$
$\Xi_c(2790)$	$(1/2^-)$
$\Xi_c(2815)$	$(3/2^-)$
$[\Xi_c(2930)$	$?^?]$
$\Xi_c(2980)$	$?^?$
$[\Xi_c(3055)$	$?^?]$
$\Xi_c(3080)$	$?^?$
$[\Xi_c(3123)$	$?^?]$

c s u

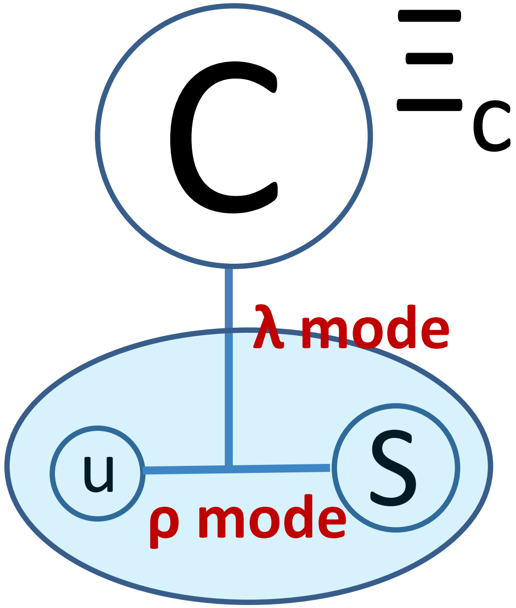
State	J^P
Ω_c	$(1/2^+)$
$\Omega_c(2770)$	$(3/2^+)$

c s s

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

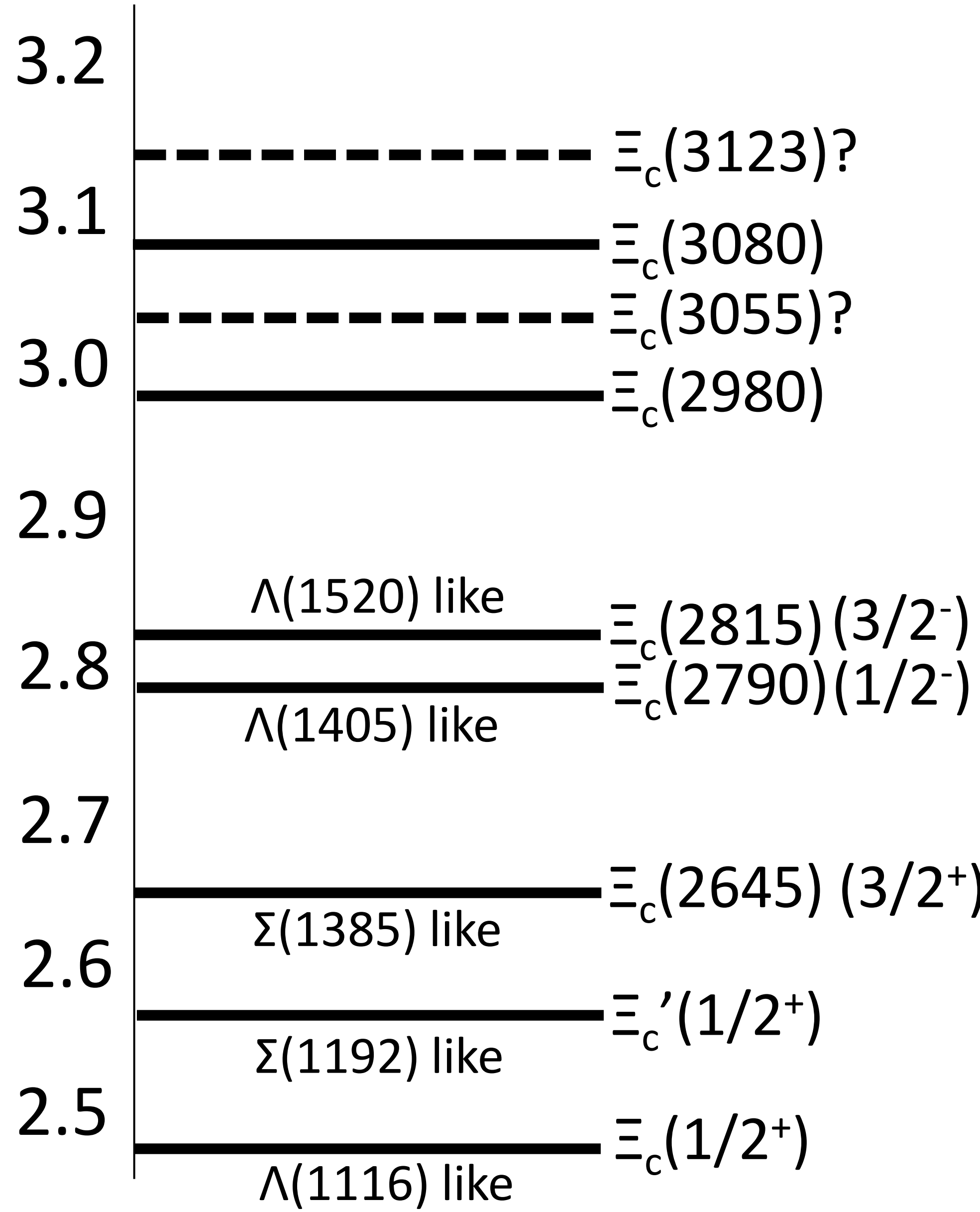
- 16/21 (12/17) charmed baryons are observed in e^+e^- collider experiment.
- Spin-parity almost from quark model prediction ().
- Some states has only poor evidence (states in []).
- They are almost observed in only 1 decay mode.
- No ρ mode excitation states identified.

Charmed strange baryons (Ξ_c)



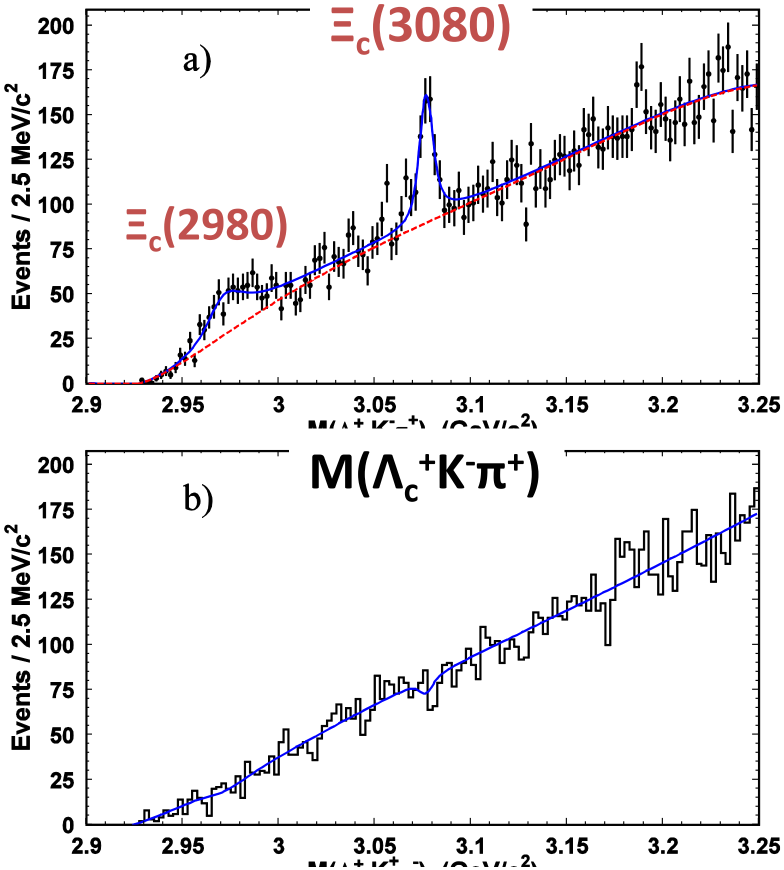
u/d-s diquark system!

- u-s di-quark, which can not be observed in the Λ state.
- Lower states (first p-wave) are consistent with quark model.
- Study dynamics with higher states

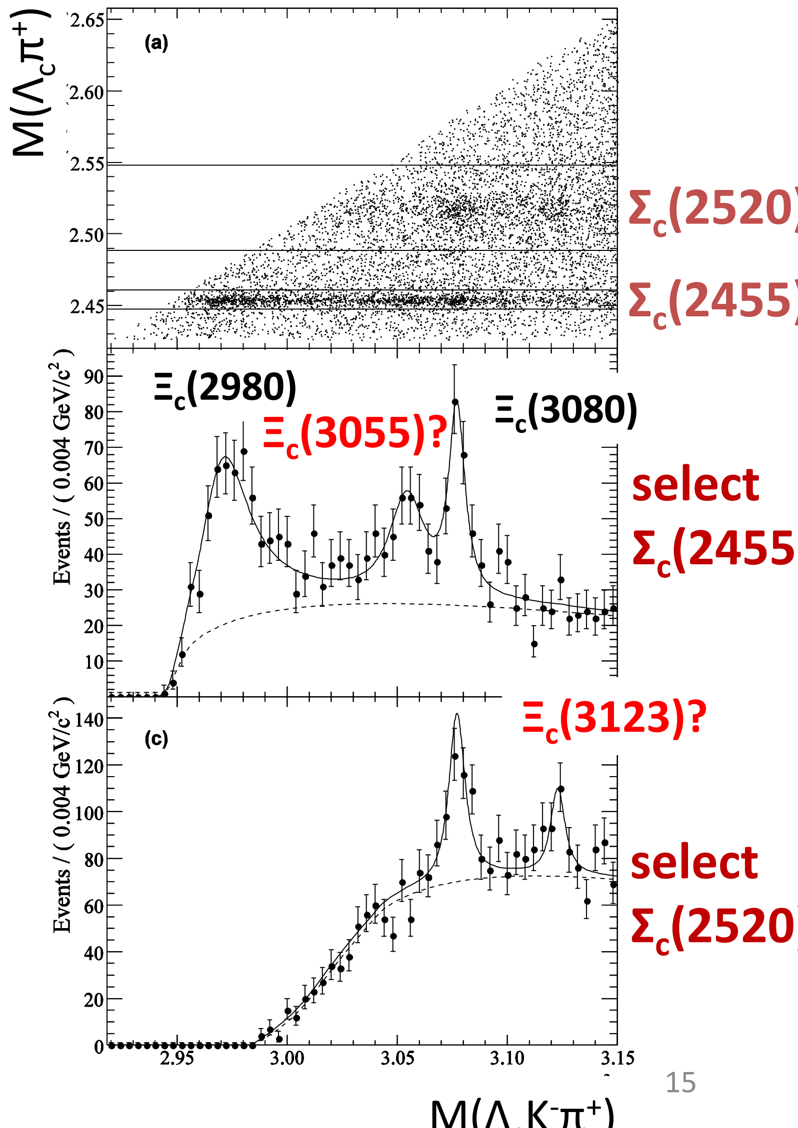


Excited Ξ_c^+ in $\Lambda_c^+K^-\pi^+$ (past results)

Phys. Rev. D 77, 012002 **Belle@461.5fb^{-1}**

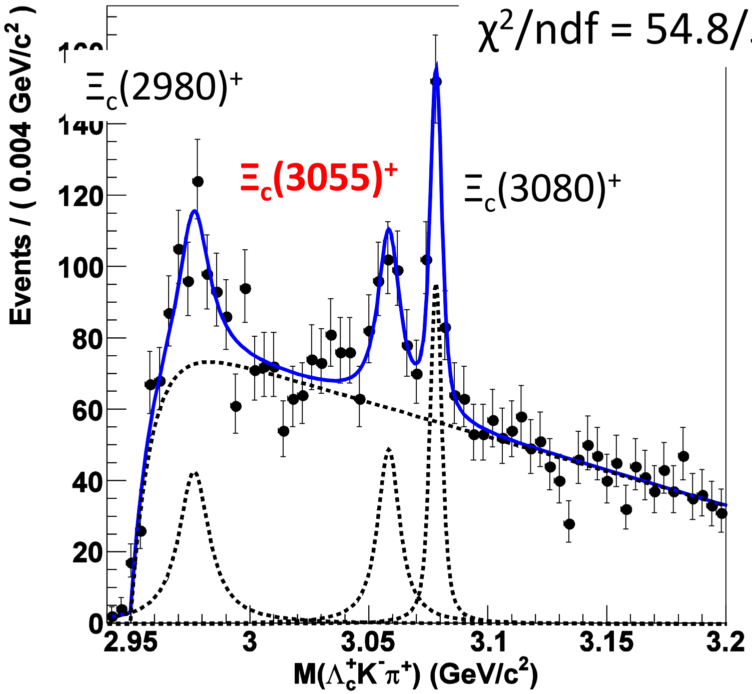


Phys. Rev. D 89, 052003 **Babar@384fb^{-1}**



- Belle: Evidence of $\Xi_c(2980)$ and $\Xi_c(3080)$
- BaBar: Confirmed them and reported another two states. $\Xi_c(3055)$→2star, $\Xi_c(3123)$→1star.

M(Σ_c(2455)$^{++}$K$^-$) by Belle



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

- Structure near 3055 MeV/c^2 is seen in addition to Ξ_c(2980), Ξ_c(3080).
- Significance of 6.6 σ.

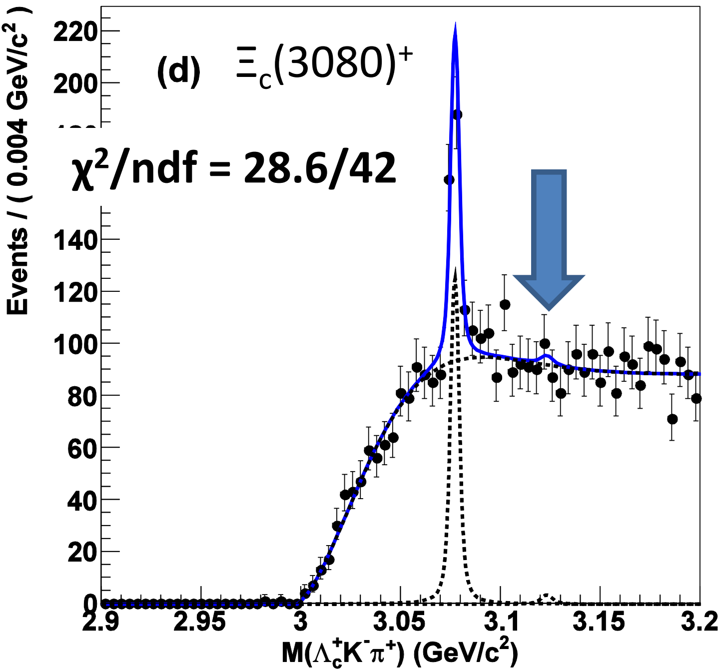
Mass/width of Ξ_c^+(3055)

	Belle	Babar
Mass (MeV/c^2)	3058.1±1.0±2.1	3054.2±1.2±0.5
Width (MeV)	9.7±3.4±3.3	17±6±1.1

Result of the BaBar is confirmed with 6.8 σ.

$M(\Sigma_c^*(2520)^{++}K^-)$ by Belle

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



- Structure near 3123 MeV/c^2 is not seen
- Signal PDF:Gaussian convoluted Breit Wigner. Mean, width was fixed from BABAR's result
- Yield = 8.2±22.0 → Measurement of upper limit

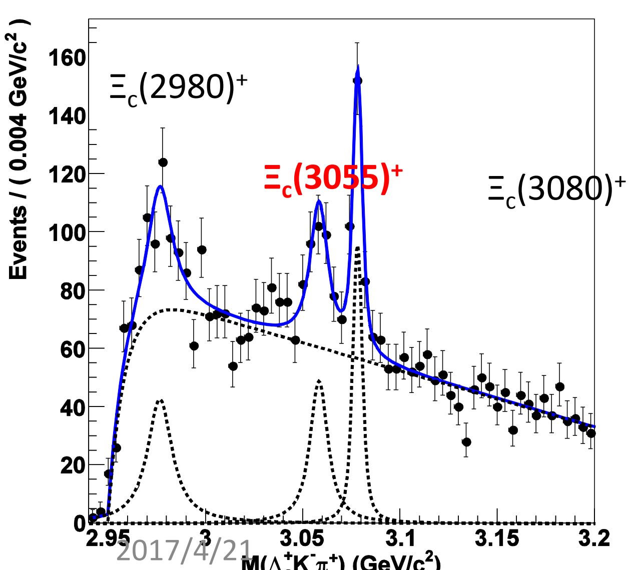
$\sigma \times Br(\Lambda_c^+ \to pK^-\pi^+)$ of $\Xi_c^+(3123)$
< 0.34 fb @95%C.L ⇔ 1.6±0.6±0.2 fb by BaBar

Result of the BaBar was not confirmed...

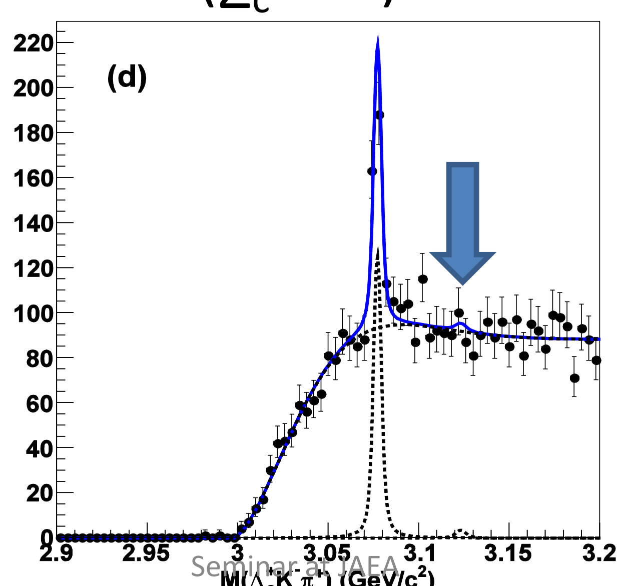
Short summary of higher excited Ξ_c

	Belle 1st	BaBar	Belle 2nd
$\Xi_c(3123)$		First Observed	Not confirmed
$\Xi_c(3080)$	First observed	Confirmed	Confirmed
$\Xi_c(3055)$		First Observed	Confirmed
$\Xi_c(2980)$	First observed	Confirmed	Confirmed

$M(\Sigma_c^{++}K^-)$



$M(\Sigma_c^{*++}K^-)$



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

$\Xi_c(3055)$ $I(J^P) = ?(?^?)$ Status: ∗∗∗

Seen in $\Sigma_c(2455)^{++}K^- \to \Lambda_c^+K^-\pi^+$ with significances of 6.4 (BABAR) and 6.6 (BELLE) standard deviations.

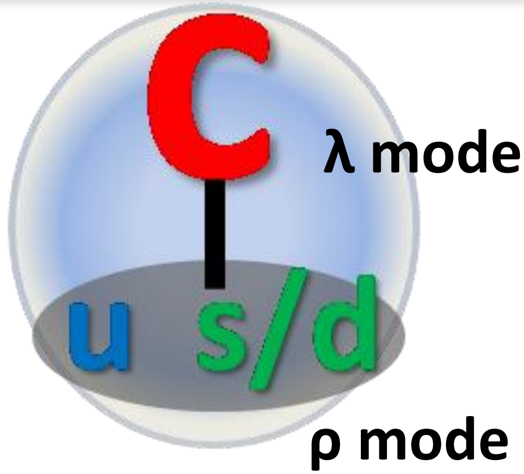
$\Xi_c(3055)$ MASSES

$\Xi_c(3055)^+$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3055.1±1.7 OUR AVERAGE	Error includes scale factor of 1.5.				
3058.1±1.0±2.1	199 ± 46	KATO	14	BELL	e^+e^- $\Upsilon(1S)$ to $\Upsilon(5S)$
3054.2±1.2±0.5	218 ± 95	AUBERT	08J	BABR	$e^+e^- \approx$ 10.58 GeV

2star→3star in Latest PDG!

Excitation mode and decay pattern



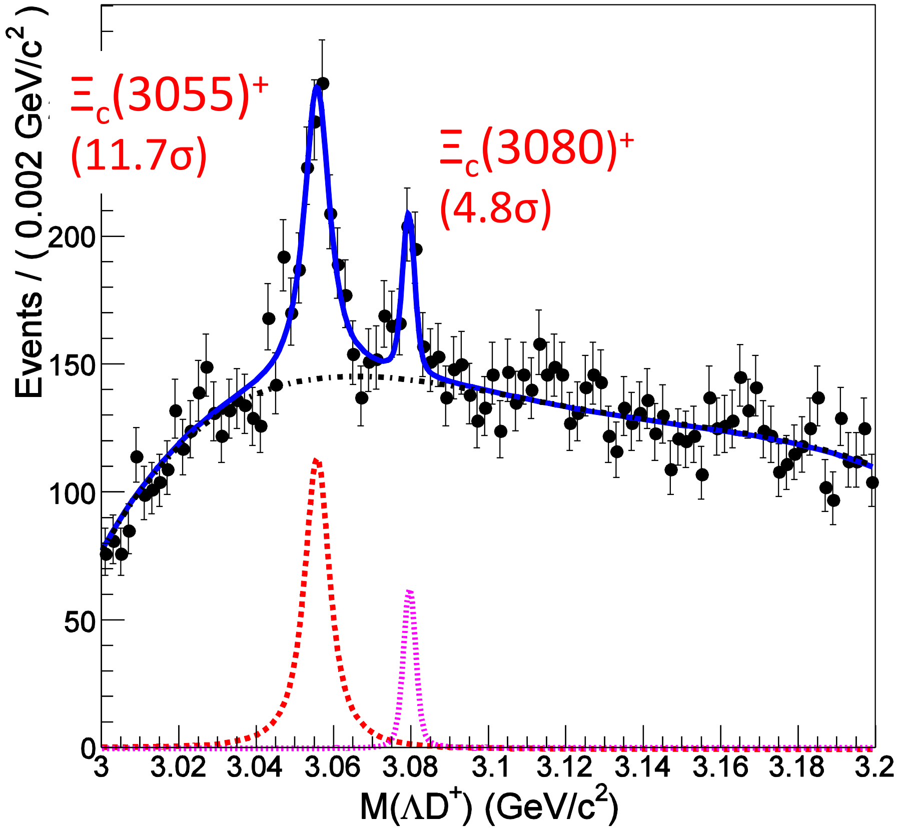
- Very naively,
  (light baryon + heavy meson) is preferred for λ mode.
  (heavy baryon + light meson) is preferred for ρ mode.

- All the Ξ_c states are studied with (heavy baryon) + (light meson)
  Λ_c^+ Σ_c Ξ_c K π
- (Light baryon) + (heavy meson) → **ΛD!**

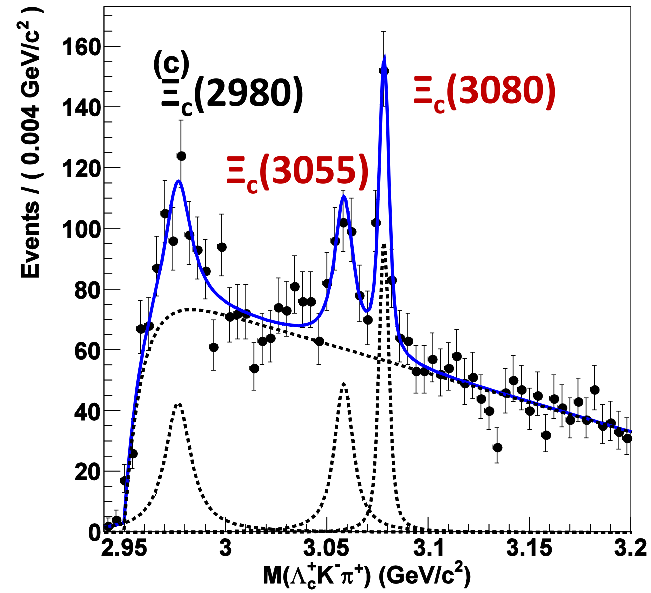
- For $\Xi_c(3055)$, neutral isospin partner is not discovered.

M(ΛD⁺) distribution

M(ΛD⁺)



M(Σc⁺⁺K⁻)



- First observation of decay of $\Xi_c(3055/3080)^+$ into ΛD^+.
- Peak hight of $\Xi_c(3055)^+$ is higher than that of $\Xi_c(3080)^+$.

Relative branching fraction measurement

Simultaneous fit to $M(\Lambda D^+)$, $M(\Sigma_c^{++}K^-)$, $M(\Sigma_c^{*++}K^-)$ with common width

- **$\Xi_c(3055)^+$**

  $Br(\Lambda D^+)/Br(\Sigma_c^{++}K^-) = 5.09 \pm 1.01 \pm 0.76$

- **$\Xi_c(3080)^+$**

  $Br(\Lambda D^+)/Br(\Sigma_c^{++}K^-) = 1.29 \pm 0.30 \pm 0.15$

  $Br(\Sigma_c^{*++}K^-)/Br(\Sigma_c^{++}K^-) = 1.07 \pm 0.27 \pm 0.04$

  - World first measurement of relative branching fraction for (light-baryon + heavy-meson)と(heavy-baryon + light-meson)

  - $Br(\Sigma_c^{*++}K^-)/Br(\Sigma_c^{++}K^-)$ has sensitivity for J^p with assuming heavy quark spin symmtery .

Comparison with chiral quark model

- Ξ_c(3055) is $^2D_{\lambda\lambda}(3/2^+)$ or $^2D_{\rho\rho}(3/2^+)$. (Phys. Rev. D 86, 034024)

Partial width (MeV)

	$\Sigma_c \bar{K}$	$\Xi_c^*(2645)\pi$	$\Xi_c'\pi$	$\Sigma_c^*\bar{K}$	$D\Lambda$	total
$\lvert\Xi_c\,^2D_{\lambda\lambda}(3/2^+)\rangle$	2.3	0.5	1.0	0.1	0.1	4.0
$\lvert\Xi_c\,^2D_{\rho\rho}(3/2^+)\rangle$	5.6	0.8	3.3	0.3	-	10.0

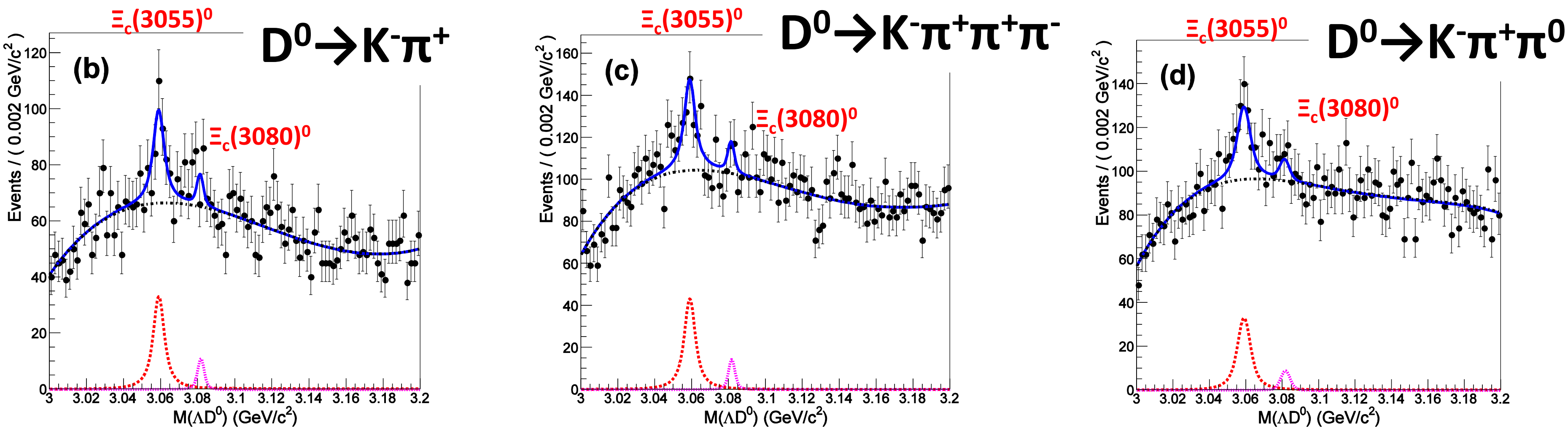
Σ_cKに比べてΛDは抑制

- Ξ_c(3080)は$^2S_{\rho\rho}$. ΛD decay is predicted to be suppressed, too.

→Both are inconsistent with our measurements.

- Good subject for theorists.

M(ΛD⁰) distribution



- Simultaneous fit to three decay modes with common mass, width and fixed relative yield.

- First observation of $\Xi_c(3055)^0$ (8.6σ)!

  1.7σ for $\Xi_c(3080)^0$

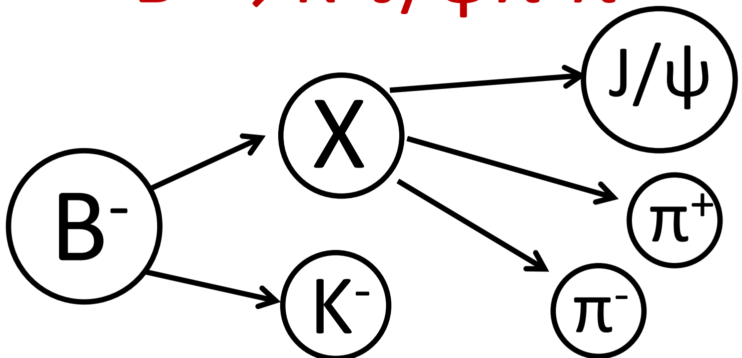
$M(\Xi_c(3055)^0) = 3059.0 \pm 0.5 \pm 0.6$ MeV/c^2
$\Gamma(\Xi_c(3055)^0) = 6.4 \pm 2.1 \pm 1.1$ MeV
$\Delta M = M(\Xi_c(3055)^+) - M(\Xi_c(3055)^0) = -3.2 \pm 0.9$ MeV/c^2

X(3872)

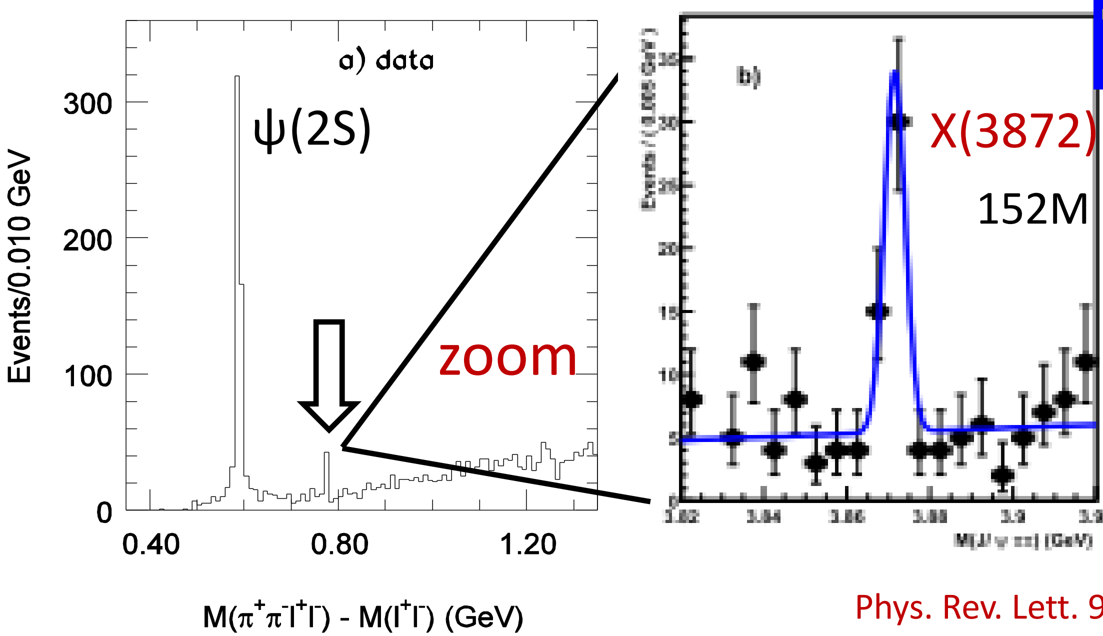
@Virginia

X(3872):First observation

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



M(ππJ/ψ)-M(J/ψ)

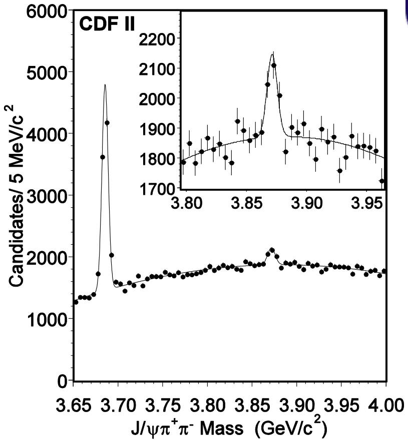


Phys. Rev. Lett. 91.262001

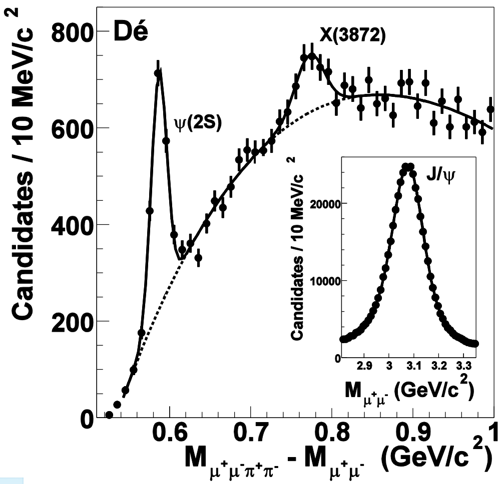
 The most cited among ~500 papers in Belle (>1200@INSPIRE)

Confirmed by many experiments

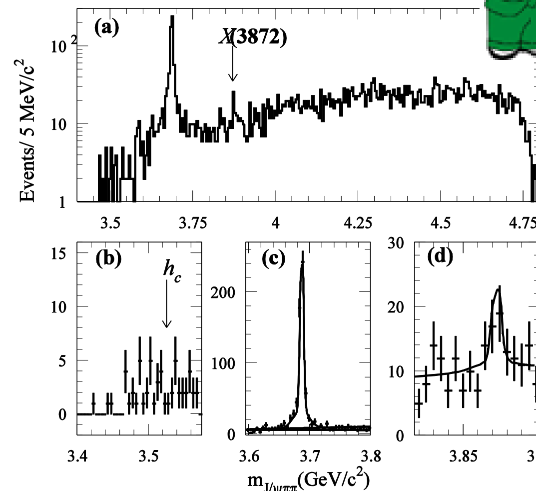
Phys.Rev.Lett.93:072001,2004



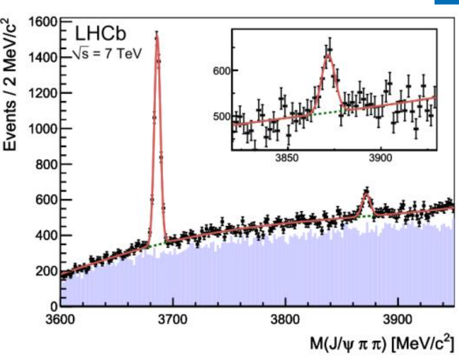
Phys. Rev. Lett. 93, 162002



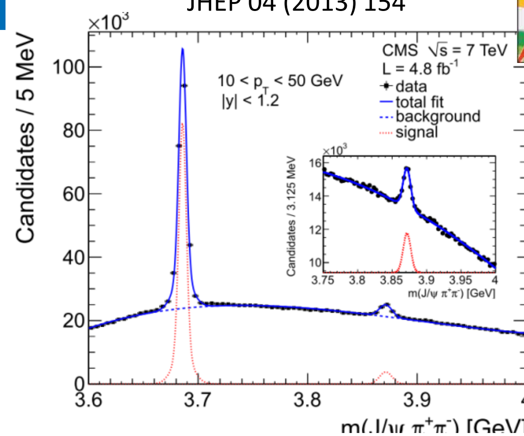
Phys.Rev.D71:071103,2005

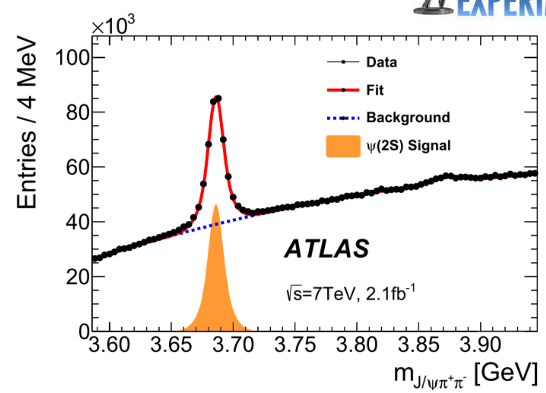


Eur. Phys. J. C. 72 (2012) 1972



JHEP 04 (2013) 154



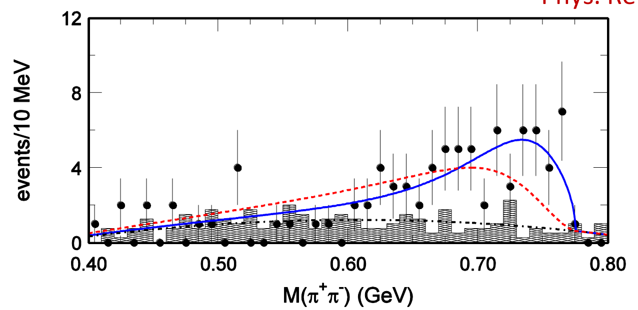


- Existence is established.
- Understanding of the property.

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.

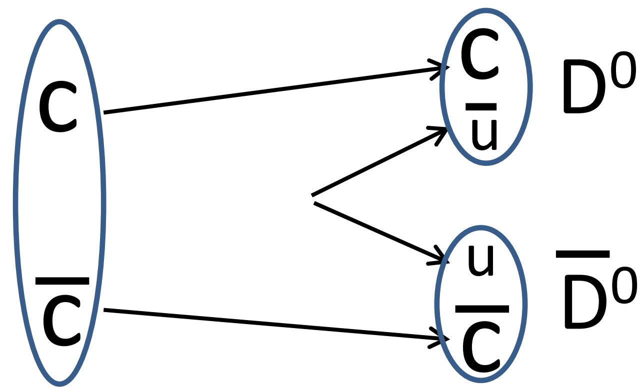
Phys. Rev. Lett. 91.262001



M(ππ)

- **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

- 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 $D^0\bar{D}^{*0}$

$3871.69 \pm 0.17\ \mathrm{MeV}/c^2 \Leftrightarrow 3871.8 \pm 0.12\ \mathrm{MeV}/c^2$

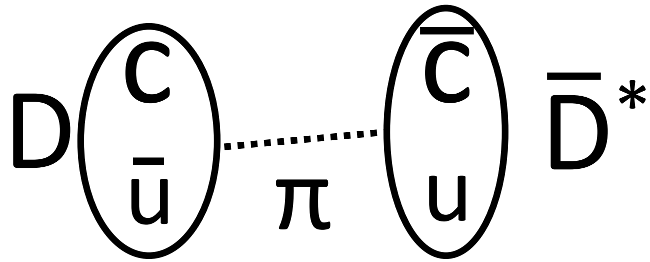
$M_{(X3872)}$ M_{DD^*}

$D\bar{D}^*$ Molecular state？(1)

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

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

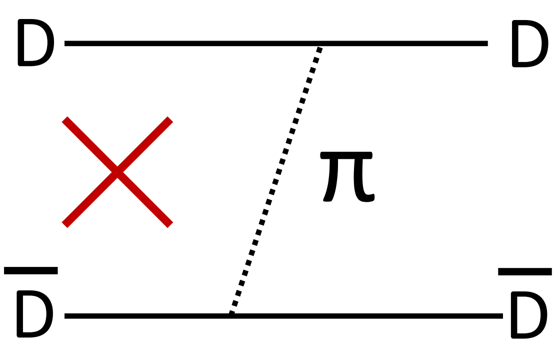
D : $J^P=0^-$



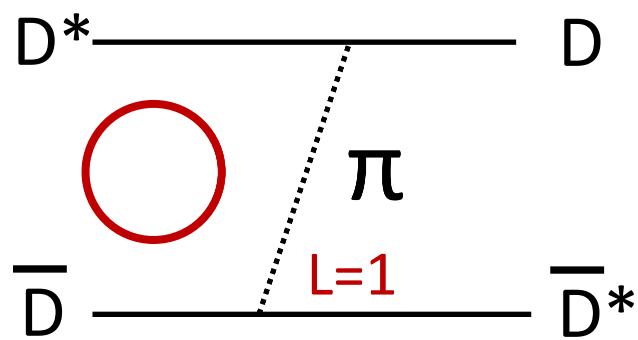
・Narrow width

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

π exchange is forbidden for DD but allowed for DD*

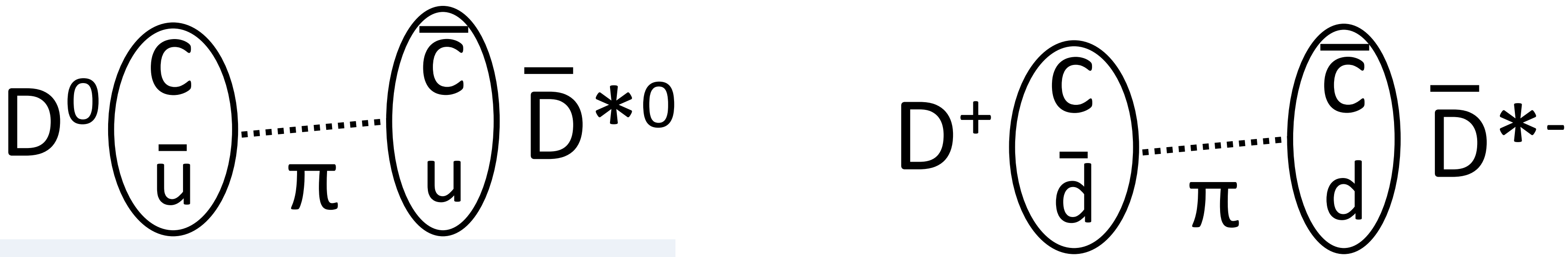


Spin-parity not conserved



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)

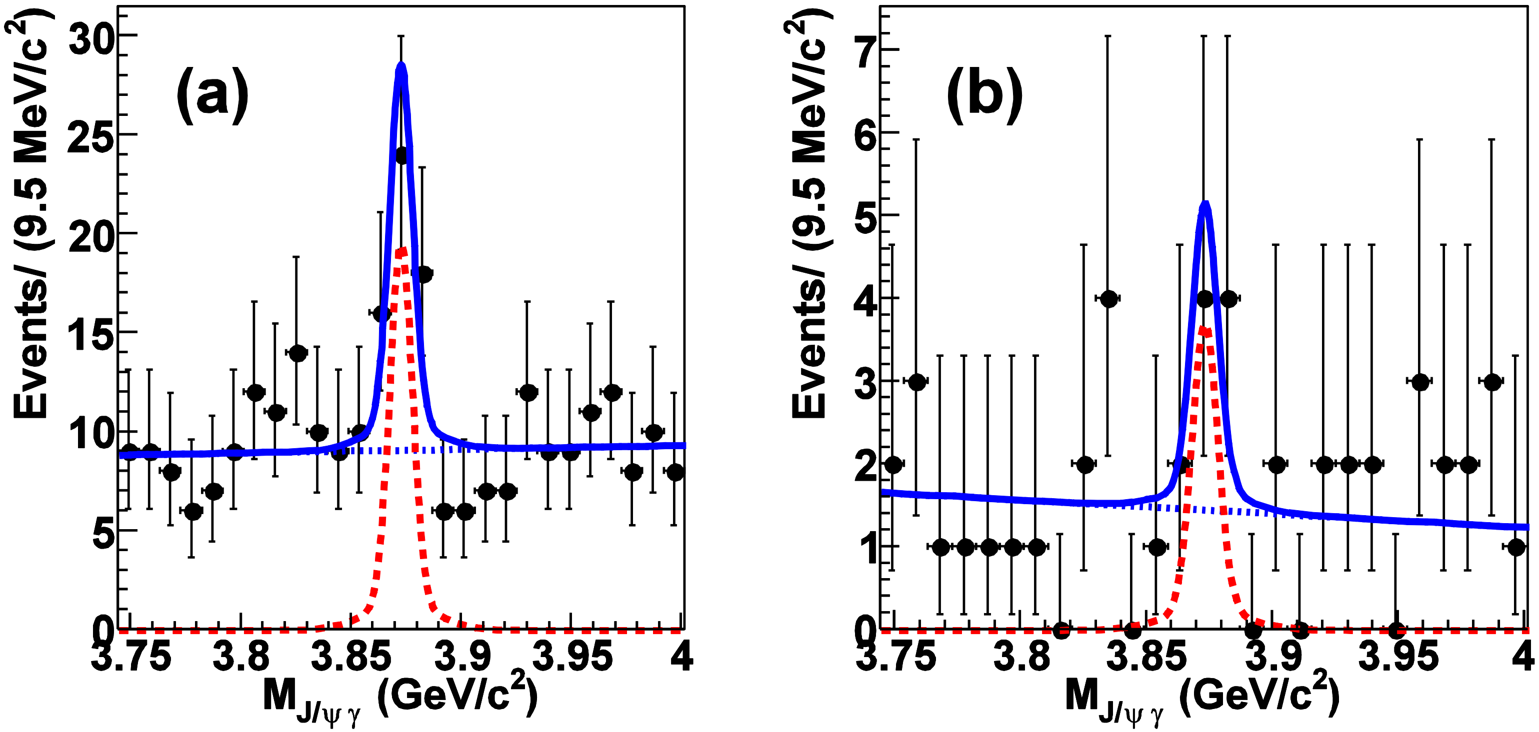
→The contribution of $D^0\bar{D}^{*0}$ becomes large and Isospin 0 and 1 are mixed.

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/ψγ

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



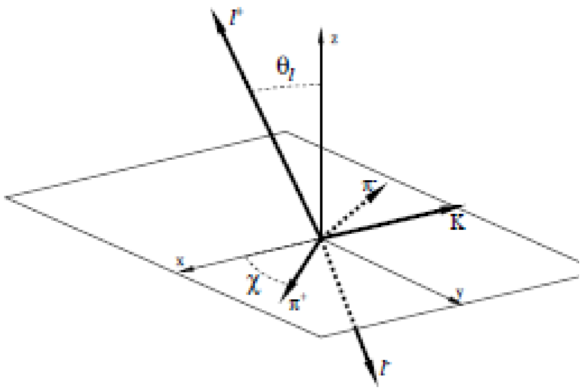
J/ψ:C=-1

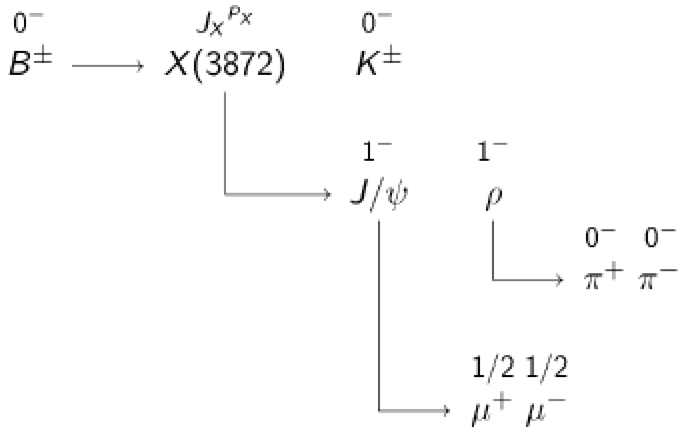
γ: C=-1

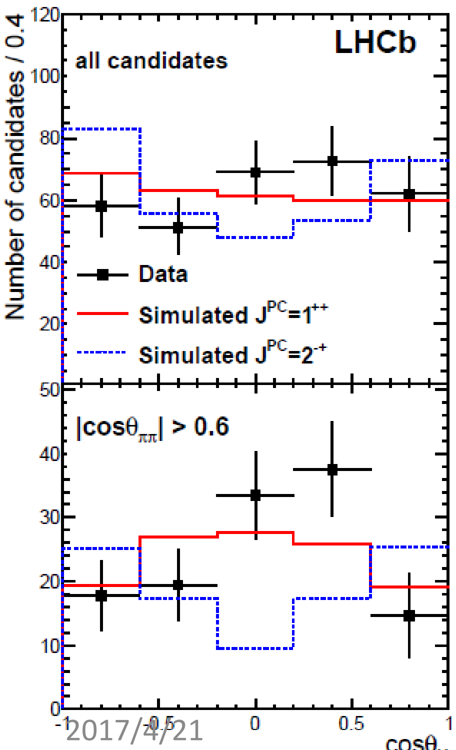
C=-1

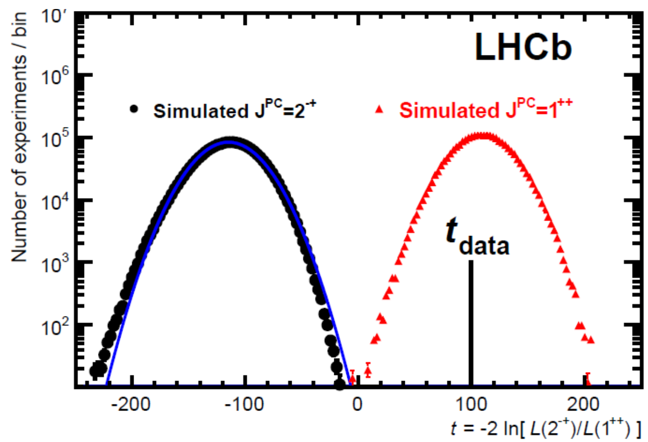
Phys.Rev.Lett. 107:9,2011

Spin-parity determination.









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

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

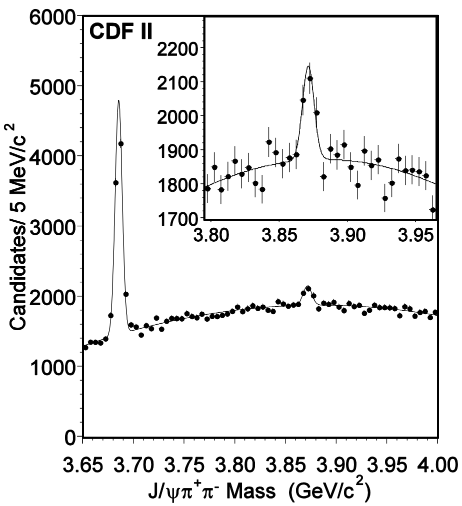
The estimated likelihood ratio for J^{PC}=2-+ and 1^{++}.
Compare with observed likelihood.

→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.

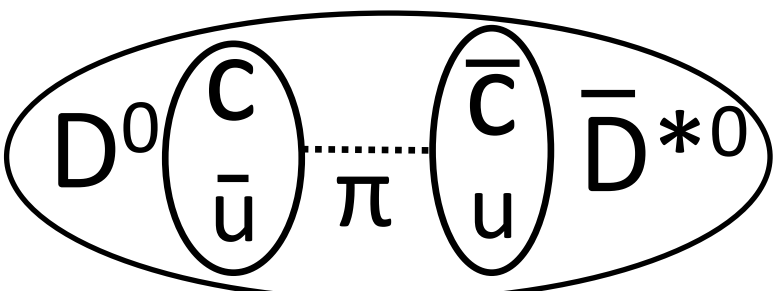
→Size is large: Radius is ~8 fm

→Easy to be broken.

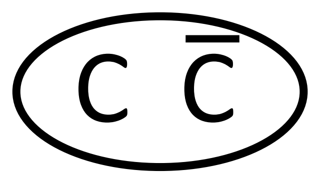
→Prompt production cross section should be small.

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

Phys.Rev.Lett.103:162001,2009



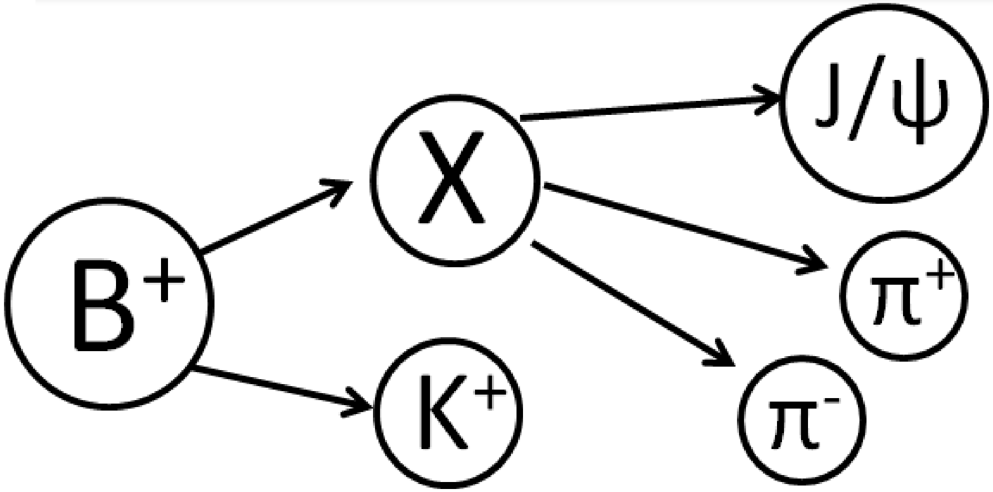
and



Hybrid?

$\chi_{c1}(2P)$

Absolute branching fraction of $B \rightarrow K^+X(3872)$ (subject I am working on)



Prediction by Quark model

$Br(B^+ \rightarrow K^+X(3872))$ =
$(2.68 \pm 0.5) \times 10^{-5}$:Pure molecule
$(0.38 \pm 0.06) \times 10^{-5}$:$c\bar{c}$
$(1.0 \pm 0.68) \times 10^{-5}$:Mixing angle 5-13°

PRB, Volume 702, Issue 5, Pages 359–363

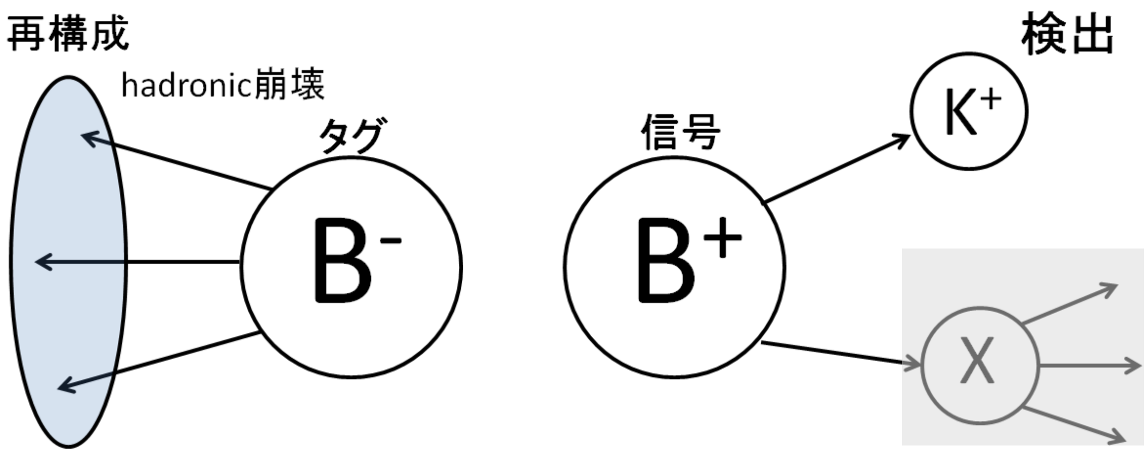
$Br(B^+ \rightarrow K^+X(3872)) \times Br(X(3872) \rightarrow J/\psi\pi^+\pi^-)$

- Only product of branching fraction is known, as X(3872) is reconstructed via invariant mass of some decay.

- Extract $Br(B^+ \rightarrow K^+X(3872))$

Analysis strategy

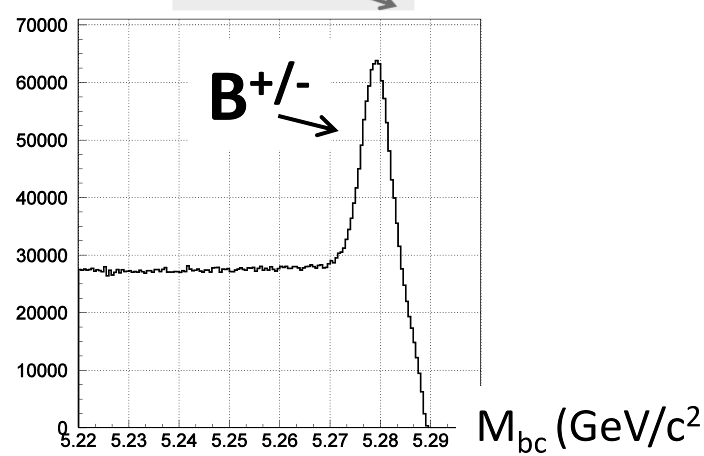
- The point is not see the decay of X(3872)
  - Fully reconstruct B-meson decaying hadronically (tag side)
  - Reconstruct K+ in the signal side
  - Reconstruct X via missing mass: $M_x^2 = (P_{beam} - P_{BTag} - P_{K+})^2$
  - Unique measurement in the B-factory (impossible in LHCb)



- Btag from Beam-energy constrained mass:

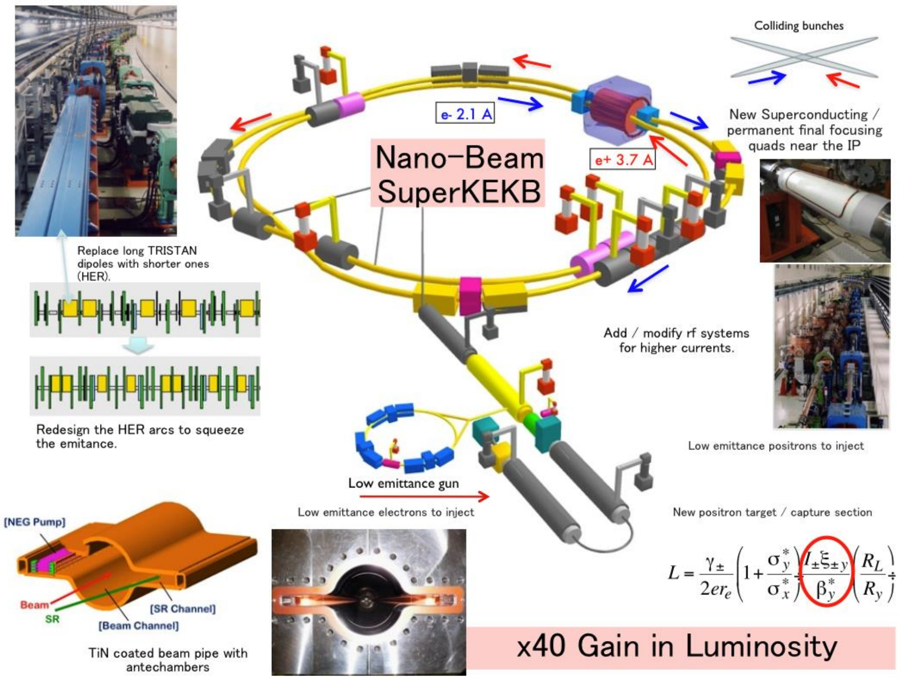
$M_{bc}^2 = E_{beam}^2 - p_B^2$

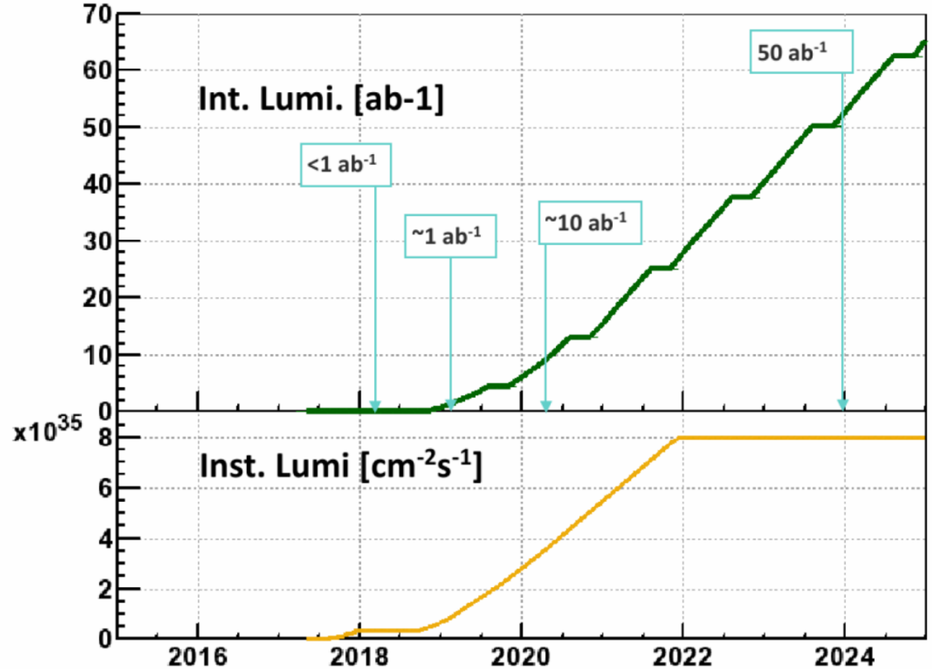
- Totally 1104 decay chains are used.
  BG seperation by neural net based method.
- The reconstruction is ~0.3% (possible with high stat).



Belle→Belle II

Aim to find physics beyond the Standard Model





$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

40 times peak luminosity.

50 times integrated luminosity.

Hadron physics with Belle II

- Spin-parity determination for all the existing charmed baryons.

- New charmed baryons,
  Precise measurement of charmed baryon decays including very small fraction.

- New decay modes for XYZ to study production mechanism.

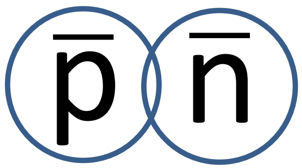
In addition...

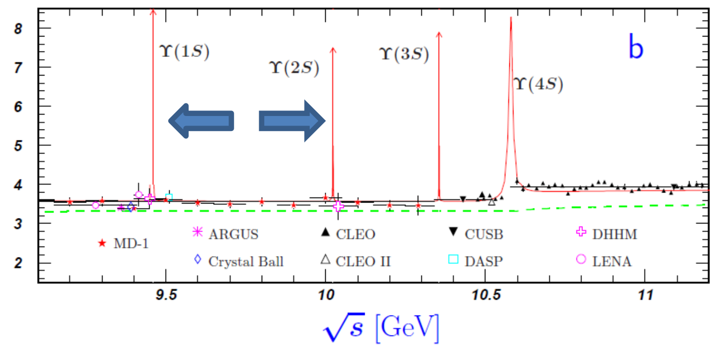
Discoveries of hadrons at (pre)B-factories

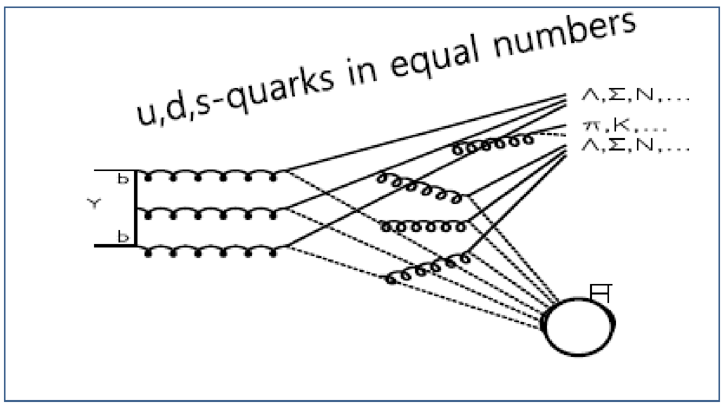
CLEO	→	Belle, BaBar	→	**Belle II**
~10 fb^{-1}		~ 1000 fb^{-1}		**~50000 fb^{-1}**
Excited charm meson/baryons		XYZ Many excited states		**!?**

Di-baryon search@Y(1-2S)

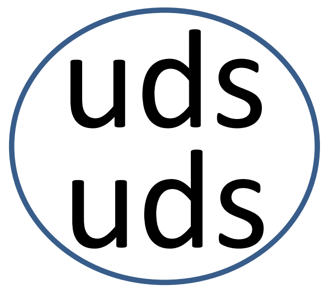
Y(1S), Y(2S) decays into anti-deuteron (Br=3 × 10^{-5})







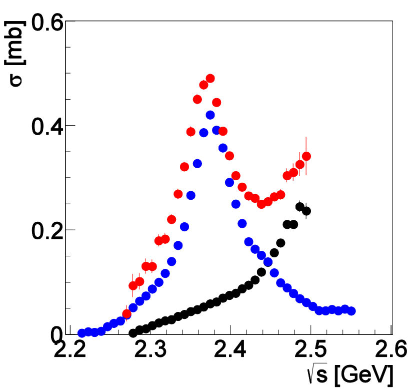
Y(1S)/(2S) decays into 3 gluons by 80%.
The same fraction for u,d,s.

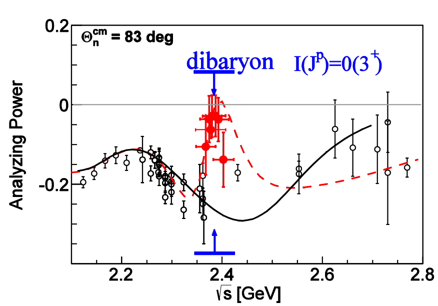


H-dibaryon

Not found in Belle

PhysRevLett.110.222002





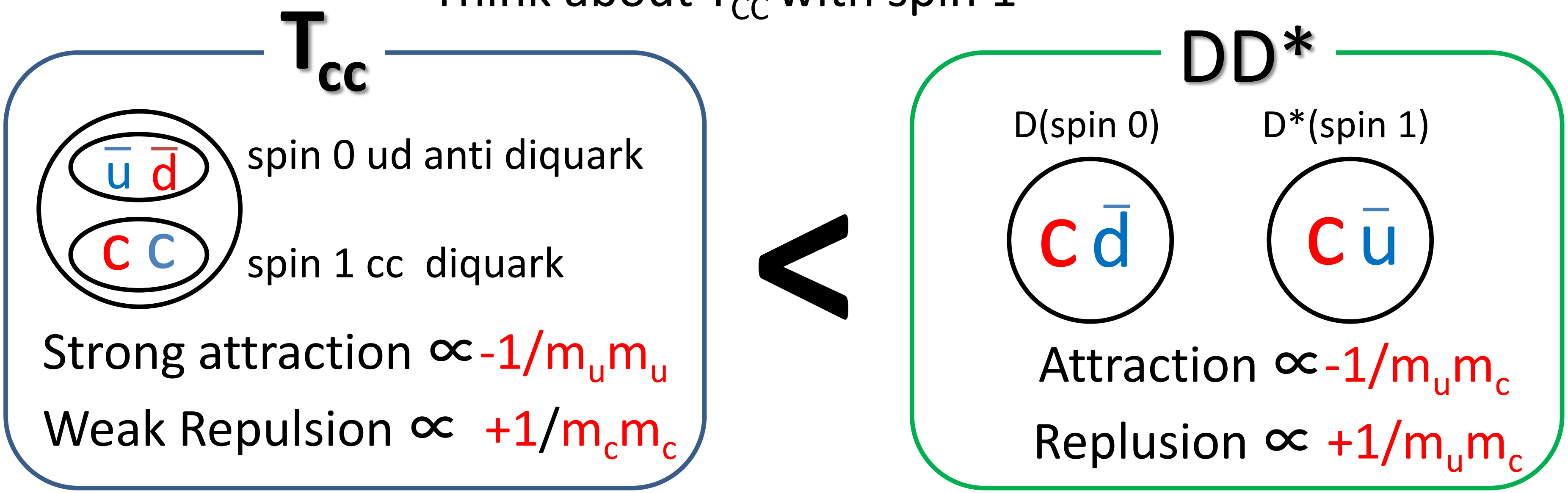
Phys. Rev. Lett. **112**, 202301

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

Doubly charmed meson (T_{cc})

The same c-flavor. Need 4 quarks.

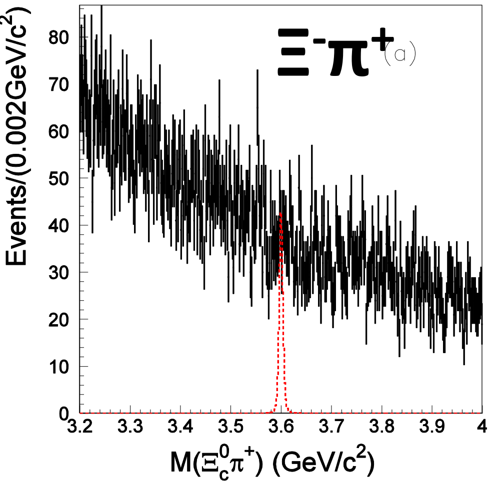
Think about T_{CC} with spin 1

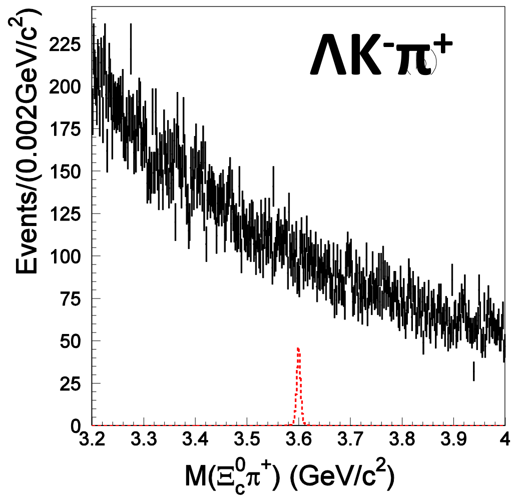


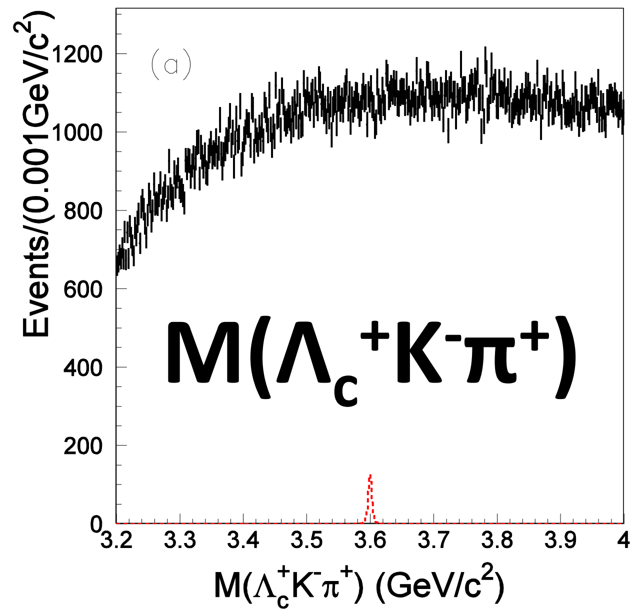
The di-quark configuration is energetically favored.

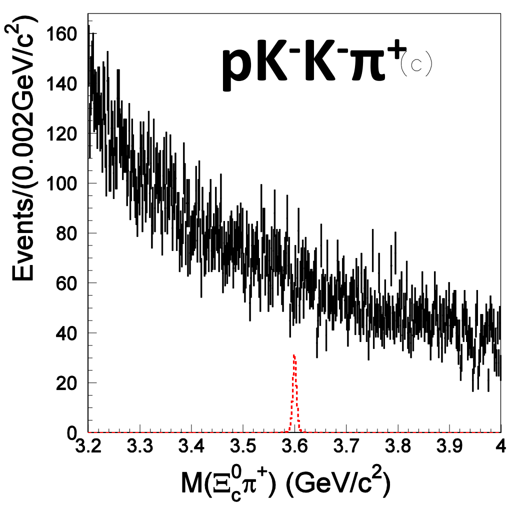
Bound T_{cc} is a good probe to study the di-quark.

Doubly charmed baryon







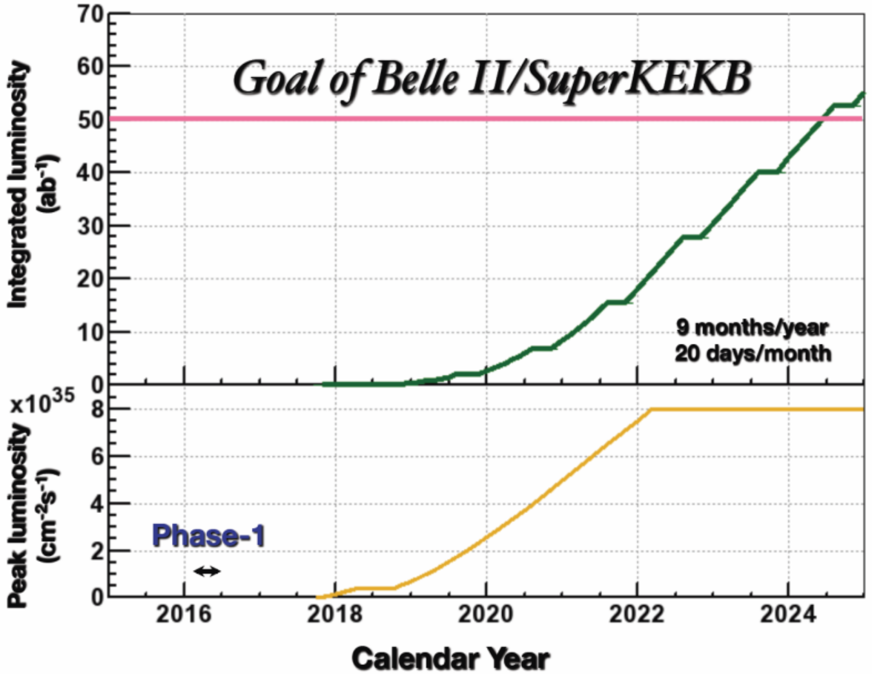


$M(\Xi_c^0\pi^+)$

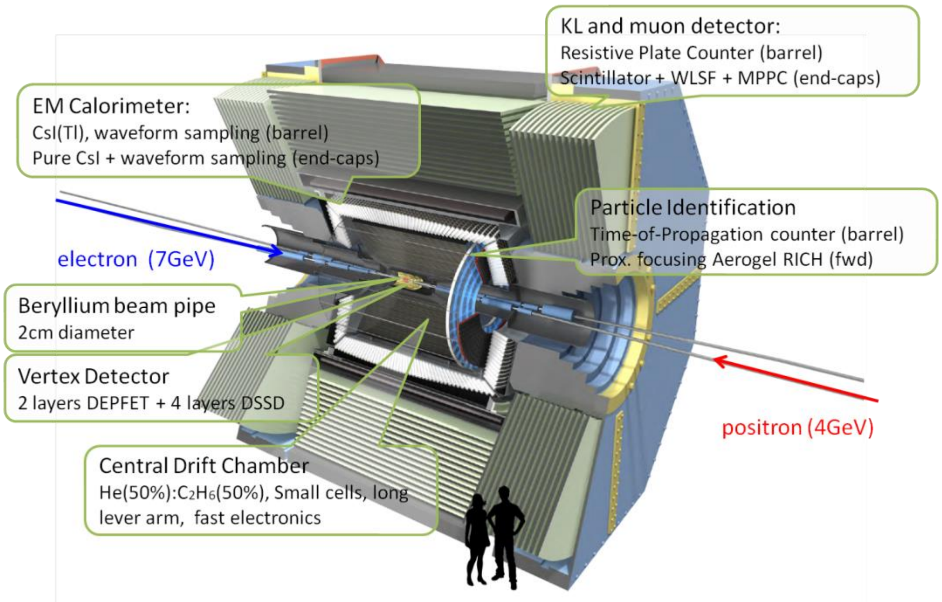
- No doubly charmed baryon (Ξ_{cc}) is discovered so far.
- Good subject at Belle II (if not discovered at LHCb).

Belle → Belle II from computing point

KEKB→SuperKEKB



Belle → Belle II



- ~40 times luminosity (8×10^{35} cm^{-2}s^{-1})
- ~50 times integrated luminosity (50 ab^{-1})

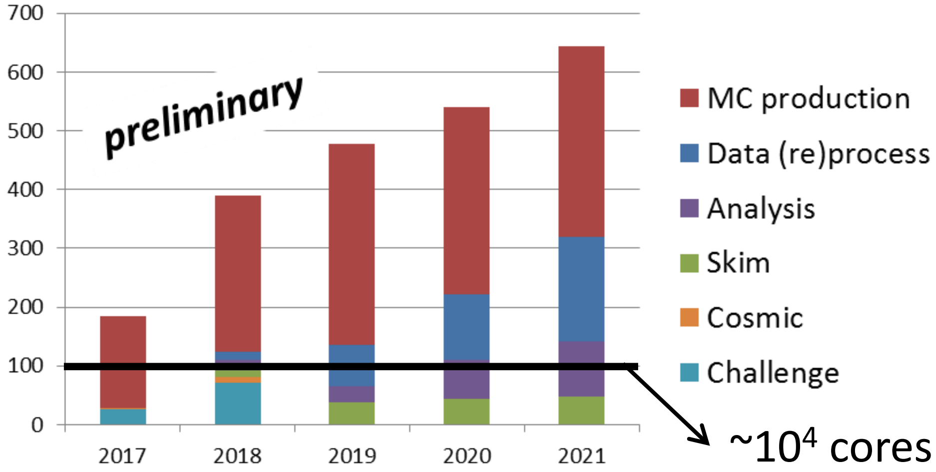
- Fine segmentation.
- Waveform sampling.

Huge data sample
for large collaboration → **Huge computing resource**

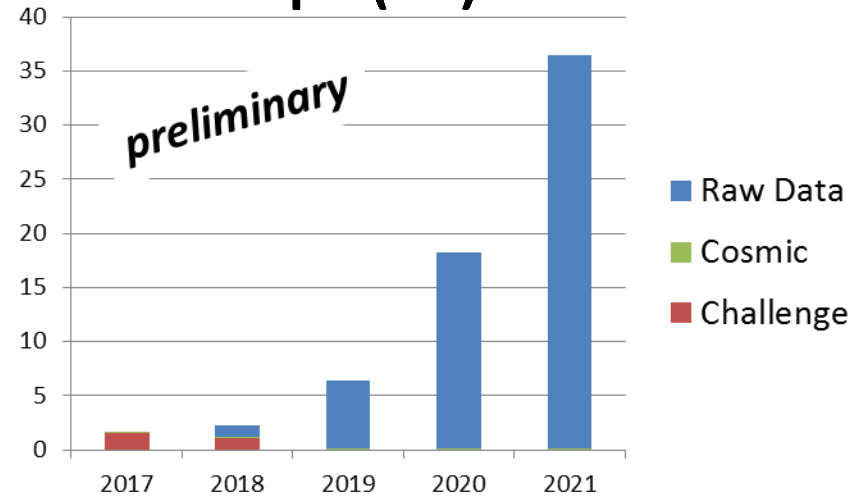
Computing resource for Belle II

CPU (kHEPSpec)

**1core~=10 HepSpec



Tape (PB)

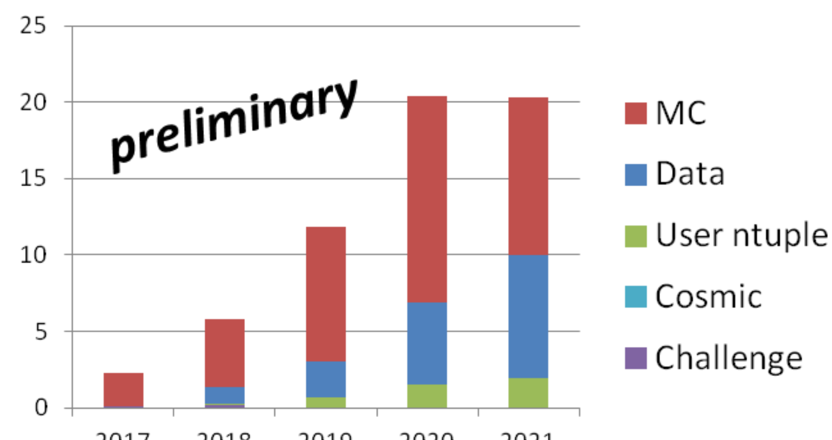


- Estimation until 2021 (~20 ab^{-1}).

- At the end of data taking (50 ab^{-1}), more than
  - 100000 core CPU
  - 100 PB storage

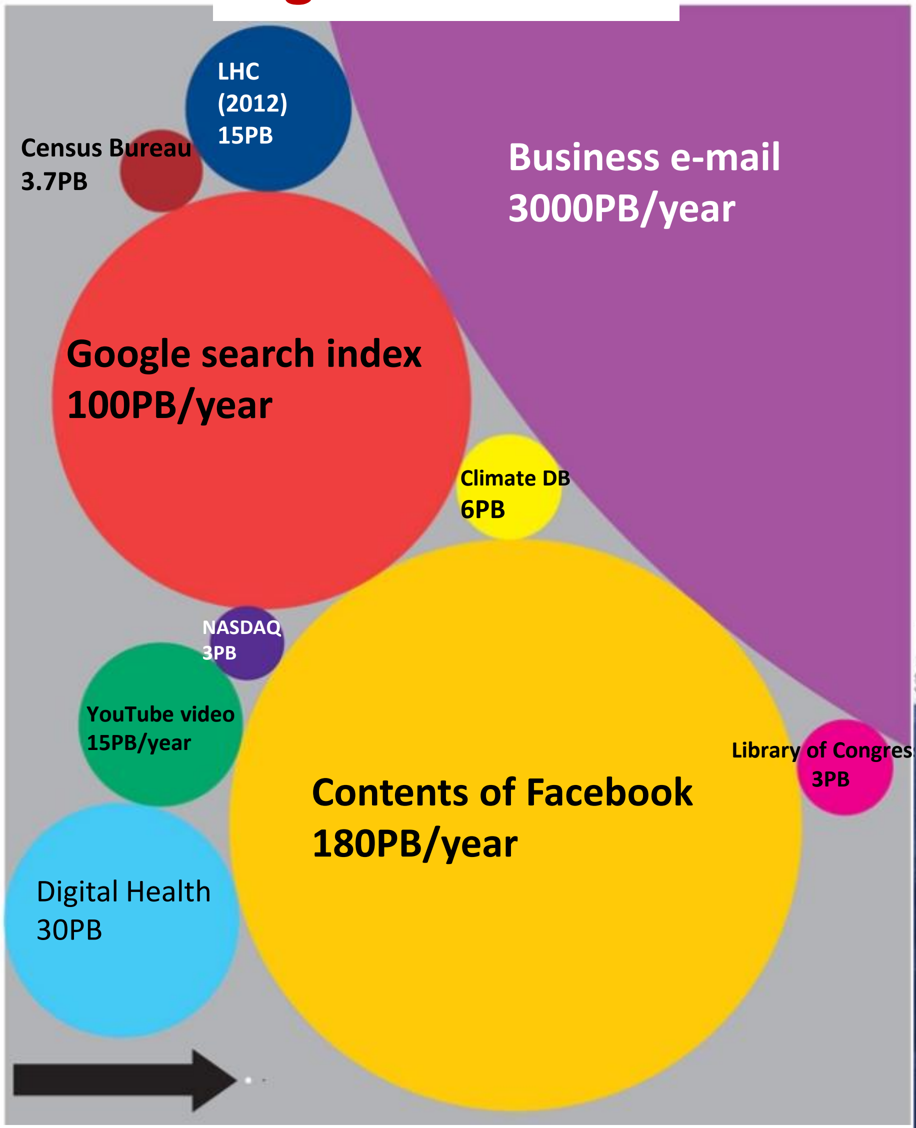
  are expected to be needed to store and analyze data in a timely manner.

Disk (PB)



More than 100 PB?

Big data in 2012



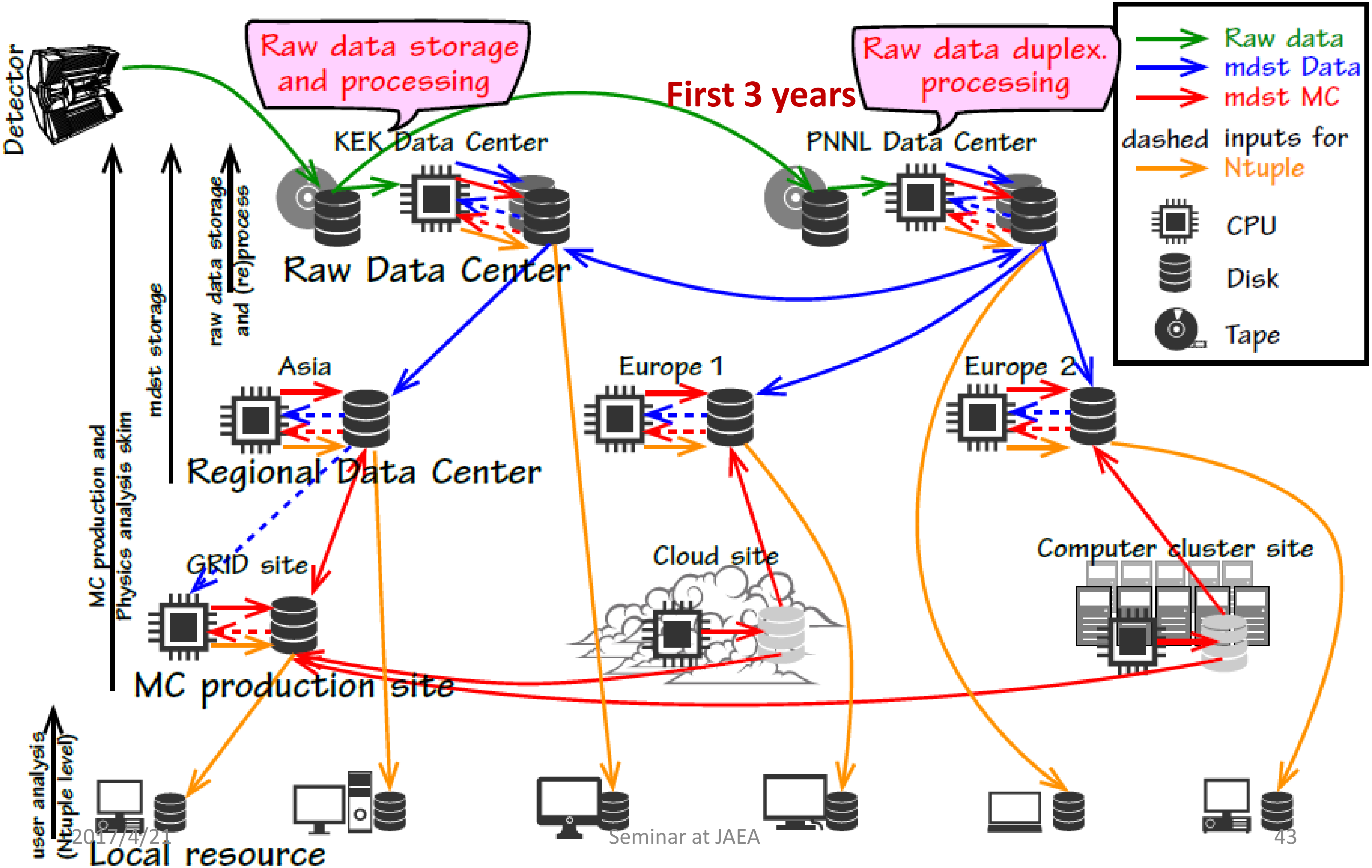
https://www.wired.com/2013/04/bigdata

- Similar to Google search index or Contents uploaded to Facebook (per year).
- Impossible to be hosted by a single institute.

→ **Distributed computing**

Each institute prepare the resources.
Connect by network.

Belle II computing model



Belle II computing system

What we need is..

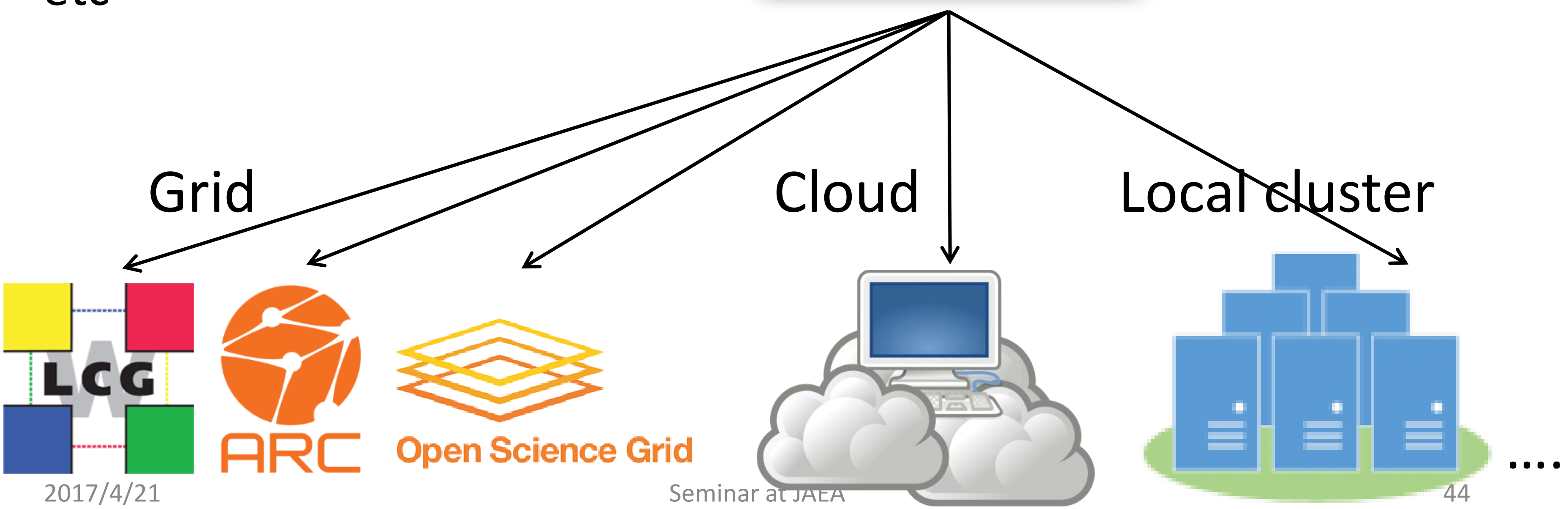
Extension to meet experimental requirements

- Automation of MC production, raw data processing

→ Production system

- User interface.
- Analysis framework
- etc

BelleDIRAC



Production system

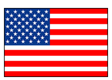
Definition

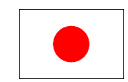
- **MC prod / data process**
- **Type (BB, ττ, ccbar..)**
- **# of events**
- **software version**
- **etc..**

PS

-Production
-Distribution
-Merge

Production manager (human)
- Define "Production"





Belle DIRAC

Distributed data management system

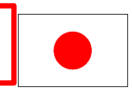
- Gather outputs to major storage (and distribute over the world)
- Check status of storages
- Define "Transfers"

Fabrication system

- Define jobs
- Re-define failed job
- Verify output files

output info

Monitor

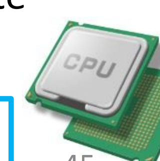


DIRAC

DIRAC Transfer management

DIRAC Job management

Submit job on site



Resource

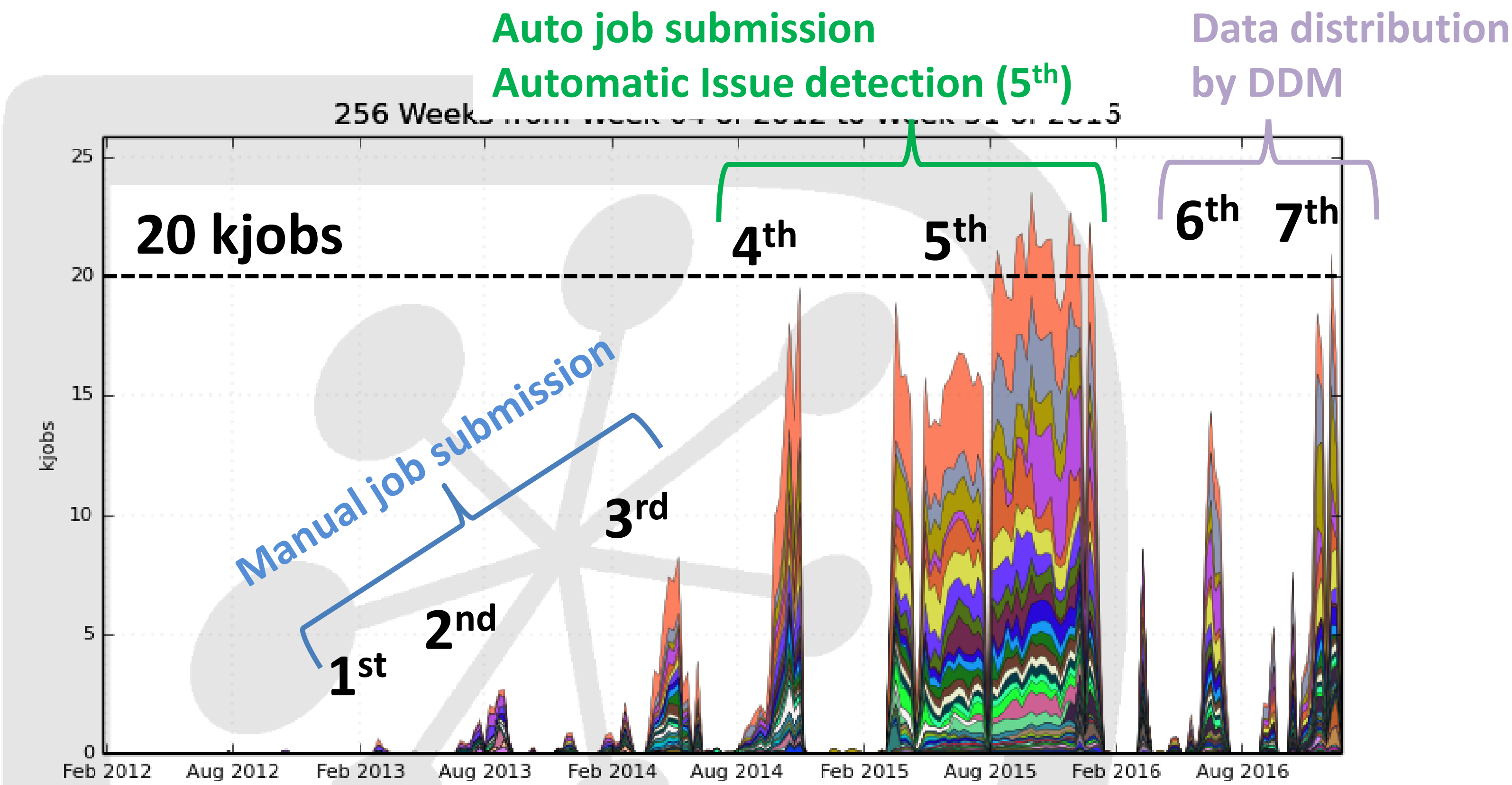
Destination storage

Temporary storage

Computing site

MC production campaigns

- Test the validity of the computing model/system.
- Provide simulation samples for the sensitivity study.



- ~50 computing sites join in the latest campaign.
- More than 20k jobs can be handled now.
- Gradually automating the production procedure.
- Belle II colleagues take computing shifts from 4th campaign as an official service task.

Nagoya contributions

Significant contribution from Nagoya

- **Resource**

Belle II dedicated resource in KMI

- ~500 (+α) CPU cores.
- 250 TB storage (destination storage).
- Grid middleware (EMI 3) installed.
- DIRAC slave.
- Operation by physicists
  → Learned a lot on operation of a computing site.

- **Development of monitoring system**
  - To maximize the availability of resources
  - Automatic detection of the problematic sites
  - Operation and development of the shift manual

Summary

- Belle is the one of the hottest places for the hadron spectroscopy.
- Many results from charmed baryons.
- X(3872) is extensively studied.
- Belle II will start physics run in 2018.
- Distributed computing is adopted at Belle II in order to handle data size of O(100 PB).

Stay tuned for exciting results from Belle and Belle II.