Recent exotic results at BESIII and Belle, and Belle II status and plans

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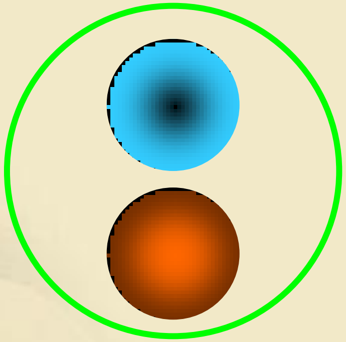
YITP, Koyto 2016.12.01

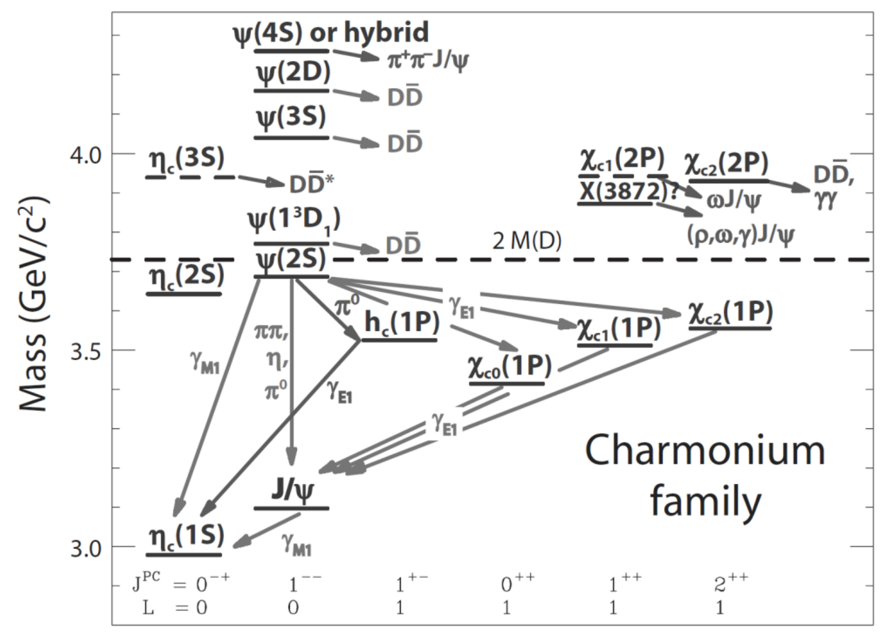
There are four interactions!

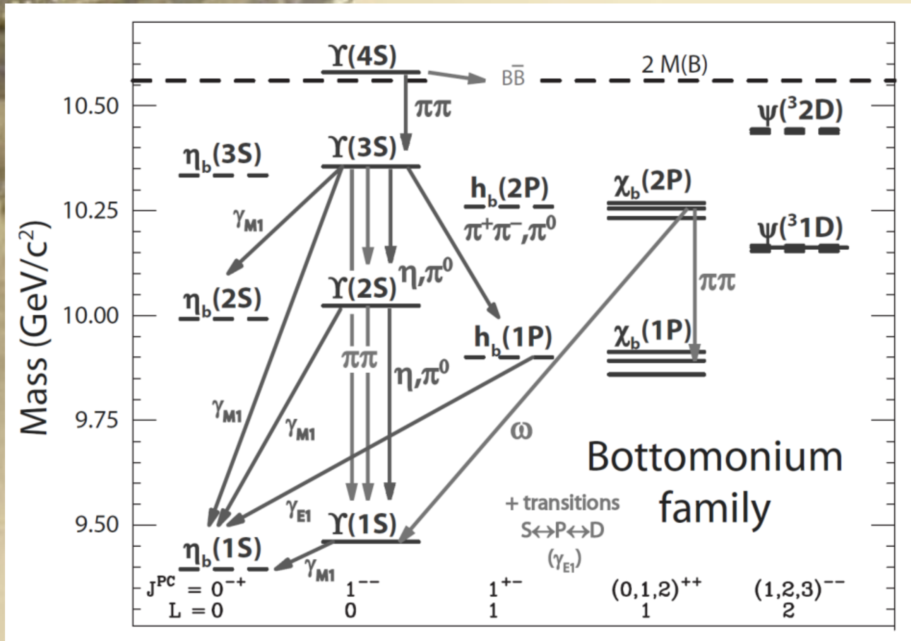
- It all started with the big bang! ➔ Gravity governed by General Relativity (it was good!)
- Let there be light: and there was light! ➔ Electromagnetic and weak interactions governed by Electroweak theory (it was good!)
- Let there be quarks and gluons! ➔ strong interaction governed by QCD (it was good at short distance only!)
- Yes, let's study the strong interaction at long distance — non-perturbative part of QCD!

The heavy quarkonium system

- At short distance
  Cornell model works pretty well
  $V(r) = -4\alpha_s/3r+kr$





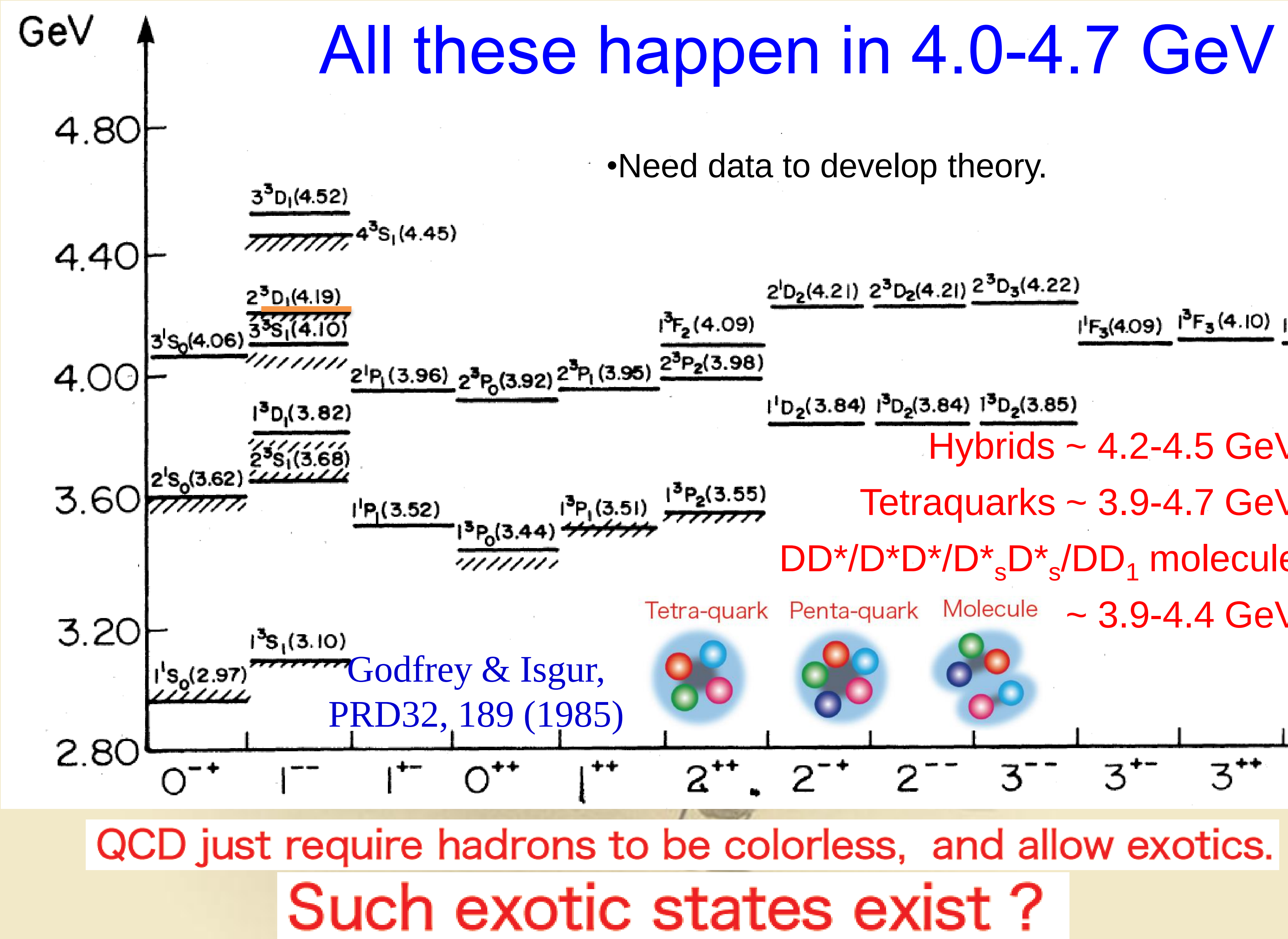


The quarkonium system

- When distance becomes larger
  - Theory 1: let there be screened potential
  - Theory 2: let there be hybrids with excited gluons
  - Theory 3: let there be tetraquark states
  - Theory 4: let there be meson molecules
  - Theory 5: let there be cusps
  - Theory 6: let there be final state interaction
  - Theory 7: let there be coupled-channel effect
  - Theory 8: let there be mixing
  - Theory 9: let there be mixture of all these effects
  - Theories …

"The absence of exotics is one of the most obvious features of QCD" – R. L. Jaffe, 2005

"The story of pentaquark shows how poorly we understand QCD" – F. Wilczek, 2005

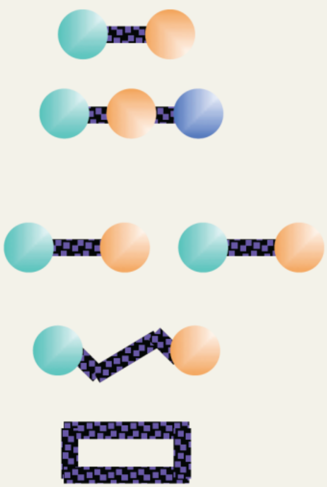


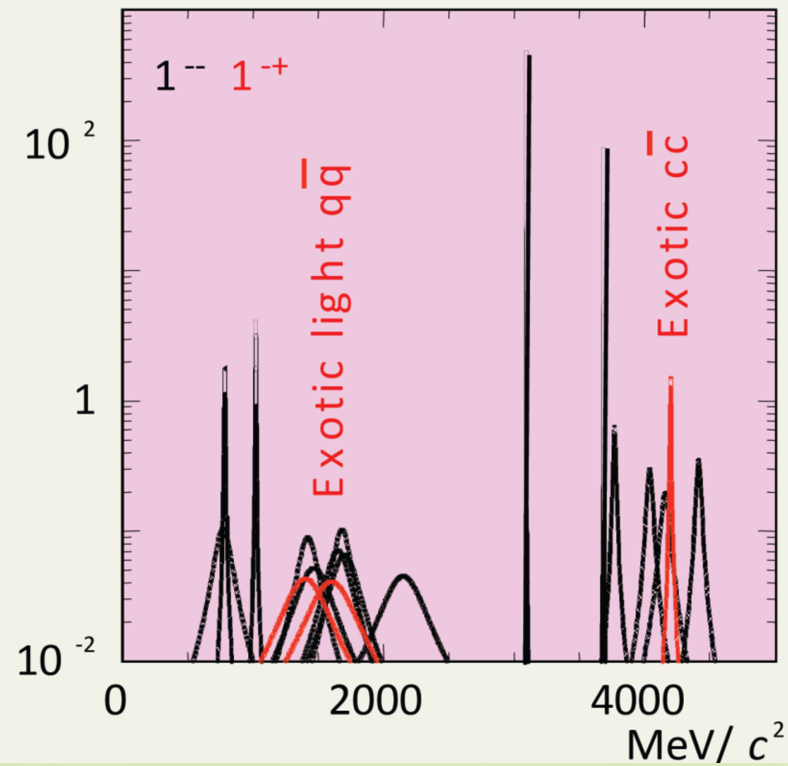
All these happen in 4.0-4.7 GeV
•Need data to develop theory.
GeV
4.80
4.40
4.00
3.60
3.20
2.80
3³D₁(4.52)
4³S₁(4.45)
2³D₁(4.19)
3³S₁(4.10)
3¹S₀(4.06)
1³D₁(3.82)
2³S₁(3.68)
2¹S₀(3.62)
1³S₁(3.10)
1¹S₀(2.97)
2¹P₁(3.96)
2³P₀(3.92)
2³P₁(3.95)
1³F₂(4.09)
2³P₂(3.98)
1¹P₁(3.52)
1³P₀(3.44)
1³P₁(3.51)
1³P₂(3.55)
2¹D₂(4.21)
2³D₂(4.21)
2³D₃(4.22)
1¹D₂(3.84)
1³D₂(3.84)
1³D₃(3.85)
1¹F₃(4.09)
1³F₃(4.10)
0⁻⁺
1⁻⁻
1⁺⁻
0⁺⁺
1⁺⁺
2⁺⁺
2⁻⁺
2⁻⁻
3⁻⁻
3⁺⁻
3⁺⁺
Hybrids ~ 4.2-4.5 GeV
Tetraquarks ~ 3.9-4.7 GeV
DD*/D*D*/D*sD*s/DD1 molecule
~ 3.9-4.4 GeV
Tetra-quark
Penta-quark
Molecule
Godfrey & Isgur,
PRD32, 189 (1985)
QCD just require hadrons to be colorless, and allow exotics.
Such exotic states exist ?

Exotic hadrons

The identification of exotic states is an important key to understand hadron spectrum and the process of mass generation.

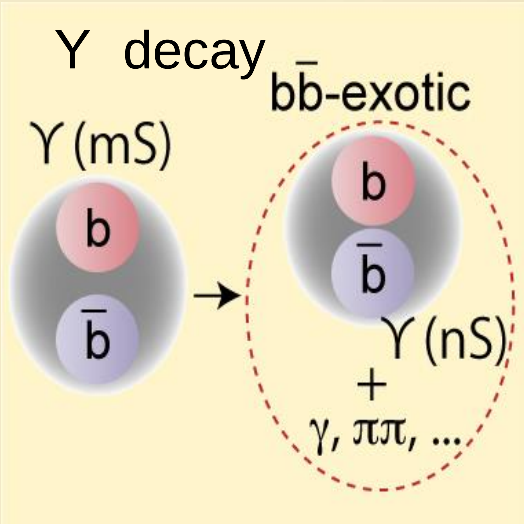
Mesons	$q\bar{q}$	
Baryons	qqq	
Multiquarks	$(q\bar{q})(q\bar{q})$	
Hybrids	$(q\bar{q})\,g$	
Glueballs	gg	

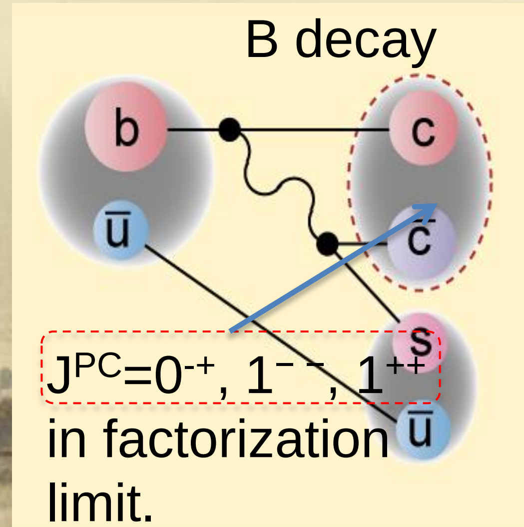


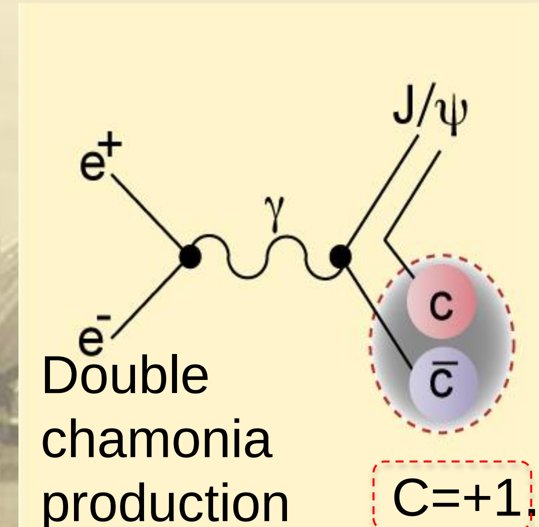


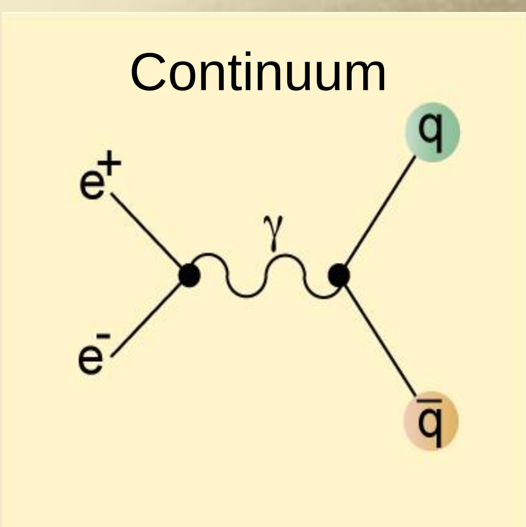
•In the light meson energy range exotic states overlap with conventional states; in the charmonium states the density is lower and also the overlap.

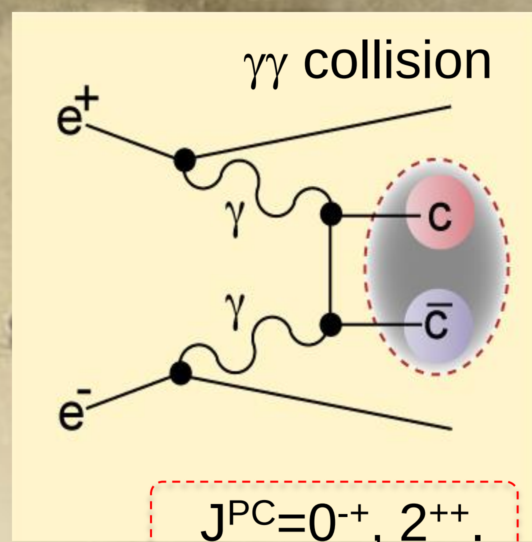
Variety of recorded reactions

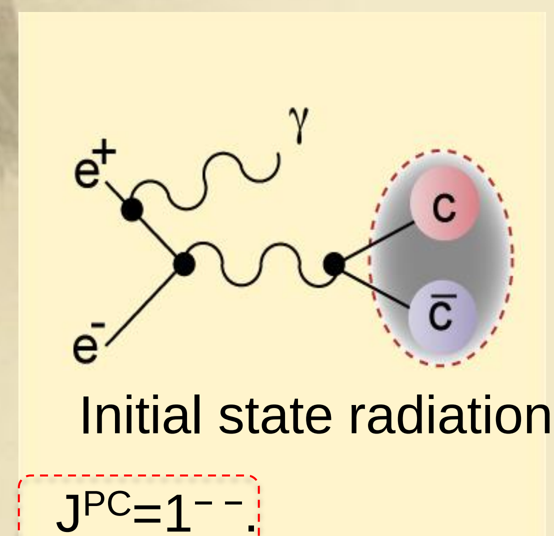






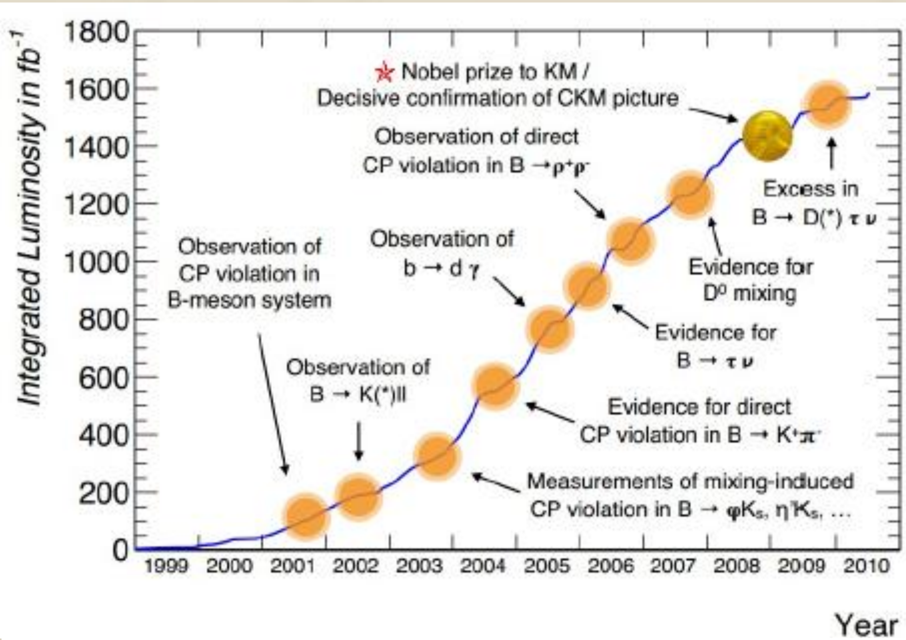


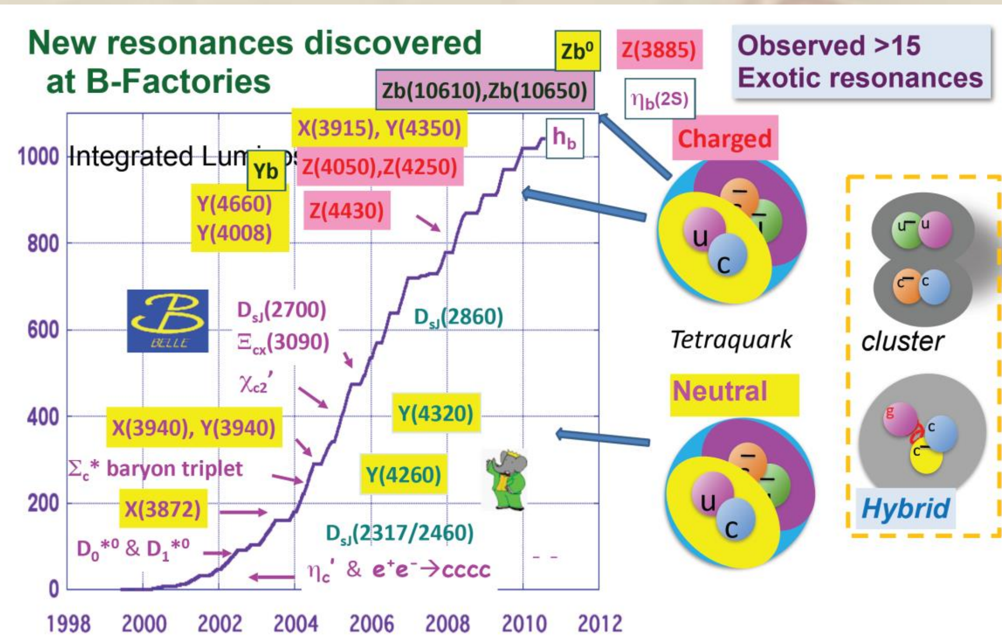




Thanks B-factories !

- **Discovery of X(3872) and other many XYZ states etc.**
- **Unexpected bonus of the B-factories**





- BaBar: PEP-II e^+e^- collider, SLAC, USA, 1999–2008.
- Belle: KEKB e^+e^- collider, KEK, Tsukuba, Japan, 1999–2010.
- Combined BaBar and Belle luminosity is ~1.5 ab^{-1} ($1.25 * 10^9$ $B\bar{B}$ pairs).
- Main focus: *CP*-violation (published in 2001)

All the XYZ

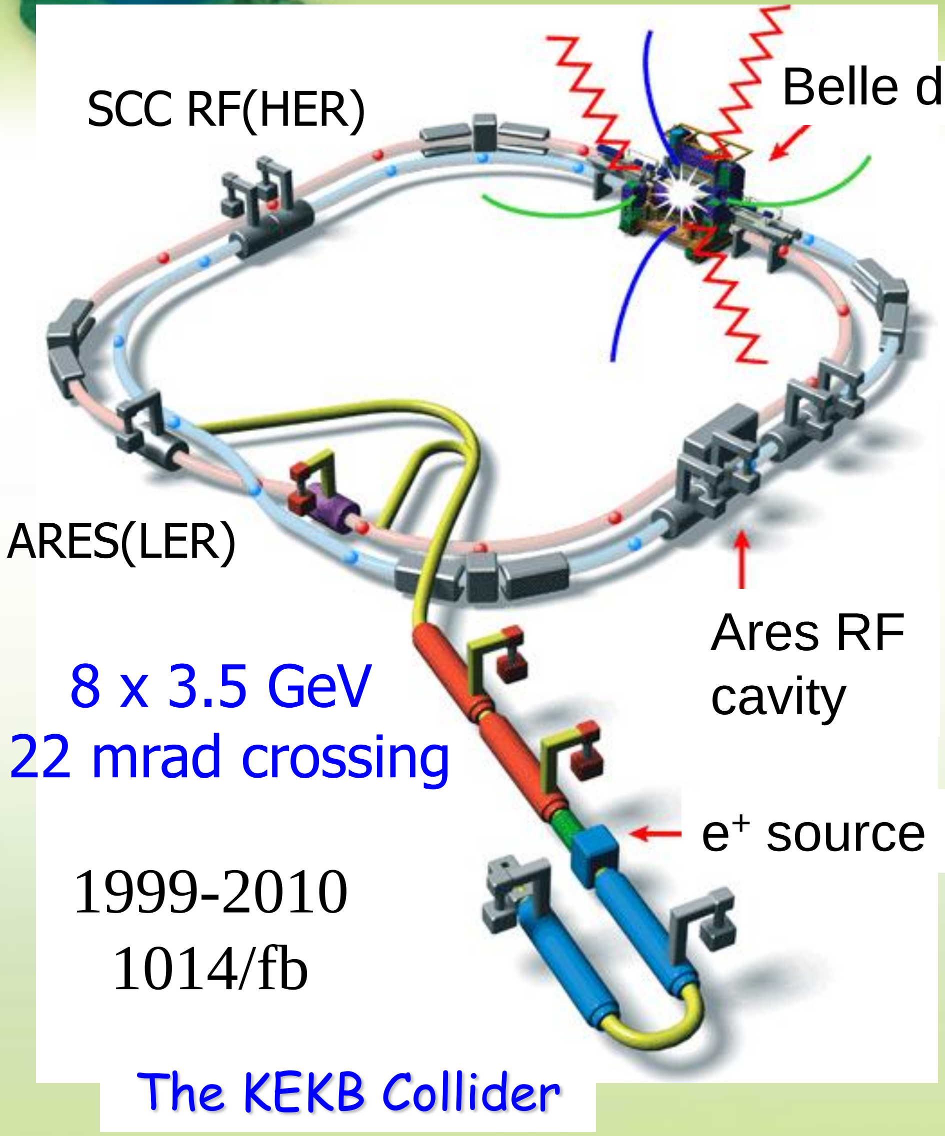
State	M /MeV	Γ /MeV	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.68±0.17	< 1.2	1^{++}	$B \to K + (J/\psi\, \pi^+\pi^-)$	Belle [95, 102], BaBar [98], LHCb [103]
				$p\bar{p} \to (J/\psi\, \pi^+\pi^-) + ...$	CDF [96, 104, 105, 160], D0 [97]
				$B \to K + (J/\psi\, \pi^+\pi^-\pi^0)$	Belle [107], BaBar [72, 73]
				$B \to K + (D^0 D^0 \pi^0)$	Belle [108, 109], BaBar [110]
				$B \to K + (J/\psi\, \gamma)$	BaBar [137], Belle [138], LHCb [141]
				$B \to K + (\psi'\, \gamma)$	BaBar [137], Belle [138], LHCb [141]
				$pp \to (J/\psi\, \pi^+\pi^-) + ...$	LHCb [99], CMS [100]
$X(3915)$	3917.4 ± 2.7	28^{+10}_{-9}	0^{++}	$B \to K + (J/\psi\, \omega)$	Belle [71], BaBar [72, 73]
				$e^+e^- \to e^+e^- + (J/\psi\, \omega)$	Belle [74], BaBar [75]
$\chi_{c2}(2P)$	3927.2 ± 2.6	24±6	2^{++}	$e^+e^- \to e^+e^- + (DD)$	Belle [78], BaBar [79]
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^* D)$	Belle [32]
				$e^+e^- \to J/\psi + (...)$	Belle [31]
$G(3900)$	3943 ± 21	52±11	1^{--}	$e^+e^- \to \gamma + (D\bar{D})$	BaBar [163], Belle [164]
$Y(4008)$	4008^{+121}_{-49}	226±97	1^{--}	$e^+e^- \to \gamma + (J/\psi\, \pi^+\pi^-)$	Belle [39]
$Y(4140)$	4144 ± 3	17 ± 9	$?^{?+}$	$B \to K + (J/\psi\, \phi)$	CDF [87, 88], CMS [90]
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^* D)$	Belle [32]
$Y(4260)$	4263^{+8}_{-9}	95±14	1^{--}	$e^+e^- \to \gamma + (J/\psi\, \pi^+\pi^-)$	BaBar [37, 165], CLEO [166], Belle [39]
				$e^+e^- \to (J/\psi\, \pi^+\pi^-)$	CLEO [167]
				$e^+e^- \to (J/\psi\, \pi^0\pi^0)$	CLEO [167]
$Y(4274)$	4292 ± 6	34 ± 16	$?^{?+}$	$B \to K + (J/\psi\, \phi)$	CDF [88], CMS [90]
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^- \to e^+e^-\, (J/\psi\, \phi)$	Belle [94]
$Y(4360)$	4361 ± 13	74±18	1^{--}	$e^+e^- \to \gamma + (\psi'\, \pi^+\pi^-)$	BaBar [38], Belle [40]
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma\, (\Lambda_c^+ \Lambda_c^-)$	Belle [168]
$Y(4660)$	4664±12	48±15	1^{--}	$e^+e^- \to \gamma + (\psi'\, \pi^+\pi^-)$	Belle [40]
$Z_c^+(3900)$	3890 ± 3	33 ± 10	1^{+-}	$Y(4260) \to \pi^- + (J/\psi\, \pi^+)$	BESIII [49], Belle [50]
				$Y(4260) \to \pi^- + (D\bar{D}^*)^+$	BESIII [69]
$Z_c^+(4020)$	4024 ± 2	10 ± 3	$1(?)^{+(?)-}$	$Y(4260) \to \pi^- + (h_c\, \pi^+)$	BESIII [51]
				$Y(4260) \to \pi^- + (D^* \bar{D}^*)^+$	BESIII [52]
$Z_1^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K + (\chi_{c1}\, \pi^+)$	Belle [53], BaBar [66]
$Z^+(4200)$	4196^{+35}_{-32}	370^{+99}_{-149}	1^{+-}	$B \to K + (J/\psi\, \pi^+)$	Belle [62]
$Z_2^+(4250)$	4248^{+185}_{-45}	177^{+321}_{-72}	$?^{?+}$	$B \to K + (\chi_{c1}\, \pi^+)$	Belle [53], BaBar [66]
$Z^+(4430)$	4477 ± 20	181 ± 31	1^{+-}	$B \to K + (\psi'\, \pi^+)$	Belle [54, 56, 57], LHCb [58]
				$B \to K + (J\psi\, \pi^+)$	Belle [62]
$Y_b(10890)$	10888.4±3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\, \pi^+\pi^-)$	Belle [152]
$Z_b^+(10610)$	10607.2±2.0	18.4±2.4	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\, \pi^+)$, $n = 1,2,3$	Belle [155, 158, 159]
				"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\, \pi^+)$, $n = 1,2$	Belle [155]
				"$\Upsilon(5S)$" $\to \pi^- + (B\bar{B}^*)^+$, $n = 1,2$	Belle [160]
$Z_b^0(10610)$	10609± 6		1^{+-}	"$\Upsilon(5S)$" $\to \pi^0 + (\Upsilon(nS)\, \pi^0)$, $n = 1,2,3$	Belle [157]
$Z_b^+(10650)$	10652.2±1.5	11.5±2.2	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\, \pi^+)$, $n = 1,2,3$	Belle [155]
				"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\, \pi^+)$, $n = 1,2$	Belle [155]
				"$\Upsilon(5S)$" $\to \pi^- + (B^* \bar{B}^*)^+$, $n = 1,2$	Belle [160]

S. Olsen, Front. Phys. (Beijing) **10**, 121 (2015)

- More than 20 quarkonium-like states identified
- Only a few seen in more than one production process, or by more than one experiment
- Are we at the dawn of a new spectroscopy?

In this seminar:
personal selection of experimental results; in light of BelleII

The Belle experiment



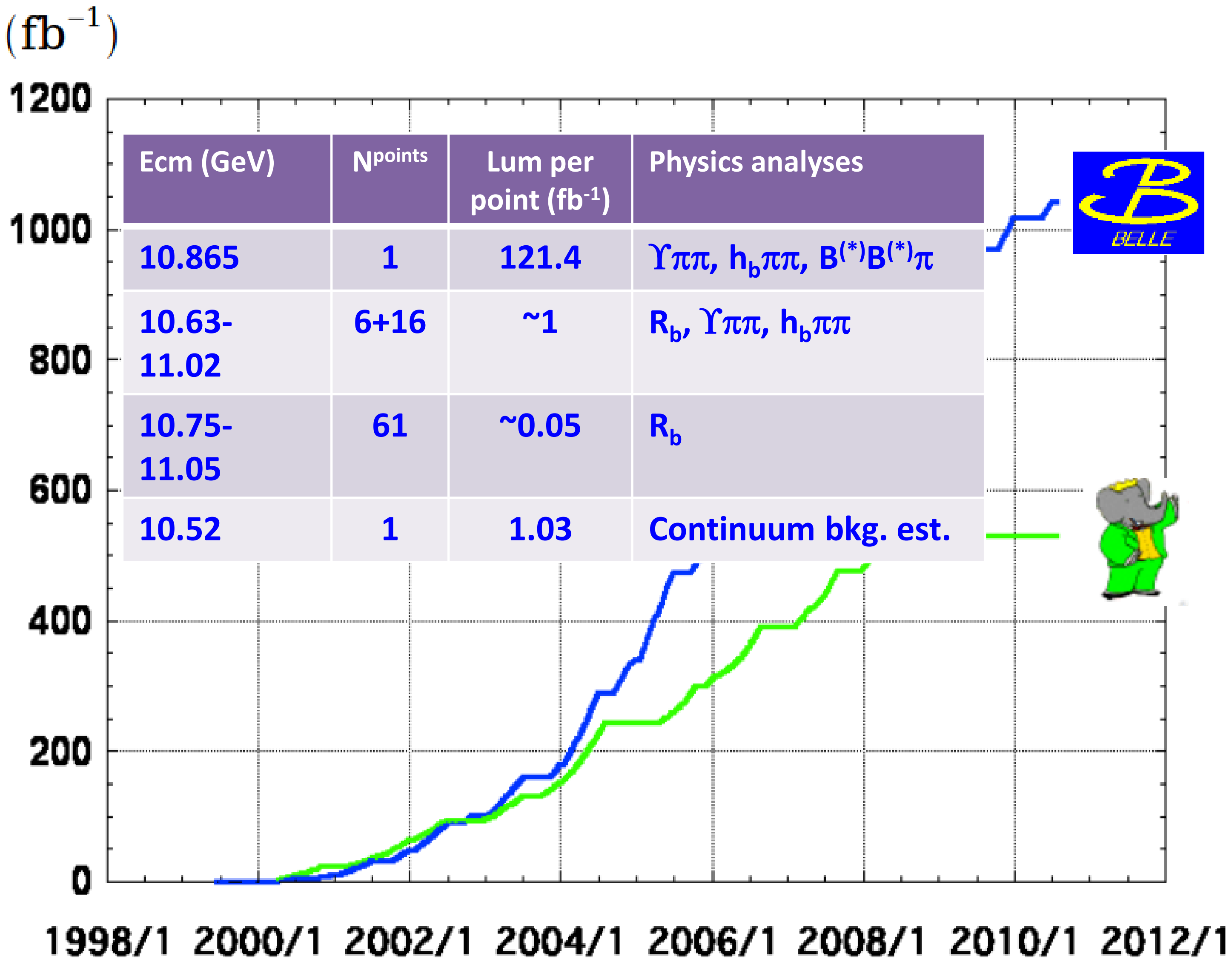
8 x 3.5 GeV
22 mrad crossing

1999-2010
1014/fb

World record:

L = 2.1 x 10^{34}/cm^{2}/sec

Integrated luminosity of B factories



Ecm (GeV)	N^{points}	Lum per point (fb^{-1})	Physics analyses
10.865	1	121.4	$\Upsilon\pi\pi$, $h_b\pi\pi$, $B^{(*)}B^{(*)}\pi$
10.63-11.02	6+16	~1	R_b, $\Upsilon\pi\pi$, $h_b\pi\pi$
10.75-11.05	61	~0.05	R_b
10.52	1	1.03	Continuum bkg. est.

> 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}

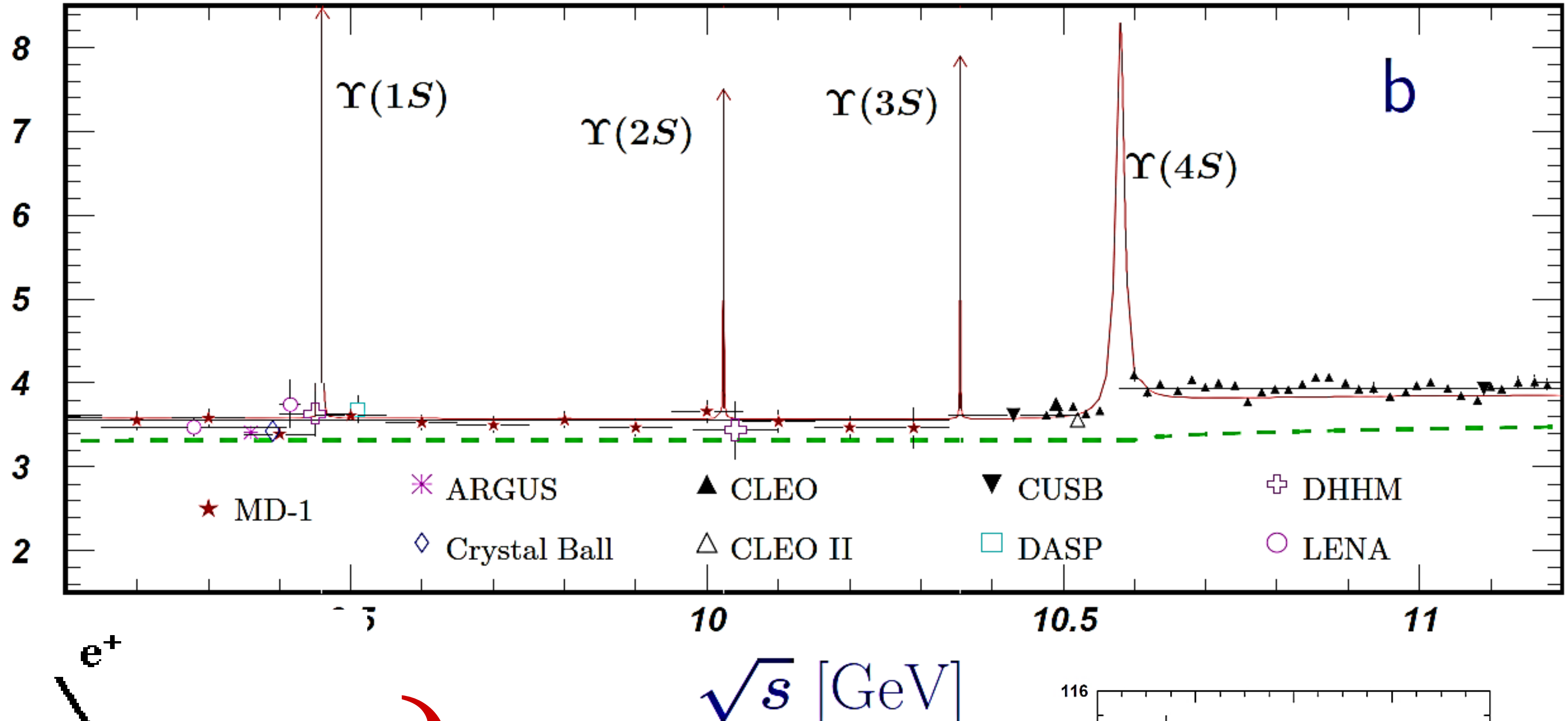
$\Upsilon(3S)$: 30 fb^{-1}

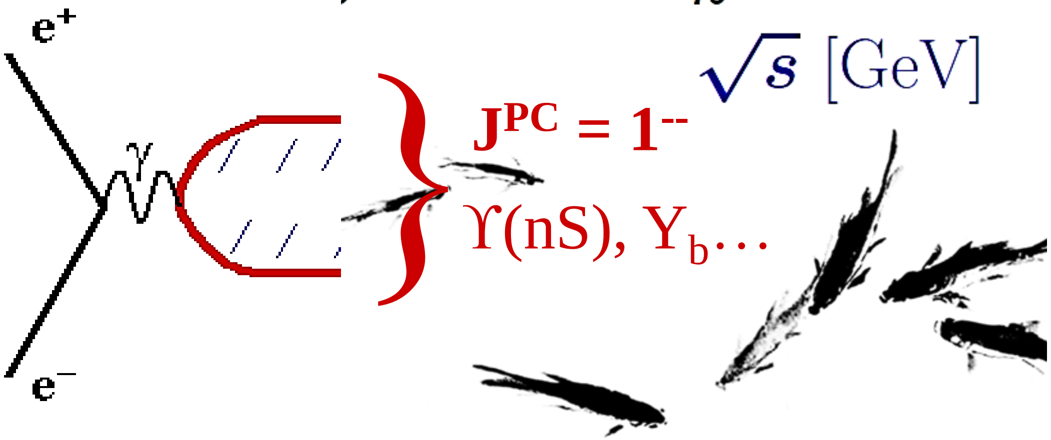
$\Upsilon(2S)$: 14 fb^{-1}

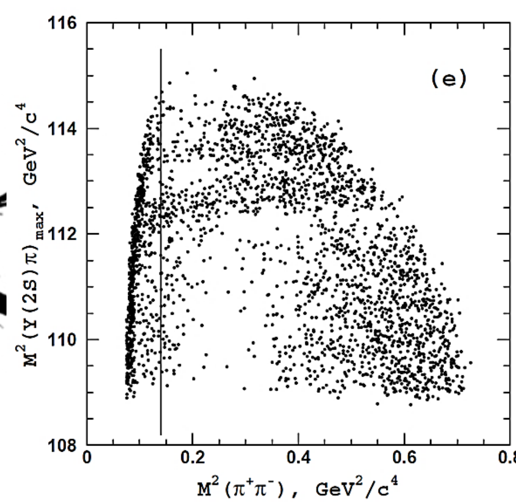
Off resonance:

~ 54 fb^{-1}

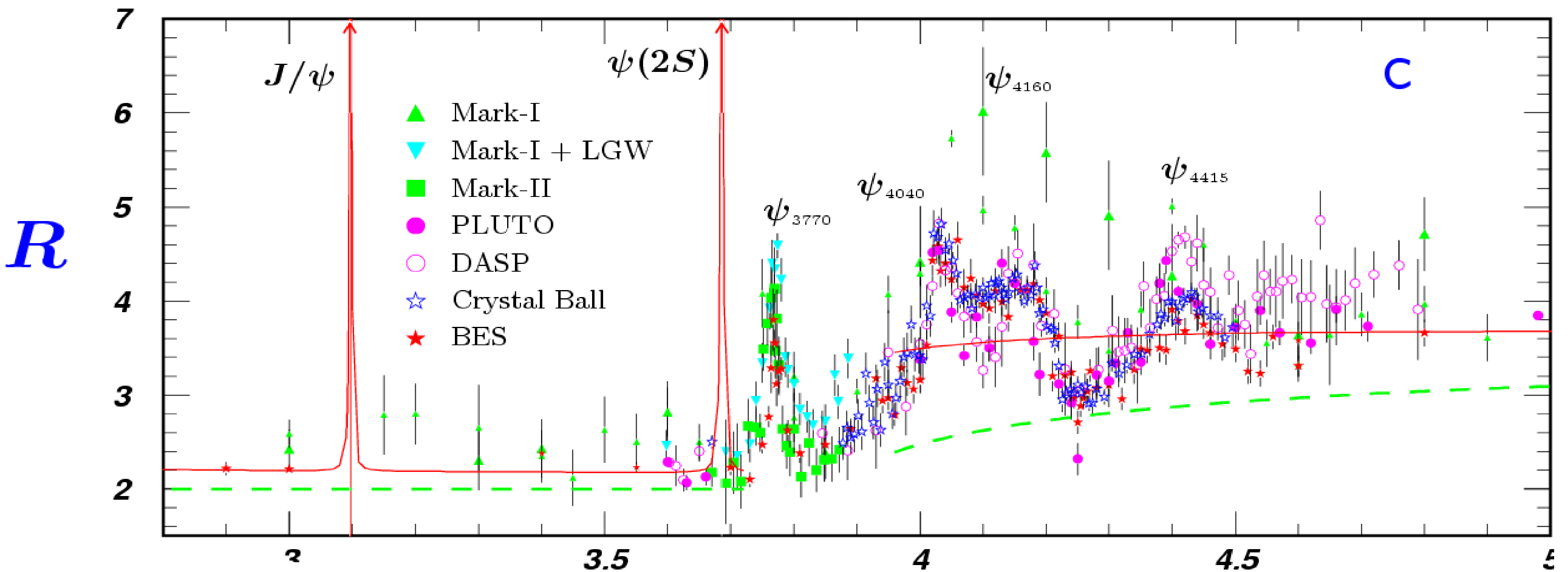
e^+e^- annihilation to vector bottomonia

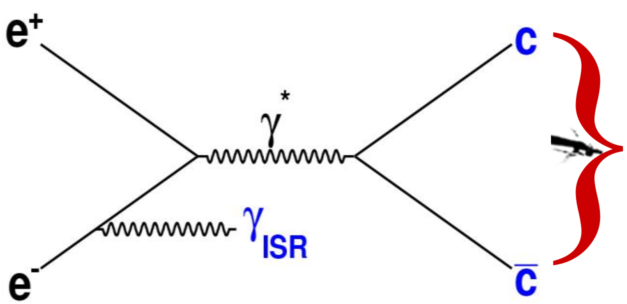






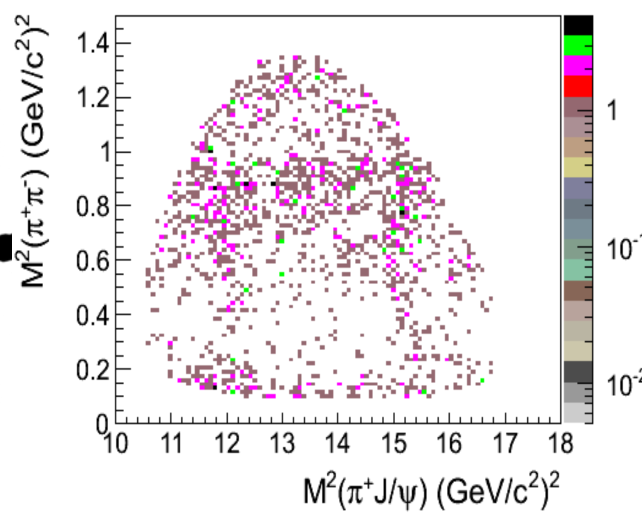
ISR production of vector charmonia





$J^{PC} = 1^{--}$

ψ', ψ'', Y. . .



$e^+e^- \to \pi^+\pi^-\Upsilon(nS)$

- tag $\Upsilon(nS) \to \mu^+\mu^-$ and select $\pi^+\pi^-$, fit to $|A_{5S}+e^{i\phi}A_{6S}|^2$

$\Upsilon(5S)$:

Mass = $(10891.9 \pm 3.2\ {}^{+0.6}_{-1.7})$ MeV

Width = $(53.7\ {}^{+7.1}_{-5.6}\ {}^{+1.3}_{-5.4})$ MeV

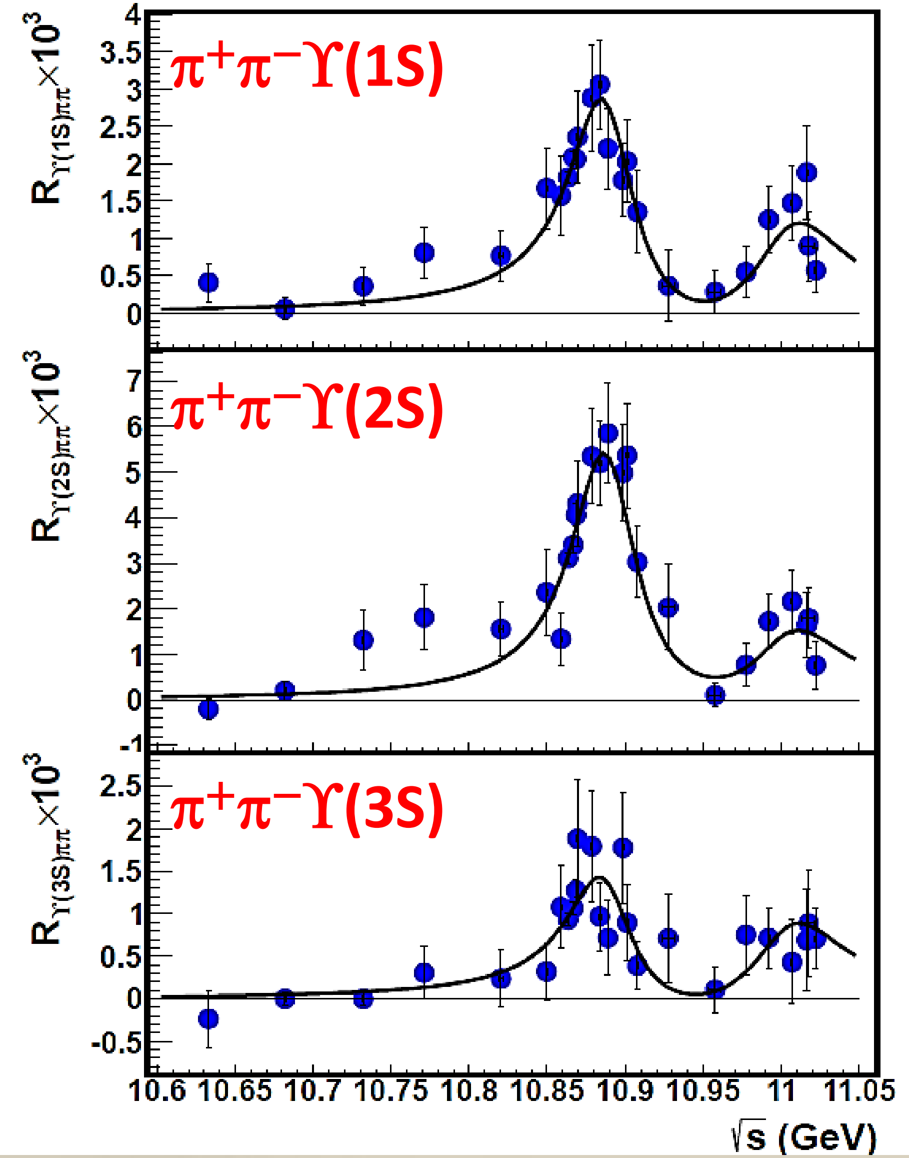
$\Upsilon(6S)$:

Mass = $(10987.5\ {}^{+6.4}_{-2.5}\ {}^{+9.0}_{-2.1})$ MeV

Width = $(61\ {}^{+9}_{-19}\ {}^{+2}_{-20})$ MeV

$\Delta\phi = -1.0 \pm 0.4\ {}^{+1.4}_{-0.1}$ rad

- Results agree with previous measurements
- Also agree with fit with Rb reasonably well
- Still room for improvement



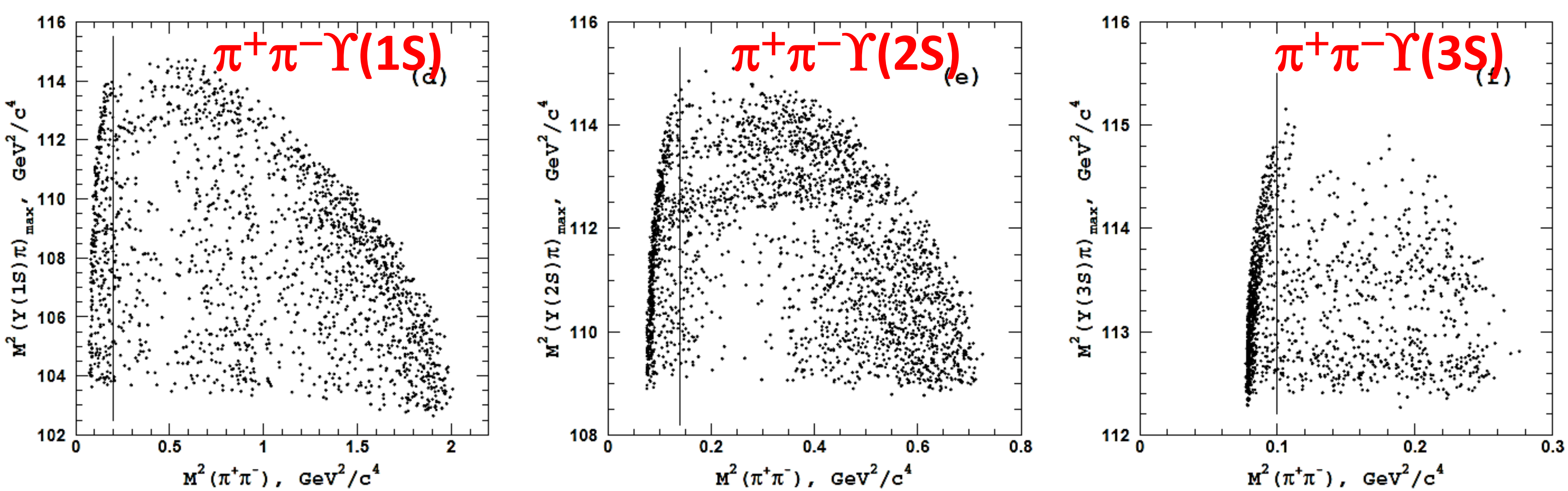
PRD93,011101(2016)

Z_b in $\Upsilon(5S) \rightarrow \pi^+\pi^-\Upsilon(nS)$

- 121 fb^{-1} data, tag $\Upsilon(nS) \rightarrow \mu^+\mu^-$ and select $\pi^+\pi^-$

Born cross section

Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
Signal yield	2090 ± 115	2476 ± 97	628 ± 41
Efficiency, %	45.9	39.0	24.4
$\mathcal{B}_{\Upsilon(nS)\to\mu^+\mu^-}$, % [14]	2.48 ± 0.05	1.93 ± 0.17	2.18 ± 0.21
$\sigma^{vis}_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb	$1.51 \pm 0.08 \pm 0.09$	$2.71 \pm 0.11 \pm 0.30$	$0.97 \pm 0.06 \pm 0.11$
$\sigma_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb	$2.27 \pm 0.12 \pm 0.14$	$4.07 \pm 0.16 \pm 0.45$	$1.46 \pm 0.09 \pm 0.16$
$\sigma^{vis}_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb [1]	$1.61 \pm 0.10 \pm 0.12$	$2.35 \pm 0.19 \pm 0.32$	$1.44^{+0.55}_{-0.45} \pm 0.19$

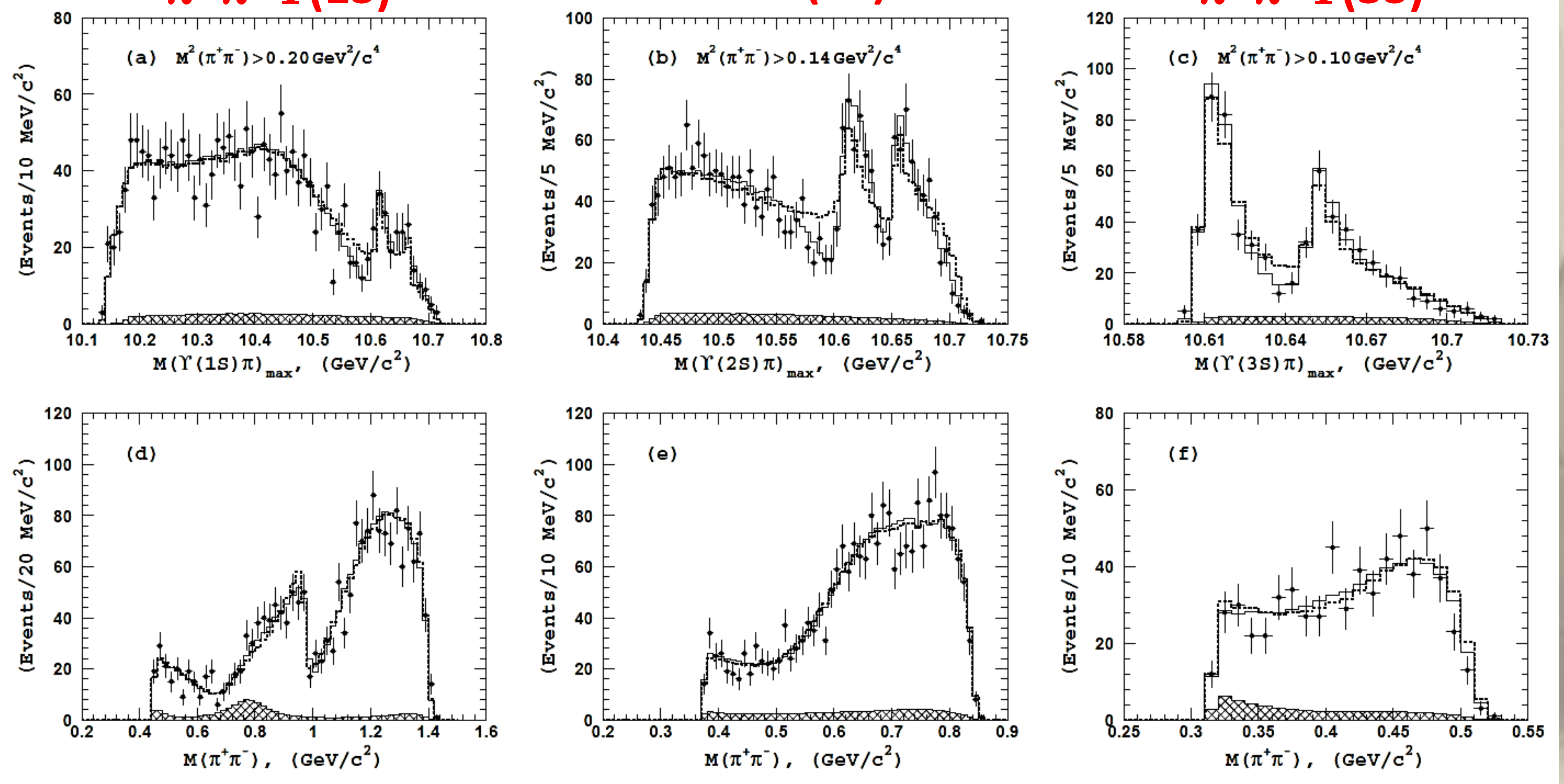


Belle: PRD91, 072003 (2015)

Z_b in $\Upsilon(5S) \rightarrow \pi^+\pi^-\Upsilon(nS)$

- Full partial wave analysis of $\Upsilon(5S) \rightarrow \pi^+\pi^-\mu^+\mu^-$
- Mass, width, fraction, and $J^P=1^+$ of Z_b states determined

$\pi^+\pi^-\Upsilon(1S)$ $\pi^+\pi^-\Upsilon(2S)$ $\pi^+\pi^-\Upsilon(3S)$



Belle: PRD91, 072003 (2015)

Z_b in $\Upsilon(5S) \to \pi^+\pi^-\Upsilon(nS)$

BELLE

Parameter	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
$f_{Z_b^\mp(10610)\pi^\pm}$, %	$4.8 \pm 1.2^{+1.5}_{-0.3}$	$18.1 \pm 3.1^{+4.2}_{-0.3}$	$30.0 \pm 6.3^{+5.4}_{-7.1}$
$Z_b(10610)$ mass, MeV/c^2	$10608.5 \pm 3.4^{+3.7}_{-1.4}$	$10608.1 \pm 1.2^{+1.5}_{-0.2}$	$10607.4 \pm 1.5^{+0.8}_{-0.2}$
$Z_b(10610)$ width, MeV/c^2	$18.5 \pm 5.3^{+6.1}_{-2.3}$	$20.8 \pm 2.5^{+0.3}_{-2.1}$	$18.7 \pm 3.4^{+2.5}_{-1.3}$
$f_{Z_b^\mp(10650)\pi^\pm}$, %	$0.87 \pm 0.32^{+0.16}_{-0.12}$	$4.05 \pm 1.2^{+0.95}_{-0.15}$	$13.3 \pm 3.6^{+2.6}_{-1.4}$
$Z_b(10650)$ mass, MeV/c^2	$10656.7 \pm 5.0^{+1.1}_{-3.1}$	$10650.7 \pm 1.5^{+0.5}_{-0.2}$	$10651.2 \pm 1.0^{+0.4}_{-0.3}$
$Z_b(10650)$ width, MeV/c^2	$12.1^{+11.3+2.7}_{-4.8-0.6}$	$14.2 \pm 3.7^{+0.9}_{-0.4}$	$9.3 \pm 2.2^{+0.3}_{-0.5}$
ϕ_Z, degrees	$67 \pm 36^{+24}_{-52}$	$-10 \pm 13^{+34}_{-12}$	$-5 \pm 22^{+15}_{-33}$
$c_{Z_b(10650)}/c_{Z_b(10610)}$	$0.40 \pm 0.12^{+0.05}_{-0.11}$	$0.53 \pm 0.07^{+0.32}_{-0.11}$	$0.69 \pm 0.09^{+0.18}_{-0.07}$
$f_{\Upsilon(nS) f_2(1270)}$, %	$14.6 \pm 1.5^{+6.3}_{-0.7}$	$4.09 \pm 1.0^{+0.33}_{-1.0}$	–
$f_{\Upsilon(nS)(\pi^+\pi^-)_S}$, %	$86.5 \pm 3.2^{+3.3}_{-4.9}$	$101.0 \pm 4.2^{+6.5}_{-3.5}$	$44.0 \pm 6.2^{+1.8}_{-4.3}$
$f_{\Upsilon(nS) f_0(980)}$, %	$6.9 \pm 1.6^{+0.8}_{-2.8}$	–	–

$$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(1S)\pi^\mp} = 109 \pm 27^{+35}_{-10} \text{ fb}$$

$$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(2S)\pi^\mp} = 737 \pm 126^{+188}_{-85} \text{ fb}$$

$$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(3S)\pi^\mp} = 438 \pm 92^{+92}_{-114} \text{ fb}$$

$$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(1S)\pi^\mp} = 20 \pm 7^{+4}_{-3} \text{ fb}$$

$$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(2S)\pi^\mp} = 165 \pm 49^{+43}_{-20} \text{ fb}$$

$$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(3S)\pi^\mp} = 194 \pm 53^{+43}_{-25} \text{ fb}$$

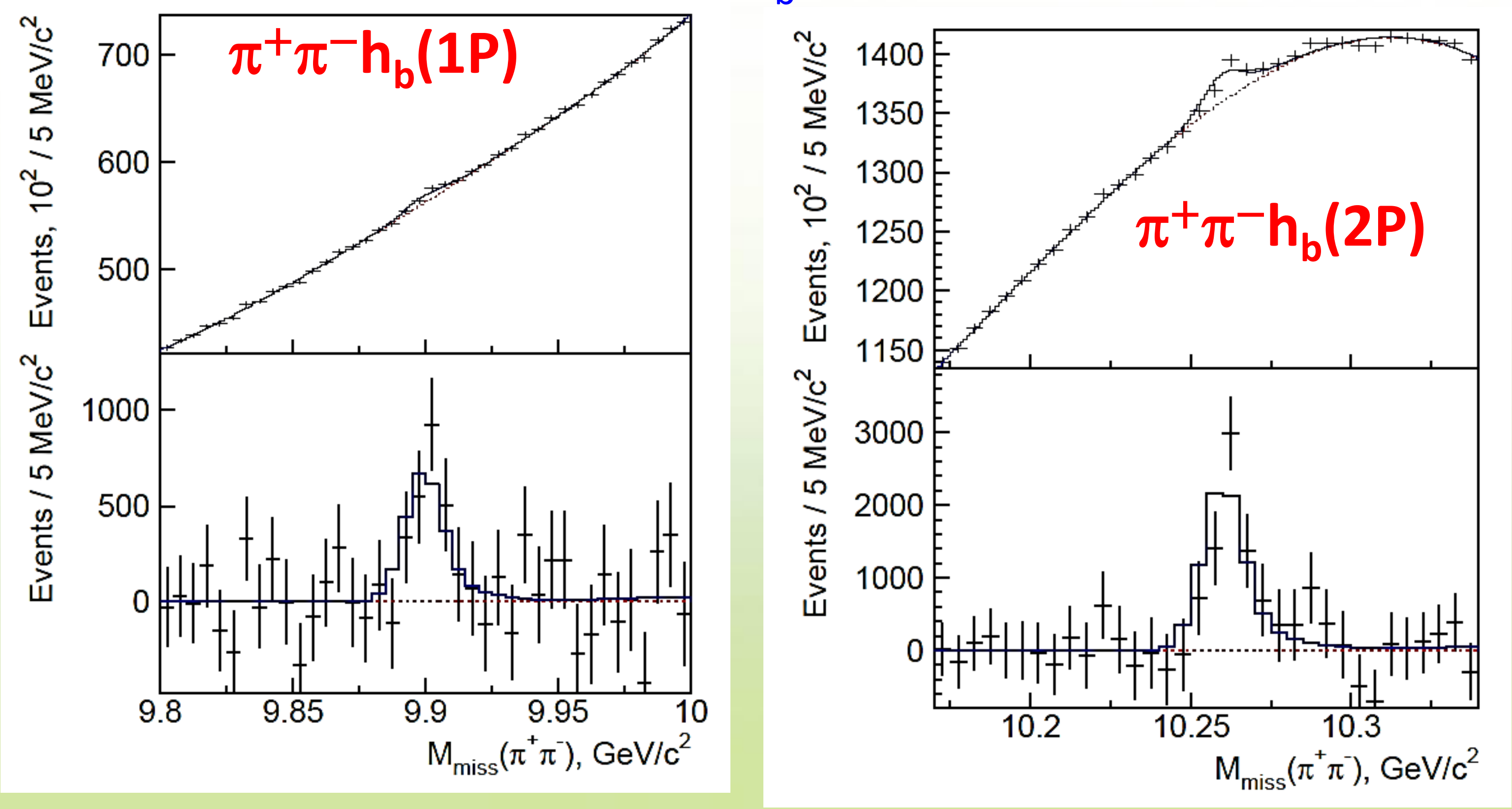
- Relative BR of Z_b decays

Belle: PRD91, 072003 (2015)

$e^+e^- \rightarrow \pi^+\pi^- h_b(nP)$

PRL117,142001(2016)

- Using scan data between Y(5S) and Y(6S)
- Reconstruct $\pi^+\pi^-$, require π^+/π^- recoil mass in Z_b region: $10.59 < M_{miss}(\pi) < 10.67\ GeV/c^2$
- check the $\pi^+\pi^-$ recoil mass for $h_b(nP)$



$e^+e^- \to \pi^+\pi^- h_b(nP)$

Simultaneous fit:

$$A_n\,\Phi_n(s)\,|F_{\rm BW}(s,M_5,\Gamma_5)+a\,e^{i\,\phi}\,F_{\rm BW}(s,M_6,\Gamma_6)|^2$$

$\Upsilon(5S)$:

Mass = $(10884.7\ \pm^{3.6}_{3.4} \pm^{8.9}_{1.0})$ MeV

Width = $(40.6\ \pm^{12.7}_{8.0}\ \pm^{1.1}_{19.1})$ MeV

$\Upsilon(6S)$:

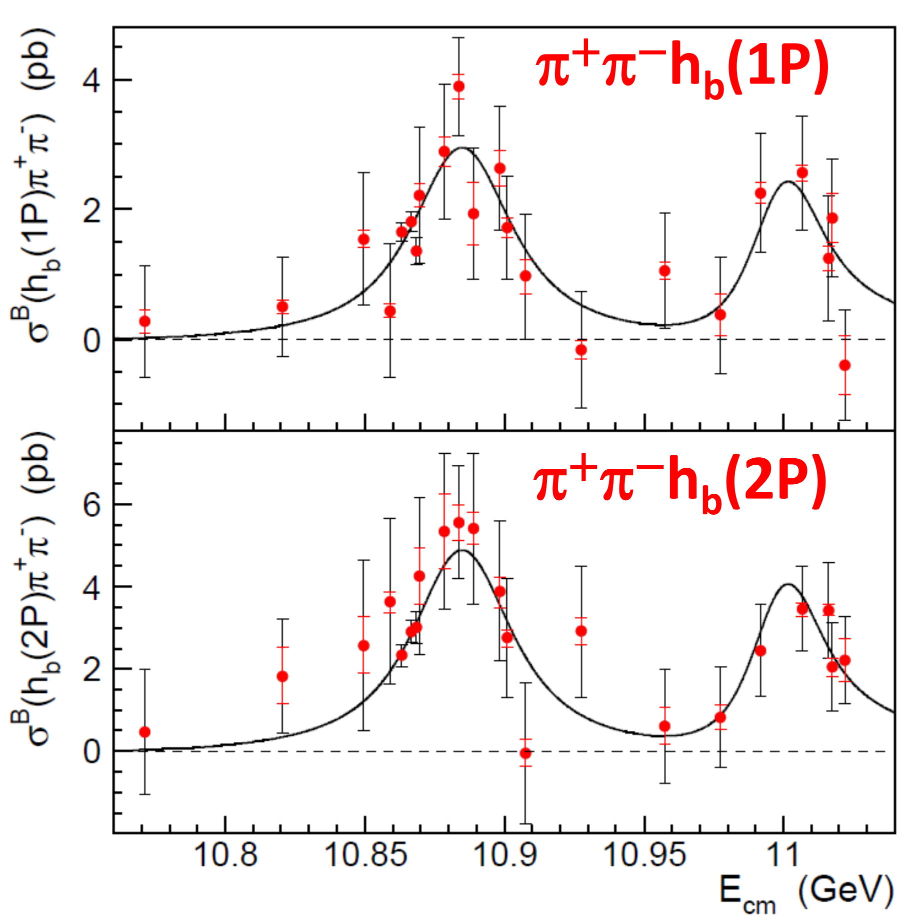
Mass = $(10999.0\ \pm^{7.3}_{7.8} \pm^{16.7}_{1.0})$ MeV

Width = $(27\ \pm^{27}_{11}\ \pm^{1}_{12})$ MeV

$\Delta\phi = 0.1\ \pm^{0.4}_{0.8} \pm^{0.1}_{0.3}$ rad

- Resonant parameters agree with from $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$
- $e^+e^- \to \pi^+\pi^- h_b(nP)$ at the same level as $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$; similar shape.
- 1st obs. of $\Upsilon(6S) \to \pi^+\pi^- h_b(nP)$

  3.6σ for 1P, 5.4σ for 2P.



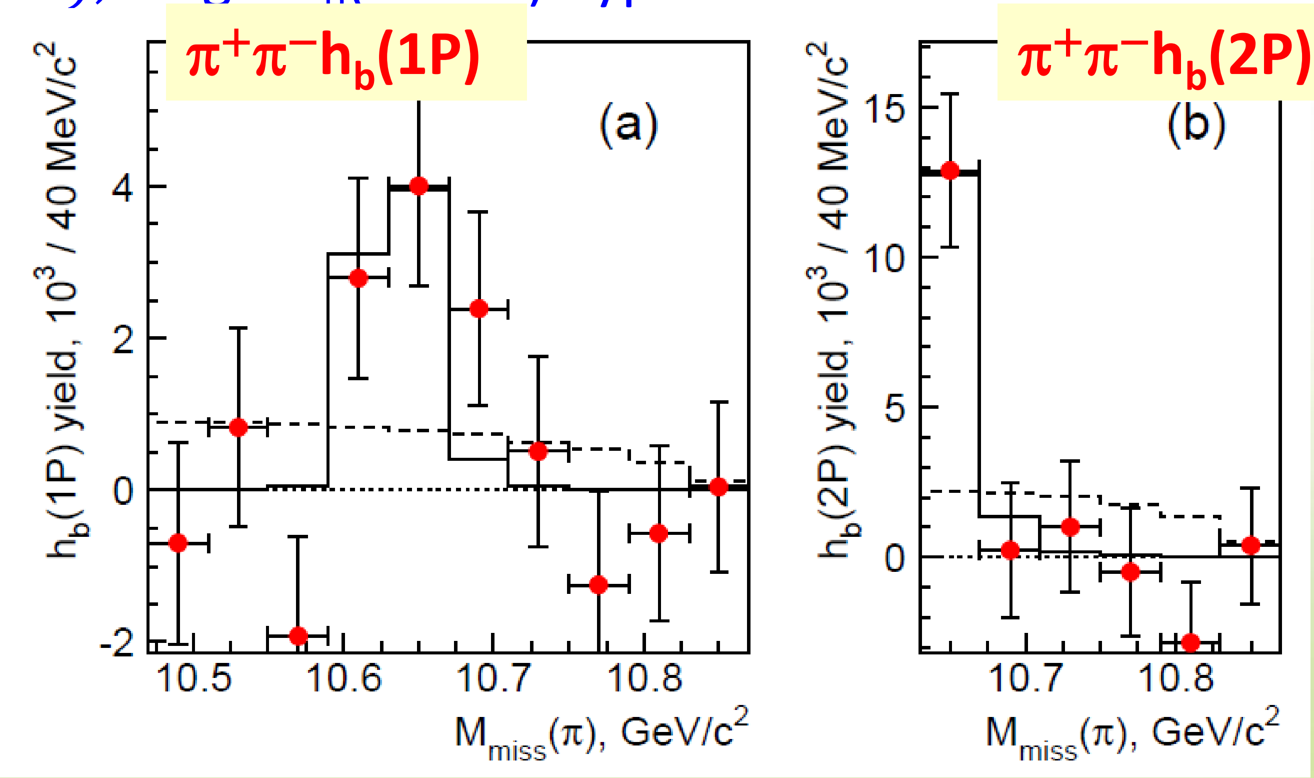
Ecm=10865.6 ±2.0 MeV

$$\sigma^B(e^+e^- \to h_b(1P)\pi^+\pi^-) = 1.66 \pm 0.09 \pm 0.10\,\text{pb},$$
$$\sigma^B(e^+e^- \to h_b(2P)\pi^+\pi^-) = 2.70 \pm 0.17 \pm 0.19\,\text{pb}.$$

PRL117,142001(2016)

Z_b in $\Upsilon(6S) \rightarrow \pi^+\pi^- h_b(nP)$

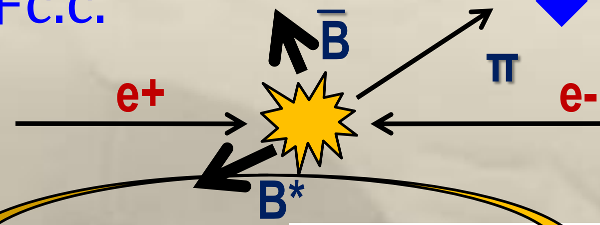
- Fit $\pi^+\pi^-$ missing in each π missing mass spectra PRL117,142001(2016)
- Events mainly from Z_b intermediate states: not clear if only one Z_b or both. Single $Z_b(10610)$ hypothesis is excluded at 3.4σ in $\pi^+\pi^-$ $h_b(1P)$; Single $Z_b(10650)$ hypothesis cannot excluded.



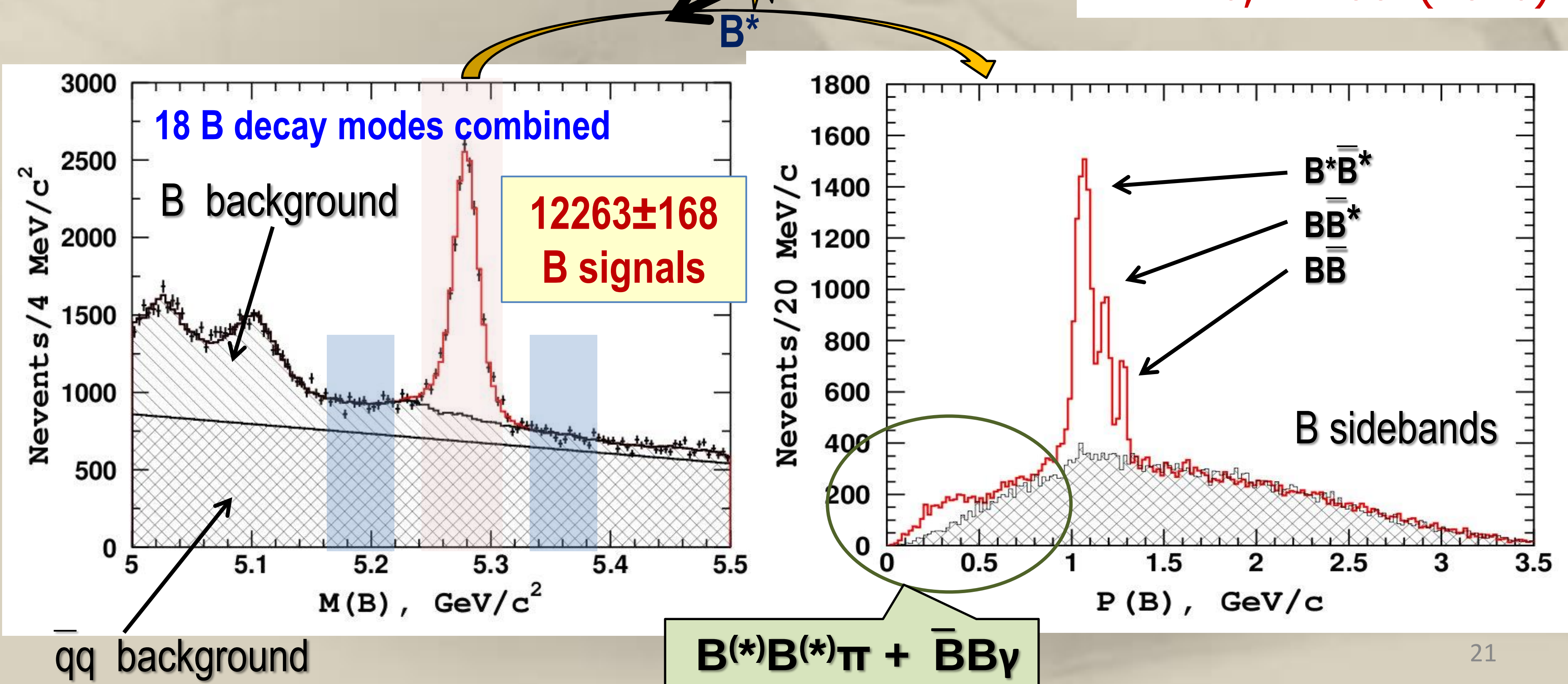
Z_b in $\Upsilon(5S) \to [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

- $B\bar{B}\pi = \bar{B}^0B^+\pi^- + c.c.$
- $BB^*\pi = \bar{B}^{*0}B^+\pi^- + c.c./\ \bar{B}^0B^{*+}\pi^- + c.c.$
- $B^*B^*\pi = \bar{B}^{*0}B^{*+}\pi^- + c.c.$

- One B is reconstructed
- Select a bachelor $\pi^\pm$
- Check $B\pi$ recoil mass



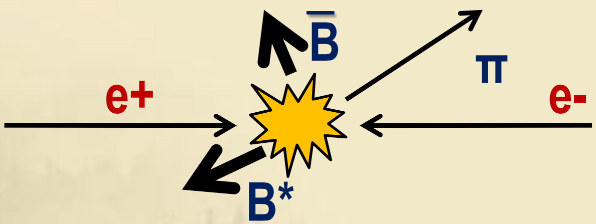
PRL116, 212001(2016)

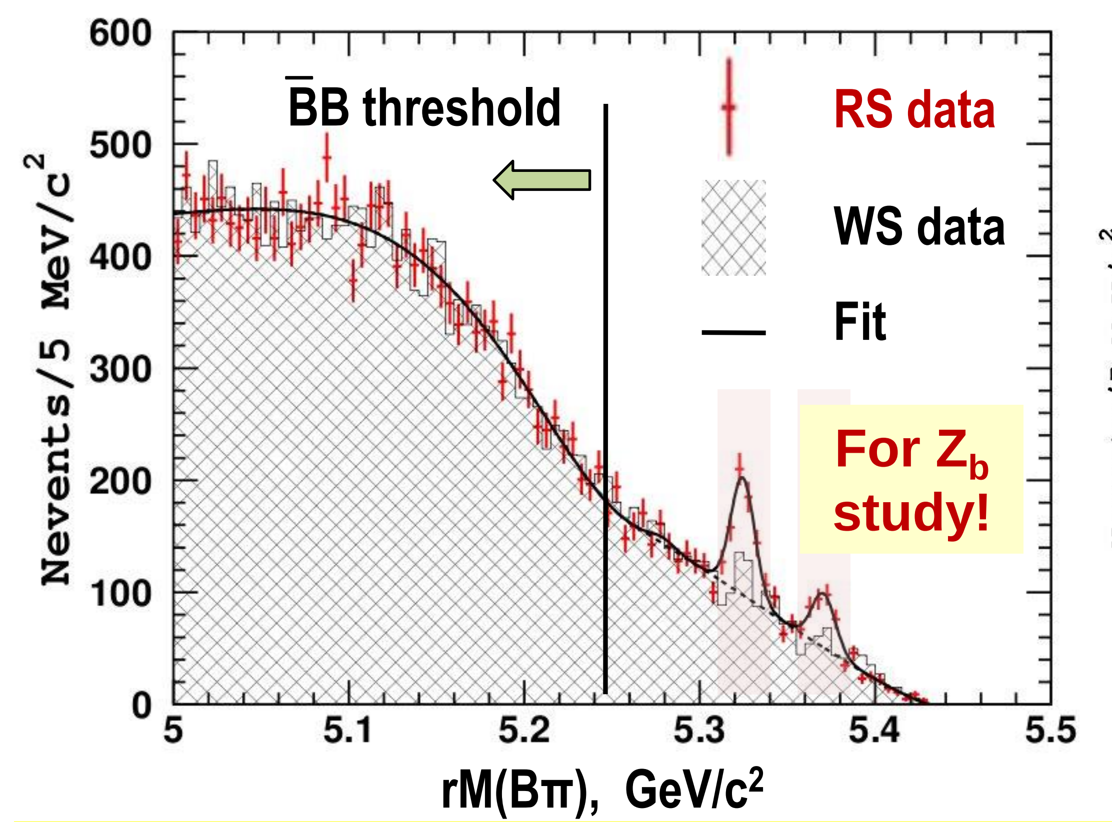


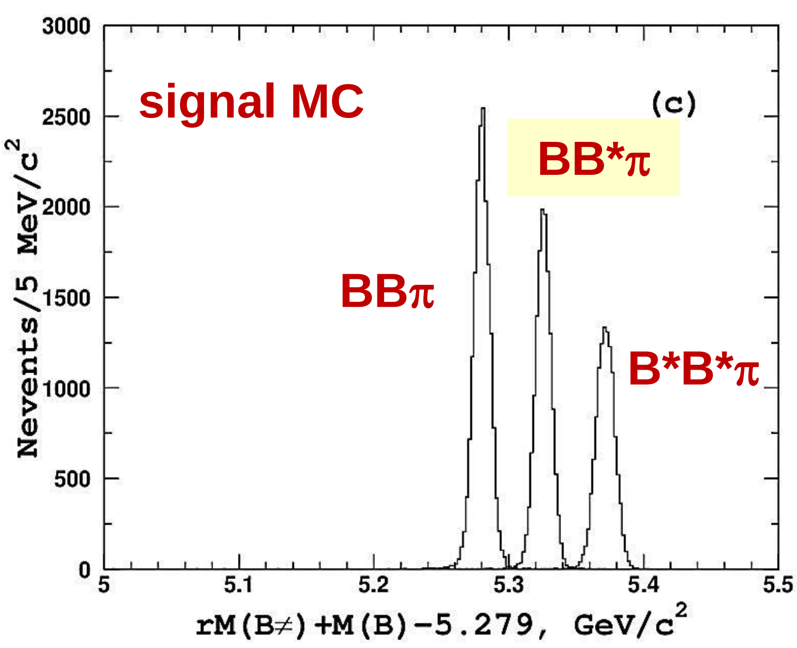
Z_b in $\Upsilon(5S) \rightarrow [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

Combine the B with a charged pion

➔ calculate recoil mass of $B\pi$







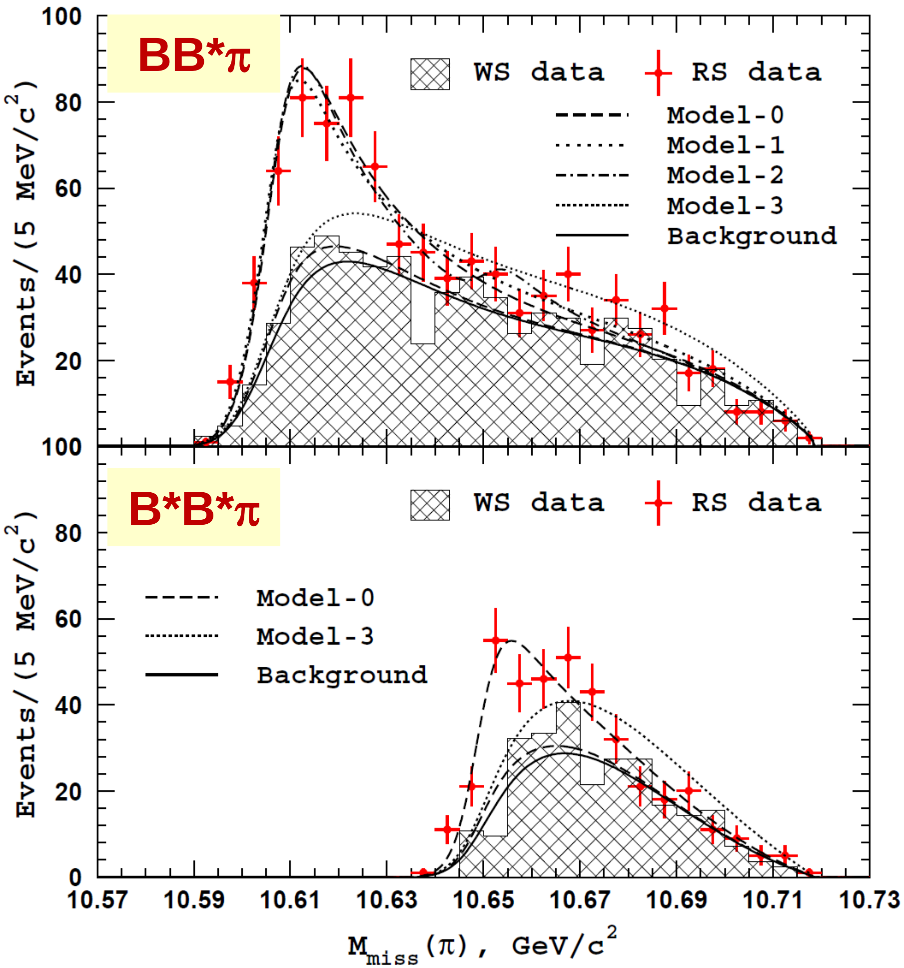
$N(BB\pi) = 13 \pm 25$ $N(BB^*\pi) = 357 \pm 30$ $N(B^*B^*\pi) = 161 \pm 21$

PRL116, 212001(2016)

Z_b in $\Upsilon(5S) \to [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

Check recoil mass of bachelor $\pi^\pm$

- Simultaneous fit of right-sign (RS) and wrong-sign (WS) samples
- Contribution of signal events to the WS sample due to B_0 mixing (at 10% level)



Model-0 : $Z_b(10650)$ only

Model-1: $Z_b(10610)$ + Non-res.

Model-2: $Z_b(10610)$ + $Z_b(10650)$ with interference

Model-3: Non-resonance

$Z_b(10610)$ saturates $BB^*\pi$ and $Z_b(10650)$ saturates $B^*B^*\pi$

Z_b in $\Upsilon(5S) \to [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

PRL116, 212001(2016)

- Simultaneous fit of right-sign (RS) and wrong-sign (WS) samples
- Contribution of signal events to the WS sample due to B_0 mixing (at 10% level)

Summary of fit results to the $M_{\rm miss}(\pi)$ distributions for the three-body $BB^*\pi$ and $B^*B^*\pi$ final states.

Mode	Parameter	Mod-0	Mod-1		Mod-2		Mod-3
			Sol 1	Sol 2	Sol 1	Sol 2	
$BB^*\pi$	$f_{Z_b(10610)}$	1.0	1.45 ± 0.24	0.64 ± 0.15	1.01 ± 0.13	1.18 ± 0.15	—
	$f_{Z_b(10650)}$	—	—	—	0.05 ± 0.04	0.24 ± 0.11	—
	$\phi_{Z_b(10650)}$, rad.	—	—	—	-0.26 ± 0.68	-1.63 ± 0.14	—
	$f_{\rm nr}$	—	0.48 ± 0.23	0.41 ± 0.17	—	—	1.0
	$\phi_{\rm nr}$, rad.	—	-1.21 ± 0.19	0.95 ± 0.32	—	—	—
	$-2\log\mathcal{L}$	-304.7	-300.6	-300.5	-301.4	-301.4	-344.5
$B^*B^*\pi$	$f_{Z_b(10650)}$	1.0	1.04 ± 0.15	0.77 ± 0.22			—
	$f_{\rm nr}$	—	0.02 ± 0.04	0.24 ± 0.18			1.0
	$\phi_{\rm nr}$, rad.	—	0.29 ± 1.01	1.10 ± 0.44			—
	$-2\log\mathcal{L}$	-182.4	-182.4	-182.4			-209.7

- Intermediate $Z_b(10610)$ dominates in the $BB^*\pi$ final state, while intermediate $Z_b(10650)$ dominates in the $B^*B^*\pi$ final state

Z_b in $\Upsilon(5S) \rightarrow [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

Decay table of the Z_b states

PRL116, 212001(2016)

- Assuming that the known decays saturate Z_b decay table =>

B branching fractions for the $Z_b^+(10610)$ and $Z_b^+(10650)$ decays. The first quoted uncertainty is statistical; the second is systematic.

BRs of Z_b decays

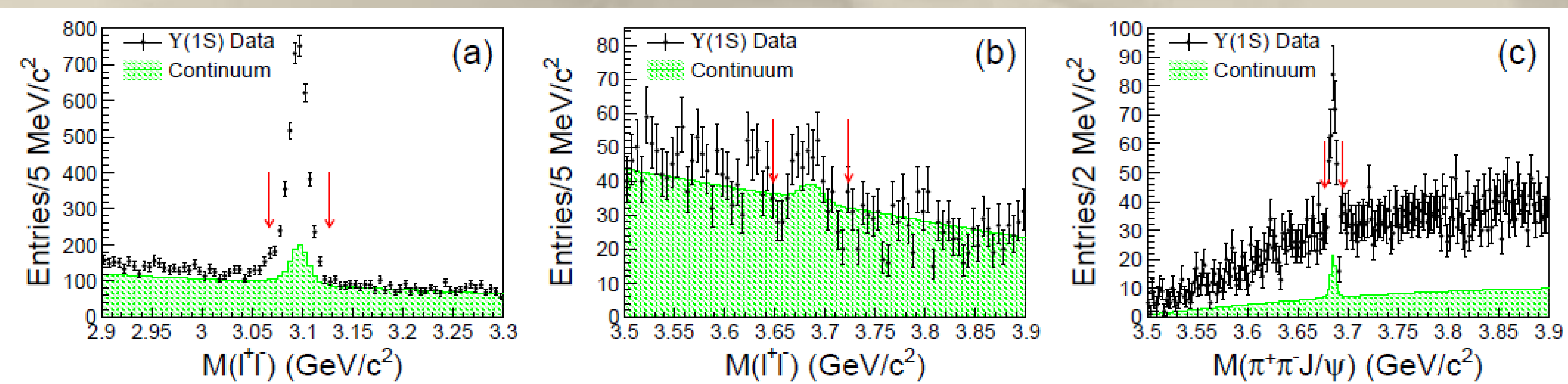
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.60 \pm 0.17 \pm 0.07$	$0.17 \pm 0.06 \pm 0.02$
$\Upsilon(2S)\pi^+$	$4.05 \pm 0.81 \pm 0.58$	$1.38 \pm 0.45 \pm 0.21$
$\Upsilon(3S)\pi^+$	$2.40 \pm 0.58 \pm 0.36$	$1.62 \pm 0.50 \pm 0.24$
$h_b(1P)\pi^+$	$4.26 \pm 1.28 \pm 1.10$	$9.23 \pm 2.88 \pm 2.28$
$h_b(2P)\pi^+$	$6.08 \pm 2.15 \pm 1.63$	$17.0 \pm 3.74 \pm 4.1$
$B^+\bar{B}^{*0} + \bar{B}^0B^{*+}$	$82.6 \pm 2.9 \pm 2.3$	–
$B^{*+}\bar{B}^{*0}$	–	$70.6 \pm 4.9 \pm 4.4$

- $Z_b^+(10610)$ and $Z_b^+(10650)$ decays to BB^* and B^*B^* dominate
- Smoking gun of molecular structure

Search for XYZ in Υ(1S) inclusive decays

- Very little available information on XYZ production in the decays of narrow Υ states
- Υ (1S) inclusive to J/Ψ and Ψ(2S) with large Brs [$(6.5\pm0.7)\times10^{-4}$ and $(2.7\pm0.9)\times10^{-4}$], some of the XYZ might have been produced

- Tag channels: Υ (1S) → J/Ψ + anything and Ψ(2S)+anything



J/Ψ → l^+l^- Ψ(2S) → l^+l^- Ψ(2S) → $\pi^+\pi^-$ J/Ψ

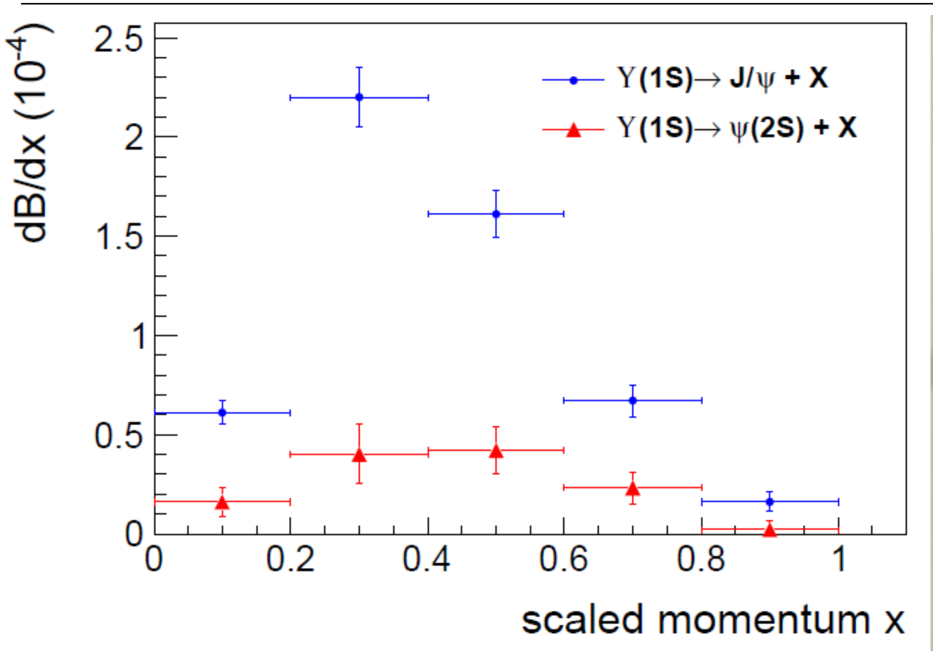
- Dots with error bars: data
- Shaded histogram: normalized continuum

PRD 93, 112013 (2016)

Search for XYZ in $\Upsilon(1S)$ inclusive decays

Define the scaled momentum $x = p^*_\psi / (\frac{1}{2\sqrt{s}} \times (s - m^2_\psi))$

x	$\Upsilon(1S) \to J/\psi + X$ $N_{\rm fit}$	ε	$\sigma_{\rm syst}$	$\mathcal{B}(\times 10^{-4})$	$\Upsilon(1S) \to \psi(2S) + X$ $N_{\rm fit}$	ε	$\sigma_{\rm syst}$	$\mathcal{B}(\times 10^{-4})$
$(0.0, 0.2)$	379.28 ± 28.05	6.06	4.3	$0.61 \pm 0.05 \pm 0.03$	30.14 ± 10.52	1.81	21.8	$0.16 \pm 0.06 \pm 0.04$
$(0.2, 0.4)$	1297.60 ± 48.60	5.78	5.4	$2.20 \pm 0.08 \pm 0.12$	71.25 ± 18.31	1.76	26.5	$0.40 \pm 0.10 \pm 0.11$
$(0.4, 0.6)$	904.56 ± 41.55	5.51	5.6	$1.61 \pm 0.07 \pm 0.09$	71.45 ± 15.37	1.68	18.6	$0.42 \pm 0.09 \pm 0.08$
$(0.6, 0.8)$	353.95 ± 29.27	5.15	6.8	$0.67 \pm 0.06 \pm 0.05$	39.52 ± 12.04	1.65	16.6	$0.23 \pm 0.07 \pm 0.04$
$(0.8, 1.0)$	54.23 ± 13.36	3.36	7.6	$0.16 \pm 0.04 \pm 0.02$	2.53 ± 5.65	1.40	78.4	$0.02 \pm 0.04 \pm 0.02$
sum	2989.62 ± 75.03	5.62	4.7	$5.25 \pm 0.13 \pm 0.25$	214.89 ± 29.31	1.71	8.9	$1.23 \pm 0.17 \pm 0.11$



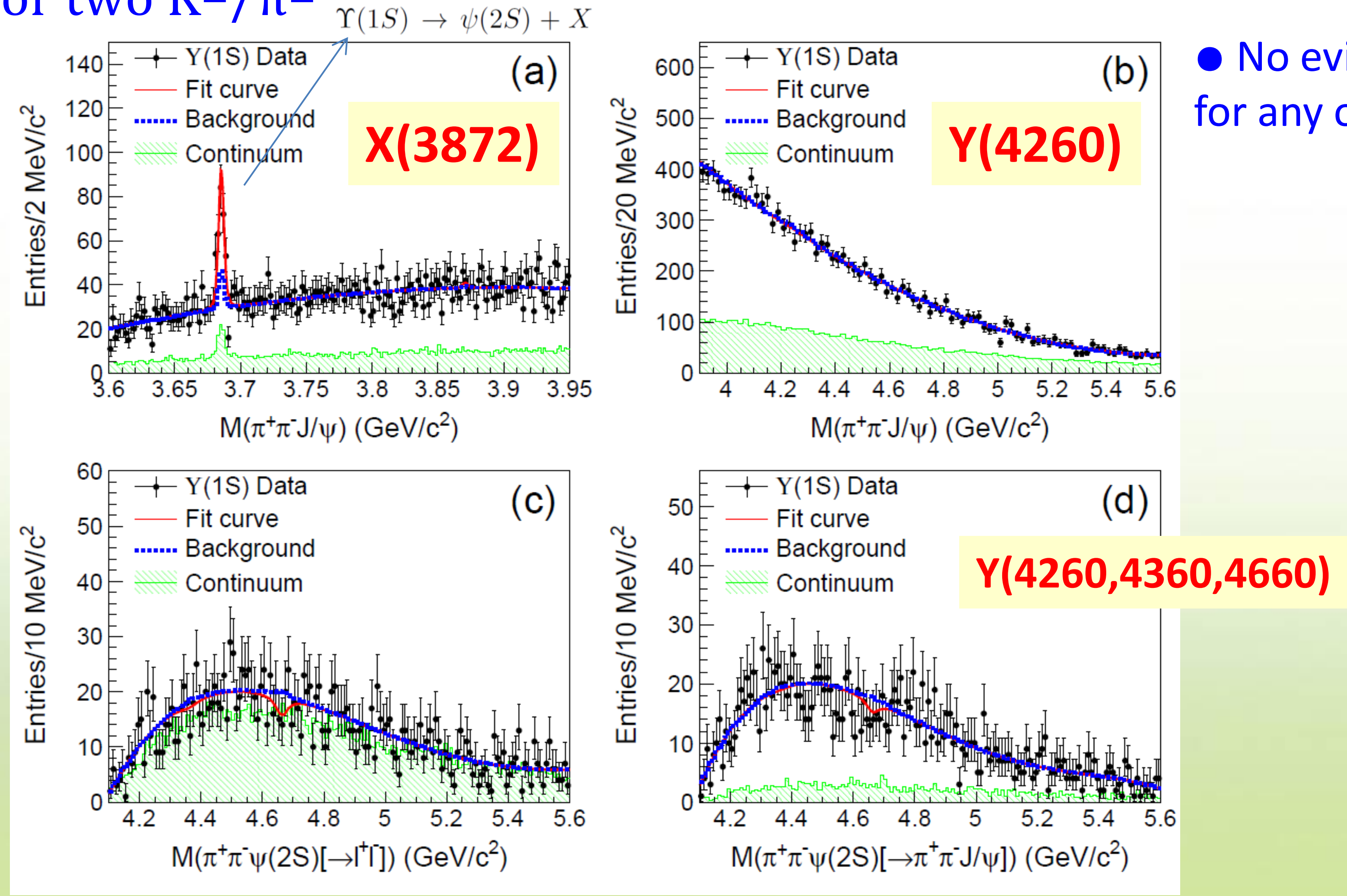
- The use of x removes the beam-energy dependence from the comparison of the continuum data to that taken at the $\Upsilon(1S)$ resonance.
- An unbinned extended simultaneous likelihood fit is applied to the x-dependent Ψ spectra to extract the signal yields in the $\Upsilon(1S)$ and continuum data samples.

PRD 93, 112013 (2016)

Ours have smaller central values and much better precision than the PDG averages

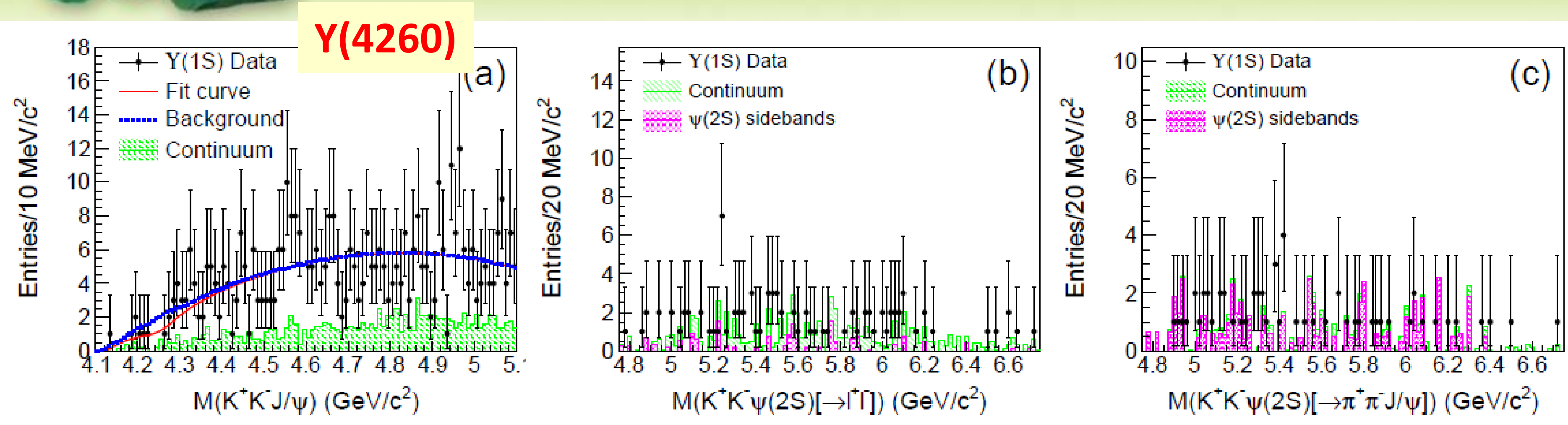
Search for XYZ in Υ(1S) inclusive decays

Search for XYZ states by combining the J/Ψ or Ψ(2S) with one or two $K^{\pm}/\pi^{\pm}$

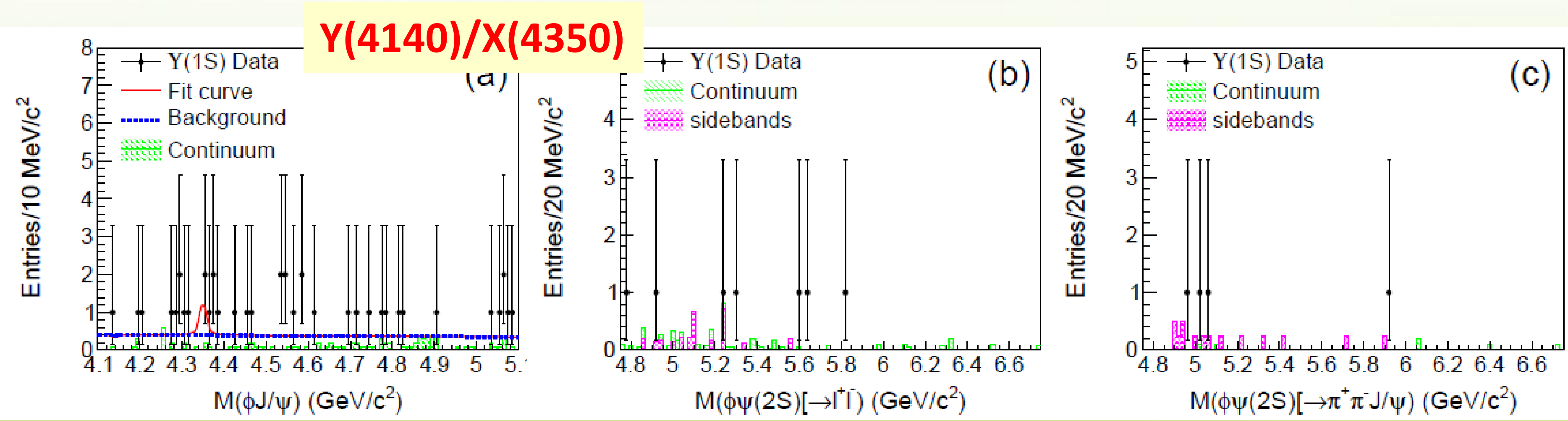


- No evident signals for any of these states

Search for XYZ in Υ(1S) inclusive decays

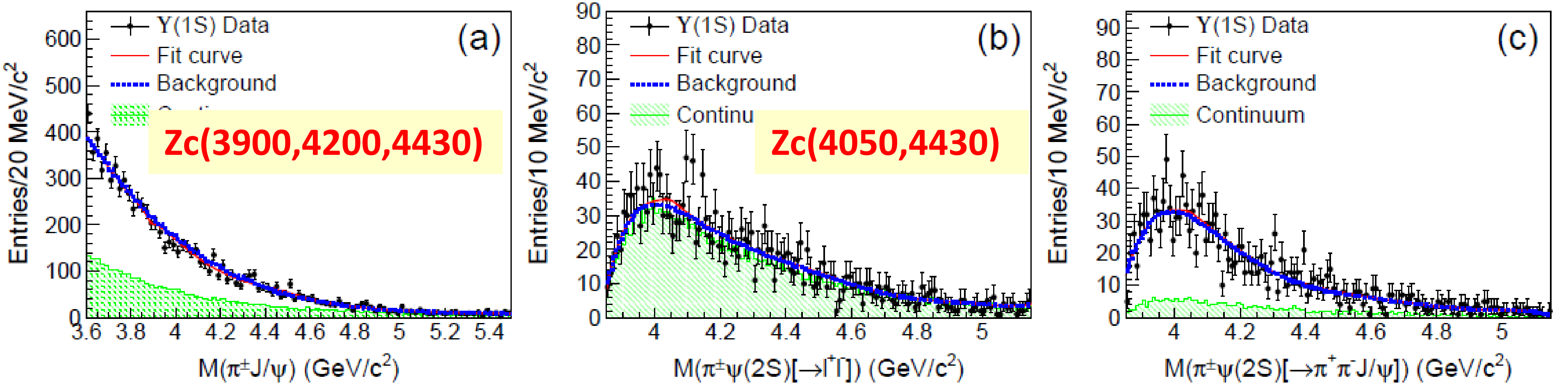


- No evidence is found for new structures or any of the known XYZ states.

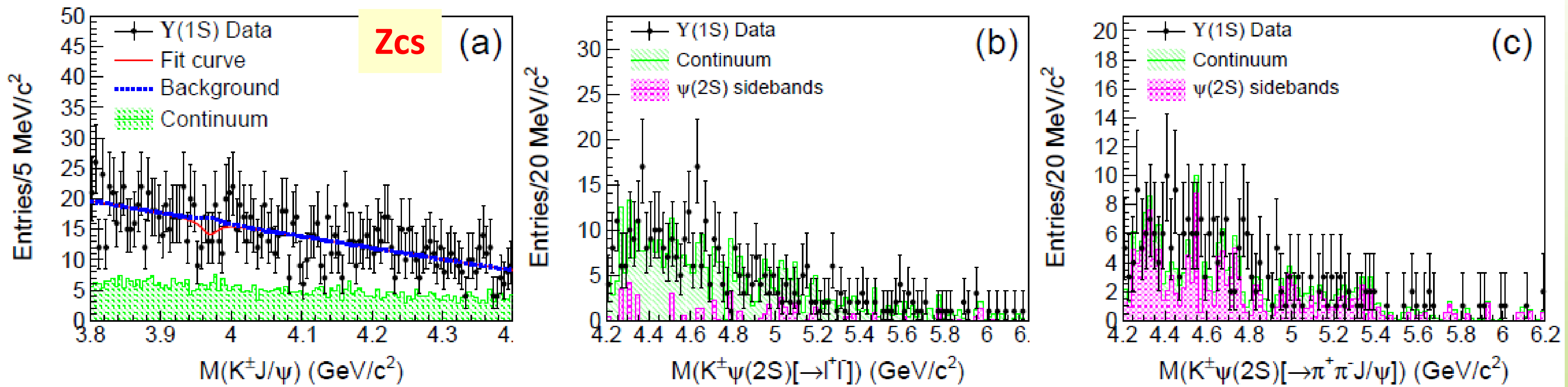


- No structures can be identified.

Search for XYZ in Υ(1S) inclusive decays



Zcs: M=(3.97$\pm$0.08) GeV/c2, Γ=(24.9$\pm$12.6) MeV [J Korean Phys. Soc. 55, 424(2009); PRD88,096014(2013)]



- No structures can be identified.

Search for XYZ in $\Upsilon(1S)$ inclusive decays

PRD 93, 112013 (2016)

State	N_{fit}	N_{up}	$\varepsilon(\%)$	$\sigma_{\text{syst}}(\%)$	$\Sigma(\sigma)$	$\mathcal{B}_R$
$X(3872) \to \pi^+\pi^- J/\psi$	4.8±15.4	31.4	3.26	18.7	0.3	$< 9.5 \times 10^{-6}$
$Y(4260) \to \pi^+\pi^- J/\psi$	−31.1±88.9	134.6	3.50	35.6	–	$< 3.8 \times 10^{-5}$
$Y(4260) \to \pi^+\pi^- \psi(2S)$	6.7±29.4	56.9	0.71	35.0	0.2	$< 7.9 \times 10^{-5}$
$Y(4360) \to \pi^+\pi^- \psi(2S)$	−25.4±30.1	45.6	0.86	50.0	–	$< 5.2 \times 10^{-5}$
$Y(4660) \to \pi^+\pi^- \psi(2S)$	−55.0±26.2	23.1	1.06	40.7	–	$< 2.2 \times 10^{-5}$
$Y(4260) \to K^+K^- J/\psi$	−13.7±10.9	14.5	1.91	45.8	–	$< 7.5 \times 10^{-6}$
$Y(4140) \to \phi J/\psi$	−0.1±1.2	3.6	0.69	11.0	–	$< 5.2 \times 10^{-6}$
$X(4350) \to \phi J/\psi$	2.3±2.5	7.6	0.92	10.4	1.2	$< 8.1 \times 10^{-6}$
$Z_c(3900)^\pm \to \pi^\pm J/\psi$	−26.5±39.1	57.5	4.39	47.3	–	$< 1.3 \times 10^{-5}$
$Z_c(4200)^\pm \to \pi^\pm J/\psi$	−238.6±154.2	235.1	3.87	48.4	–	$< 6.0 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm J/\psi$	94.2±71.4	195.8	3.97	34.4	1.2	$< 4.9 \times 10^{-5}$
$Z_c(4050)^\pm \to \pi^\pm \psi(2S)$	37.0±47.7	112.7	1.27	46.2	0.4	$< 8.8 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm \psi(2S)$	23.2±42.4	92.0	1.35	47.1	0.1	$< 6.7 \times 10^{-5}$
$Z_{cs}^\pm \to K^\pm J/\psi$	−22.2±17.4	22.4	3.88	48.7	–	$< 5.7 \times 10^{-6}$

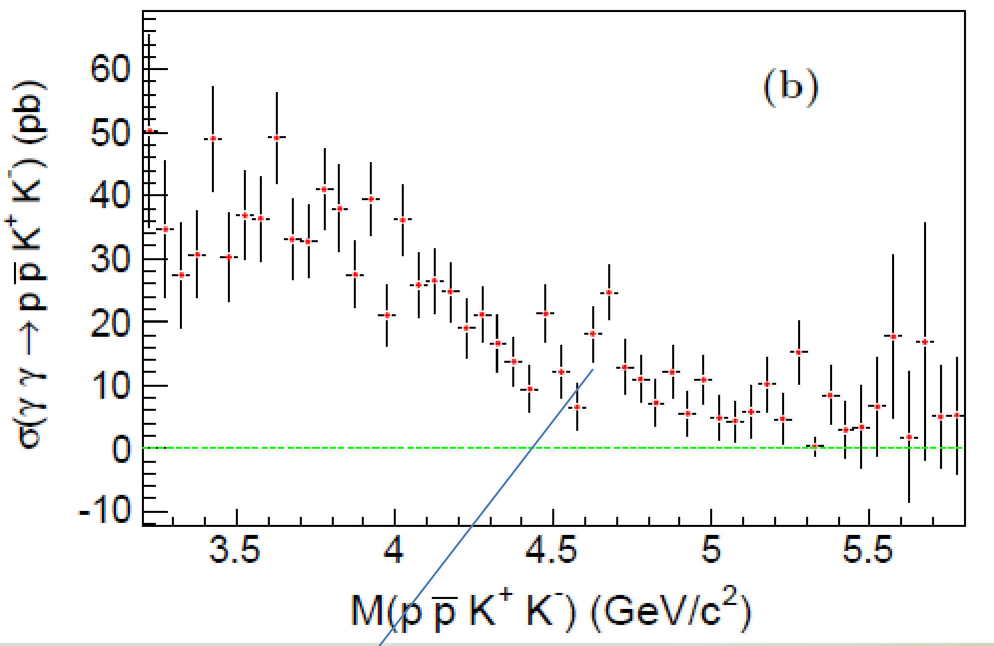
We searched for a variety of XYZ states in $\Upsilon(1S)$ inclusive decays for the first Time. No evident signal is found for any of them and 90% C.L. upper limits are set on the product branching fractions .

Search for search for exotic baryons in pK systems in γ γ $\rightarrow p\bar{p}K^+K^-$

- LHCb reported Pc(4380)$^+$ and Pc(4450)$^+$ in J/Ψ p system
- the first strong experimental evidence for a pentaquark state, Θ(1540)$^+$, was reported in γ n→n K^+ K^- in the LEPS experiment
- However, it was not confirmed in larger-statistics data samples in the same experiment and was most probably not a genuine state
- The possibility of observing additional hypothetical exotic baryons in γ γ collisions is discussed in [J. Phys. G30,1801 (2004)]
- Due to the high luminosity accumulated at B factories, searches for exotic baryons in exclusive γ γ reactions are possible.
- We search for novel exotic baryons, denoted as Θ(1540)^0→pK^- and Θ(1540)$^{++}$→p K^+ which are similar to Θ(1540)$^+$, in intermediate processes in $\gamma\gamma \rightarrow p\bar{p}K^+K^-$.

Search for search for exotic baryons in pK systems in $\gamma\gamma \rightarrow p\bar{p}K^+K^-$

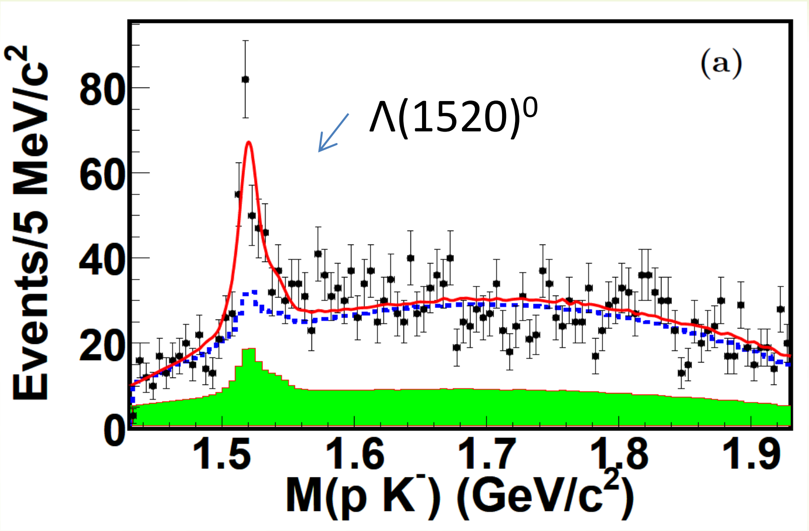
PRD 93, 1120137(2016)



- a simple Breit-Wigner plus a 2nd-order Chebychev function : signal significance is only 1.8σ at around 4.7 GeV/c^2 .
- Need larger data sample to check it.

Search for search for exotic baryons in pK systems in $\gamma\gamma \rightarrow p\bar{p}K^+K^-$

PRD 93, 1120137(2016)

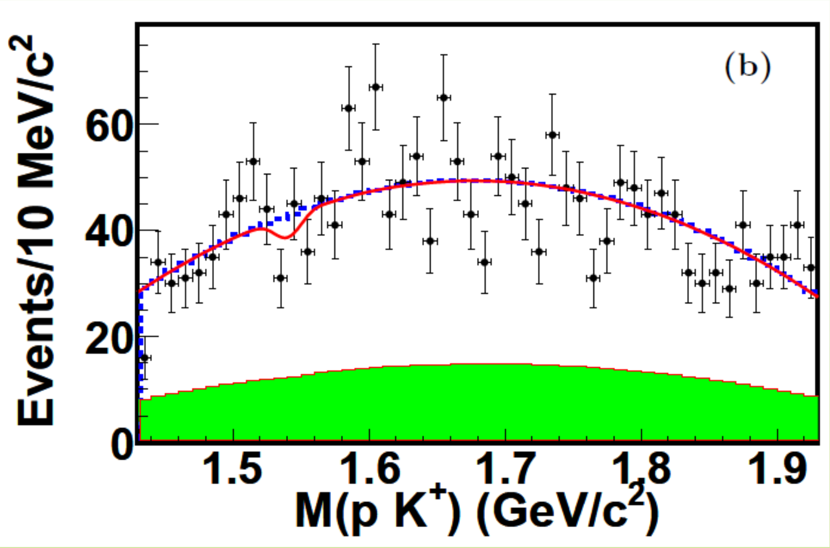


Simultaneous fit: $\Lambda(1520)^0$ and $\Theta(1540)^0$ signal are included.

The shaded histogram: $\sum Pt^*$ sideband

288 ± 48 $\Lambda(1520)^0$ events, 8.6σ

22 ± 34 $\Theta(1540)^0$ events, 1.4σ



Similar simultaneous fit: $\Theta(1540)^{++}$ signal

Solid line: the simultaneous fit

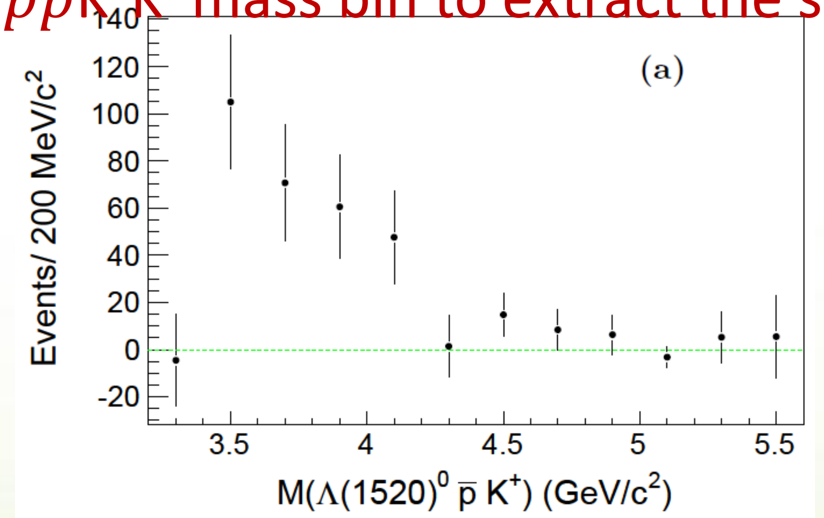
The dotted curve: background estimate

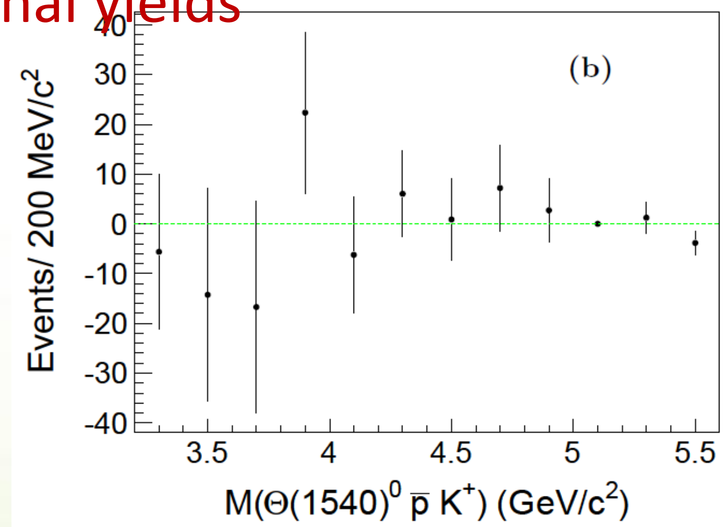
The shaded histogram: $\sum Pt^*$ sideband

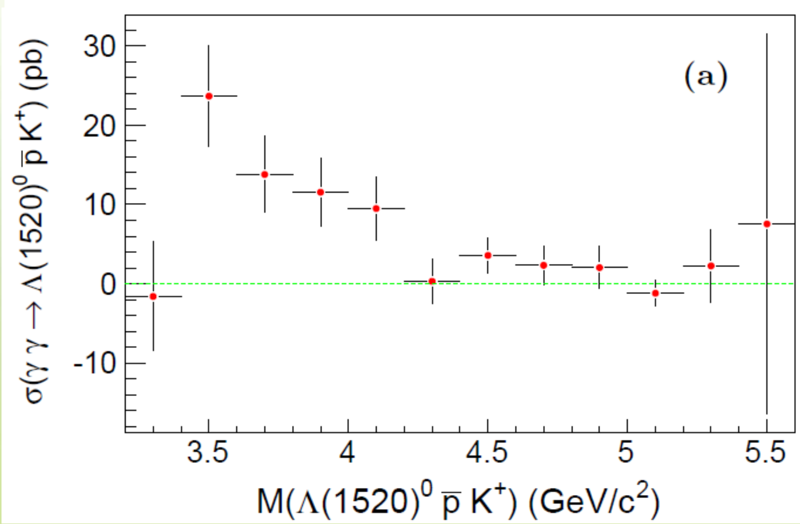
-16 ± 34 $\Theta(1540)^{++}$ events

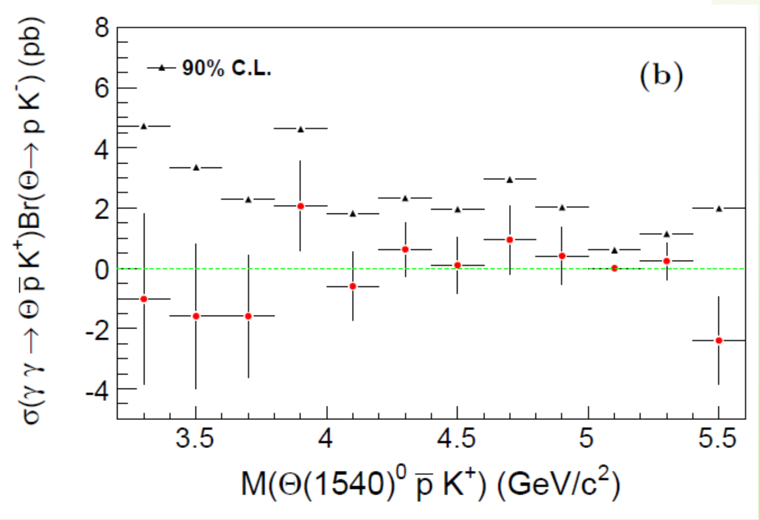
Search for search for exotic baryons in pK systems in $\gamma\gamma \to p\bar{p}K^+K^-$

Do simultaneous fit to the pK^- invariant mass distribution in each $p\bar{p}K^+K^-$ mass bin to extract the signal yields



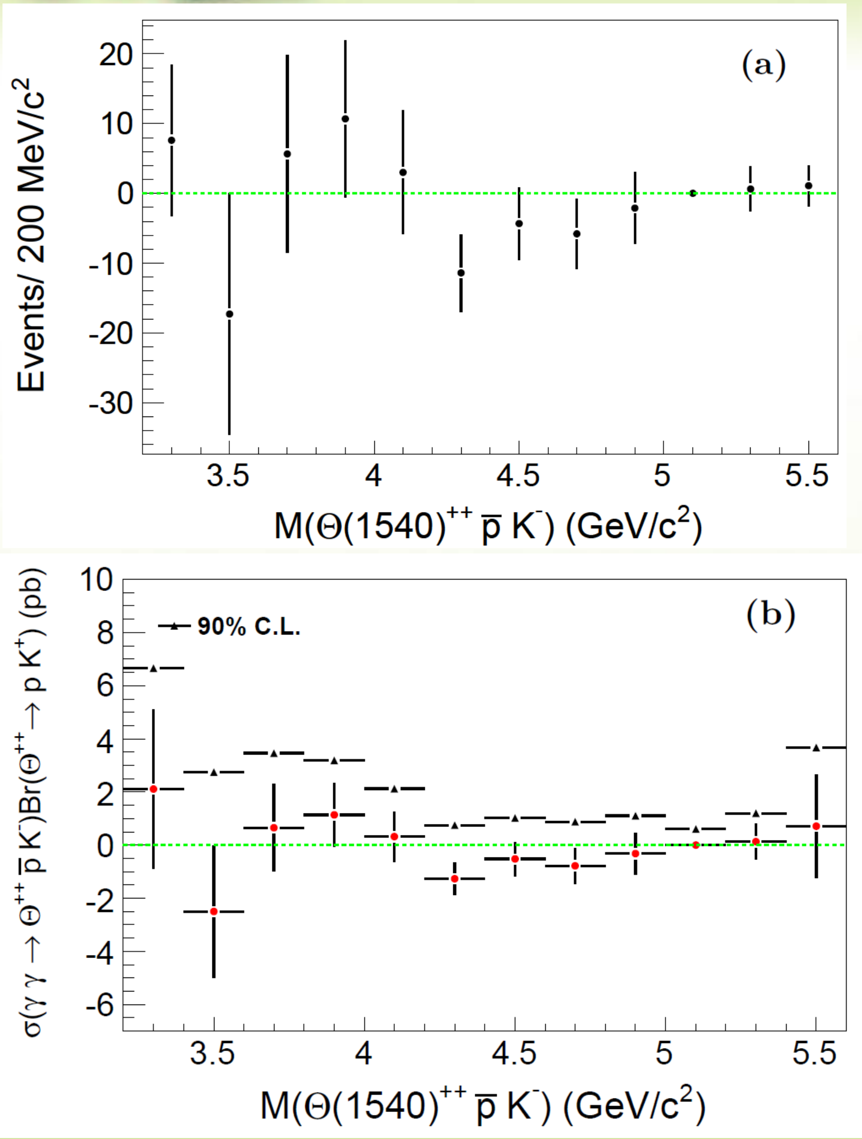






Search for search for exotic baryons in pK systems in $\gamma\gamma \to p\bar{p}K^+K^-$

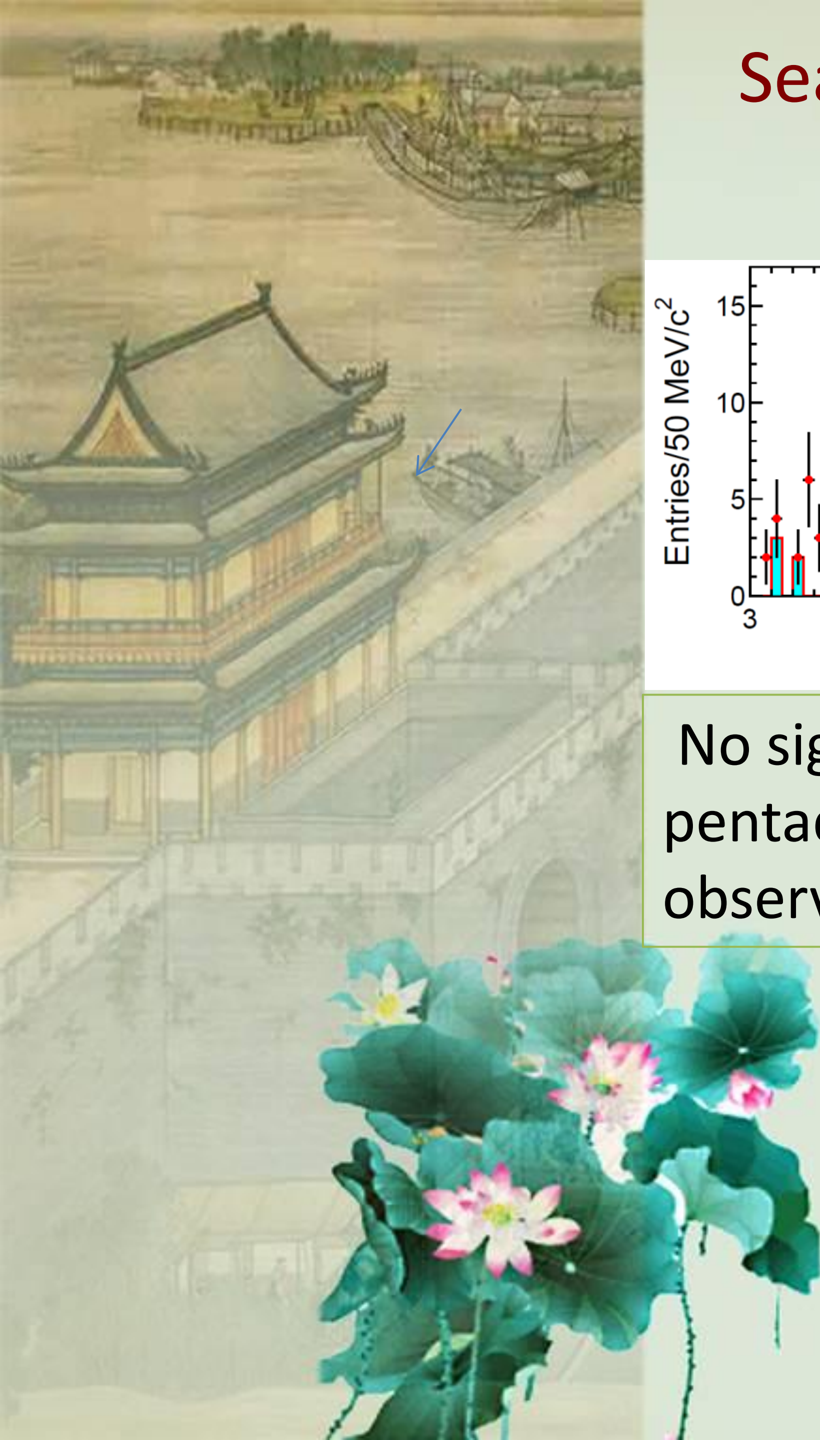
PRD 93, 1120137(2016)



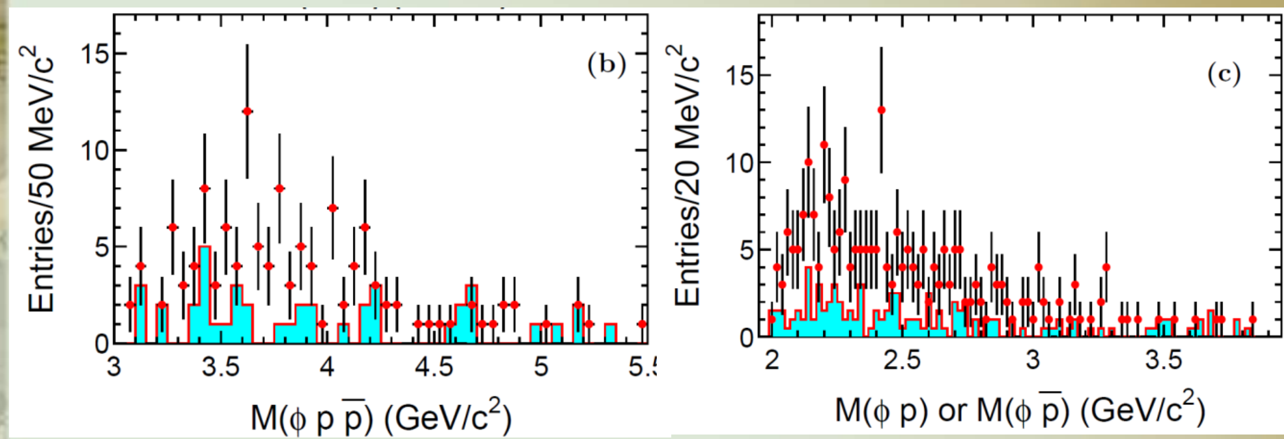
Do simultaneous fit to the pK$^+$ invariant mass distribution in each $p\bar{p}$K$^+$K$^-$ mass bin to extract the signal yields

No evidence of any Θ(1540)^0 or Θ(1540)$^{++}$ could be seen in p K- or pK+ invariant mass spectrum.

All the cross sections are measured for the first time.

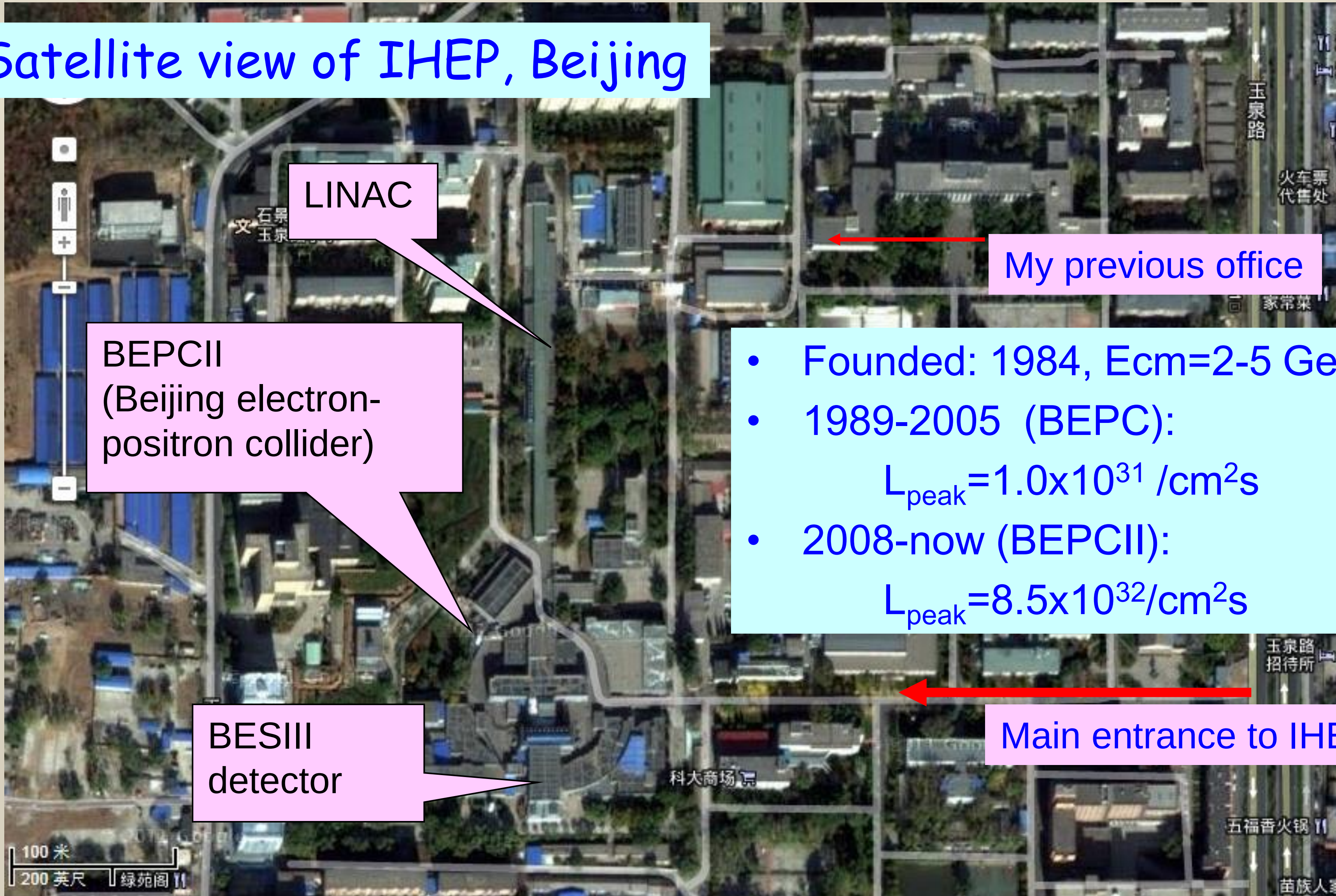


Search for search for exotic baryons in pK systems in $\gamma\gamma \to p\bar{p}K^+K^-$



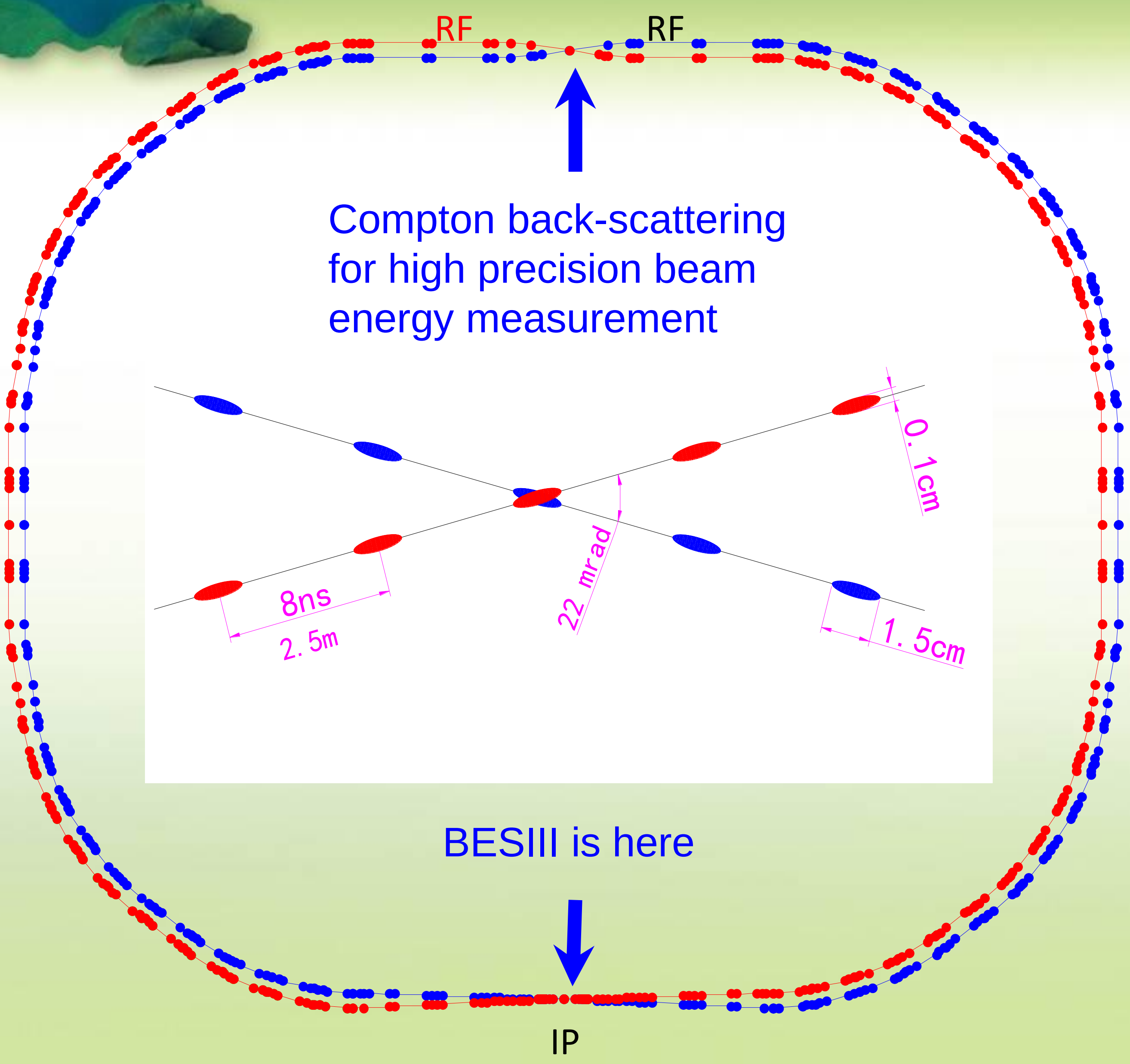
No significant evidence of an $s\bar{s}$ partner of the pentaquark states Pc(4380) and Pc(4450) is observed.

Beijing Electron Positron Collider (BEPC)



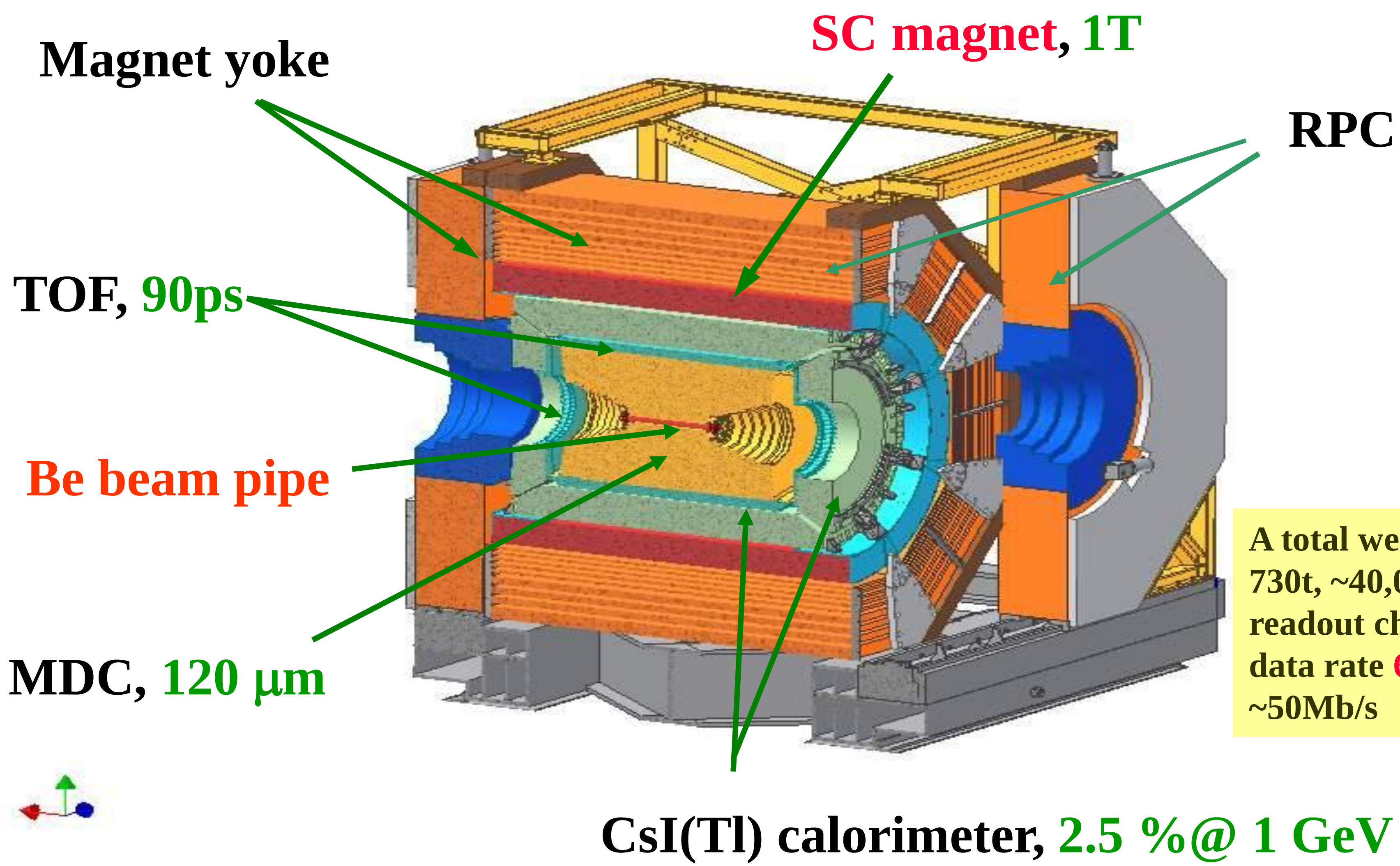
- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2008-now (BEPCII):
  L_{peak}=8.5x10^{32}/cm^{2}s

BEPC II: a double-ring machine



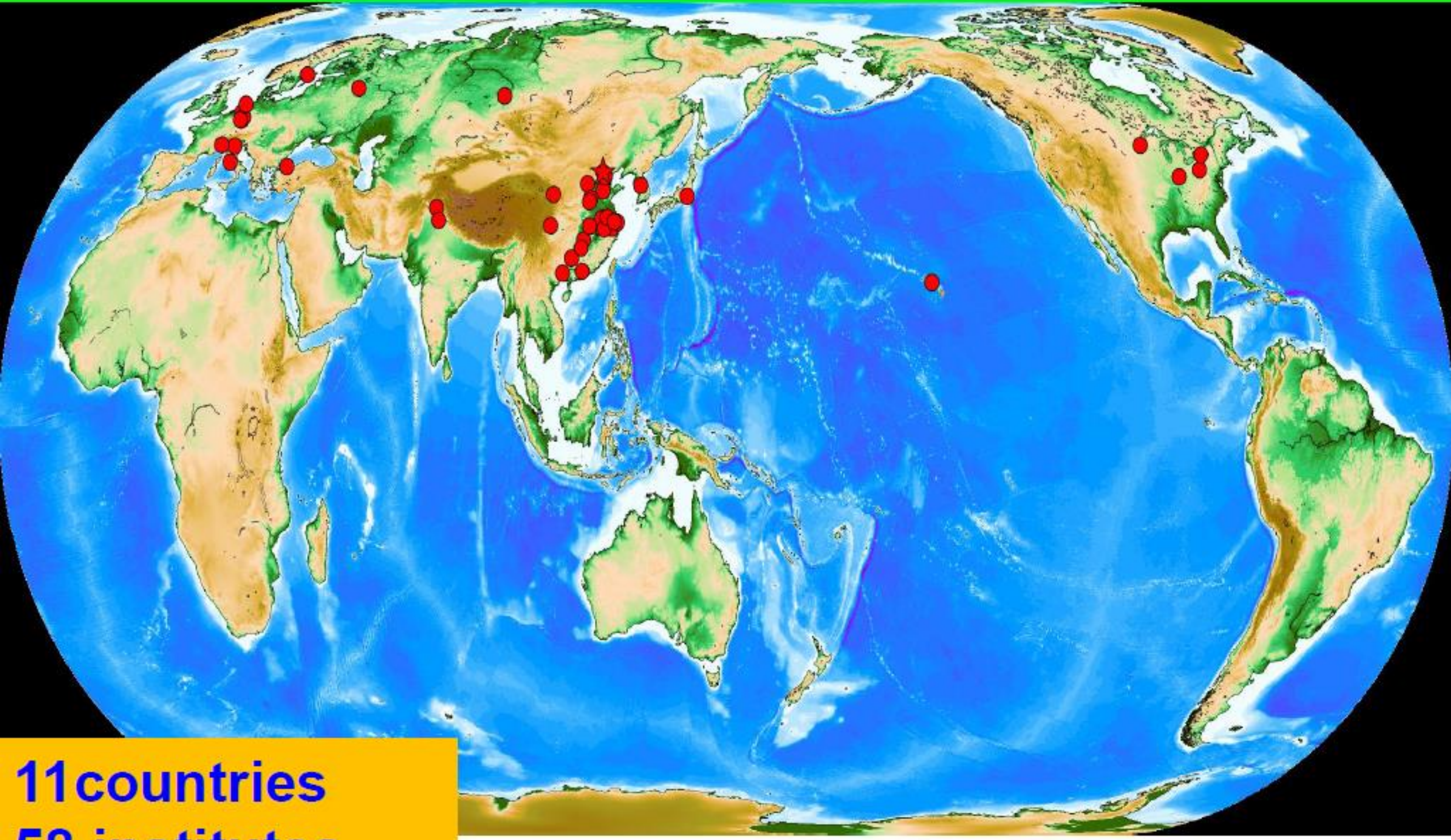
Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

The BESIII Detector



A total weight of 730t, ~40,000 readout channels, data rate 6,000Hz ~50Mb/s

The BESIII Collaboration

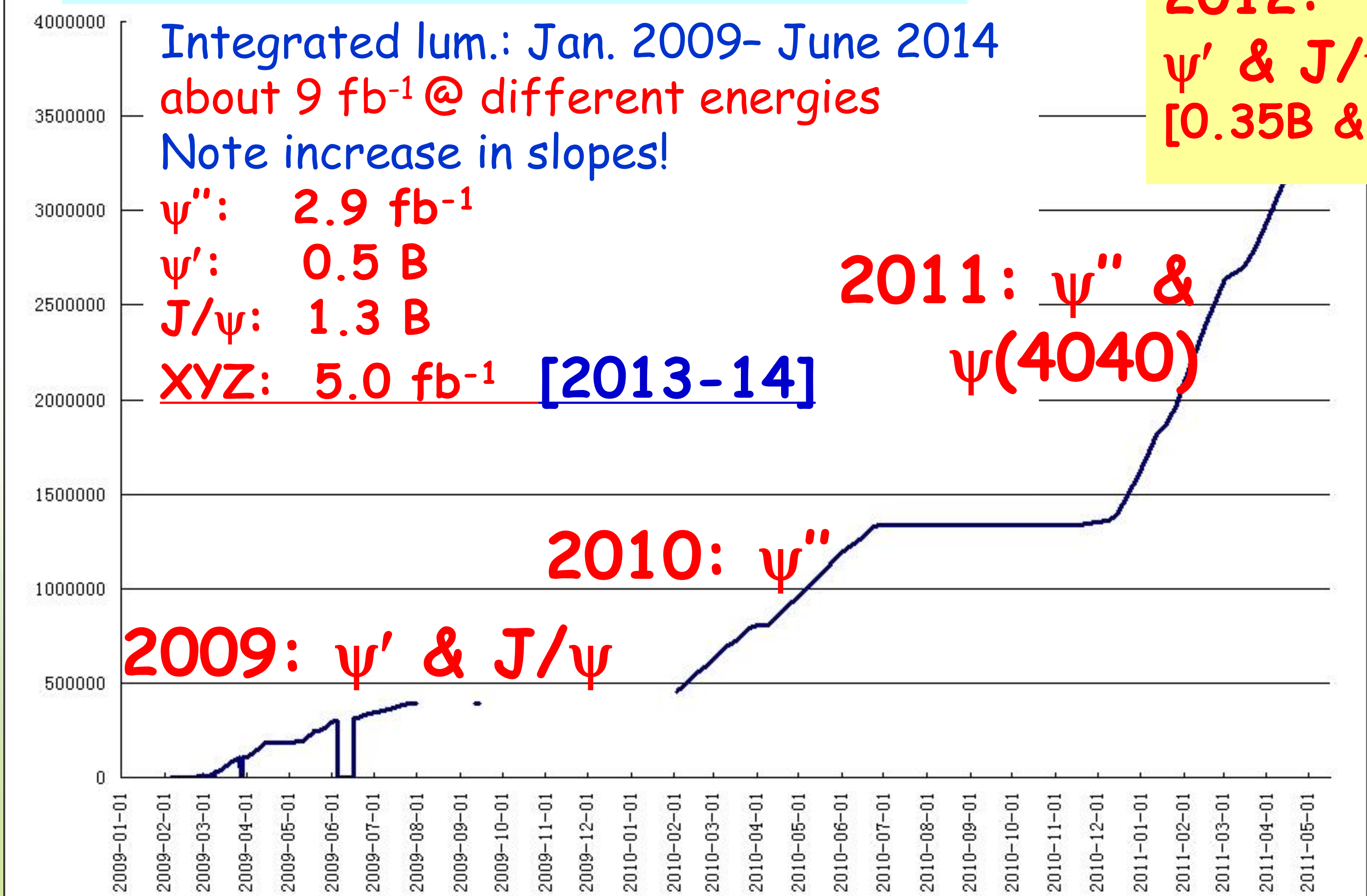


11countries
58 institutes
~450 members

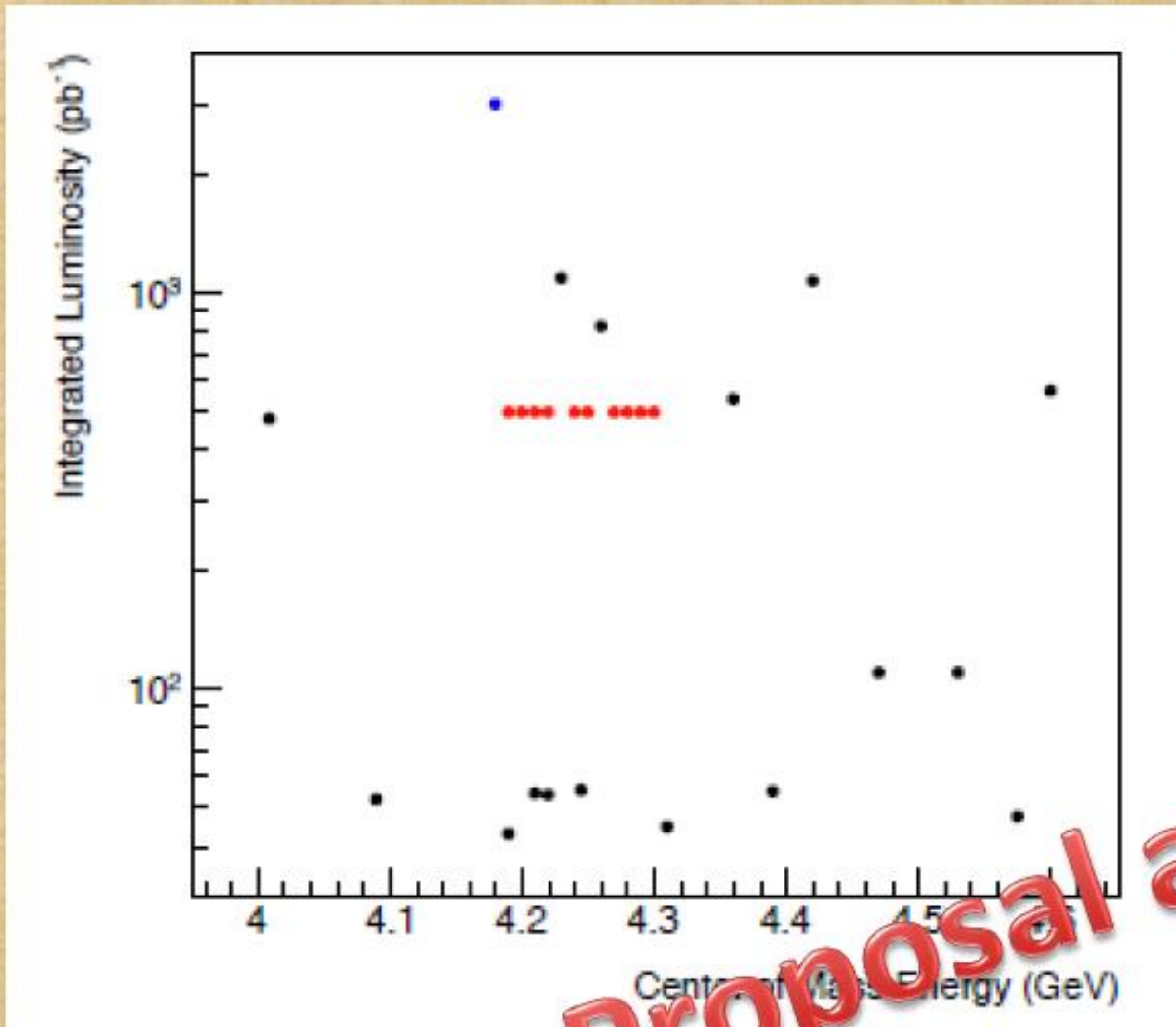
BESIII data samples

Note that luminosity is lower at J/ψ, and machine is optimal near ψ″ peak

2012: ψ′ & J/ψ [0.35B & 1.0B]



Data will come in 2017



Proposal approved

The XYZ topics

Searches for more Z_c states

- $Z_c(3900)$ J^{PC}
- $Z_c(3900) \rightarrow \rho\eta_c$
- $Z_c(3900) \rightarrow \gamma\eta_c(2S)$ or $\gamma\chi_{c0}$
- $Z_c(4040) \rightarrow \pi^0\psi'$
- $Zc(4040) \rightarrow \pi^+\psi'$
- $e^+e^- \rightarrow \gamma\eta_{c2}(^1D_2)$
- $e^+e^- \rightarrow \pi^+\pi^- X(3823)$
- $Zc(3900) \rightarrow J/\psi\eta$ in $J/\psi\eta\eta$
- $e+e- \rightarrow \eta_c\eta\ \pi\pi$ for Z(xxxx)
- $e+e- \rightarrow \chi_{c1/2}\pi\ \pi$ for Z(4050)
- …….

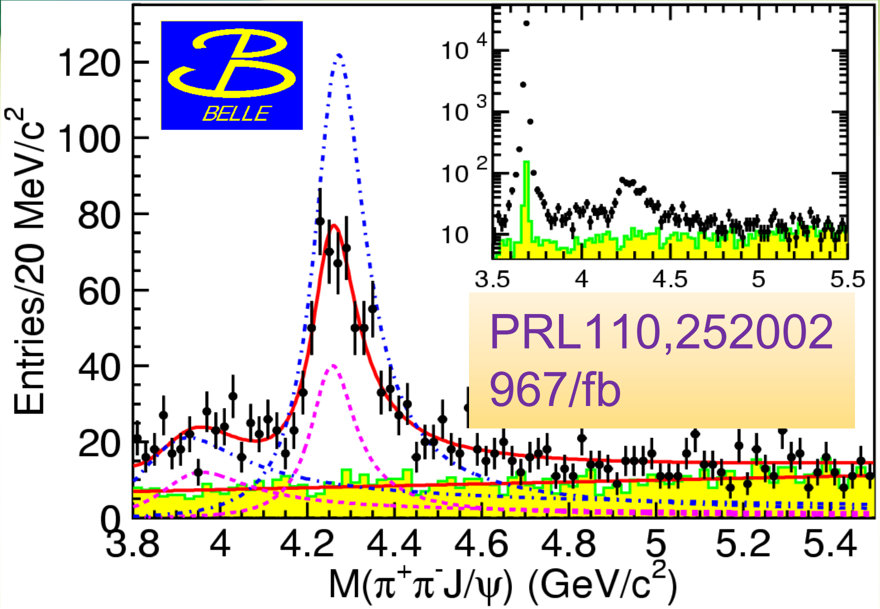
Open charm cross section

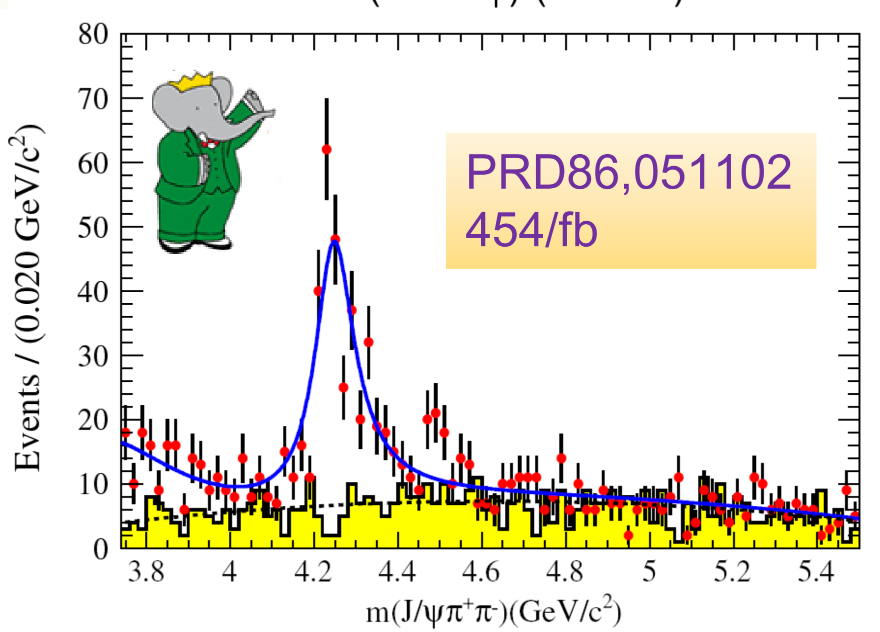
- $e^+e^- \rightarrow D+X$
- $e^+e^- \rightarrow DD$
- $e^+e^- \rightarrow D_s^+D_s^-$
- $e^+e^- \rightarrow D_s D_s^*$
- $e^+e^- \rightarrow D_s^* D_s^*$
- $e^+e^- \rightarrow D_2(2460)D \rightarrow DD\pi$
- $e^+e^- \rightarrow DD^*\pi$
- $e^+e^- \rightarrow \pi^+\pi^- DD$
- ……

Cross-section of non-DDbar

- $e^+e^- \rightarrow \gamma X(3872)$ (finish)
- $e^+e^- \rightarrow \gamma\chi_{cJ}$ (finished)
- $e^+e^- \rightarrow \gamma X(4140)$ (finish
- $e^+e^- \rightarrow \gamma\eta_c$
- $e^+e^- \rightarrow \pi^+\pi^- h_c$
- $e^+e^- \rightarrow \pi^+\pi^- J/\psi$
- $e^+e^- \rightarrow \omega J/\psi$
- $e^+e^- \rightarrow KKJ/\psi$
- $e^+e^- \rightarrow \eta\ h_c$
- $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta_c$, $\pi\rho\eta_c$
- $e^+e^- \rightarrow \mu^+\mu^-$
- $e^+e^- \rightarrow \eta Y(2175)$
- $e^+e^- \rightarrow \phi\ \chi_{cJ}$
- $e^+e^- \rightarrow \eta'\ J/\psi$
- $e^+e^- \rightarrow \eta\ \psi'$

The Y states





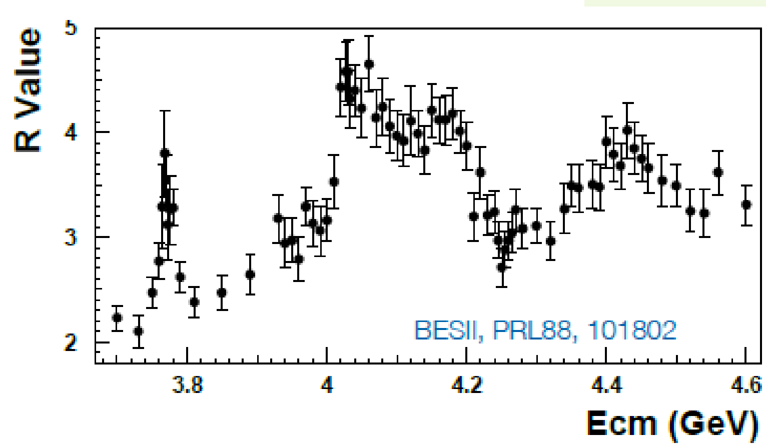
e^+e^- collisions near $\Upsilon(4S)$

in ISR production

$e^+e^- \to \gamma_{ISR} J/\psi\,\pi^+\pi^-$

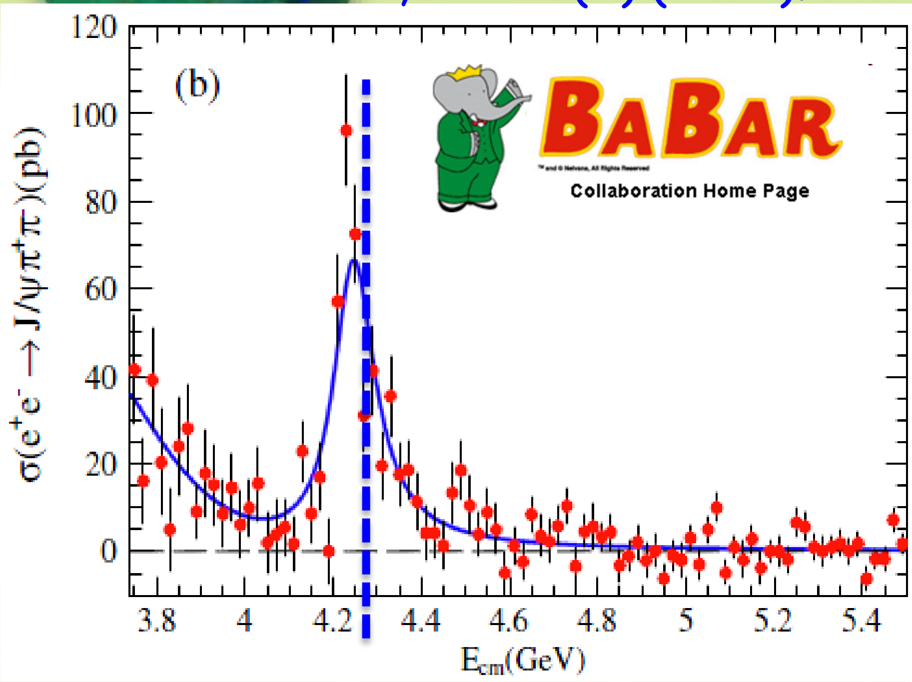
$\Rightarrow J^{PC} = 1^{--}$

- $Y(4008) \to J/\psi\,\pi^+\pi^-$?
- $Y(4260) \to J/\psi\,\pi^+\pi^-$
- $Y(4360) \to \psi(2S)\pi^+\pi^-$
- $Y(4630) \to \psi(2S)\pi^+\pi^-$
- $Y(4660) \to \Lambda_c^+\overline{\Lambda_c^-}$

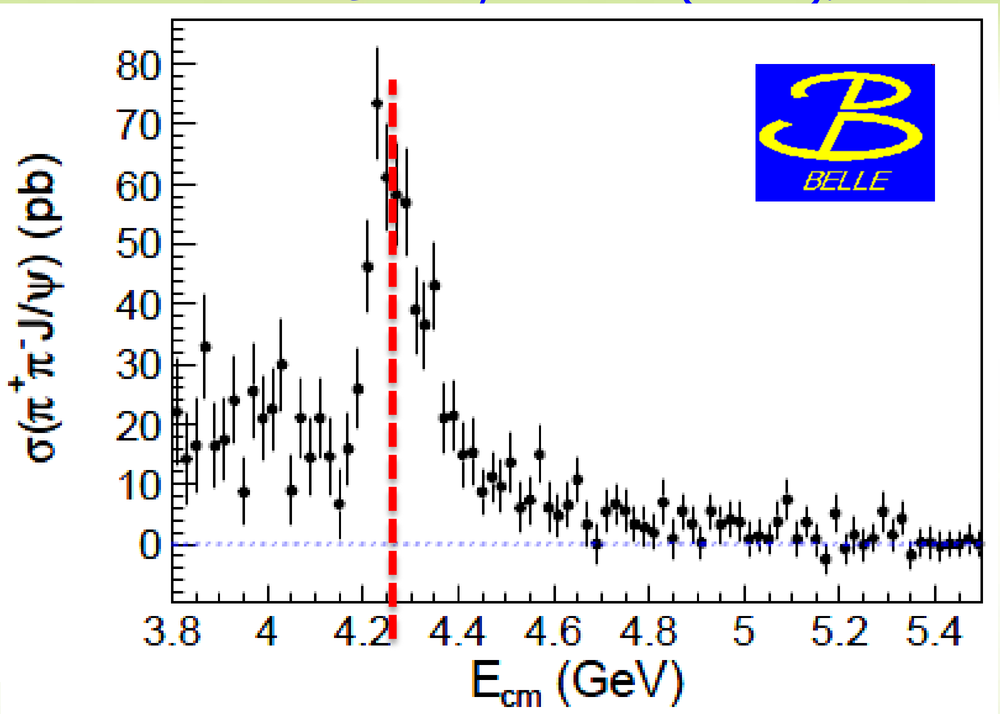


Y(4260) point at BESIII

PRD **86**,051102(R) (2012).

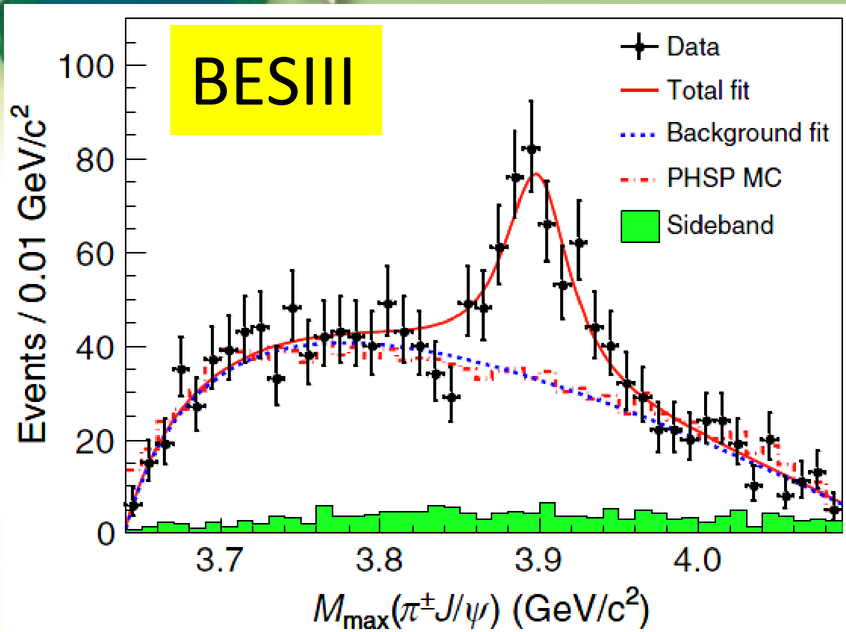


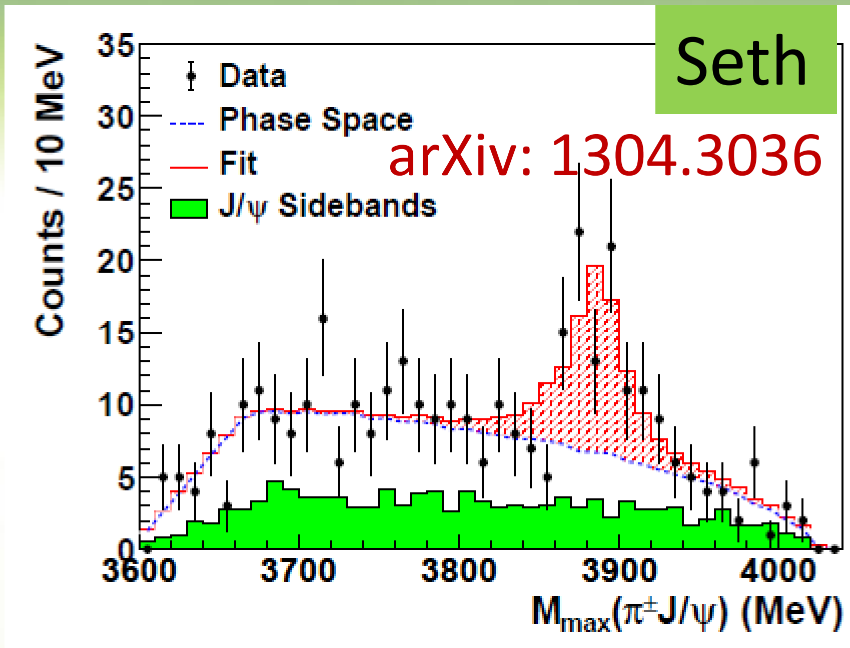
PRL **110**,252002 (2013).

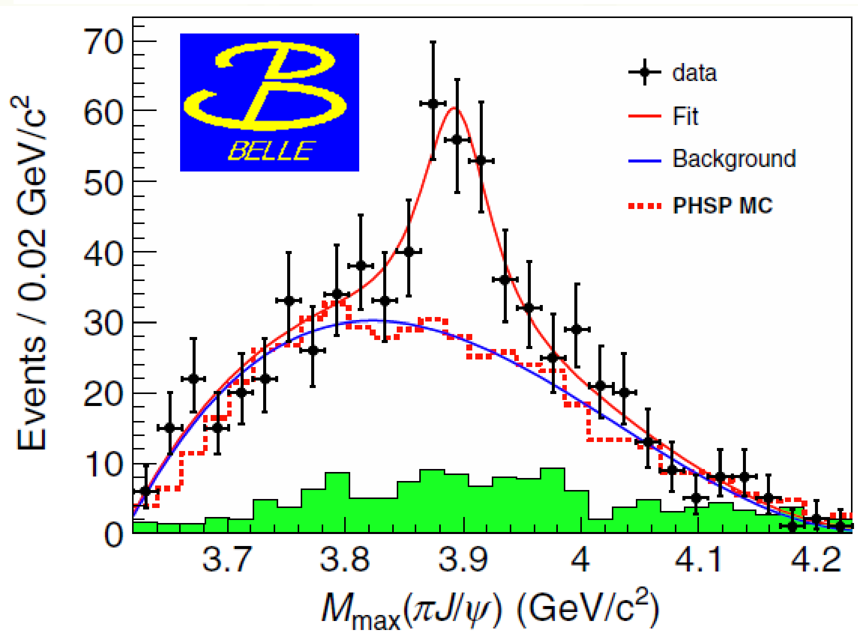


1. Dec, 2012 to Jan, 2013, BESIII accumulate 525 pb^{-1} data @ 4.26 GeV.
2. Peak position of Y(4260)→$\pi^+\pi^- J/\psi$ cross section.
3. $N(\mu+\mu-)=882\pm33$; $N(e+e-)=595\pm28$; purity ~90%.
4. Born cross section: $\sigma^B=(62.9\pm1.9\pm3.7)$ pb at BESIII. PRL **110**, 251002
5. Good agreement with Belle and BaBar.

BESIII + Belle + CLEO's data







HEP 找到 **1** 笔记录

1. **Observation of a Charged Charmoniumlike Structure**

BESIII Collaboration (M. Ablikim (Beijing, Inst. High Energy Phys.) *et al.*).
Published in **Phys.Rev.Lett. 110 (2013) 252001**
DOI: 10.1103/PhysRevLett.110.252001
e-Print: **arXiv:1303.5949 [hep-ex]** | **PDF**

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Interactions.org article; Link to WIRED; phys

详细记录 - Cited by 421 records 250+

PWA on Zc(3900) state

preliminary

In the process $e^+e^- \to \gamma^* \to \pi^+\pi^- J/\psi$

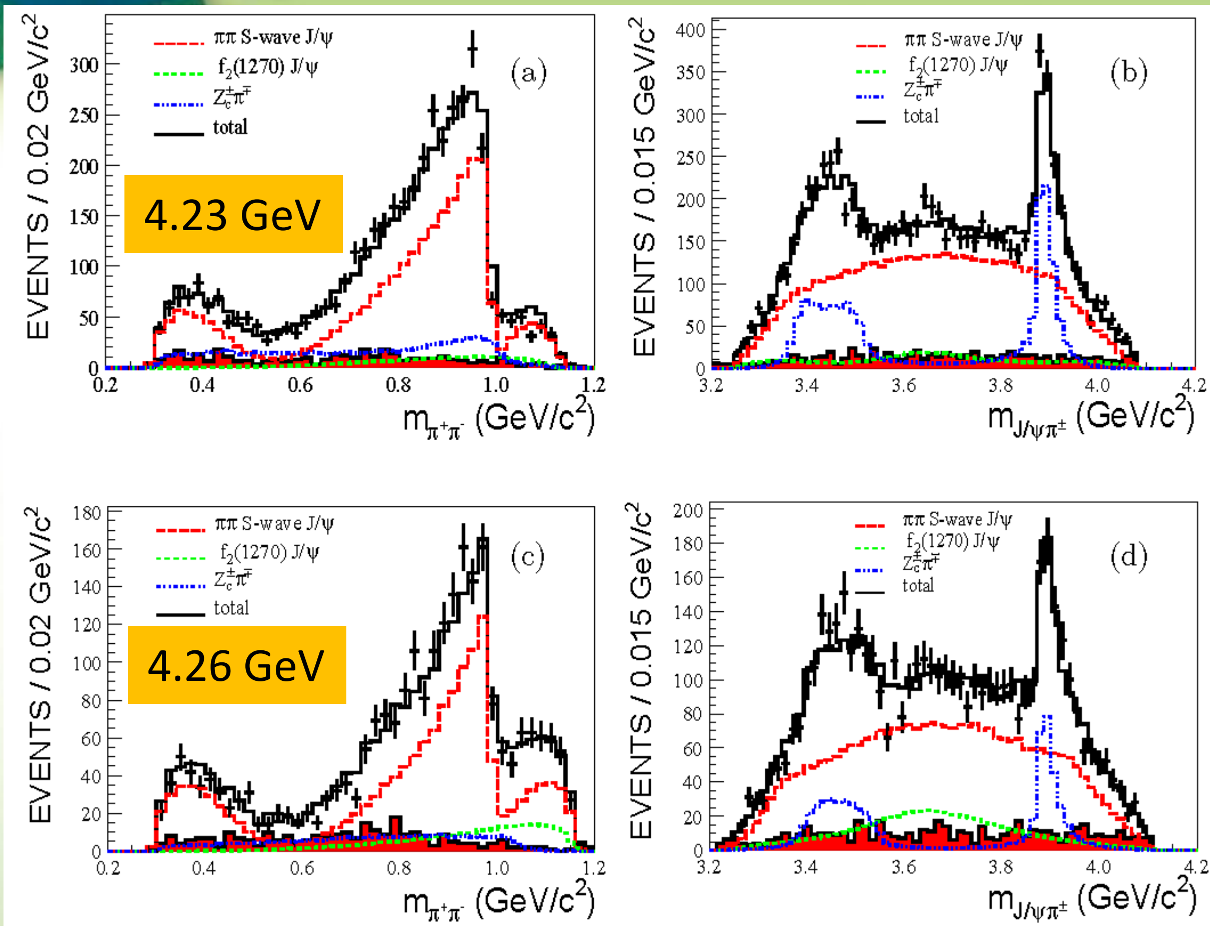
- **The helicity value of γ^* is taken as $\lambda_0 = \pm 1$ due to from e+e- annihination**
- $\gamma^* \to Z_c^\pm \pi^\mp, Z_c^\pm \to J/\psi\pi^\pm$, **we try J^P for X:** $0^-, 1^-, 1^+, 2^-, 2^+$, **and 0^+ is not allowed**
- **Z_c^+ and Z_c^- states are assumed as isospin partner, share the same mass and coupling constants**
- **Six resonances are inclued in fitting to data:**

$$\sigma_0, f_0(980), f_2(1270), f_0(1370), Z_c^\pm, \text{and } \pi^+\pi^- J/\psi$$

Z_c is taken as 1^+.

Resonance	σ	$f_0(980)$	$f_2(1270)$	$f_0(1370)$	Z_c^+	Z_c^-
Significancσ	13	25	5	11	22	22

PWA on Zc(3900) state



- Zc line shape parameterized with Flatte-like formula

$$g_2'/g_1' = 27.1 \pm 13.1$$

$$\Gamma(Z_c^\pm \to (D\bar{D}^*)^\pm)/\Gamma(Z_c^\pm \to J/\psi\pi^\pm) = 6.2 \pm 2.9$$

preliminary

The signal yields corresponding for each mode with the $Z_c^\pm$ assignment $J^P = 1^+$

$\sqrt{s}$	σ	$f_0(980)$	$f_2(1270)$	$f_0(1370)$	$Z_c^+ + Z_c^-$	$\pi^+\pi^- J/\psi$
4.23 GeV	1576.9±431.2	1050.2±157.8	4356.2±549.4	273.2±85.1	875.2±84.8	6.2±7.6
4.26 GeV	1121.5±112.0	465.1 ± 53.2	2236.8±157.6	308.8±108.2	314.2±21.2	15.9±39.3

Comparison of fit results

- Mass, g_1' and Log-likelihood

preliminary

$Z_c : J^P$	M (MeV)	$g_1'(\mathrm{GeV}^2)$	g_2'/g_1'	$-\ln L$
0^-	3906.3 ± 2.3	0.079 ± 0.007	25.8 ± 2.9	-1528.8
1^-	3903.1 ± 1.9	0.063 ± 0.005	26.5 ± 2.6	-1457.7
1^+	3900.2 ± 1.5	0.075 ± 0.006	21.8 ± 1.7	-1569.8
2^-	3905.2 ± 2.1	0.060 ± 0.004	28.7 ± 2.7	-1516.5
2^+	3894.3 ± 1.9	0.051 ± 0.005	23.4 ± 3.3	-1316.2

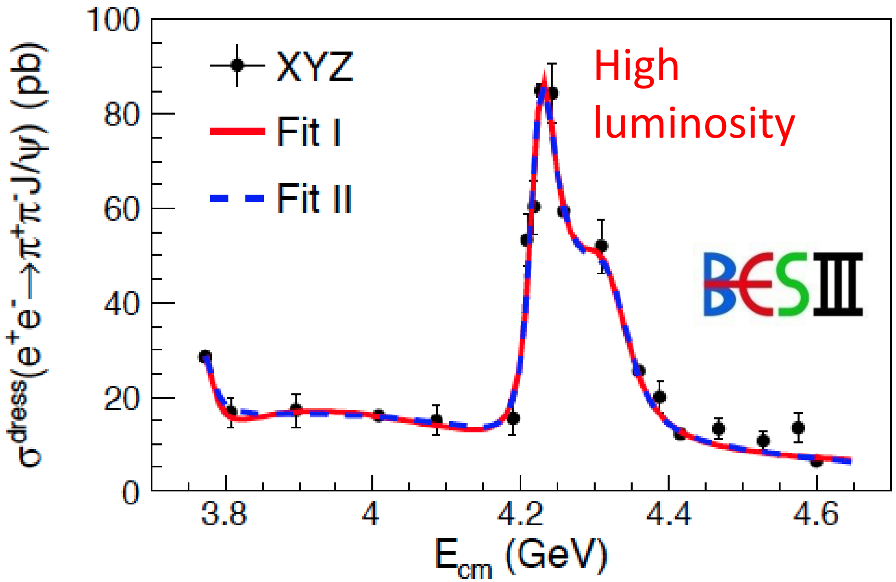
- Zc favors the quantum number $J^P=1^+$

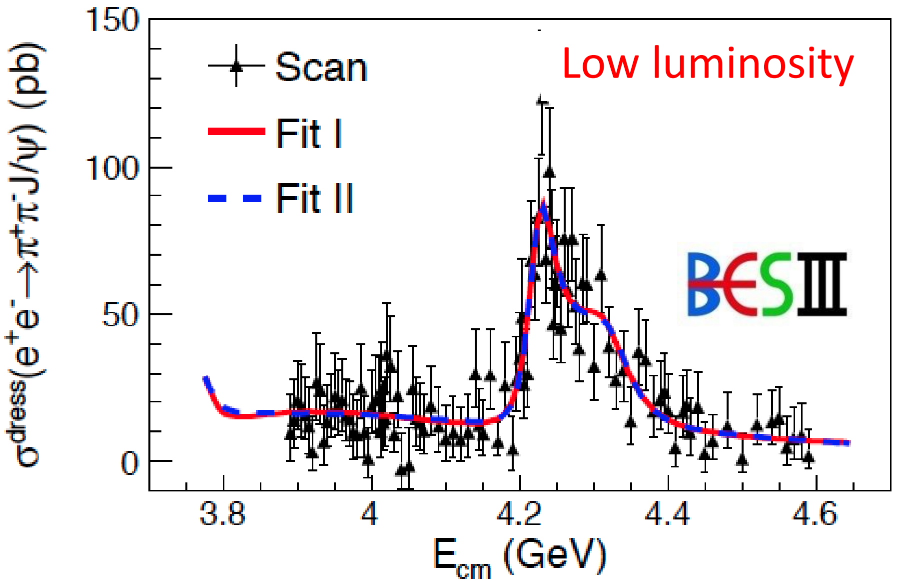
Significance to distinguish the quantum number 1^+ over other quantum numbers.

Hypothesis	$\Delta(-\ln L)$	$\Delta(ndf)$	significance
1^+ over 0^-	44.5	$4\times2+5$	7.3σ
1^+ over 1^-	107.0	$4\times2+5$	$>8.0\sigma$
1^+ over 2^-	51.8	$4\times2+5$	$>8.0\sigma$
1^+ over 2^+	193.5	$4\times2+5$	$>8.0\sigma$

Precise cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ at BESIII

arXiv:1611.01317



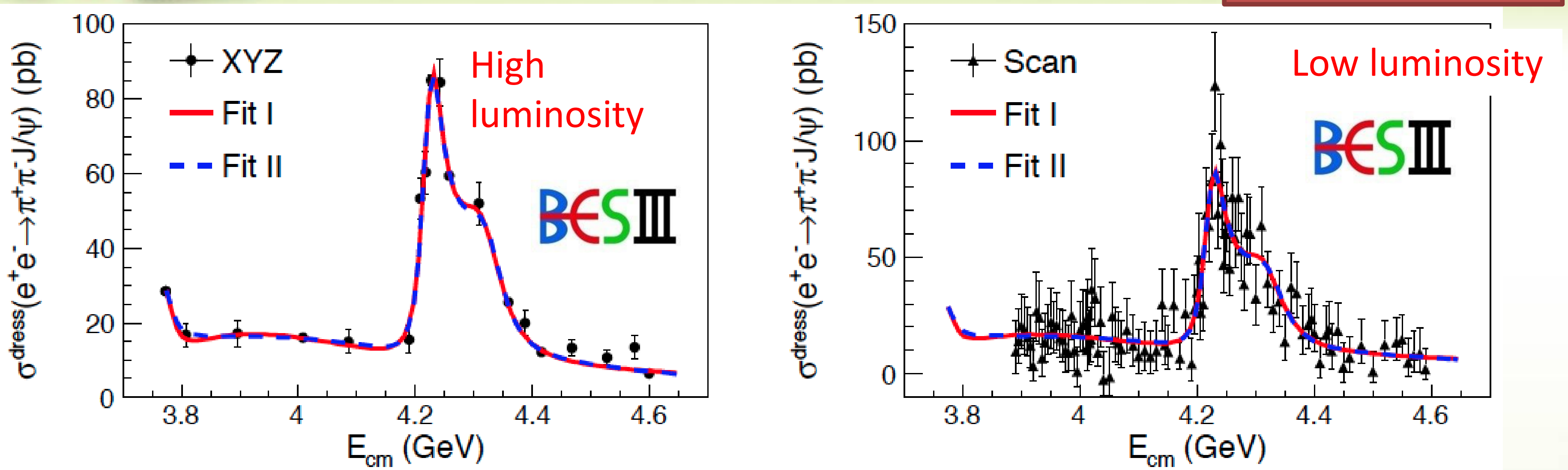


- The $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ was measured with improved precision with BESIII data.
- Fit with three coherent BW resonances (Fit I); or coherent sum of an exponential and two BW resonances (Fit II).

- The 1st resonance R1 is similar to Y(4008) by Belle, however can not be confirmed.
- The 2nd resonance R2 is similar to Y(4260), but with lower mass & width.
- The 3rd resonance R3 have a significance > 7.7σ, nature unclear.

Precise cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ at BESIII

arXiv:1611.01317



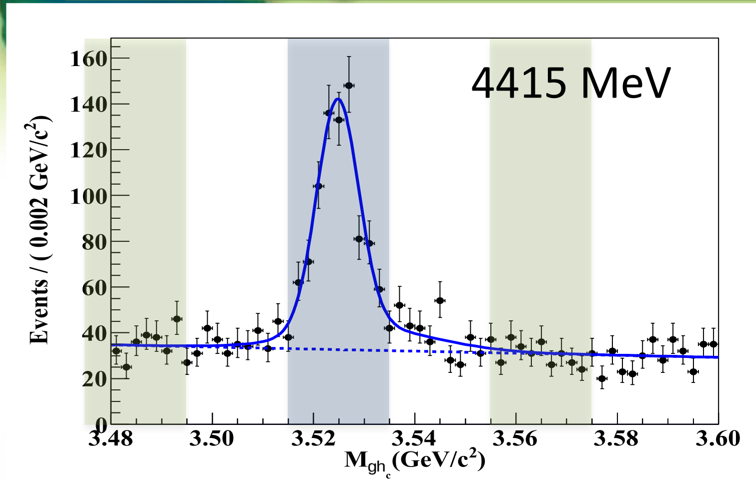
Parameter	Fit 1 / MeV	Fit 2 / MeV
$M(R_1)$	$3812.6^{+61.9}_{-96.6}$	...
$\Gamma_{tot}(R_1)$	$476.9^{+78.4}_{-64.8}$	...
$M(R_2)$	4222.0 ± 3.1	4220.9 ± 2.9
$\Gamma_{tot}(R_2)$	44.1 ± 4.3	44.1 ± 3.8
$M(R_3)$	4320.0 ± 10.4	4326.8 ± 10.0
$\Gamma_{tot}(R_3)$	$101.4^{+25.3}_{-19.7}$	$98.2^{+25.4}_{-19.6}$

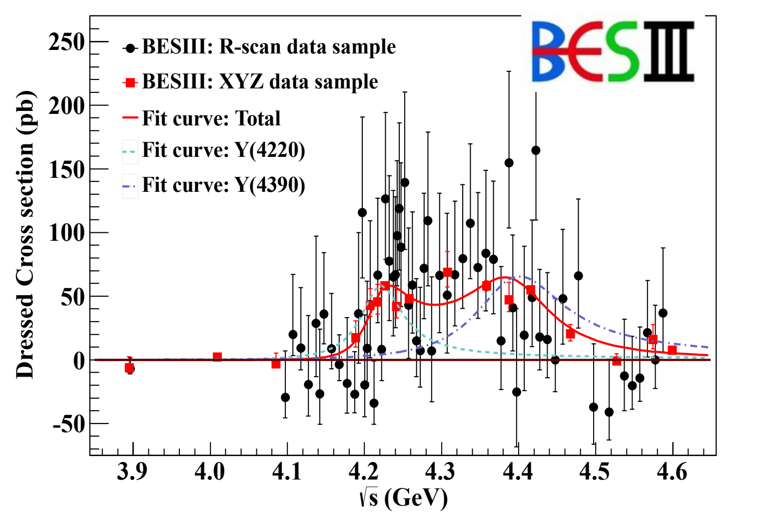
stat. errors only

- Lineshape more complicated than just a single resonance / structure
- $Y(4008)$ not needed to describe data
- Significances for R_2 and $R_3 > 7\sigma$
- $Y(4360) \to J/\psi \pi^+\pi^-$ seen?

Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- h_c$

arXiv:1610.07044





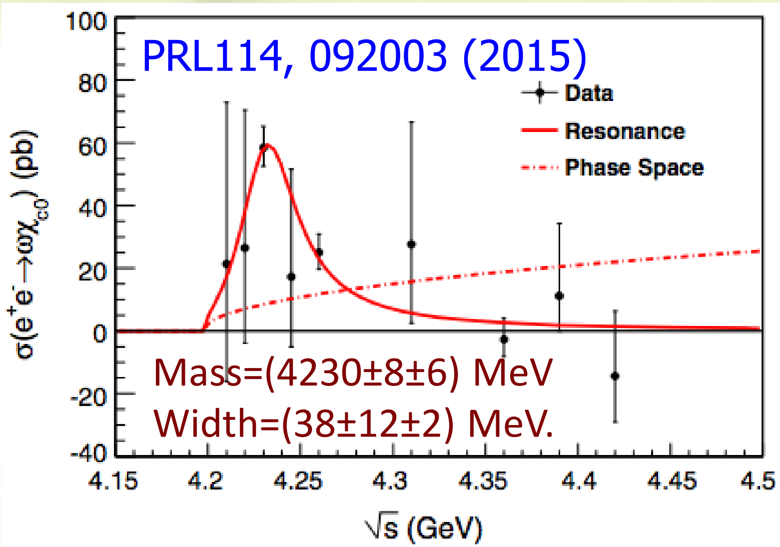
17 energy points from 3896 MeV to 4600 MeV ,total luminosity 5.26 fb^{-1} and 62 energy points from 4097 MeV to 4587 MeV, total luminosity: 0.51 fb^{-1}

- Decay channel: $\eta_c \rightarrow X_i$

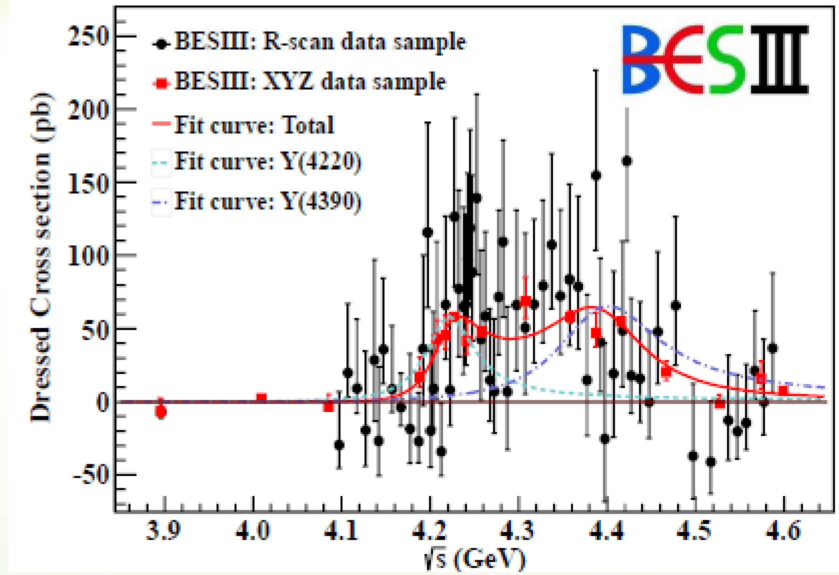
  X_i={pp-bar, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-$pp-bar, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$ +c.c., $K_S^0K^+\pi^-\pi^+\pi^-$ +c.c., $K^+K^-\pi^0$, pp-barπ^0, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$ }

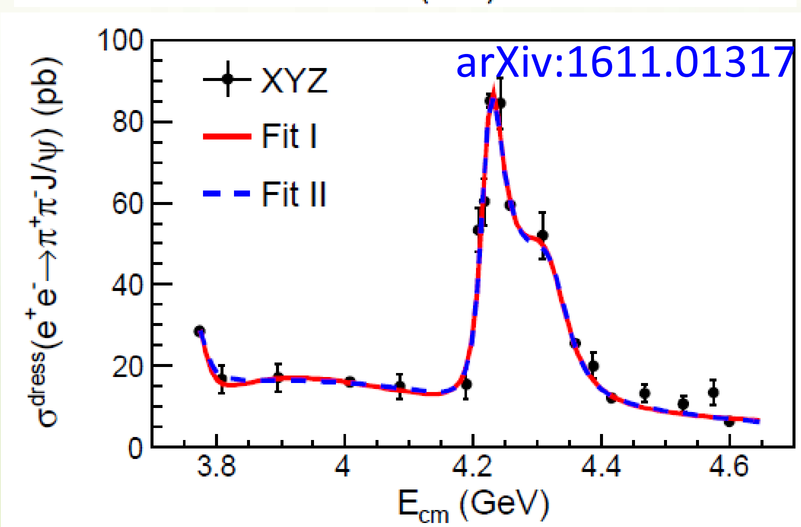
	M (MeV)	Γ_{tot} (MeV)	Γ_{ee}•Br (eV)	ϕ (rad)
Y(4220)	4218.4±4.0±0.9	66.0±9.0±0.4	4.6±4.1±0.8	--
Y(4390)	4391.6±6.3±1.0	139.5±16.1±0.6	11.8±9.7±1.9	3.1±1.5±0.2

"Y(4260)" in different channels?



arXiv:1610.07044





- In $\pi\pi J/\psi$, cross section peaks at lower than 4.26 GeV
- Possibly a narrow structure in $\omega\chi_{c0}$
  - ➢ simultaneous fit to all the modes?
  - ➢ Better model to parametrize the line shapes?

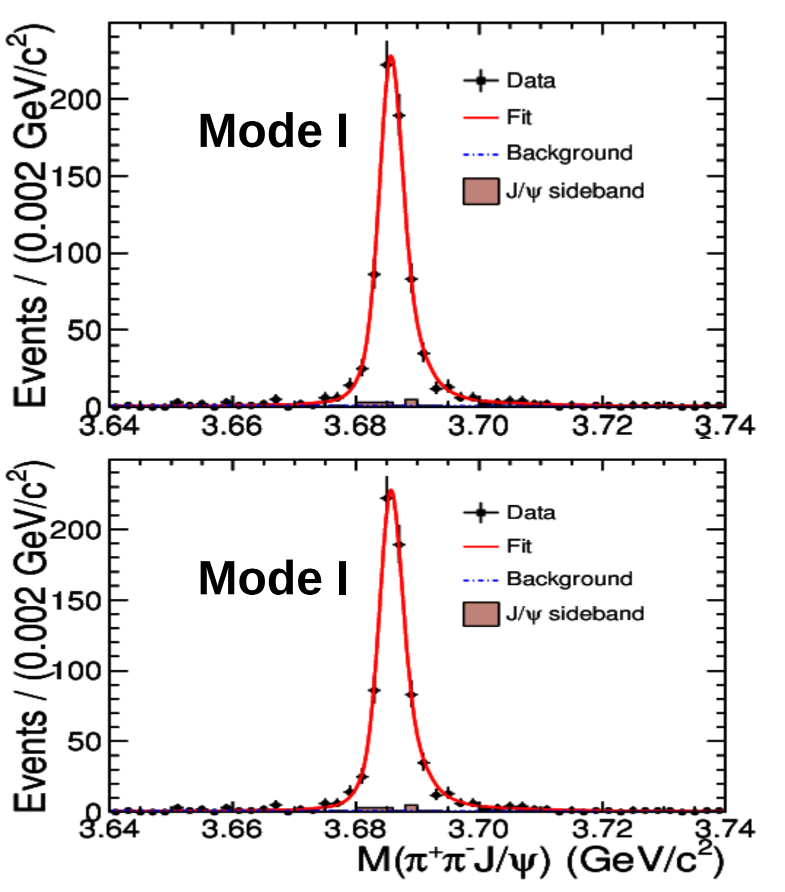
Comparsion of $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$ cross section

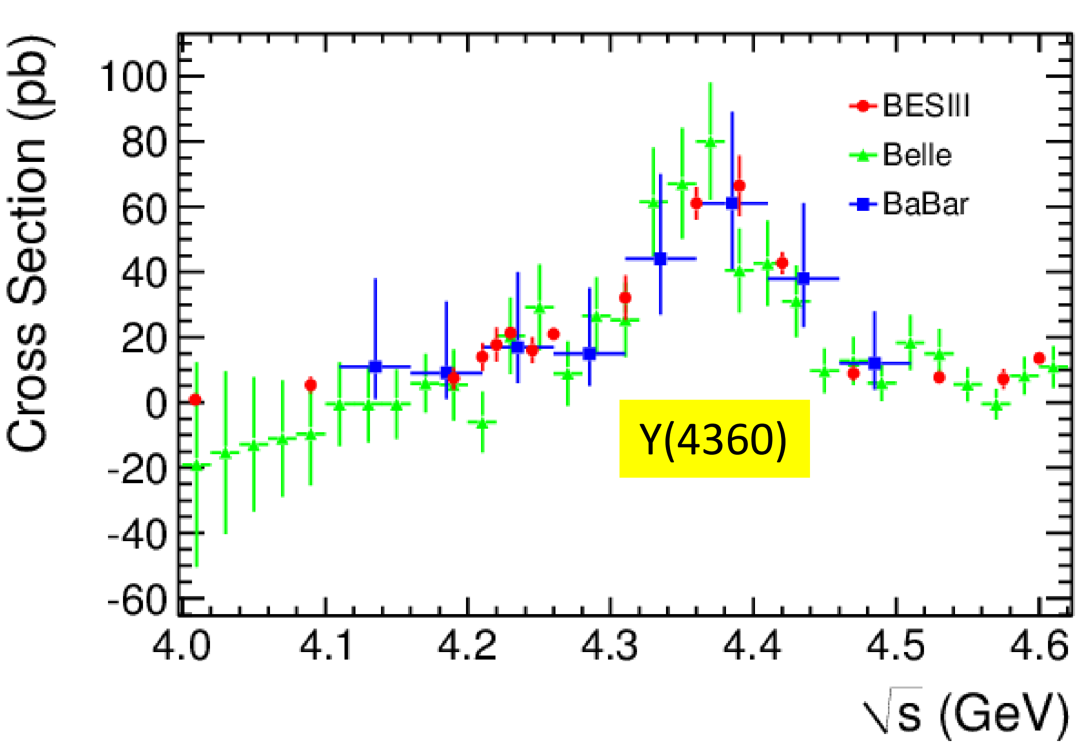
BESIII (16 energy points; L_{tot}=5.1fb^{-1})

ψ(2S) **Reconstructed modes:**

Mode I: $\Psi(3686)\rightarrow\pi^+\pi^- J/\psi$, $J/\psi\rightarrow l^+l^-$ (l=e/μ)

Mode II: $\Psi(3686)\rightarrow$*neutrals*+J/ψ, *neutrals*=($\pi^0\pi^0$, π^0, η and γγ) $J/\psi\rightarrow l^+l^-$ (l=e/μ)

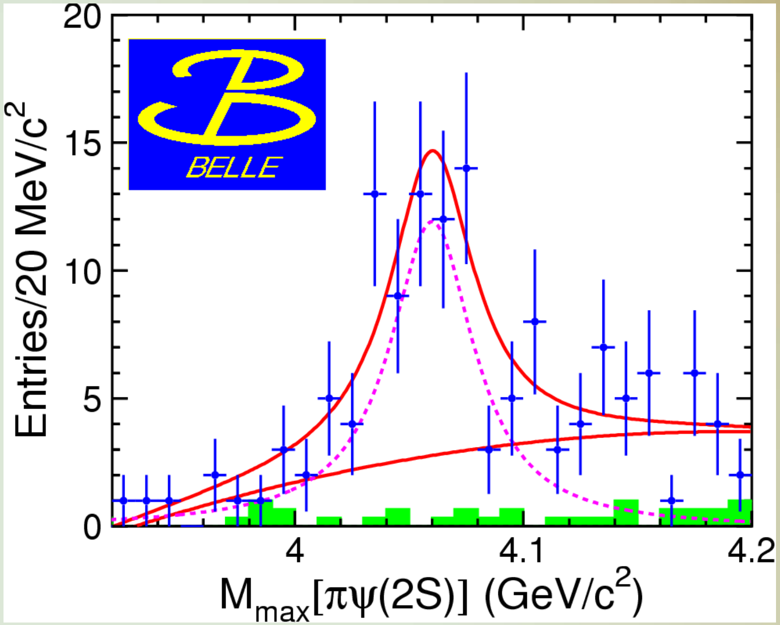




The measured Born cross sections of two modes are combined by considering the correlated and uncorrelated uncertainties.

$Z_c(4050)^{\pm} \rightarrow \pi^{\pm}\psi'$

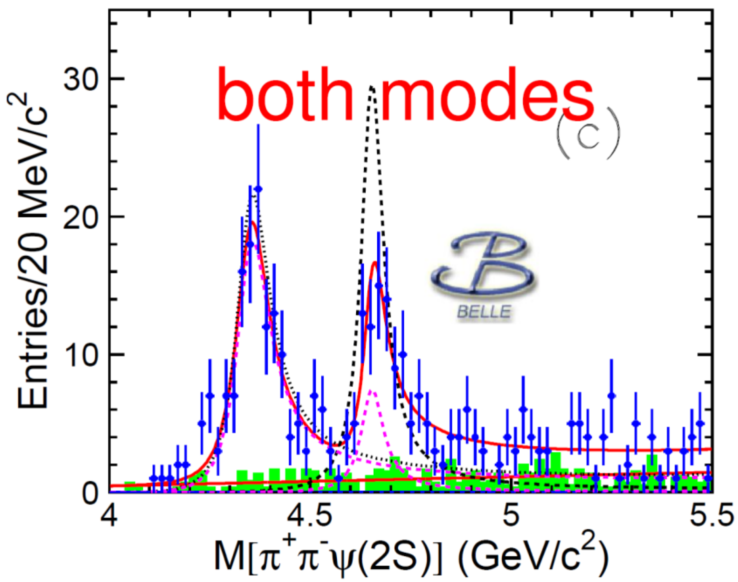
PRD91, 112007(2015)



- Y(4360) signal region
- $M(Z_c) = 4054 \pm 3 \pm 1$ MeV/c^2
- $\Gamma = 45 \pm 11 \pm 6$ MeV
- Significance: >**3.5σ**

Updated $e^+e^- \to \pi^+\pi^-\psi(2S)$ at Belle

PRD 91, 112007 (2015)

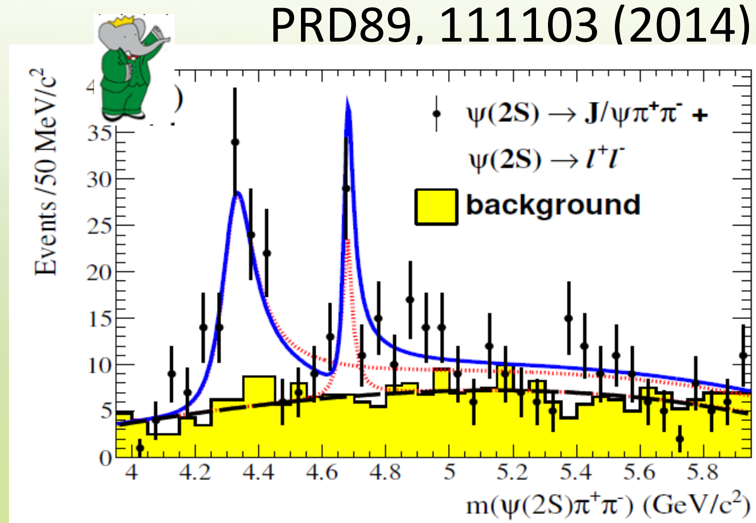


Parameters	Solution I	Solution II
$M_{Y(4360)}$ (MeV/c^2)	$4347 \pm 6 \pm 3$	
$\Gamma_{Y(4360)}$ (MeV)	$103 \pm 9 \pm 5$	
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4360)}$ (eV)	$9.2 \pm 0.6 \pm 0.6$	$10.9 \pm 0.6 \pm 0.7$
$M_{Y(4660)}$ (MeV/c^2)	$4652 \pm 10 \pm 11$	
$\Gamma_{Y(4660)}$ (MeV)	$68 \pm 11 \pm 5$	
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4660)}$ (eV)	$2.0 \pm 0.3 \pm 0.2$	$8.1 \pm 1.1 \pm 1.0$
ϕ (°)	$32 \pm 18 \pm 20$	$272 \pm 8 \pm 7$

$\chi^2/ndf = 18.7/21$.

- Consistent with previous measurement
- No obvious signal above $Y(4660)$.
- Some events accumulate at $Y(4260)$, especially the $\pi^+\pi^- J/\psi$ mode.
- If $Y(4260)$ is included in the fit, ...

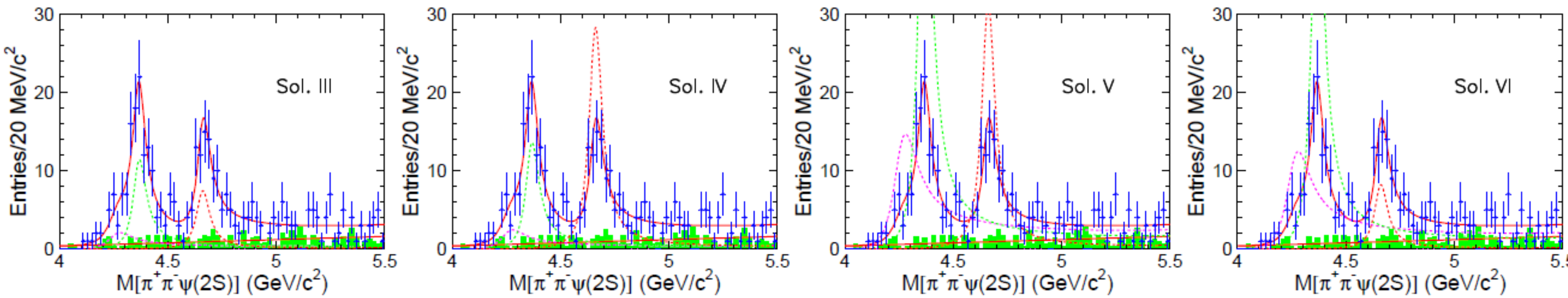
PRD89, 111103 (2014)



$M(\pi^+\pi^-\psi(2S))$ with Y(4260,4360,4660)

Unbinned simultaneous maximum likelihood fit for $Y(4260)$, $Y(4360)$ and $Y(4660)$. $Amp = BW_1 + e^{i\phi_1} \cdot BW_2 + e^{i\phi_2} \cdot BW_3$.

BELLE



Parameters	Solution I	Solution II	Solution III	Solution IV
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4260)}$ (eV)	$1.5 \pm 0.6 \pm 0.4$	$1.7 \pm 0.7 \pm 0.5$	$10.4 \pm 1.3 \pm 0.8$	$8.9 \pm 1.2 \pm 0.8$
$M_{Y(4360)}$ (MeV/c^2)		$4365 \pm 7 \pm 4$		
$\Gamma_{Y(4360)}$ (MeV)		$74 \pm 14 \pm 4$		
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4360)}$ (eV)	$4.1 \pm 1.0 \pm 0.6$	$4.9 \pm 1.3 \pm 0.6$	$21.1 \pm 3.5 \pm 1.4$	$17.7 \pm 2.6 \pm 1.5$
$M_{Y(4660)}$ (MeV/c^2)		$4660 \pm 9 \pm 12$		
$\Gamma_{Y(4660)}$ (MeV)		$74 \pm 12 \pm 4$		
$\mathcal{B} \cdot \Gamma^{e^+e^-}_{Y(4660)}$ (eV)	$2.2 \pm 0.4 \pm 0.2$	$8.4 \pm 0.9 \pm 0.9$	$9.3 \pm 1.2 \pm 1.0$	$2.4 \pm 0.5 \pm 0.3$
ϕ_1 ($^\circ$)	$304 \pm 24 \pm 21$	$294 \pm 25 \pm 23$	$130 \pm 4 \pm 2$	$141 \pm 5 \pm 4$
ϕ_2 ($^\circ$)	$26 \pm 19 \pm 10$	$238 \pm 14 \pm 21$	$329 \pm 8 \pm 5$	$117 \pm 23 \pm 25$

Significance of $Y(4260)$ is 2.4σ—low, but affects $Y(4360)$ and $Y(4660)$ masses and widths.

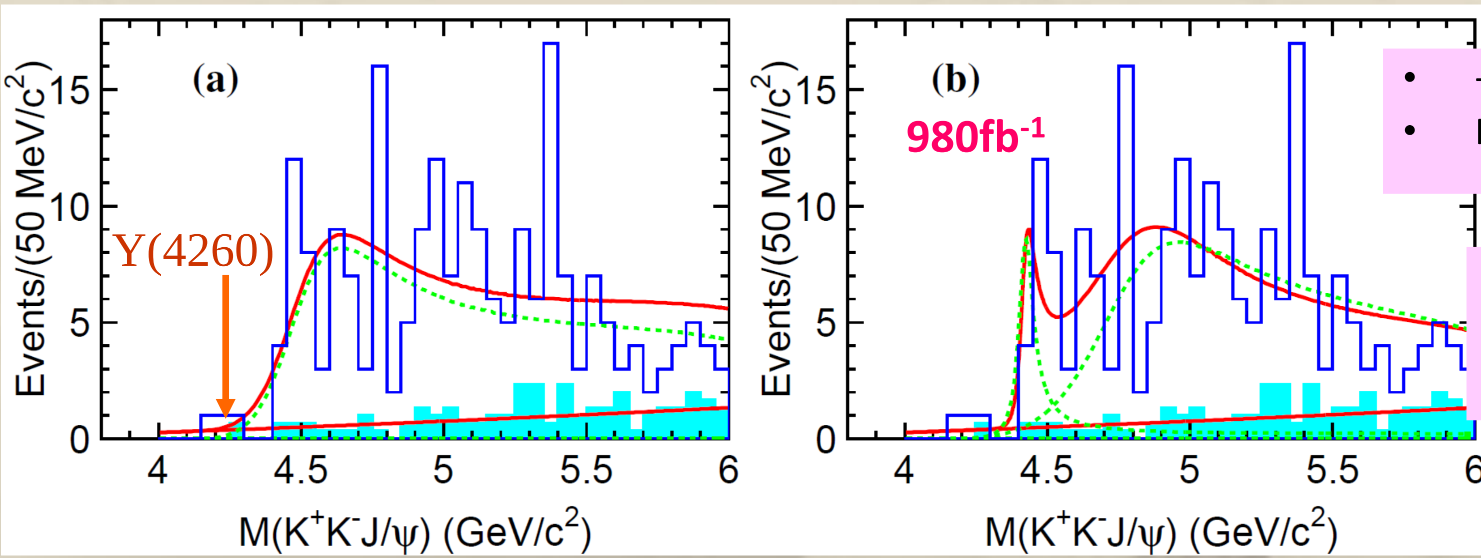
FOUR solutions with equally good fit quality, which is $\chi^2/ndf = 14.8/19$.

Updated $e^+e^- \to K^+K^-J/\psi$

PRD 89,072015(2014)

Event selections are almost the same as in Phys. Rev. D 77, 011105(R) (2008)

Shaded hist.: J/ψ mass sidebands

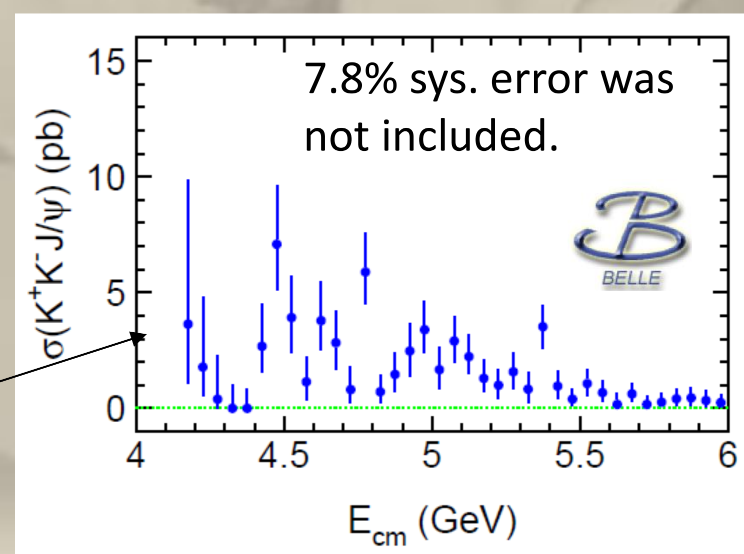


- +one resonance.
- Fit with $\psi(4415)$

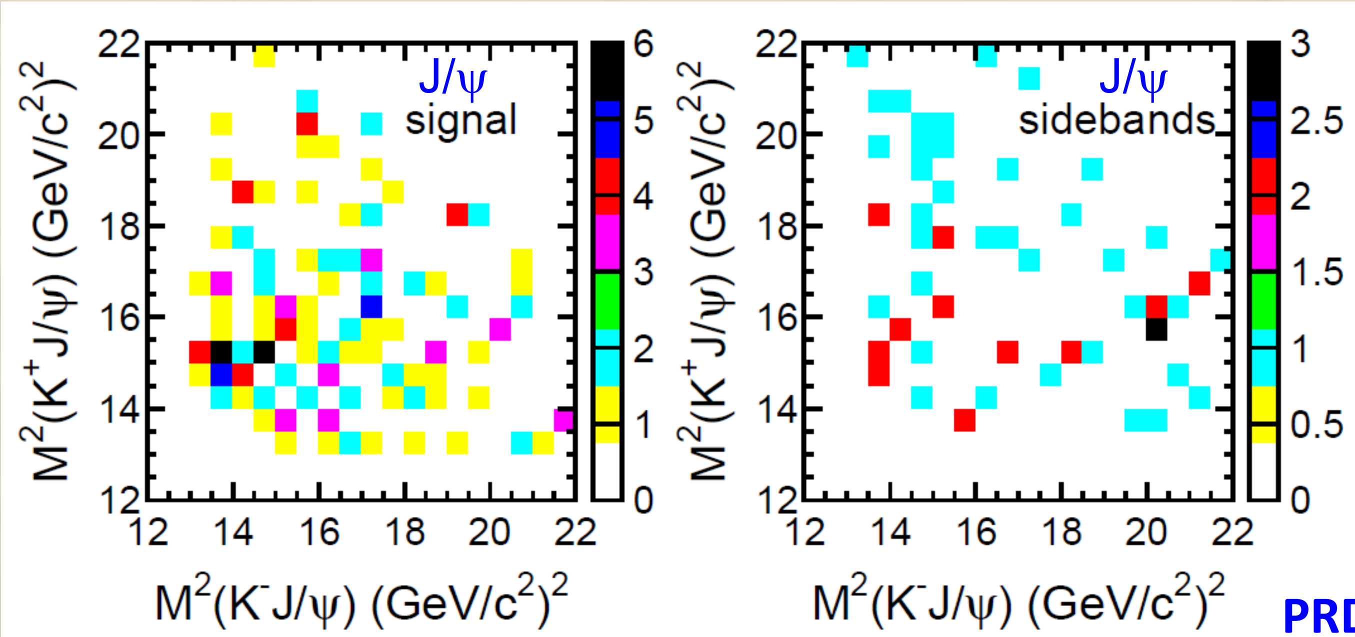
$\chi^2/ndf=30/11$
- M=4747±117MeV
- Γ=671±86 MeV

4-6 GeV: 213 events
35 bkg, 178±16 signal

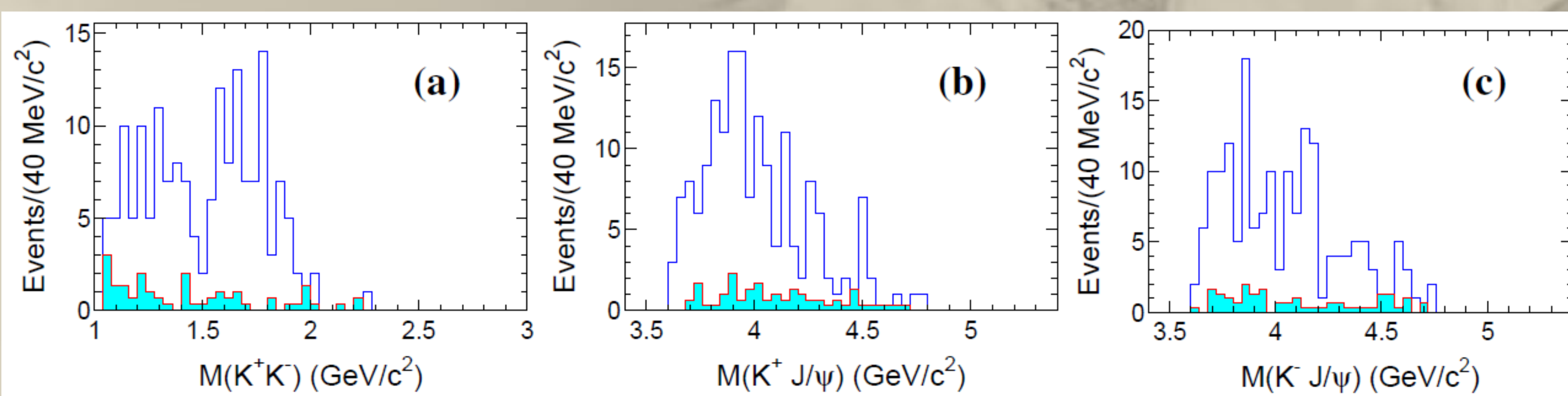
$$\sigma_i = \frac{n_i^{\text{obs}} - f \times n_i^{\text{bkg}}}{\mathcal{L}_i \cdot \epsilon_i \cdot \mathcal{B}(J/\psi \to \ell^+\ell^-)}$$



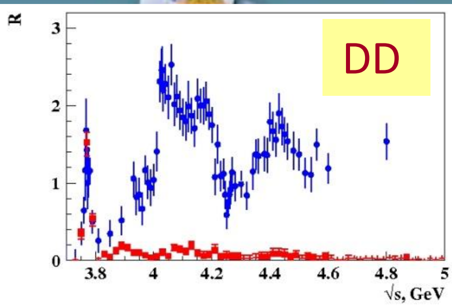
Search for Z_{cs}→KJ/ψ states

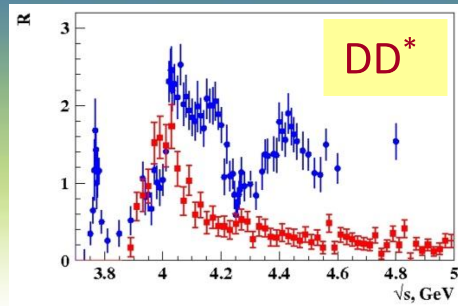


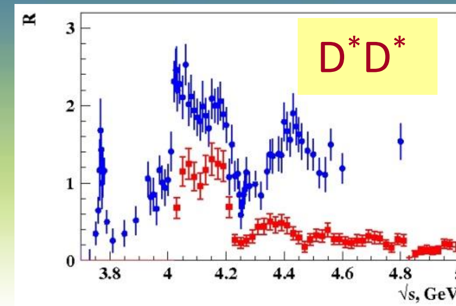
PRD 89,072015(2014)

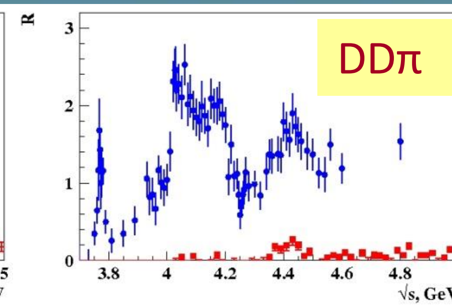


No evident structure in $K^{+-}J/\psi$ mass distribution under current statistics

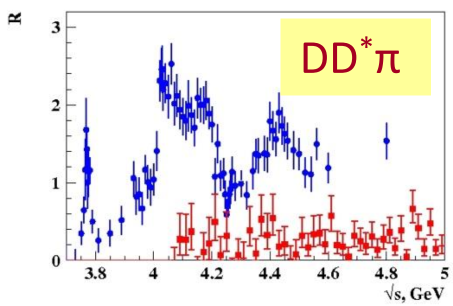


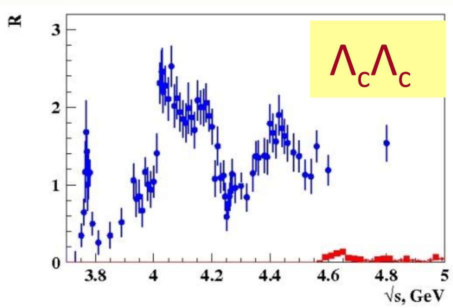


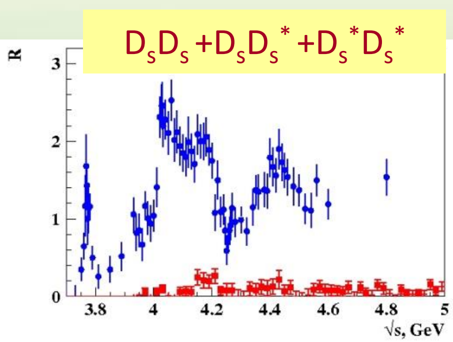


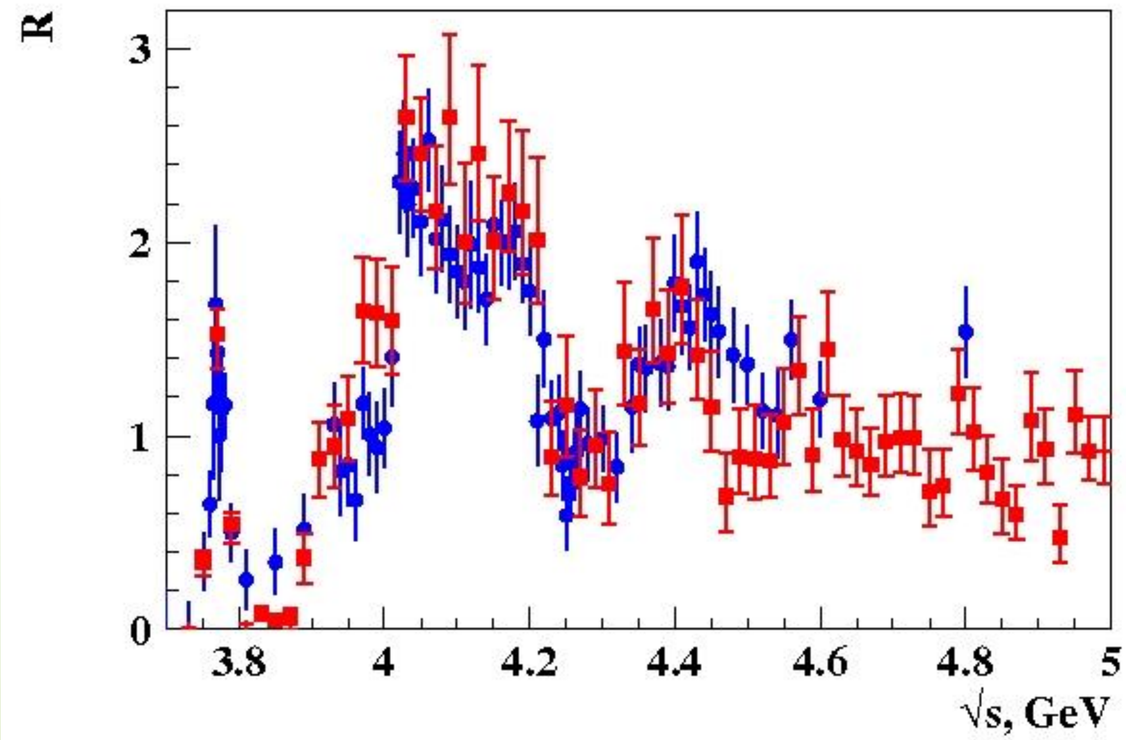


Exclusive cross sections contribution to the total cross section





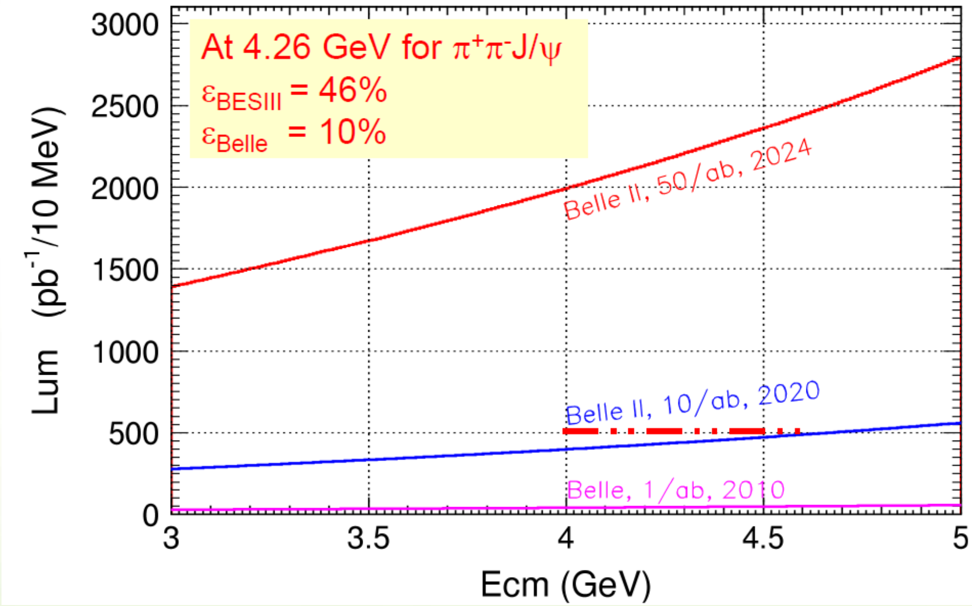




Contributions of D^+D^{*-}, $D^{*+}D^{*-}$, $D^0D^-\pi^+$ and $D^0D^{*-}\pi^+$ are scaled following isospin symmetry

ISR at Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach



Direct scan

- (very) high luminosity at a few selected $\sqrt{s}$
- better resolution in $\sqrt{s}$ — relevant for direct production of 1^{--} states

ISR

- ISR: many $\sqrt{s}$ simultaneously
- reduced point-to-point systematics
- mass resolution limited by detector res.
- boost of hadronic system vs. γ_{ISR} may actually help efficiency

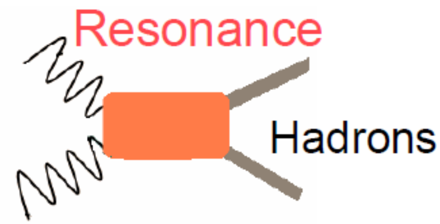
With > 5(10) ab^{-1} data sample, ISR $e^+e^- \to$ a charmonium+light hadrons[$\pi^+\pi^- J/\psi$, $\pi^+\pi^-\psi(2S)$, $K^+K^- J/\psi$, $K^+K^-\psi(2S)$, $\gamma X(3872)$, $\pi^+\pi^- X(3872)$, $\pi^+\pi^- h_c$, $\pi^+\pi^- h_c(2P)$, ωX_{cJ}, ϕX_{cJ}, $\eta J/\psi$, $\eta' J/\psi$, $\eta\psi(2S)$, ηh_c]; and charm meson pair+light hadrons [DD, DD*, DD*π, . . .]

Two-photon processes at Belle II

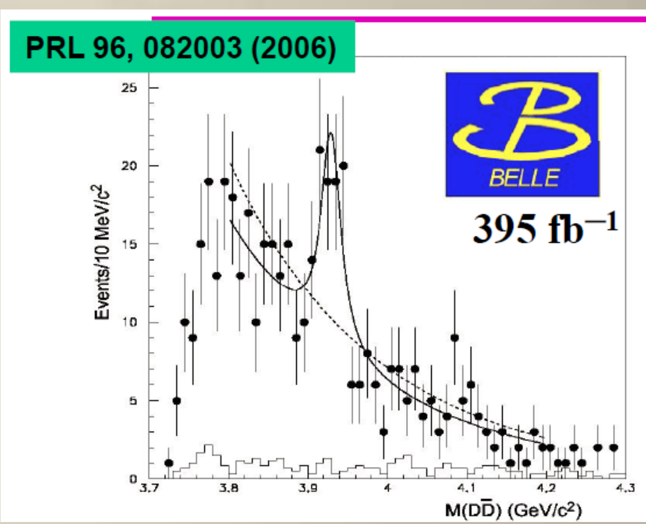
Strict constraints for quantum numbers of the resonance

$Q = 0$, $C = +$, $J^P = 0^+, 0^-, 2^+, 2^-, 3^+$, …. $(\text{even})^{\pm}$, $(\text{odd} \neq 1)^+$

$\Gamma\gamma\gamma$, two-photon partial decay width
proportional to the cross section
Important information for the **meson's internal structure**

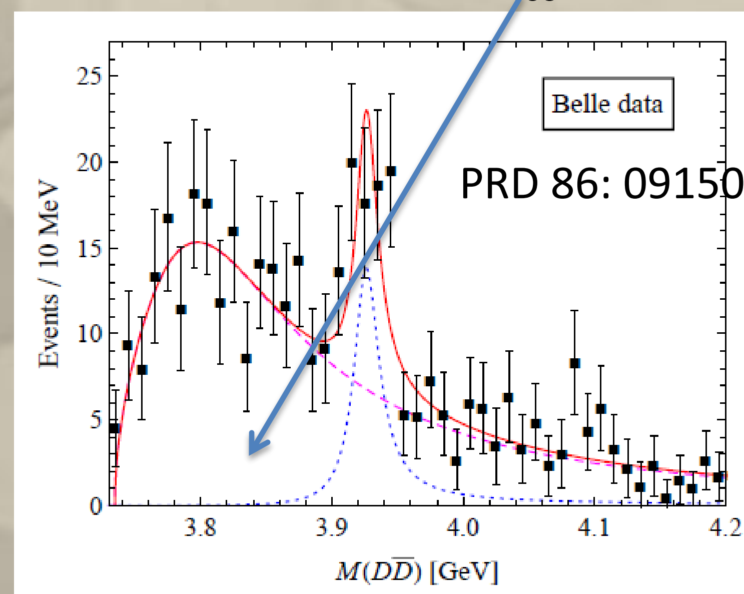


New resonances, Hadron properties



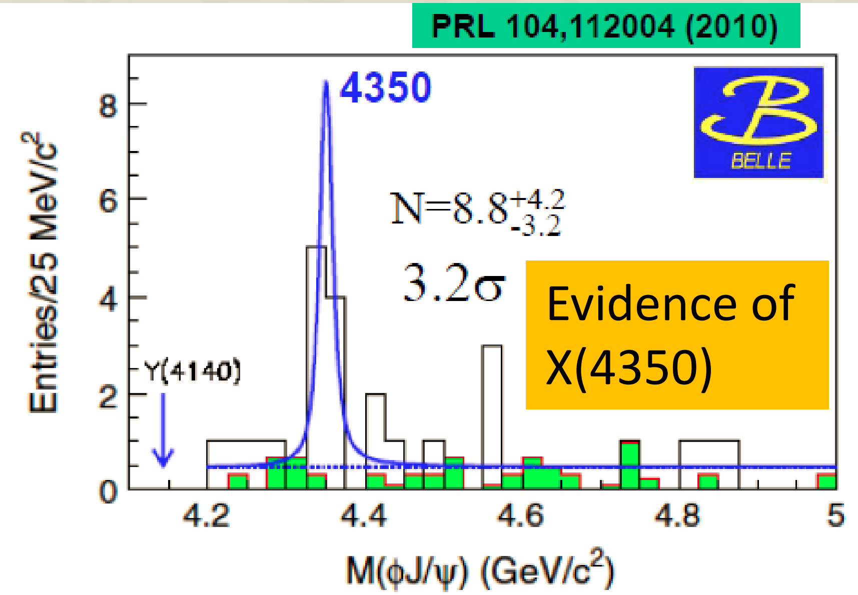
$Z(3930) = \chi_{c2}(2P)$

Where is $X_{c0}(2P)$?

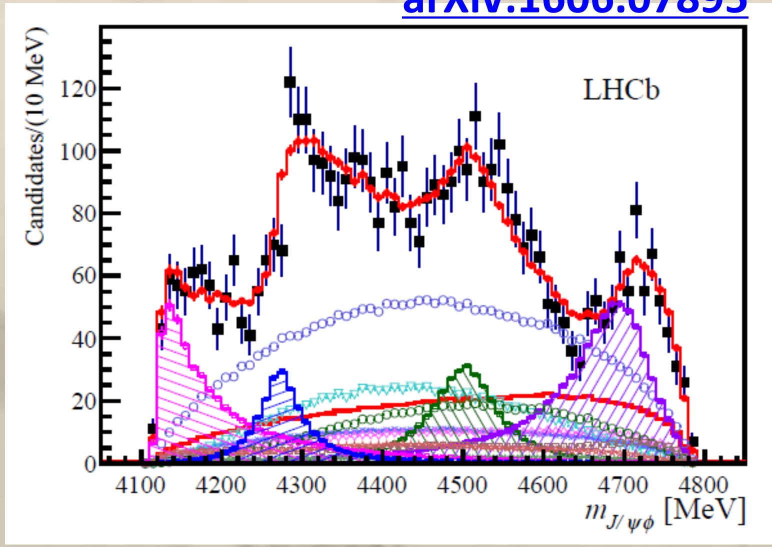


PRD 86: 091501(R), 2012

Two-photon processes at Belle II



arXiv:1606.07895

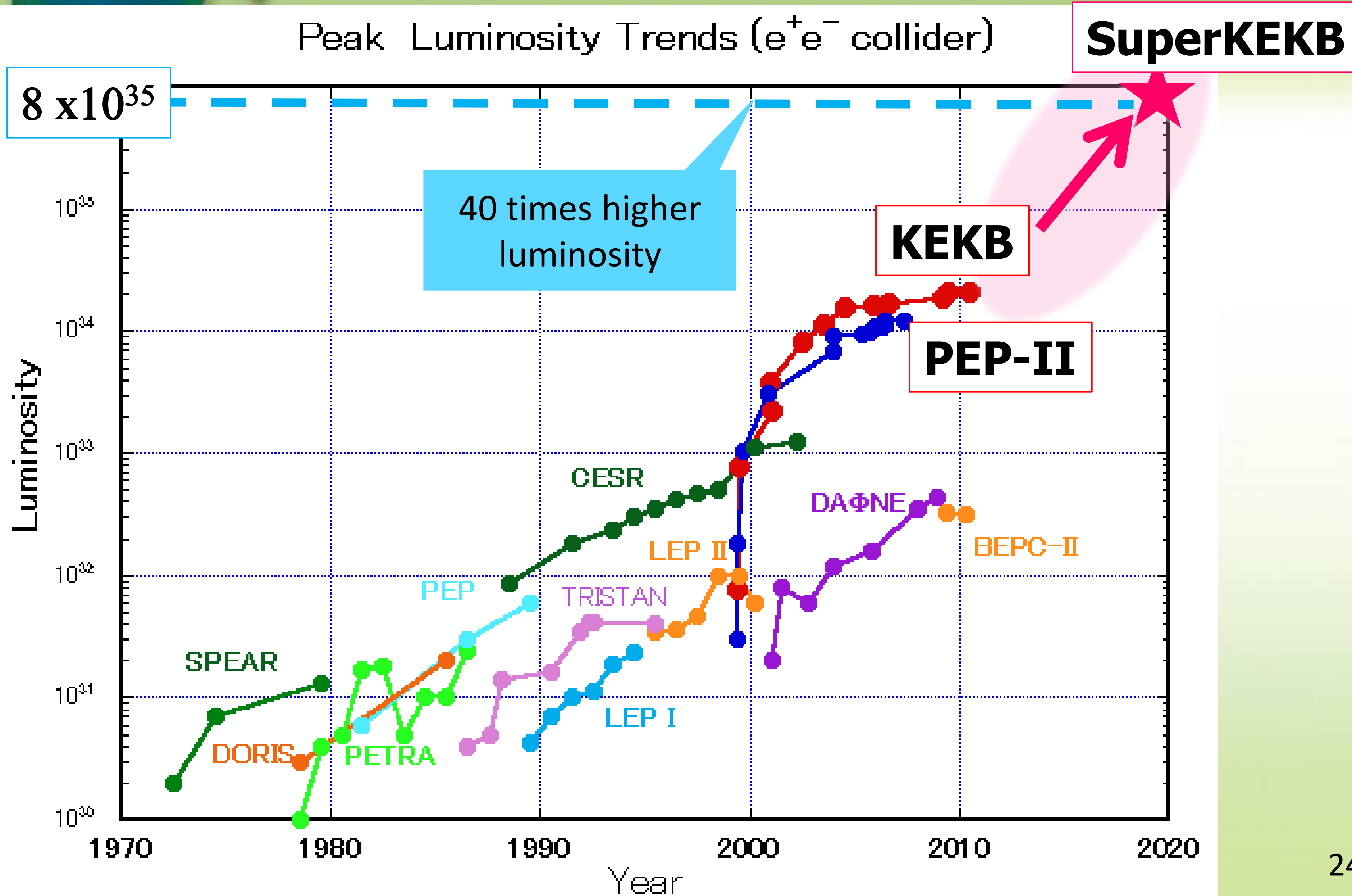


X(4140) , X(4274) , X(4500) , and X(4700)

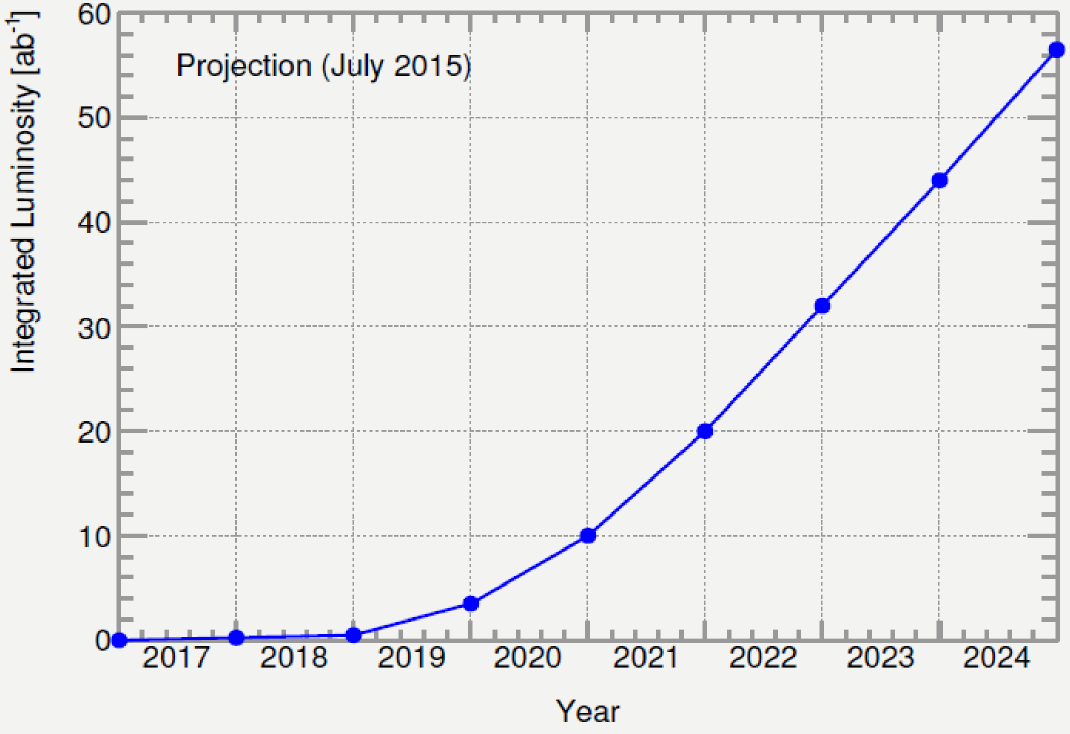
With > 5(10) ab^{-1} data sample, Two-photon processes γ γ → a charmonium+light hadrons[ϕ J/ψ, ϕ ψ(2S), ω J/ψ, ωψ(2S), ...]; and charm meson pair+light hadrons [DD, DDX(X=soft pions or photons), ...]


WE NEED
YOU
Belle II
Belle II

Need O(100x) more data →Next generation B-factories



Integrated Luminosity



- Peak instantaneous luminosity: $8 \times 10^{35} cm^{-2}s^{-1}$ (Belle: $2.11 \times 10^{34} cm^{-2}s^{-1}$)
- Total integrated luminosity: $50ab^{-1}$ (Belle: $1ab^{-1}$)

Process	$\sigma[nb]$	No. events [$\times 10^9$]
$B\bar{B}$	1.1	55
$q\bar{q}$	2.52	185.45
$\tau^+\tau^-$	0.92	45.95

High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathscr{L} = 8\mathrm{x}10^{35}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20

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

Lorentz factor ($\gamma_{\pm}$); beam current ($I_{\pm}$); beam-beam parameter ($\xi_{y\pm}$); geometrical reduction factors (R_L/R_{ξ_y}); beam aspect ratio at the IP (σ_y^*/σ_x^*); vertical beta-function at the IP ($\beta_{y\pm}^*$)

parameters		KEKB LER	KEKB HER	SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1x10		$8\mathrm{x}10^{35}$		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$

High-Luminosity Asymmetric B Factory

- ➡ Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- ➡ Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @

Lorentz factor

beam

beam-beam

$L = \frac{\gamma}{2e_e}$ …

beam aspect … at the IP

vertical beta-function at the IP

reduced CM boost

- reduced vertex separation, Δt resolution
- increased detector hermeticity

squeezed beams @ IP

- greatly improved constraint for decay chain vertex fitting

parameters		LER	H…	SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	βγ	0.425		0.28		
h…				41.5		mrad
ho…			24	3.2	4.6	nm
			0.66	37	0.40	%
b…			5.9	32/0.27	25/0.30	mm
			1.19	3.6	2.6	A
bea…			90	0.0881	0.0807	
			2	10/0.059		μm
			0	8x10^{35}		cm^{-2}s^{-1}

x40 luminosity

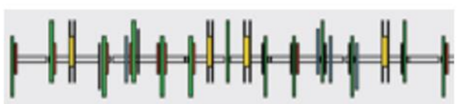
- higher background rates (~10-20x)
  - detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- x40 produced signal events

SuperKEKB Status

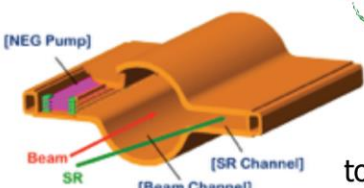
Longer LER dipoles magnets installed

increase wiggler cycles

Redesign the lattices of HER & LER to squeeze the emittance

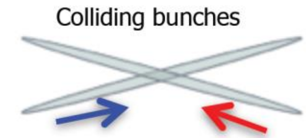


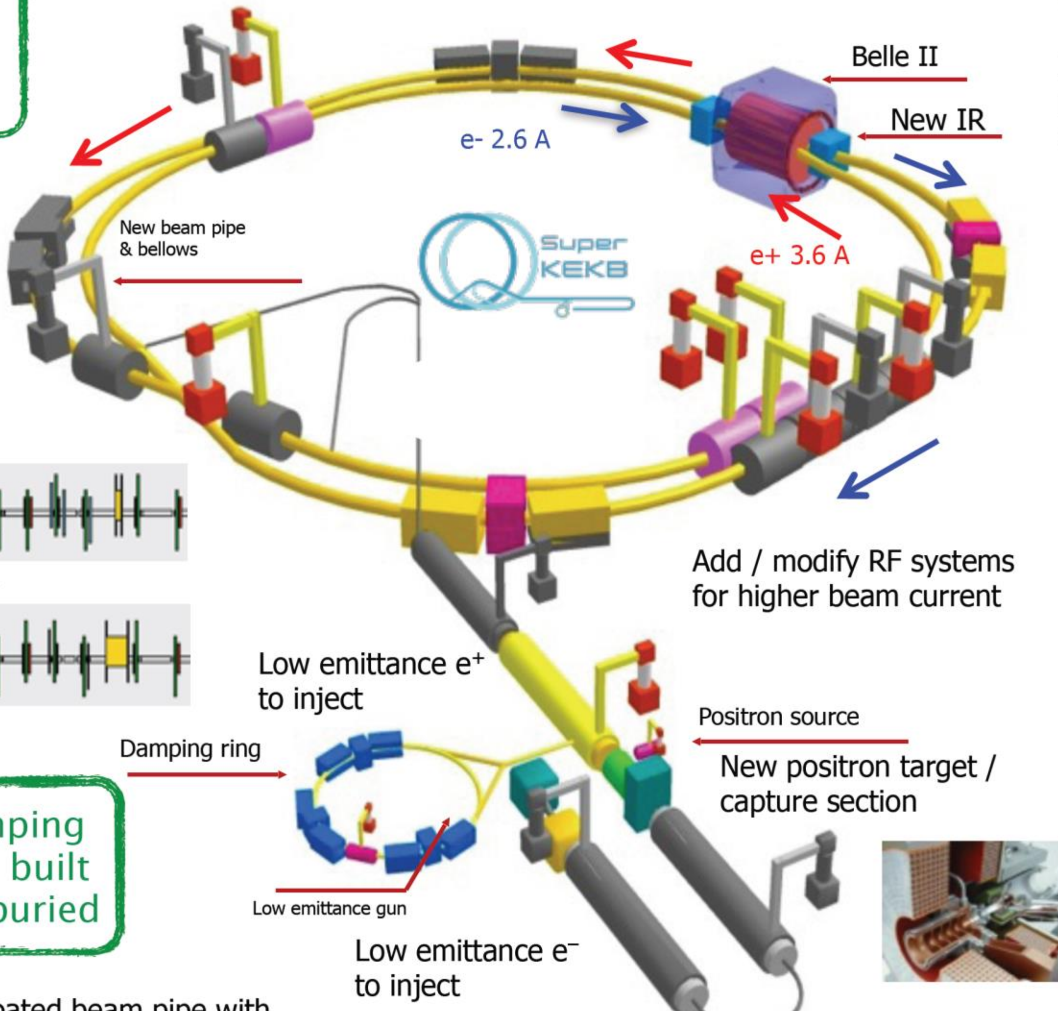
Damping Ring built and buried



TiN-coated beam pipe with antechambers

to reduce Synchrotron radiation





Belle II

New IR

New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

Low emittance e^+ to inject

Positron source

New positron target / capture section

Low emittance e^- to inject

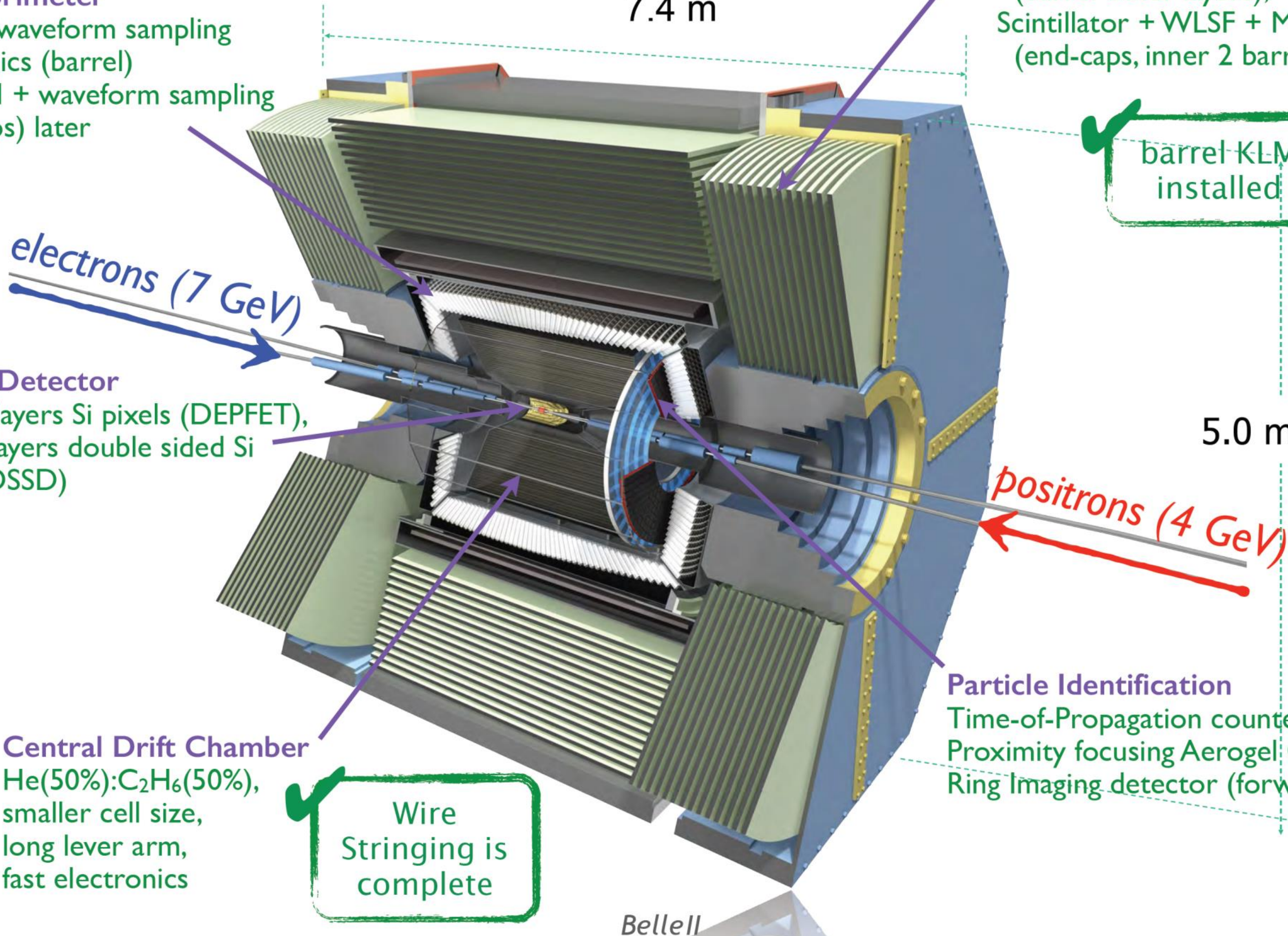
New LER & HER wiggler cavities installed

The *Belle II* Detector

K$_L$ & μ Detector
Resistive Plate Counter
(barrel outer layers),
Scintillator + WLSF + MPPC
(end-caps, inner 2 barrel layers)

barrel KLM
installed

EM calorimeter
CsI(Tl), waveform sampling
electronics (barrel)
Pure CsI + waveform sampling
(end-caps) later



Vertex Detector
PXD: 2 layers Si pixels (DEPFET),
SVD: 4 layers double sided Si
strips (DSSD)

Particle Identification
Time-of-Propagation counter (barrel),
Proximity focusing Aerogel Cherenkov
Ring Imaging detector (forward)

Central Drift Chamber
He(50%):C_2H_6(50%),
smaller cell size,
long lever arm,
fast electronics

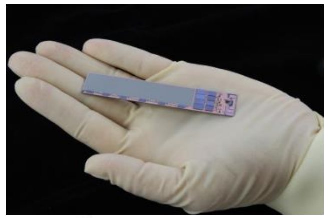
Wire
Stringing is
complete

Detector Improvements

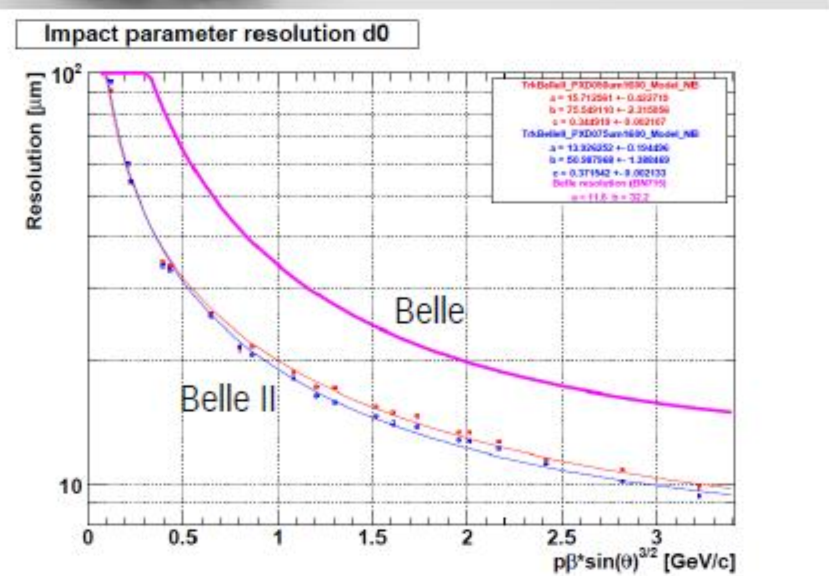
- Smaller beam pipe radius allows to place the innermost PXD layer closer to the Interaction point (r = 1.4cm)
  - Significantly improves the vertex resolution along *z* direction.
- Pixel part of the vertex detector, larger SVD and CDC
  - Increases K_S efficiency, improve vertex and timing resolution, better flavor tagging.
- PID: TOP and ARICH
  - Better K/π separation covering the whole range momentum.
- ECL and KLM
  - Improvements in ECL and KLM to compensate for a larger beam background.
- Improved hermeticity.
- Improved trigger and DAQ.

VXD=PXD+SCD

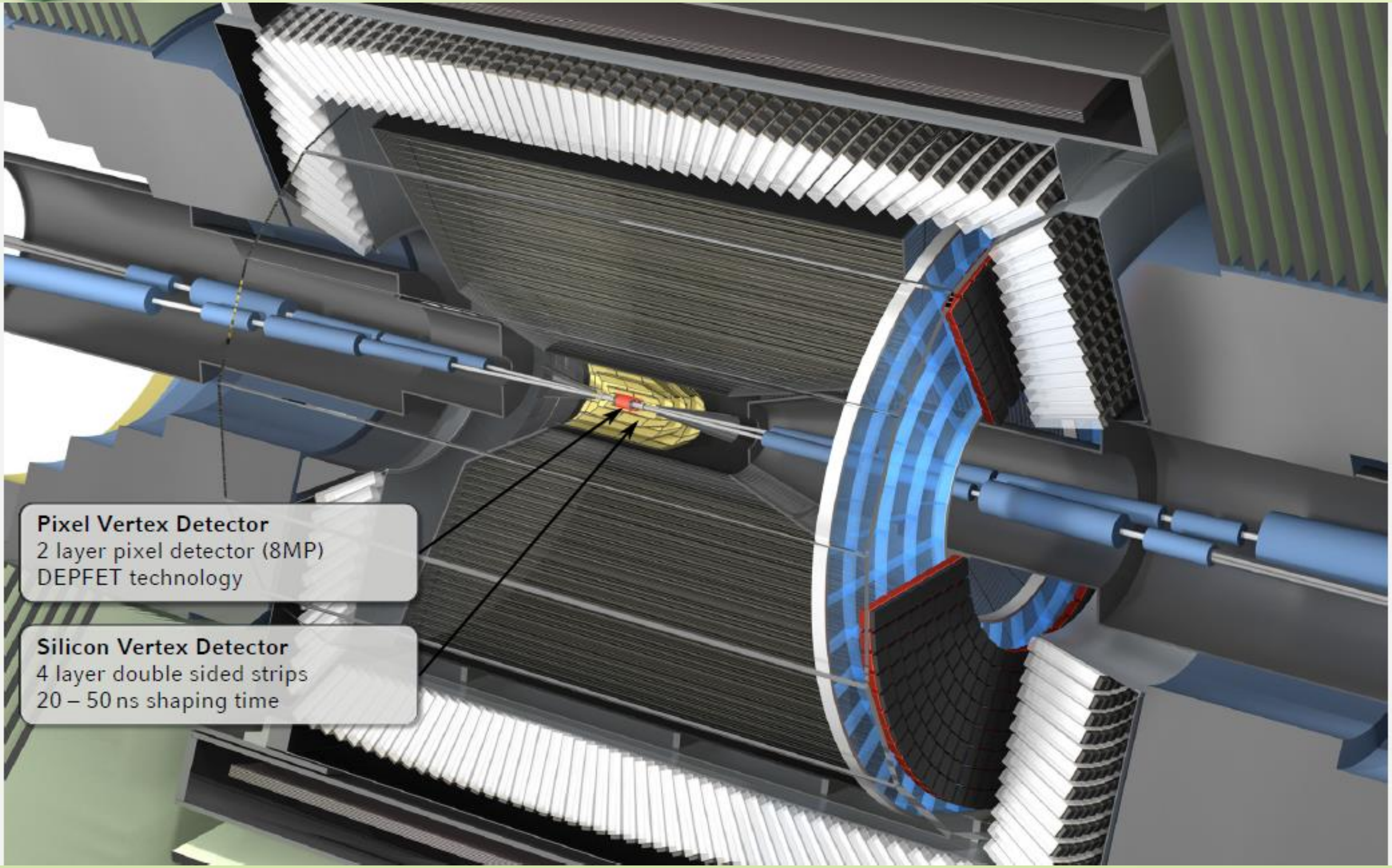
- Layers 1-2: Pixel detectors (PXD)
  - DEPFET pixels
  - 50μm thick
  - r=14mm and 22mm (vs 20mm minimum for Belle)



- Layers 3-6: Strip detectors (SVD)
  - 4 layers of DSSD detectors, well tested at Belle
  - Largest radius 135mm (vs 88mm for Belle)
- Dedicated PXD preDAQ for data rate reduction from ~8M channels (matching against tracks from SVD+CDC)



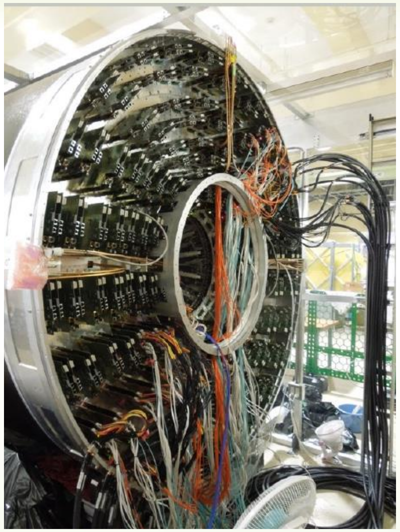
Belle II Detector



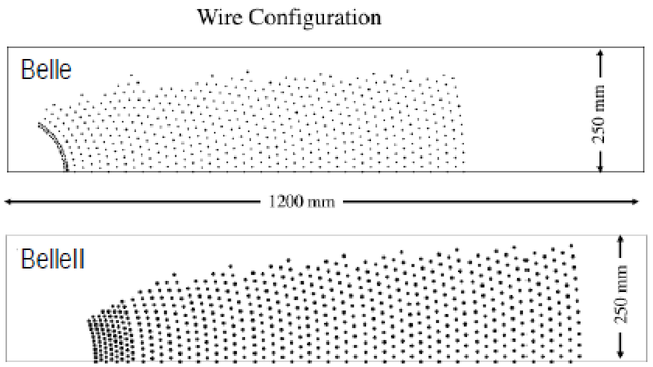
CDC

- Belle II Central Drift Chamber (CDC) is larger than that of Belle.
- Smaller drift cells with sense wires and more layers allow better charged track reconstruction and dE/dx measurement compared to Belle.
- Faster readout electronics

	Belle	Belle II
Radius of inner boundary (mm)	88	168
Radius of outer boundary (mm)	863	1111
Number of layers	50	56
Number of sense wires	8400	14336
Gas	HeC_2H_6	HeC_2H_6
Diameter of a sense wire (µm)	30	30

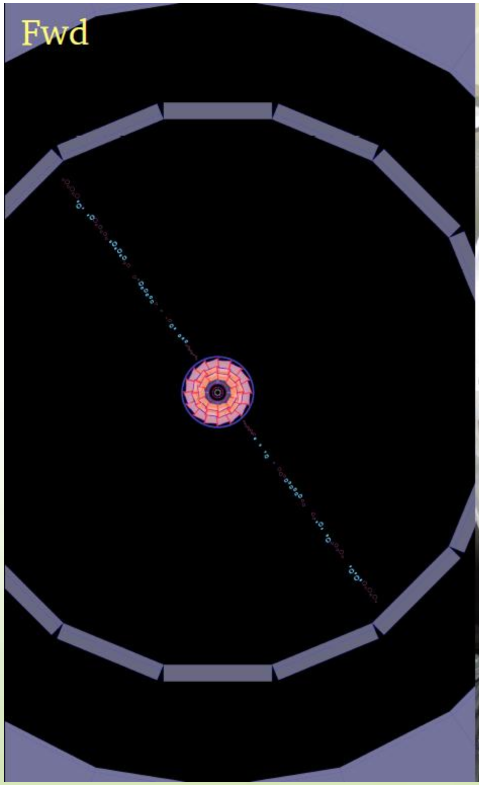


- Key roles:
  1. Reconstruct charged tracks with precision momentum measurements.
  2. Particle identification using measurements of $\frac{dE}{dx}$.
  3. Trigger for charged particles.



Before installation: CDC cosmic ray test

- A cosmic ray test was performed in the back-to-back configuration using 59(out of 299) FE boards.
- Clear tracks were observed using the real Belle-II central DAQ system.



Event display

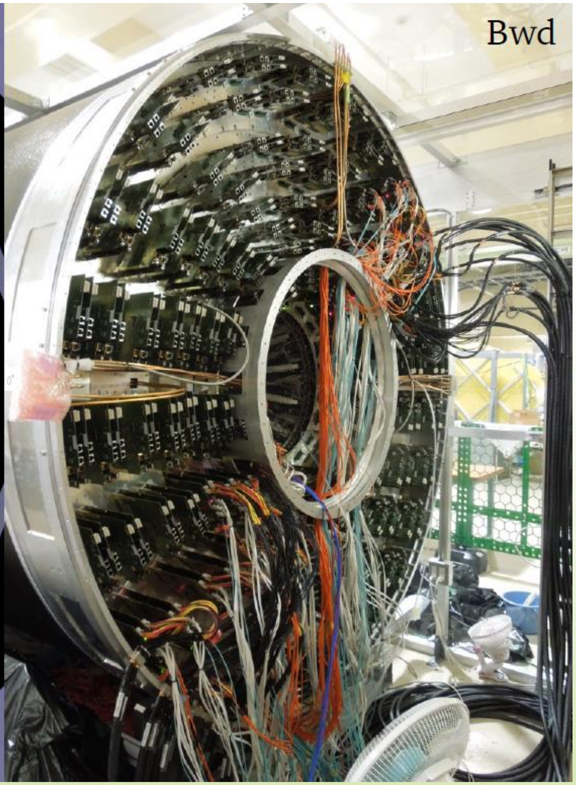
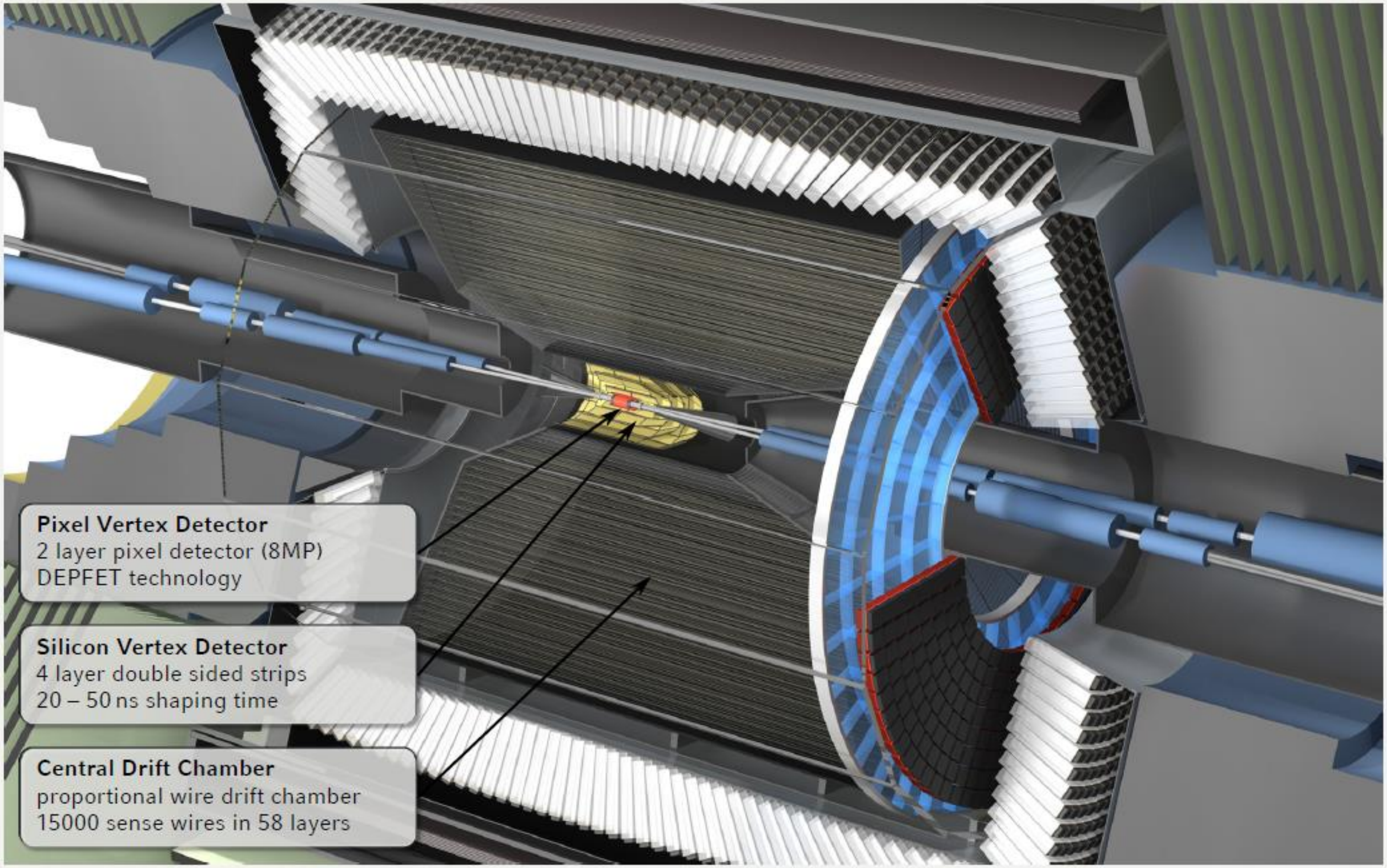


Photo in the side room with many cables

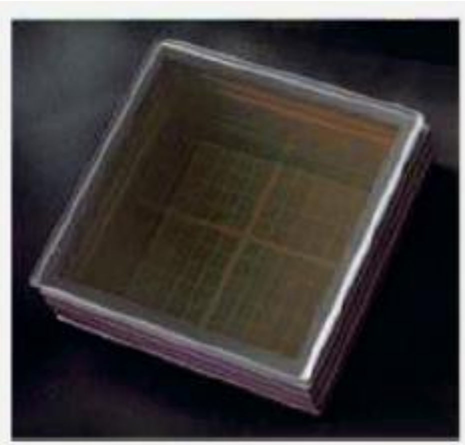
Belle II Detector

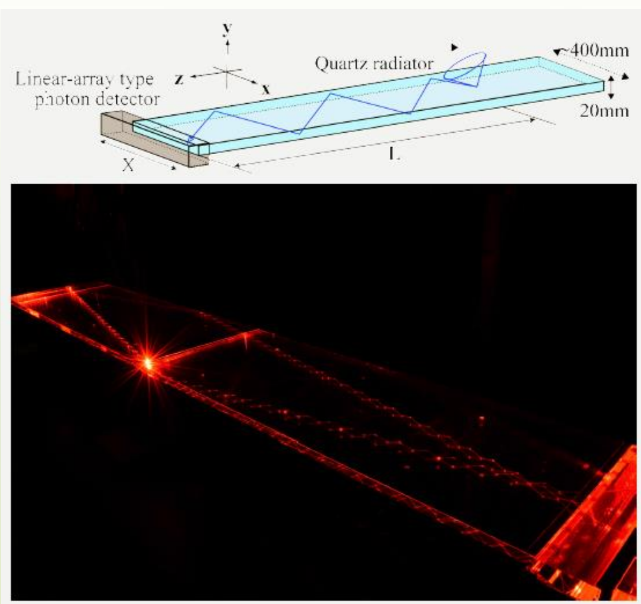


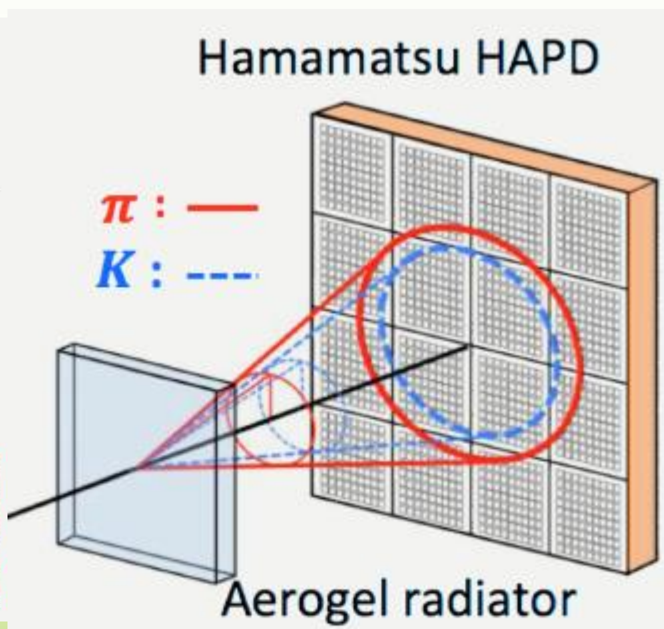
PID=TOP+ARICH

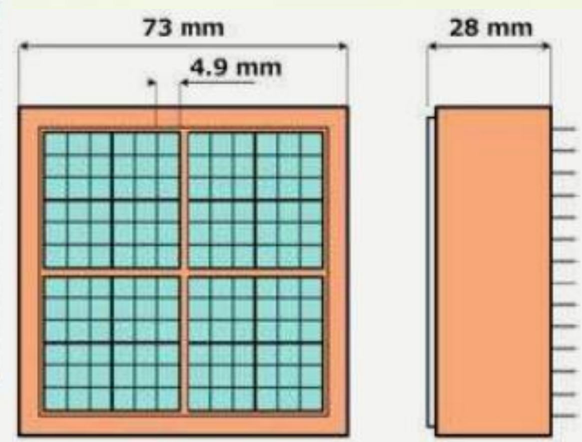
Two Cherenkov detectors for particle identification (mainly Kion and Pion)

- Barrel: Time of Propogation (TOP)
- Endcap: Aerogel Ring-Imaging Chernkov

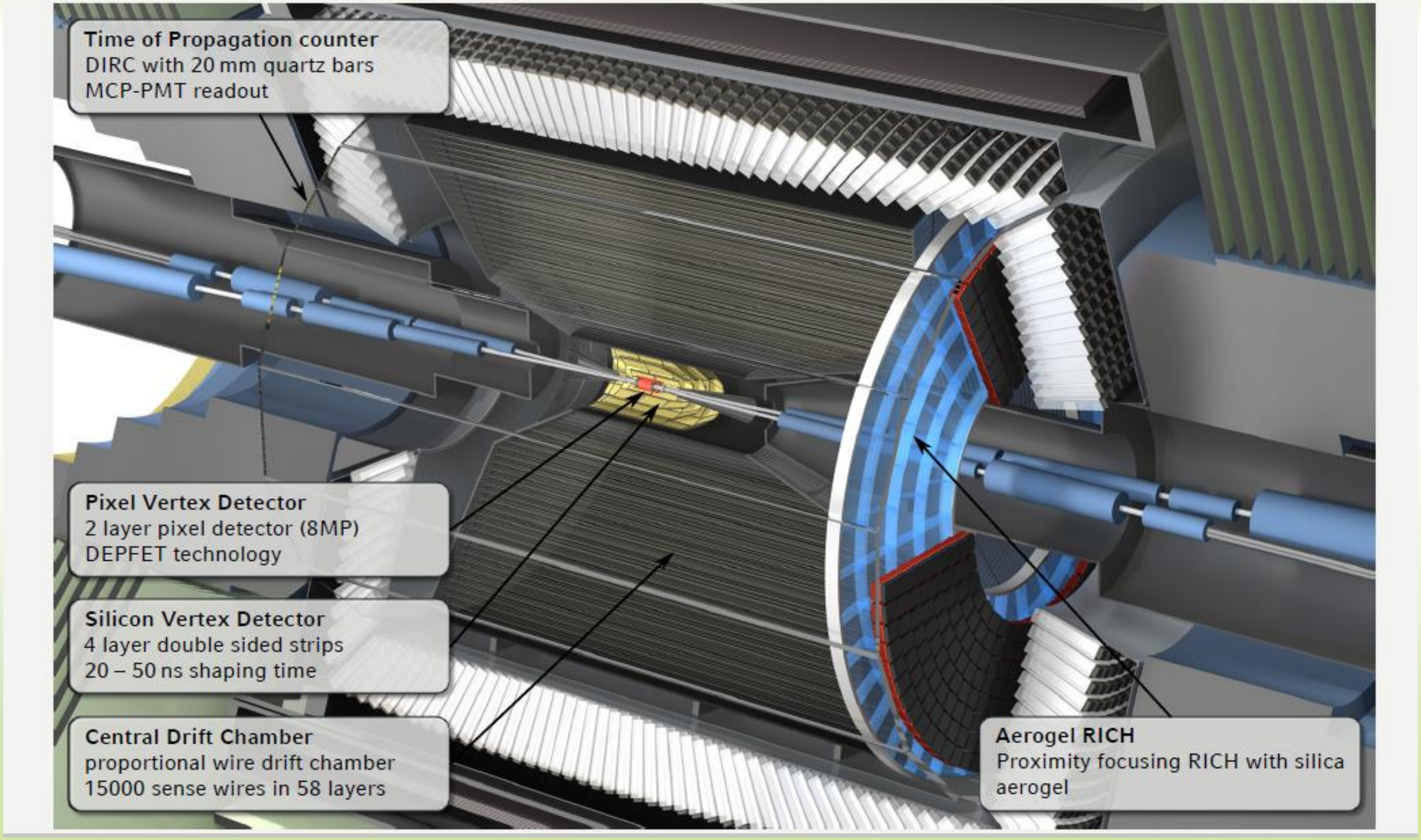








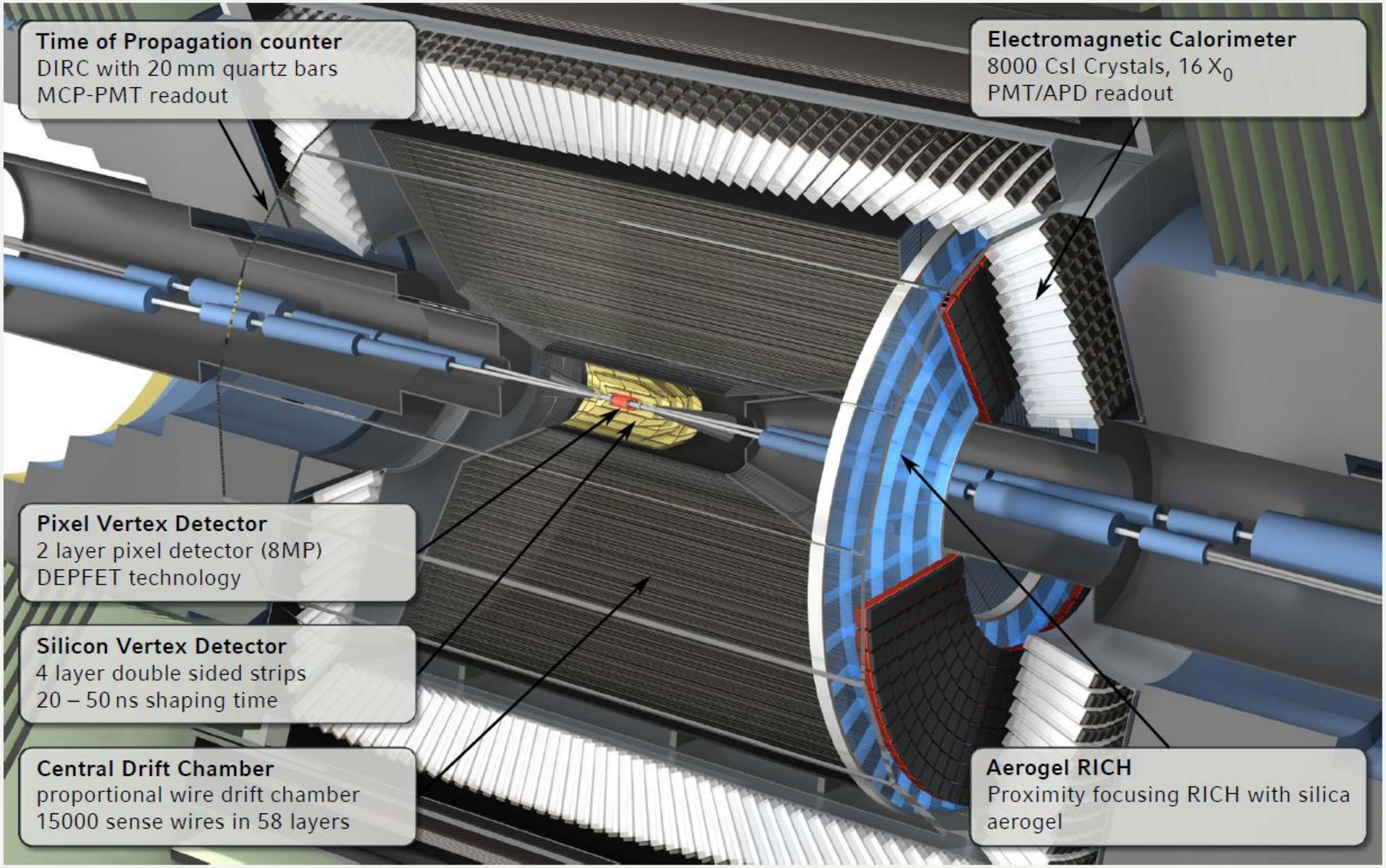
Belle II Detector



ECL

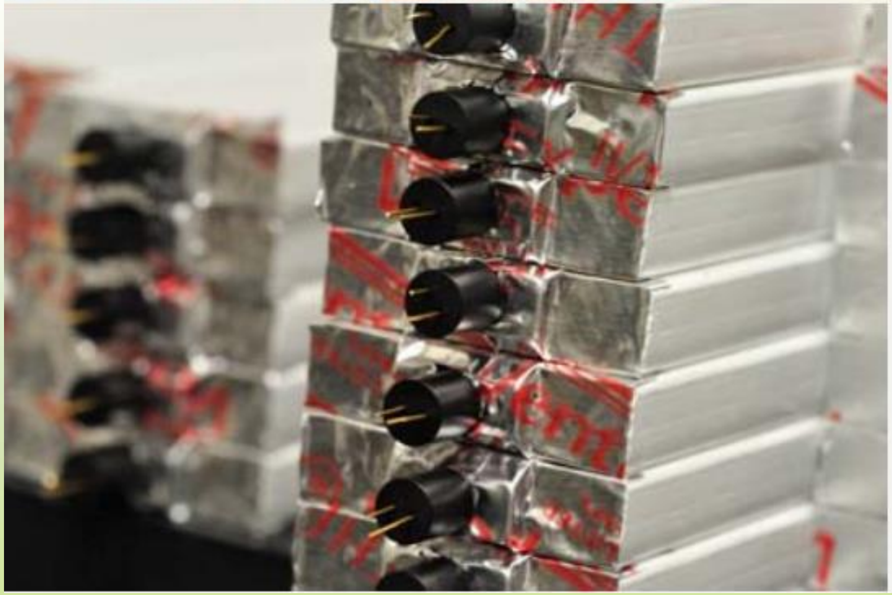
- Reuse barrel crystals from Belle (new waveform sampling electronics).
- Refurbished end–cap crystals (CsI(Tl) → CsI)
- Roles:
  - Detect photons with precision measurements.
  - Identify electrons.
  - Help detect K_L^0 together with the KLM.

Belle II Detector



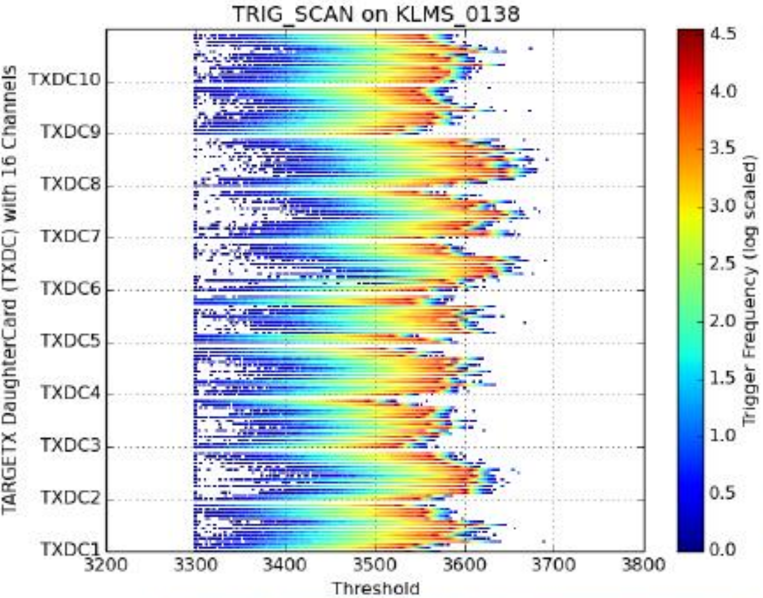
KLM

- Alternating layers of iron plates and detector components.
- Iron plates:
  - K_L shower hadronically.
  - Flux return for magnet.
- Replaced end–cap and inner–most barrel RPCs with scintillators.
- Barrel (End–cap) installed in 2013 (2014).

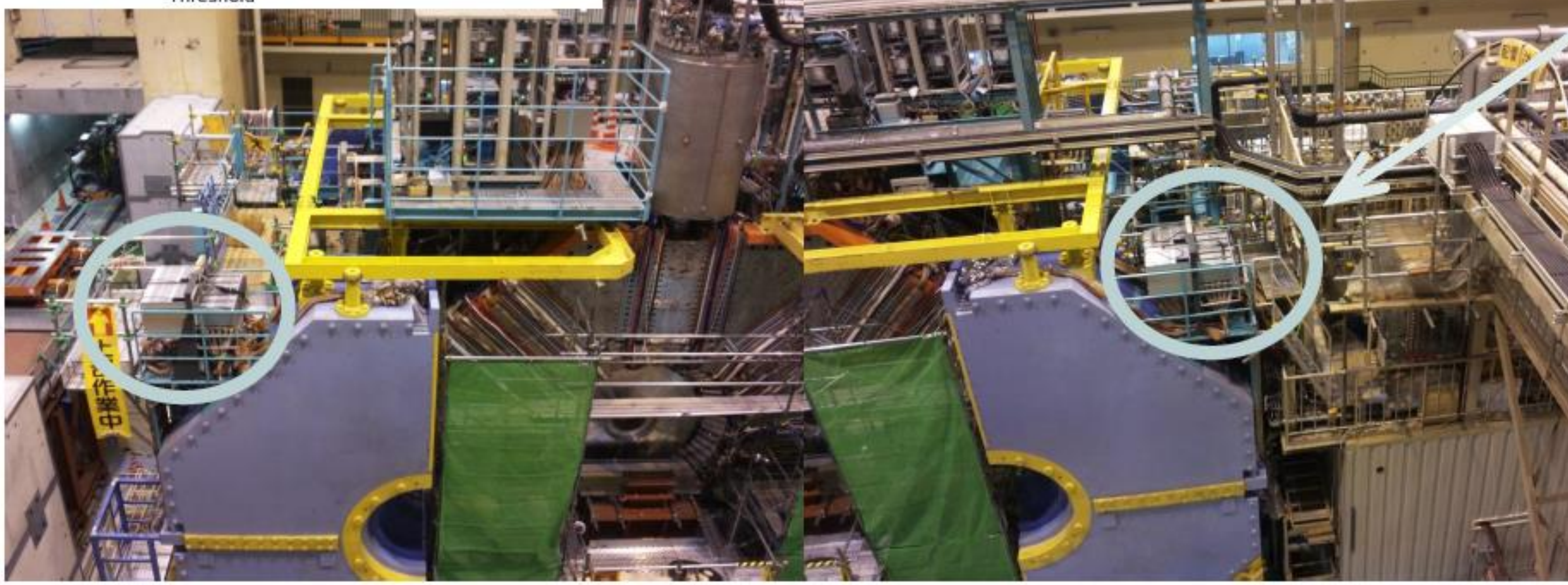


All Backward KLM sectors fully connected to DAQ boards and tested

EKLM



Test of one superlayer, 150 channels

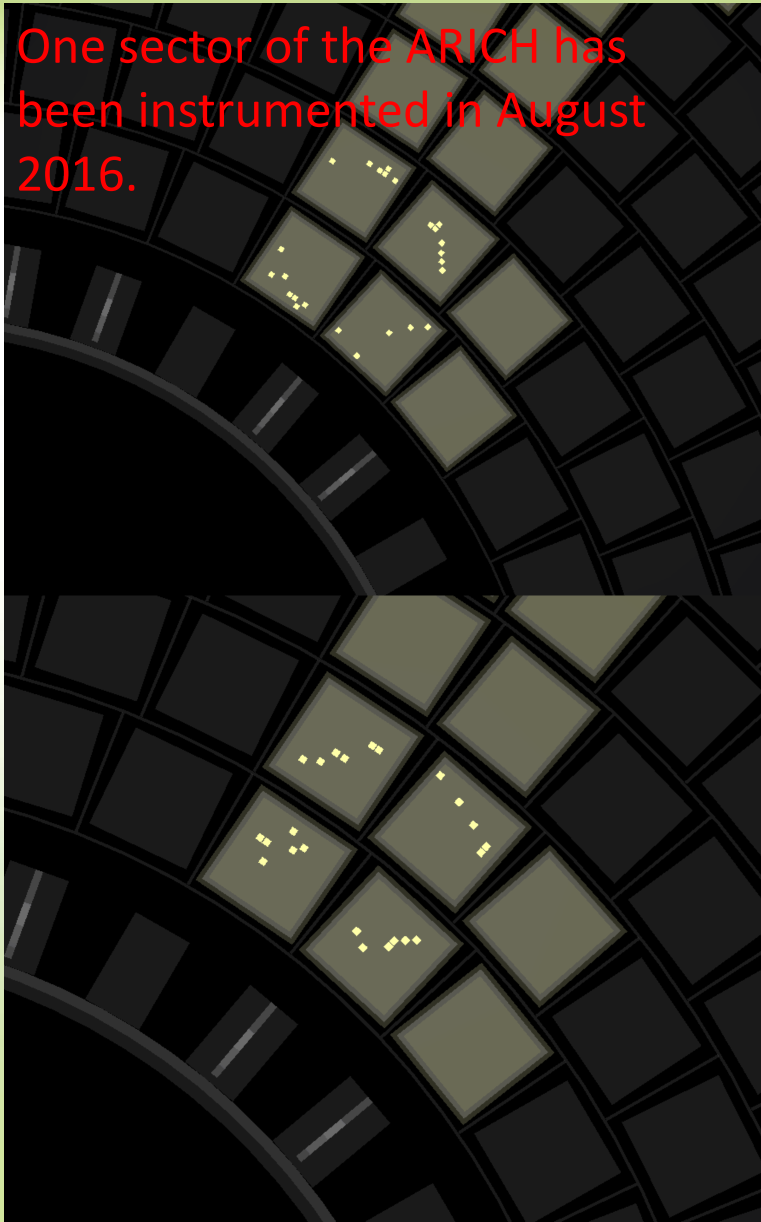


Forward KLM sectors: 30% done, complete connection by the end of this year

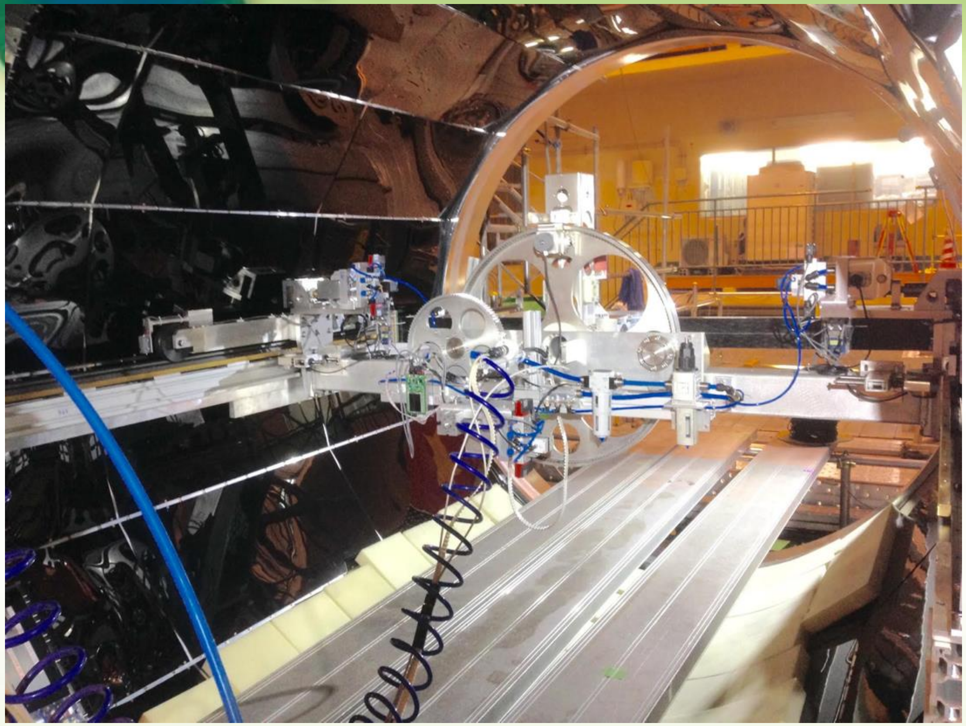
Belle II status and milestones

- Time of propagation (TOP) Cherenkov detector modules all **installed, testing** ongoing (top)
- Drift chamber (CDC) strung and **observing cosmics** (bottom)
- VXD (inner pixel/strip silicon vertexing) completed **successful beam test** at DESY with full Belle II DAQ chain
- ECL (crystal EM calorimeter) electronics **installed in summer**, test with new firmware and software ongoing
- Aerogel Ring-Imaging Cherenkov (ARICH) endplate detector tiles cut, **installation almost complete**
- K_L and muon system (KLM): installation of DAQ infrastructure in progress, **first cosmics seen** June 2016

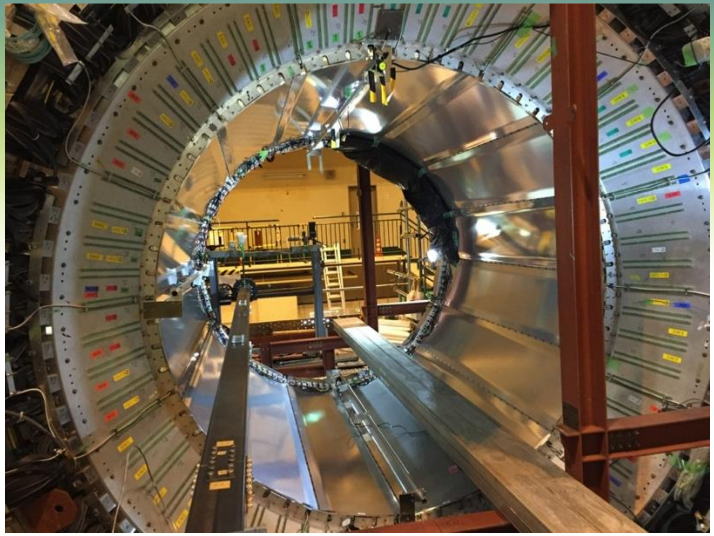
One sector of the ARICH has been instrumented in August 2016.



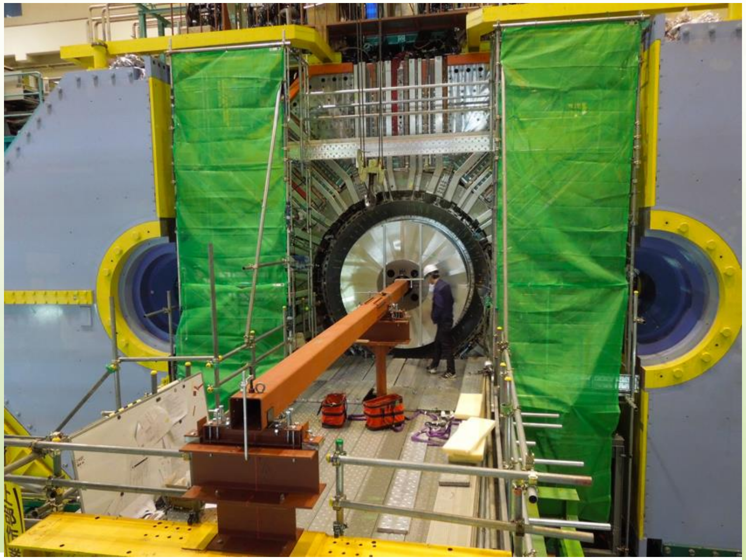
Outer detector at Tsukuba Hall



June 2016: Precision field mapper inside Belle II



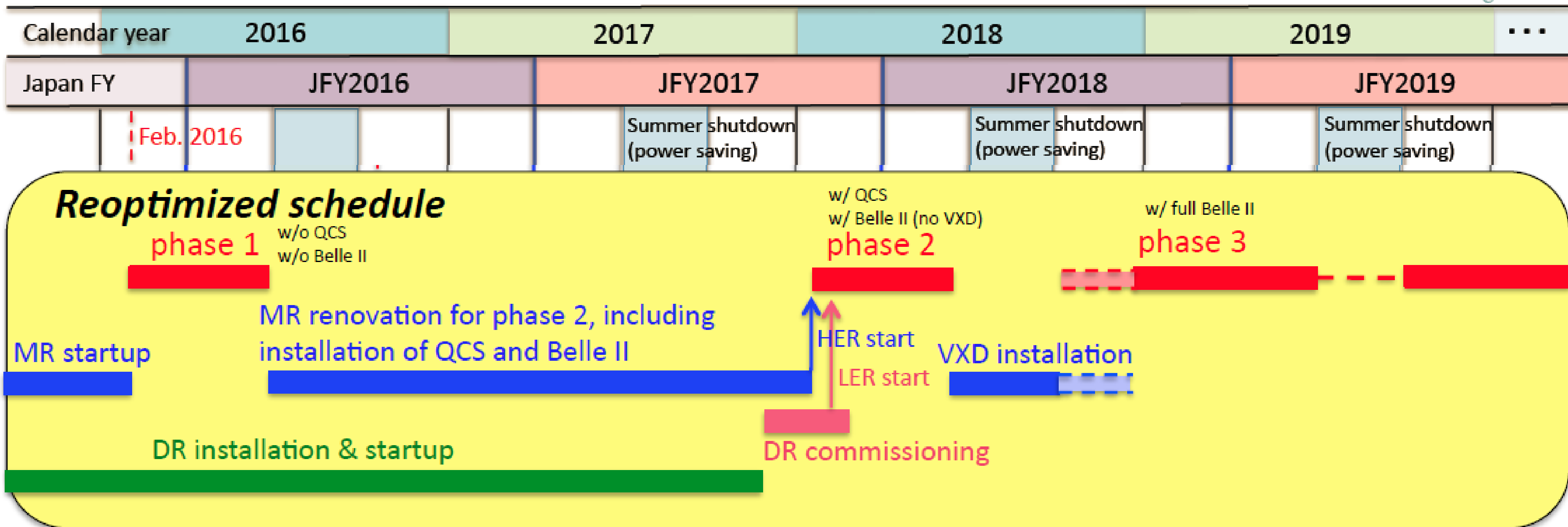
May 2016:TOP in Belle II structure



Oct 2016: CDC (Central Drift Chamber)

Status: All 16 TOP modules were installed (May 20). Magnetic field mapping (June). Shimming of TOP modules(July-August). CDC was installed into the Belle II structure in October.

Schedule shown at B2GM in Feb. 2016



Feb. – Jun. 2016 Phase 1 commissioning (without Belle II)

Jul. 2016 ~ Renovation for phase 2

- Installation of QCS and startup works, Belle II roll-in
- More collimators, more mitigation for electron cloud, etc.
- Completion of DR and startup works
- Improvements for Linac

Nov. 2017 ~ phase 2 commissioning with Belle II (w/o VXD)

- Low β_y^* tuning, collision tuning, luminosity tuning
- Low emittance beam injection with DR and improved Linac

JFY2018 ~ phase 3 operation with full Belle II

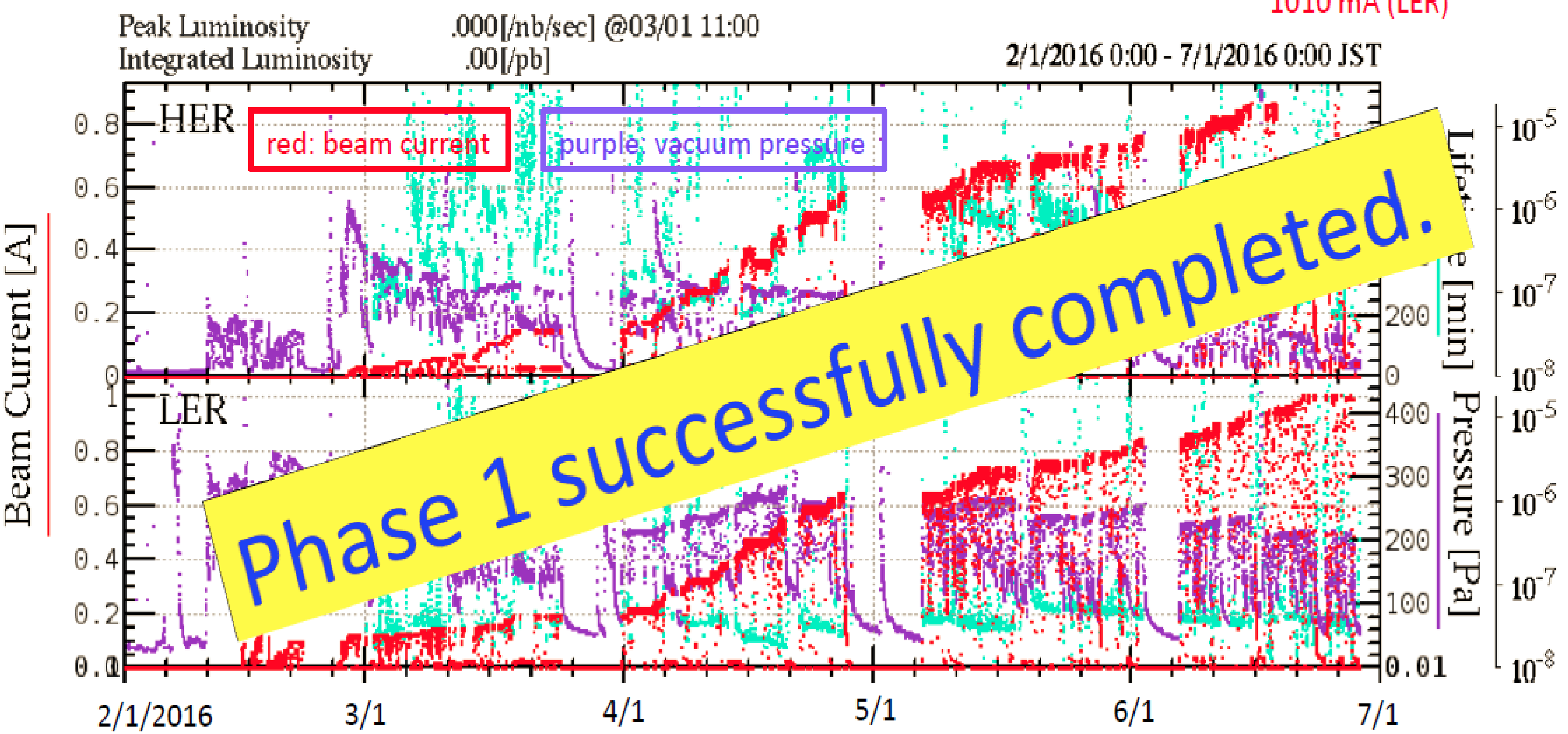

QUIET PLEASE
BOARD MEETING
in progress
It's settled. We put out a press release saying we can't remember what we decided.
Nicholson
25 April '09

Phase 1 commissioning results

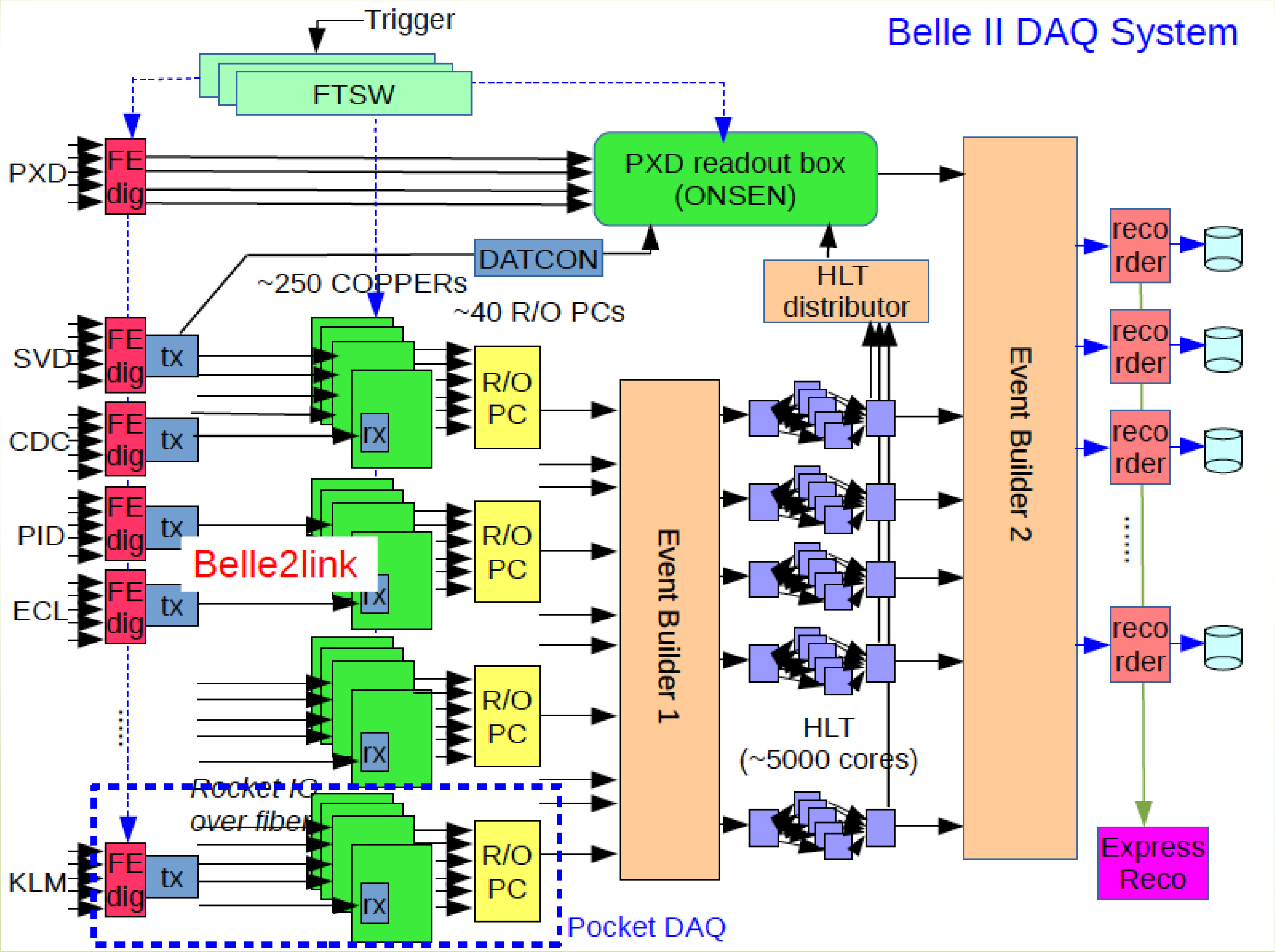
Phase 1 milestones
- Feb. 1: BT tuning started
- Feb. 8: LER injection tuning started
- Feb. 10: beam storage in LER
- Feb. 22: HER injection tuning started
- Feb. 26: beam storage in HER

Tasks during phase 1 operation
- Basic machine tuning
- Low emittance beam tuning
- Vacuum scrubbing
- Machine studies including Beast studies

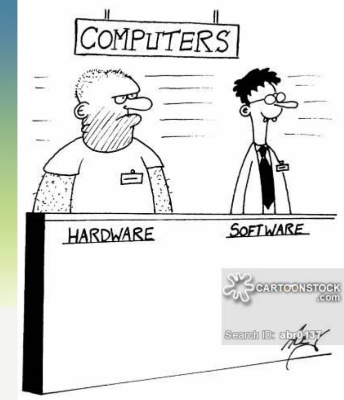
Achieved beam current
870 mA (HER)
1010 mA (LER)



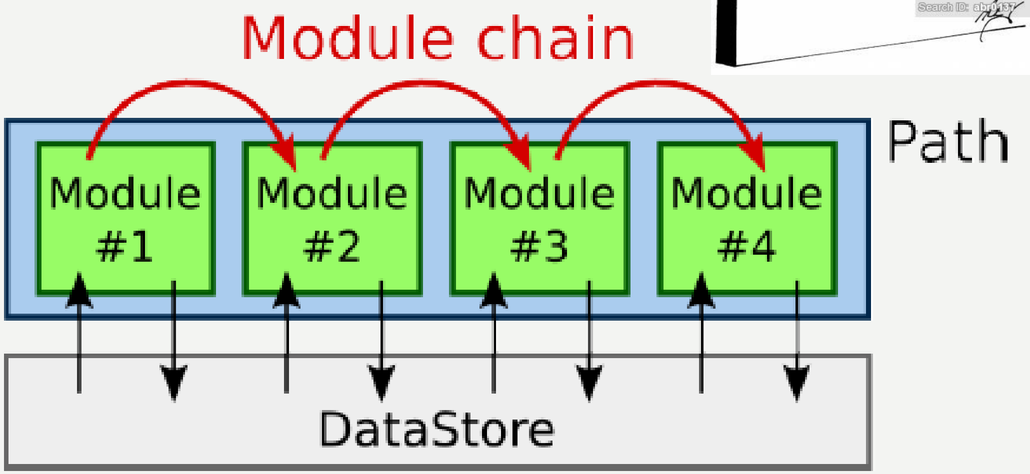
Trigger, DAQ and readout integration

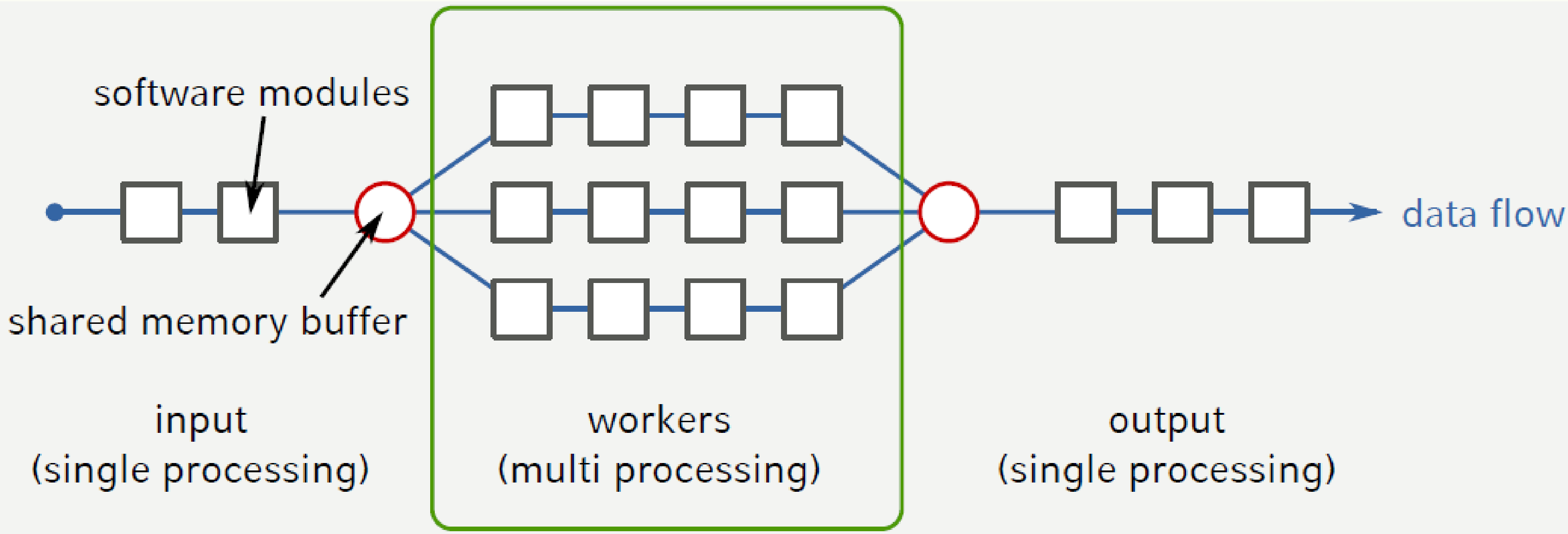


Software

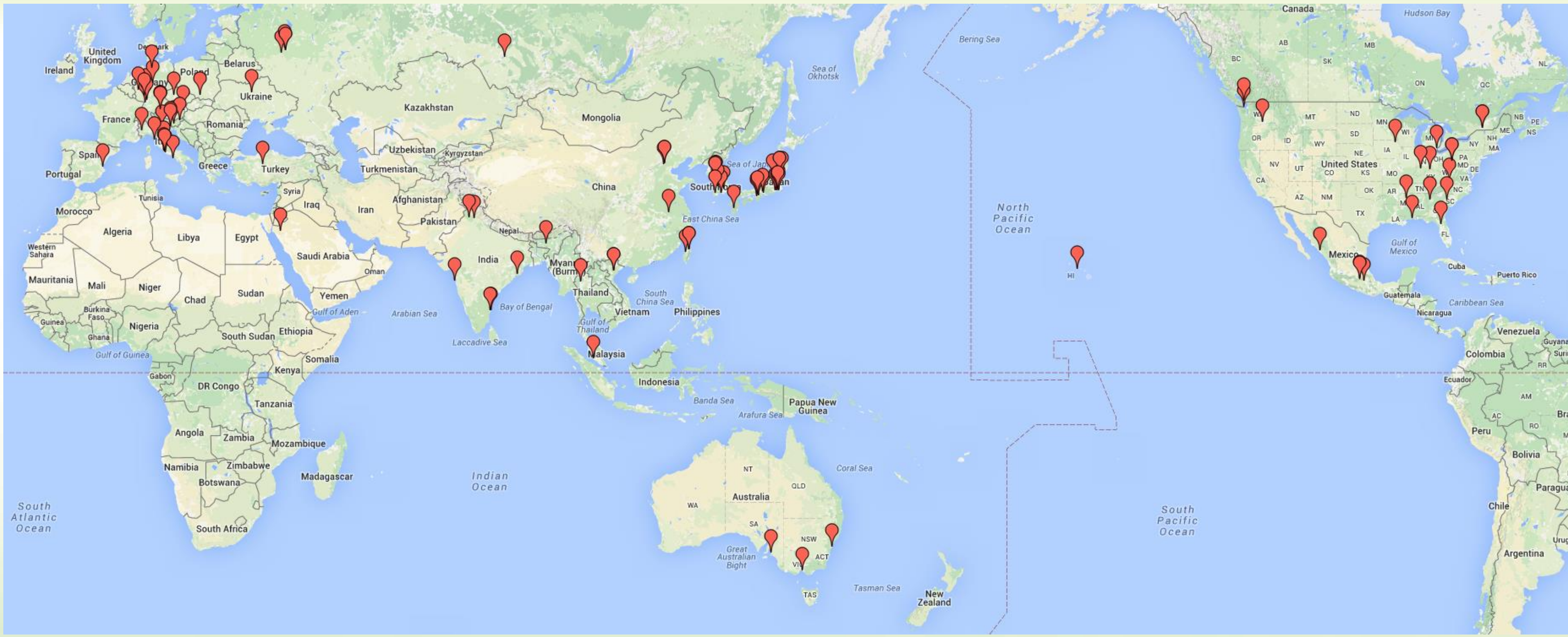


- Rewritten (mostly) from scratch.
- Standardise common processes.
- Events independent → trivial parallelisation.
- CVMFS mountable central builds OR ~ 1 min binaries setup.
- First full release: 08.2017





Belle II Collaboration



696 colleagues, 101 institutions, 23 countries/regions

Summary

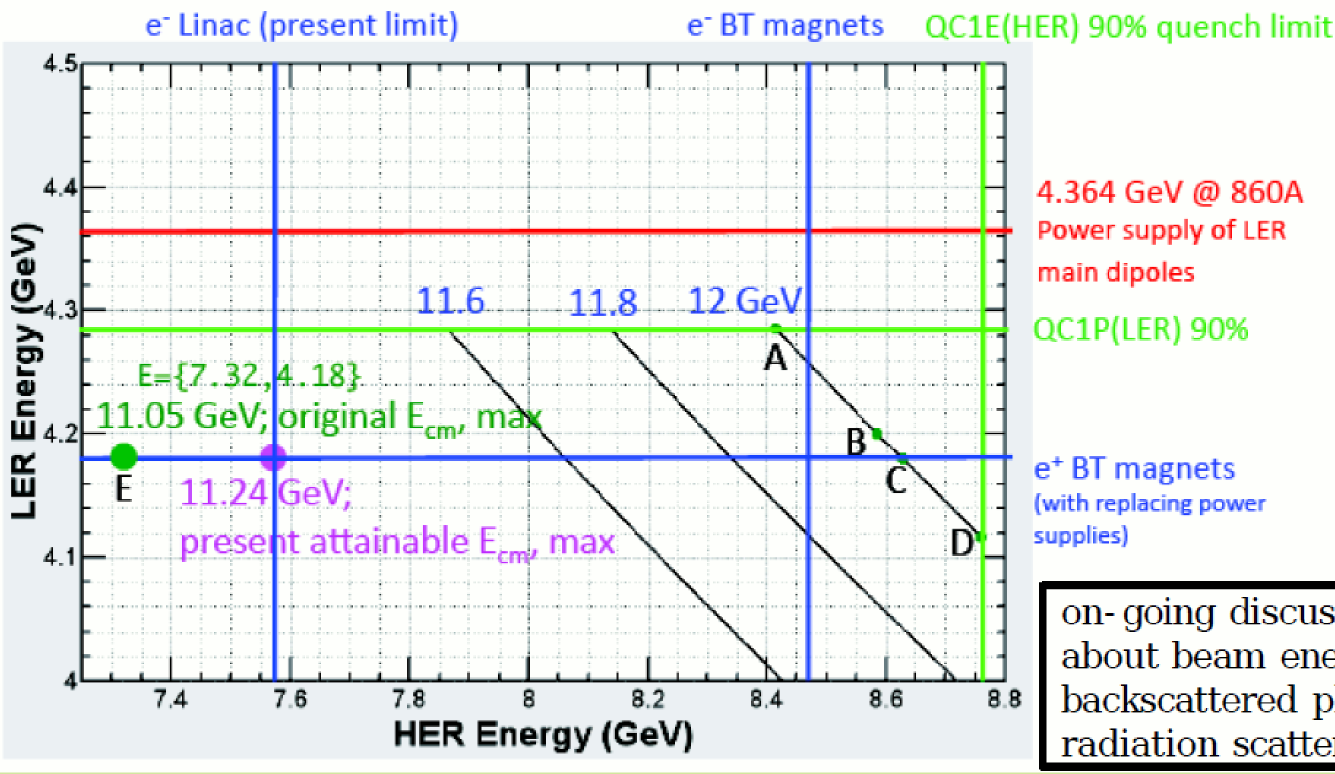
- More exotic results come out from BESIII and Belle. However, more puzzles need to be solved.
- Belle II is very promising in searching and studying exotic states with huge data sample.
- Belle II is under construction as plan although a little delay. 50ab^{-1} data sample is expected in 2024 !

Higher energy run

from K. Akai, BPAC Feb 2012

- Design: original design maximum energy is 11.05 GeV at $\Upsilon(6S)$
- Possible higher energy run (11.5 GeV – 12 GeV)?
  - If any, higher energy run will be after several years running at $\Upsilon(4S) \sim \Upsilon(6S)$
  - **present max E_{cm} is 11.24 GeV**, limited by e^- Linac and e^+ BT magnets
  - In order to inject the electron beam to HER at the required energy for 12 GeV operation, there must be huge reinforcement of Linac (replacement of S-band with C-band, 7.571 → 8.6 GeV

11.24 GeV region: $\Lambda_b \overline{\Lambda}_b$ threshold



e.g. [arXiv:1211.0103]

on-going discussion with SuperKEKB people about beam energy measurement using backscattered photons produced by laser radiation scattered head-on the beams