Prospects of XYZ Physics at Belle II

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XYZ workshop
Zhengzhou, Oct.19-23, 2018

Outline

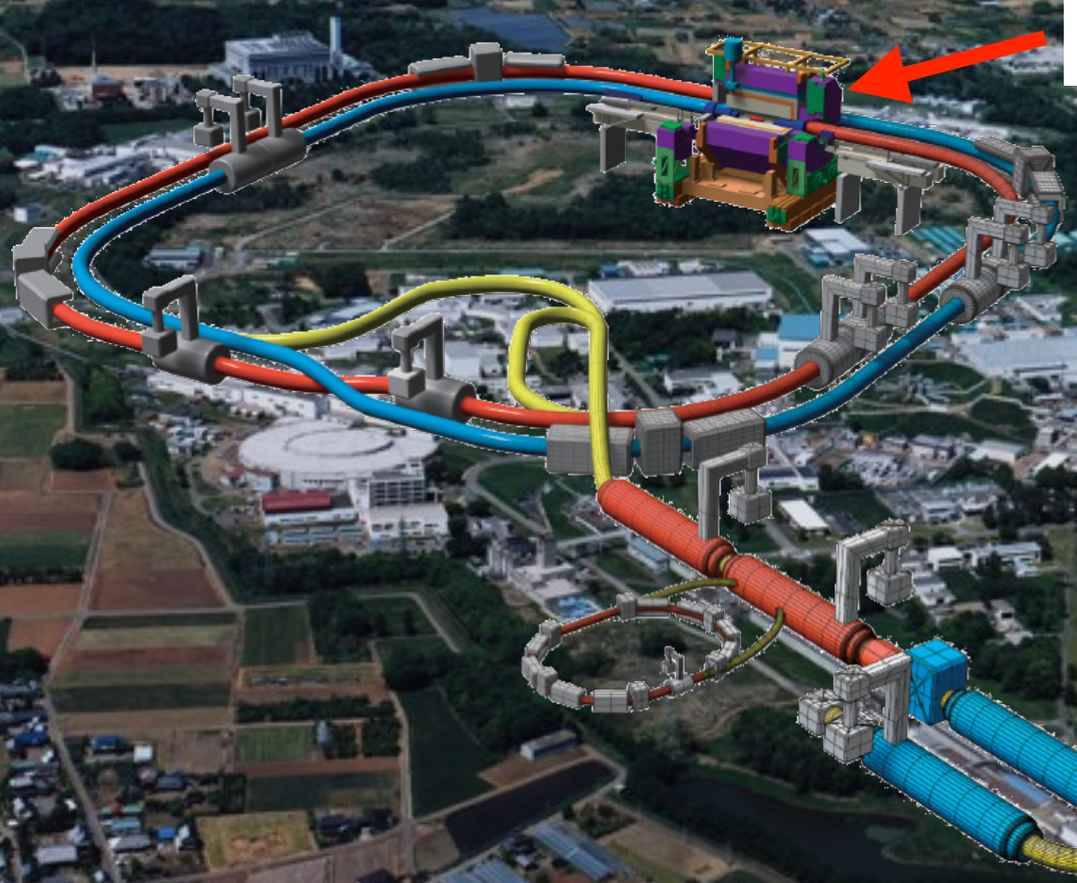
- SuperKEKB and Belle II
- Prospects of exotics and conventional quarkonium at Belle II
  - Charmonium(-like) states
  - Bottomonium(-like) states
- Status of Belle II
- Summary

SuperKEKB

An asymmetric electron-positron collider

e^+~ 4GeV e^-~ 7GeV

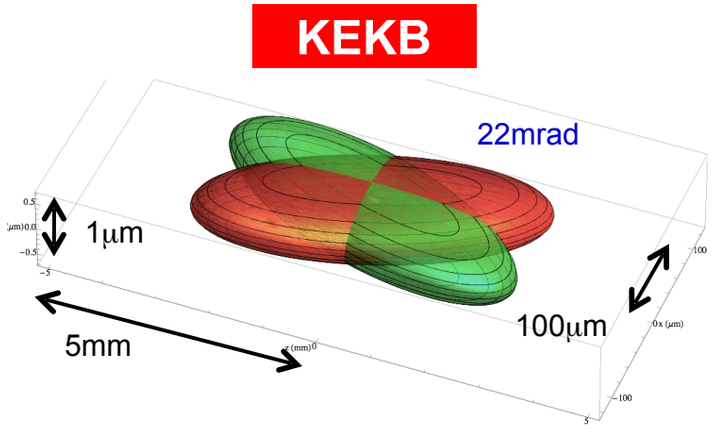
~3km circumference

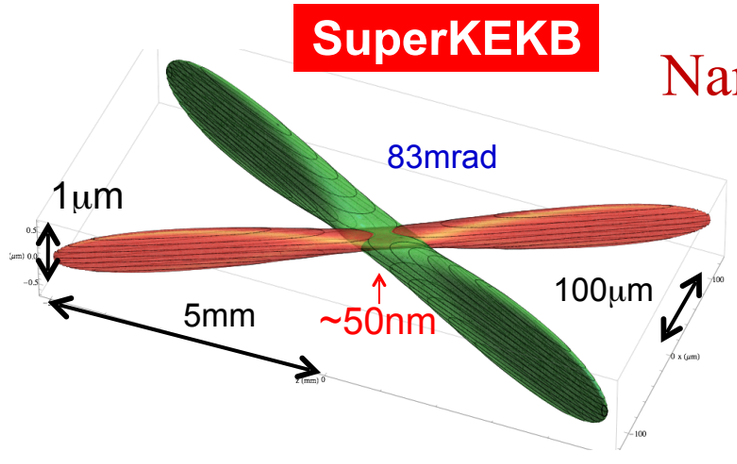


Belle II detector

@KEK, Tsukuba
One hour away from Tokyo

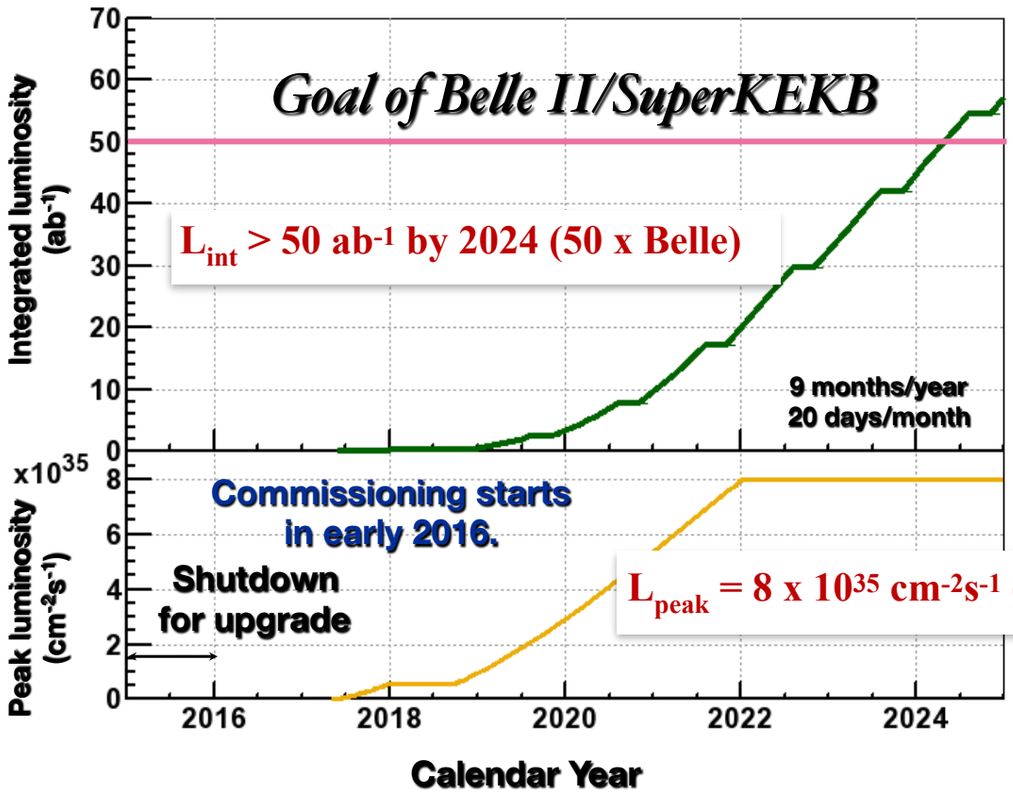
SuperKEKB

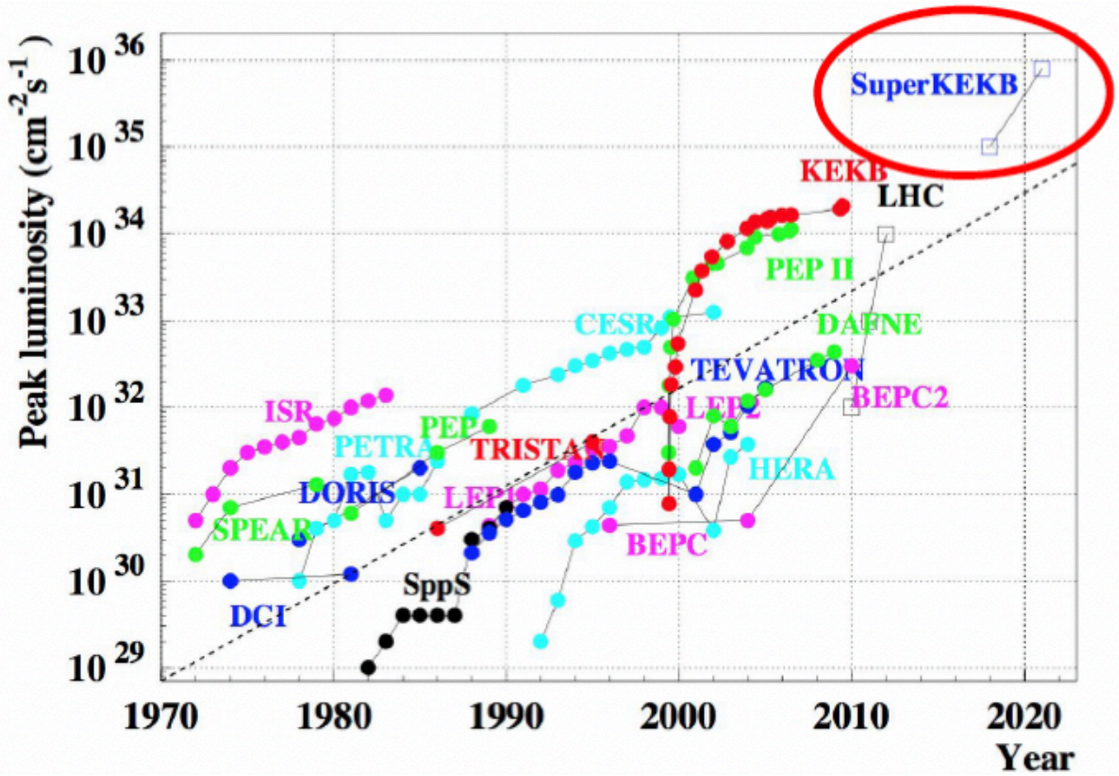




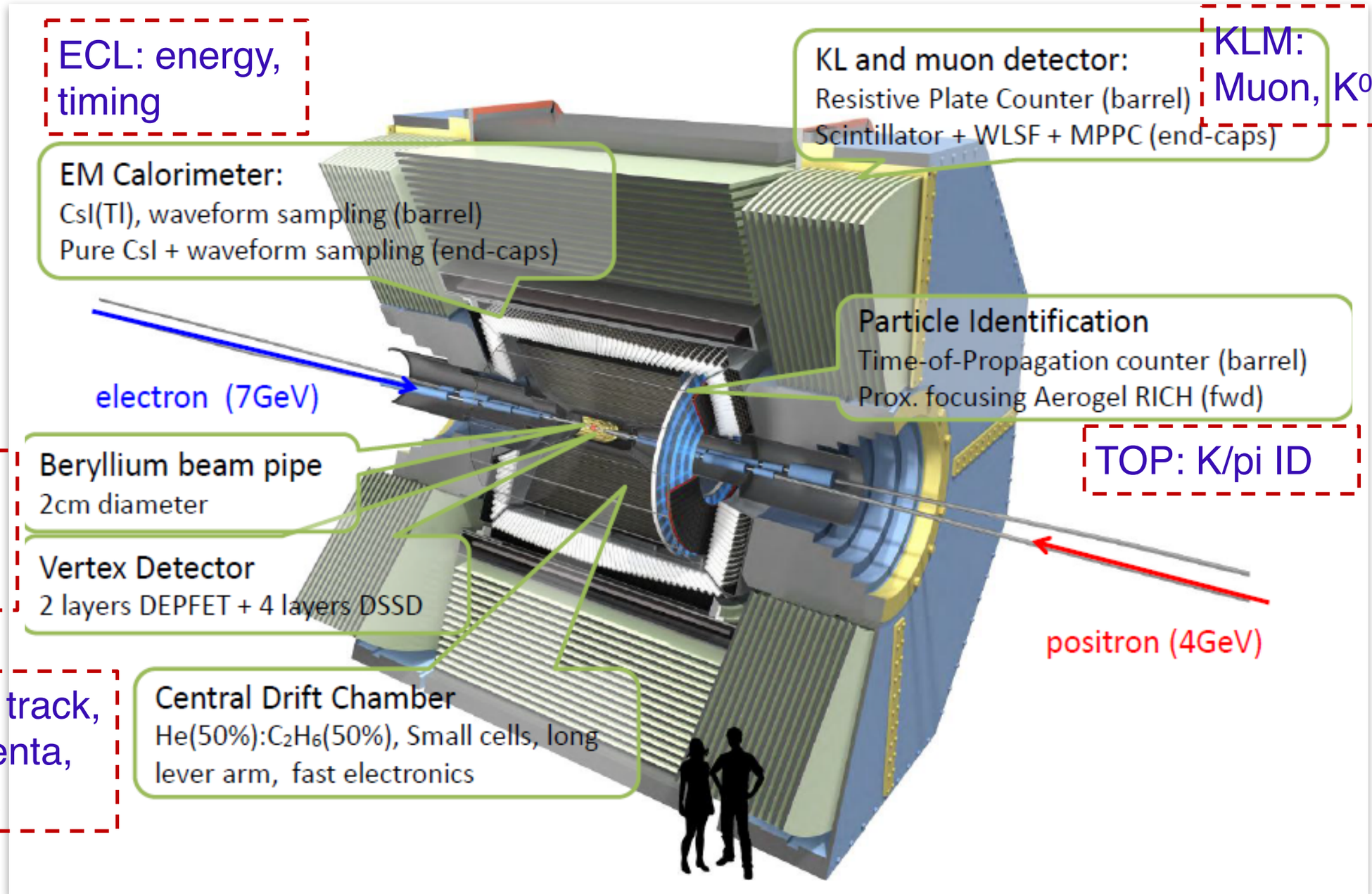
Nano-Beam Scheme

SuperKEKB Luminosity Project





Belle II Detector

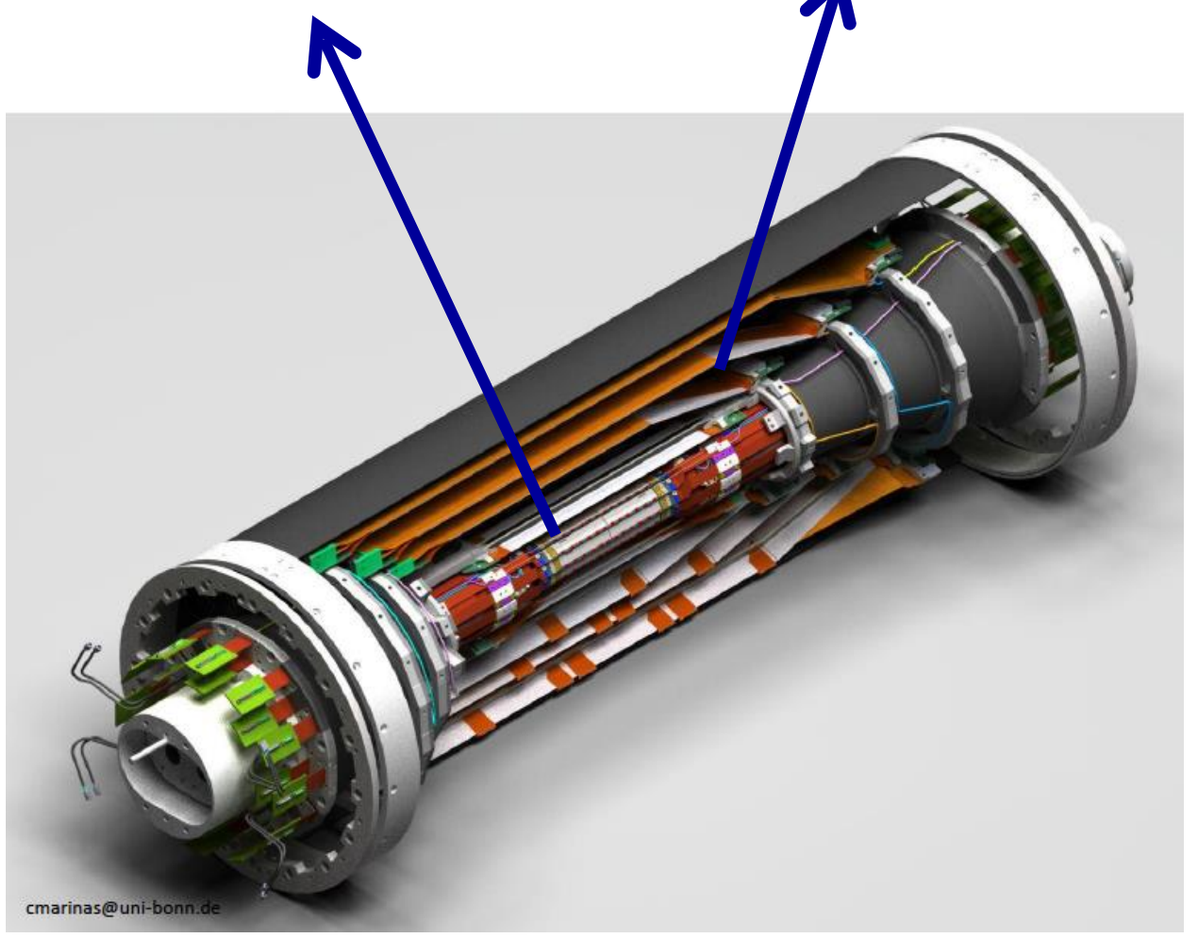


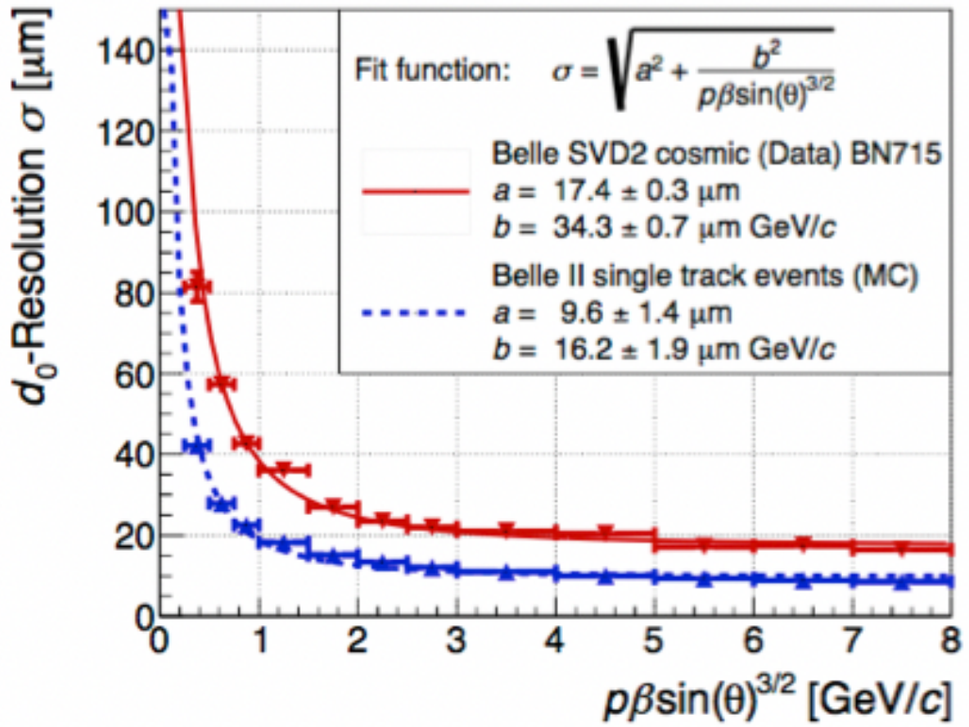
From Belle to Belle II

New Vertex Detectors

PXD: 1-2 layers
- 2 layers of pixel detectors
- Inner most layer very close to IP (r = 1.4cm)

SVD: 3-6 layers
- 4 layers of strip detectors
- covers the full Belle II angular acceptance of $17^o < \theta < 150^o$

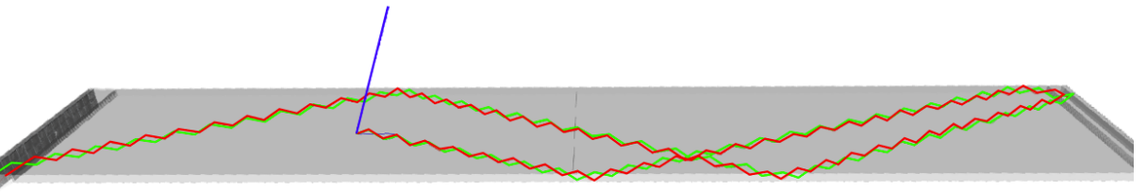


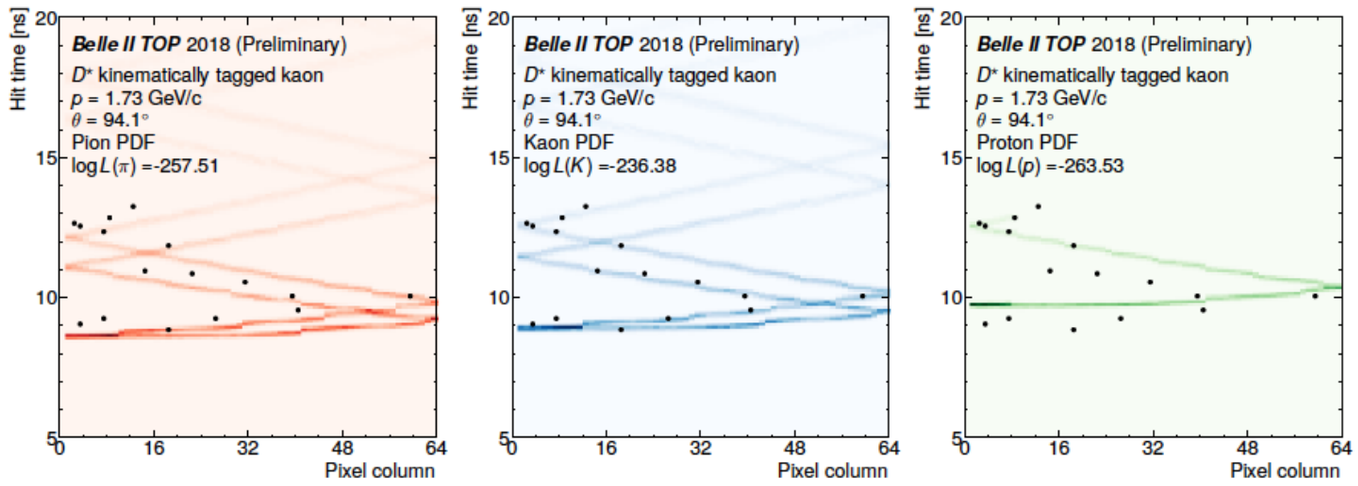


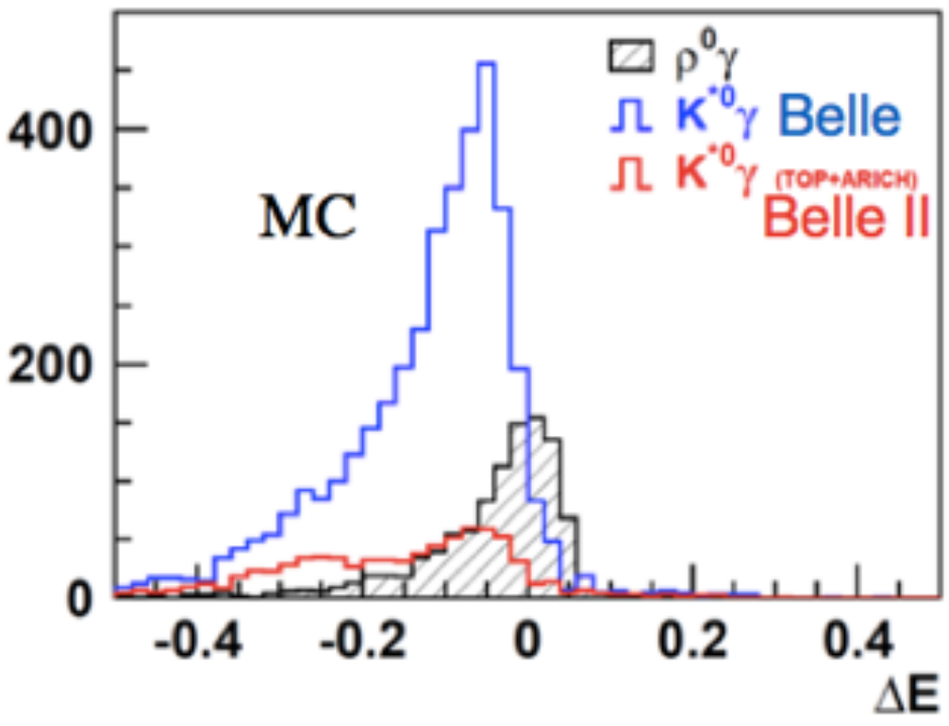
SVD

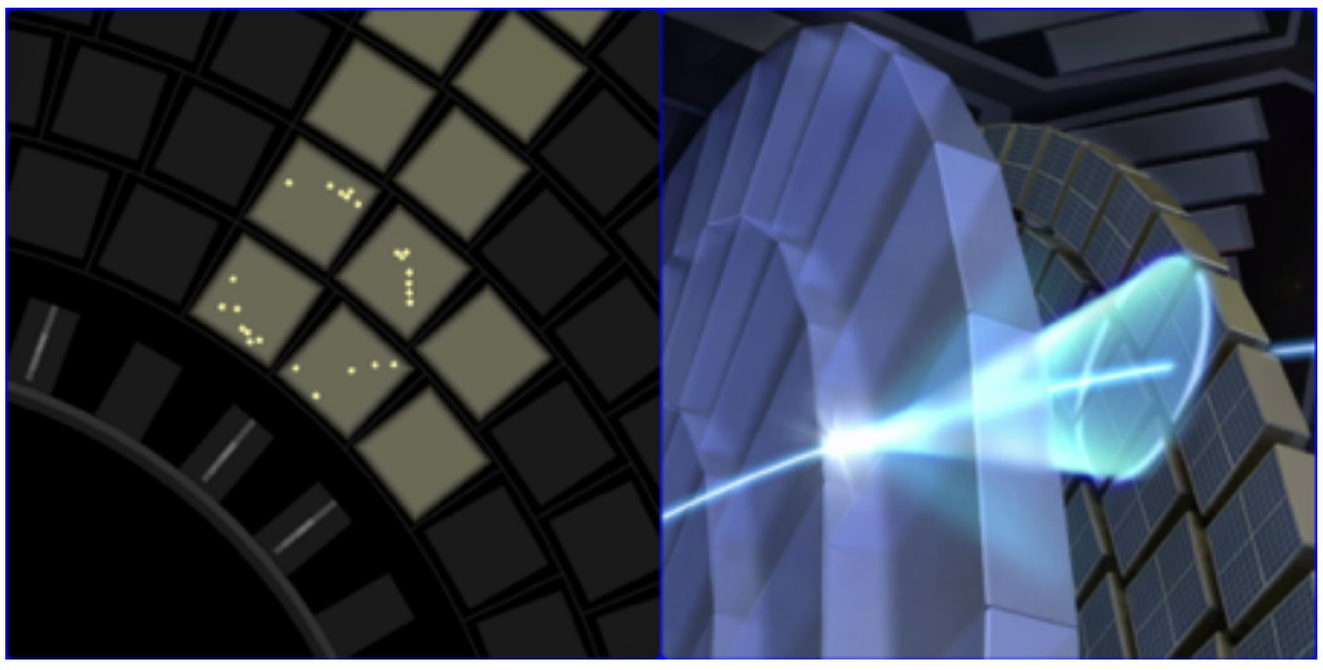
From Belle to Belle II

New PID System: Barrel TOP + Endcap ARICH



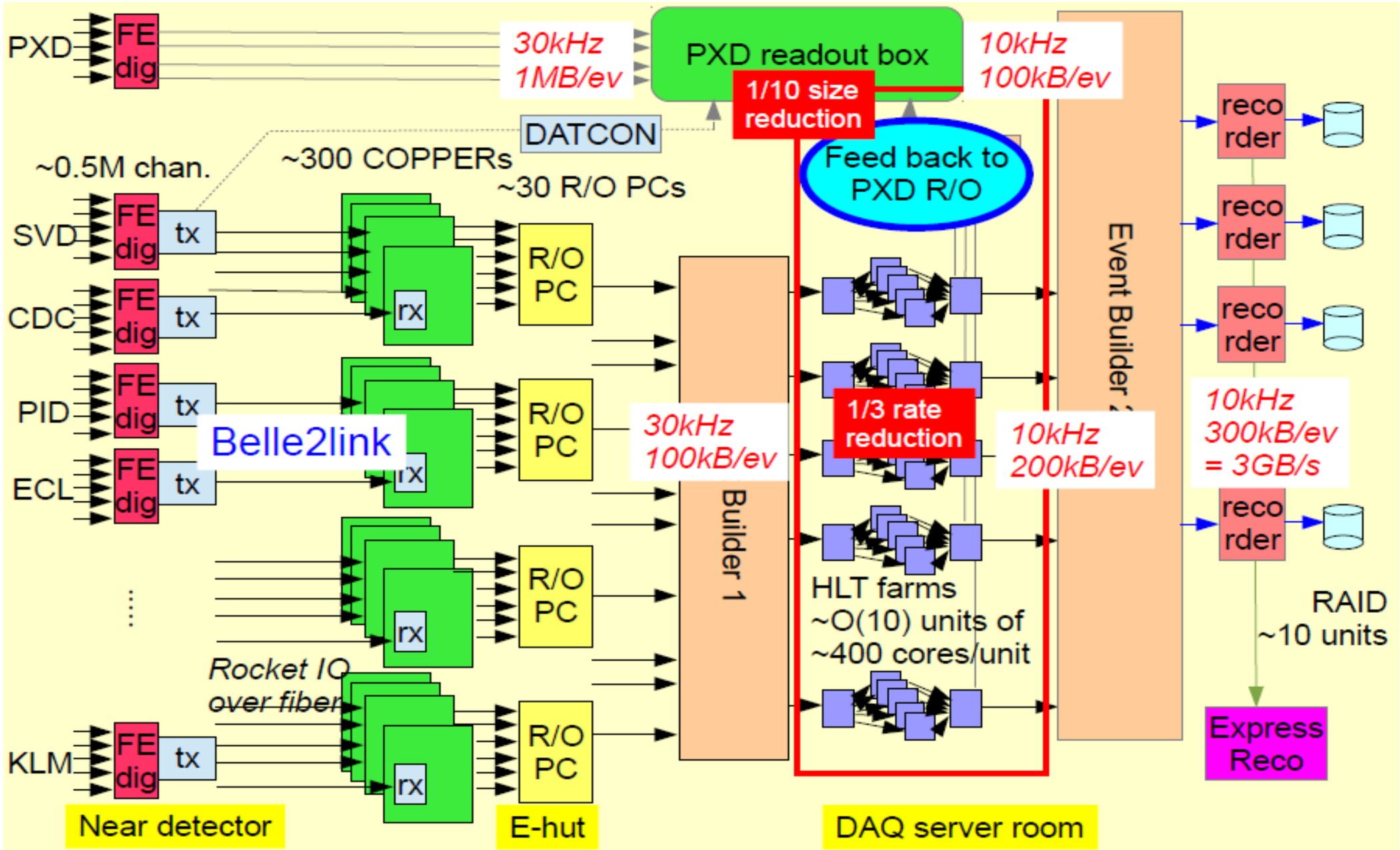






From Belle to Belle II

DAQ

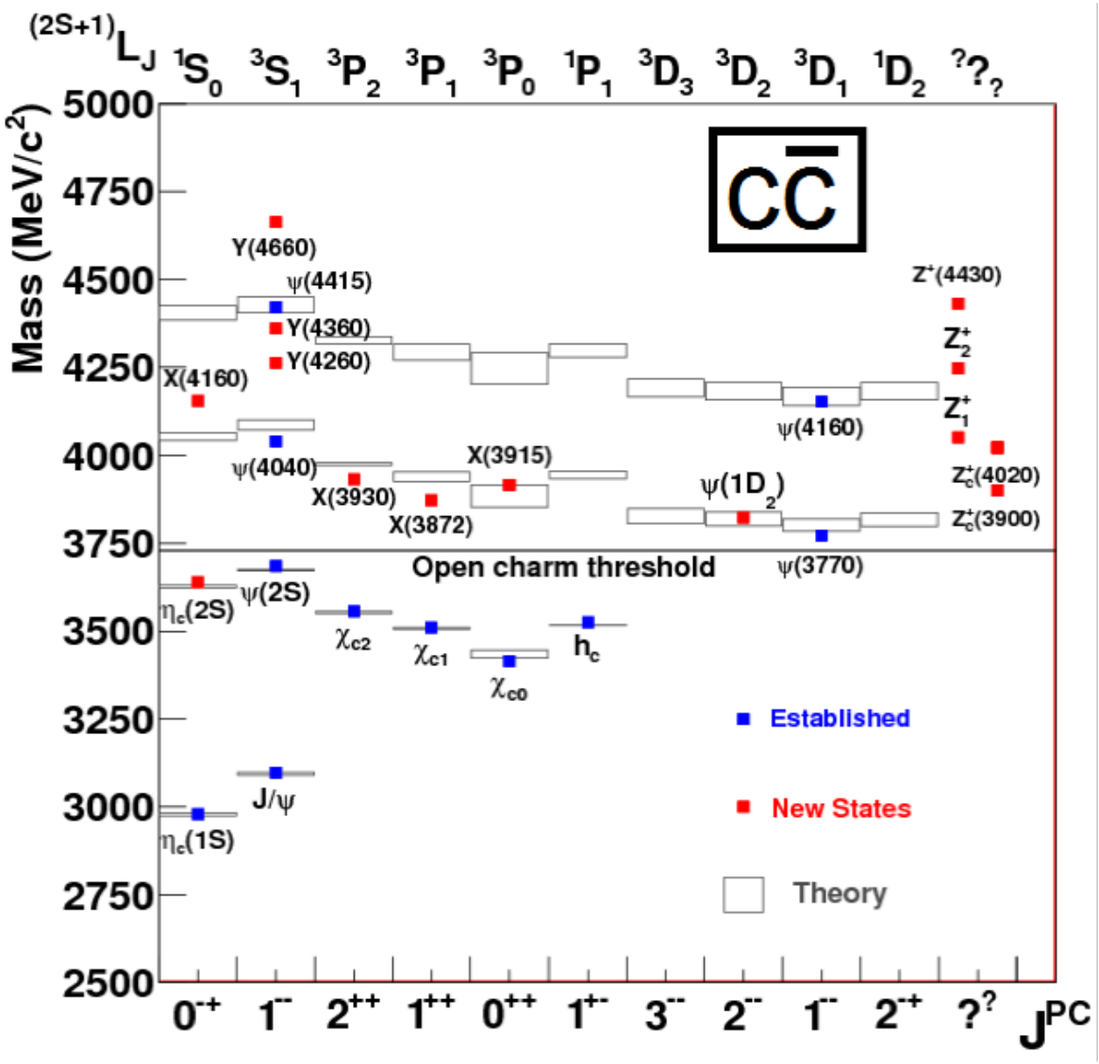


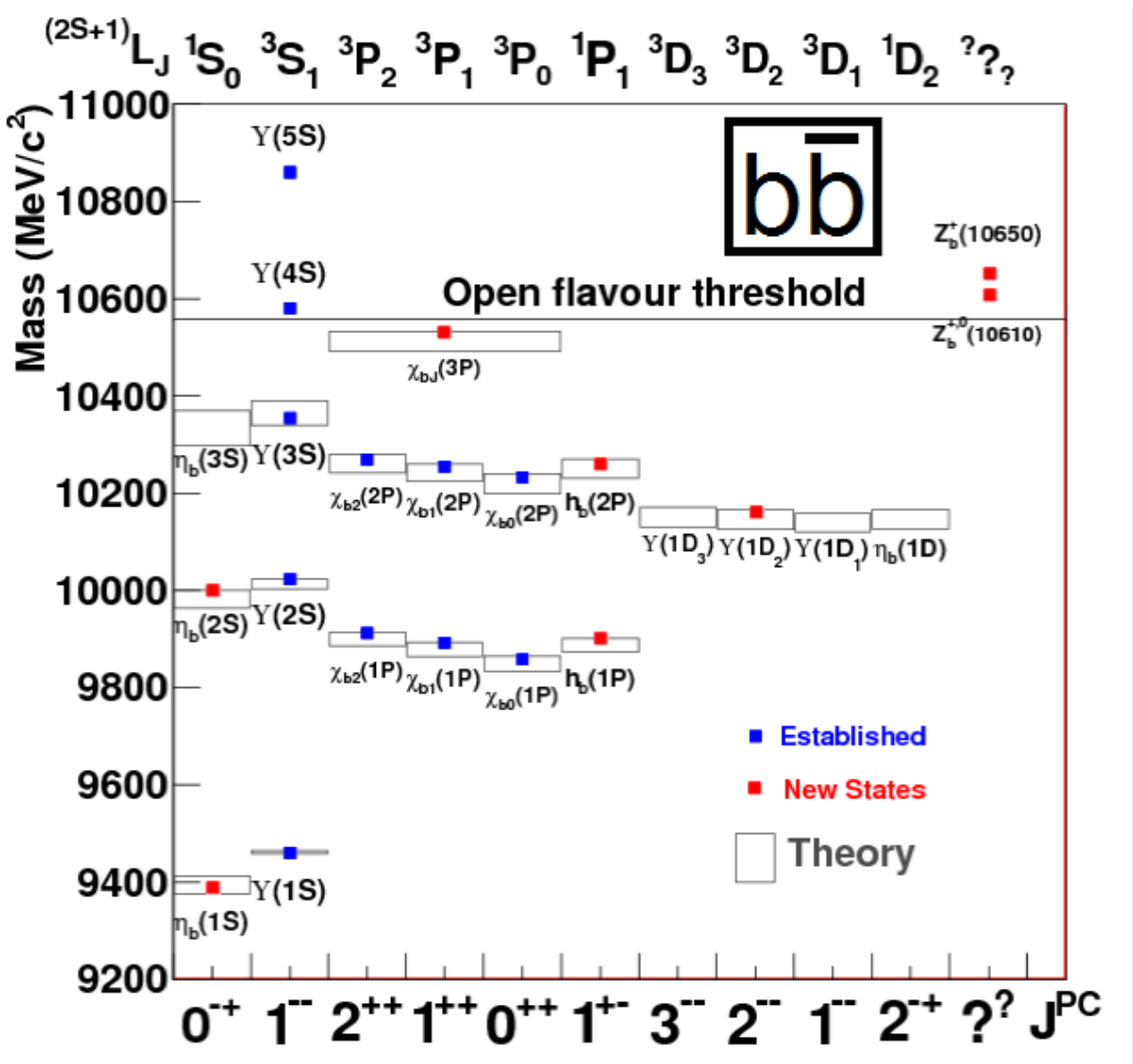
L1 trigger = 30 kHz
Software Trigger = 10kHz

Belle II Collaboration

~800 Colleagues
~100 Institutions
25 Countries/regions

Quarkonium


(2S+1)L_J 1S0 3S1 3P2 3P1 3P0 1P1 3D3 3D2 3D1 1D2 ??
Mass (MeV/c²)
5000
4750
4500
4250
4000
3750
3500
3250
3000
2750
2500
cc̄
Y(4660)
ψ(4415)
Y(4360)
Y(4260)
X(4160)
ψ(4040)
X(3930)
X(3872)
X(3915)
ψ(1D2)
ψ(4160)
Z+(4430)
Z2+
Z1+
Zc+(4020)
Zc+(3900)
ψ(3770)
Open charm threshold
ηc(2S)
ψ(2S)
χc2
χc1
χc0
hc
J/ψ
ηc(1S)
Established
New States
Theory
0-+ 1-- 2++ 1++ 0++ 1+- 3-- 2-- 1-- 2-+ ?? JPC


(2S+1)L_J 1S0 3S1 3P2 3P1 3P0 1P1 3D3 3D2 3D1 1D2 ??
Mass (MeV/c²)
11000
10800
10600
10400
10200
10000
9800
9600
9400
9200
bb̄
Y(5S)
Y(4S)
Open flavour threshold
χbJ(3P)
Zb+(10650)
Zb+0(10610)
ηb(3S)
Y(3S)
χb2(2P)
χb1(2P)
χb0(2P)
hb(2P)
Y(1D3)
Y(1D2)
Y(1D1)
ηb(1D)
ηb(2S)
Y(2S)
χb2(1P)
χb1(1P)
χb0(1P)
hb(1P)
ηb(1S)
Y(1S)
Established
New States
Theory
0-+ 1-- 2++ 1++ 0++ 1+- 3-- 2-- 1-- 2-+ ?? JPC

Production of ccbar at B-factory

Production mechanism

- **B decay**
  - **$B \to KX(c\bar{c})$**
- **Initial state radiation (ISR)**
  - **$J^{PC} = 1^{--}$**
- **Two-photon**
  - **$J^{PC} = 0^{-+}, 0^{++}, 2^{++}$…**
- **Double charmonium**

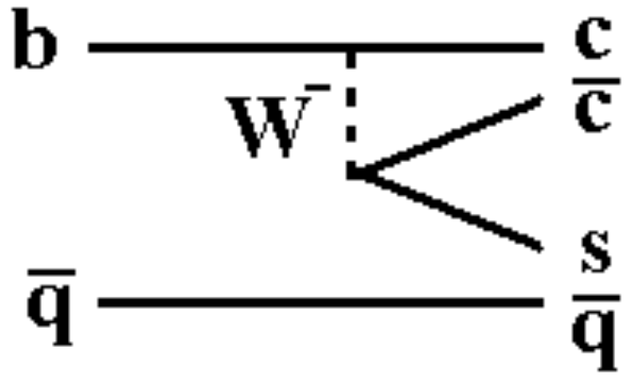
Expected statistics @50 ab^{-1} of XYZ

State	Production and Decay	N
X(3872)	$B \to K$X(3872), X(3872)$\to J/\psi\pi^+\pi^-$	$\simeq$14400
Y(4260)	ISR, Y(4260)$\to J/\psi\pi^+\pi^-$	$\simeq$29600
Z(4430)	$B \to K^{\mp}$Z(4430), Z(4430)$\to J/\psi\pi^{\pm}$	$\simeq$10200

- **Now Γ(X(3872))<1.2MeV, precious measurement of the X(3872) width at Belle II**

Charmonium(-like) by B Decays

$B \to K X_{ccbar}$



- A rich source of charmonium(-like) mesons
  - Discoveries of conventional and exotic states
  - Study the properties of these states.
- Observed two narrow charmonium
  - $\eta_c(2S) \to K_S K \pi$
  - $\psi_2(1D) \to \gamma\chi_{c1}$
- Observed charmomium-like states e.g. X(3872) in $\omega J/\psi$, $Z(4050)^+$ and $Z(4250)^+$ in $\pi^+\chi_{c1}$

Search for the missing narrow charmonium

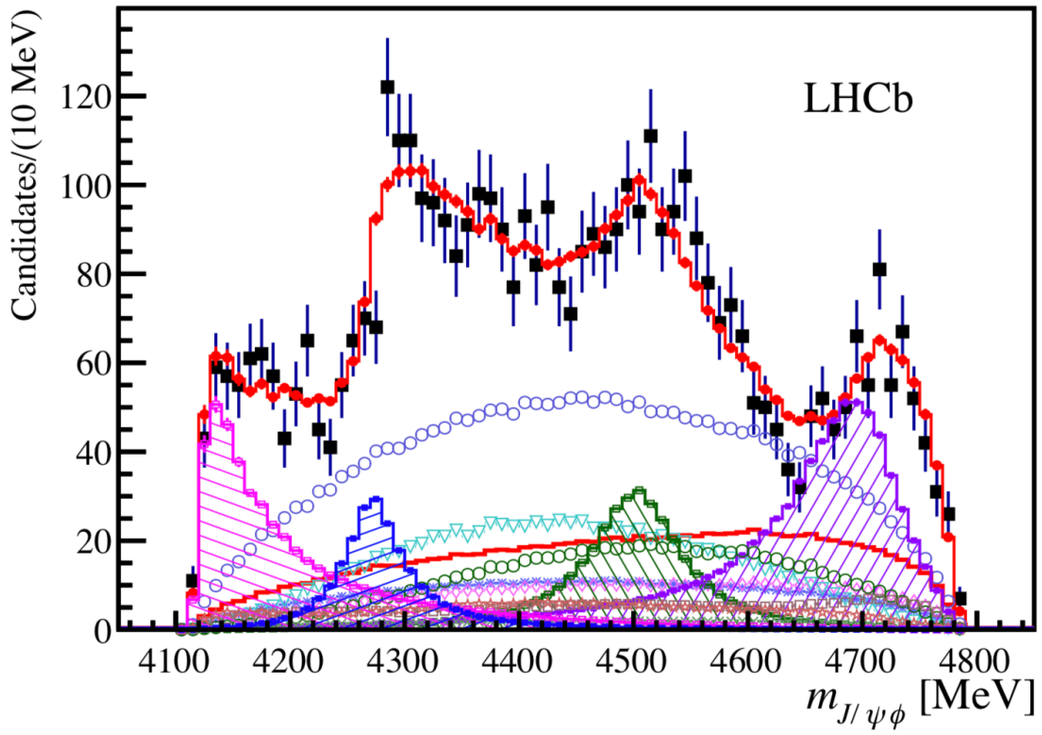
- Spin-singlet $\eta_{c2}(1D)$ $J^{PC} = 2^{-+}$
- The only unobserved narrow charmonium state
- Cannot decay to DD due to parity conservation
- Expect to reside between the DD and DD* thresholds
- Promising search channel: B->K($h_c\gamma$)

Charmonium(-like) by B Decays

$B \to K X_{ccbar}$

- Determine spin-parities of the observed states with full amplitude analyses e.g. X(3915), Z(4050), Z(4250).
- Confirm or deny the existing unconfirmed states, e.g.
  - Four states were observed by LHCb
  - $B \to K(\varphi J/\psi)$
  - X(4140), X(4274), X(4500), X(4700)
- Search for new exotics

LHCb PRL 118(2017) 022003

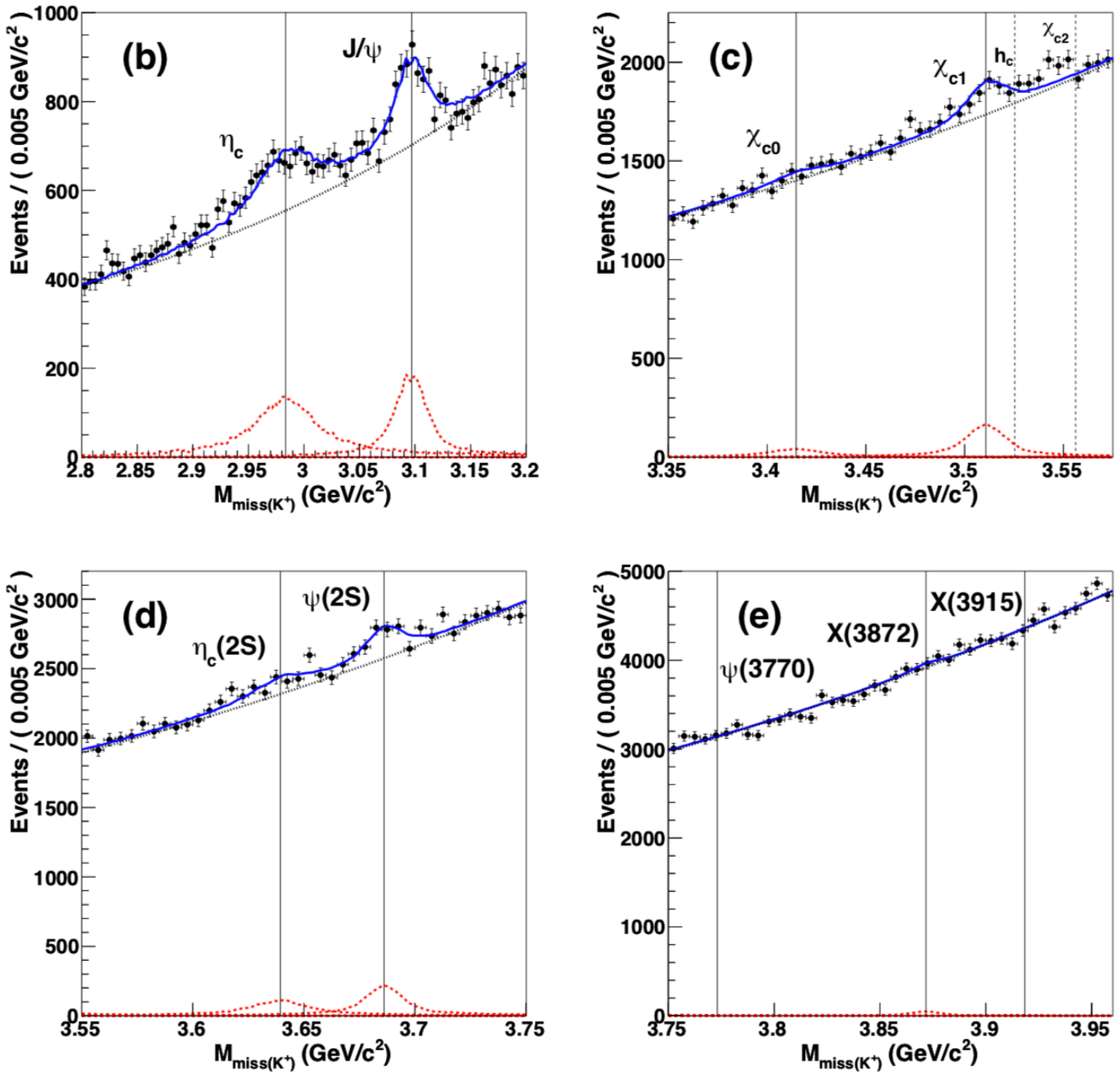


Charmonium(-like) by B Decays

$B \to K X_{ccbar}$

Determination of absolute branching of Xccbar and search for new exotics with inclusive reconstruction

- **Full reconstruction of one B**
- **Recoil of the Kaon in another B**
- **Extract the Br($B \to K X_{ccbar}$)**



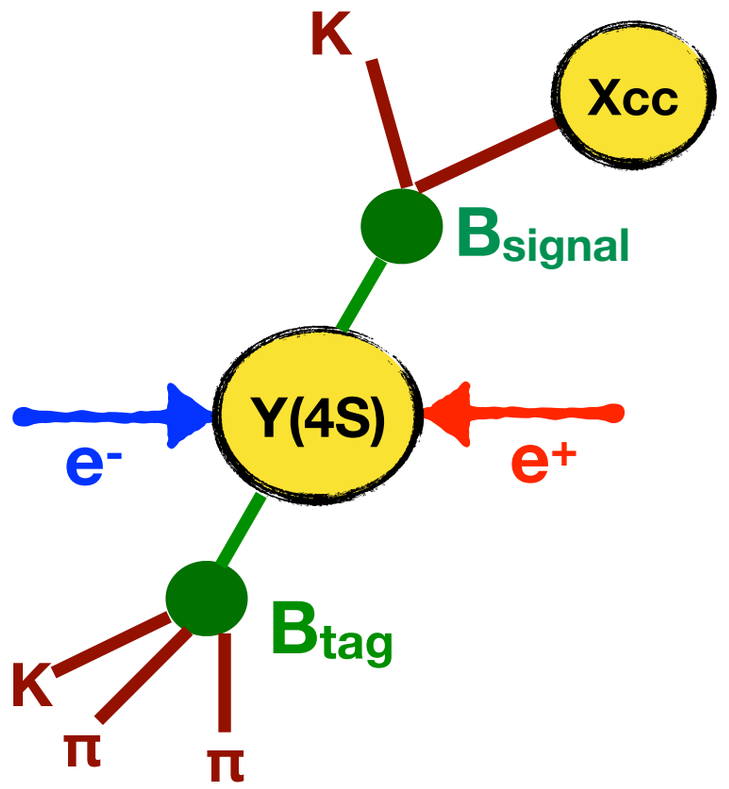
Belle: PRD 97, 012005 (2018)

$$\mathcal{B}(B^+ \to \eta_c K^+) = (12.0 \pm 0.8 \pm 0.7) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta_c(2S) K^+) = (4.8 \pm 1.1 \pm 0.3) \times 10^{-4}$$

Uniquely done in e+e- B-factories

Full Event Integration (FEI)

- **Reconstruct one out of the two B mesons**
- **Increasing efficiency by tagging more decay channels than Belle**
- **More automation and analysis-specific optimizations**
- **Training include generic-mode for analysis w/o signal-side selection and specific-mode for w/ signal-side selection**
- **Essential for the analysis w/o full reconstruction of B meson e.g. (semi-)leptonic decay, $B \to K X_{ccbar}$ inclusive analysis**

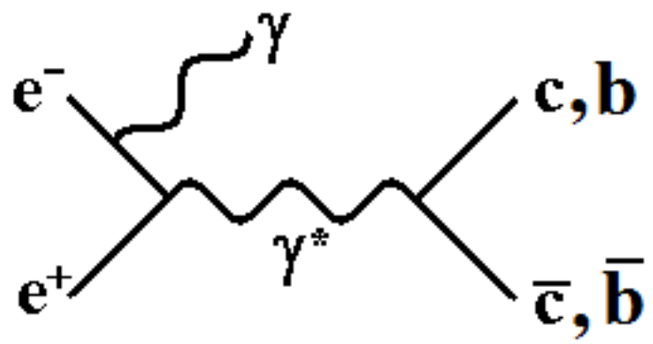


Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

Charmonium(-like) by ISR

Main force of the discovery of exotics at Belle

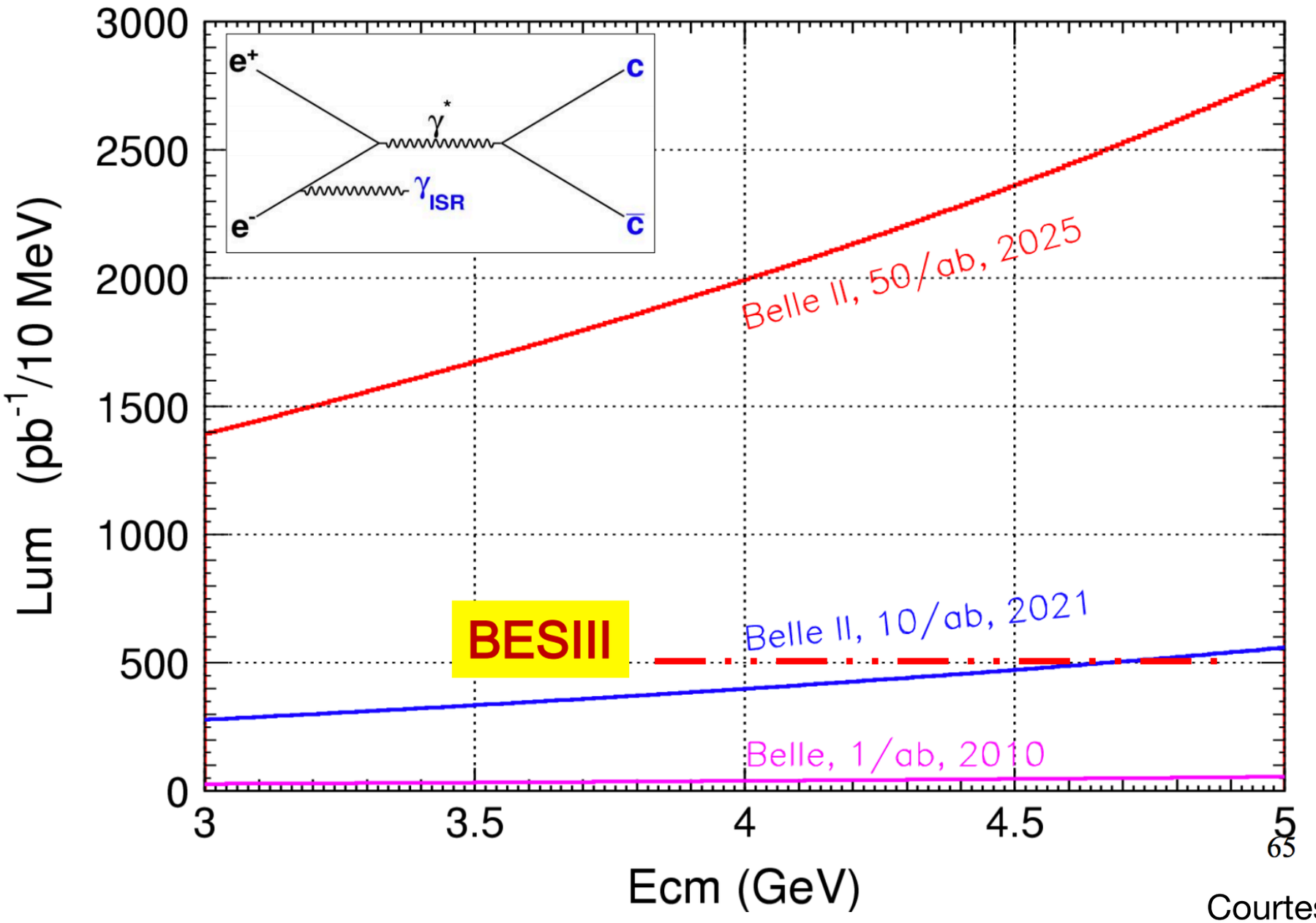
- **Discover new exotics**
- **Study of the properties of the states**



Golden Channels	$E_{c.m.}$ (GeV)	Statistical error (%)	Related XYZ states
$\pi^+\pi^- J/\psi$	4.23	7.5 (3.0)	$Y(4008)$, $Y(4260)$, $Z_c(3900)$
$\pi^+\pi^-\psi(2S)$	4.36	12 (5.0)	$Y(4260)$, $Y(4360)$, $Y(4660)$, $Z_c(4050)$
$K^+K^- J/\psi$	4.53	15 (6.5)	Z_{cs}
$\pi^+\pi^- h_c$	4.23	15 (6.5)	$Y(4220)$, $Y(4390)$, $Z_c(4020)$, $Z_c(4025)$
$\omega\chi_{c0}$	4.23	35 (15)	$Y(4220)$

$10pb^{-1}$ **$50pb^{-1}$**

Charmonium(-like) by ISR



At 4.26 GeV for ππJ/ψ

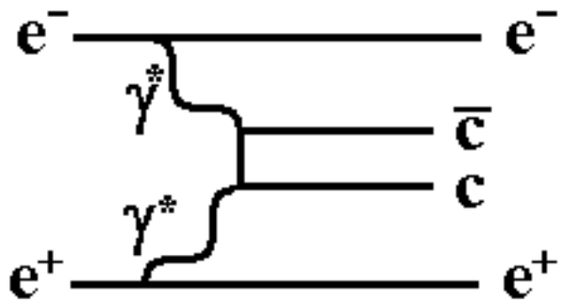
ε_{BESIII} = 46%

ε_{Belle} = 10%

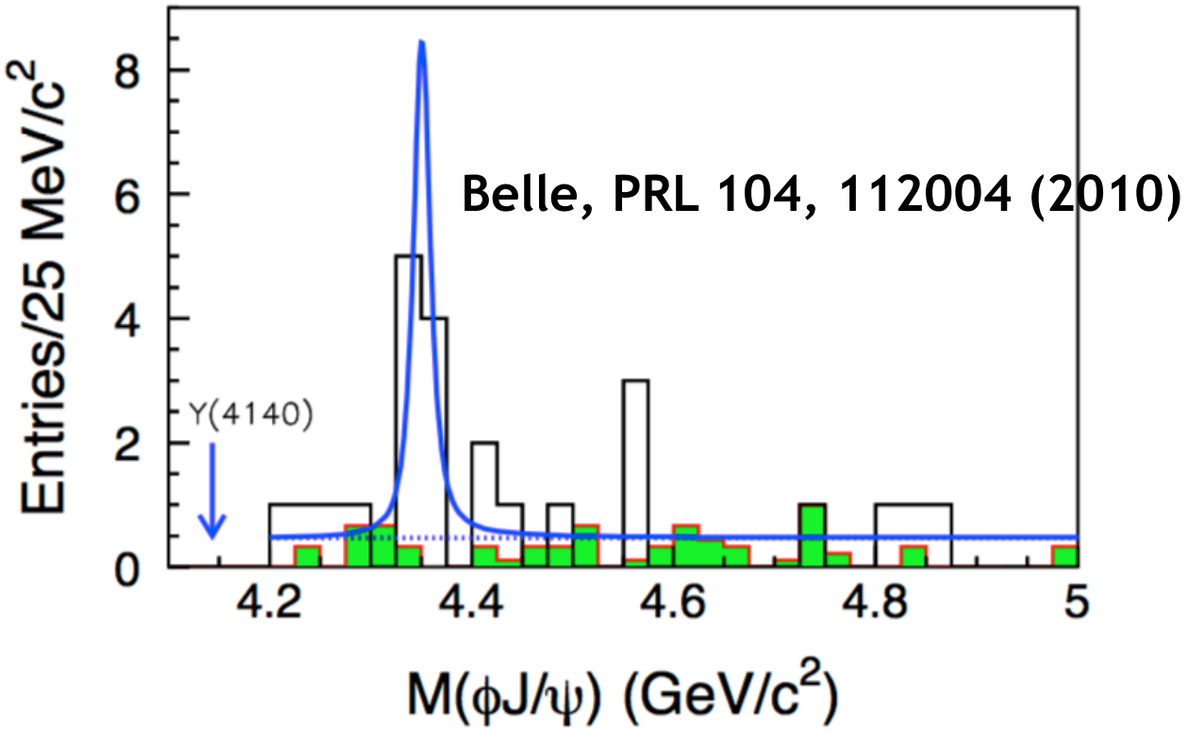
Courtesy of Prof. C. Z. Yuan

Charmonium-like by two-photon

- γγ→ωJ/ψ by Belle and BaBar
  X(3915) = $\chi_{c0}(2P)$?
- γγ→DDbar by Belle and BaBar
  X(3930) = $\chi_{c2}(2P)$?
- Precise measurements of the properties of X(3915), X(3930) are needed



- X(4350) in γγ→ϕJ/ψ (3.2σ) by Belle
- limited statistics
- Belle II will revisit the process (also in B decay) to confirm or deny the state



Double Charmonium

Observed the $x_{c0}(2P)$ candidate X(3860) by Belle

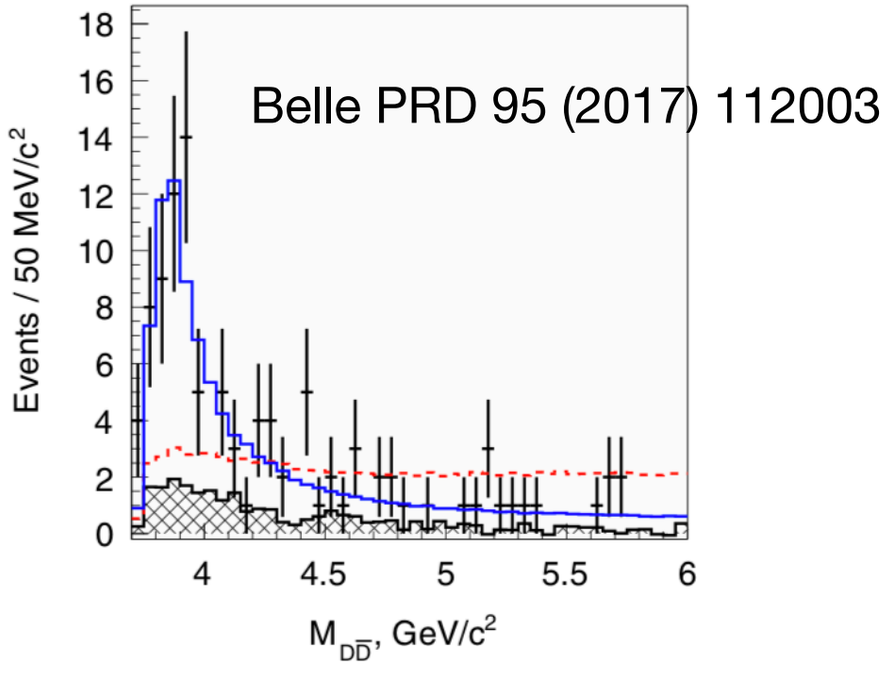
- **$e^+e^- \rightarrow J/\psi$ DDbar**
- **Reconstruct J/ψ and one D,**
- **Another D is identified by the recoil mass M(J/ψD)**

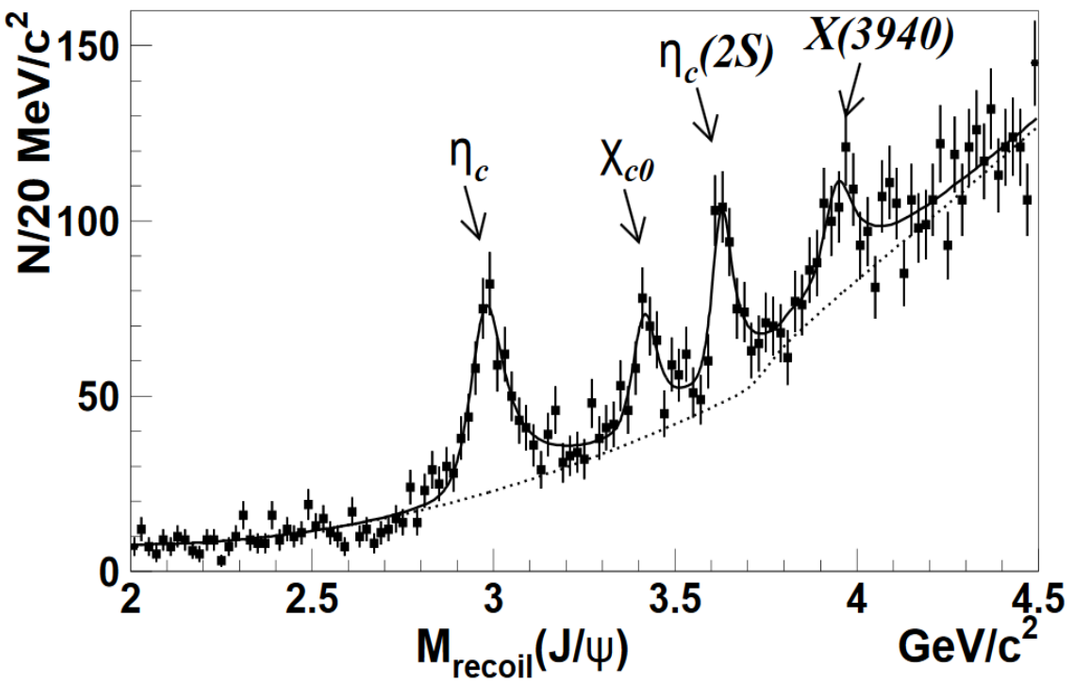
$e^+e^- \rightarrow J/\psi X$

- **The recoil of J/ψ or $\psi(2S)$**
- **Observed X(3940), X(4160)**

Prospects at Belle II

- **Full amplitude analysis to measure spin-parities of the observed new states**
- **Studies of $e^+e^- \rightarrow h_c X$, $e^+e^- \rightarrow \eta_c X$ …**



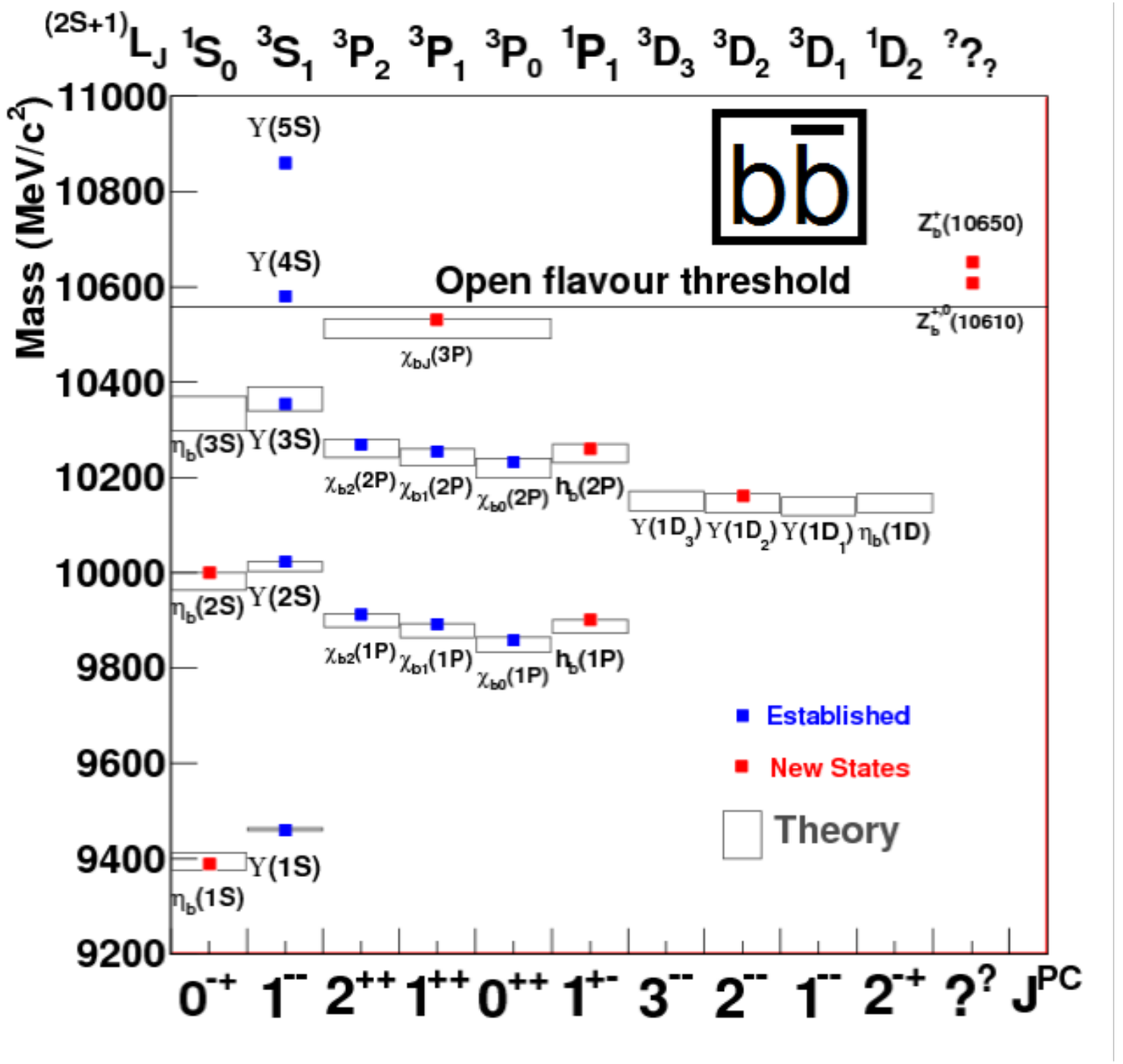


Belle, PRL 98, 082001 (2005)

Bottomonium(-like) States

- **Precious measurements of observed resonances e.g. $M(\eta_b)$, $\Gamma(\eta_b)$, $\Gamma(x_{b0})$**

- **Search for the missing conventional bottomonia below the BBbar threshold**
  - **$\chi_b(3P)$ triplet**
  - **$Y(2D_3)$ triplet**
  - **$\eta_b(3S)$, $\eta_b(1D)$, $Y(1D_{1,3})$**
  - **F-wave states**

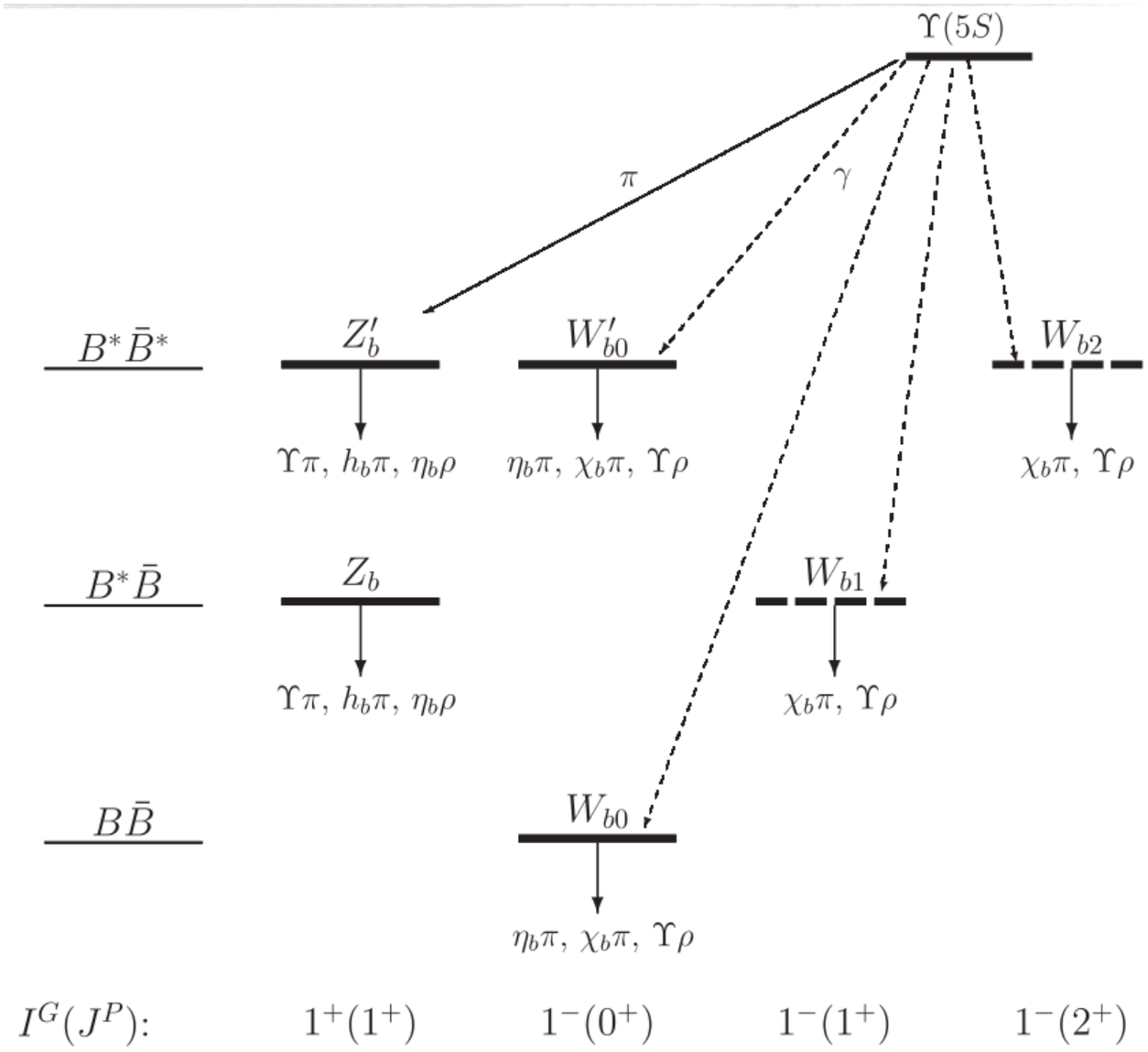


Search for new exotics

- **Observed Zb(10610), Zb(10650) in Y(5S, 6S) transitions**
- **Search for new molecular states near B(*)B(*) threshold, produced threshold is up to 11.43GeV**

Table 132: Expected molecular states with the structure $B\bar{B}$, $B\bar{B}^*$ and $B^*\bar{B}^*$ [1370].

$I^G(J^P)$	Name	Content	Co-produced particles [Threshold, GeV/c^2]	Decay channels
$1^+(1^+)$	Z_b	$B\bar{B}^*$	π [10.75]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^+(1^+)$	Z_b'	$B^*\bar{B}^*$	π [10.79]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^-(0^+)$	W_{b0}	$B\bar{B}$	ρ [11.34], γ [10.56]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(0^+)$	W_{b0}'	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(1^+)$	W_{b1}	$B\bar{B}^*$	ρ [11.38], γ [10.61]	$\Upsilon(nS)\rho$
$1^-(2^+)$	W_{b2}	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$
$0^-(1^+)$	X_{b1}	$B\bar{B}^*$	η [11.15]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^-(1^+)$	X_{b1}'	$B^*\bar{B}^*$	η [11.20]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^+(0^+)$	X_{b0}	$B\bar{B}$	ω [11.34], γ [10.56]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$, $\eta_b(nS)\eta$
$0^+(0^+)$	X_{b0}'	$B^*\bar{B}^*$	ω [11.43], γ [10.65]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$, $\eta_b(nS)\eta$
$0^+(1^+)$	X_b	$B\bar{B}^*$	ω [11.39], γ [10.61]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$
$0^+(2^+)$	X_{b2}	$B^*\bar{B}^*$	ω [11.43], γ [10.65]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$



Energy frontier of Belle II

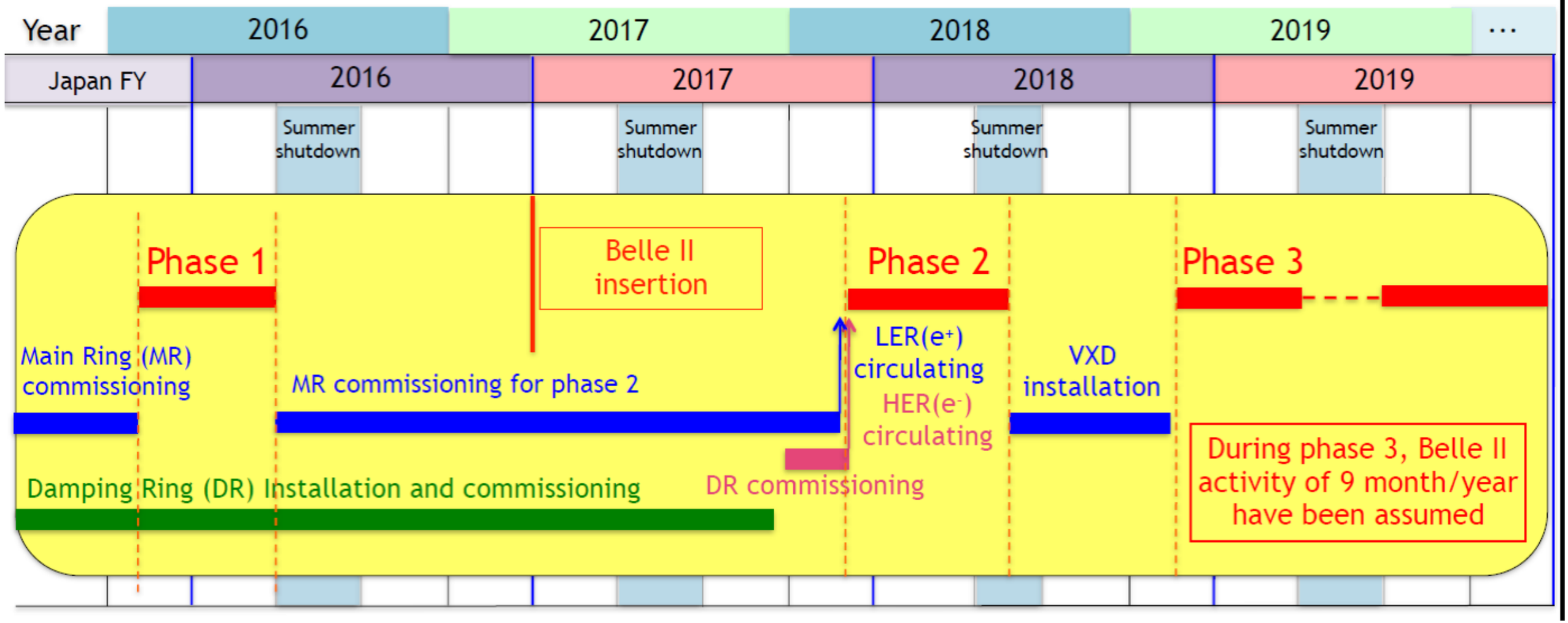
Current samples in fb^{-1} (millions of events), and the proposal for BelleII

Experiment	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\Upsilon(4S)$	$\Upsilon(5S)$	$\Upsilon(6S)$	$\frac{\Upsilon(nS)}{\Upsilon(4S)}$
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-	23%
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan	11%
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5	23%
BelleII	-	-	300 (1200)	5×10^4 (5.4×10^4)	1000 (300)	100+400(scan)	3.6%

- **Interesting physics beyond Y(6S)**
  - **$\Lambda_b\bar{\Lambda}_b$ threshold ~ 11.24 GeV, up to 11.35GeV could cover $\Lambda_b\bar{\Lambda}_b$ threshold region**
  - **Search for new molecular states around 11.5-11.6 GeV e.g. partners of X(3872) and Zb via vector states transition**
- **Machine limits**
  - **The range of beam energies covers the Y(1S) and Y(6S) resonance for physics operation, but no enough spare cavities to run safely at Y(6S)**
  - **Maximum center of mass energy is 11.24GeV in SuperKEKB due to the maximum beam energy of the injector linac**
  - **Linac upgrade is required for running beyond 11.24GeV.**

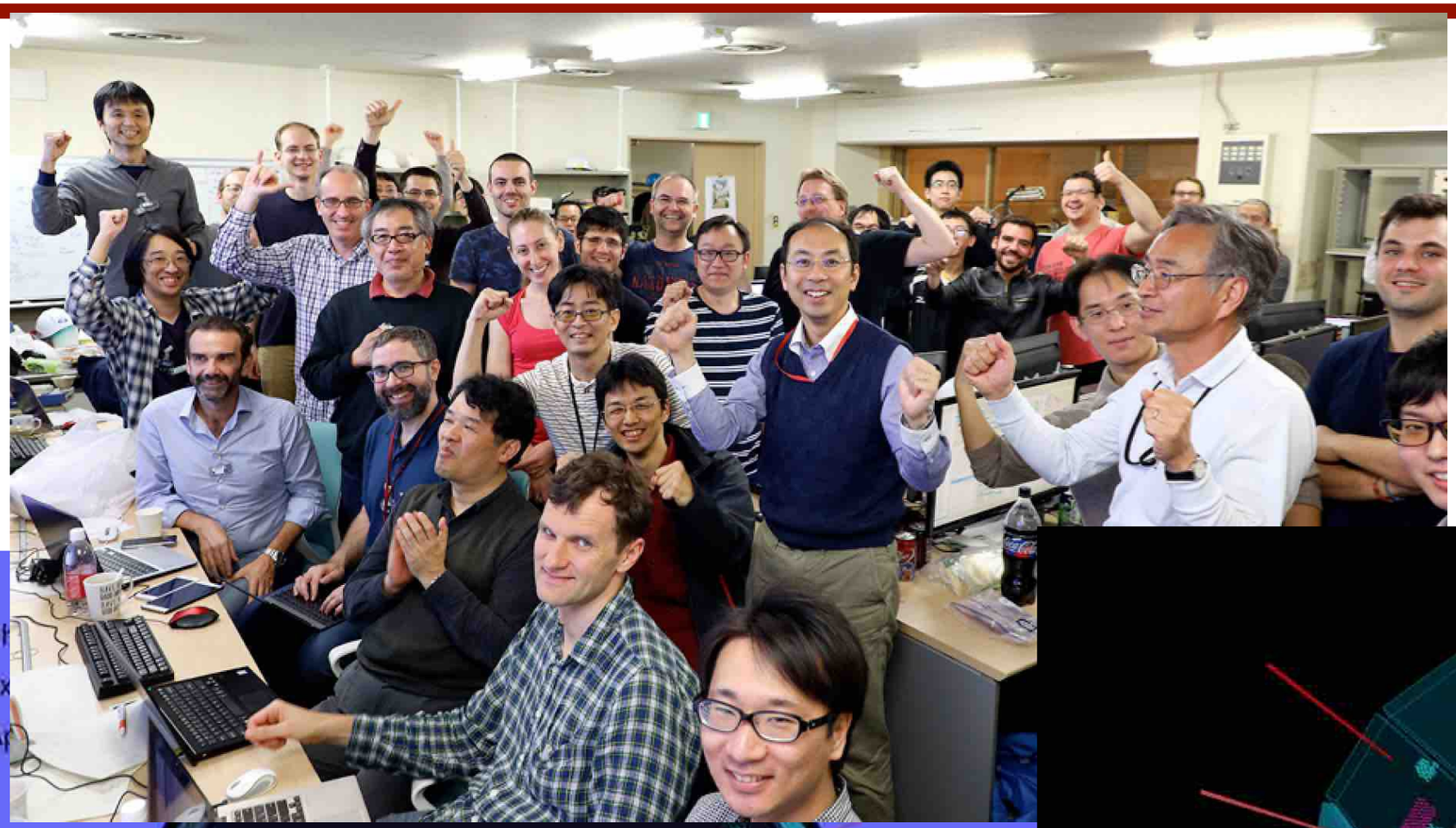
Status of Belle II

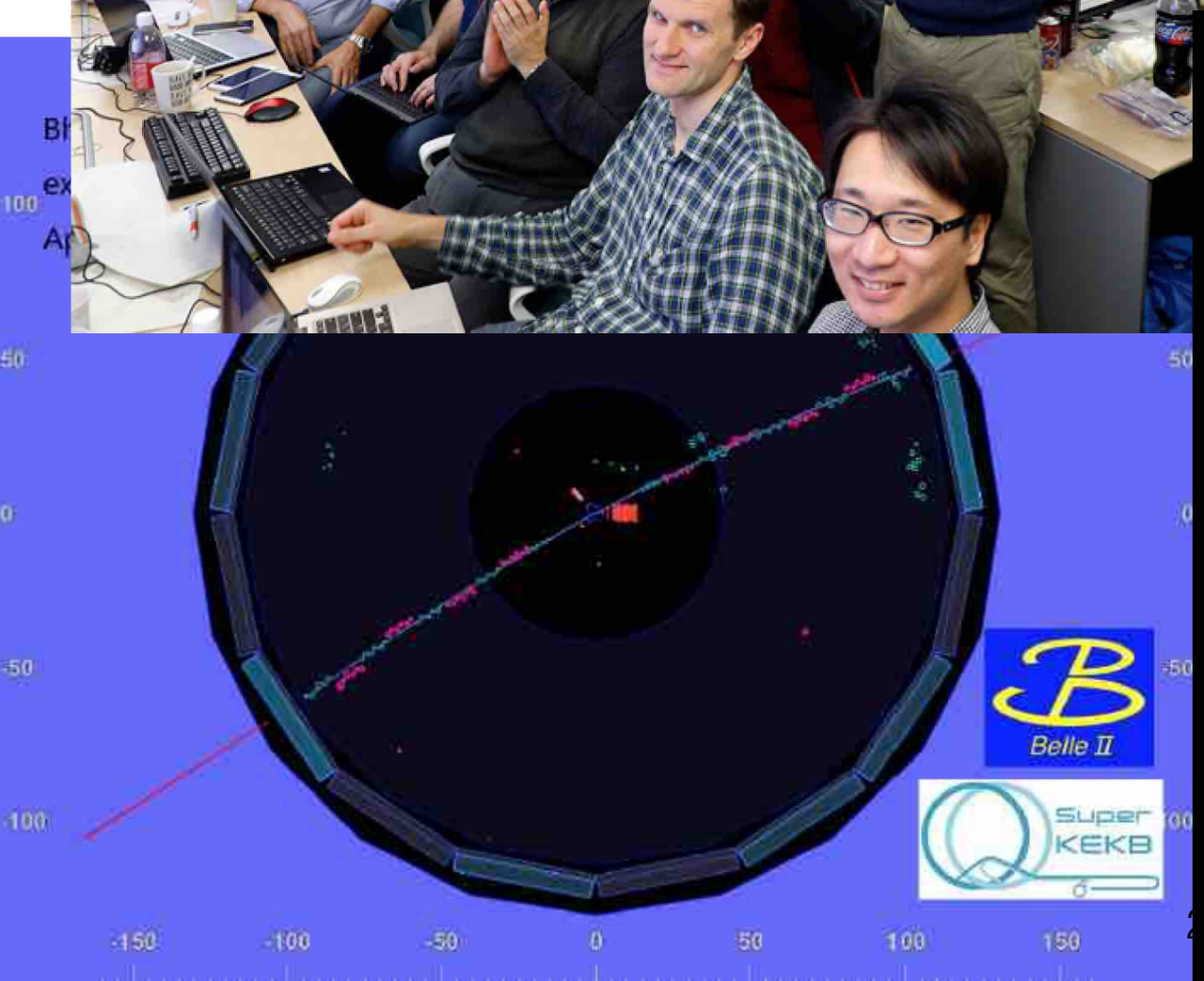
SuperKEKB and Belle II Schedule

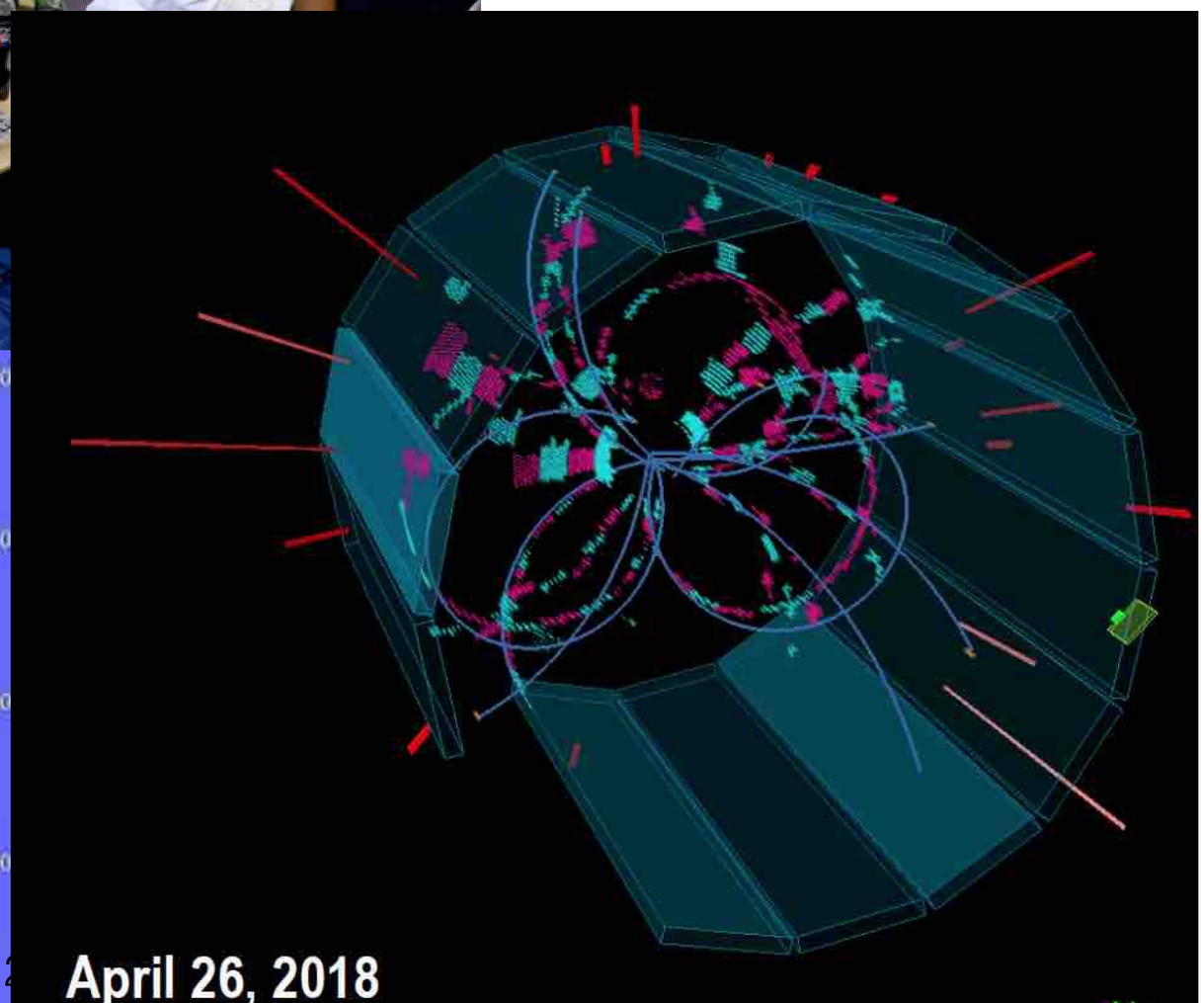


- ✅ **Phase1, Feb.-June, 2016**
  - **Accelerator commissioning, no collision**
- ✅ **Phase2, Feb.-July 17, 2018**
  - **Collision w/o vertex detectors**
  - **Understand background and detector performance**
  - **Instantaneous luminosity reach ~0.5x10^{34} cm^{-2}s^{-1}**
  - **~0.5 fb^{-1} data at the Y(4S) resonance was collected**

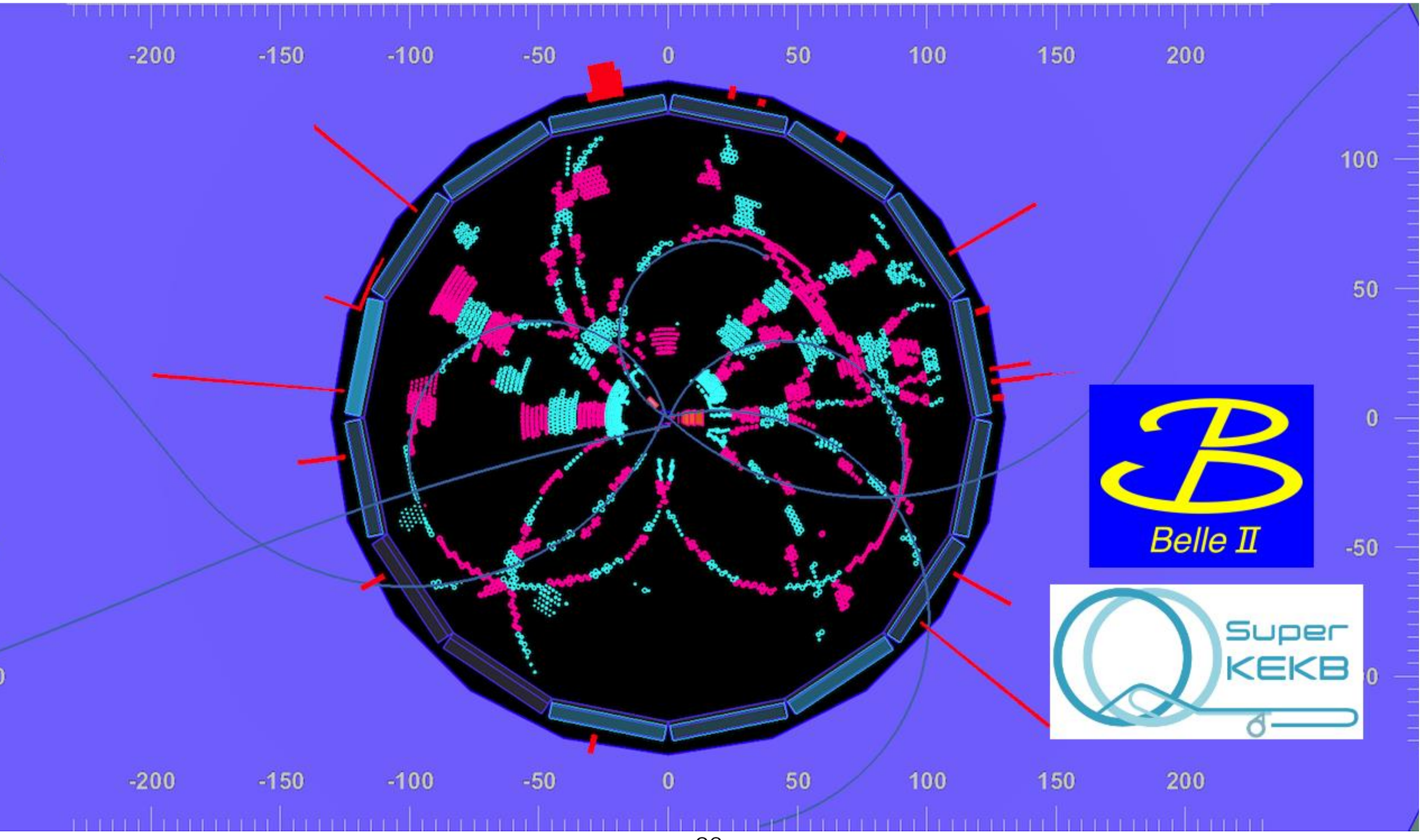
First Collision on Apr.26, 2018





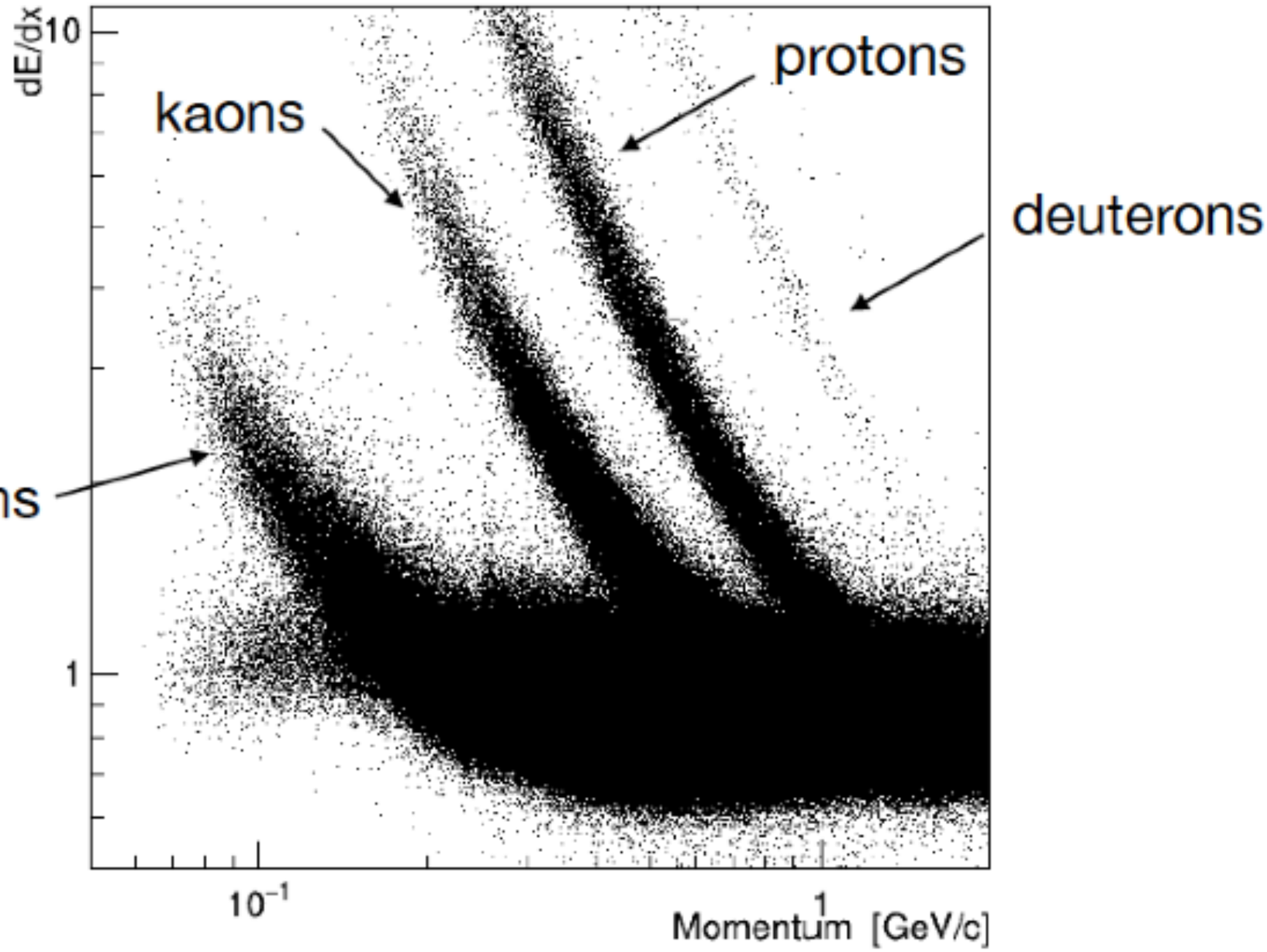


e+e-→BBbar Candidate on Apr. 26 evening



Belle II Performance

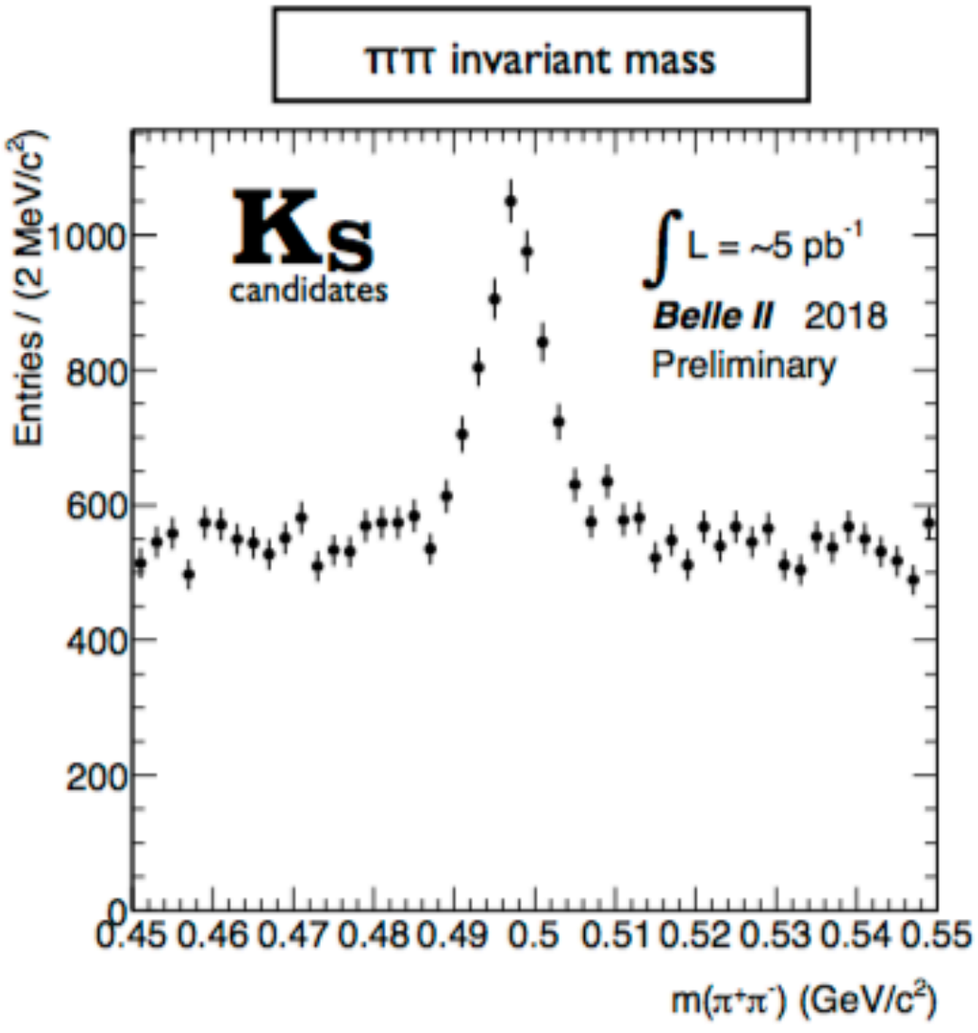
CDC dE/dx particle identification with early calibration in the hadronic event sample

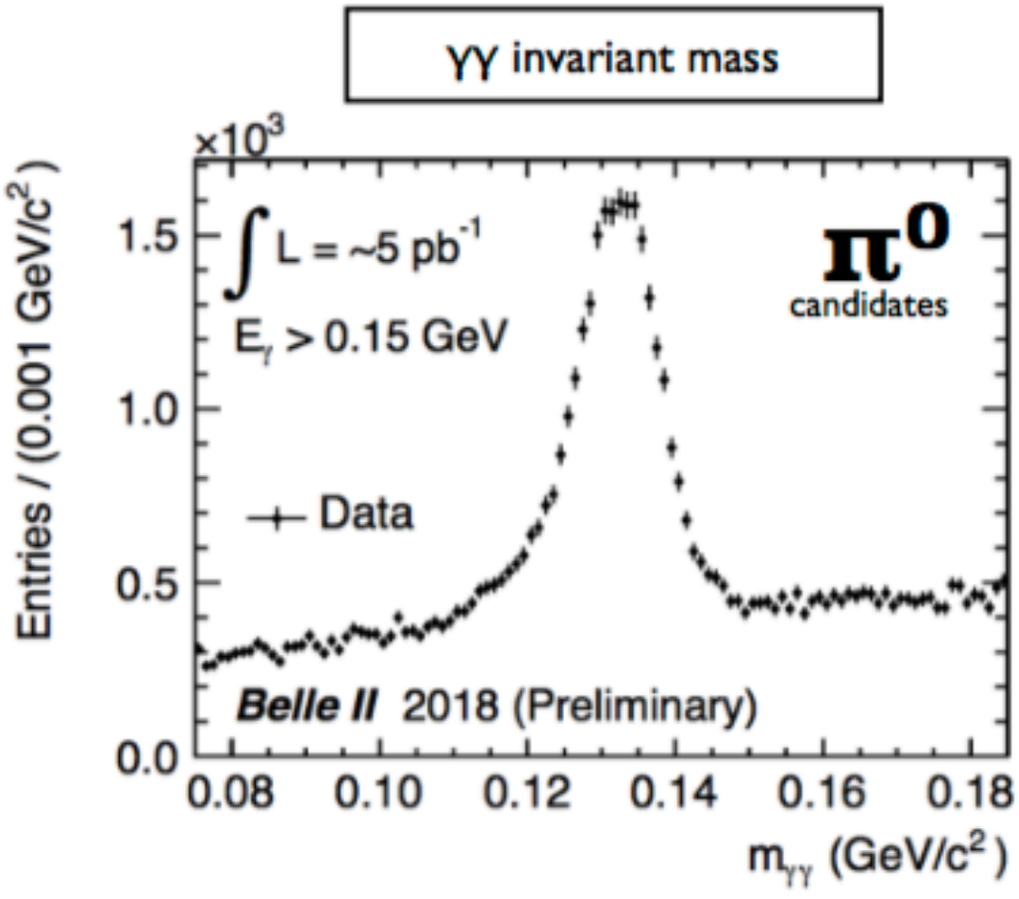


Extra cuts:
- |d0| < 1
- |dz| < 3
- # layers hit > 20

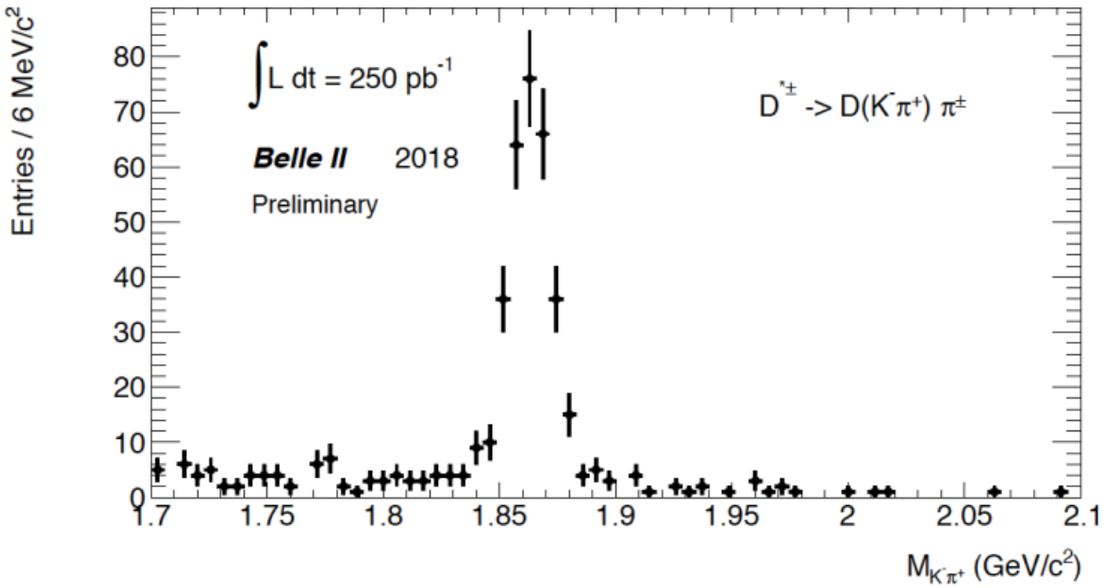
Belle II Performance

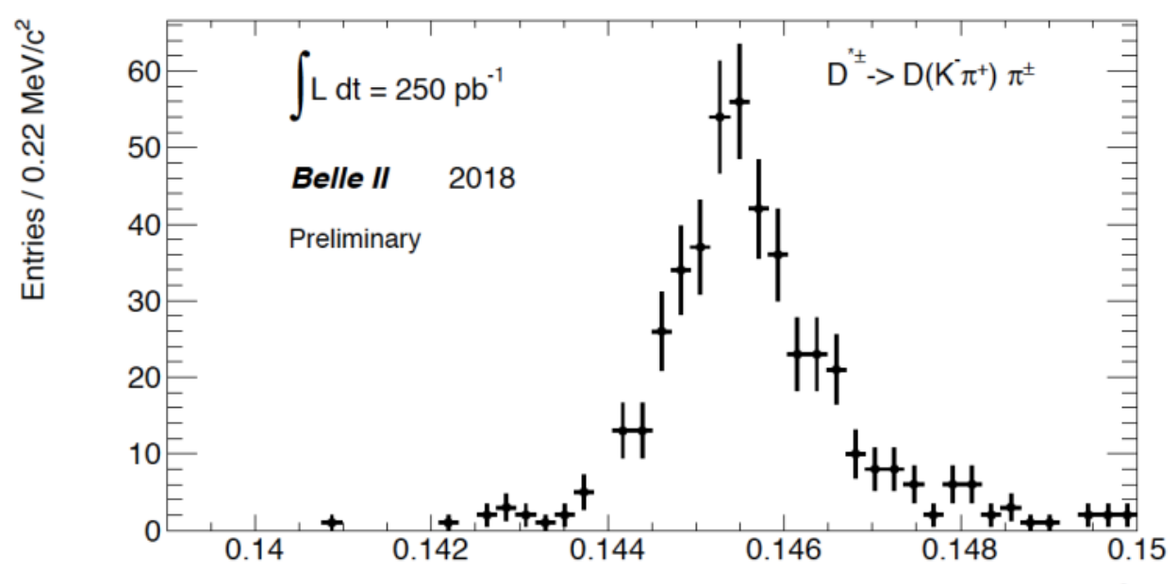
Glance at data
Clear Ks and pi0 signals

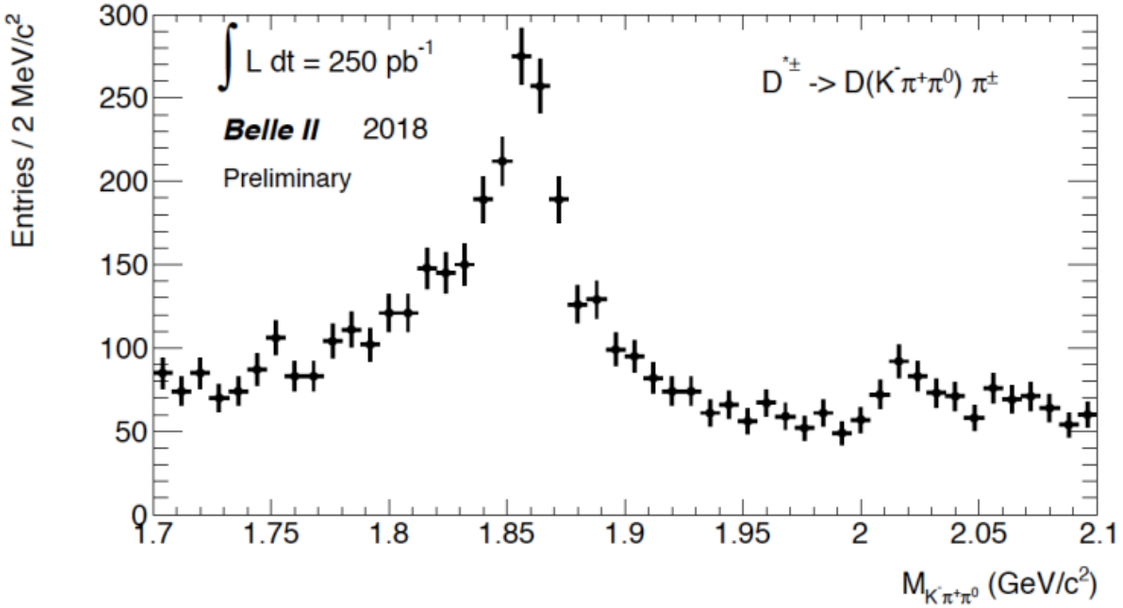


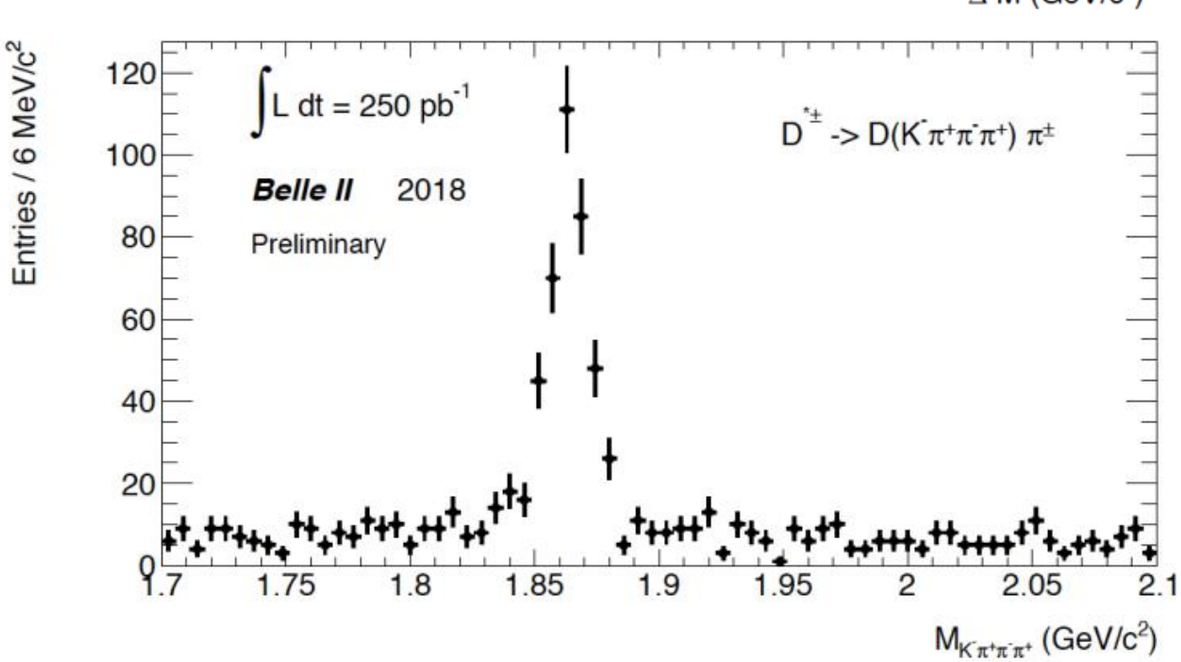


Belle II Performance





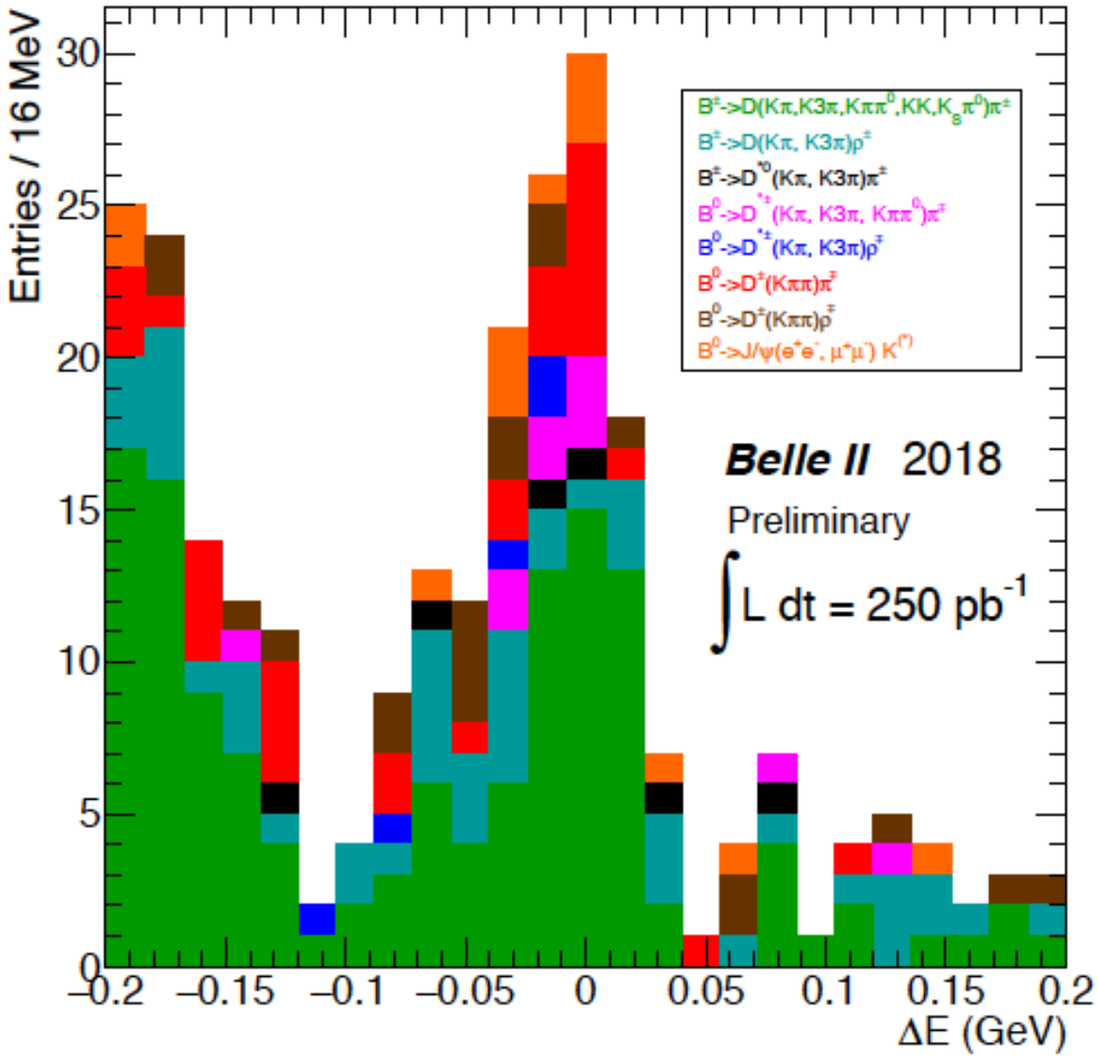


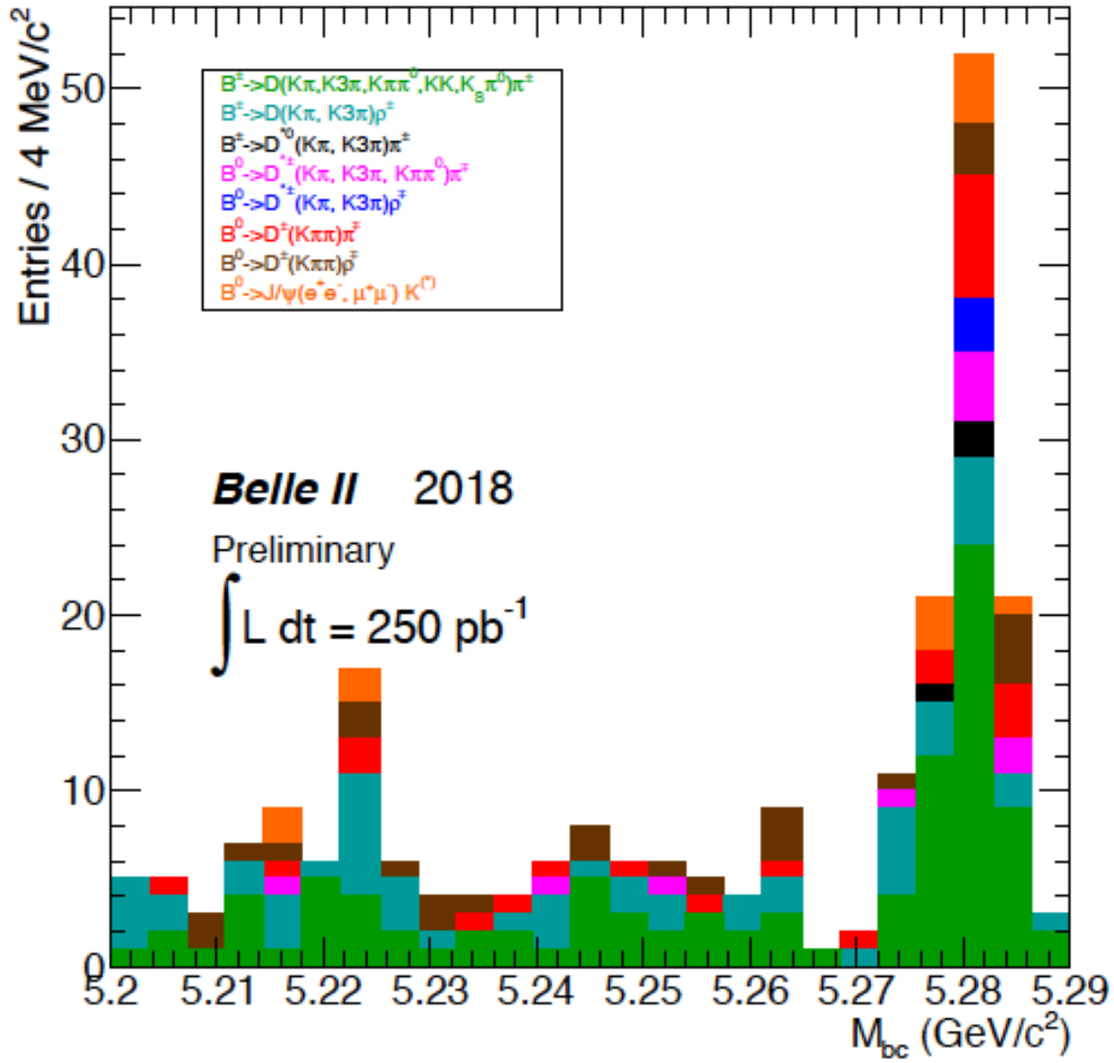


Clear charm signals e+e- → ccbar
Belle II detector is working well!

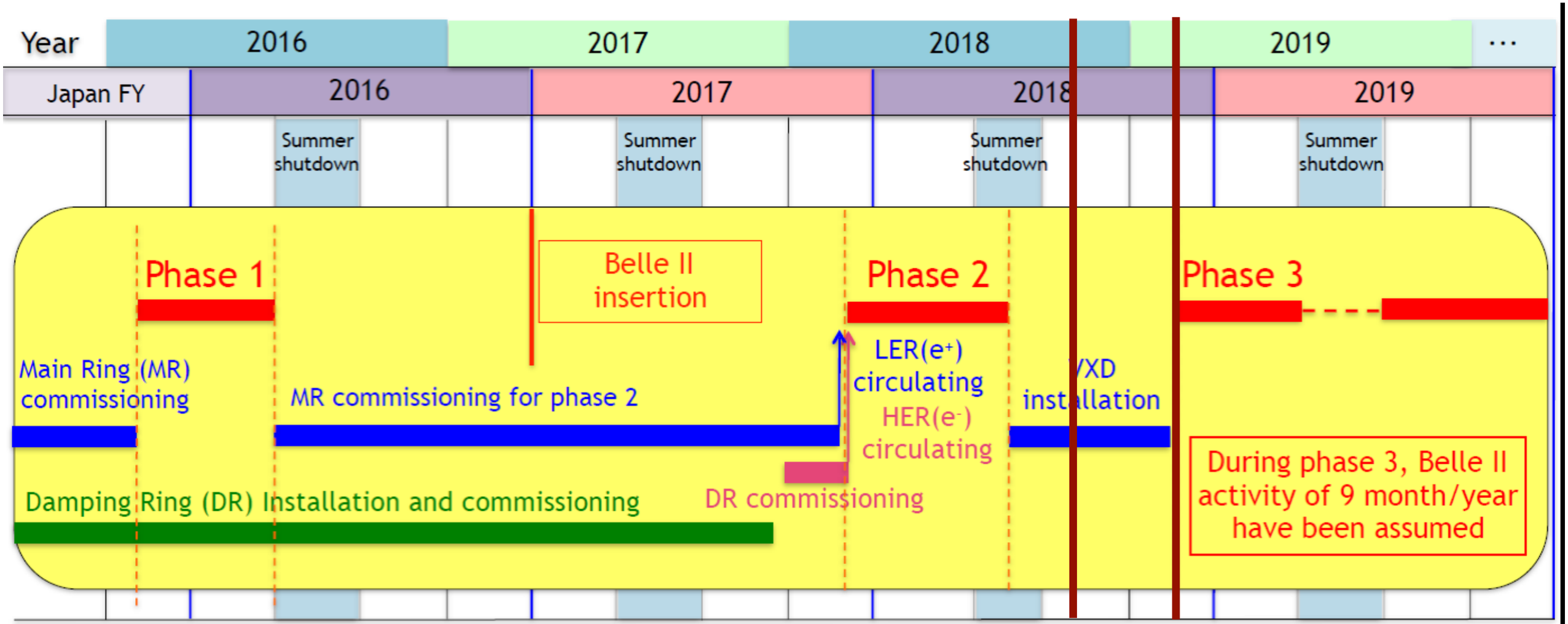
Belle II Performance

We are seeing B signals!





Belle II in future



Phase 3

- **Installation of VXD**
- **Start physics run with full detectors in Spring 2019**
- **Operate 9 months per year**

Summary

- As a “Luminosity Frontier” experiment, Belle II play an important role to answer the existing puzzles in quarkonium field.
  - Confirm or deny the observed unconventional states
  - Precious measurements of the properties of the observed exotics
  - Search for missing conventional states and new exotics
- First collision of SuperKEKB achieved on Apr.26, 2018.
- Data collected at Phase 2 illustrates that Belle II detectors are working well.
- We will start physic operation with full detectors in Spring 2019, and aim to operate 9 months per year

Backup

State	M, MeV	Γ, MeV	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
$X(3872)$	3871.69 ± 0.17	< 1.2	1^{++}	$B \to K(\pi^+\pi^- J/\psi)$	Belle [1024, 1112] (>10), BaBar [1113] (8.6)	2003	Ok
				$p\bar{p} \to (\pi^+\pi^- J/\psi)\,...$	CDF [1114–1116] (11.6), D0 [1117] (5.2)	2003	Ok
				$pp \to (\pi^+\pi^- J/\psi)\,...$	LHCb [1118–1120] (np), CMS [1121] (np)	2012	Ok
				$Y(4260) \to \gamma\,(\pi^+\pi^- J/\psi)$	BESIII [1122] (6.3)	2013	NC!
				$B \to K(\omega J/\psi)$	Belle [1123] (4.3), BaBar [1124] (4.0)	2005	NC!
				$B \to K(\gamma\, J/\psi)$	Belle [1123, 1125] (5.5), BaBar [1126, 1127] (3.6), LHCb [1128] (> 10)	2005	Ok
				$B \to K(\gamma\, \psi(2S))$	BaBar [1127] (3.5), Belle [1125] (0.2), LHCb [1128] (4.4)	2008	NC!
				$B \to K(D^0 \bar{D}^{*0})$	Belle [1129, 1130] (6.4), BaBar [1131] (4.9)	2006	NC!
$Z_c(3900)^+$	3891.2 ± 3.3	40 ± 8	1^{+-}	$Y(4260) \to \pi^-(\pi^+ J/\psi)$	BESIII [1132] (>8), Belle [1133] (5.2), CLEO data [1134] (>5)	2013	Ok
				$Y(4260, 4360) \to \pi^0(\pi^0 J/\psi)$	CLEO data [1134] (3.5), BESIII [1135] (10.4)	2013	Ok
				$Y(4260, 4390) \to \pi^-(\pi^+ h_c)$	BESIII [1136] (2.1)	2013	NC!
				$Y(4260) \to \pi^-(D\bar{D}^*)^+$	BESIII [1137, 1138] (18)	2013	Ok
				$Y(4260) \to \pi^0(D\bar{D}^*)^0$	BESIII [1139] (>10)	2015	Ok
$Z_c(4020)^+$	4022.9 ± 2.8	7.9 ± 3.7	$?^{?-}$	$Y(4260, 4390) \to \pi^-(\pi^+ h_c)$	BESIII [1136] (8.9)	2013	NC!
				$Y(4260, 4390) \to \pi^0(\pi^0 h_c)$	BESIII [1140] (>5)	2014	NC!
				$Y(4360) \to \pi^-(\pi^+ \psi(2S))$	Belle [1141] (3.5), BESIII [1142] (9.2)	2014	NC!
				$Y(4260) \to \pi^-(D^*\bar{D}^*)^+$	BESIII [1143] (10)	2013	NC!
				$Y(4260) \to \pi^0(D^*\bar{D}^*)^0$	BESIII [1144] (5.9)	2015	NC!
$Z_b(10610)^+$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	$\Upsilon(10860) \to \pi^-(\pi^+\Upsilon(1S, 2S, 3S))$	Belle [1145–1147] (>10)	2011	Ok
				$\Upsilon(10860) \to \pi^0(\pi^0\Upsilon(2S, 3S))$	Belle [1148] (6.5)	2013	NC!
				$\Upsilon(10860) \to \pi^-(\pi^+ h_b(1P, 2P))$	Belle [1145, 1146] (16)	2011	Ok
				$\Upsilon(10860) \to \pi^-(B\bar{B}^*)^+$	Belle [1149, 1150] (9.3)	2012	NC!
$Z_b(10650)^+$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	$\Upsilon(10860) \to \pi^-(\pi^+\Upsilon(1S, 2S, 3S))$	Belle [1145–1147] (>10)	2011	Ok
				$\Upsilon(10860) \to \pi^-(\pi^+ h_b(1P, 2P))$	Belle [1145, 1146] (16)	2011	Ok
				$\Upsilon(11020) \to \pi^-(\pi^+ h_b(1P))$	Belle [1151] (3.3)	2015	NC!
				$\Upsilon(10860) \to \pi^-(B^*\bar{B}^*)^+$	Belle [1149, 1150] (8.1)	2012	NC!

Table 125: Quarkonium(-like) states above the open flavour thresholds.

State	M, MeV	Γ, MeV	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
$\psi(3770)$	3773.13 ± 0.35	27.2 ± 1.0	1^{--}	$e^+e^- \to (D\bar{D})$	PDG [69]	1977	Ok
				$B \to K(D\bar{D})$	Belle [1152, 1153] (5.5), BaBar [1131] (6.4)	2003	Ok
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	BES [1154] (3), CLEO [1155] (11.6)	2003	Ok
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [1155] (3.4)	2005	NC!
				$e^+e^- \to (\eta\, J/\psi)$	CLEO [1155] (3.5)	2005	NC!
				$e^+e^- \to (\phi\, \eta)$	CLEO [1156] (5)	2005	NC!
				$e^+e^- \to (\gamma\, \chi_{c0,1})$	PDG [69]	2005	Ok
$\psi_2(3823)$	3822.2 ± 1.2	< 16	2^{--}	$B \to K(\gamma\chi_{c1})$	Belle [1157] (3.8)	2013	NC!
or $X(3823)$				$e^+e^- \to \pi^+\pi^-(\gamma\chi_{c1})$	BESIII [1158] (6.2)	2015	NC!
$X(3860)$	3862^{+48}_{-35}	201^{+177}_{-106}	$0/2^{++}$	$e^+e^- \to J/\psi\,(D\bar{D})$	Belle [1159] (6.5)	2017	NC!
$X(3915)$	3918.4 ± 1.9	20 ± 5	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [1160] (8), BaBar [1124, 1161] (19)	2004	Ok
or $Y(3940)$				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [1162] (7.7), BaBar [1163] (7.6)	2009	Ok
$\chi_{c2}(2P)$	3927.2 ± 2.6	24 ± 6	2^{++}	$e^+e^- \to e^+e^-(D\bar{D})$	Belle [1164] (5.3), BaBar [1165] (5.8)	2005	Ok
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi\,(D\bar{D}^*)$	Belle [1166, 1167] (6)	2005	NC!
$\psi(4040)$	4039 ± 1	80 ± 10	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1978	Ok
				$e^+e^- \to (\eta J/\psi)$	BESIII [1168] (>10), Belle [1169] (6.0)	2012	NC!
$Z(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle [1170] (5.0), BaBar [1171] (1.1)	2008	NC!
$X(4140)$	$4146.5^{+6.4}_{-5.3}$	83^{+30}_{-25}	1^{++}	$B^+ \to K^+(\phi J/\psi)$	CDF [1172, 1173] (5.0), Belle [1174] (1.9), LHCb [1175] (1.4), CMS [1176] (>5), D0 [1177] (3.1), BaBar [1178] (1.6), LHCb [1179, 1180] (8.4)	2009	Ok
or $Y(4140)$				$p\bar{p} \to (\phi J/\psi)$ ...	D0 [1181] (4.7)	2015	NC!
$\psi(4160)$	4153 ± 3	103 ± 8	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1978	Ok
				$e^+e^- \to (\eta J/\psi)$	Belle [1169] (6.5), BESIII [1182] (>5)	2013	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi\,(D^*\bar{D}^*)$	Belle [1167] (5.5)	2007	NC!
$Z(4200)^+$	4196^{+35}_{-32}	370^{+99}_{-149}	1^{+-}	$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle [1183] (6.2)	2014	NC!
$Z(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle [1170] (5.0), BaBar [1171] (2.0)	2008	NC!
$Y(4260)$	4221.1 ± 2.5	47.7 ± 4.0	1^{--}	$e^+e^- \to (\pi^+\pi^- J/\psi)$	BaBar [1184, 1185] (8), CLEO [1186, 1187] (11), Belle [1133, 1188] (15), BESIII [1132, 1189] (np)	2005	Ok
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [1186] (5.1), BESIII [1135] (np)	2006	Ok
				$e^+e^- \to (K^+K^- J/\psi)$	CLEO [1186] (3.7)	2006	NC!
				$e^+e^- \to (f_0(980) J/\psi)$	BaBar [1185] (np), Belle [1133] (np)	2012	Ok
				$e^+e^- \to (\pi^+\pi^- h_c)$	BESIII [1136, 1190] (10)	2013	NC!
				$e^+e^- \to (\pi^0\pi^0 h_c)$	BESIII [1140] (np)	2014	NC!
				$e^+e^- \to (\omega\chi_{c0})$	BESIII [1191] (>9)	2014	NC!
				$e^+e^- \to (\gamma\, X(3872))$	BESIII [1122] (6.3)	2013	NC!
				$e^+e^- \to (\pi^- Z_c(3900)^+)$	BESIII [1132, 1138] (>8), Belle [1133] (5.2)	2013	Ok
				$e^+e^- \to (\pi^0 Z_c(3900)^0)$	BESIII [1135, 1139] (10.4)	2015	Ok
				$e^+e^- \to (\pi^{\mp,0} Z_c(4020)^{\pm,0})$	BESIII [1136, 1140, 1143, 1144] (>10)	2013	Ok

State	M, MeV	Γ, MeV	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
$X(4274)$	$4273.3^{+19.1}_{-9.0}$	$56.2^{+13.8}_{-15.6}$	1^{++}	$B^+ \to K^+(\phi J/\psi)$	CDF [1173] (3.1), LHCb [1175] (1.0),	2011	NC!
or $Y(4274)$					CMS [1176] (>3), D0 [1177] (np),		
					LHCb [1179, 1180] (6.0)		
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	13^{+18}_{-10}	$0/2^{?+}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [1192] (3.2)	2009	NC!
$Y(4360)$	4341.2 ± 5.4	101.9 ± 9.3	1^{--}	$e^+e^- \to (\pi^+\pi^-\psi(2S))$	Belle [1141, 1193] (8), BaBar [1194] (np)	2007	Ok
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	BESIII [1189] (7.6)	2016	NC!
				$e^+e^- \to (\pi^+\pi^-\psi_2(3823))$	BESIII [1158] (np)	2015	NC!
				$e^+e^- \to (\pi^0 Z_c(3900)^0)$	BESIII [1135] (np)	2015	NC!
				$e^+e^- \to (\pi^- Z_c(4020)^+)$	Belle [1141] (3.5), BESIII [1142] (9.2)	2014	NC!
$Y(4390)$	4391.6 ± 6.4	139.5 ± 16.1	1^{--}	$e^+e^- \to (\pi^+\pi^- h_c)$	BESIII [1190] (10)	2016	NC!
				$e^+e^- \to (\pi^{\mp,0} Z_c(4020)^{\pm,0})$	BESIII [1136, 1140] (np)	2013	NC!
$\psi(4415)$	4421 ± 4	62 ± 20	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1976	Ok
				$e^+e^- \to (\eta J/\psi)$	Belle [1169] (np), BESIII [1182] (>5)	2013	NC!
				$e^+e^- \to (\omega\chi_{c2})$	BESIII [1195] (10.4)	2015	NC!
				$e^+e^- \to (D\bar{D}_2^*(2460))$	Belle [1196] (10)	2007	NC!
$Z(4430)^+$	4478^{+15}_{-18}	181 ± 31	1^{+-}	$\bar{B}^0 \to K^-(\pi^+\psi(2S))$	Belle [1197–1199] (6.4),	2007	Ok
					BaBar [1200] (2.4), LHCb [1201, 1202] (13.9)		
				$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle [1183] (4.0)	2014	NC!
$X(4500)$	4506^{+16}_{-19}	92^{+30}_{-29}	0^{++}	$B^+ \to K^+(\phi J/\psi)$	LHCb [1179, 1180] (6.1)	2016	NC!
$Y(4660)$	4643 ± 9	72 ± 11	1^{--}	$e^+e^- \to (\pi^+\pi^-\psi(2S))$	Belle [1141, 1193] (5.8), BaBar [1194] (5)	2007	Ok
				$e^+e^- \to (\Lambda_c^+\bar{\Lambda}_c^-)$	Belle [1203] (8.2)	2007	NC!
$X(4700)$	4704^{+17}_{-26}	120^{+52}_{-45}	0^{++}	$B^+ \to K^+(\phi J/\psi)$	LHCb [1179, 1180] (5.6)	2016	NC!
$\Upsilon(4S)$	10579.4 ± 1.2	20.5 ± 2.5	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1985	Ok
				$e^+e^- \to (\pi^+\pi^-\Upsilon(1S,2S))$	BaBar [1204, 1205] (>10),	2006	Ok
					Belle [1206, 1207] (11.2)		
				$e^+e^- \to (\eta\Upsilon(1S))$	BaBar [1205] (>11)	2008	Ok
				$e^+e^- \to (\eta h_b(1P))$	Belle [1085] (11)	2015	Ok
$\Upsilon(10860)$	10891 ± 4	54 ± 7	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1985	Ok
				$e^+e^- \to (\pi^+\pi^-\Upsilon(1S,2S,3S))$	Belle [1146, 1147, 1208] (>10)	2007	Ok
				$e^+e^- \to (\pi^0\pi^0\Upsilon(1S,2S,3S))$	Belle [1148] (np)	2013	Ok
				$e^+e^- \to (f_0(980)\Upsilon(1S))$	Belle [1146–1148] (>8)	2011	Ok
				$e^+e^- \to (f_2(1275)\Upsilon(1S))$	Belle [1146–1148] (np)	2011	NC!
				$e^+e^- \to (\eta\Upsilon(1S,2S))$	Belle (10)	2012	NC!
				$e^+e^- \to (K^+K^-\Upsilon(1S))$	Belle [1208] (4.9)	2007	NC!
				$e^+e^- \to (\omega\chi_{b1,2}(1P))$	Belle [1209] (12)	2014	Ok
				$e^+e^- \to ((\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b1,2}(1P))$	Belle [1209] (4.9)	2014	NC!
				$e^+e^- \to (\pi^+\pi^-\Upsilon_J(1D))$	Belle (9)	2012	NC!
				$e^+e^- \to (\eta\Upsilon_J(1D))$	Belle (np)	2014	NC!
				$e^+e^- \to (\pi Z_b(10610,10650))$	Belle [1146, 1148] (>10)	2011	Ok
				$e^+e^- \to (B_s^*\bar{B}_s^*)$	Belle [1210] (np)	2016	NC!
$\Upsilon(11020)$	$10987.5^{+11.0}_{-3.4}$	61^{+9}_{-28}	1^{--}	$e^+e^- \to$ (hadrons)	PDG [69]	1985	Ok
				$e^+e^- \to (\pi^+\pi^-\Upsilon(1S,2S,3S))$	Belle [1211] (np)	2015	NC!
				$e^+e^- \to (\pi^\mp Z_b(10610,10650)^\pm)$	Belle [1151] (5.3)	2015	NC!