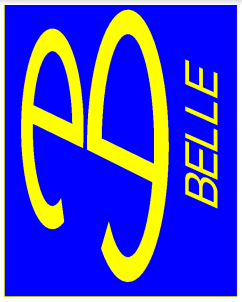


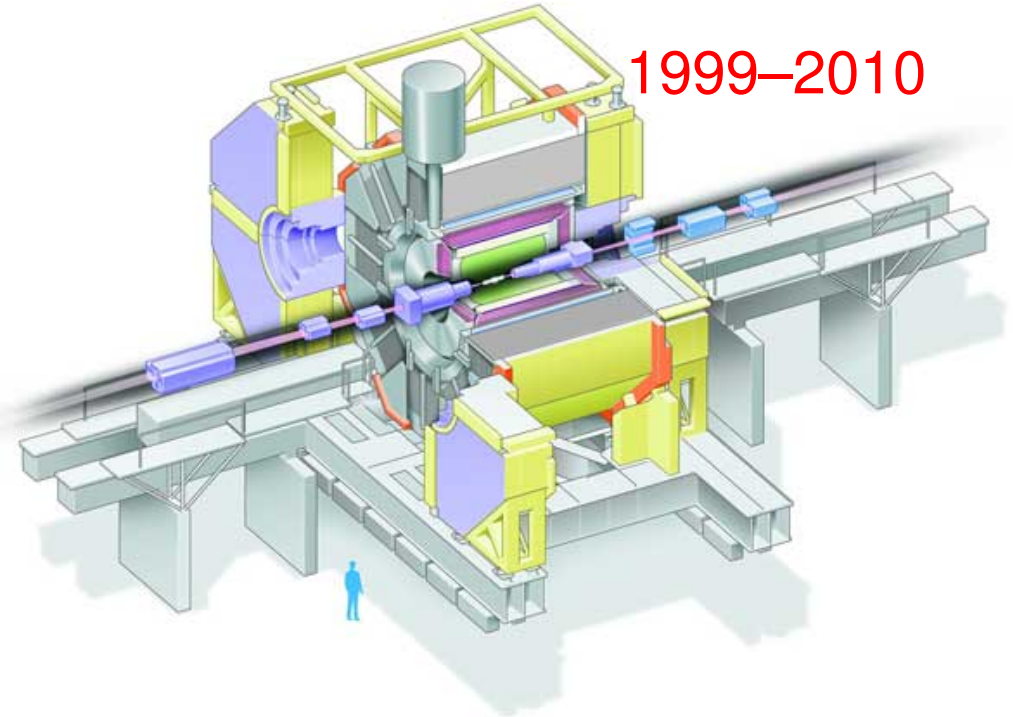
Belle and Belle II experiments

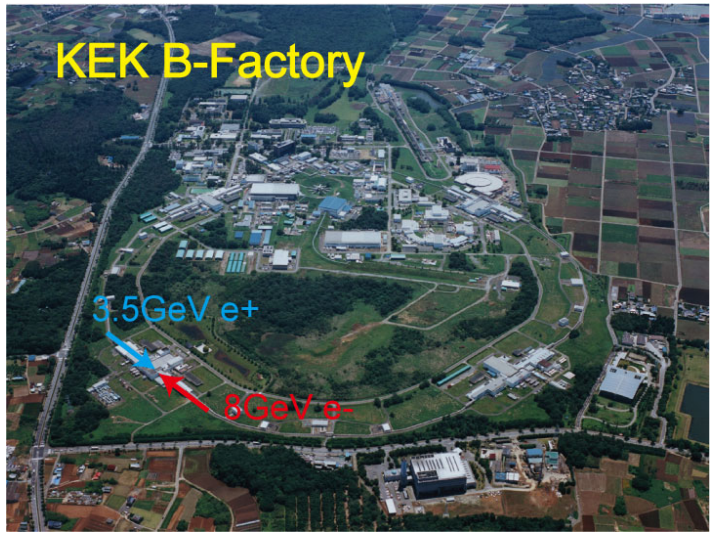
XiaoLong Wang

Fudan University, Shanghai

mini-workshop on HEP and Related Topics
IHEP, Beijing, June 16, 2018

KEKB and Belle





Physics targets:

CP Violation,
Spectroscopy,
τ Physics,
New Physics beyond Standard Model,
...

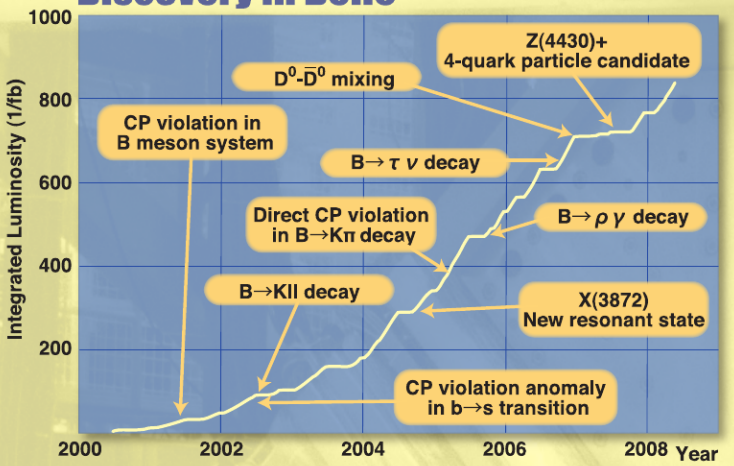
Belle data samples:

On resonances:

$\Upsilon(5S)$:	121 fb^{-1}
$\Upsilon(4S)$:	711 fb^{-1}
$\Upsilon(3S)$:	3 fb^{-1}
$\Upsilon(2S)$:	25 fb^{-1}
$\Upsilon(1S)$:	5.8 fb^{-1}
Off reson./scan:	$\sim$ 100 fb^{-1}
Total:	$\sim$ 1000 fb^{-1}

Big Success in KEKB & Belle

Discovery in Belle

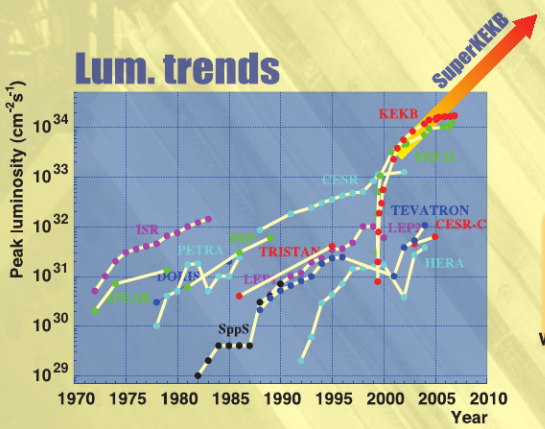


2008 Nobel Prize

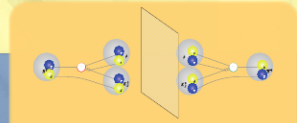
Belle results elucidates puzzle in matter & anti-matter in B meson system is explained by KM theory. This leads to the 2008 Nobel Prize in Physics for Profs. Kobayashi and Maskawa.

"New Physics" on the Horizon !

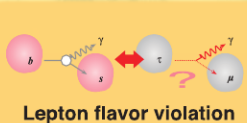
Lum. trends



Belle II future

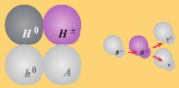


CP violation with new physics



Lepton flavor violation in τ decay

Left handed Weak interaction Right handed Unknown interaction



Charged Higgs in new physics

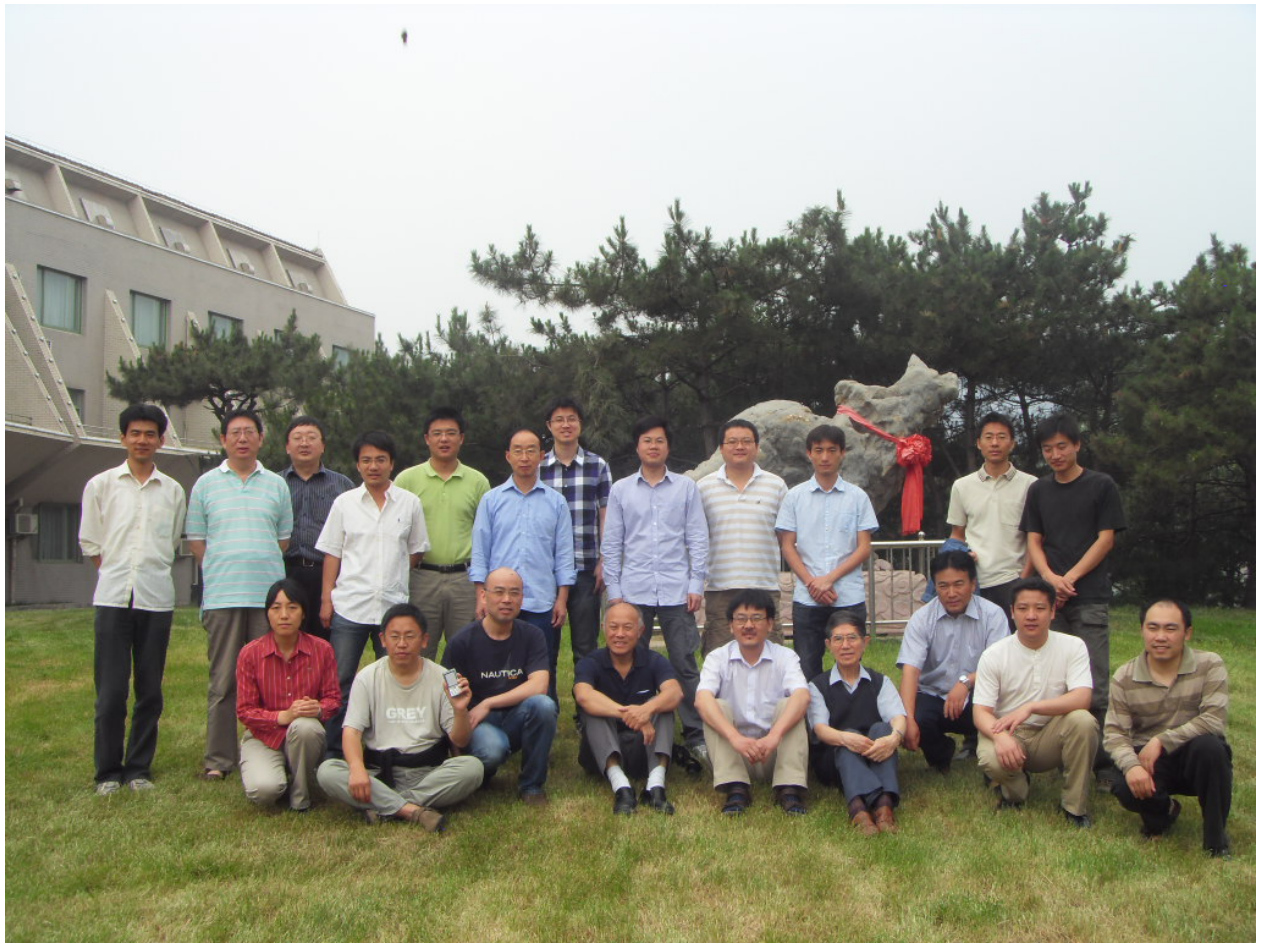
2010 2012 2014 2016 2018 2020

Schedule

- 2008 : 1st call for experimental collaboration
- 2009 : International collaboration organized
  Preliminary approval was given
  Construction started
- 2010 : Full approval expected
- 2014 : 1st beam

The Belle China Group

- Institutions: IHEP, PKU and USTC
- Manpower: about 20
- Mostly work on physics analysis



The Belle Workshop, Huairou, Beijing, 2010

A lot list of charmonium-like states

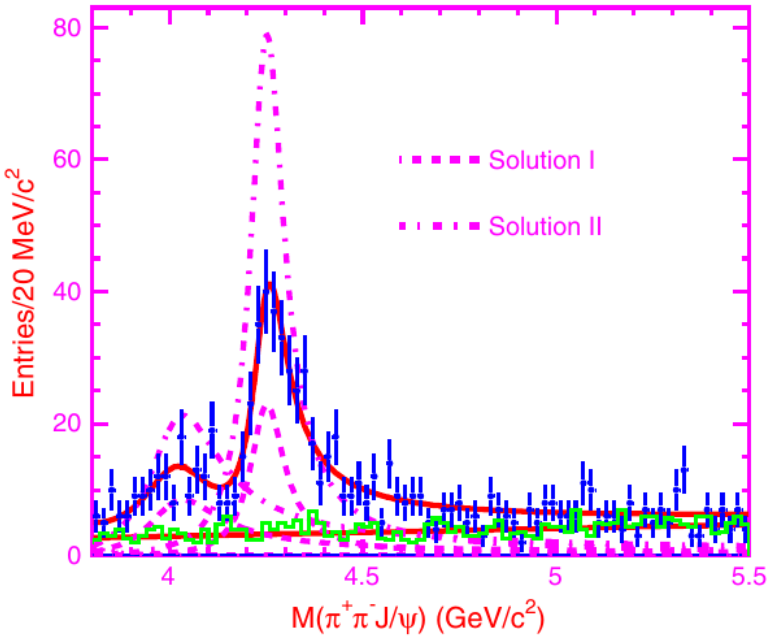
State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.69 ± 0.17	< 1.2	1^{++}	$B \to K(J/\psi\pi^+\pi^-)$	Belle (Choi *et al.*, 2003, 2011), *BABAR* (Aubert *et al.*, 2005c), LHCb (Aaij *et al.*, 2013a, 2015d)
				$p\bar{p} \to (J/\psi\pi^+\pi^-) + \cdots$	CDF (Acosta *et al.*, 2004; Abulencia *et al.*, 2006; Aaltonen *et al.*, 2009b), D0 (Abazov *et al.*, 2004)
				$B \to K(J/\psi\pi^+\pi^-\pi^0)$	Belle (Abe *et al.*, 2005), *BABAR* (del Amo Sanchez *et al.*, 2010a)
				$B \to K(D^0\bar{D}^0\pi^0)$	Belle (Gokhroo *et al.*, 2006; Aushev *et al.*, 2010b), *BABAR* (Aubert *et al.*, 2008c)
				$B \to K(J/\psi\gamma)$	*BABAR* (del Amo Sanchez *et al.*, 2010a), Belle (Bhardwaj *et al.*, 2011), LHCb (Aaij *et al.*, 2012a)
				$B \to K(\psi'\gamma)$	*BABAR* (Aubert *et al.*, 2009b), Belle (Bhardwaj *et al.*, 2011), LHCb (Aaij *et al.*, 2014a)
				$pp \to (J/\psi\pi^+\pi^-) + \cdots$	LHCb (Aaij *et al.*, 2012a), CMS (Chatrchyan *et al.*, 2013a), ATLAS (Aaboud *et al.*, 2017)
				$e^+e^- \to \gamma(J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2014d)
$X(3915)$	3918.4 ± 1.9	20 ± 5	0^{++}	$B \to K(J/\psi\omega)$	Belle (Choi *et al.*, 2005), *BABAR* (Aubert *et al.*, 2008b; del Amo Sanchez *et al.*, 2010a)
				$e^+e^- \to e^+e^-(J/\psi\omega)$	Belle (Uehara *et al.*, 2010), *BABAR* (Lees *et al.*, 2012c)
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0^{-+}(?)$	$e^+e^- \to J/\psi(D^*\bar{D})$	Belle (Pakhlov *et al.*, 2008)
				$e^+e^- \to J/\psi(\cdots)$	Belle (Abe *et al.*, 2007)
$X(4140)$	$4146.5^{+6.4}_{-5.3}$	83^{+27}_{-25}	1^{++}	$B \to K(J/\psi\phi)$	CDF (Aaltonen *et al.*, 2009a), CMS (Chatrchyan *et al.*, 2014), D0 (Abazov *et al.*, 2014), LHCb (Aaij *et al.*, 2017a, 2017d)
				$p\bar{p} \to (J/\psi\phi) + \cdots$	D0 (Abazov *et al.*, 2015)
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$0^{-+}(?)$	$e^+e^- \to J/\psi(D^*\bar{D}^*)$	Belle (Pakhlov *et al.*, 2008)
$Y(4260)$	See $Y(4220)$ entry		1^{--}	$e^+e^- \to \gamma(J/\psi\pi^+\pi^-)$	*BABAR* (Aubert *et al.*, 2005a; Lees *et al.*, 2012b), CLEO (He *et al.*, 2006), Belle (Yuan *et al.*, 2007; Liu *et al.*, 2013)
$Y(4220)$	4222 ± 3	48 ± 7	1^{--}	$e^+e^- \to (J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017c)
				$e^+e^- \to (h_c\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017a)
				$e^+e^- \to (\chi_{c0}\omega)$	BESIII (Ablikim *et al.*, 2015g)
				$e^+e^- \to (J/\psi\eta)$	BESIII (Ablikim *et al.*, 2015c)
				$e^+e^- \to (\gamma X(3872))$	BESIII (Ablikim *et al.*, 2014d)
				$e^+e^- \to (\pi^- Z_c^+(3900))$	BESIII (Ablikim *et al.*, 2013a), Belle (Liu *et al.*, 2013)
				$e^+e^- \to (\pi^- Z_c^+(4020))$	BESIII (Ablikim *et al.*, 2013b)
$X(4274)$	4273^{+19}_{-9}	56^{+14}_{-16}	1^{++}	$B \to K(J/\psi\phi)$	CDF (Aaltonen *et al.*, 2017), CMS (Chatrchyan *et al.*, 2014), LHCb (Aaij *et al.*, 2017a, 2017d)
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$(0/2)^{++}$	$e^+e^- \to e^+e^-(J/\psi\phi)$	Belle (Shen *et al.*, 2010)
$Y(4360)$	4341 ± 8	102 ± 9	1^{--}	$e^+e^- \to \gamma(\psi'\pi^+\pi^-)$	*BABAR* (Aubert *et al.*, 2007; Lees *et al.*, 2014), Belle (Wang *et al.*, 2007, 2015)
				$e^+e^- \to (J/\psi\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017c)
$Y(4390)$	4392 ± 6	140 ± 16	1^{--}	$e^+e^- \to (h_c\pi^+\pi^-)$	BESIII (Ablikim *et al.*, 2017a)
$X(4500)$	4506^{+16}_{-19}	92^{+30}_{-21}	0^{++}	$B \to K(J/\psi\phi)$	LHCb (Aaij *et al.*, 2017a, 2017d)
$X(4700)$	4704^{+17}_{-26}	120^{+52}_{-45}	0^{++}	$B \to K(J/\psi\phi)$	LHCb (Aaij *et al.*, 2017a, 2017d)
$Y(4660)$	4643 ± 9	72 ± 11	1^{--}	$e^+e^- \to \gamma(\psi'\pi^+\pi^-)$	Belle (Wang *et al.*, 2007, 2015), *BABAR* (Aubert *et al.*, 2007; Lees *et al.*, 2014)
				$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle (Pakhlova *et al.*, 2008)

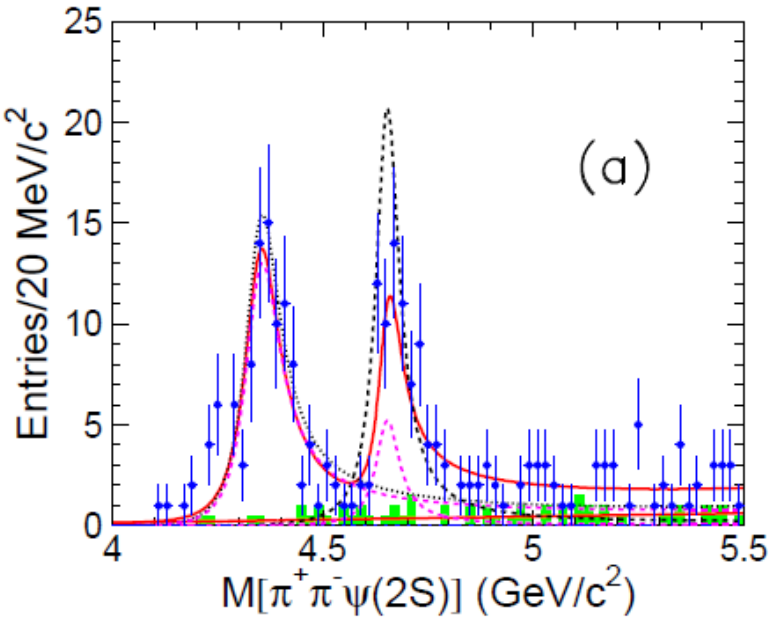
A lot list of charged charmonium-like states

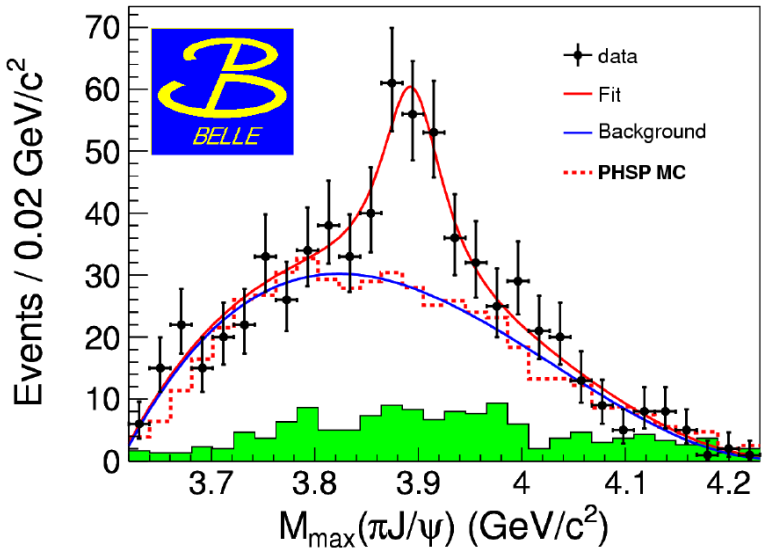
State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$Z_c^{+,0}(3900)$	3886.6 ± 2.4	28.1 ± 2.6	1^{+-}	$e^+e^- \to \pi^{-,0}(J/\psi\pi^{+,0})$	BESIII (Ablikim *et al.*, 2013a, 2015f), Belle (Liu *et al.*, 2013)
				$e^+e^- \to \pi^{-,0}(D\bar{D}^*)^{+,0}$	BESIII (Ablikim *et al.*, 2014b, 2015e)
$Z_c^{+,0}(4020)$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e- \to \pi^{-,0}(h_c\pi^{+,0})$	BESIII (Ablikim *et al.*, 2013b, 2014c)
				$e^+e^- \to \pi^{-,0}(D^*\bar{D}^*)^{+,0}$	BESIII (Ablikim *et al.*, 2014a, 2015d)
$Z^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K(\chi_{c1}\pi^+)$	Belle (Mizuk *et al.*, 2008), *BABAR* (Lees *et al.*, 2012a)
$Z^+(4200)$	4196^{+35}_{-32}	370^{+99}_{-149}	1^+	$B \to K(J/\psi\pi^+)$	Belle (Chilikin *et al.*, 2014)
				$B \to K(\psi'\pi^+)$	LHCb (Aaij *et al.*, 2014b)
$Z^+(4250)$	4248^{+185}_{-45}	177^{+321}_{-72}	$?^{?+}$	$B \to K(\chi_{c1}\pi^+)$	Belle (Mizuk *et al.*, 2008), *BABAR* (Lees *et al.*, 2012a)
$Z^+(4430)$	4477 ± 20	181 ± 31	1^+	$B \to K(\psi'\pi^+)$	Belle (Choi *et al.*, 2008; Mizuk *et al.*, 2009), Belle (Chilikin *et al.*, 2013), LHCb (Aaij *et al.*, 2014b, 2015b)
				$B \to K(J\psi\pi^+)$	Belle (Chilikin *et al.*, 2014)
$P_c^+(4380)$	4380 ± 30	205 ± 88	$(\frac{3}{2}/\frac{5}{2})^{\mp}$	$\Lambda_b^0 \to K(J/\psi p)$	LHCb (Aaij *et al.*, 2015c)
$P_c^+(4450)$	4450 ± 3	39 ± 20	$(\frac{5}{2}/\frac{3}{2})^{\pm}$	$\Lambda_b^0 \to K(J/\psi p)$	LHCb (Aaij *et al.*, 2015c)
$Y_b(10860)$	$10891.1^{+3.4}_{-3.8}$	$53.7^{+7.2}_{-7.8}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\pi^+\pi^-)$	Belle (Chen *et al.*, 2008; Santel *et al.*, 2016)
$Z_b^{+,0}(10610)$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	$Y_b(10860) \to \pi^{-,0}(\Upsilon(nS)\pi^{+,0})$	Belle (Bondar *et al.*, 2012; Garmash *et al.*, 2015), Belle (Krokovny *et al.*, 2013)
				$Y_b(10860) \to \pi^-(h_b(nP)\pi^+)$	Belle (Bondar *et al.*, 2012)
				$Y_b(10860) \to \pi^-(B\bar{B}^*)^+$	Belle (Garmash *et al.*, 2016)
$Z_b^+(10650)$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	$Y_b(10860) \to \pi^-(\Upsilon(nS)\pi^+)$	Belle (Bondar *et al.*, 2012; Garmash *et al.*, 2015)
				$Y_b(10860) \to \pi^-(h_b(nP)\pi^+)$	Belle (Bondar *et al.*, 2012)
				$Y_b(10860) \to \pi^-(B^*\bar{B}^*)^+$	Belle (Garmash *et al.*, 2016)

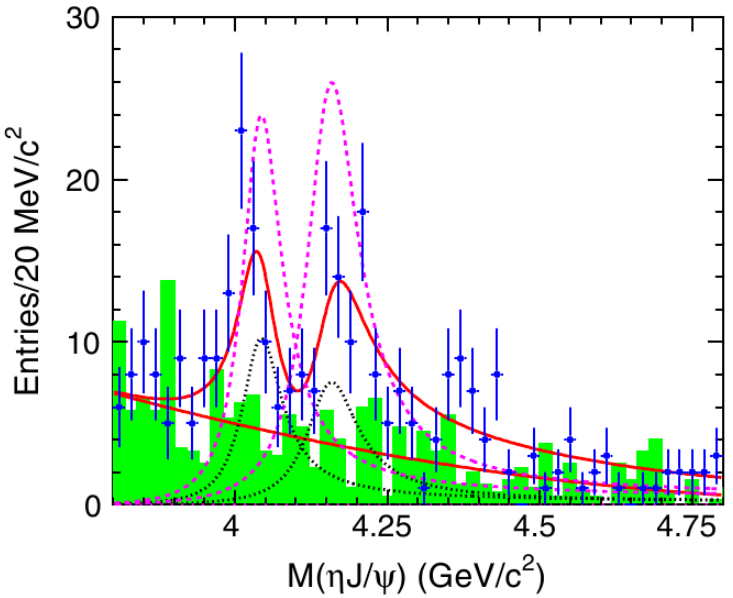
- Belle is not just a B factory, but also a charm factory.
- High luminosity and high energy open the area of open-charm, which is quite different to light hadrons.
- There may be new hadrons out of quark model discovered: multi-quarks, molecule states, hadro-charmonium, glueball, ...
- China group contributes a lot: $Y(4008)$, $Y(4260)$, $X(4350)$, $Y(4360)$, $Y(4660)$, $Z_c(3900)^+$, ...

Some exotics from Belle

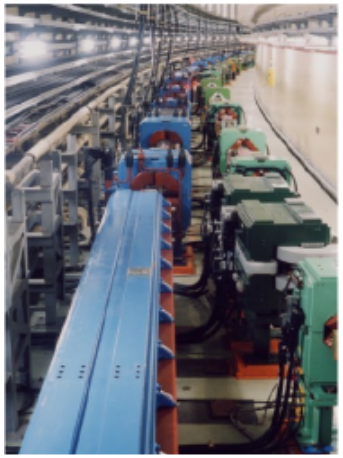


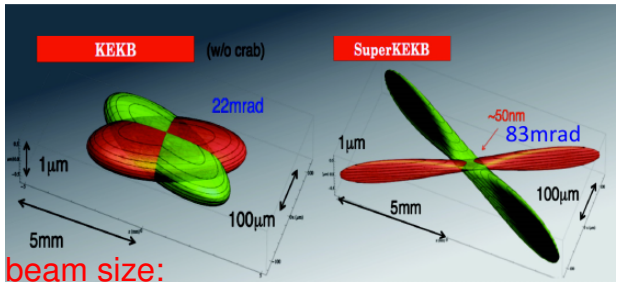




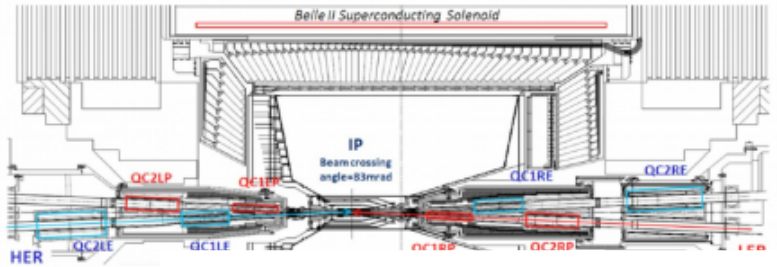


Advantage of new accelerator: SuperKEKB





beam size:
$100\mu m(H) \times 2\mu m(V) \rightarrow$
$10\mu m(H) \times 59nm(V)$



New superconducting final focusing magnets near the Interaction Point (IP)

e^+ 3.6A

e^- 2.6A

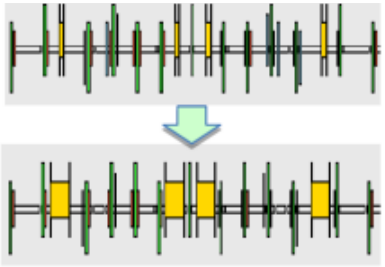
KEKB→SuperKEKB

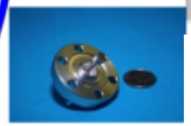
- Nano-Beam scheme, extremely small β_y^*, low emittance
- Beam current ($I_\pm$) ×2

$$L = \frac{\gamma_\pm}{2e\gamma_e}\left[1 + \frac{\sigma_y^*}{\sigma_x^*}\right]\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left[\frac{R_L}{R_{\xi y}}\right]$$

40 times higher luminosity:
$2.1 \times 10^{34} \rightarrow 8 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Redesign the lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles) (being tuned)

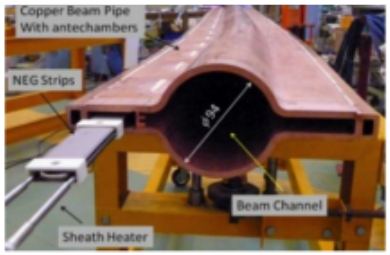




Reinforce RF systems for higher beam currents

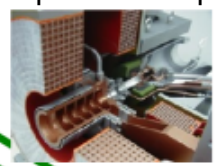
Improve monitors and control system

Replace beam pipes with TiN-coated beam pipes with antechambers (works well)

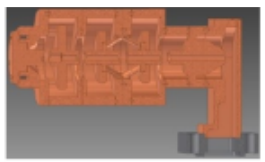


Injector Linac upgrade:

Upgrade positron capture section



Low emittance RF electron gun

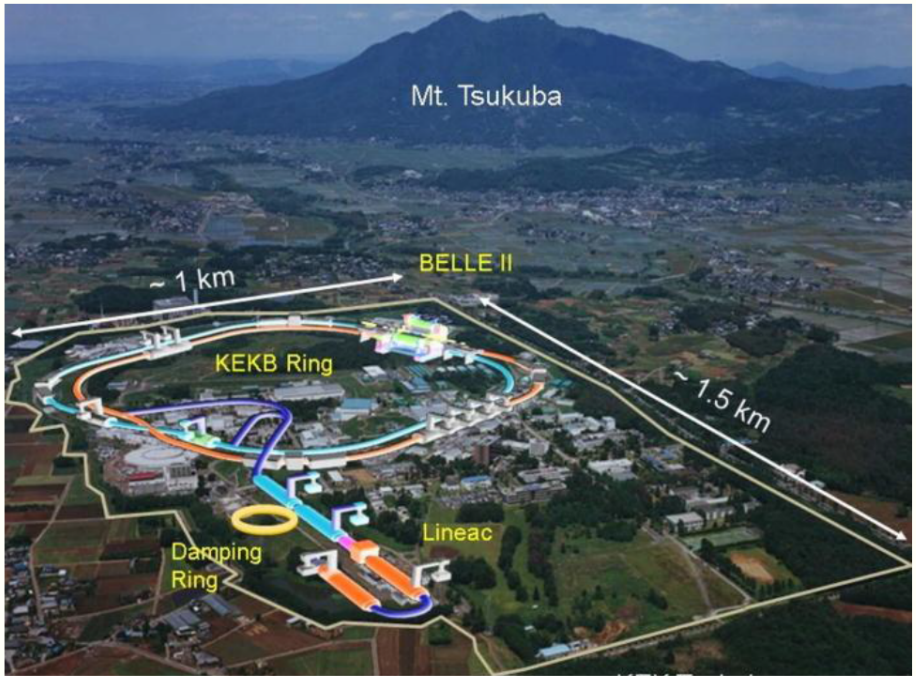


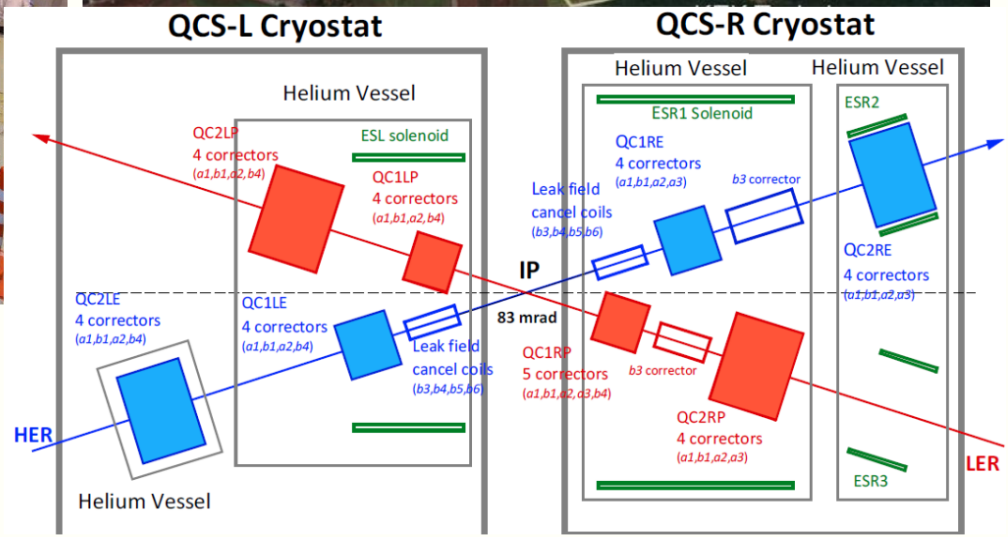
New e^+ Damping Ring constructed

The SuperKEKB project and its final focusing

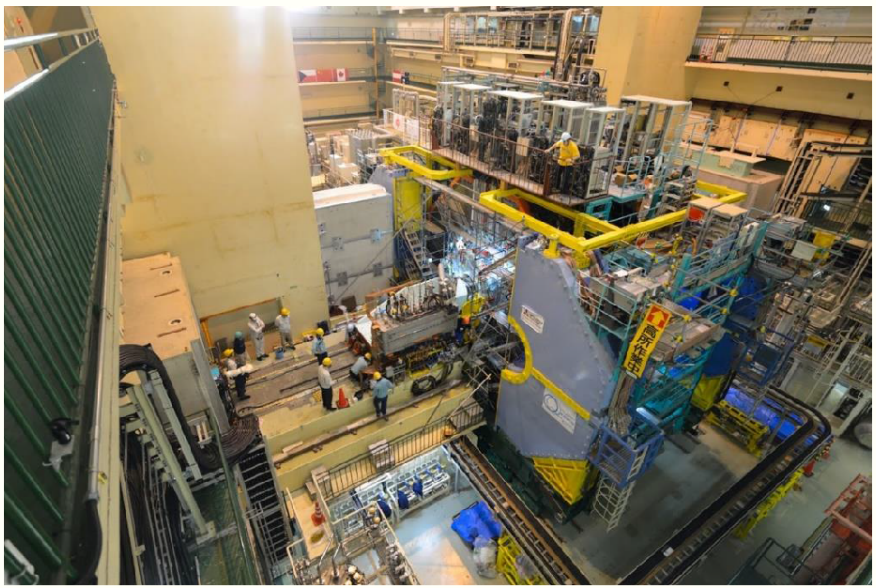
- Accelerator modified or new components
  - The injector linac sources, reinforcing RF system, new damping ring for positron, and replacing vacuum beam pipes.
  - New SC magnets for final focusing

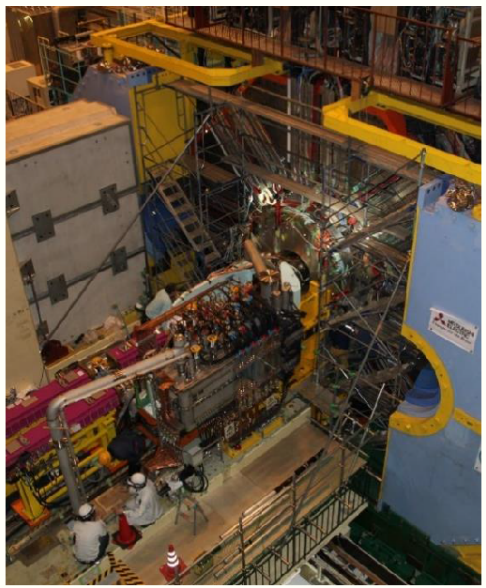
Final focusing SC magnet and cryostat

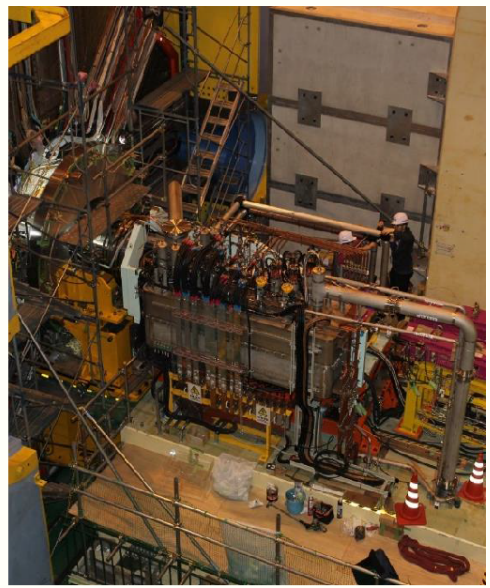




The final focusing SC magnets and cryogenic systems before and after Belle roll-in



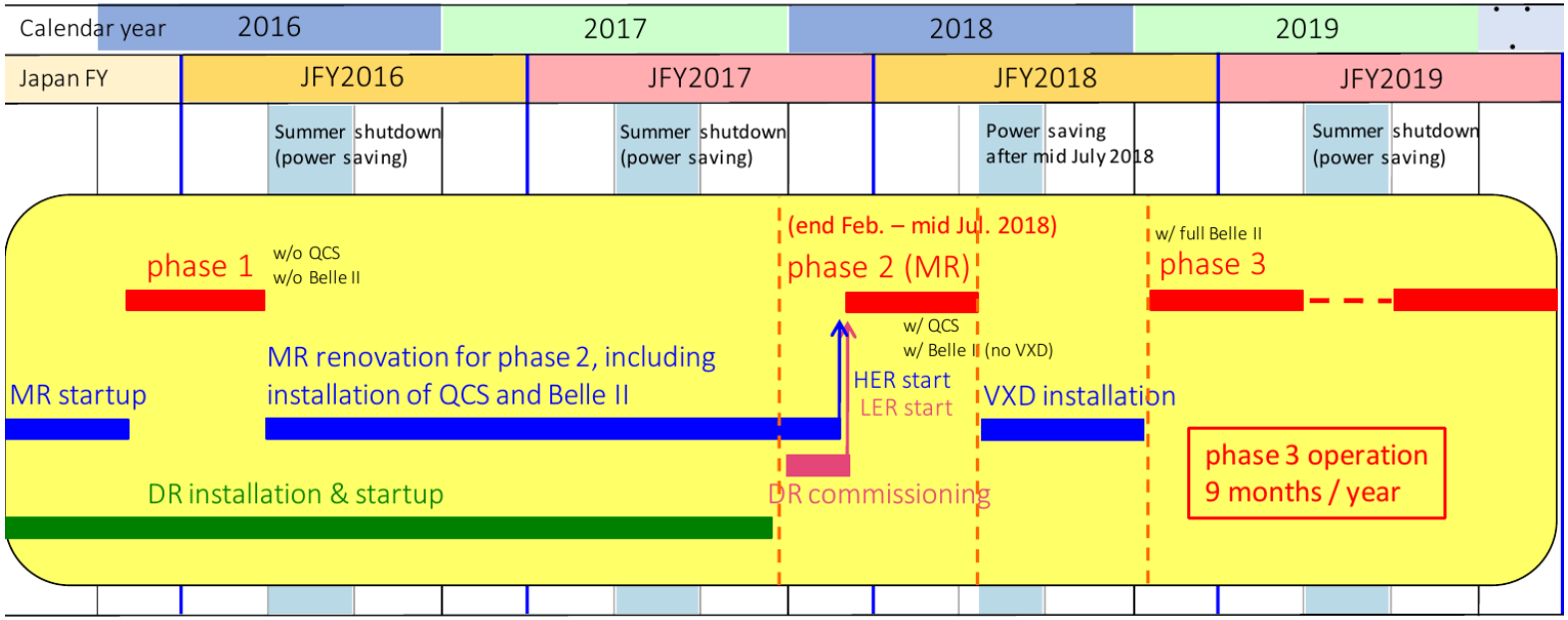




The schedule of Belle II

Start of Phase II for Belle II is unchanged

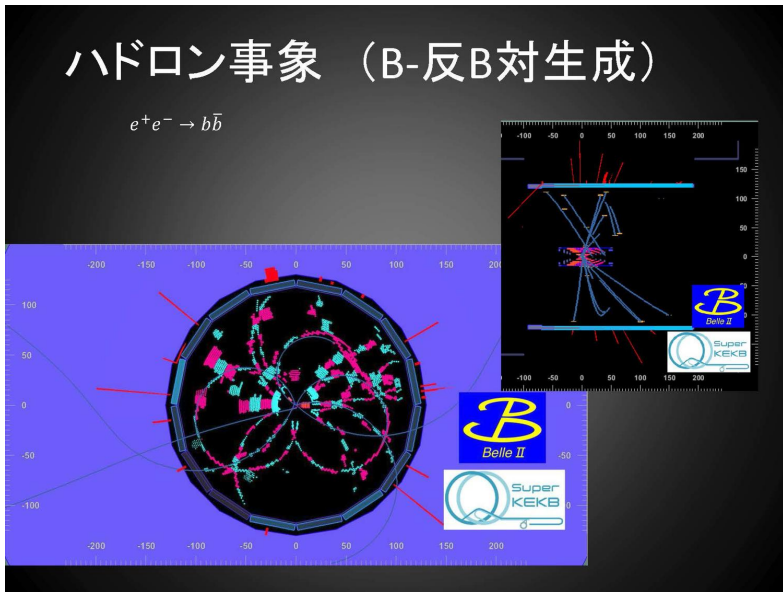
Revised Oct. 2017



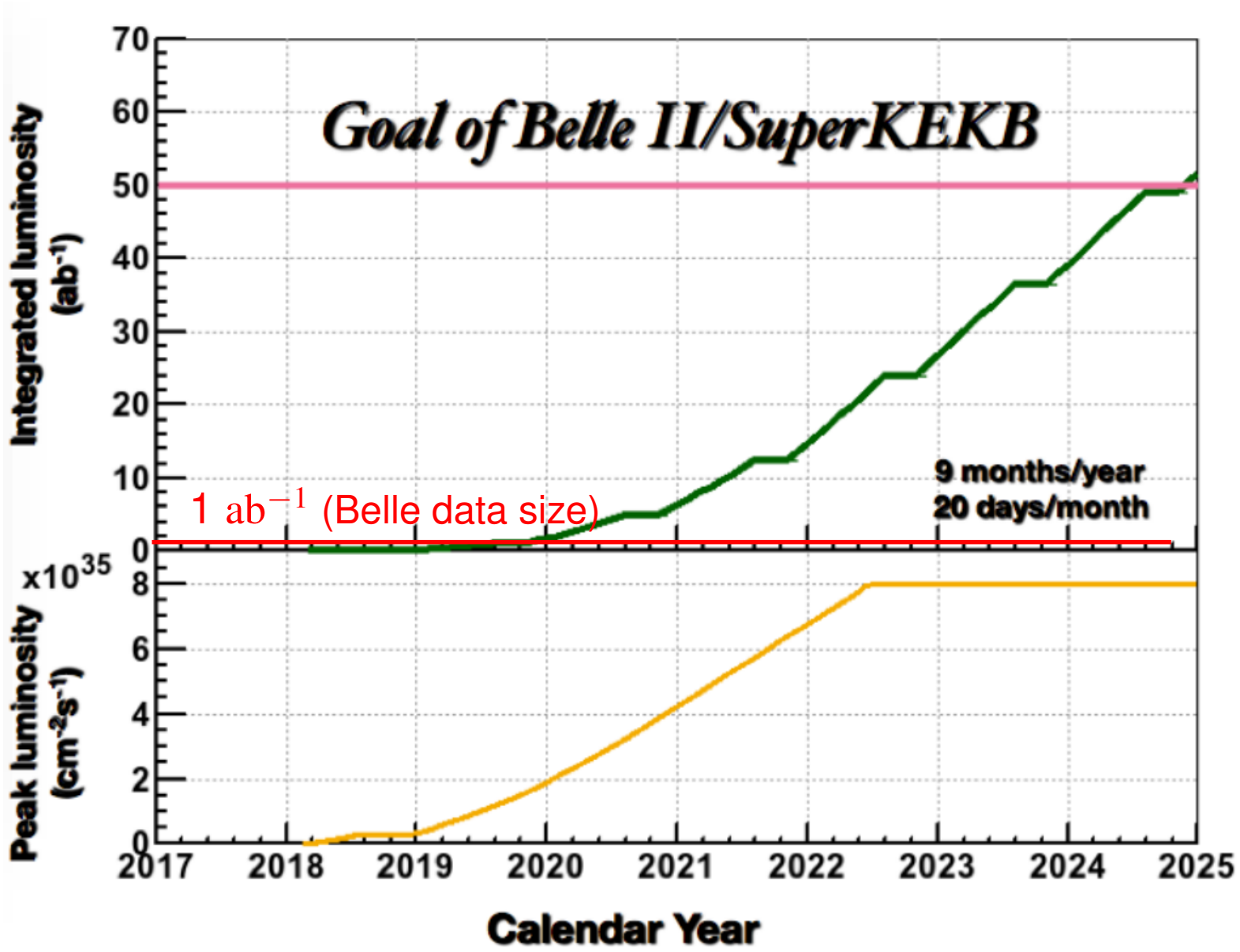
First Belle II collisions on April 26, 2018 !!!

Commissioning:

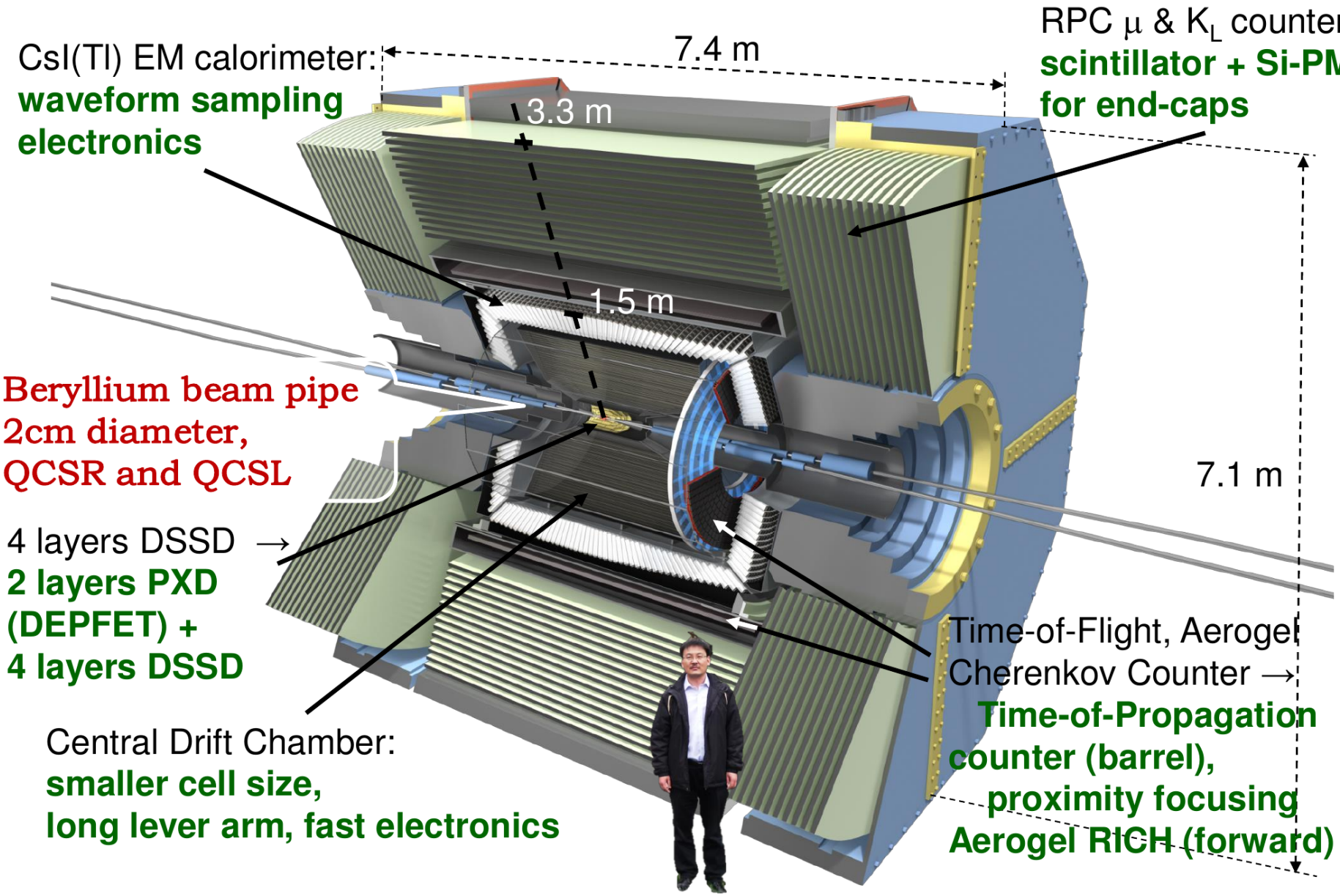
- SuperKEKB: Clean beam pipe, monitor, tuning optics, collimators, ...
- Belle II: Safe operation, bkg study, beam abort system, calibration, ...



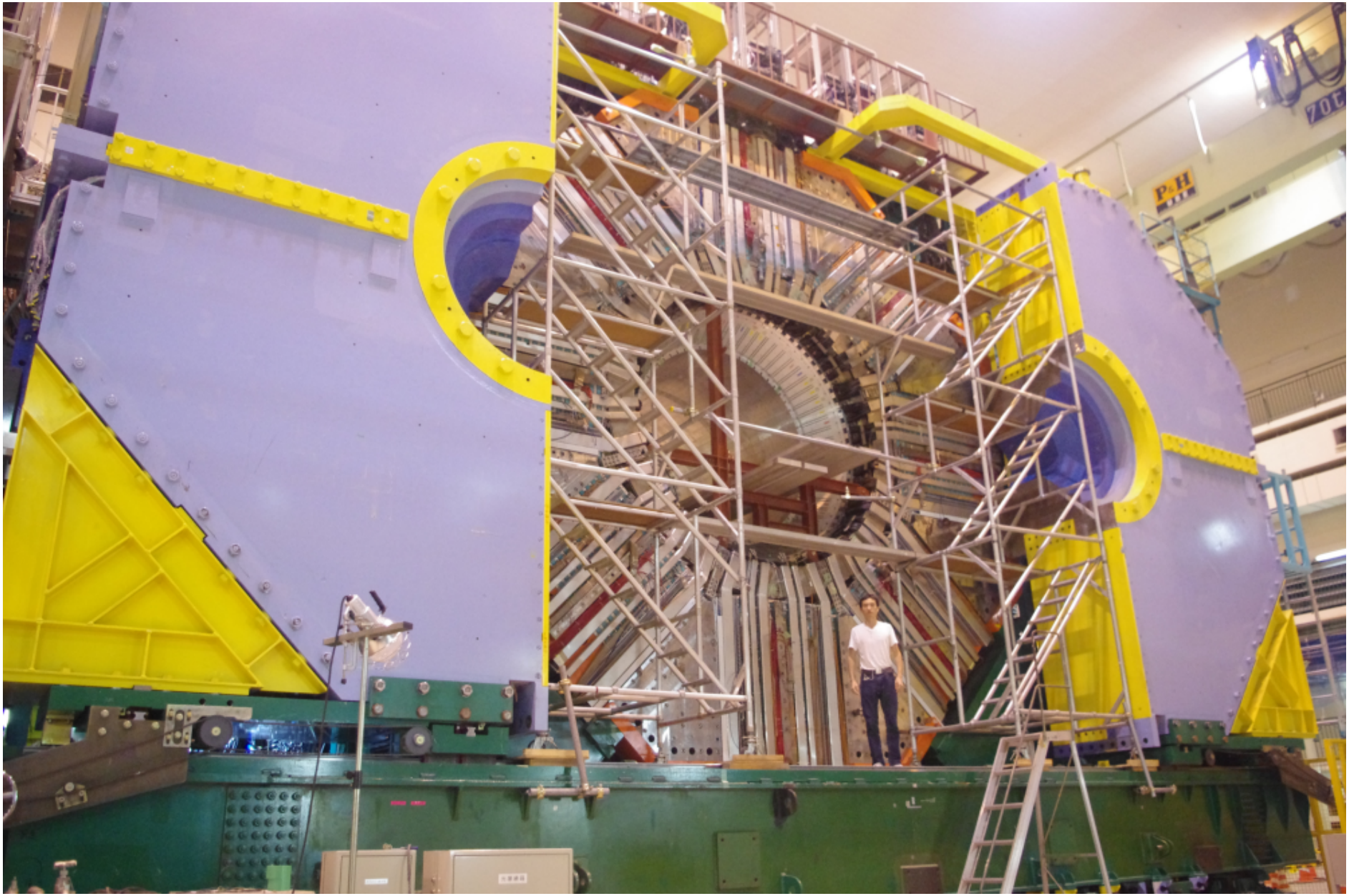
Profile of SuperKEKB luminosity and Belle II data sample



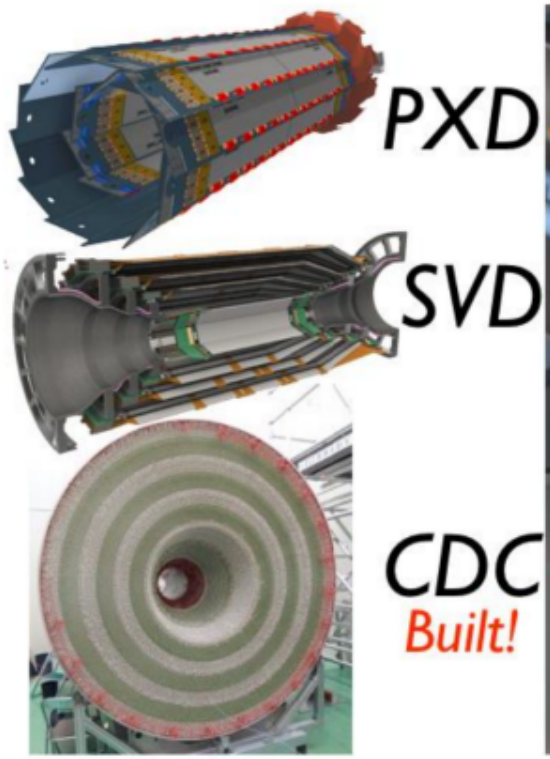
Belle II detector

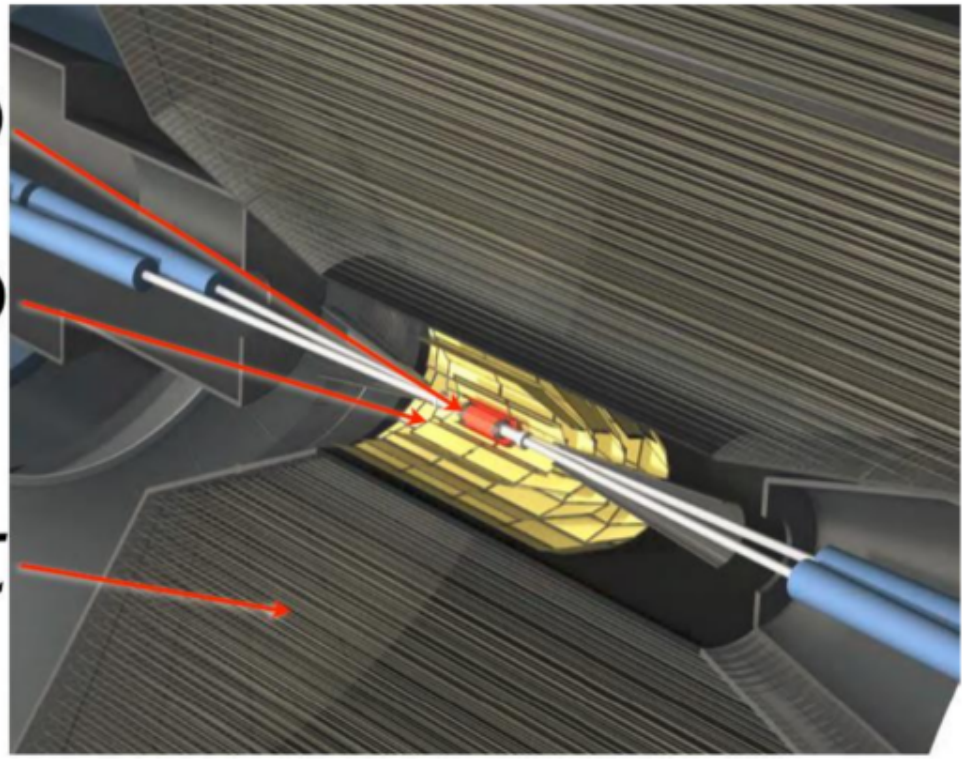


Real with Belle II



The tracking system

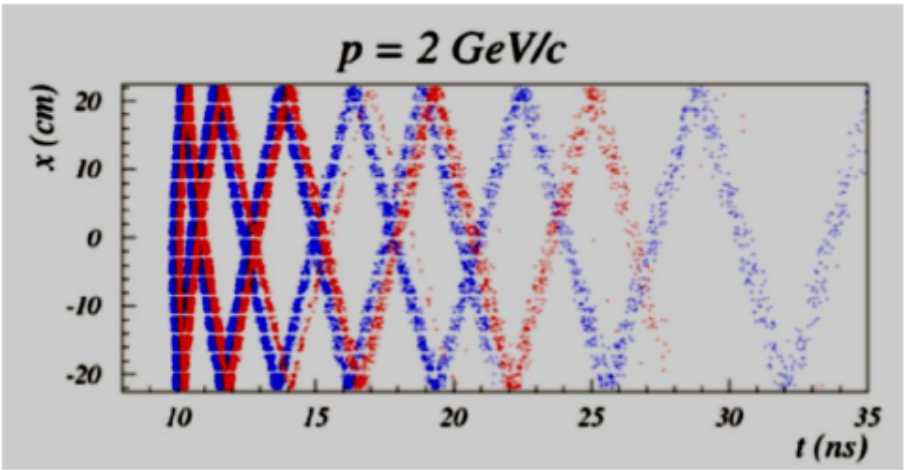


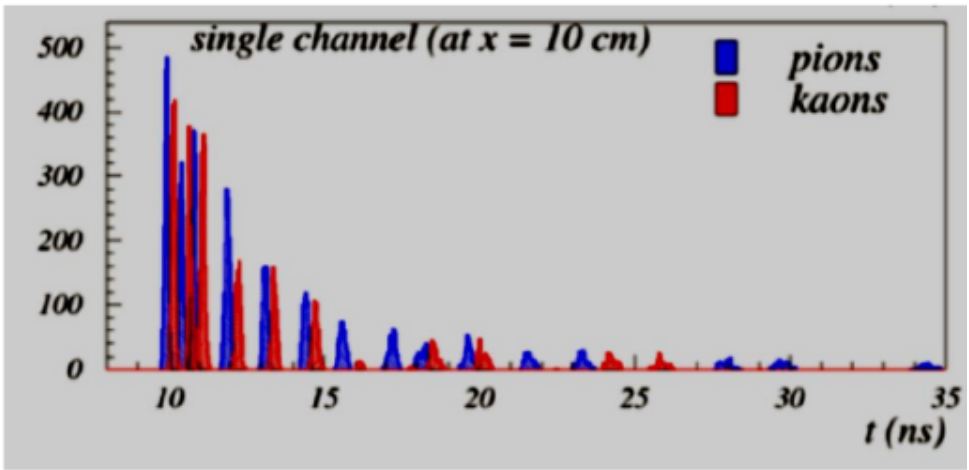


Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20$ μm (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100$ μm, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\%p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\%p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)

Barrel PID: image Time Of Propagation (iTOP)

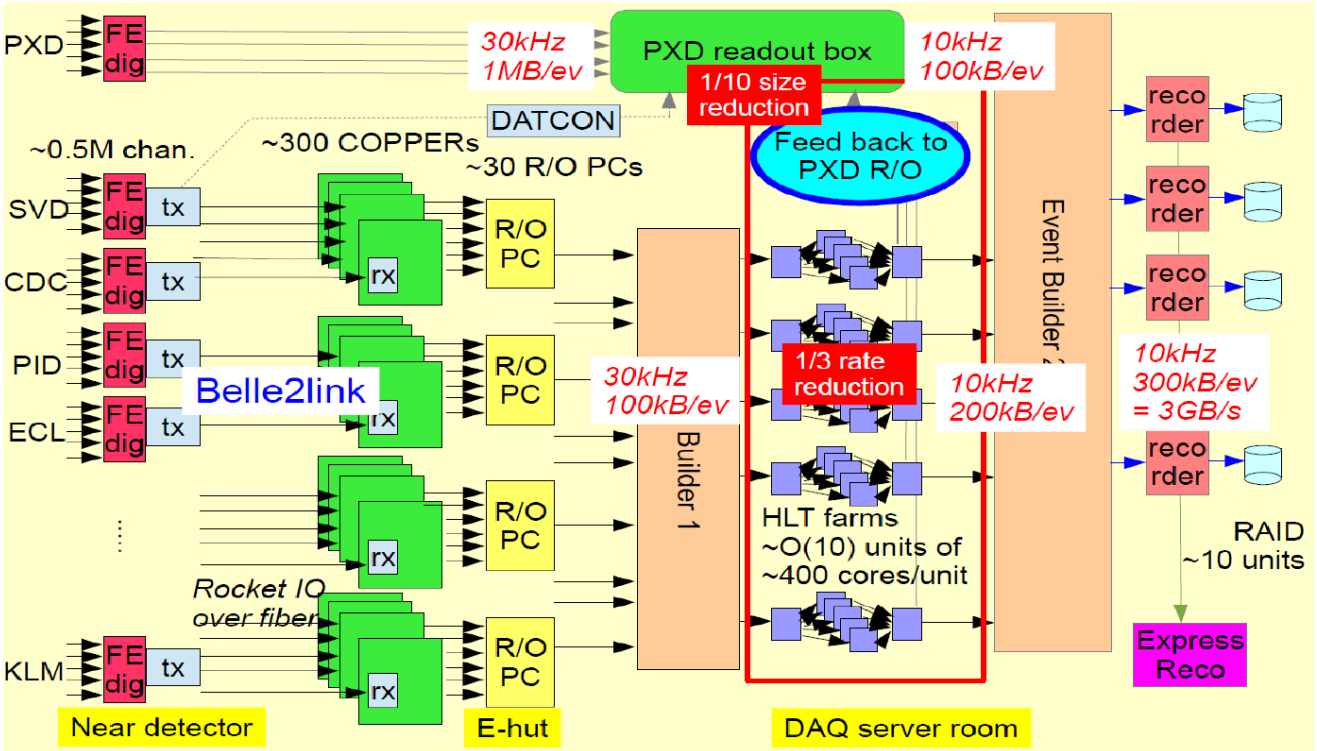
Quartz Property	Requirement
Flatness	<6.3μm
Perpendicularity	<20 arcsec
Parallelism	<4 arcsec
Roughness	< 0.5nm (RMS)
Bulk transmittance	> 98%/m
Surface reflectance	>99.9%/reflection





HLT in Belle II DAQ

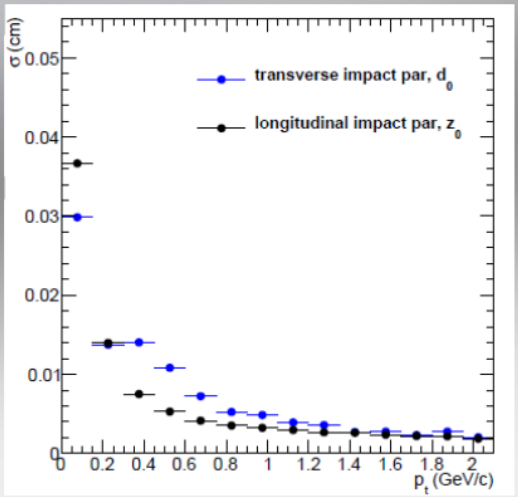
- Parallel processing: Multi-core, Multi-node
- ~10 HLT units, 20 nodes x 16 cores per unit
- Input: 100kB/event, 3kHz/unit, Output: 200kB/event, 1kHz/unit



- Slide from Dr. Chunhua Li.
- Belle2Link: contribution from IHEP.
- Several proposals of DAQ upgrade will be discussed in coming B2GM.

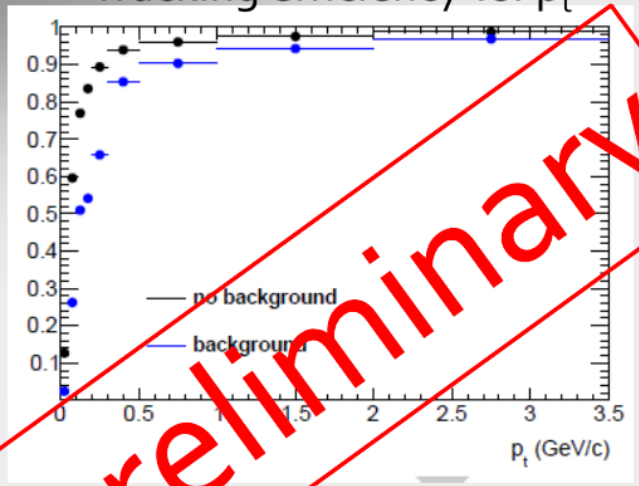
Expected performance of Belle II

IP resolution



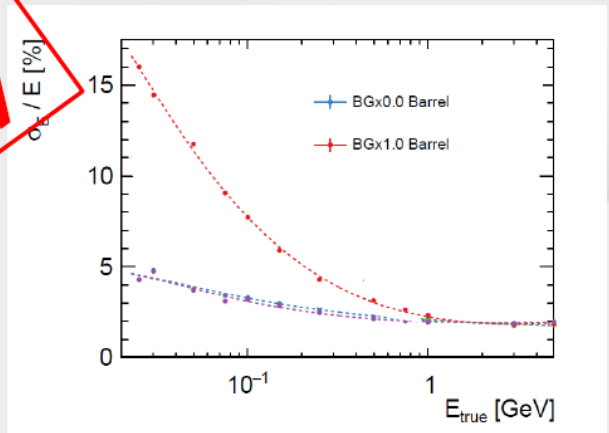
Belle II works similar to or better than Belle despite ~20 times higher beam background

Tracking efficiency vs. p_t

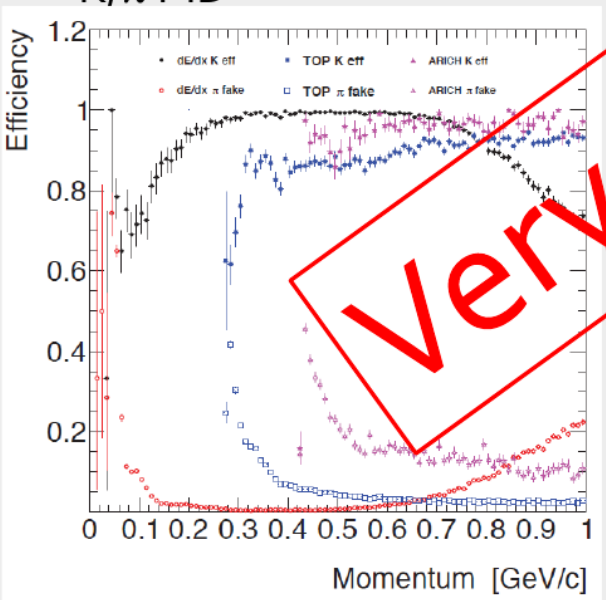


Energy resolution

Better w/ no background, worse w/ background

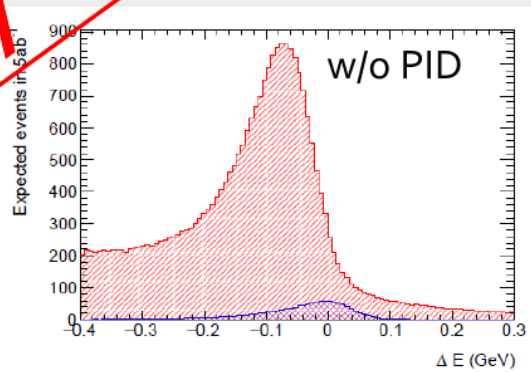


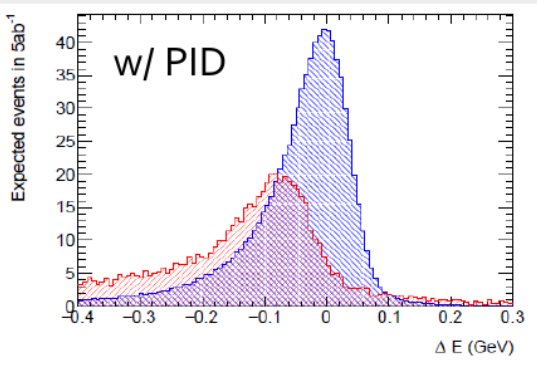
K/π PID



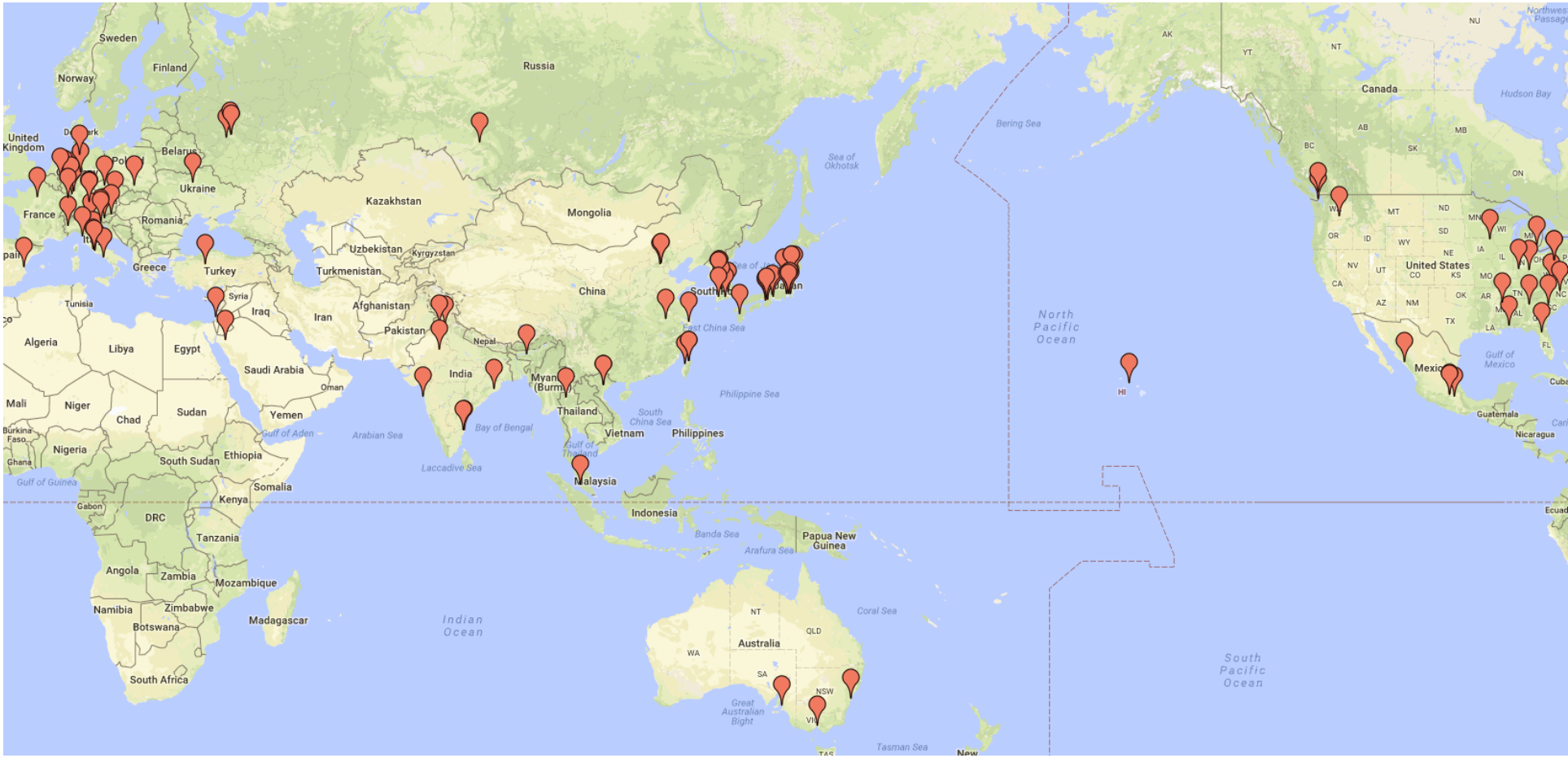
Very preliminary

$B^0 \to \rho^0\gamma$ vs. $K^{*0}\gamma$





Belle II Collaboration



- Belle II Collaboration: 25 counties/regions, 108 institutions, 810 colleagues (by Apr 11, 2018).
- China Group: IHEP, PKU, USTC, Beihang U. and Fudan U.
- Soochow U. and LLNU are applying and should join Belle II in the coming B2GM (June 11, 2018).
- Fudan U. and France joint Belle II at the same IB meeting (June, 2017).

1st workshop of Belle II China Group

- A quite successful workshop!
- Reviewed the achievements on Belle, and discussed on researches with Belle II.
- 35 participants, 20 invited talks. One session of China Group related affairs, and one afternoon for free discussion.
  - Topics of the talks: Physics, generator, hardware, software, DAQ, trigger, ...
  - Discussion: funding, research topics, cooperation, group meetings, annual workshop,
  - Sharing labs and computing resources at China

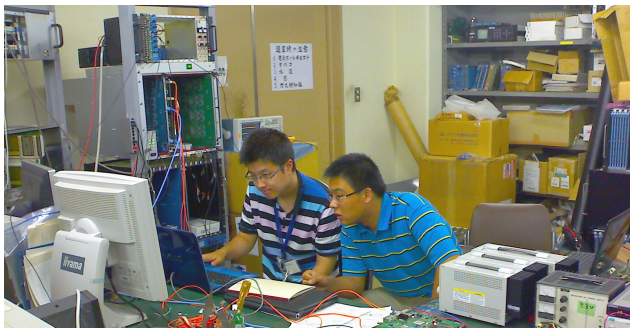
The China group at Belle II

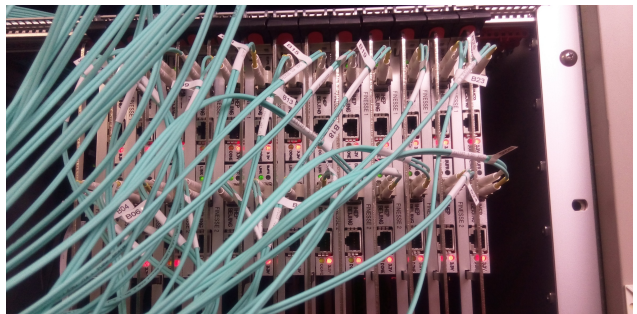
Past & now at Belle II

- China group made great contribution to Belle II
  - Belle2link (IHEP)
  - PXD DAQ (IHEP)
  - B2TIP — physics potential study (BUAA)
- China group is contributing more
  - KLM detector (Fudan, Soochow U.)
  - Computing (BUAA, Fudan)
  - PXD, SVD, Trigger/DAQ, B-field mapping, ...
  - Generator, Data validation, IP profile, luminorsity, ...
  - DAQ upgrade (Fudan, USTC, IHEP)?

Future at Belle II

- Hardware, electronics, computing
  - Fudan: hardware lab based on KLM, computing
  - IHEP: Belle II trigger, DAQ upgrade
  - BUAA: computing cluster joining Belle II GRID
  - CAS "Zhuoyue" computing cluster (2019) ?
  - DAQ upgrade: Fudan, USTC, IHEP ?
- Physics
  - Where China group has advantage
    - $D\bar{D}$-mixing and CPV
    - Exotics: XYZ & quarkonium, T_{cs}, T_{cc}, $D^*(2380)$,...
  - New idea, new method
    - Lepton universality (R_K, R_D, R_{D^*})
    - Semileptonic decays using the B decay vertex
    - Dark sector
  - What's the hot topics of heavy flavor physics? What China group can do?





Summary

- Belle is an excellent experiment, and China group contribute a lot.
- Belle II is going to start physics running in 2019.
- We are preparing...

Thank you!

Back-up