SuperKEKB and Belle II status, and prospects on two-photon physics

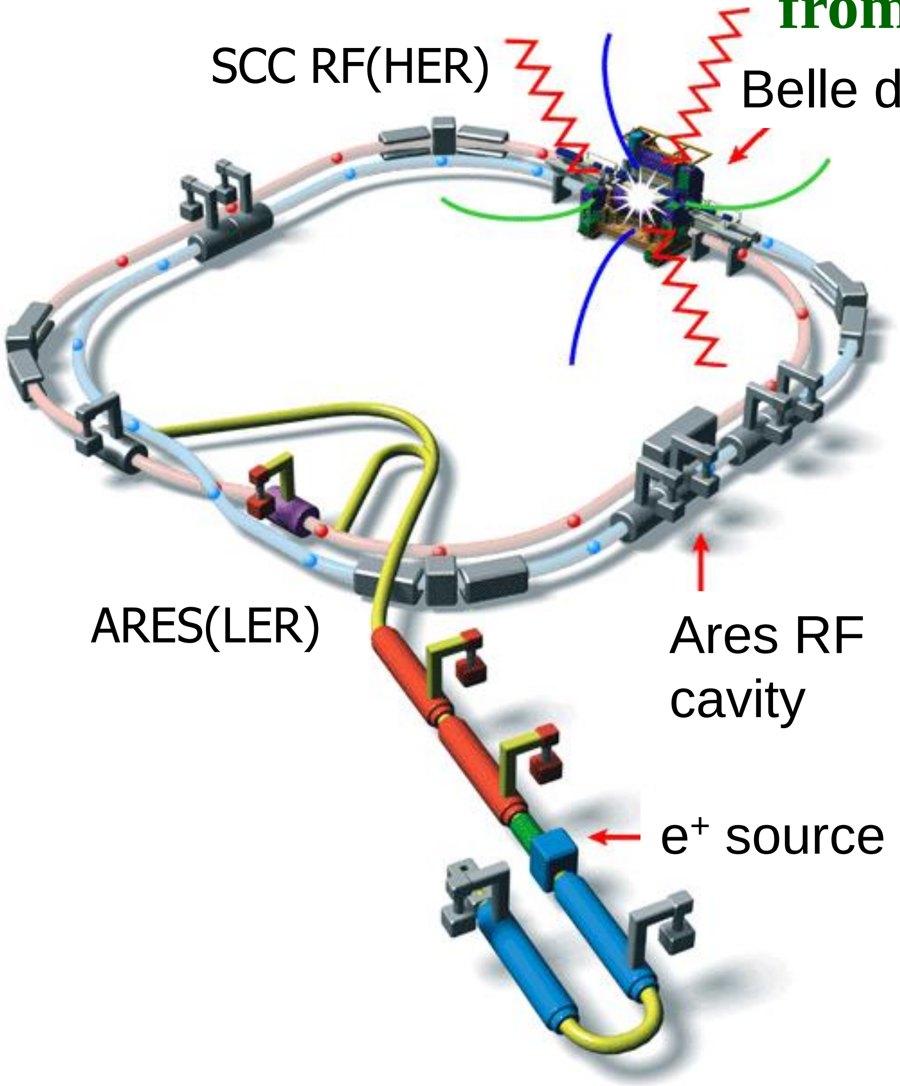
B.Shwartz, on behalf of BELLE II collaboration

Budker Institute of Nuclear Physics
Novosibirsk State University
Novosibirsk, Russia

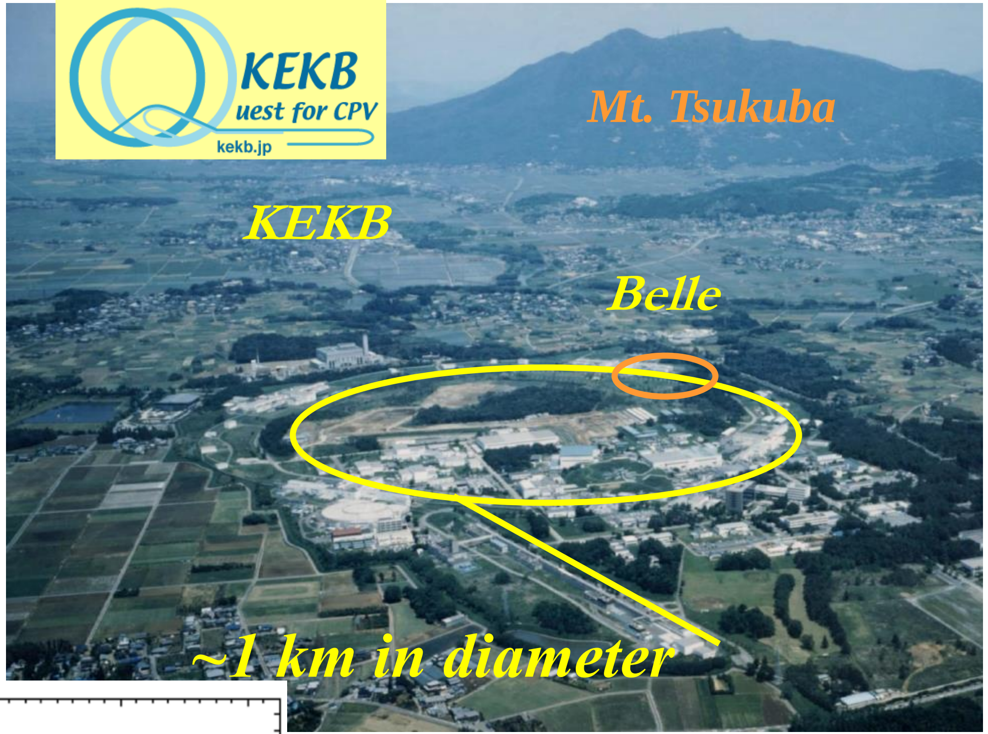
The KEKB Collider

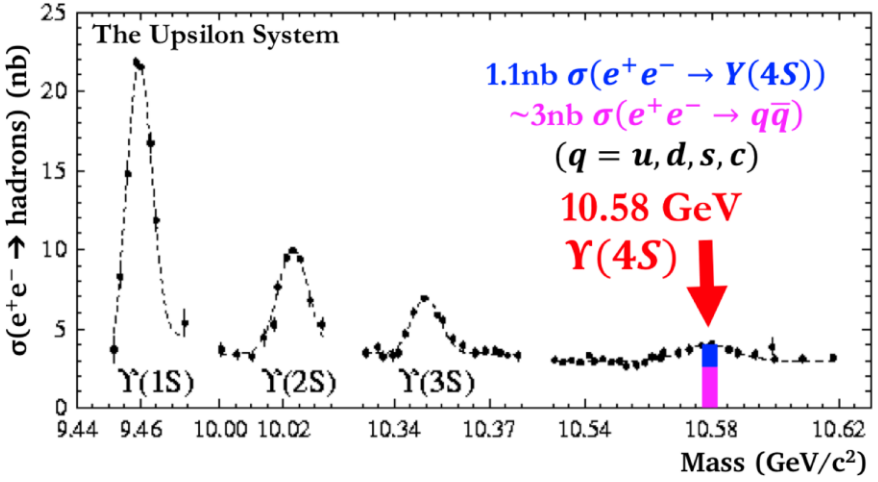
World record: $L = 2 \times 10^{34}/cm^2/sec$

from 1999 to 2010



8 x 3.5 GeV
22 mrad
crossing angle





The primary goal of the Belle and BaBar experiments was to discover the CP violation in B mesons and to measure the parameters of CPV. This was achieved by both experiments in 2001

However, a lot of other important results were obtained

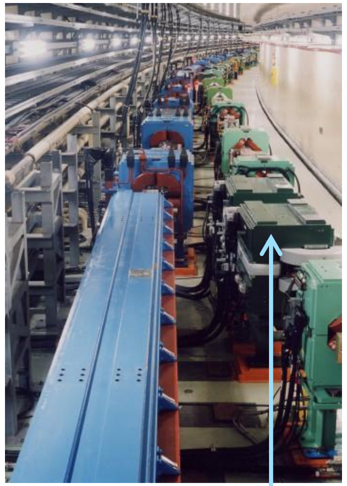
- Observation of direct CP violation in B decays
- Measurements of the CPV parameters in different modes (ϕK^0, $\eta' K^0$, $K_S K_S K_S$, …)
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$)
- Observation of new charmonium-like and bottomonium-like hadronic states
- $b \to s$ transitions: probe for new sources of CPV and constraints from the $b \to s\gamma$ branching fraction
- Forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of D mixing
- Search for lepton flavour violation in τ decays
- Study of the hadronic τ decays
- **Precise measurement of the hadronic cross sections in $\gamma\gamma$ and $e^+e^-(\gamma_{ISR})$ processes**

So wide researches area become possible because of clean event environment and well defined initial state in the e^+e^- experiments as well as high luminosity and general purpose detectors

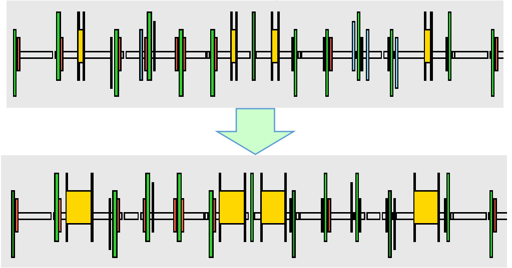
Two-Photon Measurements at Belle

	GeV	|cost*|	fb-1	Ref.	year
γ J/ψ	3.2 - 3.8		32.6	PLB540, 33	2002
π+π-	2.4 - 4.1	0.6	88	PLB15, 39	2005
	0.8 -1.5	0.6	86	PRD75, 051101	2007
				JPhySocJpn76, 074102 2007	
K+K-	1.4 - 2.4	0.6	67	EPJC32, 323	2003
	2.4 - 4.1	0.6	88	PLB15, 39	2005
ppbar	2.0 - 4.0	0.6	89	PLB621, 41	2005
4 mesons	2.75 - 3.75		395	EPJC53, 1	2006
KsKs	2.4 - 4.0	0.6	398	PLB651, 15	2007
	1.05 - 4.0	0.8	972	PTEP2013, 123C01	2013
π0π0	0.6 - 4.0	0.8	95	PRD78, 052004	2008
	0.6 - 4.1	0.8	223	PRD79, 052009	2009
ηπ0	0.84 - 4.0	0.8	223	PRD80, 032001	2009
ηη	1.096 - 3.8	1.0	393	PRD82, 114031	2010
ω J/ψ	3.9 - 4.2		694	PRL104, 092001	2010
ϕ J/ψ	4.2 - 5.0		825	PRL104, 112004	2010
$\omega\omega$,$\omega\phi$,$\phi\phi$	thr - 4.0		870	PRL108, 232001	2012
η'π+π-	1.4 - 3.4		673	PRD86, 052002	2012
π0	$Q^2 \epsilon [4,40] GeV^2$		759	PRD86, 092007	2012
π0π0	$Q^2 < 30 GeV^2$		759	PRD93, 032003	2016
ppbarK+K-	3.2 - 5.6		980	PRD93, 112017	2016

Recent results from two-photon processes at Belle – the talk of Wenbiao Yan at this conference

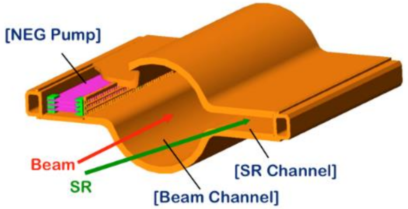


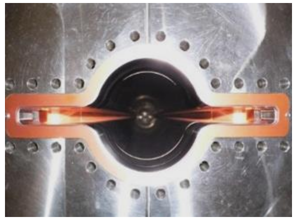
Replace short dipoles with longer ones (LER)



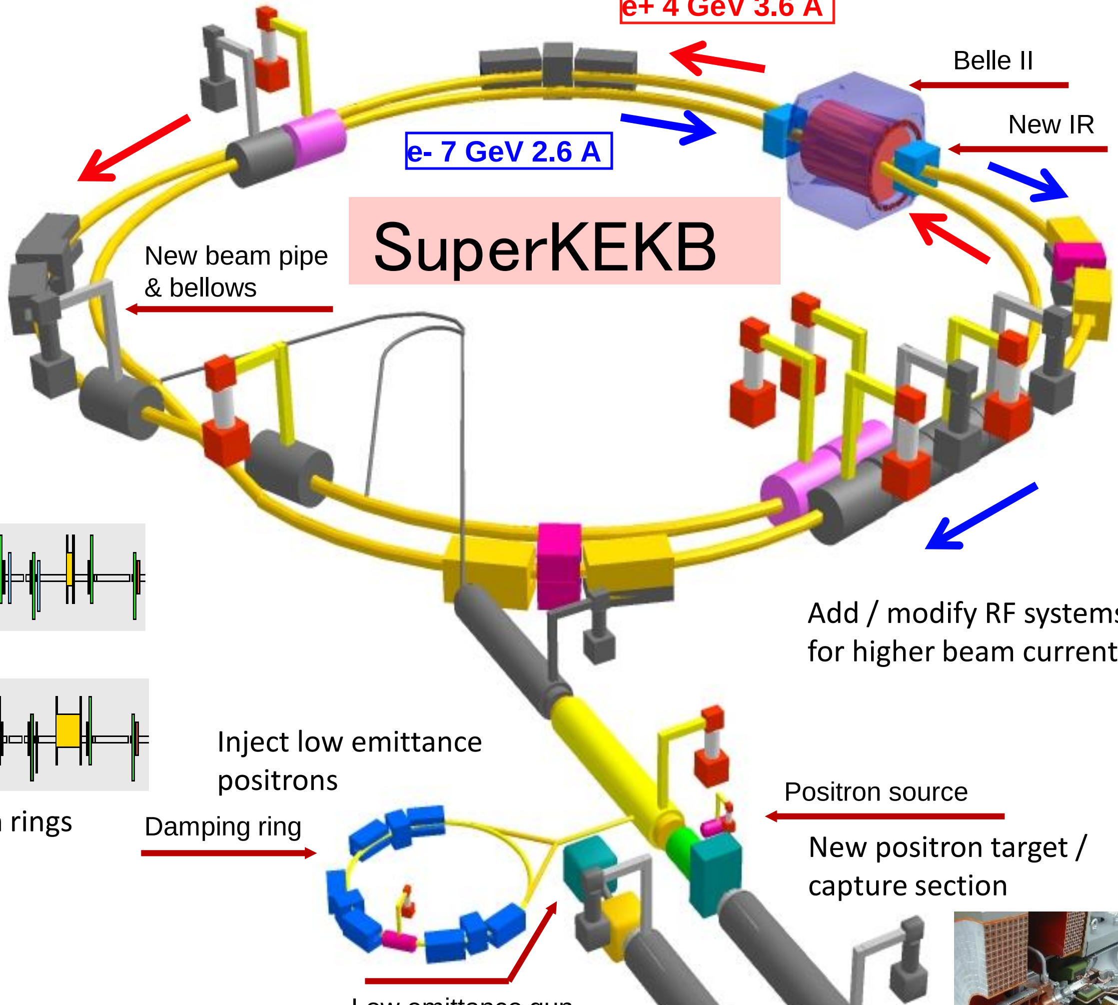
Redesign the lattices of both rings to reduce the emittance

TiN-coated beam pipe with antechambers





SuperKEKB



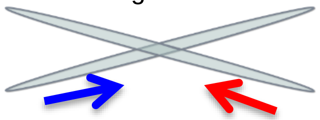
Inject low emittance positrons

Inject low emittance electrons

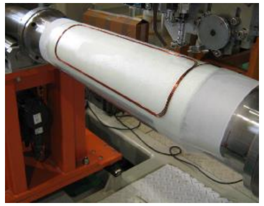
New positron target / capture section

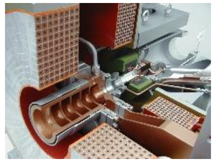
Add / modify RF systems for higher beam current

Colliding bunches



New superconducting /permanent final focusing quads near the IP





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

x 40 Increase in Luminosity

Design Concept of SuperKEKB

- Increase the luminosity by 40 times based on "Nano-Beam" scheme, which was first proposed for SuperB by P. Raimondi.

Luminosity Gain

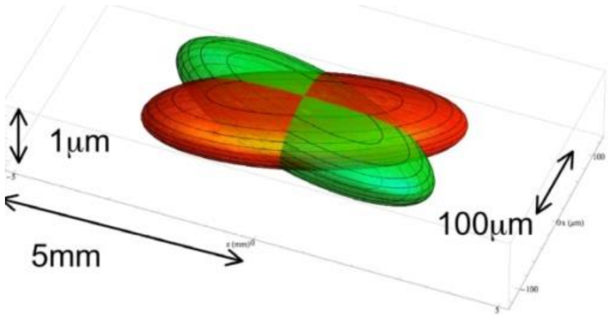
- Vertical β function at IP: 5.9 → 0.27/0.30 mm (× 20)
- Beam current: 1.7/1.4 → 3.6/2.6 A (× 2)
- Beam-beam parameter: .09 → .09 (× 1)

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

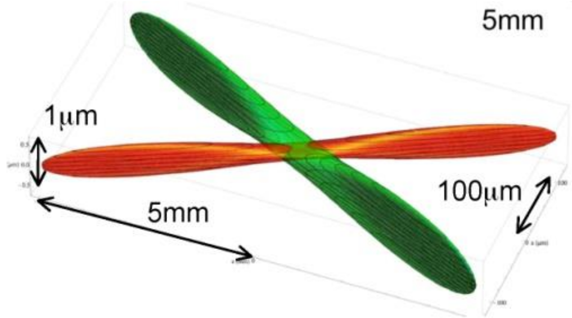
- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

  LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
  HER : Lower emittance and lower SR power

KEKB



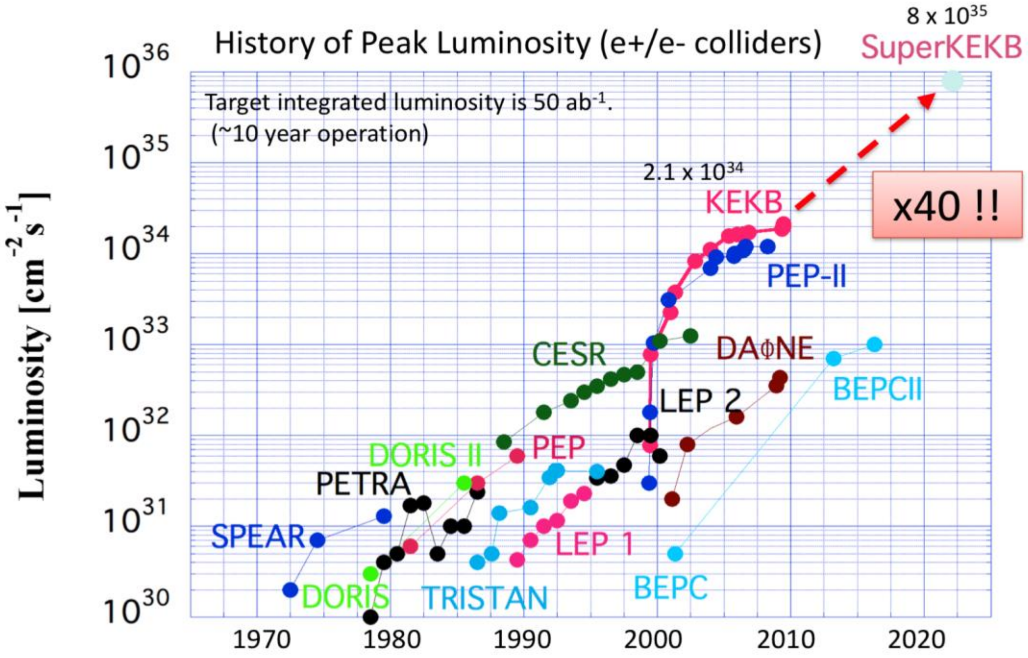
$\sigma_x \sim 100\mu m, \sigma_y \sim 2\mu m$



$\sigma_x \sim 10\mu m, \sigma_y \sim 60nm$

Nano-Beam SuperKEKB

	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}



Demands on the detector

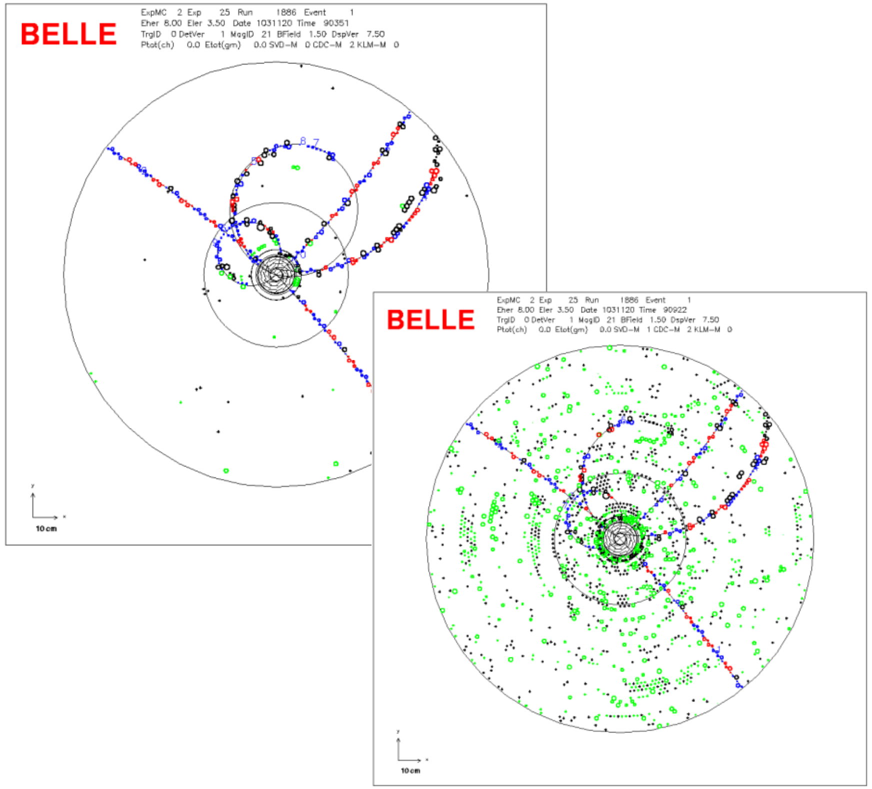
Total cross section and trigger rates with L = 8×10^{35} cm^{-2} s^{-1} from various physics processes at Υ(4S).

Physics process	Cross section (nb)	Rate (Hz)
Υ (4S) →BB	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha (θlab> 17°)	44	350[a]
γγ (θlab> 17°)	2.4	19 [a]
2γ processes (θlab> 17°, pt > 0.1GeV/c)	~80	~ 15000
Total	~130	~20000

(a) rate is pre-scaled by a factor of 1/100

The requirements for the trigger system are:

1. high efficiency for hadronic events;
2. maximum average trigger rate of 30 kHz;
3. fixed latency of about 5 μs;
4. timing precision of less than 10 ns;
5. minimum two-event separation of 200 ns;
6. trigger configuration that is flexible and robust.



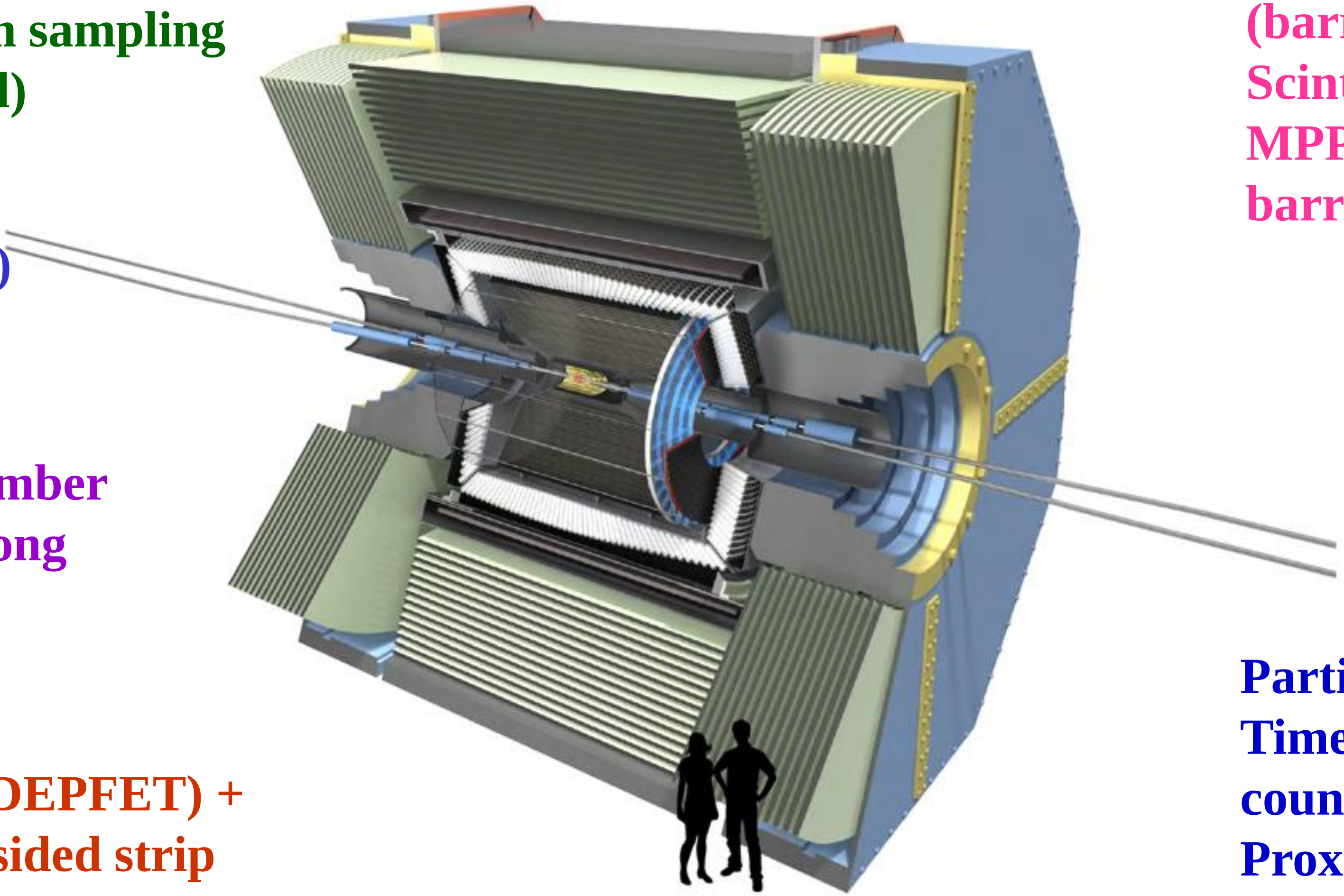
Beam-related backgrounds are 10-20 x KEKB.
Radiative Bhabha, Touschek scattering, 2-photon
Fake hits, pile up, radiation damage!!

Belle II Detector

EM Calorimeter:
CsI(Tl), waveform sampling electronics (barrel)

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

electrons (7GeV)



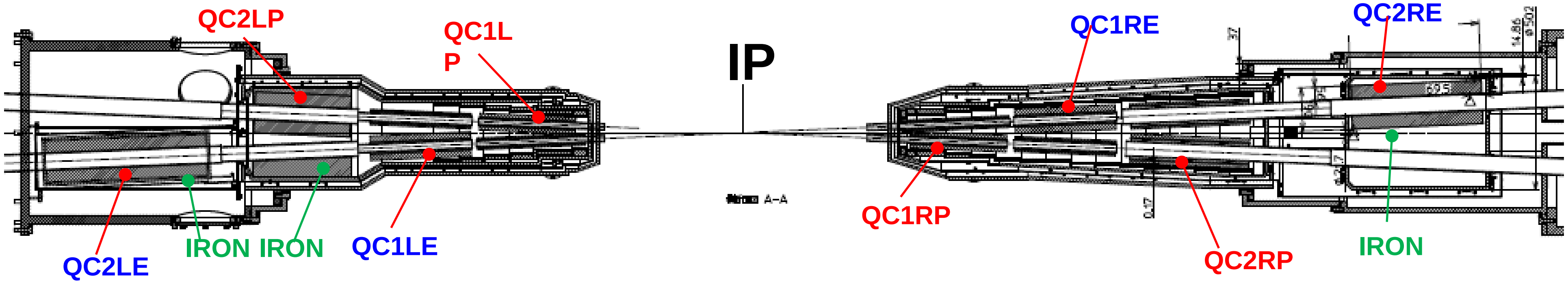
positrons (4GeV)

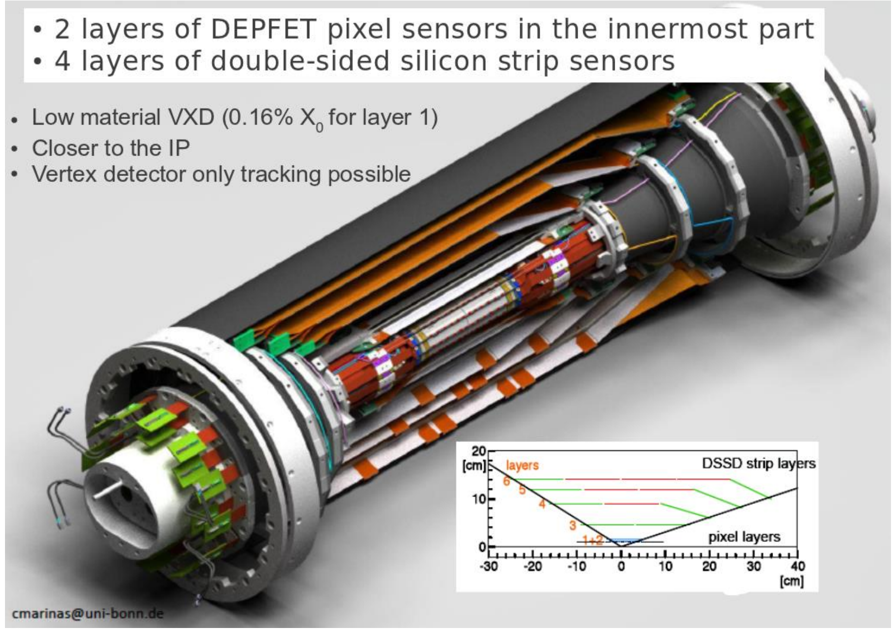
Central Drift Chamber
Smaller cell size, long lever arm

Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

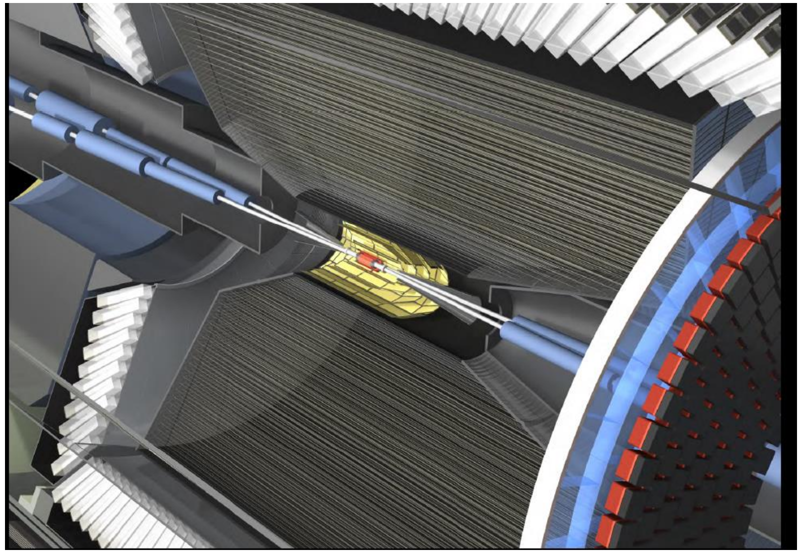
Particle Identification
Time-of-Propagation counters (barrel)
Prox. focusing Aerogel RICH (forward)

SuperKEKB/Belle II Interaction Region



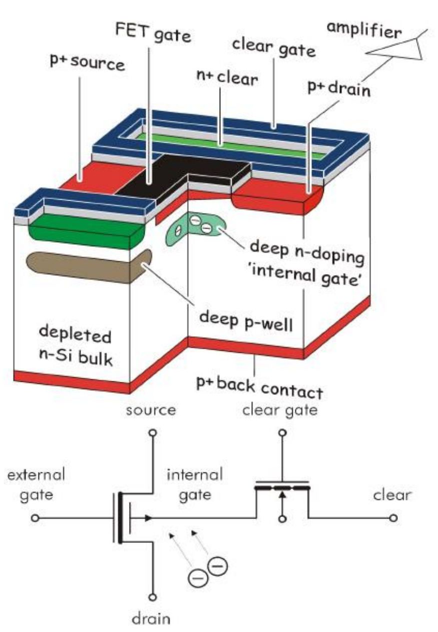


		Belle II	Belle
Beam Piper =		10mm	15mm
DEPFET			
	Layer 1	r = 14mm	
	Layer 2	r = 22mm	
DSSD			
	Layer 3	r = 38mm	20mm
	Layer 4	r = 80mm	43.5mm
	Layer 5	r = 104mm	70mm
	Layer 6	r = 135mm	88mm

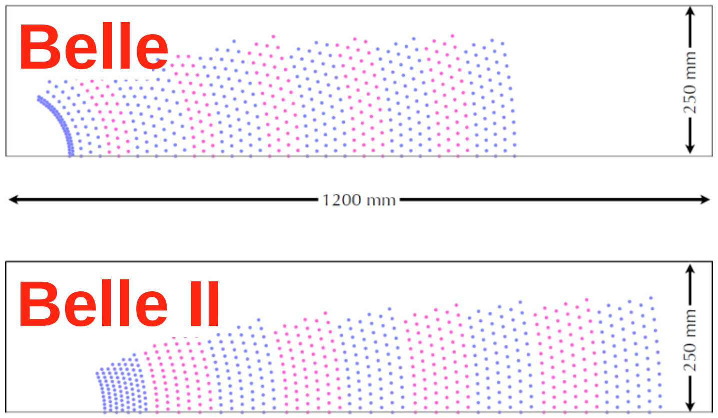


Tracking: PXD and Central Drift Chamber (CDC)

DEpleted P-channel FET



DEPFET pixel sensor

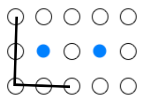


longer lever arm
Improved momentum resolution and dE/dx

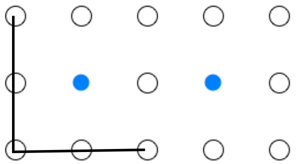
$$\sigma_{P_t}/P_t = 0.19 P_t \oplus 0.30/\beta$$

$$\sigma_{P_t}/P_t = 0.11 P_t \oplus 0.30/\beta$$

small cell



normal cell

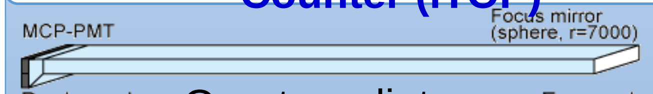


	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	He:C_2H_6	He:C_2H_6
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

PXD: excellent spatial granularity (resolution ~15 μm)
low material (0.16%X_0 for layer 1)
but significant amount of background hits, huge data rate.
SVD: precise timing (2–3 ns RMS)
but has **ambiguities in space** due to 1D strip.
Combining both yields a very powerful device!

Particle Identification in Belle II

Barrel PID: Time of Propagation Counter (iTOP)

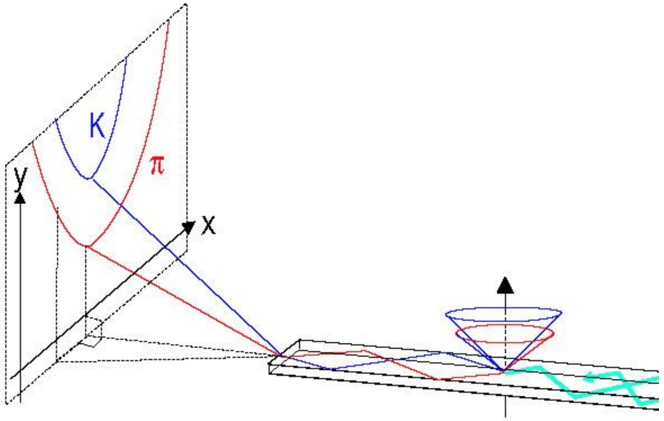


Quartz radiator

Focusing mirror

Small expansion block

Hamamatsu MCP-PMT (measure t, x and y)



16 Quartz radiators

- $2.6m^L$ x $45cm^W$ x $2cm^T$
- Excellent surface accuracy

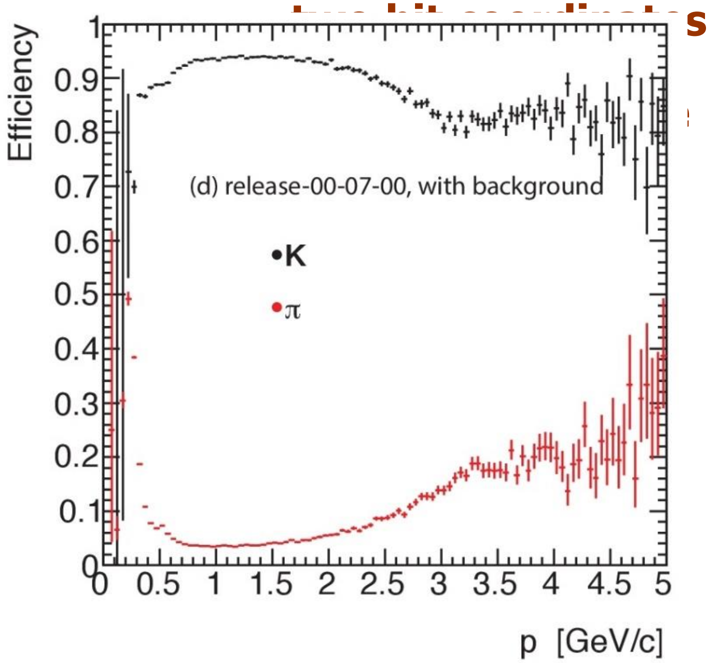
MCP-PMT

- Hamamatsu 16ch MCP-PMTGood TTS (<35ps) & enough lifetime
- Multialkali photo-cathode

Cherenkov ring imaging with precise time measurement.

Device uses internal reflection of Cerenkov ring images from quartz like the BaBar DIRC

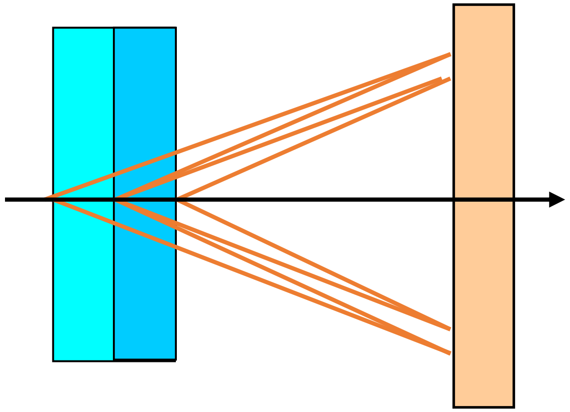
Cherenkov angle reconstruction from

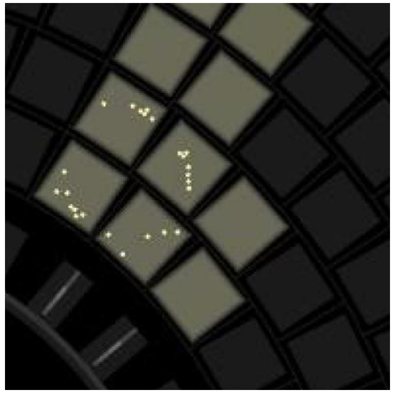


Aerogel RICH (endcap PID)

RICH with a novel "focusing" radiator – a two layer radiator

Employ multiple layers with different refractive indices→ Cherenkov images from individual layers overlap on the photon detector.

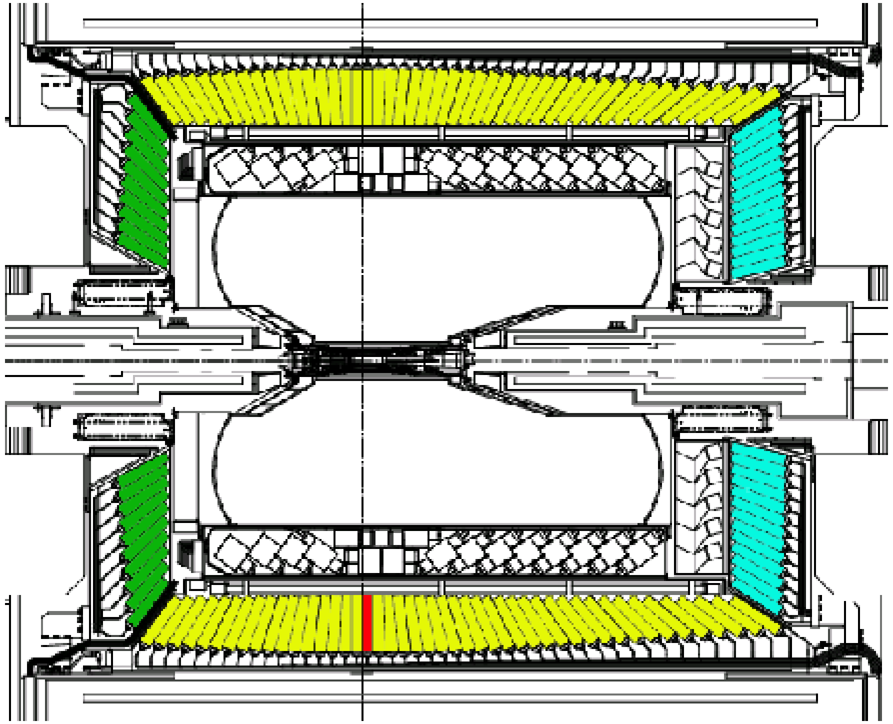




Hamamatsu HAPD

6.6 σ π/K at 4 GeV/c !

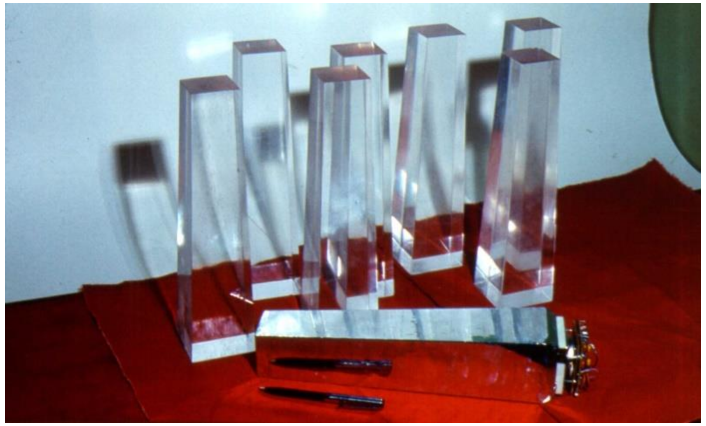
BELLE Electromagnetic Calorimeter



3 m

CsI(Tl) crystals

L_{cr} = 30 cm = 16.2X_0



Number of crystal: 8736
Total weight is ~43ton

- **Calorimeter successfully worked for more than 10 years since 1999 to 2010**
- **All 8736 channels are operable**
- **It demonstrated high resolution and good performance.**

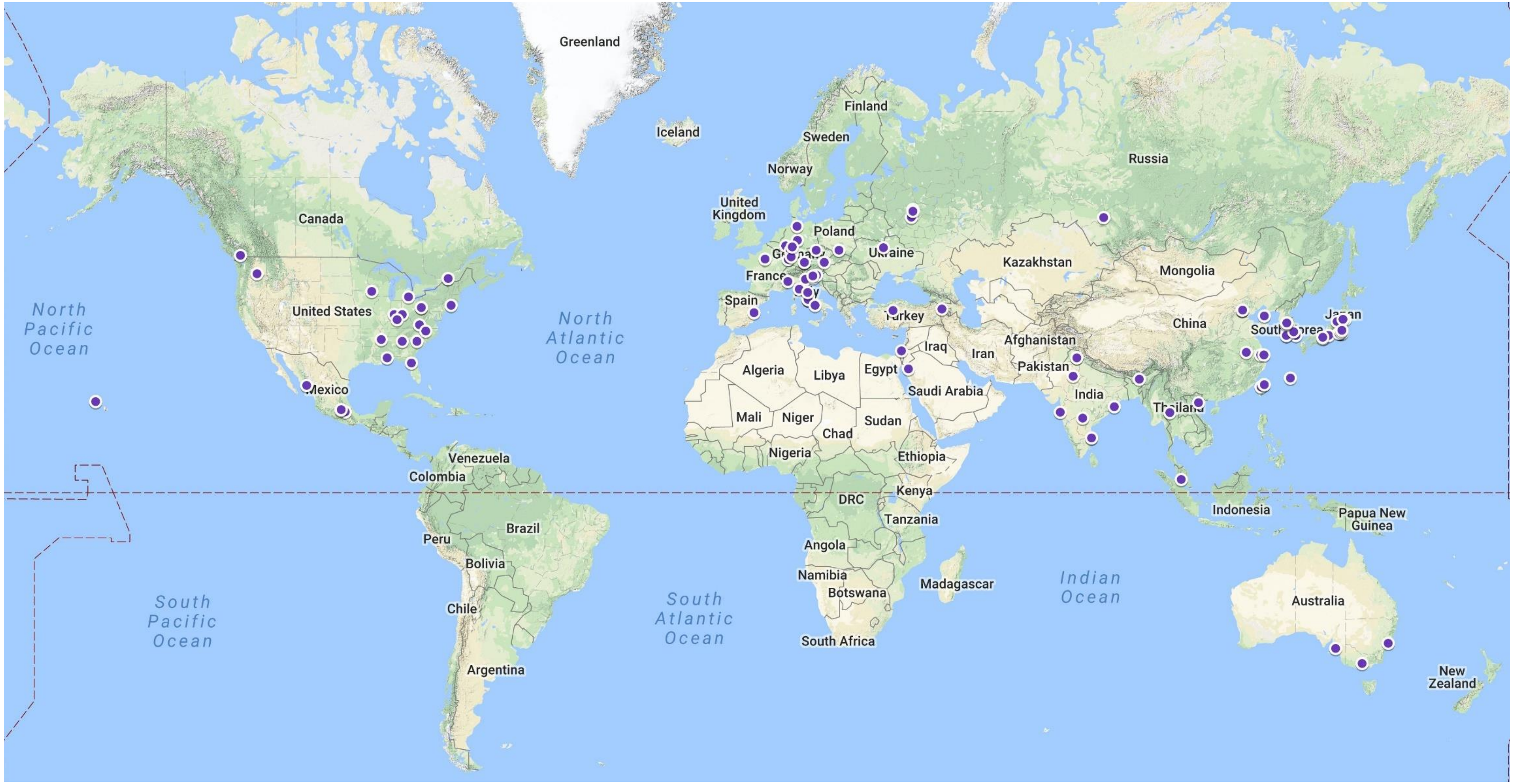
Modification of the electronics.

❖ Pipe-line readout with waveform analysis:

❖16 points within the signal are fitted by the signal function F(t):
$F(t) = H \cdot f(t-t_0)$

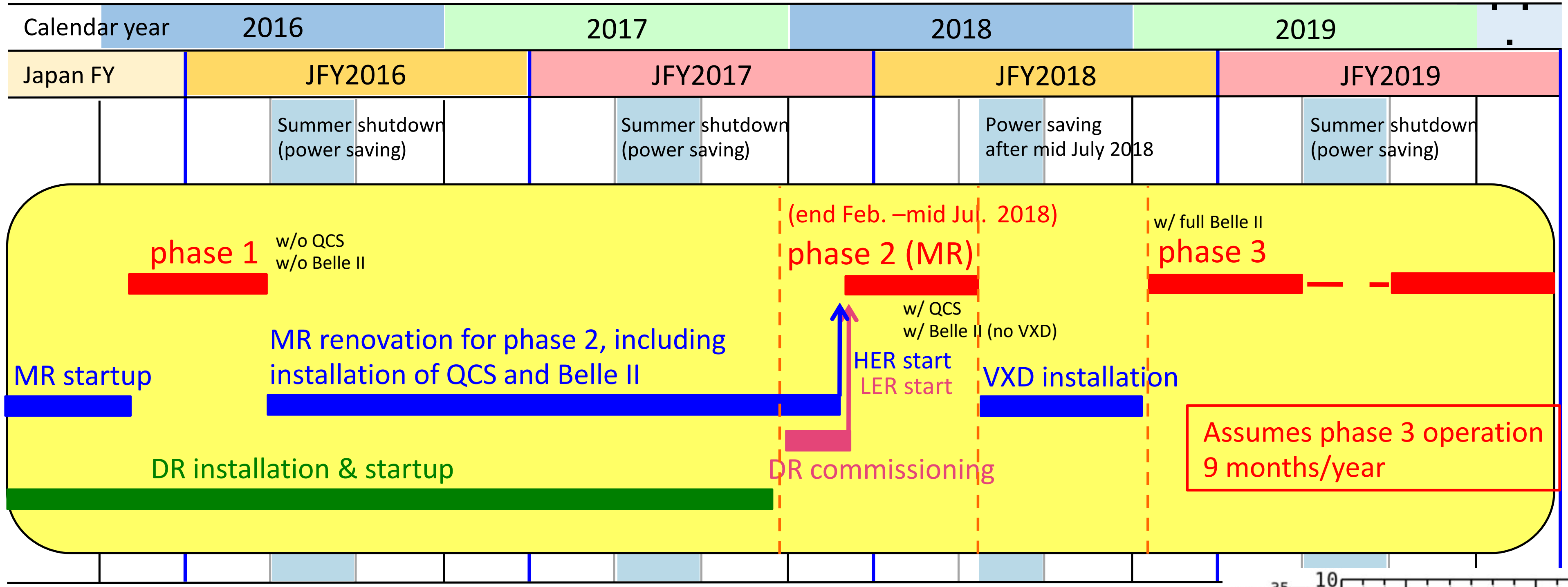
❖Both amplitude (H) and time (t_0) are obtained by the on-line shape fit.

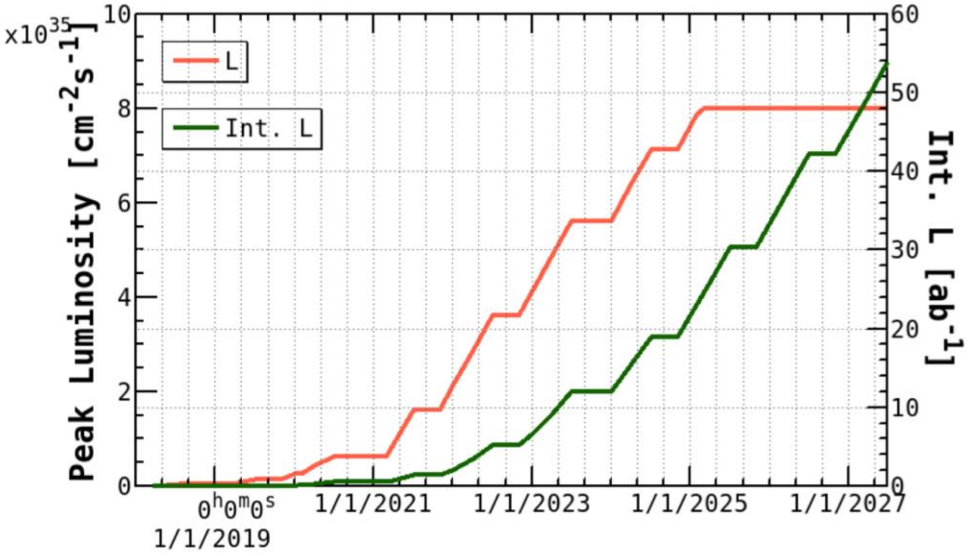
The Geography of the International Belle II collaboration



Belle II now has grown to ~900 researchers from 26 countries

SuperKEKB and Belle II status and plans





Phase 1 : Beam operation without final focus magnets and Belle II

Phase 2(ended on July 2018) :

No final vertex detector but one ladder/layer with background sensors

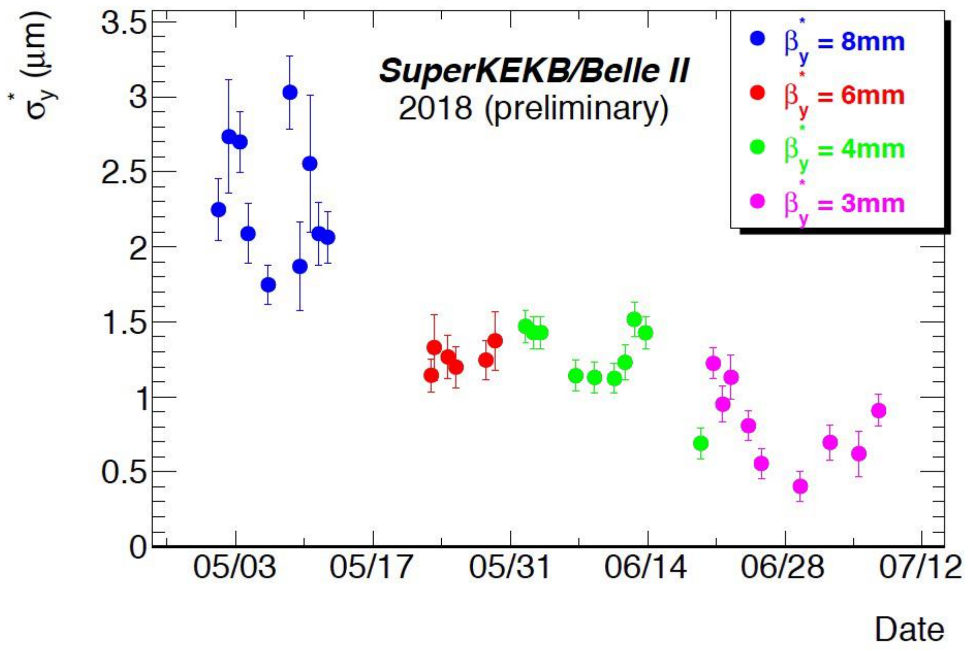
Achieved Luminosity of 5 $10^{33}cm^{-2}s^{-1}$

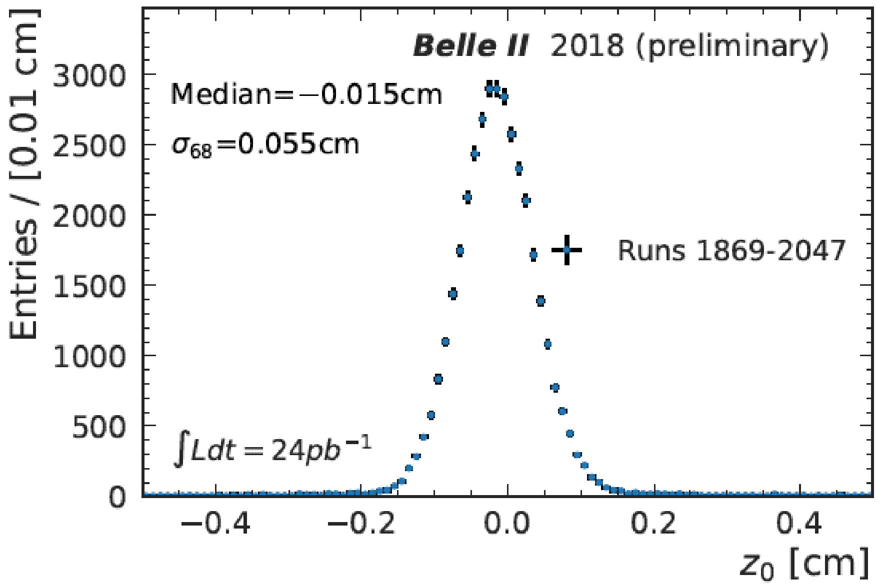
recorded integrated luminosity of 500pb^{-1}

Phase 3: 2019 - detector with silicon vertex detector

Vertical beam size (measured by the luminosity scans with diamond detectors (Phase 2)

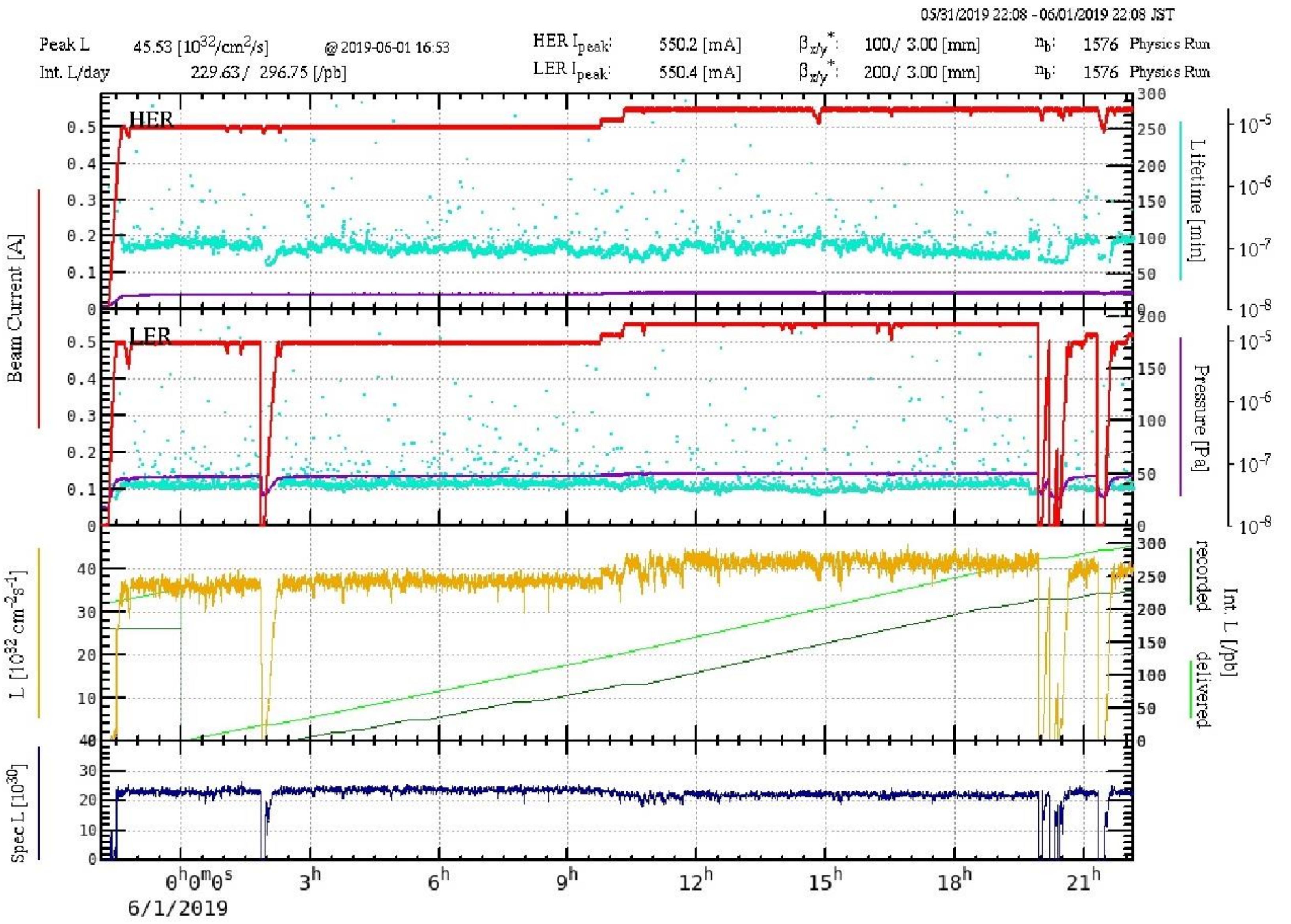
IR Z size (Phase 2)





At Phase 2 peak luminosity of 5 x 10^{33}/cm^2/sec^{-}1 , the vertical spot is ~700nm high. There is still beam-beam blowup at high currents. At low currents, the vertical spot size is 330 nmhigh (the final goal is O(50nm) with full capability of the QCS system).

Current Luminosity status



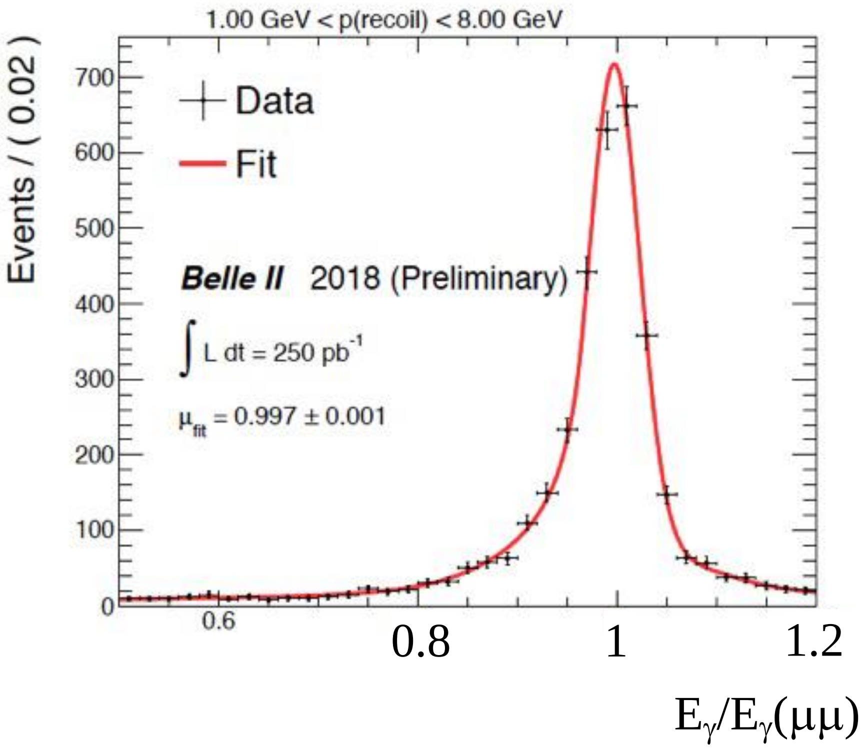
$L_{max} \approx 4.5\times10^{33}cm^{-2}s^{-1}$

By now ~ 1.6 fb^{-1}

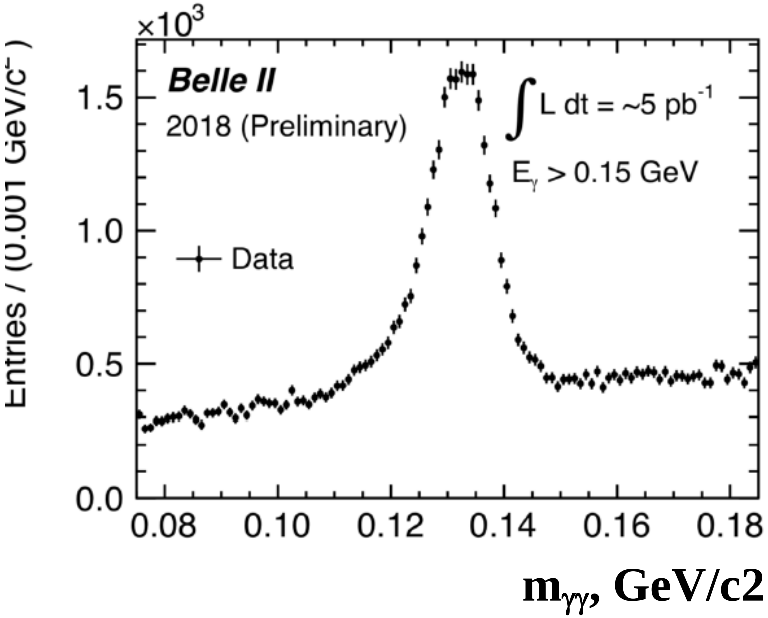
Plan – 5 fb^{-1} by end of June

Phase 2 results - photons

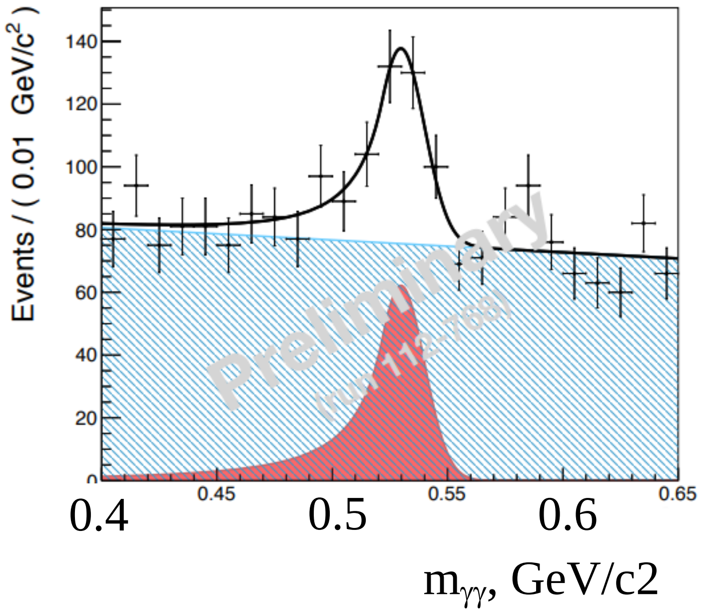
$e^+e^- \rightarrow \mu^+\mu^-\gamma$



$\pi^0 \rightarrow \gamma\gamma$

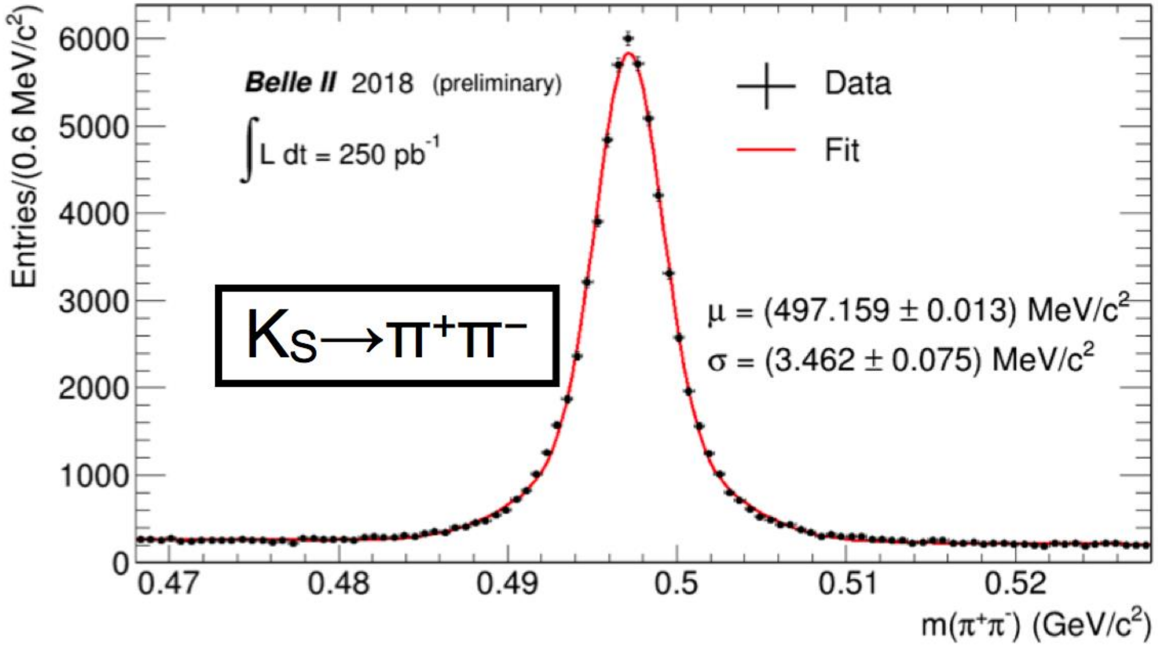


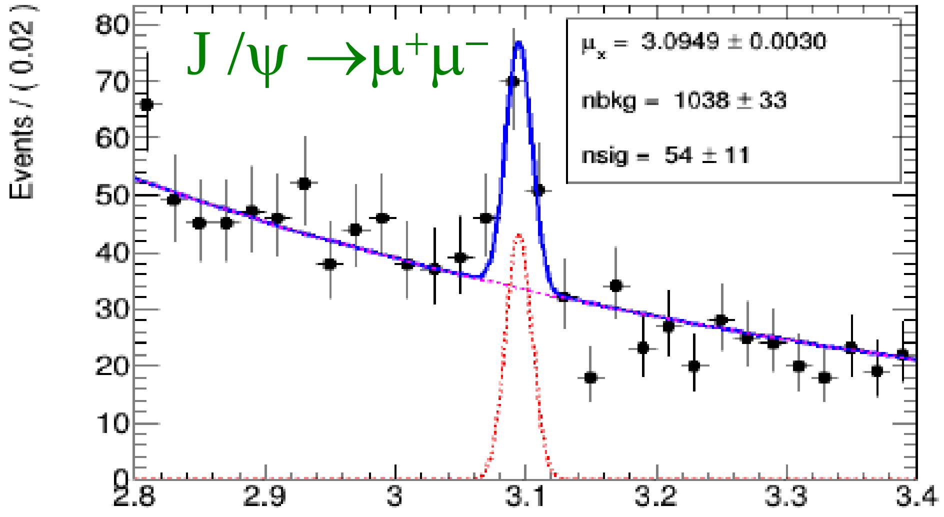
$\eta \rightarrow \gamma\gamma$



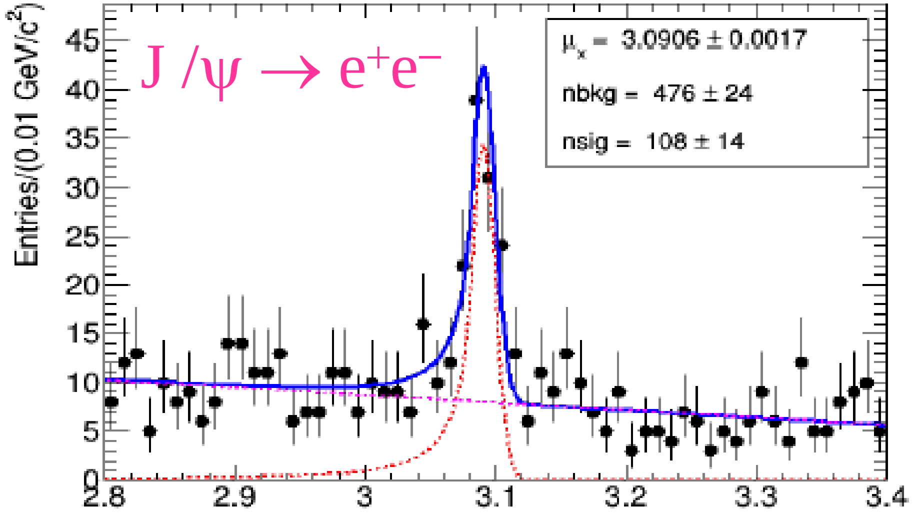
Phase 2 results - tracking

$K_S \to \pi^+\pi^-$



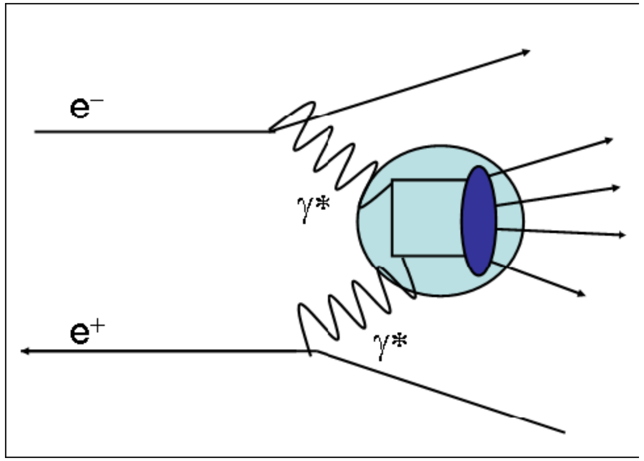


$M_{\mu^+\mu^-}$, GeV/c^2



$M_{e^+e^-}$, GeV/c^2

Study of Two-Photon Physics at Belle II



Belle II Advantages For Two-photon processes:

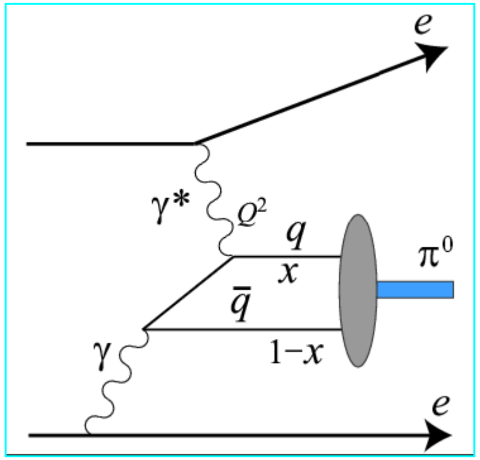
- Much higher (integrated) luminosity (up to 50 x)
- Better momentum resolution and identification
- Improved trigger efficiency due to more sophisticated neutral trigger

Most interesting two-photon studies:

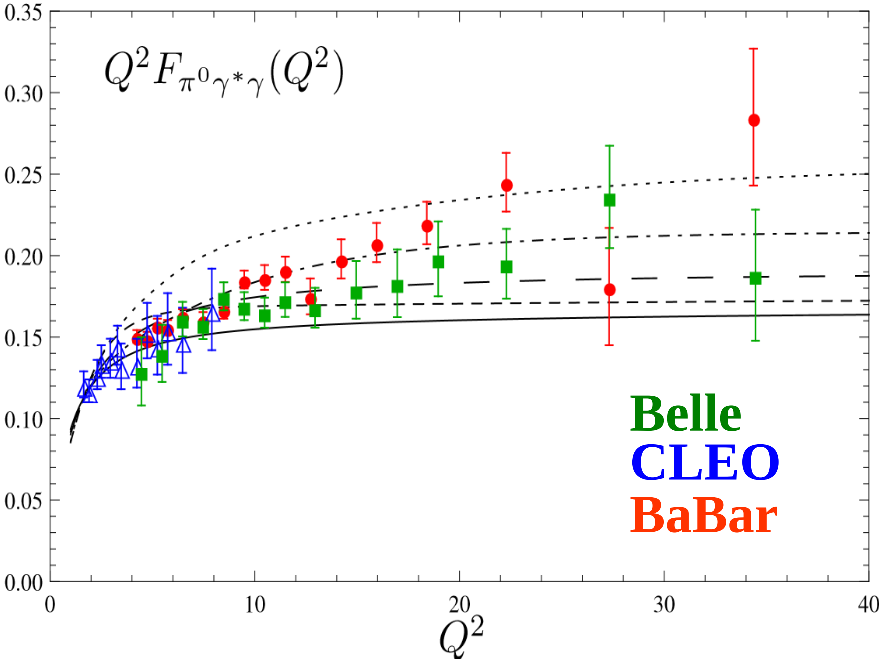
Transition form factors of π0, η and η’ mesons via single and double tagged events. These are particularly important for light-by-light contribution to muon (g-2);

Study and search for charmonium and charmonium-like states in the two-photon collisions.

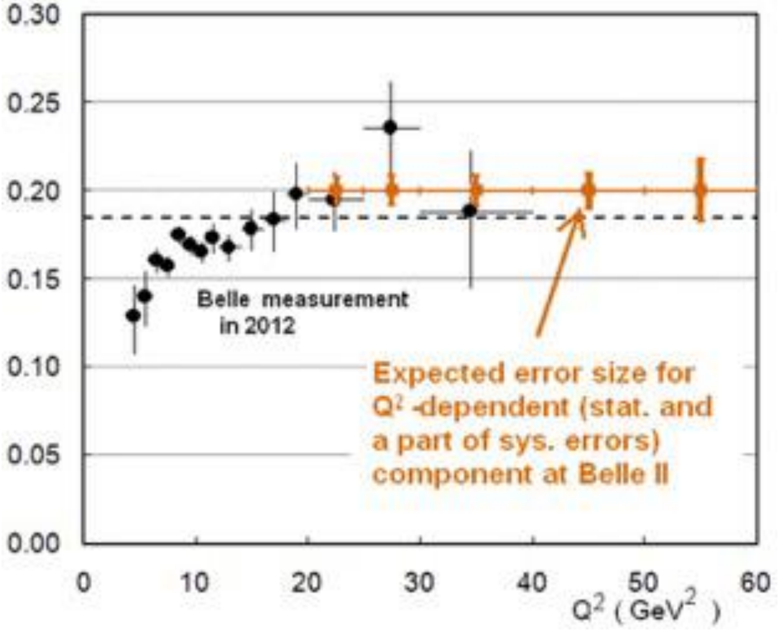
π^0 Transition Form Factor



$\gamma\gamma^* \to \pi^0$ **Single-tag π^0 production in two-photon process with a large-Q^2 and a small-Q^2 photon**



Belle II expectation



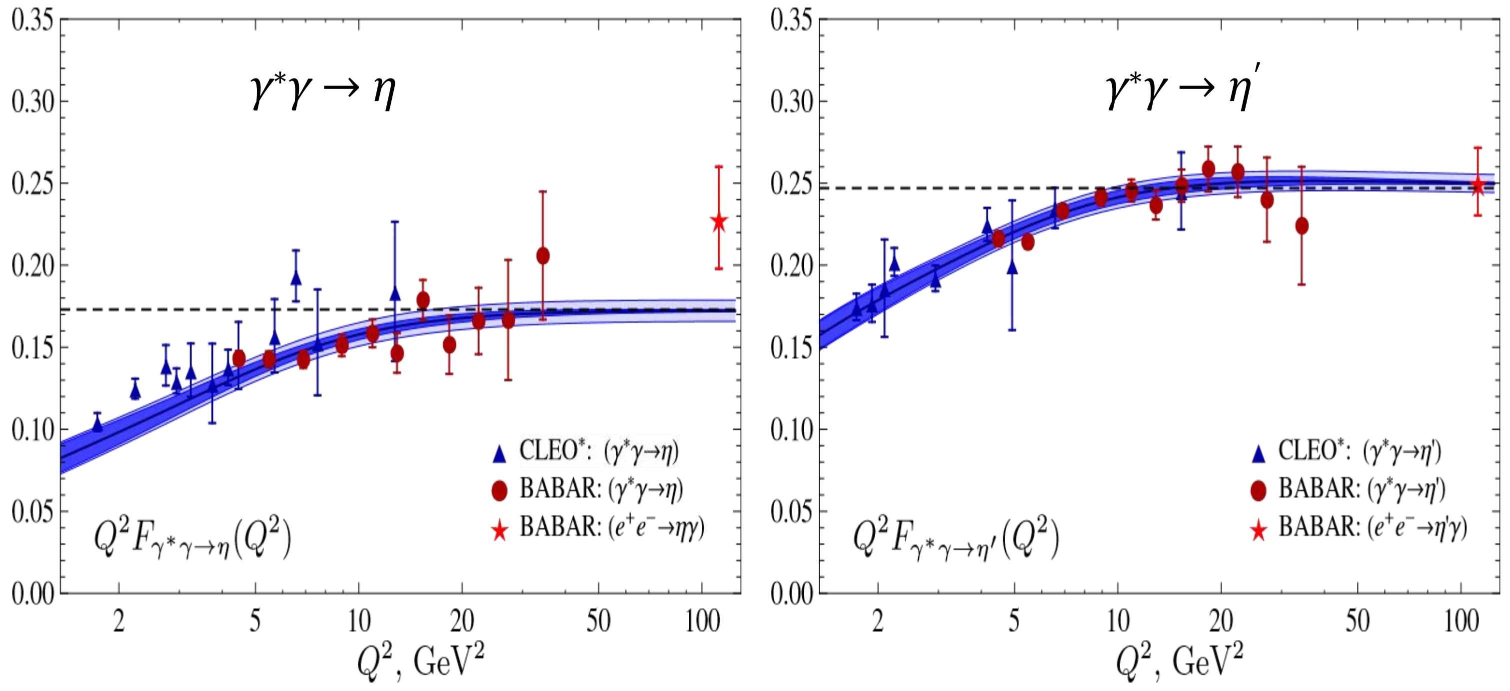
$|F(Q^2)|^2 = |F(Q^2,0)|^2 = (ds/dQ^2)/(2A(Q^2))$

$A(Q^2)$ is calculated by QED

$|F(0,0)|^2 = 64\pi\Gamma\gamma\gamma/\{(4\pi\alpha)^2 m_R^3\}$

The pion transition form factor for the “asymptotic” (solid line) and different models The experimental data are from BaBar (circles), Belle [(squares) and CLEO (open triangles).

TFF of the light pseudoscalar mesons

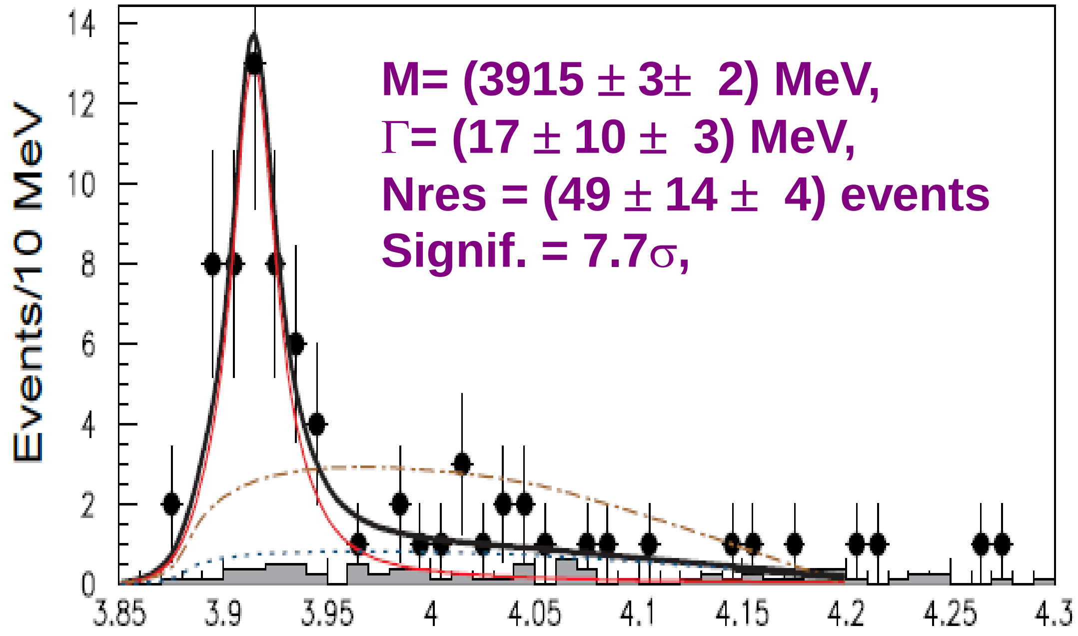


Transition form factors $\gamma^*\gamma \to \eta$ (left panels) and $\gamma^*\gamma \to \eta'$ (right panels) compared to the LCSR calculation (Phys. Rev., D90(7), 074019 (2014)).

New-Charmonium (or XYZ) production

Important task is a serch for and study above 3.6 GeV:

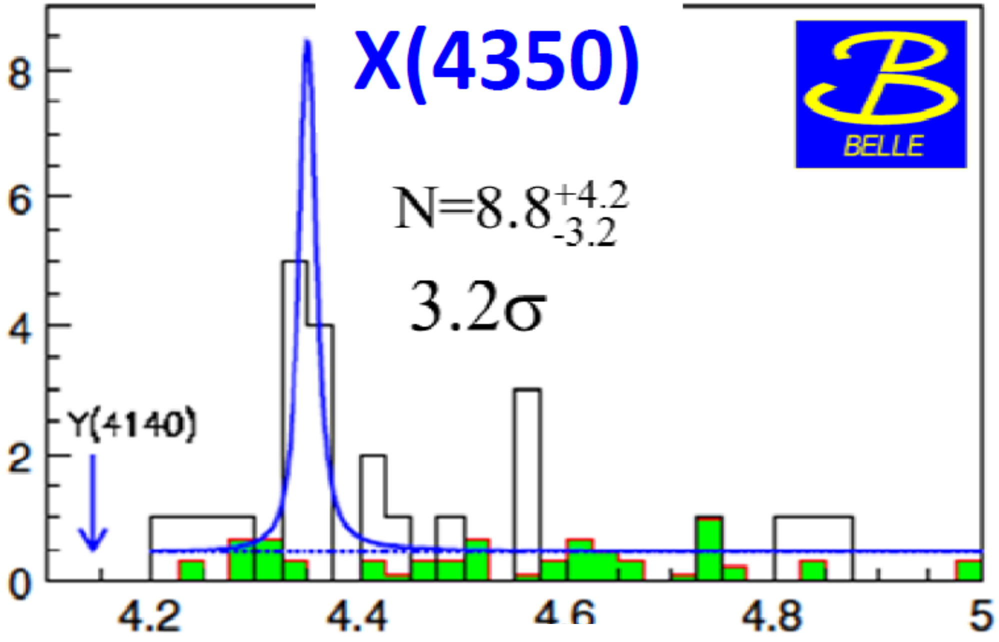
$\eta_c(2S)$, $\chi_{c2}(2P)$, X(3915) and X(4350) (Discovered by Belle in B decays and two-photon processes) **Now statistics is limited <~100 evt.**



M_{inv}

X(3915) → J/ψω

PRL 104, 092001 (2010)
PRL 104, 112004 (2010)



M_{inv}

X(4350) → J/ψφ

And search for exotic baryons in $\gamma\gamma \to p\bar{p}$ K+K-

Conclusion

•Last decade demonstrated the fruitfulness and efficiency of the flavor “factory” approach in the particle physics.

•Huge amount of results was obtained at the B-factories, but many new questions appeared and the large field of researches will be opened by the super B factory.

•High luminosity to be brought by SuperKEKB/Belle II will make various analyses possible for two-photon physics:

•QCD test with exclusive processes at High-W, at High-Q2, with Single and Double tag …

•Charmonia/XYZ above 3.6 GeV