R measurements at BELLE and perspectives for BELLE II

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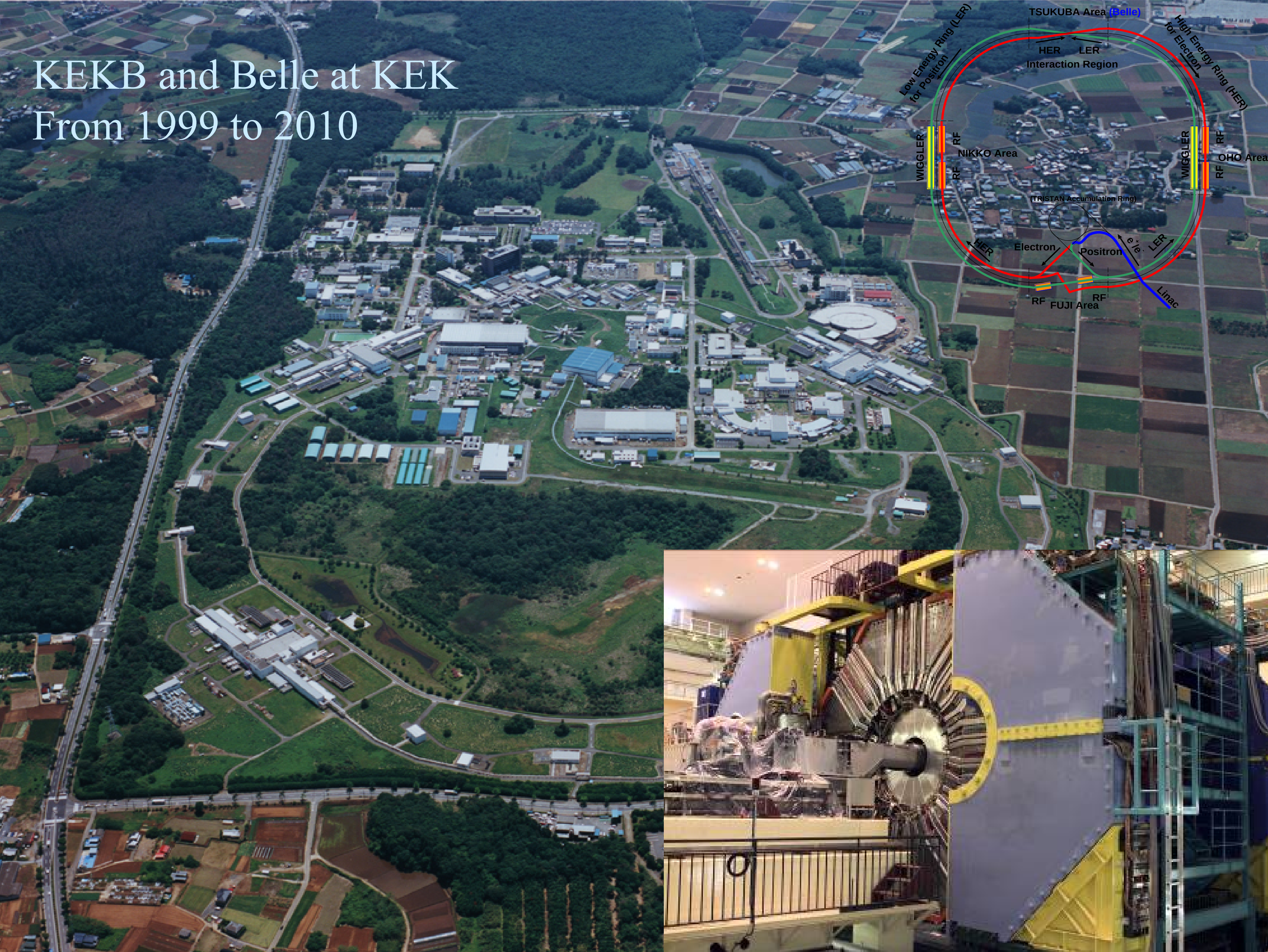
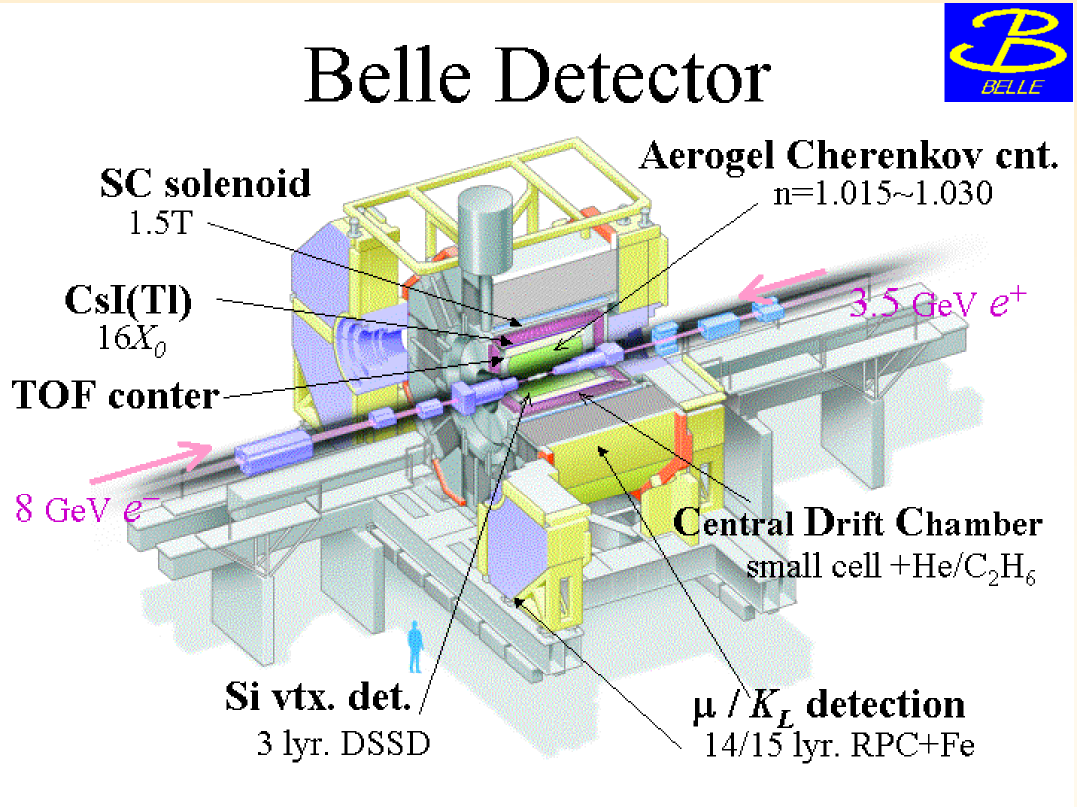
Motivations for precise measurements of hadron cross sections in low energy region

- Tests of perturbative QCD
  - QCD sum rules, quark masses, quark and gluon condensates
  - Higher order QCD corrections - Λ_{QCD}, $\alpha(s)$
- Hadronic corrections to fundamental parameters:
  - Running fine structure constant - $\alpha(M_Z^2)$
  - **Anomalous magnetic moment of the muon**
- measurement of parameters of light vector mesons ρ, ω, φ, ρ’, ρ’’, …..
- Search of and study of the exotic resonance states (X, Y, Z, …)
- Study of the final states dynamics and test of theoretical models
- comparison with spectral functions of the hadronic tau decays via CVC
- Study of nucleon-antinucleon pair production – nucleon ectromagnetic form factors, search for NNbar resonances, ..

KEKB and Belle at KEK
From 1999 to 2010





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

Peak lumi record at KEKB: L=2.1 x 10^{34}/cm2/sec with crab cavities

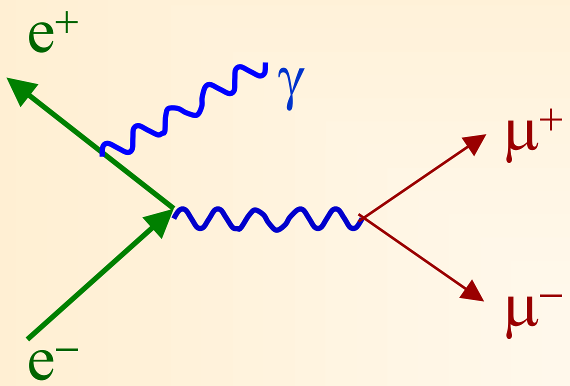
$E^+ = 8$ GeV, $E^- = 3.5$ GeV, $\sqrt{s}=10.58$ GeV, $\beta\gamma=0.42$

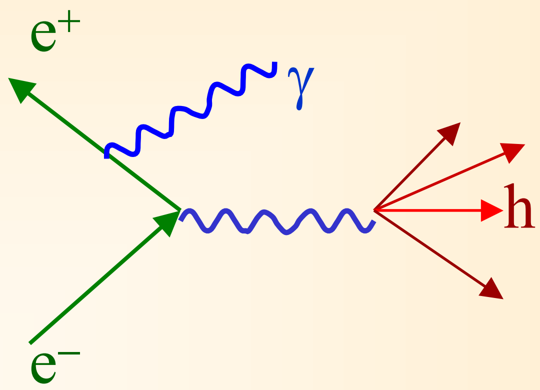
F/B asymmetric detector

High vertex resolution, magnetic spectrometry, excellent calorimetry and sophisticated particle ID ability

$$\int_{1999}^{2010} L dt = 1\ ab^{-1}$$

ISR - general remarks





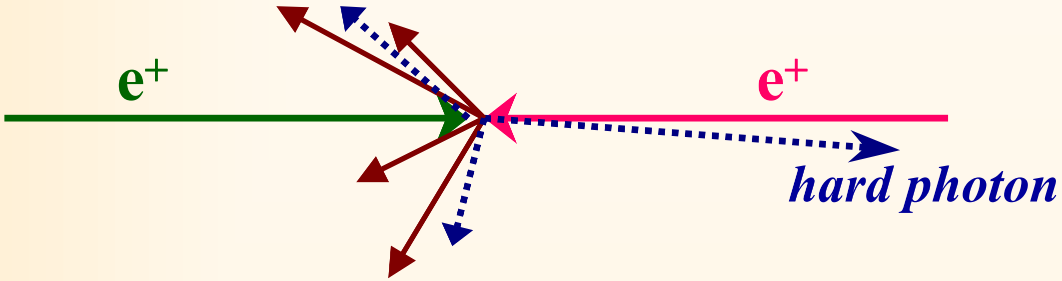
The idea is quite old*, but last ~7-10 years that became popular to possibilities provided by the high luminosity meson factories.

Many studies by this method were performed in the last years.

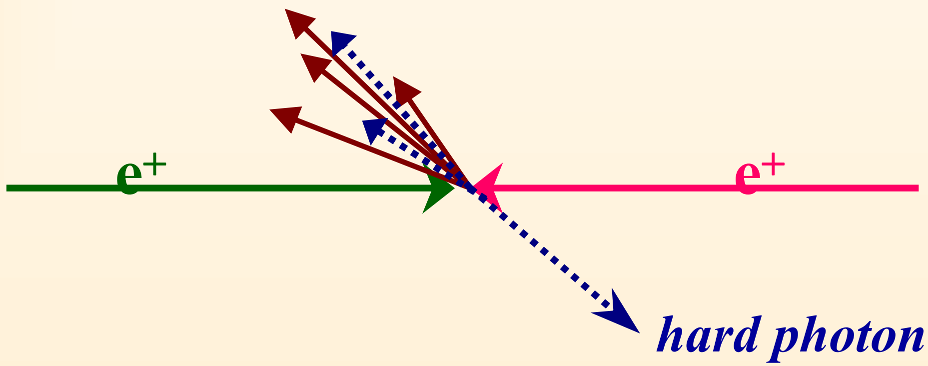
*) *V.N.Baier and V.S.Fadin, Phys.Let. B 27 (1968) 223*

M.S.Chen, P.Zerwas, Phys. Rev. D 11 (1975) 58

Two approaches



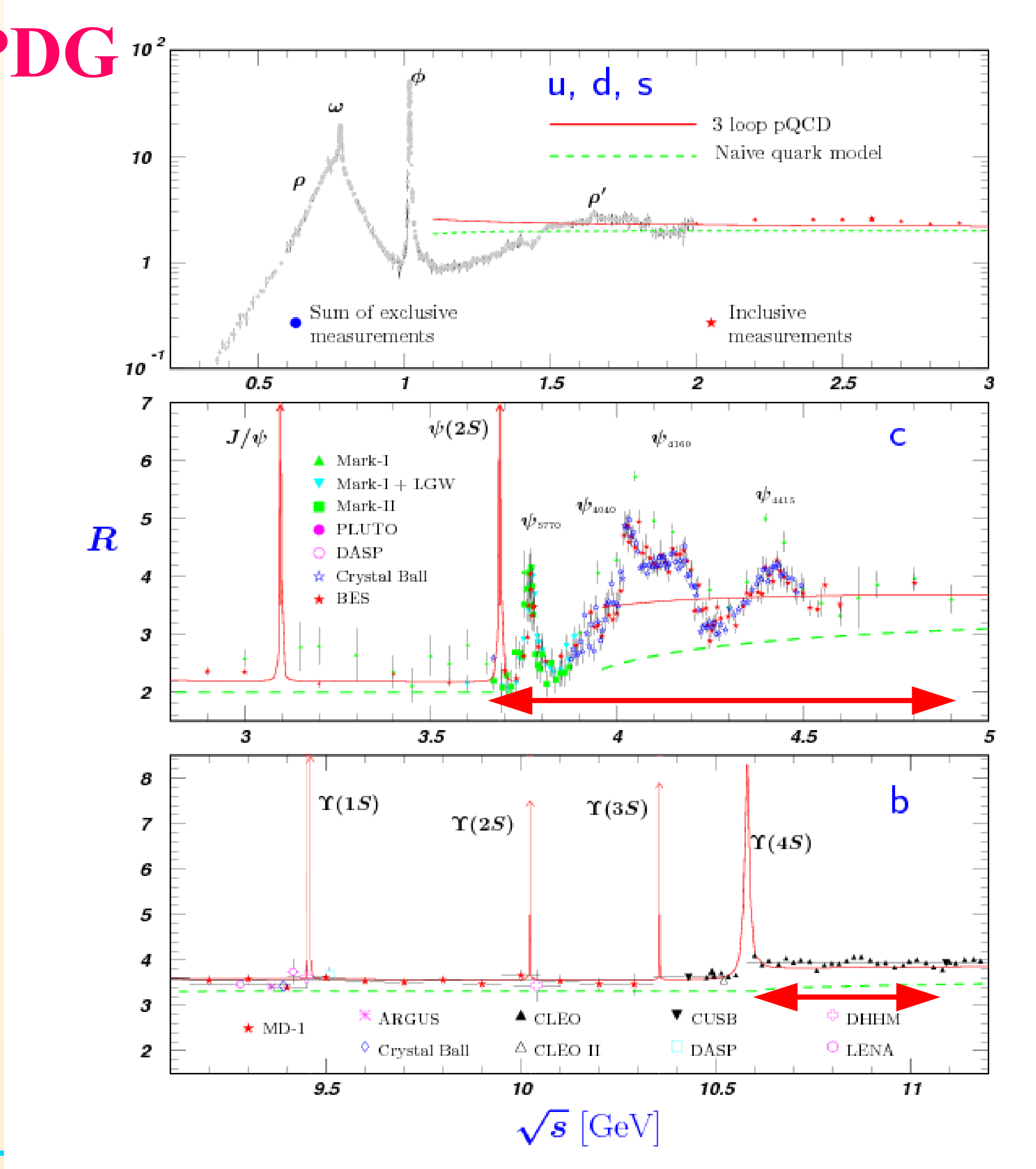
higher cross section,
but
partial reconstraction,
higher background



full reconstraction,
low background
but
lower cross section,

R(s) measurements at Belle

PDG

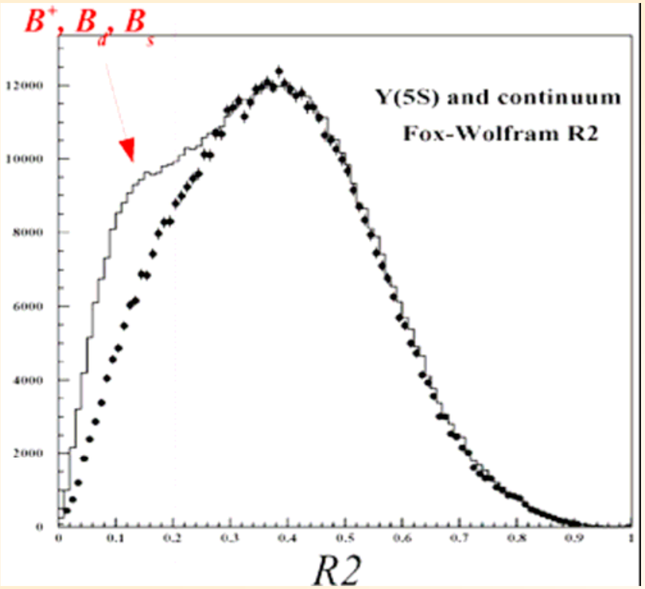


ISR: with γ_{ISR} detection, full reconstruction

ISR: mostly without γ_{ISR} detection

Direct e^+e^- scan

Measurement of R_b

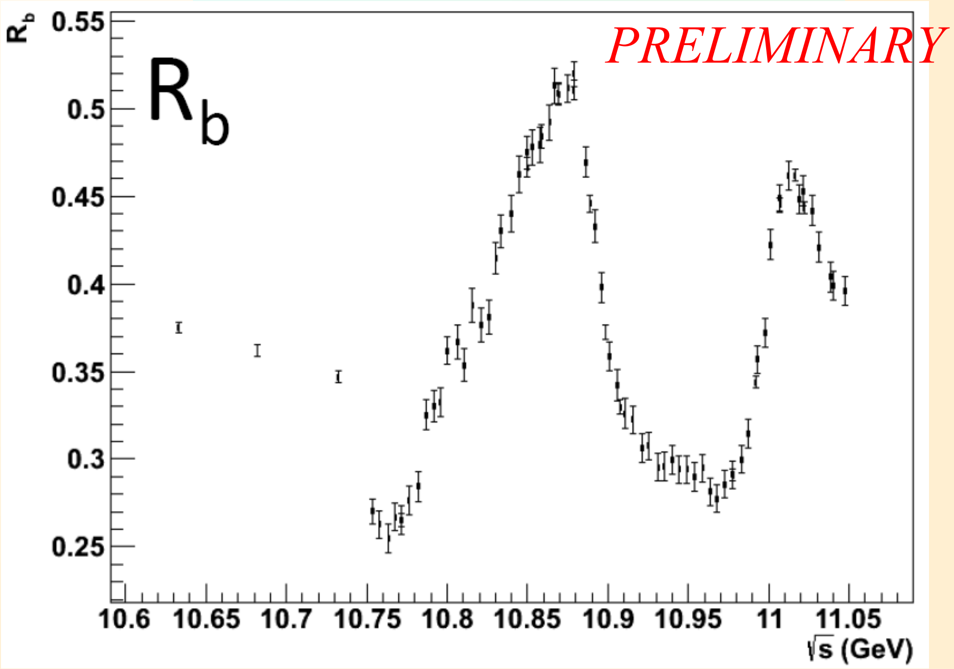


Cut on R2< 0.2

Continuum from below (4S)
3.67 fb–1 (scaled)

Event shape parameter
(Fox-Wolfram moments)

$$R_2 = \frac{\sum_{i,j} |p_i||p_i| P_2(\cos\theta)}{\sum_{i,j} |p_i||p_i| P_0(\cos\theta)}$$



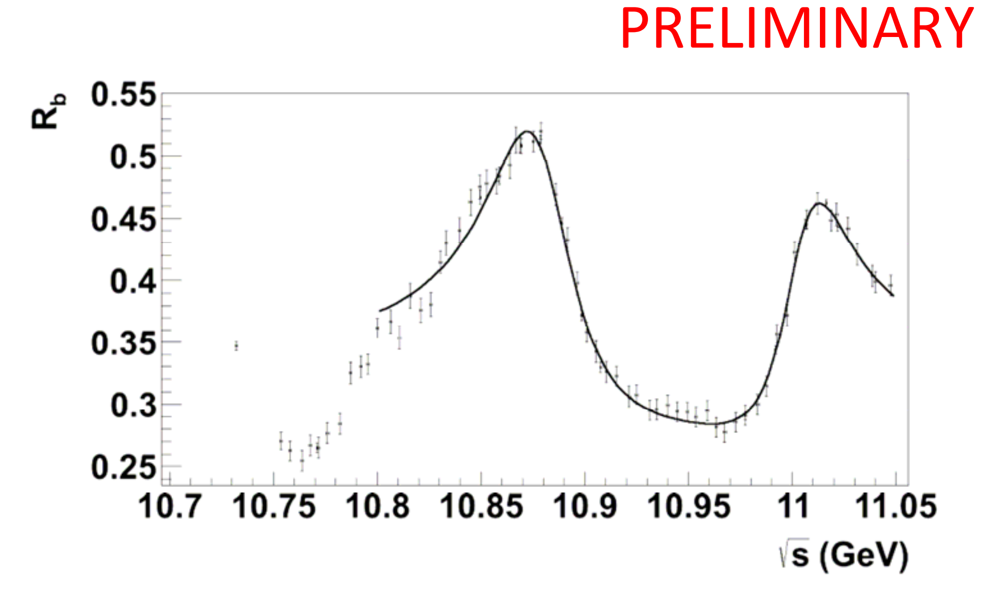
Data Sample: $e^+e^- \rightarrow bb \rightarrow$ hadrons

- 61 ~50 pb^{-1} scan point
- 16 ~1 fb^{-1} scan points

R_b: Data and Fit

$$|A_{NR}|^2 + |A_R + e^{i\phi_{5S}}(A_{5S}BW(M_{5S},\Gamma_{5S}) + A_{6S}e^{i\phi_{6S-5S}}BW(M_{6S},\Gamma_{6S}))|^2$$

	R_b Preliminary
M(5S) MeV	10880.2 ± 0.9 ± 1.4
Γ(5S) MeV	51 ± 2
ϕ(5S) Rad	2.26 ± 0.05
M(6S) MeV	11004 ± 1 ± 3
Γ(6S) MeV	40 ± 2
ϕ(6S-5S) Rad	0.62 ± 0.07



χ^2/ndf= 70.8/54

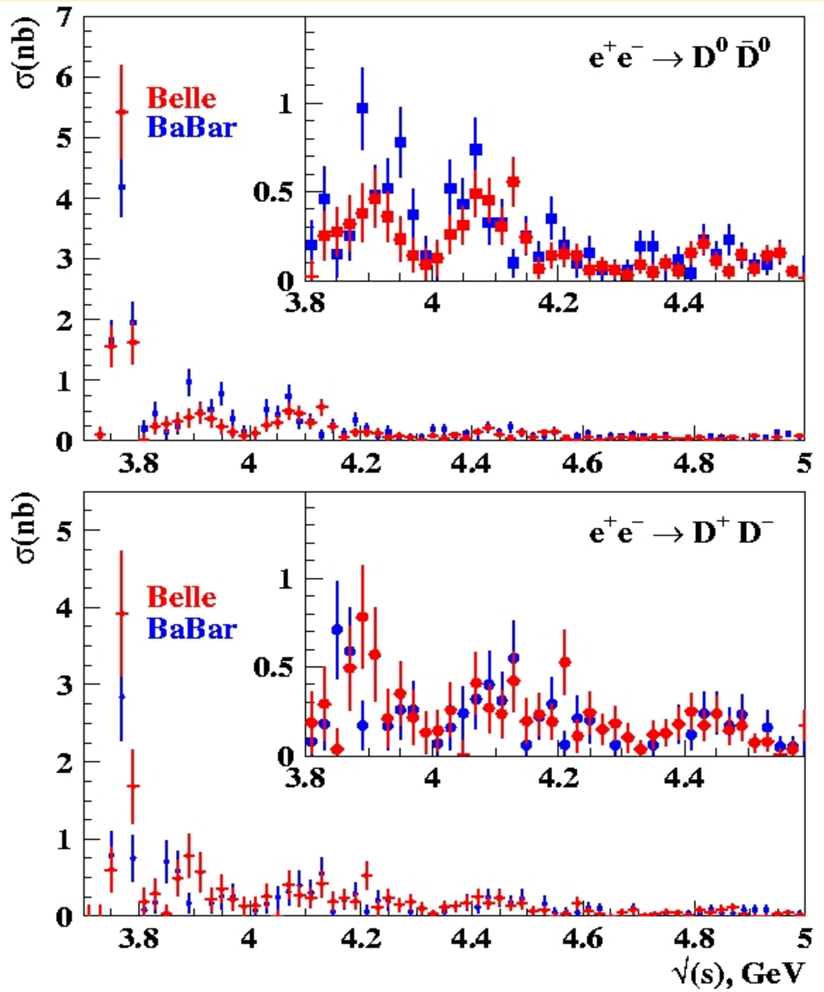
$e^+e^- \to$ hadron cross sectons via ISR at Belle

Final State	Year	Int. Lum. [fb^{-1}]	E range [GeV]	σ_{max} [nb]
$\pi^+\pi^- J/\psi$	2013	967	3.8 to 5.5	72×10^{-3}
$\eta J/\psi$	2012	980	3.8 to 5.3	80×10^{-3}
$D_s^+ D_s^-$	2011	967	3.8 to 5	0.45
$D_s^+ D_s^{*-}$	2011	967	4 to 5	0.9
$D_s^{*+} D_s^{*-}$	2011	967	4.2 to 5	0.5
$D^0 D^{*-} \pi^+$	2009	695	4 to 5.2	0.65
$\Lambda_c^+ \Lambda_c^-$	2008	695	4.56 to 5.4	0.55
$D^0 D^- \pi^+$	2008	673	4 to 5	0.6
$D\bar{D}$	2008	673	3.7 to 5	9
$D^+\bar{D}^-$	2008	673	3.7 to 5	4
$D^0\bar{D}^0$	2008	673	3.7 to 5	5.5
$K^+K^- J/\psi$	2007	673	4.1 to 6	10×10^{-3}
$\pi^+\pi^- \psi(2S)$	2007	673	4.1 to 5.5	80×10^{-3}
$\pi^+\pi^- J/\psi$	2007	548	3.8 to 5.5	70×10^{-3}
$D^{*+} D^{*-}$	2007	547.8	4 to 5	3.4
$D^+ D^{*-}$	2007	547.8	3.88 to 5	4.6
$\phi\pi^+\pi^-$	2009	673	1.5 to 3	0.7

σ(e^+e^- → charmed hadrons)

Phys.Rev. D77, 011103(2008)

Phys.Rev. D76, 111105(2007)

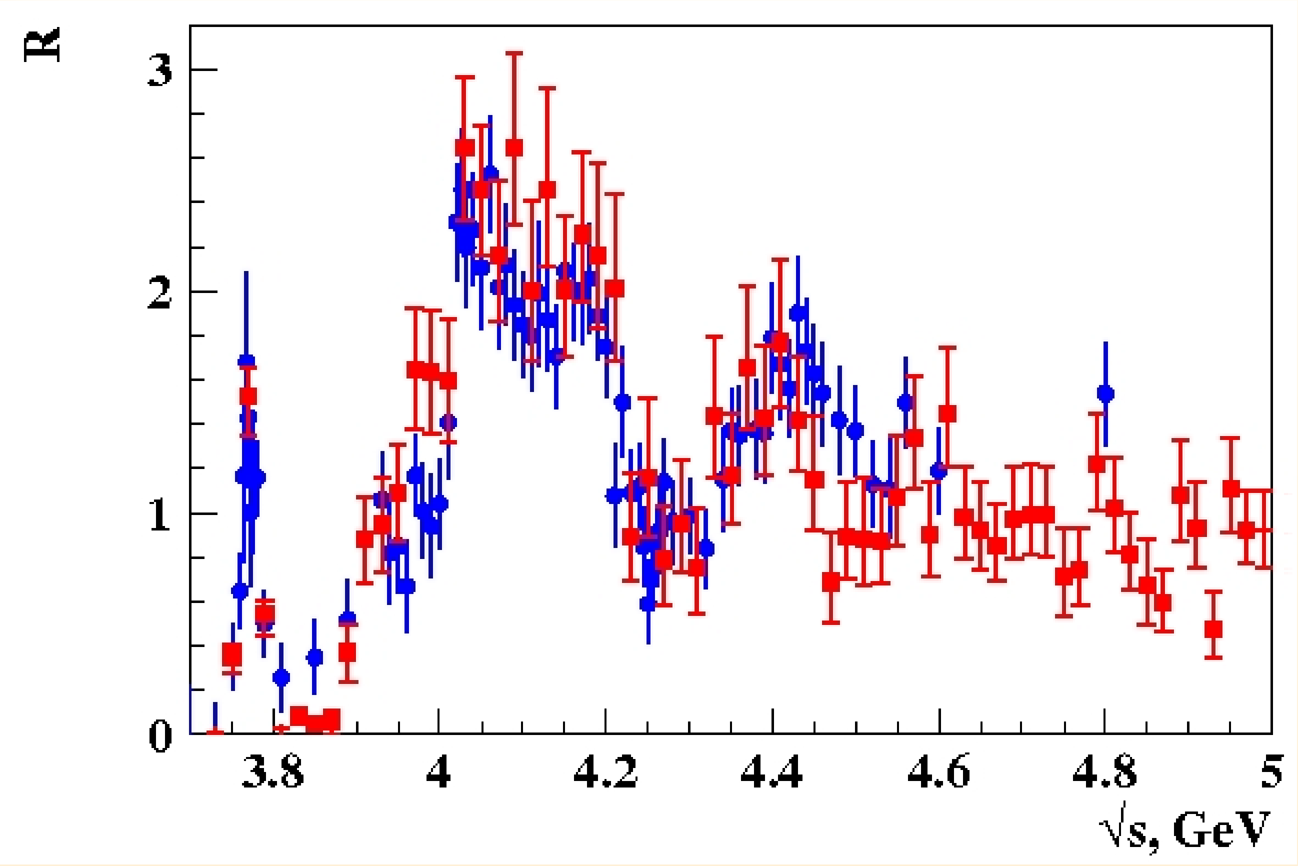


- **Good agreement between Belle и BaBar**

- **Wide structure near 3.9 GeV**
  - **agreement with coupled channel model Structure at 4.0 - 4.2 GeV**
  - **ψ(4040)? ψ(4160)?**
- **First hint of ψ(4415) →DD**

σ($e^+e^- \to D^{(*)}D^*$)
Phys. Rev.Lett. 98, 092001 (2007)
$e^+e^- \to D^0D^-\pi^+$
Phys.Rev.Lett.100,062001(2008)
$e^+e^- \to D_s(*)D_s(*)$
Phys.Rev.D 83, 011101 (2011)
$e^+e^- \to \Lambda_c^+\Lambda_c^-$
Phys.Rev.Lett. 101,172001(2008)

Exclusive cross sections contribution to the total charm cross section



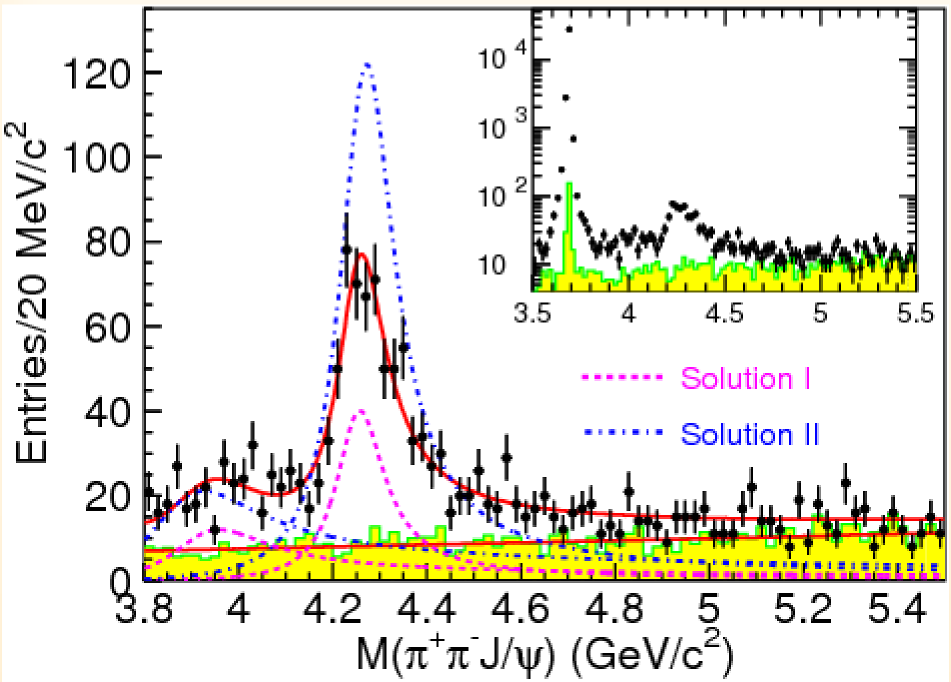
BES: $R_{tot} - R_{uds}$;

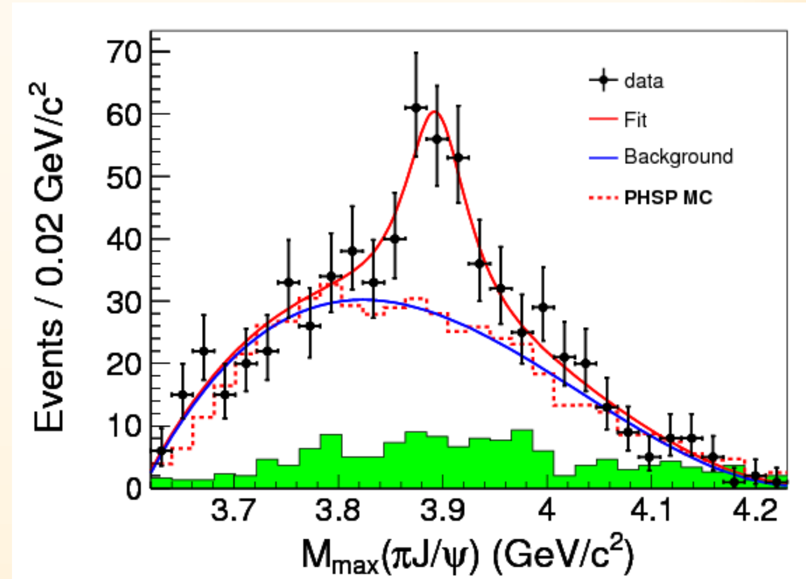
Belle : $\sum R_{excl}$

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

Study of $e^+e^- \to \pi^+\pi^- J/\psi$ and Observation of a Charged Charmonium-like State at Belle

PRL 110, 252002 (2013)
arXiv:1304.0121 [hep-ex])



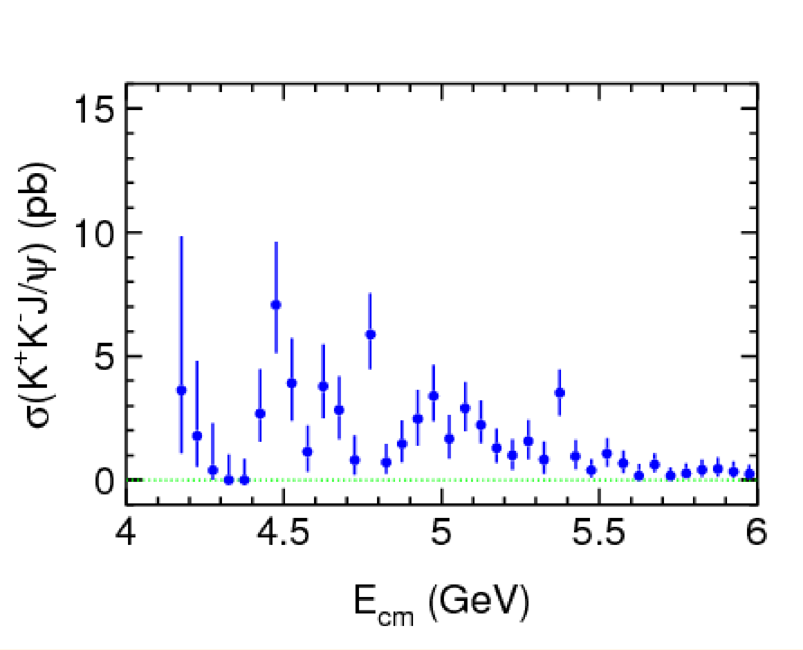


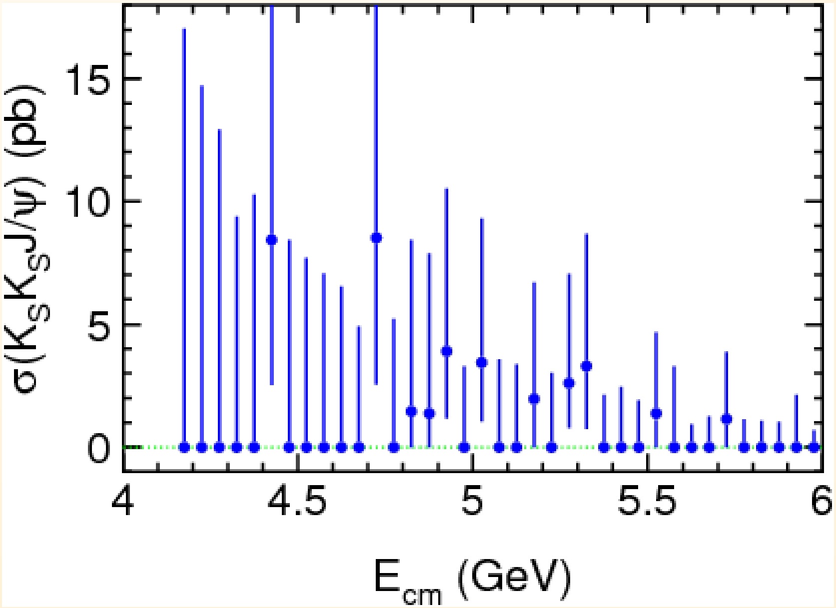
Y (4008) and Y (4260)

$Z(3900)^{\pm}$
$M = (3894.5 \pm 6.6 \pm 4.5)$ MeV/c²
$\Gamma = (63 \pm 24 \pm 26)$ MeV/c²
In agreement with BES

Updated Cross Section Measurement of $e^+e^- \rightarrow K^+K^-J/\psi$ and $K_S^0K_S^0J/\psi$

980 fb^{-1}





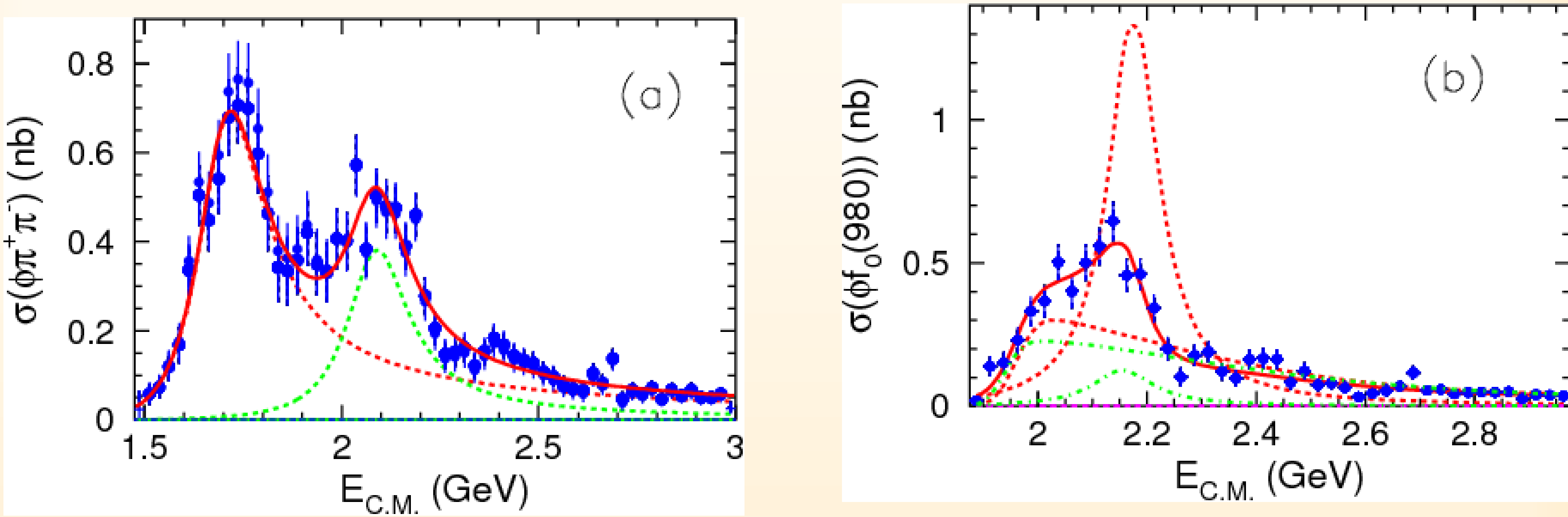
Systematic uncertainties 8% and 16%

arXiv:1402.6578 [hep-ex])

$e^+e^- \to \phi\,\pi^+\pi^-$ and $e^+e^- \to f_0(980)\,\pi^+\pi^-$

PRD 80, 031101 (2009)

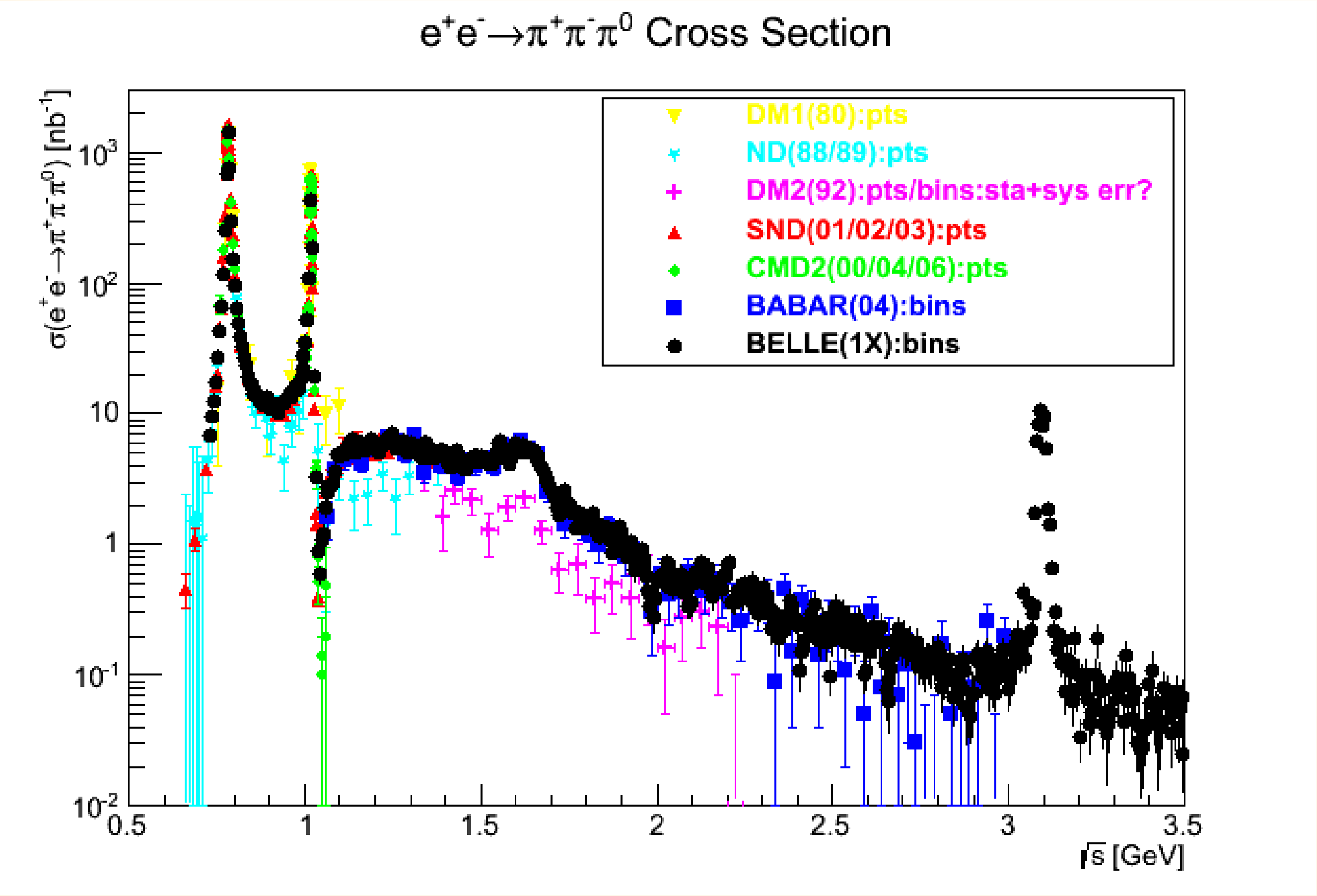
673 fb^{-1}



M (ϕ(1680)) = (1689±7±10) MeV/c^2,
Γ(ϕ(1680)) = (211 ± 14 ± 19) MeV/c^2
M (Y(2175)) = (1689±7±10) MeV/c^2,
Γ (Y(2175)) = (211 ± 14 ± 19) MeV/c^2

Cross section Syst. Errors - 8.6% and 6.9%

Belle $\sigma(e^+ e^- \to \pi^+ \pi^- \pi^0)$



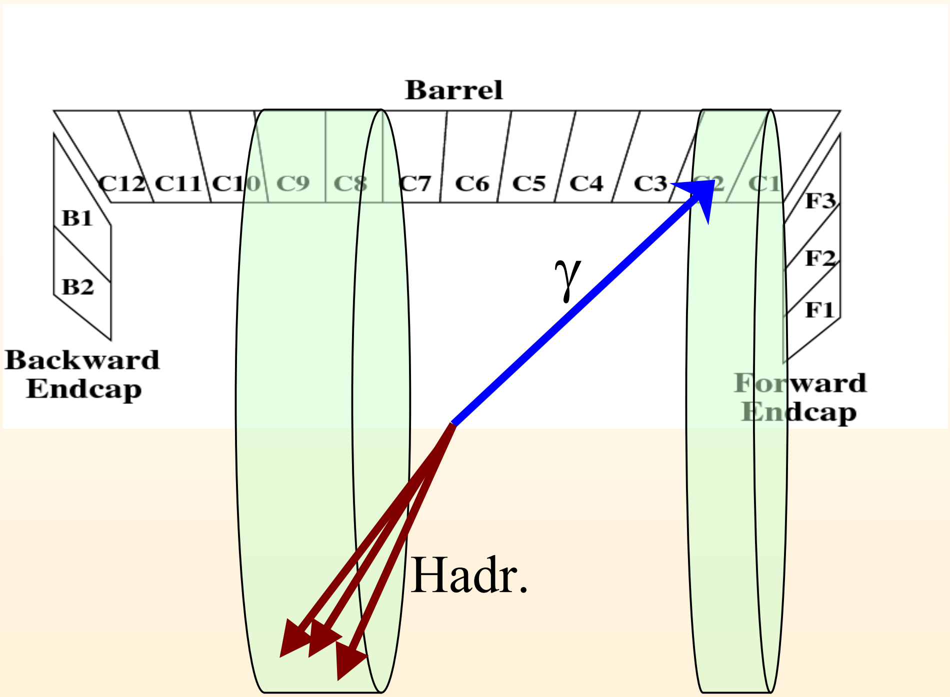
526.6 fb^{-1}

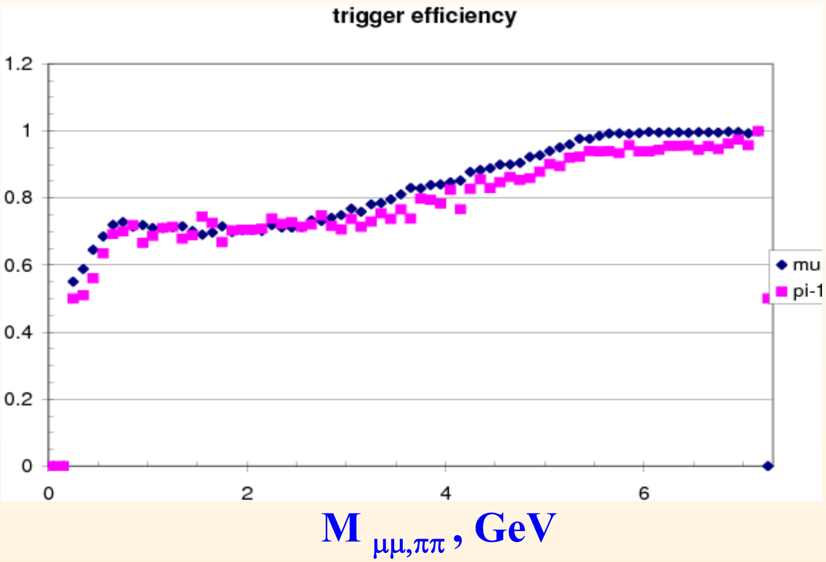
(still preliminary)

Belle systematic error goal is 5%.

Systematic errors, background leakage, and small radiative correction checks to be completed in near future

Belle trigger efficiency (due to Bhabha veto system) puts serious limitation to the systematic uncertainty of the ISR measurement of the channels with low multiplicity (μμ, ππ, …)

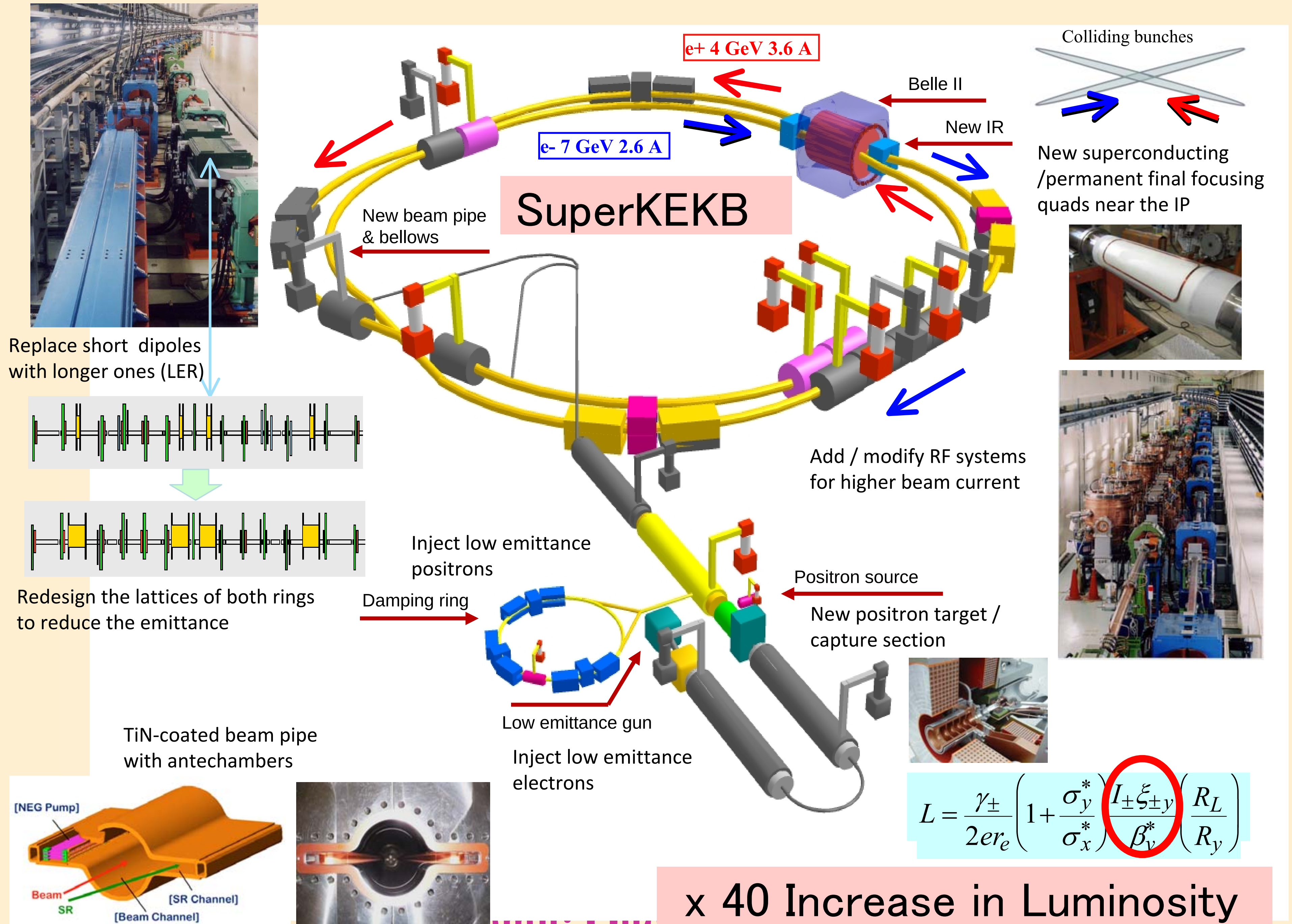




Bhabha veto example:

E(C2+C8+C9) > 5 GeV ⟶ prescaled as Bhabha

Advanced Bhabha veto based on the cluster identification at the trigger level will be implemented at Belle II


SuperKEKB
e+ 4 GeV 3.6 A
e- 7 GeV 2.6 A
Belle II
New IR
Colliding bunches
New superconducting /permanent final focusing quads near the IP
New beam pipe & bellows
Replace short dipoles with longer ones (LER)
Redesign the lattices of both rings to reduce the emittance
Add / modify RF systems for higher beam current
Inject low emittance positrons
Damping ring
Positron source
New positron target / capture section
Low emittance gun
Inject low emittance electrons
TiN-coated beam pipe with antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
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)

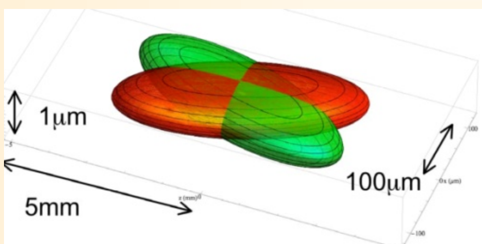
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

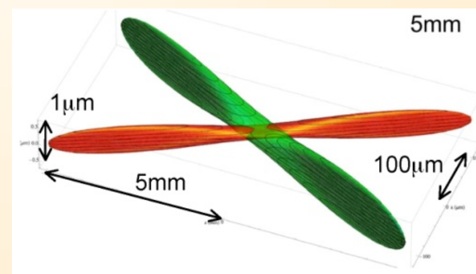
LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
HER : Lower emittance and lower SR power

❖Re-use the KEKB tunnel.
❖Re-use KEKB components as much as possible.
❖Preserve the present cells in HER.
❖Replace dipole magnets in LER, re-using other main magnets in the LER arcs.

Nano-Beam SuperKEKB

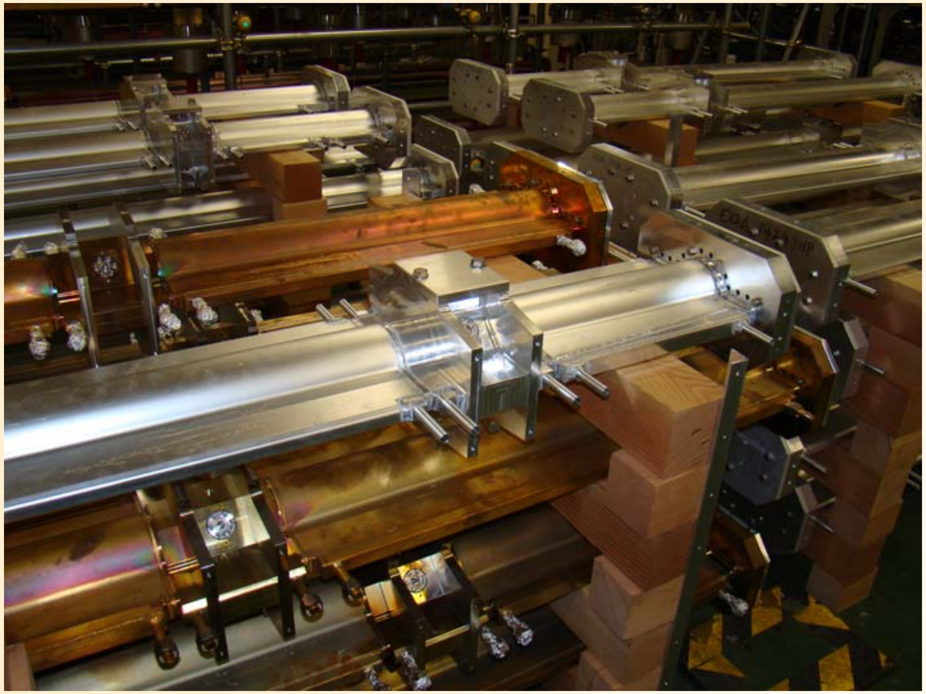


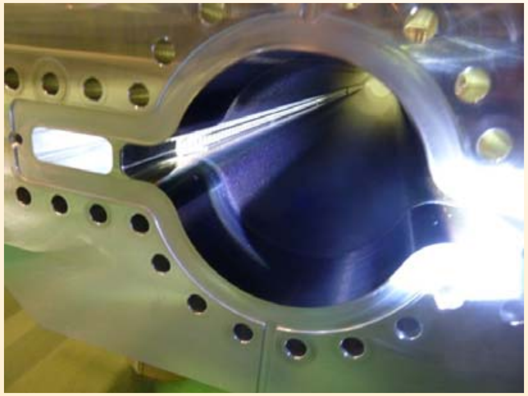
σ_x~100μm,σ_y~2μm



σ_x~10μm,σ_y~60nm

Entirely new LER beam pipe with ante-chamber and Ti-N coating

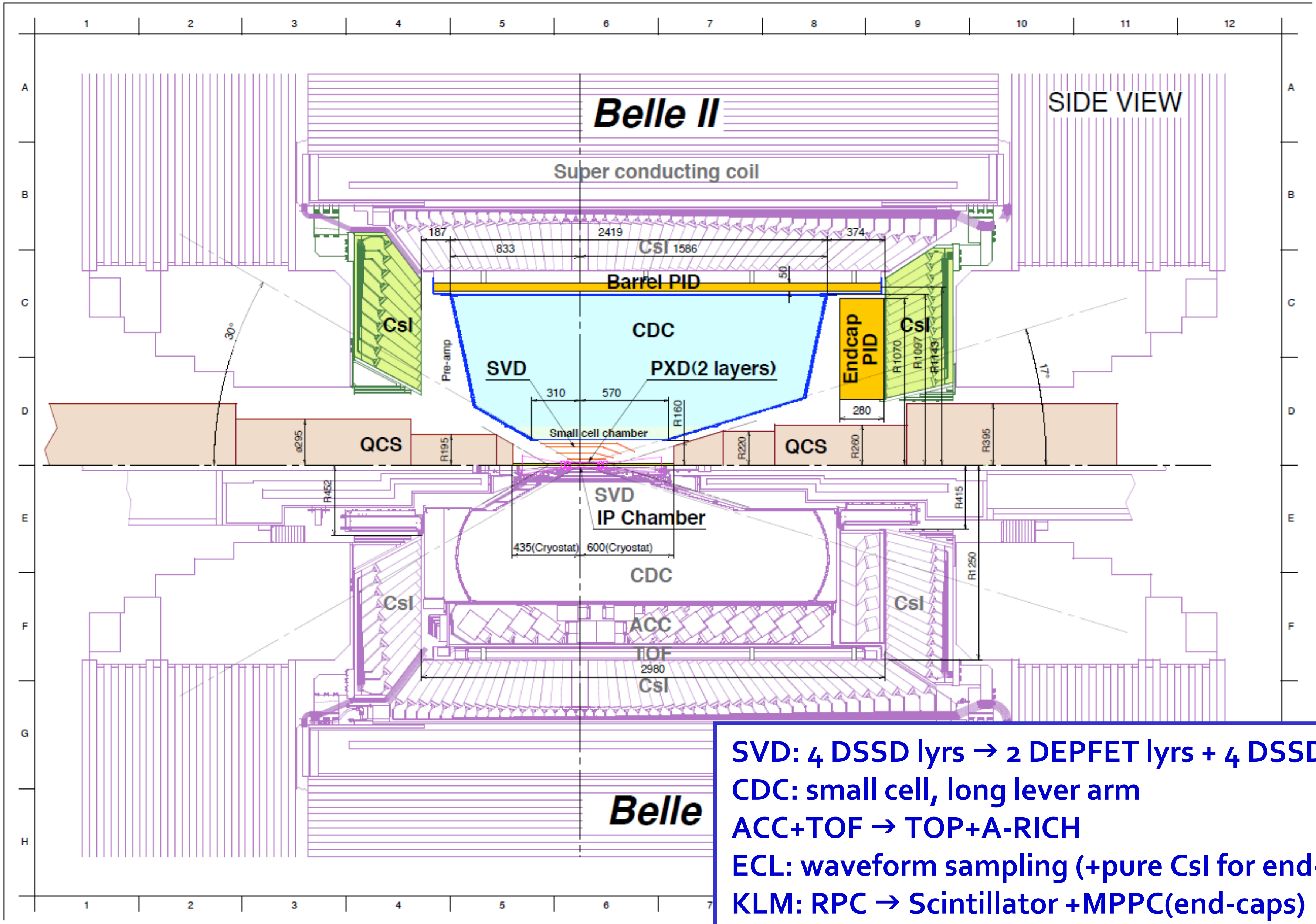




After TiN coating

Installation of 100 new LER bending magnets done

Belle II Detector (in comparison with Belle)

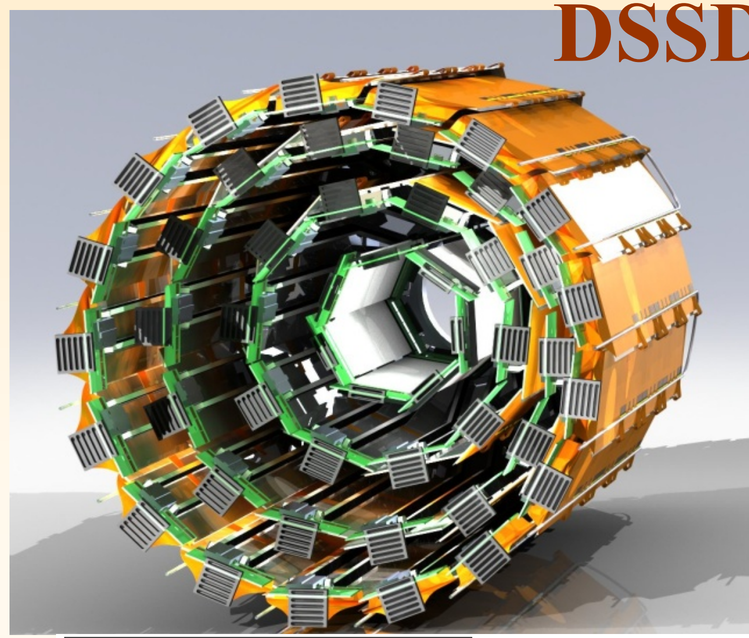


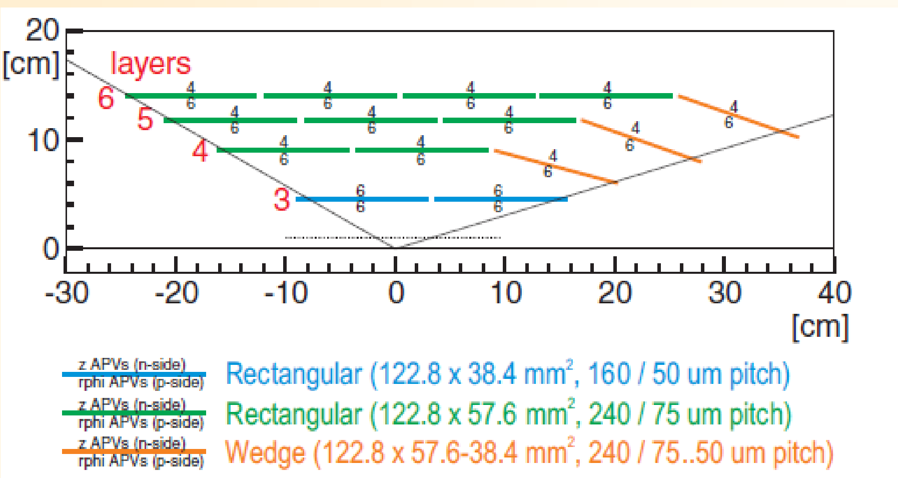
- SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
- CDC: small cell, long lever arm
- ACC+TOF → TOP+A-RICH
- ECL: waveform sampling (+pure CsI for end-caps)
- KLM: RPC → Scintillator +MPPC(end-caps)

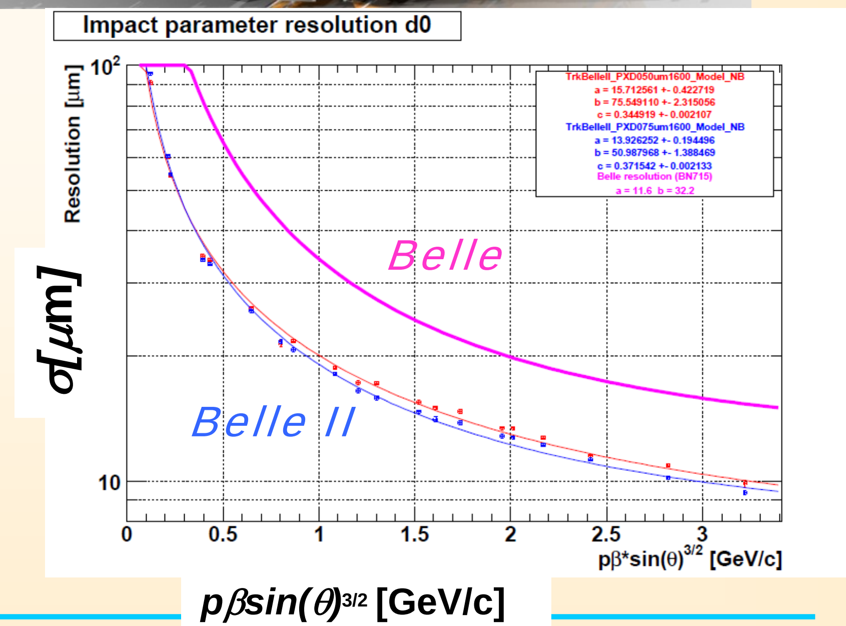
New vertex detector

DSSDs

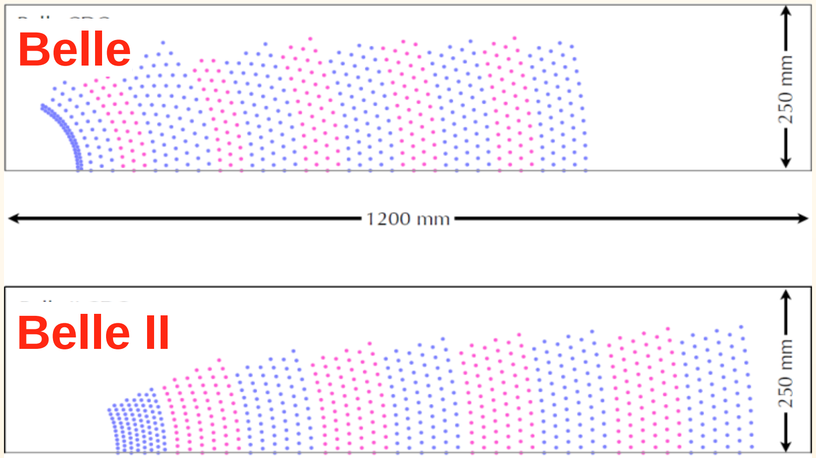
	Belle II	Belle
Beam Piper =	10mm	15mm
DEPFET		
Layer 1	r = 14mm	
Layer 2	r = 22mm	
DSSD		
Layer 3	r = 38mm	20mm
Layer 4	r = 80mm	43.5mm
Layer 5	r = 104mm	70mm
Layer 6	r = 135mm	88mm







Central Drift Chamber



longer lever arm

Improved momentum resolution and dE/dx

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

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

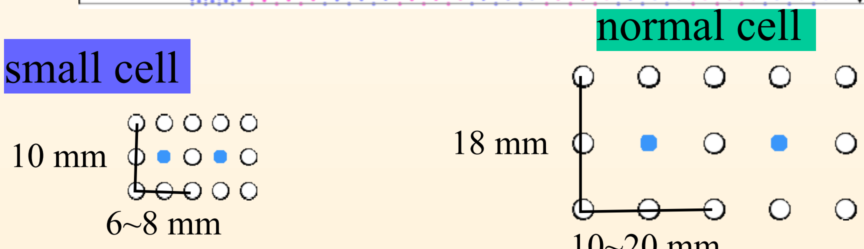
new readout system

dead time 1-2μs → 200ns

small cell

smaller hit rate for each wire

shorter maximum drift time

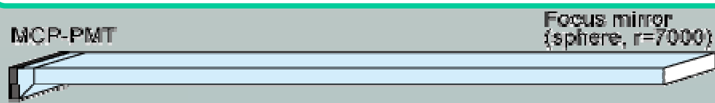


	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	$He:C_2H_6$	$He:C_2H_6$
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μm)	Al(Φ120μm)

Aug. 31:
The number of installed wires in main and conical part is 35331, corresponding to 68% of total 51456 wires.

Particle Identification in Belle II

Barrel PID: Time of Propagation Counter (iTOP)



Quartz radiator

Focusing mirror

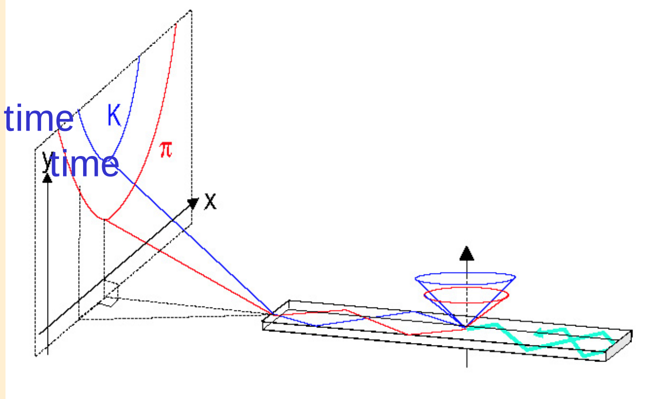
Small expansion block

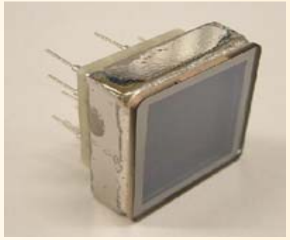
Hamamatsu MCP-PMT (measure t, x and y)

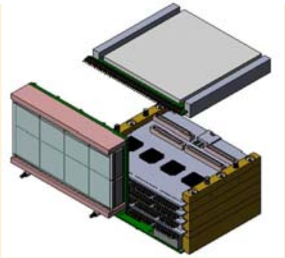
Cherenkov ring imaging with precise time measurement.

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

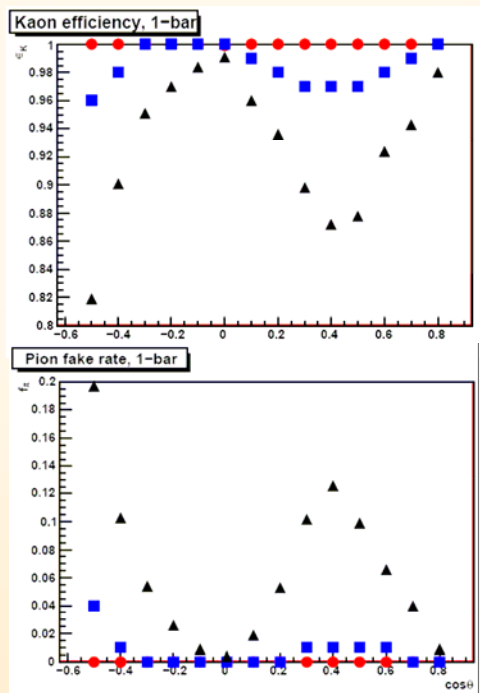
Cherenkov angle reconstruction from two hit coordinates and the time of propagation of the photon





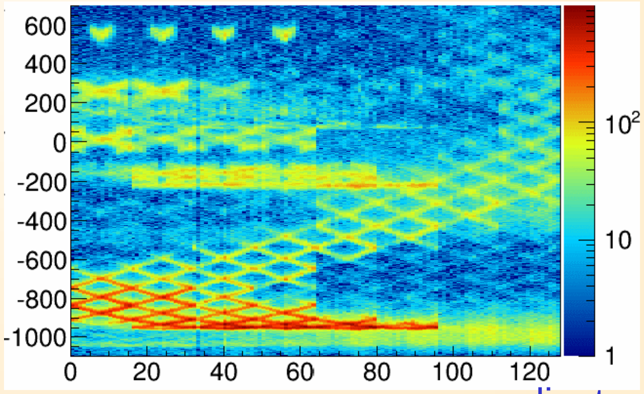


●1.5, ■2.5, ▲3.5 GeV/c



x-t diagram from beam-test

time



coordinate

Quartz radiator

2.6m^L x 45cm^W x 2cm^T

Excellent surface accuracy

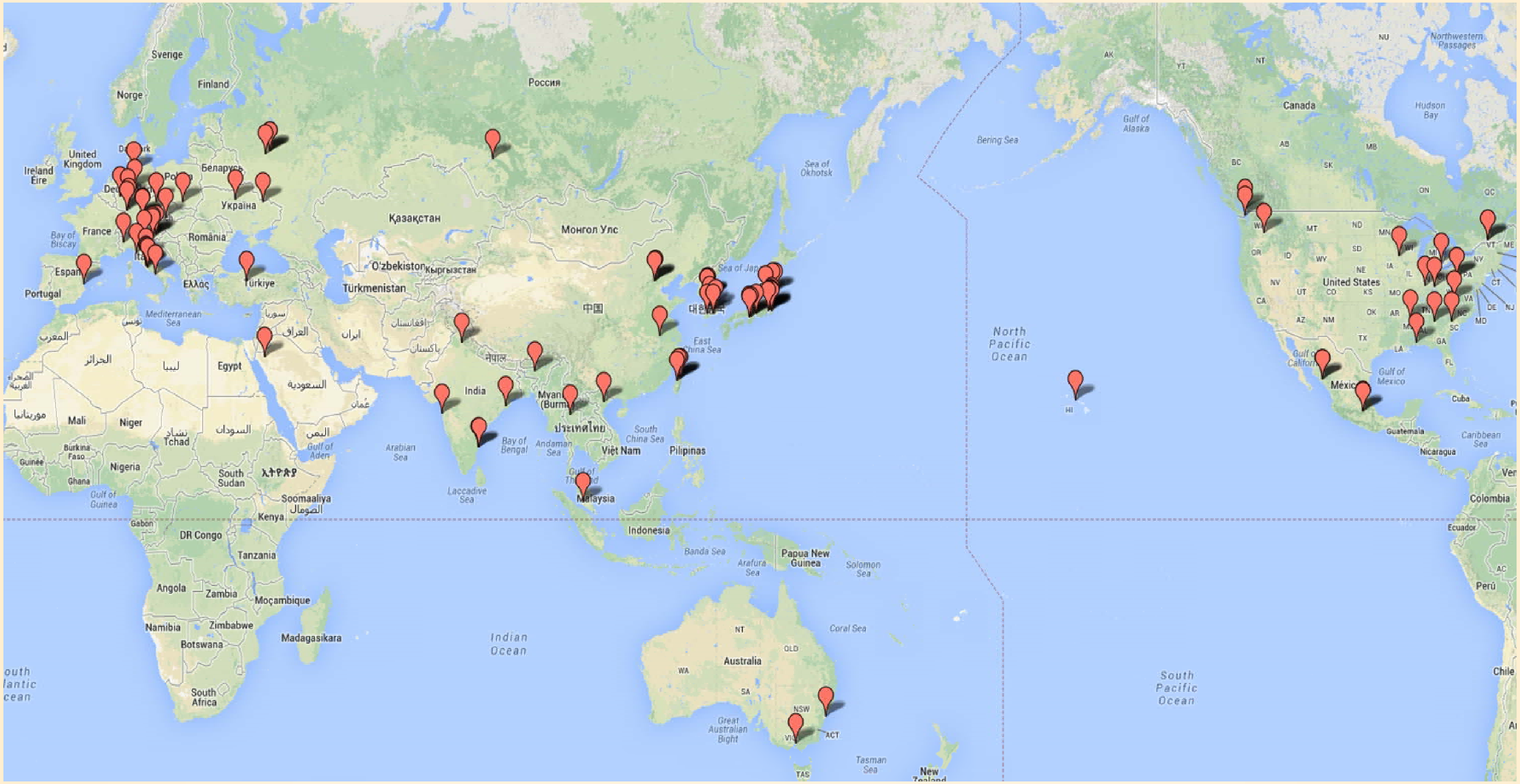
MCP-PMT

Hamamatsu 16ch MCP-PMT

Good TTS (<35ps) & enough lifetime

Multialkali photo-cathode → SBA

Belle II Collaboration

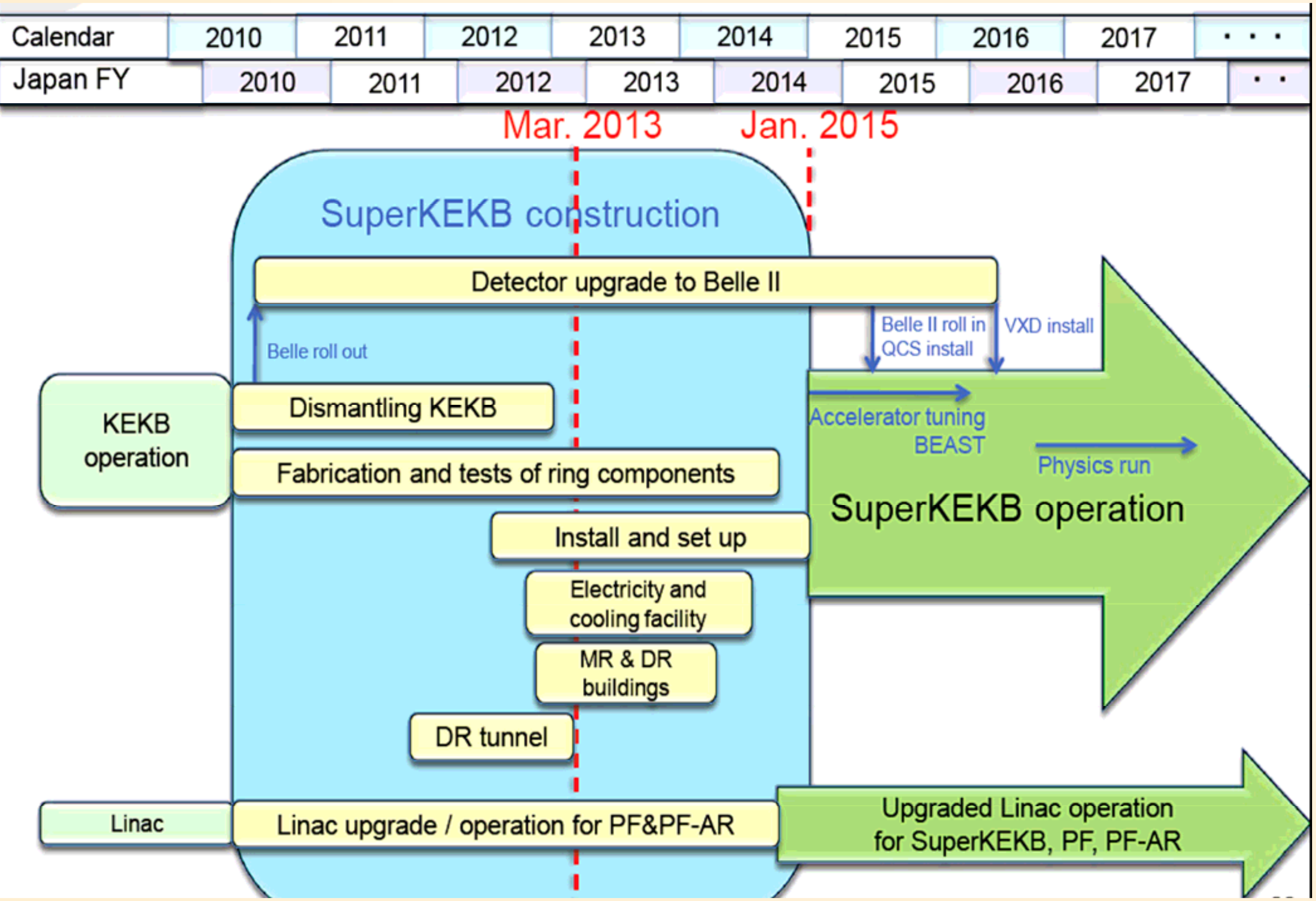


23 countries/**regions**, 94 institutions, >500 collaborators

SuperKEKB/Belle II schedule

→construction started in 2010!

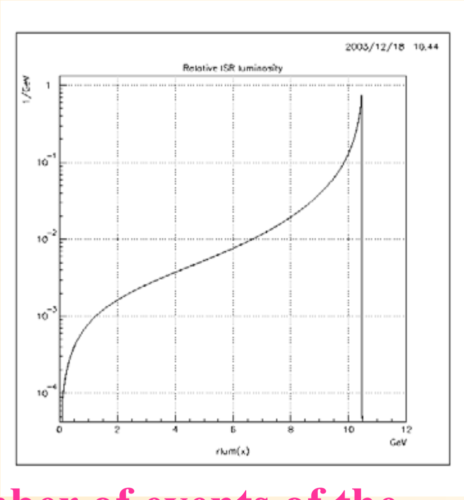
Ground breaking ceremony in November 2011



Commissioning in three phases:

- –Phase 1: w/o final quads, w/o Belle II
  - basic machine tuning
  - low emittance beam tuning
  - vacuum scrubbing
    - –At least one month at beam currents of 0.5~1A.
  - Damping ring commissioning
- –Phase 2: with final quads and Belle II, but no VXD
  - low beta* beam tuning
  - small x-y coupling tuning
  - collision tuning
  - study beam background
    - –careful checks beam background before VXD installation.
- –Phase 3: with QCS and full Belle II
  - physics run
  - luminosity increase

Potential of ISR



$$\frac{dl}{Ldm} = \frac{2\alpha m}{\pi s}\left\{\frac{s+m^4}{s(s-m^2)}\left(\ln\frac{s}{m_e^2}-1\right)\right\}$$

Number of events of the vector meson production at 8000 fb^{-1} (@Υ(4s)

ϕ	1.5×10^8
ψ	2.3×10^8
ψ(2S)	7.8×10^7
ψ(3770)	9.7×10^6
Υ(1s)	1.3×10^8
Υ(2s)	1.2×10^8
Υ(3s)	2.4×10^8

	KEKB	VEPP-2000	BEPC-II
Luminosity, $см^{-2}\ s^{-1}$	$8\cdot10^{35}$	10^{32}	10^{33}
Integrated lum. (per 10^7 s)	8000 fb^{-1}	1 fb^{-1}	10 fb^{-1}
Integrated in the range [1-2] GeV	8 fb^{-1} (~0.8 @ θ>0.7)	1 fb^{-1}	
Integrated in the range [2-3] GeV	20 fb^{-1} (~2 @ θ>0.7)		10 fb^{-1}

Conclusion

- **Last decade demonstrated the fruitfulness of the flavor "factories" for low energy hadronic cross section measurements via ISR.**
- **Since very precise measurements of R is highly desirable, both measurements via ISR and energy scan are needed, at least for cross-check.**
- **At present superKEKB/Belle II project is under construction. To provide accurate date we need to care about the proper trigger system and to prepare instruments to control stability of the charge particles and photon reconstruction efficiency duting experiment.**
- **We can wait for new exciting results in the next decade.**