Hadronic Cross Section Measurements at Belle and perspectives at BELLE-II

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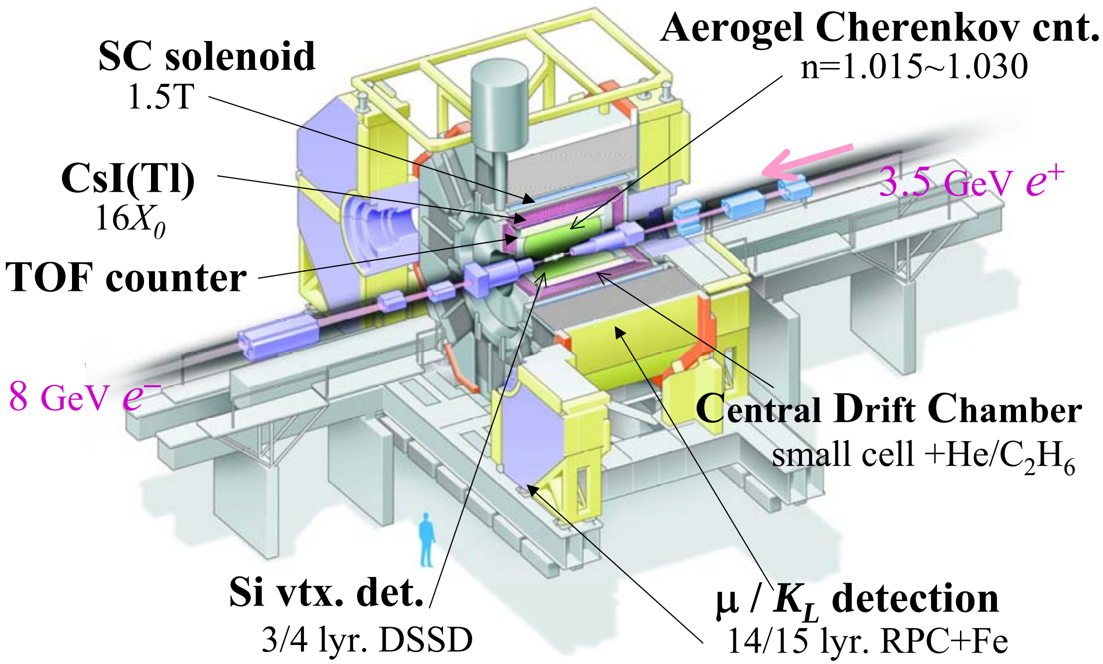
Belle Detector



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

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

F/B asymmetric detector

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

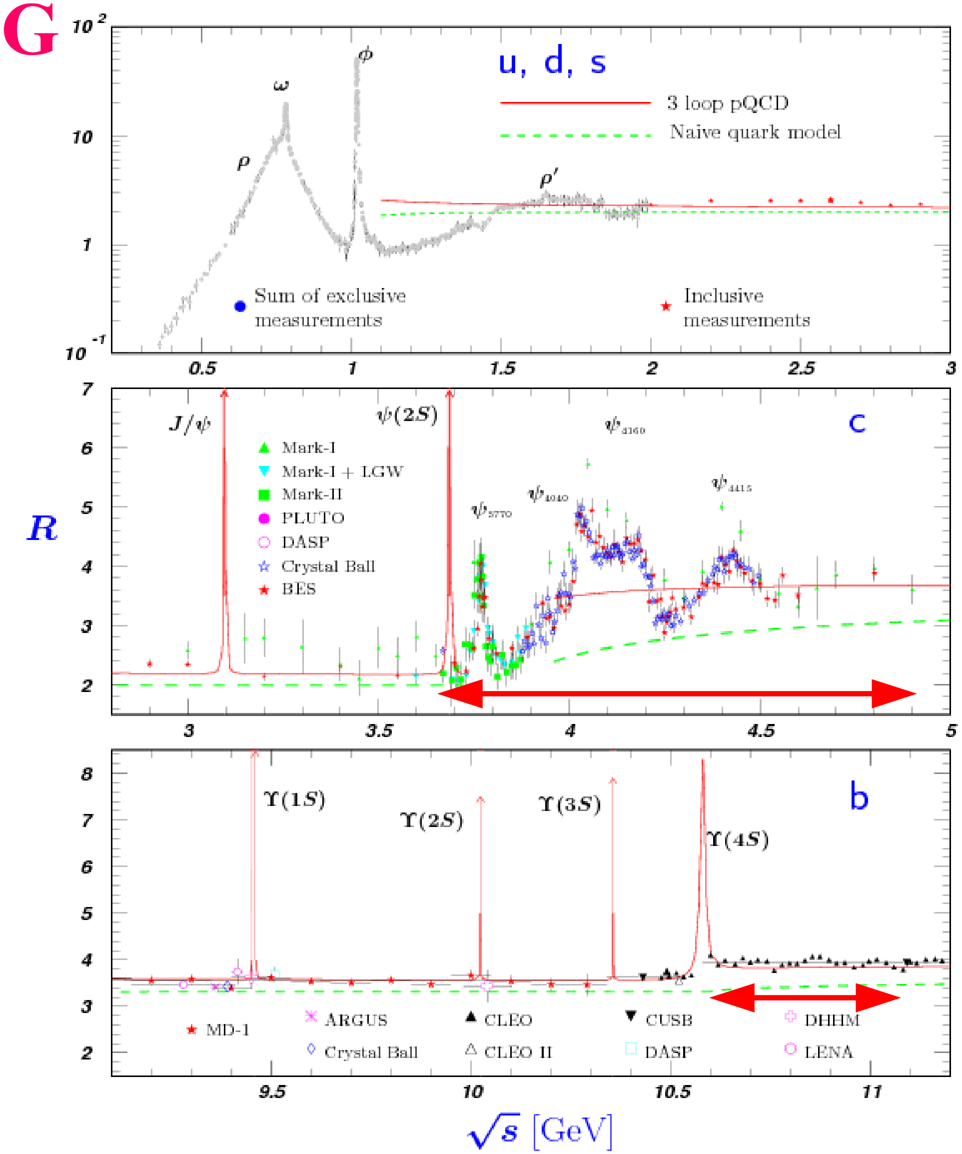
Other important results

- 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 powerful 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 research area became 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

R(s) measurements at Belle

PDG



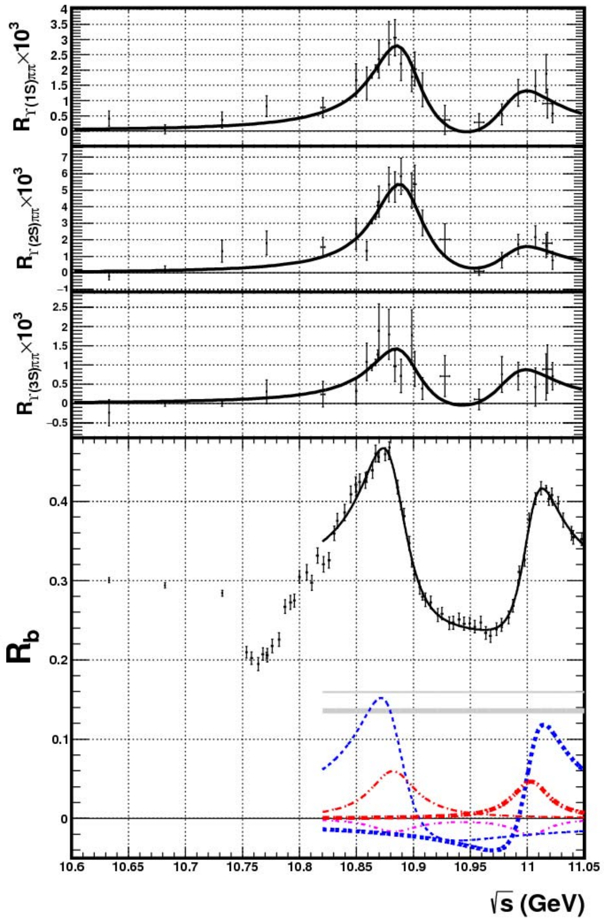
ISR: with γ_{ISR} detection, full reconstruction

ISR: mostly without γ_{ISR} detection

Direct e^+e^- scan

R_b: Data and Fit

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



PRD 93, 011101(R) (2016)

$$M_{10860} = (10891.1 \pm 3.2^{+0.6}_{-1.7})\ \mathrm{MeV/c^2}$$

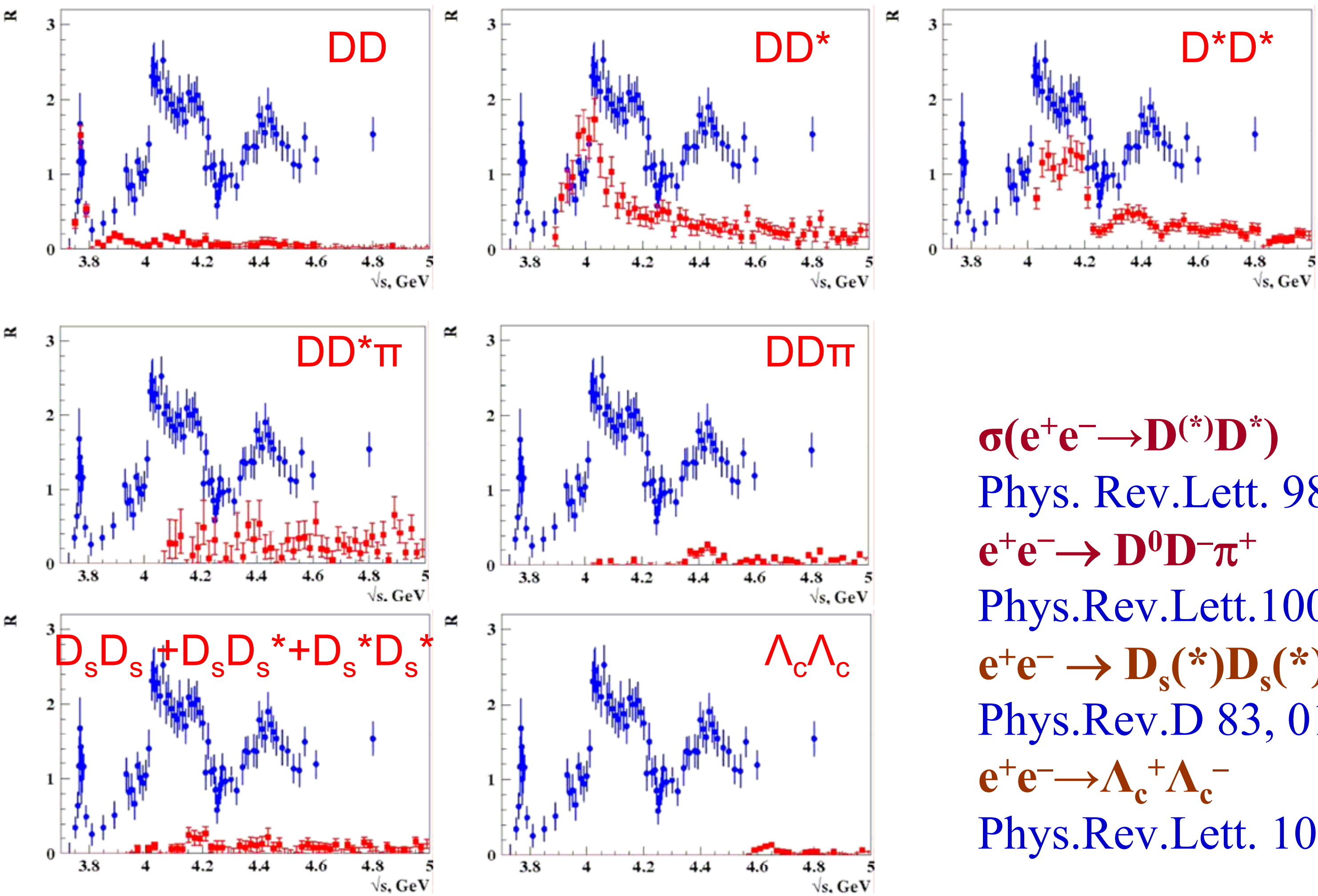
$$\Gamma_{10860} = (53.7^{+7.1}_{-5.6}\ {}^{+1.3}_{-5.4})\ \mathrm{MeV}$$

$$M_{11020} = (10987.5^{+6.4}_{-2.5}\ {}^{+9}_{-2.1})\mathrm{MeV/c^2}$$

$$\Gamma_{11020} = (61^{+9}_{-19}\ {}^{+2}_{-20})\ \mathrm{MeV}$$

$$\phi(11020) - \phi(10860) = (-1.0 \pm 0.4\ {}^{+1.4}_{-0.1})\ \text{rad.}$$

Contribution of exclusive cross sections to the total cross section



$\sigma(e^+e^- \to D^{(*)}D^*)$

Phys. Rev.Lett. 98, 092001 (2007)

$e^+e^- \to D^0D^-\pi^+$

Phys.Rev.Lett.100,062001(2008)

$e^+e^- \to D_s(*)D_s(*)$

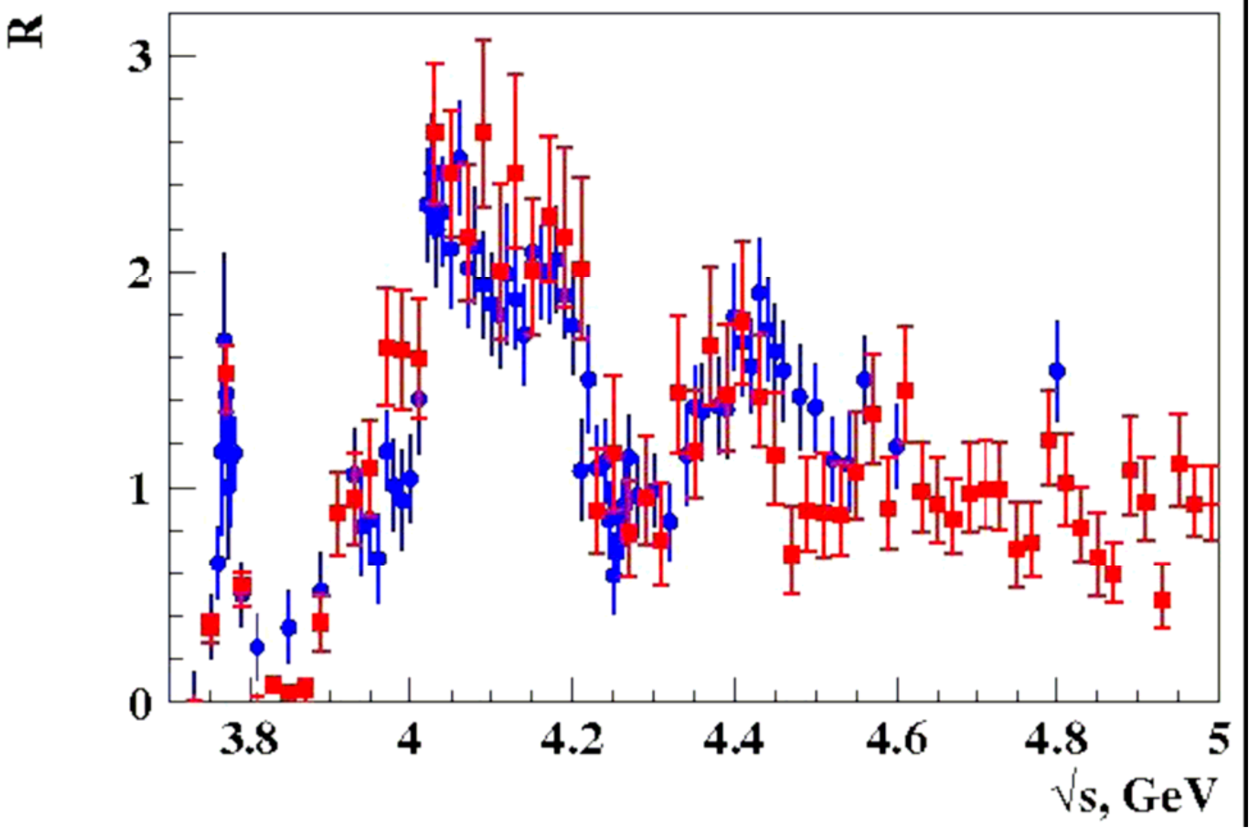
Phys.Rev.D 83, 011101 (2011)

$e^+e^- \to \Lambda_c^+\Lambda_c^-$

Phys.Rev.Lett. 101,172001(2008)

Results on XYZ states will be presented by R.Mizuk

Contribution of exclusive cross sections to the total cross section



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

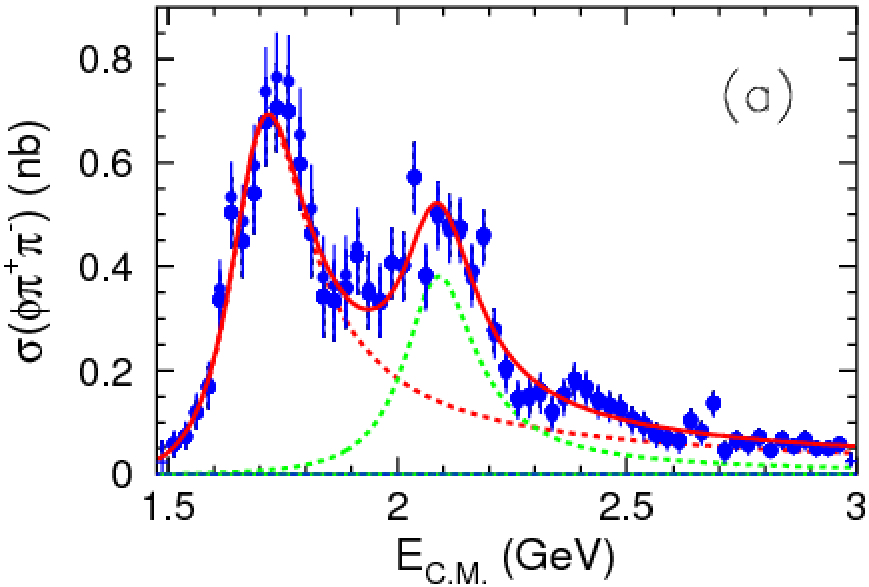
Belle : $\sum R_{excl}$

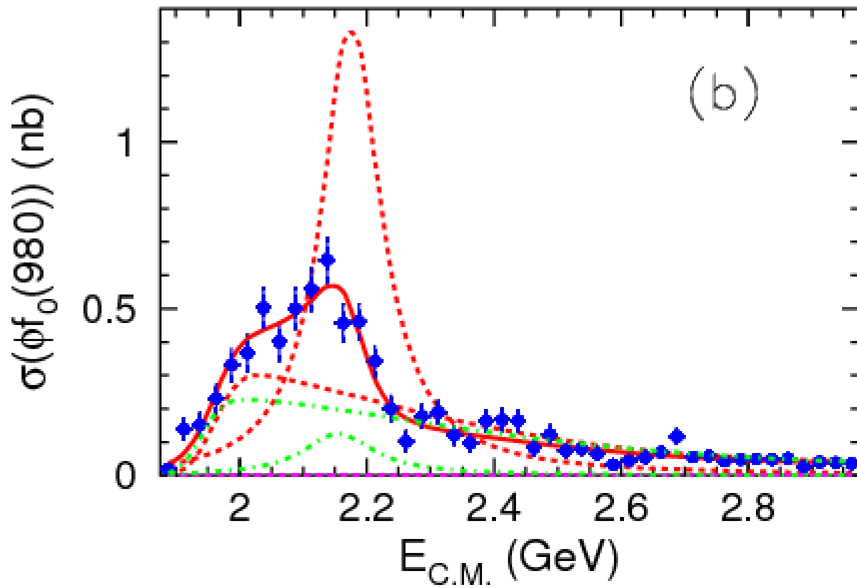
Results on XYZ states will be presented by R.Mizuk

$e^+e^- \to \phi\pi^+\pi^-$ 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

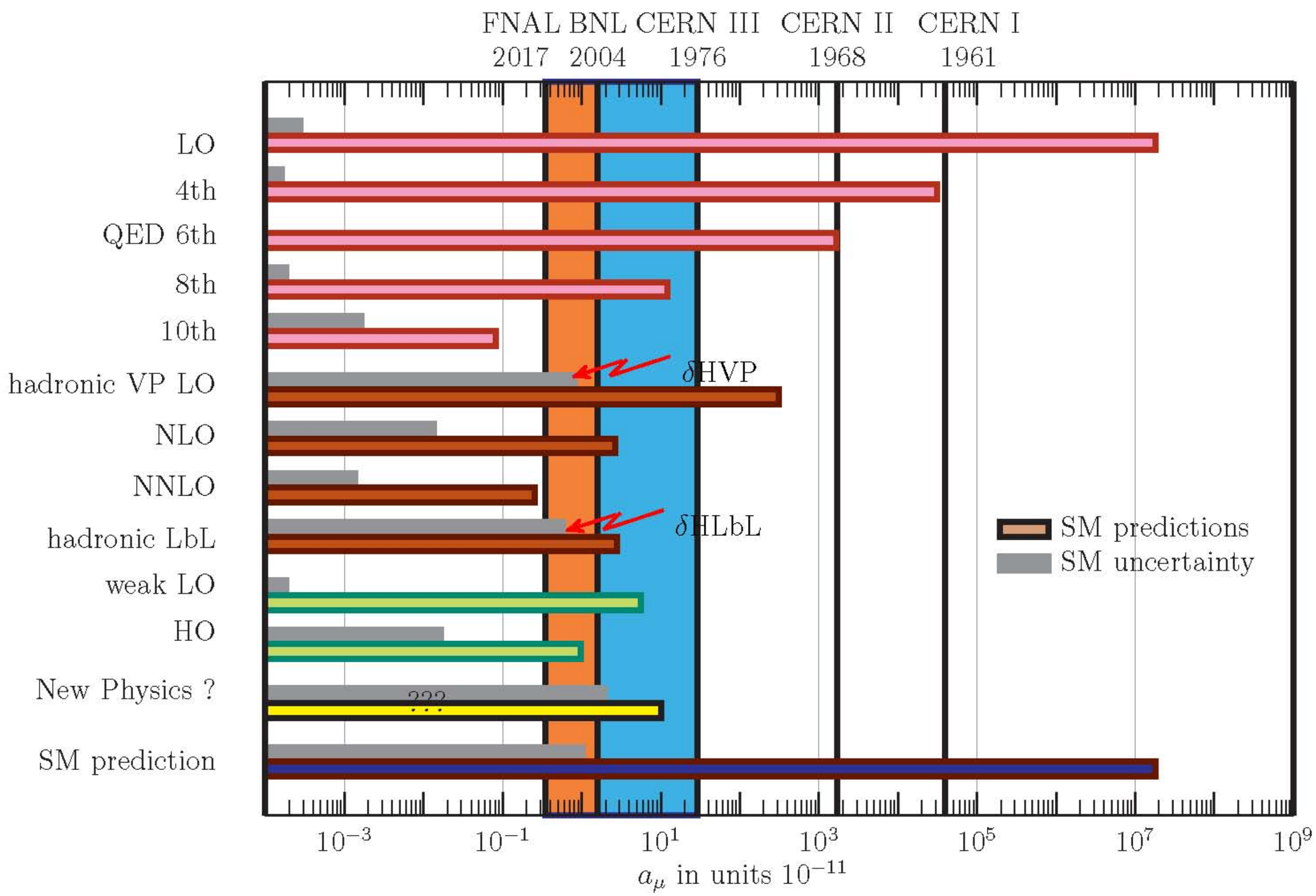
Cross section Syst. Errors - 8.6% and 6.9%

Published ISR results at Belle

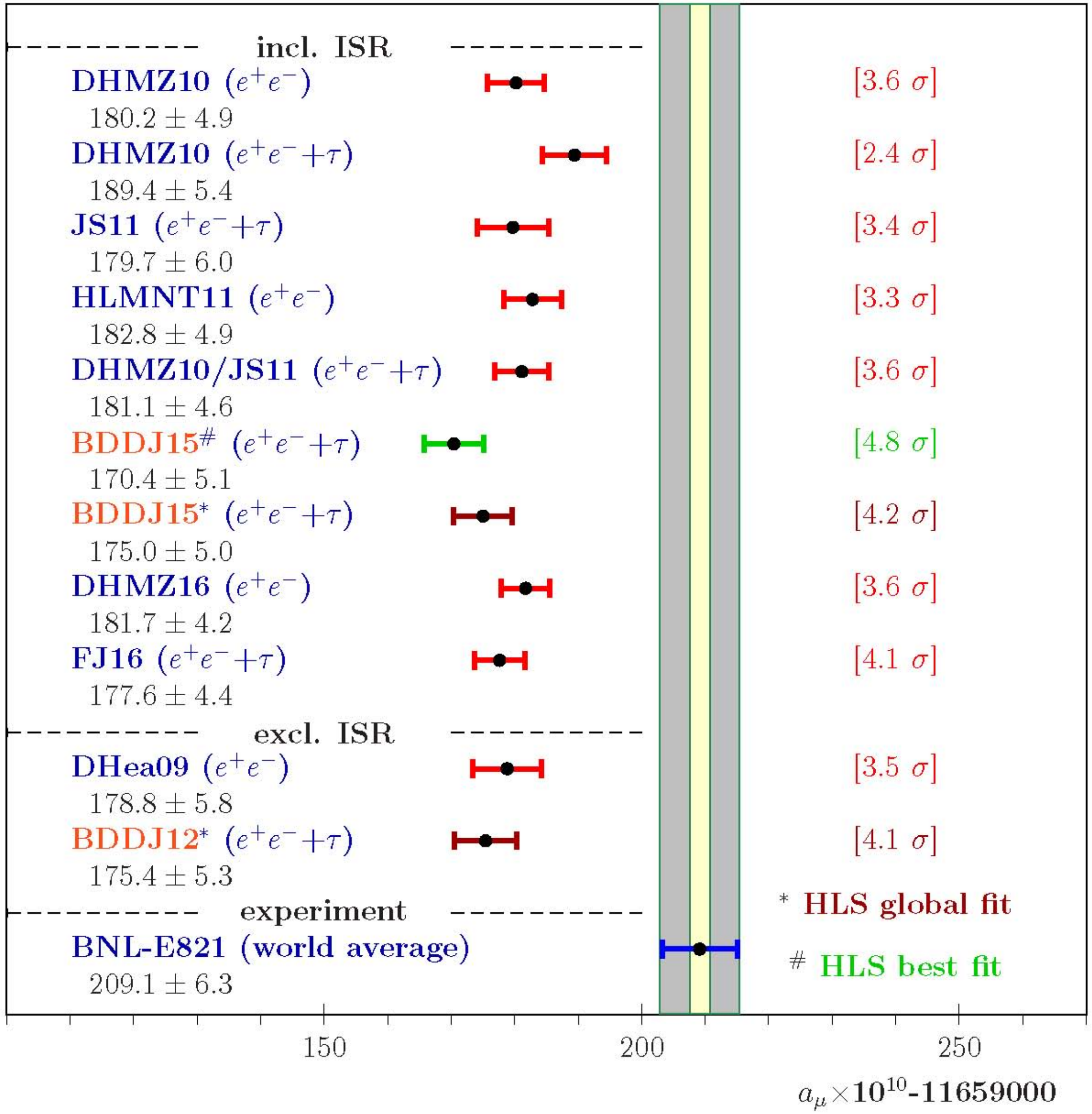
Process	Reference	Int. Lum.	c.m. ene.
$D^{(*)\pm}D^{(*)\mp}$	PRL 98.092001(2007)	547.8 fb^{-1}	3.9-5.0 GeV
$DD_2^*(2460)$	PRL 100, 062001 (2008)	673 fb^{-1}	4.0-5.0 GeV
$\Lambda_c^+\Lambda_c^-$	PRL101,172001 (2008)	695 fb^{-1}	4.8-5.4 GeV
$D^0D^{*-}\pi^+$	PRD 80, 091101(R) (2009)	695 fb^{-1}	41.-5.2 GeV
DD	PRD 77, 011103 (2008)	673 fb^{-1}	3.8-5.0 GeV
$\pi^+\pi^-J/\psi$	PRL 99, 182004 (2007)	548 fb^{-1}	3.8-5.5 GeV
$\pi^+\pi^-\psi(2S)$	PRL 99, 142002 (2007)	673 fb^{-1}	4.0-5.5 GeV
K^+K^-J/ψ	PRD 77, 011105(R) (2008)	673 fb^{-1}	4.2-6.0 GeV
$\varphi\pi^+\pi^-$	PRD 80, 031101 (2009)	673 fb^{-1}	1.3-3.0 GeV
$\eta J/\psi$	PRD 87, 051101(R) (2013)	980 fb^{-1}	3.8-5.3 GeV
$\pi^+\pi^-J/\psi$	PRL 110, 252002 (2013)	980 fb^{-1}	3.8-5.5 GeV
KKJ/ψ	PRD 89,072015 (2014)	980 fb^{-1}	4.4-5.2 GeV
$\pi^+\pi^-\psi(2S)$	PRD 91, 112007 (2015)	980 fb^{-1}	4.0-5.5 GeV
$\gamma\ \chi_{cJ}$	PRD 92, 012011 (2015)	980 fb^{-1}	3.8-5.6 GeV

Why do we need low energy hadronic cross section?

Past and future of muon (g – 2) experiments



Fred Jegerlehner, arXiv:1705.00263v1 [hep-ph] 30 Apr 2017

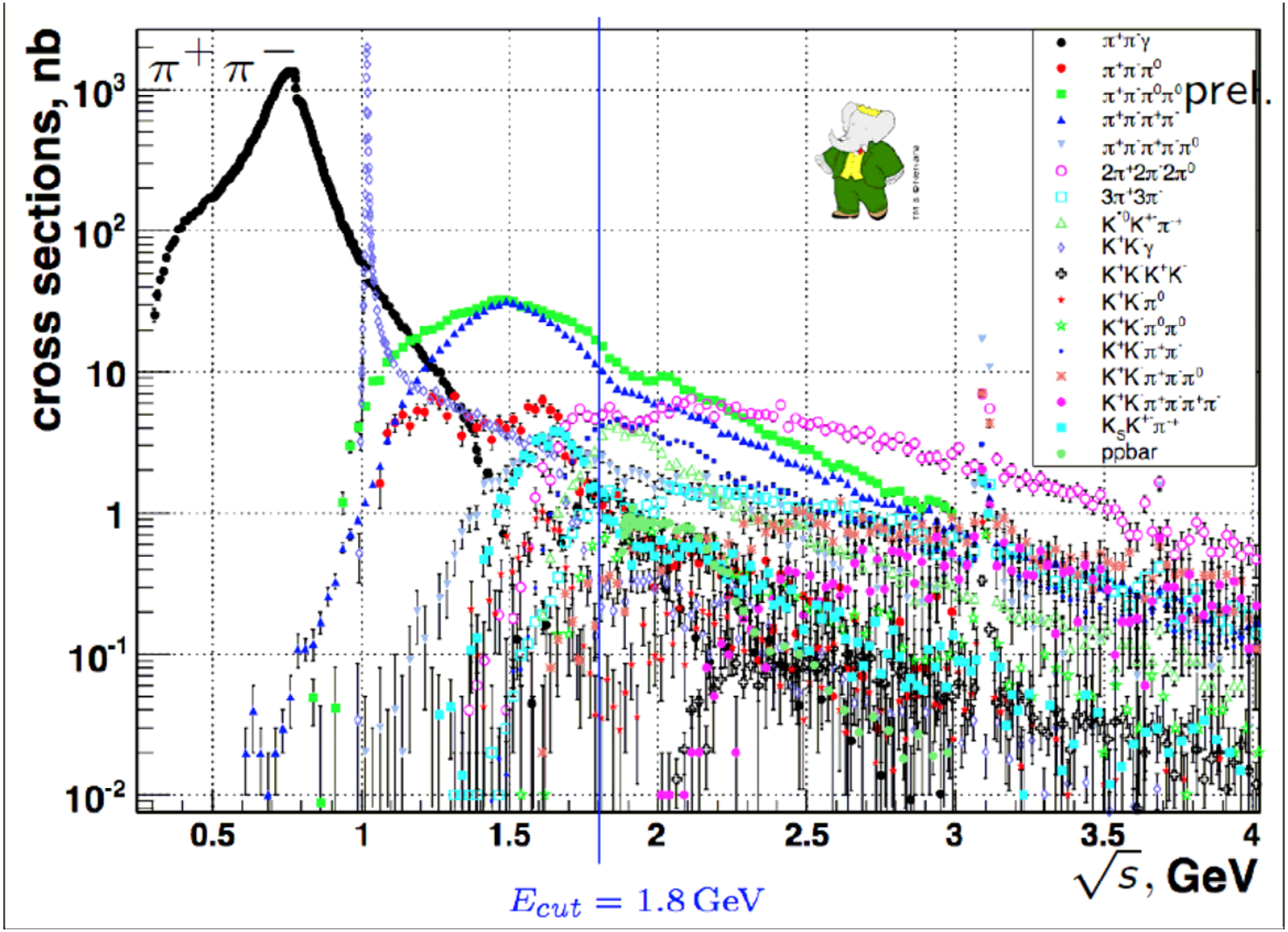


Fred Jegerlehner, arXiv:1705.00263v1 [hep-ph] 30 Apr 2017

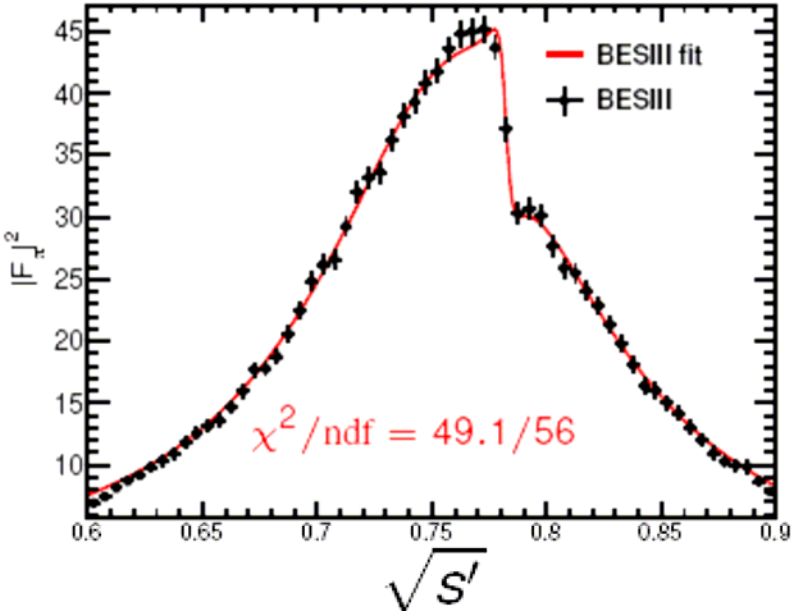
Contributions of various final states to hadronic vacuum polarization (HVP) term of a_m

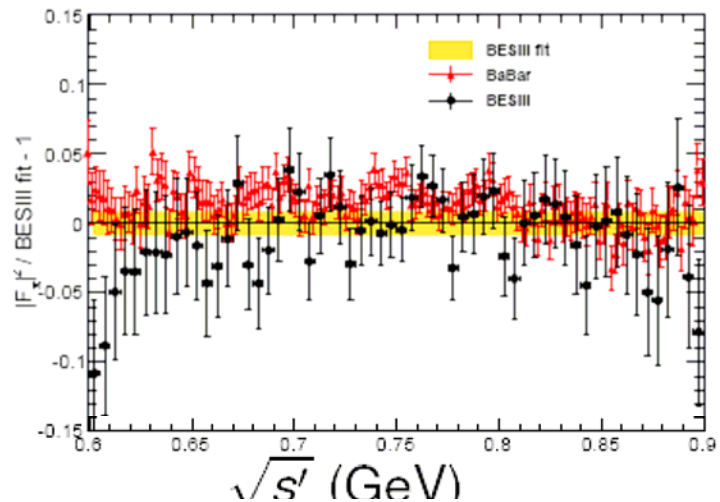
$\eta\pi^+\pi^-$	0.88 ± 0.10	$K\bar{K}\pi$	2.77 ± 0.15
K^+K^-	22.09 ± 0.46	$K\bar{K}2\pi$	3.31 ± 0.58
$K_S^0 K_L^0$	13.32 ± 0.16	$K\bar{K}3\pi$	0.08 ± 0.04
$\omega\pi^0$	0.76 ± 0.03	$\omega(\to \pi^0\gamma)K\bar{K}$	0.01 ± 0.00
$\pi^+\pi^-$	505.65 ± 3.09	$2\pi^+2\pi^-\pi^0$ (no η)	1.20 ± 0.10
$2\pi^+2\pi^-$	13.50 ± 0.44	$\pi^+\pi^-3\pi^0$ (no η)	0.60 ± 0.05
$3\pi^+3\pi^-$	0.11 ± 0.01	$\omega(\to \pi^0\gamma)2\pi$	0.11 ± 0.02
$\pi^+\pi^-\pi^0$	47.38 ± 0.99	$2\pi^+2\pi^-2\pi^0$ (no η)	1.80 ± 0.24
$\pi^+\pi^-2\pi^0$	18.62 ± 1.15	$\pi^+\pi^-4\pi^0$ (no η)	0.28 ± 0.28
$\pi^0\gamma$	4.54 ± 0.14	$\omega(\to \pi^0\gamma)3\pi$	0.22 ± 0.04
$\eta\gamma$	0.69 ± 0.02	$\eta\pi^+\pi^-$	0.98 ± 0.24
$\eta 2\pi^+2\pi^-$	0.02 ± 0.00	$\eta\omega$	0.42 ± 0.07
$\eta\omega$	0.38 ± 0.06	$\eta\phi$	0.46 ± 0.03
$\eta\phi$	0.33 ± 0.03	$\eta 2\pi^+2\pi^-$	0.11 ± 0.02
$\phi(\to$ unaccounted$)$	0.04 ± 0.04	$\eta\pi^+\pi^-2\pi^0$	0.11 ± 0.06

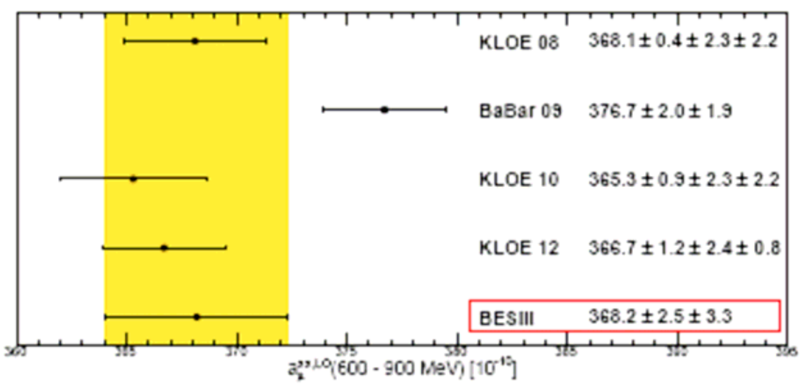
ISR measurements at BABAR

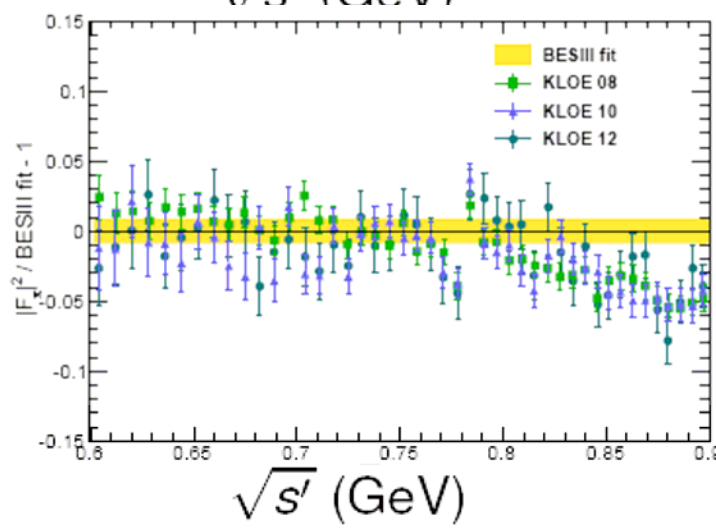


Data from BES III (Tau 2016)



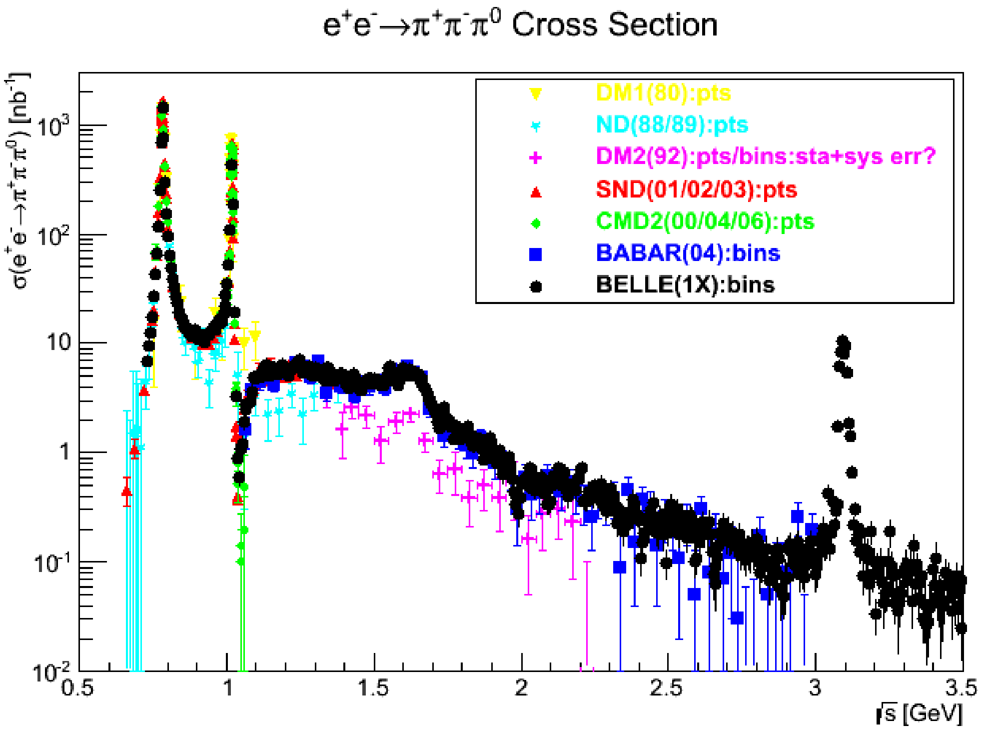






Yaqian WANG, Tau-2016

Belle: low mass ISR study



526.6 fb^{-1}

(preliminary, suspended?)

Belle systematic error goal is 5%

But difficult to achieve.

Main problems:
Improper trigger
Lack of manpower: 2-3 people only vs ~20 at BaBar

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

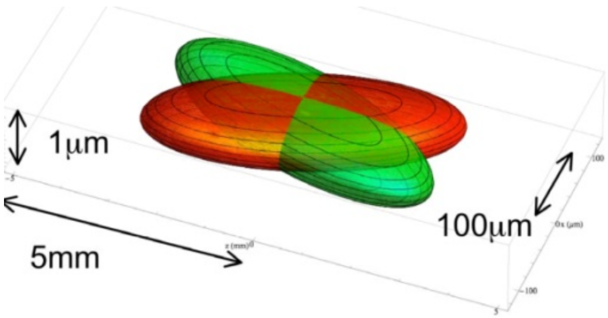
- Vertical β function at IP: 5.9 → 0.27/0.30 mm (× 20)
- Beam current: 1.7/1.4 → 3.6/2.6 A (× 2)
- Beam-beam parameter: .09 → .09 (× 1)

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

- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

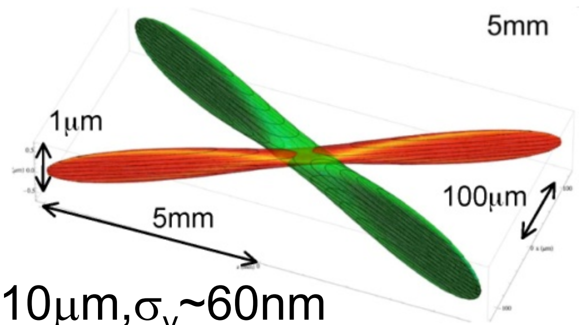
LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
HER : Lower emittance and lower SR power

KEKB



σ_x~100μm,σ_y~2μm

Nano-Beam SuperKEKB



σ_x~10μm,σ_y~60nm

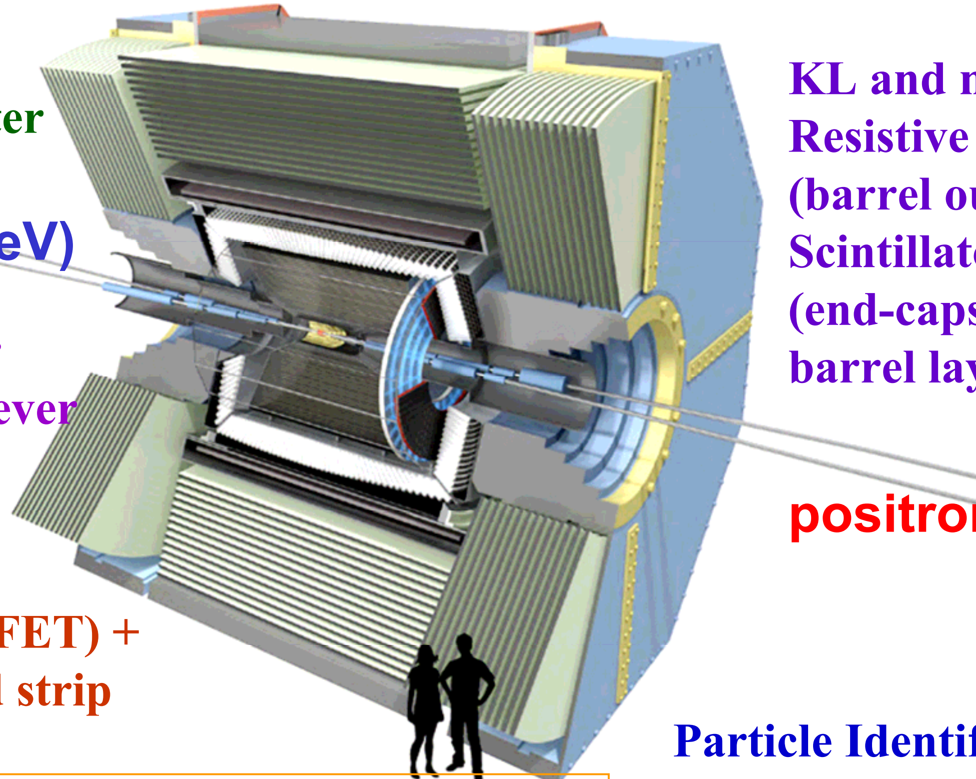
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

Belle II Detector

All details are in the Changzheng YUAN talk

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

electrons (7GeV)



positrons (4GeV)

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

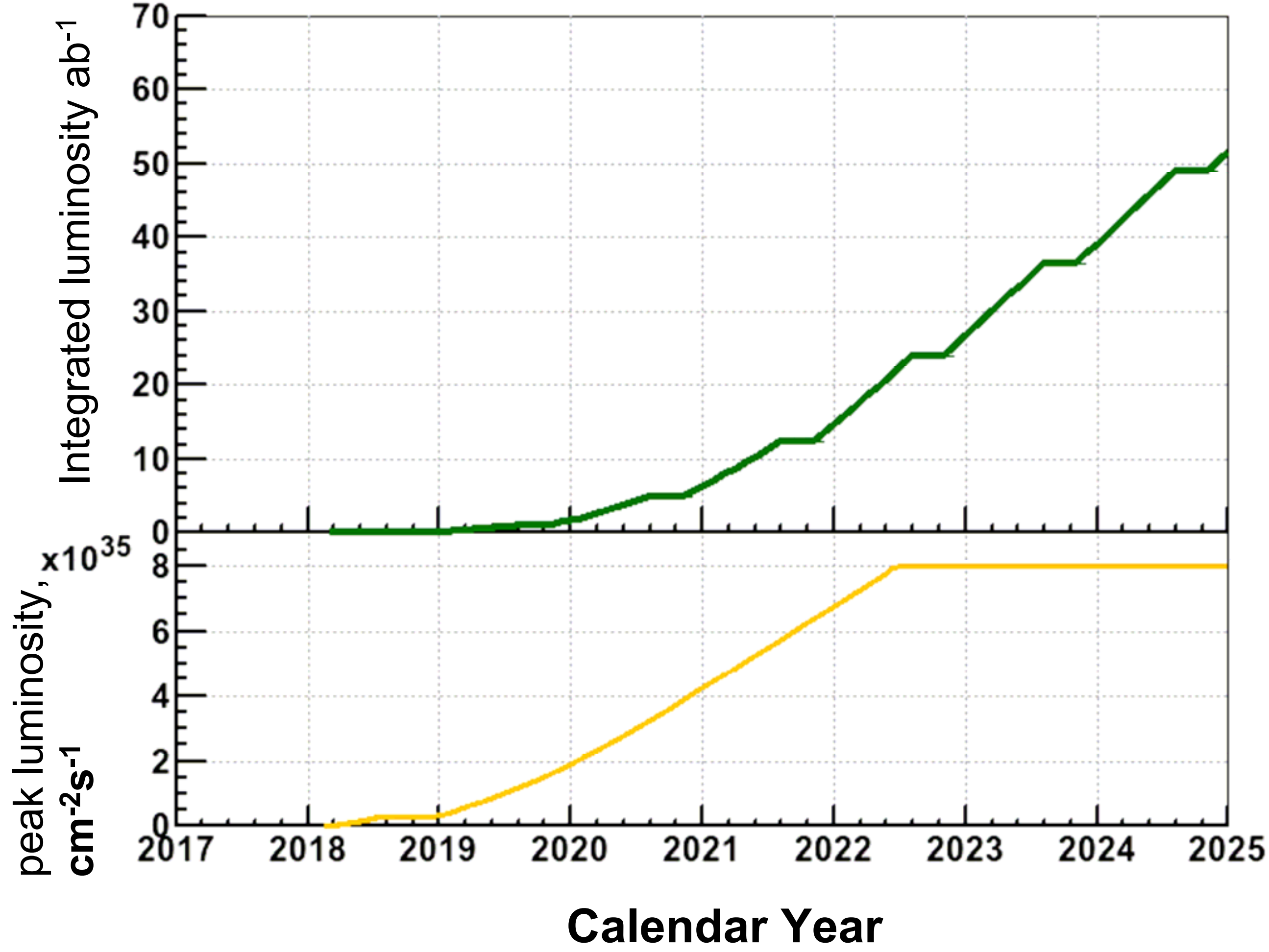
Central Drift Chamber
Smaller cell size, long lever arm

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

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

+ New software, improved tracking, ...
+ Optimization for low multiplicity trigger
+ Improved simulation, generators and GRID

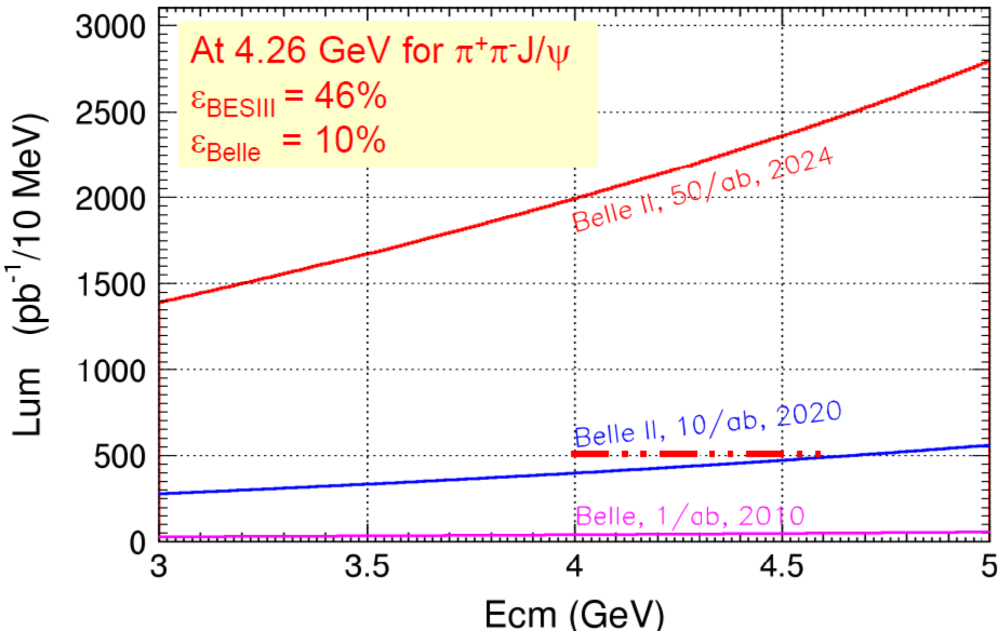
Expected Luminosity



ISR at Belle II vs. BESIII

Chengping Shen, Photon 2017

ISR produces events at all CM energies BESIII can reach



Direct scan

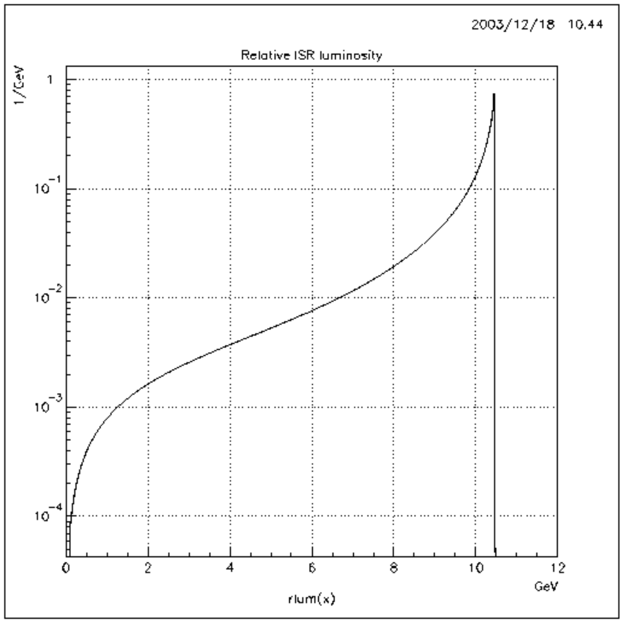
- (very) high luminosity at a few selected $\sqrt{s}$
- better resolution in $\sqrt{s}$ — relevant for direct production of 1^{--} states

ISR

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

With > 5(10) ab^{-1} data sample, ISR e+e- a charmonium+light hadrons: π+π-J/Ψ, π+π-Ψ(2S), K+K-J/Ψ, K+K-Ψ(2S), γX(3872), π+ π-X(3872), π+ π-hc, π+π-hc(2P), ωXcJ, φ XcJ, ηJ/Ψ, η'J/Ψ, ηΨ(2S), η hc]; and charm meson pair+light hadrons [DD, DD*, DD*π, . . .

Potential of ISR for low energy range

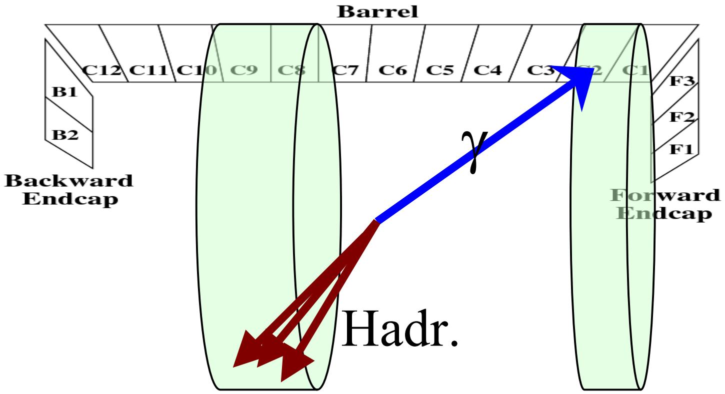


$$\frac{dl}{Ldm} = \frac{2\alpha m}{\pi s}\left\{\frac{s+m^4}{s(s-m^2)}(\ln\frac{s}{m_e^2}-1)\right\}$$

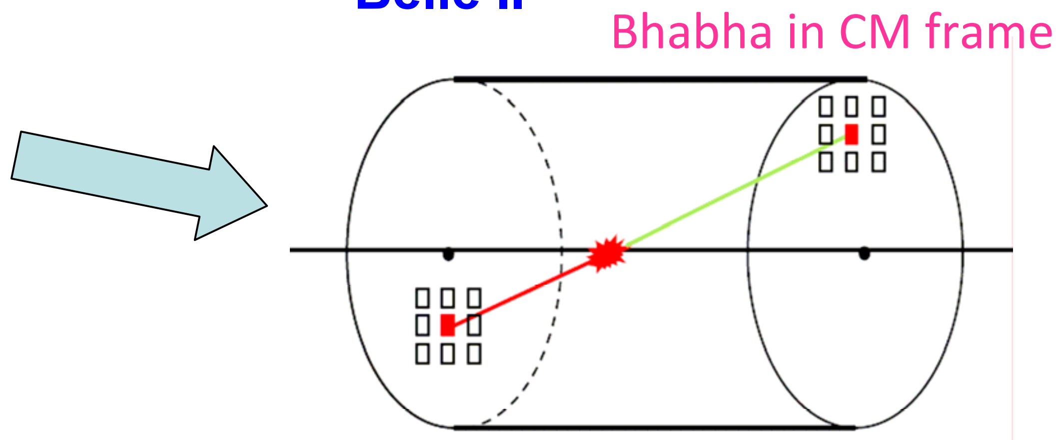
	KEKB	VEPP-2000	BEPC-II
Luminosity, см$^{-2}$ s^{-1}	$8{\cdot}10^{35}$	10^{32}	10^{33}
Integrated lum. (per 10^7 s)	8000 fb^{-1}	1 fb^{-1}	10 fb^{-1}
Integrated in the range [1-2] GeV	8 fb^{-1} (~0.8 @ cosθ<0.7)	1 fb^{-1}	
Integrated in the range [2-3] GeV	20 fb^{-1} (~2 @ cosθ<0.7)		10 fb^{-1}

Improvements at Belle II relevant to low mass ISR Trigger

Belle



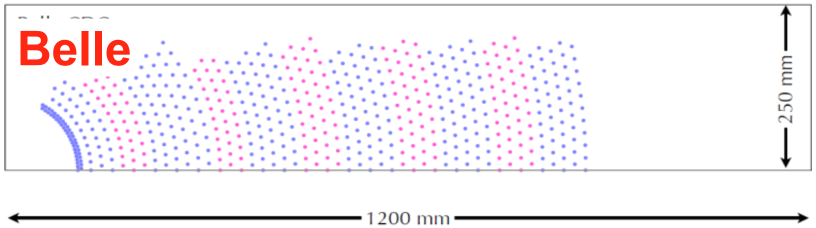
Belle II

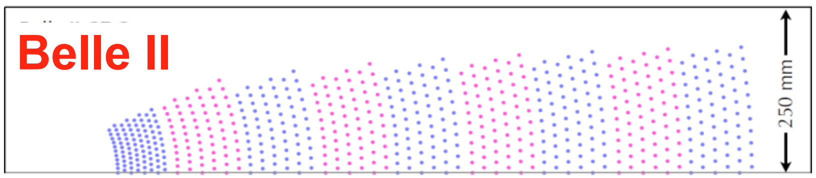


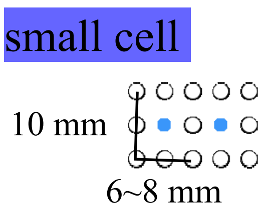
Using the Bhabha topology, sum back to back TCs Energy.

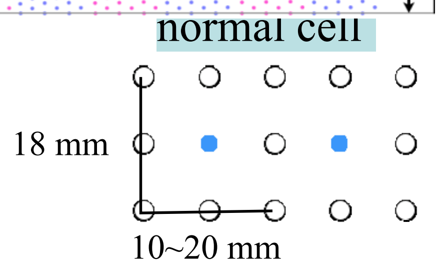
1. **Improved Bhabha veto logic for Belle II**
2. **Several independent trigger modes are invented to monitor and check the trigger efficiencies**

Improvements at Belle II relevant to low-mass ISR Central Drift Chamber









	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)

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

Better momentum resolution – better invariant mass resolution

Systematic uncertainties of BaBar measurements (PRD 86, 032013 (2012))

TABLE V. Systematic uncertainties (in 10^{-3}) on the cross section for $e^+e^- \to \pi\pi(\gamma_{FSR})$ from the determination of the various efficiencies in different $\pi\pi$ mass ranges (in GeV/c^2). The statistical part of the efficiency measurements is included in the total statistical error in each mass bin. The last line gives the total systematic uncertainty on the $\pi\pi$ cross section, including the systematic error on the ISR luminosity from muons.

Sources	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.9	0.9–1.2	1.2–1.4	1.4–2.0	2.0–3.0
Trigger/filter	5.3	2.7	1.9	1.0	0.7	0.6	0.4	0.4
Tracking	3.8	2.1	2.1	1.1	1.7	3.1	3.1	3.1
π-ID	10.1	2.5	6.2	2.4	4.2	10.1	10.1	10.1
Background	3.5	4.3	5.2	1.0	3.0	7.0	12.0	50.0
Acceptance	1.6	1.6	1.0	1.0	1.6	1.6	1.6	1.6
Kinematic fit (χ^2)	0.9	0.9	0.3	0.3	0.9	0.9	0.9	0.9
Correl. $\mu\mu$ ID loss	3.0	2.0	3.0	1.3	2.0	3.0	10.0	10.0
$\pi\pi/\mu\mu$ non-cancel.	2.7	1.4	1.6	1.1	1.3	2.7	5.1	5.1
Unfolding	1.0	2.7	2.7	1.0	1.3	1.0	1.0	1.0
ISR luminosity	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Sum (cross section)	13.8	8.1	10.2	5.0	6.5	13.9	19.8	52.4

Can we improve systematics at Belle II?

To try to do that we need to:

- **Continuously and carefully monitor the trigger efficiency, track and photon reconstruction efficiency and PID (mostly m/p) efficiency**
- **We have to study all of the main hadronic channels to accurately estimate the background**
- **We need serious help from theorists to calculate high-order correction to the cross section**
- **Since there are many things to do, a large and experienced team working on that task is necessary**

In general higher statistics provides more possibilities to study systematics

Conclusions

•Last decade demonstrated the fruitfulness of the flavor “factories” for hadronic cross section measurements via ISR as well as by the direct scan.

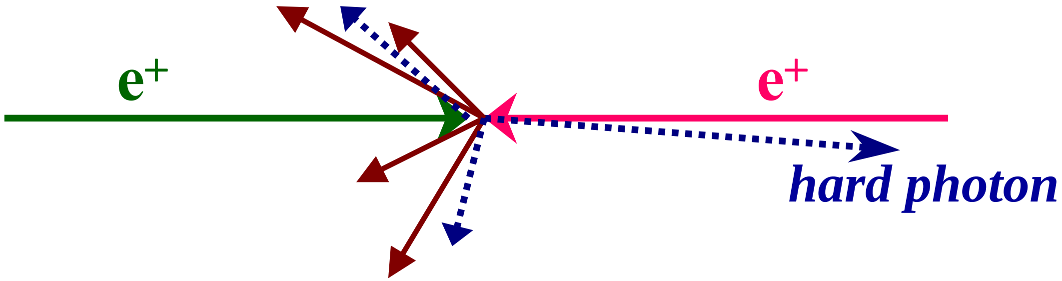
•At present SuperKEKB/Belle II project is in commissioning. Very high expected luminosity of this experiment provides a possibility of the precise measurements of the hadronic cross section in a wide energy range from production thershold to 11.5 GeV.

•We hope that high statistics and improved detector will help to reduce considerably systematic uncertainties.

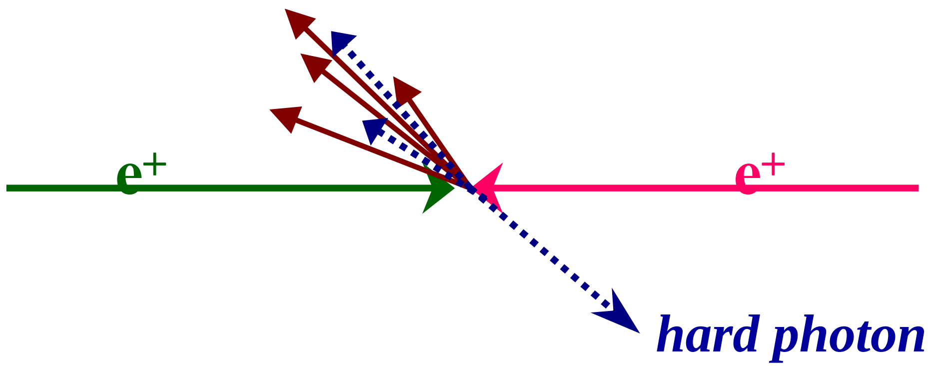
•To provide accurate data, especially for low mass range, we need to care about the proper trigger system and to prepare instruments to control stability of the charge particles and photon reconstruction efficiency during experiment.

• There are many things to do for a large and experienced team to cope with this task

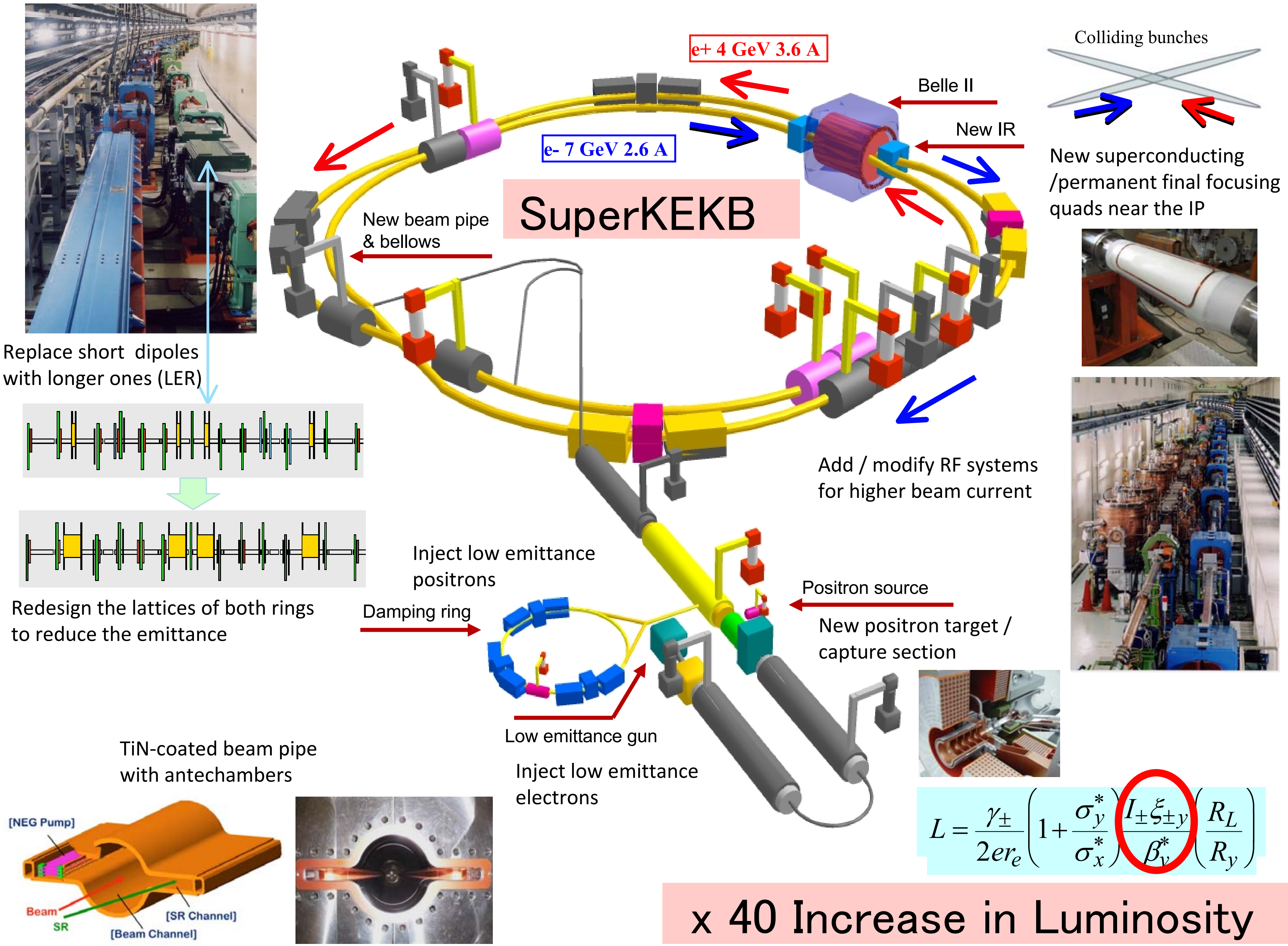
ISR -Two approaches



higher cross section,
but
partial reconstruction,
higher background



full reconstruction,
low background
but
lower cross section,



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