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 - $\Lambda_{QCD}$, $\alpha(s)$
- 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 $\rho$, $\omega$, $\phi$, $\rho'$, $\rho''$, …
- 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 electromagnetic 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: $L = 2.1 \times 10^{34}/\text{cm}^2/\text{sec}$ with crab cavities.

F/B asymmetric detector

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

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

$\int Ldt = 1 \text{ ab}^{-1}$
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

Two approaches

- Higher cross section, but partial reconstruction, higher background
- Full reconstruction, low background, but lower cross section,
R(s) measurements at Belle

ISR: with $\gamma_{\text{ISR}}$ detection, full reconstruction

ISR: mostly without $\gamma_{\text{ISR}}$ detection

Direct $e^+e^-$ scan

08.04.2014

(g-2)mu: Quo vadis?, Mainz
Measurement of $R_b$

Event shape parameter (Fox-Wolfram moments)

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

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

- $61 \sim 50$ pb$^{-1}$ scan point
- $16 \sim 1$ fb$^{-1}$ scan points

Cut on $R_2 < 0.2$

Continuum from below (4S) 3.67 fb$^{-1}$ (scaled)
R_b: Data and Fit

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

<table>
<thead>
<tr>
<th>R_b Preliminary</th>
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<tbody>
<tr>
<td>M(5S) MeV</td>
</tr>
<tr>
<td>\Gamma(5S) MeV</td>
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<tr>
<td>\phi(5S) Rad</td>
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<tr>
<td>M(6S) MeV</td>
</tr>
<tr>
<td>\Gamma(6S) MeV</td>
</tr>
<tr>
<td>\phi(6S-5S) Rad</td>
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\( \chi^2/\text{ndf}= 70.8/54 \)

08.04.2014 (g-2)mu: Quo vadis?, Mainz
### e⁺e⁻ → hadron cross sections via ISR at Belle

<table>
<thead>
<tr>
<th>Final State</th>
<th>Year</th>
<th>Int. Lum. [fb⁻¹]</th>
<th>E range [GeV]</th>
<th>σ&lt;sub&gt;max&lt;/sub&gt; [nb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>π⁺π J/ψ</td>
<td>2013</td>
<td>967</td>
<td>3.8 to 5.5</td>
<td>72 × 10⁻³</td>
</tr>
<tr>
<td>ηJ/ψ</td>
<td>2012</td>
<td>980</td>
<td>3.8 to 5.3</td>
<td>80 × 10⁻³</td>
</tr>
<tr>
<td>D⁺D⁻</td>
<td>2011</td>
<td>967</td>
<td>3.8 to 5</td>
<td>0.45</td>
</tr>
<tr>
<td>D⁺D⁺*</td>
<td>2011</td>
<td>967</td>
<td>4 to 5</td>
<td>0.9</td>
</tr>
<tr>
<td>D⁻D⁻*</td>
<td>2011</td>
<td>967</td>
<td>4.2 to 5</td>
<td>0.5</td>
</tr>
<tr>
<td>D⁰D⁺π⁺</td>
<td>2009</td>
<td>695</td>
<td>4 to 5.2</td>
<td>0.65</td>
</tr>
<tr>
<td>Λ⁺Λ⁻</td>
<td>2008</td>
<td>695</td>
<td>4.56 to 5.4</td>
<td>0.55</td>
</tr>
<tr>
<td>D⁰D⁺π⁺</td>
<td>2008</td>
<td>673</td>
<td>4 to 5</td>
<td>0.6</td>
</tr>
<tr>
<td>D⁺D⁻</td>
<td>2008</td>
<td>673</td>
<td>3.7 to 5</td>
<td>9</td>
</tr>
<tr>
<td>D⁺D⁻</td>
<td>2008</td>
<td>673</td>
<td>3.7 to 5</td>
<td>4</td>
</tr>
<tr>
<td>D⁰D⁰</td>
<td>2008</td>
<td>673</td>
<td>3.7 to 5</td>
<td>5.5</td>
</tr>
<tr>
<td>K⁺K J/ψ</td>
<td>2007</td>
<td>673</td>
<td>4.1 to 6</td>
<td>10 × 10⁻³</td>
</tr>
<tr>
<td>π⁺π ψ(2S)</td>
<td>2007</td>
<td>673</td>
<td>4.1 to 5.5</td>
<td>80 × 10⁻³</td>
</tr>
<tr>
<td>π⁺π J/ψ</td>
<td>2007</td>
<td>548</td>
<td>3.8 to 5.5</td>
<td>70 × 10⁻³</td>
</tr>
<tr>
<td>D⁺D⁻</td>
<td>2007</td>
<td>547.8</td>
<td>4 to 5</td>
<td>3.4</td>
</tr>
<tr>
<td>D⁺D⁻</td>
<td>2007</td>
<td>547.8</td>
<td>3.88 to 5</td>
<td>4.6</td>
</tr>
</tbody>
</table>
| φππ⁺          | 2009 | 673             | 1.5 to 3     | 0.7                 

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08.04.2014 \( (g-2)\mu: \text{Quo vadis?}, \text{Mainz} \) 10
\[ \sigma(e^+e^- \rightarrow \text{charmed hadrons}) \]

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

\[ \sigma(e^+e^- \rightarrow D^{(*)}D^*) \]

- \( e^+e^- \rightarrow D^0D^-\pi^+ \)
- \( e^+e^- \rightarrow D_s^{(*)}D_s^{(*)} \)
- \( e^+e^- \rightarrow \Lambda_c^+\Lambda_c^- \)

- Good agreement between
  Belle и BaBar
Exclusive cross sections contribution to the total charm cross section

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

BES: $R_{tot} - R_{uds}$;
Belle: $\sum R_{excl}$
Study of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ and Observation of a Charged Charmonium-like State at Belle

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

$Z(3900)^\pm$
$M = (3894.5 \pm 6.6 \pm 4.5) \text{ MeV/c}^2$
$\Gamma = (63\pm24\pm26) \text{ MeV/c}^2$
In agreement with BES

$Y (4008)$ and $Y (4260)$
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]
$e^+e^- \rightarrow \phi \pi^+\pi^-$ and $e^+e^- \rightarrow f_0(980) \pi^+\pi^-$

PRD 80, 031101 (2009)

673 fb$^{-1}$

$M(\phi(1680)) = (1689\pm7\pm10)$ MeV/$c^2$,
$\Gamma(\phi(1680)) = (211 \pm 14 \pm 19)$ MeV/$c^2$

$M(Y(2175)) = (1689\pm7\pm10)$ MeV/$c^2$,
$\Gamma(Y(2175)) = (211 \pm 14 \pm 19)$ MeV/$c^2$

Cross section Syst. Errors - 8.6% and 6.9%
Belle $\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \pi^0)$

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

526.6 fb$^{-1}$ (still preliminary)

Belle systematic error goal is 5%.

08.04.2014 (g-2)mu: Quo vadis?, Mainz
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 ($\mu\mu, \pi\pi, \ldots$)

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

Bhabha veto example:

$E(C2+C8+C9) > 5 \text{ GeV} \rightarrow \text{prescaled as Bhabha}$
Replace short dipoles with longer ones (LER)

Redesign the lattices of both rings to reduce the emittance

TiN-coated beam pipe with antechambers

Colliding bunches

New superconducting/permanent final focusing quads near the IP

New IR

SuperKEKB

Belle II

Add / modify RF systems for higher beam current

New positron target / capture section

Positron source

Inject low emittance positrons

Inject low emittance electrons

Damping ring

Low emittance gun

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

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.
  - Vertical $\beta$ function at IP: $5.9 \rightarrow 0.27/0.30$ mm ($\times 20$)
  - Beam current: $1.7/1.4 \rightarrow 3.6/2.6$ A ($\times 2$)
  - Beam-beam parameter: $.09 \rightarrow .09$ ($\times 1$)
  - Beam energy: $3.5/8.0 \rightarrow 4.0/7.0$ GeV

$L = \frac{\gamma^2}{2e^2} \left( 1 + \frac{e_y}{e_x} \left( \frac{\sigma_{y*}}{\sigma_{x*}} \right) \frac{R_L}{R_y} \right) = 8 \times 10^{35}$ cm$^{-2}$s$^{-1}$

- 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

$L_x \sim 100\mu m, L_y \sim 2\mu m$

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

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

Installation of 100 new LER bending magnets done

After TiN coating
Belle II Detector (in comparison with Belle)

Belle II

SVD: 4 DSSD lyr → 2 DEPFET lyr + 4 DSSD lyr

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

<table>
<thead>
<tr>
<th>Beam Piper = DEPFET</th>
<th>Belle II</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10mm</td>
<td>15mm</td>
</tr>
</tbody>
</table>

| DSSD | Layer 1 | r = 14mm |  | Layer 2 | r = 22mm |  |
|------|---------|----------|  |---------|----------|  |
|      | Layer 3 | r = 38mm | 20mm | Layer 4 | r = 80mm | 43.5mm |
|      | Layer 5 | r = 104mm | 70mm | Layer 6 | r = 135mm | 88mm |

New vertex detector

DSSDs

Impact parameter resolution $d_0$

Resolution [μm]

$p\beta\sin(\theta)^{3/2}$ [GeV/c]

08.04.2014  
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22
Central Drift Chamber

longer lever arm

Improved momentum resolution and dE/dx

\[
\frac{\sigma_{P_t}}{P_t} = 0.19P_t + 0.30/\beta
\]

\[
\frac{\sigma_{P_t}}{P_t} = 0.11P_t + 0.30/\beta
\]

new readout system

dead time 1-2\,\mu s \rightarrow 200\,ns

small cell

smaller hit rate for each wire

shorter maximum drift time

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

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner most sense wire</td>
<td>r=88mm</td>
<td>r=168mm</td>
</tr>
<tr>
<td>outer most sense wire</td>
<td>r=863mm</td>
<td>r=1111.4mm</td>
</tr>
<tr>
<td>Number of layers</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>Total sense wires</td>
<td>8400</td>
<td>14336</td>
</tr>
<tr>
<td>Gas sense wire</td>
<td>He:C_{2}H_{6}</td>
<td>He:C_{2}H_{6}</td>
</tr>
<tr>
<td>field wire</td>
<td>W(\Phi30\mu m)</td>
<td>W(\Phi30\mu m)</td>
</tr>
<tr>
<td>field wire</td>
<td>Al(\Phi120\mu m)</td>
<td>Al(\Phi120\mu m)</td>
</tr>
</tbody>
</table>
Particle Identification in Belle II

Barrel PID: Time of Propagation Counter (iTOP)

Quartz radiator
Small expansion block
Hamamatsu MCP-PMT (measure t, x and y)

Quartz radiator
2.6mL x 45cmW x 2cmT
Excellent surface accuracy
MCP-PMT
Hamamatsu 16ch MCP-PMT
Good TTS (<35ps) & enough lifetime
Multialkali photocathode → SBA

Cherenkov ring imaging with precise time measurement.
Device uses internal reflection of Cherenkov ring images from quartz like the BaBar DIRC
Cherenkov angle reconstruction from two hit coordinates and the time of propagation of the photon

x-t diagram from beam-test

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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

Calendar

<table>
<thead>
<tr>
<th>Japan FY</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>...</th>
</tr>
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<tbody>
<tr>
<td>Mar. 2013</td>
<td>Jan. 2015</td>
<td></td>
<td></td>
<td></td>
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Potential of ISR

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

<table>
<thead>
<tr>
<th>Number of events of the vector meson production at 8000 fb(^{-1}) (@Y(4s))</th>
<th>KEKB</th>
<th>VEPP-2000</th>
<th>BEPC-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi)</td>
<td>(1.5 \times 10^8)</td>
<td>(8 \times 10^{35})</td>
<td>(10^{32})</td>
</tr>
<tr>
<td>(\psi)</td>
<td>(2.3 \times 10^8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\psi(2S))</td>
<td>(7.8 \times 10^7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\psi(3770))</td>
<td>(9.7 \times 10^6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Y(1s))</td>
<td>(1.3 \times 10^8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Y(2s))</td>
<td>(1.2 \times 10^8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Y(3s))</td>
<td>(2.4 \times 10^8)</td>
<td></td>
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</table>

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<thead>
<tr>
<th>Luminosity, cm(^{-2}) s(^{-1})</th>
<th>KEKB</th>
<th>VEPP-2000</th>
<th>BEPC-II</th>
</tr>
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<thead>
<tr>
<th>Integrated lum. (per 10(^7) s)</th>
<th>KEKB</th>
<th>VEPP-2000</th>
<th>BEPC-II</th>
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<tbody>
<tr>
<td>8 fb(^{-1}) (~0.8 @ (\theta&gt;0.7))</td>
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<tbody>
<tr>
<td>20 fb(^{-1}) (~2 @ (\theta&gt;0.7))</td>
<td></td>
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</table>
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 during experiment.

• We can wait for new exciting results in the next decade.