Status of Measurement of $R$ Value at BESIII

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On behalf of BESIII Collaboration
The Born cross section of $e^+e^-$ annihilation into hadrons normalized by theoretical $\mu^+\mu^-$ cross section

\[
R = \frac{\sigma_{h,\text{had}}^0(e^+e^- \rightarrow \gamma^* \rightarrow \text{hadrons})}{\sigma_{\mu\mu}^0(e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-)}
\]

**Precision !!!**
Muon magnetic moment \((g-2)_\mu\)

- The Standard Model prediction for muon \(a_\mu = (g_\mu - 2)/2\)

\[
a_\mu^{SM} = a_\mu^{QED} + a_\mu^{had,LO} + a_\mu^{had,HO} + a_\mu^{had,LBL} + a_\mu^{\text{weak}}
\]

\[
a_\mu^{Had}[LO] = \frac{1}{3} \left( \frac{\alpha}{\pi} \right)^2 \int_{m_\pi^2}^{\infty} ds \frac{K(s)}{s} R(s)
\]

**Prof. Michel Davier @ Tau2016**

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>QED</td>
<td>11658471.885</td>
<td>± 0.004</td>
</tr>
<tr>
<td>EW</td>
<td>15.4</td>
<td>± 0.1</td>
</tr>
<tr>
<td>had LBL</td>
<td>10.5</td>
<td>± 2.6</td>
</tr>
<tr>
<td>had LO</td>
<td>692.8</td>
<td>± 3.3</td>
</tr>
<tr>
<td>had NLO</td>
<td>-9.87</td>
<td>± 0.09</td>
</tr>
<tr>
<td>had NNLO</td>
<td>1.24</td>
<td>± 0.01</td>
</tr>
<tr>
<td>prediction</td>
<td>11659181.9</td>
<td>± 4.2</td>
</tr>
<tr>
<td>exp BNL</td>
<td>11659208.9</td>
<td>± 6.3</td>
</tr>
</tbody>
</table>

**K(s): analytically known**
Muon magnetic moment \((g-2)_\mu\)

Prof. Michel Davier at Tau2016

- \([\pi^0\gamma-1.8\text{GeV}]\)
  - sum about 22→37 exclusive channels
  - estimate unmeasured channels using isospin relations

- \([1.8-3.7] \text{ GeV}\)
  - good agreement between data and pQCD calculation;
    previous extensive QCD tests with \(\tau\) data
    → use 4-loop pQCD
  - \(J/\psi, \psi(2S)\): Breit-Wigner integrals

- \([3.7-5] \text{ GeV}\)
  - charm particle thresholds
    → use data

- \(>5\text{ GeV}\)
  - use 4-loop pQCD calculation

- **BESIII**: ISR and energy scan
EM fine structure constant

- The running of the electromagnetic fine structure constant is governed by the renormalized vacuum polarization function.

\[
\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_{lep}(s) - \Delta\alpha_{top}(s) - \Delta\alpha_{had}^5(s)}
\]

\[
\Delta\alpha_{lep}(M_Z^2) = 0.03142
\]

\[
\Delta\alpha_{top}(M_Z^2) = 0.00007(1)
\]

\[
\Delta\alpha_{had}^5(M_Z^2) = 0.0280 \pm 0.0009
\]

\[
\Delta\alpha_{had}^5(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi} \operatorname{Re} \int_{4m_{\pi}^2}^{\infty} ds \frac{R(s)}{s(s - M_Z^2) - i\epsilon}
\]
**R value @ pQCD and charmonium**

- Test pQCD prediction on R values

\[
    R = 3 \sum_f Q_f^2 \left[ 1 + \left( \frac{\alpha_s(s)}{\pi} \right) + 1.411 \left( \frac{\alpha_s(s)}{\pi} \right)^2 - 12.8 \left( \frac{\alpha_s(s)}{\pi} \right)^3 + \ldots \right]
\]

- Fitting to R values: resonance parameters of \( \Psi(3770) \), \( \Psi(4040) \), \( \Psi(4160) \) and \( \Psi(4410) \).

\[\psi(4040) \quad I^{G(j\bar{p}C)} = 0^- (1^- -)\]

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4039 ± 1</td>
<td>0B0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4039 ± 6</td>
<td>0D0</td>
<td></td>
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<tr>
<td>4037 ± 2</td>
<td>0D0</td>
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<tr>
<td>4040 ± 1</td>
<td>0E0</td>
<td></td>
<td></td>
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<tr>
<td>4040 ± 10</td>
<td>0F0</td>
<td></td>
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</tbody>
</table>

PL B660 (2008) 315

\[\chi^2/d.o.f=1.06\]
Data sets for R value

● Phase I: test run @ 2012
  ✓ Ecm = 2.232/2.400/2.800/3.400 GeV, ~12pb⁻¹

● Phase II: fine scan for heavy charm resonant @2013-2014
  ✓ Ecm ∈ [3.800, 4.590]GeV, 104 energy points, ~800pb⁻¹

● Phase III: R & QCD scan @ 2015
  ✓ Ecm ∈ [2.000, 3.080]GeV, 21 energy points, ~500pb⁻¹
R value

- R values are measured as

\[
R = \frac{1}{\sigma_{\mu^+\mu^-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1 + \delta)}
\]

\[
\text{L} \quad \text{integrated luminosity}
\]
\[
1+\delta \quad \text{radiative correction factor}
\]
\[
N_{had} \quad \text{observed hadronic events}
\]
\[
N_{bg} \quad \text{from background events}
\]
\[
\varepsilon_{had} \quad \text{selection efficiency}
\]
\[
\sigma_{\mu\mu} \quad \text{Born cross section of } \mu \text{ pair production in QED}
\]
Generators @ R analysis

\[ e^+e^- \rightarrow (\gamma)e^+e^-: \text{Babayaga} \]

\[ e^+e^- \rightarrow (\gamma)\mu^+\mu^-: \text{Babayaga} \]

\[ e^+e^- \rightarrow (\gamma)\tau^+\tau^-: \text{KKMC} \]

\[ e^+e^- \rightarrow (\gamma)\gamma\gamma: \text{Babayaga} \]

\[ e^+e^- \rightarrow \text{hadrons}: \text{ConExc & LUARLW} \]

\[ e^+e^- \rightarrow e^+e^-X: \text{TWOPHOTON} \]
Luminosity

• Large-angle Bhabha $e^+e^- \rightarrow (\gamma)e^+e^-$ and diphoton $e^+e^- \rightarrow (\gamma)\gamma\gamma$: about 0.8% uncertainty

\begin{table}
\begin{tabular}{|c|c|c|}
\hline
$\sqrt{s}$/GeV & $e^+e^- \rightarrow (\gamma)e^+e^-$/pb$^{-1}$ & $e^+e^- \rightarrow (\gamma)\gamma\gamma$/pb$^{-1}$ \\
\hline
2.2324 & 2.645$\pm$0.006$\pm$0.020 & 2.627$\pm$0.009$\pm$0.028 \\
2.4000 & 3.415$\pm$0.007$\pm$0.024 & 3.428$\pm$0.011$\pm$0.040 \\
2.8000 & 3.753$\pm$0.008$\pm$0.026 & 3.766$\pm$0.014$\pm$0.042 \\
3.0500 & 14.893$\pm$0.030$\pm$0.103 & 14.919$\pm$0.029$\pm$0.158 \\
3.0600 & 15.040$\pm$0.030$\pm$0.131 & 15.060$\pm$0.029$\pm$0.158 \\
3.0800 & 31.019$\pm$0.060$\pm$0.189 & 30.942$\pm$0.044$\pm$0.338 \\
3.0830 & 4.740$\pm$0.011$\pm$0.029 & 4.769$\pm$0.017$\pm$0.052 \\
3.0900 & 15.709$\pm$0.031$\pm$0.099 & 15.558$\pm$0.030$\pm$0.162 \\
3.0930 & $\cdots$ & 14.910$\pm$0.030$\pm$0.157 \\
3.0943 & $\cdots$ & 2.143$\pm$0.011$\pm$0.023 \\
3.0952 & $\cdots$ & 1.816$\pm$0.010$\pm$0.019 \\
3.0958 & $\cdots$ & 2.135$\pm$0.011$\pm$0.023 \\
3.0969 & $\cdots$ & 2.069$\pm$0.011$\pm$0.024 \\
3.0982 & $\cdots$ & 2.203$\pm$0.011$\pm$0.023 \\
3.0990 & $\cdots$ & 0.756$\pm$0.007$\pm$0.008 \\
\hline
\end{tabular}
\end{table}
Radiative correction factor \((1+\delta)\)

- The Feynman diagrams scheme (CB) and structure function schemes (KF & WU) are used, results by their methods are consistent within \(1.2\%\).

- \(R\) value @ PDG2016 as input
\[ e^+e^- \rightarrow e^+e^- + X \]

- **Background from two photon process**
  - Underestimation by BesTwoGam MC
  - Use generator for (dominant) exclusive processes: \( e^+e^-e^+e^-; e^+e^-\mu^+\mu^-; e^+e^-\pi^+\pi^-; e^+e^-K^+K^-; e^+e^-\eta \) and \( e^+e^-\eta' \)
- **Other process:** unclear but tiny
MC generator for $e^+e^-\rightarrow$hadrons

- High energy $e^+e^-$ collision: Herwig @ Cluster model; Jetset and Pythia @ String model
- Low energy $e^+e^-$ collision: LUND Area Law, hep-ph/9910285
  - Simulate ISR inclusive continuous channels and $J^{PC}=1^-$ resonance between 2GeV and 5GeV. Need MC tuning
  - Left-right symmetry, NO
MC generator for $e^+e^-\rightarrow$ hadrons

- LUARLW: 100% by LUARLW
- ConExc generator:
  - ConExc + Phokhara + LUARLW
  - Phokhara deal with 10 exclusive processes
  - Others measured processes with ConExc
  - unknown by LUNDARLW

![Graph showing cross section vs. $M_{hadrons}$ (GeV)]

- +: inclusively light hadron
- --: exclusive measured cross section
ConExc @ [2.232, 3.671]GeV

ConExc could describe experimental data
LUARLW could describe experimental data
Status of R Measurement

- BESIII memo at Convener’s review

**BESIII Analysis Memo**
BAM-00XXX
June 13, 2017

The Measurements of R in $e^+e^-$ Annihilation at Center-of-Mass Energy from 2.2324 to 3.6710 GeV at BESIII

- MC tuning at $[3.800, 4.590]$GeV

\[
e^{+}e^{-} \Rightarrow \gamma^* \Rightarrow \begin{cases} 
\psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s; \\
\psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s; \\
\psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s, D_s^*\bar{D}_s^*;
\end{cases}
\]

\[
e^{+}e^{-} \Rightarrow \gamma^* \Rightarrow X(4160), X(4260) \cdots \text{ with } J^{PC} = 1^{-+}
\]
Summary

- R values are important for \((g-2)_\mu\), \(\alpha(M_Z)\), \(\alpha_s(s)\), and test pQCD prediction, and resonance parameters of charmonium states
- BESIII have collected with R scan data @ \([2.0, 4.6]GeV\)
- Data analysis @ \([2.232, 3.671]GeV\) is finished
  - Integrated luminosity: about 0.8% uncertainty
  - Radiative correction factor \((1+\delta)\): 1.2% uncertainty
  - MC generator: ConExc and LUARLW
- Data analysis @ \([3.800, 4.590]GeV\) is in progress
Bird’s View of BEPCII & BESIII

- BEPC-II and BES-III
- Linac
- Storage ring
- BESIII detector
- Beijing electron positron collider BEPCII

Beam energy 1.0-2.3 GeV
Energy spread: $5.16 \times 10^{-4}$

Design luminosity $1 \times 10^{33}$/cm$^2$/s @ $\psi(3770)$
BESIII Detector

- Solenoid Magnet: 1 T Super conducting
- MDC small cell & He gas
  - $\sigma_{xy} = 130 \, \mu m$
  - $\delta p/p = 0.5\% @ 1\, GeV$
  - $dE/dx = 6\%$
- TOF
  - $\sigma_T = 90\, ps$ Barrel
  - 110->80ps Endcap
- Muon ID: 8~9 layer RPC
  - $\sigma_{R\Phi} = 1.4 \, cm \sim 1.7 \, cm$
- EMCAL: CsI crystal
  - $\Delta E/E = 2.5\% \, @ \, 1\, GeV$
  - $\sigma_{\varphi,z} = 0.5\sim 0.7 \, cm/\sqrt{E}$
- Data Acquisition:
  - Event rate = 3 kHz
  - Throughput ~ 50 MB/s
- Trigger: Tracks & Showers
  - Pipelined; Latency = 6.4 $\mu s$

Hermetic spectrometer for neutral and charged particle with excellent resolution, PID, and large coverage