Measurements of the R value at BESIII

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Motivation

- Definition of R value

\[ R \equiv \frac{\sigma^0(e^+ e^- \rightarrow \text{hadrons})}{\sigma^0(e^+ e^- \rightarrow \mu^+ \mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}} \]

- Determination of running coupling constant of QED theory

\[ \alpha \equiv \frac{\alpha_0}{1 - \Delta\alpha}, \quad \Delta\alpha(s) = \Delta\alpha(s)_{\text{lep}} + \Delta\alpha(s)_{\text{had}} \]

\[ \Delta\alpha(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi} \text{Re} \int_4 M_Z^2 \frac{ds}{s(s-M_Z^2-i\epsilon)} R(s) \]

- Anomalous magnetic moment of muon \( g_\mu - 2 \)

\[ a_\mu = \frac{g_\mu - 2}{2}, \quad a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}} \]

\[ a_\mu^{\text{had}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_4 m_\mu^2 \frac{ds}{s^2} K(s) R(s) \]

\[ \Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}}, \quad 4.2\sigma \rightarrow \text{new physics} \]

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**LP2021: R value at BESIII**
**BESIII**

- **Beam energy:** 1.0 – 2.475 GeV
- **Luminosity:** $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$
- **Optimum energy:** 1.89 GeV

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- **CsI crystal, $\Delta E/E = 2.5\%$ @1 GeV**
- $\sigma_T = 100$ ps barrel, 65 ps endcaps
- $\sigma_p/p = 0.5\%$ @1 GeV, $\sigma_{dE/dx} = 6\%$

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**BEPCII**

- **Muon ID:** RPCs

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**Linac**
In experiment:

\[ R = \frac{N_{\text{had}}^{\text{obs}} - N_{\text{bkg}}}{\mathcal{L}_{\text{int}} \varepsilon_{\text{had}} \varepsilon_{\text{trig}} (1 + \delta) \sigma_{\mu \mu}^0} \]

- \( N_{\text{had}}^{\text{obs}} \): numbers of observed hadronic events
- \( N_{\text{bkg}} \): numbers of the residual background events
- \( \mathcal{L}_{\text{int}} \): integrated luminosity
- \( \varepsilon_{\text{had}} \): detection efficiency of hadronic events
- \( \varepsilon_{\text{trig}} \): trigger efficiency
- \( (1 + \delta) \): ISR correction factor
- \( \sigma_{\mu \mu}^0 \): leading order QED cross section

\[ e^+ e^- \rightarrow \mu^+ \mu^- \]
- Development of JETSET for low $E$ experiments
- Both continuum and resonance states
- Kinematics of initial hadrons determined by Lund Area Law
- Phenomenological parameters should be tuned
- Integrated the Initial-state radiation (ISR) and Vacuum Polarization (VP)
Hybrid MC

- R value: sum of hadronic processes
  - Good consistence below 2 GeV
  - Incomplete measurements above 2 GeV
- Hybrid model as an alternative model
  - ConExc + Phokhara + LUARLW
  - Phokhara: 10 modes
    \[ \text{[Phys.Rev.D90, 114021]} \]
  - ConExc: 47 modes
    \[ \text{[Chin.Phys.C40, 113002]} \]
  - LUARLW: unknown processes
- Difference with LUARLW: < 2.3%

+: cross section from $R$-value measurement
+: Sum of exclusive cross section (76 modes)
MC vs Data

- Comparison of MC and data (@3.4 GeV)
  - Data (black dot) are well reproduced by tuned LUARLW MC (red histogram)

- Number of charged tracks
  - Number of isolated photons in 2-prong events

- Angular distribution of charged tracks
- Deposit energy / momentum
Sys. Uncertainties

• Based on experimental technique:

\[
\left( \frac{\Delta R}{R} \right)_{sys} = \left( \frac{\Delta N}{N} \right)^2 + \left( \frac{\Delta L_{int}}{L_{int}} \right)^2 + \left( \frac{\Delta \varepsilon_{had}}{\varepsilon_{had}} \right)^2 + \left( \frac{\Delta \varepsilon_{trig}}{\varepsilon_{trig}} \right)^2 + \left( \frac{\Delta (1 + \delta)}{(1 + \delta)} \right)^2
\]

where \( N = N_{had}^{obs} - N_{bkg} \)

– Event selection: vary selection criteria, <0.8%

– Background estimation: different methods and background simulation model

– Integrated luminosity: quote the uncertainty in luminosity measurement, 0.8%

– Signal simulation: hybrid model as a cross check, <2.3%

– Trigger efficiency: approaches 100% with an uncertainty less than 0.1%

– ISR correction factor: considered in calculation precision, <1.3%
Summary

- Significant process of R measurement: MC tuning, simulation checking, ...
- Both LUARLW and Hybrid MC can describe data well
- R values obtained in (2.2, 3.7) GeV
- Good accuracy of R value: <3.0%
- Whole R program will cover a wide energy range: 2.0 - 4.9 GeV

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