R measurement at BESIII

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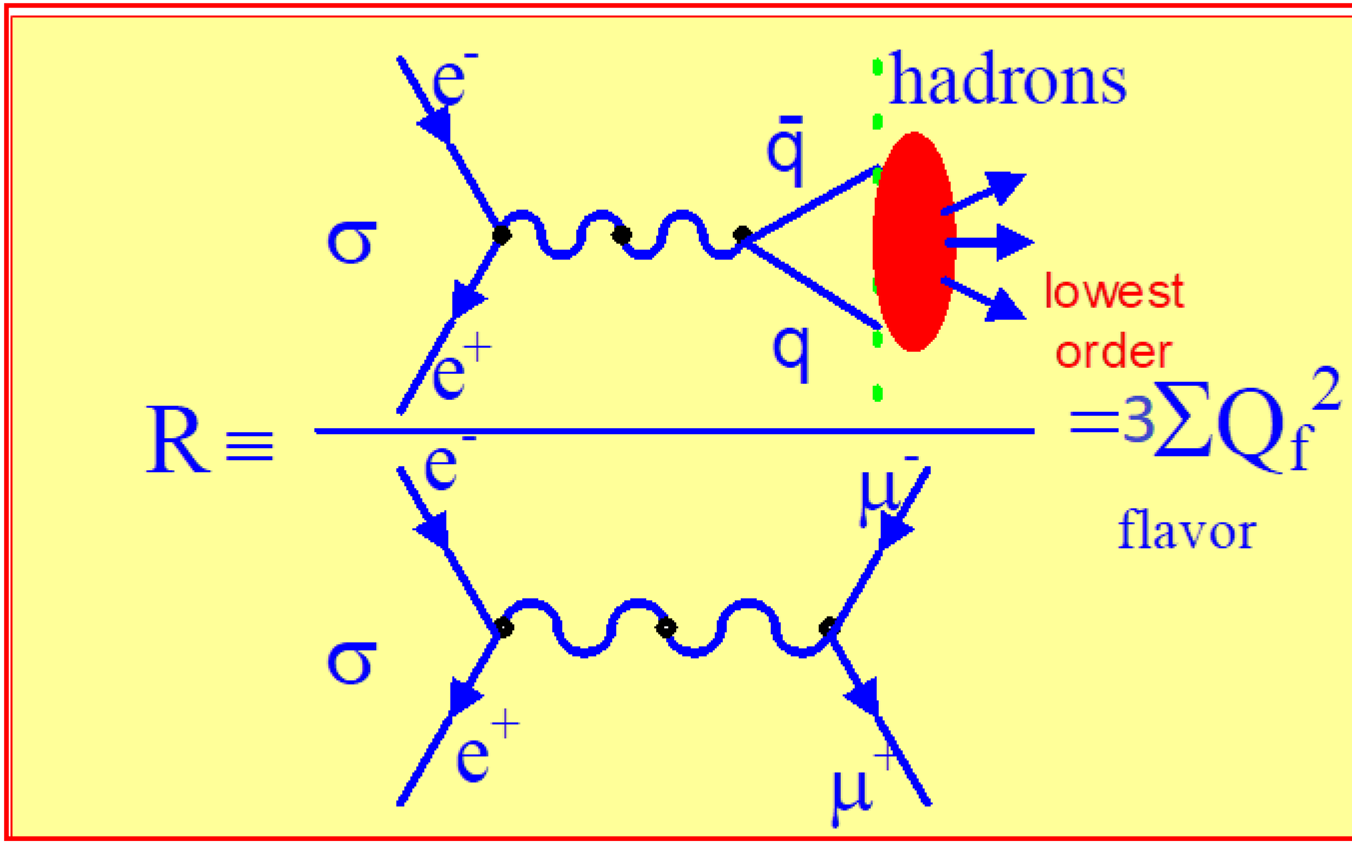
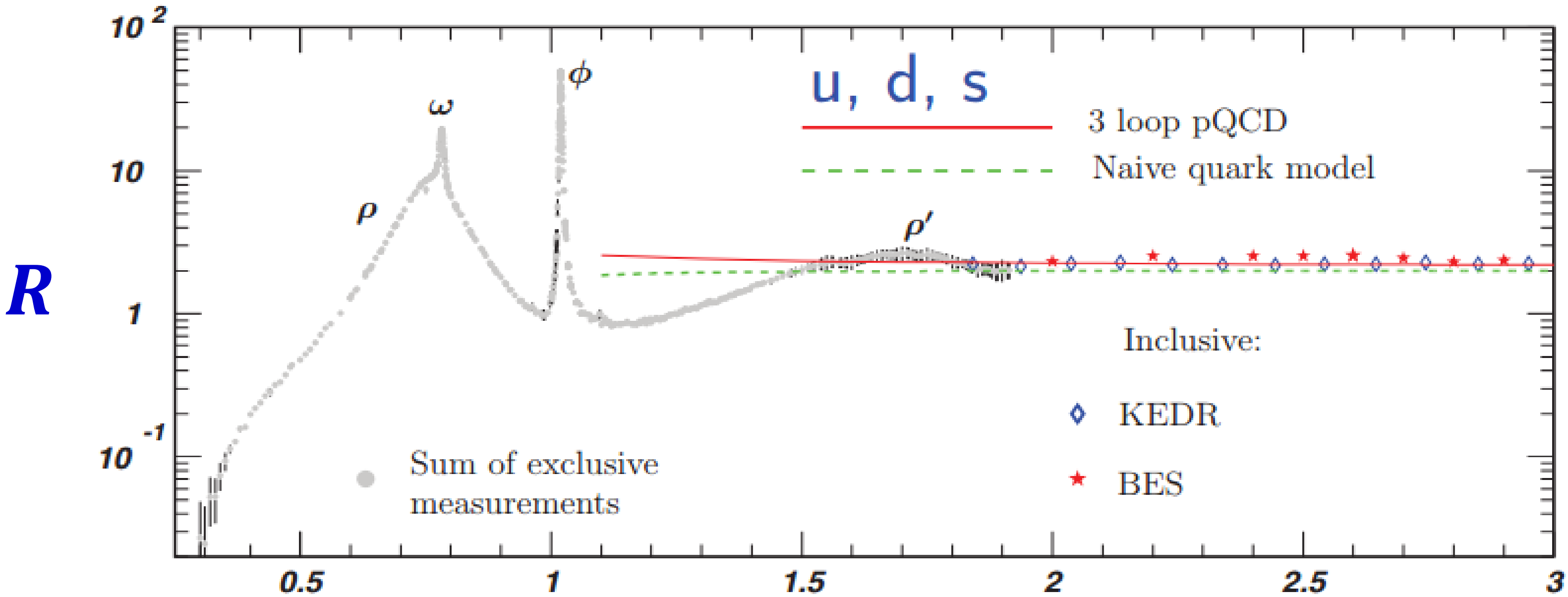
QWG2019, Torino, Italy, May 13-17, 2019

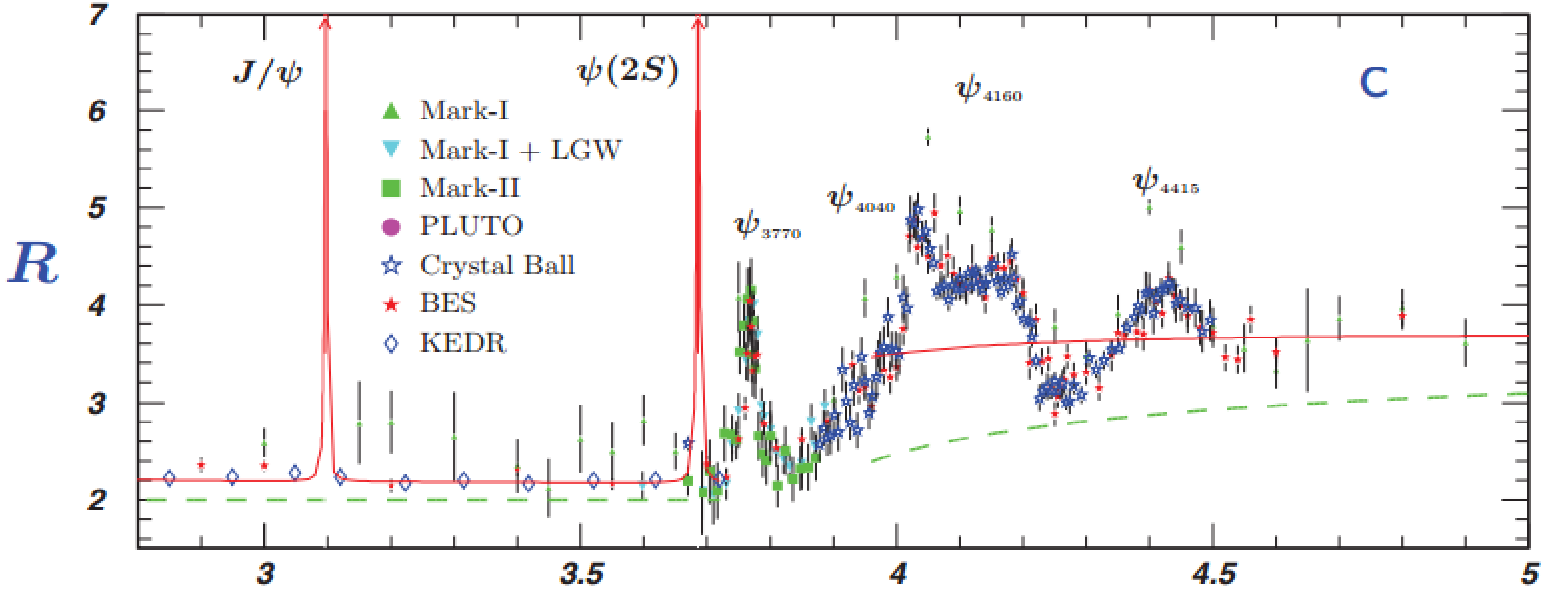
Definition of *R*-Value



$$R = 3[(2/3)^2 + (1/3)^2 + (2/3)^2] = 2 \quad \text{for } \boldsymbol{u, d, s}$$
$$= 2 + 3(2/3)^2 = 10/3 \quad \text{for } \boldsymbol{u, d, s, c}$$
$$= 10/3 + 3(1/3)^2 = 11/3 \text{ for } \boldsymbol{u, d, s, c\ b}.$$

R-Value below 5.0 GeV





Motivations

- Improve precision of $\alpha(M_Z^2)$ $\rightarrow$ essential for precision test of the standard model

$$\alpha \equiv \frac{\alpha_0}{1-\Delta\alpha}, \qquad \Delta\alpha(s) = \Delta\alpha(s)_{\mathrm{lep}} + \Delta\alpha(s)_{\mathrm{had}}$$

$$\Delta\alpha(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi} Re\int_{4m_\pi^2}^{\infty} \frac{ds\,\boldsymbol{R(s)}}{s(s-M_Z^2)-i\epsilon}$$

- Hunting for new physics from $g-2$

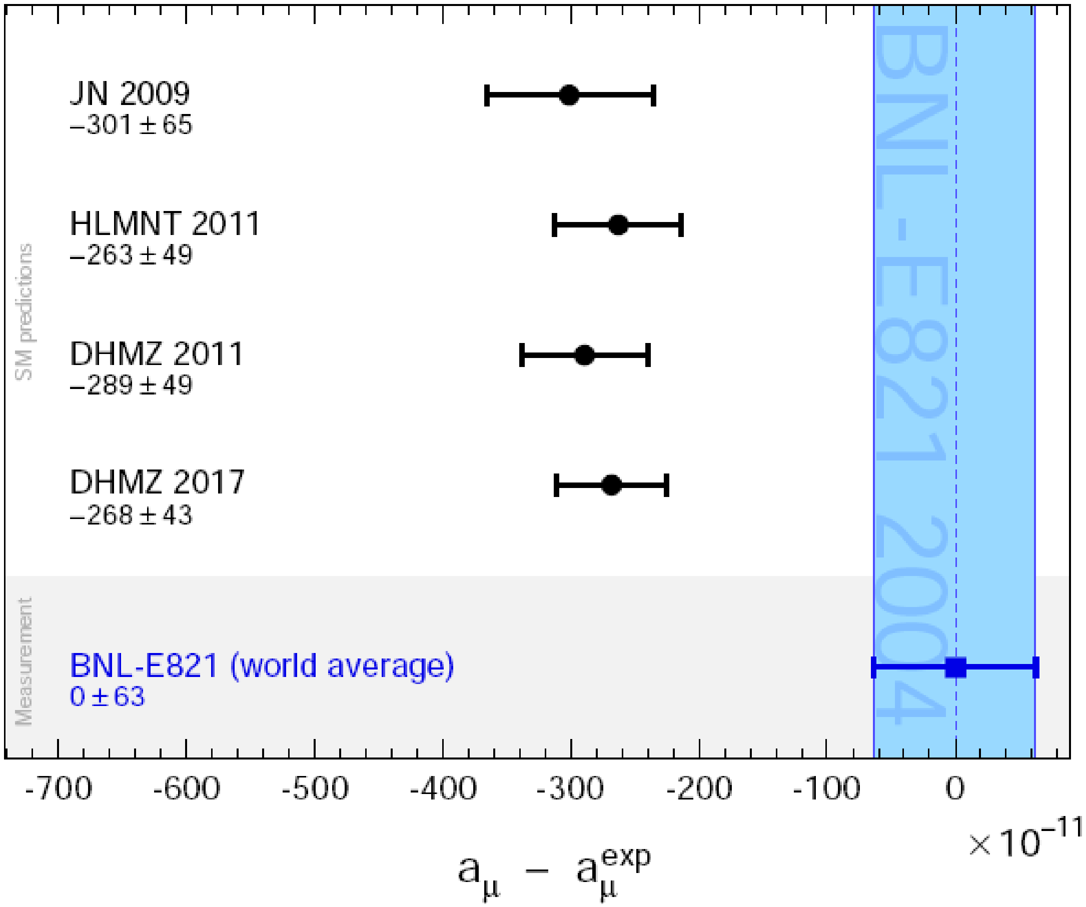
$$\alpha_\mu^{SM} = \alpha_\mu^{QED} + \alpha_\mu^{had} + \alpha_\mu^{weak}$$

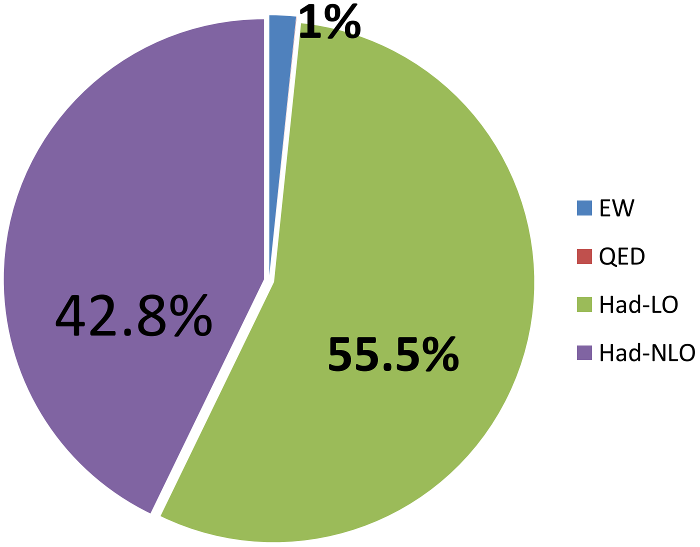
$$\alpha_\mu^{had} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{K(s)}{s^2} \boldsymbol{R(s)}$$

$\alpha_\mu^{SM} \neq \alpha_\mu^{exp}$

$\Rightarrow$ New physics

Motivations





PDG2018: 3.5σ deviation

$$\Delta\alpha_\mu = \alpha_\mu^{exp} - \alpha_\mu^{SM} = (268 \pm 63 \pm 43) \times 10^{-11}$$

$\pm$ exp.$\pm$ theo.

BESIII *R* scan

- Phase I: test run (2012)

  @ Ecm = 2.232, 2.4(2), 2.8, 3.4(2) GeV , 6 energy points, ~12/pb

  (two separate beam samples at 2.4 and 3.4 GeV)

- Phase II: fine scan for heavy charmonium line shape (2014)

  @ 3.800 – 4.590 GeV, 104 energy points,

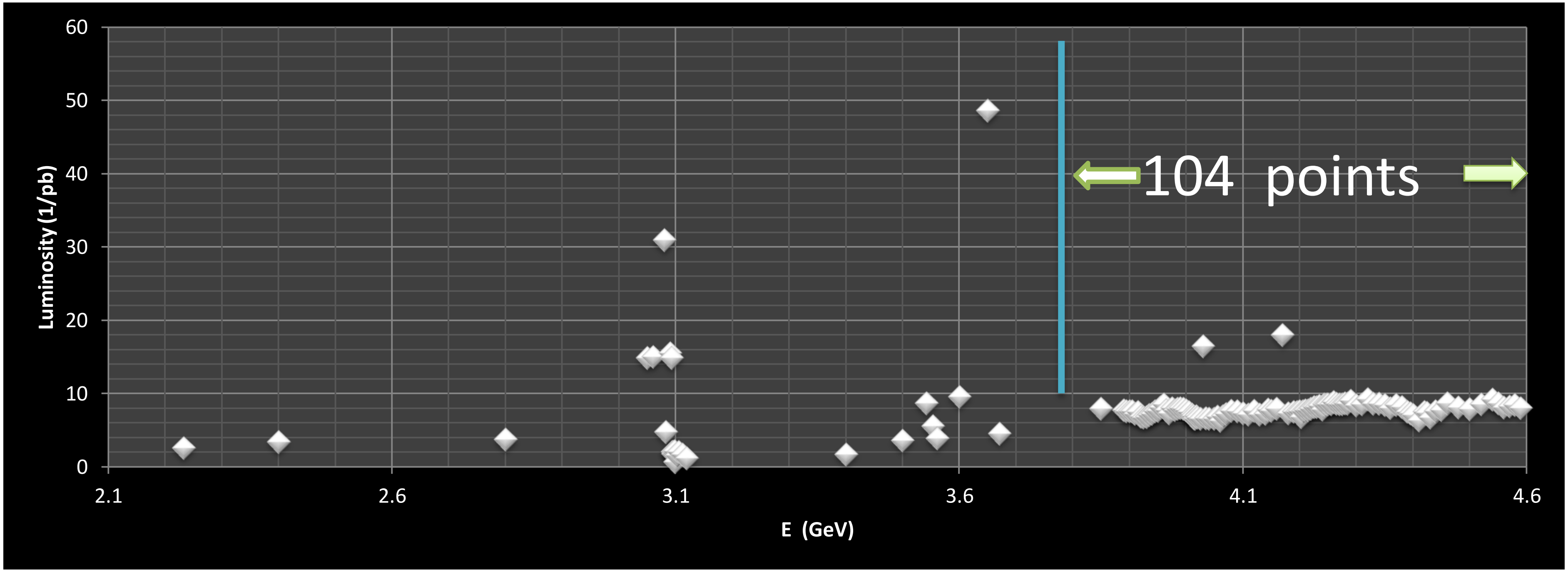
  ~ 800/pb

- Phase III: R&QCD scan (2015)

  @ 2.000 – 3.080 GeV, 21 energy points, ~ 500/pb

BESIII R scan

2013—2014: $\sqrt{s} = 2.2324 \sim 4.5$ GeV, at 131 energy points with total $\mathcal{L} = 1036.3\ \mathrm{pb}^{-1}$



Above 4.0 GeV, XYZ data with large luminosity can be used for R-value experiment

R value experiment

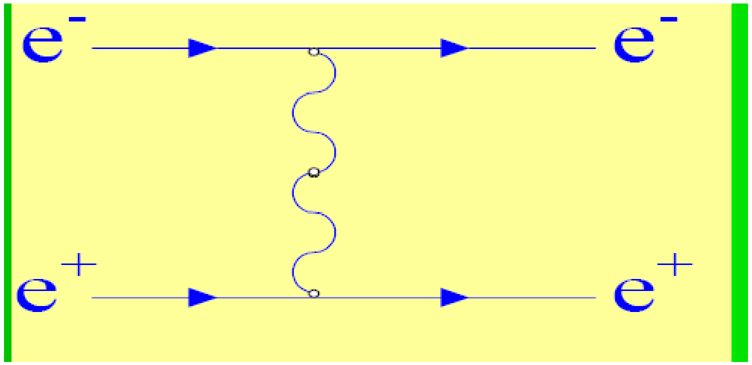
In experiment, R values are measured with

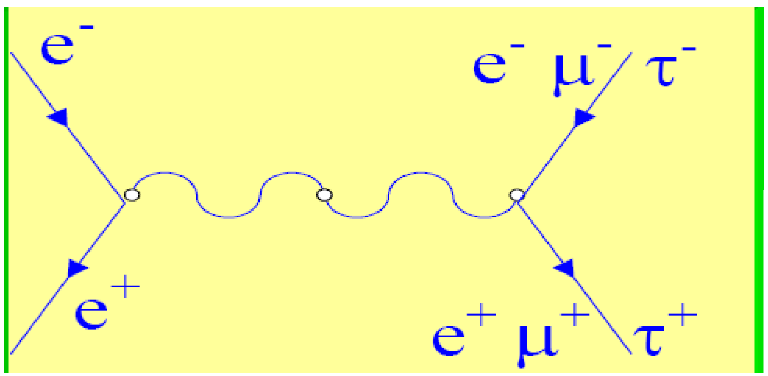
$$R = \frac{1}{\sigma_{\mu+\mu-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

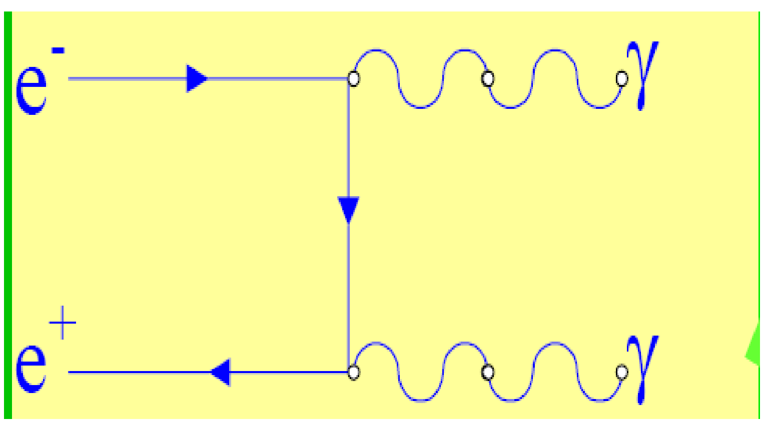
Tasks in experiment:

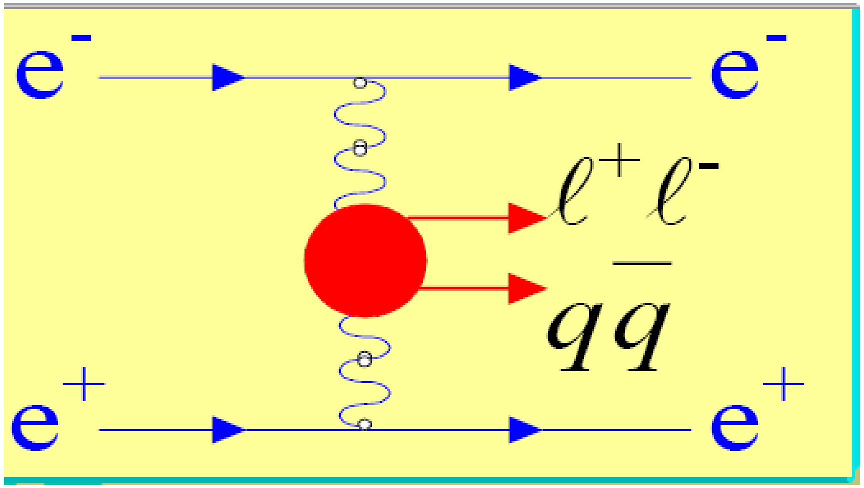
N_{had}	hadronic events
N_{bg}	background events
L	integrated luminosity
ε_{had}	detection efficiency
$1+\delta$	radiative correction factor
$\sigma_{\mu\mu}$	Born cross section of μ pair production in QED

Subtract background events

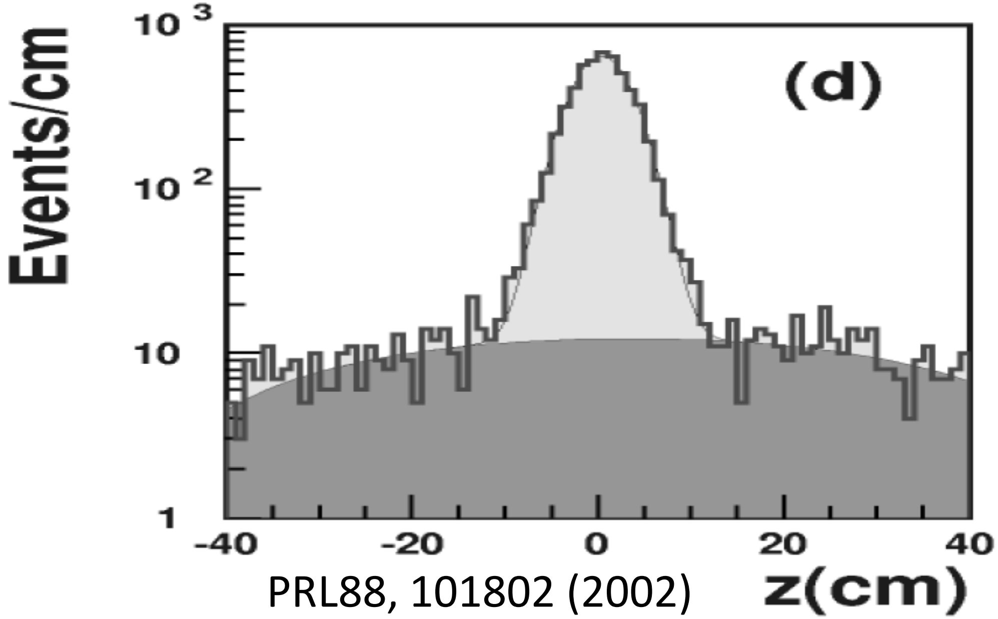






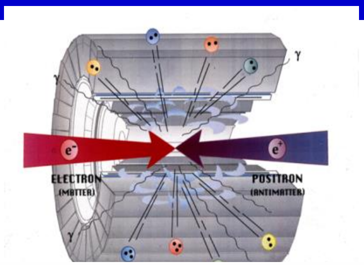


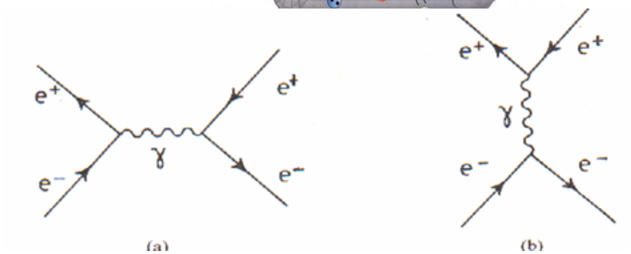
Beam associated background, e.g. BESII R-value

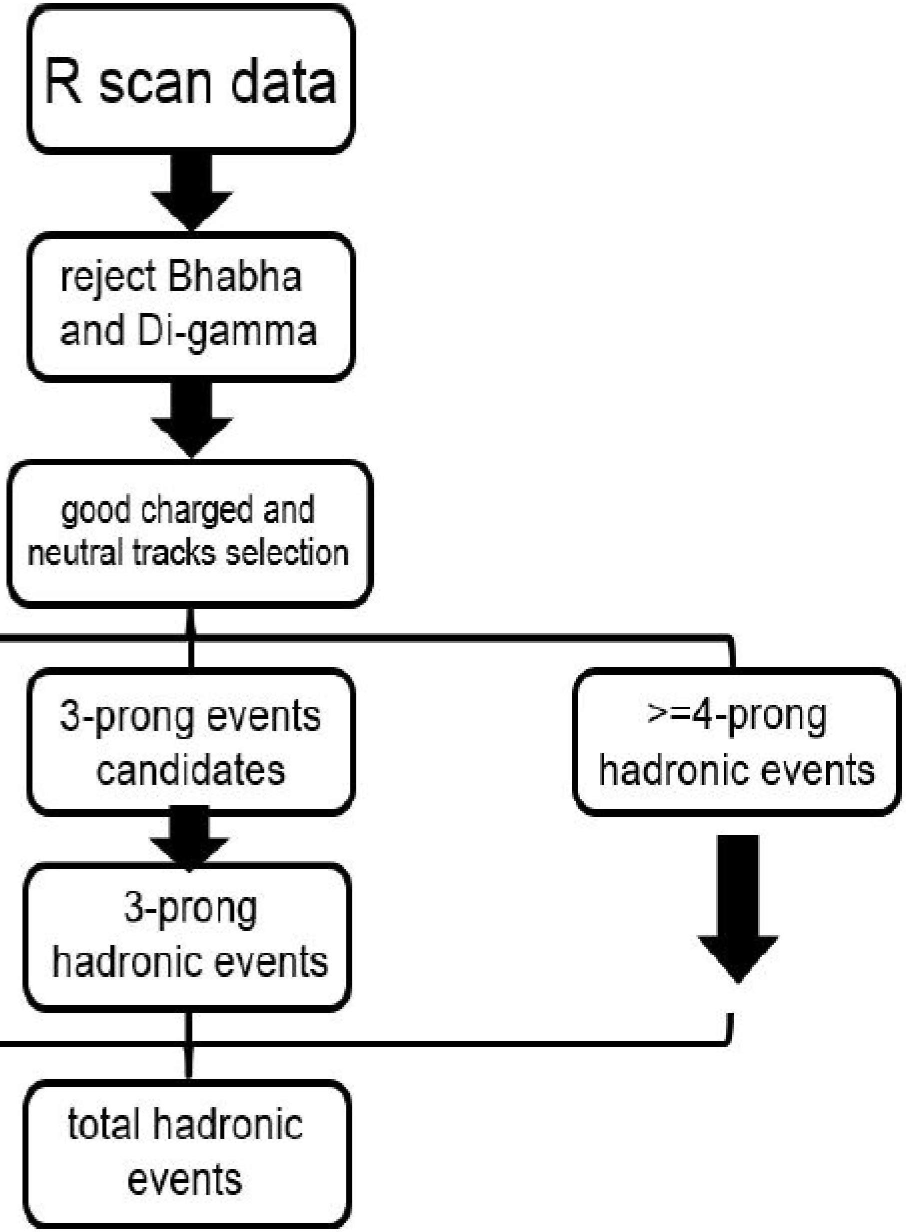


PRL88, 101802 (2002)

Hadronic event selection

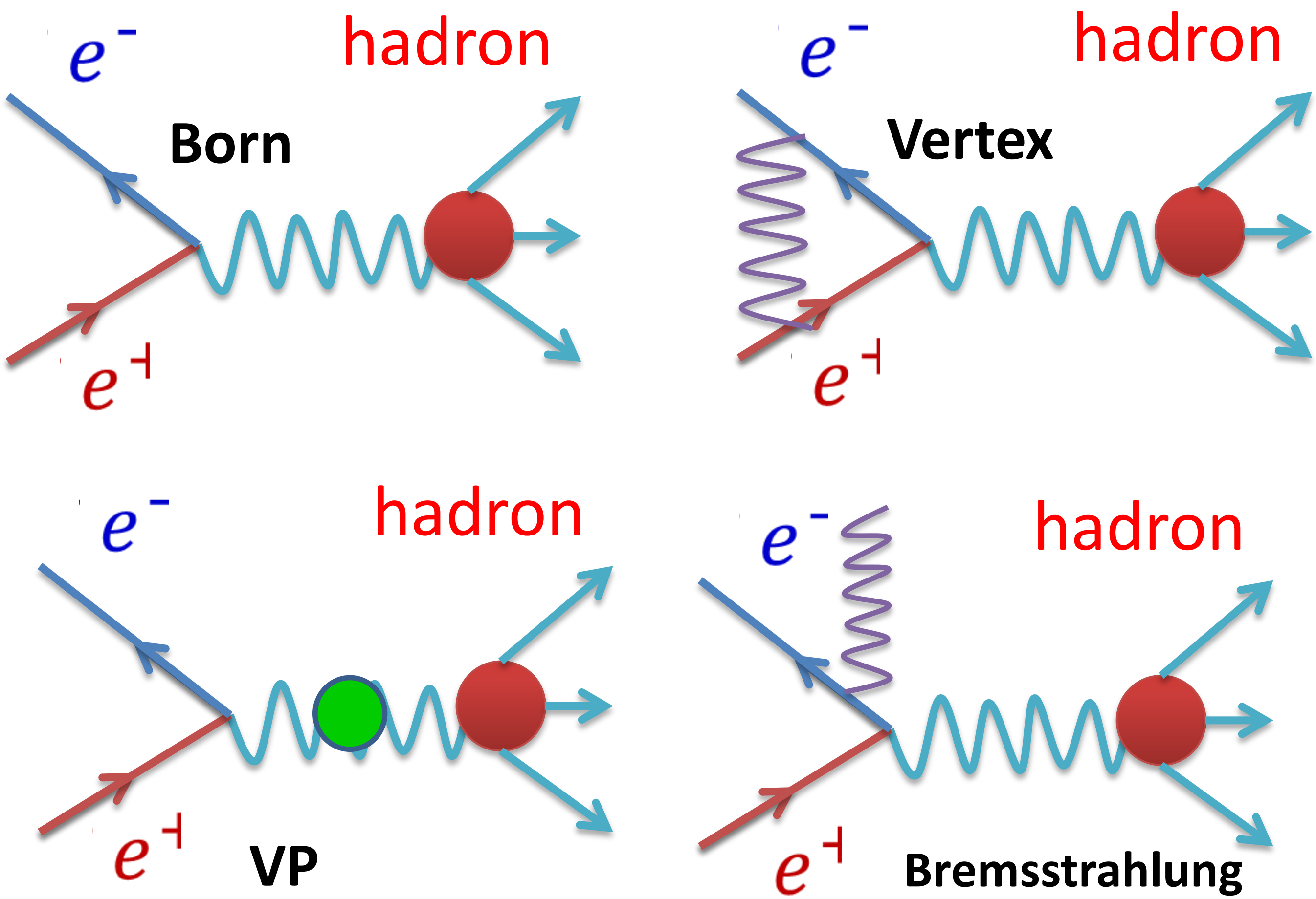






Initial state radiation correction

ISR: remove high order effects from $\sigma_{had}^{obs} = \sigma_{had}^{0}\epsilon(1+\delta)$. Leading order [$O(\alpha^2)$ diagram(a)], all the high order contributions



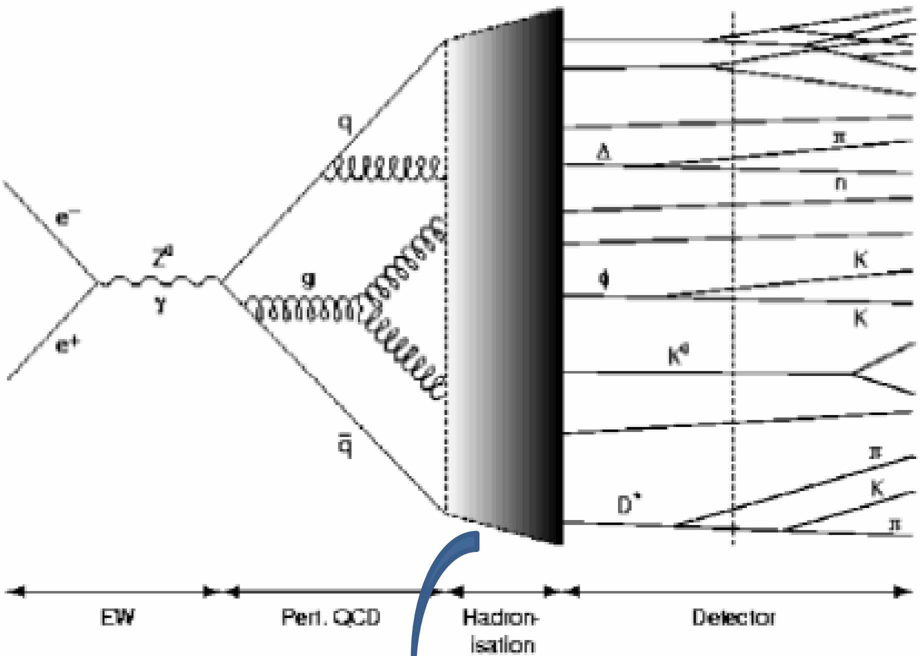
Initial state radiation correction

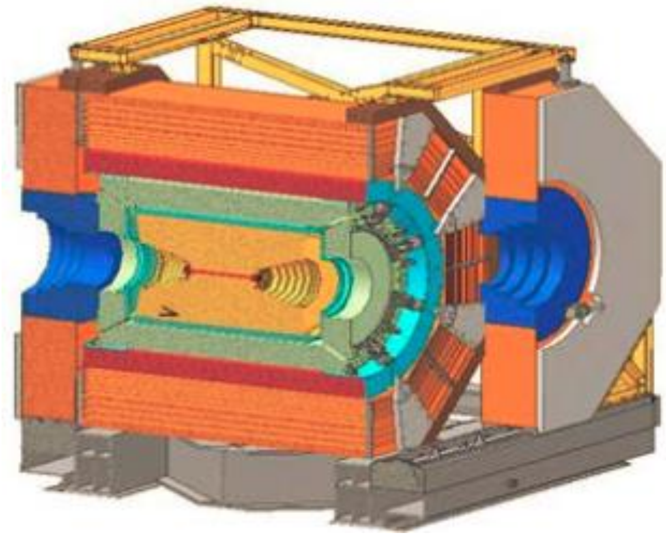
- Fourschemes are compared to calculate ISR.
  - G.Bonneauand F. Martin, NP B 27(1971)387
  - F.A. Berends and R. Kleiss, NP B 178(1981)14
  - E. A. Kuraev and V.S. Fadin, Sov. J. NP 41(1985)3
  - A. Osterheld et al., SLAC-PUB-4160, 1986. (T/E)

- (2) + multi-soft photon = (4)

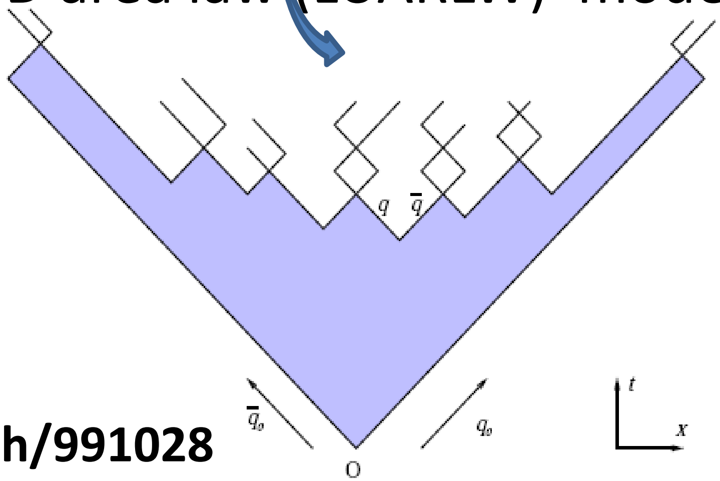
- (1) –(4) are consistent within1%in the continuum region

Hadronic event generation in e^+e^- conlisions





LUND area law (LUARLW) model



hep-ph/991028

Multiplicity distribution of primary hadron:

$$P(n) = \frac{\mu^n}{n!}\exp[c_0 + c_1(n-\mu) + c_2(n-\mu)^2]$$

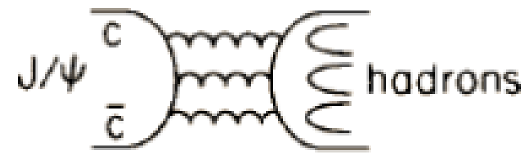
with $\mu = a + b\ \ln s + c\ \ln^2 s$.

Parameters $a, b, c, c_0, c_1,$

Event type generated by LUARLW

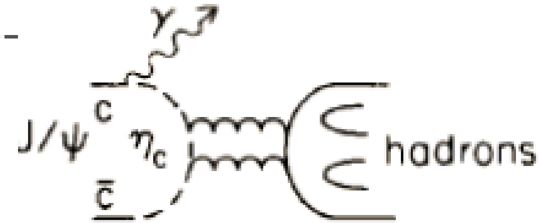
$$e^+e- \Rightarrow \gamma^* \Rightarrow \rho(770), \omega(782), \phi(1020), \omega(1420), \rho(1450), \omega(1650), \phi(1680), \rho(1700)$$

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ gq\bar{q} \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ ggq\bar{q} \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \end{cases}$$

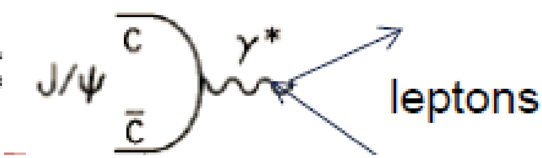


$$e^+e^- \rightarrow \gamma^* \rightarrow J/\psi \text{ or } \psi(2S) \text{ or } \psi(3770)$$

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



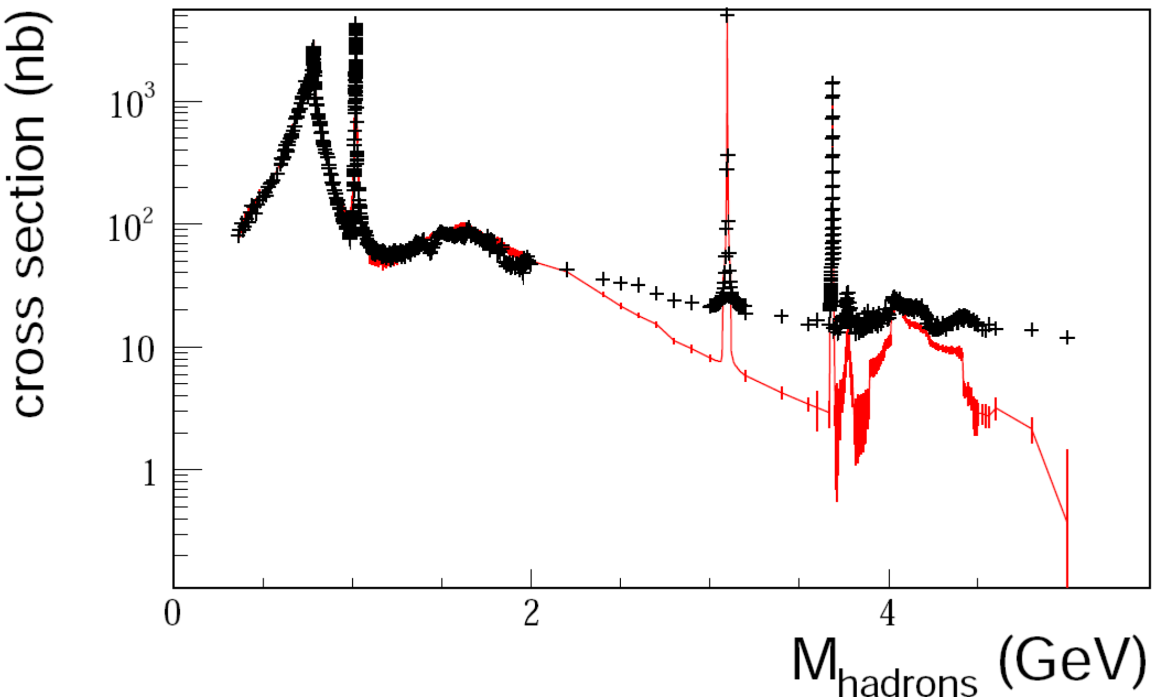
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s; \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*; \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*,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



Generate hadronic events with hybrid generator

+: cross section from *R*-value measurement

+: Sum of exclusive cross section (76 modes)



- PHOKHARA
  (Phys.Rev.D75:074026)

$$e^+e^- \to K^+K^-,$$
$$e^+e^- \to K_S^0\overline{K}_S^0,$$
$$e^+e^- \to \gamma\pi^+\pi^-,$$
$$e^+e^- \to \pi^+\pi^-\pi^0,$$
$$e^+e^- \to \Lambda\overline{\Lambda}$$

- ConExc:
  (Chin.Phys. C38, 083001)

71 exclusive modes

Known:
Missing:

PHOKHARA + ConExc + LUARLW

Components of hybrid generator

- ISR : up to α^2 accuracy with radiative functions
- VP : HADR5N
- ISR factor: with R-related cross section
- Known decay: PHOKHARA + ConExc
- Missing decay: LUNDARLW controlled by 12 parameters
- Optimize parameters with response function

$$f(\boldsymbol{p}_0 + \delta\boldsymbol{p}, x) = a_0^{(0)}(x) + \sum_{i=1}^{n} a_i^{(1)}(x)\delta p_i + \sum_{i=1}^{n}\sum_{j=i}^{n} a_{ij}^{(2)}(x)\delta p_i \delta p_j \approx MC(\boldsymbol{p}_0 + \delta\boldsymbol{p}, x),$$

Chin.Phys. C40, 113002

Optimize LUARLW parameters in hybrid generator

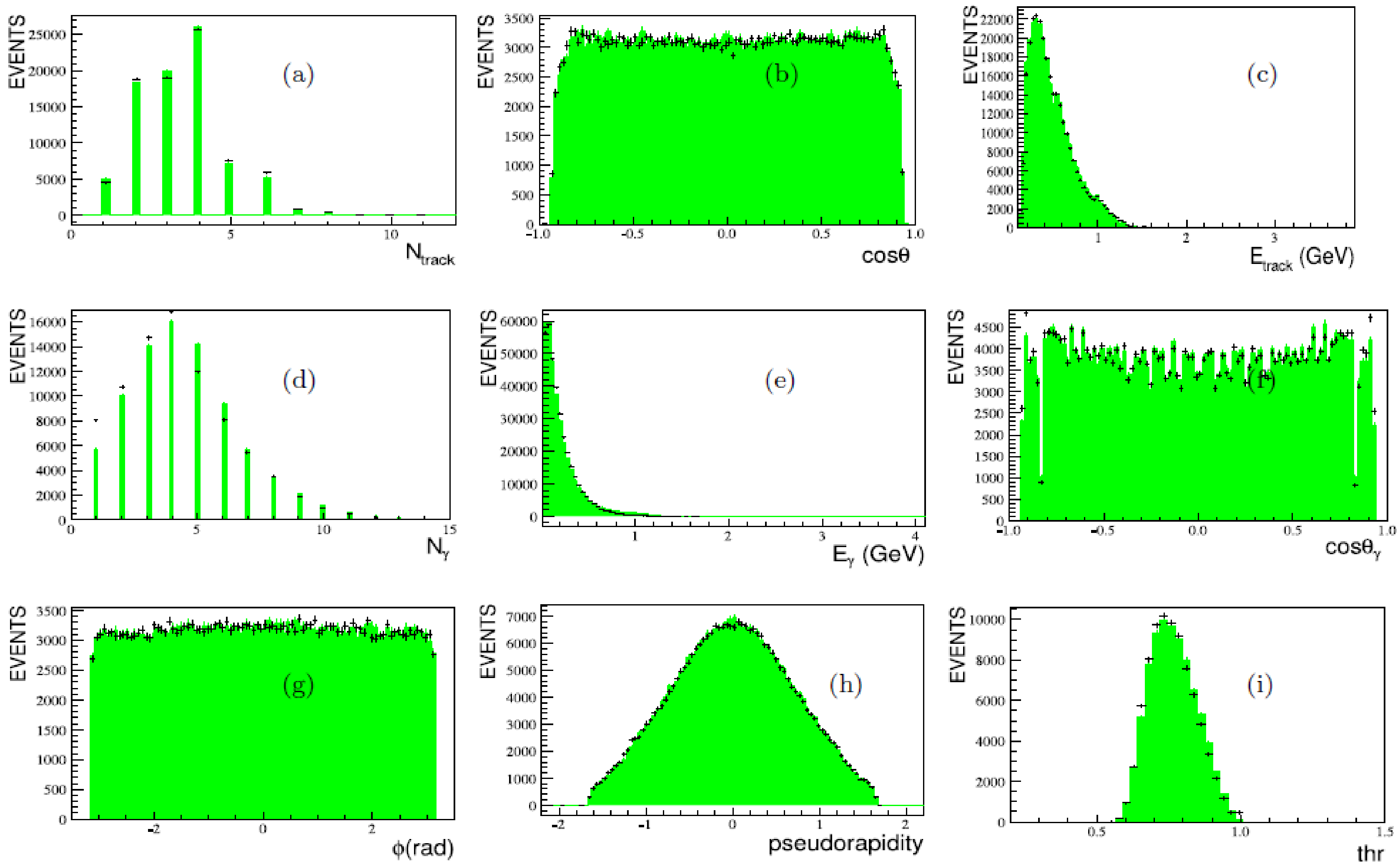


Fig. 5. Comparison of data to the MC distributions at 3.06 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, . (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine of polar angle of photons, (g)azimuthal distribution, (h) pseudorapidity and (g) thrust. Where the points with errors are data, and shaded histogram is MC distribution.

Summary

- **R scan data collected at 131 energies.**
- **The integrated luminosity are measured with about 1% precision for all points.**
- **The parameters of generator LUARLW are optimized**
- **The hybrid generator parameters are optimized**
- **The memo of R value measurement between 2.232–3.671 GeV is being reviewed in BES Collaboration.**
- **The data analysis for 3.85 – 4.59 GeV at 104 energies are in progress.**

Thanks for your attention