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Measurement of R value at BESIII

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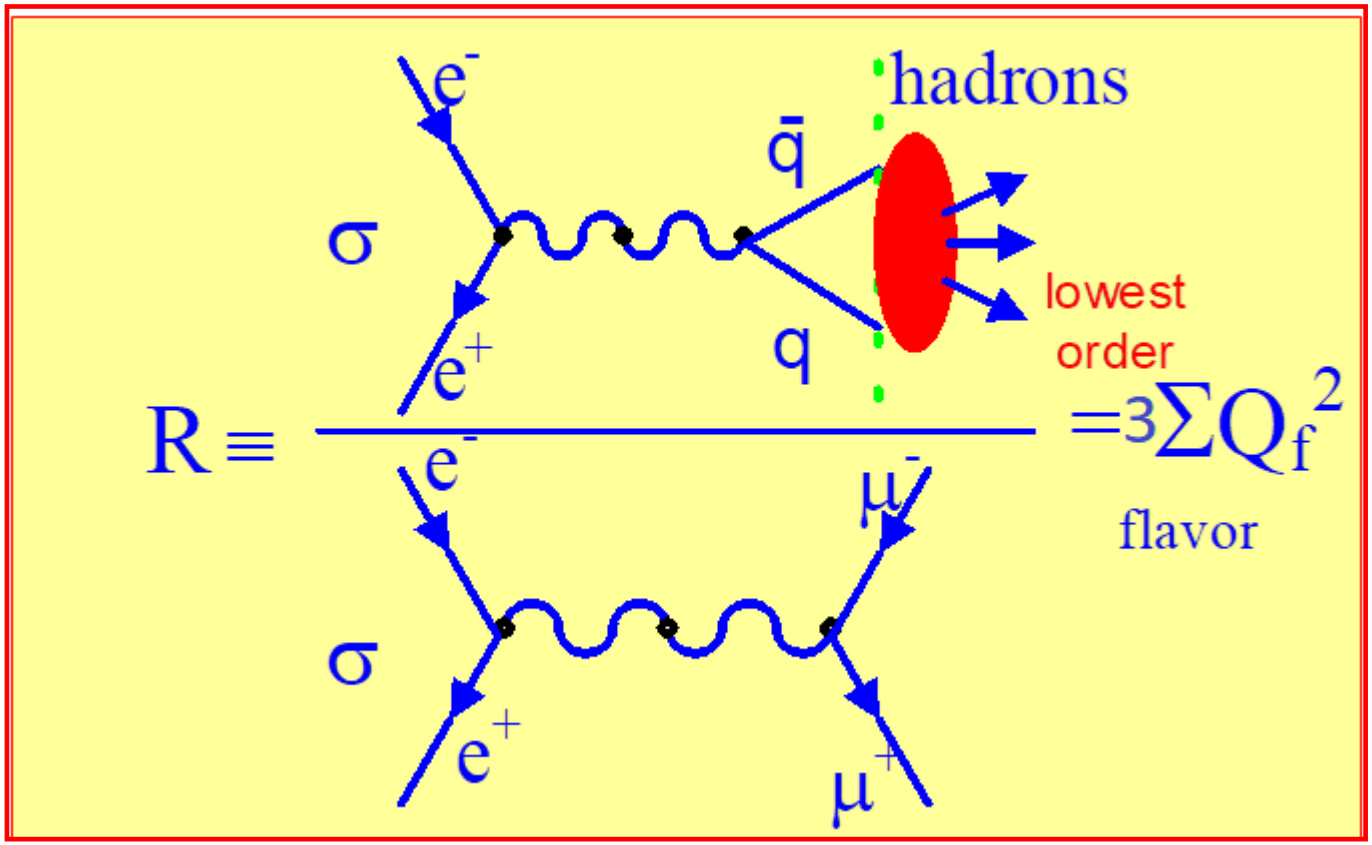
Definition of R-Value

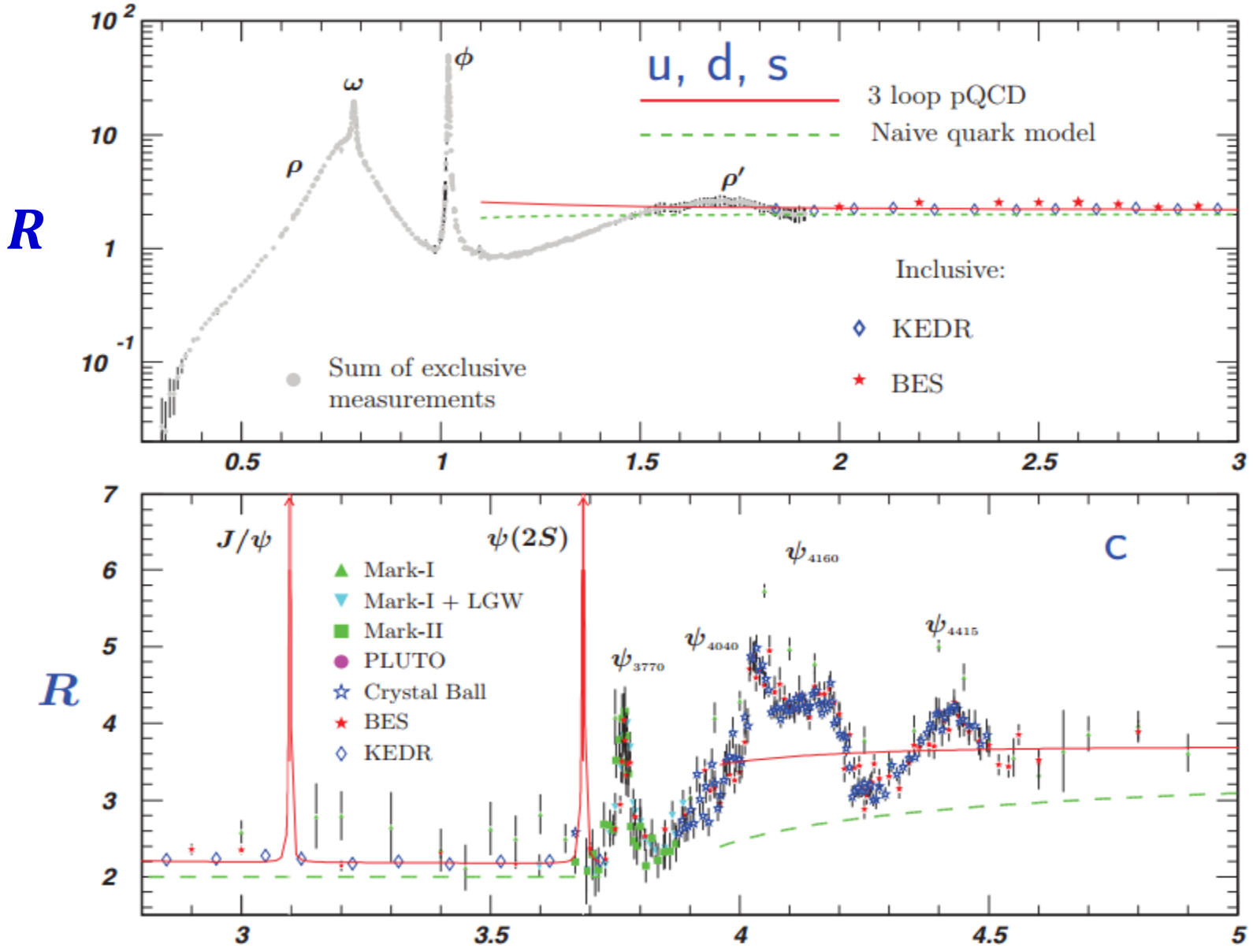


$R = 3[(2/3)^2 + (1/3)^2 + (2/3)^2] = 2$ for u, d, s

$= 2 + 3(2/3)^2 = 10/3$ for u, d, s, c

$= 10/3 + 3(1/3)^2 = 11/3$ for $u, d, s, c\ b$.

R-Value below 5.0 GeV



Motivations

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

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

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

- **Hunting for new physics from $g_\mu - 2$**

$$\boldsymbol{a_\mu = \frac{g_\mu - 2}{2}}, \qquad a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$

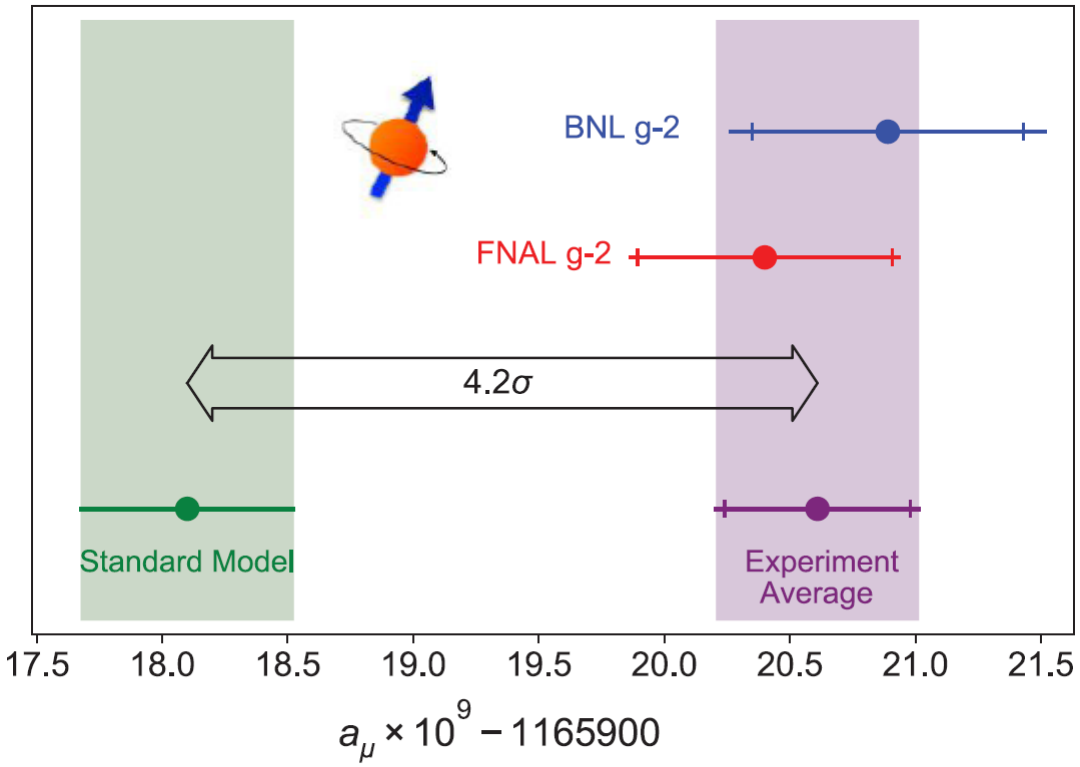
$$a_\mu^{\text{had}} = \left(\frac{a^2}{3\pi^2}\right) \int_{4m_\pi^2}^{\infty} ds \frac{K(s)}{s^2} \boldsymbol{R(s)}$$

$a_\mu^{\text{SM}} \neq a_\mu^{\text{exp}}$
$\Rightarrow$ New physics

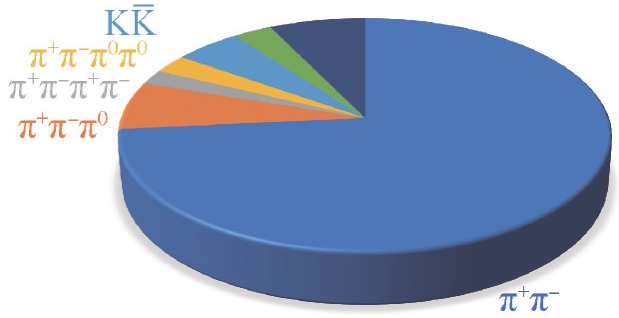
Muon anomalous magnetic moment

$$\vec{\mu} = \boldsymbol{g}\left(\frac{e}{2m}\right)\vec{S}$$

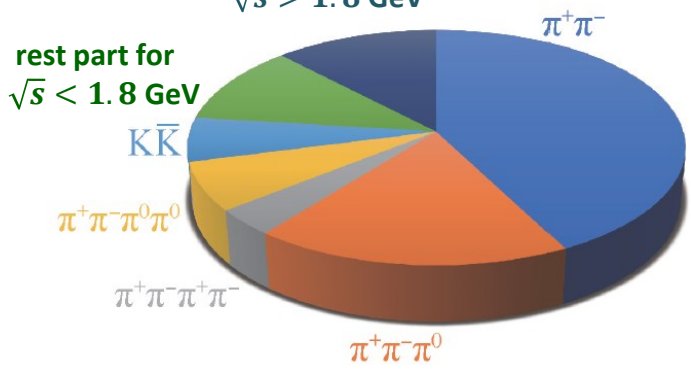
PRL126,141801(2021)



Individual contribution to a_μ



Individual contribution to uncertainty

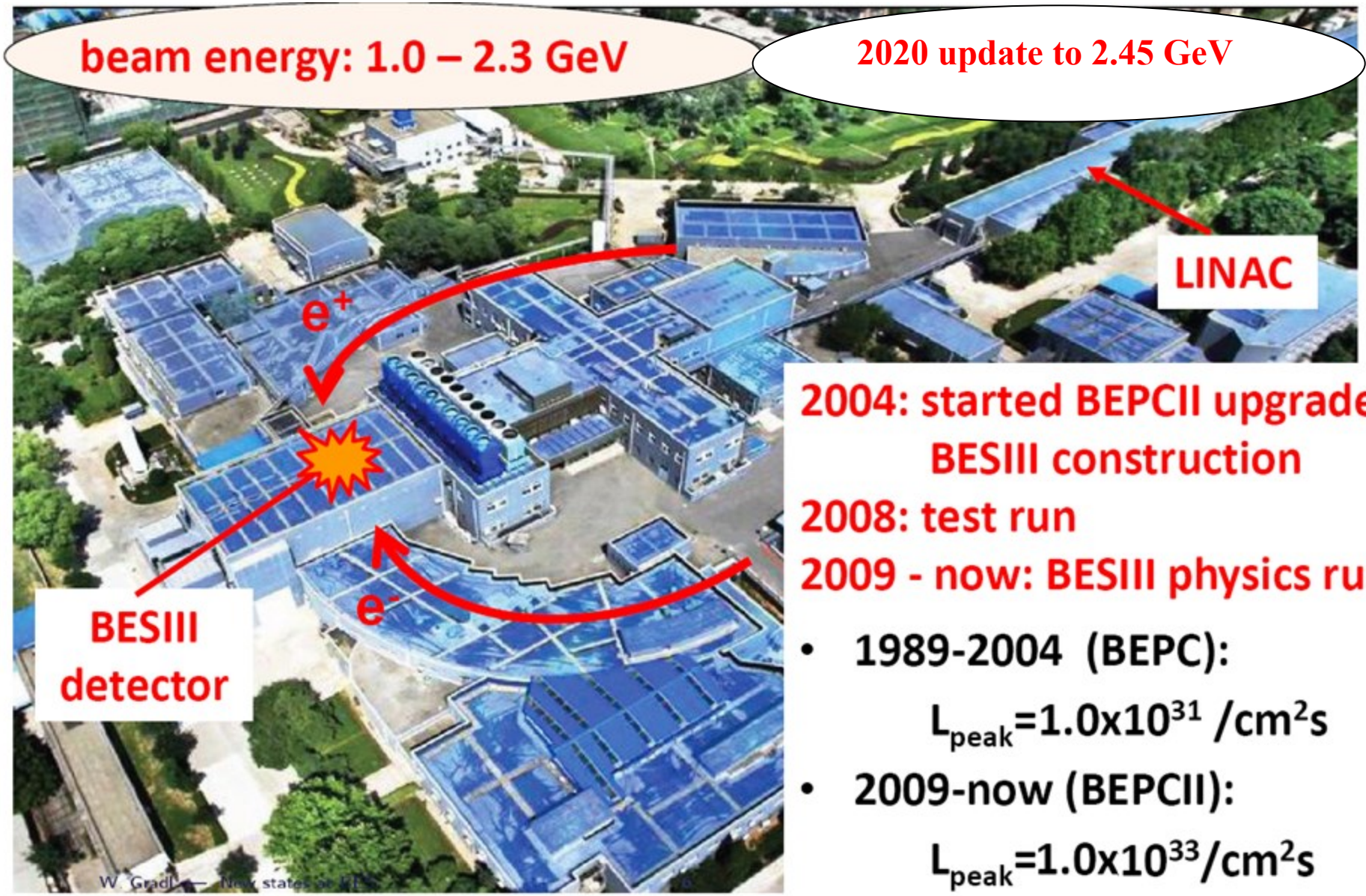


$$\boldsymbol{a_\mu(\mathrm{FNAL}) = 116\,592\,040(54) \times 10^{-11}}\ \textbf{(0.46 ppm)}$$

Difference between average and SM with 4.2σ

$$a_\mu^{exp} - a_\mu^{SM} = (251 \pm 59) \times 10^{-11}$$

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

- 1989-2004 (BEPC):

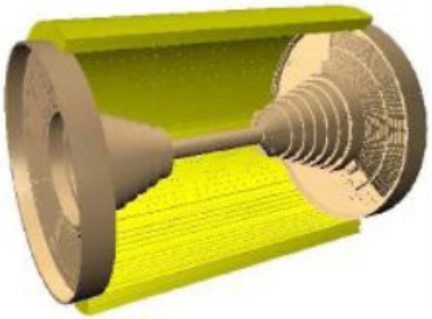
  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- 2009-now (BEPCII):

  $L_{peak}=1.0\times10^{33}$/cm^{2}s

BESIII Detector

MDC

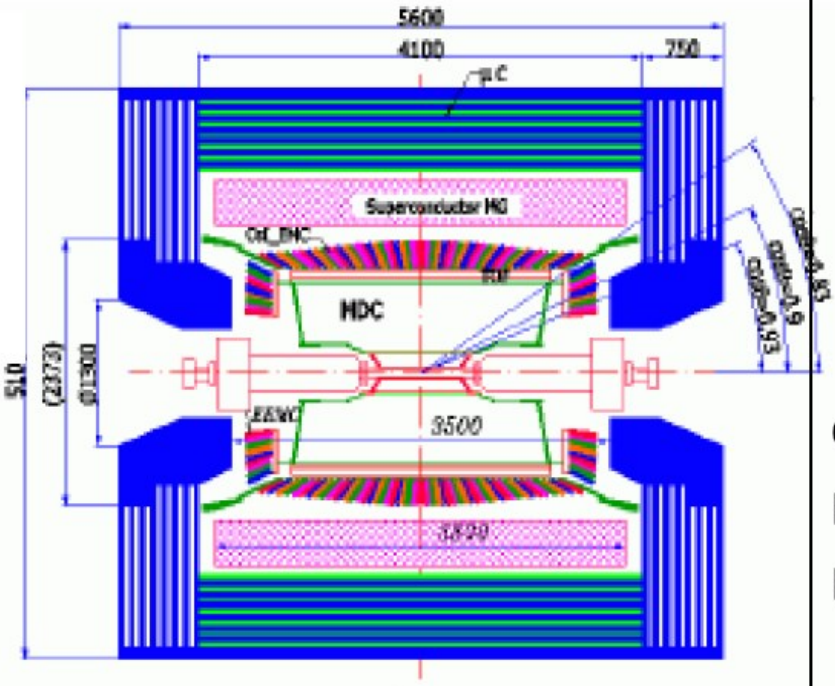


R inner: 63mm ;

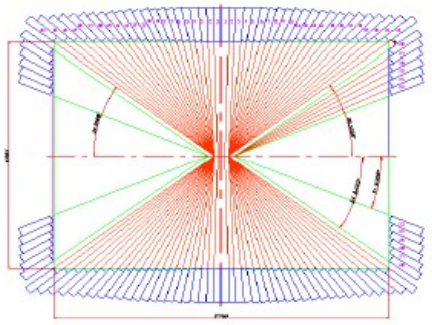
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



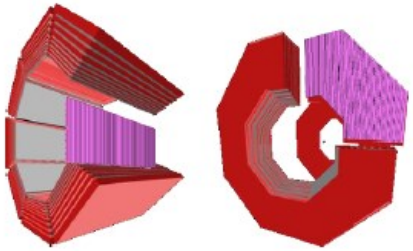
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

TOF

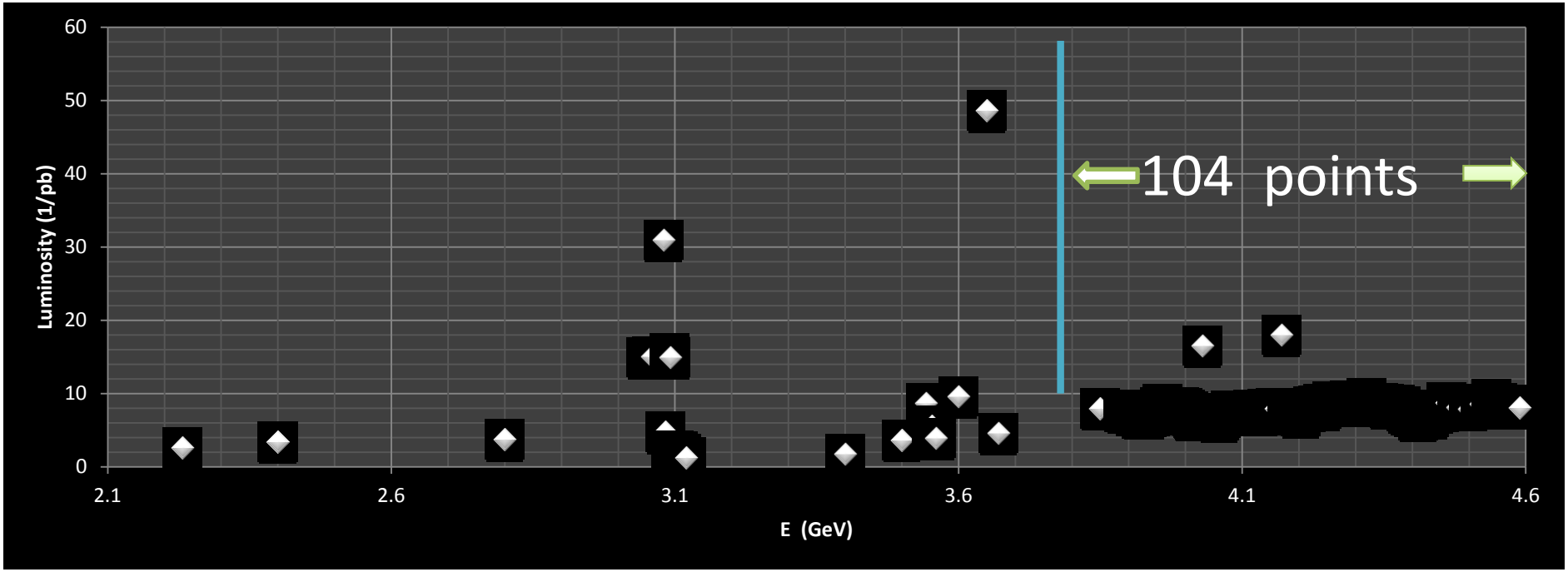
BTOF: two layers

ETOF: 48 scintillators for each

MRPC --- new ETOF

BESIII R-scan data sets

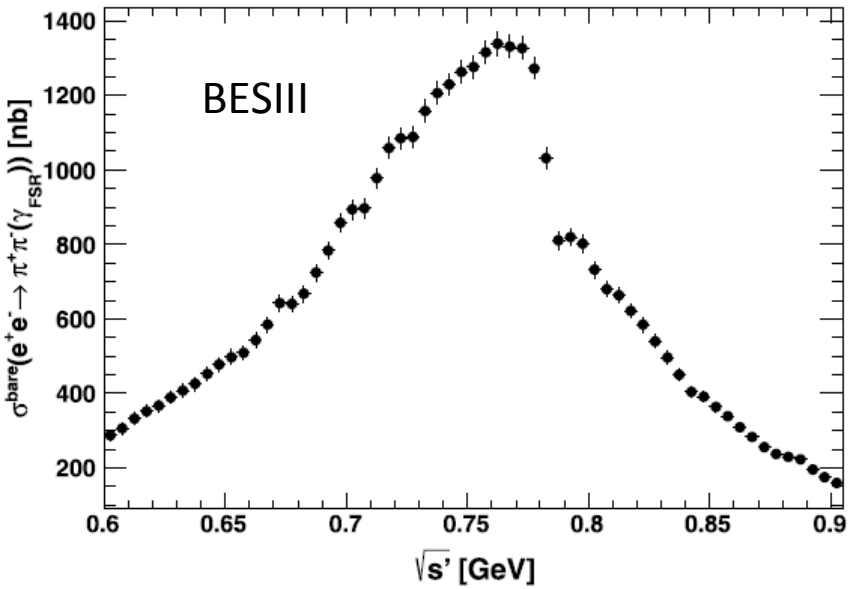
2013—2014: $\sqrt{s} = 2.2324 \sim 4.5$ GeV, at 131 energy points with total $\mathcal{L} = 1036.3\ \mathrm{pb}^{-1}$

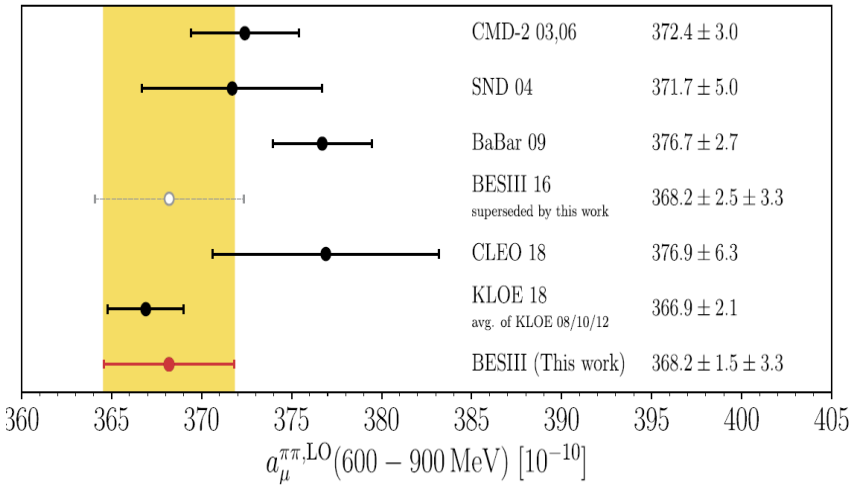


Above 4.0 GeV, XYZ data with large luminosity can be used for R-value experiment

Recent results of exclusive measurements

BESIII, PLB753, 629 (2016)
BESIII, PLB812, 135982 (2021)





- $e^+e^- \to \pi^+\pi^- (\gamma_{ISR})$
  - $\sqrt{s} = 0.6 \sim 0.9$ GeV,
  - ISR method, data 2.93 fb^{-1} @3.773 GeV
  - Systematic uncertainty of 0.9%
  - Contribution to muon anomalous magnetic moment:

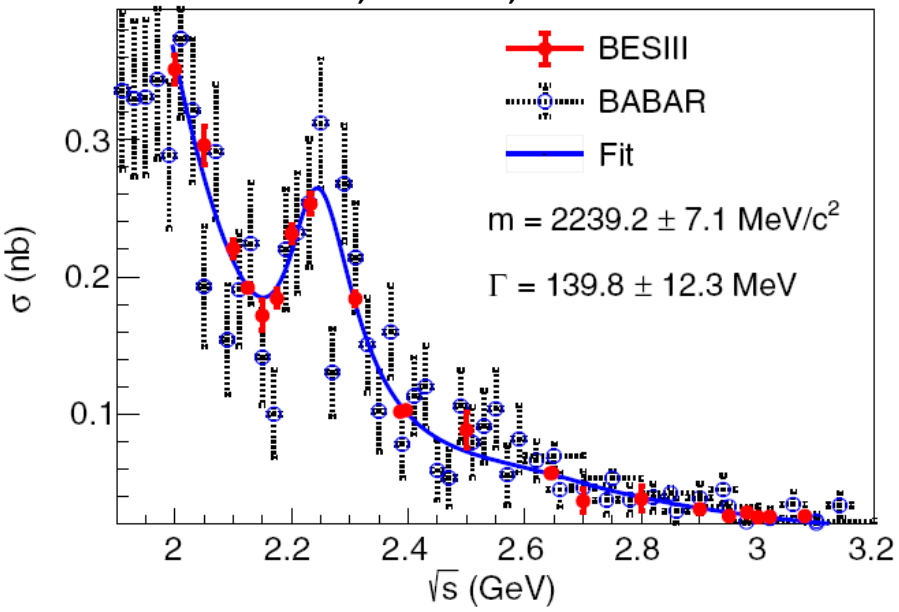
$$a_\mu^{\pi\pi,\mathrm{LO}}(600-900\ \mathrm{MeV})$$

$$= \frac{1}{4\pi^3}\int_{(600\ \mathrm{MeV})^2}^{(900\ \mathrm{MeV})^2} \mathrm{d}s'\, K(s')\,\sigma^{\mathrm{bare}}(e^+e^-\to\pi^+\pi^-(\gamma_{\mathrm{FSR}}))$$

$$= \left(368.2 \pm 1.5_{\mathrm{sta}} \pm 3.3_{\mathrm{sys}}\right) \times 10^{-10}$$

Recent results of exclusive measurements

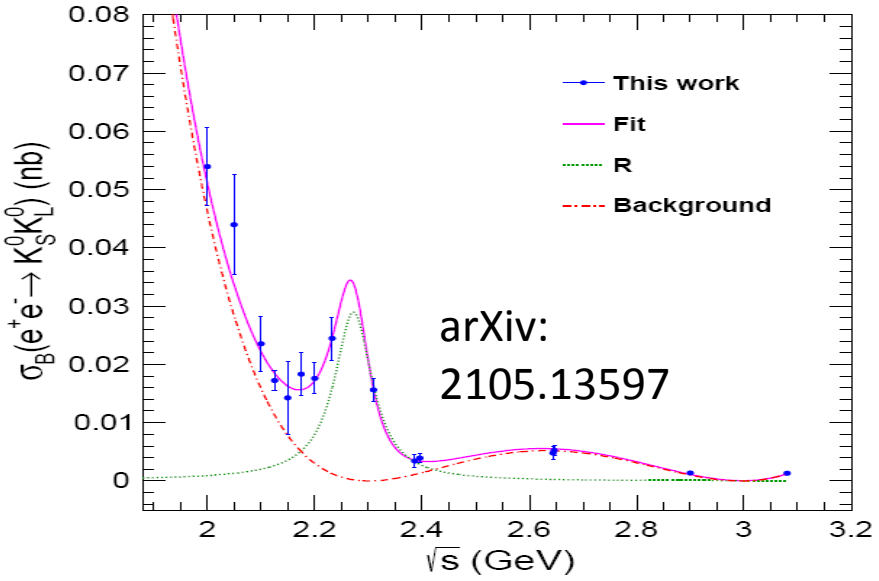
BESIII, PRD99,032001



- $e^+e^- \to K^+K^-$
  - $\sqrt{s} = 2.0 \sim 3.08$ GeV, 22 energy points
  - Consistent with Babar, but best precision
  - One structure:

m = 2239.2 ± 7.1 MeV/c²

Γ = 139.8 ± 12.3 MeV

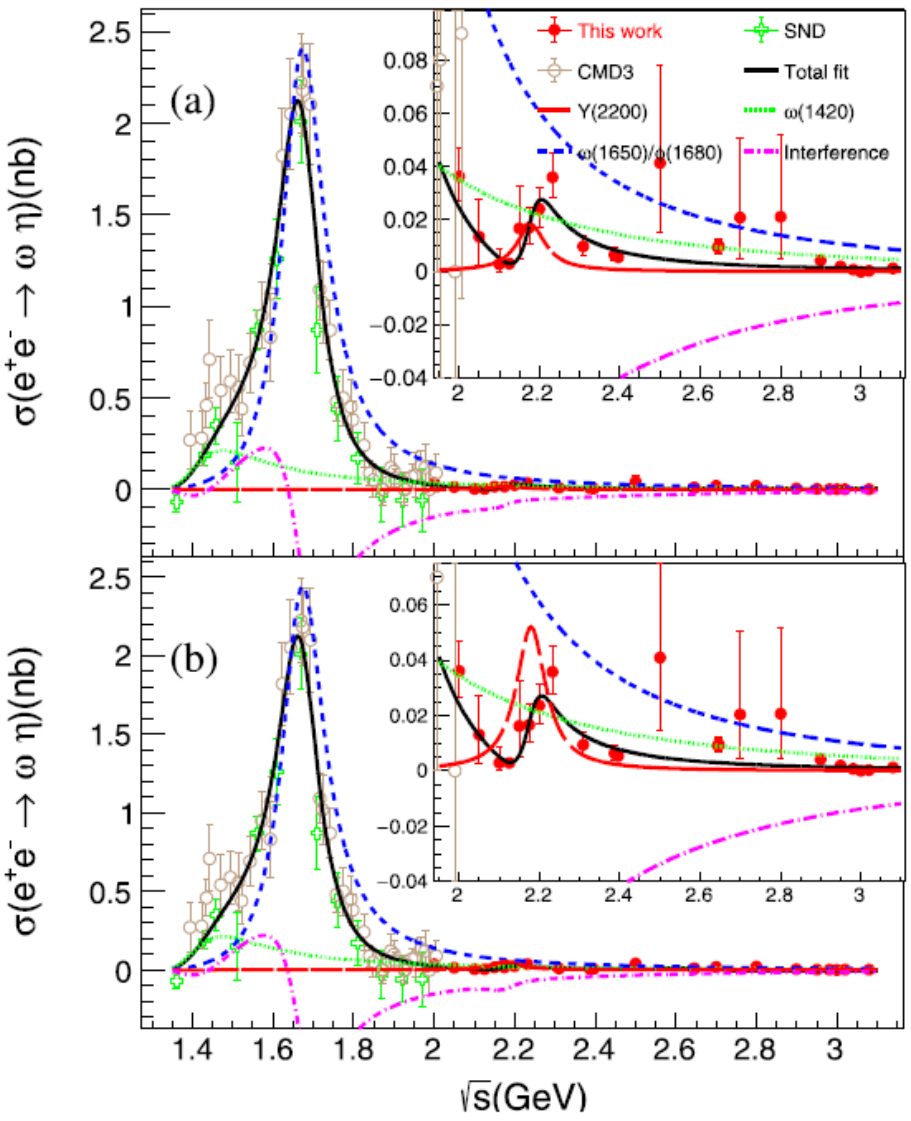


- $e^+e^- \to K_S^0K_L^0$
  - $\sqrt{s} = 2.0 \sim 3.08$ GeV, 22 energy points
  - Consistent with Babar, but best precision
  - One structure:

$$m = 2273.7 \pm 5.7 \pm 19.3\ \text{MeV}$$
$$\Gamma = 86 \pm 44 \pm 51\ \text{MeV}$$

Recent results of exclusive measurements

BESIII, PLB813,136059



- $e^+e^- \to \omega\eta$
  - $\sqrt{s} = 2.0 \sim 3.08$ GeV, 22 energy points
  - Consistent with SND measurements
  - One structure:

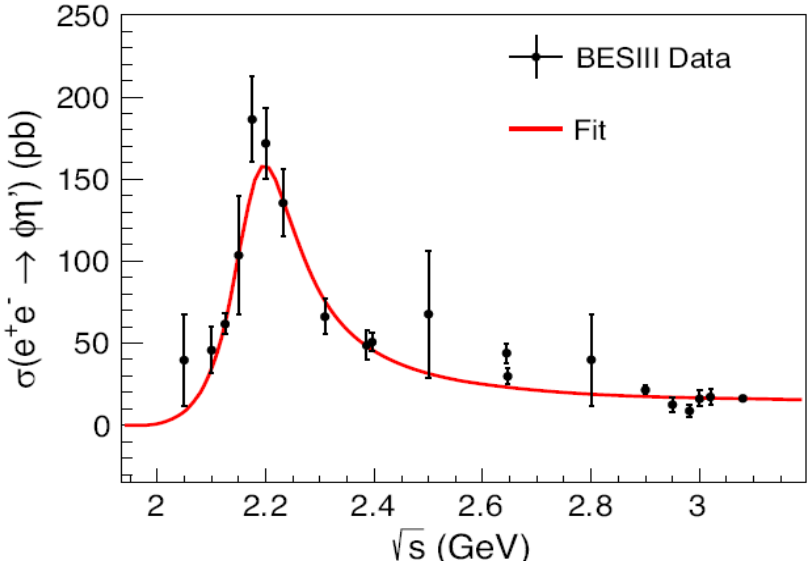
$$m = (2176 \pm 24 \pm 3)\text{MeV}$$
$$\Gamma = (89 \pm 50 \pm 5)\text{MeV}$$

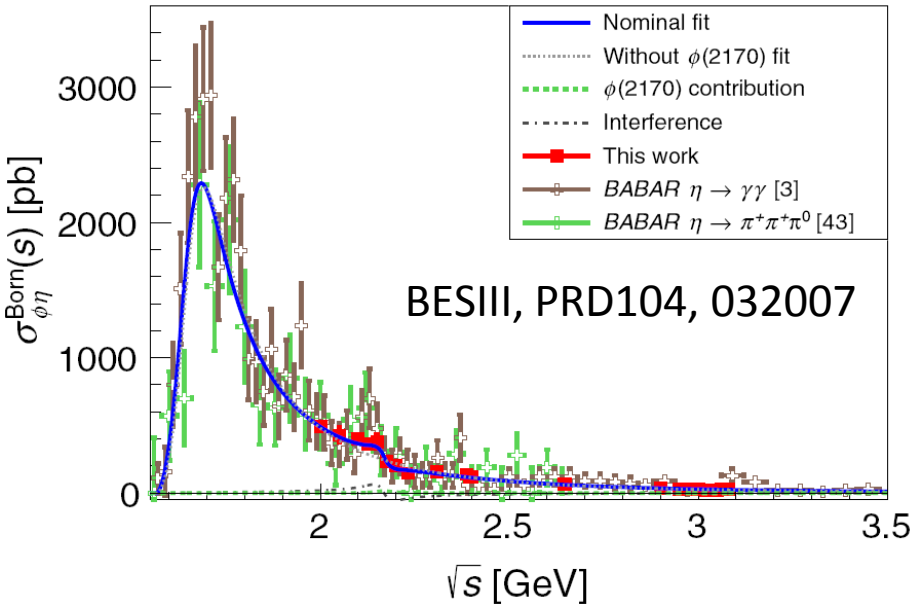
- $e^+e^- \to \omega\pi^0$
  - $\sqrt{s} = 2.0 \sim 3.08$ GeV, 22 energy points
  - Consistent with SND measurements
  - One excited ρ structure:

$$m = (2034 \pm 30 \pm 25)\text{MeV}$$
$$\Gamma = (34 \pm 11 \pm 16)\text{MeV}$$

Recent results of exclusive measurements

BESIII, PRD102, 012008





- $e^+e^- \to \phi\eta'$
  - $\sqrt{s} = 2.05 \sim 3.08$ GeV, 20 energy points
  - First measurements
  - One structure:

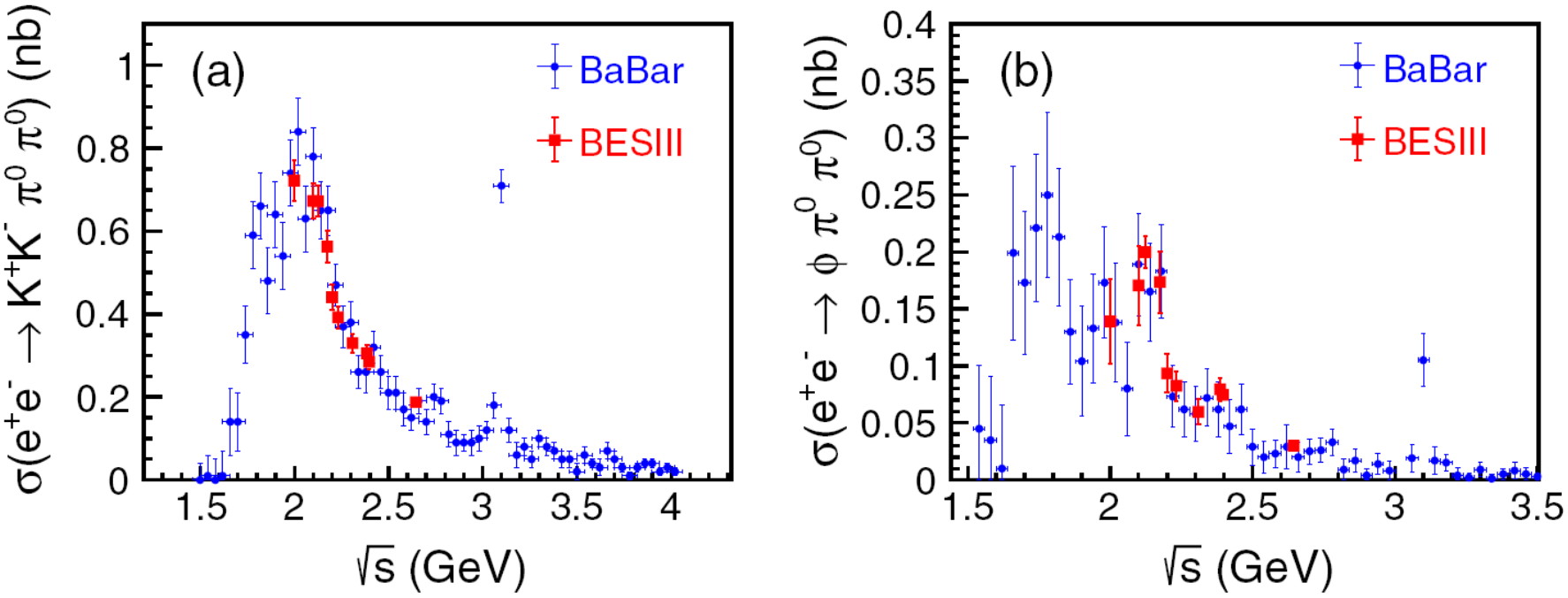
$$m = (2177.5 \pm 5.1 \pm 18.6)\text{MeV}$$
$$\Gamma = (149.0 \pm 15.6 \pm 8.9)\text{MeV}$$

- $e^+e^- \to \phi\eta$
  - $\sqrt{s} = 2.0 \sim 3.08$ GeV, 22 energy points
  - Consistent with Babar measurements
  - One excited ϕ structure:

$$m = (2163.5 \pm 6.2 \pm 3.0)\text{MeV}$$
$$\Gamma = (31.1^{+21.1}_{11.6} \pm 1.1)\text{MeV}$$

Recent results of exclusive measurements

BESIII, PRL124,112001(2020)



- $e^+e^- \to K^+K^-\pi^0\pi^0$ and $\phi\pi^0\pi^0$

  - ✓ $\mathcal{L} = 300/\text{pb}$ within $\sqrt{s} = 2.0 \sim 2.644$ GeV
  - ✓ Events with $K^+K^-\pi^0\pi^0$ final states are analyzed with PWA
  - ✓ Cross section via intermediate states, ϕ and excited Kaon states, are measured
  - ✓ A structure with $M = 2126.5 \pm 16.8 \pm 12.4$ MeV, $\Gamma = 106.9 \pm 32.1 \pm 28.1$ MeV, is observed
  - ✓ Cross sections are consistent with Babar measurements.

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 ($e^+e^- \to l^+l^-(X), \gamma\gamma$)

L integrated luminosity (at 1% precsion)

ε_{had} detection efficiency

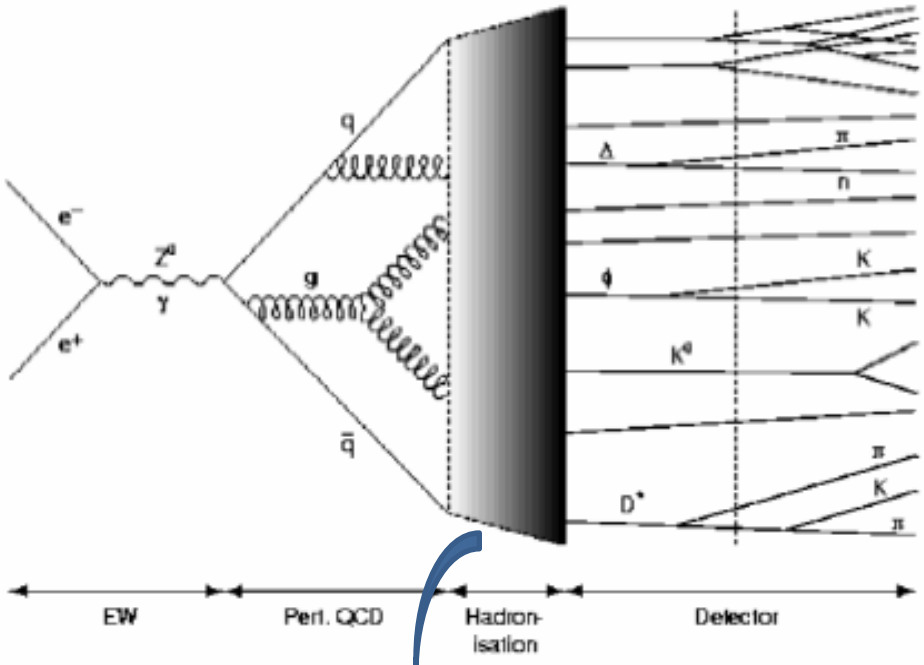
$1+\delta$ radiative correction factor (check with four schemes)

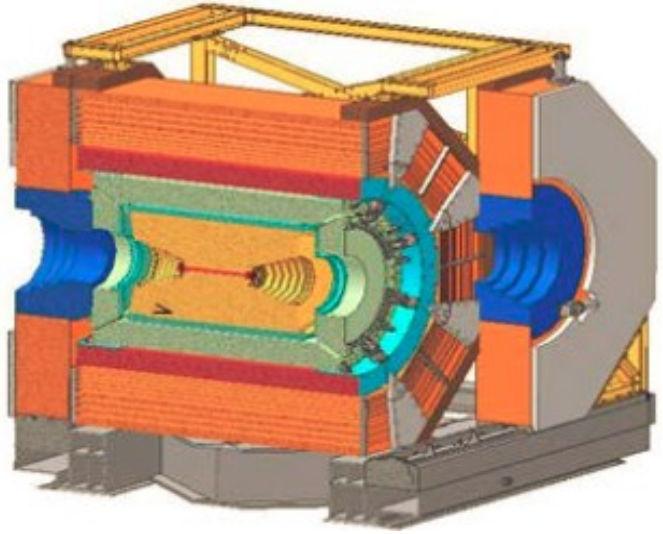
$\sigma_{\mu^+\mu^-}$ Born cross section of μ pair production in QED

To be released:

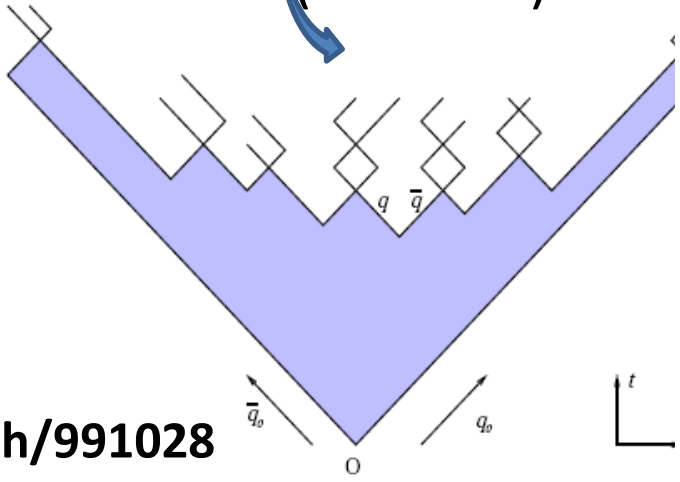
R value @14 energy points within $\sqrt{s} = 2.232$–3.671 GeV, with precision better than 3%.

Hadronic event generation in e^+e^- conlisions





LUND area law (LUARLW) model



hep-ph/991028

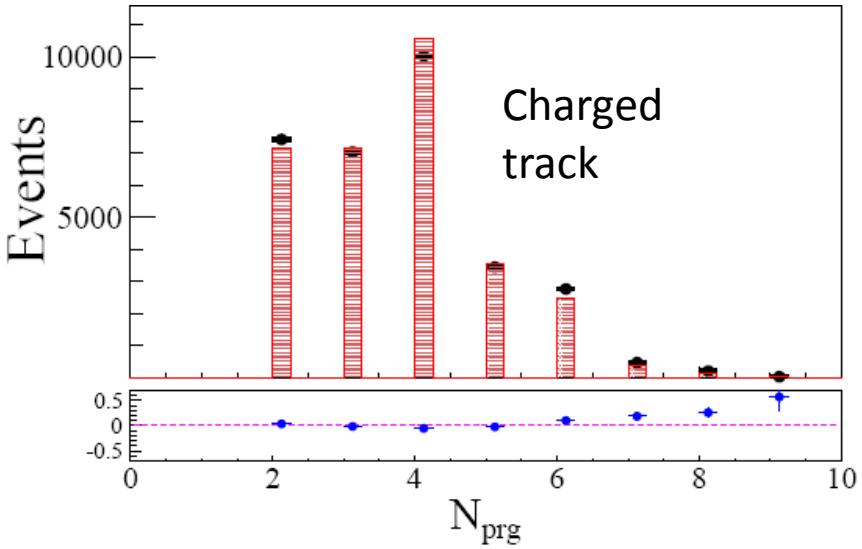
Multiplicity distribution of primary hadron:

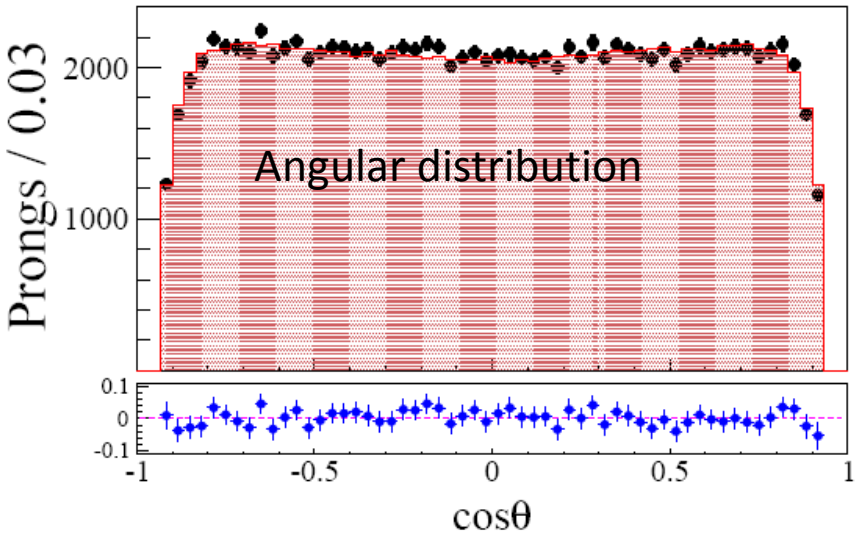
$$P(n) = \frac{\mu^n}{n!}\exp[c_0 + c_1(n-\mu) + c_2(n-\mu)^2]$$

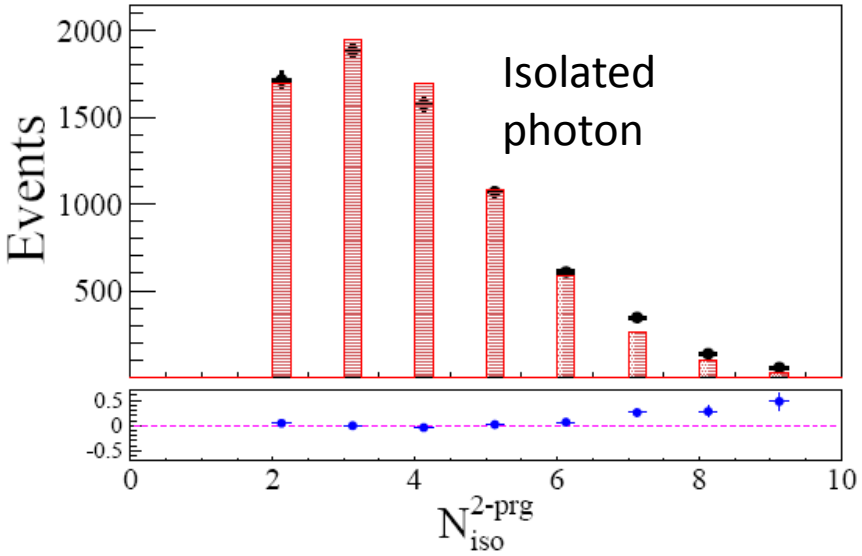
with $\mu = a + b\,\mathrm{lns} + c\ln^2 s.$

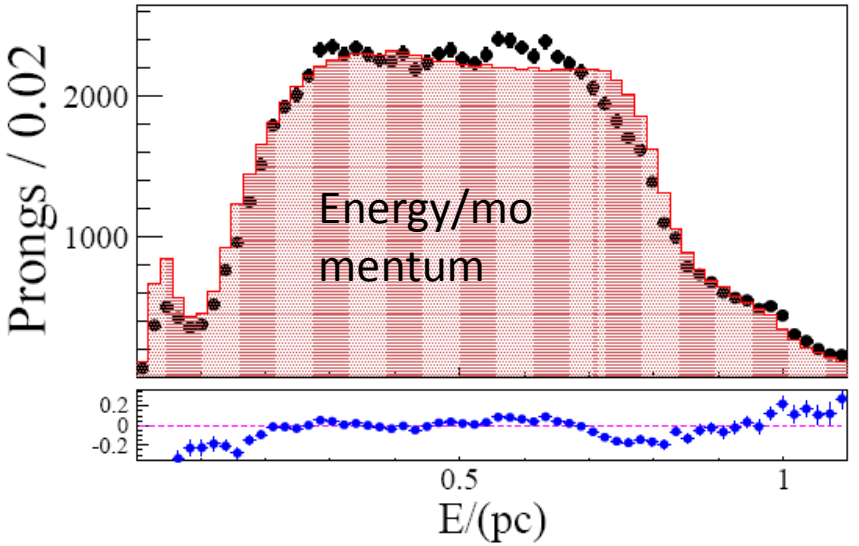
Parameters $a, b, c, c_0, c_1,$

Events generated with LUARLW







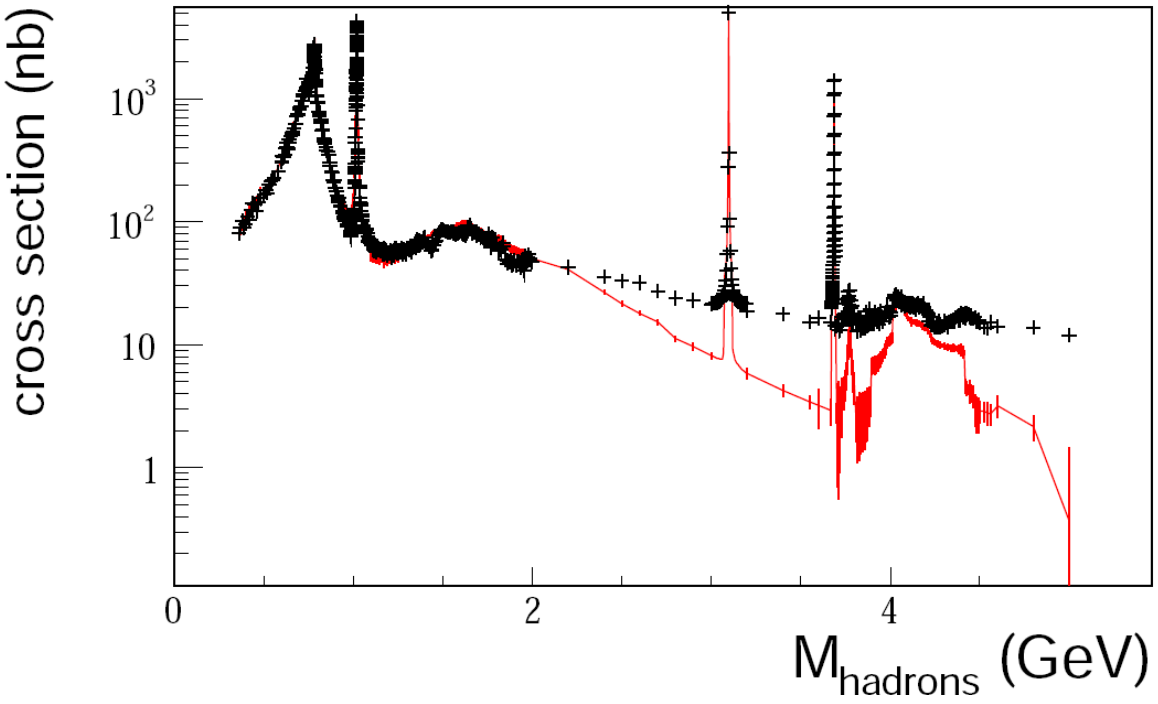


Comparison of MC events with the data at $\sqrt{s} = 3.4$ GeV.

Events generated with hybrid generator

+: cross section from R-value measurement

+: Sum of exclusive cross section (76 modes)



- PHOKHARA
  (Phys.Rev.D75:074026)

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

- Exclusive process
  (Chin.Phys. C38, 083001)

71 exclusive modes

Known: PHOKHARA + ConExc + LUARLW

Missing:

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

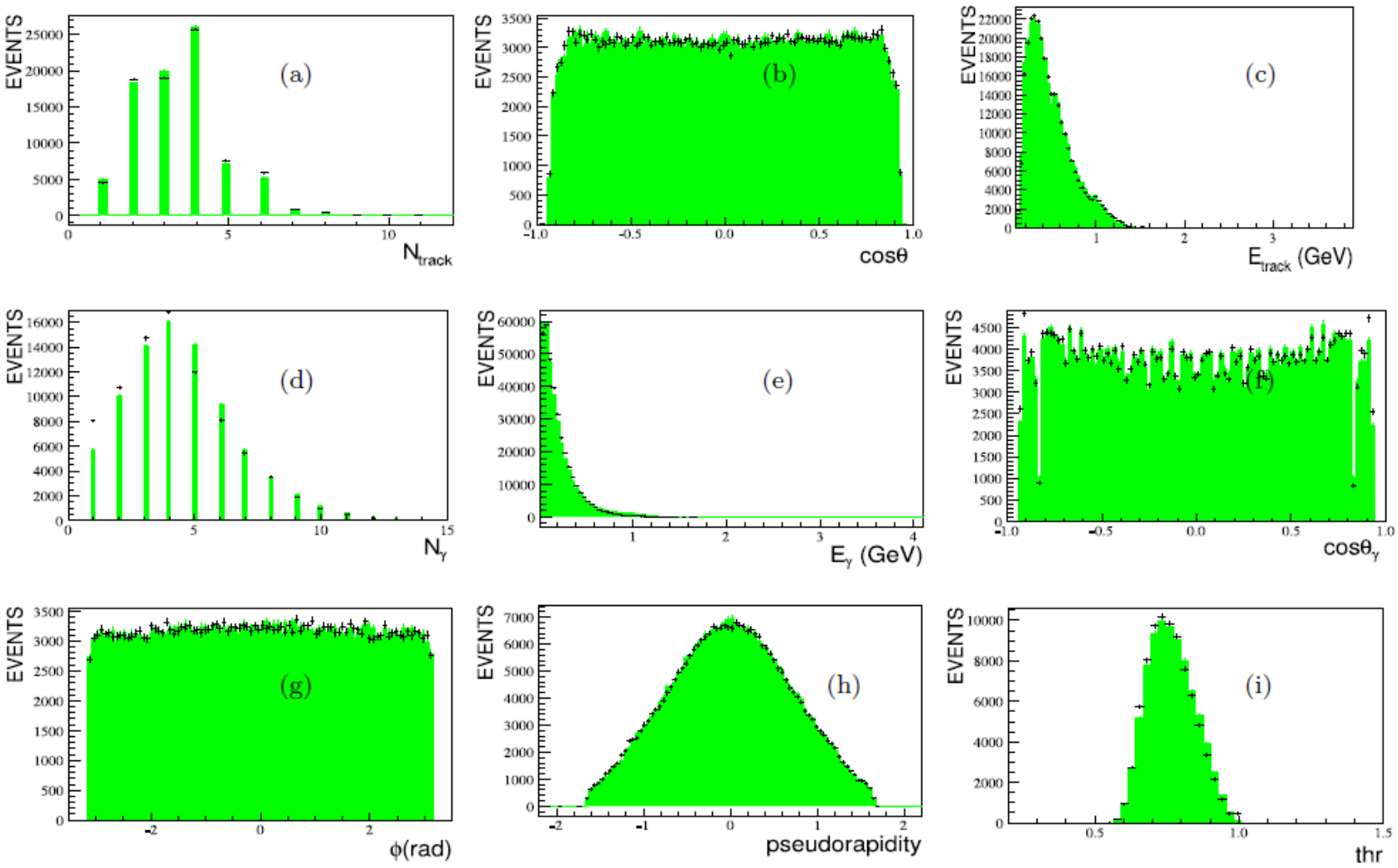


Fig. 5. Comparison of data to the MC distributions at 3.06 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, . (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine 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.
- A few exclusive decays of cross section are measured.
- The parameters of generator LUARLW and the hybrid generators are optimized
- The memo of R value measurement between 2.232–3.671 GeV is being reviewed in BESIII Collaboration, with uncertainty <3%.
- The data analysis for 3.85 – 4.59 GeV at 104 energies are in progress.

Thanks for your attention