BESIII

Status of R value measurement at BESIII

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(For BESIII Collaboration)

Outline

- Motivation
- Data samples of QCD and R scan
- Status of R value measurement
- Summary

Main projects of BESIII Physics

- BESIII physics
  - Charm
    - Light hadron spectrum ☞ J/Ψ data
    - Charmonium ☞ $\Psi(2S)$ data
    - D physics ☞ $\Psi(3770)$ line shape scan
    - Heavy charmonium
      - $\Psi(4040)$
      - $\Psi(4190)$
      - $\Psi(4415)$
      - X, Y, Z…
      - Line shape scan
  - Uncharm
    - τ
      - Mass
      - Decays
    - R&QCD
      - $R(s)$ fine scan in (u,d,s) energies
      - QED & QCD $\alpha(s)$, $(g\text{-}2)_\mu$
      - Inclusive distributions
      - Exclusive distributions
      - Correlation functions
      - Form factors
      - Fragmentation functions

Main projects for R scan

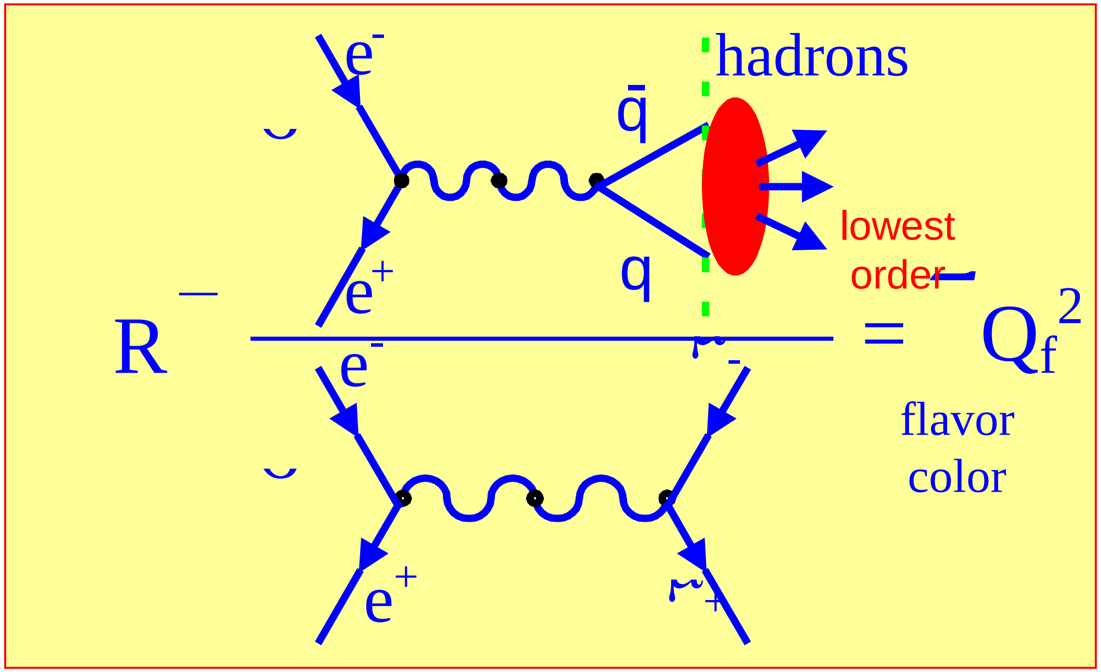
- R value at energies BEPCII can reach (2.0 – 4.6 GeV)
- ψ-family line shape and resonant parameters
- Form factors of mesons and baryons (QCD study)

What is R Value

The Born cross section of e^+e^- annihilation into hadrons normalized by theoretical $\mu^+\mu^-$ cross section.

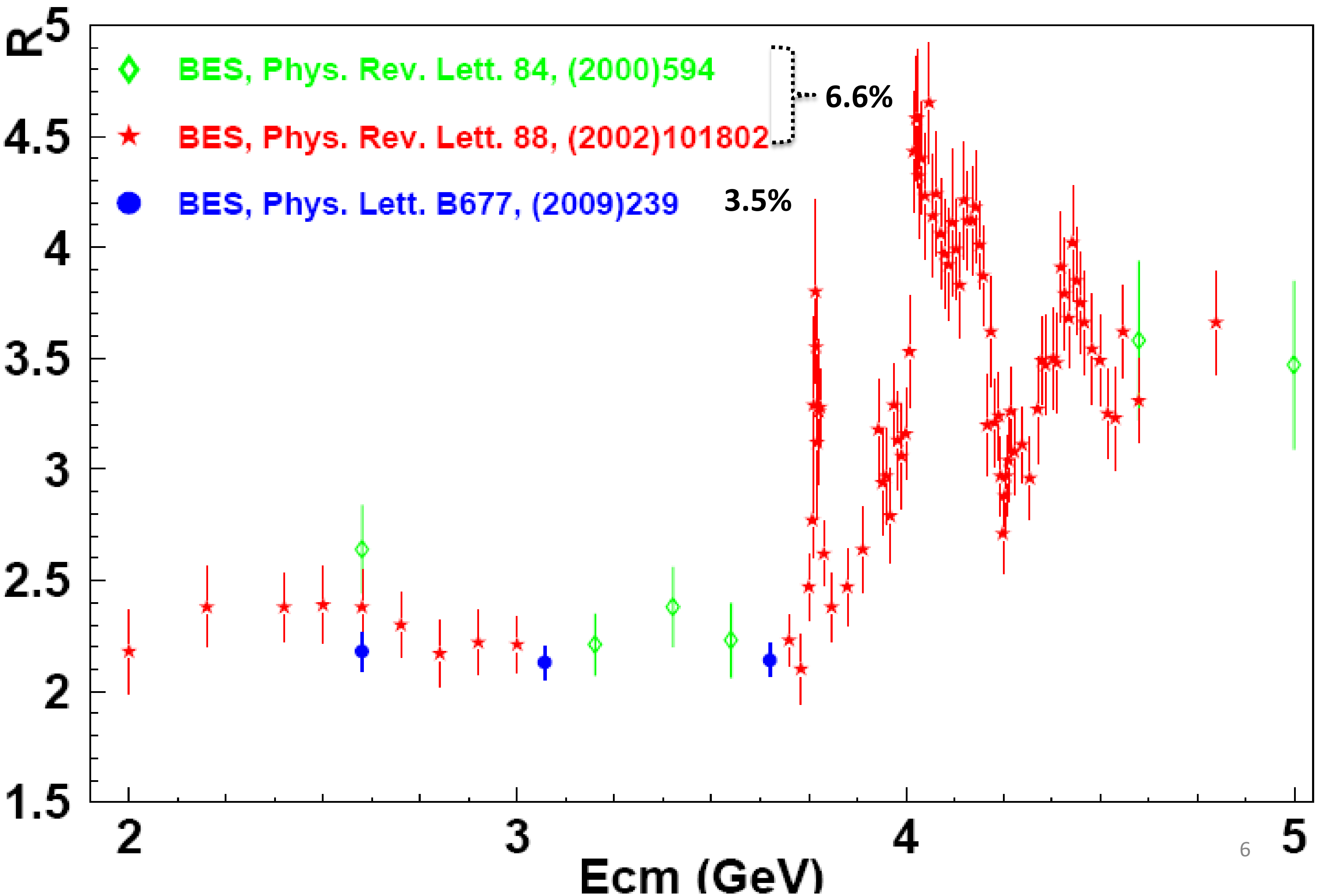
$$R = \frac{\sigma^0_{had}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma^0_{\mu\mu}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

Feynman diagram of R value



Groups ever measured R value： BESII， VEPP， DAΦNE， DM2， DASP， PLUTO， Crystal-Ball， MARKI， MARKII， CLEO-c， AMY， JADE， TASSO， CUSB， MD-1， MARKJ， SLAC-LBL， MAC， γγ2……

R value measurements at BESII



The significance of R value to the SM

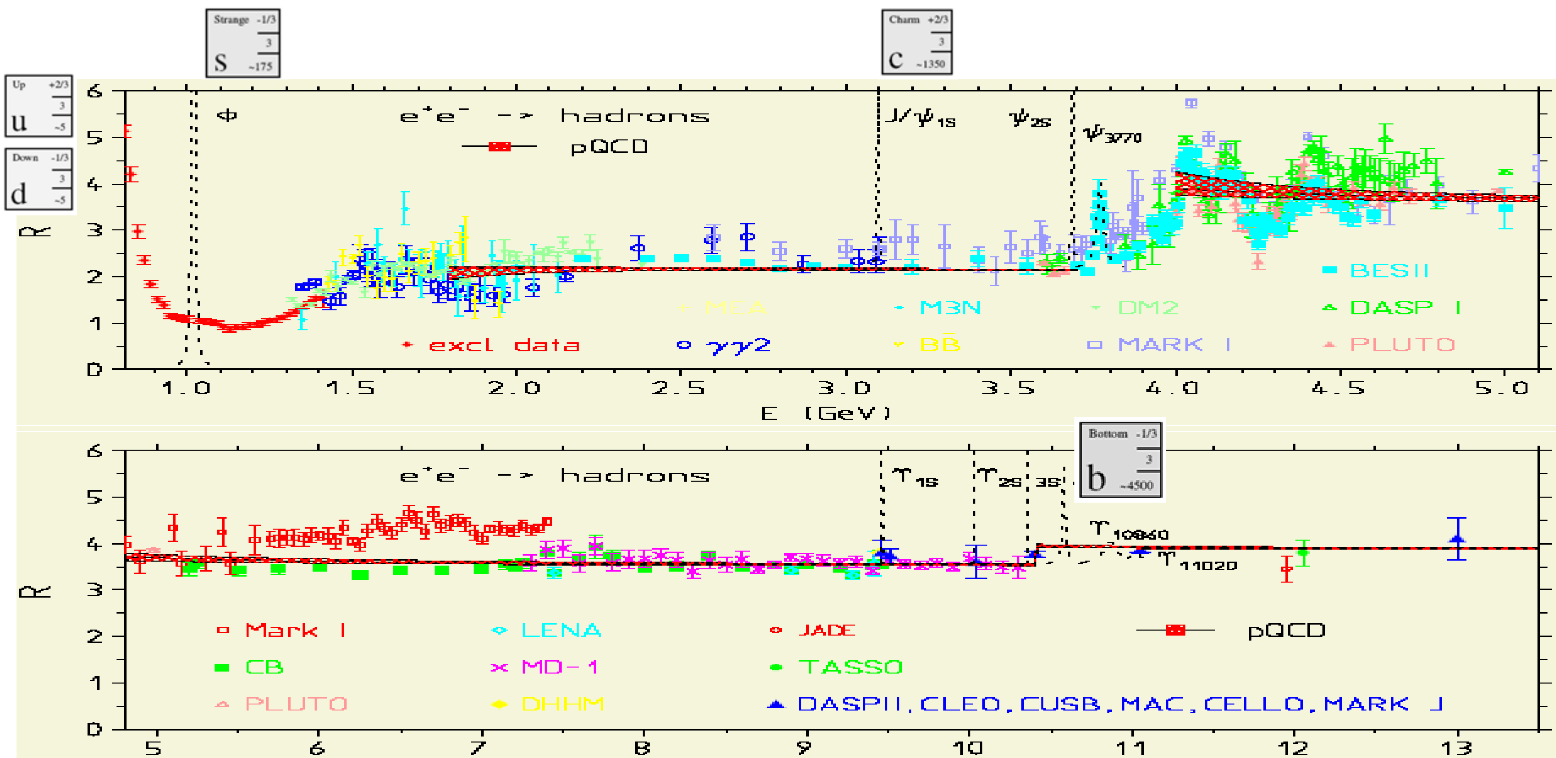
R values test QCD predictions

Quark model:

$$R_{had} = \frac{\sigma(e^+e^- \to X)}{\sigma(e^+e^- \to \mu^+\mu^-)} = \sum_{all\, q} e_q^2 = \begin{cases} 3\left[\left(\frac{2}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2\right] = 2 \\ 3\left[\underbrace{\left(\frac{2}{3}\right)^2}_{u} + \underbrace{\left(\frac{1}{3}\right)^2}_{d} + \underbrace{\left(\frac{1}{3}\right)^2}_{s} + \underbrace{\left(\frac{2}{3}\right)^2}_{c} + \underbrace{\left(\frac{1}{3}\right)^2}_{b}\right] = \frac{11}{3} \end{cases}$$

pQCD:

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

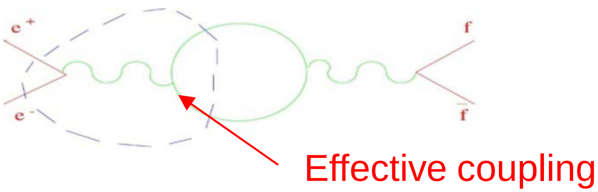


R value is the input parameter of $\alpha(s)$

At high energies, vacuum is polarized, the effective coupling is energy dependent, the so called EM running coupling constant：

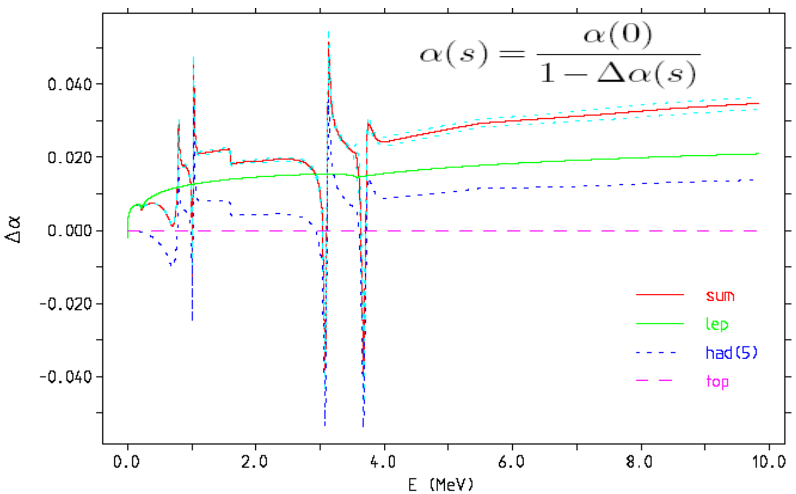
$$\alpha(s) = \frac{\alpha(0)}{1-\Delta\alpha(s)}$$

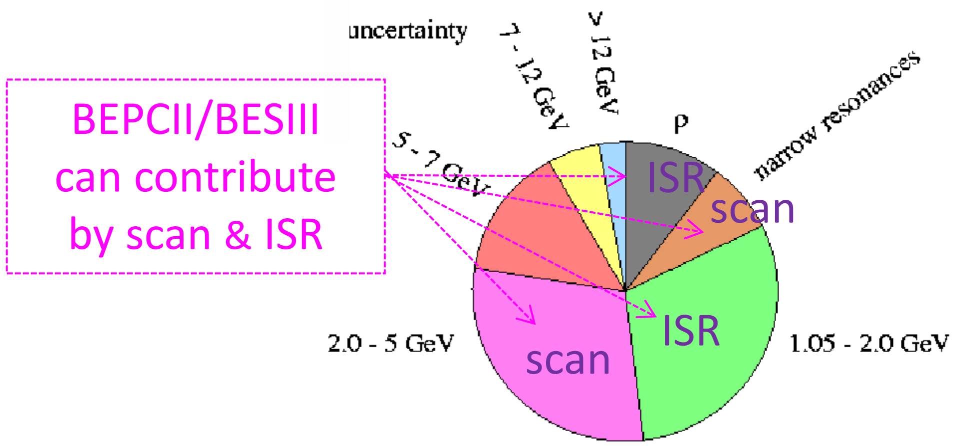
$$\Delta\alpha(s) = \Delta\alpha_{e\mu\tau}(s) + \Delta\alpha_{top}(s) + \Delta\alpha^{(5)}_{had}(s)$$



quarks with flavors (u, d, s, c, b)

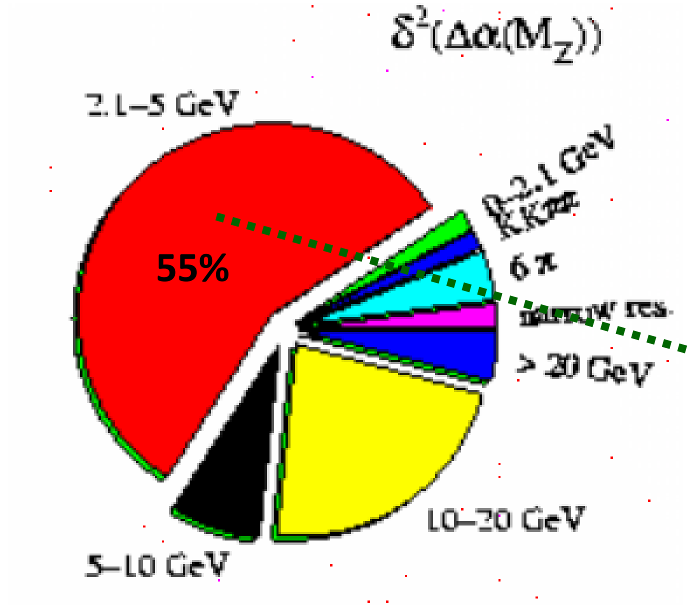
$$\begin{aligned}\Delta\alpha^{(5)}_{had}(M_Z^2) &= \frac{\alpha M_Z^2}{3\pi}\int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s-M_Z^2-i\epsilon)} \\ &= \frac{\alpha M_Z^2}{3\pi}\left[\int_{4m_\pi^2}^{(5GeV)^2} ds \frac{R_{exp}(s)}{s(s-M_Z^2-i\epsilon)} + \int_{(5GeV)^2}^{\infty} ds \frac{R_{QCD}(s)}{s(s-M_Z^2-i\epsilon)}\right]\end{aligned}$$



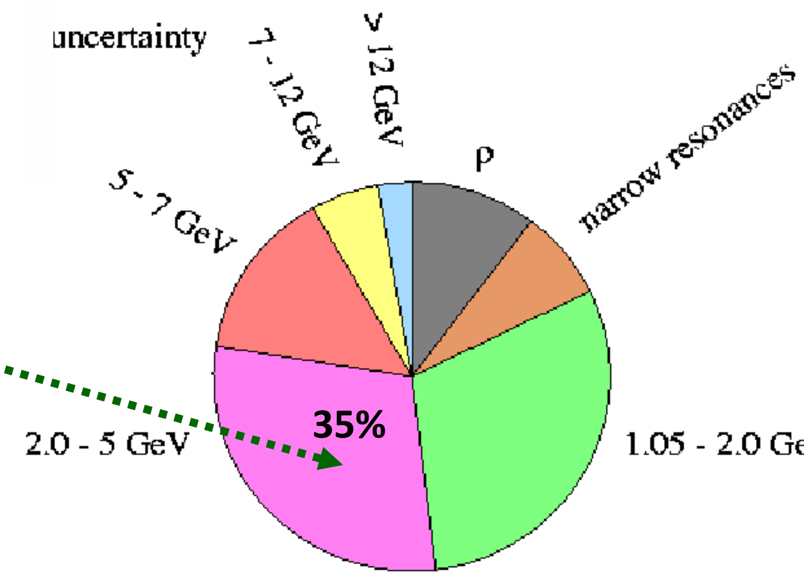


Improvement of the precision of R value can decrease the uncertainty of $\Delta\alpha$(s) effectively.

R value of BESII improved $\Delta\alpha(M_Z)$



Before BESII R measurement



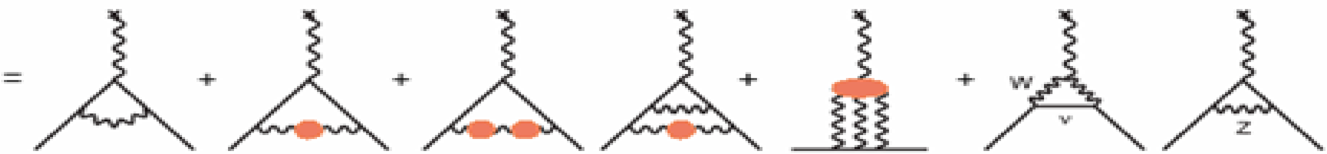
After BESII R measurement

	S. Eidelman (1995)	H.Burkhardt & B.Pietrzyk (2001)
BESII R	no used	used
$\Delta\alpha^{(5)}_{had}(M_Z^2)$	0.0280 ± 0.0007	0.0276 ± 0.00036
$\alpha^{-1}(\mathrm{M}_Z^2)$	128.90 ± 0.09	128.936 ± 0.0046

R value is input parameter of $(g\text{-}2)_\mu$

The Standard Model (SM) prediction for muon (g-2):

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



= (QED) $(11\,658\,470.35 \pm 0.28)10^{-10}$ (5-loop!)

+ (had,LO) $(684.7 \text{ to } 709.0 \pm 6)10^{-10}$ (Big spread, largest error)

+ (had,HO) $(-10.0 \pm 0.6)10^{-10}$

+ (had,LBL) $(8.0 \pm 4.0)10^{-10}$ (sign change since 1998)

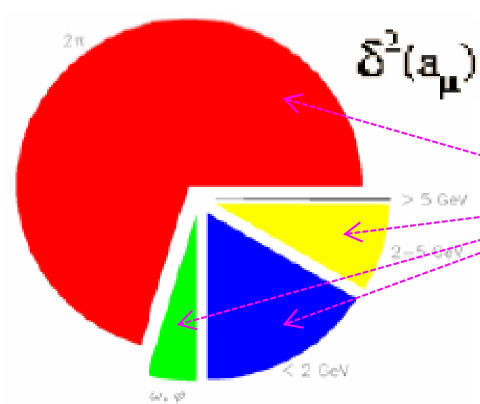
+ (weak) $(15.4 \pm 0.2)10^{-10}$ (2-loop)

The contribution of the hadronic cross section:

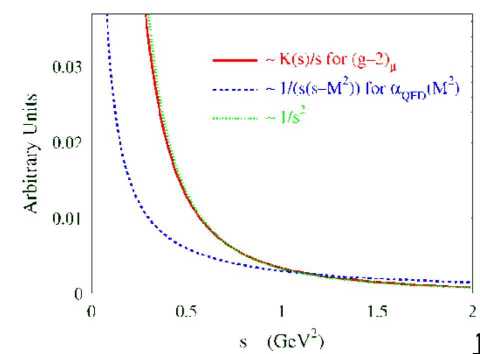
$$\alpha_\mu^{had} = (\frac{\alpha m_\mu}{3\pi})^2 \int_{4m_\pi^2}^{\infty} ds' \frac{\hat{K}(s')}{s'^2} R(s')$$

$$= (\frac{\alpha m_\mu}{3\pi})^2 [\int_{4m_\pi^2}^{(5GeV)^2} ds' \frac{\hat{K}(s')}{s'^2} R_{exp}(s') + \int_{(5GeV)^2}^{\infty} ds' \frac{\hat{K}(s')}{s'^2} R_{QCD}(s')]$$

Experiment error

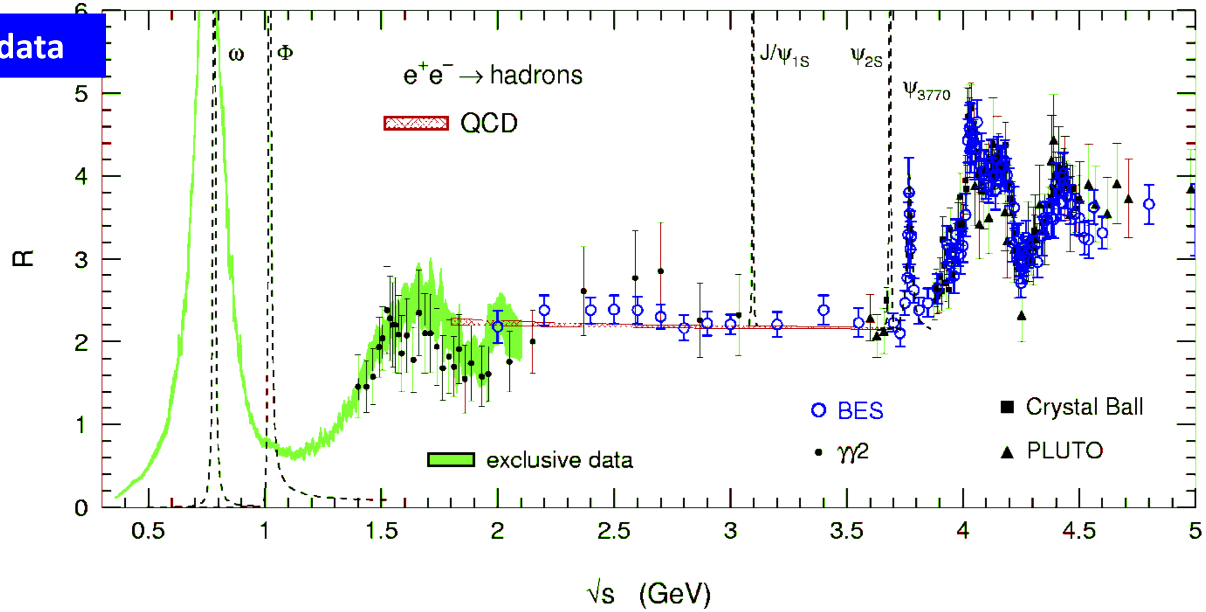


BEPCII/BESIII can contribute by scan & ISR

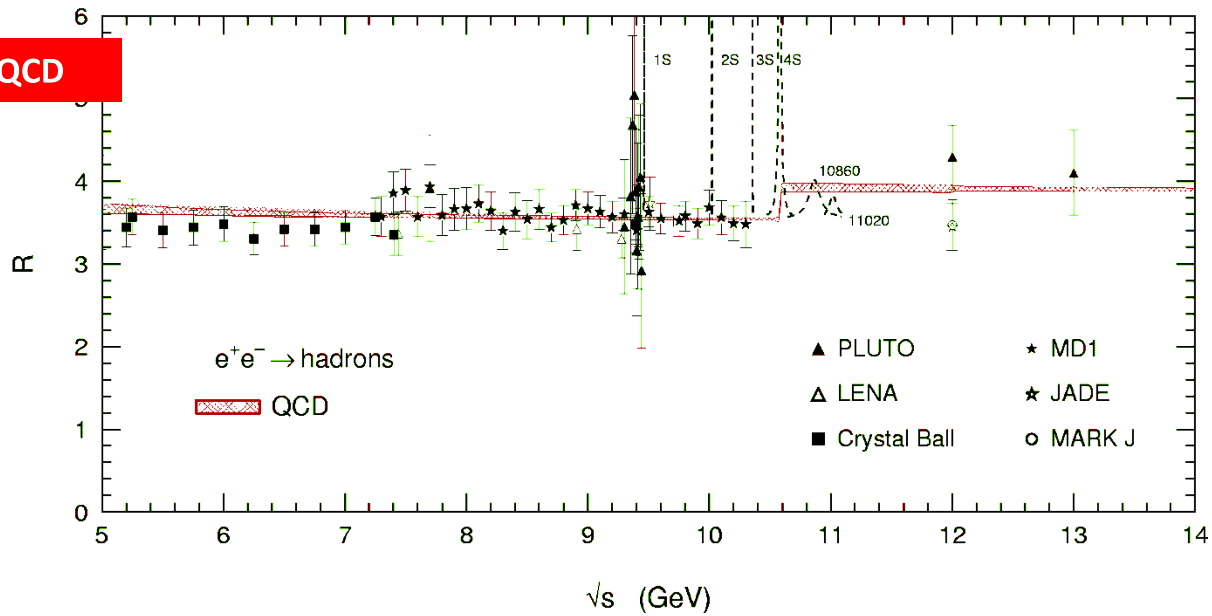


R value of BESII improved uncertainty of (g-2)

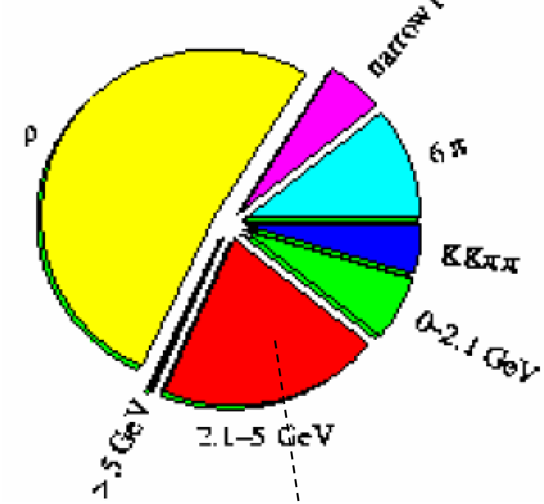
use data



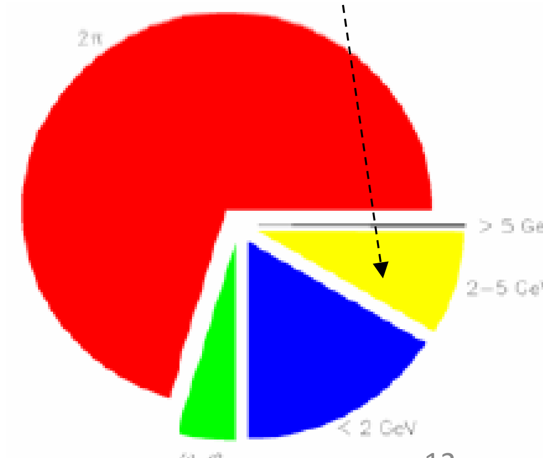
use QCD



$\delta^2(a_\mu)$ Before BESII



After BESII



Status of (g-2)$_\mu$ in theory and experiment

Discrepancy between SM and experiments:

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072
with latest value of $\lambda = \mu_\mu/\mu_p$ (Codata '06)

	$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1]	116 591 773 (53)	316 (82)	3.8
[2]	116 591 782 (59)	307 (86)	3.6
[3]	116 591 834 (49)	255 (80)	3.2
[4]	116 591 773 (48)	316 (79)	4.0
[5]	116 591 929 (52)	160 (82)	2.0

with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] HMNT06, PLB649 (2007) 173.
[2] F. Jegerlehner and A. Nyffeler, arXiv:0902.3360.
[3] Davier et al, arXiv:0908.4300 August 2009 (includes BaBar)
[4] Hagiwara, Liao, Martin, Nomura, Teubner, Oct '09 (preliminary)
[5] Davier et al, arXiv:0906.5443v2 August 2009 (τ data).

Questions : if SM agrees experiments? If new physics behind?

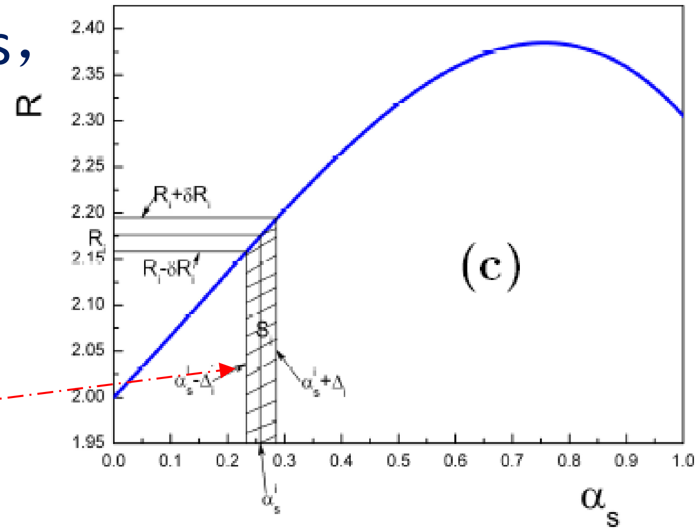
Solutions : more accurate theoretic calculations & precise experiments.

Determination of $\alpha_s(M_Z)$ by R values

Solve equation: $R_{QCD}(\alpha_s(s_i)) = R_{exp}(s_i) \pm \Delta R_{exp}(s_i)$

Obtain coupling constant at every energies, and then evolve them to 5 GeV with

$$Q^2 \frac{\partial \alpha_s(Q^2)}{\partial Q^2} = \beta(\alpha_s(Q^2))$$



weighted average

$$\overline{\alpha_s}(5GeV) = \sum_i \frac{\alpha_s(s_i)}{S_i} \Big/ \sum_i \frac{1}{S_i}$$

$$S_i = \int_{\alpha_s(s_i)-\Delta_i'}^{\alpha_s(s_i)+\Delta_i} R(\alpha_s)\, d\alpha_s$$

errors $\qquad \overline{\Delta}_{down} = \sqrt{1 \Big/ \sum_i \Delta_i'^{-2}} \qquad \overline{\Delta}_{up} = \sqrt{1 \Big/ \sum_i \Delta_i^{-2}}$

$\sqrt{s}$(GeV)	$\alpha_s^{(3)}(s)$	$\alpha_s^{(4)}(25\ \mathrm{GeV}^2)$	$\bar{\alpha}_s^{(4)}(25\ \mathrm{GeV}^2)$	$\alpha_s^{(5)}(M_Z^2)$
2.60	$0.266^{+0.030+0.125}_{-0.030-0.116}$	$0.212^{+0.018+0.068}_{-0.019-0.086}$		
3.07	$0.192^{+0.029+0.103}_{-0.029-0.101}$	$0.169^{+0.022+0.074}_{-0.023-0.086}$	$0.209^{+0.044}_{-0.050}$	$0.117^{+0.012}_{-0.017}$
3.65	$0.207^{+0.015+0.104}_{-0.015-0.104}$	$0.189^{+0.012+0.082}_{-0.013-0.091}$		

PDG2006 $\qquad \alpha_s(M_Z^2) = 0.1170 \pm 0.0012$

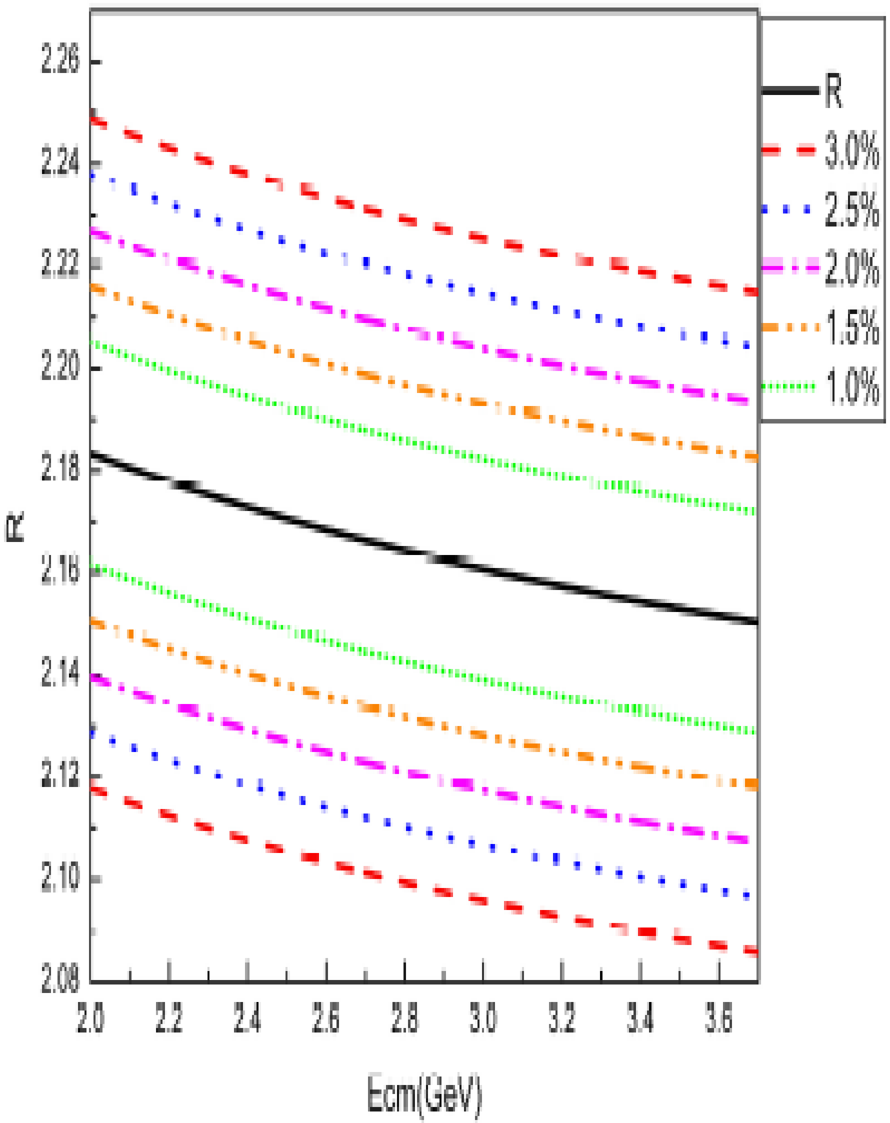
R value error → error of α_s

α_s error \ R error; E_{cm} /GeV	3.0%		2.5%		2.0%		1.5%		1.0%	
	Up(%)	Dw(%)	Up(%)	Dw(%)	Up(%)	Dw(%)	Up(%)	Dw(%)	Up(%)	Dw(%)
2.00	37.7	35.4	31.1	29.6	24.7	23.7	18.4	17.8	12.2	11.9
2.10	38.1	35.9	31.4	29.9	25.0	24.0	18.6	18.1	12.3	12.1
2.20	38.4	36.3	31.8	30.3	25.3	24.3	18.8	18.3	12.5	12.2
2.30	38.8	36.8	32.0	30.7	25.5	24.6	19.0	18.5	12.6	12.4
2.40	39.2	37.2	32.4	31.0	25.8	24.9	19.2	18.7	12.8	12.5
2.50	39.6	37.6	32.8	31.4	26.0	25.2	19.4	18.9	12.9	12.6
2.60	40.0	38.1	33.0	31.8	26.3	25.4	19.6	19.1	13.0	12.7
2.70	40.2	38.5	33.3	32.1	26.5	25.8	19.8	19.3	13.1	12.9
2.80	40.6	38.9	33.6	32.4	26.7	26.0	20.0	19.5	13.2	13.0
2.90	41.0	39.3	33.9	32.7	27.0	26.2	20.2	19.7	13.3	13.2
3.00	41.4	39.7	34.3	33.1	27.3	26.5	20.4	19.9	13.5	13.3
3.10	41.6	40.1	34.4	33.4	27.4	26.7	20.4	20.1	13.5	13.4
3.20	42.0	40.4	34.8	33.7	27.7	27.0	20.7	20.2	13.7	13.5
3.30	42.3	40.8	35.0	34.0	27.8	27.2	20.8	20.4	13.8	13.7
3.40	42.6	41.1	35.3	34.2	28.1	27.4	21.0	20.6	14.0	13.7
3.50	42.9	41.5	35.6	34.6	28.3	27.6	21.1	20.8	14.1	13.8
3.60	43.1	41.8	35.8	34.8	28.3	27.9	21.3	20.9	14.1	14.0
3.70	43.4	42.1	36.0	35.1	28.7	28.1	21.4	21.0	14.2	14.1

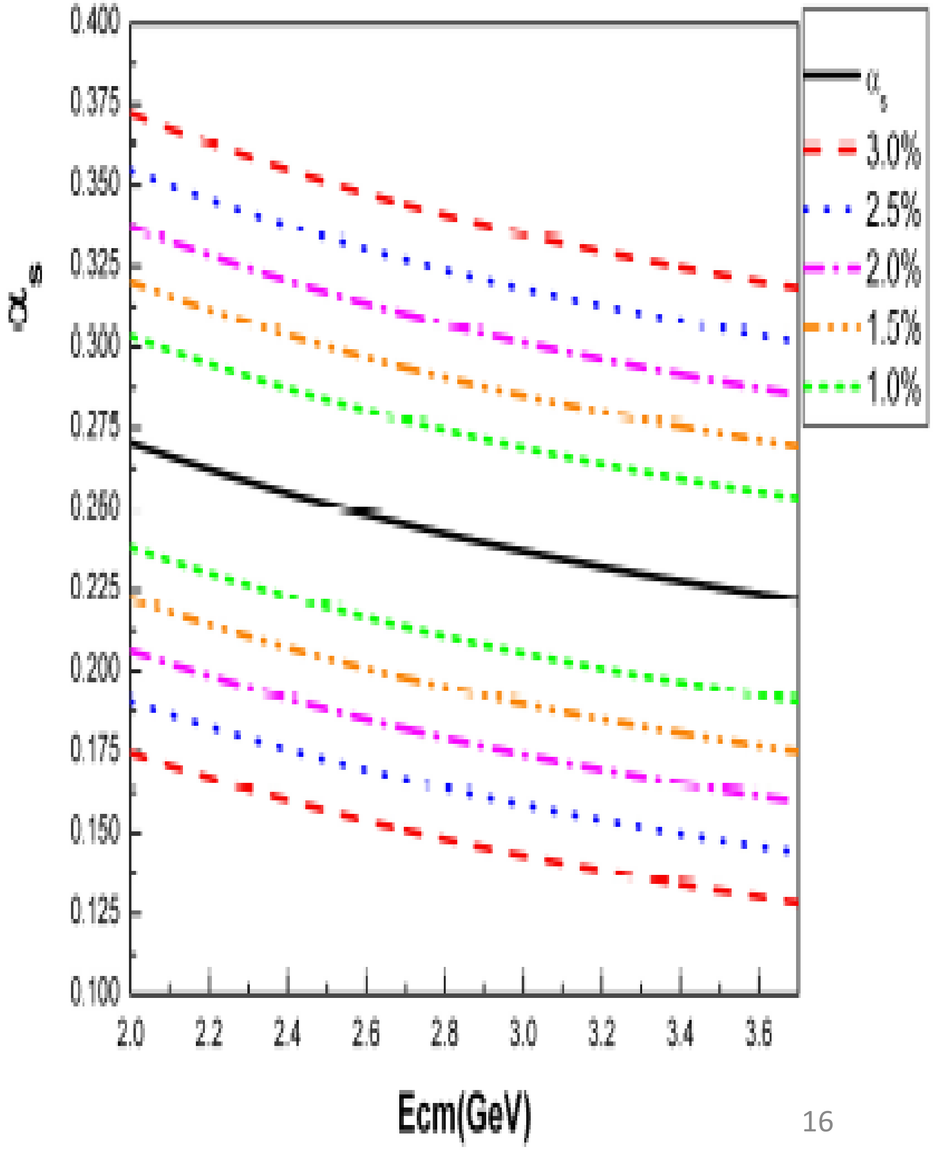
So, α_s can be determined based on R, and independent of any model, but the error of α_s larger than that of R value, it is not an "economical" way.

R value error → error of α_s

Uncertainty range of R within 1σ



Uncertainty range of α_s within 1σ



Data samples of R scan at BESIII

Status of R&QCD data taking

- Phase I: test run (2012)

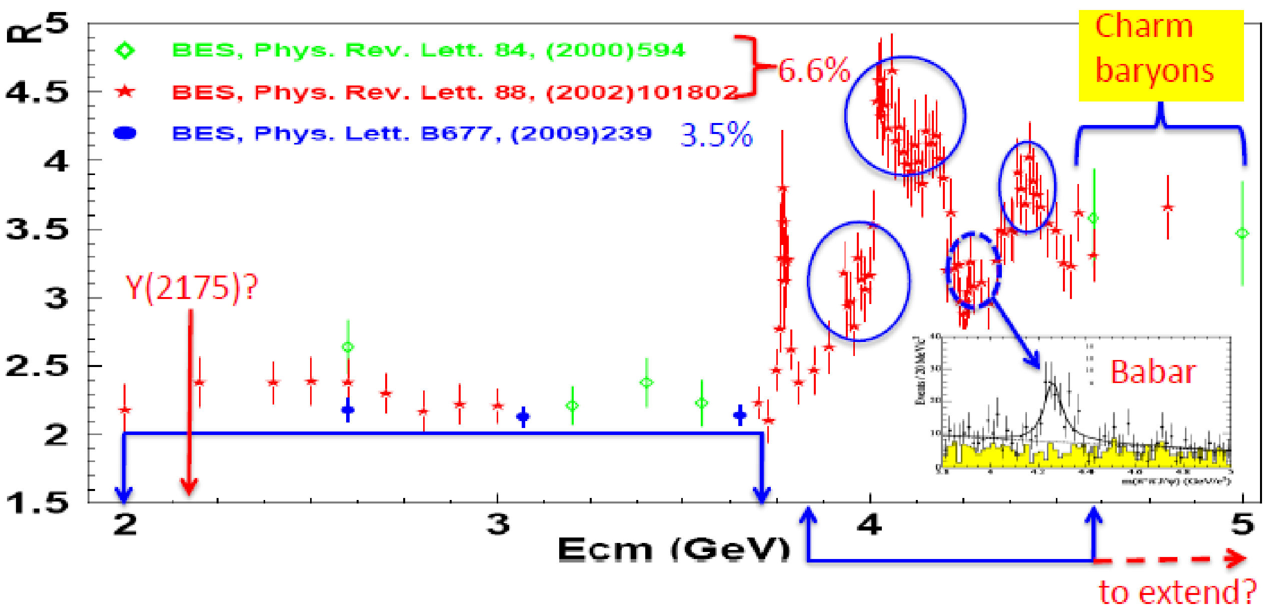
  @ Ecm = 2.232, 2.400, 2.800, 3.400 GeV , 4 energy points, ~12/pb

- 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



R value line shape has scanned in whole BEPCII energies.

R scan below open charm

Data samples between 2.0 – 3.08 GeV collected in 2015

E_{cm} (GeV)	E_{th} (GeV)	L_{Needed} (pb^{-1})	t_{beam} ($days$)	Purpose
2.0		$\geq$8.95	14.6	Nucleon FFs
2.1		10.8	14.8	Nucleon FFs
2.15		2.7	2.29	Y(2175)
2.175		10(+)	8.5	Y(2175)
2.2		13	11	Nucleon FFs, Y(2175)
2.2324	2.2314	11	4	Hyp threshold ($\Lambda\bar{\Lambda}$)
2.3094	2.3084	20	16	Nucleon & Hyp FFs Hyp Threshold ($\Sigma^0\bar{\Lambda}$)
2.3864	2.3853	20	8.7	Hyp Threshold ($\Sigma^0\bar{\Sigma}^0$) Hyp FFs
2.3960	2.3949	$\geq$64	27.8	Nucleon & Hyp FFs Hyp Threshold ($\Sigma^-\bar{\Sigma}^+$)
2.5		0.4895	8h	R scan
2.6444	2.6434	65	18	Nucleon & Hyp FFs Hyp Threshold ($\Xi^-\bar{\Xi}^+$)
2.7		0.5542	4.2h	R scan
2.8		0.6136	4h	R scan
2.9		100	18.5	Nucleon & Hyp FFs
2.95		15	2.8	$m_{p\bar{p}}$ step
2.981		15	2.8	η_c , $m_{p\bar{p}}$ step
3.0		15	2.8	$m_{p\bar{p}}$ step
3.02		15	2.8	$m_{p\bar{p}}$ step
3.08		120	13.2	Nucleon FFs (+30 pb^{-1})

Data @ 21 energy points

Main physics goals

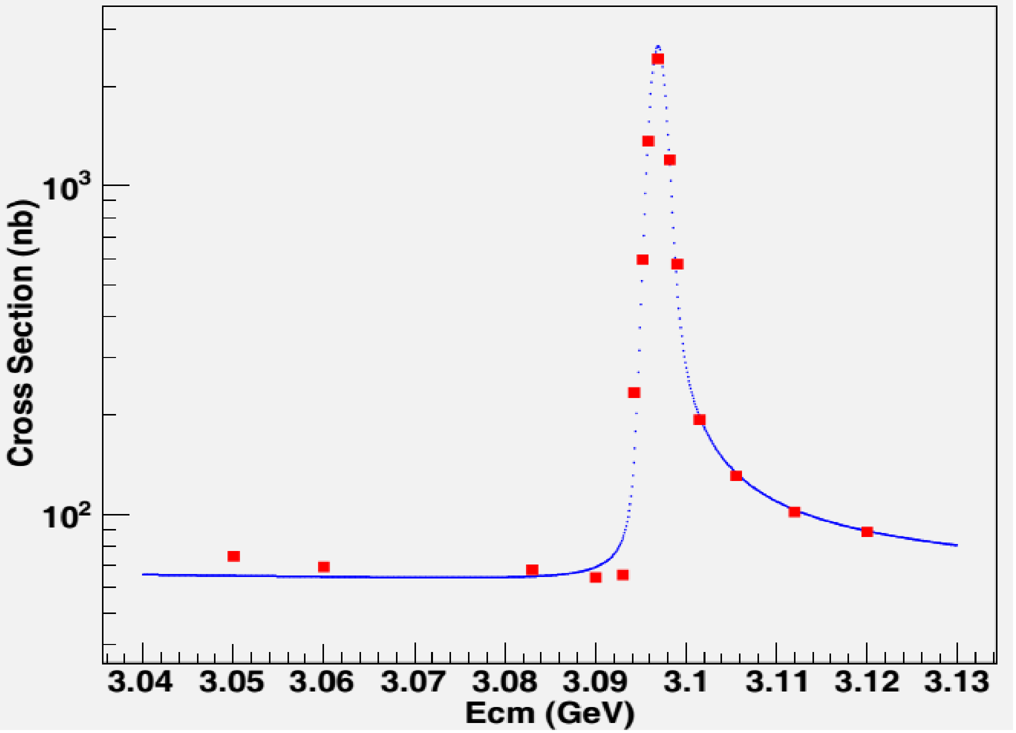
1. R value !
2. Form factors !
3. New phenomenon ?
4. New hadronic states ?

J/psi line shape scan

Data have been taken around the J/psi peak at 12 energy points

Req Ecm (GeV)	Int Lum (nb^{-1})
3.0500	14918 ± 169
3.0600	15059 ± 170
3.0830	4768 ± 58
3.0900	15558 ± 173
3.0930	14909 ± 160
3.0943	2143 ± 25
3.0952	1816 ± 22
3.0958	2134 ± 25
3.0969	2069 ± 26
3.0982	2203 ± 27
3.0990	756 ± 11
3.1015	1612 ± 21
3.1055	2106 ± 25
3.1120	1720 ± 21
3.1200	1264 ± 17

On-line cross section and J/psi line shape fit

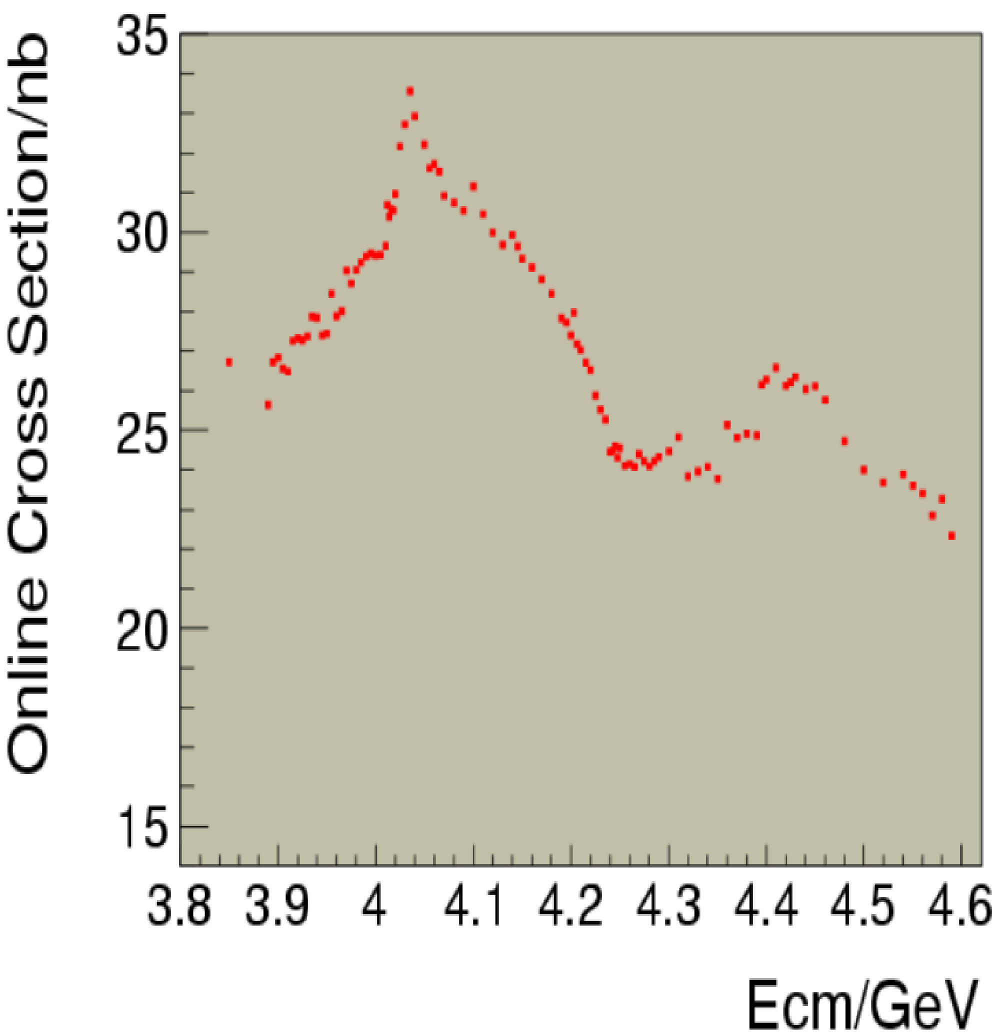


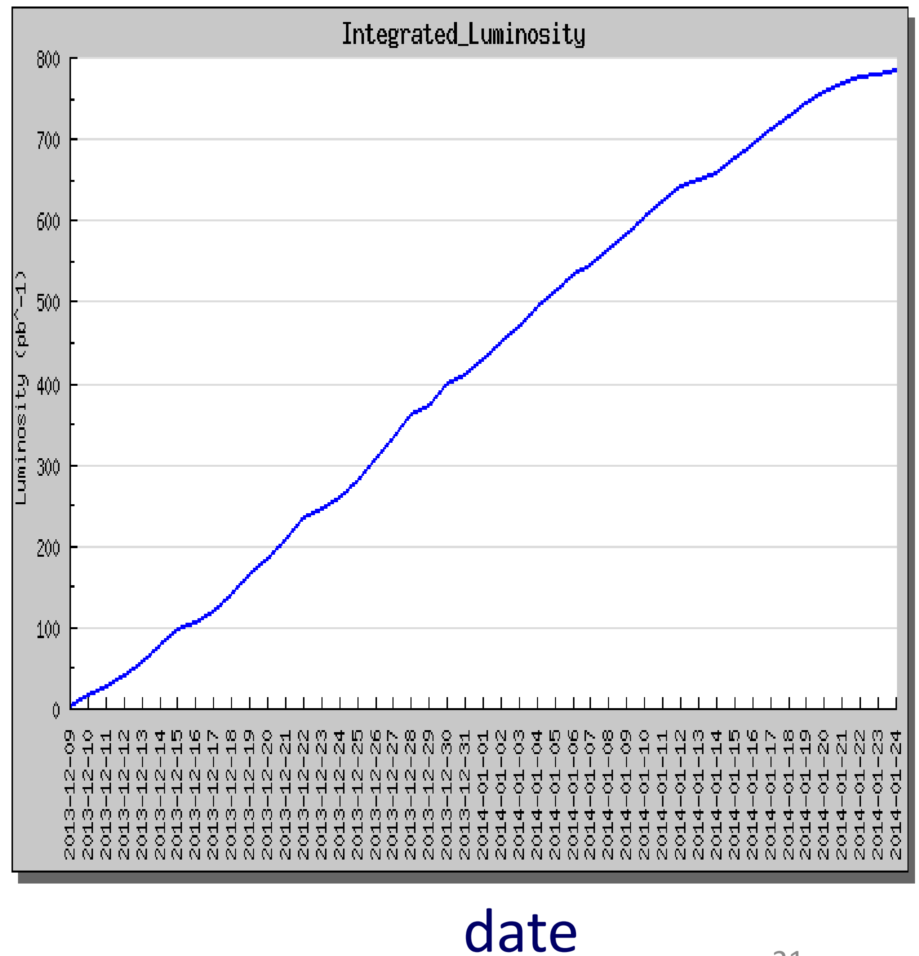
Physical goal: measure the resonant parameters of J/psi by channels:

1. $e^+e^- \rightarrow e^+e^-$
2. $e^+e^- \rightarrow \mu^+\mu^-$
3. $e^+e^- \rightarrow$ hadrons

R line shape scan above open charm

- 104 energy points, total luminosity ~ 800 pb^{-1};
- More than100k hadronic events collected at each point.





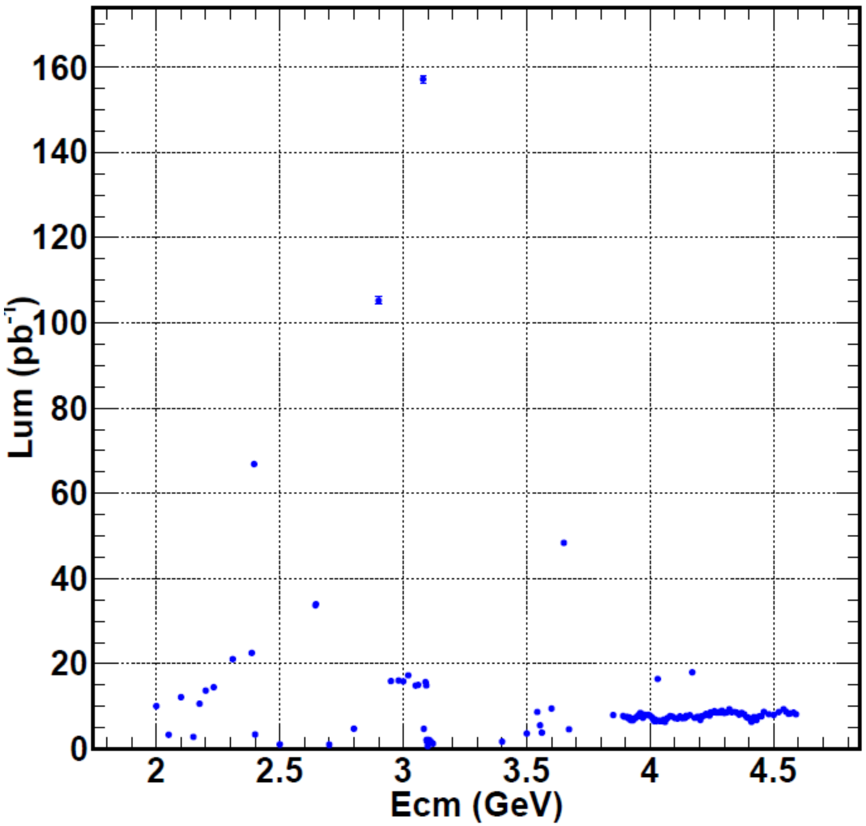
Integrated luminosities of the data samples

- The QED processes

$$e^+ e^- \rightarrow (\gamma)\, e^+ e^- \qquad e^+ e^- \rightarrow (\gamma)\, \gamma\, \gamma \qquad e^+ e^- \rightarrow (\gamma)\, \mu^+ \mu^-$$

  are used to measure luminosity.

The luminosities at all of the 149 scanned energy points are measured with about precision of 1%.



Source	$\Delta^{sys}(\%)$
$\lvert cos\theta\rvert < 0.8$	0.18
$\lvert\Delta\phi\rvert < 2.5^\circ$	0.07
Deposited energy of γ	0.10
Cluster reconstruction	0.10
Monte Carlo statistics	0.15
Background estimation	0.23
Trigger efficiency	0.10
Generator	1.00
Total	1.07

Data samples collected at BESIII

Taking data	Total Num. / Lum.	Taking time
J/ψ	225+1086 M	2009+2012
$\psi(2S)$	106+350 M	2009+2012
$\psi(3770)$	2916 pb^{-1}	2010~2011
τ scan	24 pb^{-1}	2011
Y(4260)/Y(4230)/Y(4360)/scan	806/1054/523/488 pb^{-1}	2012~2013
4600/4470/4530/4575/4420	506/100/100/42/993 pb^{-1}	2014
J/ψ line-shape scan	100 pb^{-1}	2012
R scan (2.23, 3.40) GeV	12 pb^{-1}	2012
R scan (3.85, 4.59) GeV	795 pb^{-1}	2013~2014
R scan (2.0, 3.08) GeV	~525 pb^{-1}	2014~2015

Y(2175)	~100 pb^{-1}	2015
D physics at 4.18 GeV	~ 3 fb^{-1}	2016, no finished

Status of R value measurement

R value measurement with data

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

The efficiency and ISR factor correction

Observed cross section (no physics):

$$\sigma^T_{obs} = \frac{N_{had}}{L}$$

Efficiency correction:

→ total cross section (physics)

$$\sigma^T = \frac{\sigma^T_{obs}}{\bar{\epsilon}} = \frac{N_{had}}{L\bar{\epsilon}}$$

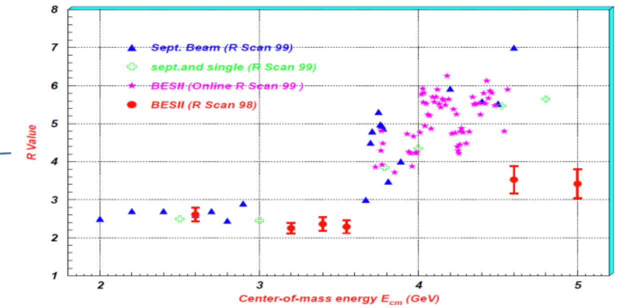
ISR factor (1+δ) correction:

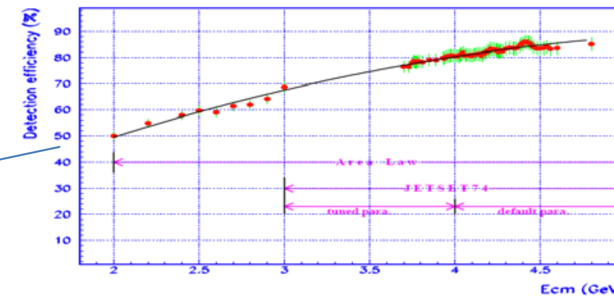
→ Born cross section

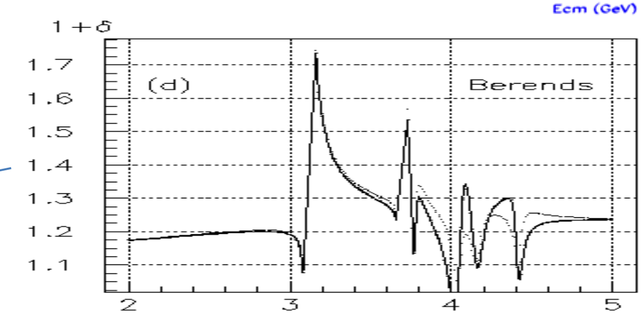
$$\sigma^0 = \frac{N_{had}}{L\bar{\epsilon}(1+\delta)}$$

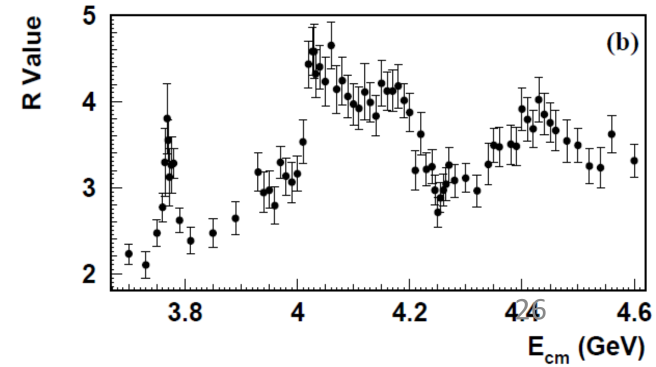
→ R value:

$$R = \frac{N_{had}}{\sigma^0_{\mu\mu} L\bar{\epsilon}(1+\delta)}$$









Present status of R value measurement

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

N_{had} , N_{bg} $\rightarrow$ event selection:

below open charm finished, above open charm in progress.

L $\rightarrow$ integrated luminosity:

finished, error ~ 1%.

ε_{had} $\rightarrow$ hadronic generator, exclusive $\oplus$ LUARLW:

parameters are optimized, cross checks, largest error source?

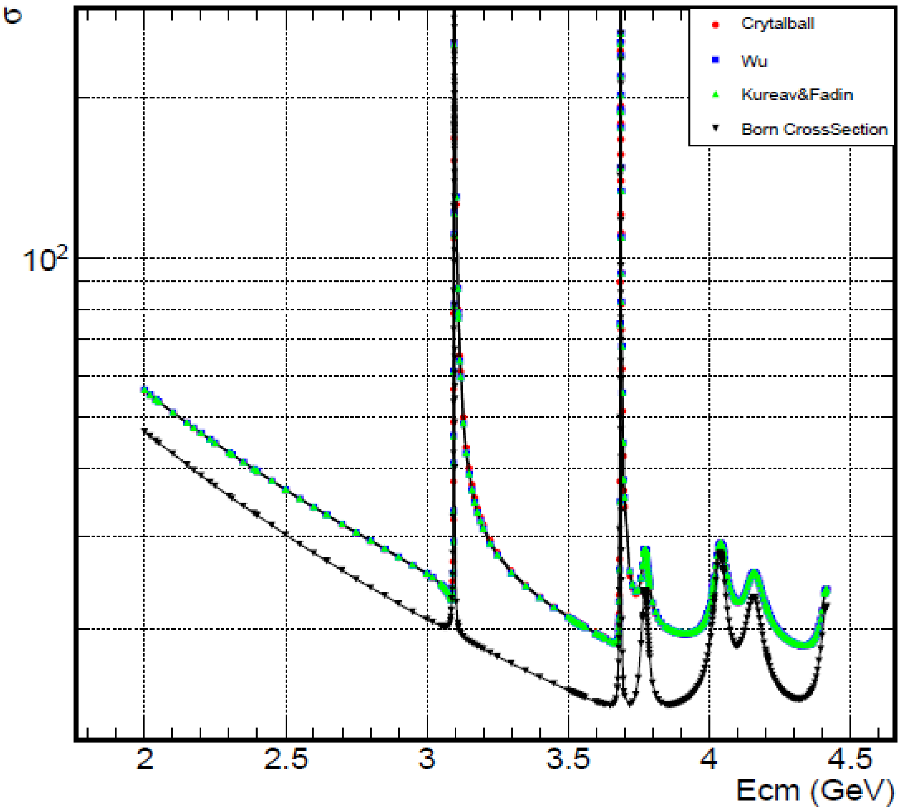
$1+\delta$ $\rightarrow$ theoretical calculations:

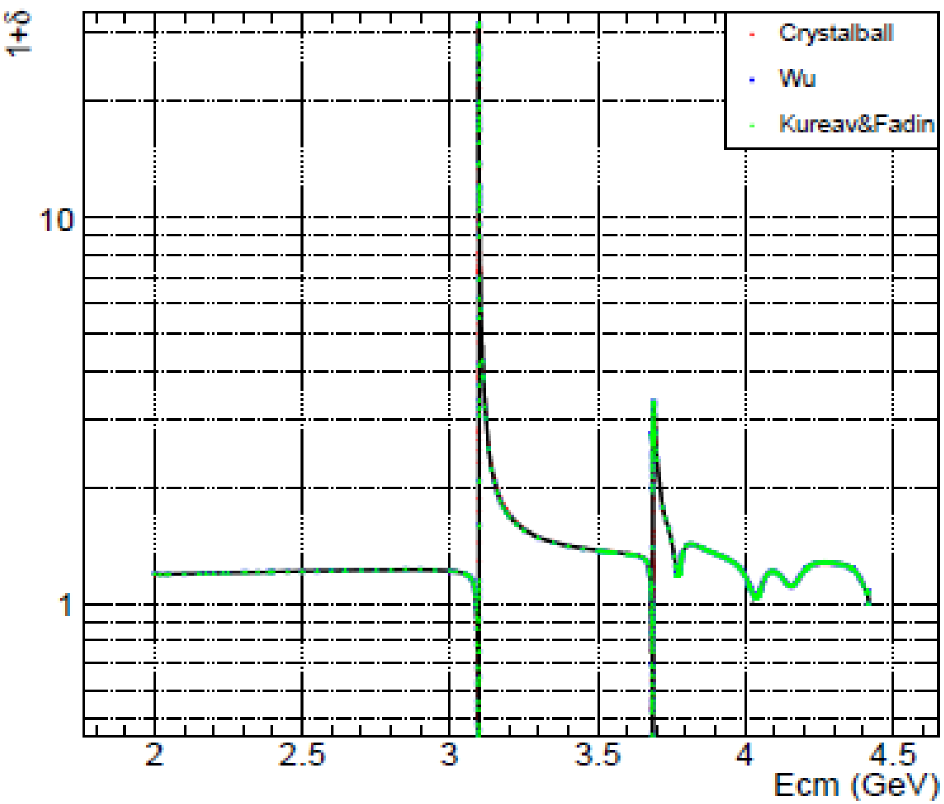
finished, error ~1.5%, including the from $\Delta\sigma^0_{had}$

Error analysis: $\frac{\Delta R}{R} \cong \sqrt{(\frac{\Delta \tilde{N}_{had}}{\tilde{N}_{had}})^2 + (\frac{\Delta L}{L})^2 + (\frac{\Delta \epsilon_{trg}}{\epsilon_{trg}})^2 + (\frac{\Delta(1+\delta)}{(1+\delta)})^2}$

- final goal $\Delta R/R$ ~2.5–3.0%.
- being reviewed with in BES Collaboration.

Theoretic cross section and ISR factor



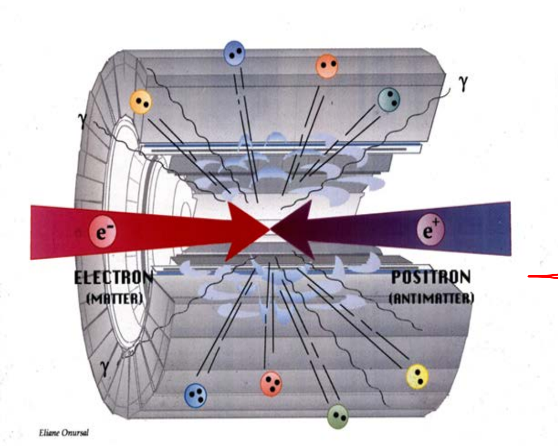


Hadronic Born and total cross section

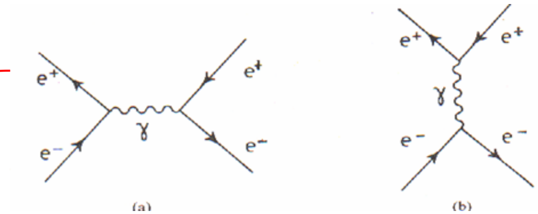
Initial state radiation factor (1+δ)

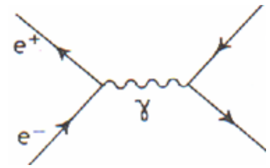
The calculations based on the Feynman diagrams and structure function schemes are compared, they are consistent within theoretical accuracy.

The generators used in R measurement



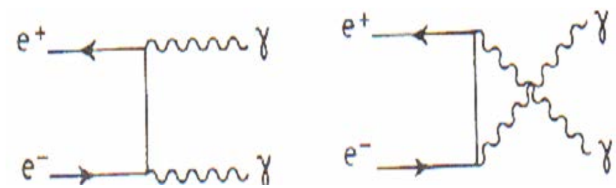
processes

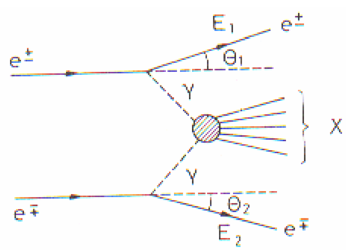


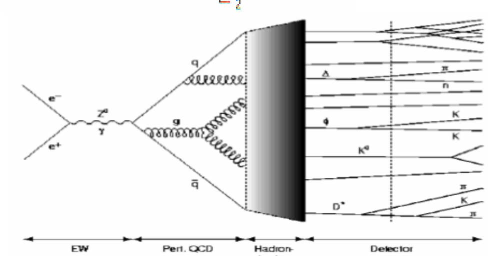


μ^+,τ^+

μ^-,τ^-







generators

$e^+e^-\rightarrow e^+e^-$ BABAYAGA (OK)

$e^+e^-\rightarrow\mu^+\mu^-$ BABAYAGA (OK)

$e^+e^-\rightarrow\tau^+\tau^-$ KKMC (OK)

$e^+e^-\rightarrow\gamma\gamma$ BABAYAGA (OK)

$e^+e^-\rightarrow e^+ e^- X$ TWOPHOTON (need check)

$e^+e^-\rightarrow$hadrons LUARLW (being optimized)

Simulation functions of LUARLW

LUARLW can simulate ISR inclusive continuous channels and $J^{PC} = 1^{--}$ resonances from 2–5 GeV, phenomenological parameters need tuning.

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

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

$$e^+e^- \Rightarrow \gamma^* \Rightarrow J/\psi \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^- \\ q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \gamma + \text{string} + \text{string} \Rightarrow \gamma + \text{hadrons} \\ \gamma\eta_c \end{cases}$$

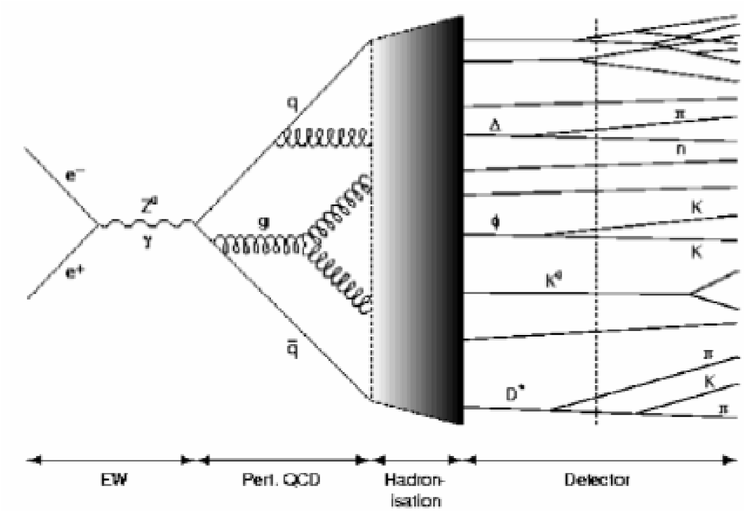
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(2S) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadr} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \gamma + \text{string} + \text{string} \Rightarrow \gamma + \text{hadrons} \\ \pi^+\pi^- J/\psi,\ \pi^0\pi^0 J/\psi,\ \pi^0 J/\psi,\ \eta J/\psi,\ \gamma\chi_{cJ},\ \phi\eta \end{cases}$$

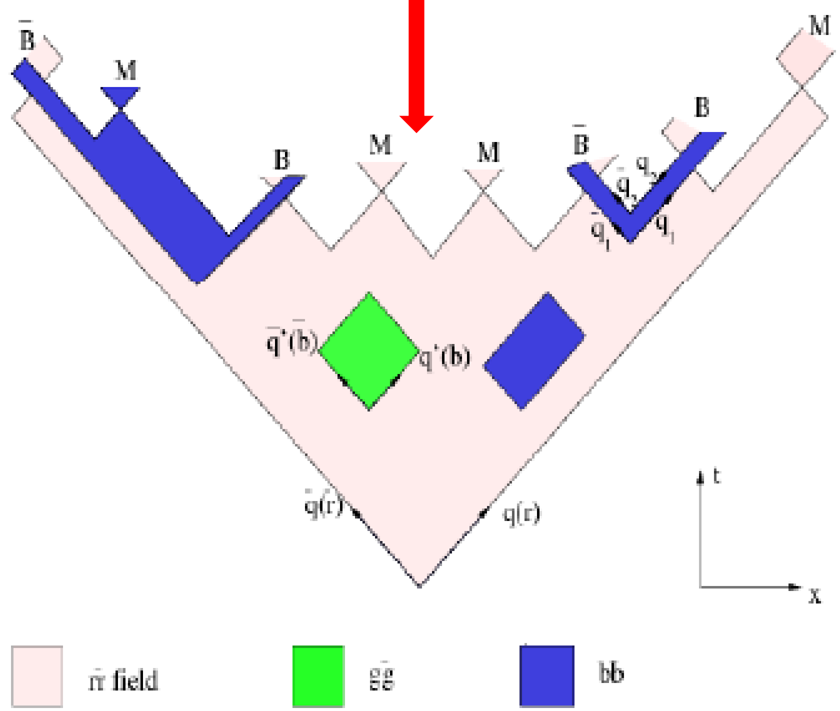
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(3770) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ D^0\bar{D}^0,\ D^+\bar{D}^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \gamma + \text{string} + \text{string} \Rightarrow \gamma + \text{hadrons} \\ \pi^+\pi^- J/\psi,\ \pi^0\pi^0 J/\psi,\ ,\ \pi^0 J/\psi,\ \eta J/\psi,\ \gamma\chi_{cJ} \end{cases}$$

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

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

Picture of Lund string fragmentation to hadrons





Basic formula of LUARLW

The lowest cross section for the exclusive channel

$$\sigma(e^+e^- \to m_1, m_2, \cdots m_n) = \int d\Omega_{q\bar{q}} \frac{d\sigma(e^+e^- \to q\bar{q})}{d\Omega_{q\bar{q}}} \cdot \wp_n(q\bar{q} \to m_1, m_2, \cdots m_n; s)$$

The QED cross section for quark pair production

$$\frac{d\sigma(e^+e^- \to q\bar{q})}{d\Omega_{q\bar{q}}} = N_c \frac{\alpha^2}{4s} \cdot e_q^2 \beta [1 + \cos^2\theta + (1 - \beta^2)\sin^2\theta]$$

The string fragmentation probability in Lund area law

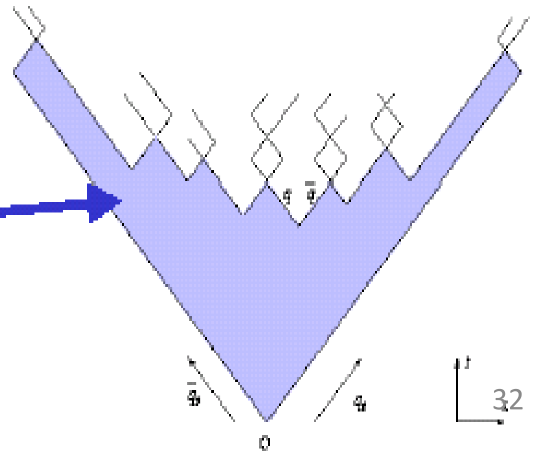
$$d\wp_n(q\bar{q} \to m_1, m_2, \cdots m_n; s) = \cdot (2\pi)^4 \delta(1 - \sum_{j=1}^{n} \frac{m_{\perp j}^2}{s z_j}) \cdot \delta(1 - \sum_{j=1}^{n} z_j) \cdot \delta^{(2)}(\sum_{j=1}^{n} \vec{k}_j) \cdot \overline{\sum} |\hat{T}_{con}^{(n)f}|^2 d\Phi_n$$

$$d\Phi_n = \prod_{j=1}^{n} d^2\vec{k}_j \frac{dz_j}{z_j}$$

$$\hat{T}_{con}(q\bar{q} \to m_1, m_2, \cdots m_n) \equiv \hat{T}_{con}^{(n)f} = \cdot N^n \cdot \hat{T}_{con\perp}^{(n)f} \cdot \hat{T}_{con//}^{(n)f}$$

$$\hat{T}_{con\perp}^{(n)f} = exp(-\sum_{j=1}^{n} \vec{k}_j^{\,2}) \qquad \vec{k}_j \equiv \frac{\vec{p}_{\perp j}}{2\sigma}$$

$$\hat{T}_{con//}^{(n)f} = exp(i\xi \mathcal{A}_n). \qquad \xi = \frac{1}{2\kappa} + i\frac{b}{2}.$$



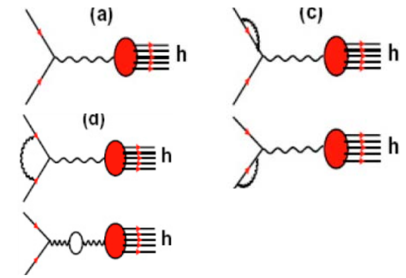
ISR sampling in LUARLW simulation

In LUARLW simulation, the events are classed into two types

① non real radiation: tree level, virtual and soft radiations events.

Weight:

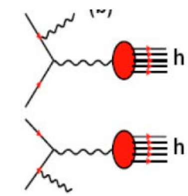
$$\sigma^{VSB} = \sigma^0(s)[1 + \beta \ln k_0 + \delta_{AR}]$$



② real radiation: hard bremsstrahlung events.

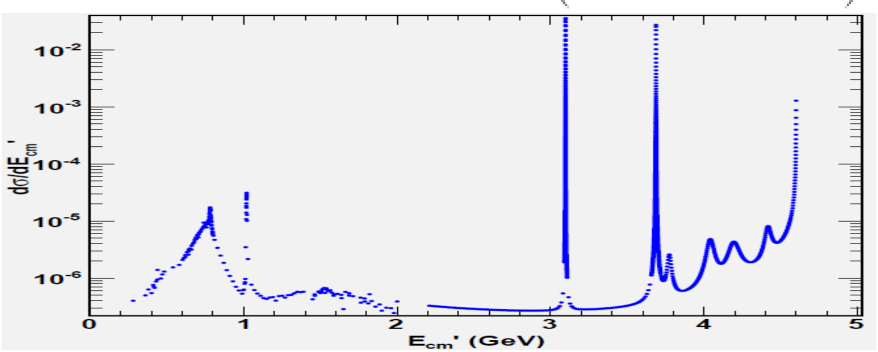
Weight:

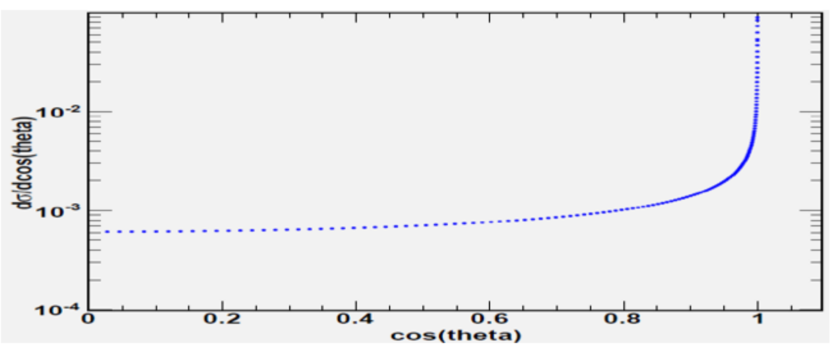
$$\sigma^{HB} = \int_{k_0}^{k_m} dk \frac{\partial \sigma^{HB}}{\partial k}$$



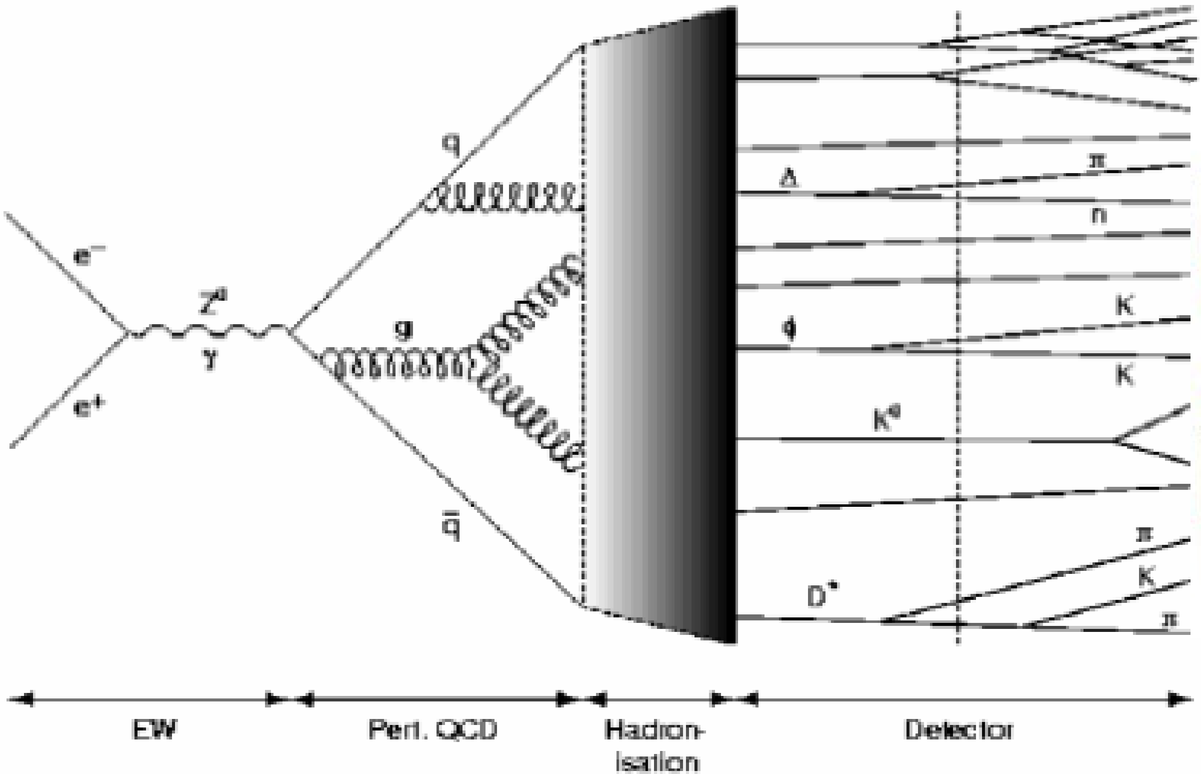
The energy and polar angle distribution of real emission photon

$$d\sigma^{HB}(s) = \frac{\alpha}{\pi^2} \frac{\sin^2\theta}{(1 - a^2\cos^2\theta)} \frac{dk d\Omega_\gamma}{k} (1 - k + \frac{k^2}{2}) d\sigma^0(s')$$

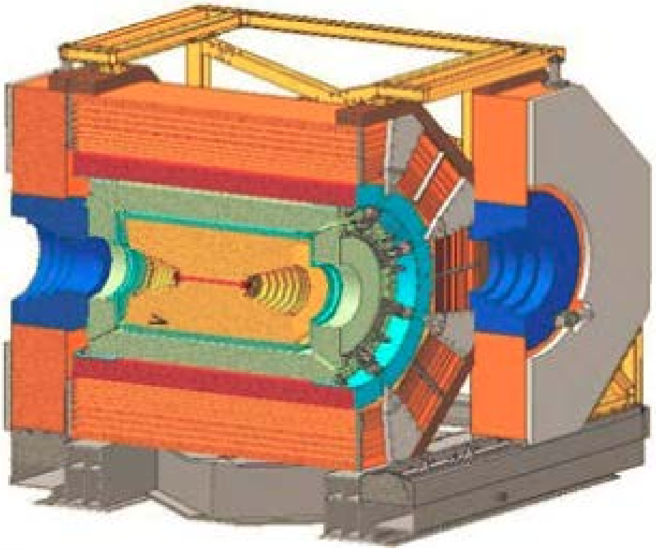




Simulation of hadron production and decay



BESIII



Hadrons production at vertex: ConExe/PHOKHARA ⊕ LUARLW

Short-life particles decay: BesEvtGen

Detector simulation: GEANT4

Parameters optimization of LUARLW

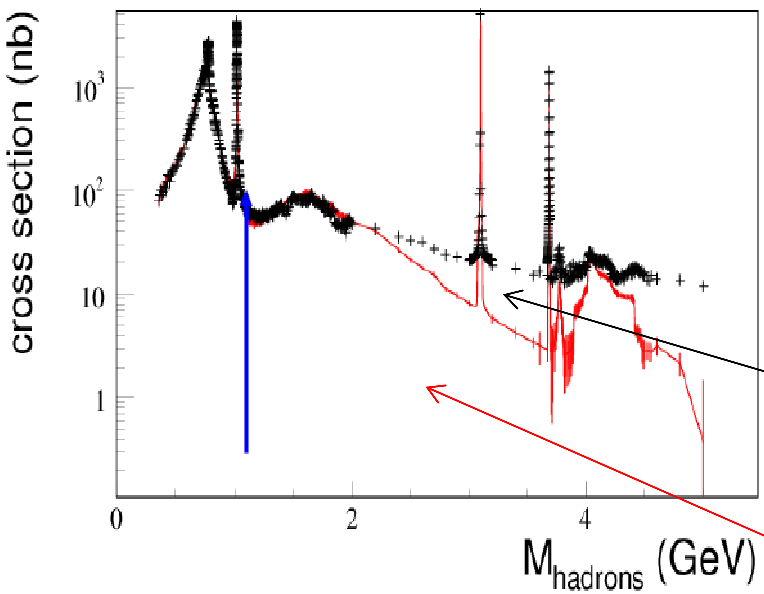
- Assume LUARLW is approximately described by a parameterized response function

Z. Phys. C 26, 157 (1984)
Z. Phys. C 41, 359(1988)
Eur. Phys. J. C 65 , 331 (2010)

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

The parameters in LUARLW are treated as free numbers in fit, the optimal values are obtained by fit this function to the data.

- The known channels employ experimental values, the unknown channels use LUARLW.



+ total hadronic cross section,

+ sum of the cross section ever measured exclusive channels

Unknown channels, simulate by LUARLW

Known channels, simulate by exclusive method
ConExc/PHOKHARA

Parameter optimization of LUARLW @3.06GeV

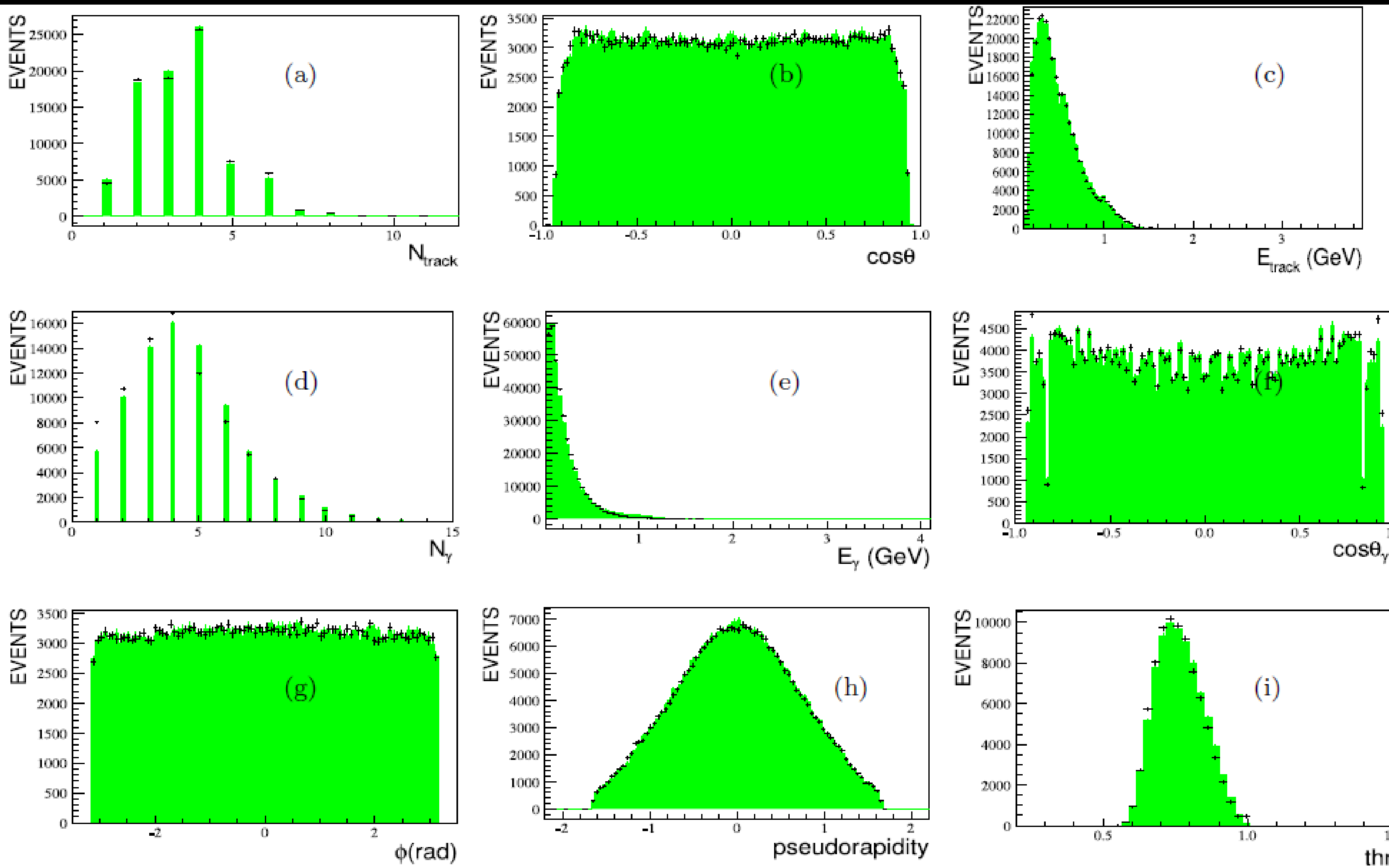


Fig. 5. Comparison of data to the MC distributions at 3.06 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, . (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine 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.

Parameter optimization of LUARLW @3.65GeV

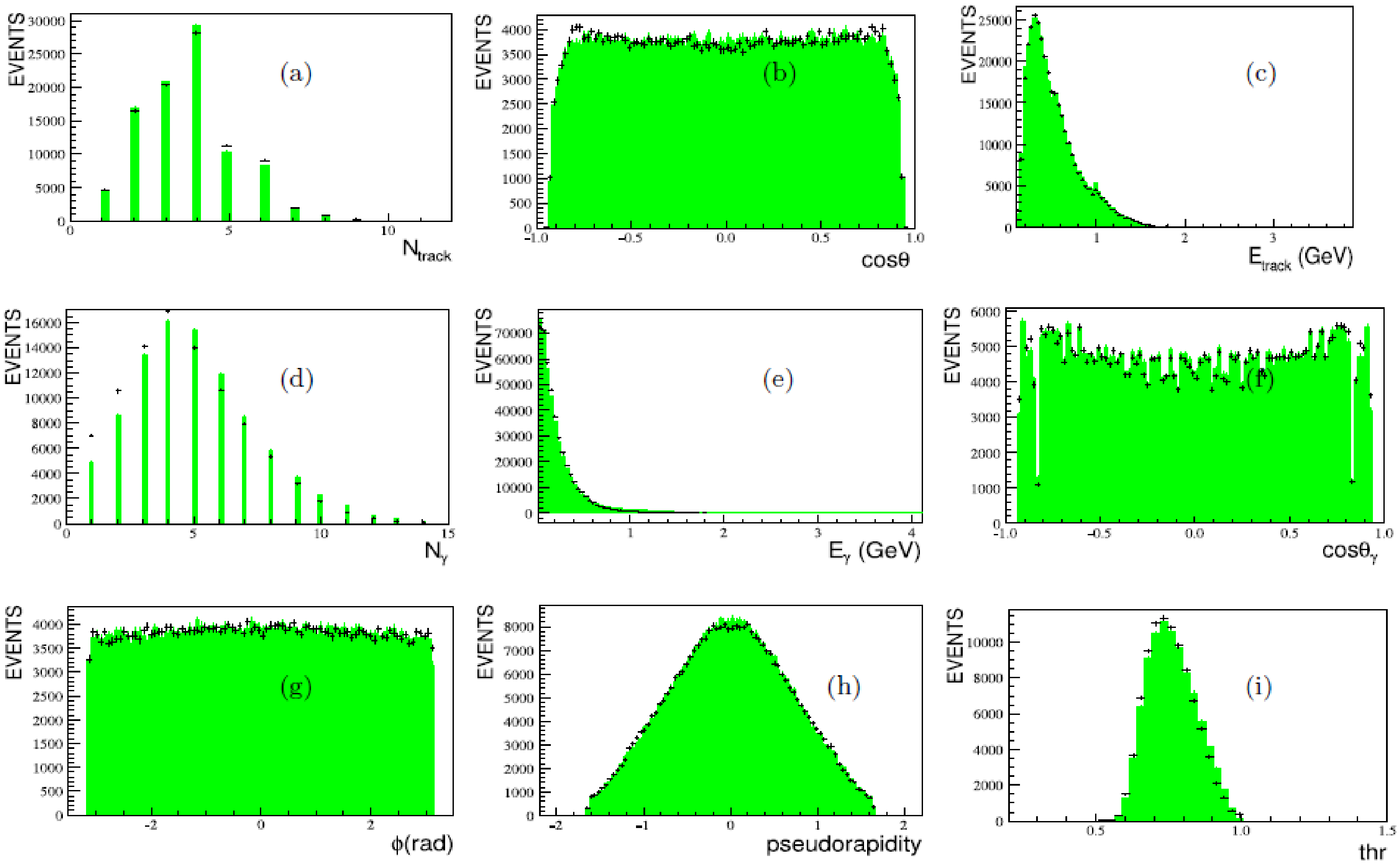


Fig. 4. Comparison of data to the MC distributions at 3.65 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine of 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.

Multiplicity of data and MC

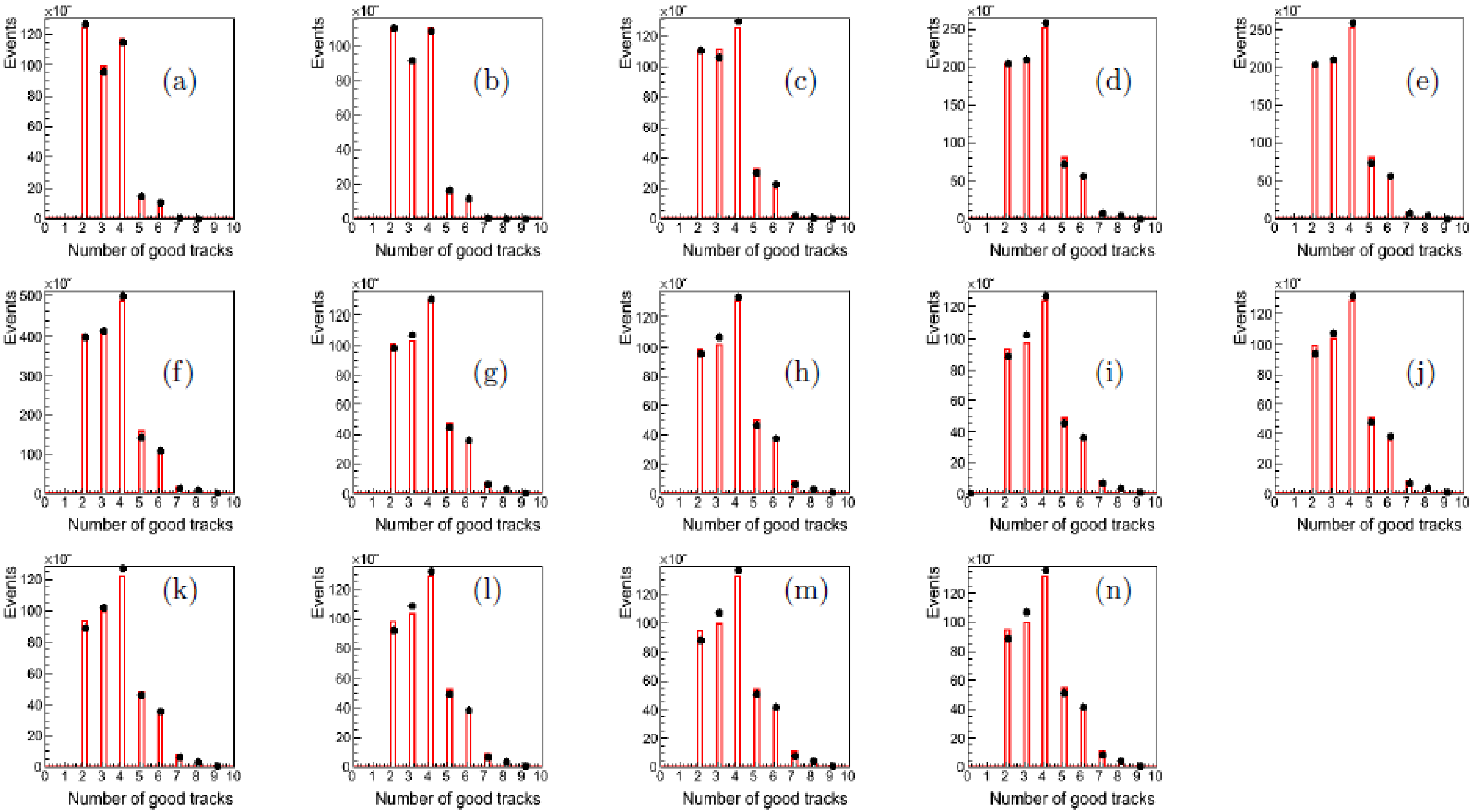
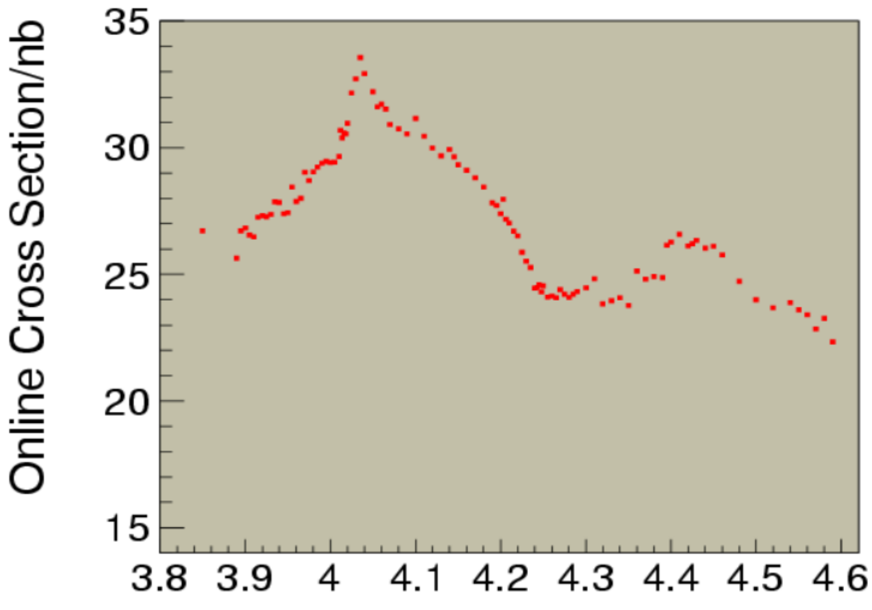
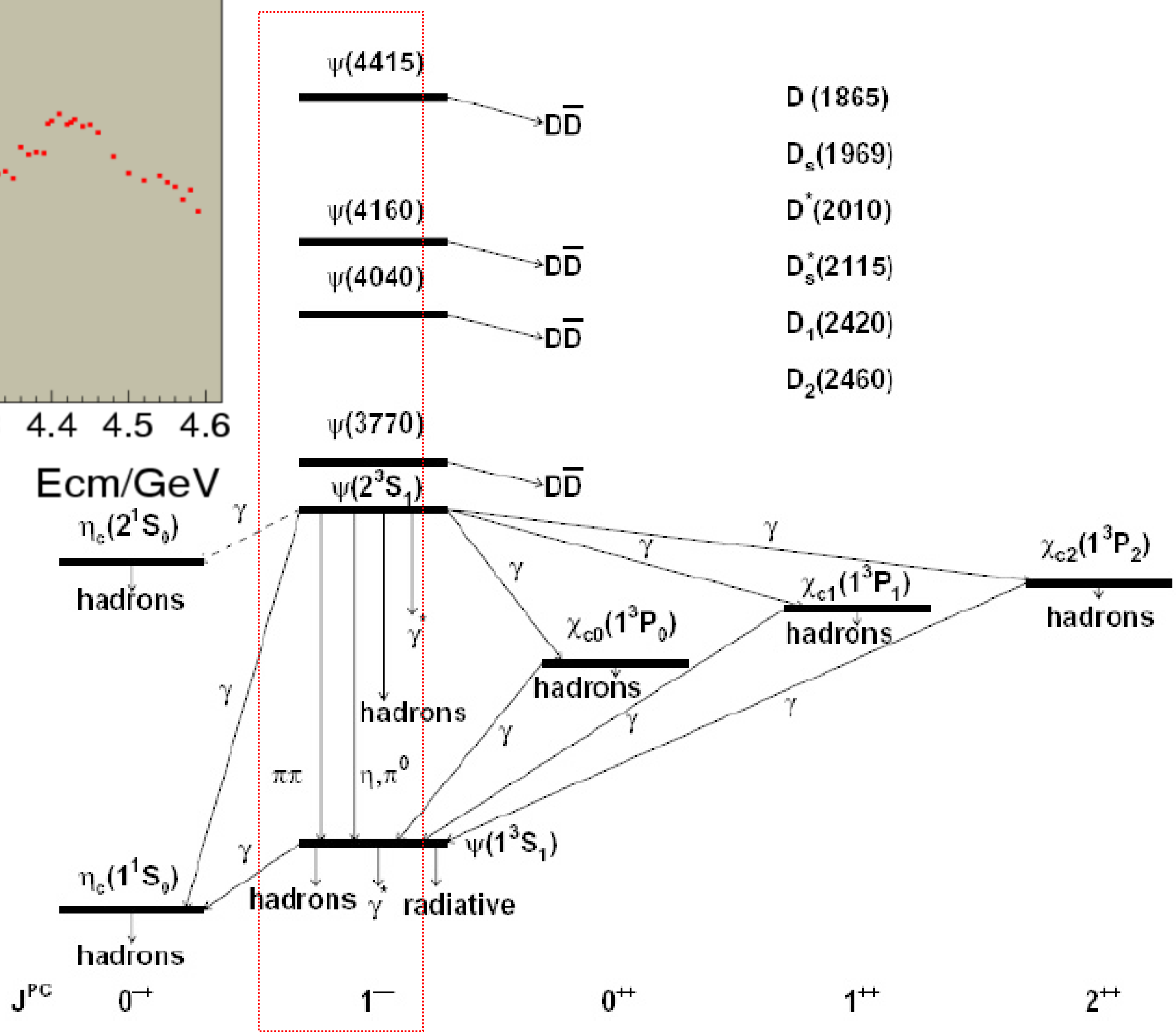


Fig. 6. Comparison of distributions between data and MC for the number of charged track at (a) 2.2324 GeV, (b) 2.4 GeV, (c) 2.8 GeV, (d) 3.05 GeV, (e) 3.06 GeV, (f) 3.08 GeV, (g) 3.4 GeV, (h) 3.5 GeV, (i) 3.5424 GeV, (j) 3.5538 GeV, (k) 3.5611 GeV, (l) 3.6002 GeV, (m) 3.65 GeV, (n) 3.671 GeV. The dots denote data, and the open bars denote MC.

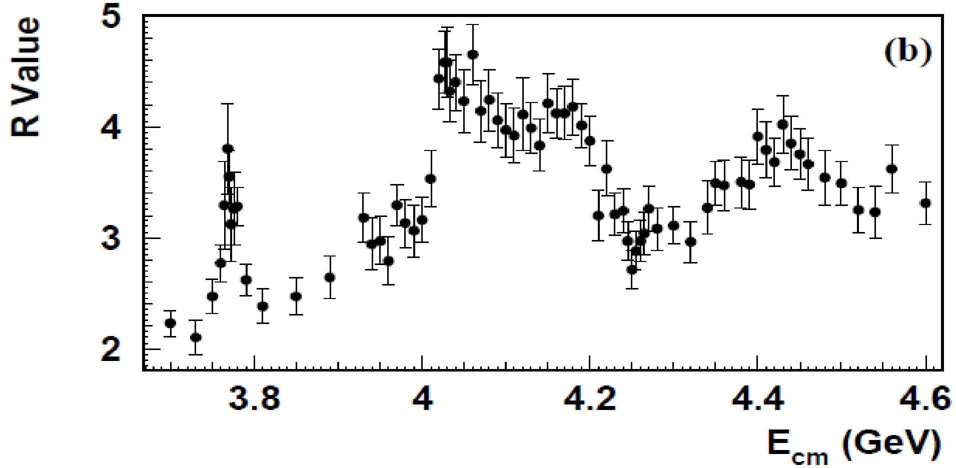
Heavy charmonia line shape scan





Aim to understand resonant structure

Phys. Rev. Letts. 88 (2002)101802



R values

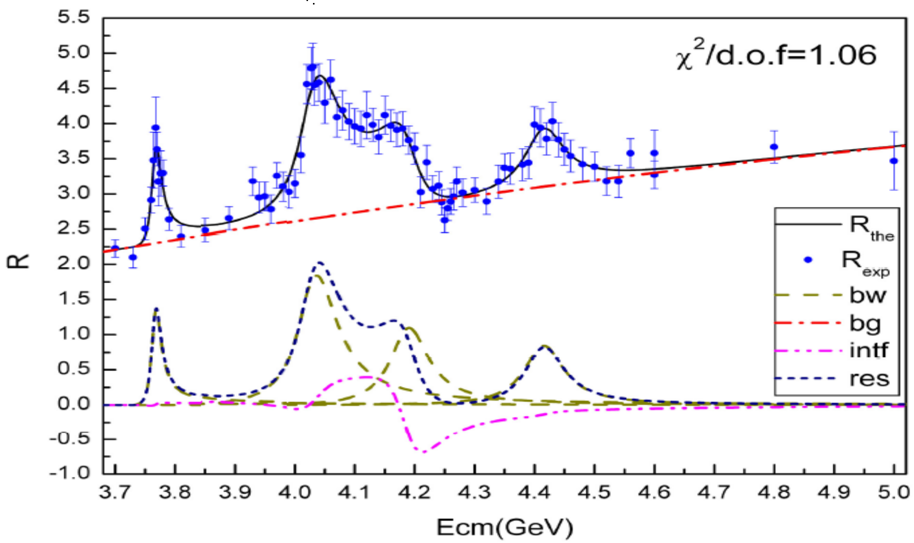
Fit

$$\chi^2 = \sum_i \frac{(f \cdot \widetilde{R}_{exp}(s_i) - \widetilde{R}_{the}(s_i))^2}{(f \cdot \Delta \widetilde{R}_{exp}^{(i)})^2} + \frac{(f-1)^2}{\sigma_f^2}$$

$$\widetilde{R}_{exp} = \frac{N_{had}^{obs} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma_{\mu\mu}^0 \cdot L \cdot \epsilon_{trg} \cdot \epsilon_{had}(0)}$$

$$\widetilde{R}_{the} = (1 + \delta_{obs}) \cdot R_{the}$$

Phys. Lett. B660 (2008)315



Resonant parameters

Parameters of the excited charmonia

Similar work like did at BESII, but improved measurement at BESIII

At BESII, parameters (M, Γ_{tot}, Γ_{ee}) of the $J^{PC} = 1^{--}$ conventional charmonia ψ(3770), ψ(4040), ψ(4160), ψ(4415) remain quite uncertain and model dependent:

	M (MeV)	Γ_{tot} (MeV)	Γ_{ee} (keV)	δ (°)	
ψ(3770)	3772.92 ± 0.35	27.3 ± 1.0	0.265 ± 0.018		PDG09
	3772.0 ± 1.9	30.4 ± 8.5	0.22 ± 0.05	0	BES08
ψ(4040)	4039 ± 1	80 ± 10	0.86 ± 0.07		PDG09
	4039.6 ± 4.3	84.5 ± 12.3	0.83 ± 0.20	130 ± 46	BES08
ψ(4160)	4153 ± 3	103 ± 8	0.83 ± 0.07		PDG09
	4191.7 ± 6.5	71.8 ± 12.3	0.48 ± 0.22	293 ± 57	BES08
ψ(4415)	4421 ± 4	62 ± 20	0.58 ± 0.07		PDG09
	4415.1 ± 7.9	71.5 ± 19.0	0.35 ± 0.12	234 ± 88	BES08

PDG2014

$\psi(4040)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4040)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4039 ± 1 OUR ESTIMATE				
4039.6 ± 4.3	[1] ABLIKIM	08D	BES2	$e^+e^- \rightarrow$ hadrons

$\psi(4040)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 ±10 OUR ESTIMATE				
84.5±12.3	[5] ABLIKIM	08D	BES2	$e^+e^- \rightarrow$ hadrons

$\psi(4040)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.86±0.07 OUR ESTIMATE				
0.83±0.20	[9] ABLIKIM	08D	BES2	$e^+e^- \rightarrow$ hadrons

[1] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (130 \pm 46)^\circ$.

PDG2014

$\psi(4160)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4160)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4191 ± 5 OUR AVERAGE				
4191^{+9}_{-8}	AAIJ	13BC	LHCB	$B^+ \to K^+ \mu^+ \mu^-$
4191.7 ± 6.5	[1] ABLIKIM	08D	BES2	$e^+ e^- \to$ hadrons

$\psi(4160)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
70 ±10 OUR AVERAGE				
65^{+22}_{-16}	AAIJ	13BC	LHCB	$B^+ \to K^+ \mu^+ \mu^-$
71.8 ± 12.3	[5] ABLIKIM	08D	BES2	$e^+ e^- \to$ hadrons

$\psi(4160)$ PARTIAL WIDTHS

$\Gamma(e^+ e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.48 ± 0.22	[9] ABLIKIM	08D	BES2	$e^+ e^- \to$ hadrons

PDG2014

$\psi(4415)$

$I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4415)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4421 ± 4 OUR ESTIMATE				
4415.1 ± 7.9	[1] ABLIKIM	08D	BES2	$e^+ e^- \rightarrow$ hadrons

$\psi(4415)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
62 ±20 OUR ESTIMATE				
71.5±19.0	[6] ABLIKIM	08D	BES2	$e^+ e^- \rightarrow$ hadrons

$\psi(4415)$ PARTIAL WIDTHS

$\Gamma(e^+ e^-)$ Γ_{16}

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.58±0.07 OUR ESTIMATE				
0.35±0.12	[11] ABLIKIM	08D	BES2	$e^+ e^- \rightarrow$ hadrons

[1] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (234 \pm 88)^\circ$.

Summary

- The planed data sets for QCD and R scan between 2.0-4.6 GeV energies have been collected.
- Data analysis between 2.2324-3.671 GeV finished, the analysis for data above 3.85 GeV are in progress.
- The integrated luminosity at all 149 energy points are measured with about 1% precision.
- The LUARLW parameters are being optimized, the uncertainty of ε_{had} could be about 2%, but need further check.
- Preliminary results of R value measurement between 2.2324-3.671 GeV are being reviewed in BES Collaboration.
- It can be expected that R value measured with BESIII data will improve the calculations of $\Delta\alpha(s)$ and (g-2).