Status of R Scan at BESIII

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Institute of High Energy Physics

(For the BESIII Collaboration)

10th International Workshop $e^+ e^-$ Collisions from Phi to Psi

USTC, Hefei, China

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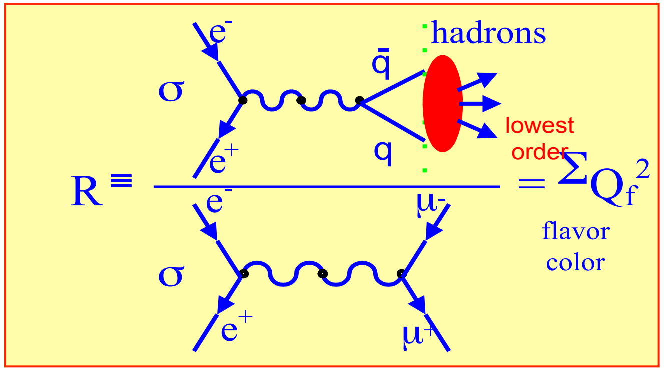
Outline

- Motivation
- Recall R value measurement with BESII data
- Data samples of R-QCD scan at BESIII
- Status of R value measurement with BESIII data
- Summary

Motivation

Definition:

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



R value is the inclusive hadronic Born cross section in e^+e^- annihilation normalized by Born cross section of $\mu^+\mu^-$.

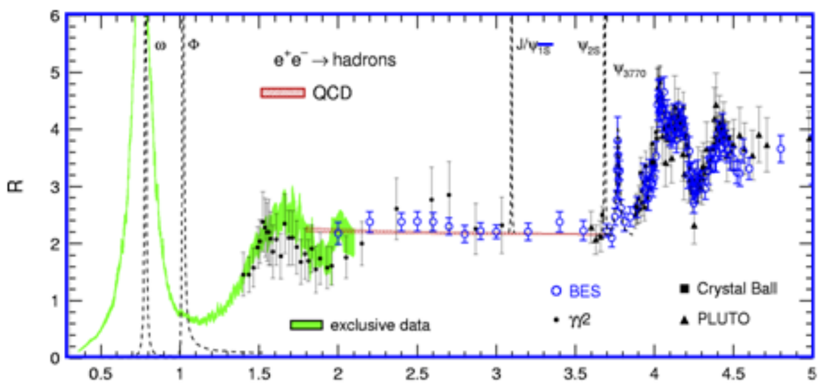
In quark model :

$$R\equiv\frac{\sigma(e^+e^-\to \text{hadrons})}{\sigma(e^+e^-\to\mu^+\mu^-)}=\frac{\sum_q\sigma(e^+e^-\to q\bar q)}{\sigma(e^+e^-\to\mu^+\mu^-)}=3\sum_q Q_q^2$$

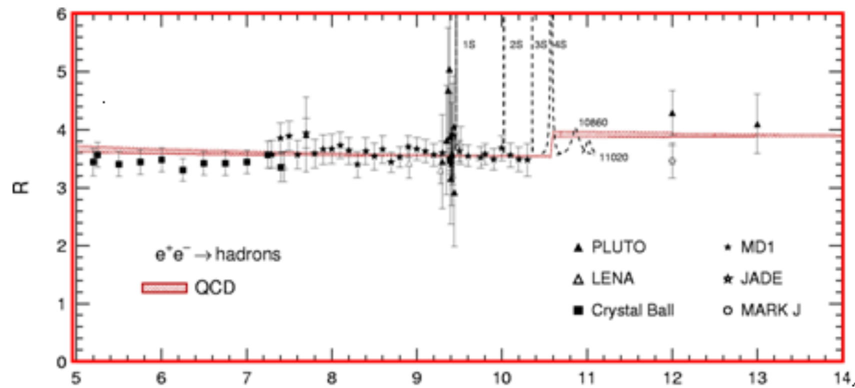
In pQCD :

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

below 5 GeV



above 5 GeV



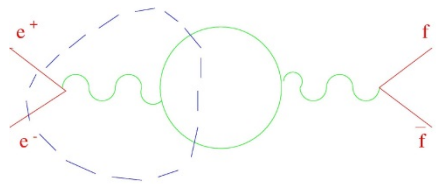
Motivation

R - basic input parameter in SM

experimental error of R → uncertainty of SM calculation

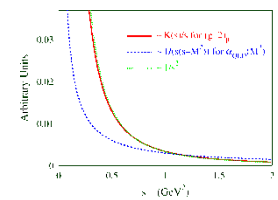
below 5 GeV use measured R value, above 5 GeV use pQCD prediction of R

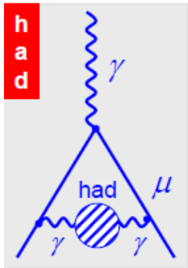
- Hadronic contribution to
  - QED running coupling constant $a_{QED}(s)$



$$\Delta\alpha_{had}^{(5)}(s) = -\frac{\alpha s}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds' \frac{R(s')}{s'-s-i\varepsilon}$$

  - Anomalous magnetic moment of the muon $a_m = g_m - 2$





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

- Strong coupling constant α_s determination;

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

- Global fitting of most probable Higgs mass in SM;
- Charm quark mass $m_c(m_c)$ determination;
- Resonance structure and components in open charm region;
- X, Y, Z particles and other possible new resonances.

R value measurement with BESII data

(1998-2008)

R value measurement with data

R value 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 N_{had}

$1+\delta$ radiative correction factor

$\sigma_{\mu\mu}$ Born cross section of μ pair production in QED.

How R value measured?

Observed cross section (no physics):

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

Efficiency corection:

→ total cross section (physics)

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

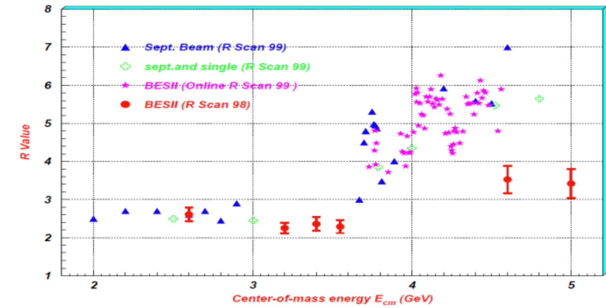
ISR factor (1+δ) correction:

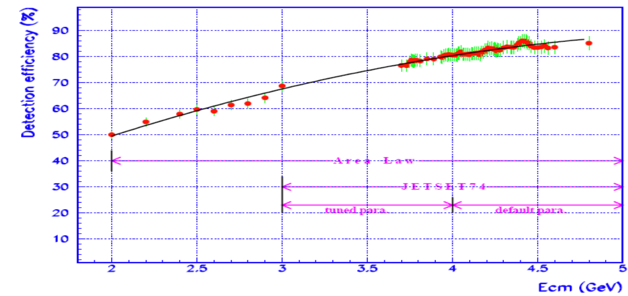
→ Born cross section

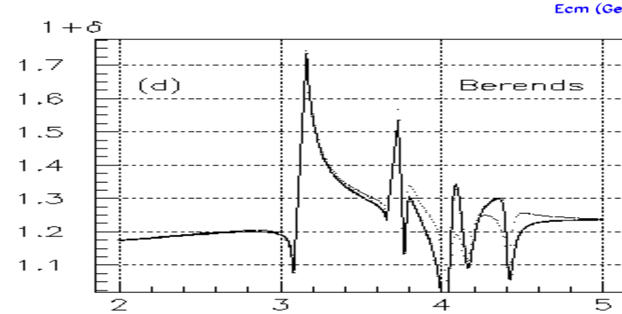
$$\sigma^0 = \frac{N_{had}}{L\bar{\epsilon}(1+\delta)}$$

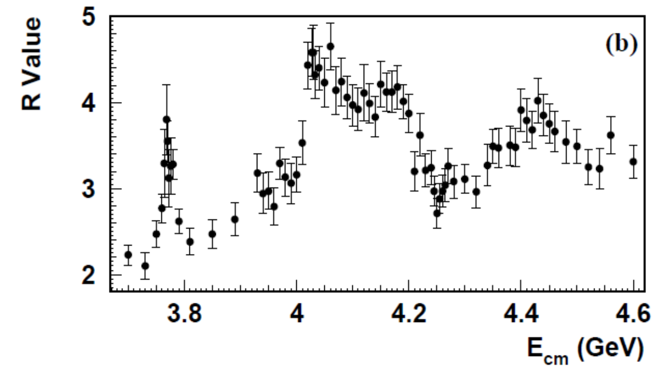
R value:

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

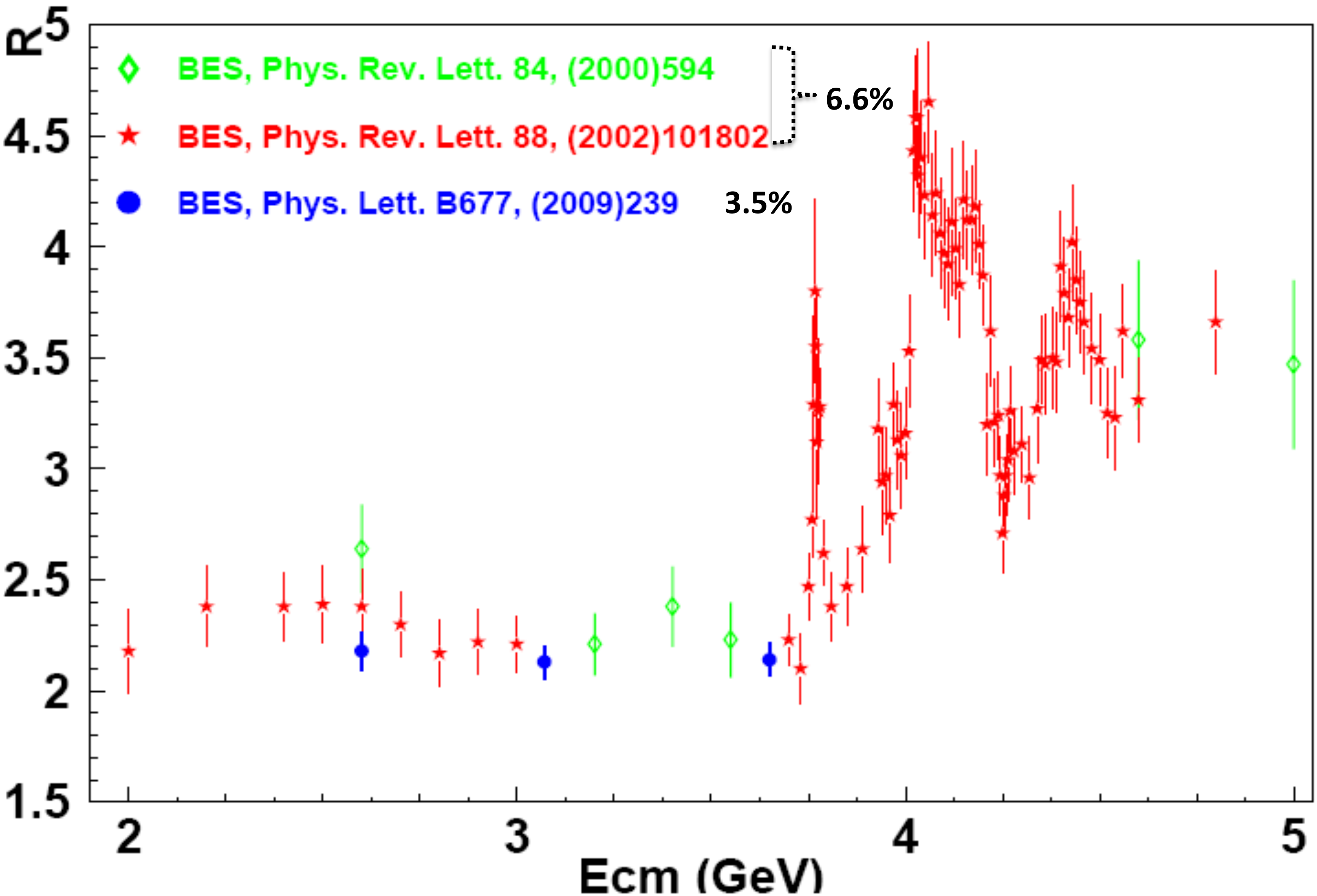








BESII: R value measurements



Determination of α_s with R value

Phys. Lett. B677, (2009) 239

E_{cm} (GeV)	R	$\alpha_s^{(3)}(s)$	$\alpha_s^{(4)}(25\ \mathrm{GeV}^2)$	$\alpha_s^{(5)}(M_Z^2)$
2.60	2.18	$0.266^{+0.030+0.125}_{-0.030-0.126}$		
3.07	2.13	$0.192^{+0.029+0.103}_{-0.029-0.101}$	$0.209^{+0.044}_{-0.050}$	$0.117^{+0.012}_{-0.017}$
3.65	2.14	$0.207^{+0.015+0.104}_{-0.015-0.104}$		

$\frac{\delta R}{R}$: sys $\sim 3.5\%$; stat $\sim 0.5 - 1\%$!

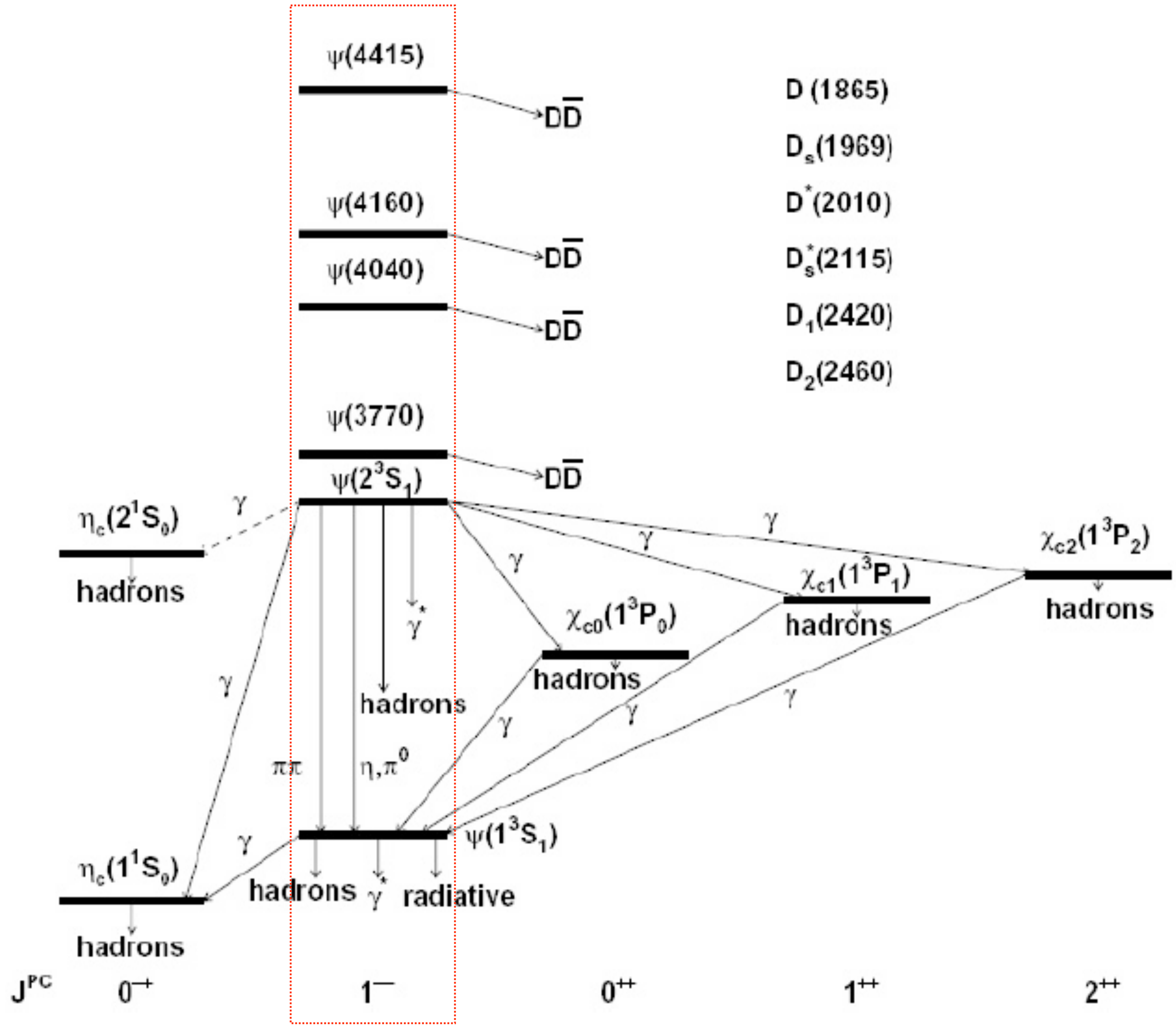
- perfect agreement with pQCD
- perfect agreement with
  - α_s from Z decay rate: $\alpha_s^{(5)}(M_Z^2) = 0.1185 \pm 0.0026$
  - τ-decays (Baikov, Chetyrkin, JK)
    $\alpha_s^{(3)}(m_\tau^2) = 0.332 \pm 0.005_{exp} \pm 0.015_{th} \Rightarrow \alpha_s^{(5)}(M_Z^2) = 0.120 \pm 0.019$
- relative importance of α_s^4-terms for BES e.g. at 2.606 GeV:
  $0.266 \pm 0.030 \pm 0.120 \quad \Rightarrow 0.286 \pm \ldots$

low energies (~ 2 GeV) of special interest

validity of pQCD? $\Rightarrow$ s-dependence!

BESII: Heavy vector charmonia line shape

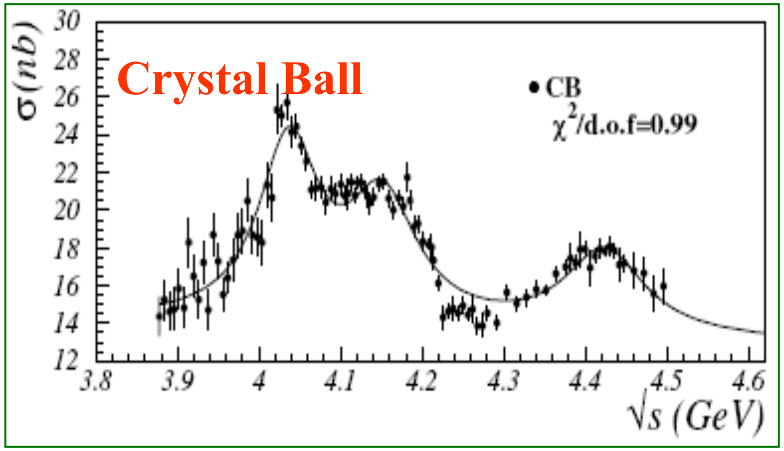
Confirmed charmoniums family in BESII era

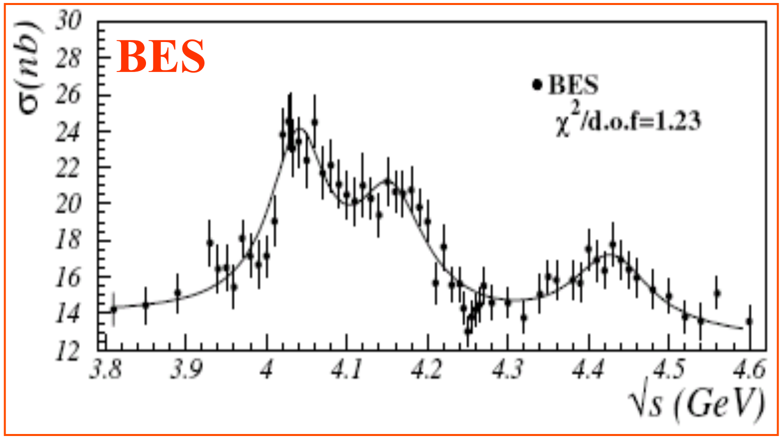


BESII: Heavy Ψ family parameters fit

Kamal. K. Seth

Phys. Rev. D72, 017501 (2005)





"It is very gratifying that two independent measurements, made 20 years apart, are in such good agreement".

Simplified considerations used:

- ✓Constant u, d, s background
- ✓ Linear form for charm continuous
- ✓Constant total width
- ✓ No interference
- ✓ Using published (fixed) R value

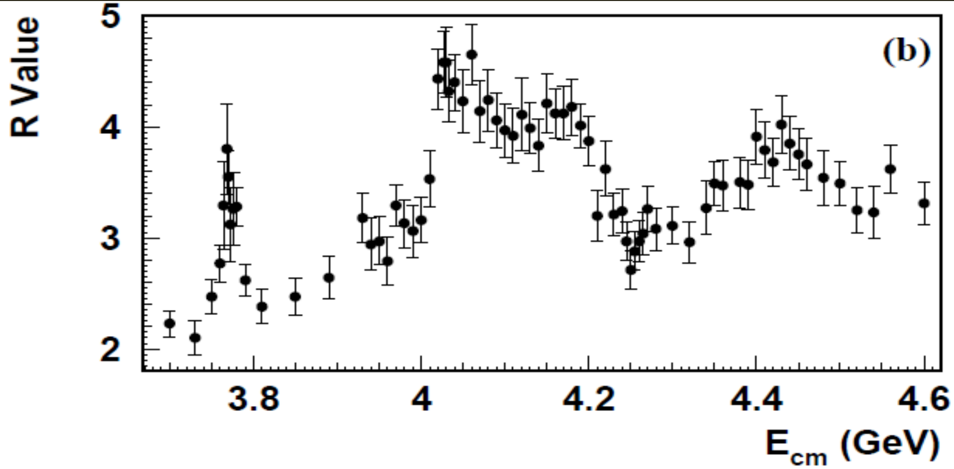
	$M^{(1)}$ (MeV)	$\Gamma_{tot}^{(1)}$ (MeV)	$\Gamma_{ee}^{(1)}$ (keV)
PDG [1]	4040 ± 10	52 ± 10	0.75 ± 0.15
CB [6]	4037 ± 2	85 ± 10	0.88 ± 0.11
BES [7]	4040 ± 1	89 ± 6	0.91 ± 0.13
CB + BES	4039.4 ± 0.9	88 ± 5	0.89 ± 0.08
	$M^{(2)}$	$\Gamma_{tot}^{(2)}$	$\Gamma_{ee}^{(2)}$
PDG [1]	4159 ± 20	78 ± 20	0.77 ± 0.23
CB [6]	4151 ± 4	107 ± 10	0.83 ± 0.08
BES [7]	4155 ± 5	107 ± 16	0.84 ± 0.13
CB + BES	4153 ± 3	107 ± 8	0.83 ± 0.07
	$M^{(3)}$	$\Gamma_{tot}^{(3)}$	$\Gamma_{ee}^{(3)}$
PDG [1]	4415 ± 6	43 ± 15	0.47 ± 0.10
CB [6]	4425 ± 6	119 ± 16	0.72 ± 0.11
BES [7]	4429 ± 9	118 ± 35	0.64 ± 0.23
CB + BES	4426 ± 5	119 ± 15	0.71 ± 0.10
	A	B	χ^2
DASP [3]	Polynomial		2.1
CB [6]	14.2 ± 3.5	1.5 ± 0.4	0.99
BES [7]	13.7 ± 4.5	1.5 ± 0.5	1.23

Theoretical problems in resonant parameters fit

The measurement of R value and the resonant parameters are closely related and affected by the following factors:

- ✓ What is the correct Breit-Wigner form for wide resonance?
- ✓ How to introduce intrinsic/effective initial phase angle?
- ✓ How amplitudes interfere between final states?
- ✓ How guarantee the unitary of the interference?
- ✓ How the total widths depend on energy?
- ✓ How to express the continuous charm backgrounds in fit?

Resonant parameters extracting at BESII

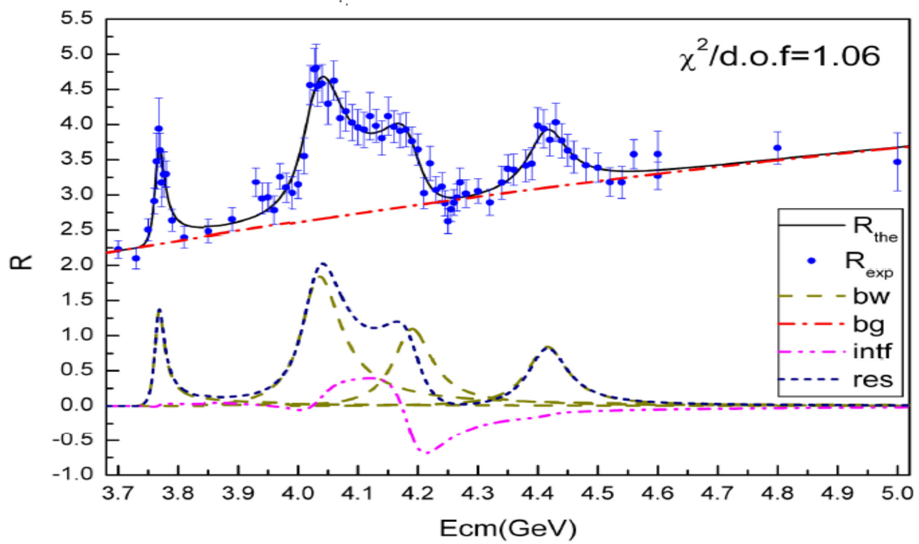


Phys. Rev. Letts. 88 (2002)101802

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

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

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



Phys. Lett. B660 (2008)315

PDG2012

$\psi(4040)$

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

$\psi(4040)$ MASS

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

$\psi(4040)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
80 ±10 OUR ESTIMATE				
84.5±12.3	[5] ABLIKIM	08D	BES2	$e^+ e^- \to$ 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	$e^+ e^- \to$ 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 $\delta = (130 \pm 46)^\circ$.

PDG2012

$\psi(4160)$

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

$\psi(4160)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
4153 ± 3 OUR ESTIMATE				
4191.7 ± 6.5	[1] ABLIKIM	08D	BES2	$e^+e^- \to$ hadrons

$\psi(4160)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
103 ± 8 OUR ESTIMATE				
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
0.83 ± 0.07 OUR ESTIMATE				
0.48 ± 0.22	[9] ABLIKIM	08D	BES2	$e^+e^- \to$ hadrons

[5] 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 $\delta = (293 \pm 57)^\circ$.

PDG2012

$\psi(4415)$

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

$\psi(4415)$ MASS

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

$\psi(4415)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
62 ±20 OUR ESTIMATE				
71.5±19.0	[6] ABLIKIM	08D	BES2	$e^+e^- \to$ 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	$e^+e^- \to$ 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 $\delta = (234 \pm 88)^\circ$.

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

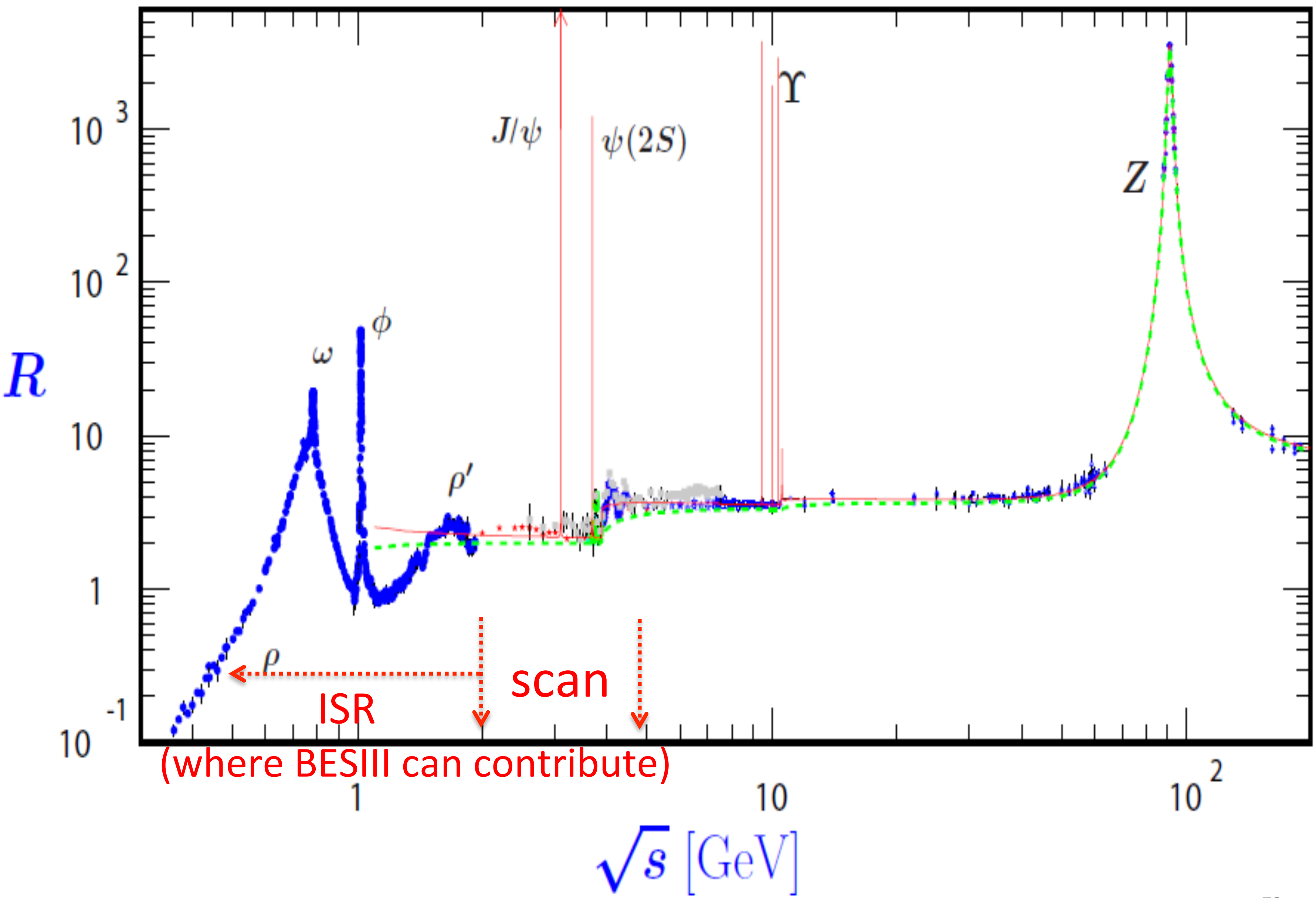
$\psi(4160)$ PARTIAL WIDTHS

$\Gamma(e^+ e^-)$ Γ_1

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

R value measurement with BESIII data

R value from threshold to Z



Projects of BESIII Physics

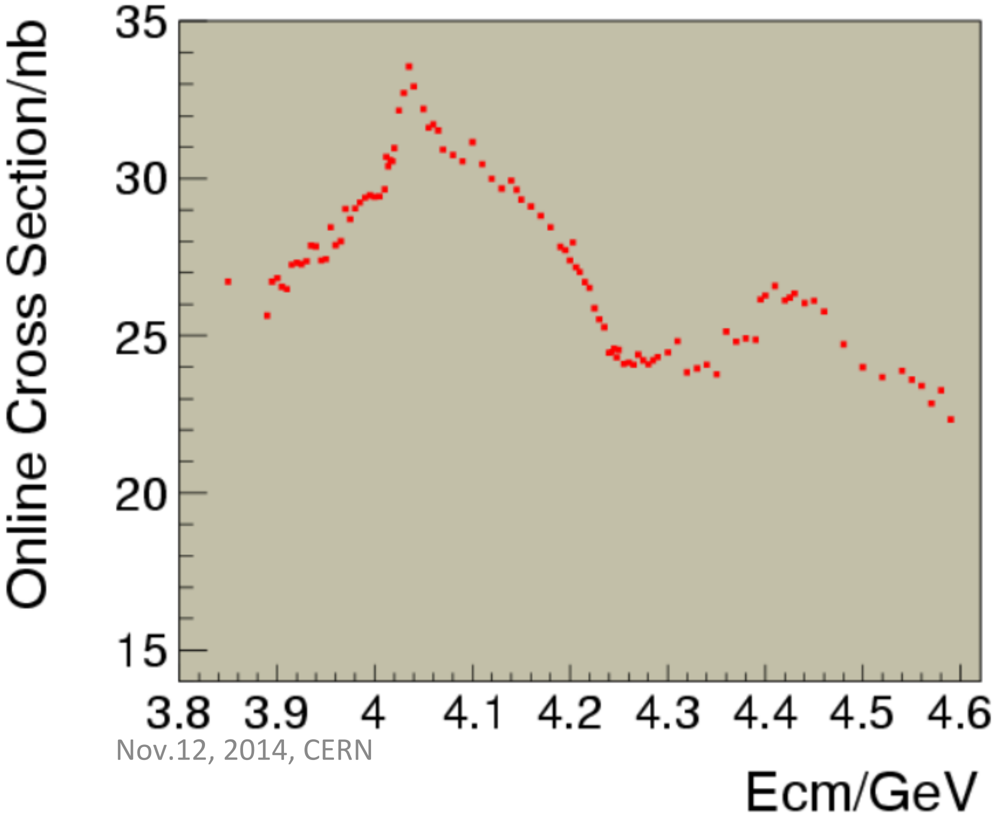
- BESIII physics
  - Charm
    - Light hadron spectrum ☞ J/Ψ data
    - Charmonium ☞ Ψ(2S) data
    - D physics ☞ Ψ(3770) data
    - Heavy charmonium
      - ☞ Ψ(4040)
      - ☞ Ψ(4190)
      - ☞ Ψ(4415)
      - ☞ X, Y, Z
  - Uncharm
    - τ
      - Mass
      - Decay channels
    - R&QCD
      - *R*(*s*) fine scan (*uds*+*c*)
      - QED & QCD α(s), (*g*-2)
      - Inclusive distributions
      - Exclusive distributions
      - Correlation functions
      - Form factors
      - Fragmentation functions

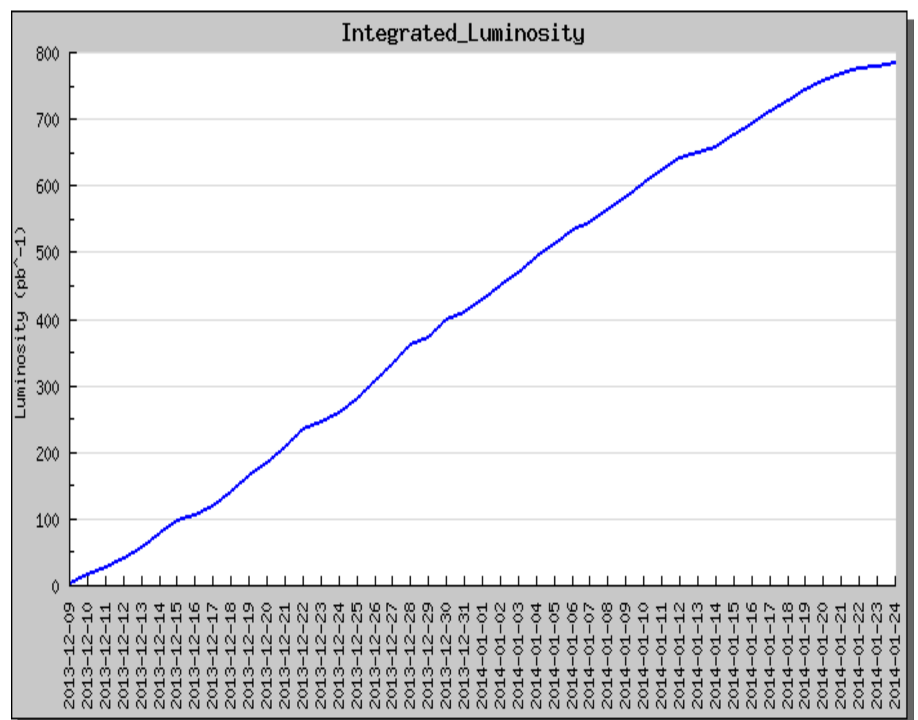
Data samples taken at BESIII

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

R Scan between 3.8 - 4.6 GeV

- Data taken 2013.12.9 - 2014.1.24;
- 104 energy points in total, ~800 pb^{-1};
- >100k hadronic events each points.





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} → event selection: almost finished

L → integrated luminosity: finished, error ~ 1%

ε_{had} → hadronic generator LUARLW tuning: in progress

$1+\delta$ → calculations: finished

Error analysis: on going

Functions of LUARLW

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

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

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

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

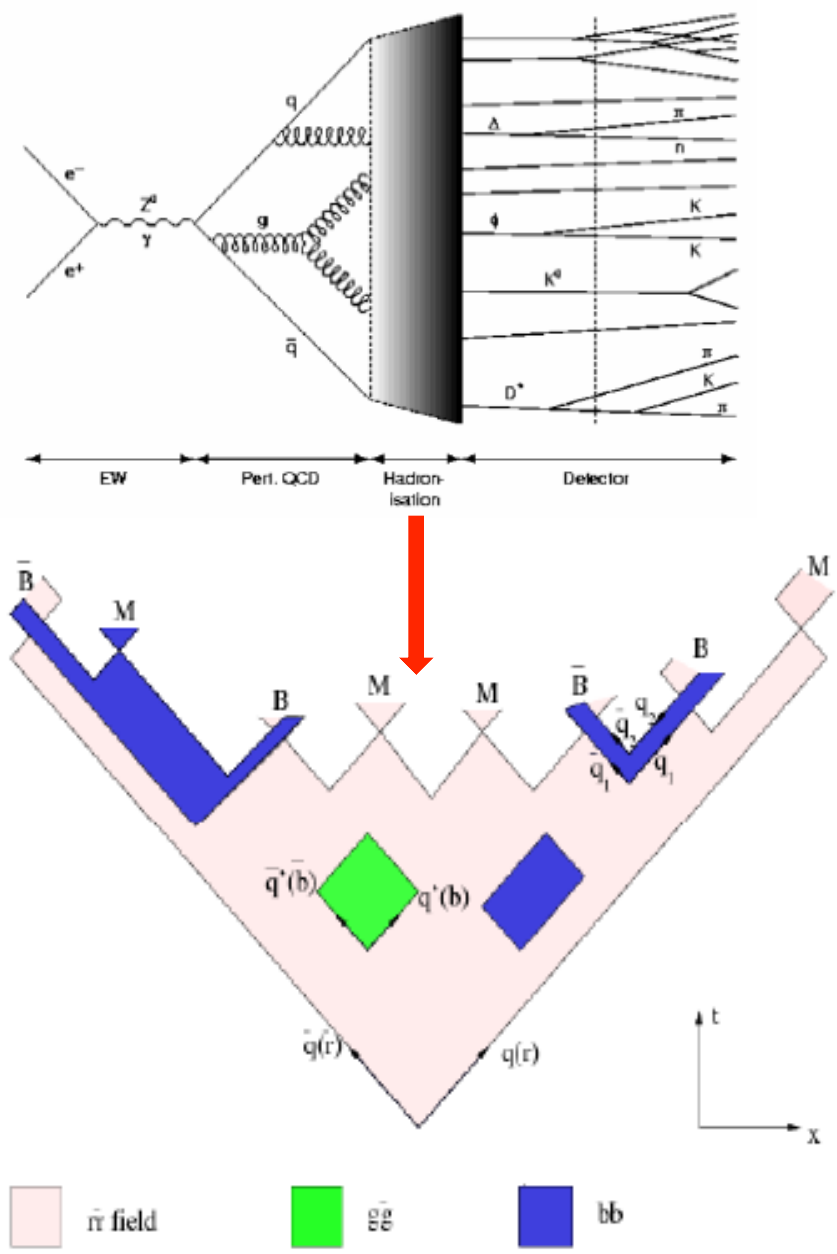
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(2S) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadr} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons}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

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

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

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

Picture of Lund string fragmentation



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

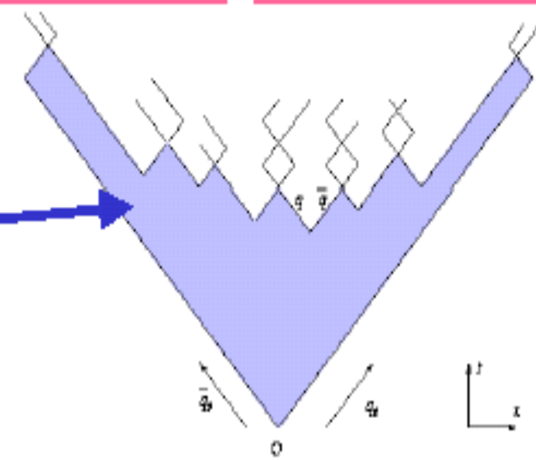
$$d\wp_n(q\bar{q} \to m_1, m_2, \cdots m_n; s) = \cdot(2\pi)^4 \delta(1 - \sum_{j=1}^{n} \frac{m_{\perp j}^2}{s z_j}) \cdot \delta(1 - \sum_{j=1}^{n} z_j) \cdot \delta^{(2)}(\sum_{j=1}^{n} \vec{k}_j) \cdot \overline{\sum} |\hat{\mathcal{T}}_{con}^{(n)f}|^2 d\Phi_n$$

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

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

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

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

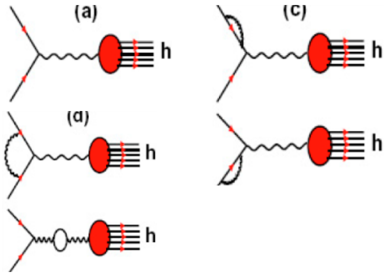


ISR sampling in LUARLW simulation

In the MC simulation, produced events are classed into two types

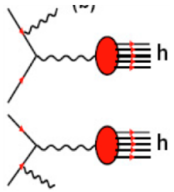
① non real radiation: tree level, virtual and soft radiations events.

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



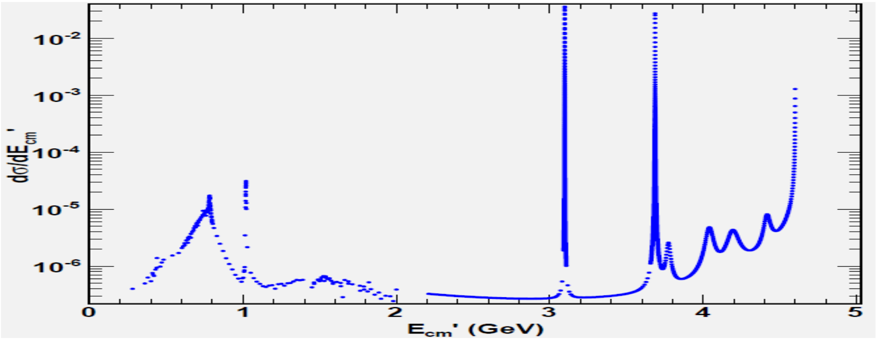
② real radiation: hard bremsstrahlung events.

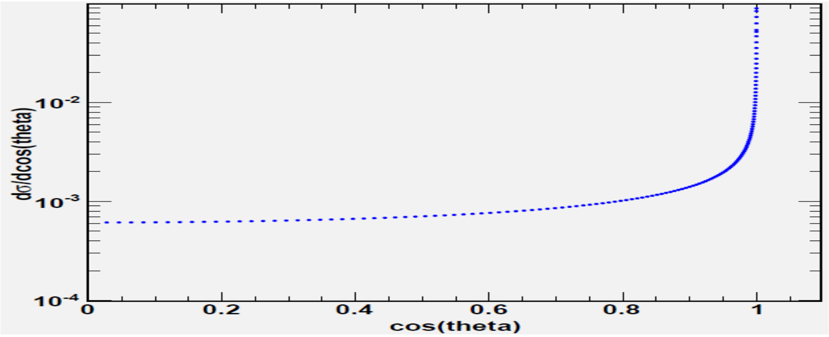
Weight: $$\sigma^{HB} = \int_{k_0}^{k_m} dk \frac{\partial \sigma^{HB}}{\partial k}$$



The energy and polar angle distribution of real emission photon

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





Parameters for primary multiplicity

N-particle system partial function in Lund area law

$$Z_n = s \int d\Phi_n \exp(-b\mathcal{A}_n)$$

Multiplicity distribution for preliminary fragmentation hadrons

$$P_n = Z_n / \sum Z_r$$

Approximate expression

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

μ Predicted by pQCD

$$\mu = \alpha + \beta \exp(\gamma\sqrt{s})$$

c_0, c_1, c_2 and α, β, γ are free parameters to be tuned

Parameters for final state hadrons

Related to ratio of baryon and meson with different quantum number

parameter	default	tuned	meaning
PARJ(1)	0.10	0.10	diquark/quark production ratio (baryon suppression) (B/M)
PARJ(2)	0.30	0.28	s/(u,d) production ratio (strange meson suppression K/π)
PARJ(3)	0.40	0.55	extra strange diquark suppression (strange baryon suppression (Λ/p))
PARJ(4)	0.05	0.07	extra suppression of spin 1 diquark compared to spin 0 ones
PARJ(11)	0.50	0.55	suppression of light meson has spin 1 compared to spin 0 (ρ/π)
PARJ(12)	0.60	0.55	suppression of strange meson has spin 1 compared to spin 0 $(K^{\star}/K)$
PARJ(13)	0.75	0.75	suppression of charm meson has spin 1 compared to spin 0 $(D^{\star}/D)$
PARJ(14)	0.00	0.09	probability that a spin s=0 and orbital L=1 with total J=1 meson
PARJ(15)	0.00	0.07	probability that a spin s=1 and orbital L=1 with total J=0 meson
PARJ(16)	0.00	0.09	probability that a spin s=1 and orbital L=1 with total J=1 meson
PARJ(17)	0.00	0.14	probability that a spin s=1 and orbital L=1 with total J=2 meson

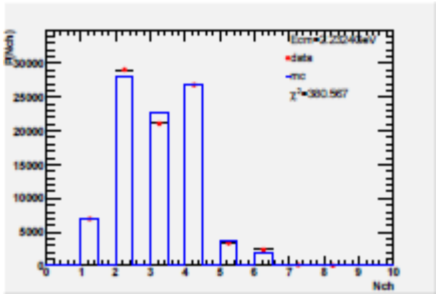
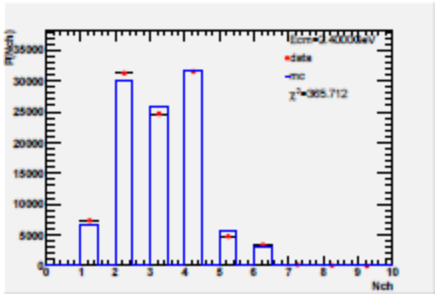
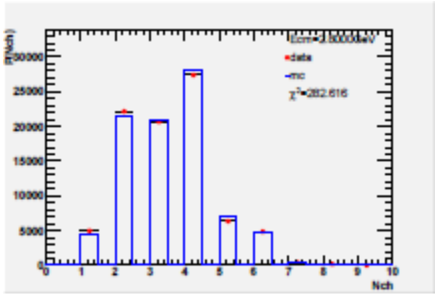
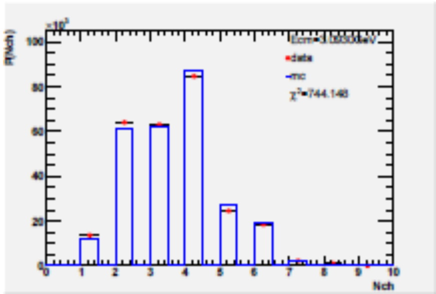
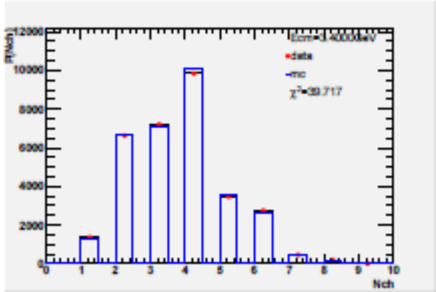
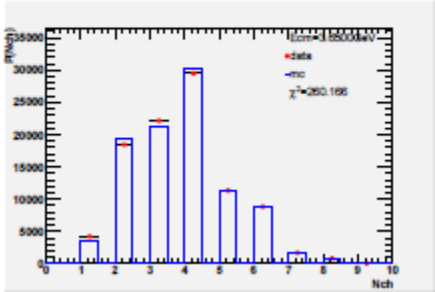
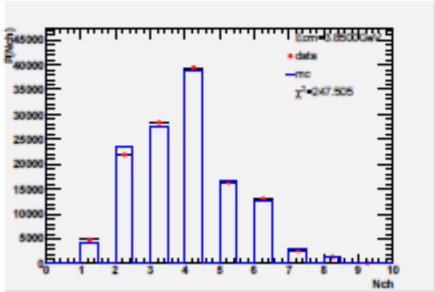
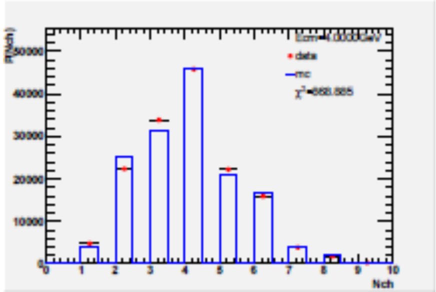
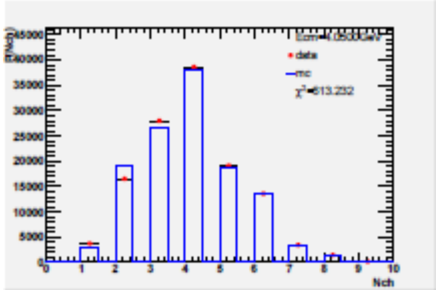
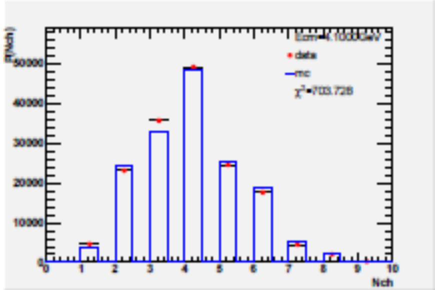
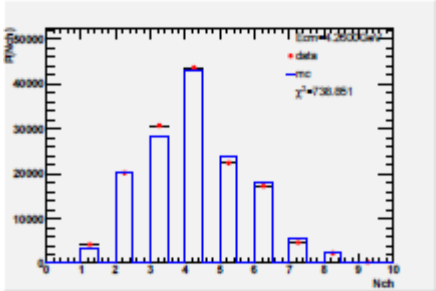
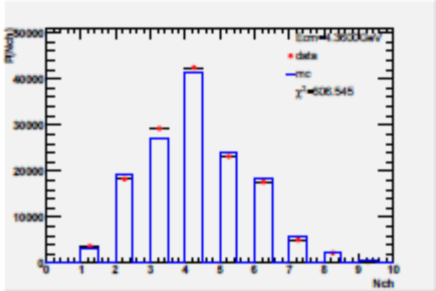
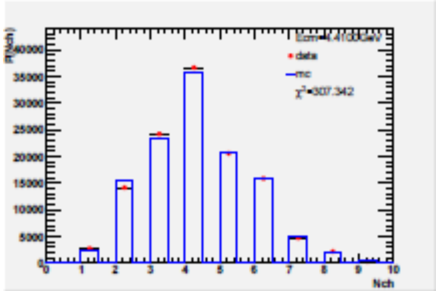
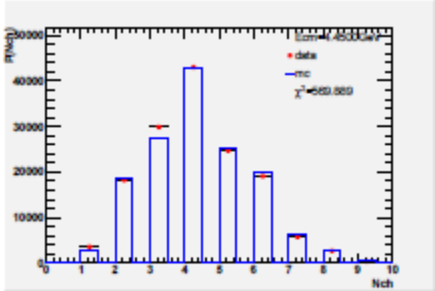
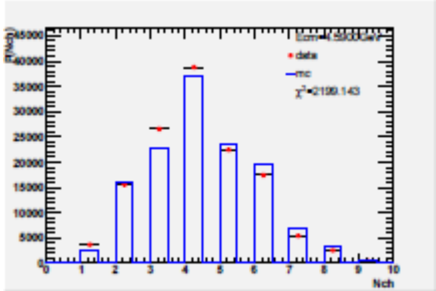
By comparing data with MC, it is found that in BEPC energy region, some parameters in the table are not constants, they are slightly energy dependent.

Effort and goal for LUARLW tuning

- Try to only use **one set** of parameters to control the simulations of continuous states and $J^{PC} = 1^{--}$ resonances between 2.0 - 4.6 GeV.

- LUARLW must agrees with data well for most of the inclusive distributions, ratios of the mesons and baryons.

Multiplicity of charged track

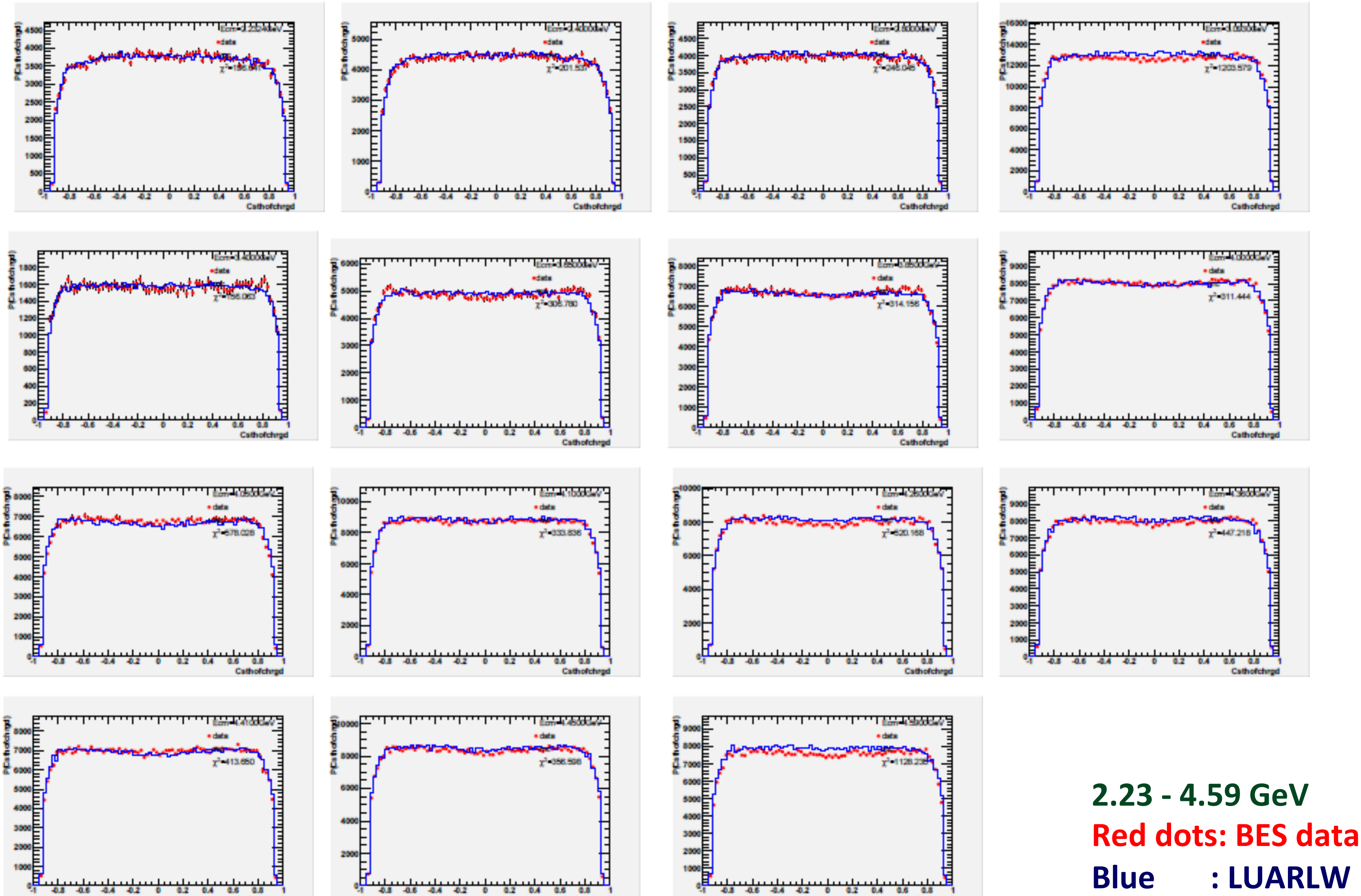
















2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Polar Angle cosθ of charged tracks

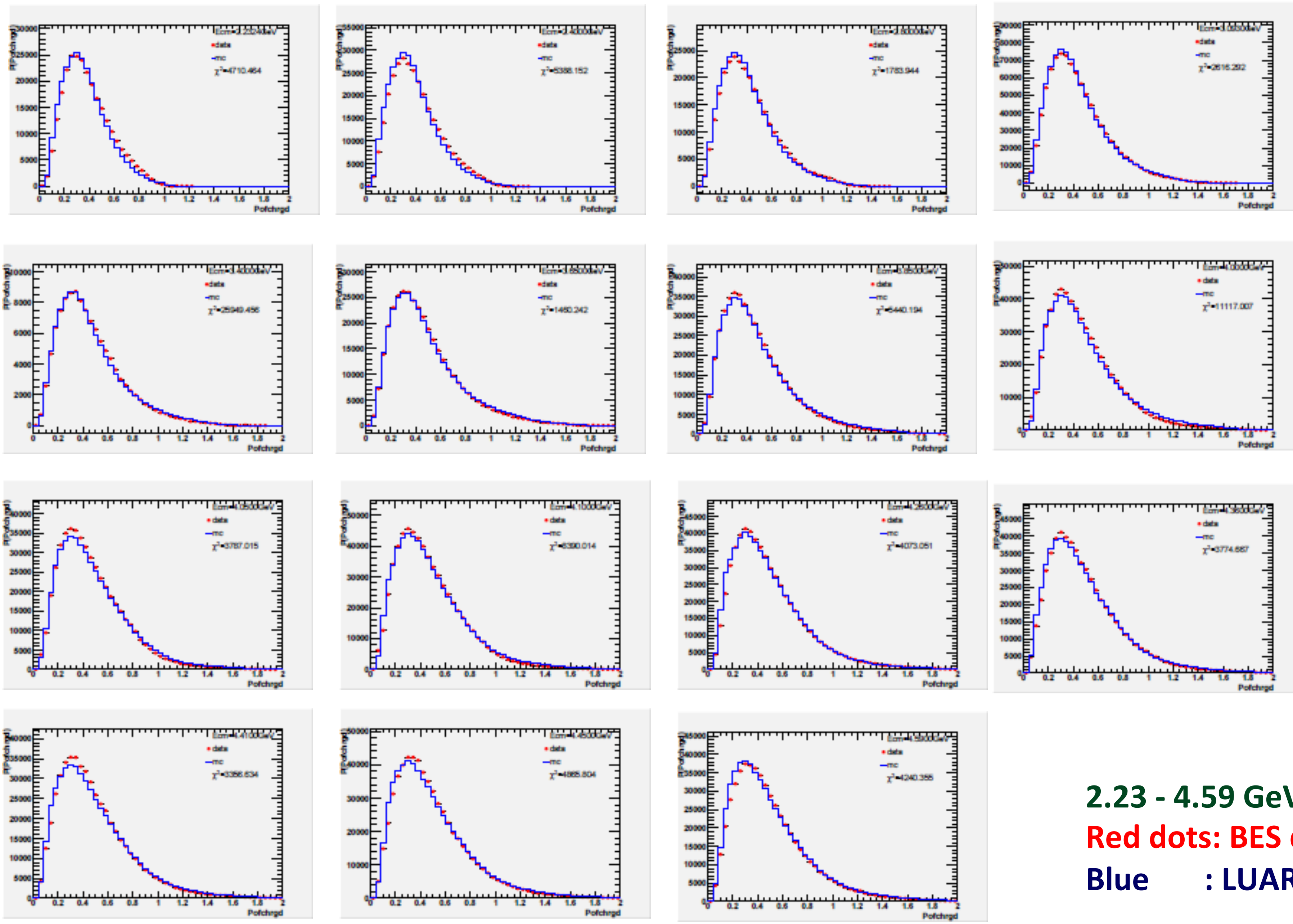


2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Momentum of charged tracks

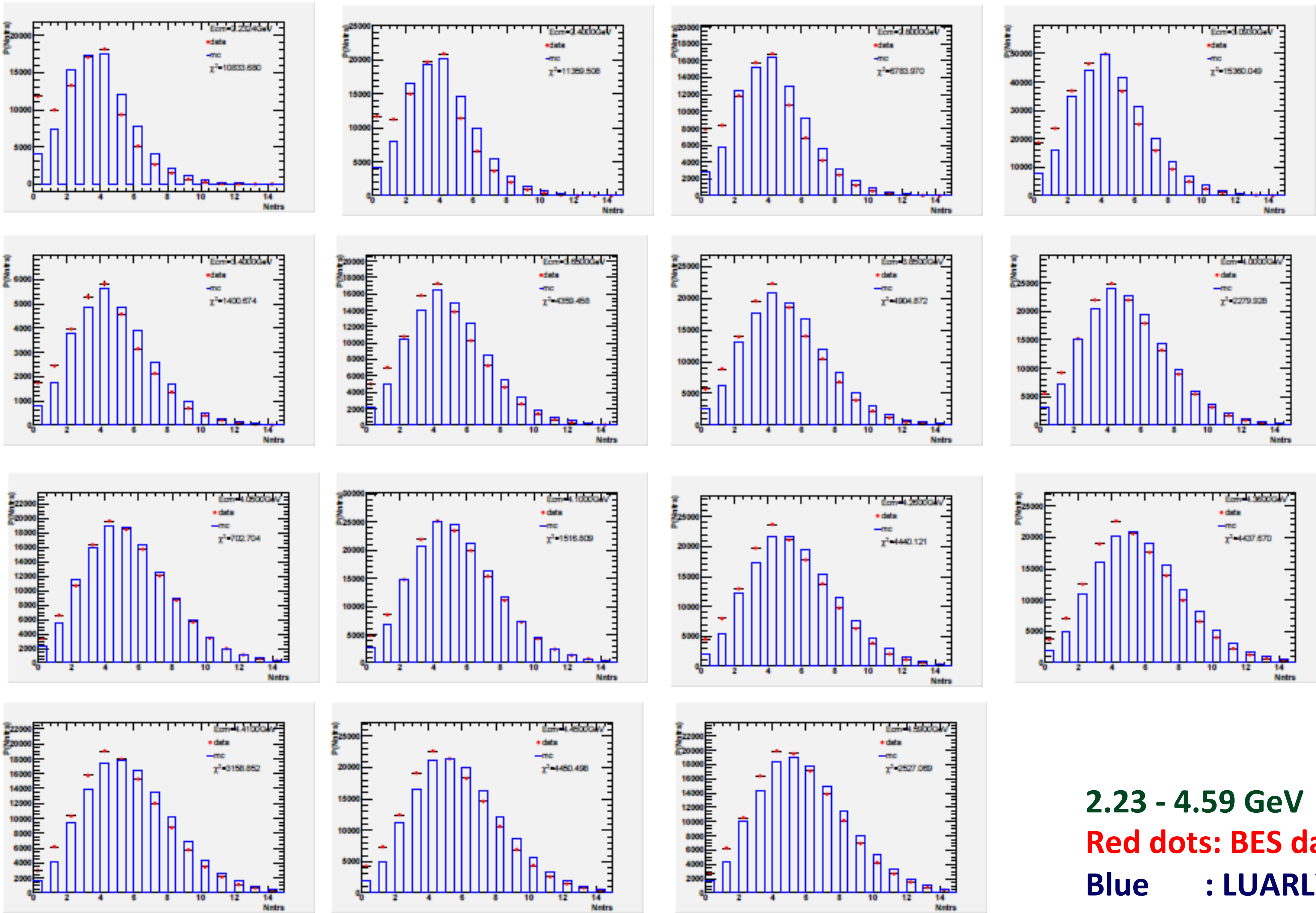


2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Multiplicity of neutral tracks

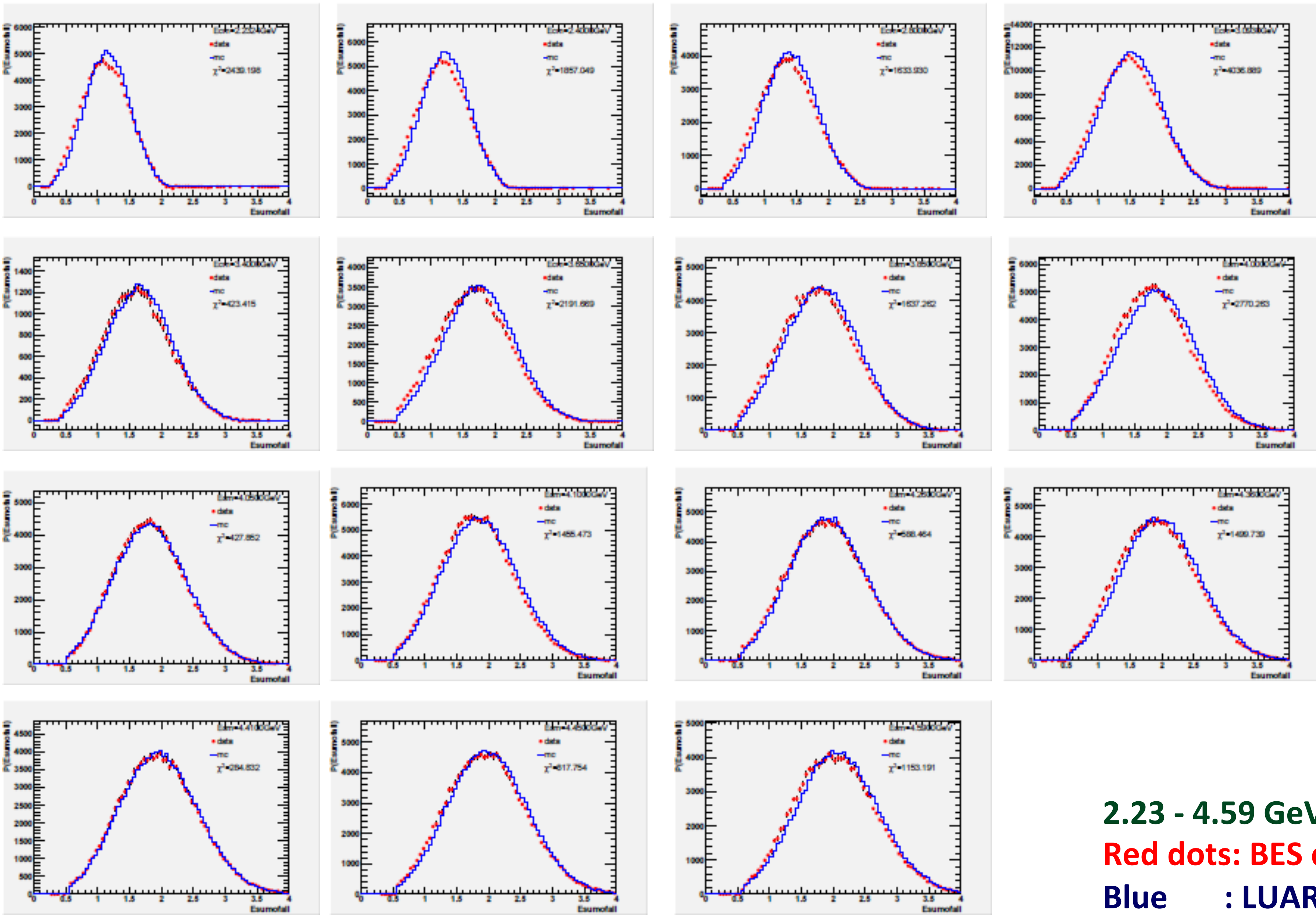


2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Deposit energy of neutral tracks

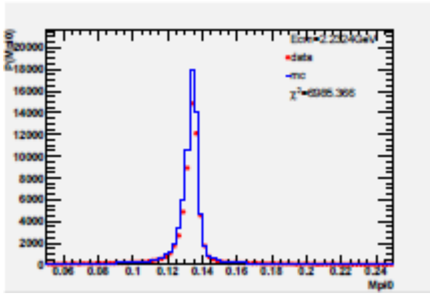
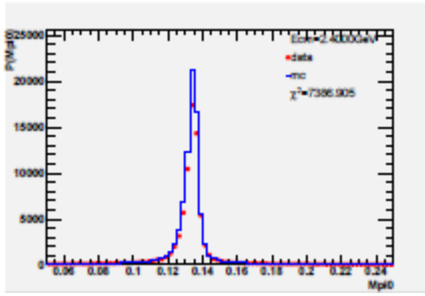
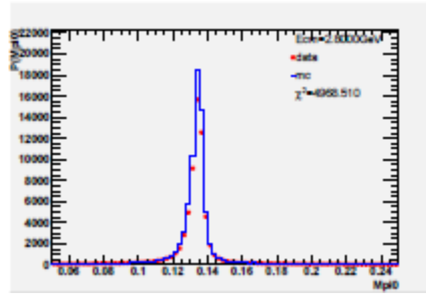
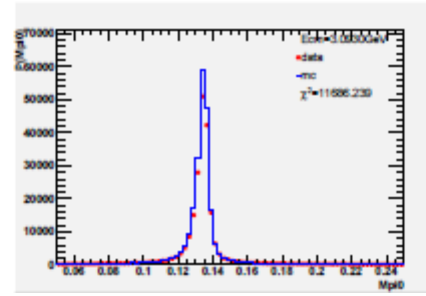
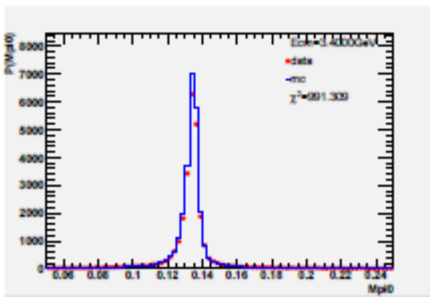
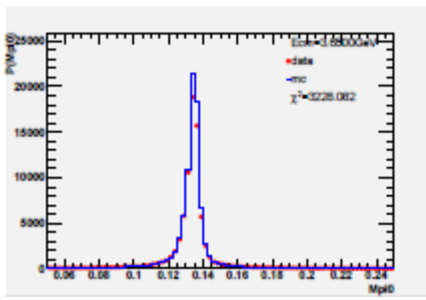
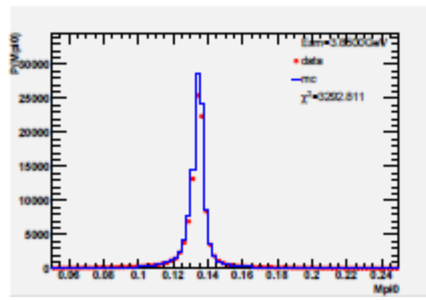
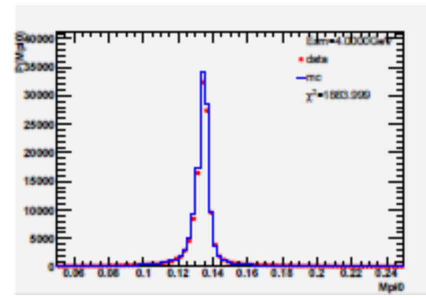
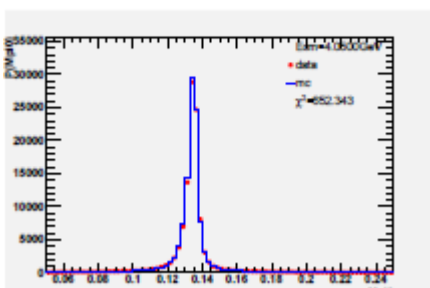
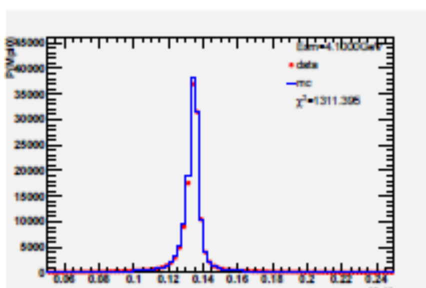
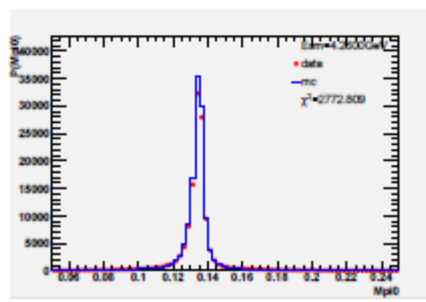
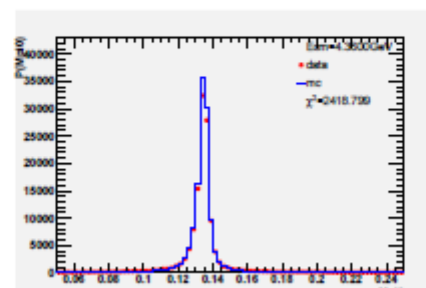
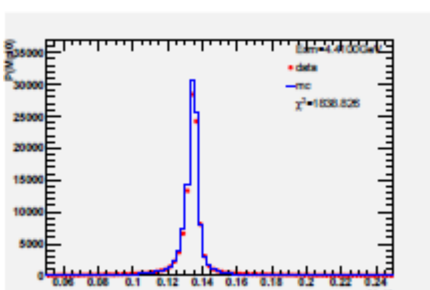
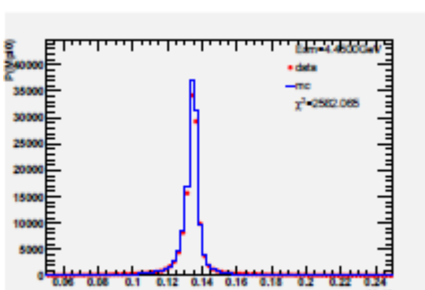
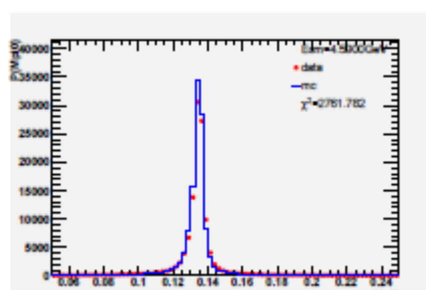


2.23 - 4.59 GeV

Red dots: BES data

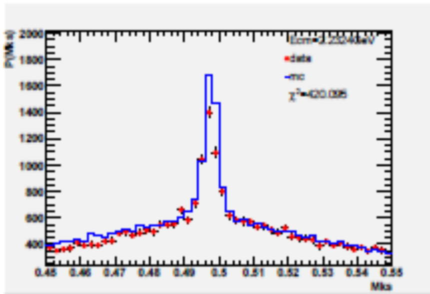
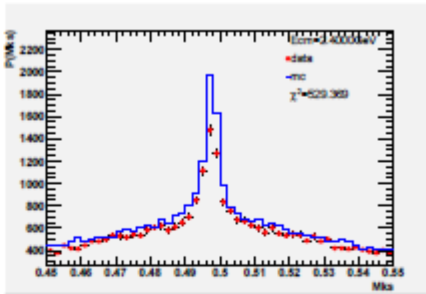
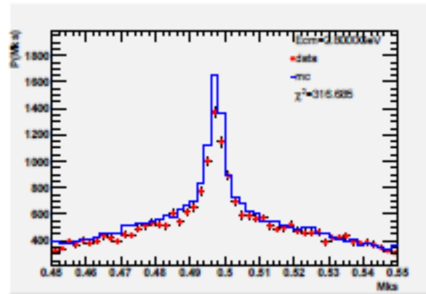
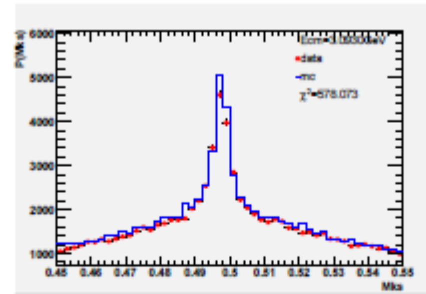
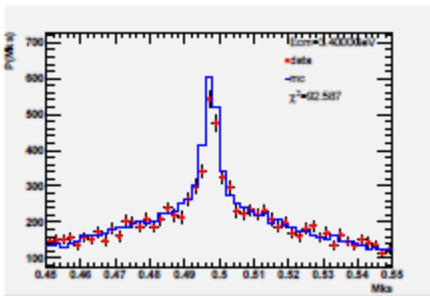
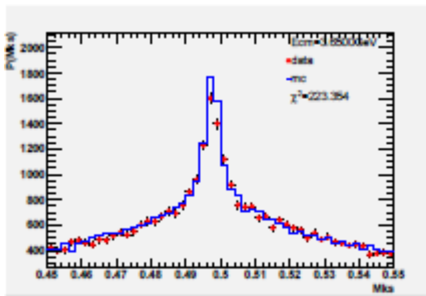
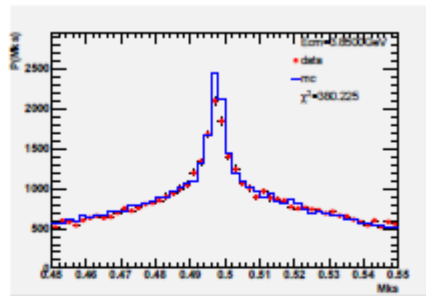
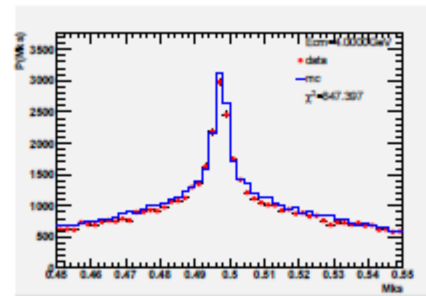
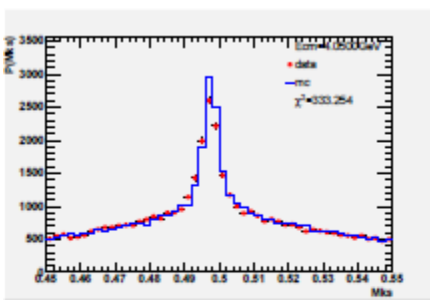
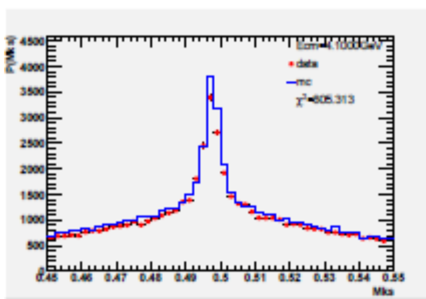
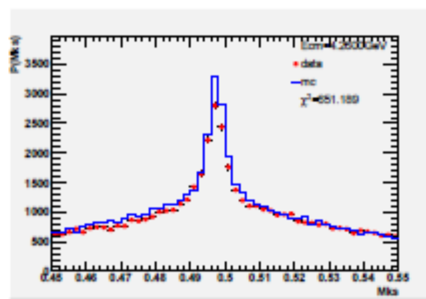
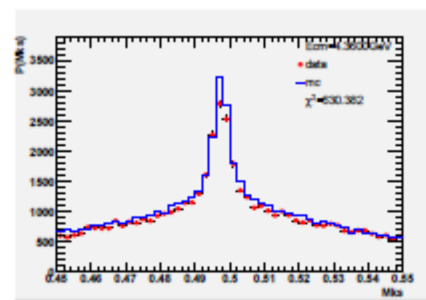
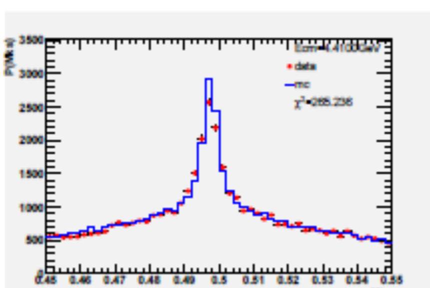
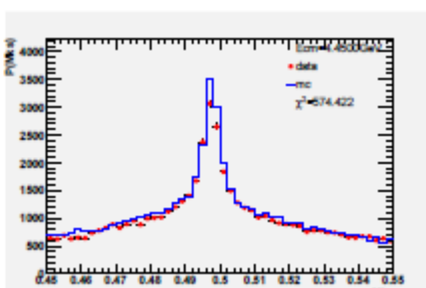
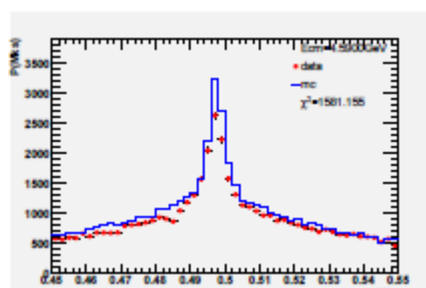
Blue : LUARLW

Number of pi0

2.23 - 4.59 GeV
Red dots: BES data
Blue : LUARLW

Number of Ks

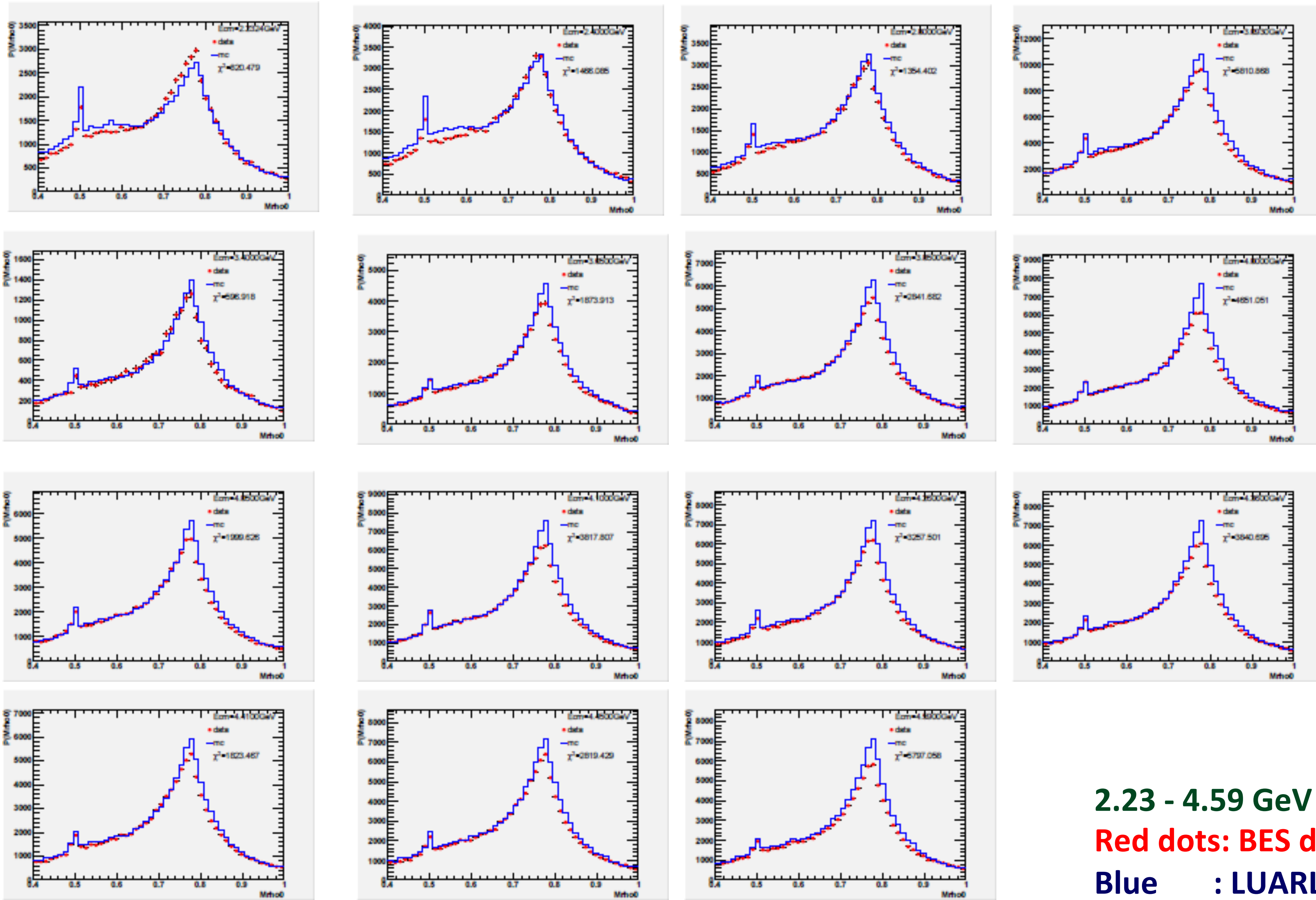
















2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Number of ρ

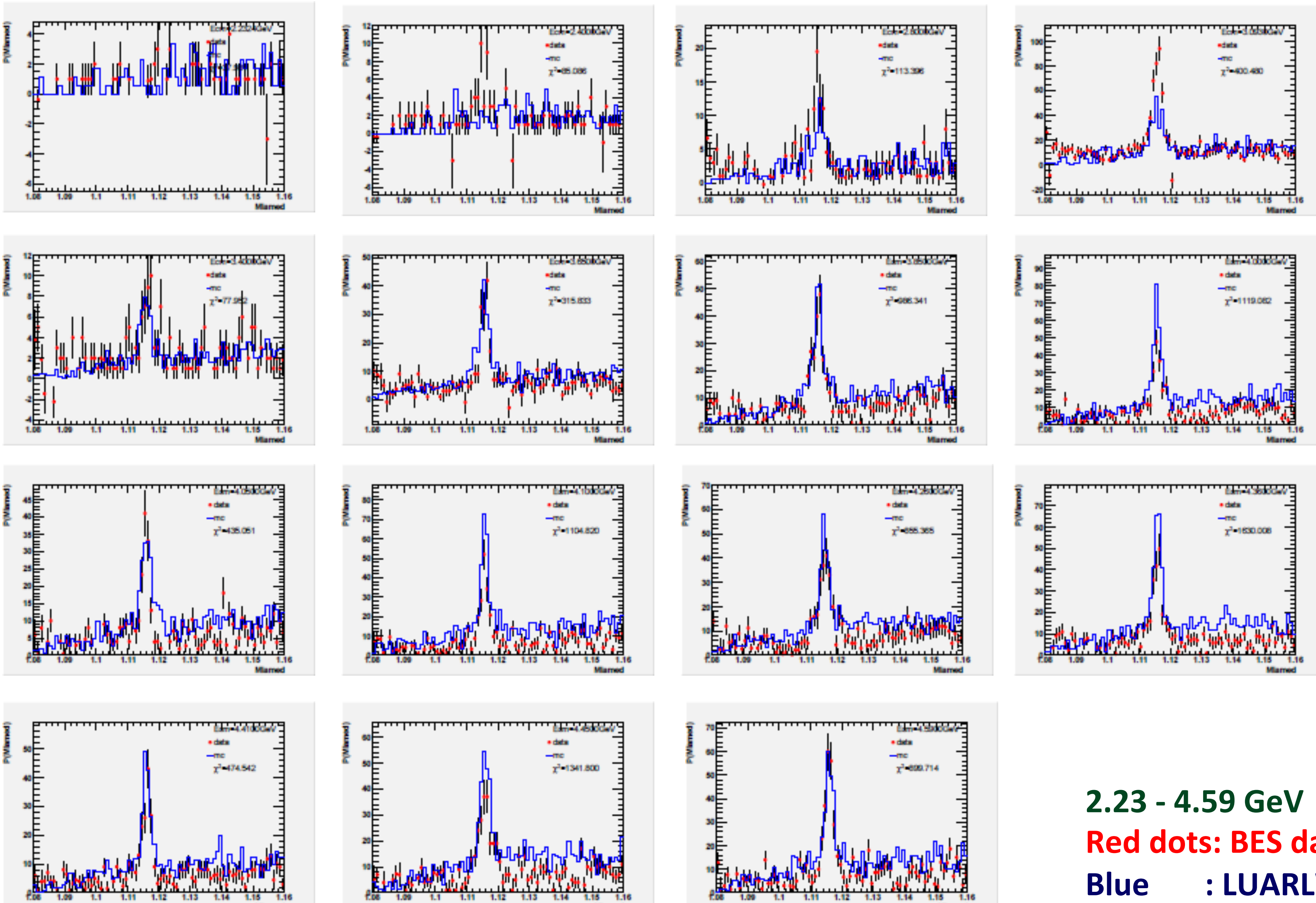


2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Number of Λ



2.23 - 4.59 GeV

Red dots: BES data

Blue : LUARLW

Summary

- Data sets for R scan and QCD study between 2.0 - 4.6 GeV have been collected.
- Data analysis for R value measurement between 2.2324-3.671 GeV are almost finished, but the analysis for other data samples need further optimization.
- The LUARLW parameter tuning are in progress, which is a tough and challenge work, and could be the largest error source for R value measurement.
- The related theoretical study about the heavy charmonia line shape fit are doing, which are crucial for resonances fit.
- Preliminary results of R measurement between 2.2324-3.671 GeV have reported inside BES Collaboration, the analysis for energy points are in going.

Back Up

R value measurement

1998 data

Phys. Rev. Lett. 84, (2000) 594

TABLE I. Summary of R data and values.

E_{cm} (GeV)	N_{had}^{obs}	N_{bg}	L (nb^{-1})	ϵ_{had} (%)	$(1+\delta)$	R	Stat. error	Syst. error
2.60	5617	127	292.9	54.11	1.009	2.64	0.05	0.19
3.20	2051	100	109.3	65.71	1.447	2.21	0.07	0.13
3.40	2149	178	135.3	69.33	1.173	2.38	0.07	0.16
3.55	2672	216	200.2	70.66	1.125	2.23	0.06	0.16
4.60	1497	282	87.7	81.75	1.079	3.58	0.20	0.29
5.00	1648	463	102.3	83.94	1.068	3.47	0.32	0.29

TABLE II. Contributions to systematic errors: hadronic selection, f factor, luminosity determination, τ-pair background, background from Bhabha events, hadronic efficiency determination, trigger efficiency, and radiative corrections. All errors are in percentages (%).

E_{cm} (GeV)	Had. sel.	f factor	L	τ-pair	Bhabhas	Had. eff.	Trig.	Rad. corr.
2.60	5.1	0.06	2.12	0.00	0.04	4.10	0.50	2.6
3.20	3.8	0.15	2.83	0.00	0.04	1.90	0.50	2.2
3.40	4.6	0.27	2.83	0.00	0.04	2.90	0.50	3.0
3.55	5.5	0.27	2.32	0.00	0.04	2.30	0.50	2.4
4.60	5.7	0.75	2.16	0.32	0.00	3.60	0.50	4.1
5.00	6.0	1.26	2.81	0.32	0.00	3.20	0.50	3.8

R value measurement

1998 data

Phys. Rev. Lett. 84, (2000) 594

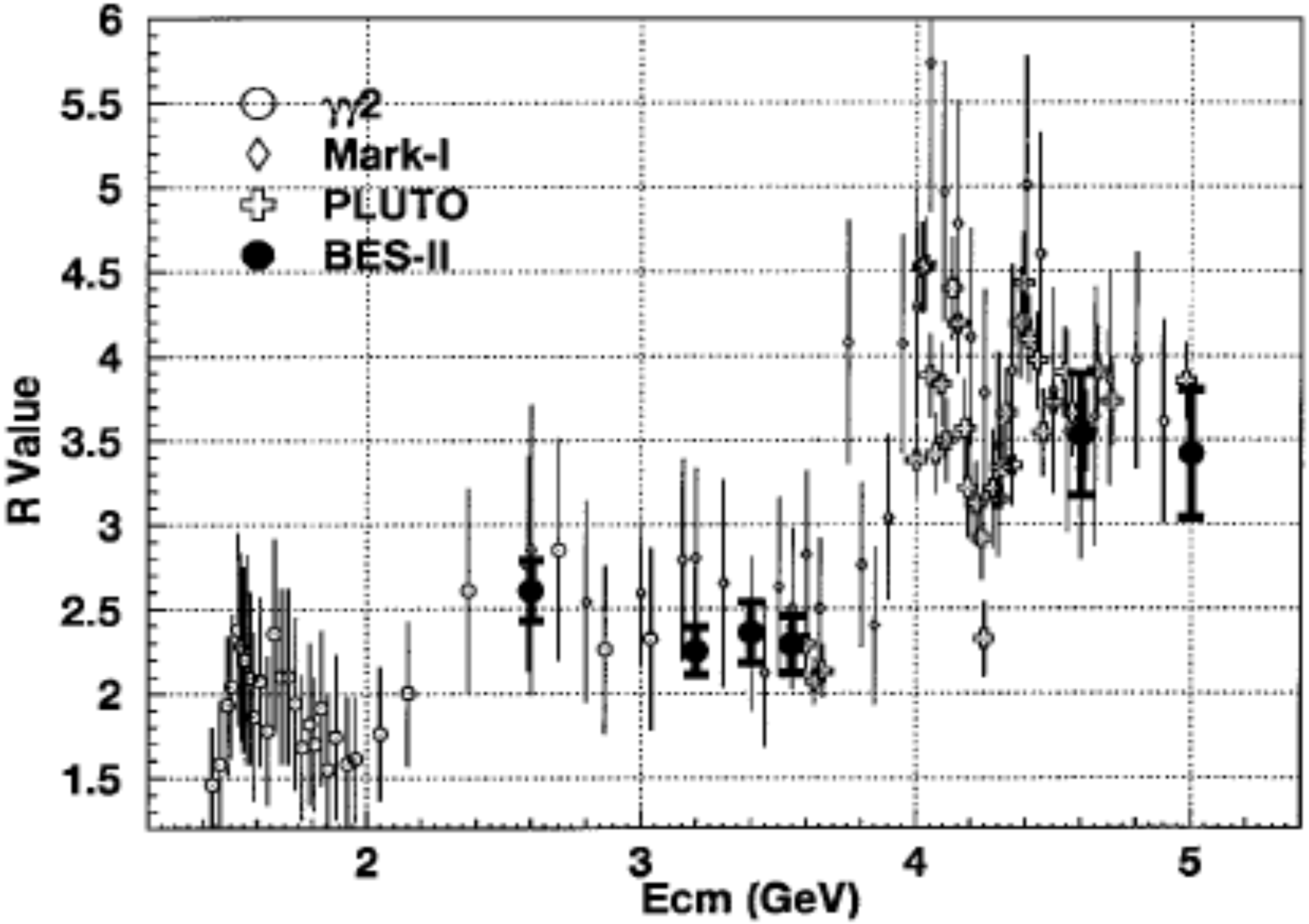


FIG. 2. Plot of R values vs E_{cm}. The R values from BES are taken from Table I with an error which combines statistical and systematic errors in quadrature.

R value measurement

1999 data

Phys. Rev. Lett. 88, (2002) 101802-1

TABLE I. Some values used in the determination of R at a few typical energy points.

$E_{c.m.}$ (GeV)	N_{had}^{obs}	$N_{ll}+N_{\gamma\gamma}$	L (nb^{-1})	$\epsilon(0)$ (%)	$1+\delta_{obs}$	R	Stat. error	Syst. error
2.000	1155.4	19.5	47.3	49.50	1.024	2.18	0.07	0.18
3.000	2055.4	24.3	135.9	67.55	1.038	2.21	0.05	0.11
4.000	768.7	58.0	48.9	80.34	1.055	3.16	0.14	0.15
4.800	1215.3	92.6	84.4	86.79	1.113	3.66	0.14	0.19

TABLE II. Contributions to systematic errors: experimental selection of hadronic events, luminosity determination, theoretical modeling of hadronic events, trigger efficiency, radiative corrections, and total systematic error. All errors are in percentages (%).

$E_{c.m.}$ (GeV)	Hadron selection	L	MC modeling	Trigger	Radiative correction	Total
2.000	7.07	2.81	2.62	0.5	1.06	8.13
3.000	3.30	2.30	2.66	0.5	1.32	5.02
4.000	2.64	2.43	2.25	0.5	1.82	4.64
4.800	3.58	1.74	3.05	0.5	1.02	5.14

R value measurement

1999 data

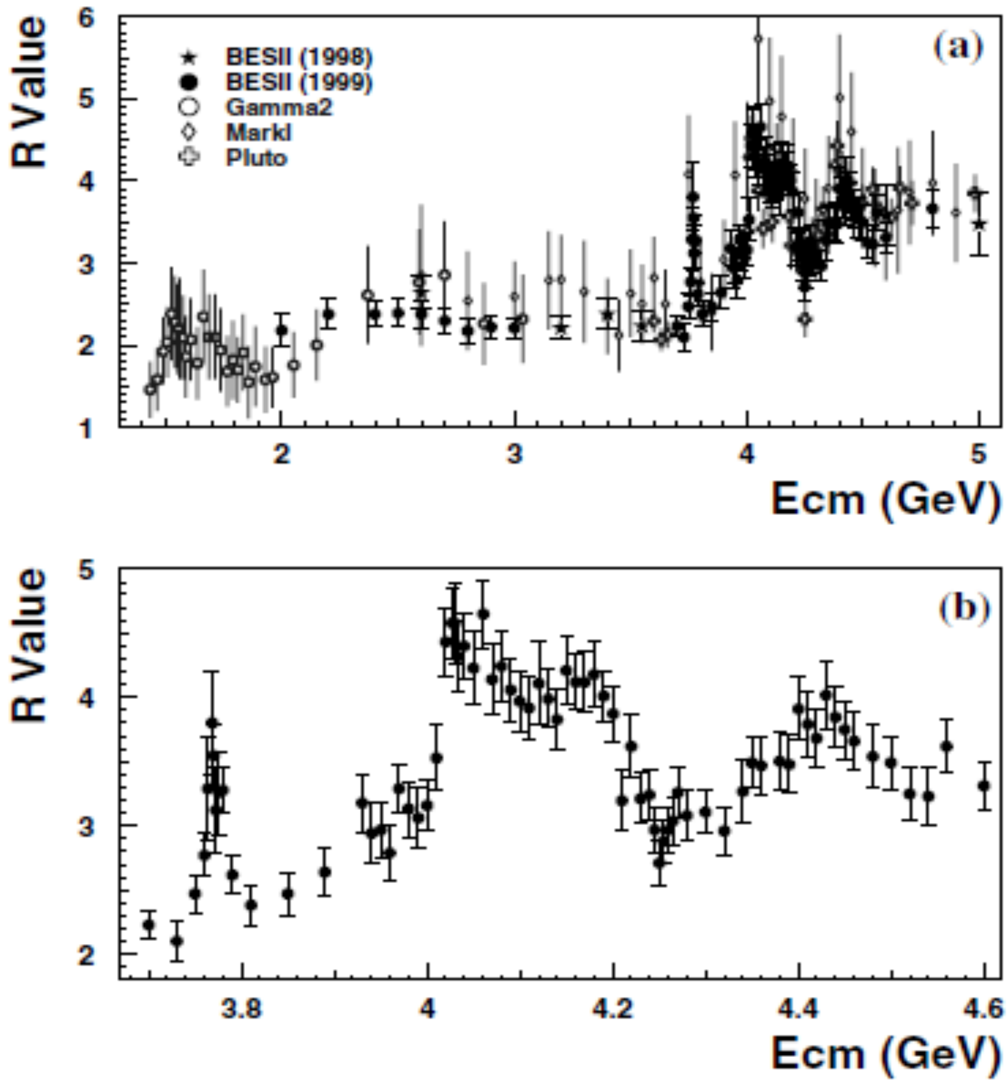


FIG. 3. (a) A compilation of measurements of R in the c.m. energy range from 1.4 to 5 GeV. (b) R values from this experiment in the resonance region between 3.7 and 4.6 GeV.

R value measurement

2004 data

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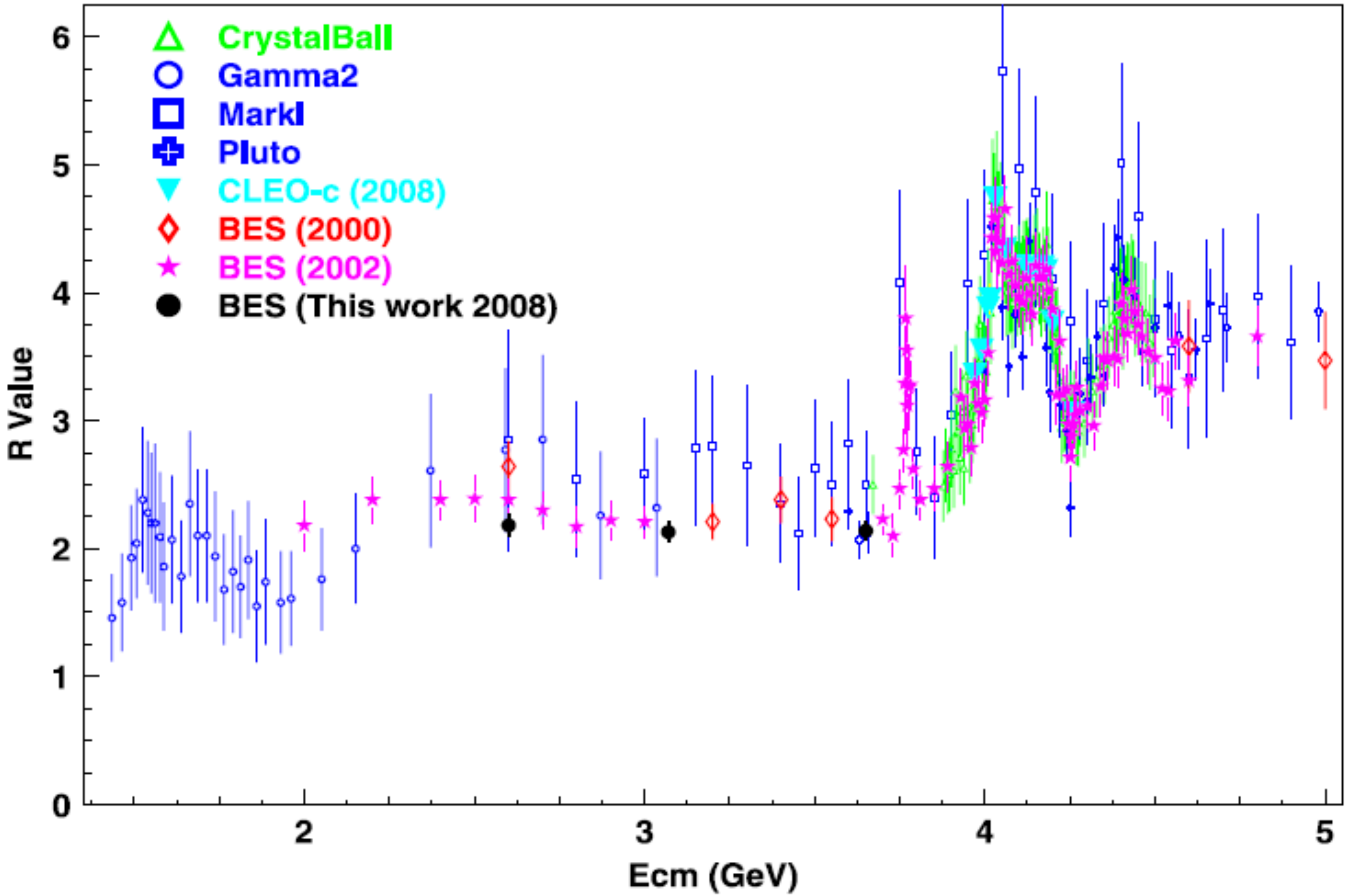
Table 1
Items used in the determination of R at each energy point.

E_{cm} (GeV)	L (pb^{-1})	N_{had}^{obs}	N_{bg}	ϵ_{trg} (%)	ϵ_{had}^{0} (%)	$(1+\delta_{obs})$	R	σ_{sta}	σ_{sys}
2.60	1.222	24026	193	99.80	63.81	1.08	2.18	0.02	0.08
3.07	2.291	33933	208	99.80	67.63	1.11	2.13	0.02	0.07
3.65	6.485	83767	4937	99.80	71.83	1.21	2.14	0.01	0.07

Table 2
Summary of the systematic errors (%).

E_{cm} (GeV)	L	N_{had}	N_{bg}	$\Delta\epsilon_{trk}$	ϵ_{trg}	$(1+\delta_{obs})$	Total
2.60	2.00	2.79	0.05	0.32	0.50	1.18	3.68
3.07	1.96	2.53	0.05	0.29	0.50	1.15	3.45
3.65	1.38	2.74	0.35	0.26	0.50	1.10	3.33

R value measurement



α_s measurement

pQCD prediction:

$$R_{QCD}(s) = 3\sum_f Q_f^2[1 + (\frac{\alpha_s(s)}{\pi}) + r_1(\frac{\alpha_s(s)}{\pi})^2 + r_2(\frac{\alpha_s(s)}{\pi})^3] + \mathcal{O}(\alpha_s^4)$$

Method 1: Fit experimental value

$$\chi^2 = \sum_i \frac{(f \cdot R_{exp}(s_i) - R_{QCD}(s_i))^2}{(f \cdot \Delta R_{exp}^{(i)})^2} + \frac{(f-1)^2}{\sigma_f^2}$$

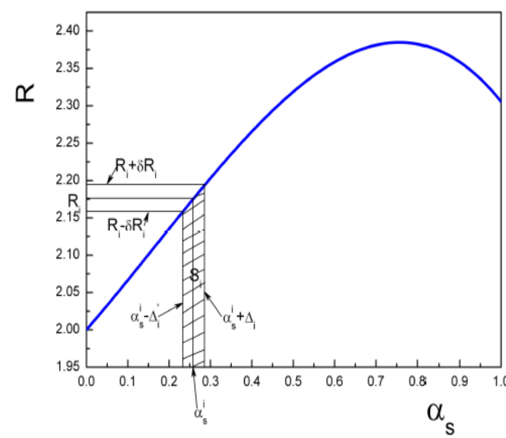
Method 2: Solve equations

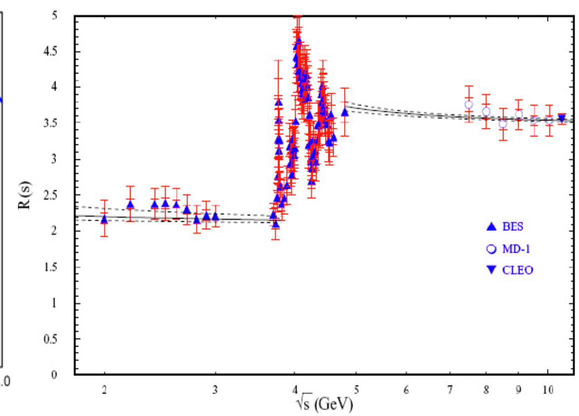
$$R_{the}(s) = R_{exp} \qquad R_{exp} = R_0 \pm \Delta R$$

$$\overline{\alpha_s} = \frac{\sum_i \frac{\alpha_s^i}{S_i}}{\sum_i \frac{1}{S_i}}$$

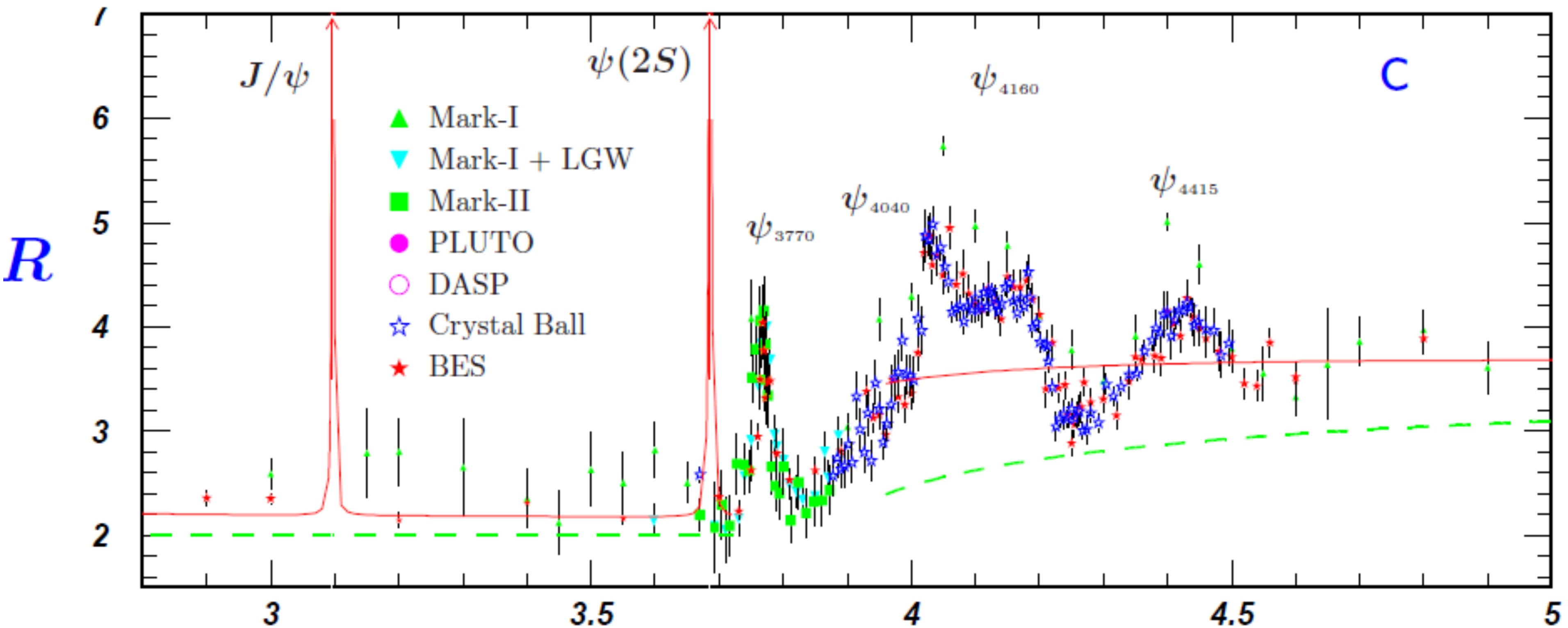
$$S_i = \int_{\alpha_s^i - \Delta_i'}^{\alpha_s^i + \Delta_i} R(\alpha_s) d\alpha_s$$

$$\overline{\Delta}_{up} = \sqrt{\frac{1}{\sum_i \frac{1}{\Delta_i}}}, \quad \overline{\Delta}_{down} = \sqrt{\frac{1}{\sum_i \frac{1}{\Delta_i'}}}$$





Heavy vector charmonia structure



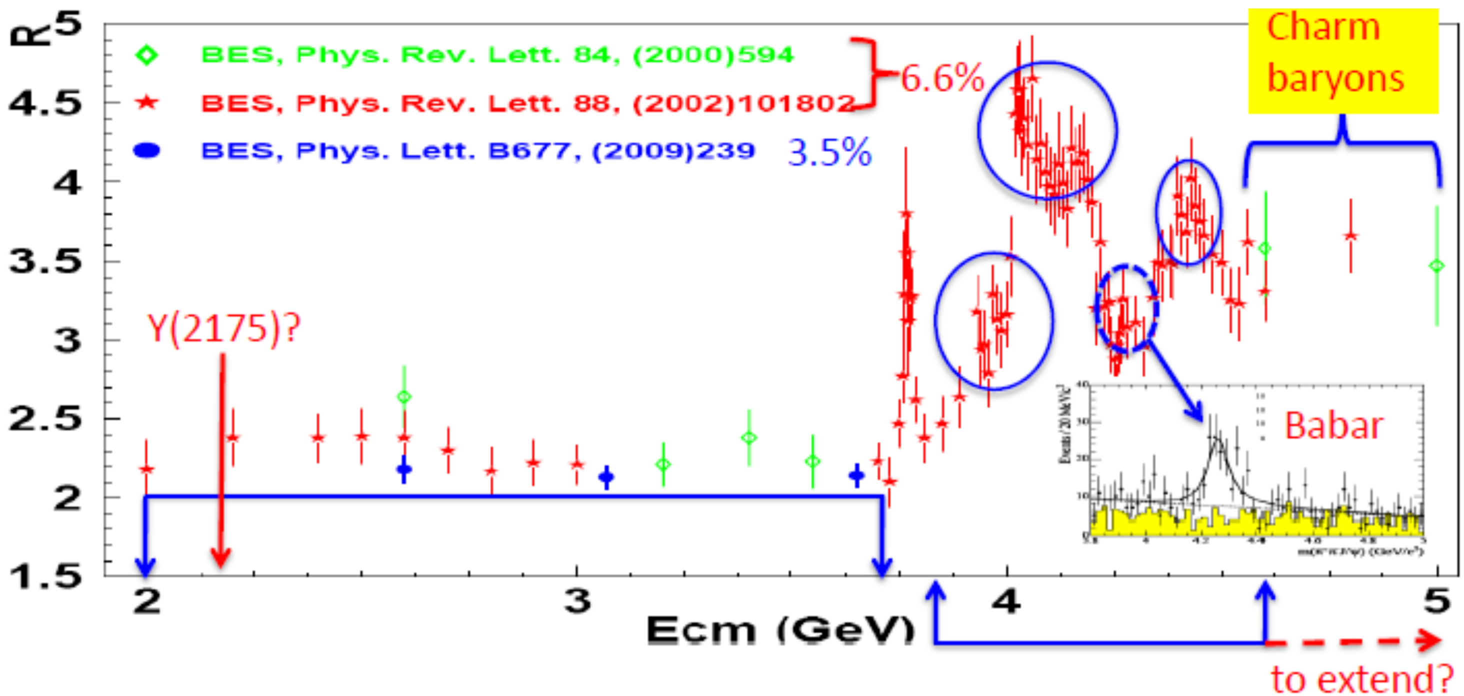
R&QCD data taking at BESIII

- Phase I: test run (2012)

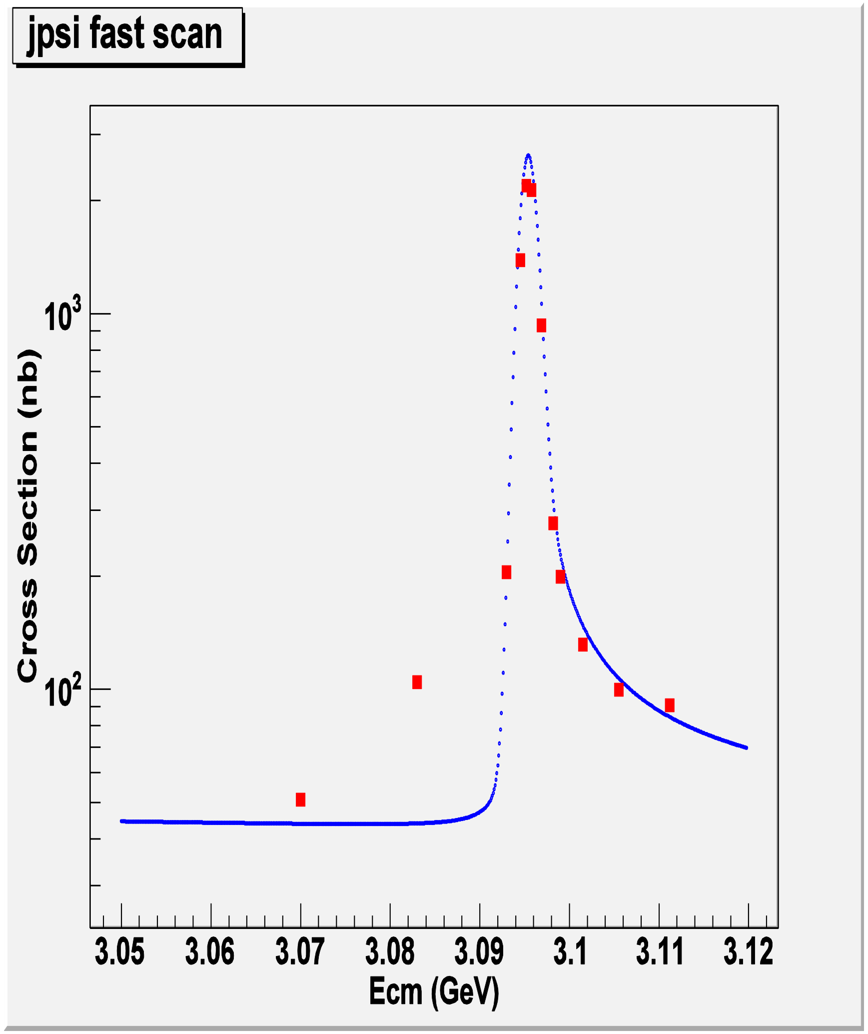
  @ Ecm = 2.232, 2.400, 2.800, 3.400 GeV , 4 energy points, ~12/pb
- Phase II: fine scan heavy charm resonant line shape (2013-2014)

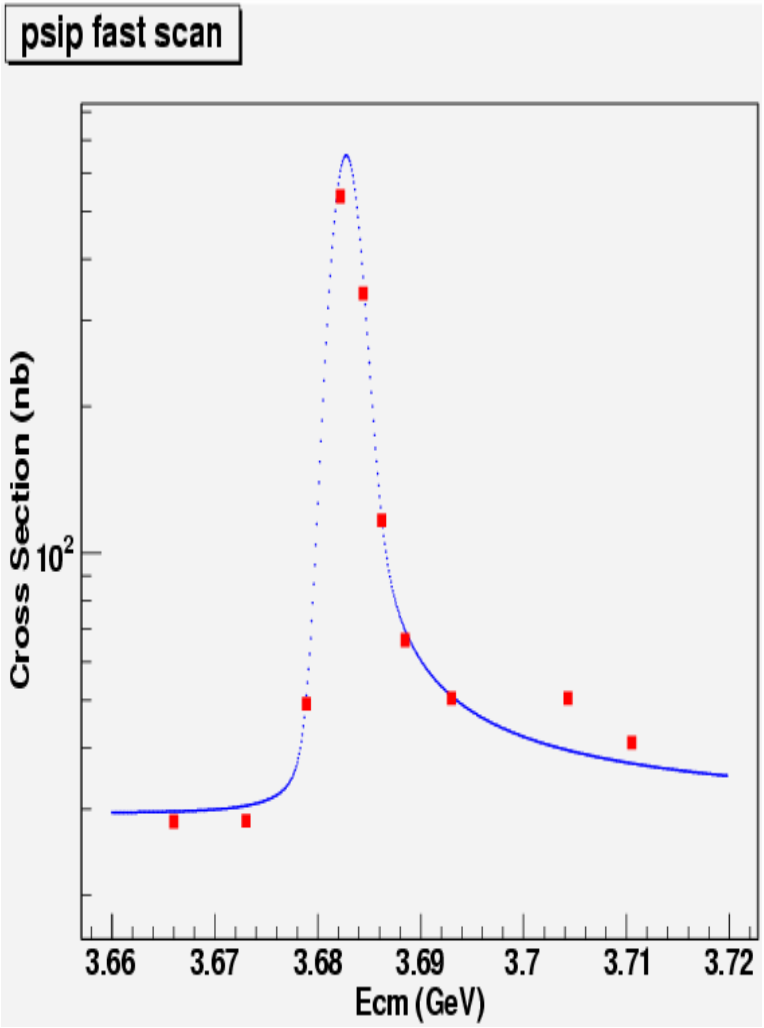
  @ 3.800 - 4.590 GeV, 104 energy points, ~ 800/pb
- Phase III: R&QCD scan (2015)

  @ 2.000 - 3.080 GeV, 19 energy points, ~ 500/pb



Energy calibration



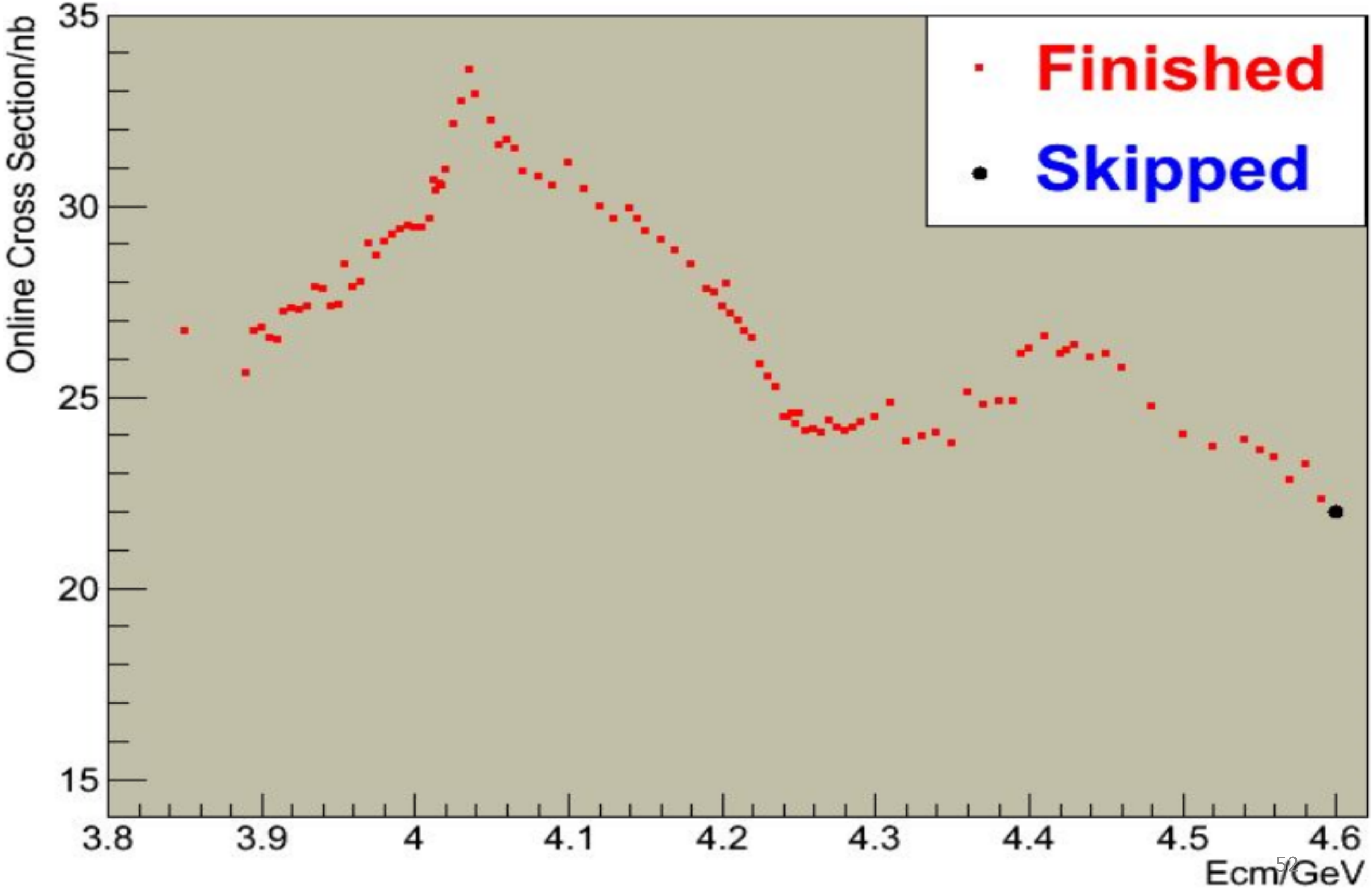


$$
\begin{aligned}
\Delta E_{cm} &= M_{J/\Psi}^{FIT} - M_{J/\Psi}^{PDG} \\
&= (3.0953 - 3.0969)\mathrm{GeV} = -0.0016\mathrm{GeV}
\end{aligned}
$$

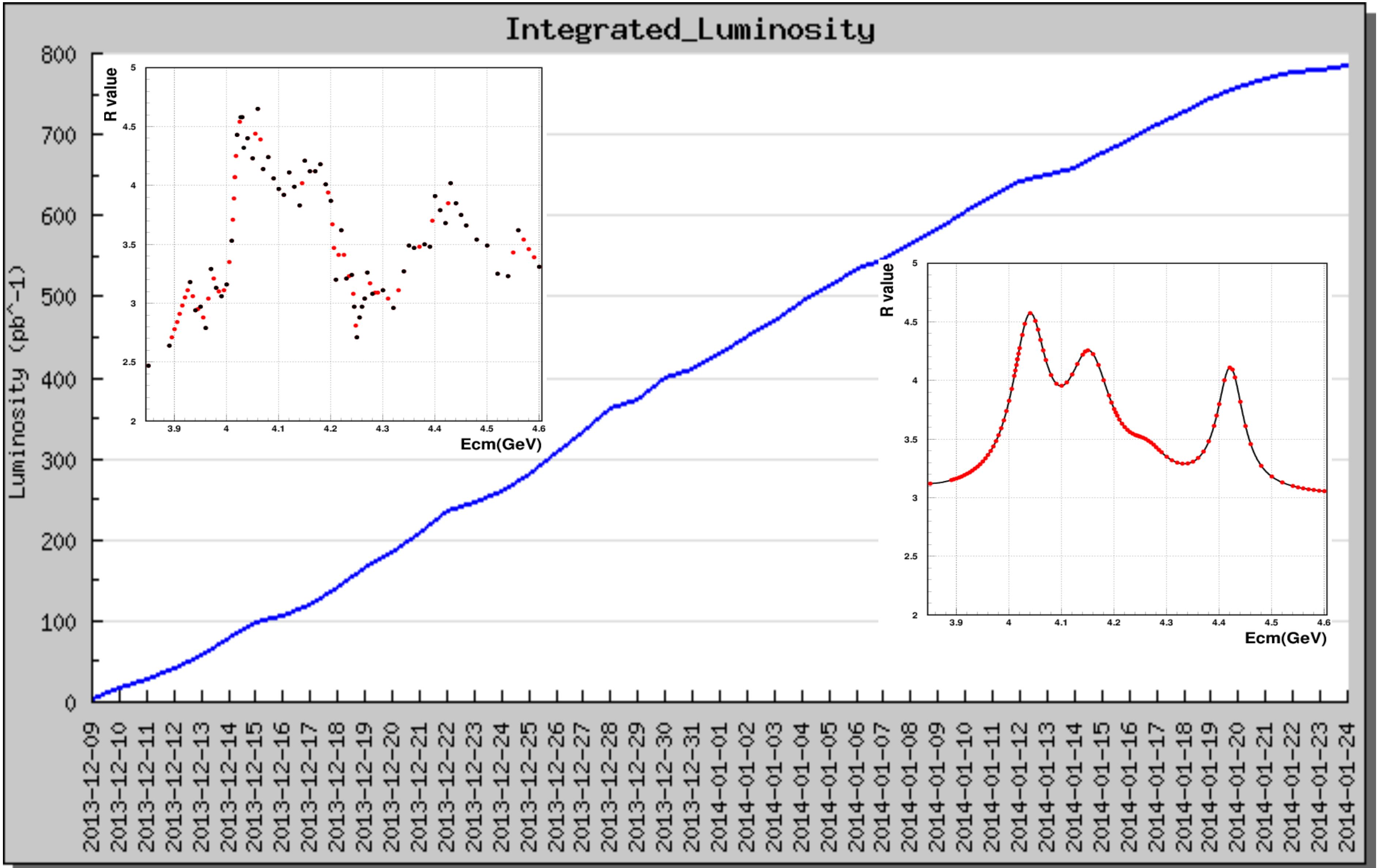
$$E_{cm}^{set} = E_{cm}^{preset} + \Delta E_{cm}$$

$$E_{beam}^{set} = E_{beam}^{preset} + \Delta E_{beam}$$

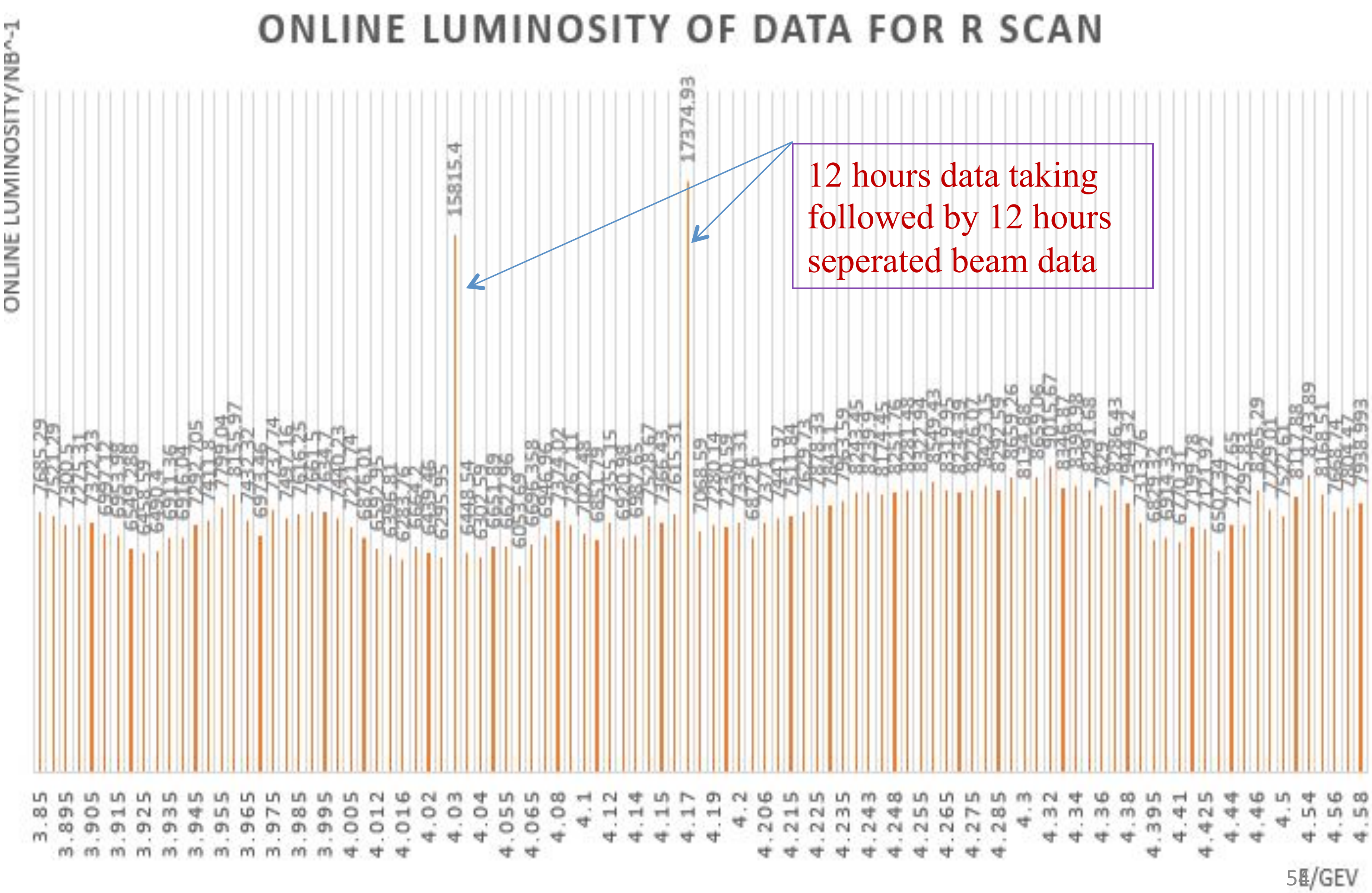
Online cross sections



Accumulated integrated luminosity

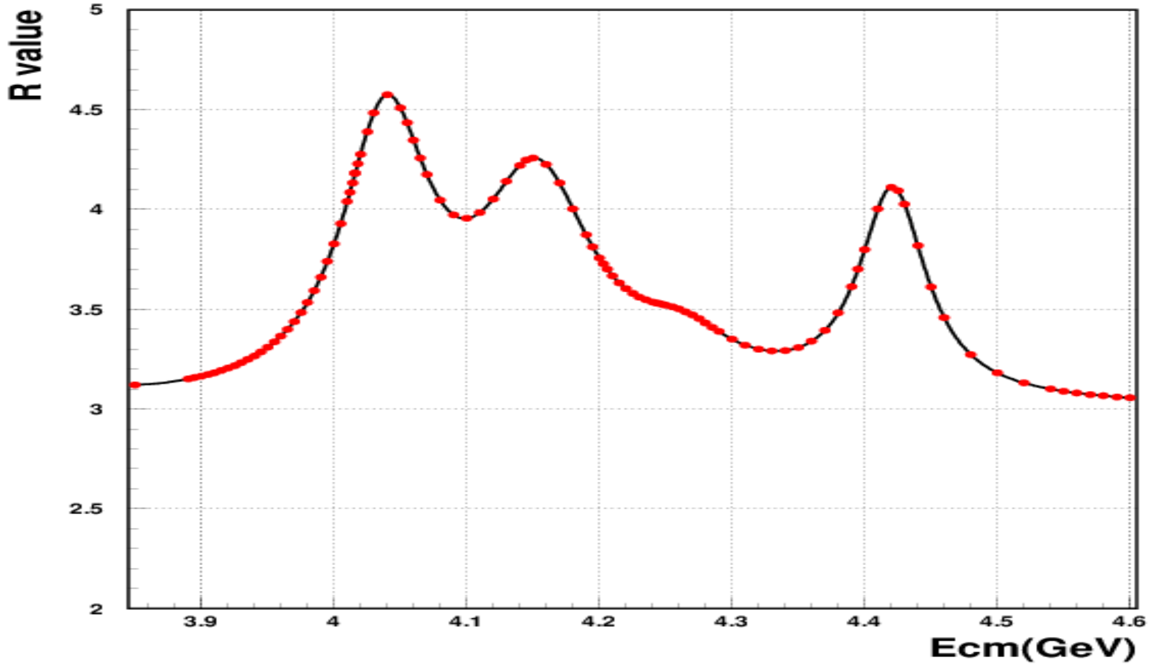


Online luminosity



Significance of accurate energies

Experiment goal: Heavy charmonia fine structure (line shape)



- Hadronic cross section is the function of energy
- All cross sections together determine line-shape

Obviously, if energies have large systematic errors, the line shape will be distorted.

So, accurate energy is very important for scan

Two ways to obtain the value of energies:

① fast scan of J/ψ & ψ(3686), set BEPCII parameter

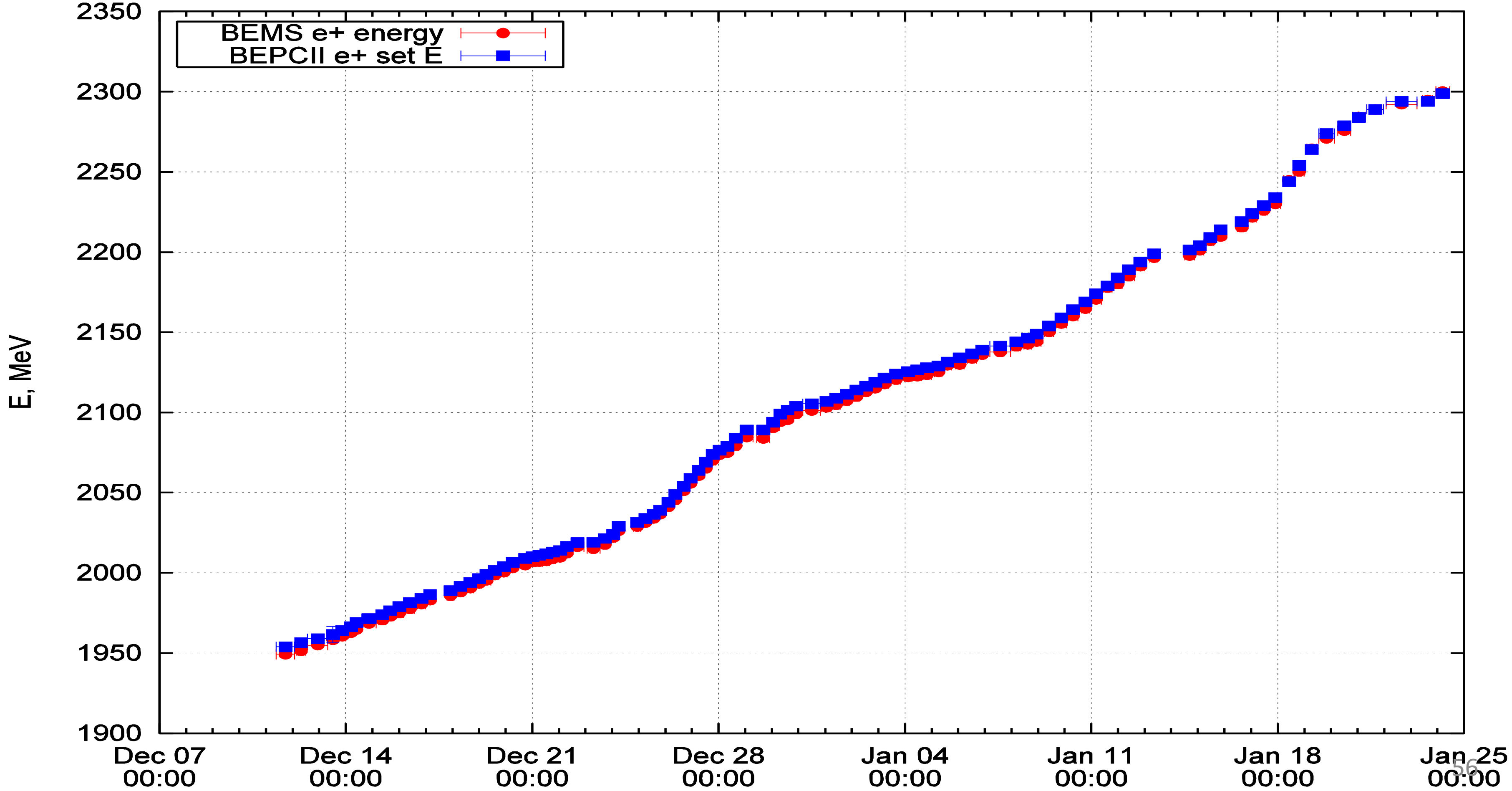
② measured with BEMS independently

Consistent ?

Energy issue

Comparison between BEMS and BEPCII (by Jianyong Zhang)

- Only e+ energy compared
- BEPCII energies read from data base (before correction)
- Values measured by BEMS and given by BEPCII roughly change in similar trend



Data taking plan in 2 – 3 GeV

- From high to low;
- Fast scans on J/ψ, prior to 3.08, 2.6444, 2.3960, 2.3094 GeV;
- Separated-beam run.
- Y(2175) to follow, 100/pb, at maximum cross section.

E_{cm} (GeV)	E_{th} (GeV)	L_{Needed} (pb^{-1})	t_{beam} ($days$)	Purpose
2.0		≥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	≥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})

Contact s: Guangshun Huang 132 2575 3796, Haiming Hu 133 9178 0929

Interference

Decay channels f_c :

$$\begin{aligned}
\psi(3770) &\Rightarrow D\bar{D};\\
\psi(4040) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s;\\
\psi(4140) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*;\\
\psi(4415) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*.
\end{aligned}$$

Coherent summation :

$$\mathcal{T}_{res}^{f_c} = \sum_R \mathcal{T}_R^{f_c}$$

Module :

$$\mathcal{T}_r^f(W) = \frac{M_r\sqrt{\Gamma_r^{ee}\Gamma_r^f}}{W^2 - M_r^2 + iM_r\Gamma_r} e^{i\delta_r}$$

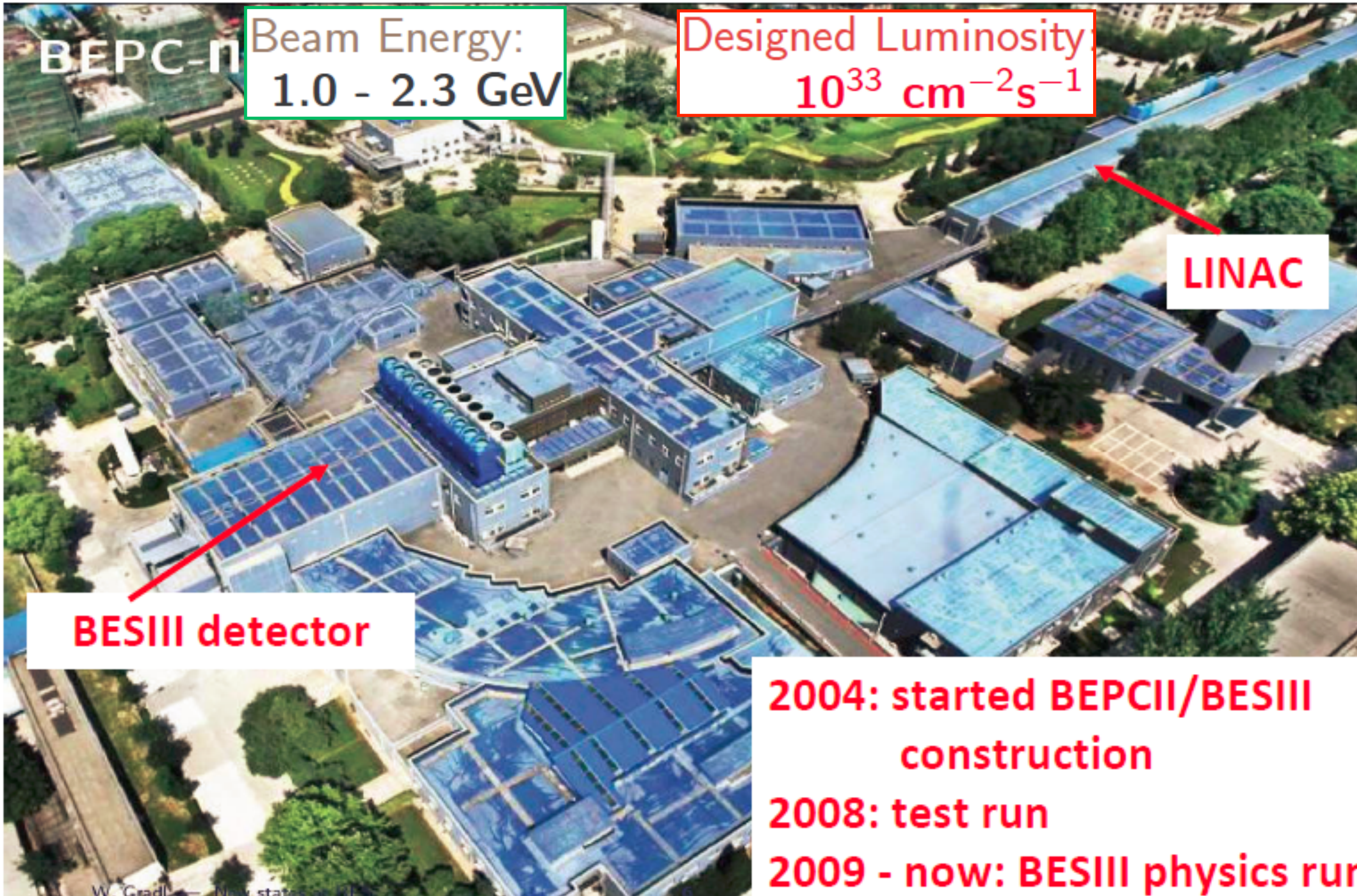
Incoherent summation :

$$|\mathcal{T}_{res}|^2 = \sum_{f_c} |\mathcal{T}_{res}^{f_c}|^2$$

Resonant cross section :

$$R_{res} = \frac{\sigma_{res}}{\sigma_{\mu\mu}^0} = \frac{12\pi}{s}|\mathcal{T}_{res}|^2$$

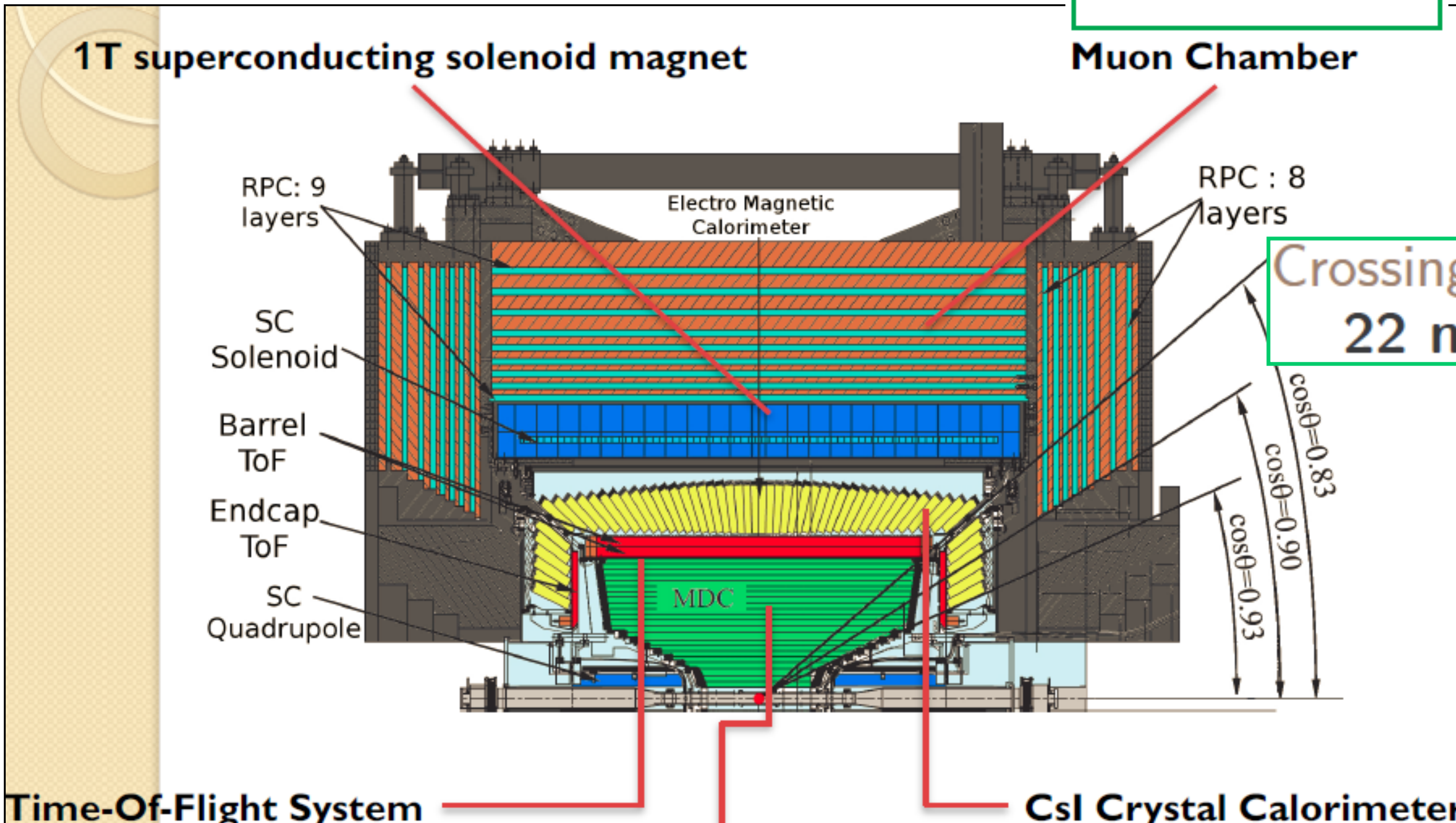
Beijing Electron-Positron Collider II (BEPCII)



Beijing Spectrometer III (BESIII)

MUC:

$\delta(xy) < 2$ cm



Crossing angle
22 mrad

TOF:

$\delta t = 100$ ps Barrel

$\delta t = 110$ ps Endcap

MDC:

$\frac{\delta p}{p} < 0.5\%$ @1 GeV

$\frac{\delta(dE/dx)}{dE/dx} < 6\%$

EMC:

$\frac{\delta E}{E} < 2.5\%$ @1 GeV

$\delta z = 0.6/\sqrt{E}$