Status of R value measurement at BESIII

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(For BESIII Collaboration)

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Outline

- Review of R value measurements
- Data samples of R scan @ BESIII
- Status of R value measurement
- Summary

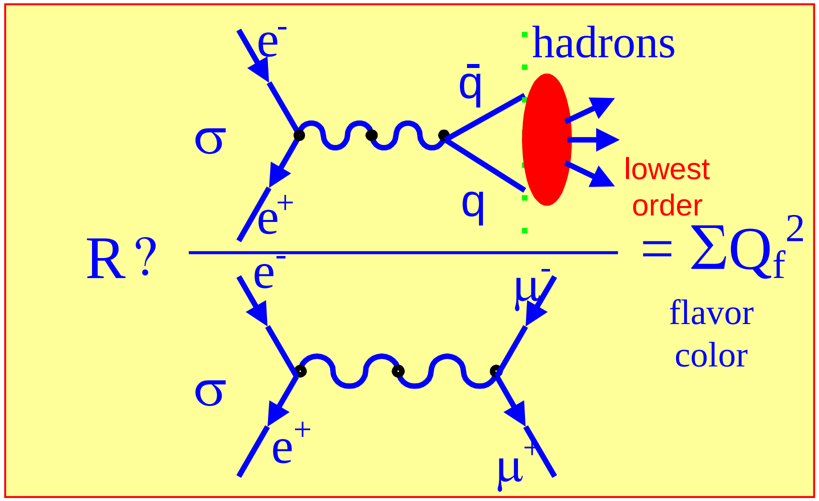
Review of R value measurements

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

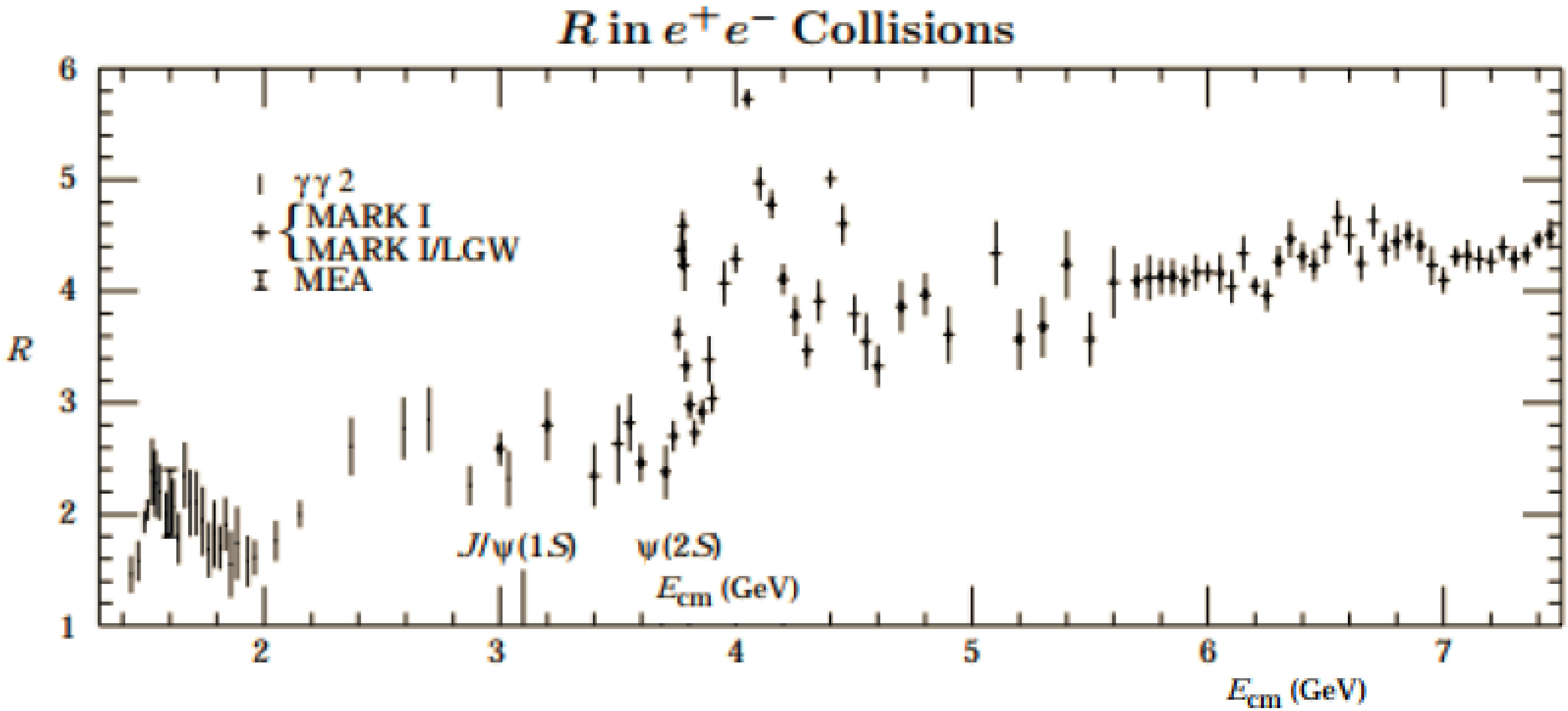


Groups ever measured R value： BESII， VEPP， DAΦNE， DM2， DASP， PLUTO， Crystal-Ball， MARKI， MARKII， CLEO-c， AMY， JADE， TASSO， CUSB， MD-1， MARKJ， SLAC-LBL， MAC， γγ2， KEDR……

Why R value important? It is an input parameter of the SM

Review of R value measurements

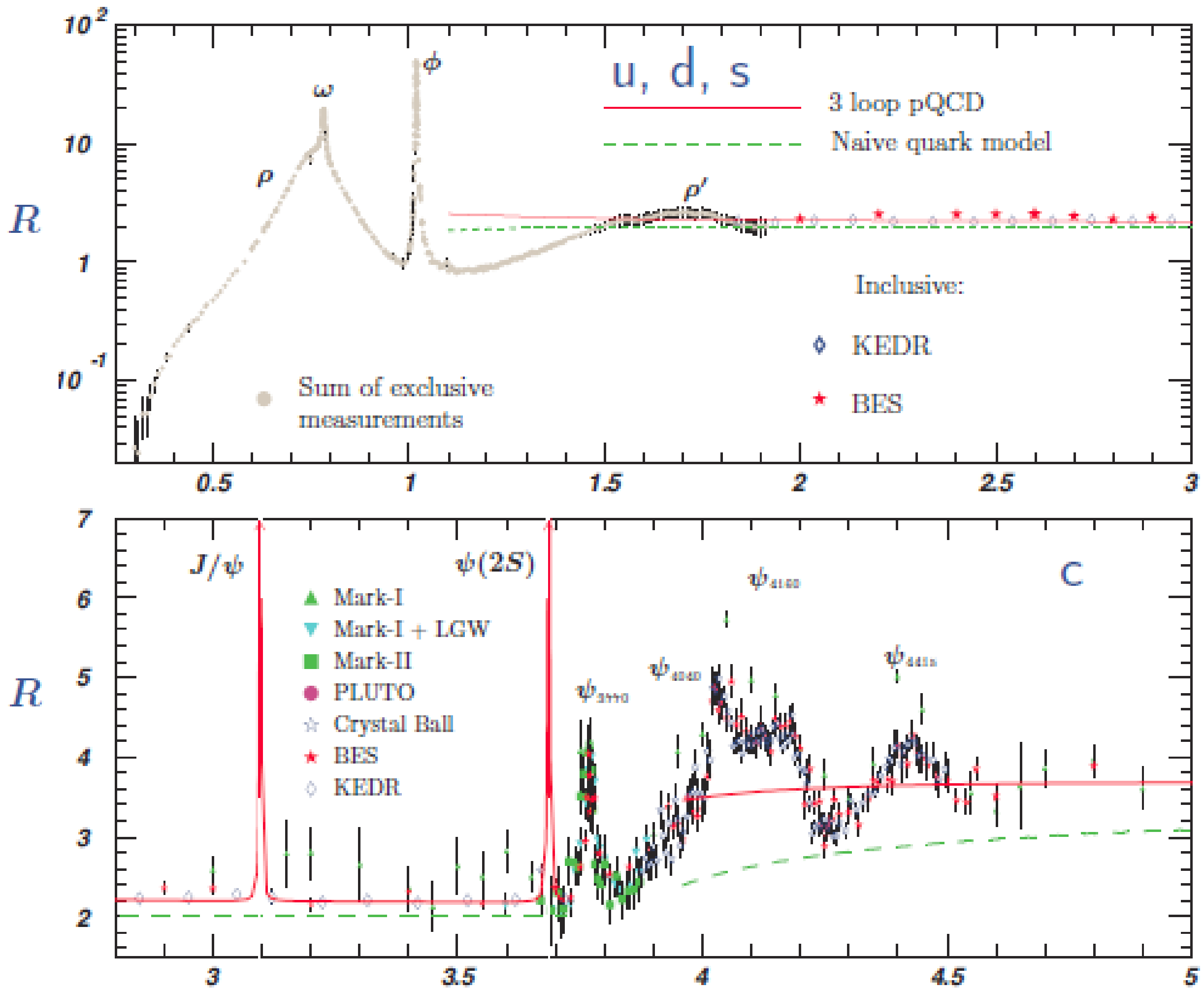
PDG2000



- Few groups
- Few energy points
- Large errors
- Ambiguous line-shape

Review of R value measurements

PDG2018



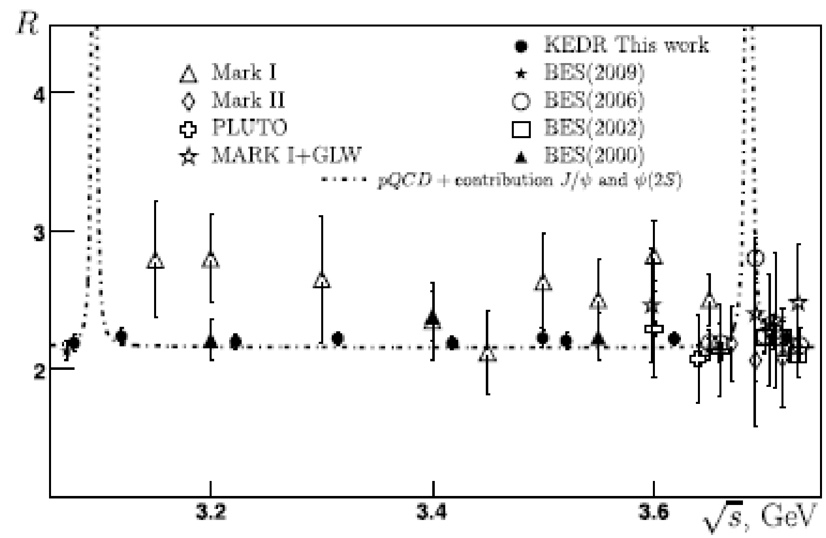
- KEDR's results included: Physics Letters B 788 (2019) 42–51
- $R_{uds} \approx R_{pQCD}$ at 2 GeV

Review of R value measurements

KEDR: Physics Letters B 788 (2019) 42–51

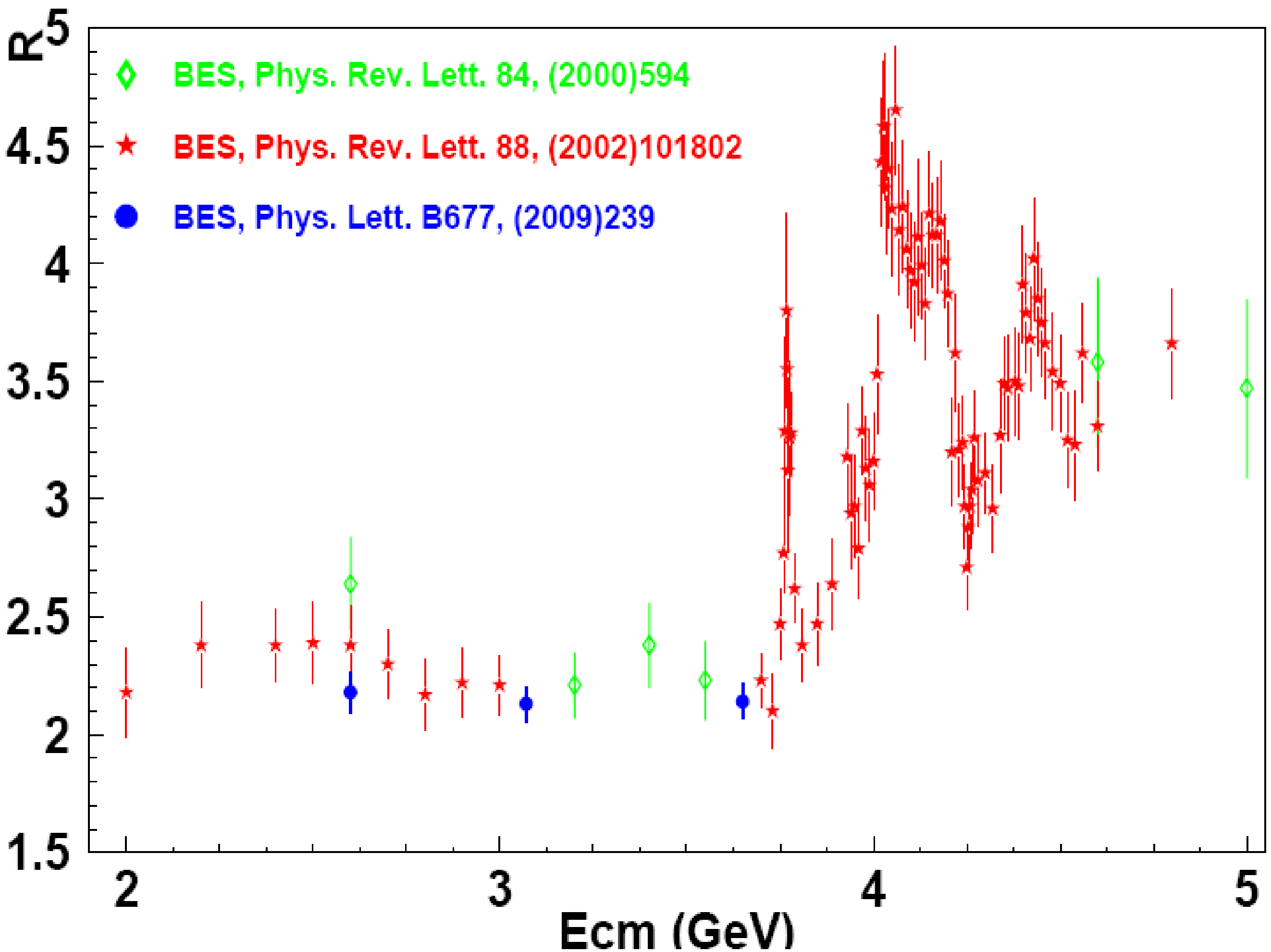
Summary table of KEDR results. Actual energies and measured R values.

Point	Energy	$R_{uds}(s)\{R(s)\}$	σ/R
Data 2010 [16]			
1	1841.0 ± 2	$2.226 \pm 0.139 \pm 0.158$	9.45 %
2	1937.0 ± 2	$2.141 \pm 0.081 \pm 0.073$	5.09 %
3	2037.3 ± 2	$2.238 \pm 0.068 \pm 0.072$	4.43 %
4	2135.7 ± 2	$2.275 \pm 0.072 \pm 0.055$	3.98 %
5	2239.2 ± 2	$2.208 \pm 0.069 \pm 0.053$	3.94 %
6	2339.5 ± 2	$2.194 \pm 0.064 \pm 0.048$	3.65 %
7	2444.1 ± 2	$2.175 \pm 0.067 \pm 0.048$	3.79 %
8	2542.6 ± 2	$2.222 \pm 0.070 \pm 0.047$	3.79 %
9	2644.8 ± 2	$2.220 \pm 0.069 \pm 0.049$	3.81 %
10	2744.6 ± 2	$2.269 \pm 0.065 \pm 0.050$	3.61 %
11	2849.7 ± 2	$2.223 \pm 0.065 \pm 0.047$	3.60 %
12	2948.9 ± 2	$2.234 \pm 0.064 \pm 0.051$	3.66 %
13	3048.1 ± 2	$2.278 \pm 0.075 \pm 0.048$	3.91 %
Combined Data 2011 [15] and 2014 (this work)			
14	3076.7 ± 0.2	$2.188 \pm 0.056 \pm 0.042$	
15	3119.6 ± 0.4	$2.212(2.235) \pm 0.042 \pm 0.049$	2.92 %
16	3222.5 ± 0.8	$2.194(2.195) \pm 0.040 \pm 0.035$	2.42 %
17	3314.7 ± 0.6	$2.219(2.219) \pm 0.035 \pm 0.035$	2.23 %
18	3418.3 ± 0.3	$2.185(2.185) \pm 0.032 \pm 0.035$	2.17 %
19	3499.6 ± 0.4	$2.224(2.224) \pm 0.054 \pm 0.040$	3.02 %
20	3520.8 ± 0.4	$2.200(2.201) \pm 0.050 \pm 0.044$	3.03 %
21	3618.2 ± 1.0	$2.212(2.218) \pm 0.038 \pm 0.035$	2.34 %
22	3719.4 ± 0.7	$2.204(2.228) \pm 0.039 \pm 0.042$	2.60 %



- Small $N_{had} < 1000$
- $\sigma_{sta} \sim \sigma_{sys}$
- Small total error !

R value measurements at BESII



BESII:

◇ $N_{had} \sim 1000$ $\sigma/R \sim 8\%$

★ $N_{had} \sim 300 \sim 2000$ $\sigma/R \sim 7\%$

● $N_{had} \sim 2000 \sim 8000$ $\sigma/R \sim 3.5\%$

Data samples of R scan at BESIII

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 at (*u*,*d*,*s*) energies
      - QED & QCD $\alpha(s)$, $(g-2)_\mu$
      - Inclusive distributions
      - Exclusive distributions
      - Correlation functions
      - Form factors
      - Fragmentation functions

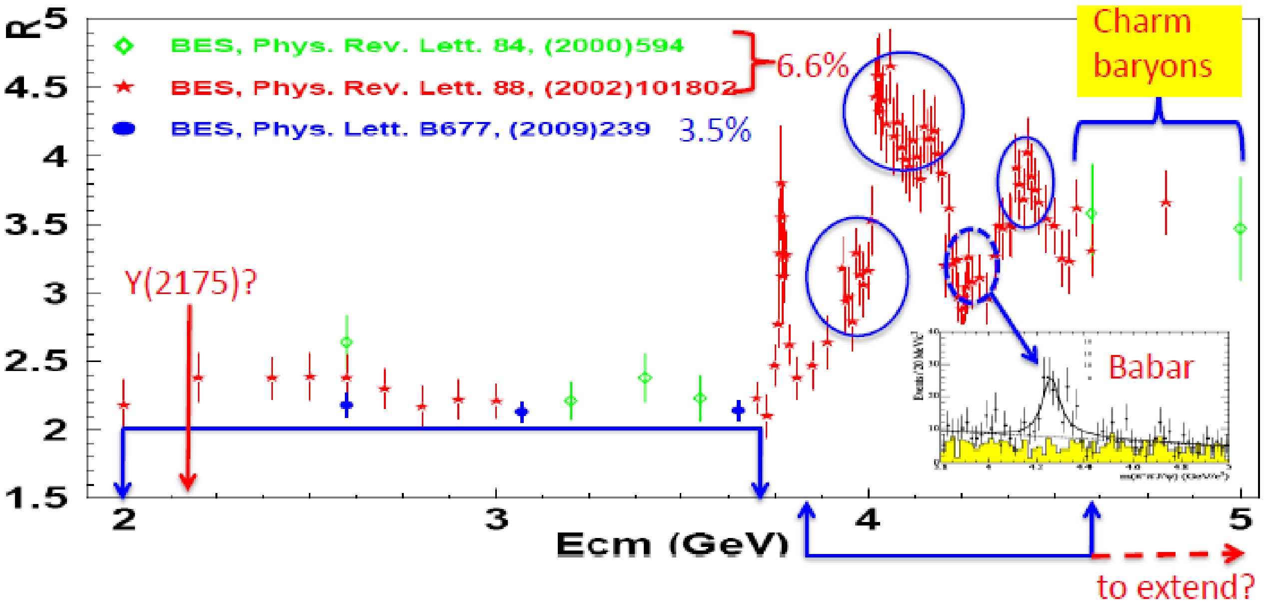
Status of R&QCD data taking

- 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.

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:

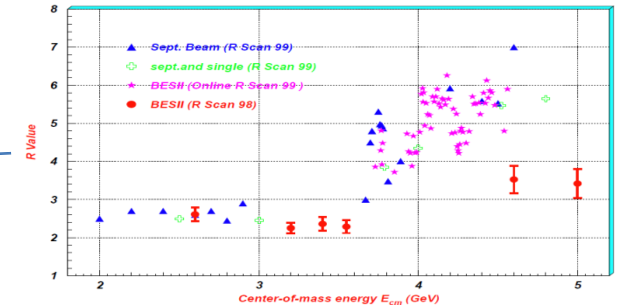
→ Born cross section

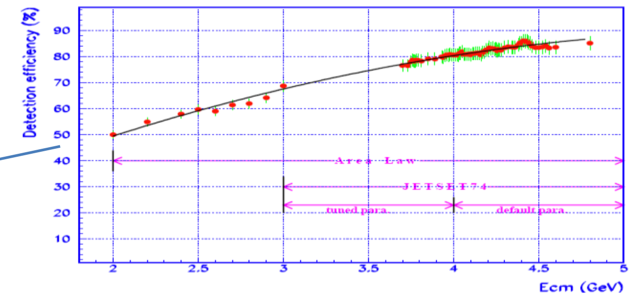
$$\sigma^0 = \frac{N_{had}}{L\bar{\epsilon}(1+\delta)}$$

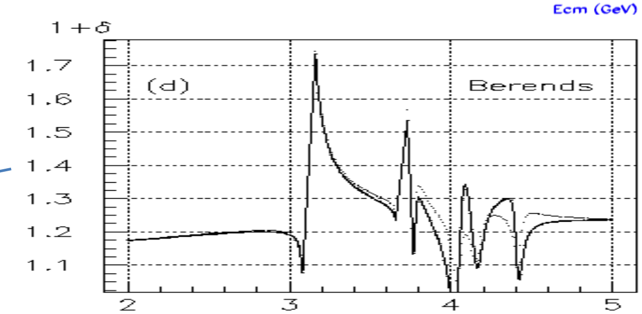
→ R value:

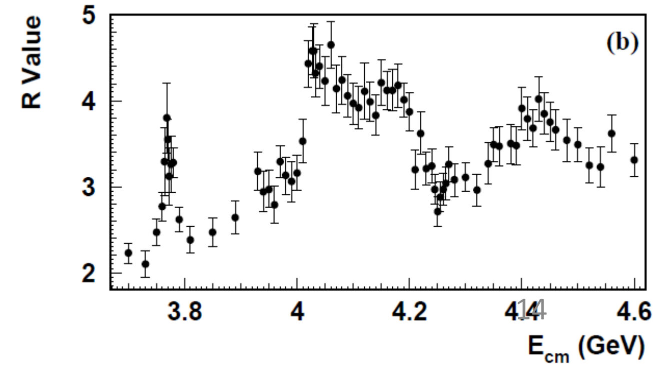
$$R = \frac{N_{had}}{\sigma^0_{\mu\mu} L\bar{\epsilon}(1+\delta)}$$

BESII









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: LUARLW:

parameters are tuned, cross checks, large systematic error source?

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

finished, error < 1.5%, including contribution of $\Delta\sigma^0_{had}$

Error analysis:

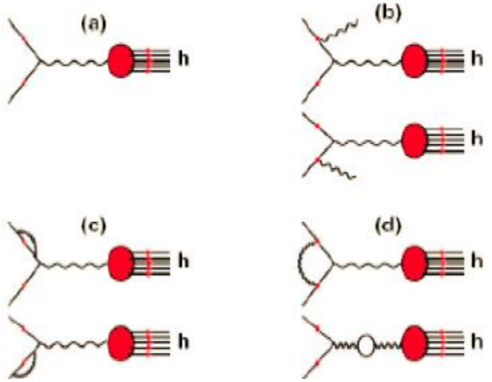
$$\frac{\Delta R}{R} \simeq \sqrt{(\frac{\Delta \tilde{N}_{had}}{\tilde{N}_{had}})^2 + (\frac{\Delta L}{L})^2 + (\frac{\Delta \epsilon_{trg}}{\epsilon_{trg}})^2 + (\frac{\Delta(1+\delta)}{(1+\delta)})^2}$$

- final goal $\Delta R/R$ ~2.5–3.0%.
- Results below open charm being reviewed in BESIII Collaboration.

Radiative correction

Initial state radiation correction

- Feynman diagrams for $e^+e^- \to(\gamma)$hadrons up to $\mathcal{O}(\alpha) \sim 1\%$



Nucl. Inst.rum Meth. 128 (1975)13

References:

G.Bonneau Nucl. Phys. B27, (1971) 281-397
F.A.Berends Nucl. Phys. B178, (1981)141-150
A.Osterfeld SLAC-PUB-4160(1986)
C.Edwards SLAC-PUB-5160(1990) (T/E)
CPC (HEP&NP)25,(2001)701

- ISR factor

$$1+\delta(s)=\frac{\sigma^{tot}(s)}{\sigma^0(s)} = (1-x_m^\beta+\delta_{vert})\frac{1}{|1-\Pi(s)|^2}+\frac{1}{\sigma^0(s)}\int_0^{x_m} dx F_{FD}(x;s)\frac{\sigma^0(s')}{|1-\Pi(s')|^2}$$

Radiator: $F_{FD}(x;s)=\beta\frac{x^\beta}{x}(1-x+\frac{x^2}{2})$

- ISR error

① theory uncertainty $\mathcal{O}(\alpha) \sim 1\%$

② $\sigma^0(s)\pm\Delta_\sigma$ experimental & pQCD errors $\leq 1\%$

↓

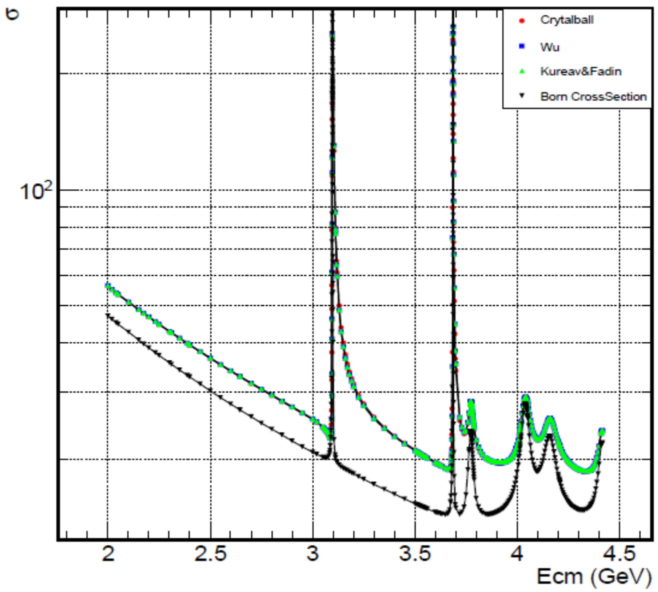
$\Delta(1+\delta)$

$\sqrt{s}$(GeV)	ISR (Feynman diagram)
2.2324	1.197±0.015 (1.25%)
2.4000	1.205±0.015 (1.22%)
2.8000	1.224±0.014 (1.17%)
3.0500	1.200±0.013 (1.12%)
3.0600	1.189±0.013 (1.12%)
3.0800	1.133±0.013 (1.16%)
3.4000	1.413±0.015 (1.07%)
3.5000	1.382±0.018 (1.29%)
3.5424	1.373±0.017 (1.25%)
3.5538	1.369±0.017 (1.22%)
3.5611	1.367±0.017 (1.22%)
3.6002	1.357±0.016 (1.20%)
3.6500	1.332±0.016 (1.23%)
3.6710	1.281±0.015 (1.15%)

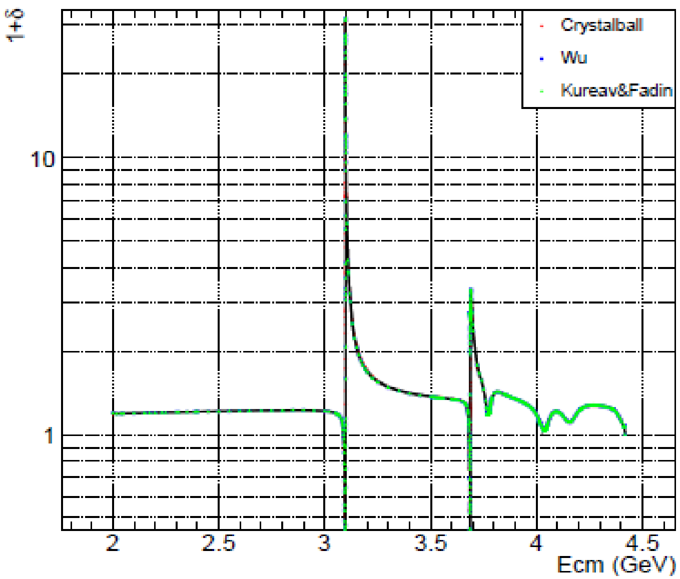
Theoretic cross section and ISR factor

Feynman diagrams: (FD)
- CRYSTABALL: SLAC-PUB-4160 (1986)T/E , SLAC-PUB-5160, (1990), T/E
- CPC (HEP&NP)25,(2001)701

Structure function: (SF)
- WU: CPC(HEP&NP) 14, (1990)585
- KUREAV&FADIN: Sov. J. Nucl. Phys. 41, (1985) 466



Hadronic Born and total cross section



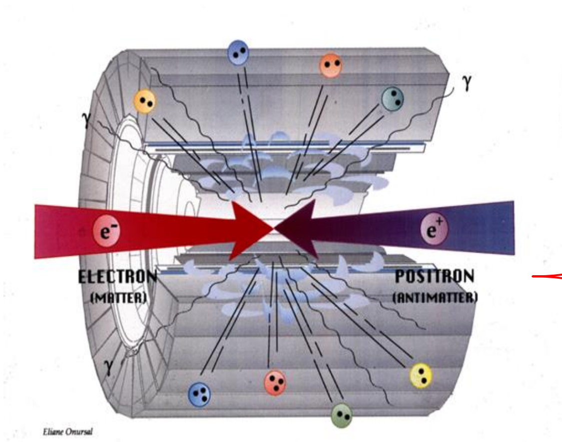
Initial state radiation factor (1+δ)

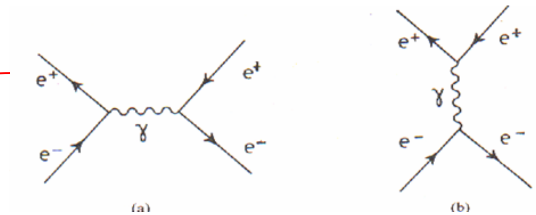
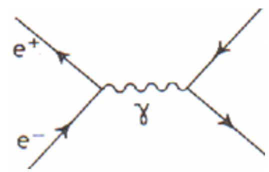
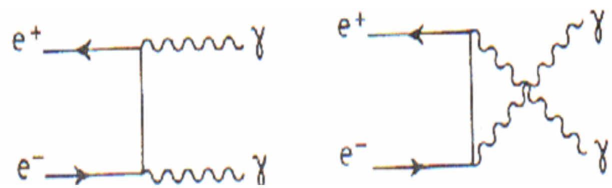
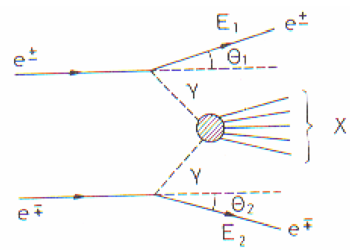
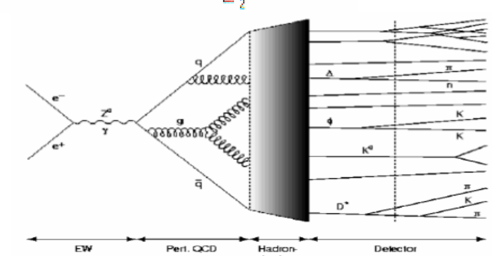
- The FD and SF schemes are compared numerically
- FD and SF are consistent within theoretical accuracy in non-resonant region

The case now

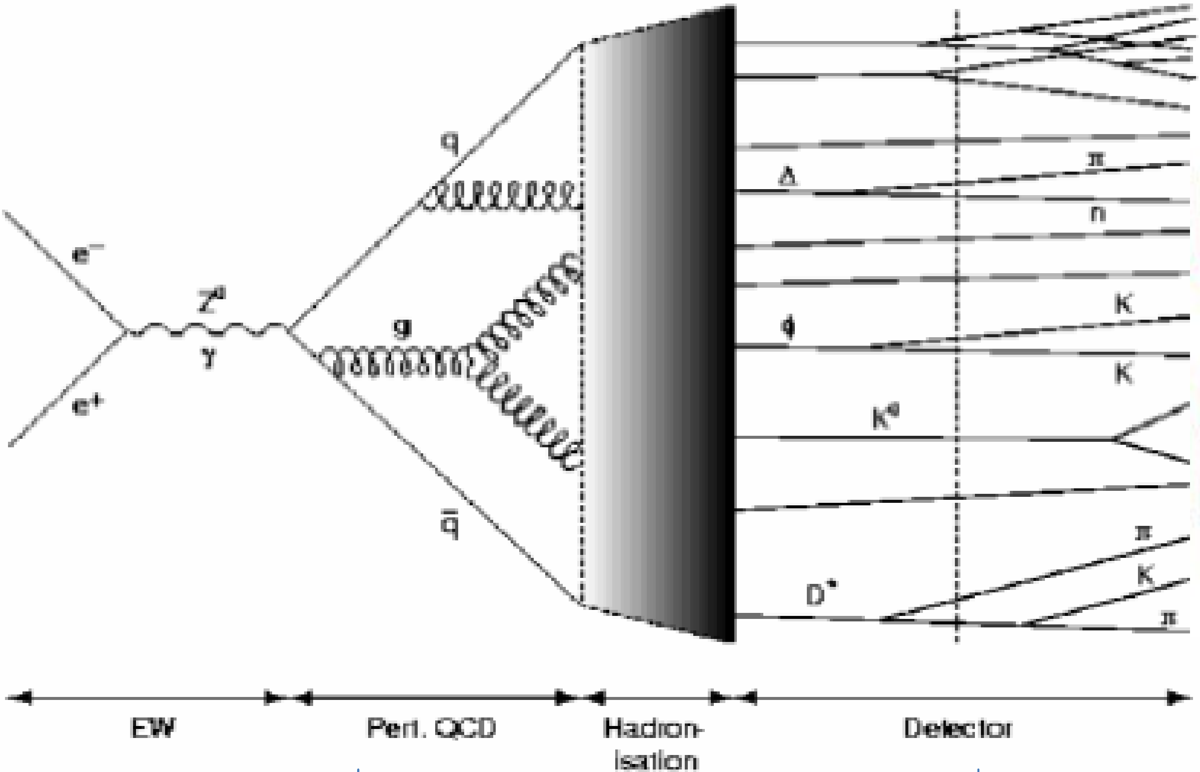
Hadronic generator

The generators used in R measurement

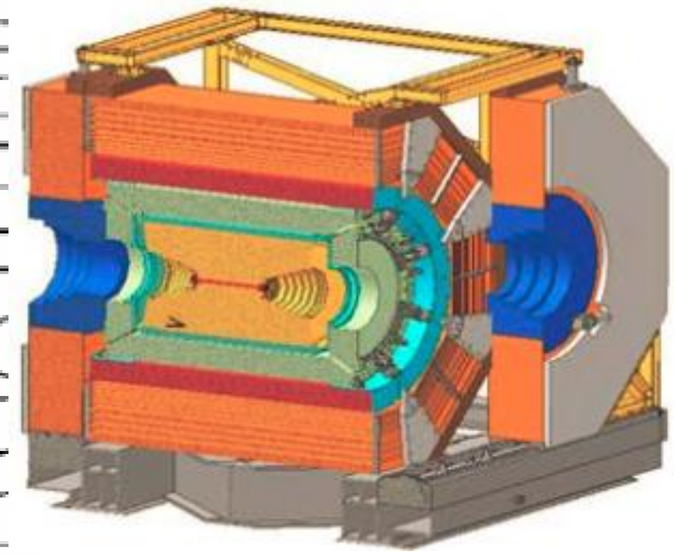


processes		generators
	$e^+e^-\to e^+e^-$	BABAYAGA (OK)
	$e^+e^-\to\mu^+\mu^-$ $e^+e^-\to\tau^+\tau^-$	BABAYAGA (OK) KKMC (OK)
	$e^+e^-\to\gamma\gamma$	BABAYAGA (OK)
	$e^+e^-\to e^+e^-X$	TWOPHOTON (need check)
	$e^+e^-\to$hadrons	LUARLW (optimized/tuned)

Simulation of hadron production and decay



BESIII



Hadron production at vertex:
LUARLW

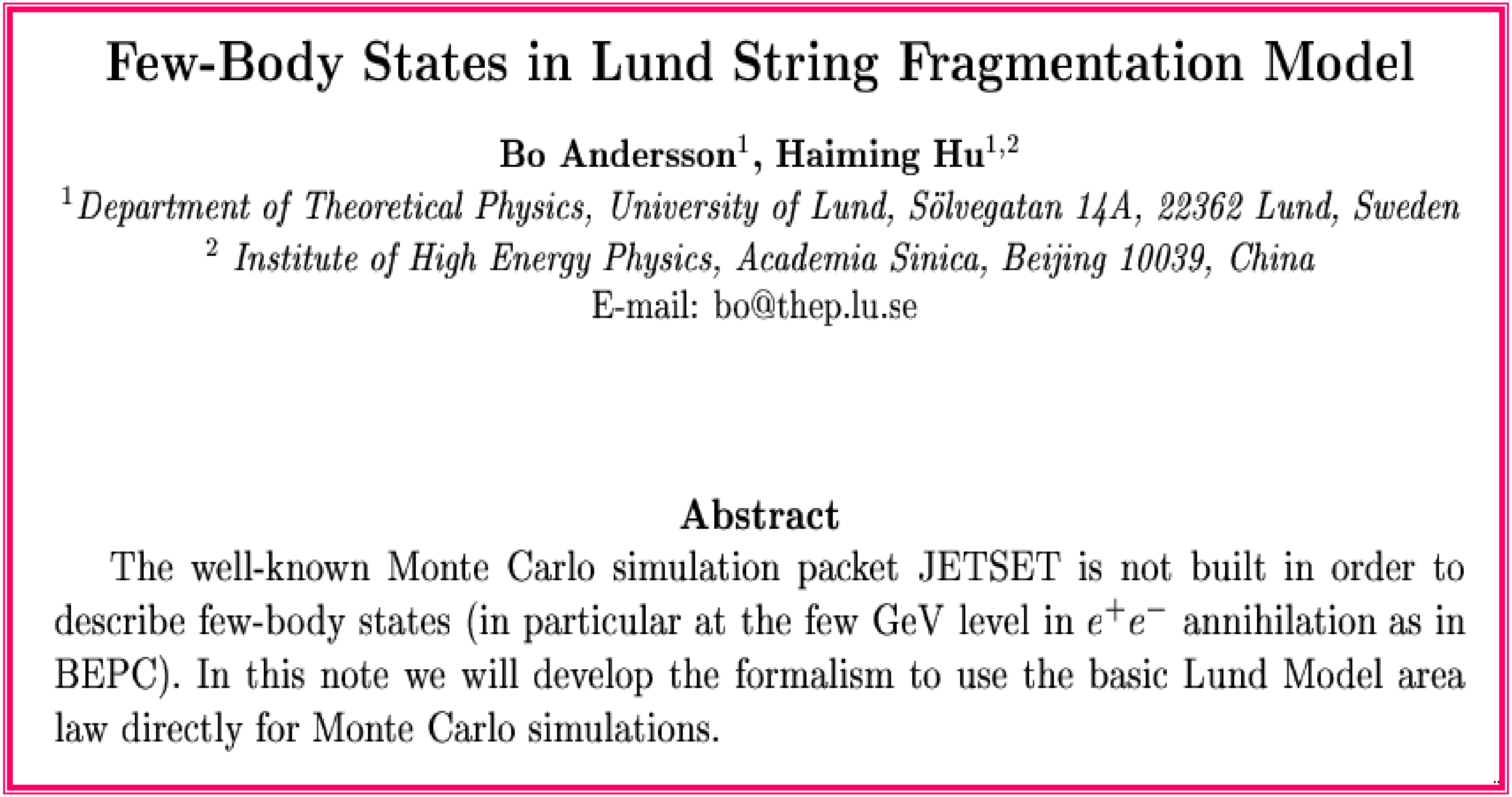
Particles decay:
LUARLW/BesEvtGen

Detector simulation:
GEANT4

BESIII data

LUARLW

hep-ph/9910285



Few-Body States in Lund String Fragmentation Model

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Abstract

The well-known Monte Carlo simulation packet JETSET is not built in order to describe few-body states (in particular at the few GeV level in e^+e^- annihilation as in BEPC). In this note we will develop the formalism to use the basic Lund Model area law directly for Monte Carlo simulations.

Simulation functions of LUARLW

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

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

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

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

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

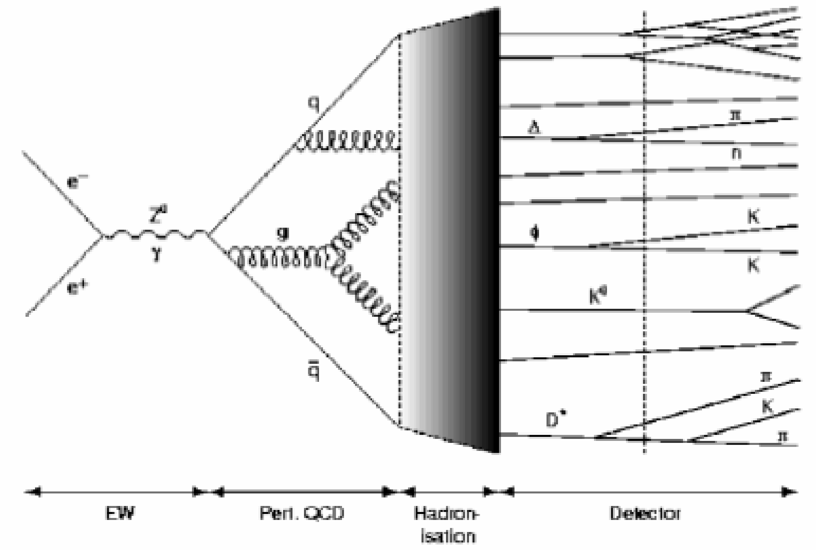
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(3770) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-, \ \mu^+\mu^-, \ \tau^+\tau^- \\ D^0\bar{D}^0, \ D^+\bar{D}^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string}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

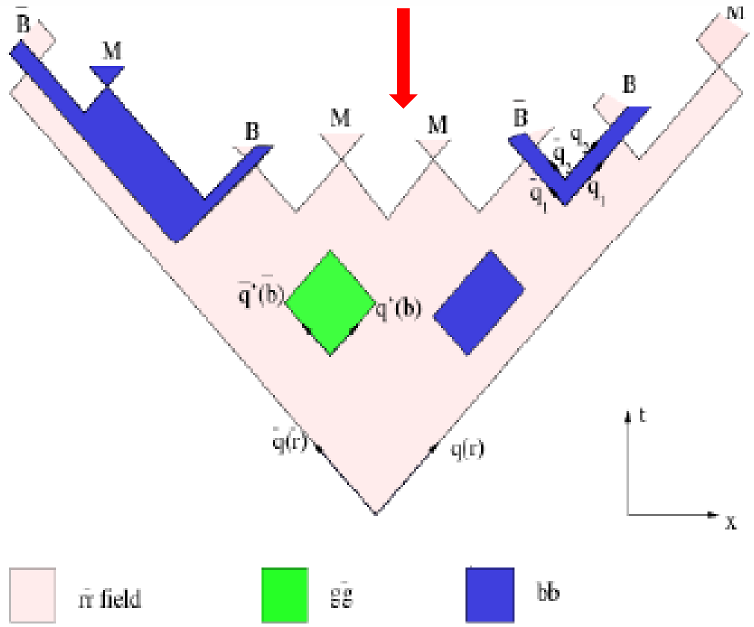
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s; \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*; \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*,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

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

Picture of Lund string fragmentation to hadrons

arXiv:hep-ph/9910285 Few-Body States in Lund String Fragmentation Model





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

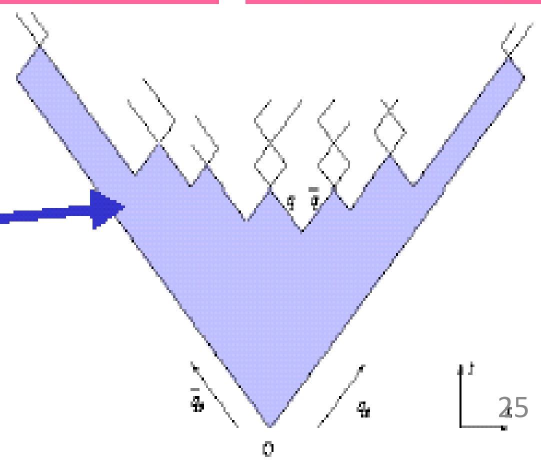
$$d\wp_n(q\bar{q} \to m_1, m_2, \cdots m_n; s) = \cdot (2\pi)^4 \delta(1 - \sum_{j=1}^{n} \frac{m_{\perp j}^2}{s z_j}) \cdot \delta(1 - \sum_{j=1}^{n} z_j) \cdot \delta^{(2)}(\sum_{j=1}^{n} \vec{k}_j) \cdot \overline{\sum} |\hat{T}_{con}^{(n)f}|^2 d\Phi_n$$

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

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

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

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



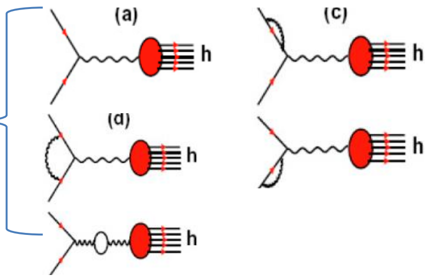
ISR sampling in LUARLW simulation

In LUARLW simulation, the events are classed into two types

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

Weight:

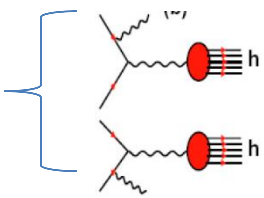
$$\sigma^{VSB} = \sigma^0(s)[1 + \beta \ln k_0 + \delta_{AR}]$$



② real radiation: hard bremsstrahlung events.

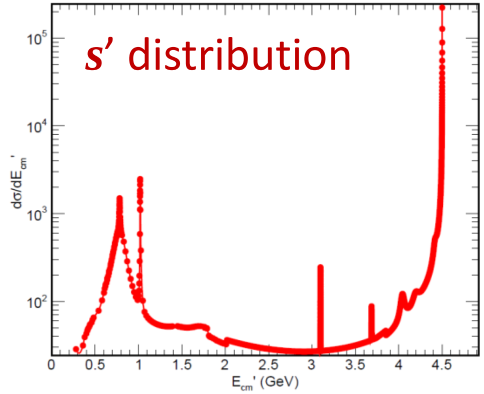
Weight:

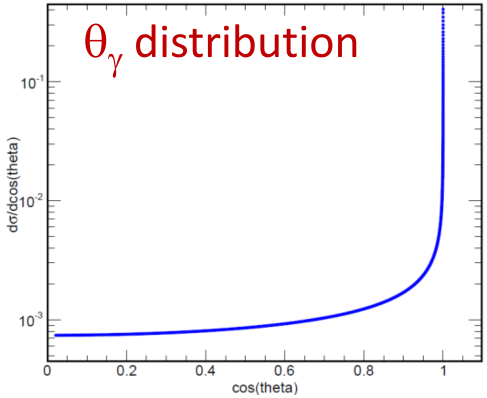
$$\sigma^{HB} = \int_{k_0}^{k_m} dk \frac{\partial \sigma^{HB}}{\partial k}$$



The energy and polar angle distribution of real emission photon

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

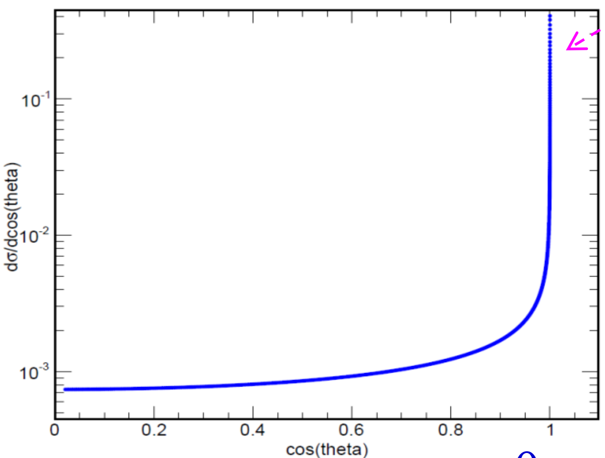




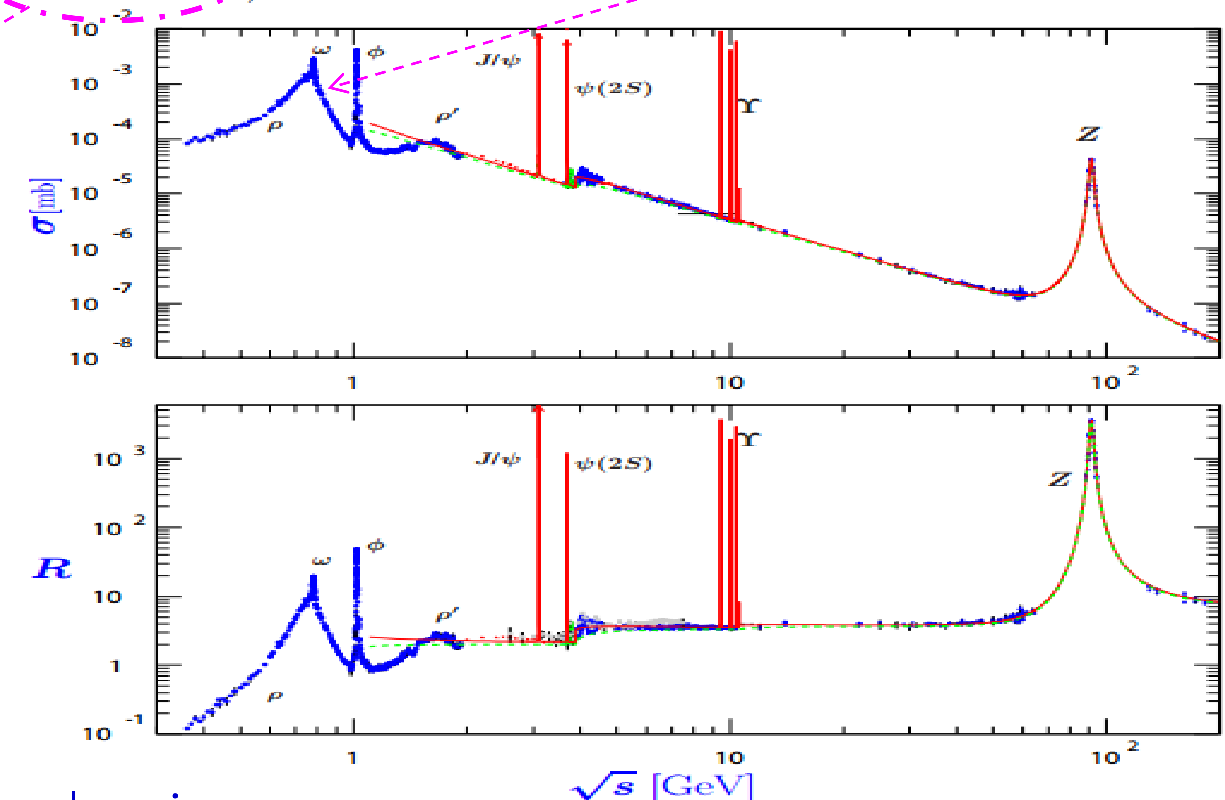
Bremsstrahlung at ρ,ϕ,ω region important

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

NPB27(1971)381



$\cos\theta_\gamma$



$\sigma^0(s')/R(s')$:

Below 2 GeV ⇒ PDG values

Above 2 GeV ⇒ pQCD values

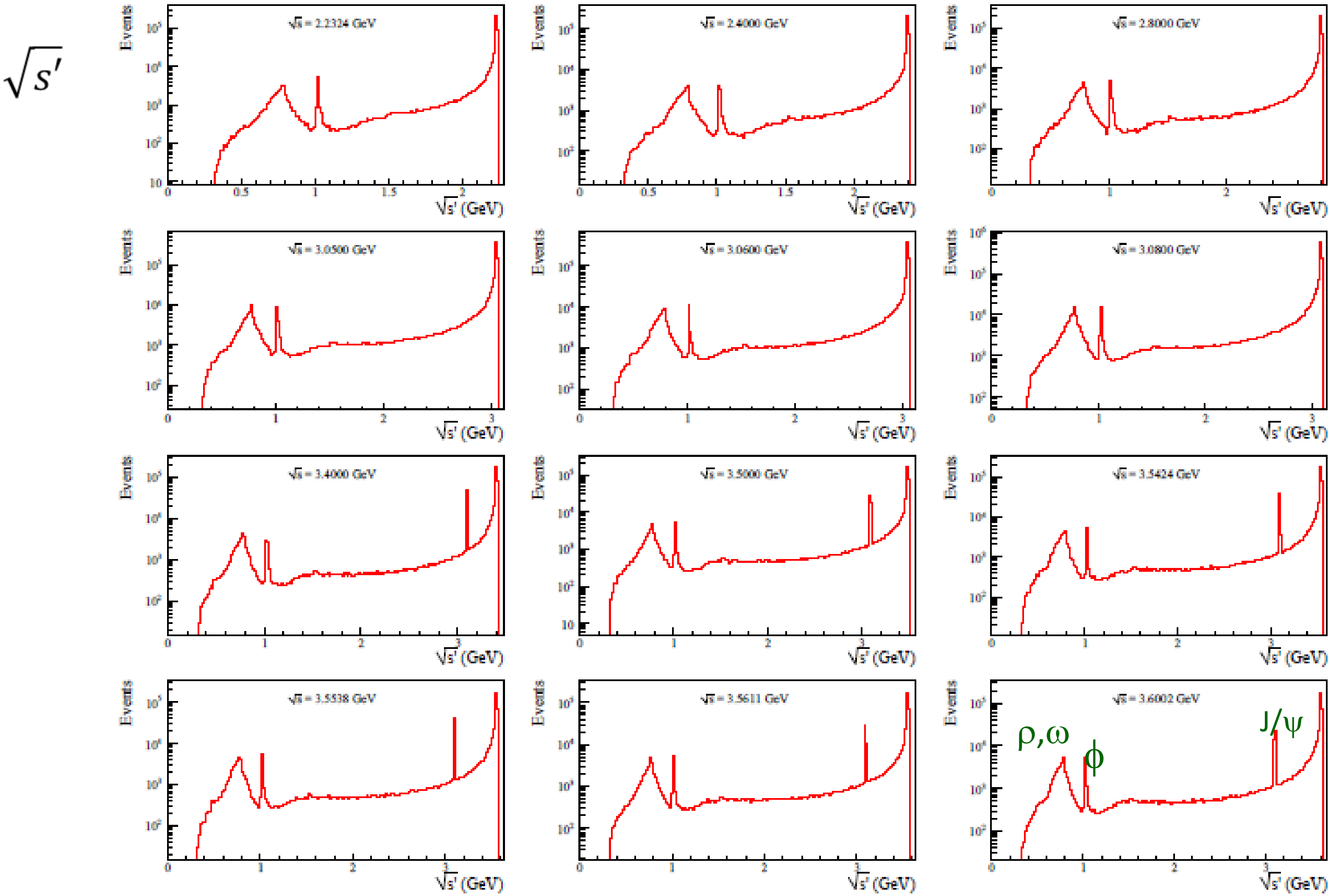
- $R(s')/\sigma^0(s')$ are large in ρ, ω, ϕ region
- A lot of events with small polar angles θ_γ and lower effective energies production
- These two factors are sensitive to hadronic efficiency
- The simulation in ρ, ω, ϕ region and at small polar angles must be correctly

Effective hadronic E'_{cm} distributions after ISR

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

MC sampling ↓

$\sqrt{s'}=(1-k)\sqrt{s}$



Examples of event production

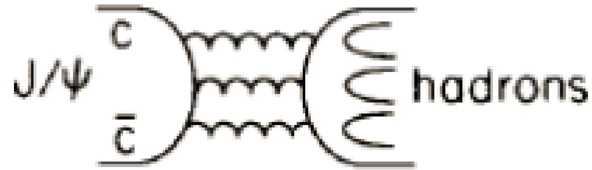
$$e^+e^- \rightarrow \gamma\ string \rightarrow \gamma + handrons$$

	I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
Initial $e^{\pm}$	1	(e-)		12	11	0	0.00000	0.00000	1.75064	1.75064	0.00051
	2	(e+)		11	-11	0	0.00000	0.00000	-1.75064	1.75064	0.00051
ISR photon	3	gamma		1	22	1	0.00000	0.00000	0.00027	0.00027	0.00000
Virtual photon	4	!gamma!		21	22	1	0.00000	0.00000	-0.00027	3.50102	3.50102
Initial quarks	5	(u)	A	12	2	4	-0.81059	-1.26438	-0.89932	1.75058	0.00560
	6	(u~)	V	11	-2	4	0.81059	1.26438	0.89905	1.75044	0.00560
string	7	(string)		11	92	5	0.00000	0.00000	-0.00027	3.50102	3.50102
four primary hadrons	8	(rho0)		11	113	7	-0.41409	-0.63658	-0.42688	1.10547	0.68053
	9	(pi0)		11	111	7	0.12991	0.04146	-0.16074	0.25031	0.13500
	10	pi-		1	-211	7	0.95775	0.09180	0.34886	1.03291	0.13960
	11	(rho+)		11	213	7	-0.67078	0.50366	0.23898	1.11539	0.69524
final particles	12	pi+		1	211	8	-0.17152	-0.39729	-0.54910	0.71293	0.13960
	13	pi-		1	-211	8	-0.24499	-0.23868	0.12616	0.39038	0.13960
	14	pi+		1	211	11	-0.38799	-0.03838	0.25920	0.48855	0.13960
	15	(pi0)		11	111	11	-0.28317	0.54110	-0.02465	0.62594	0.13500
	16	gamma		1	22	9	0.14913	0.00954	-0.14955	0.21141	0.00000
	17	gamma		1	22	9	-0.01922	0.03192	-0.01119	0.03890	0.00000
	18	gamma		1	22	15	-0.08214	0.30218	-0.00762	0.31323	0.00000
	19	gamma		1	22	15	-0.20103	0.23892	-0.01703	0.31271	0.00000
				sum:	0.00		0.00000	0.00000	0.00000	3.50128	3.50128

Five modes of J/ψ decays

CERN–EP/88–93

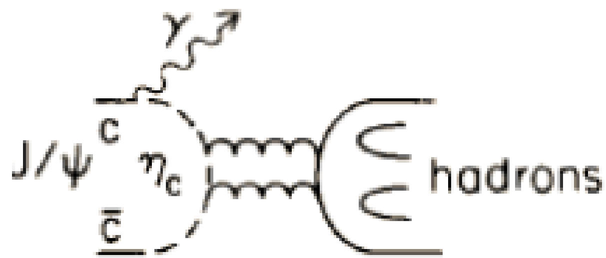
Hadronic decay via 3-gluons



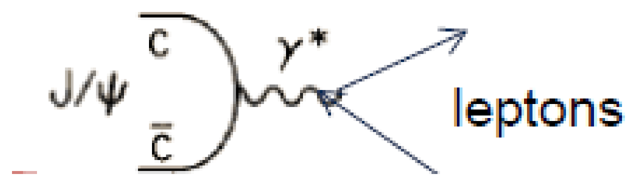
Electromagnetic decay to hadrons

Radiative decay into hadrons

Radiative M1 transition to η_c



Electromagnetic decay to leptons



All five decay modes have been included in LUARLW

Examples of event production

$$e^+e^- \rightarrow \gamma c\bar{c} \rightarrow \gamma\, J/\psi \rightarrow \gamma\, ggg \rightarrow \gamma{+}string{+}string{+}string \rightarrow \gamma hadrons$$

CPC (HEP&NP)27,(2003)673

J/ψ

I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.00000	0.00000	1.75042	1.75042	0.00051
2	!e+!		21	-11	0	0.00000	0.00000	-1.75042	1.75042	0.00051
3	gamma		1	22	2	0.00164	0.00124	-0.38074	0.38075	0.00000
4	!gamma!		21	22	1	-0.00164	-0.00124	0.38074	3.12010	3.09678
5	(c)	A	12	4	4	-0.00082	-0.00062	0.19037	1.56005	1.35000
6	(c~)	V	11	-4	4	-0.00082	-0.00062	0.19037	1.56005	1.35000
7	!J/psi!		21	443	6	-0.00164	-0.00124	0.38074	3.12010	3.09678
8	(g)	A	11	21	7	-0.67757	-0.50643	0.62514	1.05150	0.00000
9	(g)	V	11	21	7	-0.35183	-0.32003	0.38129	0.60958	0.00000
10	(g)	A	11	21	7	1.02775	0.82522	-0.62569	1.45902	0.00000
11	(d)	I	12	1	8	0.11116	0.05805	0.34162	0.36404	0.00990
12	(d~)	I	12	-1	8	-0.78873	-0.56448	0.28352	0.68744	0.00990
13	(u)	I	12	2	9	0.10741	-0.15372	0.23751	0.30267	0.00560
14	(u~)	I	12	-2	9	-0.45923	-0.16631	0.14378	0.30791	0.00560
15	(u)	I	12	2	10	-0.00756	-0.04922	-0.34974	0.35331	0.00560
16	(u~)	V	11	-2	10	1.03531	0.87444	-0.27594	1.10562	0.00560
17	(string)		12	92	11	-0.34807	-0.10825	0.48540	0.67196	0.28817
18	(string)		12	92	13	1.14271	0.72072	-0.03844	1.40829	0.39571
19	(string)		11	92	15	-0.79628	-0.61370	-0.06622	1.04075	0.26092
20	gamma		1	22	17	-0.16538	-0.14885	0.30172	0.37489	0.00000
21	pi-		4	-211	17	-0.18269	0.04060	0.18368	0.29707	0.13960
22	pi+		4	211	18	0.74416	0.33866	-0.10029	0.83548	0.13960
23	pi-		4	-211	18	0.39855	0.38205	0.06185	0.57282	0.13960
24	gamma		1	22	19	-0.37813	-0.20584	-0.08947	0.43973	0.00000
25	pi+		4	211	19	-0.41816	-0.40786	0.02325	0.60102	0.13960
			sum:	0.00		0.00000	0.00000	0.00000	3.50175	3.50175

Tuning of LUARLW parameters

- Generator contributes the dominant systematic error
- Main parameters:

For multiplicity

For Particle ratios

parameter	default	tuned	meaning
c_0	-	5.0	parameter in preliminary hadron multiplicity distribution $P_n(s)$
c_1	-	0.05	parameter in preliminary hadron multiplicity distribution $P_n(s)$
c_2	-	-0.25	parameter in preliminary hadron multiplicity distribution $P_n(s)$
α	-	1.25	parameter α in $\mu=\alpha+\beta\exp(\gamma\sqrt{s})$
β	-	0.27	parameter β in $\mu=\alpha+\beta\exp(\gamma\sqrt{s})$
γ	-	0.95	parameter γ in $\mu=\alpha+\beta\exp(\gamma\sqrt{s})$
$\sigma_\perp$	-	Ecm-dependent	effective transverse momentum width in like-Gaussian form
PARJ(01)	0.10	Ecm-dependent	diquark/quark production ratio, baryon suppression (B/M)
PARJ(02)	0.30	Ecm-dependent	s/(u,d) production ratio, strange meson suppression (K/π)
PARJ(03)	0.40	Ecm-dependent	strange diquark suppression, strange baryon suppression (Λ/p)
PARJ(04)	0.05	0.05	suppression of spin 1 diquark compared to spin 0 ones
PARJ(05)	0.50	0.50	relative occurence of baryon produced by $BM\bar{B}$ and by $B\bar{B}$
PARJ(06)	0.50	0.50	suppression for having $s\bar{s}$ shared by B and $\bar{B}$ of $BM\bar{B}$ situation
PARJ(07)	0.50	0.50	suppression for having strange meson M in $BM\bar{B}$ configuration
PARJ(11)	0.50	Ecm-dependent	suppression of light meson has spin 1 compared to spin 0 (ρ/π)
PARJ(12)	0.60	0.70	suppression of strange meson of spin 1 compared to spin 0 (K^*/K)
PARJ(13)	0.75	0.75	suppression of charm meson of spin 1 compared to spin 0 (D^*/D)
PARJ(14)	0.00	0.09	probability that spin $s=0$ and orbital $L=1$ with total $J=1$ meson
PARJ(15)	0.00	0.07	probability that spin $s=1$ and orbital $L=1$ with total $J=0$ meson
PARJ(16)	0.00	0.08	probability that spin $s=1$ and orbital $L=1$ with total $J=1$ meson
PARJ(17)	0.00	0.10	probability that spin $s=1$ and orbital $L=1$ with total $J=2$ meson
...	...	...	...

- Great efforts have been done on LUARLW parameter tuning
- LUARLW tuning/check in progress, reviewed in BESIII Collaboration

Tuning of mixing-generator

Chinese Physics C Vol. 40, No. 11 (2016) 113002

PHOKHARA ⊕ ConExc ⊕ LUARLW

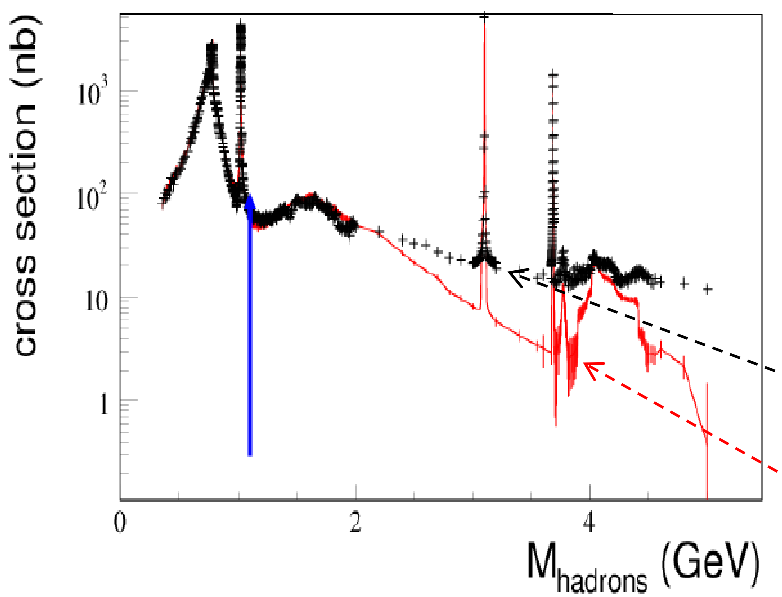
Measured exclusive channels (PHOKHARA ⊕ ConExc)

unmeasured inclusive channels (LUARLW)

Tuning scheme:

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

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



+ total hadronic cross section,

+ sum of the cross section ever measured exclusive channels

Unknown channels, simulate by LUARLW

Known channels, simulate by exclusive method

Comparison of data and mixing generator

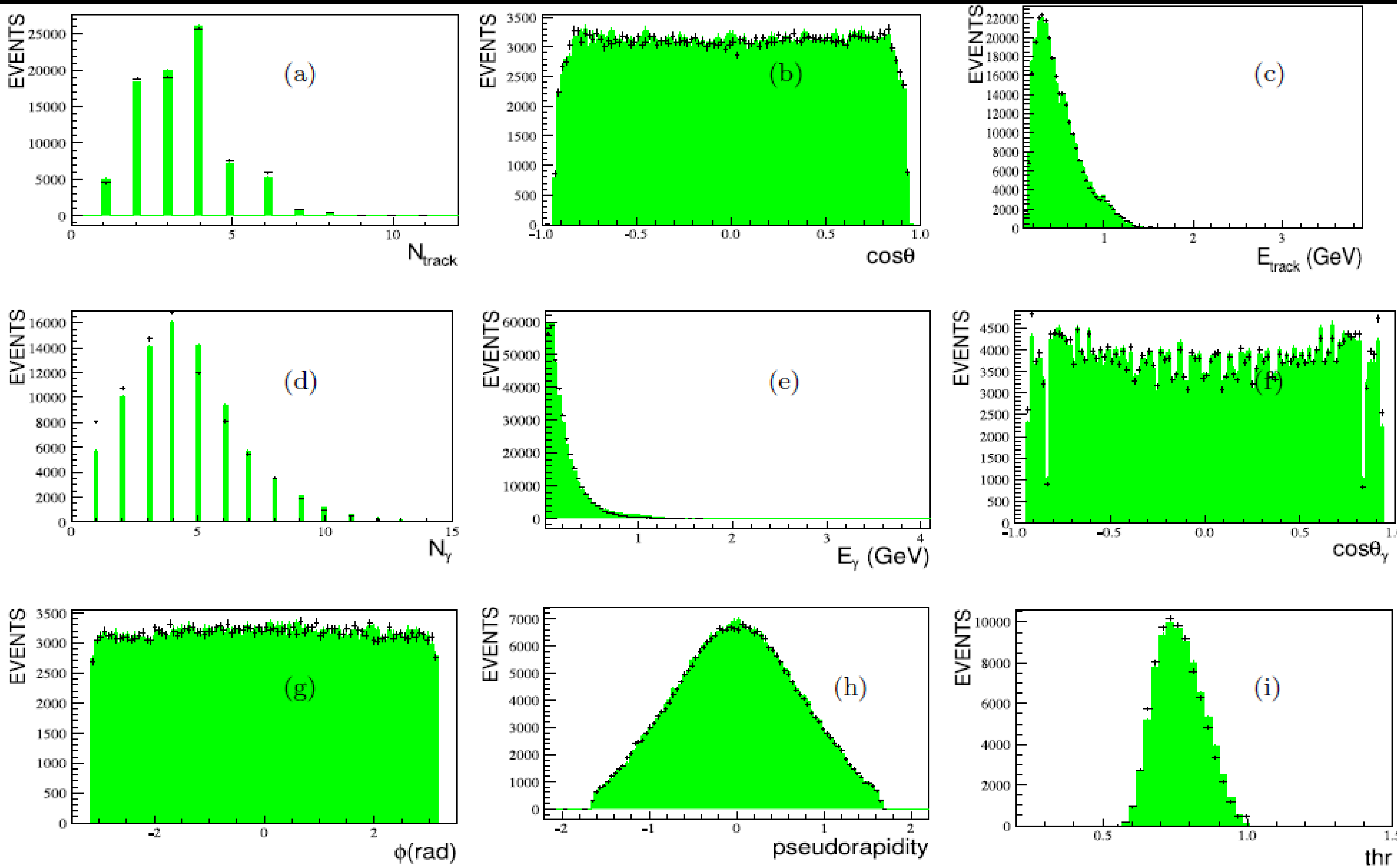


Fig. 5. Comparison of data to the MC distributions at 3.06 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine of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

Generator/MC systematic errors

- Selection efficiency for hadronic events

$$\bar{\epsilon}_{hd} = \frac{N_{obs}^{MC}}{N_{gen}^{MC}}$$

- Number of hadronic events produced at collider vertex

$$\tilde{N}_{had} = \frac{N_{had}}{\bar{\epsilon}_{had}}$$

- Experiment independent
- Proportional to physics total cross section

- Combined error of event selection and MC simulation

$$\Delta \tilde{N}_{had} = \Delta\left(\frac{N_{obs}^{dat}}{\bar{\epsilon}_{had}}\right)_{\text{cuts}}$$

Consideration:

★ event selection ⇒ cuts

★ cuts ⇒ errors

★ good MC ⇒ $\Delta\tilde{N}_{had}$ small

Data and MC are coincident with cuts

Source	Cut
veto Bhabha and $\gamma\gamma$	E_{ratio} $\Delta\theta$
good hadronic tracks determination	Vr $p(track)$ dE/dx cut E/p ratio Bhabha momentum limit isolated photon angle isolated photon energy gamma conversion angle gamma conversion mass PID ratio value
2 prong events	$\Delta\theta$ $\Delta\phi$
3 prong events	$\Delta\theta$ $\Delta\phi$
others	backgrounds

Summary

- The data sets for R value measurements between 2.0 — 4.6 GeV at about 130 energies have been collected.
- The integrated luminosity at all energy points are measured with about 1% precision.
- The parameters of generator LUARLW are optimized and tuned
- The mixing-generator are tuned and compared
- The memo of R value measurement between 2.232–3.671 GeV is being reviewed in BES Collaboration.
- The data analysis for 3.85 – 4.59 GeV at 104 energies are in progress.

Back Up

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 ?

R line shape scan above open charm

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