Status of R value measurement at BESIII

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Tau and QCD physics at present and future electron-positron colliders

December 27, 2019

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Haiming HU

(For BESIII Collaboration)

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What we did since then ???

Outline

- Review of R value measurements
- Data samples of R scan @ BESIII
- Check and tuning of generator LUARLW
- Summary

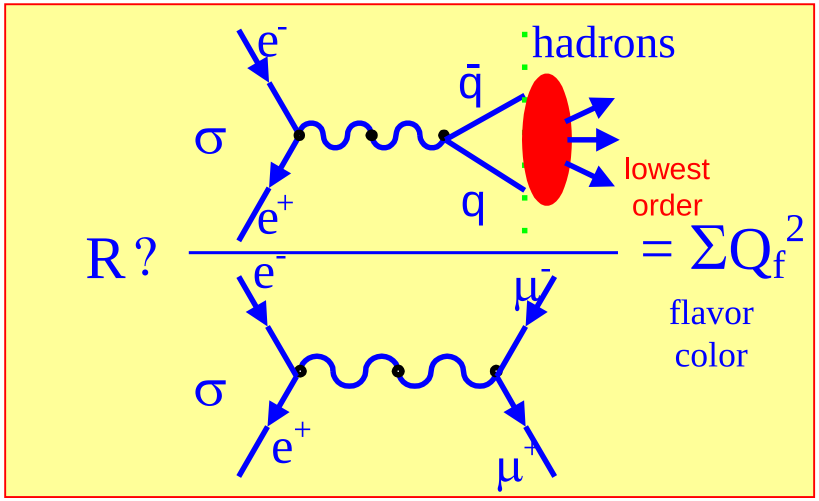
Review of R value measurements

What is R Value

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

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

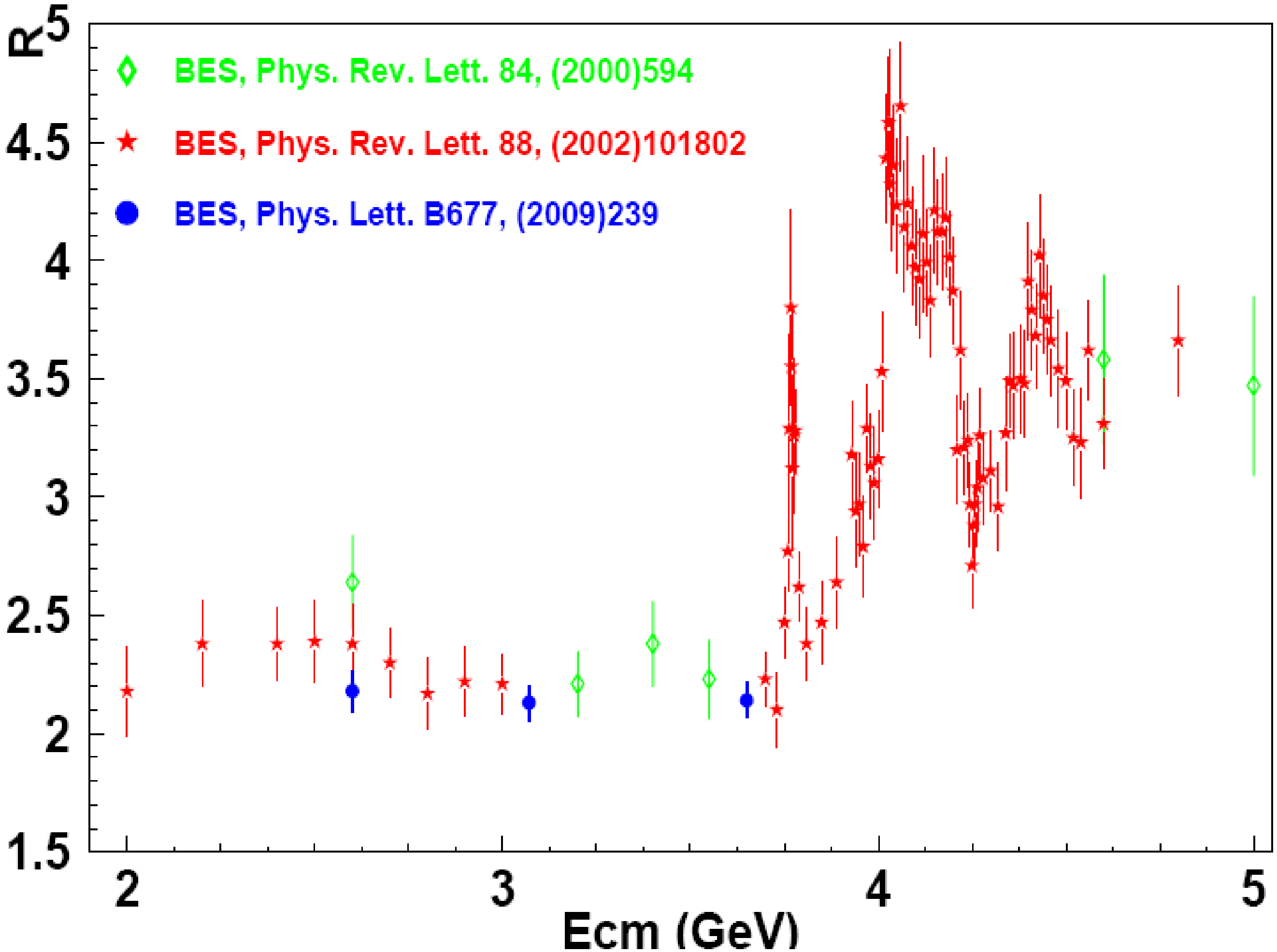
Feynman diagram of R value



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.

R value measurements at BESII



BESII:

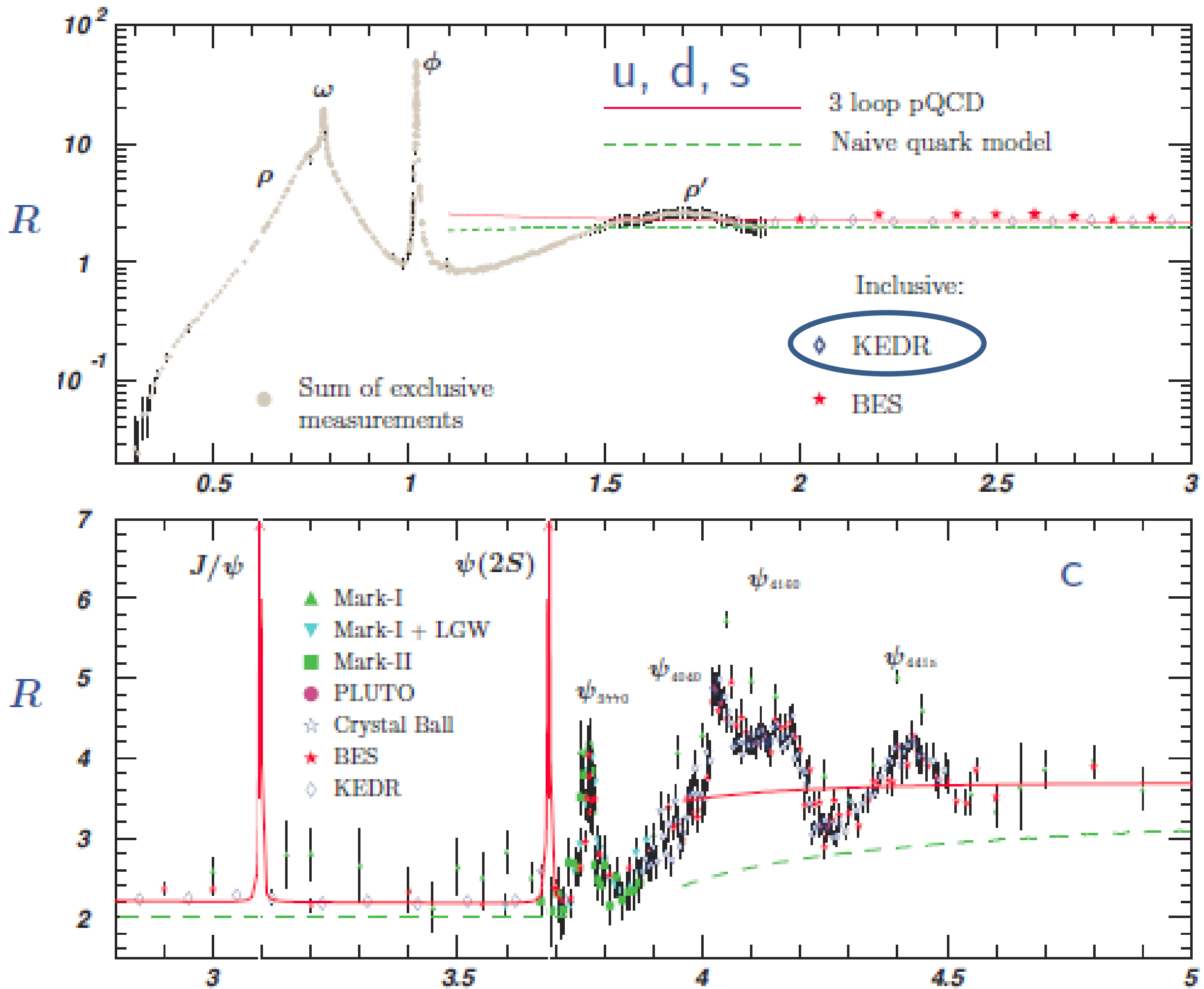
◇ N_{had} ~ 1000 σ/R ~ 8 %

★ N_{had} ~ 300 ~ 2000 σ/R ~ 7 %

● N_{had} ~ 2000 ~ 8000 σ/R ~ 3.5%

Review of R value measurements

PDG2018



- KEDR's results:
- $R_{uds} \approx R_{pQCD}$ at 2 GeV

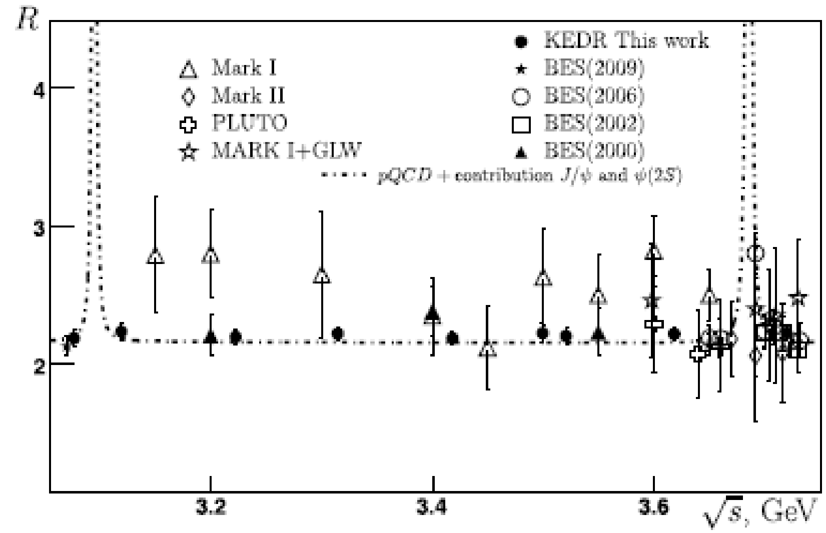
Physics Letters B 788 (2019) 42–51

Result of R value measurement with KEDR

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 !

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

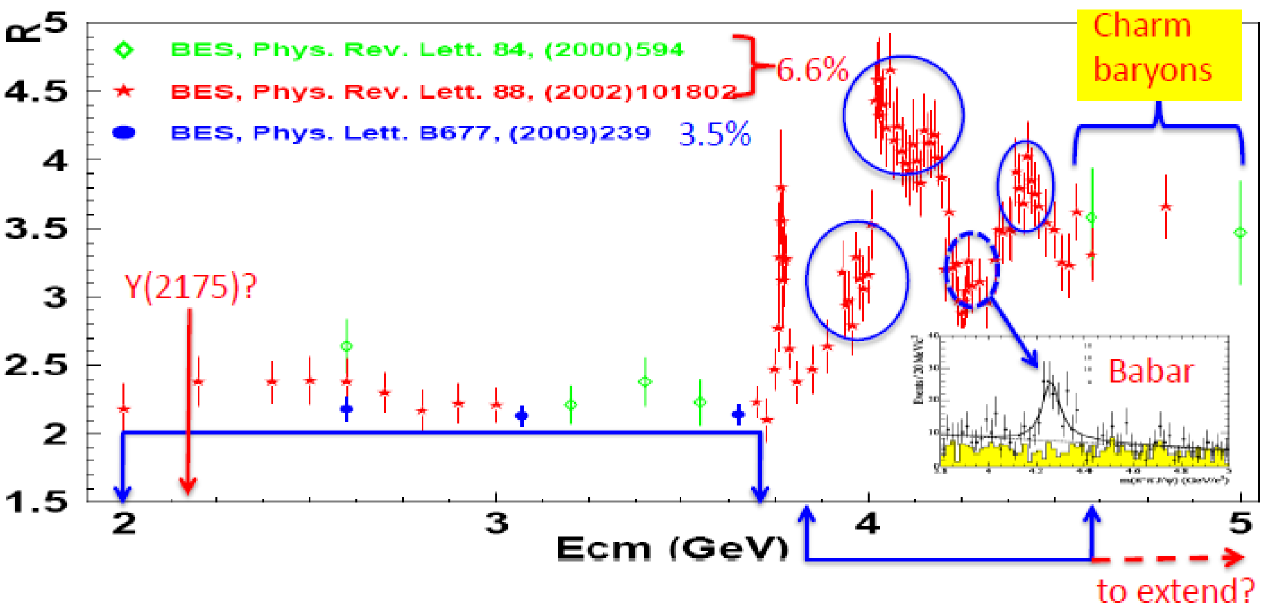
Status of R&QCD data taking

- 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

Data sample for present memo BAM-330

- BOSS version: 6.6.4.p01
- 14 energy points from 2.2324 ~ 3.6710 GeV
- BAM-330 is reviewed in BES Collaboration

	$\sqrt{s}$(GeV)	Run range	$\mathcal{L}_{\text{int.}}$ (pb^{-1})	Purpose
1	2.2324	28624 — 28648	2.645	R scan
2	2.4000	28577 — 28616	3.415	R scan
3	2.8000	28553 — 28575	3.753	R scan
4	3.0500	28312 — 28346	14.893	J/ψ scan
5	3.0600	28347 — 28381	15.040	J/ψ scan
6	3.0800	27147 — 27233,28241 — 28266	31.019	J/ψ scan
7	3.4000	28543 — 28548	1.733	R scan
8	3.5000	33725 — 33733	3.633	off $\psi(3770)$
9	3.5424	24983 — 25015,33734 — 33743	8.693	τ mass scan
10	3.5538	25016 — 25094	5.562	τ mass scan
11	3.5611	25100 — 25141	3.847	τ mass scan
12	3.6002	25143 — 25243	9.502	τ mass scan
13	3.6500	33747 — 33758	4.760	off $\psi(3686)$
14	3.6710	33759 — 33764	4.628	off $\psi(3770)$
15	2.4000	28617 — 28621	$\cdots$	separated-beam
16	3.4000	28549 — 28552	$\cdots$	separated-beam

- Analysis for other data samples will do in another memo.

Status of R value measurement

R value measurement with data

In experiment, R value is 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

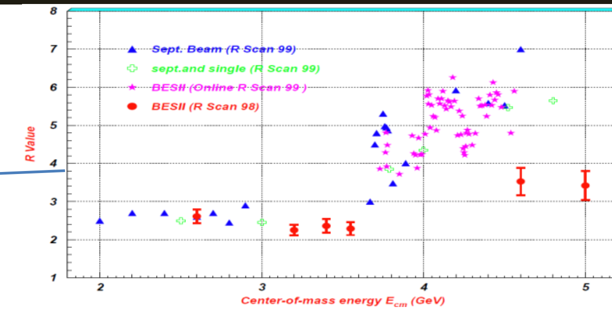
- The largest error term comes from the efficiency.
- We have been confusing on the check, fixing bugs and tuning parameters of generator this year.

The efficiency and ISR factor correction

Observed cross section (no physics):

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

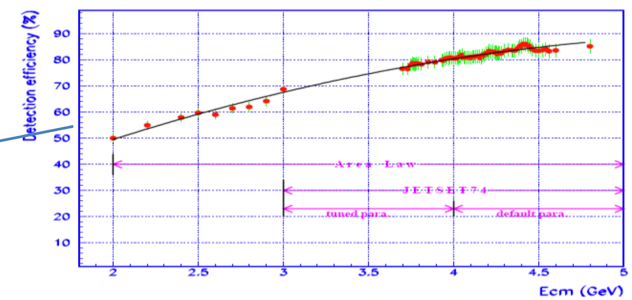
BESII



Efficiency correction:

→ total cross section (physics)

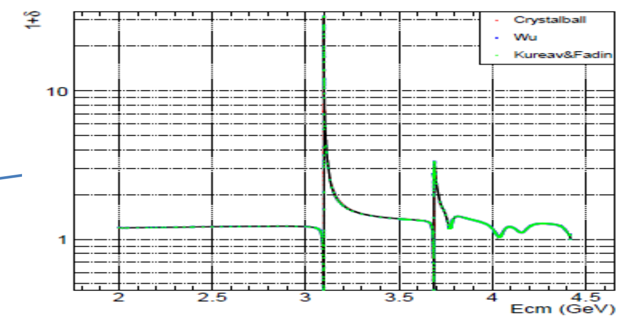
$$\sigma^T = \frac{\sigma^T_{obs}}{\bar{\epsilon}} = \frac{N_{had}}{L\bar{\epsilon}}$$



ISR factor (1+δ) correction:

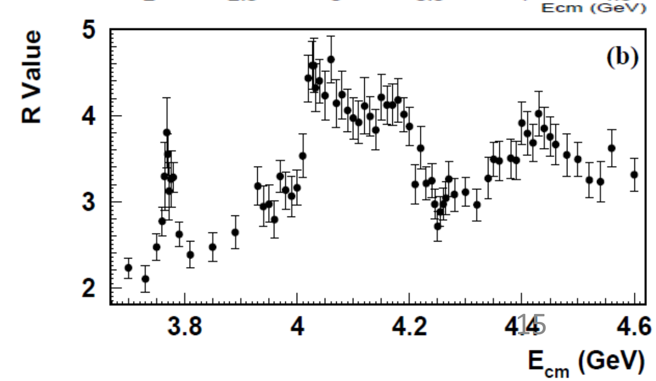
→ Born cross section

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



→ 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: 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:

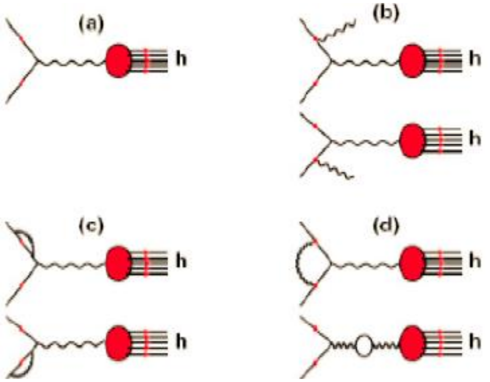
$$\frac{\Delta R}{R} \cong \sqrt{(\frac{\Delta \tilde{N}_{had}}{\tilde{N}_{had}})^2 + (\frac{\Delta L}{L})^2 + (\frac{\Delta \epsilon_{trg}}{\epsilon_{trg}})^2 + (\frac{\Delta(1+\delta)}{(1+\delta)})^2}$$

- final goal $\Delta R/R$ ~2.5–3.0%.
- check generator LUARLW, fix bugs, tuning parameters, in progress
- 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

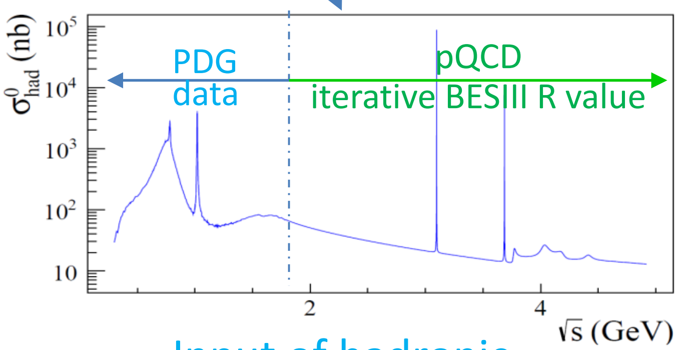
References:

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



Input of hadronic Born cross section

- ISR error

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

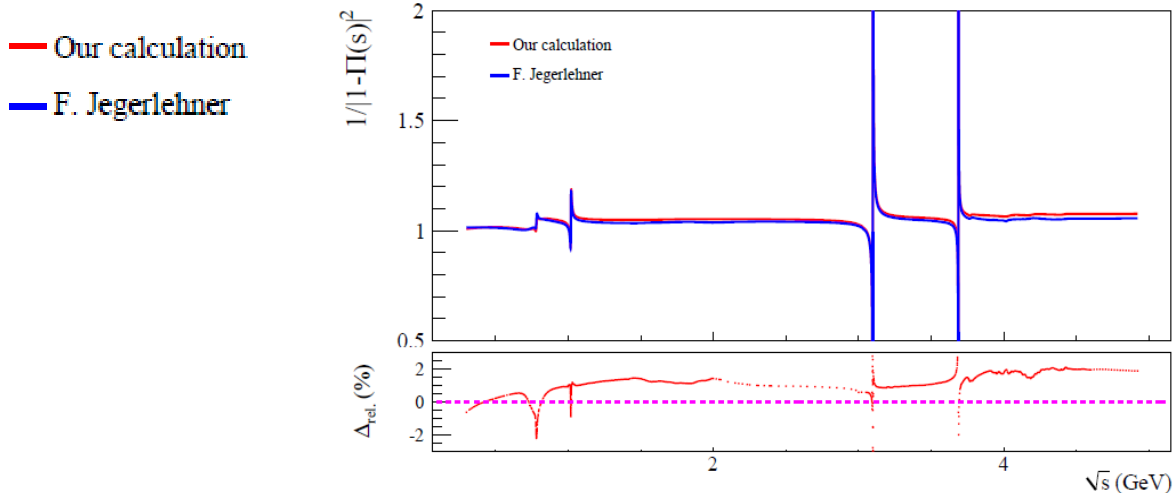
② $\sigma^0(s) \pm \Delta_\sigma$ experimental & pQCD errors $\leq 1\%$

↓

$\Delta(1+\delta)$

Vacuum polarization correction

- Two schemes are compared



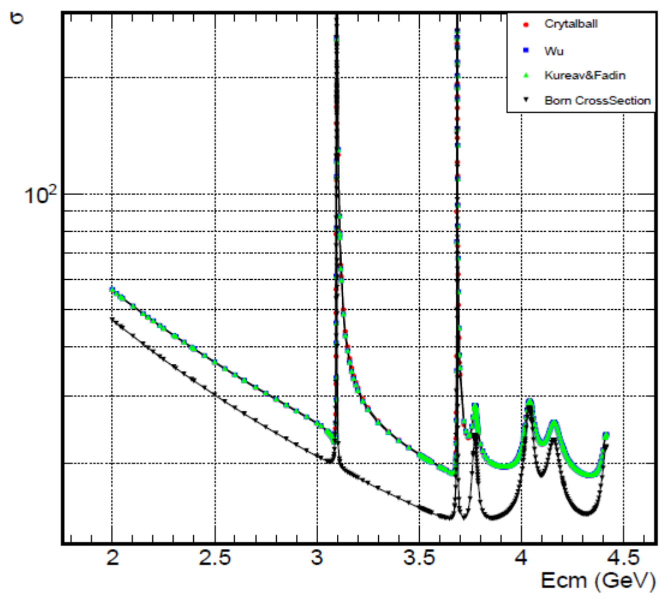
- The calculated ISR correction factors with different VP factor

$\sqrt{s}$ (GeV)	LUARLW $1+\delta$	F. Jegerlehner $1+\delta$	Δ_{rel} (%)
2.2324	1.2142	1.2021	1.00
2.4000	1.2225	1.2112	0.92
2.8000	1.2355	1.2250	0.85
3.0500	1.2075	1.1997	0.65
3.0600	1.1970	1.1894	0.63
3.0800	1.1363	1.1298	0.57
3.4000	1.3983	1.3867	0.83
3.5000	1.3686	1.3564	0.89
3.5424	1.3594	1.3465	0.94
3.5538	1.3567	1.3436	0.96
3.5611	1.3553	1.3422	0.97
3.6002	1.3472	1.3335	1.02
3.6500	1.3272	1.3116	1.17
3.6710	1.2774	1.2599	1.37

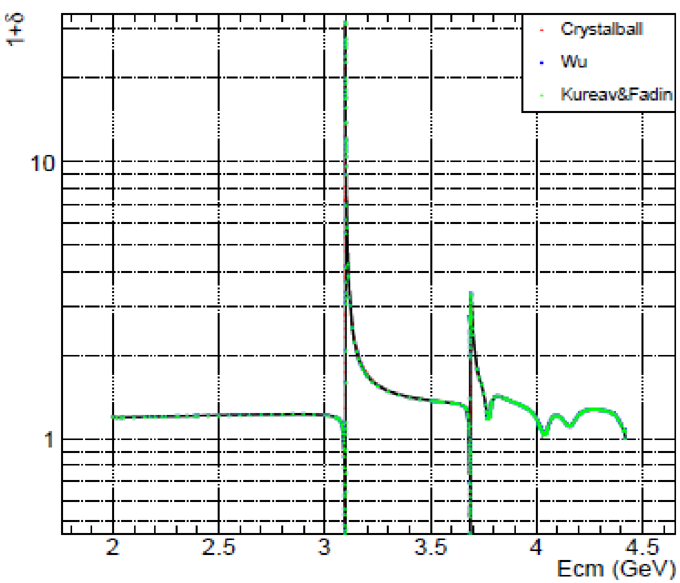
Theoretic cross section and ISR factor

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

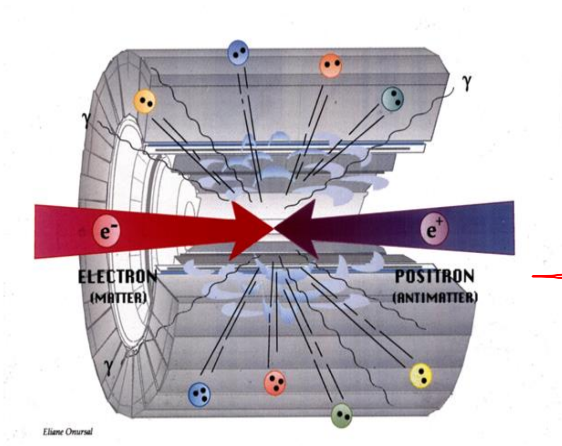


Initial state radiation factor (1+δ)

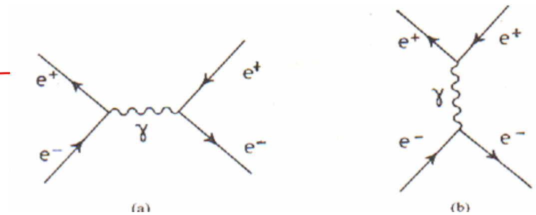
- The FD and SF schemes are compared numerically
- FD and SF are consistent within theoretical accuracy in non narrow resonant region (the case now)

Hadronic generator

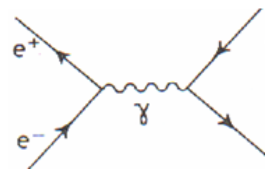
The generators used in R measurement



processes | generators



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

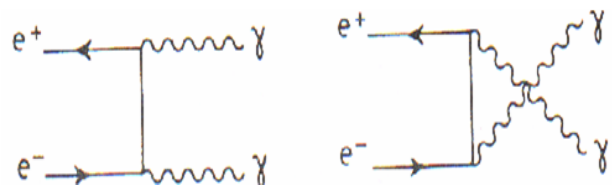


μ^+, τ^+

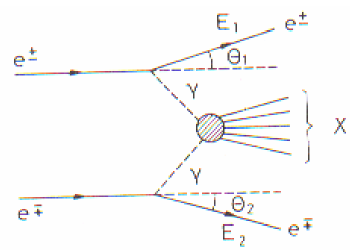
μ^-, τ^-

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

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

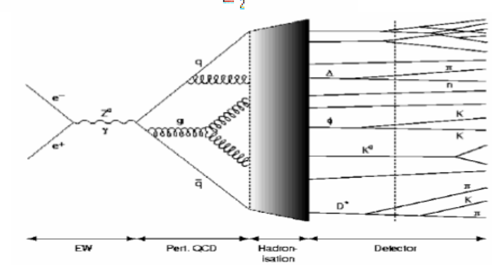


$e^+e^- \to \gamma\gamma$ BABAYAGA (OK)



$e^+e^- \to e^+ e^- X$ TWOPHOTON

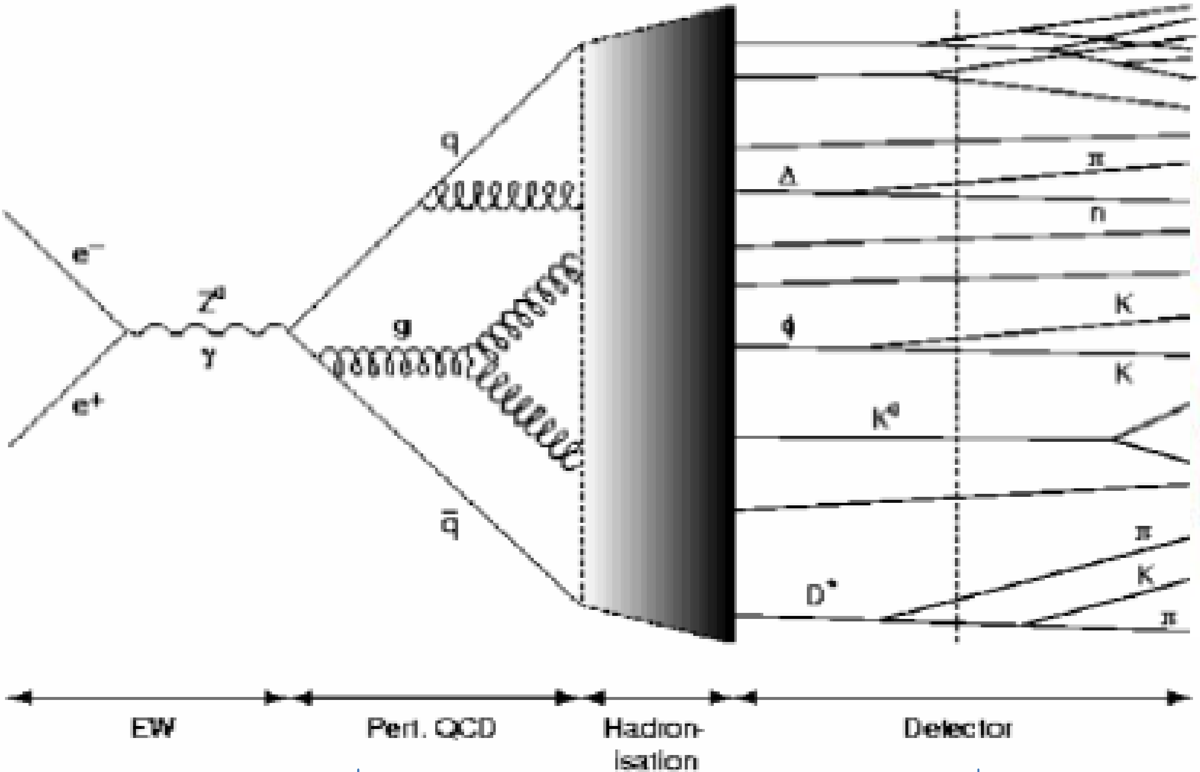
(need check)



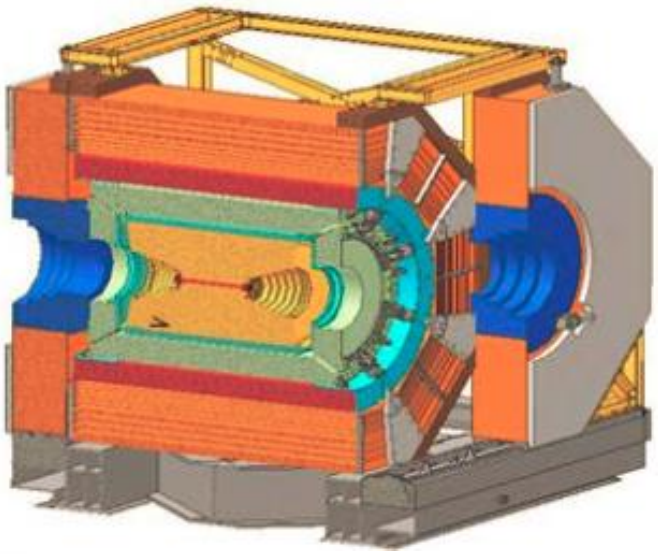
$e^+e^- \to$ hadrons LUARLW

(fixed/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.

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

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

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

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

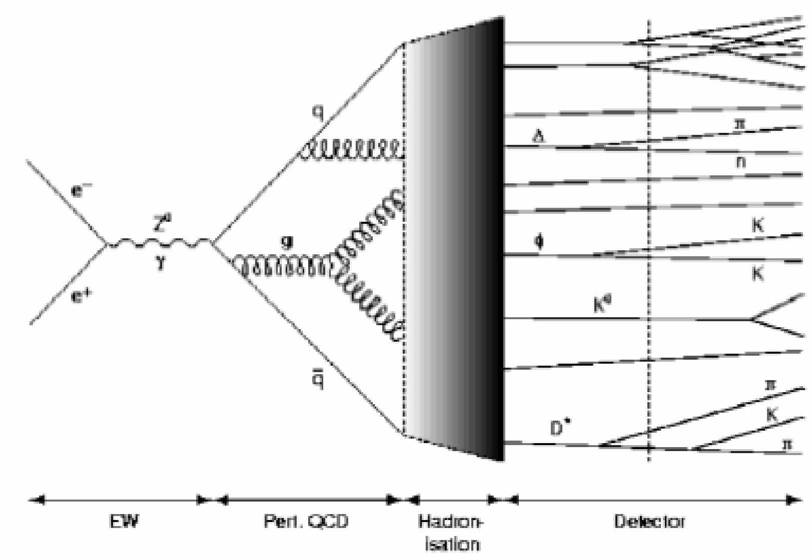
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(3770) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ D^0\bar{D}^0,\ D^+\bar{D}^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string}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

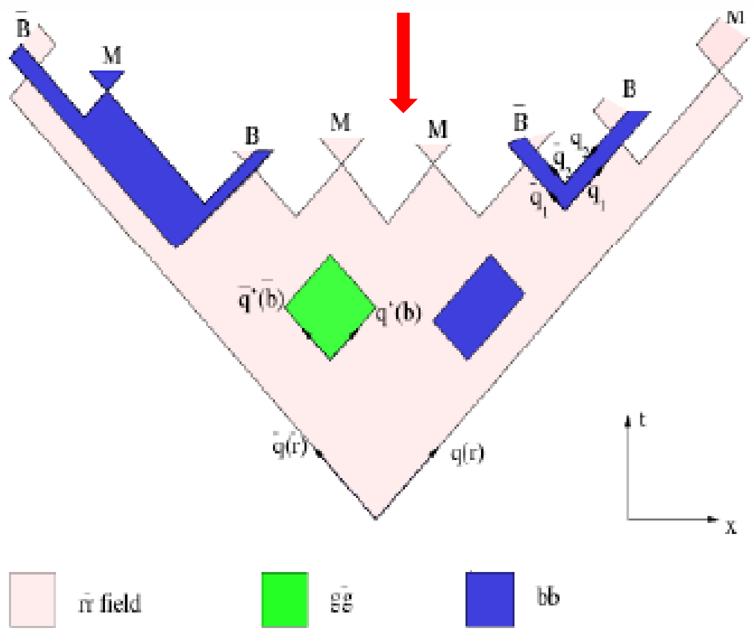
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s; \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*; \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*,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

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

Picture of Lund string fragmentation to hadrons

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





Light cone figure

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

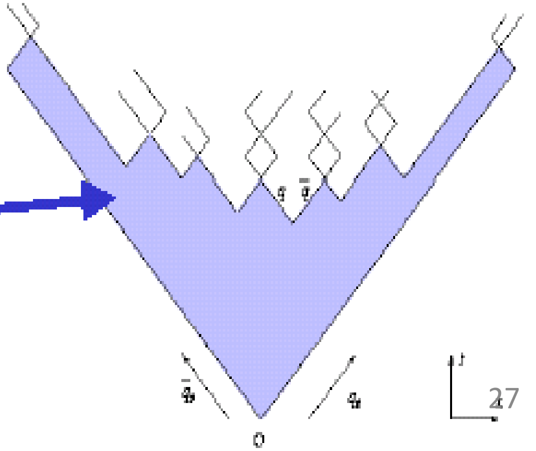
$$d\wp_n(q\bar{q} \to m_1, m_2, \cdots m_n; s) = \cdot(2\pi)^4 \delta(1 - \sum_{j=1}^{n} \frac{m_{\perp j}^2}{s z_j}) \cdot \delta(1 - \sum_{j=1}^{n} z_j) \cdot \delta^{(2)}(\sum_{j=1}^{n} \vec{k}_j) \cdot \overline{\sum} |\hat{\mathcal{T}}_{con}^{(n)f}|^2 d\Phi_n$$

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

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

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

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



Beam energy spread in simulation

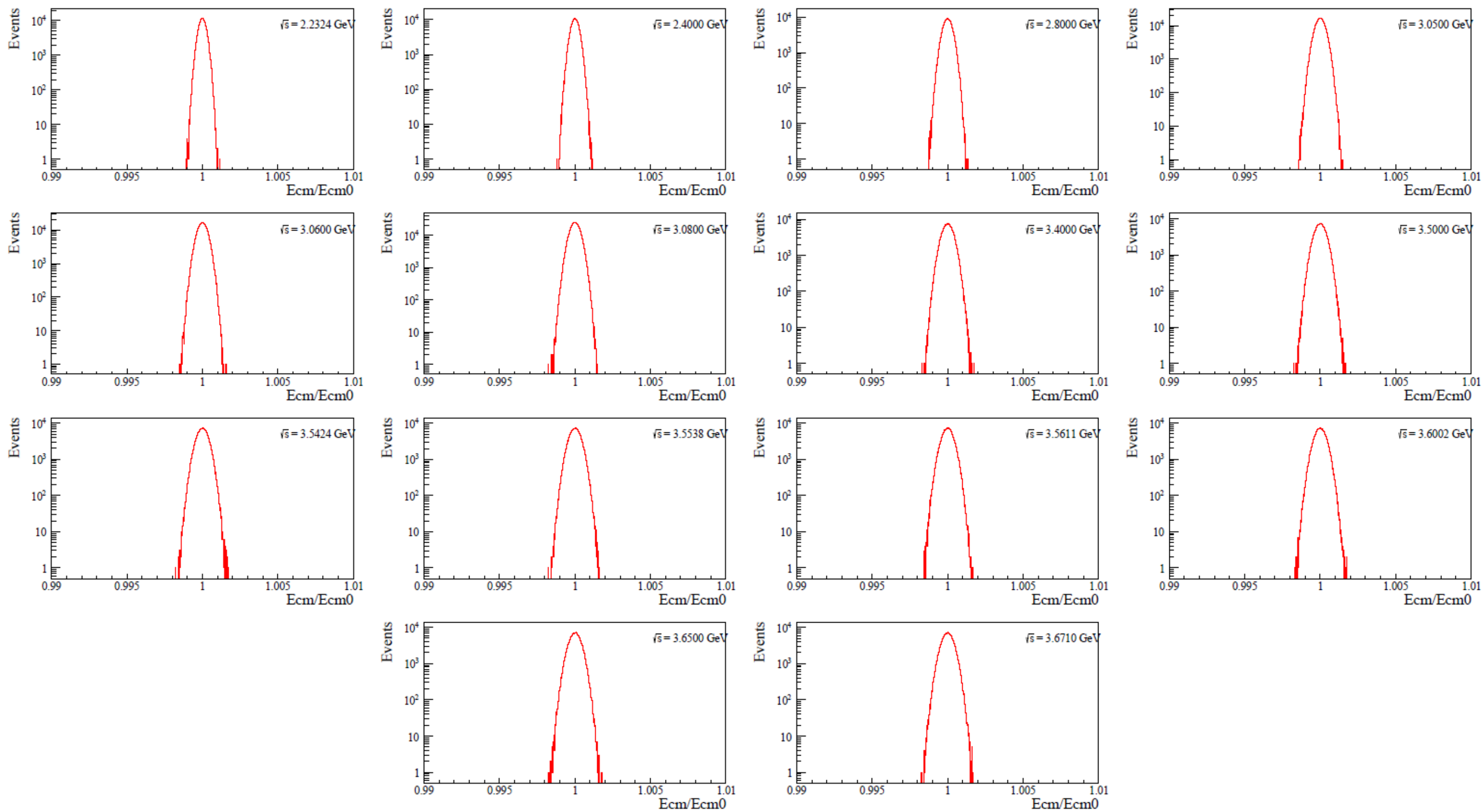
- Gaussian form beam energy spread

$$G(E_{cm}^0 - E_{cm}) = \frac{1}{\sqrt{2\pi}\Delta}\exp[-\frac{(E_{cm}^0 - E_{cm})^2}{2\Delta^2}]$$

E_{cm}^0 nominal energy

E_{cm} real energy

- Total Ecm distribution of event sampling



if $E_{cm} = \sum_i^n E_i$ → then energy is conservative in simulation

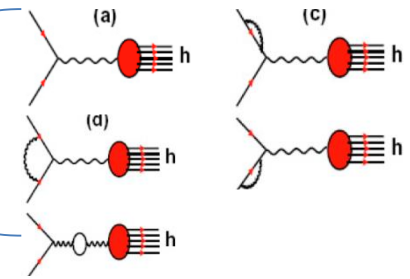
ISR sampling in LUARLW simulation

In LUARLW simulation, the events are classed into two types

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

Weight:

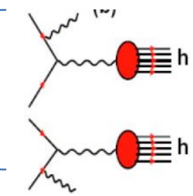
$$\sigma^{VSB} = \sigma^0(s)[1 + \beta \ln k_0 + \delta_{AR}]$$



② real radiation: hard bremsstrahlung events.

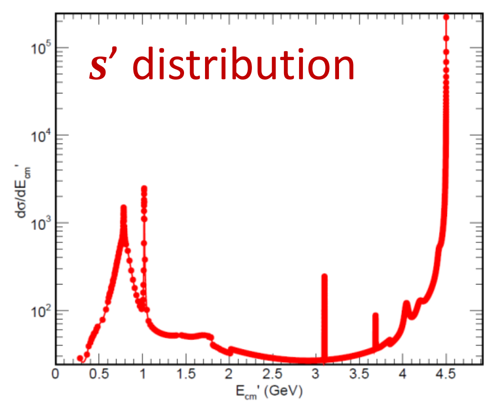
Weight:

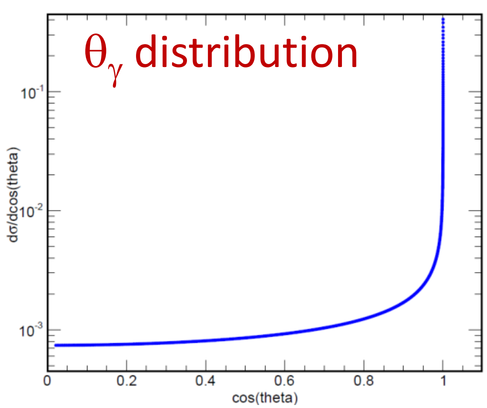
$$\sigma^{HB} = \int_{k_0}^{k_m} dk \frac{\partial \sigma^{HB}}{\partial k}$$



The energy and polar angle distribution of real emission photon

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

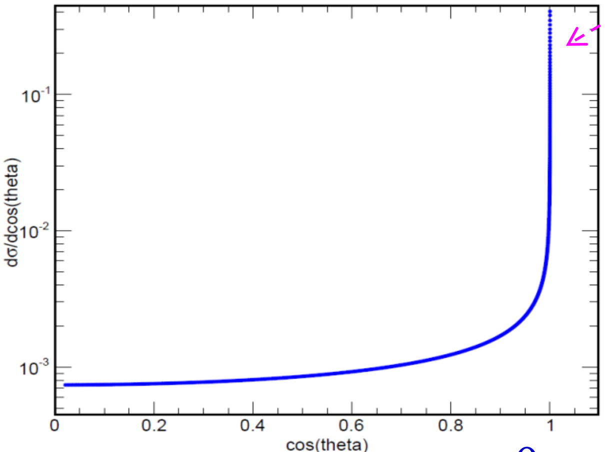




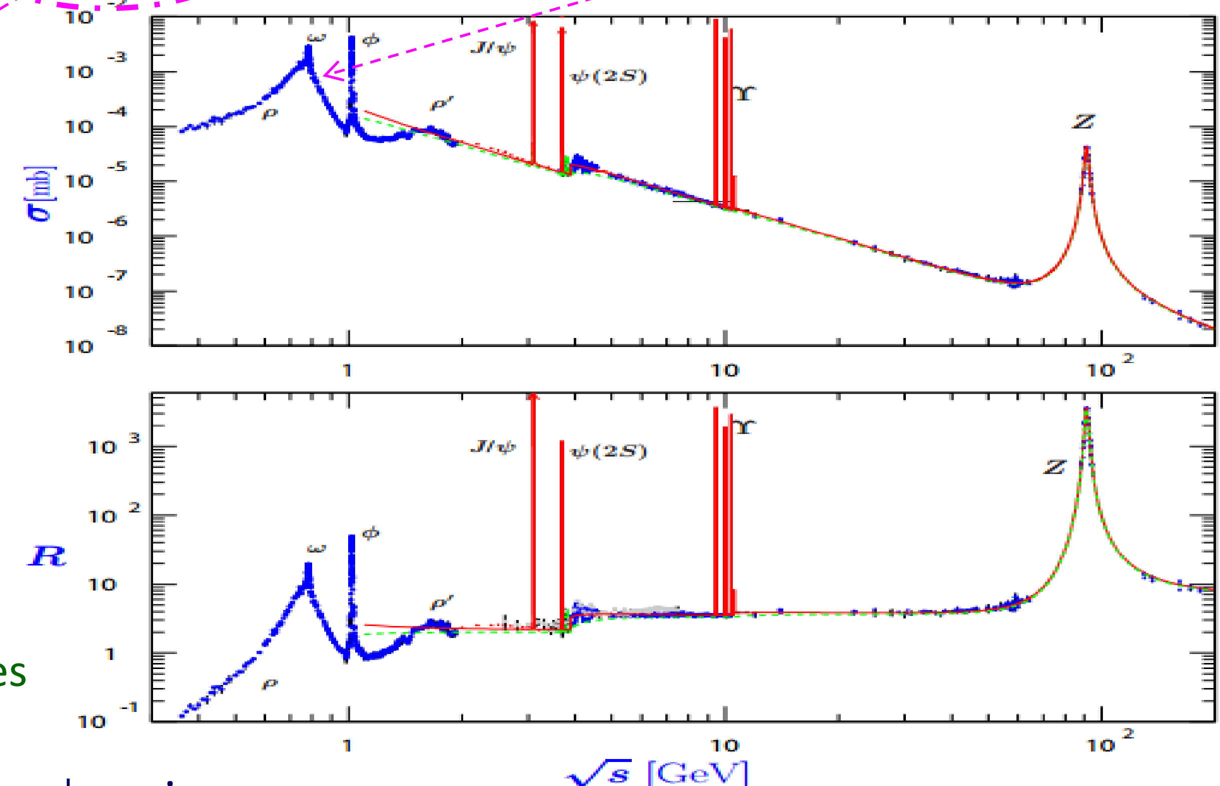
Bremsstrahlung in ρ, ϕ ,ω region important

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

NPB27(1971)381



$\cos\theta_\gamma$



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

Below 1.8 GeV ⇒ PDG values

Above 1.8 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

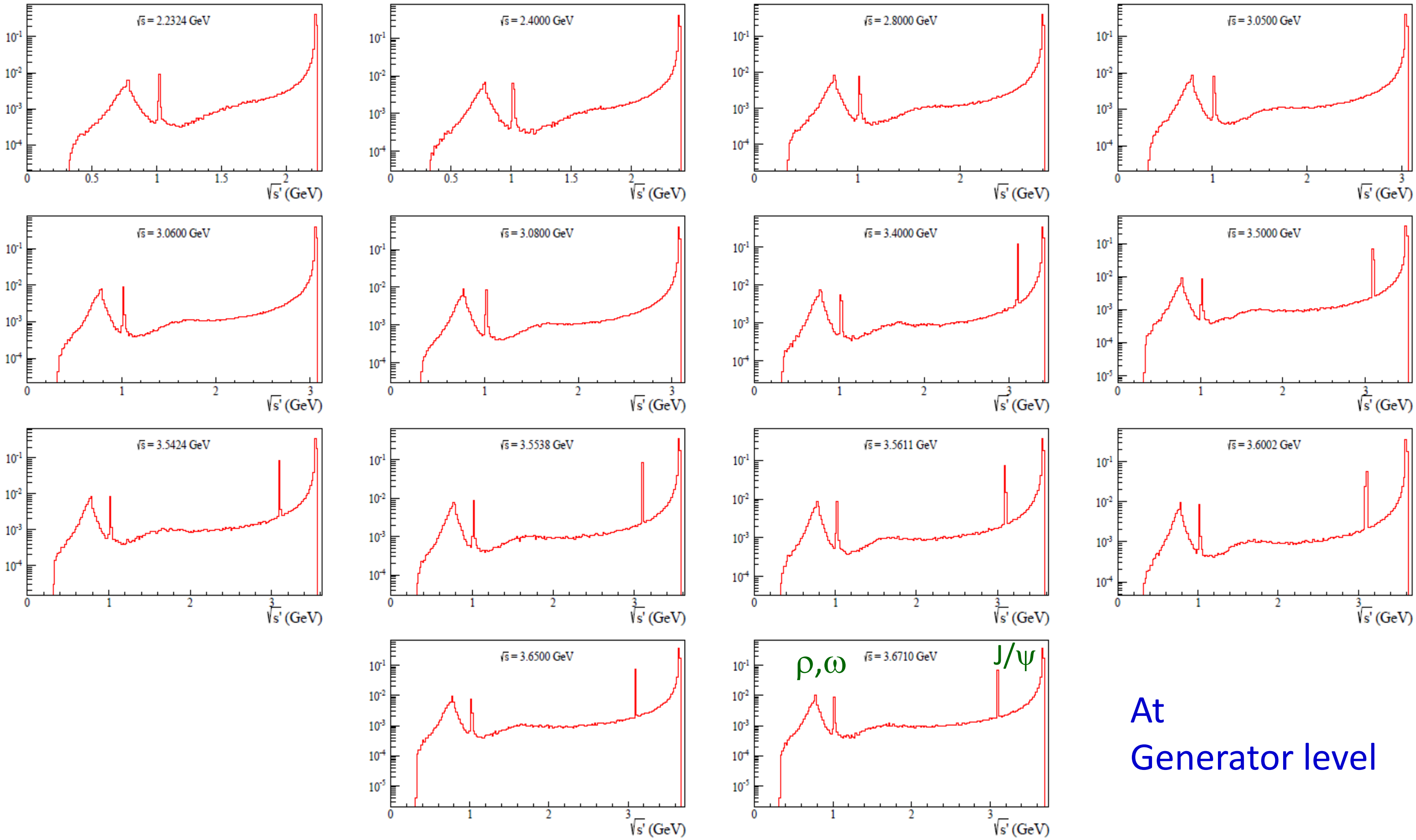
Effective hadronic E'_{cm} after bremsstrahlung

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

MC sampling

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

$\sqrt{s'}$



At
Generator level

Examples of event production

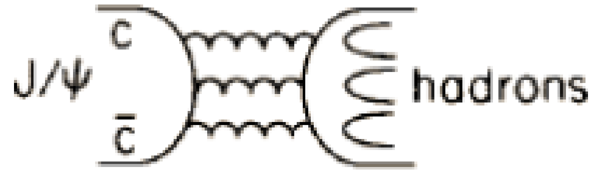
$$e^+e^- \to \gamma\ string \to \gamma + handrons$$

	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

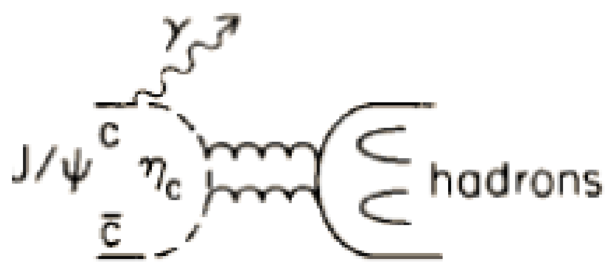
Hadronic decay via 3-gluons



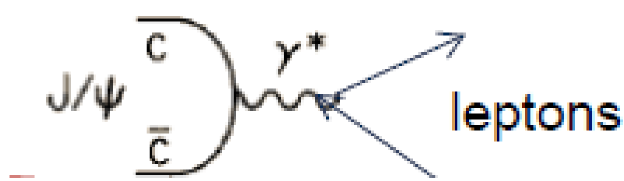
Electromagnetic decay to hadrons

Radiative decay into hadrons

Radiative M1 transition to η_c



Electromagnetic decay to leptons



All five decay modes have been used in LUARLW simulation

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 (c_0 – γ)

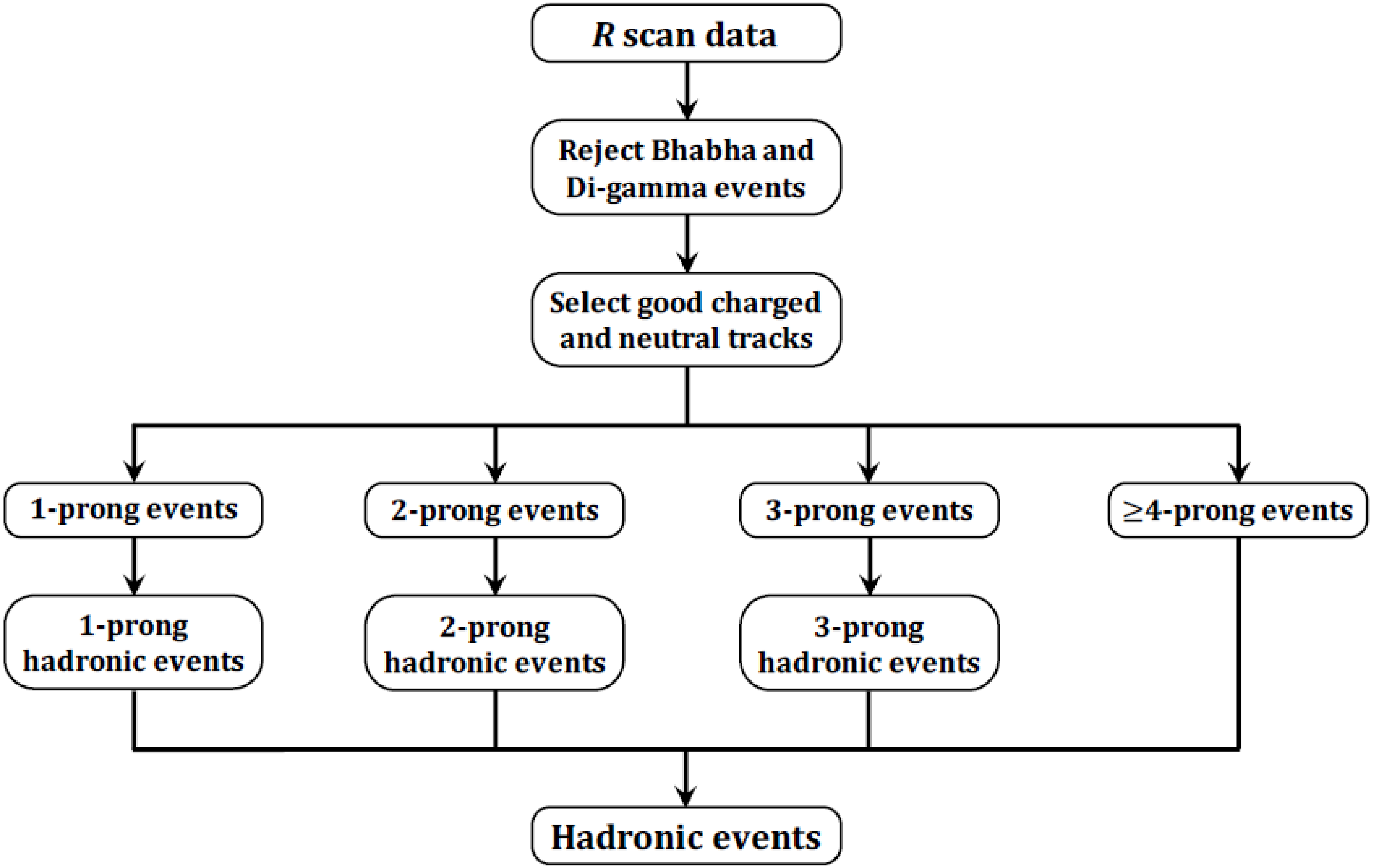
For Particle ratios (PARJ(01) – PARJ(17))

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

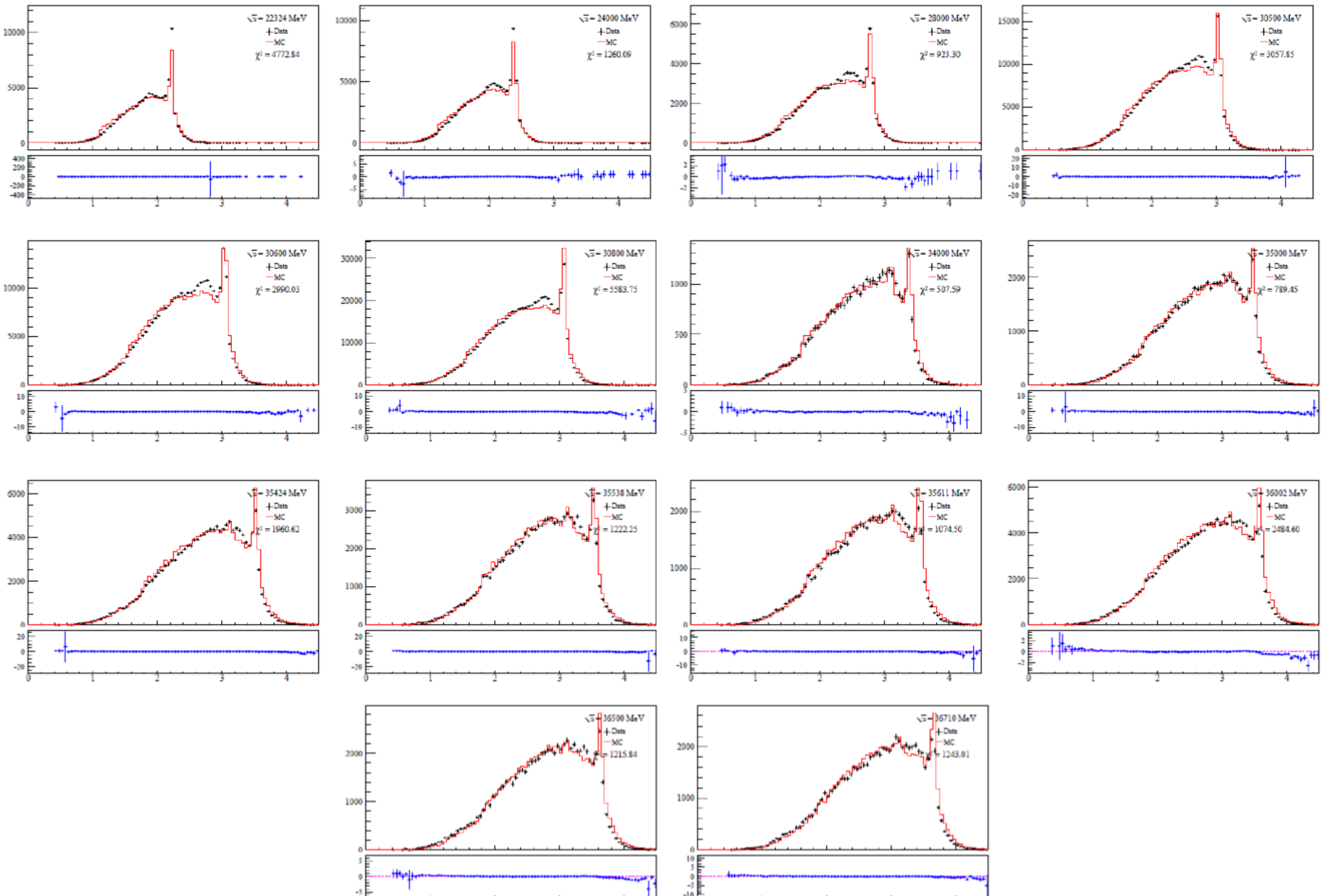
Event selection criteria



Criteria
- Track level
- Event level

Total energy of charged and neutral tracks

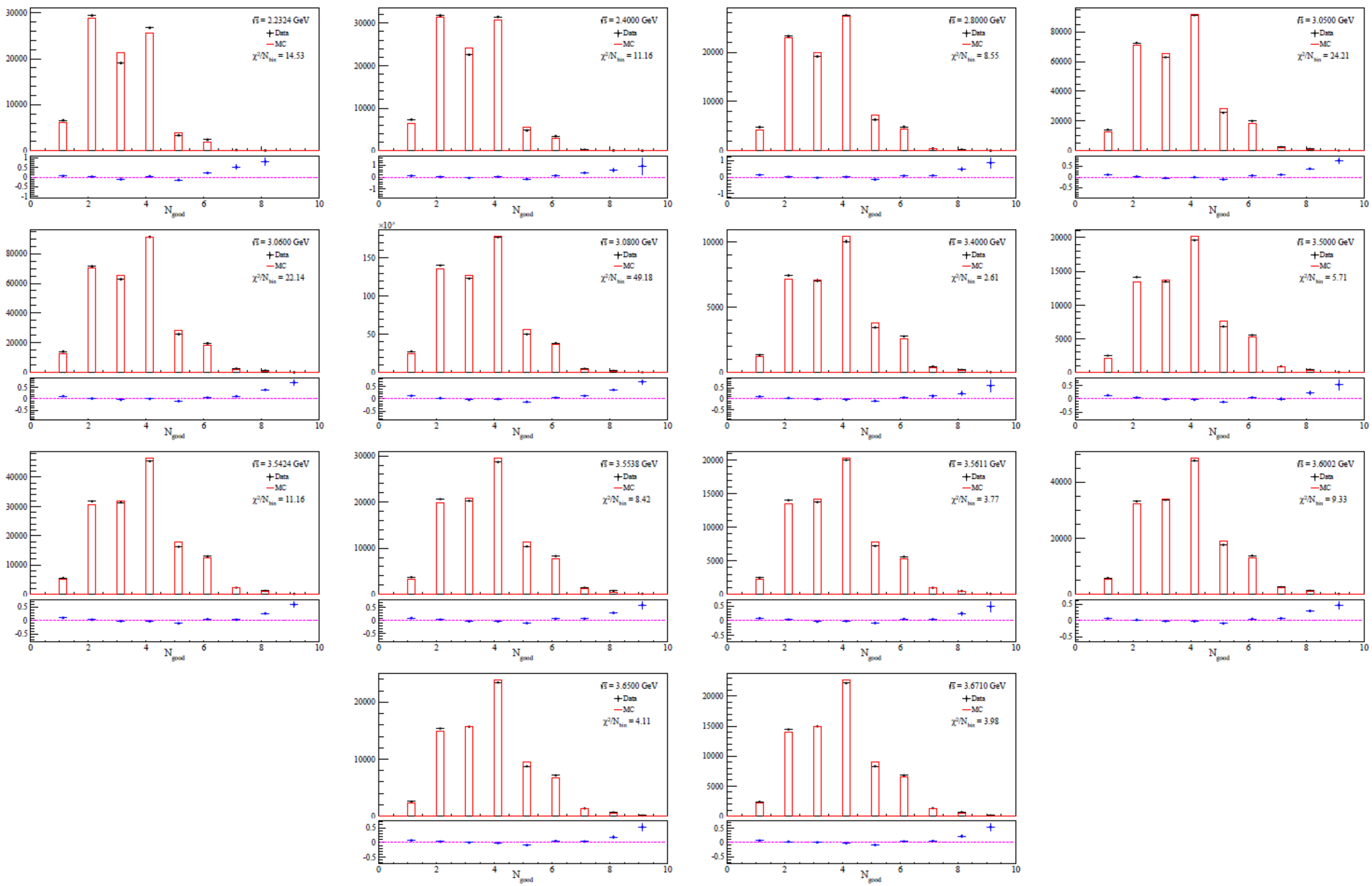
- Neutral tracks: deposit energy in EMC
- Charged tracks: assumed as pion, p_i the momentum in MDC, $E_{sum} = \Sigma\sqrt{p_i^2 + m_\pi^2}$



Multiplicity of charged particle

Simulated by LUARLW and GEANT4

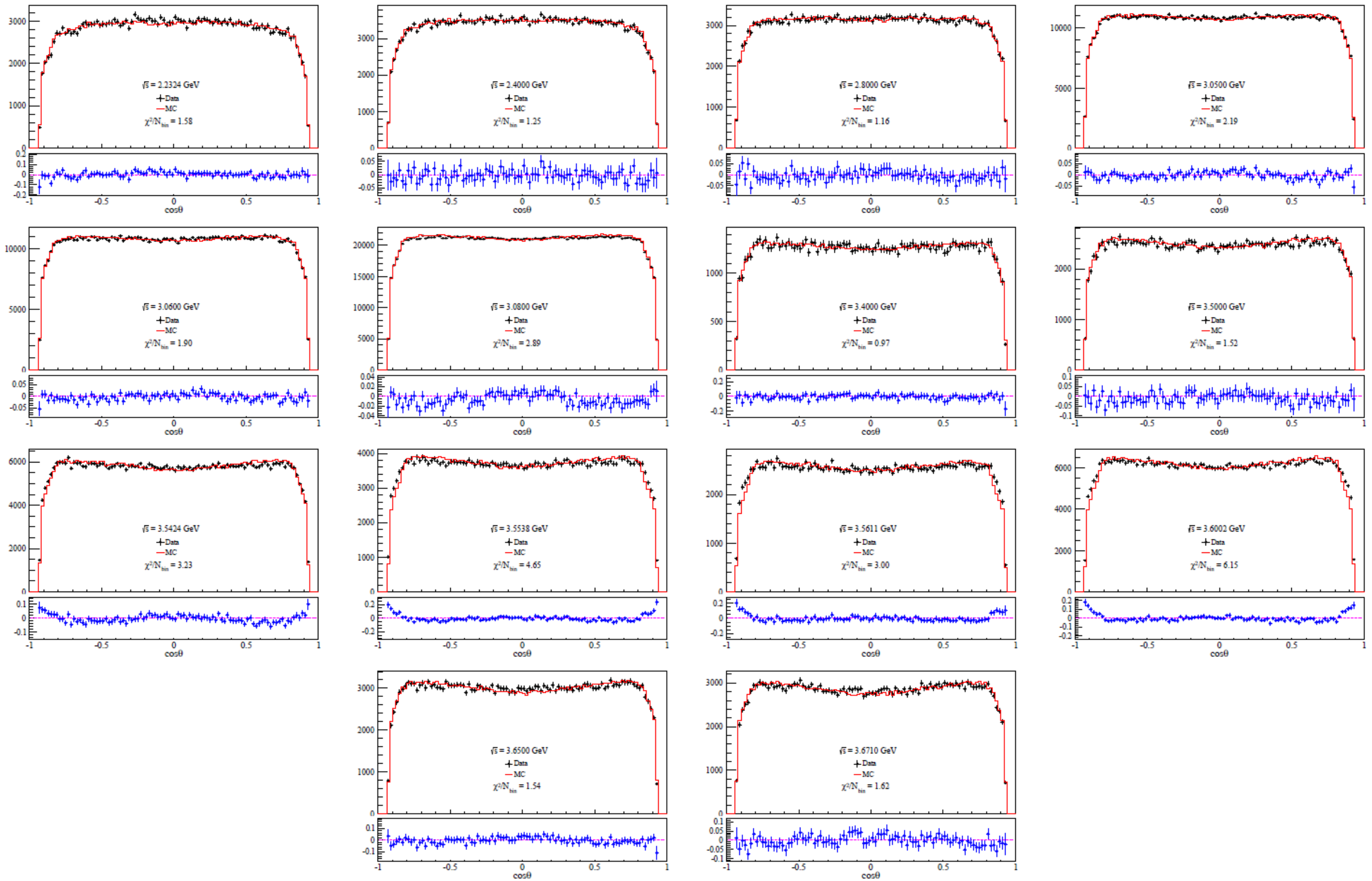
- At detector level
- + data, – MC



cosθ of charged particle

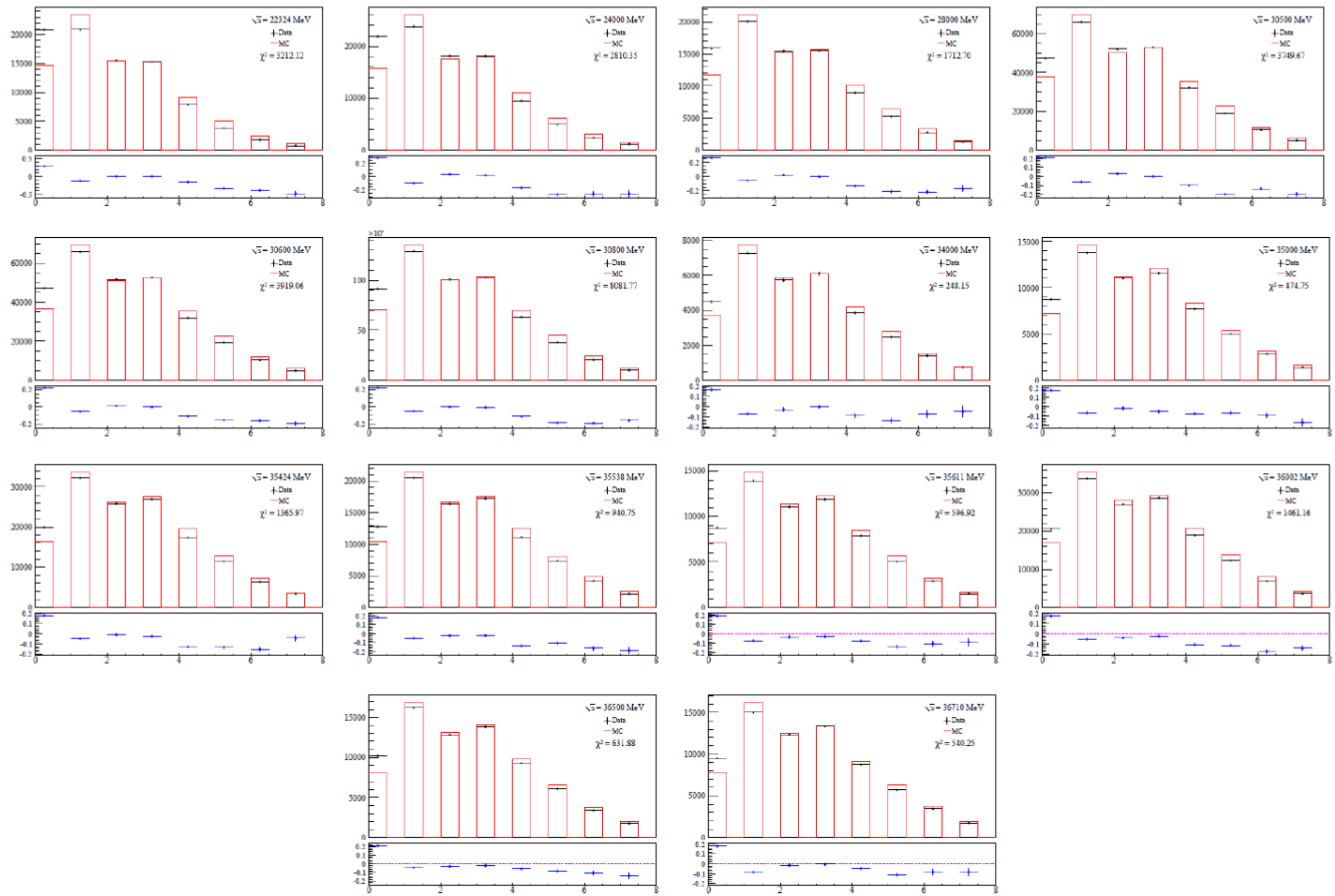
Simulated by LUARLW and GEANT4

- At detector level
- + data, – MC



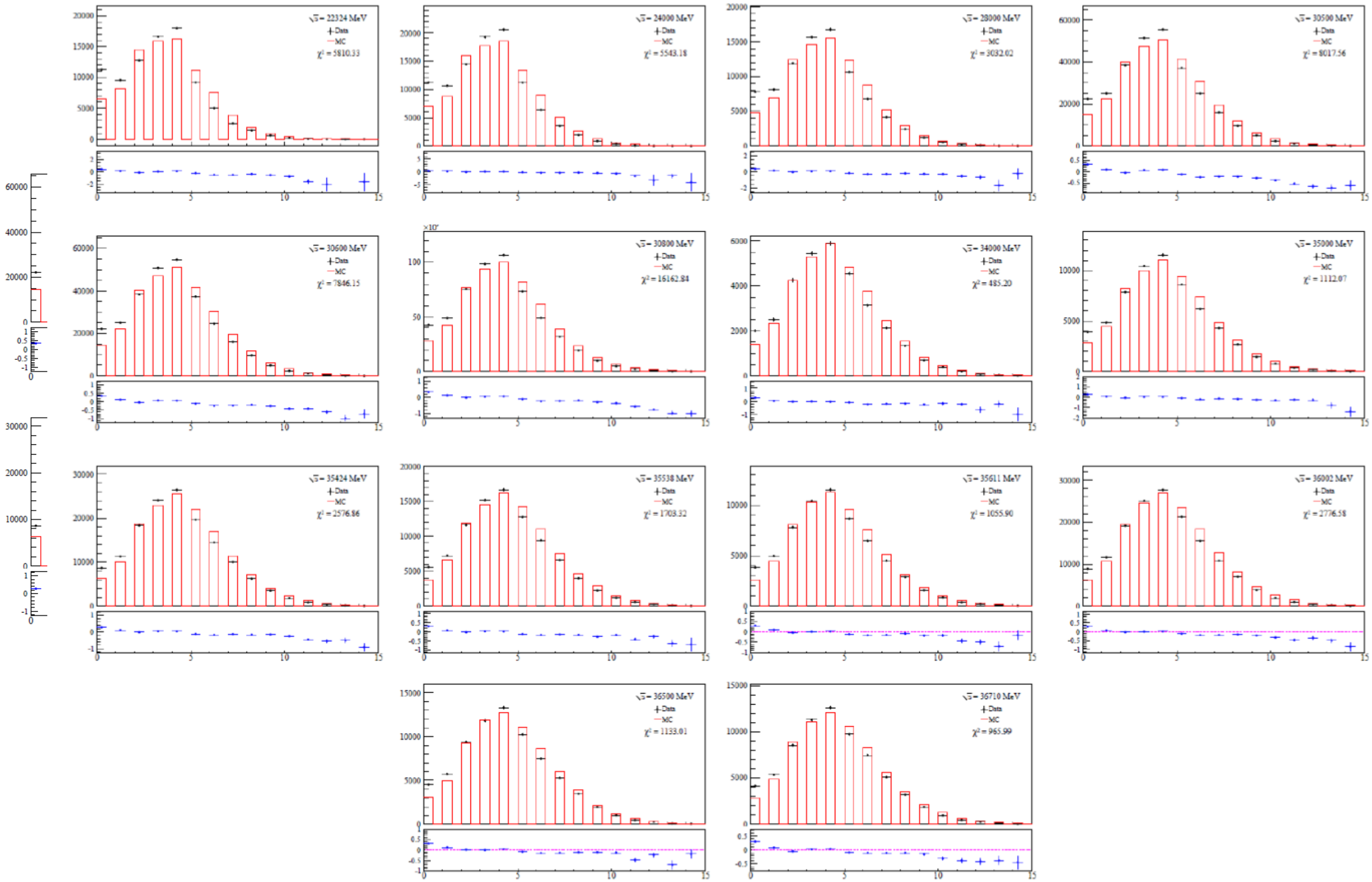
Multiplicity of π^0

Simulated by LUARLW and GEANT4



Multiplicity of photon

Simulated by LUARLW and GEANT4



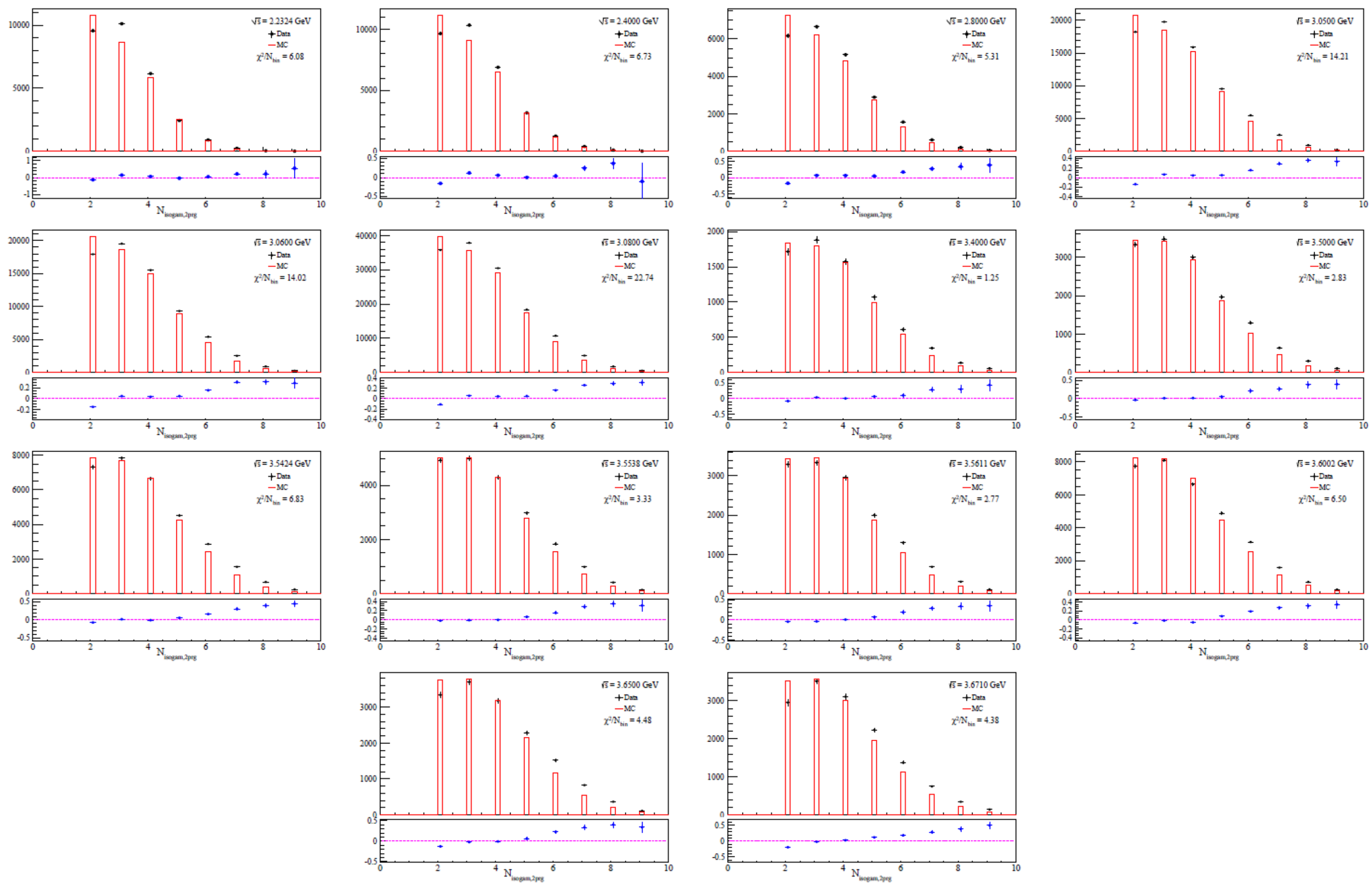
Most of photons come from decay $\pi^0 \rightarrow \gamma\gamma$

Isolated-photon for 2-prong event

For two-prong hadronic event, the isolated photon criteria is used

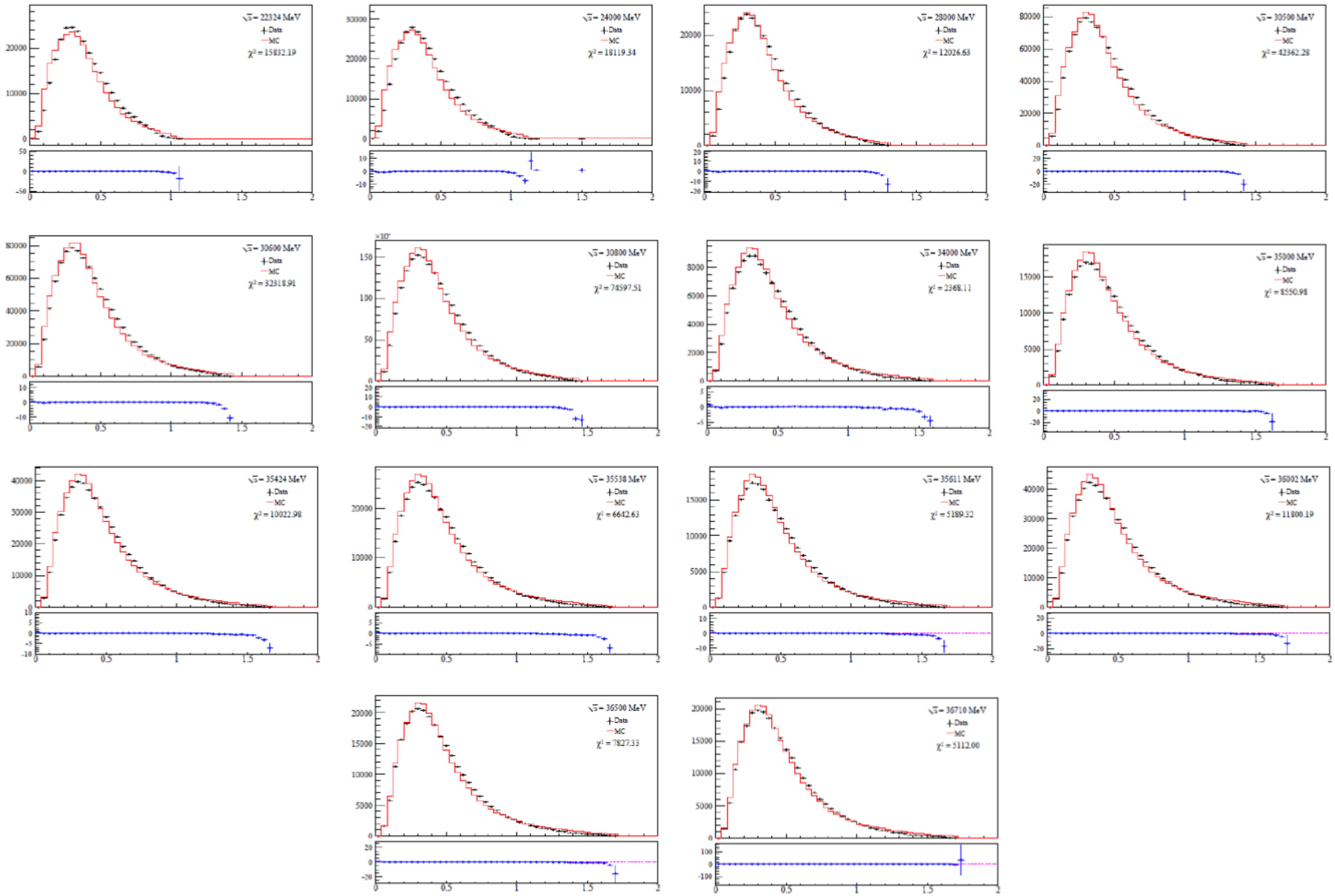
- $N_{isolated\ \gamma} \geq 2$, the angle between γ and charged track larger than $15°$
- Other criteria

Simulated by LUARLW and GEANT4



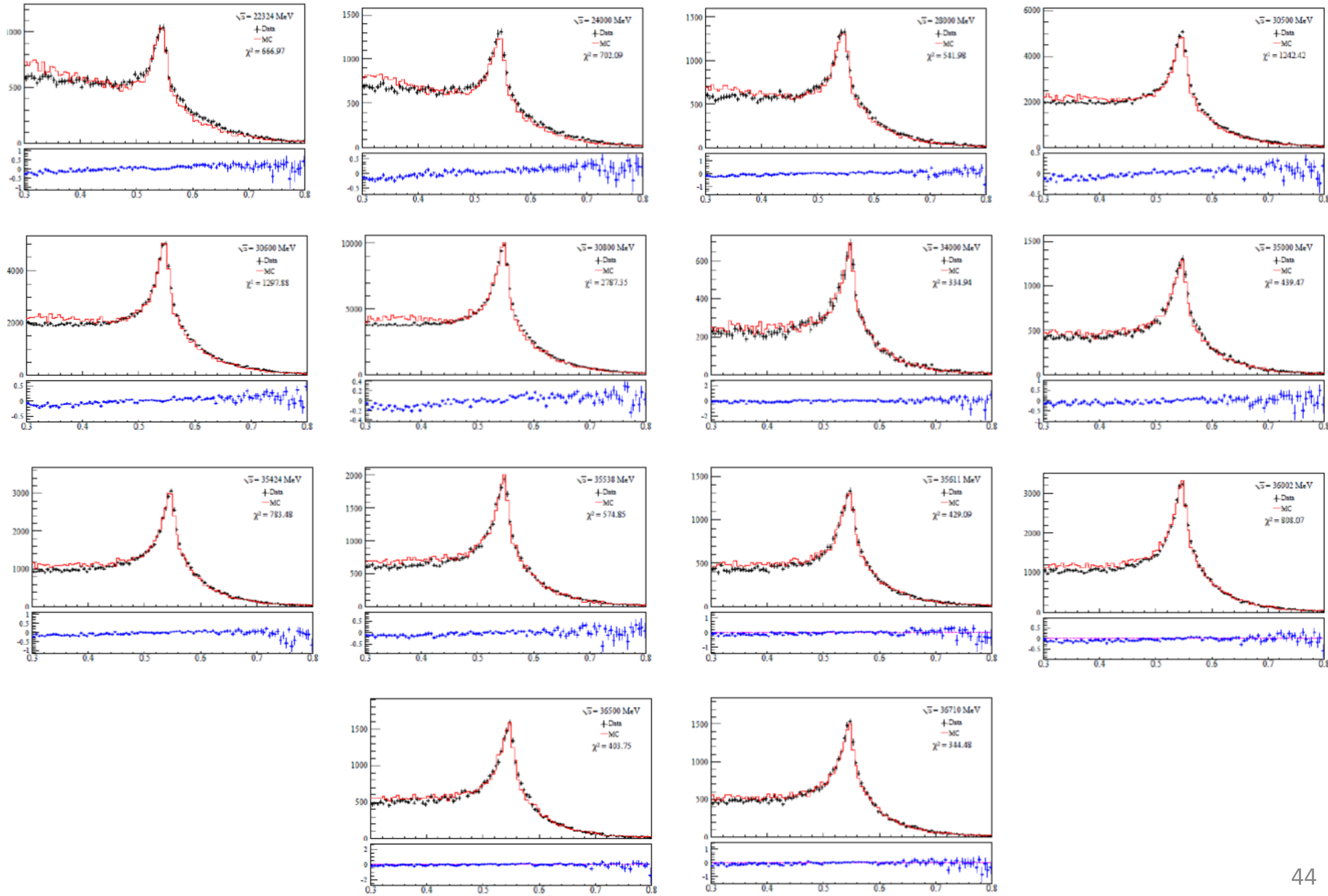
Momentum of charged tracks

Simulated by LUARLW and GEANT4



Invariant mass of η→γγ

Simulated by LUARLW and GEANT4



How to estimate the efficiency uncertainty

Synthesize two factors:

Factor A :

- Hadronic efficiency $\bar{\epsilon}_{hd} = \frac{N^{MC}_{obs}}{N^{MC}_{gen}}$
- Total number of hadronic event $\tilde{N}_{had} = \frac{N_{had}}{\bar{\epsilon}_{had}}$
- Inconsistency between data and MC $\rightarrow$ MC uncertainty

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

Change cut conditions

But that could not be all, it should consider following factor

Factor B:

- Adopt two or more reasonable generators.
- Compare their differences of hadromic efficiency.
- Now, LUARLW, Hybrid generator or PYTHIA are considered.

Generator/MC systematic errors

- Selection efficiency for hadronic events

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

- 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

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

Consideration:

★ event selection $\Rightarrow$ cuts

★ cuts $\Rightarrow$ errors

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

Hybrid-generator

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

HYBRID

PHOKHARA ⊕ ConExc ⊕ LUARLW

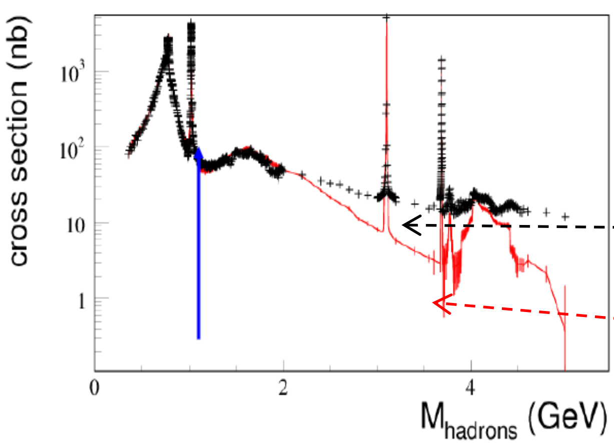
For measured exclusive channels
PHOKHARA: phenomenological model
ConExc : experience/data model

For unmeasured inclusive channels
Lund area law

Optimized 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,

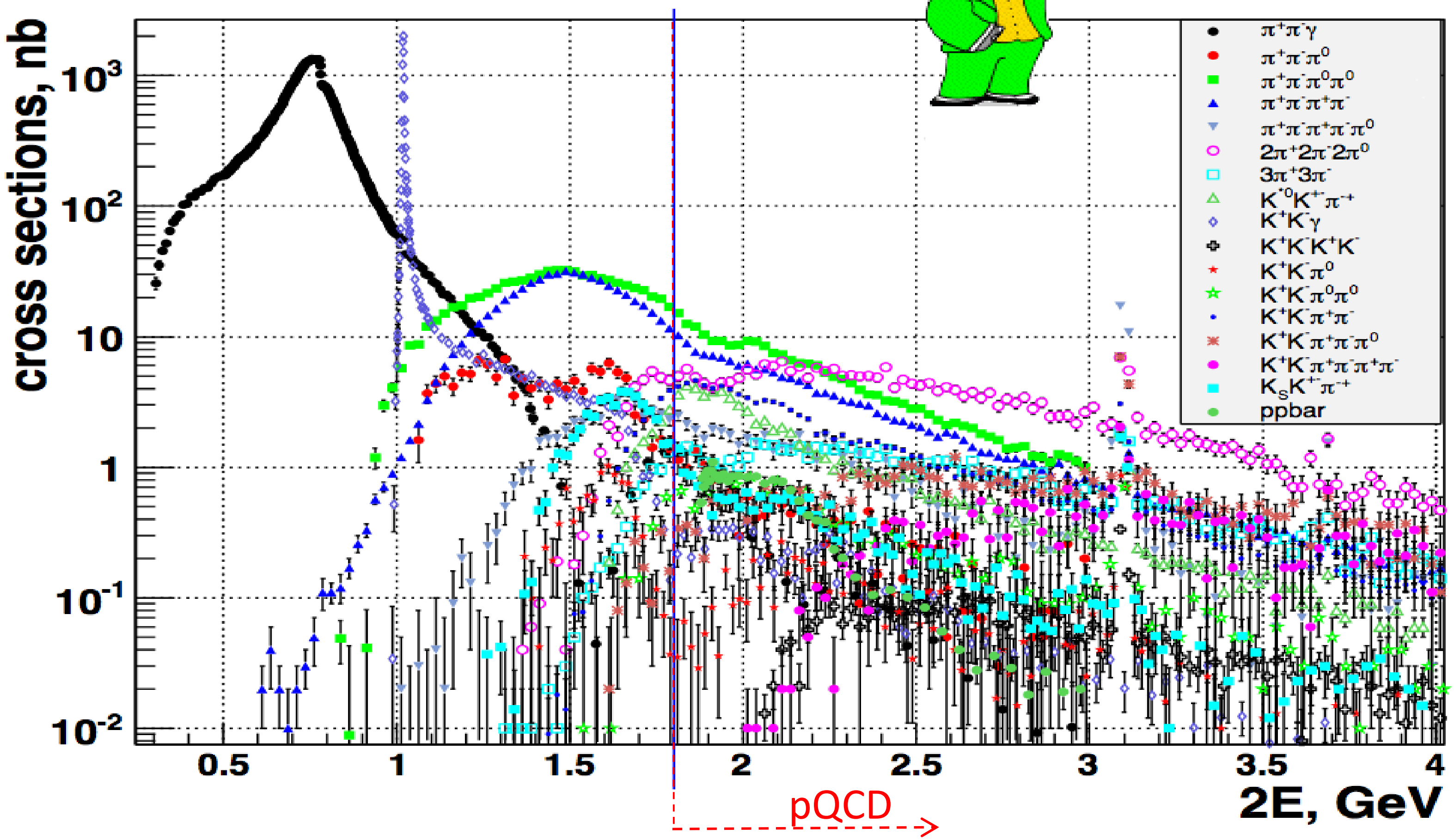
+ sum of the cross section ever measured exclusive channels

Unknown channels, simulate by LUARLW

Known channels, simulate by exclusive method

Exclusive channels ever measured

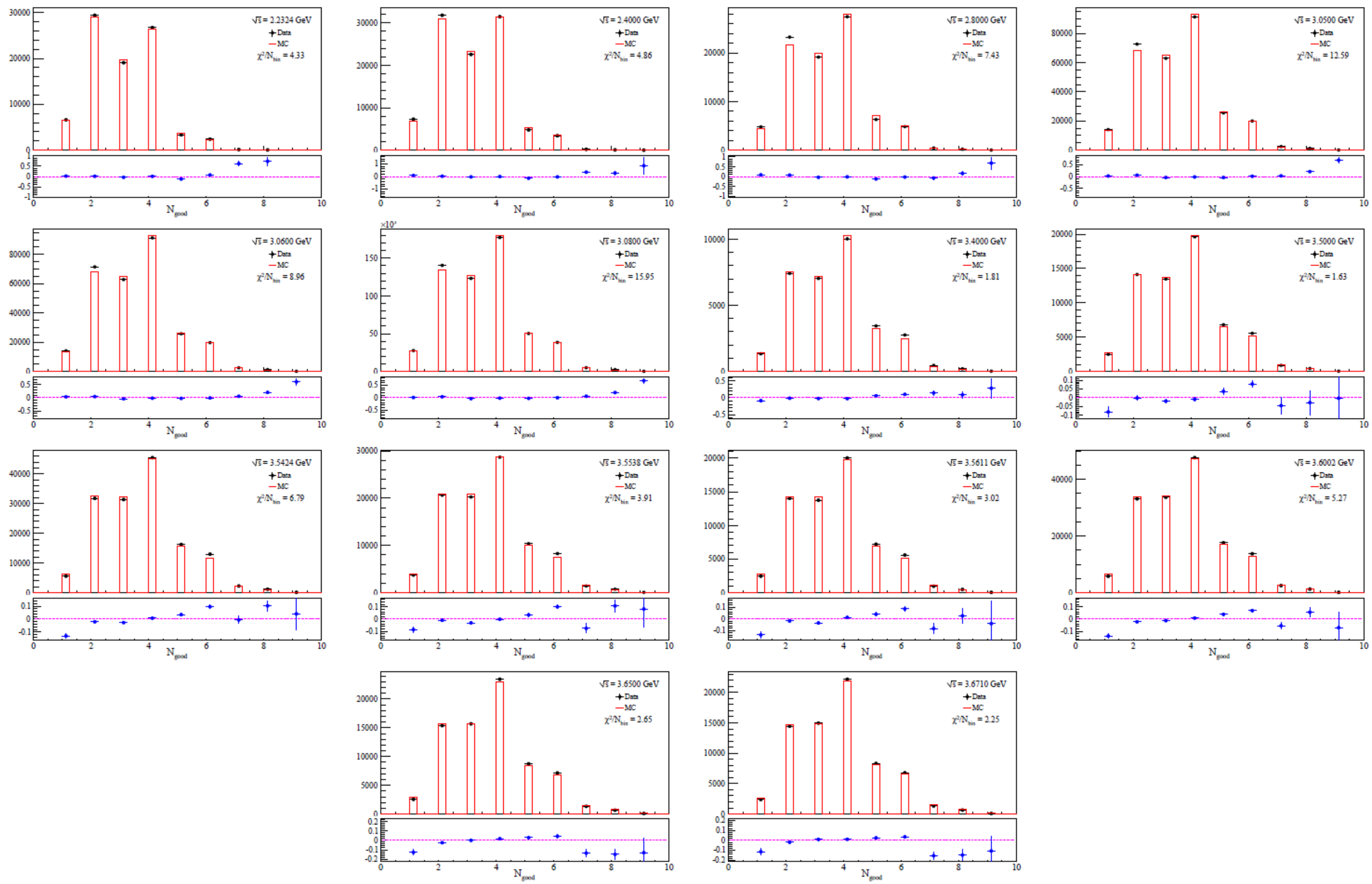
Some exclusive channels measured with ISR return method



- Study ISR return events
- Compare the simulation of LUARLW and the data

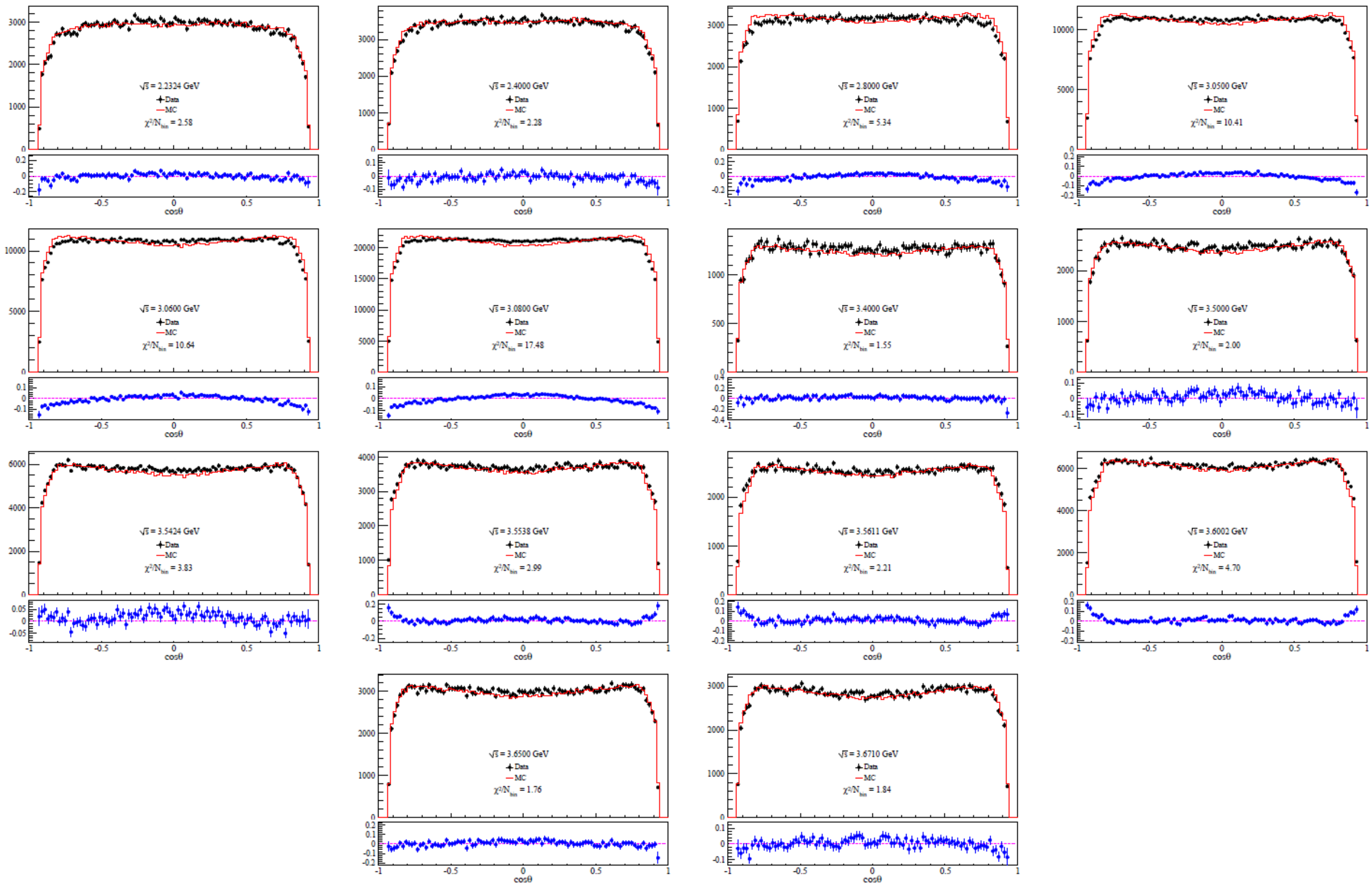
Multiplicity of charged particle

Simulated by Hybrid-generator and GEANT4



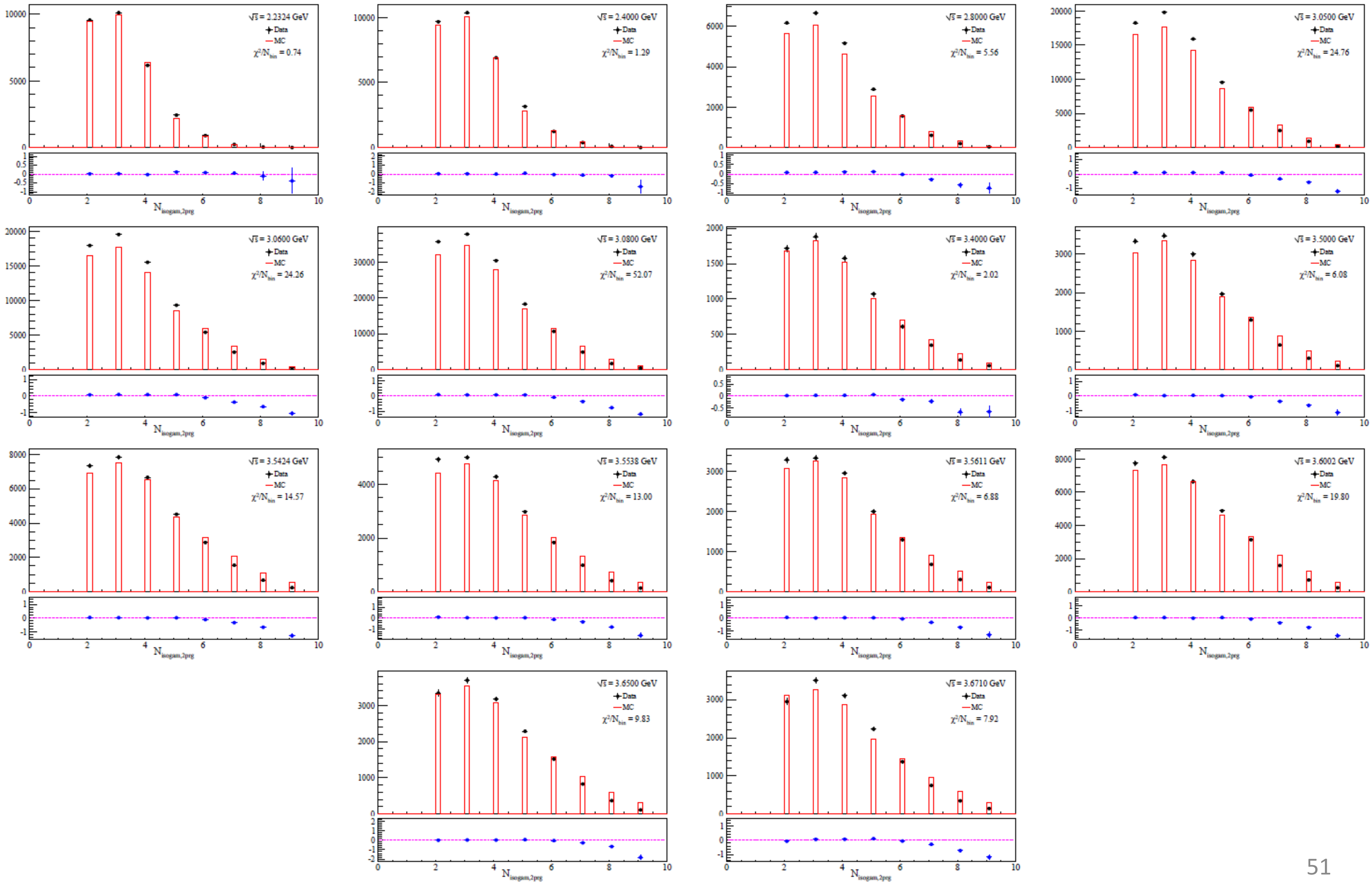
cosθ of charged particle

Simulated by Hybrid-generator and GEANT4



Isolated-photon for 2-prong event

Simulated by Hybrid-generator and GEANT4



Comparison of data and mixing generator

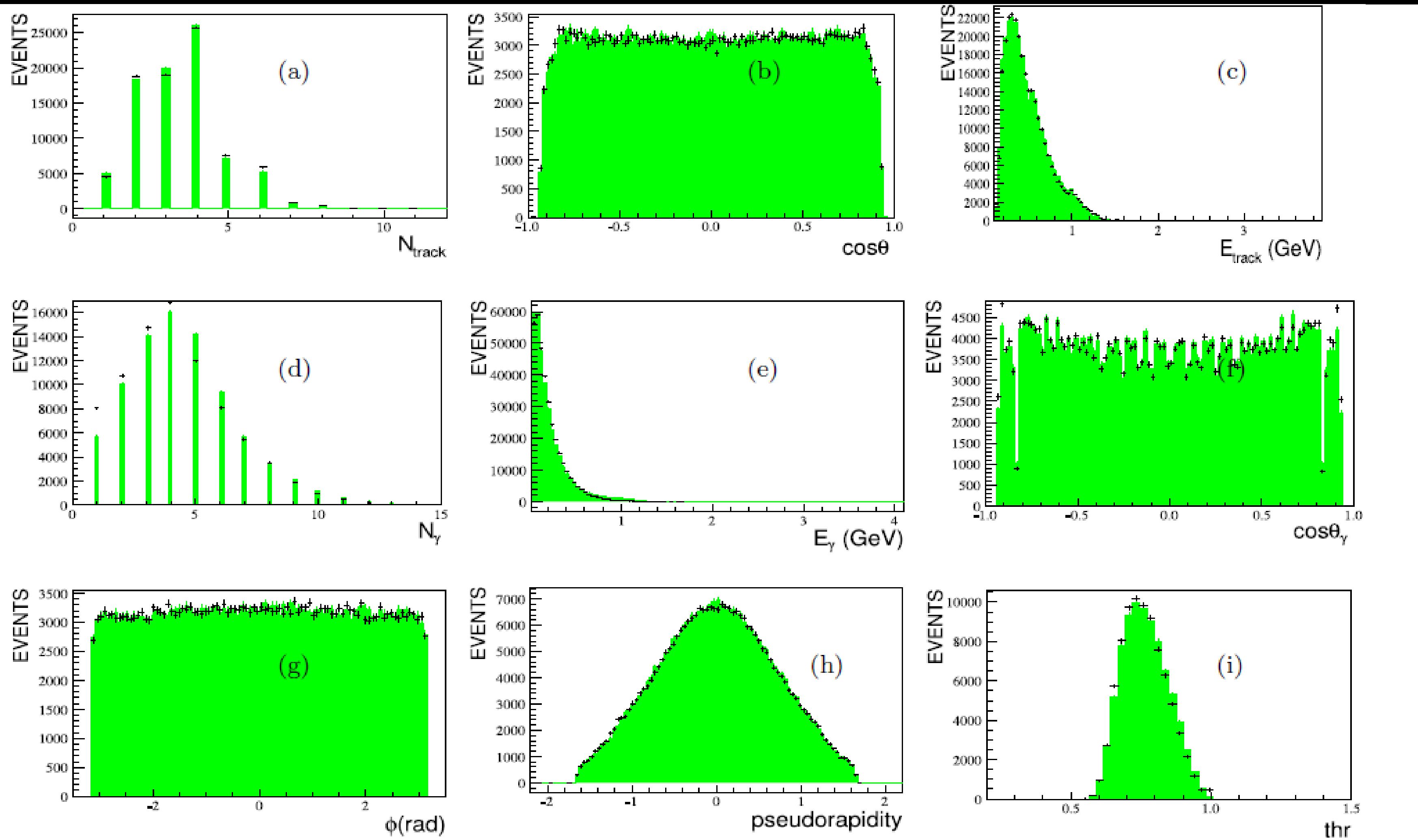


Fig. 5. Comparison of data to the MC distributions at 3.06 GeV, where the MC sample is produced with the optimized parameters. (a) multiplicity of charged tracks, (b) cosine of polar angle of charged tracks, (c) Energy of charged tracks, (d) multiplicity of photon, (e) energy of photon, (f) cosine of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

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 generator LUARLW are checked, fixed, optimized and tuned
- The hybrid-generator is 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.