(g-2)mu: Quo Vadis
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Tuning of Generator LUARLW for R Scan at BESIII

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Outline

- ☞ Motivation
- ☞ Some related problems need to solve
- ☞ Main LUARLW parameters need to tune
- ☞ Preliminary tuning results
- ☞ Work next to do

Motivation

R scan at BESIII

BESIII finished two phases of R scan data taking:

First phase: (2012.05.28 – 06.08)

J/Ψ scan: 3.050 – 3.12 GeV

R scan: 2.23 – 3.40 GeV

Second phase: (2013.12.09 – 2014.01.26)

R scan: 3.85 – 4.60 GeV

Two scans cover the whole BEPCII energy region

Main goals :

- R value
- Resonant line shape and resonance parameters
- ……

R measurement in experiment

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

Experimental expression：
$$R = \frac{N_{had} - N_{bg}}{\sigma^0_{\mu\mu} L \epsilon_{trg} \epsilon_{had} (1+\delta)}$$

The basic tasks of R measurement：

- Data taking (raw data)
- Data analysis (BG removing, hadronic selection, luminosity measurement)
- Theoretical studies (ISR calculation, generator tuning, efficiency)
- Error analysis

MC and ISR in R measurement

R value experiment is to measure the hadronic cross section.

Observed total cross section: $$\sigma_{obs}^{tot} = \frac{N_{evt}}{L}$$

Not physical quantity, experiment dependent.

Total cross section in physics : $$\sigma_{phys}^{tot} = \frac{N_{evt}}{L\bar{\epsilon}}$$

Physical quantity, experiment independent.

Hadronic detection efficiency: $$\bar{\epsilon} = \frac{N_{exp}^{obs}}{N_{exp}^{gen}} \approx \frac{N_{MC}^{obs}}{N_{MC}^{gen}}$$

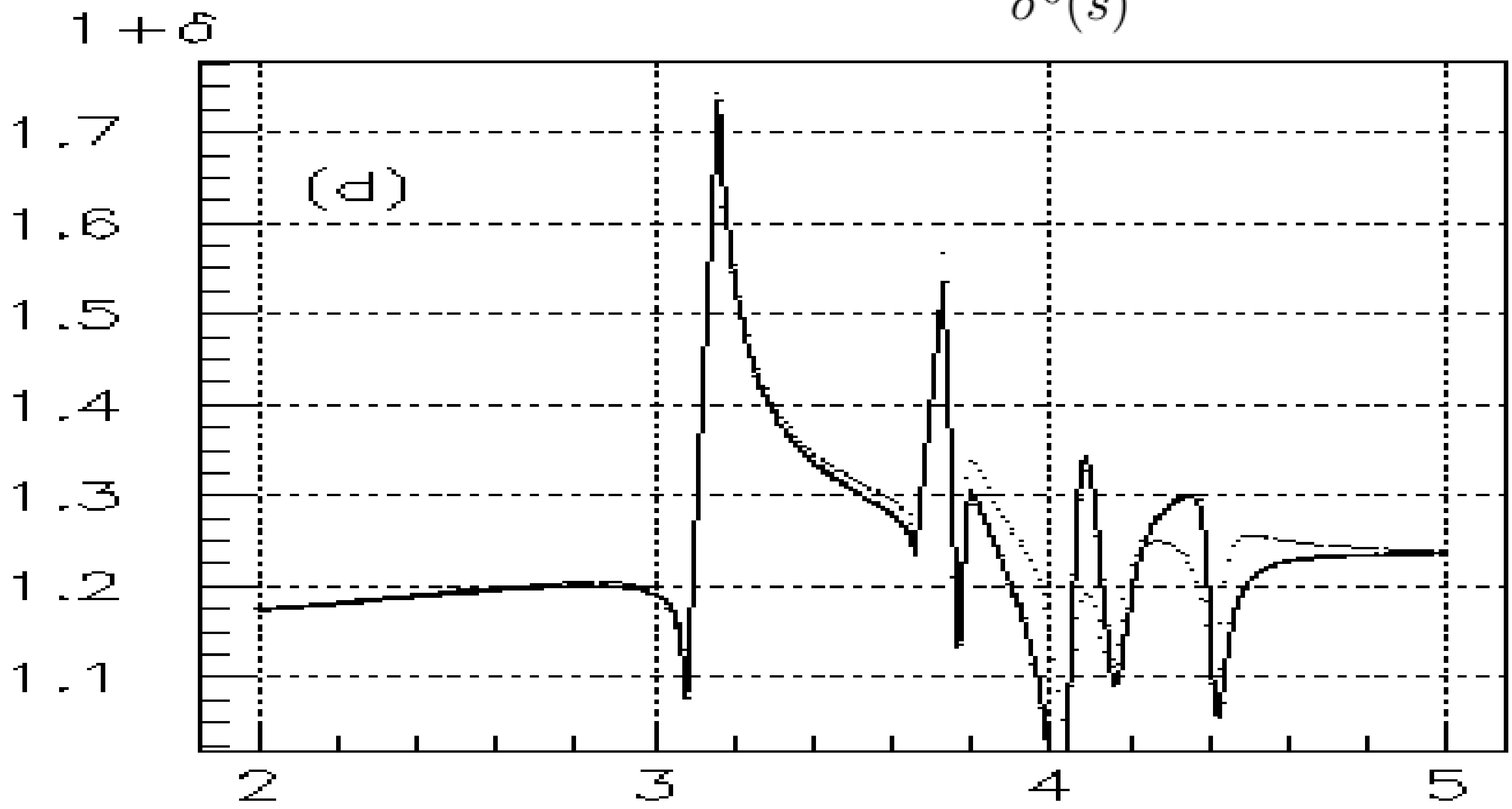
Born cross section in physics : $$\sigma_{phys}^{0} = \frac{N_{evt}}{L\bar{\epsilon}(1+\delta)}$$

ISR factor : $$\sigma(s)_{the}^{tot} = \int dx \sigma_{the}^{0}(s')F(x;s) \equiv \sigma_{the}^{0}(s)(1+\delta)$$

Main error : $$\frac{\Delta\sigma_{phys}^{0}}{\sigma_{phys}^{0}} = \sqrt{(\frac{\Delta N_{evt}}{N_{evt}})^2 + (\frac{\Delta L}{L})^2 + (\frac{\Delta\bar{\epsilon}}{\bar{\epsilon}})^2 + (\frac{\Delta(1+\delta)}{(1+\delta)})^2}$$

Energy dependence of (1+δ)

Initial state radiation factor: $$(1+\delta) \equiv \frac{\sigma^T(s)}{\sigma^0(s)}$$



The ISR factor (1+δ) is energy dependent. Energy dependence of (1+δ) reflects the energy dependence of the Born cross section $\sigma^0(s)$.

Problems need to solve

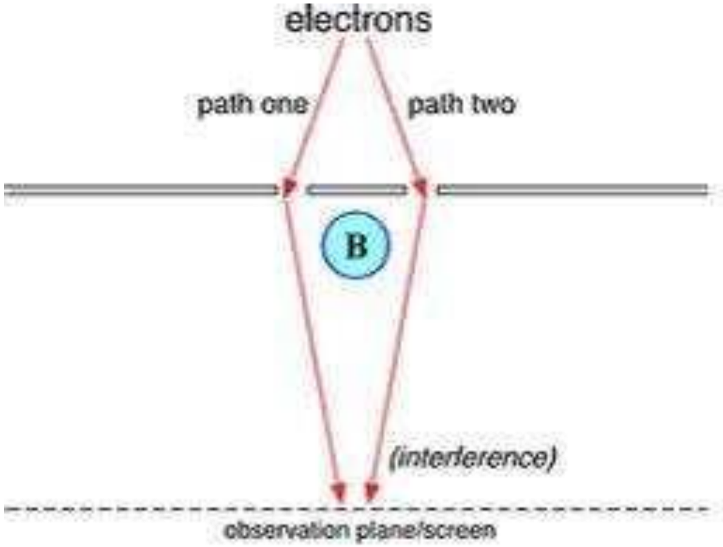
Main problems in (1+δ) calculation

Interference:

According to quantum mechanics principle, if an exclusive hadronic state can produce via *N* channels, it has *N* Feynman diagrams with amplitude A_i, the differential cross section:

$$\frac{d\sigma}{d\Omega} \propto |\sum A_i|^2 \neq \sum |A_i|^2$$

The measured distributions certainly contain interference effects.



Main problems in (1+δ) calculation

Interference:

In R scan above 3.85 GeV , DD states can produce via both continuous and resonant modes, the differences between them are the propagators

$$e^+e^- \Rightarrow \gamma^* + \psi \Rightarrow \begin{array}{l} D\bar{D}; \\ D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D_s\bar{D}_s; \\ D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D_s\bar{D}_s, D_s\bar{D}_s^*; \\ D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*, D\bar{D}_1, D\bar{D}_2^* \end{array}$$

Feynman propagators

In QCD, the expression of amplitude ***Ac*** of continuous channel are function of form factors. But in most case, form factors are unknown.

Amplitude of resonance ***Ar*** is described by Breit-Wigner form:

$$Ar \equiv \mathcal{T} = \frac{M\sqrt{\Gamma^e\Gamma^h}}{W^2 - M^2 + iM\Gamma_{tot}} e^{i\delta}$$

For wide resonance, like Ψ(4040),Ψ(4160) , Ψ(4415), the hadronic widths are energy dependent.

Main problems in (1+δ) calculation

Energy dependence of hadronic width:

for unstable particle, the width Γ = 1/ lifetime τ. the calculation of Γ relay on nonperturbative QCD, one has to employ phenomenological models. For example:

- Simple squared-potential well model:

$$\Gamma_R^{f_c}(s) = G_R \cdot \sum_L \frac{Z_{f_c}^{2L+1}}{B_L^{f_c}} \qquad Z_{f_c} = r \cdot P_{f_c} \qquad P_{f_c} = \frac{1}{2\sqrt{s}} \lambda(s, M_D^2, M_{D'}^2)$$

final state decay momentum

strong interaction scale ~ 1-3 fm

$$B_0 = 1,$$
$$B_1 = 1 + Z^2,$$
$$B_2 = 9 + 3Z^2 + Z^4,$$
$$B_3 = 225 + 45Z^2 + 6Z^4 + Z^6$$

Γ increase with the energy $s = E_{cm}^2 = W^2$ smoothly. This model is too simple to describe the details of the hadronic decay dynamics.

Main problems in (1+δ) calculation

- Hadronic width in equivalent interaction theory

Heavy Ψ family has three decay modes :

$$1^{--} \rightarrow 0^{-C} + 0^{-C} \qquad (VPP)$$
$$1^{--} \rightarrow 1^{-C} + 0^{-C} \qquad (VVP)$$
$$1^{--} \rightarrow 1^{-C} + 1^{-C} \qquad (VVV)$$

Effective Hamiltonians :

$$\mathcal{H}_{eff} = g_1 \psi_\mu [(\partial_\mu D)\bar{D}' - D(\partial_\mu \bar{D}')] \qquad (VPP)$$
$$\mathcal{H}_{eff} = g_2 \epsilon_{\mu\nu\lambda\sigma} (\partial_\mu \psi_\nu)(\partial_\lambda D^*_\sigma) \cdot \bar{D} \qquad (VVP)$$
$$\mathcal{H}_{eff} = g_4 \psi_\mu [(\partial_\mu D^*_\nu)\bar{D}^*_\nu - D^*_\nu(\partial_\mu \bar{D}^*_\nu)] + g_5 (\partial_\lambda \psi_\mu)[(\partial_\mu D^*_\nu)(\partial_\nu \bar{D}^*_\lambda) - (\partial_\nu D^*_\lambda)(\partial_\mu \bar{D}^*_\nu)] \qquad (VVV)$$

Energy dependent width :

$$\Gamma_R^{f_c}(s) = G_R^{f_c} \cdot \frac{\lambda^3(s, M_D^2, M_{\bar{D}'}^2)}{s^{5/2}}, \qquad (V\rightarrow PP)$$
$$\Gamma_R^{f_c}(s) = G_R^{f_c} \cdot \frac{\lambda^3(s, M_{D^*}^2, M_{\bar{D}}^2)}{s^{3/2}}, \qquad (V\rightarrow PV)$$
$$\Gamma_R^{f_c}(s) = G_R^{f_c} \cdot \frac{\lambda^3(s, M_{D^*}^2, M_{\bar{D}^{*\prime}}^2)}{s^{5/2}} \cdot [3 + \frac{\lambda^2(s, M_{D^*}^2, M_{\bar{D}^{*\prime}}^2)}{4M_{D^*}^2 M_{\bar{D}^*}^2}] \qquad (V\rightarrow VV)$$

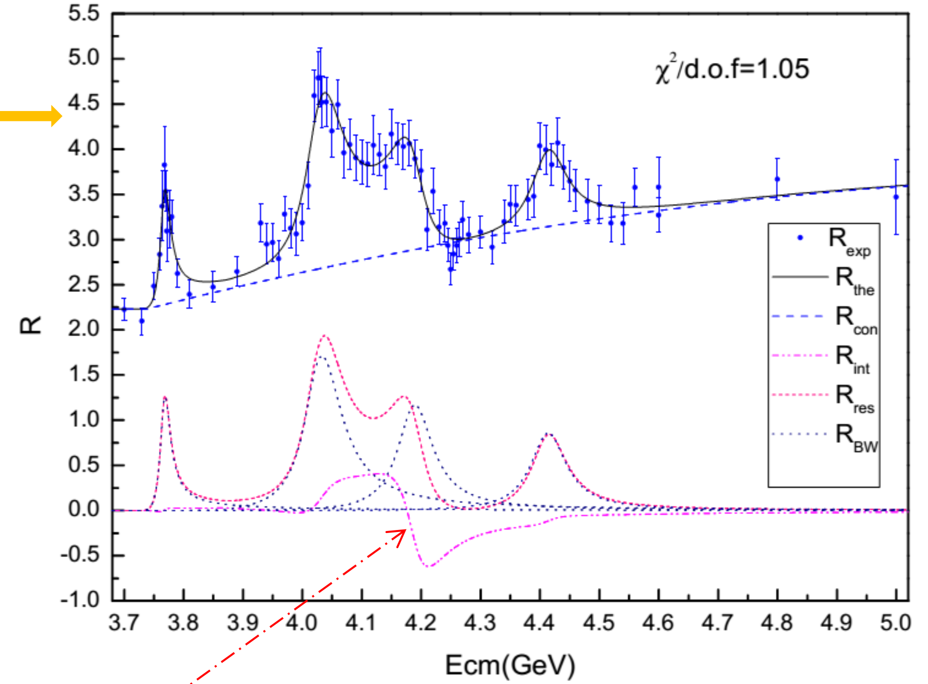
Where, G_R are the generalized form-factors, and are the scalar functions of the 4-momentum of the initial and final particles. But no enough knowledge about them, they have to be treated as the free parameters.

Model dependence of line shape

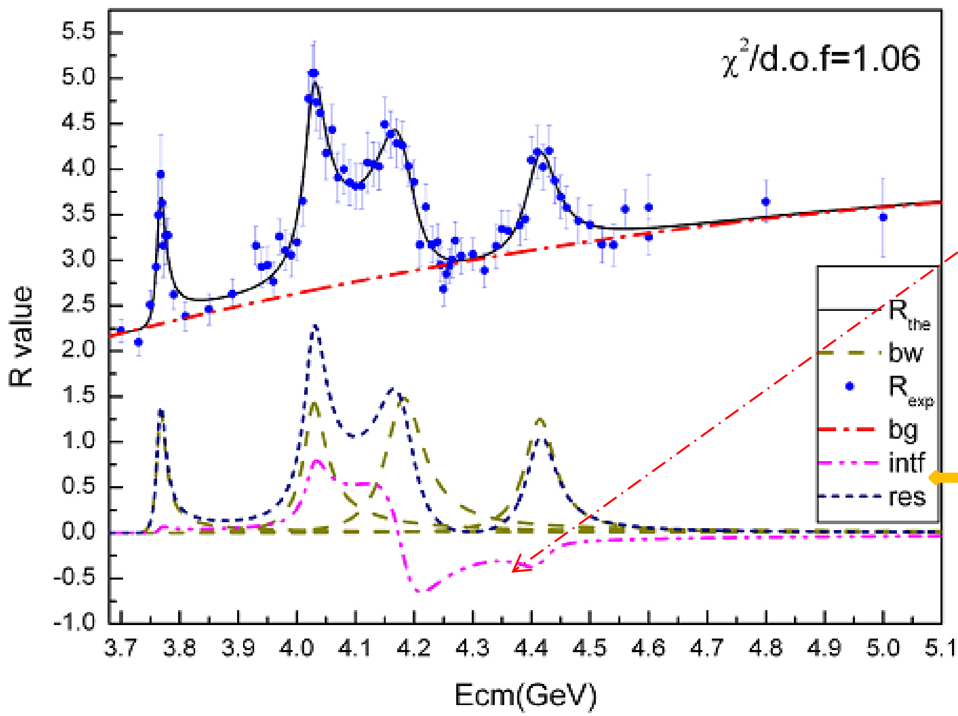
Hadronic width:
squared-potential well model

Physics Letters B 660 (2008) 315–319

PDG 2008 – 2014



Different model cause different resonant line shape.



Hadronic width:
equivalent interaction theory

PDG cites BESII measurements

$\psi(3770)$

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

$\psi(3770)$ MASS

OUR FIT includes measurements of $m_{\psi(2S)}$, $m_{\psi(3770)}$, and $m_{\psi(3770)} - m_{\psi(2S)}$.

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
3772.92±0.35 OUR FIT				Error includes scale factor of 1.1.
3775.2 ±1.7 OUR AVERAGE				Error includes scale factor of 1.4. See the ideogram below.
3772.0 ±1.9		[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons

$\psi(4040)$

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

$\psi(4040)$ MASS

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

$\psi(4415)$

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

$\psi(4415)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
4421 ± 4 OUR ESTIMATE			
4415.1± 7.9	[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4411 ± 7	[2] PAKHLOVA 08A	BELL	$10.6\ e^+e^- \to D^0 D^- \pi^+ \gamma$
4425 ± 6	[3] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4429 ± 9	[4] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4417 ±10	BRANDELIK 78C	DASP	e^+e^-
4414 ± 7	SIEGRIST 76	MRK1	e^+e^-

[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 $\delta = (234 \pm 88)^\circ$.

$\psi(4160)$

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

$\psi(4160)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
4153 ± 3 OUR ESTIMATE			
4191.7± 6.5	[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4151 ± 4	[2] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4155 ± 5	[3] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4159 ±20	BRANDELIK 78C	DASP	e^+e^-

[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 $\delta = (293 \pm 57)^\circ$.
[2] From a fit to Crystal Ball (OSTERHELD 86) data.
[3] From a fit to BES (BAI 02C) data.

$\psi(4160)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
103 ± 8 OUR ESTIMATE			
71.8±12.3	[4] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
107 ±10	[5] SETH 05A	RVUE	$e^+e^- \to$ hadrons
107 ±16	[6] SETH 05A	RVUE	$e^+e^- \to$ hadrons
78 ±20	BRANDELIK 78C	DASP	e^+e^-

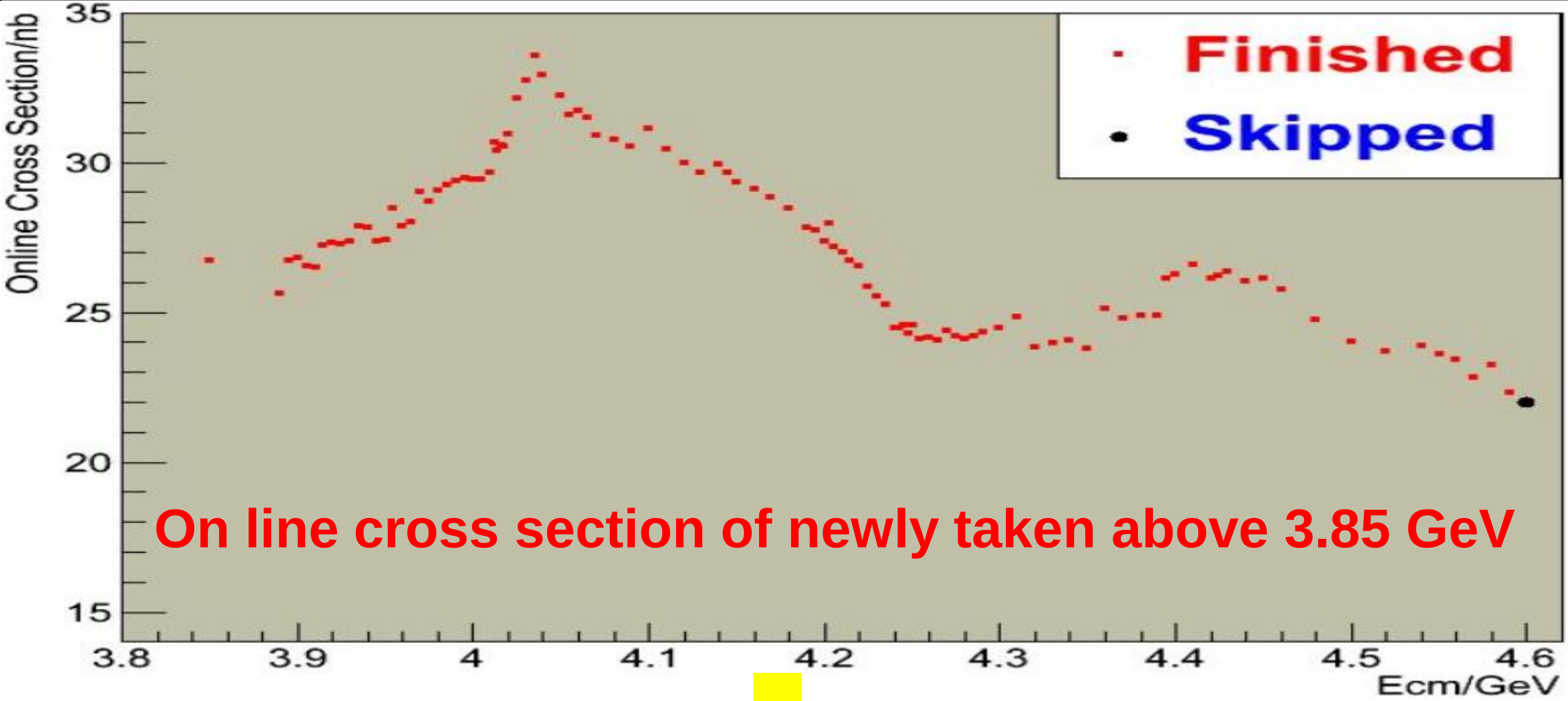
[4] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (293 \pm 57)^\circ$.
[5] From a fit to Crystal Ball (OSTERHELD 86) data.
[6] From a fit to BES (BAI 02C) data.

$\psi(4160)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
0.83±0.07 OUR ESTIMATE			
0.48±0.22	[7] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons

Line shape measured at BESIII

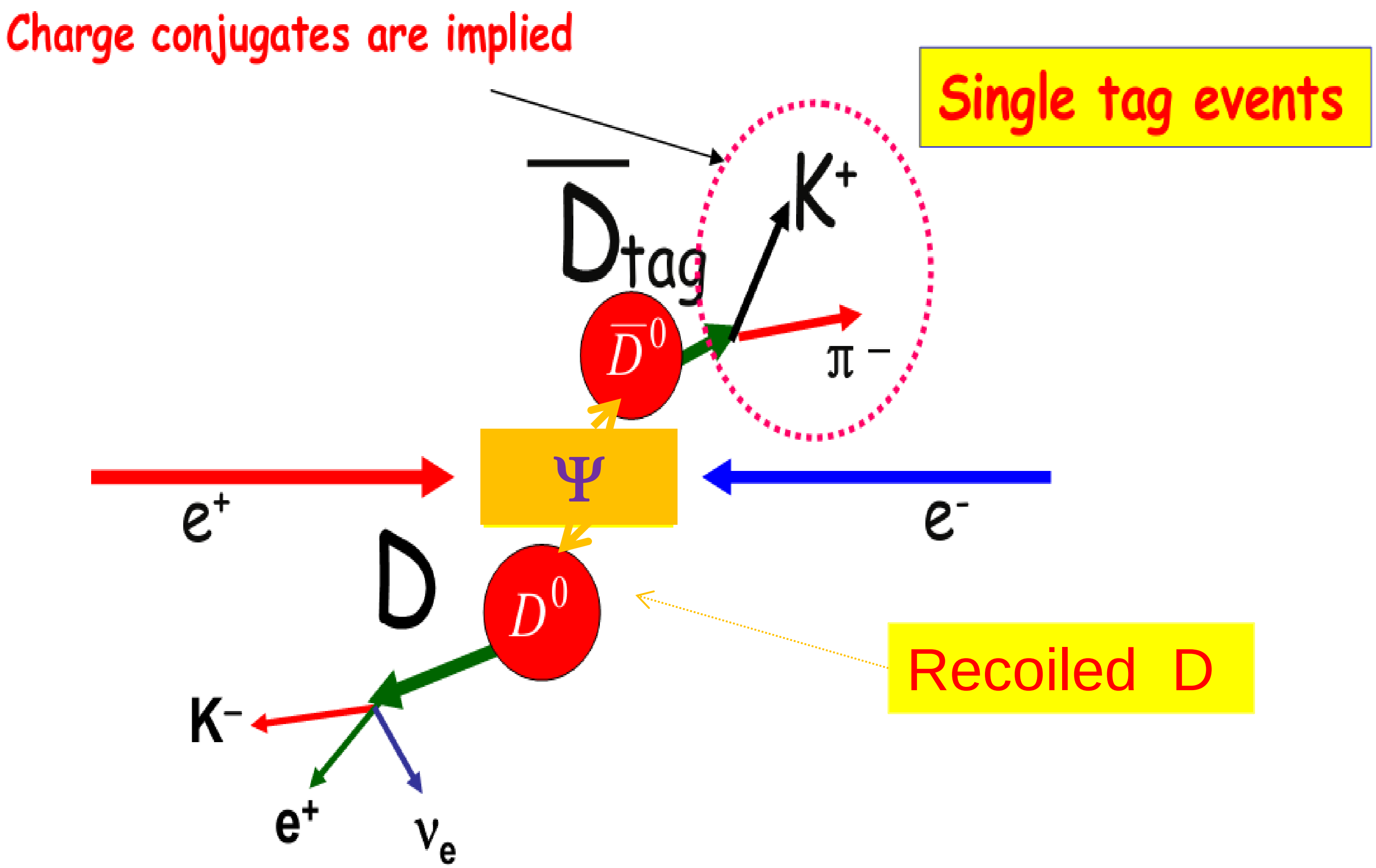


What Model

BESIII result

D tag

Determination of Γ need measure the branch ratio of DD states. We are going to use D tag package selecting DD events.



D tag

$$e^+e^- \rightarrow D^+ D^-(D^{*-})$$

$D^-(D^{*-})$ → **Anything!**

D^+ →

$K_S^0\pi^+$	1.47%
$K_S^0\rho^+,\ \rho^0 \rightarrow \pi^+\pi^-$	4.8%
$K_S^0\pi^+\pi^+\pi^-$	3.12%
$K^-\pi^+\pi^+$	9.13%
$K^-\pi^+\pi^+\pi^0$	5.99%

D tag

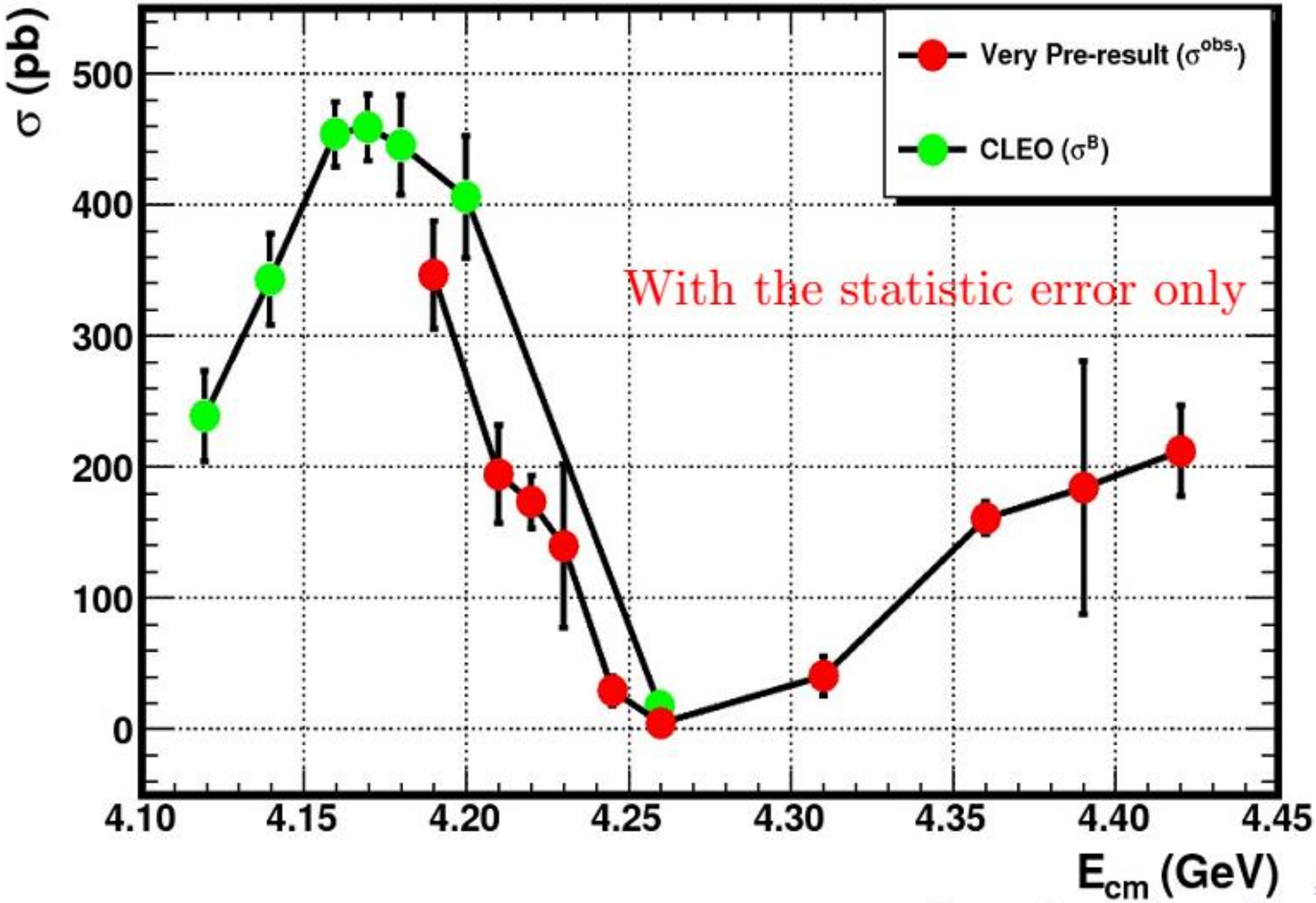
Anything!

$$e^+e^- \rightarrow D_s^+ D_s^- (D_s^{*-})$$

$D_s^+ \rightarrow K_S^0 K^+$	1.48%
$D_s^+ \rightarrow K^+ K^- \pi^+$	5.49%
$D_s^+ \rightarrow \eta \pi^+$	1.83

D tag

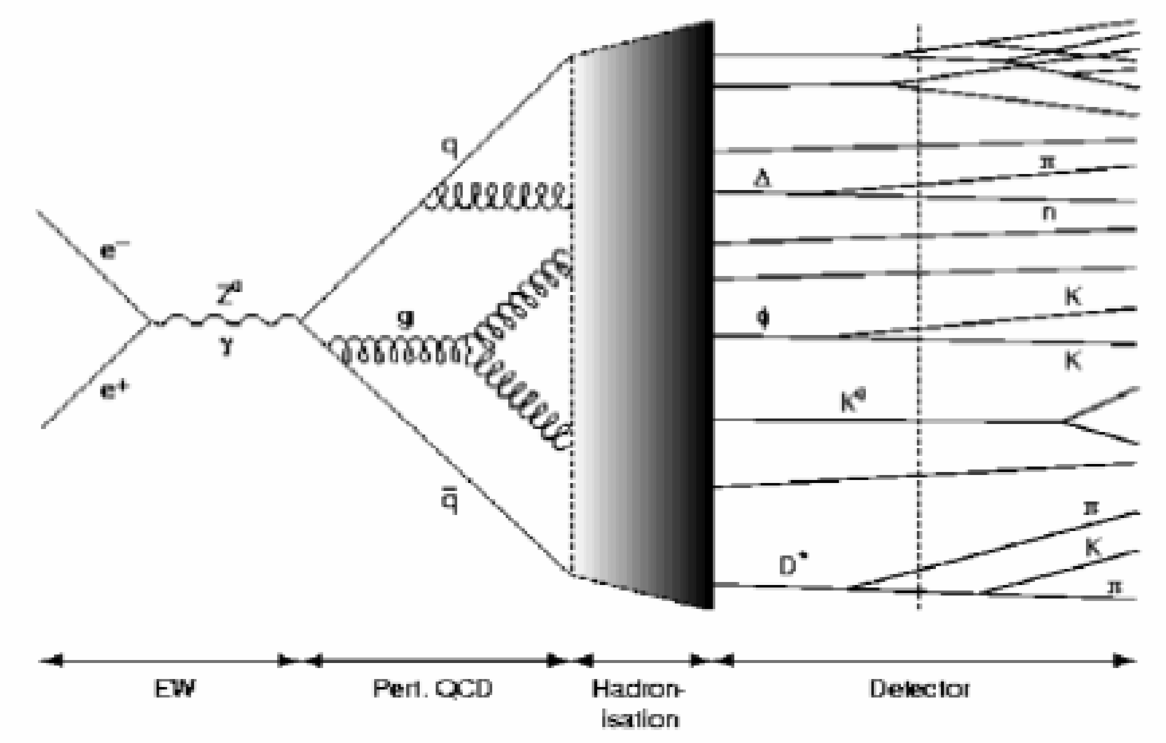
Very preliminary results for $D_s^+ D_s^{*-}$ mode



At present, our analysis is different from the measurements by CLEO, we have to check our method carefully.

Main parameters to tune

Pictures of Hadronic Production



Hadronization belongs to QCD nonperturbative problem, and one has to employ phenomenological models.

Two typical models：

- Cluster decay model (HERWIG)
- String fragmentation model (JETSET/PYTHIA) √

Motivation for Developing 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.

LUARLW simulation

LUARLW can simulate the productions and decays of inclusive continuous channels and $J^{PC} = 1^{--}$ resonances with ISR return from 2 – 5 GeV to meet the needs of R scan.

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} V \ (\rho, \omega, \phi) \\ q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ gq\bar{q} \Rightarrow \text{string} \ + \ \text{string} \Rightarrow \text{hadrons} \end{cases}$$

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

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(2S) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-, \ \mu^+\mu^-, \ \tau^+\tau^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} \ + \ \text{string} \ + \ \text{string} \ \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \text{string} \ + \ \text{string} \ \Rightarrow \text{hadrons} \\ \gamma\eta_c \Rightarrow gg \Rightarrow \text{string} \ + \ \text{string} \ \Rightarrow \text{hadrons} \\ \pi\pi J/\psi, \ \eta J/\psi, \ \pi^0 J/\psi \\ \gamma + \text{exclusive radiative decay channels} \end{cases}$$

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

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, \text{other decay modes} \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, D_s\bar{D}_s^*, \text{other decay modes} \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*, \text{other decay modes} \\ X(4260) \Rightarrow \text{possible decay modes} \end{cases}$$

Simulation of radiative events

In MC, hadronic events are classed into two types：

① **Nonradiative events**

Born, soft ($k<k_0$) and virtual radiation. The effective c.m.s. energy of the hadronic system equals to the initial e^+e^- energy

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

② **Radiative events**

Hard photon with $k>k_0$, the effective c.m.s. energy of the hadronic system smaller than the initial e^+e^- energy, $s'=s(1-k)$

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

Momentum and polar angle distribution of radiative photon:

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

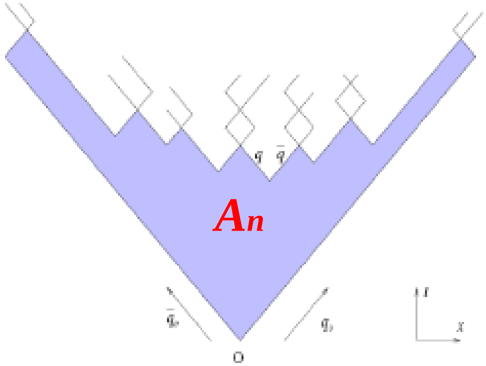
Note: for the narrow resonance, the effect of energy spread must be considered

Multiplicity distribution

In MC simulation, various events are sampled according to multiplicity distribution of preliminary hadrons P_n, which can be derived from the Lund area law.

Define partition function for string → ***n*** hadrons:

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



Multiplicity distribution for string fragmentations:

$$P_n = Z_n / \sum Z_n$$

At some approximations:

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

μ may use QCD exponential form

$$\mu = a + b\exp\{c \cdot [\ln(s/Q_0^2)]^{1/2}\}$$

where c_0, c_1, c_2, a, b, c are parameters to be tuned using data.

Main parameters to be tuned

- Parameters σ and ξ in Lund area law

$$\mathcal{M}_{\perp} = \exp(-\sum_{j=1}^{n} \vec{k}_j^{\,2}), \quad \vec{k}_j \equiv \frac{\vec{p}_{\perp j}}{2\sigma}$$

$$\mathcal{M}_{//} = \exp(i\xi \mathcal{A}_n), \quad \xi = \frac{1}{2\kappa} + i\frac{b}{2}$$

- Parameters PARJ(*) in JETSET

PARJ(01)=0.15	!p(qq)/p(q)	suppression of diquark-antidiquark production
PARJ(02)=0.30	!p(ss)/p(dd,uu)	suppression of s quark production
PARJ(03)=0.75	!P(us)/P(ud))/(P(s)/P(d))	extra suppression of strange diquark
PARJ(04)=0.10	!P(ud1)/P(ud0)	suppression of spin 1 diquark to spin 0 ones
PARJ(05)=0.50	!P(BMB)/[P(BB)+P(BMB)]	relative probability for BMB to BB
PARJ(06)=0.50	!extra suppression for having a ssbar	
PARJ(07)=0.50	!extra suppression for having a strange meson	
PARJ(11)=0.55	!ratio of light meson with spin 1/0	
PARJ(12)=0.55	!ratio of strange meson with spin 1/0	
PARJ(13)=0.75	!ratio of charm meson with spin 1/0	
PARJ(14)=0.05	!ratio of S=0 meson with L=1, J=1	
PARJ(15)=0.05	!ratio of S=1 meson with L=1, J=0	
PARJ(16)=0.05	!ratio of S=1 meson with L=1, J=1	
PARJ(17)=0.10	!ratio of S=1 meson with L=1, J=2	

Functions of the main parameters

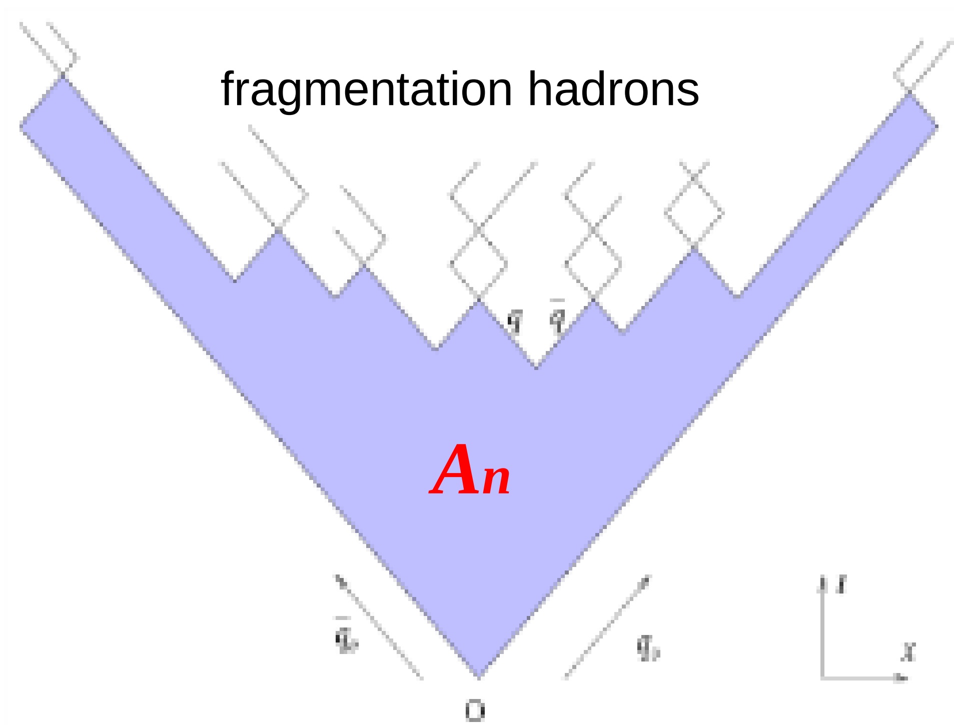
$$P_n(s) = \frac{\mu^n}{n!}\exp[c_0 + c_1(n-\mu) + c_2(n-\mu)^2]$$ → Multiplicity distribution

Parameters PARJ(**) → Fragmentation hadrons

$$\mathcal{M}_\perp = \exp(-\sum_{j=1}^{n} \vec{k}_j{}^2), \quad \vec{k}_j \equiv \frac{\vec{p}_{\perp j}}{2\sigma}$$

$$\mathcal{M}_{//} = \exp(i\xi\mathcal{A}_n), \quad \xi = \frac{1}{2\kappa} + i\frac{b}{2}$$

→ Momentum distribution



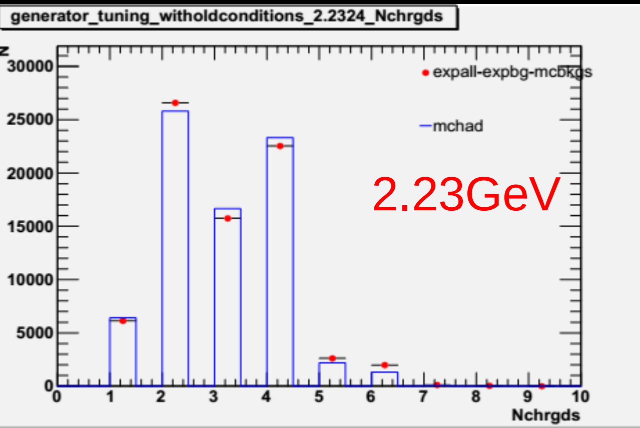
Goal of tuning

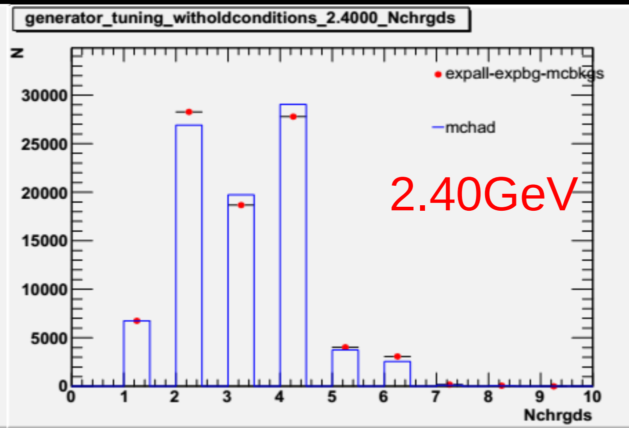
- Use **two sets** of parameters to control the simulations of continuous and $J^{PC} = 1^{--}$ resonant states.

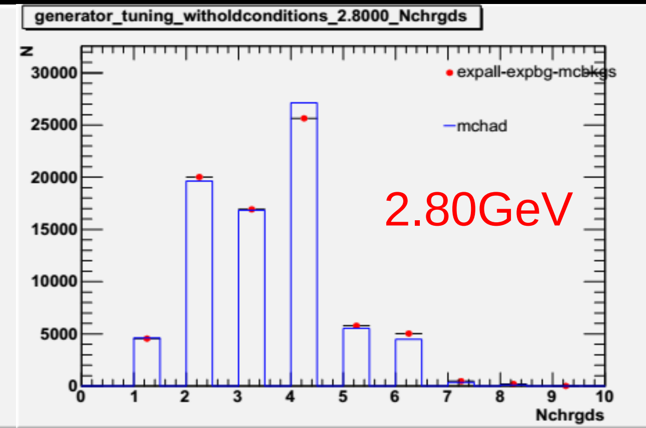
- LUARLW could agree with data well for most of the inclusive distributions and DD final states at all energies.

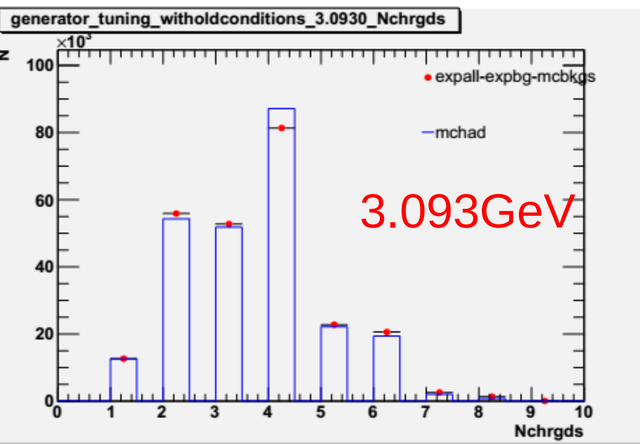
Preliminary tuning

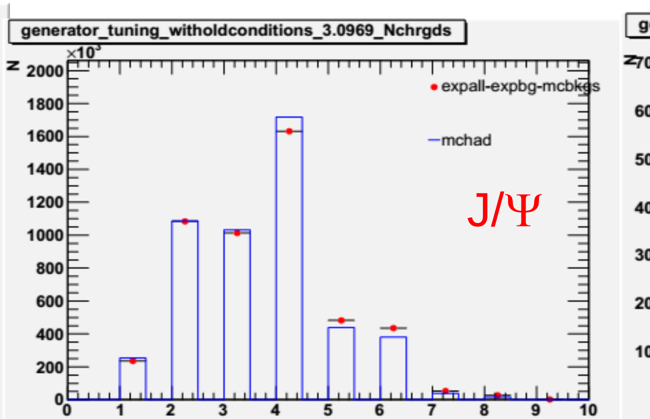
Multiplicity below open charm

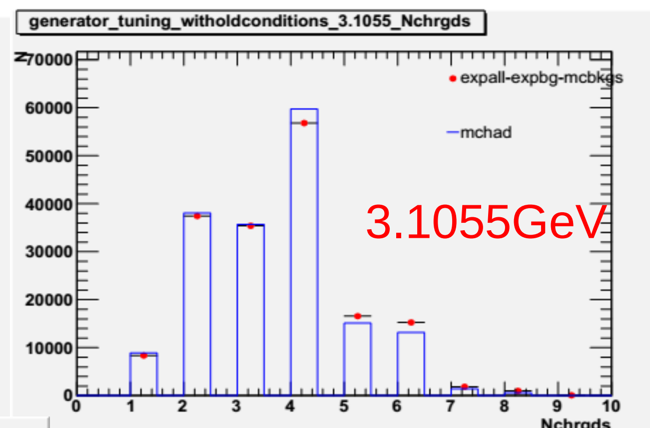


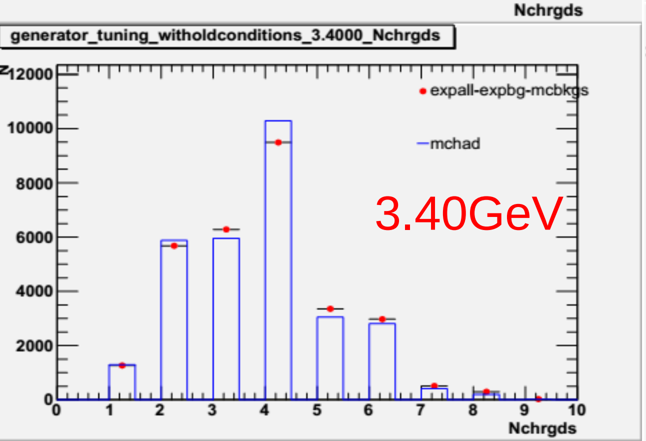


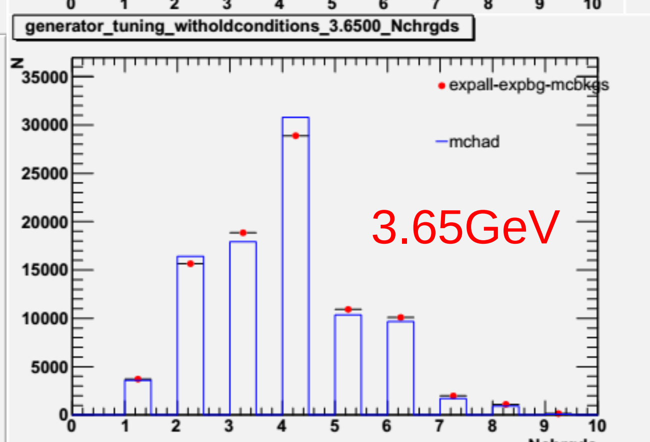






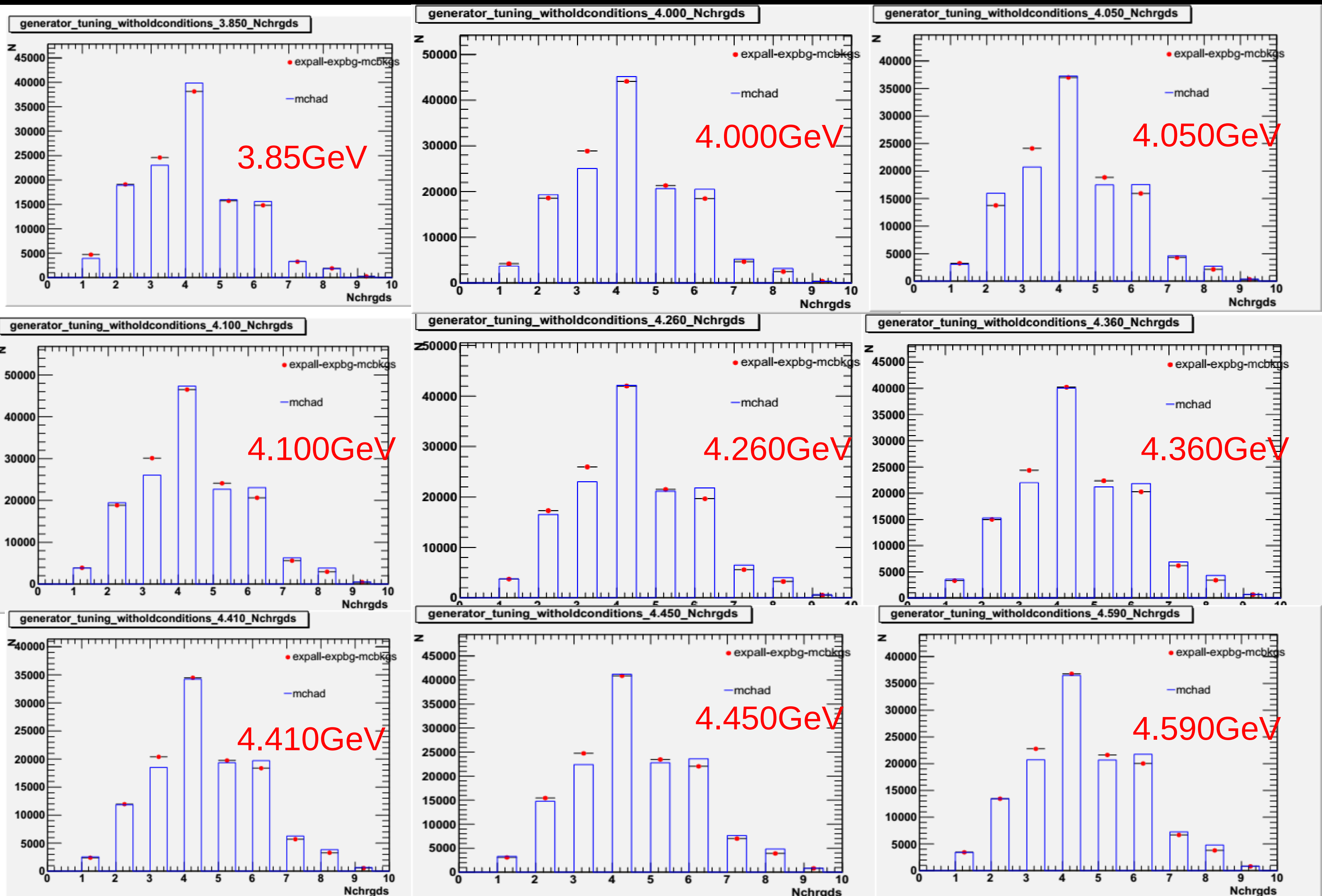




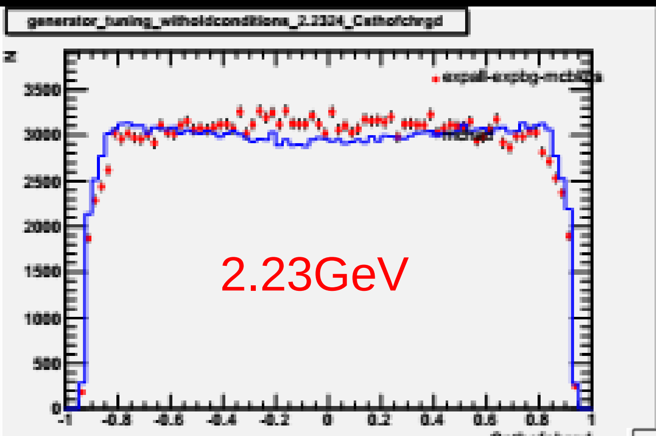


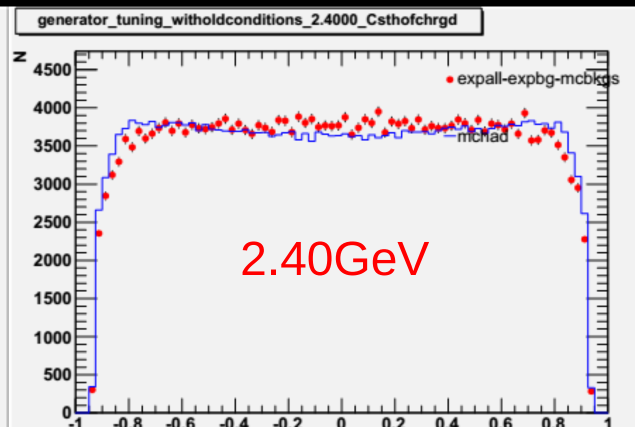
2.23 – 3.65 GeV
Red dots: BES data
Blue : LUARLW

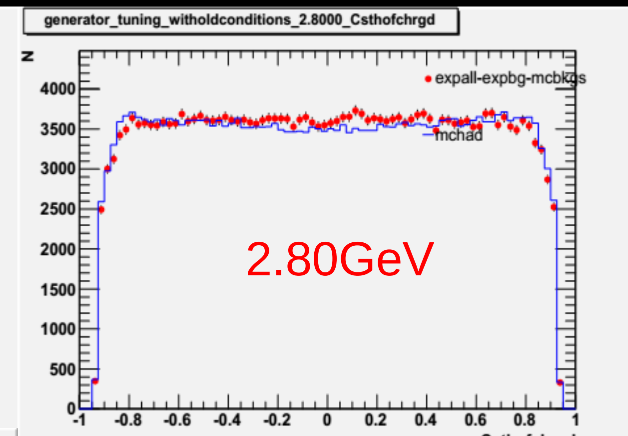
Multiplicity above open charm

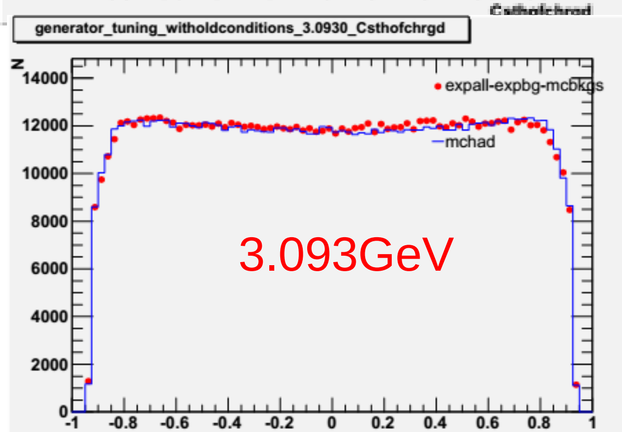


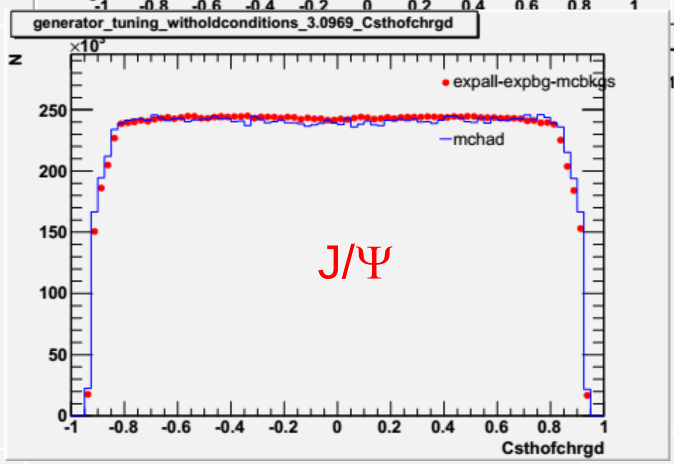
Polar Angle cosθ below open charm

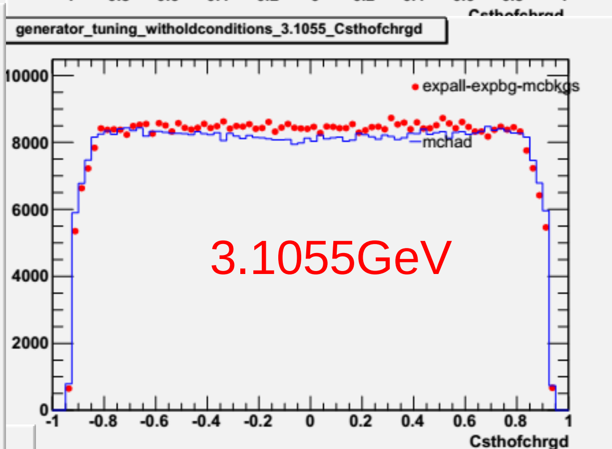


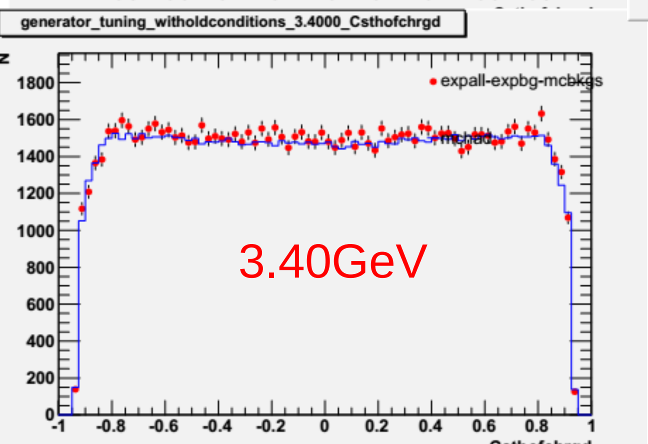


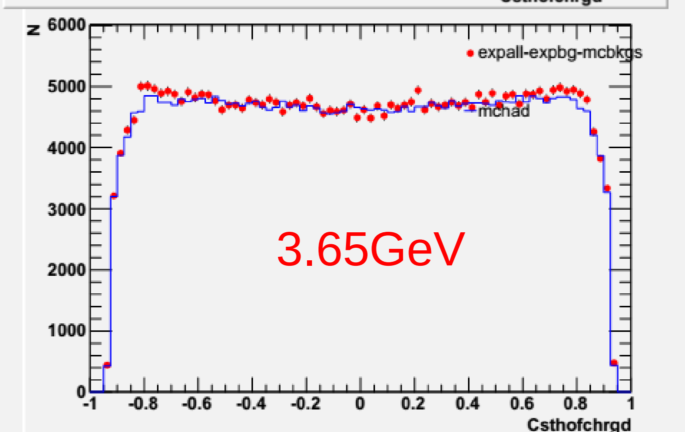






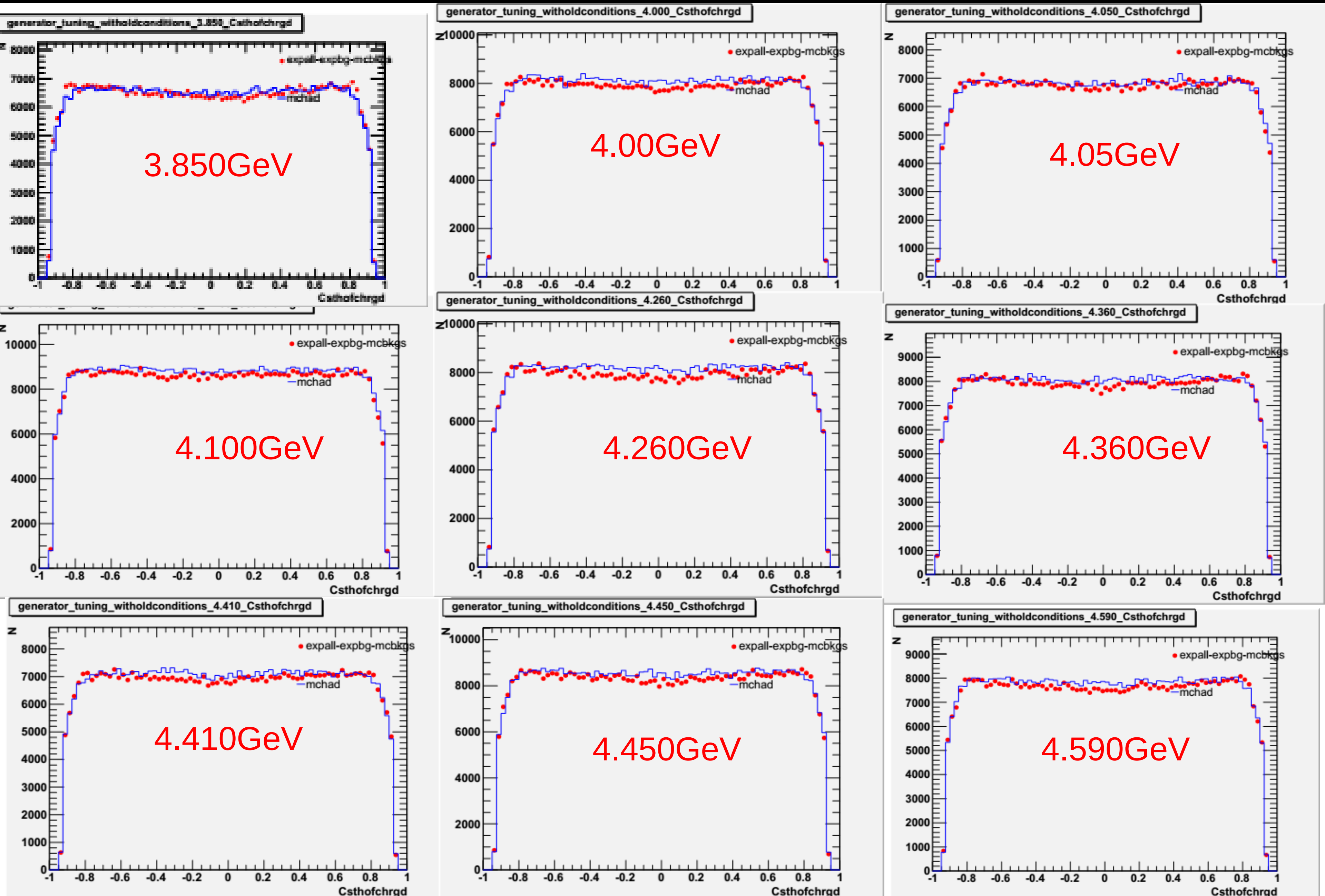




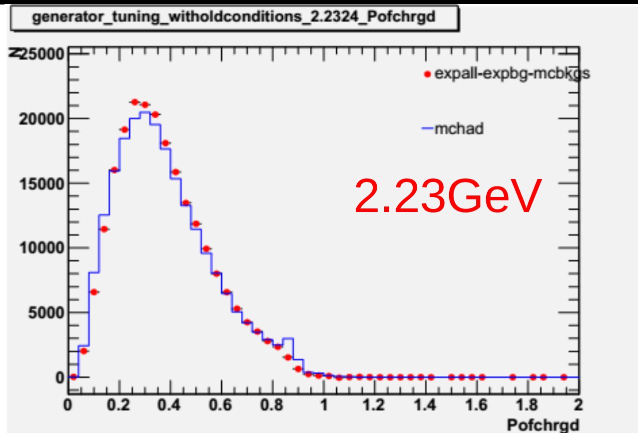


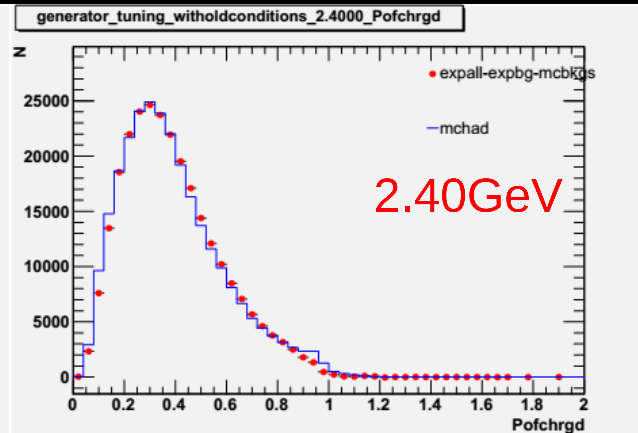
2.23 – 3.65 GeV
Red dots: BES data
Blue : LUARLW

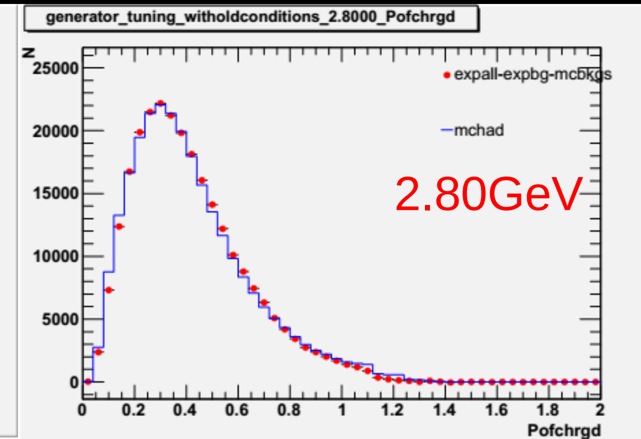
Polar Angle cosθ above open charm

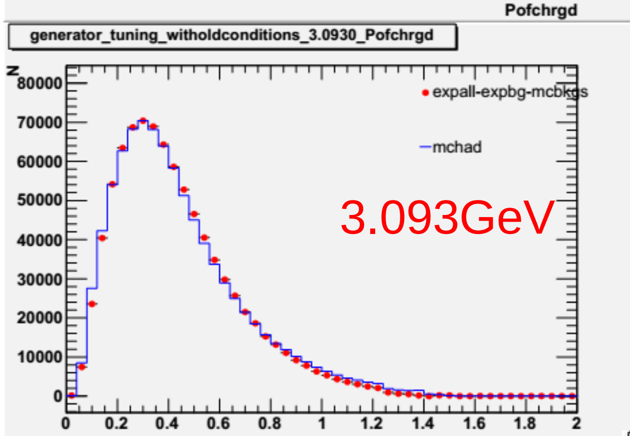


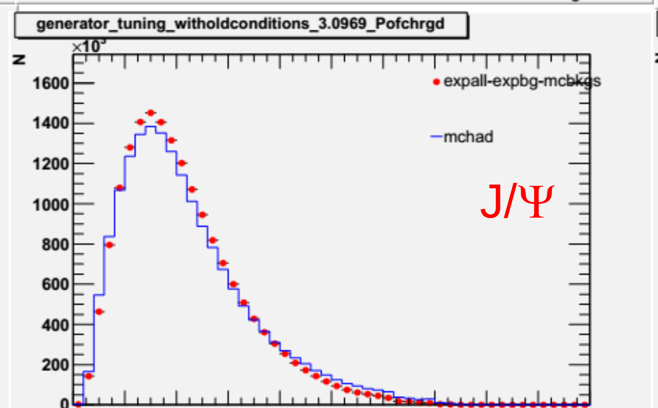
Momentum below open charm

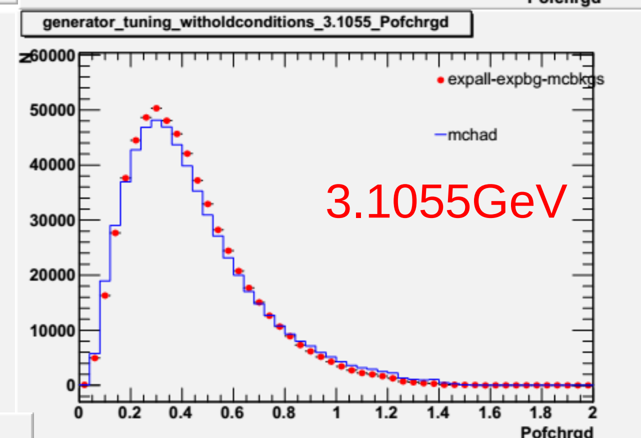


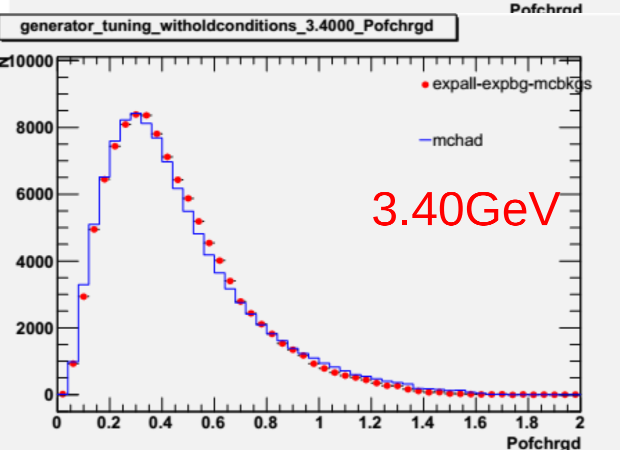


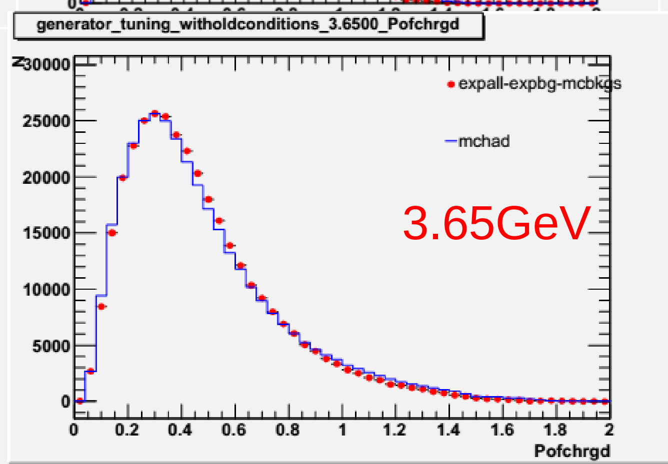






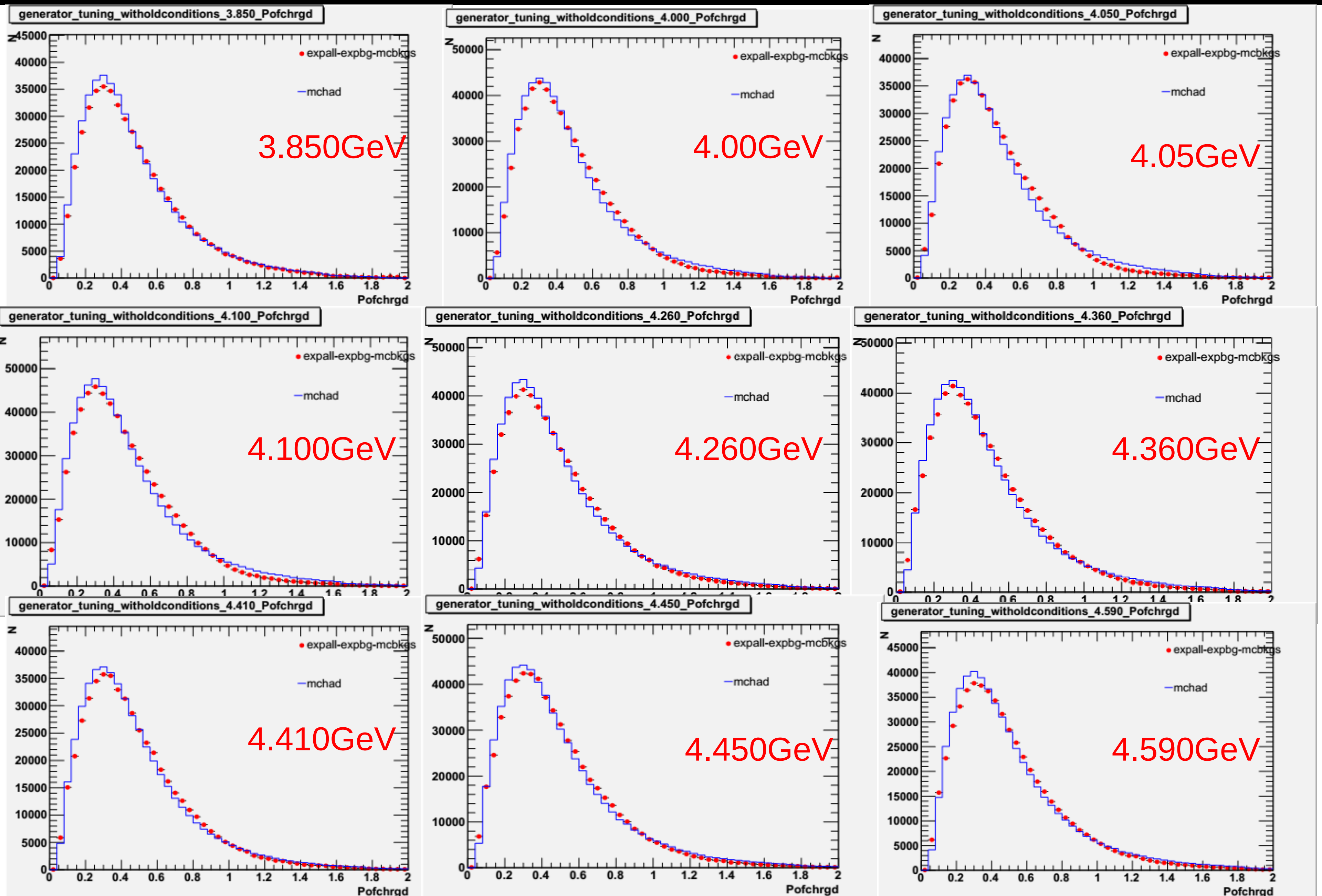






2.23 – 3.65 GeV
Red dots: BES data
Blue : LUARLW

Momentum above open charm



Summary

The parameters in LUARLW are tuning based on the data samples taken at BESIII from 2.23 – 4.59 GeV.

Present status:

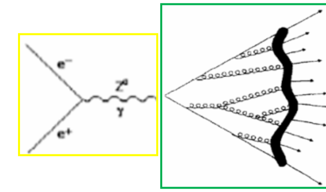
* LUARLW is tuned using two sets of parameters corresponding to the below and above open charm thresholds data separately, but now the parameters of LUARLW are far from the well tuned.
* Criteria for inclusive hadronic events need to fix.
* D tag package using for selecting DD final states has to study further.

Next to do:

* Continue tuning the LUARLW parameters.
* Study the theoretical calculations for interference effects.
* Study the width energy dependence of $\Psi(4040)$,$\Psi(4160)$ and $\Psi(4415)$.
* Calculate ISR factor employing above improvements.
* Check if the related QED generator work well.

Back Up

Key Points of Lund Area Law



Hadron production process ：

$$e^+e^- \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow m_1 + m_2 + \cdots + m_n$$

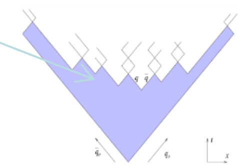
"Matrix element" ：

$$\mathcal{M} \equiv \mathcal{M}_{\text{QED}}(e^+e^- \rightarrow q\bar{q})\mathcal{M}_{\text{LUND}}(q\bar{q} \rightarrow m_1, m_2, \cdots m_n)$$

Lund model: $\mathcal{M}_{\text{LUND}}(q\bar{q} \rightarrow m_1, m_2, \cdots m_n) = C_n \mathcal{M}_{\perp} \mathcal{M}_{//}$

Transverse momentum (Gaussian) ： $\mathcal{M}_{\perp} = \exp(-\sum_{j=1}^{n} \vec{k}_j^{\,2}),\quad \vec{k}_j \equiv \frac{\vec{p}_{\perp j}}{2\sigma}$

Longitudinal momentum (area law) ： $\mathcal{M}_{//} = \exp(i\xi\mathcal{A}_n),\quad \xi = \frac{1}{2\kappa} + i\frac{b}{2}$



Probability for string fragmenting into *n* hadrons ：

$$d\wp_n(q\bar{q} \rightarrow m_1, m_2, \cdots m_n) = (2\pi)^4 \delta(1 - \sum_{j=1}^{n} \frac{m_{\perp j}^2}{s z_j})\delta(1 - \sum_{j=1}^{n} z_j)\delta(\sum_{j=1}^{n} \vec{k}_j) \sum |\mathcal{M}_{LUND}|^2 d\Phi_n$$

Fraction of light-cone momentum: $z_j \equiv (E_j \pm p_{zj})/(E_0 \pm P_{z0})$

Solutions of Lund Area Law

- String $\rightarrow$ 2 hadrons

$$\wp_2 = \frac{C_2}{\sqrt{\lambda(s, m_{\perp 1}^2, m_{\perp 2}^2)}}[exp(-b\mathcal{A}_2^{(1)}) + exp(-b\mathcal{A}_2^{(2)})]$$

$$\mathcal{A}_2^{(1,2)} = \frac{1}{2}(s + m_{\perp 1}^2 + m_{\perp 2}^2 \mp \sqrt{\lambda}) \qquad \lambda(a,b,c) \equiv a^2 + b^2 + c^2 - 2ab - 2bc - 2ca$$

- String $\rightarrow$ 3 hadrons

$$d\wp_3 = \frac{C_3}{\sqrt{\Lambda}} exp(-b\mathcal{A}_3) d\mathcal{A}_3$$

$$\Lambda = [(s - \mathcal{A}_3)(\mathcal{A}_3 - m_{\perp 1}^2 - m_{\perp 2}^2 - m_{\perp 3}^2) - m_{\perp 1}^2 m_{\perp 2}^2 - m_{\perp 2}^2 m_{\perp 3}^2 - m_{\perp 3}^2 m_{\perp 1}^2]^2 - 4s m_{\perp 1}^2 m_{\perp 2}^2 m_{\perp 3}^2$$

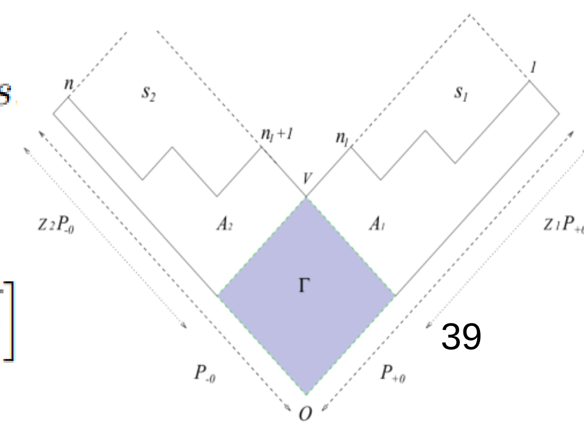
- String $\rightarrow$ *n* hadrons (*n*≥4)

$$d\wp_n(s; s_1, s_2) = \frac{ds_1 ds_2}{\sqrt{\lambda(s, s_1, s_2)}}[exp(-b\Gamma^{(1)}) + exp(-b\Gamma^{(2)})]\wp_{n_1}(s_1)\wp_{n_2}(s_2)$$

$$s_1 = (\sum_{j=1}^{n_1} p_{\circ j})^2 = Z_1(1 - Z_2)s, \qquad s_2 = (\sum_{j=n_1+1}^{n} p_{\circ j})^2 = Z_2(1 - Z_1)s$$

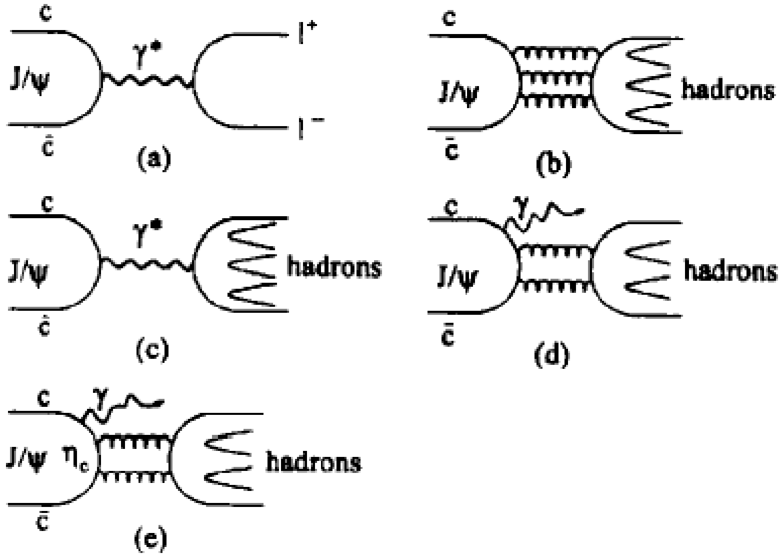
$$\mathcal{A}_n = \mathcal{A}_{n_1} + \mathcal{A}_{n_2} + \Gamma, \qquad \Gamma = (1 - Z_1)(1 - Z_2)s$$

$$\Gamma^{(1,2)} = \frac{1}{4s}\left[s - s_1 + s_2 \pm \sqrt{\lambda(s, s_1, s_2)}\right]\left[s + s_1 - s_2 \mp \sqrt{\lambda(s, s_1, s_2)}\right]$$



Charmonium Decay Modes

J/ψ and ψ(2S) are charmonia with $J^{PC} = 1^{--}$. Decay modes predicts by QCD



(a) Electric-magnetic lepton decay

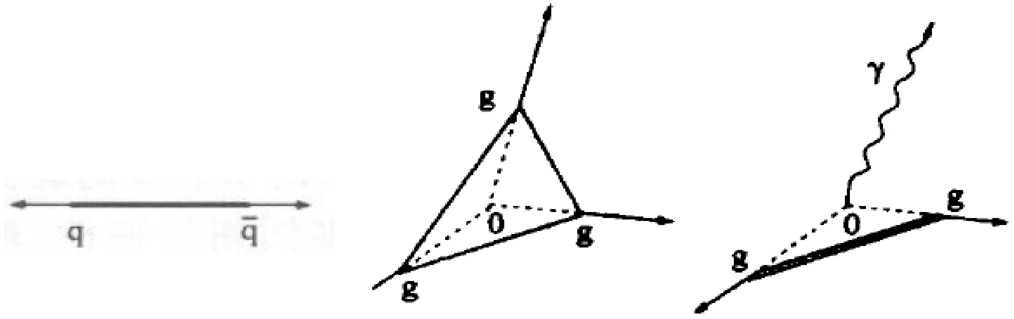
(b) Strong interaction decay

(c) Electric-magnetic hadronic decay

(d) Radiative hadronic decay

(e) Radiative M1 transision

In the Lund string fragmentation, J/ψ and ψ(2S) contain three types of string structures



(c) quark-antiquark single string

(b) triplex gluons closed string

(d) and(e) double gluons parallel strings

Due to Lund area law has the invariant relativistic property, it can be used to treat substring fragmentation independently.

Event List

Continum states

Continuum state at $E_{cm} = 1$ GeV

I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	0.500	0.500	0.001
2	!e+!		21	-11	0	0.000	0.000	-0.500	0.500	0.001
3	gamma		1	22	2	0.000	0.000	0.174	0.174	0.000
4	!gamma!		21	22	1	0.000	0.000	-0.174	0.826	0.808
5	(u)	A	12	2	4	0.000	0.000	-0.087	0.413	0.006
6	(u~)	V	11	-2	4	0.000	0.000	-0.087	0.413	0.006
7	(string)		11	92	5	0.000	0.000	-0.174	0.826	0.808
8	(rho0)		11	113	7	0.000	0.000	-0.174	0.826	0.808
9	pi+		1	211	8	-0.355	0.080	0.023	0.390	0.140
10	pi-		1	-211	8	0.355	-0.080	-0.197	0.436	0.140

Continuum state at $E_{cm} = 2$ GeV

I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	(e-)		12	11	0	0.000	0.000	1.000	1.000	0.001
2	(e+)		11	-11	0	0.000	0.000	-1.000	1.000	0.001
3	!gamma!		21	22	1	0.000	0.000	0.000	2.000	2.000
4	(s)	A	12	3	3	0.071	-0.006	-0.977	1.000	0.199
5	(s~)	V	11	-3	3	-0.071	0.006	0.977	1.000	0.199
6	(string)		11	92	4	0.000	0.000	0.000	2.000	2.000
7	(K0)		11	311	6	-0.267	0.022	-0.650	0.861	0.498
8	(K*~0)		11	-313	6	0.267	-0.022	0.650	1.139	0.897
9	(K_S0)		11	310	7	-0.267	0.022	-0.650	0.861	0.498
10	K-		1	-321	8	0.237	-0.235	0.213	0.633	0.494
11	pi+		1	211	8	0.030	0.213	0.436	0.506	0.140
12	(pi0)		11	111	9	-0.207	-0.186	-0.387	0.495	0.135
13	(pi0)		11	111	9	-0.060	0.207	-0.263	0.366	0.135
14	gamma		1	22	12	-0.190	-0.181	-0.268	0.375	0.000
15	gamma		1	22	12	-0.017	-0.004	-0.118	0.120	0.000
16	gamma		1	22	13	-0.042	0.023	-0.129	0.138	0.000
17	gamma		1	22	13	-0.018	0.184	-0.134	0.228	0.000

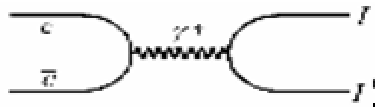
Continuum state at $E_{cm} = 3$ GeV

I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	(e-)		12	11	0	0.000	0.000	1.500	1.500	0.001
2	(e+)		11	-11	0	0.000	0.000	-1.500	1.500	0.001
3	gamma		1	22	1	0.000	0.000	0.034	0.034	0.000
4	!gamma!		21	22	1	0.000	0.000	-0.034	2.966	2.966
5	(u)	A	12	2	4	-1.088	0.832	0.553	1.477	0.006
6	(u~)	V	11	-2	4	1.088	-0.832	-0.587	1.490	0.006
7	(string)		11	92	5	0.000	0.000	-0.034	2.966	2.966
8	(eta)		11	221	7	-0.229	0.066	0.084	0.603	0.548
9	(K*-)		11	-323	7	0.148	-0.031	0.507	0.935	0.771
10	(K0)		11	311	7	-0.185	0.182	-0.832	1.004	0.498
11	pi+		1	211	7	0.266	-0.216	0.208	0.424	0.140
12	(K~0)		11	-311	9	0.129	-0.082	0.570	0.772	0.498
13	pi-		1	-211	9	0.019	0.051	-0.063	0.163	0.140
14	K_L0		1	130	10	-0.185	0.182	-0.832	1.004	0.498
15	K_L0		1	130	12	0.129	-0.082	0.570	0.772	0.498
16	(pi0)		11	111	8	0.045	0.090	0.053	0.177	0.135
17	(pi0)		11	111	8	-0.064	-0.049	0.071	0.172	0.135
18	(pi0)		11	111	8	-0.209	0.024	-0.040	0.253	0.135
19	gamma		1	22	16	0.091	0.077	0.026	0.122	0.000
20	gamma		1	22	16	-0.046	0.013	0.027	0.055	0.000
21	gamma		1	22	17	-0.002	0.034	0.060	0.069	0.000
22	gamma		1	22	17	-0.062	-0.082	0.011	0.104	0.000
23	gamma		1	22	18	-0.020	-0.020	0.035	0.045	0.000
24	gamma		1	22	18	-0.189	0.044	-0.075	0.208	0.000

Event List

J/Ψ production and decay

J/ψ

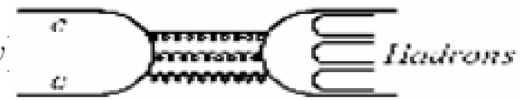


I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.550	1.550	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.550	1.550	0.001
3	gamma		1	22	1	0.000	0.000	-0.003	0.003	0.000
4	!gamma!		21	22	1	0.000	0.000	0.003	3.097	3.097
5	(c)	A	12	4	4	0.000	0.000	0.001	1.549	1.350
6	(c~)	V	11	-4	4	0.000	0.000	0.001	1.549	1.350
7	!J/psi!		21	443	6	0.000	0.000	0.003	3.097	3.097
8	!gamma!		21	22	7	0.000	0.000	0.003	3.097	3.097
9	mu+		1	-13	8	-0.231	-1.489	-0.339	1.548	0.106
10	mu-		1	13	8	0.231	1.489	0.342	1.549	0.106

J/ψ

I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.550	1.550	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.550	1.550	0.001
3	gamma		1	22	1	0.000	0.000	-0.003	0.003	0.000
4	!gamma!		21	22	1	0.000	0.000	0.003	3.097	3.097
5	(c)	A	12	4	4	0.000	0.000	0.001	1.549	1.350
6	(c~)	V	11	-4	4	0.000	0.000	0.001	1.549	1.350
7	!J/psi!		21	443	6	0.000	0.000	0.003	3.097	3.097
8	!gamma!		21	22	7	0.000	0.000	0.003	3.097	3.097
9	(u)	A	12	2	8	1.523	-0.039	-0.276	1.548	0.006
10	(u~)	V	11	-2	8	-1.523	0.039	0.278	1.549	0.006
11	(string)		11	92	9	0.000	0.000	0.003	3.097	3.097
12	pi-		1	-211	11	-0.160	0.078	-0.035	0.229	0.140
13	(eta')		11	331	11	1.327	0.134	-0.182	1.652	0.958
14	pi+		1	211	11	-1.168	-0.212	0.224	1.216	0.140
15	pi+		1	211	13	0.127	0.006	-0.178	0.260	0.140
16	pi-		1	-211	13	0.200	-0.002	-0.023	0.245	0.140
17	(eta)		11	221	13	1.000	0.129	0.019	1.148	0.548
18	gamma		1	22	17	0.033	-0.067	0.135	0.154	0.000
19	gamma		1	22	17	0.967	0.196	-0.116	0.994	0.000

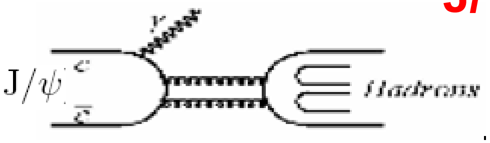
J/ψ



I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.550	1.550	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.550	1.550	0.001
3	!gamma!		21	22	1	0.000	0.000	0.000	3.100	3.100
4	(c)	A	12	4	3	0.000	0.000	0.000	1.550	1.350
5	(c~)	V	11	-4	3	0.000	0.000	0.000	1.550	1.350
6	!J/psi!		21	443	5	0.000	0.000	0.000	3.100	3.097
7	(g)	A	11	21	6	-0.539	-0.223	0.264	0.641	0.000
8	(g)	V	11	21	6	1.332	0.113	-0.737	1.528	0.000
9	(g)	A	11	21	6	-0.793	0.110	0.473	0.931	0.000
10	(d)	I	12	1	7	-0.082	-0.024	0.030	0.091	0.010
11	(d~)	I	12	-1	7	-0.457	-0.199	0.234	0.550	0.010
12	(u)	I	12	2	8	0.044	0.101	-0.076	0.134	0.006
13	(u~)	I	12	-2	8	1.289	0.012	-0.661	1.394	0.006
14	(d)	I	12	1	9	-0.235	0.213	0.189	0.369	0.010
15	(d~)	V	11	-1	9	-0.558	-0.103	0.284	0.562	0.010
16	(string)		12	92	10	1.206	-0.012	-0.632	1.485	0.593
17	(string)		12	92	12	-0.514	-0.002	0.208	0.695	0.419
18	(string)		11	92	14	-0.692	0.014	0.423	0.919	0.432
19	pi-		1	-211	16	0.455	0.033	-0.054	0.480	0.140
20	pi+		1	211	16	0.172	0.010	-0.188	0.291	0.140
21	pi-		1	-211	16	0.579	-0.055	-0.390	0.714	0.140
22	pi+		1	211	17	-0.332	-0.131	0.204	0.434	0.140
23	(pi0)		11	111	17	-0.182	0.130	0.005	0.261	0.135
24	pi-		1	-211	18	-0.342	-0.147	0.142	0.422	0.140
25	pi+		1	211	18	-0.350	0.161	0.202	0.497	0.140

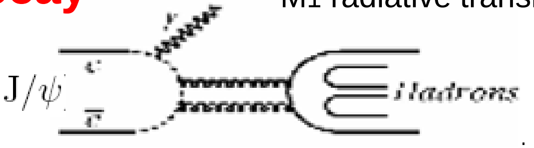
Event List

J/Ψ production and decay



I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.550	1.550	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.550	1.550	0.001
3	gamma		1	22	1	0.000	0.000	-0.003	0.003	0.000
4	!gamma!		21	22	1	0.000	0.000	0.003	3.097	3.097
5	(c)	A	12	4	4	0.000	0.000	0.002	1.548	1.350
6	(c~)	V	11	-4	4	0.000	0.000	0.002	1.548	1.350
7	!J/psi!		21	443	6	0.000	0.000	0.003	3.097	3.097
8	gamma		1	22	7	0.139	-0.478	-0.518	0.719	0.000
9	(g)	A	11	21	7	-0.830	0.017	-0.570	1.007	0.000
10	(g)	V	11	21	7	0.691	0.461	1.091	1.371	0.000
11	(d)	A	12	1	9	-0.276	0.479	-0.346	0.652	0.010
12	(d~)	I	12	-1	9	-0.554	-0.462	-0.224	0.355	0.010
13	(s)	I	12	3	10	0.265	-0.010	0.349	0.481	0.199
14	(s~)	V	11	-3	10	0.426	0.471	0.743	0.890	0.199
15	(string)		12	92	11	0.150	0.950	0.397	1.542	1.139
16	(string)		11	92	12	-0.289	-0.472	0.124	0.836	0.614
17	pi-		1	-211	15	-0.139	0.713	-0.102	0.747	0.140
18	K+		1	321	15	0.289	0.237	0.500	0.796	0.494
19	gamma		1	22	16	0.006	-0.171	-0.004	0.171	0.000
20	(K~0)		11	-311	16	-0.295	-0.301	0.129	0.665	0.498

M1 radiative transition



I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.549	1.549	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.551	1.552	0.001
3	gamma		1	22	2	0.000	0.000	0.003	0.003	0.000
4	!gamma!		21	22	1	0.000	0.000	-0.006	3.097	3.097
5	(c)	A	12	4	4	0.000	0.000	-0.003	1.549	1.350
6	(c~)	V	11	-4	4	0.000	0.000	-0.003	1.549	1.350
7	!J/psi!		21	443	6	0.000	0.000	-0.006	3.097	3.097
8	gamma		1	22	7	0.022	-0.105	-0.042	0.115	0.000
9	(eta_c)		11	441	7	-0.022	0.105	0.036	2.982	2.979
10	(g)	A	12	21	9	0.129	0.490	1.435	1.523	0.000
11	(g)	V	11	21	9	-0.151	-0.385	-1.399	1.459	0.000
12	(u)	A	12	2	10	0.146	-0.094	0.478	0.509	0.006
13	(u~)	I	12	-2	10	-0.017	0.584	0.957	1.014	0.006
14	(d)	I	12	1	11	0.018	-0.066	-0.235	0.245	0.010
15	(d~)	V	11	-1	11	-0.169	-0.319	-1.164	1.214	0.010
16	(string)		12	92	12	-0.023	-0.413	-0.686	1.723	1.526
17	(string)		11	92	13	0.001	0.518	0.722	1.258	0.891
18	pi+		1	211	16	0.129	-0.147	-0.565	0.614	0.140
19	(K0)		11	311	16	0.083	-0.170	0.021	0.533	0.498
20	(K~0)		11	-311	16	-0.235	-0.096	-0.142	0.576	0.498
21	(pi0)		11	111	17	0.029	0.317	0.476	0.588	0.135
22	pi-		1	-211	17	-0.158	0.064	0.352	0.415	0.140
23	(pi0)		11	111	17	0.130	0.136	-0.105	0.255	0.135

Event List

Ψ(2S) production and decay

$$\psi(2S) \rightarrow \pi^+\pi^- J/\psi$$

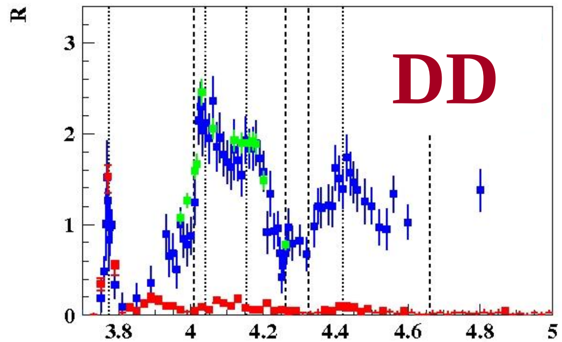
I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.844	1.844	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.844	1.844	0.001
3	gamma		1	22	2	0.000	0.000	-0.003	0.003	0.000
4	!gamma!		21	22	1	0.000	0.000	0.003	3.686	3.686
5	(c)	A	12	4	4	0.000	0.000	0.002	1.843	1.350
6	(c~)	V	11	-4	4	0.000	0.000	0.002	1.843	1.350
7	!psi3686!		21	100443	6	0.000	0.000	0.003	3.686	3.686
8	pi+		1	211	7	-0.206	-0.102	-0.074	0.279	0.140
9	pi-		1	-211	7	-0.186	-0.146	-0.010	0.275	0.140
10	(J/psi)		11	443	7	0.392	0.248	0.087	3.133	3.097
11	(g)	A	11	21	10	-0.415	-0.607	-0.243	0.775	0.000
12	(g)	V	11	21	10	1.400	0.164	0.074	1.412	0.000
13	(g)	A	11	21	10	-0.593	0.691	0.256	0.946	0.000
14	(s)	I	12	3	11	-0.230	-0.436	-0.136	0.548	0.199
15	(s~)	I	12	-3	11	-0.185	-0.172	-0.108	0.226	0.199
16	(u)	I	12	2	12	0.718	-0.424	0.044	0.835	0.006
17	(u~)	I	12	-2	12	0.682	0.588	0.031	0.577	0.006
18	(u)	I	12	2	13	-0.102	0.795	0.225	0.832	0.006
19	(u~)	V	11	-2	13	-0.491	-0.104	0.031	0.114	0.006
20	(string)		12	92	14	0.452	0.152	-0.105	1.125	1.014
21	(string)		12	92	16	0.226	-0.528	0.075	0.948	0.751
22	(string)		11	92	18	-0.287	0.623	0.118	1.059	0.798
23	(K~0)		11	-311	20	-0.072	0.172	-0.211	0.572	0.498
24	pi-		1	-211	20	0.525	-0.020	0.106	0.554	0.140
25	(pi0)		11	111	21	0.424	-0.401	-0.152	0.618	0.135
26	(pi0)		11	111	21	-0.020	0.069	0.283	0.321	0.135
27	gamma		1	22	22	-0.279	0.185	0.206	0.393	0.000
28	K+		1	321	22	-0.008	0.439	-0.088	0.666	0.494

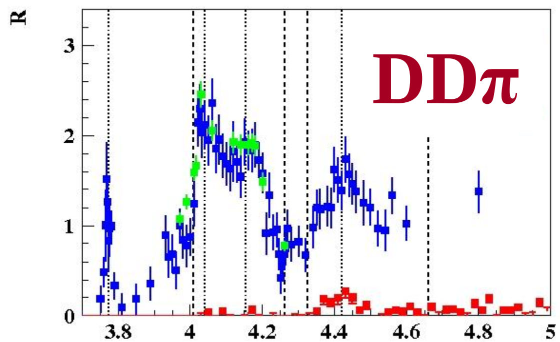
$$\psi(2S) \rightarrow \eta J/\psi$$

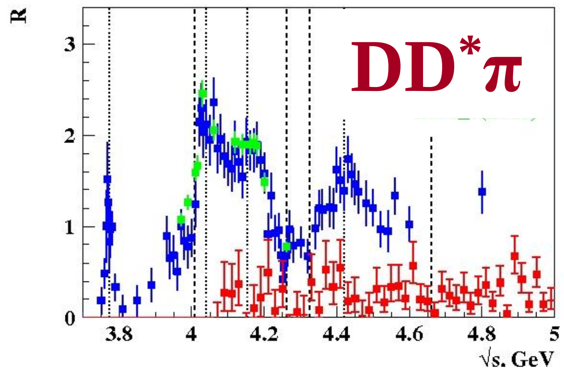
I	particle		KS	KF	orig	p_x	p_y	p_z	E	m
1	!e-!		21	11	0	0.000	0.000	1.844	1.844	0.001
2	!e+!		21	-11	0	0.000	0.000	-1.844	1.844	0.001
3	!gamma!		21	22	1	0.000	0.000	0.000	3.689	3.689
4	(c)	A	12	4	3	0.000	0.000	0.000	1.844	1.350
5	(c~)	V	11	-4	3	0.000	0.000	0.000	1.844	1.350
6	!psi3686!		21	100443	5	0.000	0.000	0.000	3.689	3.686
7	(eta)		11	221	6	-0.105	0.068	0.155	0.583	0.548
8	(J/psi)		11	443	6	0.105	-0.068	-0.155	3.106	3.097
9	!gamma!		21	22	8	0.105	-0.068	-0.155	3.106	3.097
10	(u)	A	12	2	9	0.425	-0.555	1.333	1.506	0.006
11	(u~)	V	11	-2	9	-0.320	0.487	-1.488	1.599	0.006
12	(string)		11	92	10	0.105	-0.068	-0.155	3.106	3.099
13	(eta)		11	221	12	0.759	0.111	1.091	1.443	0.548
14	(pi0)		11	111	12	-0.479	-0.022	-0.485	0.696	0.135
15	(eta)		11	221	12	-0.175	-0.157	-0.761	0.967	0.548
16	pi-		1	-211	13	0.263	-0.049	0.409	0.509	0.140
17	pi+		1	211	13	0.137	0.157	0.311	0.400	0.140
18	(pi0)		11	111	13	0.359	0.003	0.370	0.534	0.135
19	gamma		1	22	14	-0.016	0.015	0.002	0.022	0.000
20	gamma		1	22	14	-0.463	-0.038	-0.487	0.673	0.000
21	gamma		1	22	15	0.129	-0.073	-0.588	0.607	0.000
22	gamma		1	22	15	-0.304	-0.084	-0.173	0.360	0.000
23	gamma		1	22	18	0.313	-0.015	0.243	0.396	0.000
24	gamma		1	22	18	0.047	0.018	0.128	0.137	0.000

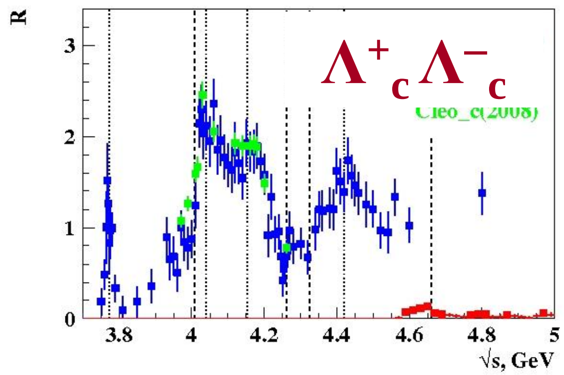
Main problems in generator tuning

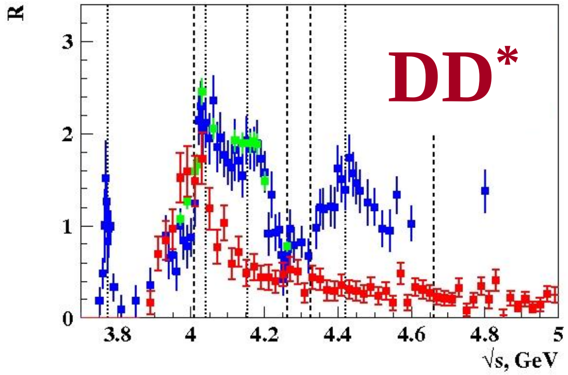
- Some of free parameters in LUARLW need to tune via comparing the related experimental data.
- Before parameter tuning, one has to have a set of event selection criteria and obtain a group of hadronic spectra.
- For data below open charm threshold, hadronic events selection conditions are almost fixed. But for the data newly taken above 3.85 GeV, we are studying the criteria for DD states, there are many problems to discuss.

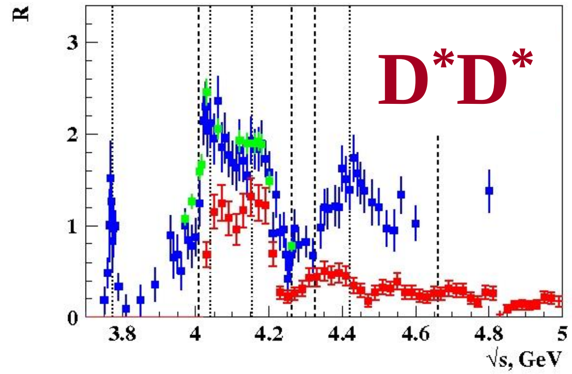




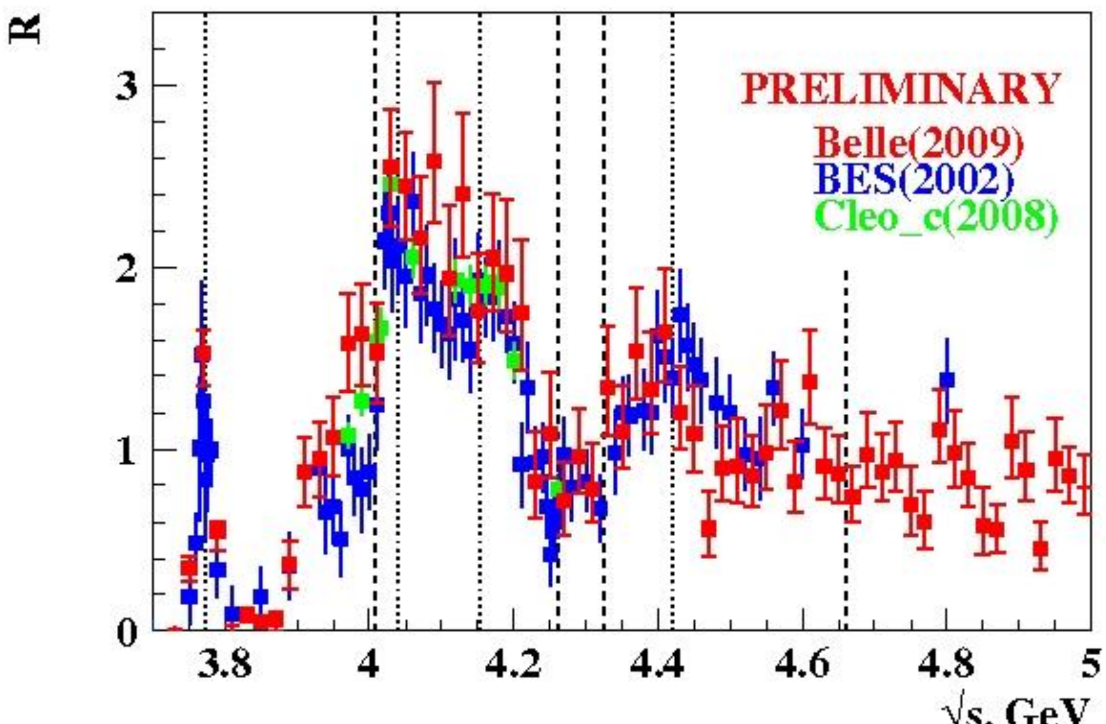








Sum of all exclusive contributions



Only small room for unaccounted contributions

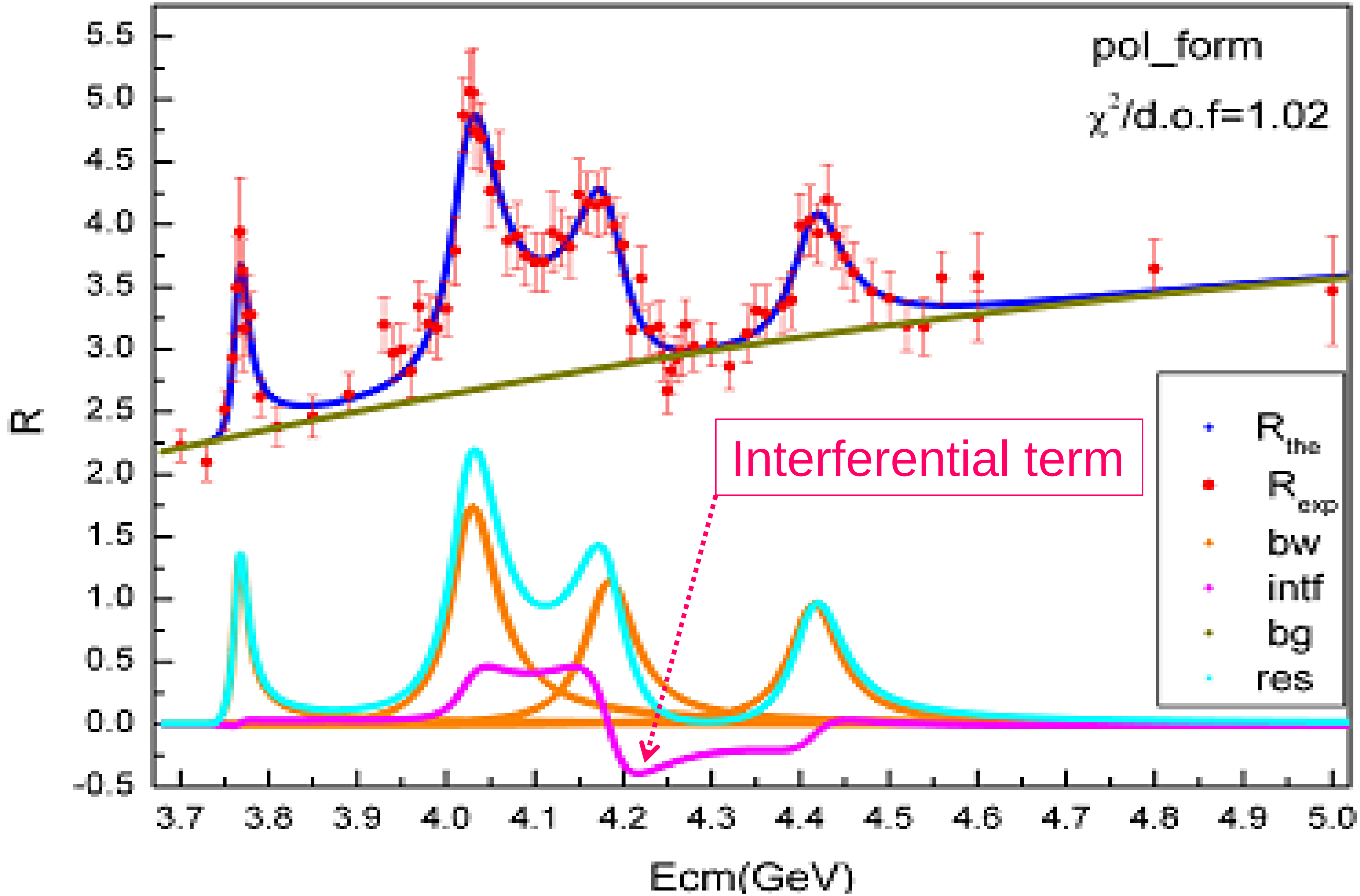
- **Charm strange final states**

Limited inclusive data above 4.5 GeV

- **Charm baryons final states**

Interferential in resonant line shape

For example, the line shape of heavier Ψ family

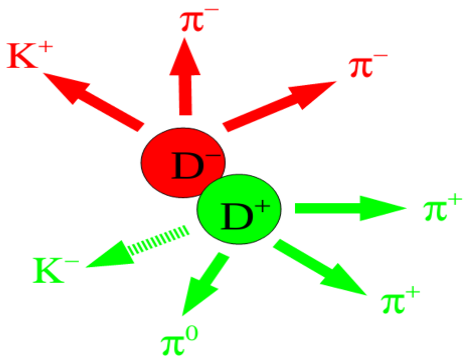


D tag

- Hadron D decay reconstruction to find all possible D candidates (tags)
- Check the D tag information if no tag is found, the event is discarded
- Only the events with tags are kept , and compare data with MC
- Tag methods : single D tag and Double D tag

D tag

D-Tag Candidates (1)



- $\Delta E = E_D - E_{beam}$
- $m_{BC} = \sqrt{E_{beam}^2 - P_D^2}$
- D^0 modes : $K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^+\pi^-\pi^-$
- D^+ modes: $K\text{-}\pi\text{+}\pi\text{+}$, $K\pi^+\pi^+\pi^0$, $K_s\pi^+$, $K_s\pi^+\pi^0$, $K_s\pi^+\pi^+\pi^-$, $K^-K^+\pi^+$
- D_s^+ modes: $K_sK^+, K^-K^+\pi^+, K_sK^+\pi^0$
- Charge-conjugate modes implied

D tag

D-Tag Candidates (2)

- Ingredients:
  - charged K/π pass vertex and PID cuts
  - Ks from $\pi^+\pi^+$, π^0 from $\gamma\gamma$, invariant mass cuts
- Cut on ΔE and fit m_{BC} distributions to extract yields
- Analyze MC samples with same procedure
- Compare Data's distribution with MC's

Summary for D tag prestudy

1. **Summary**
   - Observe obviously signals for $e^+e^- \to D\bar{D}, D\bar{D}^*$ with D tag at energy $\Upsilon(4260)$, $\Upsilon(4230)$, $\Upsilon(4360)$ and scan data at $\Upsilon(4260)$, $\Upsilon(4360)$.
   - A very preliminary observed cross section for $D_s^+ D_s^{*-}$ mode is presented with the statistic error only (without implying the charged-conjugate mode).
2. **Next to do**
   - Carefully check for every tag channel
   - Detailed background study
   - Improve fitting method (the current fit is very preliminary).
   - Understand ISR effect
   - Systematic error study
   -

Procedure of R measurement

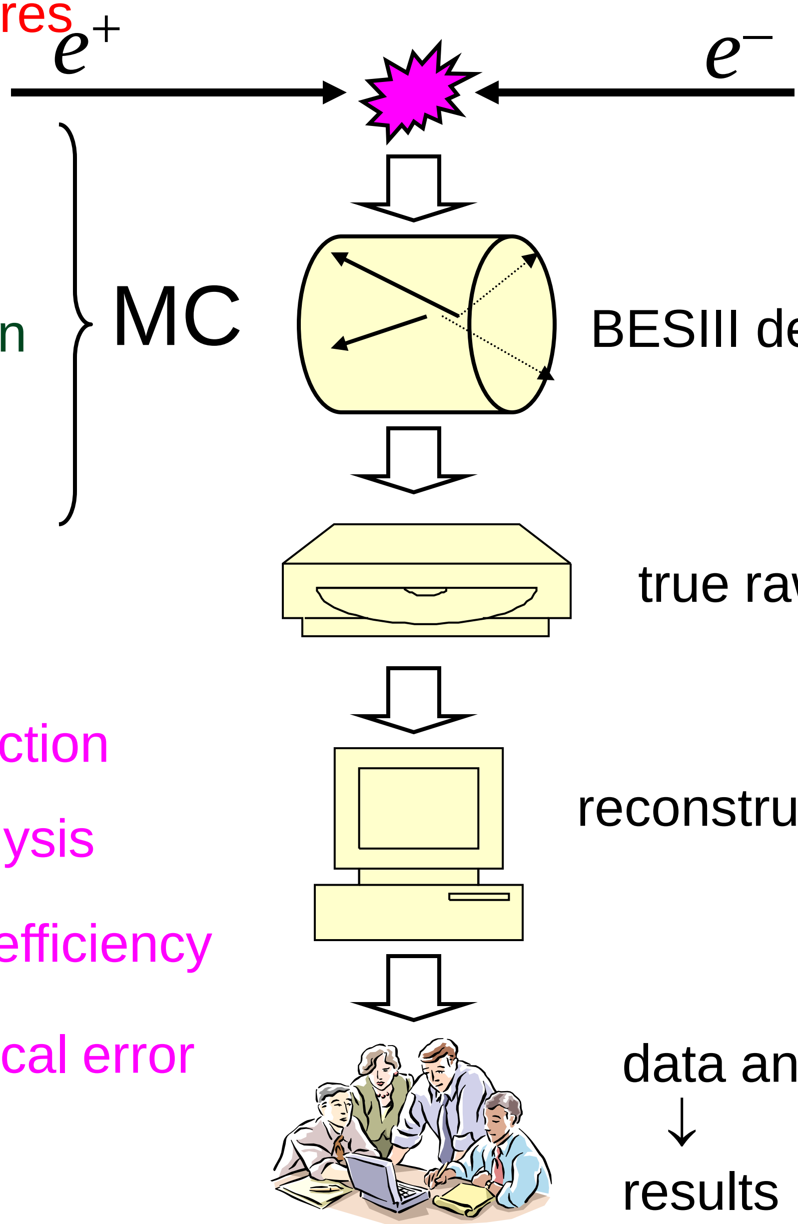
Simulation procedures

generator

event simulation

detector simulation

MC



True processes

$e^+ e^-$ collide

event produce

BESIII detector

hit, interaction, production, decay, noise, BG, signal

MC raw data

true raw data

trigger, digital, data record

MC
- reconstruction
- data analysis
- detector efficiency
- systematical error

reconstruction

calibration tracking

data analysis

↓

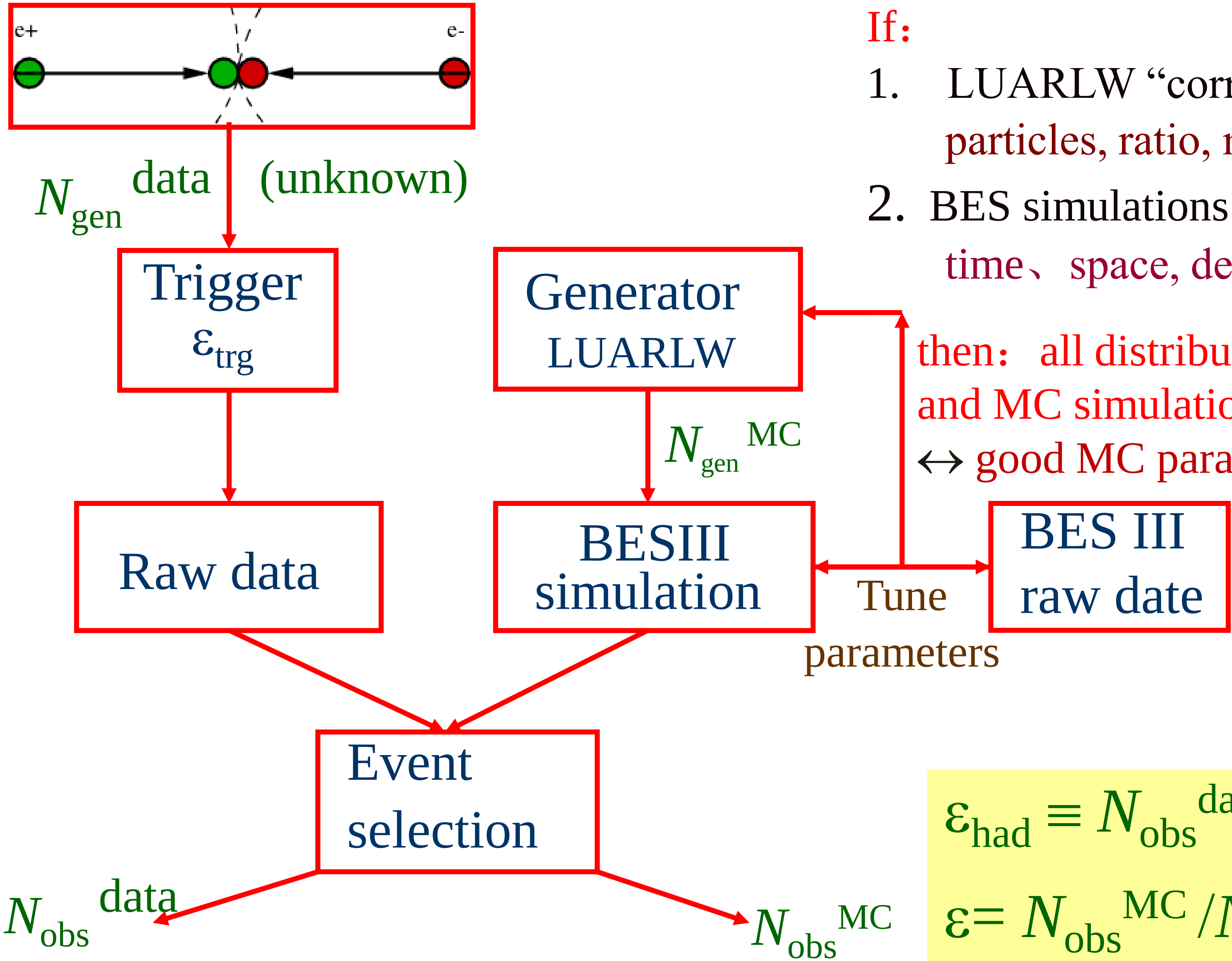
results

BGs, signal

central value ± error

Parameters Tuning Flow Chart

Compare true data with MC simulated distributions



If：

1. LUARLW "correct"
   particles, ratio, momentum …
2. BES simulations reliable
   time、space, decay…

then： all distributions of data and MC simulations agree well
↔ good MC parameters set

$$\varepsilon_{had} \equiv N_{obs}^{data}/N_{gen}^{data}$$

$$\varepsilon = N_{obs}^{MC}/N_{gen}^{MC}$$