Updates on measurement of $\boldsymbol{e^+e^- \to \eta h_c}$ cross section

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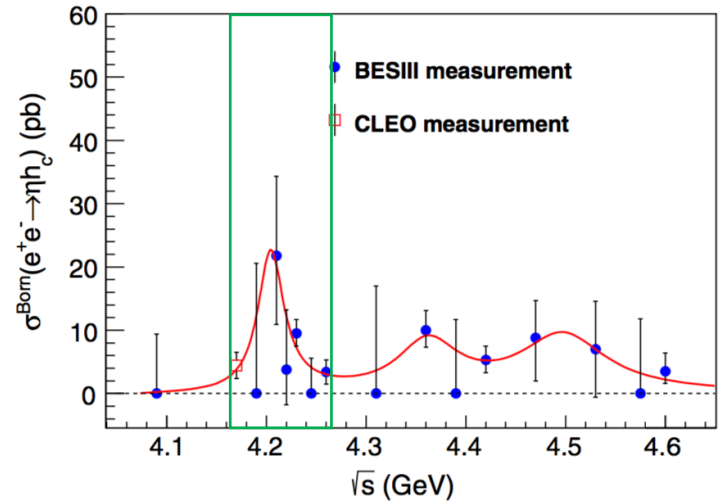
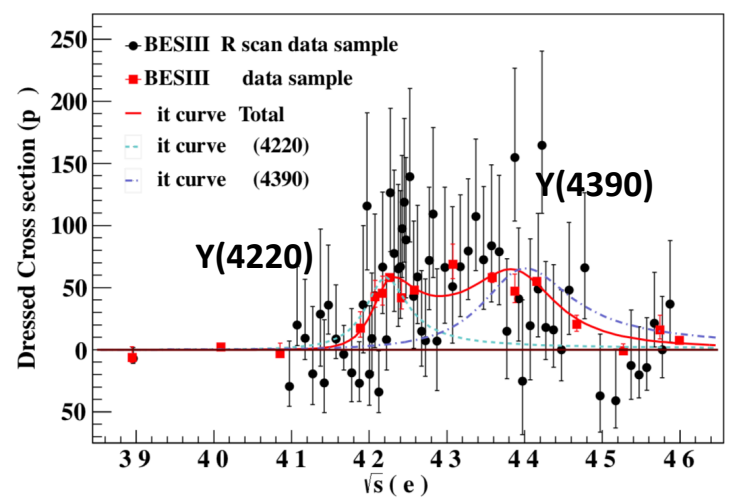
Motivation

- The previous observations show a hint of new resonance around 4.2 GeV but we can't draw a clear conclusion because of the limited statistics.
- Similar structure also was observed in $e^+e^- \to \pi\pi h_c$, The strong coupling to h_c indicate this structure likely to be a hybrid.
- Shed light on the nature of Y(4260)
  - Is it one state? Recent study of exclusive process $e^+e^- \to \pi^+\pi^- J/\psi, \pi^+\pi^- h_c$ shows a fine structure near 4.2 GeV
  - Is it hybrid state?

PRD96, 012001 (2017)



PRL 118, 092002 (2017)



Data sets and event topology

Event topology:

$e^+e^- \to \eta h_c; h_c \to \gamma\eta_c; \eta_c \to$Xi;

Data sets:

2016:

- 4180 : 3160 pb^{-1}

2017:

- 4190 : 521.9 pb^{-1}
- 4200: 523.7 pb^{-1}
- 4210: 511.2 pb^{-1}
- 4220: 508.2 pb^{-1}
- 4237: 528.9 pb^{-1}
- 4246: 532.7 pb^{-1}
- 4270: 529.3 pb^{-1}
- 4280: 174.5 pb^{-1}

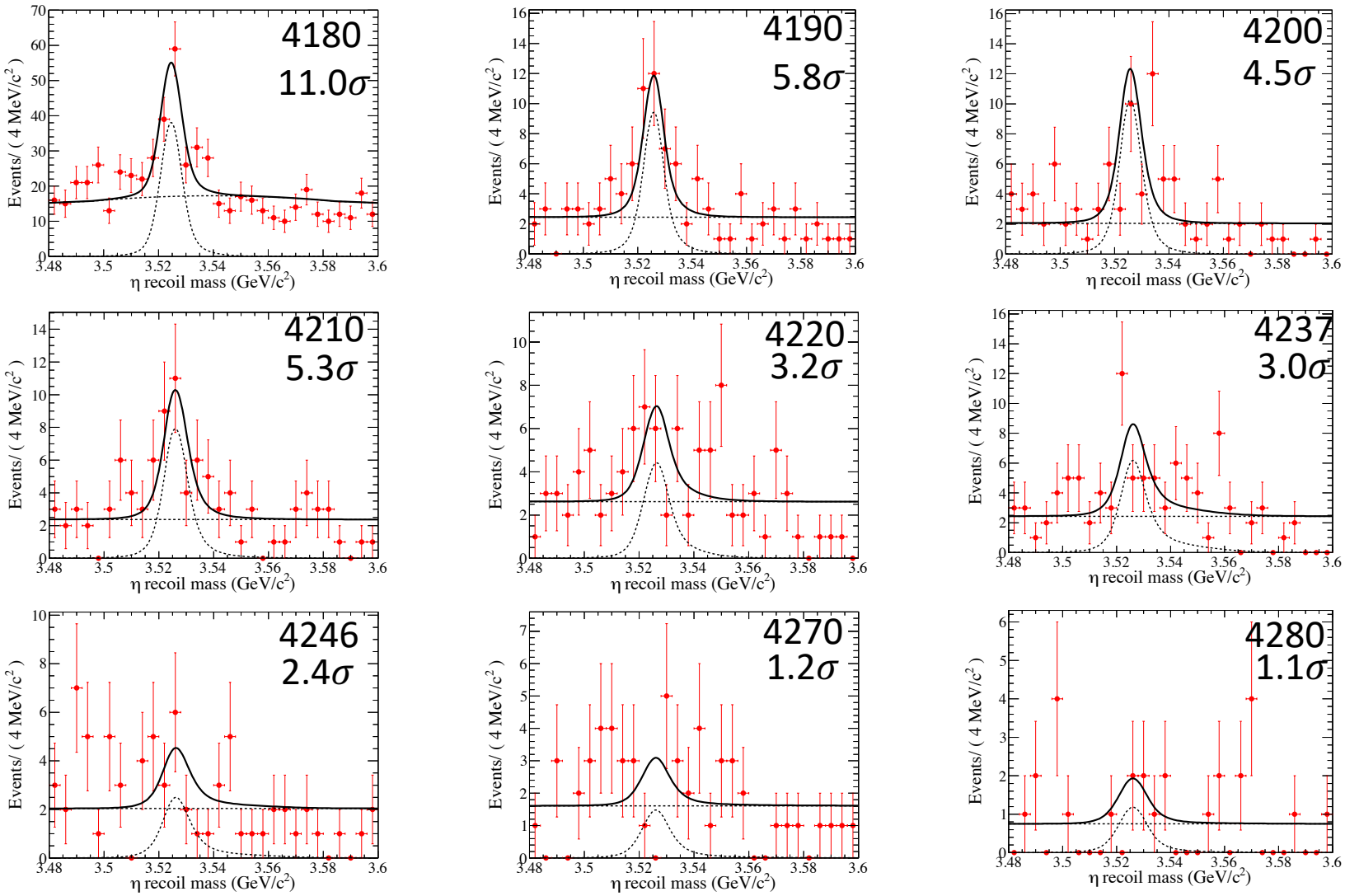
Decay mode	BR
$\eta_c \to \boldsymbol{p\bar{p}}$	~0.13%
$\eta_c \to \pi^+\pi^-\boldsymbol{p\bar{p}}$	~0.45%
$\eta_c \to 2(\pi^+\pi^-)$	~1.20%
$\eta_c \to 2(K^+K^-)$	~0.15%
$\eta_c \to \pi^+\pi^-K^+K^-$	~1.50%
$\eta_c \to 3(\pi^+\pi^-)$	~2.00%
$\eta_c \to K^+K^- 2(\pi^+\pi^-)$	~1.00%
$\eta_c \to K^+K^-\pi^0$	~1.20%
$\eta_c \to \boldsymbol{p\bar{p}}\pi^0$	~0.18%
$\eta_c \to K_SK\pi$	~1.80%
$\eta_c \to K_SK3\pi$	~2.40%
$\eta_c \to \pi^+\pi^-\eta$	~1.60%
$\eta_c \to K^+K^-\eta$	~0.57%
$\eta_c \to 2(\pi^+\pi^-)\,\eta$	~2.70%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%
$\eta_c \to 2(\pi^+\pi^-)\,\pi^0\pi^0$	~11.0%

Brief review of data analysis

- Standard criteria are used to reconstruct charged tracks, photon, π^0 η and K_S^0 candidates
- 4c and 5c kinematic fit are performed
- Get the best candidates

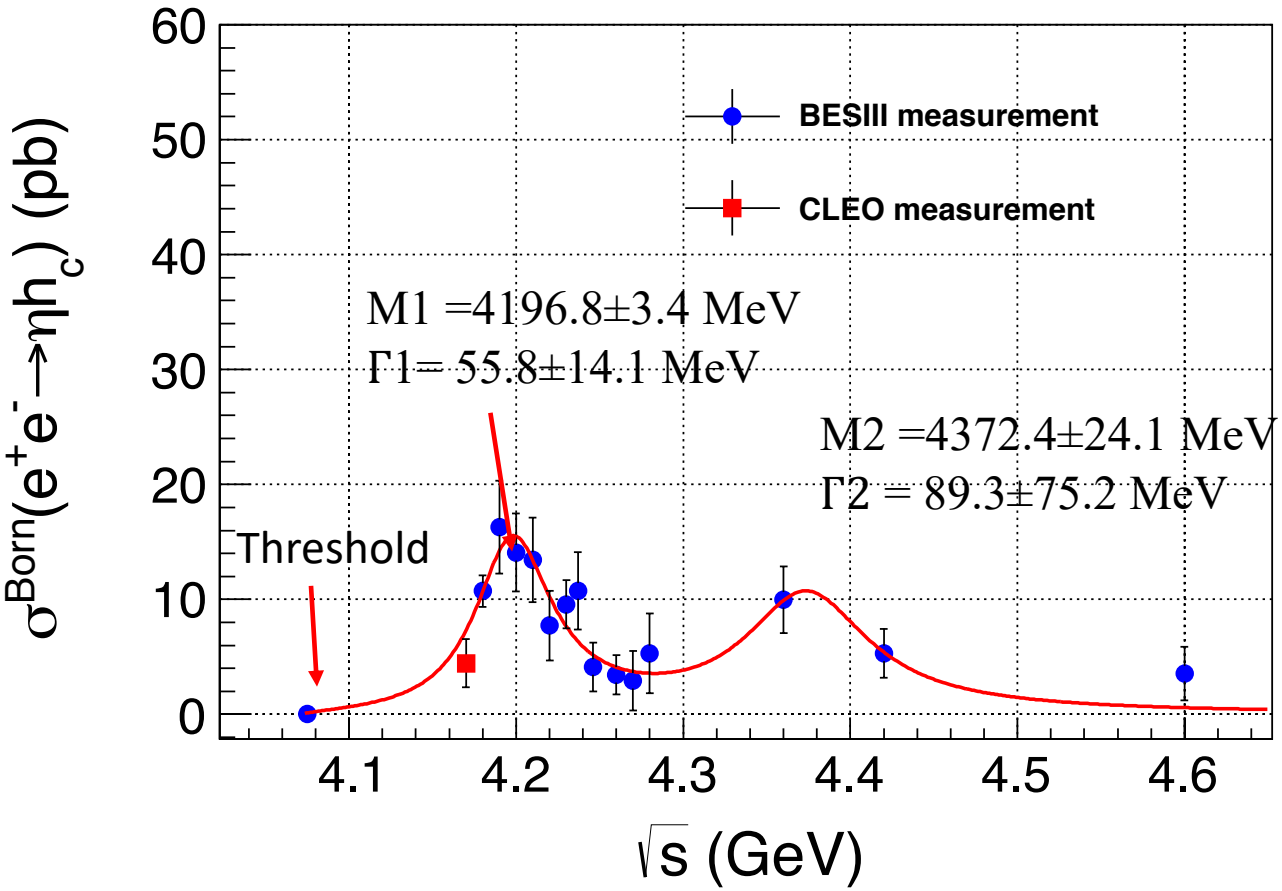
  Minimize: $\chi^2_{sum} = \chi^2_{4C} + \chi^2_{1C} + \chi^2_{vertex} + \chi^2_{PID}$
- Chisq requirement, mass(energy) windows are quoted from previous analysis
- 16 channels are fitted simultaneously with unbinned maximum likelihood method
  - Signal shape: MC simulation.
  - Background shape: Polynomial function.
  - Relative signal yield of each channel: $Br(\eta_c \rightarrow Xi) \times \varepsilon(i)$

Result at 2018 Phys.&Soft. meeting

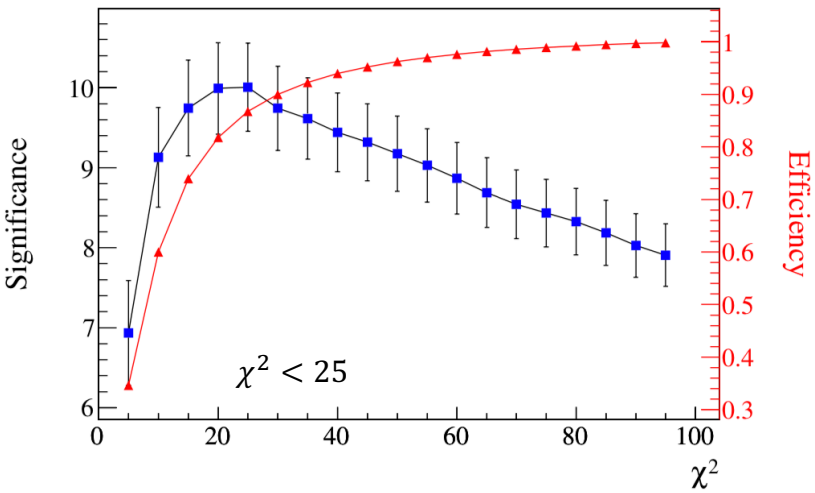


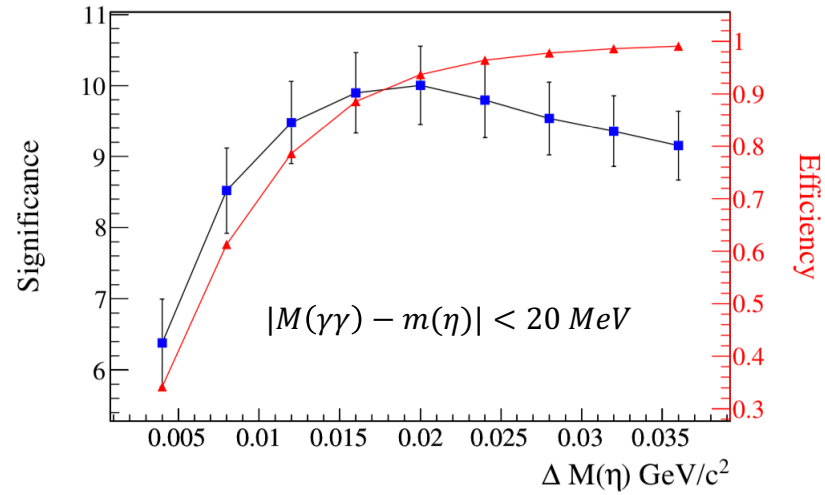
Fit to energy dependent cross section

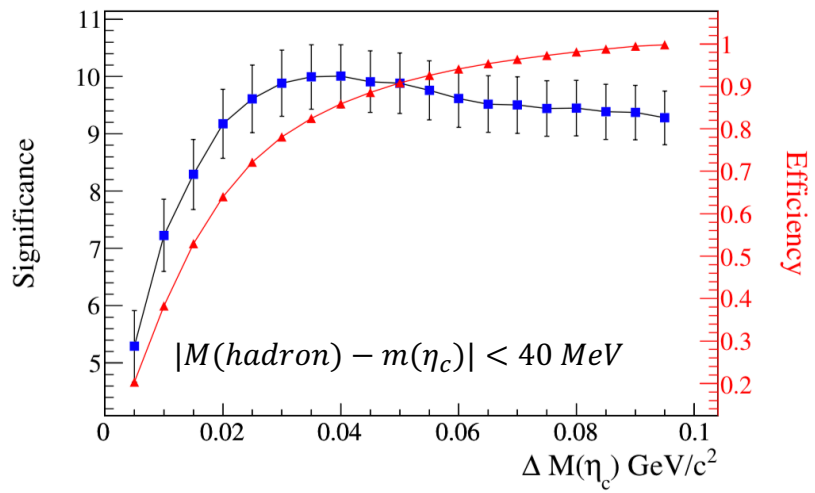
Line shape: two coherent BW functions.
parameters of the two BW are free

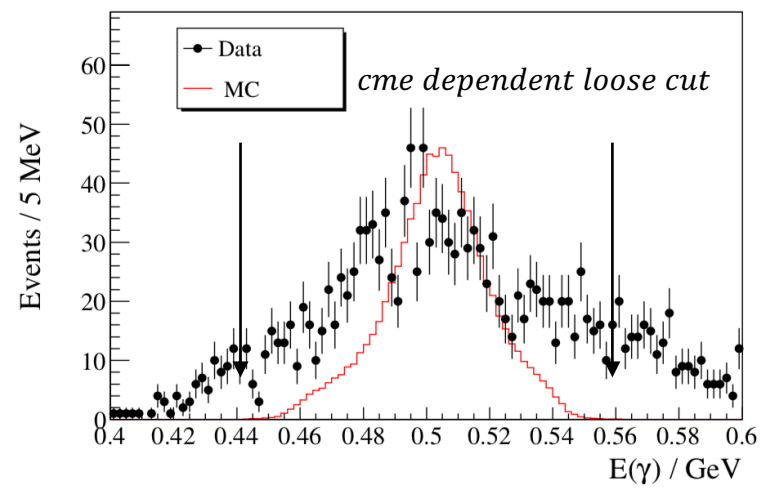


Recent progress



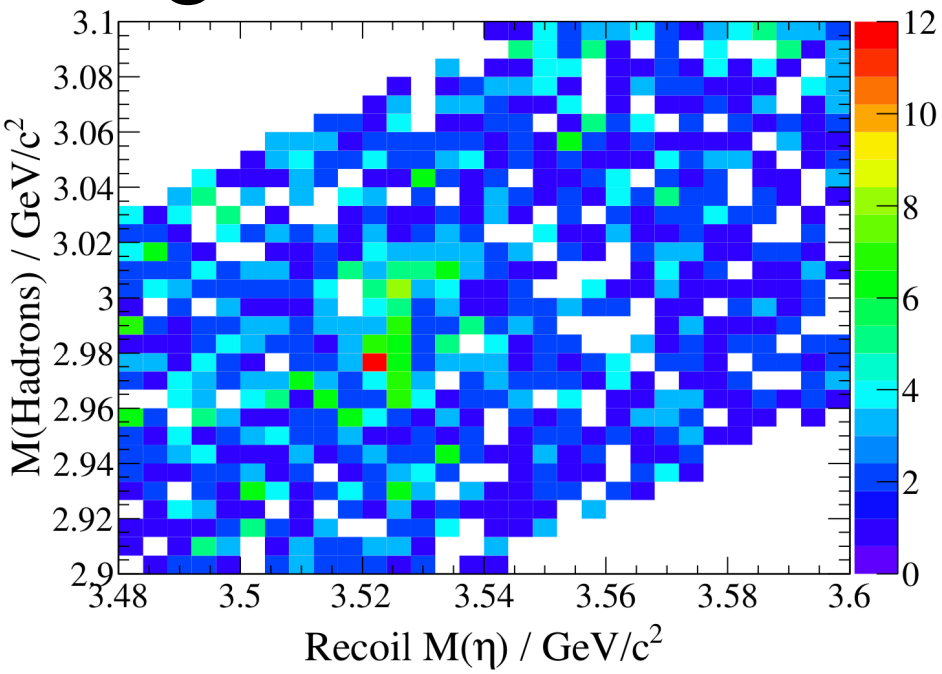






Data sets taken at 4180,4190,4200,4210 MeV are used

Study of background



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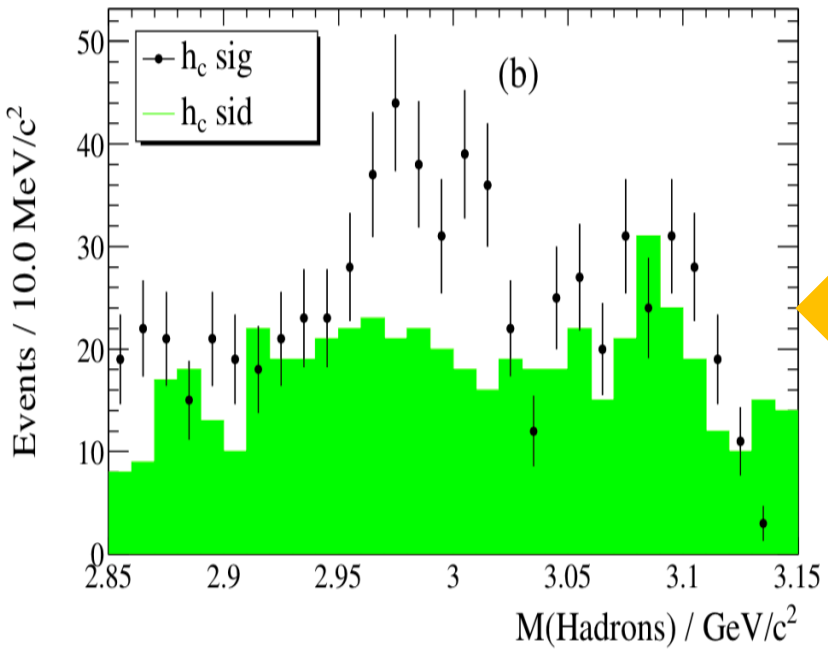
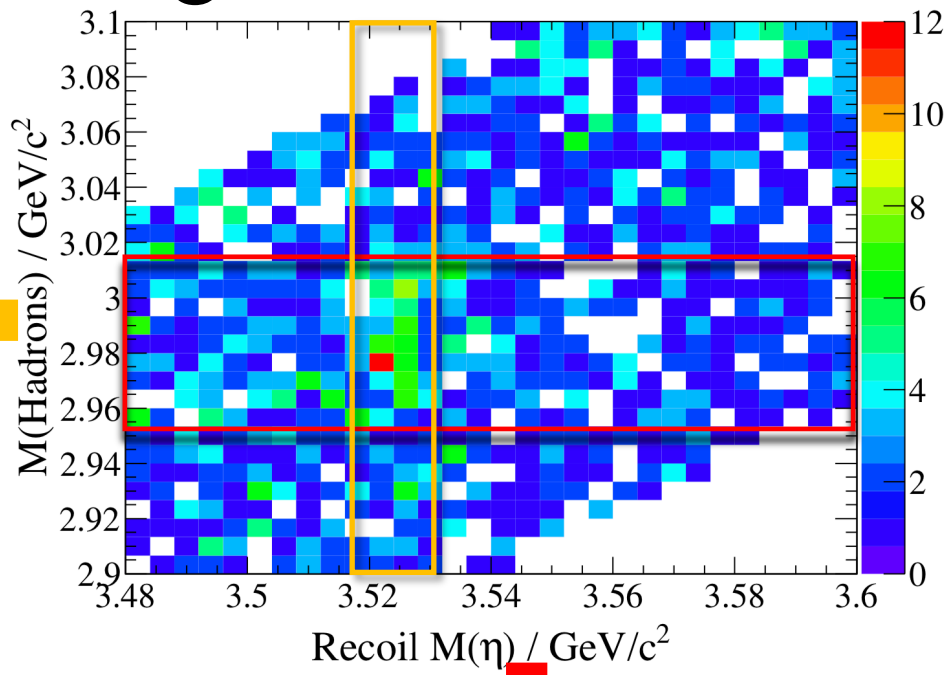
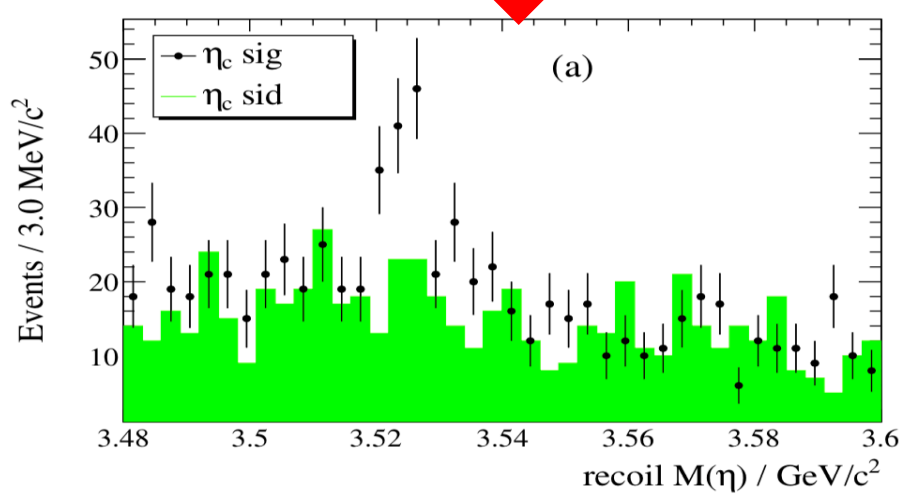
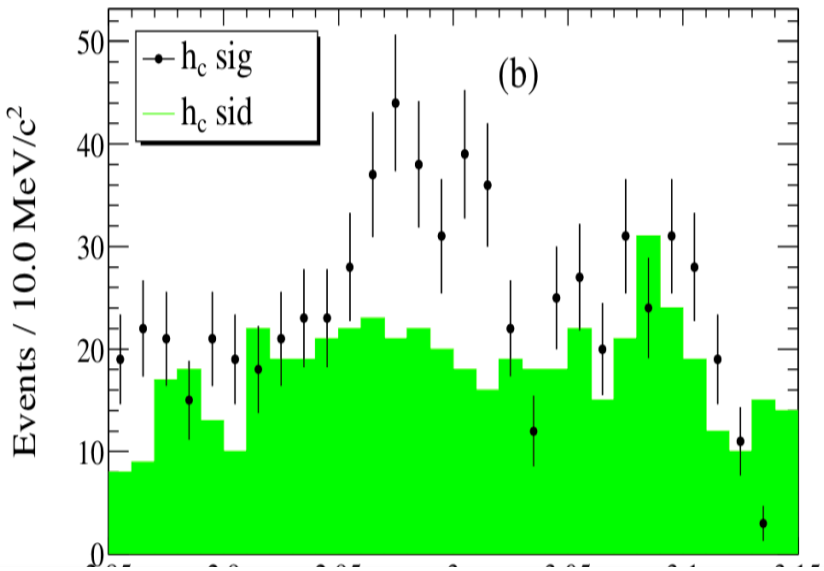
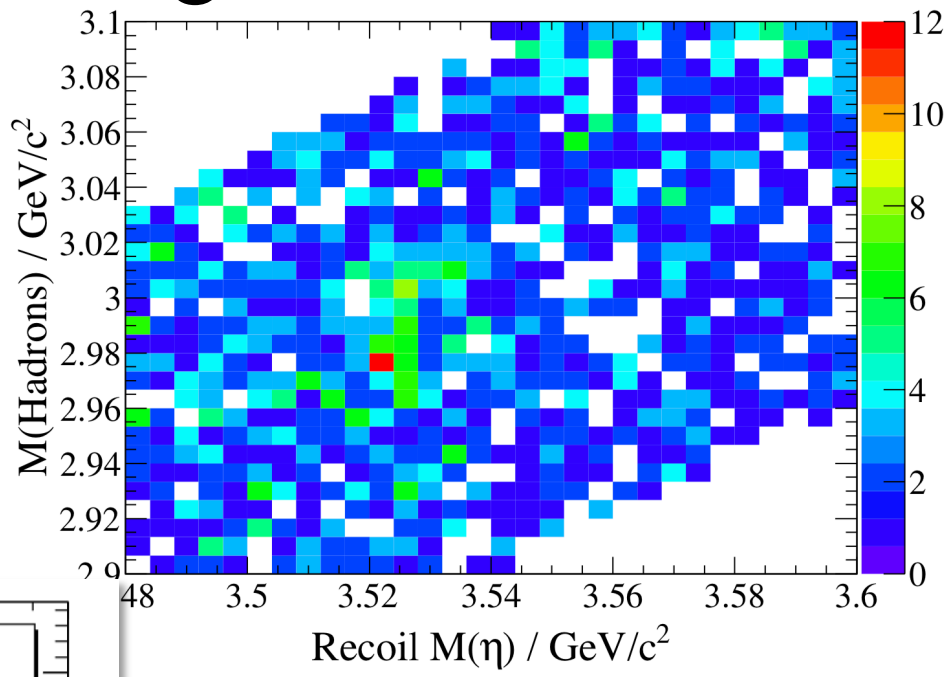


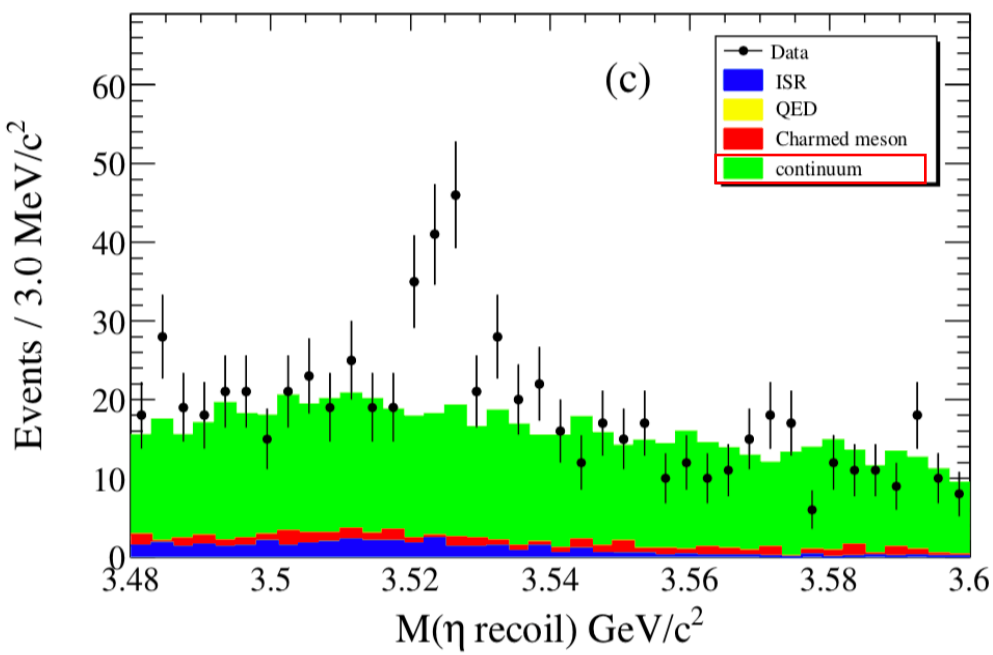


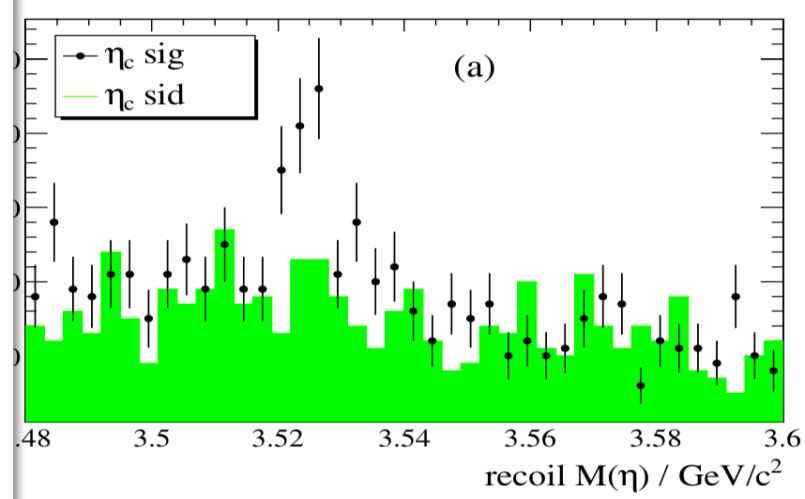


Study of background



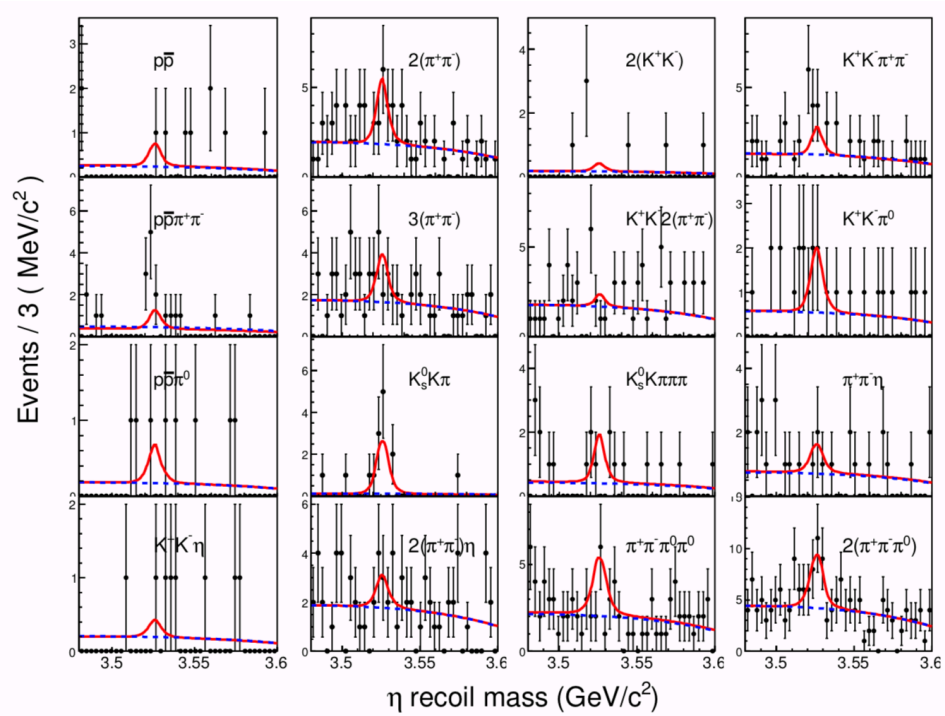




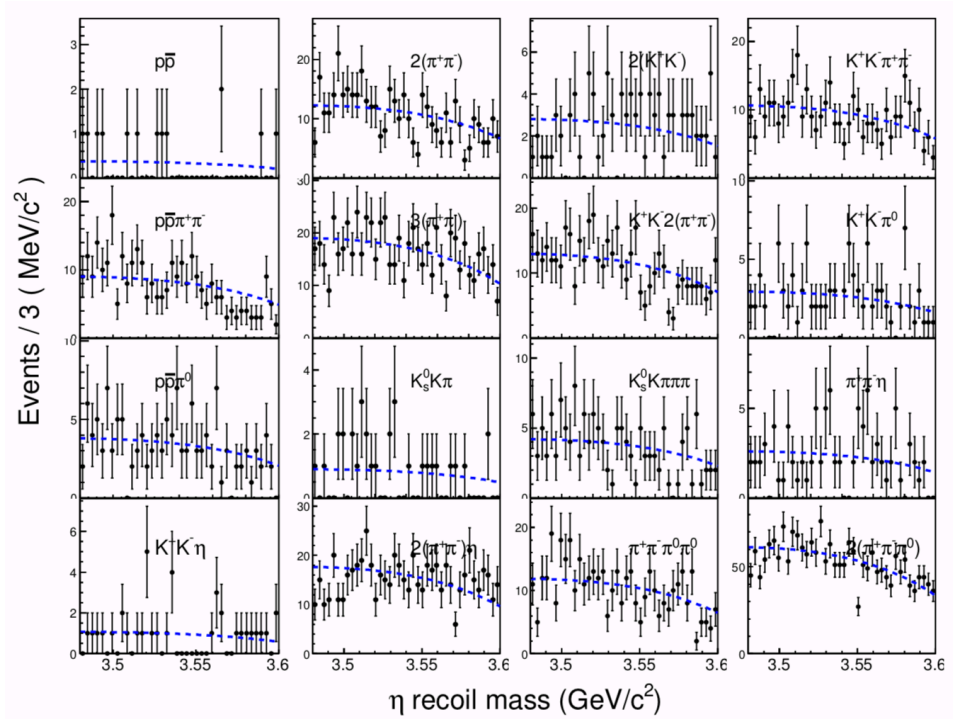


Fit to recoil mass of η @ 4180 MeV

Data



Inclusive MC



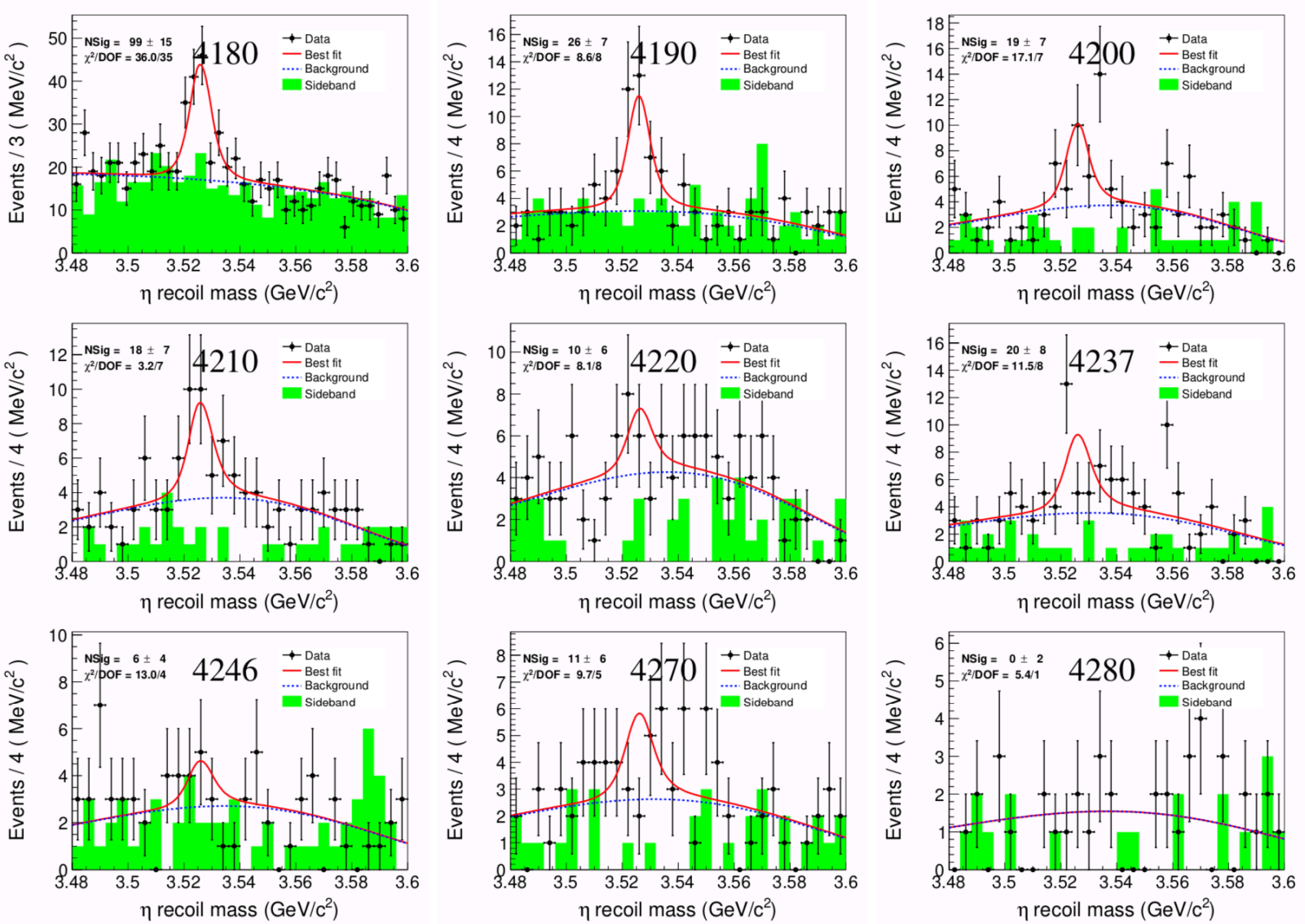
Unbinned maximum likelihood fit is performed to data and inclusive MC simultaneously

Signal: MC simulation.

Background: Argus function. Inclusive MC and data share the same parameters

Signal yield: Constrained by Br*ϵ

Fit results at all data-sets



C.M. energy dependent cross section

$$\sigma^{\mathrm{Born}}(e^+e^- \to \eta h_c) = \frac{N_{\mathrm{obs}}}{\mathcal{L}(1+\delta)|1+\Pi|^2\mathcal{B}(\eta \to \gamma\gamma)\mathcal{B}(h_c \to \gamma\eta_c)\Sigma_i\epsilon_i\mathcal{B}_i}.$$

$E_{c.m.}$ (MeV)	Luminosity	N_{sig}	$(1+\delta)$	$\lvert 1+\Pi\rvert^2$	$\sigma^{Born}(pb)$	significance
4180.0	3189.0	99 ± 15	0.73	1.056	8.4 ± 1.3	$8.3\,\sigma$
4190.0	521.9	26 ± 7	0.74	1.056	14.4 ± 4.1	$4.9\,\sigma$
4200.0	523.7	19 ± 7	0.76	1.056	9.5 ± 3.4	$3.2\,\sigma$
4210.0	511.2	19 ± 7	0.80	1.057	9.3 ± 3.4	$3.7\,\sigma$
4220.0	508.2	10 ± 6	0.85	1.057	4.8 ± 2.7	$2.0\,\sigma$
4237.0	528.9	20 ± 8	0.92	1.056	8.8 ± 3.4	$2.9\,\sigma$
4246.0	532.7	6 ± 4	0.95	1.056	2.7 ± 1.7	$1.6\,\sigma$
4270.0	529.3	11 ± 6	0.97	1.054	5.2 ± 2.6	$1.7\,\sigma$
4280.0	174.5	0 ± 3	0.95	1.054	0.0 ± 3.6	$0.0\,\sigma$

Fit to C.M. energy dependent cross section

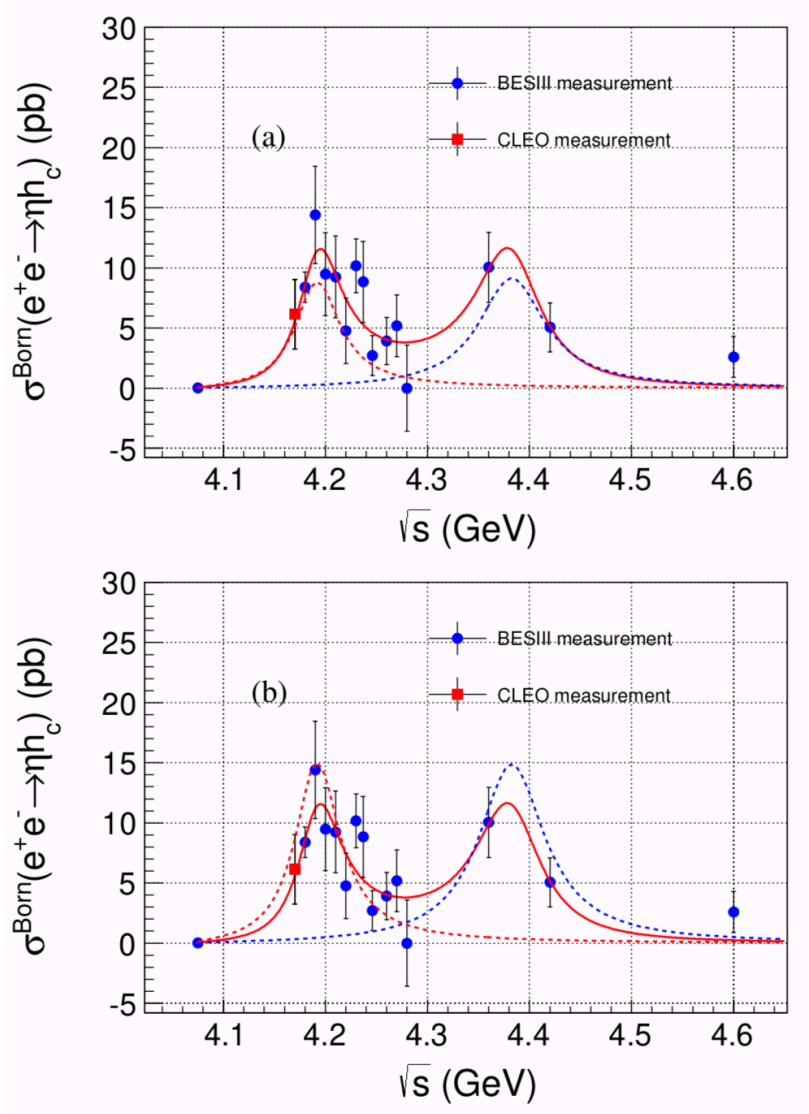
c.m. energy dependent cross section can be parameterized as 2 coherent BW functions:

$$\sigma^{Born}(s) = |BW_1(s)e^{i\phi} + BW_2(s)|^2$$

The amplitude of BW is:

$$BW(s) = \frac{\sqrt{12\pi\Gamma_{ee}\Gamma_{tot}Br(Y \to \eta h_c)}}{s - M^2 + iM\Gamma_{tot}}\sqrt{\frac{PS(\sqrt{s})}{PS(M)}}$$

Parameters	Solution1	Solution2
M_1 (MeV)	4191.1 ± 7.6	4191.0 ± 5.2
$\Gamma_{tot}^{Y_1}$ (MeV)	53.9 ± 23.2	53.9 ± 22.1
$\Gamma_{ee}^{Y_1}Br$ (eV)	0.6 ± 0.3	1.0 ± 0.1
ϕ_1 (rad)	-2.0 ± 1.6	2.3 ± 0.2
M_2 (MeV)	4379.1 ± 27.3	4379.2 ± 22.7
$\Gamma_{tot}^{Y_2}$ (MeV)	85.0 ± 89.3	84.8 ± 86.1
$\Gamma_{ee}^{Y_2}Br$ (eV)	0.9 ± 0.4	1.7 ± 0.8



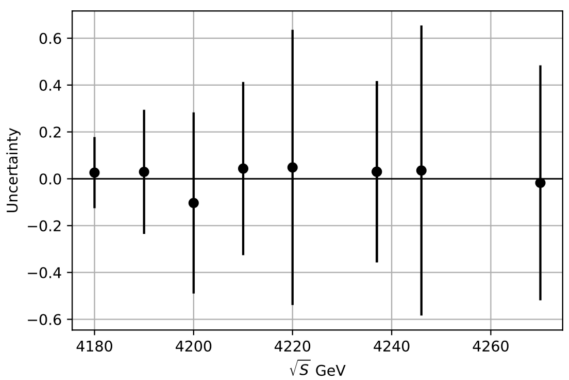
Sys. for cross section measurement

Source \ Data-set	4180	4190	4200	4210	4220	4237	4246	4270	4280
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\Sigma_i \epsilon_i \times \mathcal{B}(\eta_c \to X_i)$	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Signal shape	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Background shape	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Fitting range	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
$\mathcal{B}(h_c \to \gamma\eta_c)$	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
ISR correction	1.7	2.5	3.0	2.0	2.4	6.4	6.5	5.8	3.6
VP correction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total	22.6	22.7	22.8	22.7	22.7	23.5	23.5	23.3	22.9

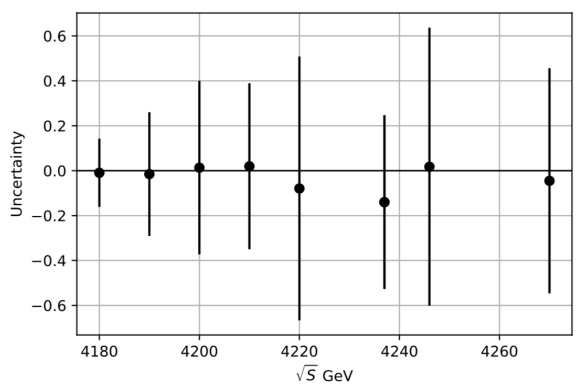
Systematic uncertainty – Fit method

- Mass resolution – smear signal according to control sample
- Background shape – polynomial instead of Argus
- Fit range – vary range randomly
- Take the average discrepancy from 4180~4270 MeV as uncertainty

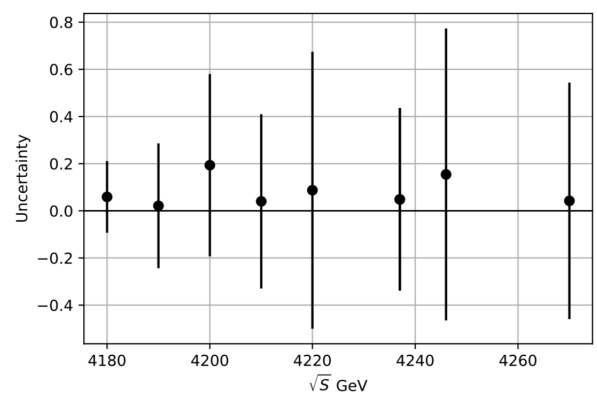
Mass resolution



Background shape



Fit range

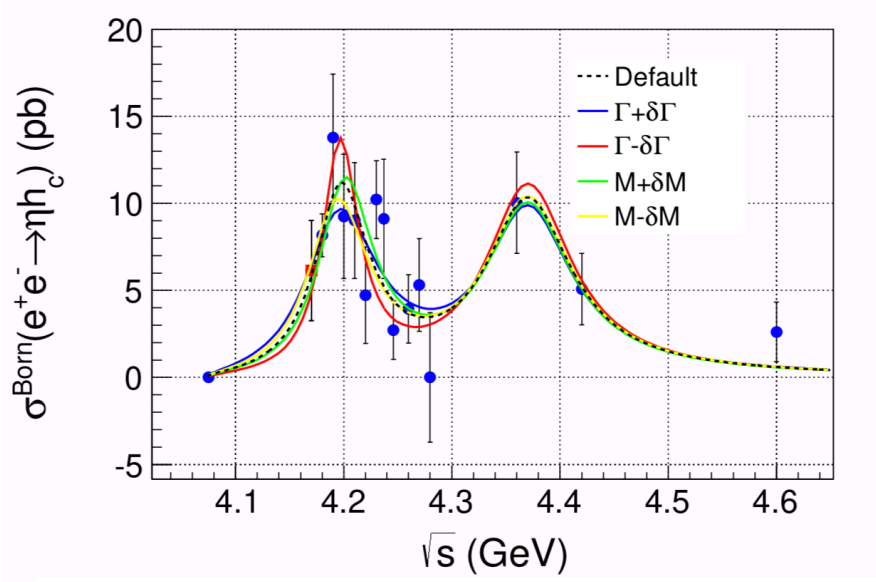


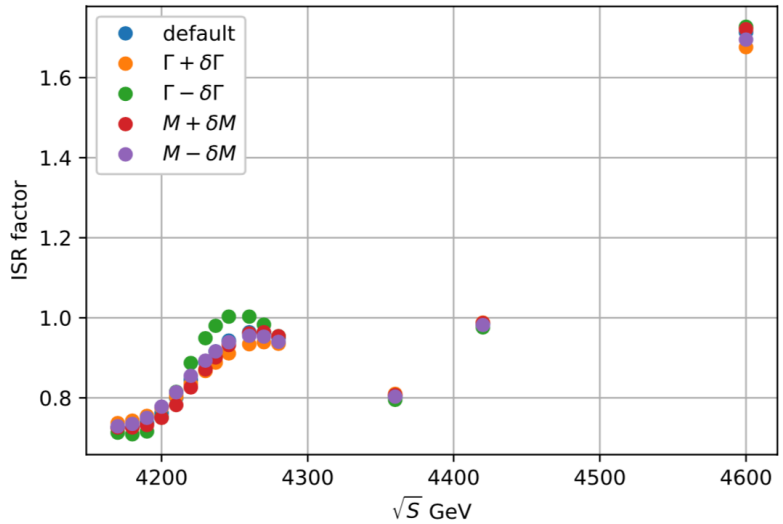
Systematic uncertainty – ISR

- Vary the resonant parameters within its error
- Largest difference to nominal line-shape on ISR factor is taken as uncertainty

TABLE VI. ISR correction factor and its error

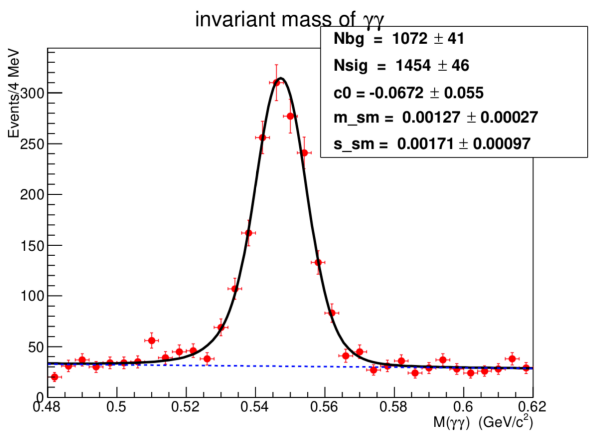
Energy(MeV)	Max Error (in %)
4180	1.7
4190	2.5
4200	3.0
4210	2.1
4220	2.3
4237	5.0
4237	6.7
4246	7.0
4270	6.4
4280	4.0





Systematic uncertainty due to $\sum \epsilon_i * B_i$

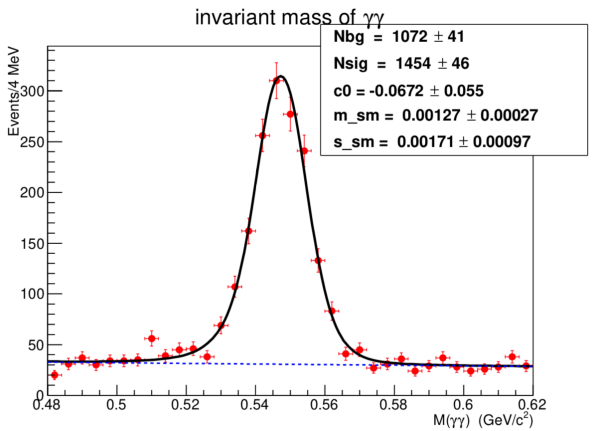
- The M($\gamma\gamma$) mass resolution discrepancy between data and MC is studied by control sample $e^+e^- \rightarrow \eta J/\psi$



Sources	$p\bar{p}$	$2(\pi^+\pi^-)$	$2(K^+K^-)$	$K^+K^-\pi^+\pi^-$	$p\bar{p}\pi^+\pi^-$	$3(\pi^+\pi^-)$	$K^+K^-2(\pi^+\pi^-)$	$K^+K^-\pi^0$
Tracking eff.	2.0	4.0	4.0	4.0	4.0	6.0	6.0	2.0
Photon eff.	3.0	3.0	3.0	3.0	3.0	3.0	3.0	5.0
PID	2.0	4.0	4.0	4.0	4.0	6.0	6.0	2.0
K_S^0 eff.	–	–	–	–	–	–	–	–
π^0 eff.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
η eff.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
η_c decay model	0.0	2.5	5.3	3.4	2.3	0.0	0.2	0.0
η_c line shape	6.3	6.5	5.2	5.2	6.3	5.2	6.3	5.2
KmFit eff.	2.0	2.6	2.6	2.2	2.3	4.1	2.6	0.1
Cross feed	0.0	0.4	0.0	2.4	0.0	0.0	0.0	0.0
MC sample	2.0	2.1	2.2	2.1	2.2	2.2	2.2	2.2
$\mathcal{B}(\eta_c \rightarrow X_i)$	37.0	22.0	46.0	26.0	34.0	28.0	54.0	23.0

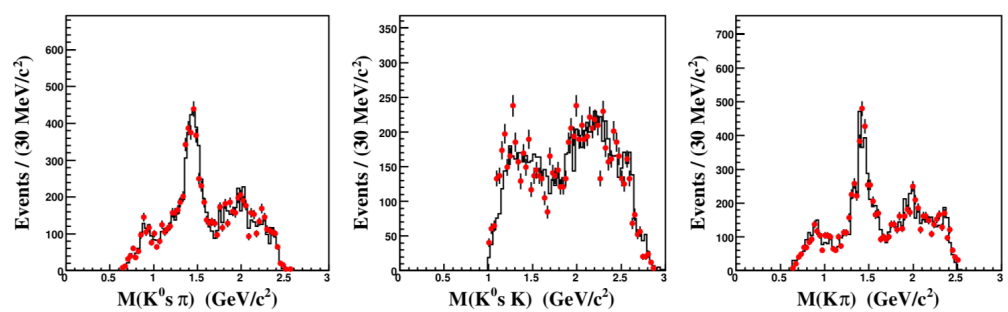
Systematic uncertainty due to $\sum \epsilon_i * B_i$

- The M($\gamma\gamma$) mass resolution discrepancy between data and MC is studied by control sample $e^+e^- \to \eta J/\psi$



- To simulated η_c decay:
  - 3 body: Body3
  - 4 body: mH2
  - 5/6: mix intermediate states according to PDG

Sources	$p\bar{p}$	$2(\pi^+\pi^-)$	$2(K^+K^-)$	$K^+K^-\pi^+\pi^-$	$p\bar{p}\pi^+\pi^-$	$3(\pi^+\pi^-)$	$K^+K^-2(\pi^+\pi^-)$	$K^+K^-\pi^0$
Tracking eff.	2.0	4.0	4.0	4.0	4.0	6.0	6.0	2.0
Photon eff.	3.0	3.0	3.0	3.0	3.0	3.0	3.0	5.0
PID	2.0	4.0	4.0	4.0	4.0	6.0	6.0	2.0
K_S^0 eff.	–	–	–	–	–	–	–	–
π^0 eff.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
η eff.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
η_c decay model	0.0	2.5	5.3	3.4	2.3	0.0	0.2	0.0
η_c line shape	6.3	6.5	5.2	5.2	6.3	5.2	6.3	5.2
KmFit eff.	2.0	2.6	2.6	2.2	2.3	4.1	2.6	0.1
Cross feed	0.0	0.4	0.0	2.4	0.0	0.0	0.0	0.0
MC sample	2.0	2.1	2.2	2.1	2.2	2.2	2.2	2.2
$\mathcal{B}(\eta_c \to X_i)$	37.0	22.0	46.0	26.0	34.0	28.0	54.0	23.0



Control sample: $\psi(3686) \to \gamma\eta_c; \eta_c \to K_S K\pi$

Sys. for resonances measurement

- CME calibration
  - Affect mass by 1 MeV
- Beam spread
  - Smear the CME by 1.6 MeV
- Uncertainty of cross section measurement
  - Fit: using the cross section measured with different fit model
  - Correlated part: ~22% for $\Gamma_{ee}Br$

Parameters	Solution1					Solution2				
	CME	Beam	Fit	σ^{Born}	Sum	CME	Beam	Fit	σ^{Born}	Sum
M_1 (MeV)	1.0	−0.7	0.7	–	1.4	1.0	−0.7	0.8	–	1.4
$\Gamma_{tot}^{Y_1}$ (MeV)	–	−2.6	1.4	–	3.0	–	−2.6	1.4	–	2.9
$\Gamma_{ee}^{Y_1}Br$ (eV)	–	−0.0	0.0	0.1	0.1	–	−0.1	0.0	0.2	0.3
ϕ_1 (rad)	–	−0.32	0.06	–	0.33	–	0.17	0.05	–	0.18
M_2 (MeV)	1.0	0.7	2.3	–	2.6	1.0	0.6	2.2	–	2.5
$\Gamma_{tot}^{Y_2}$ (MeV)	–	−4.1	13.3	–	13.9	–	−3.8	13.2	–	13.7
$\Gamma_{ee}^{Y_2}Br$ (eV)	–	0.1	0.0	0.1	0.1	–	−0.1	0.1	0.2	0.3

Summary

- Cross sections of $e^+e^- \to \eta h_c$ from 4.18~4.28 GeV are measured
- Line shape can be described as 2 coherent BW
- Memo is ready
- New data taken this year will be analyzed soon.

Resonance	Mass (MeV)	Width (MeV)
This work	$4191.1 \pm 7.6 \pm 1.4$	$53.9 \pm 23.2 \pm 3.0$
Y(4220) in $e^+e^- \to \pi\pi h_c$	$4218.4^{+5.5}_{-4.5} \pm 0.9$	$66^{+12.3}_{-8.3} \pm 0.4$
$\psi(4160)$	4191 ± 5	70 ± 10

Systematic error VP