Study of h_c at BESIII

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Outline

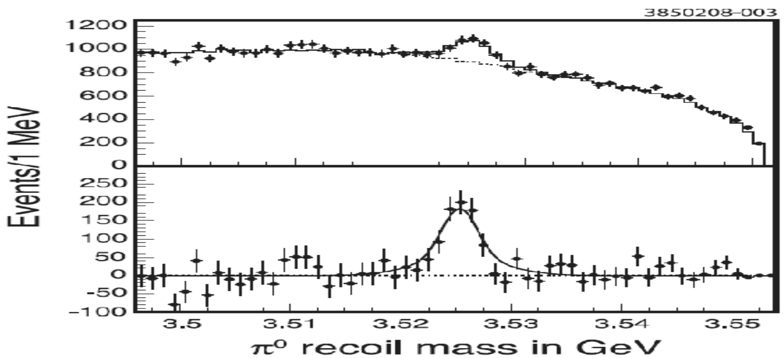
- Introduction
- Event selection
- Analysis and results
- summary

Introduction

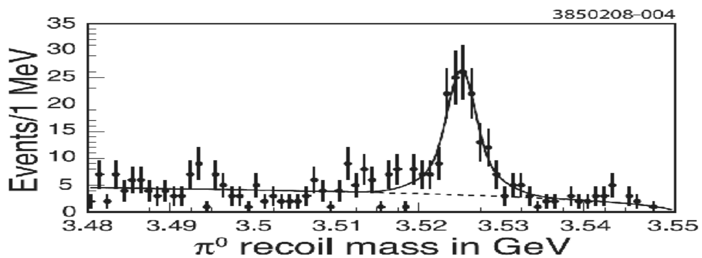
- The CLEO Collaboration has observed the h_c and measured its mass and product branching ratio $B(\psi' \to p^0 h_c) \times B(h_c \to \gamma h_c)$.
- The absolute branching ratios of $\psi' \to \pi^0 h_c$ and E1 transition $h_c \to \gamma \eta_c$ are very important for the further study of h_c, but neither has been measured
- High luminosity and very good low energy photon detection of BESIII permit us to study h_c in inclusive $\psi' \to \pi^0 h_c$ process directly.

Introduction

CLEO's Result – $h_c \to \gamma\eta_c$ inclusive

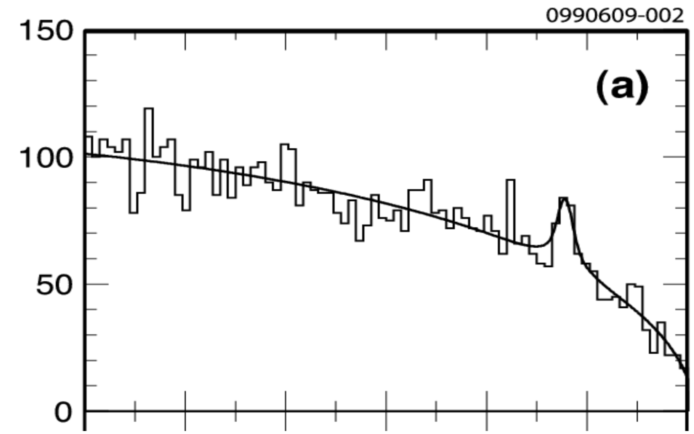


CLEO's Result - $h_c \to \gamma\eta_c$ exlusive



	Inclusive	Exclusive
Counts	1146 ± 118	136 ± 14
Significance	10.0σ	13.2σ
$M(h_c)$ (MeV)	$3525.35 \pm 0.23 \pm 0.15$	$3525.21 \pm 0.27 \pm 0.14$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^4$	$4.22 \pm 0.44 \pm 0.52$	$4.15 \pm 0.48 \pm 0.77$

CLEO's Result – $h_c \to 2(\pi^+\pi^-)\pi^0$

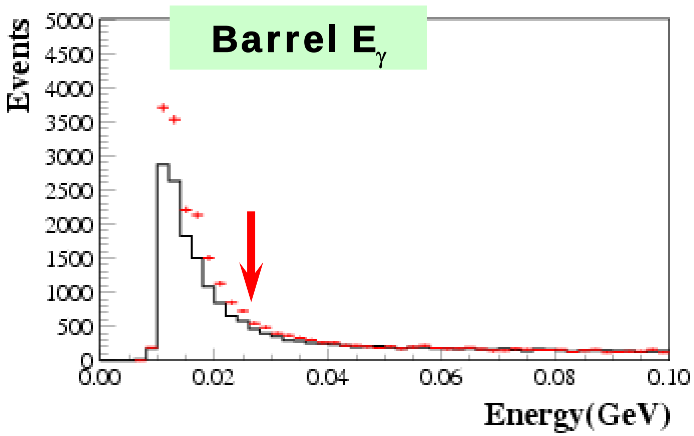


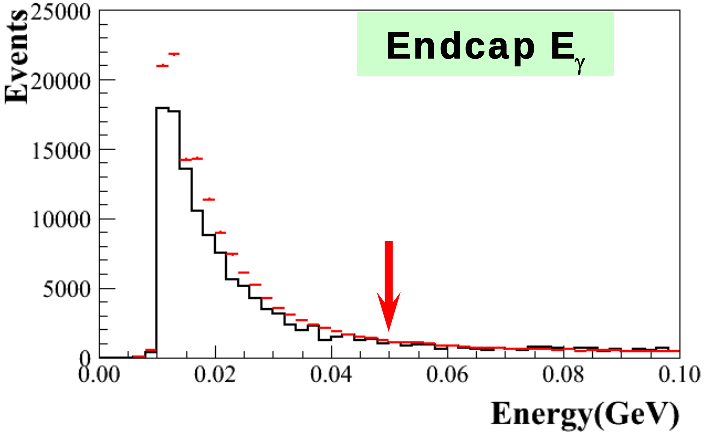
Mode	efficiency (%)	Yield	$B_1 \times B_2 \times 10^5$
$\pi^+\pi^-\pi^0$	27.0	$1.6^{+6.7}_{-5.9}$	< 0.19
$2(\pi^+\pi^-)\pi^0$	18.8	92^{+23}_{-22}	$(1.88^{+0.48+0.47}_{-0.45-0.30})$
$3(\pi^+\pi^-)\pi^0$	11.5	35 ± 26	$(1.2 \pm 0.9 \pm 0.3)$ (< 2.5)

The product branching ratios
$Br(\psi(2S) \to \pi^0 h_c) \times Br(h_c \to \gamma\eta_c)$,
$Br(\psi(2S) \to \pi^0 h_c) \times Br(h_c \to n(\pi^+\pi^-)\pi^0)$
and $M(h_c)$
have been measured by CLEO

The absolute branching ratios
$Br(\psi(2S) \to \pi^0 h_c)$
$Br(h_c \to \gamma\eta_c)$ and $\Gamma(h_c)$
Have NOT been measured yet

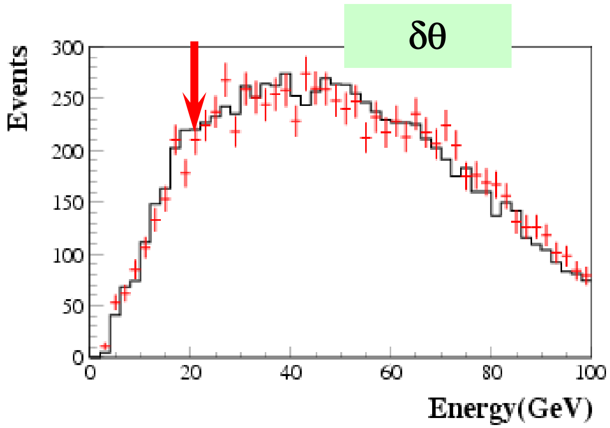
Good Photon selection





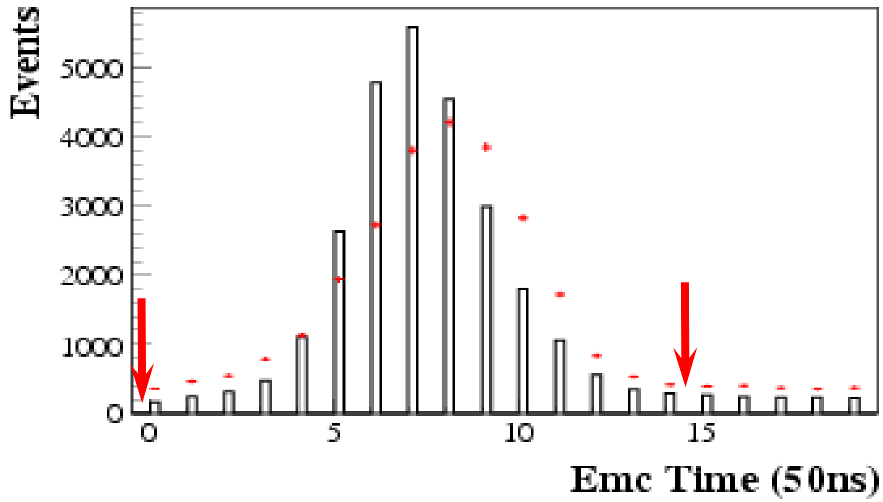
Barrel(|cosθ|<0.8): Eγ > 25MeV

Endcap(0.84<|cosθ|<0.92): Eγ > 50MeV



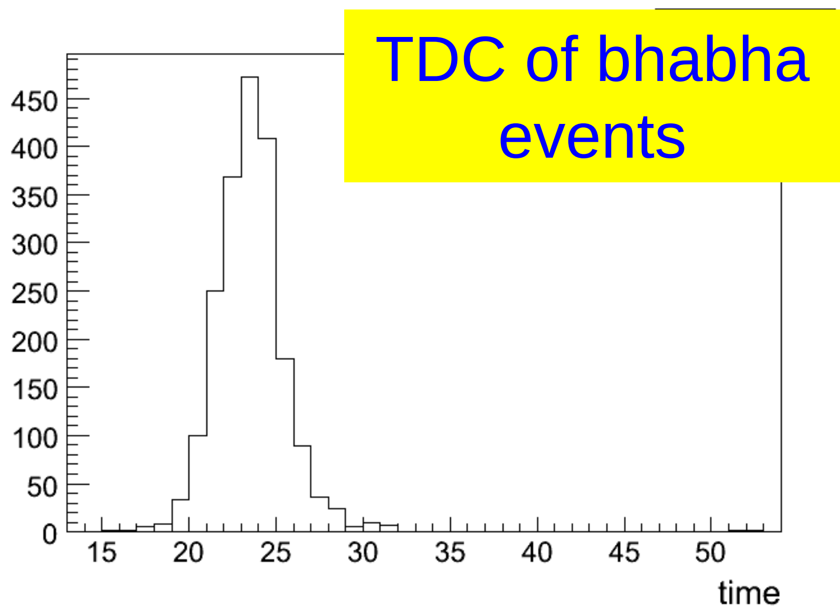
Angle between neutral track and the nearest charged track **δθ<20°**

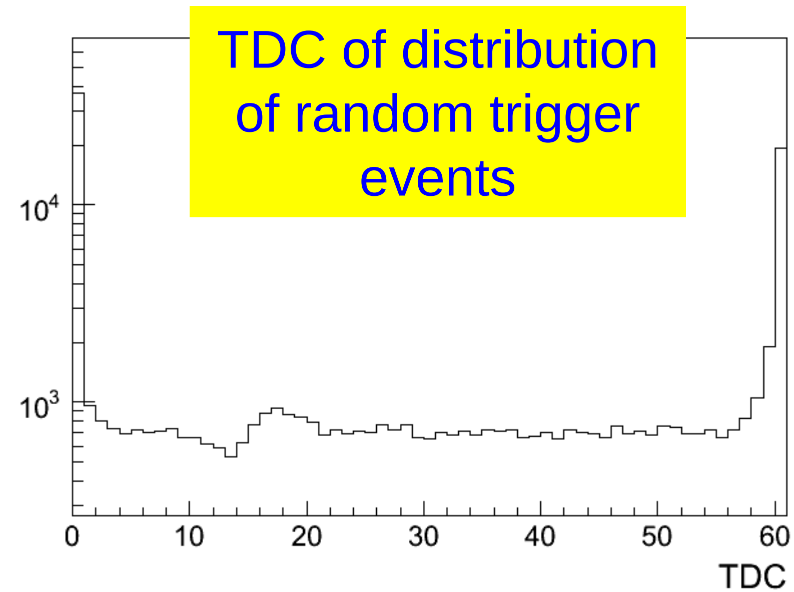
TDC time



Special cut on the photon selection at BESIII

- Time window for the EMC signals
- This can suppress the Incoherent electronics noise and beam related background significantly



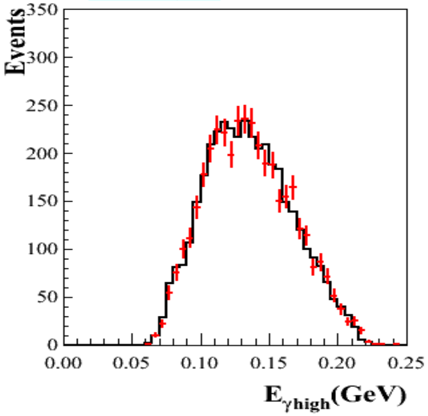


Event selection – for $\psi(2S)\rightarrow\pi^0 h_c$

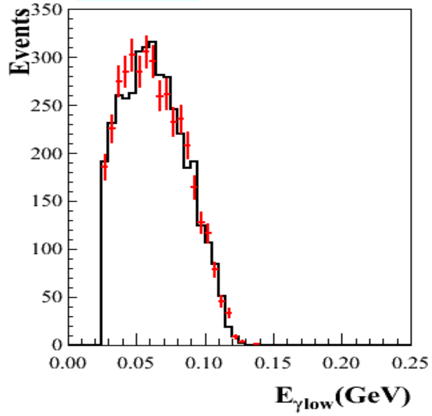
- π^0 candidates selection
  - Photon polar angle: $|\cos\theta|<0.8$
  - Photon energy: $E_\gamma>40MeV$
  - Each photon belongs to only one π^0
  - $M_{\gamma\gamma}\in[0.12, 0.145]GeV/c^2$
  - Perform 1C kinematic fit for each π^0 candidate (no χ^2 requirement)
- Background Veto
  - $\pi^+\pi^- J/\psi$: $|M^{rec}(\pi^+\pi^-)-3.097|>0.007GeV/c^2$
  - $\pi^0\pi^0 J/\psi$: $|M^{rec}(\pi^0\pi^0)-3.097|>0.030GeV/c^2$

Distributions of π^0 candidate and $\pi\pi$ recoiling mass

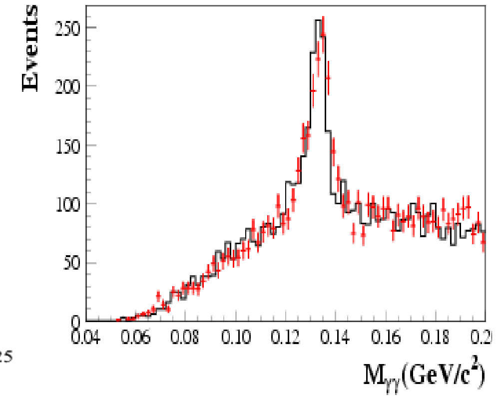
E_{high}



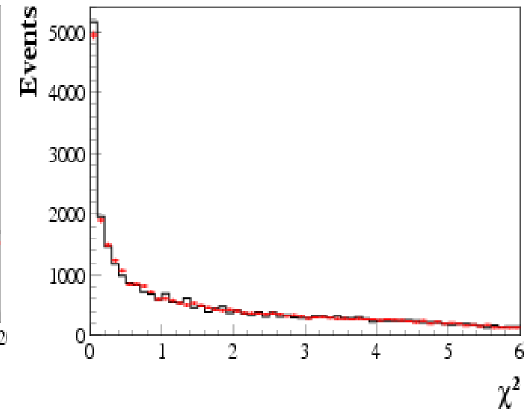
E_{low}



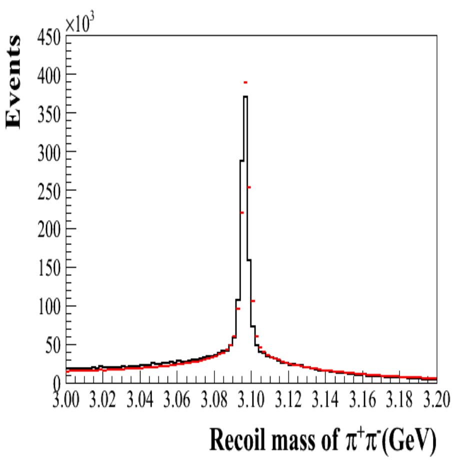
$M_{\gamma\gamma}$



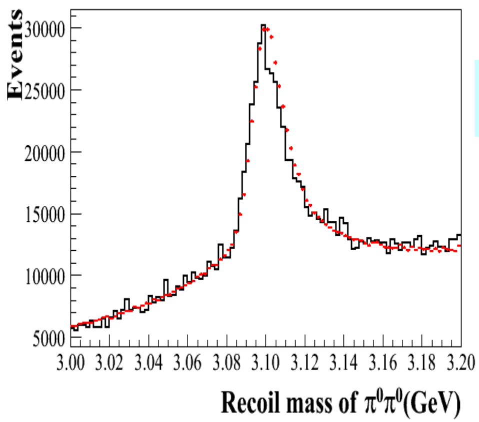
χ^2 of 1C



$\pi^+\pi^-$ recoil mass



$\pi^0\pi^0$ recoil mass



DATA / MC agree well

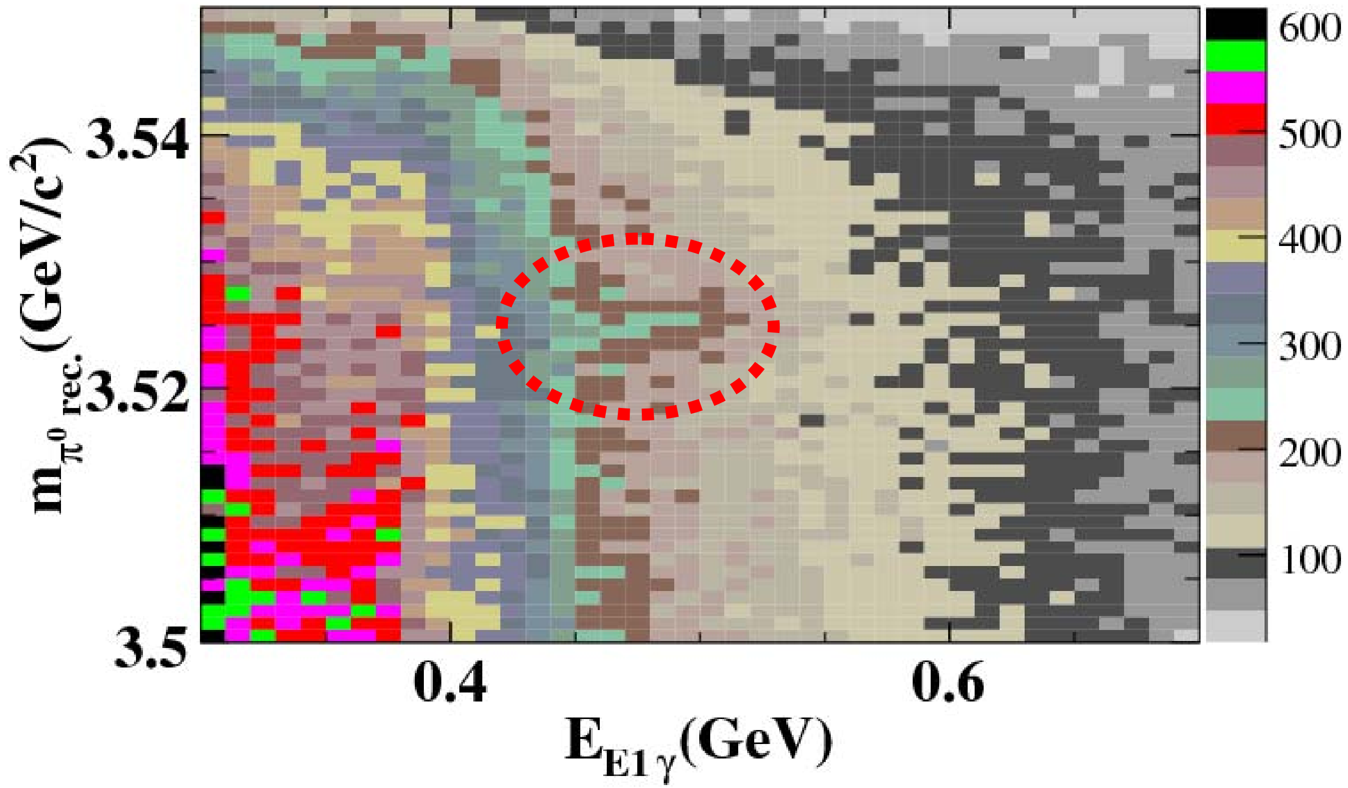
Event selection – for $h_c \to \gamma\eta_c$

- **π^0 selection similar to the inclusive analysis** $\psi(2S) \to \pi^0 h_c$

- **E1-photon tagging in** $h_c \to \gamma\eta_c$
  - $450 MeV < E_\gamma < 540 MeV$
  - Veto π^0 (0.100–0.145GeV/c^2)
  - Veto η (0.530–0.560GeV/c^2)

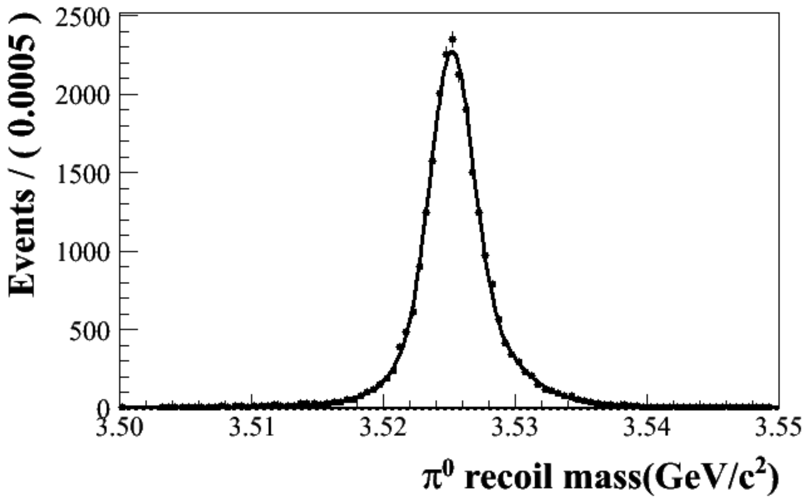
If the invariant mass of the E1 photon and any other photon in the event is compatible with either a π^0 or a η, the E1 photon candidate is rejected.

Tagged photon energy vs $M_{\pi^0 rec}$



Events cluster of $h_c \rightarrow \gamma\eta_c$

Signal Shape



Breit-Wigner convoluted with Double Gaussian

Modeling of h_c signal is very good

	Input	Output
$M(h_c)$(MeV)	3525.28	3525.28 ± 0.02
$\Gamma(h_c)$(MeV)	0.9	0.87 ± 0.03
N	24678	24677 ± 22

On the Fits

h_c signal described by Breit-Wigner functions convoluted with the instrument resolution from MC

When fitting to the E1-photon-tagged spectrum, the mass and width of h_c are free. The shape of background modeled by sideband of the E1 photon.

When fitting to the inclusive π^0 spectrum, the mass and width fixed to results of the E1-photon-tagged case. The background parameterized by a 4th-order Chebychev polynomial.

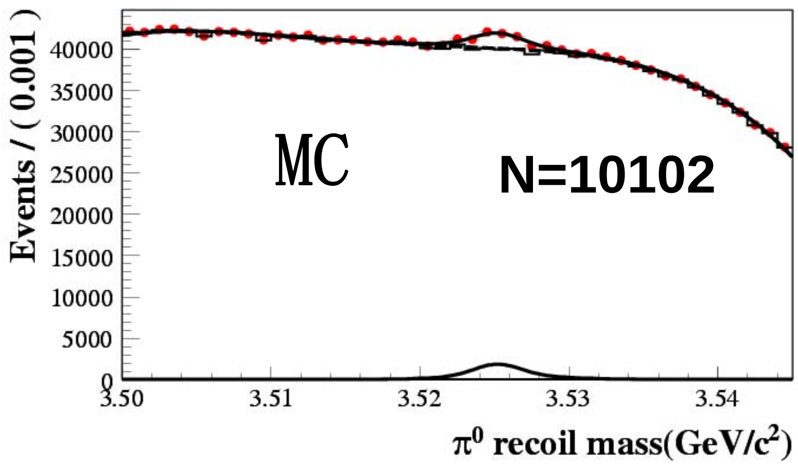
Input/Output checking in MC

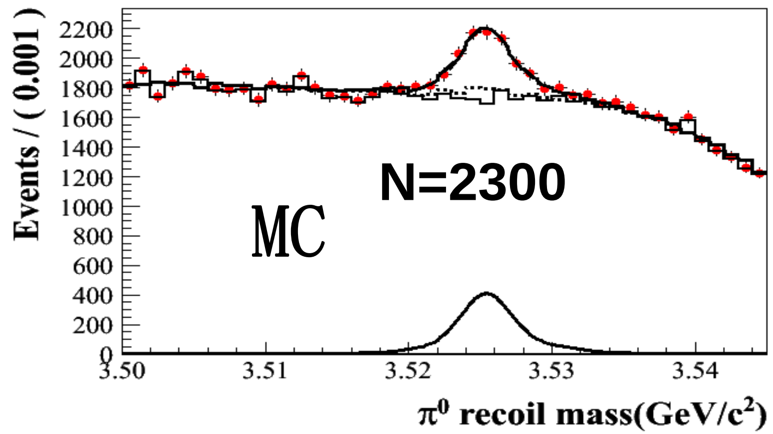
- **Mix** 100,000 $\psi(2S)\to\pi^0 h_c$, $h_c\to$ **anything with 100M inclusive** $\psi(2S)$ MC

Inclusive π^0 recoil mass spectrum

- No peaking background
- Input consist with output

E1-tagged

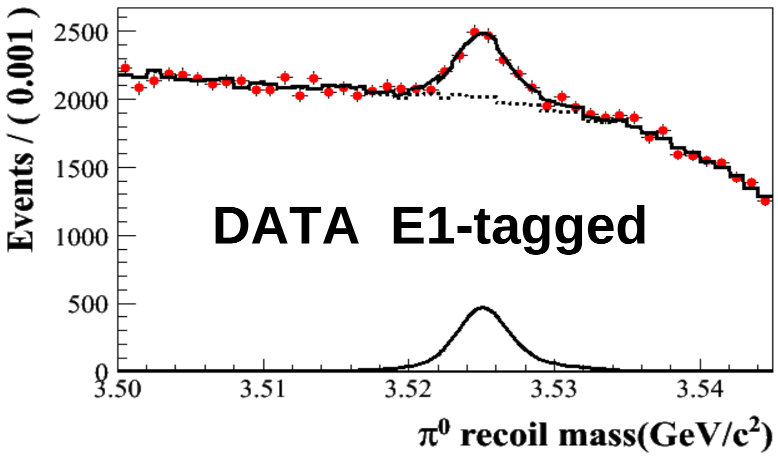




	Input	Output
$M(h_c)$(MeV)	3525.28	3525.45±0.18
$\Gamma(hc)$(MeV)	0.9	1.06±0.62
$B(\psi(2S)\to\pi^0 h_c)$ ($\times10^{-4}$)	10.0	10.07±1.53
$B(hc\to\gamma\eta c)$(%)	50	45.1±4.7
$B(\psi(2S)\to\pi^0 h_c)\times B(h_c\to\gamma\eta_c)$ ($\times10^{-4}$)	5.0	4.54±0.50

Fit of $h_c \rightarrow \gamma\eta_c$

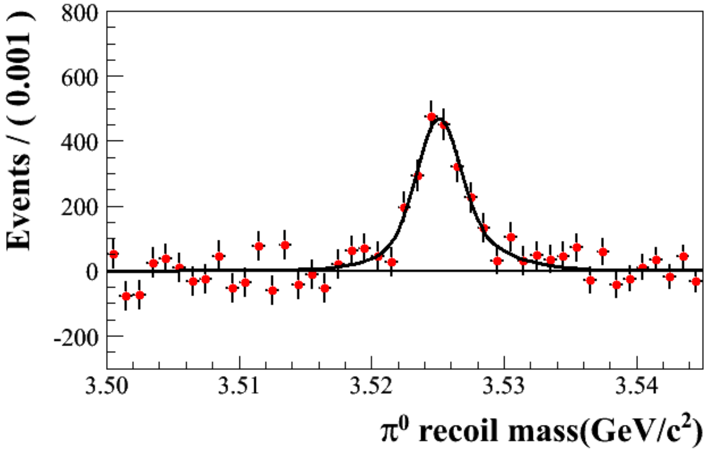
E1-tagged spectrum



Fit with
background shape + signal

sideband of E1 gamma

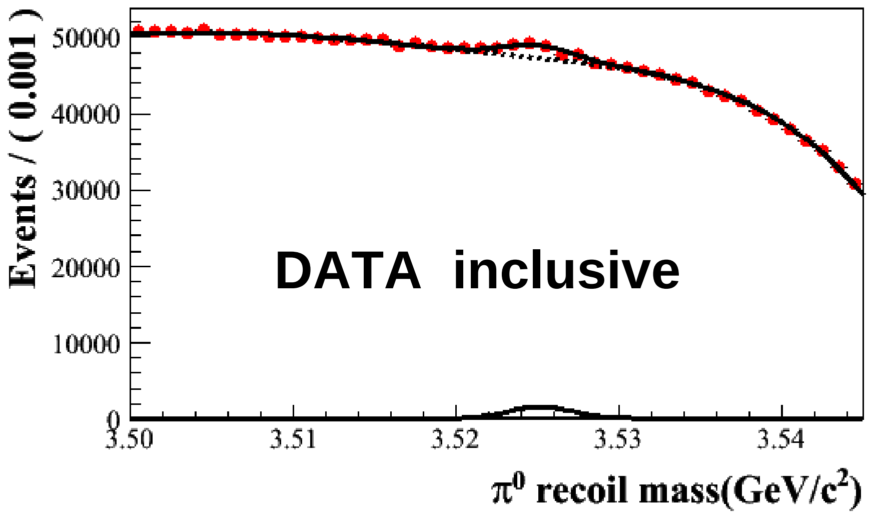
background subtracted



Significance = 16.5σ
$M(h_c)$=3525.16±0.16MeV
$N(h_c)$= 2540±261
$\Gamma(h_c)$ = 0.89±0.57MeV
χ^2/d.o.f = 39.5/41.0

Fit of $\psi(2S)\rightarrow\pi^0 h_c$ in DATA

Inclusive π^0 recoil mass spectrum



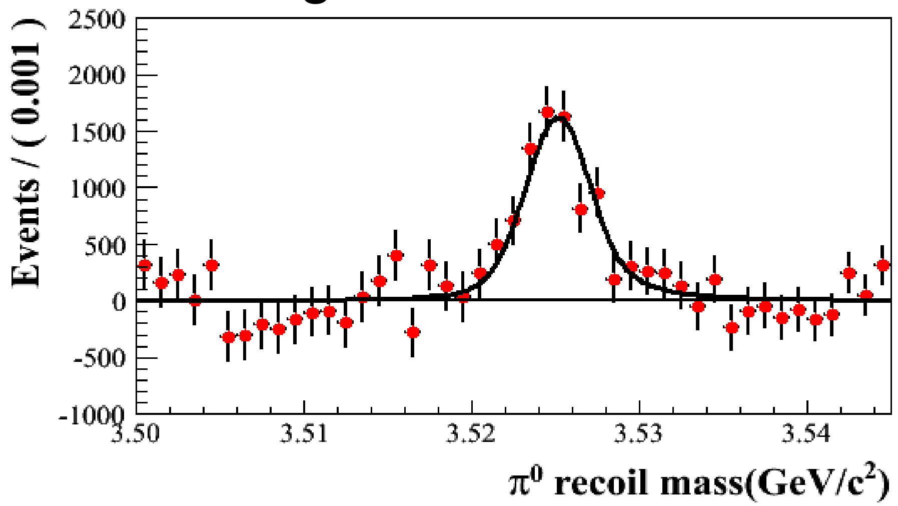
Fit with 4th –Polynomial + signal

Significance = 8.9σ

$N(h_c)$ = 9233±935

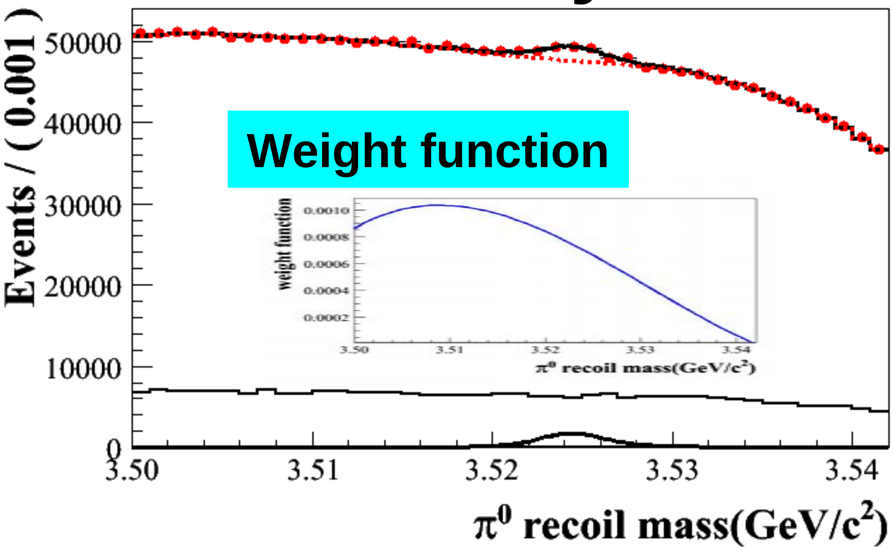
χ^2/d.o.f = 38.8/38.0

background subtracted



The goodness of the fit is good

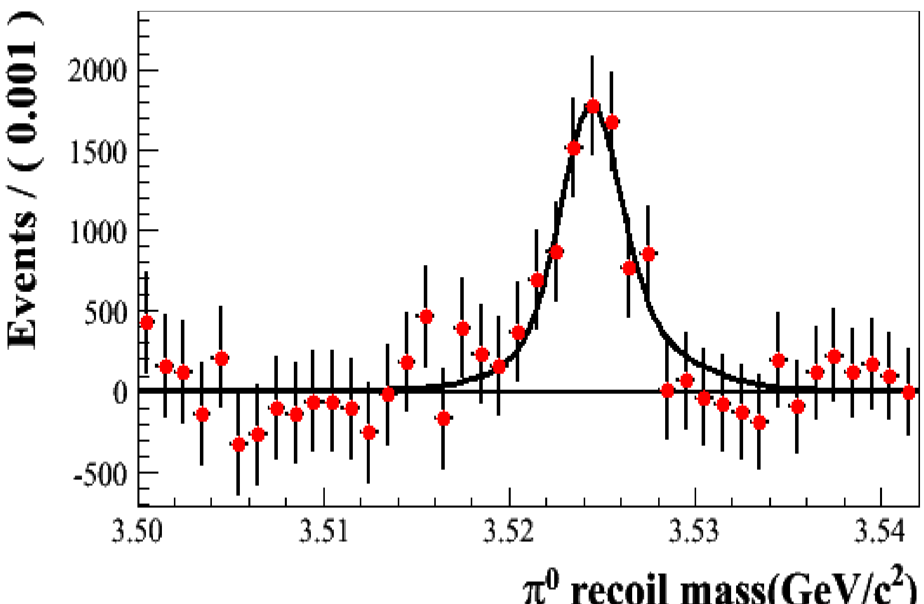
Background modeled by MC + Continuum



(MC bkgd + Continuum) * 2poly + signal

$N(h_c) = 9492 \pm 912$

χ^2/d.o.f = 37.0/36.0



Re-weighted MC shape to model the background got consistent result of 4-poly background fitting.

Calculation of Branching fractions

N^{E1}	2540 ± 261
$\epsilon_{12}(\%)$	5.06
$N(\psi(2S))(10^6)$	107.0
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_2(h_c \to \gamma\eta_c)$ (10^{-4})	4.69 ± 0.48

N^{tot}	9233 ± 935
N^{E1}	2540 ± 261
$\epsilon_1^{E1}(\%)$	11.15
$\epsilon_1^{had}(\%)$	9.10
$\epsilon_{12}(\%)$	5.06
$N(\psi(2S))(10^6)$	107.0
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c)(10^{-4})$	8.42 ± 1.29
$\mathcal{B}_2(h_c \to \gamma\eta_c)(\%)$	55.68 ± 6.3

Systematic errors

- **Sources**
  - **Background shape, fit range, width of bin**
  - **Absolute energy calibration**
  - **Instrument resolution shape**
  - **E1 photon efficiency**
  - π^0 **efficiency**
  - **Number of charged track**
  - **Number of** π^0
  - **Veto XJpsi**
  - **N(**ψ**(2S))**
  - **Mass of** ψ**(2S)(in the calculation of recoiling mass)**
  - **Modeling of signal shape**

Summary

$M(h_c)^{Inc}$ = 3525.16±0.16±0.10 MeV
(3525.28±0.19±0.12 arXiv 0805.4599v1, CLEOc)

$\Gamma(h_c)^{Inc}$ = 0.89±0.57±0.23 MeV
(First measurement)

$Br(\psi' \to \pi^0 h_c)$
= (8.42±1.29±0.93) $\times 10^{-4}$
(First measurement)

$Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma \eta_c)^{Inc}$
= (4.69±0.48±0.46) $\times 10^{-4}$
((4.22±0.44±0.52) $\times 10^{-4}$ inc
(4.16±0.30±0.37) $\times 10^{-4}$ avg)

$Br(h_c \to \gamma \eta_c)$
= (55.7±6.3±4.4)%
(First measurement)

- **Resonant parameters and some branching ratios of h_c have been measured**
- **Consistent with the results of CLEOc**
- **The Γ of h_c and the two absolute branching ratios are the first measurements**

Thanks a lot!

Backup slides

Branching fractions

$$\mathcal{B}_1 \times \mathcal{B}_2 = \frac{N^{E1}}{\epsilon_{12} \times N(\psi(2S))},$$

From E1-tagged spectrum directly

- $\mathcal{B}_1 \equiv \mathcal{B}_1(\psi(2S) \to \pi^0 h_c)$
- $\mathcal{B}_2 \equiv \mathcal{B}_2(h_c \to \gamma\eta_c)$
- $\mathcal{B}_1 \times \mathcal{B}_2 \equiv \mathcal{B}_1(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_2(h_c \to \gamma\eta_c)$
- ϵ_1^{had} is the event selection efficiency of $\psi(2S) \to \pi^0 h_c$, h_c is taken to decay to hadronic final states (simulated by PYTHIA).
- ϵ_1^{E1} is the event selection efficiency of $\psi(2S) \to \pi^0 h_c$, h_c is takend to decay to $\gamma\eta_c$.
- ϵ_{12} is the event selection efficiency of $\psi(2S) \to \pi^0 h_c, h_c \to \gamma\eta_c$
- N^{E1} is the fit number of $h_c \to \gamma\eta_c$
- N^{tot} is the fit number of $\psi(2S) \to \pi^0 h_c$

$$\mathcal{B}_1 = \frac{\mathcal{B}_1 \times \mathcal{B}_2}{\mathcal{B}_2},$$

$$\mathcal{B}_1 = \frac{N^{tot}}{(\epsilon_1^{E1}\mathcal{B}_2 + \epsilon_1^{had}(1-\mathcal{B}_2)) \times N(\psi(2S))},$$

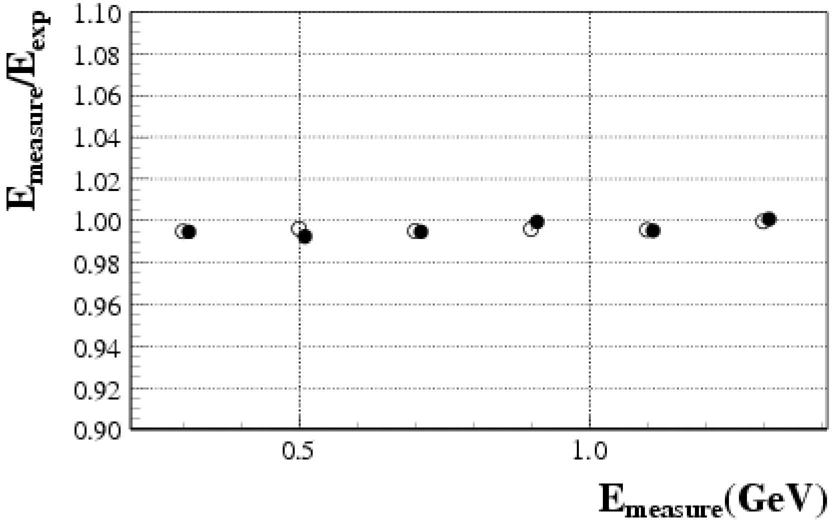
$$\mathcal{B}_1 \times \mathcal{B}_2 = \frac{N^{E1}}{\epsilon_{12} \times N(\psi(2S))},$$

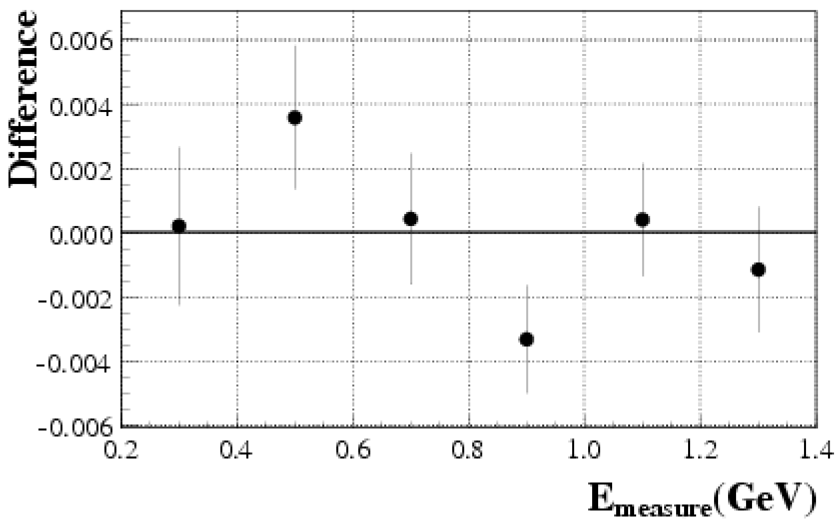
$$\mathcal{B}_2 = \frac{\frac{\epsilon_1^{had}}{\epsilon_{12}}}{\frac{N^{tot}}{N^{E1}} + \frac{\epsilon_1^{had} - \epsilon_1^{E1}}{\epsilon_{12}}},$$

Due to the efficiencies of $\psi(2S) \to \pi^0 h_c$ are different for $h_c \to \gamma\eta_c$ and $h_c \to$ other final states, we considered them separately. Then we calculate B1($\psi' \to \pi^0 h_c$) and B2($h_c \to \gamma\eta_c$) from the four formula.

Uncertainty of absolute energy calibration

From radiative Bhabha





Systematic ~ 0.5%

From $\psi(2S) \rightarrow \gamma\chi_{c1,2}$

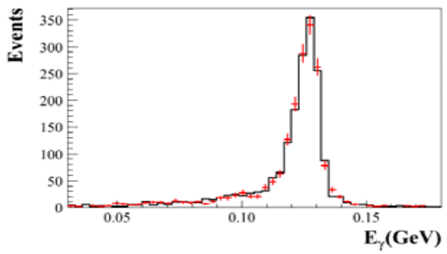
	MC	DATA
E_γ(MeV)	127.97 ± 0.36	128.11 ± 0.35
σ_E(MeV)	3.99 ± 0.18	4.01 ± 0.2
σ_E/E_γ(%)	3.12 ± 0.09	3.13 ± 0.05

	MC	DATA
E_γ(MeV)	171.33 ± 0.17	170.80 ± 0.19
σ_E(MeV)	4.62 ± 0.12	4.88 ± 0.12
σ_E/E_γ(%)	2.70 ± 0.02	2.86 ± 0.02

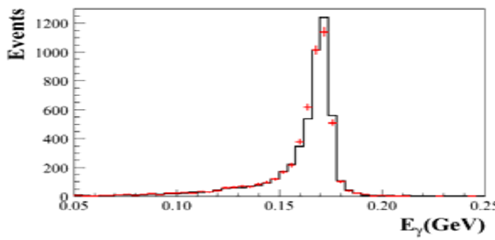
Uncertainty of signal resolution

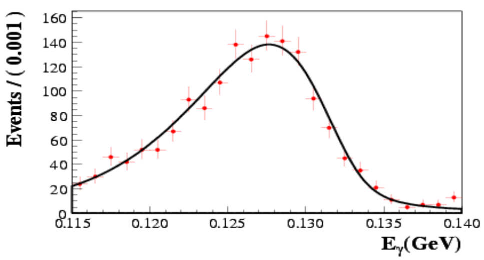
Photon resolution $\psi(2S)\to\gamma\chi_{cJ}$

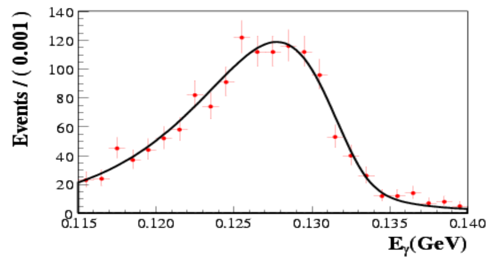
$\psi(2S)\to\gamma\chi_{c2}$



$\psi(2S)\to\gamma\chi_{c1}$



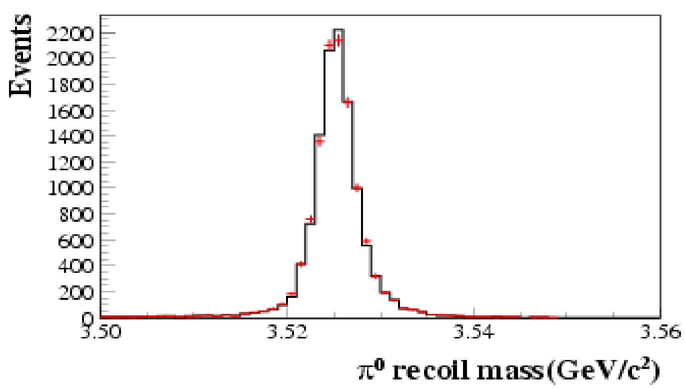




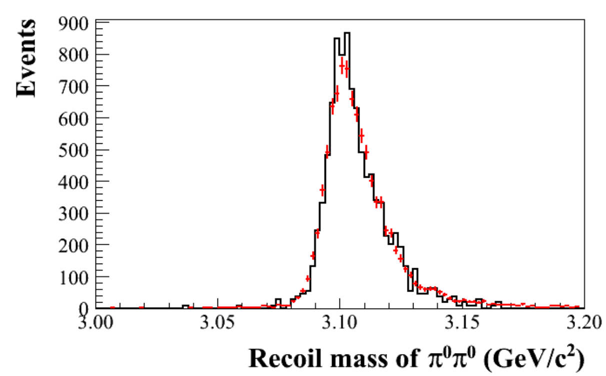
We smear daughter photon energy of π^0 in MC with the resolution in the data obtained from $\psi(2S)\to\gamma\chi_{cJ}$ to estimate uncertainty in signal shape of h_c

$\pi^0\pi^0$ recoil mass in $\psi'\to\pi^0\pi^0 J/\psi$ is another proof of the consistency of DATA/MC.

h_c signal in MC after smearing with the data photon resolution



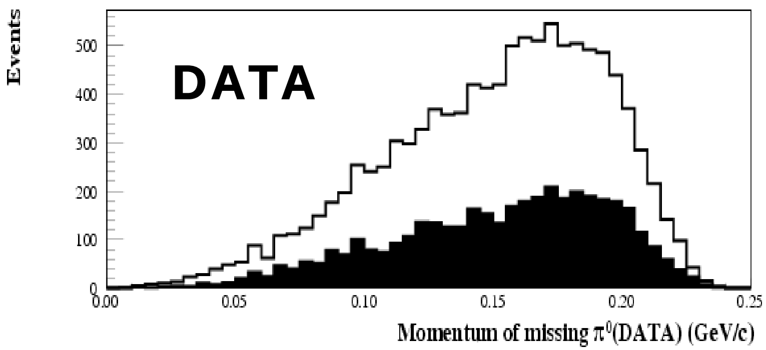
$\pi^0\pi^0$ recoil mass in $\pi^0\pi^0 J/\psi$

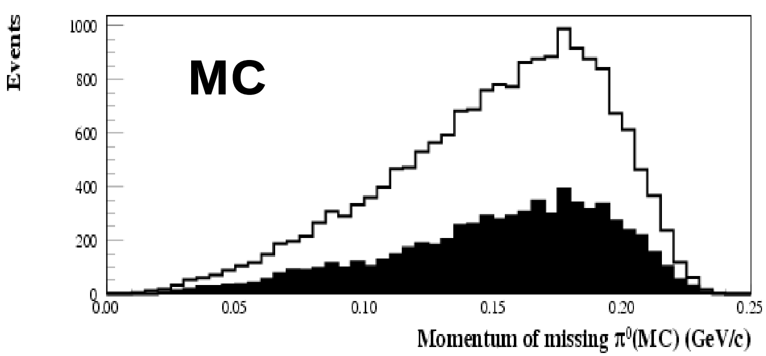


π^0 efficiency

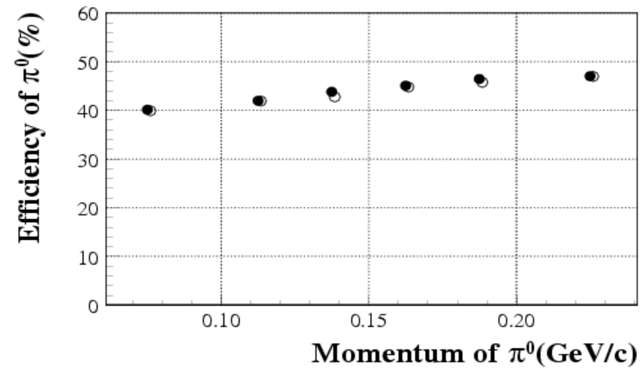
Obtained from $\psi(2S)\rightarrow\pi^0\pi^0 J/\psi$, $J/\psi\rightarrow l^+l^-$

Expected-Observed π^0

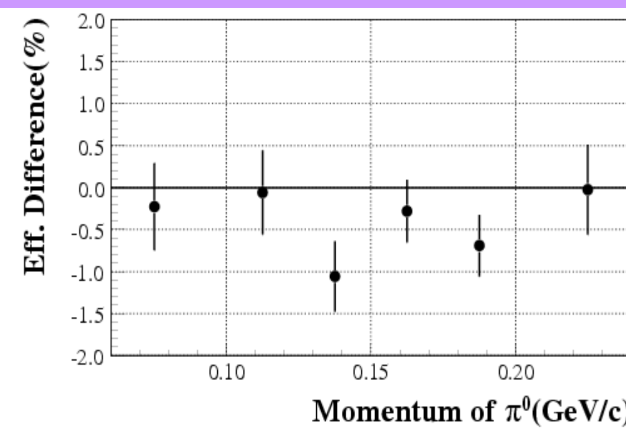




π^0 efficiencies in DATA / MC



Difference between DATA / MC



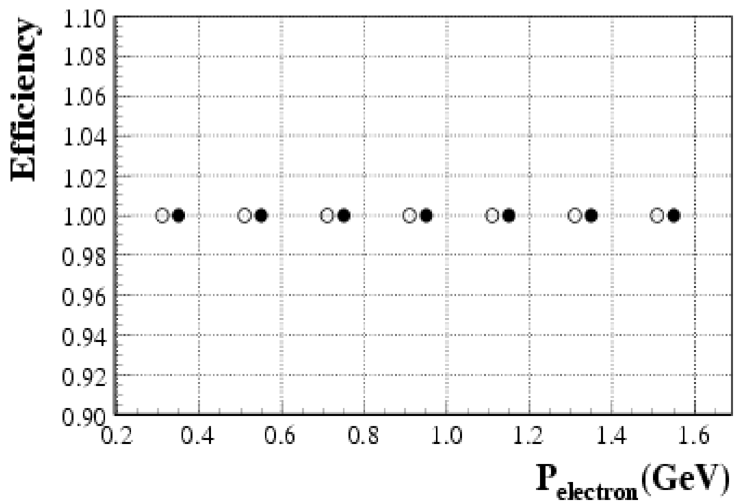
Systematic ~ 1.5%

E1 photon efficiency

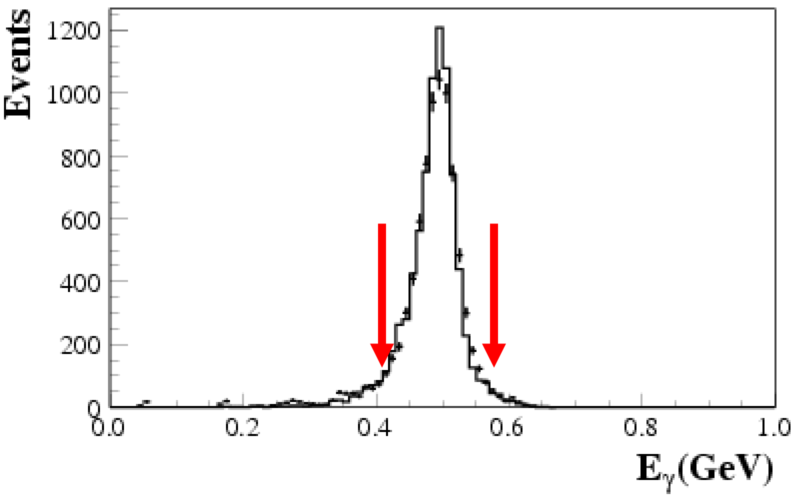
Absolute Detection efficiency: → **Obtained from radiative Bhabha**

Photon line shape: → **Obtained from radiative Bhabha**

Absolute photon efficiency (Radee)~100%



E1 photon line shape



Systematic ~ 2.5%

MC Study

➢ Signal

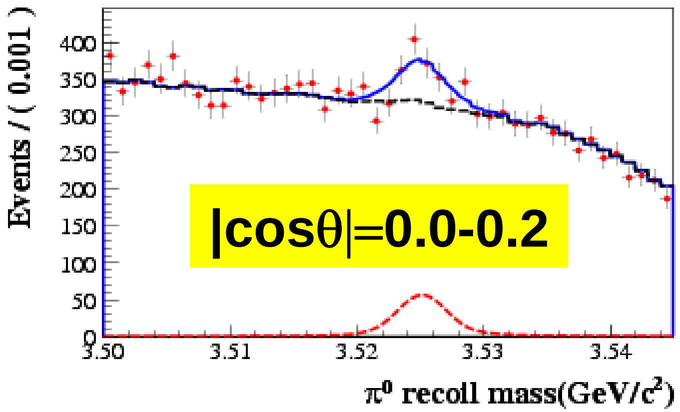
- $\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow$ hadronic
  - PYTHIA

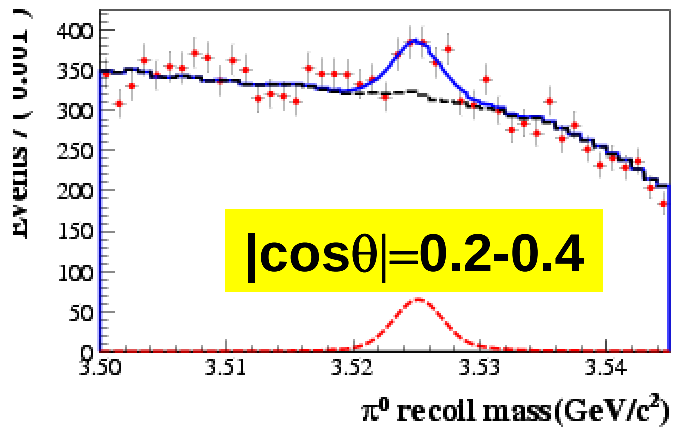
- $\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$
  - $h_c \rightarrow \gamma \eta_c$ Angular distribution of E1 photon: $1+\cos^2\theta$
  - η_c (known part): EvtGen
  - η_c (unknown part): PYTHIA

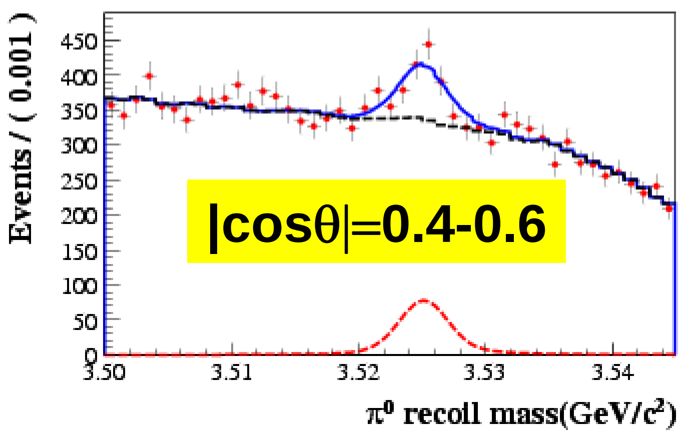
➢ background

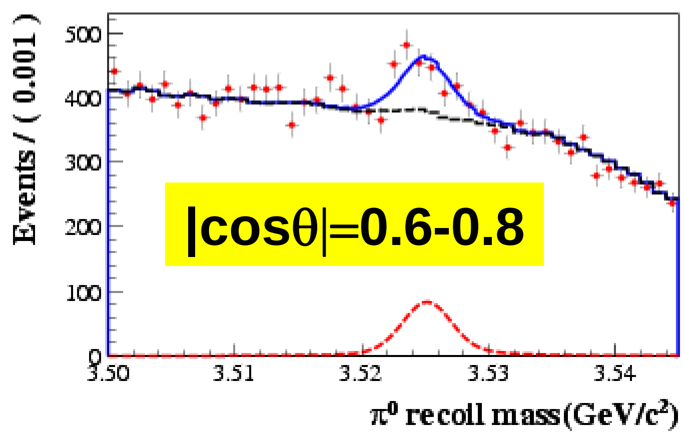
- Inclusive $\psi(2S)$ MC (100M)

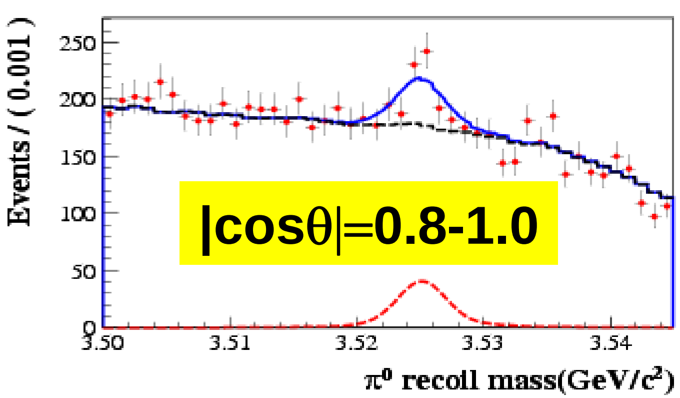
Fit by polar angle of E1 photon



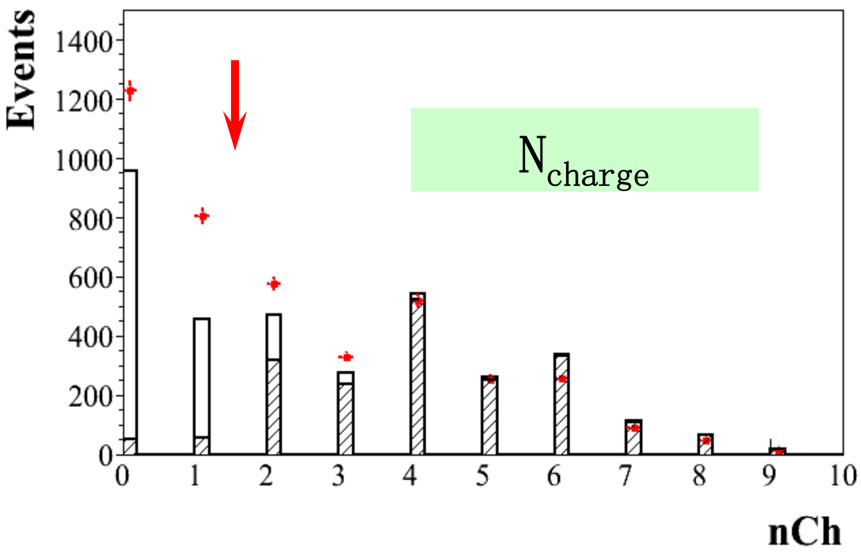


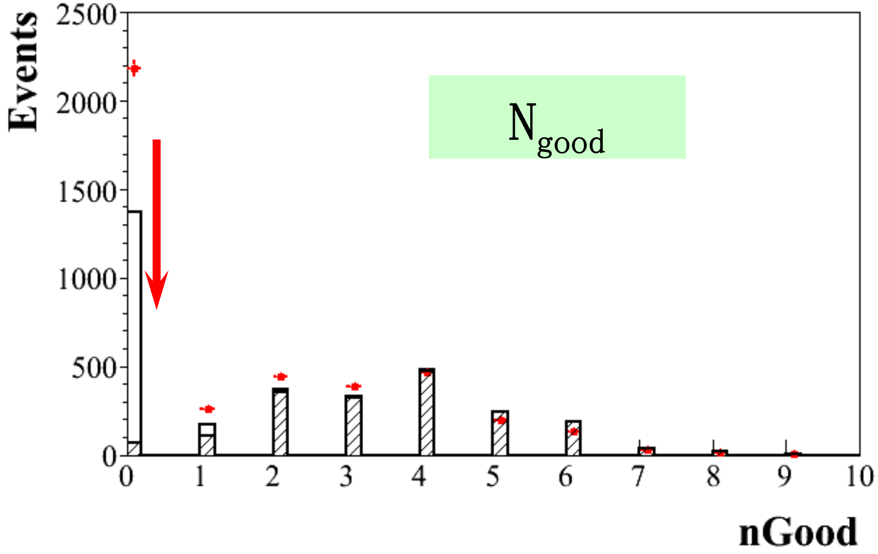


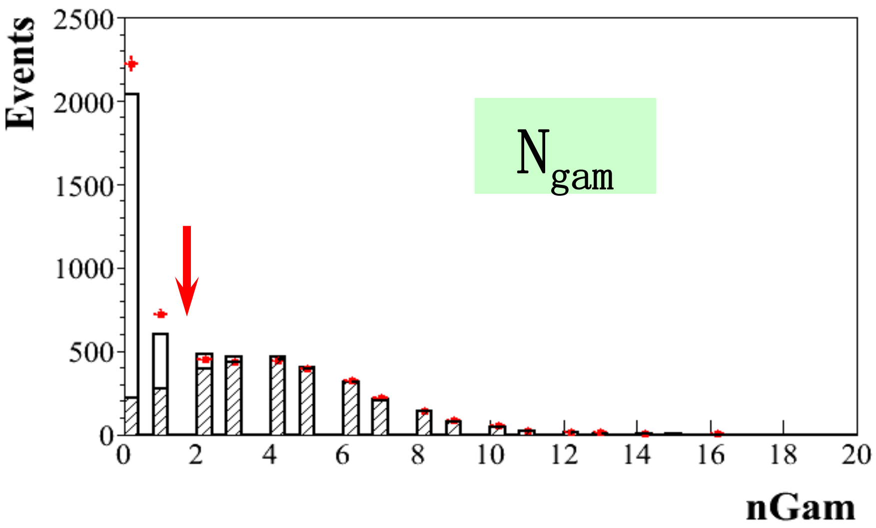




Mixing continuum and inclusive MC



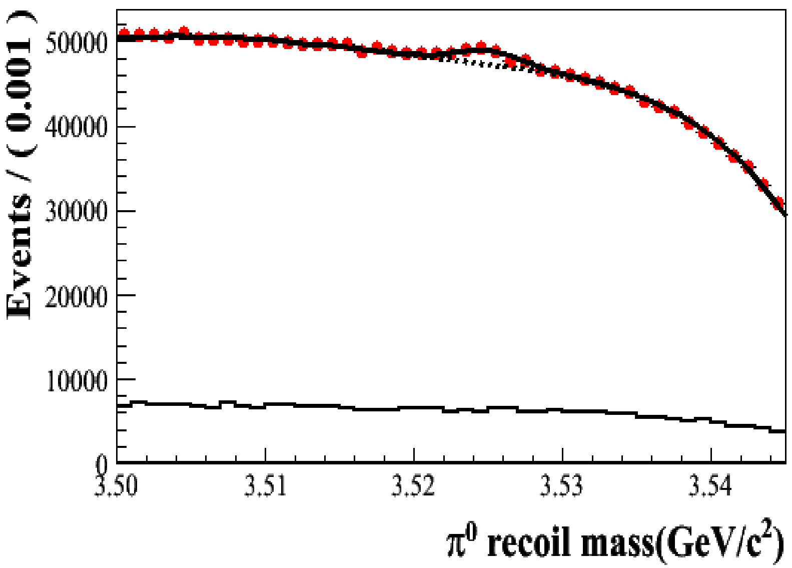




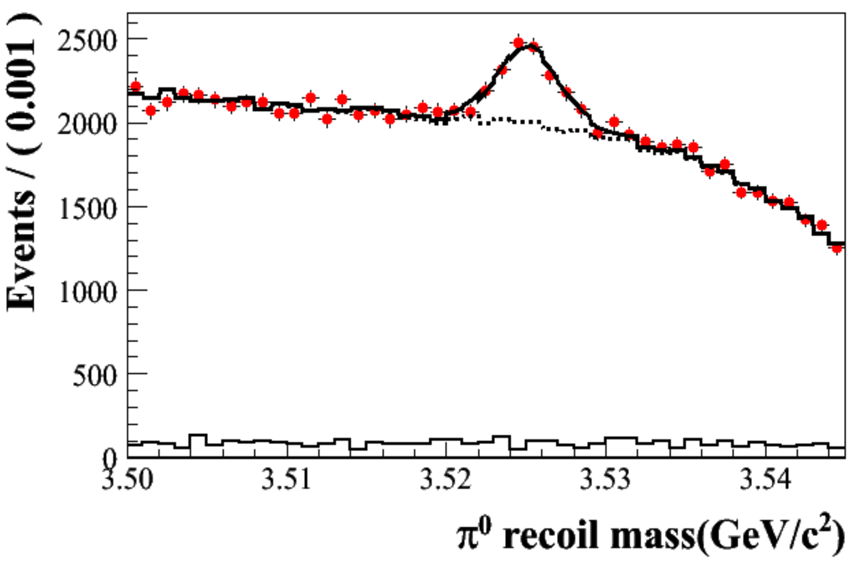
Multiplicity

Contribution of Continuum

Inclusive



E1 tagged



Continuum and Normalized by luminosity

$\psi(2S)$~160 pb^{-1}

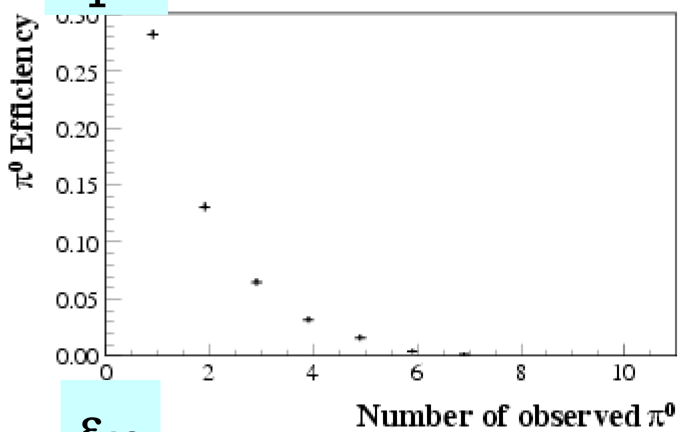
Continuum ~40 pb^{-1}

Number of π^0

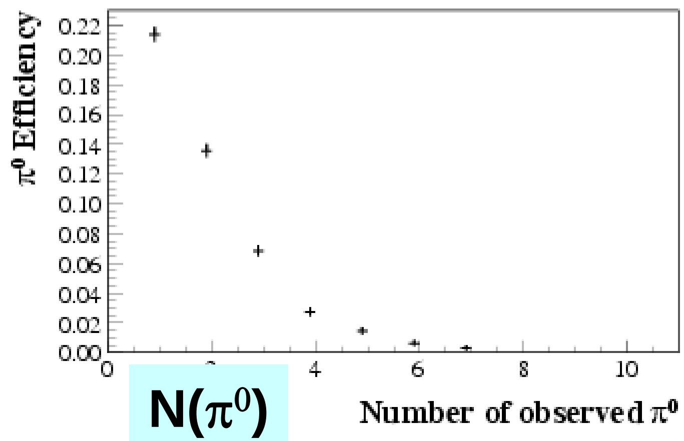
Determine the efficiencies vs. observed $N_{\pi 0}$ in MC
Compare observed numbers of π^0 in inclusive MC and $\psi(2S)$ data

$$\Delta\epsilon = \sum \epsilon_i \times \Delta N_i^{\pi^0},$$

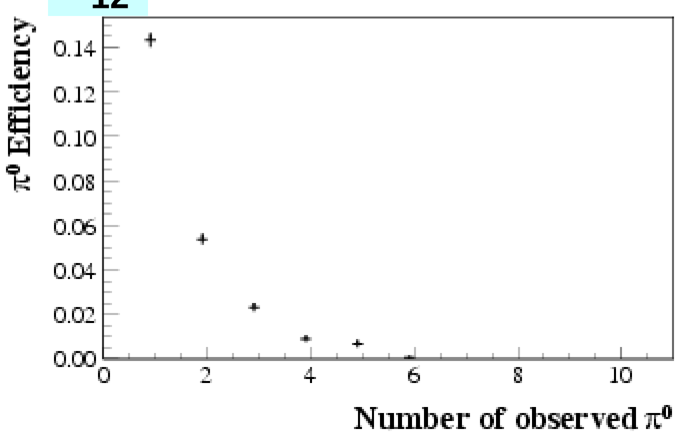
ε_1^{E1}



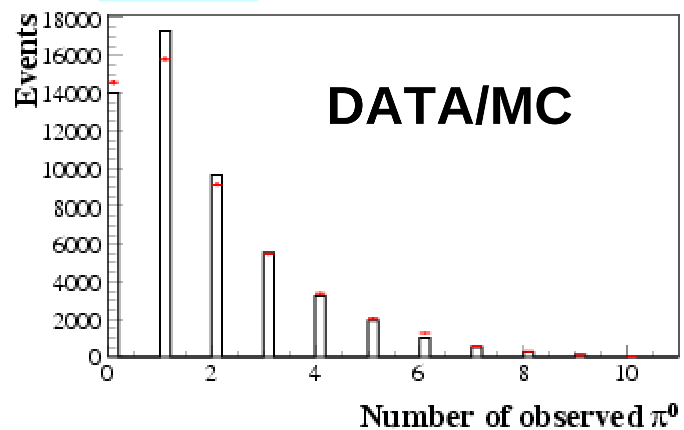
ε_1^{had}



ε_{12}

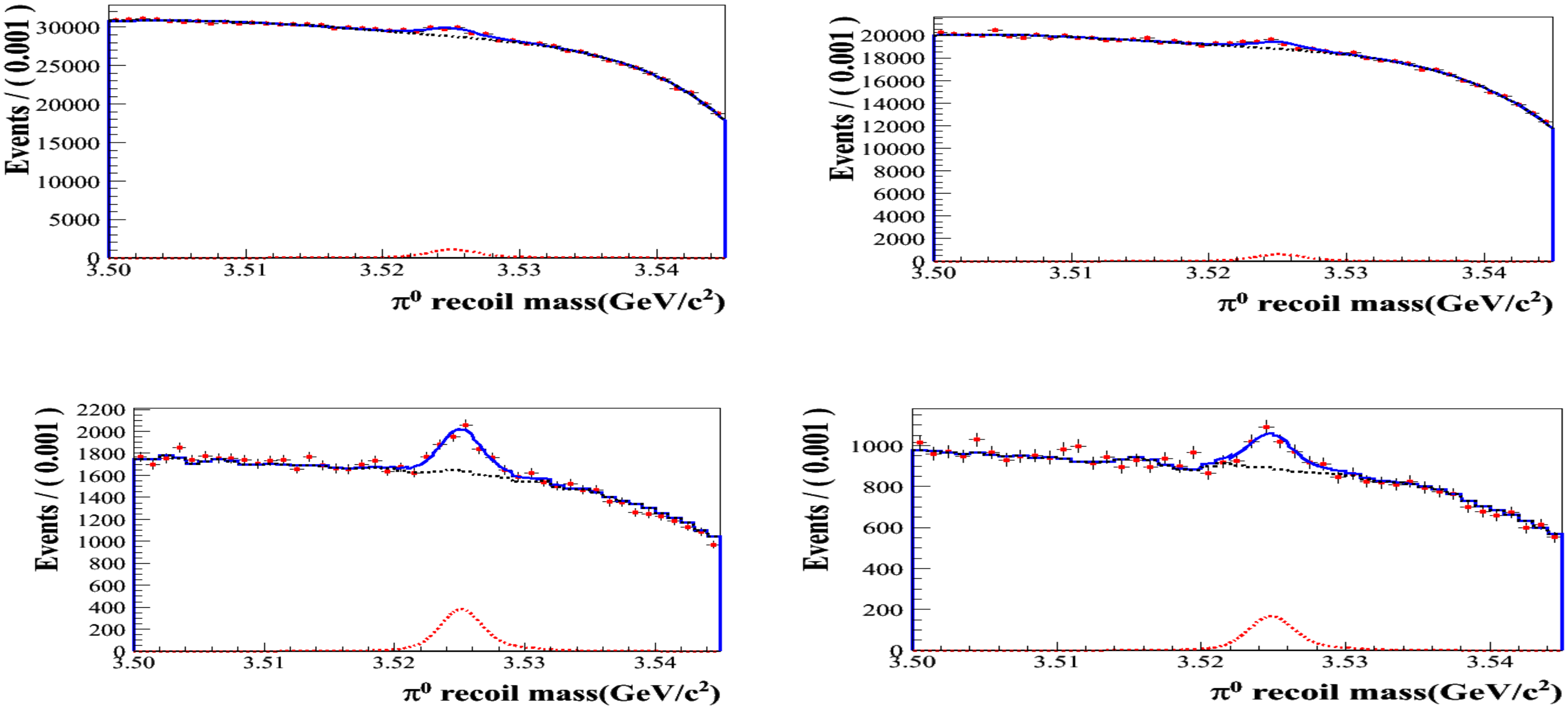


$N(\pi^0)$



Fits of sub-sample of $N_{\pi 0}$=1 and $N_{\pi 0}$>1

Npi0=1 Npi0>1



	$N_{\pi^0} = 1$	$N_{\pi^0} > 1$	Sum	Global
N^{tot}	5970 ± 803	3388 ± 656	9358 ± 1037	9233 ± 935
N^{E1}	1781 ± 226	761 ± 120	2542 ± 256	2540 ± 261
$\mathcal{B}_1 \times \mathcal{B}_2\ (10^{-4})$	4.67 ± 0.59	4.76 ± 0.75	4.70 ± 0.46	4.69 ± 0.48
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c)\ (10^{-4})$	8.93 ± 1.87	8.10 ± 1.97	8.54 ± 1.35	8.42 ± 1.29
$\mathcal{B}_2(h_c \to \gamma\eta_c)\ (\%)$	52.3 ± 8.7	58.8 ± 10.9	54.8 ± 6.8	55.7 ± 6.3

Summary of syst.

	$M(h_c)$(MeV)	$\Gamma(h_c)$(MeV)	B1(10^{-4})	B12(10^{-4})	B2(%)
Order	0.01	0.10	0.55	0.11	3.38
Bin	0.01	0.16	0.06	0.02	0.58
Range	0.08	0.10	0.05	0.11	1.14
Calib.	0.04	0.02	0.33	0.10	1.89
Ins. Res.	0.00	0.07	0.08	0.02	0.78
Veto XJpsi	0.03	0.02	0.02	0.02	0.36
E1 eff	0.00	0.00	0.00	0.11	1.30
π^0 eff	0.00	0.00	0.26	0.14	0.00
Ntrk	0.00	0.00	0.24	0.16	0.38
N(π^0)	0.00	0.00	0.52	0.33	0.53
N(psi(2S))	0.00	0.00	0.22	0.12	0.00
M(psi(2S))	0.03	0.02	0.00	0.00	0.00
Beam	0.00	0.01	0.00	0.01	0.1
MC	0.03	0.02	0.00	0.00	0.00
Sum	0.10	0.23	0.93	0.46	4.41