Study of $h_c(^1P_1)$ at BESIII

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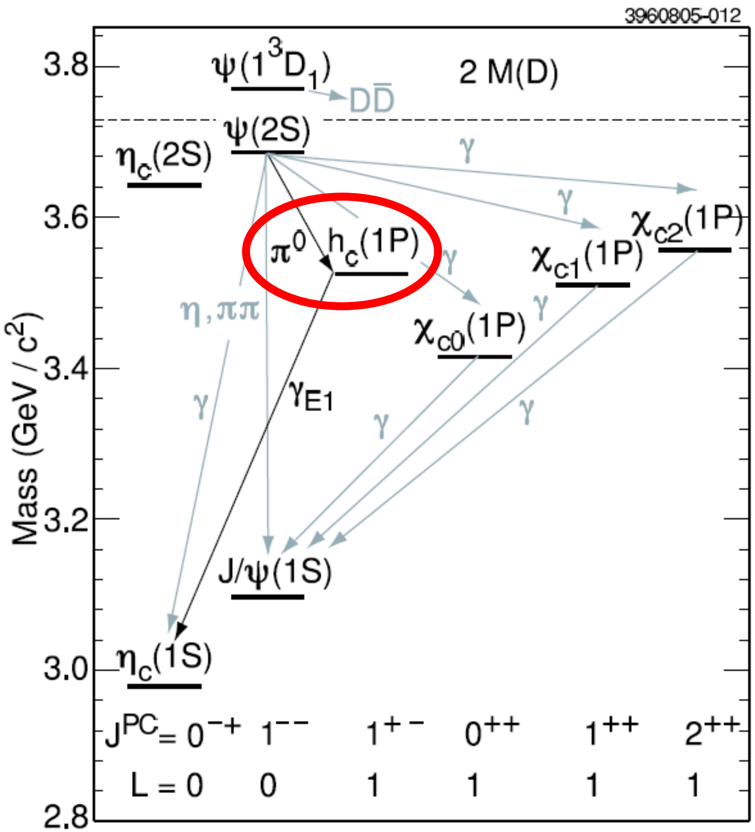
Outline

- **Introduction**
- **Event Selection**
- **DATA analysis**
- **Systematic errors**
- **Summary and discussion**

$h_c(^1P_1)$ in charmonium family



Although the charmonium family has been studied for many years, knowledge is sparse on the $c\bar{c}$ singlet state h_c

Non strong spin-spin interactions in charmonium potential models

$\Delta M_{hf} = M<1^3P> - M<1^1P_1> = 0$

$\rightarrow M(h_c) = M<1^1P_1> \approx 3525$MeV

Theoretical predictions of branching ratios:

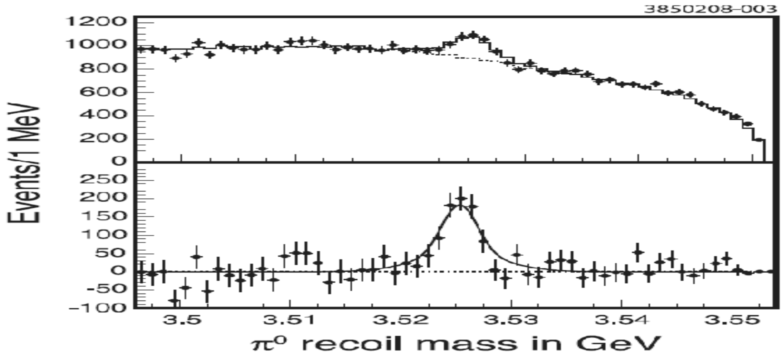
$B(\psi(2S)\rightarrow\pi^0 h_c) = (0.4\text{-}1.3)\times10^{-3}$
$B(h_c\rightarrow\gamma\eta_c) = 41\%$(NRQCD)
$B(h_c\rightarrow\gamma\eta_c) = 88\%$ (PQCD)
(Y.P.Kuang, PRD65,094024 (2002))
$B(h_c\rightarrow\gamma\eta_c) = 38\%$
(S. Godfrey and J.Rosner,PRD66,014012(2002))
…

Among this map, h_c is the last charmonium confirmed experimentally.
The process $\psi'\rightarrow\pi^0 h_c$ is the only known way to produce h_c in ψ' decay.

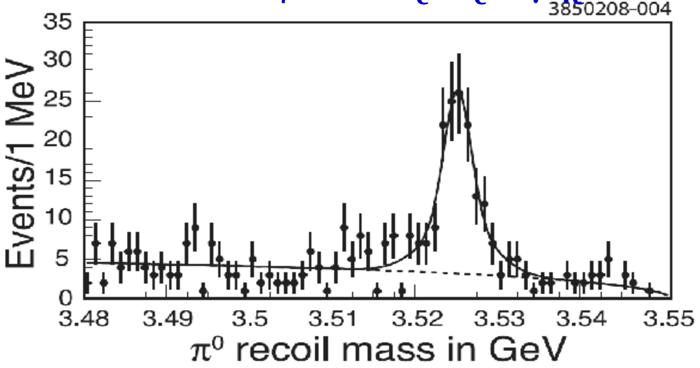
$h_c(^1P_1)$ at CLEOc

PRL101,182003(2008)

CLEO's Result –$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$ E1 tagged



CLEO's Result – $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$ exlusive



CLEOc obtained:

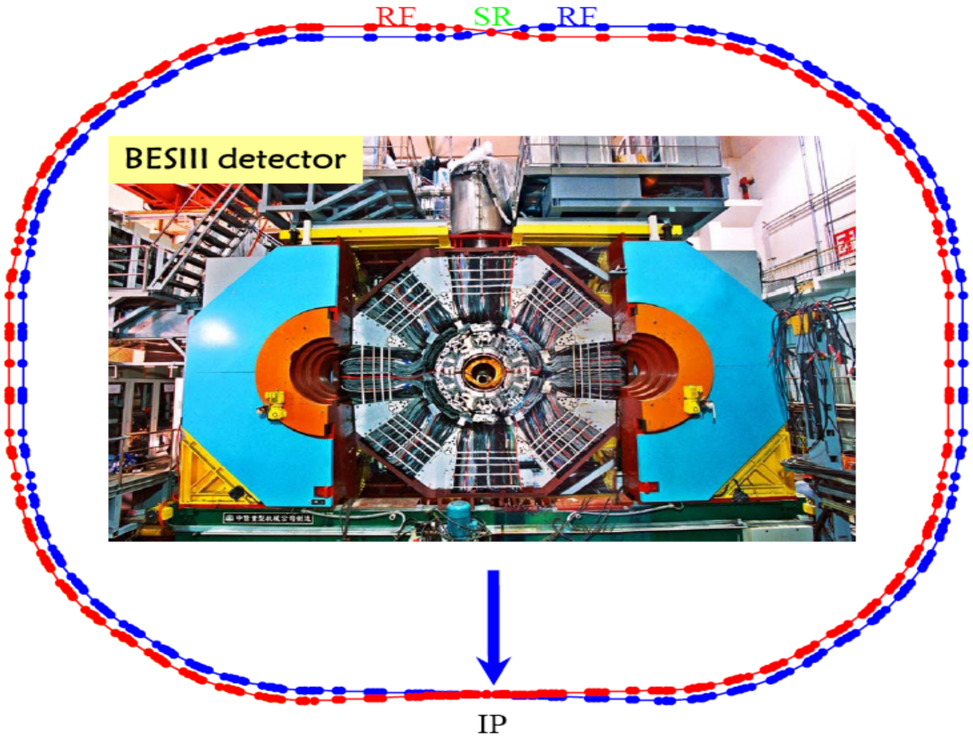
	Inclusive	Exclusive
Counts	1146 ± 118	136 ± 14
Significance	10.0σ	13.2σ
$M(h_c)$ (MeV)	$3525.35 \pm 0.23 \pm 0.15$	$3525.21 \pm 0.27 \pm 0.14$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^4$	$4.22 \pm 0.44 \pm 0.52$	$4.15 \pm 0.48 \pm 0.77$

$$M(h_c) = 3525.28 \pm 0.19(\text{stat.}) \pm 0.12(\text{syst.})\ \text{MeV},$$

$$\mathcal{B}(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c) = (4.19 \pm 0.32 \pm 0.45) \times 10^{-4}$$

$B(\psi' \rightarrow \pi^0 h_c)$ and the width of h_c have not been measured

BEPCII and BESIII



BESIII DATA as so far:
April 14, 2009 ~106M ψ'
(Largest $\psi(2S)$ sample in the world, $\times$4 CLEOc)

May 30, 2009 ~42 pb^{-1} at continuum

July 28, 2009 ~220M J/ψ (Largest J/ψ sample in the world)

2010 – ~400pb^{-1} ψ'' data

High luminosity and good low-energy photon identification of BESIII permit us to study physics involving low-energy photon such as $\psi(2S) \to \pi^0 h_c$, $\psi(2S) \to \gamma\eta_c(2S)$, …

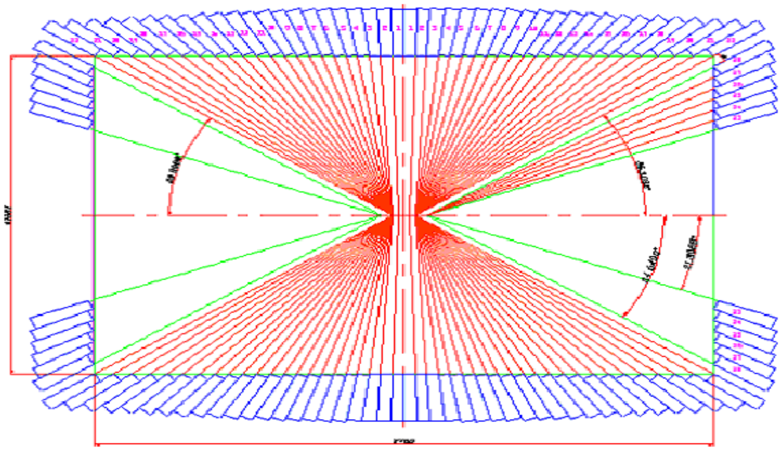
DATA Sample and Overview of Analysis

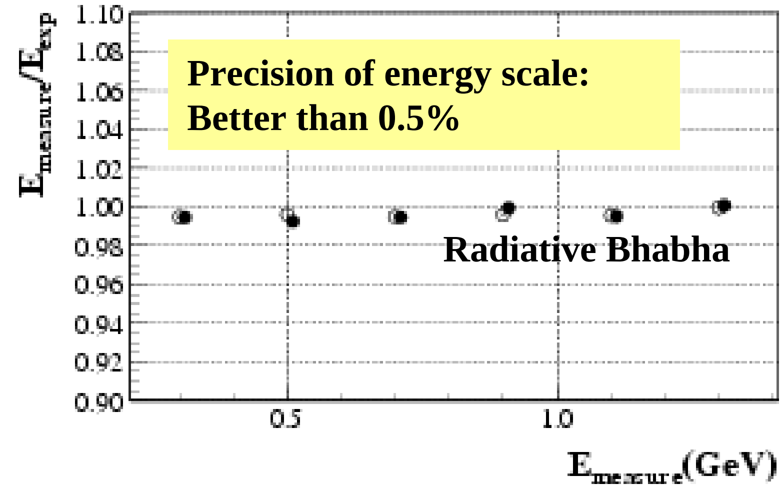
- **DATA Sample:**
  - **~106M $\psi(2S)$ events collected by BES-III at BEPC-II in March and April 2009**

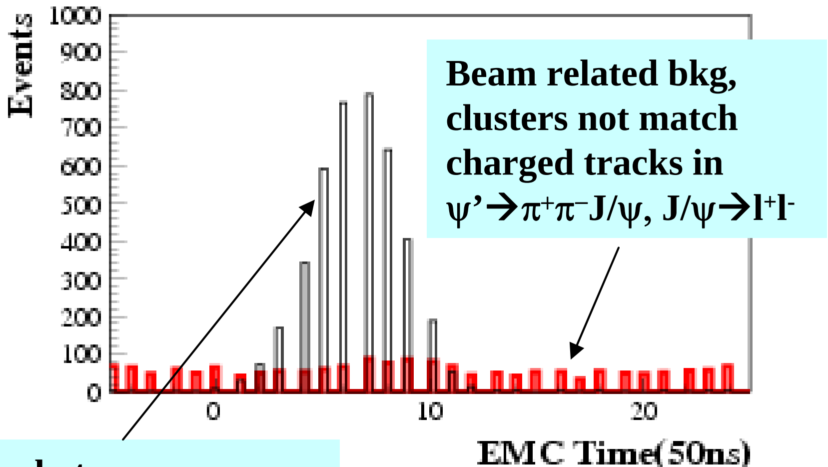
- **E1-tagged analysis of $\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$**
  - **Tag the E1 photon(~503MeV) emitted in $h_c \rightarrow \gamma_{E1} \eta_c$. No further constrains on the final states of the h_c are imposed. The h_c signal in π^0 recoil mass spectrum will be improved significantly.**

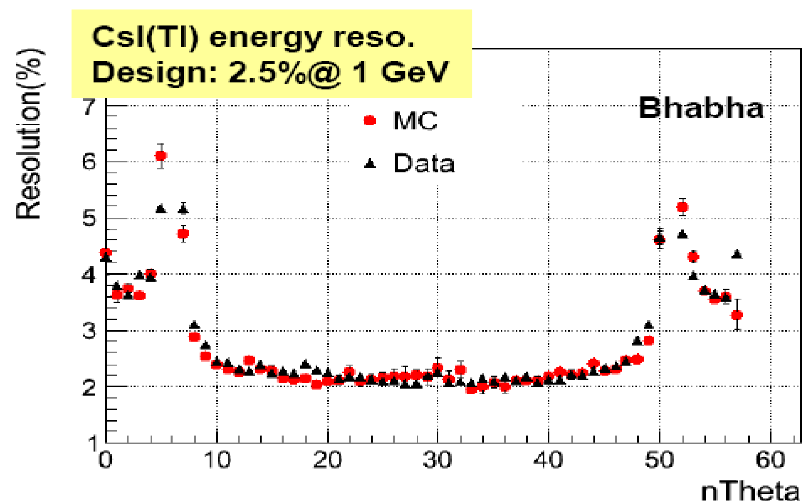
- **Inclusive analysis of $\psi(2S) \rightarrow \pi^0 h_c$**
  - **Identify the h_c signal by searching for an enhancement in the inclusive recoiling mass spectrum of π^0**

Performance of BESIII EMC









Physics photon,
from $\psi' \to \pi^0\pi^0 J/\psi$, $J/\psi \to l^+l^-$

Event selection

Good charged track

- IP region: $|R_{xy}| \leqslant 1$cm, $|Rz| \leqslant 10$cm
- Momentum: p<2.0GeV
- Polar angle: $|\cos\theta|<0.93$

Good photon

- $|\cos\theta|<0.8$: $E_\gamma > 25$MeV
- $0.86<|\cos\theta|<0.92$: $E_\gamma > 50$MeV
- Angle between charged track and neutral track: Dang>10°
- EMC time: $0 \leqslant t \leqslant 14$ (×50ns)

Event level

- Etot > 0.5 GeV
- $N_{charge} \geqslant 2$, $N_{good} \geqslant 1$
- $N_\gamma \geqslant 3$ for E1-tagged
- $N_\gamma \geqslant 2$ for inclusive

signal π^0 candidate selection

- Photon polar angle: $|\cos\theta|<0.8$
- Photon energy: $E_\gamma>40$MeV
- one π^0 in 3500-3560MeV (for E1-tagged)
- Each photon belongs to only one π^0 (for inclusive)
- $M_{\gamma\gamma} \in [0.12, 0.145]$GeV/$c^2$
- Do 1C fit for each π^0 candidate (no cut on χ^2)

Tag E1 photon in $h_c \rightarrow \gamma_{E1}\eta_c$

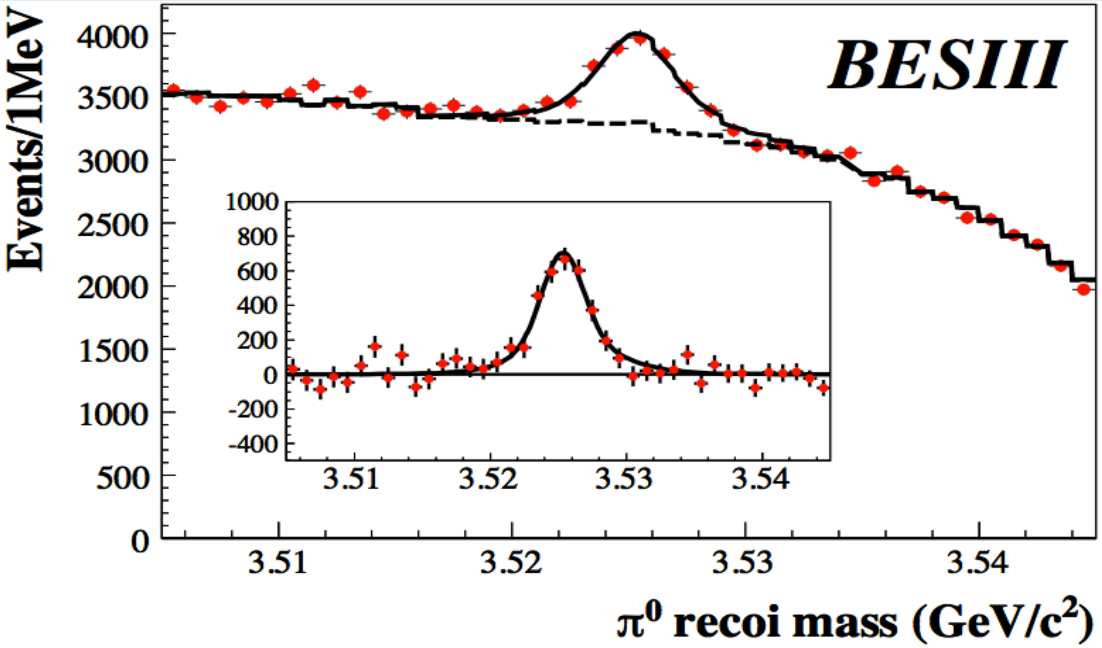
- 450MeV<E_γ<540MeV
- Not belonging to π^0 (0.10-0.145GeV/c^2)

Background Veto

- $\pi^+\pi^- J/\psi$: $|M^{rec}(\pi^+\pi^-)-3.097|>0.007$GeV/$c^2$
- $\pi^0\pi^0 J/\psi$: $|M^{rec}(\pi^0\pi^0)-3.097|>0.015$GeV/$c^2$

E1-tagged $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$

π^0 recoil mass spectrum in E1-tagged analysis



Significance = 18.6σ

$M(h_c)$=3525.40±0.13MeV

$N(h_c)$= 3679±319

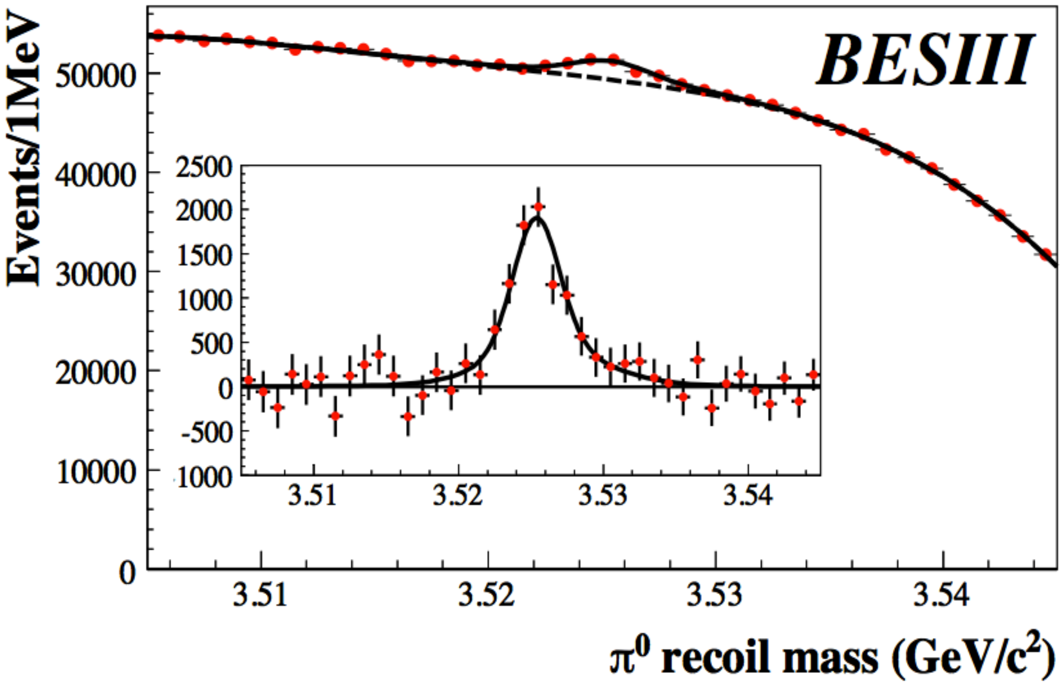
$\Gamma(h_c)$ = 0.73±0.45MeV

χ^2/d.o.f = 33.5/36

Breit-Wigner convoluted with a D-Gaussian resolution + bkg.
The mass and width of h_c are allowed to float. The background is represented by the π^0 recoil mass spectrum in the sideband of the E1 photon and the normalization is allowed to float.

Inclusive $\psi' \rightarrow \pi^0 h_c$

Inclusive π^0 recoil mass spectrum in ψ' decay



Significance = 9.5σ

$N(h_c) = 10353 \pm 1097$

χ^2/d.o.f = 24.5/34

The mass and width of h_c are fixed to the values obtained from E1-tagged analysis. The background is parameterized by a 4th-order Chebychev polynomial, and all of its parameters are allowed to float.

Branching fractions

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

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

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

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

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

- $\mathcal{B}_1 \equiv \mathcal{B}_1(\psi(2S) \to \pi^0 h_c)$
- $\mathcal{B}_2 \equiv \mathcal{B}_2(h_c \to \gamma\eta_c)$
- $\mathcal{B}_1 \times \mathcal{B}_2 \equiv \mathcal{B}_1(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_2(h_c \to \gamma\eta_c)$
- 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 $\psi(2S) \to \pi^0 h_c$

N^{tot}	10353 ± 1097
N^{E1}	3679 ± 319
$\epsilon_1^{E1}(\%)$	12.89
$\epsilon_1^{had}(\%)$	10.02
$\epsilon_{12}(\%)$	7.57
$N(\psi(2S))(10^6)$	106.0
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_2(h_c \to \gamma\eta_c)$ (10^{-4})	4.58 ± 0.40
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c)(10^{-4})$	8.4 ± 1.3
$\mathcal{B}_2(h_c \to \gamma\eta_c)(\%)$	54.3 ± 6.7

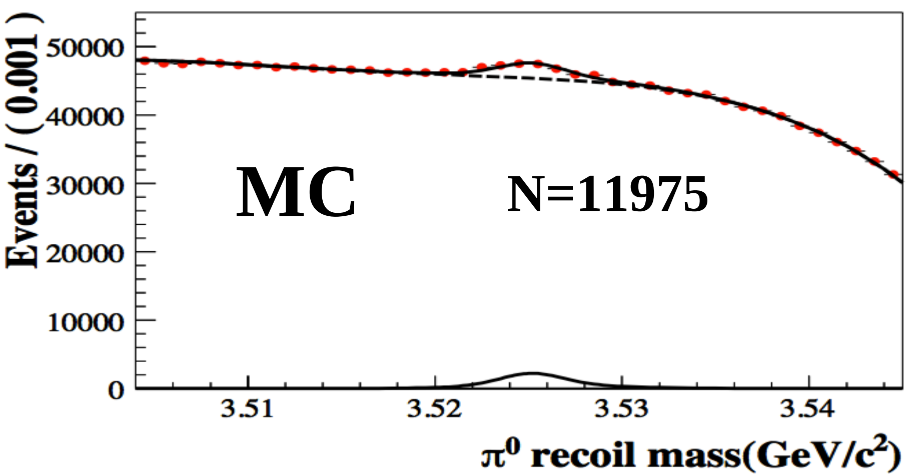
Input/Output checking in MC

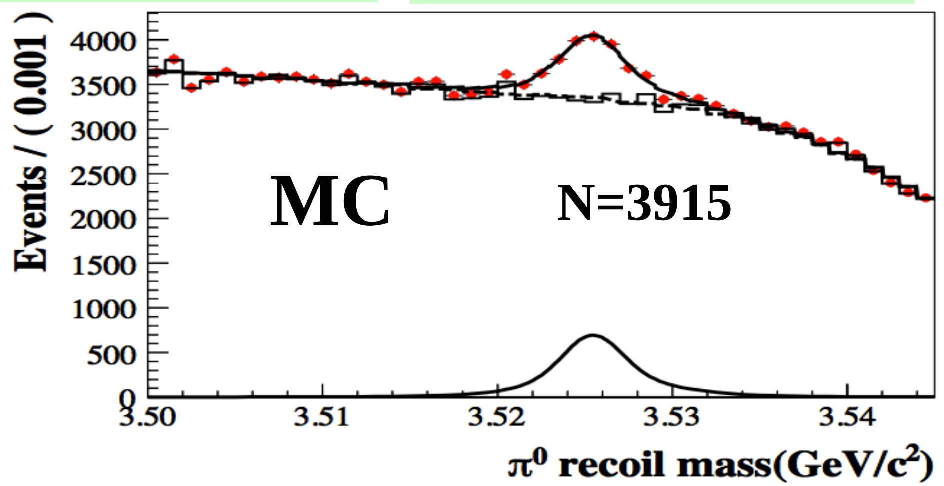
- Mix 100,000 $\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow$anything (50% set to $h_c \rightarrow \gamma\eta_c$) MC with 100M inclusive $\psi(2S)$ MC

Inclusive $\psi(2S) \rightarrow \pi^0 h_c$

- No peaking background
- Input consist with output

E1-tagged $\psi(2S) \rightarrow \pi^0 h_c, hc \rightarrow \gamma\eta_c$





	Input	Output
$M(h_c)(MeV/c^2)$	3525.28	3525.35±0.15
$\Gamma(h_c)(MeV/c^2)$	0.90	1.37±0.57
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c) \times \mathcal{B}_2(h_c \to \gamma\eta_c)$	5.00×10^{-4}	$5.17 \pm 0.49 \times 10^{-4}$
$\mathcal{B}_1(\psi(2S) \to \pi^0 h_c)$	10.0×10^{-4}	$(10.5 \pm 1.5) \times 10^{-4}$
$\mathcal{B}_2(h_c \to \gamma\eta_c)$	50%	(49.4 ± 5.2)%

Summary of systematic errors

Source	$M(h_c)$ (MeV/c^2)	$\Gamma(h_c)$ (MeV)	$\mathcal{B}_1(10^{-4})$	$\mathcal{B}_1 \times \mathcal{B}_2(10^{-4})$	$\mathcal{B}_2(\%)$
Background shape and fit range	0.11	0.23	0.4	0.22	4.4
Energy scale, position reconstruction and 1-C fit	0.13	0.06	0.5	0.10	2.1
Energy resolution	0.00	0.15	0.2	0.03	1.0
Background veto	0.05	0.03	0.0	0.03	0.3
π^0 efficiency	0.00	0.00	0.3	0.14	0.0
$E1$ photon efficiency	0.00	0.00	0.0	0.10	1.2
Number of π^0	0.00	0.00	0.6	0.35	0.6
Number of charged tracks	0.00	0.00	0.1	0.06	0.1
$N(\psi')$	0.00	0.00	0.4	0.19	0.0
$M(\psi')$	0.03	0.02	0.0	0.00	0.0
$M(\eta_c)$ and $\Gamma(\eta_c)$	0.00	0.00	0.0	0.01	0.3
Total systematic error	0.18	0.28	1.0	0.50	5.2

The total systematic errors are the square root of the sum of all systematic errors squared

Summary and Discussion

Combine the fully inclusive and E1-tagged analysis, we get:

	BESIII	CLEO (E1-tagged)
$M(h_c)$	$3525.40 \pm 0.13 \pm 0.18$ MeV	$3525.35 \pm 0.23 \pm 0.15$ MeV
Γ(hc)	$0.73 \pm 0.45 \pm 0.28$ MeV (<1.44MeV at CL=90%)	-
$B(\psi' \rightarrow \pi^0 h_c) \times B(h_c \rightarrow \gamma \eta_c)$	$(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$ ($\Gamma(h_c)$ float)	$(4.22 \pm 0.44 \pm 0.52) \times 10^{-4}$ ($\Gamma(h_c)$ fixed to 0.9MeV)
$Br(\psi' \rightarrow \pi^0 h_c)$	$(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$	-
$Br(h_c \rightarrow \gamma \eta_c)$	$(54.3 \pm 6.7 \pm 5.2)\%$	-

Summary and Discussion

- $B(\psi' \rightarrow \pi^0 h_c)=$**$(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$** is consistent with prediction in

  Y.P.Kuang, PRD65, 094024(2002)

- $B(h_c \rightarrow \gamma\eta_c)$ **= $(54.3 \pm 6.7 \pm 5.2)\%$** is consistent with $B(\chi_{c1} \rightarrow \gamma J/\psi)=(36.0 \pm 1.9)\%$ and predictions in

  Y.P.Kuang, PRD65, 094024(2002)

  S. Godfrey and J.Rosner,PRD66,014012(2002)

- The total width $\Gamma(h_c)$ = **$0.73 \pm 0.45 \pm 0.28$ MeV(<1.44MeV@CL=90%)** is consistent with $\Gamma(\chi_{c1}) = 0.89 \pm 0.05$MeV , also consistent with prediction in

  Y.P.Kuang, PRD65, 094024(2002)

  J.J. Dudek, R.G. Edwards and D.G. Richards, RD73, 074450(2006)

- 1P hyperfine mass splitting

  $\Delta M_{hf}=\langle M(1^3P)\rangle - \langle M(1^1P_1)\rangle =$ **$-0.10 \pm 0.13 \pm 0.18 MeV/c^2$**

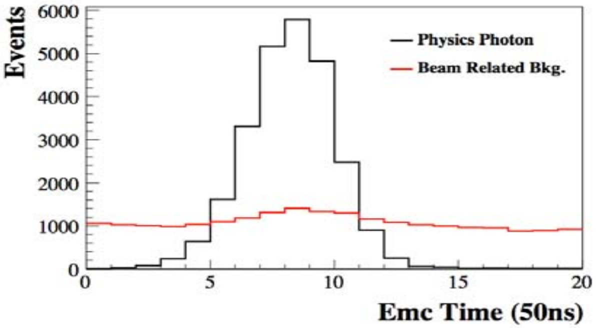
  consistent with no strong spin-spin interaction.

Thank you!

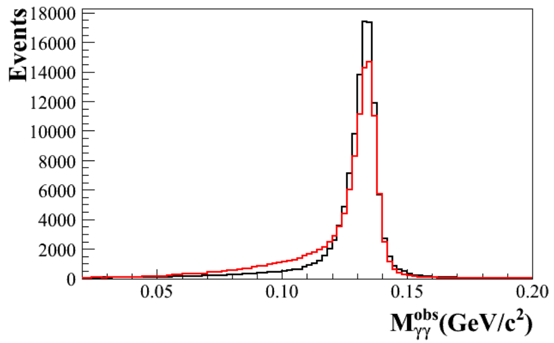
Backups

Efforts for improving low momentum γ/π^0 detection

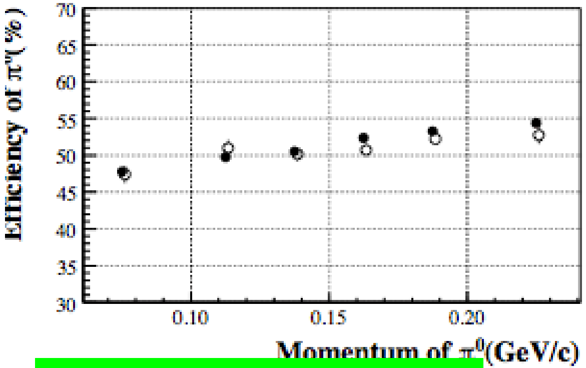
Use time information to reject beam gas



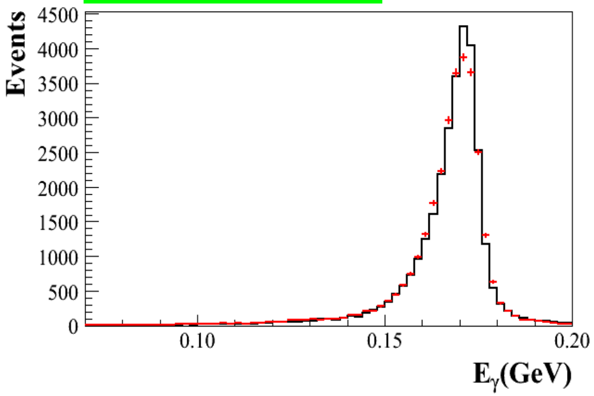
Add energy deposit in TOF to improve efficiency



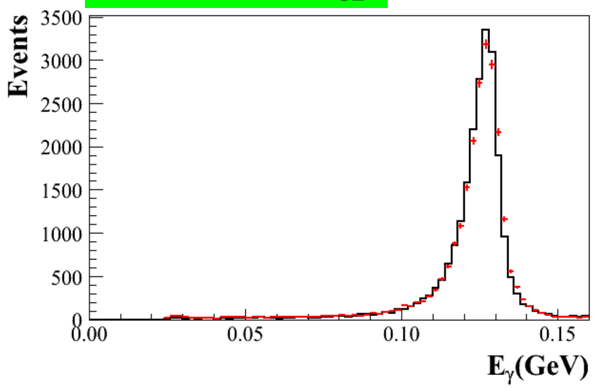
π^0 efficiency



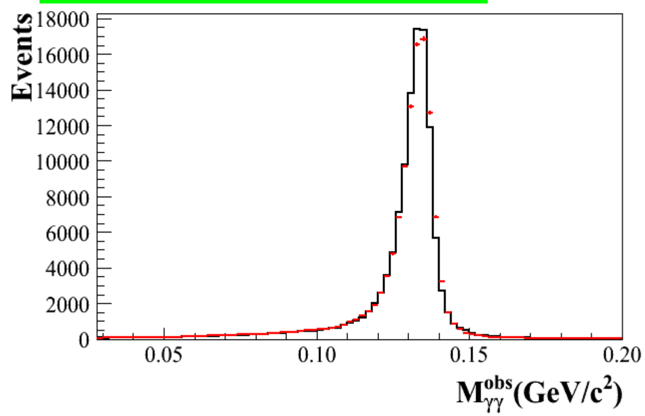
γ in $\psi' \rightarrow \gamma\chi_{c2}$



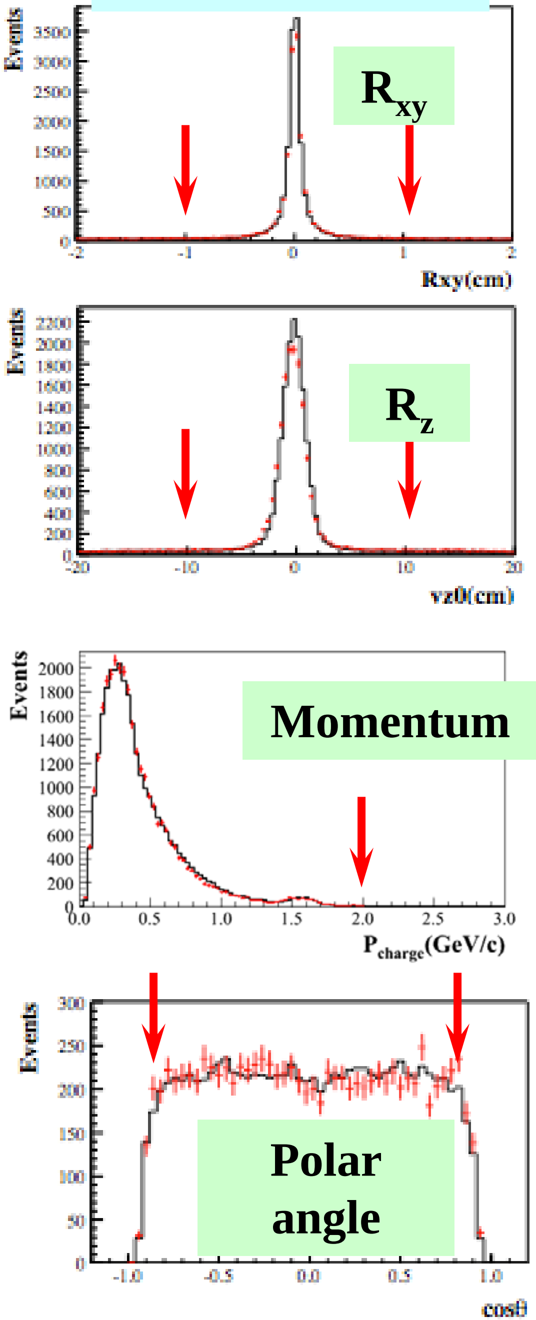
γ In $\psi' \rightarrow \gamma\chi_{c1}$



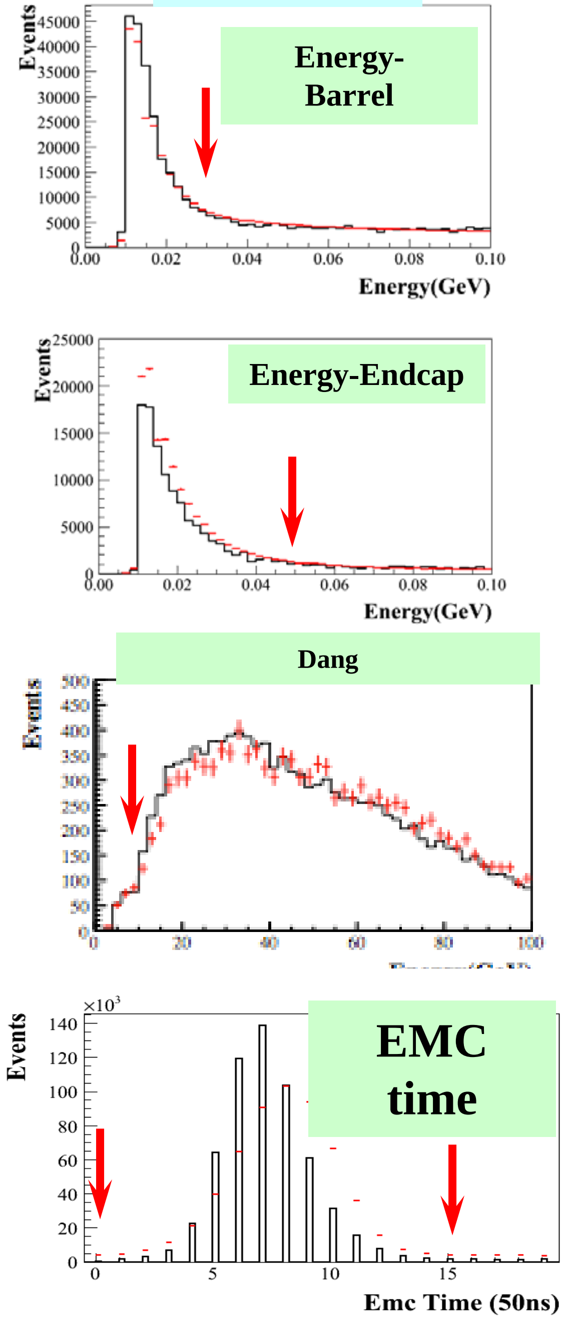
π^0 in $\psi' \rightarrow \pi^0\pi^0 J/\psi$



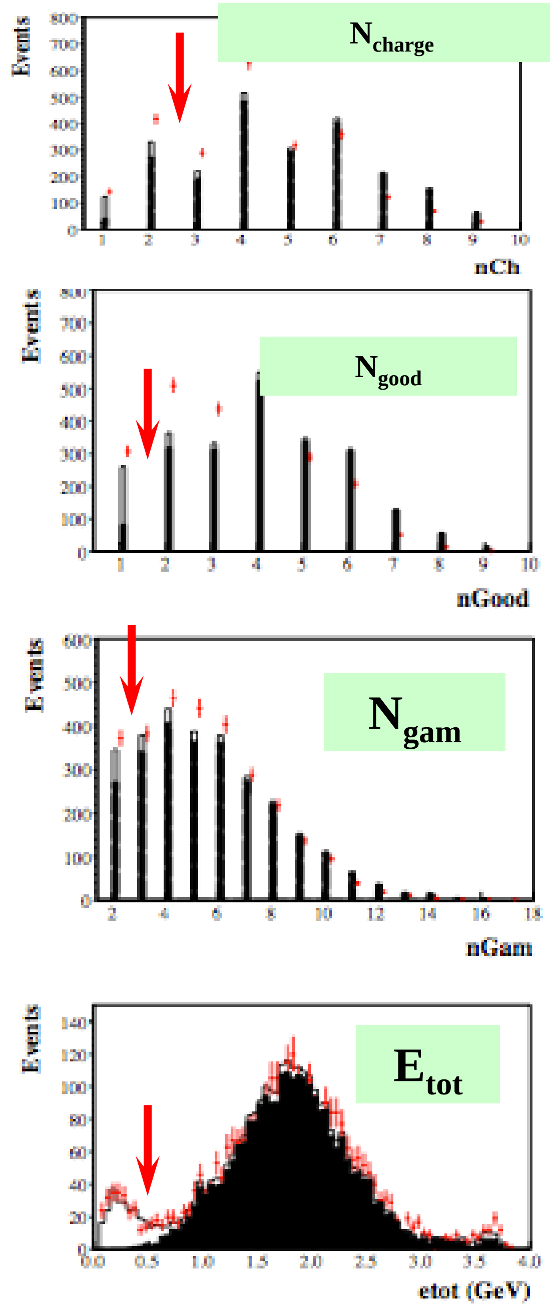
Charged



Photon

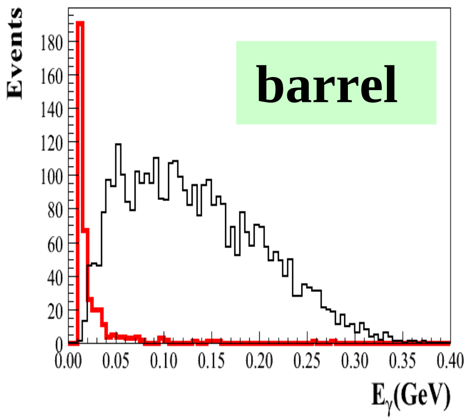


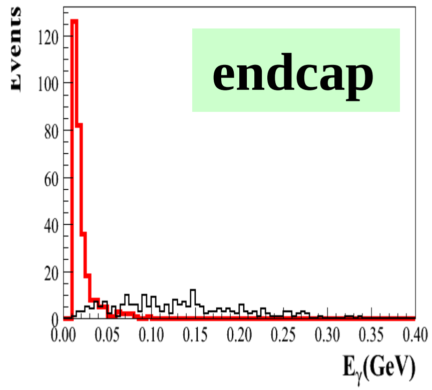
Event level



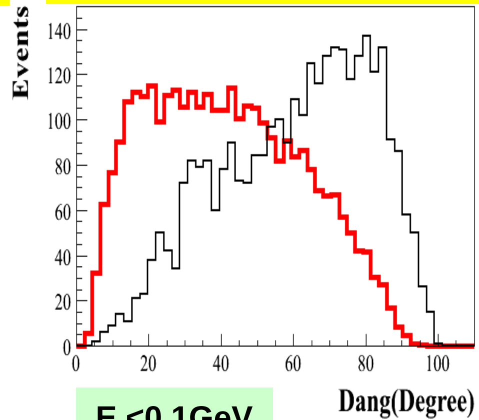
Determination of good photon selection

Energy deposit for real and fake photons

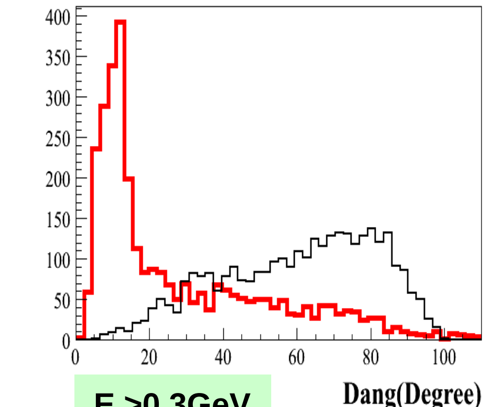




Angle between photon and charged track at EMC (fake photons are from $y(2S) \to p^+p^-J/y \to p^+p^-l^+l^-$)

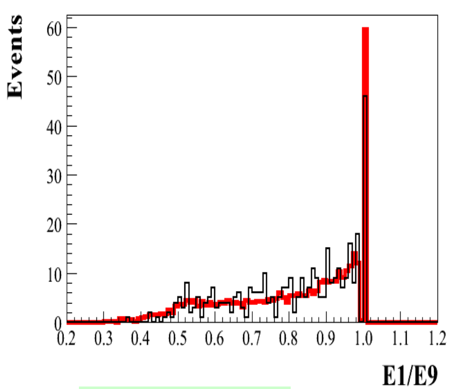


$E_\gamma < 0.1$GeV

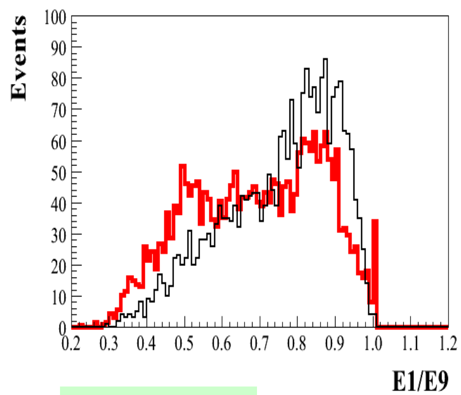


$E_\gamma > 0.3$GeV

E1/E9

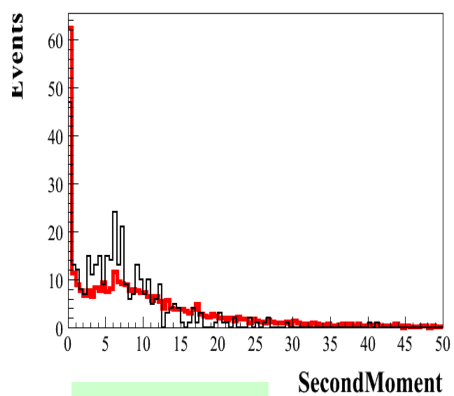


$E_\gamma < 0.1$GeV

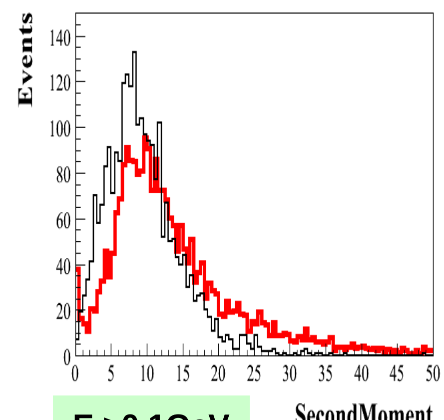


$E_\gamma > 0.1$GeV

Second moment



$E_\gamma < 0.1$GeV



$E_\gamma > 0.1$GeV

Selection Optimization in Monte Carlo Simulation

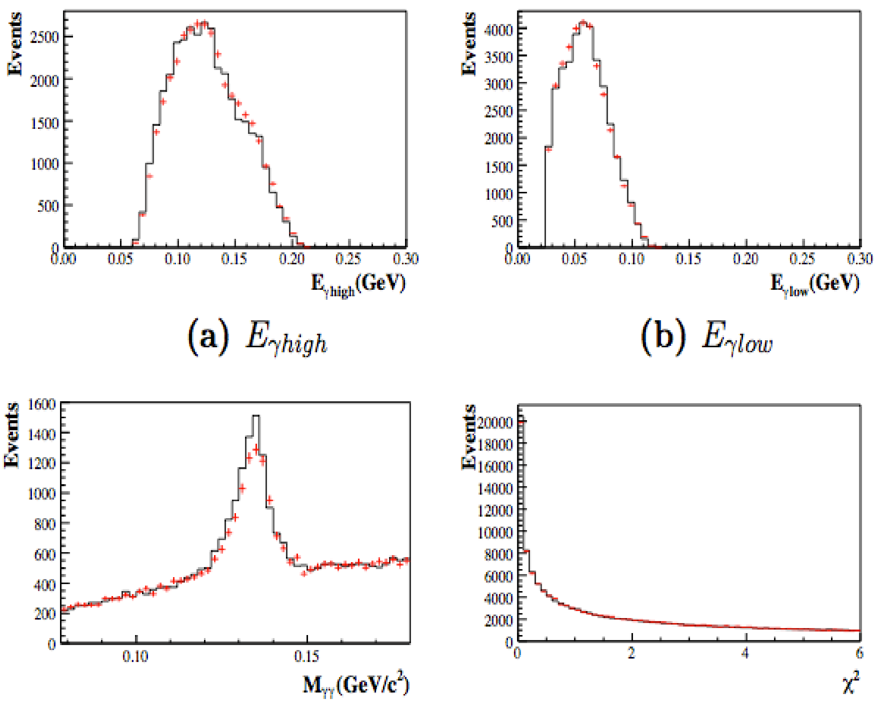
Selection criteria	$S/\sqrt{N(MC)}$	$S/\sqrt{N(DATA)}$
Angle between the neutral and charged track		
0 °	15.62	15.23
*10 °	15.72	15.31
20 °	15.38	15.01
Photon energy of signal π^0		
30 MeV	15.51	15.06
*40 MeV	15.72	15.31
50 MeV	14.09	13.71
Total energy		
0.5 GeV	15.69	15.29
*0.6 GeV	15.72	15.31
0.7 MeV	15.70	15.29
If the daughter photons from signal π^0 come from only one π^0		
No	14.75	14.13
*Yes	15.76	15.31
Mass range for vetoing $\pi^+\pi^- J/\psi$		
±0MeV	14.72	14.36
*±7MeV	15.72	15.31
±15MeV	15.62	15.21
Mass range for vetoing $\pi^0\pi^0 J/\psi$		
±0MeV(don't veto)	15.54	14.90
*±15MeV	15.72	15.31
±30MeV	15.51	15.08
Mass range for vetoing $\gamma\gamma J/\psi$		
*±0MeV(don't veto)	15.72	15.31
±5MeV	15.66	15.19
±10MeV	15.61	15.18

Selection criteria	$S/\sqrt{N(MC)}$	$S/\sqrt{N(DATA)}$
The minimum χ^2 π^0 are selected, the number of π^0 in the signal region equal to one		
No	19.54	18.10
* Yes	20.07	18.54
Lower limit of E1 photon(GeV)		
0.46	19.90	18.34
*0.465	20.13	18.57
0.47	20.07	18.54
Upper limit of E1 photon(GeV)		
0.53	19.99	18.19
*0.535	20.13	18.57
0.54	20.00	18.54
Lower limit of $M_{\gamma\gamma}$ for π^0 suppression on E1 photon(GeV/c^2)		
0.11	20.19	18.57
*0.115	20.21	18.57
0.12	20.13	18.54
Upper limit of $M_{\gamma\gamma}$ for π^0 suppression on E1 photon(GeV/c^2)		
0.14	19.82	18.49
*0.145	20.21	18.57
0.15	20.17	18.50

Selection criteria	$S/\sqrt{N(MC)}$	$S/\sqrt{N(DATA)}$
Lower limit of $M_{\gamma\gamma}$ for η suppression on E1 photon(GeV/c^2)		
0.53	20.09	18.52
* –	20.21	18.57
Upper limit of $M_{\gamma\gamma}$ for η suppression on E1 photon(GeV/c^2)		
* –	20.21	18.57
0.56	20.03	18.47
If there is only one E1 photon candidate (after π^0 and η suppression on E1 photon)		
Yes	19.42	18.23
*No	20.21	18.57

Selected π^0 and P_{π^0} vs $E_{\gamma E1}$

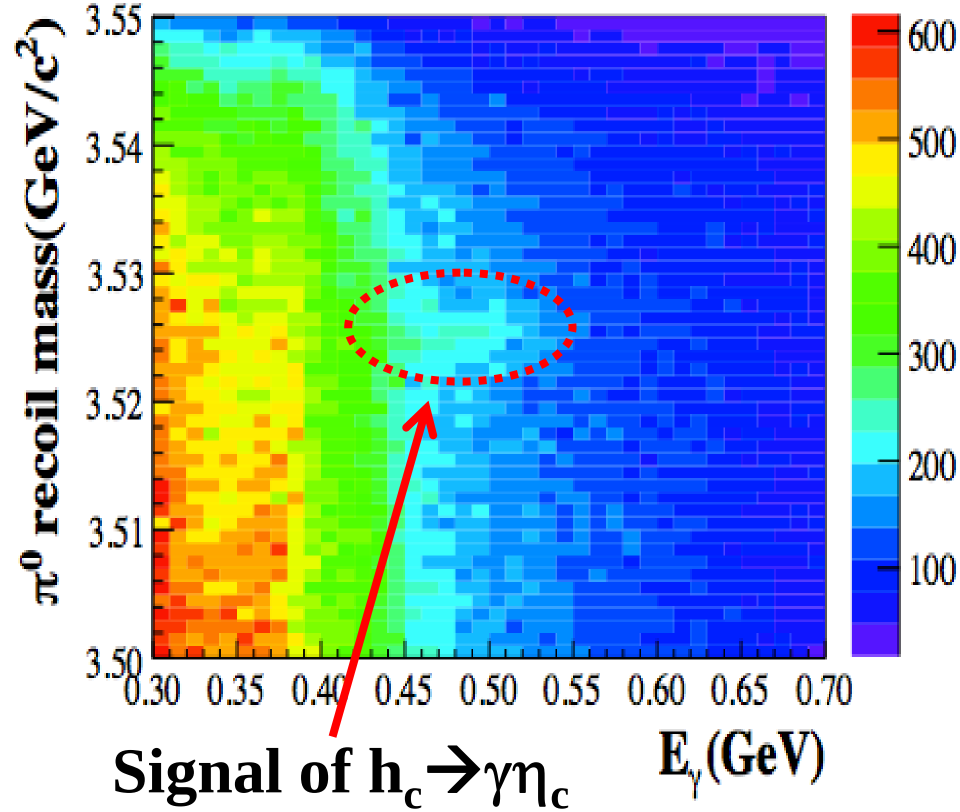
Selected π^0 in the inclusive analysis



(a) $E_{\gamma high}$ (b) $E_{\gamma low}$

(c) $M_{\gamma\gamma}$ (d) χ^2 of 1-C fit

$P_{\pi 0}$ vs $E_{\gamma E1}$ in the inclusive analysis



Systematic errors

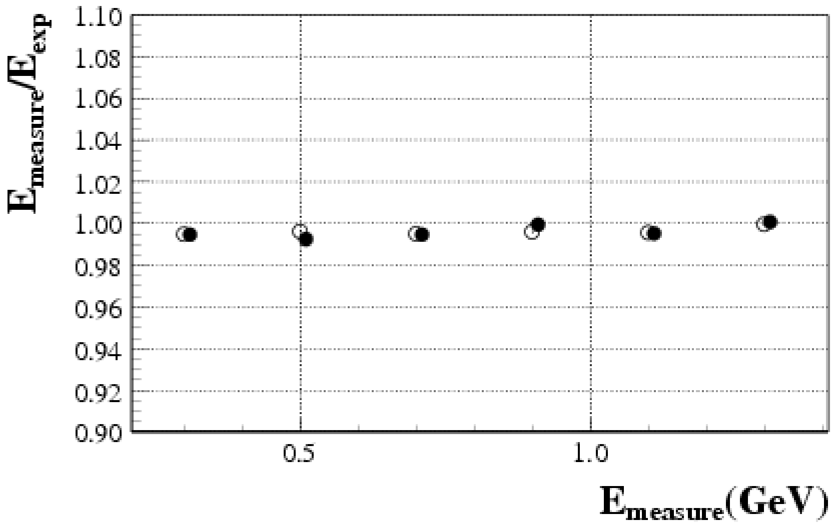
- **Sources**
  - **Background shape, fit range, bin size**
  - **Absolute energy calibration**
  - **Instrument resolution shape**
  - **E1 photon efficiency**
  - **π^0 efficiency**
  - **Number of charged track**
  - **Number of π^0**
  - **Veto XJpsi**
  - **N(ψ(2S))**
  - **Mass of ψ(2S)**
  - **Modeling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

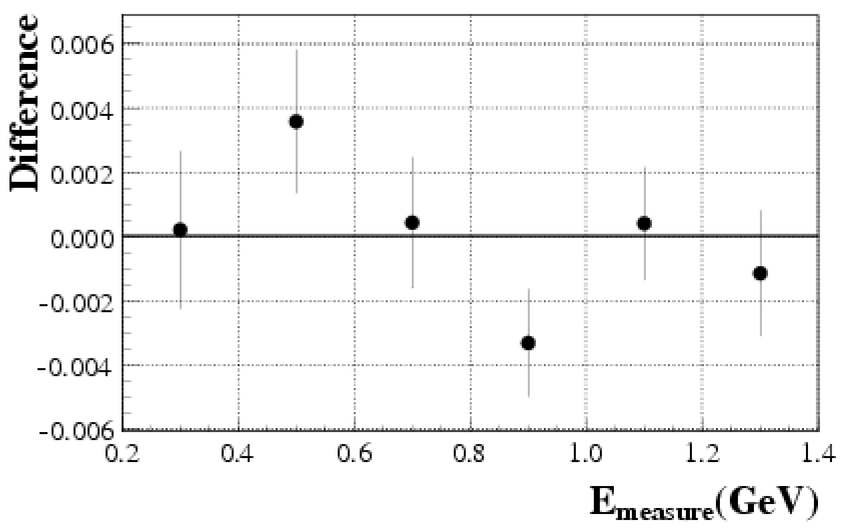
Systematic errors in bkg shape

	N^{tot}	N^{E1}	$M(h_c)$	$\Gamma(h_c)$	$\mathcal{B}_1(\times 10^{-4})$	$\mathcal{B}_{12}(\times 10^{-4})$	$\mathcal{B}_2(\%)$
Effect of Change the order of polynomial background and use MC bkg. for inclusive analysis							
3-order	10983 ± 1015	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	9.0 ± 1.2	4.58 ± 0.40	50.8 ± 5.4
*4-order	10353 ± 1097	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.4 ± 1.3	4.58 ± 0.40	54.3 ± 6.7
*5-order	10337 ± 1075	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.4 ± 1.2	4.58 ± 0.40	54.4 ± 6.5
*MC bkg	10019 ± 906	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.1 ± 1.1	4.58 ± 0.40	56.4 ± 5.9
Syst.	–	–	–	–	0.3	–	2.1
Change sideband of E1 photon and use MC bkg for E1-tagged analysis							
* no γ in $400-600$MeV	10353 ± 1097	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.4 ± 1.3	4.58 ± 0.40	54.3 ± 6.7
* no γ in $450-550$MeV	10353 ± 1097	3696 ± 341	3525.42 ± 0.13	0.77 ± 0.49	8.4 ± 1.3	4.61 ± 0.42	54.6 ± 6.7
* no γ in $350-600$MeV	10353 ± 1097	3680 ± 321	3525.38 ± 0.13	0.76 ± 0.45	8.4 ± 1.3	4.59 ± 0.40	54.4 ± 6.7
* no γ in $400-650$MeV	10353 ± 1097	3697 ± 322	3525.38 ± 0.13	0.77 ± 0.46	8.4 ± 1.3	4.61 ± 0.40	54.7 ± 6.7
* $380-450$ and $550-620$ MeV	10353 ± 1097	3728 ± 324	3525.51 ± 0.13	0.81 ± 0.46	8.4 ± 1.3	4.65 ± 0.40	55.2 ± 6.8
* $330-400$ and $600-670$ MeV	10353 ± 1097	3747 ± 317	3525.48 ± 0.13	0.69 ± 0.44	8.4 ± 1.3	4.67 ± 0.40	55.5 ± 6.8
* $260-330$ and $670-740$ MeV	10353 ± 1097	3785 ± 330	3525.37 ± 0.14	0.91 ± 0.47	8.4 ± 1.3	4.72 ± 0.41	56.2 ± 6.8
4-order	10353 ± 1097	3581 ± 553	3525.41 ± 0.13	0.74 ± 0.57	8.5 ± 1.7	4.46 ± 0.69	52.7 ± 6.4
MC bkg	10353 ± 1097	3551 ± 404	3525.51 ± 0.12	0.56 ± 0.46	8.5 ± 1.4	4.42 ± 0.69	52.2 ± 6.4
Syst.	–	–	0.11	0.18	0.0	0.14	1.9
Effect of bin size							
1MeV	10714 ± 988	3690 ± 341	3525.40 ± 0.14	0.73 ± 0.47	8.8 ± 1.2	4.60 ± 0.42	52.4 ± 5.6
0.5MeV	10798 ± 1103	3707 ± 337	3525.40 ± 0.13	0.78 ± 0.45	8.8 ± 1.3	4.62 ± 0.42	52.2 ± 6.1
0.25MeV	10500 ± 1138	3685 ± 337	3525.41 ± 0.13	0.76 ± 0.46	8.6 ± 1.3	4.59 ± 0.42	53.6 ± 5.6
0.125MeV	10382 ± 921	3683 ± 319	3525.40 ± 0.13	0.74 ± 0.45	8.5 ± 1.1	4.59 ± 0.40	54.2 ± 5.6
0.0625MeV	10372 ± 921	3678 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.5 ± 1.1	4.59 ± 0.40	54.2 ± 5.6
0.03125MeV	10365 ± 921	3679 ± 319	3525.40 ± 0.13	0.74 ± 0.45	8.5 ± 1.1	4.59 ± 0.40	54.2 ± 5.6
* Unbined	10353 ± 1097	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.4 ± 1.3	4.58 ± 0.40	54.3 ± 6.7
Syst.	–	–	–	–	–	–	–
Effect of changing fit range, MeV/c^2							
* 3505−3545	10353 ± 1097	3679 ± 319	3525.40 ± 0.13	0.73 ± 0.45	8.4 ± 1.3	4.58 ± 0.40	54.3 ± 6.7
* 3510−3545	10404 ± 1034	3535 ± 323	3525.40 ± 0.13	0.59 ± 0.46	8.7 ± 1.2	4.41 ± 0.40	50.9 ± 5.2
* 3505−3540	10538 ± 942	3609 ± 320	3525.40 ± 0.13	0.69 ± 0.46	8.6 ± 1.2	4.50 ± 0.40	52.1 ± 5.4
Syst.	–	–	0.00	0.14	0.3	0.17	3.4
Summed Syst.	–	–	0.11	0.23	0.4	0.22	4.4

Systematic errors in energy calibration

From radiative Bhabha





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

	MC	DATA
E_γ(MeV)	127.48 ± 0.20	127.98 ± 0.14
σ_E(MeV)	3.71 ± 0.11	3.80 ± 0.07
$\sigma_E/E_\gamma(\%)$	2.91 ± 0.08	2.97 ± 0.07

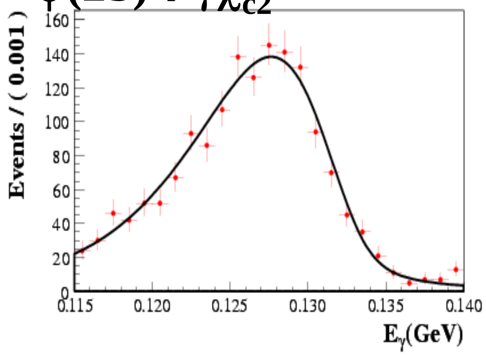
Systematic ~ 0.4%

	MC	DATA
E_γ(MeV)	171.19 ± 0.10	171.36 ± 0.12
σ_E(MeV)	4.79 ± 0.06	5.00 ± 0.07
$\sigma_E/E_\gamma(\%)$	2.80 ± 0.04	2.91 ± 0.04

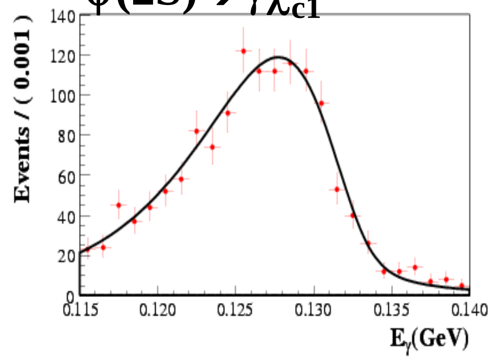
Systematic errors in energy resolution

Photon resolution $\psi' \rightarrow \gamma\chi_{cJ}$

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



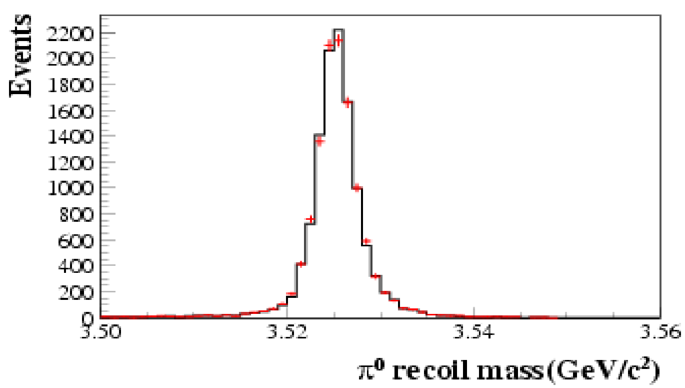
$\psi(2S) \rightarrow \gamma\chi_{c1}$



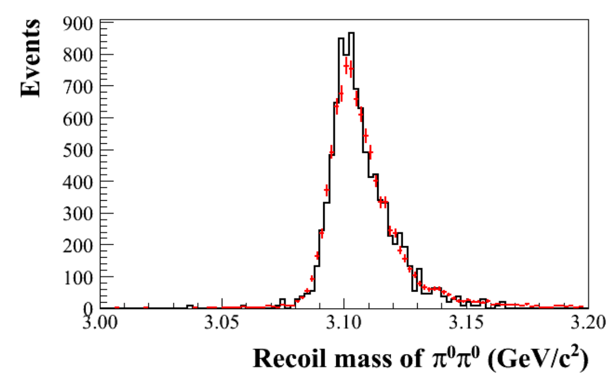
We smear daughter photon energy of π^0 in MC with the resolution in the data obtained from $\psi(2S) \rightarrow \gamma\chi_{cJ}$ to estimate uncertainty in signal shape of h_c

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

h_c signal in MC after smearing with the data photon resolution



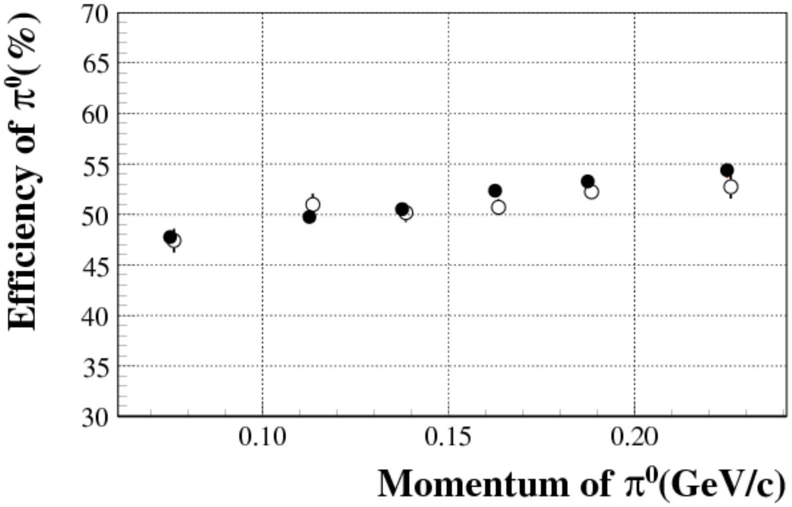
$\pi^0\pi^0$ recoil mass in $\pi^0\pi^0 J/\psi$



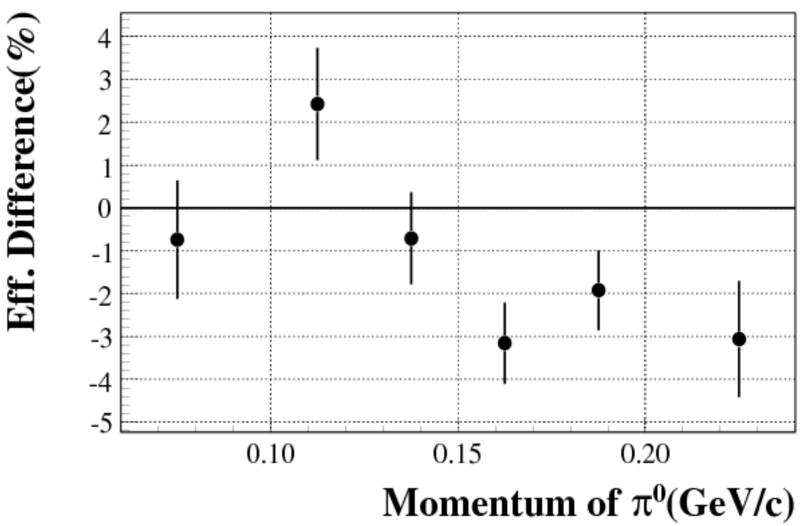
π^0 efficiency

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

π^0 efficiencies in DATA/MC



Difference between DATA/MC



Systematic ~ 3%

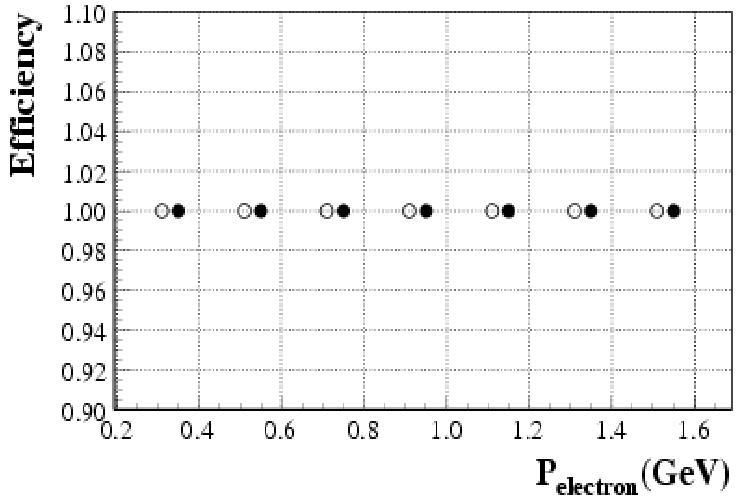
E1 photon efficiency

Absolute Detection efficiency:

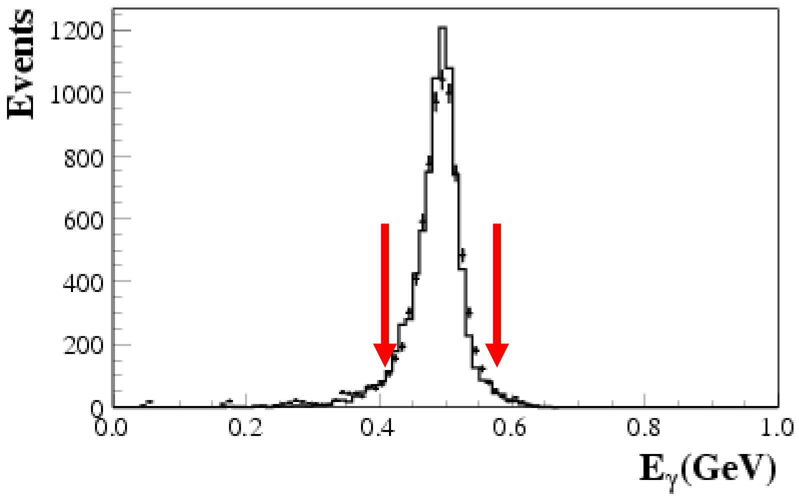
Photon line shape:

Obtained from radiative Bhabha

Absolute photon efficiency (Radee)~100%

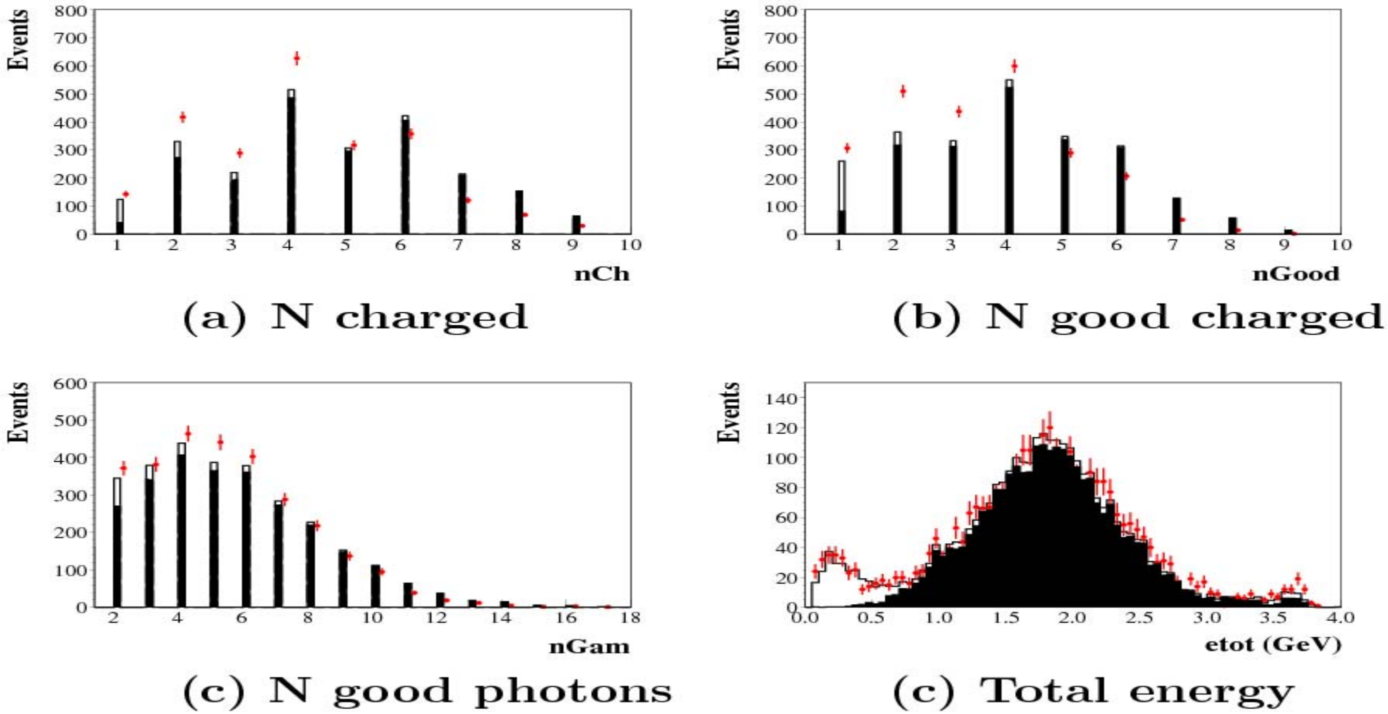


E1 photon line shape



Systematic ~ 2.5 %

Multiplicity and total energy



(a) N charged

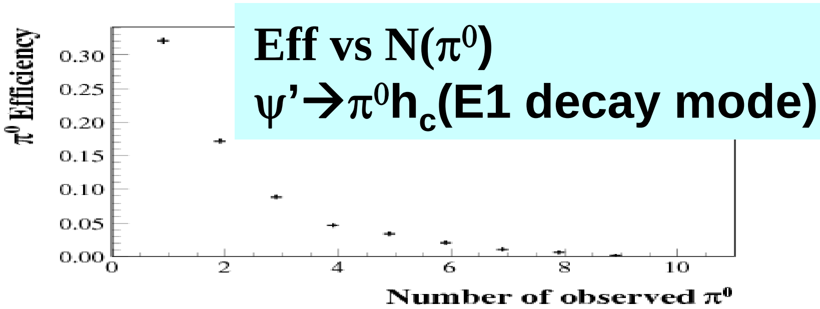
(b) N good charged

(c) N good photons

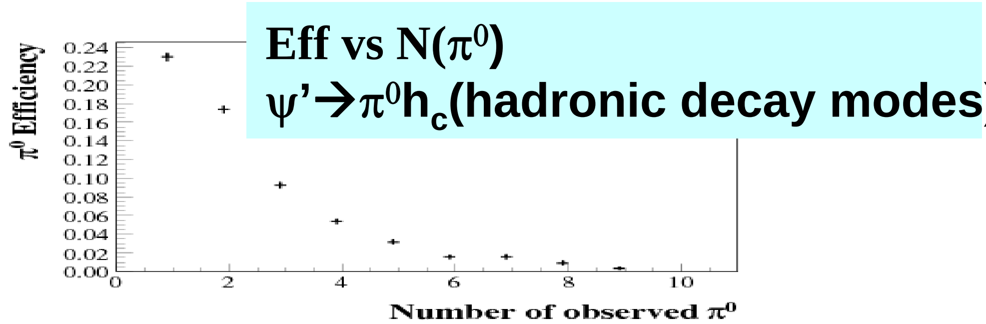
(c) Total energy

Compare the difference between the inclusive MC and the DATA to determine the systematic error from multiplicity of charged track.

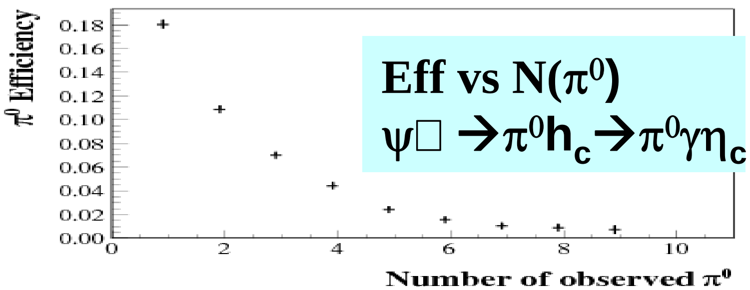
Number of π^0



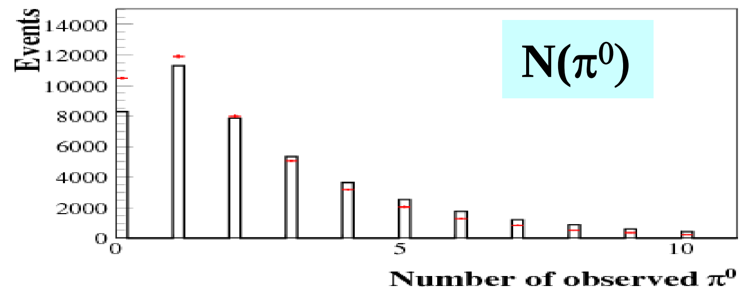
(a) ϵ_1^{E1}



(b) ϵ_1^{had}



(c) ϵ_{12}



(d) N_{π^0}

Compare the difference of π^0 multiplicity in the inclusive MC and DATA to determine the systematic error from number of π^0