Recent Results of Charmonium Transitions at BESIII

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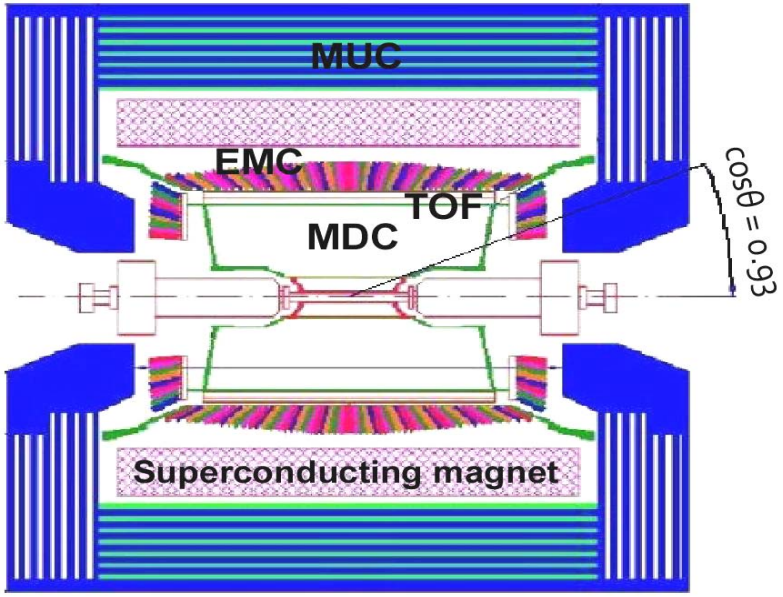
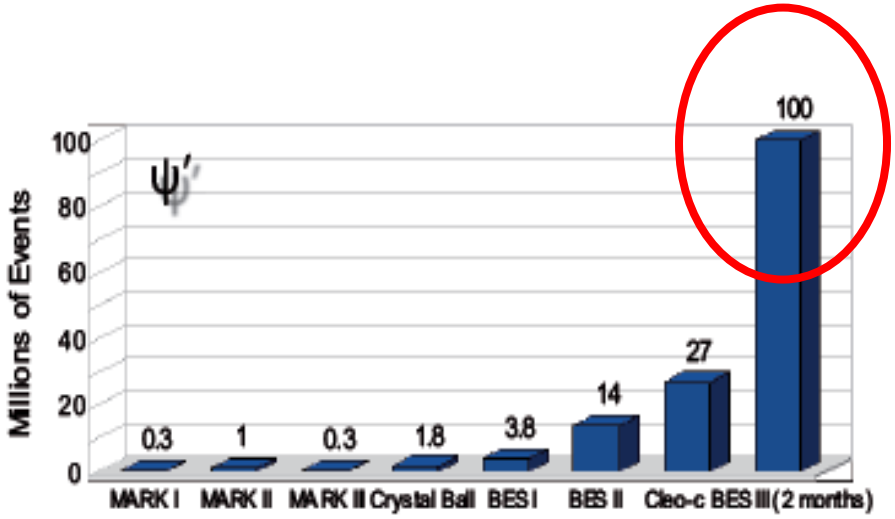
Charmonium transitions:

- ✓ $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$
- ✓ **Two photon transition:** $\psi' \rightarrow \gamma\gamma J/\psi$



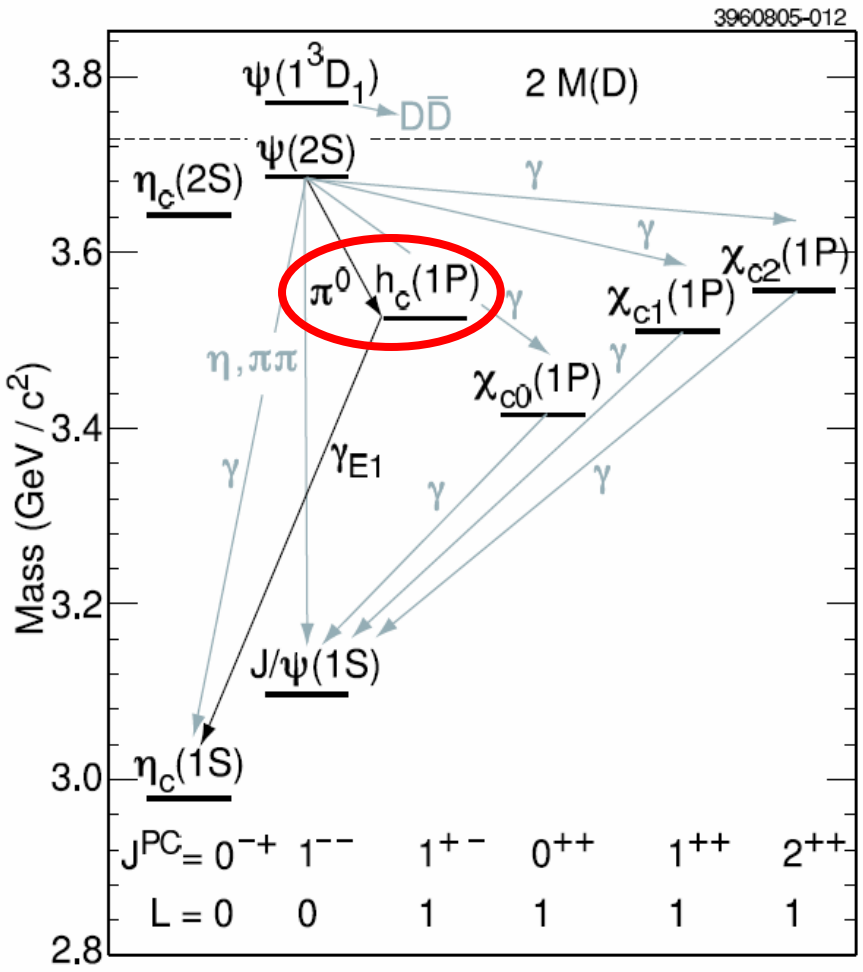


Improvements of BEPCII/BESIII

Device	Performance
BEPCII	$1 \times 10^{33} cm^{-2} s^{-1}$
MDC	$\sigma_{p_t}/p_t = 0.5\%,\ dE/dx < 6\%$
TOF	90ps(Bhabha)
EMC	$\sigma_E/E = 2.5\%@1GeV$
MUC	9 barrel + 8 end cap laysers
Magnet	1T Solennoidal

Before BESIII

h_c :What's it? What do we know?



- **Spin singlet P wave (L=1, S=0) charmonium state**
- **potential model spin-spin-interaction tells us:**

$$\Delta M_{hf}(1P) = m(h_c) - \frac{1}{9}\left(m(\chi_{c0}) + 3m(\chi_{c1}) + 5m(\chi_{c2})\right)$$

$\Delta M_{hf}(1P) \neq 0$: **Non-zero spin-spin interaction**

- E835: Evidence in $\bar{p}p \to h_c \to \eta_c\gamma$

- CLEO: Observation in

$$e^+e^- \to \psi(2S) \to h_c\pi^0$$
$$h_c \to \eta_c\gamma$$

$$\Delta M_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12\ \mathrm{MeV}/c^2$$

h_c : how we observe it?

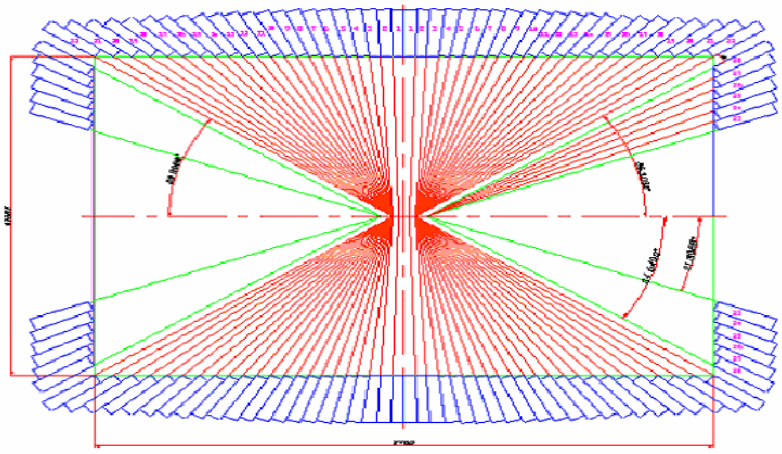
- E1-tagged analysis of $\psi' \to \pi^0 h_c$, $h_c \to \gamma \eta_c$
- Inclusive analysis of $\psi' \to \pi^0 h_c$

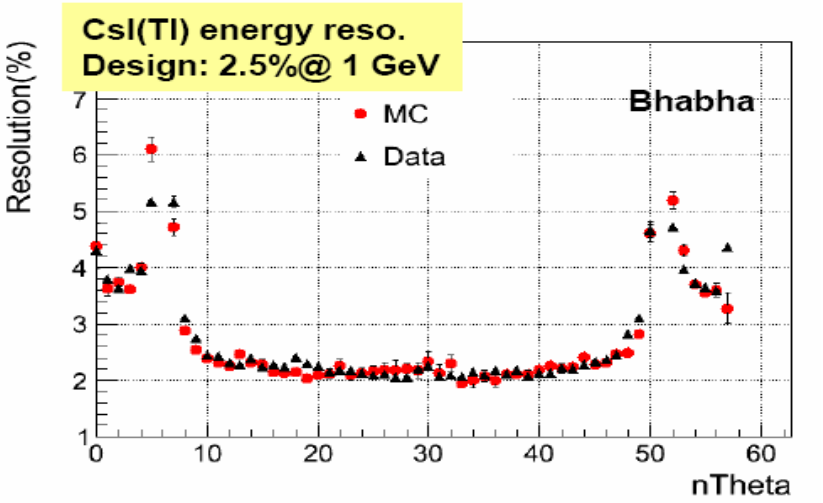
Performance of BESIII EMC
Very important

EMC: 6240 CsI crystals, 28 cm

$\Delta E/E$ = 2.5% @1 GeV

$\sigma z = 0.6\ cm/\sqrt{E}$

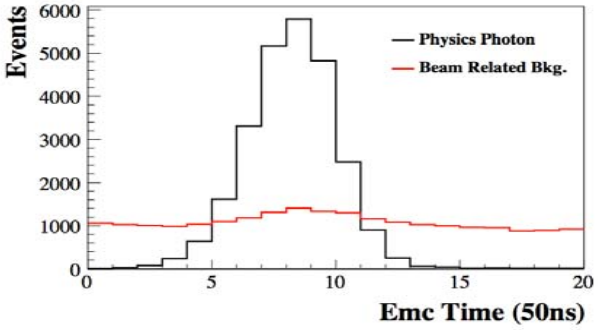




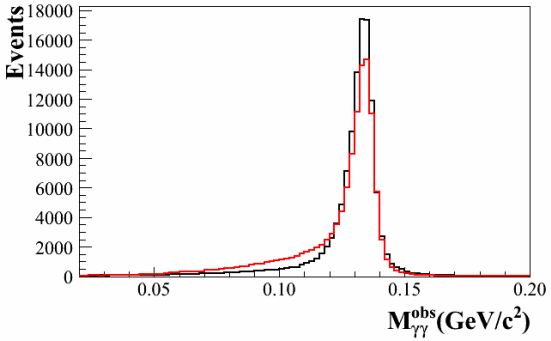
Improve detection : veto backgrounds and add TOF energy

Compare MC with data

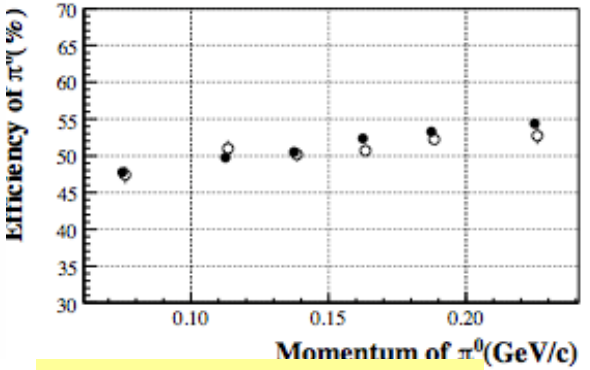
Use time information to reject beam gas



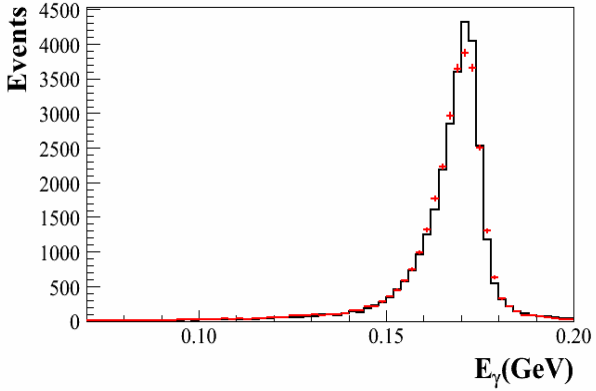
Add energy deposit in TOF to improve efficiency



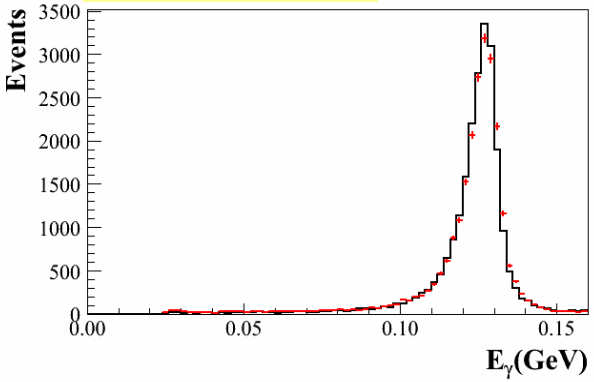
π^0 efficiency



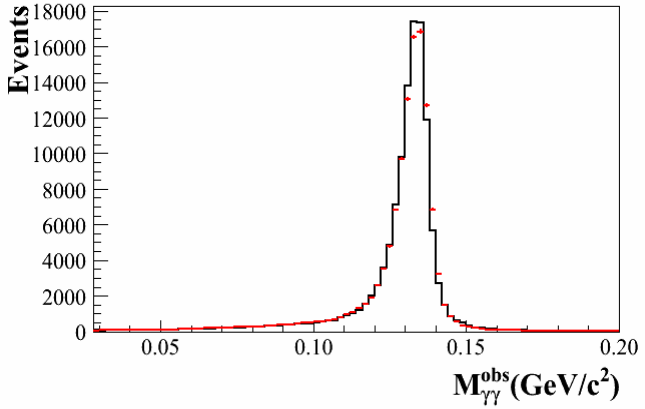
γ in $\psi' \rightarrow \gamma\chi_{c2}$



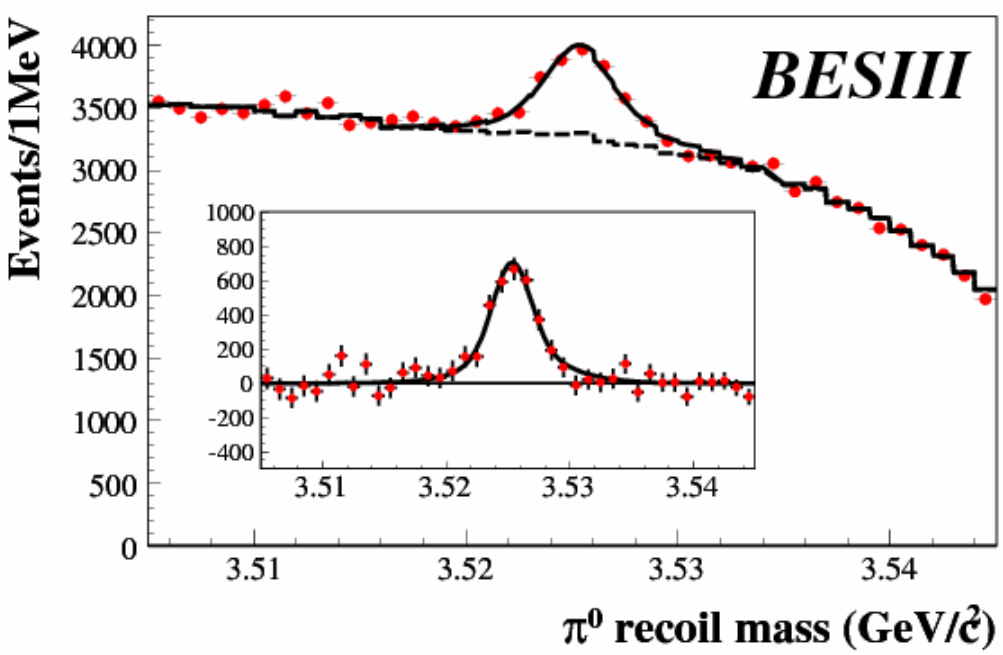
γ in $\psi' \rightarrow \gamma\chi_{c1}$



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



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



$N(h_c) = 3679 \pm 319$

$M(h_c) = 3525.40 \pm 0.13 \pm 0.18$MeV

$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$MeV

< 1.44MeV@90%CL

First measurement

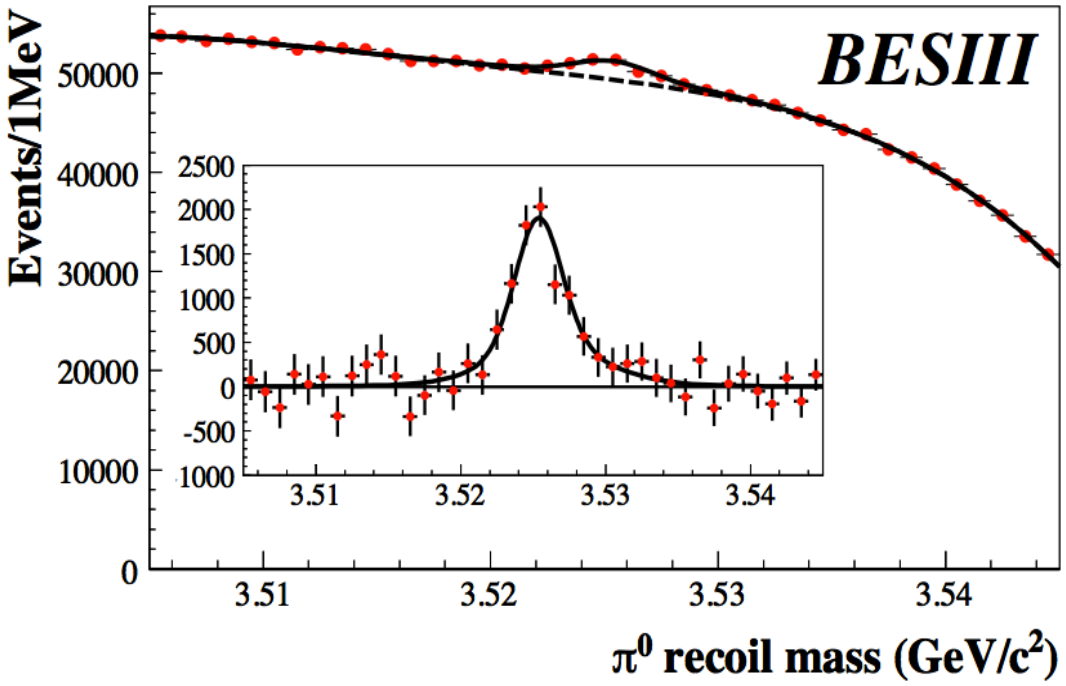
Consistent with CLEO:
$3525.35 \pm 0.19 \pm 0.11$MeV
and theoretical prediction.

BW (signal) convolved with Di-Gaussian (reso) + background.

Mass, width and strength of h_c floated.

BG modeled by the π^0 recoil mass spectrum in the sideband of the E1 photon.

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



First measurement

$N(h_c) = 10353 \pm 1097$

$Br(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
$Br(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

$Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma\eta_c)$
$=(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$
consistent with CLEO:
$(4.22 \pm 0.44 \pm 0.52) \times 10^{-4}$

The shape of h_c fixed to that from the fit of E1-tagged

The background parameterized by a 4th-order polynomial.

BESIII Collaboration, PRL 104, 132002 (2010)

Short summary of h_c

	BESIII	CLEO
$m[\mathrm{MeV}/c^2]$	$3525.4 \pm 0.13 \pm 0.18$	$3525.8 \pm 0.19 \pm 0.11$
$\Delta_{hf}(1\mathrm{P})[\mathrm{MeV}/c^2]$	$0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$
$\Gamma[\mathrm{MeV}/c^2]$	$(0.73 \pm 0.45 \pm 0.28)$ $< 1.44(90\%\mathrm{CL})$	
$Br(\psi' \to h_c\pi^0)$ $\times Br(h_c \to \gamma\eta_c)[10^{-4}]$	$4.58 \pm 0.40 \pm 0.50$	$4.22 \pm 0.44 \pm 0.52$

→Consistent with CLEO

	BESIII	Theory
$Br(\psi' \to h_c\pi^0)[10^{-4}]$	$8.4 \pm 1.3 \pm 1.0$	$4...13^{(1)}$
$Br(h_c \to \gamma\eta_c)[\%]$	$54.3 \pm 6.7 \pm 5.2$	$48(\mathrm{NRQCD})^{(1)}$ $88(\mathrm{PQCD})^{(1)}$ $38^{(2)}$

First Measurement!

(1) Kuang, PRD65, 094042 (2002)
(2) Godfrey, Rosner, PRD66, 014012 (2002)

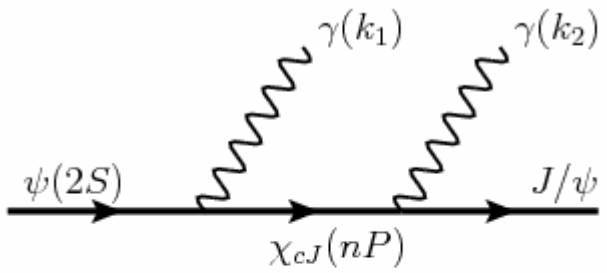
ψ' → γγJ/ψ: two photon transition

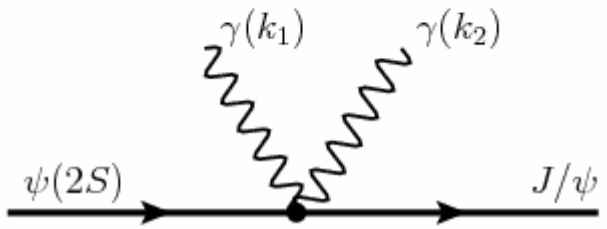
naive theoretical pictures :

Potential model :

- **Discrete part**:
  double E1 transition via discrete χ_{CJ} (nP) (n=1,2) states (virtual and real parts).
  (including main source of the background)
  (well described χ_{CJ} states)
- **Relativistic correction**:

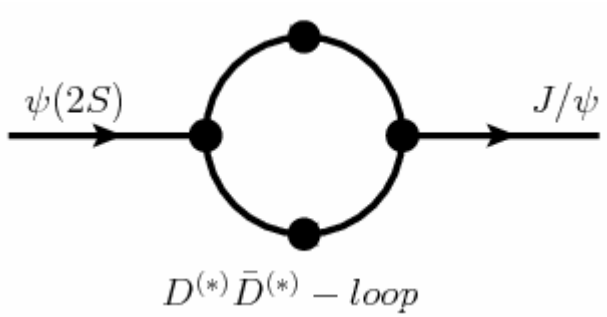
  Higher order v^2 operators corrections





Potential model + couple channel:

- **Besides discrete contribution, the hadron-loop effect also may play an important role.**



Theoretical study is on going. (Z.G. He et al)

Scattering Plot: $M_{\gamma\gamma}$ VS $M_{\gamma\,2\,rec.}$

γ_1 : high energy photon γ_2 : low energy photon

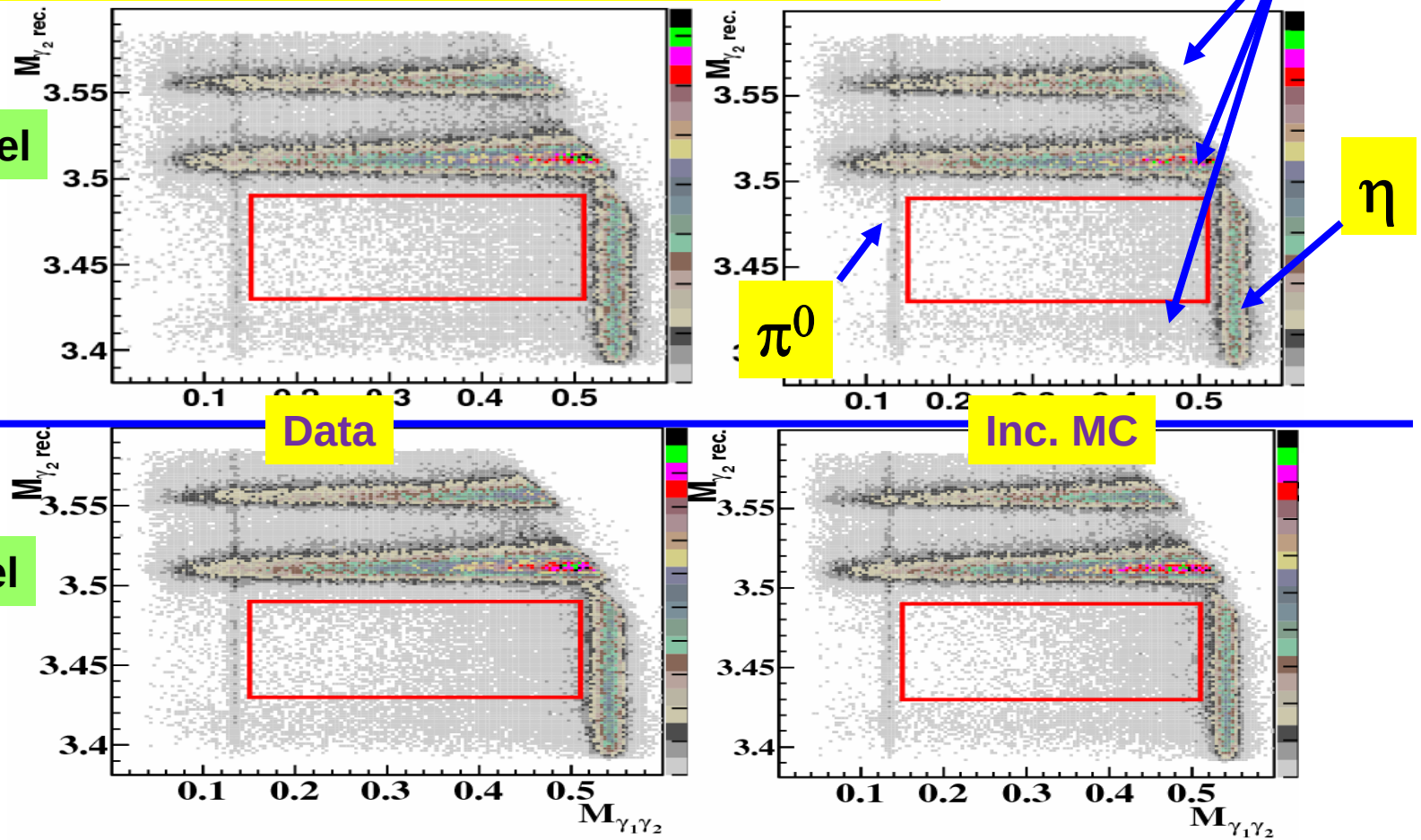
χ_{cJ}

η

π^0

ee channel

μμ channel

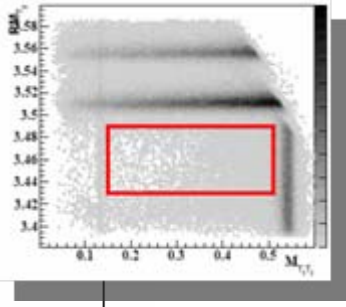


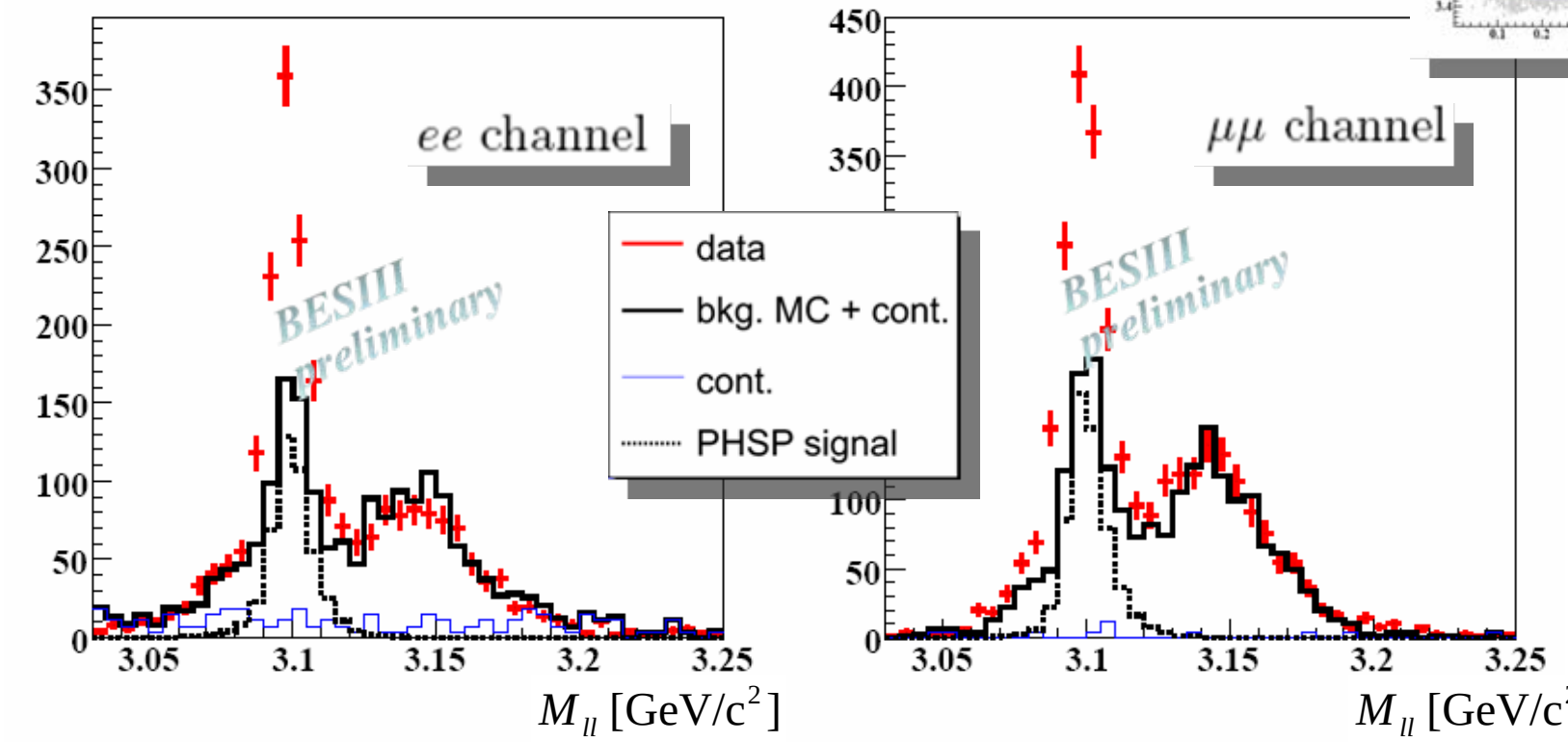
box cut:

$0.15 < M_{\gamma\gamma} < 0.51$ GeV

$3.43 < M_{\gamma\,2\,rec.} < 3.49$ GeV

Di-lepton Invariant Mass





Known backgrounds:

- QCD background from ψ' decay
- QED background from continuum data

Significant enhancement **around J/ψ peak**

Preliminary Numerical Results

	ee channel	$\mu\mu$ channel
No. of signals	495.8 ± 37.9	615.9 ± 40.9
acceptance	$(7.44 \pm 0.02)\%$	$(9.92 \pm 0.02)\%$
significance	12.5σ	14.3σ
$Br(\psi' \to \gamma\gamma J/\psi)[10^{-3}]$	$1.06 \pm 0.08^{+0.17}_{-0.18}$	$0.99 \pm 0.07^{+0.19}_{-0.18}$
	$1.02 \pm 0.05^{+0.19}_{-0.20}$(average)	

- **Simulation of physics mechanism of signal process under study and not included here**
- **Possible signal-χ_{cJ}-decay interference not included**

Summary

- **Some charmonium transitions processes investigate based on 106M ψ' data at BESIII**
  - Observation of hc from $\psi' \to \pi^0$ hc
    - ✓ First measurement: Br($\psi' \to \gamma h_c$) & Br($h_c \to \gamma\eta_c$) seperately, as well as the width of h_c
    - ✓ Mass of h_c and Br($\psi' \to \pi^0 h_c$) X Br($h_c \to \gamma\eta_c$) consistent with CLEOc's results
  - **A significant enhancement of two-photon transition of ψ' to J/ψ observed for the first time : significance>10.**
    The branching ratio determined by two independent channels to be

$$Br(\psi(2S) \to \gamma\gamma J/\psi) = (1.02 \pm 0.05(\text{stat.})^{+0.19}_{-0.20}(\text{syst.})) \times 10^{-3}.$$

- **More exciting results, which will improve our knowledge at this energy region, are coming soon.**

Thanks!

ψ' → γγJ/ψ: two photon transition

Two-photon transition from ψ' to J/ψ :

On experimental side:

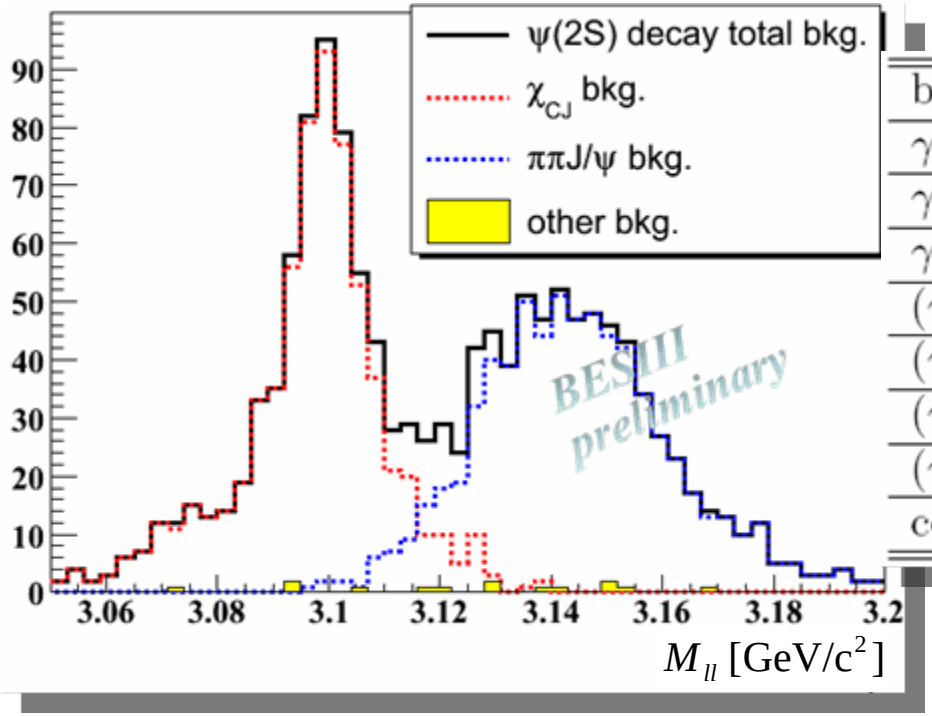
- Analogous process to positronium and hydrogen two-photon transition
- CLEO reported Upsilon(3S)→rrUpsilon(2S)
- Escaped from experimental measurement

On theoretical side:

- Order α^2 QED transition between two hadrons
- Similar process studied in heavy-light quark system
- Improve understanding of heavy quarkonium characters such as spectrum, decay et al, and the strong interaction
- Testing the hadron-loop effect

Background Components

estimated with MC Simulation and continuum data

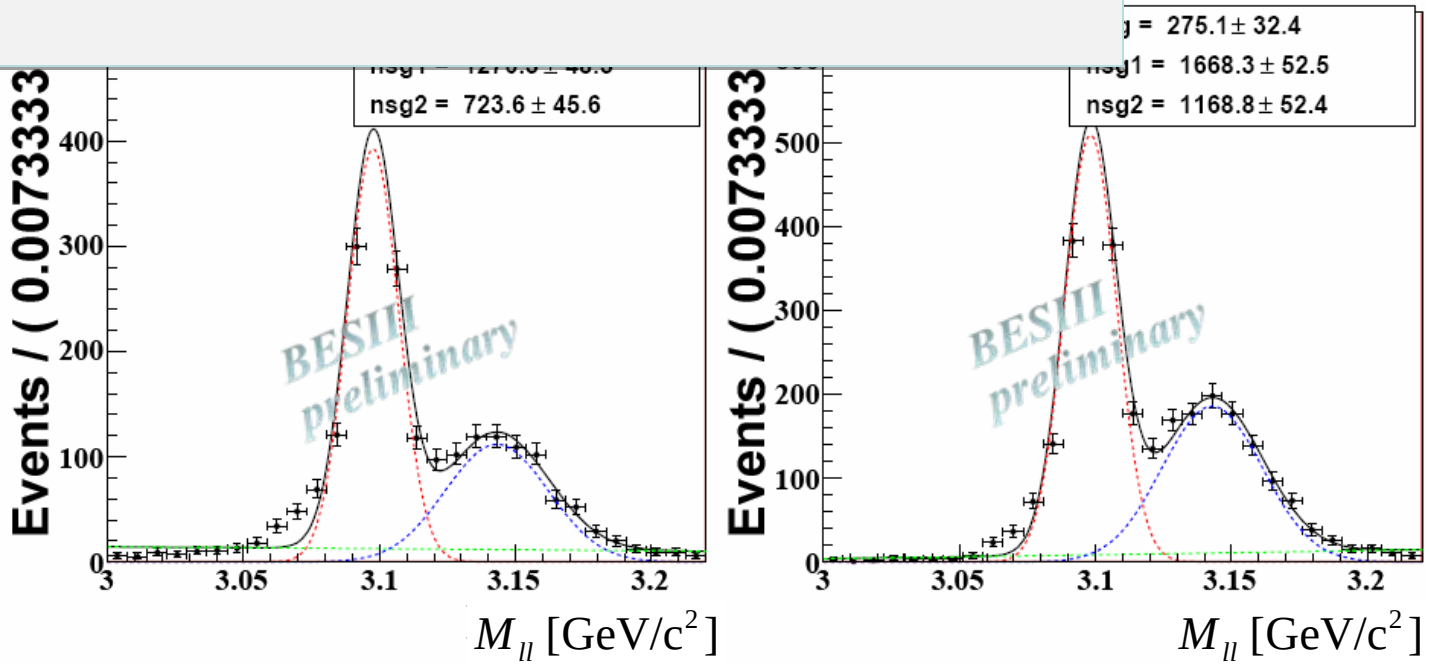


bkg. channels	ee chnl (ex.)	$\mu\mu$ chnl (ex.)
$\gamma(\gamma J/\psi)_{\chi c0}$	263.1 ± 3.2	367.2 ± 3.7
$\gamma(\gamma J/\psi)_{\chi c1}$	517.6 ± 5.1	659.1 ± 5.7
$\gamma(\gamma J/\psi)_{\chi c2}$	86.9 ± 2.1	116.1 ± 2.5
$(\gamma\gamma)_{\pi^0} J/\psi$	0.5 ± 0.2	< 0.1
$(\gamma\gamma)_{\eta} J/\psi$	0.6 ± 0.2	1.3 ± 0.3
$(\gamma\gamma)_{\pi^0}(\gamma\gamma)_{\pi^0} J/\psi$	755.2 ± 6.3	1179.8 ± 7.8
$(\gamma\gamma)_{\pi^0}(ee\gamma)_{\pi^0} J/\psi$	8.9 ± 0.7	12.9 ± 0.8
continuum@3.65 GeV	375.4	36.8

- ✓ **Branching fractions based on PDG**
- ✓ **ψ' decay bkg. shape and magnitude as the main background description**

$\pi^0\pi^0 J/\psi$ Background Validation

simple fit: two Guassian plus 1st-order polynominal
assuming right bump comes from $\pi^0\pi^0 J/\psi$ *process*



$$\epsilon_{ee}^{\pi^0\pi^0 J/\psi} = 0.073 \times (1 \pm 0.0083)\%$$

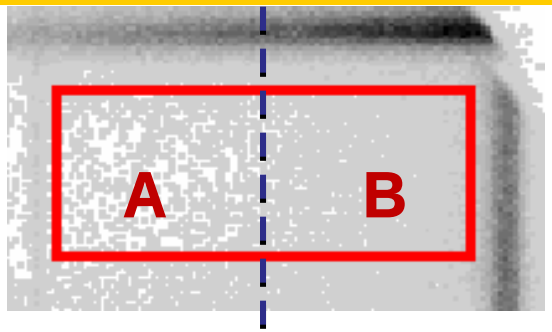
BR: $(16.16 \pm 1.03)\%$

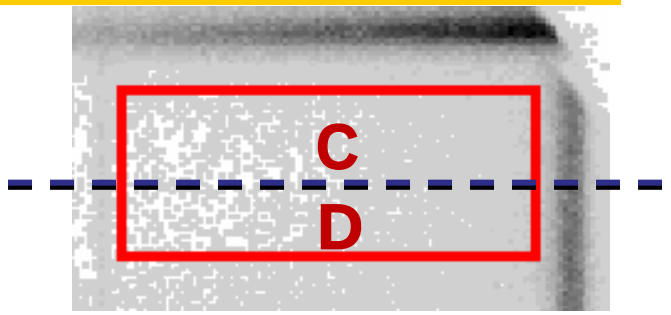
$$\epsilon_{\mu\mu}^{\pi^0\pi^0 J/\psi} = 0.114 \times (1 \pm 0.0066)\%.$$

BR: $(16.73 \pm 0.76)\%$

agree well with PDG value: 16.84%

Test Enhancement in Different Box Region





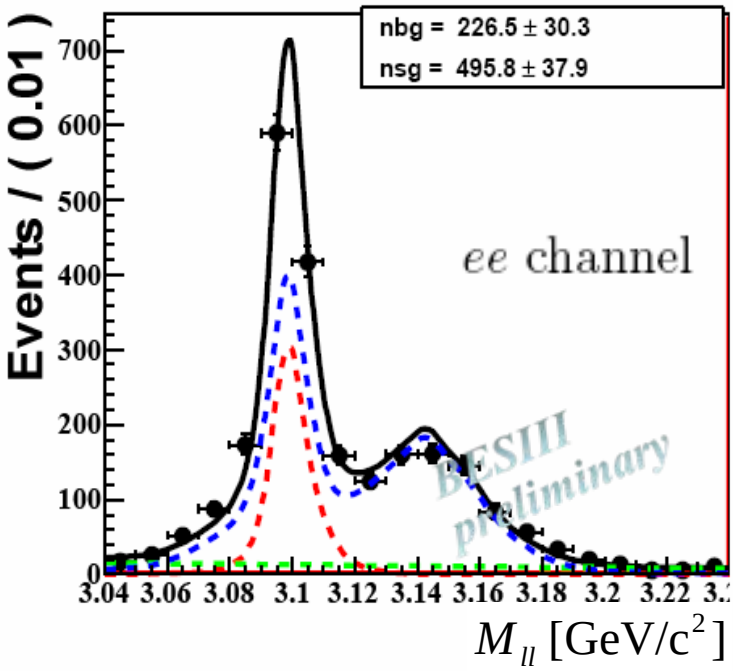
$RM_{\gamma_2}(\mathrm{GeV}/c^2)$	$M_{\gamma\gamma}(\mathrm{GeV}/c^2)$	$Br_{ee}\ (\times 10^{-3})$	$Br_{\mu\mu}\ (\times 10^{-3})$
A (3.43, 3.49)	(0.15, 0.33)	1.17 ± 0.13	1.25 ± 0.11
B (3.43, 3.49)	(0.33, 0.51)	0.97 ± 0.10	0.79 ± 0.08
C (3.43, 3.46)	(0.15, 0.51)	0.97 ± 0.11	1.04 ± 0.08
D (3.46, 3.49)	(0.15, 0.51)	1.16 ± 0.12	0.98 ± 0.10

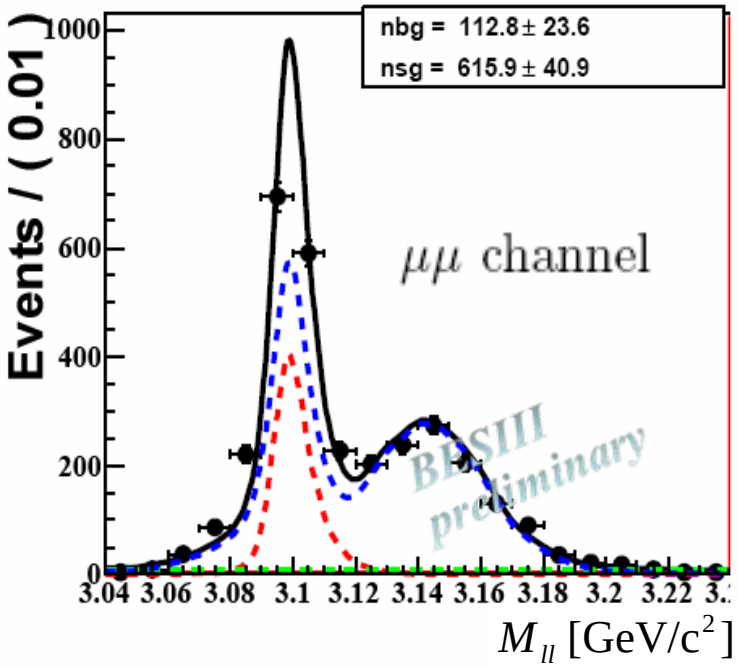
- **existence of the enhancement is robust**
- **variation of the measurements in different regions:**
  - statistical fluctuation
  - physics mechanism of signal process
  - to be included in the systematic uncertainties

Determination of signal

unbinned maximum likelihood fit with composition of three PDFs:

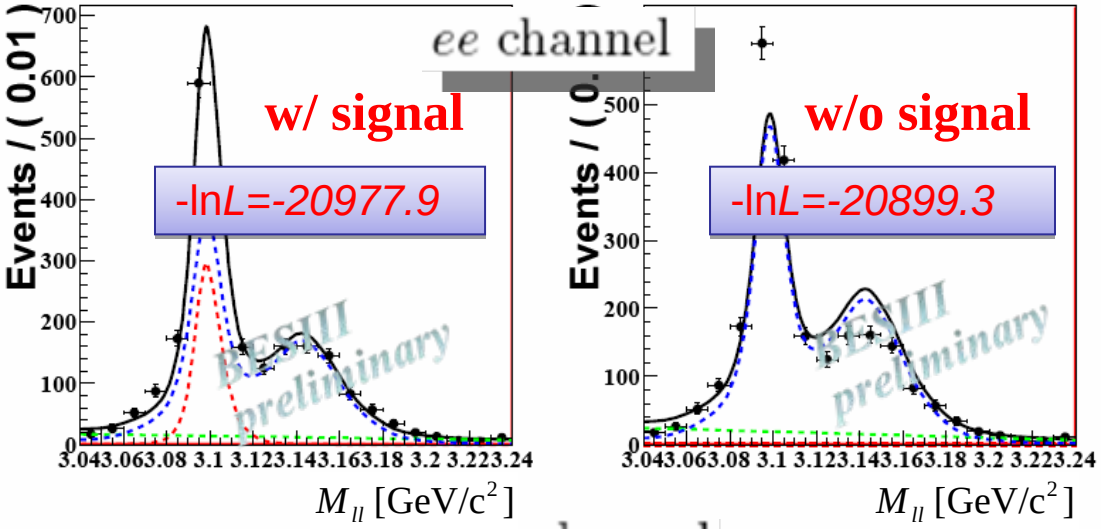
- **signal** : shape from phase-space-like MC simulation
- **ψ(2S) bkg.** : shape and magnitude from exclusive MC simulation
- **other bkg.** : 1st-order polynomial



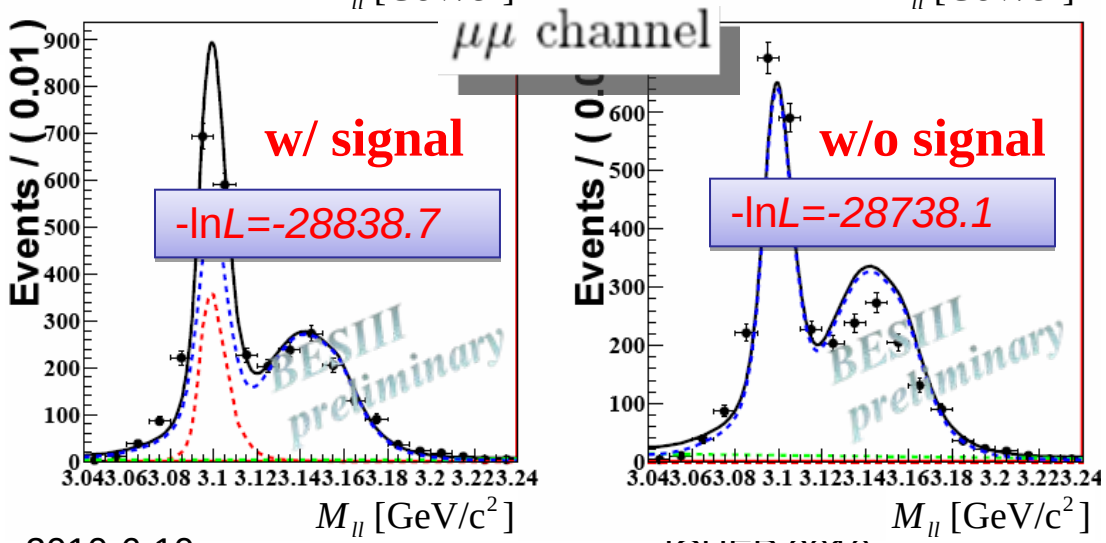


Calculation of Significance

floating all fitting components



significance:
12.5 σ



significance: **14.3 σ**

Compilation of Preliminary Systematic Uncertainties

	systematic uncertainties (%)	
	$J/\psi \to ee$	$J/\psi \to \mu\mu$
lepton tracking	-0.7	$+1.0$
photon detection	± 1.0	± 1.0
photon number cut	$+3.8$	± 1.0
4C KF	$+1.1$	$+1.1$
relative branching fraction	$^{+11.3}_{-11.6}$	$^{+12.5}_{-12.8}$
χ_{cJ} decay width	$^{+7.4}_{-5.2}$	$^{+10.5}_{-4.2}$
χ_{cJ} inter-interferences	-4.7	-6.1
background shape	± 0.1	± 0.1
fitting range	$^{+0.9}_{-2.8}$	-5.1
$\psi(2S)$ Total Number	$^{+7.9}_{-7.5}$	$^{+8.7}_{-8.4}$
$Br(J/\psi \to ll)$	± 1.0	± 1.0
total	$^{+15.4}_{-16.7}$	$^{+18.6}_{-17.8}$

big sources

- ✓ another important source, physics mechanism MC simulation of the signal process, not included yet
- ✓ possible signal- χ_{CJ}- decay interference not included