Study on the Two-Photon Transition from ψ(2S) to J/ψ at BESIII

吕 晓睿

Xiao-Rui Lu

(E-mail: xiaorui@gucas.ac.cn)

Graduate University of Chinese Academy of Sciences (GUCAS)

(on behalf of BESIII Collaboration)

List of Contents:

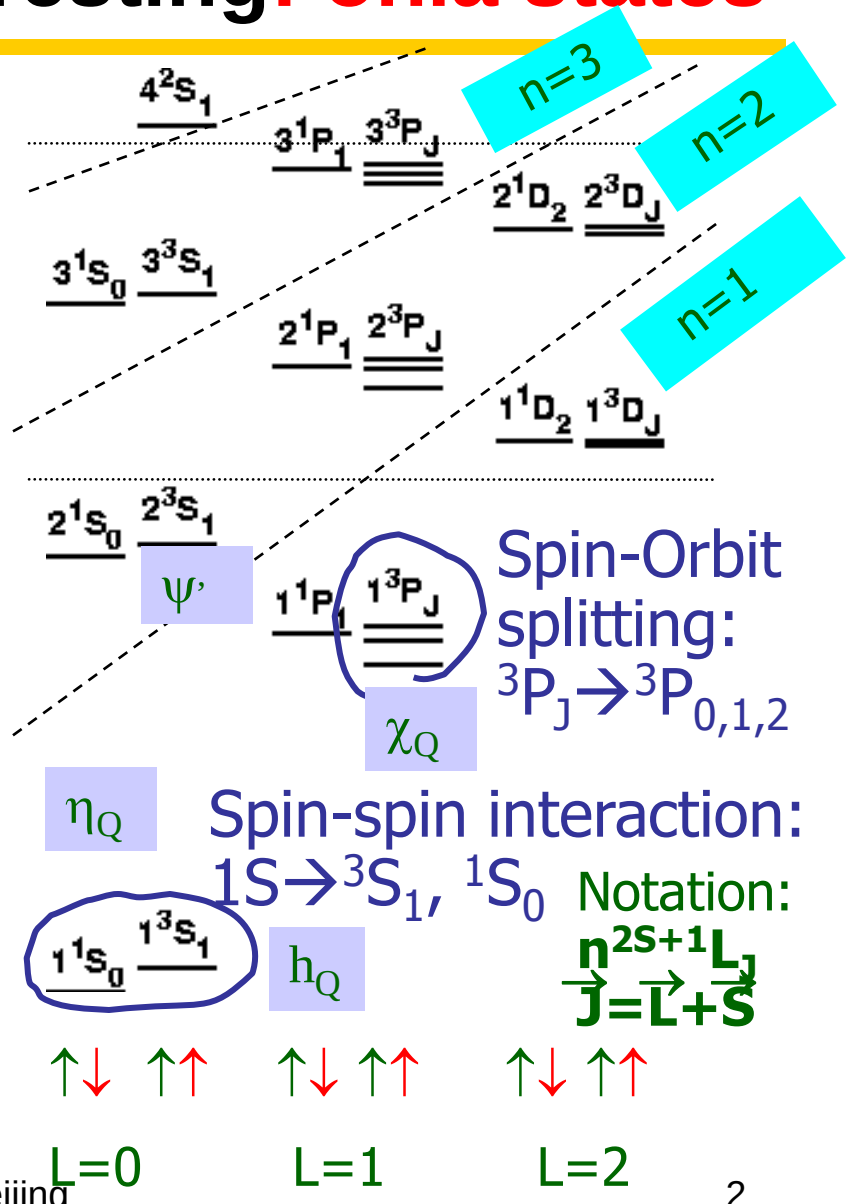
- Introduction
- BEPCII and BESIII Experiment
- Data Analysis
- Systematic Studies on the Enhancement
- Summary

Why Charmonium Insteresting: onia states

- Strongly bound $q\bar{q}$ states
- Non-relativistic QM applicable (Appelquist, Politzer)
  - QCD analog to positronium
  - Provide insight into QCD
- Low Q^2, non-perturbative

? **Masses**
? **Widths**
? **Production and decay dynamics**

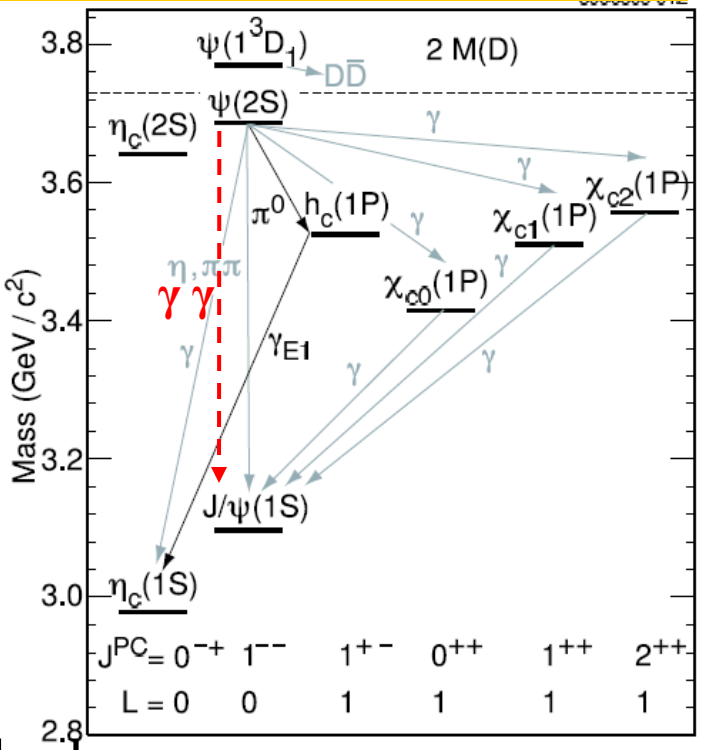
Partly discovery, partly precision measurements



Two-photon transition from ψ(2S) to J/ψ

On experimental side:

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



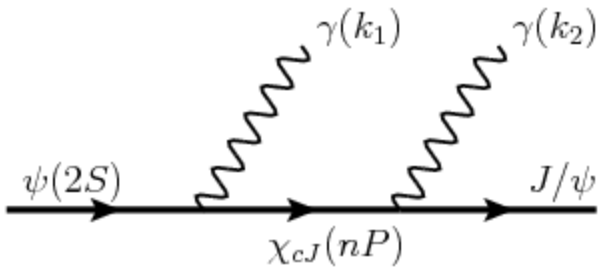
On theoretical side:

- order α^2 QED transition between two hadrons
- similar process has been studied in heavy-light quark system
- improve understanding of heavy quarkonium characters such as spectrum, decay et al, and the strong interaction
- possibility of testing the hadron-loop effect

Naive Theoretical Pictures

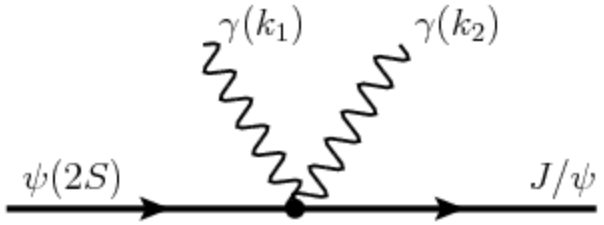
Potential model :

- **discrete part**:
  double E-1 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)



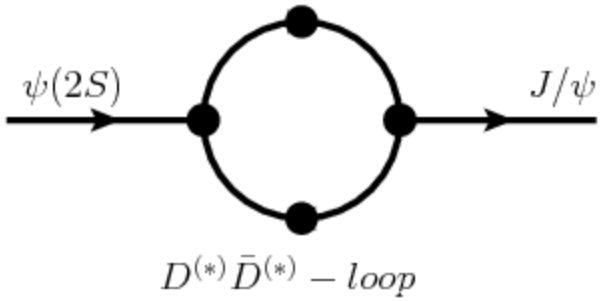
- **relativistic correction**:

  relatively higher order v^2 operators corrections



Potential model + couple channel:

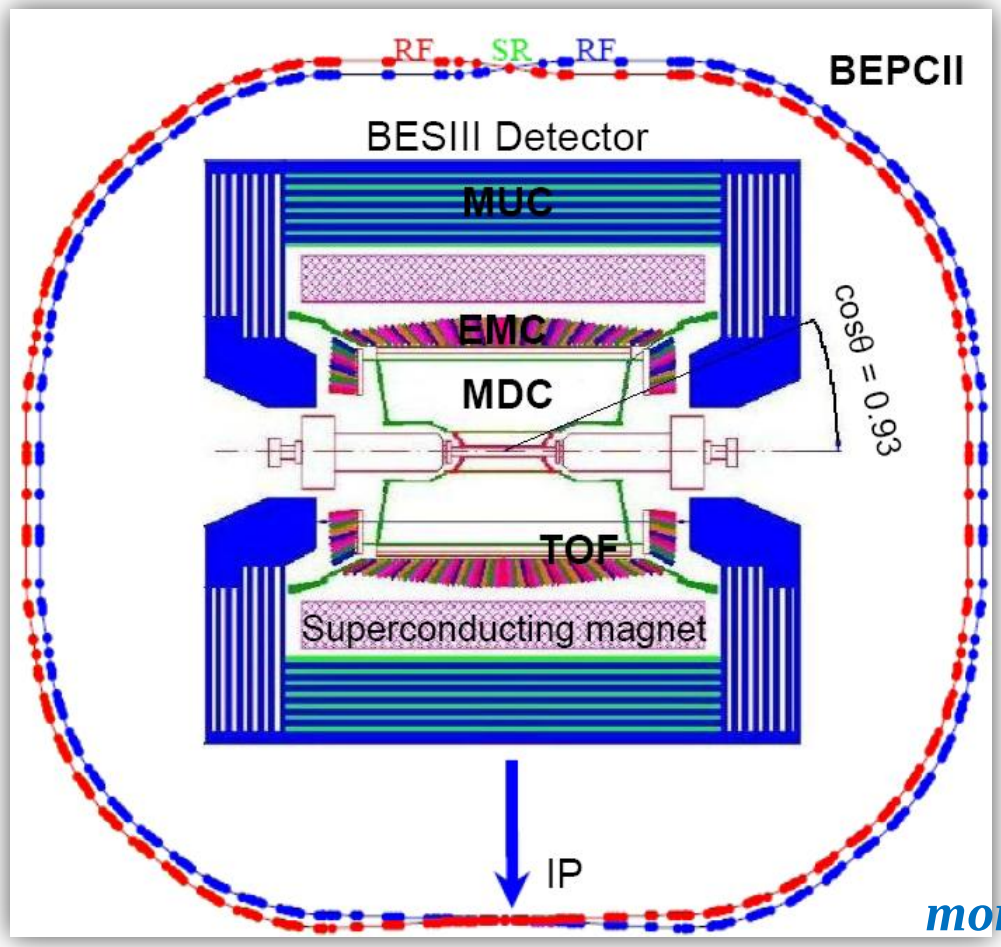
- **besides discrete contribution, the hadron-loop effect also may play an important role.**



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

BEPCII and BESIII

world-solo charm-factory



BEPCII:

- Beam energy: 1.0 ~ 2.3 GeV
- Luminosity: 1×10^{33} $cm^{-2}s^{-1}$
- Optimum energy: 1.89 GeV

BESIII Spectrometer:

MDC: $\sigma(p_T)/p_T$ ~ 0.5% @ 1GeV
dE/dx_{reso} < 6%

TOF: 80 ps (for bhabha, barrel)

EMC: $\sigma(E)/E$ ~ 2.5%$\times\sqrt{E}$

MUC: 8~9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

July 20, 2008: first e^+e^- collision event in BESIII

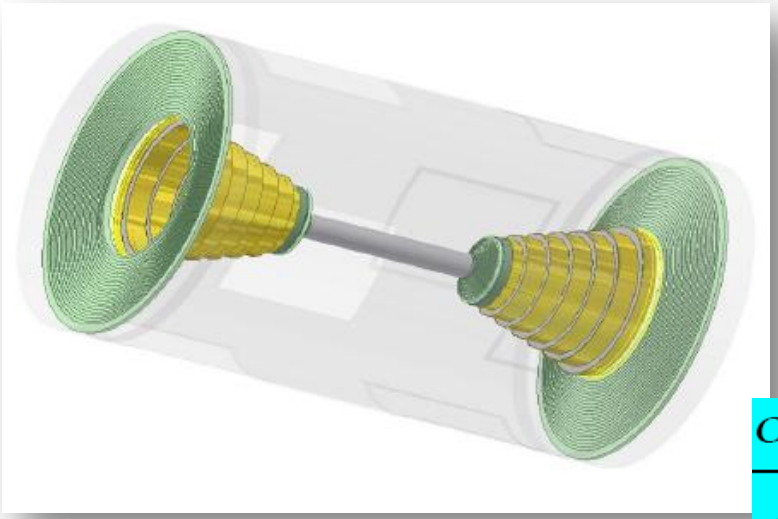
April 14, 2009: took ~100M $\psi(2S)$ events (~40 days)

May 29, 2009: took ~41 pb^{-1} continuum data @3.65GeV

more in Prof. X.-Y. Shen's morning talk

MDC Tracking

- 7000 Signal wires: 25 μm gold-plated tungsten
- 22000 Field wires: 110 μm Al
- Gas: He + C_3H_8 (60/40)



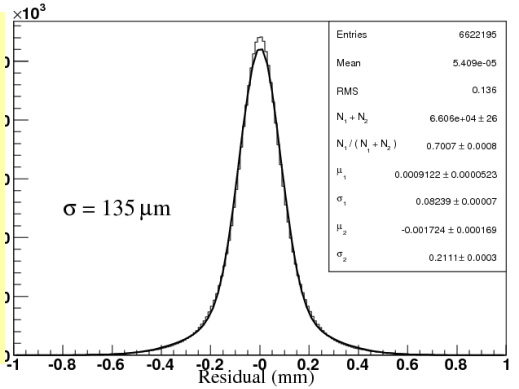
Babar: ~ 110 μm

BELLE: ~ 130 μm

CLEO: ~ 110 μm

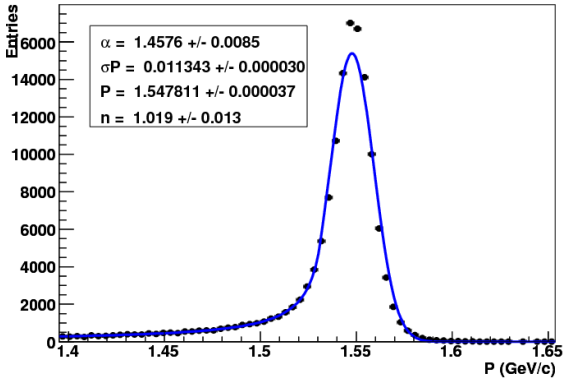
BESIII: ~ 130 μm

σ= 135 μm



$$\frac{\sigma_{P_t}}{P_t} = 0.32\% \oplus 0.37\%$$

δP=11.3MeV/c@1.548GeV/c

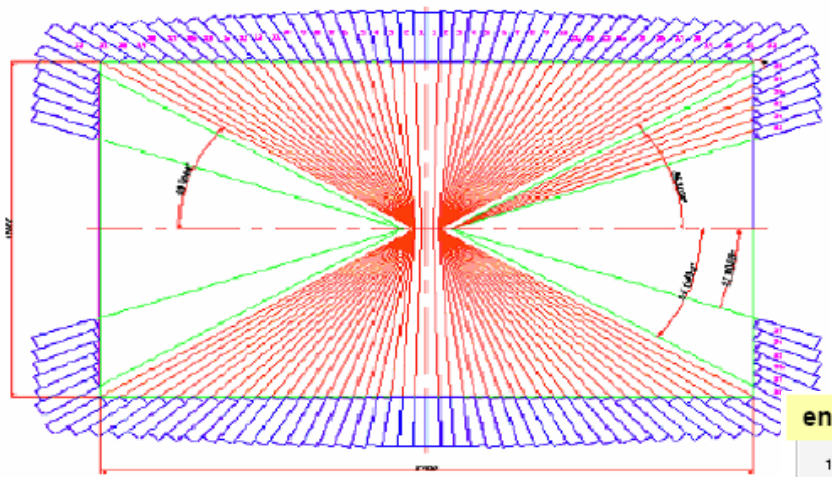


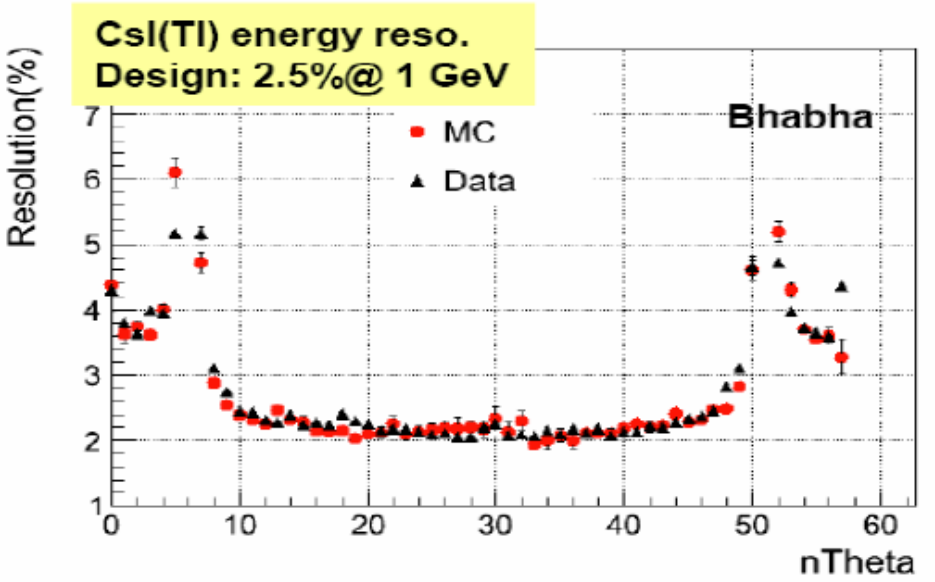
Precise Photon Measurement

EMC: 6240 CsI crystals, 28 cm

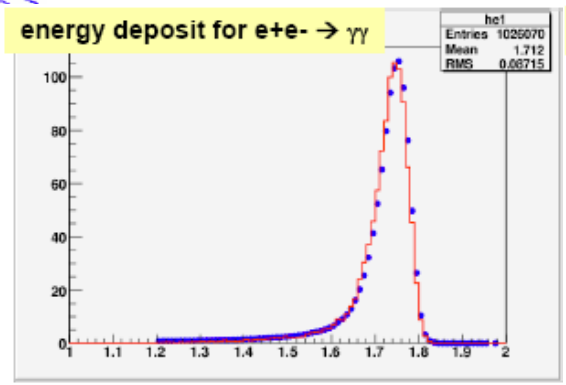
ΔE/E = 2.5% @1 GeV

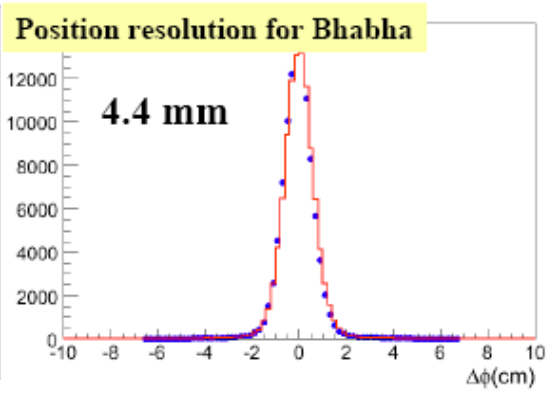
σz = 0.6 cm/√E





Performance of BESIII EMC
Very important





Data Samples at BESIII

Until June 2010:

Type	BES-III ($\times 10^6$)	BESII ($\times 10^6$)	CLEO-c ($\times 10^6$)
J/ψ	230	58	-
$\psi(2S)$	108	14	27
DDbar	6.58(0.98)fb^{-1})	0.2(0.03fb^{-1})	5.4(0.8fb^{-1})
DsDs	-	-	Scan
DsDs*	-	-	0.55(0.6fb^{-1})

And continues …

the world largest resonance-produced Charmonium data

➔ study the Charmonium-related physics:

- ✓ Spectroscopy and decays
- ✓ New hidden charm

Dataset and Selection Criteria

Dataset:

- ~160pb^{-1} data taken @3.686GeV in 2009, which was estimated to contain 106±4 million ψ(2S) decays
- 41 pb^{-1} continuum data @3.65GeV in 2009

Data Selection:

$$\psi(2S) \to \gamma\gamma J/\psi,\ J/\psi \to ee(\mu\mu)$$

- At most 3 good photon candidates
  - EMC energy threshold: E>0.025GeV(barrel), E>0.050GeV(Endcap)
  - EMC TDC time window (0, 14)
  - energy less than 0.9GeV
  - nearest angle to charged tracks: $d_{\text{angle}}>10^{\circ}$
- Only one good-lepton-pair candidate
  - closest approach to interaction point: less than 1cm in x-y plane and less than 10cm in z-axis
  - energy deposit in EMC: $E_{\text{deposit}}/P < 0.6$ (muon), $E_{\text{deposit}}/P > 0.7$(electron)
  - lepton momentum: 0.8GeV/c < P <2.0 GeV/c
- Only the $\gamma\gamma ll$ combination with least χ^2 of 4-momentum-constrain kinematic fit will be kept: $\chi^2 < 60$

Dataset and Selection Criteria

Dataset:

- ~160pb^{-1} data taken @3.686GeV in 2009, which was estimated to contain 106±4 million ψ(2S) decays
- 41 pb^{-1} continuum data @3.65GeV in 2009

Data Selection:

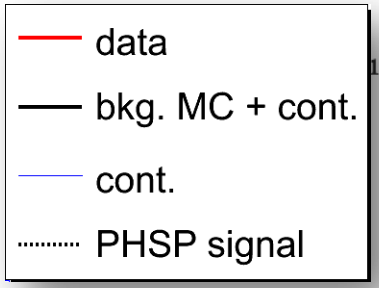
$$\psi(2S) \to \gamma\gamma J/\psi,\ J/\psi \to ee(\mu\mu)$$

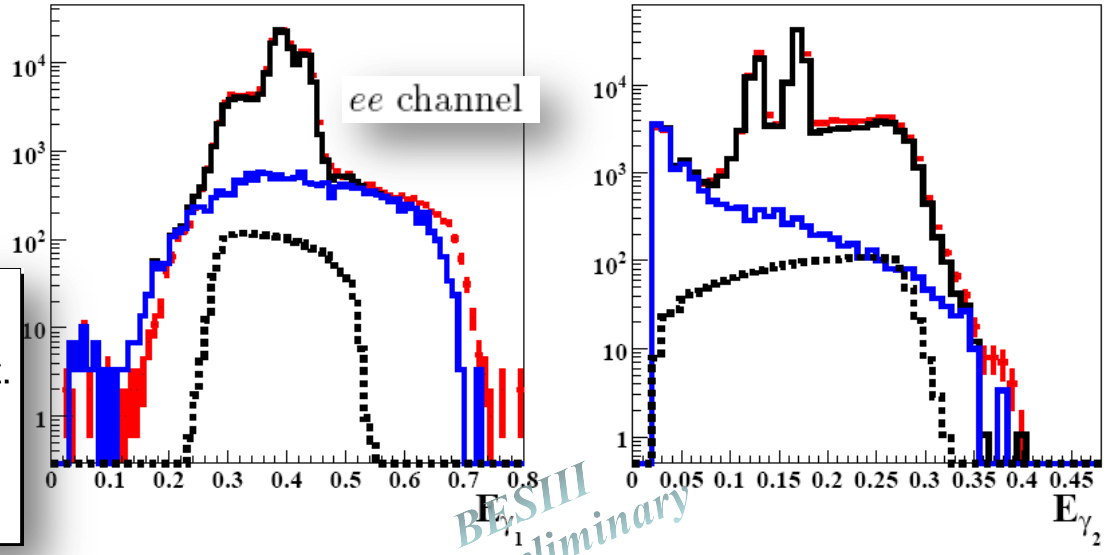
- At most 3 good photon candidates
  - EMC energy threshold: E>0.025GeV(barrel), E>0.050GeV(Endcap)
  - EMC TDC time window (0, 14)
  - energy less than 0.9GeV
  - nearest angle to charged tracks: $d_{\text{angle}}>10^{\circ}$
- Only one good-lepton-pair candidate
  - closest approach to interaction point: less than 1cm in x-y plane and less than 10cm in z-axis
  - energy deposit in EMC: $E_{\text{deposit}}/P < 0.6$ (muon), $E_{\text{deposit}}/P > 0.7$(electron)
  - lepton momentum: 0.8GeV/c < P <2.0 GeV/c
- Only the $\gamma\gamma ll$ combination with least χ^2 of 4-momentum-constrain kinematic fit will be kept: $\chi^2 < 60$

Photons

definition:

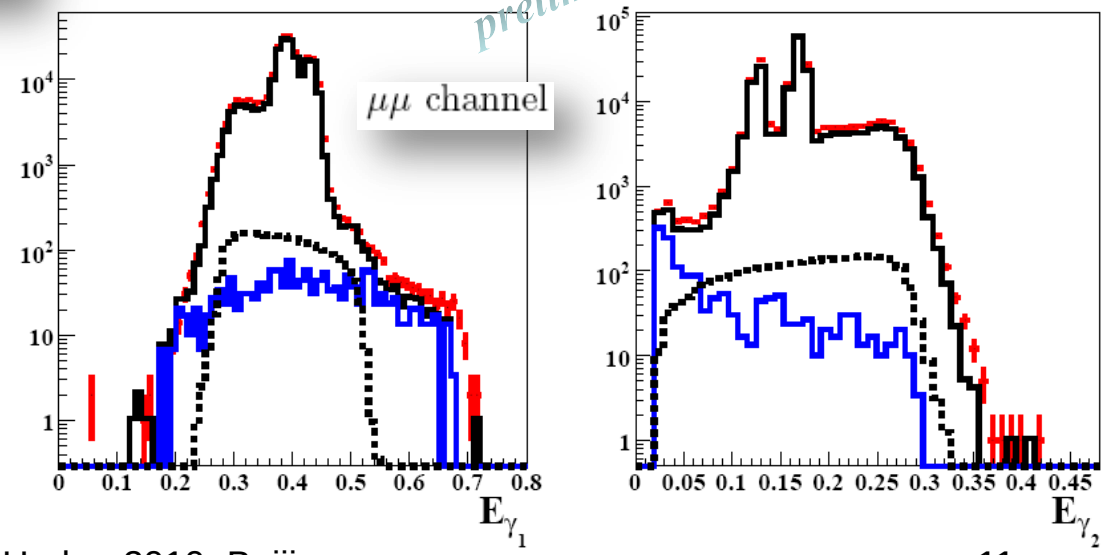
- γ_1 higher energy photon
- γ_2 lower energy photon





PHSP signal: plotted with the assumption of

$$Br(\psi(2S) \to \gamma\gamma J/\psi) = 1 \times 10^{-3}$$



further photon selections:

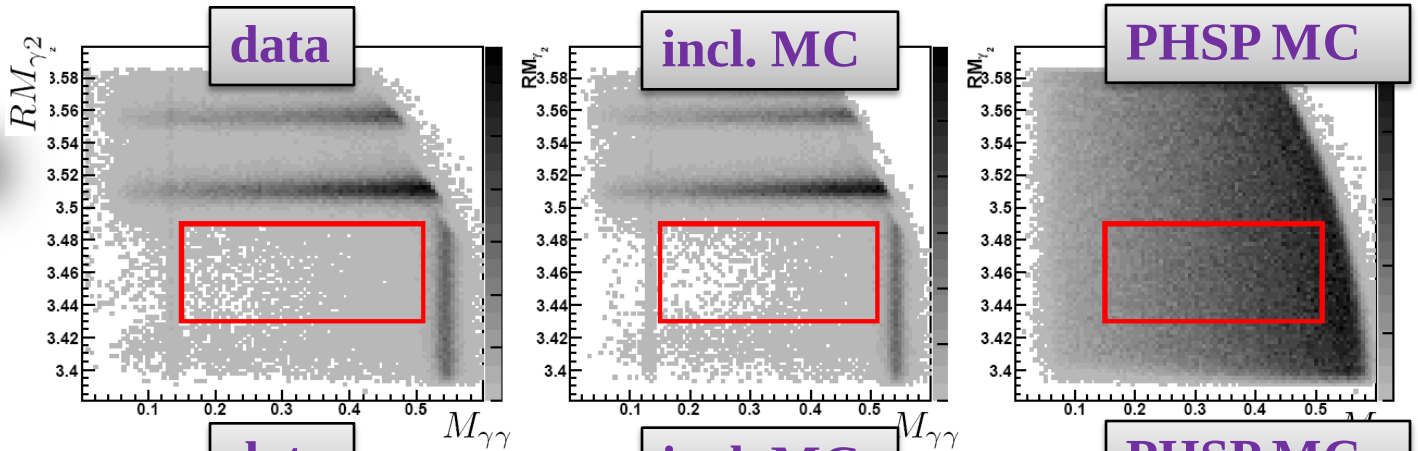
$0.2 < E_{\gamma 1} < 0.54$ GeV

$0.1 < E_{\gamma 2} < 0.28$ GeV

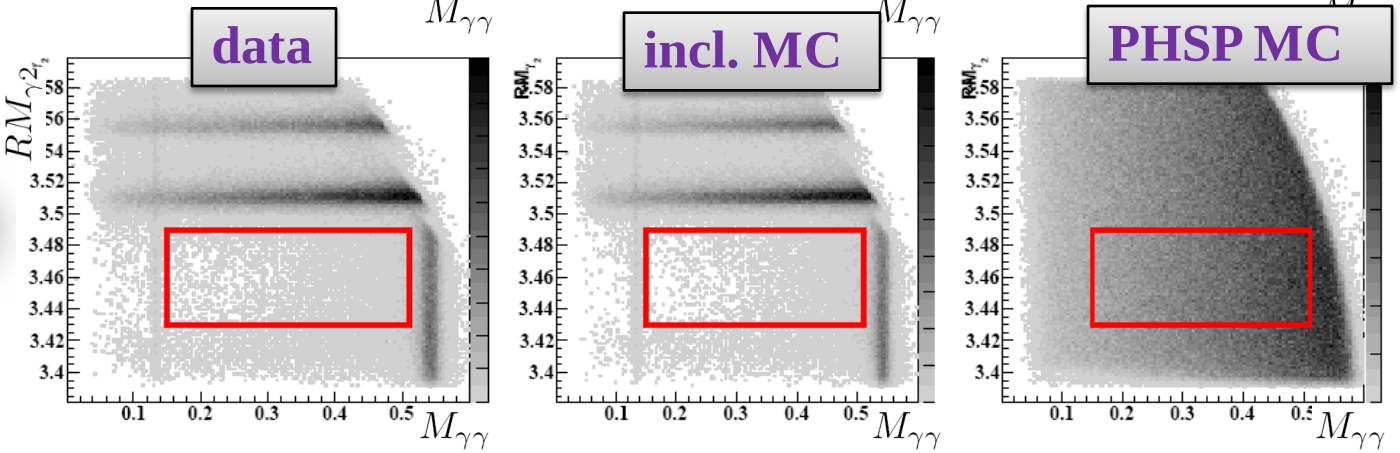
Scattering Plot: $M_{\gamma\gamma}$ VS $RM_{\gamma 2}$

$RM_{\gamma 2}$: Recoil Mass of lower energy photon γ_2

ee channel



$\mu\mu$ channel



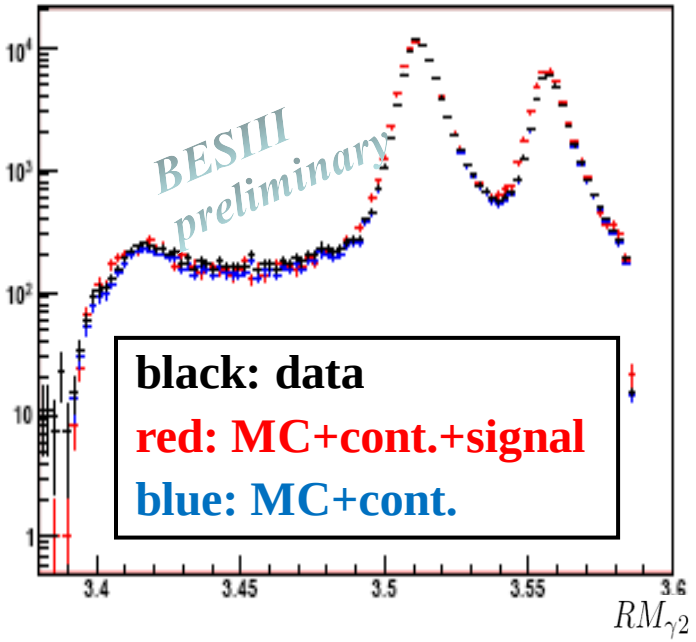
box cut:

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

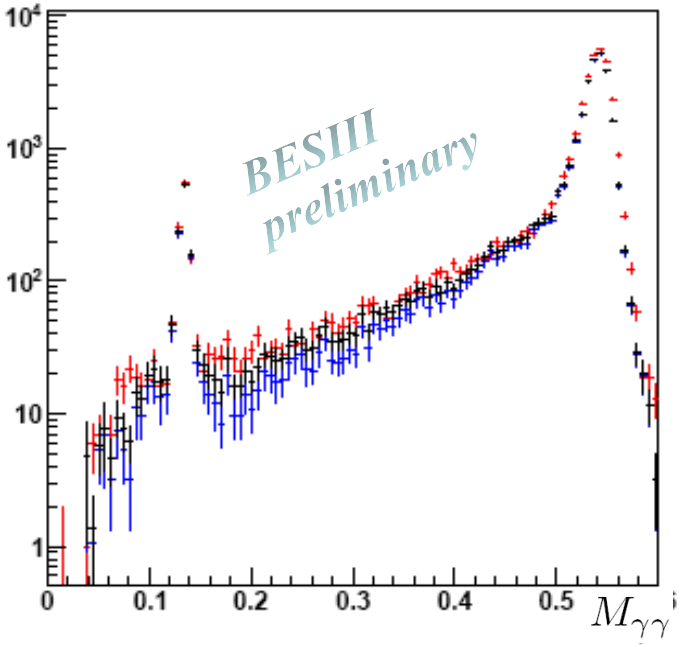
$3.43 < RM_{\gamma 2} < 3.49$ GeV

Projection Plots on $M_{\gamma\gamma}$ and $RM_{\gamma 2}$

loose $RM_{\gamma 2}$ border cut

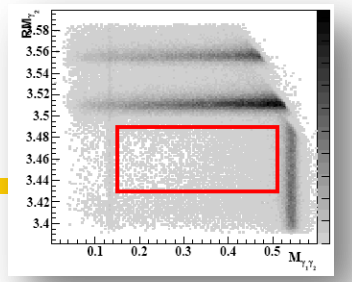


loose $M_{\gamma\gamma}$ border cut

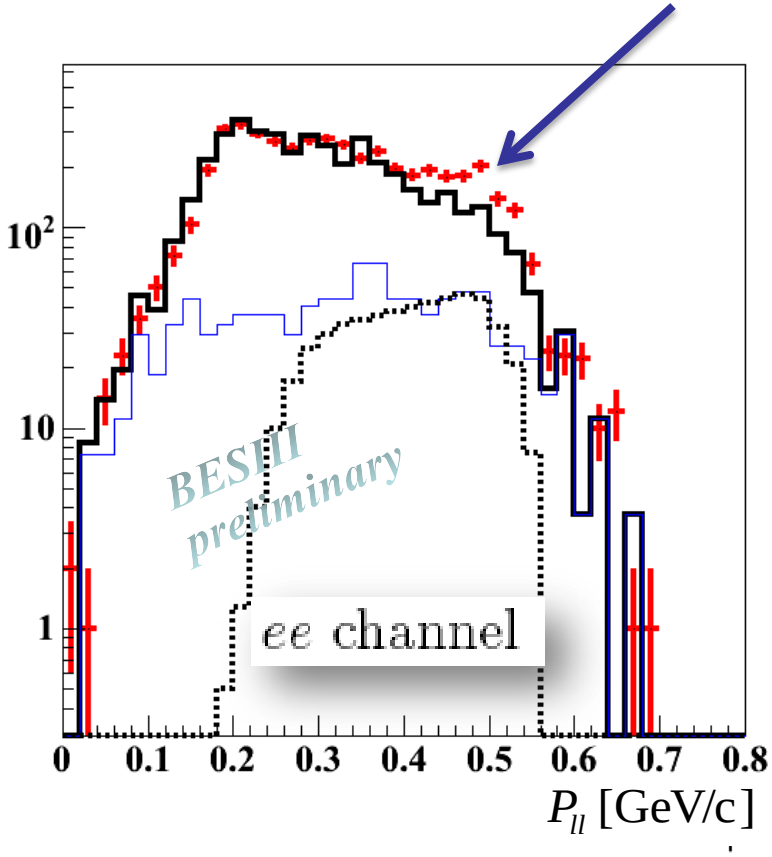


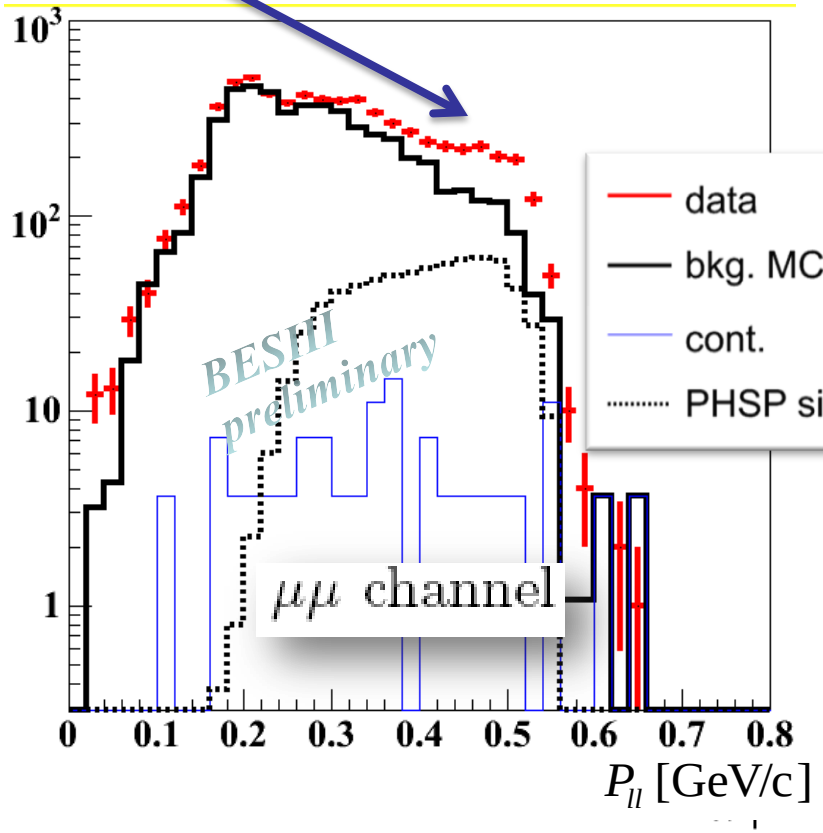
- **consistent data/MC line-shapes**
- **good MC description of the tails of $\chi_{CJ}/\pi^0/\eta$**

J/ψ Momentum inside Box



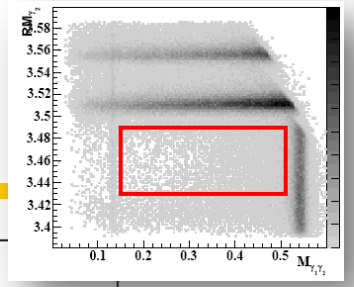
clear enhancement from understood bkg.

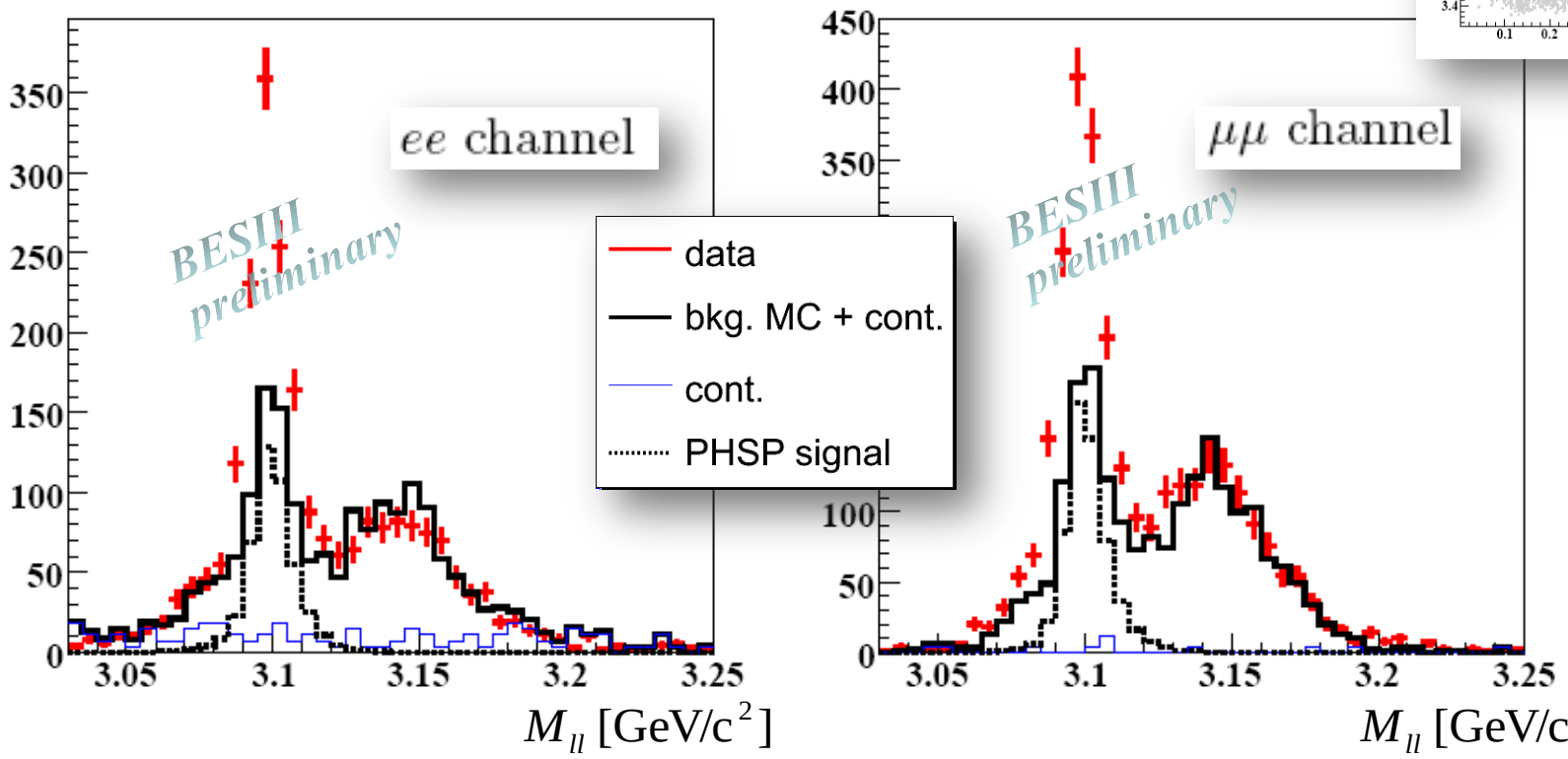




further cut: $0.30\,\mathrm{GeV/c} < P_{ll} < 0.55\,\mathrm{GeV/c}$

Dilepton Invariant Mass





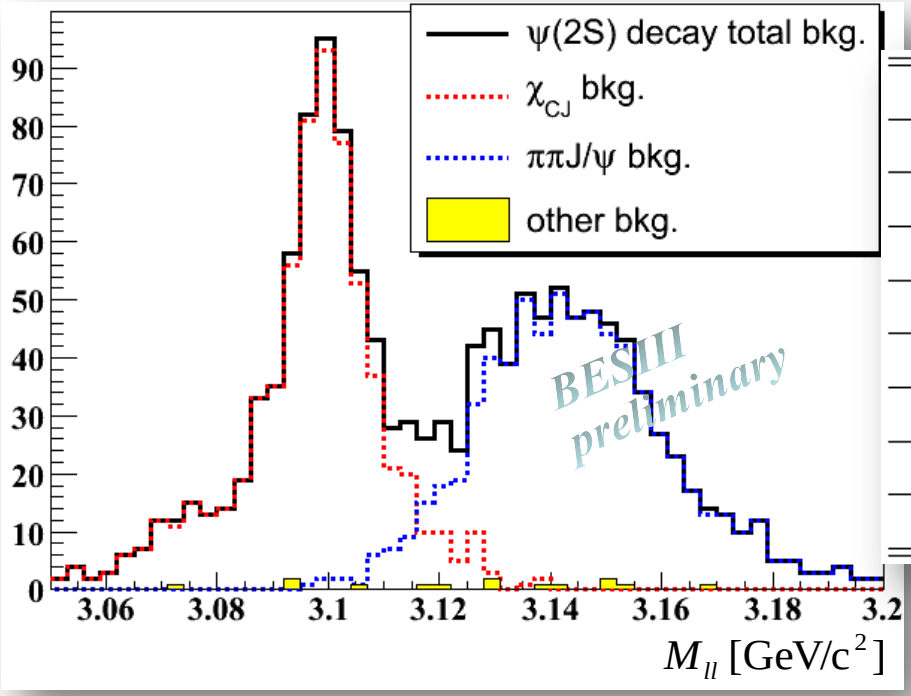
understood backgrounds:

- QCD background from psi(2S) decay
- QED background from continuum data

significant enhancement
around J/ψ peak

Background Components

estimated with MC Simulation and continuum data



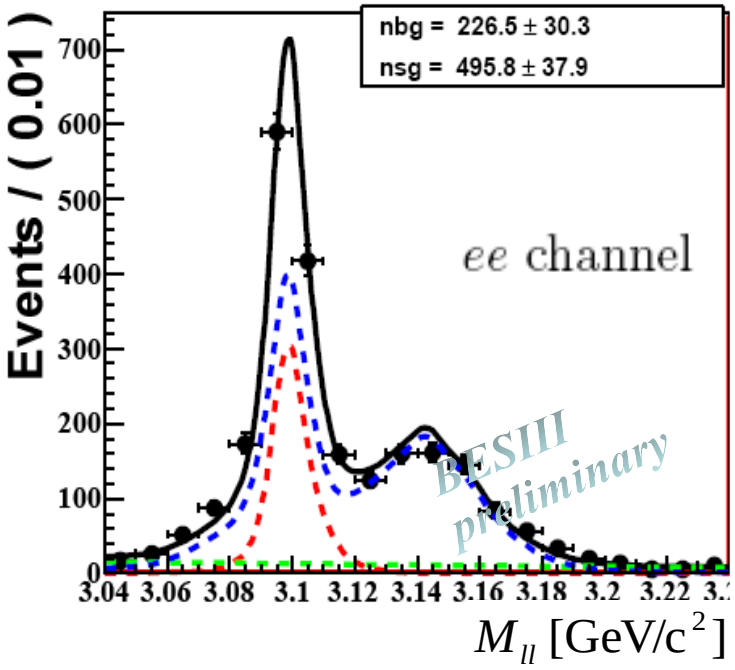
bkg. channels	ee chnl (ex.)	$\mu\mu$ chnl (ex.)
$\gamma(\gamma J/\psi)_{\chi_{c0}}$	263.1 ± 3.2	367.2 ± 3.7
$\gamma(\gamma J/\psi)_{\chi_{c1}}$	517.6 ± 5.1	659.1 ± 5.7
$\gamma(\gamma J/\psi)_{\chi_{c2}}$	86.9 ± 2.1	116.1 ± 2.5
$(\gamma\gamma)_{\pi^0} J/\psi$	0.5 ± 0.2	< 0.1
$(\gamma\gamma)_{\eta} J/\psi$	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

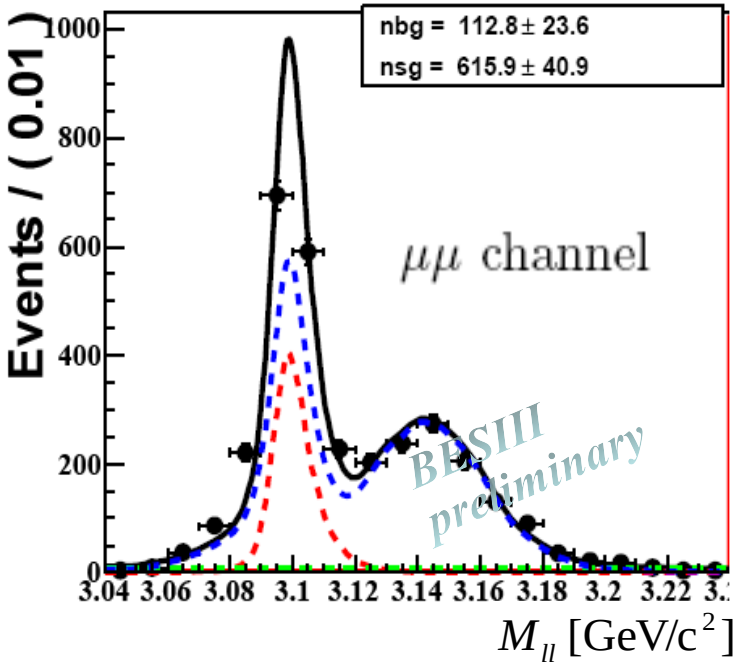
- ✓ **relative branching fractions based on PDG**
- ✓ **take ψ(2S) decay bkg. shape and magnitude as the main background description**

Signal Estimation

unbinned maximum likelihood fit with composition of three PDFs:

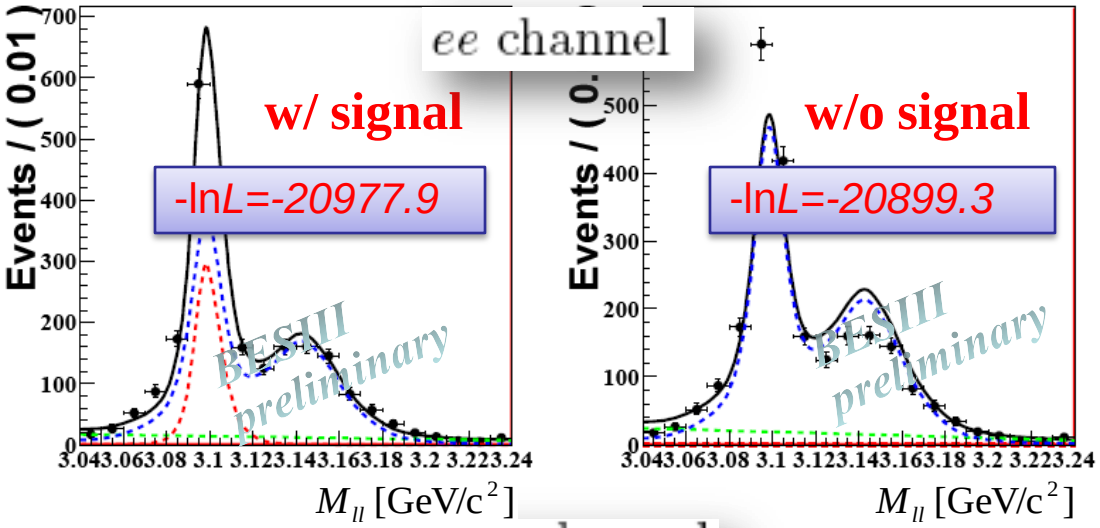
- **signal (red)**: shape from phase-space-like MC simulation
- **ψ(2S) bkg.(blue)**: shape and magnitude from exclusive MC simulation
- **other bkg.(green)**: 1st-order polynominal



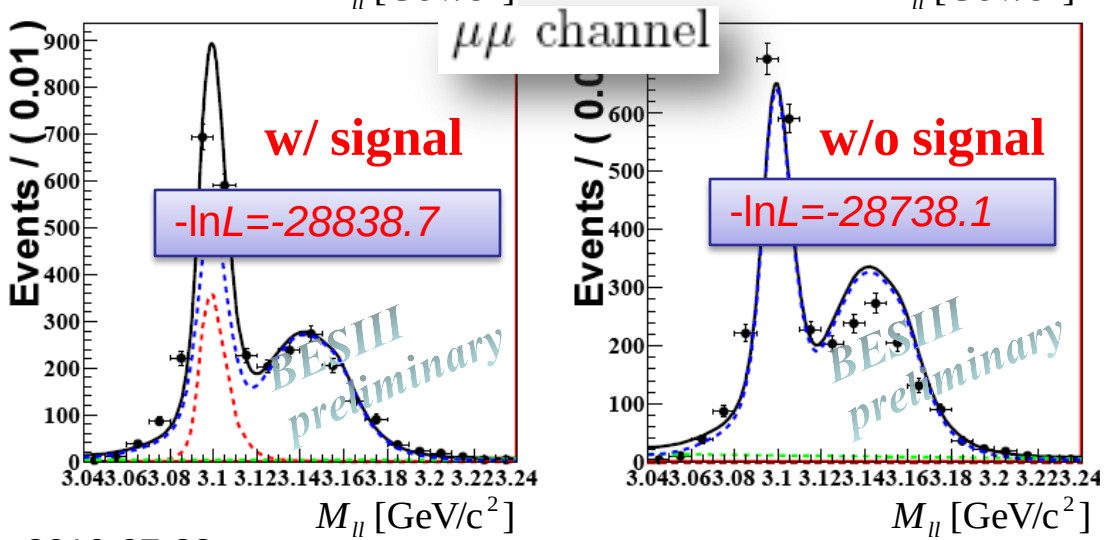


Significance Estimation

floating all fitting components



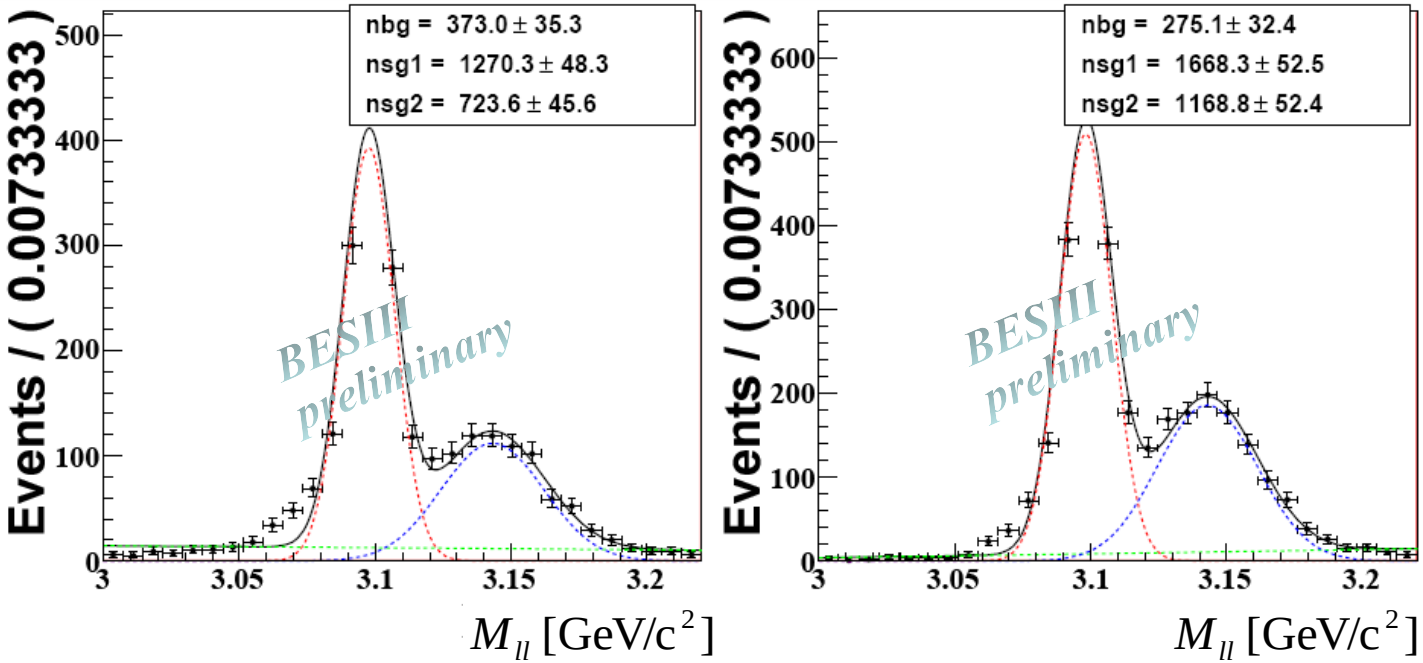
significance: **12.5σ**



significance: **14.3σ**

$\pi^0\pi^0 J/\psi$ 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%

Preliminary Numerical Results and Systematic Uncertainties

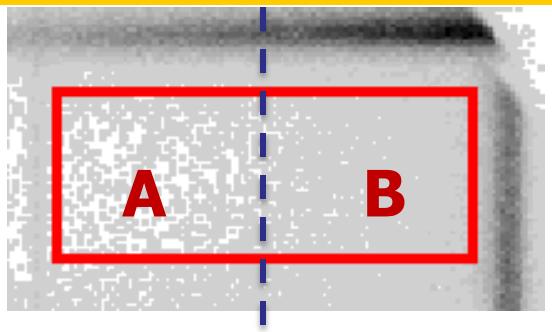
	ee channel	*uu* channel
signals	495.8±37.9	615.9±40.9
efficiency	(7.44 ±0.02)%	(9.92±0.02)%
significance	12.5σ	14.3σ
BR($\psi(2S) \to \gamma\gamma J/\psi$)	$(1.06\pm0.08))\times10^{-3}$	$(0.99\pm0.07))\times10^{-3}$

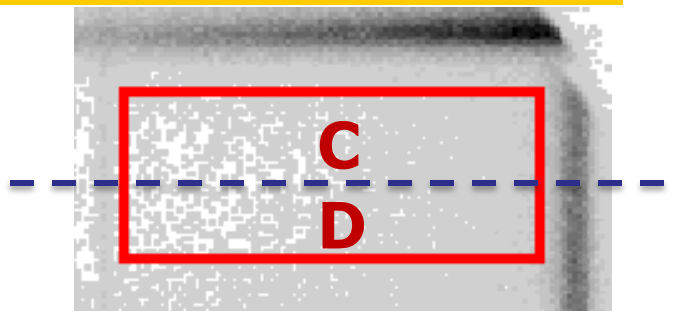
statistically consistent

sources of systematic uncertainties

- lepton tracking
- photon detection
- photon number cut
- kinematic fit
- BRs of ψ(2S) decay bkg.
- χ_{CJ} decay width uncertainties
- bkg. shape
- fitting range
- extrapolation from box region to full phase space
- signal MC simulation
- ψ(2S) total number
- J/ψ decay BR
- interferences

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

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

Summary

- **Charmonium is an interesting topic to understand non-perturbative QCD**
- **Thanks to the high-luminosity of BEPCII and high-quality BESIII data, a significant enhancement of two-photon transition of ψ(2S) to J/ψ was observed for the first time in the world: significance>10σ**
- **The branching ratio was measured at BESIII with combination of two independent channels.**
- **Preliminary result shows:**

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

Thank You!

谢谢！