



JOHANNES GUTENBERG  
UNIVERSITÄT MAINZ



THE LOW-ENERGY FRONTIER  
OF THE STANDARD MODEL



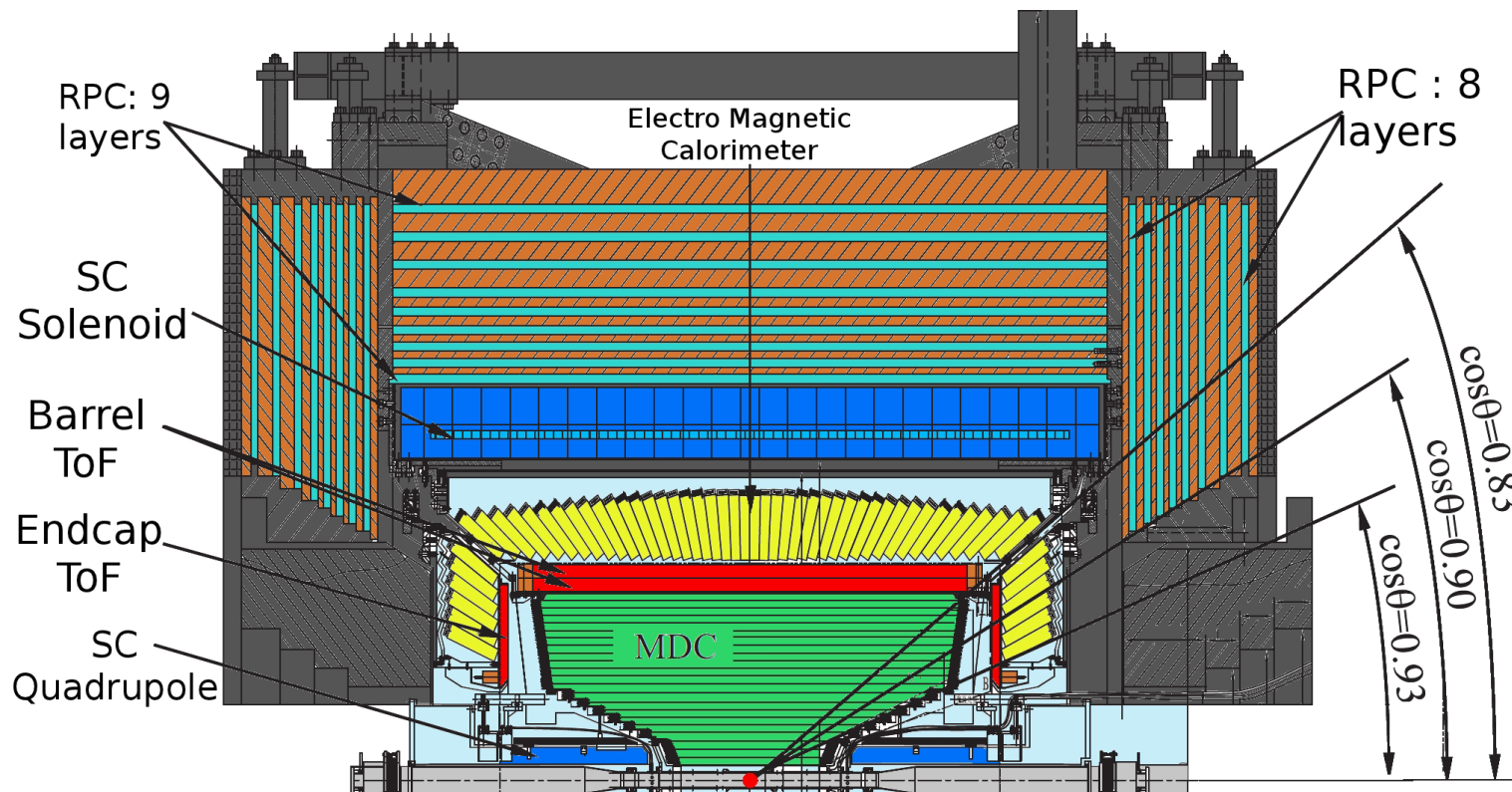
# Hadronic Cross Sections at BESIII

June 4, 2017 | Christoph Florian Redmer

First Workshop of the Muon  $g-2$  Theory Initiative

# BESIII at BEPCII

NIM A614 (2010) 345



## ■ Main Drift Chamber (MDC)

- $\sigma(p)/p = 0.5\%$
- $\sigma_{dE/dx} = 6.0\%$

## ■ Superconducting Magnet

- 1 T magnetic field

## ■ Time-of-flight system (TOF)

- $\sigma(t) = 90\text{ps}$  (barrel)
- $\sigma(t) = 110\text{ps}$  (endcap)

## ■ Muon Chambers

- RPC in flux return yoke

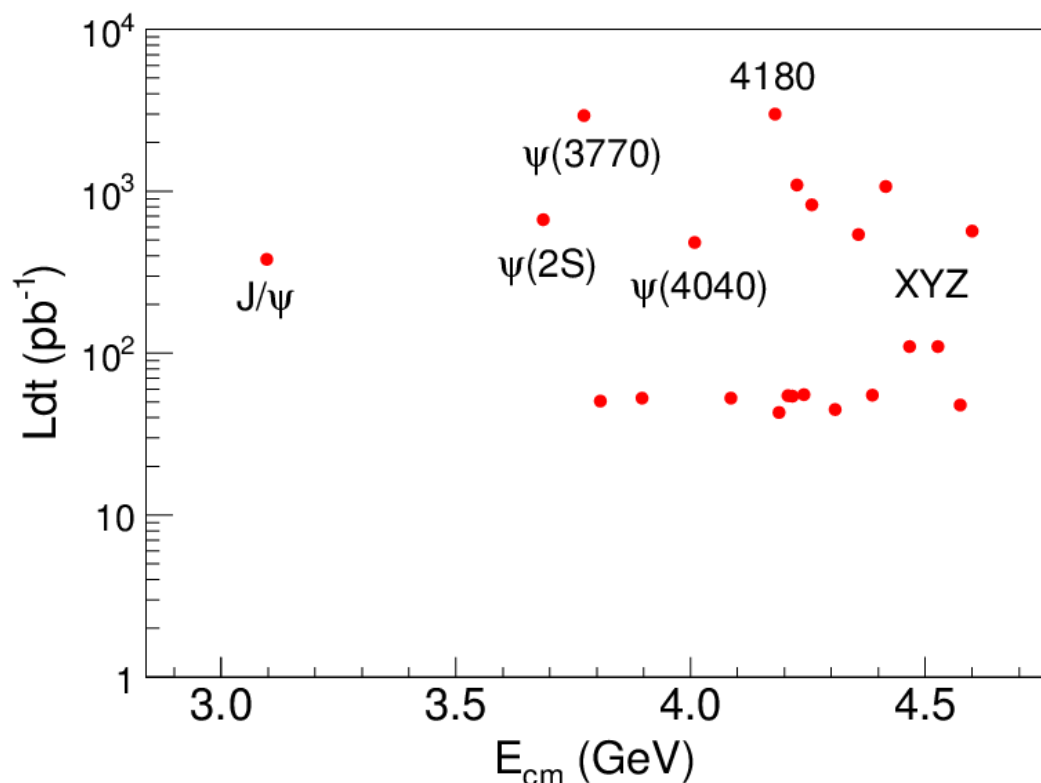
## ■ EMC

- 6240 CsI(Tl) crystals
- $\sigma(E)/E = 2.5\%$
- $\sigma_{Z,\phi}(E) = 0.5 - 0.7 \text{ cm}$

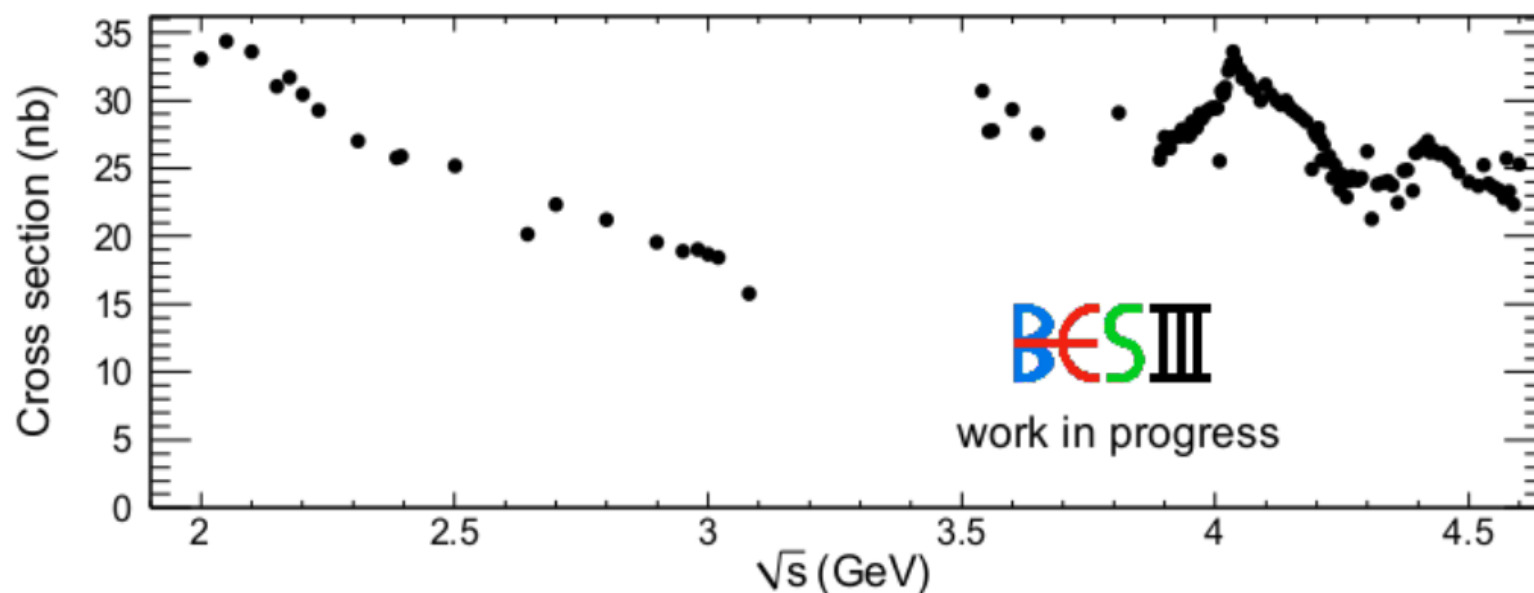


- Large data sets for
  - Charmonium spectroscopy
  - Charm physics
  - Light hadrons
  - $\tau$  and R-scan

- Operated at BEPCII collider
- $2.0 \leq \sqrt{s} \text{ [GeV]} \leq 4.6$
- Design luminosity achieved
  - $\mathcal{L} = 1.0 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  at  $\psi(3770)$



- Line-shape scans in the charmonium and XYZ region
- R-Scan
  - From 2.0 GeV to 4.6 GeV
  - About 150 scan points
  - 3% accuracy targeted



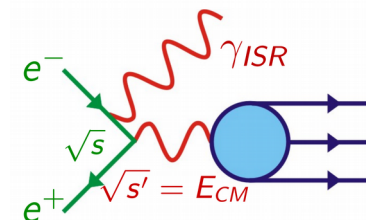
- Scan around  $\chi_{c1}$  resonance (data taking ended May 31)
  - $J^{PC} = 1^{++}$
  - 2-photon production

- Reduces effective CMS energy

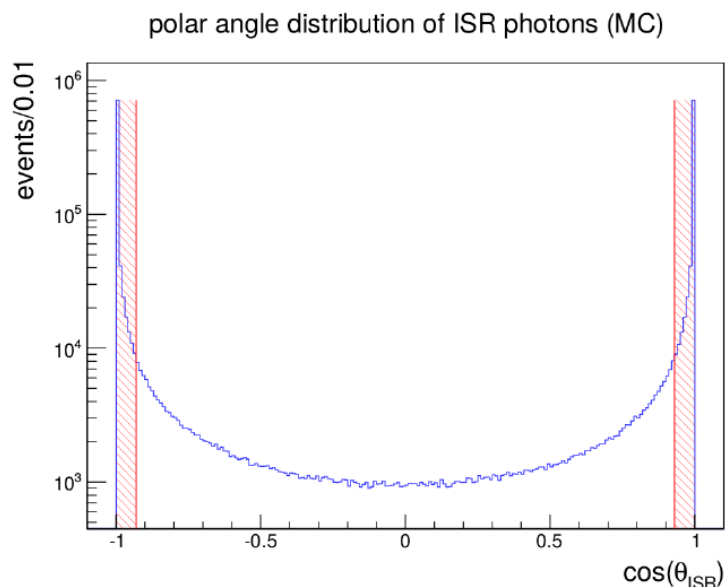
- $\sqrt{s'} = \sqrt{s - 2\sqrt{s}E_\gamma}$

- Radiator function relates to non-radiative process

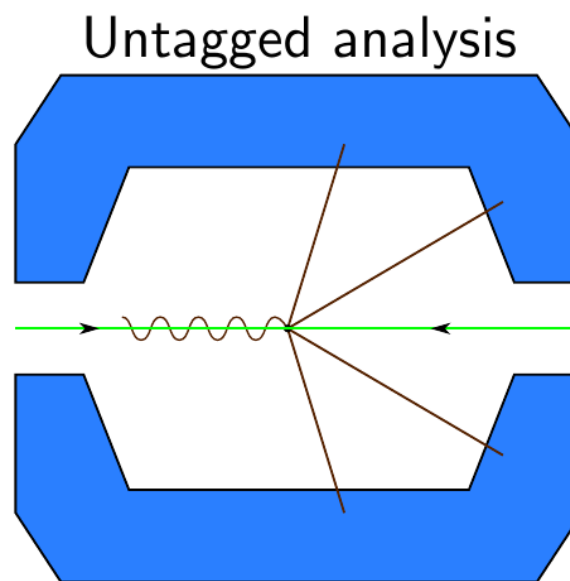
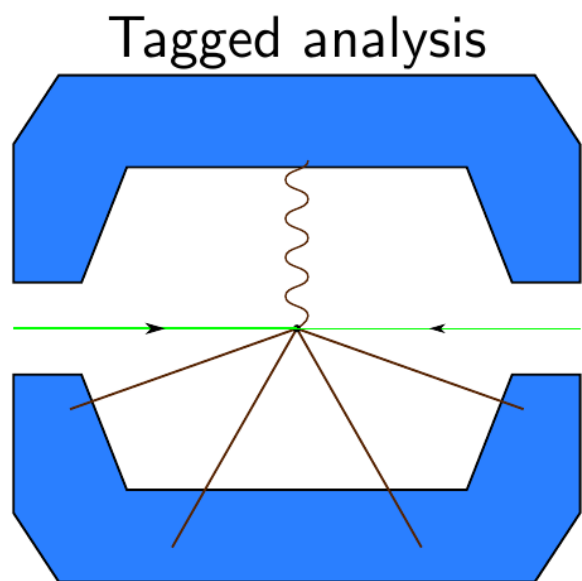
- $\frac{d\sigma_{\text{had}+\gamma}}{dm_\gamma} = \frac{2m_{\text{had}}}{s} W(s, E_\gamma, \theta_\gamma)_{\text{had}}$



- Emission of ISR suppressed by  $\frac{\alpha}{\pi}$
- Large integrated luminosity needed for precision studies
  - Studies presented in the following based on  $2.93 \text{ fb}^{-1}$  at  $\psi(3770)$



- Detect hadronic system
- ISR photon detected
  - Acceptance from  $\pi^+\pi^-$  threshold
  - Large background contamination at high  $\sqrt{s'}$
- ISR photon undetected
  - High statistics
  - Acceptance for  $\sqrt{s'} > 1$  GeV
  - Small background contamination





$$e^+e^- \rightarrow \pi^+\pi^-$$

Phys.Lett.B753 (2016) 629

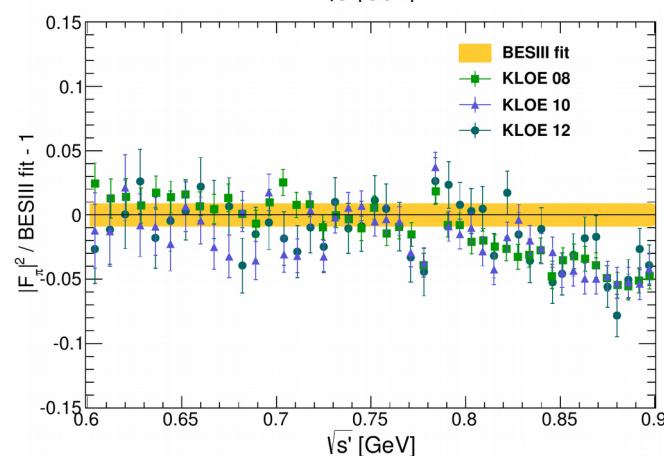
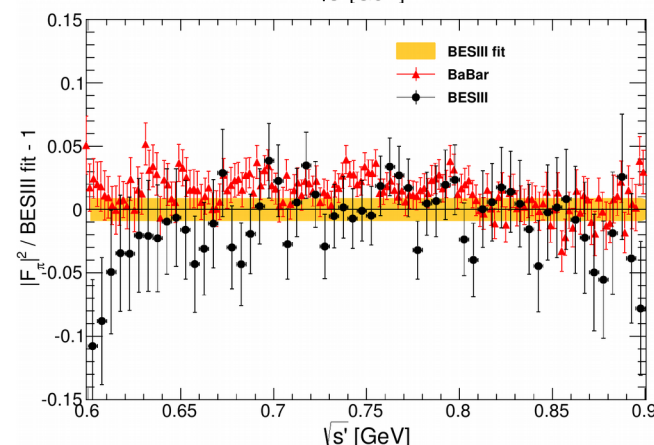
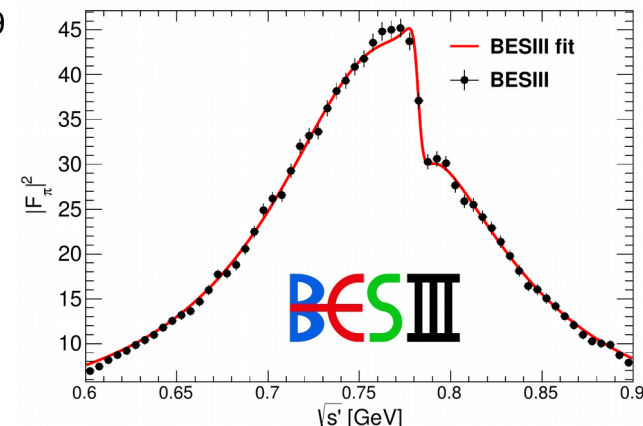
- Tagged measurement
- No dedicated background subtraction
- $\mu - \pi$  separation with neural network
- careful evaluation of systematics

Source	Uncertainty (%)
Photon efficiency	0.2
Tracking efficiency	0.3
Pion ANN efficiency	0.2
Pion e-PID efficiency	0.2
Angular acceptance	0.1
Background subtraction	0.1
Unfolding	0.2
FSR correction $\delta_{FSR}$	0.2
Vacuum polarization correction $\delta_{vac}$	0.2
Radiator function	0.5
Luminosity $\mathcal{L}$	0.5
<b>Sum</b>	<b>0.9</b>

- evaluation for  $0.6 \leq m_{\pi\pi} \leq 0.9$ 
  - 70% of total  $2\pi$  contribution
  - 50% of  $a_\mu^{hVP}$  contribution

Comparison to previous measurements:

- Systematic shift in pion form factor
  - below  $\rho/\omega$  interference wrt BaBar
  - above  $\rho/\omega$  interference wrt KLOE

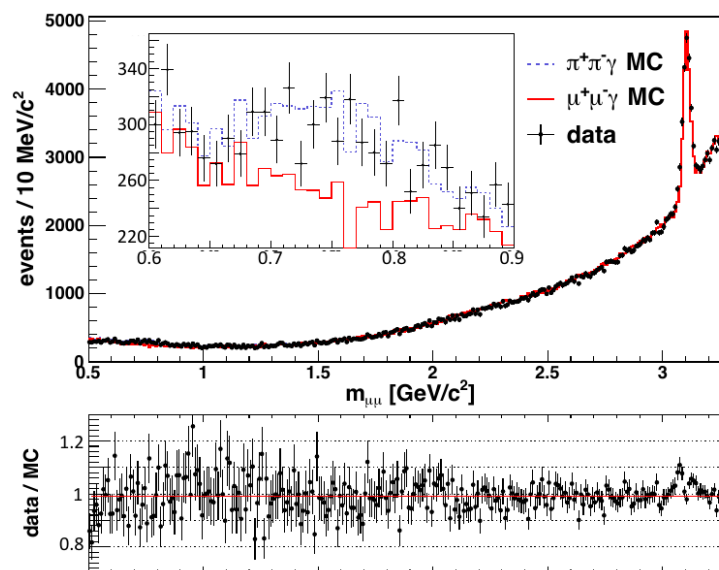
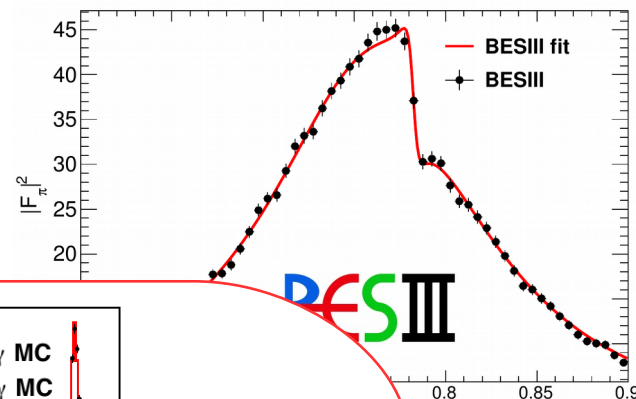


$$e^+e^- \rightarrow \pi^+\pi^-$$

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- Tagged measurement
- No dedicated background subtraction
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- careful evaluation of systematics

Source
Photon efficiency
Tracking efficiency
Pion efficiency
Pion energy
Angular
Background
Unit
FSR correction
Vacuum polarization
Radiator function
Luminosity
Sum



- evaluation for
  - 70% of total
  - 50% of  $a_\mu$

- Use ANN to select muons
- Compare to QED prediction
- Excellent agreement!
- Spin-off: Electronic width of  $J/\psi$

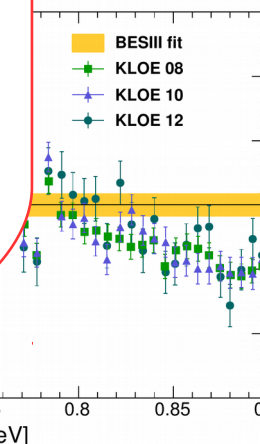
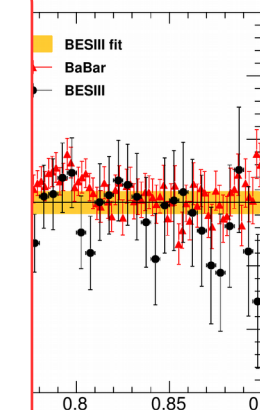
Phys.Lett.B761 (2016) 98

Comparison to

- Systematic shift

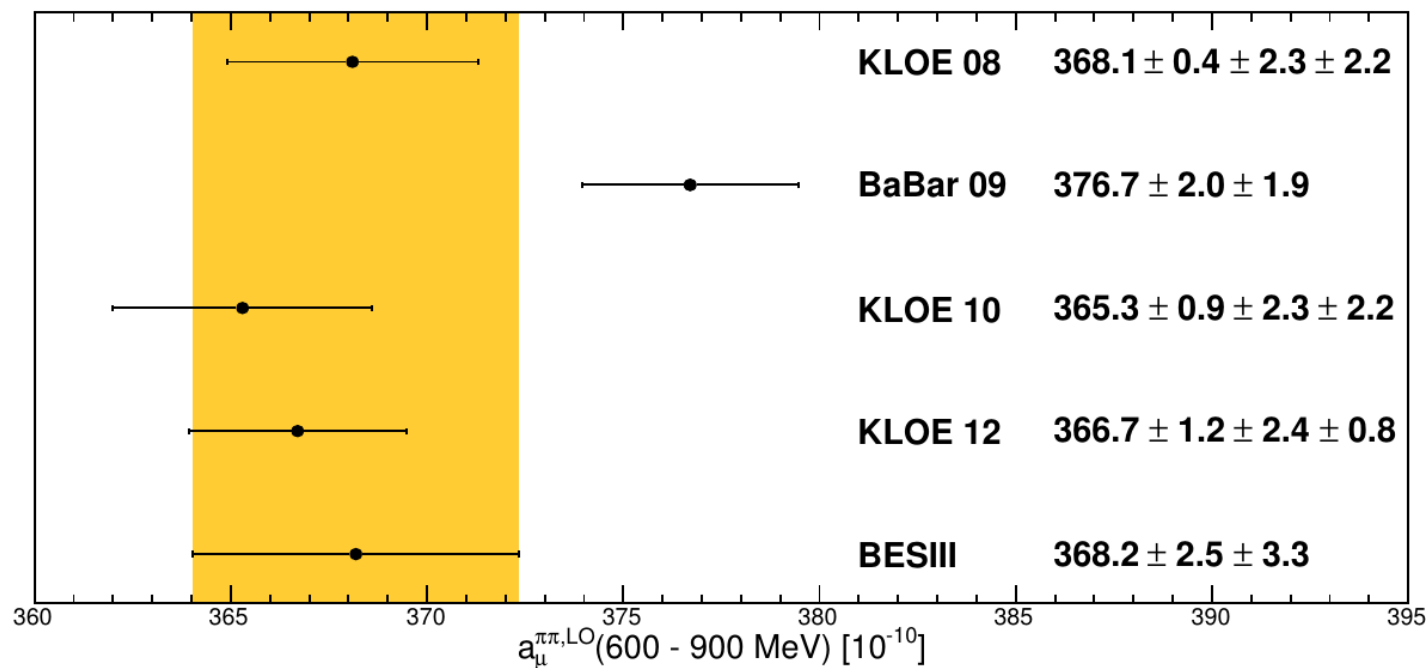
- below  $\rho/\omega$  interference
- above  $\rho/\omega$  interference wrt KLOE

$$\Gamma_{ee}(J/\psi) = (5.58 \pm 0.05_{stat} \pm 0.08_{syst}) \text{ keV}$$





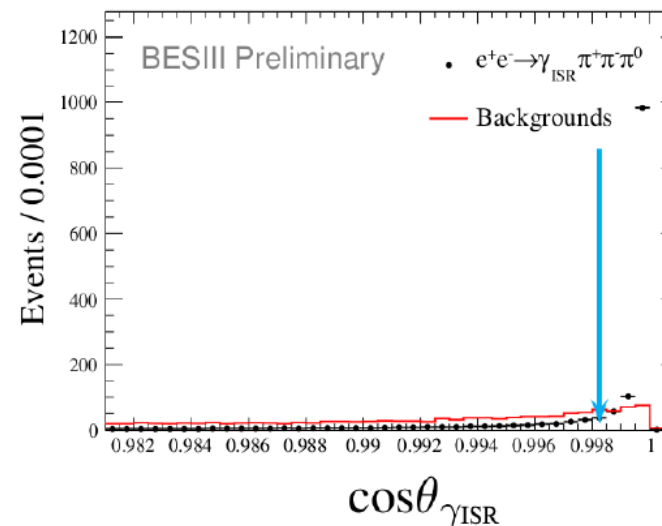
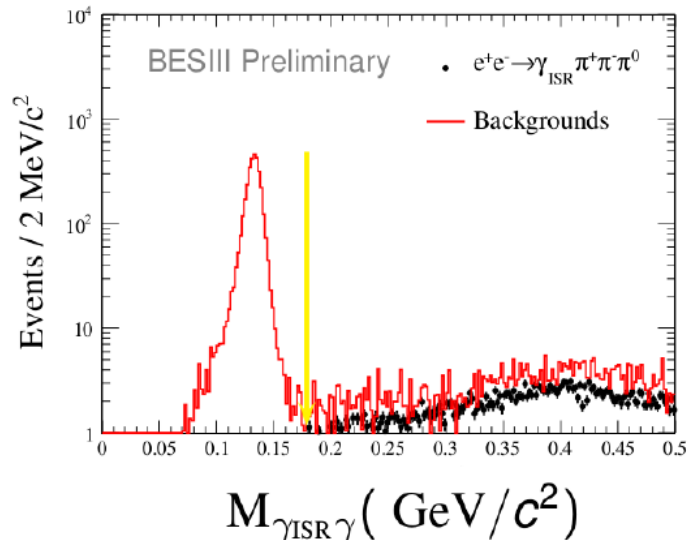
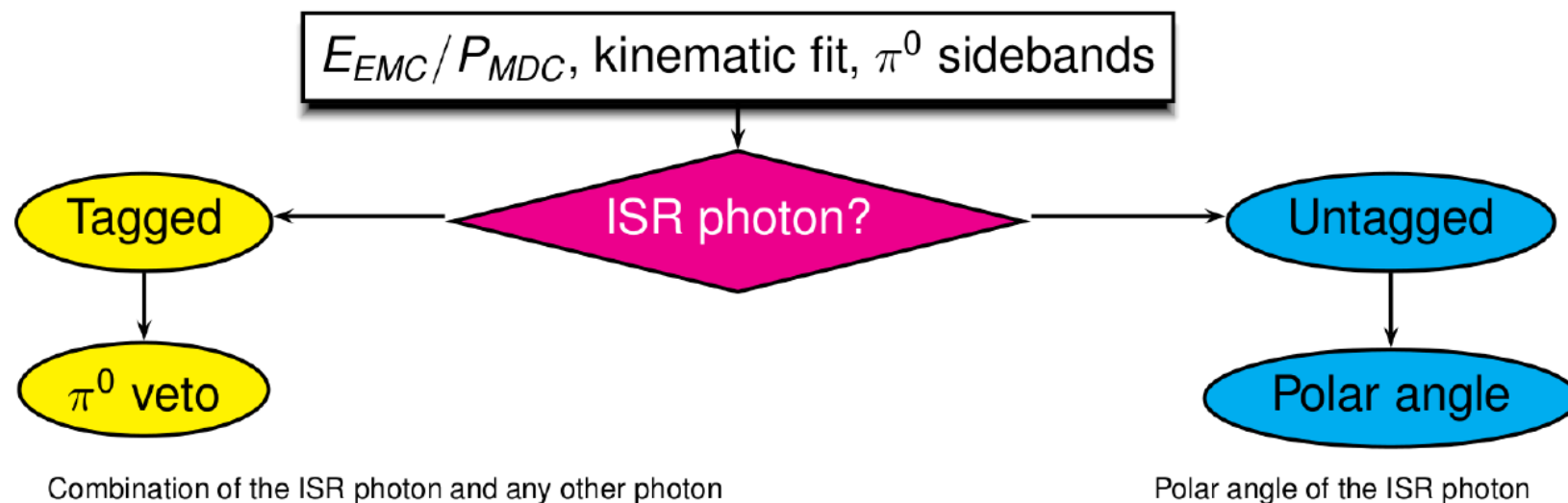
$$e^+e^- \rightarrow \pi^+\pi^-$$



Ablikim et al., Phys.Lett.B753 (2016) 629

- Precision competitive to measurements by BaBar and KLOE
- Good agreement with all KLOE results
- BESIII result confirms  $a_\mu^{\text{theo, SM}} - a_\mu^{\text{exp}} > 3\sigma$

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$



- Measure  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0(\gamma)$  to correct background description

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$

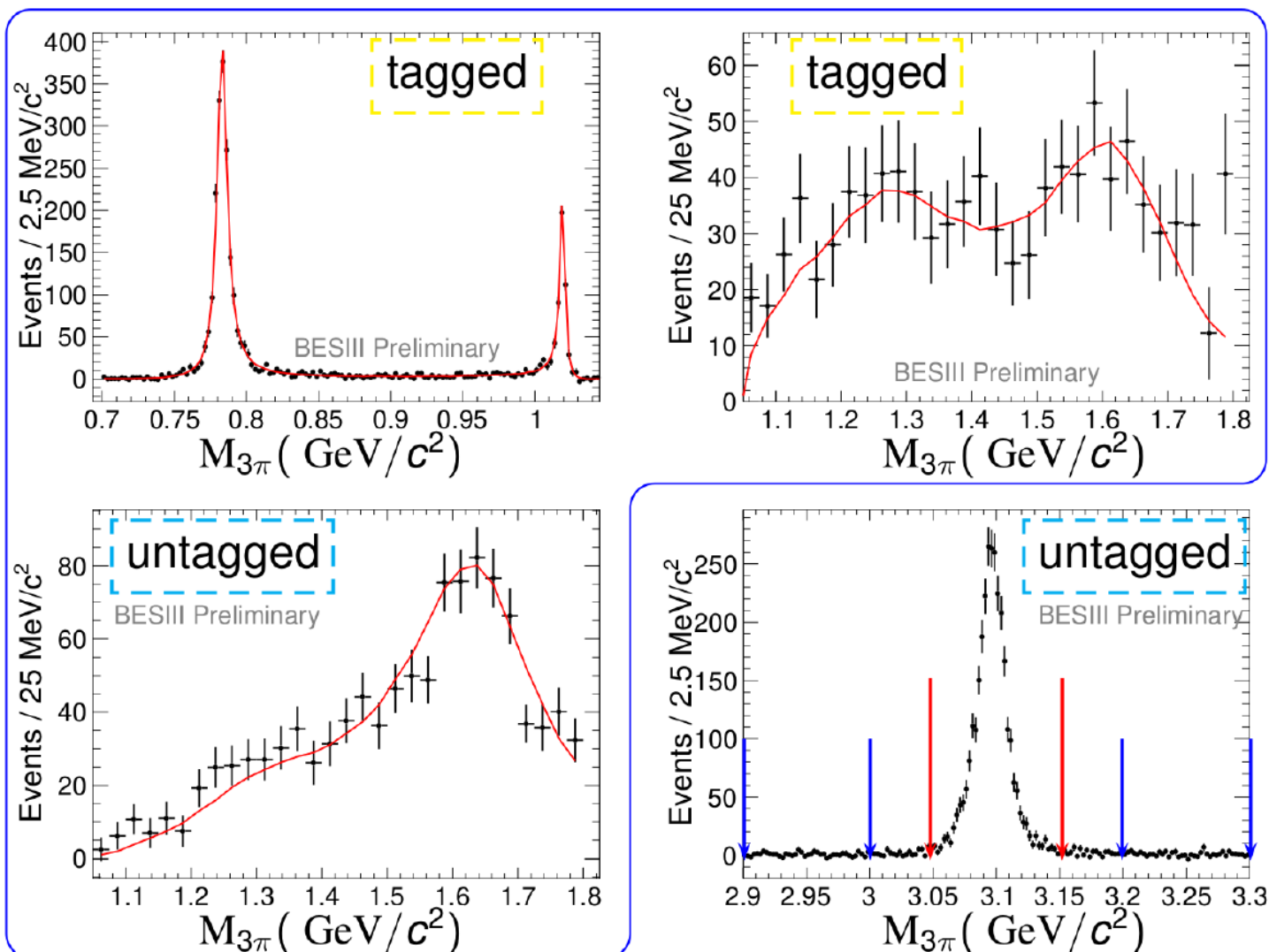
BESIII Preliminary

Data samples	Data I		Data II	
Source	Tagged	Untagged	Tagged	Untagged
Tracking	0.4-1.0	0.4-0.9	0.4-0.7	0.4-0.7
Photon reconstruction	0.9	0.6	0.9	0.6
E/P	0.7-0.9	0.4	0.4	0.4
$\pi^0$ side band	0.6-0.9	0.4	0.4	0.4
Kinematic fit ( $\chi^2$ cut)	1.0-1.4	0.4	0.6	0.4
Veto $\pi^0$ for $\gamma_{\text{ISR}}$	0.6	-	0.5-1.0	-
$\cos \theta_{\gamma_{\text{ISR}}}^{2C}$	-	1.5	-	1.5
Vertex	-	0.2	-	0.2
BG subtraction	0.0-19	0-12	0.04-26	0-6.1
Vacuum polarization	0.02-0.23	0.02-0.07	0.02-0.23	0.02-0.07
Unfolding	0.91-1.7	1.3	0.61-0.93	0.77
Radiative function	0.5	0.5	0.5	0.5
Luminosity	1.1	1.1	1.1	1.1
Total	> 2.4	> 2.6	> 2.0	> 2.4

in unit [%]

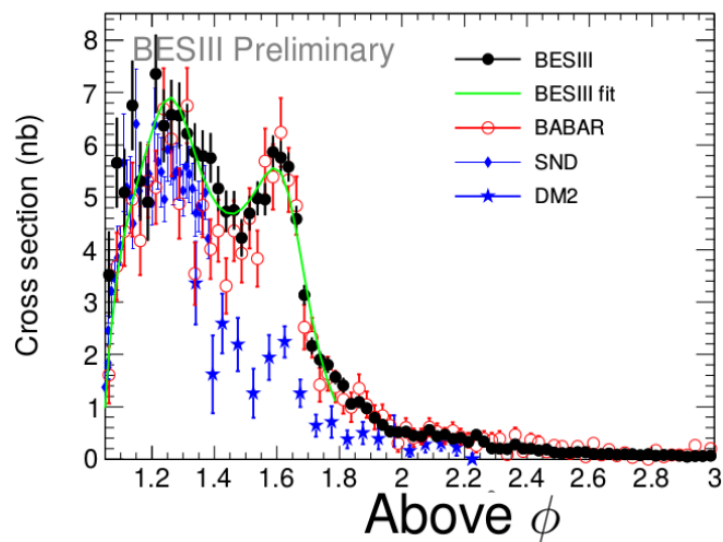
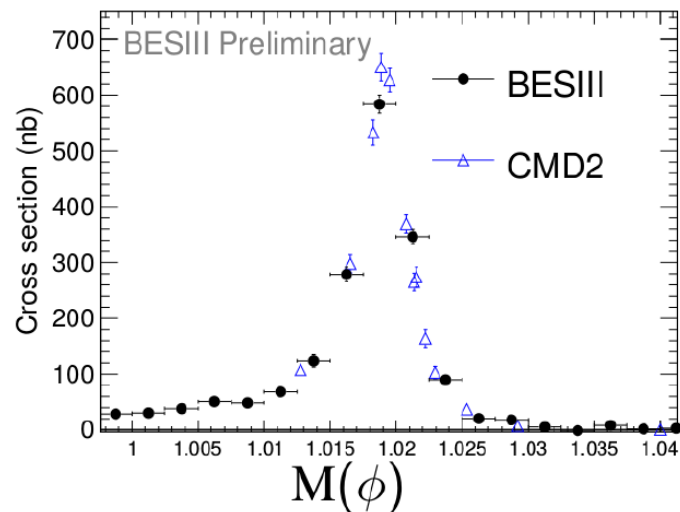
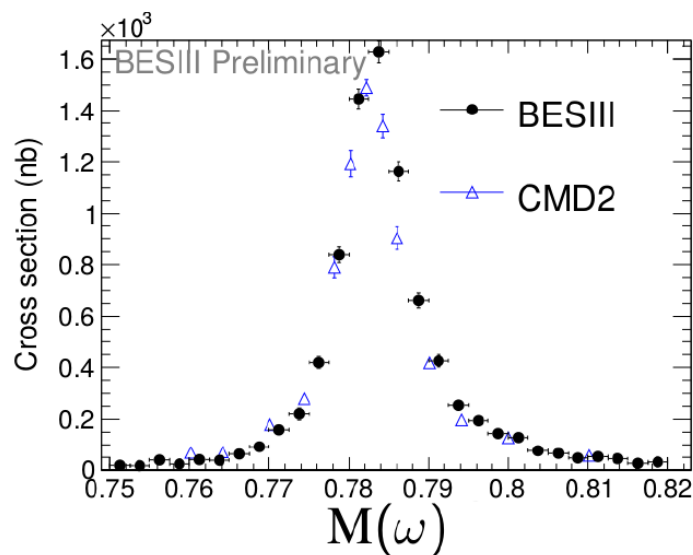
- Systematic error < 2% in the resonance regions

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$



$$\sigma(m) = \frac{12\pi}{m^3} F_{\rho\pi}(m) \left| \sum_{V=\omega, \phi, \omega', \omega''} \frac{\Gamma_V m^3 \sqrt{\Gamma_V^{ee} \mathcal{B}(V \rightarrow 3\pi)}}{D_V(m)} \frac{e^{i\varphi_V}}{\sqrt{F_{\rho\pi}(m_V)}} \right|^2$$

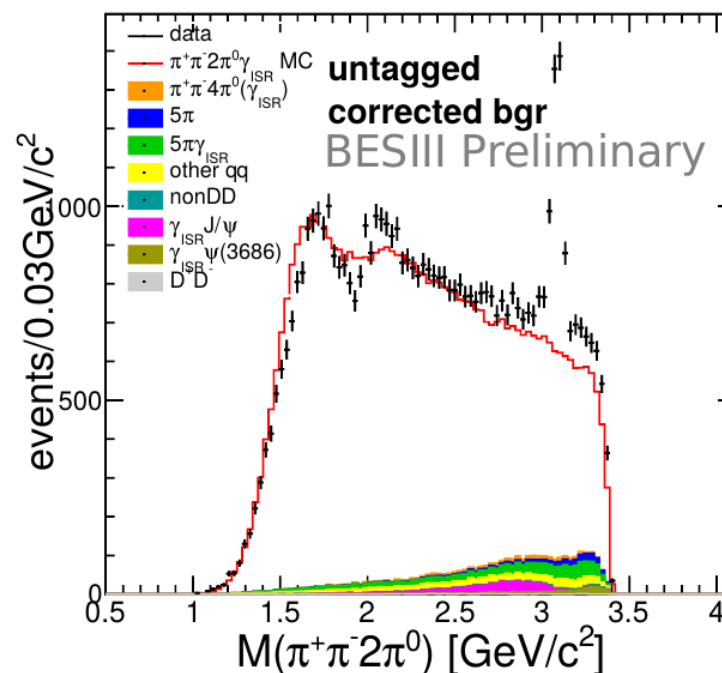
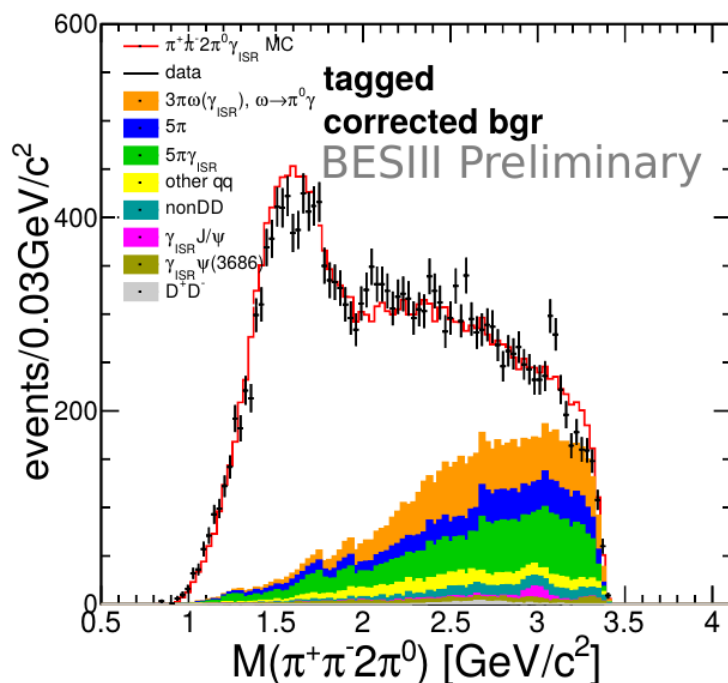
$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$



- Good agreement with previous measurements
- Improved precision
- Confirms BaBar result at  $\omega''$
- Input for  $a_\mu^{\text{hVP}}$

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$$

- Strategy similar to  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  analysis:
  - Tagged photon:
    - Kinematic fit (6C)
    - Veto  $\pi^0$  with ISR photons
  - Untagged photon:
    - Kinematic fit (3C)
    - require  $|\cos\theta_{\text{ISR}}| > 0.995$
- Measure  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0(\gamma)$  to correct background description



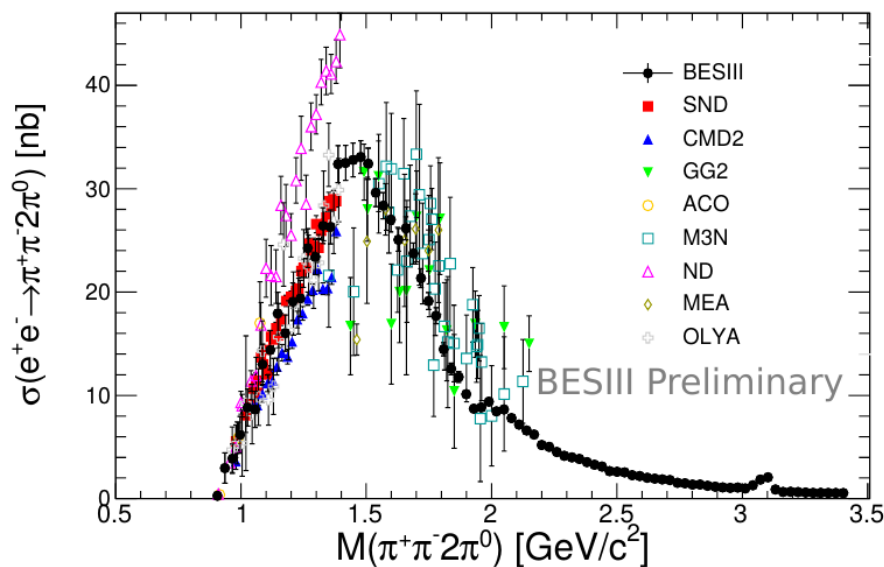


$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$$

Region	Mass range [ GeV]
R1	$0.5 < M(4\pi) < 1.5$
R2	$1.5 < M(4\pi) < 2.0$
R3	$2.0 < M(4\pi) < 3.0$
R4	$3.0 < M(4\pi) < 3.8$

Source	Tagged [%]				Untagged [%]			
	R1	R2	R3	R4	R1	R2	R3	R4
Luminosity	0.50				0.50			
Tracking	0.60				0.60			
VP correction	0.05				0.05			
FSR correction	0.20				0.20			
Radiator Function	0.50				0.50			
ISR Photon Eff.	0.30				-			
$\pi^0$ Eff.	2.57				2.52			
Signal Eff.	0.58				0.61			
Kin. fit	0.42				0.45			
Event selection	0.60	1.46			0.64			
Bgr. Subrt. $5\pi$	0.01	0.13	2.47	3.23	0.00	0.01	0.08	0.15
Bgr. Subrt. $5\pi\gamma_{ISR}$	0.48	0.47	7.77	10.27	0.59	0.25	0.65	0.71
Bgr. Subrt. $q\bar{q}$	0.50	0.98	12.68	21.05	0.58	0.22	0.82	0.76
Bgr. Subrt. other	0.05	0.14	2.31	5.34	0.01	0.02	0.30	0.32
$\omega$ fits (only for $\omega\pi^0$ )	2.26				2.26			
$\pi^+\pi^-2\pi^0$ Total	2.97	3.09	15.58	24.45	2.95	2.85	3.04	3.04
$\omega\pi^0$ Total	3.80	4.84	7.71	3.73	3.91	3.70	4.48	3.68

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$$

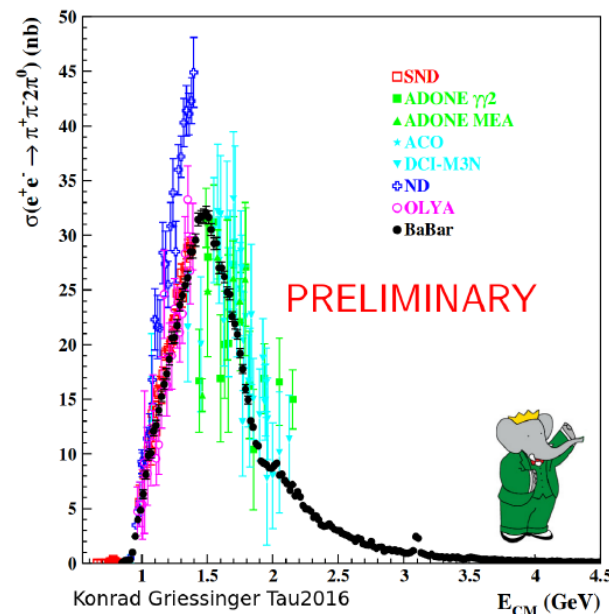
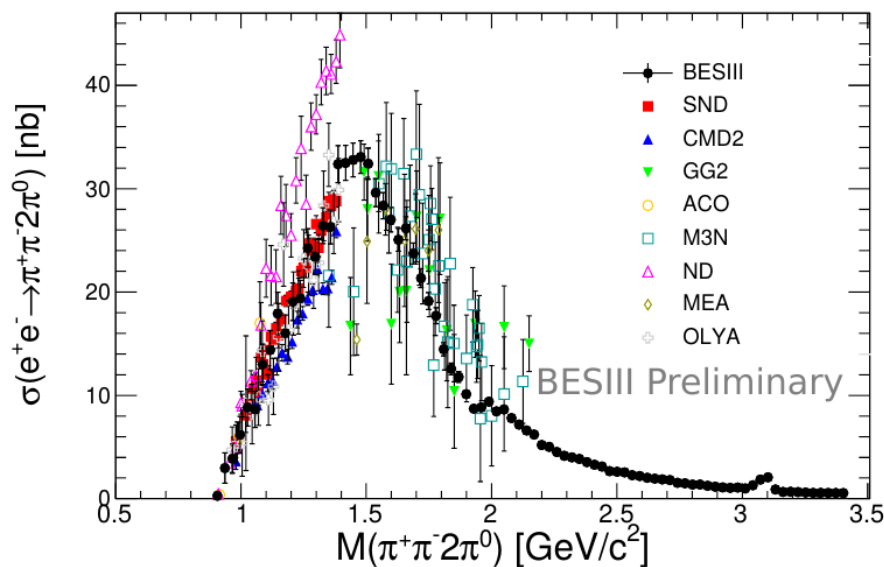


- Error weighted mean of tagged and untagged results
- Good agreement with previous measurements
- Improved precision

$$a_{\mu}^{\pi^+\pi^-\pi^0, \text{LO}} = \frac{1}{4\pi^3} \int_{(4m_{\pi})^2}^{(1.8 \text{ GeV})^2} ds K(s) \sigma_{\pi^+\pi^-\pi^0}(s)$$

	$a_{\mu}^{\pi^+\pi^-\pi^0, \text{LO}} / 10^{-10}$
BESIII (preliminary)	$18.63 \pm 0.27 \pm 0.57$

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$$



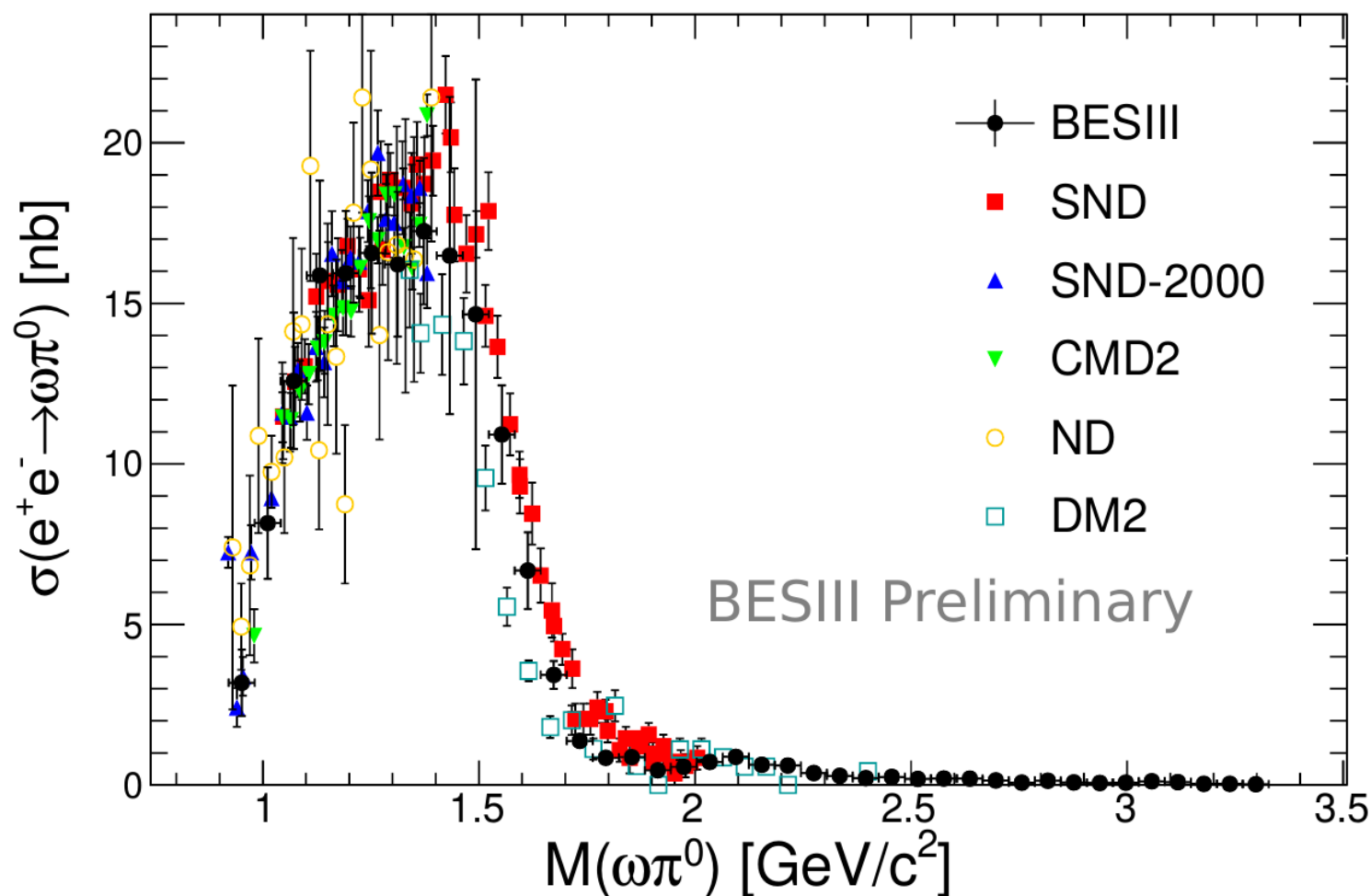
- Error weighted mean of tagged and untagged results
- Good agreement with previous measurements – also with BaBar preliminary
- Improved precision

$$a_{\mu}^{\pi^+\pi^-\pi^0, \text{LO}} = \frac{1}{4\pi^3} \int_{(4m_{\pi})^2}^{(1.8 \text{ GeV})^2} ds K(s) \sigma_{\pi^+\pi^-\pi^0}(s)$$

	$a_{\mu}^{\pi^+\pi^-\pi^0, \text{LO}} / 10^{-10}$
BESIII (preliminary)	$18.63 \pm 0.27 \pm 0.57$
BABAR (preliminary)	$17.9 \pm 0.1 \pm 0.6$

$$e^+e^- \rightarrow \omega\pi^0$$

- Fit  $\omega$  signal on smooth background in every bin of  $M_{\pi^+\pi^-\pi^0\pi^0}$
- Good agreement with previous measurements



- Hadronic cross section measurements at BESIII
  - Scan, tagged and untagged ISR methods
  - Competitive accuracy
  - $\pi^+\pi^-$  result confirms  $a_\mu^{\text{theo,SM}} - a_\mu^{\text{exp}} > 3\sigma$
  - Preliminary results on  $e^+e^- \rightarrow \pi^+\pi^-\pi^0$  and  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$
- Ongoing analyses:
  - Pion form factor from:
    - R-Scan data between 2.0 and 3.08 GeV
    - Low mass tail in tagged ISR analysis
    - At masses larger 1 GeV
- Additional final states ?

# PHIPSI: INTERNATIONAL WORKSHOP on $e^+e^-$ collisions from Phi to Psi 2017

Ph<sup>↑</sup>i<sup>17</sup>  
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26-29 June 2017  
Mainz, Germany

## TOPICS

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