

Pion Form Factor Measurement at BESIII via ISR

Yaqian WANG



(on behalf of the BESIII Collaboration)



Johannes Gutenberg University Mainz

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Budapest, Hungary

Outline

- 1 Introduction
- 2 BESIII Experiment
- 3 Initial State Radiation
- 4 $\pi^+\pi^-$
- 5 3π and 4π
- 6 Summary

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1 Introduction

2 BESIII Experiment

3 Initial State Radiation

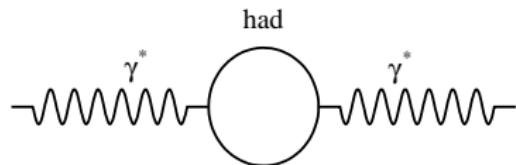
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Hadronic VP and muon $g - 2$

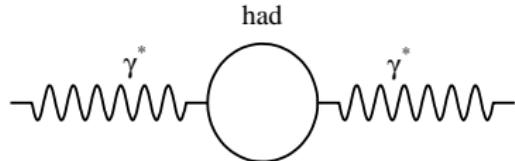
- Hadronic vacuum polarization



- $a_\mu^{\text{SM}} = (\frac{g-2}{2})_\mu = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{weak}}$
- Diagram illustrating the components of the muon g-2 effect:
- γ and leptonic (green dashed box)
 - $Z, W^\pm, \text{ and Higgs}$ (green dashed box)
 - $a_\mu^{\text{had,LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_\pi^2}^\infty ds \frac{K(s)}{s} R(s)$ (red dashed box)

Hadronic VP and muon $g - 2$

- Hadronic vacuum polarization



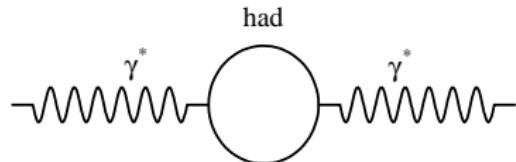
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Diagram illustrating the components of the muon g-2 effect:

- γ and leptonic (green dashed box)
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- $a_\mu^{\text{had,LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_\pi^2}^\infty ds \frac{K(s)}{s} R(s)$ (red dashed box)
- $\frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$ (red arrow)

Hadronic VP and muon $g - 2$

- Hadronic vacuum polarization

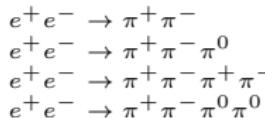


- $a_\mu^{\text{SM}} = (\frac{g-2}{2})_\mu = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{weak}}$

γ and leptonic

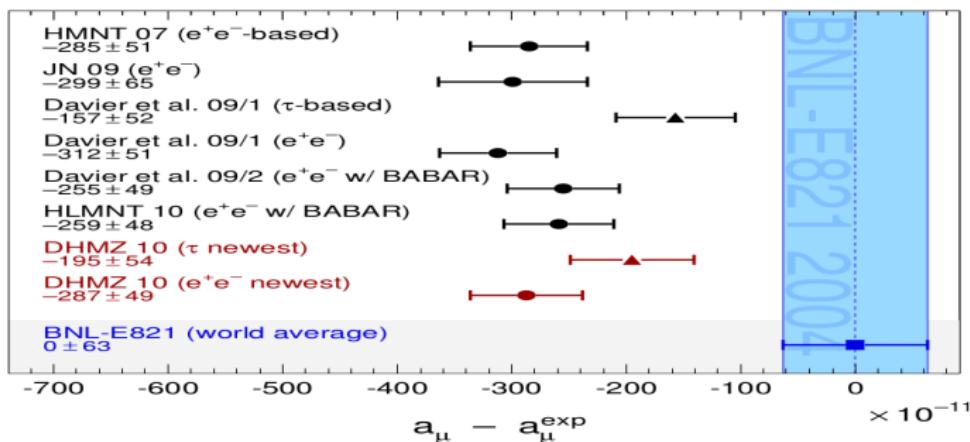
Z , W^\pm , and Higgs

$$a_\mu^{\text{had,LO}} = \frac{\alpha^2(0)}{3\pi^2} \int_{4m_\pi^2}^\infty ds \frac{K(s)}{s} R(s) \xrightarrow{\sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$



g - 2

- $a_\mu = (g_\mu - 2)/2$
- $a_\mu^{\text{expe}} = 116592089 \pm 54 \pm 33 \times 10^{-11}$ at BNL
- $a_\mu^{\text{theo}} = 116591802 \pm 42 \pm 26 \times 10^{-11}$
- $a_\mu^{\text{expe}} - a_\mu^{\text{theo}} = (287 \pm 80) \times 10^{-11} \Rightarrow 3.6\sigma$ deviation



M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C **72** 1874 (2012)

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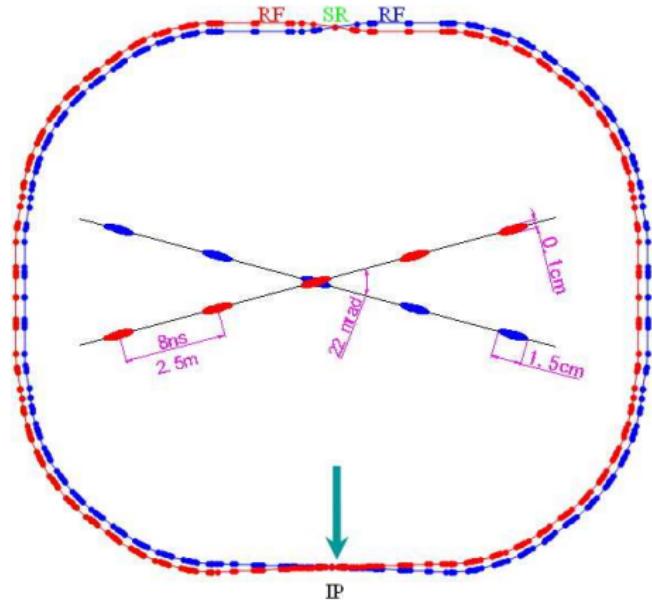
Beijing Spectrometer III Collaboration

ITICAL MAP OF THE WORLD, JUNE 1999

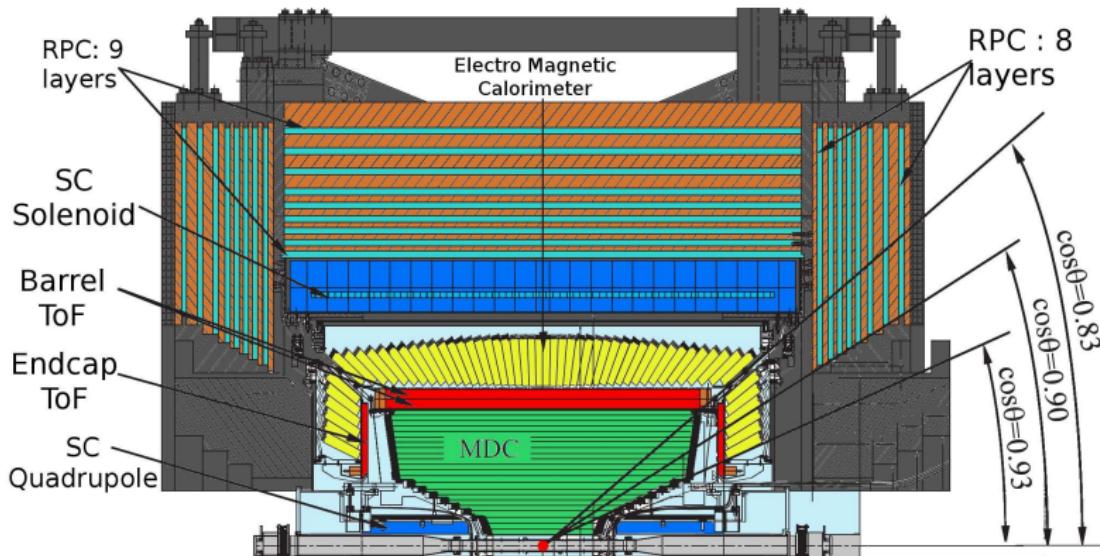


Beijing Electron-Positron ColliderII

- τ -charm factory
- Beam energy: 1.0 – 2.3 GeV
- Beam spread: 5.16×10^{-6}
- Design luminosity:
 $10^{33} \text{ cm}^{-2} \text{s}^{-1}$ (at 3.773 GeV)
69% achieved



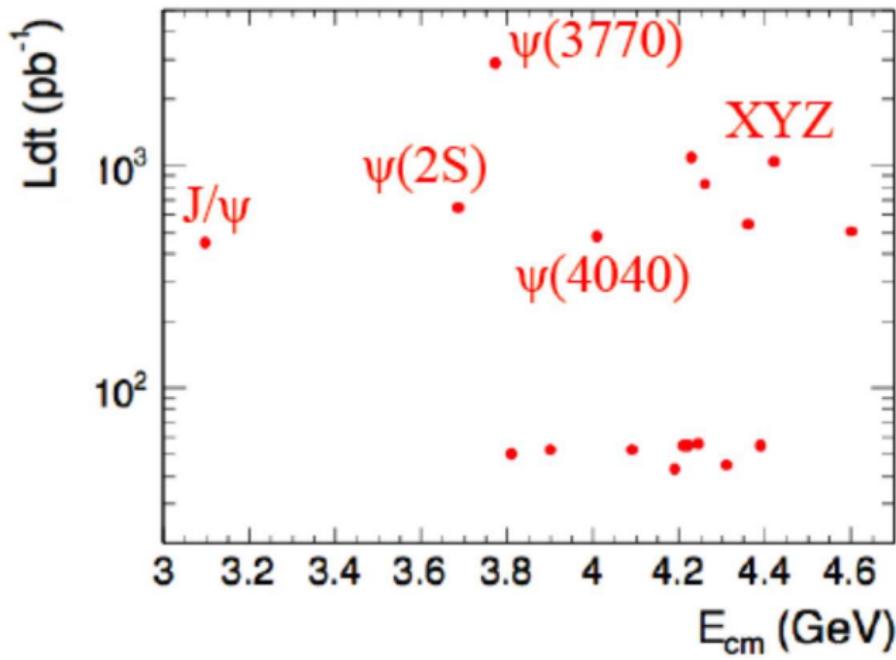
BESIII Detector



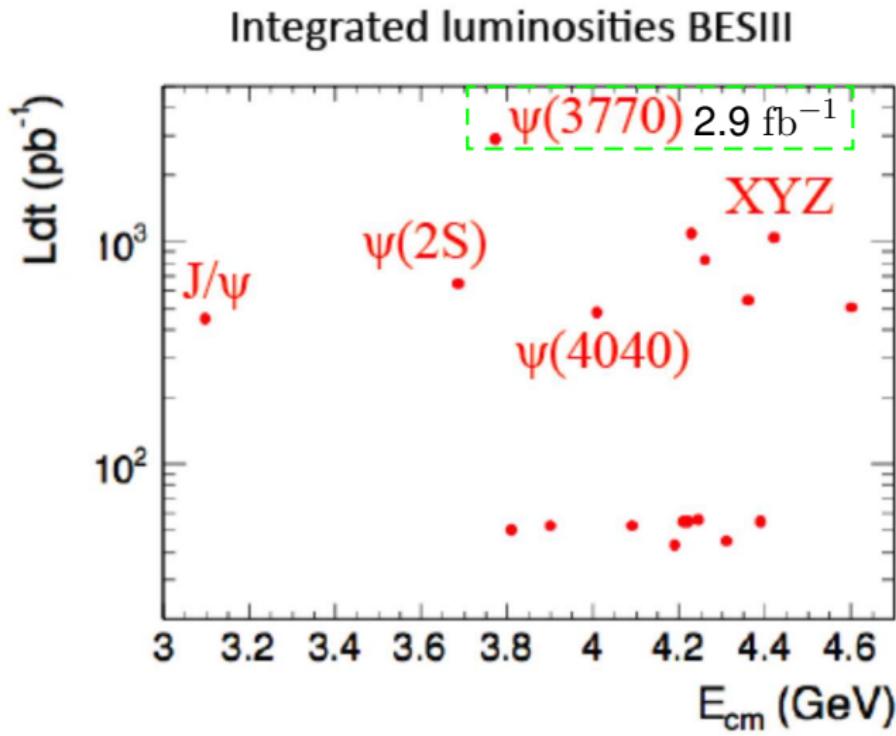
- Multilayer Drift Chamber
- Time of Flight system
- EM Calorimeter
- Muon Chamber

Data samples

Integrated luminosities BESIII



Data samples

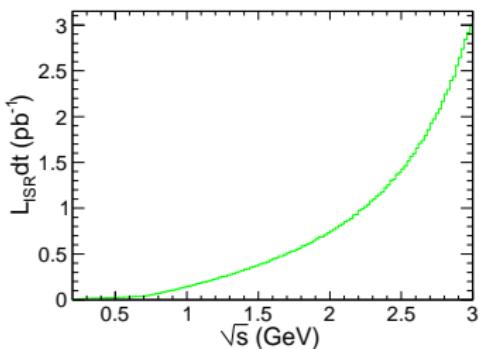
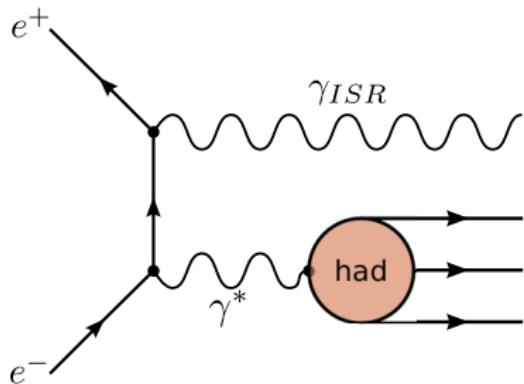


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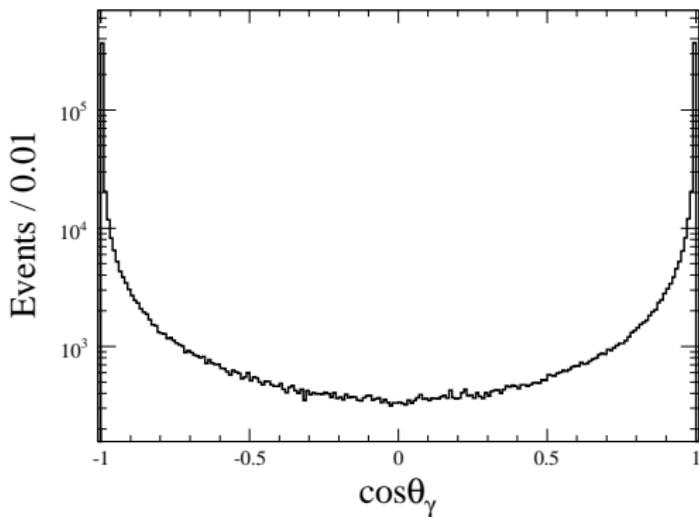
Radiator Function

- Emission of ISR photons is suppressed by α/π
- High integrated luminosity needed for precision measurements
- $\sqrt{s'} = \sqrt{s - 2\sqrt{s}E_\gamma}$



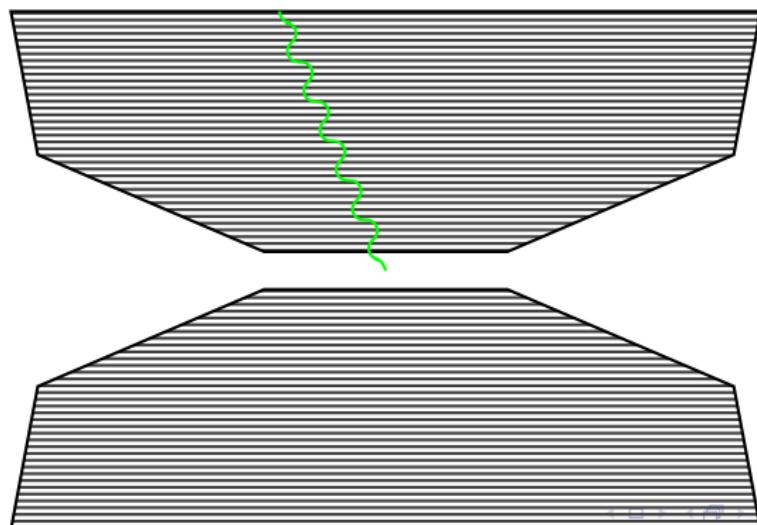
Strategy: tag and untag the γ_{ISR}

- Hadronic system should be detected
- Angular distribution of the γ_{ISR}



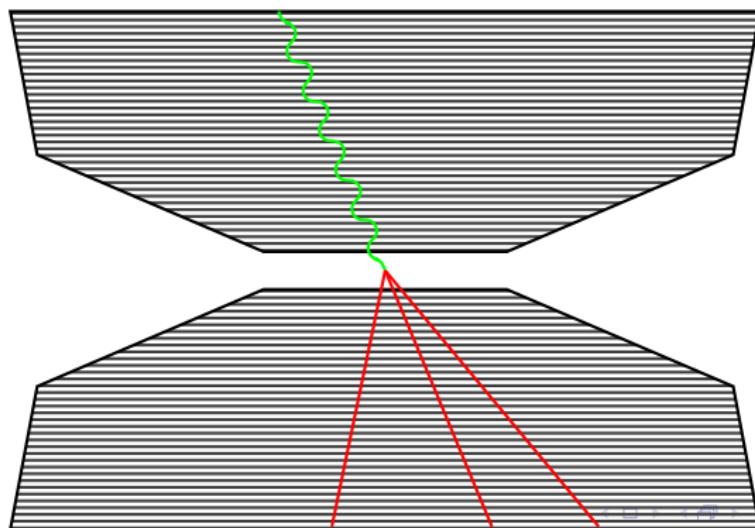
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- Hadronic system should be detected
- Angular distribution of the γ_{ISR}
 - tagged: Wide range, huge BG



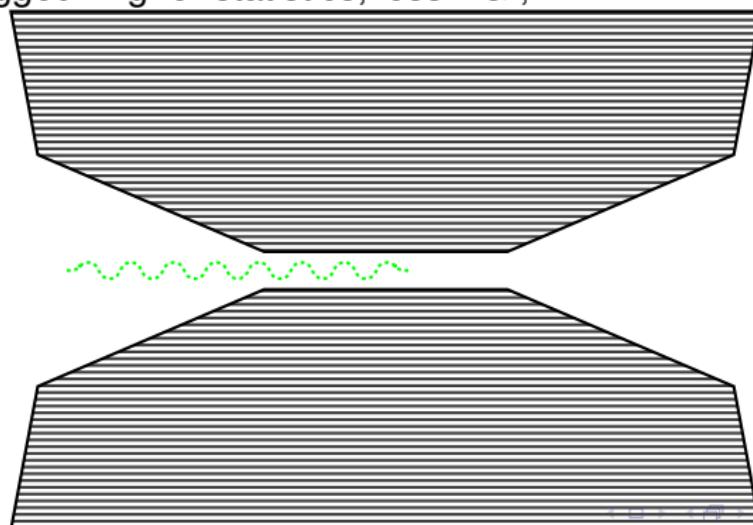
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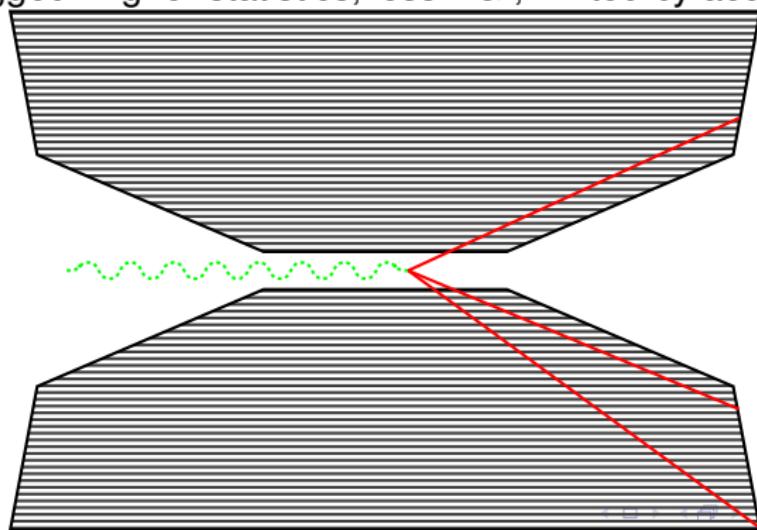
Strategy: tag and untag the γ_{ISR}

- Hadronic system should be detected
- Angular distribution of the γ_{ISR}
- untagged: higher statistics, less BG ,

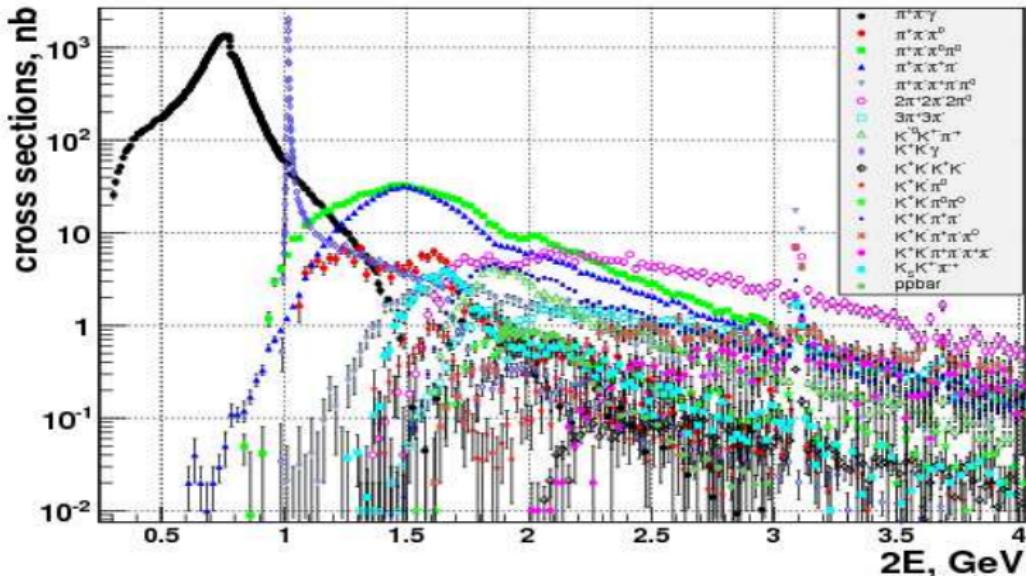


Strategy: tag and untag the γ_{ISR}

- Hadronic system should be detected
- Angular distribution of the γ_{ISR}
- untagged: higher statistics, less BG , limited by acceptance



Results from BaBar



D. Bernard [BaBar Collaboration], PoS Hadron **2013**, 126 (2013) [arXiv:1402.0618 [hep-ex]].

- Most important channels: $\pi^+\pi^-$, KK , $\pi^+\pi^-\pi^0$, $\pi^+\pi^-2\pi^0$
- Largest contribution to uncertainty: $\pi^+\pi^-$, $\pi^+\pi^-2\pi^0$, $KK\pi\pi$

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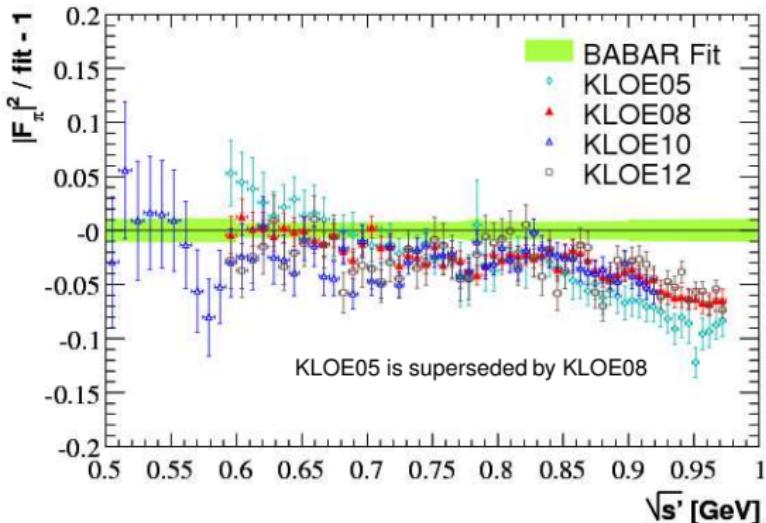
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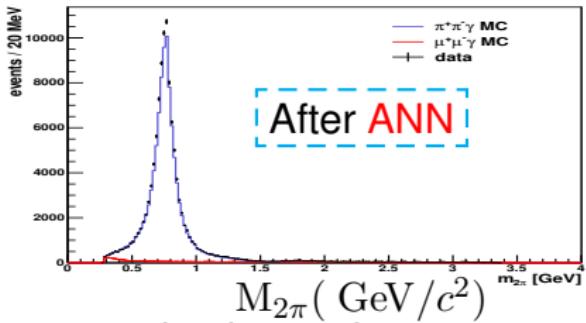
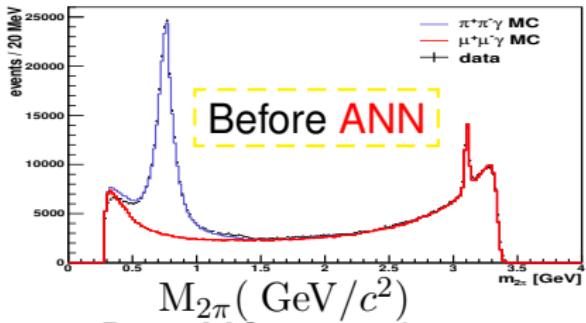
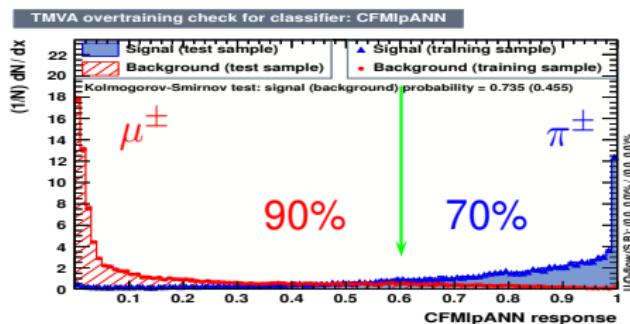
$\pi^+ \pi^-$ at BaBar and KLOE



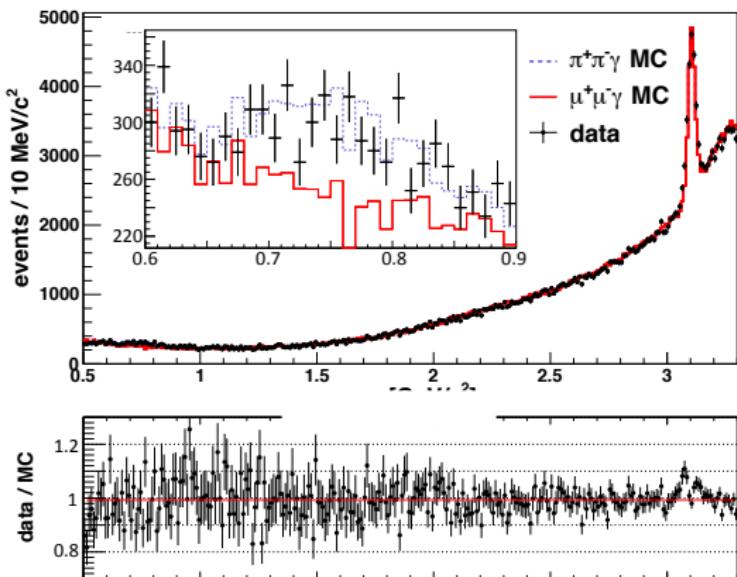
- Obvious discrepancy between BaBar and KLOE
- High precision measurement @ **BESIII**

Event Selections

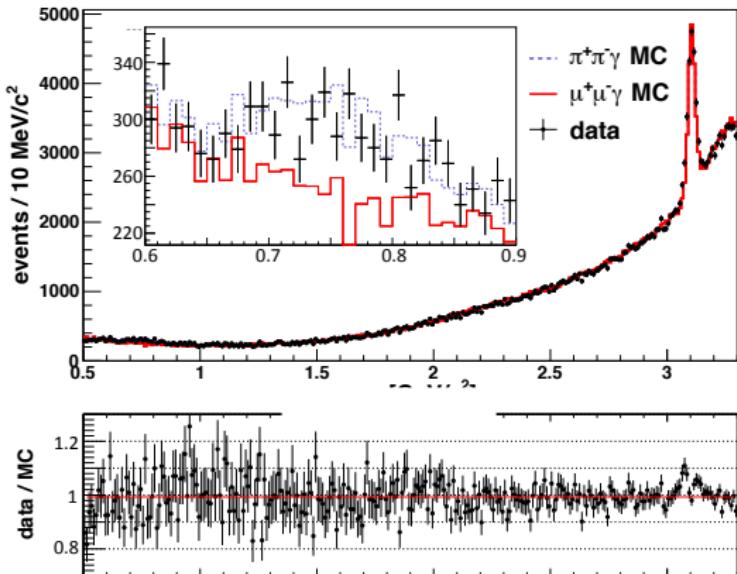
- Kinematic Fit for $\pi^+ \pi^- \gamma_{ISR}$
- MDC, TOF, and EMC for electron rejection
- Artificial Neuronal Network (ANN) for $\mu - \pi$ separation



- Data-MC corrections vs. momentum and polar angle

QED test $e^+e^- \rightarrow \mu^+\mu^-\gamma$ 

$$M_{\mu^+\mu^-} (\text{GeV}/c^2)$$

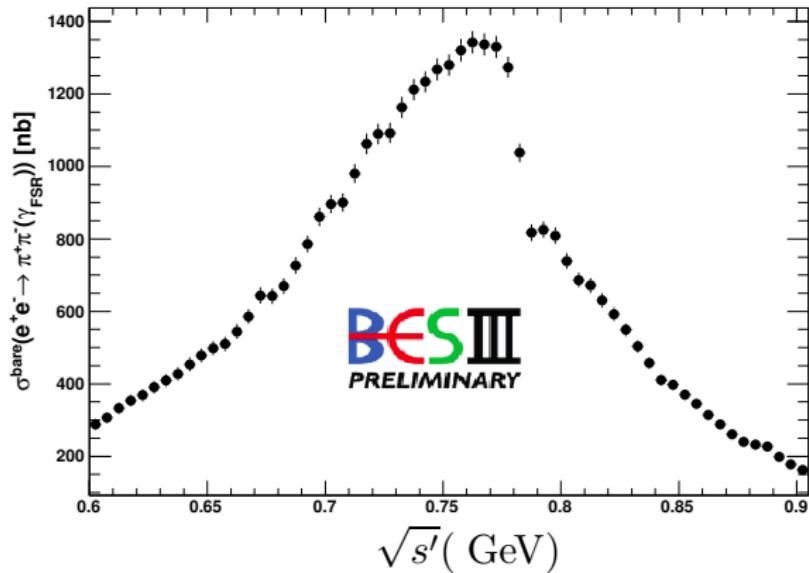
QED test $e^+e^- \rightarrow \mu^+\mu^-\gamma$  $M_{\mu^+\mu^-} \text{ (GeV}/c^2)$ $\chi^2/\text{ndf} = 134/139$
 $(1.0 \pm 0.3 \pm 0.9)\%$

Systematic Uncertainties

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 δ_{FSR}	0.2
Vacuum polarization correction δ_{vac}	0.2
Radiator function	0.5
Luminosity \mathcal{L}	0.5
Sum	0.9

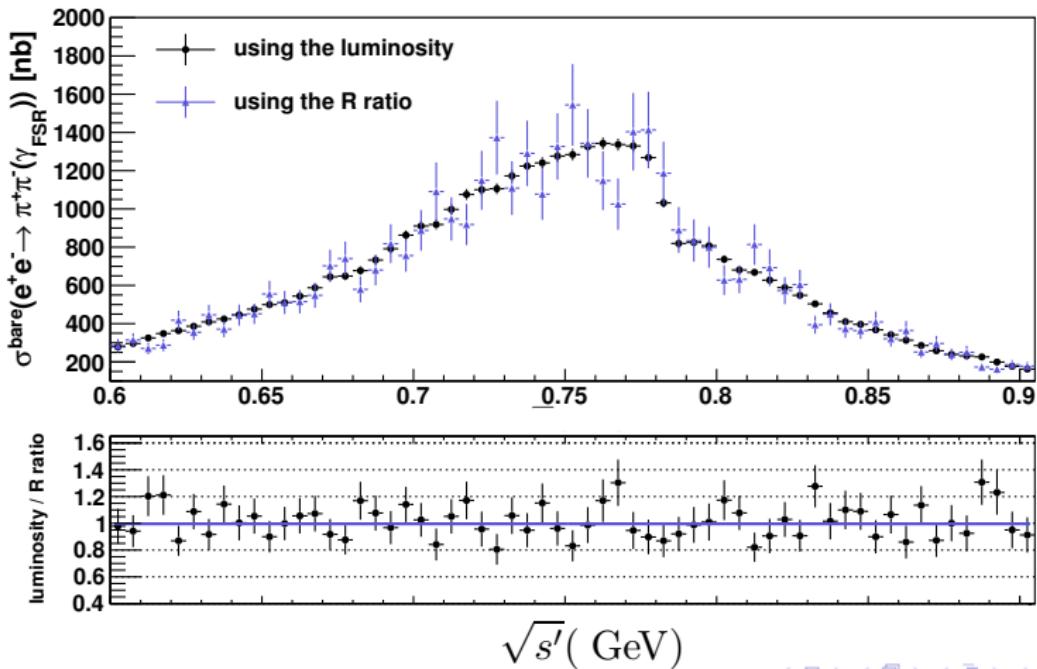
$\pi^+ \pi^-$ Cross Section

- $\sigma_{\pi\pi(\gamma_{\text{FSR}})}^{\text{bare}} = \frac{N_{\pi\pi\gamma} \cdot (1 + \delta_{\text{FSR}}^{\pi\pi})}{\mathcal{L} \cdot \epsilon_{\text{global}}^{\pi\pi\gamma} \cdot H(s) \cdot \delta_{\text{vac}}}$
- ρ - ω interference clearly visible



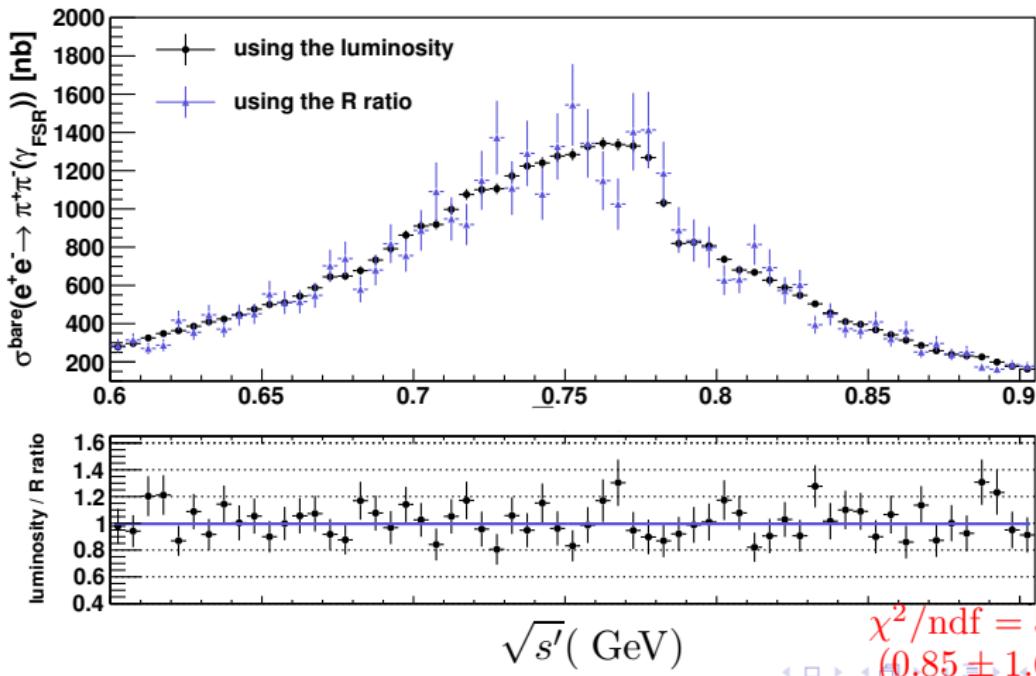
Comparison Normalized by $\sigma_{\mu^+\mu^-}$

- $\sigma_{\pi\pi(\gamma_{\text{FSR}})}^{\text{bare}} = \frac{N_{\pi\pi\gamma}}{N_{\mu\mu\gamma}} \cdot \frac{\epsilon_{\text{global}}^{\mu\mu\gamma}}{\epsilon_{\text{global}}^{\pi\pi\gamma}} \cdot \frac{1 + \delta_{\text{FSR}}^{\mu\mu}}{1 + \delta_{\text{FSR}}^{\pi\pi}} \cdot \sigma_{\mu^+\mu^-}^{\text{bare}}$

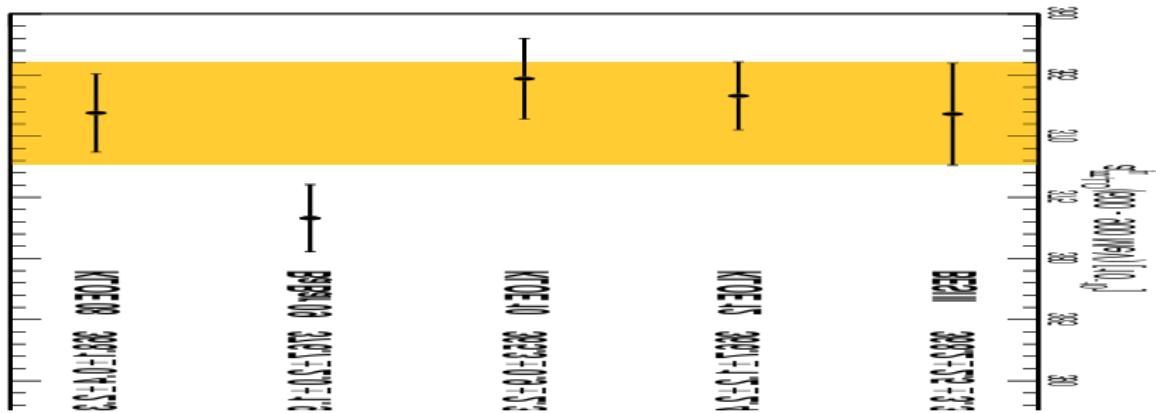


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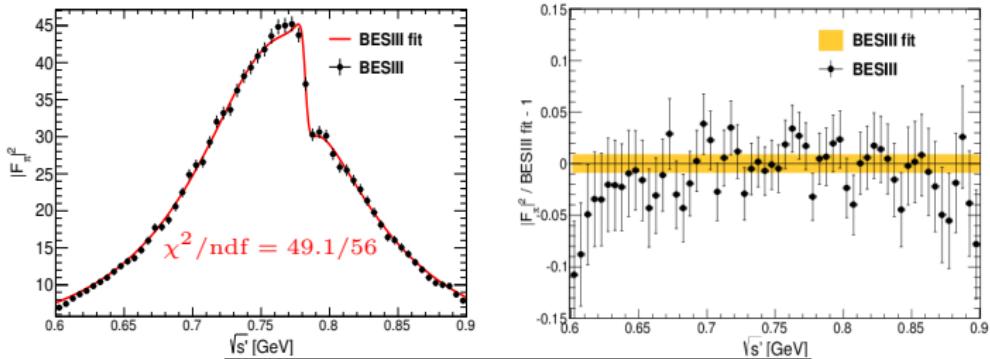
Contribution to $a_\mu^{\text{VP,LO}}$



- $a_\mu^{\pi\pi, \text{LO}}(600 - 900 \text{ MeV}) = (370.0 \pm 2.5_{\text{stat}} \pm 3.3_{\text{sys}}) \cdot 10^{-10}$
- Precision competitive with previous measurements
- BESIII measurement between BaBar and KLOE
- Confirmed deviation between experiment and theory
- arXiv:1507.08188 and submitted to PLB

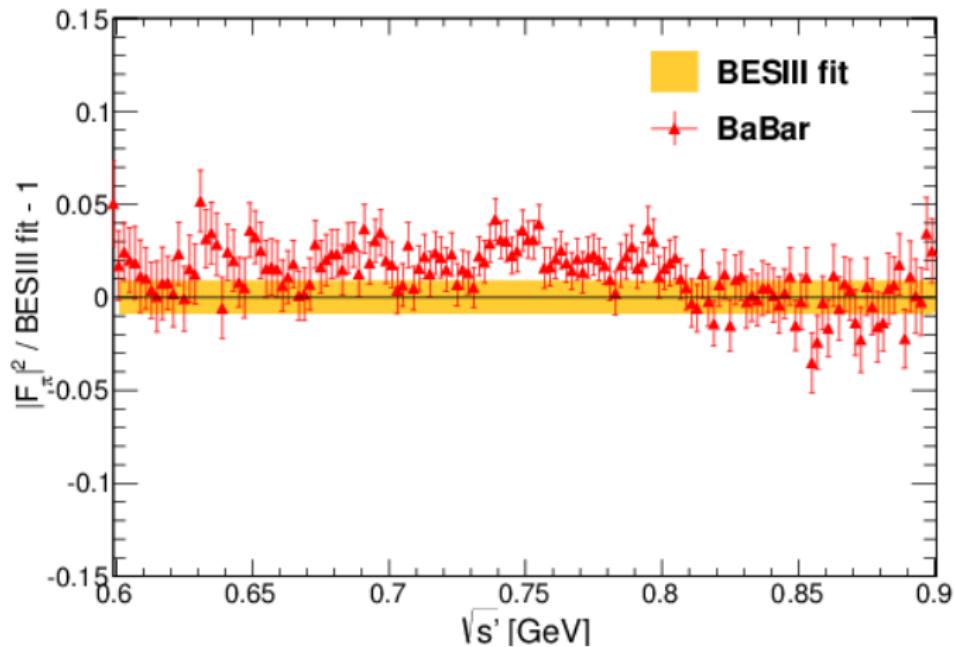
$\pi^+ \pi^-$ Form Factor (Gounaris-Sakurai Parameterization)

- Issue with extraction of $|F_\pi|^2$ from cross section measurement
- Updated $|F_\pi|^2$ with respect to arXiv:1507.08188

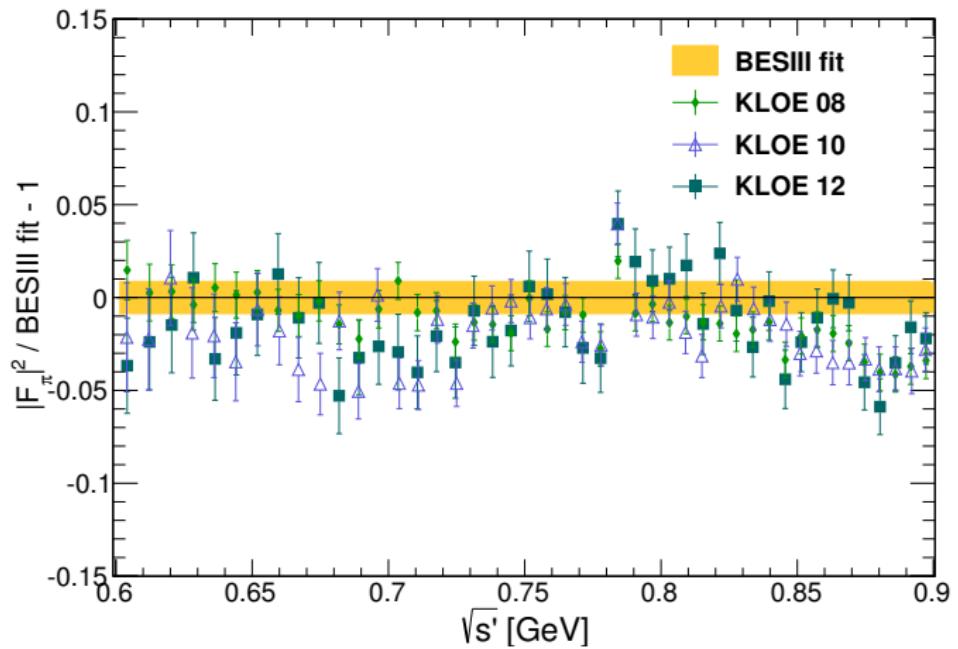


Parameter	BESIII value	PDG 2014	
m_ρ [MeV/ c^2]	776.0 ± 0.4	775.26 ± 0.25	
Γ_ρ [MeV]	151.7 ± 0.7	147.8 ± 0.9	2.9σ
m_ω [MeV/ c^2]	782.2 ± 0.6	782.65 ± 0.12	
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08	
$ c_\omega $ [10^{-3}]	1.7 ± 0.2	-	
$ \phi_\omega $ [rad]	0.04 ± 0.13	-	

Comparison with BaBar



Comparison with KLOE



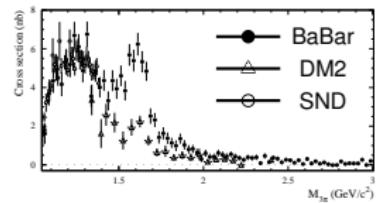
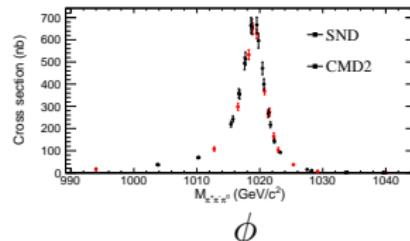
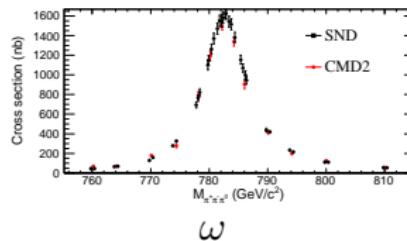
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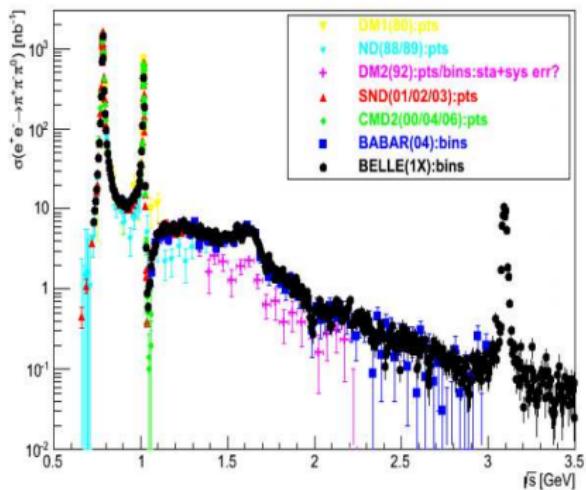
$$e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$$

- History of σ for $e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$:

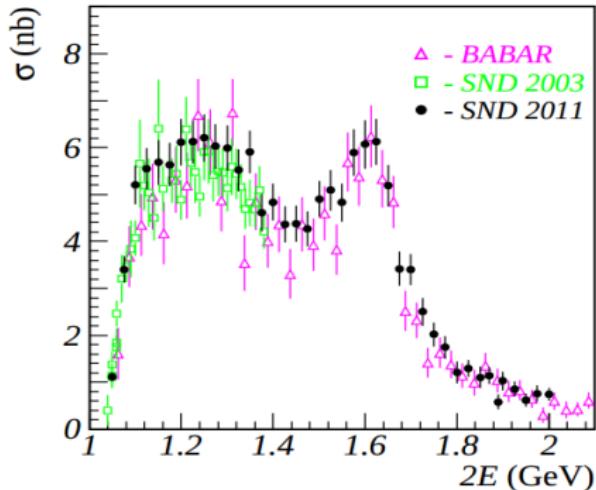
- $\sqrt{s} \lesssim 1$ GeV: $\omega(782)$ and $\phi(1020)$
- Published results above ϕ :
 - SND : up to 1.4 GeV
 - DM2 : 1.34 \sim 2.40 GeV
 - BaBar : 1.05 \sim 3.00 GeV



Belle and SND

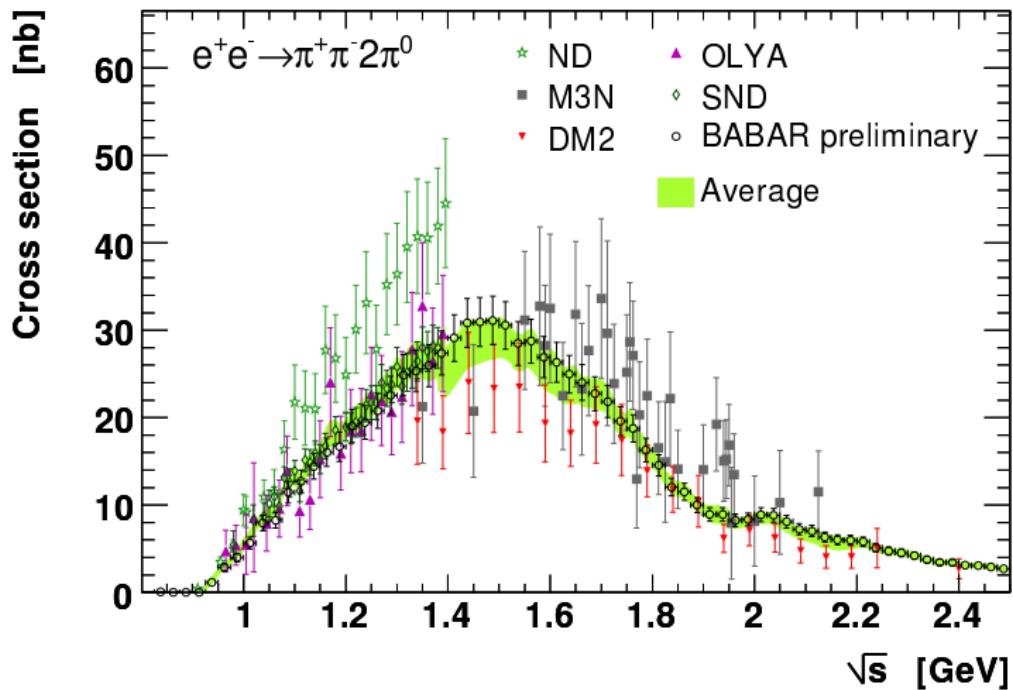


$e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\pi^0$ from Belle



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

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



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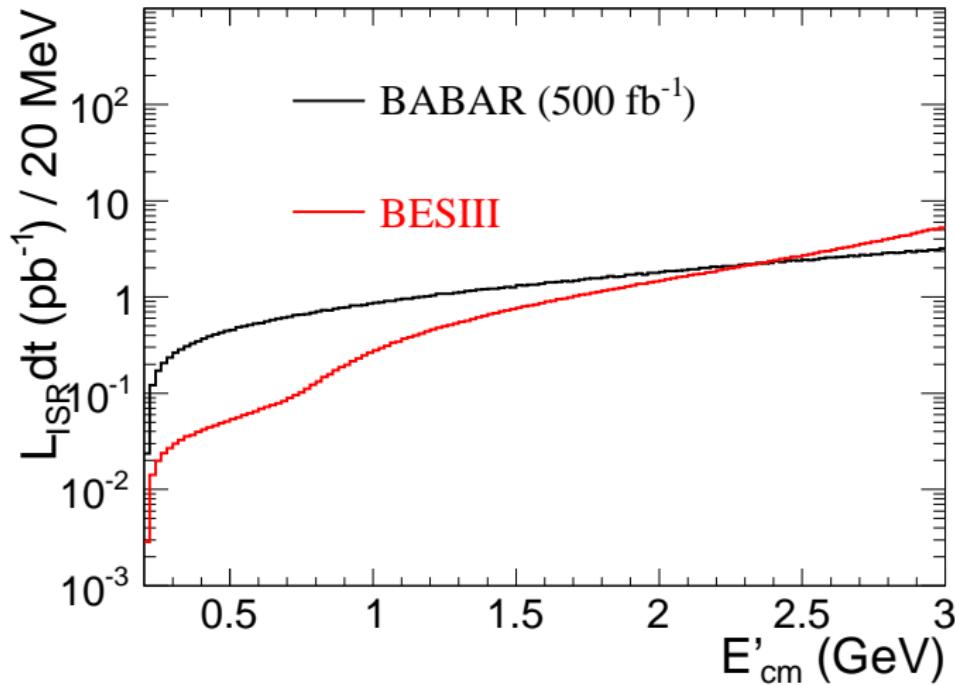
- $e^+e^- \rightarrow \pi^+\pi^-$
 - Cross section is measured at BESIII with sys. below 1%
 - Δa_μ is confirmed
- $e^+e^- \rightarrow \pi^+\pi^-\pi^0(\pi^0)$
 - Ongoing study at BESIII
 - Benefit from both tagged and untagged
- Outlook
 - Extend tagged $\pi^+\pi^-$ ISR study to threshold region
 - Untagged ISR for $\pi^+\pi^-$ cross section at higher mass range
 - Analyze $\pi^+\pi^-$ form factor from R-scan data
(130 points, $\mathcal{L} \approx 1.3\text{fb}^{-1}$)

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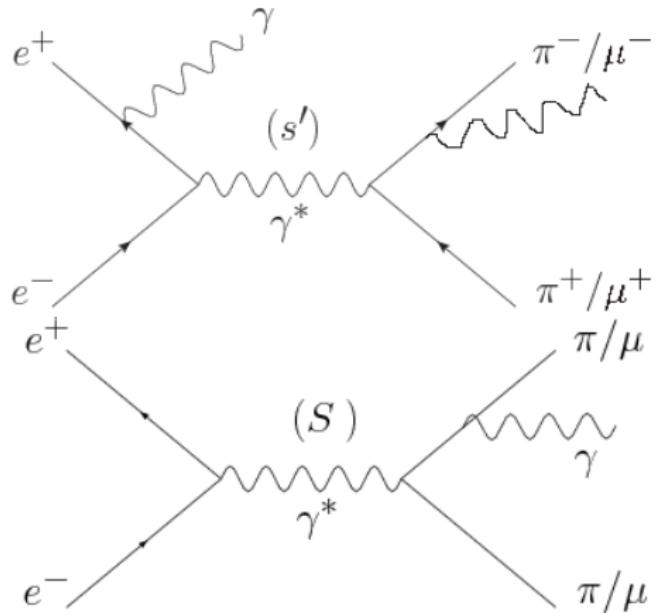
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Thank you!

Effective Luminosity



FSR Correction



Theoretical calculation of a_μ

$$a_\mu^{theo} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{QCD}}$$

$$a_\mu^{\text{QED}} = (116584718.104 \pm 0.148) \times 10^{-11}$$

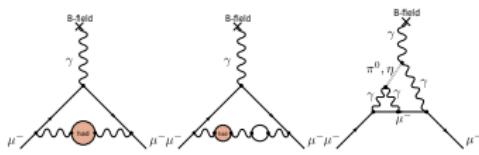
$$a_\mu^{\text{weak}} = (153.2 \pm 1.0 \pm 1.5) \times 10^{-11}$$

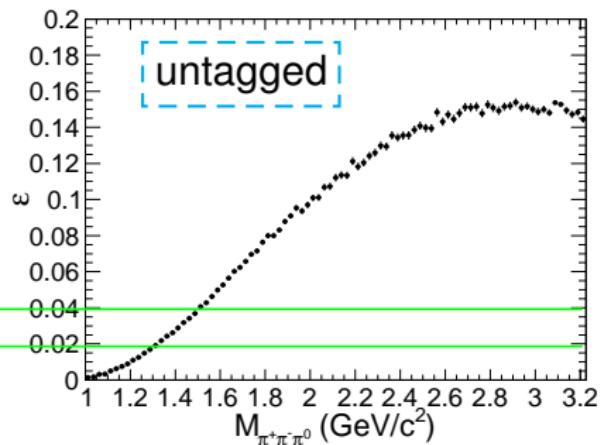
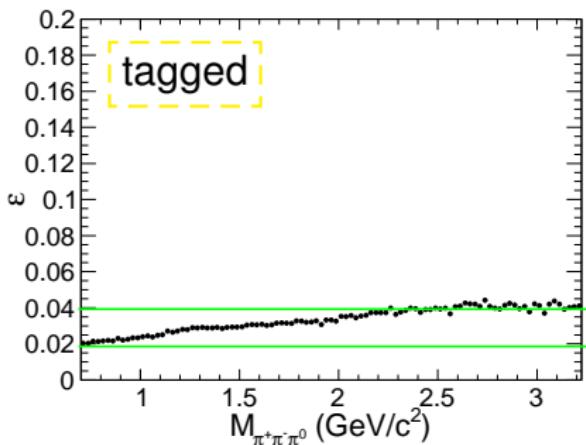
$$a_\mu^{\text{QCD}} = a_\mu^{\text{LbL}} + a_\mu^{\text{VP,LO}} + a_\mu^{\text{VP,HO}}$$

$$a_\mu^{\text{VP,LO}} = (6949.1 \pm 42.7) \times 10^{-11}$$

$$a_\mu^{\text{VP,HO}} = (-97.9 \pm 0.9) \times 10^{-11}$$

$$a_\mu^{\text{LbL}} = (105 \pm 26) \times 10^{-11} \quad (\text{Glasgow consensus})$$



$e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\pi^0$ at BESIII


- Tagged is necessary in low mass range
- Untagged is more efficient in high mass range
- Both** tagged and untagged are feasible at **BESIII**. Our goal: < 5%