Pion Form Factor Measurement at BESIII via ISR

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(on behalf of the BESIII Colaboration)

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International Conference on Precision Physics and Fundamental Physical Constants
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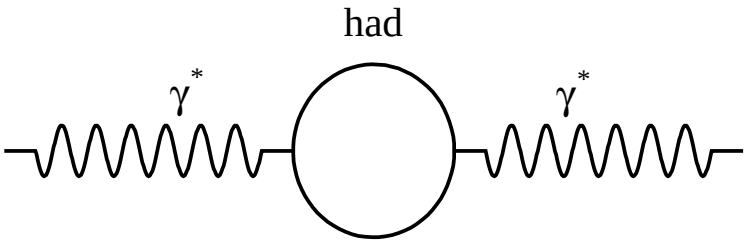
Budapest, Hungary

Outline

Outline

Hadronic VP and muon $g-2$

- Hadronic vacuum polarization



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

γ and leptonic

Z, $W^\pm$, and Higgs

$$a_\mu^{\rm had,LO} = \frac{\alpha^2(0)}{3\pi^2}\int_{4m_\pi^2}^{\infty} {\rm d}s \frac{K(s)}{s} R(s)$$

Hadronic VP and muon $g-2$

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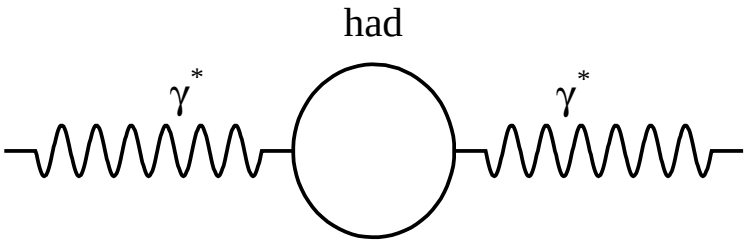

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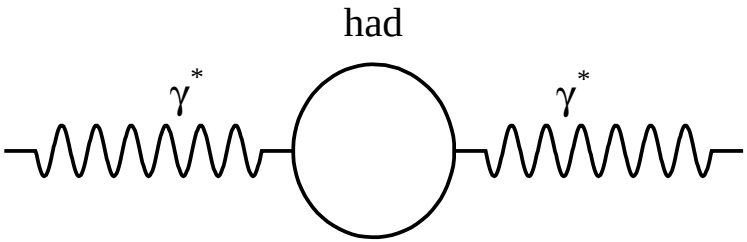
γ and leptonic

Z, $W^\pm$, and Higgs

$$a_\mu^{\rm had,LO} = \frac{\alpha^2(0)}{3\pi^2}\int_{4m_\pi^2}^{\infty} {\rm d}s \frac{K(s)}{s} R(s) \longrightarrow \frac{\sigma(e^+e^-\to {\rm hadrons})}{\sigma(e^+e^-\to \mu^+\mu^-)}$$

Hadronic VP and muon $g-2$

- Hadronic vacuum polarization



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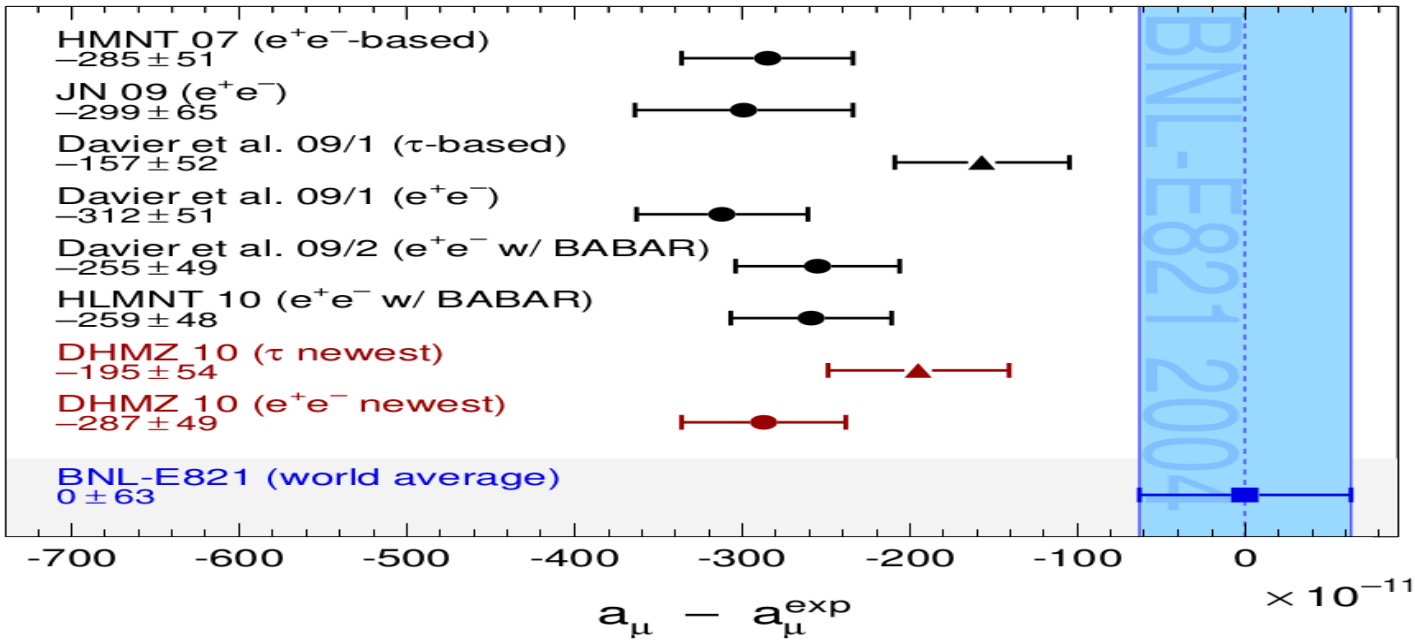
$$a_\mu^{\rm had,LO} = \frac{\alpha^2(0)}{3\pi^2}\int_{4m_\pi^2}^{\infty} {\rm d}s \frac{K(s)}{s} R(s)$$

$$R(s) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

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

$g-2$

- $a_\mu = (g_\mu - 2)/2$
- $a_\mu^{\text{expe}} = 116592080 \pm 54 \pm 33 \times 10^{-11}$ at BNL
- $a_\mu^{\text{theo}} = 116591802 \pm 42 \pm 26 \times 10^{-11}$
- $a_\mu^{\text{expe}} - a_\mu^{\text{theo}} = (28.7 \pm 80) \times 10^{-11} \quad \Rightarrow 3.6\sigma$ deviation



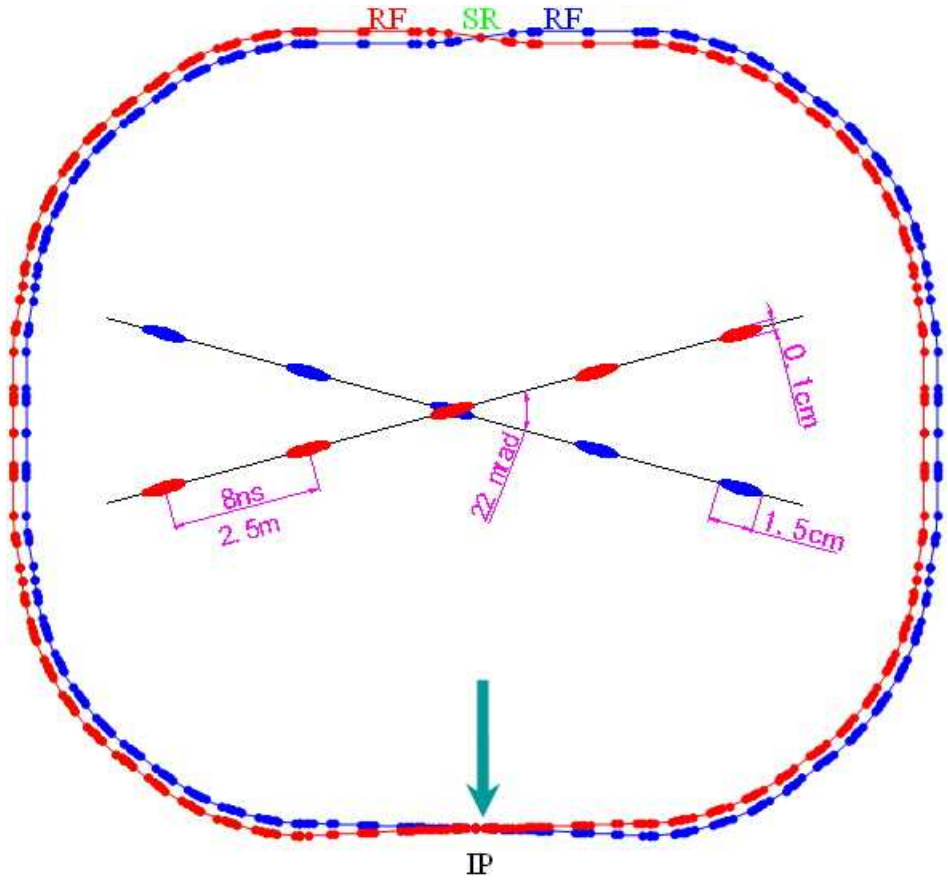
M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C **71** 1515 (2011)

Outline

BESIII Collaboration

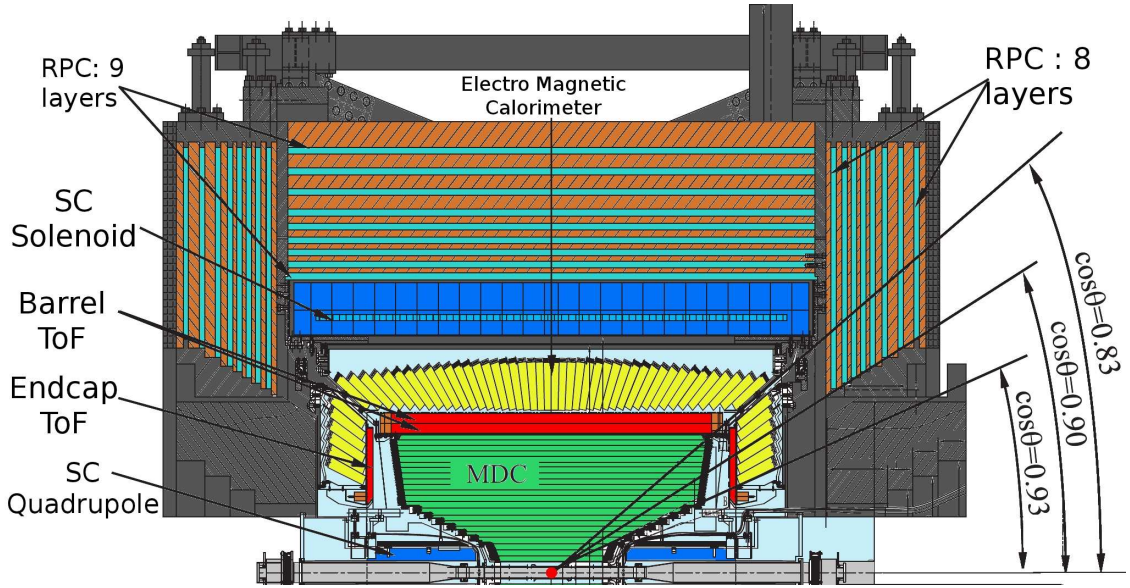
BEPCII

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

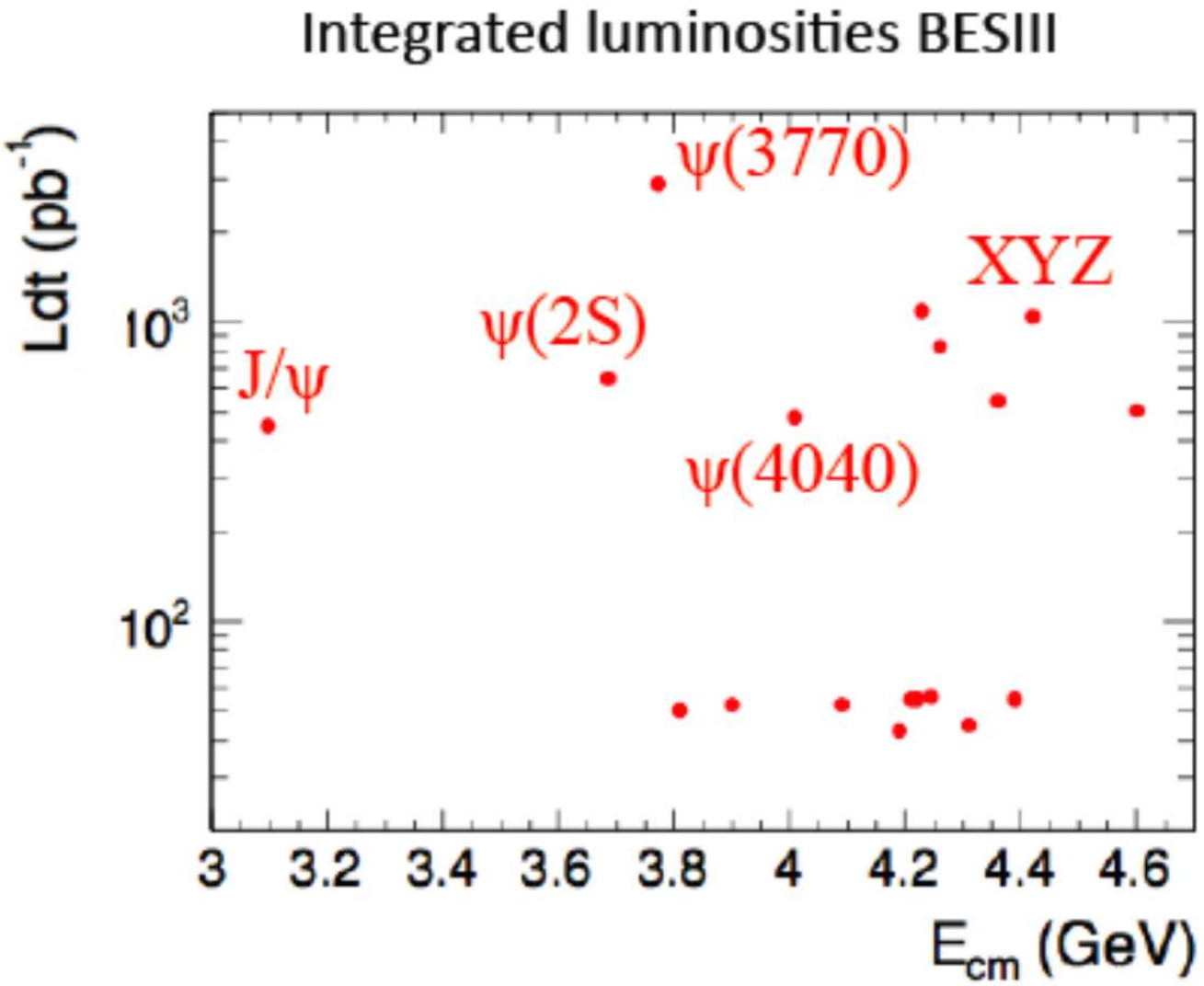


BESIII Detector

- Multilayer Drift Chamber
- Time of Flight system
- EM Calorimeter
- 1 Tesla Magnet
- Muon Chamber



Data samples



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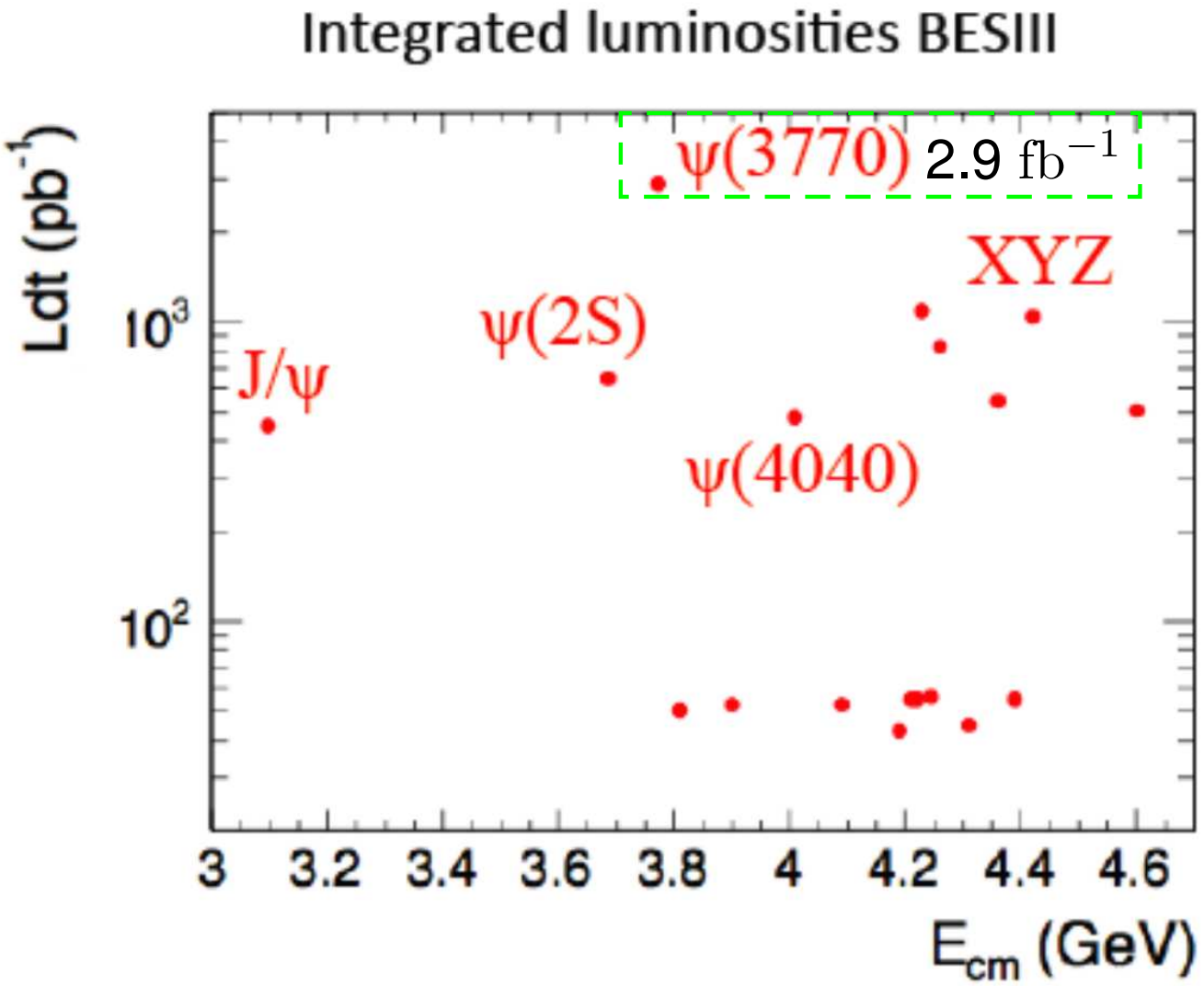
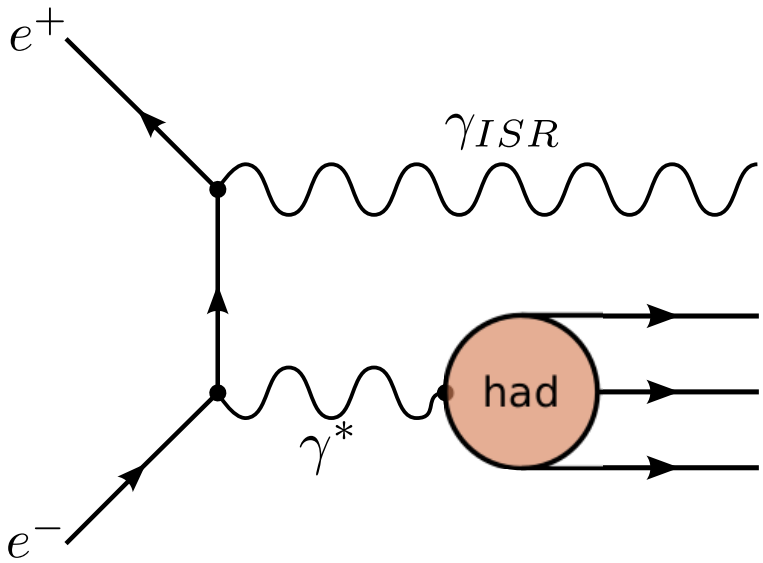
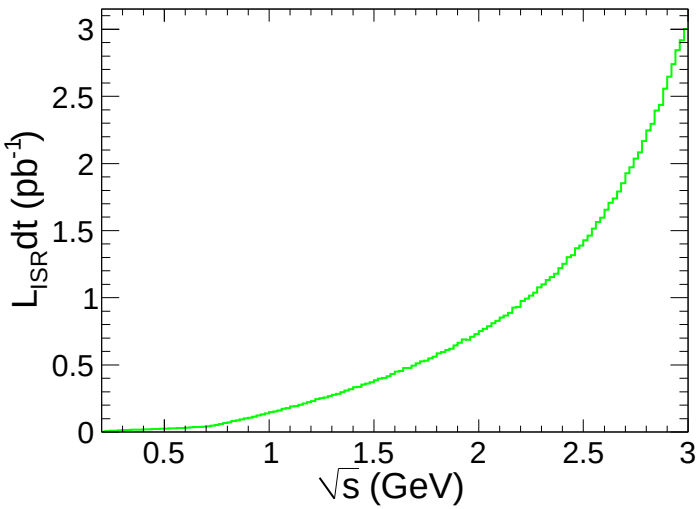


Outline

Radiator Function

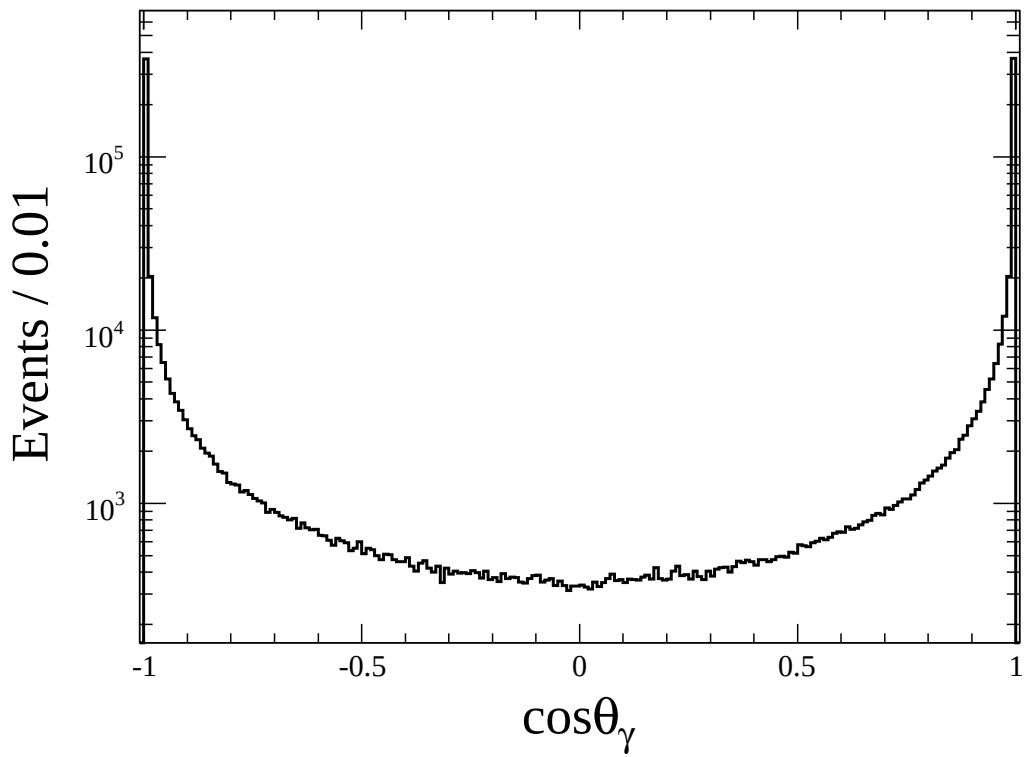
- Emission of ISR photons is suppressed by α/π
- High integrated luminosity needed for precision measurements
- $\sqrt{s'} = \sqrt{s - 2\sqrt{s}E_\gamma}$





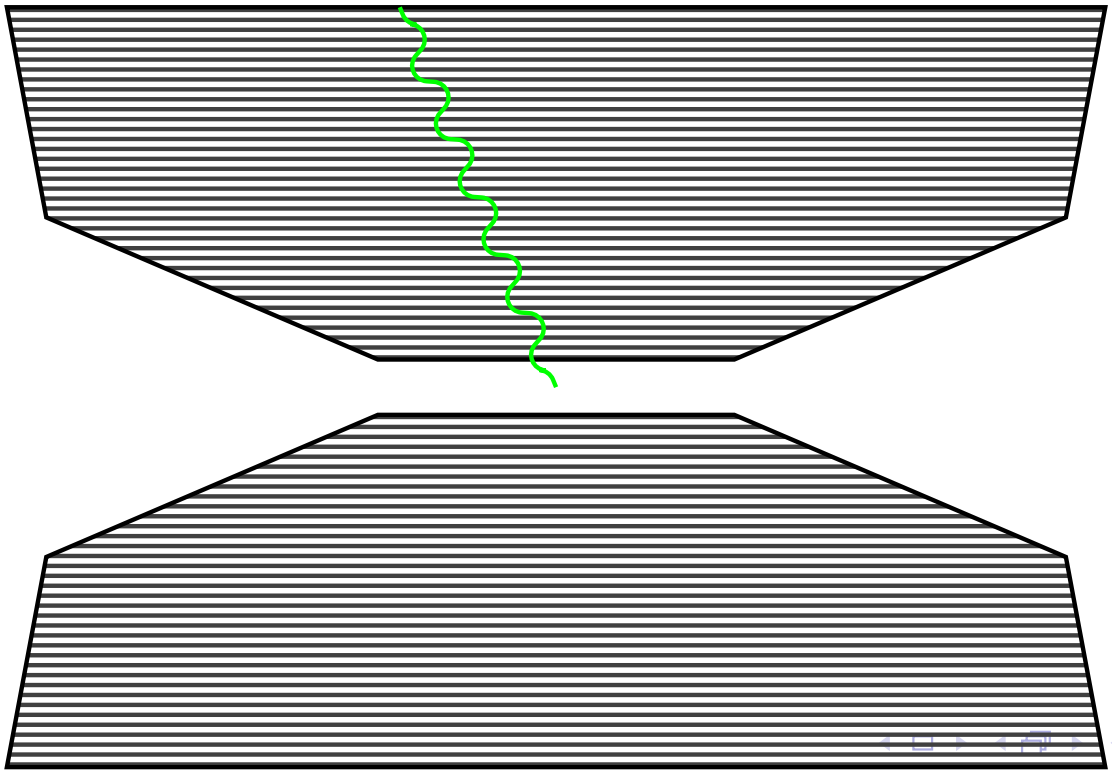
Strategy: tag and untag the γ_{ISR}

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



Strategy: tag and untag the γ_{ISR}

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



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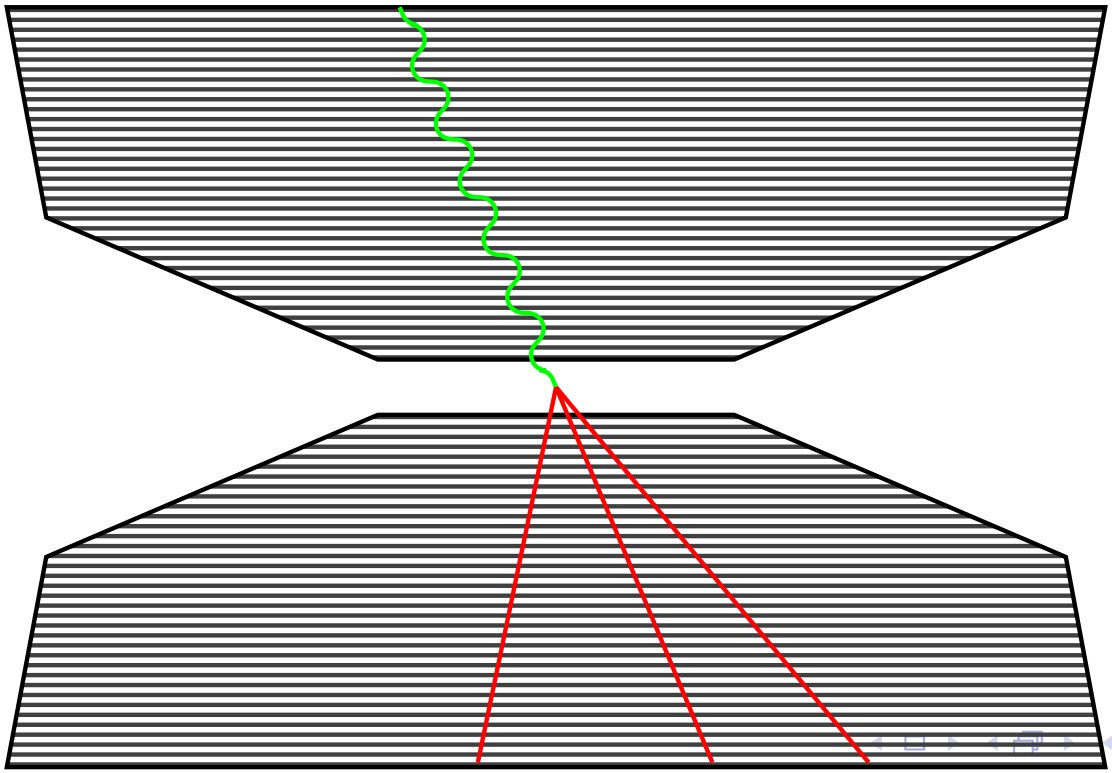

Strategy: tag and untag the γ_{ISR}

- Hadronic system should be detected
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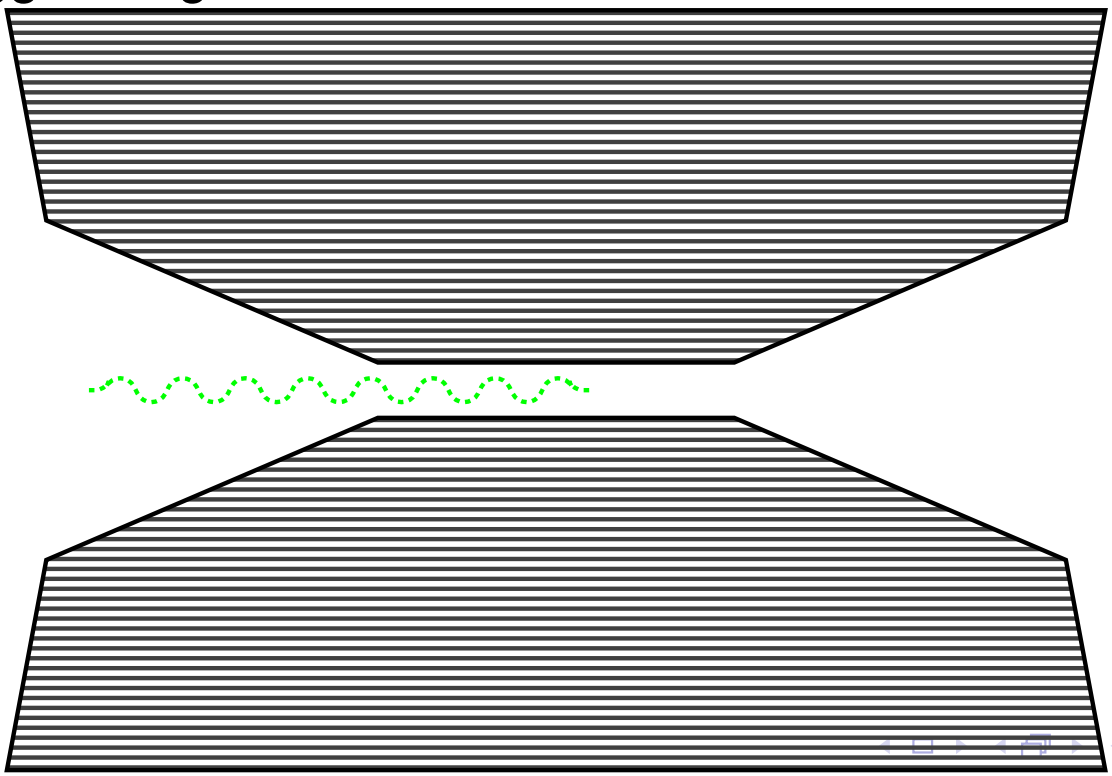
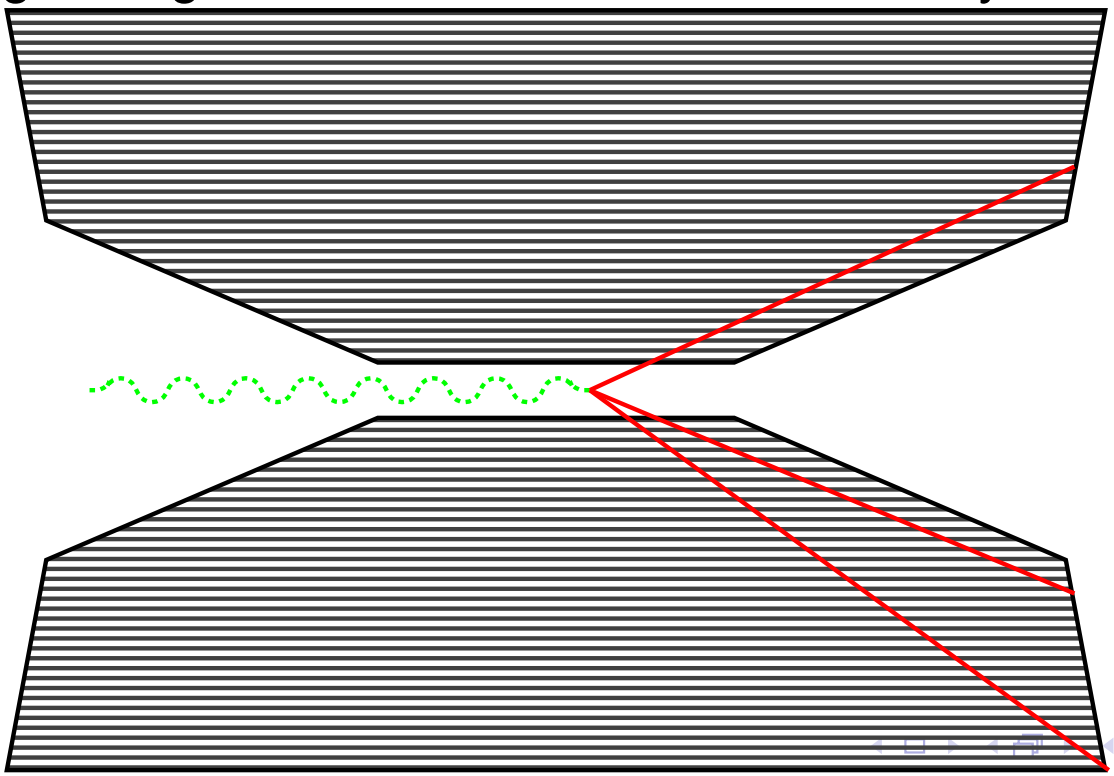
  - untagged: higher statistics, less BG ,

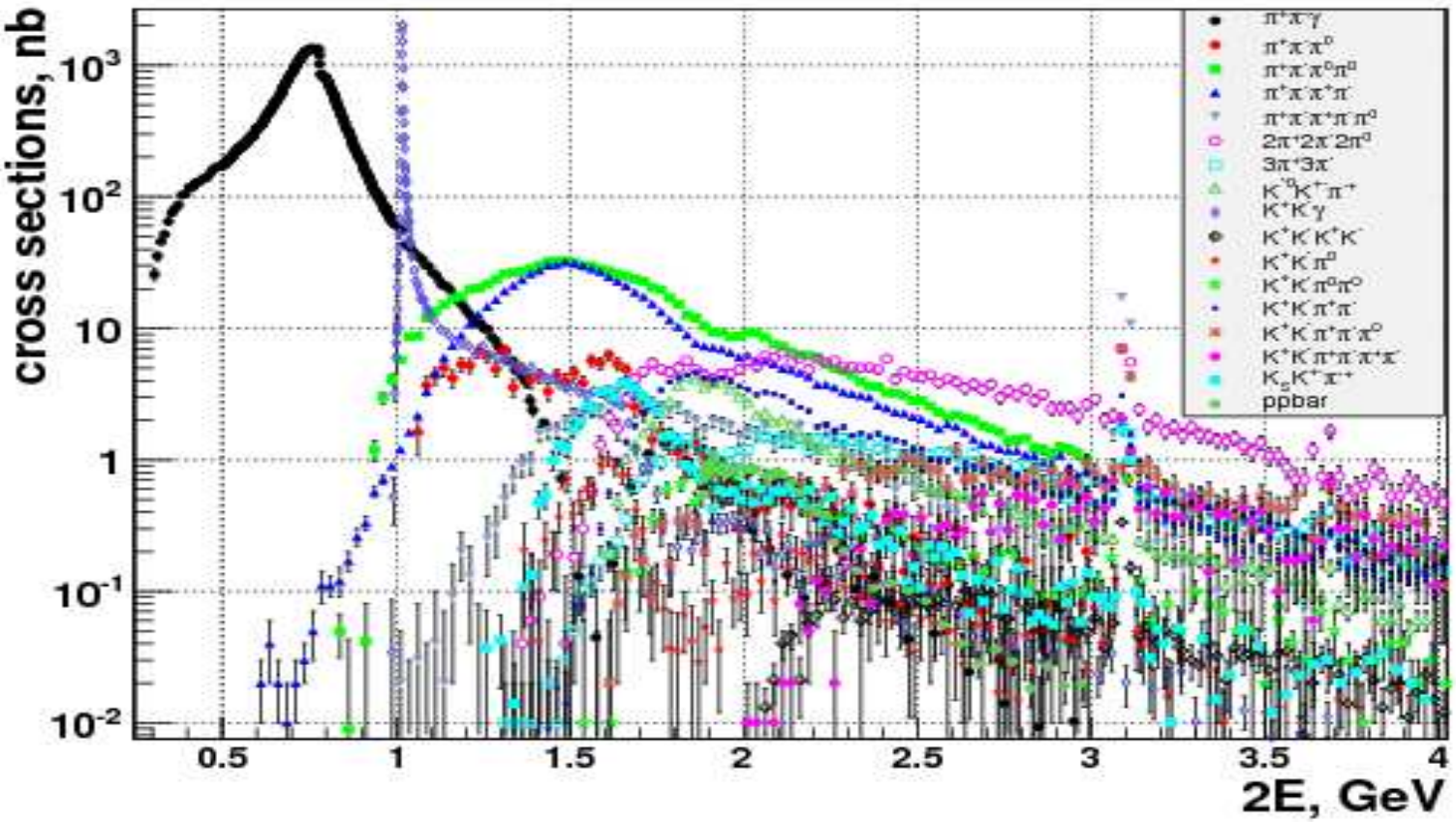


Strategy: tag and untag the γ_{ISR}

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



Results from BaBar

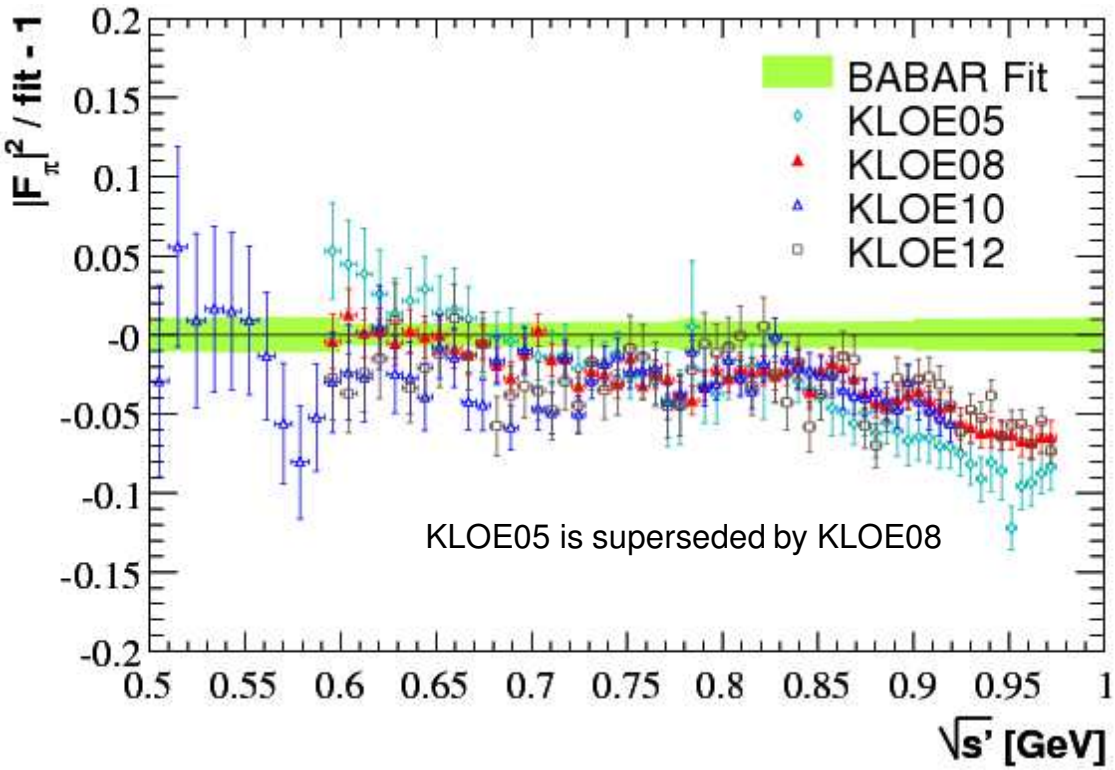


D. Bernard [BaBar Collaboration], PoS Hadron **2013**, 126 (2013) [arXiv:1402.0618 [hep-ex]].

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

Outline

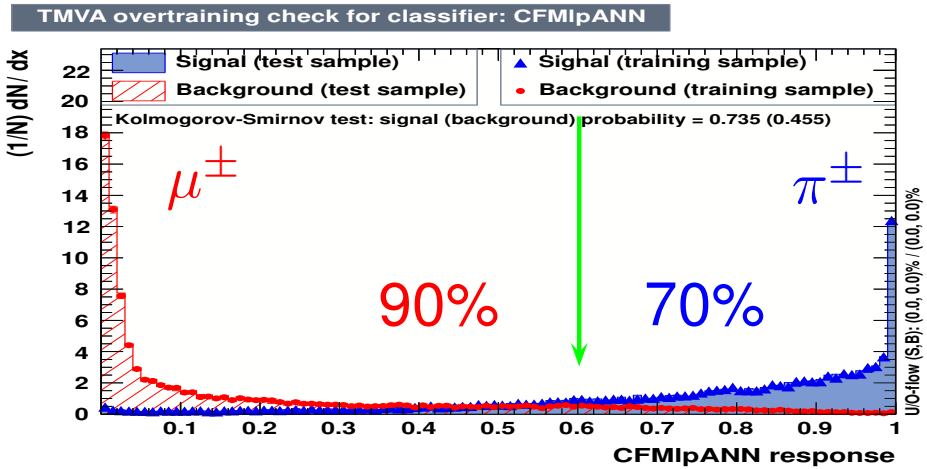
$\pi^+\pi^-$ at BaBar and KLOE

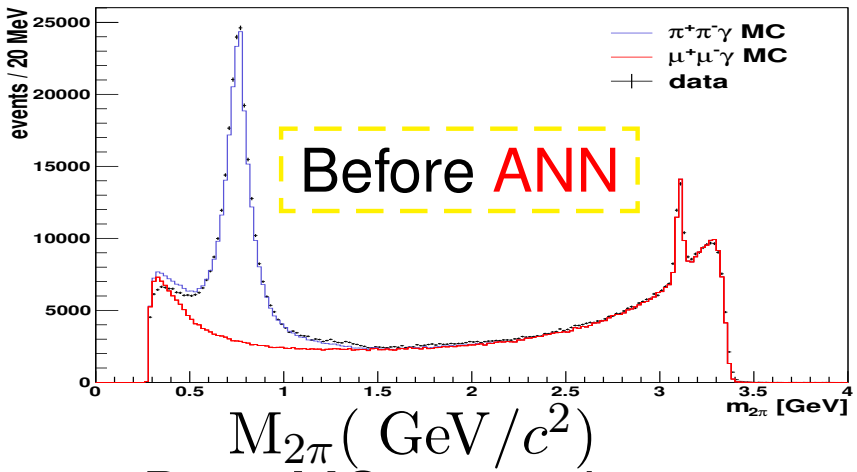


- Obvious discrepancy between BaBar and KLOE
- High precision measurement @ BESIII

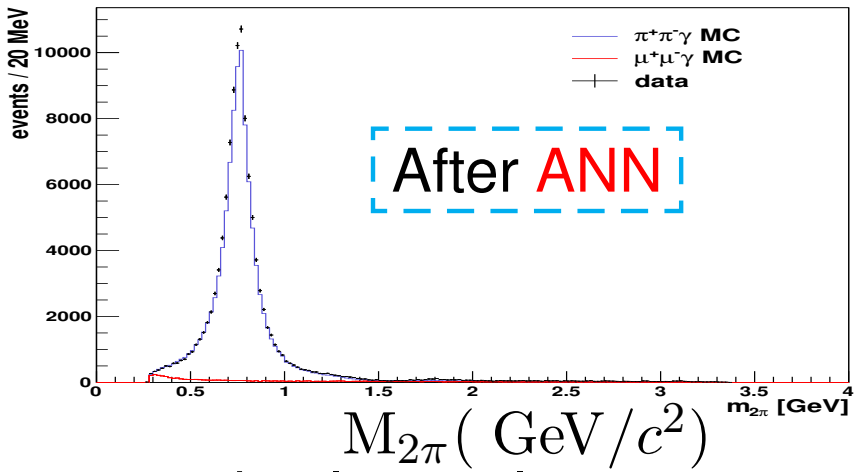
Event Selection and Particle Identification

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





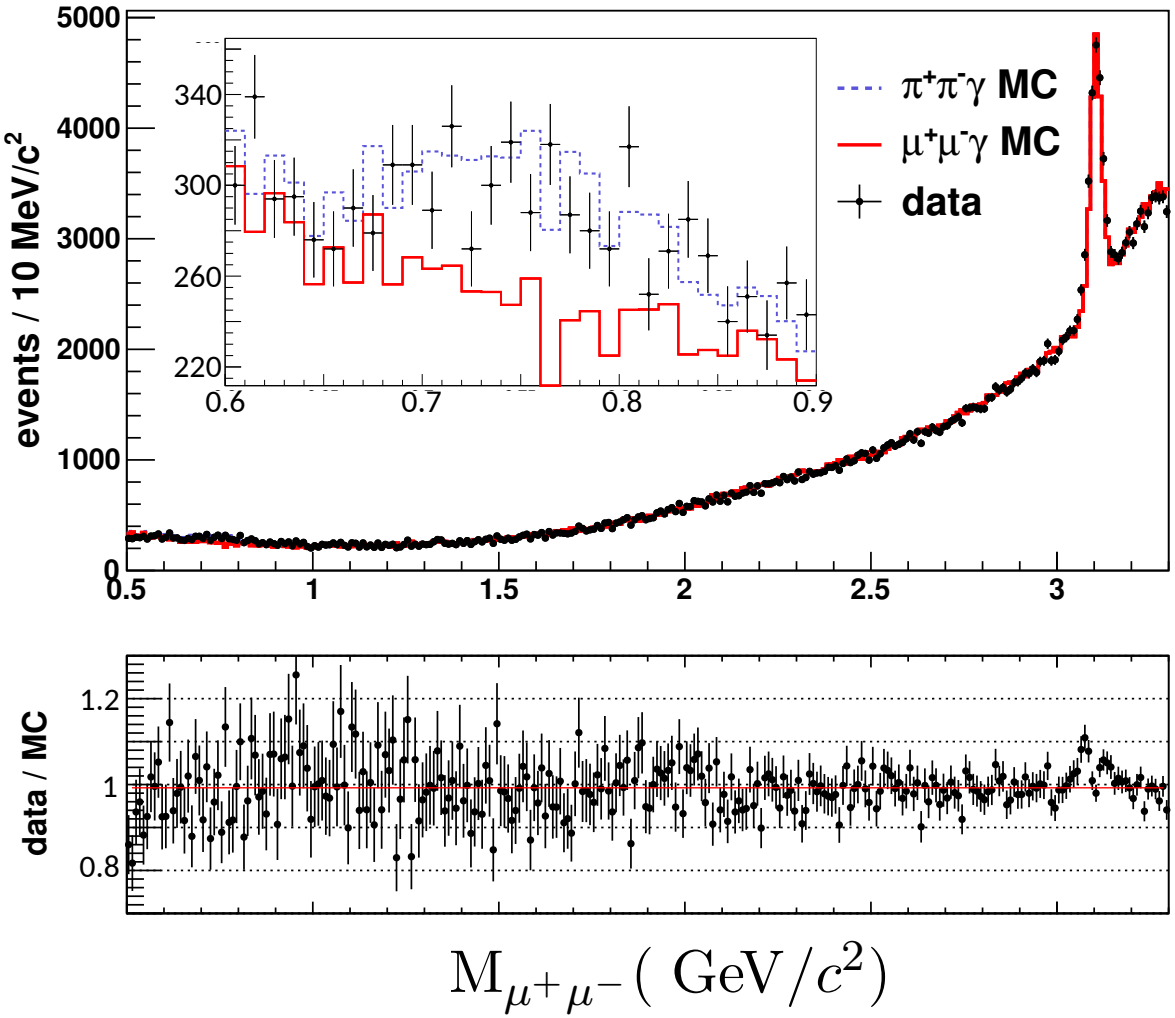
$M_{2\pi}(\ \mathrm{GeV}/c^2)$



$M_{2\pi}(\ \mathrm{GeV}/c^2)$

- Data-MC corrections vs. momentum and polar angle

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



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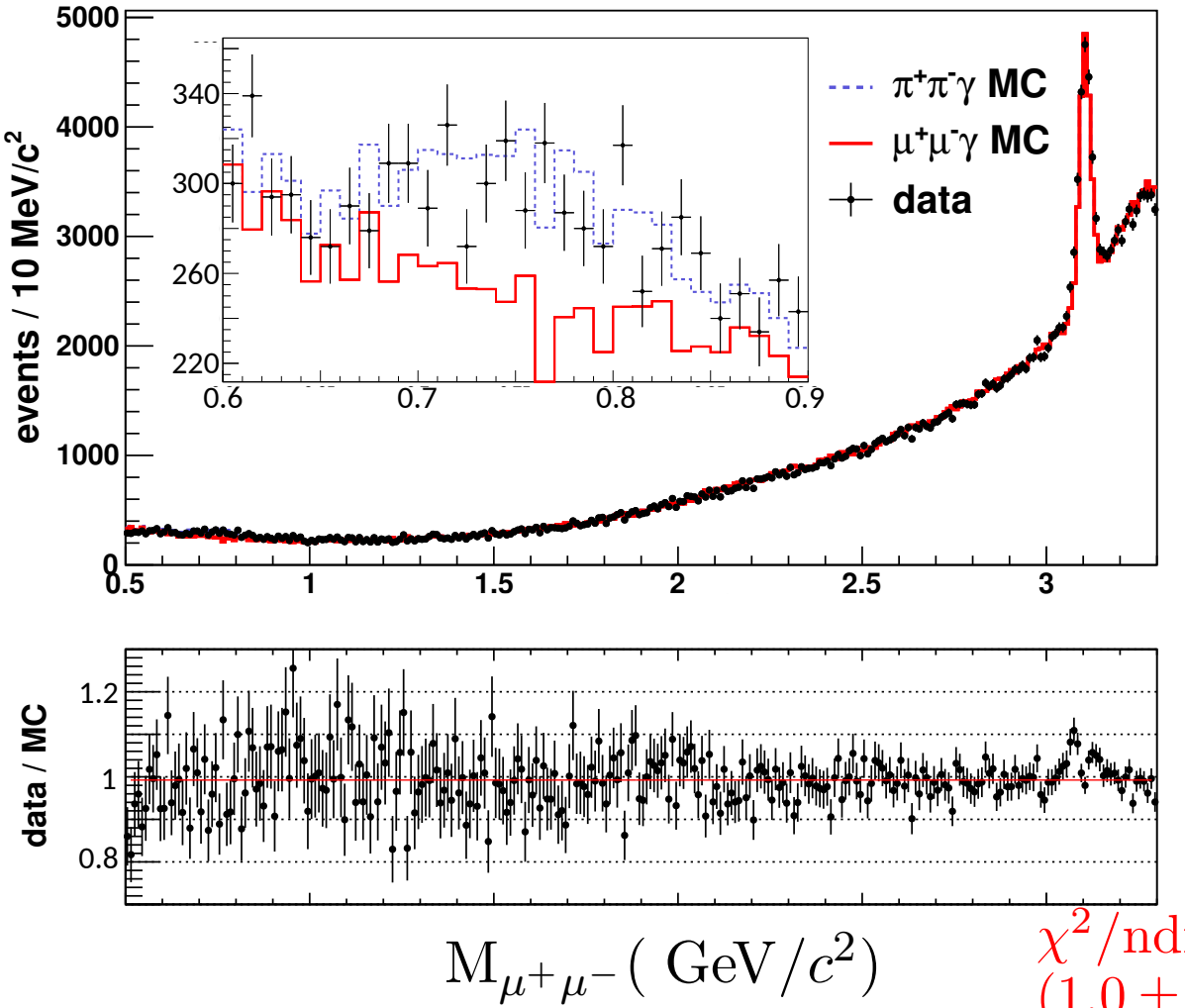


$\chi^2/\mathrm{ndf} = 134/139$

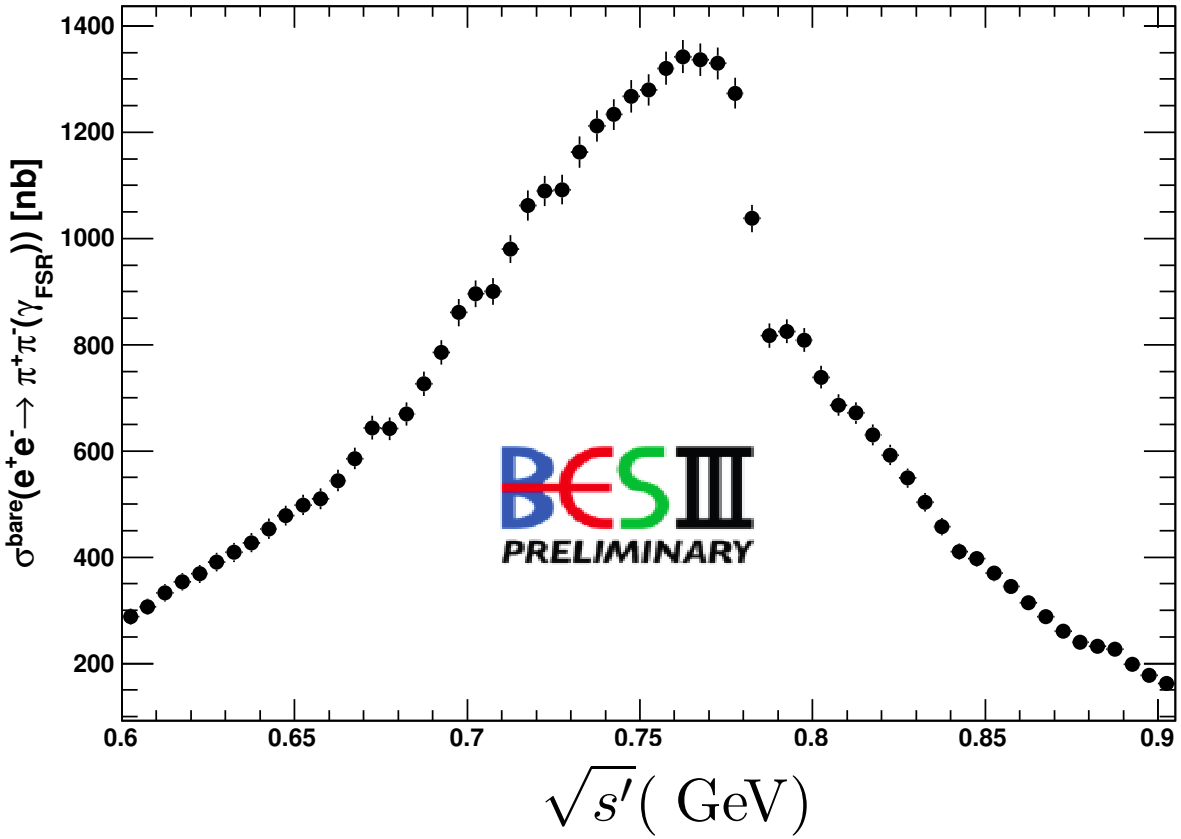
$(1.0 \pm 0.3 \pm 0.9)\%$

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**

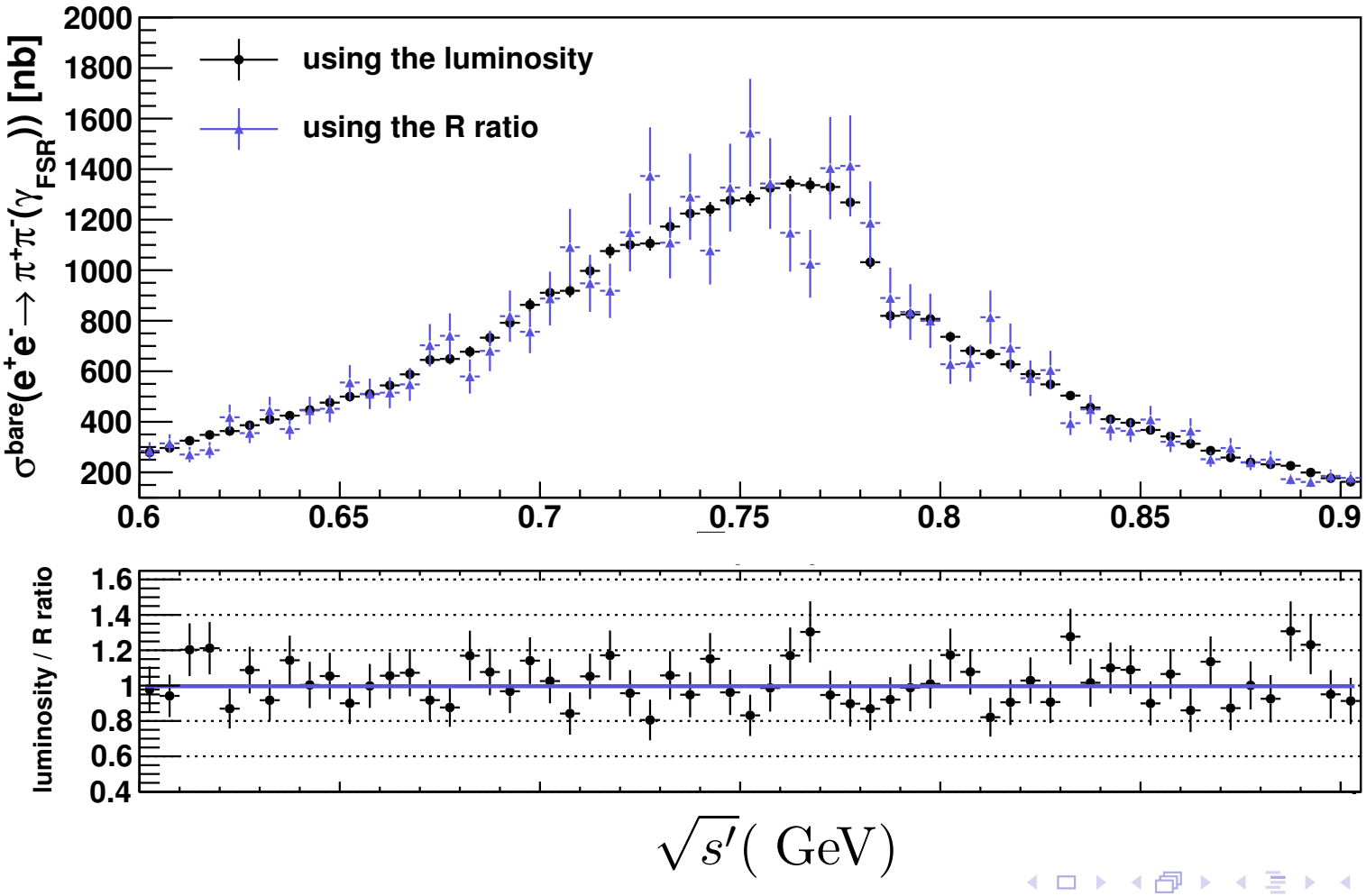
$\pi^+\pi^-$ Cross Section

- $\sigma^{\rm bare}_{\pi\pi(\gamma_{\rm FSR})} = \frac{N_{\pi\pi\gamma}\cdot(1+\delta^{\pi\pi}_{\rm FSR})}{\mathcal{L}\cdot\epsilon^{\pi\pi\gamma}_{\rm global}\cdot H(s)\cdot\delta_{\rm vac}}$
- ρ-ω interference clearly visible



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

- $\sigma^{\rm bare}_{\pi\pi(\gamma_{\rm FSR})} = \frac{N_{\pi\pi\gamma}}{N_{\mu\mu\gamma}} \cdot \frac{\epsilon^{\mu\mu\gamma}_{\rm global}}{\epsilon^{\pi\pi\gamma}_{\rm global}} \cdot \frac{1+\delta^{\mu\mu}_{\rm FSR}}{1+\delta^{\pi\pi}_{\rm FSR}} \cdot \sigma^{\rm bare}_{\mu\mu}$



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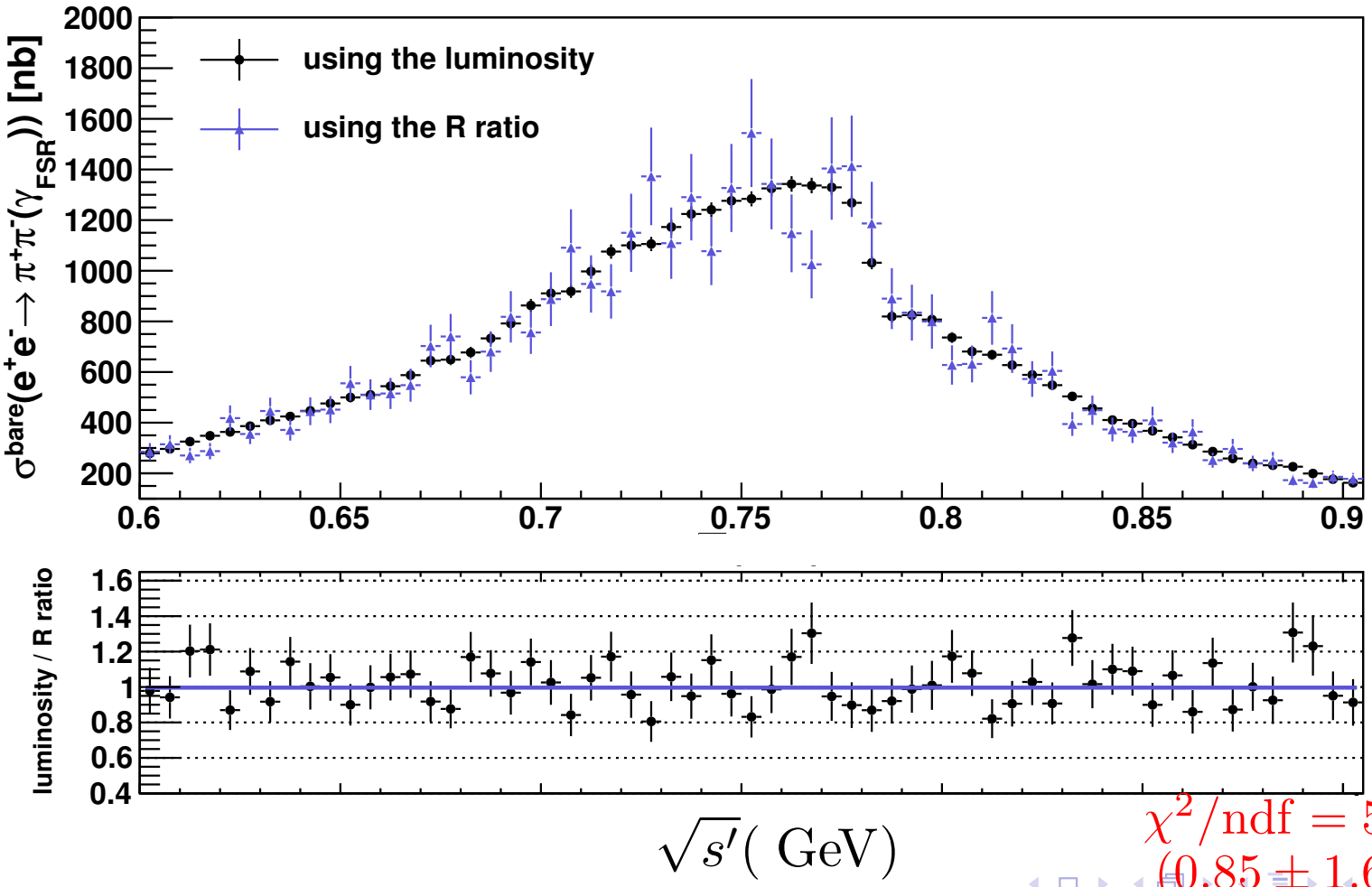
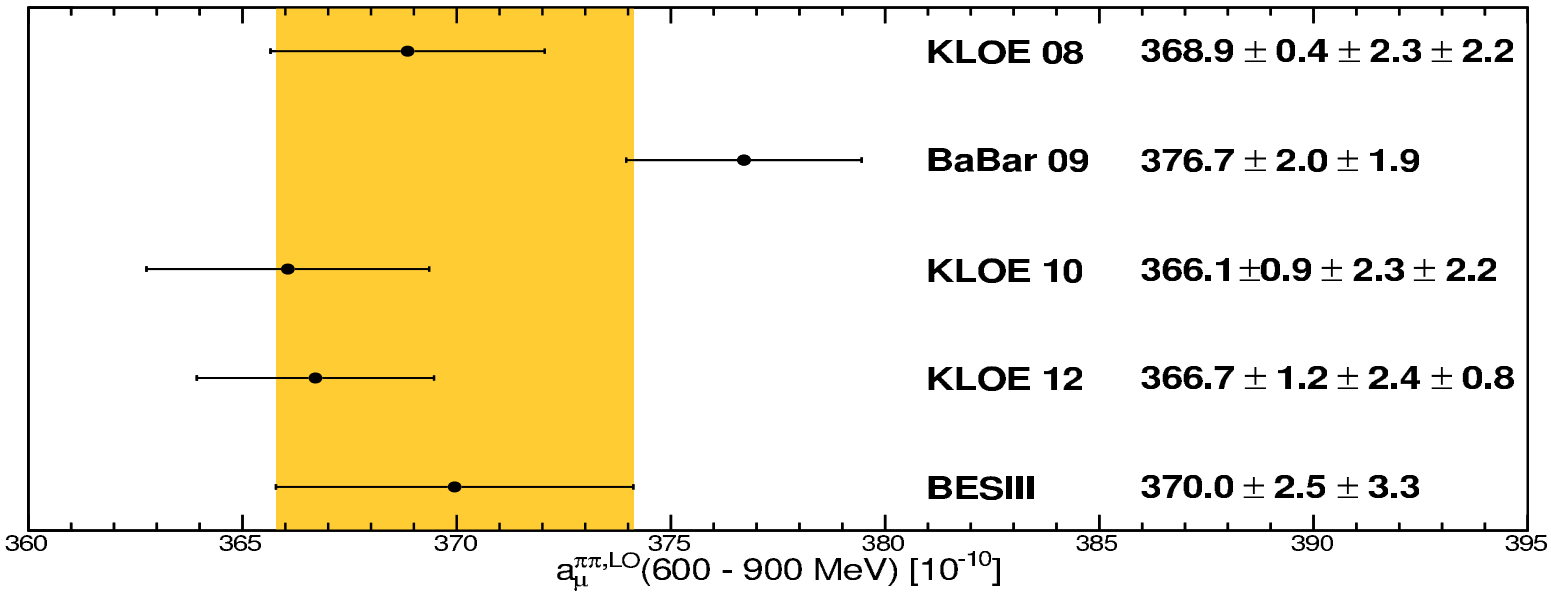


$\chi^2/\mathrm{ndf} = 50/60$

$(0.85 \pm 1.68)\%$

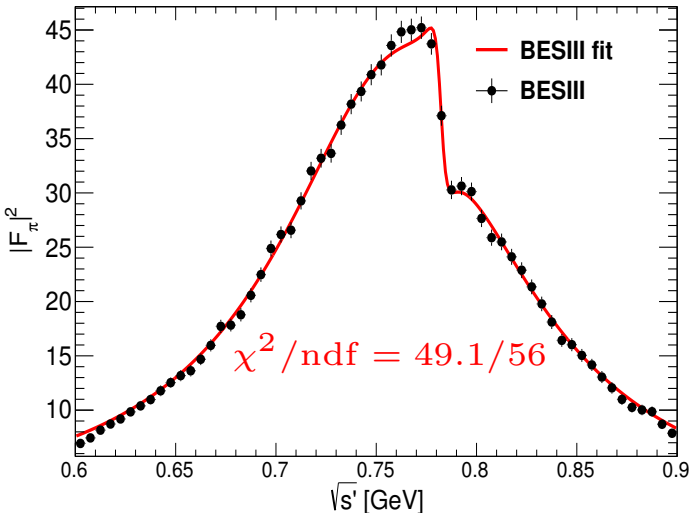
Contribution to $a_\mu^{\text{VP,LO}}$

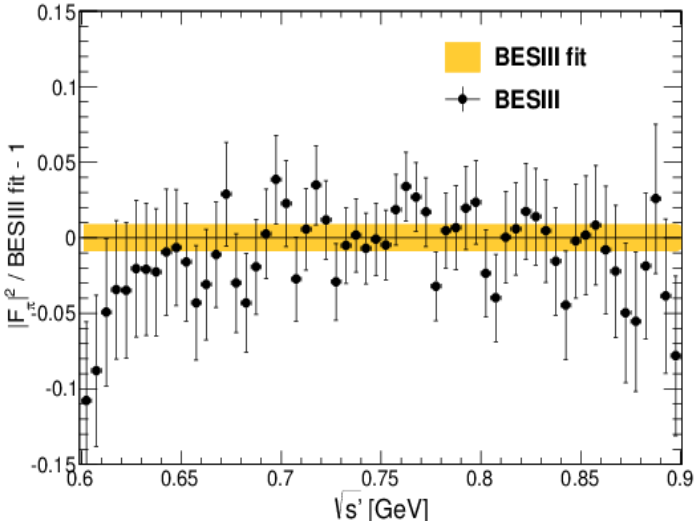


- $a_\mu^{\pi\pi,\text{LO}}(600-900\,\text{MeV}) = (370.0 \pm 2.5_{\text{stat}} \pm 3.3_{\text{sys}}) \cdot 10^{-10}$
- Precision competitive with previous measurements
- BESIII measurement between BaBar and KLOE
- Confirmed deviation between experiment and theory
- arXiv:1507.08188 and submitted to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

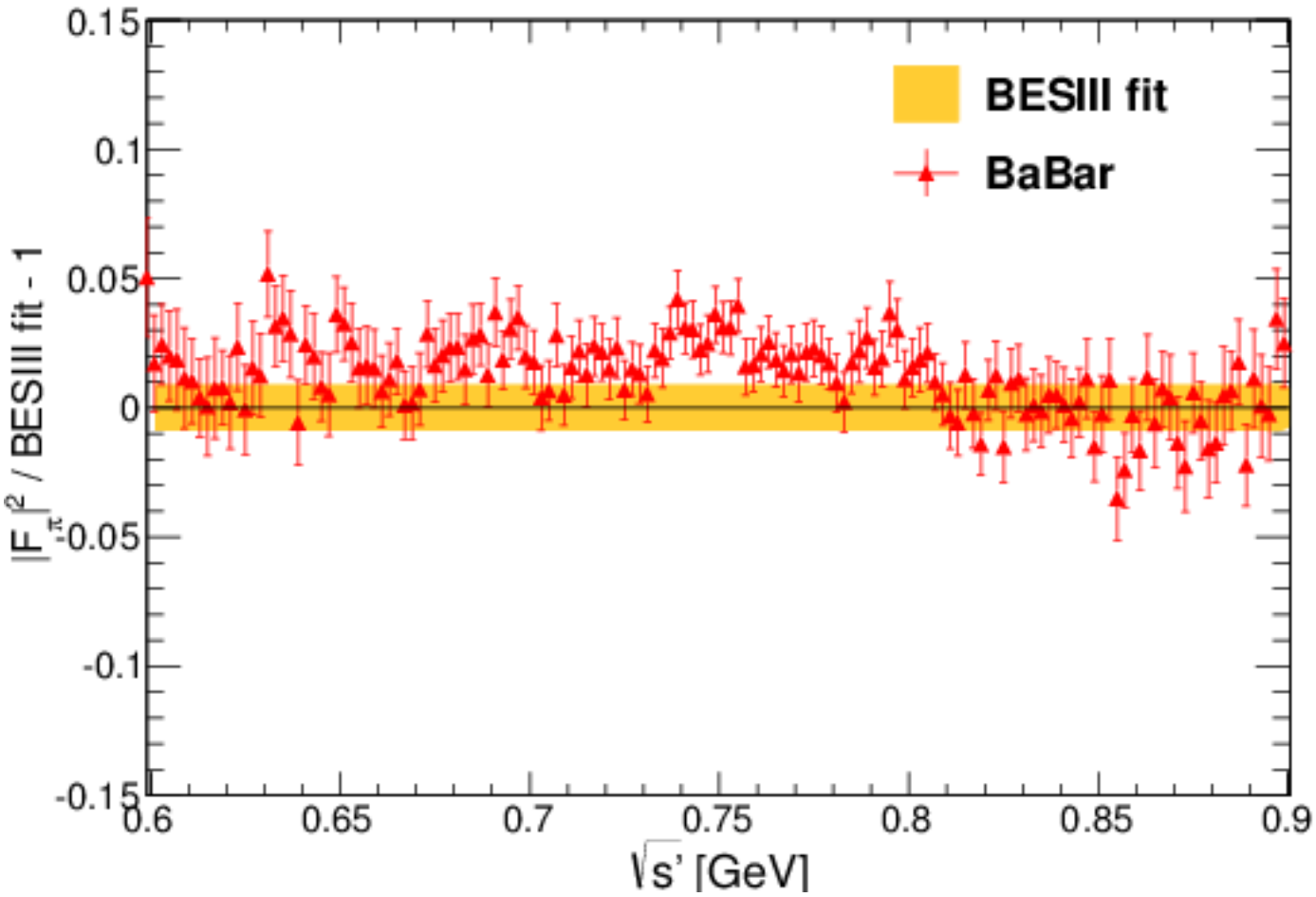




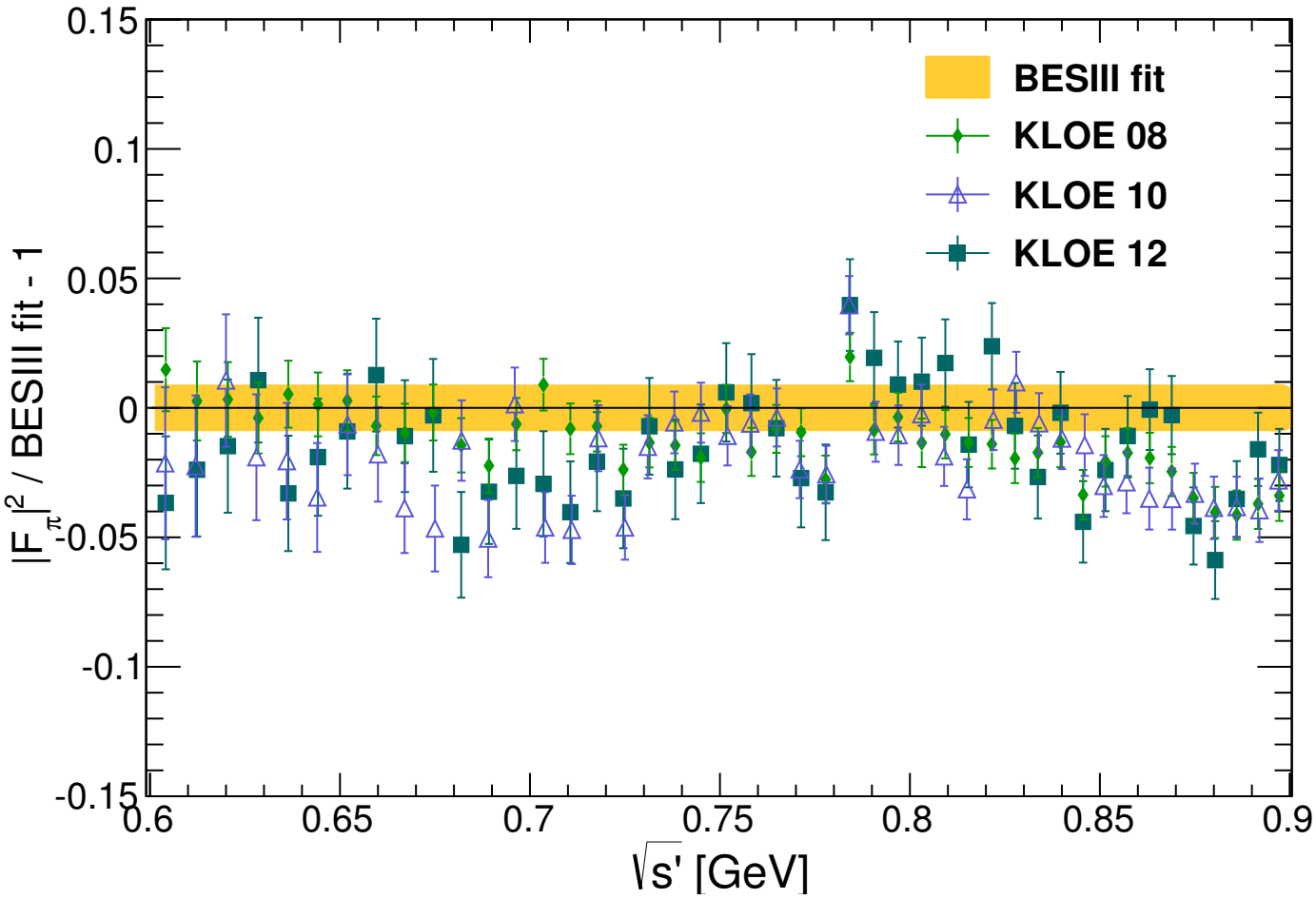
Parameter	BESIII value	PDG 2014
m_ρ [MeV/c^2]	776.0 ± 0.4	775.26 ± 0.25
Γ_ρ [MeV]	151.7 ± 0.7	147.8 ± 0.9
m_ω [MeV/c^2]	782.2 ± 0.6	782.65 ± 0.12
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08
$\lvert c_\omega \rvert$ [10^{-3}]	1.7 ± 0.2	-
$\lvert \phi_\omega \rvert$ [rad]	0.04 ± 0.13	-

2.9σ

Comparison with BaBar



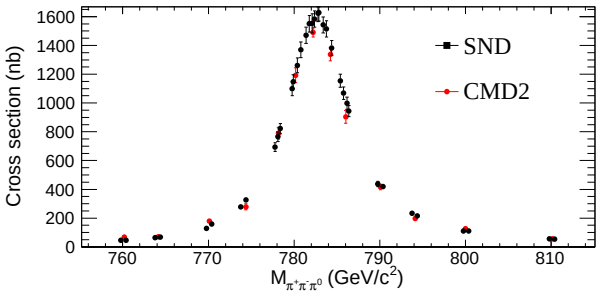
Comparison with KLOE



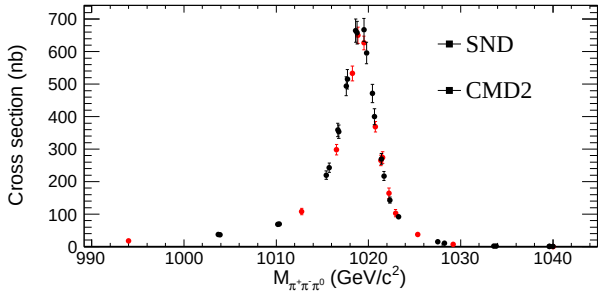
Outline

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

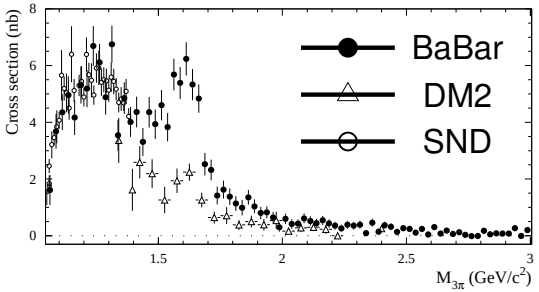
- History of σ for $e^+e^- \to \pi^+\pi^-\pi^0$:
  - $\sqrt{s} \lesssim 1$ GeV: $\omega(782)$ and $\phi(1020)$
  - Published results above ϕ :
    - SND : up to 1.4 GeV
    - DM2 : $1.34 \sim 2.40$ GeV
    - BaBar : $1.05 \sim 3.00$ GeV



ω

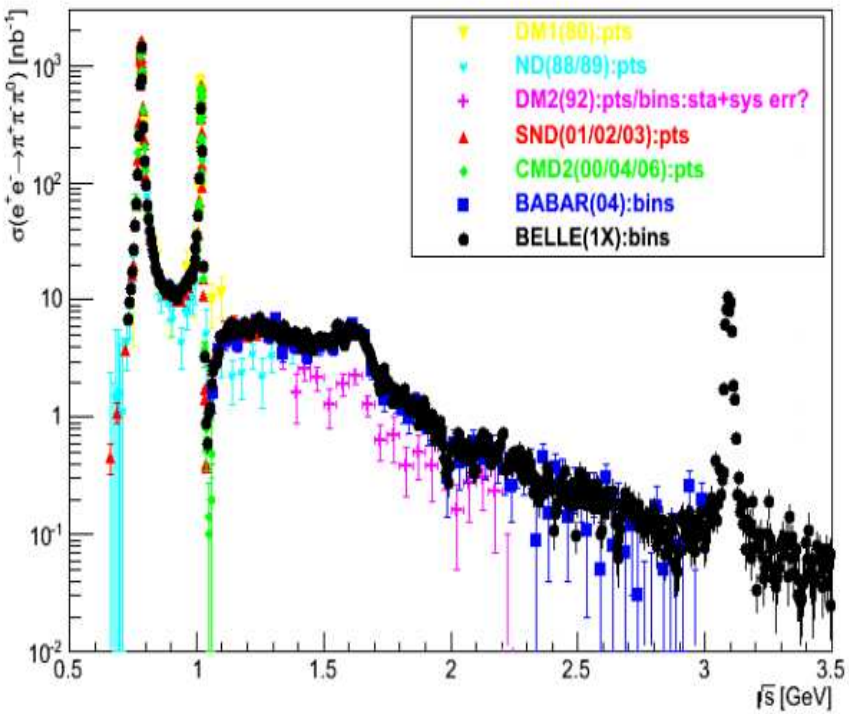


ϕ

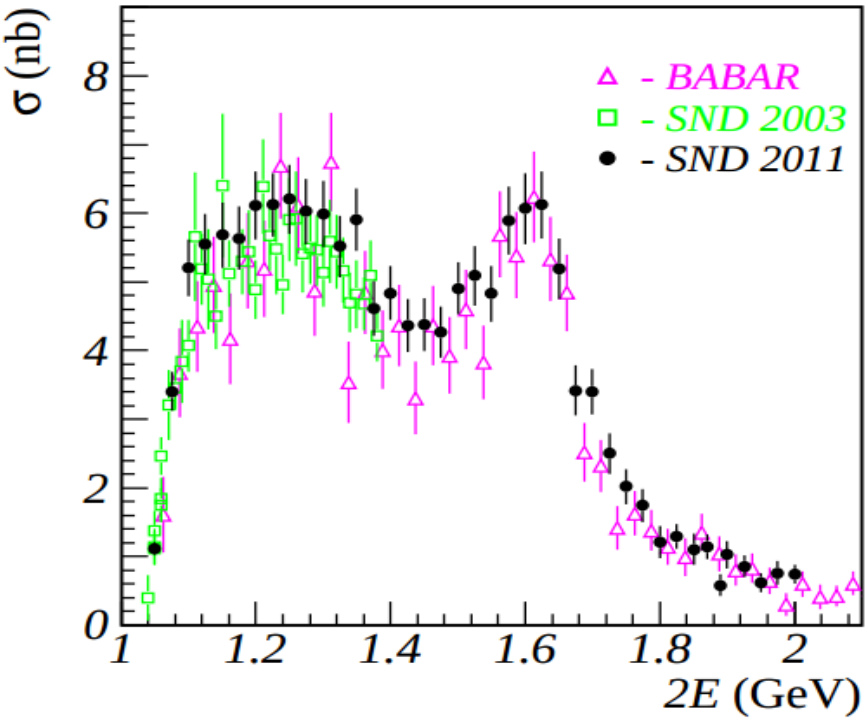


ω' and ω''

Belle and SND

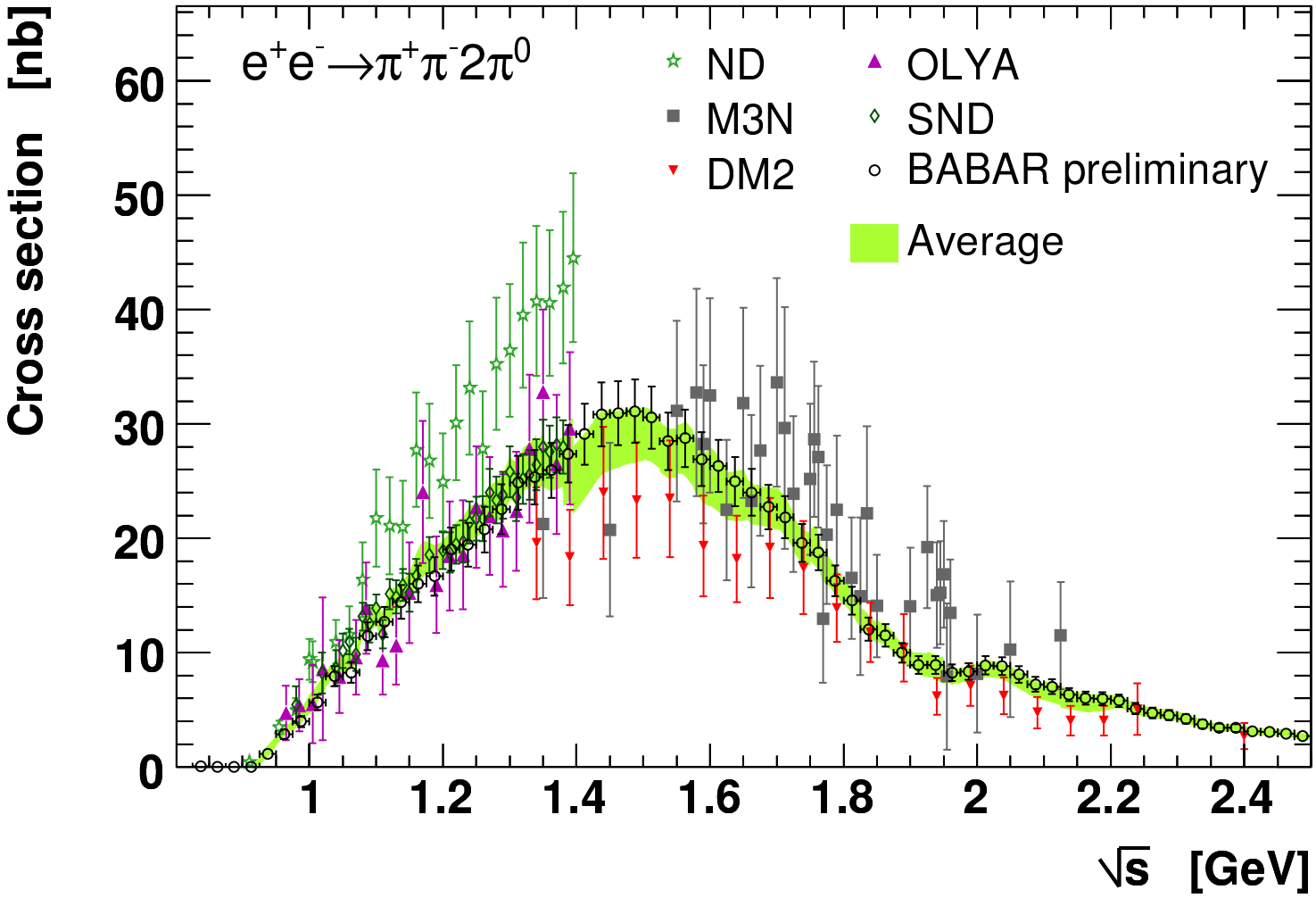


$e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^-\pi^0$ from Belle



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

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



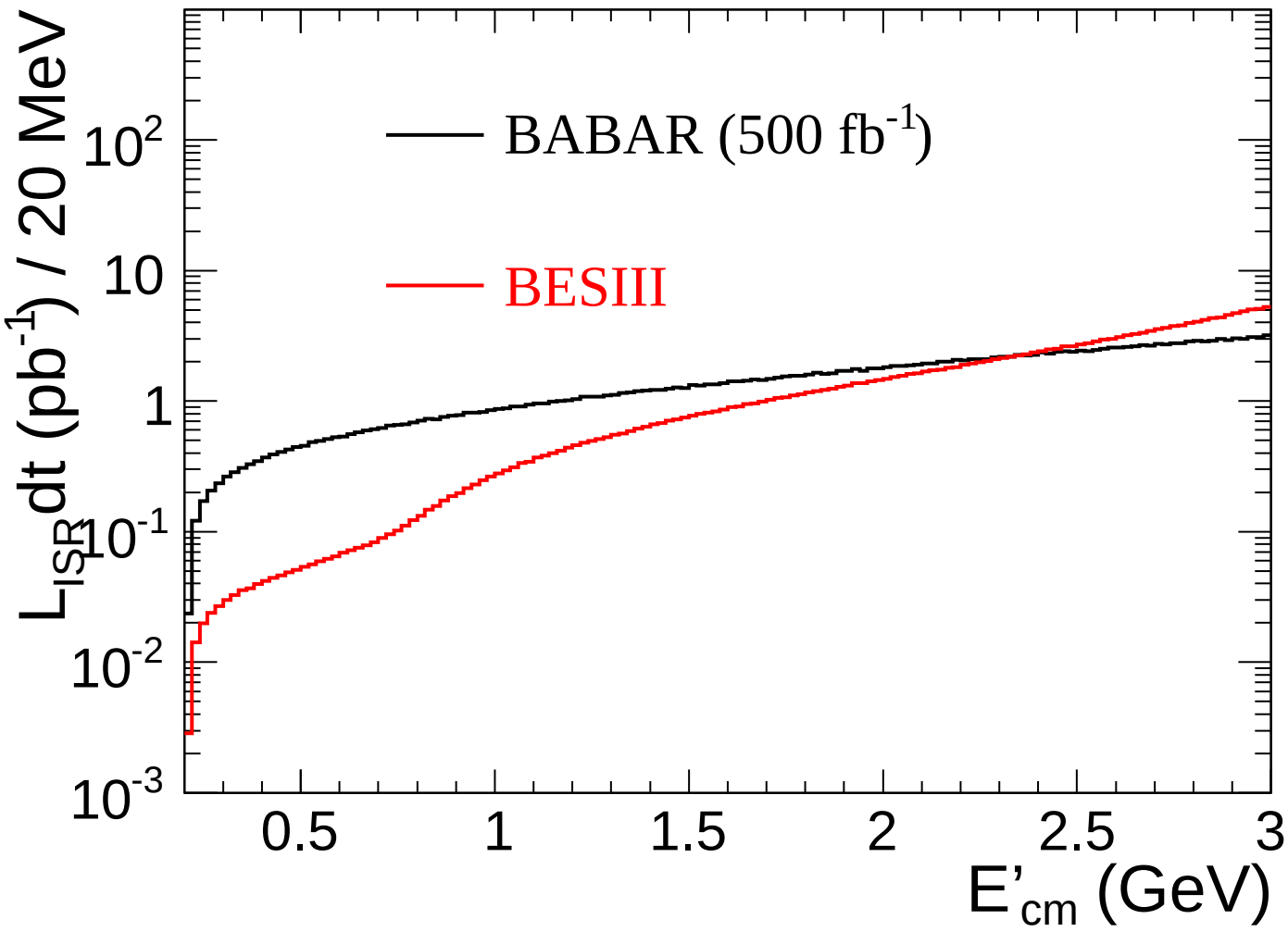
Outline

Summary

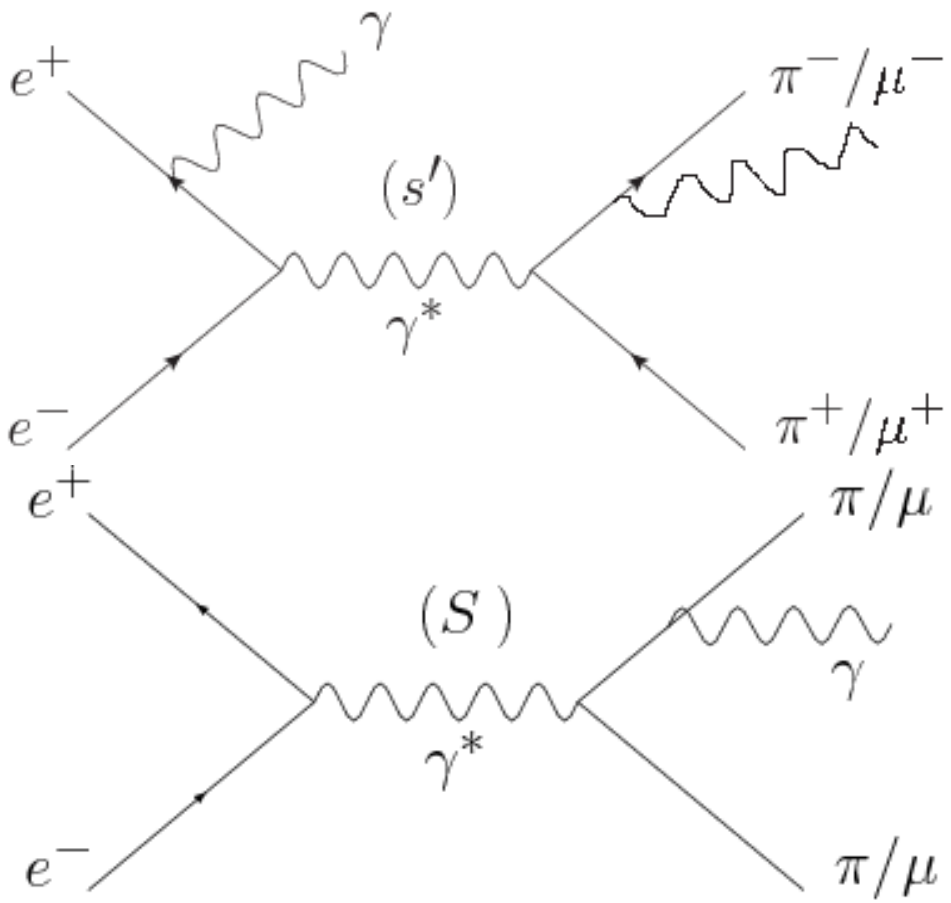
- $e^+e^- \to \pi^+\pi^-$
  - Cross section is measured at BESIII with sys. below 1%
  - Δa_μ is confirmed
- $e^+e^- \to \pi^+\pi^-\pi^0(\pi^0)$
  - Ongoing study at BESIII
  - Benefit from both tagged and untagged
- Outlook
  - Extend tagged $\pi^+\pi^-$ ISR study to threshold region
  - Untagged ISR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

Thank you!

Effective Luminosity



FSR Correction



Theoretical calculation of a_μ

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

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

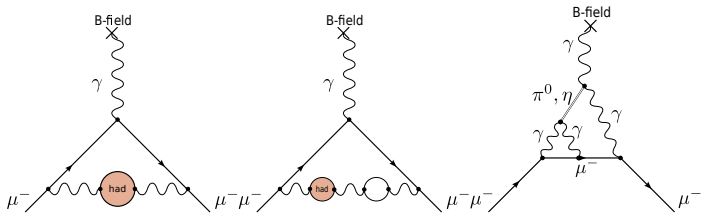
$$a_\mu^{\text{weak}} = (153.2 \pm 1.0 \pm 1.5) \times 10^{-11}$$

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

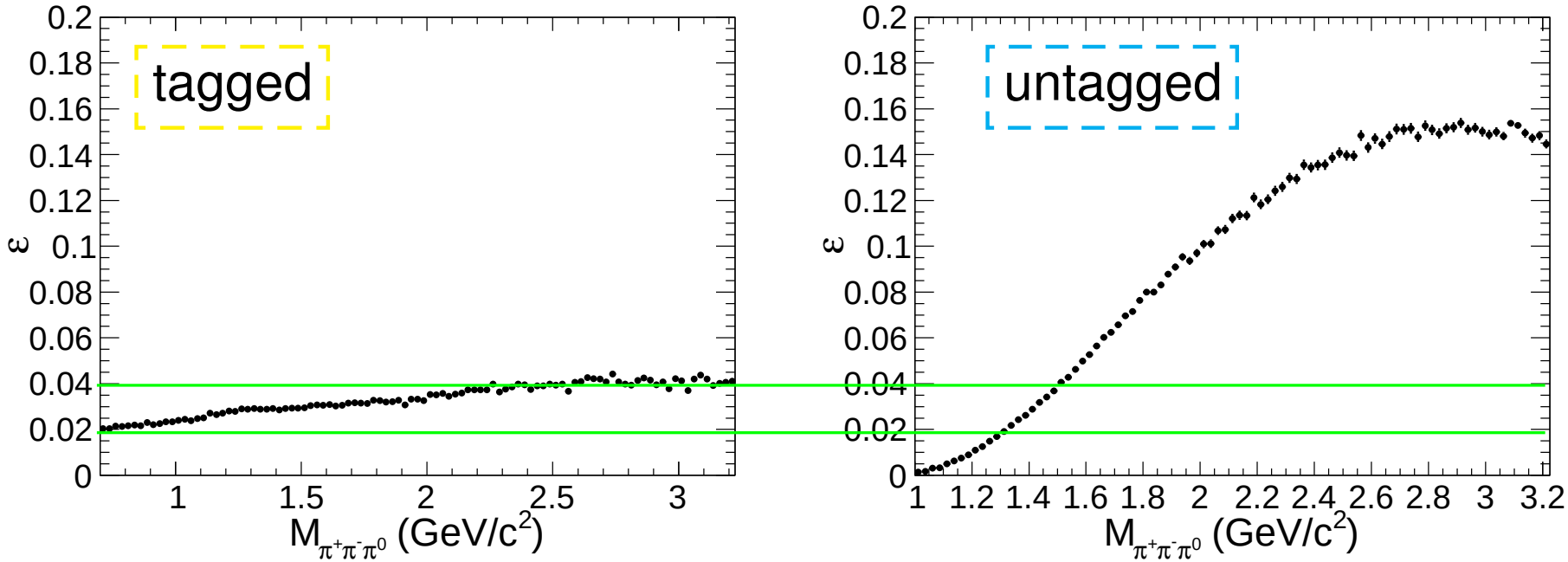
$$a_\mu^{\text{VP,LO}} = (6949.1 \pm 42.7) \times 10^{-11}$$

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

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



$e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^-\pi^0$ 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: $< 5\%$