Pion Form Factor Measurement and ISR at BESIII

Yaqian WANG

Johannes Gutenberg University Mainz

The 14th International Workshop on Tau Lepton Physics

19-23 September 2016 Beijing, China

Outline

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$g-2$

- Muon magnetic moment: $\vec{\mu}_\mu = g_\mu \left(\frac{q}{2m}\right) \vec{S}$
- Anomalous magnetic moment: $a_\mu = \frac{1}{2}(g_\mu - 2)$
- Experiments and precisions:

  E821@BNL

  0.54 ppm

  ppm:parts per million

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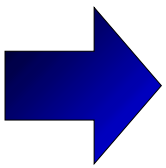
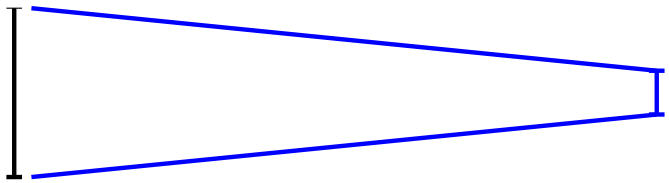


E989@Fermilab

0.14 ppm



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E821@BNL → E989@Fermilab → E34@J-PARC

0.54 ppm → 0.14 ppm → 0.10 ppm

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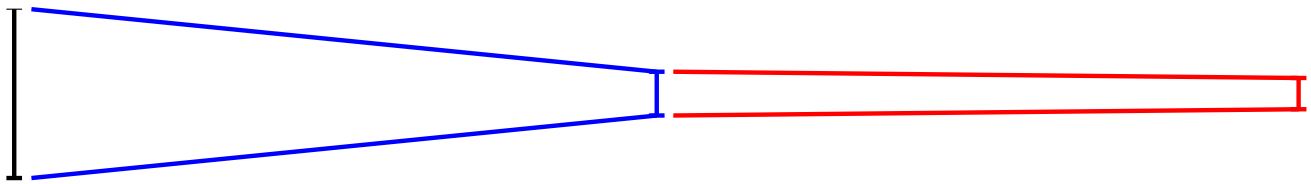

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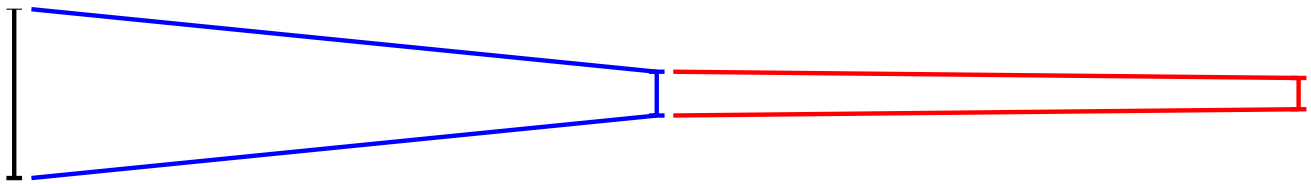
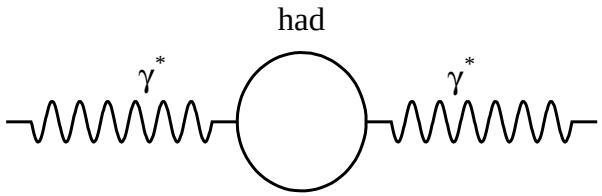


Theoretical precision: 0.42 ppm

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

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

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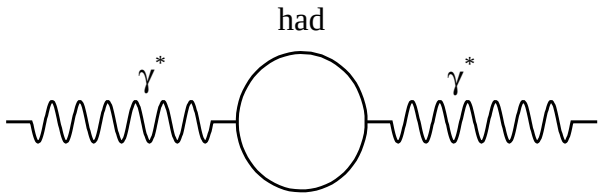

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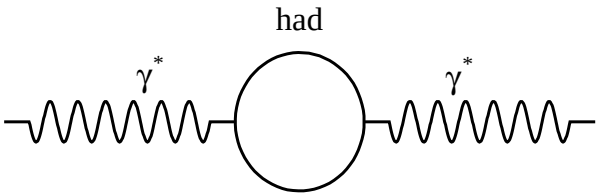

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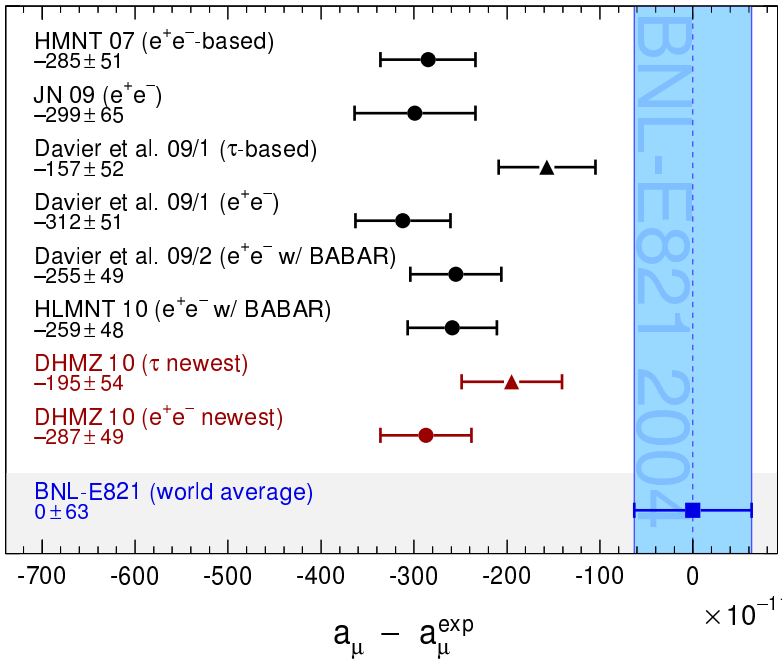
$$R(s) = \frac{\sigma(e^+e^- \to \underbrace{\text{hadrons}}_{e^+e^- \to \pi^+\pi^- (>70\%),\ e^+e^- \to \pi^+\pi^-\pi^0 (>6\%),\ e^+e^- \to \pi^+\pi^-\pi^+\pi^-,\ e^+e^- \to \pi^+\pi^-\pi^0\pi^0,\ \cdots})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$g-2$

- $a_\mu^{\text{exp}} = (116592089 \pm 54 \pm 33) \times 10^{-11}$ [PRD **73** 072003 (2006); PDG]
- $a_\mu^{\text{SM}} = (116591802 \pm 42 \pm 26) \times 10^{-11}$ [EPJC **71** 1515 (2011)]
- $\Delta a_\mu = (287 \pm 80) \times 10^{-11} \quad \Rightarrow 3.6\sigma$ deviation



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

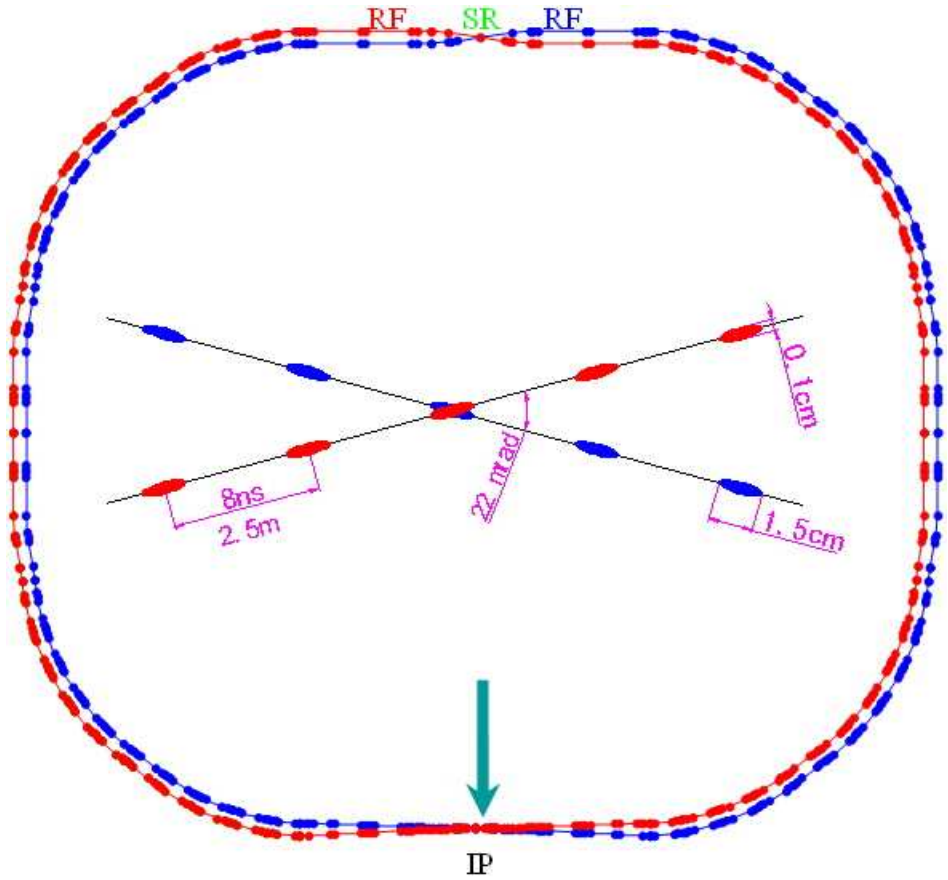
Outline

Beijing Spectrometer III Collaboration

~450 members
from 57 institutions in 13 countries

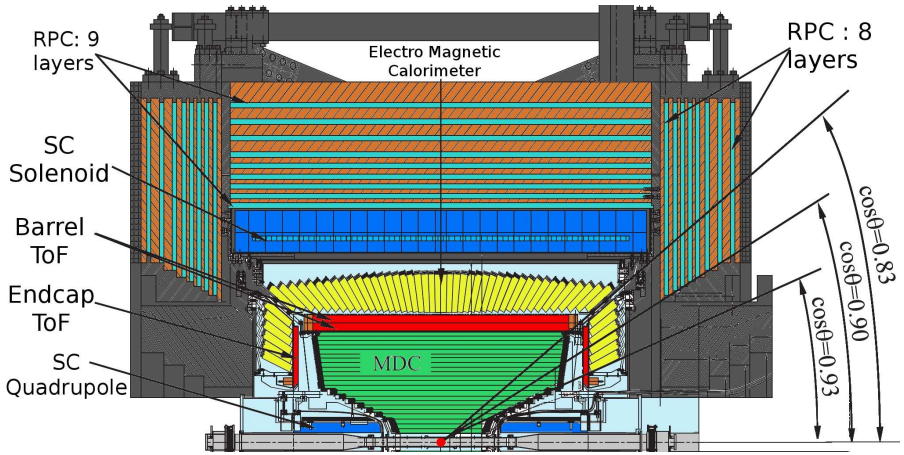
Beijing Electron-Positron ColliderII

- τ-charm factory
- Beam energy: $1.0 - 2.3$ GeV
- Beam spread: 5.16×10^{-6}
- Design luminosity:
  $1 \times 10^{33}\,\mathrm{cm}^{-2}s^{-1}$ @ 3.773 GeV 100% achieved



BESIII Detector

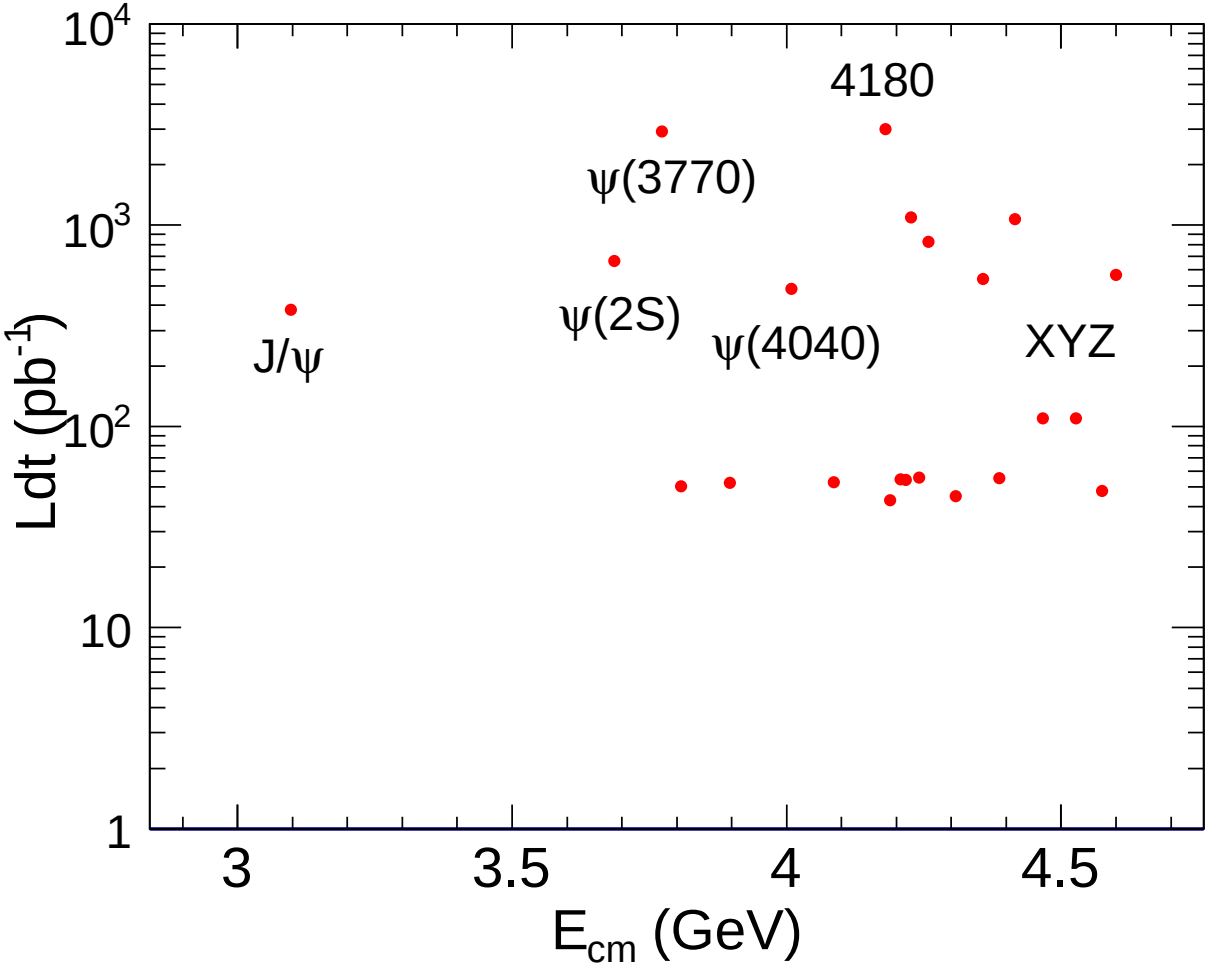
- Multilayer Drift Chamber
  - $\sigma(p)/p = 0.5\%$
  - $\sigma_{\mathrm{dE/dx}} = 6.0\%$
- Time of Flight system
  - $\sigma(t) = 90$ ps (barrel)
  - $\sigma(t) = 110$ ps (endcap)
- EM Calorimeter
  - 6240 CsI(T1) crystals
  - σ(E)/E=2.5%
  - $\sigma_{Z,\phi}$(E)=0.5-0.7 cm



- Superconducting Manet
  - 1T magnetic field
- Muon Chamber
  - 8-9 layers of RPC
  - $\delta_{R\phi}$=1.4-1.7 cm

Data samples

- World's largest
  - J/ψ
  - $\psi(3686)$
  - $\psi(3770)$
  - 4180
  - XYZ
  - R scan



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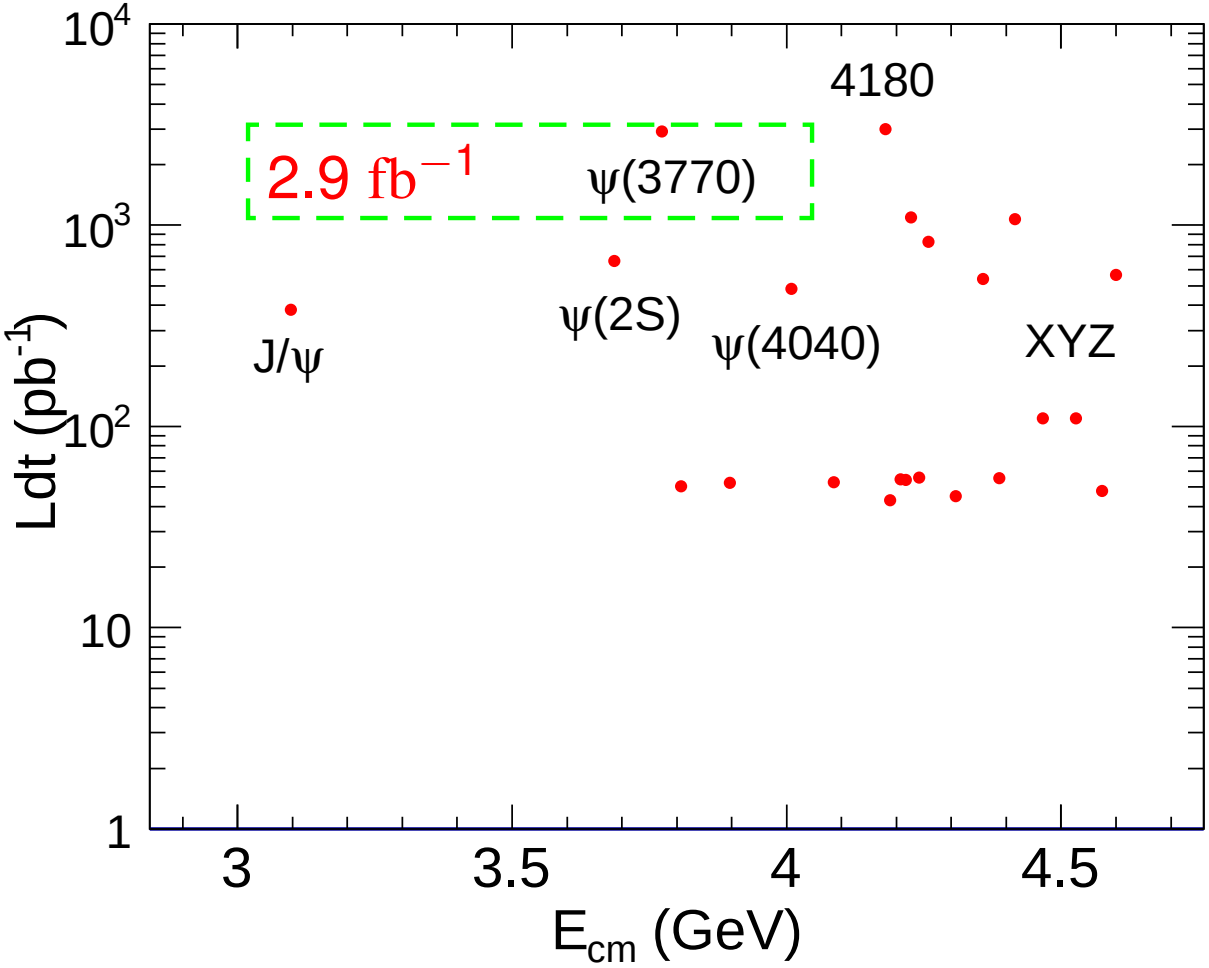
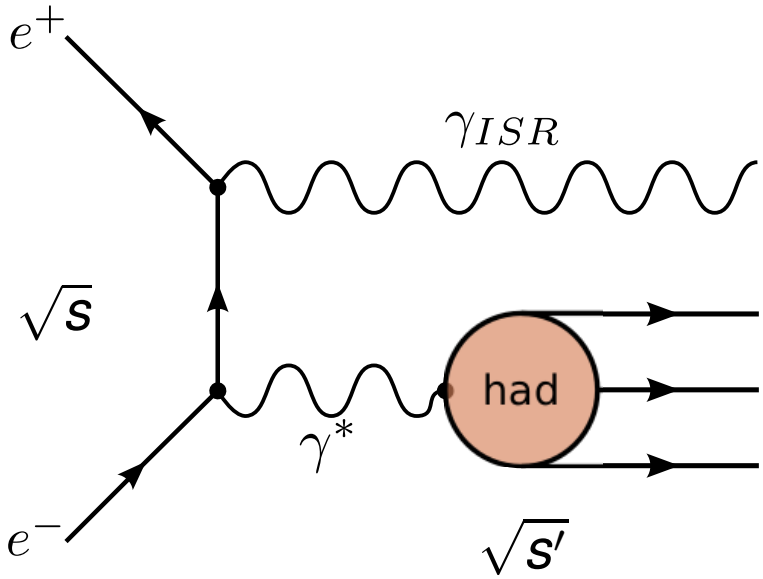
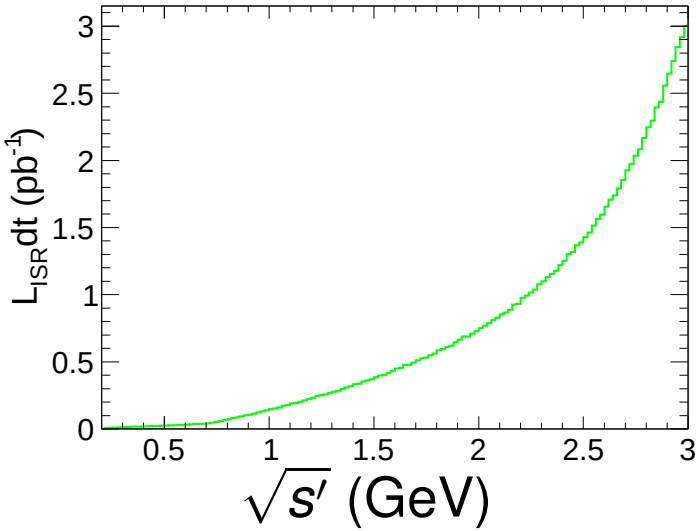


Outline

Radiator Function

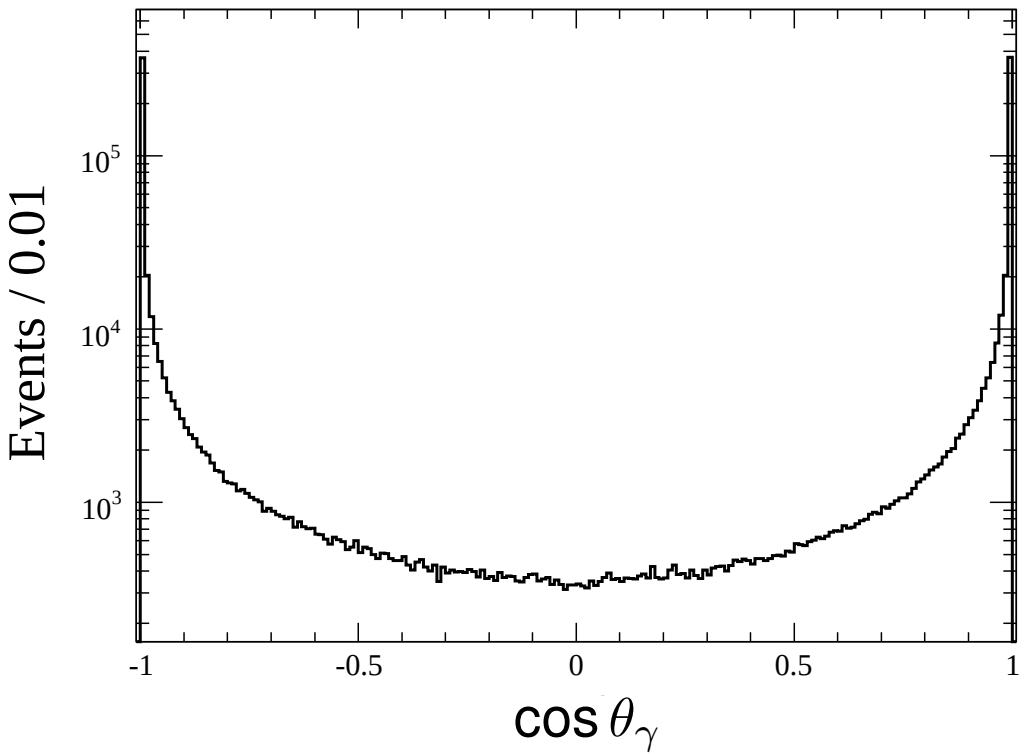
- $\sqrt{s'} = \sqrt{s - 2\sqrt{s}E_\gamma}$
- Emission of ISR photon is suppressed by α/π
- High integrated luminosity is necessary





Strategy: tag and untag the γ_{ISR}

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



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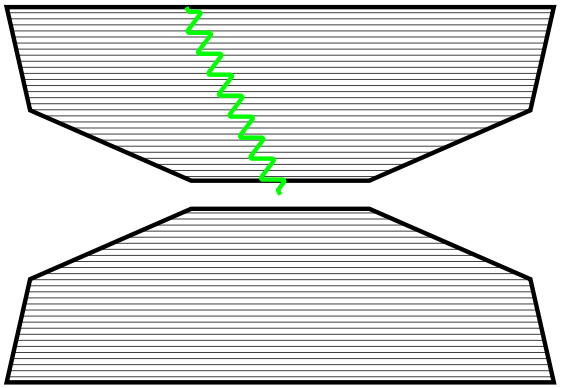

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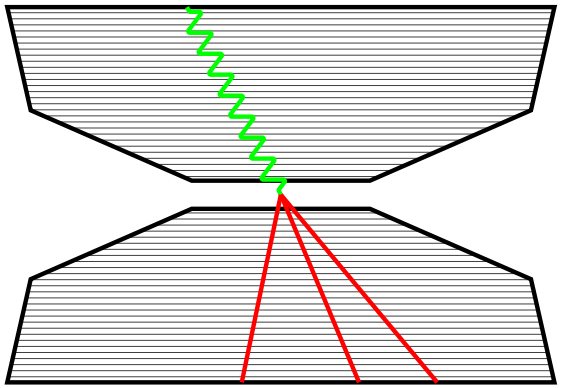

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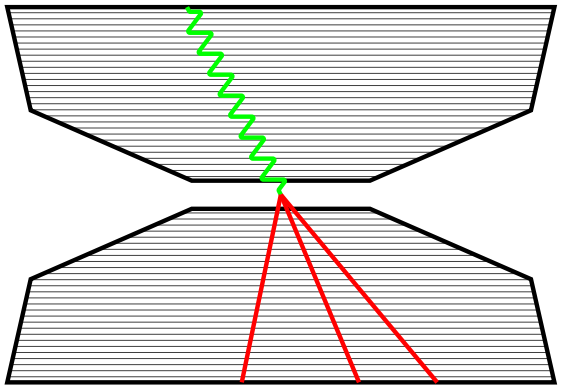

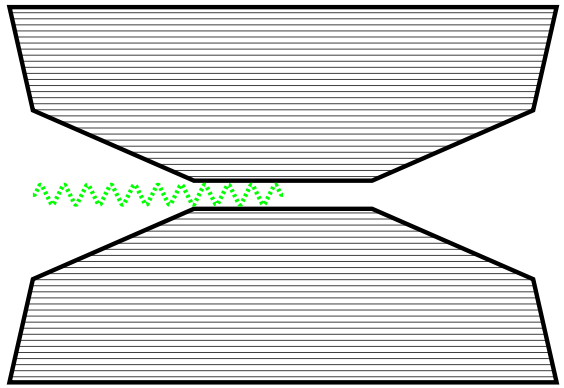

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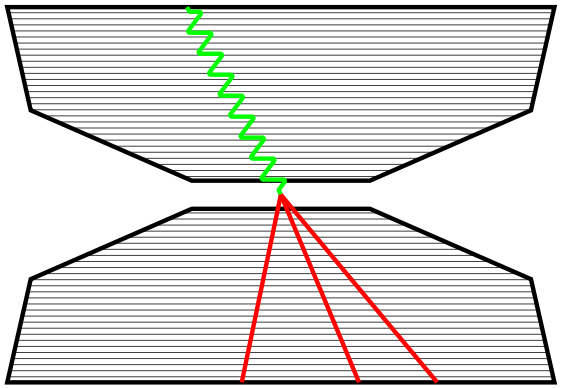
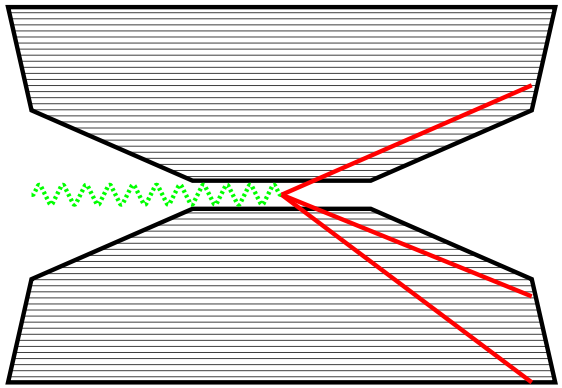
- Hadronic system should be detected
- Angular distribution of the γ_{ISR}
  - tagged: Wide range, huge BG in high $\sqrt{s'}$ $\sqrt{s'} < 1$ GeV
  - untagged: higher statistics, less BG $\sqrt{s'} > 1$ GeV

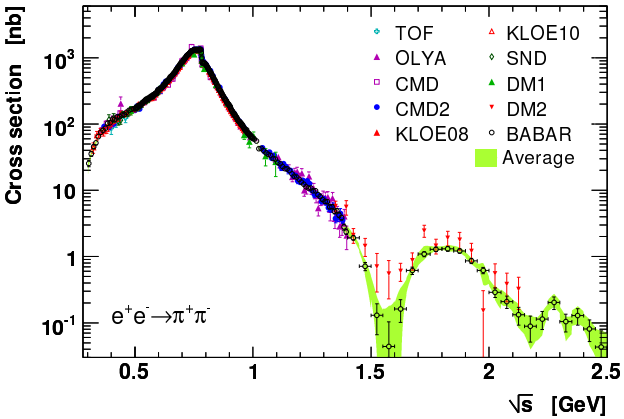


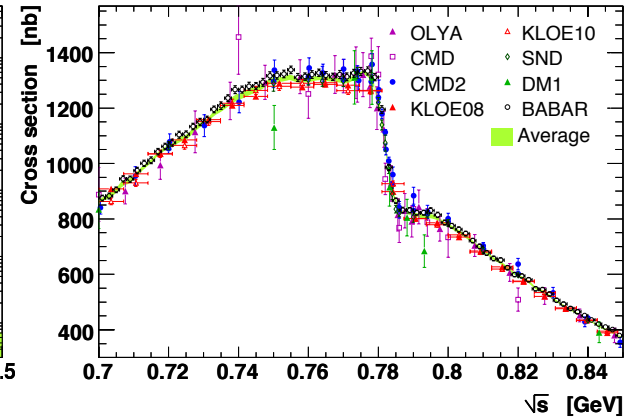


Outline

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

M. Davier et al., Eur. Phys. J. C **71** 1515 (2011)





Precision measurements

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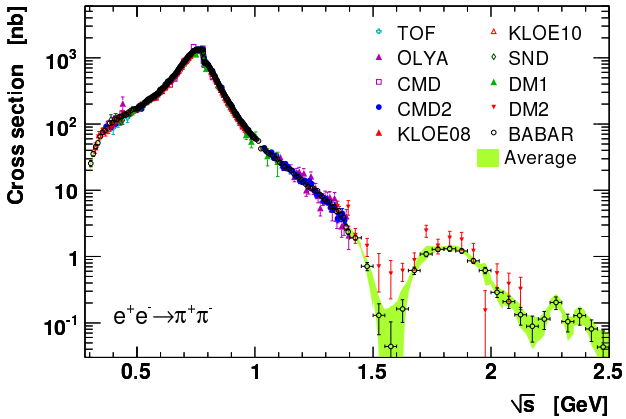
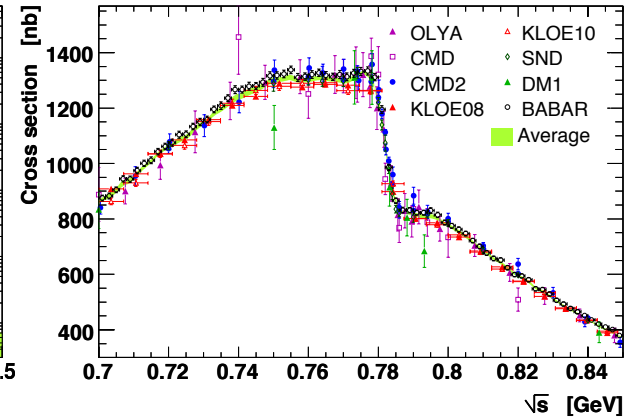
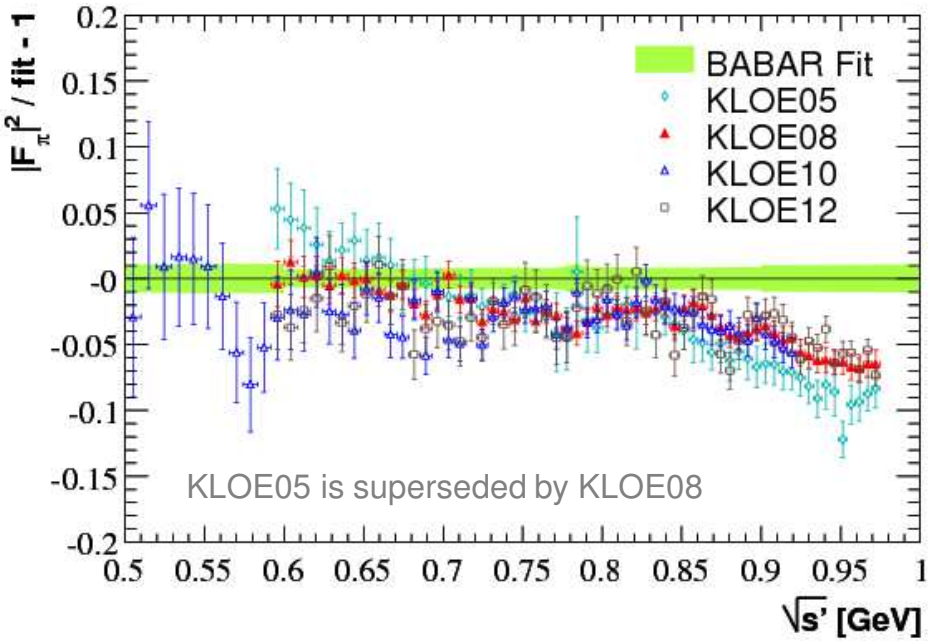




Precision measurements

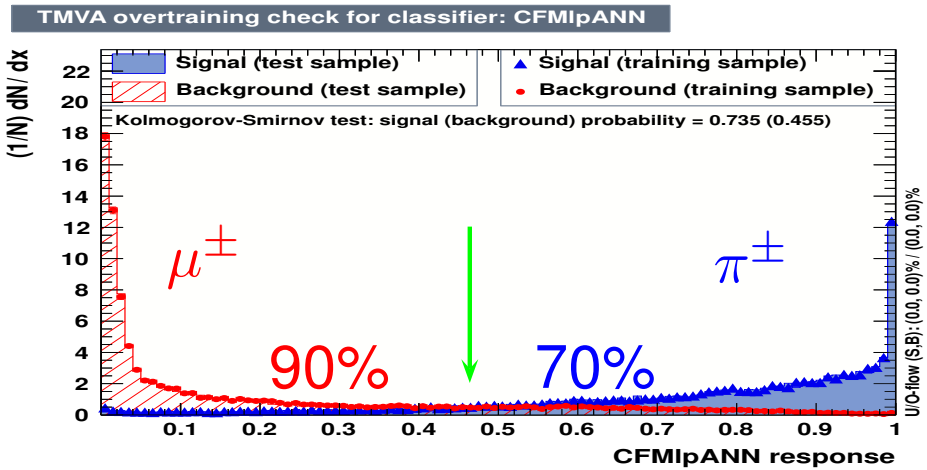
BaBar and KLOE

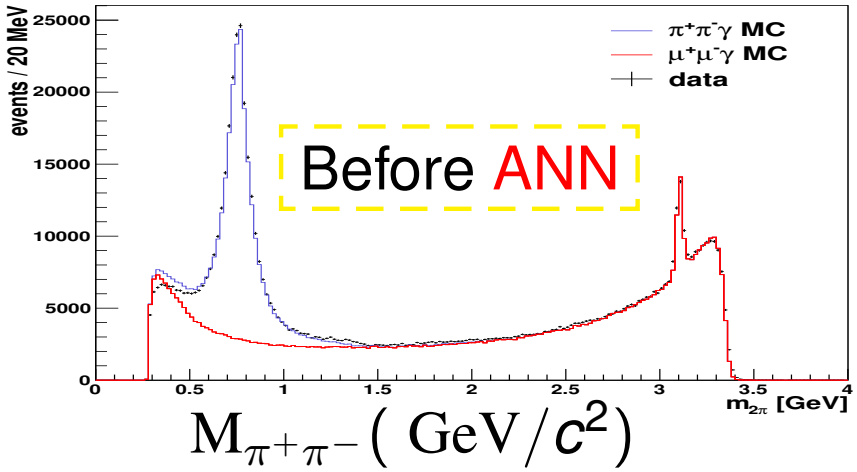
- 3% diff. on ρ peak
- New measurement

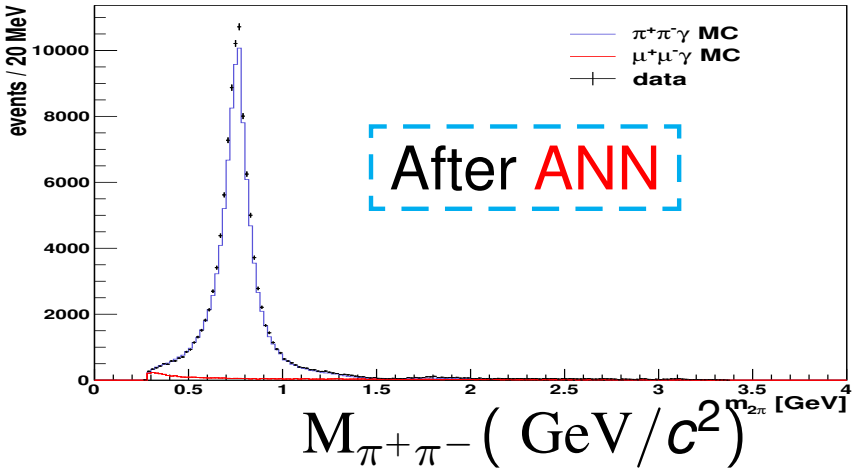


Tagged Selections

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



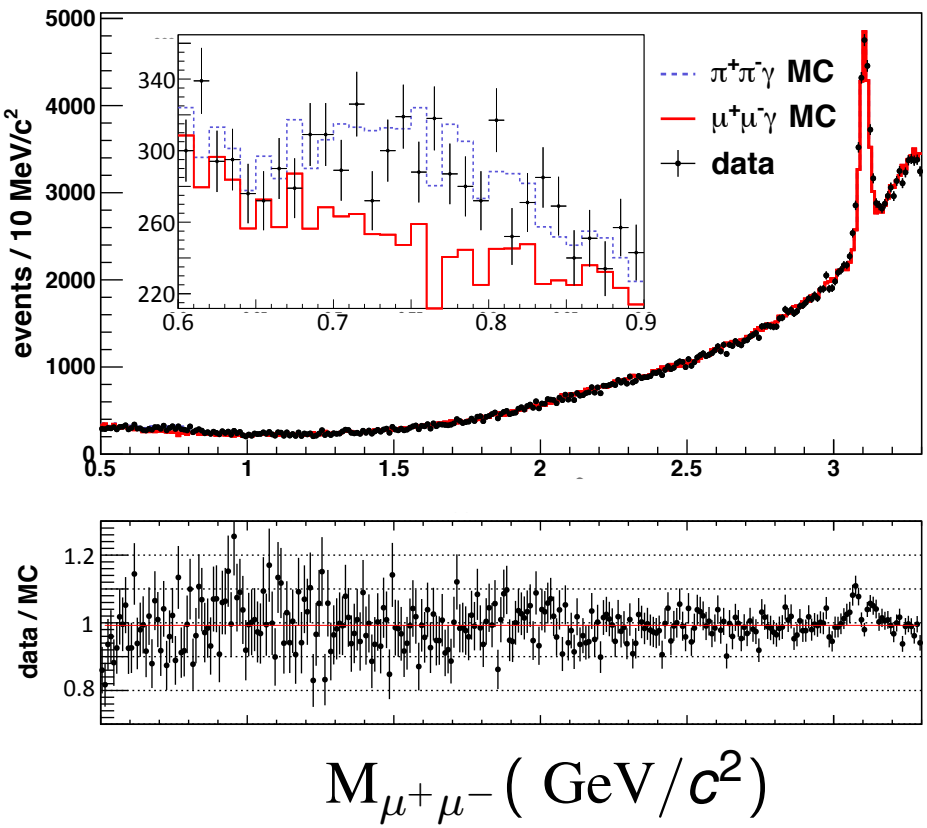




- Data-MC corrections vs. momentum and polar angle

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

- Select μ using ANN
- Small π background
- Efficiency corrections
- Compare to PHOKHARA
  - 0.5% accuracy



- Good agreement:
  - $1.0 \pm 0.3 \pm 0.9\%$ $(\chi^2/\mathrm{ndf} = 134/139)$
  - $2.0 \pm 1.7 \pm 0.9\%$ $(0.6 < M_{\mu^+\mu^-} < 0.9)$

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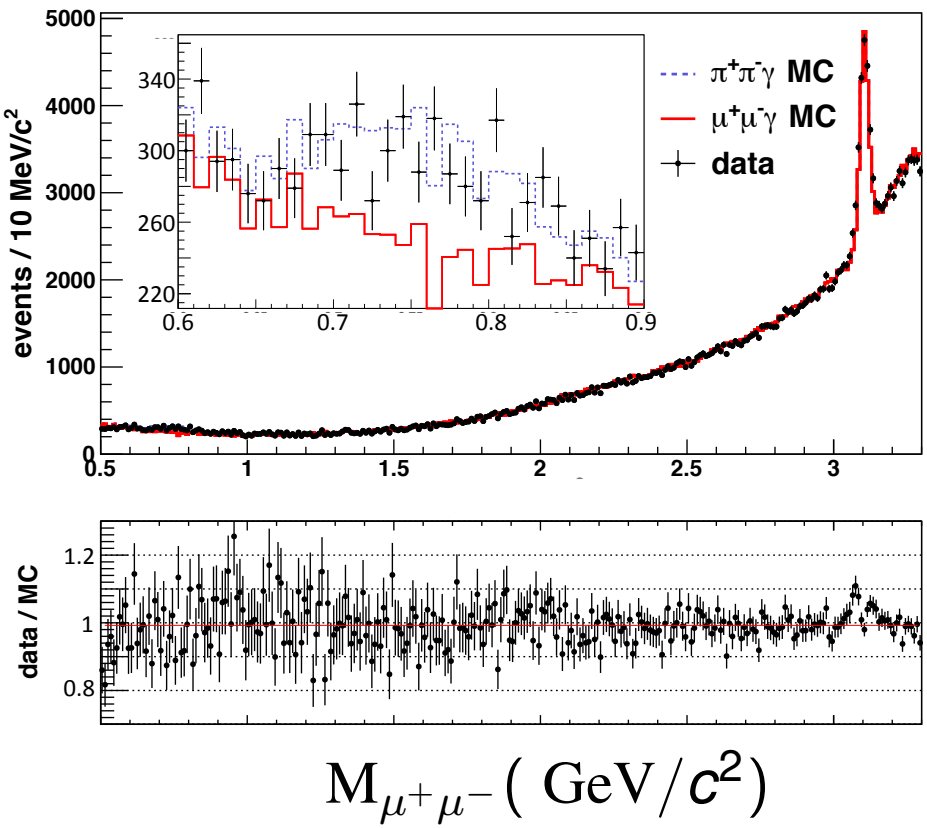

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Validation!

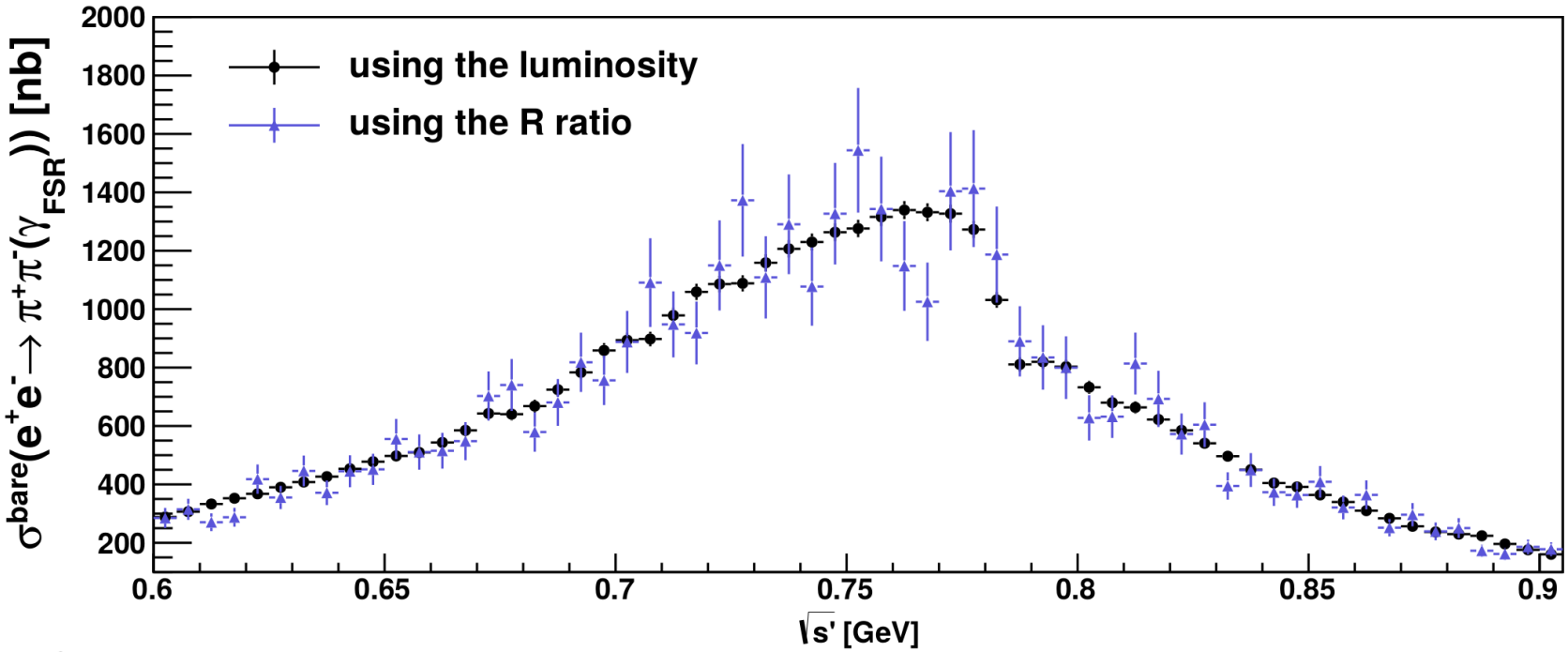
Systematic Uncertainties

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**

Cross section

$$\sigma^{\text{bare}}_{\pi\pi(\gamma_{\text{FSR}})} = \frac{N_{\pi\pi\gamma}\cdot(1+\delta^{\pi\pi}_{\text{FSR}})}{\mathcal{L}\cdot\epsilon^{\pi\pi\gamma}_{\text{global}}\cdot H(s)\cdot\delta_{\text{vac}}}$$

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



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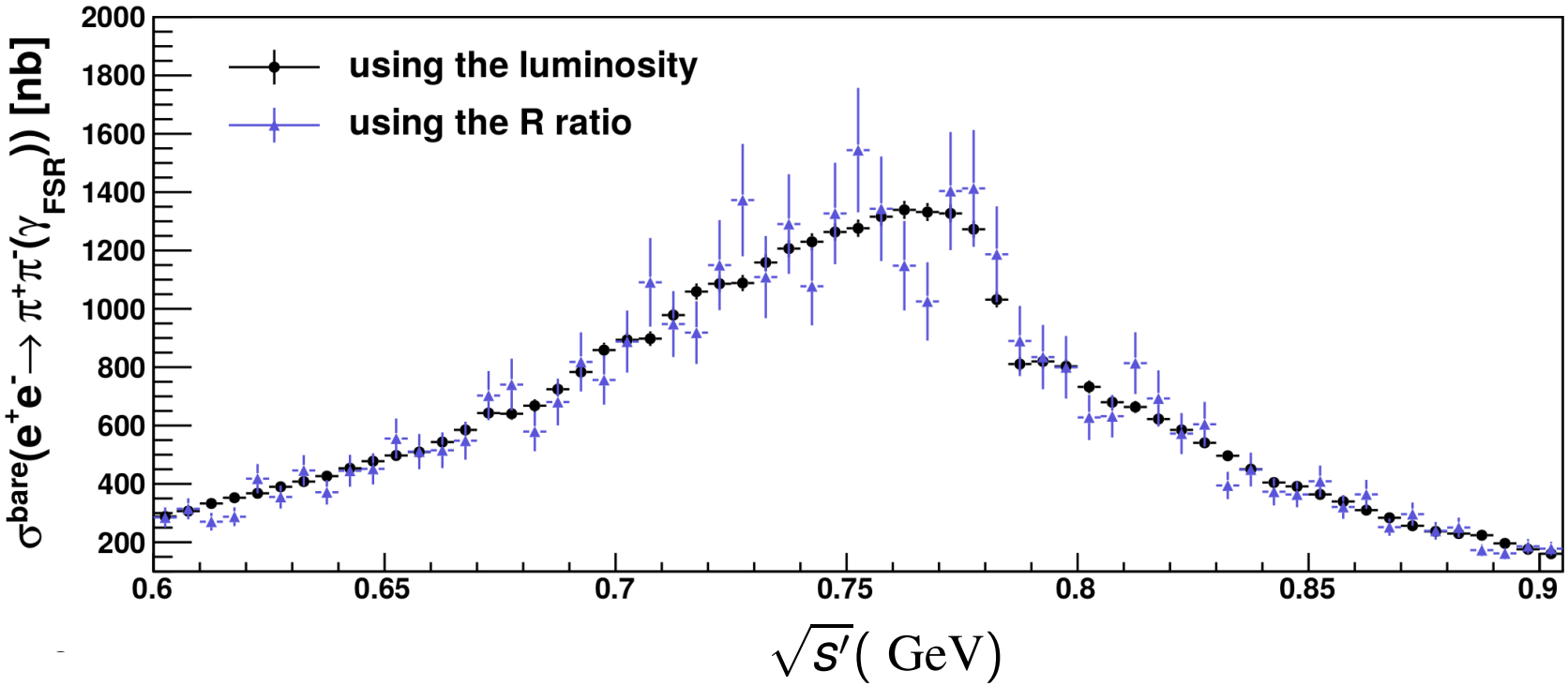
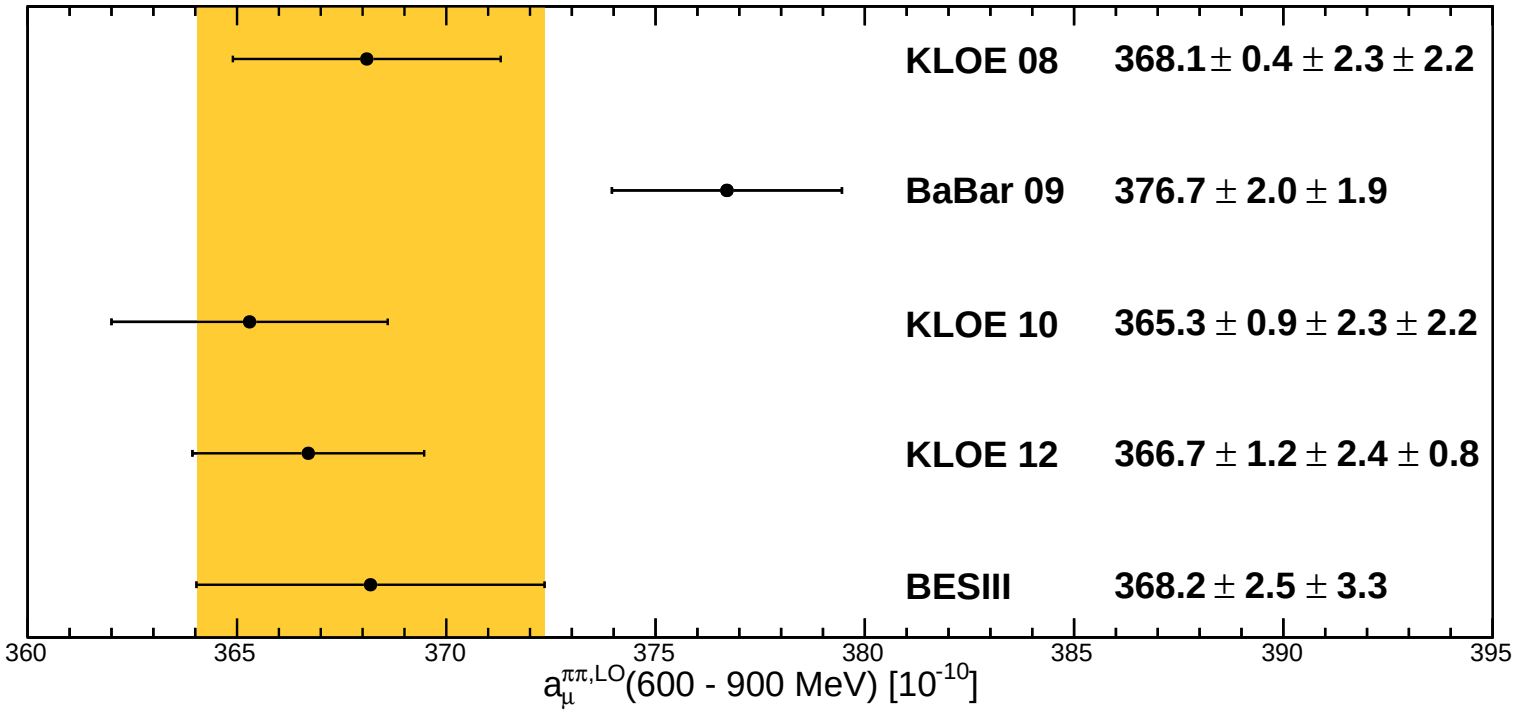


Relative difference: $(0.85 \pm 1.68)\%$

Good agreement!

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



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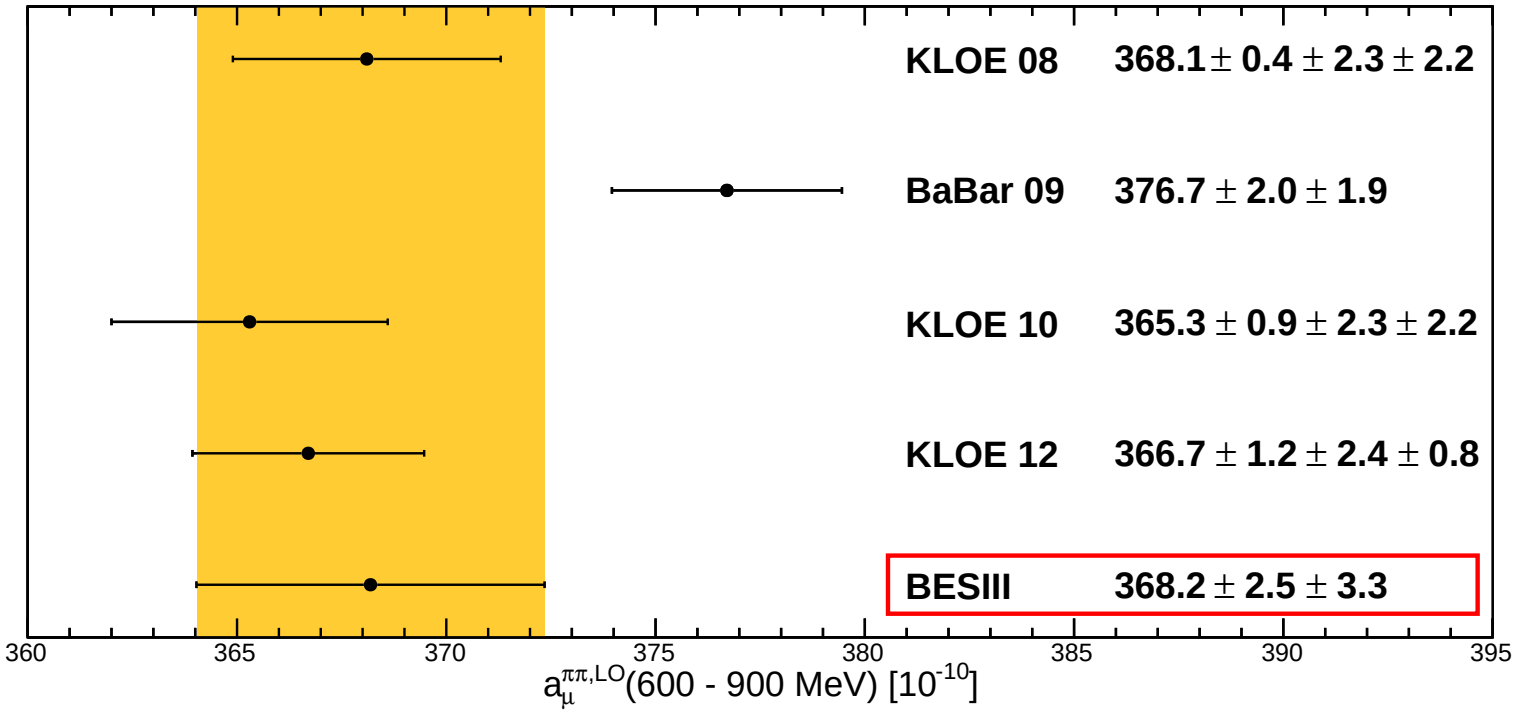

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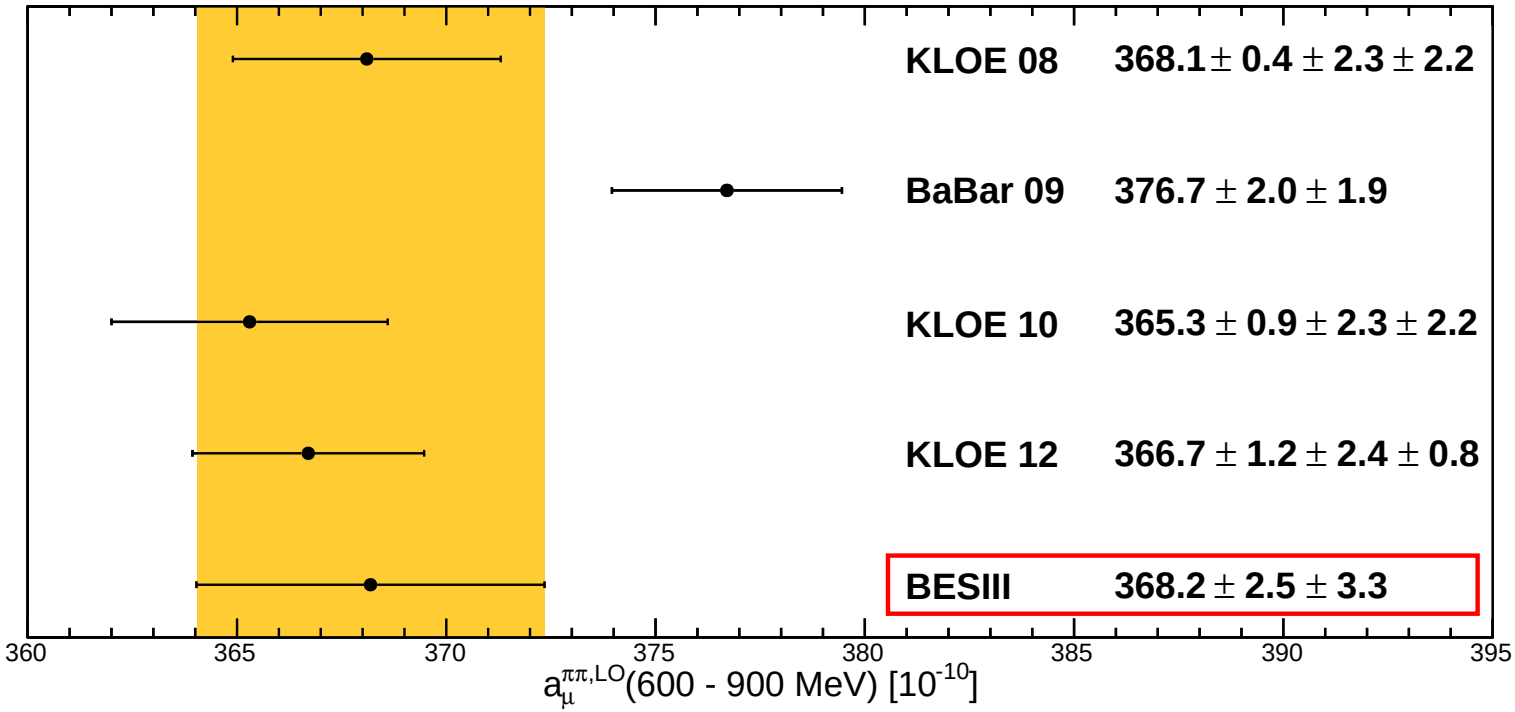

- Precision competitive with previous measurements

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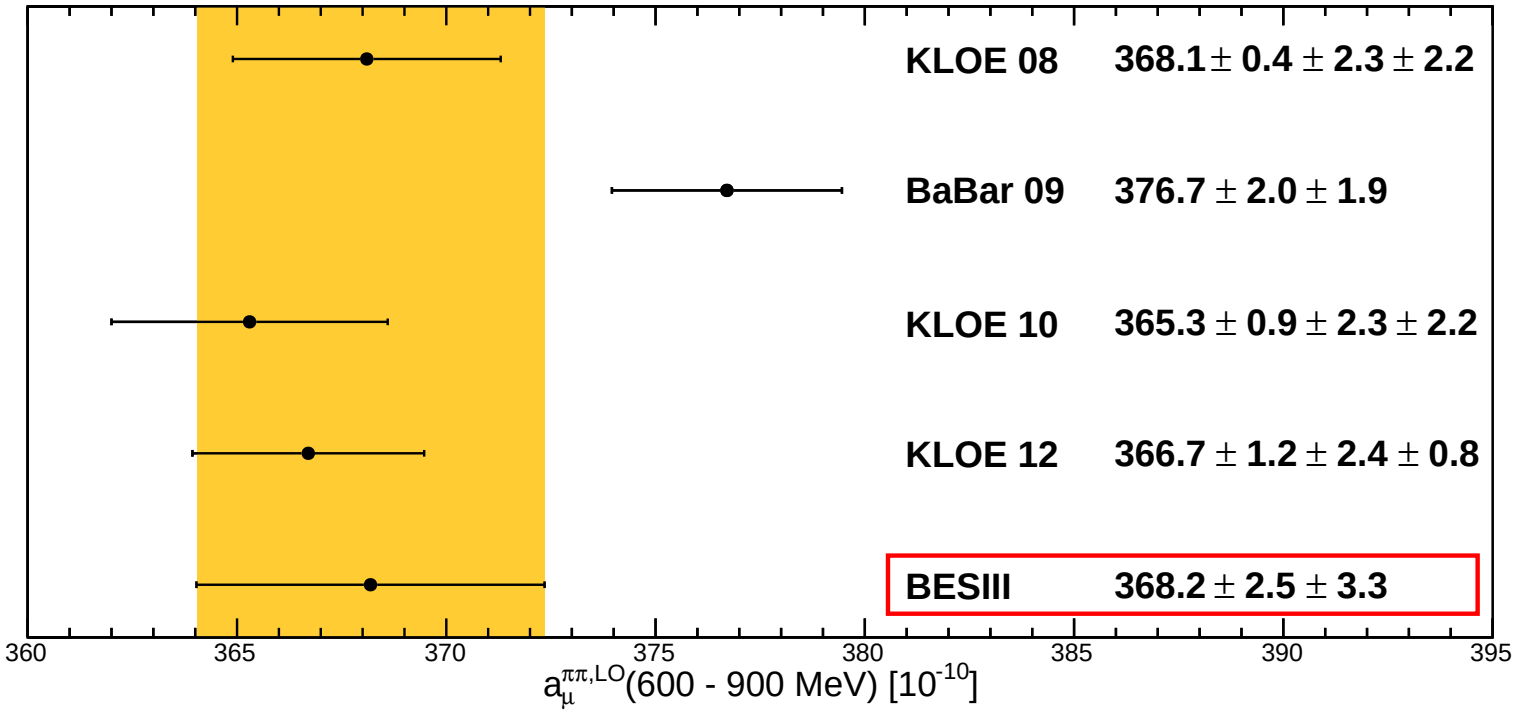

- Precision competitive with previous measurements
- BESIII measurement well agrees with KLOE

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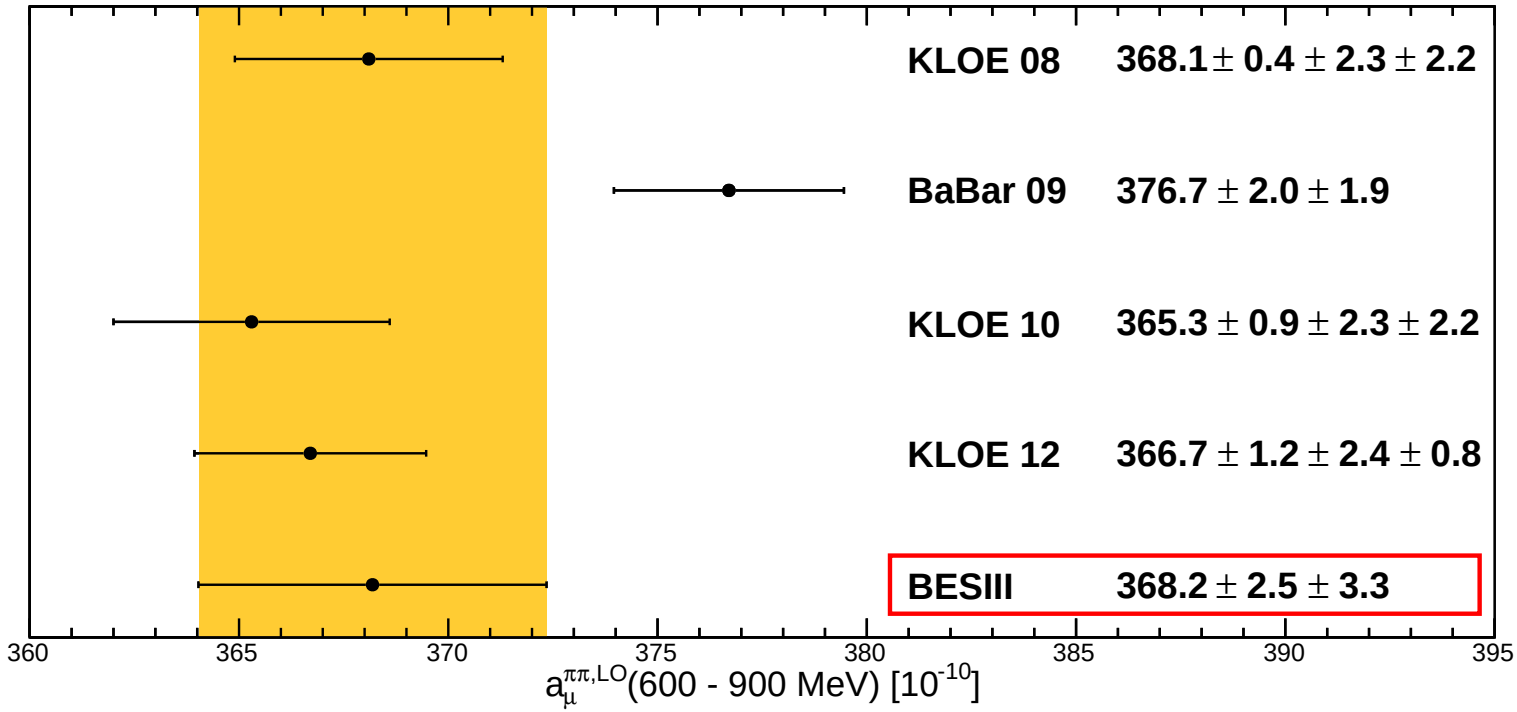
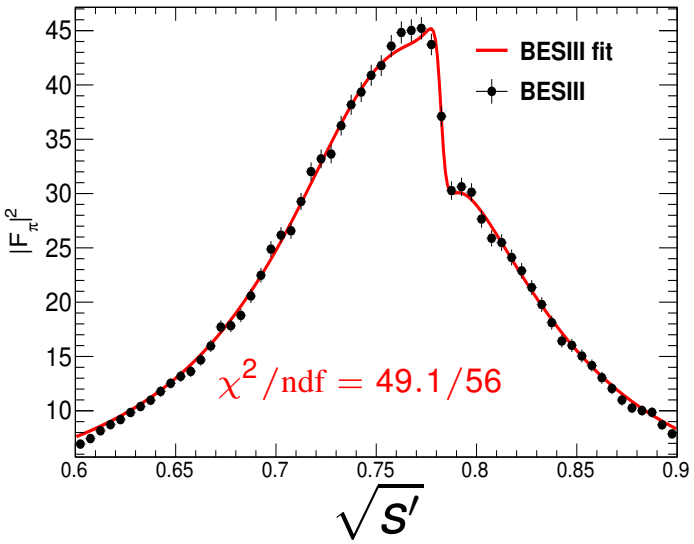
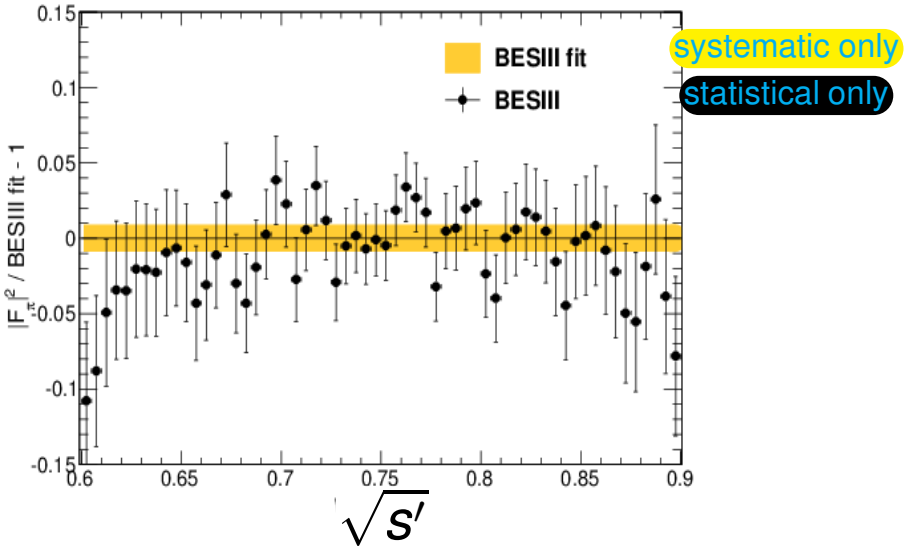


- Precision competitive with previous measurements
- BESIII measurement well agrees with KLOE
- Confirmed deviation between experiment and theory

$\pi^+\pi^-$ Form Factor

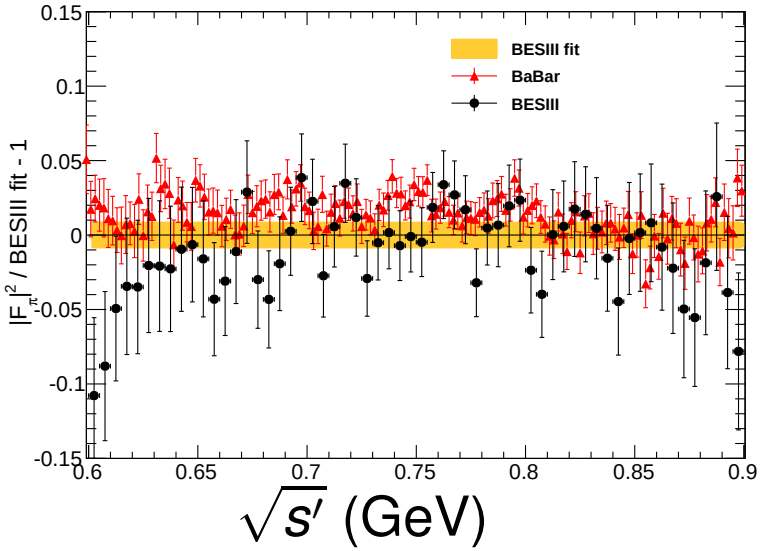
- $|F_\pi|^2(s') = \frac{3s'}{\pi\alpha\beta_\pi^3(s')}\sigma_{e^+e^-\to\pi^+\pi^-}(s')$

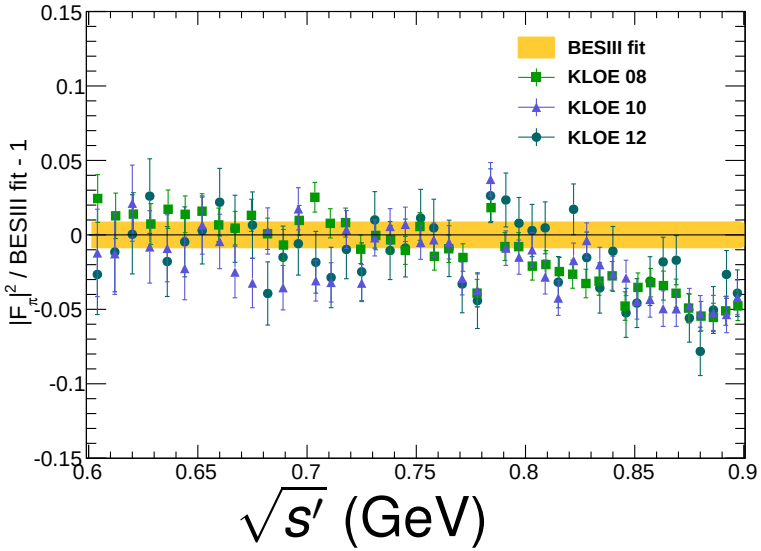




Parameter	BESIII value	PDG 2014
m_ρ [MeV/c^2]	776.0 ± 0.4	775.26 ± 0.25
Γ_ρ [MeV]	151.7 ± 0.7	147.8 ± 0.9
m_ω [MeV/c^2]	782.2 ± 0.6	782.65 ± 0.12
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08
$\lvert c_\omega \rvert$ [10^{-3}]	1.7 ± 0.2	-
$\lvert \phi_\omega \rvert$ [rad]	0.04 ± 0.13	-

Comparison with BaBar and KLOE

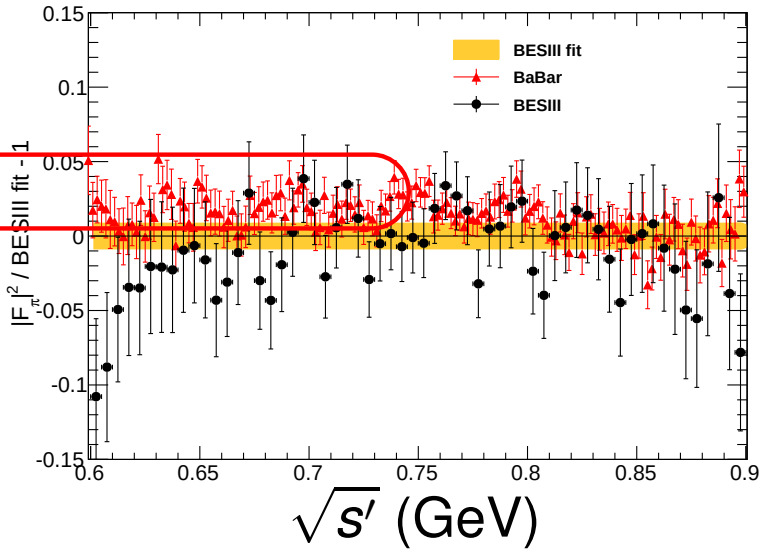




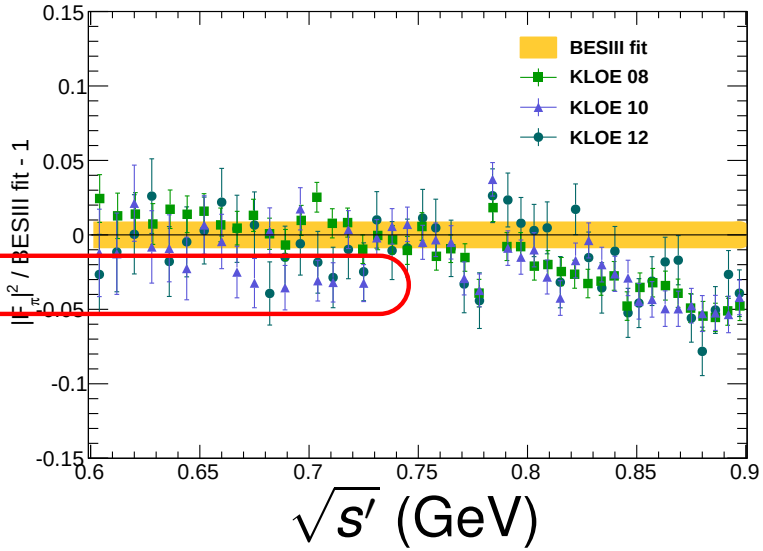
Comparison with BaBar and KLOE

systematic shift

BaBar



KLOE 10



Comparison with BaBar and KLOE

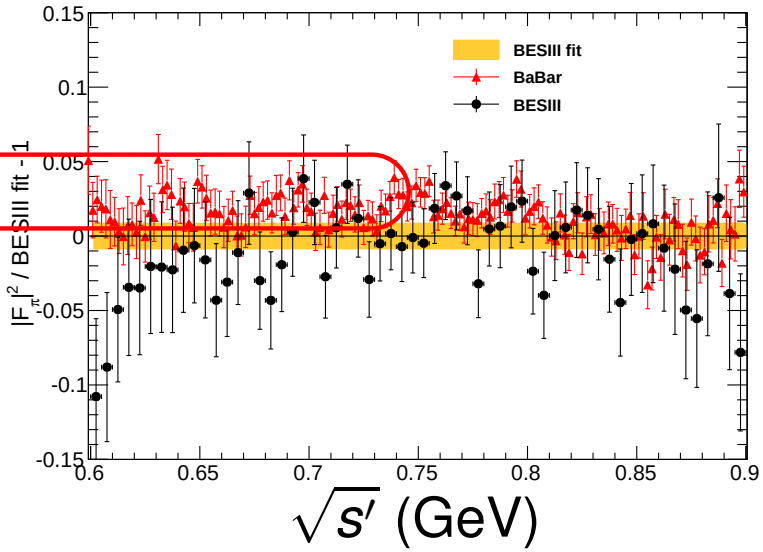
systematic shift

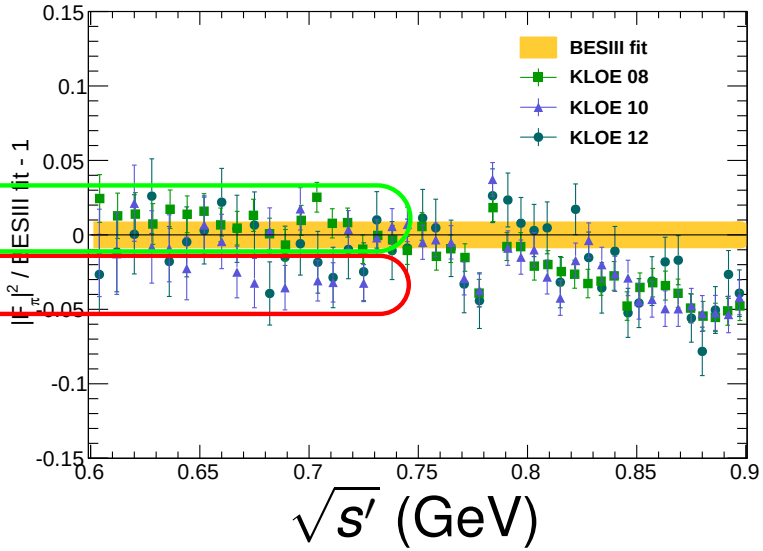
BaBar

KLOE08&12

KLOE 10

Agreement





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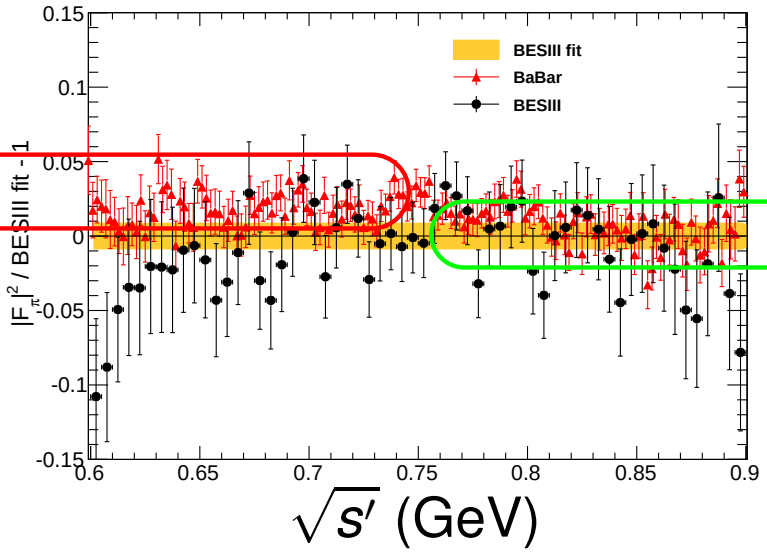
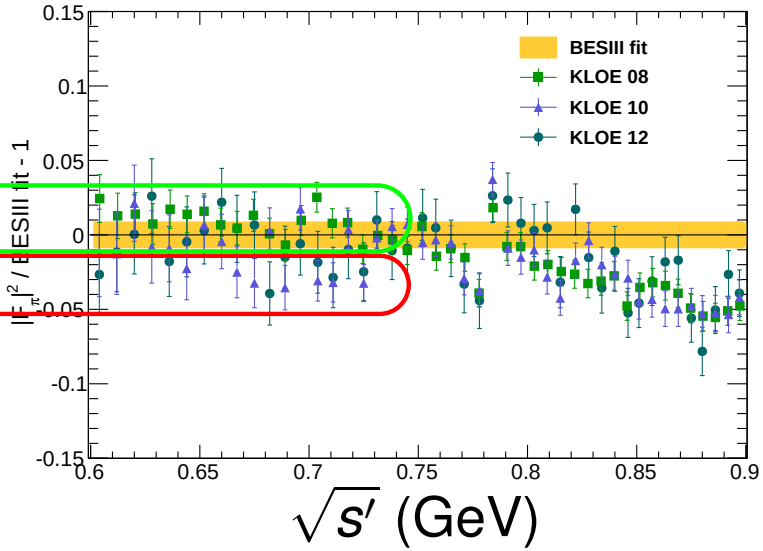




Agreement

BaBar

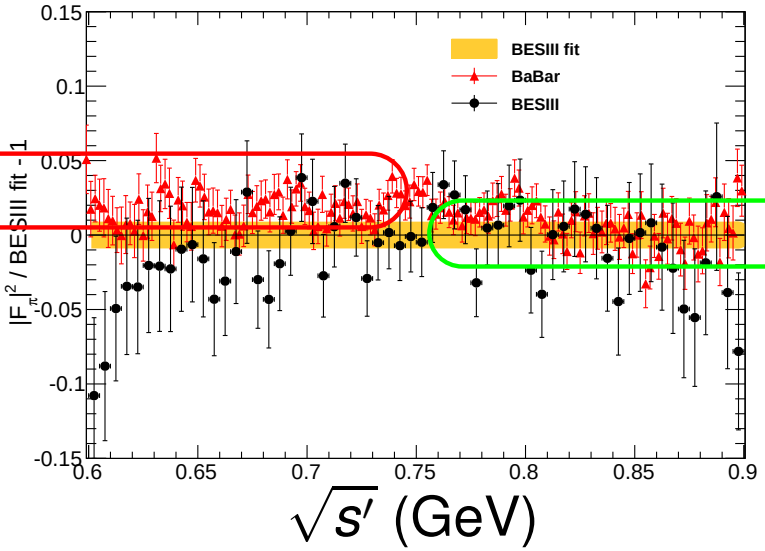
Comparison with BaBar and KLOE

systematic shift

Agreement

BaBar

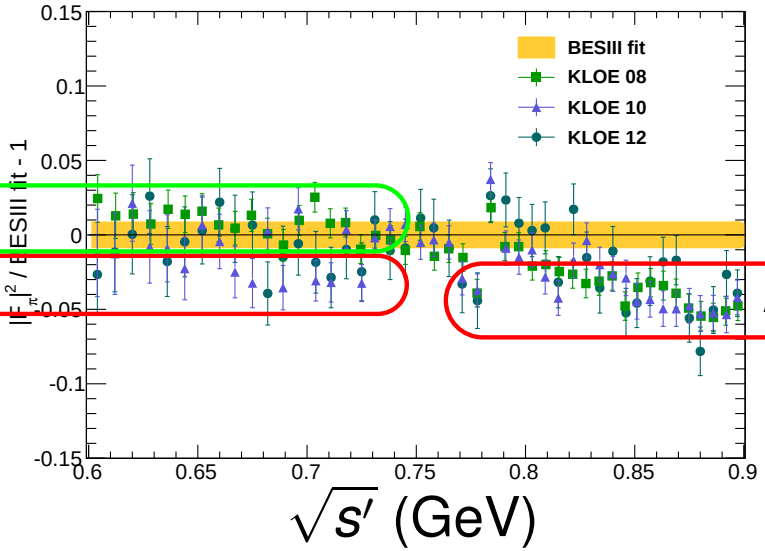
BaBar



KLOE08&12

KLOE 10

All KLOE



Agreement

systematic shift

Outline

Summary

- $e^+e^- \to \pi^+\pi^-$
  - Cross section is measured with sys. below 1%
  - Δa_μ is confirmed
- 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, $\mathcal{L} \approx 1.3\text{fb}^{-1}$)
  - Studies for $\pi^+\pi^-\pi^0(\pi^0)$ are under study

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Thank you!