Pion Form Factor Measurement at BESIII

Martin Ripka on behalf of the BESIII colaboration

EINN - November, 2015

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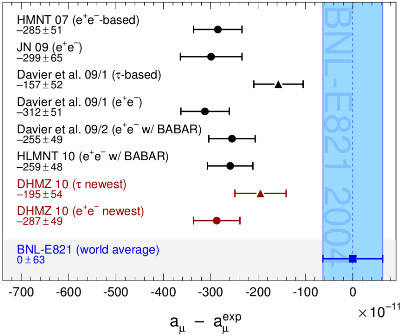
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Motivation: Why Form Factor Measurements at BESIII?

- Muon anomalous magnetic moment $a_\mu = (g_\mu - 2)/2$
- Experimental measurement at BNL:
  $a_\mu^{exp} = 11659208.9(5.4)(3.3) \times 10^{-10}$ [PRD **73** 072003 (2006)]
- Theoretical calculation:
  $a_\mu^{theo} = 11659182.8(4.9) \times 10^{-10}$ [J. Phys. G **38**, 085003 (2011)]
- Theory and experiment not in agreement:
  $a_\mu^{exp} - a_\mu^{theo} \approx (30 \pm 8) \times 10^{-10} \quad \Rightarrow 3 - 4\,\sigma$ deviation



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

Theoretical calculation of a_μ

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

$$a_\mu^{\text{QED}} = (11658471.8 \pm 0.0) \times 10^{-10}$$ [PRL **109**, 111808 (2012)]

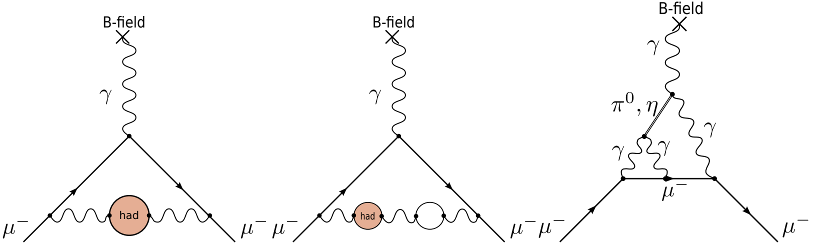
$$a_\mu^{\text{weak}} = (15.36 \pm 0.1) \times 10^{-10}$$ [PRD **88**, 053005 (2013)]

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

$$a_\mu^{\text{VP,LO}} = (694.9 \pm 4.2) \times 10^{-10}$$ [J. Phys. G **38**, 085003 (2011)]

$$a_\mu^{\text{VP,HO}} = (-98.4 \pm 0.7) \times 10^{-10}$$ [J. Phys. G **38**, 085003 (2011)]

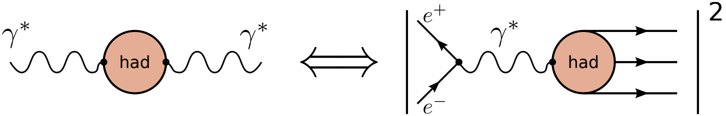
$$a_\mu^{\text{LbL}} = (11.6 \pm 3.9) \times 10^{-10}$$ [Phys. Rept. **477**, 1 (2009)]



The Vacuum Polarisation Contribution to a_μ^{QCD}

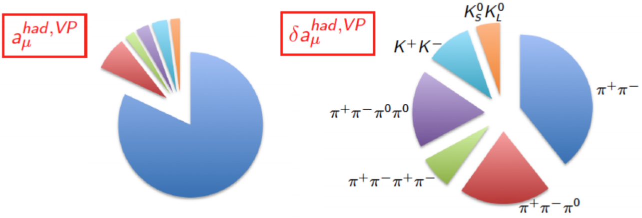
- Loop can not be calculated for low momentum hadrons
- Optical theorem connects VP amplitude with hadronic cross sections:

$$\sigma(s)_{e^+e^-\to\mathrm{hadrons}} = \frac{4\pi\alpha}{s}\,\mathrm{Im}\,\Pi_\gamma(s)$$



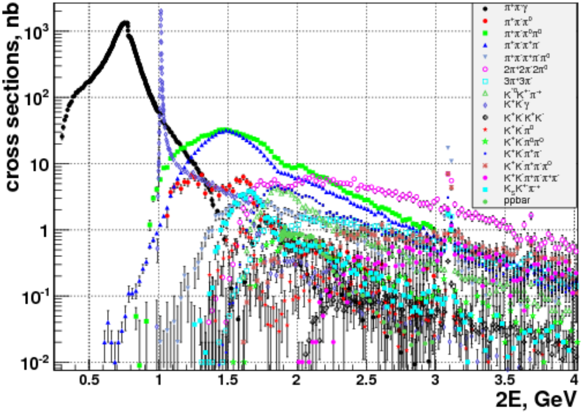
photon self-energy function $\mathrm{Im}\Pi_\gamma(s)$ hadronic cross-section $\sigma_{had}(s)$

- $a_\mu^{\mathrm{VP,LO}} = \frac{1}{4\pi^3}\int_0^\infty ds\, K(s)\sigma_{e^+e^-\to\mathrm{hadrons}}(s)$
- Hadronic contributions to a_μ^{QCD}:



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

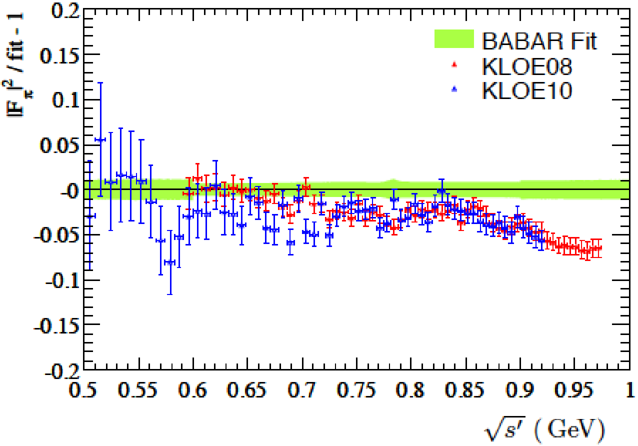
Hadronic Final States contributing to $a_\mu^{\mathrm{VP,LO}}$



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

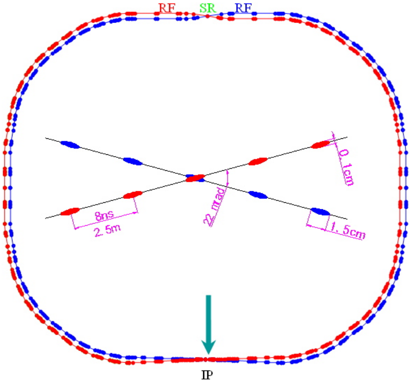
$\pi^+\pi^-$ at Babar and Kloe



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

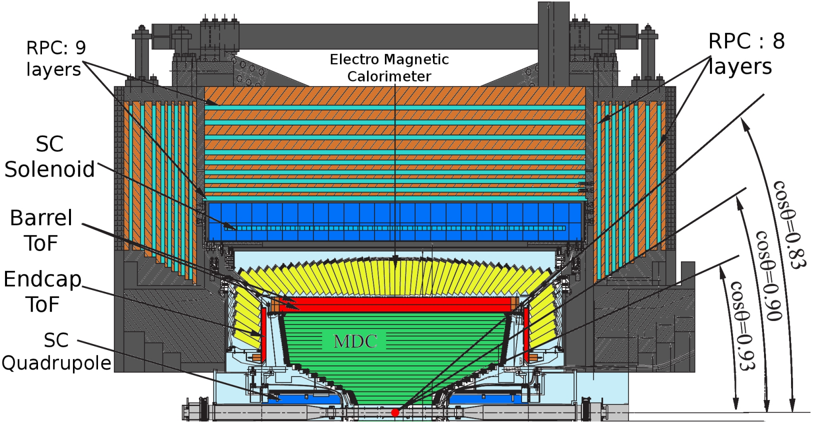
- Babar and Kloe each claim sub-percent precision
- Measurements do not agree with each other
- Another high precision measurement needed $\Rightarrow$ BESIII

BEPCII



- τ-charm factory
- Energy range: 2 - 4.6 GeV
- Design luminosity: $10^{33}\,\mathrm{cm}^{-2}s^{-1}$ (at 3.77 GeV)
- Linac + double storage ring

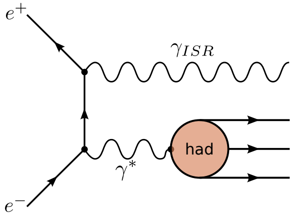
BESIII Detector



- Multilayer Drift Chamber (MDC)
- Time of Flight system (ToF)
- Electromagnetic Calorimeter (EMC)
- Super Conducting magnet 1 Tesla (SC)
- Resistive Plate Chamber (RPC) for muon detection

Initial State Radiation Technique I

- Need $\sigma_{had}(s)$ in the entire energy range where pQCD fails

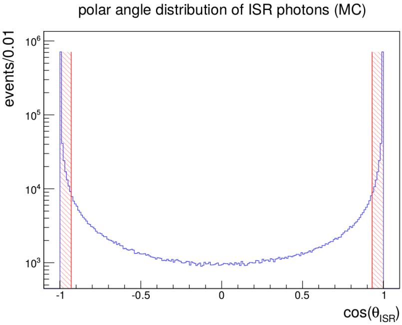


- Initial State Radiation (ISR) reduces the effective CMS-energy of the collision: $m_{had}^2 = E_{CMS}^2 - 2E_{CMS}E_{ISR}$
- Non radiative cross-section can be obtained by

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

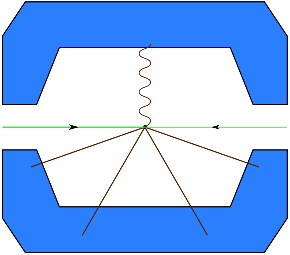
- Radiator-function $W(s, E_{ISR}, \theta_{ISR})$ gives the amplitude to emit an ISR photon

Initial State Radiation Technique II

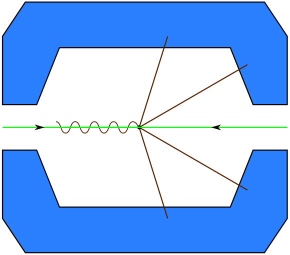


- Emission of ISR photons is suppressed by α/π
- High integrated luminosity needed for precision measurements
- Untagged analysis possible above $\approx 1\,\text{GeV}$

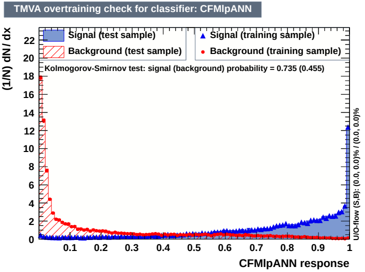
Tagged analysis



Untagged analysis

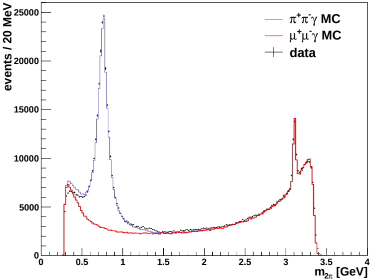


Event Selection and Particle Identification (PID)

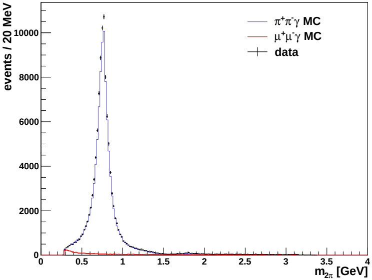


- Kinematic Fit for $\pi^+\pi^-\gamma_{ISR}$ final state
- Standard BESIII PID system for electron rejection
- Artificial Neuronal Network for muon-pion separation

Before ANN



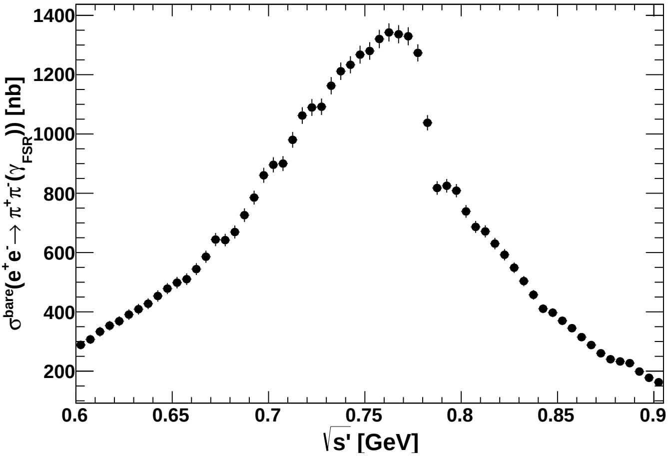
After ANN



Systematic Uncertainties

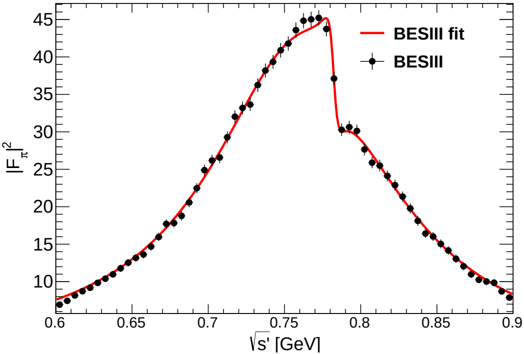
Source	Uncertainty (%)
Photon efficiency correction	0.2
Pion tracking efficiency correction	0.3
Pion ANN efficiency correction	0.2
Pion e-PID efficiency correction	0.2
ANN	negl.
Angular acceptance	0.1
Background subtraction	0.1
Unfolding	0.2
FSR correction δ_{FSR}	0.2
Vacuum polarisation correction δ_{vac}	0.2
Radiator function	0.5
Luminosity $\mathcal{L}$	0.5
Sum	**0.9**

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



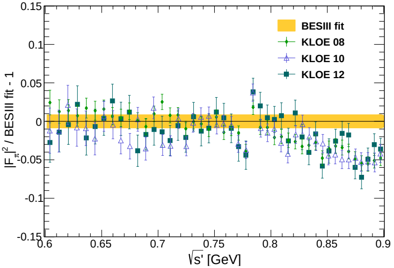
- $\sigma^{\textbf{bare}}(\sqrt{s'}) = \frac{1}{\frac{2\sqrt{s'}}{s} W(s,x)\epsilon(\sqrt{s'})\mathcal{L}\delta_{vac}\delta_{FSR}} \frac{dN}{d\sqrt{s'}}$
- ρ-ω interference clearly visible

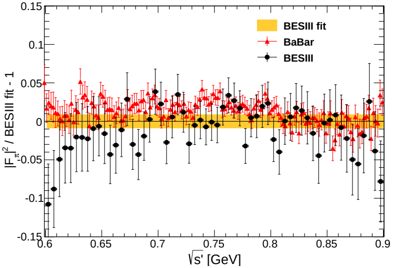
$\pi^+\pi^-$ Form Factor (Gounaris-Sakurai Parametrisation)

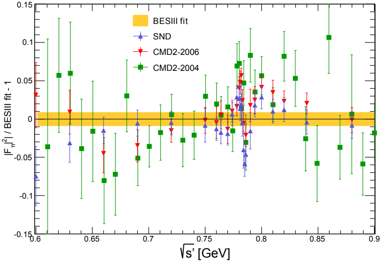


parameter	BESIII value	PDG 2014
m_ρ [MeV/c^2]	776.0 ± 0.4	775.26 ± 0.25
Γ_ρ [MeV]	151.7 ± 0.7	147.8 ± 0.9
m_ω [MeV/c^2]	782.2 ± 0.6	782.65 ± 0.12
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08
$\lvert c_\rho \rvert$ [10^{-3}]	1.7 ± 0.2	-
$\lvert \phi_\omega \rvert$ [rad]	0.04 ± 0.13	-

Comparison to Other $\pi^+\pi^-$ Measurements

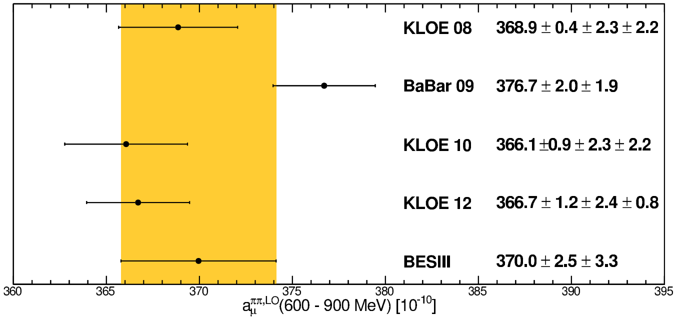






- New BESIII measurement agrees with KLOE and BaBar
- Small shift wrt. BaBar above ρ-ω interference

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



- Precision competitive with previous measurements
- BESIII measurement between BaBar and KLOE
- $a_\mu^{\pi\pi,\mathrm{LO}}(600 - 900\,\mathrm{MeV}) = (370.0 \pm 2.5_{\mathrm{stat}} \pm 3.3_{\mathrm{sys}}) \cdot 10^{-10}$
- Confirms deviation of 3.4σ between experiment and theory
- arXiv:1507.08188 and submitted to PLB

Outlook

- Extend tagged $\pi^+\pi^-$ ISR study to threshold region
- Use Untagged ISR technique for $\pi^+\pi^-$ cross section at higher energies
- Analyse $\pi^+\pi^-$ form factor from R-scan data (130 points, $\mathcal{L} \approx 1.3\text{fb}^{-1}$)

- Ongoing investigation of $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^0\pi^0$

Thank You