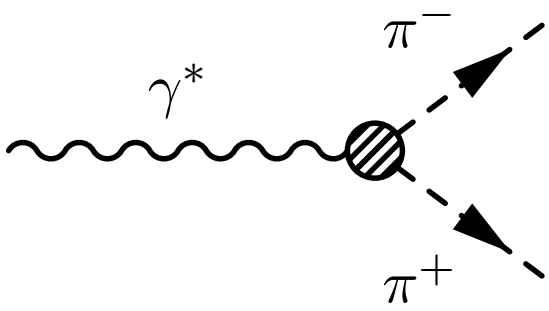
Meson form factors and $P \to \gamma^*\gamma^*$ physics at BESIII

For the BESIII Collaboration
Speaker: Joachim Pettersson
joachim.pettersson@physics.uu.se
Uppsala University

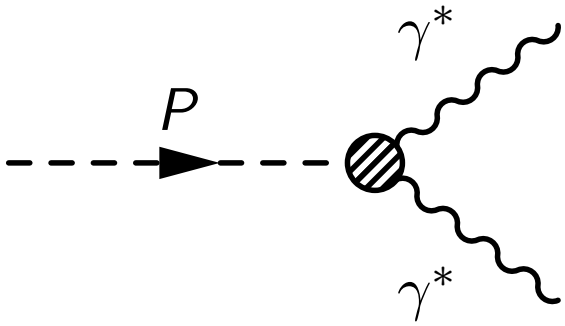
FAIRNESS,
14-19 February 2016

Outline

- Introduction
- BESIII experiment
- Recent results from BESIII, $\pi^+\pi^-$ form factor:

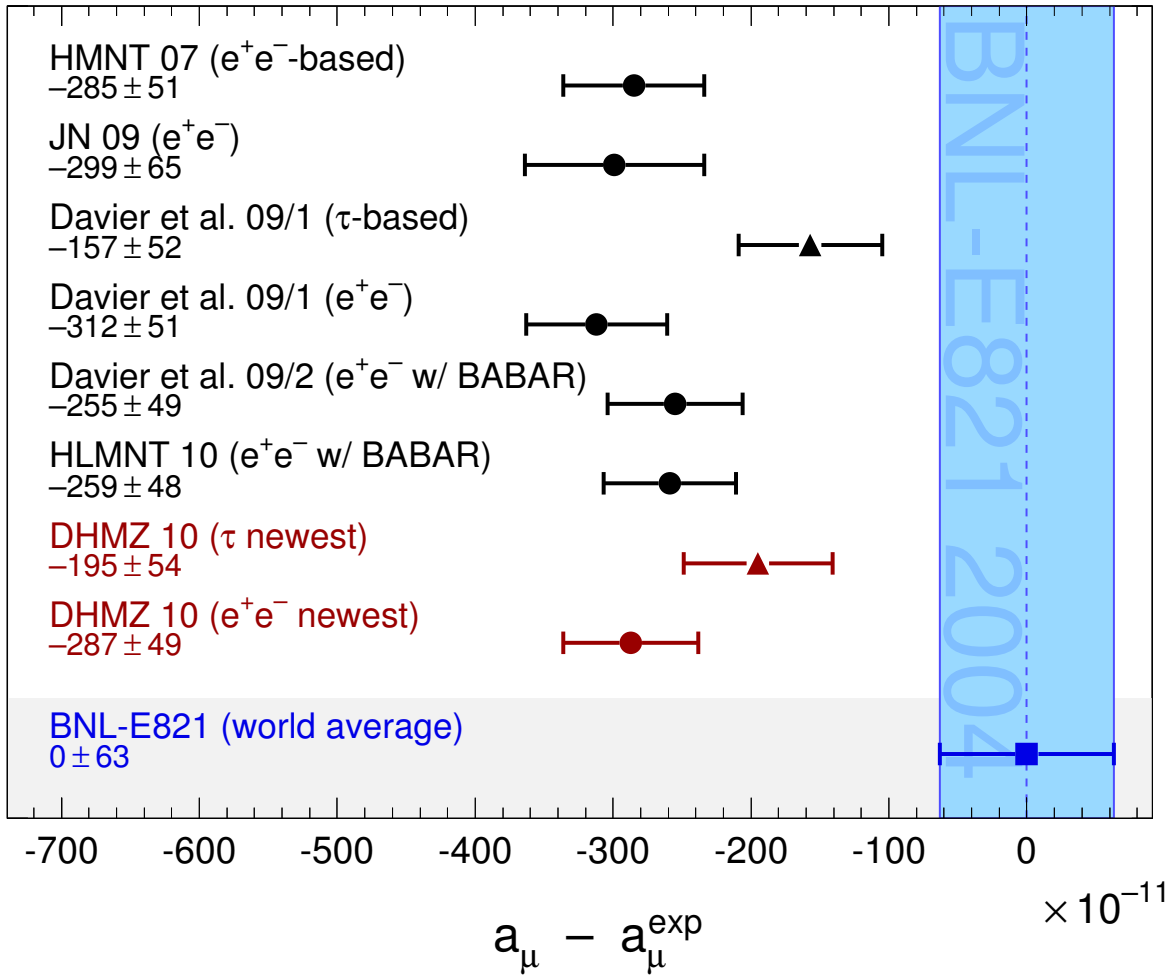


- Physics in the $P \to \gamma^*\gamma^*$ vertex:



Anomalous magnetic moment of the muon

$$a_\mu = (g-2)/2$$



Eur. Phys. J. C 71 1515 (2011)

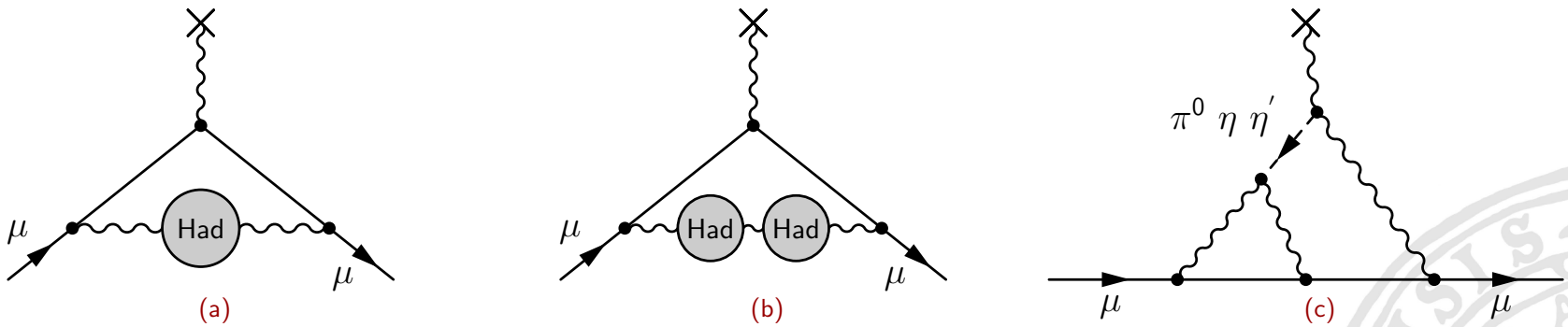
Contributions to a_μ

Breakup of a_μ^{theo}

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

Breakup of a_μ^{QCD}

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



Example diagrams: **(a)** Leading-, **(b)** higher order hadronic vacuum polarisation and **(c)** Light-by-light contributions.

Theory vs. experiment a_μ

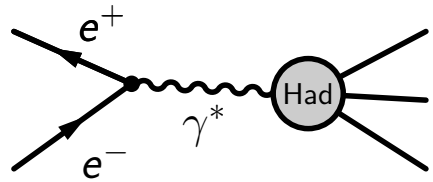
Sector	Contribution $\times 10^{-10}$	Reference
a_μ^{QED}	11658471.8$\pm$ 0.0	[PRL 109, 111808 (2012)]
a_μ^{weak}	15.3 $\pm$0.1	[PRD 88, 053005 (2013)]
$a_\mu^{VP,LO}$	694.9$\pm$4.2	[J. Phys. G 38, 085003 (2011)]
$a_\mu^{VP,HO}$	98.4$\pm$0.7	[J. Phys. G 38, 085003 (2011)]
a_μ^{LbL}	11.6$\pm$3.9	[Phys. Rept. 477, 1 (2009)]
a_μ^{theo}	11659182.8$\pm$4.9	[J. Phys. G 38, 085003 (2011)]
a_μ^{exp}	11659208.9$\pm$5.4$\pm$3.3	[PRD 73 072003 (2006)]
$a_\mu^{exp} - a_\mu^{theo}$	$\approx$30$\pm$8	3-4σ deviation

Theory vs. experiment a_μ

Sector	Contribution $\times 10^{-10}$	Reference
a_μ^{QED}	11658471.8$\pm$ 0.0	[PRL 109, 111808 (2012)]
a_μ^{weak}	15.3 $\pm$0.1	[PRD 88, 053005 (2013)]
$a_\mu^{VP,LO}$	694.9$\pm$4.2	[J. Phys. G 38, 085003 (2011)]
$a_\mu^{VP,HO}$	98.4$\pm$0.7	[J. Phys. G 38, 085003 (2011)]
a_μ^{LbL}	11.6$\pm$3.9	[Phys. Rept. 477, 1 (2009)]
a_μ^{theo}	11659182.8$\pm$4.9	[J. Phys. G 38, 085003 (2011)]
a_μ^{exp}	11659208.9$\pm$5.4$\pm$3.3	[PRD 73 072003 (2006)]
$a_\mu^{exp} - a_\mu^{theo}$	$\approx$30$\pm$8	3-4σ deviation

Vacuum polarisation

(a) Photon self energy



(b) Hadronic cross section

$$\sigma(s)_{e^+e^- \to hadrons} = \frac{4\pi\alpha}{s} Im\ \Pi_\gamma(s) \tag{1}$$

$Im\ \Pi_\gamma(s)$ is the photon vacuum polarization/self-energy function.

Calculating VP

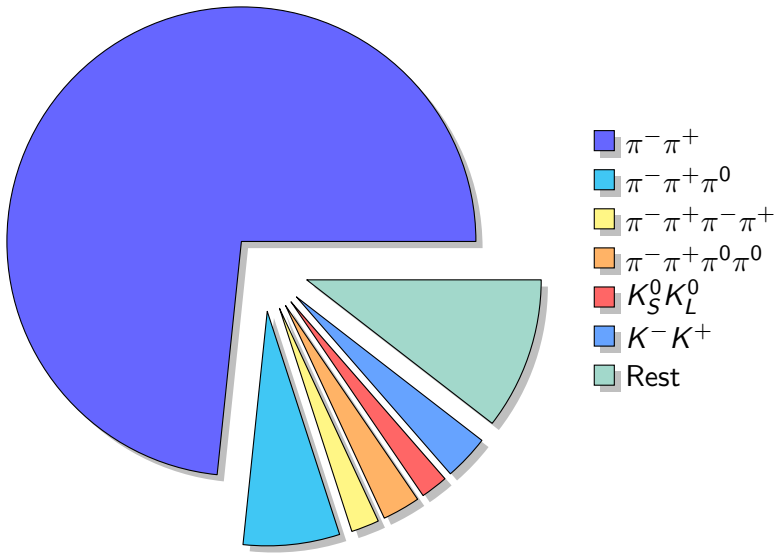
- Calculating the contribution of low momentum hadrons not possible in QCD.
- Optical theorem relates VP amplitude to final state cross sections.

Hadronic contributions to $a_\mu^{VP,LO}$

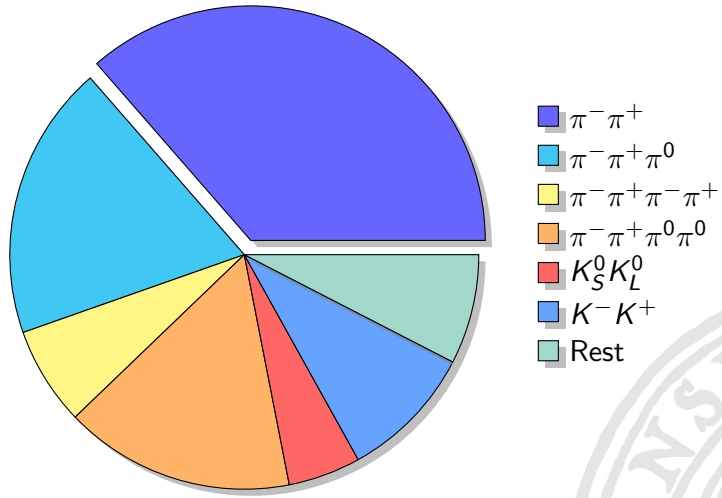
Relating cross section VP to $a_\mu^{VP,LO}$

- Many hadronic final states contribute.

$$a_\mu^{VP,LO} = \frac{1}{4\pi^3} \int_0^\infty ds\ K(s)\ \sigma(s)_{e^+e^- \to hadrons} \tag{2}$$



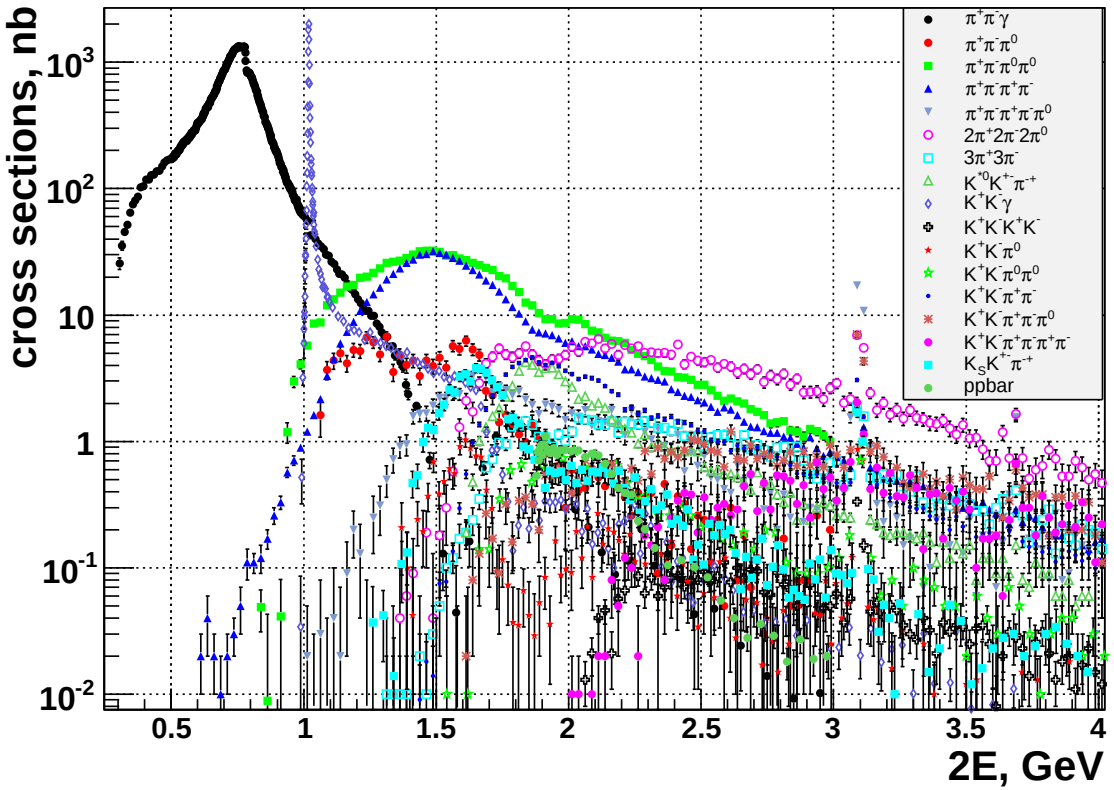
(a) Contributions to $a_\mu^{VP,LO}$.



(b) Contributions to $\sigma_{a_\mu^{VP,LO}}$.

Eur. Phys. J. C 71 1515 (2011)

Hadronic contributions to $a_\mu^{VP,LO}$



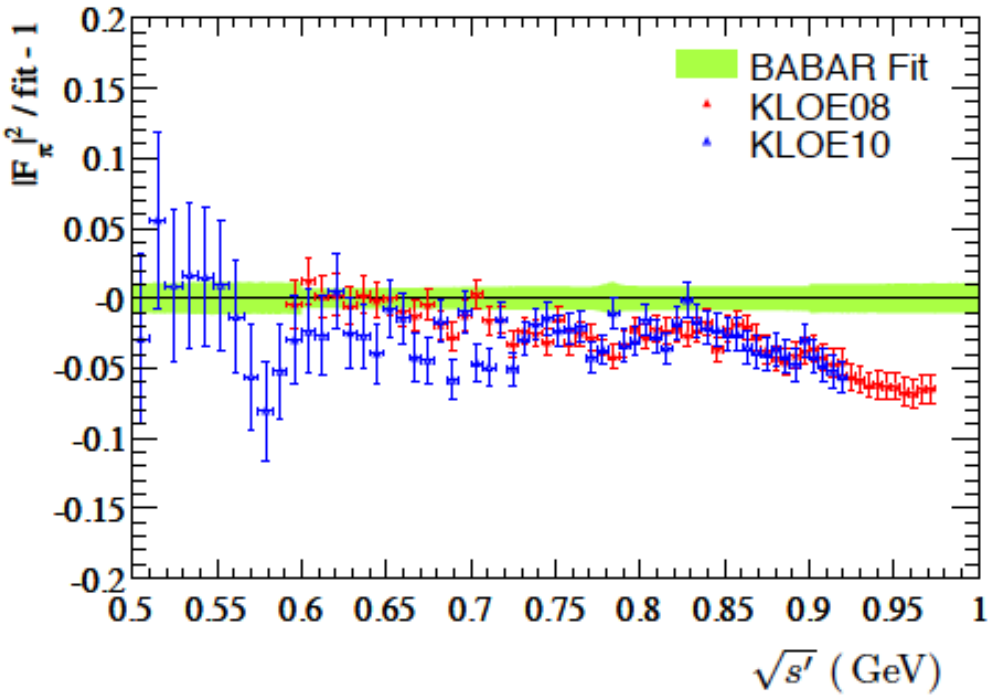
PoS Hadron 2013, 126 (2013) [arXiv:1402.0618 [hep-ex]].

- Most important: $\pi^-\pi^+$, $\pi^-\pi^+\pi^0$, ,$\pi^-\pi^+2\pi^0$, K^-K^+.
- Largest errors $\pi^-\pi^+$, $\pi^-\pi^+2\pi^0$, K^-K^+.

Status of $\pi^-\pi^+$ form factor

$|F(s)_{\pi\pi}|^2 \propto \sigma(s)_{\pi\pi}$

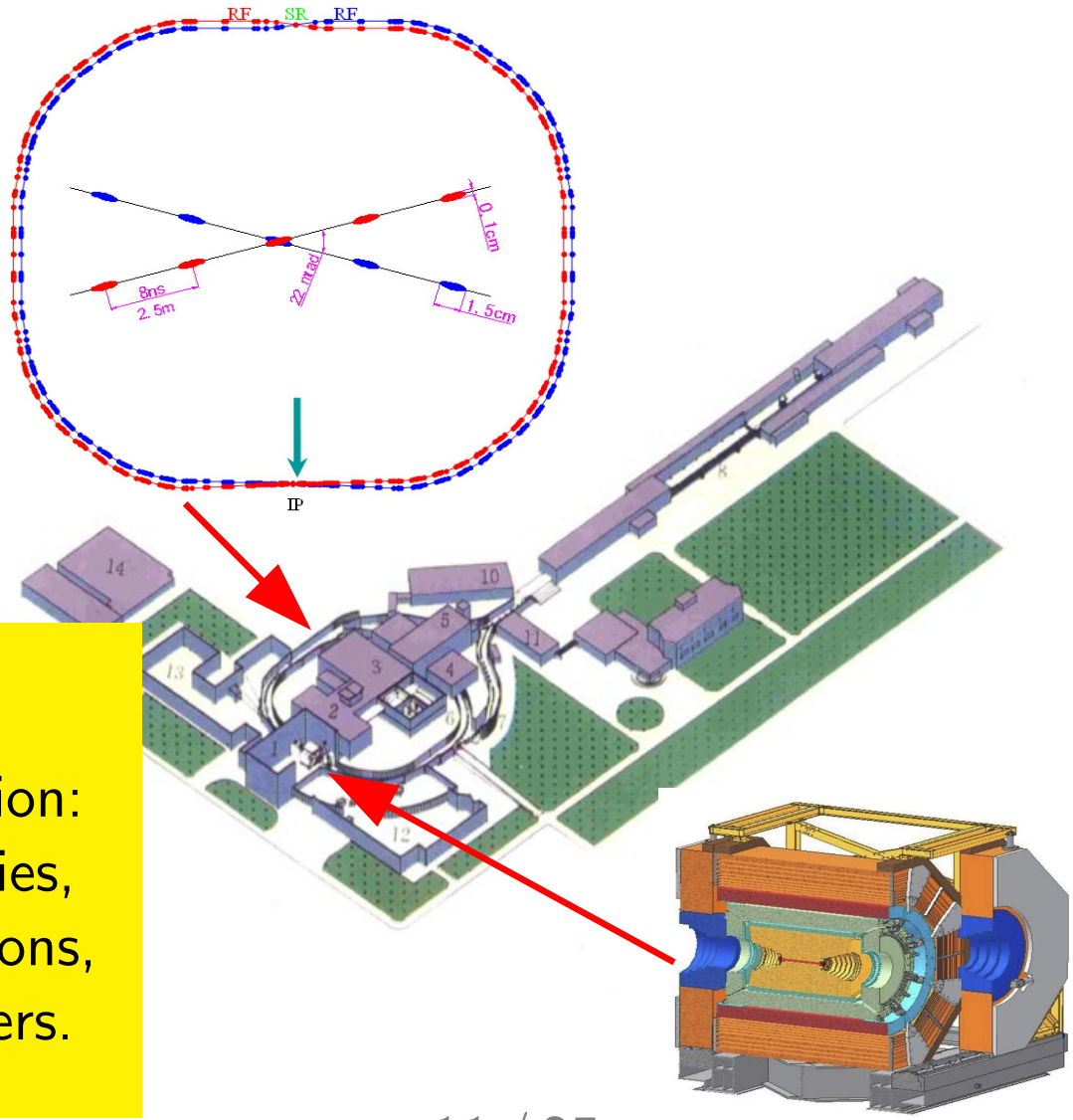
15 (2011)



BABAR and KLOE

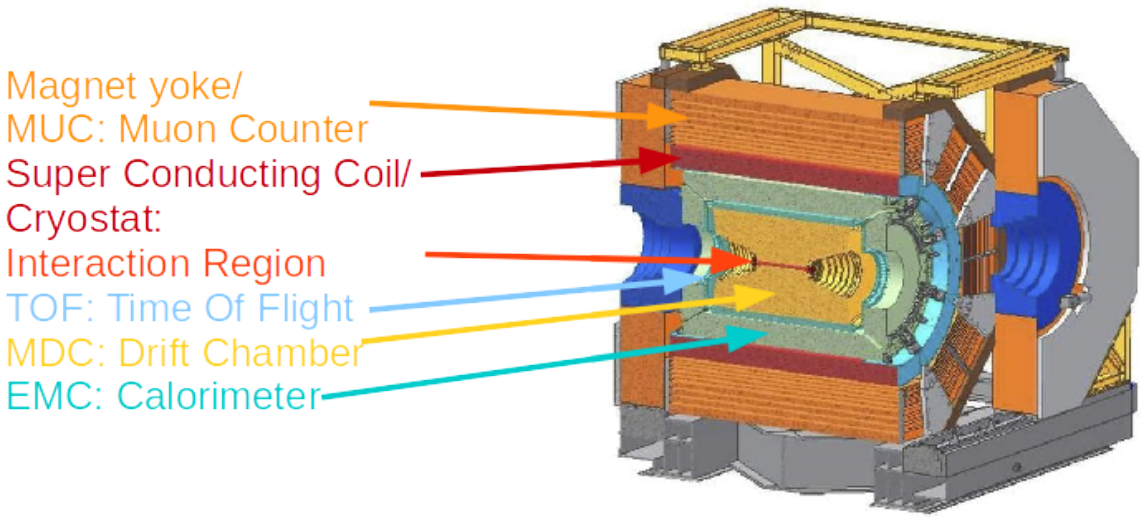
- High precision measurements, do not agree.
- New measurement needed, BESIII can provide!

Beijing Electromagnetic Spectrometer III
Beijing Electron Positron Collider II



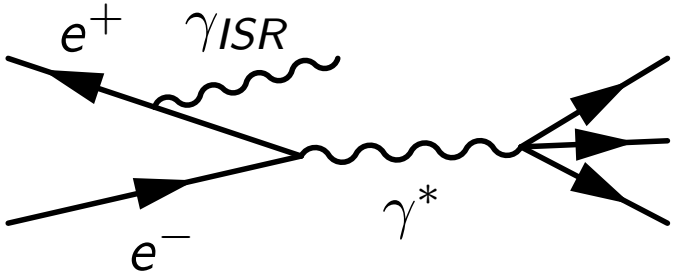
BESIII Collaboration:
12 Countries,
55 Institutions,
400 Members.

BESIII Detector

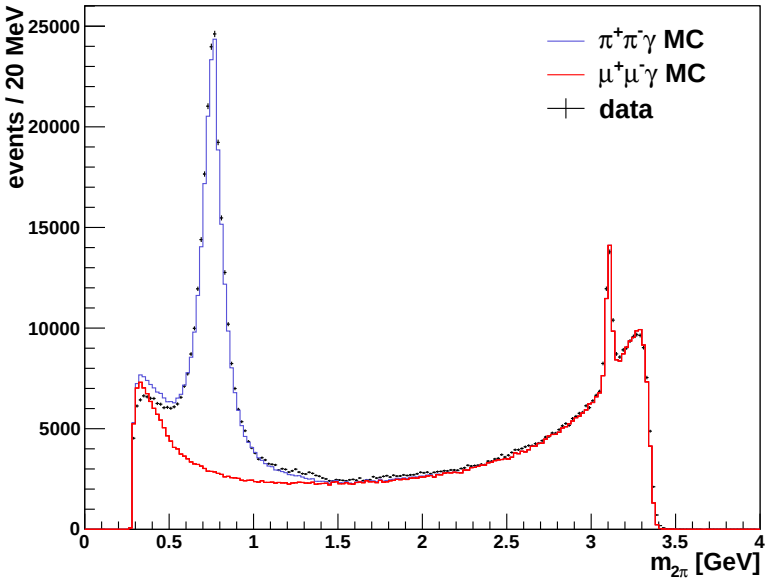


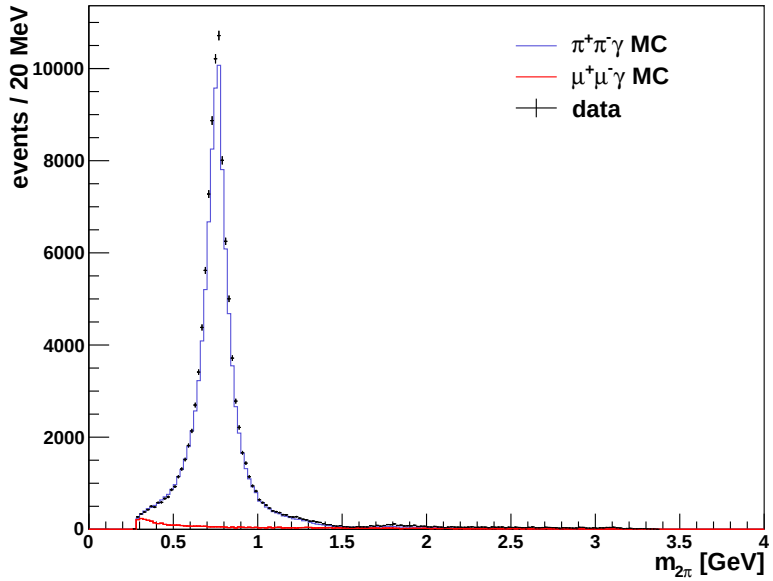
BESIII sub-system resolutions

- MDC: spatial 135 μm, σ_p ≈0.5 % @ 1 GeV.
- TOF: 80 ps, barrel, 90 ps endcaps.
- Calorimeter (CsI(Ti)): σ_E ≈2.5 %, barrel, σ_E ≈5 % endcaps @ 1 GeV.
- PID using MDC, TOF.



Event selection

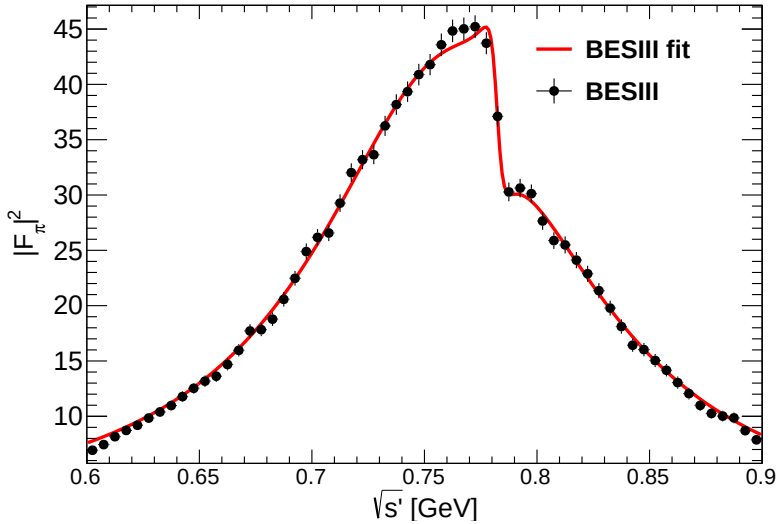




Event selections

- Kinematic fit of $\pi^+\pi^-\gamma_{ISR}$ final state
- Electrons rejected by BESIII standard PID system.
- Artificial Neural Network for differentiating $\mu^\pm - \pi^\pm$

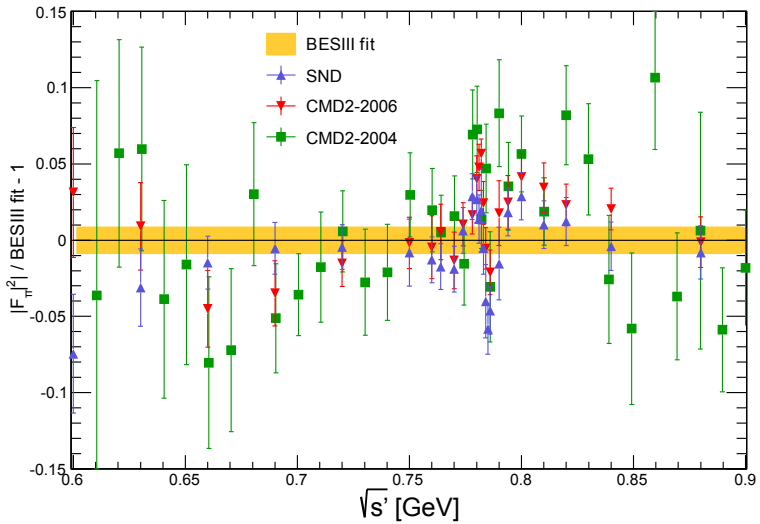
Form Factor of $\pi^+\pi^-$ (Gounaris-Sakurai Parametrisation)

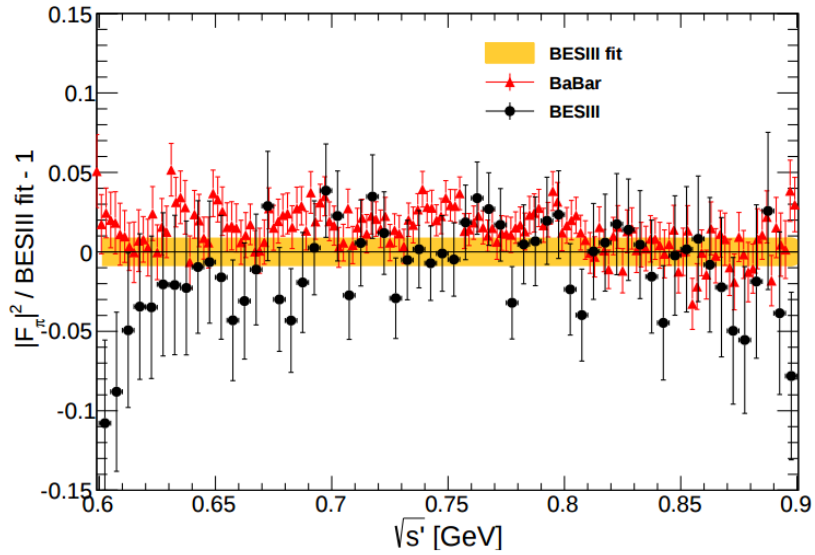


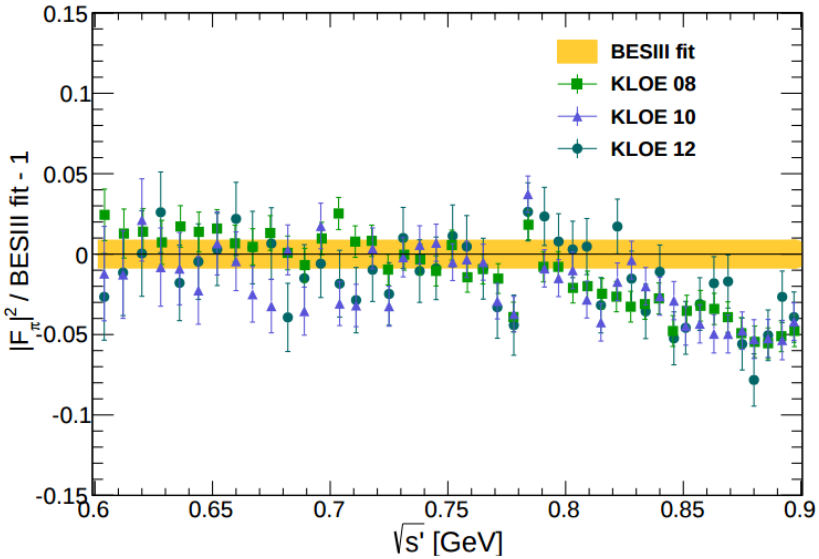
Parameter	BESIII	PDG14
m_ρ[MeV/c^2]	776.0 ± 0.4	775.26 ± 0.25
Γ_ρ[MeV]	151.7 ± 0.7	147.8 ± 0.9
m_ω[MeV/c^2]	782.2 ± 0.6	782.65 ± 0.12
Γ_ω [MeV]	fixed to PDG	8.49 ± 0.08
$\lvert c_\rho \rvert$ [10^{-3}]	1.7 ± 0.2	-
$\lvert \phi_\omega \rvert$ [rad]	0.04 ± 0.13	-

Comparison of form factor result

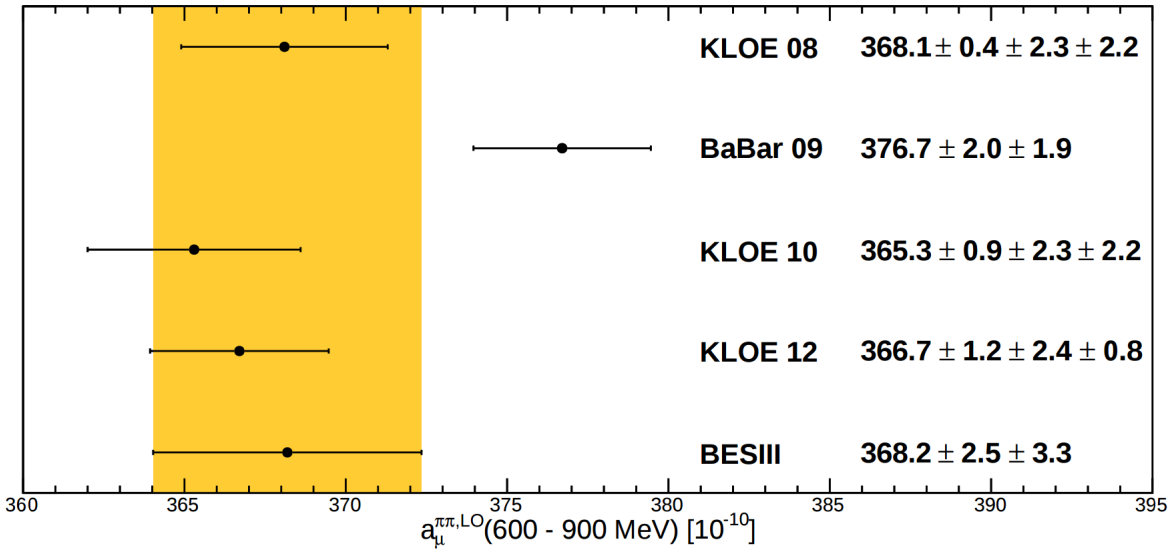
- New BESIII measurement in better agreement with KLOE than BaBar.







Comparison of contribution to $a_\mu^{VP,LO}$

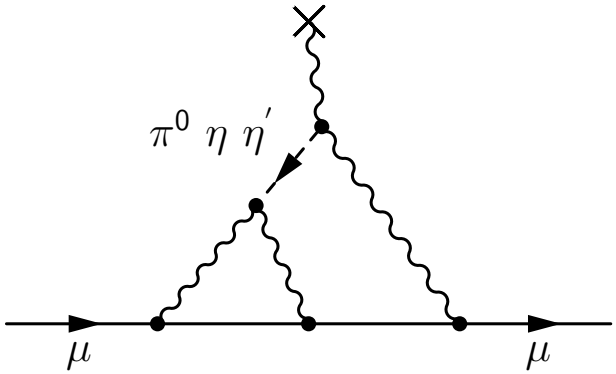


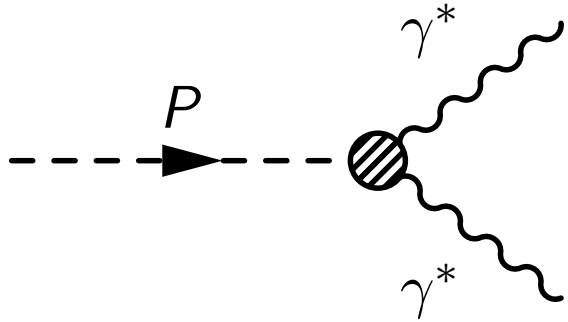
- Precision comparable with previous measurements
- BESIII compatible with KLOE, confirms deviation of 3.4 σ
- Phys.Lett. B753 (2016) 629-638, arXiv:1507.0818

Outlook

- Full low energy range: Improve g-2
- High energy range: Meson spectroscopy, pion form factor.

Physics in the $P \to \gamma^*\gamma^*$ vertex





Light-by-light contribution to a_μ

Data on process involving $P \to \gamma^*\gamma^*$ needed for a_μ^{LbL} calculations.

Pseudo scalars $\rightarrow$ leptons

$P \rightarrow \gamma^*\gamma^*$ vertex in $P \rightarrow e^+e^-$

Experiment $\neq$ theory:

- $\pi^0 \rightarrow e^+e^-$ branching ratio, $\approx 2-3\sigma$ deviation [Masjuan15,Dorokhov07].
- What about other $P \rightarrow \gamma^*\gamma^*$ processes involving η, η', η_c?
- $P \rightarrow e^+e^-$ door to new physics? U-bosons, leptoquarks etc. [Phys. Rev. D78, 115002],[arxiv:0704.3498v2].

Status of $P \to e^+e^-$

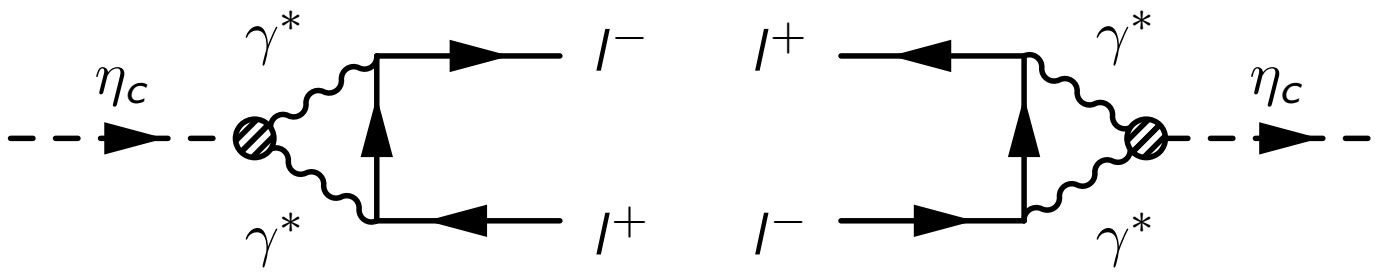
Table : Pseudoscalar to lepton branching ratios.
Theory from [Petri2010,Dorokhov2009].
Experiments: [KTeV2007], [HADES2012], [CMD,SND2015].

Branching ratio	Theory	Experiment
$\mathcal{B}(\pi^0 \to e^+e^-)$	$(6.23 \pm 0.12) \times 10^{-8}$	$(7.49 \pm 0.38) \times 10^{-8}$
$\mathcal{B}(\eta \to e^+e^-)$	$(5.2 \pm 0.3) \times 10^{-9}$	$\leq 5.6 \cdot 10^{-6}$
$\mathcal{B}(\eta^{'} \to e^+e^-)$	$(1.9 \pm 0.3) \times 10^{-10}$	$\leq 1.2 \cdot 10^{-8}$
$\mathcal{B}(\eta_c \to e^+e^-)$	-	-

No prediction or measurement for η_c!

Enter BESIII!

Pseudo scalars $\rightarrow$ leptons

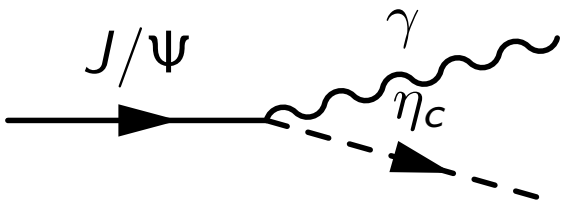


(a) Decay. (b) Formation.

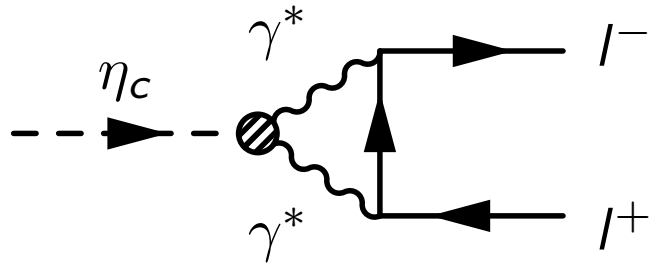
The $P \rightarrow l^+ l^-$ process

- Physics accessible in bot decay and formation.

Modes of access: Decay



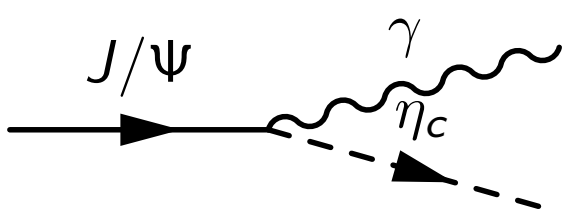
(a) η_c in J/Ψ radiative decay.



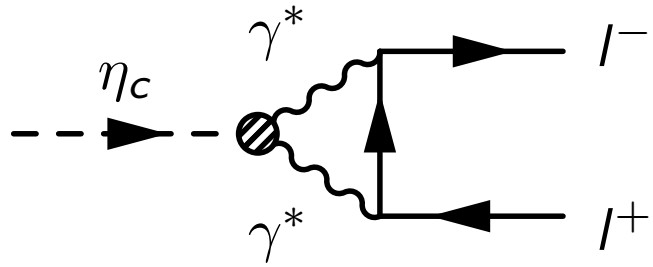
(b) η_c Decay.

- Decay product $J/\Psi \to \eta_c\gamma \to (e^+e^-)_{\eta_c}\gamma$.

Modes of access: Decay



(a) η_c in J/Ψ radiative decay.



(b) η_c Decay.

- Decay product $J/\Psi \to \eta_c\gamma \to (e^+e^-)_{\eta_c}\gamma$.
  - BESIII have 10^9 J/Ψ on tape.
    $\mathcal{B}(J/\Psi \to \eta_c\gamma) \approx 1.7\% \to \approx 10^7$ η_c candidates.
  - $\eta_c\gamma \to (e^+e^-)_{\eta_c}\gamma \to$ Background from $(e^+e^-)_{bhaba}\gamma_{ISR}$.
  - $\eta_c\gamma \to (\mu^+\mu^-)_{\eta_c}\gamma \to$ Background from
    $e^+e^- \to \mu^+\mu^-\gamma_{ISR}/(\mu^+\mu^-)_{J/\Psi}\gamma_{ISR}$

Modes of access: Formation

(a) η_c Formation in e^+e^-. (b) η_c Decay into final state.

- Direct production $e^+e^- \to \eta_c$. Possible at BESIII!
  - Only background from em-continuum.
  - Choice of final state(s) to study.
  - C-even final states suppress direct γ^* background.

Modes of access: Formation

(a) η_c Formation in e^+e^-. (b) η_c Decay into final state.

- Direct production $e^+e^- \to \eta_c$. Possible at BESIII!
  - Only background from em-continuum.
  - Choice of final state(s) to study.
  - C-even final states suppress direct γ^* background.

Work in progress!

Summary

- BESIII $\pi^+\pi^-$ form factor and $a_\mu^{VP,LO}$ measurement precision comparable with previous measurements.
- BESIII compatible with KLOE, confirms deviation of 3.4 σ.
- $\pi^+\pi^-$ pater published: Phys.Lett. B753 (2016) 629-638, arXiv:1507.0818.
- $e^+e^- \to \eta_c$ in progress.

Thank you for the attention!