Measurement of the Singly Virtual Transition Form Factor of the $f_1(1285)$ in a Partial Wave Analysis at BESIII

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Hadronic Light-by-Light Scattering (HLbL)

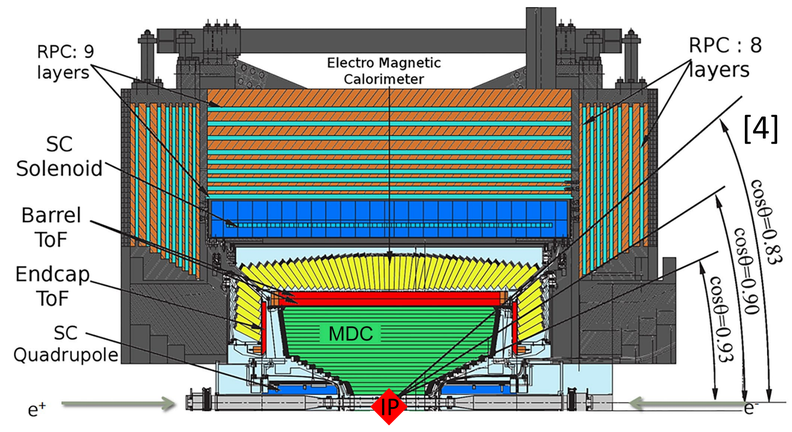
- Large relative uncertainty for data-driven HLbL contribution to a_μ^{SM}
- **Axial-vector mesons** contribute to a large part to the uncertainty [2]
- Transition form factor (TFF) measurements of two-photon coupling to axial-vectors needed [1]
- TFFs depend on momentum transfer Q^2
- BESIII is perfectly suited for singly virtual TFF measurements in the low Q^2 range

Contribution to a_μ^{HLbL} [2]	$[10^{-11}]$
PS-poles	$91.2^{+2.9}_{-2.4}$
π, K-box	-16.4 ± 0.2
S-waves	-9.1 ± 1.0
Short-distance	$6.2^{+0.2}_{-0.3}$
Mixed regime	15.9 ± 1.7
Long-distance	12.5 ± 5.9
NLO charm	3 ± 1
Total HLbL	103.3 ± 8.8

The BESIII Experiment

- Located at the Beijing Electron Positron Collider II (BEPCII)
- Energies between 2.0 GeV < $\sqrt{s}$ < 5.0 GeV
- Covers 93 % of the full solid angle
- Data set: 20.2 fb^{-1} at $\sqrt{s} = 3.773$ GeV [3]

Muon Chambers
Superconducting Magnet
Electromagnetic Calorimeter
Time of Flight System
Multilayer Drift Chamber



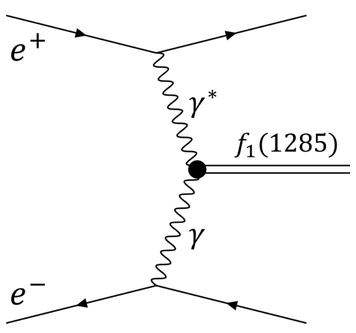
[4]

The Axial-Vector Meson $f_1(1285)$

Two-photon production cross section measured in:

$$e^+e^- \to e^+e^-\gamma^*\gamma, \qquad \gamma^*\gamma \to f_1(1285) \to \eta\pi^+\pi^-$$

- Two-photon production of $J^{PC} = 1^{++}$ state
  → At least one virtual photon needed (Landau–Yang theorem) [5]
- Different helicity configurations due to polarization of the photons: Longitudinal (L) or Transversal (T)
- In the single virtual case, the $\gamma^*\gamma \to \eta\pi^+\pi^-$ amplitude only contains the independent LT and TT TFFs [8]



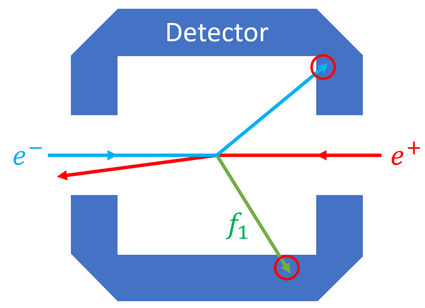
$$\mathcal{M}_{f_1\gamma^*\gamma} = ie^2\varepsilon_\mu(q_1,\lambda_1)\varepsilon_\nu(q_2,\lambda_2)\varepsilon^{\omega *}(q_1+q_2,\Lambda_{f_1})\,\epsilon_{\rho\sigma\tau\omega}$$
$$\times\Bigg\{\Big[\nu g^{\mu\rho}g^{\nu\sigma}(q_1-q_2)^\tau - g^{\mu\rho}q_1^\nu q_2^\sigma q_1^\tau + g^{\nu\rho}\left(q_1^\mu + q_2^\mu + \frac{Q_1^2}{\nu}q_2^\mu\right)q_2^\sigma q_1^\tau\Big]\frac{1}{M_{f_1}^2}F^{TT}_{f_1\gamma^*\gamma^*}(Q_1^2,0) - g^{\nu\rho}\left(q_1^\mu + \frac{Q_1^2}{\nu}q_2^\mu\right)q_1^\sigma q_2^\tau\frac{1}{M_{f_1}^2}F^{LT}_{f_1\gamma^*\gamma^*}(Q_1^2,0)\Bigg\}$$

Analysis Strategy

Single-Tag technique:

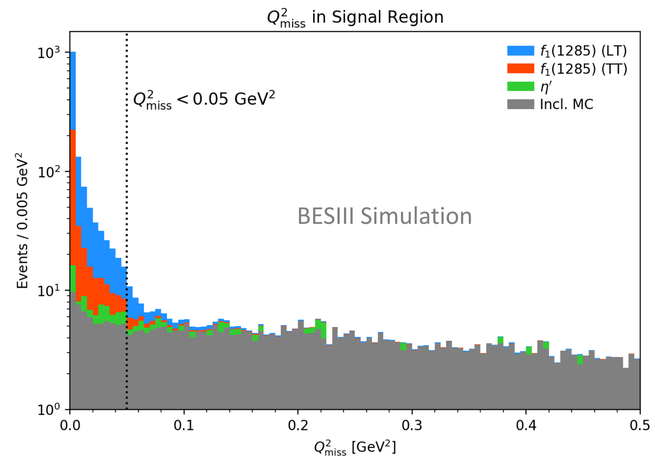
One detected $e^\pm$
→ virtual photon with high Q^2_{tag}

One missing $e^\mp$
→ quasi real photon with low Q^2_{miss}



Event selection:

- PID for π^+, π^-, $e^\pm_{\mathrm{tag}}$ and require ≥ 2 photons for η
- 2C kinematic fit with all $\gamma\gamma$-combinations and missing $e^\pm$
- Conditions for $\chi^2_{2C} < 50$ and $Q^2_{\mathrm{miss}} < 0.04\ \mathrm{GeV}^2$



Partial Wave Analysis of $\gamma^*\gamma \to \eta\pi^+\pi^-$

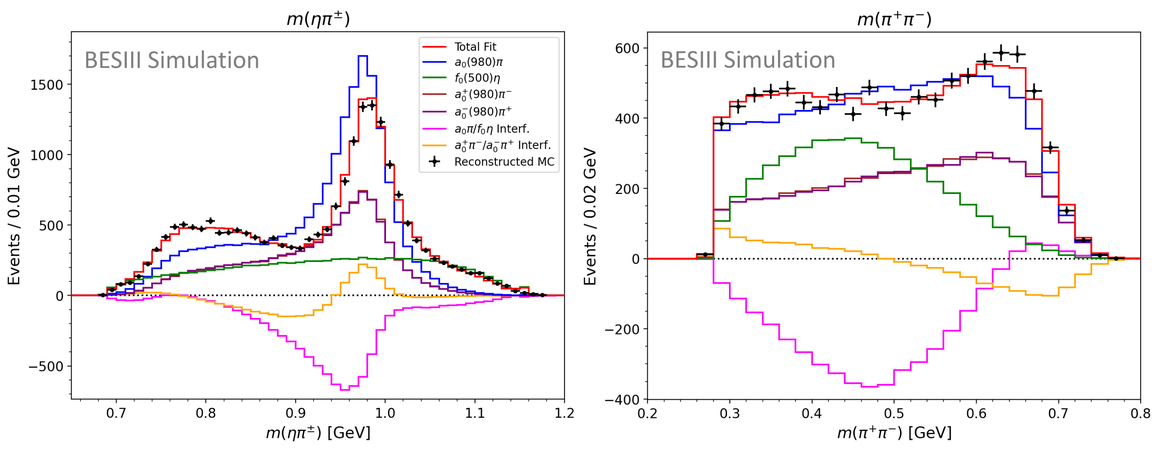
Two intermediate states in decay to $\pi^+\pi^-\eta$:

- $f_1(1285) \to a_0^\pm(980)\pi^\mp \to \eta\pi^+\pi^-$ $(38 \pm 4\ \%)$ [6]
- $f_1(1285) \to \eta f_0(500) \to \eta\pi^+\pi^-$ $(14 \pm 4\%)$ [6]
- Each channel has LT and TT contributions

Interferences between $a_0^+\pi^-$ and $a_0^-\pi^+$ and between $a_0^\pm(980)\pi^\mp$ and $\eta f_0(500)$ intermediate states:

- Dedicated $\gamma^*\gamma \to \eta\pi^+\pi^-$ amplitude [8] in new HadroTOPS generator and partial wave analysis framework AmpTools

→ Simulation and fit of interferences (in LT and TT) possible



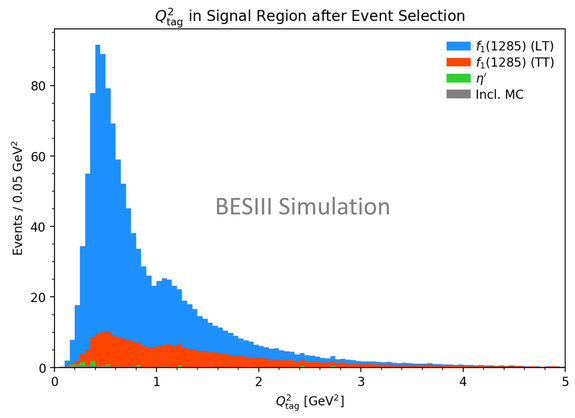
Parametrization:

- $f_1(1285)$ and $a_0(980)$ parametrized as Breit-Wigner with energy-dependent width, considering all branching ratios
- $f_0(500)$ parametrized as s-wave isospin $I = 0$ Omnes function

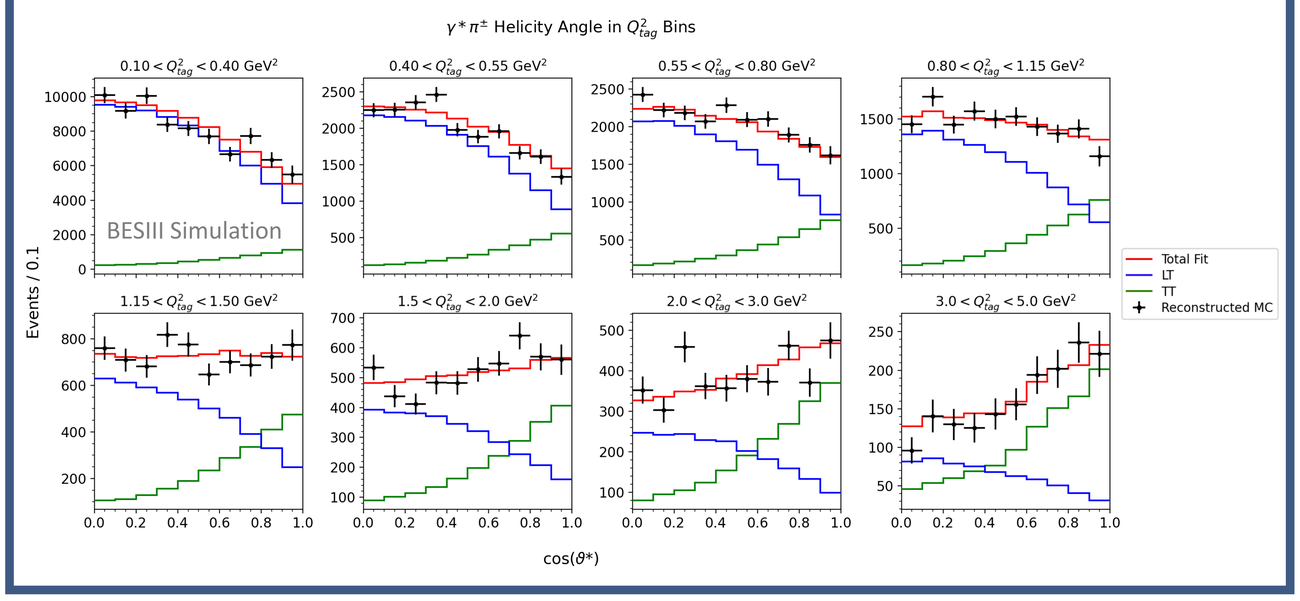
→ Mass and width measurements of $f_1(1285)$ and $a_0(980)$ possible

Form Factor Measurement

- **Form factor measurement** in range $0.1\ \mathrm{GeV}^2 < Q^2_{\mathrm{tag}} < 5.0\ \mathrm{GeV}^2$
- Singly virtual LT and TT transition form factors ($Q^2_{\mathrm{miss}} \approx 0$)
- Fit with quark model TFF to compare to previous measurements
- Direct fit in Q^2_{tag} bins in PWA



Goal: Direct measurement of $F^{LT}_{f_1\gamma^*\gamma}(Q^2_{\mathrm{tag}}, Q^2_{\mathrm{miss}})$ and $F^{TT}_{f_1\gamma^*\gamma}(Q^2_{\mathrm{tag}}, Q^2_{\mathrm{miss}})$ distribution with PWA



References:

[1] JHEP 07 (2021) 106
[2] arXiv:2505.21476 [hep-ph] (WP25)
[3] arXiv:2406.05827
[4] Nucl.Instrum.Meth.A 614 (2010) 345-399
[5] Phys. Rev. 77, 242
[6] Phys. Rev. D 110, 030001 (Particle Data Group 2024)
[7] Comput.Phys.Commun. 185 (2014) 236-243
[8] *Phys.Rev.D* 110 (2024) 9, 094043