JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Meson Transition Form Factors

an experimental overview

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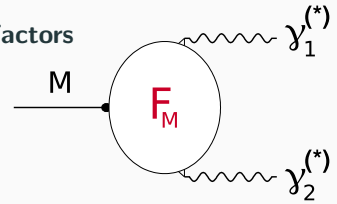
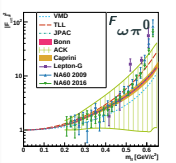
Introduction

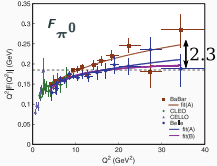
Meson Transition Form Factors

$$\mathcal{A}\left(M \leftrightarrow \gamma^{(*)}\gamma^{(*)}\right) \quad \sim \quad \mathcal{F}_M(q_1^2, q_2^2)$$



- Benchmark and input to phenomenological models in low-energy region and pQCD

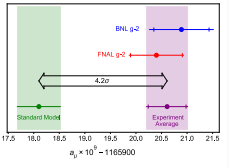




Belle, Phys.Rev.D 86 (2012) 092007

- Important for in-medium studies of hadrons in heavy-ion collisions
  - *See next talk by Witold Przygoda!*

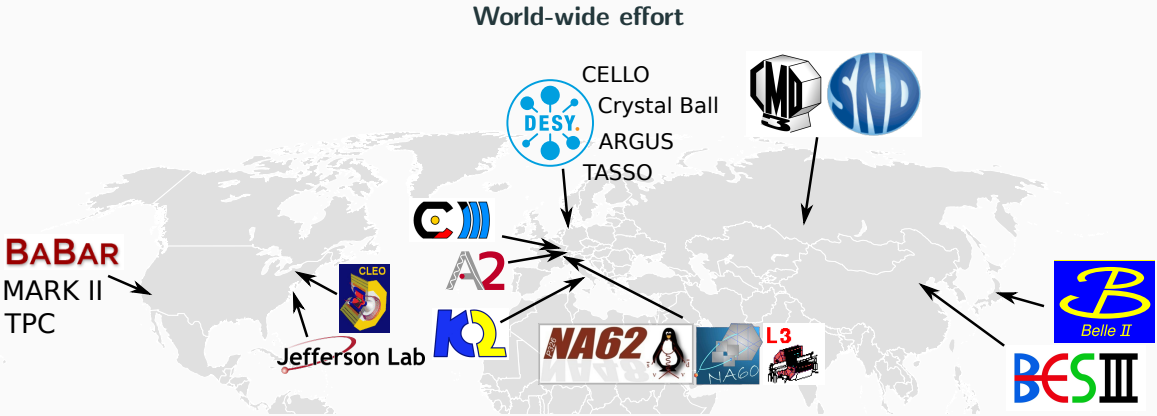
- Precise knowledge needed for calculations of the anomalous magnetic moment of the muon



Talks on Thursday:
- *Dinko Pocanic*
- *Bastian Kubis*
- *Achim Denig*

Muon g-2 Collaboration, Phys.Rev.Lett. 126 (2021) 14

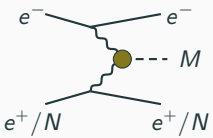
Introduction



Canuckguy et al., Public domain, via Wikimedia Commons

Introduction

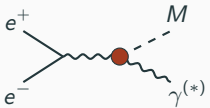
Space-like



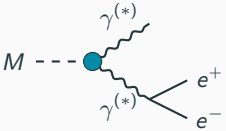
- Two-photon fusion in e^+e^- scattering
- Primakoff production on fixed targets

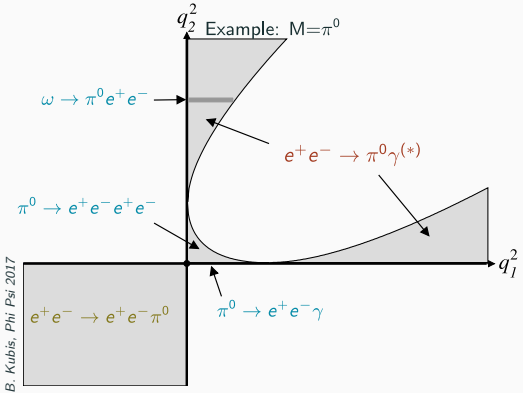
Time-like

- Radiative meson production



- Meson decays





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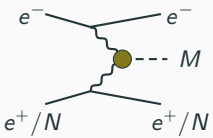

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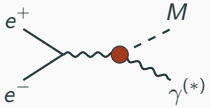

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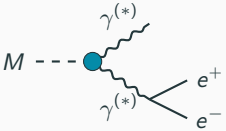
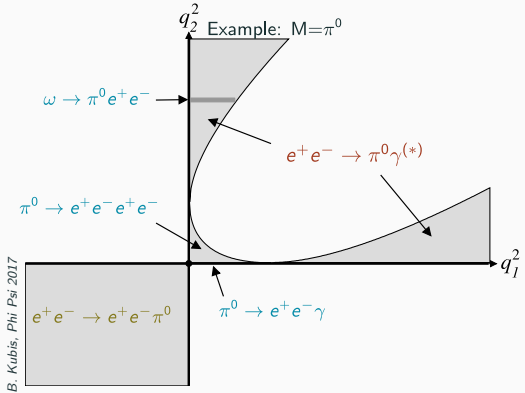
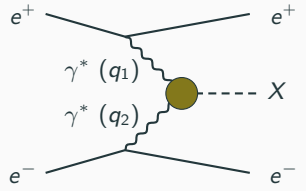




TFF studies from $\gamma\gamma$ fusion at e^+e^- colliders

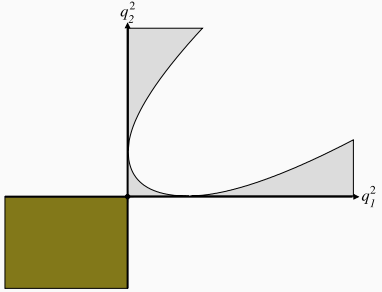
$\gamma\gamma$ fusion at e^+e^- colliders

Space-like TFF measurements



$W = M(X)$

$Q^2 = -q^2$



Low Q^2: Study resonance properties and TFFs

High Q^2: Verify pQCD predictions

$$X = \pi^0,\ \eta,\ \eta', \ldots$$

Direct access to meson TFFs

$$\frac{\sigma(\gamma^*\gamma^* \to X)}{dQ_1^2 dQ_2^2} \sim |F(Q_1^2, Q_2^2)|^2$$

$$X = \pi\pi,\ \pi\eta,\ KK \ldots$$

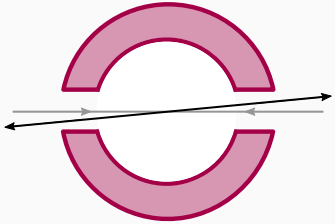
Study scalar and tensor mesons

PWA studies of $\frac{\sigma(\gamma^*\gamma^* \to X)}{dW dQ_1^2 dQ_2^2}$

$\gamma\gamma$ fusion at e^+e^- colliders

Leptons are dominantly scattered at small angles

Untagged

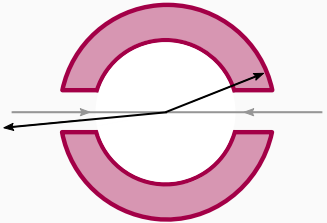


$Q_1^2 \approx Q_2^2 \approx 0$

High-statistics

$\Gamma_{X\to\gamma\gamma}$ via $\frac{d\sigma}{dW}$ studies

Single-tagged

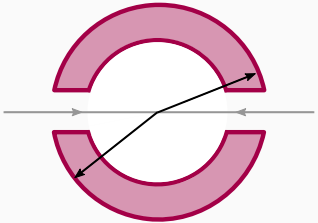


$Q_1^2 \geq 0,\ Q_2^2 \approx 0$

Single-virtual TFF studies

$F(Q_1^2, 0) = F(Q^2)$

Double-tagged



$Q_1^2 \geq 0,\ Q_2^2 \geq 0$

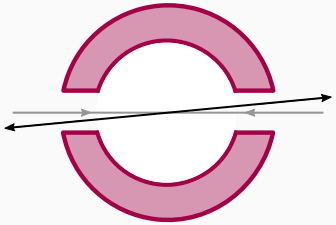
Very low statistics

Double-virtual TFF studies

$\gamma\gamma$ fusion at e^+e^- colliders

Leptons are dominantly scattered at small angles

Untagged



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High-statistics
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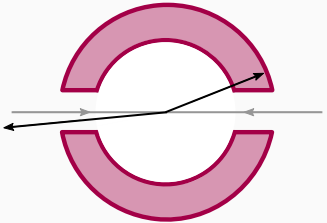

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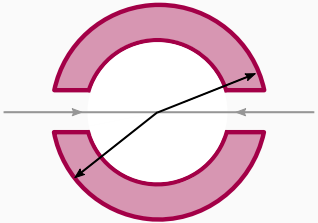


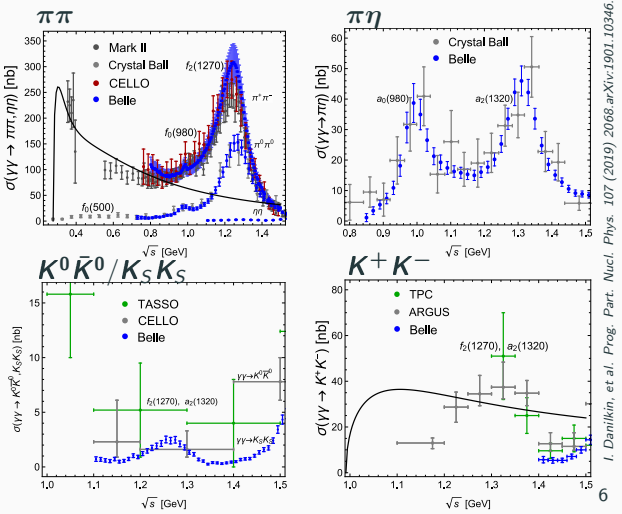
Only result from BABAR
See talk by Evgeny Kozyrev on Wednesday!

Studies of $X = \pi\pi,\ \pi\eta,\ KK$ – access scalar and tensor mesons ($J^{PC} = 0^{\pm+}, 2^{\pm+}$)

- Strict cut on $\left|\sum_X \vec{p}_t^{\,*}\right|$ to ensure quasi-real $\gamma\gamma$
- $\sigma_{ee} = \int \sigma_{\gamma\gamma}(W)\frac{dL_{\gamma\gamma}}{dW}dW$

Fits of PWA to $\frac{d\sigma_{\gamma\gamma}}{4\pi d\cos(\theta^*)}$ to study resonances

Extract, masses, widths and $\Gamma_{\gamma\gamma}\mathrm{BR}(MM)$



I. Danilkin, et al. Prog. Part. Nucl. Phys. 107 (2019) 2068.arXiv:1901.10346.

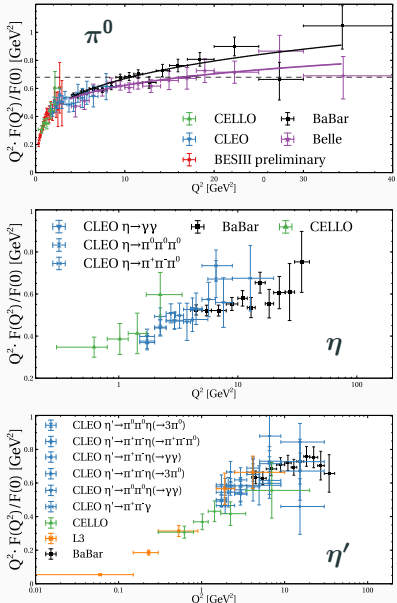
Studies of singly-virtual space-like TFF for $X = \pi^0,\ \eta,\ \eta'$

- Ensure $Q_2^2 \approx 0$ with requirement on small θ_{eX}
- $\sigma_{\gamma\gamma} \sim F^2(Q_1^2) \to F^2(Q^2) = \frac{(d\sigma/dQ^2)_{data}}{(d\sigma/dQ^2)_{MC}} F_{MC}$

pQCD LO prediction: $Q^2 F_\pi(Q^2) \overset{Q^2\to\infty}{=} \sqrt{2} f_\pi$
$\longrightarrow$ Belle-BaBar puzzle

Studies of $X = \pi\pi,\ \pi\eta,\ KK$

One measurement by Belle of single-tagged $X = \pi^0\pi^0$

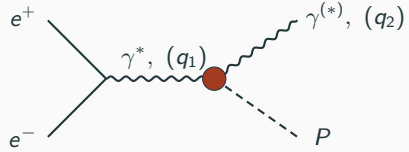


I. Danilkin, et al. Prog. Part. Nucl. Phys. 107 (2019) 2068.arXiv:1901.10346.

TFF studies from radiative meson production

Radiative meson production in colliders

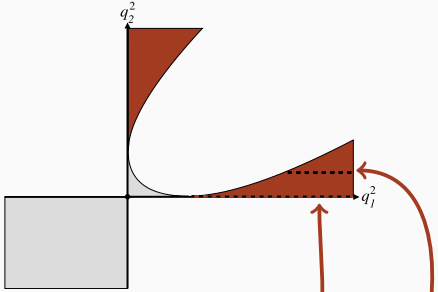
Time-like TFF measurements



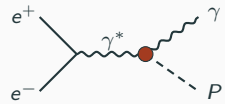
$$\sigma(e^+e^- \to P\gamma^{(*)}) \sim \left|F_P(q^2)\right|^2$$

$q_1^2 = s$

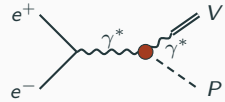
- Energy scans
- Initial state radiation



- Singly virtual TFF ($q_2^2 = 0$):



- Doubly-virtual TFF ($q_2^2 = m_V^2$):



Radiative meson production in colliders

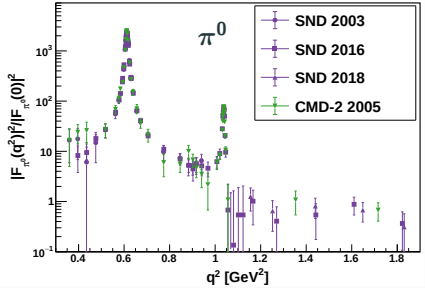
Singly-virtual time-like TFF of $P = \pi^0,\ \eta,\ \eta'$

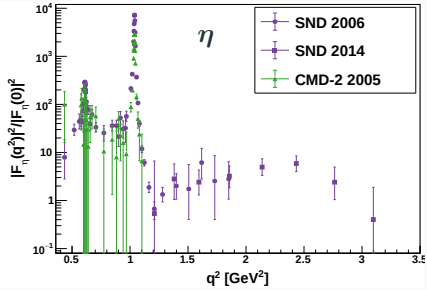
$$\sigma(e^+e^- \to P\gamma) = \frac{2\pi^2\alpha^3}{3}\left|F_P(q^2)\right|^2$$

Low q^2: Studies of excited vector meson states

High q^2: pQCD tests on $\eta,\ \eta'$ by

- BABAR: $q^2 = 112$ GeV^2
- CLEO : $q^2 = 14$ GeV^2





Radiative meson production in colliders

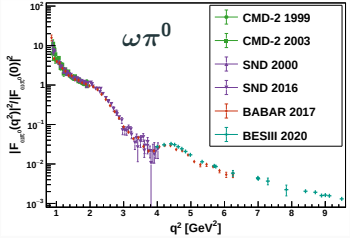
Doubly-virtual time-like TFF of $P = \pi^0,\ \eta,\ \eta'$ $V = \omega,\ \phi$

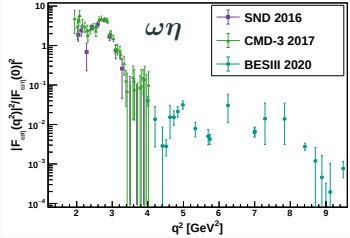
$$F_P(q_1^2, m_V^2) \sim F_{VP}(q_1^2)$$

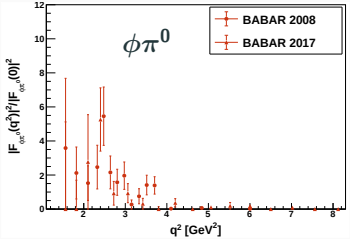
$$\sigma(e^+e^- \to PV) = \frac{4\pi^2\alpha^3}{3s^{3/2}} \left|F_{VP}(q_1^2)\right|^2 P_f(s)$$

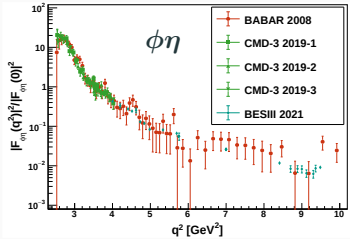
- Studies of excited vector meson states
- From OZI rule: ϕP channels
  $\to$ investigations of ϕ resonances

  Also $\phi\eta'$ results from BESIII 2020





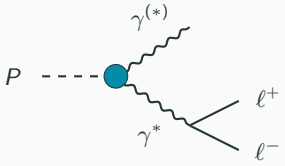


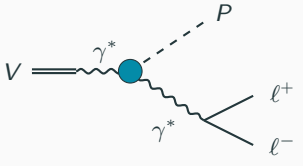


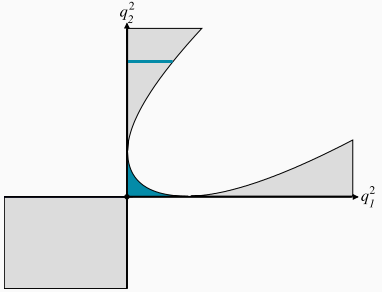
Decay studies at meson factories

Decay studies at meson factories

Time-like TFF measurements







Accessing the TFF from the decay rate

$$\frac{d\Gamma(A \to B\ell^+\ell^-)}{dq^2\Gamma(A \to B\gamma)} = [QED]\left|\frac{\mathcal{F}_{AB}(q^2)}{\mathcal{F}_{AB}(0)}\right|^2 = [QED]\left|F_{AB}(q^2)\right|^2$$

Slope parameter close to $q^2 = 0$:

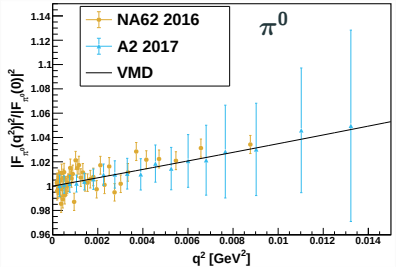
$$b_P = \left.\frac{dF_{AB}(q^2)}{dq^2}\right|_{q^2=0}$$

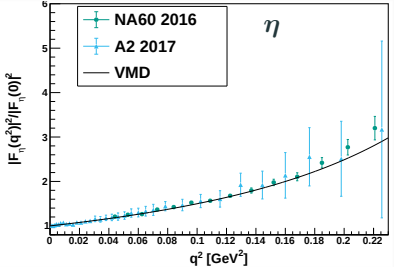
Decay studies at meson factories

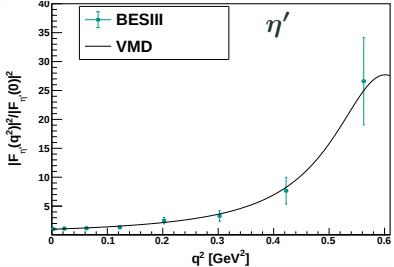
Singly-virtual time-like TFF, $P = \pi^0,\ \eta,\ \eta'$

Very close to $q^2 = 0$:

- EM radius of P
- Extrapolations from space-like TFF
- Good theory agreement
- NLO QED corrections only used for π^0





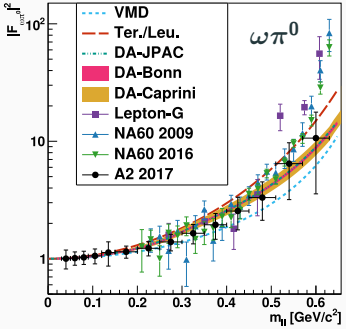


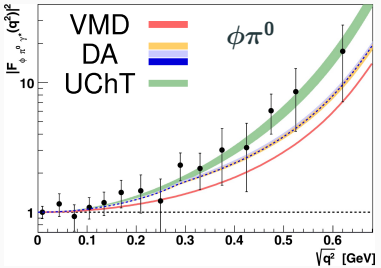
Decay studies at meson factories

Doubly-virtual time-like TFF, $P = \pi^0,\ \eta \quad V = \omega,\ \phi$

$F_P(q_1^2, m_V^2) \ \sim \ F_{VP}(q^2)$

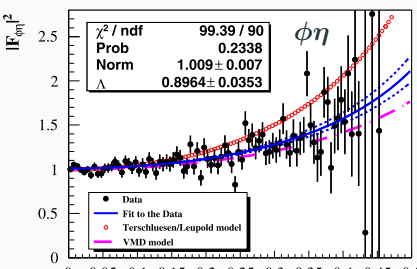
Puzzling theory-experiment differences!





KLOE-2 (2016)

A. Anastasi et al., Phys.Lett.B 757 (2016) 362-367, arXiv: 1601.06565



KLOE-2 (2015)

D. Babusci et al., Phys.Lett.B 742 (2015) 1-6, arXiv: 1409.4582

Summary

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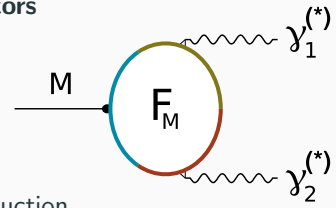

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- $\gamma\gamma$ fusion

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- Radiative meson production
- Meson decays