Meson transition form factor measurements with A2

15th International Workshop on Meson Physics

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SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Introduction

Meson transition form factors

$$\mathcal{A}(P \leftrightarrow \gamma^{(*)}\gamma^{(*)}) = q_1^\mu \varepsilon_1^\nu q_2^\alpha \varepsilon_2^\beta \epsilon_{\mu\nu\alpha\beta} \mathcal{F}_P(q_1^2, q_2^2)$$

Different virtualities accessible in different physical processes

- $\gamma^* \to P\gamma^{(*)}$

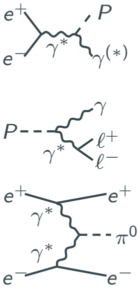
  e.g. e^+e^- annihilation

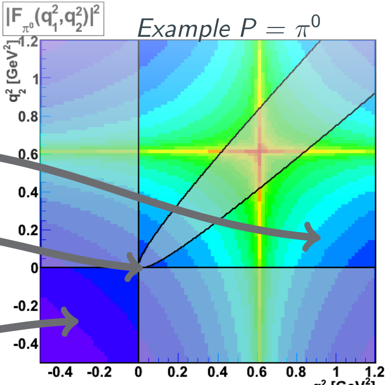
- $P \to \gamma^{(*)}\gamma^{(*)}$

  e.g. Dalitz decay

- $\gamma^{(*)}\gamma^{(*)} \to P$

  e.g. e^+e^- scattering





Courtesy of A. Kupść, Uppsala University

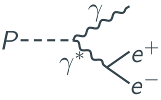
- Intrinsic probe of the electromagnetic structure of the hadron
- Precise knowledge needed for calculations of a_μ^{SM}

From meson decays

- $P \to \gamma e^+ e^-$ $\quad P = \pi^0,\ \eta,\ \eta'$

$\sqrt{q_2^2} = 0$

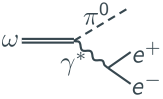
$2m_e \le \sqrt{q_1^2} \le m_P$

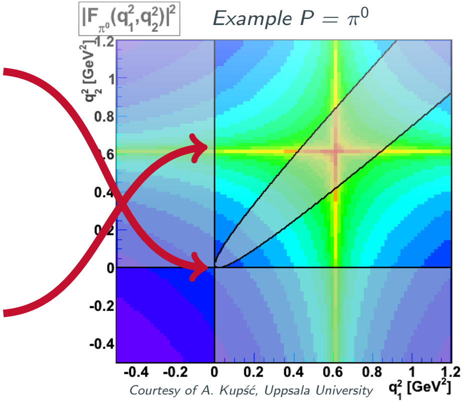


- $\omega \to \pi^0 e^+ e^-$

$\sqrt{q_2^2} = m_\omega$

$2m_e \le \sqrt{q_1^2} \le m_\omega - m_\pi$





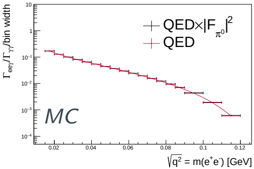
Courtesy of A. Kupść, Uppsala University

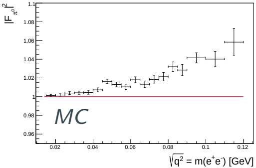
Time-like transition form factors at A2

Accessing the TFF — Momentum transfer spectrum of the decay rate

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

Example $P = \pi^0$ $\qquad \frac{d\Gamma(\pi^0 \to \gamma e^+ e^-)}{dq^2\Gamma(\pi^0 \to \gamma\gamma)} \qquad\qquad \left|F_{\pi^0}(q^2)\right|^2$





Compare results — VMD-inspired parametrisation

$$F(q^2) \;=\; \frac{\Lambda_V^2}{\Lambda_V^2 - q^2 - i\Gamma_V\Lambda_V} \overset{q^2<\Lambda_V}{\approx} 1 + \Lambda^{-2}q^2$$

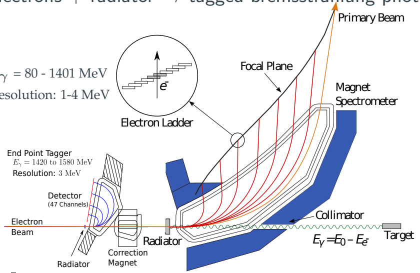
The A2 setup

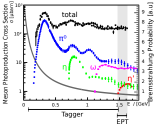
MAinzer MIkrotron (MAMI) — (un)polarised electron accelerator, $E_{max} = 1.6$ GeV.

The Glasgow photon tagger
or
The end point tagger

Electrons + radiator → tagged bremsstrahlung photons

E_γ = 80 - 1401 MeV
Resolution: 1-4 MeV

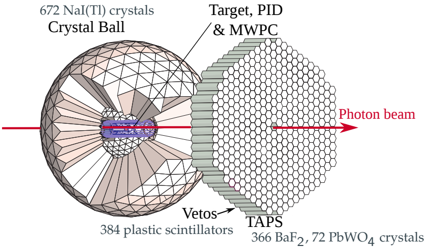




New tagger installed
in end of 2017

The Crystal Ball + TAPS setup

$\gamma + p \rightarrow p + X$



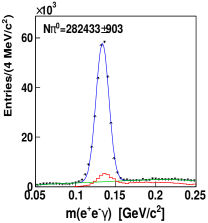
A2 TFF measurements

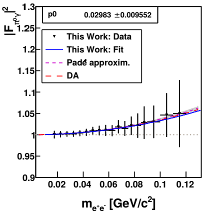
$F_{\pi^0}(q^2)$: Leading individual contribution to a_μ^{hLbL}
Essential for precision of $\Gamma(\pi^0 \to e^+e^-)$

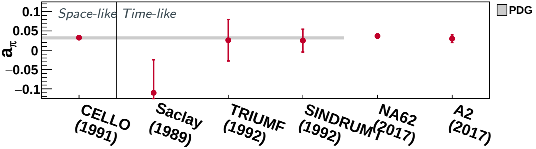
A2 publication*

- $4 \cdot 10^5\ \pi^0 \to e^+e^-\gamma$ events
- $a_\pi = 0.003(1) \quad \left[\frac{a_\pi}{m^2_{\pi^0}} = \Lambda^{-2}\right]$

QED with radiative corrections†







Ongoing A2 project

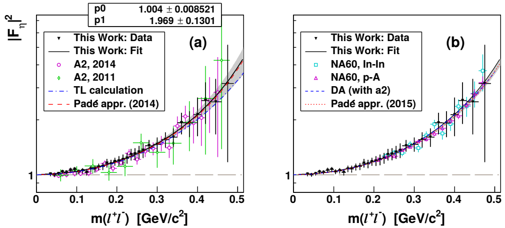
Dedicated data collection,
5.5 more statistics
→ reach current PDG precision

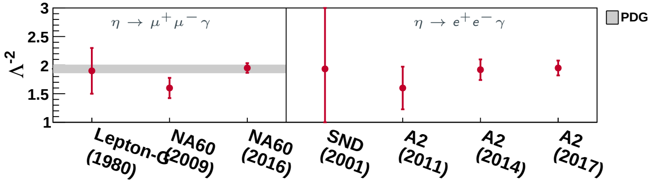
* A2, Phys.Rev. C95 (2017) no.2, 025202
† T. Husek, K. Kampf, and J. Novotny , Phys. Rev. D 92, 054027 (2015).

$F_\eta(q^2)$: With $\eta - \eta'$ mixing, tool for understanding light-quark dynamics

A2 publication*

- $5.4 \cdot 10^4$ signal events
- Systematic errors on individual data points
- $\Lambda^{-2} = 1.97 \pm 0.11_{tot}$ GeV $^{-2}$





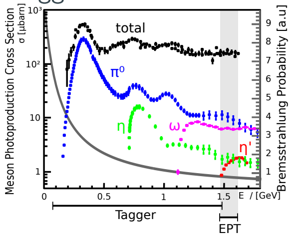
* *A2, Phys. Rev. C95 (2017), 035208*

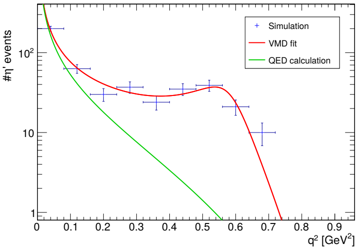
$\boldsymbol{F_{\eta'}(q^2)}$: Covers the ρ and ω poles

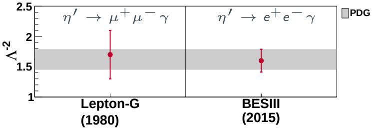
A2 ongoing project

η' initiative - 10 weeks of beam time with End Point Tagger

- More than 6 million η'
- Analysis of $\eta' \to e^+e^-\gamma$ ongoing
- Cover range up to $q^2 \approx 0.7$ GeV^2



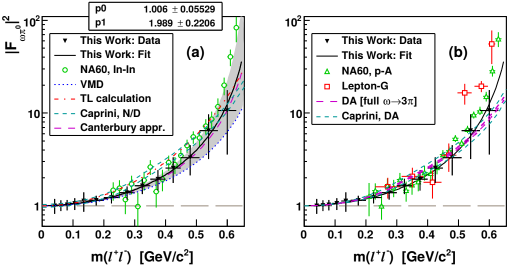


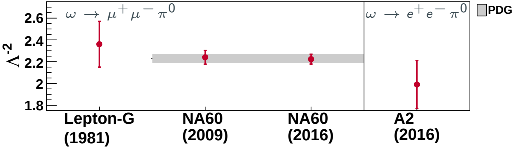


$F_{\omega\pi^0}(q^2)$: Theory and experiment differences

A2 publication*

- 1100 signal events
- Systematic errors on individual data points
- $\Lambda^{-2} = 1.99 \pm 0.21_{tot}$ GeV $^{-2}$





* A2, Phys. Rev. C95 (2017), 035208

Summary

Time-like transition form factors

$P \to \gamma\ell^+\ell^-$

Good theory/experiment accord.

- $\pi^0 \to e^+e^-\gamma$
- $\eta \to e^+e^-\gamma$
- $\eta' \to e^+e^-\gamma$

$V \to P\ell^+\ell^-$

Theory - experiment disagreement.

- $\omega \to \pi^0 e^+e^-$

Summary

Time-like transition form factors

$P \to \gamma \ell^+ \ell^-$

Good theory/experiment accord.

- $\pi^0 \to e^+ e^- \gamma$
- $\eta \to e^+ e^- \gamma$
- $\eta' \to e^+ e^- \gamma$

$V \to P \ell^+ \ell^-$

Theory - experiment disagreement.

- $\omega \to \pi^0 e^+ e^-$

Thank you for your attention.