Meson decays studies from MAMI A2

International Workshop on e^+e^- collisions from Phi to Psi

Lena Heijkenskjöld

Institute for Nuclear Physics
Johannes Gutenberg University Mainz

25 February - 1 March, 2019

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

A2

Outline

- The A2 experiment at MAMI

Recent results from A2:

- Transition form factor measurements

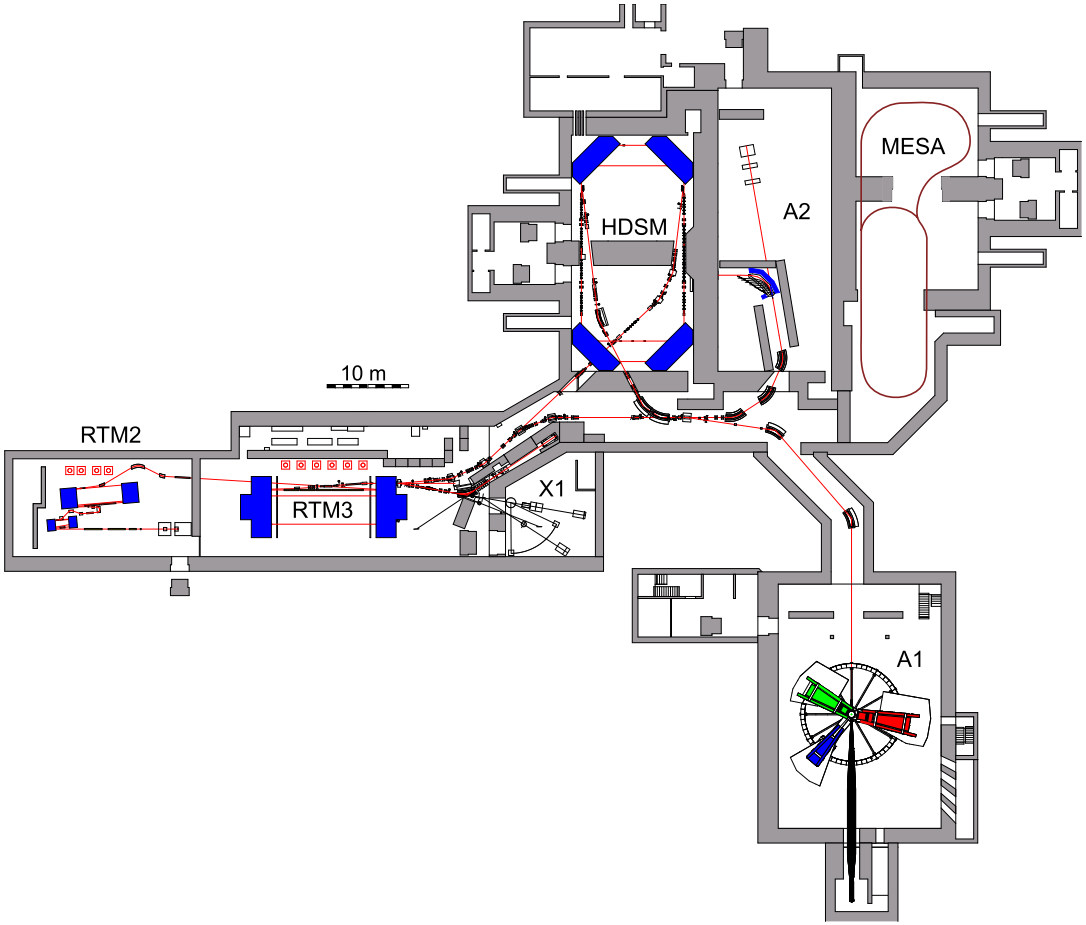
  Decays of π^0, η, η' and ω

- Dalitz plot studies

  $\eta \to \pi^0\pi^0\pi^0$ and $\eta' \to \eta\pi^0\pi^0$

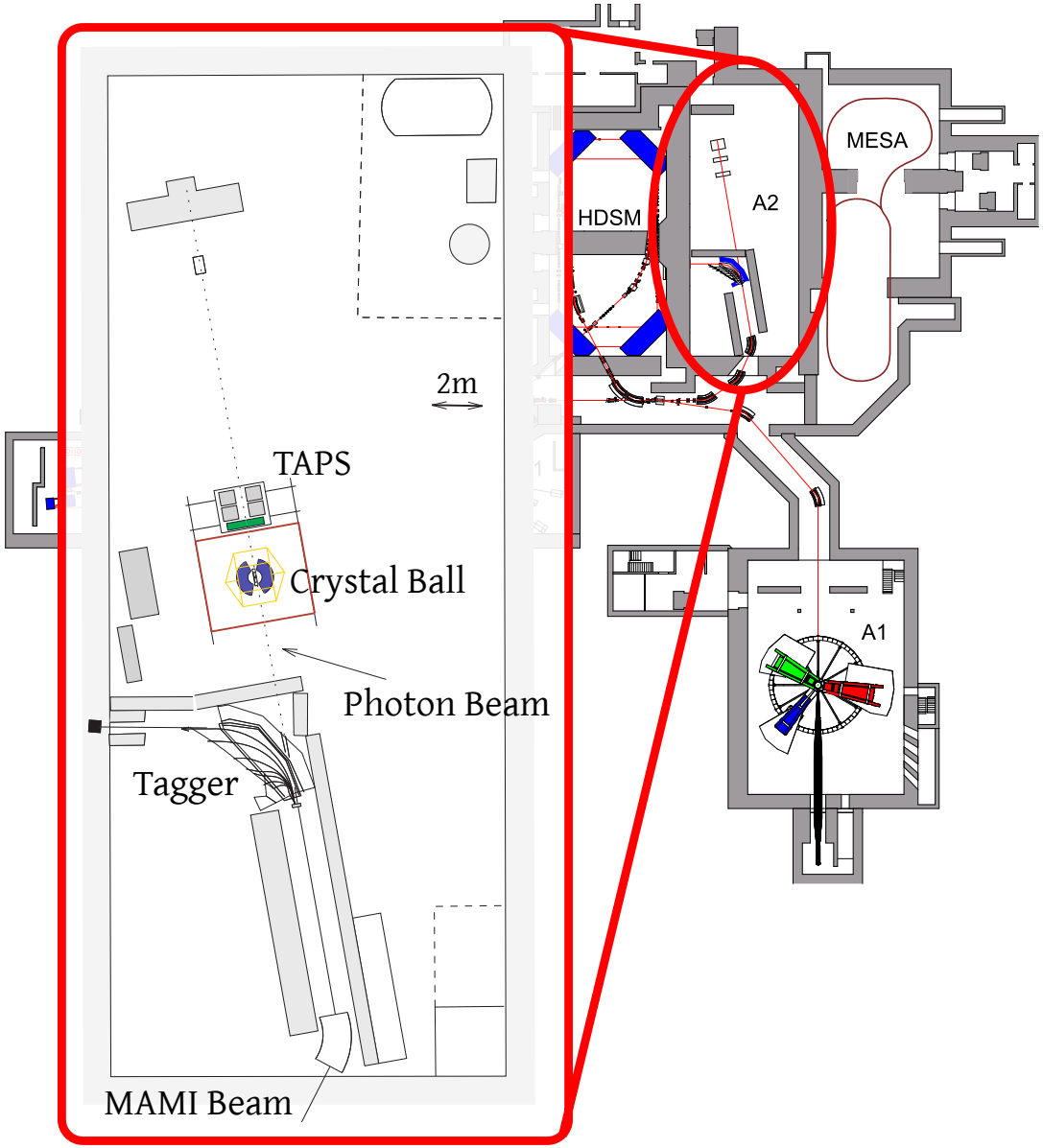
The A2 Experiment

Mainzer Mikrotron - MAMI



- Quasi continuous (100 % duty factor) and very stable electron beam
- Linac and 3 RTMs $\rightarrow$ 883 MeV
- HDSM (MAMI C) $\rightarrow$ 1604 MeV
- A2 experimental hall: CB/TAPS setup

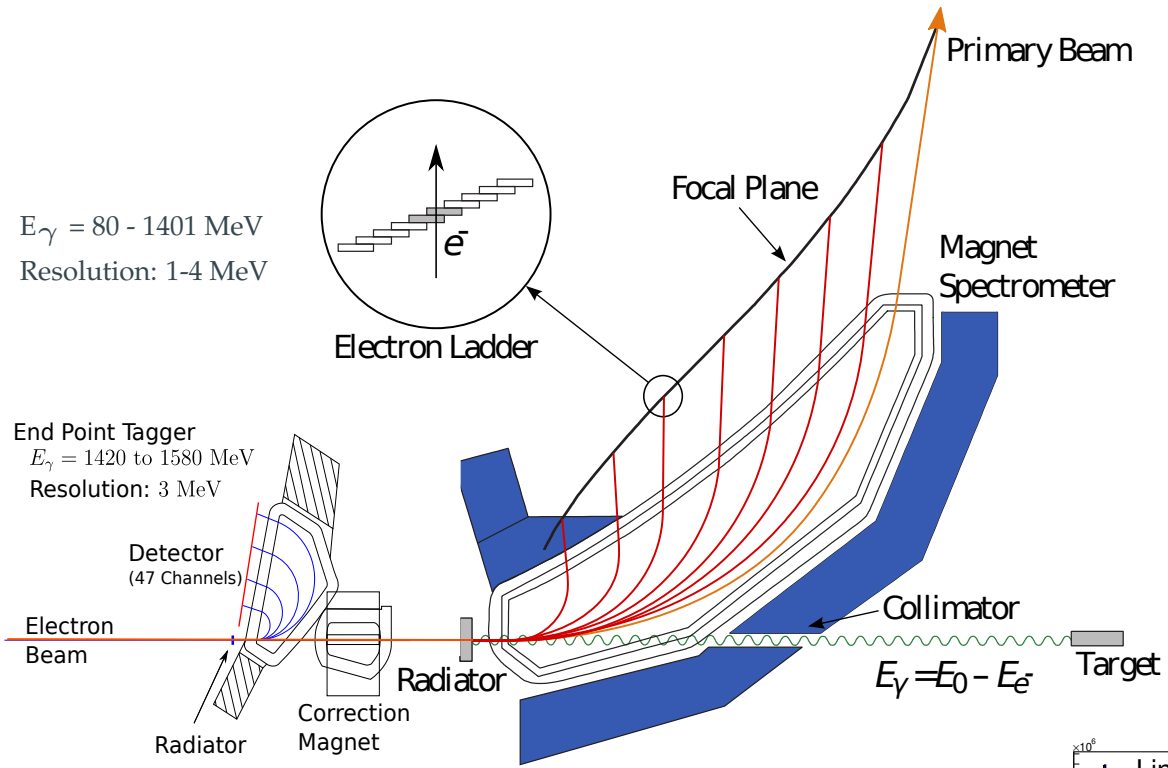
Mainzer Mikrotron - MAMI

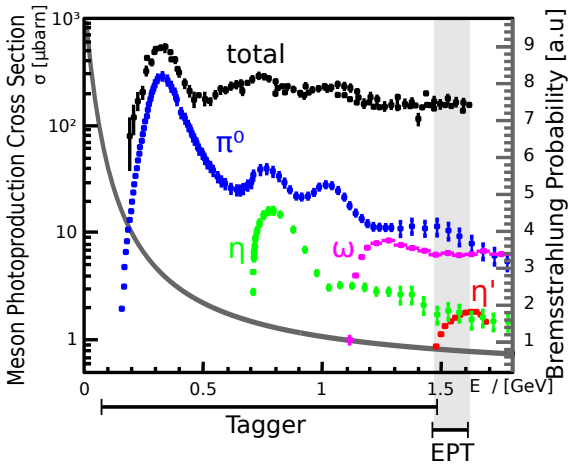


- Quasi continuous (100 % duty factor) and very stable electron beam
- Linac and 3 RTMs $\rightarrow$ 883 MeV
- HDSM (MAMI C) $\rightarrow$ 1604 MeV
- A2 experimental hall: CB/TAPS setup
  - Meson factory
  - High precision nuclear experiments with real photons
  - Investigation of meson decays

The Glasgow photon tagger or The end point tagger

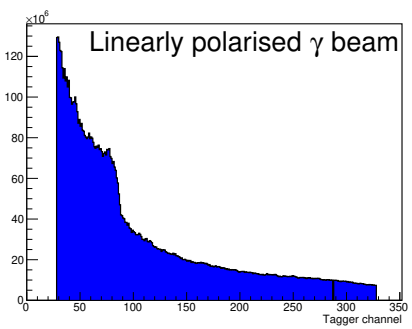
Electrons + radiator → tagged bremsstrahlung photons

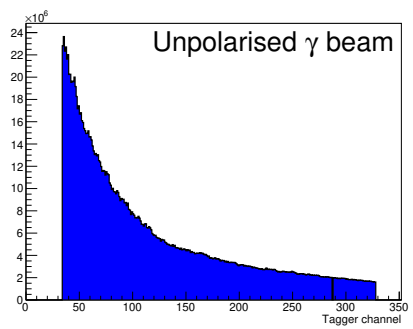




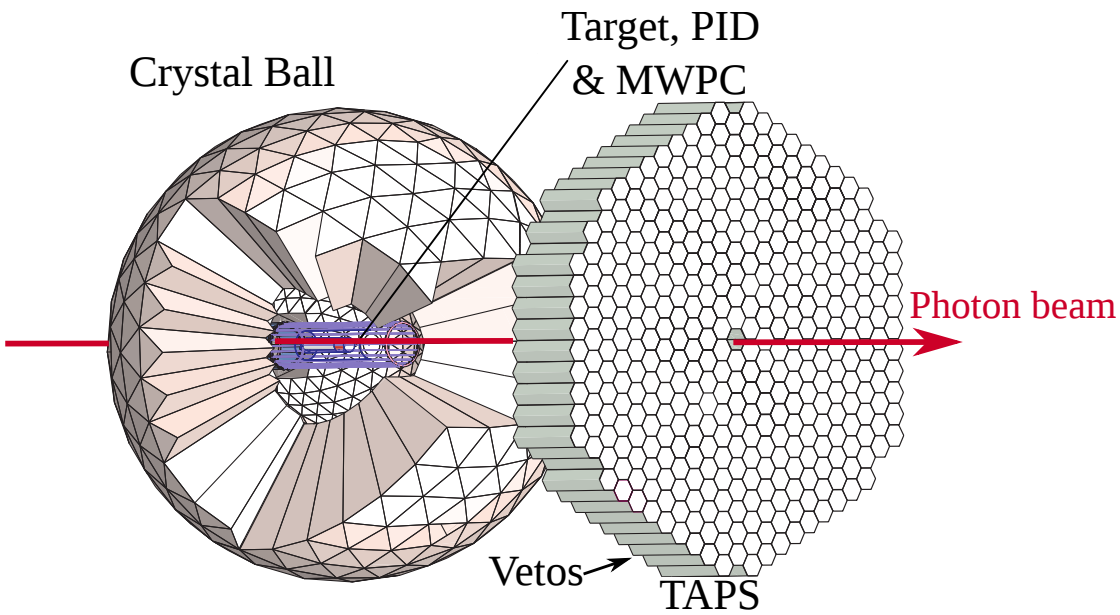
New tagger installed in end of 2017

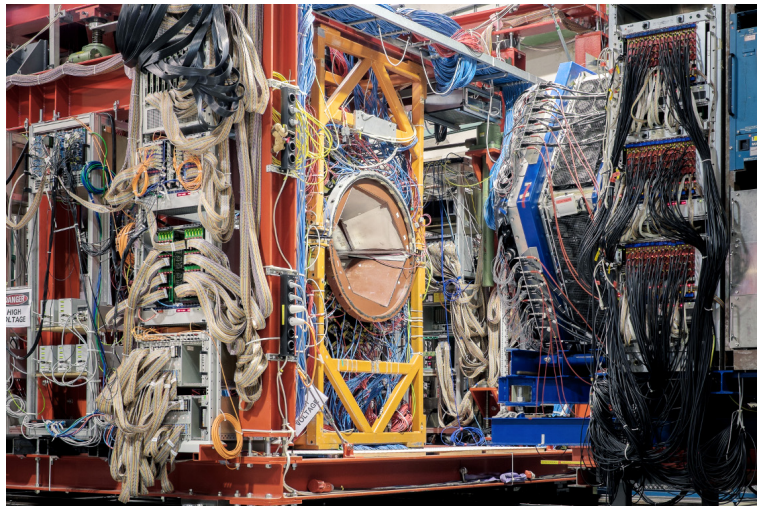
Photon beam





A2 – CB/TAPS setup





Crystal Ball (CB)

- 672 NaI Crystals
- 24 Particle Identification Detector (PID) Paddles
- 2 Multiwire Proportional Chambers (MWPCs)

Two Arms Photon Spectrometer (TAPS)

- 366 BaF_2 and 72 $PbWO_4$ Crystals
- 384 Veto Paddles

Unpolarised targets

- Cryo: $\underline{LH^2}$, LD^2, ^3He ^4He
- Solid: (C, Al, Pb, etc.)

Meson transition form factors

Meson transition form factors

$$\mathcal{A}(P \to \gamma^{(*)}\gamma^{(*)}) = q_1^\mu \epsilon_1^\nu q_2^\alpha \epsilon_2^\beta \epsilon_{\mu\nu\alpha\beta} \mathcal{F}_P(q_1^2, q_2^2)$$

Different virtualities accessible in different physical processes

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

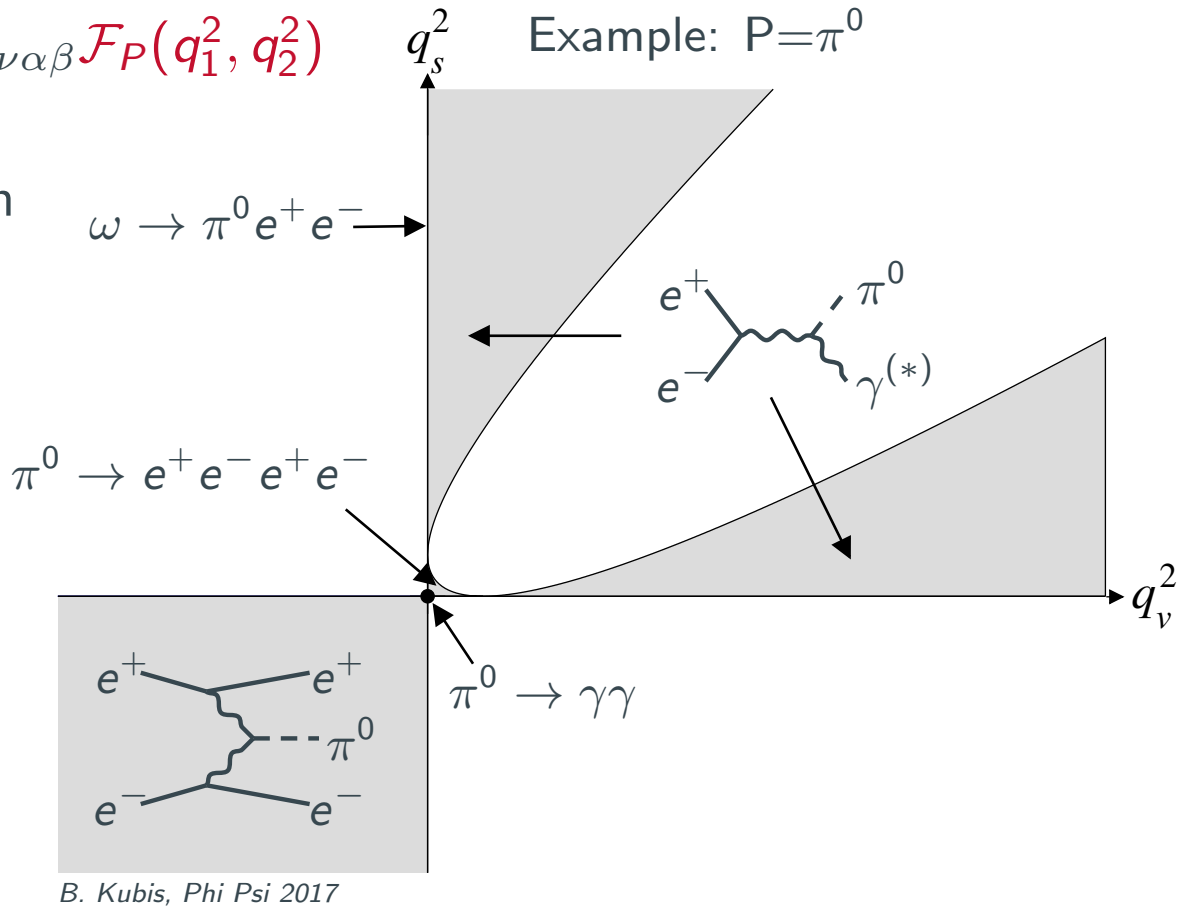
  e.g. e^+e^- annihilation

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

  e.g. Dalitz decay

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

  e.g. e^+e^- scattering



B. Kubis, Phi Psi 2017

- Intrinsic probe of the hadron structure
- Important for in-medium studies of hadrons in heavy-ion collisions
- Precise knowledge needed for calculations of a_μ^{SM}

Importance for anomalous magnetic moment of the muon

3-4σ discrepancy in $a_\mu^{\text{SM}} - a_\mu^{\text{exp}}$

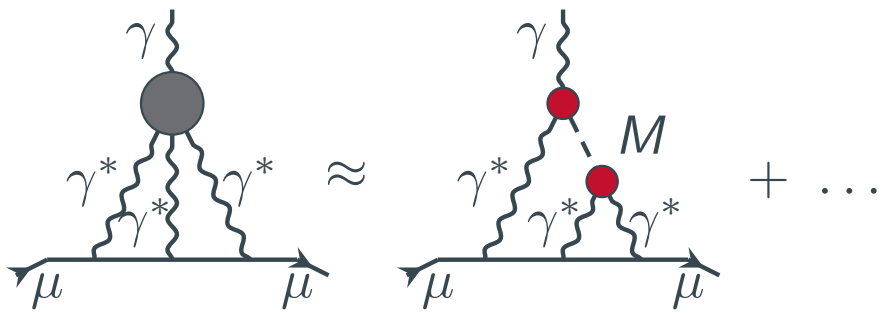
Increase precision of

$$a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{Strong}}$$

SM contribution	$a_\mu \times 10^{11}$
QED[1]	116 584 718.971(0.075)
EW[2]	153.6 (1.0)
Strong[3]	
HVP-LO	6894.6 (32.5)
HLbL-LO	103.4 (28.8)

Hadronic Light-by-Light scattering

- Model calculations
- Dispersive approaches
- Lattice



Experiments needed as input and tests

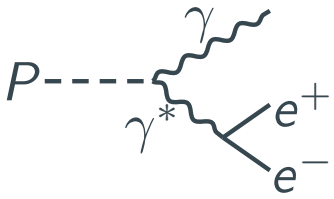
$$\bullet = \mathcal{F}(q_1^2, q_2^2)$$

[1] *Aoyama, et al., Phys. Rev. D 97, (2018) 036001* [2] *Gnendiger, et al, Phys.Rev. D88 (2013) 053005* [3] *Jegerlehner, arXiv:1711.06089 [hep-ph]*

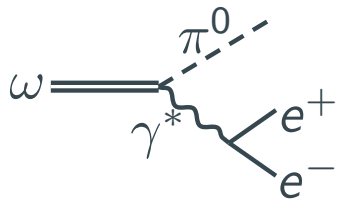
Time-like transition form factors at A2

From meson decays

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



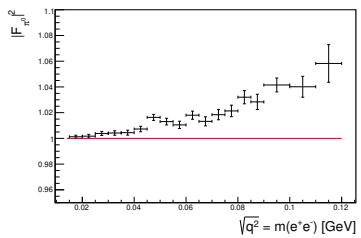
- $\omega \to \pi^0 e^+ e^-$



Accessing the TFF — Momentum transfer spectrum of the decay rate

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

$\left|F_{\pi^0}(q^2)\right|^2$



Compare results — VMD-inspired parametrisation

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

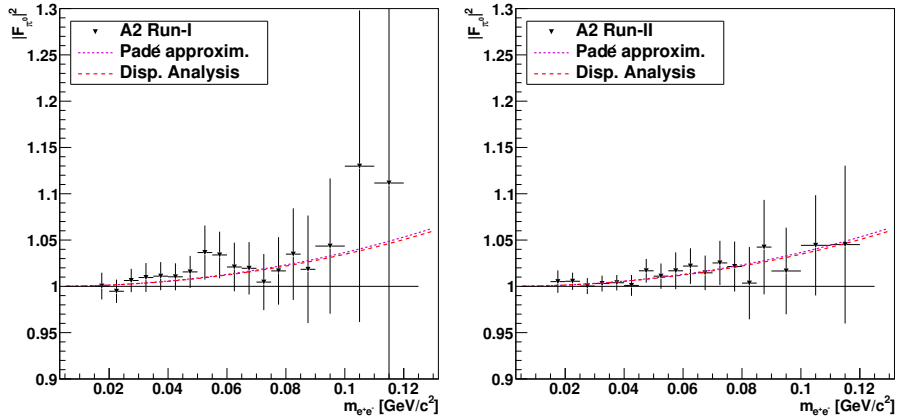
A2 results - $\pi^0 \to e^+e^-\gamma$

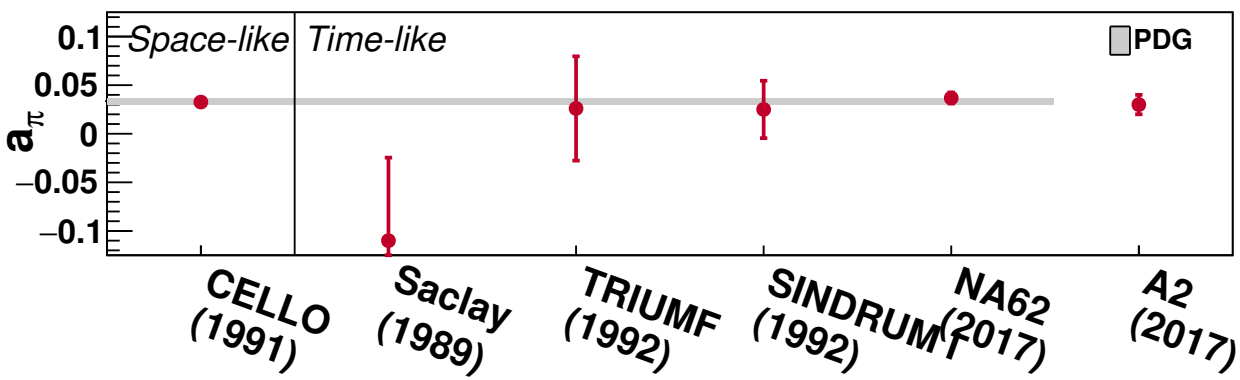
$F_{\pi^0}(q^2)$: Leading individual contribution to a_μ^{hLbL}
Essential for precision of $\Gamma(\pi^0 \to e^+e^-)$

A2 publication[5]

- $4 \cdot 10^5$ $\pi^0 \to e^+e^-\gamma$ events
- $a_\pi = 0.03(1)$ $\left[\frac{a_\pi}{m^2_{\pi^0}} = \Lambda^{-2}\right]$

  QED with radiative corrections[5]





Ongoing A2 project

5.5 more statistics

World leading precision of time-like measurement

[4] *A2, Phys.Rev. C95 (2017) no.2, 025202*

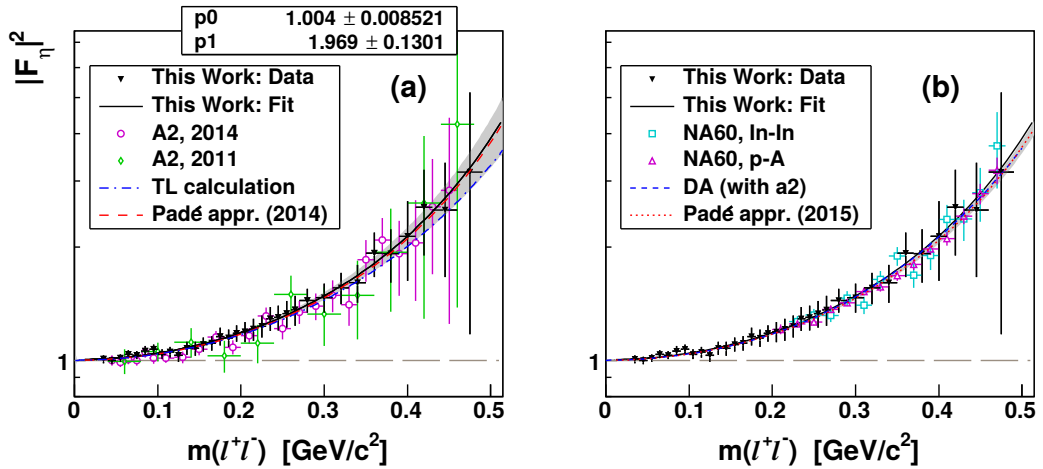
[5] *T. Husek, K. Kampf, and J. Novotny , Phys. Rev. D 92, 054027 (2015).*

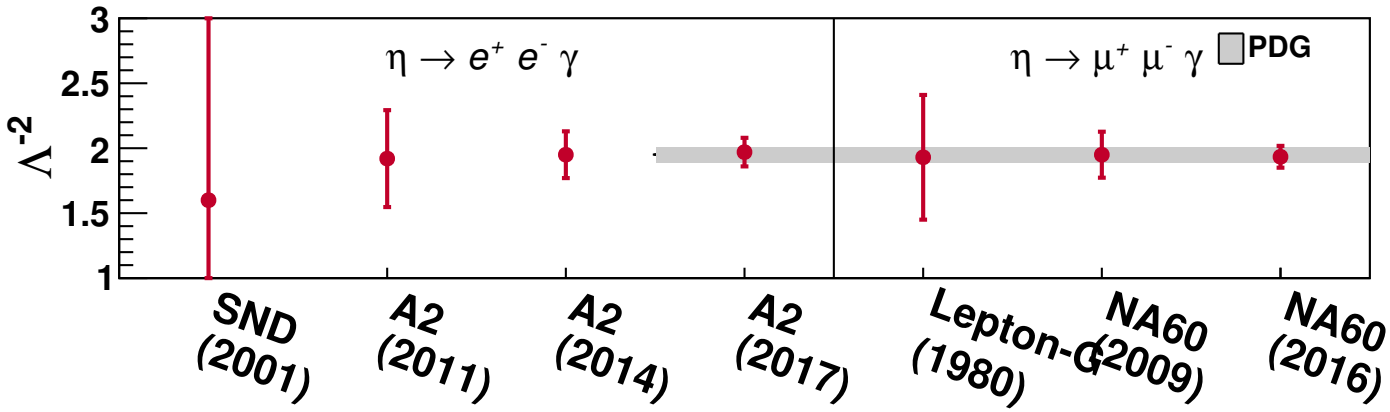
A2 results - $\eta \to e^+e^-\gamma$

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

A2 publication[6]

- $5.4 \cdot 10^4$ signal events
- $\Lambda^{-2} = 1.97 \pm 0.11_{tot}$ GeV $^{-2}$





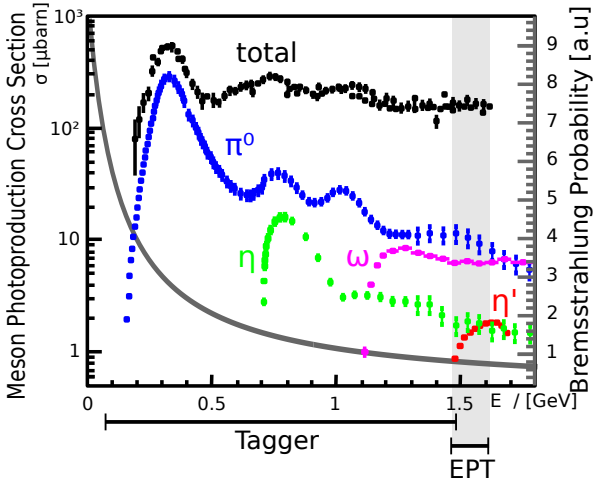
[6] *A2, Phys. Rev. C95 (2017), 035208*

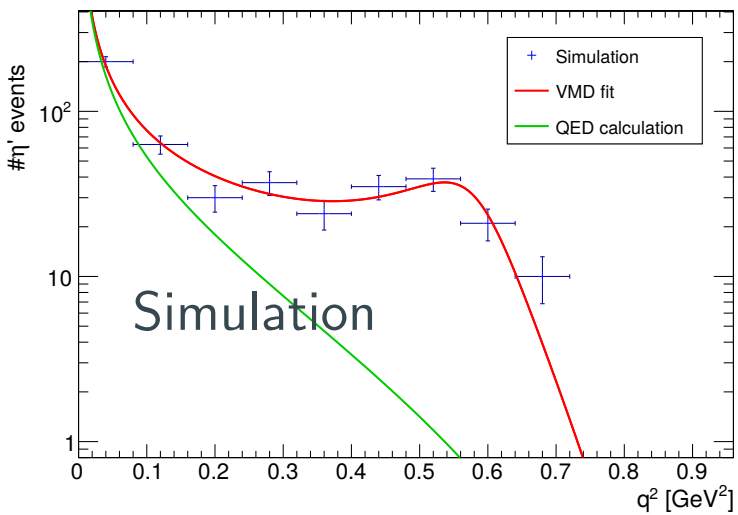
$F_{\eta'}(q^2)$: Covers the ρ and ω poles

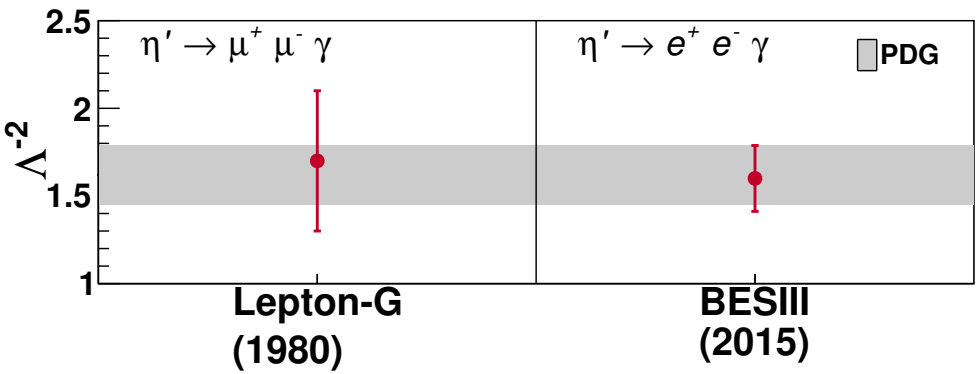
A2 ongoing project

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

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





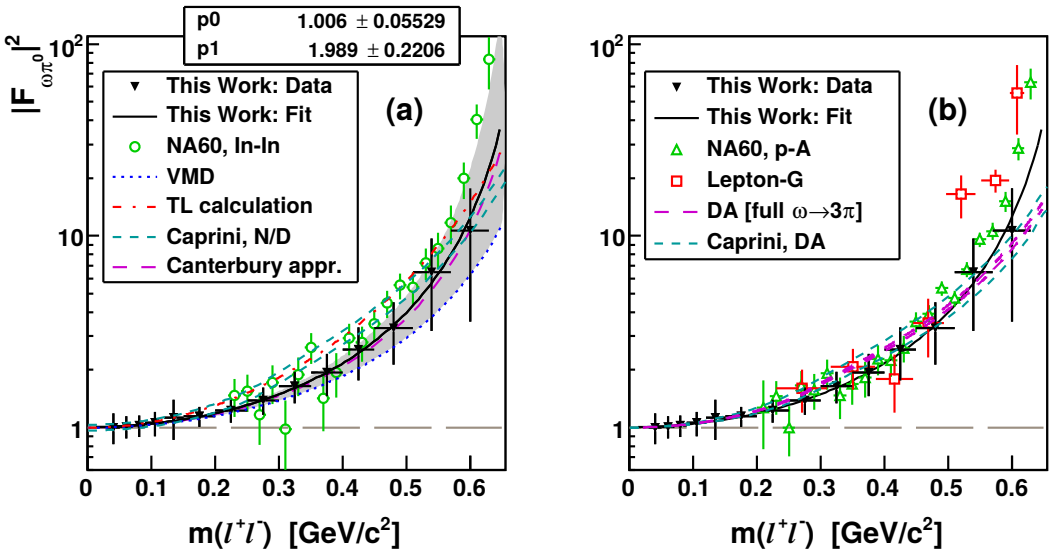


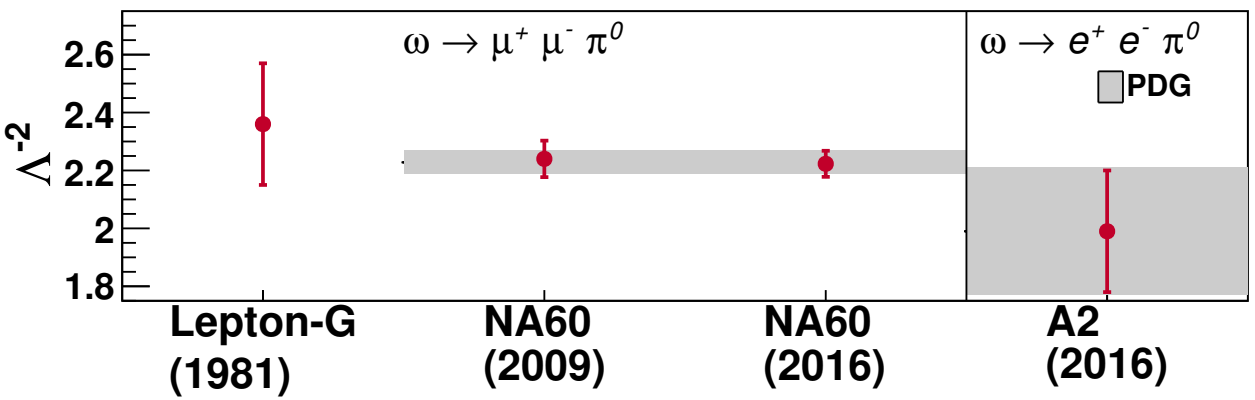
A2 results - $\omega \to e^+e^-\pi^0$

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

A2 publication[7]

- 1100 signal events
- $\Lambda^{-2} = 1.99 \pm 0.21_{tot}$ GeV $^{-2}$





[7] *A2, Phys. Rev. C95 (2017), 035208*

Dalitz plot studies

Dalitz plot studies

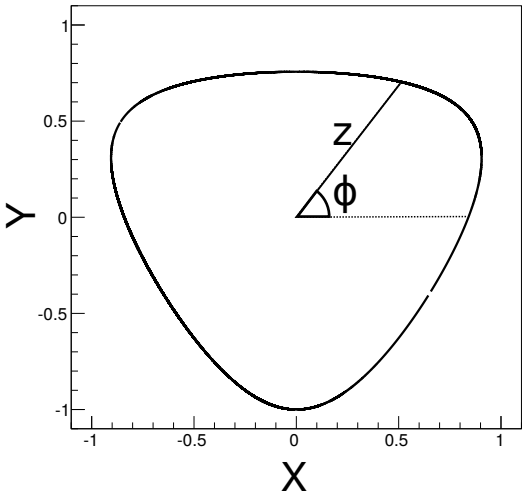
3-body decay: $\mathcal{A}$ given by two independent variables

Parametrisation for smooth distributions:

$$|\mathcal{A}|^2 \propto N(1 + aY + bY^2 + cX + dX^2 + ...)$$

$$|\mathcal{A}|^2 \propto N(1 + 2\alpha z + 2\beta z^{3/2} \sin(3\phi) + ...)$$

When $m_1 = m_2$

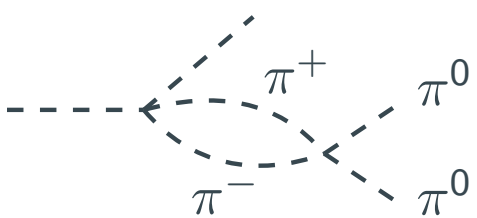


$$X = \sqrt{3}\frac{T_1^* - T_2^*}{Q} \quad Y = \frac{(2m_1 + m_3)T_3^*}{(m_1 Q)} - 1$$

$$z = X^2 + Y^2 \quad \phi = \arctan(Z/X)$$

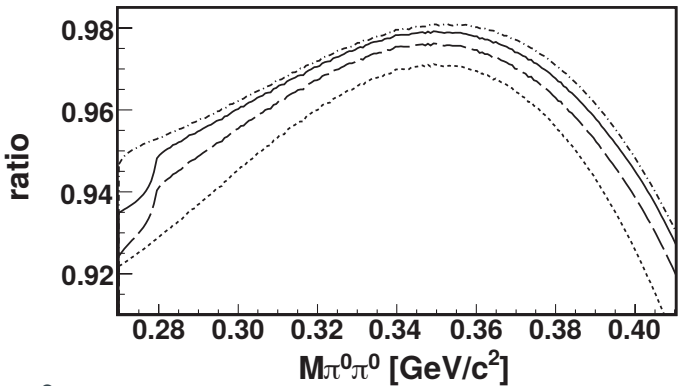
Recent A2 result: $\eta \to \pi^0\pi^0\pi^0$ and $\eta' \to \eta\pi^0\pi^0$

- $\pi\pi/\pi\eta$ re-scattering
- Cusp at $m_{\pi^+\pi^-}$ threshold $\to (a_2 - a_0)$
  a_i - $\pi\pi$ S-wave scattering lengths for I=0,2

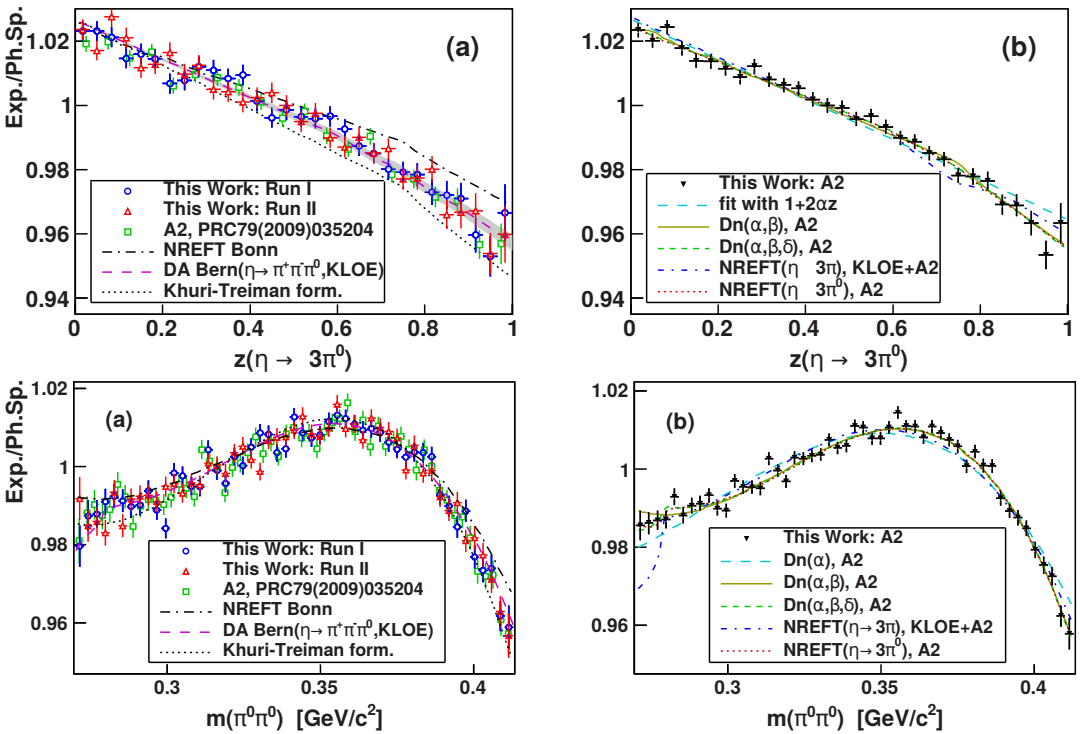


A2 results - $\eta \to 3\pi^0$

- $\Gamma(\eta \to \pi\pi\pi) \sim \frac{m_d^2 - m_u^2}{m_s^2 - m_{ud}^2}$
- $\pi\pi$ cusp - NREFT[8] $\sim$ 1% effect
- Predictions of β-parameter



[8] *Gullström, et al., Phys.Rev. C79 (2009) 028201*



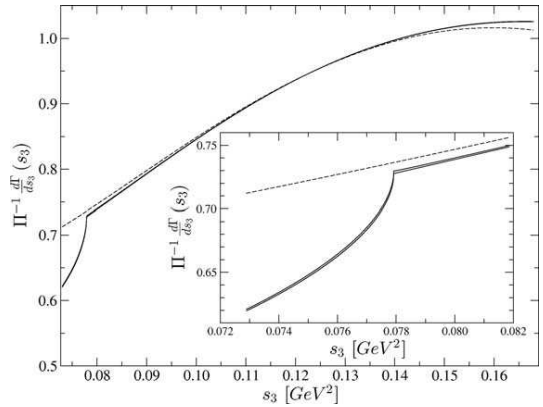
A2 publication[9]

- 7×10^6 events
- Most precise measurement of α-parameter
- First measurement of β + cusp parametrisation

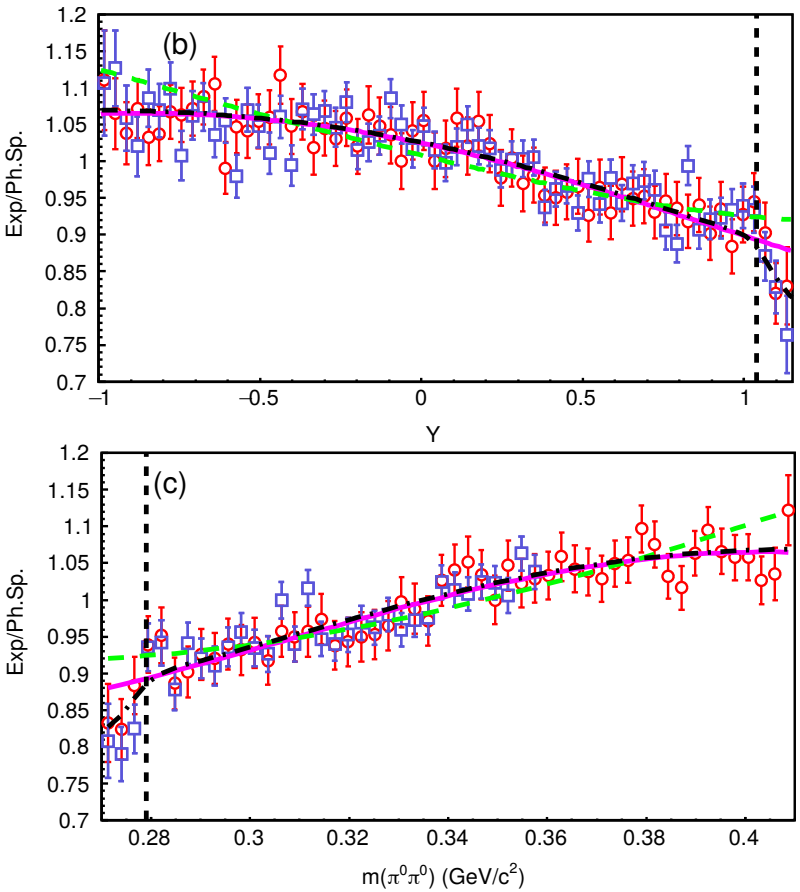
[9] *A2, Phys. Rev C97 (2018) 065203*

A2 results - $\eta' \to \eta\pi^0\pi^0$

- Tests of ChPT expansions
- $\pi\pi$ cusp - NREFT[10] $\sim$ 6% effect



[10] *Kubis, et al., Eur.Phys.J. C62 (2009) 511-523*



A2 publication[11]

- 1.2×10^5 events
- Fit $1 + aY + bY^2 + dX^2$
- First observation of cusp in this channel

[11] *A2, Phys. Rev D98 (2018) 012001*

Summary

A2 at MAMI...

...is an ideal facility for light meson investigations.

Mesons $\pi^0,\ \eta, \eta'$ and ω produced in photoproduction.

... contributes significantly to

- meson transition form factor measurements
  Decays of $\pi^0,\ \eta,\ \eta',\ \omega$
- precision tests and experimental input to low energy theory
  Dalitz plots studies of $\eta,\ \eta'$