

The *End Point Tagger* physics program at A2@MAMI
– η' and others –

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for the A2-Collaboration at MAMI

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wwwa2.kph.uni-mainz.de

Outline

1 Introduction

2 Experimental Setup

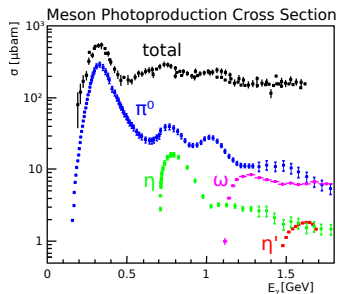
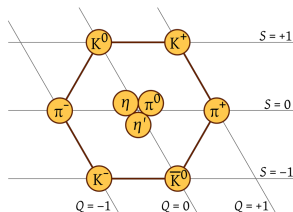
3 Analyses

4 Summary

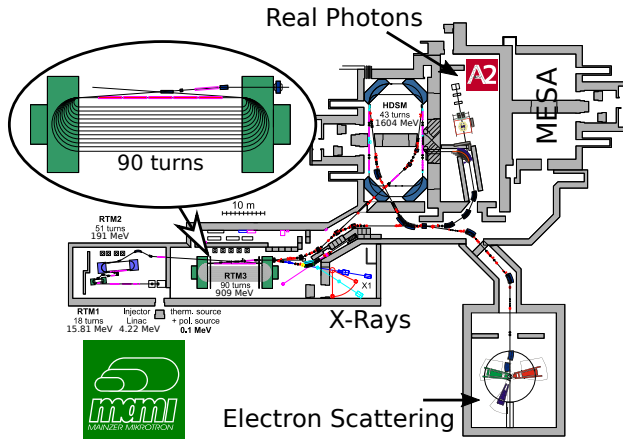
Introduction



- Experiments with real photons
 - Baryon Resonances
 - Meson photoproduction
 - Study light mesons
- Study the η'
 - Transition Formfactors
 - Rare decays
 - Hadronic decays
- η' Production
 - Specialized tagging device
 - Upgraded DAQ speed
 - 10 weeks beam time (2014):
over 6M η' produced



The Mainz Microtron MAMI

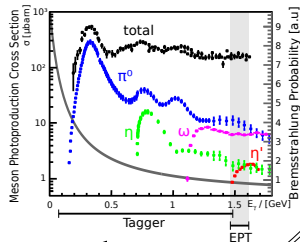
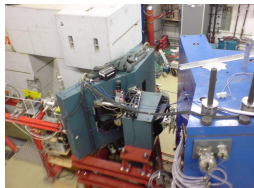


- e^- accelerator
- up to 1604 MeV
- 100 % duty factor

- Excellent beam properties

Eur. Phys. J. Spec. Top. (2011) 198: 19

Energy Tagged Photons

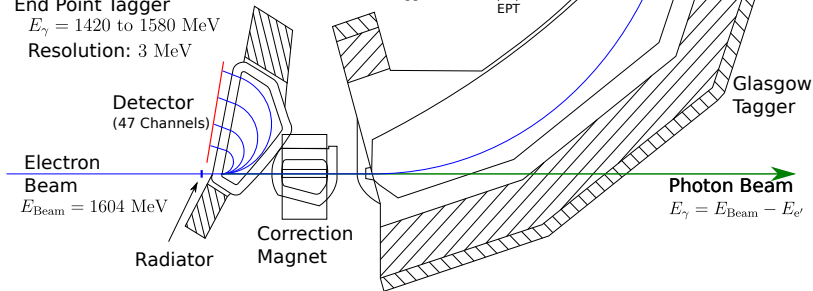


A2

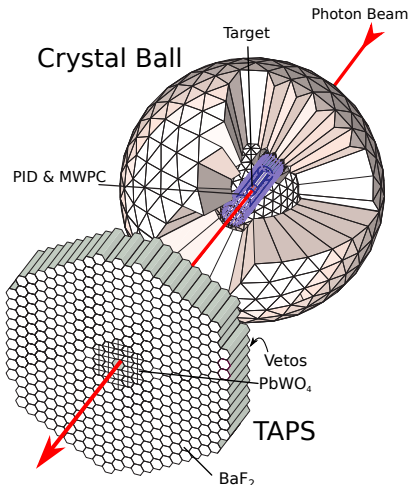
End Point Tagger

$E_\gamma = 1420$ to 1580 MeV

Resolution: 3 MeV



Detector System: Crystal Ball & TAPS



Crystal Ball:

- 672 NaI(Tl) Crystals

- $\frac{\sigma}{E_\gamma} = \frac{2\%}{\sqrt[4]{E_\gamma/\text{GeV}}}$

- $\sigma_\theta = 2^\circ \text{ to } 3^\circ$

- $\sigma_\phi = \frac{\sigma_\theta}{\sin \theta}$

TAPS:

- 366 BaF₂

- 72 PbWO₄ at low angles

- $\frac{\sigma}{E_\gamma} = \frac{0.8\%}{\sqrt{E_\gamma/\text{GeV}}} + 1.8\%$

Particle ID:

- Plastic Scintillators
- (MWPCs)

Together:

- $> 96\% 4\pi$
- Perfect for photons in the final state

Ongoing Analyses

Large dataset obtained!

First analyses started:

- $3\pi^0$ photoproduction cross section
- $\eta' \rightarrow \eta \pi^0 \pi^0$:
Dalitz Plot and Cusp Effect
- Pseudo-scalar-Vector- γ interactions:
 - $\eta' \rightarrow \omega \gamma$
 - $\omega \rightarrow \eta \gamma$
- Electromagnetic Transition Formfactor
 $\eta' \rightarrow e^+ e^- \gamma$

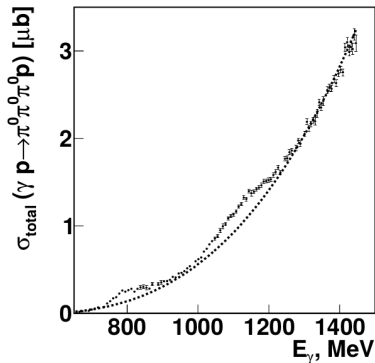
3 π^0 photoproduction cross section

$$\gamma p \rightarrow 3\pi^0 p$$

$$\gamma p \rightarrow N_1^* \xrightarrow{\pi^0} N_2^* \xrightarrow{\pi^0} \Delta(1232) \xrightarrow{\pi^0} p$$

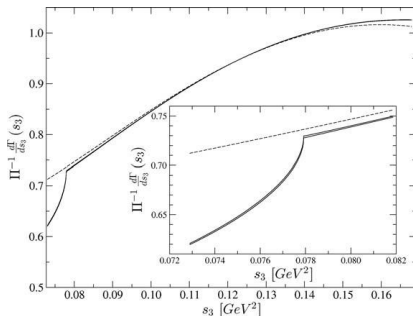
- Isobar Model
- Extend previous multi-pion and multi-meson production analyses

Previous Analysis:

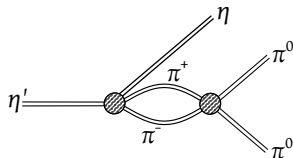


arXiv:1101.3744 [nucl-ex]

Martin Wolfes, PhD Thesis, in preparation

$\eta' \rightarrow \eta \pi^0 \pi^0$: Cusp Effect

- First seen in $K^+ \rightarrow \pi^0 \pi^0 \pi^+$ by NA48/2
Phys. Lett. B 633 (2006) 2-3
- Predicted in $\eta/K_L^0 \rightarrow 3\pi^0$, few % effect

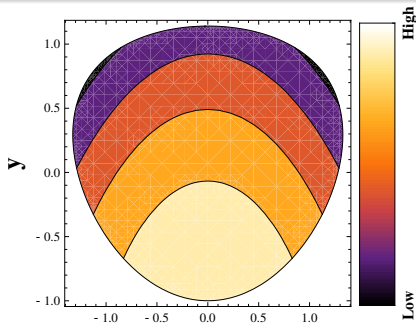


- $\pi^+ \pi^- \rightarrow \pi^0 \pi^0$ rescattering
- Allows extraction of the S-wave $\pi^0 \pi^0$ scattering length
- Prediction for $\eta' \rightarrow \eta \pi^0 \pi^0$: 8 % below $\pi^+ \pi^-$ threshold

Kubis, Schneider, S.P. Eur. Phys. J. C (2009) 62: 511

Cabbibo, Isidori, JHEP03(2005)

Gullström, Kupść, Rusetsky, Phys. Rev. C 79, 028201

$\eta' \rightarrow \eta \pi^0 \pi^0$: Dalitz Plot

$$X = \frac{\sqrt{3}(T_{\pi_1} - T_{\pi_2})}{Q} \quad Y = \frac{(m_{\eta} + 2m_{\pi})}{m_{\pi}} \frac{T_{\eta}}{Q} - 1$$

$$Q = T_{\pi_1} + T_{\pi_2} + T_{\eta} = m_{\eta'} - m_{\eta} - 2m_{\pi}$$

Dalitz Plot Parameters:

$$|A|^2 = |N|^2 [1 + aY + bY^2 + cX + dX^2]$$

Kaiser, Leutwyler, Eur. Phys. J. C (2000) 17: 623

Ecker, Gasser, et al., Phys. Lett. B 223 (1989) 425

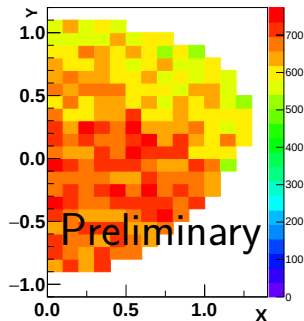
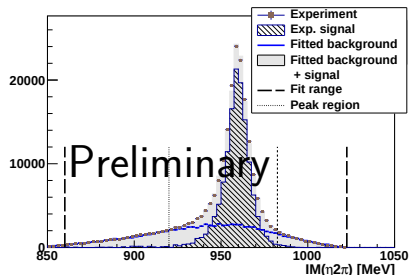
Escubano, Masjuan, Sanz-Cillero, JHEP(2011) 2011: 94.

- Test χ PT extensions:
- Test of large N_C models
- Test Resonance models

$\eta' \rightarrow \eta \pi^+ \pi^-$ (BESIII) 4.3×10^4 Events
Phys. Rev. D83 (2011) 012003

$\eta' \rightarrow \eta \pi^0 \pi^0$ (GAMS4 π) 1.5×10^4 Events
Phys. Atomic Nucl., 2009, Vol. 72, 231

$\eta' \rightarrow \eta \pi^0 \pi^0$ (A2) 1.3×10^5 Events
preliminary

$\eta' \rightarrow \eta \pi^0 \pi^0$: Status

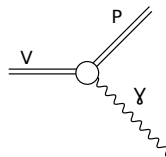
$$\sum_i \chi_i^2 = \left(\frac{N_{rec,i} - \varepsilon_i N(1 + aY_i + bY_i^2 + dX_i^2)}{\sigma_i} \right)^2$$

Result	a	b	d	χ^2/dof
A2 preliminary	-0.073(8)	-0.072(13)	-0.054(9)	233.6/195 = 1.198
GAMS4 π	-0.067(16)(4)	-0.064(29)(5)	-0.067(20)(3)	
Large N_c	-0.098(48)	-0.050(1)	-0.092(8)	
RChT	-0.098(48)	-0.033(1)	-0.072(1)	

Patrik Adlarson, Sergey Prakhov, paper in preparation

Pseudo-scalar-Vector- γ interactions

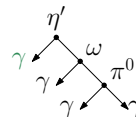
- $PV\gamma$ type interaction interesting input for effective field theories implementing vector particles
- Goal: Consistent picture of pseudo-scalar, and vector mesons
- Measure Branching Ratios
 - $\text{BR}(\eta' \rightarrow \omega \gamma)$
 - $\text{BR}(\omega \rightarrow \eta \gamma)$



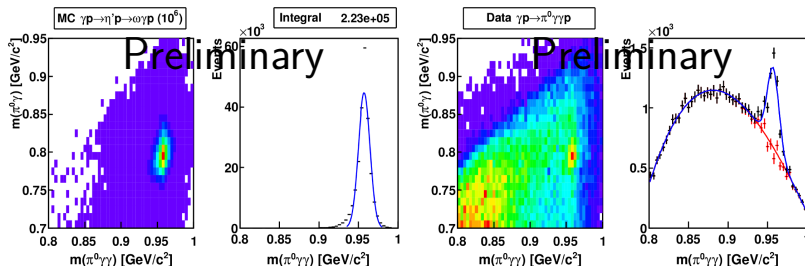
BR($\eta' \rightarrow \omega \gamma$)

- Relative measurement

		Γ_i/Γ (PDG)
Signal	$\eta' \rightarrow \omega \gamma$	$(2.75 \pm 0.23) \%$
	$\omega \rightarrow \pi^0 \gamma$	
Reference	$\eta' \rightarrow \gamma \gamma$	$(2.20 \pm 0.08) \%$



- Estimated signal events: $\approx 10^4$
- BESIII Result: $(2.55 \pm 0.03_{\text{stat}} \pm 0.16_{\text{syst}}) \%$
Phys. Rev. D 92, 051101(R)



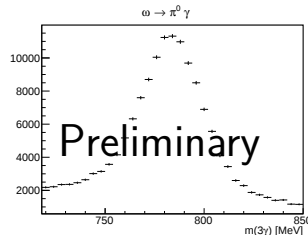
A. Neiser, PhD Thesis, in preparation

BR($\omega \rightarrow \eta\gamma$)

- 29×10^6 ω produced
- Relative measurement

		Γ_i/Γ (PDG)
Signal	$\omega \rightarrow \eta\gamma$	$(4.6 \pm 0.4) \times 10^{-4}$
	$\eta \rightarrow \gamma\gamma$	$(39.41 \pm 0.20) \%$
Reference	$\omega \rightarrow \pi^0\gamma$	$(8.28 \pm 0.28) \%$
	$\pi^0 \rightarrow \gamma\gamma$	$(98.82 \pm 0.03) \%$

- Expected Signal Events: ≈ 1500



Oliver Steffen, PhD Thesis, in preparation

Electromagnetic Transition Formfactor: $\eta' \rightarrow e^+ e^- \gamma$

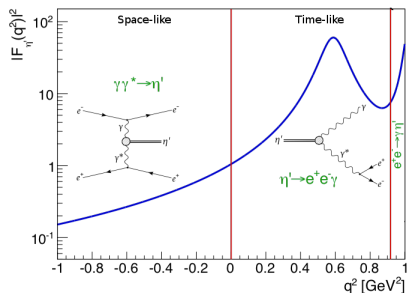
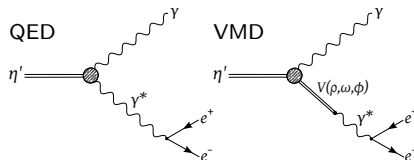
- η' Dalitz: $\eta' \rightarrow e^+ e^- \gamma$
(BR < 9×10^{-4})
- Differential decay width

$$\frac{d\Gamma}{dq^2 \Gamma(\eta' \rightarrow \gamma\gamma)} = \left[\frac{d\Gamma}{dq^2} \right]_{\text{QED}} \cdot |F(q^2)|^2$$

- Possible VMD parametrization

$$|F(q^2)|^2 = \frac{\Lambda^2(\Lambda^2 + \gamma^2)}{(\Lambda^2 - q^2) + \Lambda^2 \gamma^2}$$

- $\Lambda_{\eta'} = 0.767 \text{ GeV}$, $\gamma_{\eta'} = 0.1 \text{ GeV}$

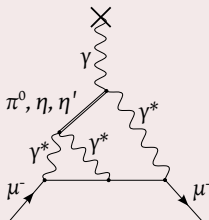


Escribano, Masjuan, Sanchez-Puertas, Phys. Rev. D 89 (2014) 034014

Hanhart, C., Kupść, A., Meißner, U. et al. Eur. Phys. J. C (2013) 73: 2668

Electromagnetic Transition Formfactor: Motivation

$(g-2)_\mu$



- $a_\mu = \frac{g-2}{2}$ anomalous magnetic moment of the muon
- Deviation from SM by $> 3\sigma$
- Theoretical predictions limited
 - hadronic Light-by-Light
 - hadronic vacuum polarization
- TFF: model validation

arXiv:1207.6556 [hep-ph]

η/η' mixing

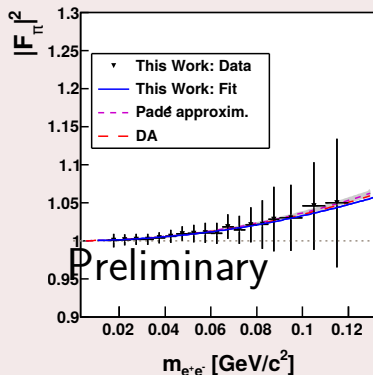
- Pseudo-scalar Mesons: $J^P = 0^-$
- $3 \otimes 3 = 8 \oplus 1 \rightarrow$ Octet, Singlet
- SU(3) Flavor Symmetry broken: $m_s \neq m_{u,d}$
- $\rightarrow \eta_8, \eta_0$ mixing

$$\eta = \eta_8 \cos \vartheta - \eta_0 \sin \vartheta$$

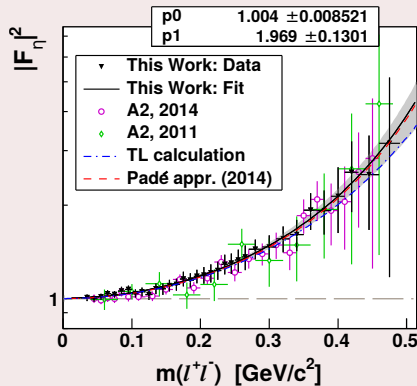
$$\eta' = \eta_8 \sin \vartheta + \eta_0 \cos \vartheta$$

- TFF enters into mixing angle calculation

arXiv:hep-ph/0111278

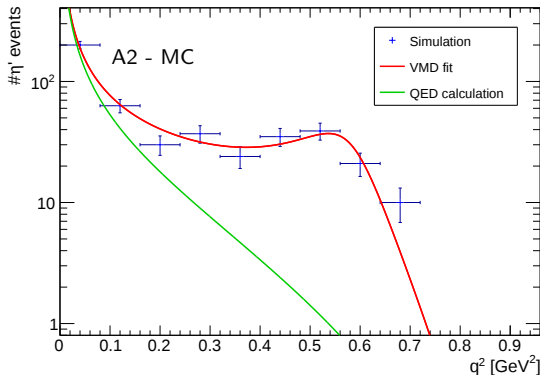
π^0 and η Transition Form FactorsTFF in $\pi^0 \rightarrow e^-e^+\gamma$ 

Paper in preparation

TFF in $\eta \rightarrow e^-e^+\gamma$ 

arXiv:1609.04503 [hep-ex]

Electromagnetic Transition Formfactor: $\eta' \rightarrow e^+ e^- \gamma$: Status



- BESIII Result Phys. Rev. D 92, 012001 (2015)

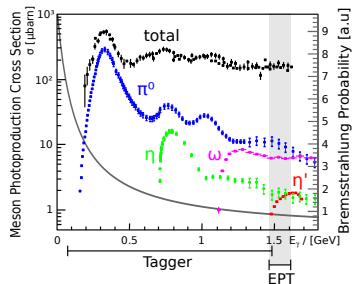
• A2:

- covering up peak region
- slightly higher statistics at large q^2

Sascha Wagner, PhD Thesis, in preparation

Summary

- Large dataset of η' (and other) decays has been obtained
- First analyses ongoing:
 - $3\pi^0$ photoproduction cross section
 - $\eta' \rightarrow \eta\pi^0\pi^0$
 - Cusp Effect
 - Dalitz Plot
 - $PV\gamma$
 - $BR(\eta' \rightarrow \omega\gamma)$
 - $BR(\omega \rightarrow \eta\gamma)$
 - η' electromagnetic TFF
- Many opportunities for further studies



Backup

The Target System: IH_2



- Liquid Hydrogen / deuterium
- $T = 20\text{ K}$
- Kapton Windows
- 10 cm long cell

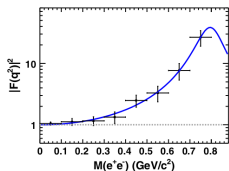


FIG. 6 (color online). Fit to the single-pole form factor $|F|^2$ using Eq. (4). The (black) crosses are data, where the statistical and systematic uncertainties are combined; the (blue) solid curve shows the fit results. The (gray) dotted line shows the pointlike case (i.e. with $|F|^2 = 1$) for comparison.

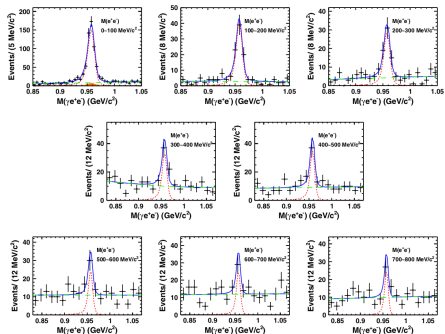


FIG. 4 (color online). Results from bin-by-bin fits to the $M(\gamma e^+ e^-)$ distributions for different $M(e^+ e^-)$ bins. The (black) crosses are data, the (red) dashed curves represent the signal, the (green) dot-dashed curves show the nonpeaking backgrounds, and the (orange) shaded component for the $M(e^+ e^-) < 100$ MeV/ c^2 bin is the shape of the peaking background from $J/\psi \rightarrow \gamma\gamma$, $\eta' \rightarrow \gamma\gamma$. The total fit results are shown as (blue) solid curves.