



Studies of electromagnetic η and η' decays with the Crystal Ball-TAPS detector

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For the A2 collaboration

Swedish Nuclear Physics meeting 2014

Motivation η and η' decays

A plethora of information can be obtained from these decays

- Determination of light quark masses $\eta / \eta' \rightarrow 3\pi$
- Searches for light dark matter $\eta / \eta' \rightarrow e^+e^-$, $\eta \rightarrow \pi^0e^+e^-$
- Tests fundamental symmetries, (C / P / CP) e.g $\eta \rightarrow 2\pi$, $\eta/\eta' \rightarrow 3\pi$,
 $\eta \rightarrow \pi^+\pi^-e^+e^-$
- Experimental input to anomalous magnetic moment of μ $\eta / \eta' \rightarrow e^+e^-\gamma$
- Test of low energy effective field theory $\eta \rightarrow \pi^0\gamma\gamma$

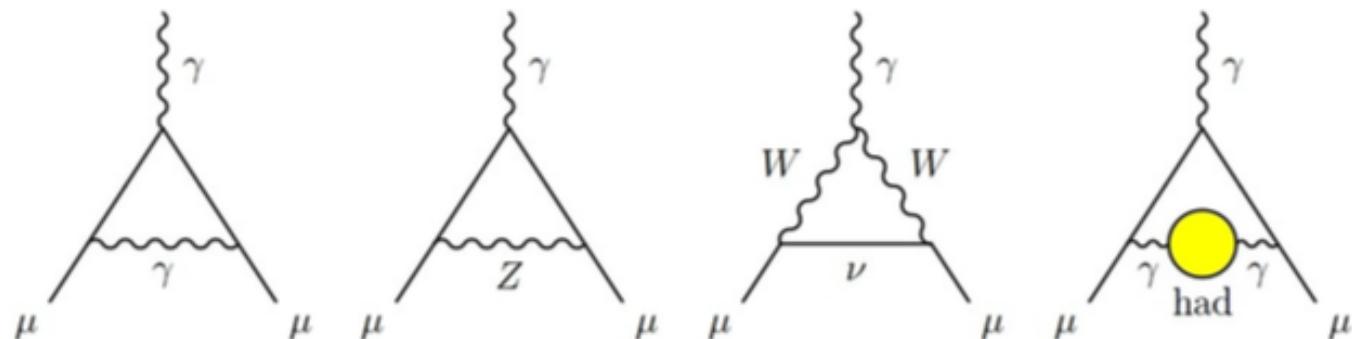
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Anomalous magnetic moment

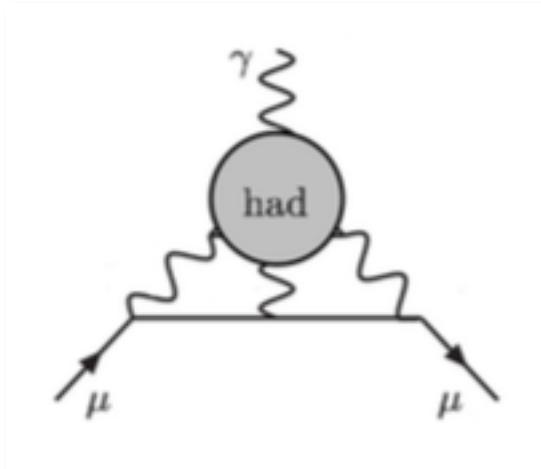
- The anomalous magnetic moment of the muon, a_μ :
- $a = (g-2) / 2$
 g is gyromagnetic ratio and $g = 2$ is predicted value of the Dirac equation.
- $a_\mu (\text{EXP}) = 11659208.0(63) \times 10^{-11}$ *Phys. Rev. D 73, 072003 (2006)*
- $a_\mu (\text{EXP}) - a_\mu (\text{SM})$ differ by $\sim 3.6 \sigma$



$$a_\mu (\text{SM}) = a_\mu \text{ QED} + a_\mu \text{ EW} + a_\mu \text{ hadronic}$$

Anomalous magnetic moment

- Greatest relative uncertainty to the hadronic term comes from the light – by – light contribution
- Leading contribution comes from hadrons coupled to two virtual photons
- Contributions are expected to scale in importance as m_{had}^{-2} , i.e. π, η, η'



Dalitz decay, $\eta \rightarrow e^+ e^- \gamma$

- EM Transition Form Factors (TFF) describes the intrinsic structure of Pseudoscalar mesons (P). Space- and **time-like TFFs**

$$d\Gamma(\eta \rightarrow l^+ l^- \gamma) / dm_{ll} / \Gamma(\eta \rightarrow \gamma\gamma) = [\text{QED}] \times |F_\eta(m_{ll})|^2$$

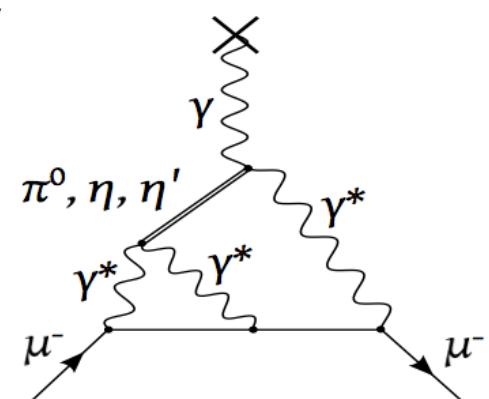
- Off-shell P form factors not accessible experimentally, but any good theoretical model should describe the on-shell scenario
- Slope parameter, b, reflects form factor slope at $m_{ll} = 0$, extracted from m_{ll}^2 distribution - compared to theory

$$P \rightarrow \gamma^{(*)} \gamma^{(*)}$$

Photons either real or virtual

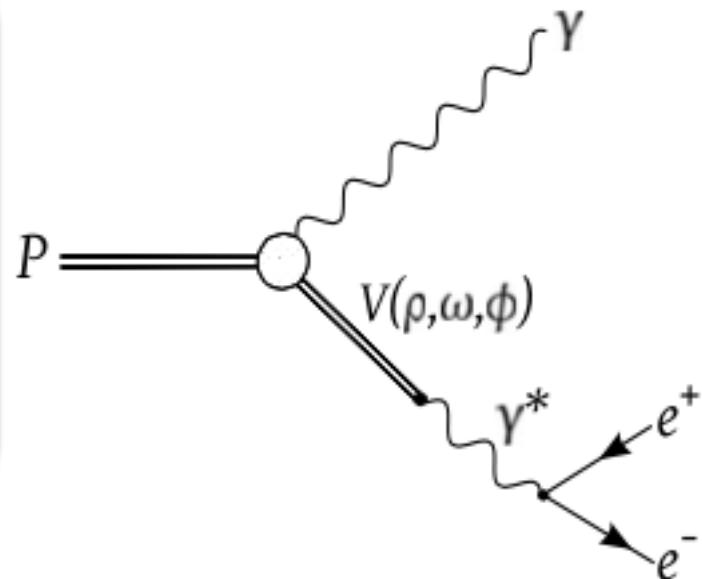
$$P \rightarrow \gamma^* \gamma \rightarrow e^+ e^- \gamma$$

e.g. Dalitz decay



VMD Dalitz decay, $\eta \rightarrow e^+ e^- \gamma$

- In the Vector Meson Dominance picture the virtual photon is coupled to a vector meson
- This influences TFF slope
- Under VMD TFF parametrized
 $F(m_{ll}) = 1 / (1 - m_{ll}^2 / \Lambda^2)$
 $b = \Lambda^{-2}$
 $\Lambda = \text{effective mass of virtual vector meson}$



Experimental setup CB-TAPS

$$\gamma p \rightarrow p \eta$$

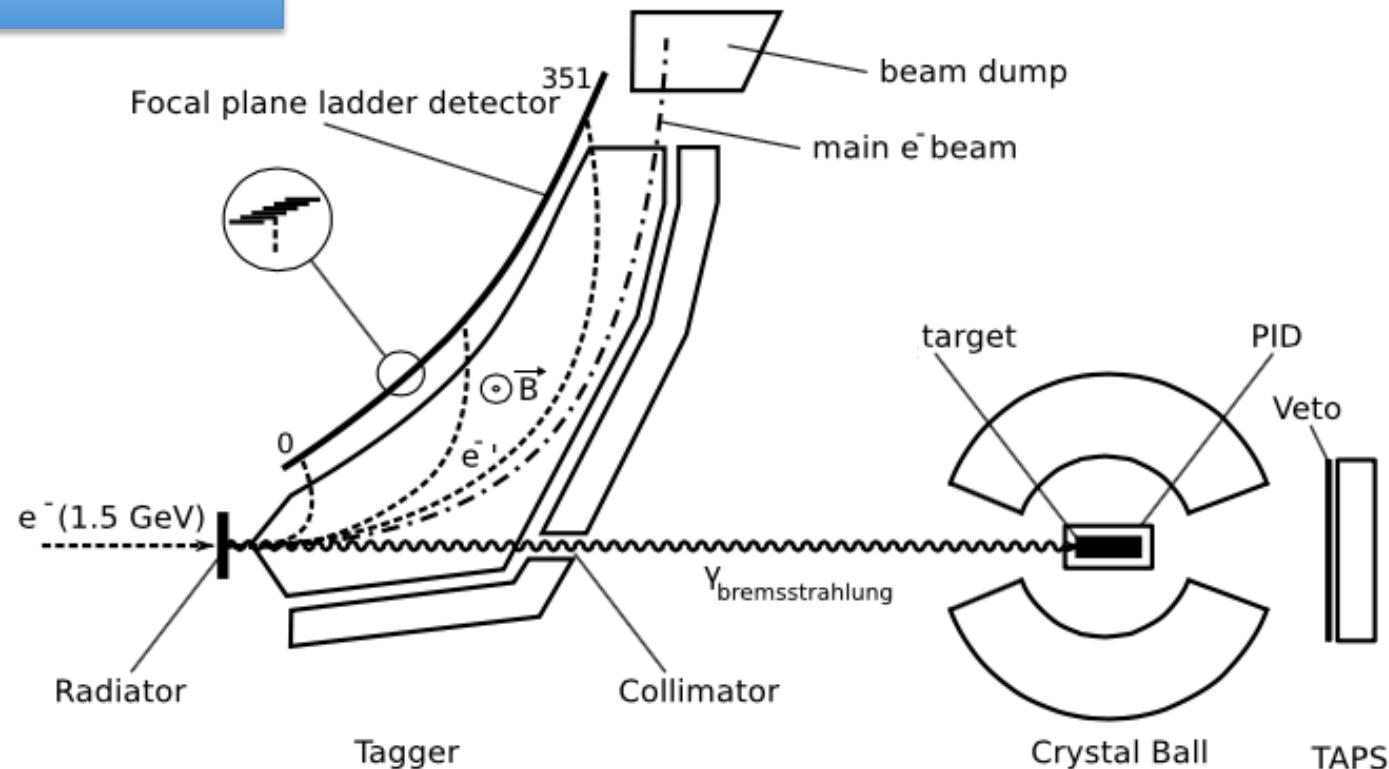


Figure from thesis D. Werthmüller

Experimental setup CB-TAPS

Central Part

- CB - 672 NaI(Tl) crystals
PID - discr. charged/neutrals

Forward Part

- TAPS - 384 BaF₂ crystals
Veto - 384 plastic sc.

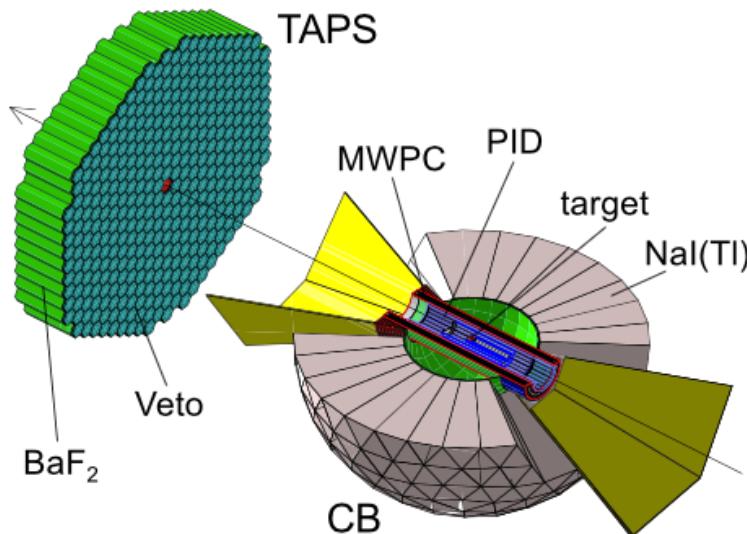


Figure from thesis D. Werthmüller

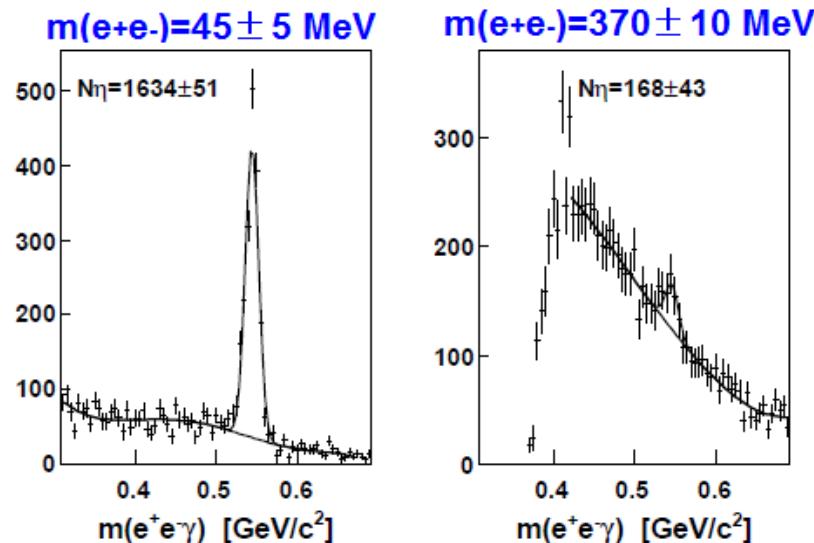
$$\frac{\Delta E}{E_{\text{dep}}} = \frac{2\%}{(E[\text{GeV}])^{0.36}} \quad (\text{CB})$$

$$\frac{\Delta E}{E_{\text{dep}}} = 1.8\% + \frac{0.8\%}{(E[\text{GeV}])^{0.5}} \quad (\text{TAPS})$$



Dalitz decay, $\eta \rightarrow e^+e^-\gamma$

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$2.2 \times 10^4 \eta \rightarrow e^+e^-\gamma$, (based on $3 \times 10^7 \eta$ decays)

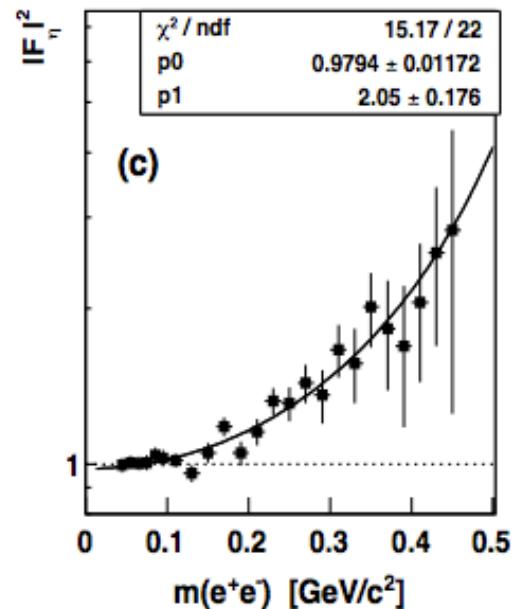
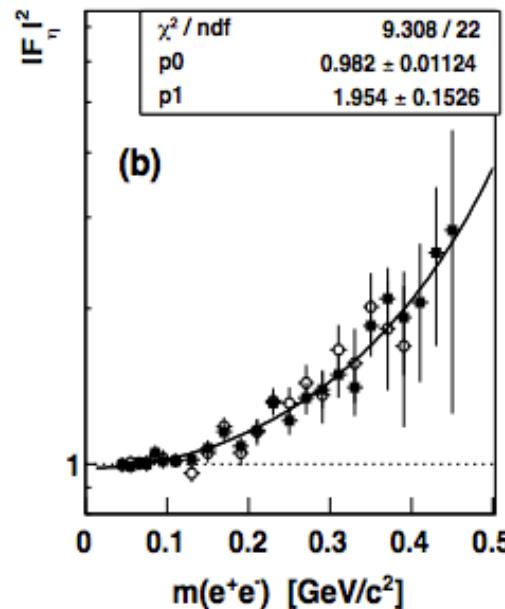
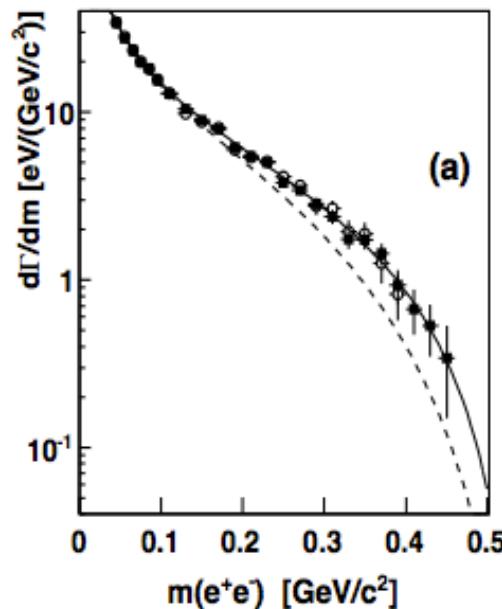
1.3×10^3 in previous measurement A2

Berghäuser et al. (A2-Collaboration) Phys. Rev. B 701 (2011) 562

New analysis based on kinematic fit
3 x more data in final event sample

Dalitz decay, $\eta \rightarrow e^+ e^- \gamma$

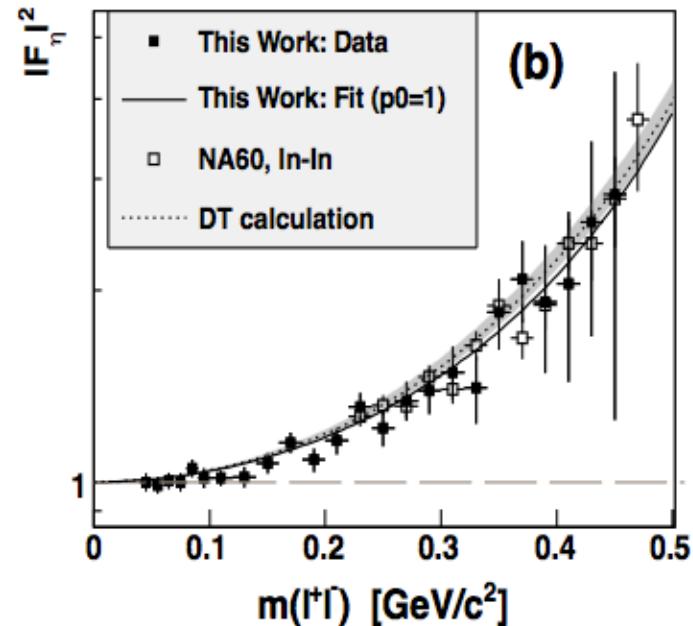
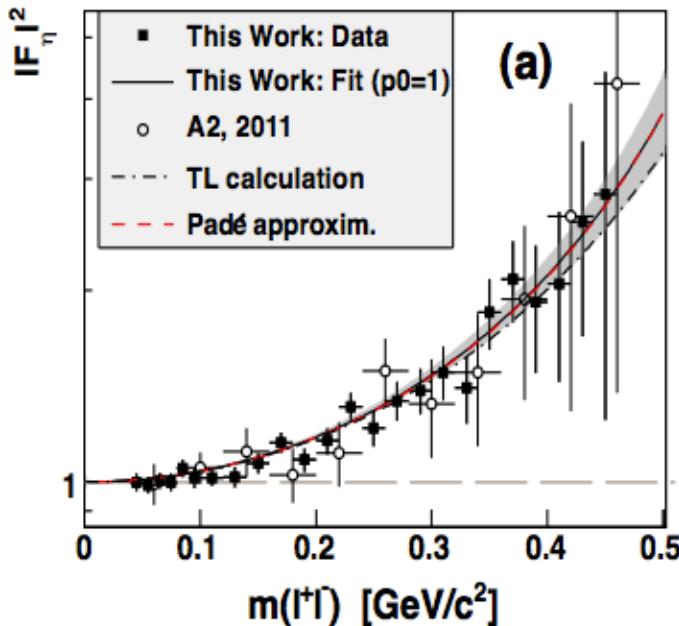
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Most precise measurement of
 $\eta - e^+ e^- \gamma$ to date

$b = \Lambda^{-2} = 1.95 (15)_{\text{stat}} (10)_{\text{syst}} \text{ GeV}^{-2}$ Reflects FF slope at $m_{\parallel} = 0$

$|F_\eta|^2 = 0.982(11) \rightarrow$ compatible to 1 within 2σ

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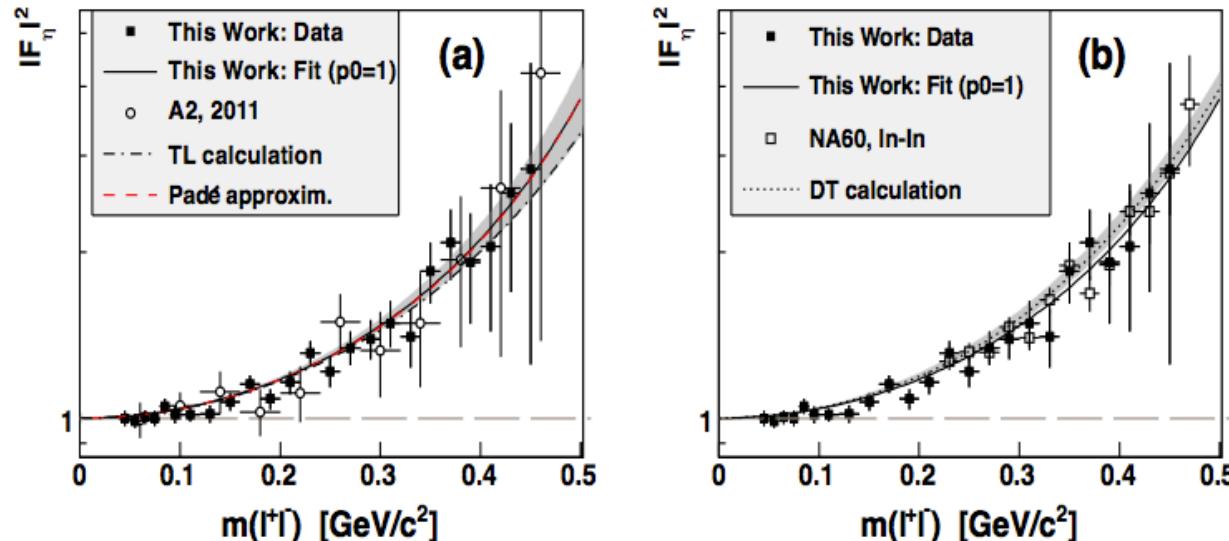
TL calculation: C. Terschlüsen, Diploma thesis, University Gießen, 2010.

Padé-approximants: R. Escribano, P. Masjuan, P. Sanchez-Puertas, Phys. Rev. D 89 (2014) 034014.

DT calculation: C. Hahnhart, A. Kupść, U.-G. Meißner, F. Stollenwerk, A. Wirzba, Eur. Phys. J. C73 (2013) 2668.

Result agrees best with Padé, all within statistical uncertainty

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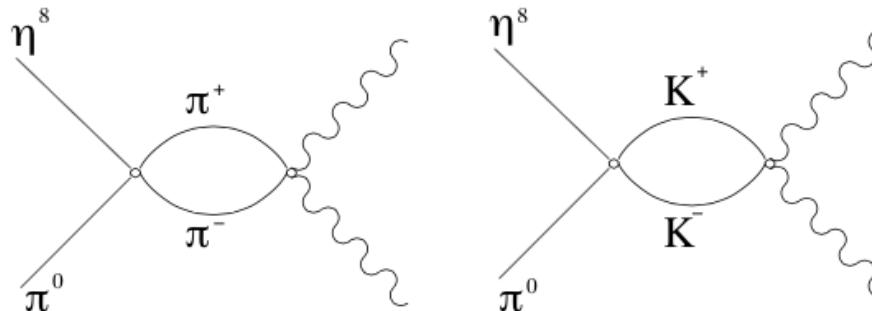
VMD models used to calculate hadr. LbL with $\Lambda = 774(29)$ MeV

Result of this work $\Lambda = 716(33)$ MeV

Smaller effective vector-meson masses ought to be used in VMD like models

Motivation $\eta \rightarrow \pi^0 \gamma\gamma$

- Calculated from the low energy effective field theory of QCD, ChPT
- No contribution at $O(p^2)$, heavily suppressed at $O(p^4)$
- Contribution from $O(p^6)$ comes from counterterms in ChPT. The coefficients determined from models

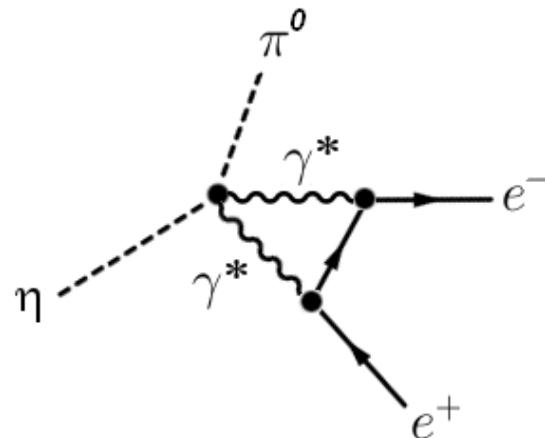


Contributions at $O(p^4)$ low due to G-parity conservation and large K masses

- Experimental input : decay width and partial width $d\Gamma(\eta \rightarrow \pi^0 \gamma\gamma) / dm(\gamma\gamma)^2$

Motivation $\eta \rightarrow \pi^0 \gamma\gamma$

- Photon fusion reactions, $\gamma\gamma - P P$ (e.g. $\pi^0 \eta$) crosssections have $\eta \rightarrow \pi^0 \gamma\gamma$ data as part of input to determine constants
- May be used to predict the Standard Model contribution to $\eta \rightarrow \pi^0 e^+ e^-$

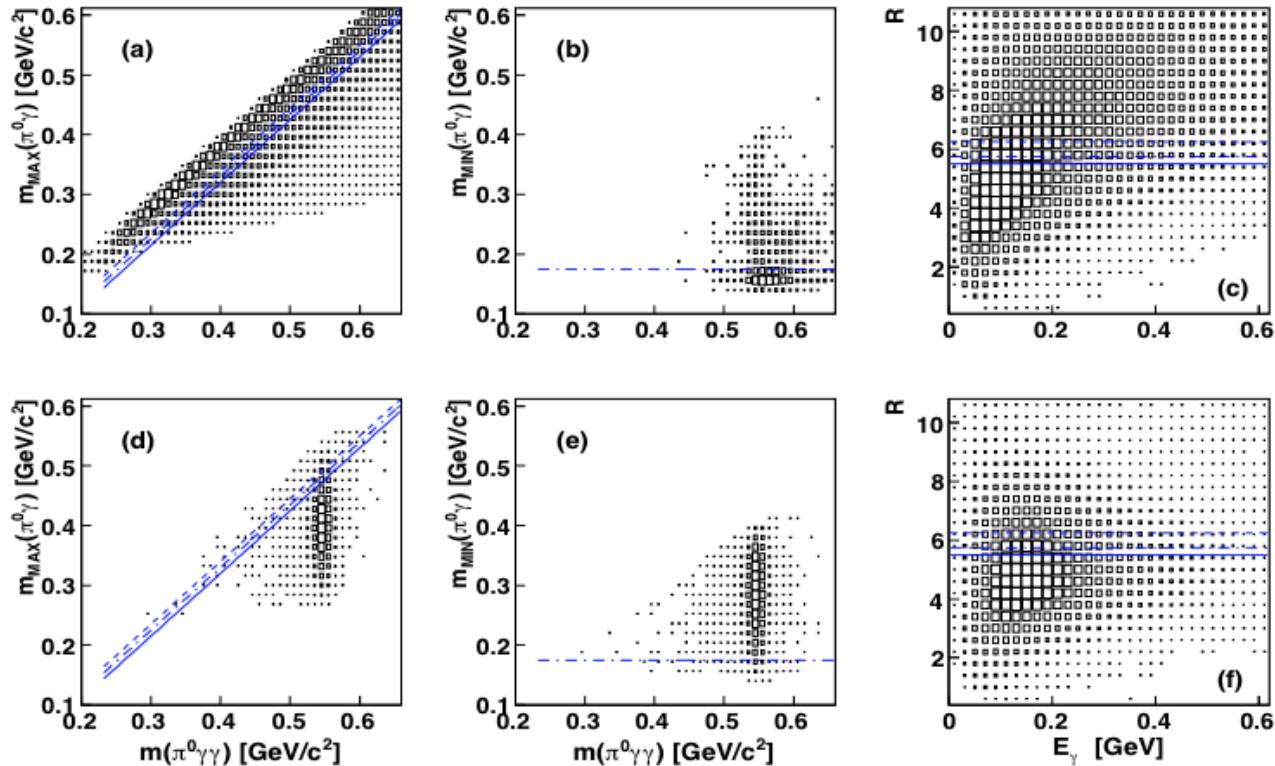


$\eta \rightarrow \pi^0 e^+ e^-$ proceeds via two virtual photons and therefore contains $\eta \rightarrow \pi^0 \gamma\gamma$ offshell

- Experimental input : decay width and partial width $d\Gamma(\eta \rightarrow \pi^0 \gamma\gamma) / dm(\gamma\gamma)^2$

Background removal

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$p \pi^0\pi^0$
y -axis: $m_{\max}(\pi^0\gamma)$

$p \eta(\rightarrow \gamma\gamma)$
 $m_{\min}(\pi^0\gamma)$

$p \eta(\rightarrow 3\pi^0)$
eff cl radius

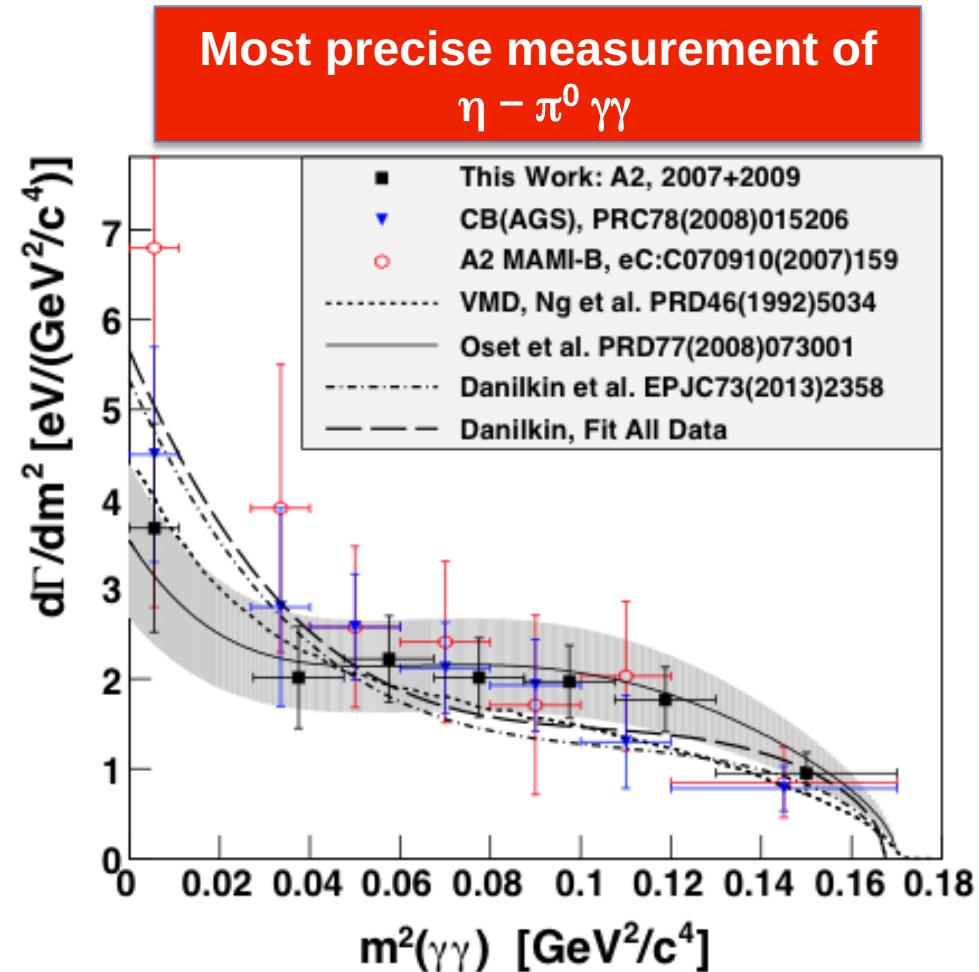
Results

Phys. Rev. C 90 (2014) 025206

Total decay width

- Theoretical calculation:
 $0.33(8)$ eV – Chiral Unitarity
 $0.30^{(+16)}_{(-0.13)}$ VMD

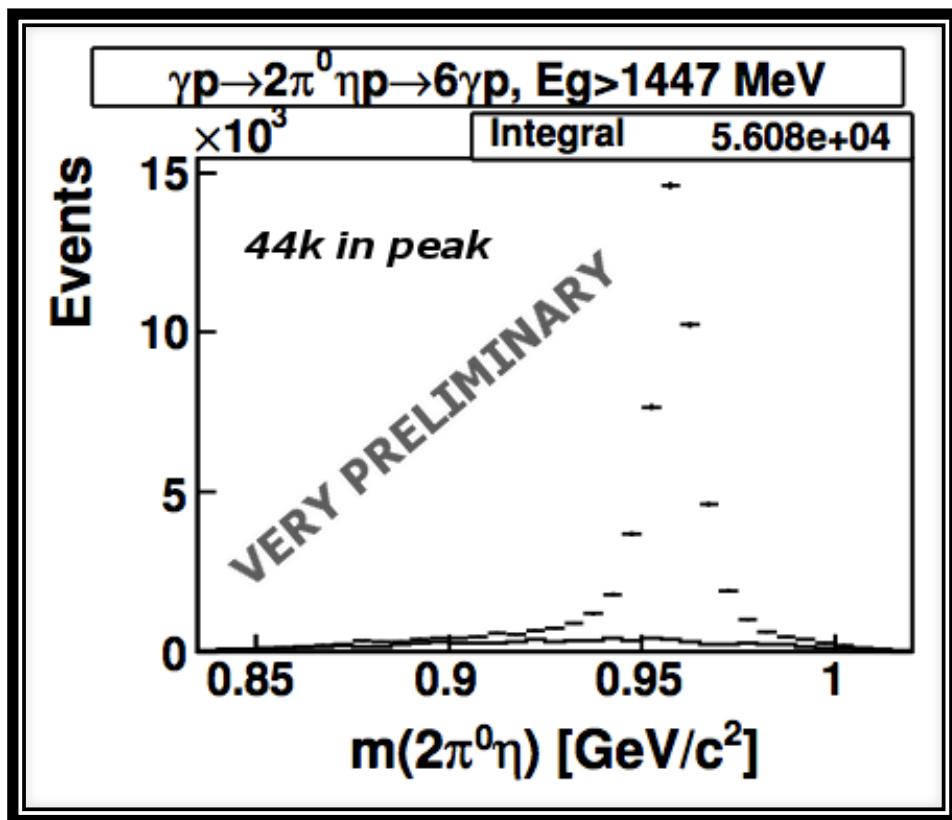
- Experiment
PDG $0.35(7)$ eV
This work: $0.330(30)$ eV



Differential decay width slightly favors Chiral Unitary approach
More high statistics input needed



Outlook



η' decays with A2

η' production run ends dec 2014.
(2012) $1.2 \times 10^6 \eta'$ on disk

(2014) 3.3×10^6 (July-Aug) –improved DAQ
(2014) Oct – Nov

Projected nr of η' on disk $\sim 8 \times 10^6$

Experience from η decays

Summary

η and η' decays give us important information related to low energy QCD

CB –TAPS detector setup can provide experimental input into common and rare em decays of η/η'

One can expect precision results on η' photo production and decays from A2 in the near future

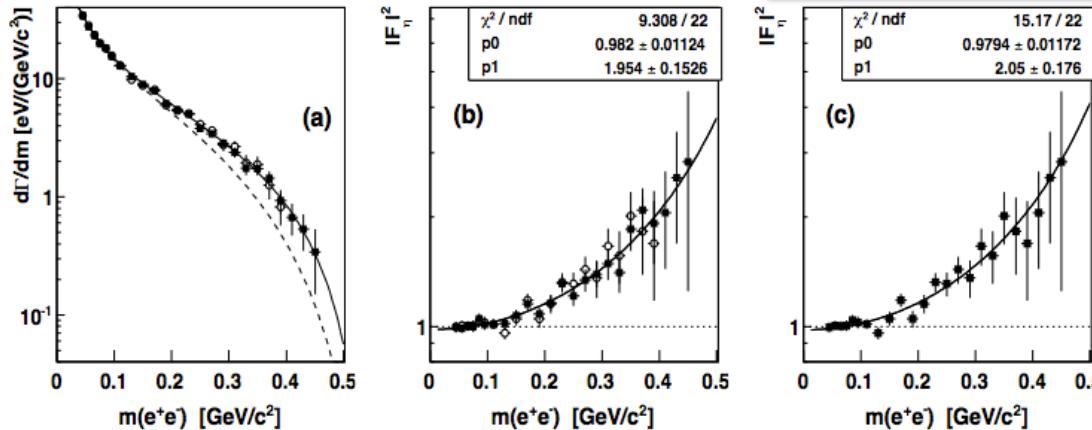
Thank you

Dalitz decay, $\eta \rightarrow e^+ e^- \gamma$

Phys. Rev. C 89 (2014) 044608

JOHANNES GUTENBERG
UNIVERSITÄT MAINZ

Most precise measurement of
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$$\Lambda^{-2} = 1.95(15)_{\text{stat}}(10)_{\text{syst}} \text{ GeV}^{-2}$$

Good agreement with NA60 result ($I = \mu$)
G.Usai (NA60 Coll.) Nucl. Phys. A 855, 189(2011)

$$\Lambda^{-2} = 1.950(59)_{\text{stat}}(42)_{\text{syst}} \text{ GeV}^{-2}$$