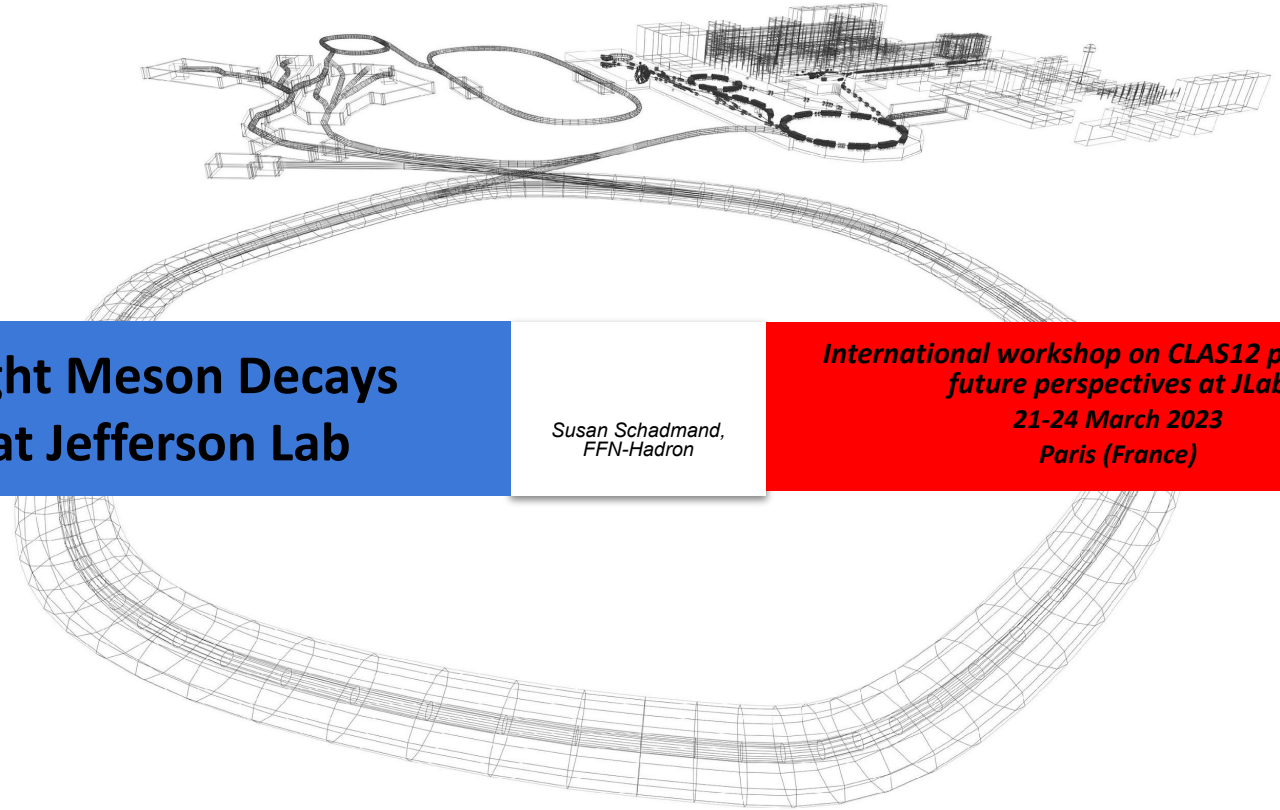


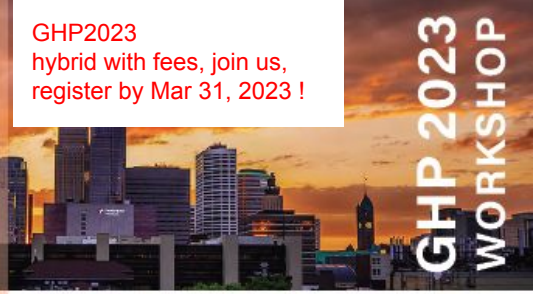
Light Meson Decays at Jefferson Lab

Susan Schadmand,
FFN-Hadron

International workshop on CLAS12 physics and future perspectives at JLab
21-24 March 2023
Paris (France)

GHP2023
hybrid with fees, join us,
register by Mar 31, 2023 !

APRIL 12-14
Minneapolis, MN



WORKSHOP TOPICS INCLUDE:

- Artificial intelligence and machine learning for hadron physics
- Electron Ion Collider and other future facilities and experiments
- Electroweak probes
- Extreme matter and neutron star collisions
- Hadrons in nuclei
- Hadron spectroscopy
- Hadron tomography
- Hadronization
- Heavy flavor and jet production
- Neutrino-hadron interactions
- New physics and discrete symmetry violation in hadron physics
- Nonequilibrium dynamics
- Nucleon and nuclear spin physics
- Origin of hadron mass
- Physics of the quark-gluon plasma
- Quantum information for hadron physics
- Small systems and collectivity
- Transverse and longitudinal structure of hadrons
- Ultraperipheral Collisions

10th WORKSHOP OF THE APS TOPICAL GROUP ON HADRONIC PHYSICS

The GHP workshop is a great opportunity for nuclear and particle physicists to share their research and common interests in hadronic physics. We welcome your attendance and participation. Please encourage your students and postdocs to take part.

APS Advancing Physics

The workshop immediately precedes the APS April Meeting 2023 and is at the same venue.

ORGANIZING COMMITTEE:

Ron Belmont (UNC Greensboro)
William Brooks (Federico Santa Maria Technical University) - *workshop co-chair*
Ian Cloët (Argonne National Laboratory)
Martha Constantinou (Temple University)
James Dunlop (Brookhaven National Laboratory)
Dave Gaskell (Jefferson Lab)
Spencer Klein (Lawrence Berkeley National Laboratory)
Alexei Prokudin (Penn State Berks)
Susan Schadmand (GSI Helmholtzzentrum für Schwerionenforschung GmbH)
Axel Schmidt (George Washington University)
Julia Velkovska (Vanderbilt University) - *workshop co-chair*
Ramona Vogt (Lawrence Livermore National Laboratory & UC Davis)

contact: ghpworkshops@gmail.com https://www.jlab.org/indico/e/ghp2023

DNP2022

Fall Meeting of the Division of Nuclear Physics of the American Physical Society
Oct. 27 – 30, 2022
Hyatt Regency Hotel, New Orleans, LA

APS physics

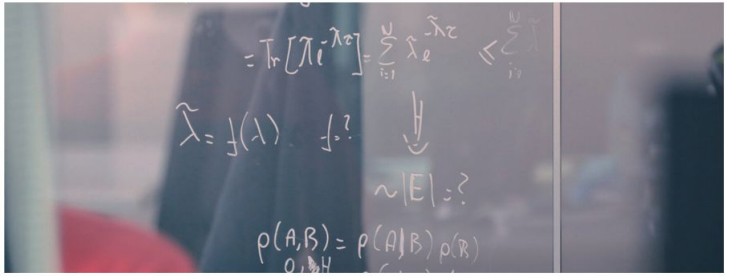
- Home
- Dates
- Registration
- Program
- Workshops
- Undergrads
- Session Chairs
- Info for Speakers
- Code of Conduct
- Travel

Minisymposia

- (19a) Don't Look Up: Nuclear Data for Planetary Defense and Space Exploration
- (19b) Inspiring the Next Generation Through Nuclear Research
- (19c) Mass Measurements for Extreme Astrophysical Environments
- (19d) Nuclear Pandemonium: How TAS Informs Outstanding Issues in Nuclear Physics
- (19e) Nucleon Structure and Interactions
- (19f) Probing Low-Energy QCD, Fundamental Symmetries and BSM Physics via π^0, η and η' Decays
- (19h) The Initial State of Heavy-Ion Collisions
- (19j) The Physics of Double Beta Decay
- (19k) Time Reversal Invariance Violation

FONDAZIONE BRUNO KESSLER | ECT* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

PRECISION TESTS OF FUNDAMENTAL PHYSICS WITH LIGHT MESONS



12 June 2023 — 16 June 2023

Aula Renzo Leonardi - Villa Tambosi

Str. delle Tabarelle, 286, 38123 Villazzano TN
Villazzano

Light Meson Decays: physics and experiments, the case of $\eta^{(\prime)}$

Decay channel	Standard Model	Discrete symmetries	Light BSM particles
$\eta \to \pi^+\pi^-\pi^0$	light quark masses	C/CP violation	scalar bosons (also η')
$\eta^{(\prime)} \to \gamma\gamma$	η–η' mixing, precision partial widths		
$\eta^{(\prime)} \to \ell^+\ell^-\gamma$	$(g-2)_\mu$		Z' bosons, dark photon
$\eta \to \pi^0\gamma\gamma$	higher-order χPT, scalar dynamics		$U(1)_B$ boson, scalar bosons
$\eta^{(\prime)} \to \mu^+\mu^-$	$(g-2)_\mu$, precision tests	CP violation	
$\eta \to \pi^0\ell^+\ell^-$		C violation	scalar bosons
$\eta^{(\prime)} \to \pi^+\pi^-\ell^+\ell^-$	$(g-2)_\mu$		ALPs, dark photon
$\eta^{(\prime)} \to \pi^0\pi^0\ell^+\ell^-$		C violation	ALPs

Review article: Precision tests of fundamental physics with η and η′ mesons
Liping Gan, Bastian Kubis, Emilie Passemar, Sean Tulin, Phys.Rept. 945 (2022) 1-105

KLOE-II CLAS 6GeV era *WASA-at-COSY*	PrimeX GlueX-JEF CLAS12	MAMI A1, A2 BESIII *REDTOP*

Light Meson Decays: Rare decay $\eta \to \pi^0 \gamma\gamma$

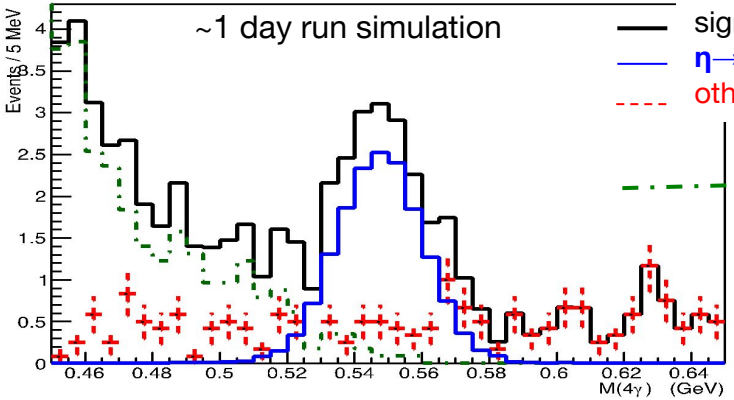
- higher order Chiral Perturbation Theory
- VMD and scalar resonances
- Low Energy Constants
- search for a dark scalar mediator
- search for a leptophobic dark boson

- **Dalitz distribution Mγγ** sensitivity to scalars
- BESIII: $\eta' \to \pi^0 \gamma\gamma$ PRD 96 (2017) 012005

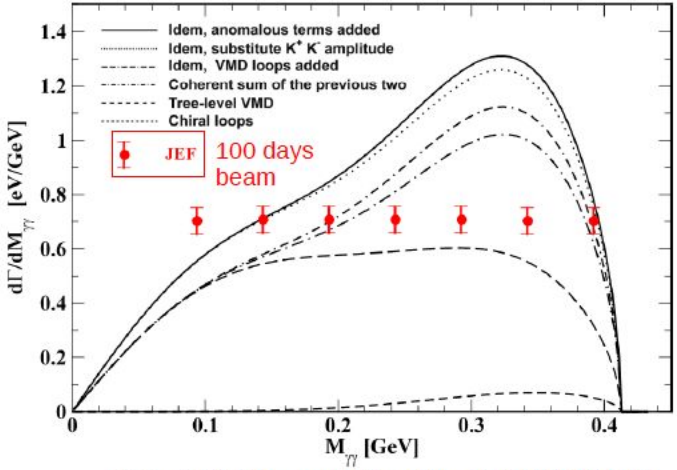
MAMI: $\gamma p \to \eta p$ ($E_{\gamma,max}$ = **1.402 GeV**)
B. M. K. Nefkens, S. Prakhov *et al.* (A2 Collaboration at MAMI)
Phys.Rev.C 90 (2014) 2, 025206

JEF experiment
- **12 GeV electron beam**
- **upgraded calorimeter FCAL-II**

JEF: $\gamma p \to \eta p$ (E_γ = **8.4-11.7 GeV**)

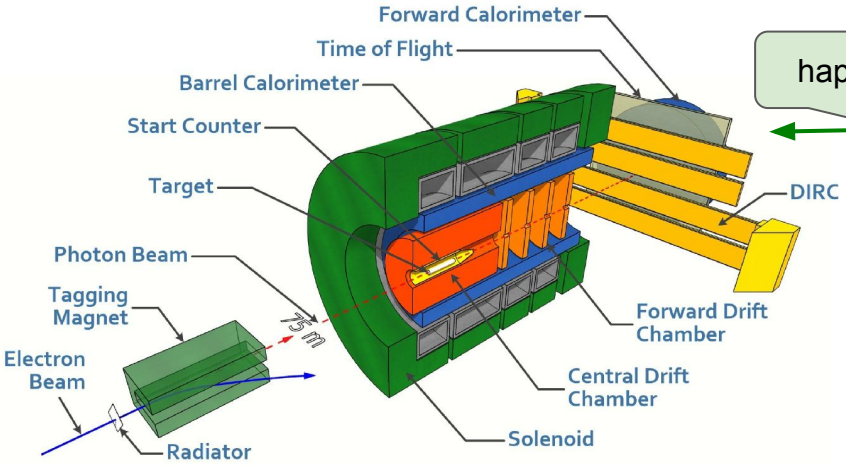


simulated $\eta \to \pi^0\pi^0\pi^0$ **background at small masses**
$\pi^0\gamma\gamma$ analysis

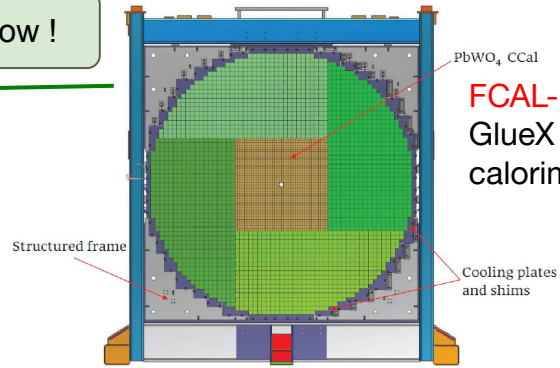


E. Oset, J.R. Pelaez, and L. Roca, Phys.Rev.D77:073001,2008

JLab Eta Factory (JEF) Experiment γ+p → η/η'+p



happening now !



FCAL-II
GlueX upgraded forward calorimeter with PWO insert

data taking starts 2024 !

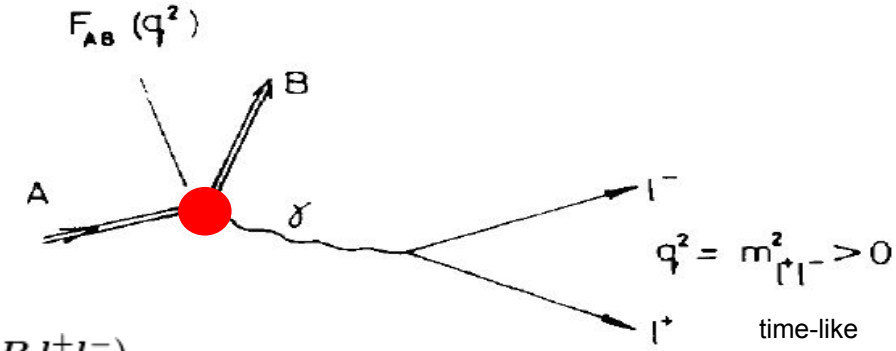
η/η' radiative decays

- ★ 8.4 - 11.7 GeV tagged photon beam and LH_2 target
- ★ detect recoil protons with GlueX detector
- ★ detect multi photon final states with FCAL-II
- ★ high resolution, high granularity, **highly suppressed background**

JEF (100 days)	η	η'
tagged mesons	6.5×10^7	4.9×10^7

concurrent with GlueX-II

Light Meson Decays: Transition Form Factor



$$\frac{d\Gamma(A \to B\, l^+ l^-)}{dq^2 \cdot \Gamma(A \to B\gamma)} = \left|F_{A\to B}(q^2)\right|^2 \cdot |\mathrm{QED}|$$

form factor: divide experimental q^2 distribution by QED

$$F_{AB}(q^2) \simeq 1 + q^2[\mathrm{d}F_{AB}/\mathrm{d}q^2]|_{q^2\simeq 0} = 1 + q^2 b_{AB} = 1 + \tfrac{1}{6}q^2\langle r^2_{AB}\rangle$$

$$\Lambda \simeq m_\rho \; (\Lambda^{-2} = b_{AB})$$

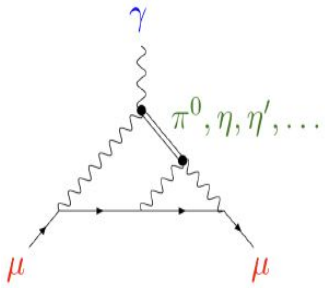
'standard' VMD, b~1.69/GeV^2

slope parameter

size (transition region)

- intrinsic structure of hadrons
- hadron coupling to photon
- background for BSM physics

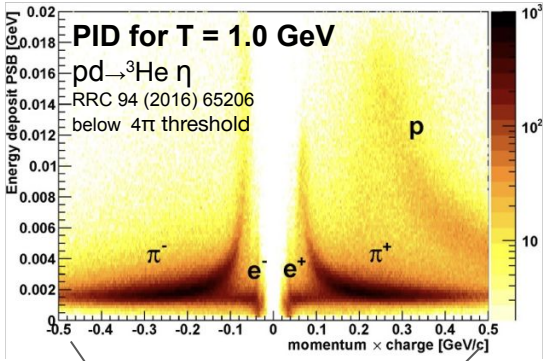
relevance for muon g-2

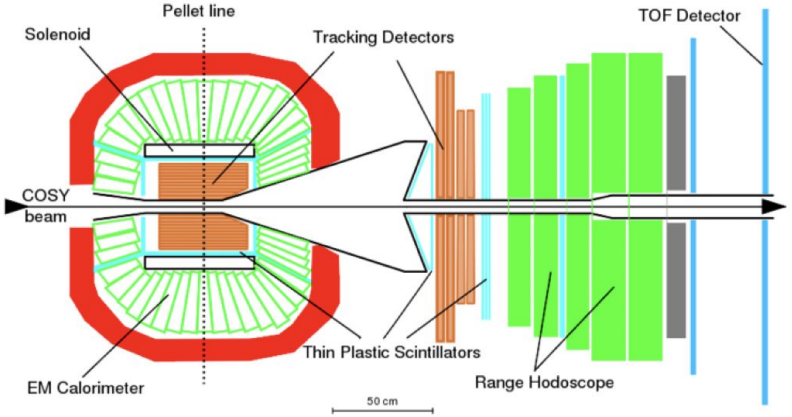


L.G. Landsberg, Electromagnetic decays of light mesons
PHYSICS REPORTS 128, No. 6 (1985) 301—376.

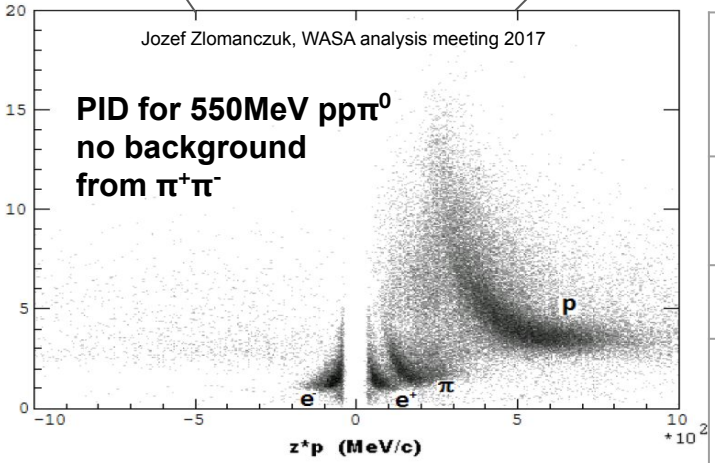
WASA-at-COSY data mining: towards double Dalitz decays

plastic scintillator vs signed momentum





WASA-at-COSY decommissioned 2014



T = 550 MeV **pp → pp π^0 data sets** **below the double pion production threshold**		
Jul 2013	62.3 TB	2.5 γee candidates
Aug 2012	70.1 TB	
Mar 2010	10.7 TB	**0.5M γee** PLB 726 (2013) 187

WASA p + p reactions: statistics for Dalitz decays

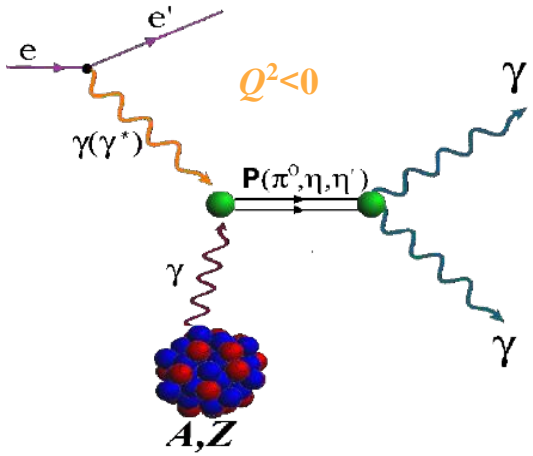
5.5M? **ppπ^0** - single Dalitz
5.5k?? ppπ^0 - double Dalitz

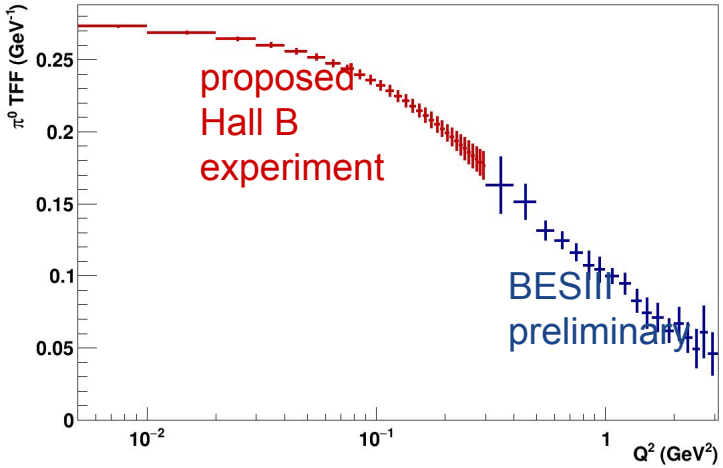
30M ^{3}He η produced
14k ^{3}He η - single Dalitz
18 ^{3}He η - double Dalitz

500M ppη - with trigger on charged decay particles
80k? ppη - single Dalitz

Approved JLab Hall B Proposal E12-22-003:
"Precision Measurement of the Neutral Pion Transition Form Factor"

Spokespersons: D.S. Dale, D. Dutta, L. Gan, I. Larin (contact person), R. Miskimen, and E. Pasyuk

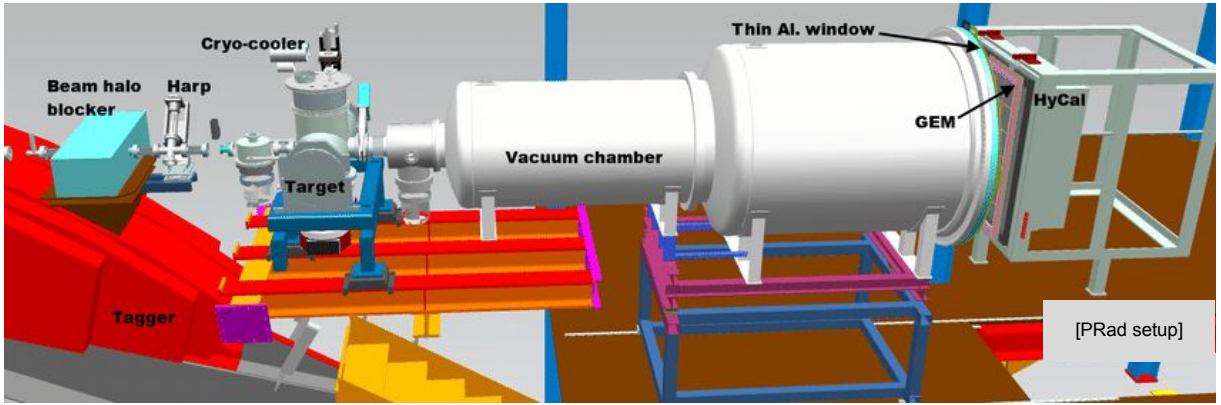




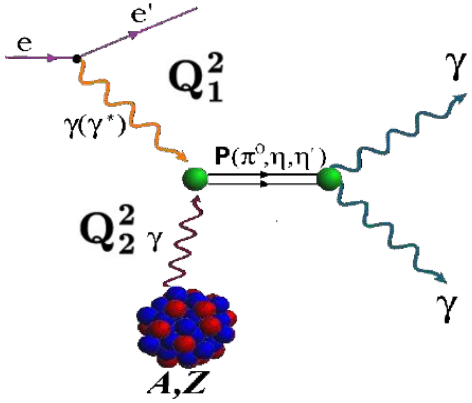
- **space-like π^0 transition form factor at low Q^2**
- **sensitivity to π^0 radiative decay width**

At MAMI: PAC A1-LOI-2020 Measurement of the Electromagnetic Transition Form Factor of the π^0 in the space-like region via Primakoff Electroproduction
L. Capozza, M. Gorshteyn, F. Maas, O. Noll, S. Wolff ... plan: pilot run 2024

Hall B setup for π^0 TFF measurement



- ultra-low background
- vacuum chamber
- GEM detector (VETO)
- new solid target
- high resolution electromagnetic calorimeter ($PbWO_4$) for **measuring scattered e' and reconstructing $\pi^0 \to \gamma\gamma$**



$$F_{\gamma^*\gamma^* \to \pi^0}(-Q_1^2, -Q_2^2)$$

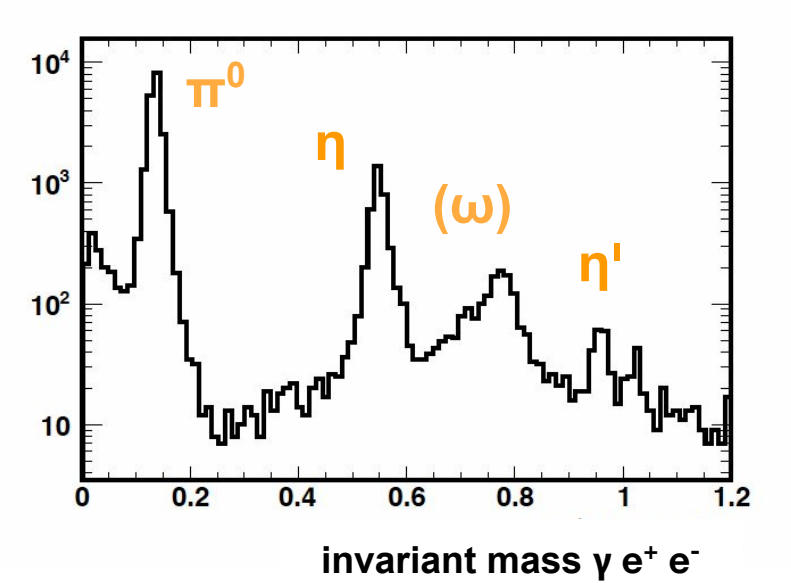
- **Q_1^2 from scattered e'**
- **Q_2^2 from $\pi^0 \to \gamma\gamma$**
  - **$Q_2^2 = t = (p_{\gamma^*} - p_{\pi 0})^2$**

plan: hope to run 2024 or 2025

CLAS Approved Analysis - Light Mesons from the 6 GeV Era

Photoproduction and Decay of Light Mesons in CLAS
M. Amaryan *et al.* (ODU and 20 other institutes),
CAA-HS12-01, October 2012
(g11,g12)

$\gamma\, p \rightarrow p\, \gamma\, e^+ e^-$



CLAS g12 experiment: $\gamma + p$

$\pi^0 \rightarrow \gamma\, e^+ e^-$
Exclusive photoproduction extended to higher energies
[CLAS PRC 98, 015207 (2018)]

$\eta \rightarrow \gamma\, e^+ e^-$ **(would benchmark channel)**

$\omega \rightarrow \pi^0\, e^+ e^-$
limited statistics, discrepancies with theory / SND experiment [Phys. Rev. D 94, (2016) 112001]

$\eta' \rightarrow \gamma\, e^+ e^-$
CLAS6 not competitive with BESIII

data mining ? Or: further data from CLAS12 !

Transition Form Factor of the η′ Meson with CLAS12

Proposal E12-06-108B PAC44 (2016) addition to Run Group A (**MesonX**)

CLAS12, the dilepton spectrometer

BESIII $J/\psi \rightarrow \gamma\eta'$

- **864 ± 36 $\eta' \rightarrow \gamma ee$**
  single Dalitz decay
  based on 1.31 x 10^9 J/ψ events
  BESIII PR D92 (2015) 012001

- **30.1 ± 7.0 $\eta' \rightarrow eeee$**
  double Dalitz decay
  based on (10087 ± 44) x 10^6 J/ψ events
  BESIII PRD 105 (2022) 112010

proposed:

- **$\eta' \rightarrow \gamma ee$ single Dalitz decay**
  projected 28,200 events / 80 days

- **further objectives**
  - **$\eta \rightarrow \gamma ee$** to show how well it works
  - **$\eta' \rightarrow eeee$** feasibility
  - **$\omega \rightarrow \pi^0$ ee** ω-π transition form factor
  - **$\pi^0 \rightarrow \gamma ee$, $\pi^0 \rightarrow eeee$**
    can we reach that?

CLAS12 analysis should begin in summer 2023 (postdoc being hired)

Light Meson Decays at Jefferson Lab

1. Light Meson Decays: physics and experiments, the case of η(')
2. JLab Eta Factory (JEF) ⊗ GlueX-II

   (combined Hall D proposal)
3. Light Meson Decays: Transition Form Factor
4. WASA-at-COSY data mining: towards double Dalitz decays
5. Precision Measurement of the Neutral Pion Transition Form Factor

   (Hall B proposal of the Primex group)
6. CLAS Approved Analysis - Light Mesons from the 6 GeV Era
7. Transition Form Factor of the η′ Meson with CLAS12

   (addition to Run Group A)