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Tests of Symmetries with η Decays at WASA-at-COSY

Daniel Coderre
Chiral Dynamics Workshop
2012

Introduction: the η Meson

Properties of the η

- Light pseudoscalar, mass $m_\eta = 547.853 \pm 0.024$ MeV/c^2 [1]
- Simple quantum numbers $J^{PC} = 0^{-+}$
- All strong and EM decays forbidden on the first order
  - Rare processes experimentally accessible

Decay Studies

- Test fundamental symmetries
  - C-symmetry in $\eta \rightarrow \pi^0 e^+ e^-$
  - CP-symmetry in $\eta \rightarrow \pi^+ \pi^- e^+ e^-$
- Study structure of the η meson
  - EM transition form factor measurements $\eta \rightarrow e^+ e^- \gamma$, $\eta \rightarrow e^+ e^- e^+ e^-$
- Provide precise tests of theoretical predictions (ChPT)
  - $\eta \rightarrow \pi^+ \pi^- \pi^0$, $\eta \rightarrow \pi^0 \pi^0 \pi^0$
  - $\eta \rightarrow \pi^0 \gamma\gamma$
  - $\eta \rightarrow \pi^+ \pi^- \gamma$
- Search for new physics outside standard model
  - $\eta \rightarrow e^+ e^-$

[1] J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012).

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- Study structure of the η meson
  - EM transition form factor measurements $\eta \rightarrow e^+e^-\gamma$, $\eta \rightarrow e^+e^-e^+e^-$
- Provide precise tests of theoretical predictions (ChPT)
  - $\eta \rightarrow \pi^+\pi^-\pi^0$, $\eta \rightarrow \pi^0\pi^0\pi^0$
  - $\eta \rightarrow \pi^0\gamma\gamma$
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- Search for new physics outside standard model
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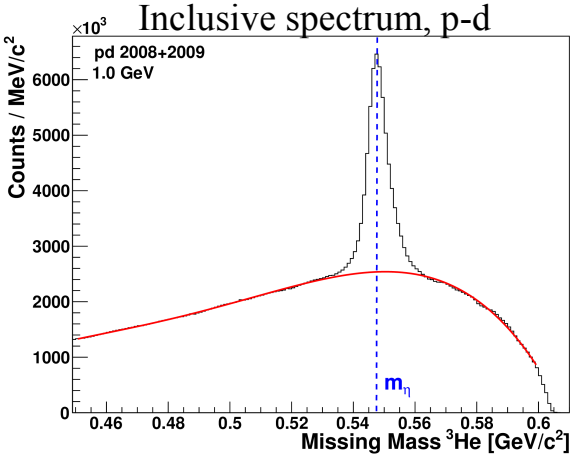
The WASA-at-COSY Experiment

- Meson production via. $p\,d \rightarrow {}^3He\,\eta$
  $p\,p \rightarrow p\,p\,\eta$

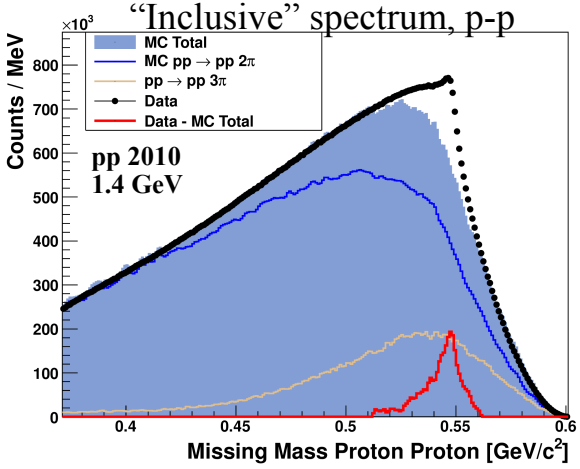
- Measurement of recoil particles in forward detector
- Tagging of η-mesons via missing mass

$$Missing\ Mass = \sqrt{(E_{in} - E_{out})^2 - (P_{in} - P_{out})^2}$$

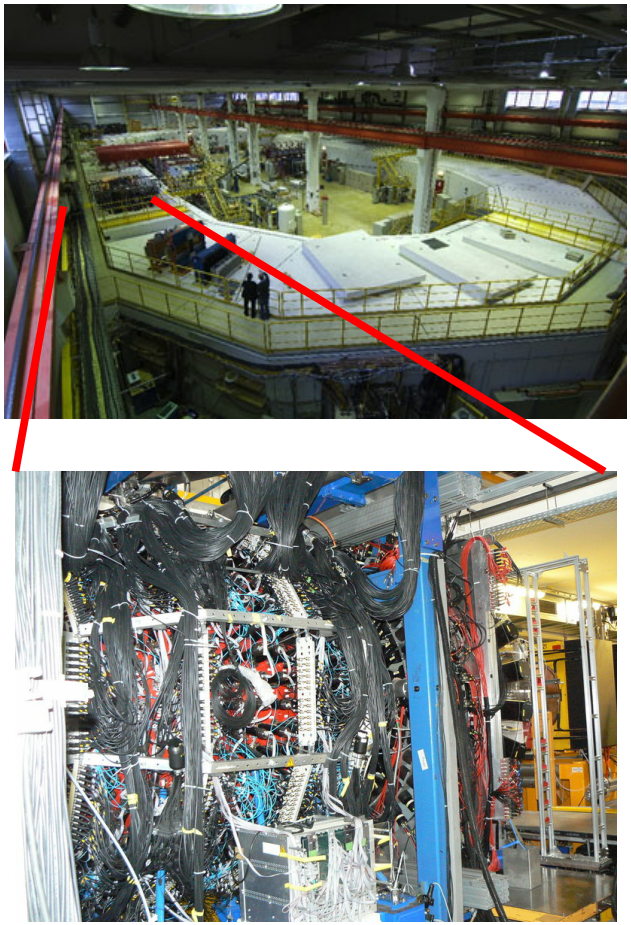
Inclusive spectrum, p-d



"Inclusive" spectrum, p-p

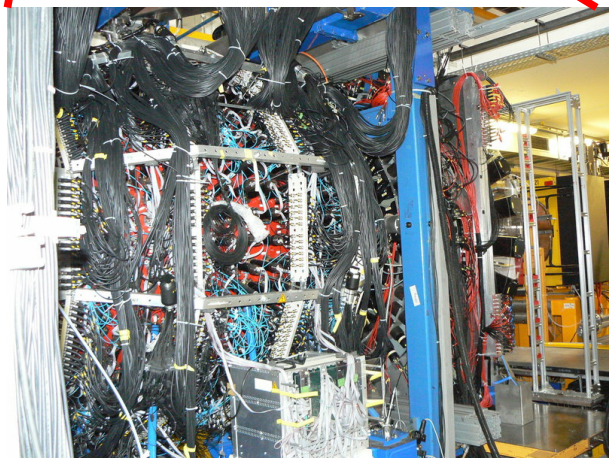


proton-deuteron	proton-proton
• Lower backgrounds	• Higher backgrounds
• Unbiased trigger	• Selective trigger
• 10 η/s produced	• 100 η/s produced

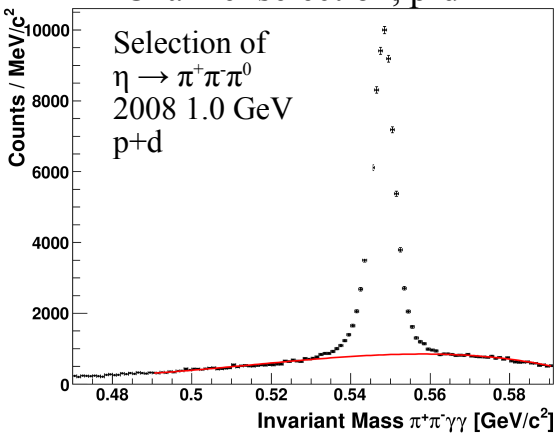


The WASA-at-COSY Experiment

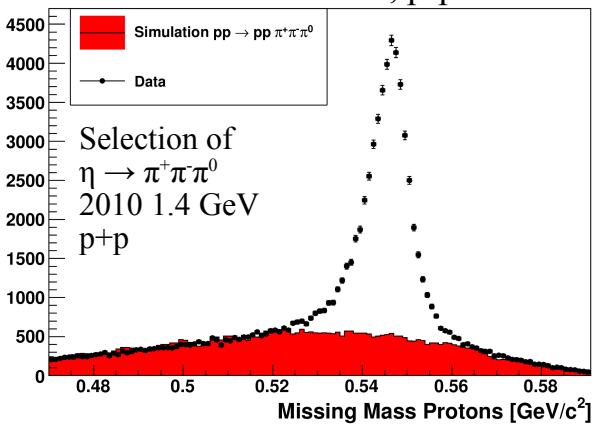
- Selection of a final state → measurement of decay products of the η in central detector
- Full reconstruction of charged and neutral particles
- Total ~4π acceptance



Channel selection, p-d



Channel Selection, p-p



proton-deuteron	proton-proton
• Analysis of main channels • Train analyses of rare decays • 30 Million η on disk	• Analysis of rare channels • 10^9 η produced

$\eta \rightarrow \pi^+\pi^-\pi^0$ Motivation

- Isospin-violating process, proceeds due to difference in masses of the light quarks
- Measurement of this channel sensitive to quark mass ratio

$$\Gamma = \left(\frac{Q_D}{Q}\right)^4 \bar{\Gamma} \qquad \text{where} \quad Q^2 = \frac{m_s^2 - \frac{1}{4}(m_u + m_d)^2}{m_d^2 - m_u^2} \qquad Q_D = 24.2$$

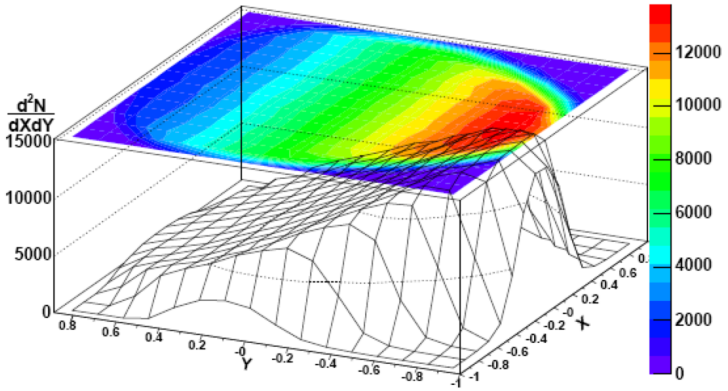
- Current challenge: investigate theoretical predictions including pion final state interactions
- Expand decay rate around X = Y = 0 in Dalitz plot

$$\frac{d\Gamma}{dXdY} \propto |A(X,Y)^2| \propto 1 + aY + bY^2 + dX^2 + fY^3 + \ldots$$

$$X = \sqrt{3}\,\frac{T_+ - T_-}{Q_\eta} \qquad Y = \frac{3T_0}{Q_\eta} - 1 \qquad Q_\eta = T_+ + T_- + T_0$$

Recent Experimental Results from KLOE

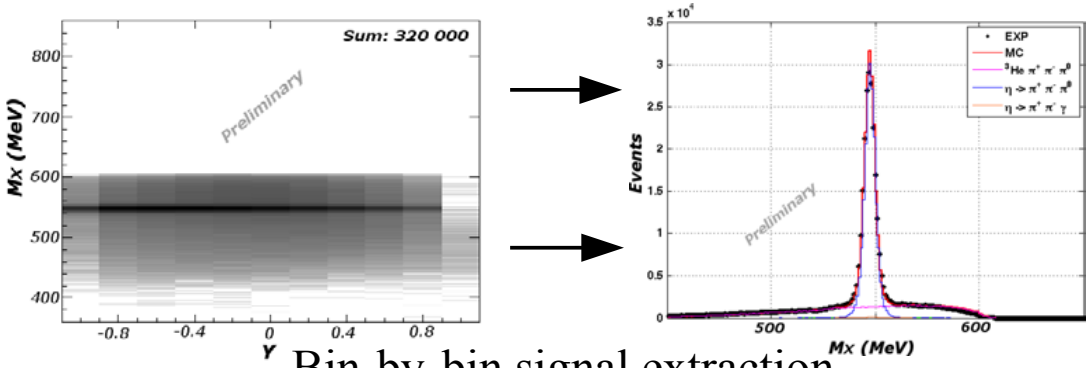
- Dalitz plot based on 1.34 million events
- b and f parameters difficult to reproduce theoretically
- Important to produce an independent Dalitz plot measurement



F. Ambrosino et al. (KLOE Collaboration) *JHEP* **05,** 006 (2008)

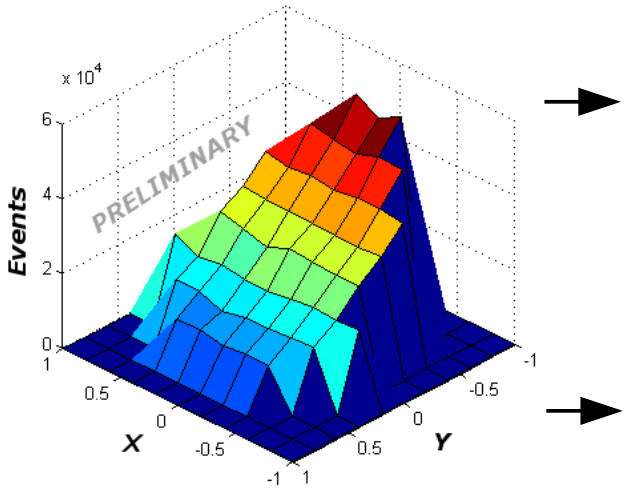
$\eta \rightarrow \pi^+\pi^-\pi^0$ at WASA-at-COSY

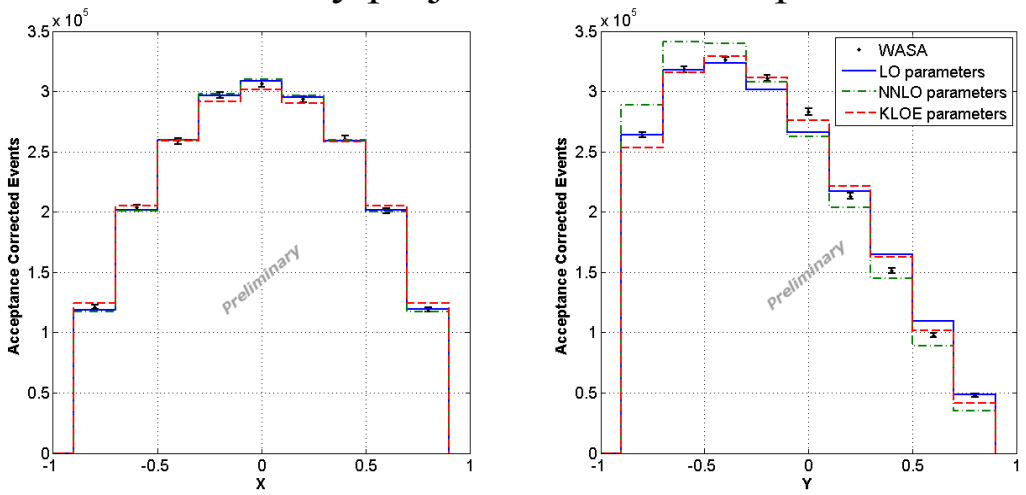
- Analysis of 10 x 10^6 η mesons from pd → ^{3}He η
- 200,000 events in Dalitz plot
- Dalitz plot parameters pending
- Final thesis writing currently in progress



Bin-by-bin signal extraction

x and y projections of Dalitz plot





Analysis: P. Adlarson

In addition:

Analysis of proton proton data → over 1 million events expected in Dalitz Plot

Analysis of ω → $\pi^+\pi^-\pi^0$ Dalitz plot in proton-deuteron and proton-proton interactions

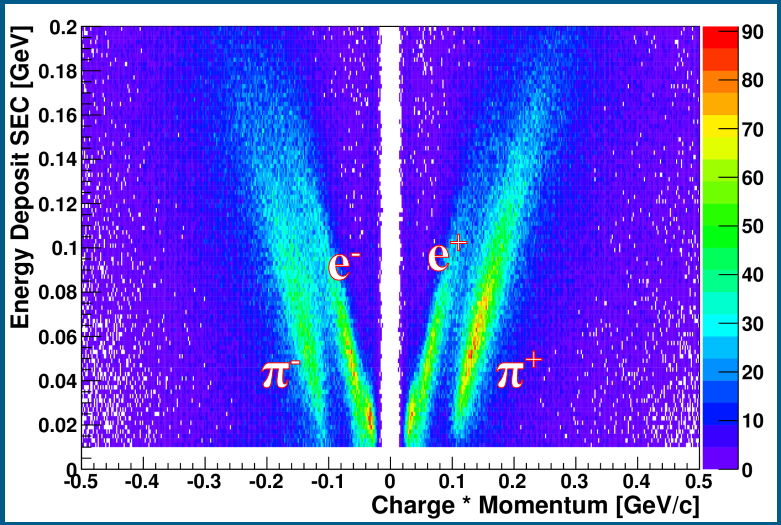
Rare Decays – $\eta \rightarrow \pi^+\pi^-e^+e^-$

- Rare decays are also analyzed at WASA-at-COSY
  - Example: $\eta \rightarrow \pi^+\pi^-e^+e^-$ **BR($\eta \rightarrow \pi^+\pi^-e^+e^-$) =(2.68 ± 0.11) x 10^{-4}**
- Special analysis procedures necessary for rare channels

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012).

Particle Identification

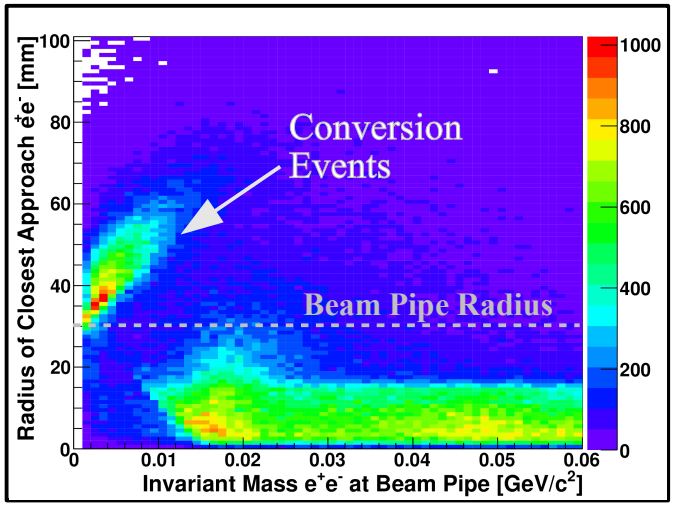
- Energy bands separate electrons from pions
  - Momentum vs. energy deposit



- Neural networks trained with simulated electron/pion signals
- Information from all particles used
  - Reduces ambiguities
- High efficiency: ~95% correct identifications for signal channel

Photon Conversion Pair Rejection

- Signal $\eta \rightarrow \pi^+\pi^-e^+e^-$ mimicked by channels with photon converting to e^+e^- pairs
  - $\eta \rightarrow \pi^+\pi^-\gamma \rightarrow \pi^+\pi^-e^+e^-$
  - $\eta \rightarrow \pi^+\pi^-\pi^0 \rightarrow \pi^+\pi^-\gamma\ \gamma \rightarrow \pi^+\pi^-e^+e^-\gamma$
- Contribution minimized by beryllium beam pipe to ~1%
  - Still significant for rare processes
- Reconstruct e^+e^- vertex



$\eta \rightarrow \pi^+\pi^-e^+e^-$ at WASA-at-COSY

WASA-at-COSY

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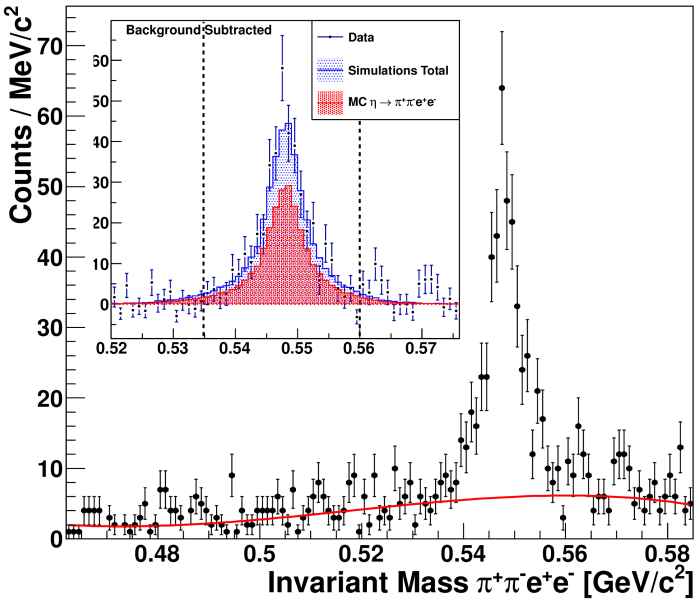
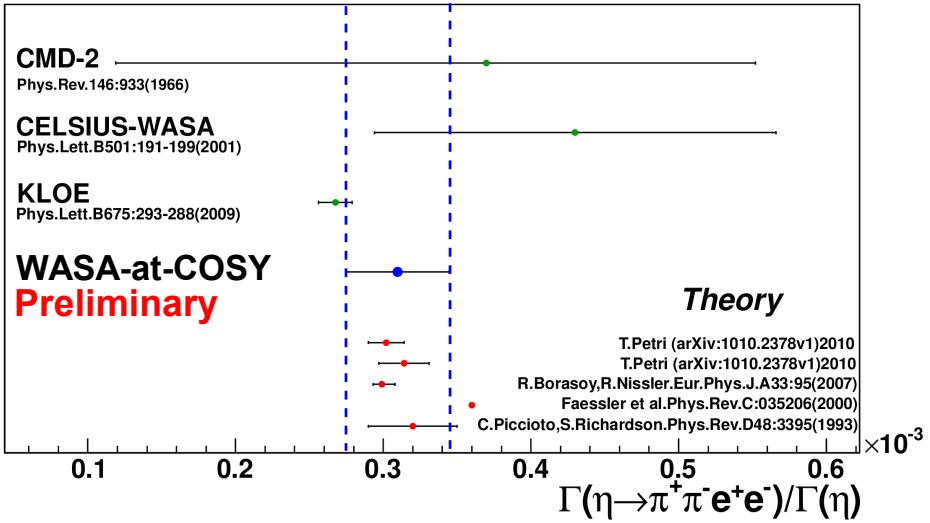
Branching Ratio Extraction

- Recent measurements of BR($\eta \rightarrow \pi^+\pi^-\gamma$) disagree with older experiments [1,2]
  - Measure branching ratios in $\eta \rightarrow \pi^+\pi^-\gamma$ and $\eta \rightarrow \pi^+\pi^-e^+e^-$ at WASA-at-COSY
- Analysis in proton-deuteron reactions
  - $(263 \pm 24_{stat})$ event candidates
- Several new sources of systematic error investigated and corrected
  - Reproduced branching ratios for several known channels within same analysis



$$BR(\eta \rightarrow \pi^+\pi^-e^+e^-) = (3.10 \pm 0.27_{stat} \pm 0.22_{sys}) \times 10^{-4}$$

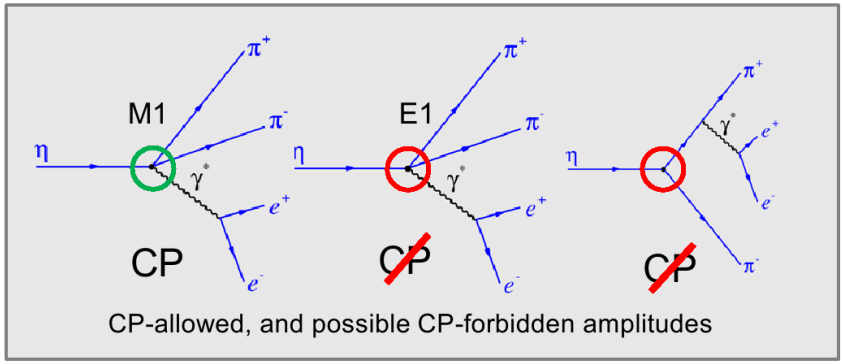


- Result in agreement with theoretical and experimental values
- Higher precision necessary to confirm compatibility with KLOE measurement

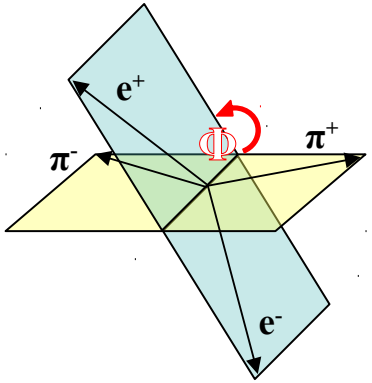
[1] Lopez et. al. (CLEO Collaboration) Phys. Rev. Lett. **99** (2007) 122001.
[2] Ambrosino et. al.(KLOE Collaboration) arXiv:1107.5733v1 (2011)

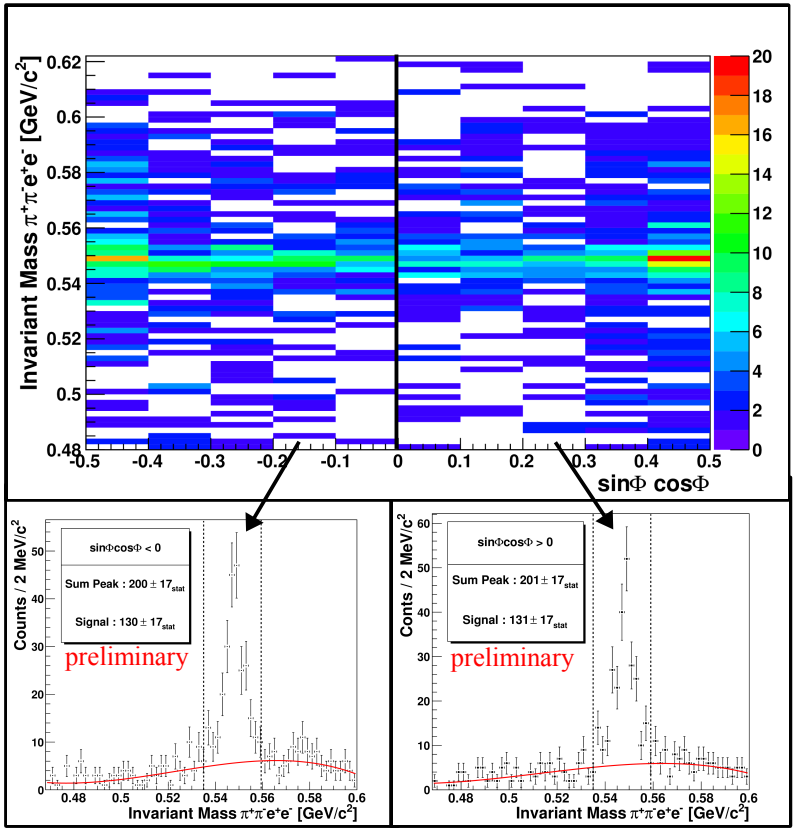
$\eta \to \pi^+\pi^-e^+e^-$ at WASA-at-COSY

- In some unconventional cases, amplitude could include a CP-violating component [1,2]
  - No CP-violation expected in this decay by Standard Model



- Would cause an asymmetry in the electron/pion decay planes of up to 1% [2]





$$A_\Phi = \frac{Count\left(\sin\Phi\cos\Phi>0\right) - Count\left(\sin\Phi\cos\Phi<0\right)}{Count\left(\sin\Phi\cos\Phi>0\right) + Count\left(\sin\Phi\cos\Phi<0\right)}$$

$$\mathbf{A_\Phi = (0.4 \pm 9.0_{stat} \pm 2.8_{sys}) \times 10^{-2}}$$ preliminary

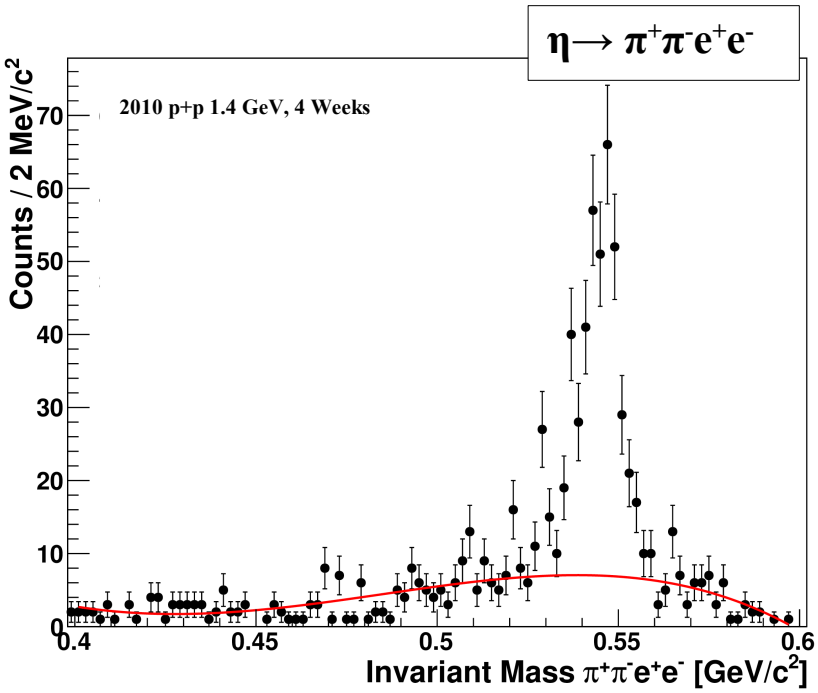
KLOE value: $A_\Phi = (-0.6 \pm 2.5_{stat} \pm 1.8_{sys}) \times 10^{-2}$

1. Mod. Phys. Lett. A **17** (2002) 1489.
2. Mod. Phys. Lett. A **17** (2002) 1583.

Phys.Lett.B675:283-288,2009

Outlook: pp → ppη Data

- 17 weeks of pp → ppη data on disk
- Preliminary analysis performed on a portion of the data
- Several channels identified via kinematic fit of various hypotheses
- 20 times higher η production cross section than pd
  - But higher beam energy, larger Lorentz boost, lower acceptance
  - In practice 5 times higher statistics available than p-d
- Extrapolation to full data set predicts competitive statistics available



4 weeks p+p data, (222 ± 22) events

Scales to (1,117 ± 49) events in full data

WASA-at-COSY

Summary

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- Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ is nearly completed in pd with 200,000 events in the Dalitz plot

- The rare decay $\eta \rightarrow \pi^+\pi^-e^+e^-$ has been analyzed and the branching ratio and dihedral asymmetry have been measured

Branching Ratio: $BR(\eta \rightarrow \pi^+\pi^-e^+e^-) = (3.10 \pm 0.27_{stat} \pm 0.22_{sys}) \times 10^{-4}$ preliminary

Decay Plane Asymmetry: $A_\Phi = (0.4 \pm 9.0_{stat} \pm 2.8_{sys}) \times 10^{-2}$ preliminary

- Analysis of higher statistics in proton-proton data is in progress

- This is just a part of an extensive light meson decay program at WASA-at-COSY

WASA-at-COSY

Outlook: pp → ppη Data

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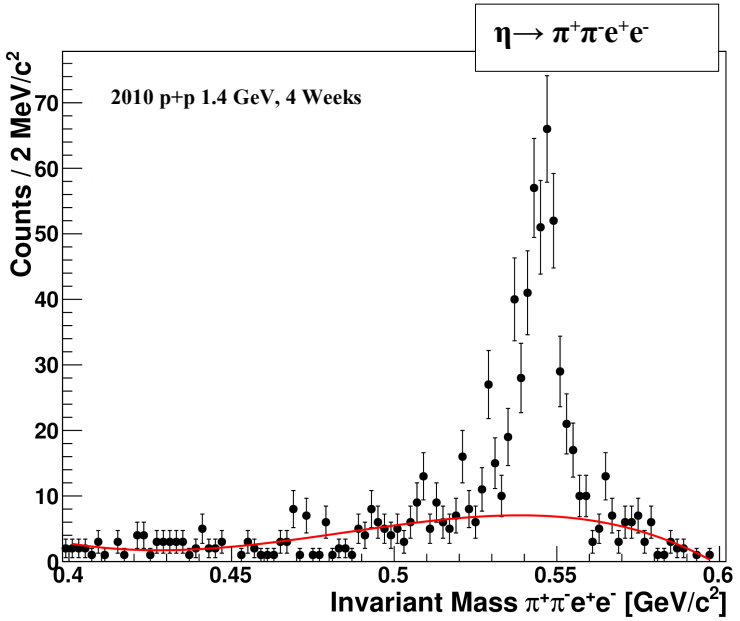
- Preliminary analysis performed on a portion of the data
- Several channels identified via kinematic fit of various hypotheses
- 10 times higher η production cross section
  - But higher beam energy, larger Lorentz boost, lower acceptance
  - In practice 5 times higher statistics available than p-d
- Extrapolation to full data set predicts competitive statistics available



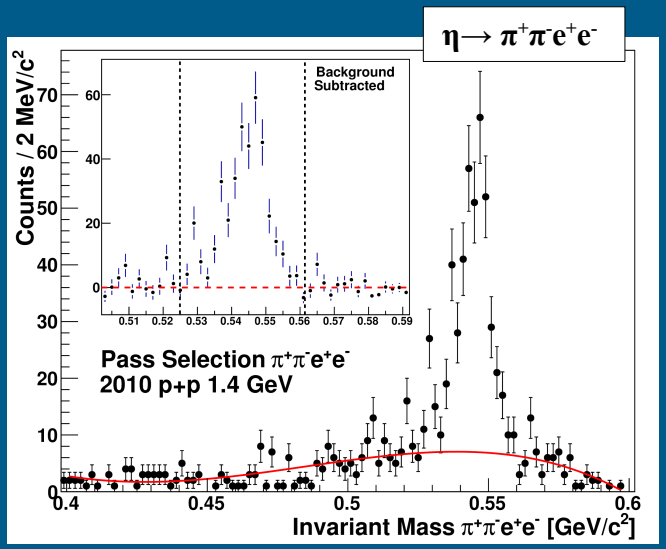
Channel	Events	Data Analyzed	Expected in Full Data Sample
$\eta \to \pi^+\pi^-\pi^0$	(43,871 ± 254)	1 Week	(883,184 ± 1,140)
$\eta \to \pi^+\pi^-\gamma$	(14,406 ± 336)	1 Week	(290,013 ± 1,508)
$\eta \to e^+e^-\gamma$	(2,973 ± 72)	1 Week	(59,850 ± 323)
$\eta \to \pi^+\pi^-e^+e^-$	(222 ± 22)	4 Weeks	(1,117 ± 49)

Current PhD theses focus on this data. Shown here → results from a preliminary analysis

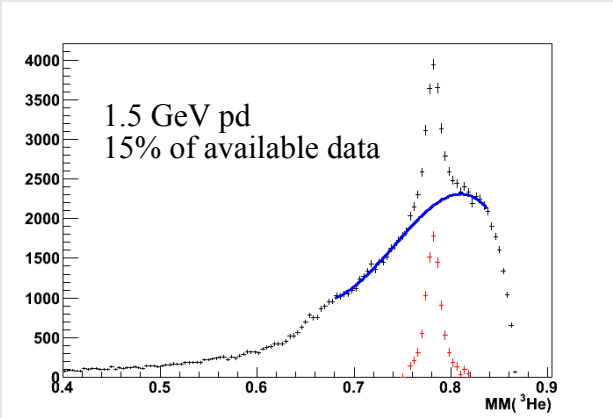
Outlook: Next Steps

$\eta \rightarrow \pi^+\pi^-e^+e^-$ in proton-proton Reactions

- Expect >1100 events in complete data set
- Analysis steps from pd successfully applied



$\omega \rightarrow \pi^+\pi^-\pi^0$ in pd and pp

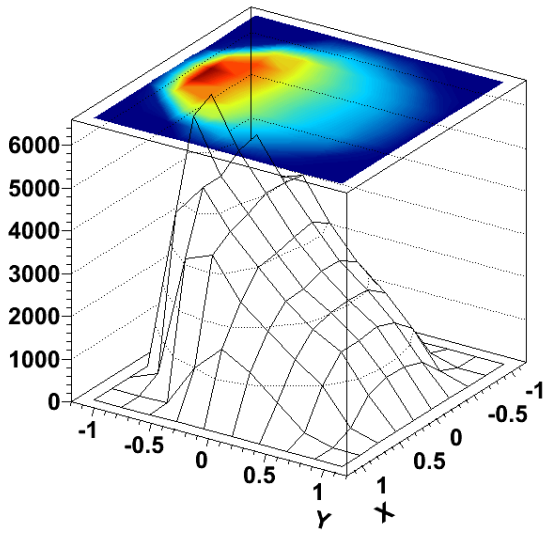


- Exploratory analysis to measure Dalitz plot parameters
- Dedicated PhD topic in pd and pp

Analysis: L. Heijkenskjöld, S. Sawant

$\eta \rightarrow \pi^+\pi^-\pi^0$ in proton-proton Reactions

- Expect ~1 Million events in final Dalitz plot
- Topic of two dedicated PhD theses
- Build on methods learned from proton-deuteron analysis



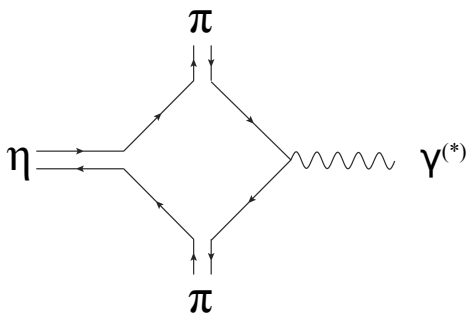
Analysis: M. Zielinski, W. Bardan

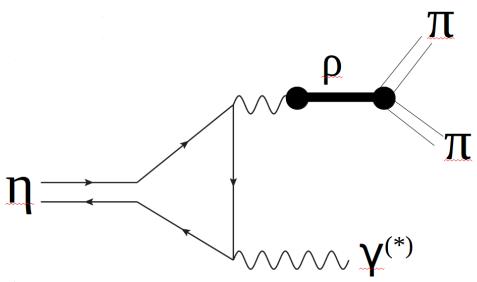
$\eta \rightarrow \pi^+\pi^-\gamma$

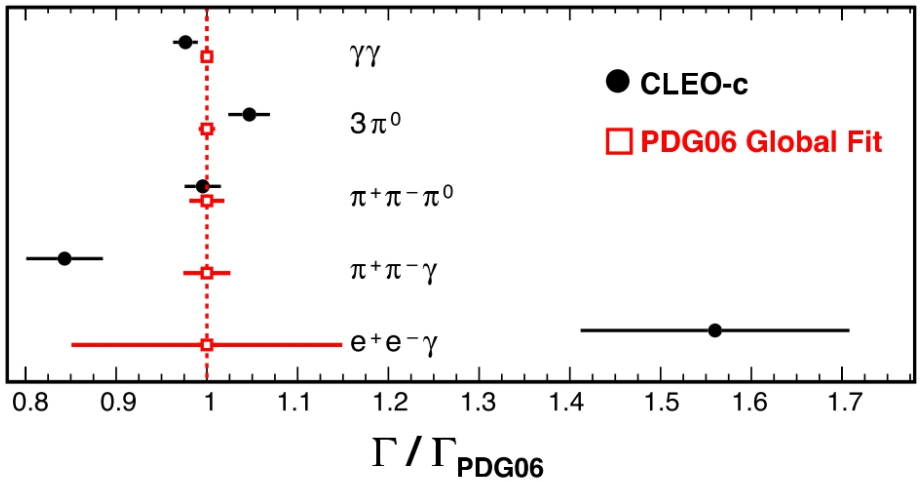
Study of Anomalous QCD

- At chiral limit, proceeds via QCD box-anomaly
  - In reality, signal obscured by resonant contributions
- Two experimental observables
  - Kinematic spectra

    Adlarson et al. Phys. Lett. **B707** (2012) 243-249.
  - Branching ratio







Reproduced from: Lopez et. al. Phys. Rev. Lett. **99** (2007) 122001.

Branching Ratio

- CLEO measured BR($\eta \rightarrow \pi^+\pi^-\gamma$) about 10% lower than PDG value

  Lopez et. al. Phys. Rev. Lett. **99** (2007) 122001.
- Discrepancy later confirmed by KLOE

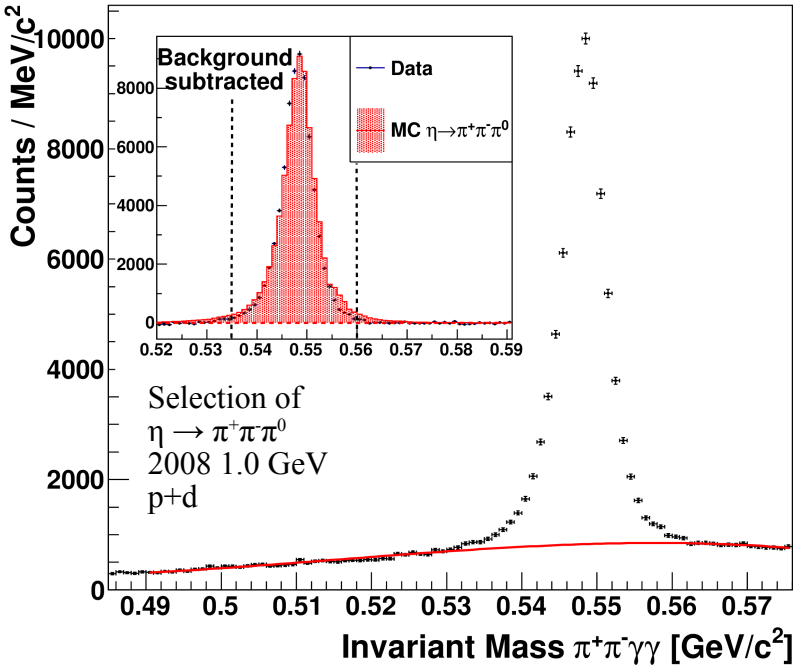
  Ambrosino et. al. arXiv:1107.5733v1 (2011)
- Dedicated PhD thesis topic at WASA-at-COSY
- Also investigating closely-related process $\eta \rightarrow \pi^+\pi^-e^+e^-$

η Production at WASA-at-COSY

$pd \rightarrow {}^3He\,\eta$ $\quad E_{kin} = 1.0$ GeV

- $\sigma_\eta = 0.4\ \mu b \rightarrow \sim 10\ \eta/s$ produced
- Trigger just on ^3He unbiased w.r.t. η decay
- Low direct-pion cross section
- 30 million η on disk

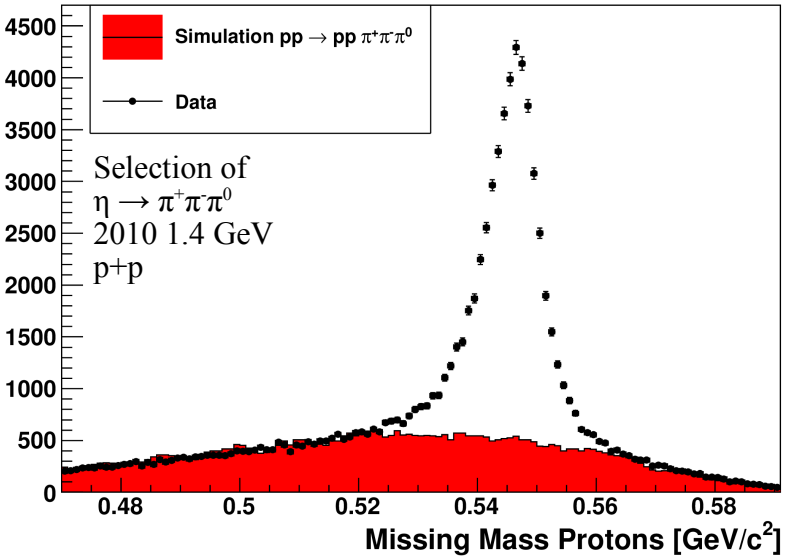
Well suited for measurement of common channels



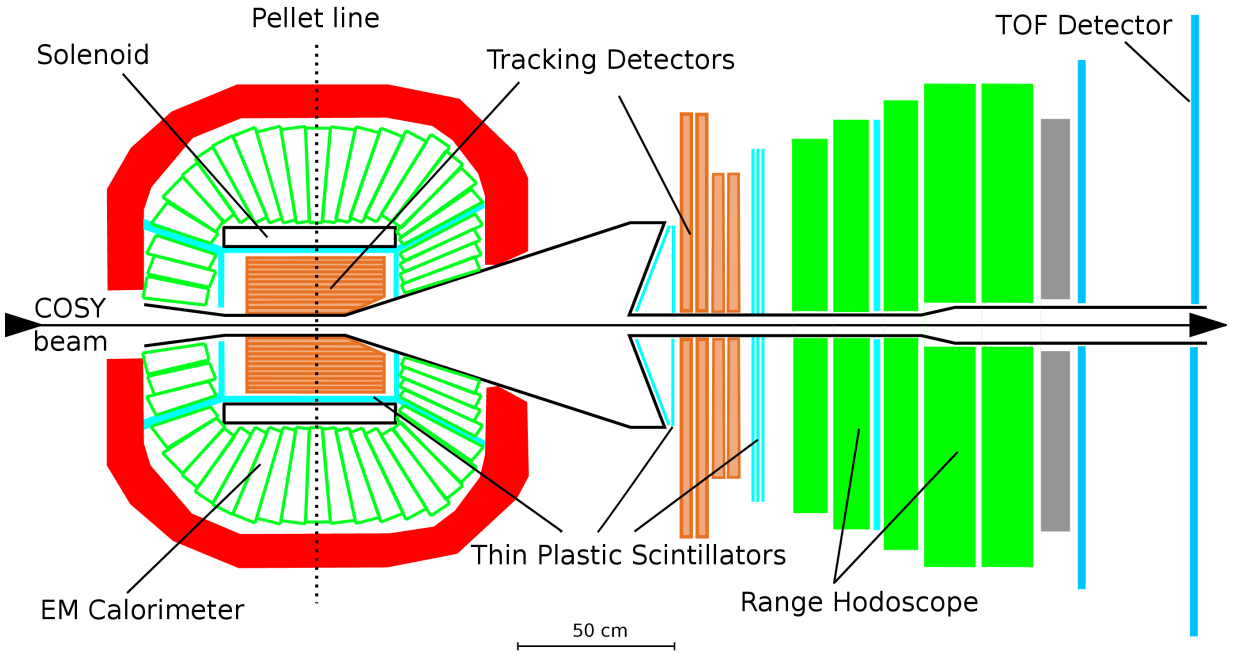
$pp \rightarrow pp\,\eta$ $\quad E_{kin} = 1.4$ GeV

- $\sigma_\eta = 9.8\ \mu b \rightarrow >100\ \eta/s$ produced
- Selective trigger required
- High cross-section of multi pion production
- 1×10^9 η produced

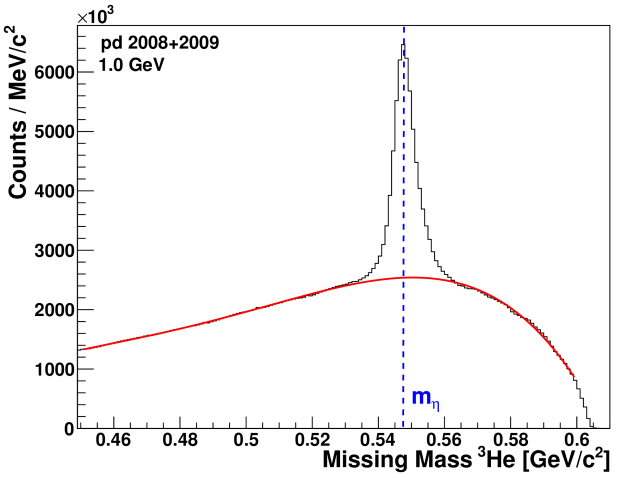
Well suited for measurement of rare decays



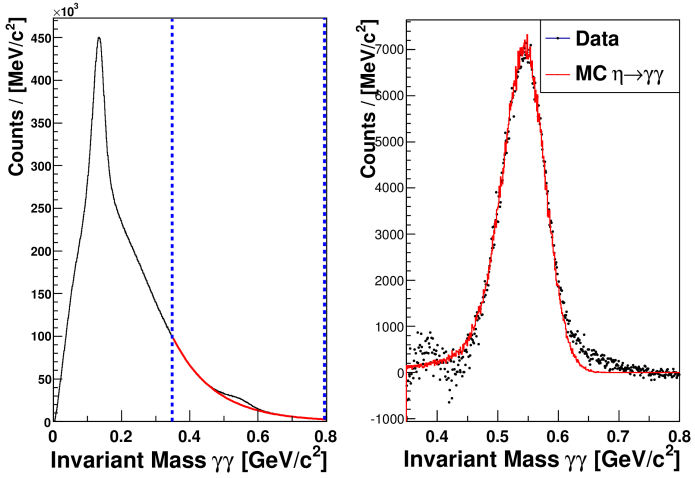
The WASA-at-COSY Experiment



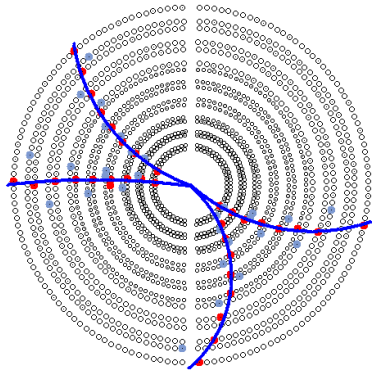
Forward Detector



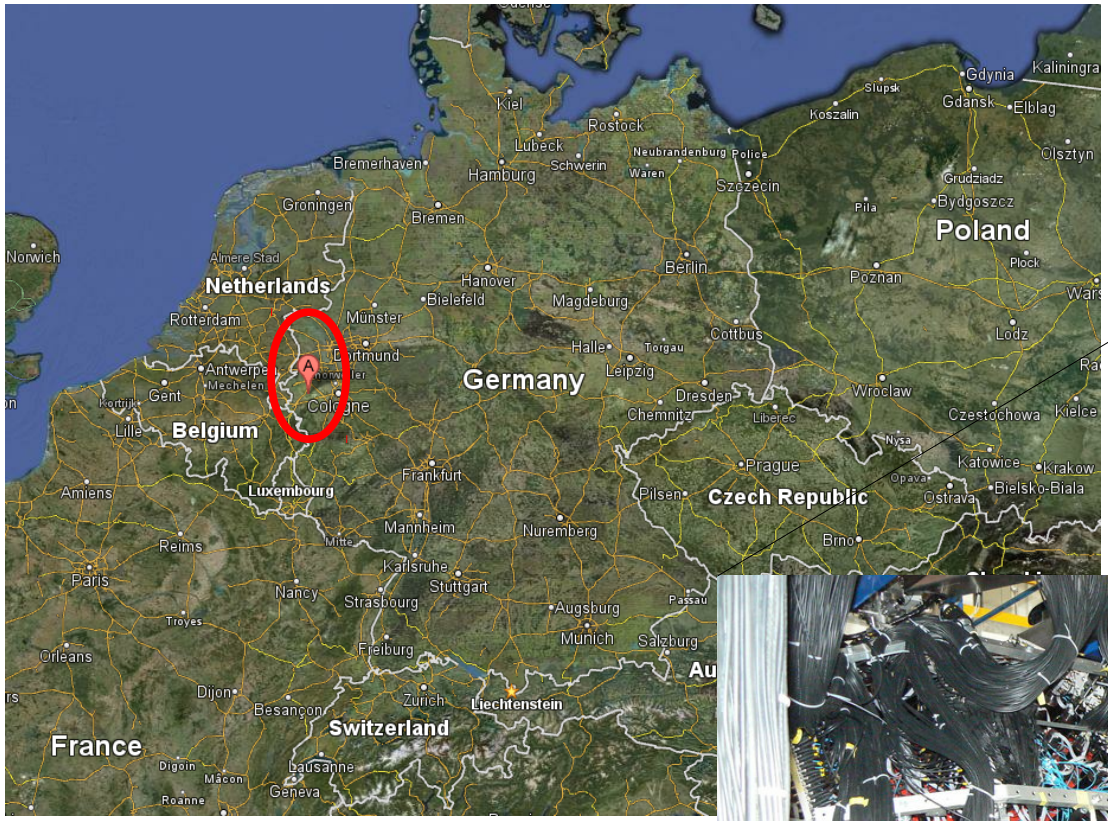
Electromagnetic Calorimeter

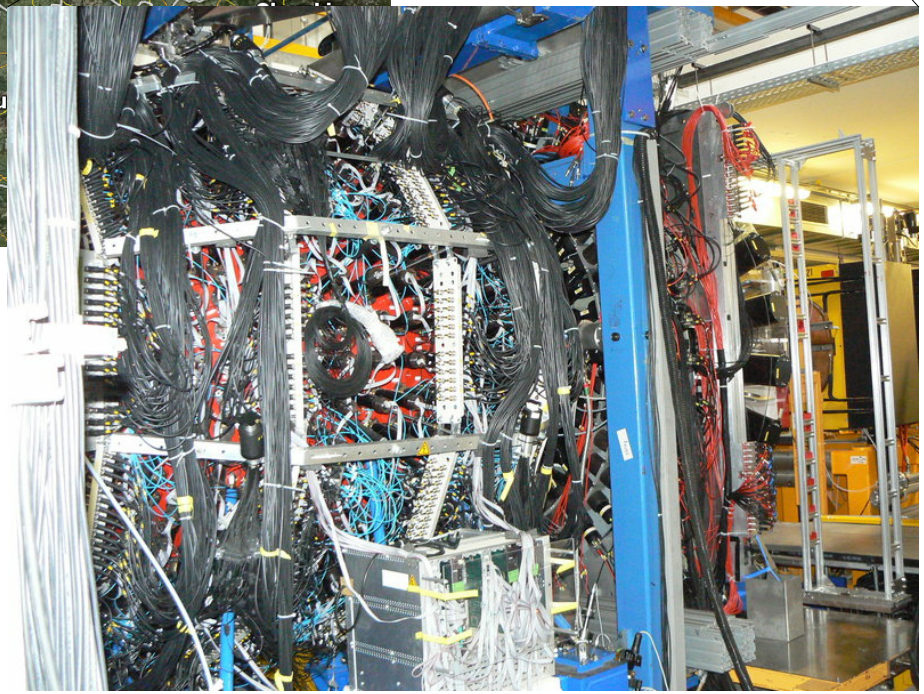


Mini Drift Chamber



The WASA-at-COSY Experiment





Interesting Decays of the η

Decay mode	Fraction Γ_i/Γ_{total}*	Issue
$\eta \rightarrow \pi^0\pi^0\pi^0$	$(32.57 \pm 0.23) \times 10^{-2}$	G-parity, Dalitz plot parameter, Quark masses
$\eta \rightarrow \pi^+\pi^-\pi^0$	$(22.74 \pm 0.28) \times 10^{-2}$	
$\eta \rightarrow \pi^+\pi^-\gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	Box anomaly
$\eta \rightarrow \gamma e^+e^-$	$(6.9 \pm 0.4) \times 10^{-3}$	Transition form factor
$\eta \rightarrow \pi^0\gamma\gamma$	$(2.7 \pm 0.5) \times 10^{-4}$	ChPT
$\eta \rightarrow \pi^+\pi^-e^+e^-$	$(2.68 \pm 0.11) \times 10^{-4}$	CP-Violation
$\eta \rightarrow e^+e^-e^+e^-$	$(2.40 \pm 0.22) \times 10^{-5}$	Transition form factor
$\eta \rightarrow \pi^0e^+e^-$	$< 4 \times 10^{-5}$	C-Violation
$\eta \rightarrow e^+e^-$	$< 5.6 \times 10^{-6}$	New physics?

The Decay $\eta \rightarrow \pi^+\pi^-e^+e^-$

The η meson:

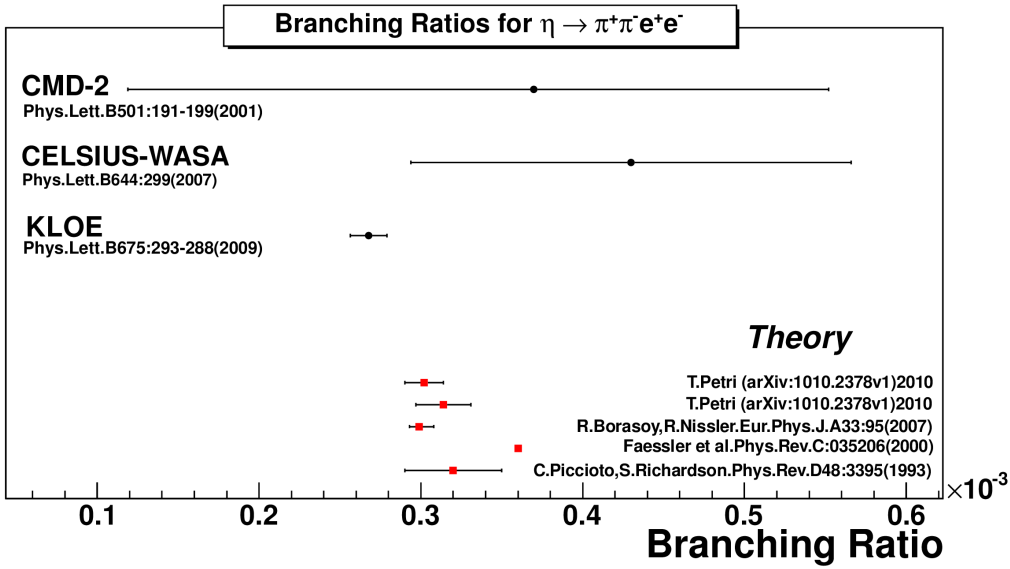
- Is a light pseudoscalar with mass:
  $m = 547.853 \pm 0.024$ MeV/c^2 [1]
- Quantum numbers:
  $J^{PC} = 0^{-+}$
- All strong and electromagnetic decays suppressed in first order
  - Rare processes experimentally accessible

Branching Ratios for a Few η Decays[1]

$\eta \rightarrow \gamma\gamma$	.3931	~ 99.9%
$\eta \rightarrow \pi^0\pi^0\pi^0$	.3256	
$\eta \rightarrow \pi^+\pi^- \pi^0$	.2274	
$\eta \rightarrow \pi^+\pi^- \gamma$	.046	
$\eta \rightarrow e^+e^- \gamma$	.007	
...		
$\eta \rightarrow \pi^+\pi^-e^+e^-$	$(2.68 \pm 0.11) \times 10^{-4}$ [1]	

Brancing Ratio of $\eta \rightarrow \pi^+\pi^-e^+e^-$

- Closely related to $\eta \rightarrow \pi^+\pi^-\gamma$
  - Based on same underlying, anomalous processes
  - Relative branching ratios well-established
- Possible experimental discrepancy in absolute branching ratio of both channels
  - Recent measurements of $\eta \rightarrow \pi^+\pi^-\gamma$ find a value about 10% lower than previous
  - Both final states can be investigated at WASA-at-COSY



[1] J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012).

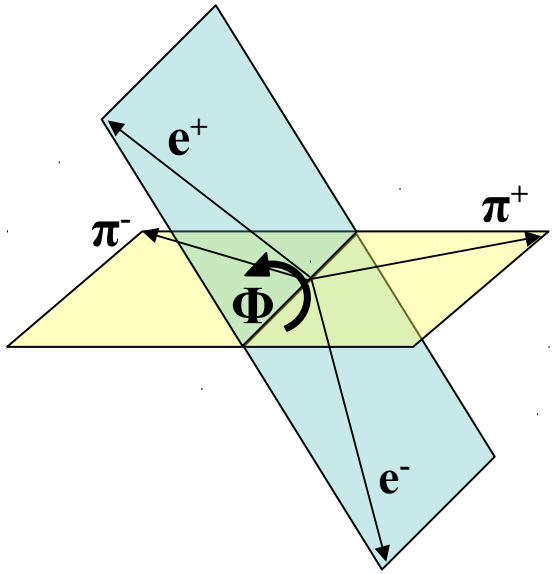
CP-Violation in $\eta \rightarrow \pi^+\pi^-e^+e^-$

CP-Violation in the Standard Model

- **In Weak Interactions**
  - Well-established in kaon and B-meson decays
  - Quantified via a single phase in flavor-changing reactions
  - Relatively small effect, considering cosmological expectations
- **In Strong Interactions**
  - QCD naturally contains a CP-violating component
  - Highly constrained by experimental measurements

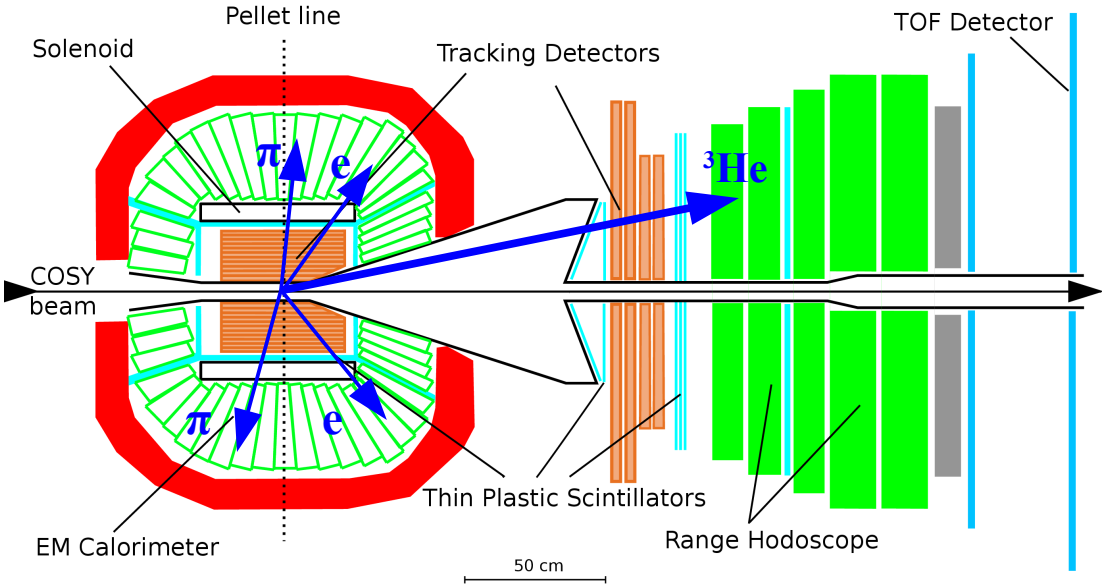
CP-Violation in $\eta \rightarrow \pi^+\pi^-e^+e^-$

- No CP-violation predicted for this channel by Standard Model
- CP-violation would cause an asymmetry in the angle between electron and pion decay planes[2]:
- Theoretical upper limit $A_\Phi \sim 2\%$ [2]
  - Measurement requires high statistics



[2] D.N. Gao, Mod. Phys. Lett. A **17** (2002) 1583.

Experiment (Detector)



Experimental Conditions

Beam: Protons with p = 1.7 GeV/c

Target: Deuterium pellets (6-8 kHz)

Luminosity: Average 3.1 x10^{31} $cm^{-2}s^{-1}$

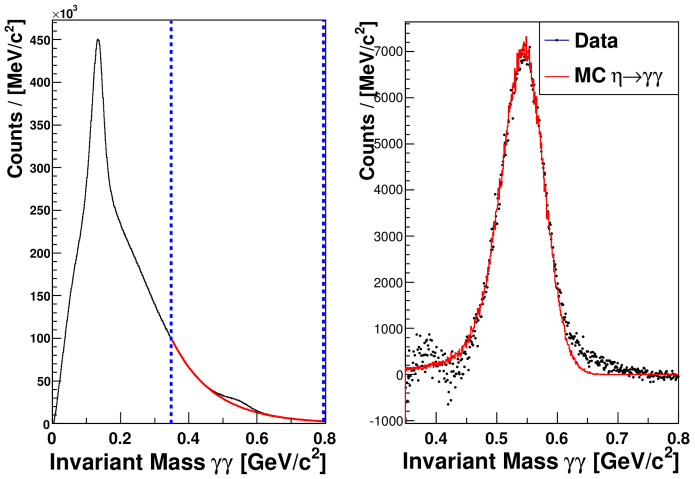
σ_η = (0.413 ± 0.015) μb [3]

~10 η/s produced

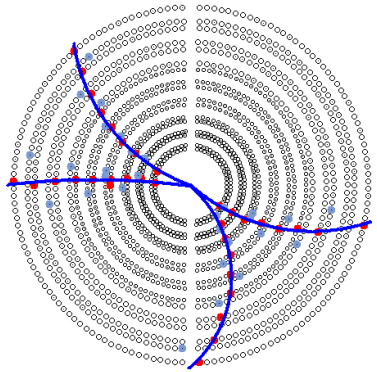
Production Reaction: pd → ^{3}He η

Reconstructed η-mesons: 30 x 10^6 in 12 weeks of data tagged via missing mass technique

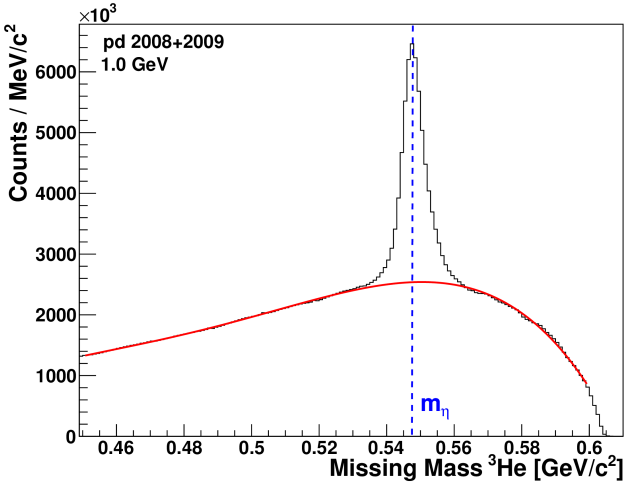
Electromagnetic Calorimeter



Mini Drift Chamber



Forward Detector



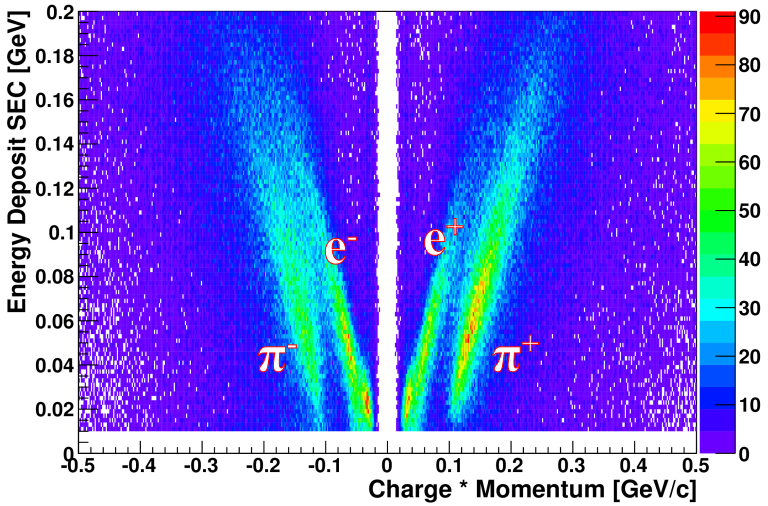
[3] R. Bilger et al. Phys.Rev.**C65**(4):1–6, March 2002.

Analysis Steps/Highlights

Four-vector Reconstruction → Particle Selection → Particle Identification → Kinematic Fitting → Final Selection Criteria

Particle Identification

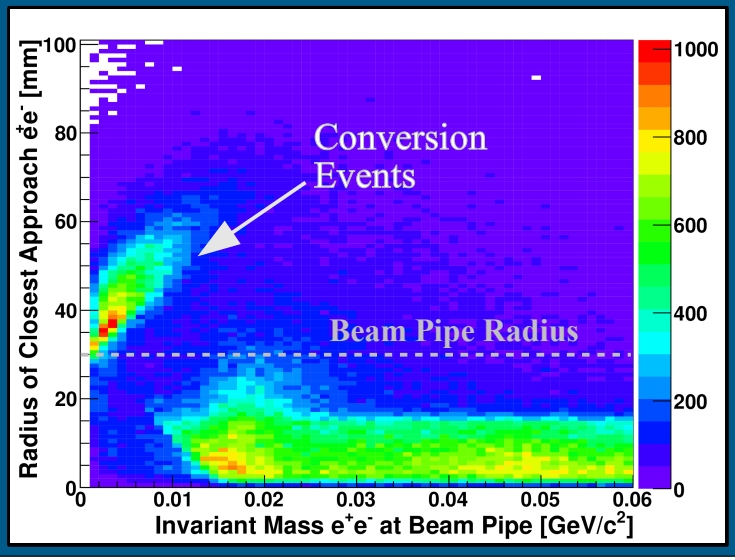
- Energy bands separate electrons from pions
  - Momentum from Mini Drift Chamber
  - Energy from plastic scintillators and calorimeter



- Neural networks trained with simulated electron/pion signals
- Information from all particles used
  - Reduces ambiguities
- High efficiency: ~95% correct identifications for signal channel

Photon Conversion Pair Rejection

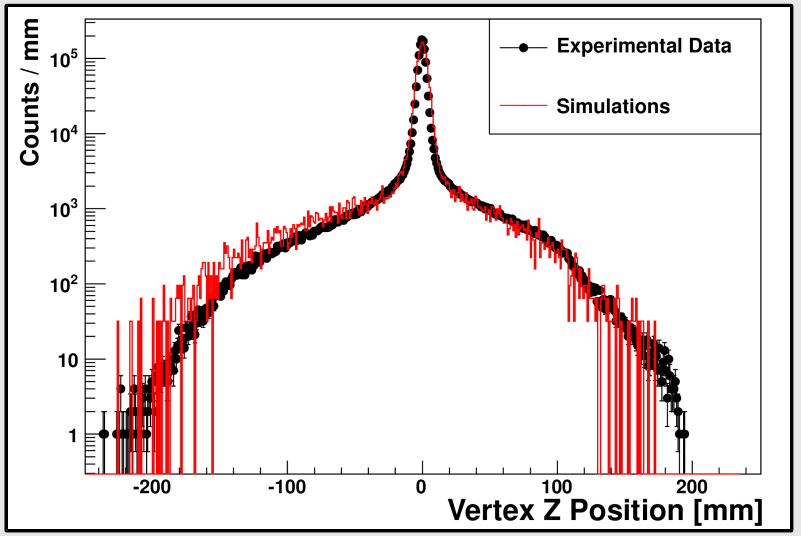
- Signal $\eta \rightarrow \pi^+\pi^-e^+e^-$ mimicked by channels with photon converting to e^+e^- pairs
  - $\eta \rightarrow \pi^+\pi^-\gamma \rightarrow \pi^+\pi^-e^+e^-$
  - $\eta \rightarrow \pi^+\pi^-\pi^0 \rightarrow \pi^+\pi^-\gamma\,\gamma \rightarrow \pi^+\pi^-e^+e^-\gamma$
- Contribution minimized by beryllium beam pipe to ~1%
  - Still significant for rare processes
- Suppression based on reconstruction of primary vertex, ~90% effective



Systematics

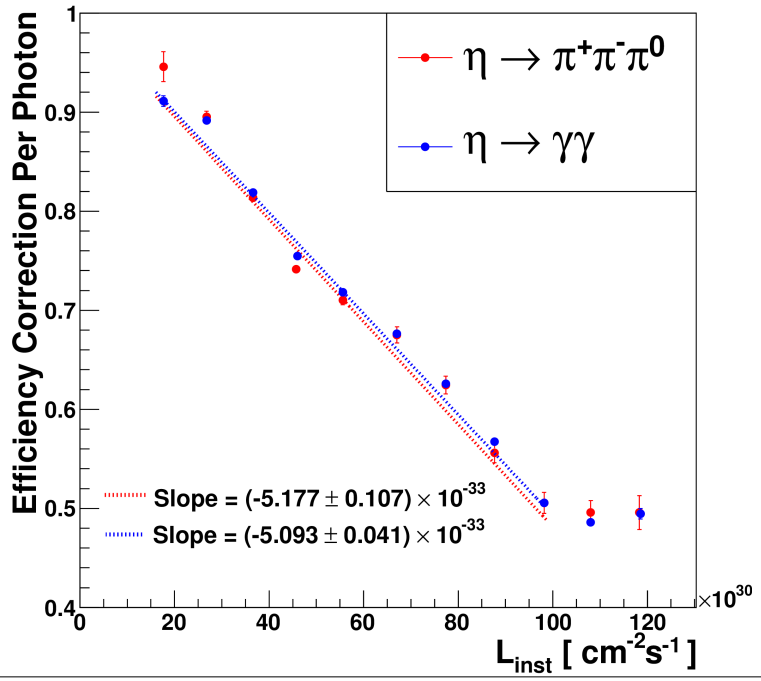
Rest Gas

- Evaporated gas from pellets interacts with beam particles
- Rest Gas events look similar to beam-pellet events
  - Different reconstruction efficiency
  - Certain information relies on primary vertex, will be incorrectly reconstructed
- Quantify rest gas via $\pi^+\pi^-$ vertex position
- Include rest gas in simulations



Luminosity Effects

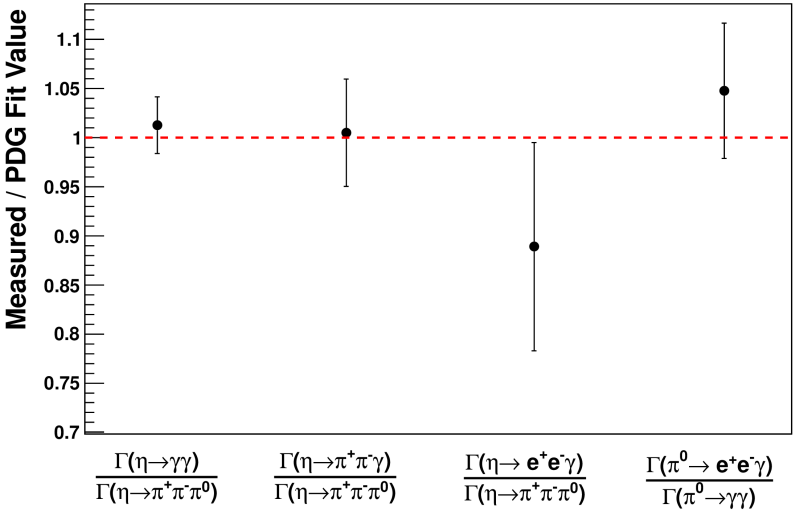
- Yield of all channels decreases with luminosity
- Inefficiency to number of photons in event to first order
  - Photon efficiency correction derived using two independent channels
  - Function used to correct efficiencies for other channels
- Cross-check: measure relative branching ratios between several different channels with different numbers of photons in final state



Selection of Decay Channels

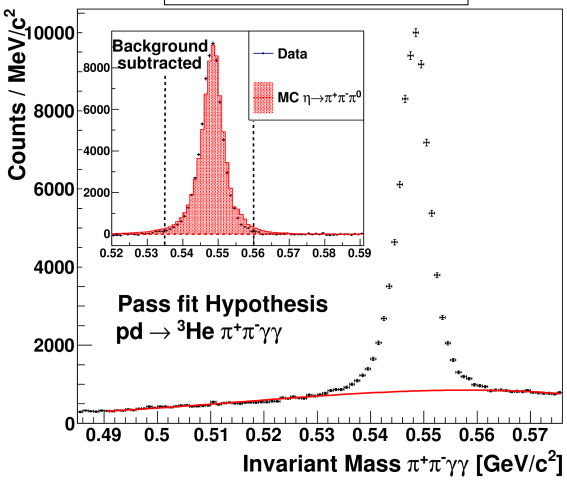
Channel	Branching Ratio*	Tests
$\eta \to \gamma\gamma$	$(39.31 \pm 0.20) \times 10^{-2}$	• Photon reconstruction efficiency
$\eta \to \pi^+\pi^- [\pi^0 \to \gamma\gamma]$	$(22.47 \pm 0.28) \times 10^{-2}$	• Fit errors for pions
$\eta \to \pi^+\pi^-\gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	• Fit errors for pions • Relative efficiency
$\eta \to e^+e^-\gamma$	$(6.9 \pm 0.4) \times 10^{-3}$	• Fit errors for electrons • Particle identification • Conversion suppression
$\eta \to \pi^+\pi^- [\pi^0 \to e^+e^-\gamma]$	$(2.67 \pm 0.09) \times 10^{-3}$	• Nearly identical f.s. to signal channel

Tests of Several Relative Branching Ratios*

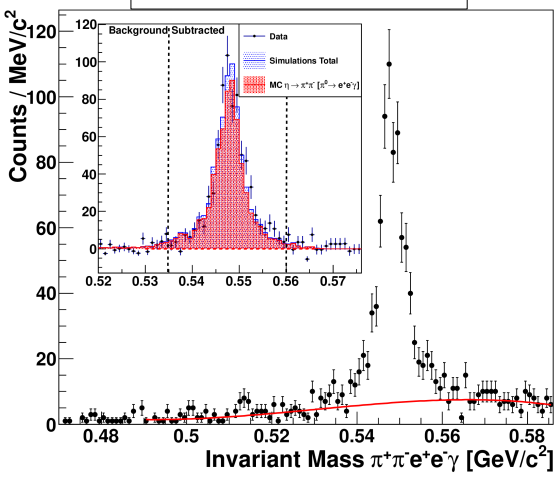


* 2012 Review of Particle Physics. J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)

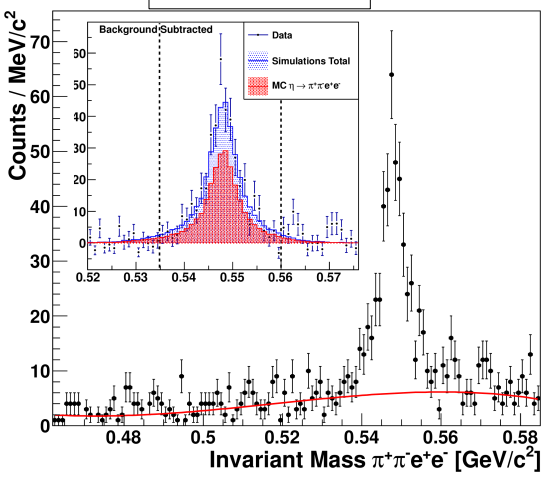
$\eta \to \pi^+\pi^- [\pi^0 \to \gamma\gamma]$



$\eta \to \pi^+\pi^- [\pi^0 \to e^+e^-\gamma]$



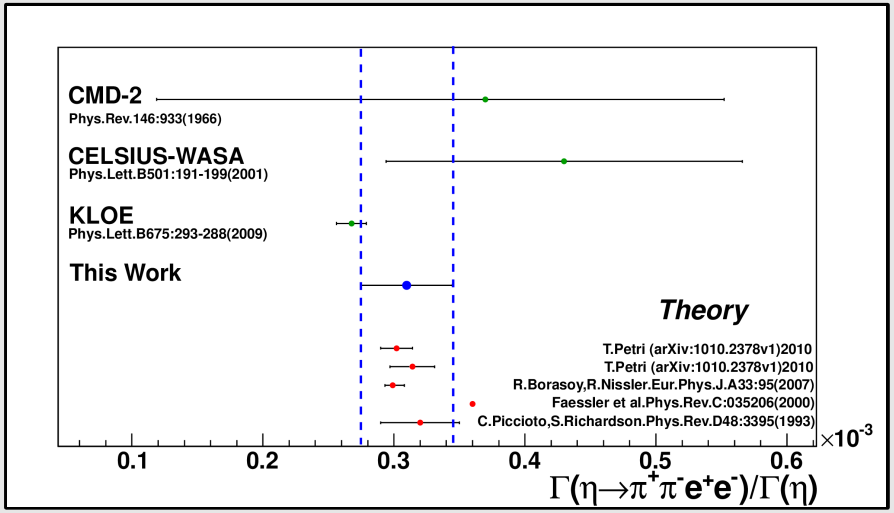
$\eta \to \pi^+\pi^-e^+e^-$



Results

Branching Ratio

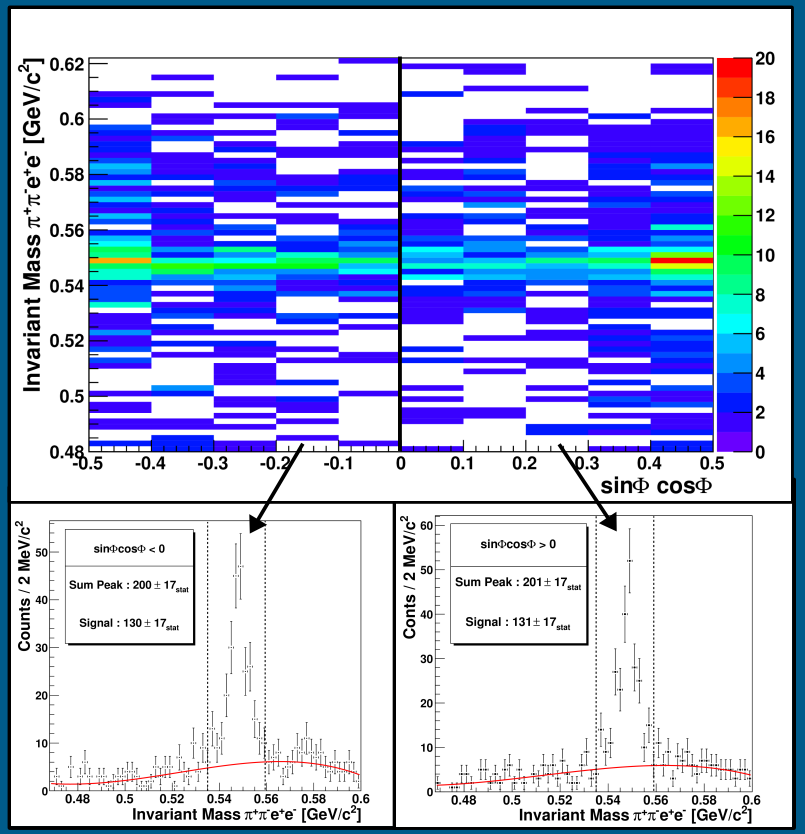
$$BR(\eta \to \pi^+\pi^-e^+e^-) = (3.10 \pm 0.27_{stat} \pm 0.22_{sys}) \times 10^{-4}$$



- Agreement with theoretical calculations
- Compatible with other experimental results
  - Higher precision required to clarify discrepancy between theory and KLOE result
  - Compare to measurements of $\eta \to \pi^+\pi^-\gamma$ branching ratio

CP-Violating Asymmetry

- $(263 \pm 24_{stat})$ signal event candidates



$$A_\Phi = (0.4 \pm 9.0_{stat} \pm 2.8_{sys}) \times 10^{-2}$$

Conclusion

Summary

- ($263 \pm 24_{stat}$) event candidates for the channel $\eta \to \pi^+\pi^-e^+e^-$ have been identified in p-d data and the branching ratio and possible CP-violating observable have been measured

- Several analysis techniques used at WASA-at-COSY for the first time
  - Particle identification with neural networks
  - Photon conversion suppression using primary vertex reconstruction

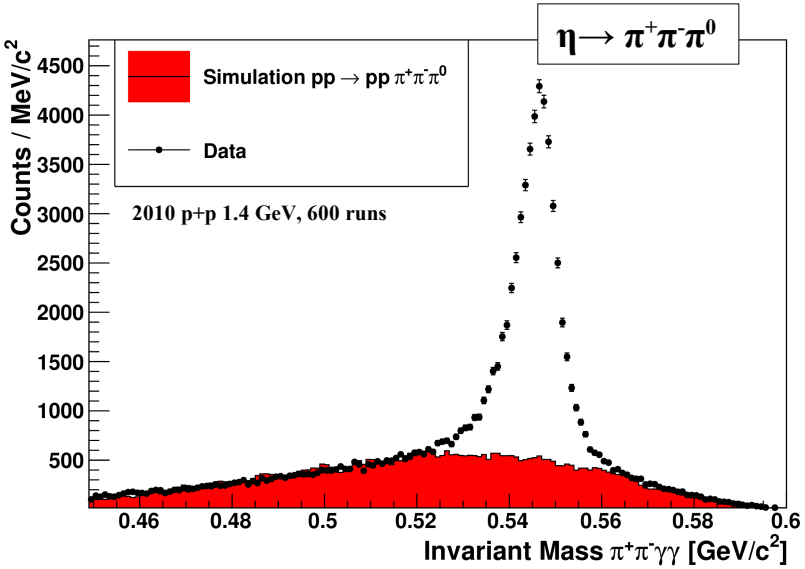
- Several systematic effects thoroughly investigated
  - Effects of rest-gas (more accurate parameterization using primary vertex)
  - Inefficiencies related to luminosity

Outlook

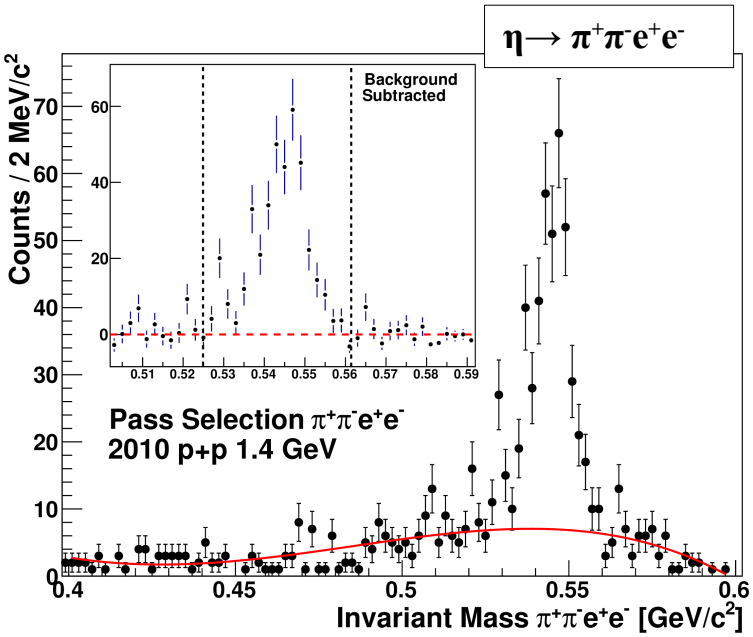
- 17 weeks of data in available in proton-proton reactions
  - Higher cross section → over 10^9 eta mesons produced
- Preliminary analyses of several channels have been completed on a subset of this data as part of this work
  - Clear signals are visible from all decay channels previously studied in p-d
  - Competitive statistics are available
    - Estimated (1,117 ± 49) reconstructed $\eta \to \pi^+\pi^-e^+e^-$ event candidates available in complete data

Proton-Proton Data

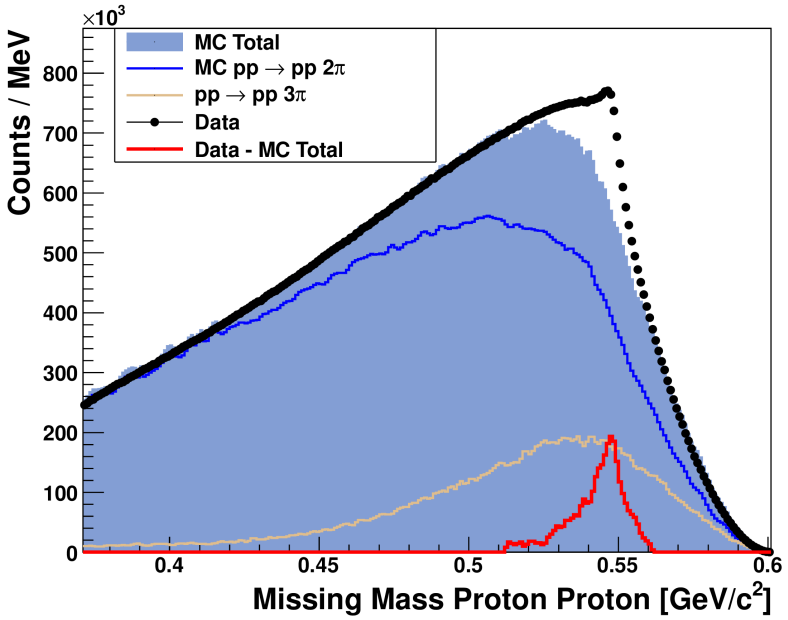
Channel	Events	Data Analyzed	Expected in Full Data Sample
$\eta \rightarrow \pi^+\pi^-\pi^0$	(43,871 ± 254)	1 Week	(883,184 ± 1,140)
$\eta \rightarrow \pi^+\pi^-\gamma$	(14,406 ± 336)	1 Week	(290,013 ± 1,508)
$\eta \rightarrow e^+e^-\gamma$	(2,973 ± 72)	1 Week	(59,850 ± 323)
$\eta \rightarrow \pi^+\pi^-e^+e^-$	(222 ± 22)	4 Weeks	(1,117 ± 49)

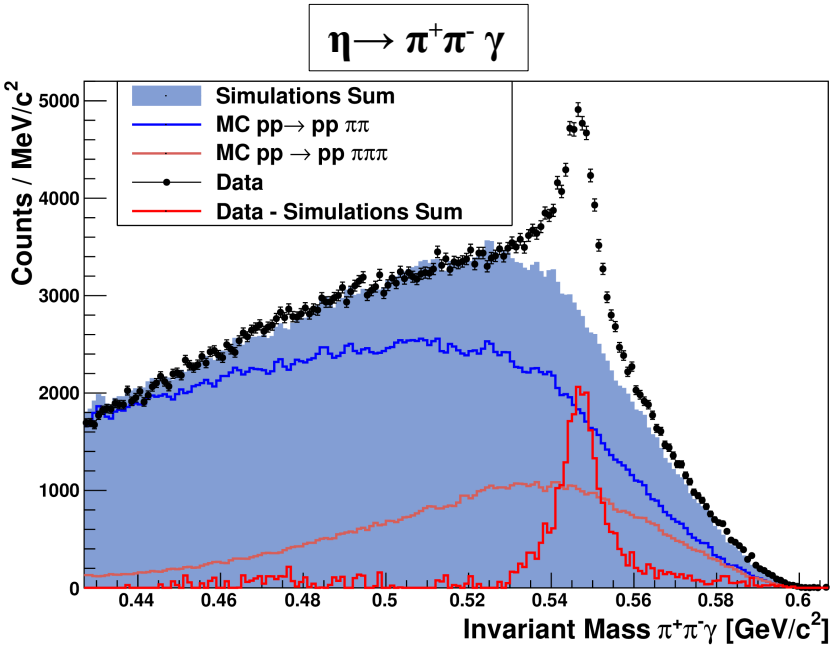


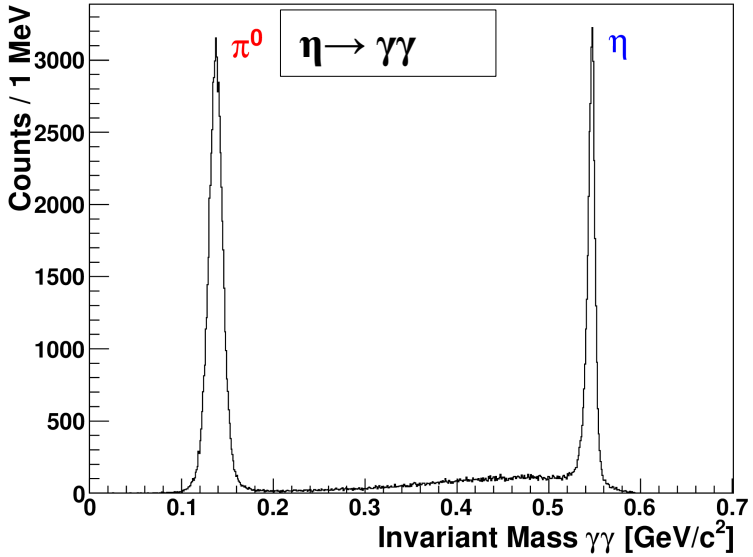
- σ_η 25 times higher than in p-d
  - Beam momentum 2.14 GeV/c
  - pp → pp η
- 17 weeks of data available
  - ~10^9 produced η-mesons
- Preliminary analysis of a portion of the data
  - Clean signals extracted for several channels
  - Extrapolation to full data set predicts competitive statistics available

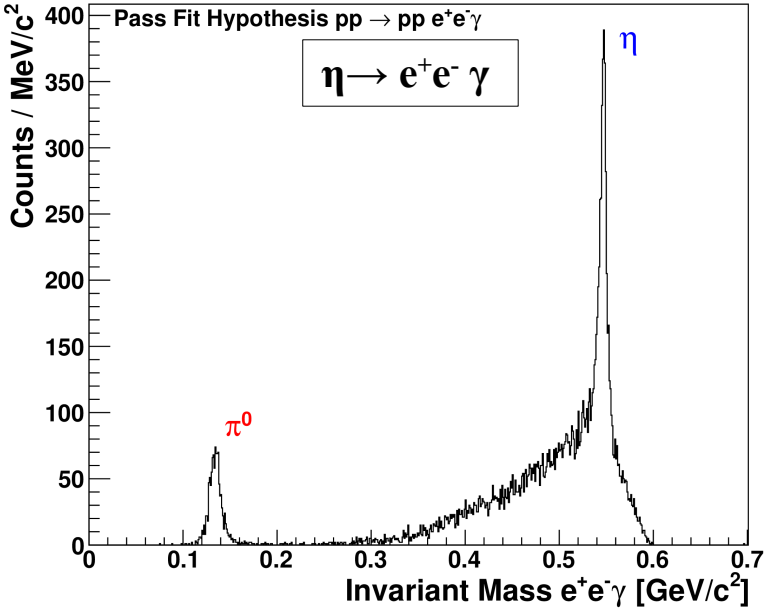


More Signals in pp









Motivation 1 : Introduction

- **The η meson**
  - q=0, I=0, $J^{PC} = 0^{-+}$
  - Mass = 547.9 MeV/c^2
  - Decay studies
    - » Test fundamental symmetries
    - » Hadron structure and dynamics

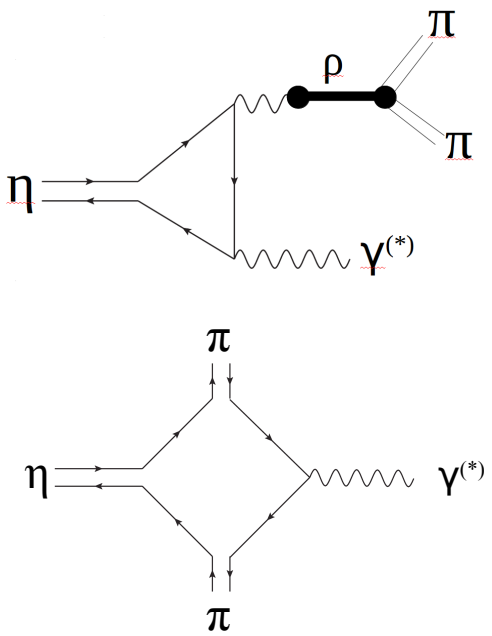
      See: P.Wurm HK-54 – Tomorrow

Branching Ratios for a few η Decays[1]

$\eta \to \gamma\gamma$	.3931	~ 99.9%
$\eta \to \pi^0\pi^0\pi^0$	.3256	
$\eta \to \pi^+\pi^- \pi^0$	.2274	
$\eta \to \pi^+\pi^- \gamma$	.046	
$\eta \to e^+e^- \gamma$	.007	
...		
$\eta \to \pi^+\pi^-e^+e^-$	2.68×10^{-4}	

- **The decay $\eta \to \pi^+\pi^-e^+e^-$**
  - Low-level diagrams same as $\eta \to \pi^+\pi^- \gamma$

    See: D.Lersch HK-38
  - Experimental observables
  - » $\eta \to \pi^+\pi^- \gamma$
    - ∘ Kinematic distributions
    - ∘ Branching ratio
  - » $\eta \to \pi^+\pi^- e^+e^-$
    - ∘ Branching ratio



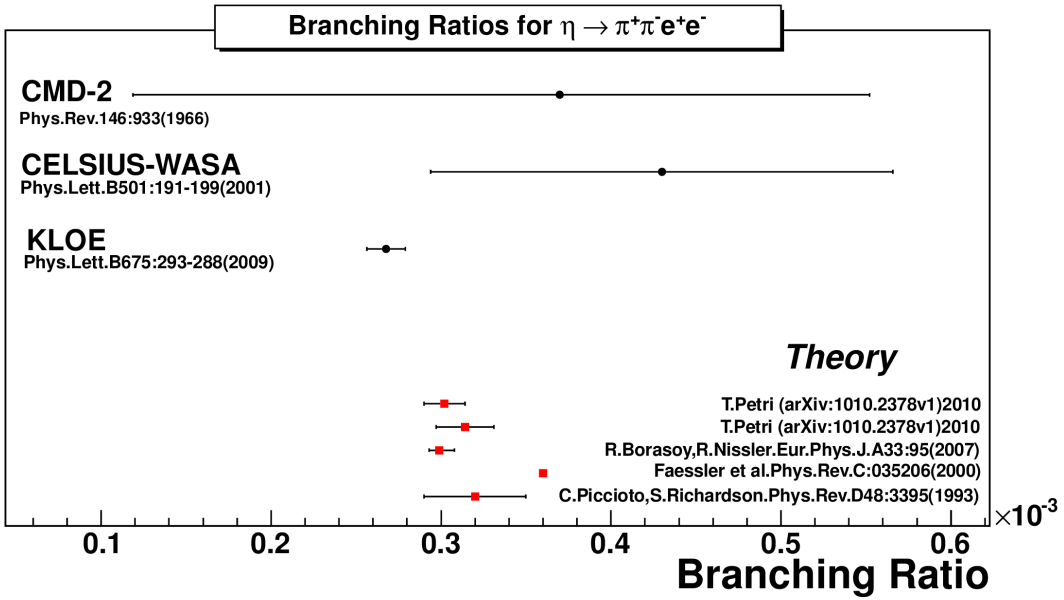
1 – K. Nakamura et al. (Particle Data Group), Journal of Physics G37, 075021 (2010) and 2011 partial update for the 2012 edition.

See: T.Petri. *Anomalous Decays of Pseudoscalar Mesons*. Master's Thesis, Uni. Bonn. (2010). arXiv:1010.2378

Motivation 2 : Observables

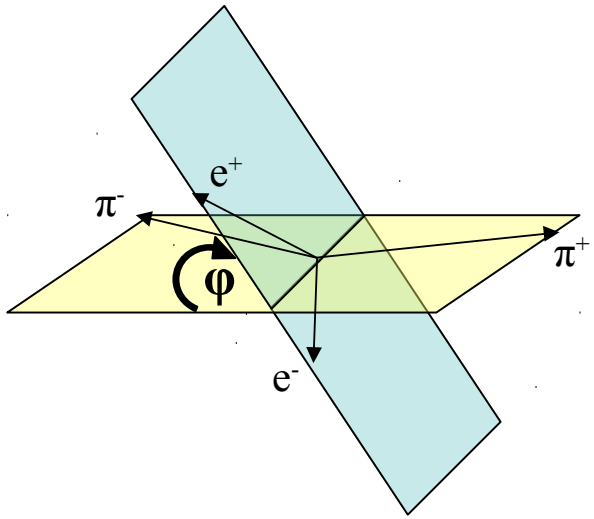
Branching Ratio

- $\Gamma(\eta \rightarrow \pi^+\pi^-e^+e^-)/\Gamma(\eta \rightarrow \pi^+\pi^-\gamma)$ well established theoretically
- Recent measurements of absolute branching ratio in both channels lower than expected



CP-Violating Observable

- Possible CP-violation outside of Standard Model See: D.N. Gao, Mod. Phys. Lett. A **17** (2002) 1583.
- Would produce asymmetry in angle between electron and pion decay planes
- Theoretical upper limit → ~1 x 10^{-2}
  - High statistics needed!

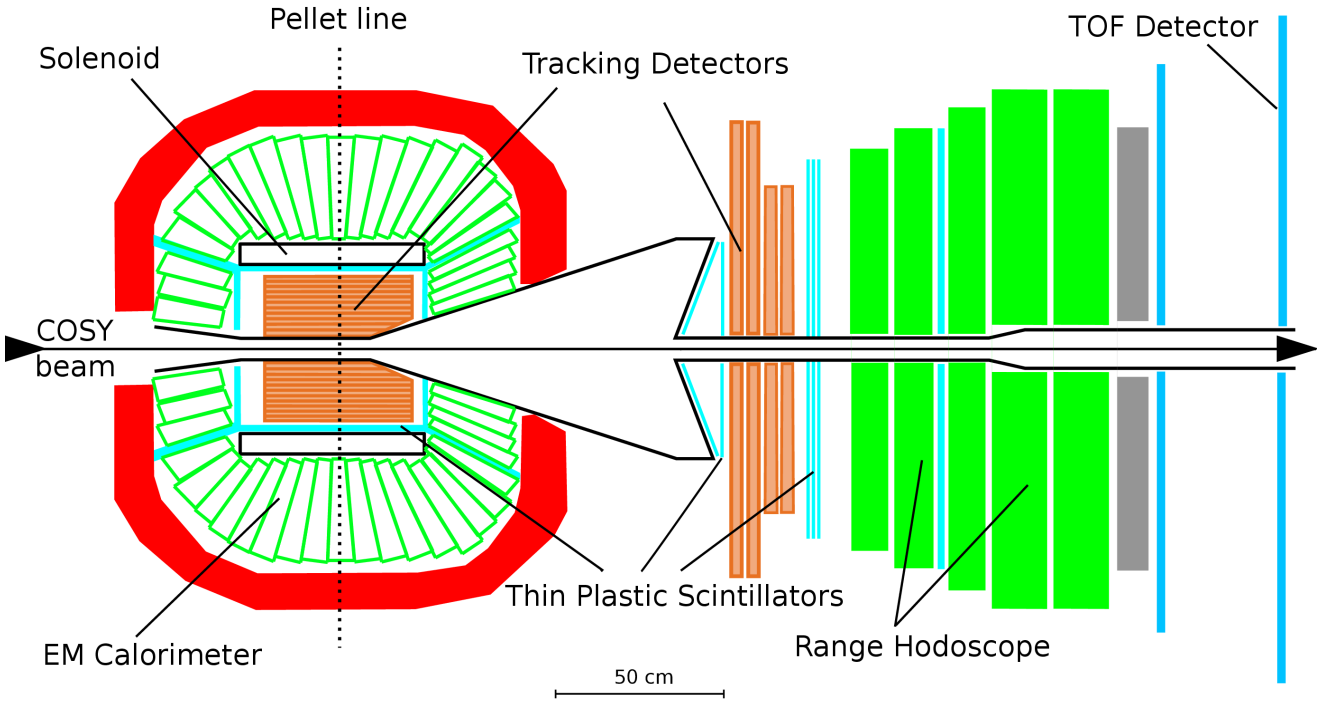


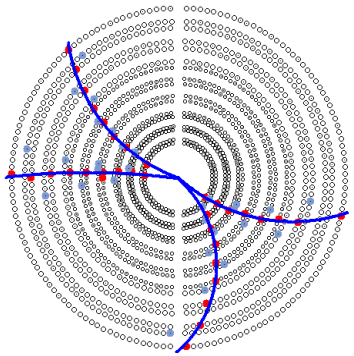
Experimental upper limit from KLOE:

$A_\Phi = (-0.6 \pm 2.5_{stat} \pm 1.8_{syst}) \times 10^{-2}$

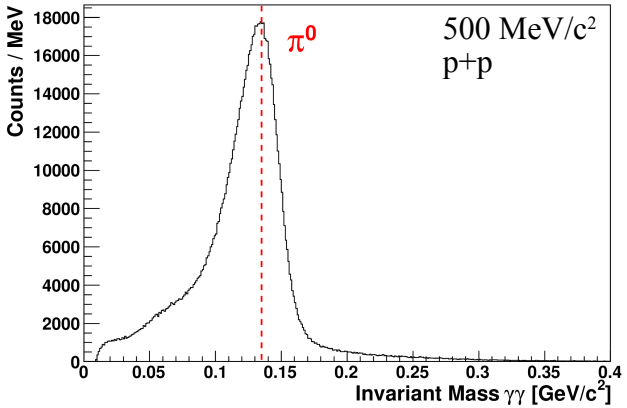
Phys.Lett.B675:283-288,2009

Experiment: WASA Detector

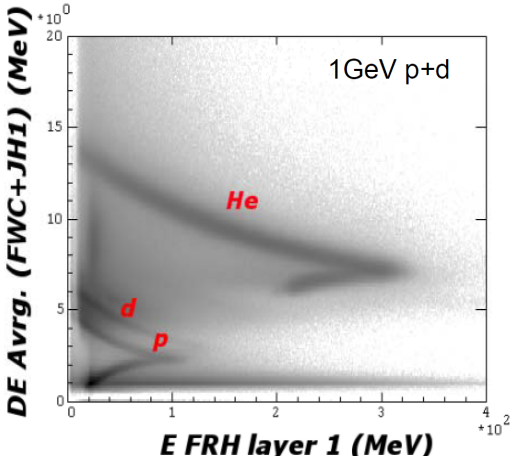




Charged Particle
Track Reconstruction



Photon Reconstruction



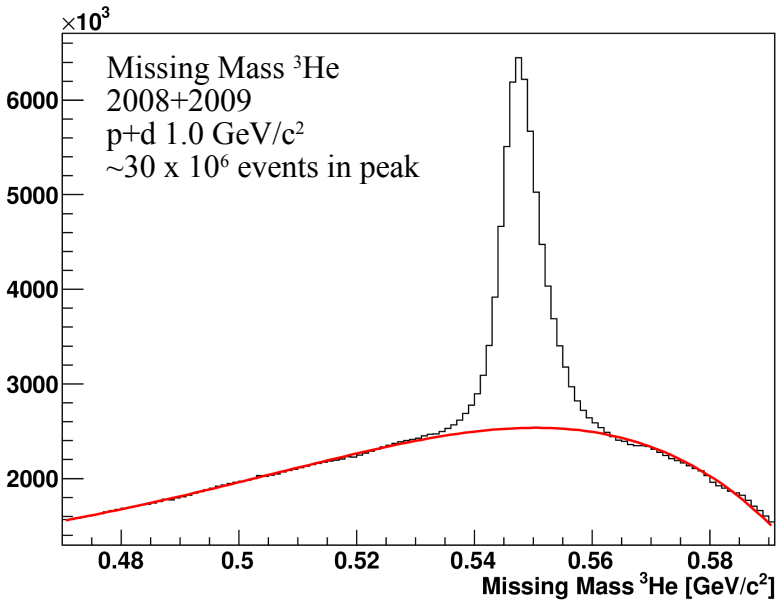
Forward Range for PID and
Reconstruction

η Production

$pd \rightarrow {}^3He\ \eta$ $\quad E_{kin} = 1.0$ GeV

- $\sigma_\eta = 0.4\ \mu b \rightarrow \sim 10\ \eta/s$ produced
- Trigger just on ^3He unbiased w.r.t. η decay
- Low direct-pion cross section
- 30 million η on disk

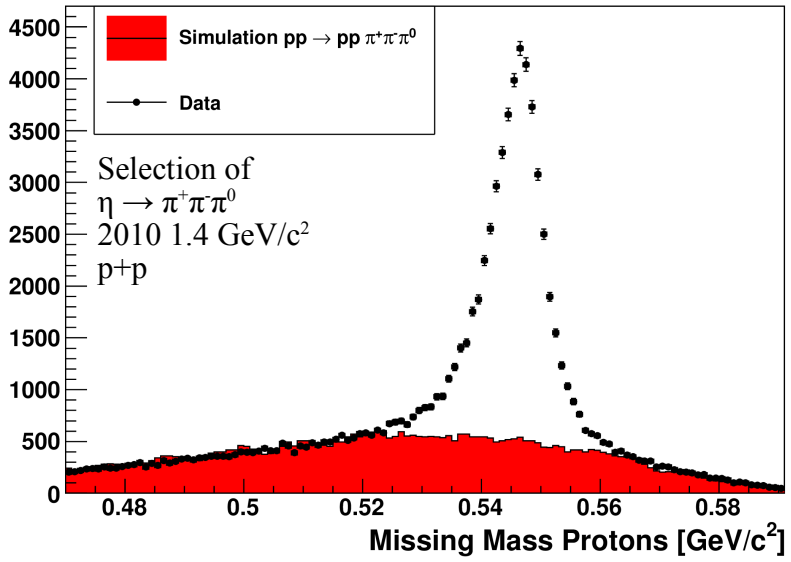
Well suited for measurement of common channels



$pp \rightarrow pp\ \eta$ $\quad E_{kin} = 1.4$ GeV

- $\sigma_\eta = 9.8\ \mu b \rightarrow >100\ \eta/s$ produced
- Selective trigger required
- High cross-section of multi pion production
- 5 x 10^8 η produced

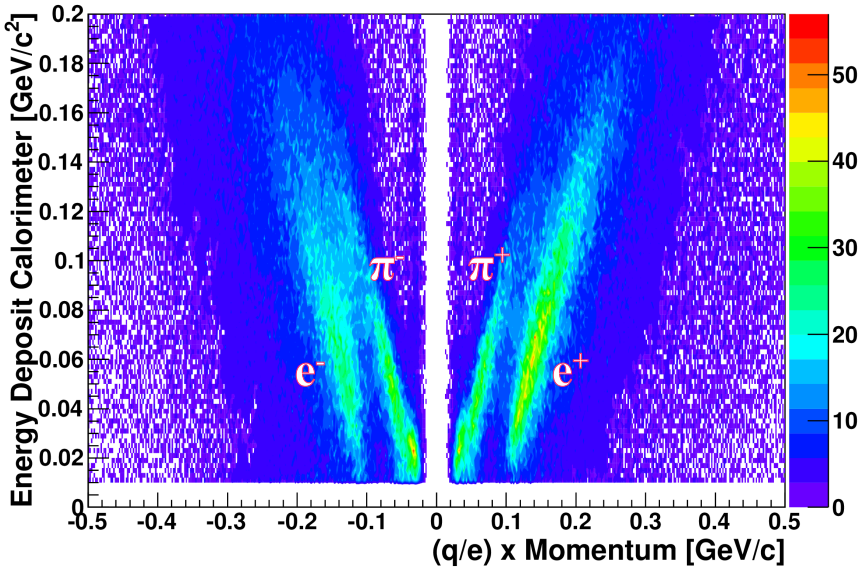
Well suited for measurement of rare decays



Analysis

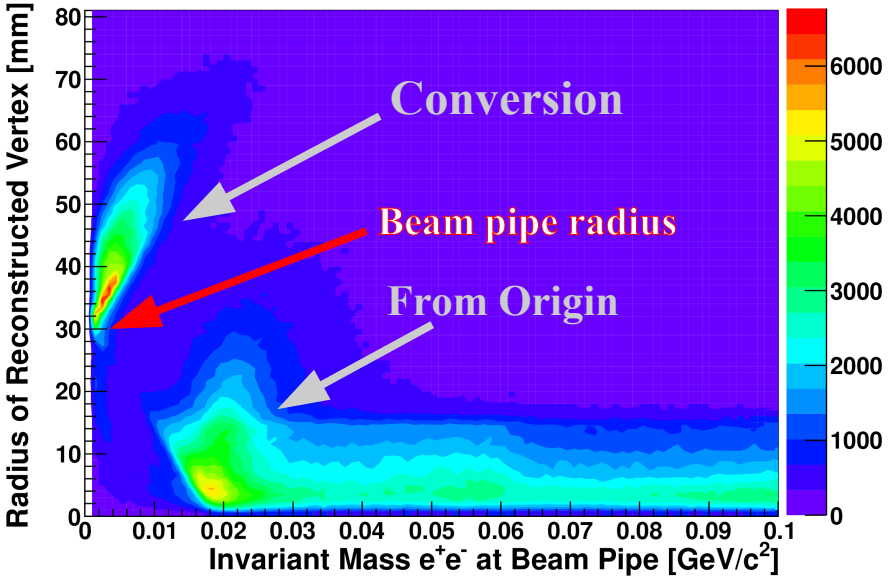
Particle Identification

- In $\eta \rightarrow \pi^+\pi^-e^+e^-$, PID necessary for mass assignment
- Large pion background makes PID important for clean selection of channels with e^+e^-
- Energy bands separate electrons and pions → trained into neural networks



Suppression of Photon Conversion

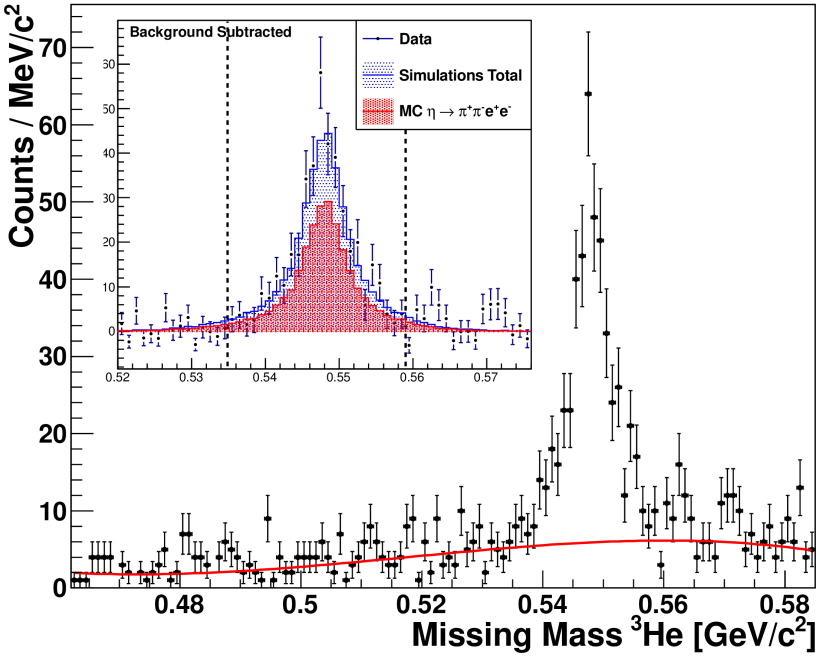
- Background from e^+e^- pairs from external conversion important when analyzing rare decays
- Tracking from drift chamber allows determination of primary vertex
- 90% of conversion pairs can be reliably rejected

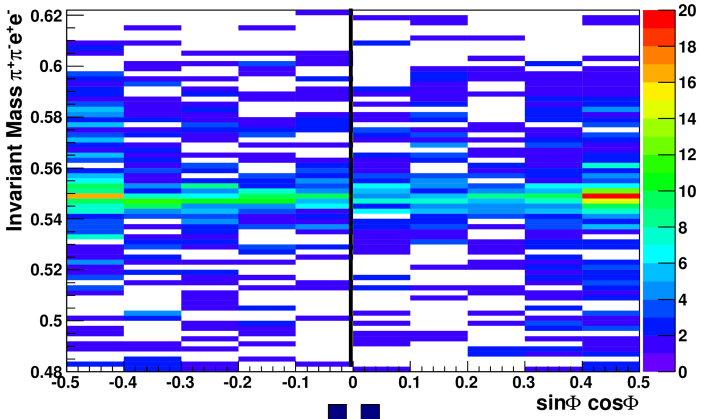


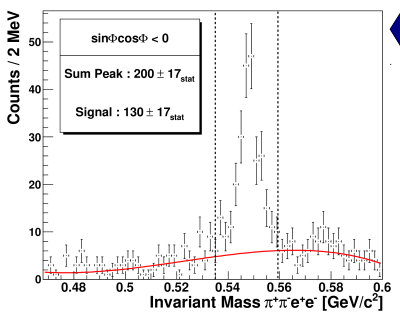
Results

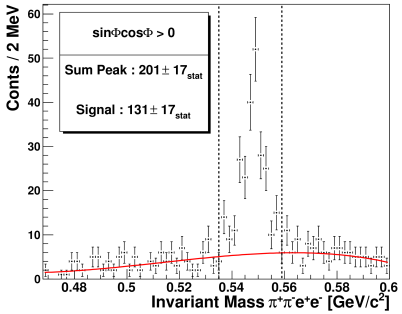
Branching Ratio

- $263 \pm 24_{stat}$ signal event candidates
- Signal:Background ratio 2:1
- Final systematical checks in progress









Decay Plane Asymmetry

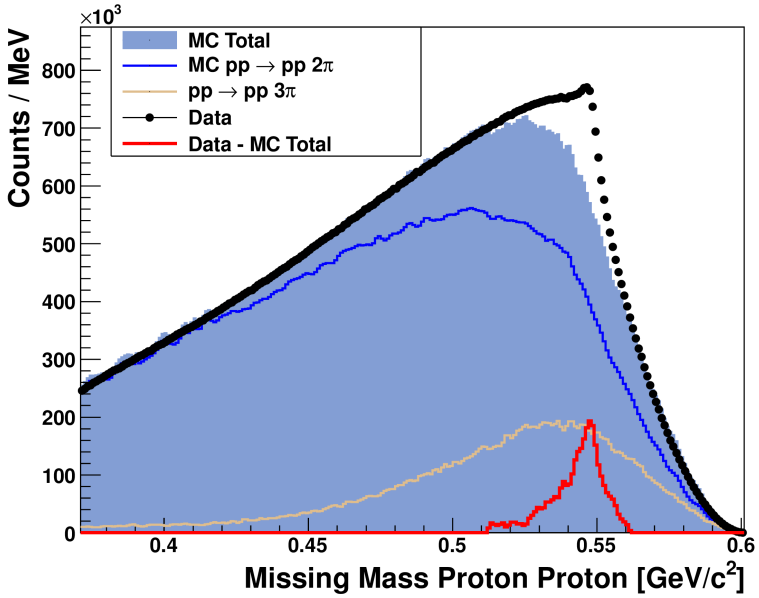
- Check asymmetry around 0 of sinΦcosΦ
- $A_{\Phi} = 0.3 \pm 9.0_{stat}$ *Preliminary*
- Extend analysis to proton-proton data
  - Higher rate of η production
  - Reduce statistical error to ~4% assuming no other changes

Conclusion

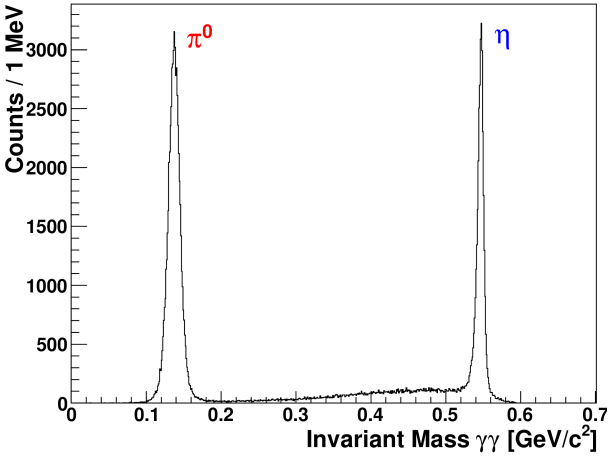
- The decay $\eta \rightarrow \pi^+\pi^-e^+e^-$ has been measured in proton-deuteron reactions at WASA-at-COSY
  - $263 \pm 24_{stat}$ signal events identified
  - $\mathbf{A_\Phi}$ compatible with zero (9×10^{-2} statistical error)
- Meson decay program at WASA-at-COSY
  - Dedicated beam times for η, ω, and π^0 decays
  - 7 weeks of data taking in $pp \rightarrow pp\eta$ successfully concluded last week

Proton-Proton Data

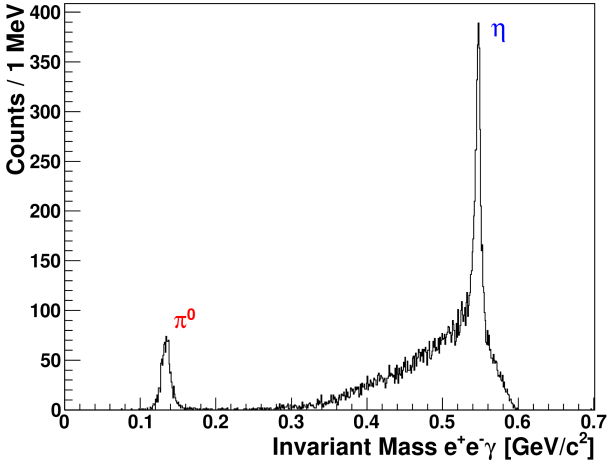
- Higher backgrounds than in pd
- Analysis techniques developed in proton-deuteron allow clean signals from η decays to be seen
  - Particle identification
  - Conversion suppression
  - Kinematic fitting



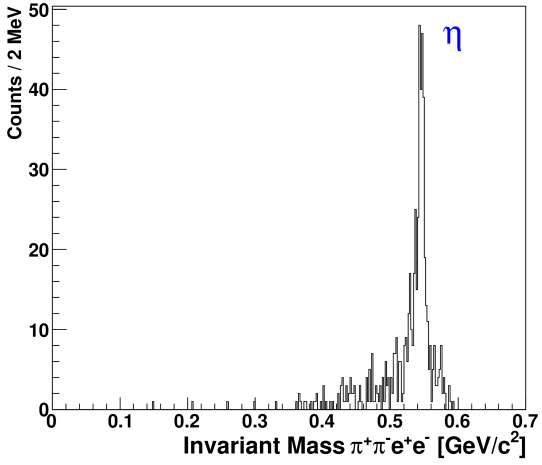
$pp \rightarrow pp\,[\,X \rightarrow \gamma\gamma]$



$pp \rightarrow pp\,[\,X \rightarrow e^+e^-\gamma]$



$pp \rightarrow pp\,[\,X \rightarrow \pi^+\pi^-e^+e^-]$

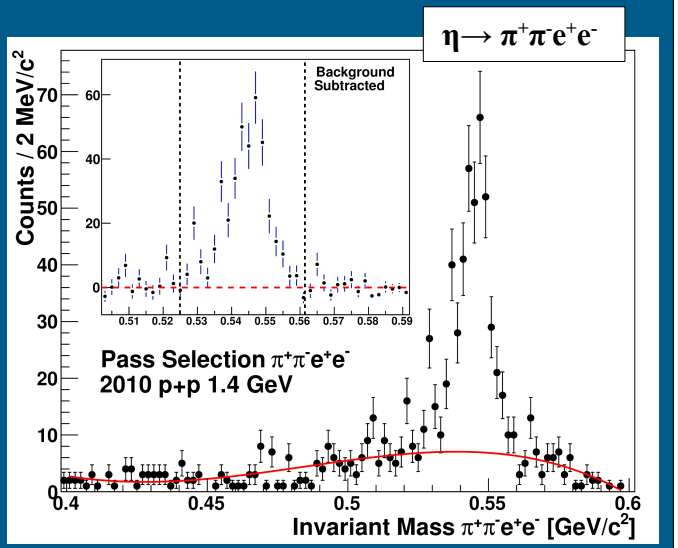
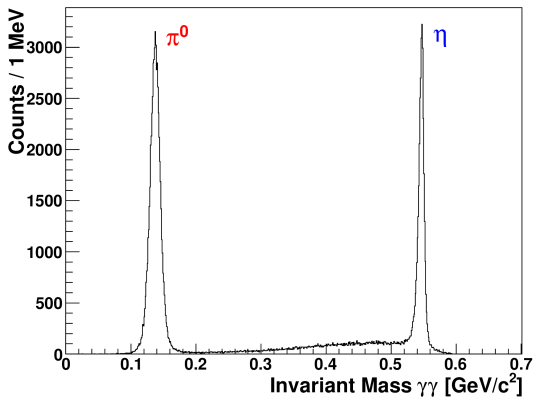
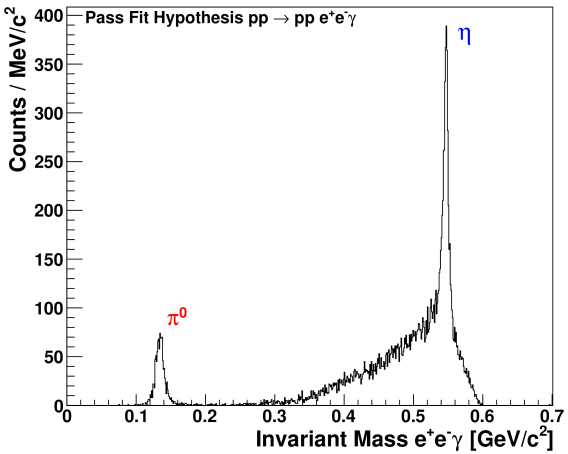


* a portion of the total statistics is shown

Outlook: Next Steps

$\eta \rightarrow \pi^+\pi^-e^+e^-$ in proton-proton Reactions

- Expect >1100 events in complete data set
- Analysis steps from pd successfully applied



Channel	Events	Data Analyz
$\eta \rightarrow \pi^+\pi^-\pi^0$	(43,871 ± 254)	1 Wee
$\eta \rightarrow \pi^+\pi^-\gamma$	(14,406 ± 336)	1 Wee
$\eta \rightarrow e^+e^-\gamma$	(2,973 ± 72)	1 Wee
$\eta \rightarrow \pi^+\pi^-e^+e^-$	(222 ± 22)	4 Week