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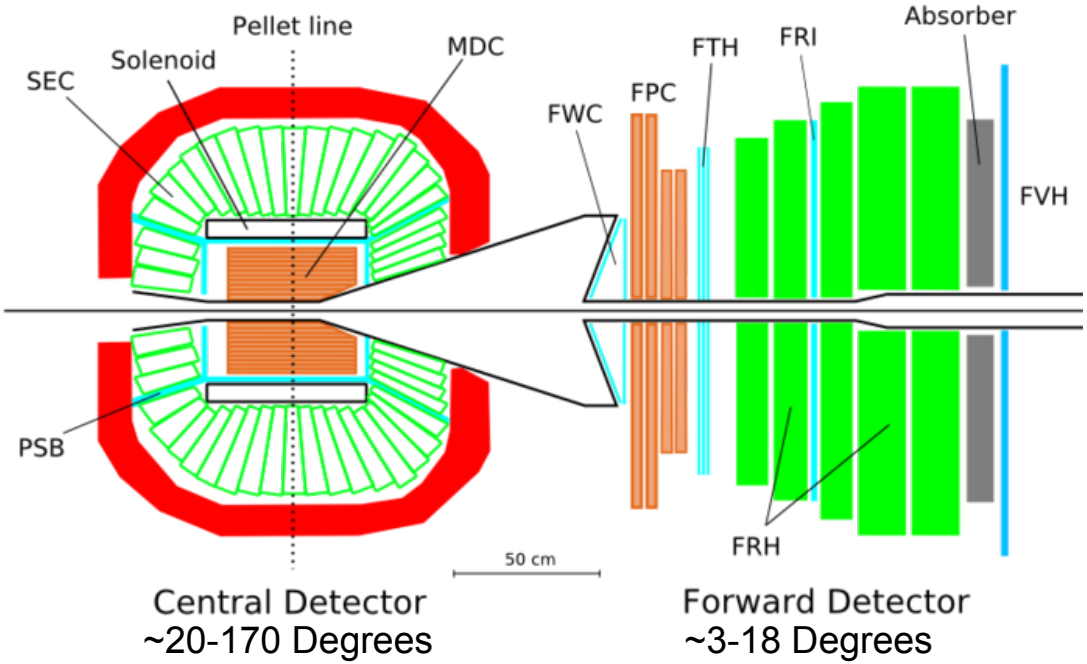
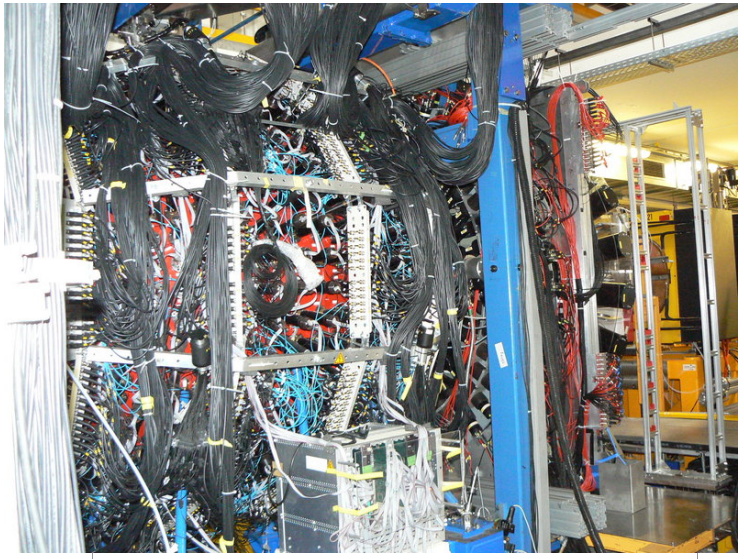
Measuring $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ with WASA at COSY

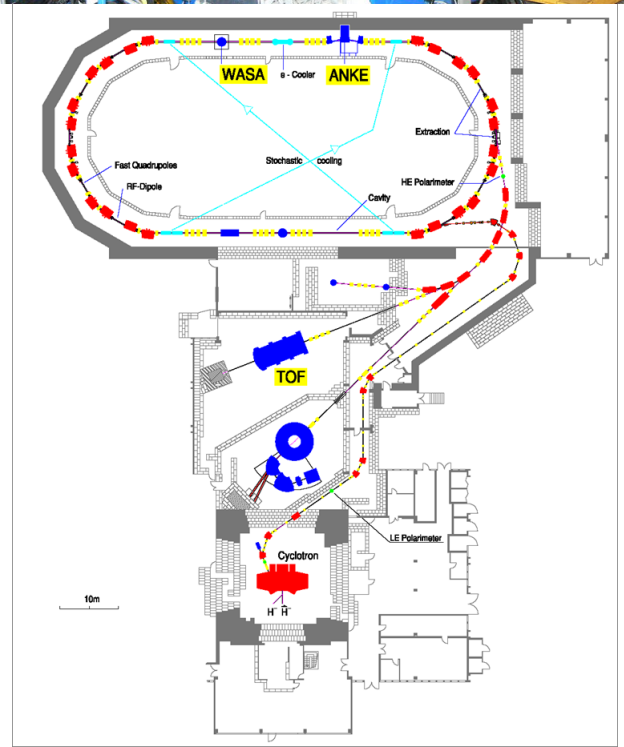
Daniel Coderre

Hirschegg 2010

The WASA Detector







- Internal experiment at COSY ring, Jülich, Germany

- Hydrogen/deuterium pellet target

- Forward detector → measurement of low-angle particles for accurate meson tagging

- Central detector → measurement of *both charged and neutral* decay products

Meson Production at WASA-at-COSY

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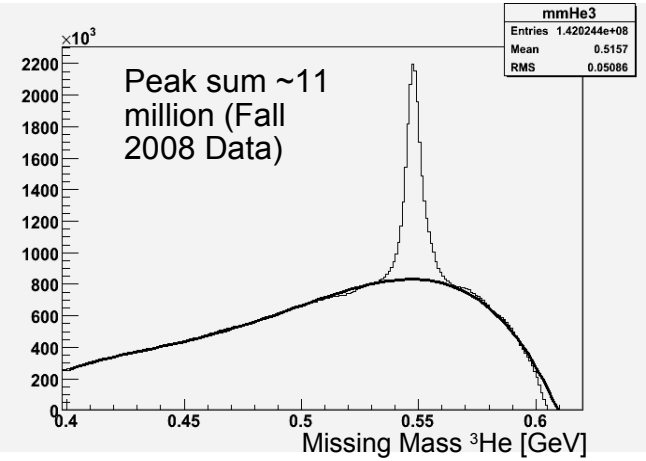
Major Production Runs

Fall 2008	pd → ^{3}Heη	4 Weeks	1.1×10^7 η on disk
Fall 2009	pd → ^{3}Heη	8 Weeks	2.1×10^7 η on disk

+ Unbiased data sample (all decays of η present)
+ Clean η tagging via missing mass technique
+ Low multi-π background

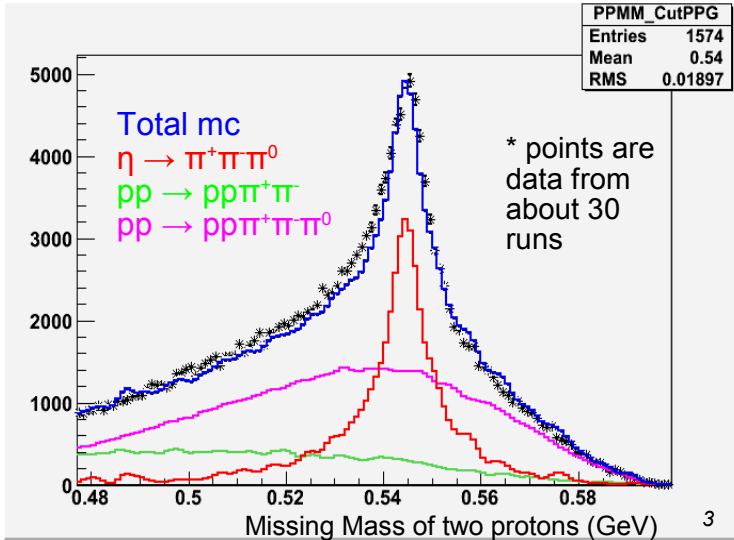
- Lower statistics, very rare decays unreachable



Spring 2010 pp → ppη 8 Weeks ~1×10^7 η → $\pi^+\pi^-\pi^0$ reconstructed

- Trigger conditions → bias towards charged decays
- Higher level cuts needed to see η signal at all
- Very high multi-π background

+ Much higher statistics for rare decays



Meson Production at WASA-at-COSY

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Major Production Runs

Decay mode	Fraction Γ_i/Γ_{total} (pdg)	issue
$\eta \rightarrow \pi^0\pi^0\pi^0$	$(32.57 \pm 0.23) \times 10^{-2}$	Dalitz plot parameter
$\eta \rightarrow \pi^+\pi^-\pi^0$	$(22.74 \pm 0.28) \times 10^{-2}$	
$\eta \rightarrow \pi^+\pi^-\gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	Box anomaly
$\eta \rightarrow \gamma e^+e^-$	$(7.0 \pm 0.7) \times 10^{-3}$	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**
$\eta \rightarrow e^+e^-e^+e^-$	$< 6.9 \times 10^{-5}$	Transition form factors
$\eta \rightarrow \pi^0e^+e^-$	$< 4 \times 10^{-5}$	C
$\eta \rightarrow e^+e^-$	$< 2.7 \times 10^{-5}$	New physics?

Spring 2011 pd → ^{3}Heω ----- Starts in a few weeks!

Missing Mass of two protons (GeV)

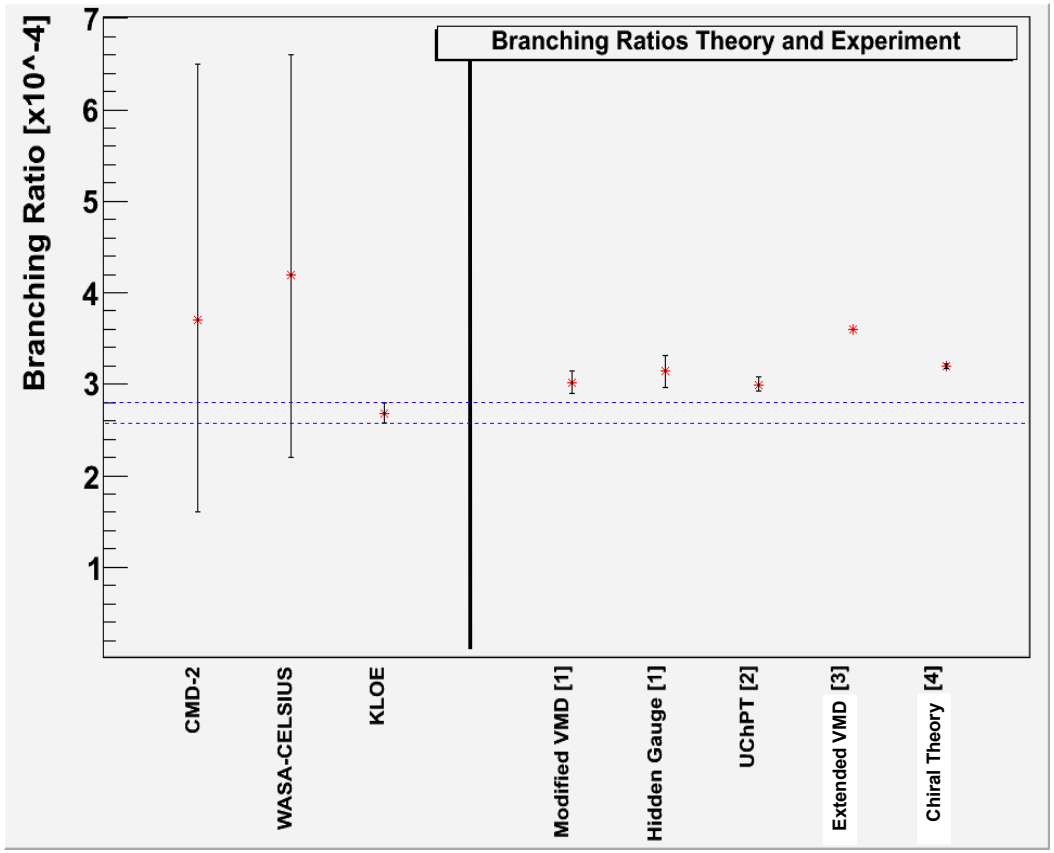
$\eta \rightarrow \pi^+ \pi^- e^+ e^-$ Motivation (1)

Branching ratio measurement:

Discrepancy exists between modern theory and modern experiment

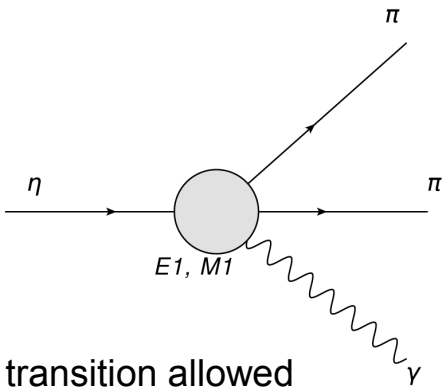
Former Experimental Results

1966 – 1 Candidate Event (bubble chamber)
Grossman, Price, Crawford
Phys.Rev.146:933,1966
2001 – 4 Candidate Events (.5 event background)
CMD-2 Experiment
Phys.Lett.B501:191-199,2001c
2007 – 24 Events (8 event background)
WASA-CELSIUS
Phys.Lett.B644:299-303,2007
2009 – 1555 events
KLOE Collaboration
Phys.Lett.B675:293-288,2009

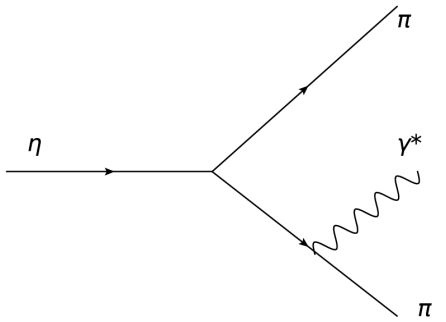


[1] Petri, T. Master's Thesis.(2010) arXiv:1010.2378v1
[2] R.Borasoy and R.Nissler, Eur.Phys.J. A **33** (2007) 95.
[3] A. Faessler, C. Fuchs, and M.I. Krivoruchenko, Phys.Rev. C **61** (2000) 035206.
[4] C.Piccioto and S. Richardson, Phys.Rec. D **48** (1993) 3395.

$\eta \to \pi^+ \pi^- e^+ e^-$ Motivation (2)



M1 transition allowed
E1 transition violates CP



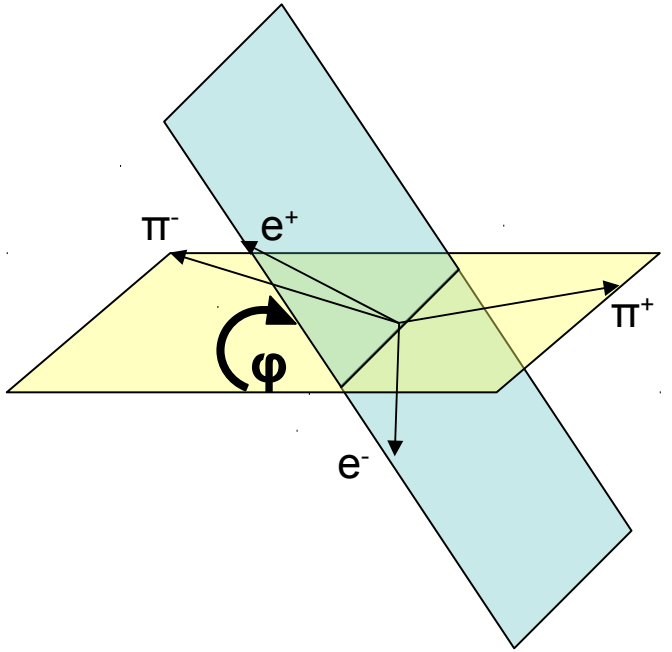
$\eta \to \pi^+\pi^-$ violates CP directly

Geng[1], 2002 – Possible flavor conserving CP violation in $\eta \to \pi^+\pi^-\gamma$ could cause a "sizeable linear photon polarization."

Gao[2], 2002 – If such a linear polarization were to exist, it could create an observable for non-SM CP violation in the asymmetry of the electron and pion decay planes.

$$A_\varphi = \frac{Count(\varphi > 90) - Count(\varphi < 90)}{Count(\varphi > 90) + Count(\varphi < 90)}$$

theoretical upper limit ~10^{-2}



Experimental upper limit from KLOE:

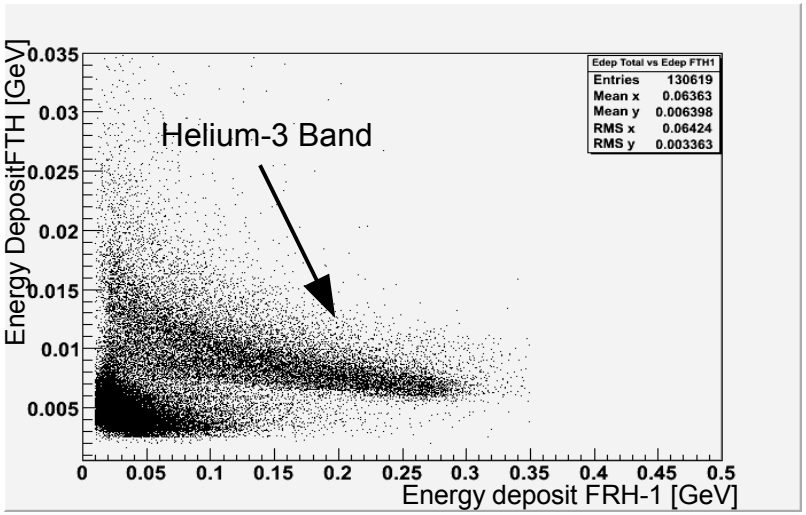
$A_\Phi = (-0.6 \pm 2.5_{stat} \pm 1.8_{syst}) \times 10^{-2}$

Phys.Lett.B675:283-288,2009

1. C.Q. Geng, J.N. Ng, and T.H. Wu, Mod. Phys. Lett. A **17** (2002) 1489.
2. D.N. Gao, Mod. Phys. Lett. A **17** (2002) 1583.

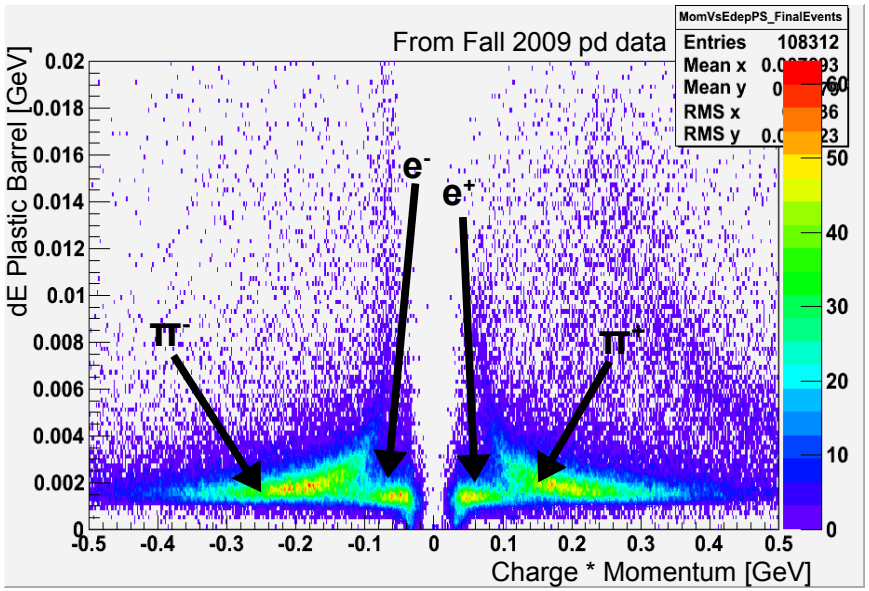
Analysis 1: Particle Identification

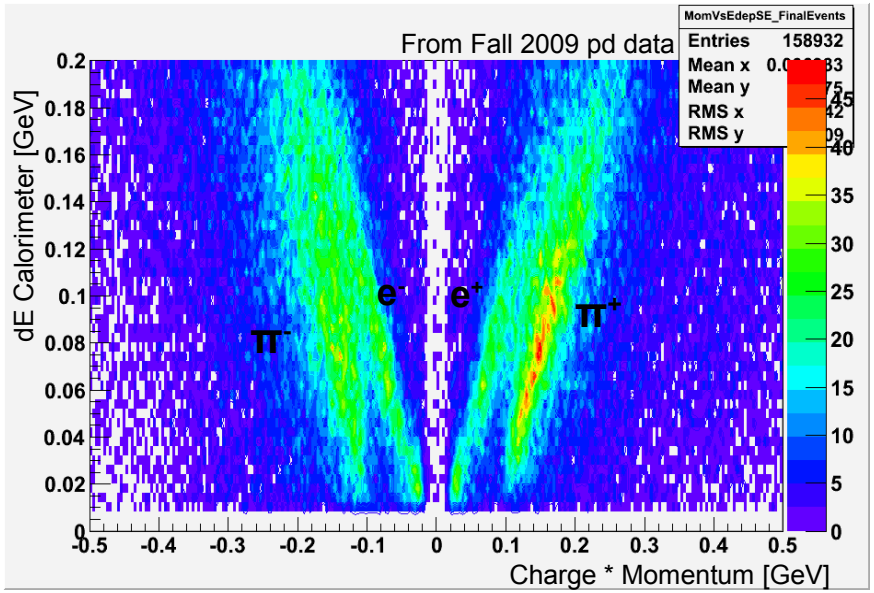
Forward Detector Particle Identification



- Clean ^{3}He identification via. E/dE method (simple graphical cut)
- Protons selected by time difference
- Pions and electrons selected via. E/dE method. Neural networks used to get probability.
- Angular distributions additionally used to identify dilepton pair

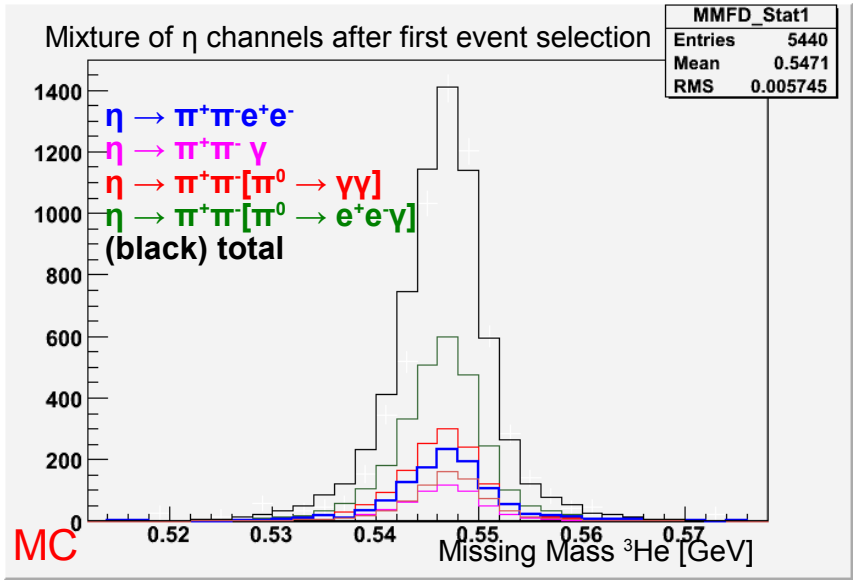
Central Detector Particle Identification





Background from Other η Decays

Channel	Branching Ratio	Final State Particles
$\eta \rightarrow \pi^+\pi^-e^+e^-$ (signal)	$(2.68 \pm .11) \times 10^{-4}$	$\pi^+ \pi^- e^+ e^-$
$\eta \rightarrow \pi^+\pi^- \gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	$\pi^+ \pi^- e^+ e^-$
$\eta \rightarrow \pi^+\pi^-\pi^0$ $\pi^0 \rightarrow \gamma\gamma$	$(22.74 \pm 0.28) \times 10^{-2}$ x ~99%	$\pi^+ \pi^- e^+ e^- \gamma$
$\eta \rightarrow \pi^+\pi^-\pi^0$ $\pi^0 \rightarrow e^+e^-\gamma$	$(22.74 \pm 0.28) \times 10^{-2}$ x ~1%	$\pi^+ \pi^- e^+ e^- \gamma$
$\eta \rightarrow \pi^0\pi^0\pi^0$	$(32.57 \pm 0.23) \times 10^{-2}$	$e^+e^-e^+e^-\gamma\gamma\gamma\gamma$
$\eta \rightarrow \gamma\gamma$	$(39.31 \pm 0.20) \times 10^{-2}$	$e^+e^-e^+e^-$

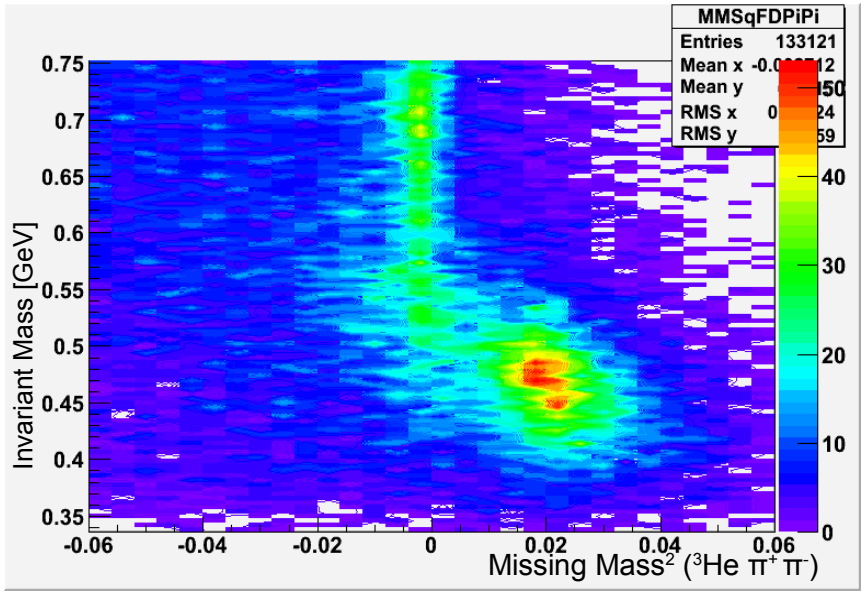


* Background channels with an extra photon are sensitive to cuts on the missing energy of the photon

* Background channels coming from conversion are sensitive to cuts on the primary vertex

* The final two (neutral) channels are not specifically considered as they are automatically suppressed by the other cuts

Background Rejection

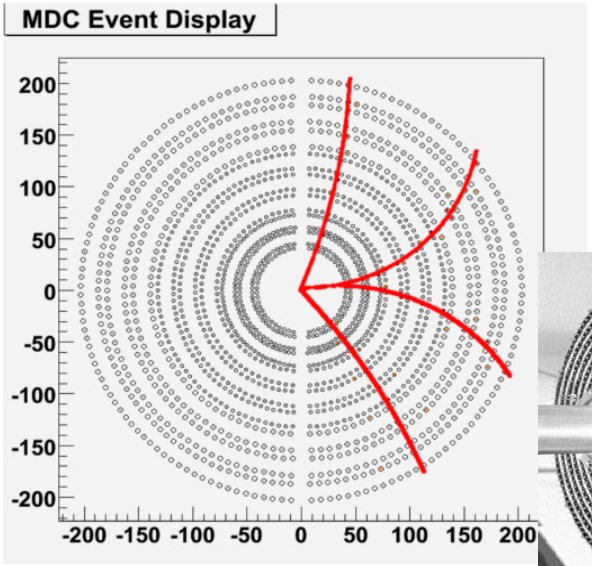


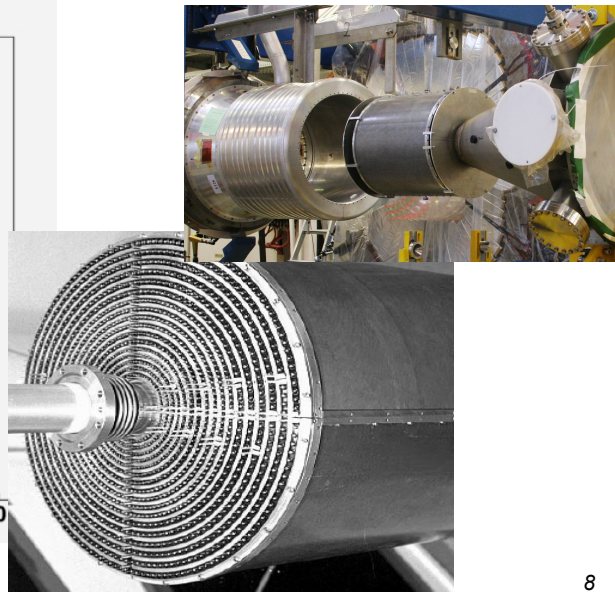
Cut on kinematics:

- Missing mass (^{3}He,π^+,π^-) → see π^0 signal
- Invariant mass ($\pi^+\pi^-e^+e^-$) offset from different event types
- Kinematic fit – E/p conservation

Cut on primary vertex:

- Tracking information from Mini Drift Chamber
- Closest approach of particle helices
- Invariant mass at beam pipe



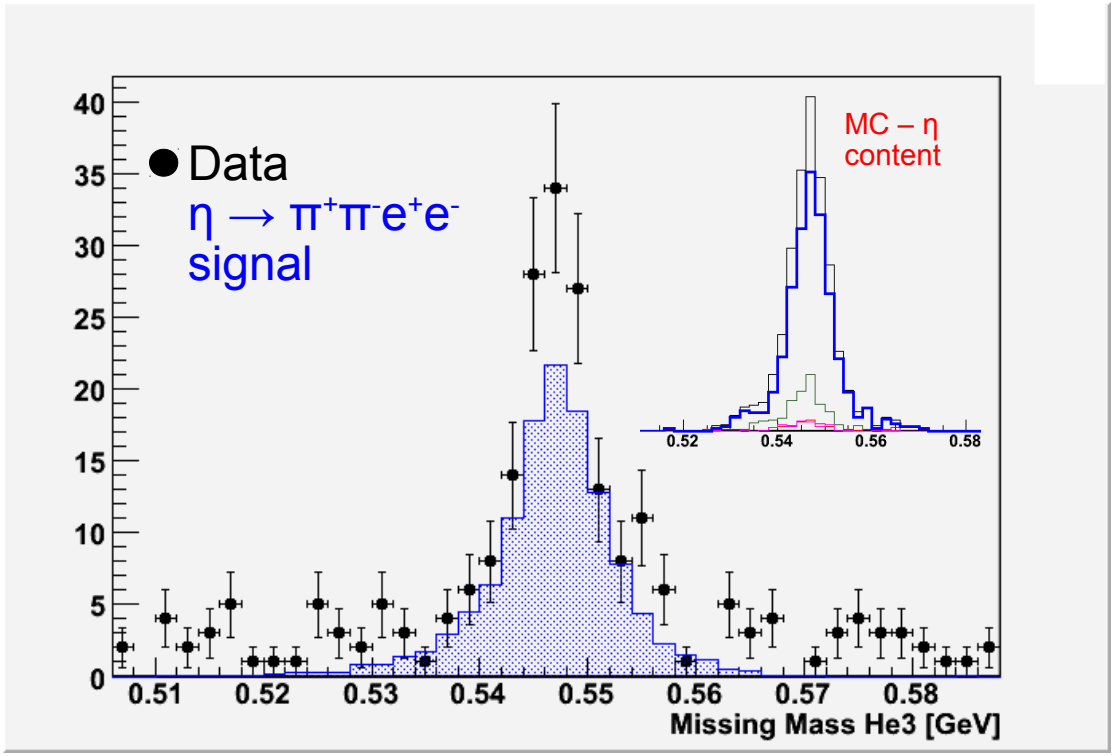


Remaining Event Samples from p-d

- After background suppression, around 125 signal events remain from pd data. η content is 80% signal

- Loosening of cut conditions can also yield over 300 signal events, but η content drops to 60% signal

- Work is ongoing to address efficiency of reconstruction



Outlook

- The decay $\eta \rightarrow \pi^+\pi^-e^+e^-$ has been observed in $pd \rightarrow {}^3He\eta$

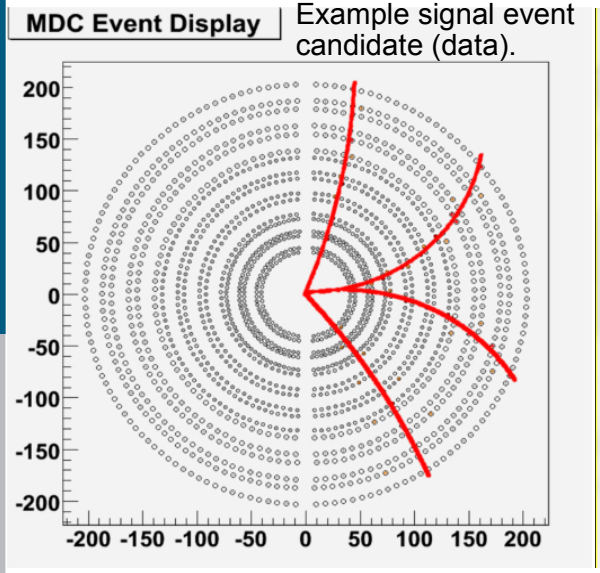
- 12 weeks of pd data yields a sample of one to a few hundred events, depending on selectiveness of cuts

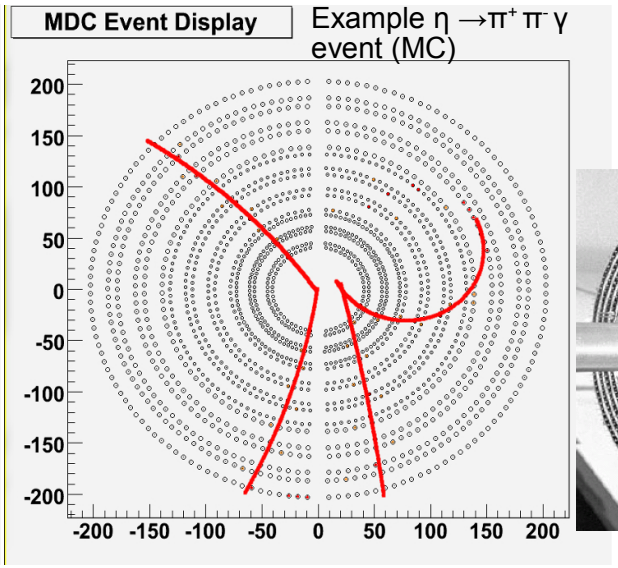
- Extension of analysis to proton-proton data → already begun

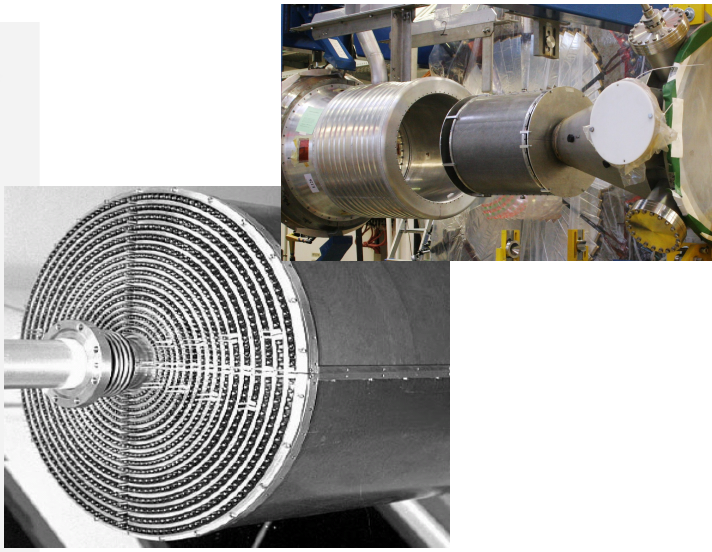
- WASA experiment continues taking data
    - First ω production run starts Feb. 2011
    - Design goal: sensitivity on $\eta \rightarrow e^+e^-$ (>10^9 η's)
        - New Trigger board
        - Drift Chamber

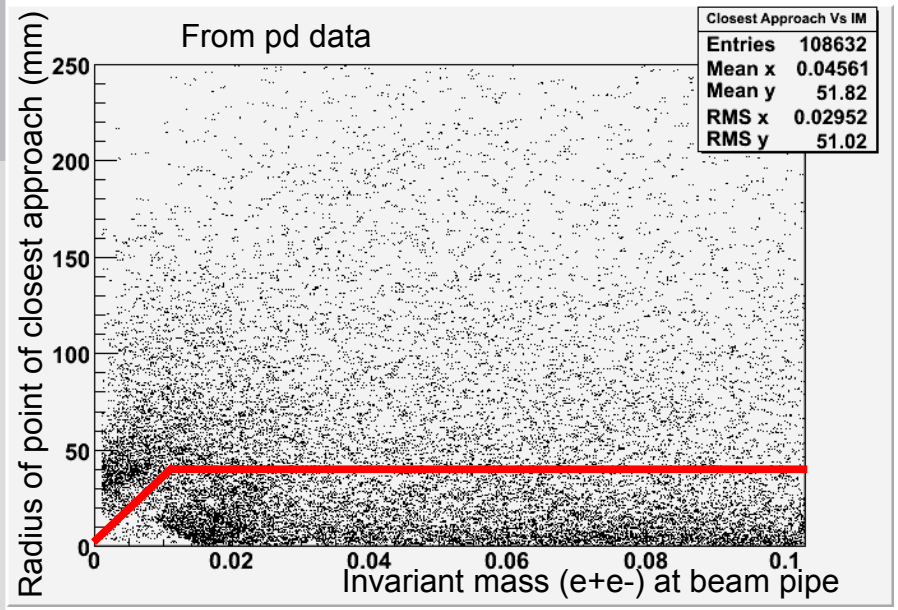
Extra slides

Conversion Decays

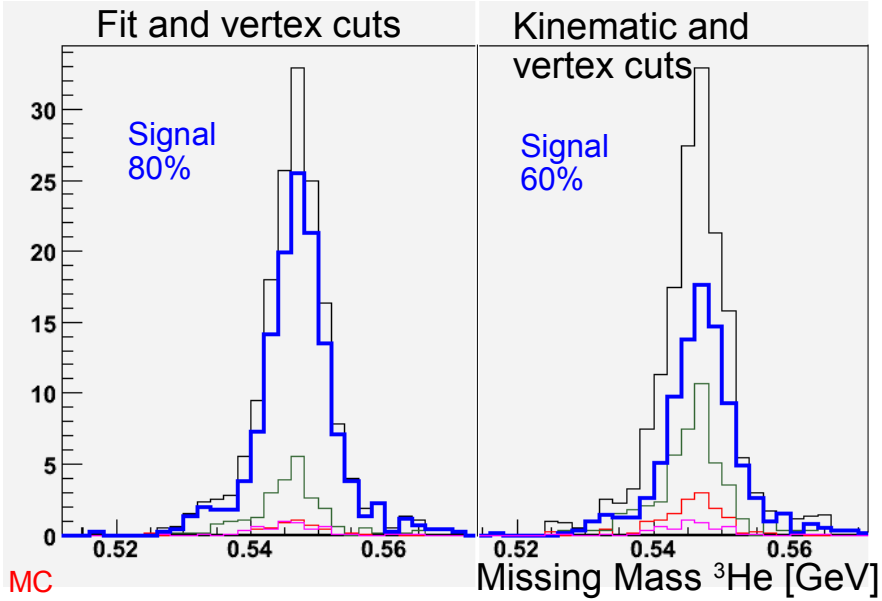






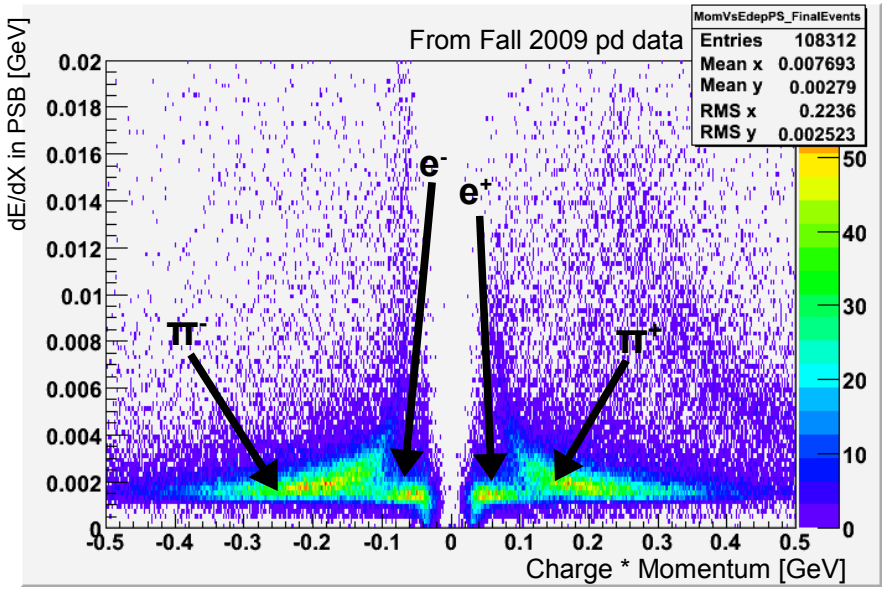


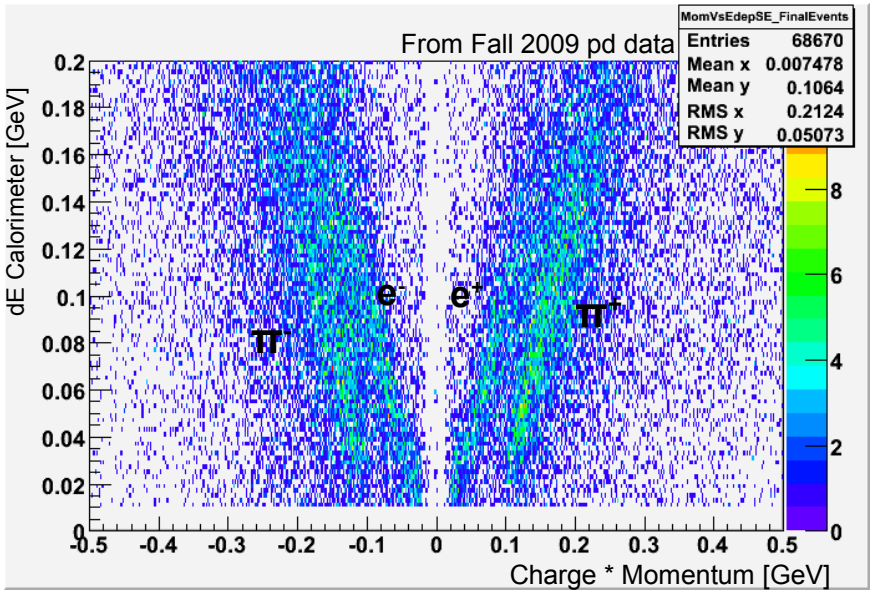
Effect on background channels



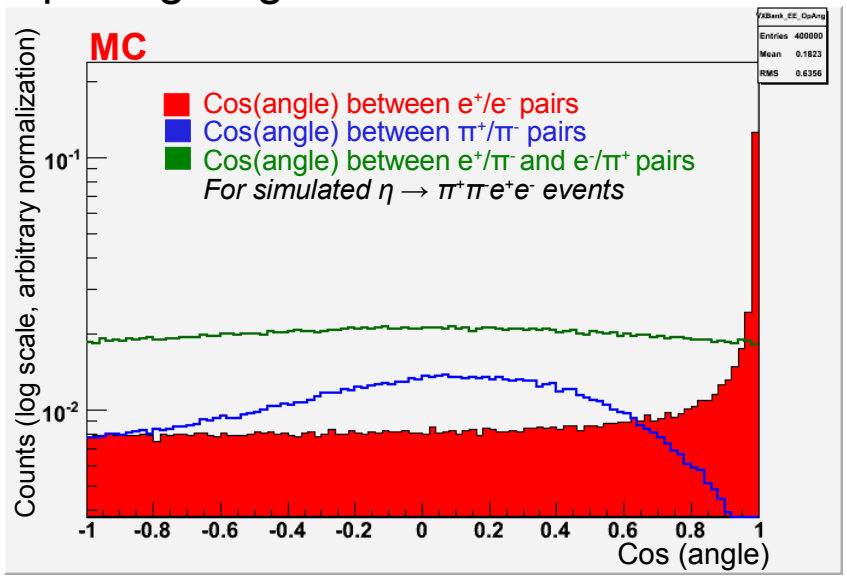
Particle Identification

Energy/Momentum Identification





Opening Angle Information



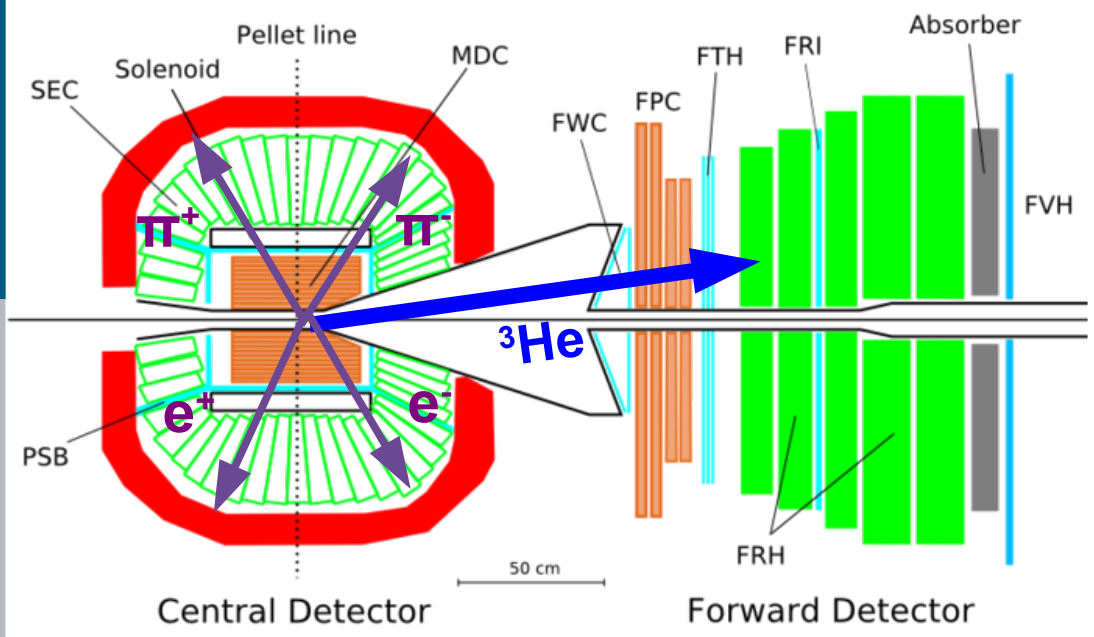
* Identification takes in 2 positive and 2 negative tracks and assumes 2 **π** and 2 **e.**

* Four possible configurations each have starting probability 1/4

* Probabilities are updated using Bayes' equation with information from E/dE graphs and opening angles

* Highest probability configuration is chosen

Measuring $\eta \rightarrow \pi^+\pi^-e^+e^-$ with the WASA Detector



Beam times:

pd → ^{3}Heη

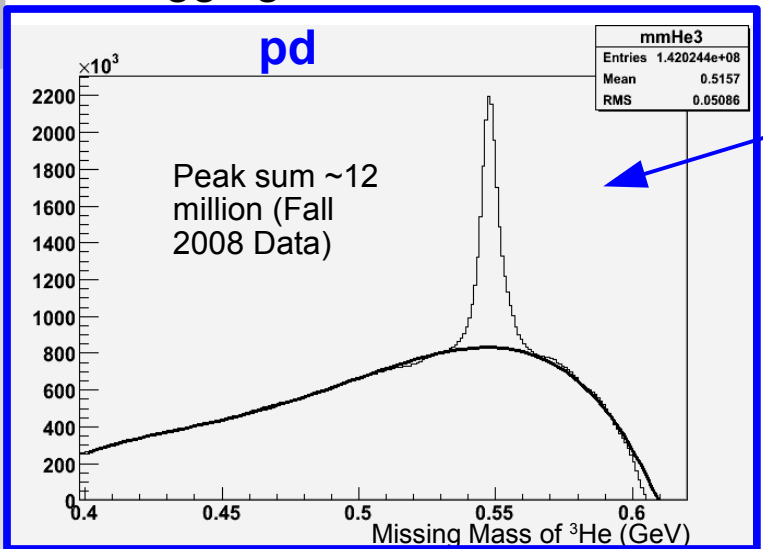
- 4 weeks Fall 2008
- 8 weeks Fall 2009

Total ~3x10^7 unbiased η on disk

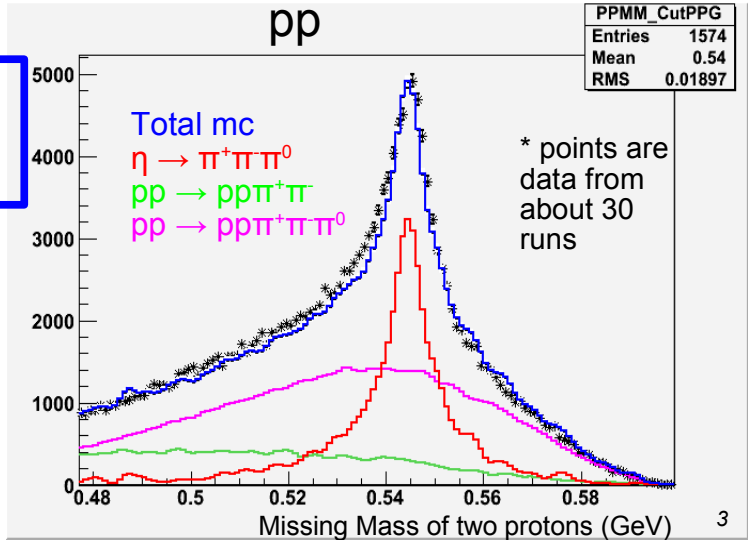
Pros: Unbiased trigger
Clean η tagging
Low backgrounds

Cons: Limited statistics

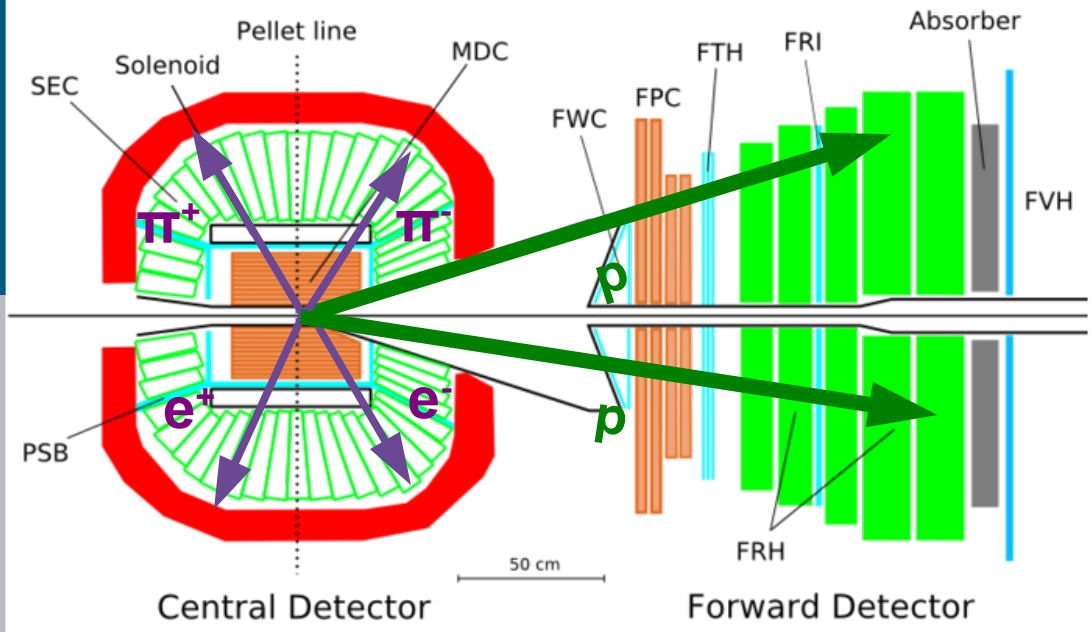
Eta Tagging



- In pd, missing mass of ^{3}He shows clear η peak without any cuts
- In pp, eta only visible when selecting a decay channel
- Here $\eta \rightarrow \pi^+\pi^-\pi^0$ selected
- Estimated 1x10^7 $\eta \rightarrow \pi^+\pi^-\pi^0$ reconstructed in Spring 2010 data



Measuring $\eta \rightarrow \pi^+\pi^-e^+e^-$ with the WASA Detector



Beam times:

pp → ppη

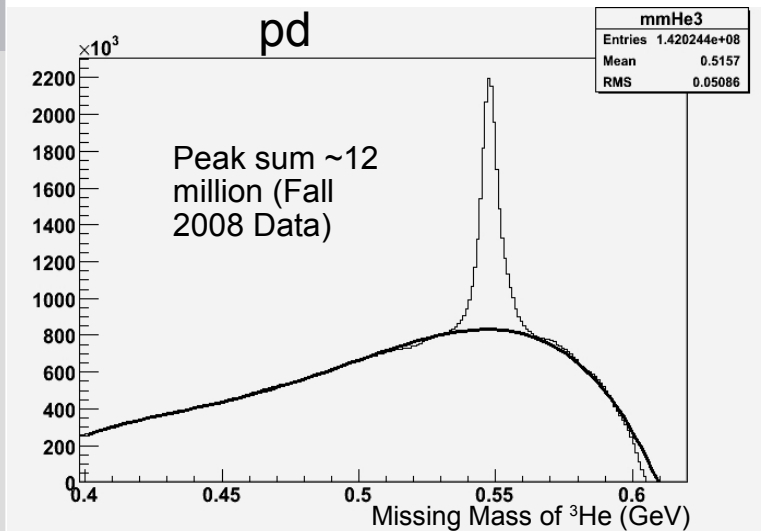
- 8 weeks Spring 2010

Total ~20x10^7 η. Bias towards charged decay channels

Pros: Much higher statistics

Cons: Lower acceptance
Higher backgrounds
Selective trigger needed

Eta Tagging



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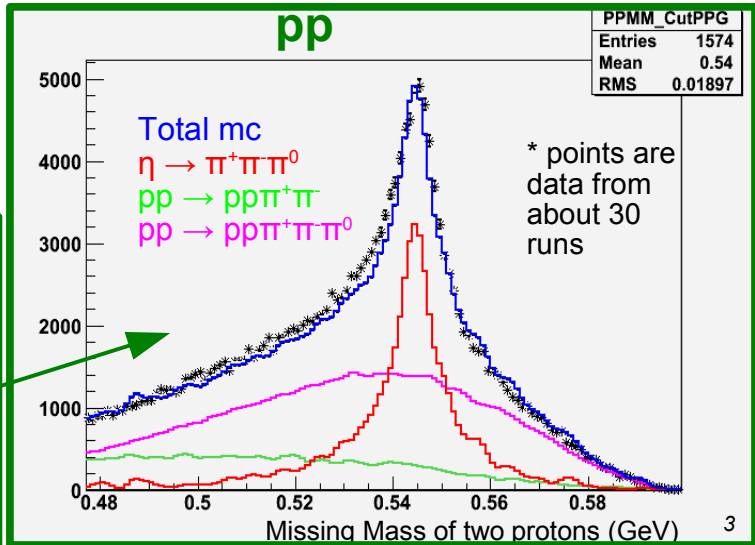
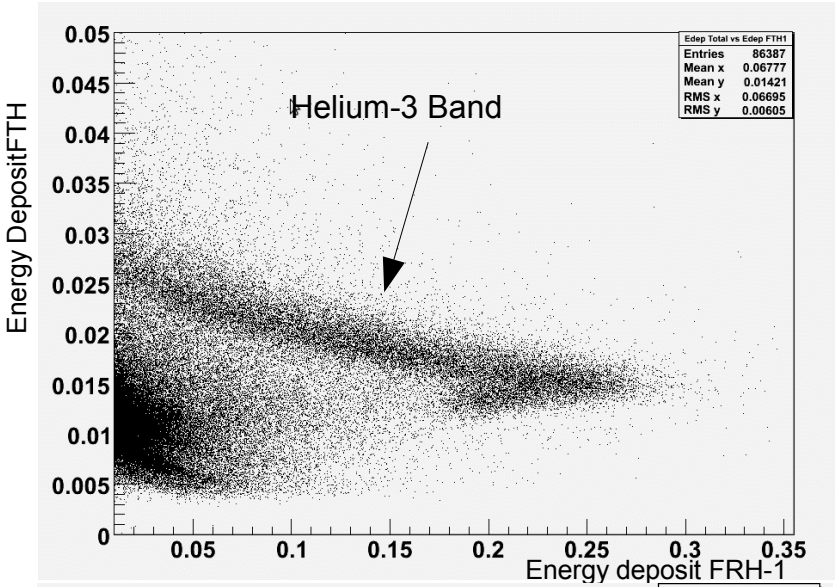
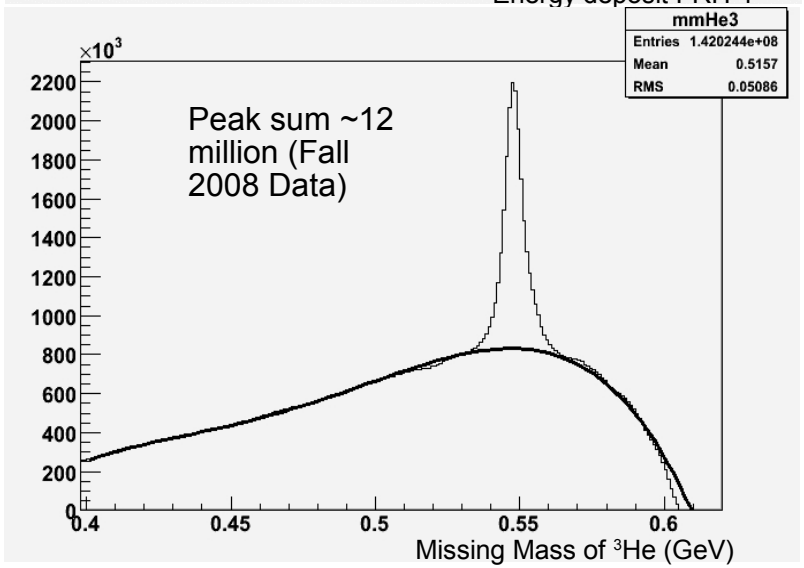


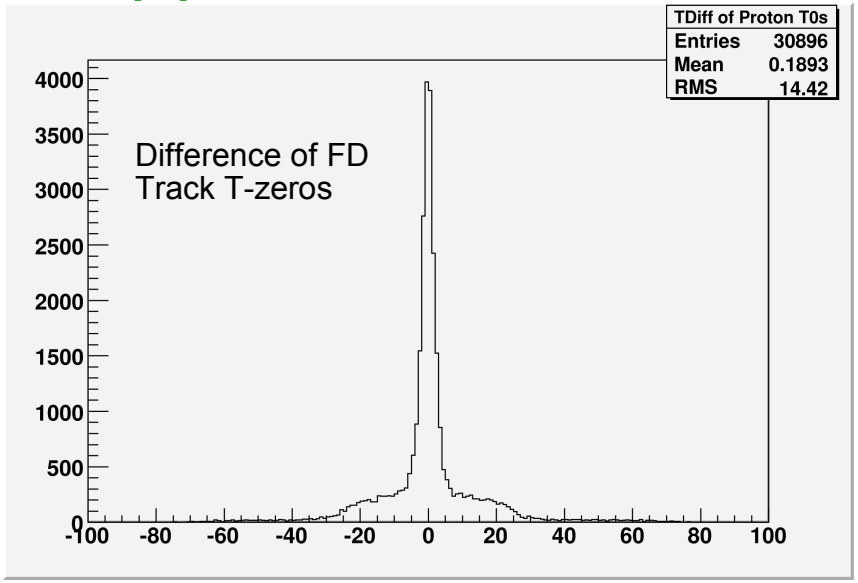
Identifying η-mesons in pd and pp

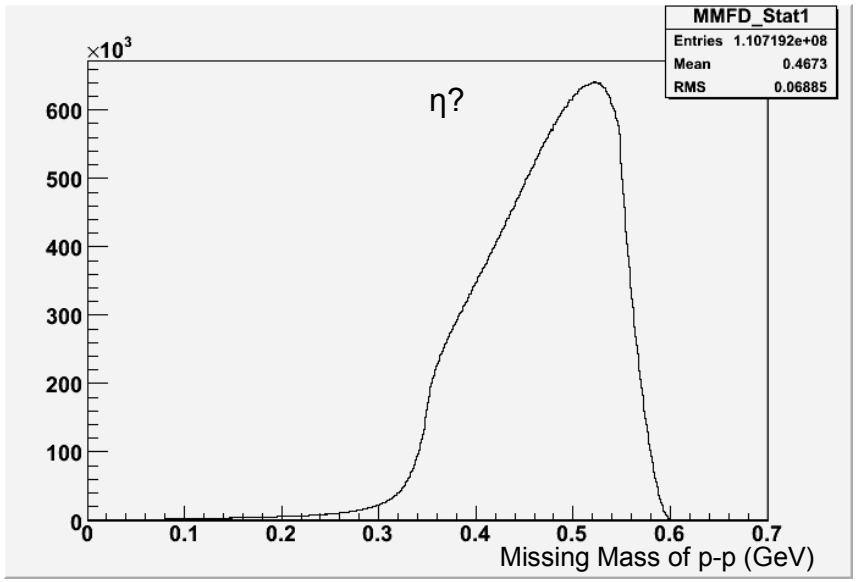
p-d: E/dE method



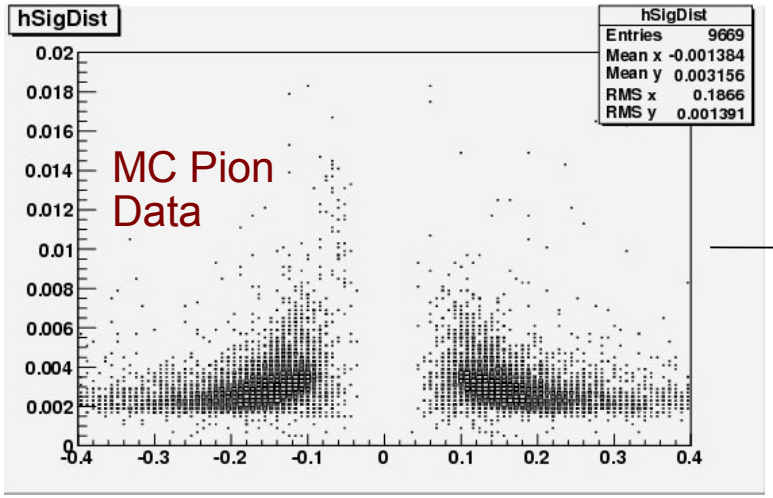


p-p: Time Coincidence Method

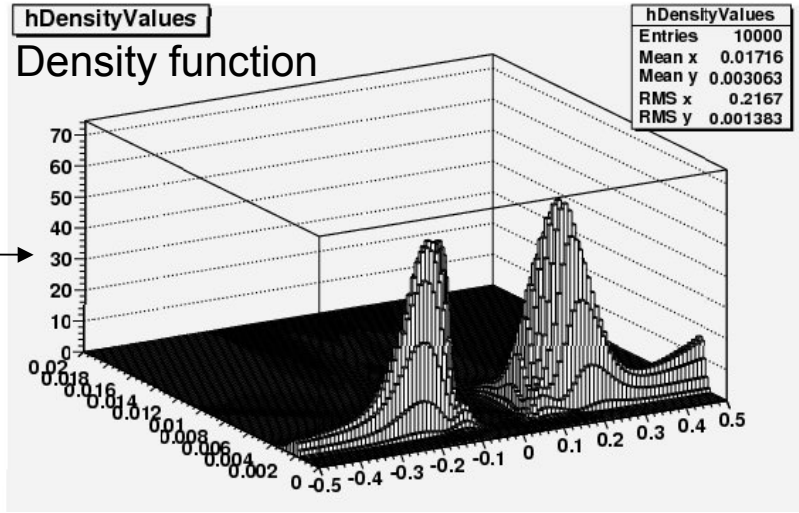




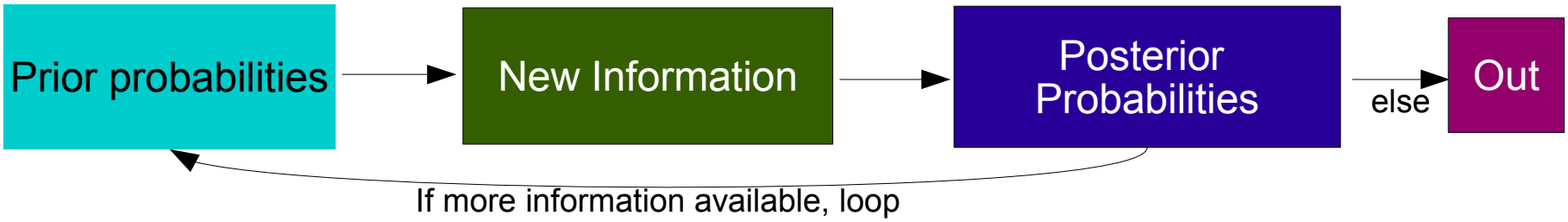
Particle Identification



Neural Network



Add information recursively, update probabilities every step:



- In MC ~92% of signal events correctly identified
- Algorithm can be easily extended if more ways to discriminate electrons and pions are found

Charged Particles in the Central Detector

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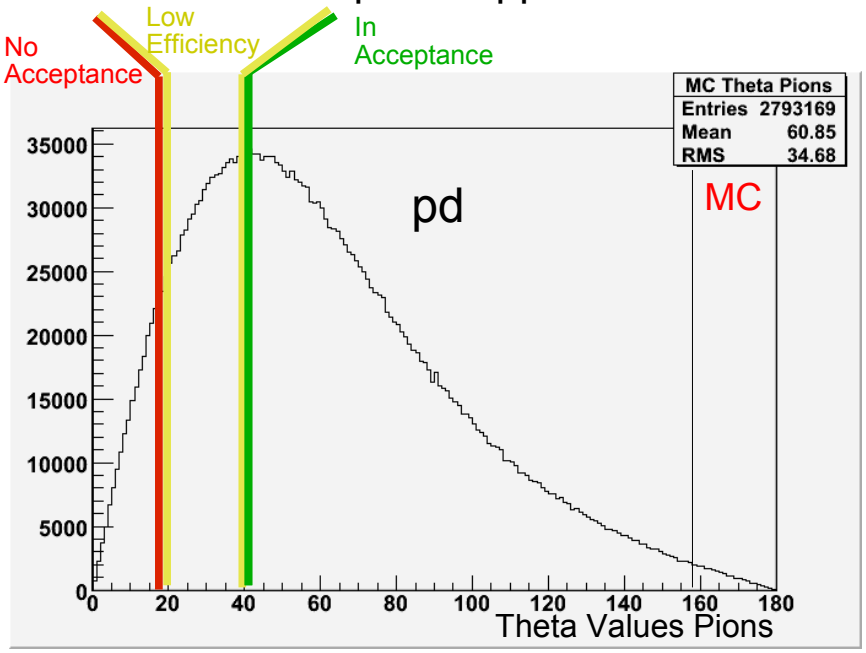
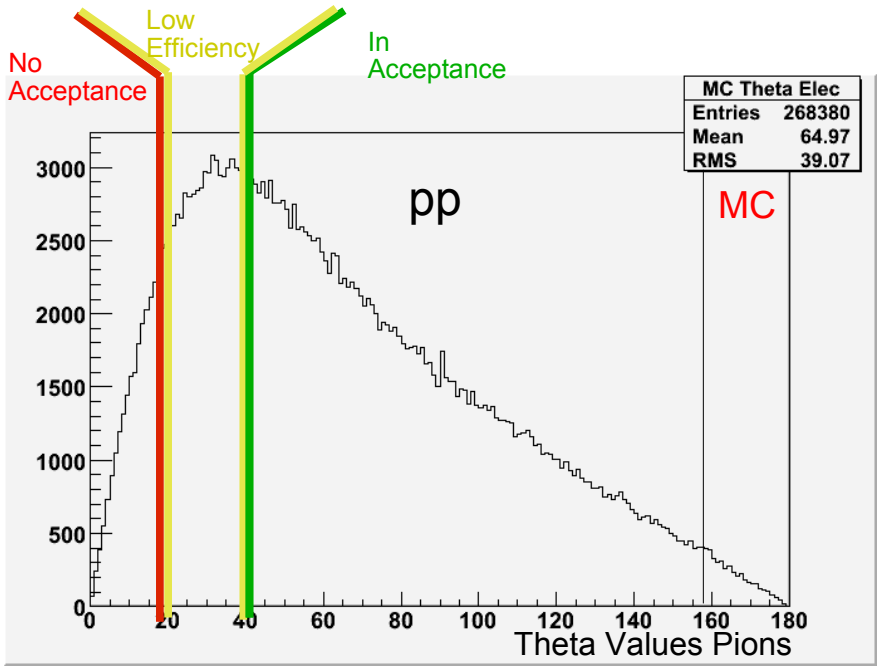
Different boost in pd and pp



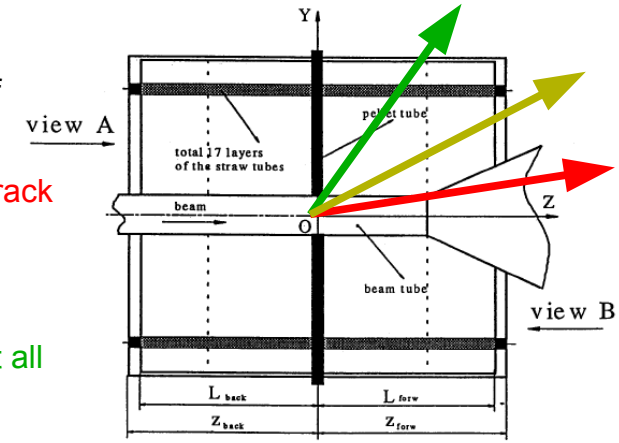


In our MDC

Side view of MDC

Low angle track out of acceptance

High angle track can hit all straws:



Result: Lower track finding efficiency and higher errors for particles hitting less straws.

How low?

- In pd 17% of events remain after asking for at least 4 charged tracks
- In pp only 8% remain