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Analysis of $\eta \to \pi^+\pi^-\gamma$

measured with the WASA facility at COSY

June 14, 2010 | Christoph Florian Redmer
for the WASA-at-COSY Collaboration

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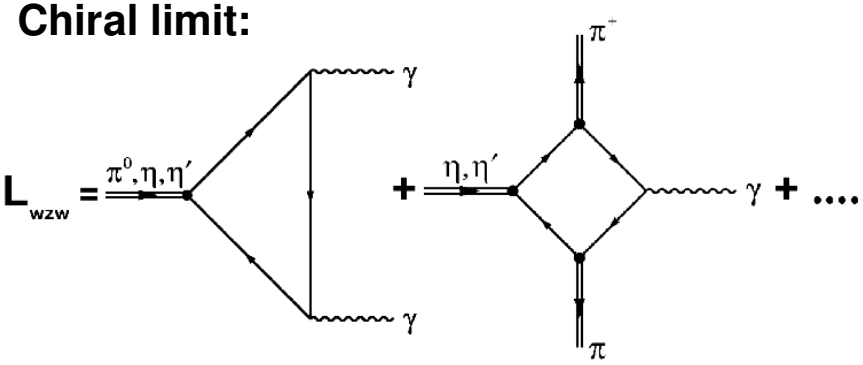
Motivation

Chiral limit:



Wess,Zumino, Phs.Lett. B 37 (1971) 95
Witten, Nucl Phys B 223 (1983) 422

Include FSI by unitarized extensions:

- momentum dependent VMD — Picciotto, Phys. Rev. D45 (1992) 1569
- one loop corrections — Bijnens, Nucl. Phys. B637 (1991) 709
- one loop + Omnes function — Holstein, Phys Scr T99 (2002) 55
- Chiral Unitary Approach — Borasoy,Nissler, Nucl Phys A 740(2004) 362
- Hidden Local Symmetries — Benayoun et al, EPJ C 31 (2003) 525

Previous Measurements:

7250 events	M. Gormley et al.	Phys.Rev. D2 (1970) 501
18150 events	J. G. Layter et al.	Phys.Rev. D7 (1973) 2565

- low in statistics
- largest samples not efficiency corrected → new measurement
- ambiguous theoretical interpretation of the samples

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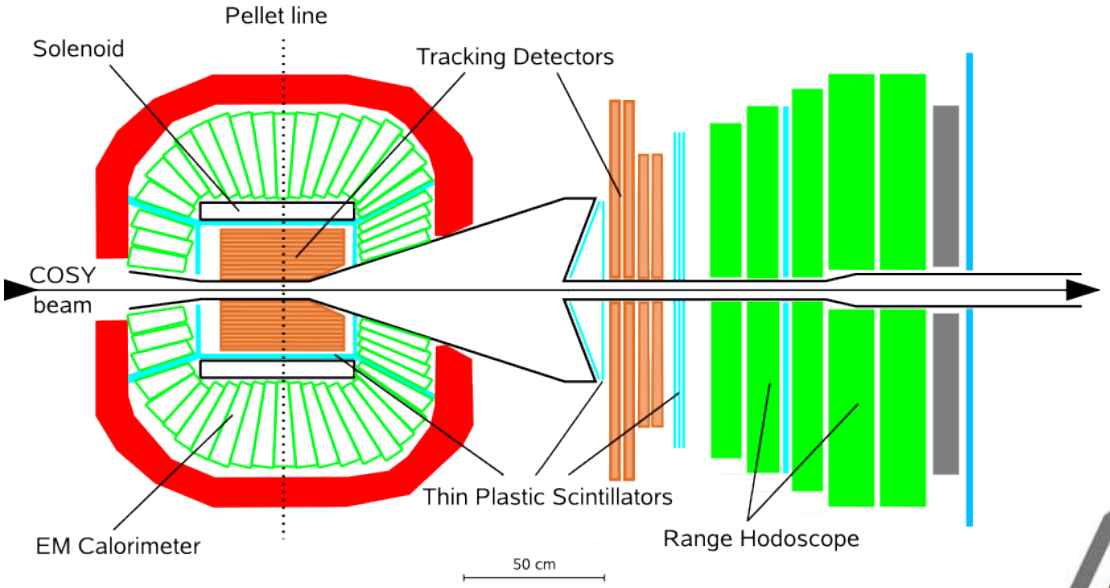
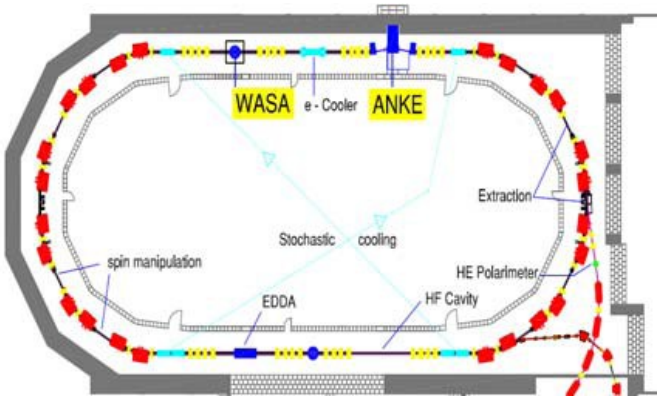
The WASA facility at COSY



- high density pellet target
- 4π - acceptance
- charged and neutral particle detection



- p, d beams up to 3.7 GeV/c
- high intensity
- phase space cooling

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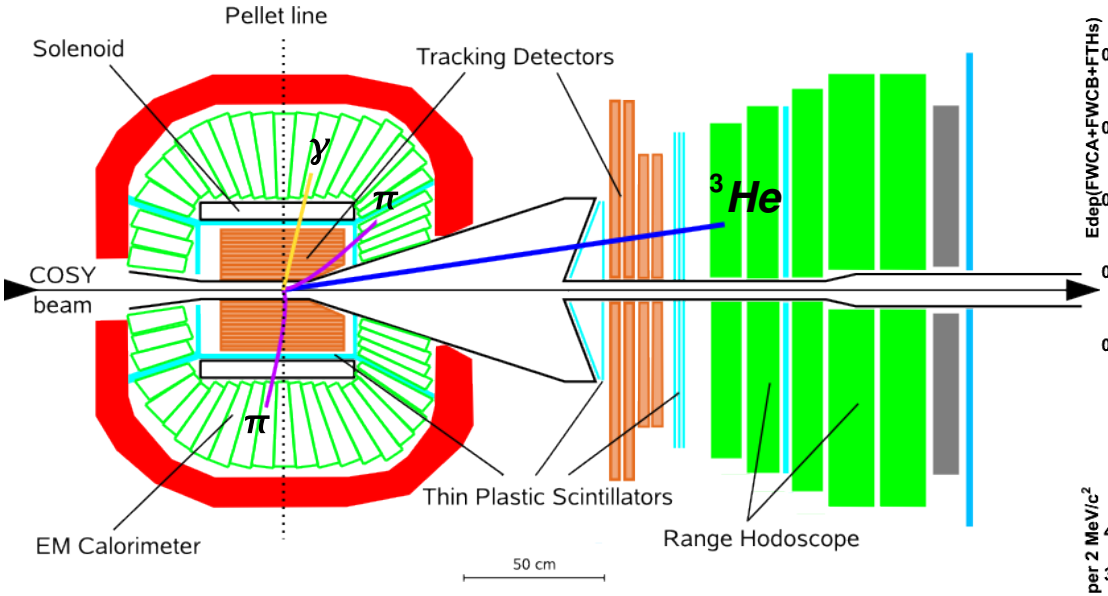
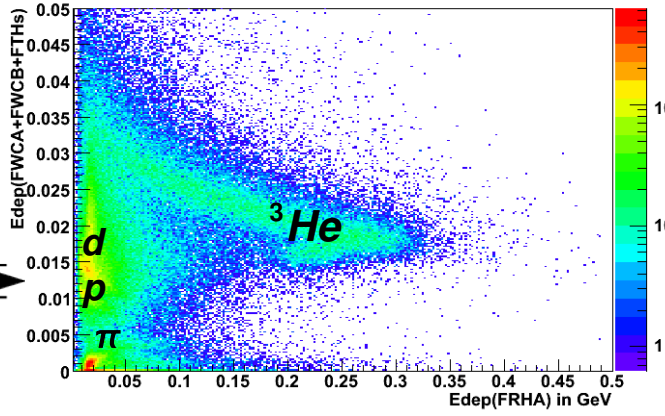
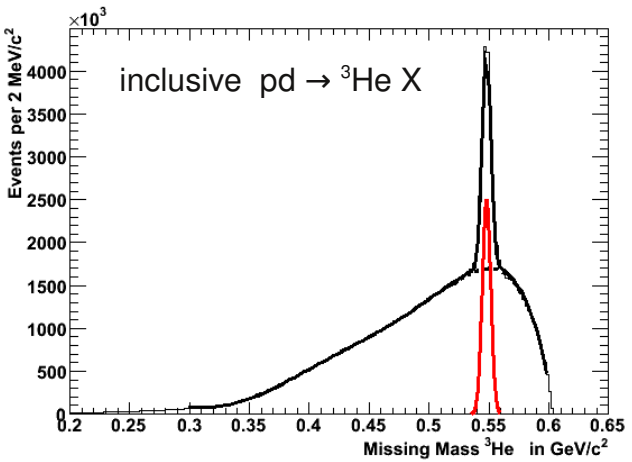
$\eta \to \pi^+\pi^-\gamma$ at WASA







- pd $\to$ ^{3}He η (October 2008)
- 10^7 tagged η mesons on disk
- exclusive measurement (Acceptance: 70%)

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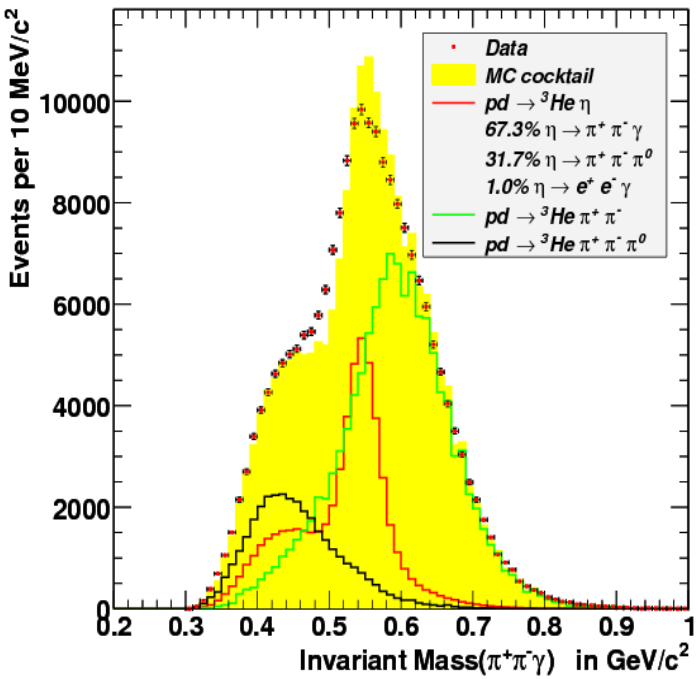
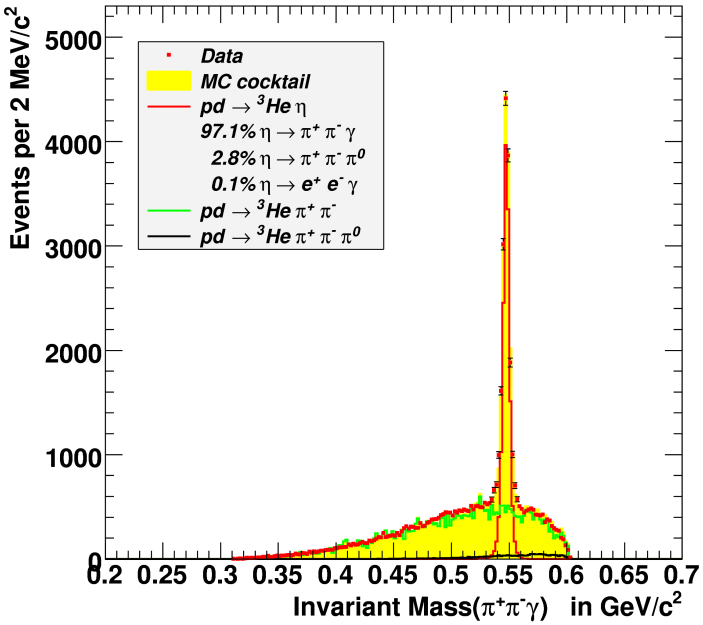
Event Selection

- π and γ candidates selected
- Missing Mass (^{3}Heγ) ≥ 2 m_π
- reduction of hadronic splitoffs
- cut on π^0 in Missing Mass (^{3}He$\pi^+\pi^-$)

dominated by pd → ^{3}He $\pi^+\pi^-$

- Kinematic Fit
  - *4C (energy and momentum)*
  - *cut on probability $P(\chi^2_{KF},N) > 0.1$*
  - *resolution improved by factor 10*





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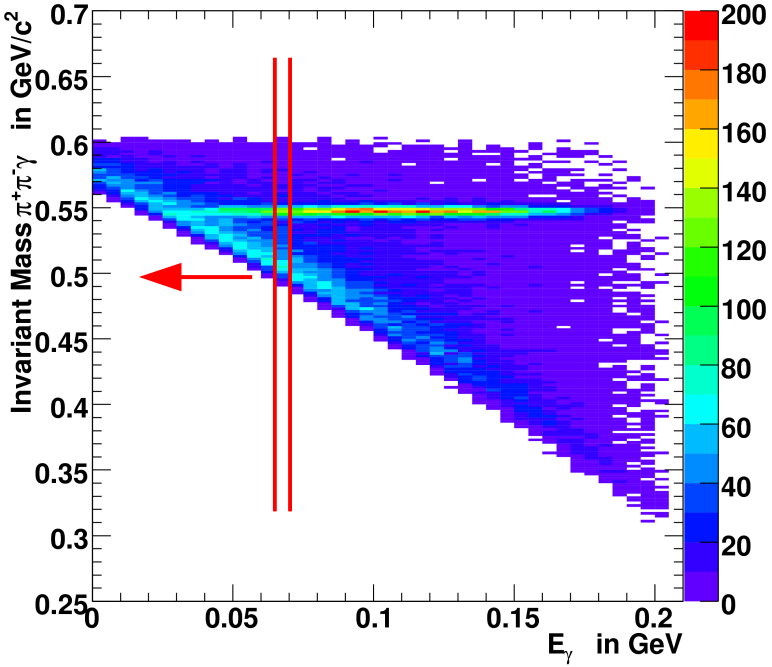
Background Subtraction

For each bin of a distribution:

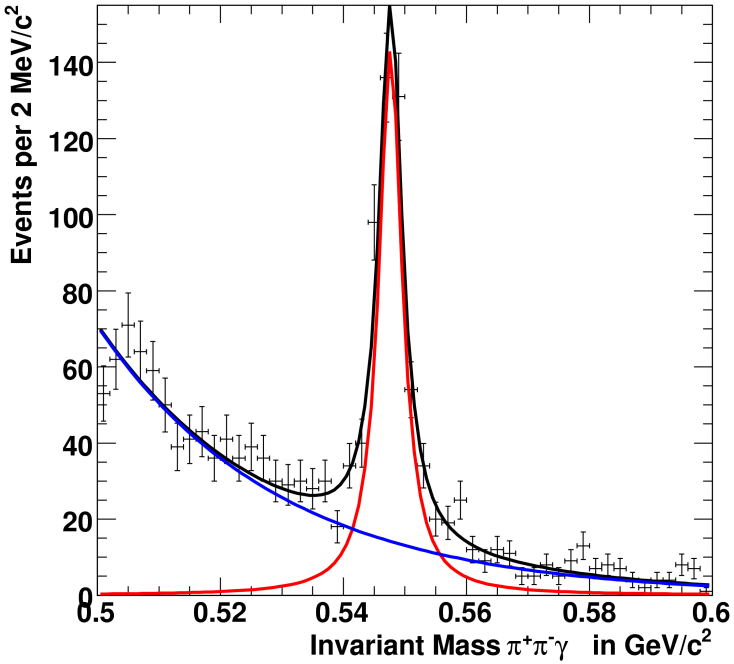
- calculate invariant mass of $\pi^+\pi^-\gamma$
- fit signal and background
- count signal events



Background from η decays is subtracted using Monte Carlo distributions

After background subtraction:

13738 ± 136 events



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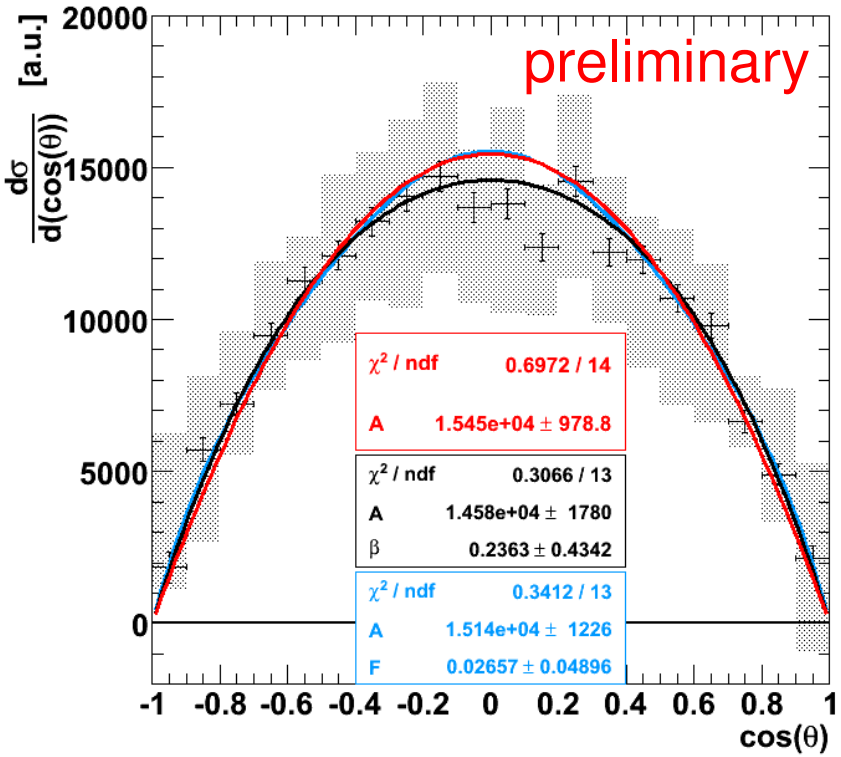
Dalitz Plot Distributions



-0.1 < cos(θ) < 0.4 excluded from fit

cos(θ): Angle between γ and π^+ in the pion-pion rest frame

p – wave:

$$\frac{d\sigma}{d(\cos\theta)} = A \cdot \sin^2\theta$$

p – wave + d – wave:

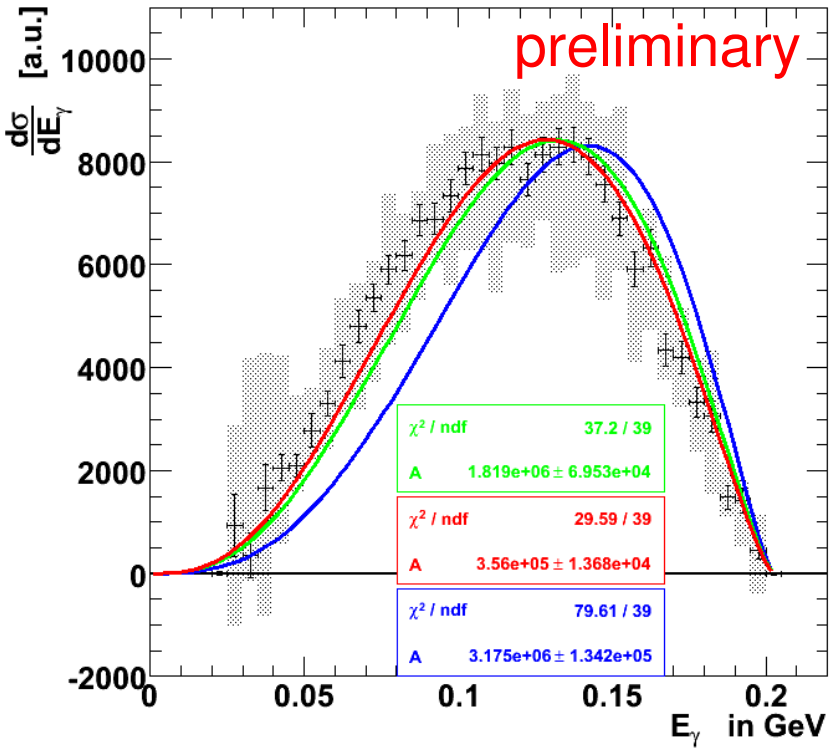
$$\frac{d\sigma}{d(\cos\theta)} = A \cdot \sin^2\theta \cdot \left(1 + \beta\cos^2\theta\right)$$

p – wave + f – wave:

$$\frac{d\sigma}{d(\cos\theta)} = A \cdot \sin^2\theta \cdot \left(1 + F\left(5\cos^2\theta - 1\right)^2\right)$$

- $\pi^+\pi^-$ system in relative *p* – wave
- contributions of higher partial waves negligible

Dalitz Plot Distributions



E_γ: Photon momentum in the η - rest frame

simplest matrix element:

$$\frac{d\sigma}{dE_\gamma} = A \cdot \left(\frac{E_\gamma}{m_\eta}\right)^3 \cdot \sqrt{1 - \frac{2E_\gamma}{m_\eta} - \frac{4m_\pi^2}{m_\eta^2}}^{\,3} \cdot \frac{1}{\sqrt{1 - \frac{2E_\gamma}{m_\eta}}}$$

VMD with box anomaly term:

$$|A_\eta(s_{\pi\pi})|^2 = |A_\eta(0,0,0) \cdot \left(-1 + \frac{3m_\rho^2}{m_\rho^2 - s_{\pi\pi} - i m_\rho \Gamma_\rho(s_{\pi\pi})}\right)|^2$$

without box anomaly term:

$$|A_\eta(s_{\pi\pi})|^2 = |A_\eta(0,0,0) \cdot \left(\frac{m_\rho^2}{m_\rho^2 - s_{\pi\pi} - i m_\rho \Gamma_\rho(s_{\pi\pi})}\right)|^2$$

- simplest matrix element does not describe data
- description of FSI important

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Summary

Published data of low statistics, significant sets not efficiency corrected

WASA-at-COSY has a clean, high statistics sample of $\eta \to \pi^+\pi^-\gamma$

Studies of Dalitz plot distributions show:

- pions in relative p-wave, no evidence for higher partial waves
- FSI important to describe photon energy spectrum
  - *test of effective theories*

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Outlook

- three times more statistics available (pd $\rightarrow$ ^{3}He η)
- an 8 week production run just finished (pp $\rightarrow$ pp η)
  - *the statistics of this work corresponds to 2 – 3 days of pp $\rightarrow$ pp η*
- ongoing improvements on systematic errors:
  - efficiency correction with VMD based distributions
  - alternative / additional means of multi pion suppression
  - charged particle reconstruction
- determination of the box anomaly contribution
- gain insight into anomalies of QCD with $\eta \rightarrow \pi^+\pi^-\gamma$

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Backup

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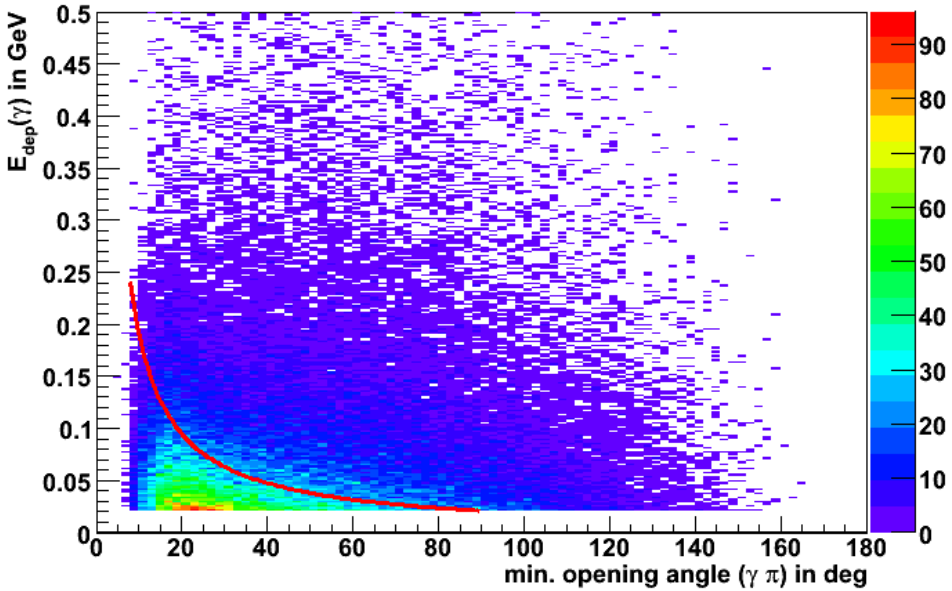
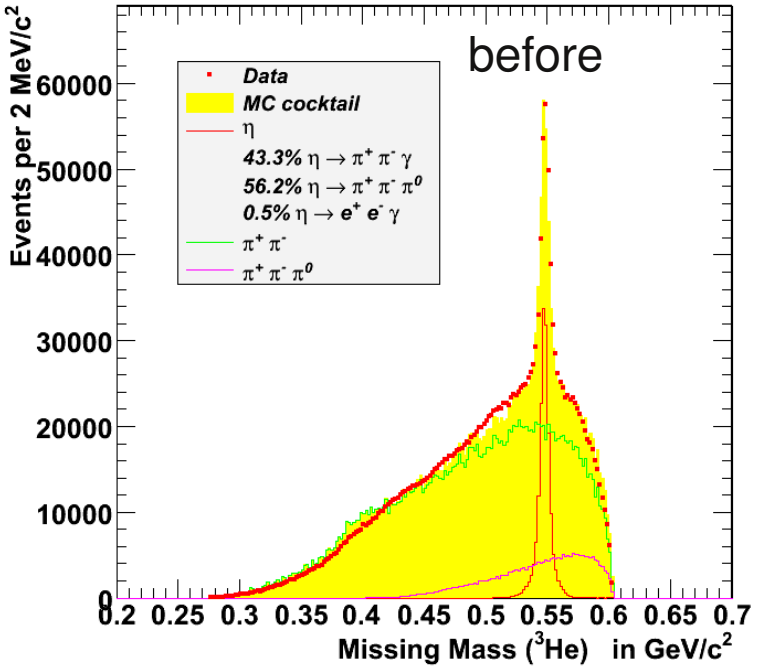
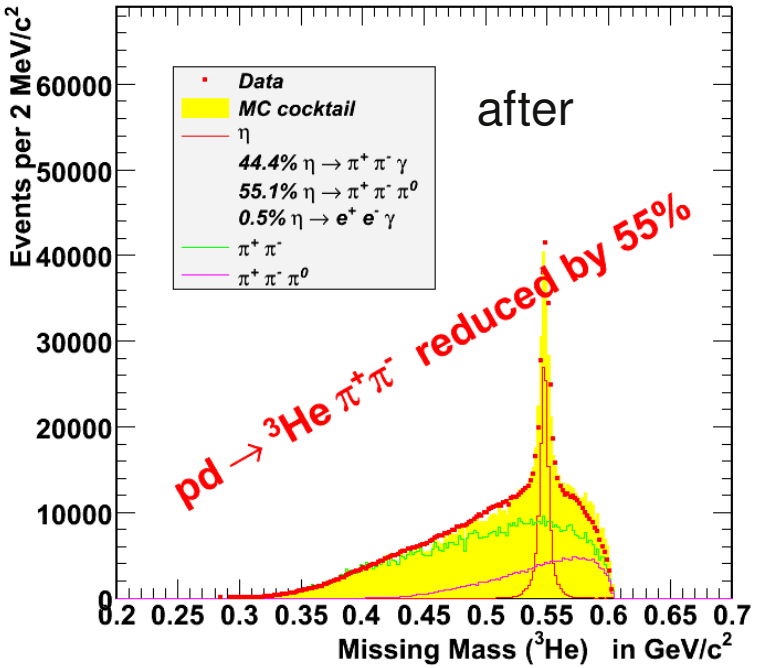
Splitoff Suppression







Characteristics:

- small distance to tracks
- small energy deposits

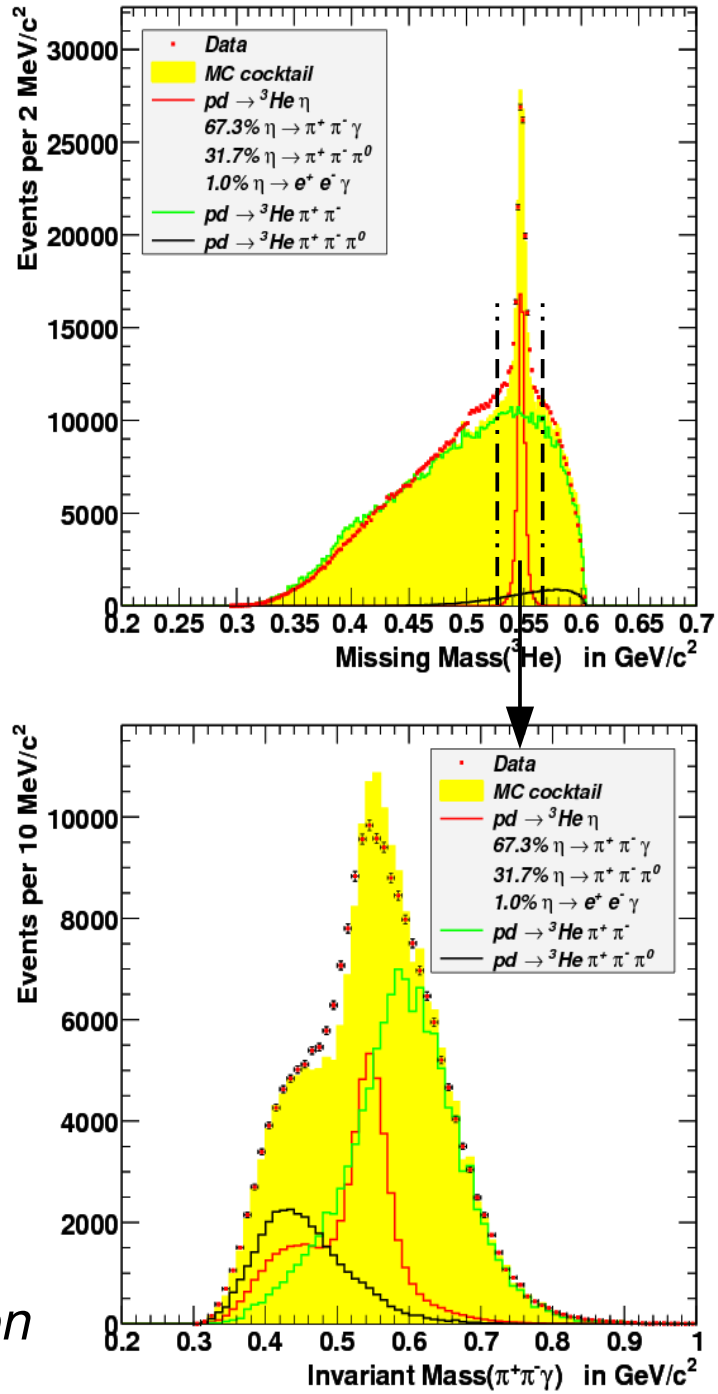
Event Selection

- π and γ candidates selected
- Missing Mass (^{3}Heγ) ≥ 2 m_π
- reduction of hadronic splitoffs
- cut on π^0 in Missing Mass (^{3}He$\pi^+\pi^-$)

dominated by pd → ^{3}He $\pi^+\pi^-$

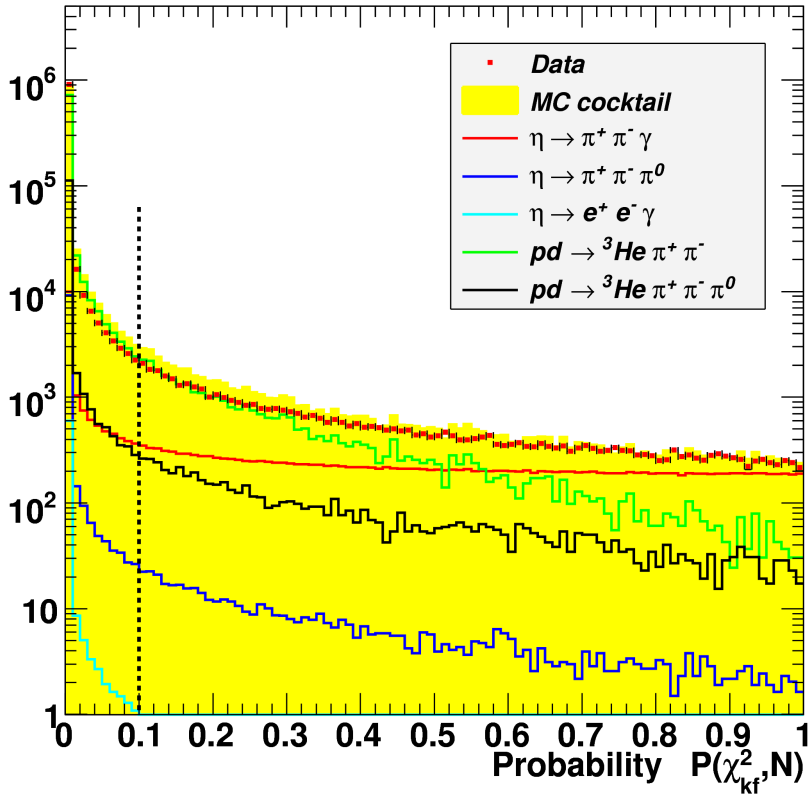
⟶ use Kinematic Fit

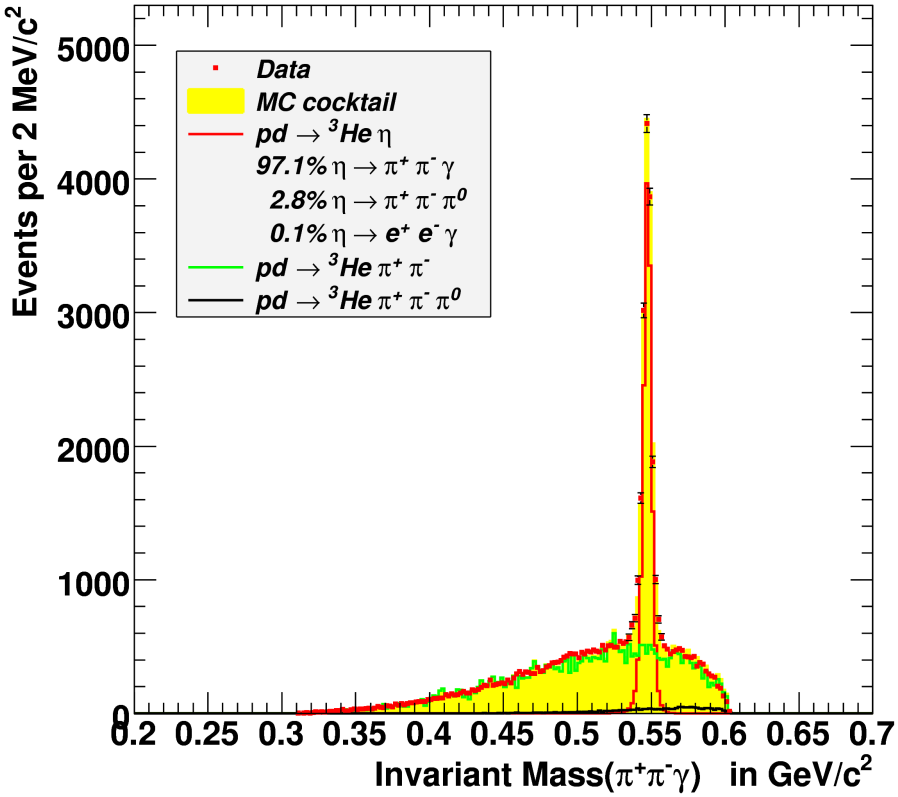
- *gain in resolution*
- *additional background suppression*



Kinematic Fit

- 4C – Fit (four-momentum conservation, no η mass constraint)
- Cut on Probability > 10%
- Invariant Mass resolution improved from 80 MeV to 9 MeV (FWHM)





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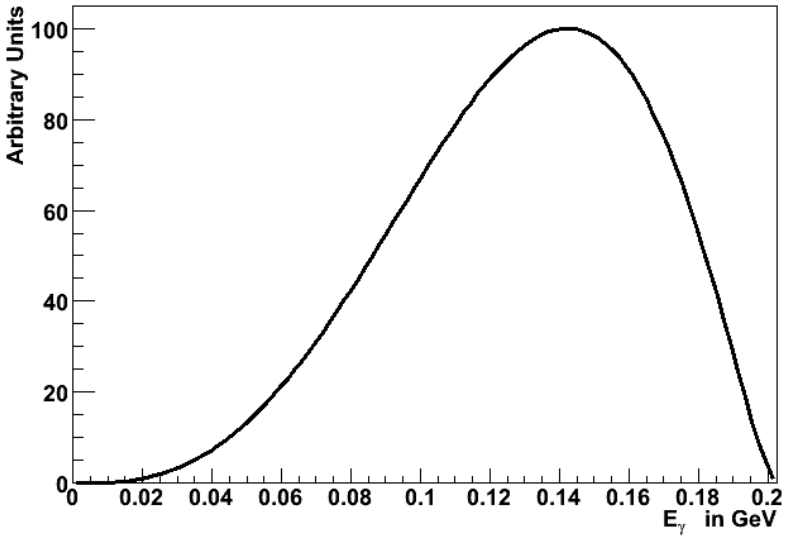
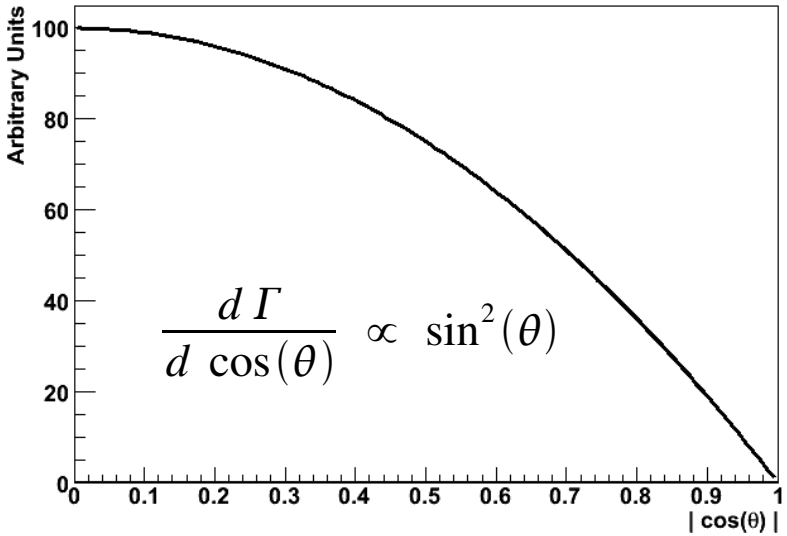
Parametrization of the Dalitz Plot

E_γ: Photon momentum in the η - rest frame



cos(θ): Angle between γ and π^+ in the pion-pion rest frame



Here:

simplest gauge invariant matrix element with p-wave interaction of the pions

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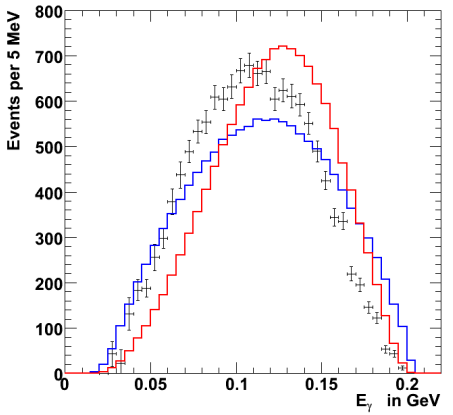
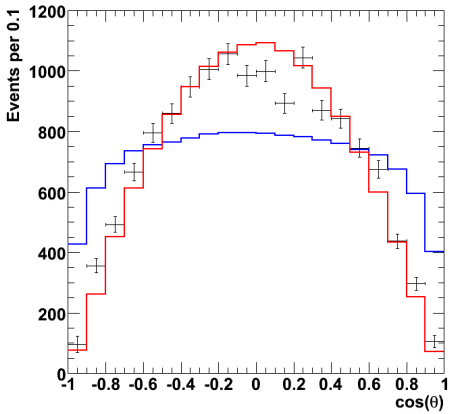
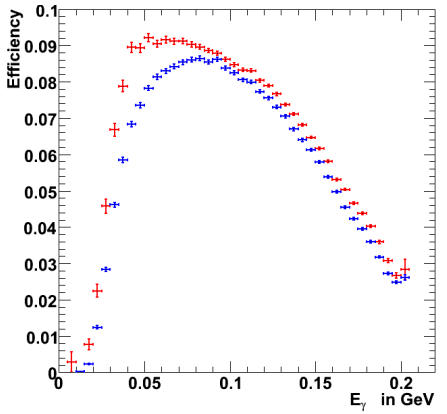
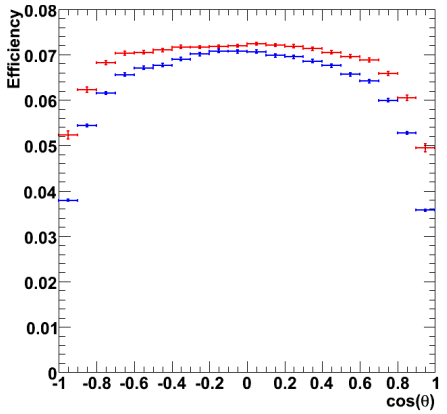
Efficiency

- average efficiency: 7%
- Monte Carlo distributions:
  - phase space
  - simplest matrix element









- corrections based on the simplest gauge invariant matrix element
  - *matches observed angular distribution of the pions*
- regions without acceptance due to cut on splitoffs

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Systematic Checks

- conditions on energy-momentum conservation prior to kinematic fit
- suppression of hadronic splitoffs
- probability distribution of the kinematic fit
- background subtraction
- efficiency correction
- accelerator mode
- luminosity

 conditions for background suppression most influential

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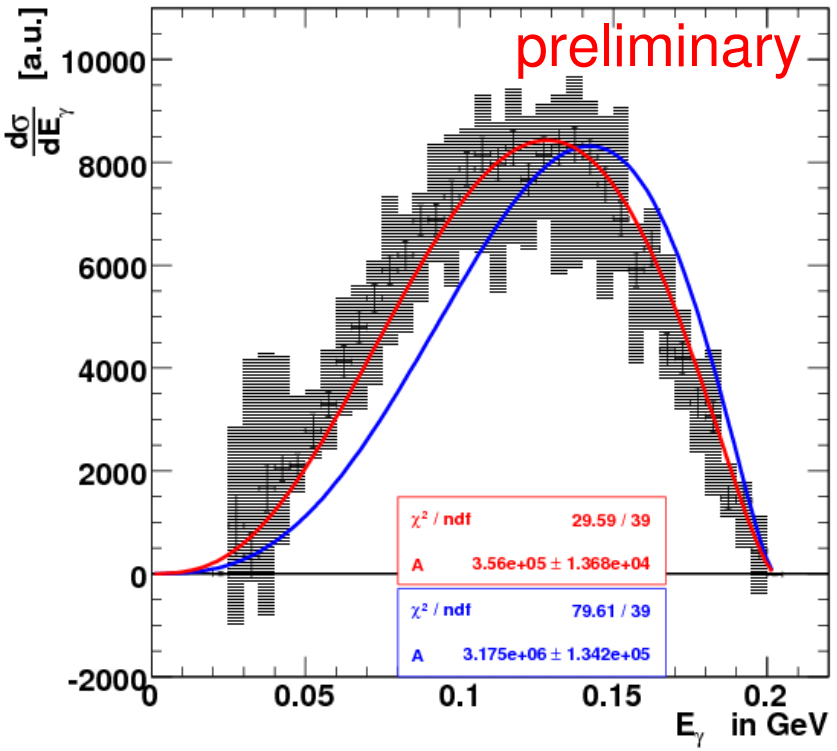
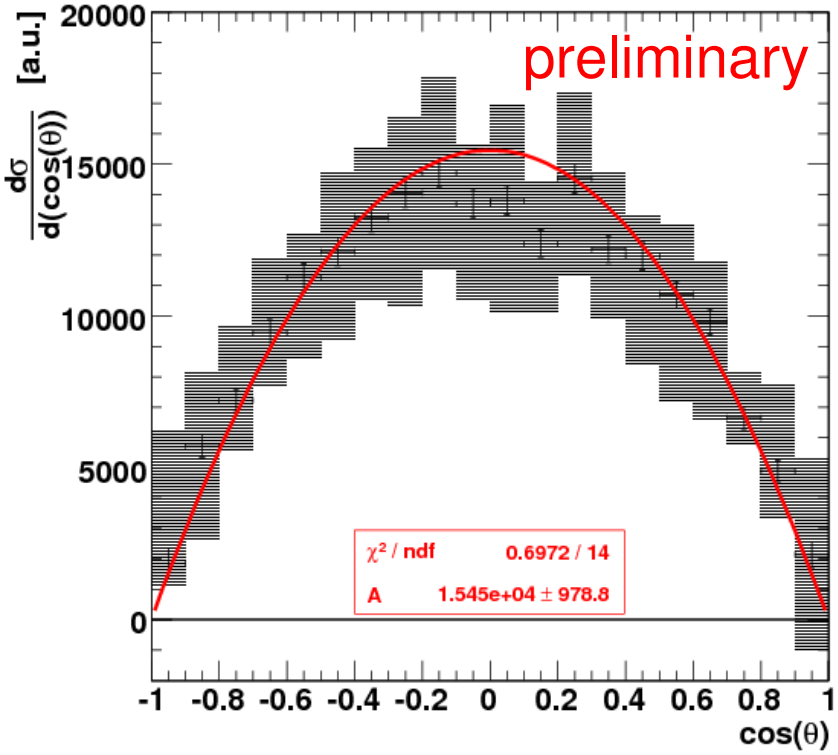
Dalitz Plot Distributions





- simplest matrix element does not describe data (blue)
- better agreement with VMD (red)

- p – wave interaction
- higher partial waves negligible