Studies of eta meson decays with WASA

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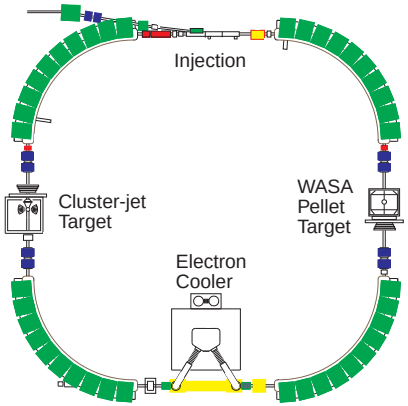
for the CELSIUS/WASA and the WASA-at-COSY Collaborations

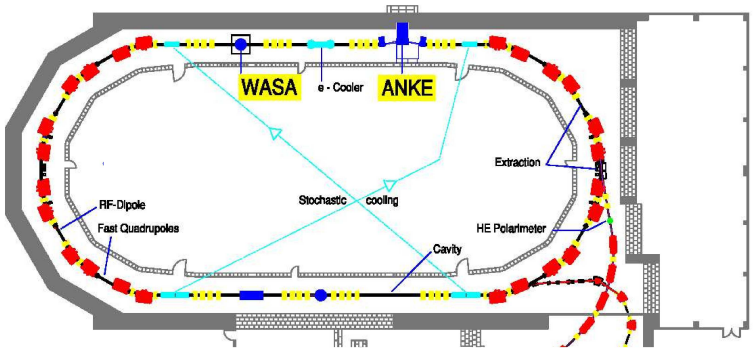
- Introduction
- Experiments with WASA
- Analysis of the 2008 data
- Outlook

WASA

Uppsala, CELSIUS 2002–2005



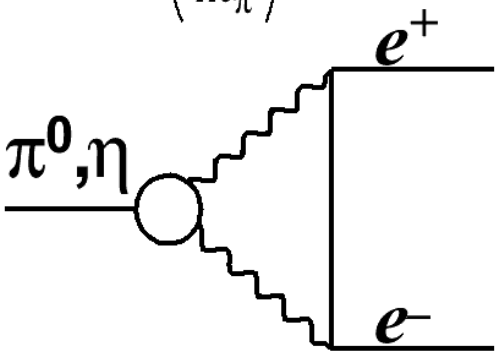
Jülich, COSY 2007–



- Designed to measure rare decays:

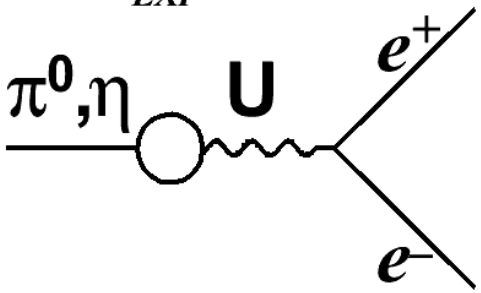
$\pi^0, \eta \to e^+e^-$, $\eta \to \pi^0 e^+e^-$

$BR \approx \alpha^2 \left(\frac{m_e}{m_\pi}\right)^2 \approx O(10^{-8})$



π^0: BR_{EXP}-BR_{SM}=3 σ

η: $BR_{EXP} < 2.7 \times 10^{-5}$ (WASA)



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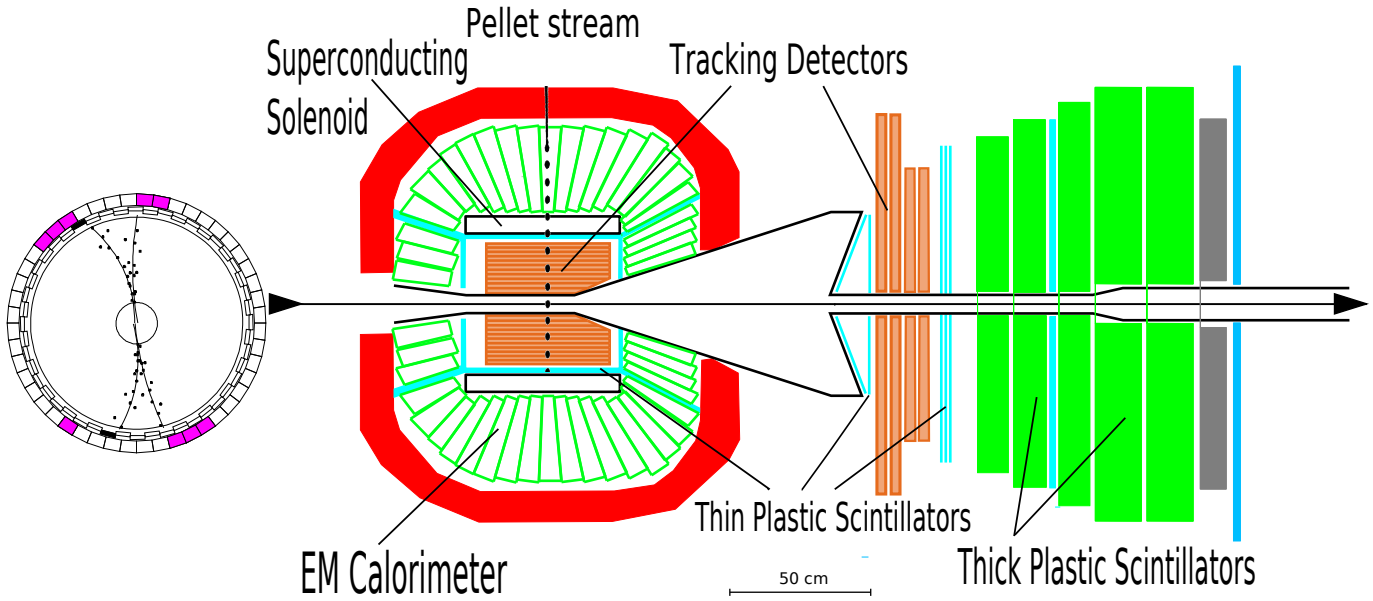
WASA detector



Main features

- Pellet: high luminosity, 4π acceptance
- Forward Part: charged particles $\Delta E - E$
- Central Part: charged particles and photons (optimized for electrons and photons)
- Minimize γ conversion

NIM,A594,339 (2008)

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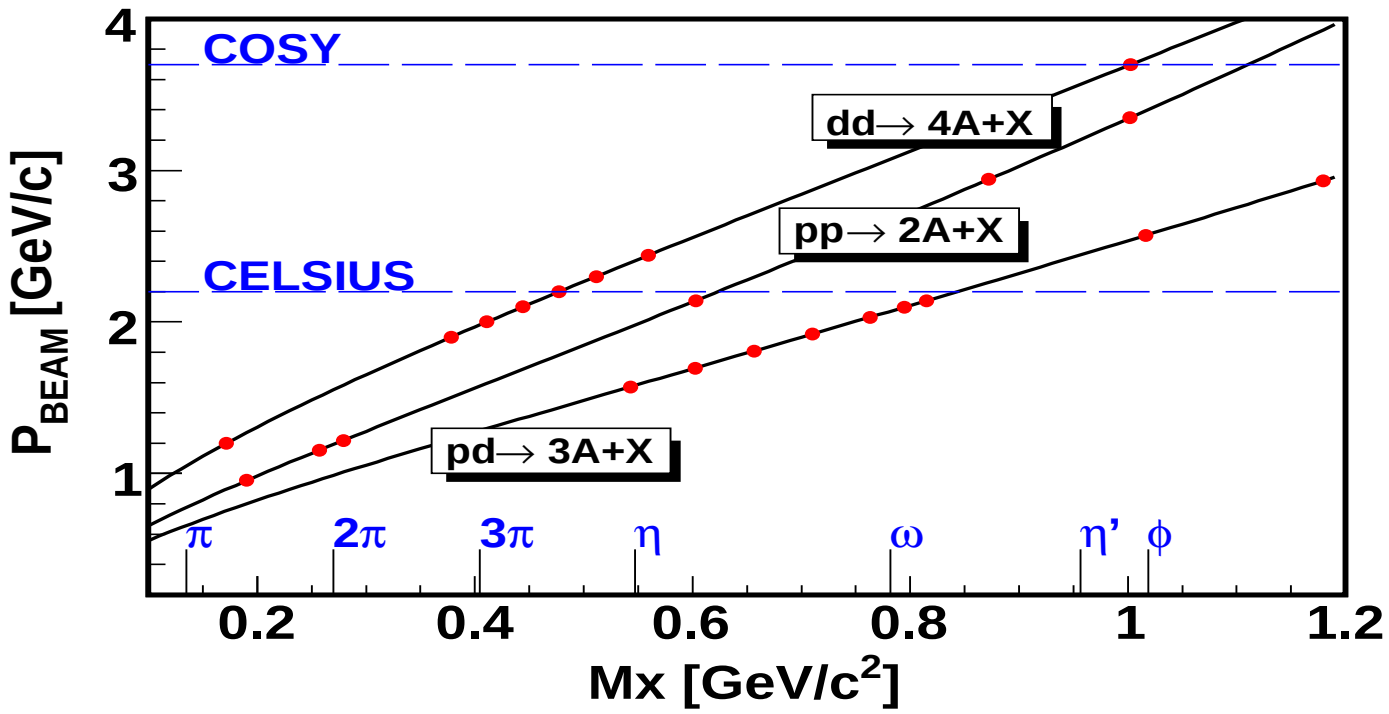
Experiments



From CELSIUS to COSY

- Higher energies
- Polarized beams

Key topics

- Tests of symmetries
- Crypto-exotic hadrons

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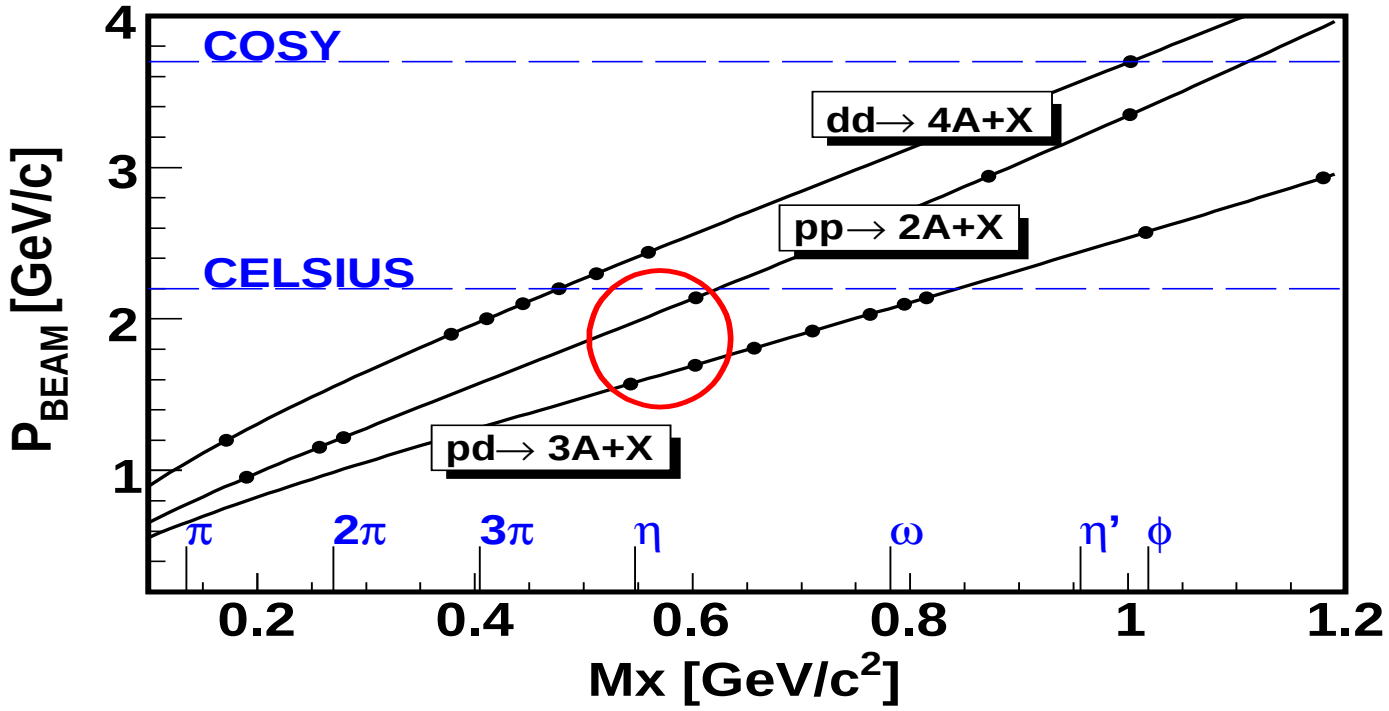
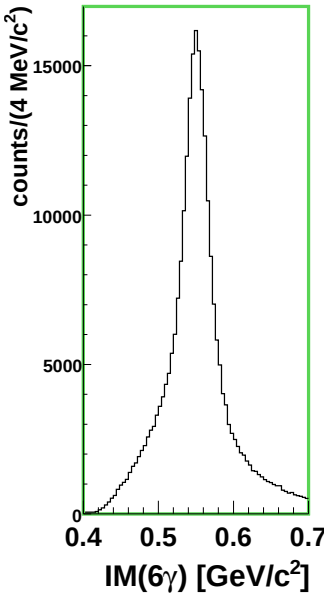
Studies of η Decays

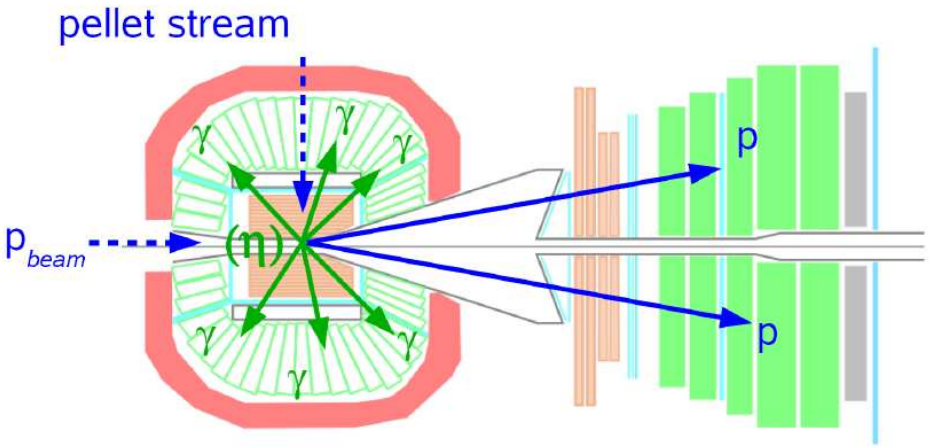


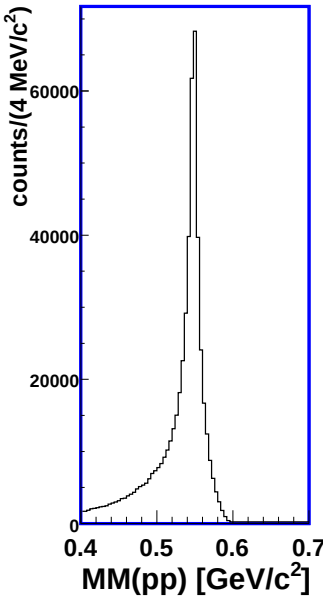
Reactions:

- CELSIUS and COSY: $pp \rightarrow pp\eta$ $Q = 40$ MeV
- CELSIUS: $pd \rightarrow {}^3\mathrm{He}\eta$ $Q = 2$ MeV
- COSY: $pd \rightarrow {}^3\mathrm{He}\eta$ $Q = 40$ MeV

η Decays: Reaction $pp \rightarrow pp\eta$







- Cross section σ=10μb at 1.4 GeV
- Requires trigger selecting specific decay channel
- Status:10^{31}cm^{-2}s^{-1}(2 events/s of $\eta \rightarrow 3\pi^0$)

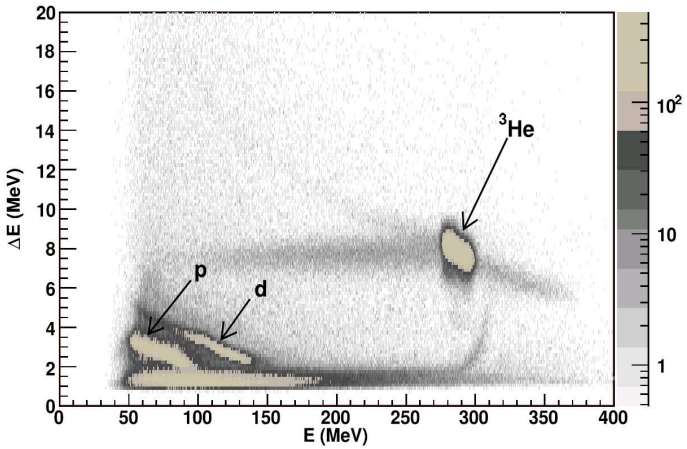
- To be used for rare decays (goal: 10^{32}cm^{-2}s^{-1})

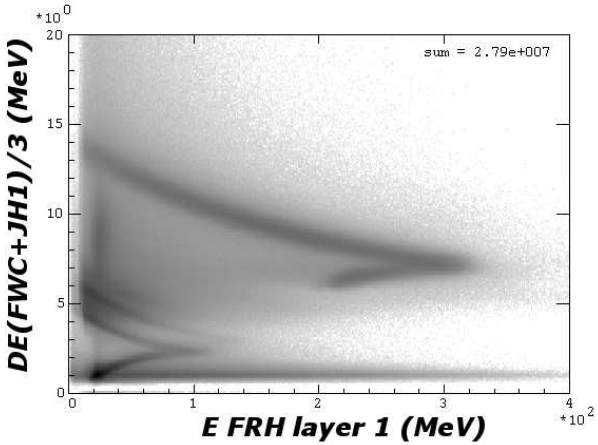
η Decays: Reaction $pd \rightarrow {}^3\mathrm{He}\eta$

+ Simple selective trigger, no bias on decay system
+ Low physics background
− Low cross section (0.4 μb)

CELSIUS
runs in 2004
Q =2 MeV
spectrometer
2.7×10^5 η decays
$\Delta E - E$ germanium det.

COSY
October 2008 run
Q =40 MeV
Forward detector
10^7 η decays
$\Delta E - E$





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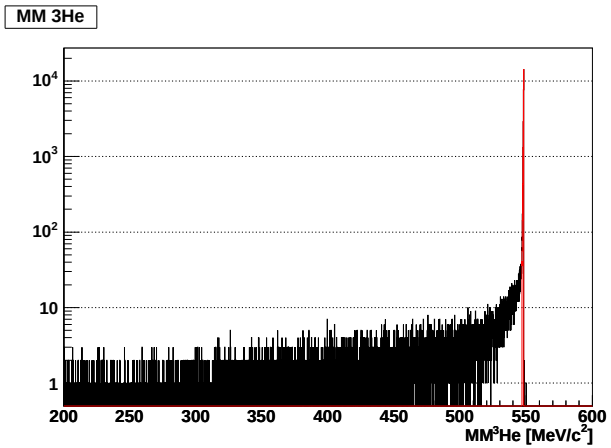

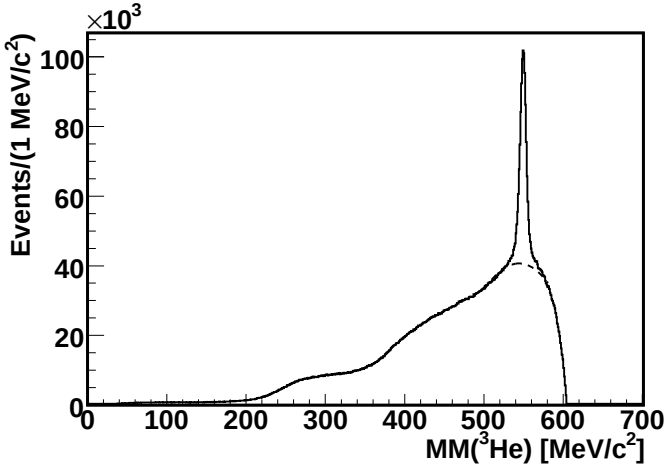

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Analysis of 2008 $pd \rightarrow {}^3\mathrm{He}\eta$ Data

$\Rightarrow$ $\eta \rightarrow \pi^+\pi^-\pi^0$	P. Adlarsson
• $\eta \rightarrow \pi^0\pi^0\pi^0$	P. Vlasov
$\Rightarrow$ $\eta \rightarrow \pi^+\pi^-\gamma$	Ch. F. Redmer
$\Rightarrow$ $\eta \rightarrow \gamma e^+e^-$	M. Berlowski, M. Hodana
$\Rightarrow$ $\eta \rightarrow \pi^+\pi^-e^+e^-$	M. Janusz, D. Coderre
• $\eta \rightarrow e^+e^-e^+e^-$	L. Yurev
• $\eta \rightarrow \pi^0\gamma\gamma$	L. Chandwani
$\Rightarrow$ $\eta \rightarrow \pi^0e^+e^-$	A. Winnemöller

PRELIMINARY analysis:

- Not all data
- Analysis not fine tuned
- Not all background in MC
- ...

$\eta \to 3\pi$ in ChPT

$$\Gamma_{exp} = \left(\frac{Q_D}{Q}\right)^4 \Gamma_{th}$$

$$Q^{-2} \approx \frac{m_d^2 - m_u^2}{m_s^2}$$

$\Rightarrow$ constraints for m_s/m_d, m_u/m_d

Leutwyler 1996

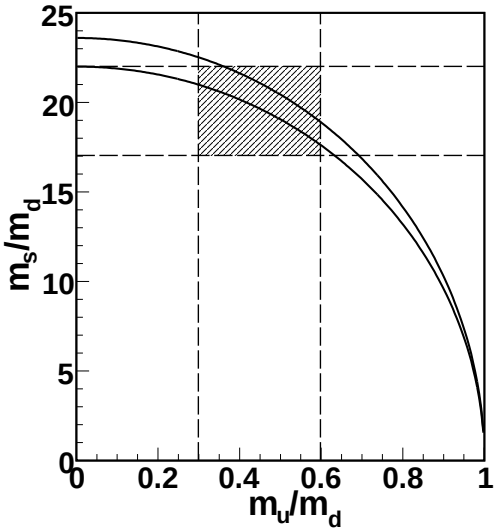
- $Q_D = 24.1$

  $(m_{\pi^+}^2 - m_{\pi^0}^2) = (m_{K^+}^2 - m_{K^0}^2)_{EM}$

$\Rightarrow$ $\frac{d\Gamma}{dxdy}_{exp}$ vs $\frac{\Gamma}{dxdy}_{th}$

$x = (T_+ - T_-)/\sqrt{3}\langle T \rangle$

$y = T_0/\langle T \rangle - 1$



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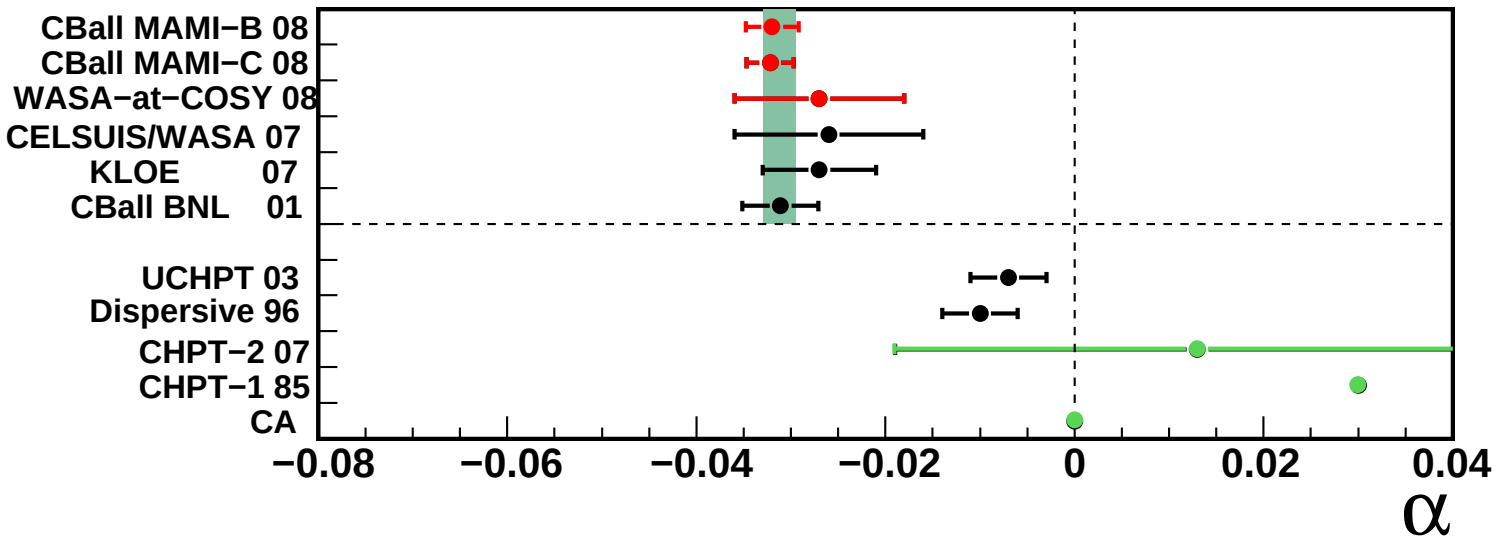
Status of $\eta \to 3\pi^0$ Dalitz plot



Dalitz plot for $\eta \to \pi^0\pi^0\pi^0$

- $|\mathcal{A}_{000}(z,\phi)|^2 \propto 1 + 2\,\alpha\,(x^2+y^2) + ...$
- Experiments: weighted average $\alpha = -0.0312 \pm 0.0017$
- ChPT LO: $\alpha = 0$, NLO, NNLO $\alpha > 0$

- Next generation of experiments: search for the cusp ...

$\Rightarrow$ Lage statistics, good $\Delta M_{\pi\pi}$

CELSIUS: 75k events, PRC76,048201(07)

COSY: 120k events PLB667,24(09)

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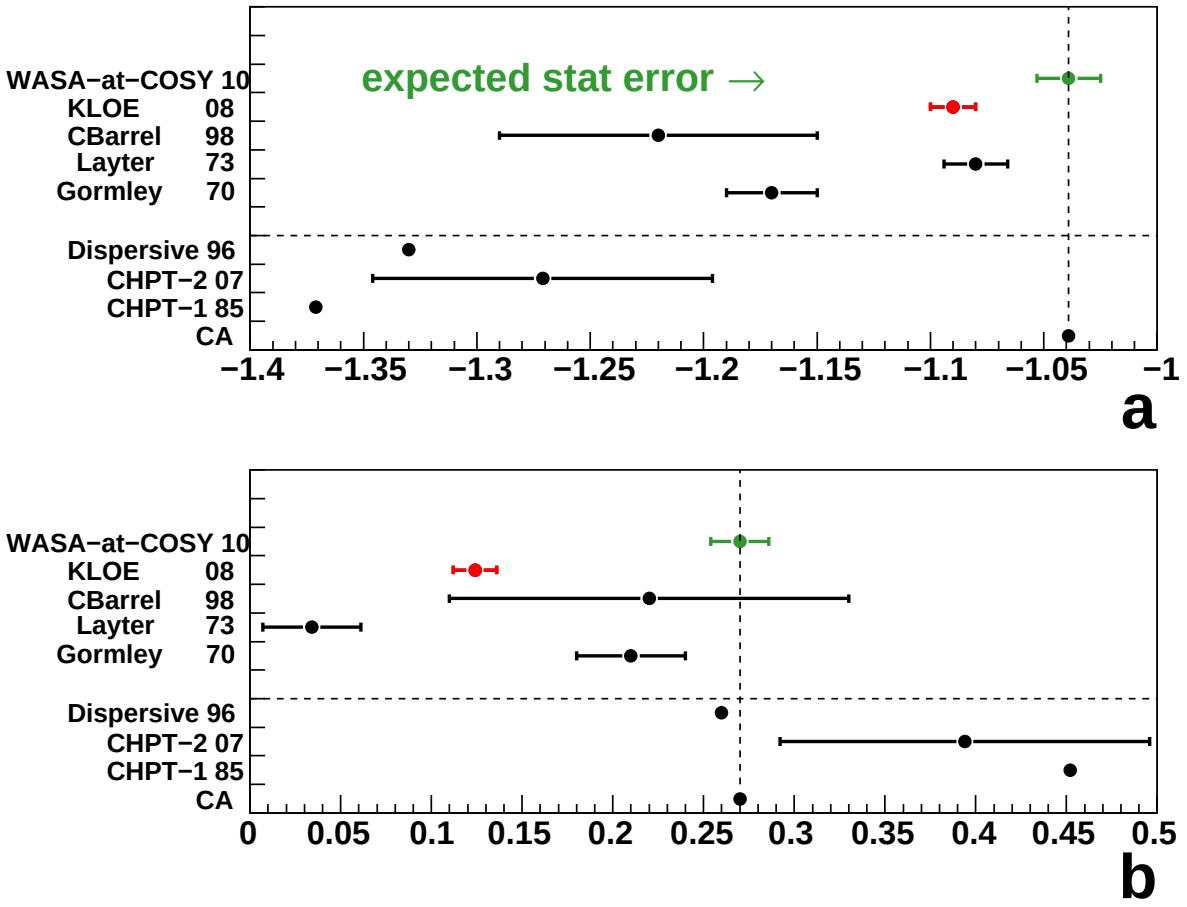
Status of $\eta \longrightarrow \pi^+\pi^-\pi^0$ Dalitz plot



Dalitz plot $\eta \longrightarrow \pi^+\pi^-\pi^0$

KLOE 1.3×10^6 JHEP 0805:006(08)

- $|\mathcal{A}_{+-0}(x,y)|^2 \propto 1 + ay + by^2 + dx^2 + fy^3 + ...$
- a, b, f do not agree with NNLO ChPT

Bijnens, Ghobani JHEP11:030(07)

$\eta \to \pi^0\pi^0\pi^0$ vs $\eta \to \pi^+\pi^-\pi^0$

$$r = \frac{\Gamma(\eta \to \pi^0\pi^0\pi^0)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)}$$

- PDG: $r_{exp} = 1.44 \pm 0.04$

- Exp. Dalitz plot densities + $\Delta I = 1$ rule $\Rightarrow r = 1.54$

  $s_1 = s_2 = s_3 \equiv \bar{s} \;\Rightarrow y = +0.052$

  $$\mathcal{A}_{000}(\bar{s},\bar{s},\bar{s}) = -3\mathcal{A}_{+-0}(\bar{s},\bar{s},\bar{s})$$

- Experimental inconsitency?
- ChPT LO: $r = 1.53$; NNLO $r = 1.46$ (with $\Delta I = 1$)

$\Rightarrow$ new r measurement in $pd \to {}^3\mathrm{He}\eta$

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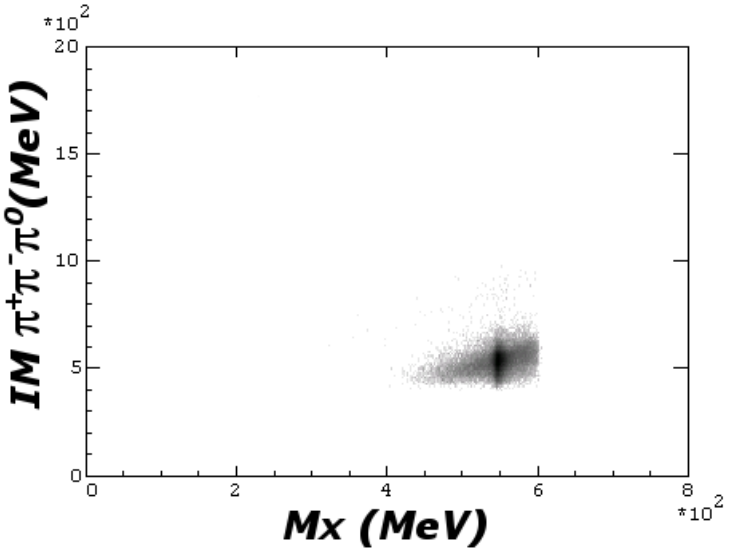
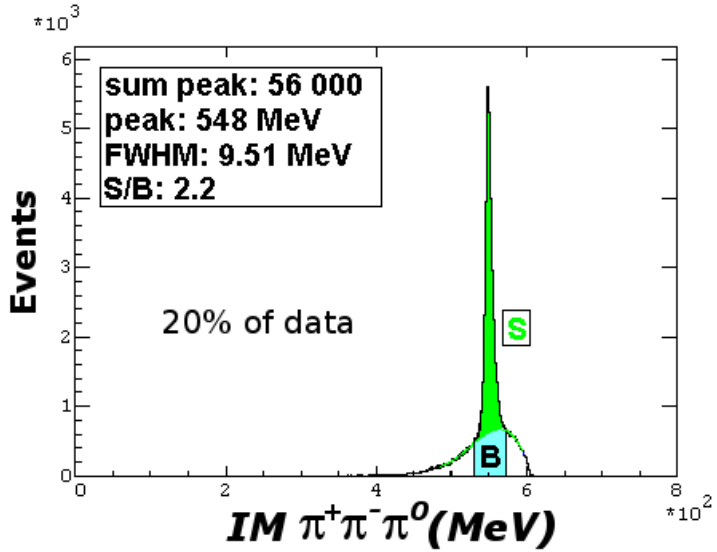
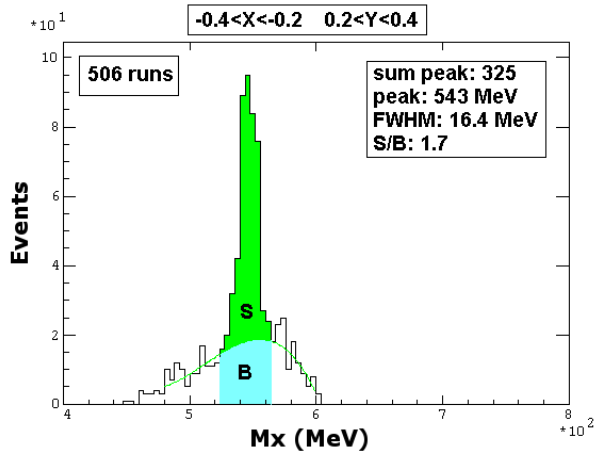
$\eta \to \pi^+\pi^-\pi^0$ in $pd \to {}^3\mathrm{He}\eta$







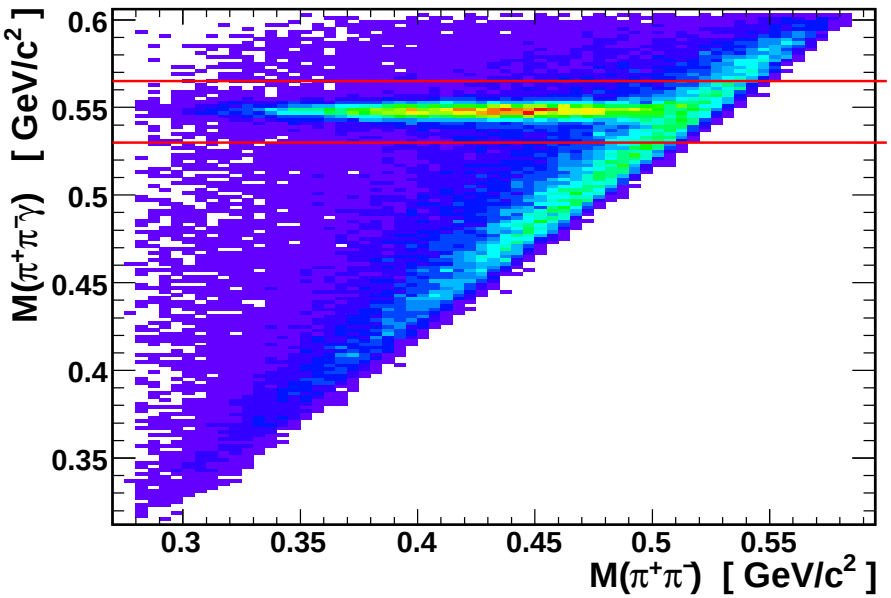
Expect 2–4$\times 10^5$ $\eta \to \pi^+\pi^-\pi^0$ in the Dalitz plot

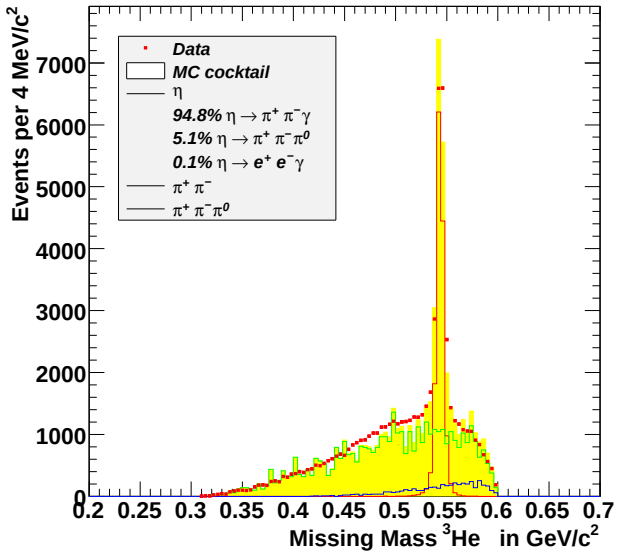
PRELIMINARY

Analysis P. Adlarsson

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

- Goal: measure E_γ ($M_{\pi^+\pi^-}$) distribution
- Background: $\eta \rightarrow \pi^+\pi^-\pi^0$, $pd \rightarrow {}^3\mathrm{He}\pi^+\pi^-$, $pd \rightarrow {}^3\mathrm{He}\pi^+\pi^-\pi^0$
- Kinematical fit $pd \rightarrow {}^3\mathrm{He}\pi^+\pi^-\gamma$

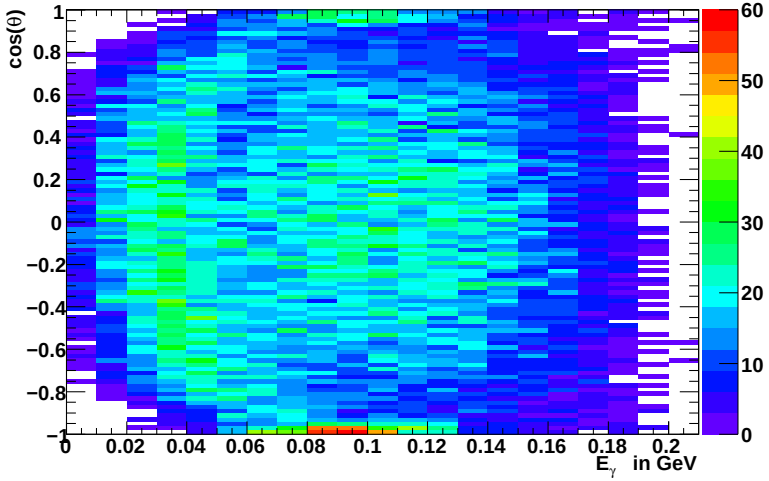


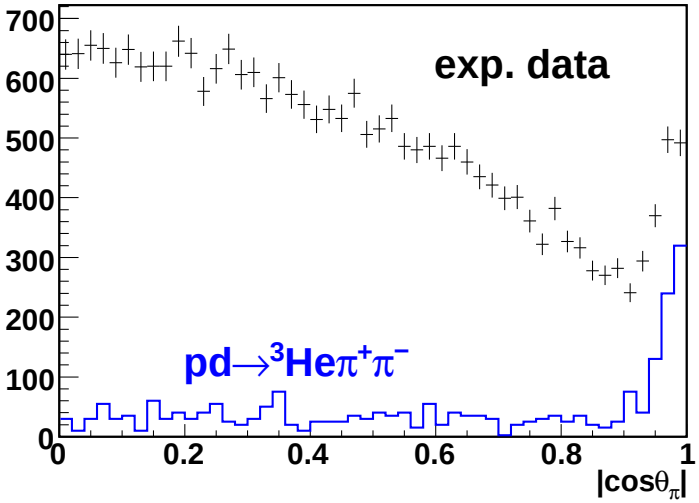


PRELIMINARY (50% data)

Analysis Ch. F. Redmer

- Second variable θ_π (π^+ angle in Di-pion CMS)
- $|\mathcal{A}(M^2_{\pi^+\pi^-}, \theta_\pi)|^2 \propto \sin^2\theta_\pi$
- Flat distribution for $\eta \to \pi^+\pi^-\pi^0$





PRELIMINARY (50% data)

Analysis Ch. F. Redmer

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Leptonic Decays

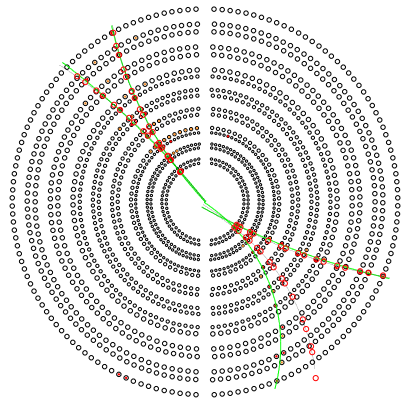
CELSIUS 2.7×10^5 events:

Decay mode	BR PDG	BR theor.	CELSIUS/WASA
$\eta \to e^+e^-\gamma$	$(6.0 \pm 0.8)10^{-3}$	$6.4 \cdot 10^{-3}$	$(7.8\pm0.5\pm0.8)\times10^{-3}$
$\eta \to e^+e^-e^+e^-$	$< 6.9 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$	$<9.7\times10^{-5}$
$\eta \to e^+e^-\mu^+\mu^-$	–	$2 \cdot 10^{-7}$	$<1.6\times10^{-4}$
$\eta \to \mu^+\mu^-\mu^+\mu^-$	–	$2.4 \cdot 10^{-9}$	$<3.6\times10^{-4}$
$\eta \to e^+e^-$	$< 7.7 \cdot 10^{-5}$	$\geq 1.7 \cdot 10^{-9}$	$<2.7\times10^{-5}$
$\eta \to \pi^+\pi^-e^+e^-$	$(4.0^{+5.3}_{2.5})10^{-4}$ *	$3.3 \cdot 10^{-4}$	$(4.2^{+2.0}_{-1.6} \pm 0.4)10^{-4}$
$\eta \to \pi^+\pi^-\mu^+\mu^-$	–	$7.5 \cdot 10^{-9}$	$<3.6\times10^{-4}$

CELSIUS/WASA PLB644:299,2007; PRD77:032004,2008

WASA-at-COSY 11×10^6 events:

- $\eta \to e^+e^-\gamma$ 5000 ev
- $\eta \to e^+e^-\pi^+\pi^-$ 300 ev, Acc 5%, S/B=1
- $\eta \to e^+e^-e^+e^-$ 30 ev, Acc 5%, S/B=1



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

Analysis L. Yurev

* KLOE 09: $(26.8 \pm 0.9 \pm 0.7)\times10^{-5}$ based on 1500 events

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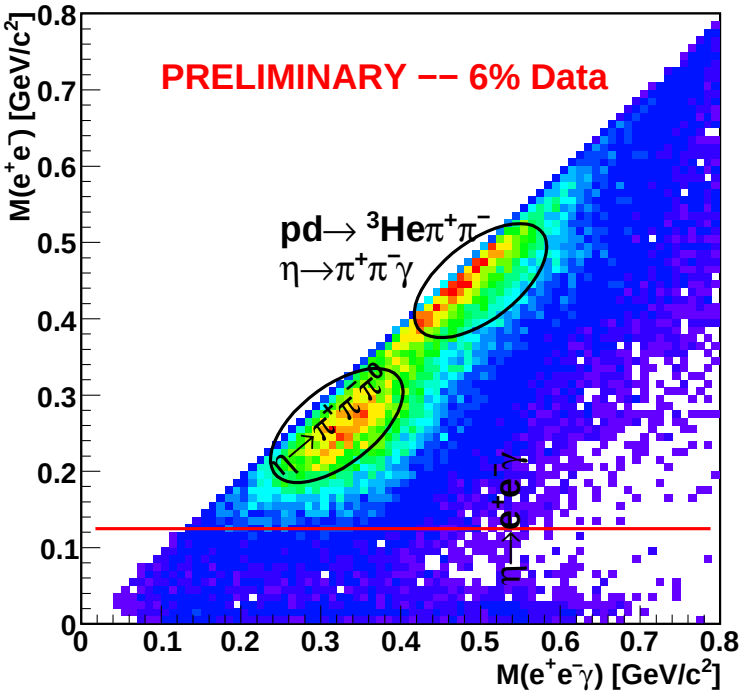
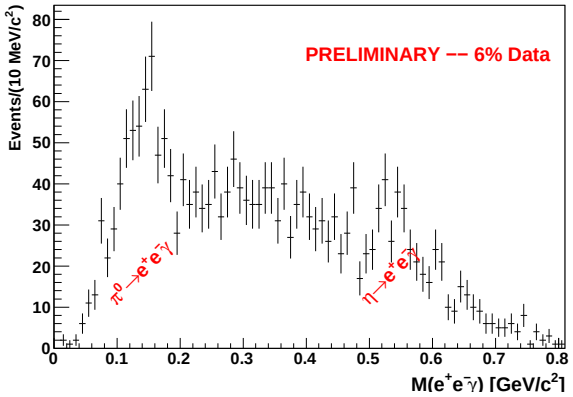
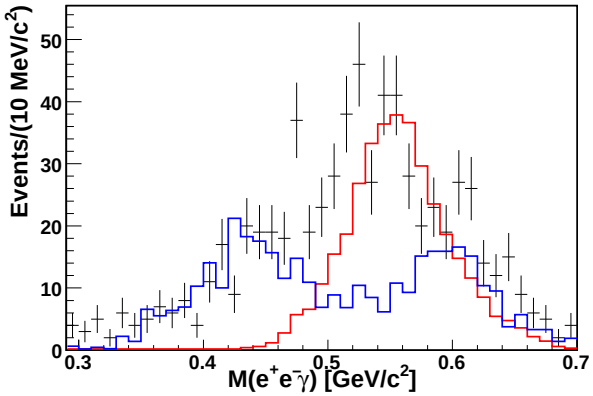
$\eta \rightarrow e^+e^-\gamma$







PRELIMINARY

Analysis M. Berłowski

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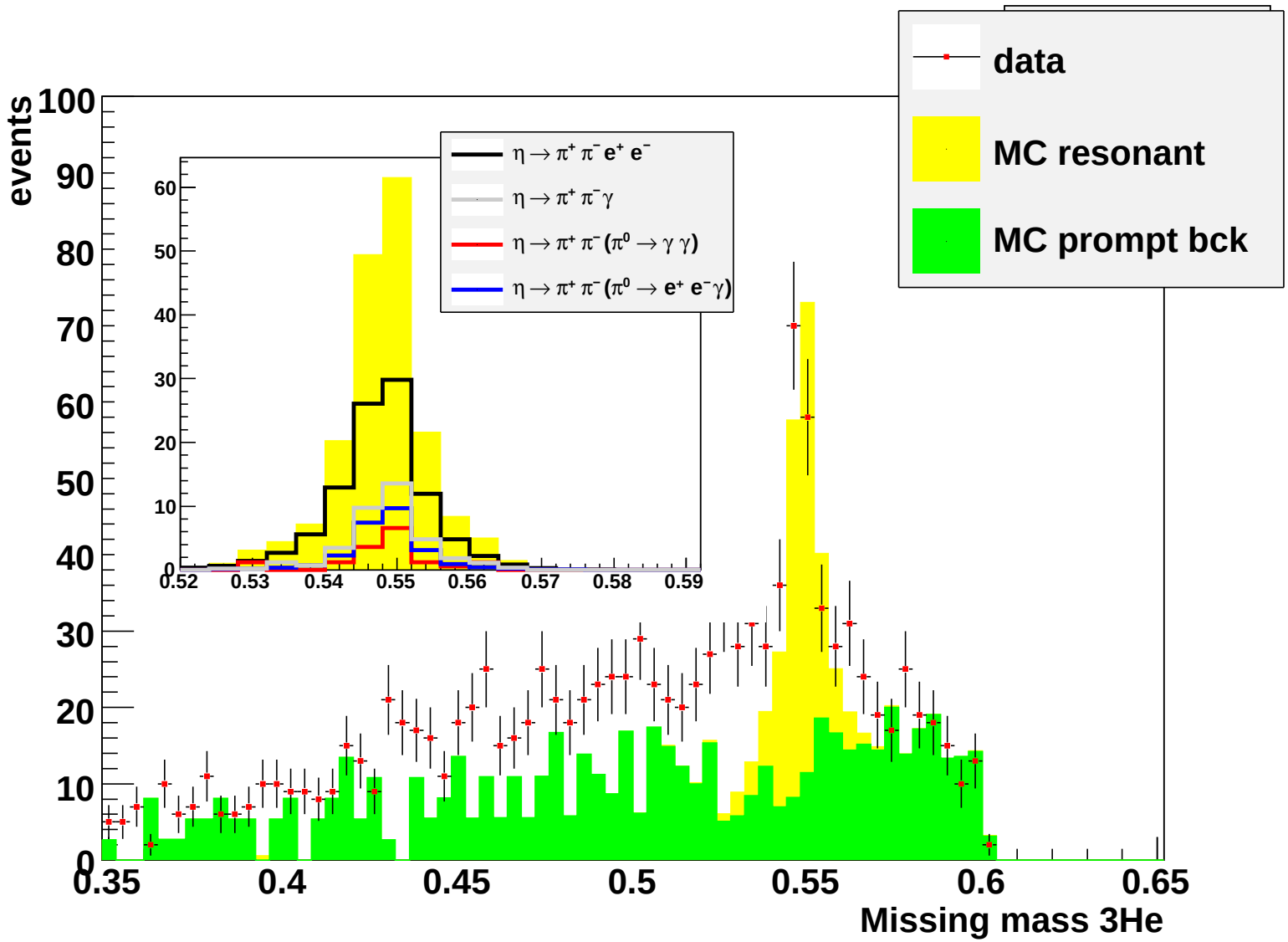
$\eta \rightarrow e^+e^-\pi^+\pi^-$



PRELIMINARY (40% of data)

Analysis M. Janusz, D. Coderre

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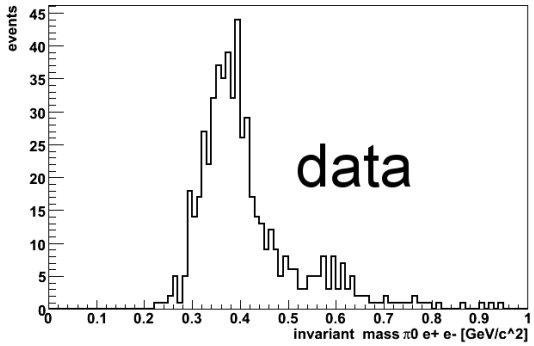
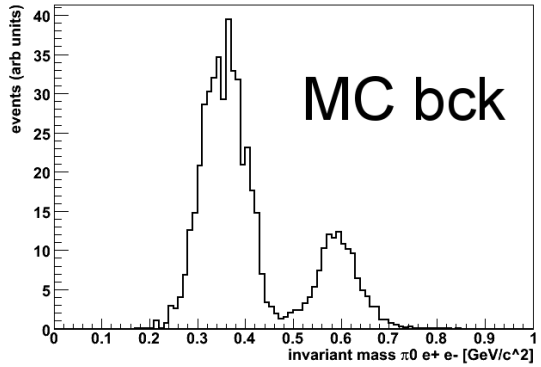
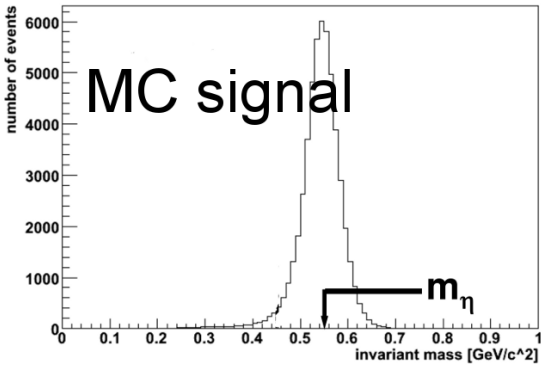
$\eta \to e^+e^-\pi^0$







- PDG $BR < 4\times10^{-5}$
- SM: decay via $\pi^0\gamma\gamma$ $BR \approx 10^{-8}$
- Goal: improve the BR limit

PRELIMINARY

Analysis A. Winnemöller

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Summary

- Results on η decays from 11×10^6 events

  minimum bias sample from 4 week October 2008
  $pd \rightarrow {}^3\mathrm{He}\eta$ run

  ... deadline for many PhD students this year ...
- Plan to increase statistics to 3×10^7 events in 2009
- Experiments with $pp \rightarrow pp\eta \geq$ 2010

WASA-at-COSY Collaboration

190 members
33 institutions

Uppsala

Dubna

Moscow

Novosibirsk

spokesperson: M. Wolke (Uppsala)

deputy spokesperson: P. Moskal (Cracow)

Cracow

Katowice

Warsaw

Lodz, Swierk, Warsaw

physics coordinators:
S. Schadmand (Jülich)
A. Kupsc (Uppsala)

technical coordinators:
H. Calen (Uppsala)
F. Goldenbaum (Jülich)

Bochum

Bonn

Erlangen

Hamburg

Jülich

Münster

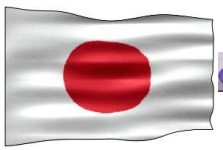
Tübingen

Lanzhou

IT coordinator : V. Hejny (Jülich)

Mumbai

Sofia



KEK

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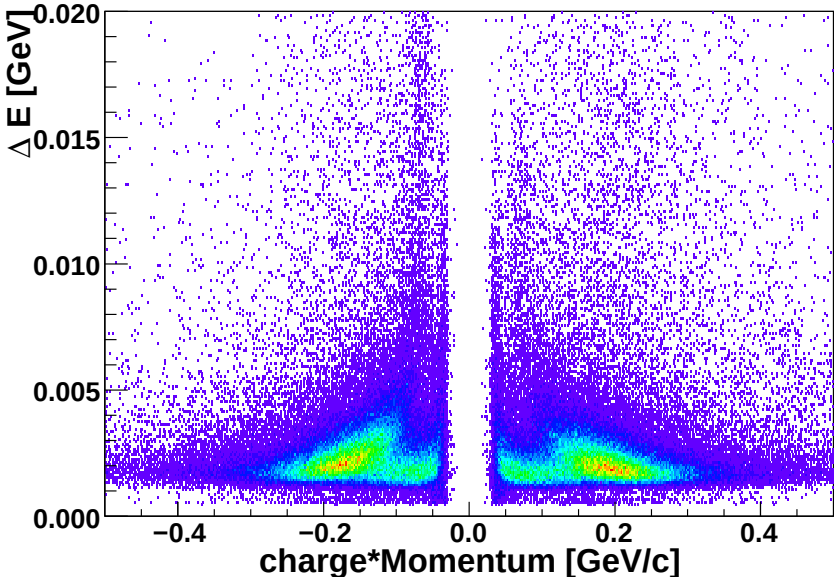
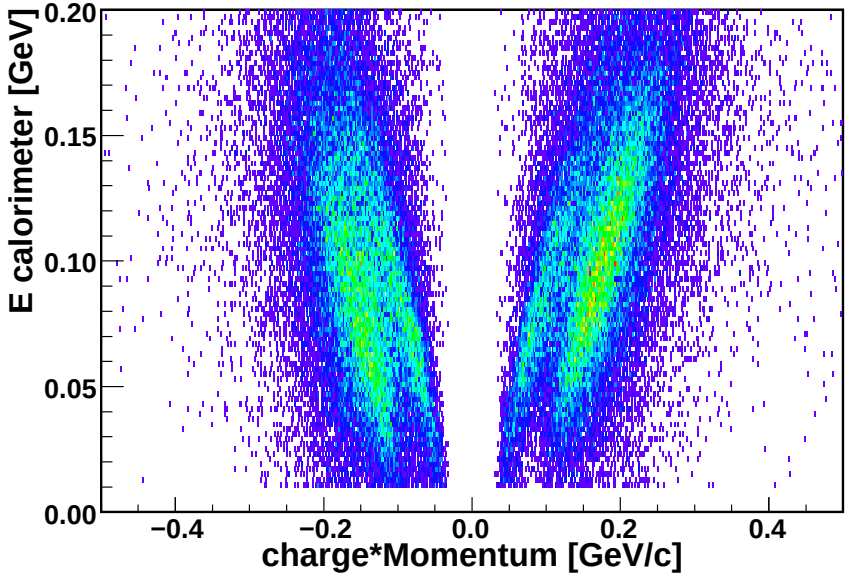
PID $\pi^{\pm}$ vs $e^{\pm}$



$\Delta E - p$



$E - p$

Analysis M. Janusz