Light meson studies with WASA-at-COSY

Lena Heijkenskjöld
for the WASA-at-COSY collaboration

Uppsala University

International Workshop on e^+e^- collisions from Phi to Psi
2013-09-12

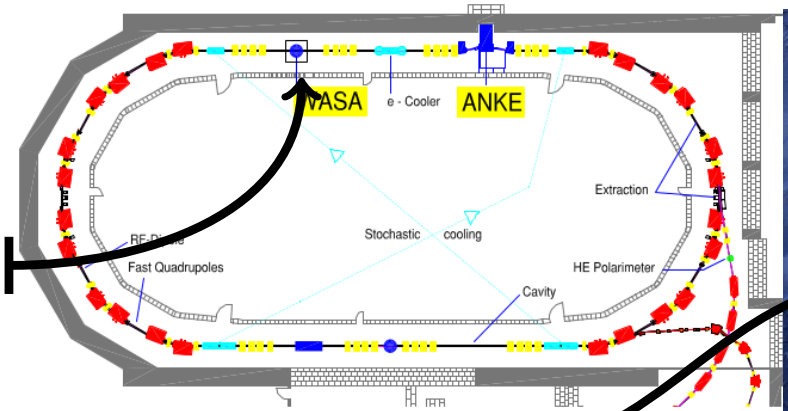
Presentation outline

- The WASA-at-COSY collaboration
  - Who and where
  - Our contribution to light meson decay studies
- The experimental set-up
  - The production and detection methods
- Current analyses
  - Mention all ongoing analyses
  - Present selected channels in detail

The WASA program

WASA-at-COSY

36 institutes



COSY
Cooler Synchrotron

Study of the decays of the light mesons π^0, η and ω
ideal for investigations of physics in the medium energy range

- Precision tests and experimental input to ChPT
- Form factor measurements
- Test symmetries and their breaking
- Search for physics beyond the Standard Model

Experimental set-up

Meson production

Beam:
High intensity proton or deuteron beam

$p + p \rightarrow p + p + X$

- Large cross sections
- Selective triggers required

$\rightarrow$ High statistics studies on rare decays

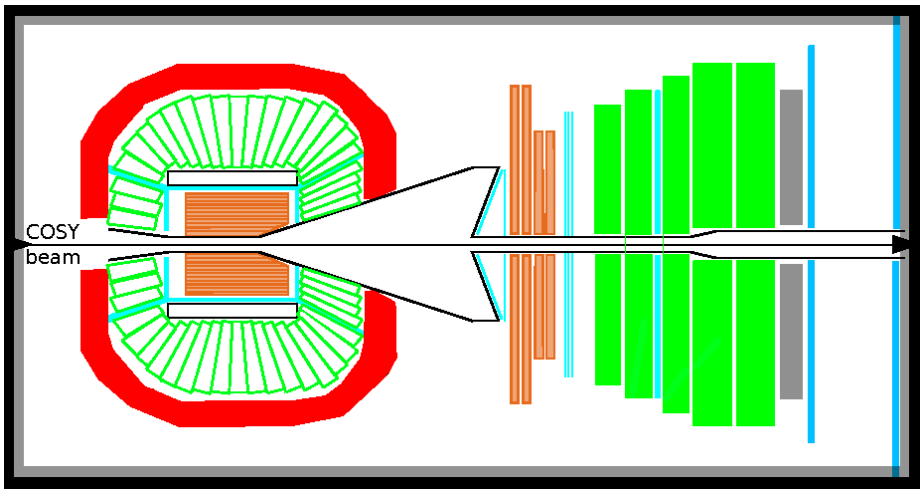
Target:
Frozen pellets of hydrogen or deuterium

$p + d \rightarrow {}^3He + X$

- Lower cross sections
- Unbiased triggers can be used

$\rightarrow$ Precision studies on common decays

Meson detection



Experimental set-up

Meson production

Beam:
High intensity proton or deuteron beam

Target:
Frozen pellets of hydrogen or deuterium

$p + p \rightarrow p + p + X$

- Large cross sections
- Selective triggers required

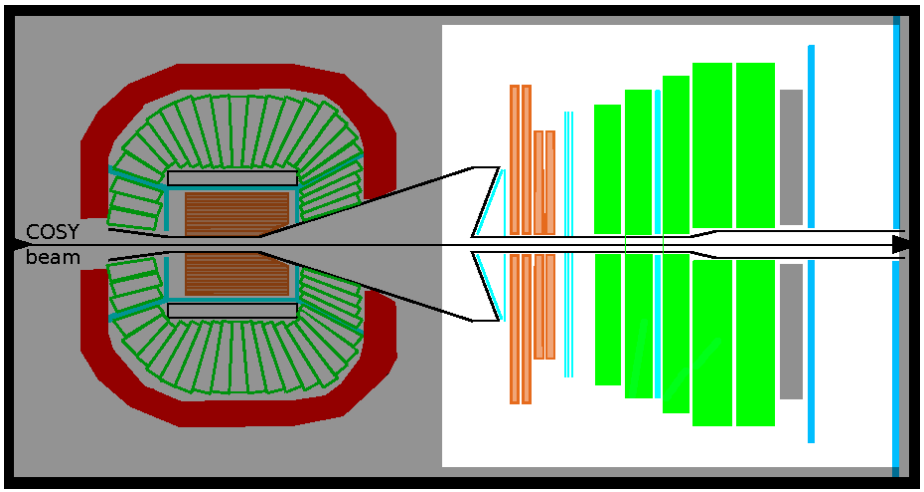
$\rightarrow$ High statistics studies on rare decays

$p + d \rightarrow {}^3He + X$

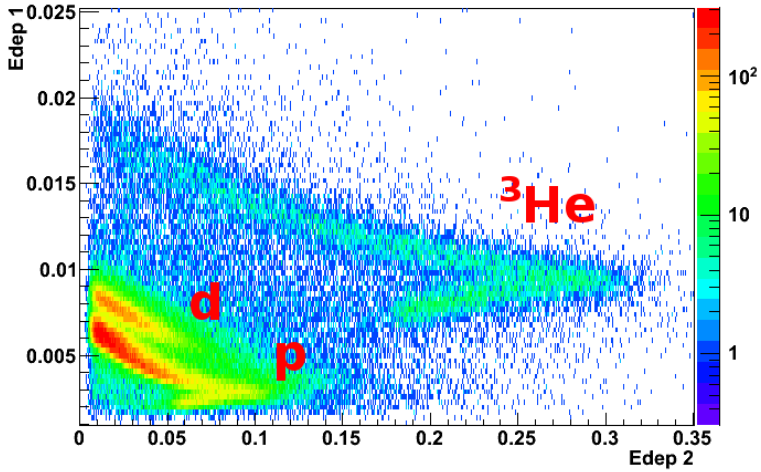
- Lower cross sections
- Unbiased triggers can be used

$\rightarrow$ Precision studies on common decays

Meson detection



Clean tagging of recoil particles



Experimental set-up

Meson production

Beam:
High intensity proton or deuteron beam

$p + p \rightarrow p + p + X$

- Large cross sections
- Selective triggers required

$\rightarrow$ High statistics studies on rare decays

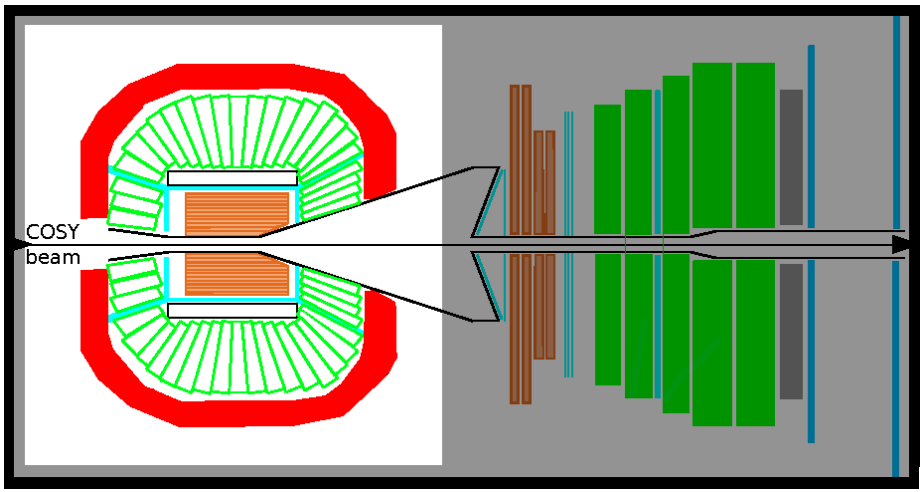
Target:
Frozen pellets of hydrogen or deuterium

$p + d \rightarrow {}^3He + X$

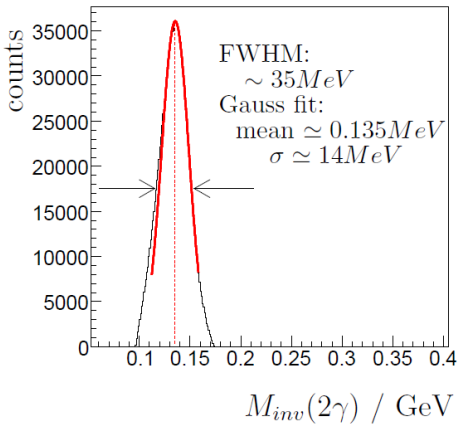
- Lower cross sections
- Unbiased triggers can be used

$\rightarrow$ Precision studies on common decays

Meson detection



$\sim 4\pi$ coverage of decay particles



Charged tracks PID using drift chamber and solenoid $\sim$ 1 T

γ reconstruction in calorimeter

π^0

Decay	Branching ratio	Interesting physics
$\pi^0 \to e^+e^-\gamma$	$(1.174 \pm 0.035) \times 10^{-2}$	Physics beyond SM
$\pi^0 \to e^+e^-$	$(6.46 \pm 0.33) \times 10^{-8}$	

π^0 produced in p - p, P_{beam} 1.155 GeV/c

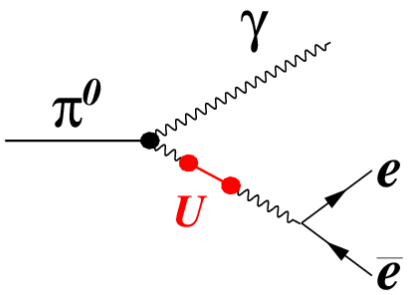
$\pi^0 \to e^+e^-\gamma$

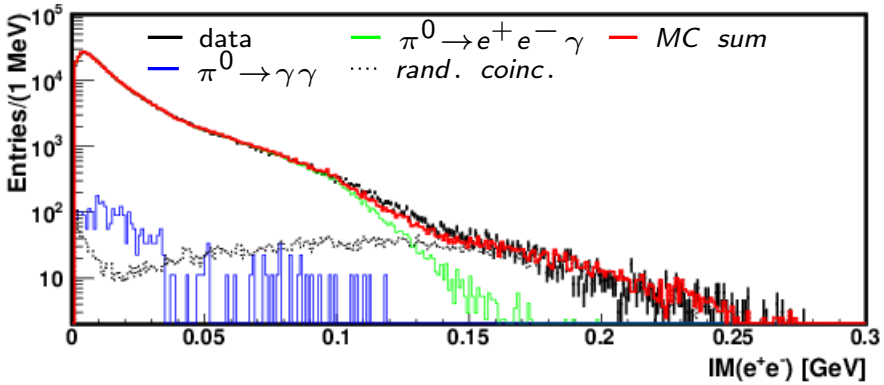
Goal: search for U boson

"The dark photon" - suggested reason for

- 511 keV γ radiation from galactic centre [1]
- excess of positrons in cosmic radiation [2]

$U - \gamma$ mixing $\to$ narrow structure in $IM(e^+e^-)$





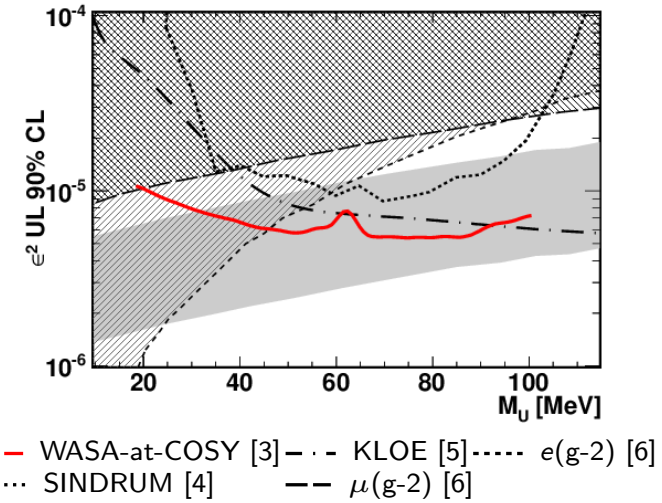
- The $U - \gamma$ mixing parameter, ϵ;

$$\frac{\Gamma(\pi^0 \to \gamma U)}{\Gamma(\pi^0 \to \gamma\gamma)} = 2\epsilon^2 |F(M_U^2)|^2 \left(1 - \frac{M_U^2}{M^2}\right)^3$$

- To be analysed: 8×10^6 $\pi^0 \to e^+e^-\gamma$

WASA: publication in press (PLB) [3]

- 5×10^5 $\pi^0 \to e^+e^-\gamma$
- Upper limit of $\Gamma(\pi^0 \to \gamma U)$ in range $M_U \in [20, 100] MeV$



[1] Astron.Astrophys.407 (2003) L55, [2] Nature458 (2009) 607, [3] arXiv:1304.0671v2, [4] PRL68 (1992) 3845, [5] PLB720 (2013) 111, [6] PRD86 (2012)

η

All decay modes are supressed $\longrightarrow$ access to rare decays

Decay	Branching ratio	Interesting physics
$\eta \to \pi^+\pi^-\pi^0$	$(22.74 \pm 0.28) \times 10^{-2}$	ChPT test: Dalitz plot parameters
$\eta \to \pi^+\pi^-\gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	ChPT test: Box anomaly & BR
$\eta \to e^+e^-\gamma$	$(7.0 \pm 0.7) \times 10^{-3}$	Transition form factor & BR
$\eta \to \pi^+\pi^-e^+e^-$	$(2.68 \pm 0.11) \times 10^{-4}$	CP test of SM & BR
$\eta \to e^+e^-e^+e^-$	$(2.4 \pm 0.2) \times 10^{-5}$	Double transition form factor & BR
$\eta \to \pi^0e^+e^-$	$< 4 \times 10^{-5}$	C test of SM & BR
$\eta \to e^+e^-$	$< 5.6 \times 10^{-6}$	Physics beyond SM

p - d production

3×10^7 η tagged

P_{beam} 1.7 GeV/c

p - p production

$\sim 5 \times 10^8$ η produced

P_{beam} 2.14 GeV/c

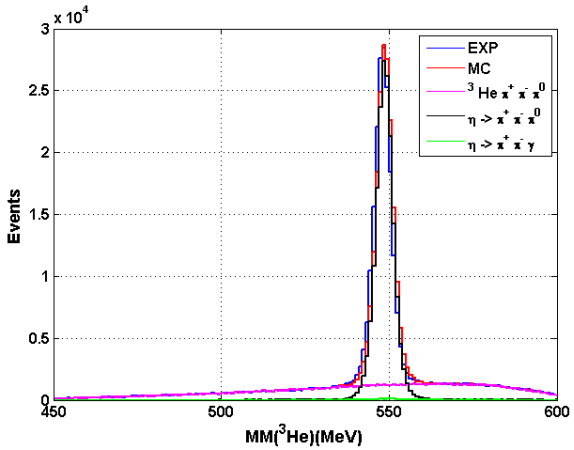
$\eta \to \pi^+\pi^-\pi^0$

Goal: benchmarking ChPT

- Large branching ratio - ideal for tests of ChPT
- Produce high statistics Dalitz plot

$$X = \frac{\sqrt{3}(T_+ - T_-)}{T_+ + T_- + T_0} \qquad Y = \frac{3T_0}{T_+ + T_- + T_0} - 1$$

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



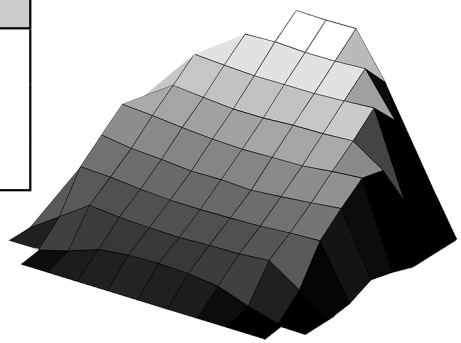
Ongoing WASA analysis

- p - d
- Clear $\eta \to \pi^+\pi^-\pi^0$ signal
- 1.33×10^5 signal events in Dalitz plot
  include second data set $\sim \times 2$ statistic

- Preliminary parameters consistent with measurement from KLOE

Experiment	-a	b	d	f
KLOE [7]	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
WASA [PREL.]	1.074(23)(3)	0.179(27)(8)	0.059(25)(10)	0.089(58)(110)
ChPT NNLO [8]	1.271(75)	0.394(102)	0.055(57)	0.025(160)

c and e are consistent with zero - charge symmetry



- Ongoing analysis of p - p data $\to$ 10^6 events

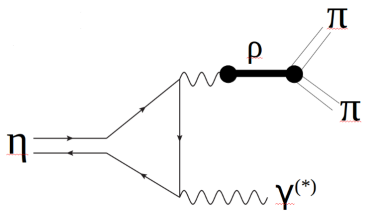
[7] JHEP 0805:006,2008, [8] JHEP 0711:030,2007

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

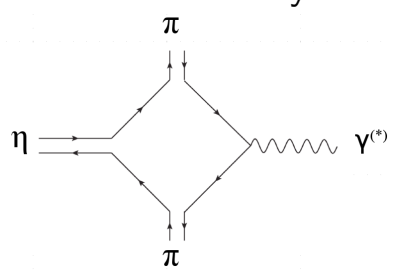
Goal: study decay dynamics

- Occurs through chiral anomaly of QCD
- $\Gamma(\eta \to \pi^+\pi^-\gamma)_{box} < \Gamma(\eta \to \pi^+\pi^-\gamma)_{exp}$
- High precision experimental values of BR and Dalitz distributions needed

Triangle anomaly



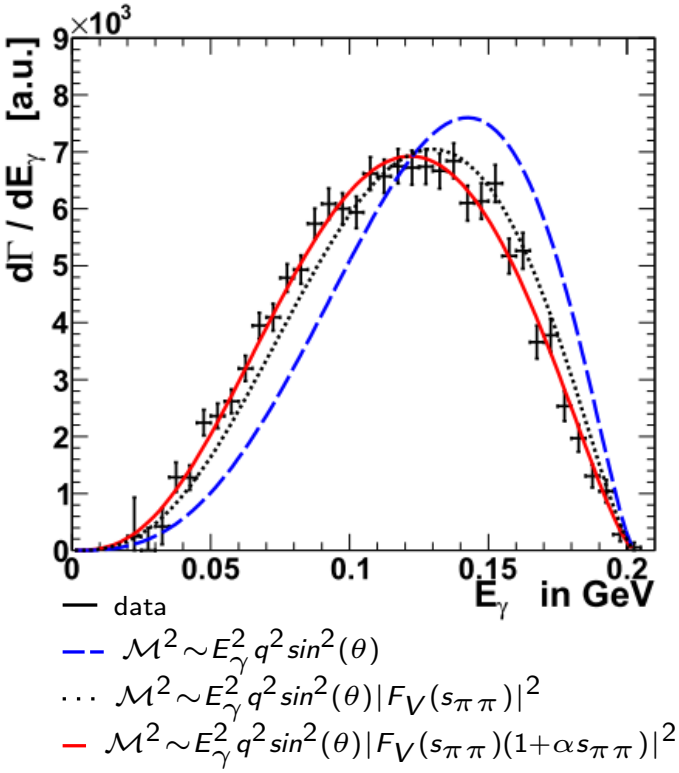
Box anomaly



WASA: publication PLB707 (2012)

- p - d
- 1.4×10^4 signal events to measure
  i) $\cos(\theta_\pi)$ $\to$ consistent with P wave
  ii) E_γ $\to$ parametrised by $1 + \alpha s_{\pi\pi}$

$$\alpha_{fit} = 1.89 \pm 0.25_{stat} \pm 0.59_{sys} \pm 0.02_{theo}\ GeV^{-2}$$



Ongoing WASA analysis

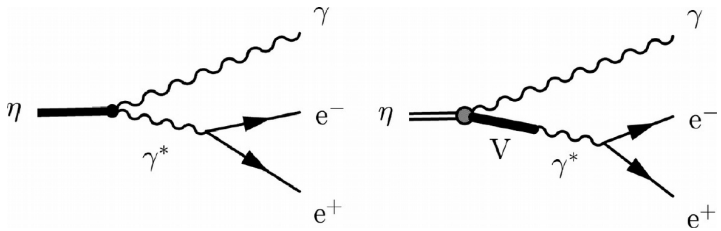
- p - d: BR_{exp} measurement
- p - p: Re-measurement of decay dynamic

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

Goal: η transition form factor

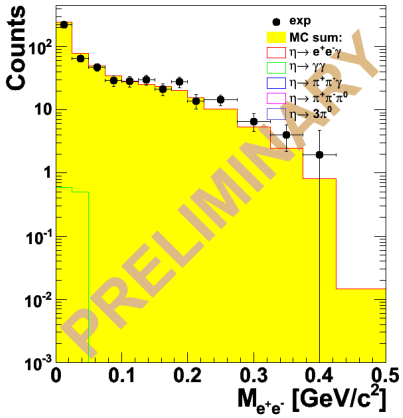
- $M_{l^+l^-}$ distribution contains the interaction of intermediate vector meson
- Form factor $F_\eta(q^2)$ defined by

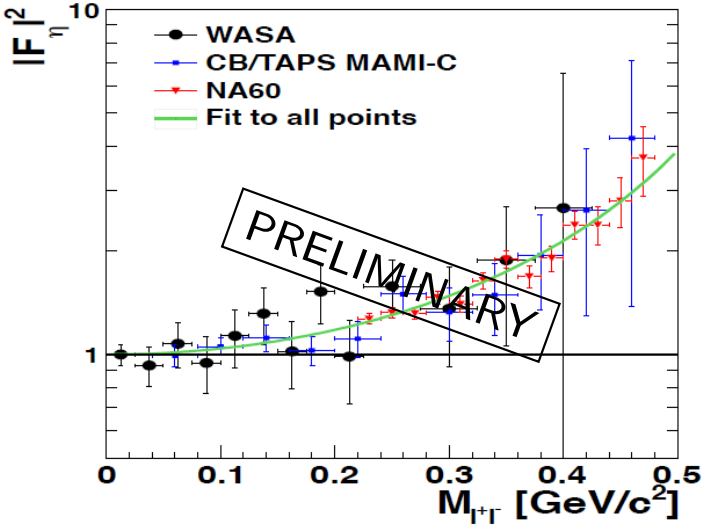
$$\frac{d\Gamma}{dq^2} = \left[\frac{d\Gamma}{dq^2}\right]_{QED} |F_\eta(q^2)|^2$$



WASA PhD thesis work

- p - d
- Preliminary $|F_\eta|^2$





Ongoing WASA analysis

Include larger data set in analysis

→ measure BR_{exp} using 17×10^3 signal events

→ improve errors on $|F(q^2)|^2$ slope parameter

ω

Decay	Branching ratio	Interesting physics
$\omega \to \pi^+\pi^-\pi^0$	$(89.2 \pm 0.7) \times 10^{-2}$	Dalitz plot parameters
$\omega \to \pi^0\gamma$	$(8.28 \pm 0.28) \times 10^{-2}$	Branching ratio
$\omega \to \pi^+\pi^-$	$(1.53^{+0.11}_{-0.13}) \times 10^{-2}$	$\rho - \omega$ mixing
$\omega \to \pi^0 e^+ e^-$	$(7.7 \pm 0.6) \times 10^{-4}$	Transition form factor

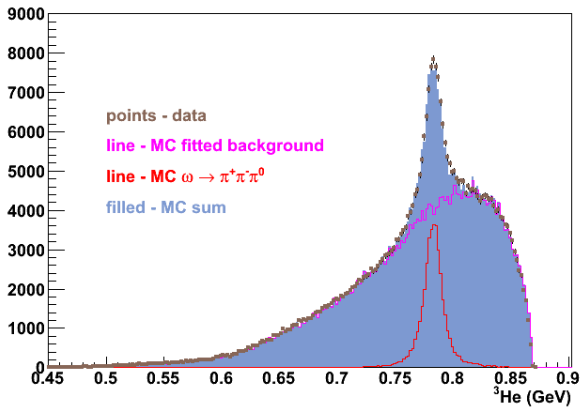
Collected data sets

p+ d, $\sim$ 2 weeks,
P_{beam} 2.25 & 2.19 GeV/c

p +p, pilot run,
P_{beam} 2.851 & 3.350GeV/c

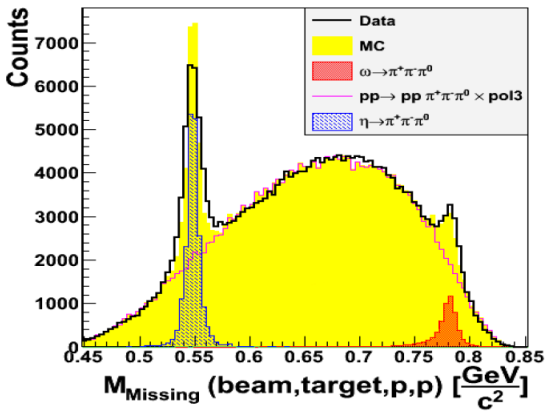
A glance at $\omega \to \pi^+\pi^-\pi^0$

p + d



Cut based selection: 72 000 signal events

p + p



With kinematical fit: 5600 signal events
(1/3 of collected data)

Summary

WASA-at-COSY...

...is an ideal facility for light meson investigations.

Mesons π^0, η and ω produced in p-p and p-d reactions.

...contributes significantly to

- tests on ChPT (decay dynamics variables, QCD anomalies . . .).
- form factor measurements.
- tests of Standard Model and searches for new physics.

...will soon

- release BR measurements on several η decays.
- finalise Dalitz plot parameters for $\eta \to \pi^+\pi^-\pi^0$.

Back up

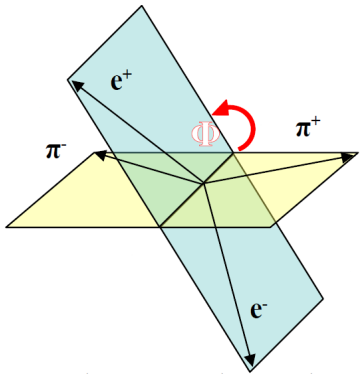
BACK UP SLIDES

Back up - η

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

- Driven by same QCD anomalies as $\eta \to \pi^+\pi^-\gamma$.
- The $\pi\pi\gamma$ vertex could contain new source of CP violation. $\to$ an asymmetry in the angle between $e^{+/-}$ and $\pi^{+/-}$ decay planes.

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



Preliminary results: $BR = (3.10 \pm 0.27_{stat} \pm 0.22_{sys}) \times 10^{-4}$

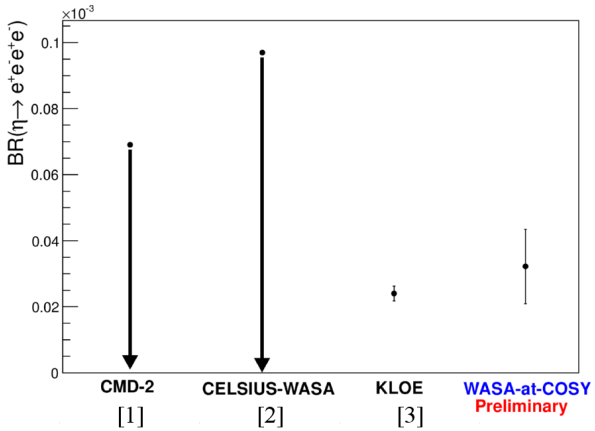
(263±24 signal events) $A_\Phi = (0.4 \pm 9.0_{stat} \pm 2.8_{sys}) \times 10^{-2}$

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

- Allows measurement of the η double form factor.
- Current analysis on p - d data with goal of BR measurement.

Preliminary results: $BR = (3.0 \pm 0.8_{stat} \pm 0.7_{sys}) \times 10^{-5}$

(50±13) signal events)



Future analysis of p -p data, higher statistics
$\longrightarrow$ possibly sensitive to form factor measurement.