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Recent results from the WASA-at-COSY experiment

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Uppsala University
for the WASA-at-COSY Collaboration

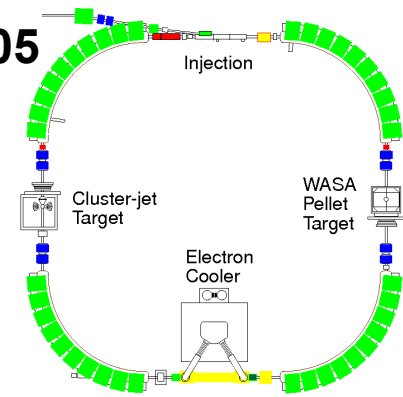
MENU 2010, Williamsburg 2009-06-03



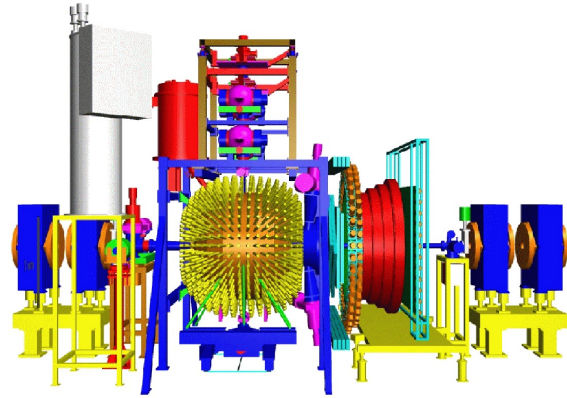
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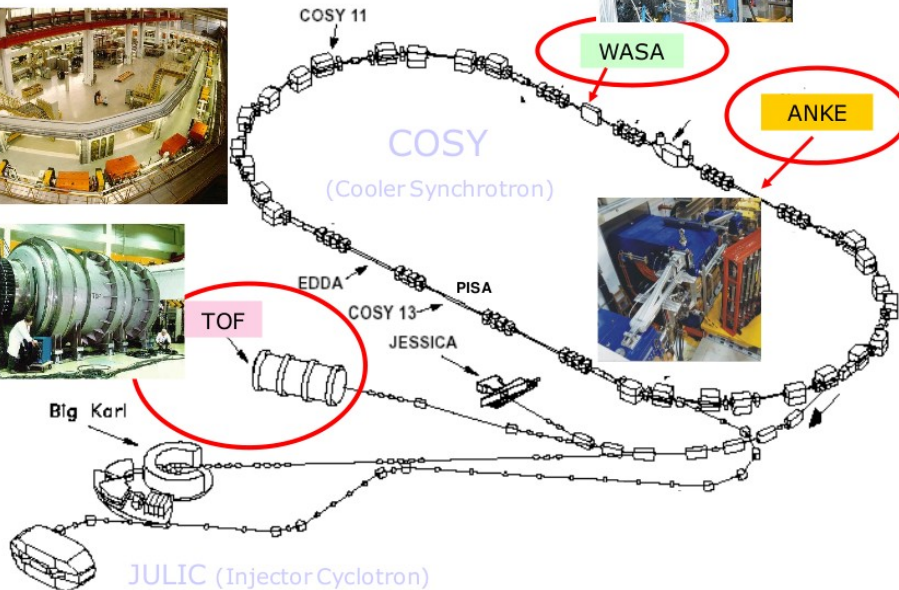
CELSIUS/WASA <2005



WASA

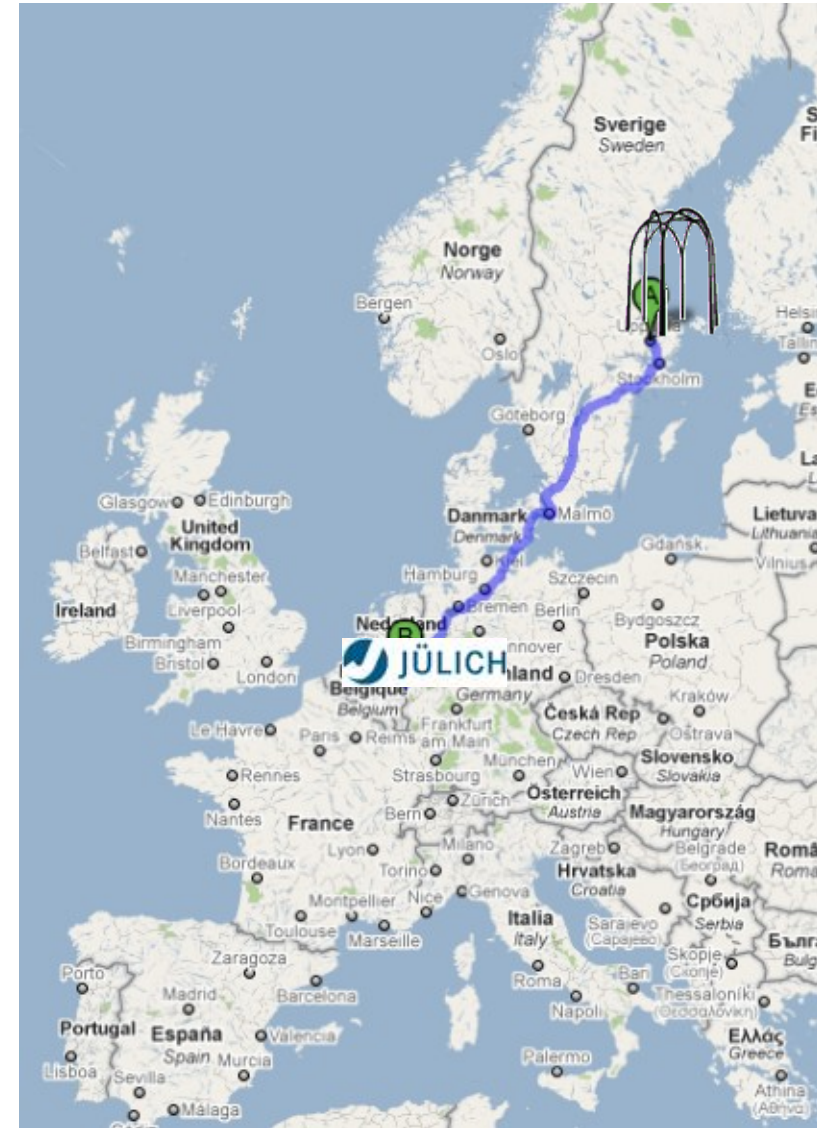


WASA-at-COSY >2007



Schematic overview COSY Facility (FZ-Jülich)

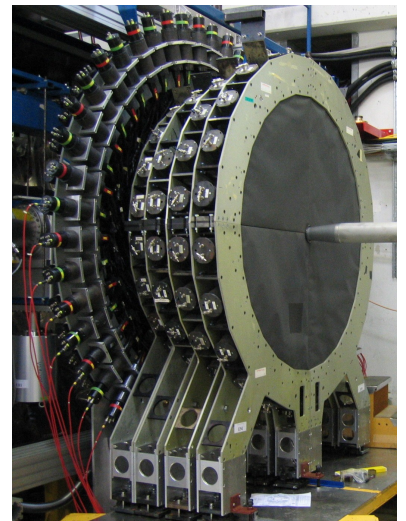
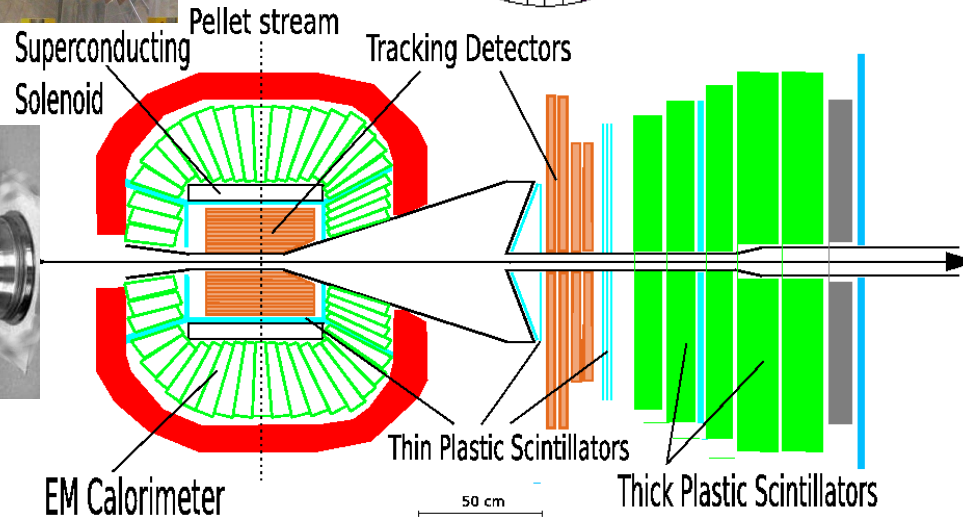
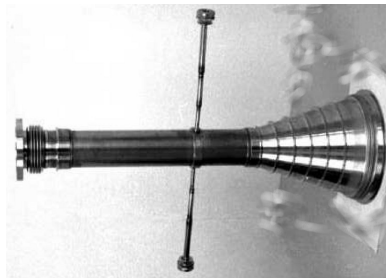
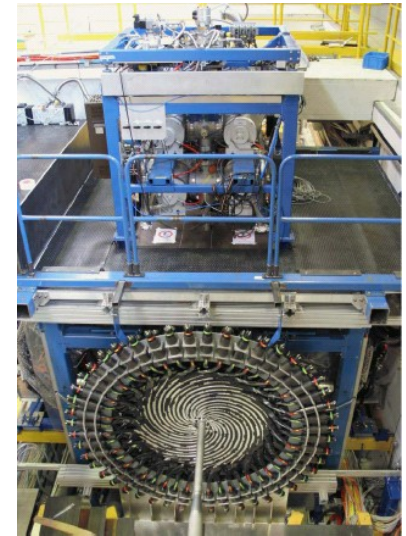
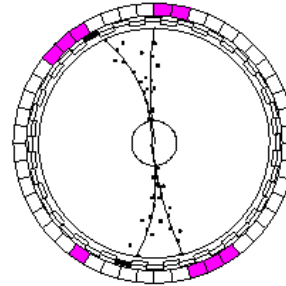
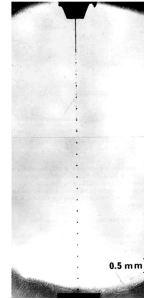
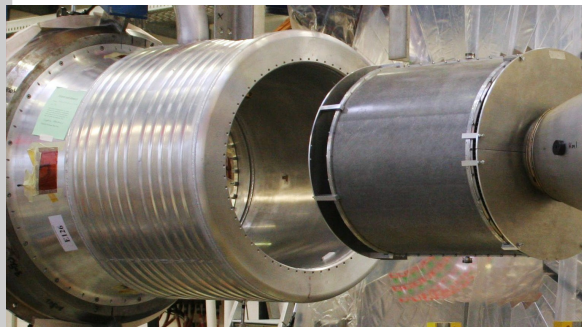
Recent results from Experiments at COSY, HADRON2009, 4/12/09



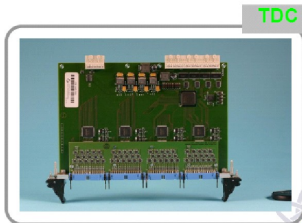


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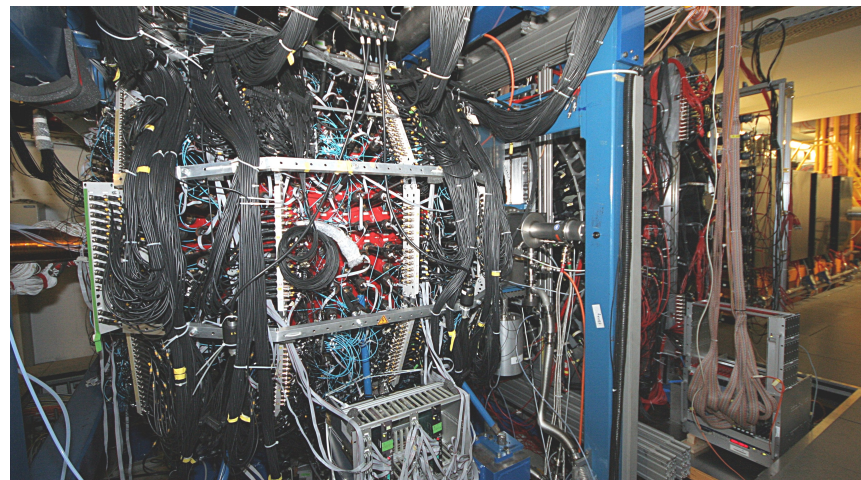
WASA detector



QDC



TDC



NIM A594,339



WASA-at-COSY Collaboration

190 members
33 institutions



Uppsala

spokesperson: M. Wolke (Uppsala)

deputy spokesperson: P. Moskal (Cracow)



Dubna



Moscow



Novosibirsk



Cracow

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



Katowice

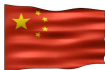


Warsaw



Lodz, Swierk, Warsaw

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



Lanzhou

IT coordinator : V. Hejny (Jülich)



Mumbai



Sofia



KEK



Bochum



Bonn



Erlangen



Hamburg



Jülich



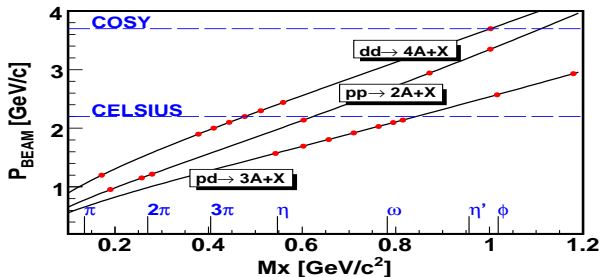
Münster



Tübingen



Experimental programme



Goals:

- Symmetries and Symmetry Breaking
Isopin, Chiral symmetry, Fundamental symmetries
- (crypto) exotic hadrons

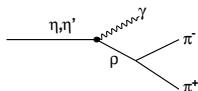
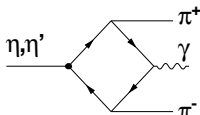
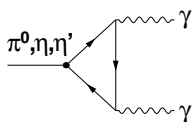
Main projects:

- ⇒ Decays (production) of light mesons π^0 , η , ω , η' , a_0 , f_0
- Dynamical CSB in $dd \rightarrow \alpha\pi^0$ reaction (⇒ A.Wrońska)
- Studies of ABC effect (e.g. basic $pn \rightarrow d\pi^0\pi^0$ system)
- Search for ${}^4\text{He}\eta/{}^3\text{He}\eta$ bound states



- Radiative decays

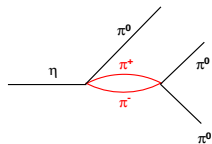
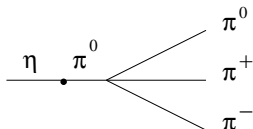
Chiral anomaly vs Vector Meson Dominance



- Hadronic decays

$\eta \rightarrow 3\pi$ ($m_d - m_u$)

$\pi - \pi$ interactions, cusp



- SM tests:

rare decays $\pi^0, \eta \rightarrow e^+e^-$, $\eta \rightarrow \pi^0 e^+e^-$

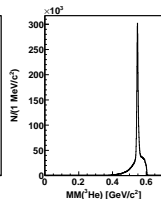
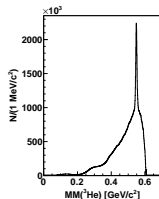
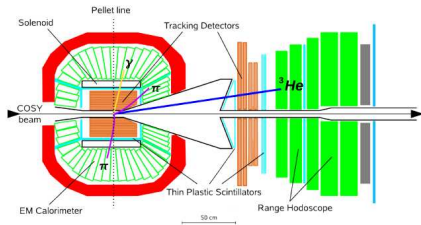
Symmetries of the decays distributions eg.

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



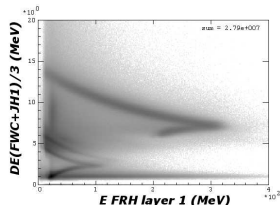
Sources of the mesons

- Close threshold $pd \rightarrow {}^3\text{He}X$ and $pp \rightarrow ppX$ reactions
- ${}^3\text{He}$ or p in FD: $3^\circ < \theta < 18^\circ$
- Precise $MM({}^3\text{He}) / MM(pp)$ ($\Delta MM < \Delta IM$)



$pd \rightarrow {}^3\text{He}X$

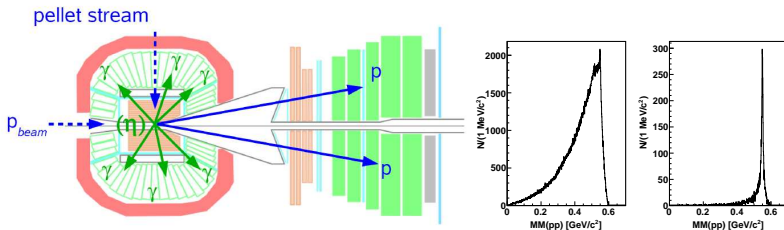
- + Clean trigger – ${}^3\text{He}$ only
- + $\Delta E({}^3\text{He})$ good for heavier mesons
- Low cross section
- ⇒ For exploratory/precision studies





Sources of the mesons

- Close threshold $pd \rightarrow {}^3\text{He}X$ and $pp \rightarrow ppX$ reactions
- ${}^3\text{He}$ or p in FD: $3^\circ < \theta < 18^\circ$
- Precise $MM({}^3\text{He}) / MM(pp)$ ($\Delta MM < \Delta IM$)

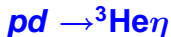


$pp \rightarrow ppX$

- Trigger: conditions for decay mode
- $\Delta E(p)$ only up to η (TOF, DIRC?)
- + Larger cross section
- \Rightarrow For rare decays with simple signature



Collected data



$$T_p = 1.0 \text{ GeV}$$

$$10 \text{ } \eta/\text{s} \text{ (} 0.4 \mu\text{b)}$$

$$3 \times 10^7 \text{ } \eta \text{ decays}$$

Beam energy

Yield/ cross section

Collected data



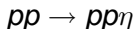
$$T_p = 1.4 \text{ GeV}$$

$$\geq 100 \text{ } \eta/\text{s} \text{ (} 10 \mu\text{b)}$$

$$> 10^8 \text{ } \eta \text{ decays}$$

Main data sets:

- $pd \rightarrow {}^3\text{He}\eta$
 - \Rightarrow (2008) – $1.1 \times 10^7 \text{ } \eta\text{s}$
 - (2009) – $2.0 \times 10^7 \text{ } \eta\text{s}$



- \Rightarrow 4 weeks (2007)+(2008)
- 8 weeks (2010)



- $\eta \rightarrow 3\pi$
- $\eta \rightarrow \pi^+\pi^-\gamma$
- $\eta \rightarrow e^+e^-\gamma$ (\Rightarrow H. Bhatt)
- $\eta \rightarrow \pi^+\pi^-e^+e^-$
- $\eta \rightarrow e^+e^-e^+e^-$
- $\eta \rightarrow \pi^0\gamma\gamma$ (\Rightarrow K.Lalwani)
- Rare decays: $\eta, \pi^0 \rightarrow e^+e^-$, $\eta \rightarrow \pi^0e^+e^-$
- Towards ω and η' decays



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

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

\Rightarrow constraints for m_s/m_d , m_u/m_d

Leutwyler 1996

- $Q_D = 24.1$ (Dashen limit)
- Γ_{th} from ChPT
- $\Gamma(\gamma\gamma) \Rightarrow$ GlueX, KLOE2

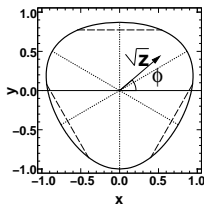
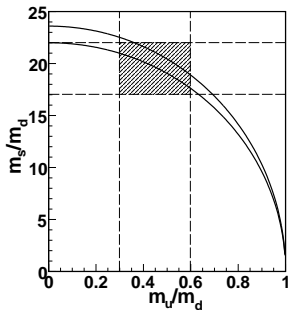
Test of ChPT calculations

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

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

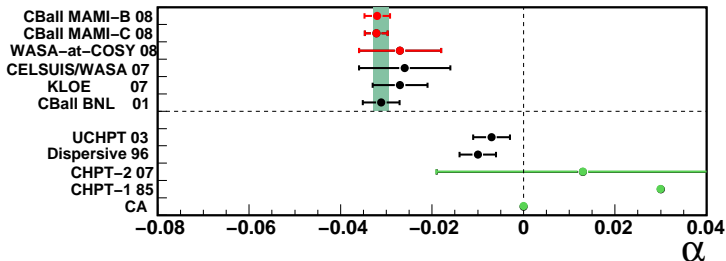
$$y = T_0/\langle T \rangle - 1$$

$$z = x^2 + y^2$$





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



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

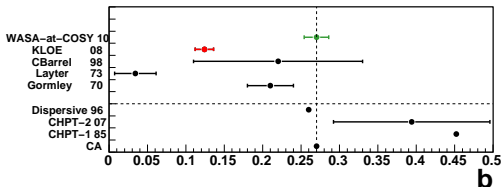
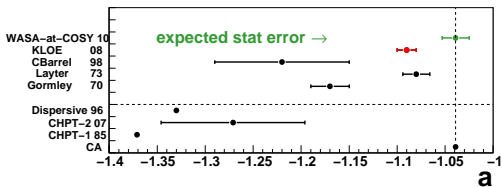
- $|\mathcal{A}_{000}(z, \phi)|^2 \propto 1 + 2 \alpha z + \dots$
- Experiments: weighted average $\alpha = -0.0312 \pm 0.0017$
- ChPT LO: $\alpha = 0$, NLO, NNLO $\alpha > 0$

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

WASA-at-COSY: 120k events $pp \rightarrow pp\eta$ PLB667,24(09)



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

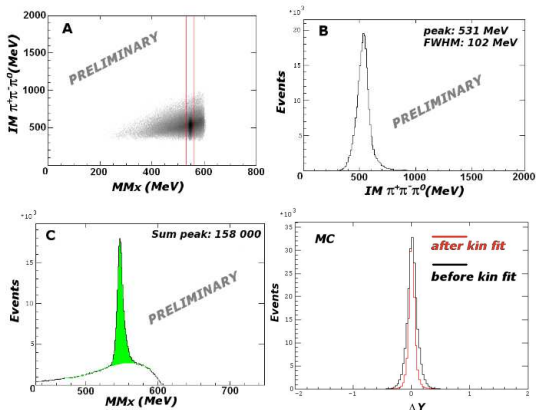


$$|\mathcal{A}_{+-0}(x, y)|^2 \propto 1 + ay + by^2 + dx^2 + fy^3 + \dots$$

- Recent precise data KLOE 1.3×10^6 JHEP 0805:006(08)
- a, b, f do not agree with NNLO ChPT Bijnens, Ghobani JHEP11:030(07)
- WASA-at-COSY two independent measurements



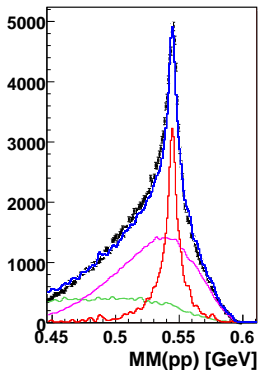
$\eta \rightarrow \pi^+ \pi^- \pi^0$ in $pd \rightarrow {}^3\text{He} \eta$



- 2008 data $1 - 2 \times 10^5$ $\eta \rightarrow \pi^+ \pi^- \pi^0$ in the Dalitz plot
- background $pd \rightarrow {}^3\text{He} \pi^+ \pi^- \pi^0$



$\eta \rightarrow \pi^+ \pi^- \pi^0$ in $pp \rightarrow pp\eta$

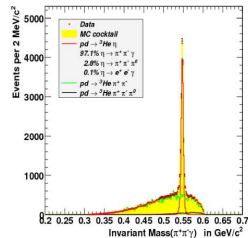
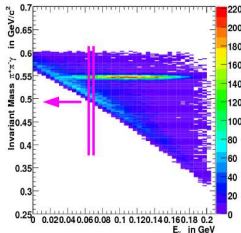
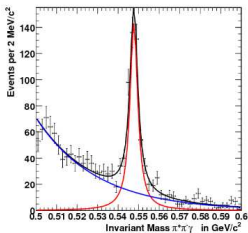


- 2-3 $\eta \rightarrow \pi^+ \pi^- \pi^0/s$
- Run finished last Monday:
 $\approx 10^7$ $\eta \rightarrow \pi^+ \pi^- \pi^0$
- Trigger accepts all decays with charged particles



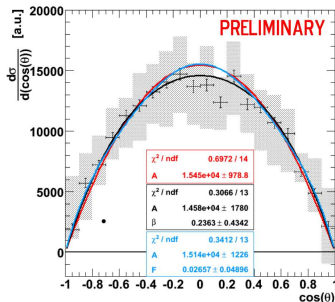
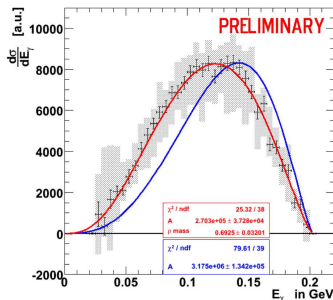
$$\eta \rightarrow \pi^+ \pi^- \gamma$$

- Goal: measure E_γ distribution:
VMD vs box anomaly
- Main background: $\eta \rightarrow \pi^+ \pi^- \pi^0$, $pd \rightarrow {}^3\text{He} \pi^+ \pi^-$
- Kinematical 4C fit $pd \rightarrow {}^3\text{He} \pi^+ \pi^- \gamma$
- Sample 13750 ± 150 events





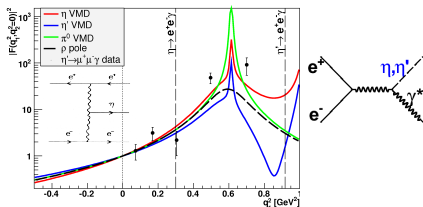
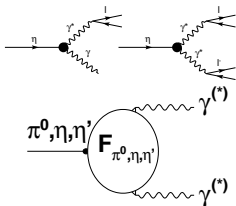
- Second variable θ_π (π^+ angle in di-pion CMS)
- $|\mathcal{A}(E_\gamma, \cos \theta_\pi)|^2 \propto \sin^2 \theta_\pi$



- simplest matrix element does not describe data (blue)
- good agreement with VMD (red)
- p – wave interaction
- *higher partial wave contributions negligible*

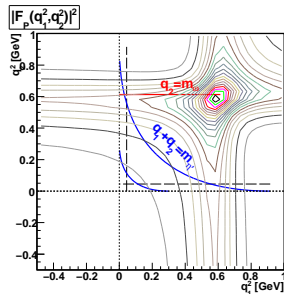


Conversion decays



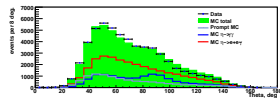
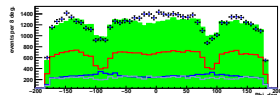
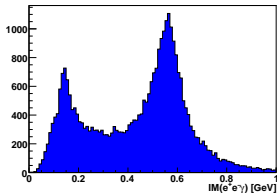
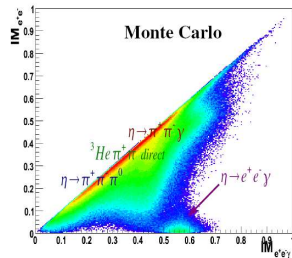
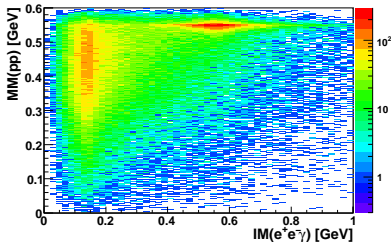
Double off shell form factors:

- Test VMD
- Give SM contribution to
- ... $\mathcal{P} \rightarrow e^+ e^-$
- ... muon $g - 2$
- Decays of interest:
 - $\eta \rightarrow e^+ e^- e^+ e^-$
 - $\omega \rightarrow \pi^0 e^+ e^-$...





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



- Background $\eta \rightarrow \gamma\gamma$ (conversion in the detector)
- Direct $\pi^+ \pi^-$ production

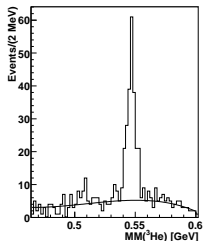


$$\eta \rightarrow e^+ e^- \pi^+ \pi^- / \eta \rightarrow e^+ e^- e^+ e^-$$

Exploratory analysis of the 2008 pd data

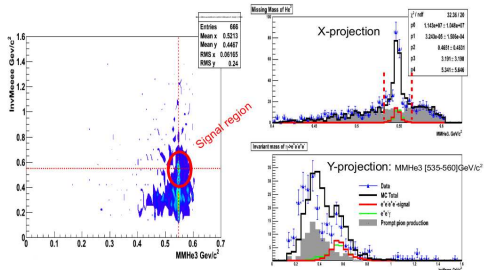
$$\eta \rightarrow e^+ e^- \pi^+ \pi^-$$

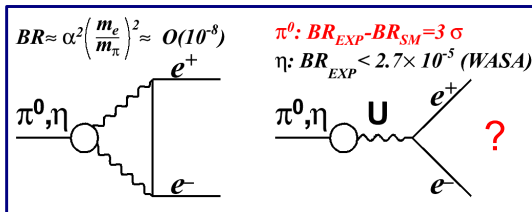
- 150 – 200 events
- S/B \sim 2.5:1
- acceptance ca. 7%
- Normalization to $\eta \rightarrow \pi^+ \pi^- \pi_D^0$



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

- 15 – 30 candidates
- acceptance ca. 5%
- S:B \sim 1:1

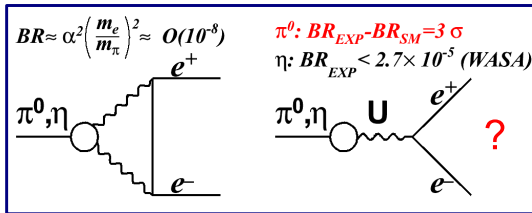


Rare decays: $\pi^0 \rightarrow e^+ e^-$ 

- Exp $BR_{\text{no-rad}} = (7.48 \pm 0.29_{\text{stat}} \pm 0.25_{\text{syst}}) \times 10^{-8}$
 KTeV (794 events) PRD75:012004,2007
- $BR^{\text{SM}}(\pi^0 \rightarrow e^+ e^-) = (6.23 \pm 0.09) \times 10^{-8}$
 Dorokhov et al., PRD75:114007,2007
- $pp \rightarrow pp\pi^0$ $T_p = 0.55$ GeV (1.3 mb) below $pp \rightarrow pp\pi^+\pi^-$
- background ($\pi^0 \rightarrow e^+ e^- \gamma, \dots$) studied in 2010 test run:
 reconstructed $\pi^0 \rightarrow e^+ e^- \gamma$ 9/s (total 4.5×10^6)
 Expect about 100 $\pi^0 \rightarrow e^+ e^-$



Rare decays: $\eta \rightarrow e^+ e^-$



- 2008 $pp \rightarrow pp\eta$ data with 4.4×10^7 η s:
- Goal improve BR limit

CELSIUS/WASA PRD77:032004(08)

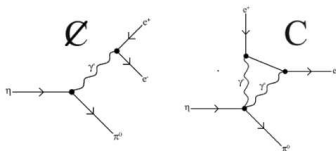
acceptance 5%

background $\eta \rightarrow e^+ e^- \gamma$, $pp \rightarrow pp\pi^+ \pi^-$, ..

Analysis: M. Berlowski



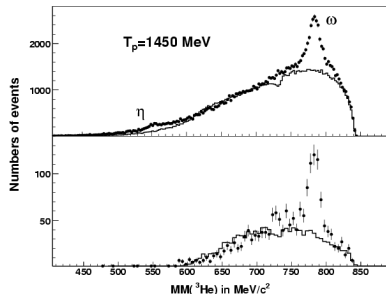
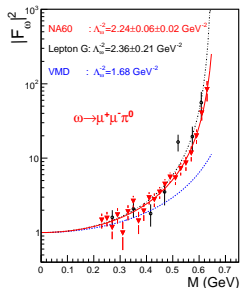
Rare decays: $\eta \rightarrow e^+ e^- \pi^0$



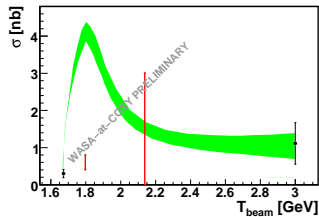
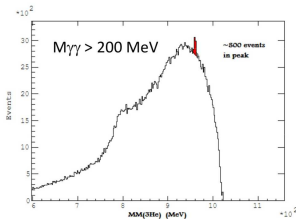
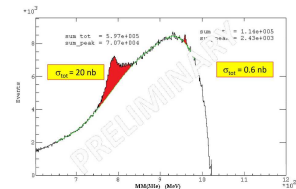
- PDG $BR < 4 \times 10^{-5}$
- Test C up to $BR \approx 10^{-8}$ (decay via $\pi^0 \gamma^* \gamma^*$)
- Analysis of 2008 $pd \rightarrow {}^3\text{He} \eta$ data
Goal: improve BR limit
Background $pd \rightarrow {}^3\text{He} \pi^0 \pi^0$
Acceptance $\approx 1\%$
- Continue with $pp \rightarrow pp \eta$ data



Goal $\omega \rightarrow \pi^0 e^+ e^-$ form factor



- $pd \rightarrow {}^3\text{He}\omega$ at 1.45 GeV
- $\sigma = 85$ nb CELSIUS/WASA PLB668:258,08
- 2×10^6 ω /month (from $pd \rightarrow {}^3\text{He}\eta$)
- $pp \rightarrow pp\omega$ at $Q = 60 - 90$ MeV (2.85–2.95 GeV/c)
- $\sigma = 6 - 10$ μb



green: nucl-th/9510010

black points: PRD9,1917(74),
PRL374,283(96)

- Estimate of $\sigma(pd \rightarrow {}^3\text{He}\eta')$ at $T_p = 1.80, 2.14$ GeV ≈ 1 nb too low for decays
- $pp \rightarrow pp\eta'$ $T_p = 2.54$ GeV 300 nb (COSY-11)
- ... fast protons



- Analysis of 2008 pd soon will be finished
- *Second generation* analysis of 2009 pd data
- Analysis of new large statistics $pp \rightarrow pp\eta$ data
- Starting ω decay programme
- $\sigma(pd \rightarrow {}^3\text{He}\eta', a^0, f^0) = \mathcal{O}(\text{nb})$ too low for decays
 \Rightarrow try $pp \rightarrow pp\eta'$
- *byproduct*: meson production dynamics

- Other results: ABC effect, CSB $dd \rightarrow \alpha\pi^0$, search for η -mesic nuclei



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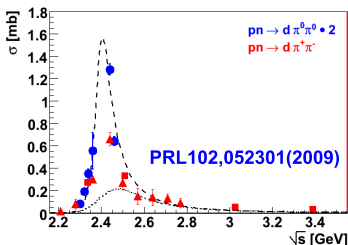




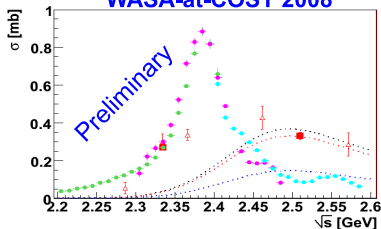
$pn \rightarrow d\pi^0\pi^0$ reaction

- ABC $M(\pi\pi)$ enhancement in light ion reactions (1961)
- WASA: Exclusive measurement of the simplest system:
 $pn \rightarrow d\pi^0\pi^0$

CELSIUS/WASA 2004



WASA-at-COSY 2008



$T_p = 1.0, 1.2, 1.4$ GeV

- Narrow $\Delta\Delta$ (np) state $M = 2.37 \text{ GeV}/c^2$ $\Gamma \approx 75 \text{ MeV}/c^2$?