Recent results from the WASA-at-COSY experiment

Andrzej Kupść
for the WASA-at-COSY Collaboration

MESON 2010, Kraków 2010-06-14

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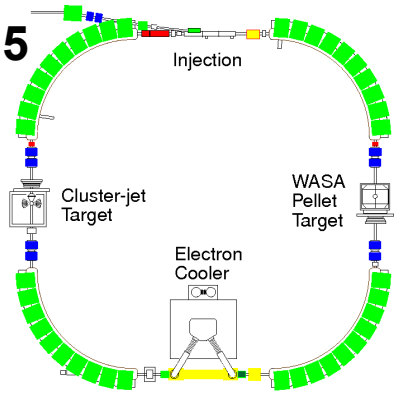
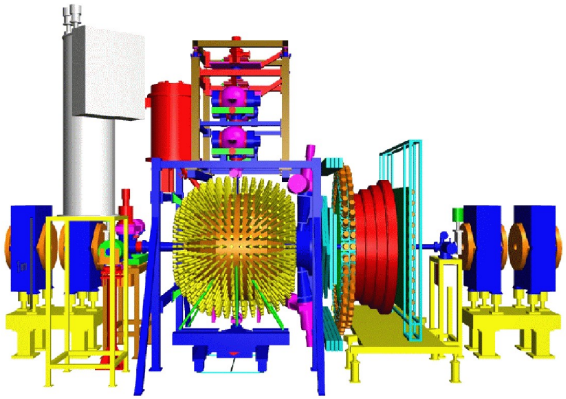
CELSIUS/WASA <2005

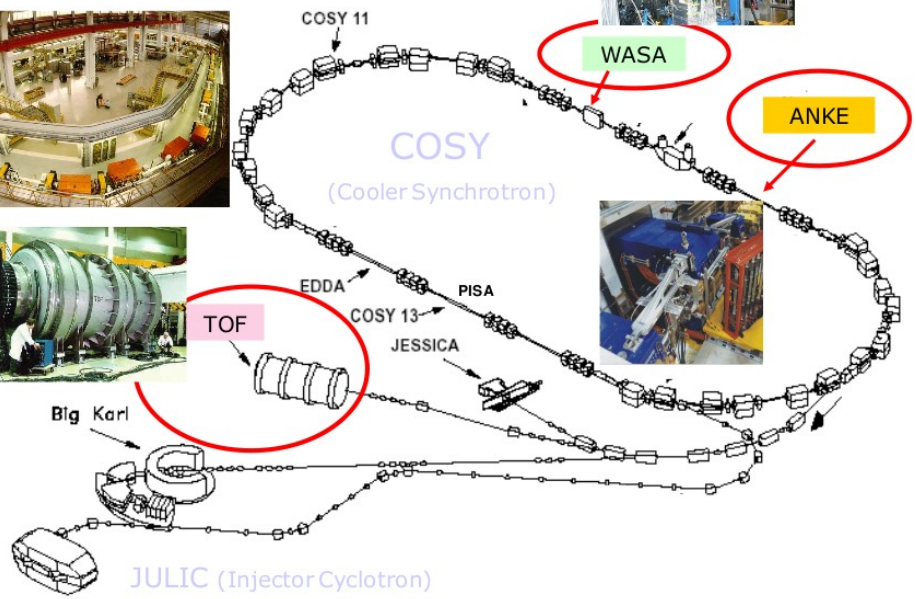


WASA



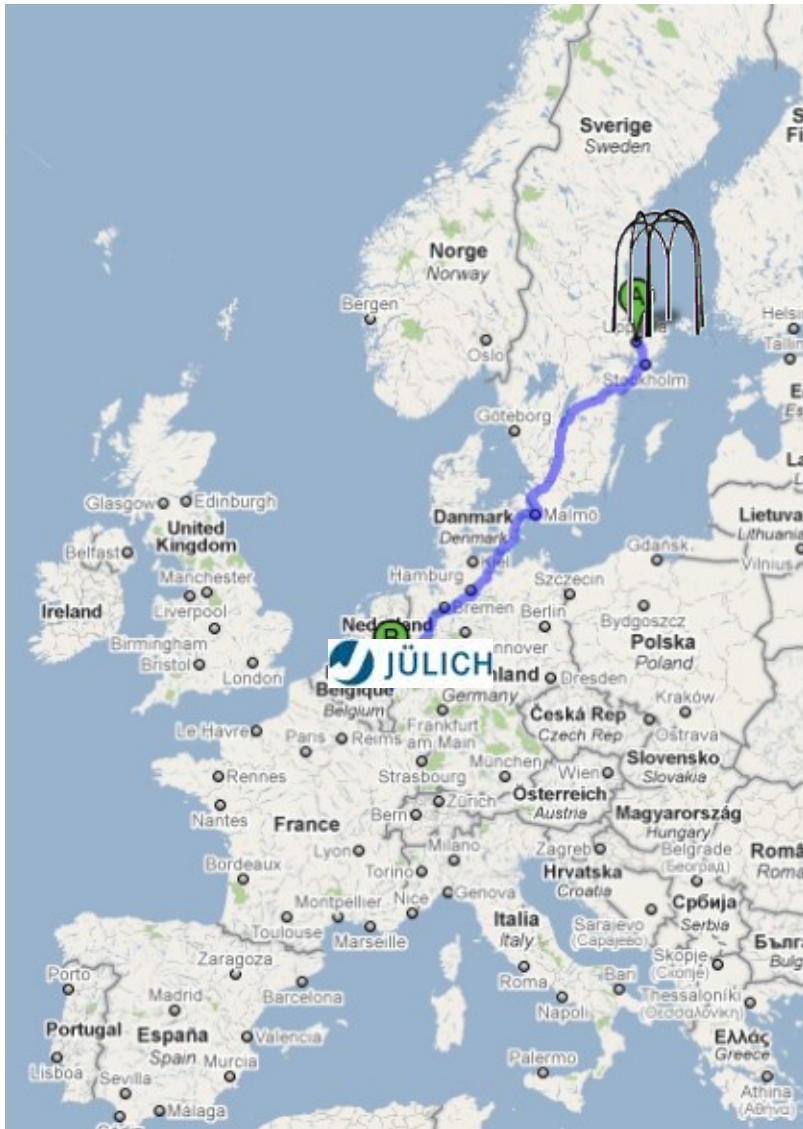
WASA-at-COSY >2007

JÜLICH FORSCHUNGSZENTRUM



Schematic overview COSY Facility (FZ-Jülich)

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



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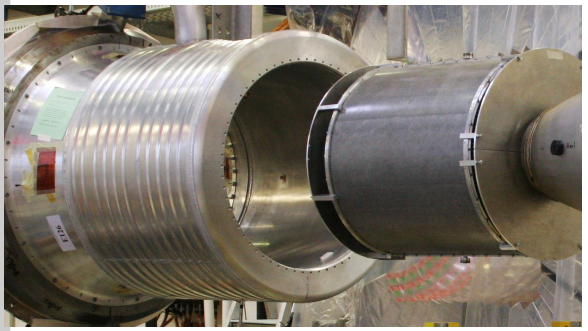
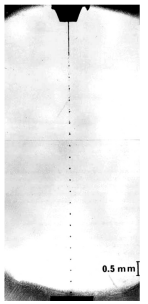
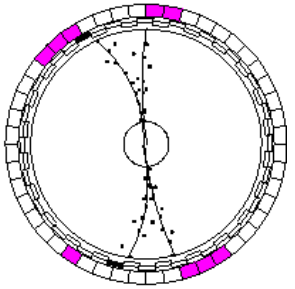
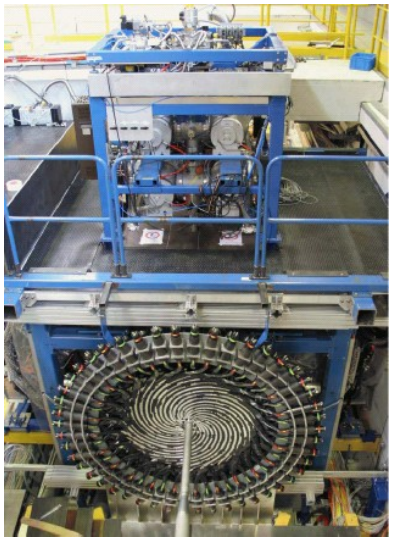
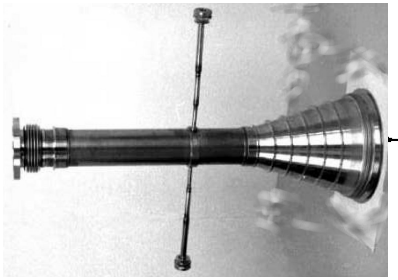
WASA detector

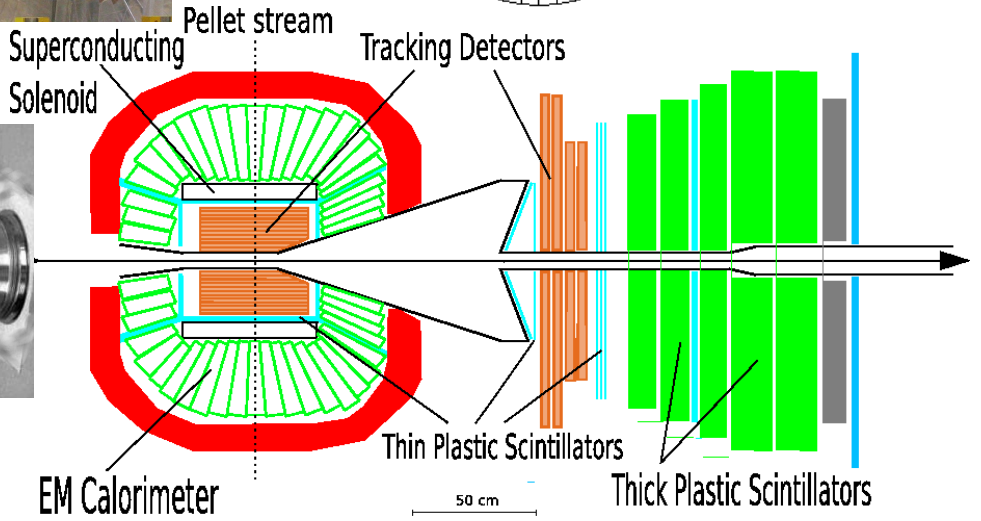


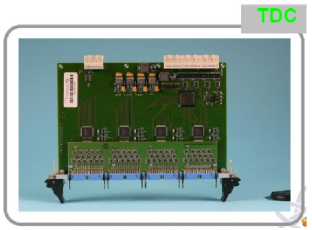


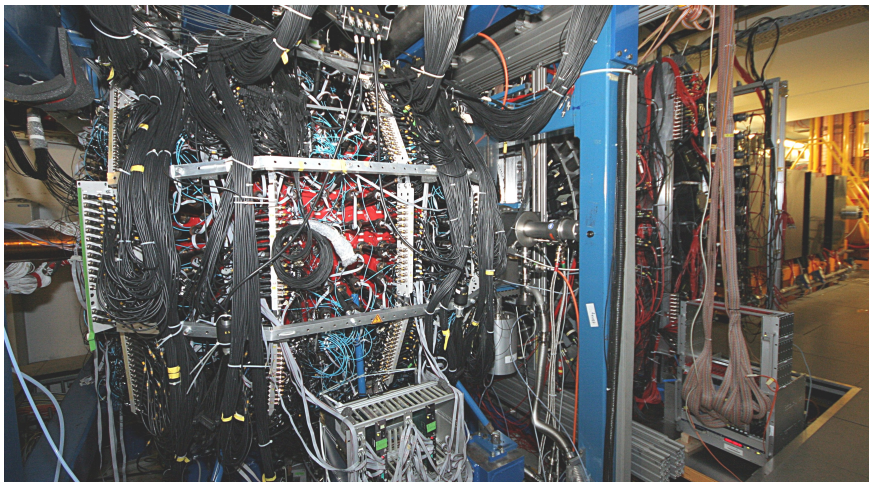


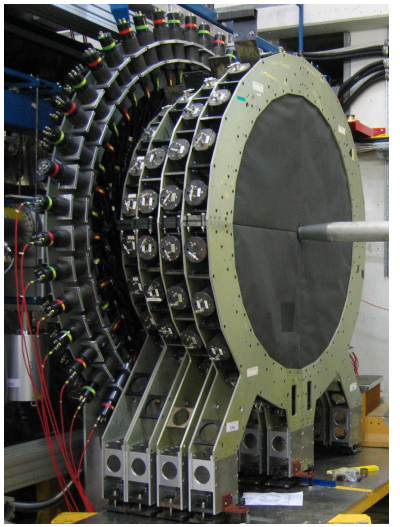












NIM A594,339

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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

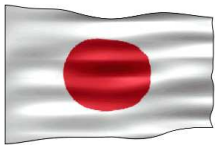
Tübingen

Lanzhou

IT coordinator : V. Hejny (Jülich)

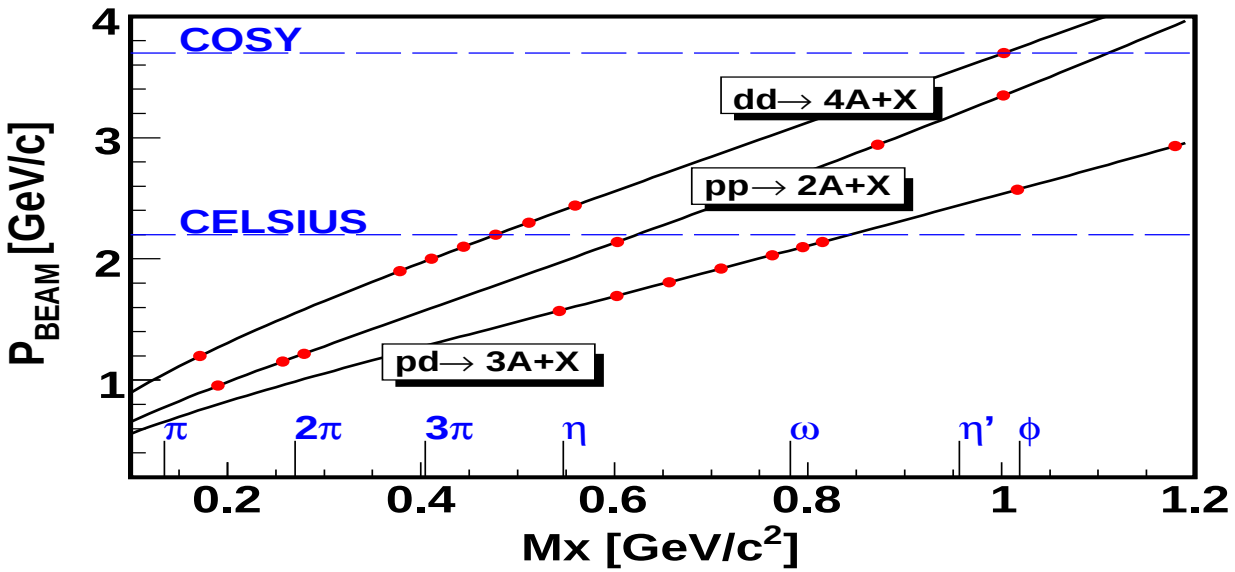
Mumbai

Sofia



KEK

Experimental programme



Goals:

- Symmetries and Symmetry Breaking

  Isopin, Chiral symmetry, Fundamental symmetries
- (crypto) exotic hadrons

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WASA-at-MESON2010

- Charge Symmetry Breaking in $dd \rightarrow \alpha\pi^0$
  - V. Hejny (talk overview) $dd \rightarrow \alpha\pi^0$
  - P. Podkopał(talk) $dd \rightarrow {}^3\mathrm{He}n\pi^0$
  - W.Weglorz $dd \rightarrow {}^3\mathrm{He}p\pi^-$
- ABC effect
  - T. Skorodko (talk) $pp \rightarrow pp\pi^0\pi^0$
  - M. Bashkanov $pn \rightarrow d\pi^0\pi^0$
  - A. Pricking (talk) $dd \rightarrow \alpha\pi\pi$
- ${}^4\mathrm{He}\eta/{}^3\mathrm{He}\eta$ bound states $\Rightarrow$ workshop 16th June
- Decays (production) of light mesons π^0, η, ω, η'
  - P. Adlarson, M. Zieliński $\eta \rightarrow \pi^+\pi^-\pi^0$
  - C.F. Redmer (talk) $\eta \rightarrow \pi^+\pi^-\gamma$
  - M. Hodana $\eta \rightarrow e^+e^-\gamma$
  - M. Berłowski $\eta \rightarrow e^+e^-$
  - H. Petrén $pp \rightarrow pp\eta$
  - B.R. Jany $pp \rightarrow pp\pi^0\pi^0\pi^0$
  - A. Jany $pd \rightarrow {}^3\mathrm{He}X$

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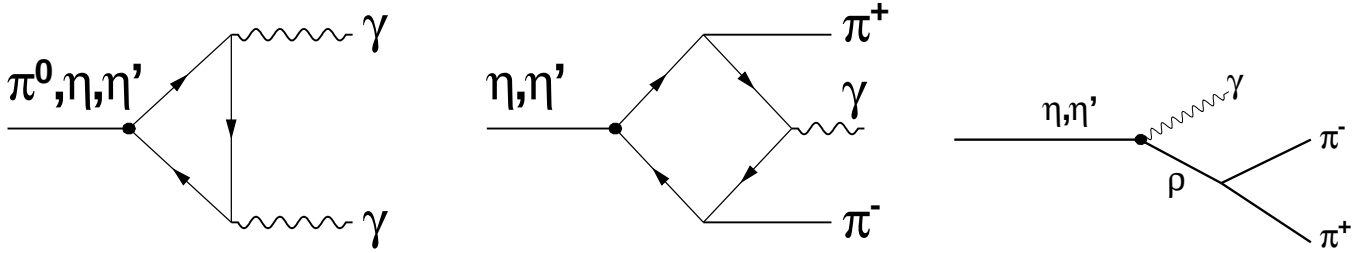
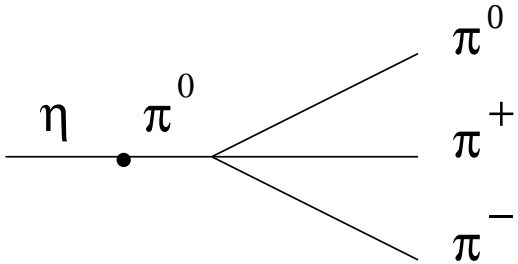
η decays: physics motivation

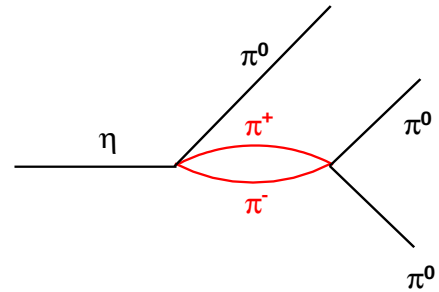
- Radiative decays
  Chiral anomaly vs Vector Meson Dominance



- Hadronic decays
  $\eta \to 3\pi$ $(m_d - m_u)$

$\pi - \pi$ interactions, cusp



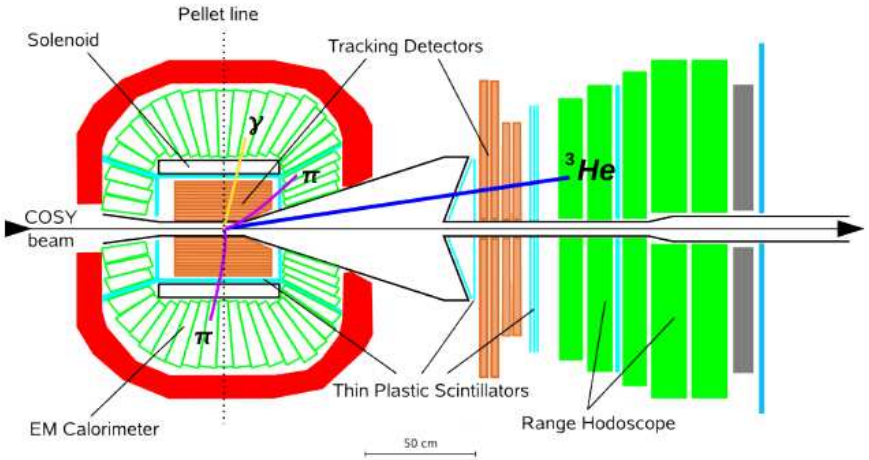


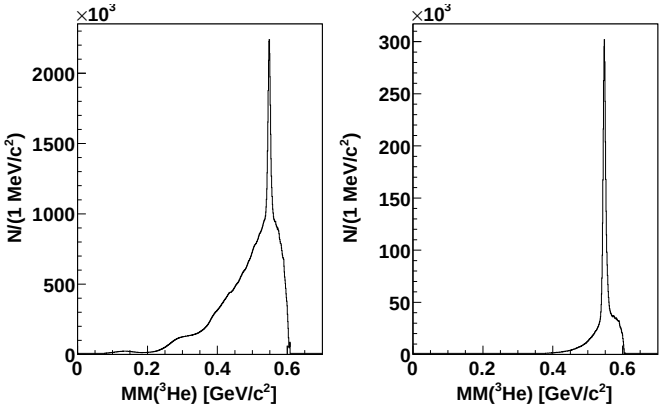
- SM tests:

  Rare decays *eg.* $\pi^0, \eta \to e^+e^-$, $\eta \to \pi^0 e^+e^-$
  Symmetries of the decays distributions *eg.*
  $\eta \to \pi^+\pi^-e^+e^-$ (CP), $\eta \to \pi^+\pi^-\pi 0$ (C)

Sources of the mesons

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

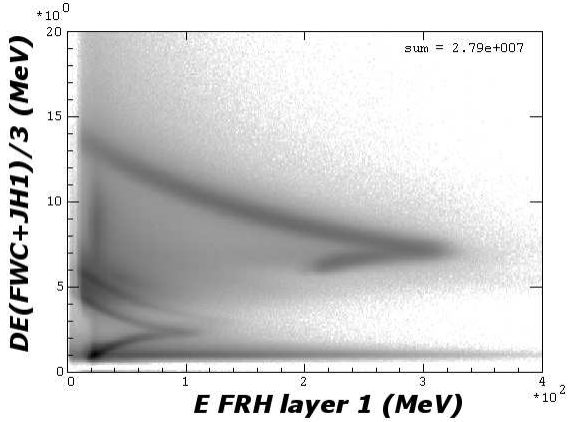




$pd \rightarrow {}^3\mathrm{He}X$

+ Clean trigger – ^{3}He only
+ $\Delta E({}^3\mathrm{He})$ good for heavier mesons
– Low cross section

$\Rightarrow$ For exploratory/precision studies



Sources of the mesons

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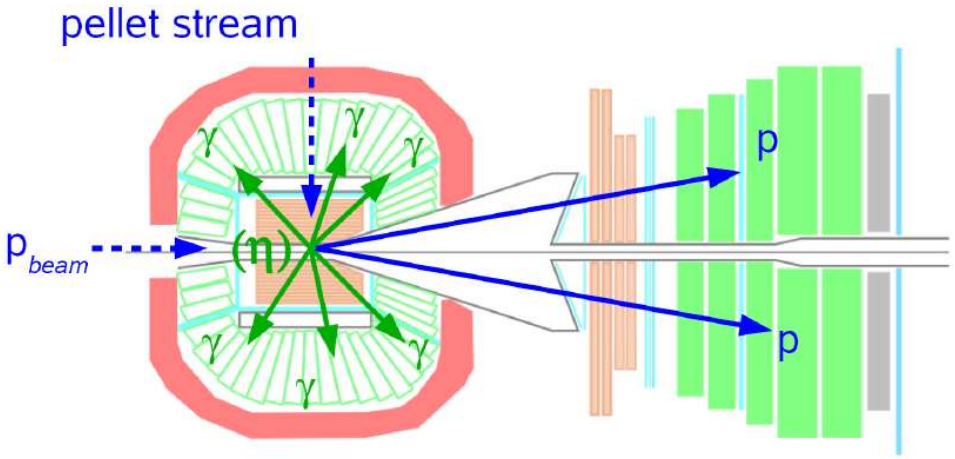

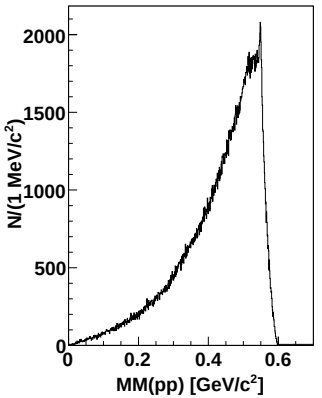

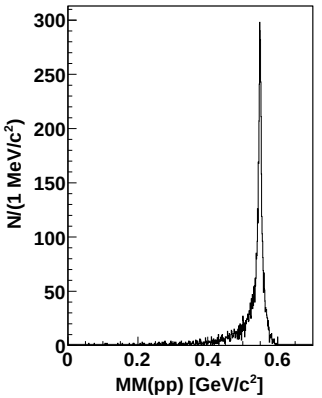

$pp \rightarrow ppX$

- – Trigger: conditions for decay mode
- – $\Delta E(p)$ only up to η (TOF, DIRC?)
- \+ Larger cross section

$\Rightarrow$ For rare decays with simple signature

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Collected data

$pd \rightarrow {}^3\mathrm{He}\eta$		$pp \rightarrow pp\eta$
	Beam energy	
T_p =1.0 GeV		T_p =1.4 GeV
	Yield/ cross section	
10 η/s (0.4μb)		$\geq$100 η/s (10μb)
	Collected data	
3×10^7 η decays		$>10^8$ η decays

Main data sets:

- $pd \rightarrow {}^3\mathrm{He}\eta$
  - $\Rightarrow$ (2008) – 1.1×10^7 ηs
    - (2009) – 2.0×10^7 ηs
  - $pp \rightarrow pp\eta$
    - $\Rightarrow$ 4 weeks (2007)+(2008)
      8 weeks (2010)

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Status of the analysis

	BR
$\eta \to \pi^0\pi^0\pi^0$	33%
$\eta \to \pi^+\pi^-\pi^0$	23%
$\eta \to \pi^+\pi^-\gamma$	5%
$\eta \to e^+e^-\gamma$	7×10^{-3}
$\eta \to \pi^+\pi^-e^+e^-$	4×10^{-4}
$\eta \to e^+e^-e^+e^-$	$\approx 2\times10^{-5}$
$(\eta \to \pi^0\gamma\gamma)$	$\approx 3\times10^{-4}$

- Rare decays: $\eta, \pi^0 \to e^+e^-$, $\eta \to \pi^0e^+e^-$
- Towards ω and η' decays

$\eta \to 3\pi$: motivation

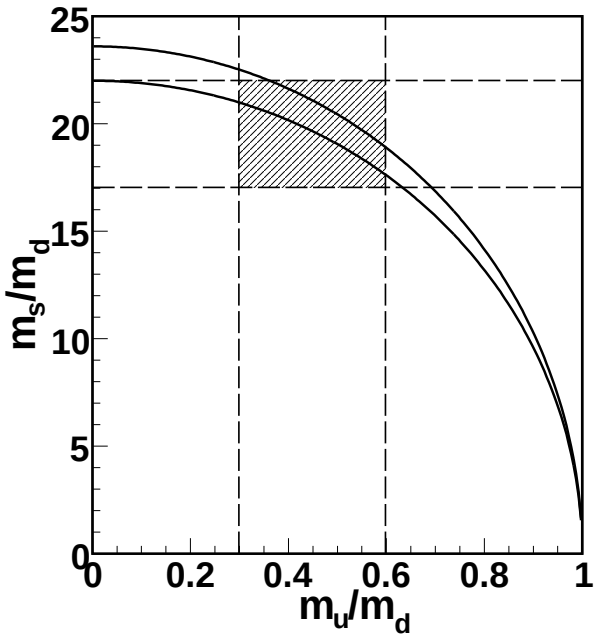
$$\Gamma_{exp} = \left(\frac{Q_D}{Q}\right)^4 \Gamma_{th}$$

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

$\Rightarrow$ 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



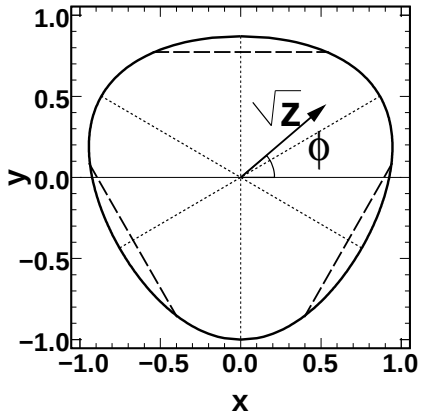
Test of ChPT calculations

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

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

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

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



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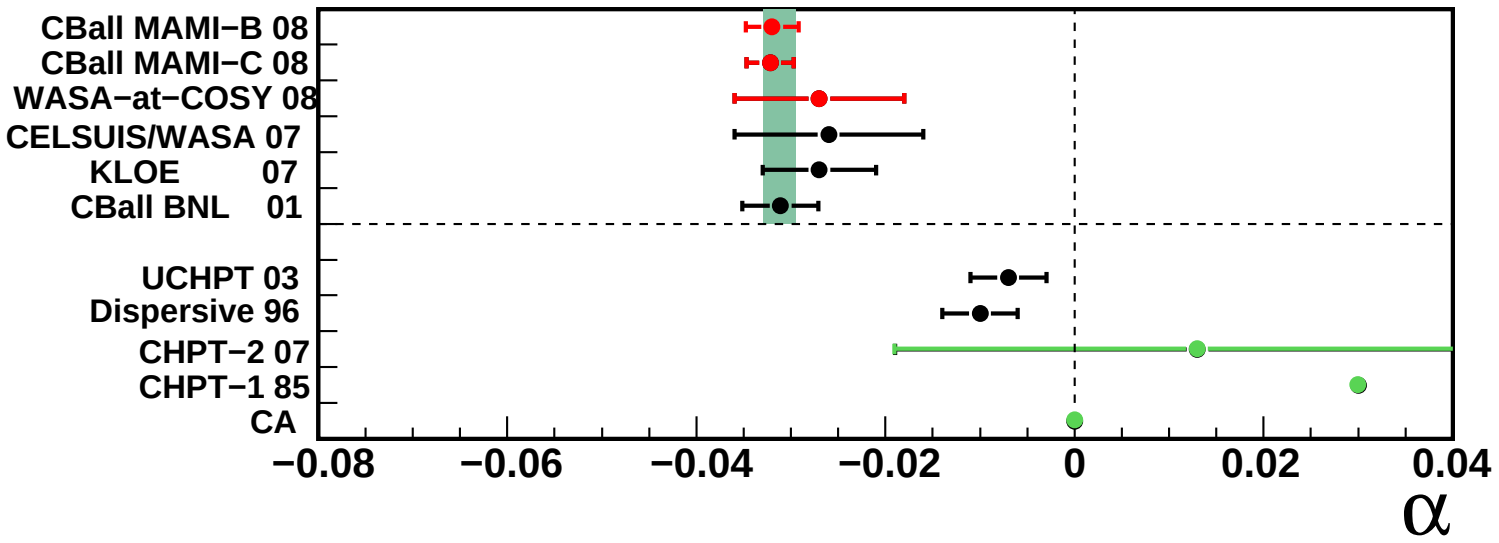
Status of $\eta \to 3\pi^0$ Dalitz plot



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

- $|\mathcal{A}_{000}(z,\phi)|^2 \propto 1 + 2\,\alpha\,z + \ldots$
- 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 $pp \to pp\eta$ PLB667,24(09)

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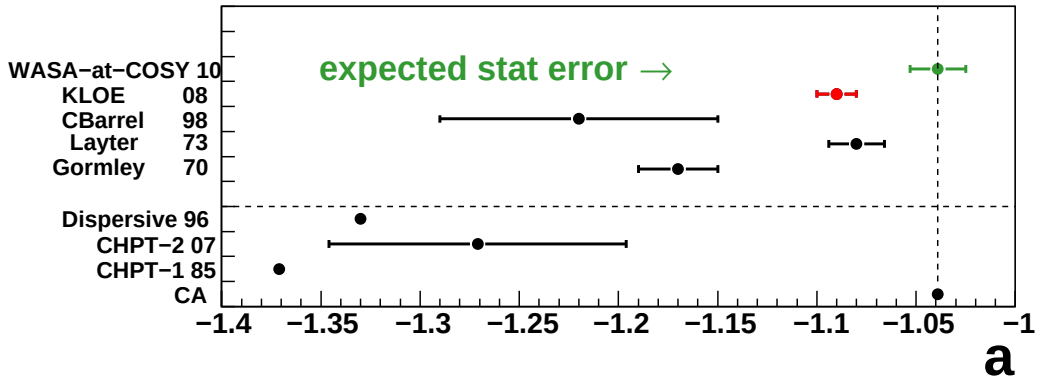
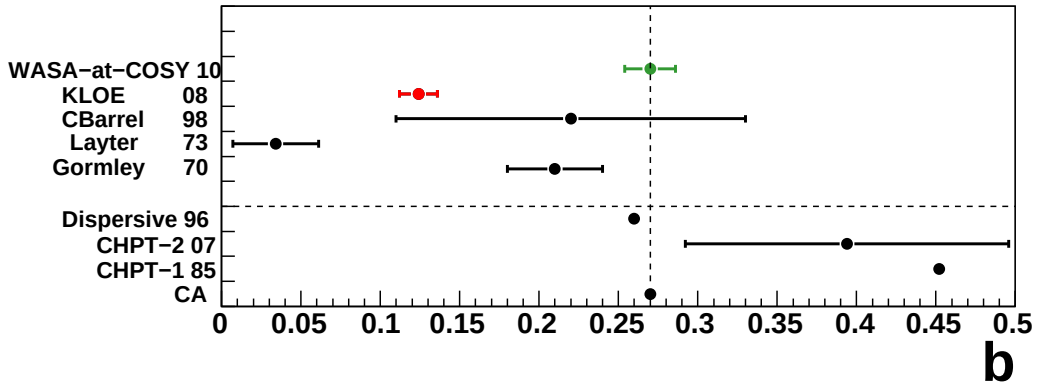
Status of $\eta \longrightarrow \pi^+\pi^-\pi^0$ Dalitz plot





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

- 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

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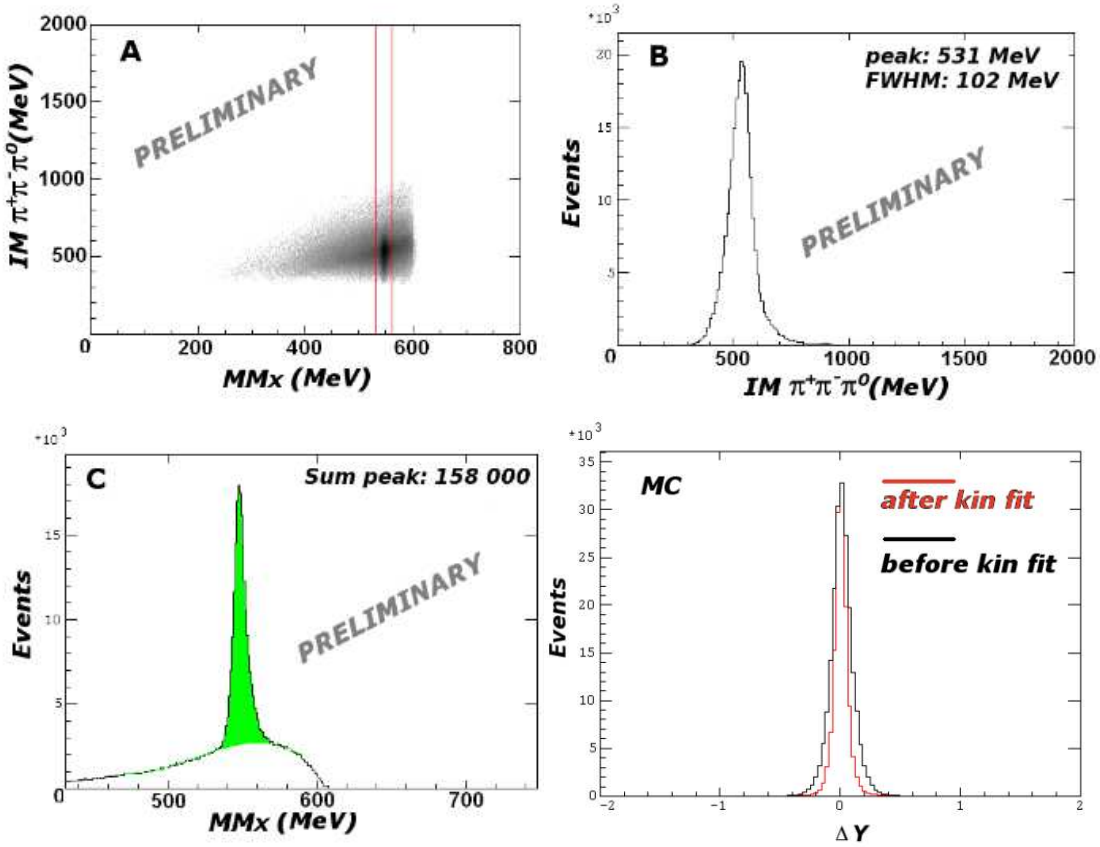
$\eta \to \pi^+\pi^-\pi^0$ in $pd \to {}^3\mathrm{He}\eta$



- 2008 data $1-2\times10^5$ $\eta \to \pi^+\pi^-\pi^0$ in the Dalitz plot
- background $pd \to {}^3\mathrm{He}\pi^+\pi^-\pi^0$

Analysis P. Adlarsson

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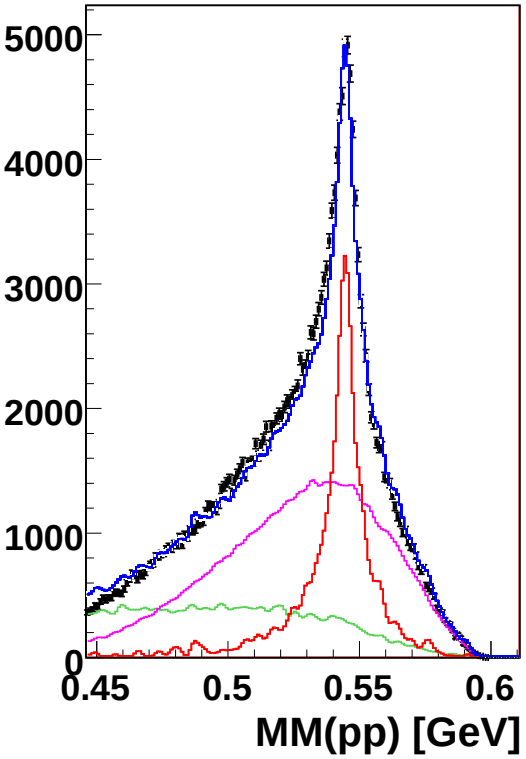
$\eta \to \pi^+\pi^-\pi^0$ in $pp \to pp\eta$



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

Analysis D. Coderre, M. Zieliński

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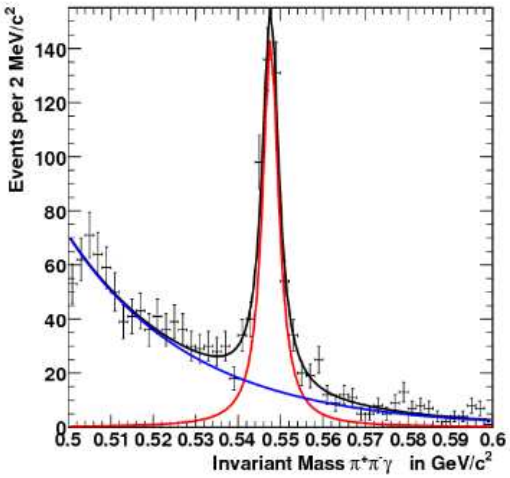
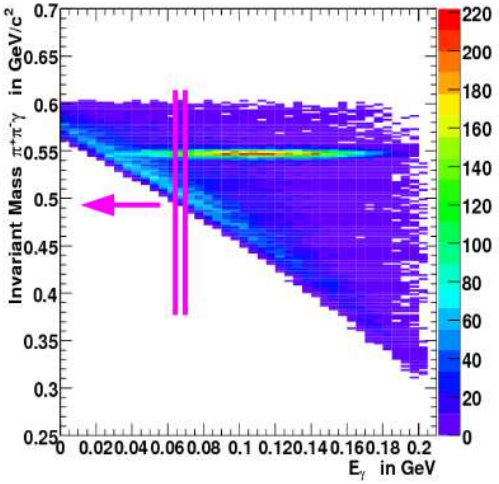
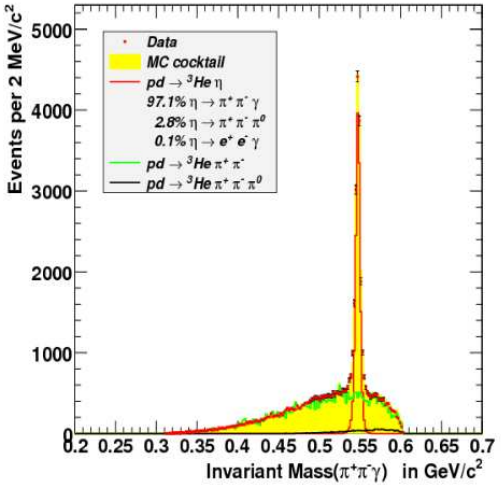
$\eta \to \pi^+\pi^-\gamma$

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







Analysis Ch. F. Redmer

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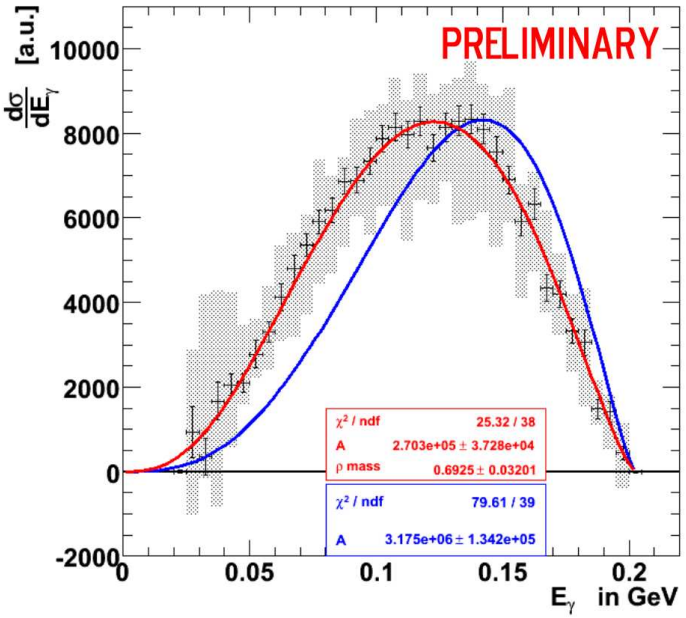
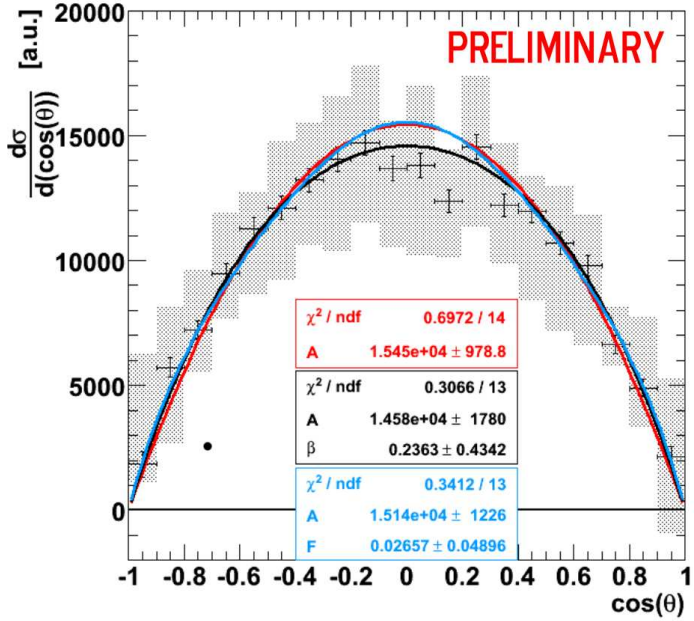
$\eta \to \pi^+\pi^-\gamma$ results

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



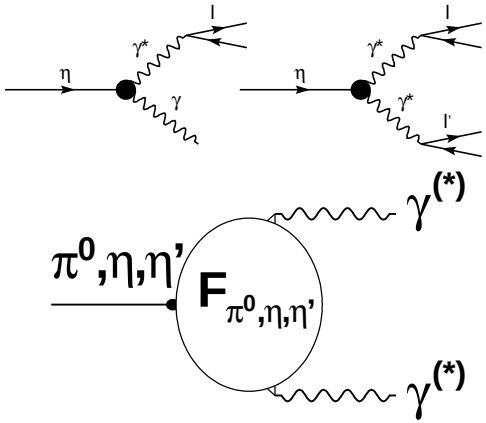


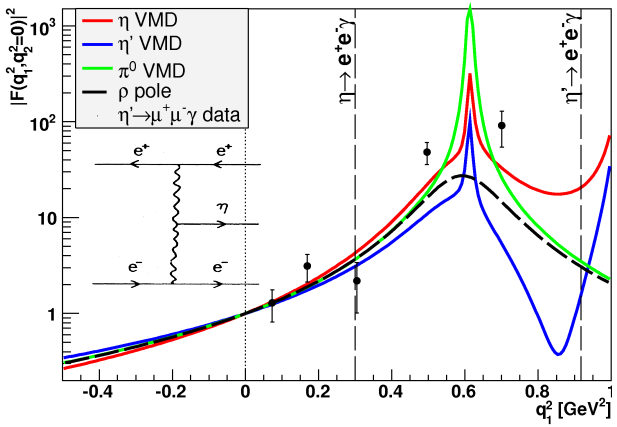
- simplest matrix element does not describe data (blue)
- good agreement with VMD (red)

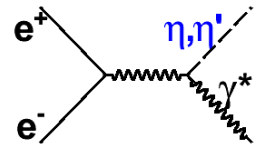
- p – wave interaction
- *higher partial wave contributions negligible*

Ch. F. Redmer

Conversion decays







Double off shell form factors:

- Test VMD
- Give SM contribution to

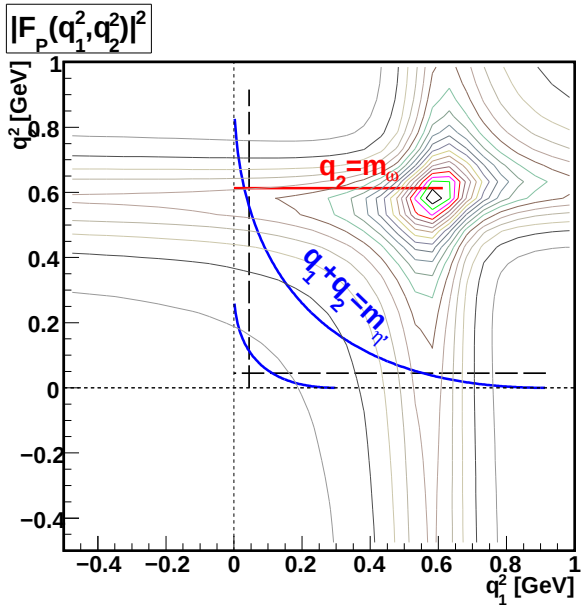
... $\mathcal{P} \to e^+e^-$

... muon $g-2$

- Decays of interest:

– $\eta \to e^+e^-e^+e^-$

– $\omega \to \pi^0 e^+e^-$ ...



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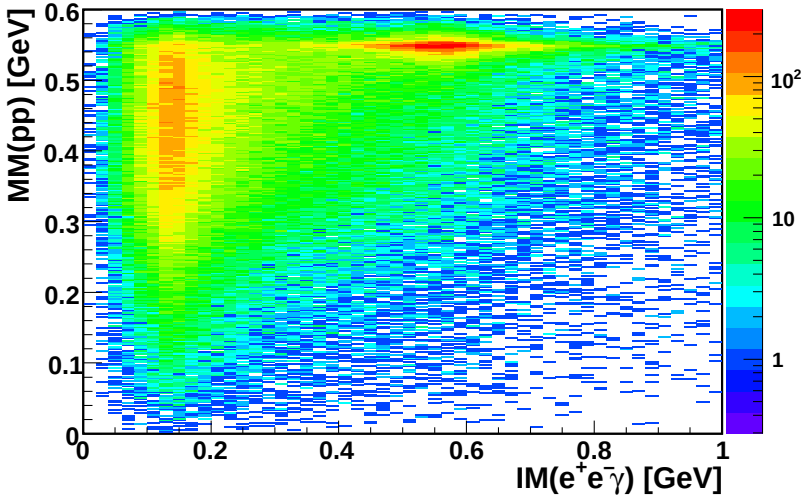
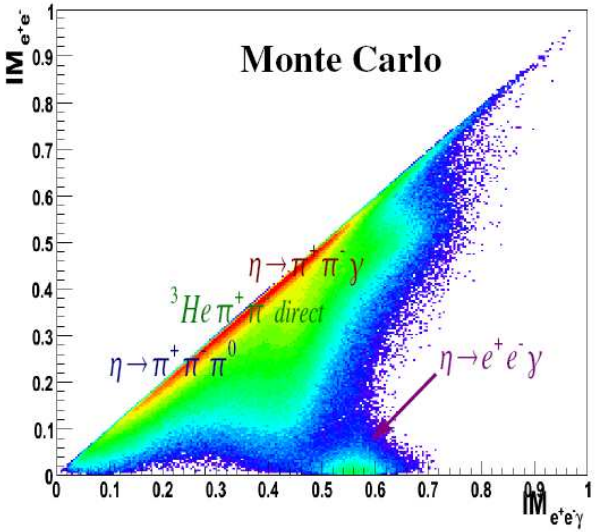
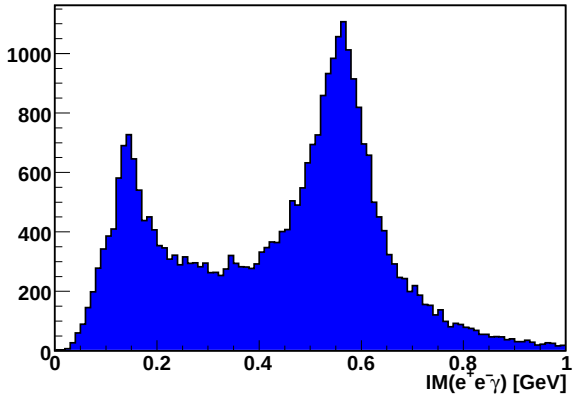
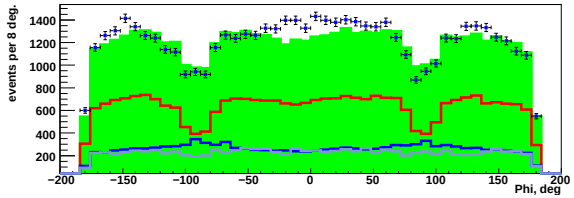
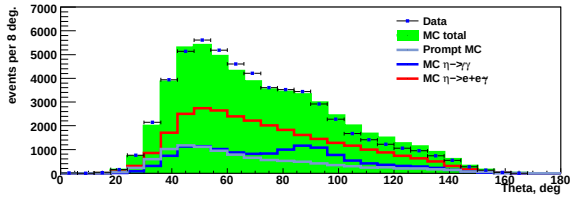
$\eta \to e^+e^-\gamma$











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

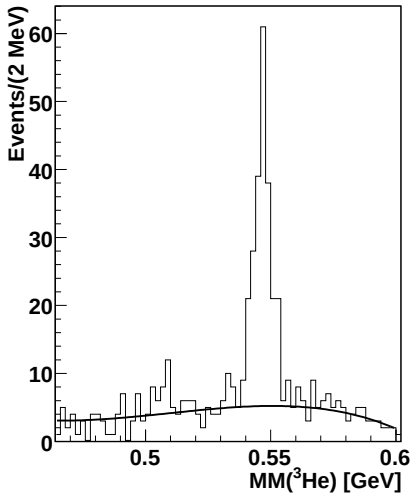
Analysis M. Berlowski, M. Hodana, L. Yurev

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

Exploratory analysis of the 2008 *pd* data

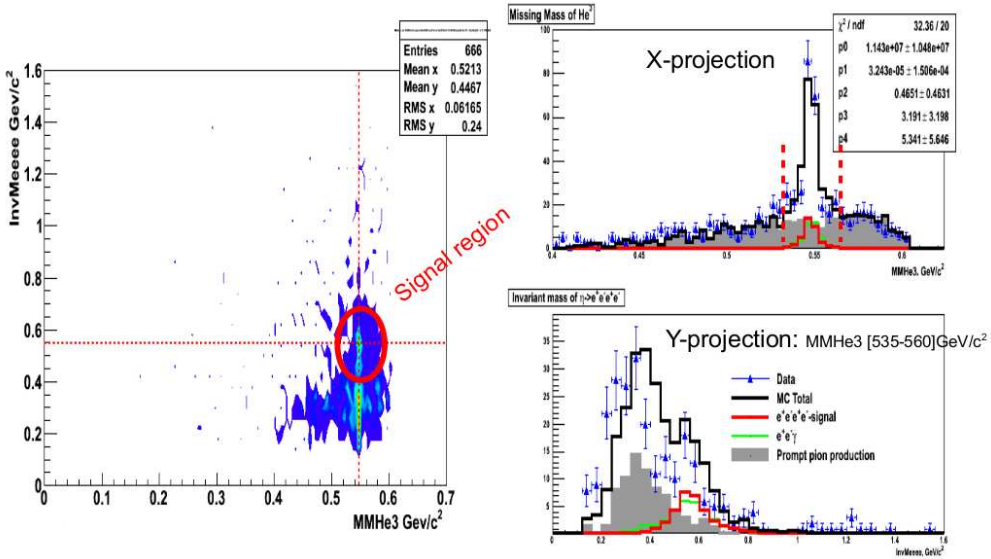
$\eta \to e^+e^-\pi^+\pi^-$

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



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

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



Analysis D. Coderre, M. Janusz, L.Yurev

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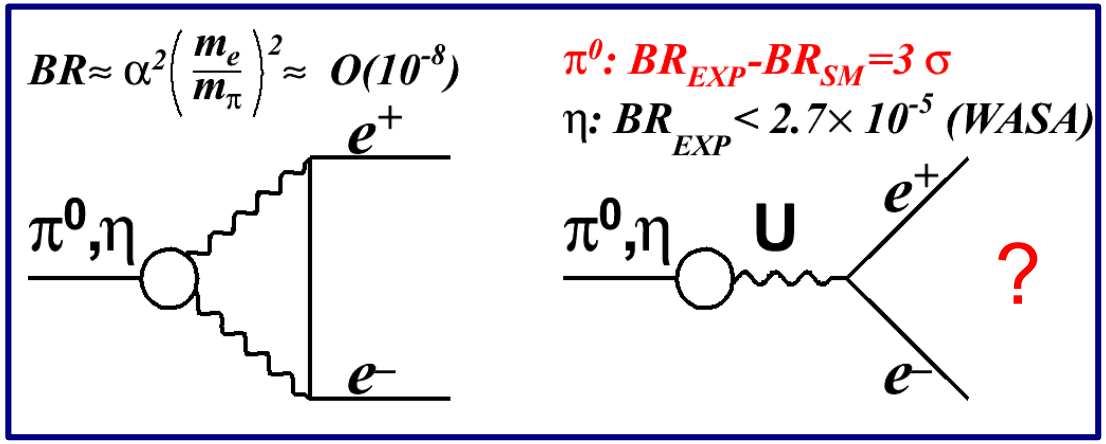
Rare decays: $\pi^0 \to e^+e^-$



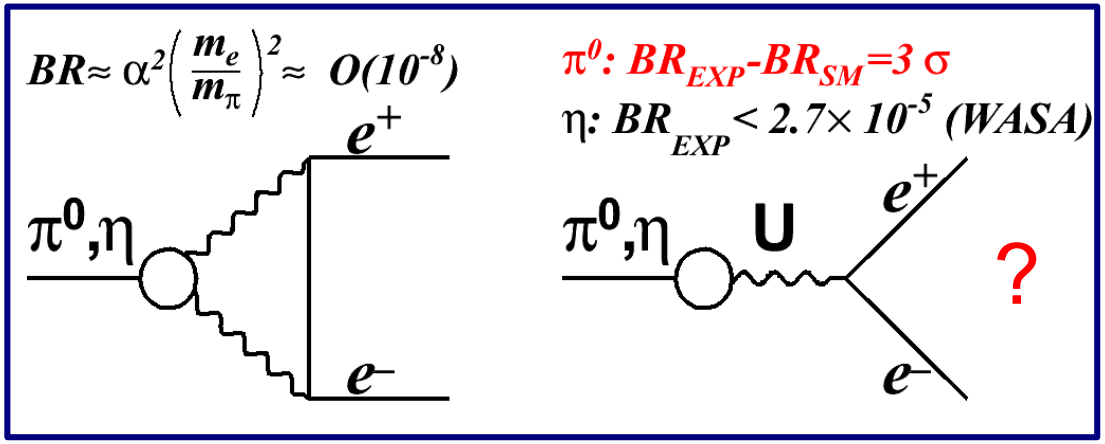
- Exp $BR_{\text{no-rad}} = (7.48 \pm 0.29_{stat} \pm 0.25_{syst}) \times 10^{-8}$
  KTeV (794 events) PRD75:012004,2007
- $BR^{\text{SM}}(\pi^0 \to e^+e^-) = (6.23 \pm 0.09) \times 10^{-8}$
  Dorokhov et al., PRD75:114007,2007
- $pp \to pp\pi^0$ $T_p = 0.55$ GeV (1.3 mb) below $pp \to pp\pi^+\pi^-$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

  reconstructed $\pi^0 \to e^+e^-\gamma$ 9/s (total 4.5×10^6)

  Expect about 100 $\pi^0 \to e^+e^-$

Analysis: C-O. Gullström

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



- 2008 $pp \to pp\eta$ data with 4.4×10^7 ηs:
- Goal improve BR limit

CELSIUS/WASA PRD77:032004(08)

acceptance 5%

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

Analysis: M. Berlowski

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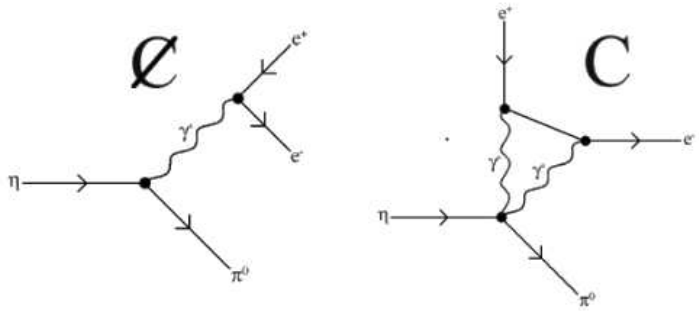
Rare decays: $\eta \to e^+e^-\pi^0$



- PDG $BR < 4\times10^{-5}$
- Test C up to $BR \approx 10^{-8}$ (decay via $\pi^0\gamma^*\gamma^*$)
- Analysis of 2008 $pd \to {}^3\mathrm{He}\eta$ data

  Goal: improve BR limit

  Background $pd \to {}^3\mathrm{He}\pi^0\pi^0$

  Acceptance $\approx$ 1%
- Continue with $pp \to pp\eta$ data

Analysis: A. Winnemöller

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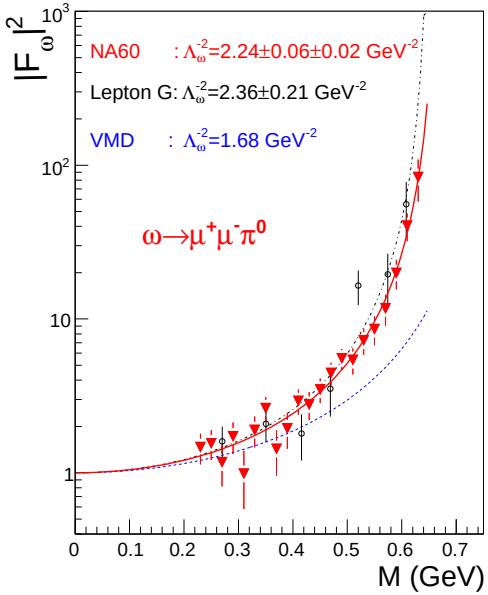
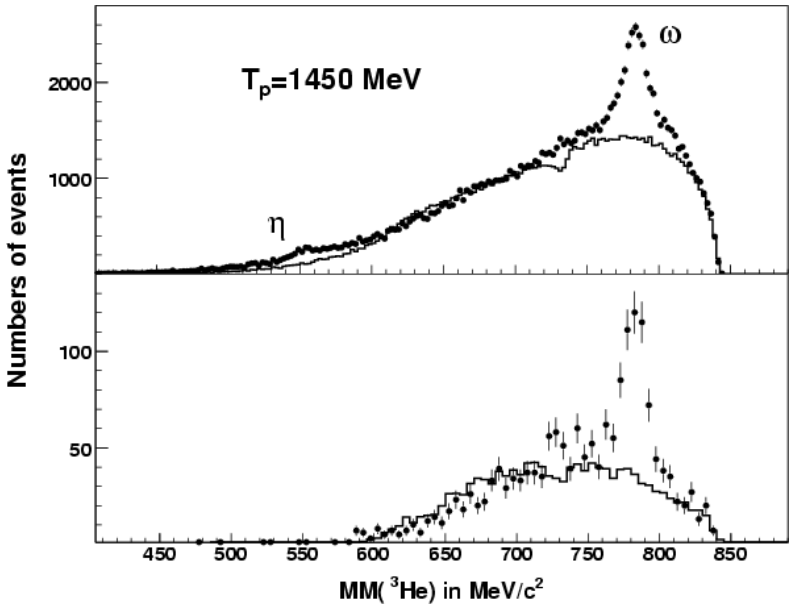
Towards ω decays

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



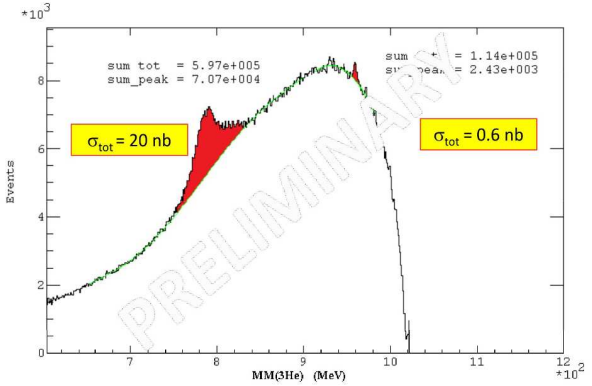


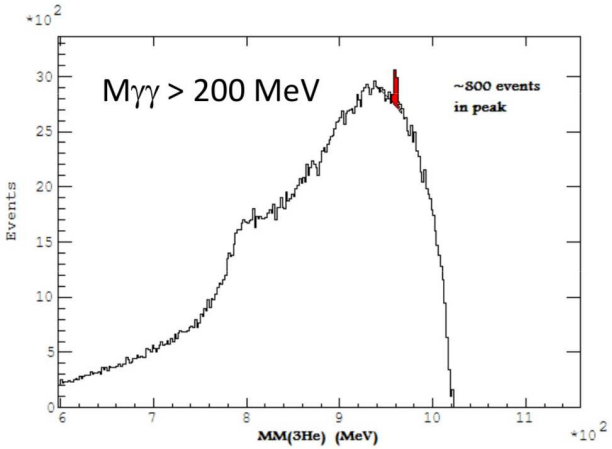
- ***pd*** $\to$ **^{3}Heω** at 1.45 GeV
- $\sigma = 85$ nb
- 2×10^6 ω/month (from $pd \to {}^3\mathrm{He}\eta$)

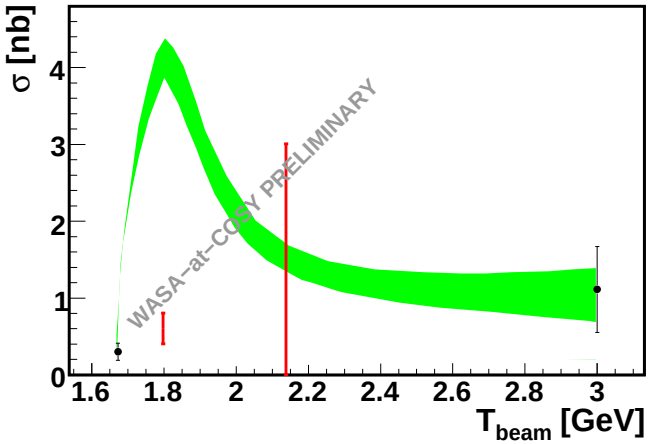
CELSIUS/WASA PLB668:258,08

- ***pp*** $\to$ ***pp*ω** at $Q = 60 - 90$ MeV (2.85–2.95 GeV/c)
- $\sigma = 6 - 10$ μb

Towards η' decays







green: nucl-th/9510010

black points: PRD9,1917(74), PRLB374,283(96)

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

Analysis J. Zlomanczuk, C. Zheng

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Outlook

- Analysis of 2008 *pd* data nearly ready
- *Second generation* analysis of 2009 *pd* data
- Analysis of new large statistics $pp \rightarrow pp\eta$ data
- Starting ω decay programme
- $\sigma(pd \rightarrow {}^3\mathrm{He}\eta') = \mathcal{O}(\mathrm{nb})$ 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 ...