What can be learned

from light meson decays

October 13, 2011 | Christoph Florian Redmer
                 for the WASA-at-COSY Collaboration

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WASA-at-COSY - Collaboration

Precision Tests of ChPT

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

Form Factors

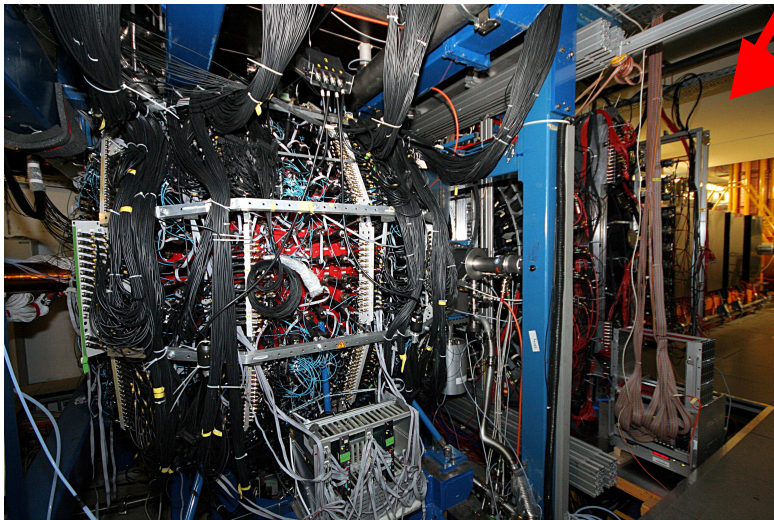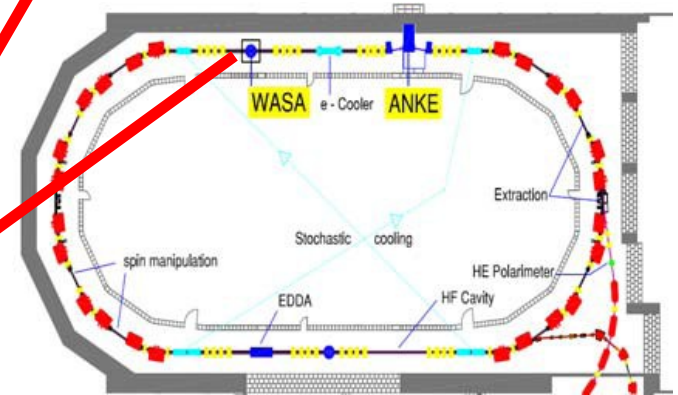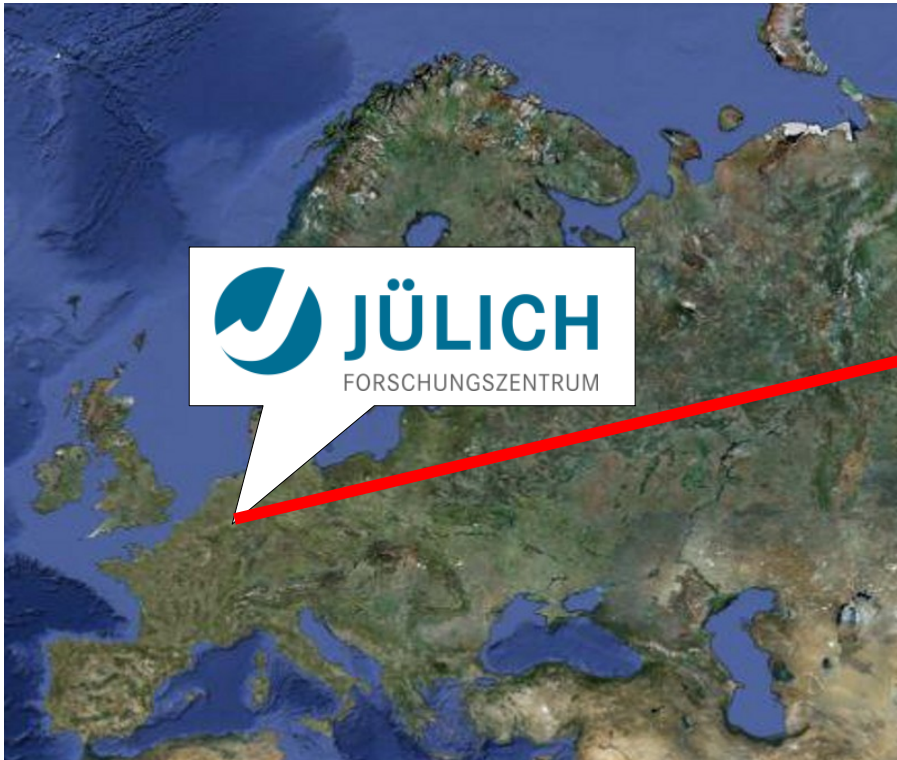- $\pi^0, \eta \to e^+e^-\gamma$
- $\pi^0, \eta \to e^+e^-e^+e^-$
- $\omega \to \pi^0 e^+e^-$

Tests of Standard Model

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

The WASA Facility at COSY

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

The WASA Facility at COSY
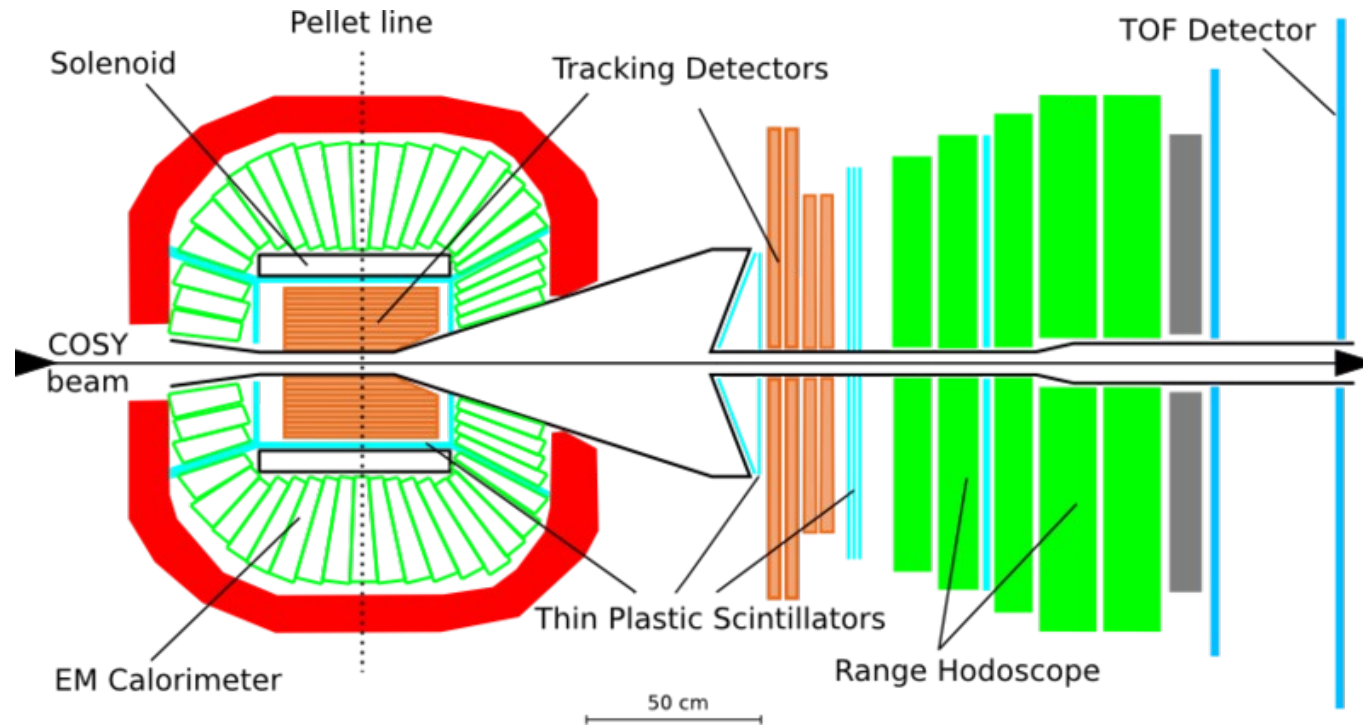

- high density pellet target

- 4π - acceptance

- charged and neutral particle detection

The WASA Facility at COSY
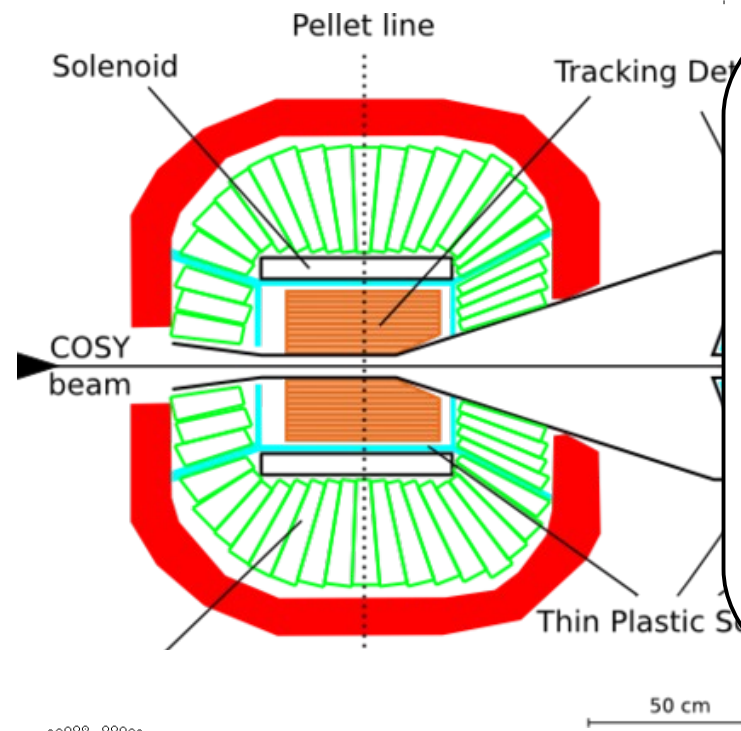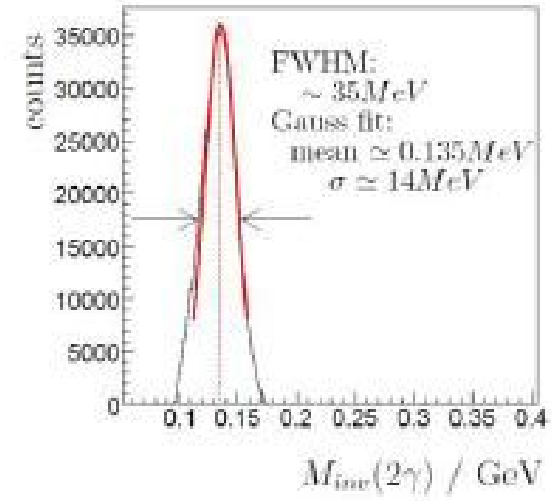
Central Detector

- Straw tube drift chamber
- Superconducting solenoid
- Plastic scintillators
- EM calorimeter
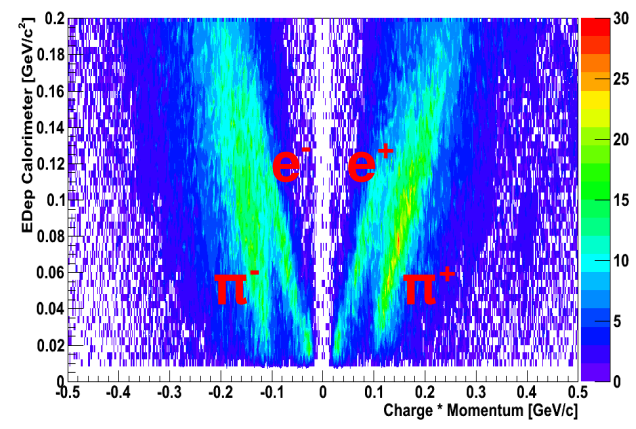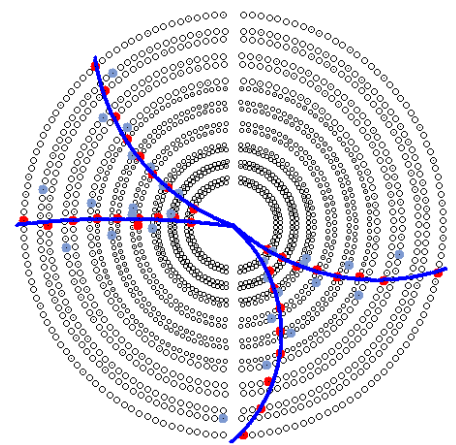
Pellet line

Solenoid

Tracking De

COSY beam

Thin Plastic S

50 cm

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

e^- e^+

π^- π^+

EDep Calorimeter [GeV/c²]

Charge * Momentum [GeV/c]

counts

FWHM:
$\sim 35 MeV$
Gauss fit:
mean $\simeq 0.135 MeV$
$\sigma \simeq 14 MeV$

$M_{inv}(2\gamma) / GeV$

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Forward Detector

- Straw tube drift chamber

- Plastic scintillators

  - energy

  - time-of-flight

Detectors

TOF Detector

tic Scintillators

Range Hodoscope

50 cm

DE Avrg. (FWC+JH1) (MeV)

He

d

p

E FRH layer 1 (MeV)

Counts per 0.002 GeV/c²

FWHM ≈ 7 MeV/c²

^{3}He-missing mass [GeV/c²]
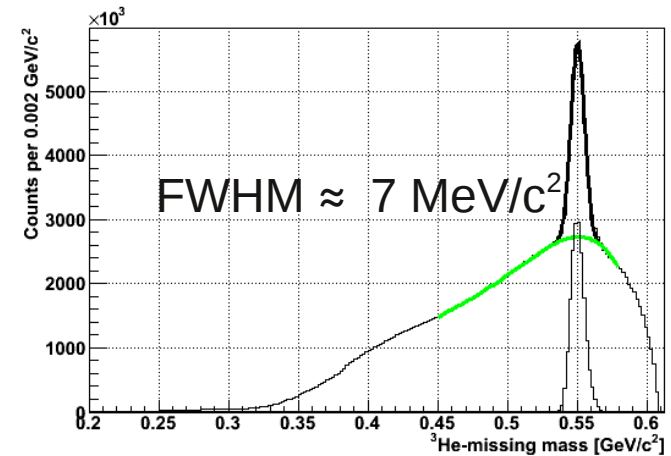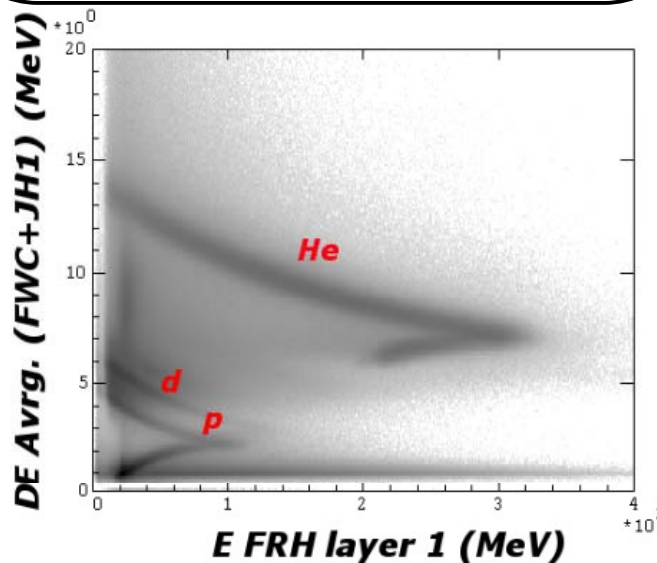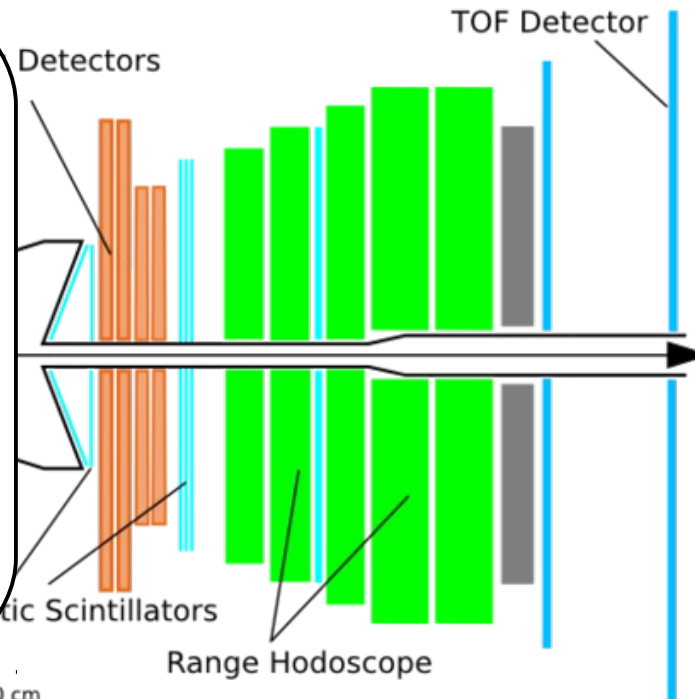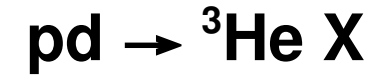
Production of Light Mesons

pp → pp X

- Large cross section

- Selective trigger needed

High statistics runs for rare decays

> Collected Data:
>
> - T_p = 550 MeV
>   - $3 \cdot 10^8$ tagged π^0 mesons
>
> - T_p = 1400 MeV
>   - $2 \cdot 10^7$ tagged $\eta \rightarrow \pi^+ \pi^- \pi^0$
>
> - T_p = 2060 MeV
>   - pp $\rightarrow$ pp ω

pd → ^{3}He X

- Lower cross section

- Unbiased trigger

Precision studies of not-so-rare decays

> Collected Data:
>
> - T_p = 1000 MeV
>   - $3 \cdot 10^7$ tagged η mesons
>
> - T_p = 1500 MeV
>   - $5 \cdot 10^5$ tagged ω mesons

The following slides will show only 1% of the total collected statistics!

η → π⁺π⁻π⁰

- Isospin violating process → sensitive to quark mass difference

$$\Gamma_{\text{exp}} = \left|\frac{Q_D}{Q}\right|^4 \cdot \bar{\Gamma}$$

$$Q^2 = \frac{m_d^2 - m_u^2}{m_s^2 - (m_d + m_u)^2/4}$$

$$Q_D = 24.2$$

$\bar{\Gamma}$: Γ at Dashen limit, from ChPT

- Study Dalitz plot to test ChPT　(implementation of ππ scattering)

- Dalitz plot density:

$$X = \frac{\sqrt{3}(T_1 - T_2)}{T_1 + T_2 + T_3} \qquad Y = \frac{3T_3}{T_1 + T_2 + T_3} - 1$$

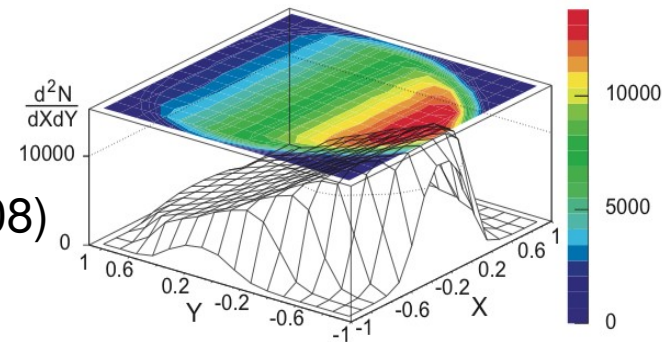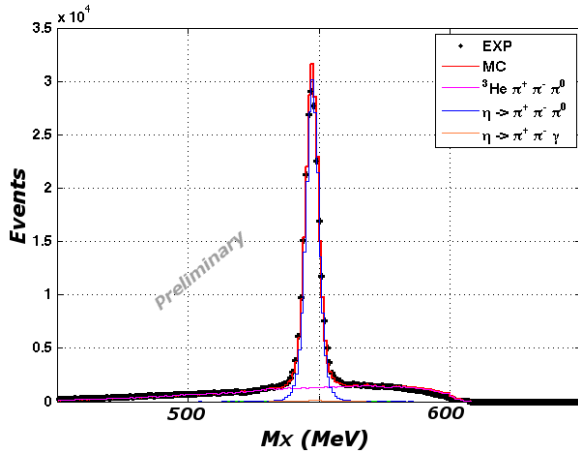 - $\Gamma \propto |A(X,Y)|^2 = N \cdot (1 + aY + bY^2 + dX^2 + fY^3 + \ldots)$

- Recent precision result
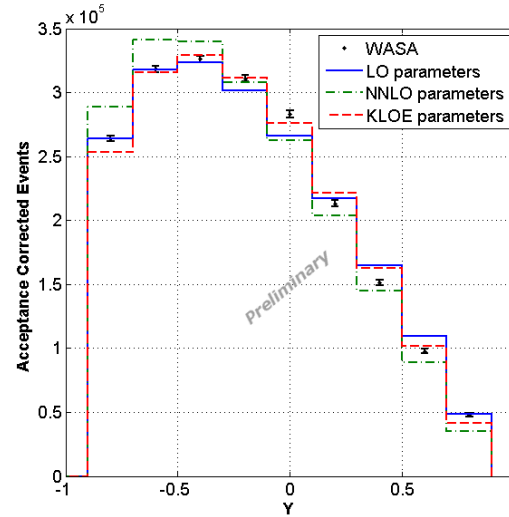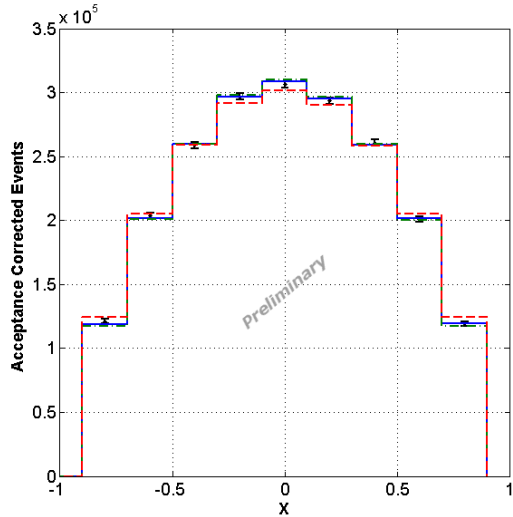
  - KLOE (1.34·10⁶ events) JHEP 0805:006(08)

- Comparison with predictions:

  - *Parameter a, b, f do not agree with NNLO ChPT*

Bijnens, Ghobani: JHEP 11:030(07)

η → π⁺π⁻π⁰

- 10^7 tagged η mesons analyzed
- bin wise background subtraction
- $2 \cdot 10^5$ events in Dalitz plot
- Systematic studies in progress

Analysis:
 P. Adlarson (U Uppsala)

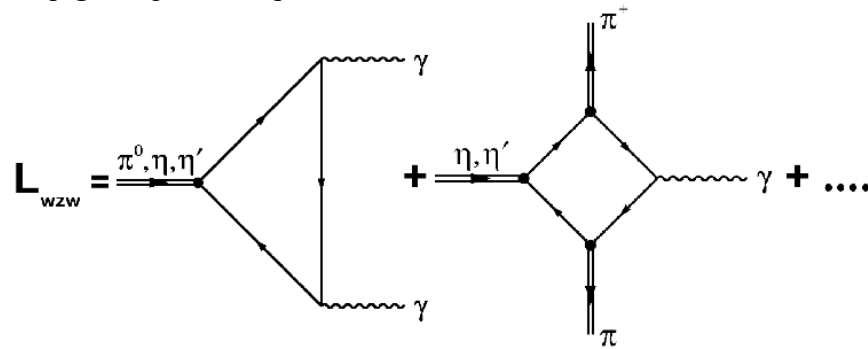Talk: Tue. 17:30

Two independent measurements from WASA-at-COSY !

- Analysis of pp data: M. Zielinski (JU Cracow)
- At least an order of magnitude more statistics on disk ...

η → π⁺π⁻γ

At chiral limit:

Include FSI by unitarized extensions:

$L_{wzw} = $ [diagram with π^0, η, η' and γ] $+$ [diagram with η, η', π^+, π^-, γ] $+$ ....

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

- 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

Factor two off from exp. decay rate !

Observables: Branching ratio and $m^2_{\pi\pi}$ / E_γ distribution

Previous Measurements of $m^2_{\pi\pi}$ / E_γ distribution:
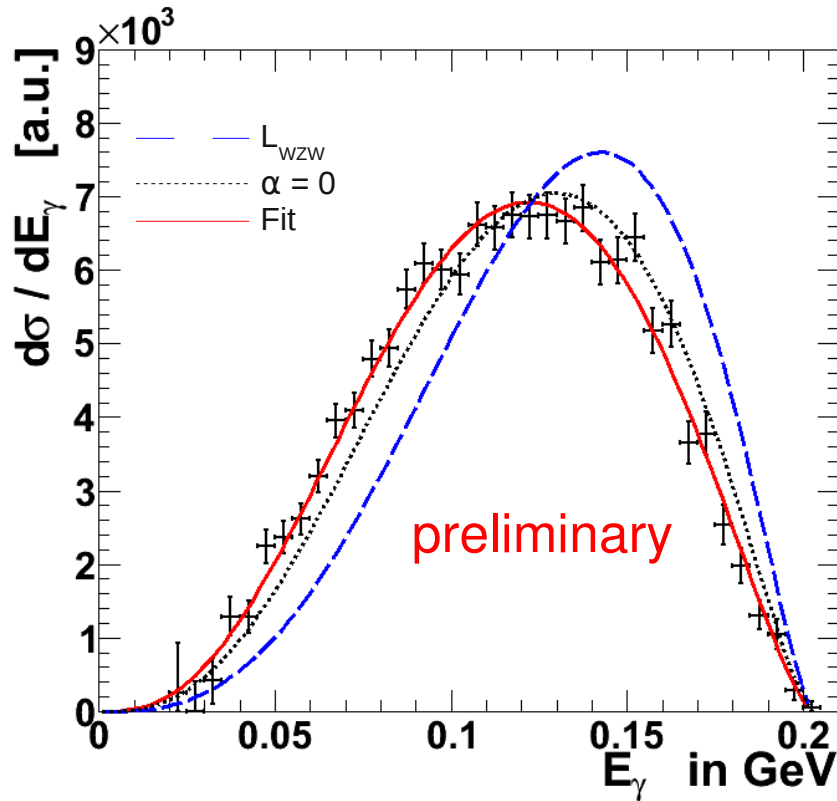
7250 events   M. Gormley et al.   Phys.Rev. D2 (1970) 501

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

η → π⁺π⁻γ

preliminary

simplest matrix element (L_{WZW}):

$$\left|A_\eta(s=0, t=0, u=0)\right|^2 \;\propto\; q^2 E_\gamma^2 \sin^2\theta$$

realistic description:

$$\left|A_\eta(s_{\pi\pi})\right|^2 = \left|A_\eta(0,0,0)\cdot F(s_{\pi\pi})\right|^2$$
$$= \left|A_\eta(0,0,0)\cdot\left(F_{PV}\cdot(1+\alpha\, s_{\pi\pi})\right)\right|^2$$

Preliminary Result:
α = 2.0 ± 0.3$_{stat}$ **± 1.0**$_{syst}$
Analysis: C.F. R. (U Uppsala)
Submitted to PLB, arXiv:1107:5277

- 13340 ± 140 events extracted (based on 10^7 tagged η mesons)

- model independent description of E_γ with a single parameter α

F. Stollenwerk et al.,
arXiv:1108:2419

- new analysis started: D. Lersch (FZ Jülich)

- Goal: E_γ distribution and branching ratio

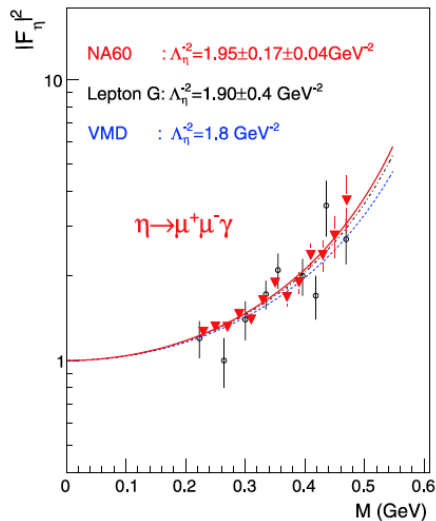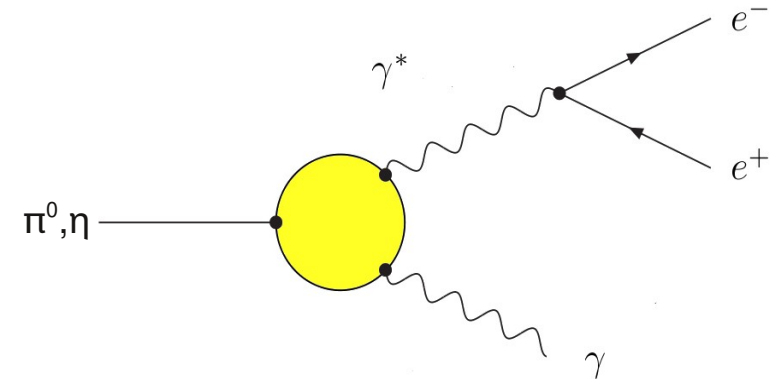# π⁰, η → e⁺e⁻γ

- **determination of transition form factor in the time-like region**

  - study el.-mag. structure of the decaying neutral meson

  - Input to hadronic contribution of the light-by-light scattering (g-2 of μ)

$$\frac{d\Gamma_{e^+e^+\gamma}}{dq^2} = \left[\frac{d\Gamma_{e^+e^+\gamma}}{dq^2}\right]_{QED} \cdot |F(q^2)|$$
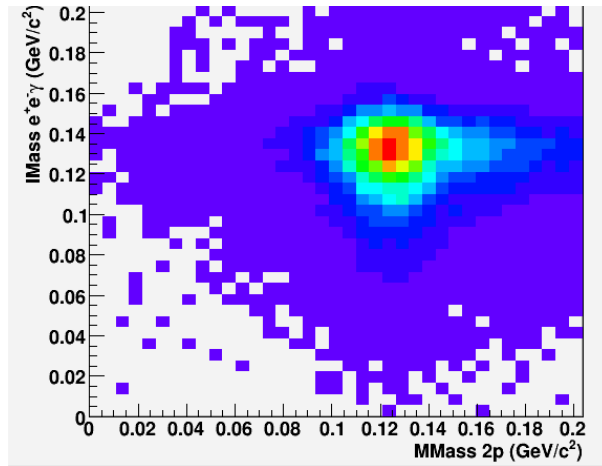
$$F(q^2) \approx 1 + \frac{q^2}{\Lambda^2} = 1 + bq^2$$

Recent result for η transition form factor:

NA60: b = (1.95 ± 0.17 ± 0.05) GeV⁻²

- periphal In-In collisions at 160 AGeV
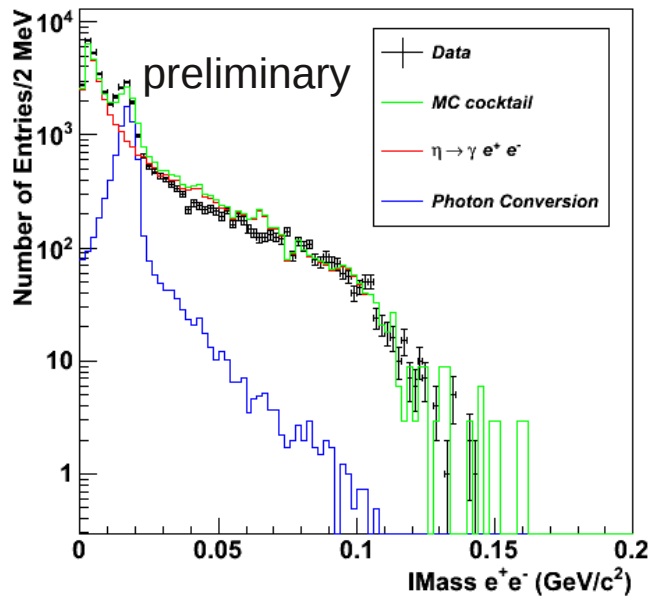- η → μ⁺μ⁻γ
- no photon measurement
- decomposition of inclusive di-muon spectrum

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

$1.2 \cdot 10^6$ events reconstructed

preliminary

Analysis: C.-O. Gullström (U Uppsala)
Talk :   Mon. 17:50

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

preliminary
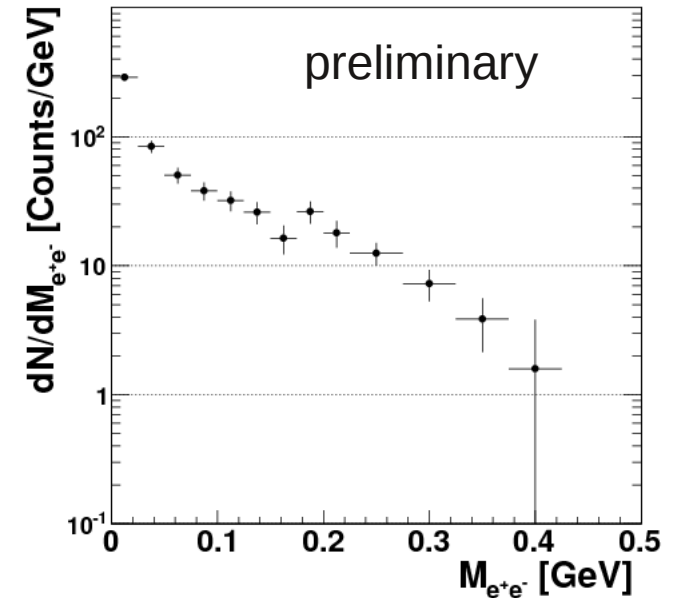
- 700 events reconstructed
- 10^7 tagged η mesons analyzed

Analysis: M. Hodana (JU Cracow)
             H. Bhatt (IIT Bombay)
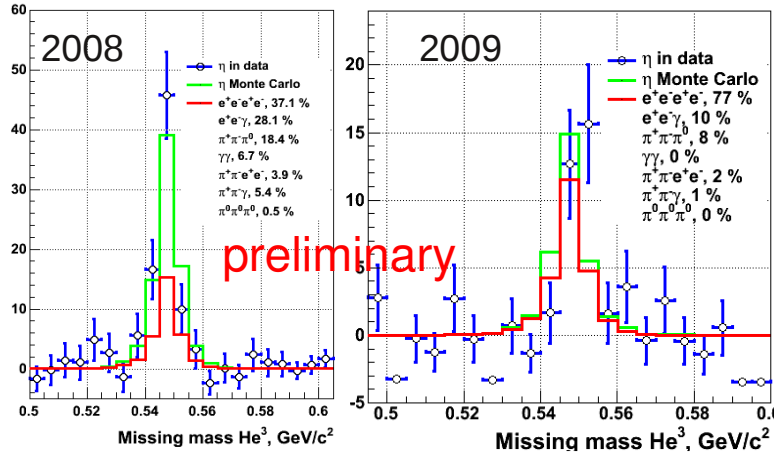
Work in progress:
- acceptance correction
- systematics

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STORI'11
LNF, Frascati
October 13, 2011

η → e⁺e⁻e⁺e⁻

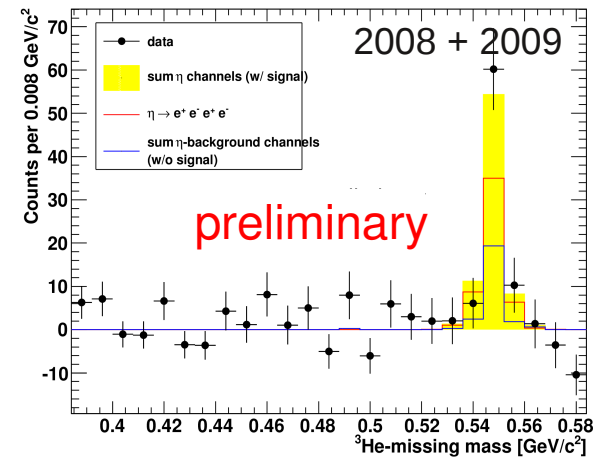- 3·10⁷ tagged η events analyzed

- two independent analyses

- Conditions on decay topology

- 50 ± 20 signal events

- S/B ~ 3/1

Analysis: L. Yurev (JINR Dubna)

- Advanced PID using ANN

- 52 ± 13 signal events

- S/B ~ 2/1

Analysis: P. Wurm (FZ Jülich)

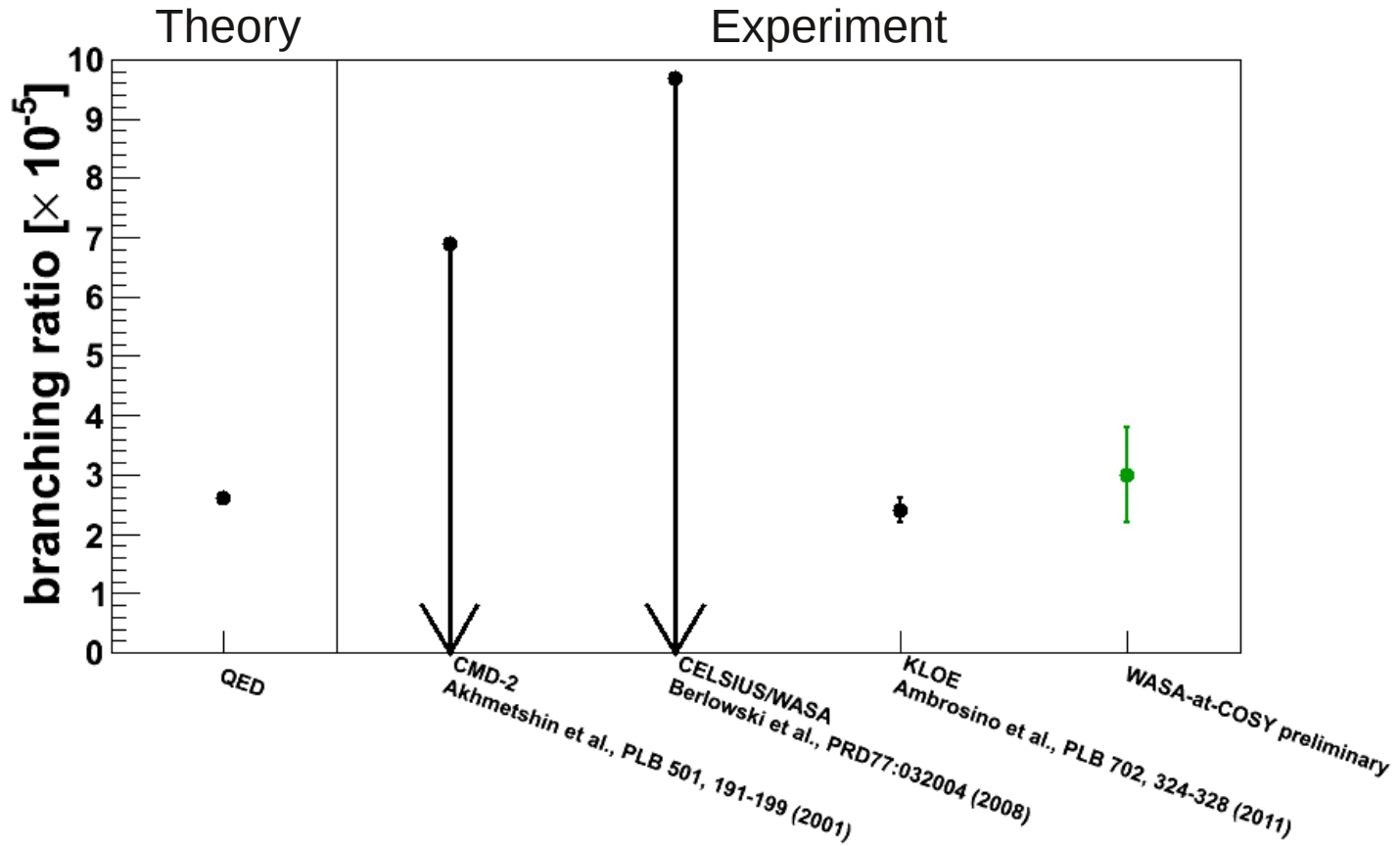- Preliminary branching ratio: $(3.0 \pm 0.8_{stat} \pm 0.7_{syst\ (norm.)}) \cdot 10^{-5}$

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WASA-at-COSY

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

- Preliminary: Agreement with KLOE result

- At least an order of magnitude more statistics already on disk
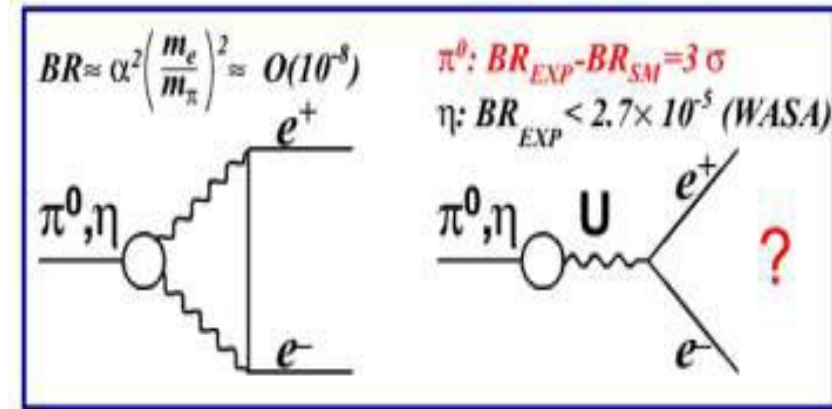
  - probe form factor $F(q_1^2, q_2^2)$

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

- SM: Two photon process

  - Suppressed w. r. t. $\pi^0, \eta \to \gamma\gamma$ by α^2 and $2(m_e/m_{\pi,\eta})^2$

  - $BR(\pi^0 \to e^+e^-) \approx 6 \cdot 10^{-8}$

  - $BR(\eta \to e^+e^-) \approx 5 \cdot 10^{-9}$

  - Possible physics beyond SM ?

e.g.: Boehm, Fayet NPB683, 2004
Kahn et al. arXiv:0712.0007

Light (MeV) Dark Matter

  - Neutral scalar χ, $m_\chi \sim 1 - 10$ MeV

  - $\chi\chi \to e^+e^- \Rightarrow$ 511 keV line from galactic center

  - Annihilation via light vector boson U, $m_U \sim 10 - 100$ MeV

  - Coupling of U to both l and q could increase $BR(\pi^0, \eta \to e^+e^-)$

$\pi^0 \rightarrow e^+e^-$
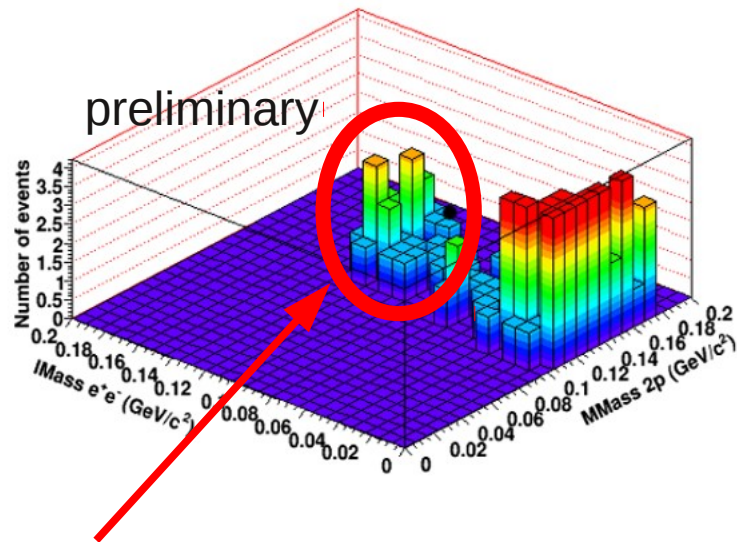
Recent KTeV result:

$BR = (7.48 \pm 0.29_{stat} \pm 0.25_{sys}) \cdot 10^{-8}$

3σ deviation from SM prediction

WASA-at-COSY:

preliminary

- 15 candidates observed

Analysis: C.-O. Gullström (U Uppsala)
Talk : Mon. 17:50

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

- Experimental upper limit:
  - *< 2.7·10⁻⁵ (CELSIUS/WASA)*

- WASA-at-COSY Preliminary:
  - current upper limit improved by one order of Magnitude
    - *20% of data analyzed*

Analysis: M.Berłowski (NCNR Warsaw)

Summary

- Decays of light mesons provide valuable information on

  - *Precision Tests of ChPT*

  - *Form Factors*

  - *Test of Standard Model predictions*

- WASA-at-COSY provides data on π^0, η, ω decays of

  - *high statistics*

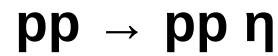 - *high quality*

- and there is more to come.....

Backup

η production

pp → pp η

large cross section
σ = 10 µb at Q = 60 MeV

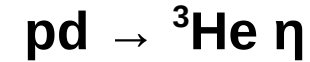multi pion background
$\sigma(2\pi^0)/\sigma(\eta) \approx 20$
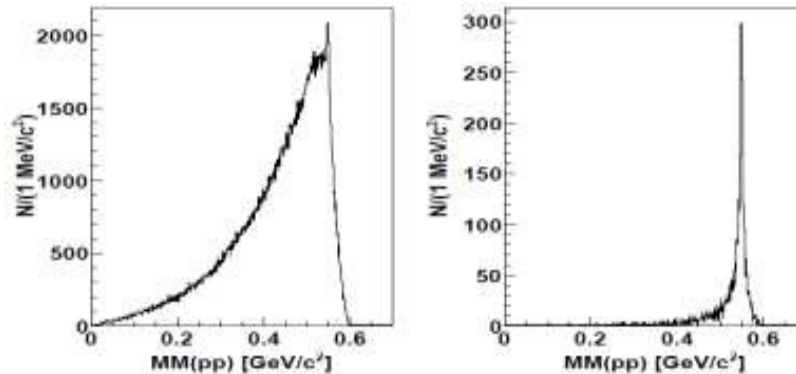
selective trigger needed
η production rate > 100 s^{-1}
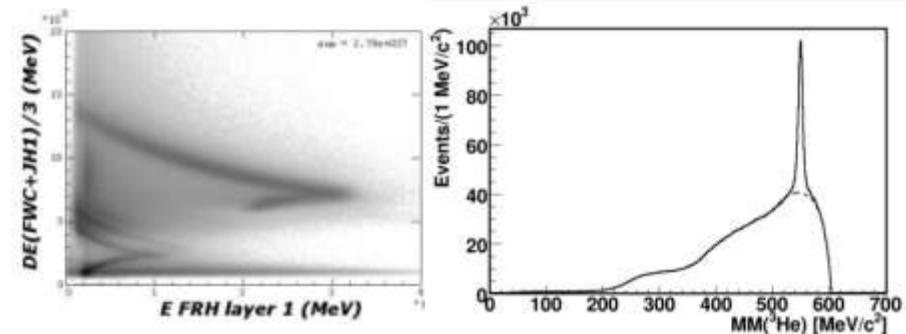
→ high statistics runs for rare and very rare decays

pd → ^{3}He η

low cross section
σ = 0.4 µb, const.

multi pion background
$\sigma(2\pi^0)/\sigma(\eta) \approx 1$
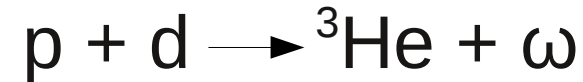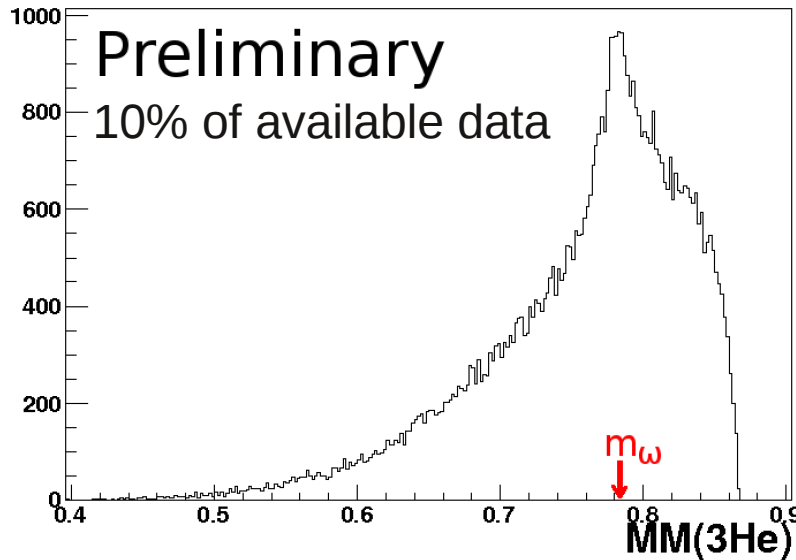

unbiased sample of η decays
η production rate ≈ 10 s^{-1}

→ precision studies of not-so-rare decays
→ exploratory studies for rare decays

$\omega \rightarrow \pi^+\pi^-\pi^0$

Preliminary
10% of available data

m_ω

MM(3He)

$p + d \longrightarrow {}^3He + \omega$

Data taken during in Feb 2011

At least 26000 fully reconstructed
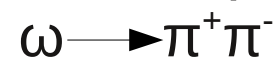$\omega \rightarrow \pi^+\pi^-\pi^0$ events

In parallel:

$p + p \longrightarrow p + p + \omega$

First data taken in April 2011

$\omega \longrightarrow \pi^+\pi^-\pi^0$	Dalitz plot
$\omega \longrightarrow \pi^0 e^+ e^-$	Dalitz decay
$\omega \longrightarrow \pi^0 \gamma$	
$\omega \longrightarrow \pi^+\pi^-$	ρ-ω interference

η → π⁰γγ

unique test of higher orders of ChPT

- $O(p^6)$ is first sizable contribution

Aims:

Analysis: K. Lalwani (IIT Bombay)

- Branching ratio

- γγ invariant mass distribution

Status:
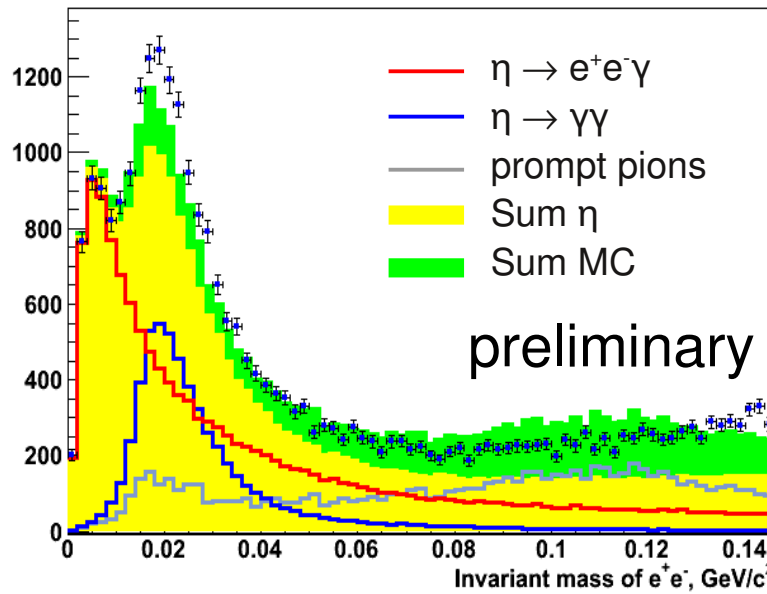
- 30% of pd data analyzed

- $360\pm90_{stat}$ event candidates

- $\eta \to \pi^0\pi^0\pi^0$ dominating
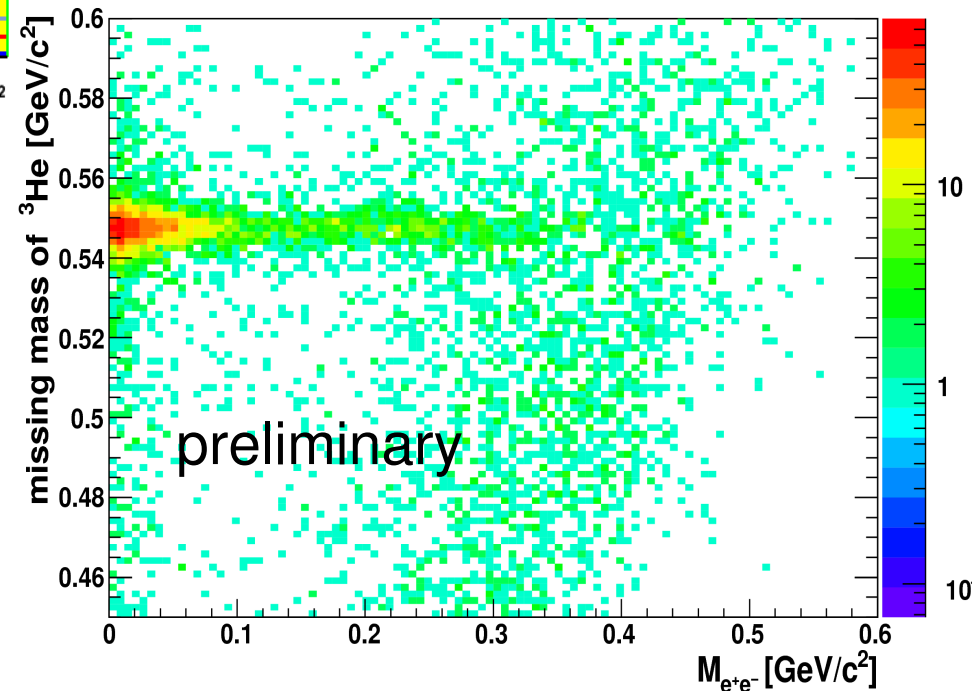
- next step:

  Systematic background studies

S/B = 1/16

η → e⁺e⁻γ

preliminary
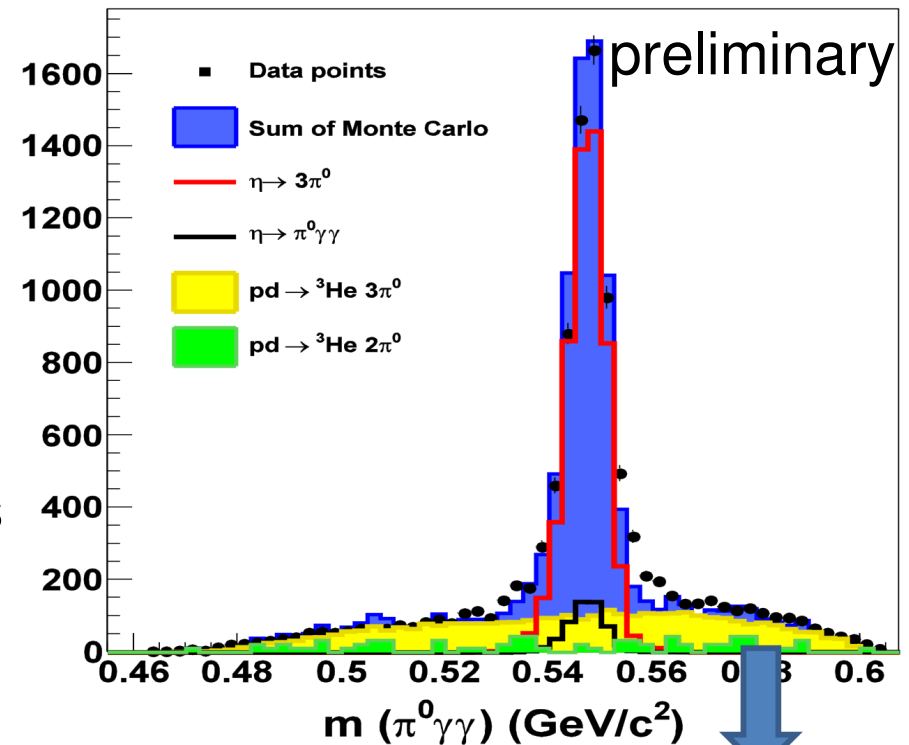
- **30 % of pd data analyzed**
- **important issues:**
  - **photon conversion**
  - **pion background**

preliminary

Analysis: M. Hodana (JU Krakow)
H. Bhatt (IIT Bombay)

η → π⁺π⁻e⁺e⁻

- **10⁷ η events analyzed**
  - PID with neural nets
  - Vertex information
  - Kinematic fit
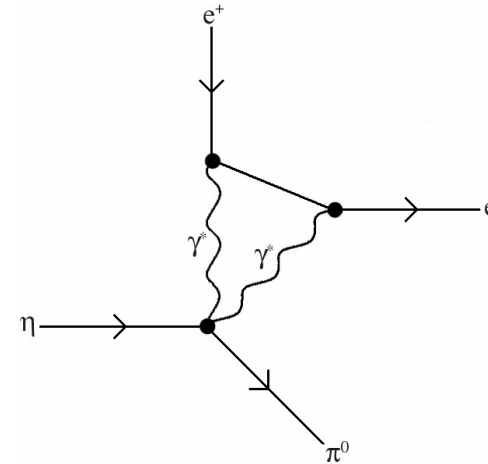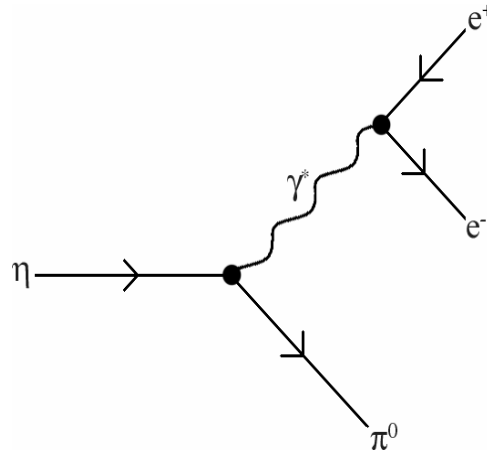- **230±22 event candidates**
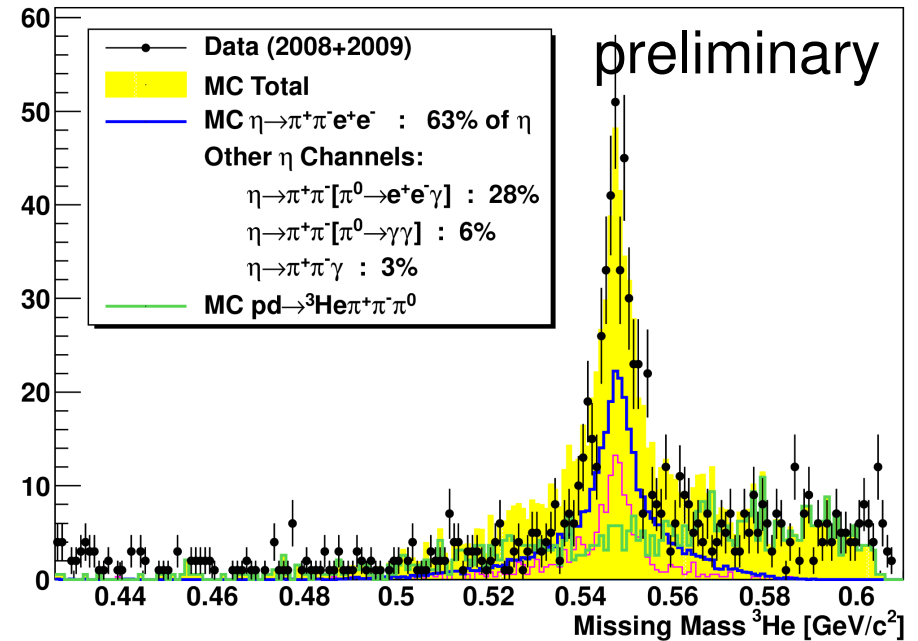
Analysis: D.Coderre (FZ Jülich)

- **<u>Preliminary:</u>**

  - branching ratio compatible with theory and experiment

- Analysis of pp data has begun
  - 2010 pp run: > 10⁸ ηs

η → π⁰e⁺e⁻

- decay via single photon exchange is C-forbidden

- BR from SM limited by two photon process

- experimentally:

$$\frac{BR(\eta \to \pi^0 e^+ e^-)}{BR(\eta \to \pi^0 \pi^+ \pi^-)} < 1.9 \cdot 10^{-4} \quad 90\% \quad CL$$

Jane et al., Phys.Lett.B59:99-102,1975.

- WASA analysis addresses a different kinematic region

  - *small invariant masses of the lepton pairs*

    Analysis: A. Winnemöller, F. Bergmann (WWU Münster)