

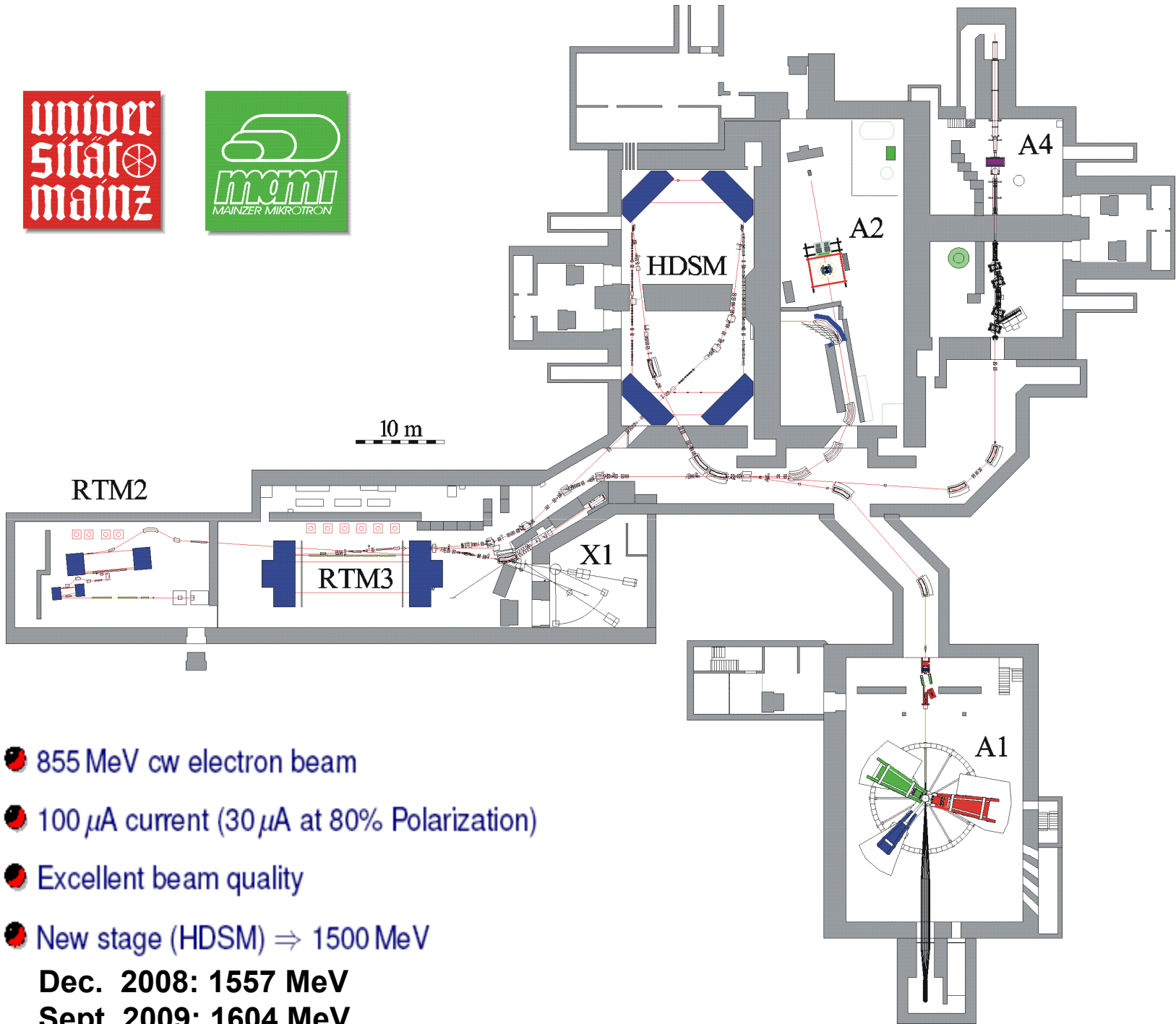
Recent Results from MAMI

Hans-Jürgen Arends
Mainz University



JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



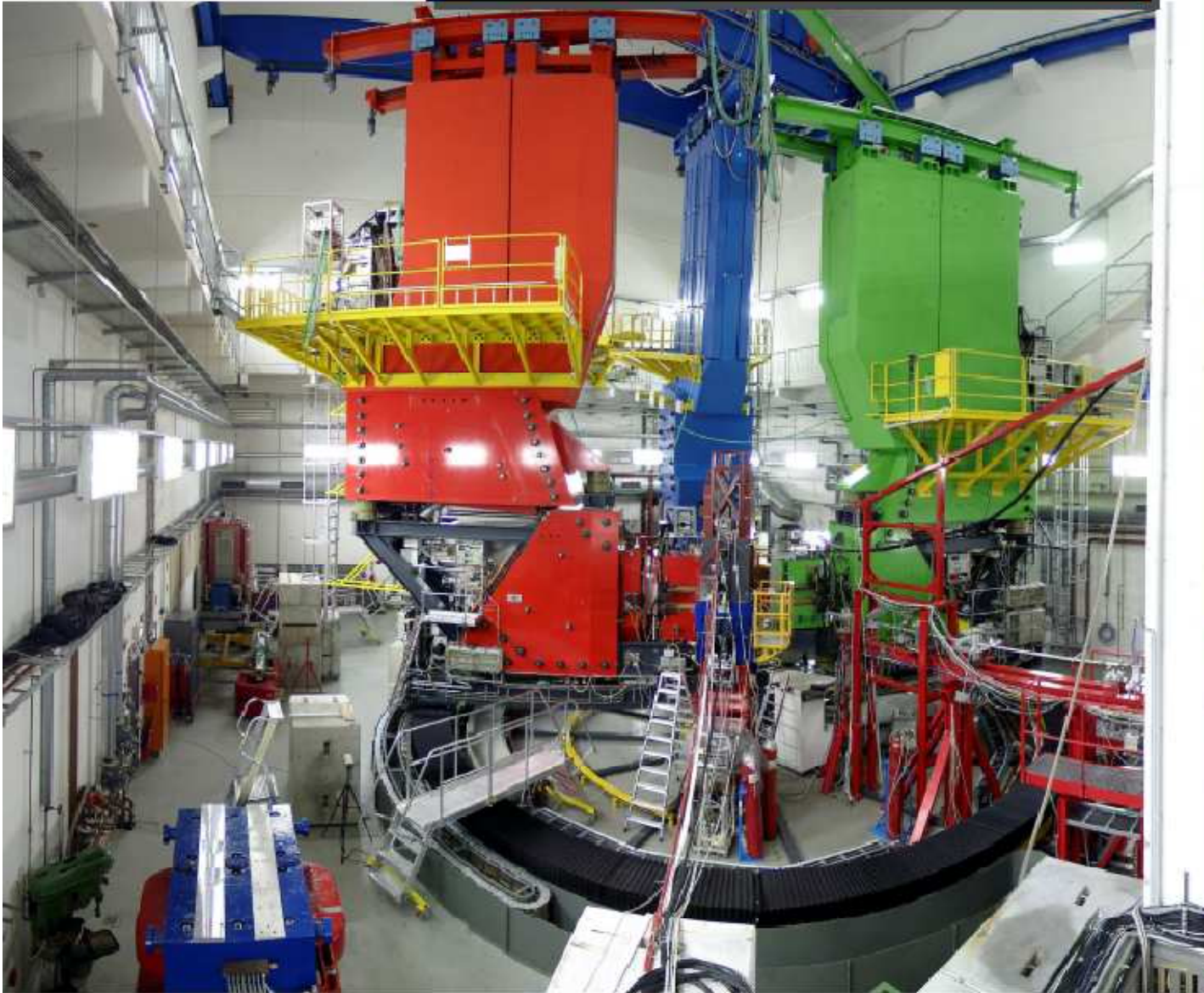


- 855 MeV cw electron beam
- 100 μA current (30 μA at 80% Polarization)
- Excellent beam quality
- New stage (HDSM) \Rightarrow 1500 MeV

Dec. 2008: 1557 MeV

Sept. 2009: 1604 MeV

A1: The »three« spectrometer facility



Spectrometer A:

$$\alpha > 20^\circ$$

$$p < 735 \frac{\text{MeV}}{c}$$

$$\Delta\Omega = 28 \text{ msr}$$

$$\Delta p/p = 20\%$$

Spectrometer B:

$$\alpha > 8^\circ$$

$$p < 870 \frac{\text{MeV}}{c}$$

$$\Delta\Omega = 5.6 \text{ msr}$$

$$\Delta p/p = 15\%$$

Spectrometer C:

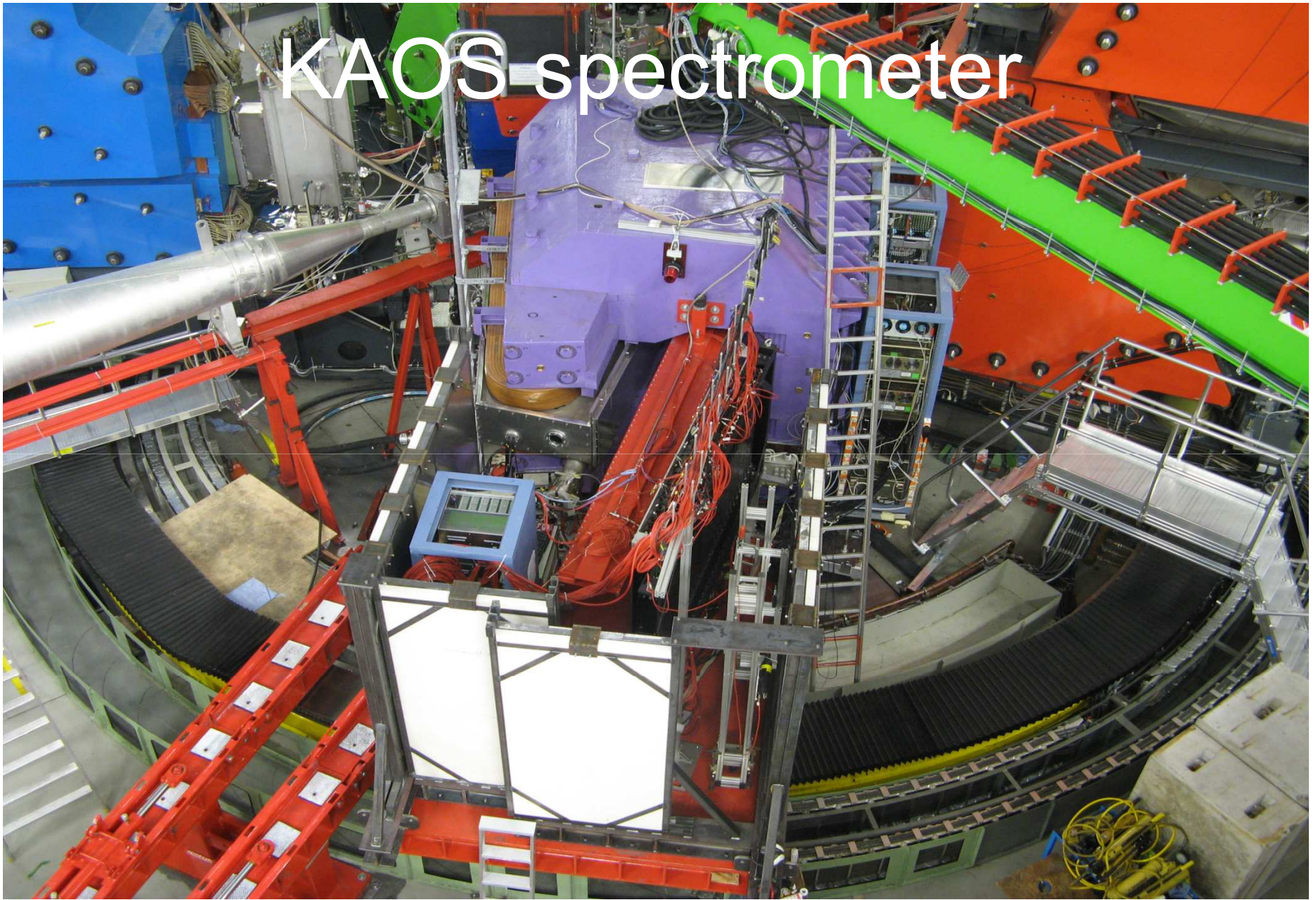
$$\alpha > 55^\circ$$

$$p < 655 \frac{\text{MeV}}{c}$$

$$\Delta\Omega = 28 \text{ msr}$$

$$\Delta p/p = 25\%$$

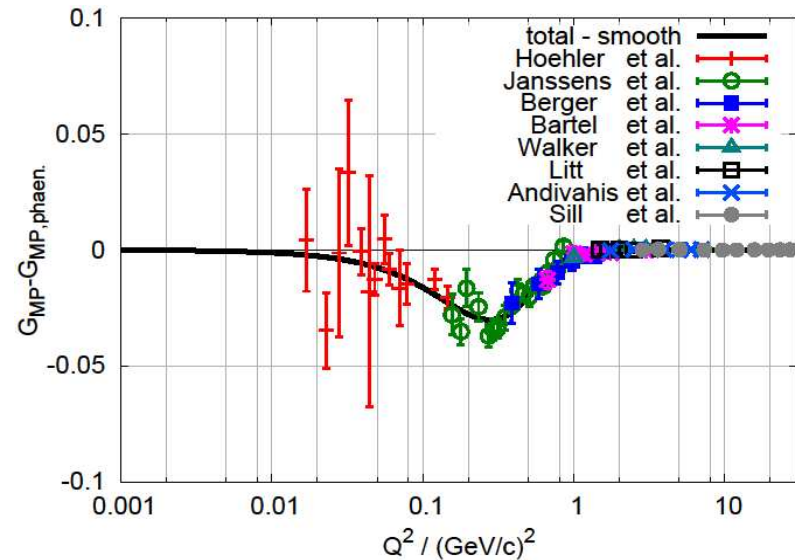
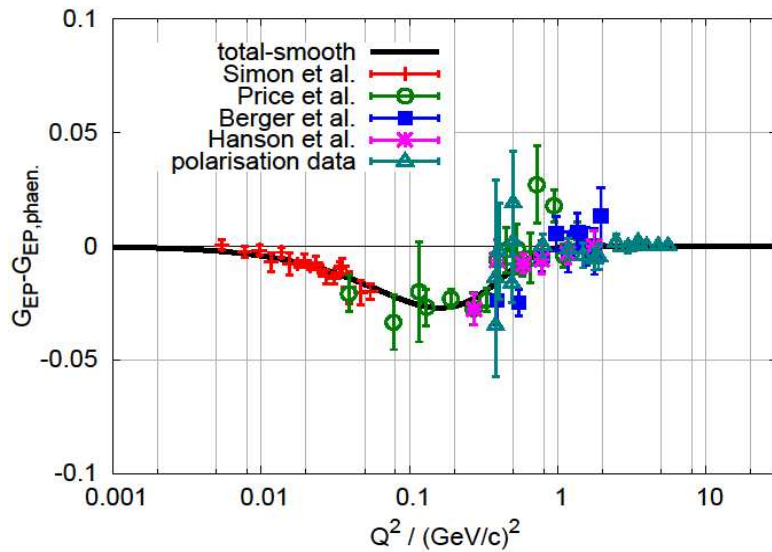
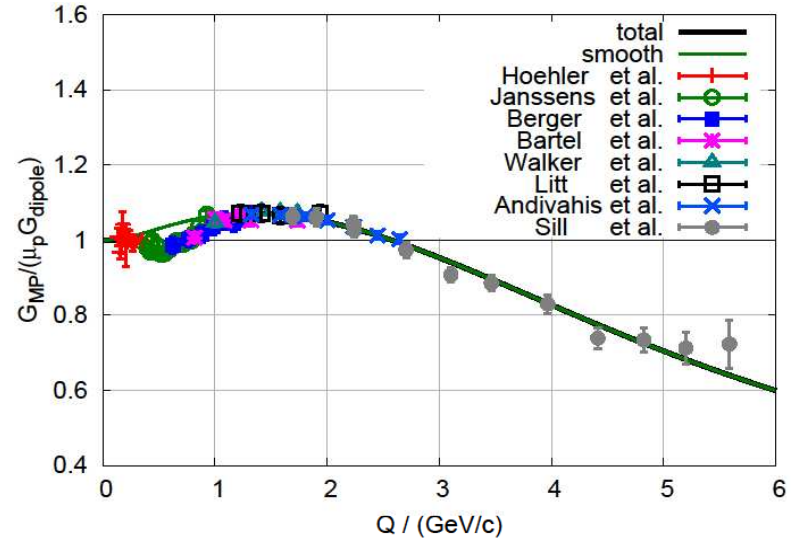
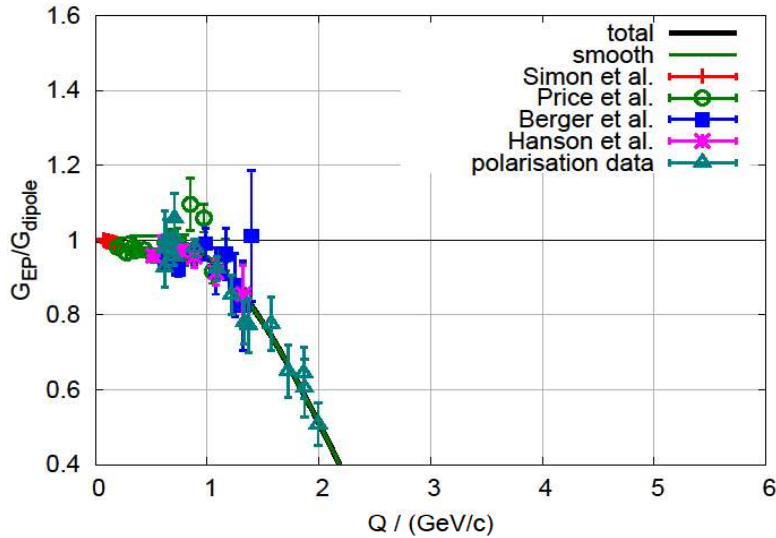
KAOS spectrometer



High-precision $p(e, e')p$ measurement at MAMI



Motivation

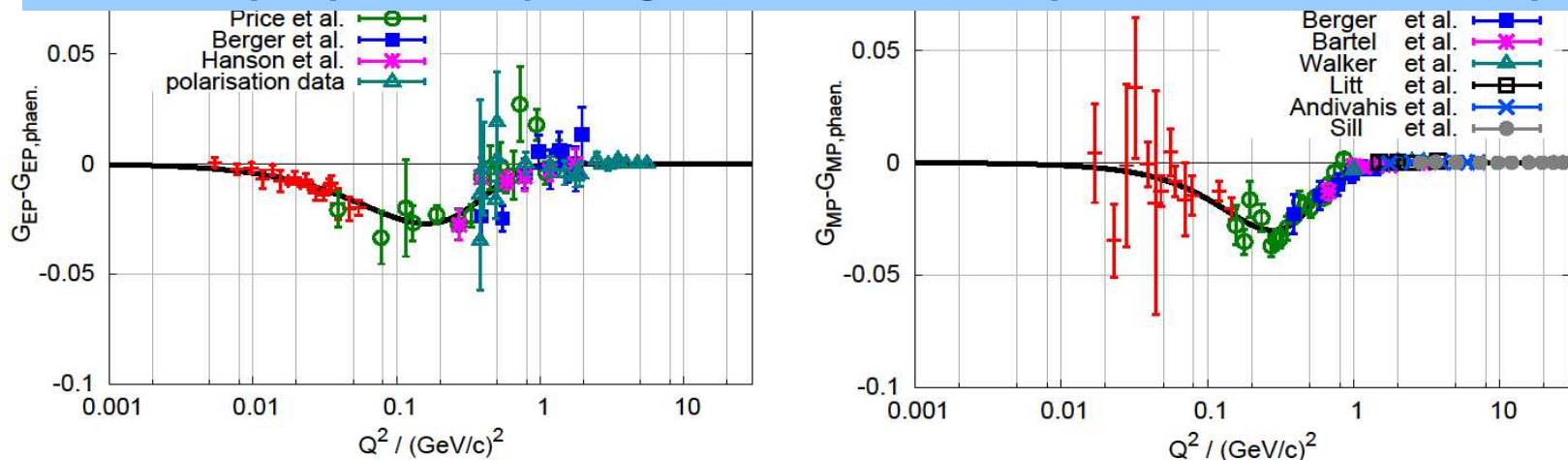


(see J. Friedrich and Th. Walcher, EPJ A 17 (2003) 607)

Motivation

Discrepancies for the proton charge radius

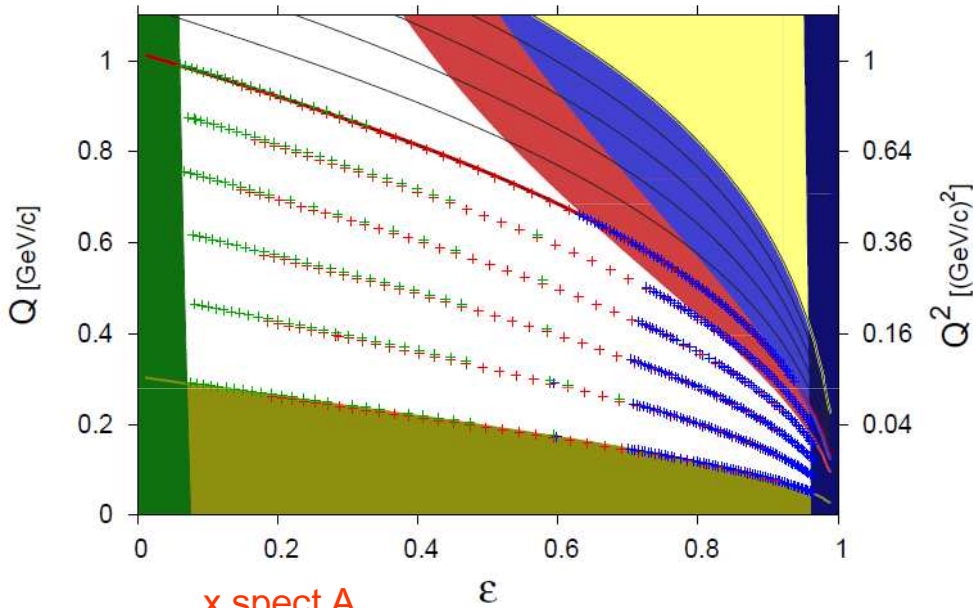
- 0.809(11) fm: Stanford (Hand et al., 1963)
- 0.862(12) fm: low Q^2 at Mainz (Simon et al., 1979)
- 0.847(09) fm: dispersion relation (Mergell et al., 1996)
- 0.890(14) fm: Hydrogen Lamb shift (Udem et al., 1997)



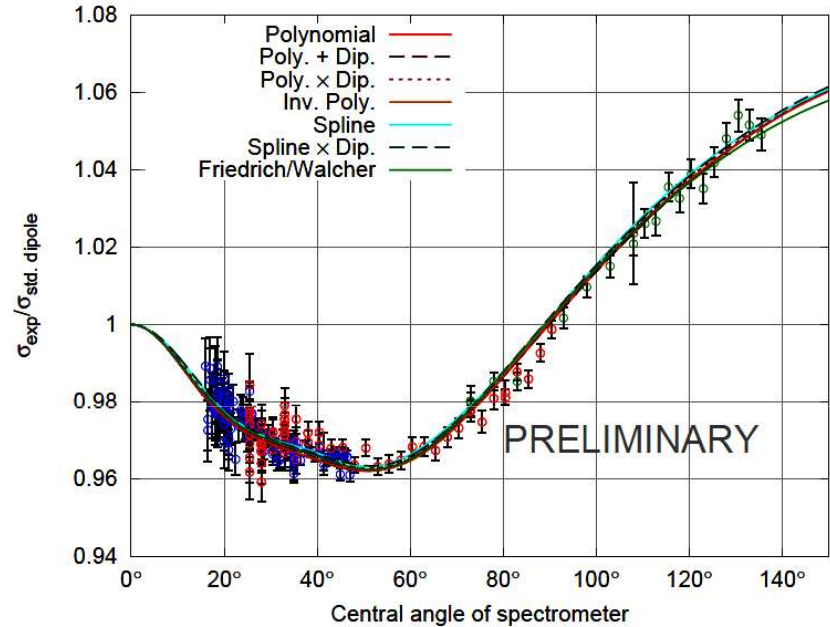
(see J. Friedrich and Th. Walcher, EPJ A 17 (2003) 607)

High-precision $p(e, e')p$ measurement at MAMI

Q^2 : 0.004 to 1 $(\text{GeV}/c)^2$



x spect A
x spect B
x spect C



Global fit of form factor models to cross sections

J. Bernauer et al., to be published

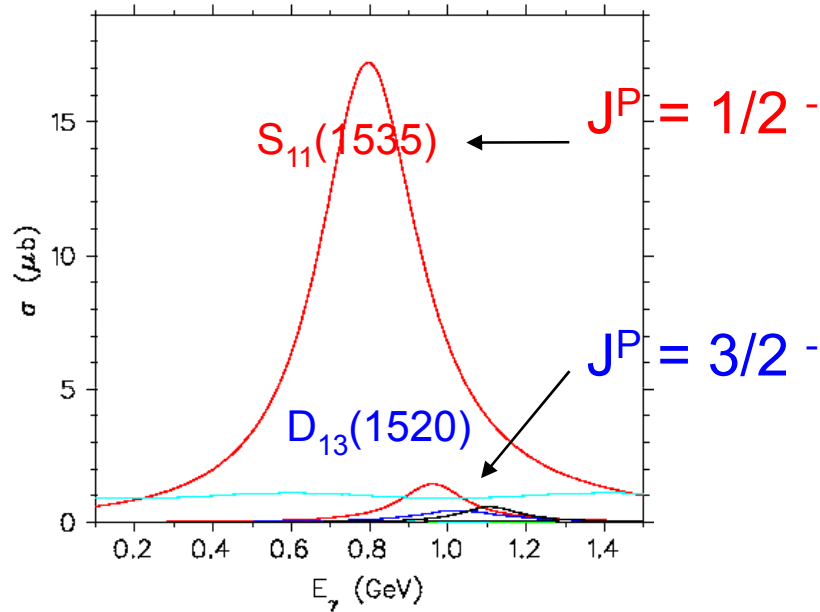
~ 1000 settings (overlapping)
~ 10^9 events

$$r_E = \langle r_E^2 \rangle^{1/2} = 0.879 \text{ fm} \quad \begin{array}{l} \pm 0.005 \text{ (stat)} \pm 0.004 \text{ (syst)} \\ \pm 0.002 \text{ (model)} \pm 0.004 \text{ (group)} \end{array}$$

PRELIMINARY

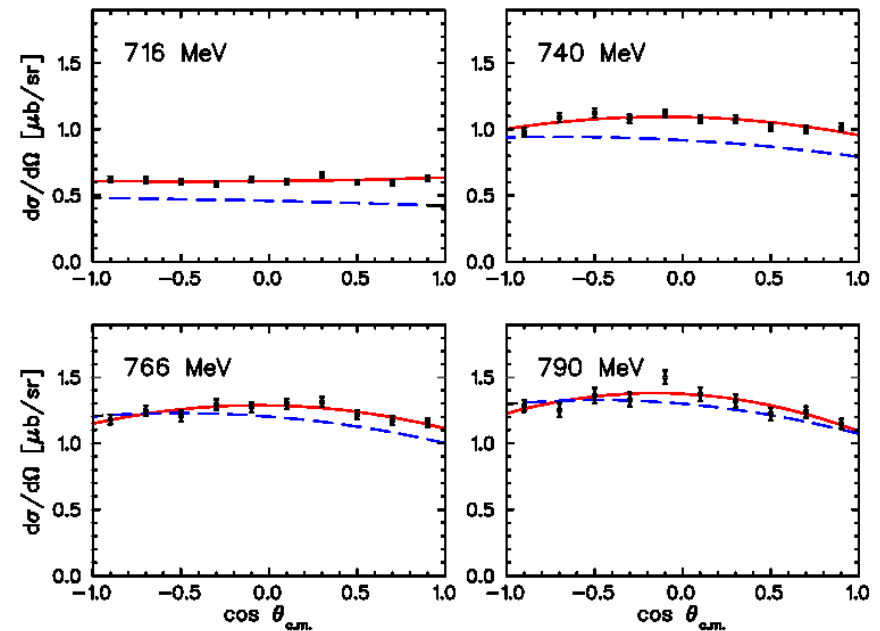
Polarisation observables in $\gamma p \rightarrow \eta p$

$\gamma p \rightarrow \eta p$



Sensitivity to D_{13} :

diff. cross section

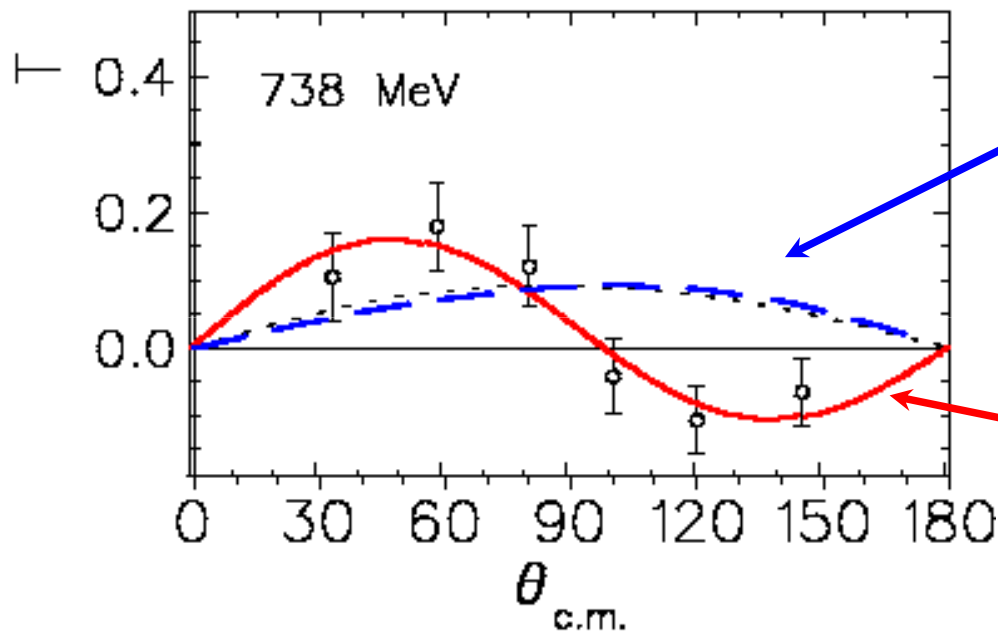


dominance of S_{11}

Asymmetry with transverse polarised target: $T \sim \text{Im} (E_{0+}^* (E_{2-} + M_{2-}))$

Target asymmetry in $\gamma \vec{p} \rightarrow \eta p$

$$T \sim \text{Im} (E_{0+}^* (E_{2-} + M_{2-}))$$



Breit-Wigner resonances in $J^P = 1/2^-$ and $3/2^+$ partial waves (standard η -MAID)

energy dependent phase shift between $J^P = 1/2^-$ and $3/2^+$ partial wave amplitudes

Tiator et al., PRC C60 (1999)

Phoenix (Bonn): A. Bock et al., PRL 81 (1998)

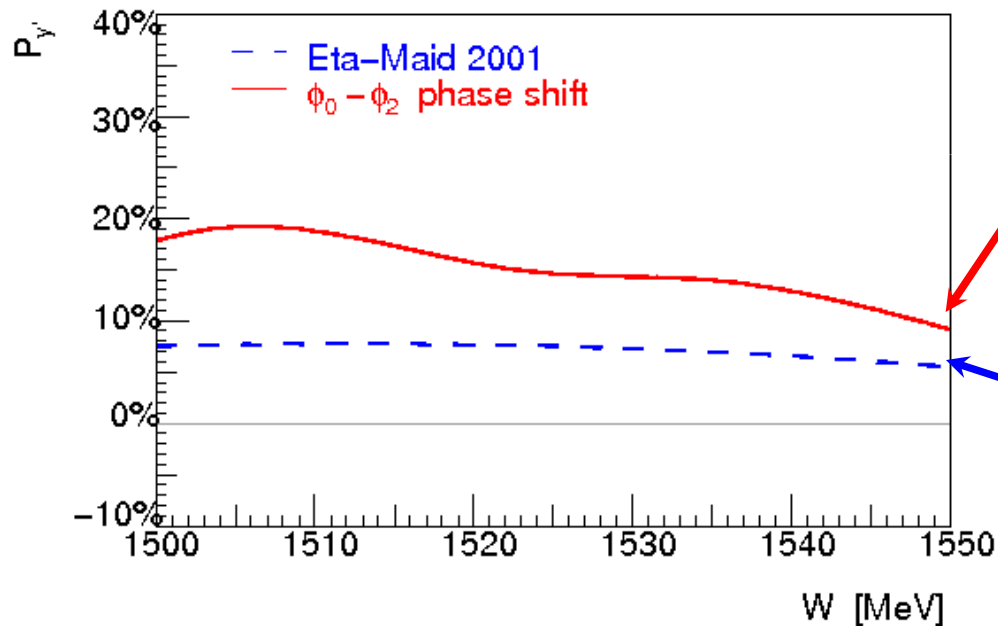
Recoil proton polarisation: $p(e, e' \vec{p}) \eta$

First experiment with MAMI C and the 3-spectrometer setup

Merkel et al., PRL 99:132301 (2007)

$$P_y \sim \text{Im} (E_{0+}^* (E_{2-} + M_{2-})) \sim T$$

$$\Theta = 120^\circ$$



energy dependent phase shift
between $J^P = 1/2^-$ and $3/2^+$
partial wave amplitudes

Breit-Wigner resonances in
 $J^P = 1/2^-$ and $3/2^+$ partial waves

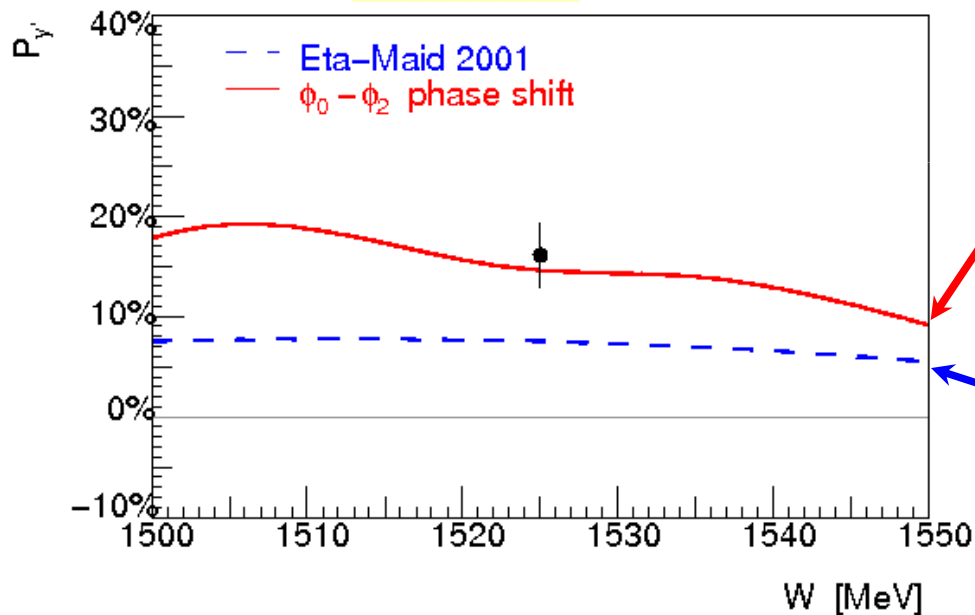
Recoil proton polarisation: $p(e, e' \vec{p}) \eta$

First experiment with MAMI C and the 3-spectrometer setup

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$$P_y \sim \text{Im} (E_{0+}^* (E_{2-} + M_{2-})) \sim T$$

$$\Theta = 120^\circ$$



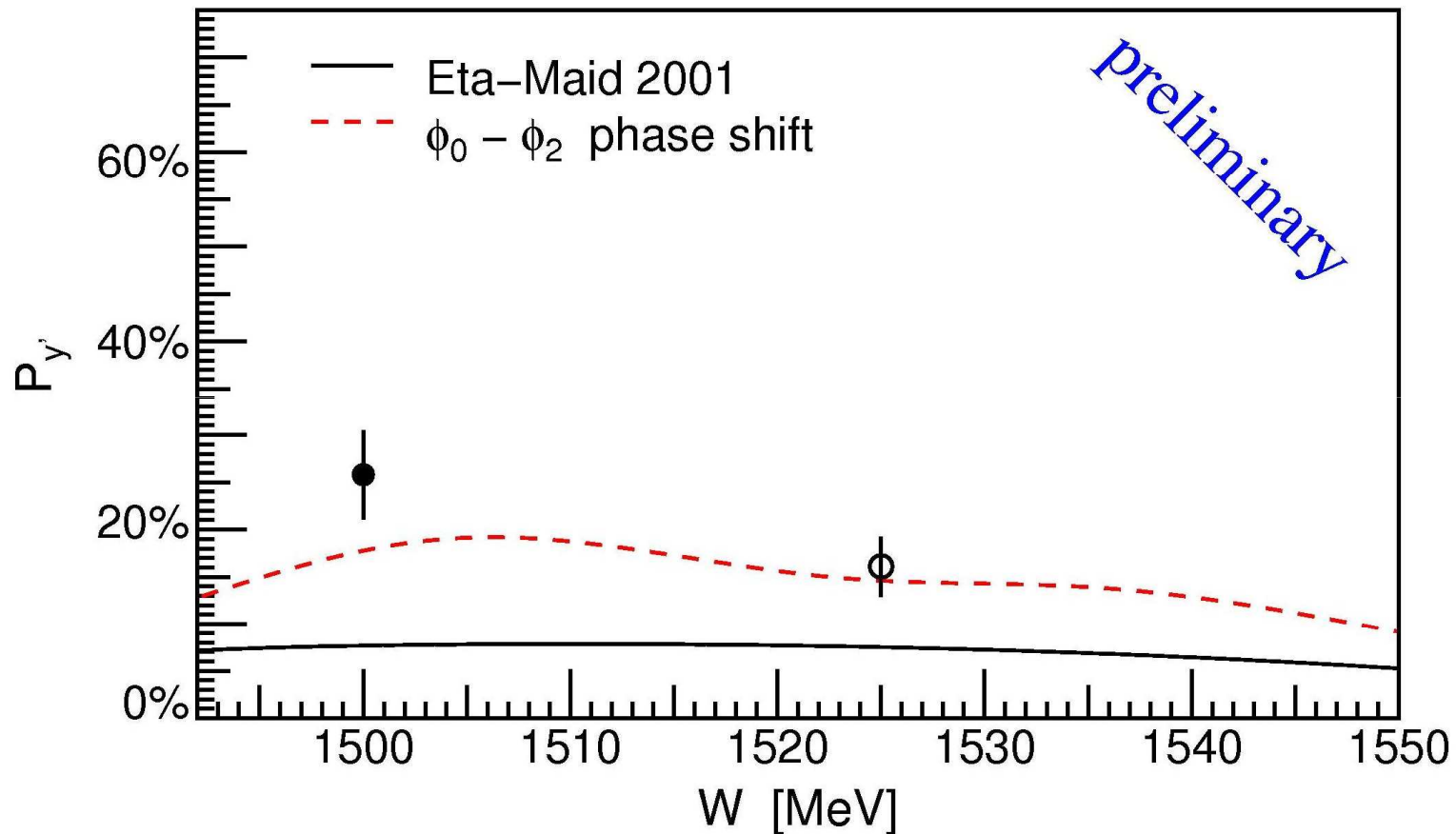
energy dependent phase shift
between $J^P = 1/2^-$ and $3/2^+$
partial wave amplitudes

Breit-Wigner resonances in
 $J^P = 1/2^-$ and $3/2^+$ partial waves

More kinematic settings: $W=1525$ MeV, $\Theta=90^\circ$, $W=1500$ MeV, $\Theta=120^\circ$

Recoil proton polarisation: $p(e, e' p) \eta$

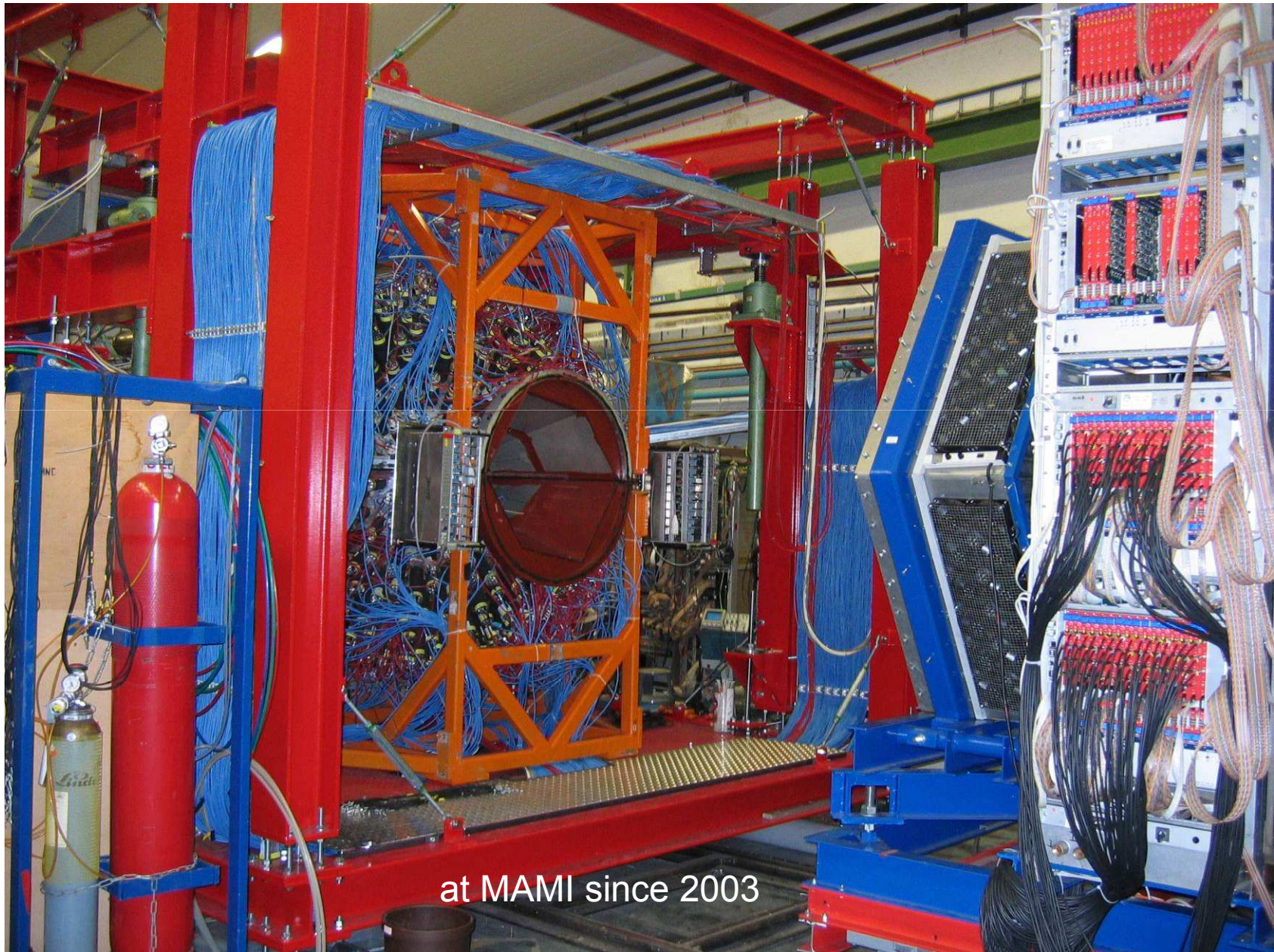
$\Theta = 120^\circ$



K. Grißinger et al., to be published

target asymmetry measurement with real photons in progress
in A2 (MAMI) and ELSA

Crystal Ball / TAPS

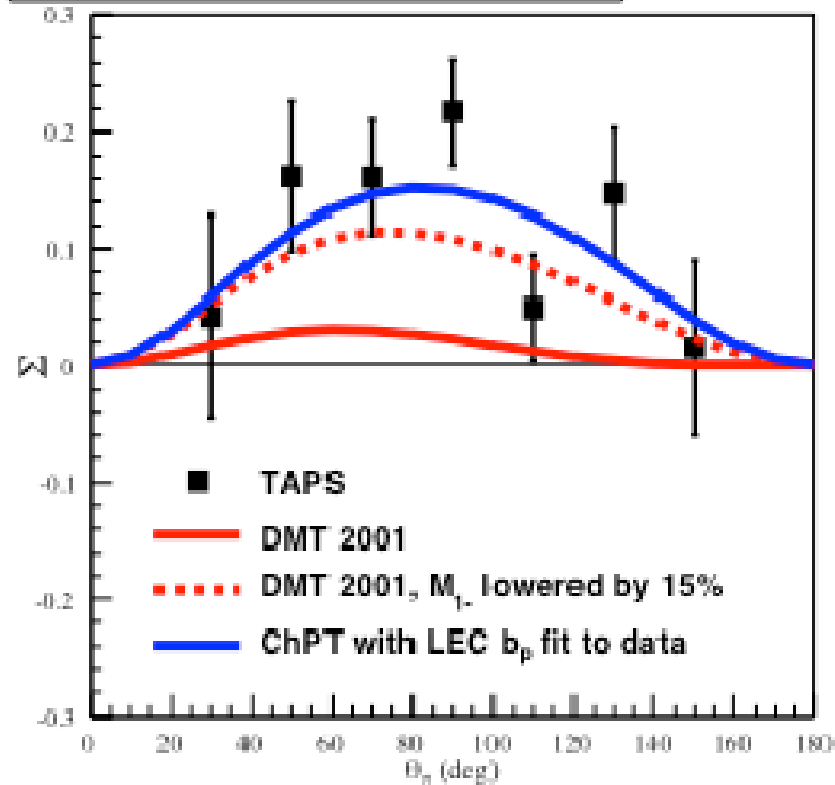


at MAMI since 2003

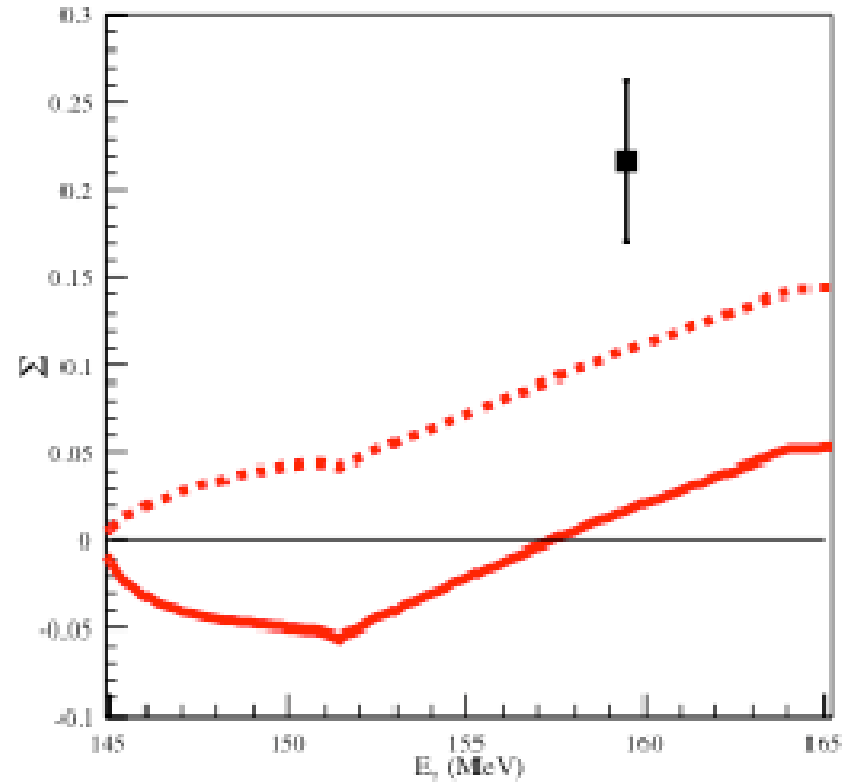
π^0 photoproduction near threshold

Test of LETs

Asymmetry for $E_\gamma = 159.5$ MeV



Asymmetry for $\theta_\pi = 90$ deg

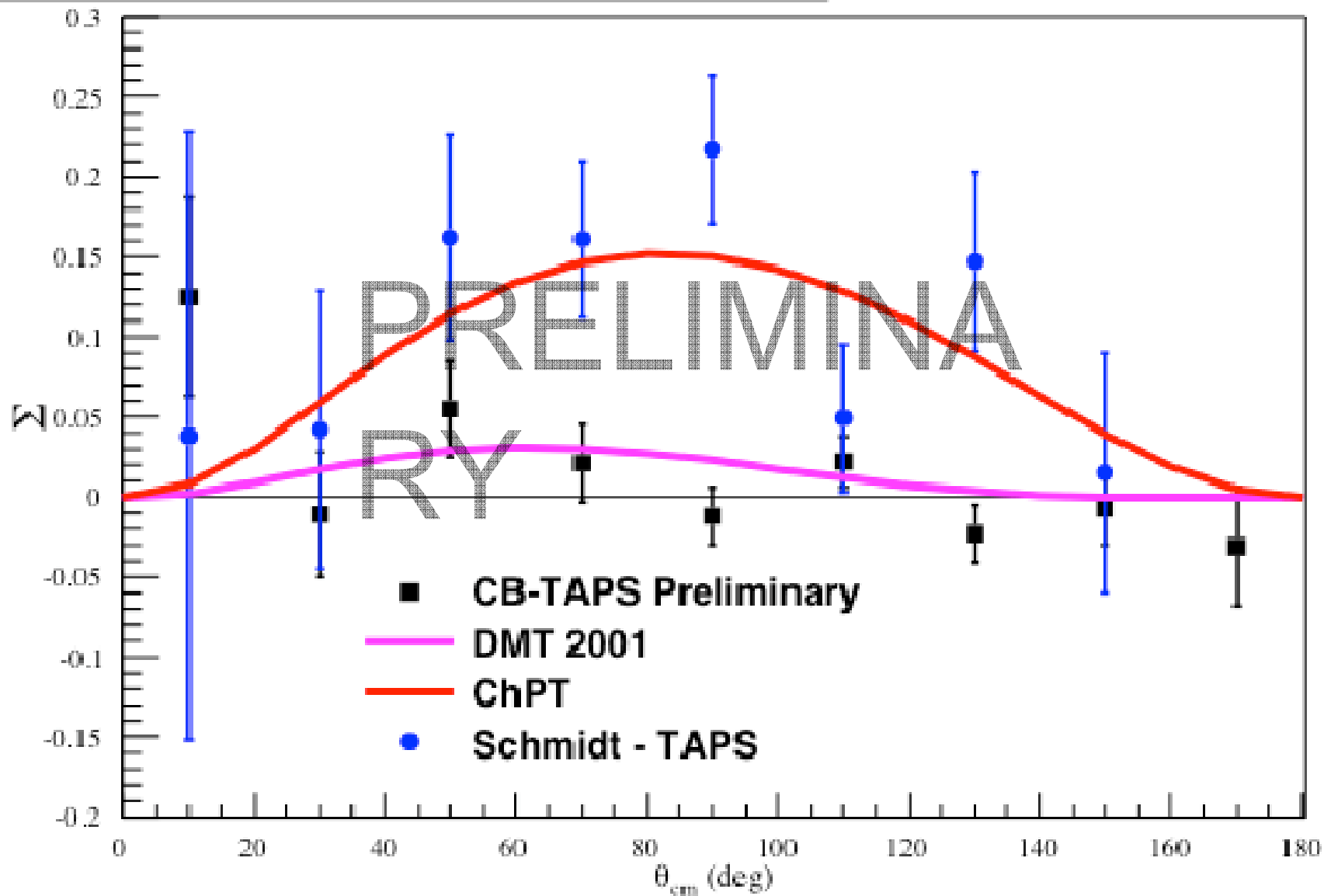


A. Schmidt et al., PRL 87 (2001) 23501

S. Kamalov et al., Phys. Rev. C (2001) 03220

V. Bernard et al., EPJ A 11 (2001) 209

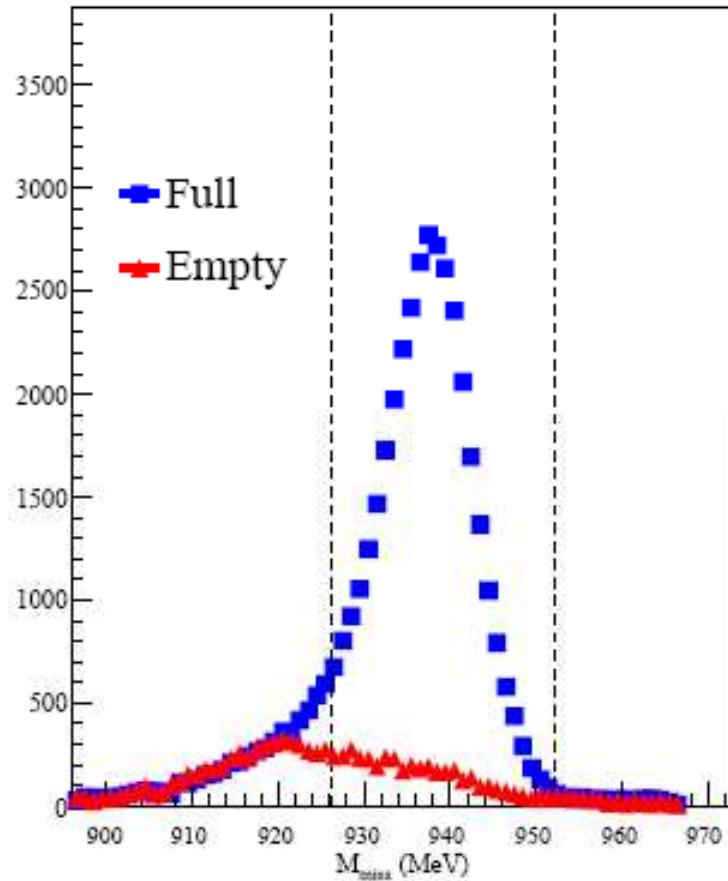
Asymmetry for $E_\gamma = 157.4 \pm 11.5$ MeV



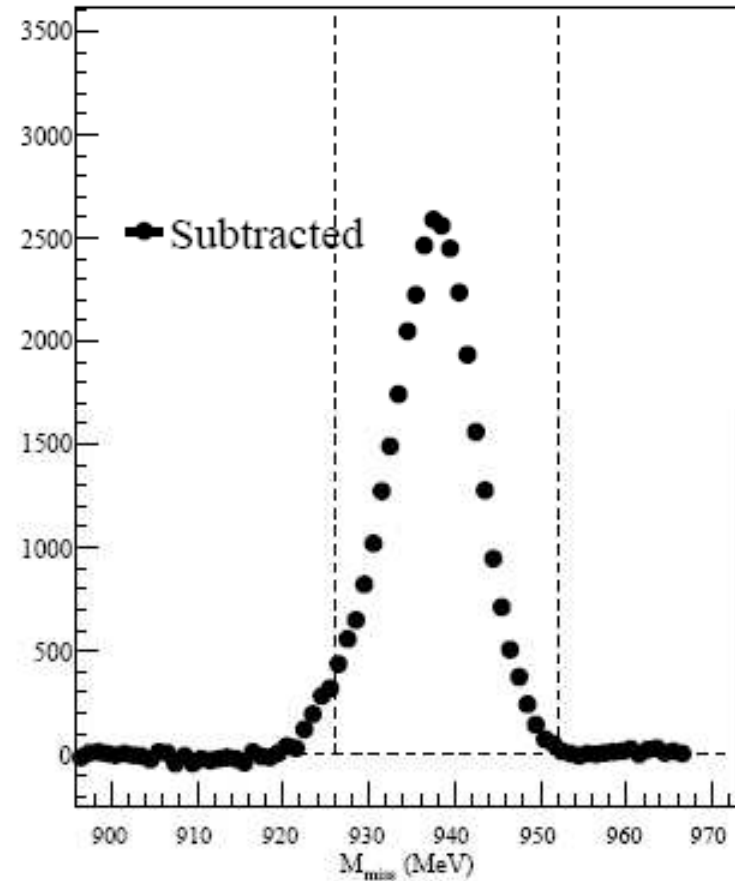
(Dave Hornidge)

Full-Empty Contributions

$E_\gamma = 177.8 \pm 0.7$ MeV

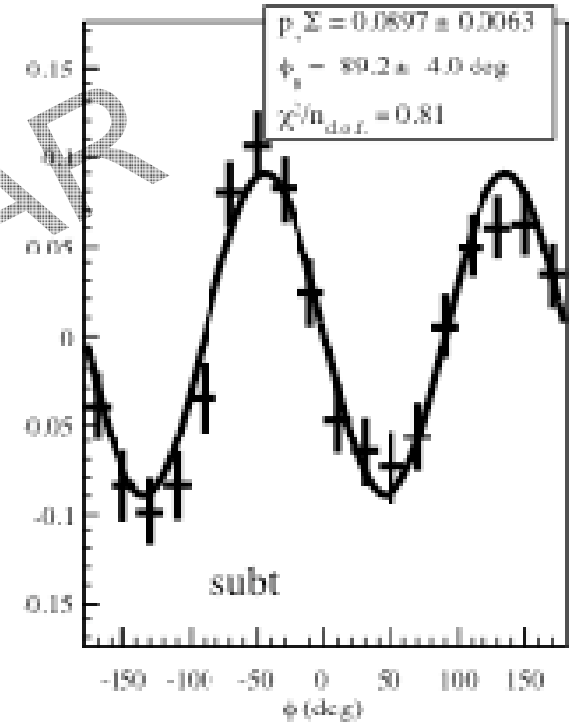
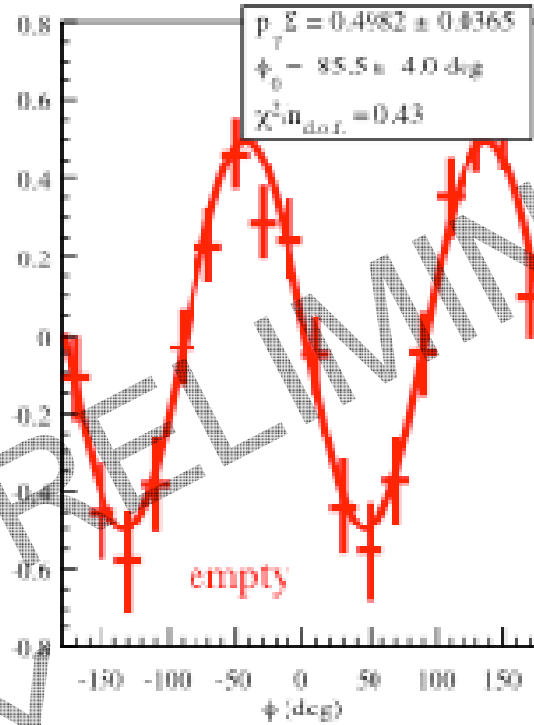
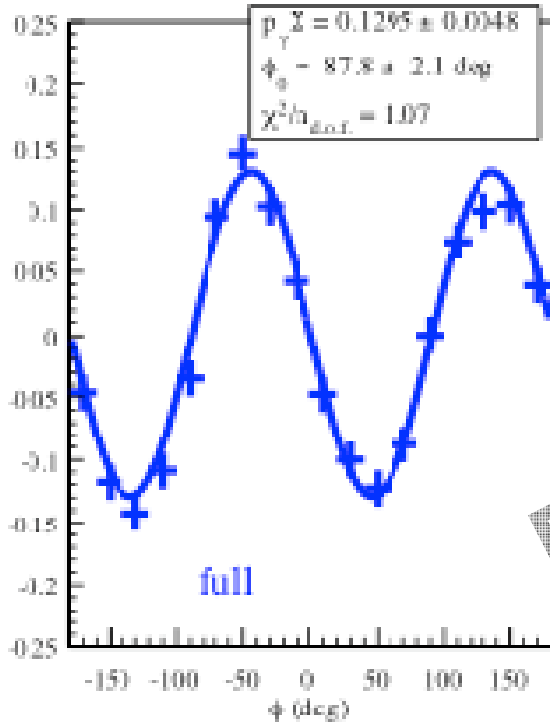


$\theta_{\text{CM}} = 0 - 180$ deg



(Dave Hornidge)

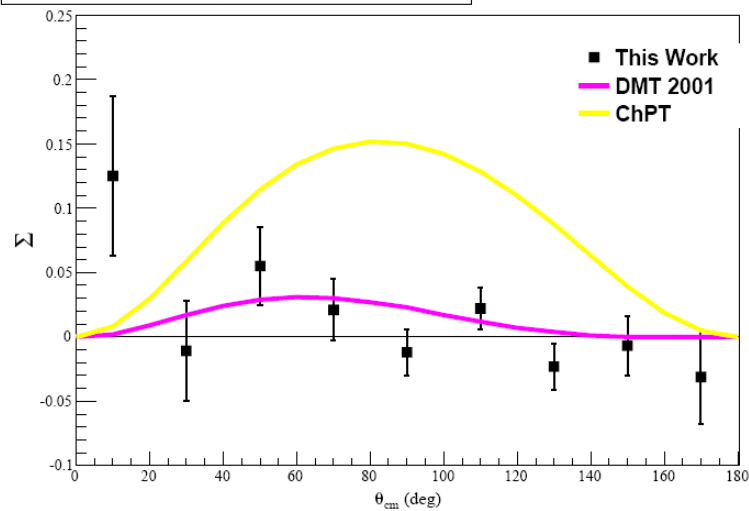
$E_\gamma = 179.3 \pm 4.3$ MeV $\theta = 90 \pm 10$ deg



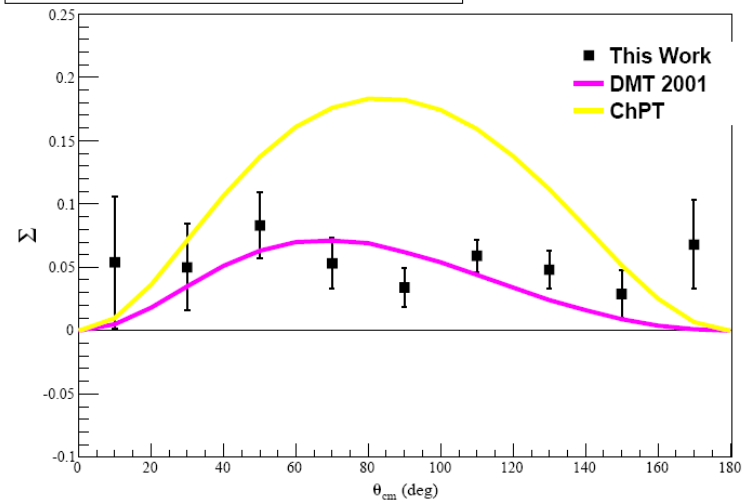
Target windows account for $\sim 30\%$ at 90 deg and 180 MeV!

π^0 production near threshold

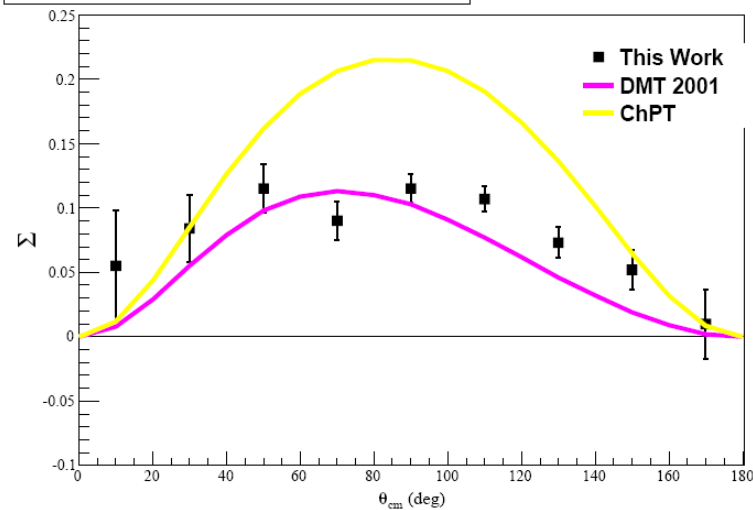
Asymmetry for $E_\gamma = 157.4 \pm 11.5$ MeV



Asymmetry for $E_\gamma = 169.3 \pm 4.3$ MeV



Asymmetry for $E_\gamma = 179.0 \pm 4.3$ MeV



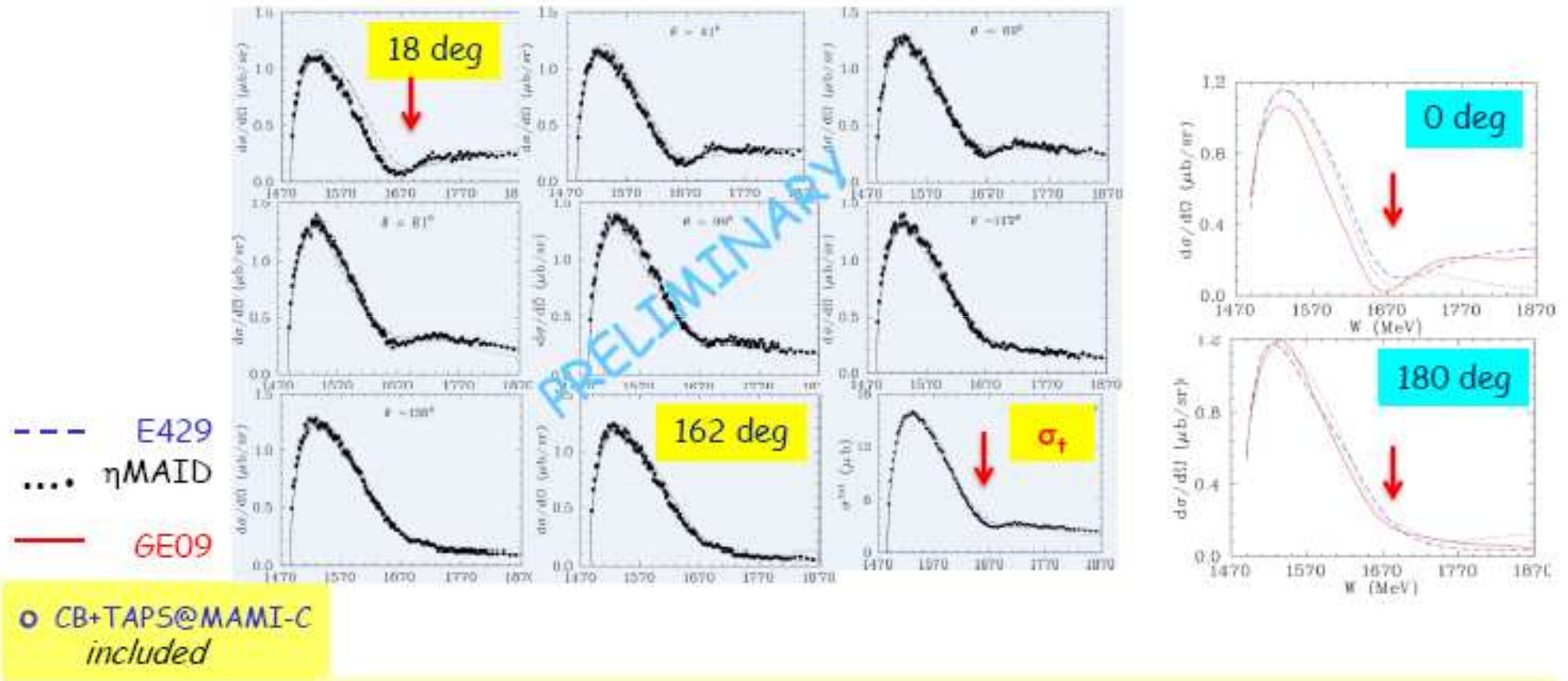
Preliminary

(D. Hornidge, publ. in prep)

measurement of T and F
in preparation at MAMI
and HI γ S (H. Weller)

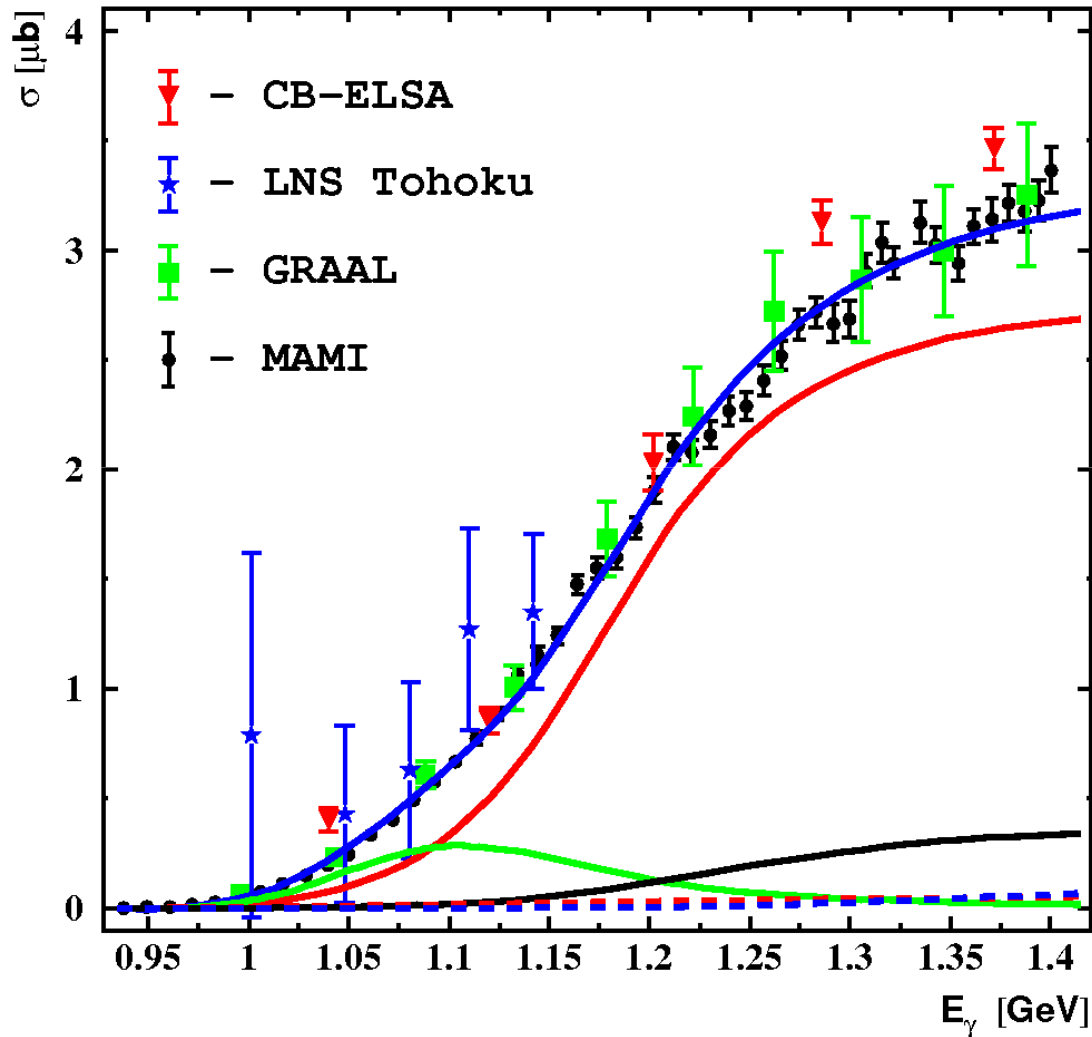
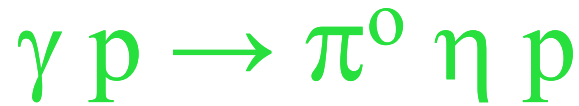
η photoproduction $\gamma p \rightarrow \eta p$

(see I. Strakovsky, 6B)



- Our data show a dip near $W = 1670$ MeV in the total cross section and its association with a significant dip in the forward differential cross section
- This feature was missed or questionable in the analysis of previous data

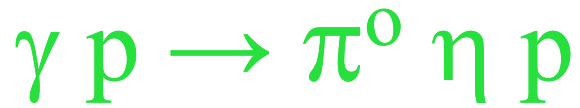
(E.F. McNicoll et al., in preparation)



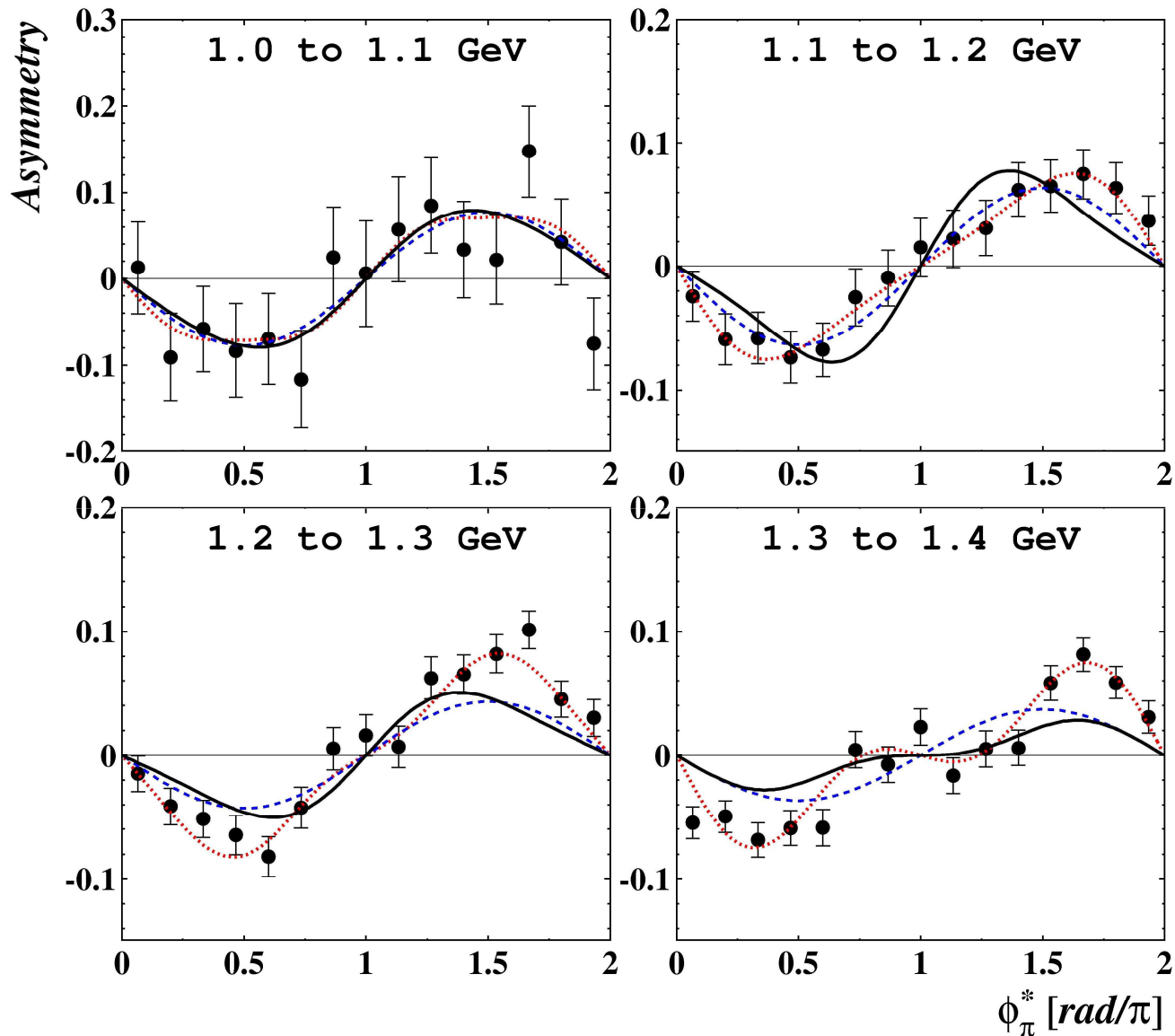
blue line: the best fit with
 $D_{33}(1700)$,
 $P_{33}(1600)$,
 $P_{31}(1750)$,
 $F_{35}(1905)$,
 and Born terms

Partial contributions:

Red line: $D_{33}(1700)$
 Green line: $P_{33}(1600)$
 Black line: $P_{31}(1750)$
 Dashed red line: $F_{35}(1905)$
 Dashed blue line: Born terms



Beam helicity asymmetry



(preliminary)
to be published

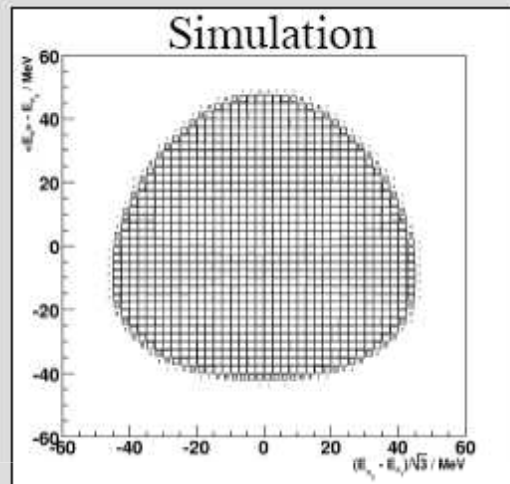
**Data from
July 2007 and
April 2009 runs**

- Fourier fit (3 terms)
- - - - $D_{33}(1700)$ only
- Isobar model 6 resonances (A. Fix et al.)

More spin observables will be measured (T and F, pol. beam and pol. target)

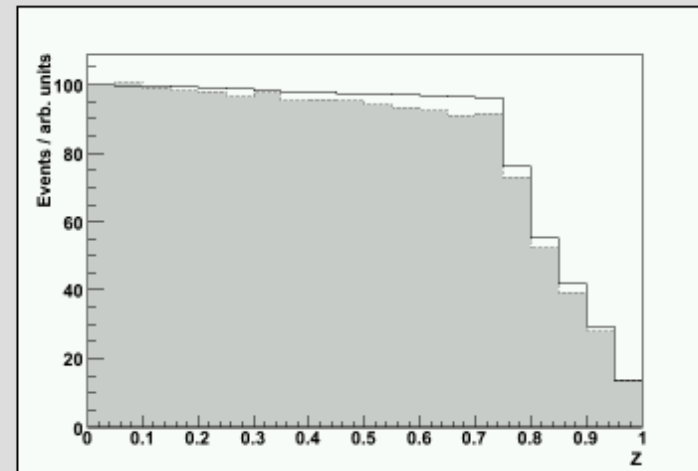
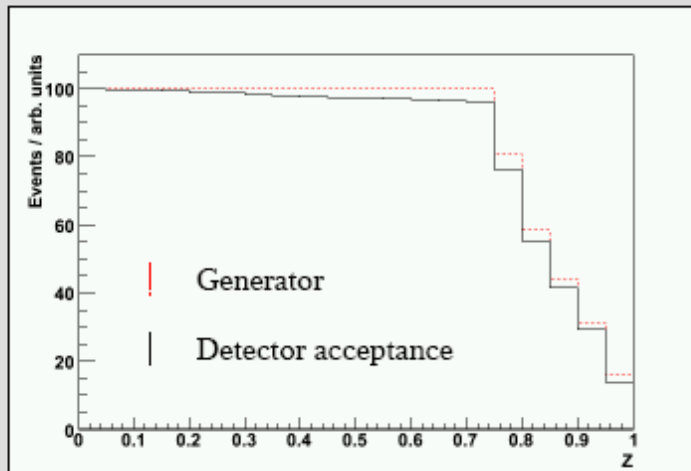
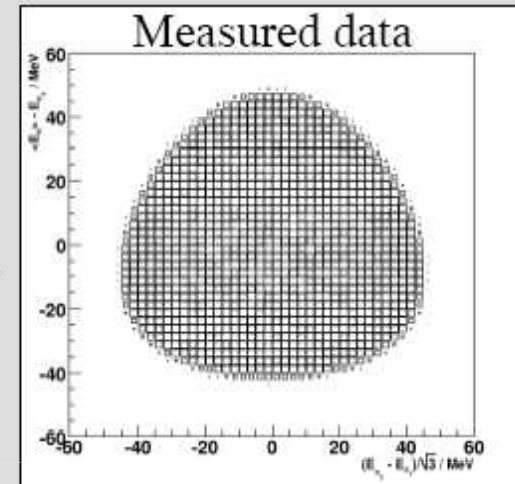
Dalitz Plot Parameter α for $\eta \rightarrow 3\pi^0$

Basic strong interaction process $\pi^0 \pi^0 \rightarrow \pi^0 \pi^0$



$$|A(\eta \rightarrow 3\pi^0)|^2 \sim [1 + 2\alpha z]$$

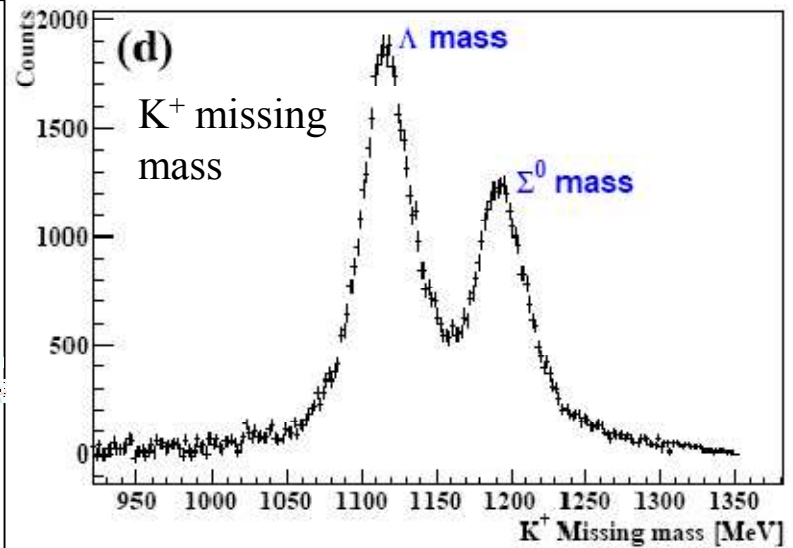
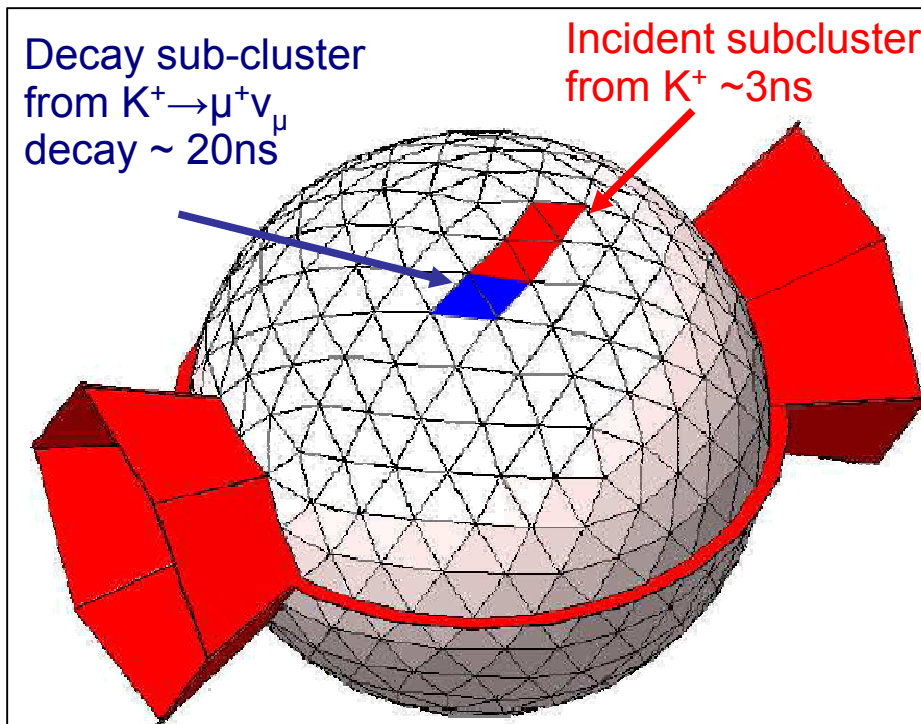
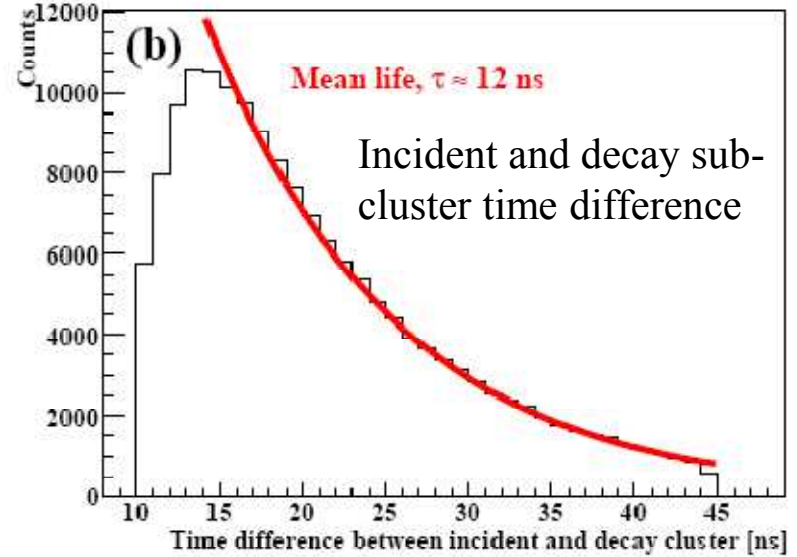
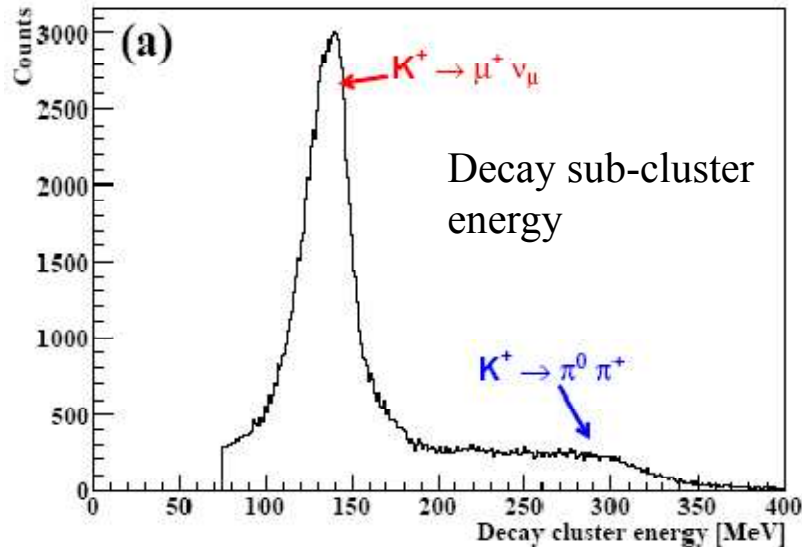
$$z = 6 \sum_{i=1}^3 \left(\frac{E_i - m_\eta / 3}{m_\eta - 3m_{\pi^0}} \right)^2 = \frac{\rho^2}{\rho_{max}^2}$$



M. Unverzagt et al., EPJ A (2009)
 S. Prakhov et al., Phys. Rev. C79 (2009)

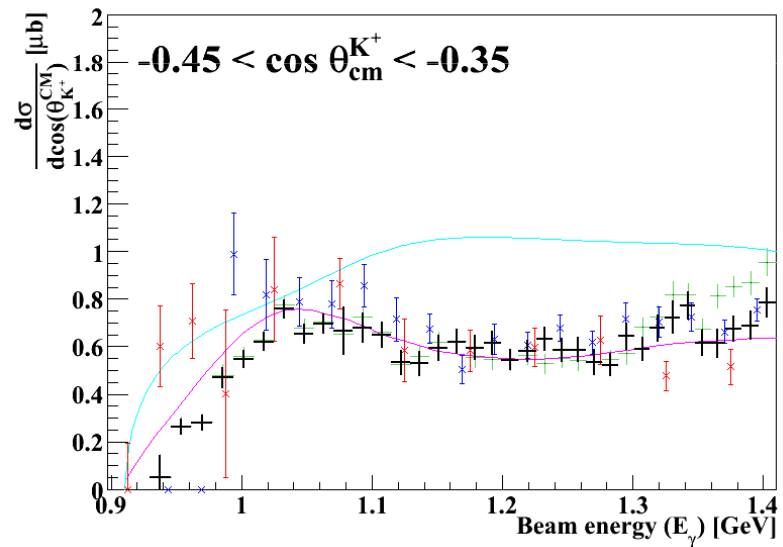
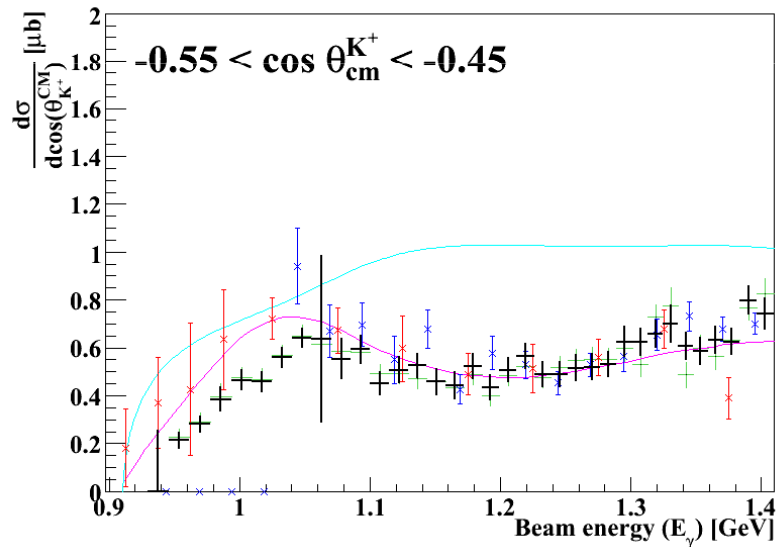
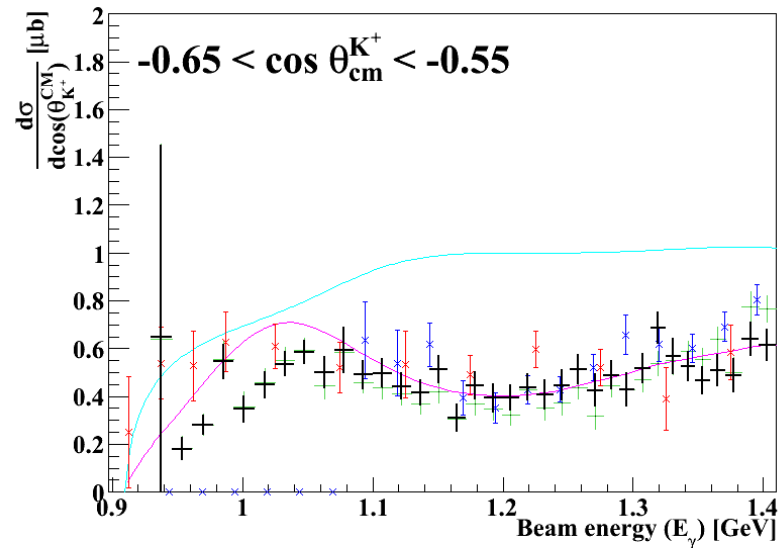
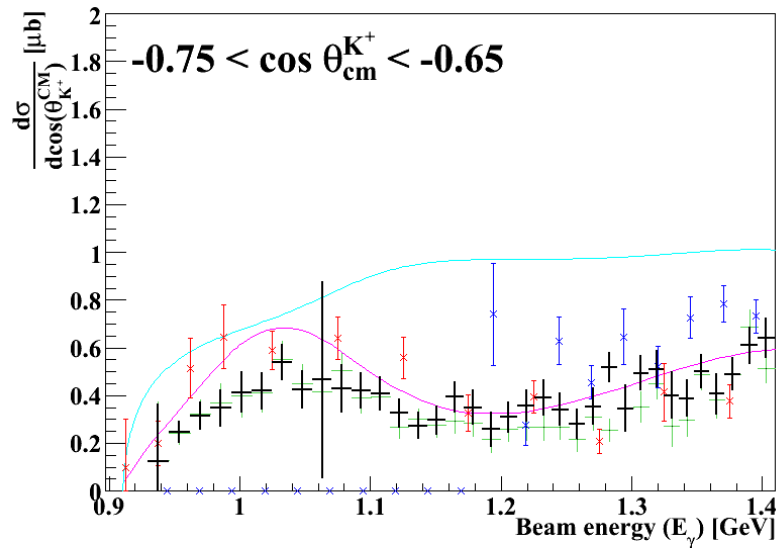
$\alpha = -0.032 \pm 0.003$

Kaon Photoproduction



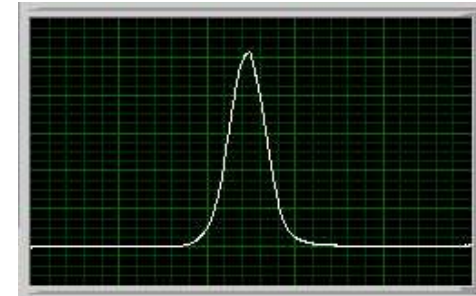
T. Jude (Edinburgh)

Kaon Photoproduction $\gamma p \rightarrow \Lambda K^+$ (Preliminary)

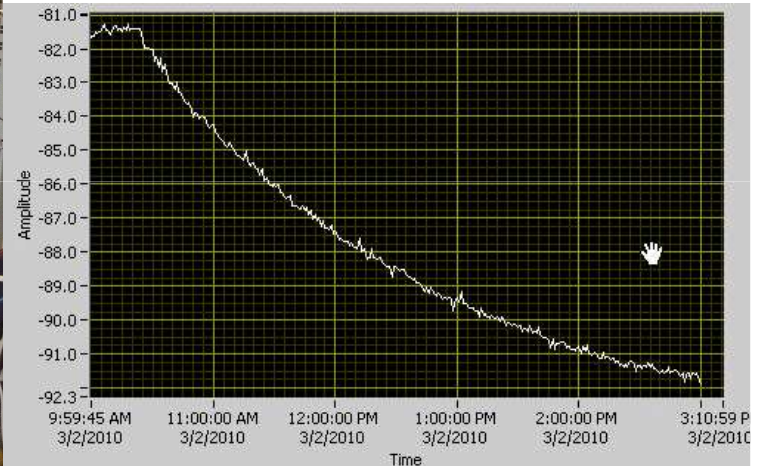


SAPHIR: K.H. Glander *et al.*, Eur Phys. J. A **19**, 251 (2004)
JLAB (blue): R. Bradford *et al.*, Phys Rev. C **73**, 035202 (2006)
Kaon MAID with $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$ and $D_{13}(1900)$
Regge-Plus Resonance (RPR) Model: T. Van Cauteren *et al.* Phys. Rev. C **73**, 045207 (2006), Pieter Vancraeyveld, The University of Ghent. Priv. com. (2010)

Polarized Frozen Spin Target

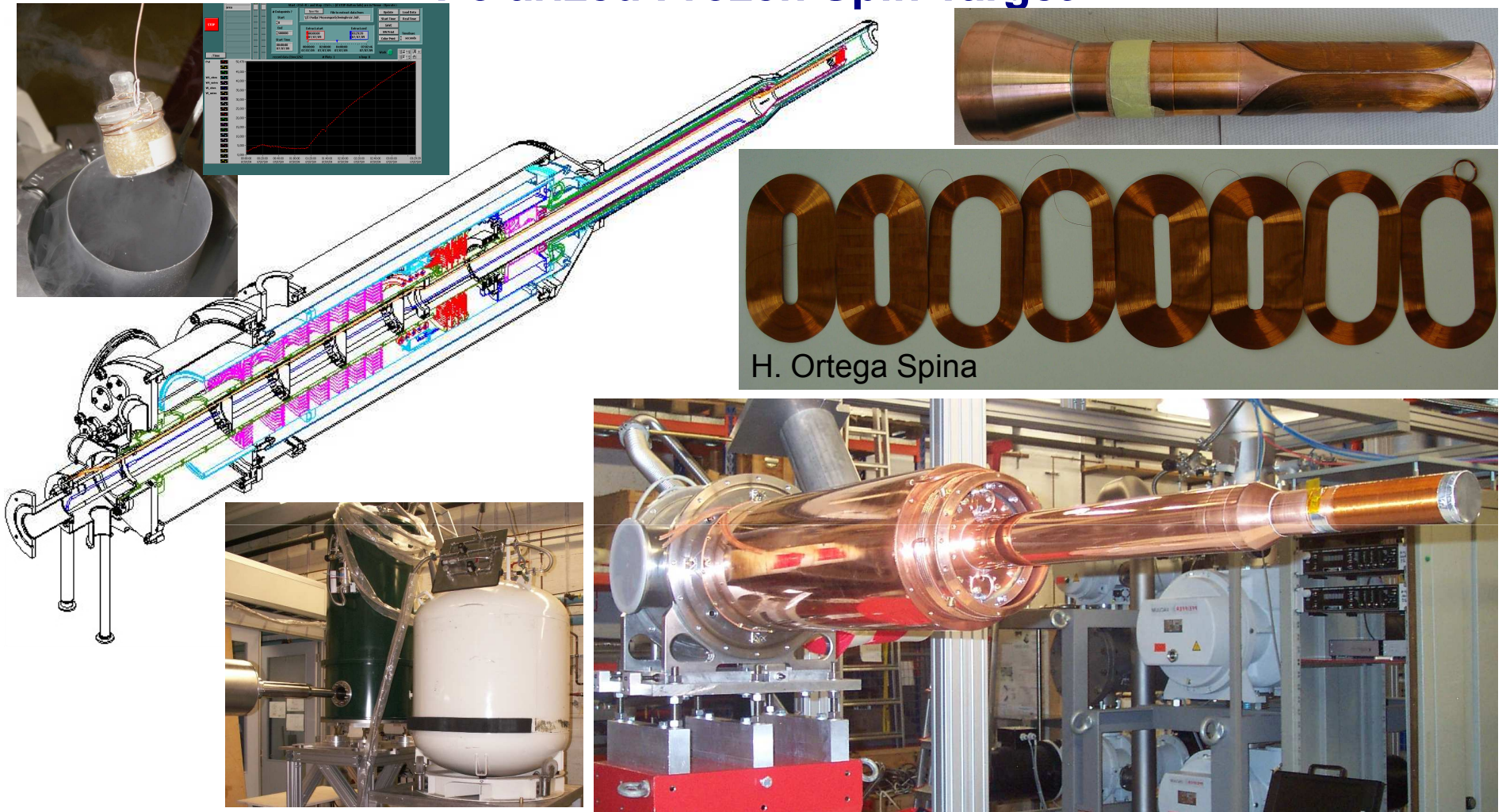


$$P = P_0 \exp(t/\tau)$$



- ◆ Frozen spin target fully functioning – **Polarization > 90%**
- ◆ **~1000 hours relaxation time** & low He consumption – long measurement time!
- ◆ Running with **transverse** polarized target!

Polarized Frozen Spin Target



- ◆ DNP to achieve ~ 90 % proton, 80 % deuteron
- ◆ Horiz. Dilution cryostat (Dubna), $T \sim 30$ mK
- ◆ Two holding coils: solenoid \rightarrow longitudinal, saddle coil \rightarrow transverse

First measurement of transverse spin observable F in $\gamma p \rightarrow \pi^0 p$

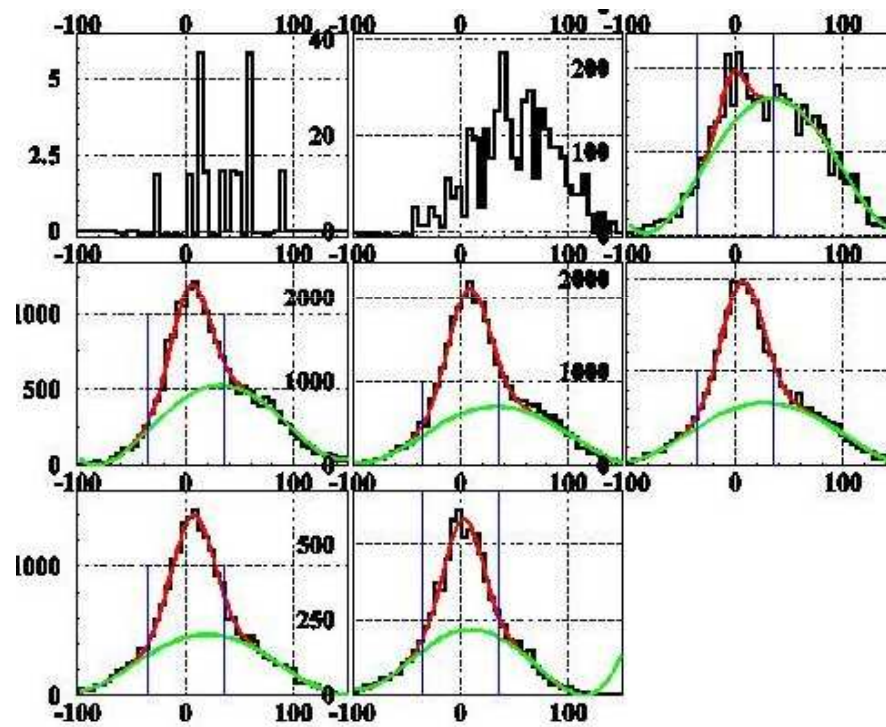
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega} \right)_{unpol} \left[1 - P_\gamma^{lin} \Sigma(\theta) \cos(2\phi) \right. \\ \left. + P_x \left[-P_\gamma^{lin} H(\theta) \sin(2\phi) + P_\gamma^{circ} F(\theta) \right] \right. \\ \left. + P_y \left[-T(\theta) + P_\gamma^{lin} P(\theta) \cos(2\phi) \right] \right. \\ \left. + P_z \left[-P_\gamma^{lin} G(\theta) \sin(2\phi) + P_\gamma^{circ} E(\theta) \right] \right]$$

- ◆ F asymmetry: circ. polarized photons, transverse pol. Target
 - ◆ Need to separate out contribution from ^{12}C and ^{16}O and $^3/4\text{He}$
 - ◆ Requiring proton removes coherent contributions
 - ◆ Other kinematic cuts and remaining underground fitted & subtracted
 - ◆ Data shown from 39 hours minus, 39 hours plus pol. **test** data, Crystal Ball only
- ◆ VERY PRELIMINARY!

First measurement of transverse spin observable F in $\gamma p \rightarrow \pi^0 p$

Background Subtraction on $MM(\gamma, \pi^0) - m_p$

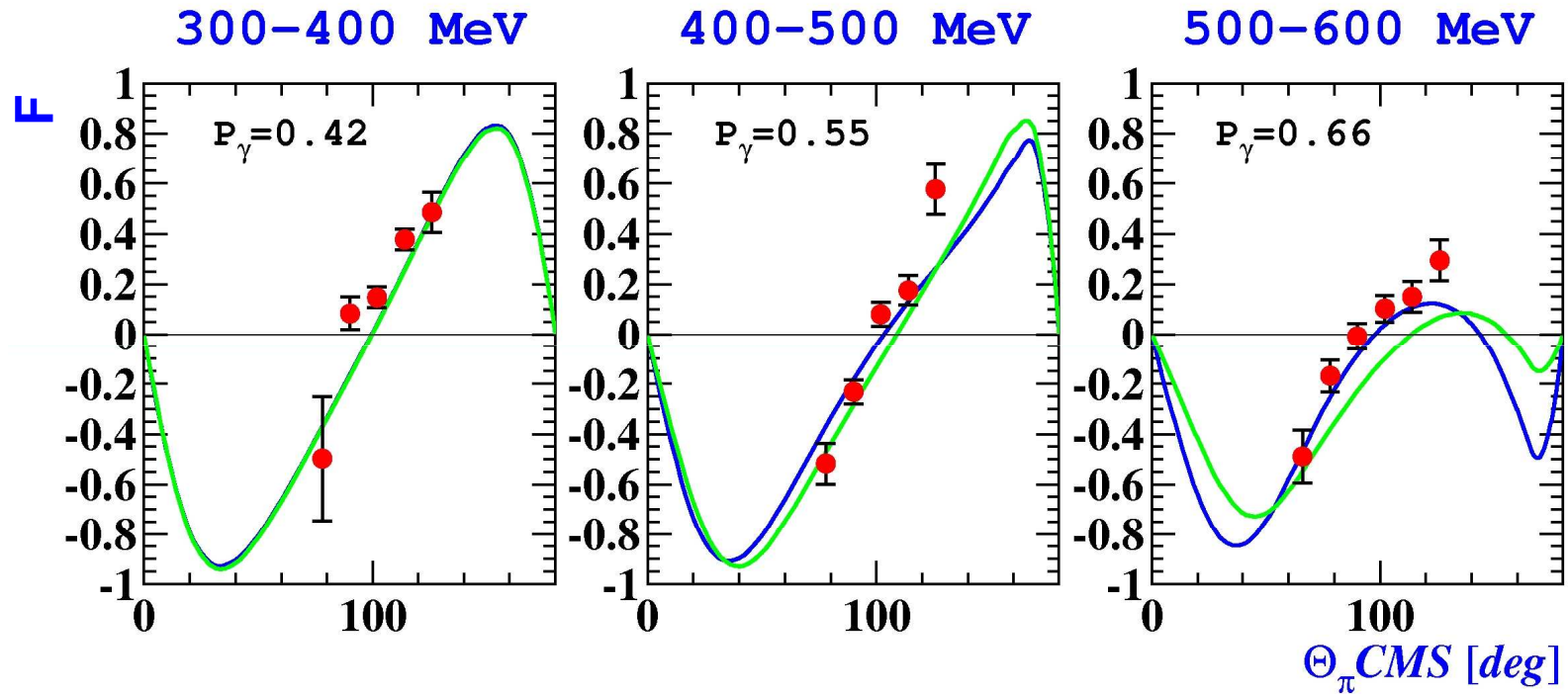
$E_\gamma = 400 - 500$ MeV



different Θ_π bins

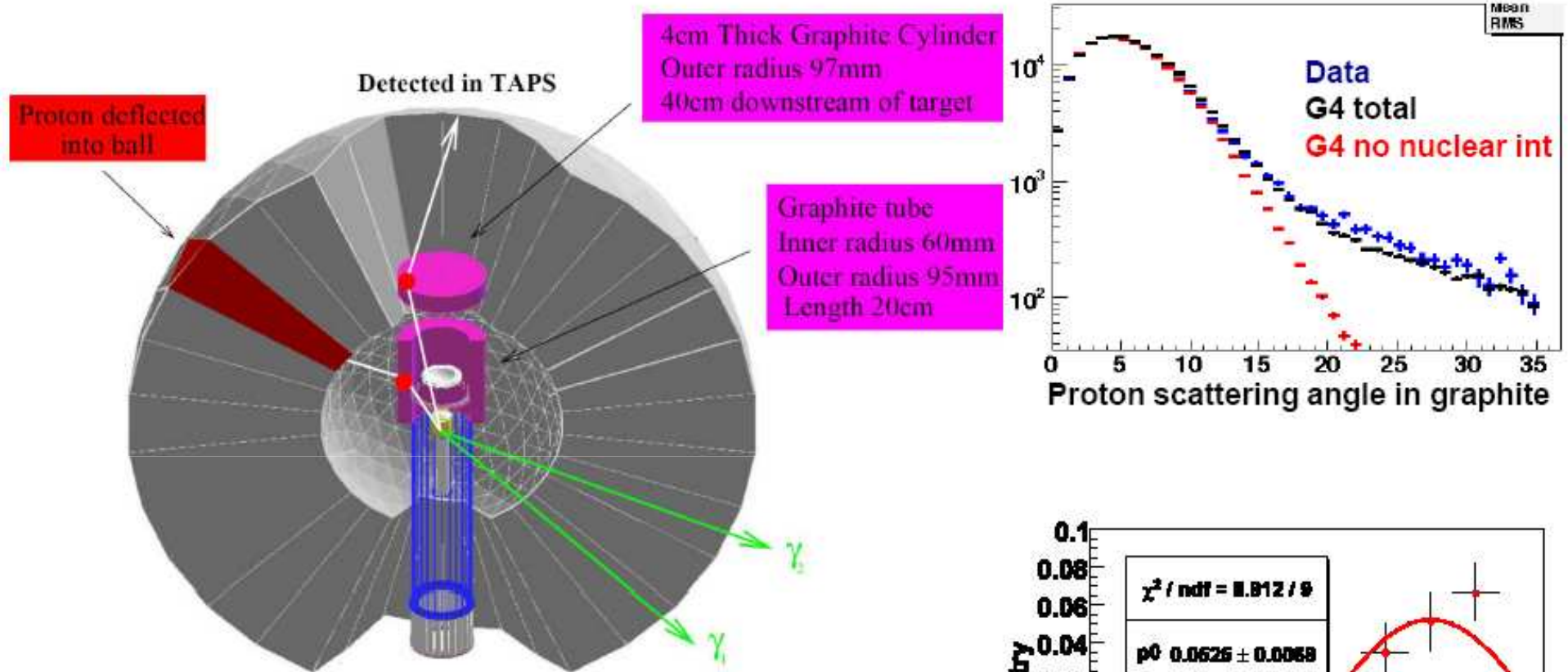
First measurement of transverse spin observable F in $\gamma p \rightarrow \pi^0 p$

PRELIMINARY

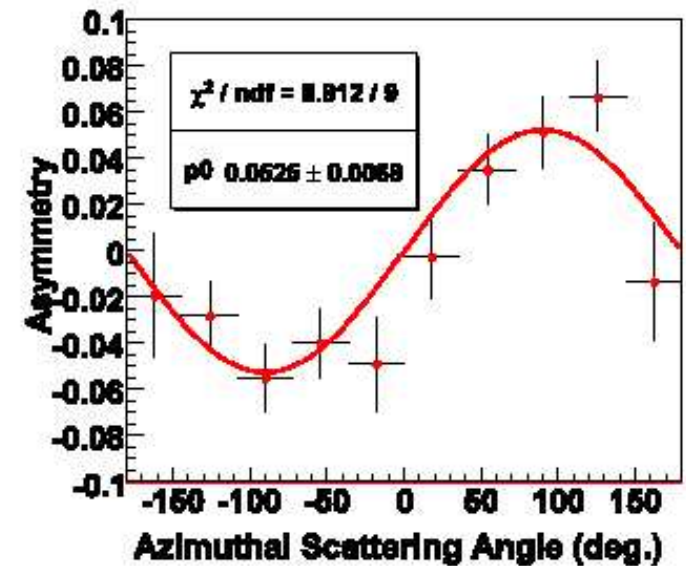


Data at 1.5 GeV has been taken

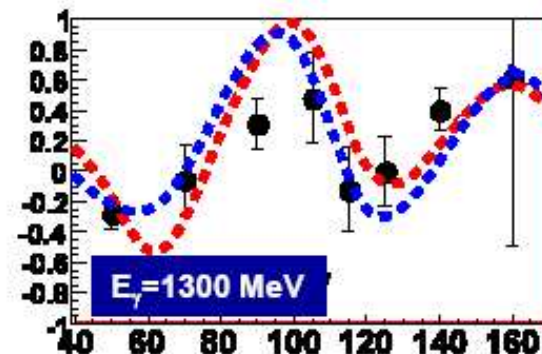
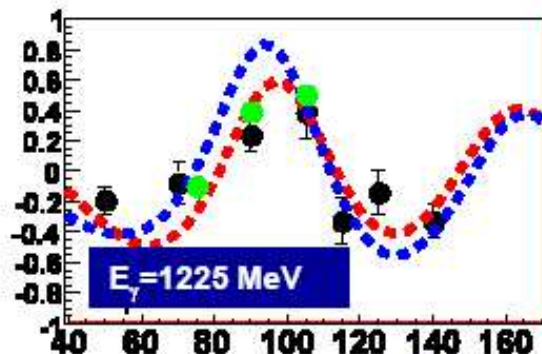
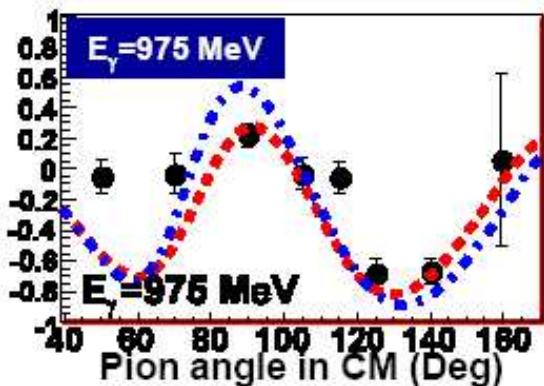
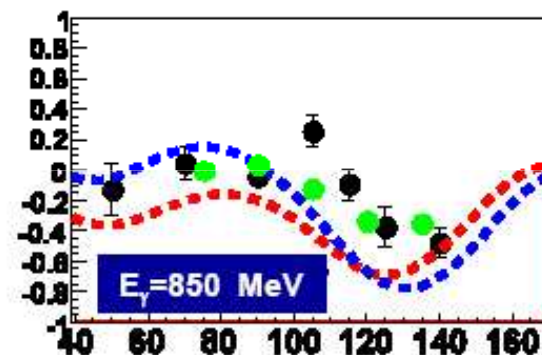
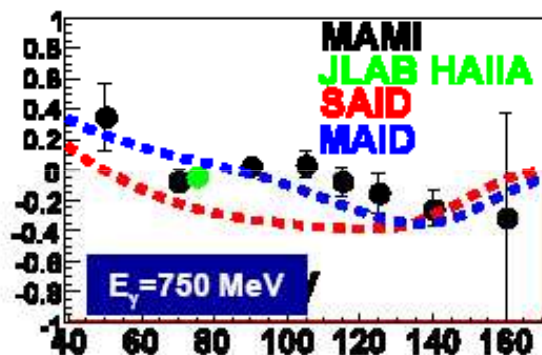
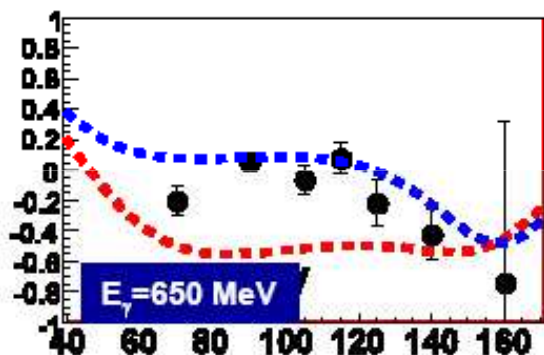
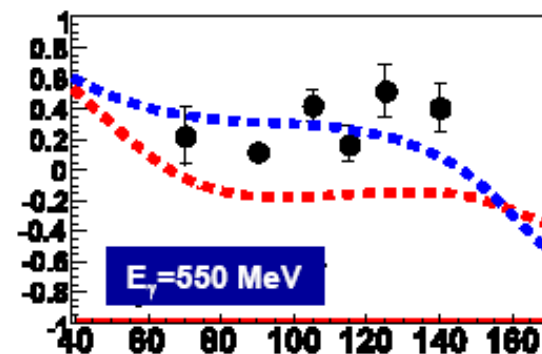
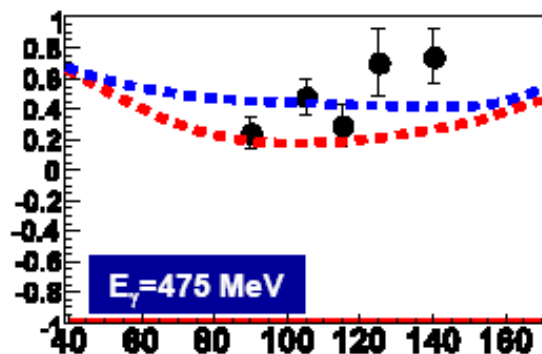
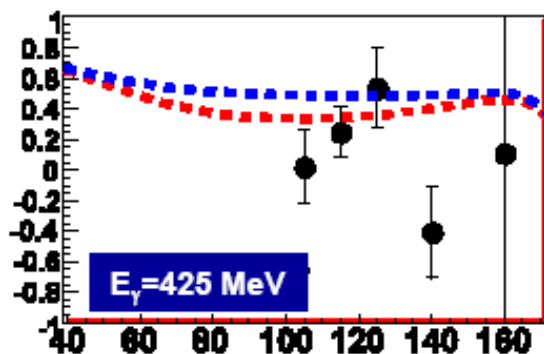
The CB proton polarimeter



$$\frac{N^+(\phi'_p) - N^-(\phi'_p)}{N^+(\phi'_p) + N^-(\phi'_p)} = C_{x'} P_\gamma^{circ} A \sin \phi'_p$$



C_x - transferred poln. from circ. pol γ : $\rho(\gamma, \pi^0)p$

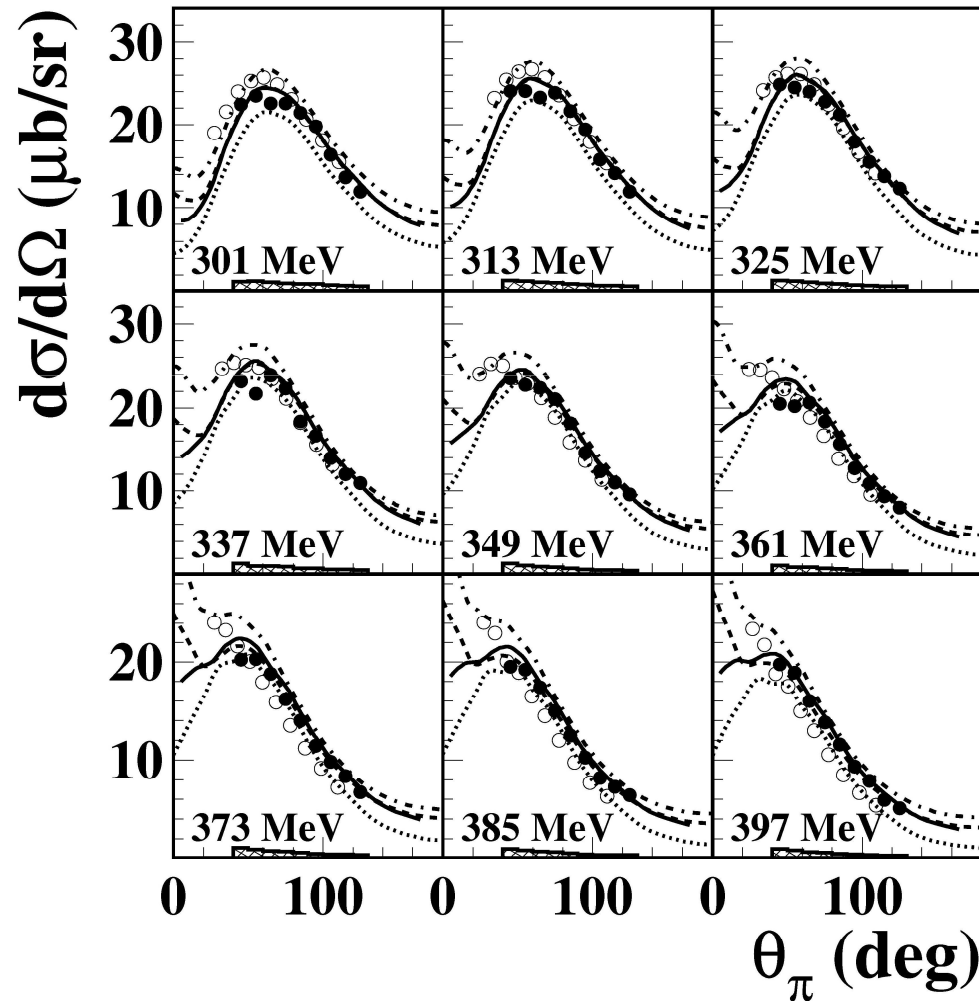


Preliminary!

Pion production on the deuteron

(as a neutron target)

π^+



Data:

full circles: $\gamma d \rightarrow \pi^+ nn$

empty circ.: $\gamma p \rightarrow \pi^+ n$

Curves: models by

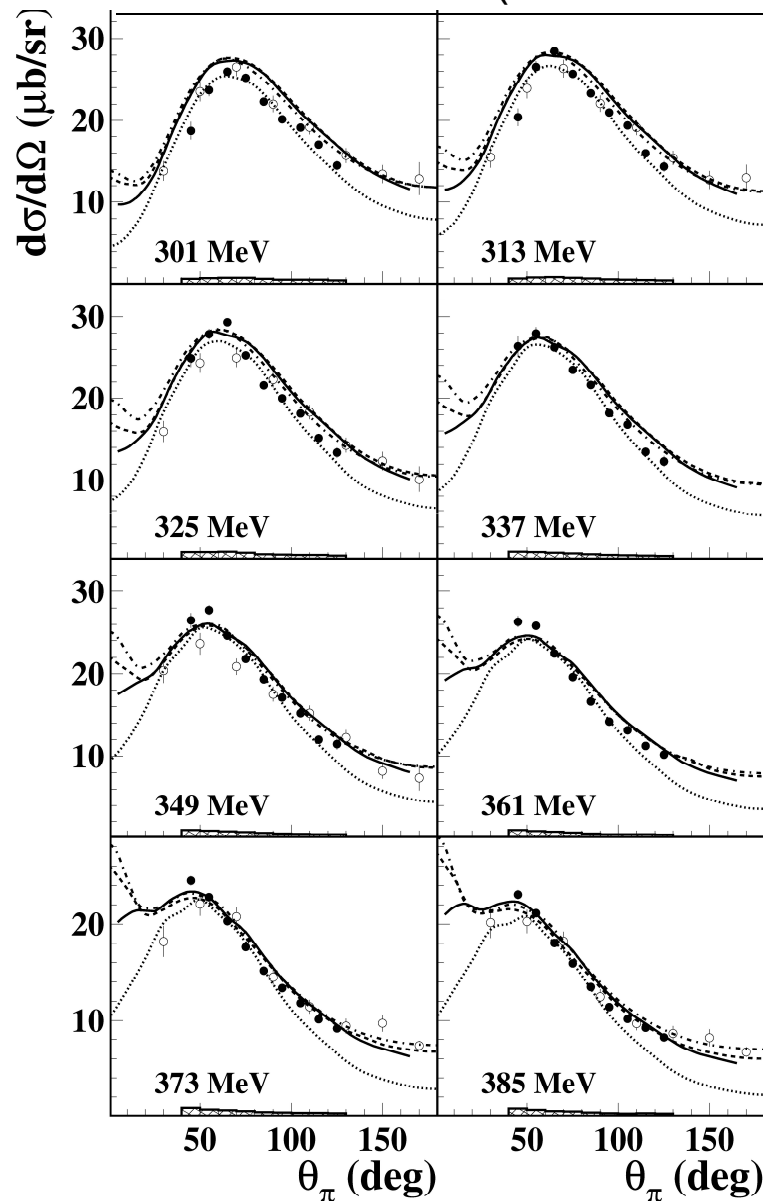
Arenhövel & Fix (solid)

Levchuk (dashed)

Schwamb (dash-dotted)

Darwish (dotted)

Pion production on the deuteron (as a neutron target)

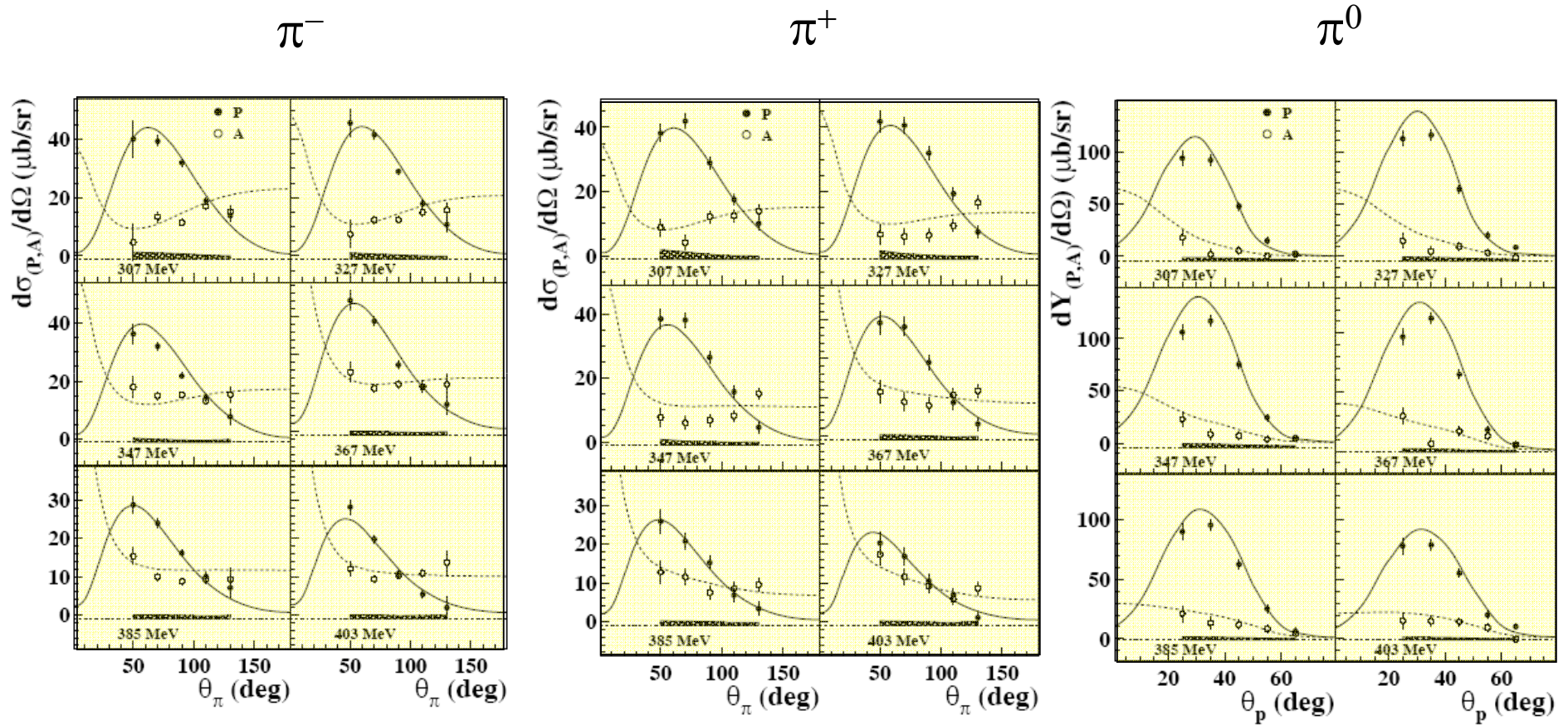


π^-

Data:
full circles: $\gamma d \rightarrow \pi^- pp$
(MAMI)
open circles: Benz et al. (1973)

Curves: models by
Arenhövel & Fix (solid)
Levchuk (dashed)
Schwamb (dash-dotted)
Darwish (dotted)

Helicity dependent $\vec{\gamma} \vec{d} \rightarrow \pi$ NN diff. cross sections

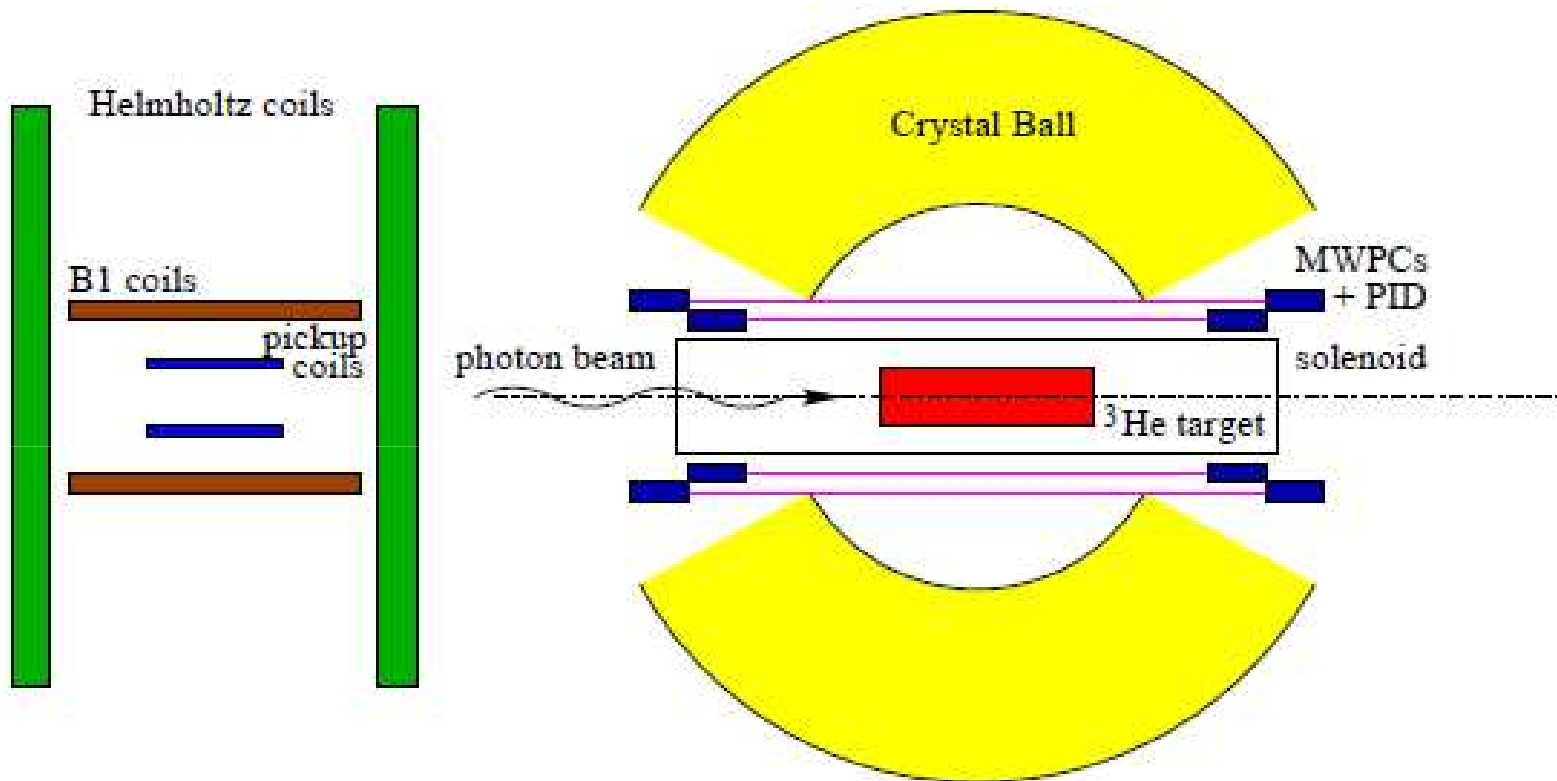


Data: J. Ahrens et al., Eur. Phys. J. A 44, 189 (2010)

Model: Levchuck et al., Phys. Rev. C 74, 014004 (2006)

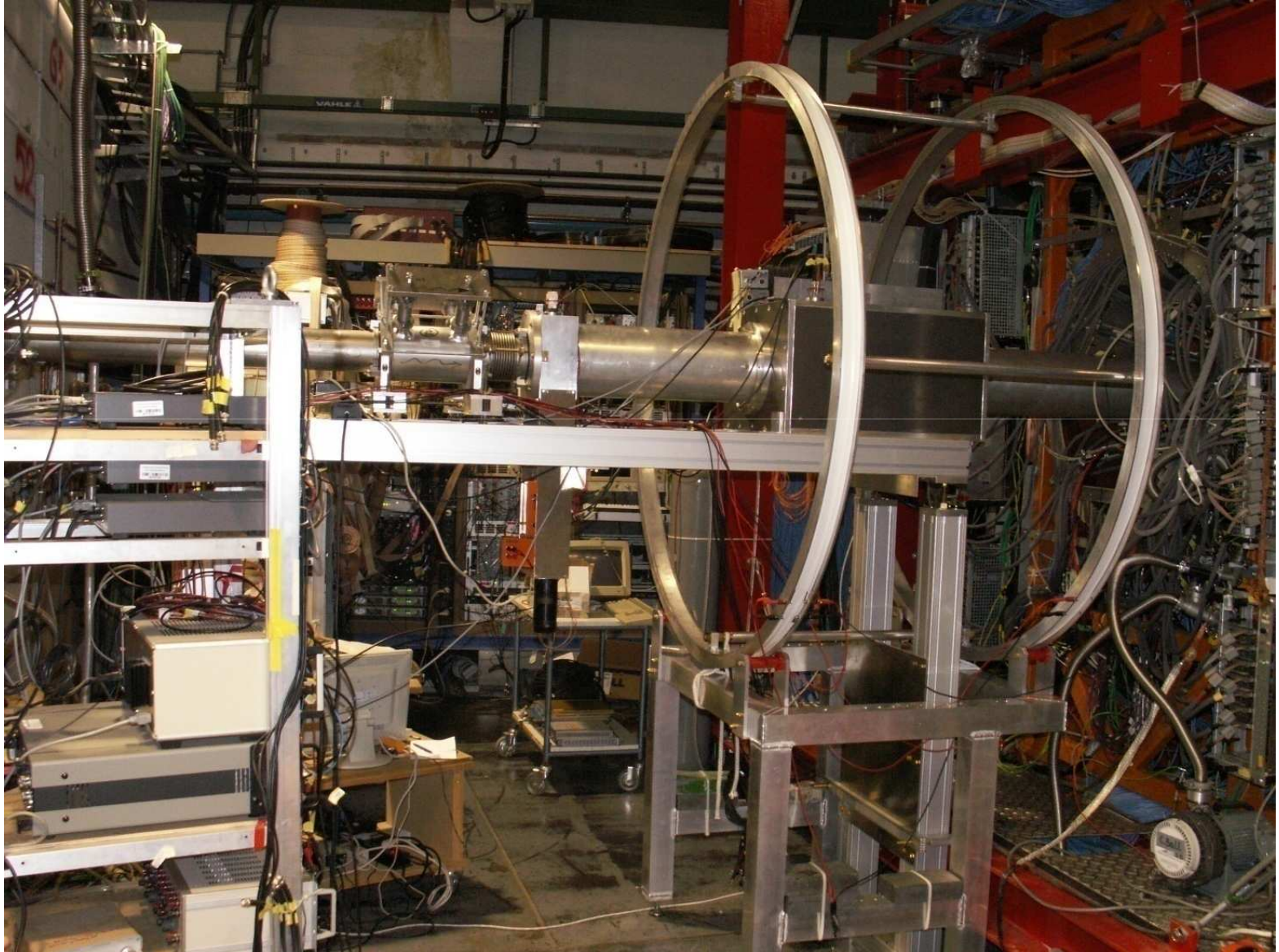
Polarized ^3He gas target for real photons

(with Institute of Physics, Mainz)

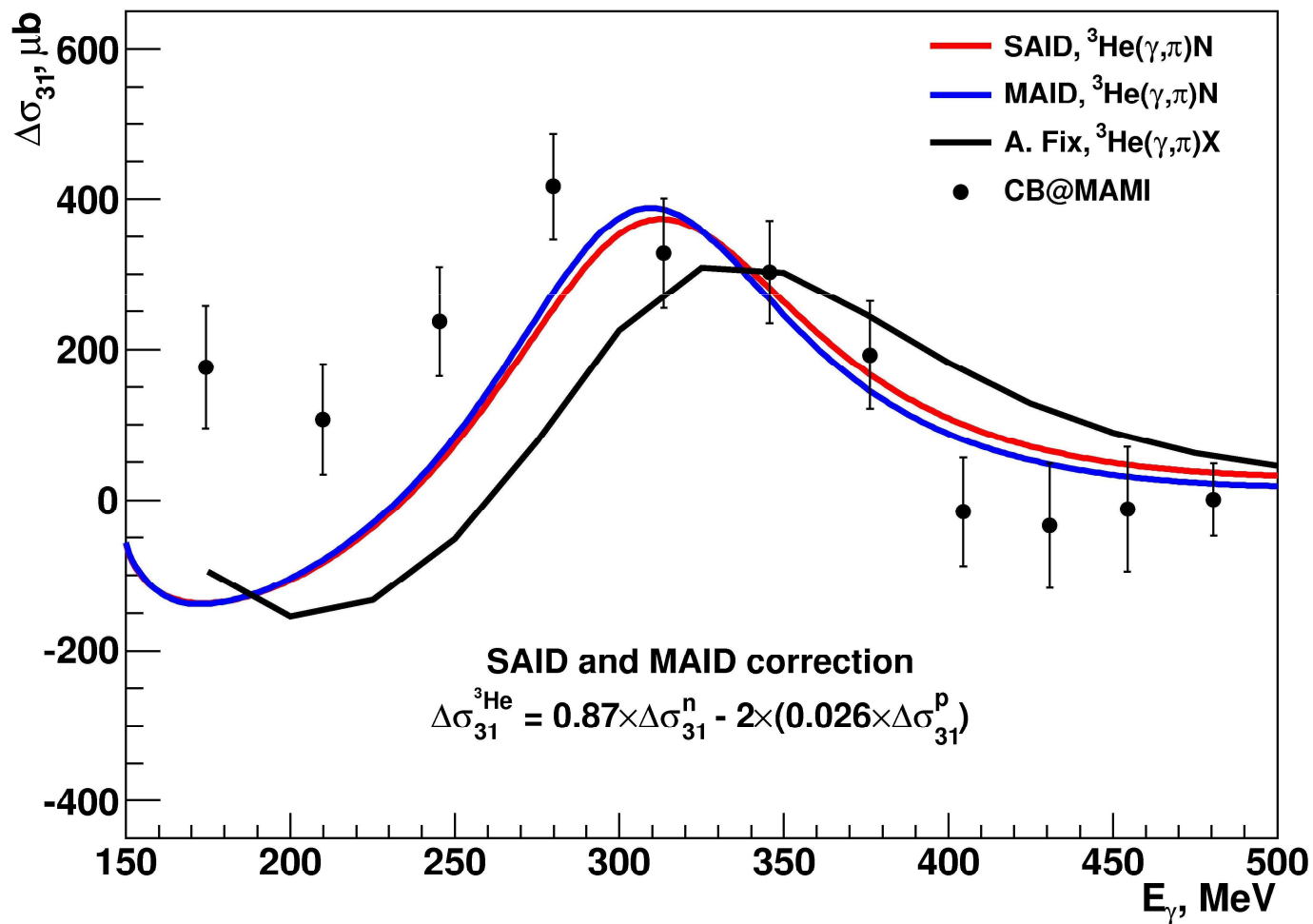


- ▶ Solenoid inside CB
- ▶ Polarimetry inside Helmholtz coils on upstream side
- ▶ Automatic transport between both positions

Setup



Helicity difference of total photoabsorption on ^3He (preliminary)



Summary

A1 Collaboration:

- High-precision $p(e,e')p$, prelim. charge radius compatible with value from Lamb shift
- $p(e,e' p)\eta$ recoil polarization agrees with previous T data

A2 Collaboration:

- new π^0 photoproduction near threshold, prelim. Σ smaller than previous results
- new high-precision η photoproduction data
- helicity asymmetry of $\gamma p \rightarrow \pi^0 \eta p$
- K^+ photoproduction with Crystal Ball feasible via weak K^+ decay

Summary

- Mainz polarized frozen-spin target with transverse polarization in operation, first preliminary data on F observable for π^0 production
- Polarized D and ^3He as neutron targets
preliminary helicity-dependent cross sections
- pol. beam, pol. target, recoil polarimeter available,
heading towards a „complete experiment“