

# Crystal Ball at MAMI

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For the CB@MAMI Collaboration



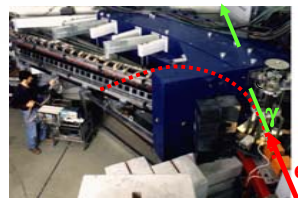
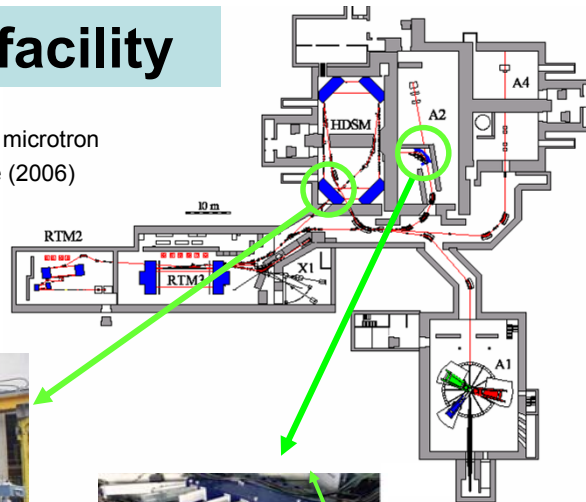
# CB@MAMI: Main physics objectives

(mainly involving low cross sections and/or precision measurements)

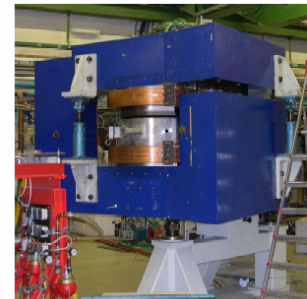
- **Precision spectroscopy of low lying baryon states:**
  - $\mu(\Delta(1232))$  from  $\gamma p \rightarrow \pi^0 \gamma p$  and  $\pi^+ \gamma n$
  - $\mu(S_{11}(1535))$  from  $\gamma p \rightarrow \eta \gamma p$  reaction
- **Threshold meson production: (test of LET/ ChPT):**
  - Strangeness ( $\gamma N \rightarrow \Lambda K$ )
  - $\pi^0$  photoproduction at threshold
- **Ambiguity free amplitude analysis of meson photoproduction**
  - Requires Double polarization measurements:
  - $\gamma N \rightarrow N\pi(\pi); N\eta(\rho, \dots)$  channels
- **Tests of fundamental symmetries (C, CP, CPT...)**
  - Rare  $\eta, \eta'$  decays
- **In medium properties of hadrons & nuclear physics:**
  - Meson photo production on nuclei

# The MAMI facility

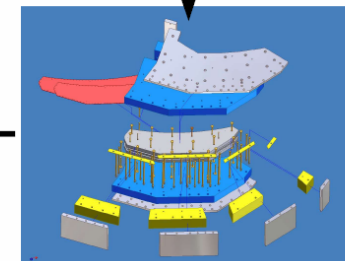
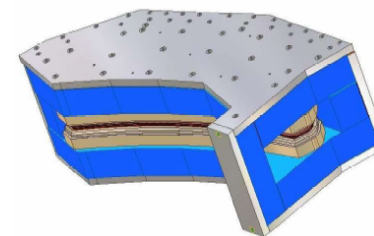
- 100% duty factor electron microtron
- MAMI-C 1.5 GeV upgrade (2006)  
(MAMI-B 0.85 GeV)






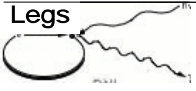


# Photon Tagger upgrade



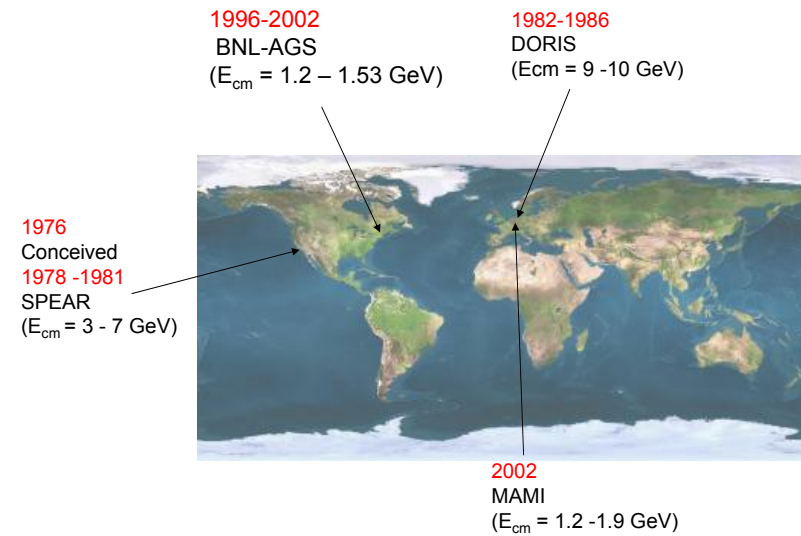
+



# Photon beam facilities

	$E_{\gamma}^{\max}$ (GeV)	$I_{\gamma}^{\max}$ ( $s^{-1}MeV^{-1}$ )	$\Delta E_{\gamma}$ (FWHM) (MeV)	$Pol_{\gamma}^{\text{lin}}$ (%)	$Pol_{\gamma}^{\text{circ}}$ (%)
	3.5	$\approx 10^4$	5	70	80
	1.5	$\approx 10^3$	15	100	100
<b>Jefferson Lab</b> 	5.4	$\approx 10^4$	5	70	80
	0.45	$\approx 10^3$	5	100	100
 <b>B</b> <b>0.8</b> <b>C</b> <b>1.5</b>		$\approx 10^5$	<b>1</b>	<b>70</b>	<b>80</b>
	3.0	$\approx 10^3$	30	100	100

# Crystal Ball history



# Crystal Ball arrives at Frankfurt



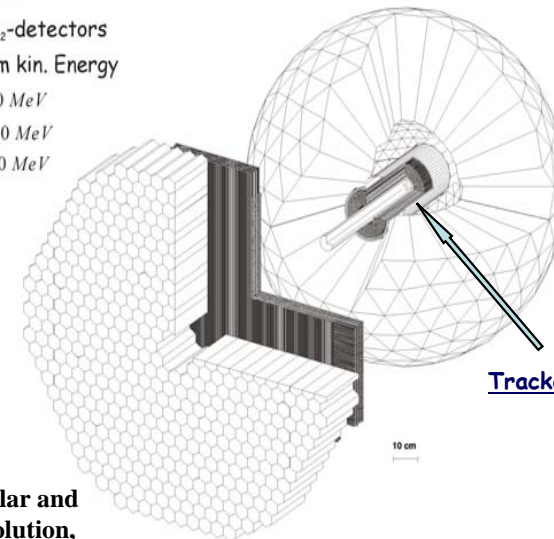
# Setup at MAMI

### TAPS:

510 BaF<sub>2</sub>-detectors  
maximum kin. Energy  
 $\pi^{\pm}$ : 180 MeV  
 $K^{\pm}$ : 280 MeV  
 $p$ : 360 MeV

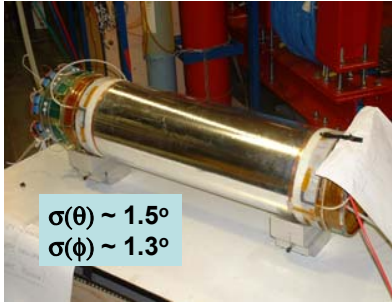
### Crystal Ball:

672 NaI-detectors  
maximum kin. energy  
 $\mu^{\pm}$ : 233 MeV  
 $\pi^{\pm}$ : 240 MeV  
 $K^{\pm}$ : 341 MeV  
 $p$ : 425 MeV

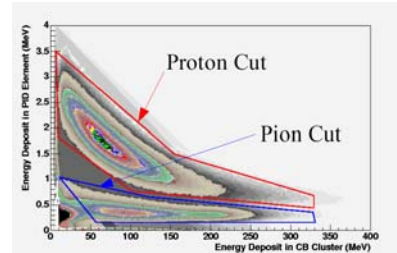
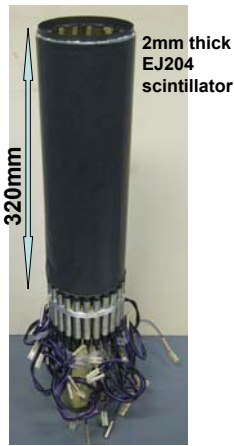


Good angular and energy resolution, close to  $4\pi$  acceptance

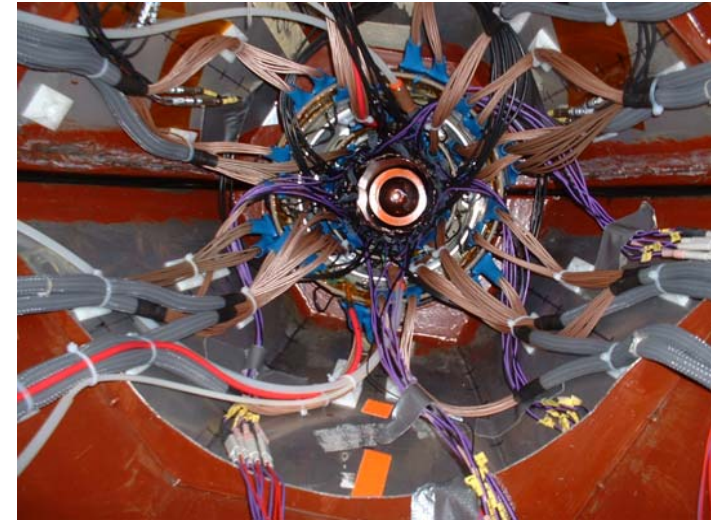
## Tracker & Particle-ID



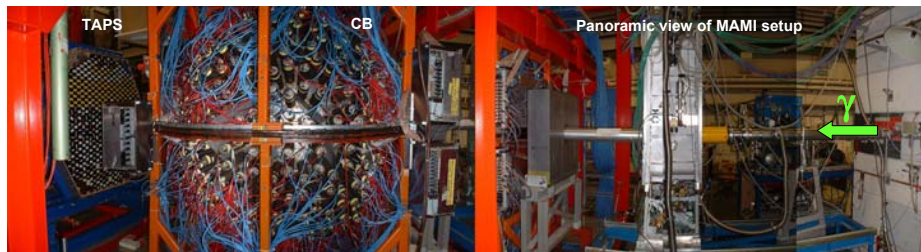
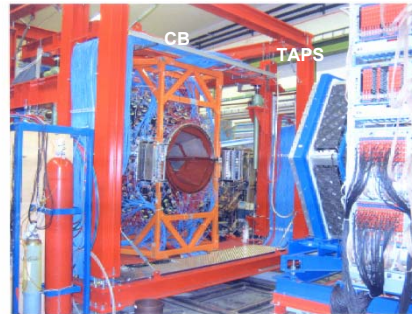
- Two cylindrical wire chambers
- 480 anode wires, 320 strips
- Adapted from DAPHNE
- New MWPC tracker under construction (2006)



## MWPC & Particle-ID in situ



## MAMI Photo Gallery

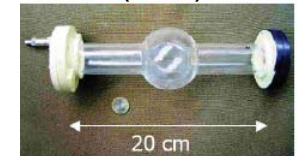


## Targets at MAMI

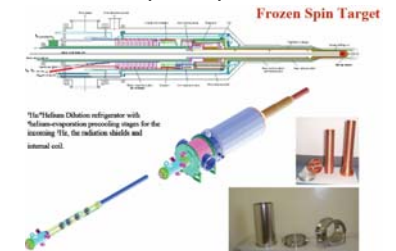
Liquid hydrogen (deuterium) target



Polarised  $^3\text{He}$  gas target (~2008)



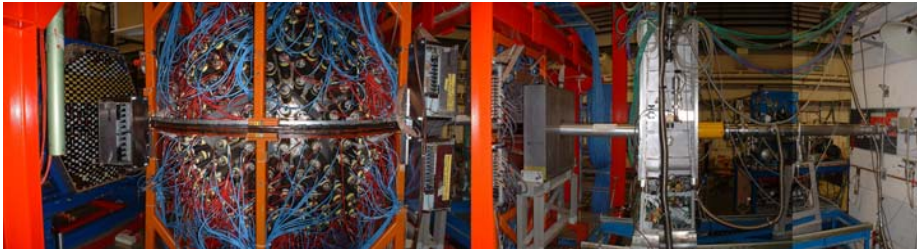
Frozen spin Target butanol / deuterated butanol (~2007)



Liquid  $^3\text{He}$  target (2006)



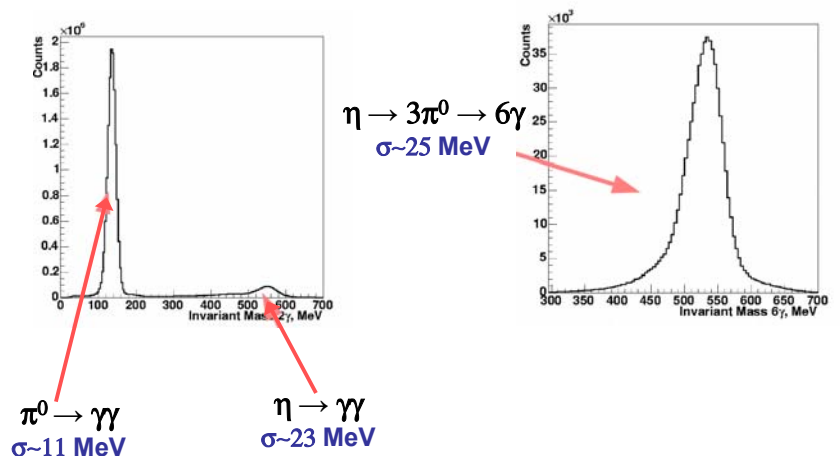
# CB@MAMI – timetable



Nov '02:	Crystal Ball moved to Mainz
Nov '03:	Crystal Ball installed at photon beam at MAMI
Mar '04:	TAPS installed
Apr '04:	MWPC and PID installed
May '04:	First test run tests with the complete setup
Jun'04-Apr '05 :	First production runs $E_\gamma=0.1-0.8$ GeV: unpolarized $H_2$ or $D_2$ targets, nuclear targets
Apr '05-Jan'06 :	MAMI-C upgrade, photon tagger upgrade
'06 onwards :	Second production runs $E_\gamma=0.1-1.5$ GeV: unpolarized, polarised, nuclear targets

**Selection of preliminary spectra from first round of experiments**  
 **$E_\gamma = 0.1 - 0.8$  GeV**

## Preliminary analyses: $\pi^0$ , $\eta$ identification

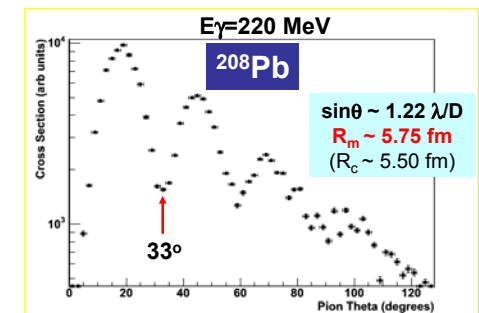


## Preliminary analyses: $A_{gs}(\gamma, \pi^0)A_{gs}$ coherent $\pi^0$ photoproduction from nuclei

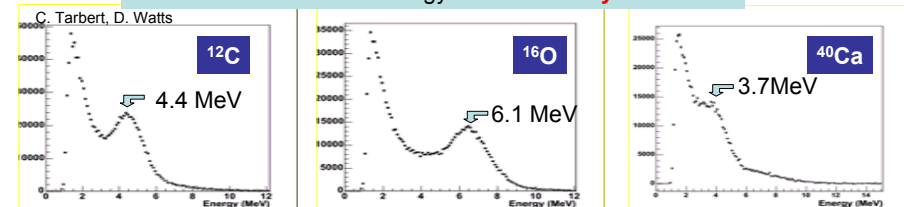
- Clear diffraction patterns for  $^{208}\text{Pb}$ ,  $^{40}\text{Ca}$ ,  $^{16}\text{O}$ ,  $^{12}\text{C}$

$$d\sigma/d\Omega \sim A^2(q/k_\gamma) P_3^2 |F_m(q)|^2 \sin^2\theta_\pi$$

- Matter form factor,  $\Delta$  properties in the medium



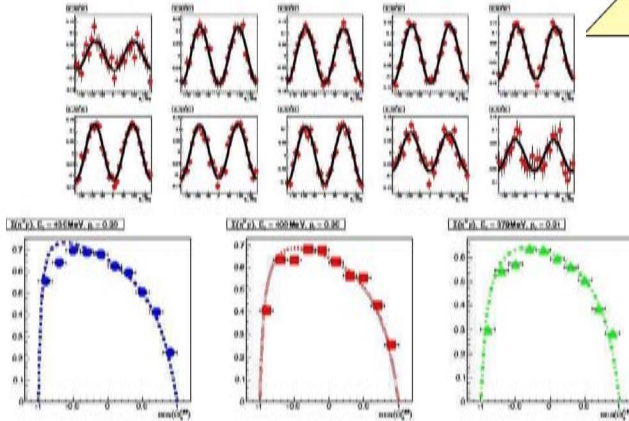
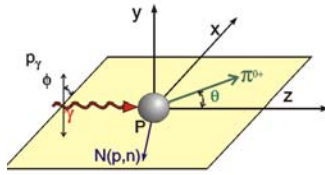
Also see coincident low energy **Nuclear Decay Photons !!**



# Preliminary analyses: $(\vec{\gamma}, p)\pi^0$

Photon Asymmetry  $\Sigma$ :

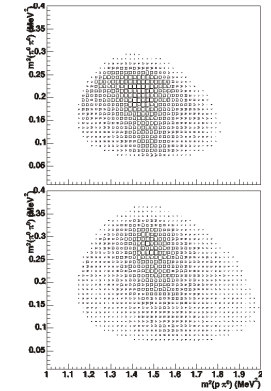
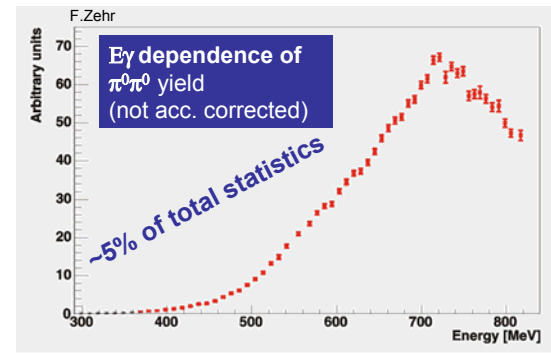
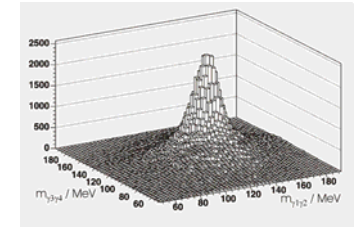
$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega}(\theta)(1 - p_\gamma \cdot \Sigma \cos(2\phi))$$



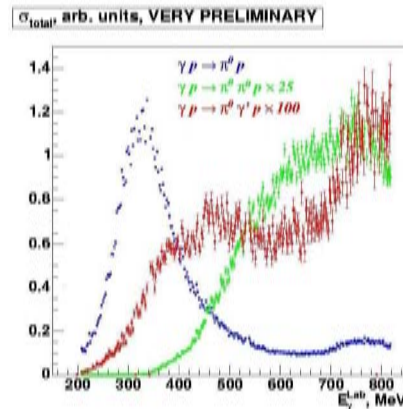
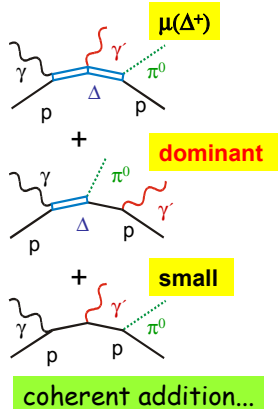
A. Starostin

# Preliminary analyses: $p(\vec{\gamma}, p)\pi^0\pi^0$

- High statistics measurement
- With  $\gamma$  beam polarisation  $\rightarrow \Sigma, \Sigma_{\text{circ}}$



# Preliminary analyses: $p(\vec{\gamma}, p)\pi^0\gamma$ to measure $\mu(\Delta^+)$

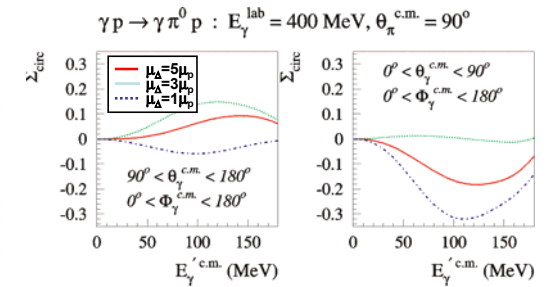
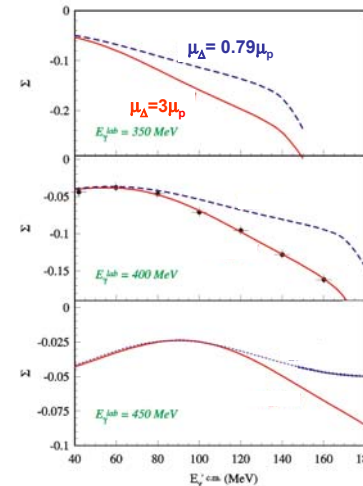


	$\Delta^{++}$	$\Delta^+$	$\Delta^0$
SU(6)	5.58	2.79	0
RQM Schlumpf, PRD48 (1993)	4.76	2.38	0
lattice QCD Leinweber et al., PRD46 (1992)	$4.9 \pm 0.6$	$2.5 \pm 0.3$	0
$\chi$ PT Butler et al., PRD49 (1994)	$4.0 \pm 0.4$	$2.1 \pm 0.2$	$-0.17 \pm 0.04$
$\chi$ QSM Kim et al., PRD87 (1998)	4.73	2.19	-0.35
<b>PDG2000</b>	<b>3.7 - 7.5</b>	<b>0</b>	<b>-</b>

MAMI pilot measurement with TAPS only  
M. Kotulla et al., PRL 89 (2002) 272001

# $p(\vec{\gamma}, p)\pi^0\gamma$ to measure $\mu(\Delta^+)$

- $\times 100$  in statistics
- measure  $\gamma$  beam polarisation observables
- Both  $p\pi^0$  and  $n\pi^+$  decay of  $\Delta^+$



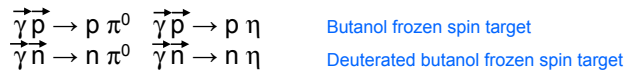
# Future plans with MAMI-C

$E_\gamma = 0.1 - 1.5 \text{ GeV}$

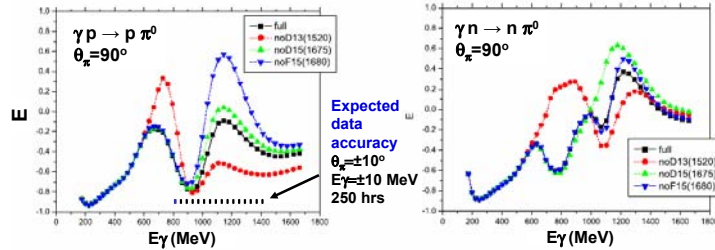
## Double-polarisation in pseudo-scalar meson photoproduction

Observable	Polarisation of		
	$\gamma$	target recoil	
1. $\{d\sigma/d\Omega\}/\mathcal{N}$			$=  b_1 ^2 +  b_2 ^2 +  b_3 ^2 +  b_4 ^2$
<b>Single polarization</b>			
2. $P$		$y'$	$=  b_1 ^2 -  b_2 ^2 +  b_3 ^2 -  b_4 ^2$
3. $\Sigma$	$p$		$=  b_1 ^2 +  b_2 ^2 -  b_3 ^2 -  b_4 ^2$
4. $T$		$y$	$=  b_1 ^2 -  b_2 ^2 -  b_3 ^2 +  b_4 ^2$
<b>Double polarization</b>			
<b>Beam-target</b>			
5. $E$	$c$	$z$	$= 2 \text{Re}(b_1 b_3^* + b_2 b_4^*)$
6. $F$	$c$	$x$	$= 2 \text{Im}(b_1 b_3^* - b_2 b_4^*)$
7. $G$	$t$	$z$	$= 2 \text{Im}(b_1 b_2^* + b_3 b_4^*)$
8. $H$	$t$	$x$	$= -2 \text{Re}(b_1 b_2^* + b_3 b_4^*)$
<b>Beam-recoil</b>			
9. $C_x$	$c$	$x'$	$= -2 \text{Im}(b_1 b_4^* - b_2 b_3^*)$
10. $C_y$	$c$	$z'$	$= 2 \text{Re}(b_1 b_4^* + b_2 b_3^*)$
11. $O_x$	$t$	$x'$	$= 2 \text{Re}(b_1 b_2^* - b_3 b_4^*)$
12. $O_z$	$t$	$z'$	$= 2 \text{Im}(b_1 b_4^* + b_2 b_3^*)$
<b>Target-recoil</b>			
13. $T_x$		$x$	$= 2 \text{Re}(b_1 b_2^* - b_3 b_4^*)$
14. $T_z$		$x$	$= 2 \text{Im}(b_1 b_2^* - b_3 b_4^*)$
15. $L_x$		$z$	$= -2 \text{Im}(b_1 b_2^* + b_3 b_4^*)$
16. $L_z$		$z$	$= 2 \text{Re}(b_1 b_2^* + b_3 b_4^*)$

## Beam-target observable: E



Circularly polarised photons + longitudinally polarised protons (or neutrons)



Previous E measurement for  $\gamma p \rightarrow p \pi^0$  led to significant revision of helicity amplitudes for  $D_{13}(1520)$  [PRL 88, 232002 (2002)]

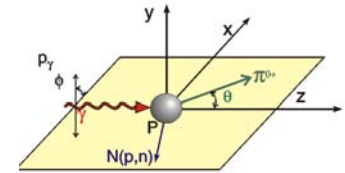
Neutron targets: different resonance contributions, isospin structure

Also get  $\pi\pi$  channels – mechanisms, contributions to GDH integrand

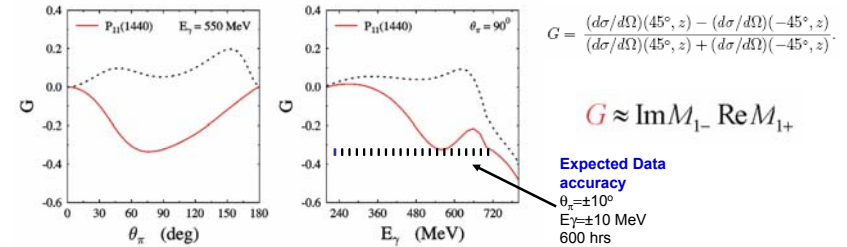
## Beam-target observable: G



linearly polarised photons + longitudinally polarised protons



$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega}(\theta) (1 - p_\gamma \Sigma \cdot \cos(2\phi) + p_\gamma p_z G \cdot \sin(2\phi))$$



$$G = \frac{(\frac{d\sigma}{d\Omega}(45^\circ, z) - \frac{d\sigma}{d\Omega}(-45^\circ, z))}{(\frac{d\sigma}{d\Omega}(45^\circ, z) + \frac{d\sigma}{d\Omega}(-45^\circ, z))}$$

$$G \approx \text{Im} M_{1-} \text{Re} M_{1+}$$

Variable well suited to studies of Roper resonance ( $P_{11}(1440)$ )

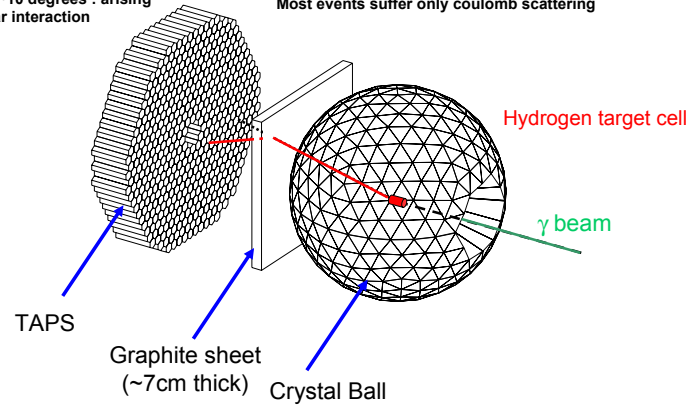
# Beam-Recoil Observables: $C_x$ , $O_x$ , $T$ , $P$

## Useful scattered event

Select events with scattering angles larger than  $\sim 10$  degrees : arising from nuclear interaction

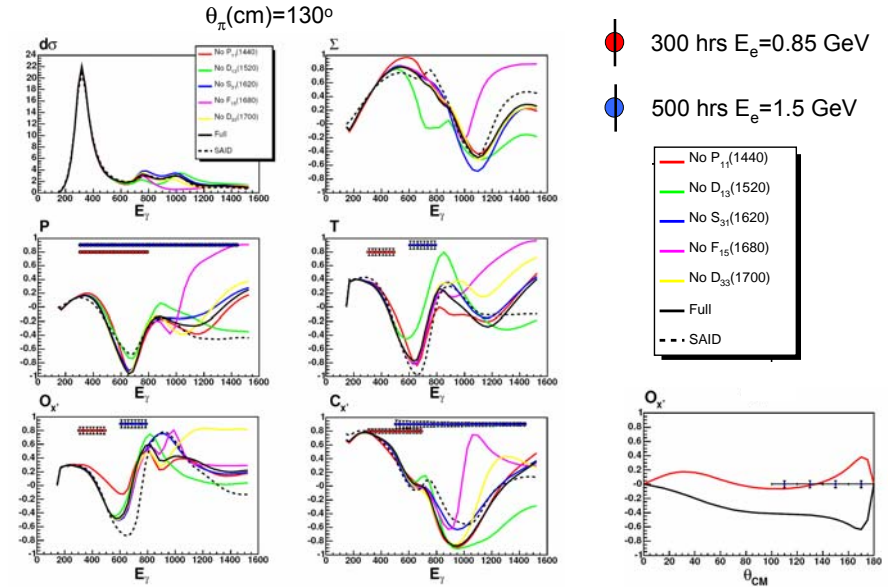
## Initial path of proton

Polarimeter acceptance :  $\pm 20^\circ$  polar angle (target at centre)  
Most events suffer only coulomb scattering



$$n(\theta, \phi) = n_o(\theta) \{ 1 + A(\theta) [P_y \cos(\phi) - P_x \sin(\phi)] \}$$

# Beam-Recoil Observables- $p(\gamma, \pi^0)p$



# Summary

$\sim 4\pi$  detector system

Very good neutral (and charged) particle detection capabilities

Excellent properties of MAMI beam

Availability of polarized targets

Recoil nucleon polarimetry possibilities

→ High quality data for meson photoproduction for  $E_\gamma$  up to  $\sim 1.5$  GeV can be expected

J.Brudvik, J. Goetz, B.M.K.Nefkens, S.N.Prakhov, A.Starostin, I. Saurez, [University of California, Los Angeles, CA, USA](#)

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