«Активная» поляризованная мишень: измерение спиновых поляризуемостей протона

V Черенковские чтения

Москва, 10.04.2012

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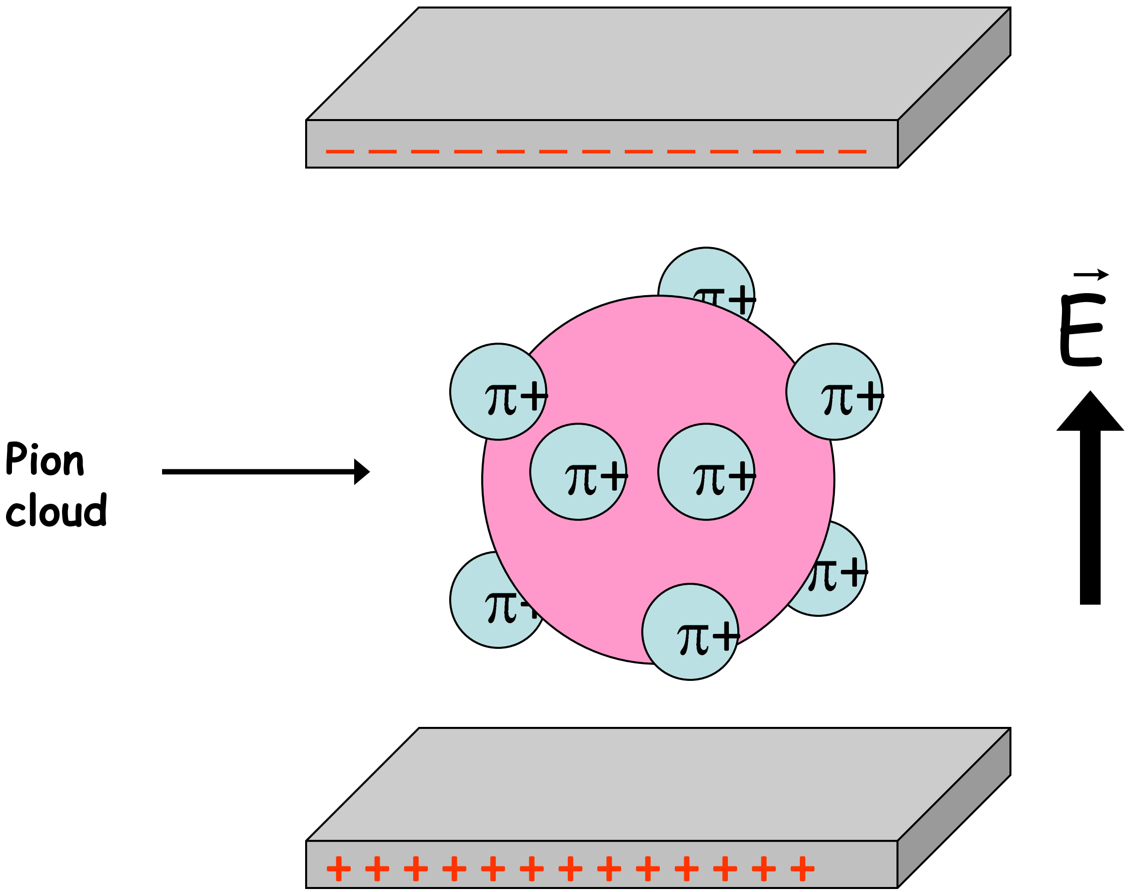
Proton properties as listed by the Particle Data Group

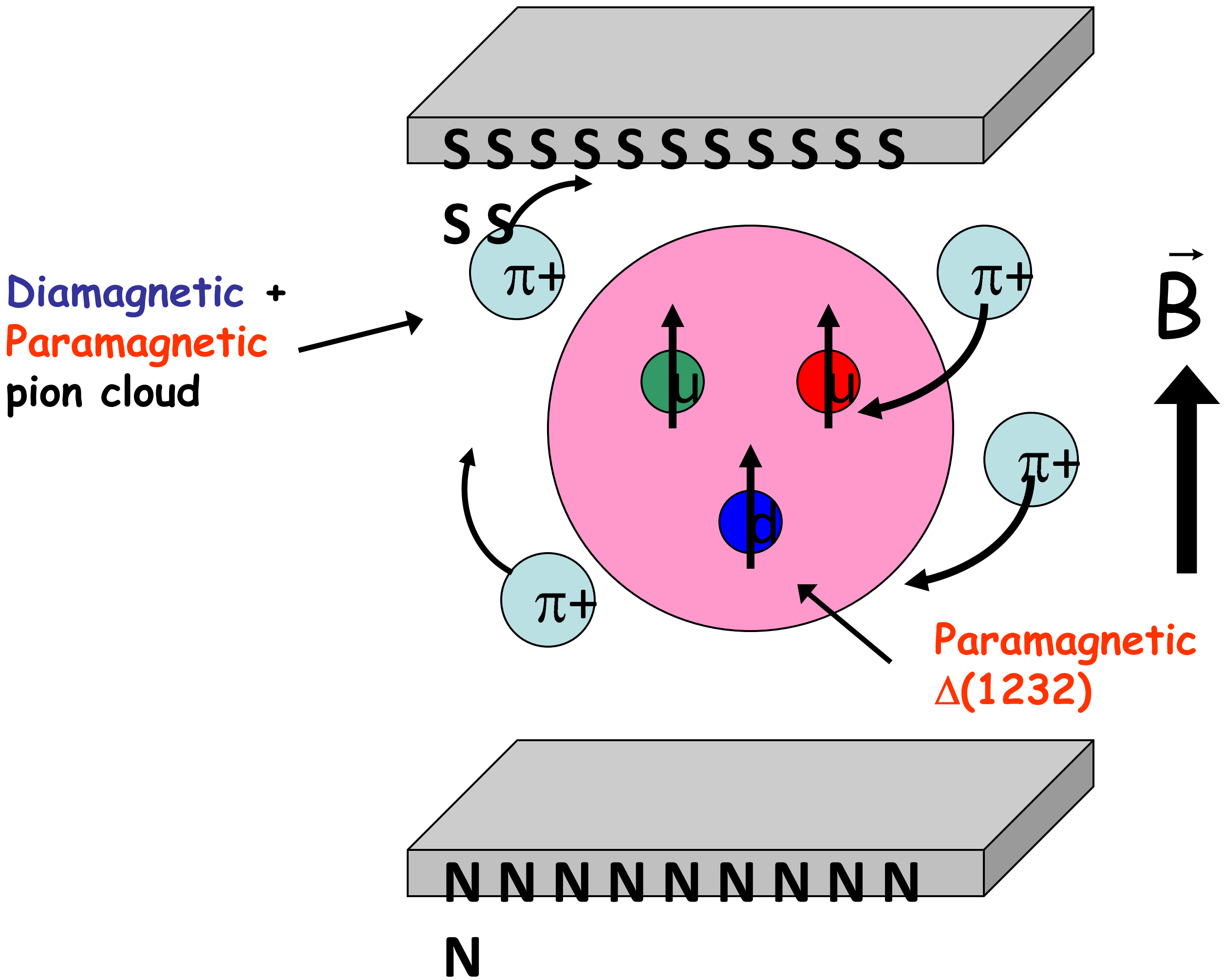
Mass	**938.272013 ± 0.000023 MeV**
Charge	**+1**
$I(J^P)$	**1/2** $(1/2^+)$
Charge radius	**0.8768 ± 0.0069 fm**
Mean life	$> 5.8 \cdot 10^{29}$ **years**
Magnetic moment	**2.792847356 ± 0.000000023** μ_N
Electric dipole moment	$< 0.54 \cdot 10^{-23}$ **e · cm**
Valence quarks	**uud**
Electric polarisability α_{E1}	$12 \pm 0.6 \cdot 10^{-4}$ **fm**^{3}
Magnetic polarisability β_{M1}	$1.9 \pm 0.5 \cdot 10^{-4}$ **fm**^{3}

Proton electric polarizability



α_{E1} : electric “stretchability”

Proton magnetic polarizability



β_{M1} : magnetic "alignability"

Nucleon Scalar Polarisabilities

- Polarisabilities are fundamental structure constants of the nucleon
- Scalar polarisabilities (α, β) describe a response of nucleon structure to static EM field
- They appear in effective interaction Hamiltonian at second order in photon energy:

$$H_{\rm eff}^{(2)} = -4\pi \left[\frac{1}{2}\alpha_{E1}\vec{E}^2 + \frac{1}{2}\beta_{M1}\vec{H}^2 \right]$$

(α, β) measured in real Compton scattering for proton

Nucleon Vector Spin Polarisibilities

- Spin Vector polarizabilities describe spin response to a changing EM field (parametrizing the "stiffness" of the nucleon against EM induced deformations relative to the nucleon spin axis)

- Four vector pol. (γ_{E1E1} γ_{M1M1} γ_{E1M2} γ_{M1E2}) appear at 3rd order in eff. Hamiltonian

$$H_{\rm eff}^{(3)} = -4\pi\left[\tfrac{1}{2}\gamma_{E1E1}\vec{\sigma}\cdot(\vec{E}\times\dot{\vec{E}}) + \tfrac{1}{2}\gamma_{M1M1}\vec{\sigma}\cdot(\vec{H}\times\dot{\vec{H}}) - \gamma_{M1E2}E_{ij}\sigma_i H_j + \gamma_{E1M2}H_{ij}\sigma_i E_j\right].$$

- Only two linear combinations of vector polarizabilities measured

$$\gamma_0 = -\gamma_{E1E1} - \gamma_{M1M1} - \gamma_{E1M2} - \gamma_{M1E2} = -1.01 \pm 0.08 \pm 0.10 \times 10^{-4} fm^4$$
$$\gamma_\pi = -\gamma_{E1E1} + \gamma_{M1M1} - \gamma_{E1M2} + \gamma_{M1E2} = 8.0 \pm 1.8 \times 10^{-4} fm^4$$

- Most model-independent way to measure (γ_{E1E1} γ_{M1M1} γ_{E1M2} γ_{M1E2}) is in double-polarized Compton scattering below pion threshold

Nucleon Vector Spin Polarisibilities (Theory)

γ	Theory / 10^{-4}fm^4								Experiment / 10^{-4}fm^4
	$\mathcal{O}(p^4)$ [1]	$\mathcal{O}(p^5)$ [2]	LC4 [3]	SSE [4]	BGLMN [5]	HDPV [6]	KS [7]	DPV [8]	
E1E1	-1.4	-1.8	-2.8	-5.7	-3.4	-4.3	-5.0	-4.3	no data
M1M1	3.3	2.9	-3.1	-3.1	2.7	2.9	3.4	2.9	no data
E1M2	0.2	0.7	0.8	0.98	0.3	-0.01	-1.8	0	no data
M1E2	1.8	1.8	0.3	0.98	7.9	2.1	1.1	2.1	no data
0	3.9	-3.6	4.8	0.64	-1.5	-0.7	2.3	-0.7	$-1.01 \pm 0.08 \pm 0.13$ [9]
π	6.3	5.8	-0.8	8.8	7.7	9.3	11.3	9.3	8.0 ± 1.8 [10]

1. G. Gellas, T. Hemmert, and Ulf-G. Meißner, Phys. Rev. Lett. 85, 14 (2000).
2. K.B. Vijaya Kumar, J.A. McGovern, M.C. Birse, Phys. Lett. B 479, 167 (2000).
3. D. Djukanovic, Ph.D. Thesis, University of Mainz, 2008.
4. R.P. Hildebrant et al., Eur. Phys. J. A 20, 293 (2004).
5. D. Babusci et al., Phys. Rev. C 58, 1013 (1998).
6. B. Holstein, D. Drechsel, B. Pasquini, and M. Vanderhaeghen, Phys. Rev. C 61, 034316 (2000).
7. S. Kondratyuk and O. Scholten, Phys. Rev. C 64, 024005 (2001).
8. B. Pasquini, D. Drechsel, and M. Vanderhaeghen, Phys. Rev. C 76, 015203 (2007).
9. J. Ahrens et al., Phys. Rev. Lett. 87, 022003 (2001).
10. M. Schumacher, Prog. Part. Nucl. Phys. 55, 567 (2005).

Proton Spin Polarizabilities (Measurement)

- Linearly polarised photons, parallel and perpendicular to the scattering plane, unpolarised target

$$\Sigma_3 = \frac{\sigma^{||} - \sigma^{\perp}}{\sigma^{||} + \sigma^{\perp}}$$

- Circularly polarised photons (left-handed (L) and right-handed (R)), longitudinally polarised target

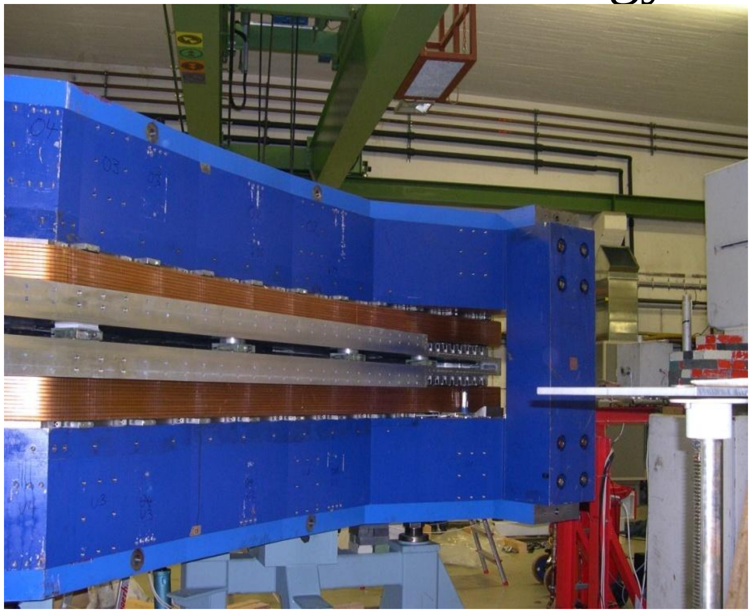
$$\Sigma_{2z} = \frac{\sigma^R_{+z} - \sigma^L_{+z}}{\sigma^R_{+z} + \sigma^L_{+z}} = \frac{\sigma^R_{+z} - \sigma^R_{-z}}{\sigma^R_{+z} + \sigma^R_{-z}}$$

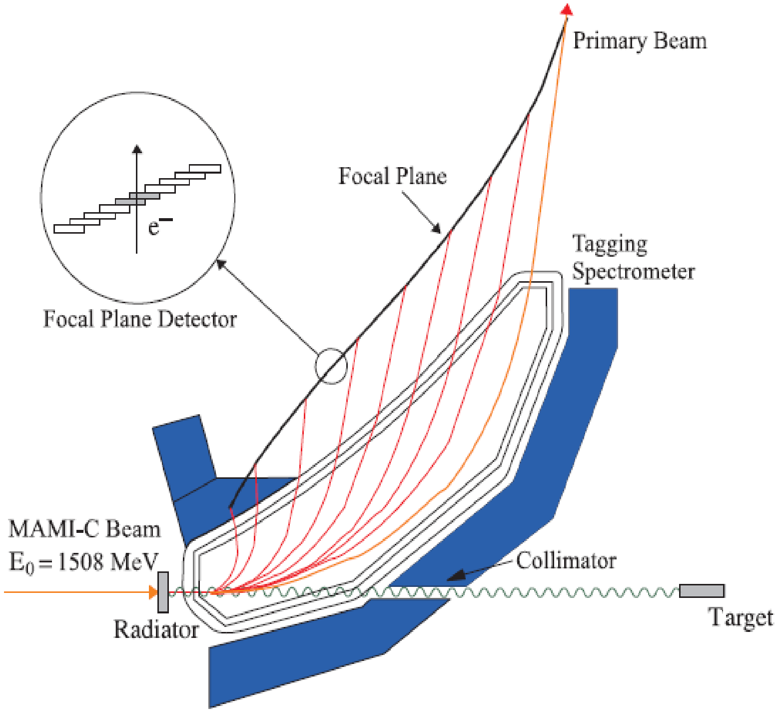
- Circularly polarised photons (left-handed (L) and right-handed (R)), transversely polarised target

$$\Sigma_{2x} = \frac{\sigma^R_{+x} - \sigma^L_{+x}}{\sigma^R_{+x} + \sigma^L_{+x}} = \frac{\sigma^R_{+x} - \sigma^R_{-x}}{\sigma^R_{+x} + \sigma^R_{-x}}$$

Upgraded A2 Tagging system (Glasgow, Mainz)

1. Production and energy measurement of the Bremsstrahlung photons.

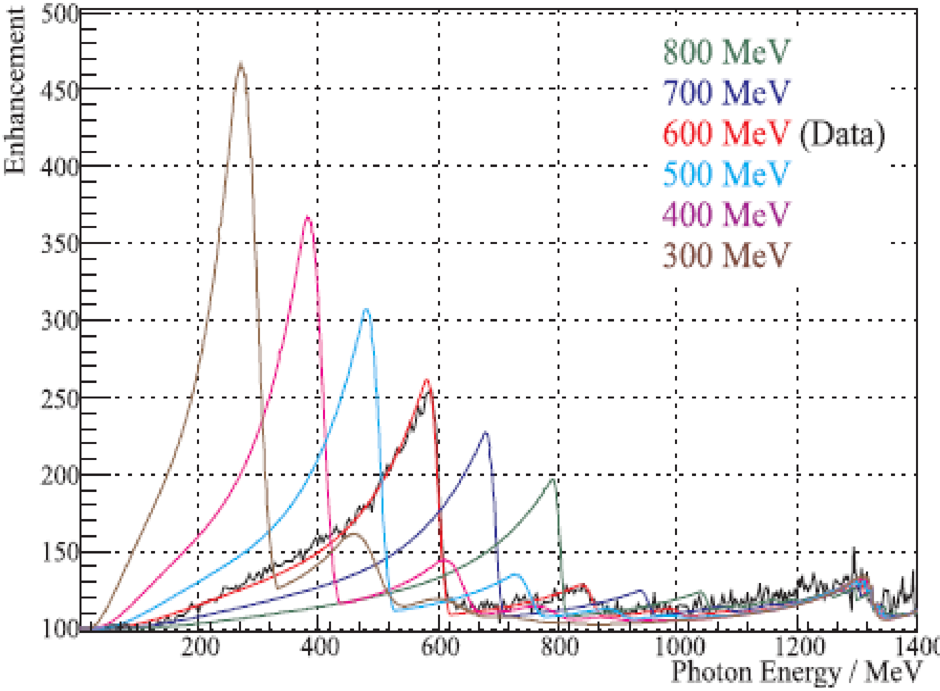


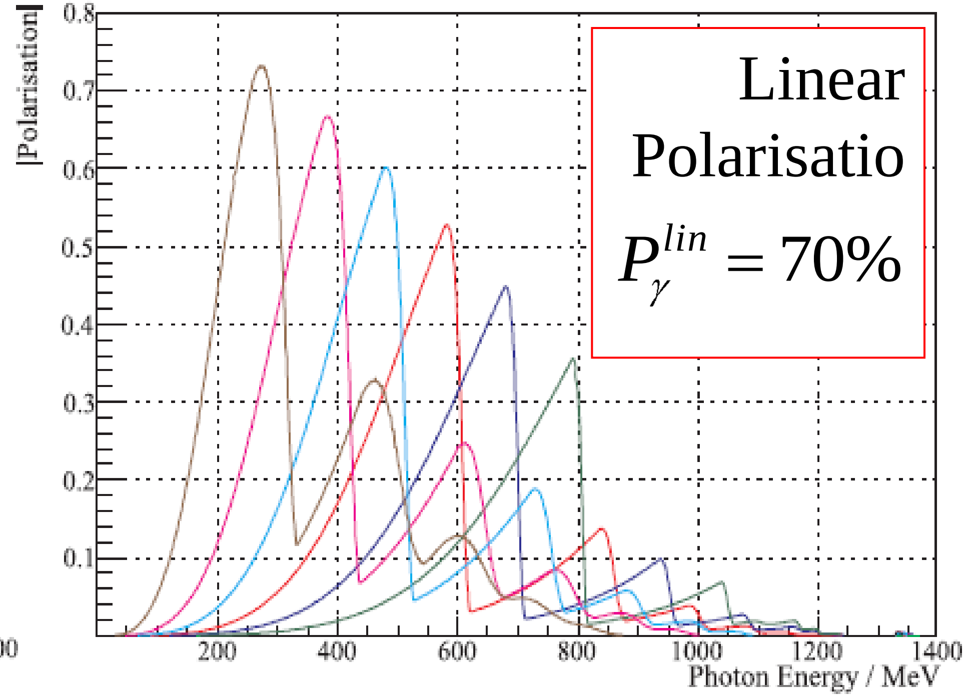


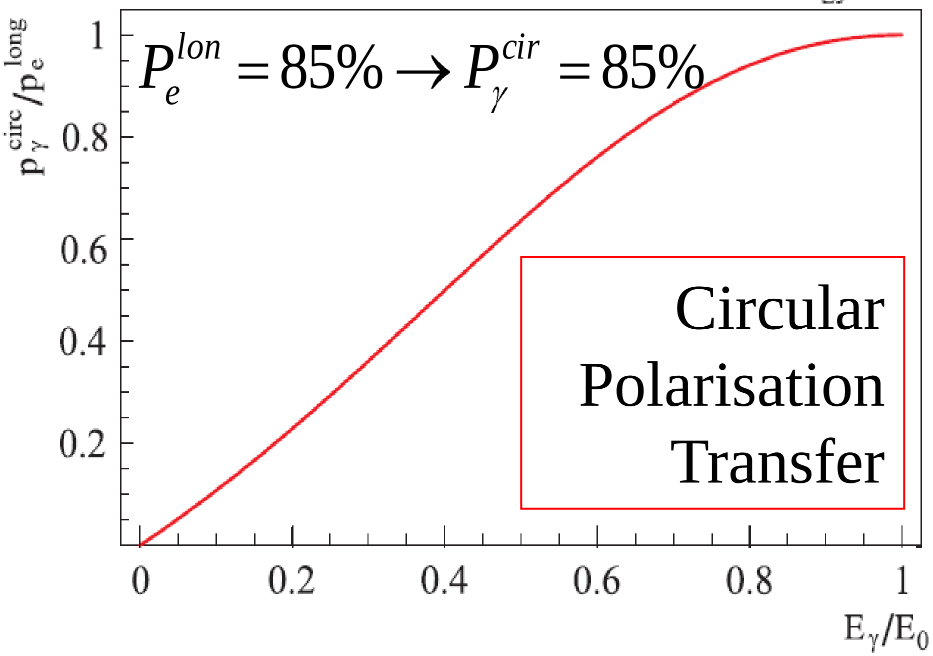
2. Determination of the degree of polarization of
the electron beam (Moeller Polarimeter).
Circularly polarized photons.

3. Coherent production of linearly polarized photons on a diamond radiator

Polarised Photons @ MAMI C





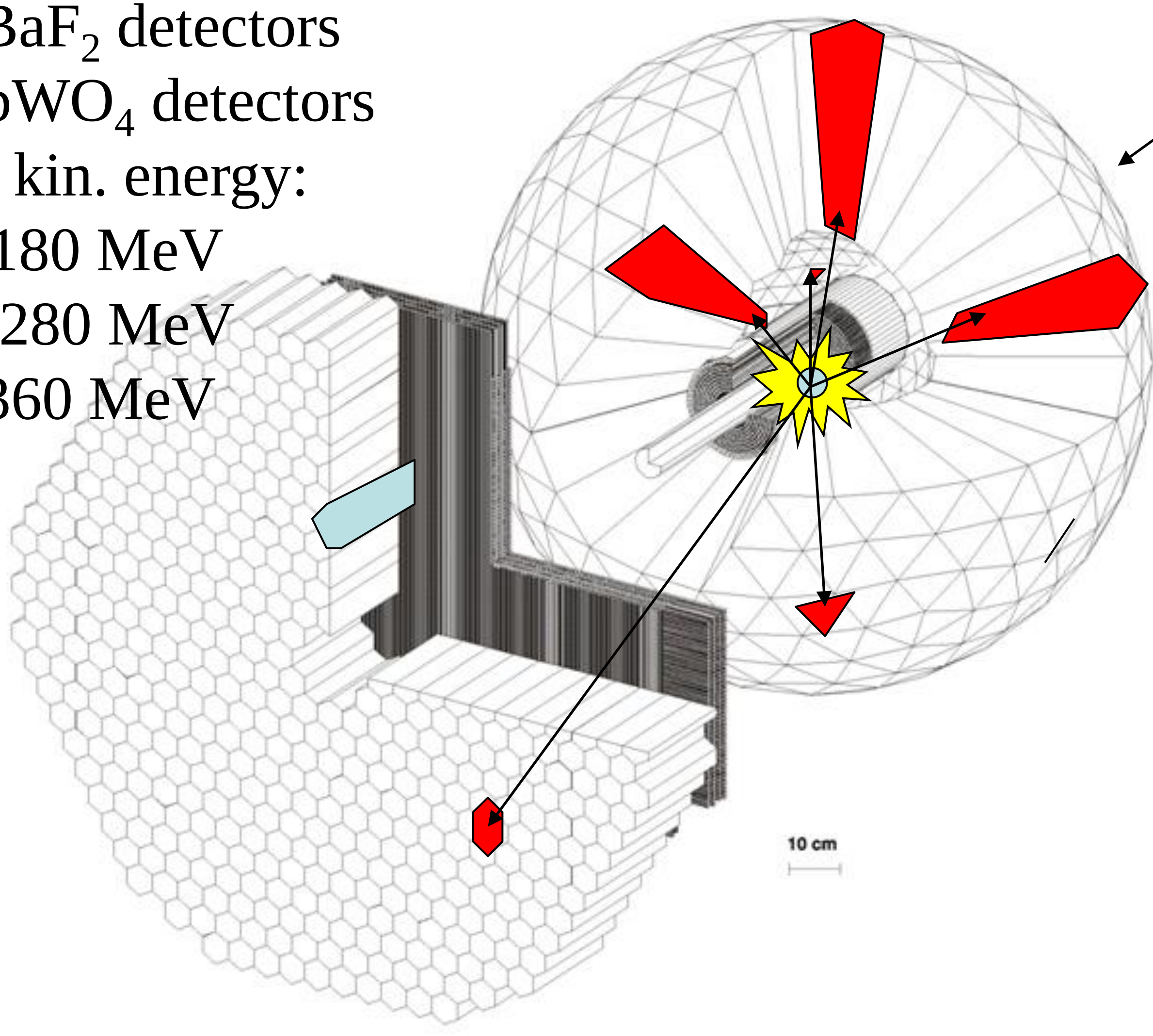


E_γ = 75 ... 1480 MeV
ΔE_γ = 4 MeV
N_γ = $2 \cdot 10^5\ s^{-1}\ MeV^{-1}$

→ High Polarisation
High Photon Flux

4π photon Spectrometer @ MAMI

TAPS:
366 BaF_2 detectors
72 $PbWO_4$ detectors
Max. kin. energy:
π^{+-} : 180 MeV
K^{+-} : 280 MeV
P : 360 MeV

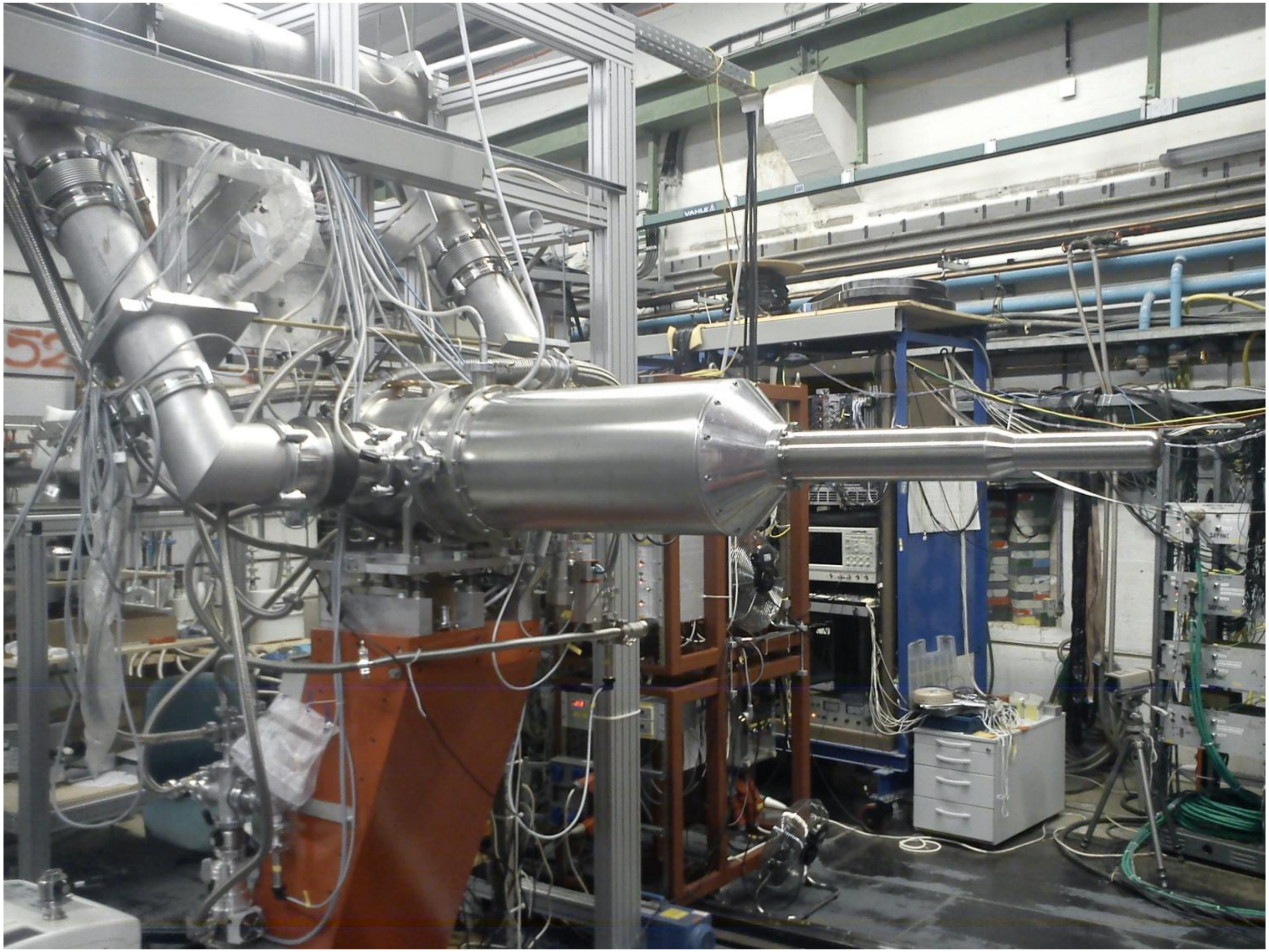


Crystal Ball:
672 NaJ detectors
Max. kin. energy:
μ^{+-} : 233MeV
π^{+-} : 240 MeV
K^{+-} : 341 MeV
P : 425 MeV

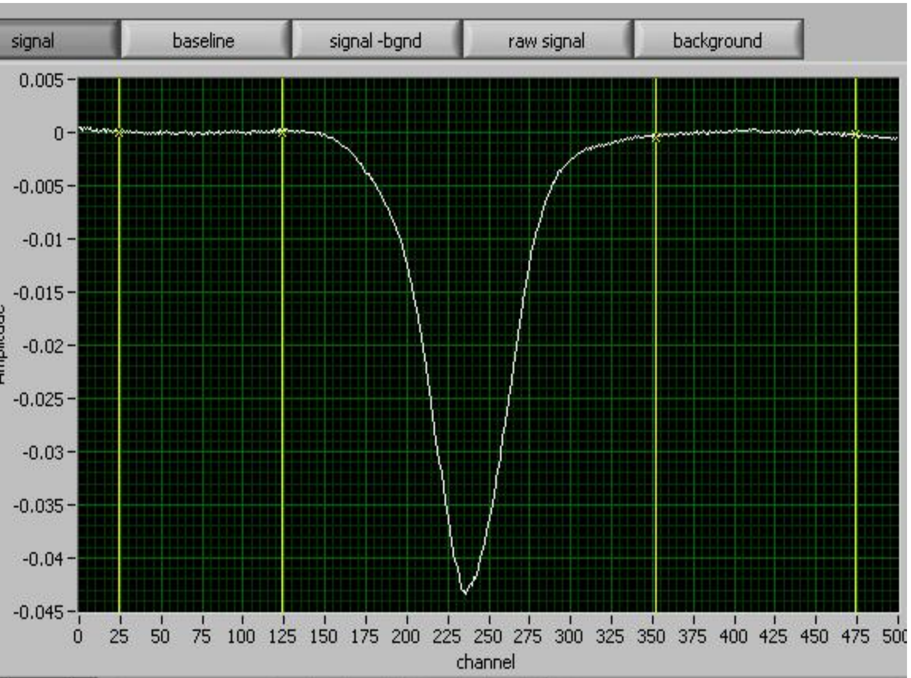
Vertex detector:
2 Cylindr. MWPCs
480 wires,
320stripes

PID detector:
24 thin plastic detectors

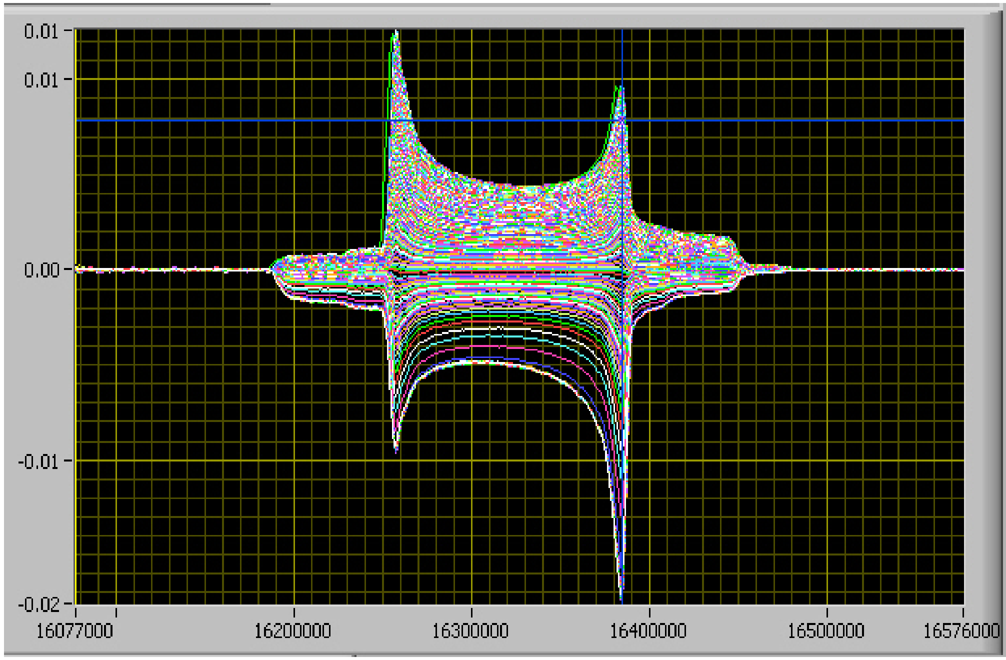
Frozen spin target



Proton and deuteron polarisation NMR signals

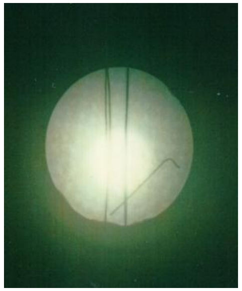


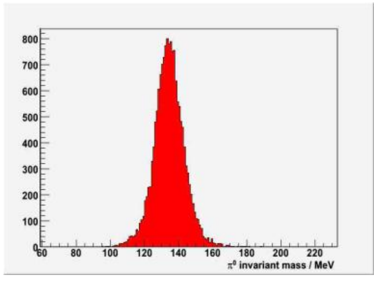
Proton polarisation (longitudinal or transverse) up to 95%



Deuteron polarisation up to 80%

$$P_{dyn} = P_{TE} \cdot \frac{AU_{dyn}}{AU_{TE}}$$





More than 5000 h polarised data taking in 2010/11

Beam Photo

π invariant mass

Target material

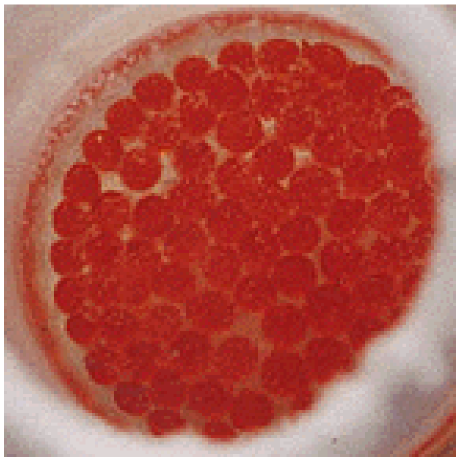
Saturated electrons of target material not polarized (Pauli principle)

Free electrons → **Radicals in material by chemical or radiative doping**

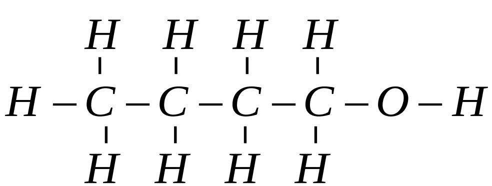
$$\frac{\#\,radicals}{\#\,protons} \approx 10^{-4}$$

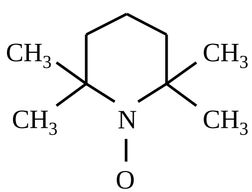
Dilution factor ($f_{Butanol}$=10/74) determines quality of target material.

We have 9***10**^{22} pol. Protons per cm2 in our 2cm long target cell.

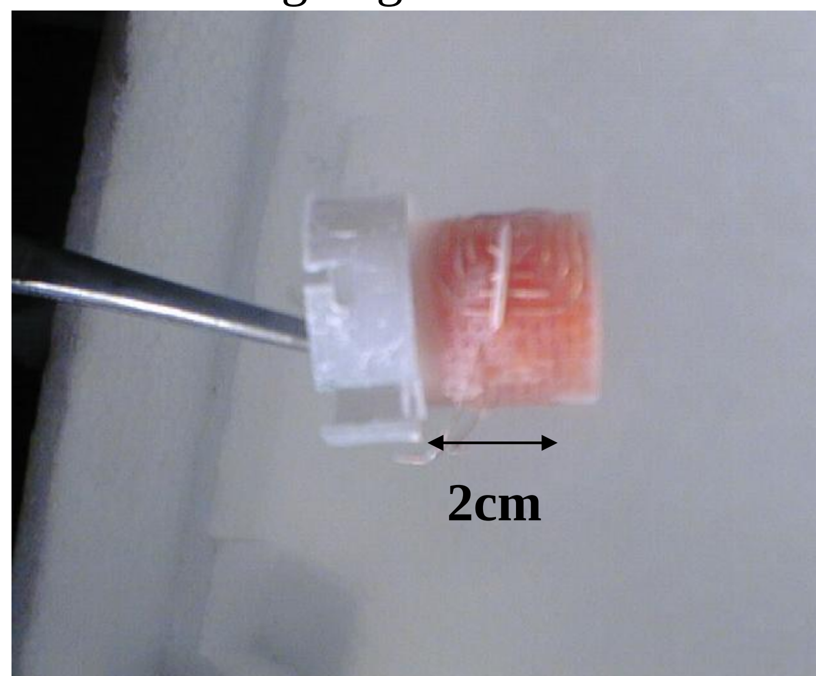


Butanol



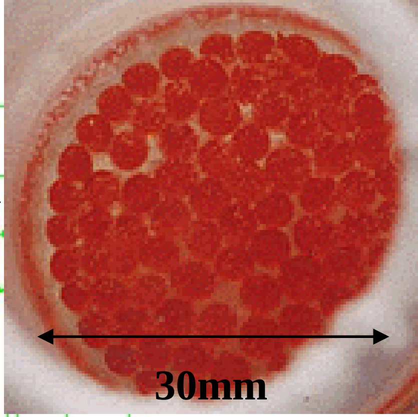


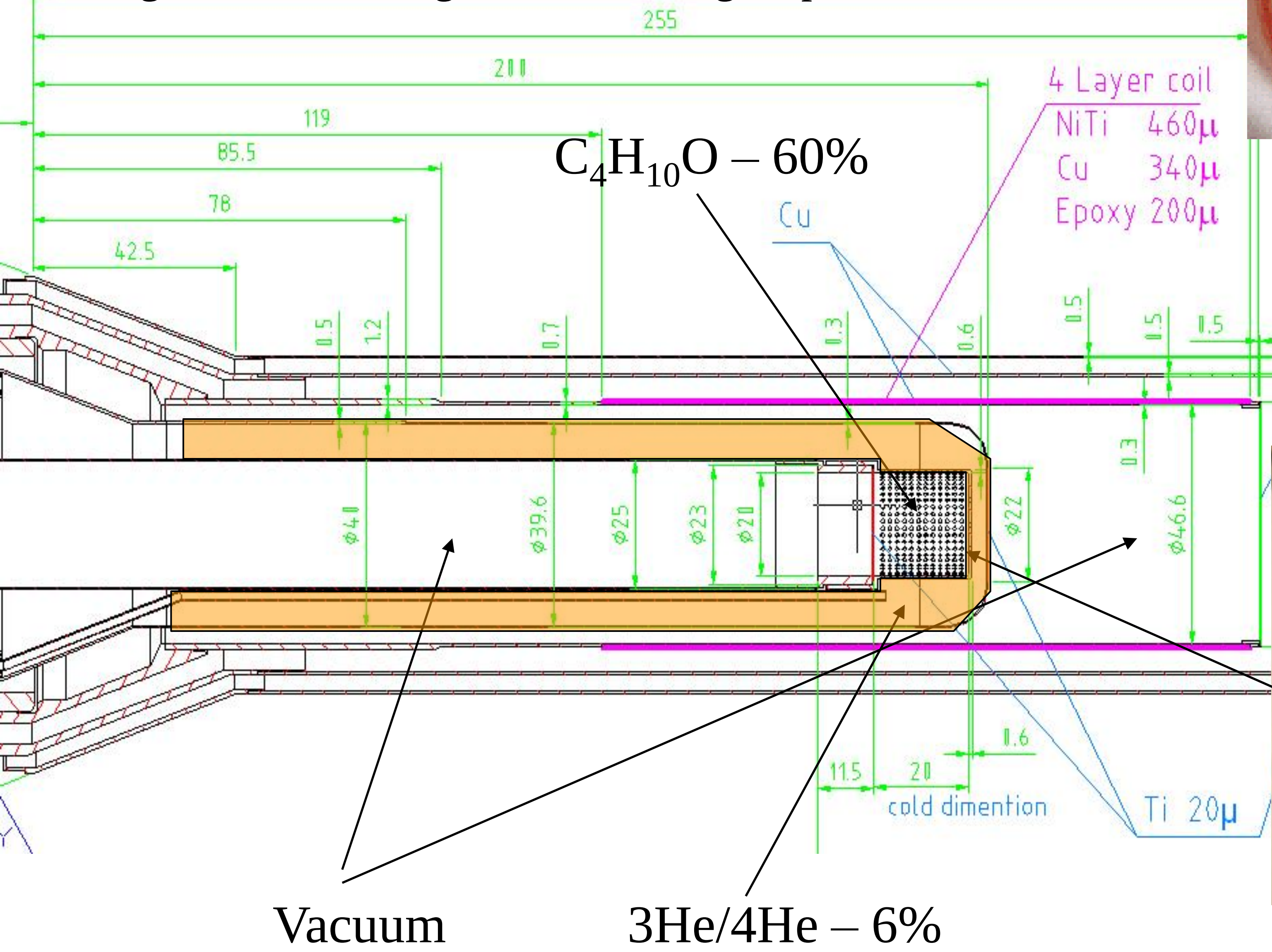
Tempo



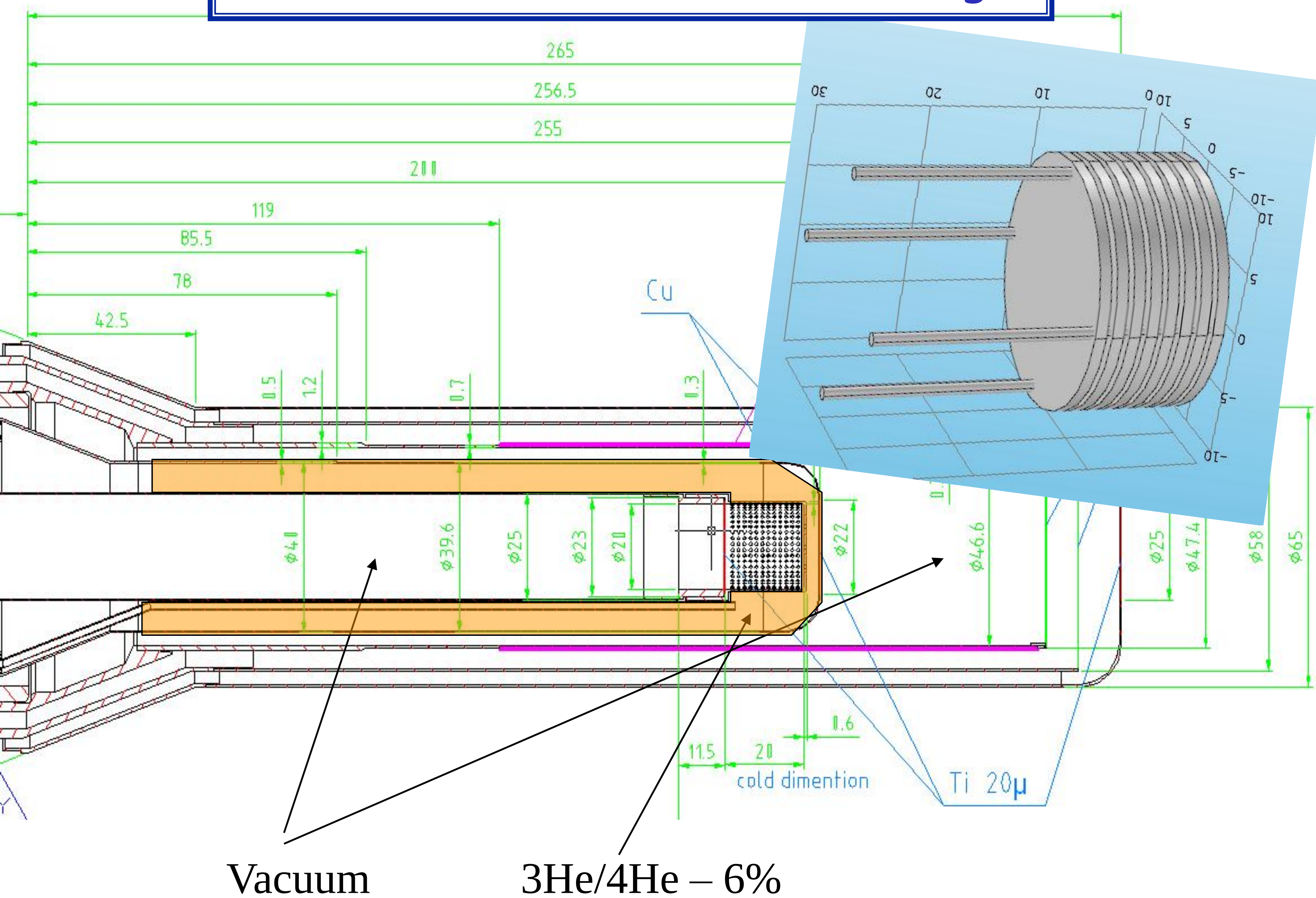
Target material is mixture of H, C and He → require p in analysis

Holding coil and cooling infrastructure give p threshold over 50 MeV

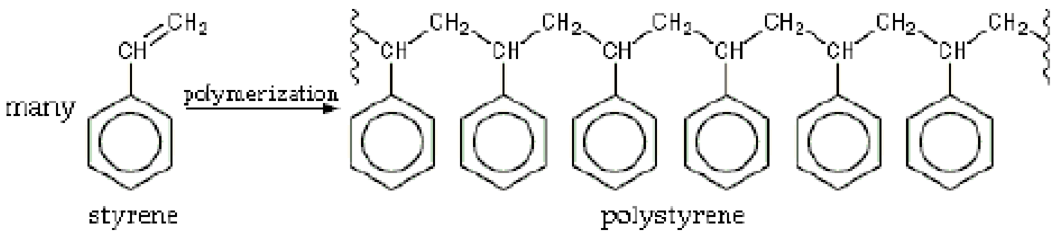


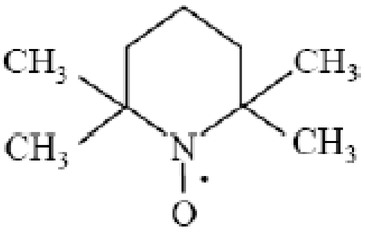


Modification: Active Polarised Target



Material for active target

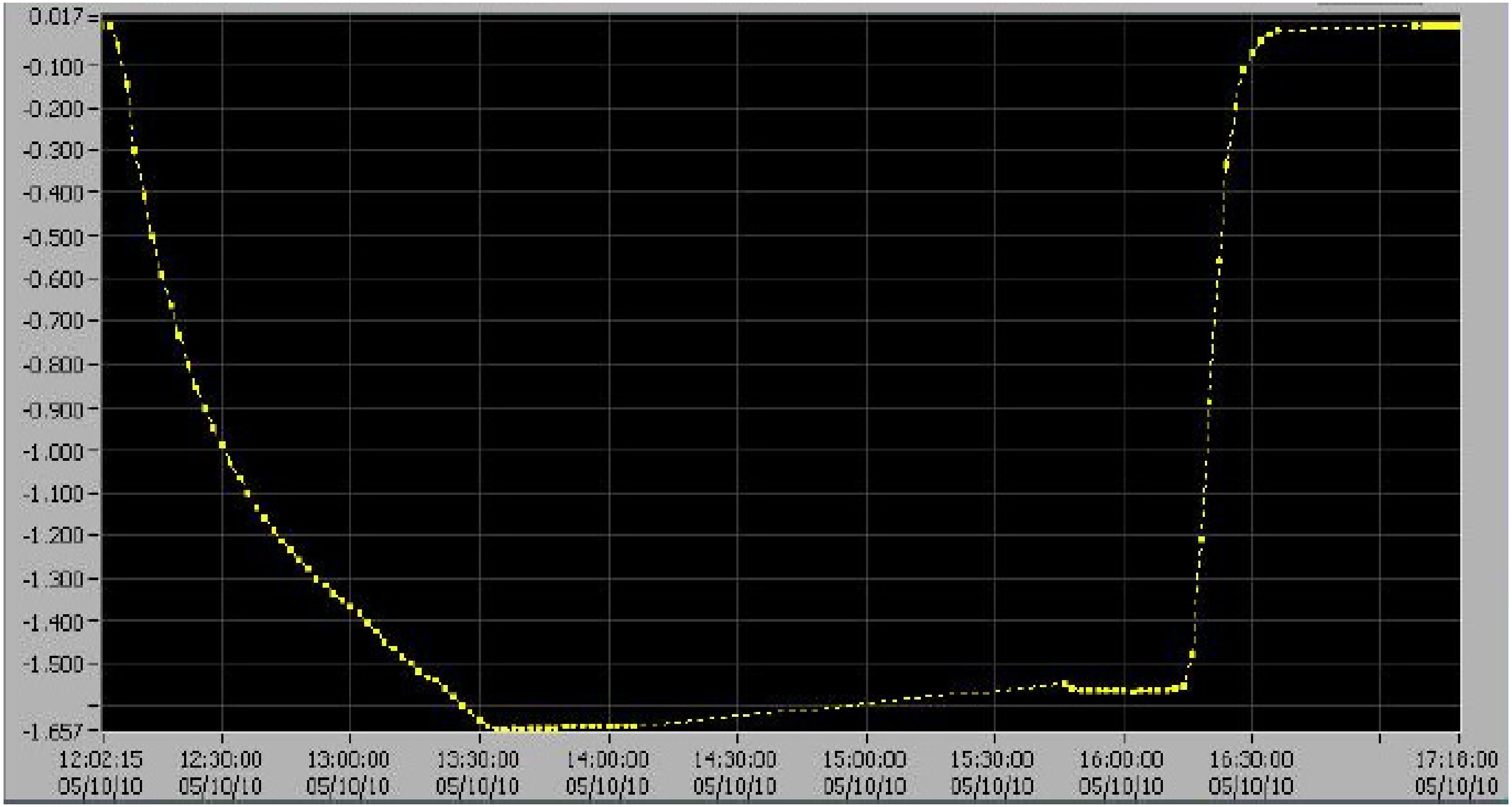




Material for active target

Discs with $r = 10$ mm and $d = 0,5$ mm, $m \approx 300$ mg

Test of material: Build-up of polarisation and relaxation



Maximum values

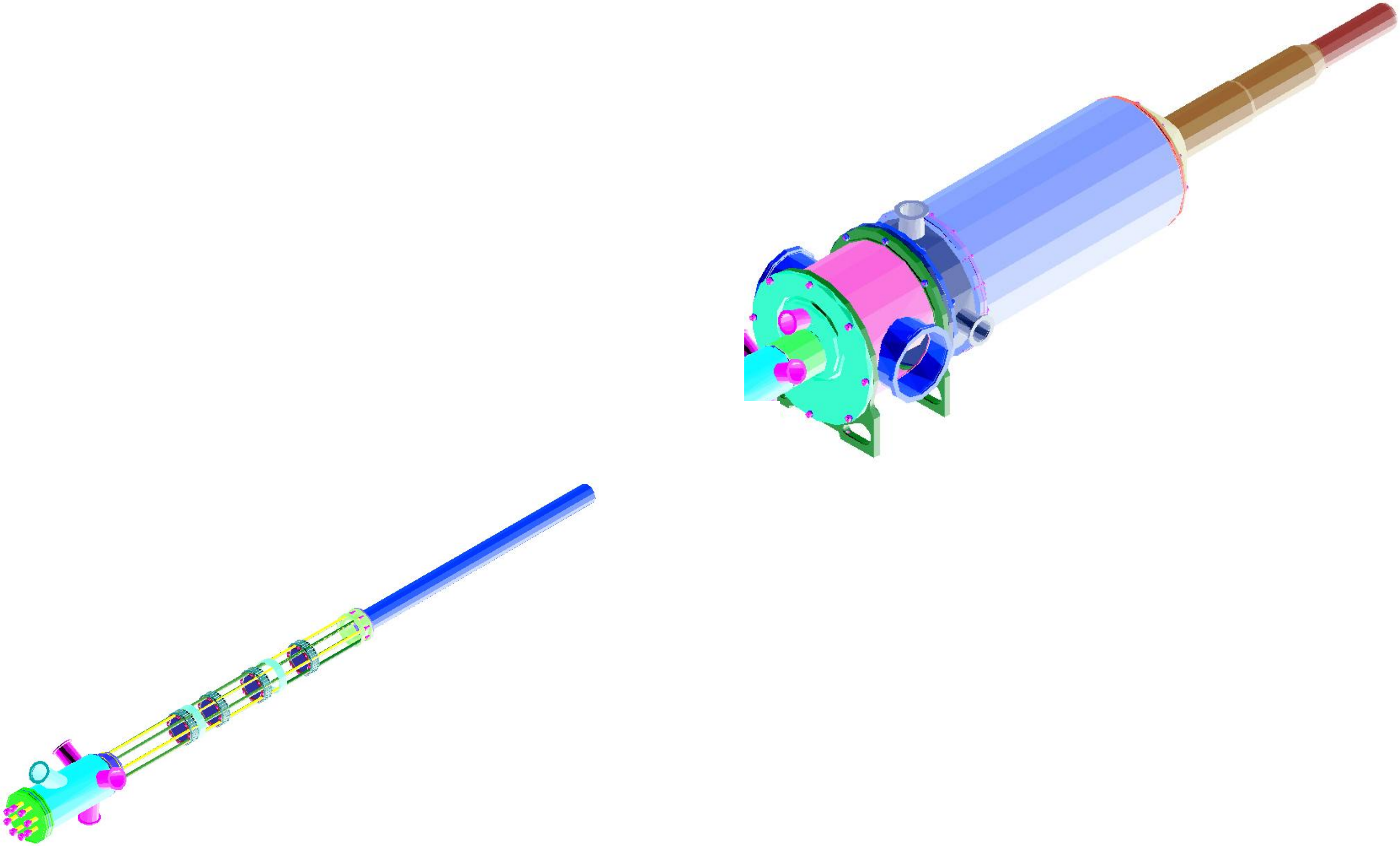
Density $3.0 \cdot 10^{19}$ cm^{-3} at 32 mK and 0.2 T:
Polarisation $P \approx 70\%$
Relaxation time $\tau = 5.5$ h

Density $1.5 \cdot 10^{19}$ cm^{-3} at 26 mK and 0.2 T:
Polarisation $P \approx 44\%$
Relaxation time $\tau = 35$ h

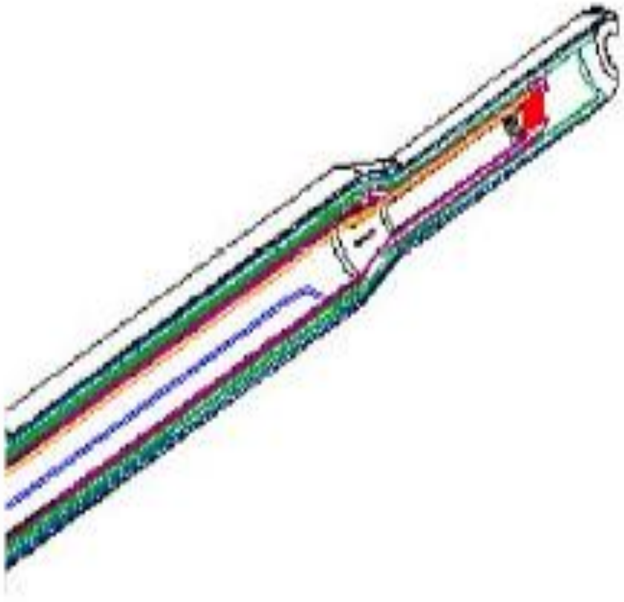
Dependence of τ

$$T_{1n} = \left(\frac{H}{\hbar\gamma_n}\right)^2 (d^3R^3) \frac{T_{1e}}{1-P_eP_0}$$

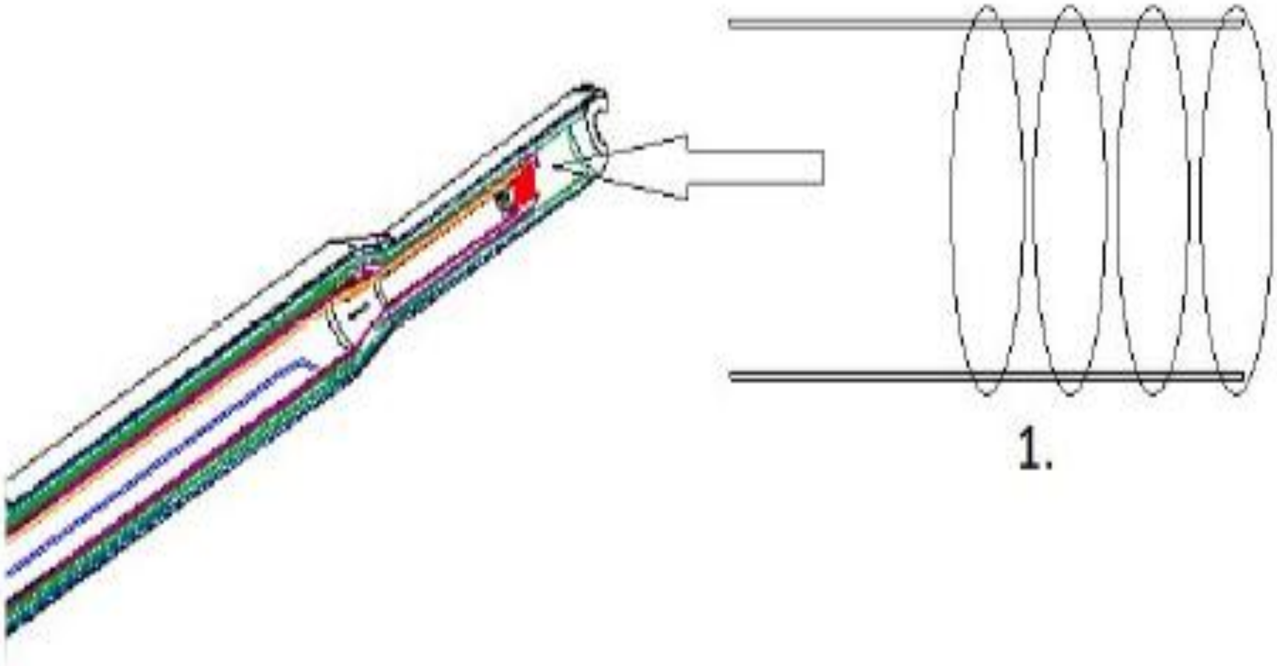
Loading of the target material



Insert with light guide

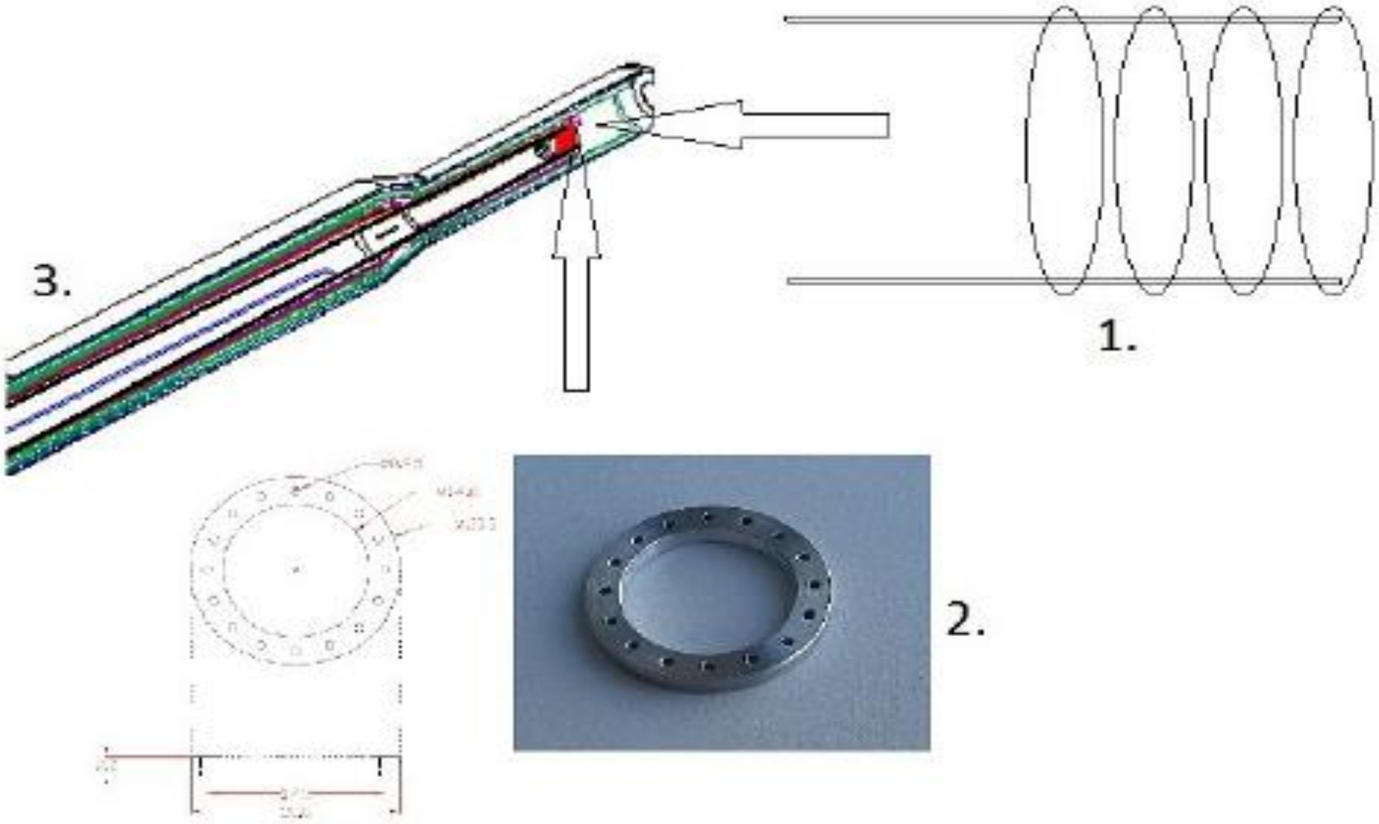


Insert with light guide

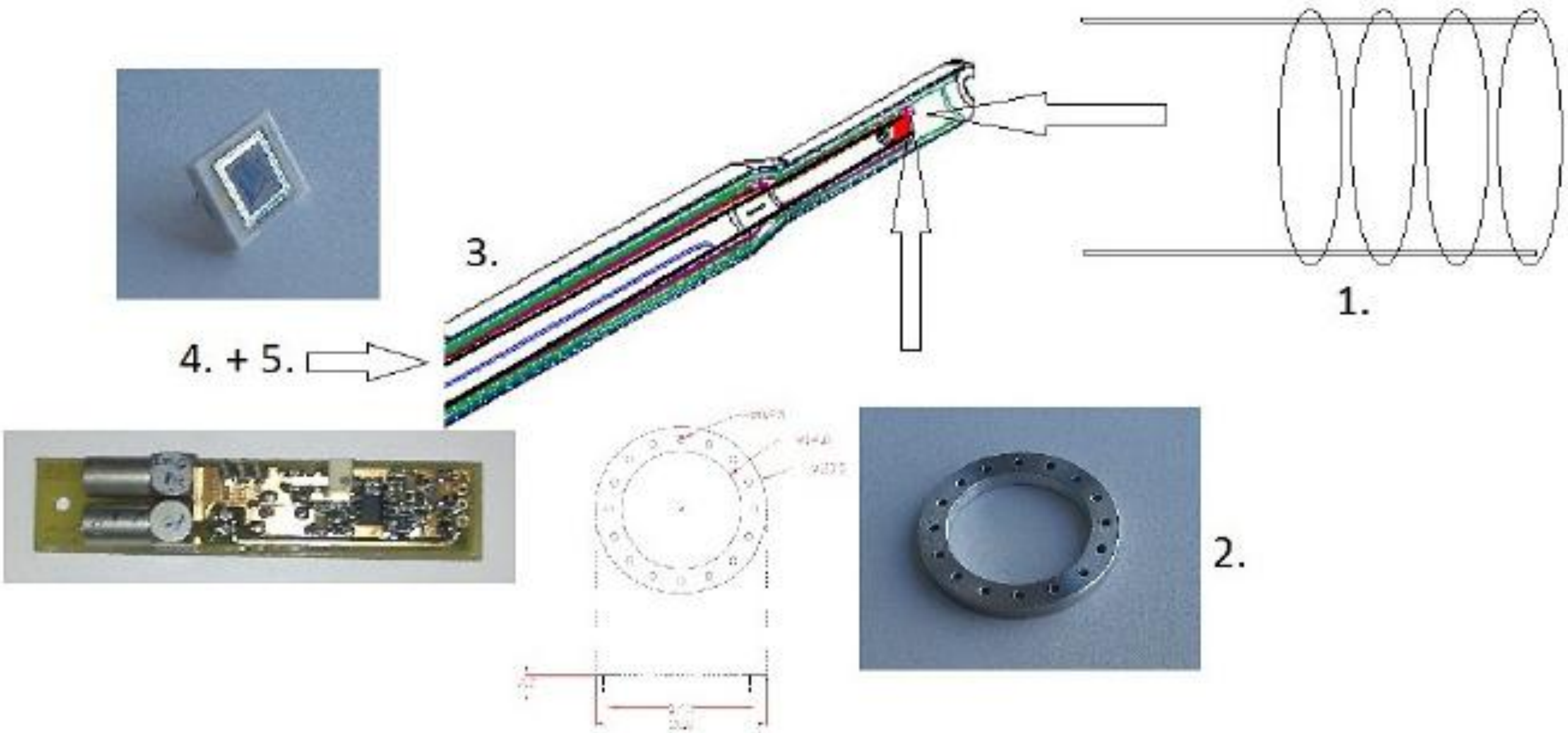


1.

Insert with light guide



Insert with light guide



Conclusions @ Outlook

- Measurements of spin polarisabilities important but challenging!
- Measurements with active target below π-meson threshold are most model-independent way to extract γ's independently
- They could be complemented by measurement of spin asymmetries with butanol target at higher energies (up to 300 MeV)
- The measurements so far:

Σ_{2x} measurements (circularly pol. photons, transversely pol. Butanol):
2 Wks Sept 2010, 3 Wks February 2011

Carbon subtraction data: 1 Wk December 2010, 2 Wks January 2011

- Planned for 2012/2013:

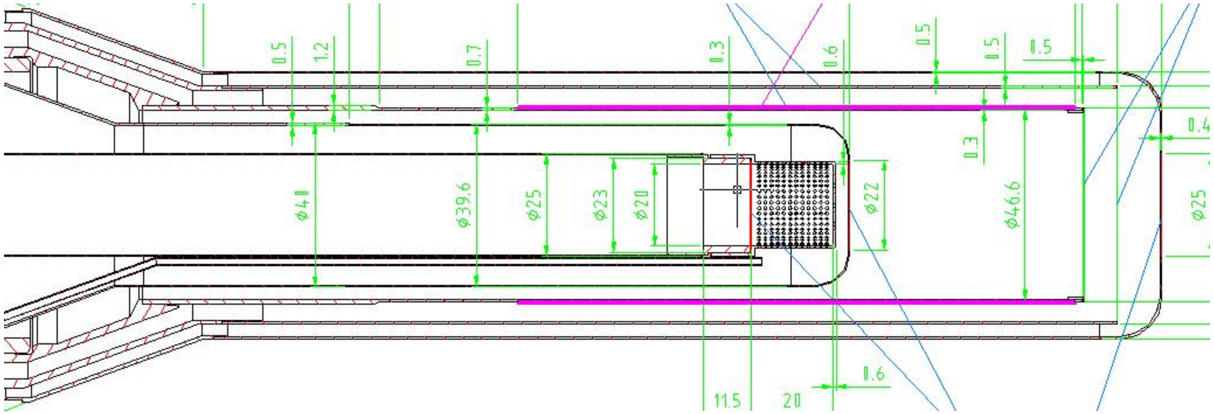
Σ_3 measurements (linearly pol. photons, liquid H2 target)

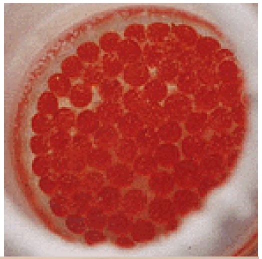
Σ_{2z} mesurements (circ. pol. photons, linearly pol. Butanol)

Preparation of target insert with scintillating polystyrene and light guide for measurements with active target

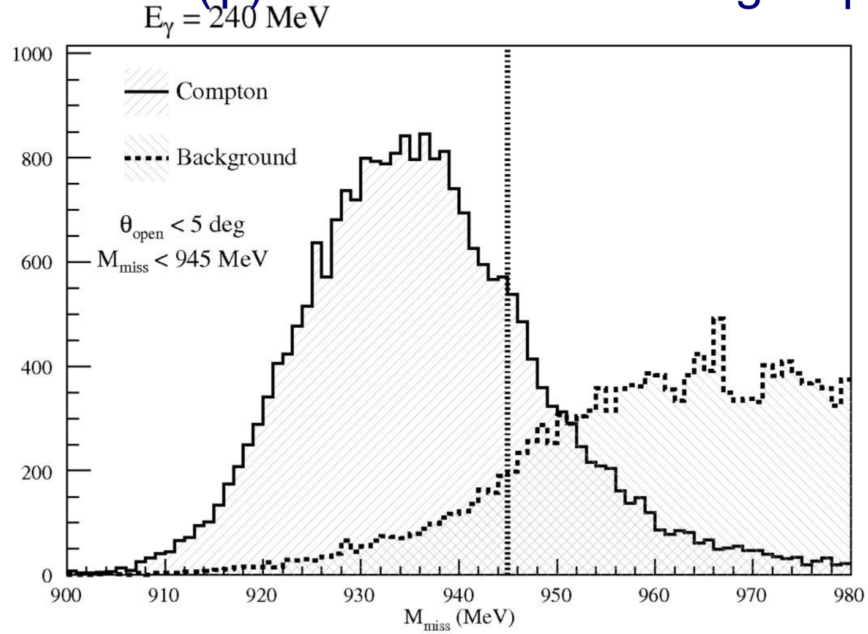
Thank you!

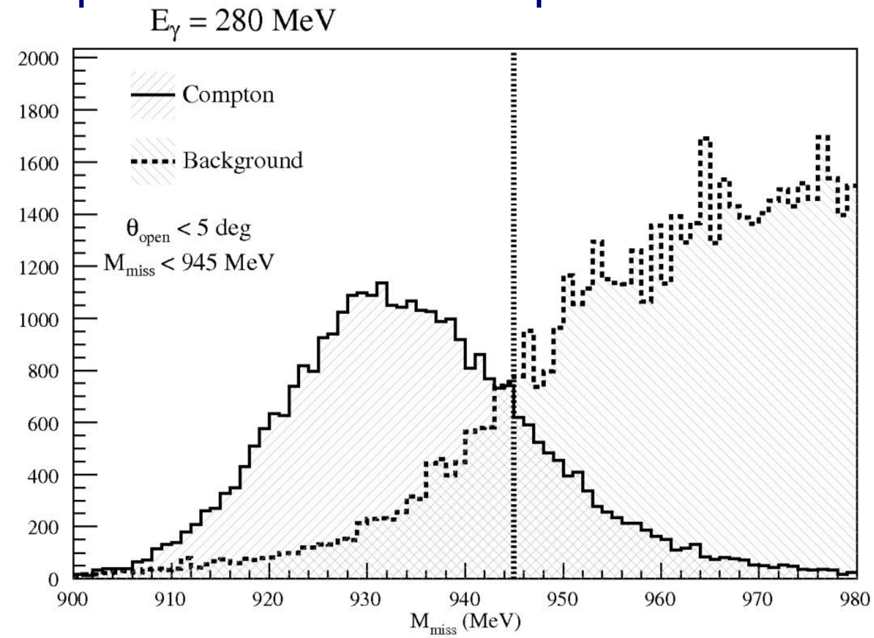
Nucleon Vector Spin Polarizabilities



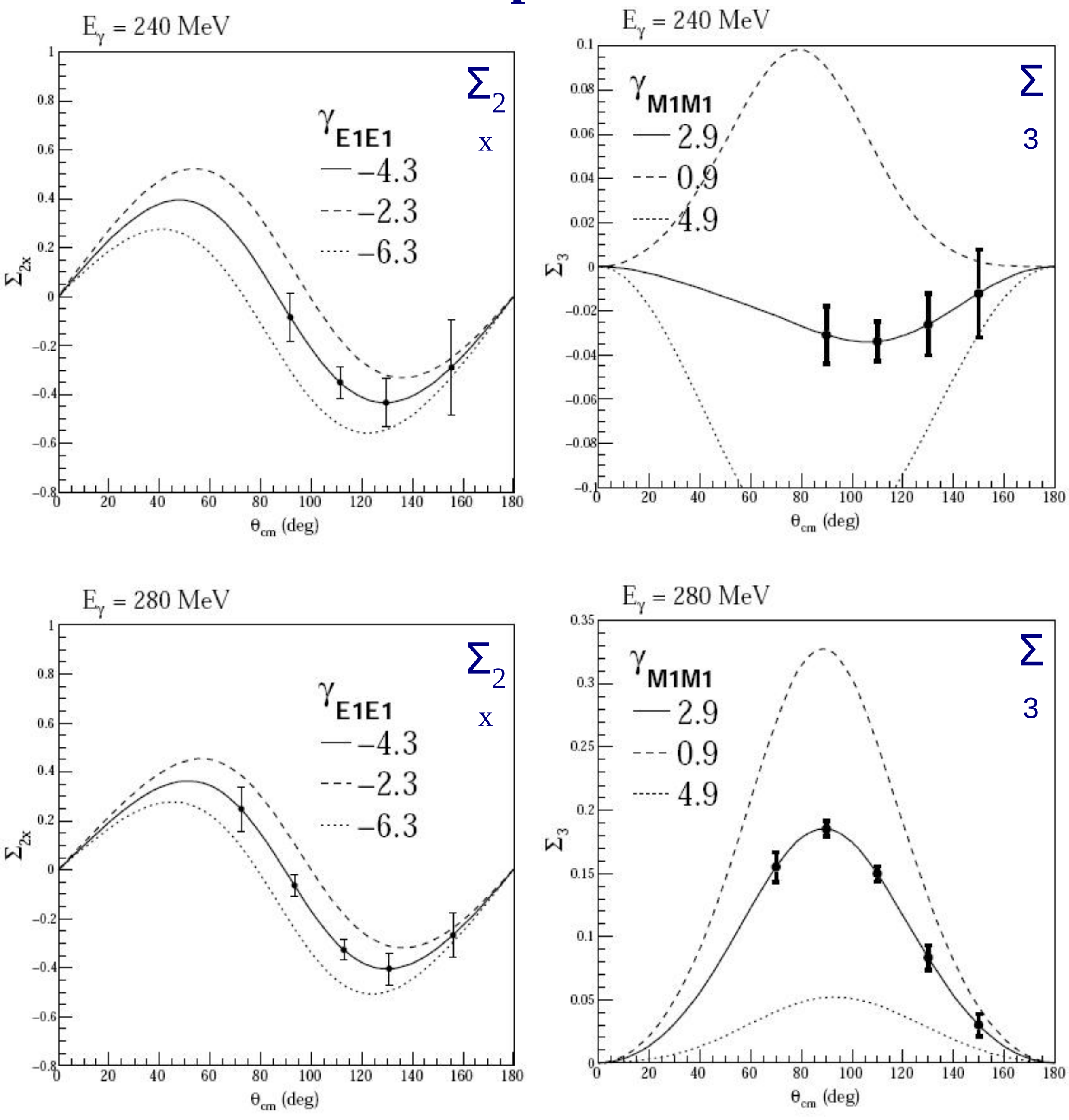


Sim. MM(γ') on Butanol – showing π^0 photoproduction and Compton contributions





Nucleon Vector Spin Polarizabilities

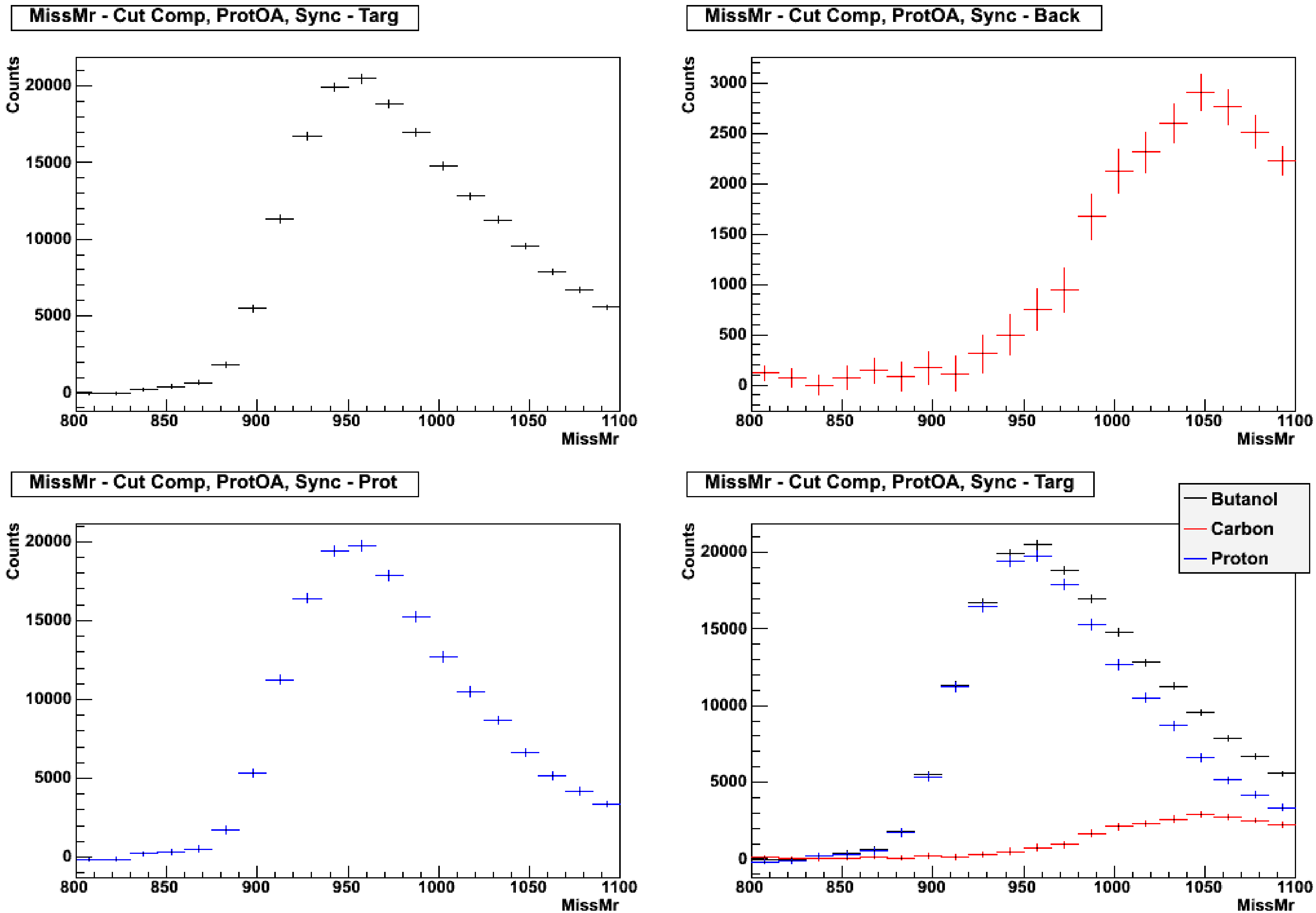


- Σ_3 100 hours measurement
- Σ_{2x} 300 hours measurement
- Curves from:-

B. Pasquini, D. Drechsel, M. Vanderhaeghen, Phys. Rev. C **76** 015203 (2007)

B. Pasquini, D. Drechsel, M. Vanderhaeghen, Phys. Rept. **378** 99 (2003)

Butanol target: Missing mass spectrum (Preliminary results)



Butanol target: Asymmetry Σ_{2x} (Preliminary results)