The Crystal Ball programme at MAMI

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For the CB@MAMI Collaboration

MESON 2012

MAINZER MIKROTRON

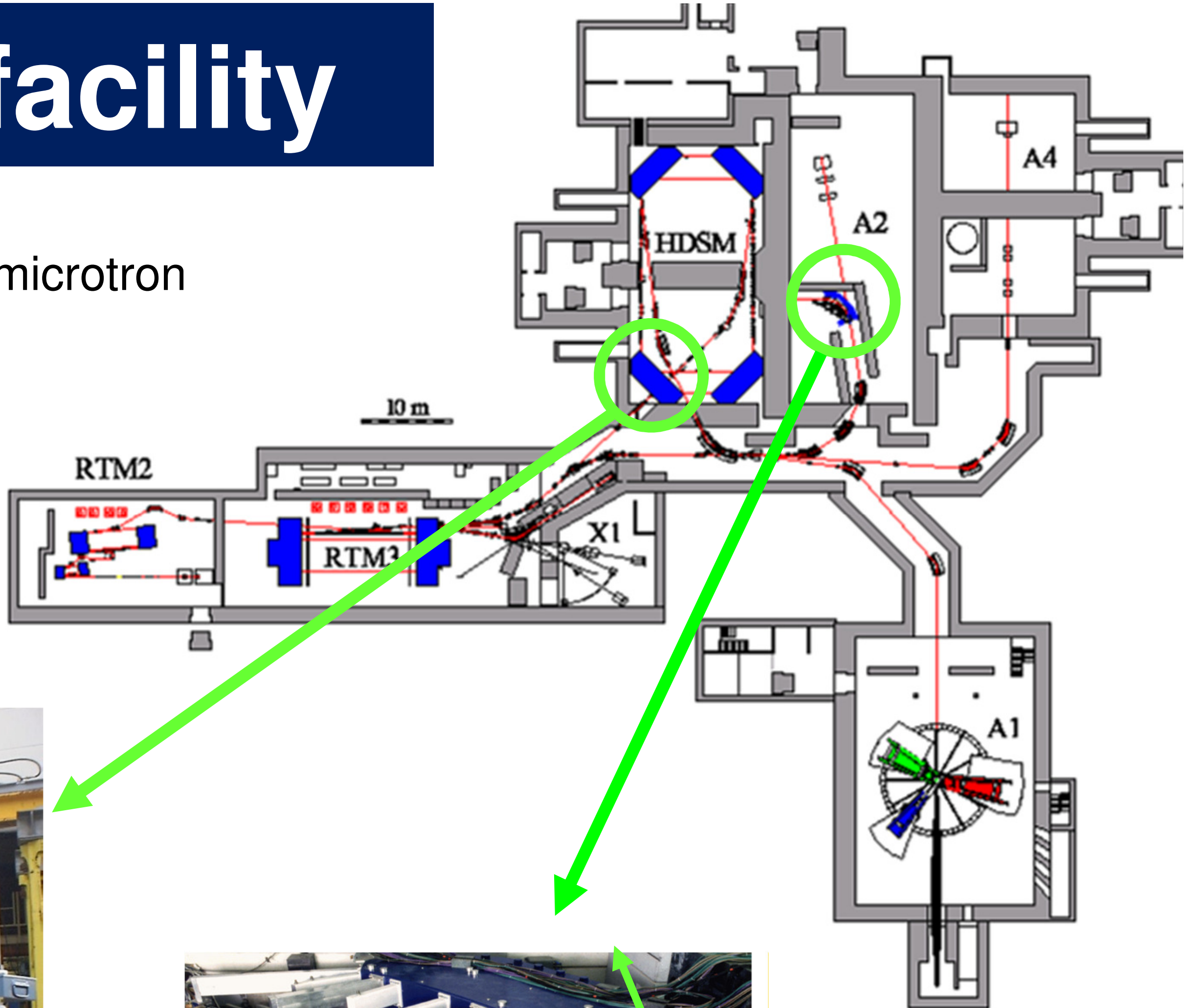
Talk outline

- Outline of the real photon facility at MAMI (A2)
- Latest results from **selected** parts of the programme

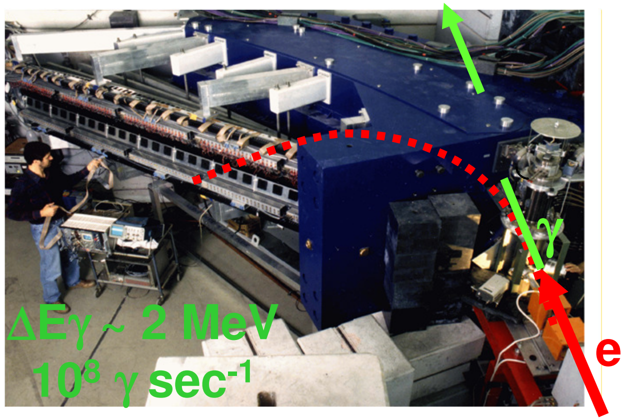
Mainz/Dubna Polarised nucleon target
Strangeness production
Neutron skins

The MAMI facility

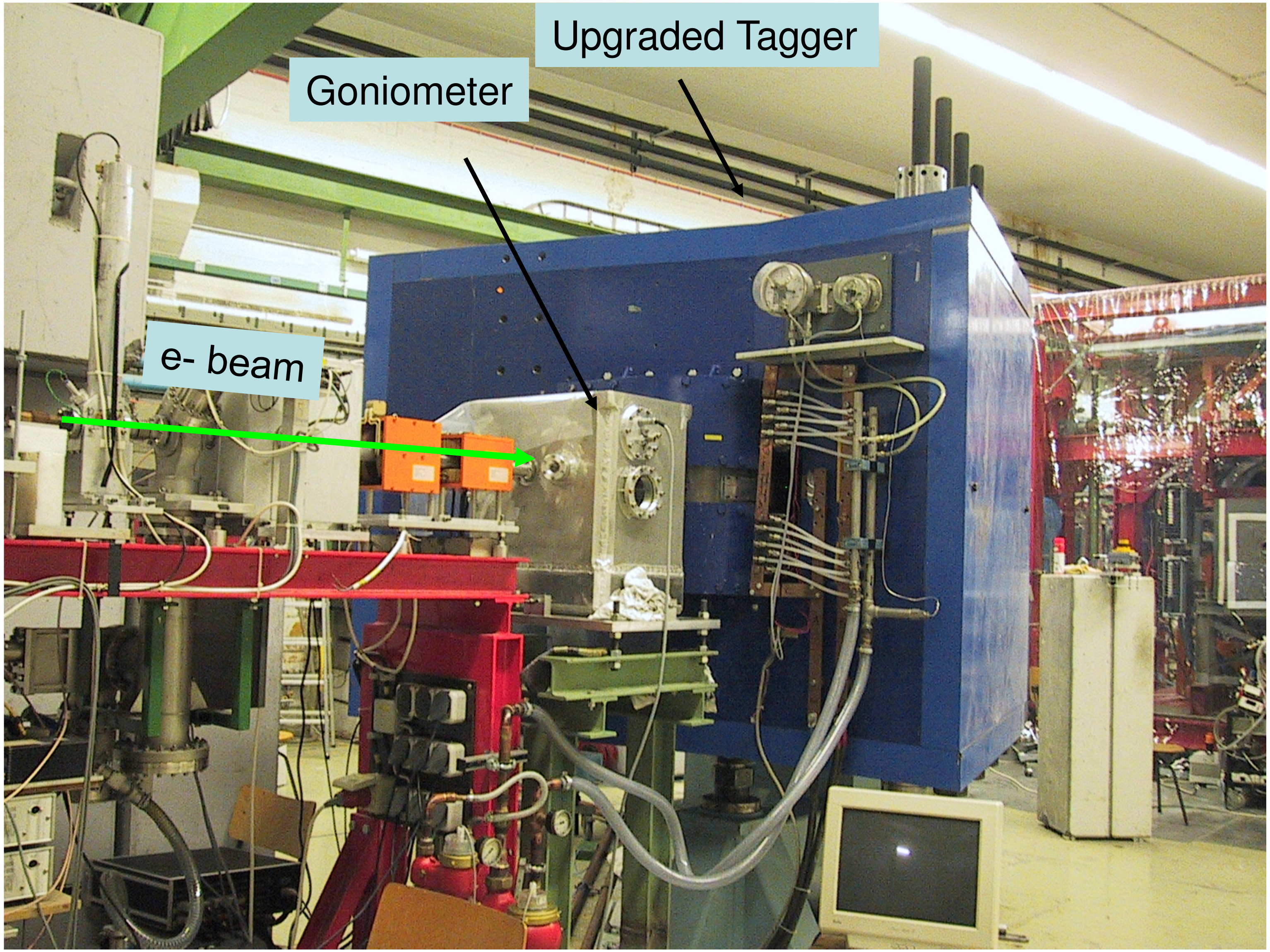
- 100% duty factor electron microtron
- MAMI-C 1.6 GeV upgrade
  (MAMI-B 0.85 GeV)



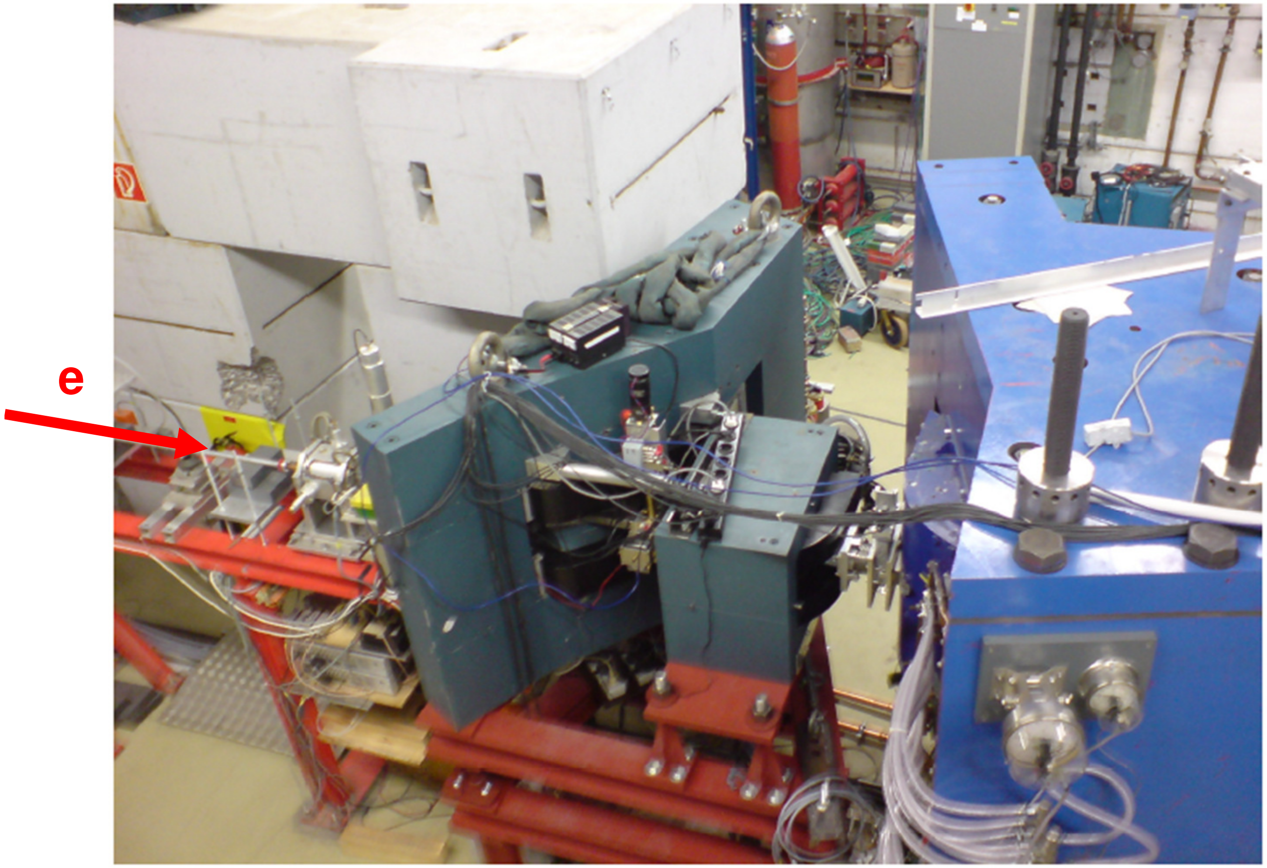

One of the MAMI-C magnets

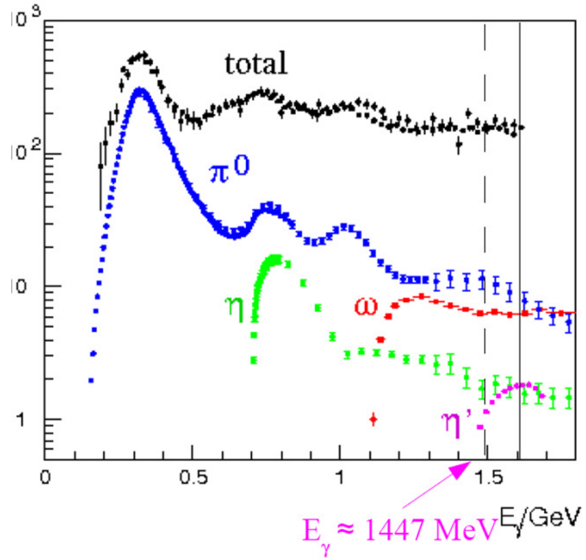


Glasgow-Mainz tagger



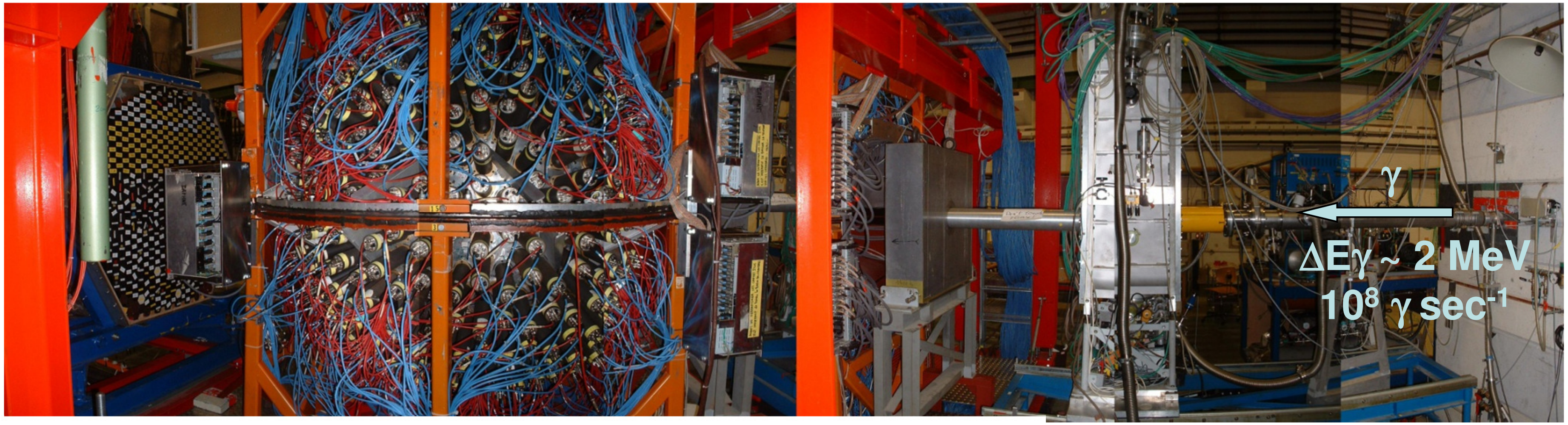
New endpoint tagger

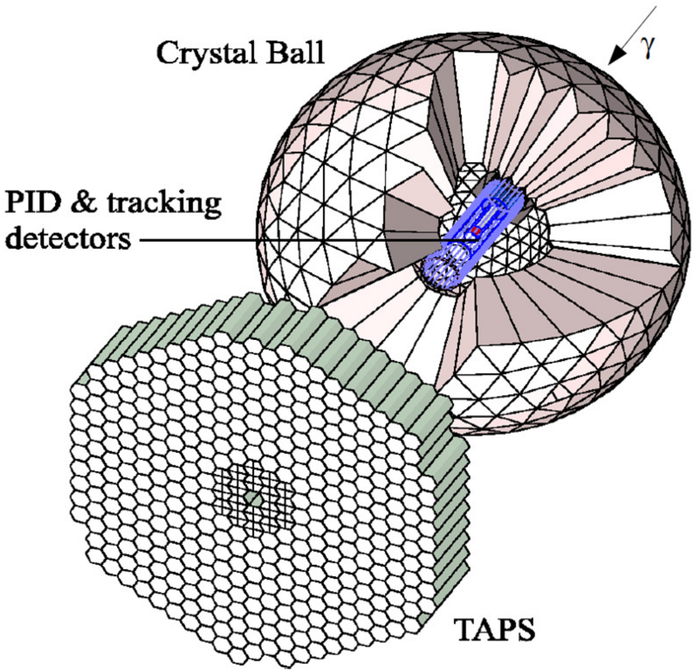




- Standard tagger provides photons 0.05 E_e - 0.93 E_e (max 1.45 GeV)
- EPT provides tagged photons up to 1.59 GeV
- Commissioned March 2012

The MAMI photon beamline





Crystal Ball:

672 NaI(Tl) crystals

93,3% of total solid angle

Each crystal equipped with PMT

$$\frac{\sigma}{E_\gamma} = \frac{2\%}{(E_\gamma/GeV)^{0.25}} \qquad \sigma(\theta) = 2^\circ \ldots 3^\circ$$

$$\Delta t = 2.5 \text{ ns FWHM} \qquad \sigma(\phi) = \frac{2^\circ \ldots 3^\circ}{\sin(\theta)}$$

TAPS:

Up to 510 BaF_2 crystals

Polar acceptance: 4-20°

$\Delta t = 0.5$ ns FWHM

$$\frac{\sigma}{E_\gamma} = \frac{0{,}79\%}{\sqrt{E_\gamma/GeV}} + 1{,}8\%$$

Scope of real photon programme

M. Unverzagt

Meson physics:

- Rare decays – tests of fundamental symmetries — $\eta \rightarrow ?$ $\eta' \rightarrow ?$
- Meson form factors — $\eta \rightarrow e^+e^-\gamma$

Baryon physics:

- Establishing nucleon resonance properties
- Test of low energy theories e.g. ChPT

(both: $\gamma N \rightarrow N m(m)$)

- Polarisabilities of the nucleon — $\gamma N \rightarrow \gamma' N$

V. Metag

Nuclear/medium:

- Mass shifts/line shape changes in nuclear medium — $\gamma A \rightarrow A\omega$
- Neutron skins of stable nuclei — $\gamma A \rightarrow A\pi$
- Search for mesic nuclei — $\gamma A \rightarrow A\eta$

CRC1044

2012 - Major funding announced for MAMI →

The Low Energy Frontier of the Standard Model:

From Quarks and Gluons To Hadrons and Nuclei

Polarisation observables in meson photoproduction

- *16 experimental observables*
- Current world data set is sparse – partial wave analyses currently underconstrained

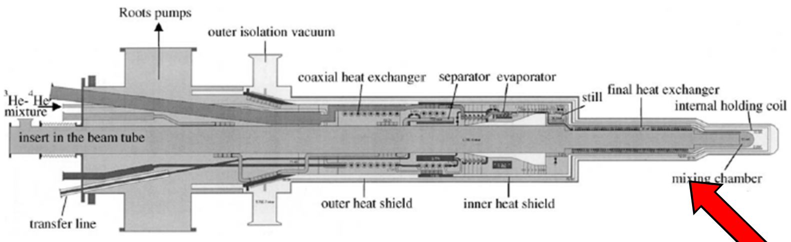
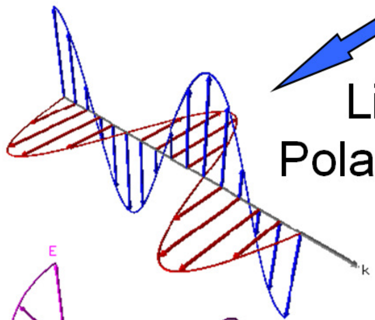


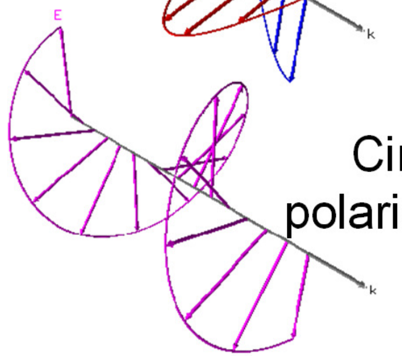
Fig. 4. Schematic diagram of the dilution refrigerator.

Longitudinally polarised nucleon target ✓
Transversely polarised ✓

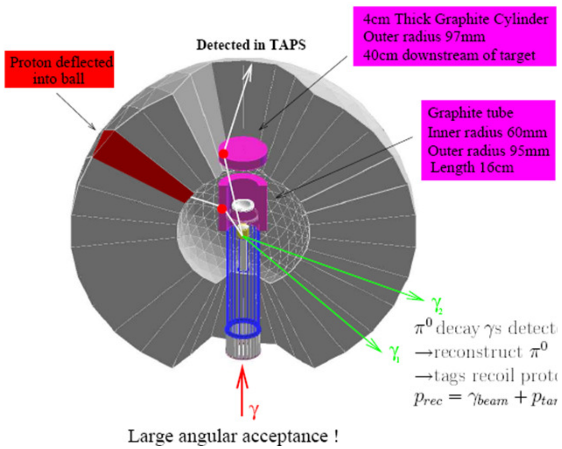
γ + N → N* → N + *meson(s)*



Linear Polarisation ✓



Circular polarisation ✓

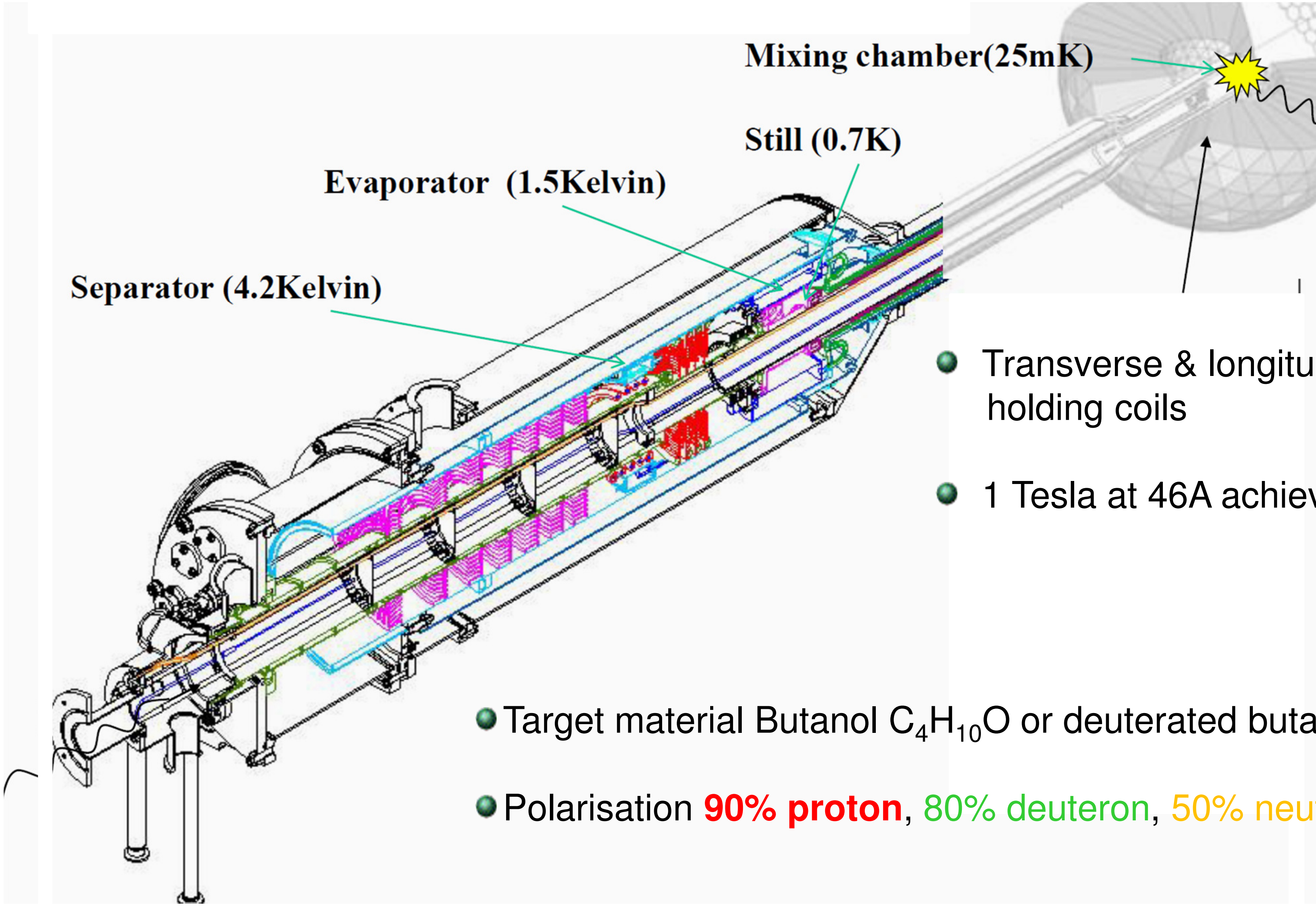


Recoil polarimeter ✓

Observables in pdeuso scalar meson photoproduction

Observable	Polarisation of γ	target	recoil	
1. $\{d\sigma/d\Omega\}/\mathcal{N}$				$=\|b_1\|^2+\|b_2\|^2+\|b_3\|^2+\|b_4\|^2$
Single polarization				
2. P			↑	$=\|b_1\|^2-\|b_2\|^2+\|b_3\|^2-\|b_4\|^2$
3. Σ	→			$=\|b_1\|^2+\|b_2\|^2-\|b_3\|^2-\|b_4\|^2$
4. T		→		$=\|b_1\|^2-\|b_2\|^2-\|b_3\|^2+\|b_4\|^2$
Double polarizaton				
Beam-target				
5. E	●	●		$=2\,\mathrm{Re}(b_1 b_3^* + b_2 b_4^*)$
6. F	●	→		$=2\,\mathrm{Im}(b_1 b_3^* - b_2 b_4^*)$
7. G	→	●		$=2\,\mathrm{Im}(b_1 b_3^* + b_2 b_4^*)$
8. H	→	→		$=-2\,\mathrm{Re}(b_1 b_3^* + b_2 b_4^*)$
Beam-recoil				
9. C_x	●		→	$=-2\,\mathrm{Im}(b_1 b_4^* - b_2 b_3^*)$
10. C_y	●		●	$=2\,\mathrm{Re}(b_1 b_4^* + b_2 b_3^*)$
11. O_x	→		→	$=2\,\mathrm{Re}(b_1 b_4^* - b_2 b_3^*)$
12. O_z	→		●	$=2\,\mathrm{Im}(b_1 b_4^* + b_2 b_3^*)$
Target-recoil				
13. T_x		→	→	$=2\,\mathrm{Re}(b_1 b_2^* - b_3 b_4^*)$
14. T_z		→	●	$=2\,\mathrm{Im}(b_1 b_2^* - b_3 b_4^*)$
15. L_x		●	→	$=-2\,\mathrm{Im}(b_1 b_2^* + b_3 b_4^*)$
16. L_z		●	●	$=2\,\mathrm{Re}(b_1 b_2^* + b_3 b_4^*)$

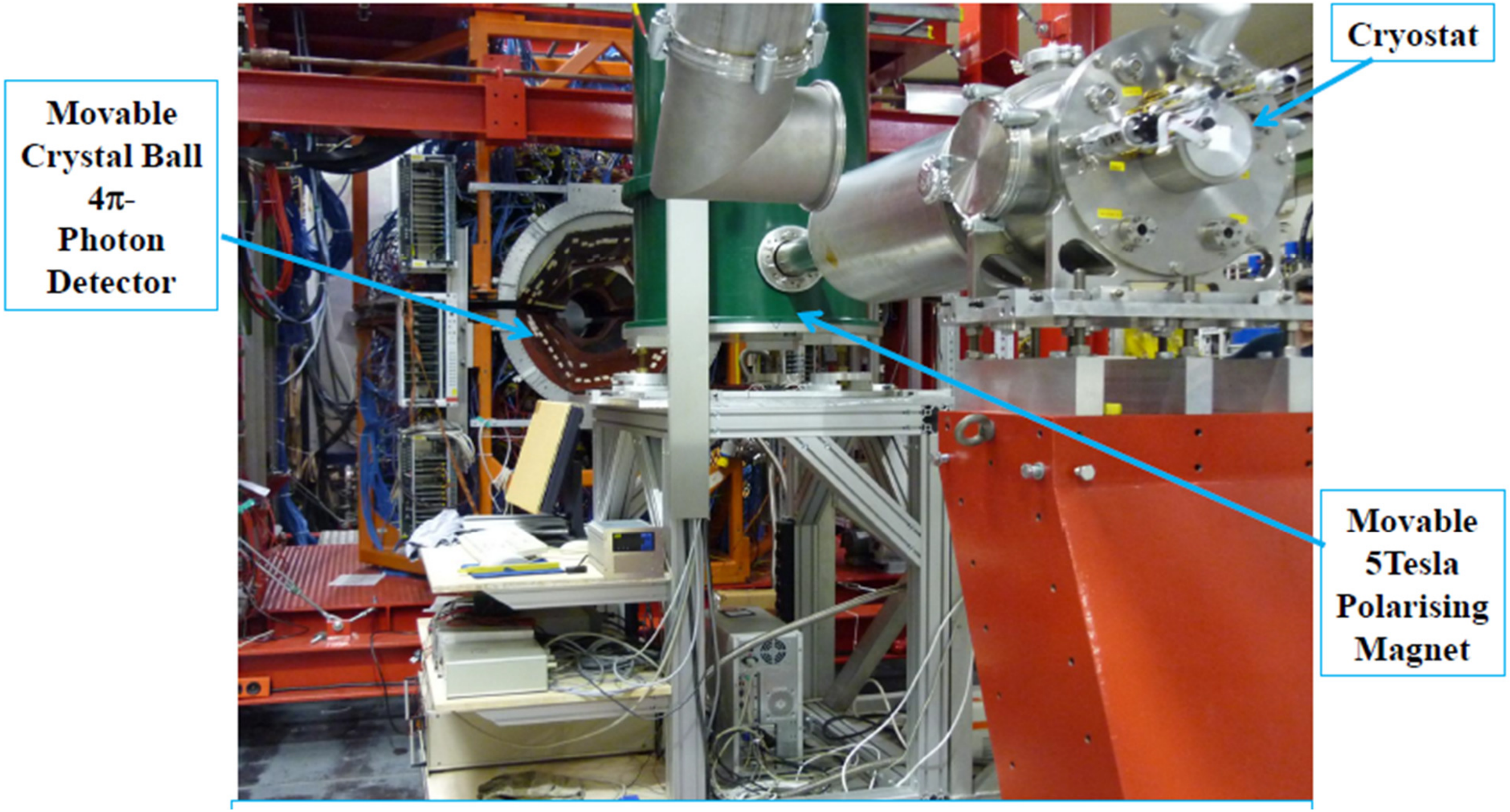
The Mainz/Dubna frozen spin target



- Transverse & longitudinal holding coils
- 1 Tesla at 46A achieved

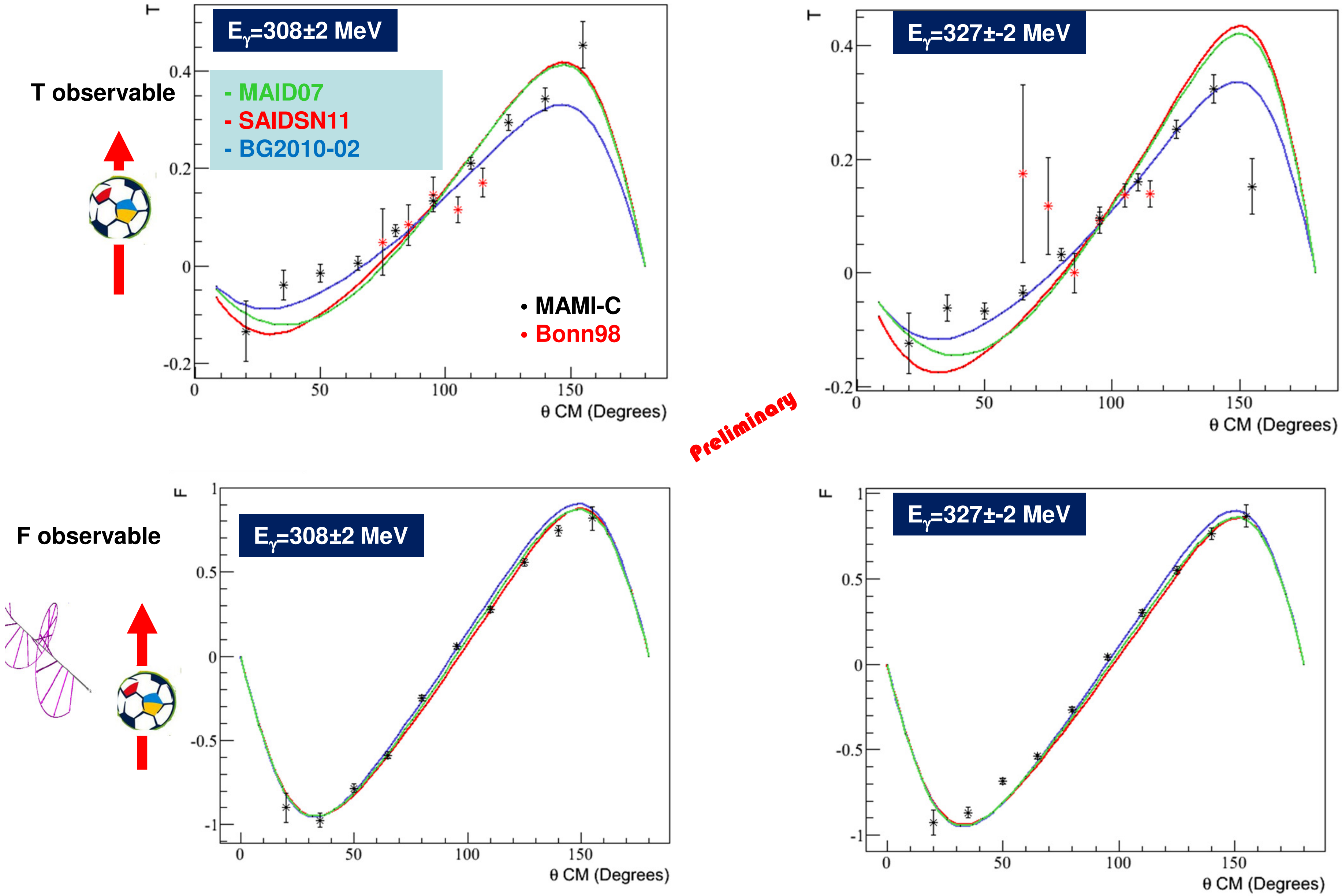
- Target material Butanol $C_4H_{10}O$ or deuterated butanol
- Polarisation **90% proton**, 80% deuteron, 50% neutron

Mainz/Dubna polarised target



- 5000 hours beam on target in 2010/2011
- Maximum polarisation 90%. Relaxation time ~1000 hours

p(γ,π^0)p : T and F in Δ(1232) region



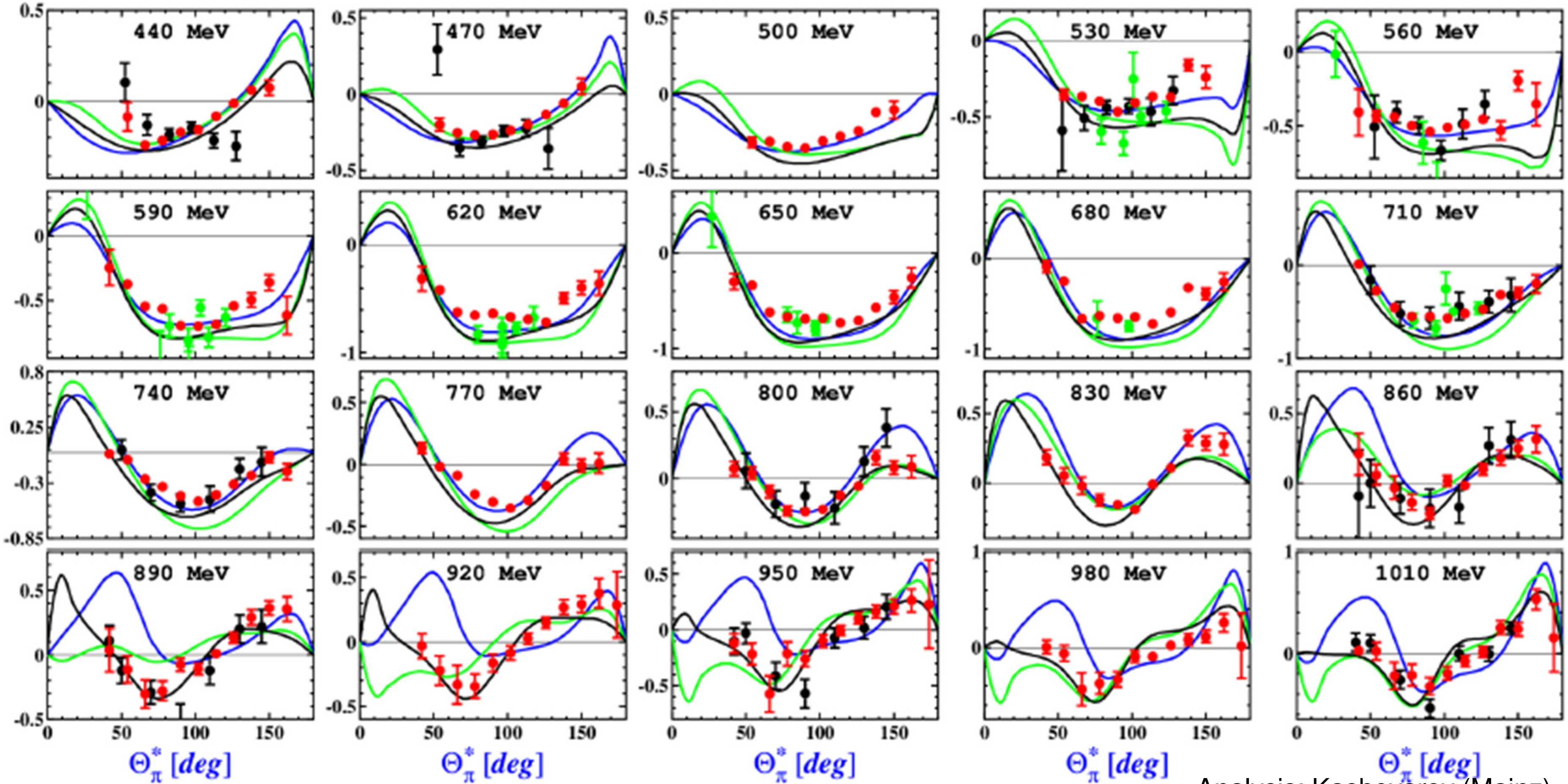
- Data near threshold will also constrain Unitary, ChPT models

PhD: Barrientos (Edinburgh)

$p(\gamma,\pi^0)p$: T in higher resonance regions

- MAMI-C
- Bonn98,77
- Tokyo78

blue line: MAID-2007
green line: SAID
black line: BG2010-02l

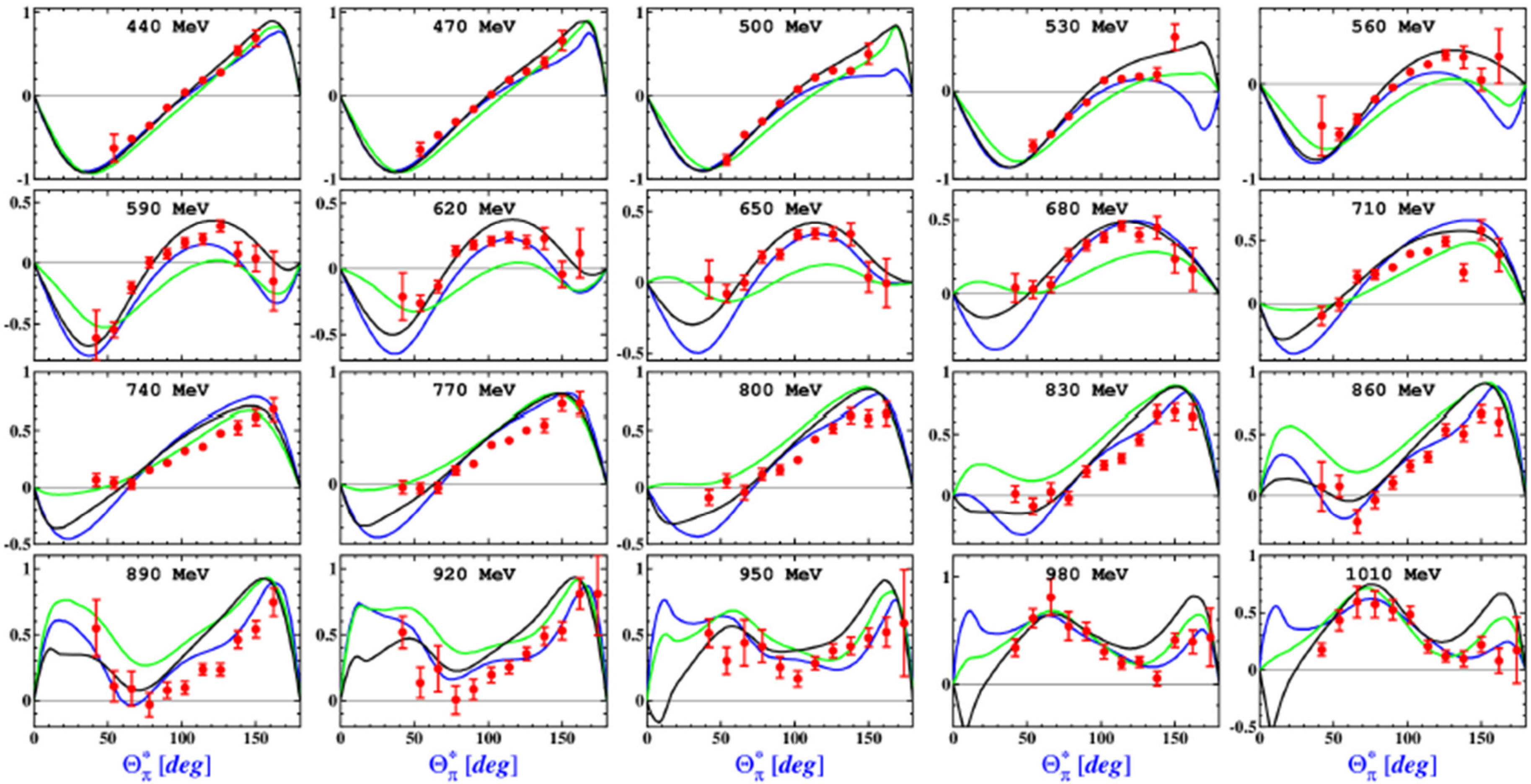


Analysis: Kashevarov (Mainz)

p(γ,π⁰)p : F in higher resonance regions

- **MAMI-C**

blue line: MAID-2007
green line: SAID
black line: BG2010-02l

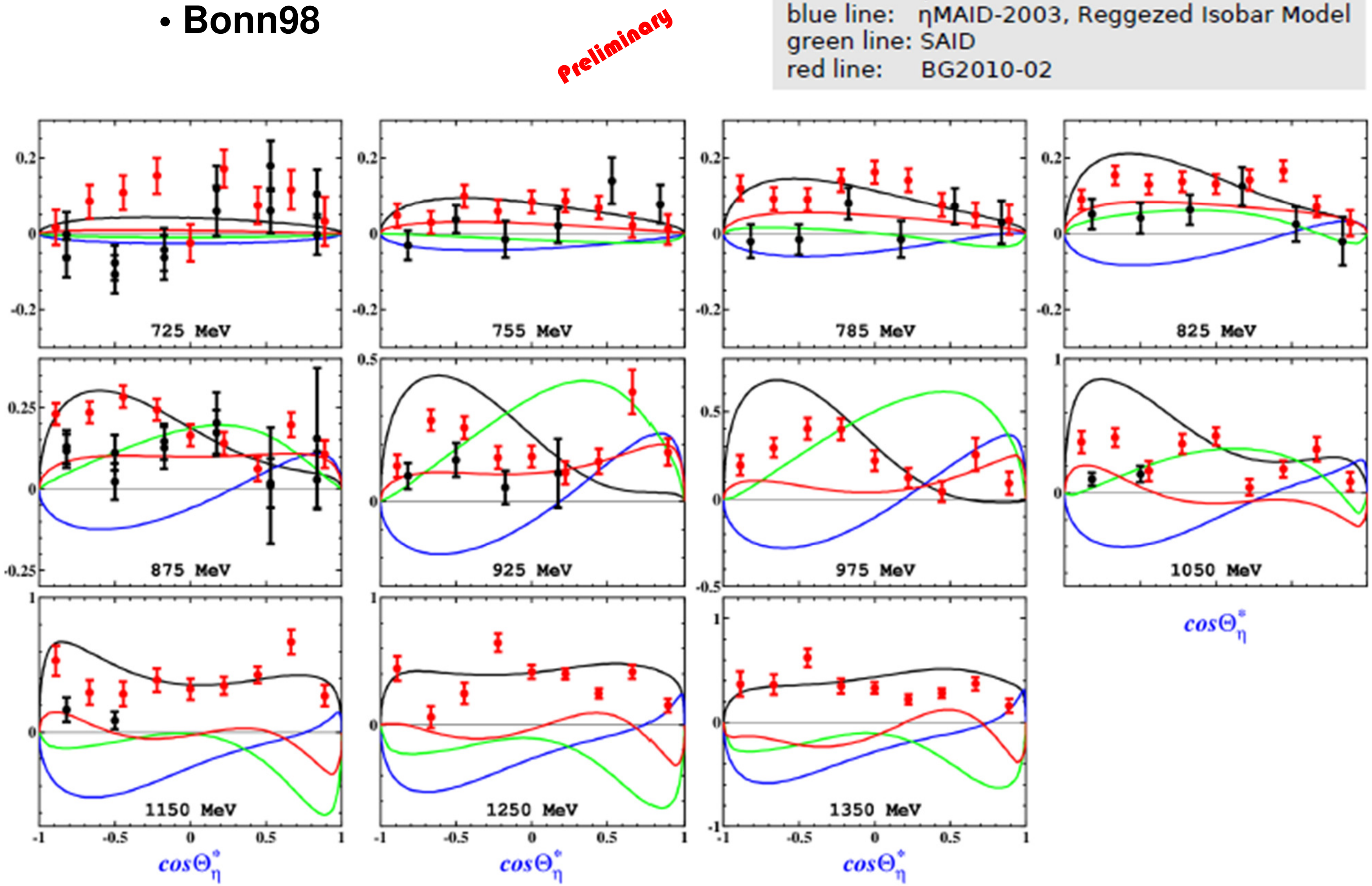


Analysis: Kashevarov (Mainz)

p(γ,η)p : T observable

- MAMI-C
- Bonn98

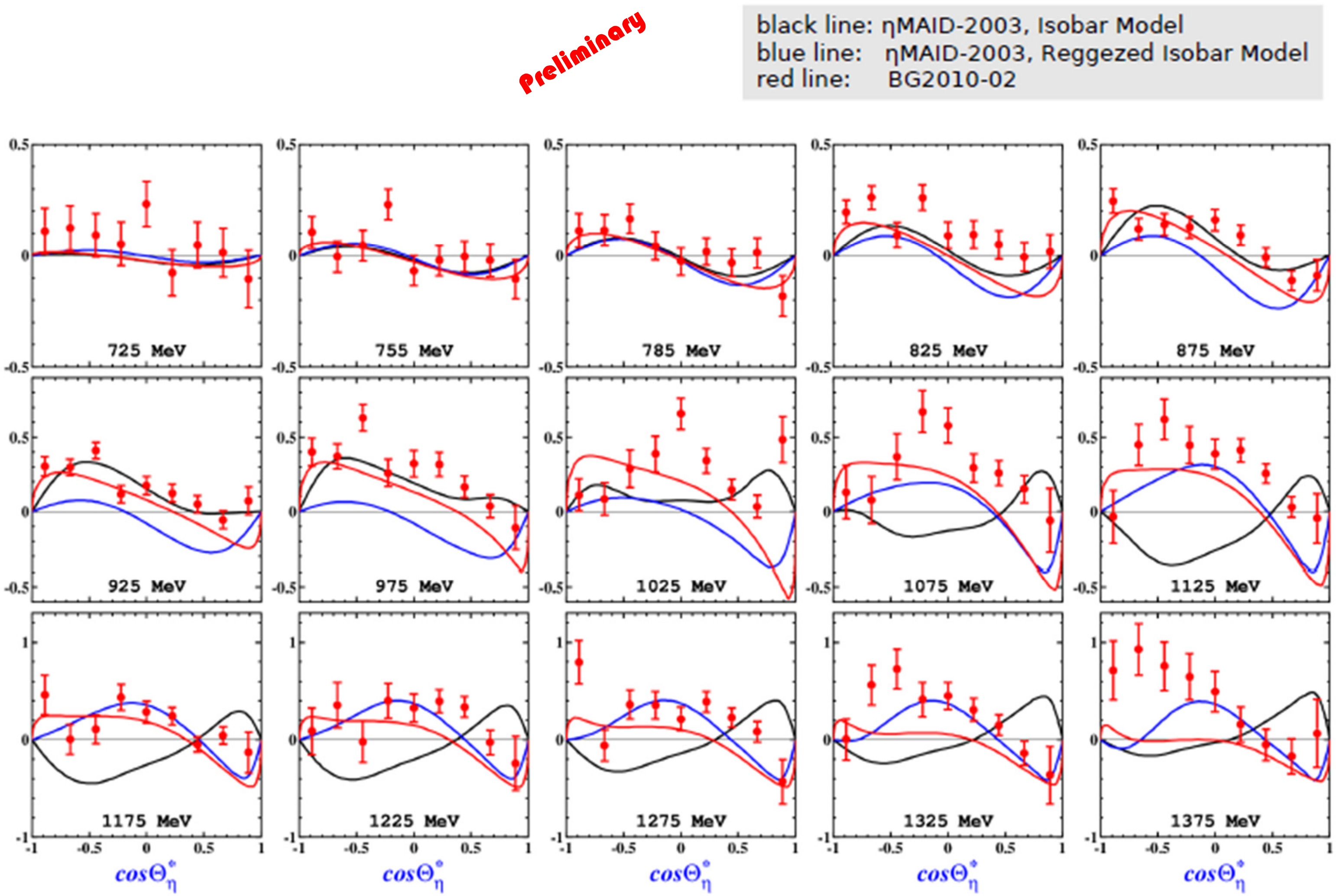
black line: ηMAID-2003, Isobar Model
blue line: ηMAID-2003, Reggezed Isobar Model
green line: SAID
red line: BG2010-02



Analysis: Kashevarov (Mainz)

p(γ,η)p : F observable

- **MAMI-C**



Analysis: Kashevarov (Mainz)

K^+ meson detection in segmented calorimeters

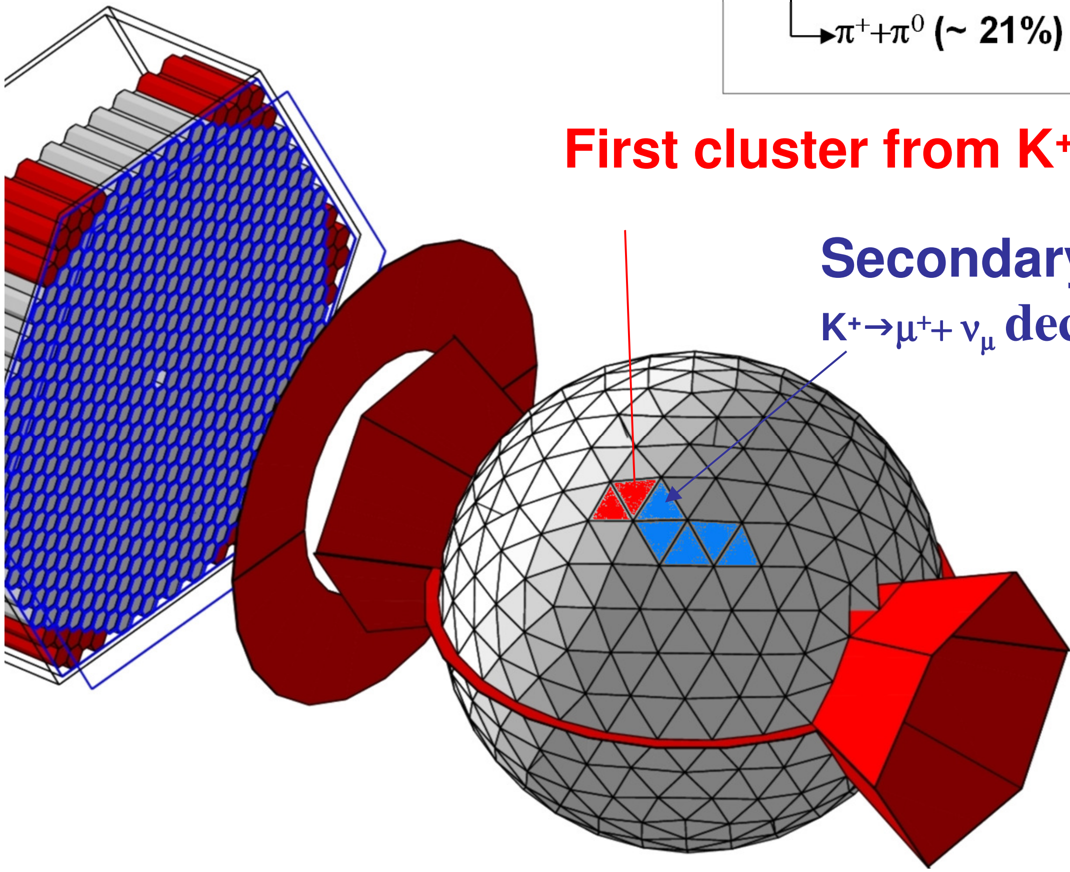
- Identify the K^+ decay within the crystals of the Crystal Ball and TAPS

$K^+ \to \mu^+ + \nu_\mu$ (~ 63%)   Mean lifetime of K^+ ~ 12 ns

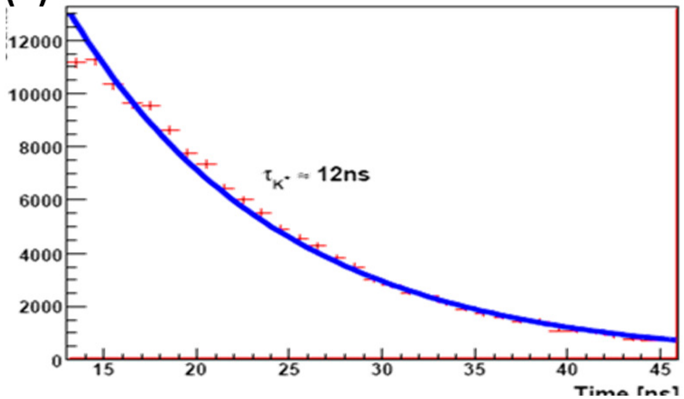
$K^+ \to \pi^+ + \pi^0$ (~ 21%)

First cluster from K^+ < 3ns

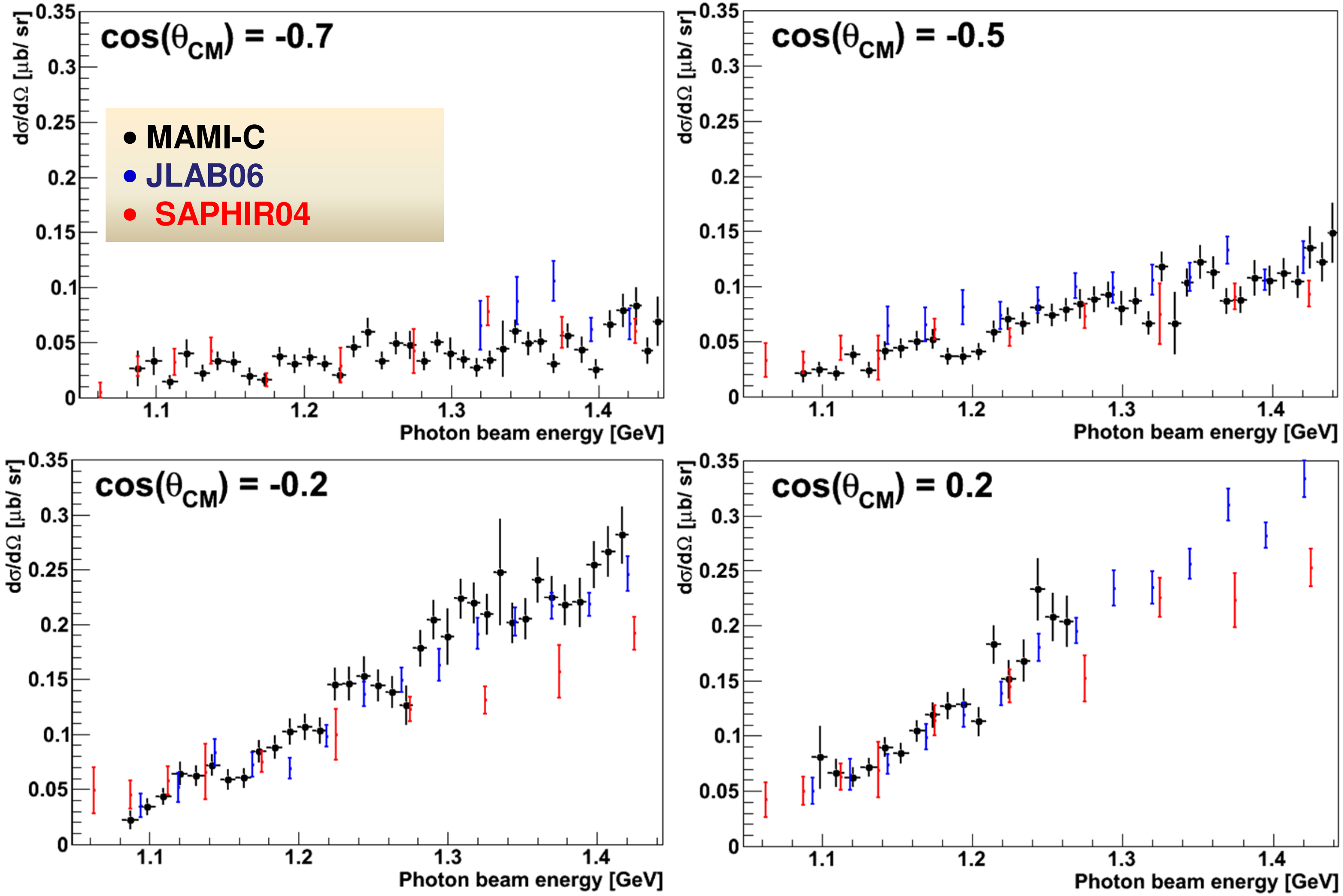
Secondary cluster from $K^+ \to \mu^+ + \nu_\mu$ decay > 10ns



(a) Time diff. Between 1st and 2nd clusters



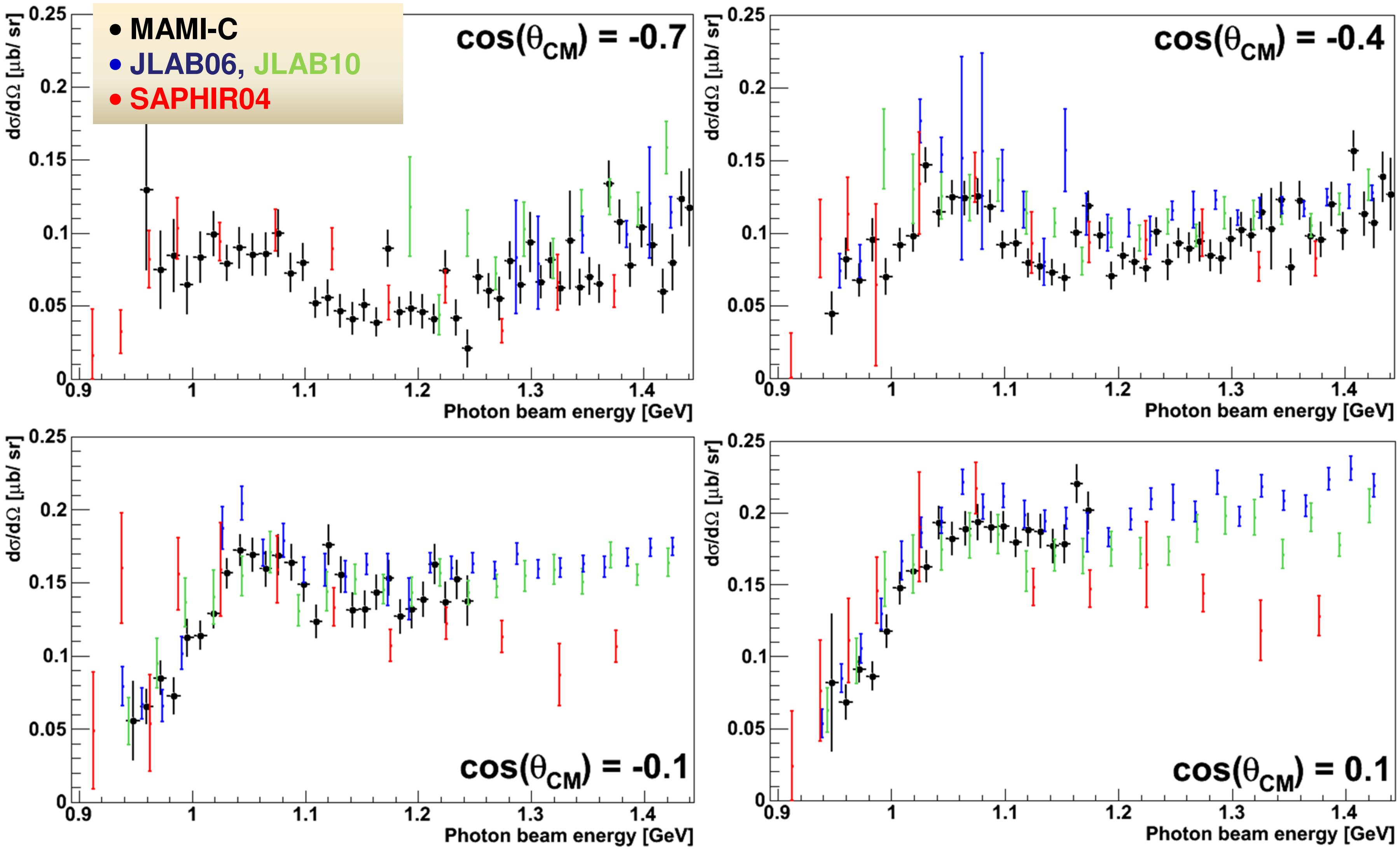
$\gamma(p,K^+)\Sigma^0$



- Σ^0 tagged from detecting $\Sigma^0 \rightarrow \Lambda\gamma$ decay

PhD: Jude(Edinburgh)

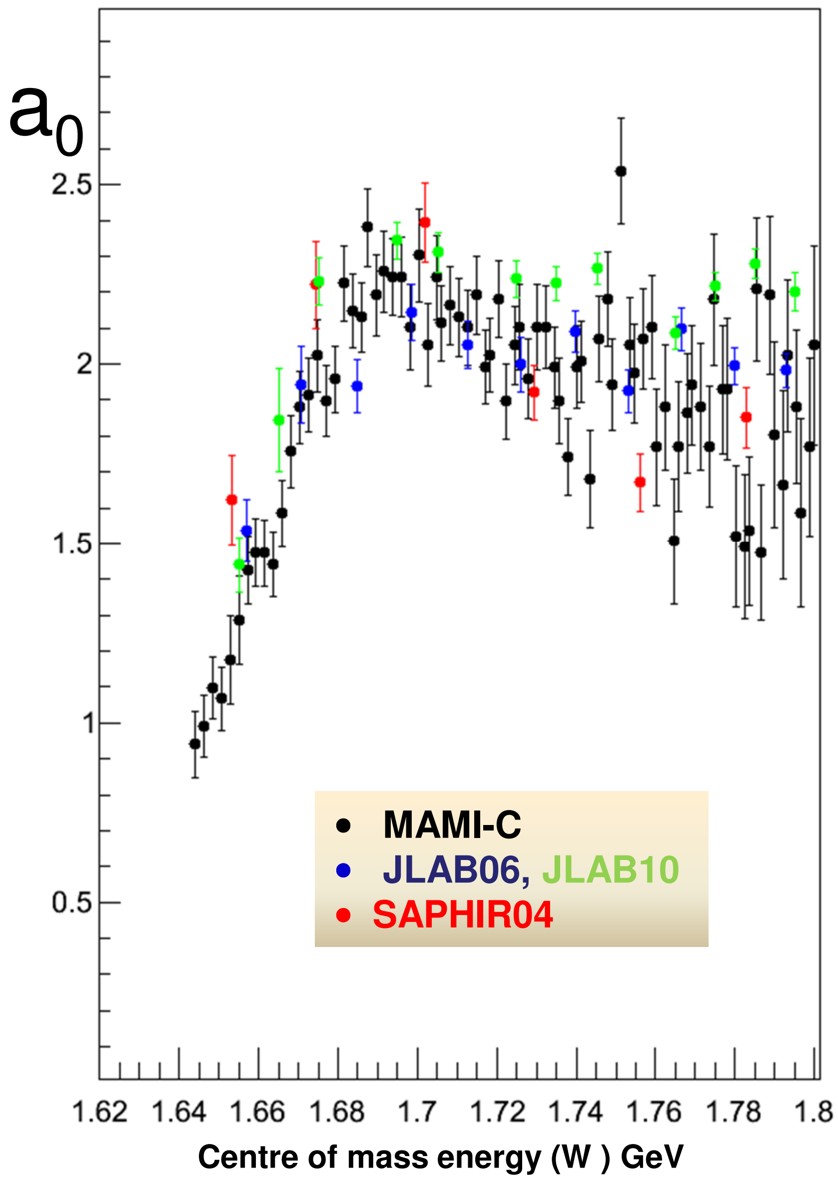
$\gamma(p,K^+)\Lambda$

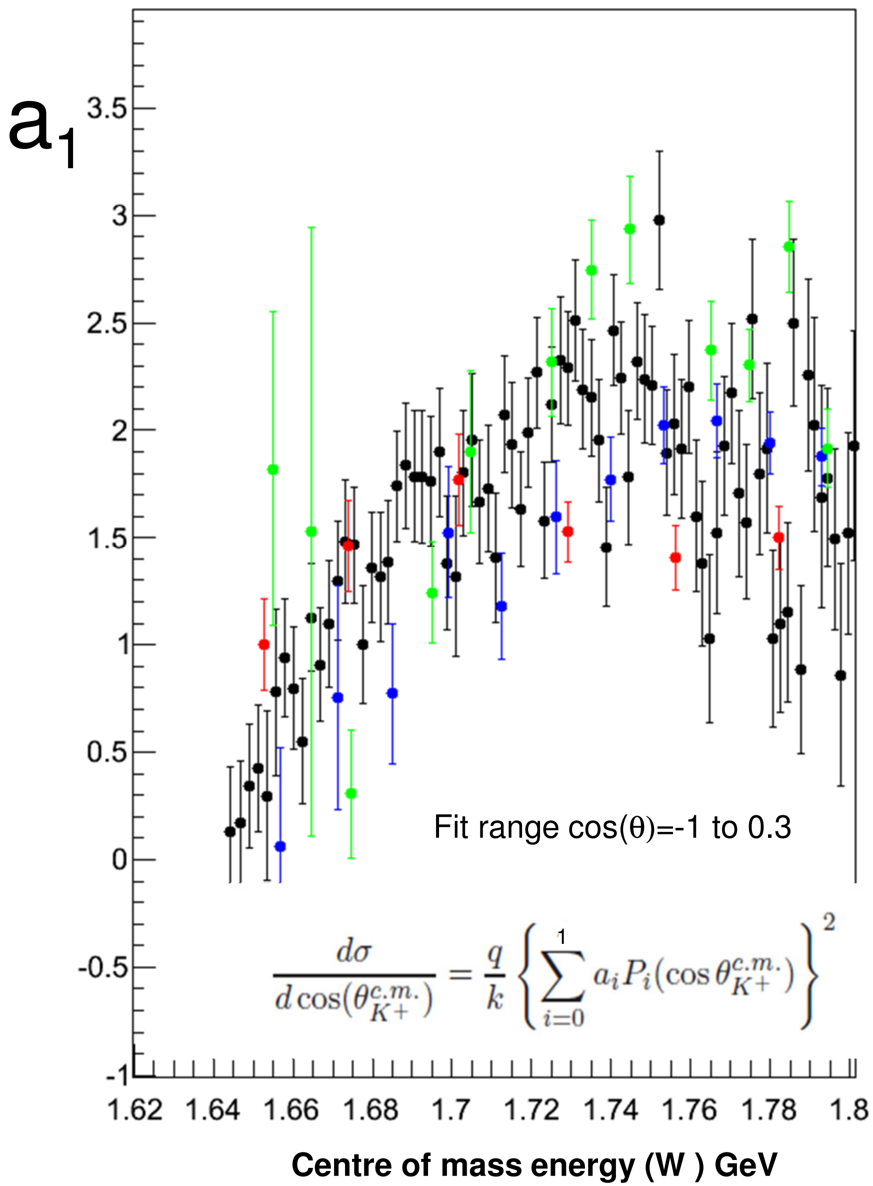


- Possible to bin data in W < 2 MeV !

PhD: Jude(Edinburgh)

γ(p,K⁺)Λ : Legendre analysis

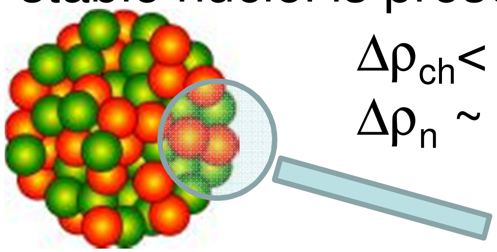




PhD: Jude(Edinburgh)

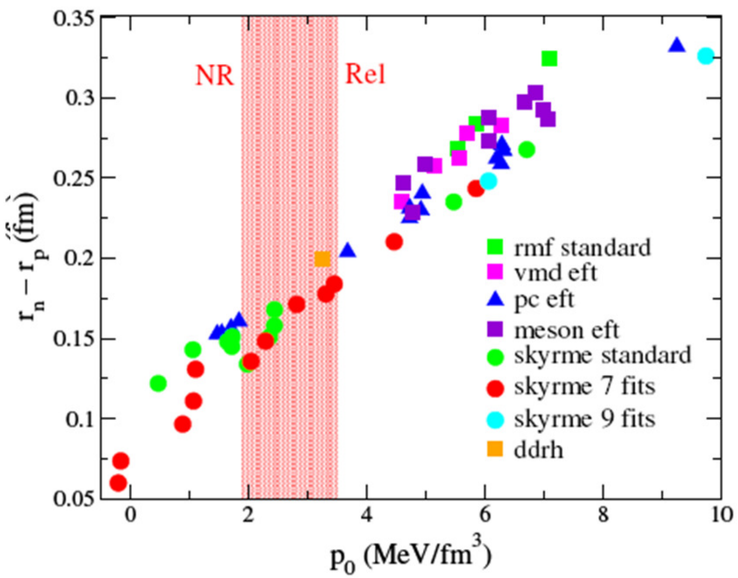
Matter form factor and the neutron skin

- Our knowledge of the shape of stable nuclei is presently incomplete

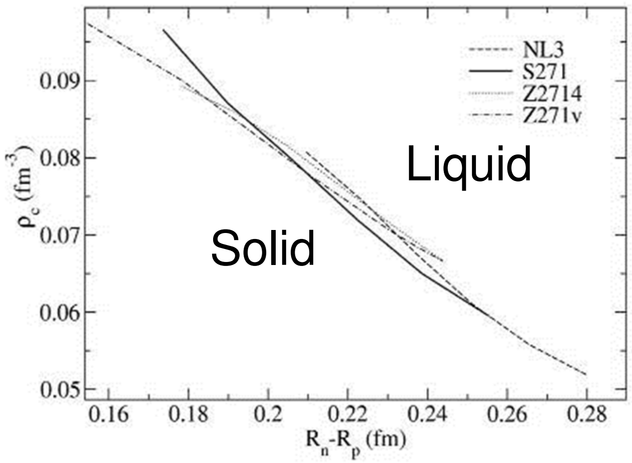


$\Delta\rho_{ch} < 0.001 \text{fm}$
$\Delta\rho_n \sim 0.2 \text{ fm}$

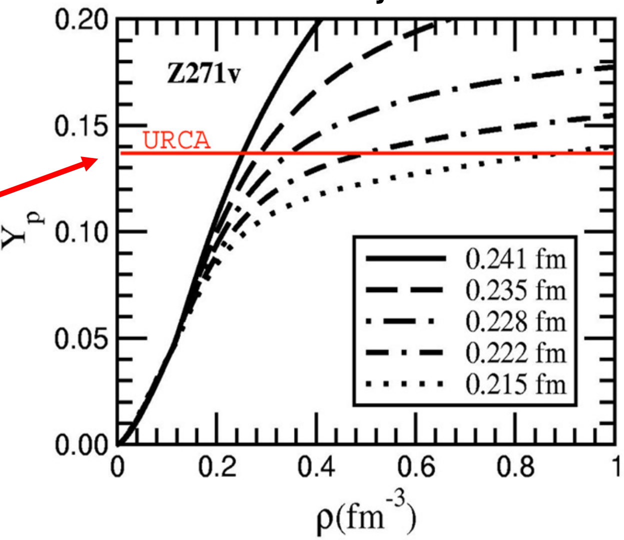
Horowitz et al. PRC63 025501 (2001)
Piekarewicz et al. NPA 778 (2006)



Thick neutron skin
→ Low transition density in neutron star



Proton fraction as a function of density in neutron star



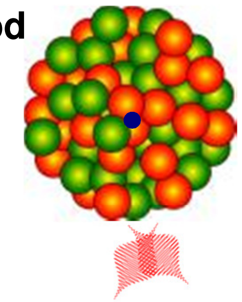
Direct URCA Cooling

$n \to p + e^- + \overline{\nu}$

$e^- + p \to n + \nu$

Coherent pion photoproduction

Photon probe ✓
Interaction well understood



π^0 meson – produced with ~equal probability on protons *AND* neutrons.

Select reactions which leave nucleus in ground state

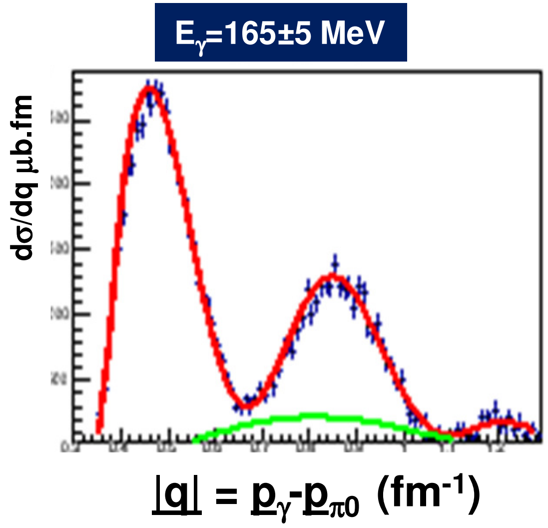
Reconstruct π^0 from $\pi^0 \rightarrow 2\gamma$ decay

- Angular distribution of π^0 $\rightarrow$ PWIA contains the matter form factor

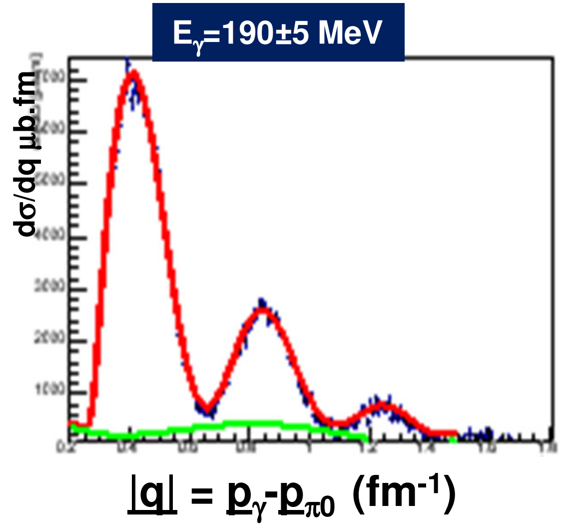
$$d\sigma/d\Omega(\mathrm{PWIA}) = (s/m_N^2)\, A^2\, (q_\pi^*/2k_\gamma)\, F_2(E_\gamma^*, \theta_\pi^*)^2\, |F_m(q)|^2 \sin^2\theta_\pi^*$$

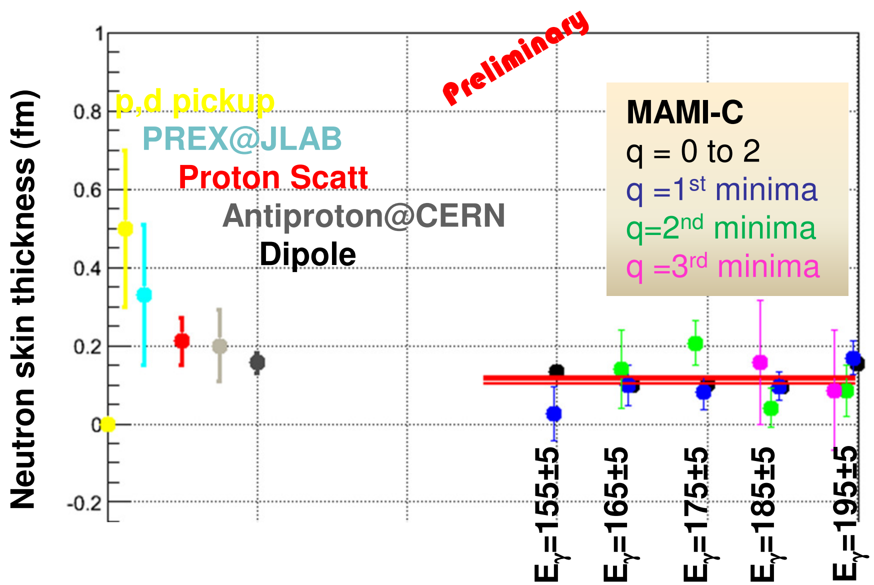
- π^0 final state interactions - complex optical potential tuned to π-A scattering data.
- Corrections modest at **low** pion momenta - $E\gamma < 200$ MeV data scale as A^2

^{208}Pb neutron skin from Coherent π^0



- (γ,π) + π^0-A complex optical potential (Drecschel et al NPA 660 (1999)) Including detector resolution + interpolated fit for neutron skin + incoherent background
- Incoherent background alone





Skin ~ 0.12 ±0.02(stat) fm *Preliminary*

Systematic error currently being finalised. expect < ~0.05 fm

PhD: Tarbert(Edinburgh)

Summary

- The intense polarised photon beam at MAMI is producing world class data for the study of the properties of mesons, baryons, nuclei and nuclear matter.