Possibilities for large acceptance nucleon polarimetry & (γ,NN) revisited

Dan Watts,
University of Edinburgh

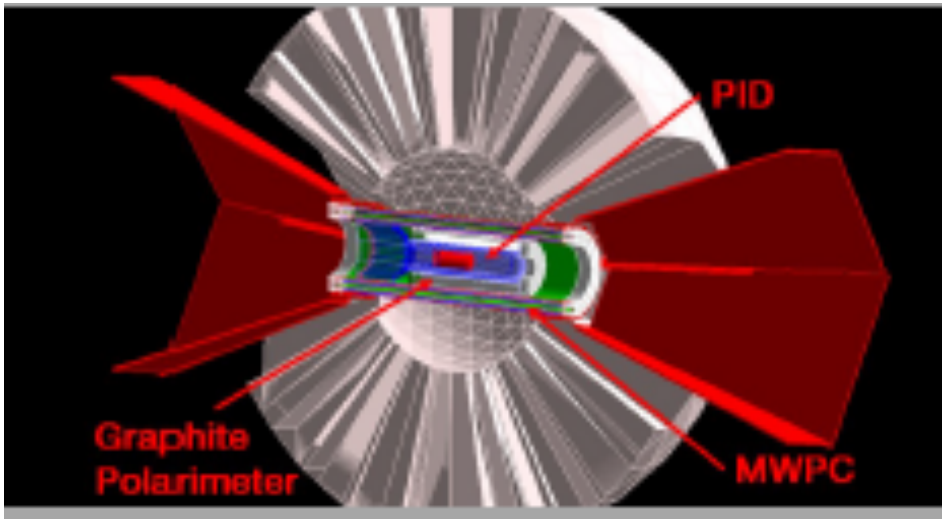
Outline

- Recent work on large acceptance nucleon polarimetry

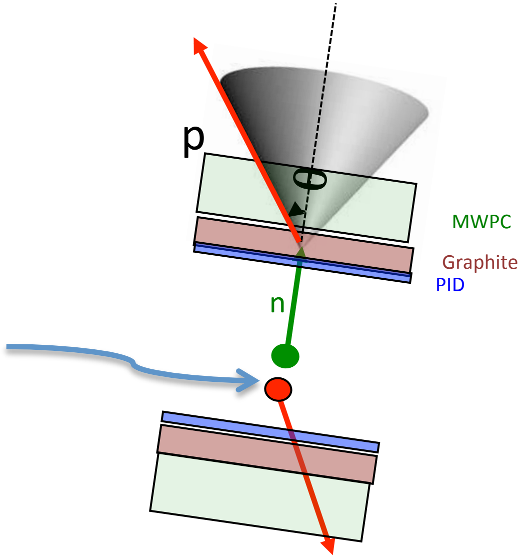
  -> Useful in next generation SRC experiments?

- Revisit some (γ,NN) results

EDPOL2: CB@MAMI

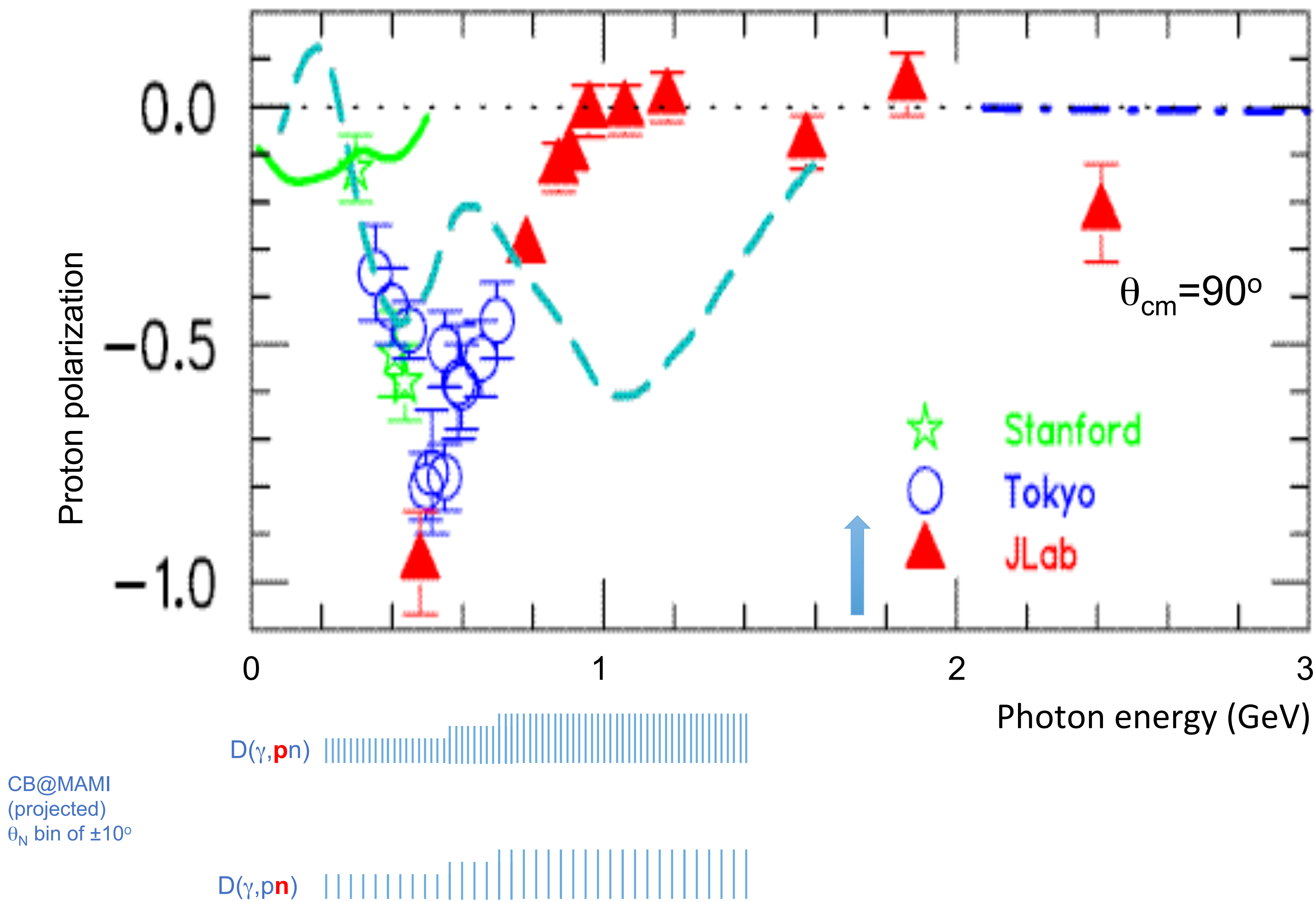


- EDPOL2 Run completed Aug ’17
- 10cm liquid deuterium target
- d(**γ,pn**) n(γ,π^0)**n** n(γ,η)**n**



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

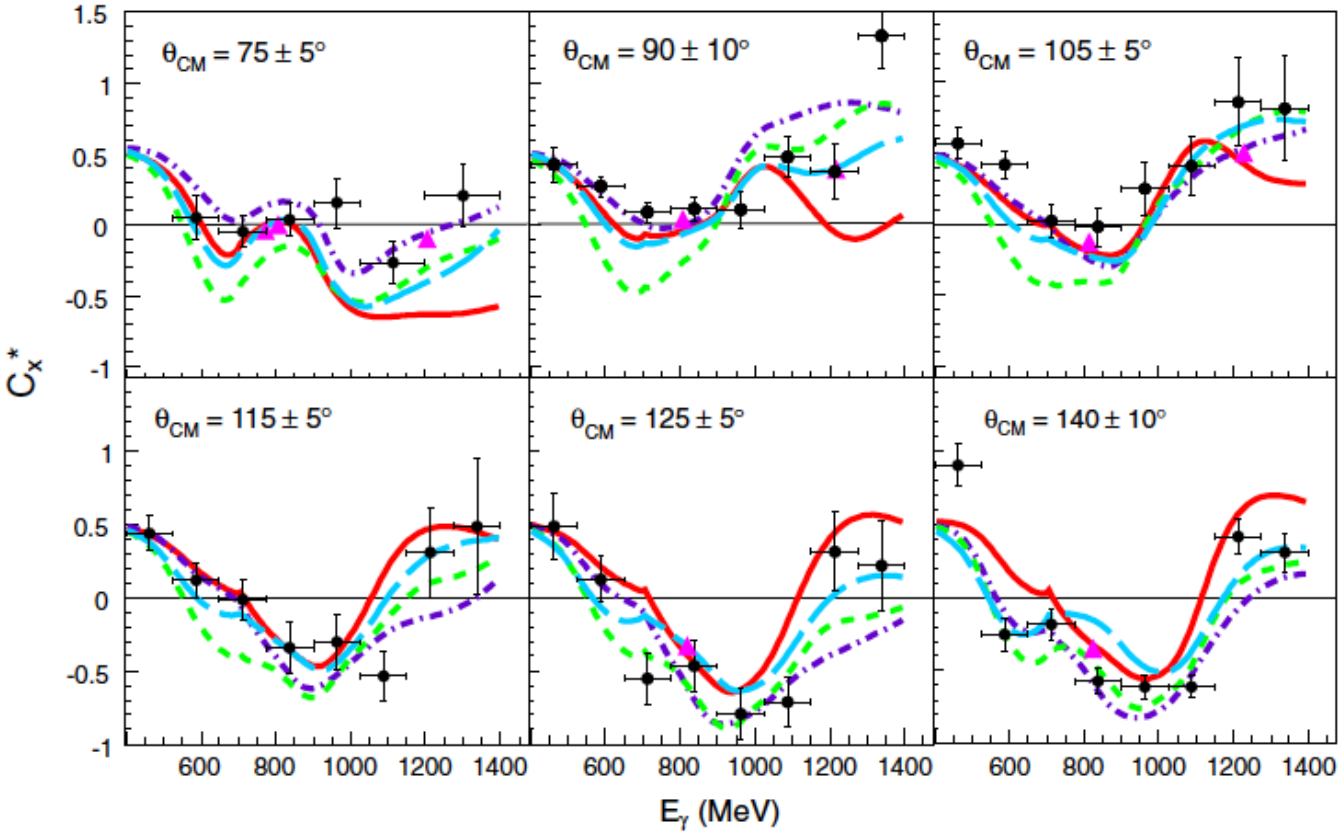
Expected statistical accuracy for D(γ,pn)



EDPOL1 CB@MAMI – hydrogen target

PRL 112, 022501 (2014) PHYSICAL REVIEW LETTERS week ending 17 JANUARY 2014

Measurement of the $^1H(\vec{\gamma},\vec{p})\pi^0$ Reaction Using a Novel Nucleon Spin Polarimeter



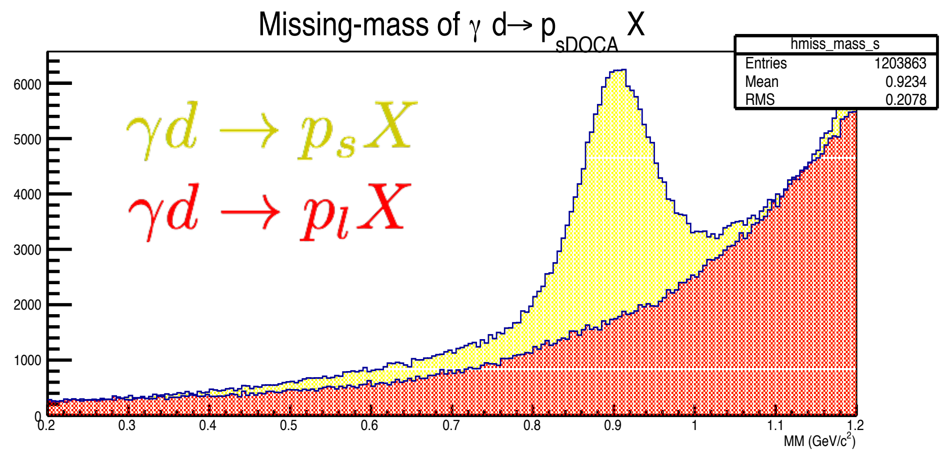
PhD Sikora
Edinburgh

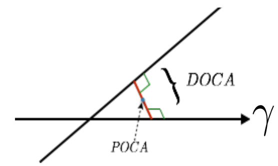
FIG. 3 (color online). C_x^* excitation functions for $\vec{\gamma}p \to \pi^0\vec{p}$ (black circles) for fixed pion polar angles θ_{cm}. Previous data came from JLab [2] (magenta triangles). The PWA solutions shown are SAID CM12 [36] (cyan long-dash line), SAID SN11 [37] (green short-dash line), BnGa2011-2 [38] (solid red line), and MAID07 [39] (violet dash-dotted line).

- EDPOL1 – no MWPC.
- Geant4: New classes: Parameterise p-^{12}C scattering data (+SAID PWA for QF NN)

d(γ,**p<u>n</u>**) with CLAS@JLAB

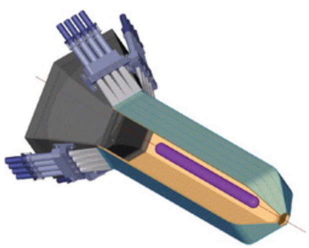
- CLAS start counter as analysing medium
- Two ***proton*** final state
  -> Incident neutron vector from kinematics
  & intercept of scatter track with SC
  -> Scatter vector from CLAS drift chambers



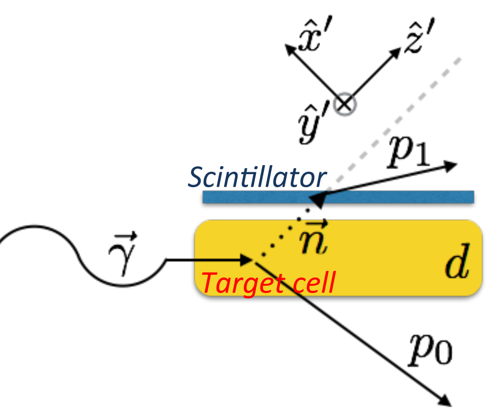


p_s smallest DOCA Proton

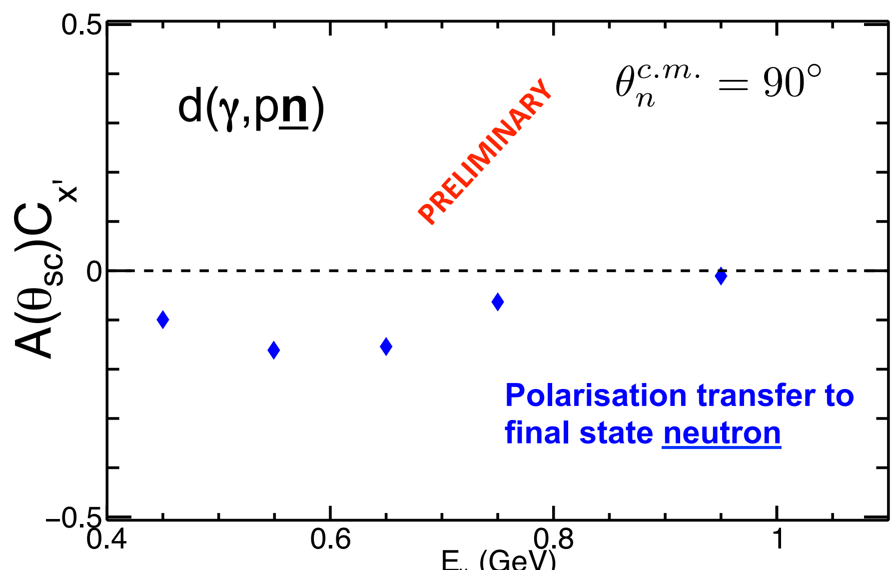
p_l largest DOCA Proton



<u>g13 Experiment@CLAS</u>
Liq D_2 target 40 cm long
Circular (g13a) 20 triggers
Linear (g13b) 30 triggers



Analysis of Zachariou (Edinburgh)



SRC

- Next step with CLAS data A(γ,**NN**)

  Physics -> Test Glauber predictions, HHC in medium, .. (more?)
  Evolution of transferred/induced nucleon polarisation with A, E_γ
  Analysing powers may cancel to first order in ratios of targets ✓
  Glue-X possibilities?

- Use in future experiments at CLAS12, .. ?

  Wide range of kinematic variables (Q^2,ω, *x*..) in one experiment ✓

  Gives access to neutron (as well as proton) polarisation ✓

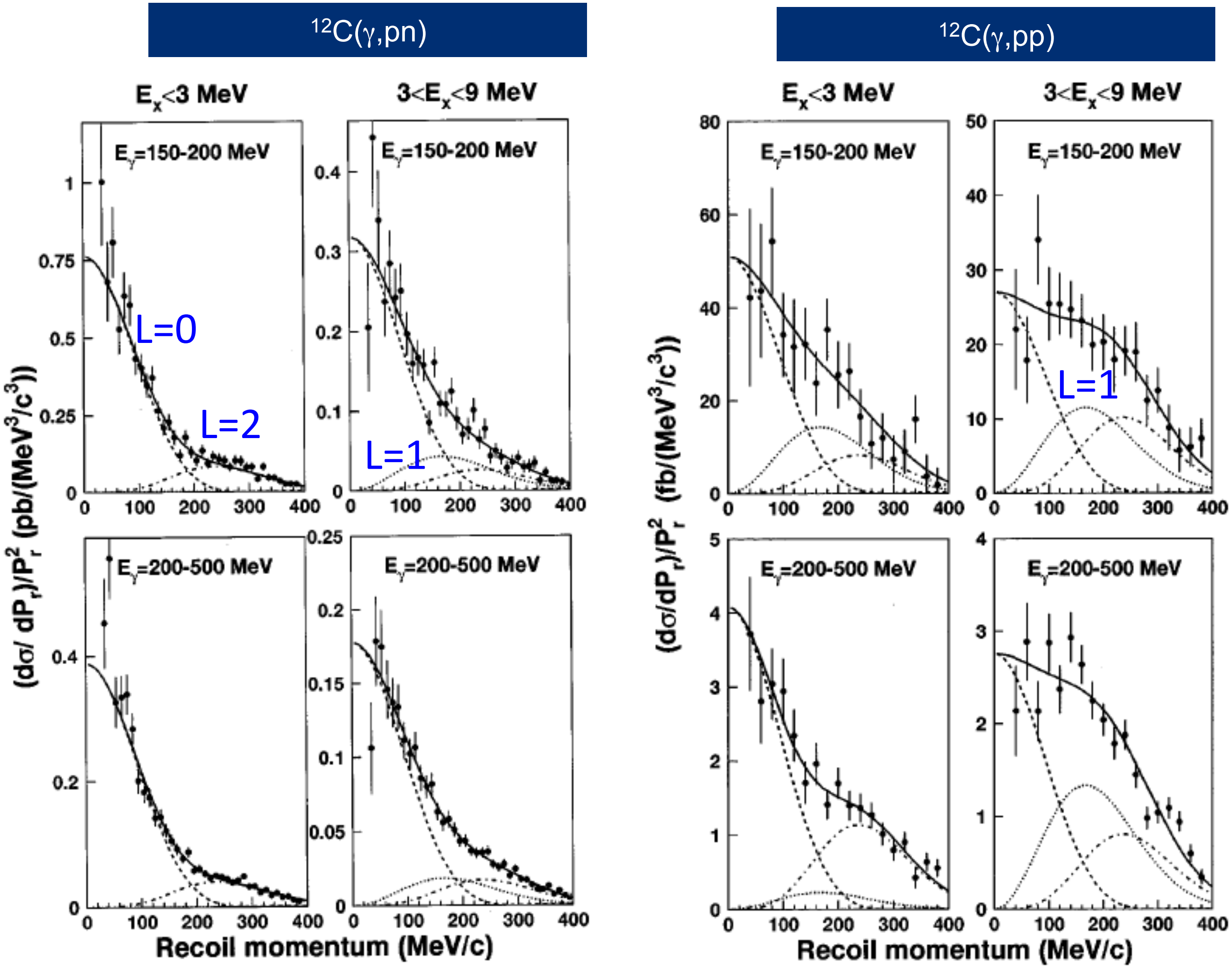
  Transferred polarisation (likely) only measurable transverse to the nucleon scatter plane ✗

- Worth the effort? Need steer from theory

$$\frac{P_x}{P_z} = -\frac{2M_p}{(E+E')\tan(\theta/2)} \frac{G_E^P(Q^2)}{G_M^P(Q^2)}$$

(γ,NN) revisited

$^{12}C(\gamma,NN)$ @ MAMI – pair momentum distributions



True for mean field.
SRC nucleons?

- Q distribution sensitive to

  Relative pair momentum (s- wave, p-wave, d-wave)

  Final state of (A-2) nucleus

  Contributing shells – e.g. (1s)(1p) narrower and at higher Q than $(1p)^2$

DPW, MacGregor et. al.
PRC 62 014616 (2000)

$^{12}C(\gamma,pn)$ – high Q excess

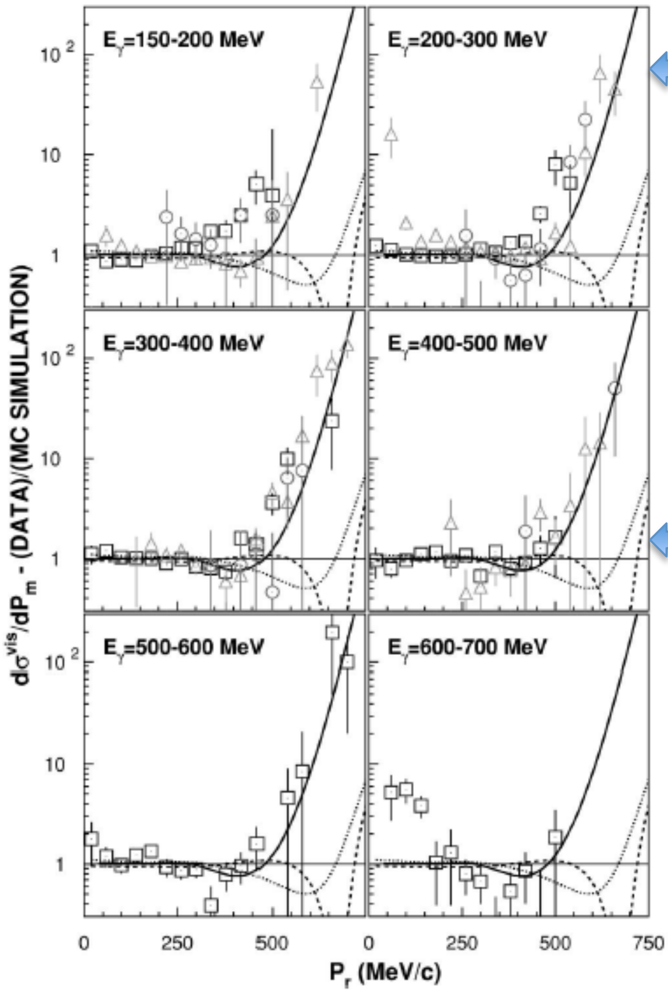


FIG. 10. Recoil momentum distributions for $^{12}C(\gamma,np)$ for $E_m \leq 40$ MeV presented as a ratio to the $2N$ knockout MC predictions. The plot shows data from the kinematic regions I (squares), II (triangles), and III (circles) described in the text. The solid line shows the ratio of the pair momentum distribution obtained with SRC's to that calculated without SRC's for ^{16}O [8]. The dotted (dashed) lines show the ratio of the P_r distribution predicted using Hartree-Fock (Woods-Saxon) wave functions (with no SRC's) to that using HO.

SRC/No SRC (Orlandini)

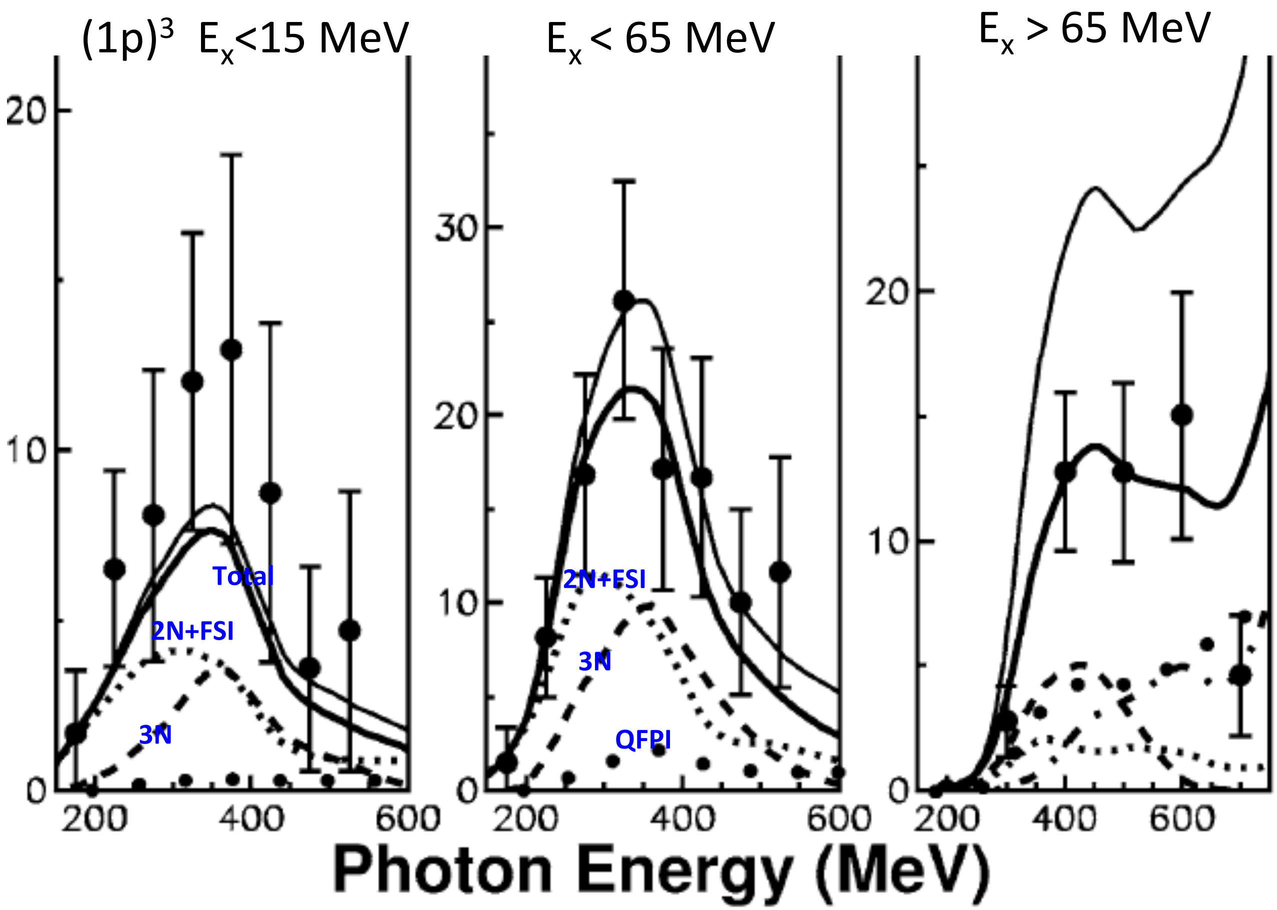
HF,WS/HO

- Clear excess at high Q over mean field (selecting $(1p)^2$ knockout)
- Excess rather uniform for different photon energy ranges, kinematics (different reaction mechanisms, different nucleon energies, different phase space)
- Is comparison possible with the new more detailed theories?
- Can other processes fool us? e.g. 2N+FSI

DPW, Macgregor et. al. PRC 62 014616 (2000)

Photoinduced 3-nucleon knockout $^{12}C(\gamma,ppn)$

- Comparison with Valencia model
  -> Suggestion of direct 3-nucleon knockout (3N) contribution
  -> Significant 2N+FSI and QFπ +(π,2N)



All include kinematic cut to suppress contribution of QFπ

DPW et. al. PLB 553 (2003) 25-30

Summary

- Recoil nucleon polarimetry may be possible – is it worthwhile?
- The A(γ,NN) MAMI data may be worth revisting given the exciting advances in theory in recent years.
- Other ongoing studies - subthreshold Kaon photoproduction from nuclei.

- We are also looking at possiblities for sub-threshold Kaon photoproduction
  - Kaon has large mean free path – less sensitive to FSI
  - Need forward angle Kaon detection (new weak sub-cluster method)
  - Possibility to tag isospin of struck nucleon?
    - $\gamma+p \rightarrow K^{+} \Sigma^{0}$ (tag with gamma from sigma decay, or proton pi0)
    - $\gamma+n \rightarrow K^{+} \Sigma^{-}$ (Tag with pi- or neutron)
- Ratio of these reactions above and below the fermi surface?

TABLE I. Ratio $a_0:a_1:a_2$ obtained from fitting the $^{12}C(\gamma,np)$ and $^{12}C(\gamma,pp)$ recoil momentum spectra with the combination $\Sigma_L a_L F_L(P)$ for two excitation regions of the residual nucleus and E_γ regions below and through the Δ resonance. Errors in the fitted parameters are shown in brackets.

	E_γ	$E_X \leqslant 3$ MeV	$3 \leqslant E_X \leqslant 9$ MeV
(γ,np)	150–200	0.35(±0.02): 0.02(±0.13): 0.63(±0.07)	0.20(±0.01): 0.53(±0.13): 0.27(±0.07)
	200–500	0.37(±0.01): 0.01(±0.10): 0.62(±0.05)	0.22(±0.01): 0.43(±0.08): 0.35(±0.04)
(γ,pp)	150–200	0.11(±0.02): 0.59(±0.29): 0.30(±0.18)	0.06(±0.01): 0.54(±0.17): 0.40(±0.12)
	200–500	0.15(±0.02): 0.16(±0.17): 0.69(±0.09)	0.06(±0.01): 0.62(±0.09): 0.32(±0.05)

Nucleon scattering and polarisation

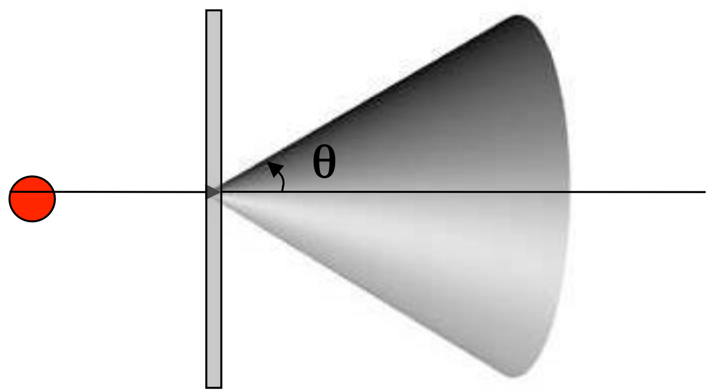
$$n(\theta,\phi) = n_o(\theta)\{1 + A(\theta)[P_y\cos(\phi) - P_x\sin(\phi)]\}$$

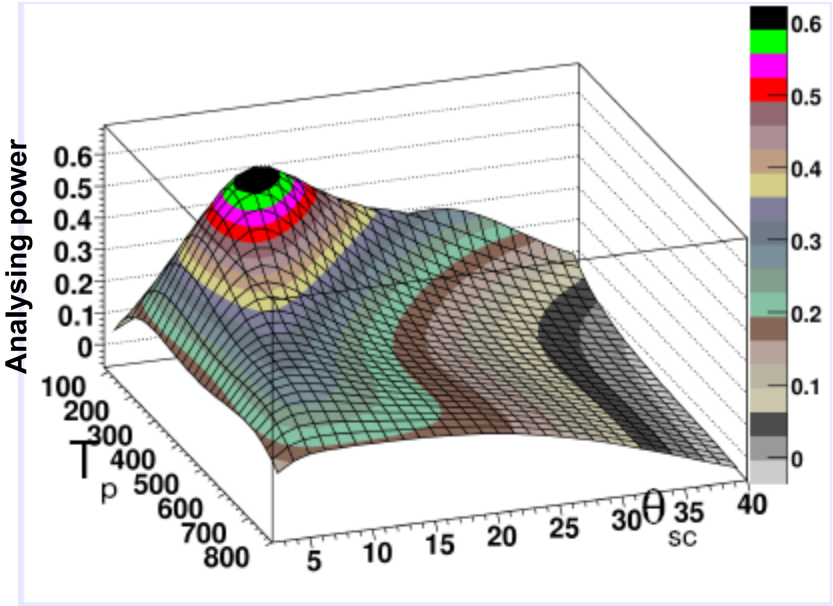
Number of nucleons scattered In the direction θ, ϕ

Polar angle distribution for unpolarised nucleons

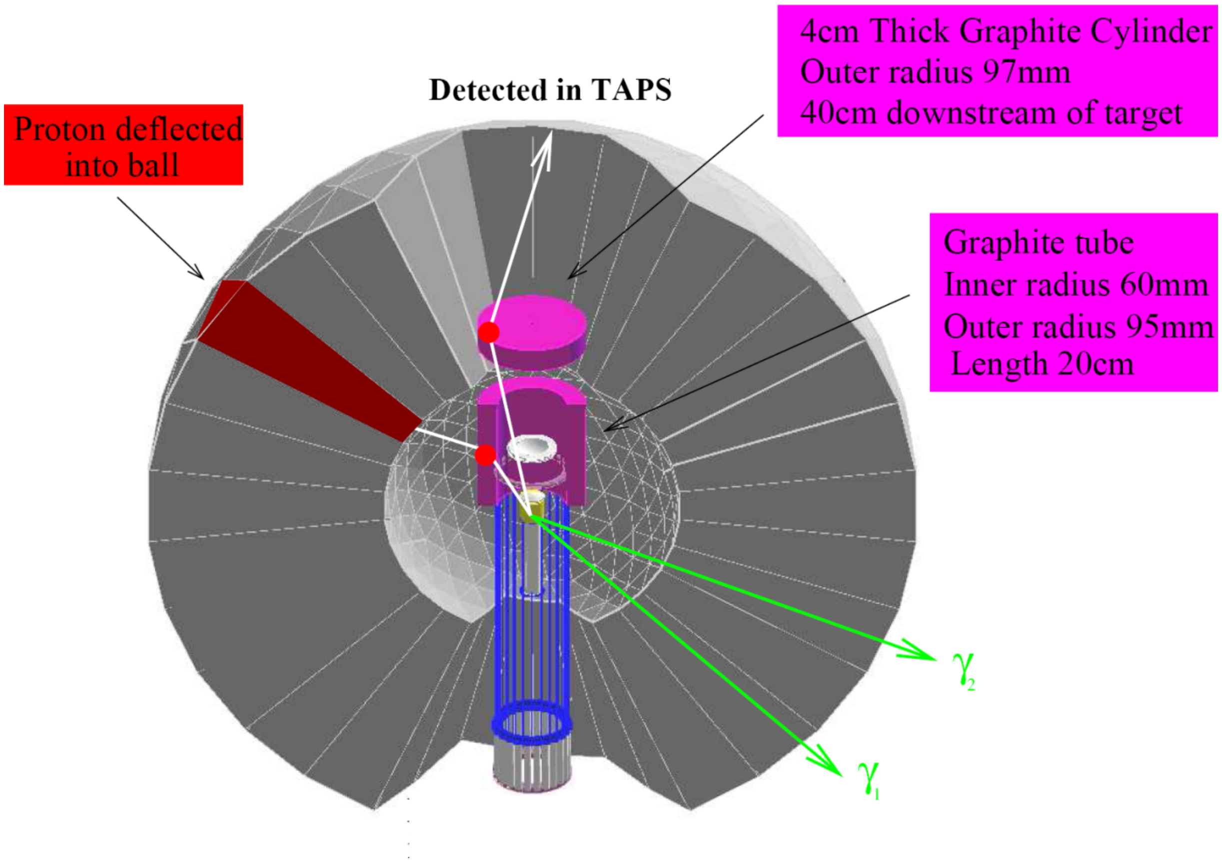
Analysing power of scatterer

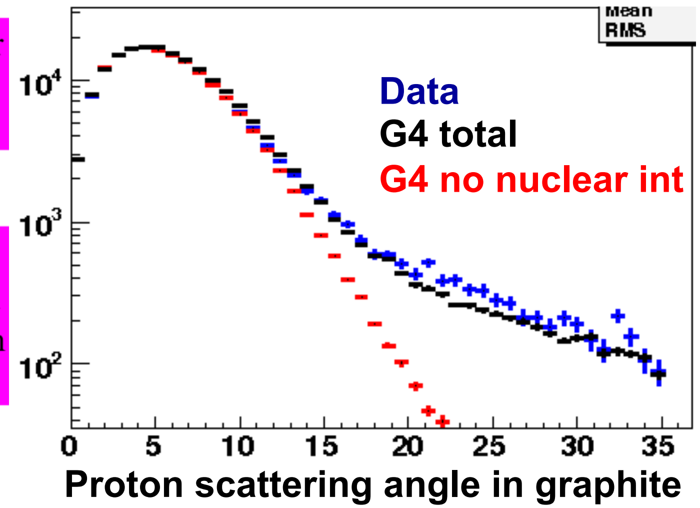
x and y (transverse) components of nucleon polarisation

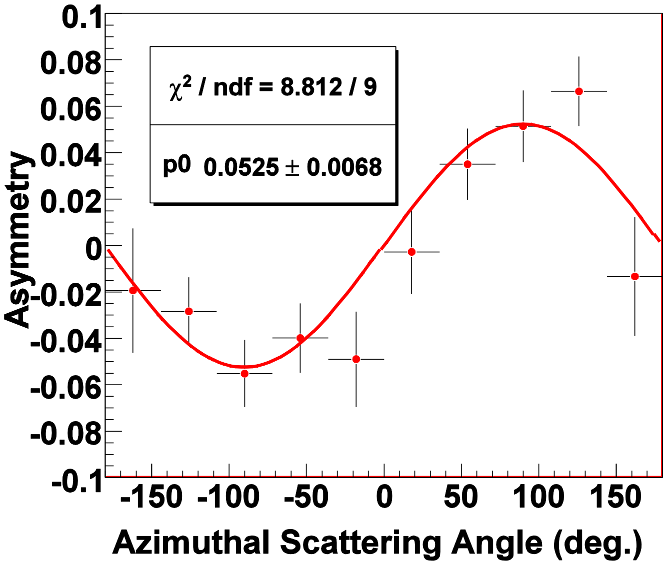




The CB proton polarimeter

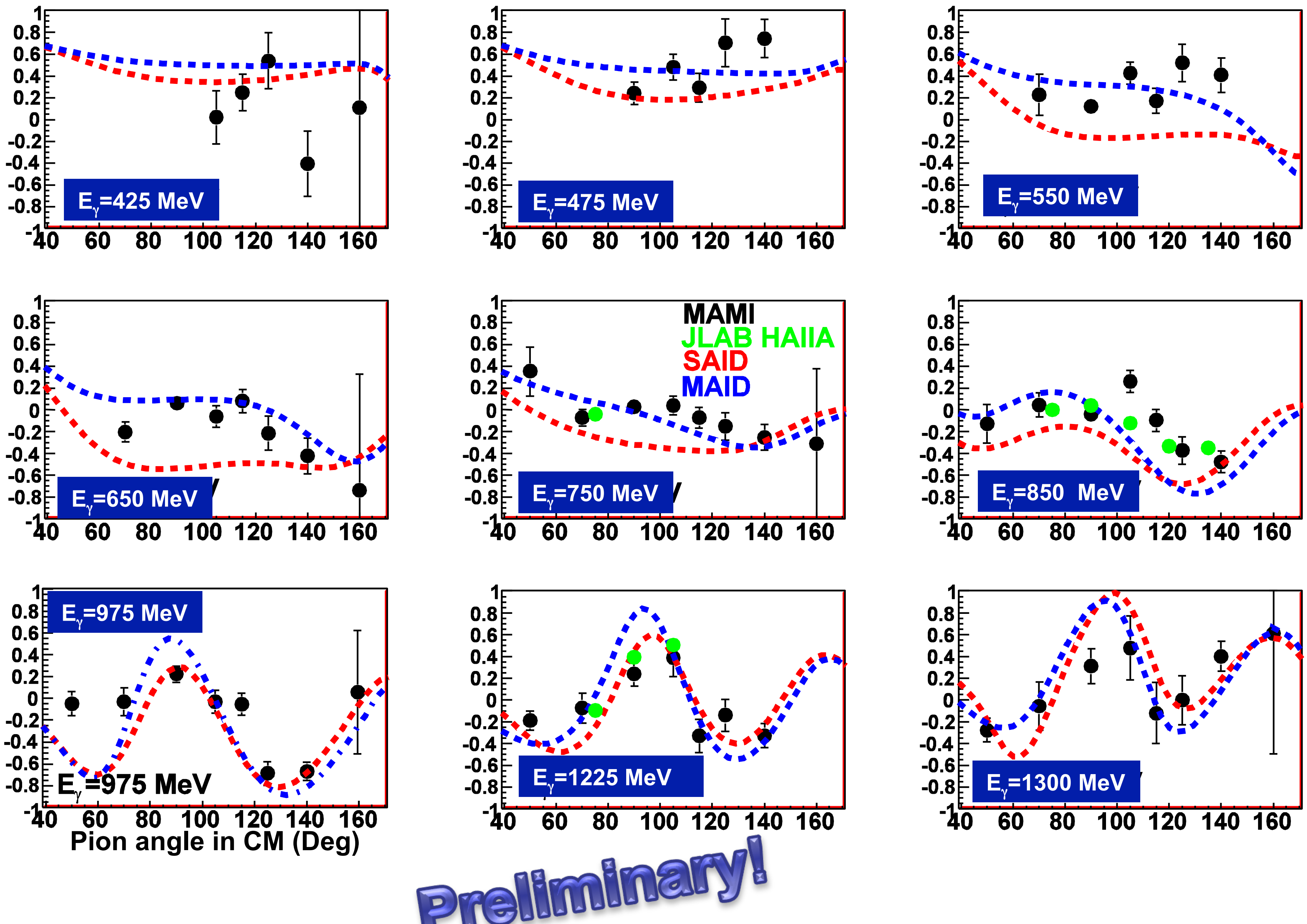




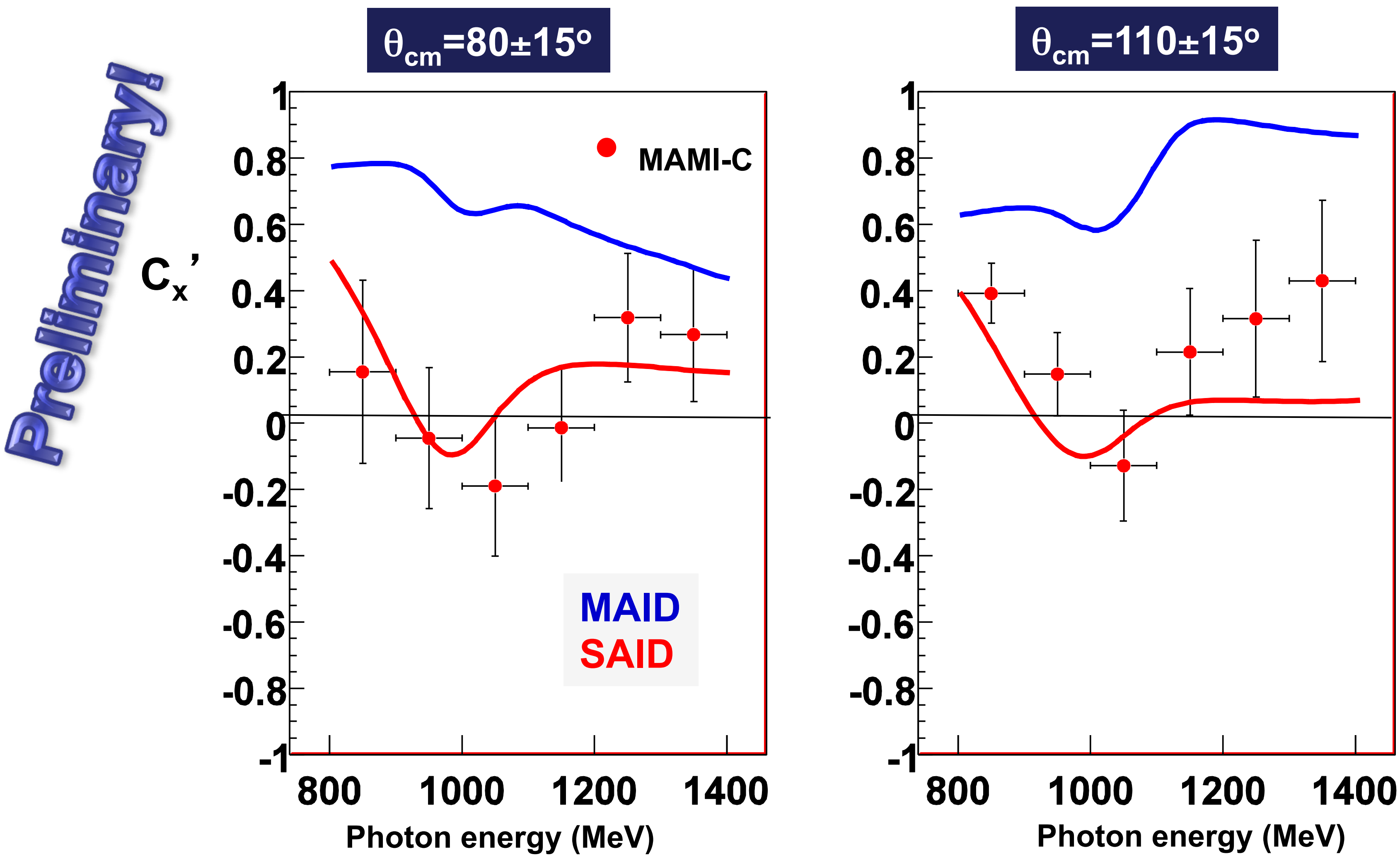


$$\frac{N^+(\phi'_p) - N^-(\phi'_p)}{N^+(\phi'_p) + N^-(\phi'_p)} = C_{x'} P_\gamma^{circ} A \sin\phi'_p$$

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

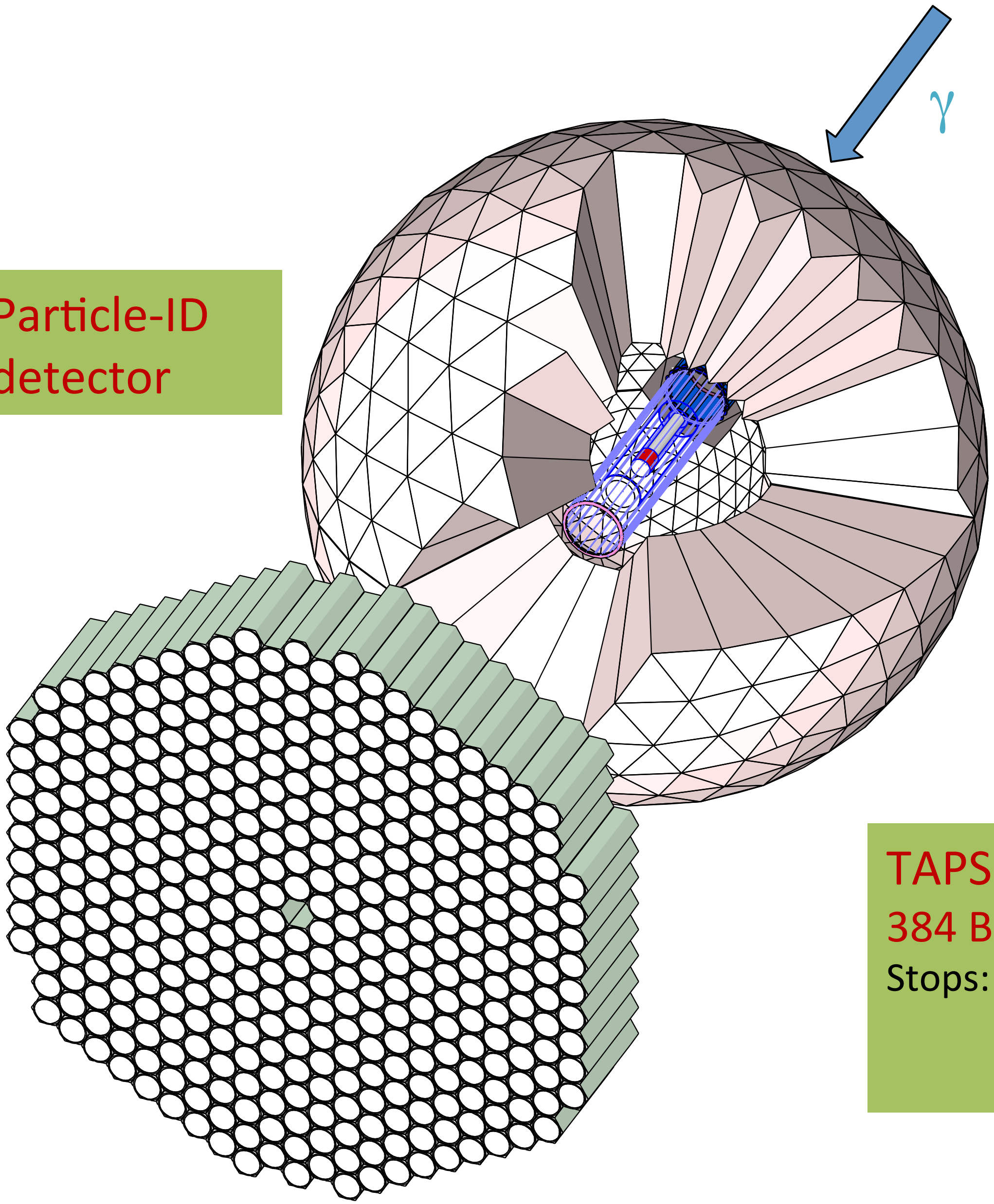


p(γ,η)p C_x'



- Next steps O_x, T, P also p(γ,2π) and p(γ,πη) channels

The Crystal Ball and TAPS

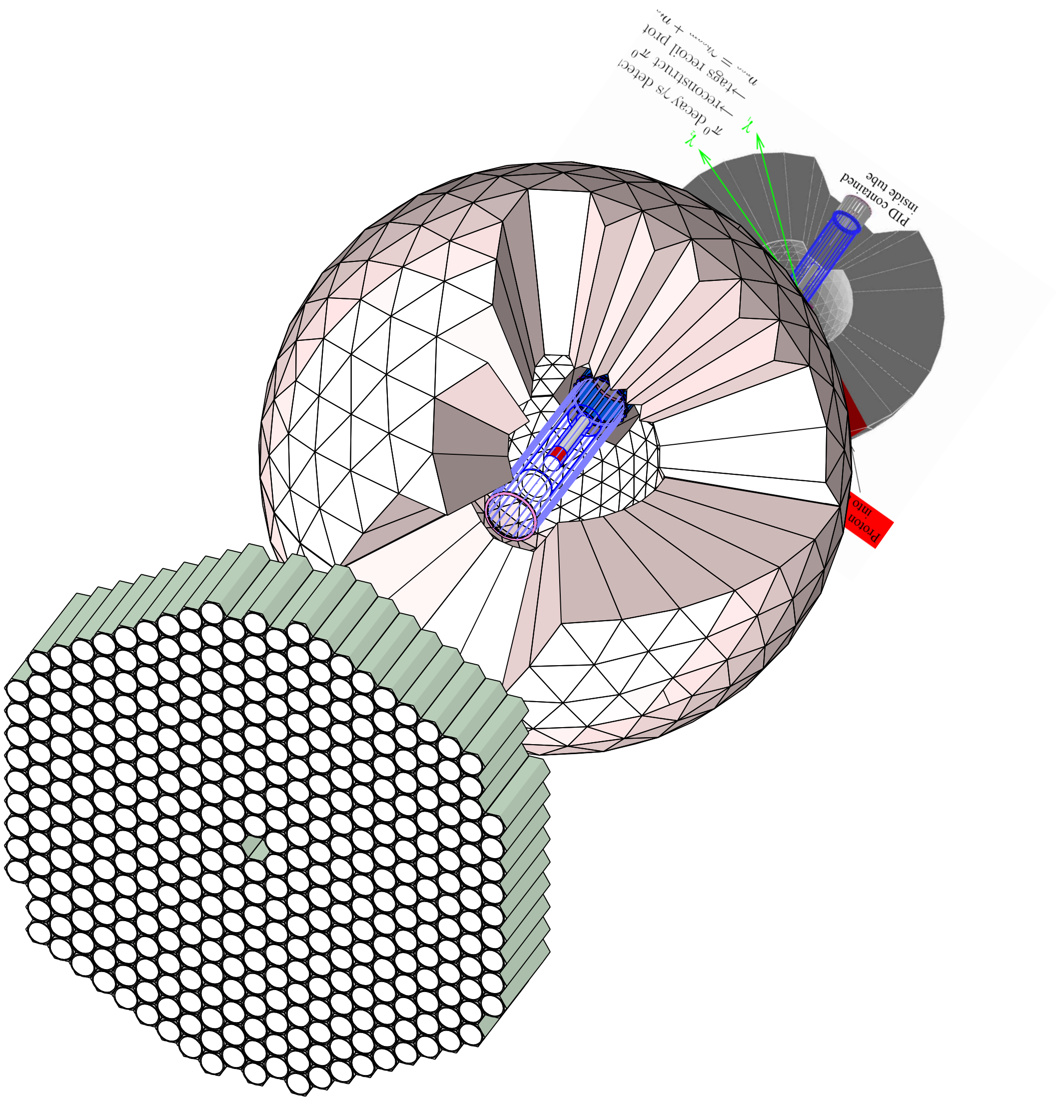


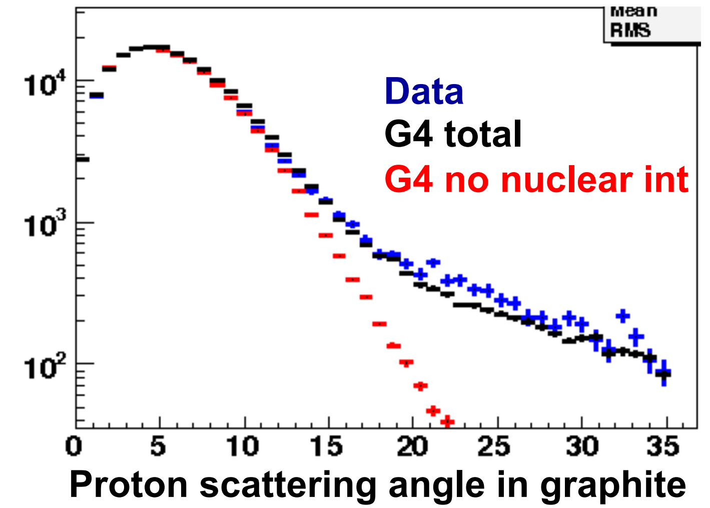
Particle-ID detector

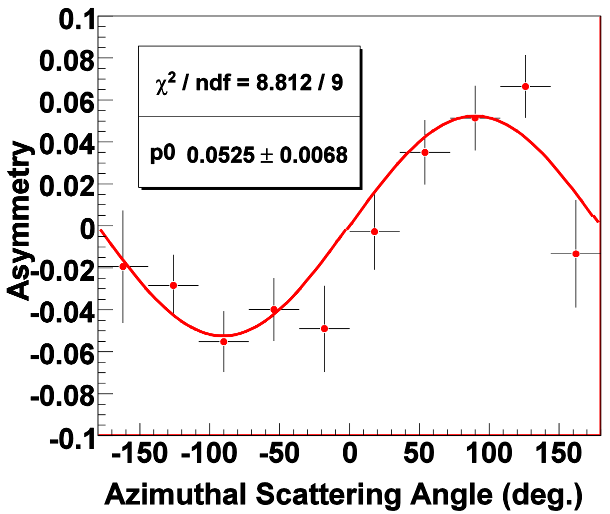
Crystal Ball
672 NaI Crystals
Stops: Protons ~ 420 MeV
Chrg. π ~ 240 MeV
Kaons ~ 341 MeV
Muons ~ 233 MeV

TAPS
384 BaF_2 crystals
Stops: Protons ~ 360 MeV
Chrg. π ~ 180 MeV
Kaons ~ 280 MeV

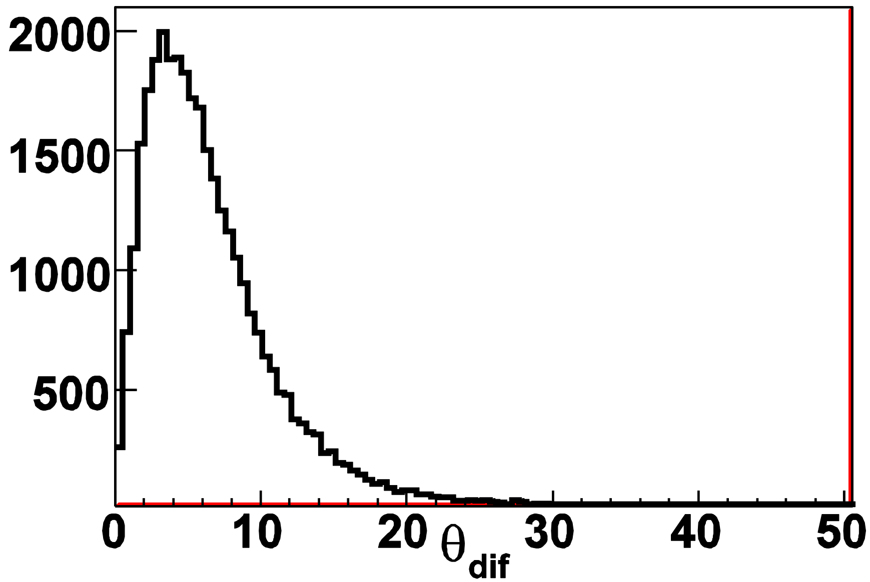
EDPOL1 with CB@MAMI

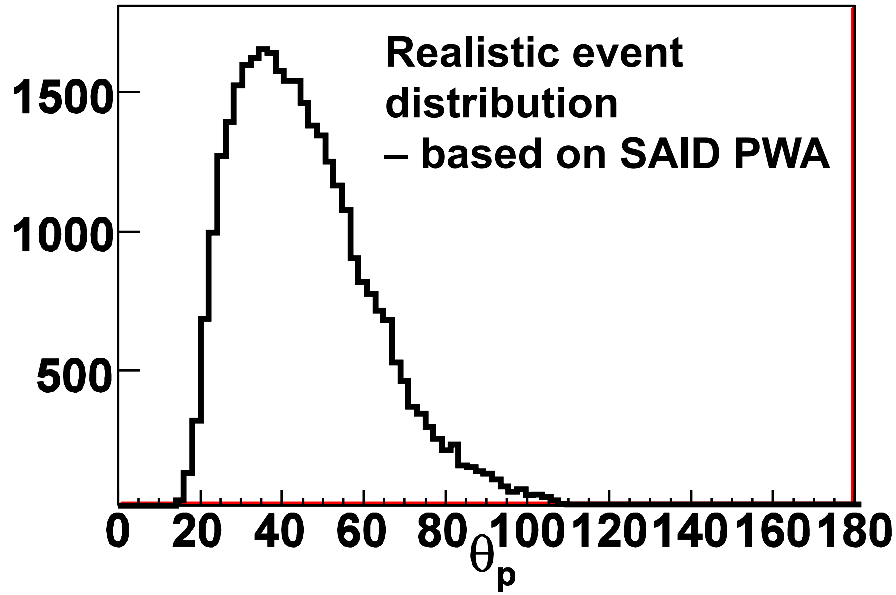


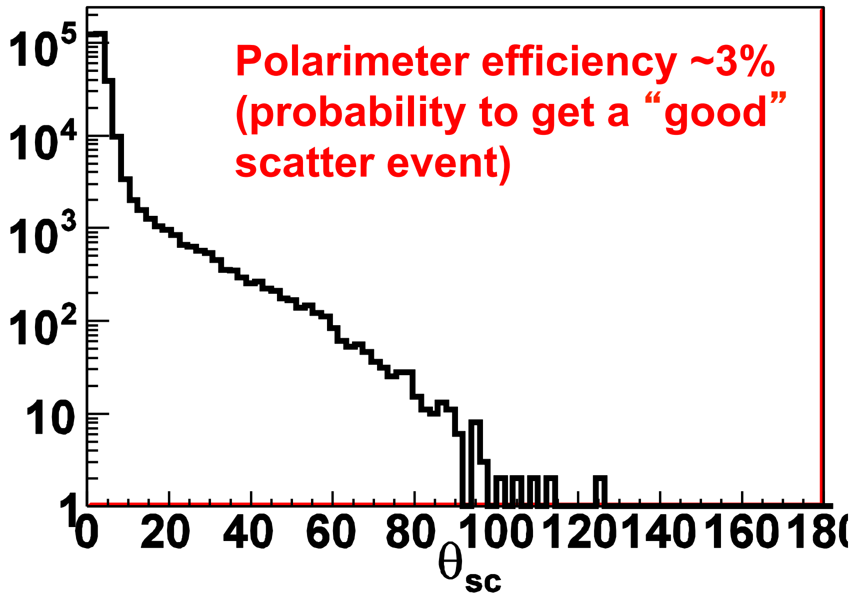


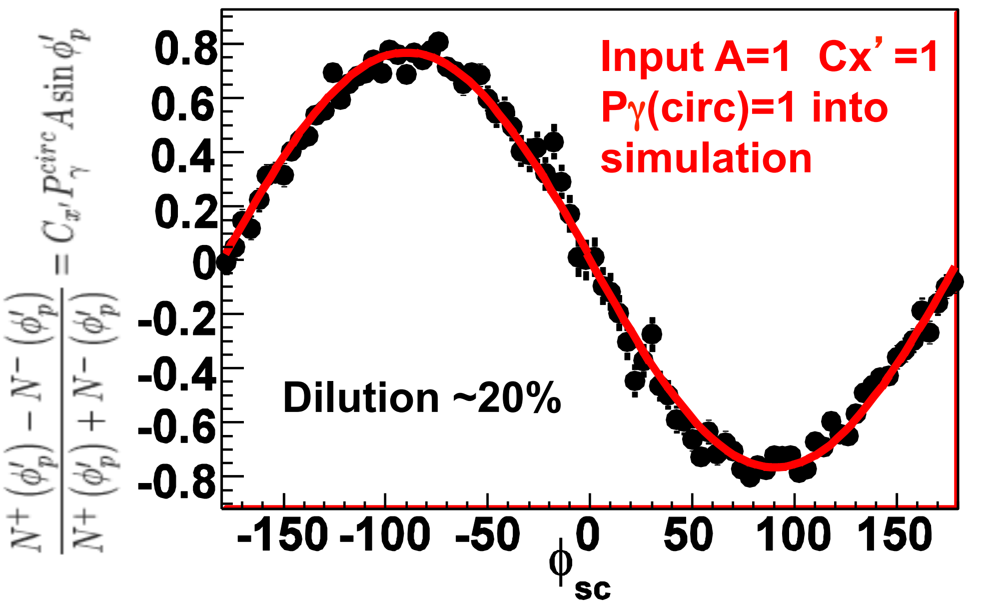


G4 – Stationary proton target: p(γ,π^0)p

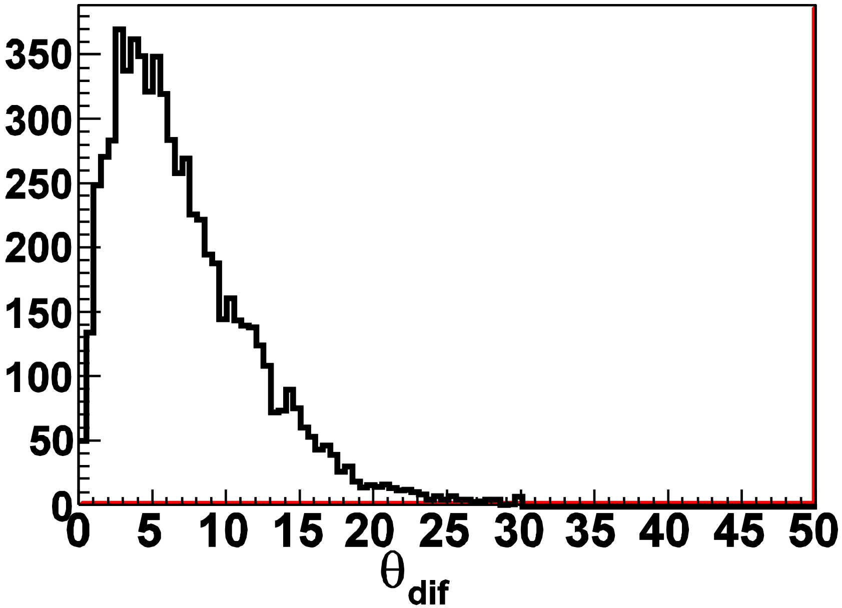


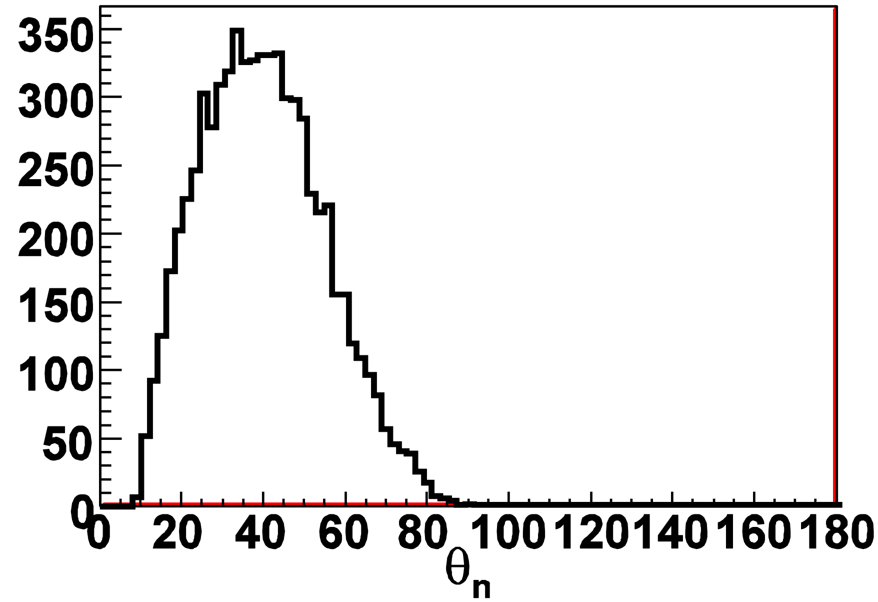


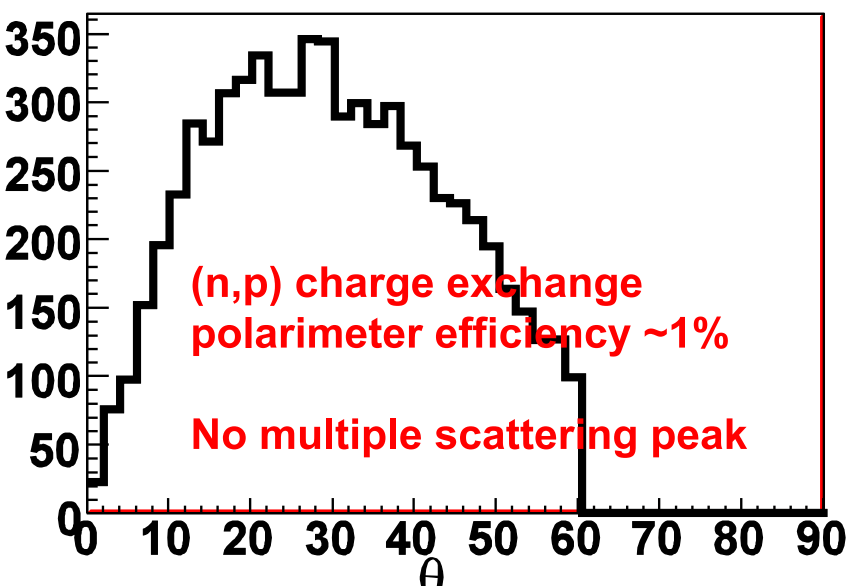


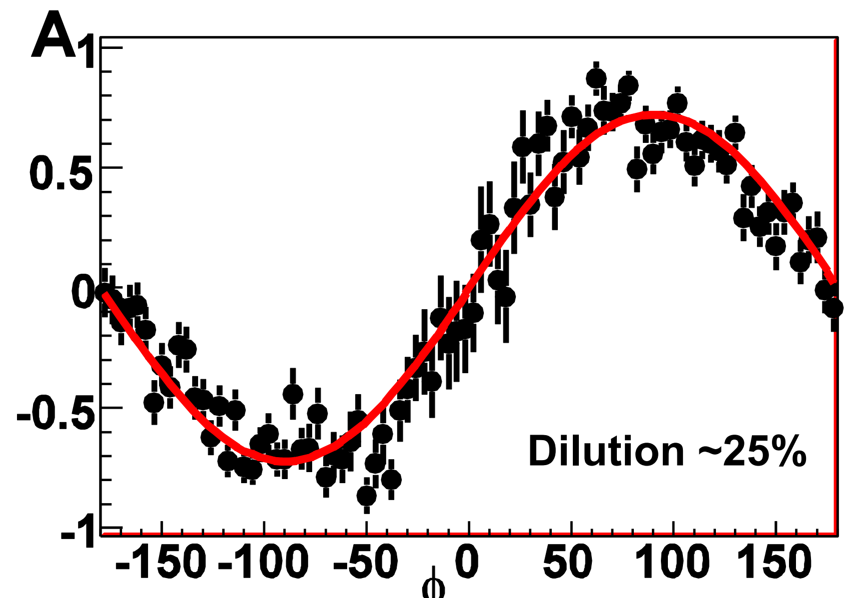


G4 – typical (n,p) charge exchange: $p(\gamma,\pi^+)n$









Count rate estimate – as per PAC proposal

γ-flux : $1.2 \times 10^5\ \gamma s^{-1} MeV^{-1}$
target nuclei 2.1×10^{23} nuclei/cm^2
Meson det. eff π^0~80% η~35%
DAQ live ~70%
Polarimeter efficiency prot 3%
neut 1% (G4)
$d\Omega_{avg}$ for $\theta_\pi \pm 10^0$ ~2 sr
Beamtime 950 hours (inc. TO)

Analyzing power = ~0.2 prot
~0.1 neut

$d\sigma/d\Omega_{avg}$ = 3 μb/sr for π
$d\sigma/d\Omega_{avg}$ = 0.7 μb/sr for η
$d\sigma/d\Omega_{avg}$ = 0.3 μb/sr for D(γ,pn)

No. of analyzable nucleon scatters = $d\sigma/d\Omega_{avg}$ x $d\Omega_{avg}$ x γ x nuclei x daq x pol eff x meson eff x beamtime

Channel	σ:O_x/T	σ: C^l_x	σ: P
p(γ,π^0)p	0.06	0.03	0.02
n(γ,η)n	------	0.2	0.14
p(γ,π^+)n	0.21	0.09	0.04
n(γ,π^0)n	0.21	0.09	0.04
p(γ,η)n	------	0.1	0.07
D(γ,**p**n)	0.27	0.08	0.04

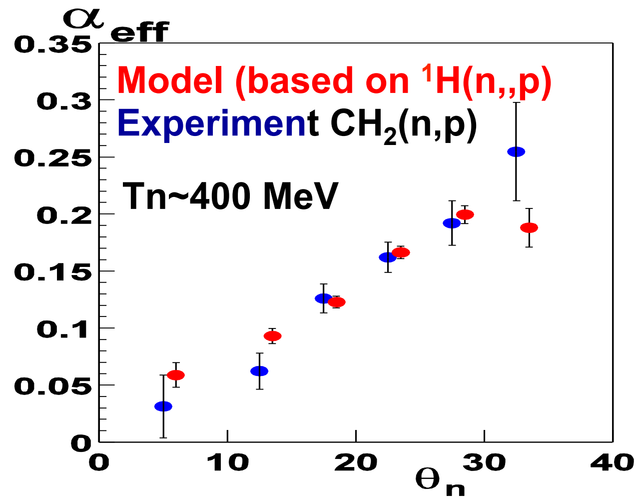
For 400 hours errors would be a factor 1.55 larger

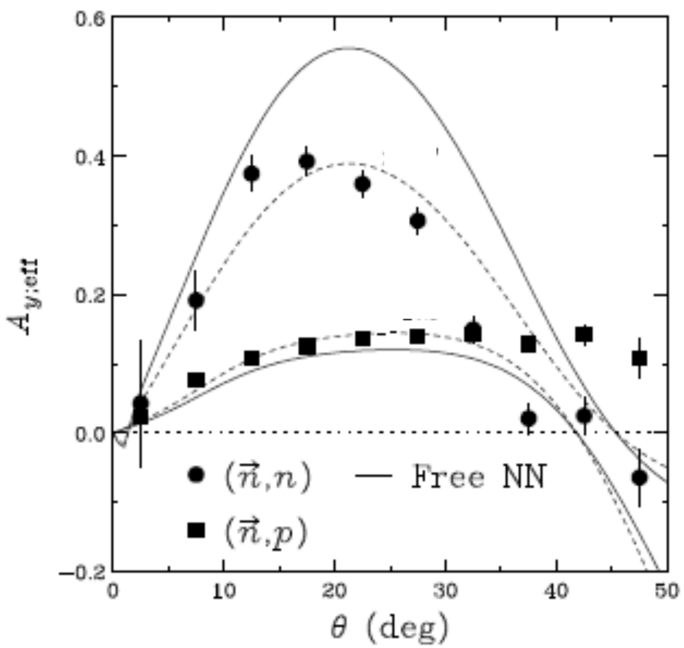
$\Delta C_x = \sqrt{(2/A^2N)}$
$\Delta O_x = 2/\sqrt{(A^2N)}$

$E\gamma$ bin ± 25 MeV
$\theta_{\pi/N}$ bin ± 10^o

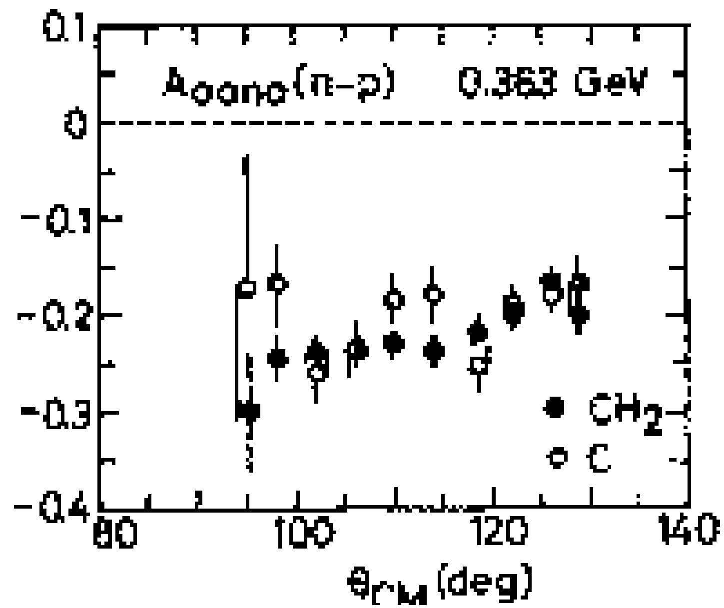
Analysing powers for $^{12}C(n,p)$ scattering

- Previous polarimeters (e.g. Yerevan) use $^{1}H(n,p)$ analysing powers for $^{12}C(n,p)$.
- Supported by recent RCNP measurements, older Saclay data, A1 at MAMI

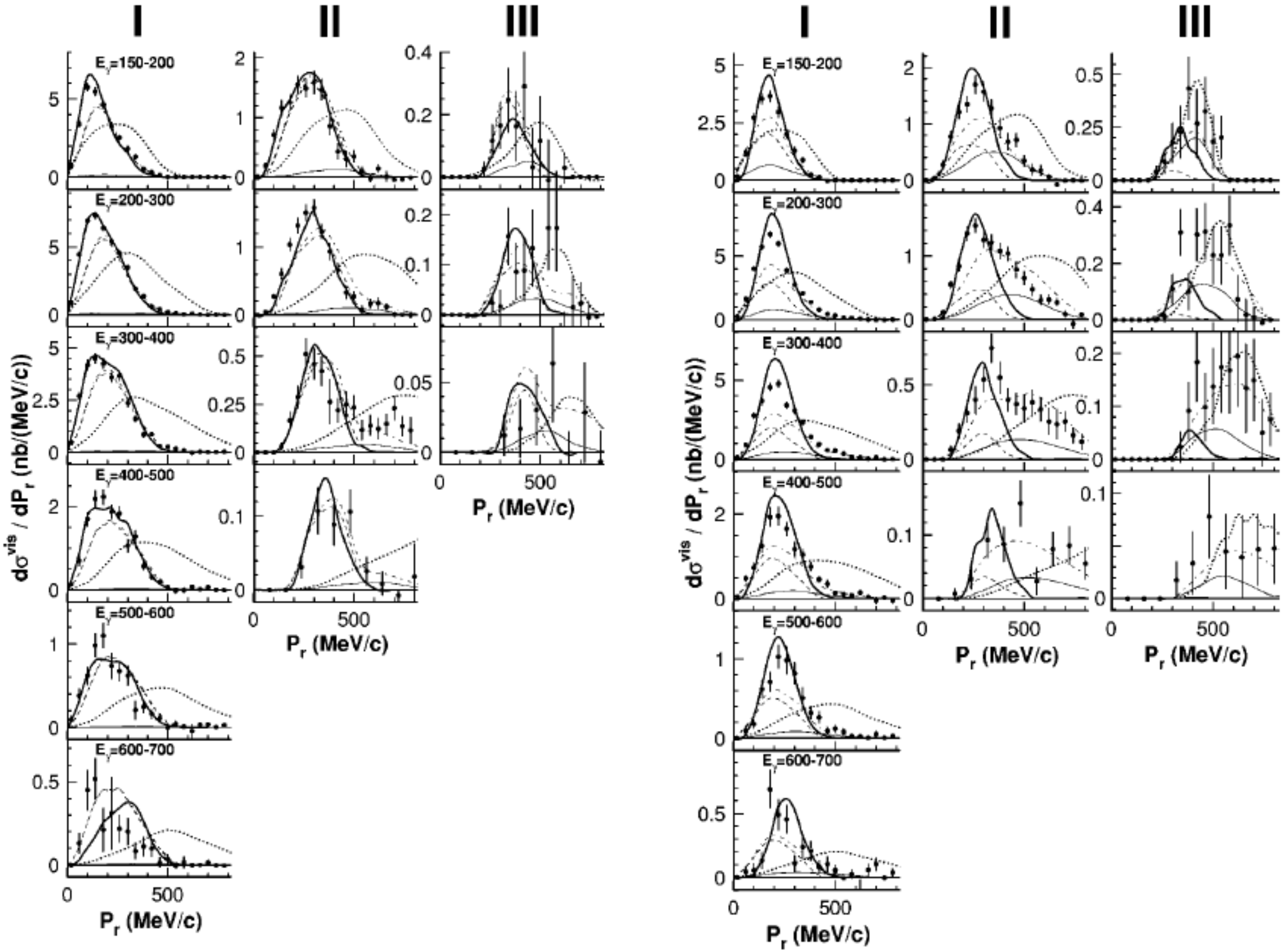




Wakasa et. al. NIM A547 (2005) 269
NPOL3 at RCNP Cyclotron



Saclay measurements



I
II
III
E_γ=150-200
E_γ=200-300
E_γ=300-400
E_γ=400-500
E_γ=500-600
E_γ=600-700
$d\sigma^{vis} / dP_r$ (nb/(MeV/c))
P_r (MeV/c)