Coherent Bremsstrahlung and its Application in Photoninduced 2N Knockout Reactions *

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A2 collaboration Mainz

17.02.2000, Adelaide

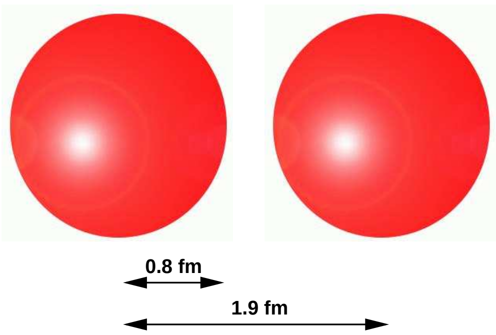
- Introduction
  - Shell Model and SRC
  - Experiments
- Results
  - Previous experiments
  - New approaches
- Coherent Bremsstrahlung
  - Introduction
  - Improvements
  - Predictions
- The ^{4}He($\vec{\gamma}$,2N) reaction
  - Cross section and asymmetries

*supported by DFG(Schwerpunkt/Graduiertenkolleg),DAAD,NATO

Introduction and Motivation

Independent particles ↔ correlations

Nuclear structure



Independent particle model (IPM) surprising success;explains ground state properties (spin, parity, excitation energies,...)

realistic potentials + HF ⇒ unbound nuclei

MeV	CDB	ArgV18	Nijm1	Bonn C	Reid
E_{HF}	4.64	30.34	12.08	29.56	176.20
E_{Corr}	-17.11	-15.85	-15.82	-14.40	-12.47
$V_{\pi HF}$	16.7	15.8	15.0	17.8	
$V_{\pi Corr}$	–2.30	-40.35	-28.98	-45.74	
T	36.23	47.07	39.26	40.55	49.04

Approaches:

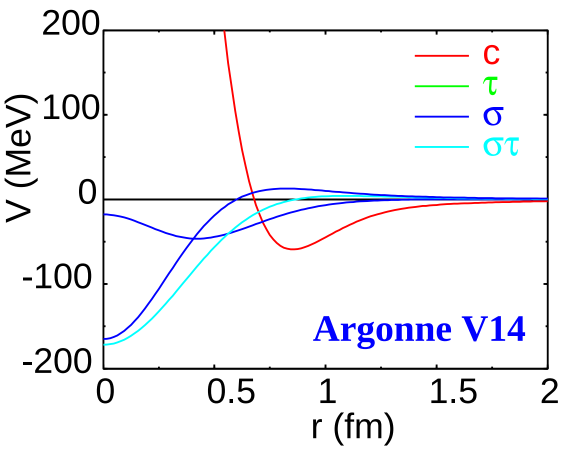
- effective 1p potentials + NN correlations
- direct solutions using realistic NN potentials
  (Brückner-Bethe-Goldstone eq../BHF, Fermi-Hypernetted chain, VMC, CBF, ...)

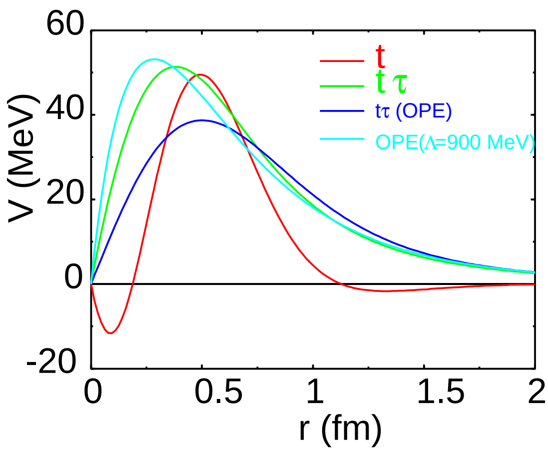
Realistic Description

Modern 2N potentials:
(fundamental invariance principles,2N scattering data)

$$V_{ij} = \sum_{p=1}^{14} v_p(r_{ij}) \hat{O}^p_{ij}$$

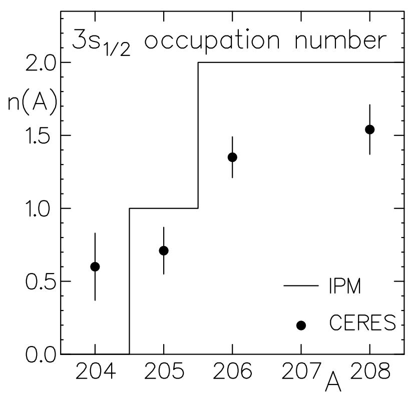
$$\hat{O}^p_{ij} : \mathbf{1},\ \tau_i\tau_j,\ \sigma_i\sigma_j,\ \sigma_i\sigma_j\cdot\tau_i\tau_j,\ S_{ij},\ S_{ij}\cdot\tau_i\tau_j,\ LS,\ LS\cdot\tau_i\tau_j,\ L^2,\ L^2\cdot\tau_i\tau_j,\ L^2\cdot\sigma_i\sigma_j,\ L^2\cdot\sigma_i\sigma_j\cdot\tau_i\tau_j,\ (LS)^2,\ (LS)^2\cdot\tau_i\tau_j$$

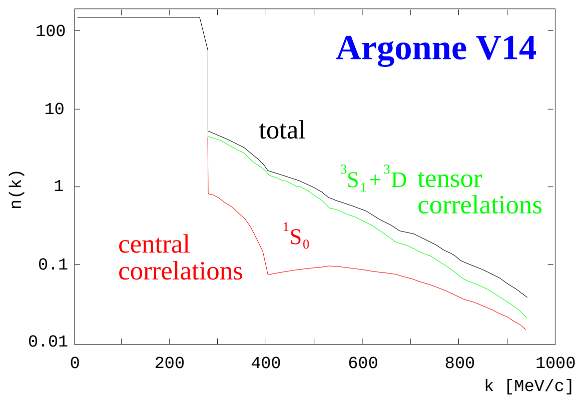




CERES (P. Grabmayr)
Prog.Part.Nucl.Phys **29** (92) 251

H. Müther
BHF calculation





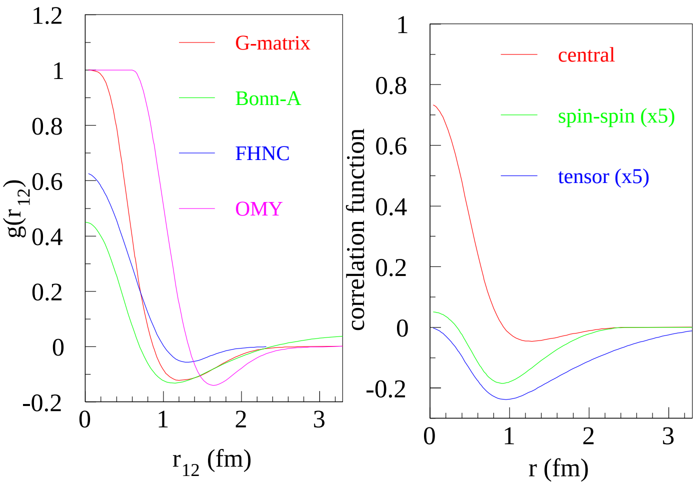
Correlations

Many Body treatment

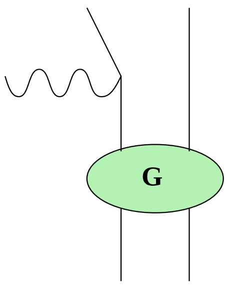
exp(S), G-Matrix

Correlations fcts of Jastrow type:

$\psi_{12} = \phi_1 \phi_2 f_c(r_{12})$



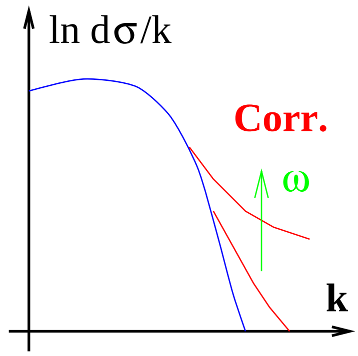
1N knockout



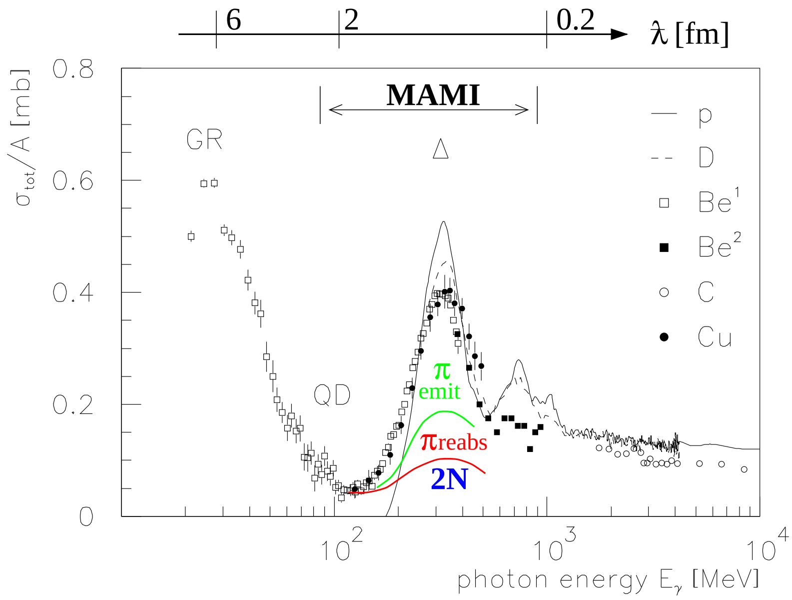
BHF calculations with corr. Ψ_{NN} + real. V_{NN} (Müther et al., PRC **51**(95)3040)

idea: high $\omega \rightarrow$ SRC $\nearrow$

but: $E_x >$ 2N treshold

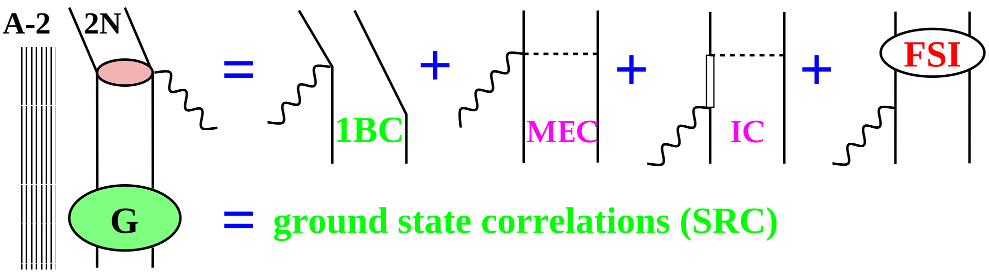


Total photo-absorption cross section



Experimental Approaches

2N knock-out



$(e, e'pp)$

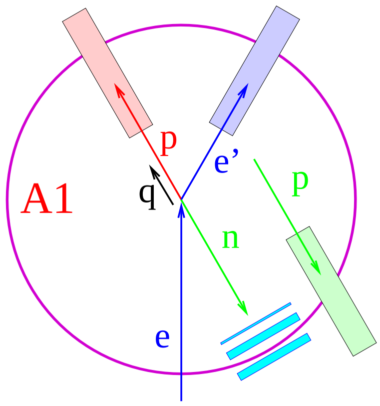
- superparallel kinematic: MEC=0, IC=0 für σ_L

$\rightarrow$ *central* SRC (XS very small)

$(e, e'pn)$

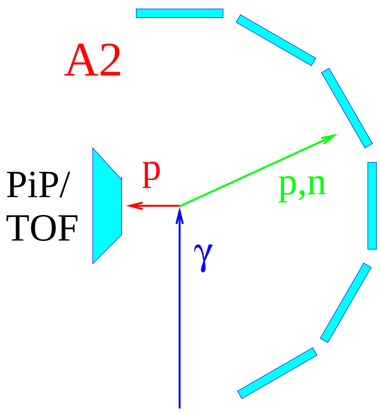
- superparal. kin.: IC=0 for σ_L

$\rightarrow$ $+$ *Tensor* correlations (MEC)



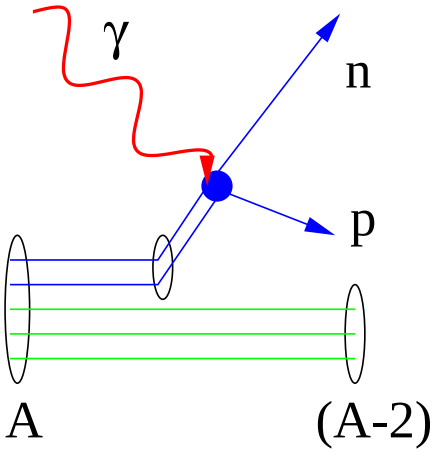
(γ, pp),(γ, pn)

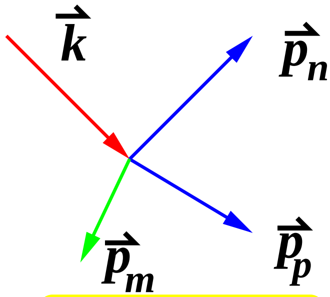
- Coincidence measurement (large angle- and E_γ acceptance)
- Real (transversal) photons sensitive to *tensor* correlations
- MEC/IC separable via kinematics and isospin (D. Knödler Diss., M. Heim)



Kinematics and Observables

kinematics of the (γ,np) reaction





PWIA:

$\vec{p}_m = - \vec{p}_{(qp)}$

$$\vec{p}_m = \vec{k} - \vec{p}_p - \vec{p}_n \qquad - \quad \vec{p}^{\,pair}_{Fermi}$$

$$E_m = E_\gamma - T_p - T_n - T_R \qquad - \quad E_x \text{ in (A-2)}$$

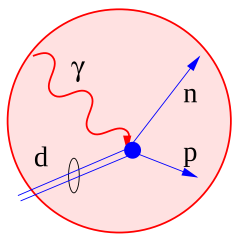
$$\vec{p}_{rel} = (\vec{p}_p - \vec{p}_n)/2 \qquad - \quad \text{rel. motion}$$

factorised 2N-model by K. Gottfried (1958)

$$d\sigma = (2\pi)^{-4}\, F(p_m) \cdot S_{fi}(p_{rel})\, \delta(E_f\text{-}E_i) d^3p_n\, d^3p_p$$

2h-spectral-fct.
global properties

$\Psi^\star \Psi_{HO} \cdot \sigma(\gamma D)$

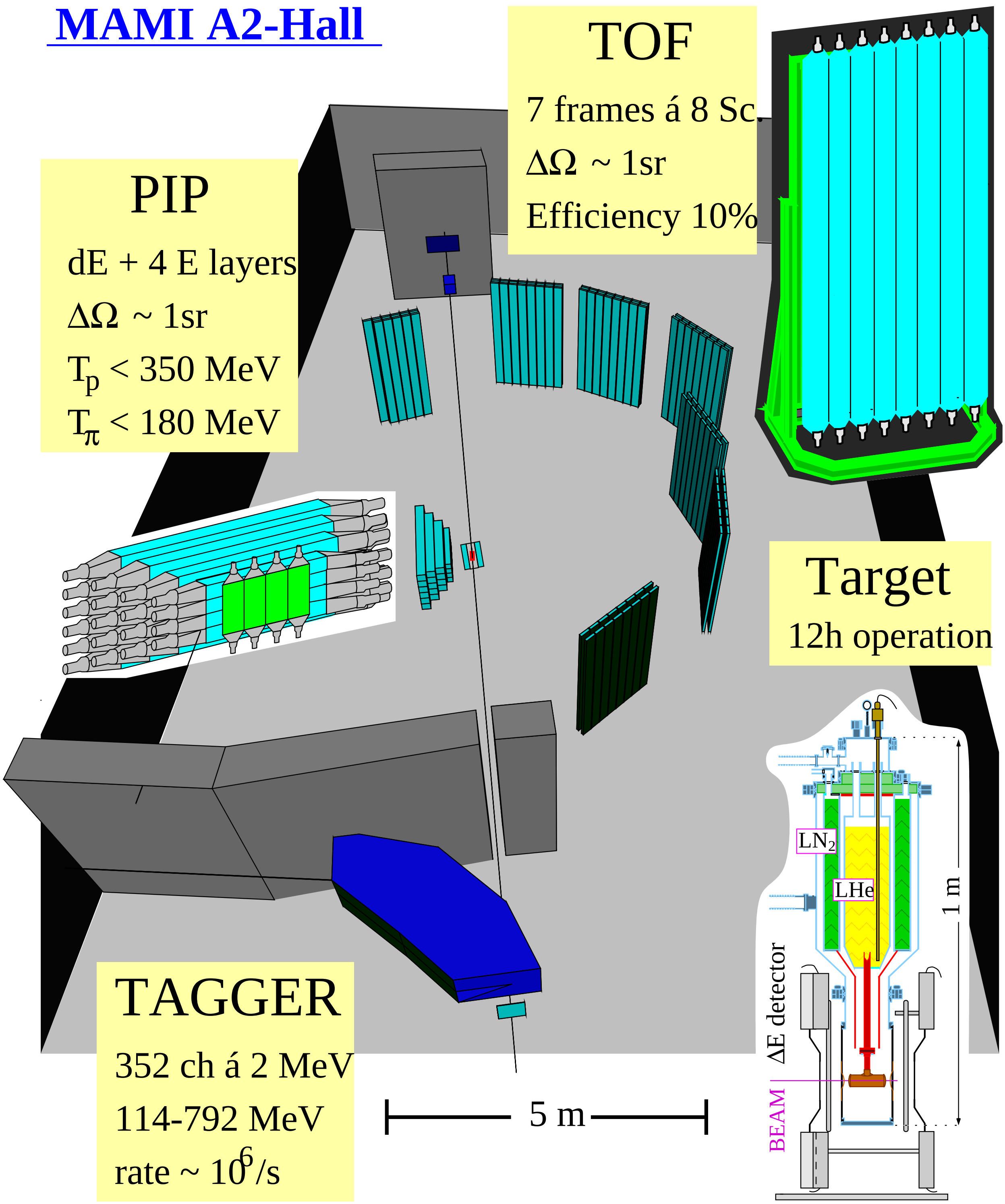


dynamics

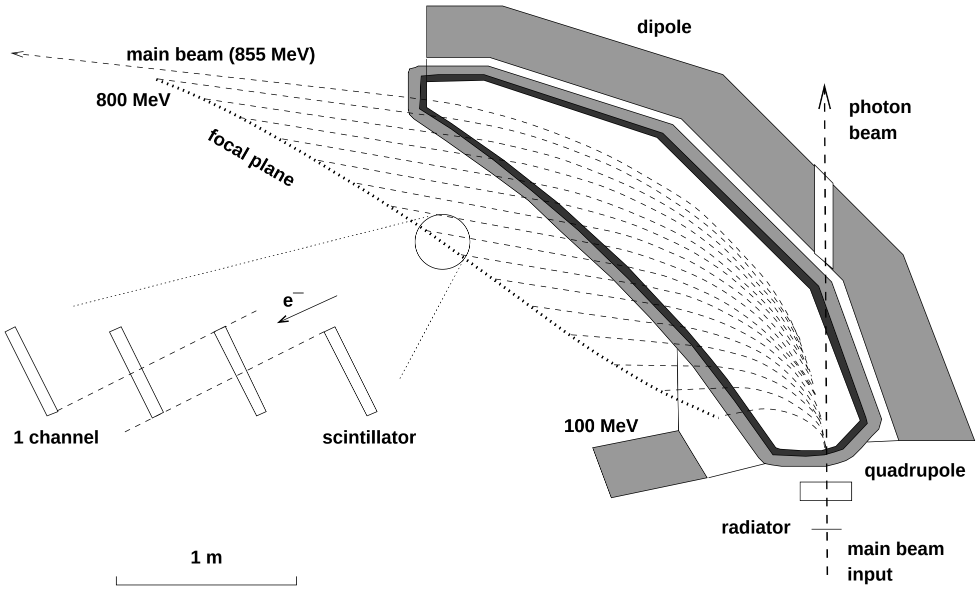
f(E_γ-E_m)

correlations

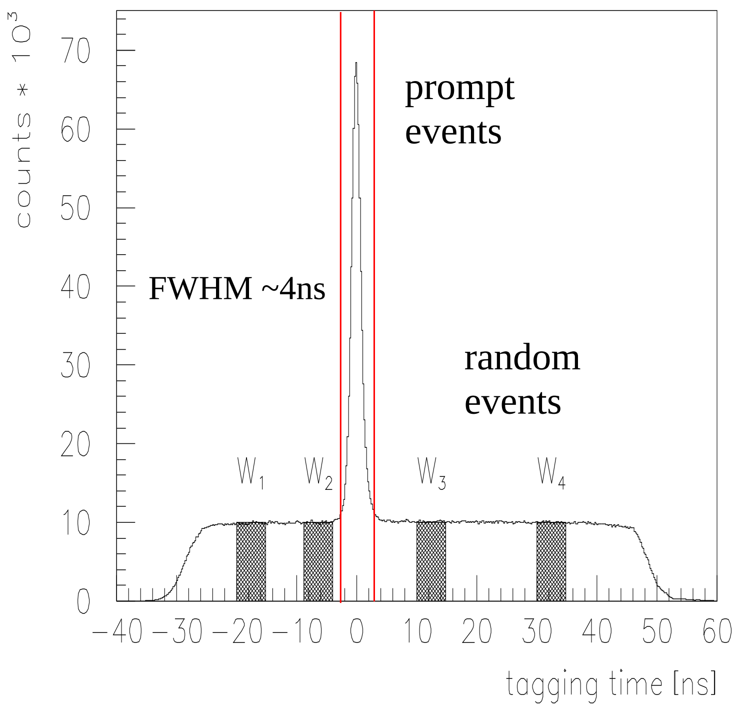
Experimental Setup



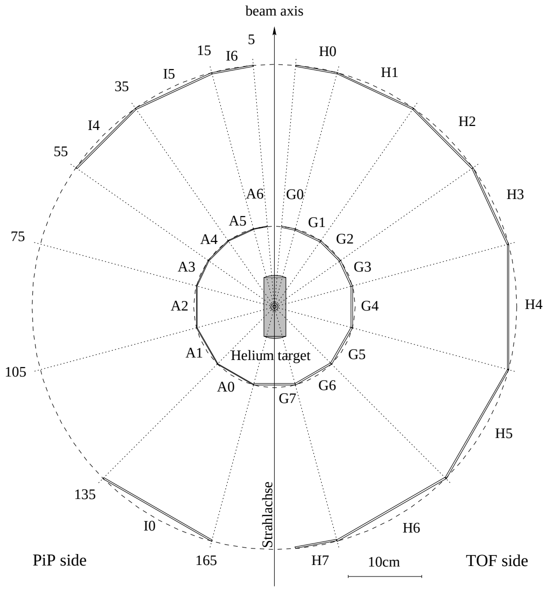
Tagger



Background subtraction



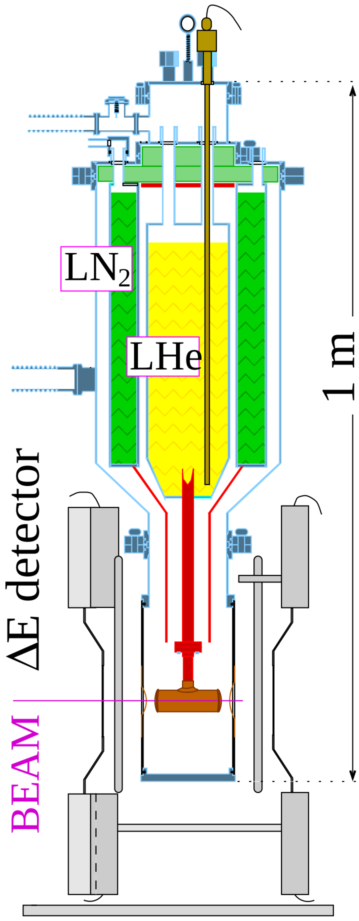
Startdetector and Target



Start- and
Veto detector

Defines
reaction time

Particle-
discrimination



Targt requirements

high ^{4}He density

little perturbing material in beam
(windows: $100\mu m$ kapton)

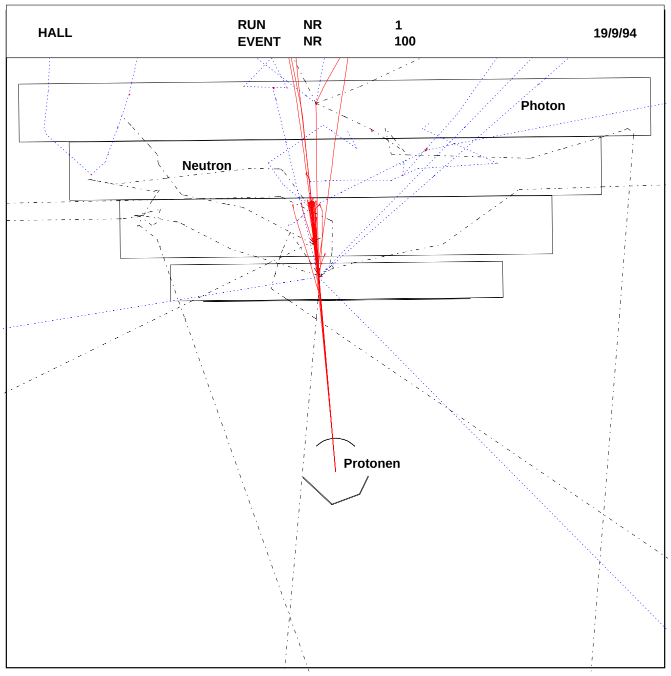
long life times (12h)
(large He reservoir, LN_2 shield)

geometric limitations due to start
detector

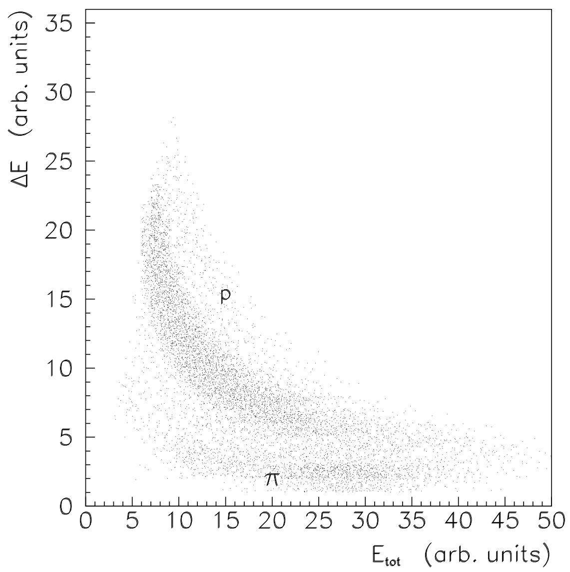
Calibration

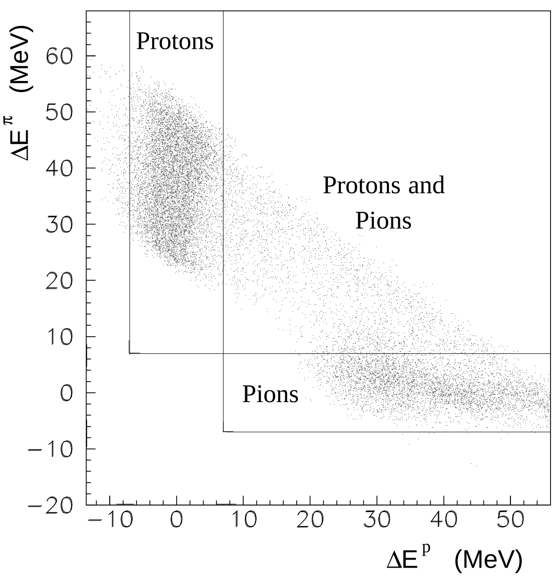
Muons
CD_2

Geant simulation
for detector efficency and
particle identification

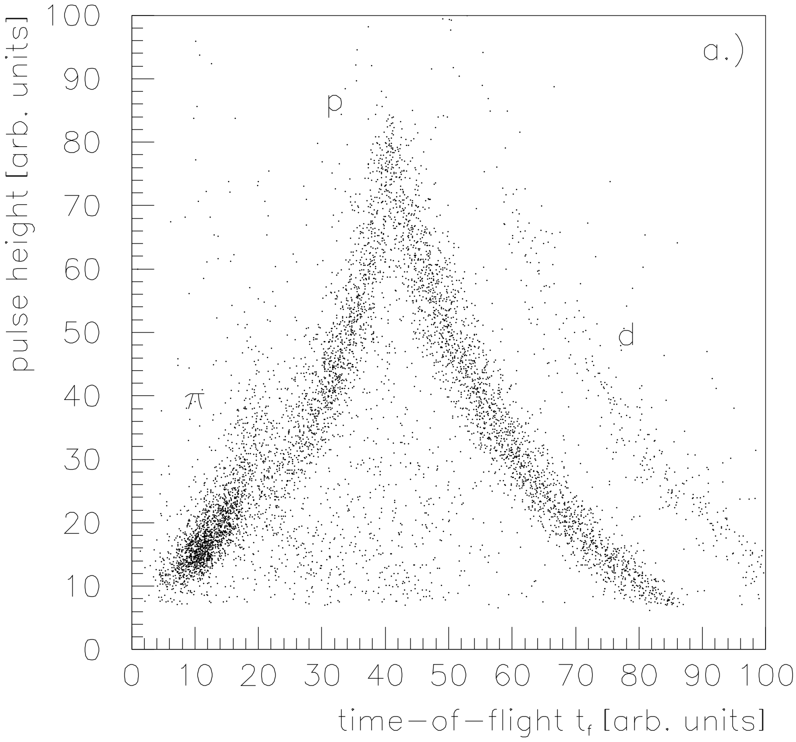


Particle identification with ΔE-E and Range Method





TOF



Particle-identification

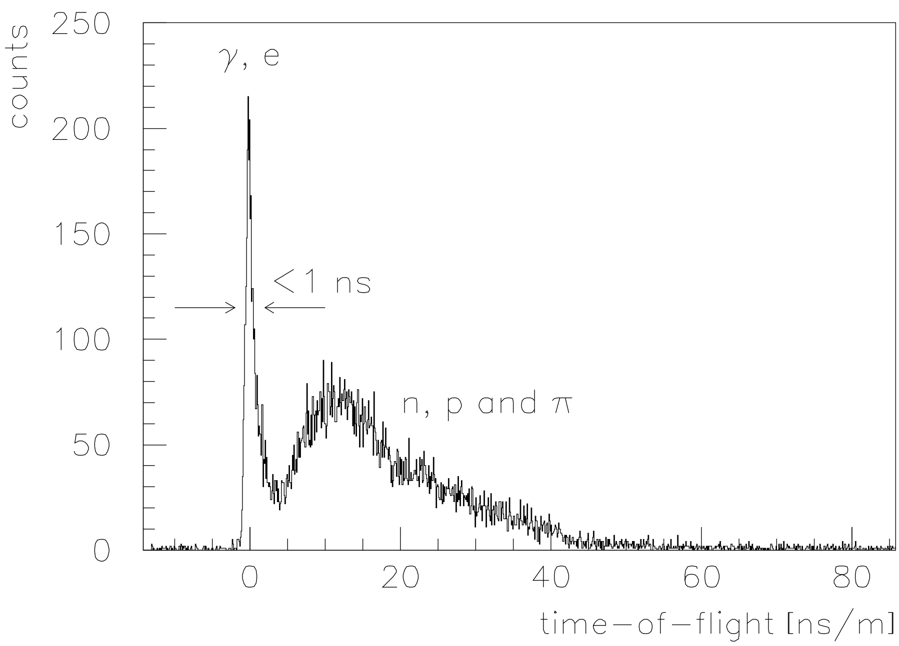
Charged particles: ΔE-E

Uncharged: Veto det.

Energy

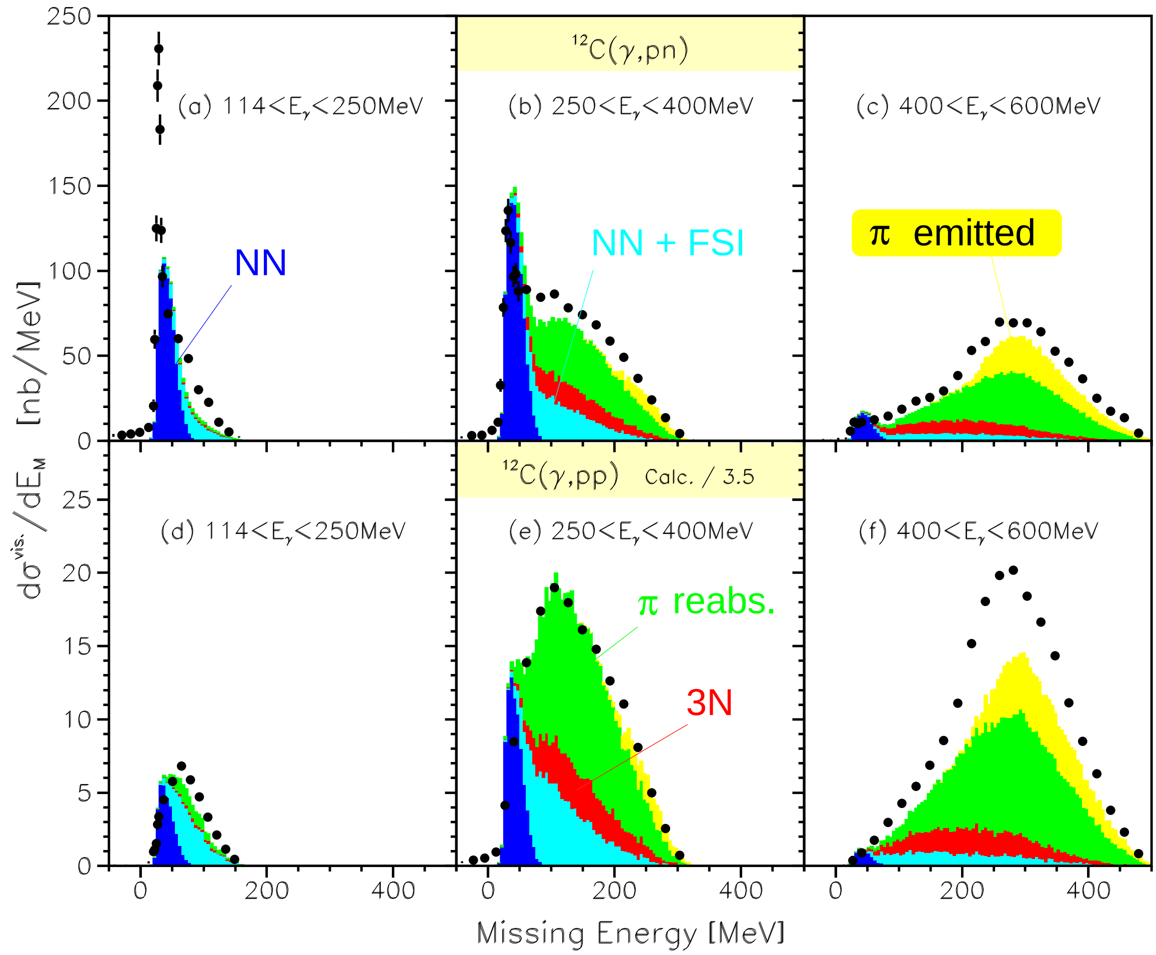
from TOF:

Flight path corrected flight time (all ToF detectors)



PiP TOF

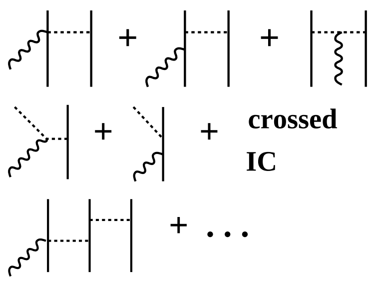
Reaction Mechanisms: ^{12}C



2N absorption (+ FSI)

QFπ production (emit/reabs)

3N absorption



$\underline{E_{2m}}$ cut enhances direct 2N absorption

T. Lamparter et. al. ,Z. Phys. A **355** (96)
T. Hehl, Prog.Part.Nucl.Phys. **34** (95)

Ph.-self energy + LDA:

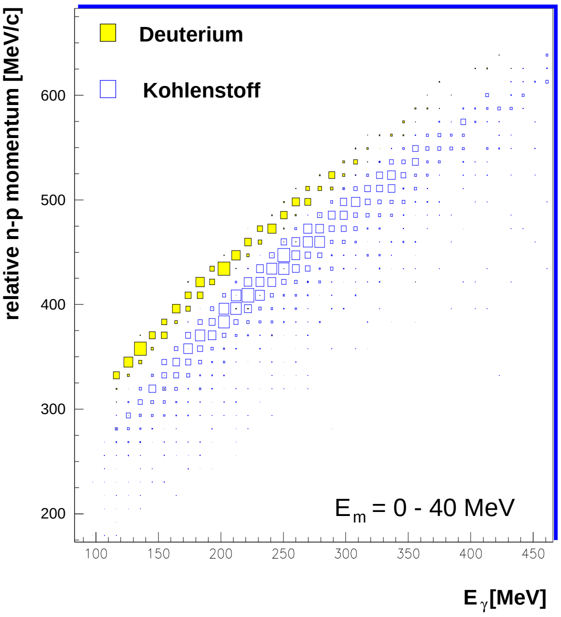
$$\sigma_{\rm tot} = -\frac{1}{k}\int d^3r\,\rho(r)\,{\rm Im}\Pi(k,\rho)$$

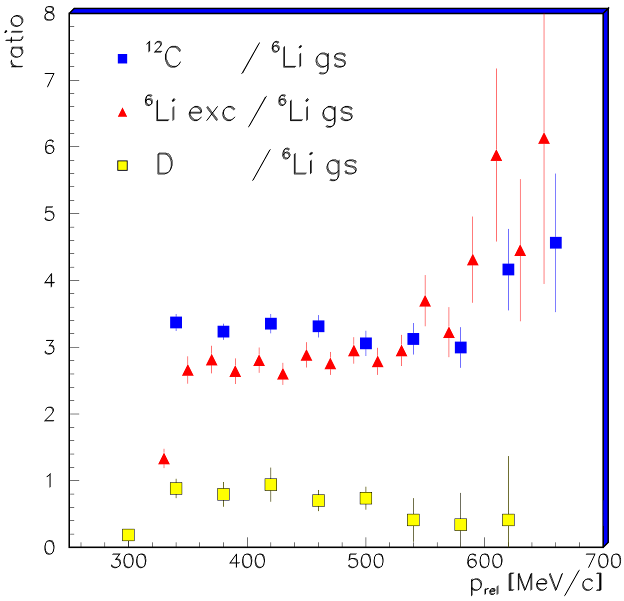
Carrasco,Oset NPA **536** (92) 445

Relativ Momentum Distribution

$p_{\text{rel}} = \frac{1}{2}\,|\vec{p}_p - \vec{p}_n|$

Q-value corrected





MC simulation

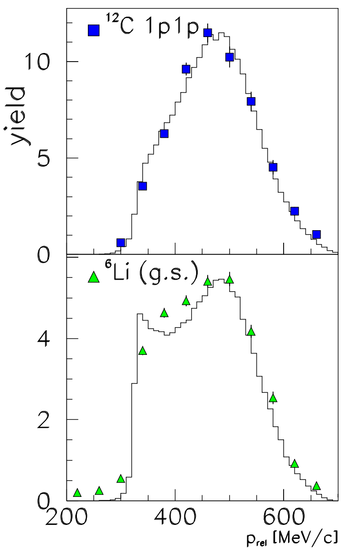
exp. σ_D
(Jenkins et al.)

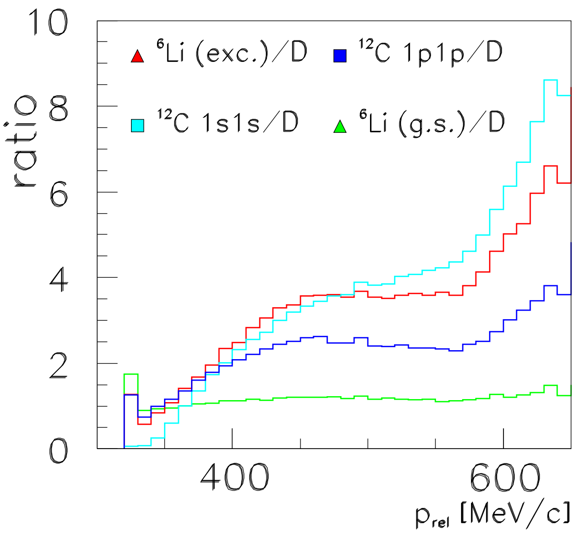
HO pair
momentum

acceptance

T. Hehl

DPG Göttingen





PiP TOF

^{12}C Pair Momentum Distribution

Pair momentum

Quasideuteron-Kinematic:

$$\vec{p}_m = \vec{k} - \vec{p}_p - \vec{p}_n = -\vec{P}$$

Quasideuteron model

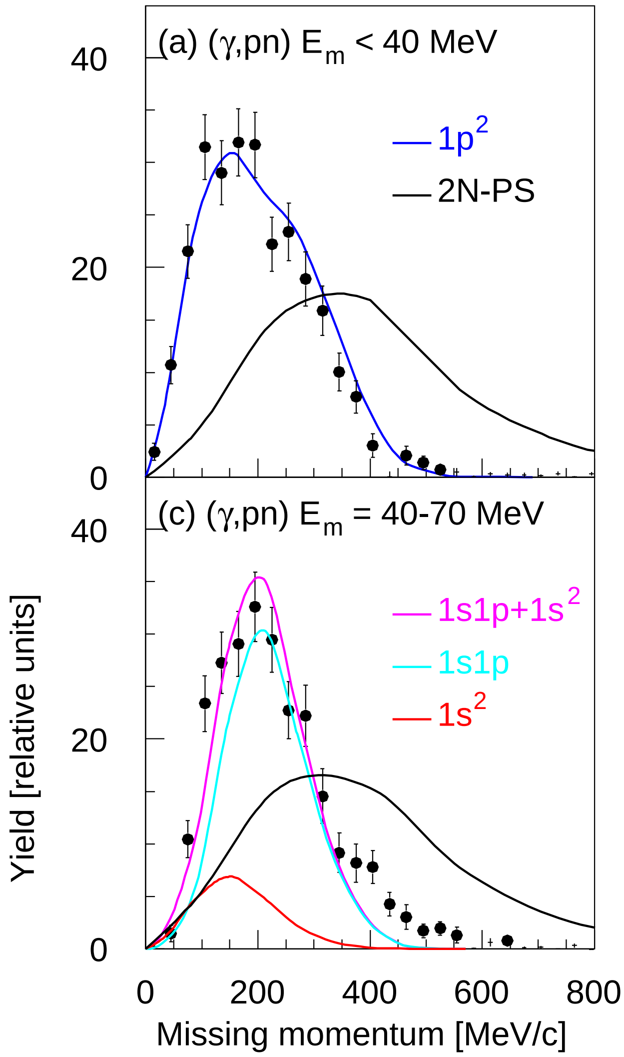
HO-wavefunction
for np-pair

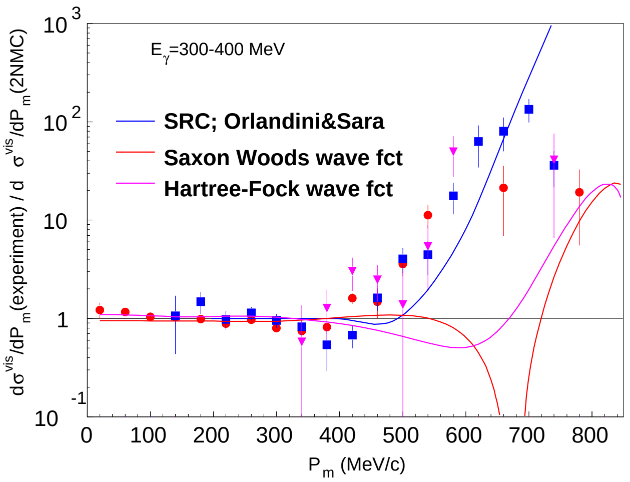
shell contrib.
adjusted

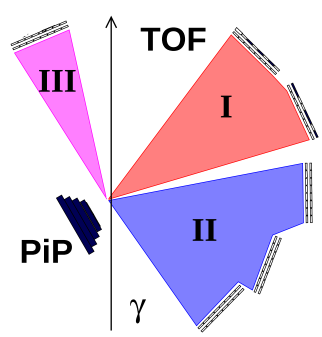
good description
without correlations

P. Harty et al.

Phys. Lett. **B380**(1996)247







New Approaches

High resolution ^{16}O$(\gamma^*, \mathrm{NN})^{14}$C/^{14}N

Study of individual reaction mechanisms in separat resolved final states (E_m resol.: 1.5 MeV) $\longrightarrow$ beam time A2: april 2000

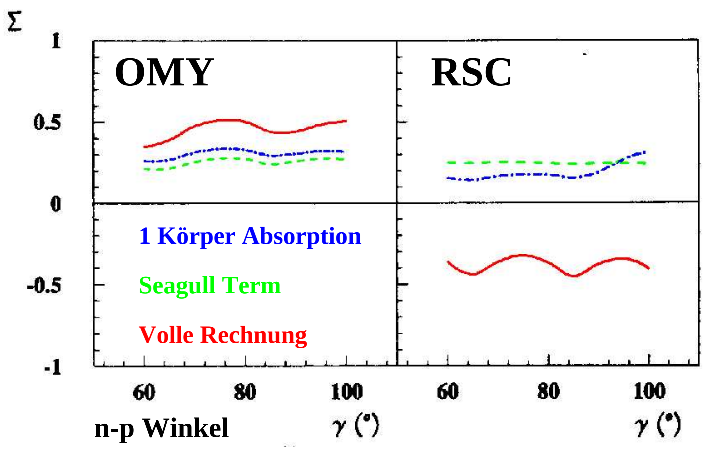
^{4}He as Target

- simple structure $\longrightarrow$ less shell mixing
- high density, few nucleons $\longrightarrow$ more SRC, less FSI
- meeting ground of mikroscopic calcuations and phenomenological models

Photon asymmetry

New observable Σ (photon asymmetry) is sensitive on SRC

$$\sigma_{\|,\perp} = \sigma_0(1 \pm P_\gamma \Sigma), \quad \Sigma = \frac{1}{P_\gamma}\frac{\sigma_\| - \sigma_\perp}{\sigma_\| + \sigma_\perp} \quad \text{für } (\vec{\epsilon} \,\|, \perp\, n'p')$$



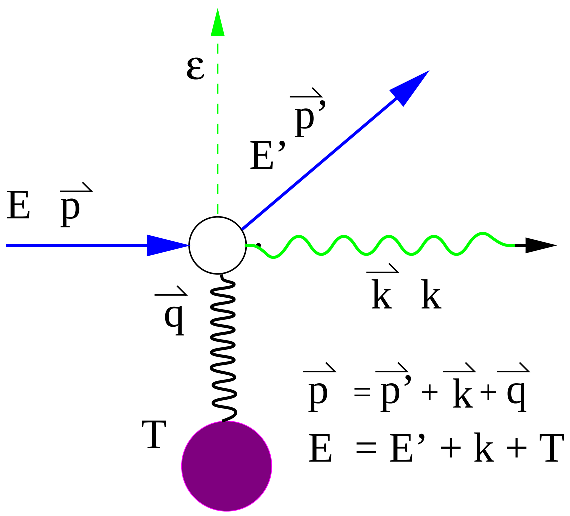
^{16}O$(\gamma, \mathrm{pn})^{14}$N

Boffi et. al.
Nucl. Phys. A
564 (1993) 473

Ryckebusch: Phys. Lett. B383 (96)

Boato, Giannini: J. Phys. G15 (89)

Polarized Bremsstrahlung



Kinematics:

$\delta = q_l^{\min}(E_\gamma) < q < 2\delta$

$q_t / q_l \approx 10^3 \rightarrow$ pancake

Cross section:

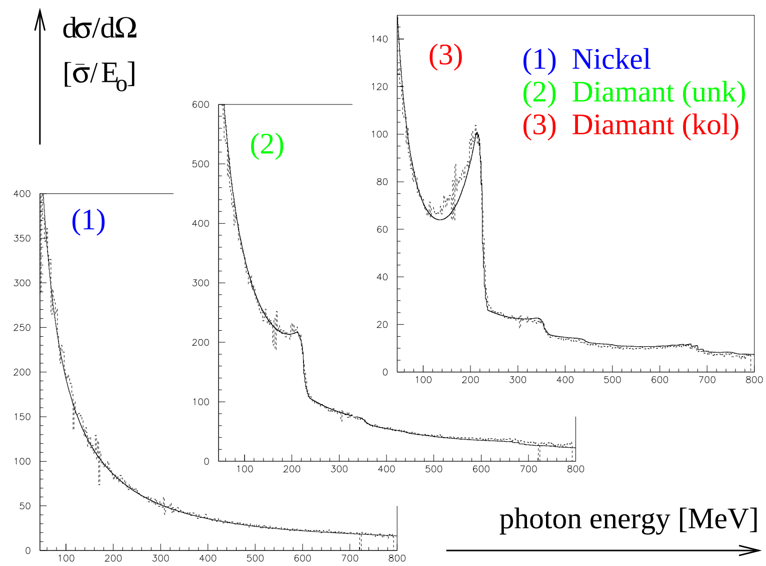
$\sigma \sim \frac{1}{k} \cos^2 \phi$

main contribution:

$\vec{E} \parallel \vec{\epsilon} \in (\vec{p}, \vec{q}\,)$ plane

Lattice radiator (diamond) and Bragg condition $\vec{q} = \vec{g}$

$\rightsquigarrow$ additional coherent (polarized) intensity: $I = \frac{k}{\bar{\sigma}} \frac{d\sigma}{dk}$



Collimation:

incoherent:

gets reduced

coherent:

not affected

in $x_c < x < x_d$

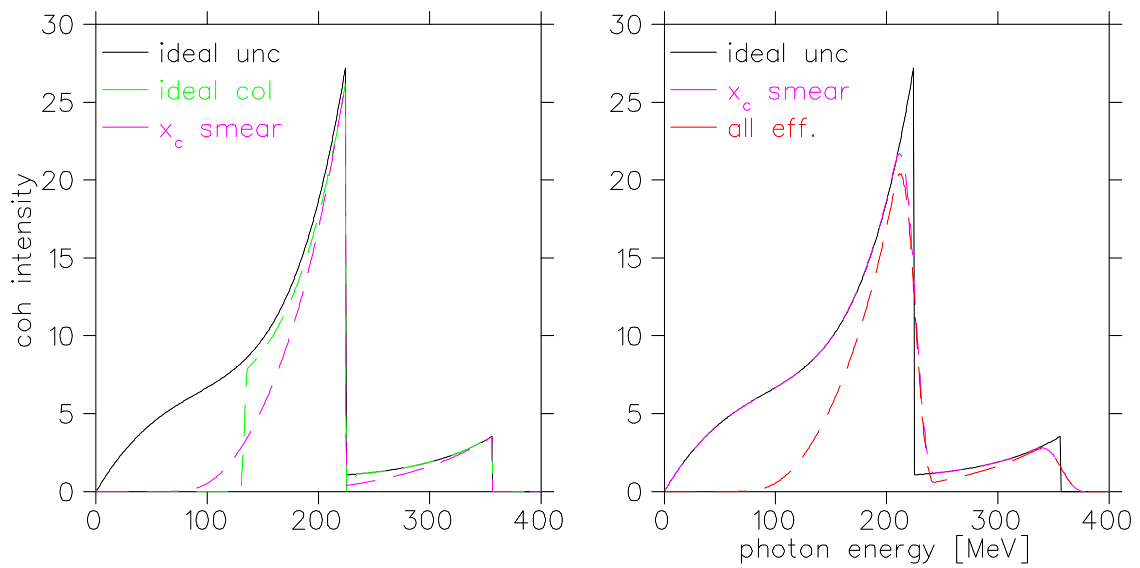
$x_d, x_c \leftarrow \vartheta_c, \vec{g}$

Experimental Effects

source	$\rightarrow$	effect	influence
temperature	$\rightarrow$	Debye Waller factor	$I_{\text{coh}}/I_{\text{inc}}$
BS : beam spot size	$\rightarrow$	fuzzycollimator	x_c
BD: beam divergence	$\rightarrow$	+ variation of θ, α	x_d
MS : multiple scattering	$\rightarrow$	increases *BD*	x_d

$$I_{\text{exp}} = \int_{MS} ds \int_{BD} d^2 t_b \; w(\vec{t}_b) \otimes w(\vec{t}_m(s))$$

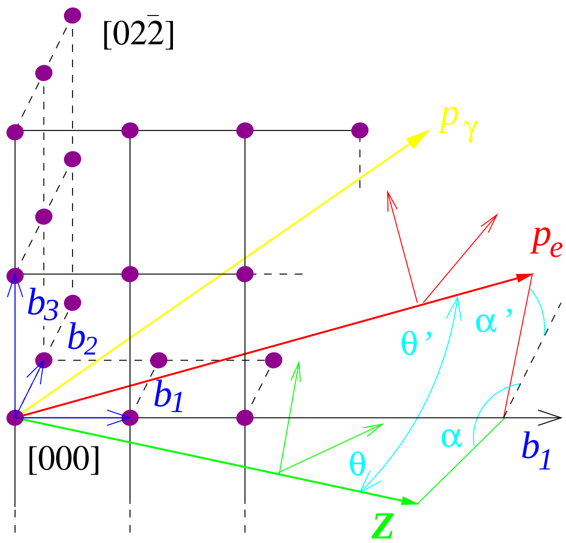
$$\times \int_{BS} d^2 r_e \; w(\vec{r}_e) \; I_{\text{coh}}(\theta_0, \alpha_0, \vec{t}_e)\Big|_{r_c > |\vec{r}_\gamma^{\,c}|}$$



Monte Carlo Simulation (MCB)

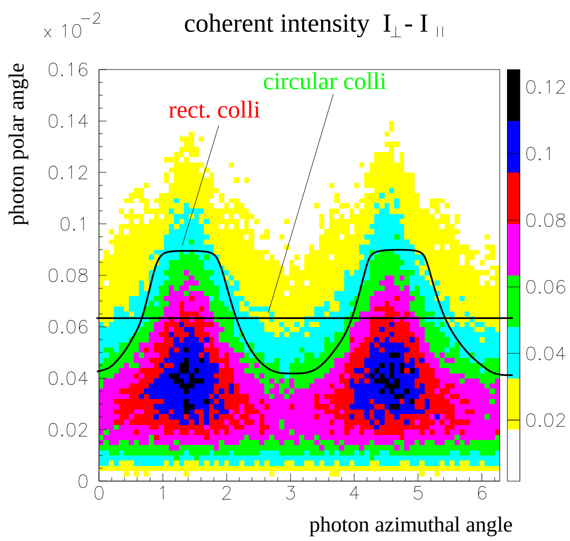
Parmeters:
ES (E_0), *BS* ($\vec{r}_e$), *BD*($\vec{t}_b$),
MS ($\vec{t}_m(s)$) distr.
radiator properties

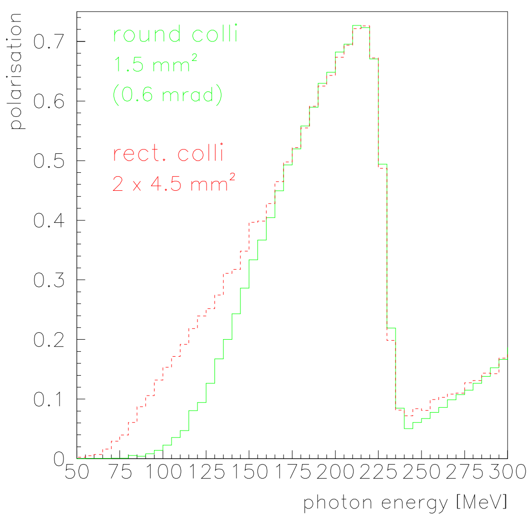
Brems process
$\theta_0, \alpha_0 \xrightarrow{\vec{p}_e} \theta_e, \alpha_e$
calc intensity $I^{\text{coh,inc}}$
photon $\longrightarrow$ lab sys
check collimation



$\longrightarrow$Advantage: 'precise', evaluation of each event

Rectangular collimator
same total collimated cross section (tagging efficiency)





PiP TOF

Approximative Analytical Calculation (ANB)

Approximations

- 2d transversal distributions $\longrightarrow$ spherical symmetrical
- mean multiple scattering distribution: $\bar{\sigma}_m$ (Moliére therory)
- 'total' electron divergence (ED): $\sigma_{ED}^2 = \bar{\sigma}_m^2 + \sigma_{BD}^2$

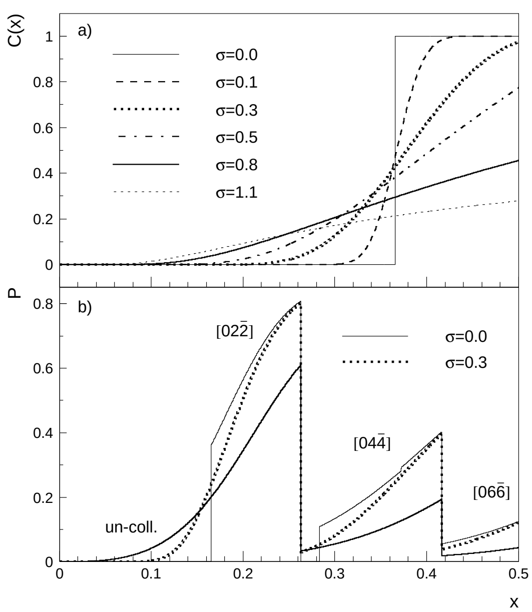
$\Rightarrow I_{\text{exp}}^{\text{inc,coh}} = \int_{\text{6 fold}}$

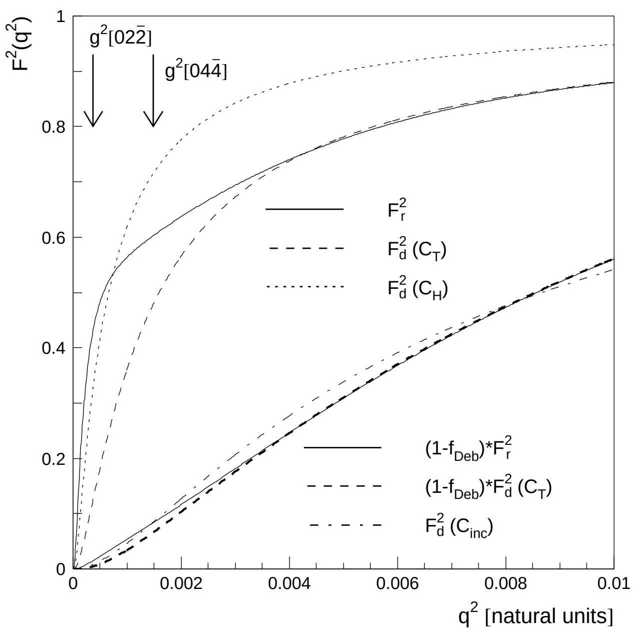
$\rightarrow \int_{\vartheta_c} C'_{ED}(\vartheta_c) I^{\text{inc}}$

$C_{ED}\bar{I}^{\text{coh}}$

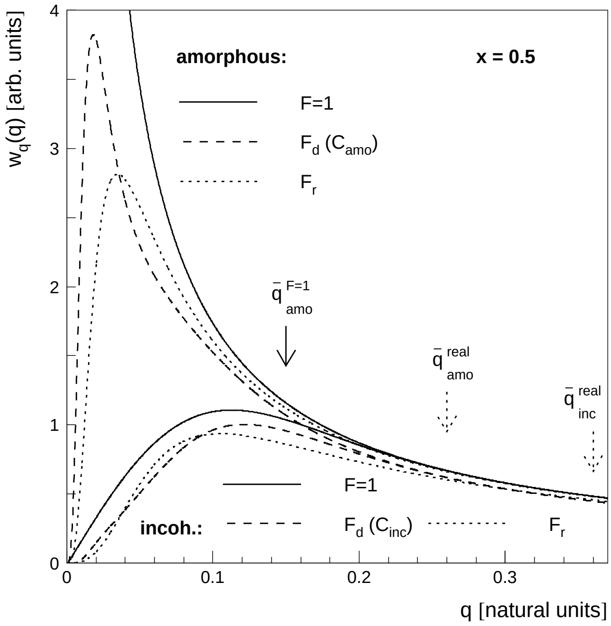
Improvements

(ANB,MCB $\leftrightarrow$ Göttingen)
Hubbell xsec (eff. screening)
realistic form-factor
(Wilson, Int. Tab. f. Crys. (92))





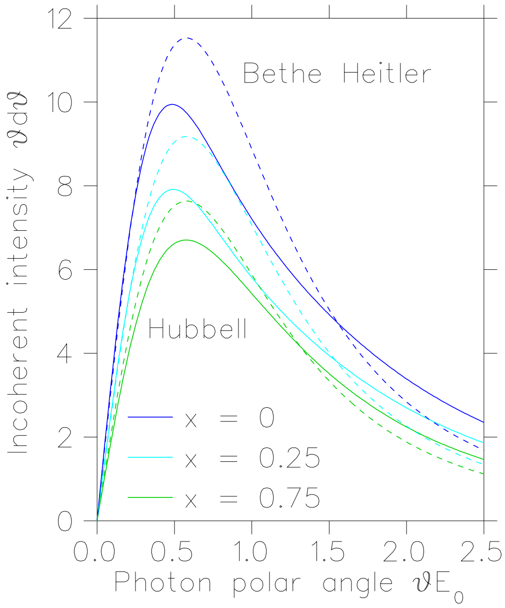
Debye- and Formfactor

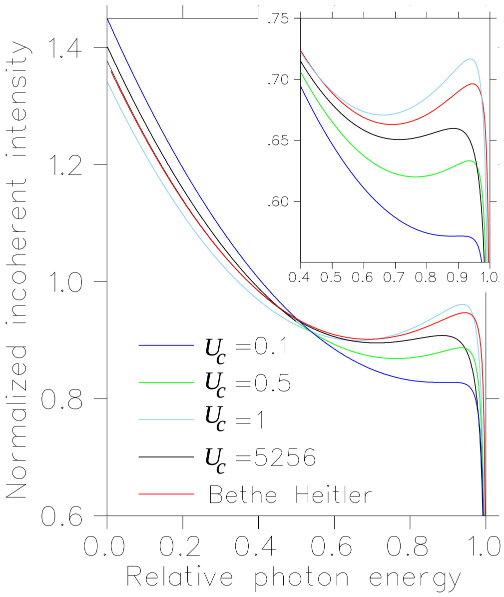


$$I^{\text{inc}} = f_{\text{Deb}}(q^2)\, I^{\text{inc}}$$

Eff. form-factor from realistic form-factor and Debye factor

+ Hubbells xsec: better Z, x, ϑ_c dependence — JAP 30/7(59)981
+ e^- contrib. more exact: Z, x, E_B dependent — Mathew, Owens NIM 111(73)157





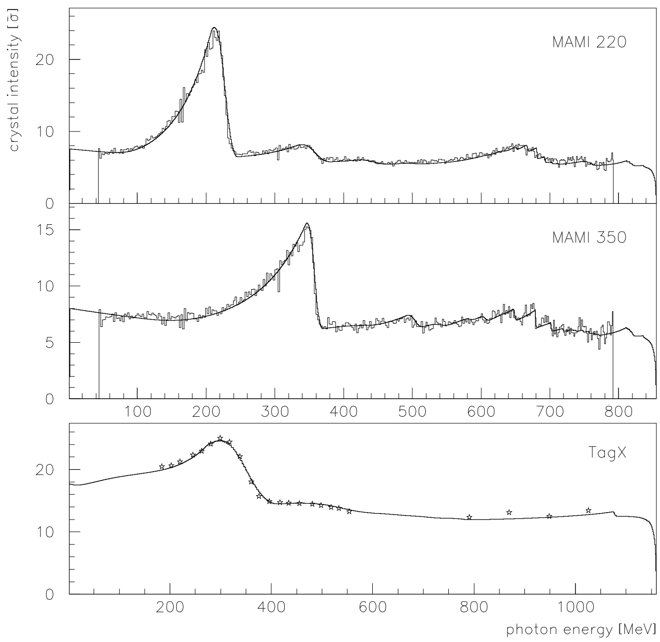
Results

^{4}He($\vec{\gamma}$,2N) @ MAMI:

Diamond-yield compared to total crystal intensity for $k_d = 220, 350$ MeV

TagX @ Tokio:

1.2 GeV, $k_d = 350$ MeV

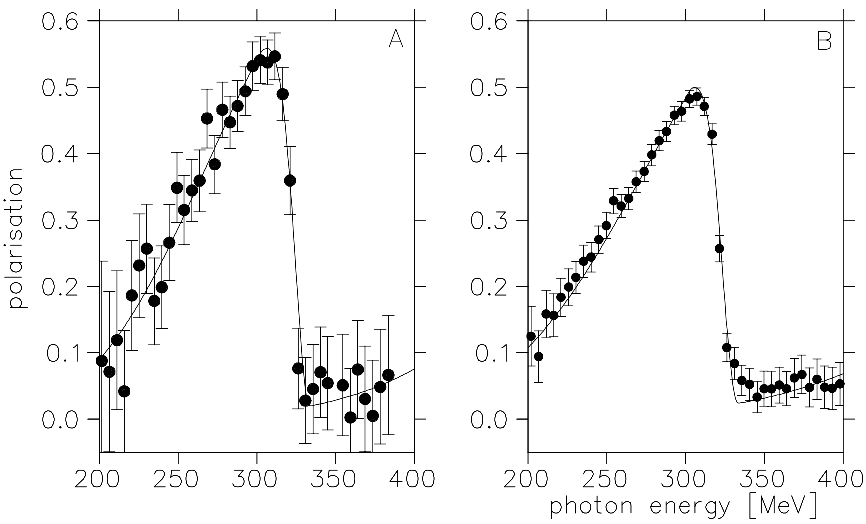


^{4}He(γ, π^0)

@ MAMI/TAPS

P_γ completely transferred to azimuthal asym. of π^0 mesons:

$P_\gamma \propto \mathcal{A}^{\pi^0}(\epsilon_{\parallel,\perp})$

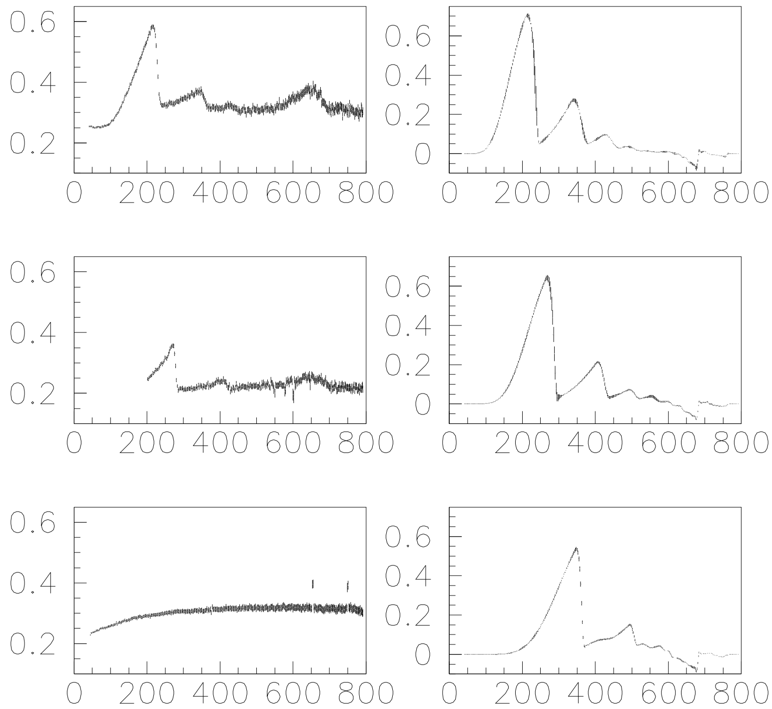


$\longrightarrow$ ANB calc. for 2 colli angles: $\vartheta_c^{A,B} = 0.5, 0.7$ mrad

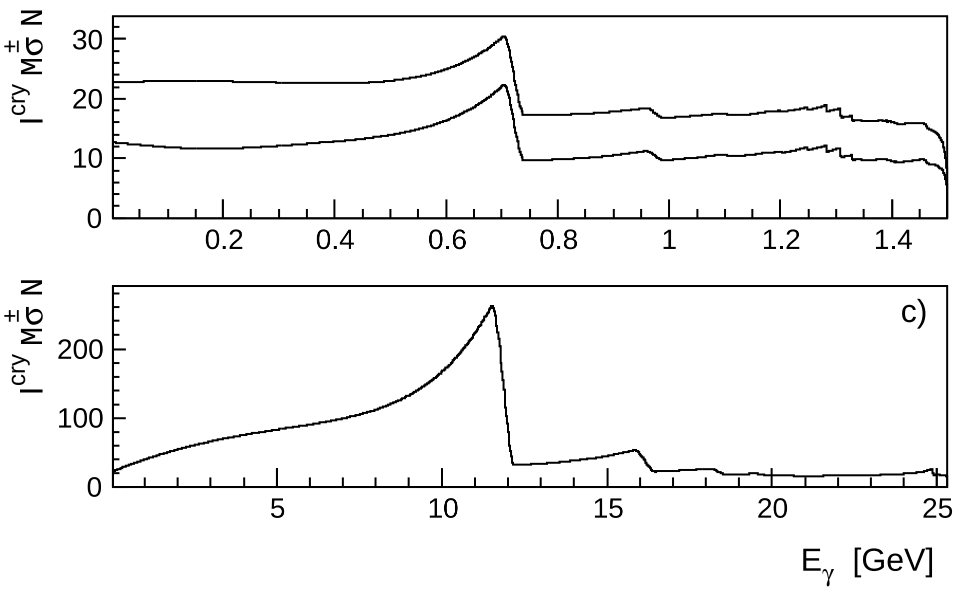
Predictions

Tagging efficiency and polarisation

for 3 different diamond settings



[Predictions](#) for MAMI C, ELFE



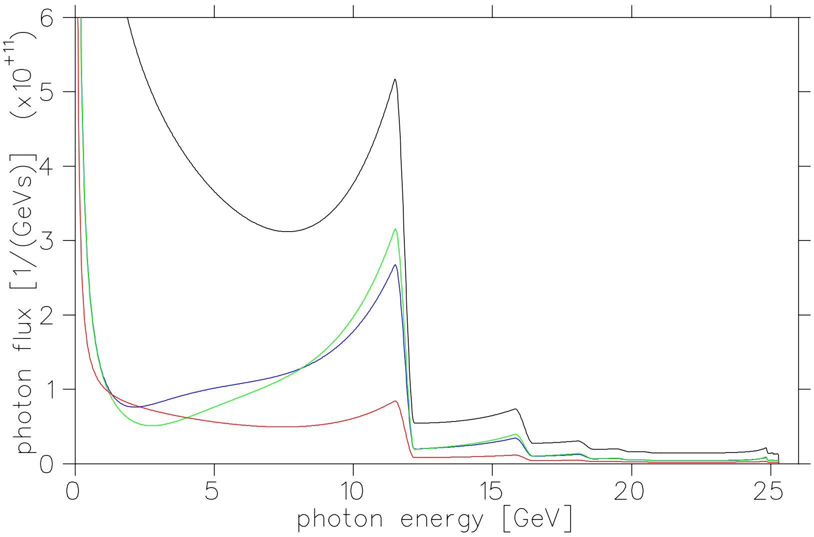
PiP TOF

Predictions

ELFE

beam div.: 10^{-2} mrad

radiator: 0.1 mm

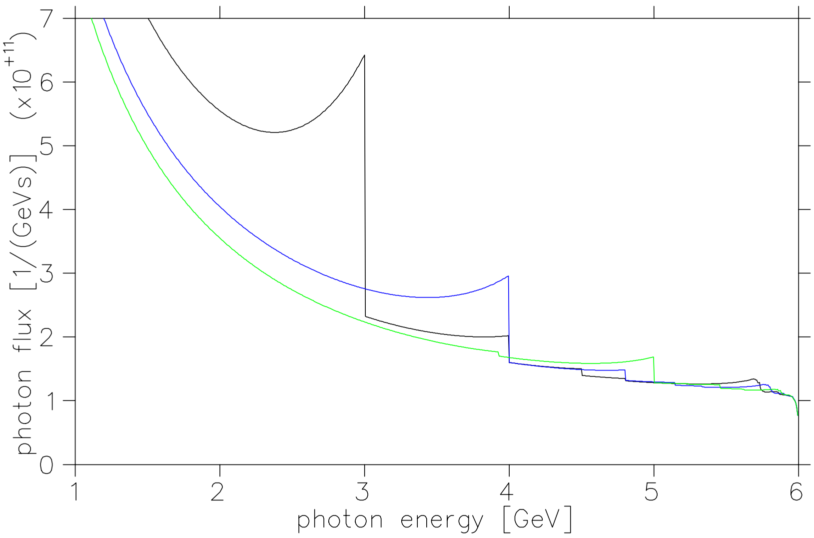


beam spot (σ_s) [mm]	colli/target distance [m]	colli radius [mm]	max. pol.	tagg. eff.
1	10	uncoll	.74	1
1	10	0.6	.75	.15
1	50	1.5	.77	.30
0.1	10	1.2	.78	.30

JLAB

ideal beam

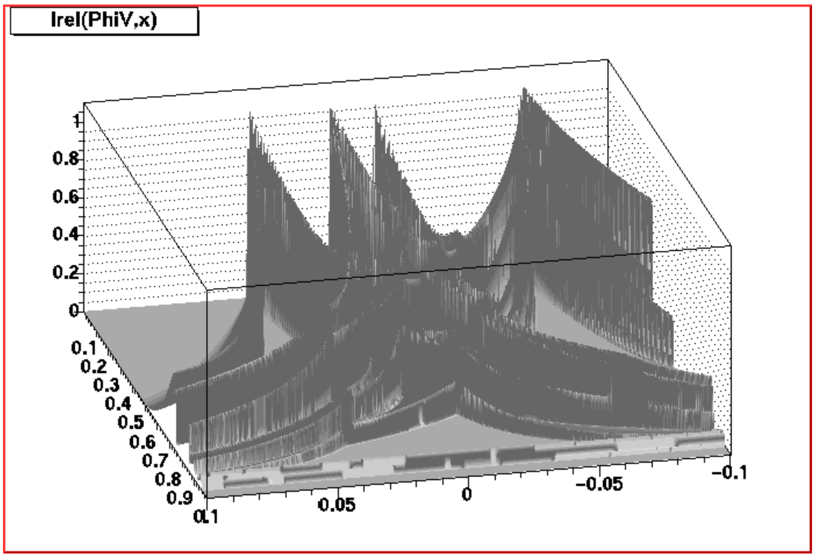
diff. crystal settings



Crystal Alignement

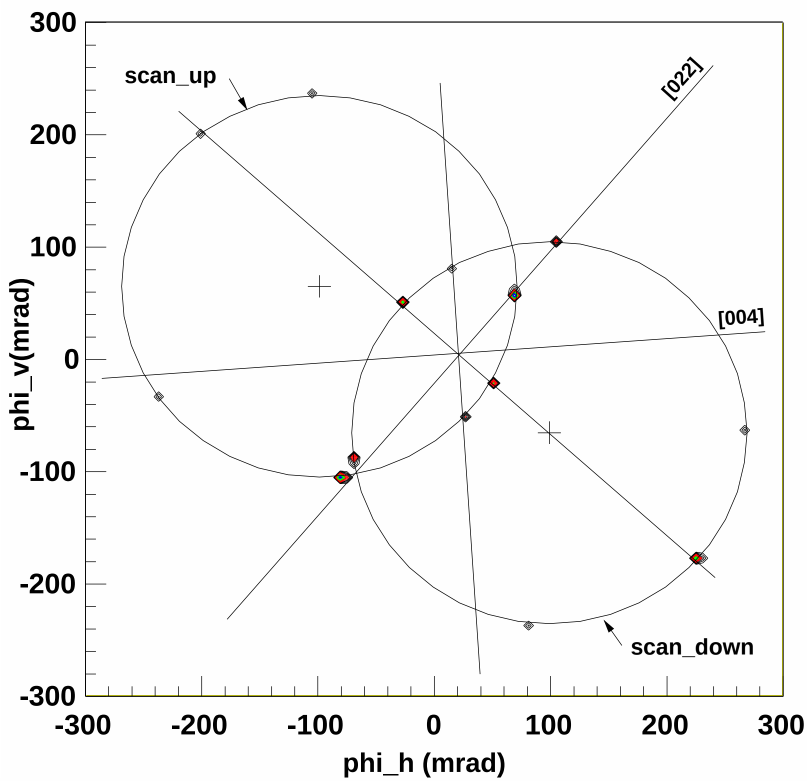
Azimuthal scan

3rd crystal angle ϕ

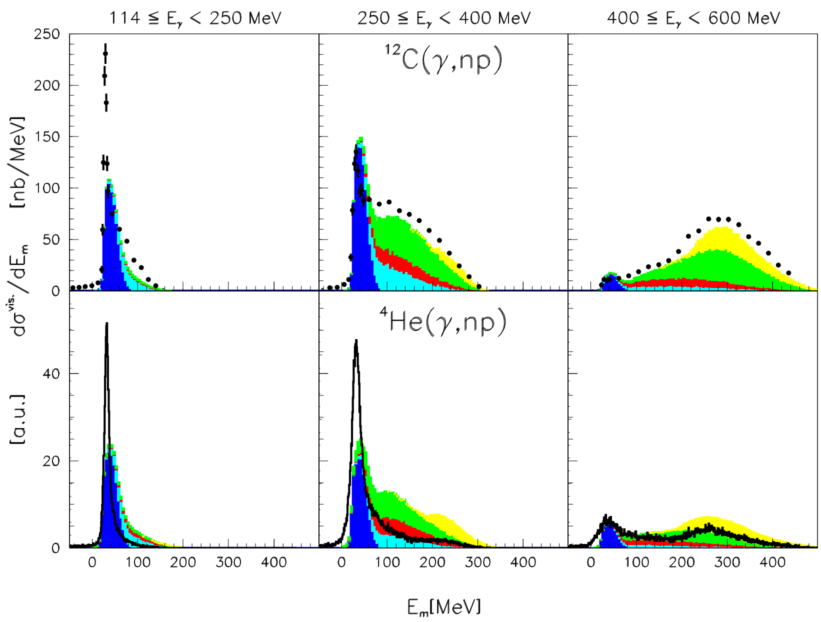


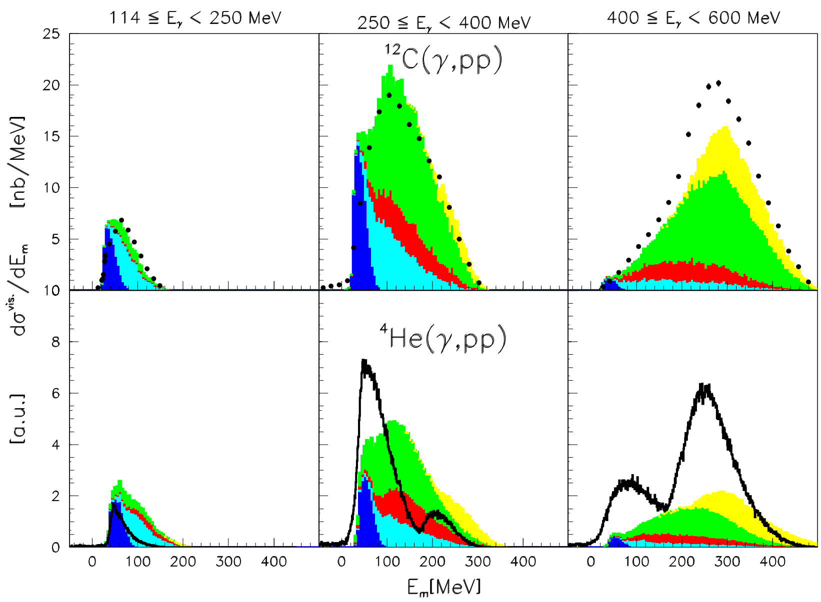
Stonehenge method

peaks when e-beam parallel to crystal plane



^{4}He Missing Mass



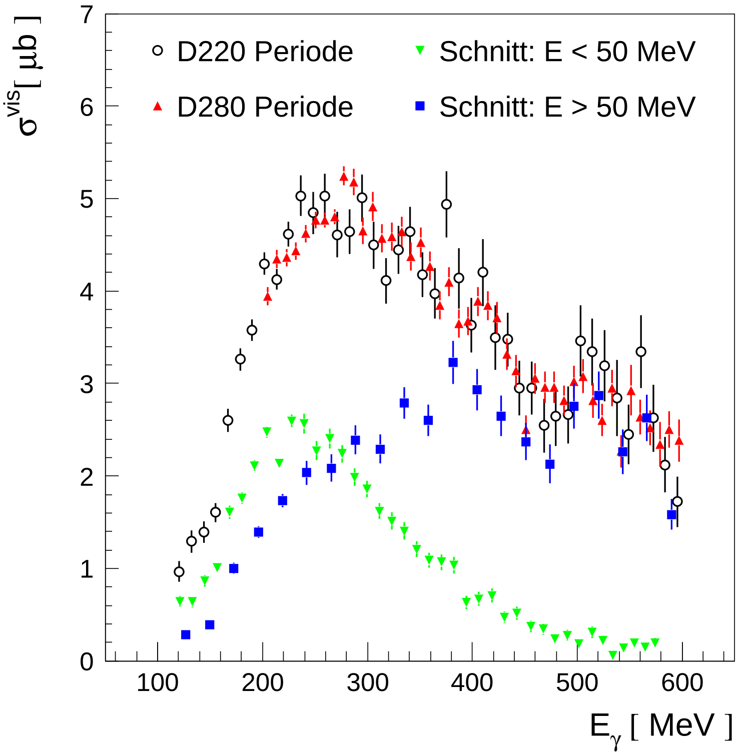


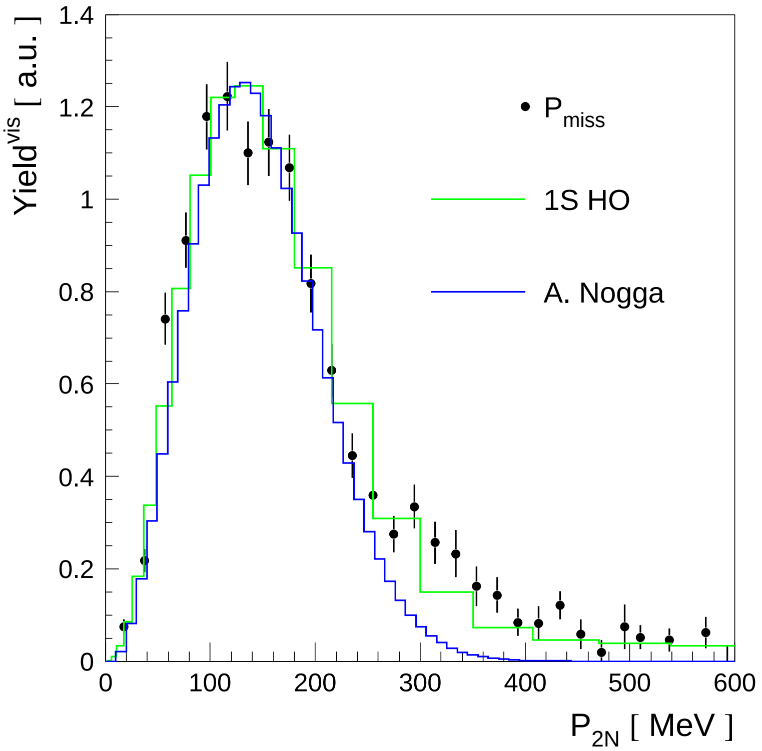
→ same features, less FSI, direct 2N absorption stronger

But: Nuclear structure wrong treated in Valencia model

^{4}He Cross Section

Excitation-function





Pair momentum

Theor. calc. of ^{4}He from Bochum group (Glöckle)

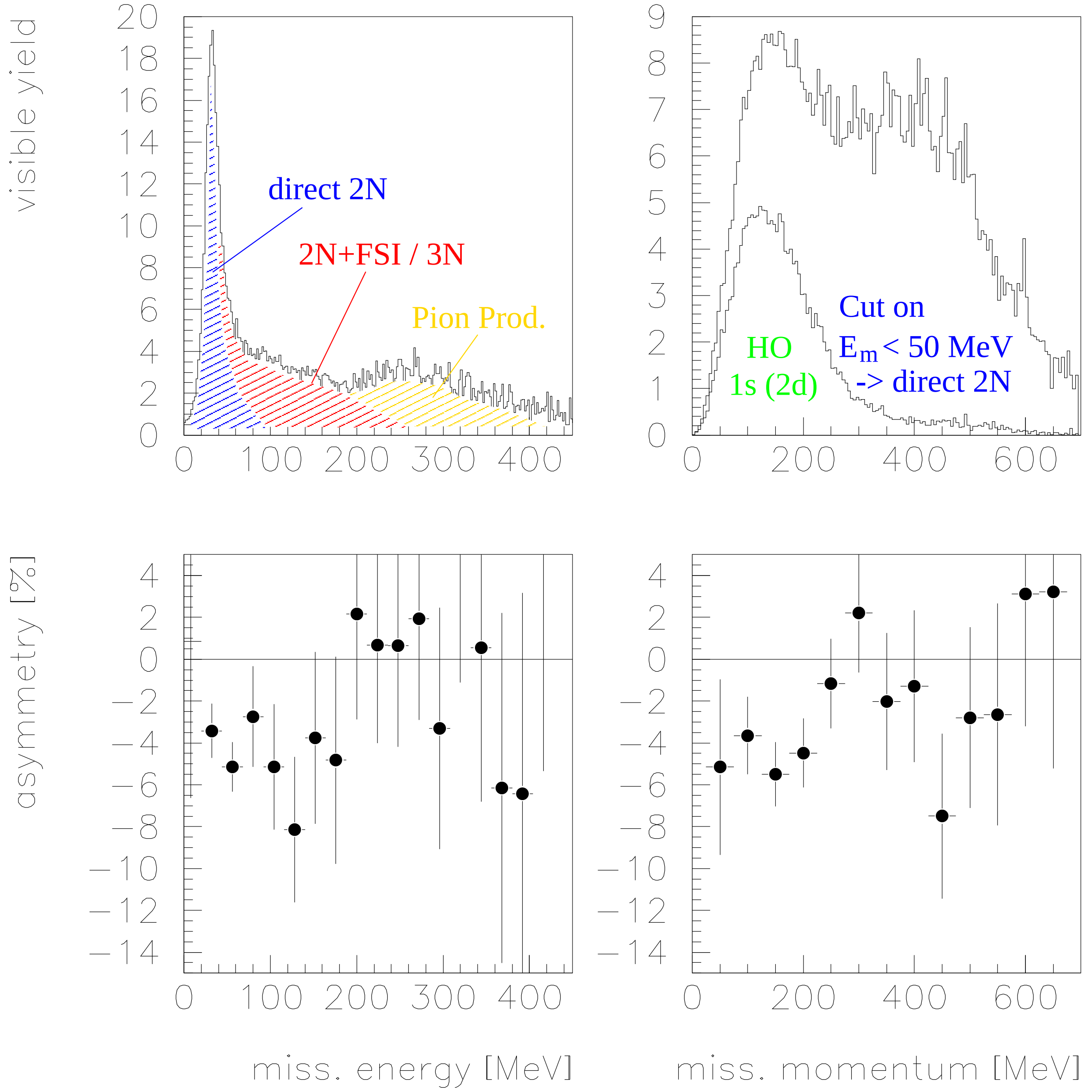
and HO

preliminary!

Asymmetry ^{4}He

Asymmetry A: $\sigma_{\parallel,\perp} = \sigma_0(1 \pm P_\gamma \Sigma) = \sigma_0 \pm A$

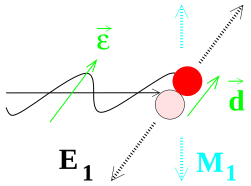
$E_{2m} = E_\gamma - T_p - T_n - T_{\text{rec}}$ $\qquad$ $\vec{p}_m = \vec{k}_\gamma - \vec{p}_p - \vec{p}_n$



^{4}He/^{12}C Photon Asymmetry in Comparison

Low E_γ :

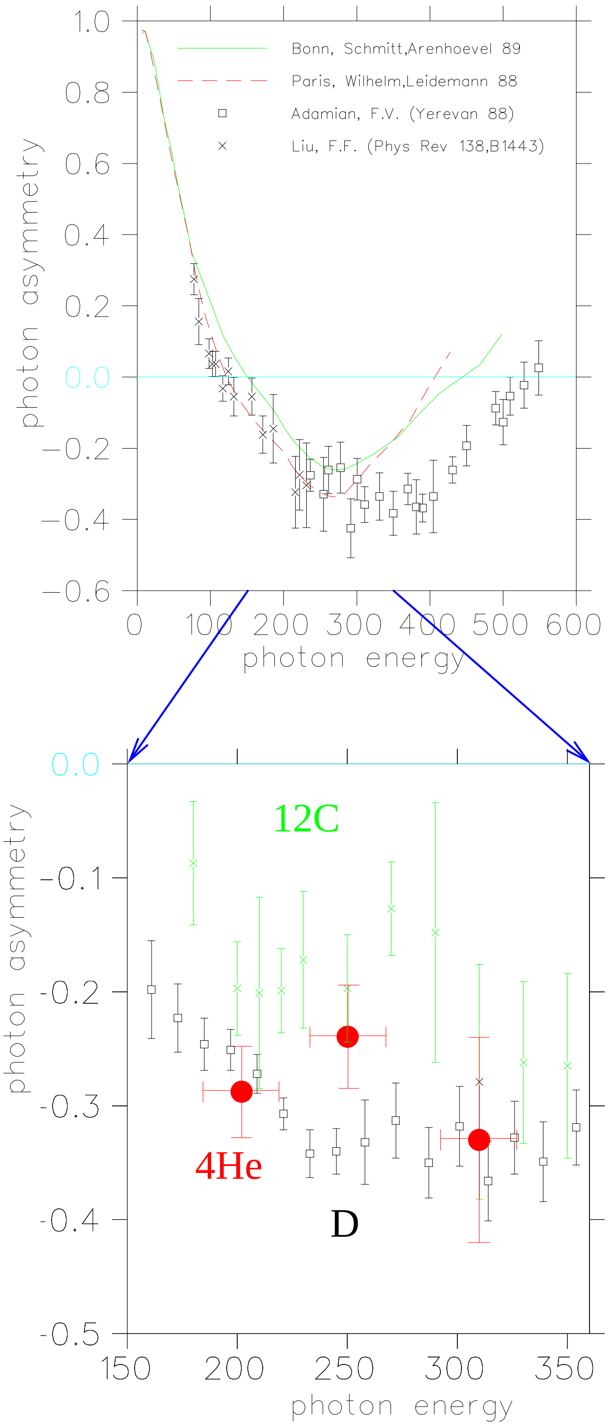
E1 dominant $\rightarrow \Sigma$ pos



$E_\gamma > \pi$ threshold :

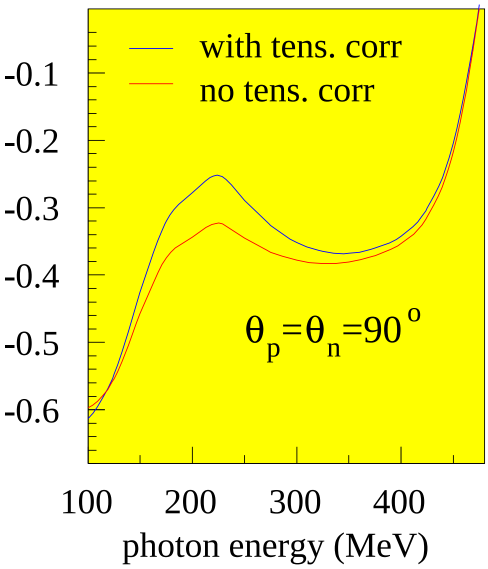
Δ excitation $\rightsquigarrow$

M1 dominant $\rightarrow \Sigma$ neg



^{12}C(γ,pn)^{10}B (p-shell)^2

$\theta_p = \theta_n = 90^\circ$ (Ryckebusch)

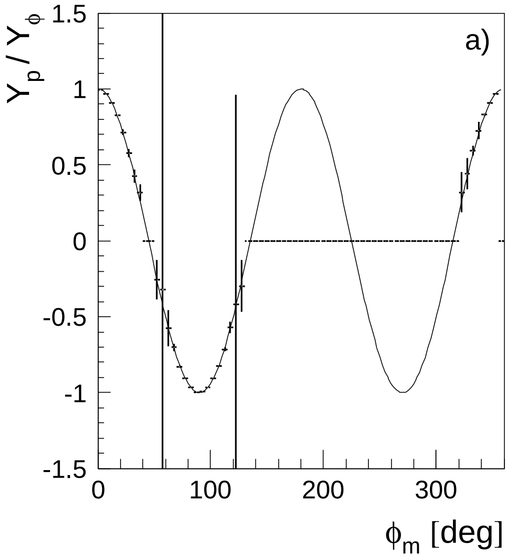


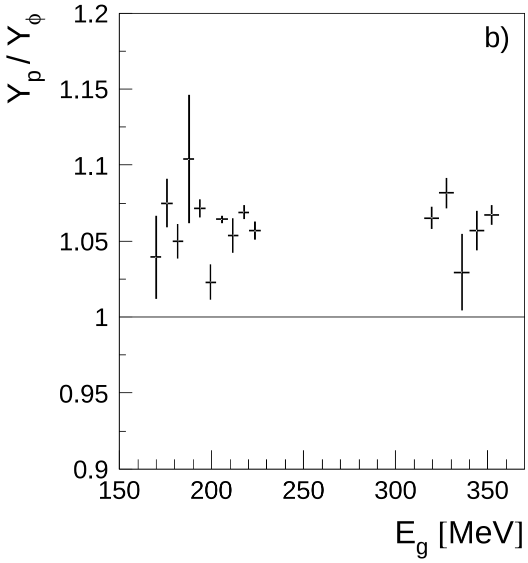
Asymmetry ^{4}He

Eventwise analysis

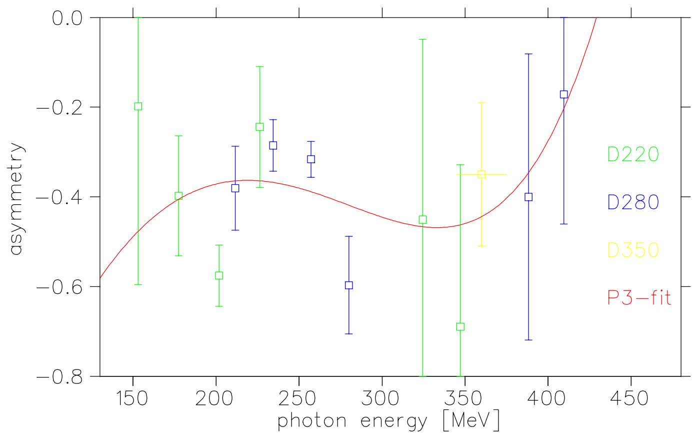
$$\sigma_\phi = \sigma_0 \cdot (1 + P_\gamma A \cos 2\phi_m) \quad \rightarrow$$

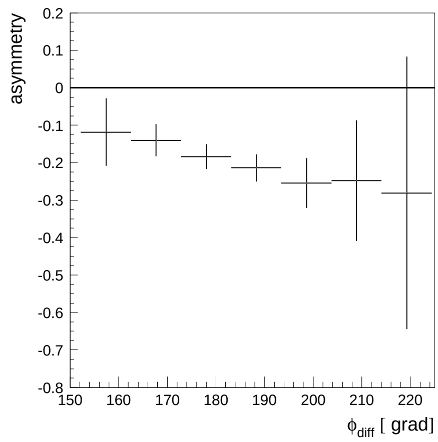
$$Y_A = \frac{1}{n_t} \sum_{\text{ev}} w_{\text{BG}} \left(\epsilon_p \epsilon_{\text{ToF}} \epsilon_t \cdot N_\gamma P_\gamma \cos 2\phi_m\right)^{-1}$$





Xsection dependencies: $\phi_m = (\phi_p + \phi_n)/2$ & $\phi_d = \phi_p - \phi_n$





Summary

- Previous experiments:
  - reaction mechanisms understood
  - direct 2N absorption separable
- Improved description of polarised Bremsstrahlung
  → reliable determination of degree of polarisations
  → two codes: ANB approximative but fast,
  MCB slow but 'exact'
- Photon asymmetry measurements on ^{4}He finished
  - reliable data and high statistics
  - encouraging preliminary results

Prospects

- Continue analysis on all E_γ for both (np,pp) channels
  → (Σ) in dependence of E_γ and ϑ_N
- Better theoretical calculations necessary, in particular ^{4}He
  → enhanced cooperation with theorists
  from Gent, Trento, Pavia, Valencia, Tübingen
- Successful pilot experiment: high-resolution ^{16}O(γ,pp)
  → 2N knockout into discrete final states
- high-res. (e,e'np) in MAINZ-A1 with TOF + spectrometers