The EDDA Experiment at COSY

Polarized Elastic Proton Proton Scattering at $T_{Lab} < 2.5$ GeV

1. Why?
2. What?
3. Where?
4. How?
5. So?
6. And now?

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The EDDA experiment was a small collaboration between University of Bonn, University of Hamburg, and Forschungszentrum Jülich.

Proton Proton Scattering

Nuclear models → meson exchange, phenomenological, QCD inspired → QCD

0 GeV | 0.3 GeV | 1 GeV | 10 GeV | T_{Lab}

EDDA data: 0.35-2.5 MeV

NN potentials:

One meson exchange

$\pi, \rho, \sigma, \eta, \omega$

Bonn, Paris, Nijmegen and others

Inelasticity:

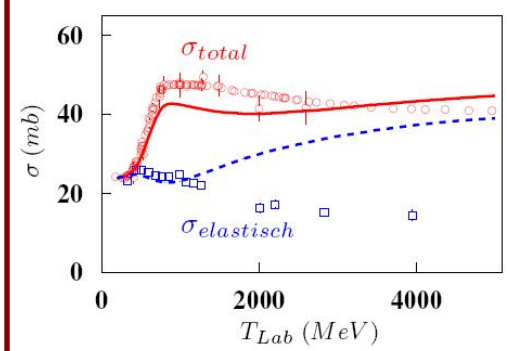
π production

Two meson exchange

Imaginary masses

Total cross section

Vector mesons ρ, ω



Regge Theory

good results from meson exchange models

Observables

$$\rho_f = \mathbf{M}\rho_i\mathbf{M}^* \qquad \rho = \sum_n p_n |n\rangle\langle n|$$

$$P = Tr(\mathbf{I}_S\rho)$$

$$\rho_i = \rho_{beam} \otimes \rho_{target}$$

$$\frac{d\sigma}{d\Omega} = Tr(\rho_f) = \sum_n p_n \left|\langle n|\mathbf{M}|n\rangle\right|^2$$

$$\mathbf{M} = \sum_{i,f} a_{f,i}\sigma_i \otimes \sigma_f$$

$$\frac{d\sigma}{d\Omega} = a_{0000} + \sum_n P_n a_{00n0} + \sum_m Q_m a_{000m} + \sum_{m,n} P_n Q_m a_{00nm} + \ldots$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \left(1 + \sum_n P_n A_{00n0} + \sum_m Q_m A_{000m} + \sum_{m,n} P_n Q_m A_{00nm} + \ldots\right)$$

$\rightarrow$ 4^4=256 possible Observables

Pauli principle
Parity conservation
Time invariance

$\rightarrow$ 25 independent Observables

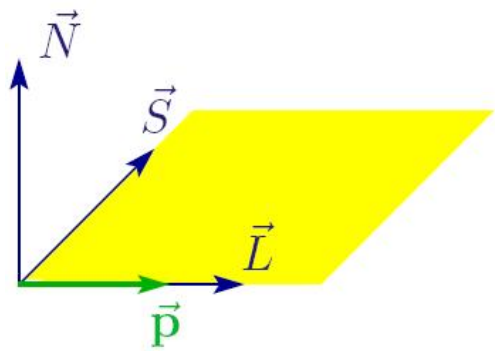
Parametrization of **M**

$$\phi_1 = \langle ++|\mathbf{M}|++\rangle$$
$$\phi_2 = \langle --|\mathbf{M}|--\rangle$$
$$\phi_3 = \langle +-|\mathbf{M}|+-\rangle$$
$$\phi_4 = \langle +-|\mathbf{M}|-+\rangle$$
$$\phi_5 = \langle ++|\mathbf{M}|+-\rangle$$

Helicity amplitudes
described by nine independent amplitudes

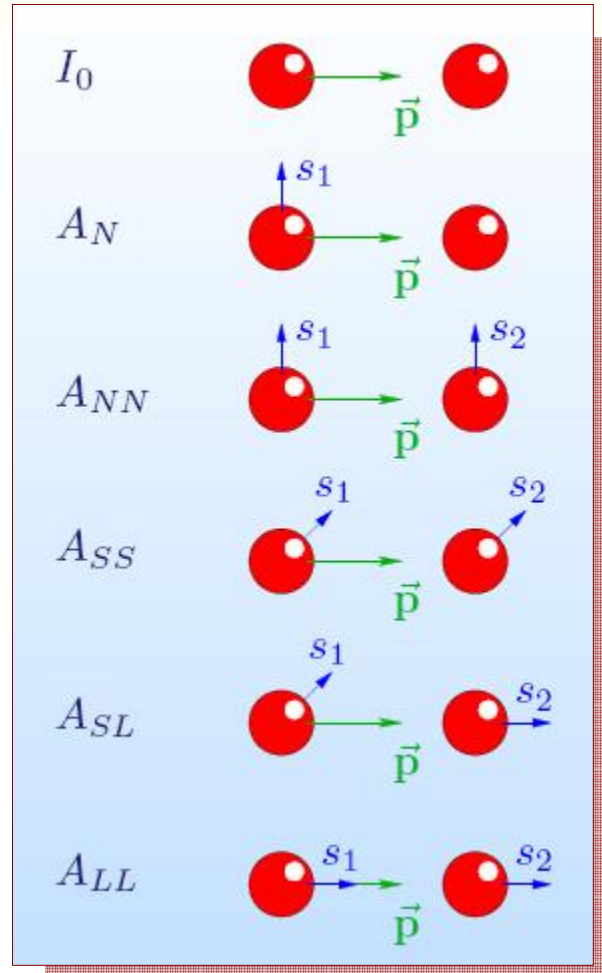
Observables

Scattering frame

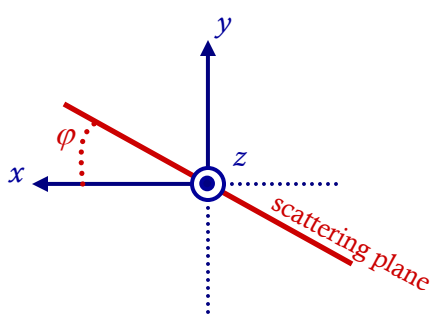


$$\frac{d\sigma}{d\Omega} \propto 1 + A_N (P_N + Q_N)$$
$$+ A_{NN} \cdot P_N \cdot Q_N$$
$$+ A_{SS} \cdot P_S \cdot Q_S$$
$$+ A_{LL} \cdot P_L \cdot Q_L$$
$$+ A_{SL} (P_S \cdot Q_L + P_L \cdot Q_S)$$

$$A_{NN} \cdot \sigma_0 = \mathrm{Re}(\phi_1 \phi_2^* - \phi_3 \phi_4^*) + 2|\phi_5|^2$$
$$A_{SS} \cdot \sigma_0 = \mathrm{Re}(\phi_1 \phi_2^* + \phi_3 \phi_4^*)$$



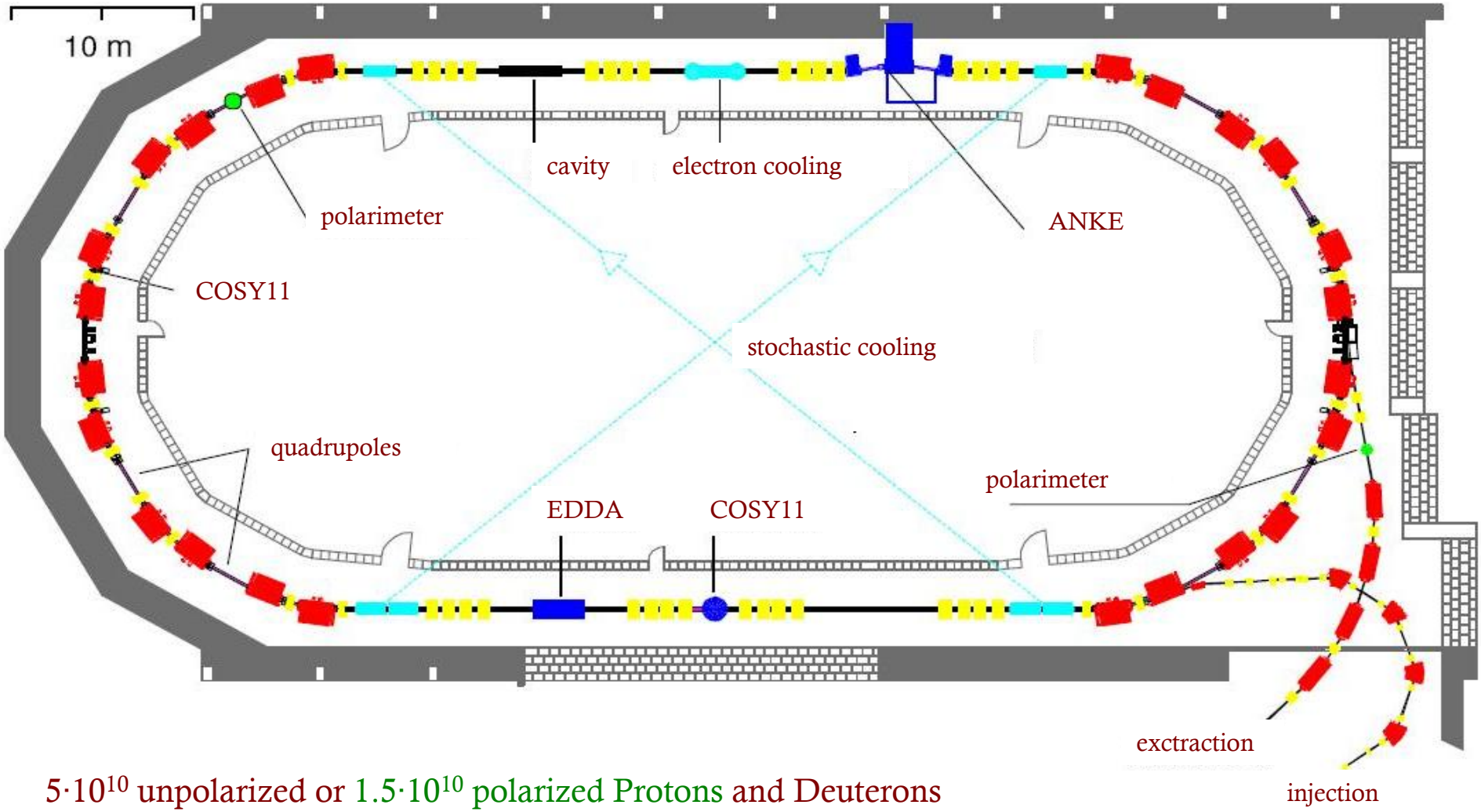
Laboratory frame



$$P_N = -P_x \sin\varphi + P_y \cos\varphi$$
$$P_S = P_x \cos\varphi + P_y \sin\varphi$$
$$P_L = P_z$$

COSY seen from Space?

Cooler Synchrotron COSY



$5 \cdot 10^{10}$ unpolarized or $1.5 \cdot 10^{10}$ polarized Protons and Deuterons

$T_{Lab} < 2500$ MeV

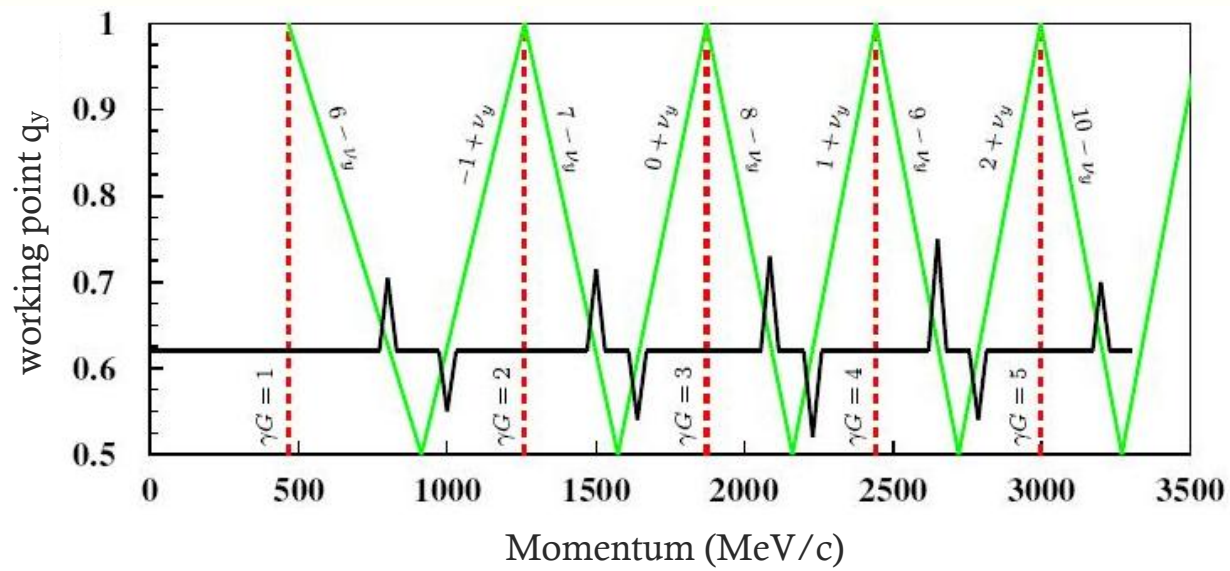
Depolarizing Resonances

Intrinsic resonances

$$\gamma G = kP \pm (\nu_y - 2)$$

Imperfection resonances

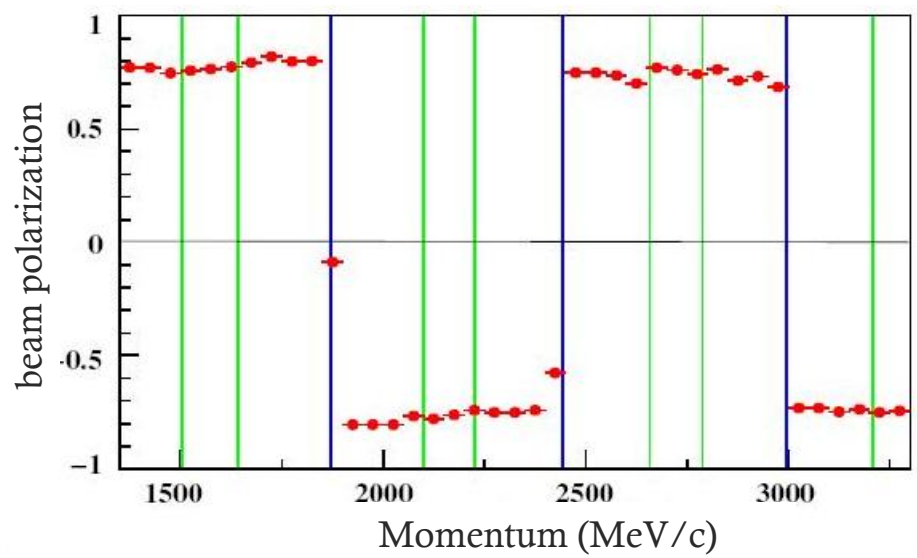
$$\gamma G = k$$



Resonance stregth

$$P_f = (2e^{-\pi\varepsilon^2/2\alpha} - 1)P_i$$

Polarization at 3300 MeV/c
P ≈ 75%

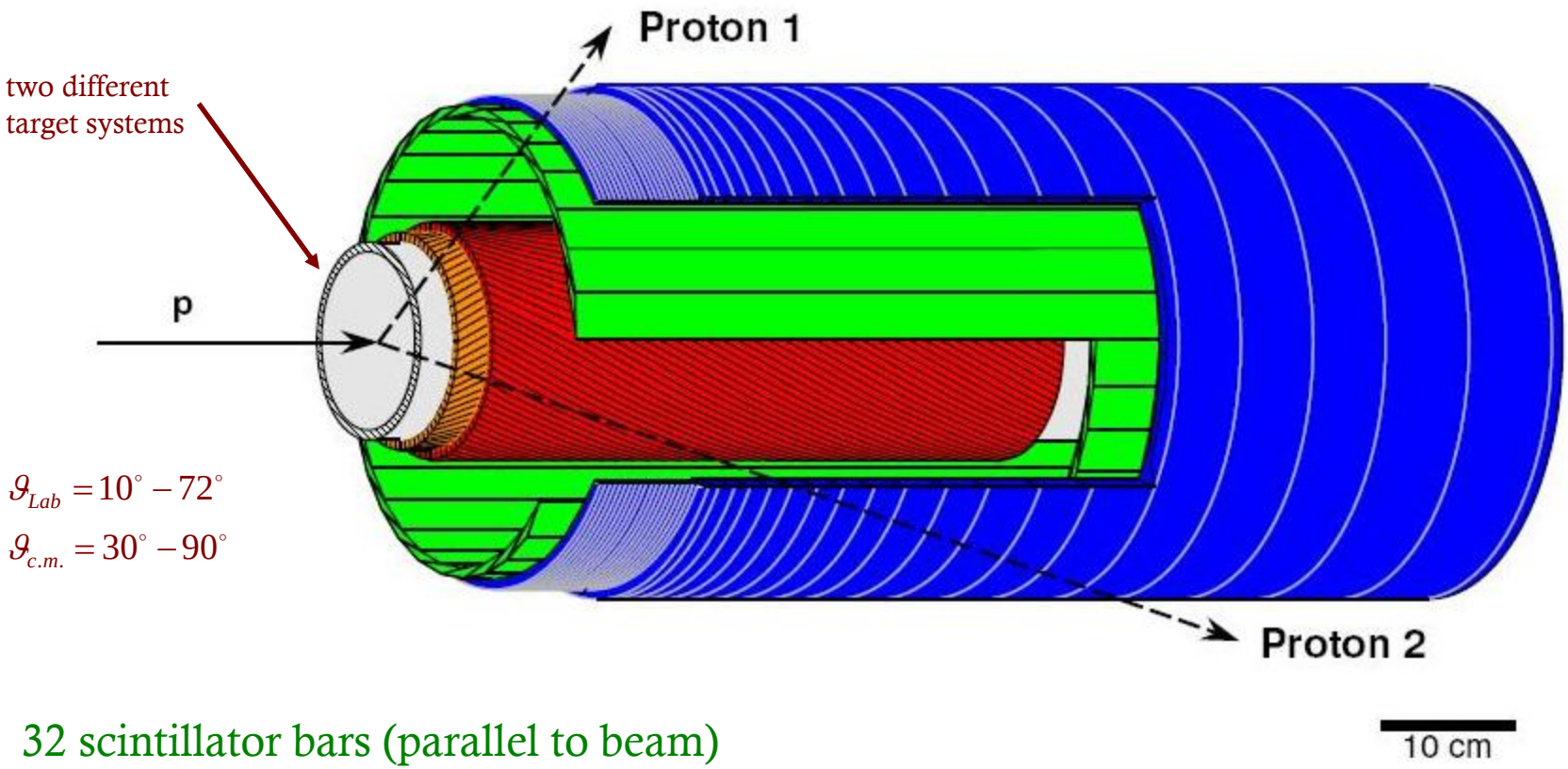


EDDA

Kinematic Correlation of Elastic Scattering

$$\varphi_1 - \varphi_2 = \pi$$

$$\tan\vartheta_1 \cdot \tan\vartheta_2 = \frac{1}{\gamma_{c.m.}^2}$$



$\vartheta_{Lab} = 10^\circ - 72^\circ$

$\vartheta_{c.m.} = 30^\circ - 90^\circ$

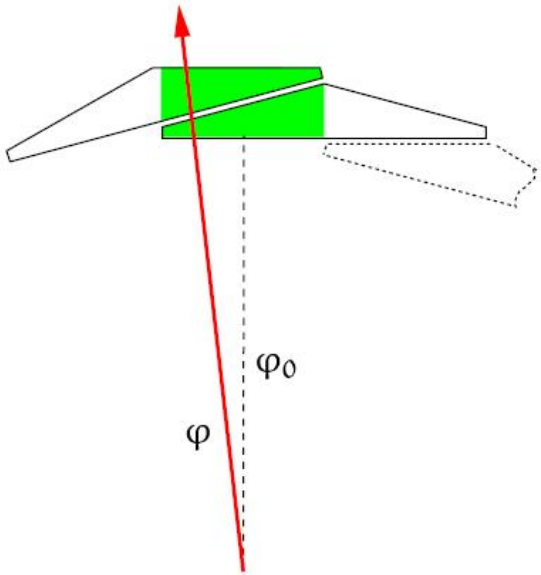
32 scintillator bars (parallel to beam)

2·20 scintillator half-rings + 4·64 scintillating fibers

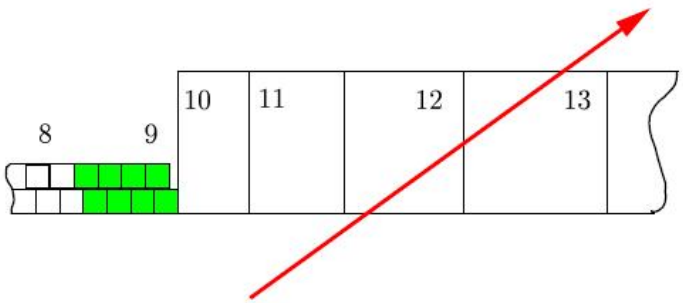
4·160 scintillating fibers

Light Splitting

scintillator bars



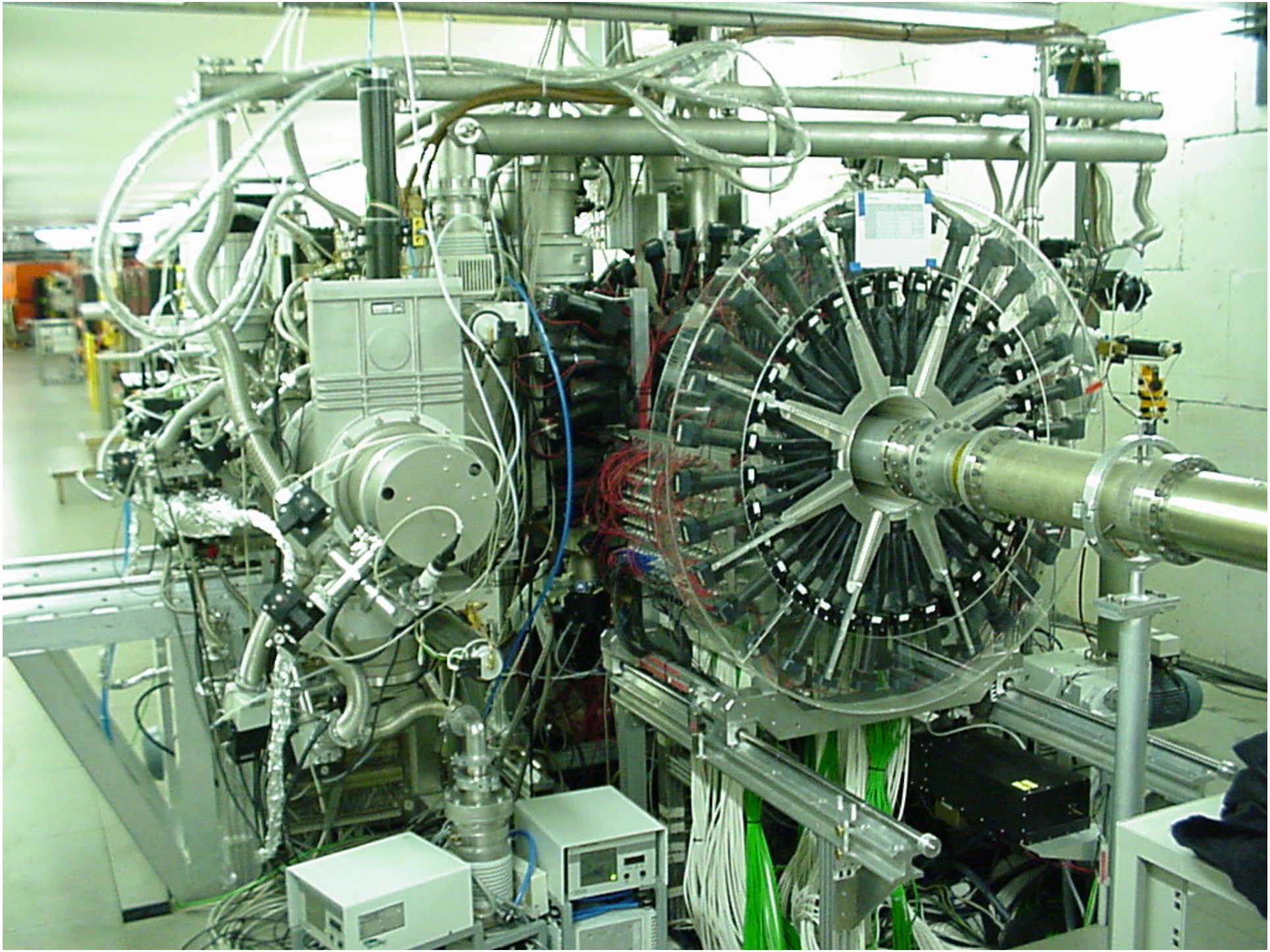
scintillator half-rings



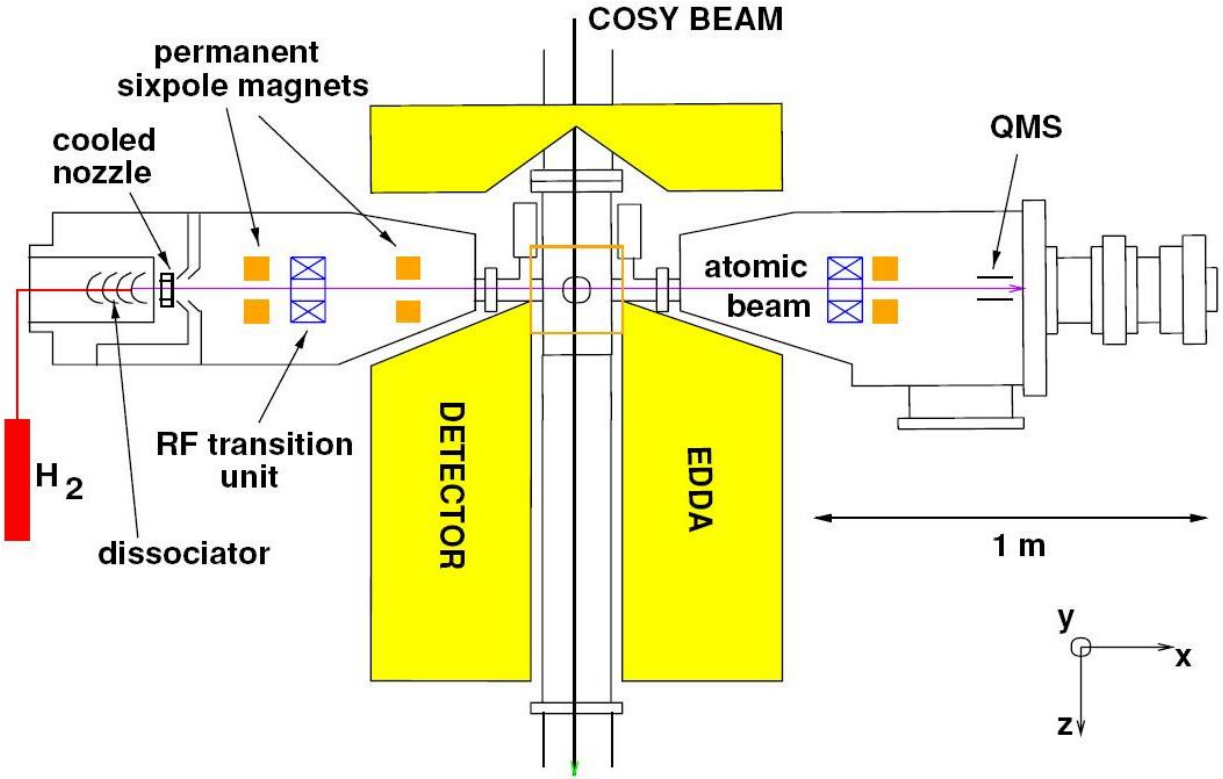
compare light yield in adjacent scintillators

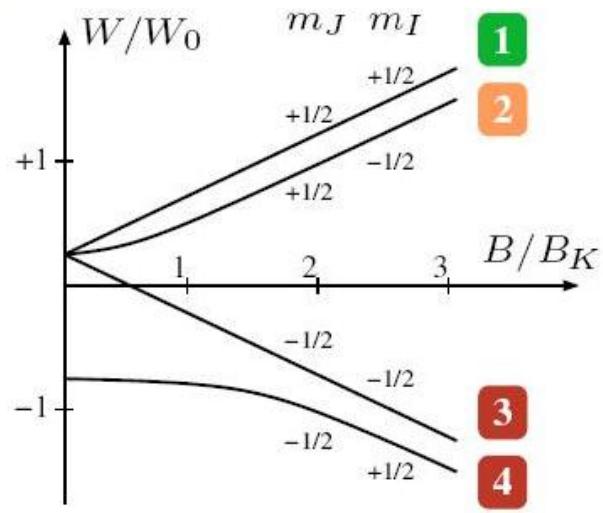
resolution: five times better than granularity $\Delta\varphi = 2.5^\circ$

$\Delta\vartheta = 2^\circ$



Atomic Beam Target

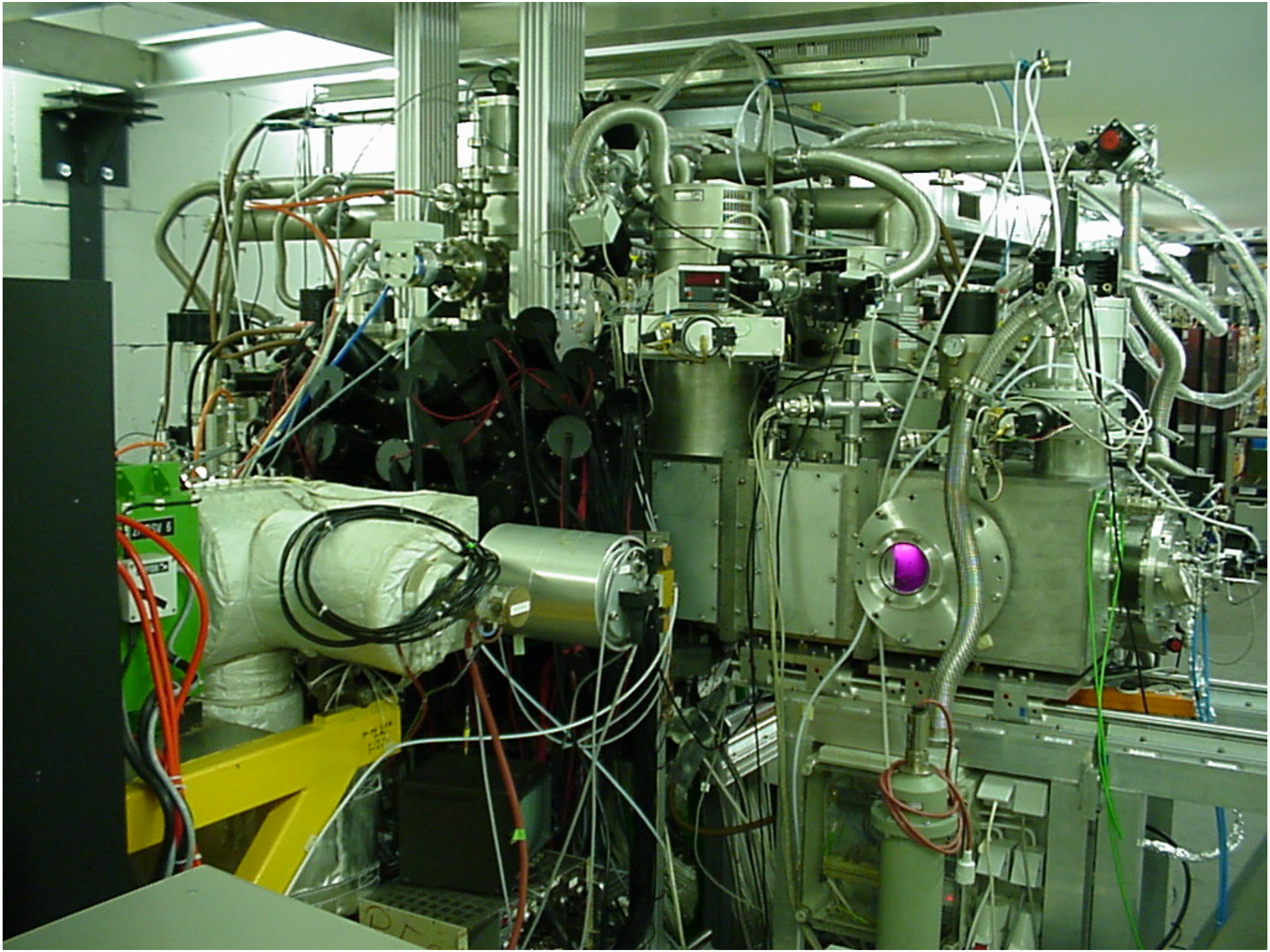




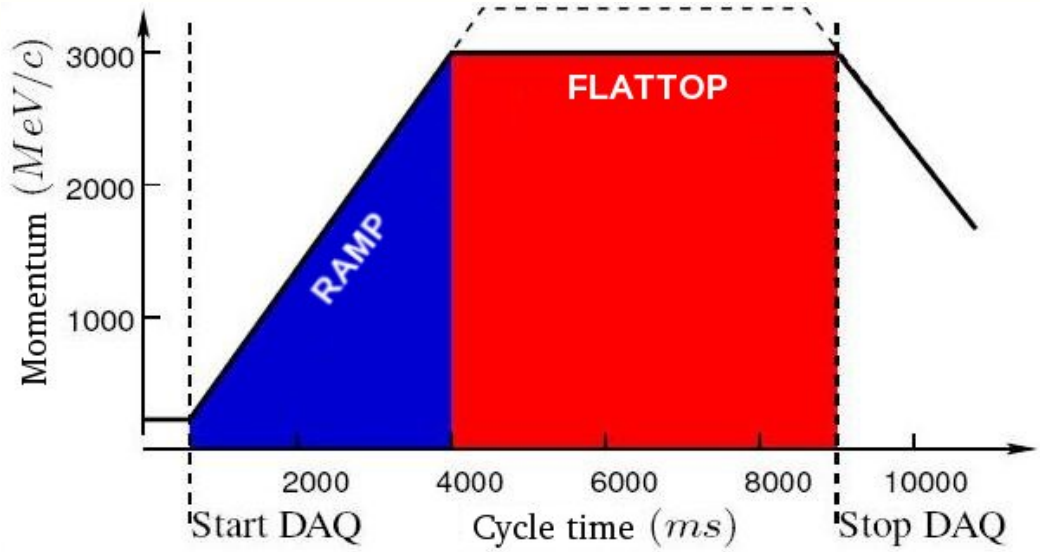
Target holding field B < 1 mT ($\pm Q_x$, $\pm Q_y$, and $\pm Q_z$)

Effective Polarization Q ≈ 70%

Effective Target thickness $1.8 \cdot 10^{11}$ cm^{-2}



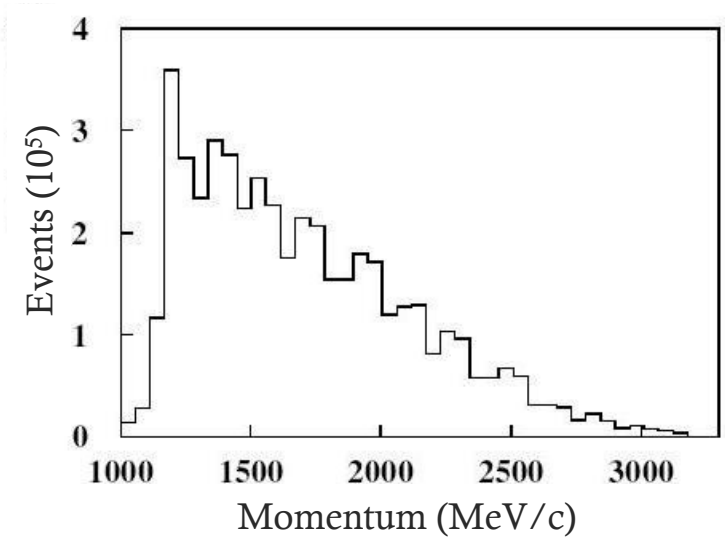
Measurement



Excitation functions:
measurement during acceleration

MultiPass Technique:
thousands of cycles

Change polarization between cycles
$\ldots+P_y\ldots-P_y\ldots+P_y\ldots-P_y\ldots$



Low cross section at high momenta:
longer storage at flattop
several flattop momenta
above 2300 MeV/c

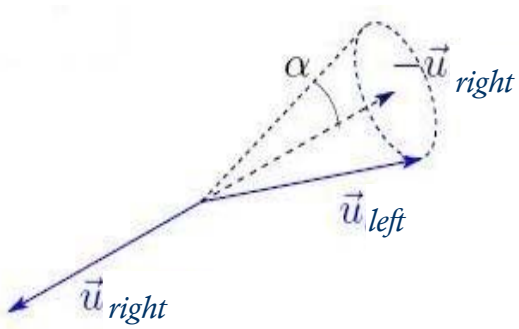
Event Selection

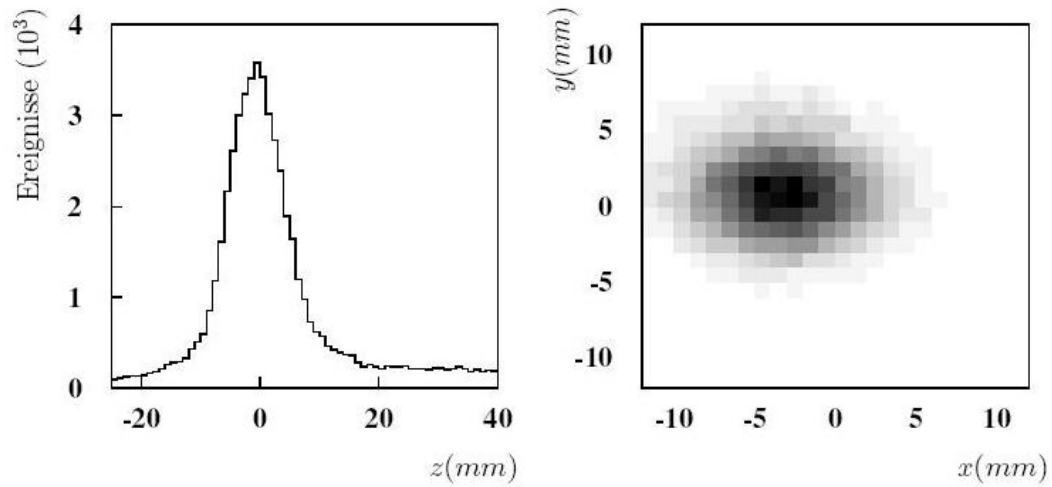
Kinematic Correlation
- Vertex Reconstruction
- Hit Pattern Outer/Inner Layers

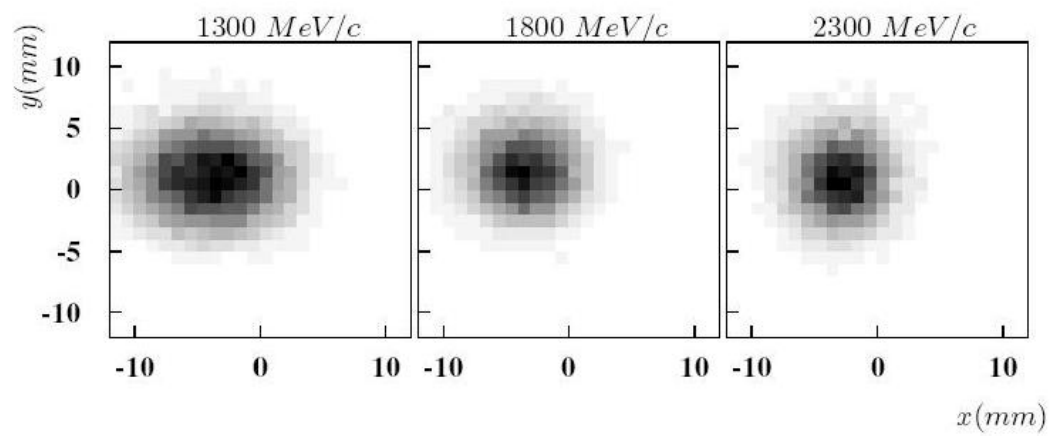
Detector Acceptance

Vertex Cut

Kinematic Deficit
- Compare CH_2 / C fiber targets

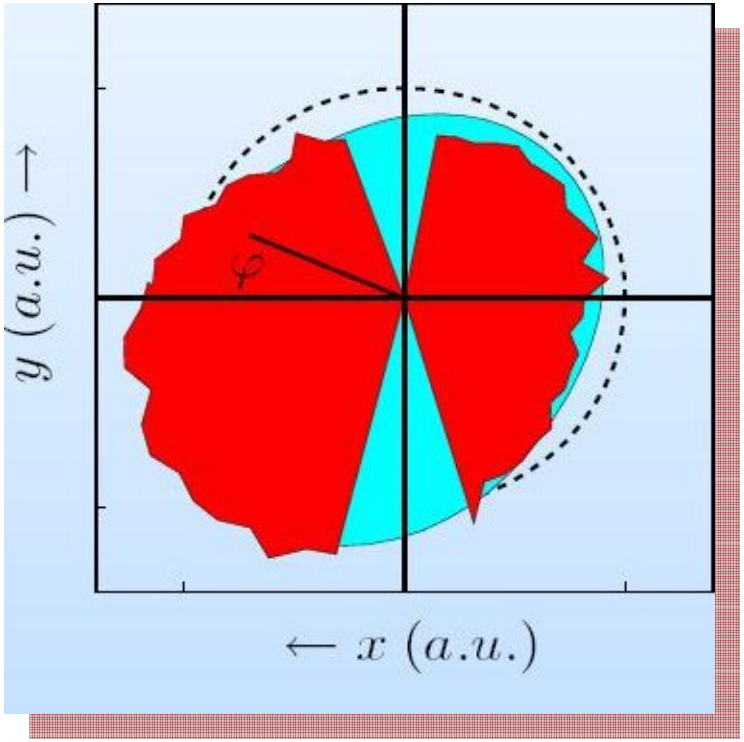






Asymmetries

$$\frac{d\sigma}{d\Omega} = I_0(\vartheta)[1 + A_N(\vartheta)\cdot(P_y \cos\varphi - Q_x \sin\varphi) + (A_{SS}(\vartheta) - A_{NN}(\vartheta))\cdot P_y \cdot Q_x \sin\varphi \cos\varphi]$$



Asymmetries

left-right → A_N or P_y

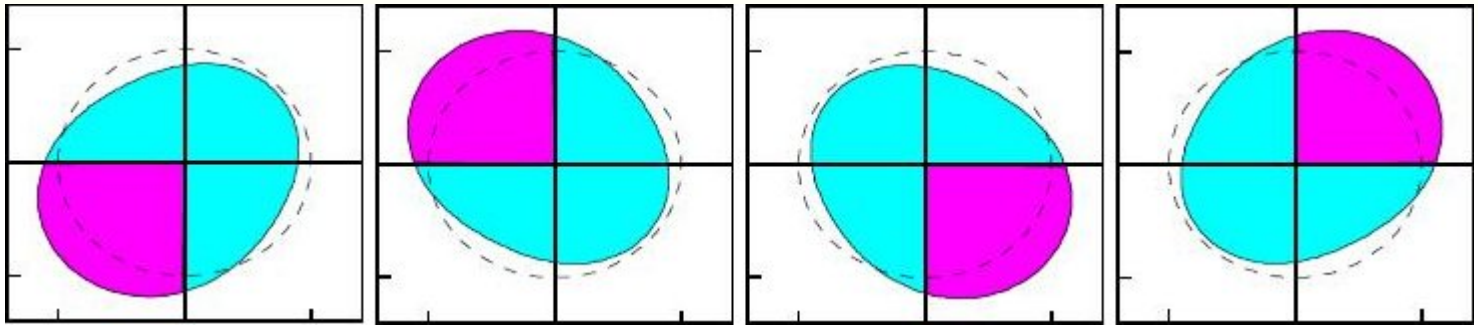
top-bottom → Q_x

diagonal strain → $A_{SS} - A_{NN}$

Yield:

$$N(\vartheta,\varphi) = n_{beam} \cdot \rho_{target} \cdot \Delta\Omega \cdot E(\vartheta,\varphi) \cdot \frac{d\sigma}{d\Omega}(\vartheta,\varphi)$$

Asymmetries



$+P_y+Q_x$ $\quad$ $+P_y-Q_x$ $\quad$ $-P_y+Q_x$ $\quad$ $-P_y-Q_x$

$$N = \sqrt[4]{N_{++}^{(315)} \cdot N_{+-}^{(45)} \cdot N_{-+}^{(225)} \cdot N_{--}^{(135)}}$$

$$|+P_y| = |-P_y|$$

$$|+Q| = |-Q|$$

$$E(\vartheta,\varphi) \neq f(\pm P_y, \pm Q)$$

$$\rho_{target} \neq f(\pm P_y)$$

$$n_{beam} \neq f(\pm Q)$$

$$\varepsilon_{1,x} = c_1 \cdot A_N \cdot P_y \qquad \varepsilon_{1,y} = c_1 \cdot A_N \cdot P_y \qquad \varepsilon_{1,z} = c_1 \cdot A_N \cdot P_y$$

$$\varepsilon_{2,x} = -c_1 \cdot A_N \cdot Q_x \qquad \varepsilon_{2,y} = c_1 \cdot A_N \cdot Q_y \qquad \varepsilon_{2,z} = 0$$

$$\varepsilon_{3,x} = c_2 \cdot P_y \cdot Q_x (A_{SS} - A_{NN}) \qquad \varepsilon_{3,y} = c_3 \cdot P_y \cdot Q_y (A_{SS} + A_{NN}) \qquad \varepsilon_{3,z} = c_1 \cdot P_y \cdot Q_z \cdot A_{SL}$$

Analyzing Power A_N

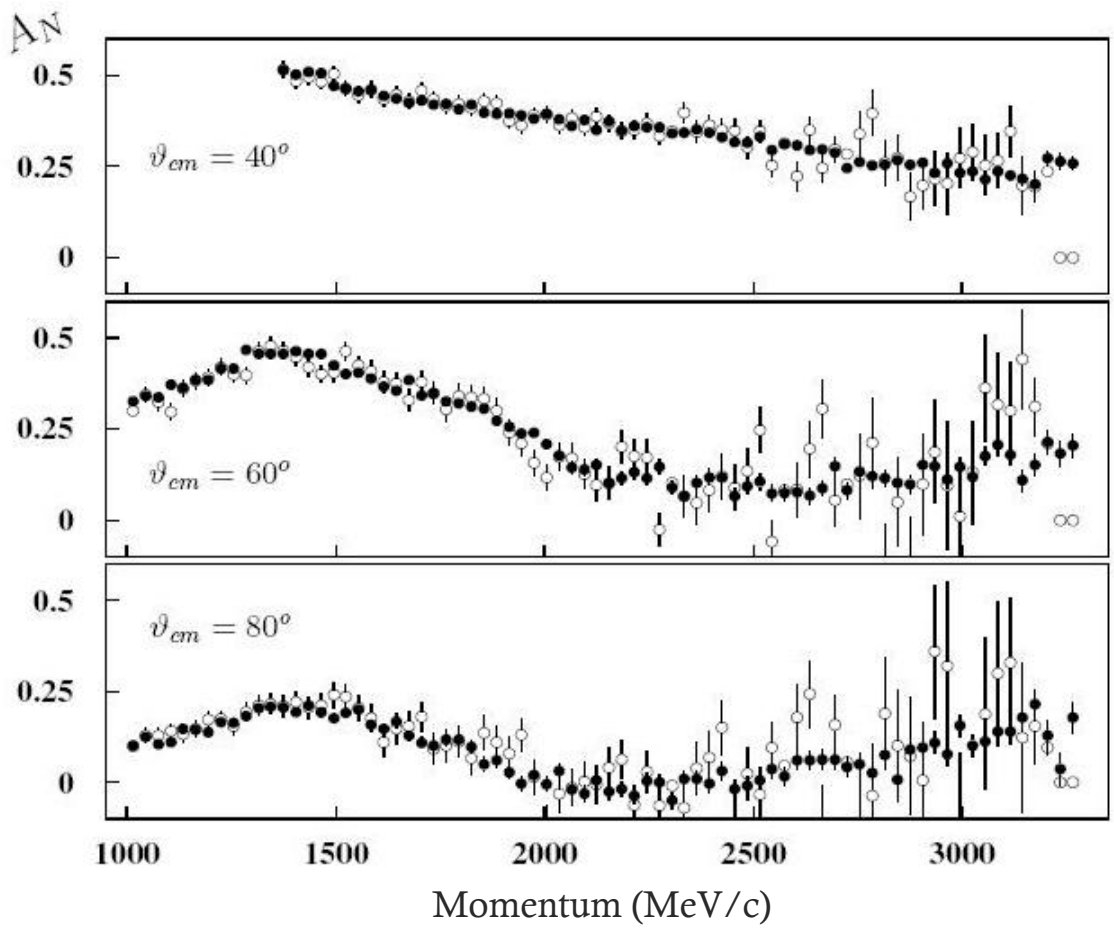
Measured as in: M. Almeier et al., Phys. Rev. Lett. **85** (2000), 1819.

Normalized with: M.W. McNaughton et al., Phys. Rev. C 41 (1990), 2809.

Different momentum bins (Depolarizing resonances) → Legendre-Polynomials

Normalization of A_{NN}, A_{SS}, and A_{SL}

Consistency in double polarized measurement



Systematic Uncertainties

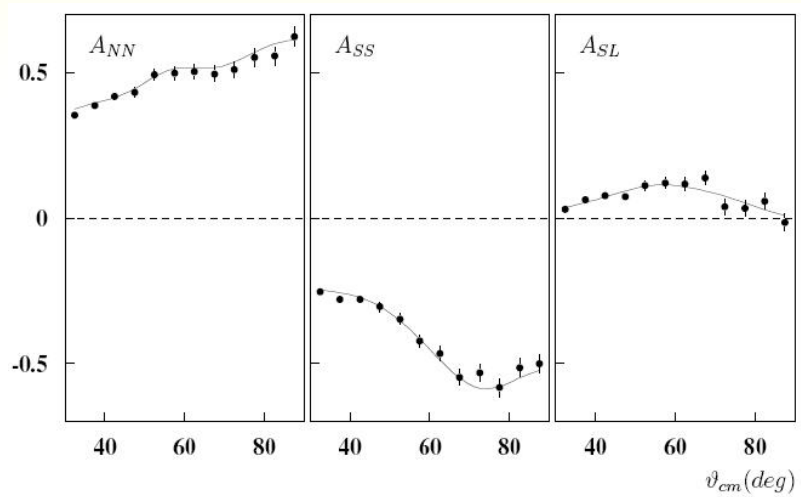
Simulation:

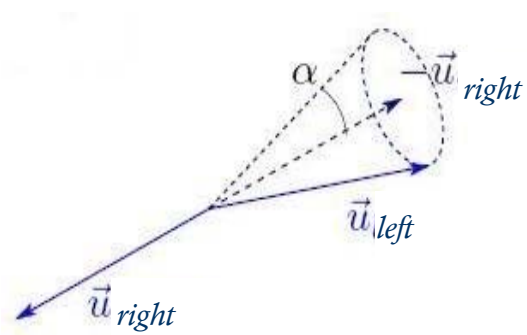
False Asymmetries

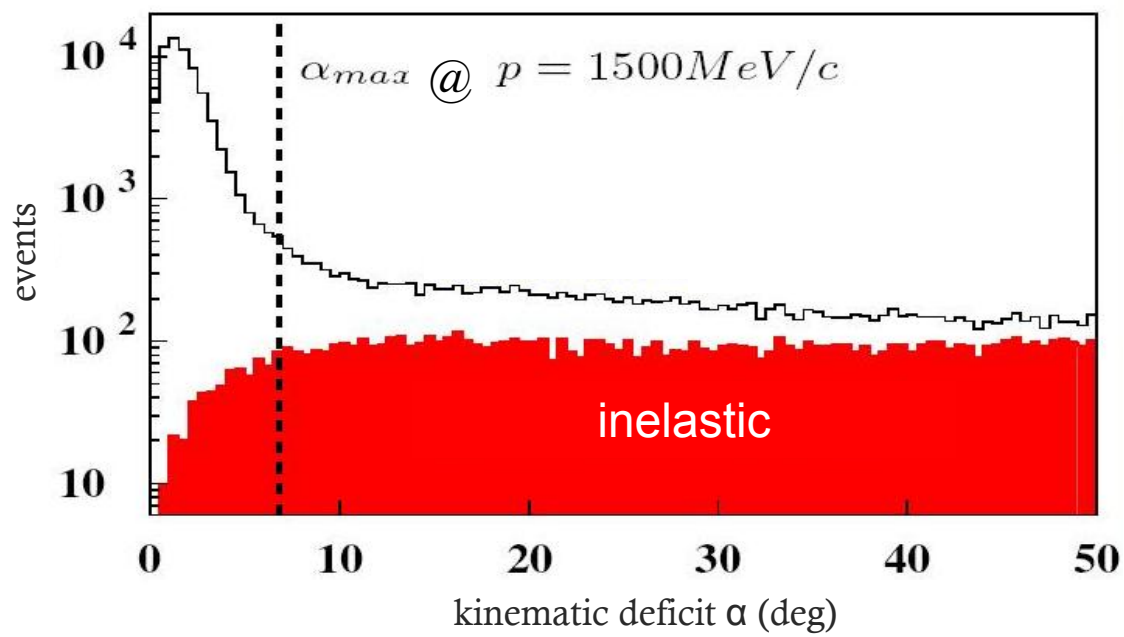
Direction of Polarization Vectors

Differences in +P and –P, +Q and –Q

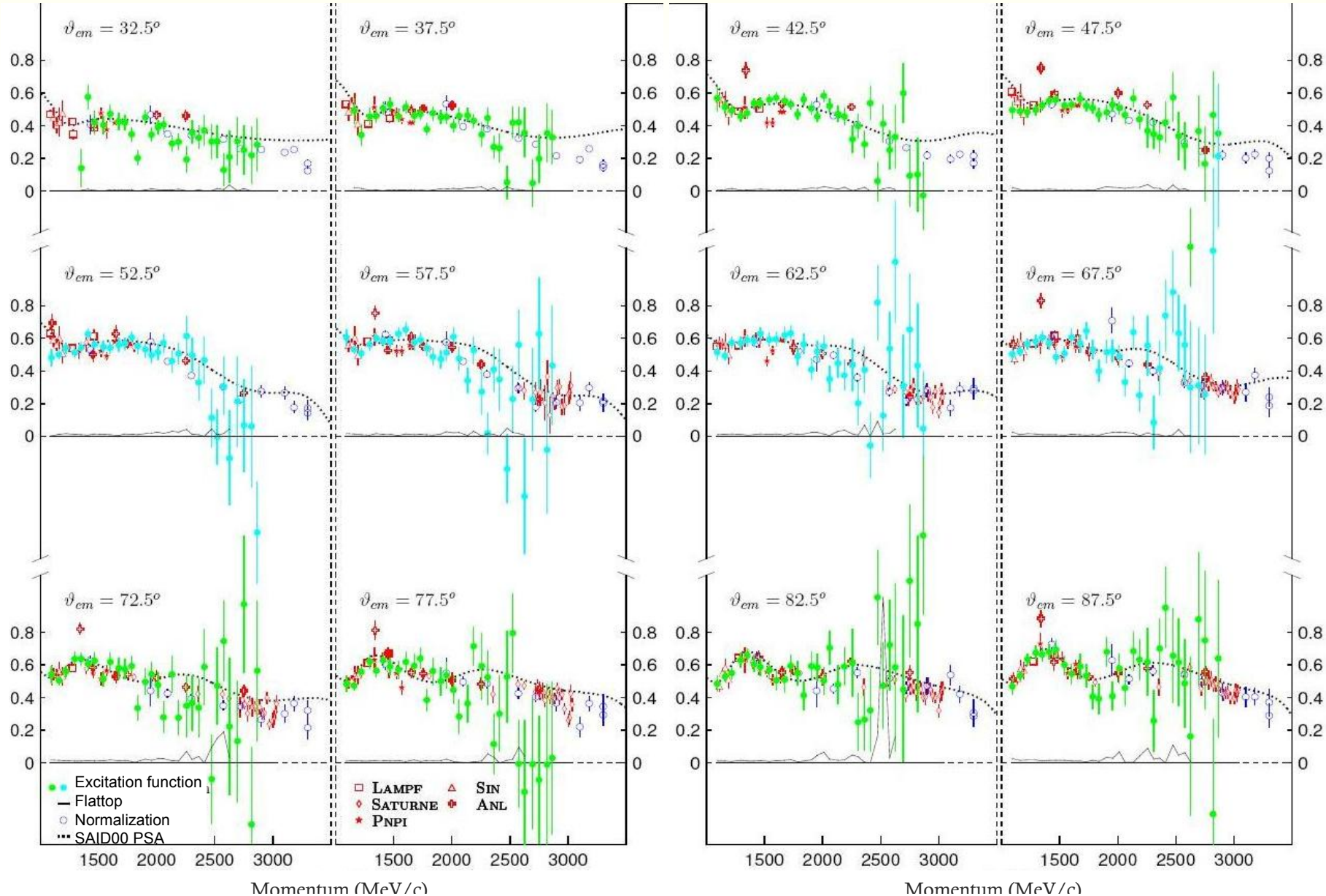
Inelastic Background



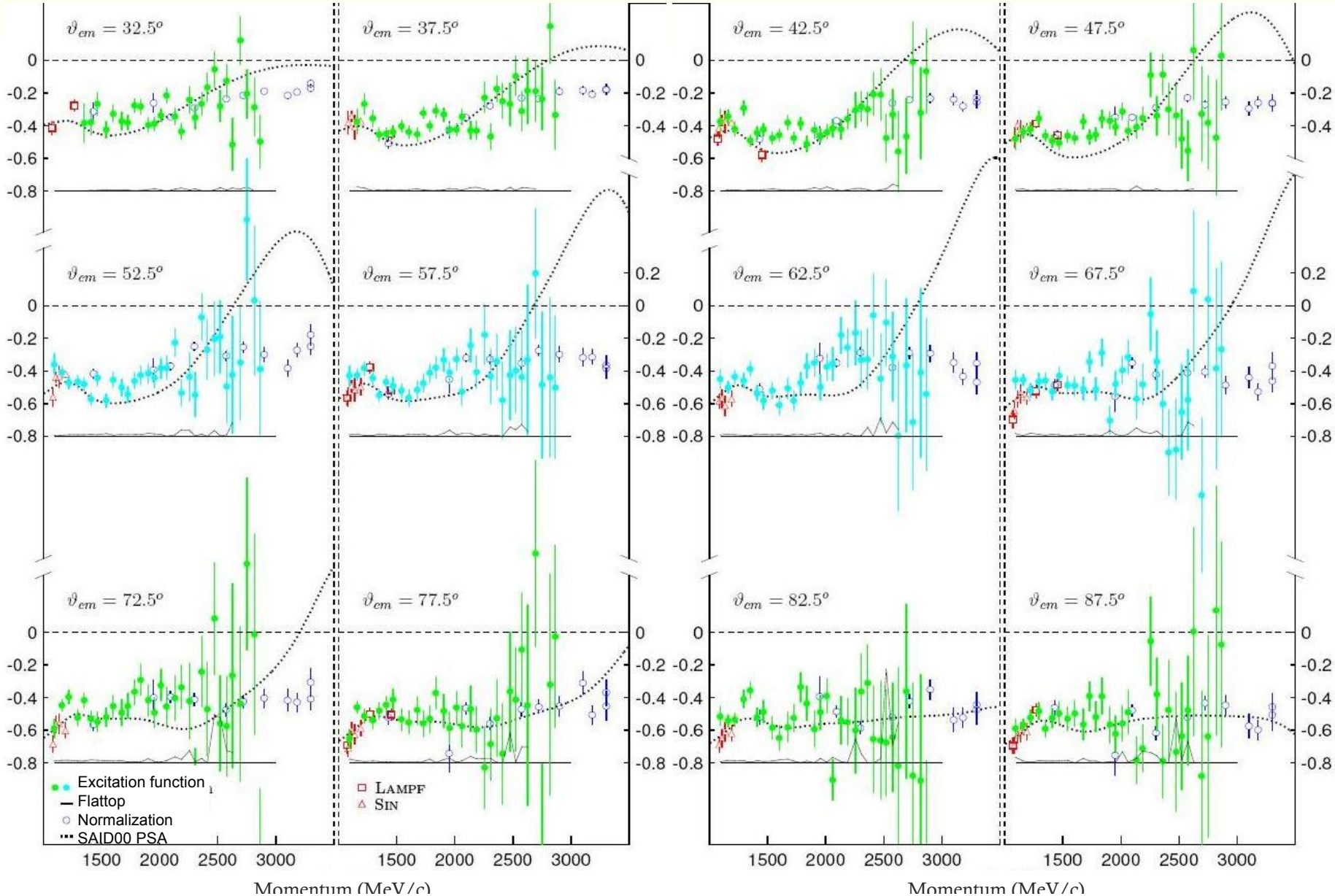




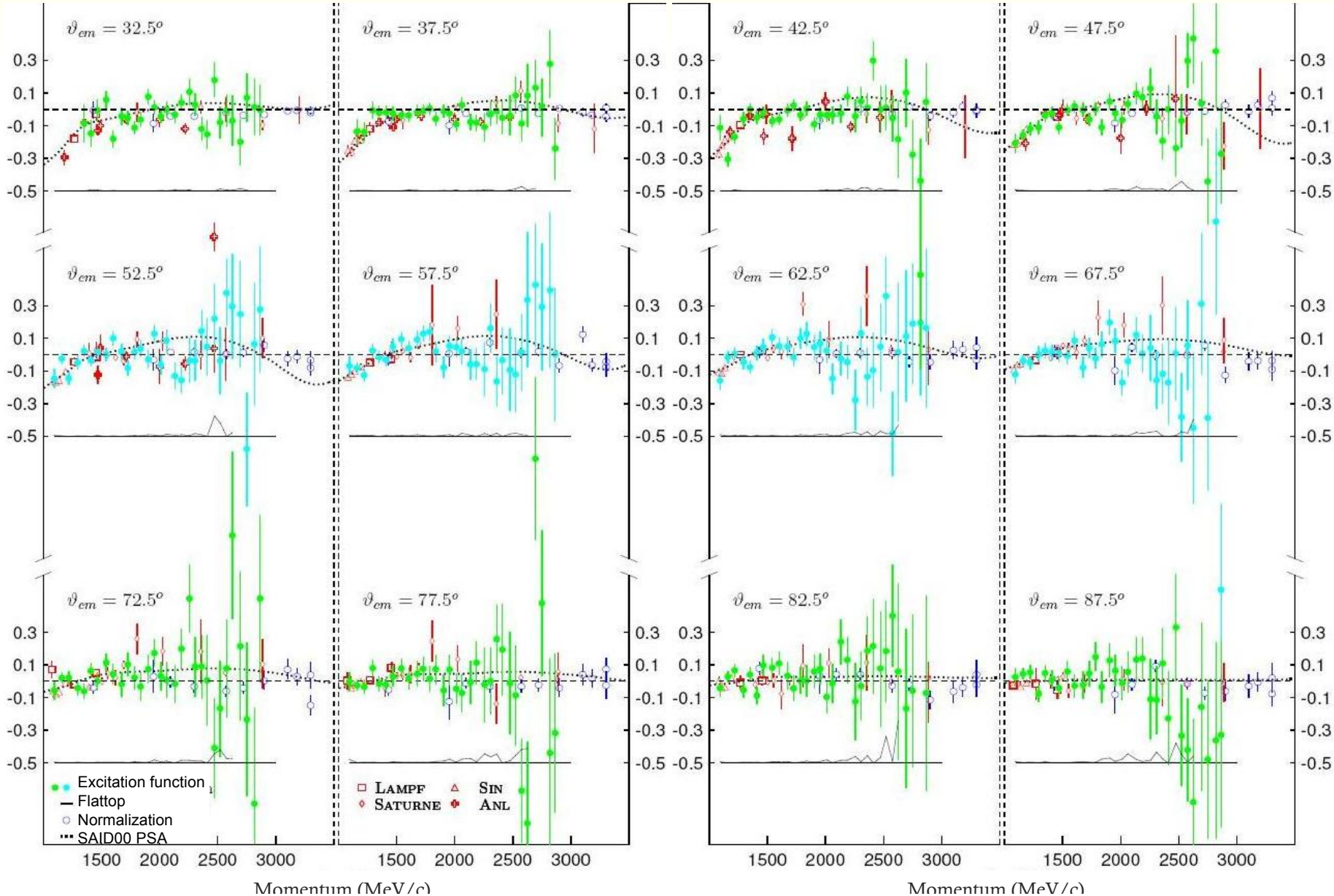
Excitation functions A_{NN}



Excitation functions A_{SS}



Excitation functions A_{SL}



Direct Reconstruction of Scattering Amplitude

Usually needs more than nine Observables

Only few energies

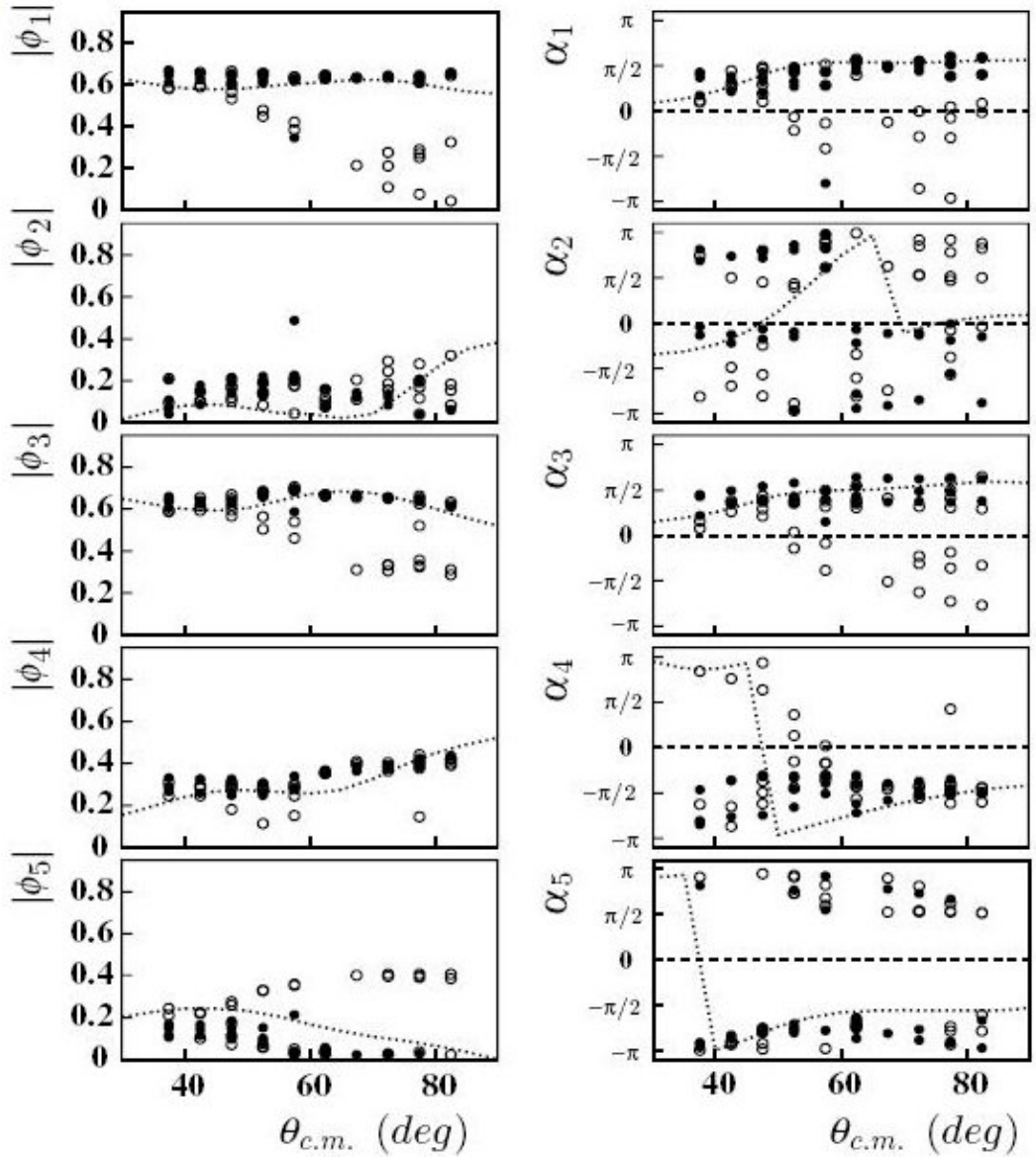
1300 MeV: 16

1600 MeV: 16

1800 MeV: 21 →

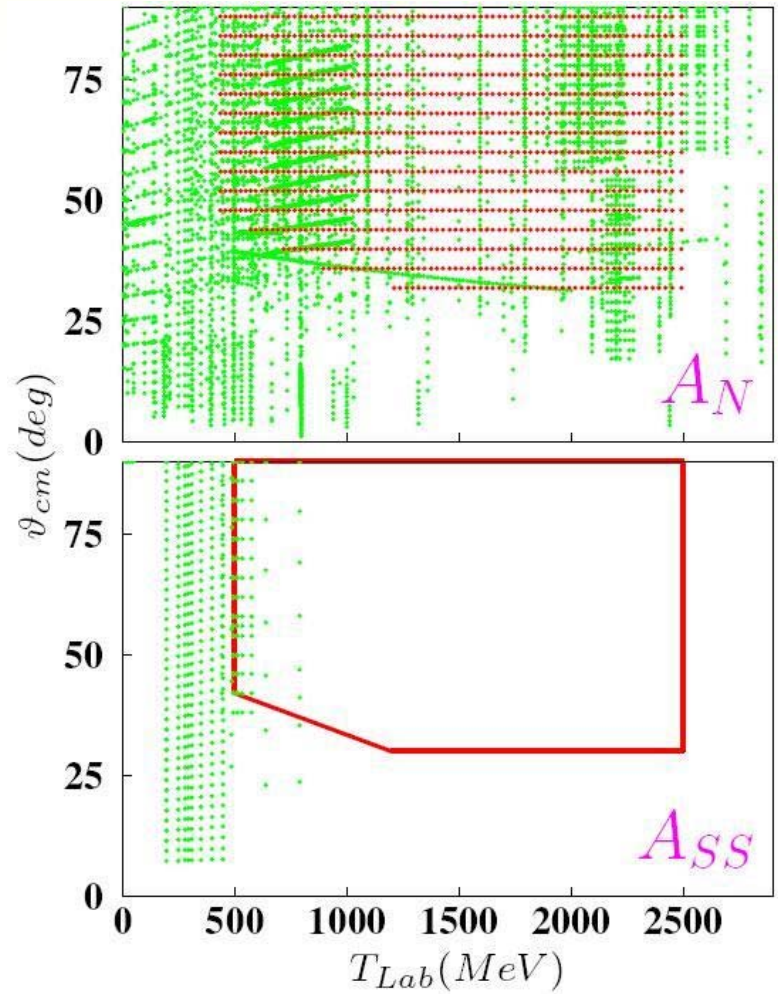
2100 MeV: 19

2400 MeV: 17



Summary

- Five observables of elastic p+p scattering
  - Statistical accuracy
  - Excitation functions for unpolarized and single polarized scattering
  - Excitation functions and fixed momentum for double polarized scattering
    - 3 · (343 + 120) data points
  - F. Bauer et al.
    Phys. Rev. C 71 (2005), 045002.
  - Internal consistency
  - First data for A_{SS} above 800 MeV



- Direct reconstruction of scattering amplitude for five energies
- Impact on new phase shift analyses
- Attempts of meson exchange model variations incorporating phenomenological Regge-effects on vector mesons
  O. Eyser, R. Machleidt, and W. Scobel
  Europ. Phys. J. A 22 (2005), 105