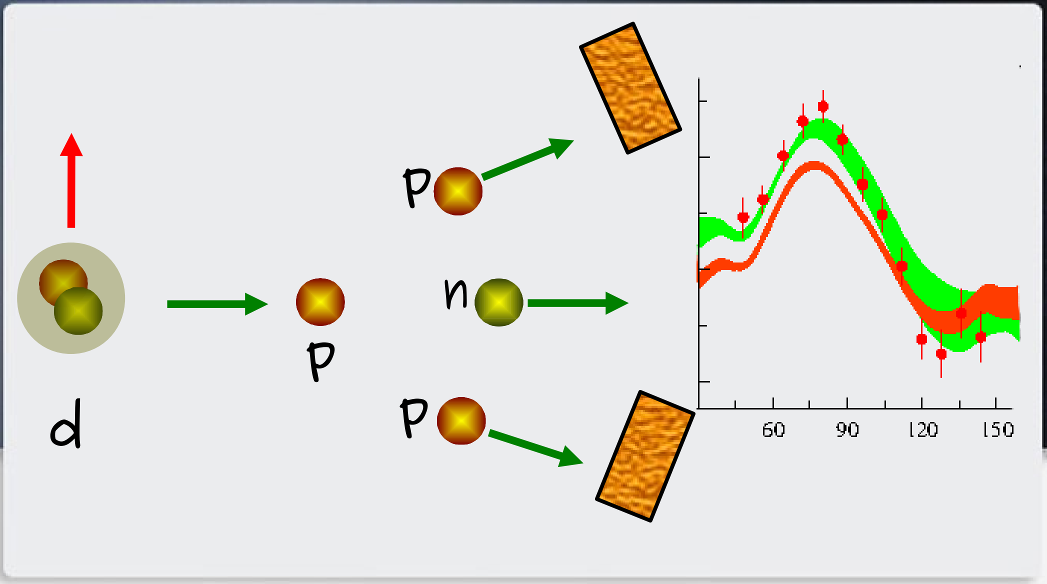
PSTP 2015

Polarized Sources, Targets and Polarimetry

Outline:

1. Goals and motivation,
2. Few-nucleon system dynamics,
3. Experiments with polarized deuteron beams,
4. Plans for ^{3}He polarized target at CCB.



Applications of Polarized Deuteron Beams for Studies of Few-Nucleon Dynamics in d-p Breakup

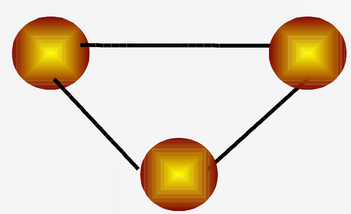
Izabela Ciepał

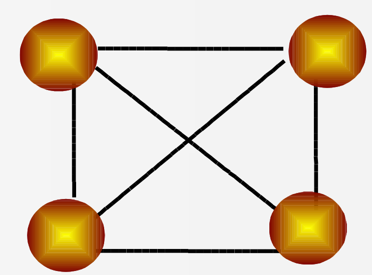
Institute of Nuclear Physics PAS

intermediate energies

50-200 MeV/A

2N, 3N, 4N





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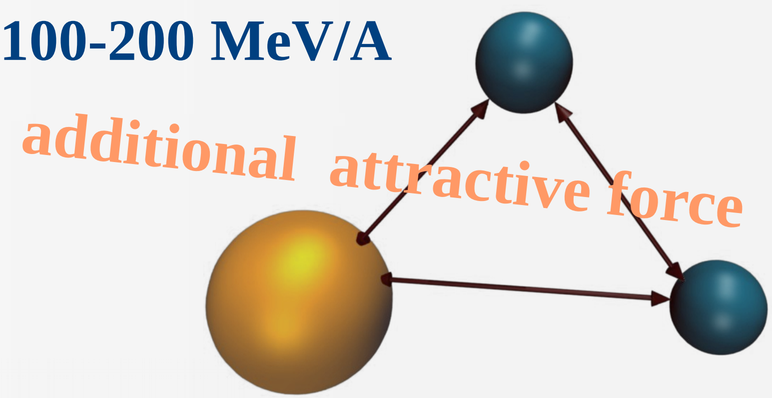
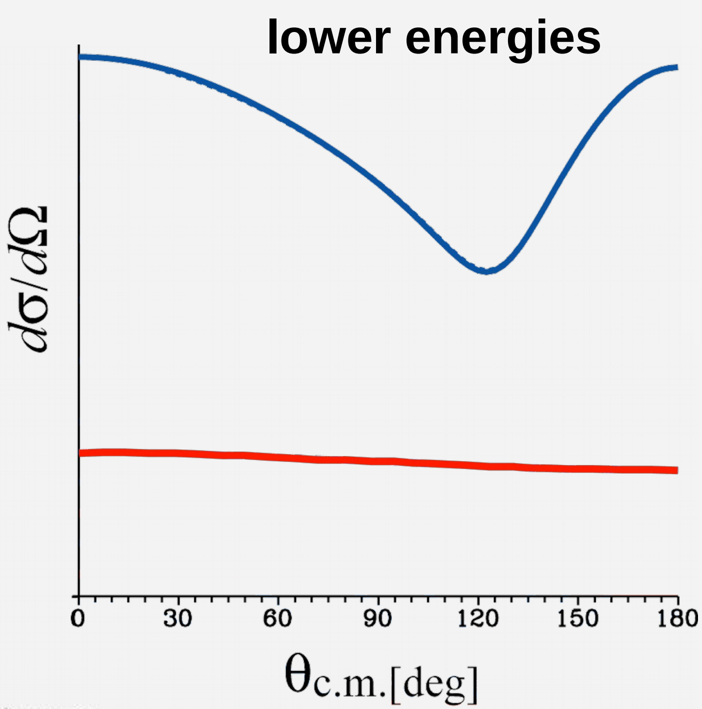
Motivations: studies of few-nucleon system dynamics

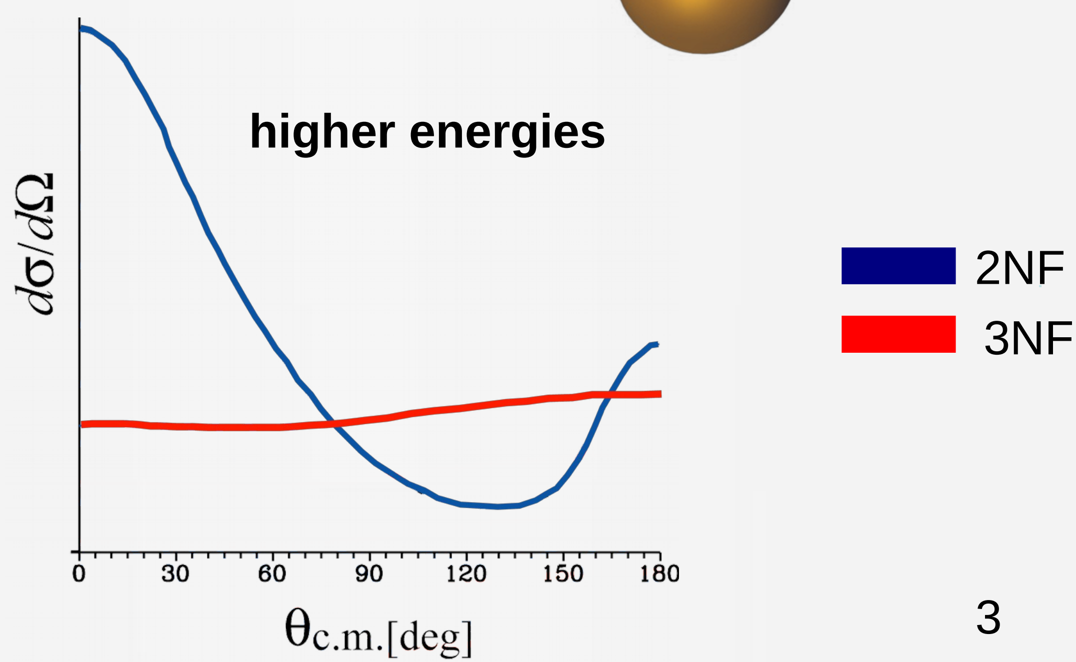
Predictions by H. Witala et al. (1998)

Cross-section minimum for Nd Scattering at 100-200 MeV/A

$$V = \sum V_{NN} + V_{3N}$$







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Motivations: studies of few-nucleon system dynamics

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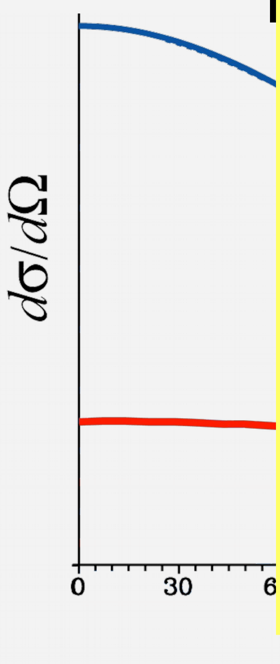
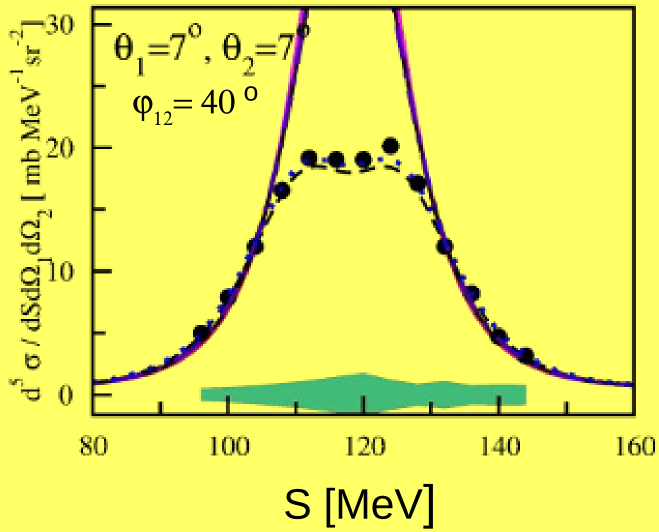


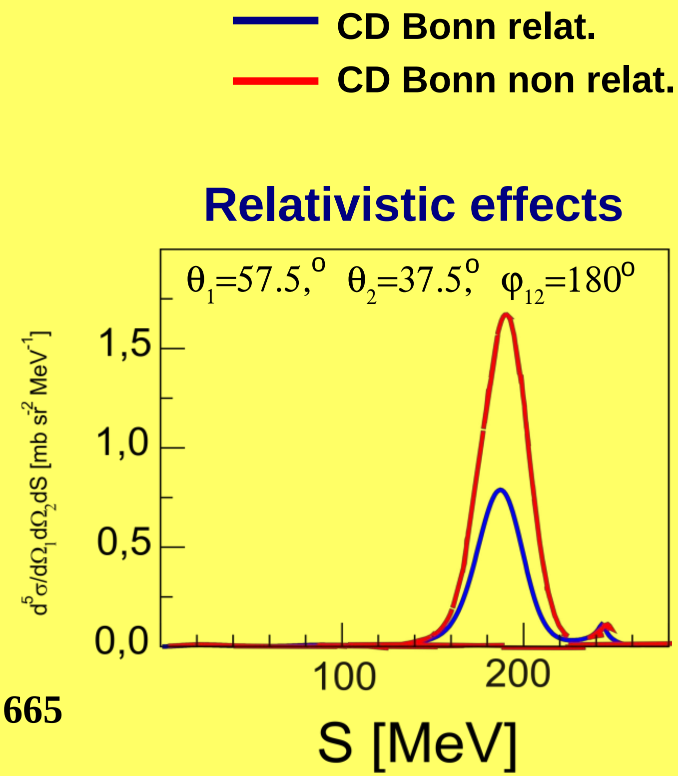
OTHER DYNAMICAL EFFECTS:

Coulomb effects



I. Ciepał *et al.*, Few-Body Sys. 56 (2015) 665

Relativistic effects



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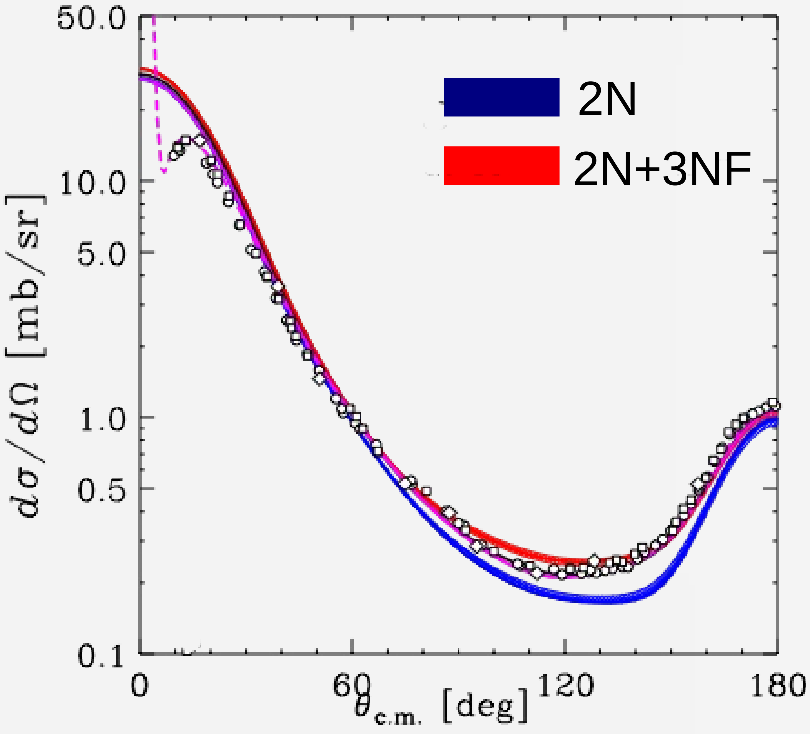
Motivations: studies of few-nucleon system dynamics

Discovery of ππ3NF in 1998



- 3N system - is *non-trivial* as compared to NN ones and probably reacher in dynamics,
- The nuclear potentials tested in those simple systems can be used in more complicated ones,
- To learn about nuclear interaction one needs to have:

✓ **Complete set of the observables (spin observables are crucial !) as possible**
✓ **Wide Angular Range**
✓ **High accuracy**

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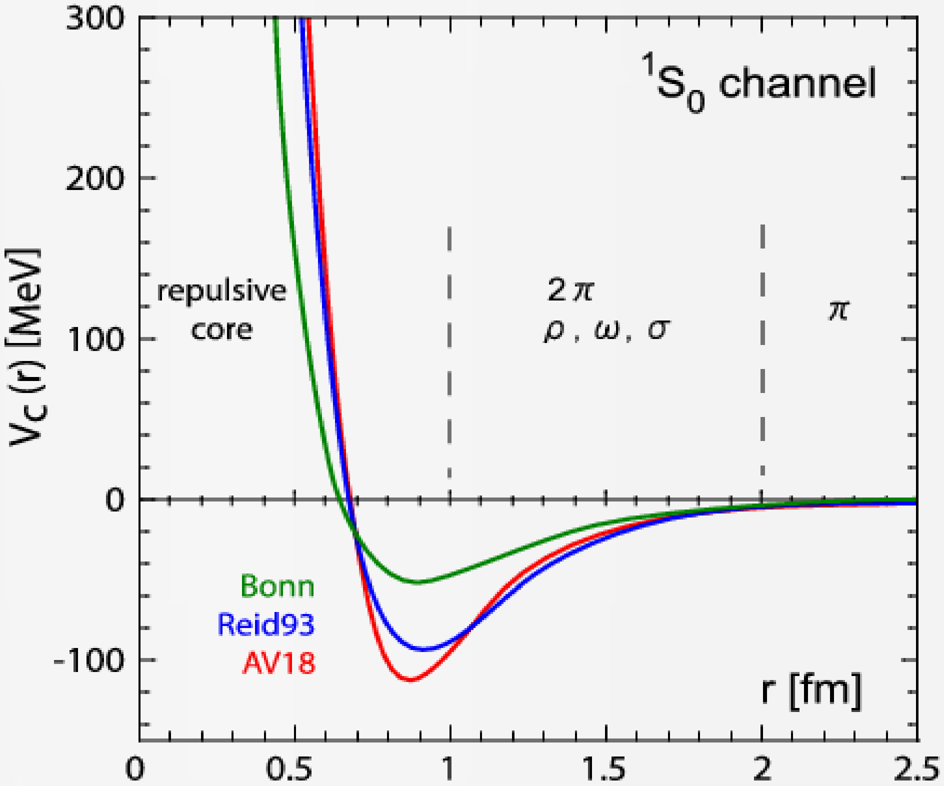
N-N potentials

Modern (realistic) phenomenological (+ meson exchange) N-N potentials:

2NF input:

- CD Bonn
- Argonne V18
- Nijmegen I, II
- …..



Comparison with experimental np&pp database (3 500) gives: χ^2/data ~ 1

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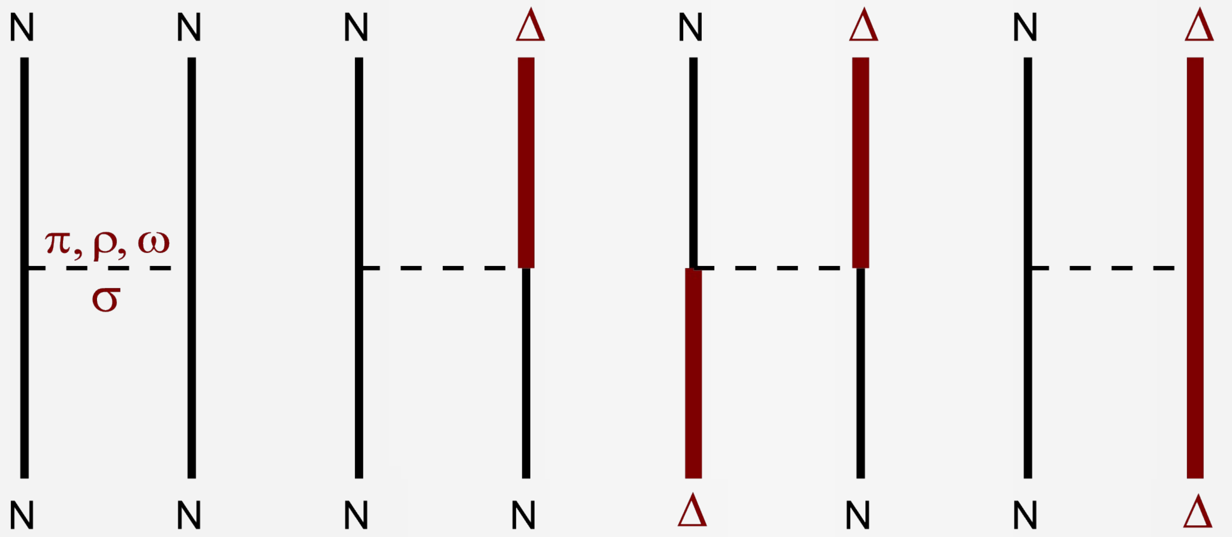
N-N potentials

Modern (realistic) phenomenological (+ meson exchange) N-N potentials:

Modified version of CD-Bonn potential (coupled-channel approach):



CD Bonn + Δ

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N-N potentials

Modern (realistic) phenomenological (+ meson exchange) N-N potentials:

Chiral perturbation theory (ChPT)
E. Epelbaum *et al.* :

- ✘ non-perturbative **QCD**
- ✘ a coupling of pions and nucleons in EFT
- ✘ self-consistent
- ✘ 1PE, 2PE
- ✘ LEC's – contact terms
- ✘ works only @ relatively low energies

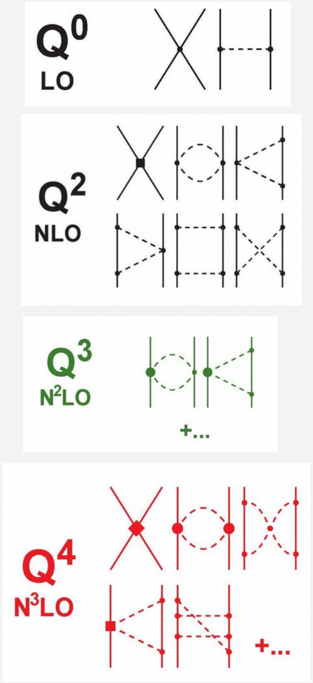
2N forces

Leading Order

Next-to Leading Order

Next-to-Next-to Leading Order

Next-to-Next-to-Next-to Leading Order



OBSERVABLES: Faddeev equations can be solved exactly!

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Phenomenological 3N forces

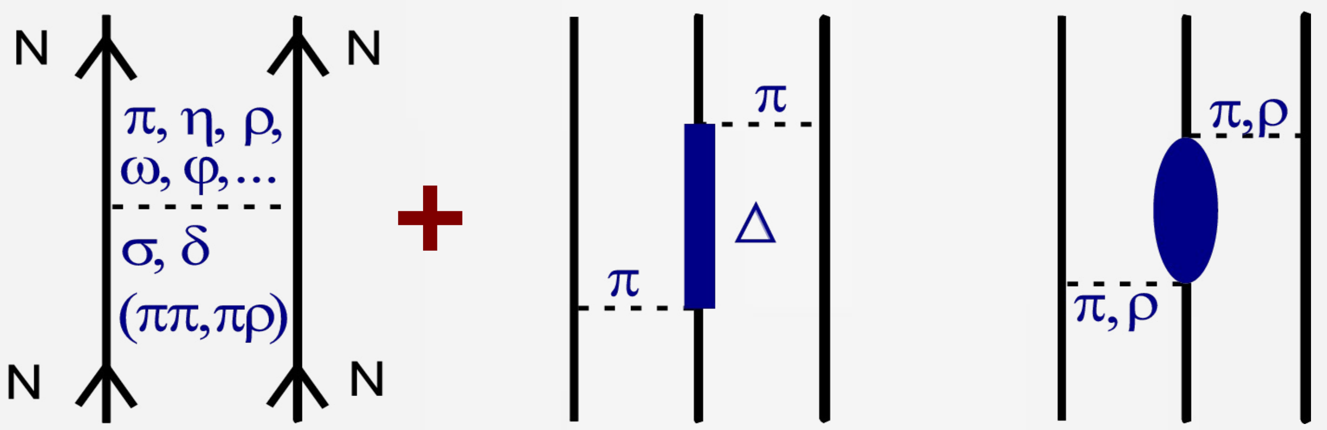
2NF input:

- CD Bonn
- Argonne V18
- Nijmegen I, II
- …..

\+

3NF input:

- Tucson-Melbourne TM99
- Urbana IX
- ……



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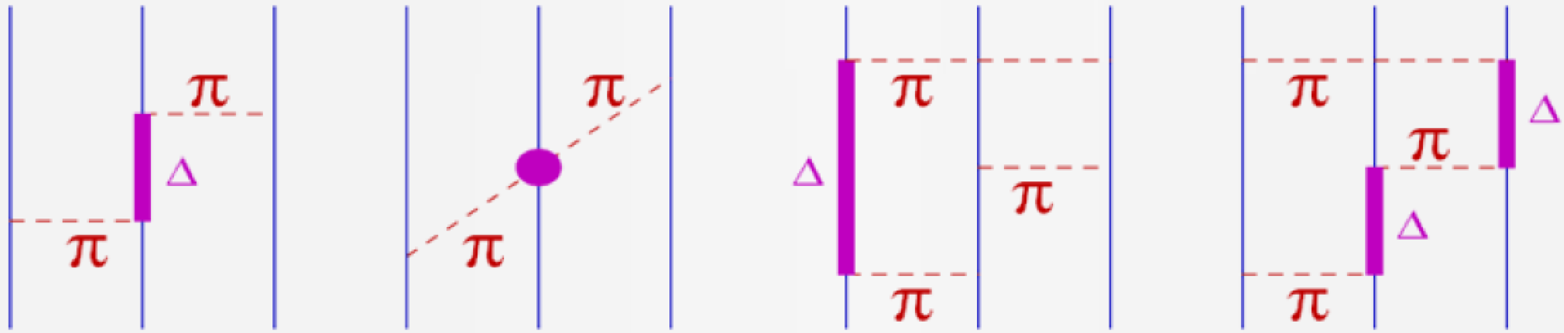
Phenomenological 3N forces



Fujita-Miyazawa,
Tucson-Melbourne,
Urbana IX,
Illinois, …

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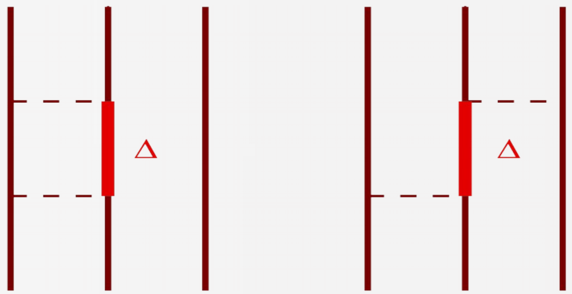
3NF models

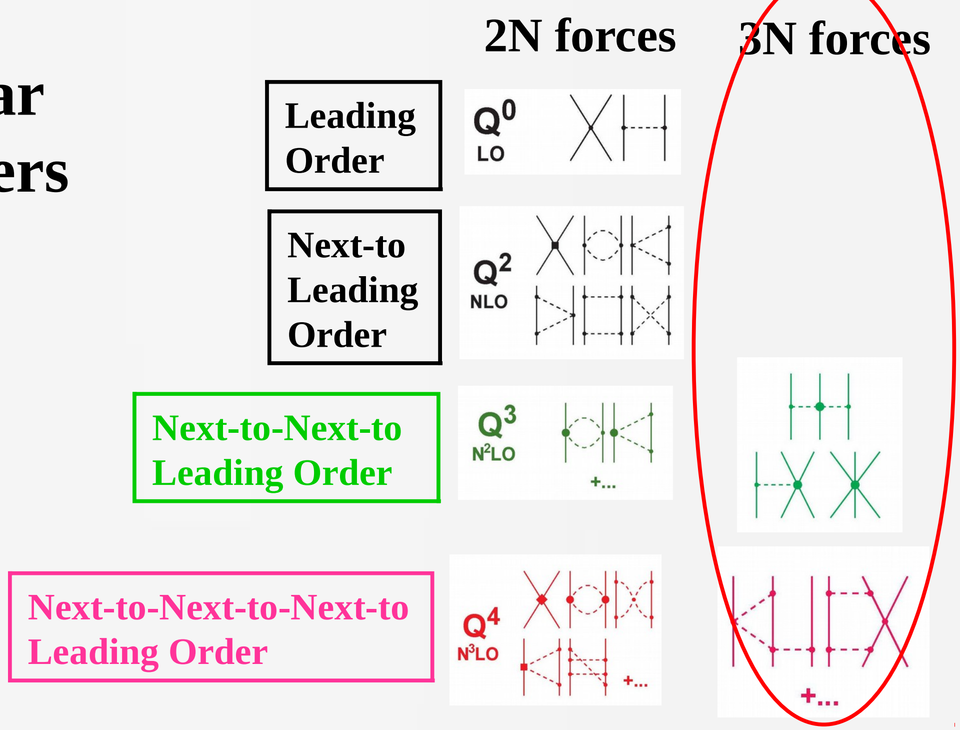
- **Virtual Δ−isobar mediates the 3NF**
- Self-consistent model which generates Fujita-Miyazawa 3NF, π-ring type 3NF, πρ, ρρ exchanges



- **ChPT: 3NF effects appear at N2LO and higher orders**

  3NF<<2NF
- accurate 2NF @ N4LO
- 3NF still is a challenge

Experimental challenge!



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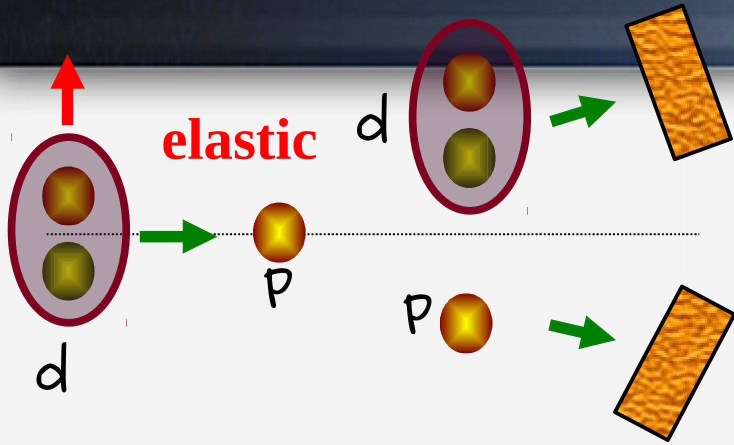
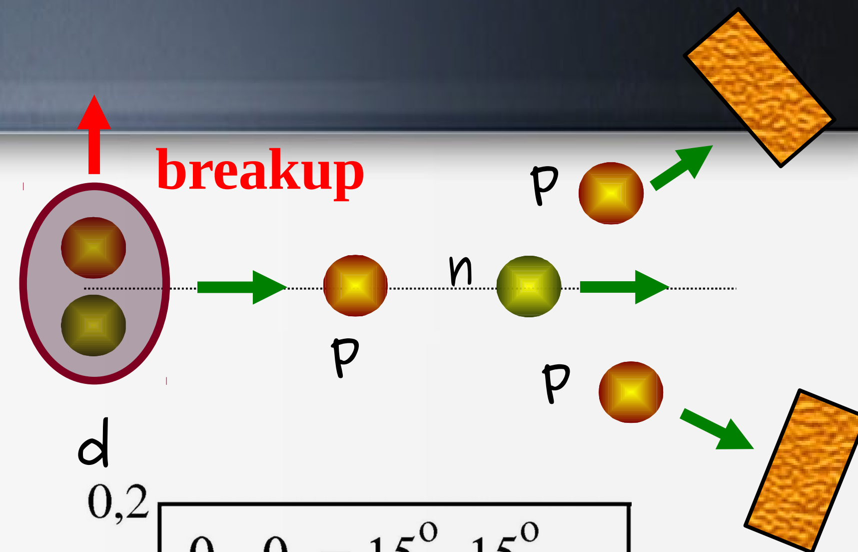
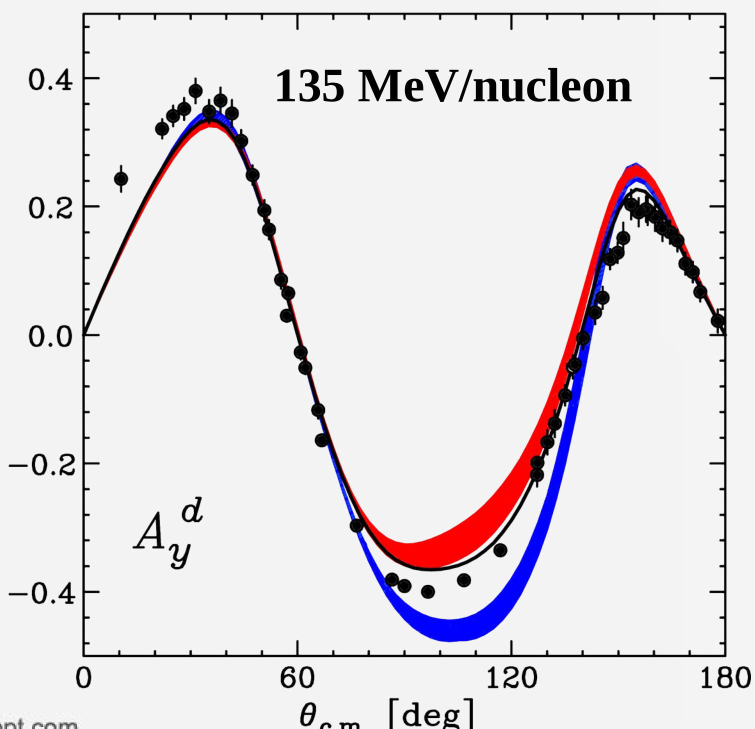
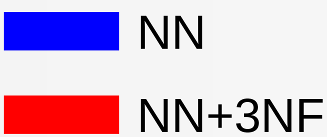
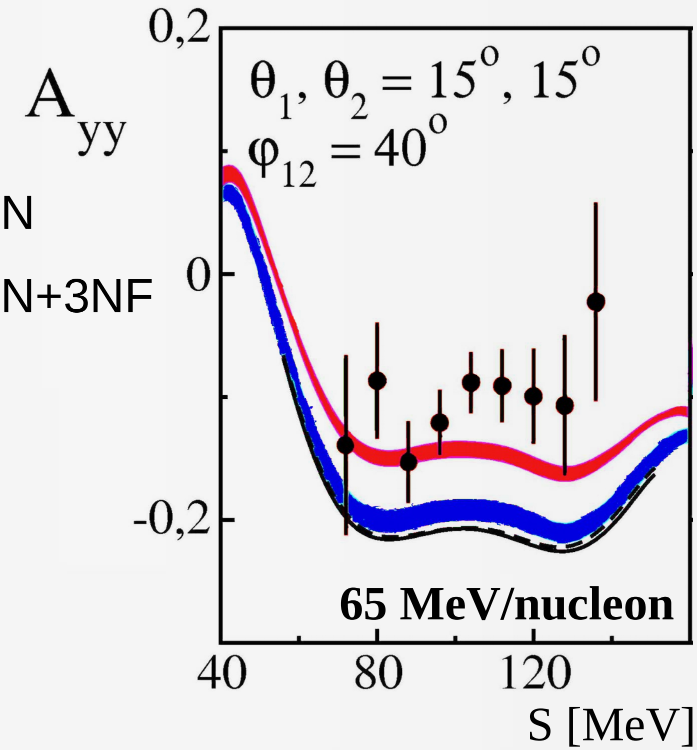
Experimental tools: scattering of $\vec{d}p$ system











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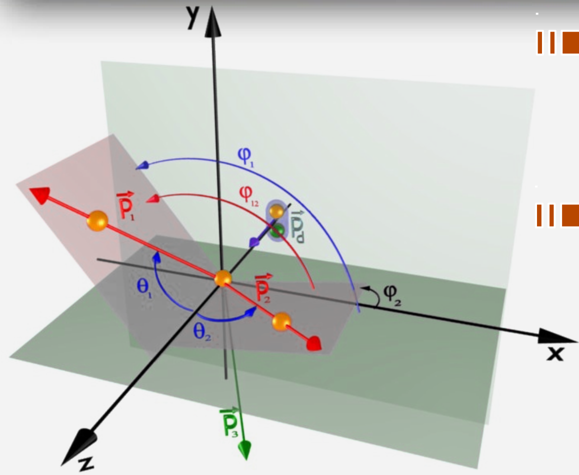
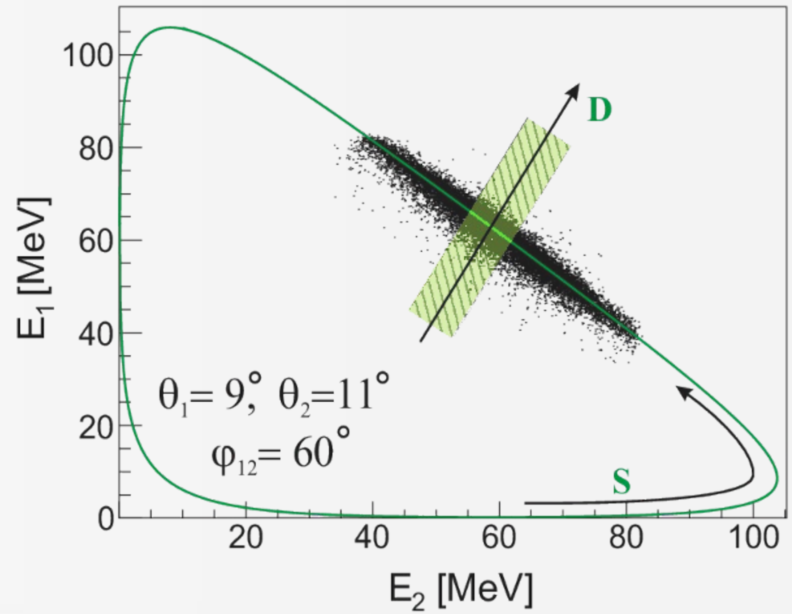
Breakup: N + d → N + N + N



- **deuteron-nucleon breakup** reaction is best suited to study 3N system dynamics
- **observables:** $d\sigma / d\Omega, A_i, A_{ij}, K_{ij}, C_{ij}$

arclength variable S

distance from kinematical curve D



- rich phase-space: a large amount of kinematical configurations
- selectivity
- leading channel @ inetrmediate energies

Five independent kinematical variables:

$\theta_1, \theta_2, \varphi_{12}=\varphi_1-\varphi_2, E_1, E_2$

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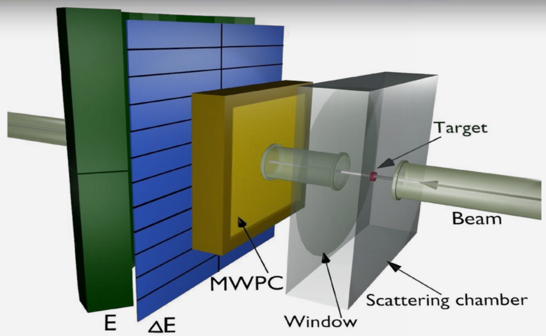
Experimental tools

$^{1}H(\vec{d}, pp)n$

SALAD

KVI

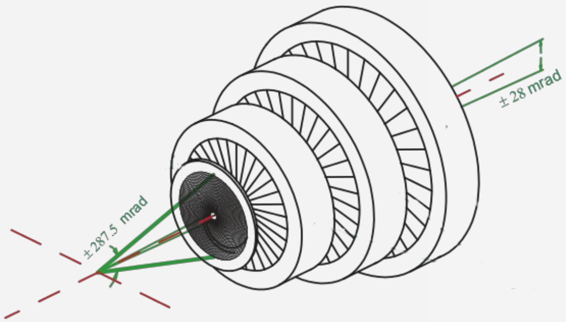


θ_{LAB} =15°- 40°

130 MeV

GEM

JÜLICH
FORSCHUNGSZENTRUM

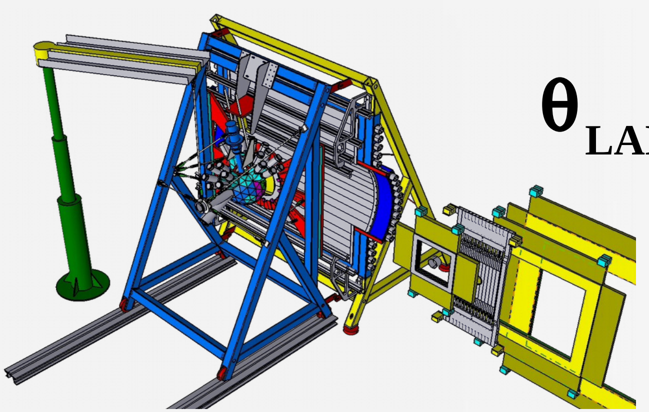


θ_{LAB} = 5°- 13°

130 MeV

BINA

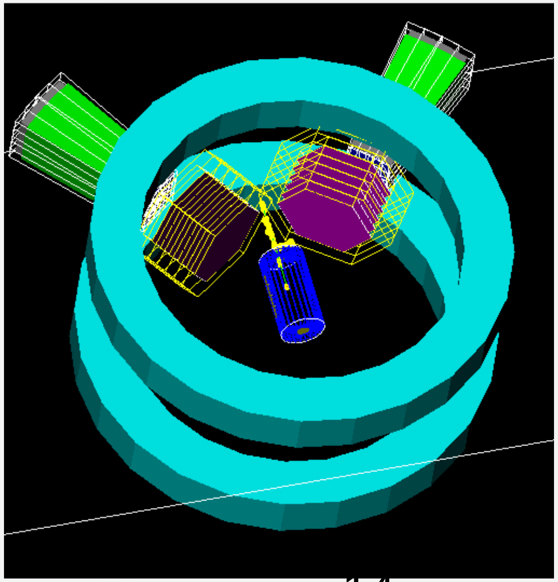
KVI



θ_{LAB} = 15°- 40°

100 MeV

future studies
PolHe-3 @ CCB



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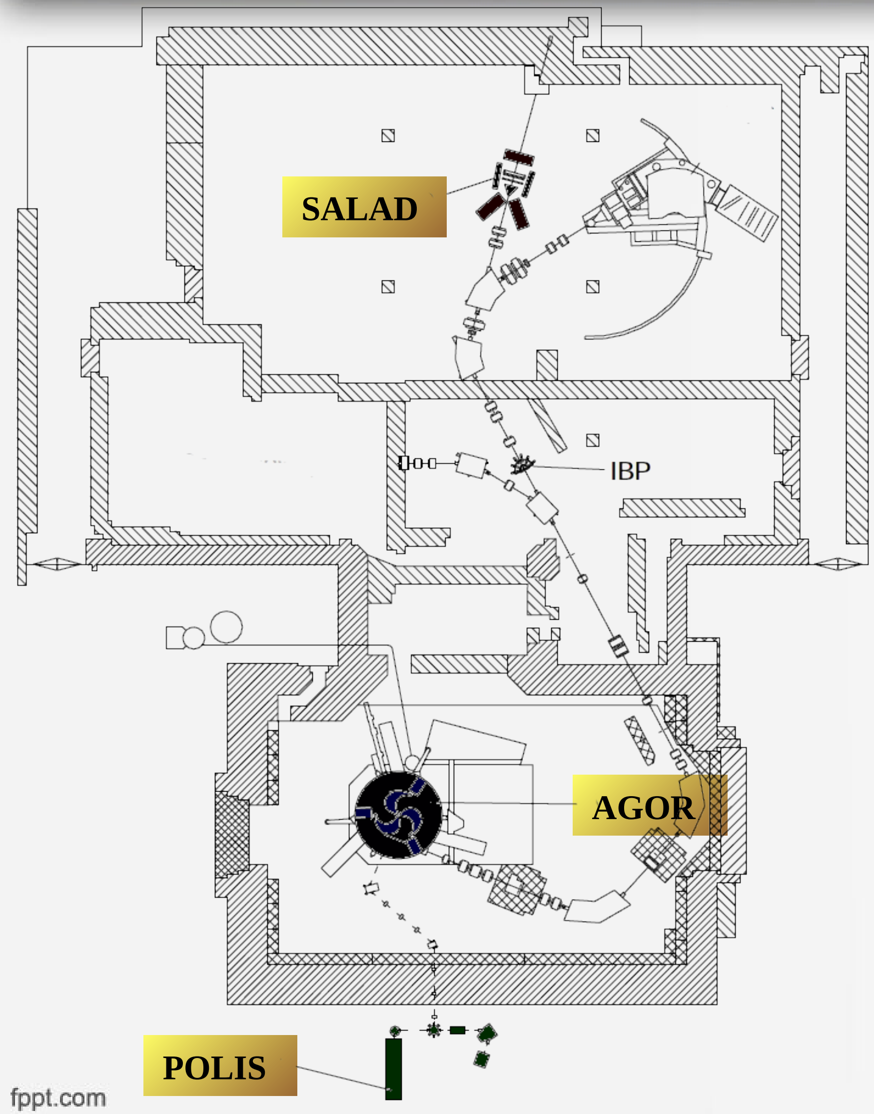
AGOR cyclotron



KVI atomic-beamtype Polarised Ion Source (POLIS)

- **hydrogen or deuterium atoms are aligned by selecting some of the atomic hyperfine sub-states**

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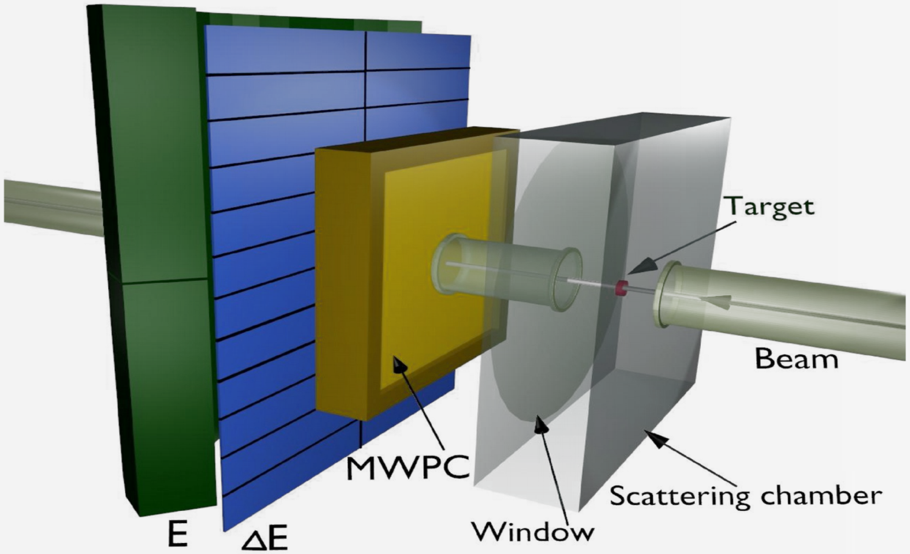
SALAD detector

- 140 ΔE-E telescopes
- 3-plane MWPC
- Angular range :
  θ = (12º, 38º), φ = (0º, 360º)



130 MeV SALAD 7 states:		ΔP_z 0.008	ΔP_{zz} 0.05
P_z^{max}	P_{zz}^{max}	P_z	P_{zz}
+1/3	-1	0.256	-0.757
+2/3	0	0.449	-0.118
-2/3	0	-0.444	0.050
0	+1	-0.068	0.556
0	-2	0.021	-1.340
+1/3	+1	0.198	0.672
0	0		

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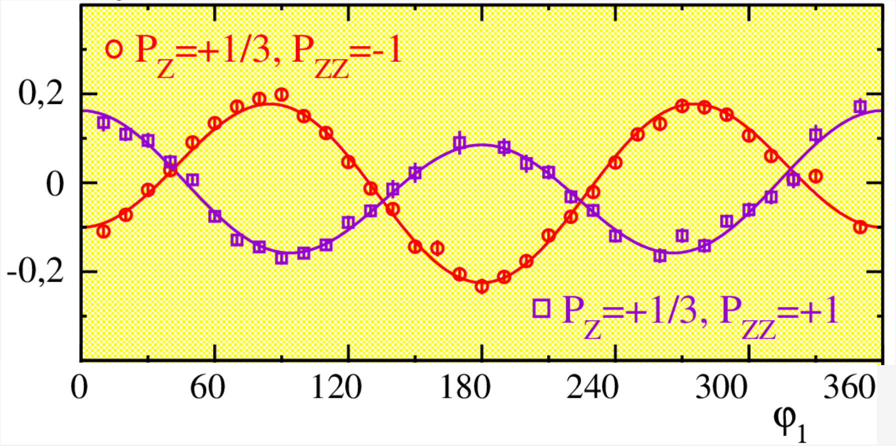
Beam polarization

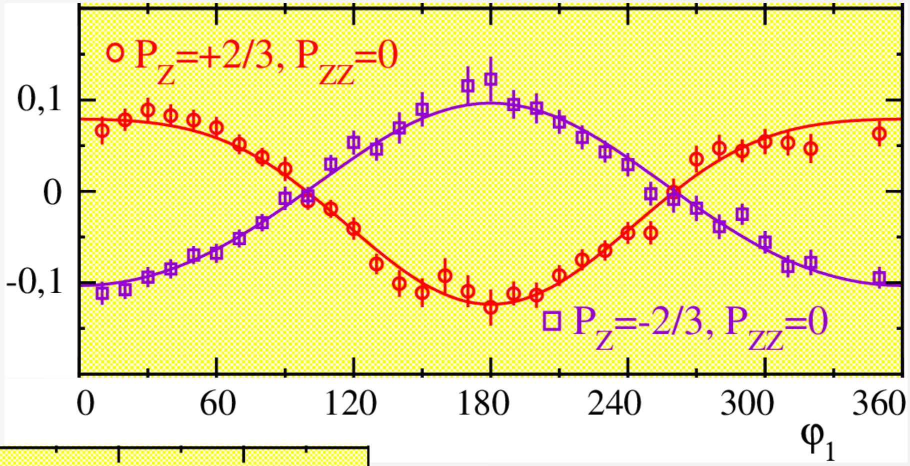
Elastic scattering cross section:

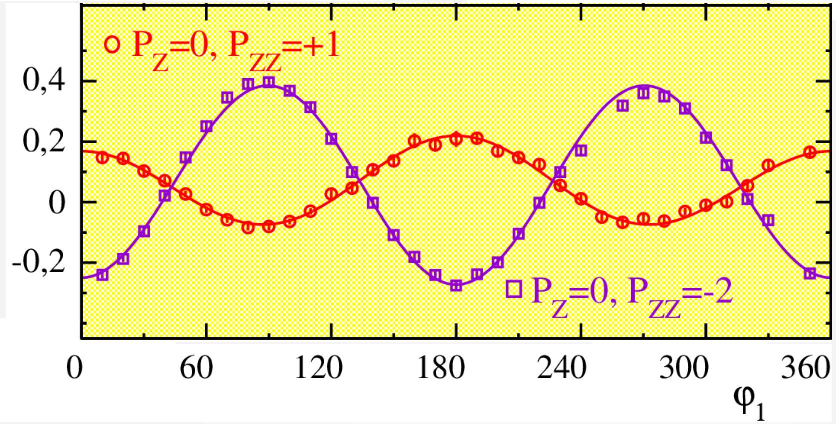
$$\sigma_P(\theta_p,\phi_p)=\sigma_0(\theta_p)\cdot\left[1+\sqrt{3}\cdot iT_{11}(\theta_p)\cdot P_z\cdot\cos\phi_p-\frac{\sqrt{3}}{2}\cdot T_{22}(\theta_p)\cdot P_{zz}\cdot\cos2\phi_p-\frac{\sqrt{2}}{4}\cdot T_{20}(\theta_p)\cdot P_{zz}\right]$$

$$\frac{N_P-N_0}{N_0}=a\cdot\cos\phi+b\cdot\cos2\phi+c$$

iT_{11}, T_{20}, T_{22} : measured at RIKEN, Eur. Phys. J. 31, 383 (2007)







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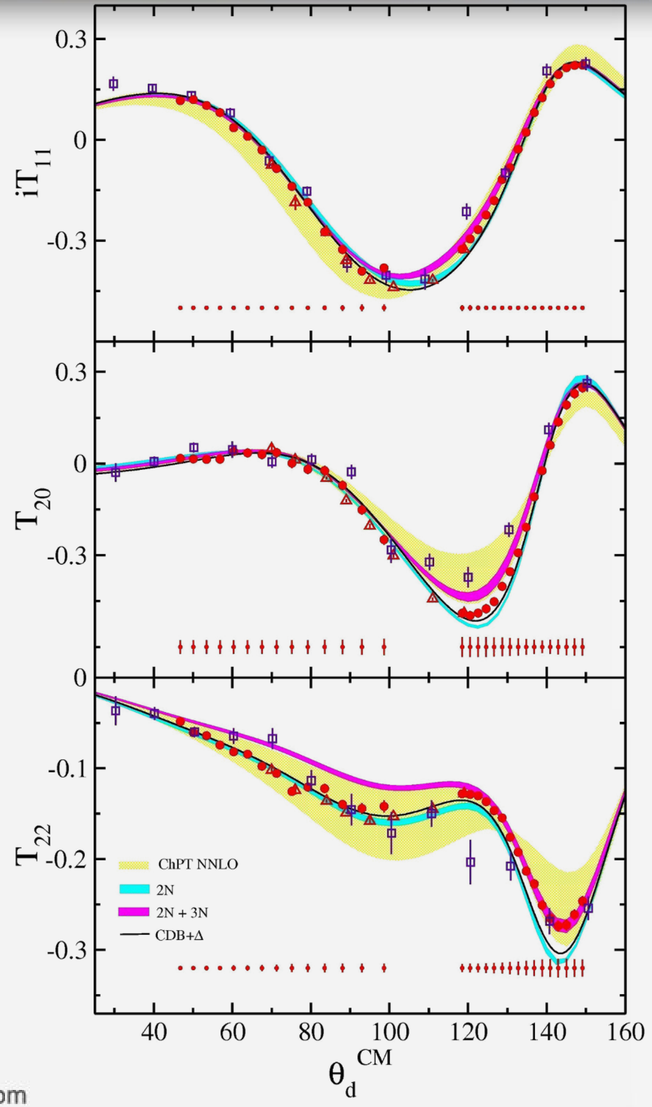
Elastic scattering - analyzing powers

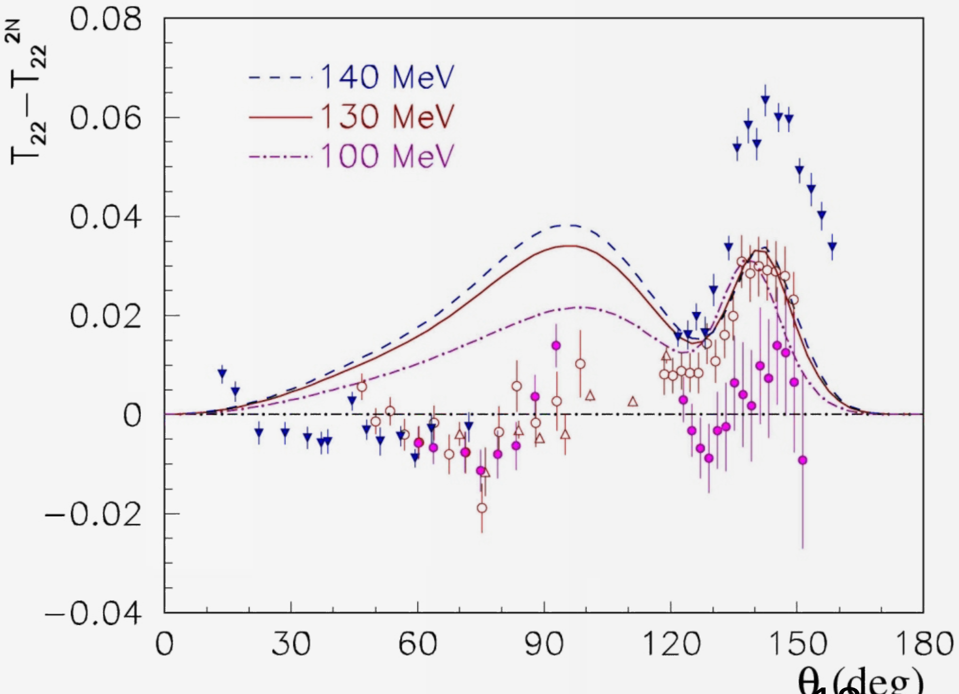
systematic studies

E. Stephan et al., Phys. Rev. C 76 (2007) 057001



data - T^{2N}_{22}

T^{2N+3NF}_{22} - T^{2N}_{22}



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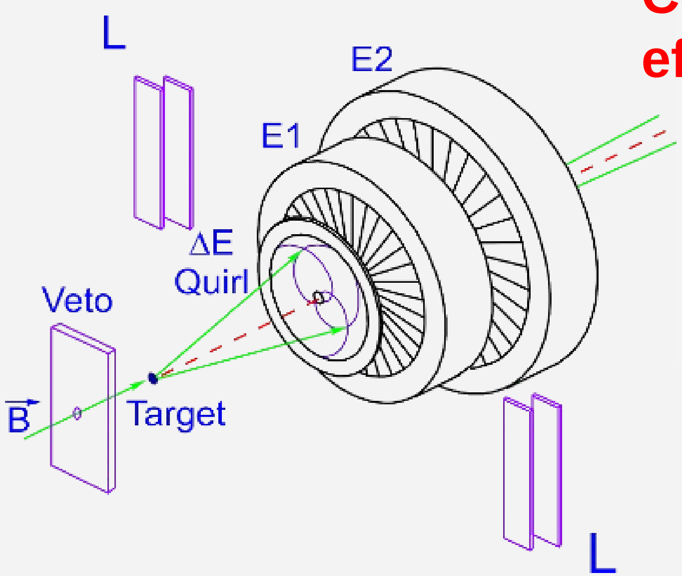
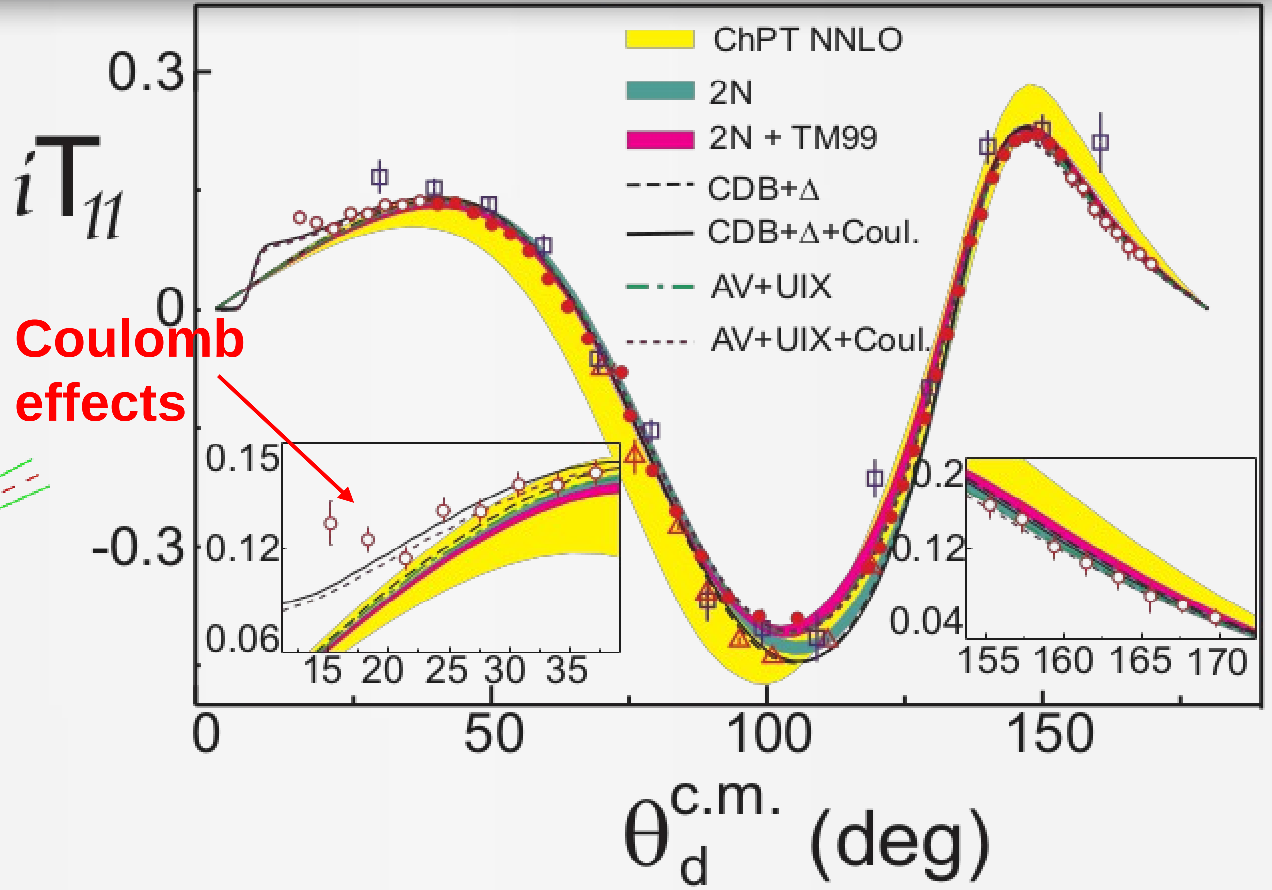
Elastic scattering - analyzing powers

GEM @ COSY





E. Stephan et al., Phys. Rev. C 76 (2007) 057001
I. Ciepał et al. Phys. Rev. C 85 (2012) 017001

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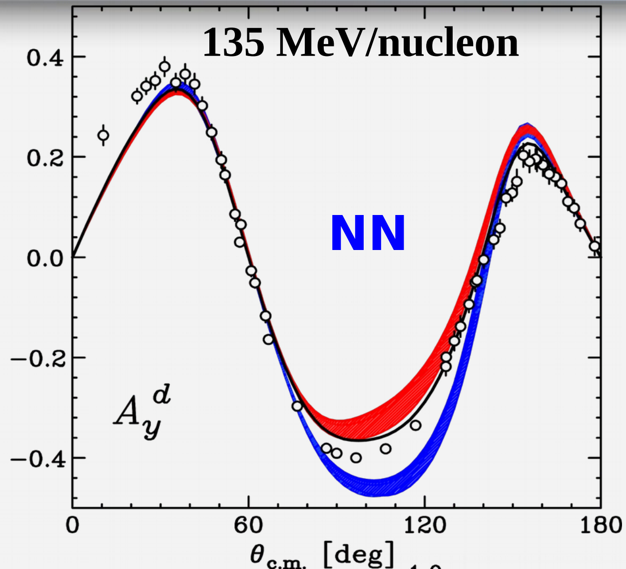
Elastic scattering & 3NF effects analyzing powers

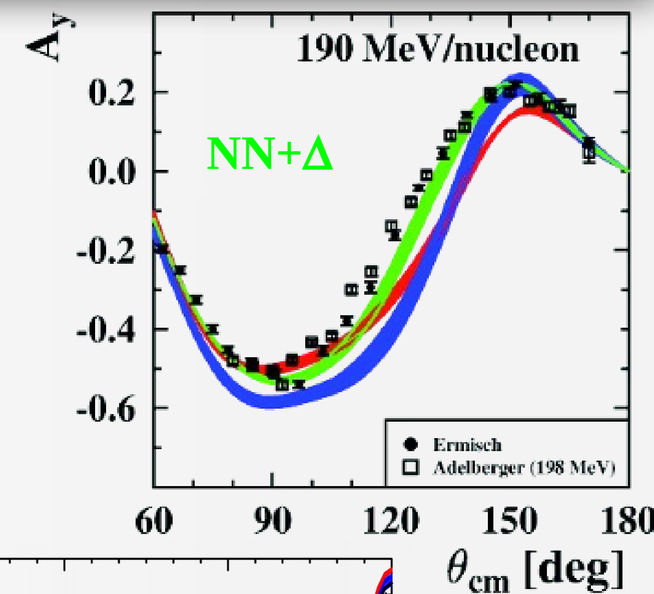


red: NN +TM3NF

blue: NN

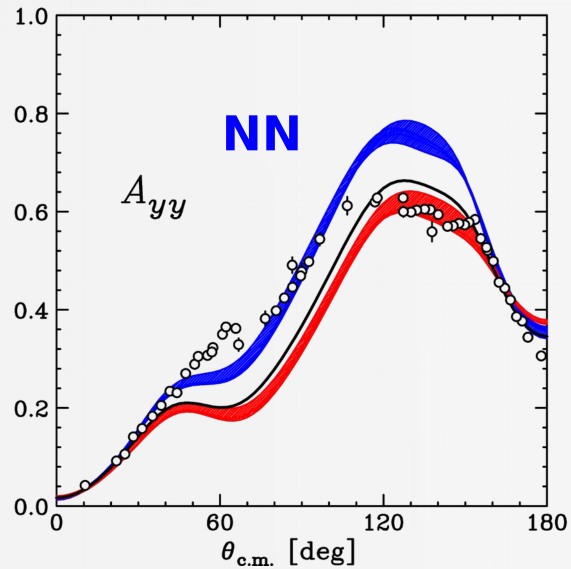
black: AV18 + UIX3NF

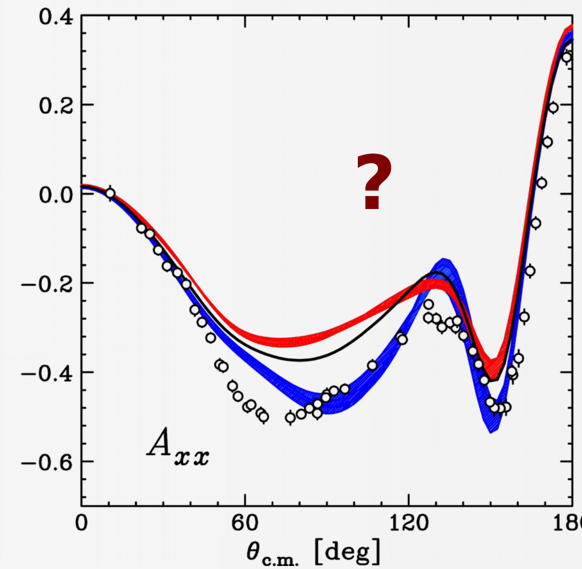
green: NN + Δ



RIKEN

K. Sekiguchi *et al.*,
PRC 65, 034003(2002)





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Breakup – analyzing powers

$$\sigma_p(\varsigma,\phi_1)=\sigma_0(\varsigma)\cdot[1+P_z\cdot\left(-\frac{3}{2}\sin\phi_1 A_x+\frac{3}{2}\cos\phi_1 A_y\right)+$$

$$P_{zz}\cdot\left(-\sin\phi_1\cos\phi_1 A_{xy}\right)+P_{zz}\cdot\left(\frac{1}{2}\sin^2\phi_1 A_{xx}+\frac{1}{2}\cos^2\phi_1 A_{yy}\right)]$$

$$\varsigma=(\theta_1,\theta_2,\phi_{12},S)$$

$$\frac{N_P-N_0}{N_0}=a\cdot\sin\phi_1+b\cdot\cos\phi_1+c\cdot\sin\phi_1\cdot\cos\phi_1+d\cdot\sin^2\phi_1+e\cdot\cos^2\phi_1$$

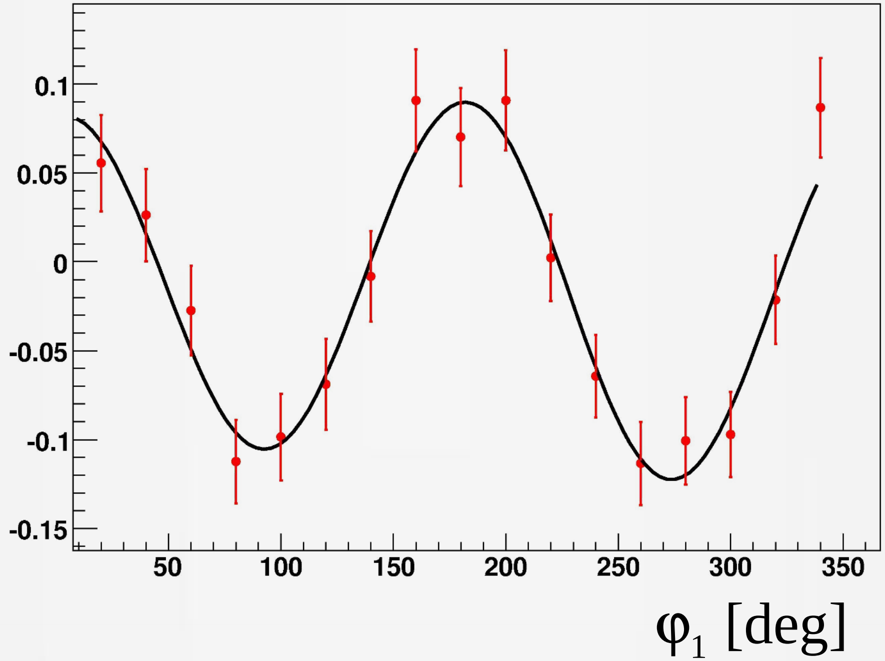
$$a=-\frac{3}{2}P_z A_x(\varsigma)$$

$$b=\frac{3}{2}P_z A_y(\varsigma)$$

$$c=-P_{zz}A_{xy}(\varsigma)$$

$$d=\frac{1}{2}P_{zz}A_{xx}(\varsigma)$$

$$e=\frac{1}{2}P_{zz}A_{yy}(\varsigma)$$



$\theta_1=25^o$

$\theta_2=20^o$

$\phi_{12}=120^o$

$S=96\,MeV$

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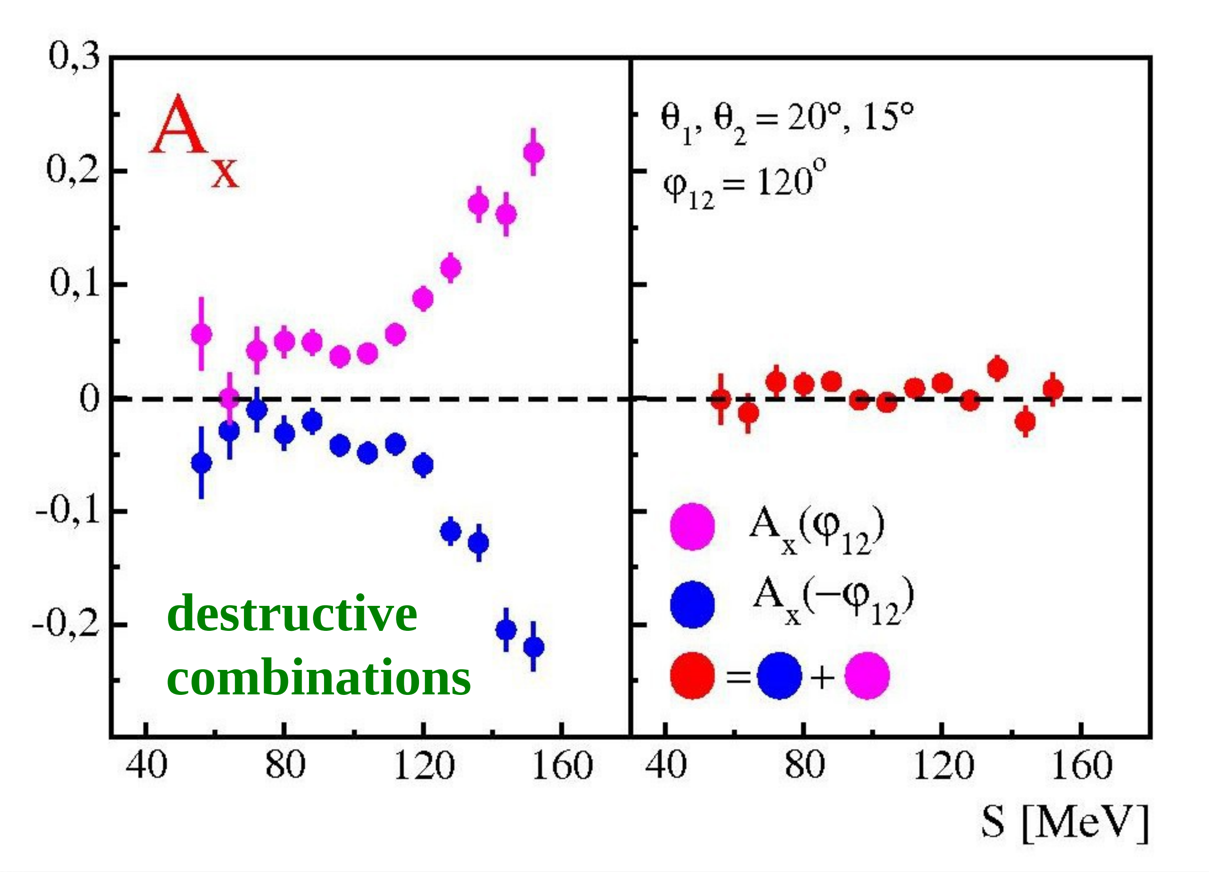
Parity restriction check

even observables: A_y, A_{xx}, A_{yy}

odd observables: A_x, A_{xy}

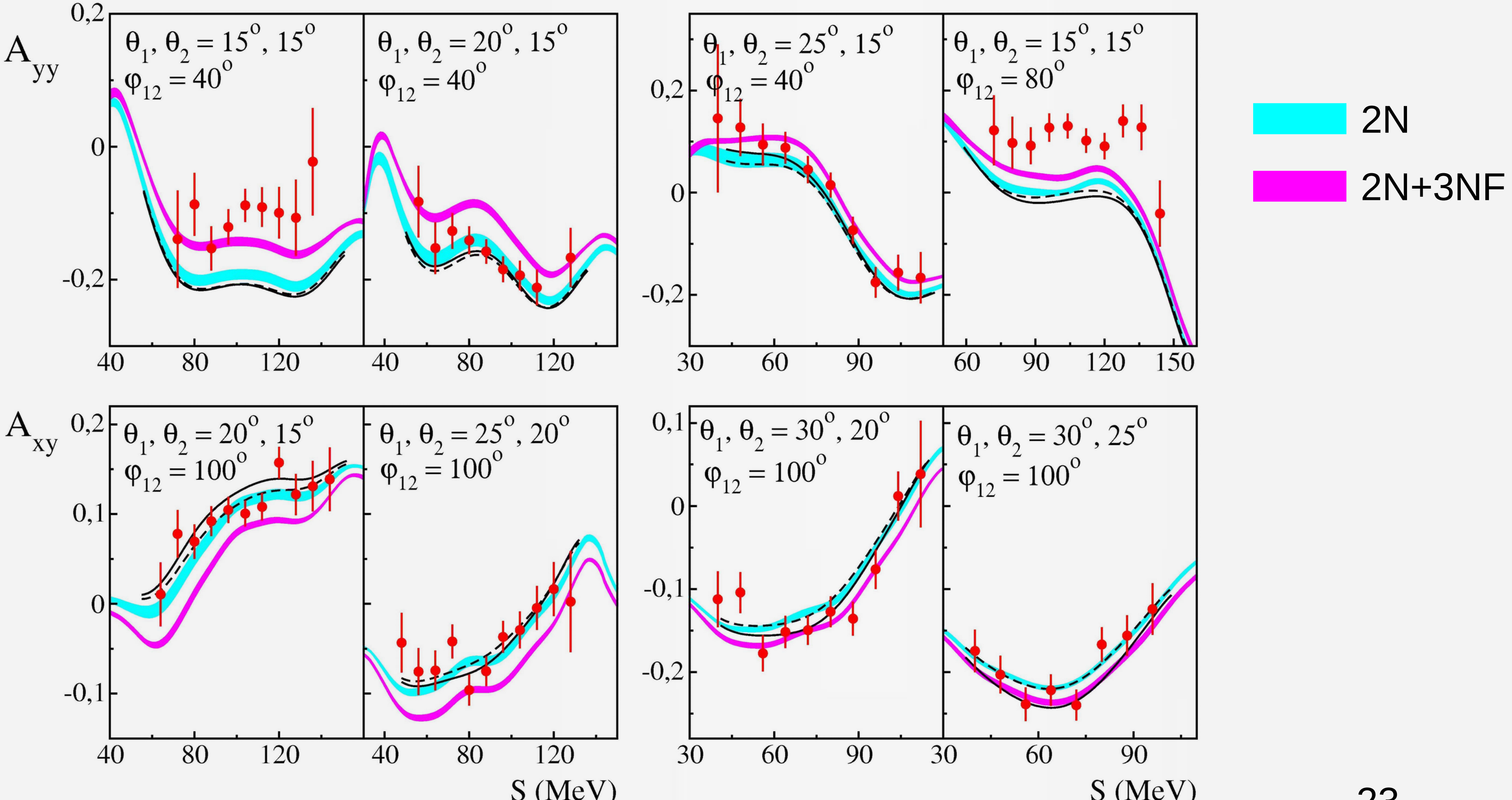
$$\varsigma' = (\theta_1, \theta_2, S)$$

$$A_x(\varsigma', \phi_{12}) = -A_x(\varsigma', -\phi_{12})$$



➔ **control of the data consistency - agreement with zero**

Breakup – analyzing powers @ 130 MeV



E. Stephan *el al*., Phys. Rev. C 82(2010) 014003

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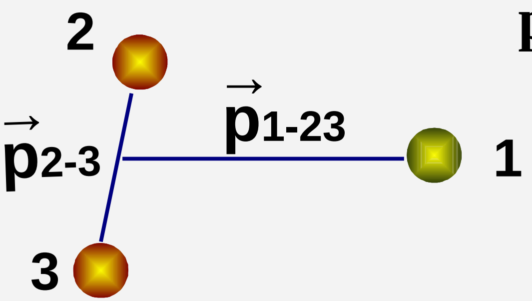
Analyzing powers - independent variables

Jacobi momenta – defined as relative momentum of 2 particles in the 2-body subsystem of the 2 breakup protons:

p(a)+d(b) → p(2)+p(3)+n(1)



modified to *intuitive* energy variables

$$s_{pp} = (p_{p1} + p_{p2})^2$$
$$s_{pn} = (p_{p1} + p_n)^2$$
$$t_n = (p_d/2 - p_n)^2$$
$$t_p = (p_p - p_{p2})^2$$

$$E_{rel}^{pp} = \sqrt{s_{pp}} - 2m_p$$
$$E_{rel}^{pn} = \sqrt{s_{pn}} - m_p - m_n$$
$$E_{tr}^{p} = \frac{-t_p}{2m_p}$$
$$E_{tr}^{n} = \frac{-t_n}{2m_n}$$

FSI:	$E_{rel}^{pp} = 0$ $E_{rel}^{pn} = 0$
QFS:	$E_{tr}^{p} = 0$ $E_{tr}^{n} = 0$

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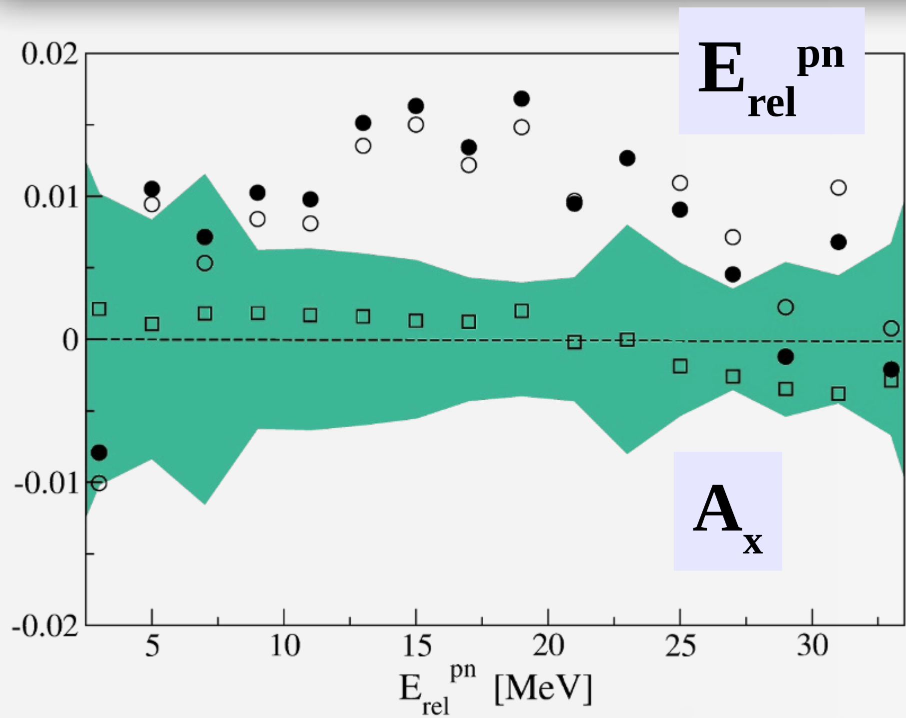
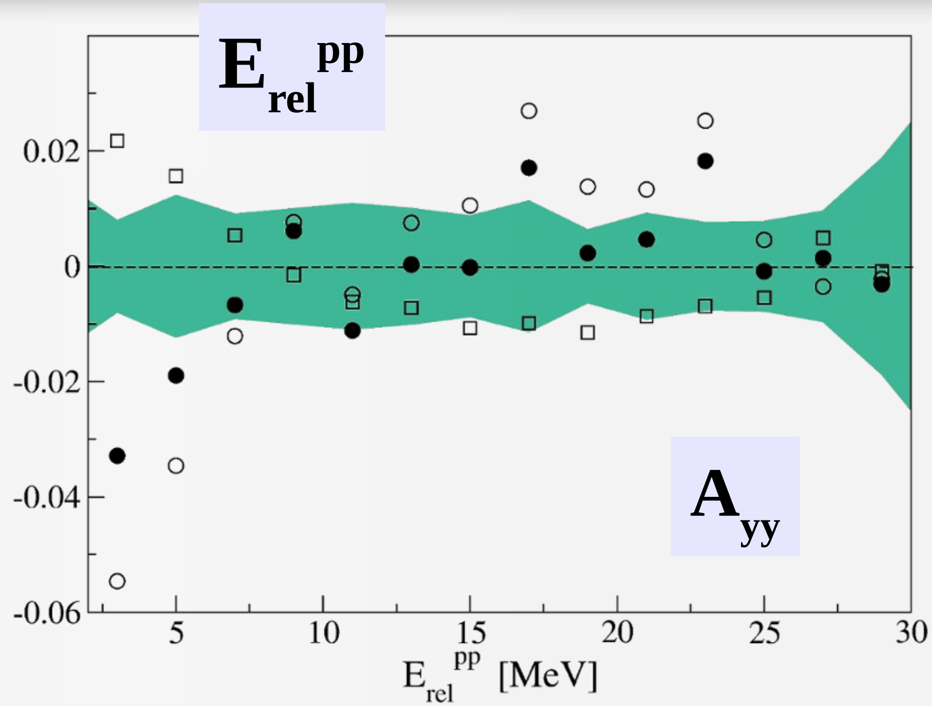
Analyzing powers - independent variables

Coulomb force effects – 1D spectra





□ A_i (AV18+UIX+C) -A_i (AV18+UIX)

● A_i (data) -A_i (AV18+UIX)

○ A_i (data) -A_i (AV18+UIX+C)

➔ **including the Coulomb force worsens the data description**

STATISTICAL ERRORS

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Analyzing powers - independent variables

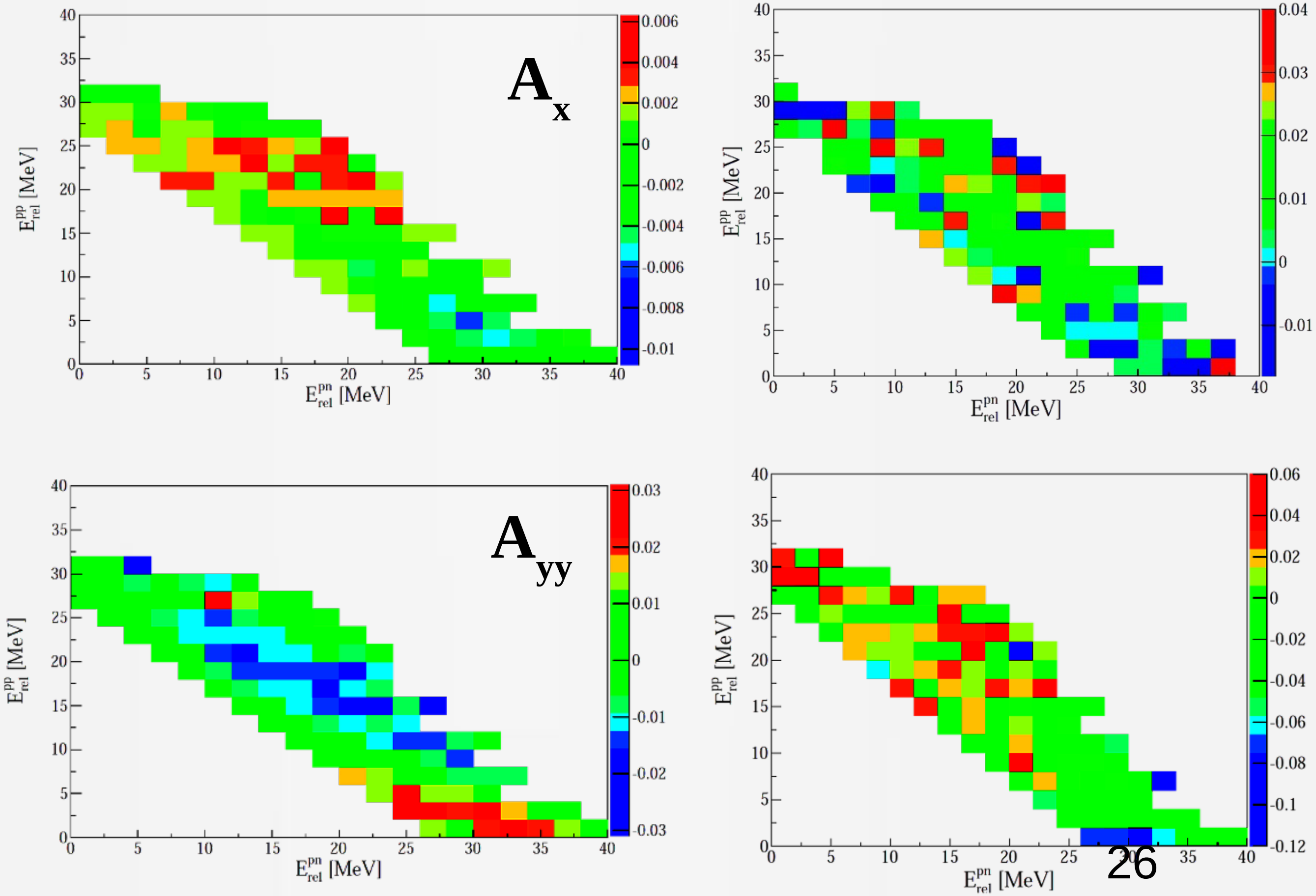
Coulomb force effects – 2D spectra

E^{pp} *vs.* E^{pn}

Small Coulomb force effects, but not negligible; non-localized effects

- relativistic effects rather negligible
- problems with the spin-dependent part of the 3NF

theory **data**



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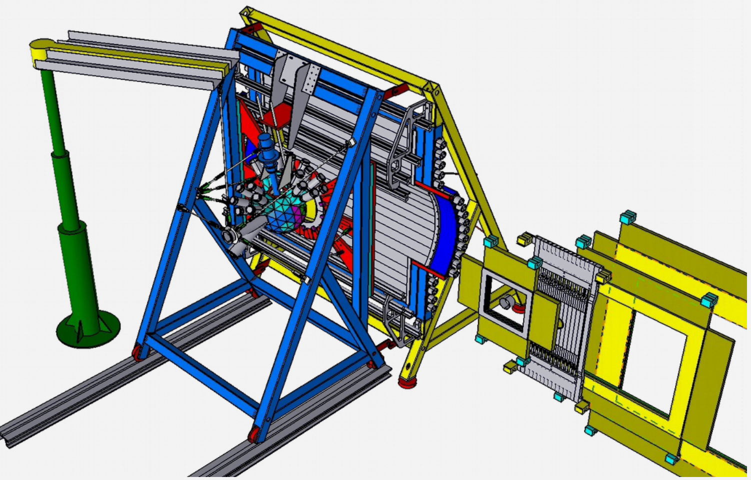
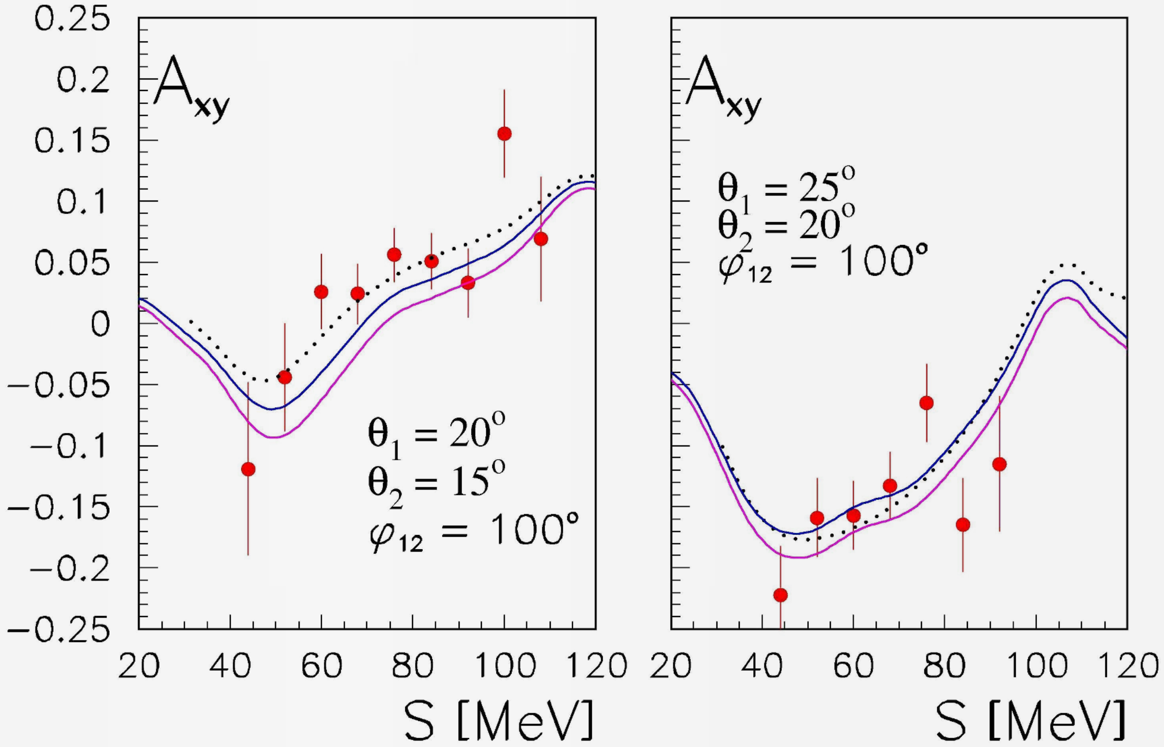
Breakup – analyzing powers @ 100 MeV

- **BINA detector: SALAD+Ball**
- **almost 4π**





E. Stephan *et al.*, Eur. Phys. J. A (2013) 49: 36

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Cyclotron Center Bronowice
Kraków, Poland

Cyclotron PROTEUS (IBA)

- **proton beam energy: 70 - 230 MeV**
- **energy resolution: ΔE/E < 0.7%**
- **intensity: 500 - 0.1 nA**
  (3.3×10^{12} - 6.6×10^{8} p/s)

Experimental program:
studies of few-nucleon systems physics

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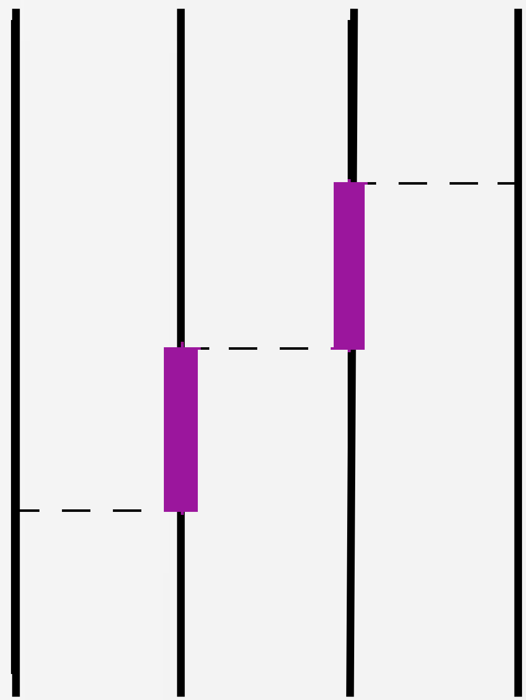
4N studies with ^{3}He polarized target

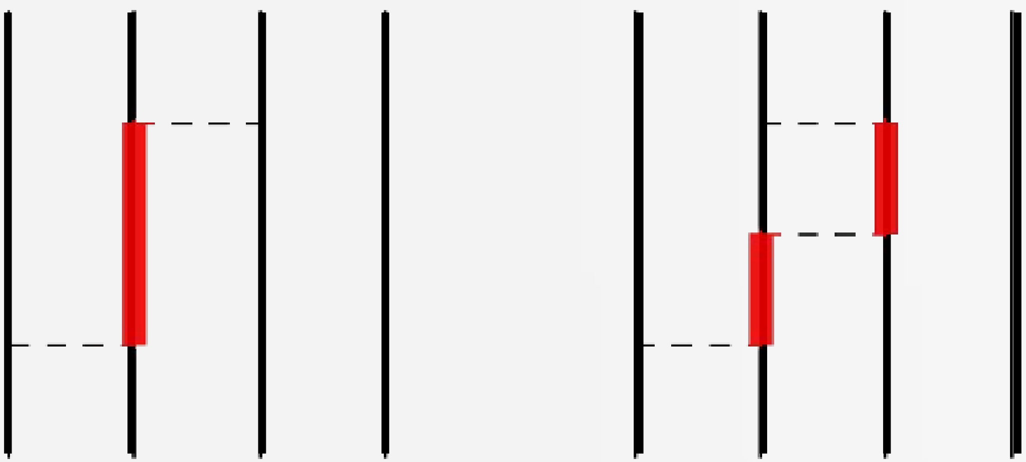
$$V = \sum V_{NN} + V_{3N} + V_{4N}$$

→ the isolation of Δ-isobar effects possible within the couple-channel calculations

4N component



3N components



A. Deltuva, A. C. Fonseca, P. U. Sauer, Phys. Lett. B 660 , 471 (2008)

Four-nucleon system with Δ-isobar excitation.

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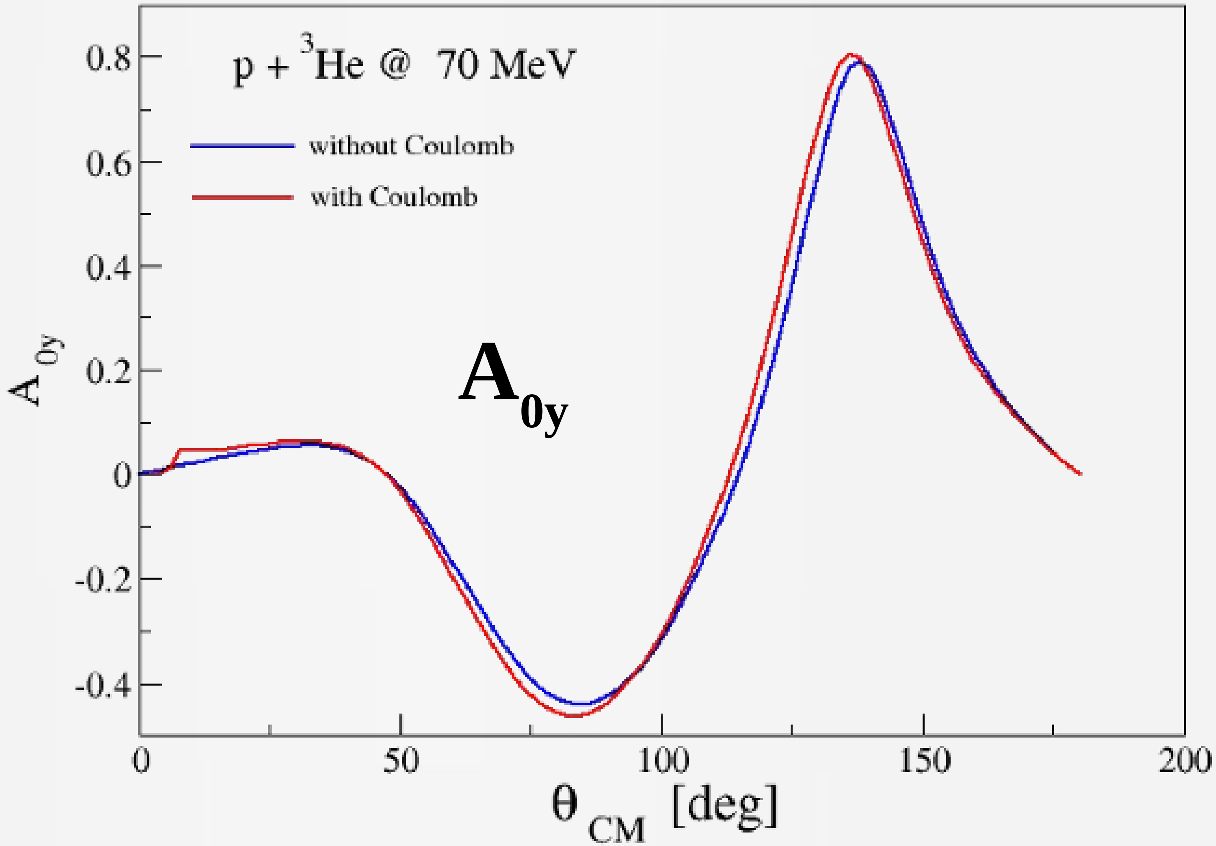
4N studies with ^{3}He polarized target

calculations by A. Deltuva, private communication

$^3\vec{He} + p \to p + ^3He$



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Experimental setup – GEANT4 simulations

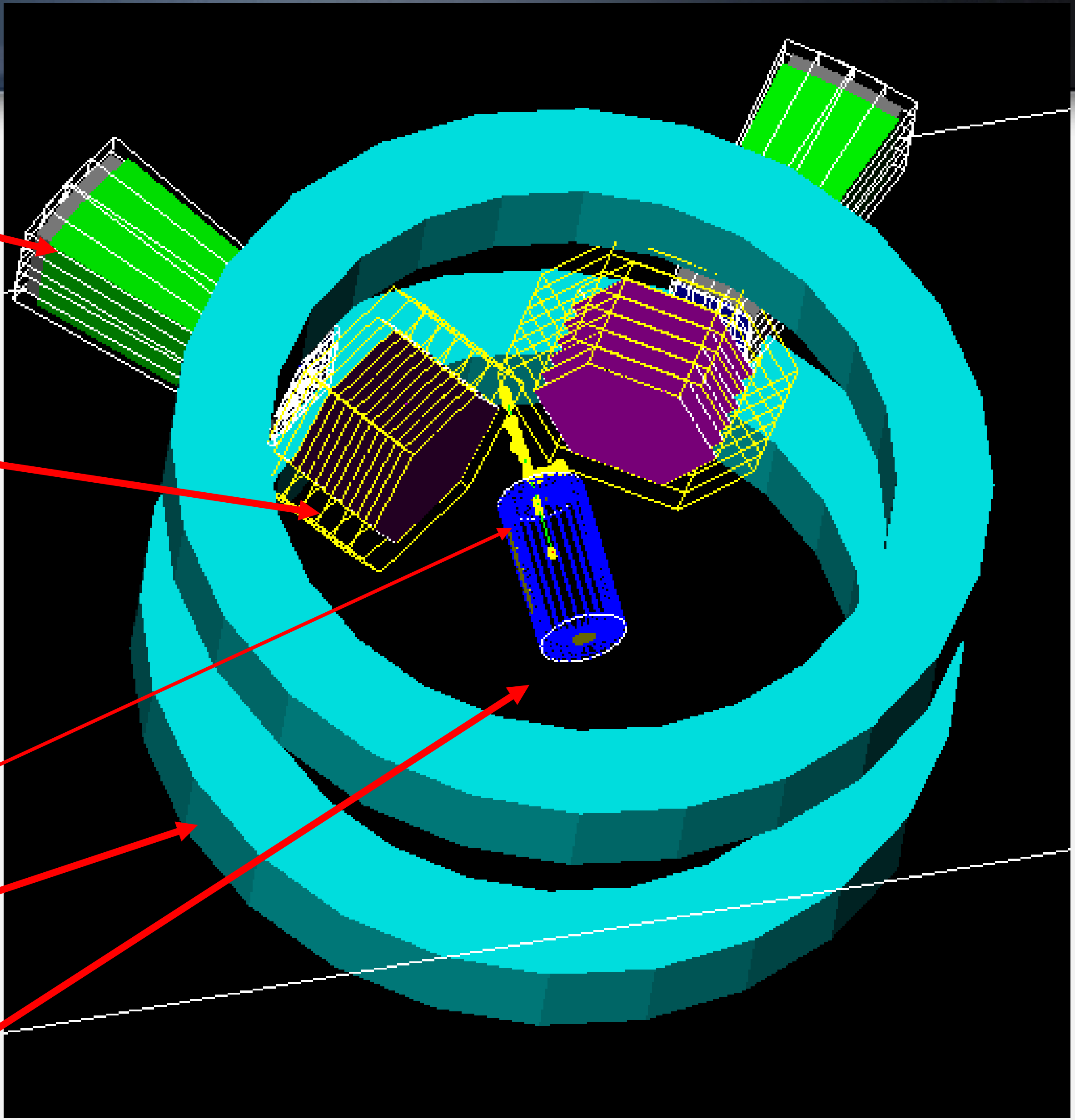
Energy Detectors

Mini Drift Chamber

Particle Trajectory

Helmholtz Coils

Target Cell



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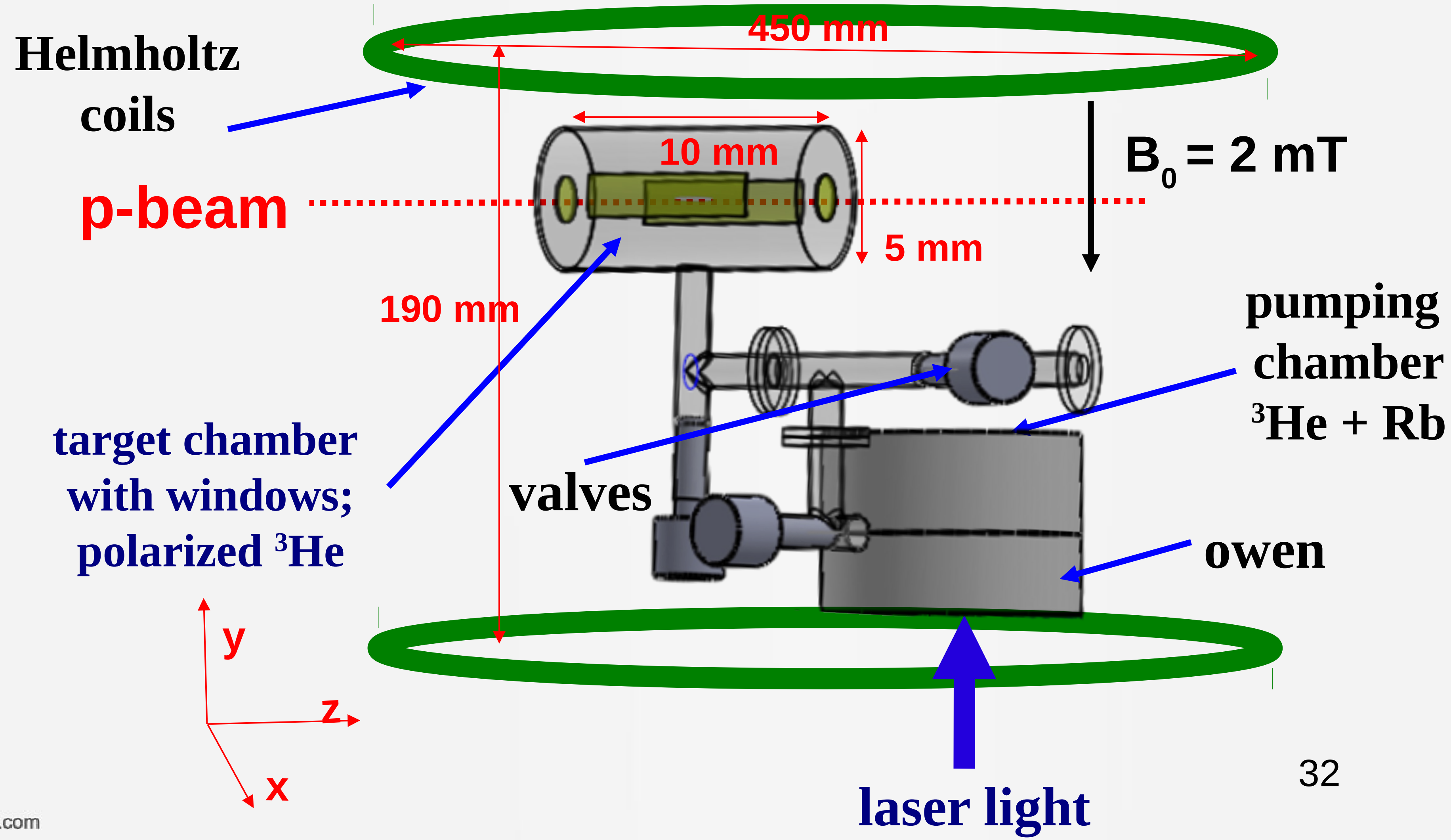
^{3}He polarized target system - SEOP



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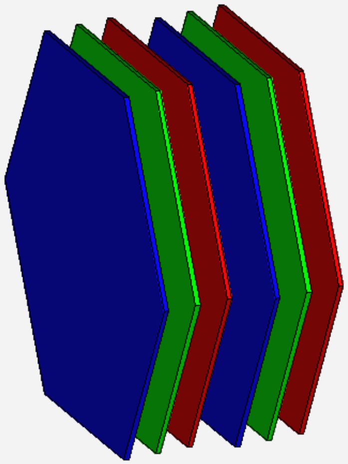
Experimental setup - plans

Requirements:

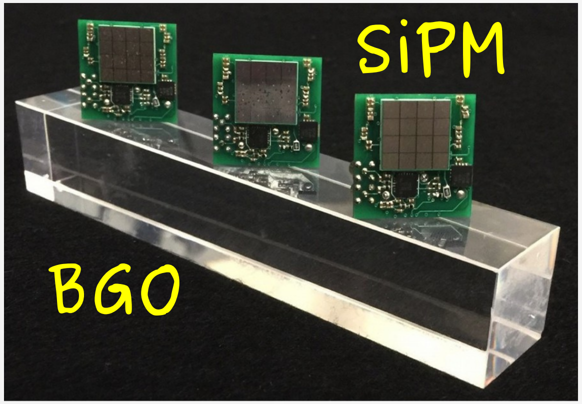
1) low-energy detectors (low treshold) + PID (ΔE - E),
2) momentum and vertex reconstruction (particle trajectory),
3) acceptance as large as possible.

Mini Drift Chambers - trajectory



will be constructed

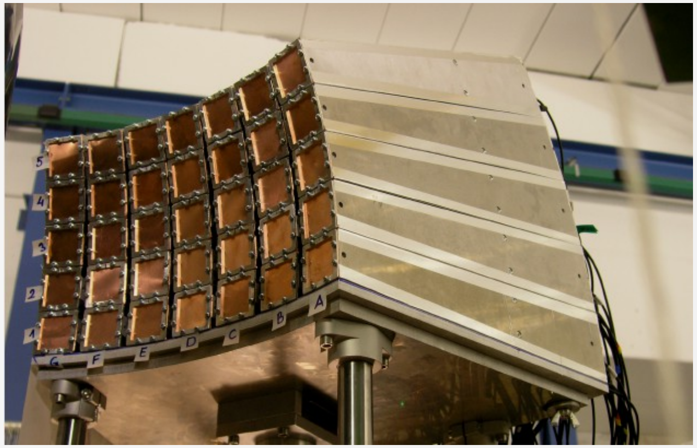
ΔE



will be constructed

KRATTA - energy

J. Łukasik *et al.* NIM A 709 (2013) 120



already exists

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Summary

- **Systematic, precise set of analyzing powers data at 130 and 100 MeV** was presented:
  - ➔ solid basis for comparison of the approaches which predict dynamical effects in the 3N system
- **In the sector of cross sections the data reveal:**
  - ➔ tensor analyzing powers:

    Coulomb effects visible only at 100 MeV, local problems with theoretical description
  - ➔ vector analyzing powers:

    very low sensitivity to 3NF and Coulomb
- Experimental studies of **p+^{3}He** are planned at CCB with the use of the proton beam at energies of 70 - 230 MeV: elastic scattering and breakup reactions.
- **Near future: test measurements with polarized ^{3}He and the new target cell.**

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THANK YOU
FOR
YOUR ATTENTION !

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Analyzing powers - independent variables

3NF effects – 1D spectra

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Analyzing powers - independent variables

3NF effects – 2D spectra

the largest 3NF effects in breakup observed

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