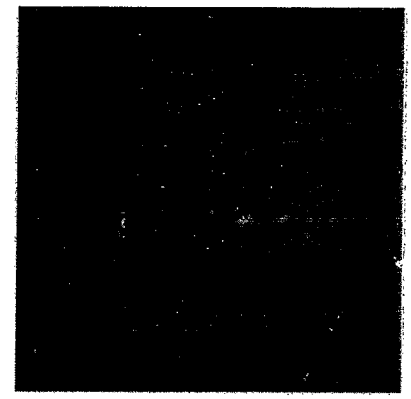
Spin Effects and the 3 Nucleon force

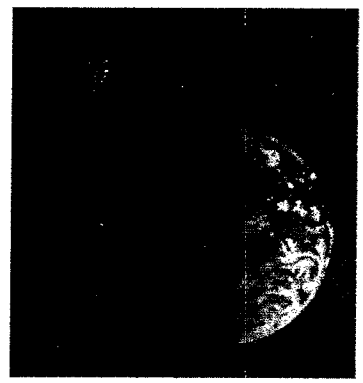
B.v. Przewoski
BNL

Spin 2002

9/10/2002

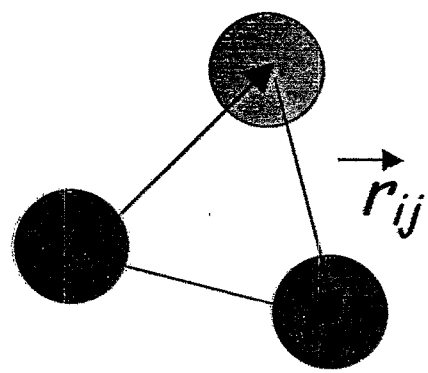
Three body problem large ...





... and small:

Three-Nucleon Systems



Not just pairwise interactions, but 3rd nucleon alters the potential between the other two

Three-Nucleon Systems

Faddeev: $V = \sum_{i,j} V_{NN}(\vec{r}_{ij})$ $\xrightarrow{\text{exact!}}$ nd → nd , nd → nnp observables

(mostly amazing agreement with existing data, but there are discrepancies !)

possible improvement: $V = \sum_{i,j} V_{NN}(\vec{r}_{ij}) + \sum_{i,j,k} V_{3N}(\vec{r}_{ij}, \vec{r}_{jk}, \vec{r}_{ki}) + \ldots$

by definition, discrepancies are due to three-body force V_{3N}

3NF ≡ $V^3(r_{ij}, r_{ik}, r_{jk})$ constructed from

- ❑ 2π, 2ρ, $\pi\rho$ exch. (Tucson-Melbourne 3NF, TM')
- ❑ + virtual Δ excitation
- ❑ + phenomenol. short-range part (Argonne 3NF)
- ❑ constructs based on χPT (van Kolk, Friar...)

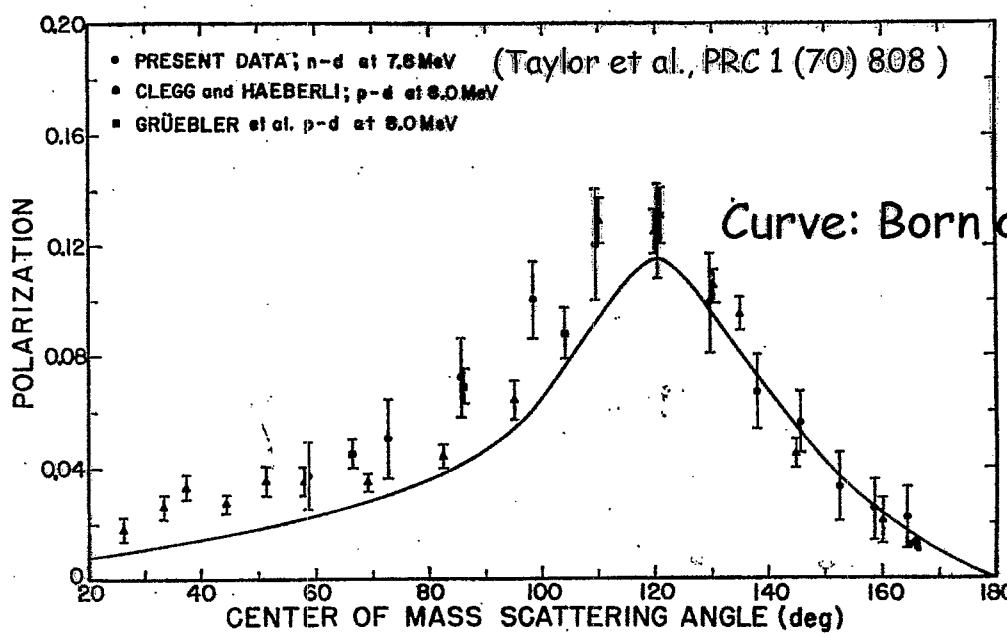
Best NN calculations fail to reproduce properties of ^{3}H

- ❑ Binding energy too small (7.6 MeV instead of 8.5 MeV)
- ❑ Charge radius too small (by ~ 10%)
- ❑ D- to S-state ratio too small (by ~10%)

3NF models are adjusted to reproduce ^{3}H binding energy

First interest in 3N system in '60s

Early measurements of analyzing powers, e.g.



(Taylor et al., PRC 1 (70) 808)

Curve: Born approx.

pd experimentally easier than nd, but Coulomb (important at low energies) not calculable

experimental goal was to compare pd and nd

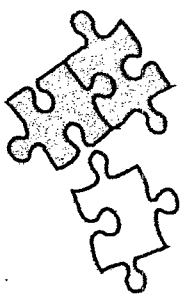
Low energy (T_p<20 MeV):

3NF effects scale with shift in binding energy E_B, decrease with energy

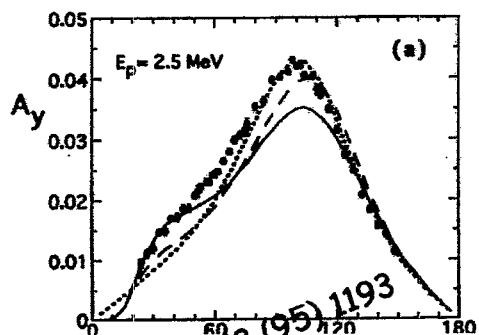
nd scattering free of Coulomb

→thought to be ideal to study 3N system

rigorous Faddeev calculations become available in late 80's (L.D. Faddeev, JETP(Sov. Phys.) 12 (1961) 1014

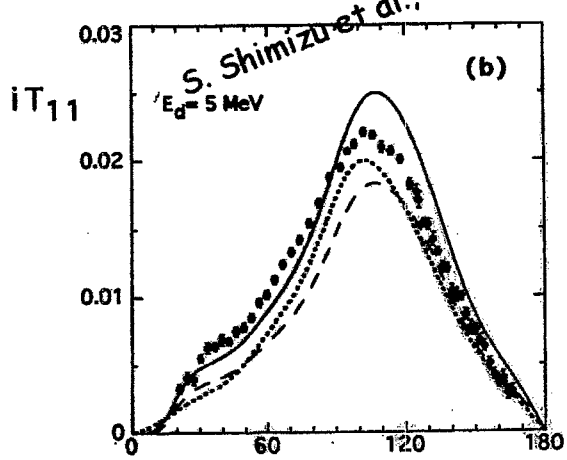


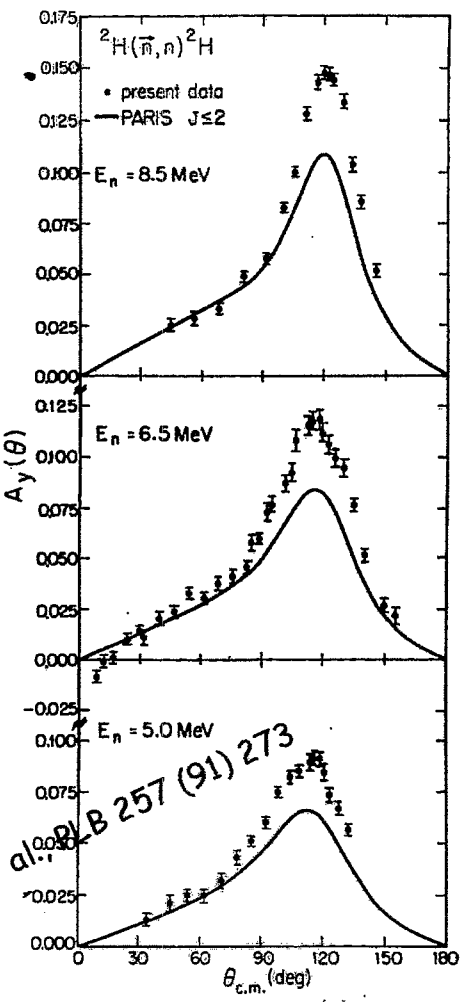
...the "A_y puzzle" emerges



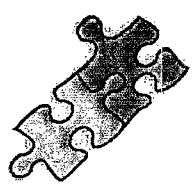
S. Shimizu et al., PRC 52 (95) 1193

Below d breakup threshold...

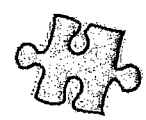




W. Tornow et al., PL B 257 (91) 273



... still not resolved



High energy (T_p =100 - 200 MeV):

(below π production threshold)

3NF effects dominated by the Δ, increase with energy

Coulomb effects decrease with energy

↳ pd scattering instead of nd

Relativistic effects increase with energy

↳ ?

Faddeev calculations now converge ($j \leq 5$)

K. Ermisch et al.

PRL 86 (2001) 5862

KVI, $\vec{p}$ beam

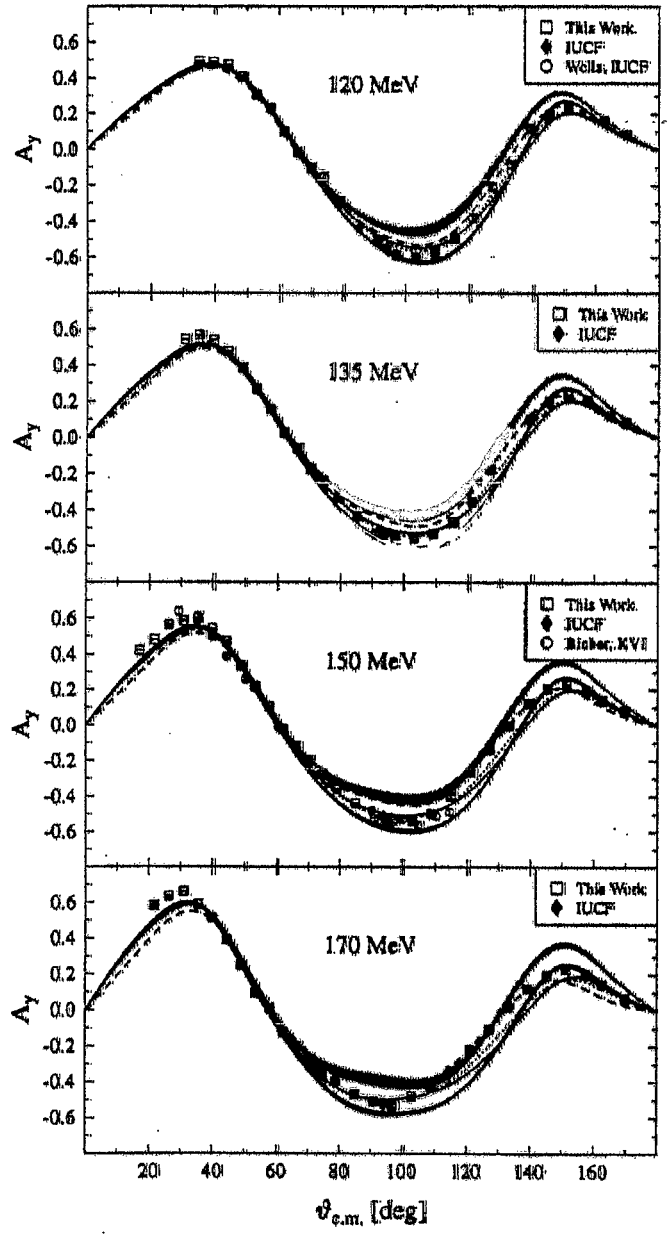
NN force predictions:
AV18, CD-Bonn, Nijm I,II

NN predictions + TM3NF

..... AV18 + Urbana IX

——— CD-Bonn + TM'

– – – A2 model Hannover (Paris potential + intermediate Δ)



None of the presently available 3NF describe the angular dependence of A_y^p

K. Ermisch, N. Kalantar-Nayestanaki

KVI Newsletter #9, Aug 2002

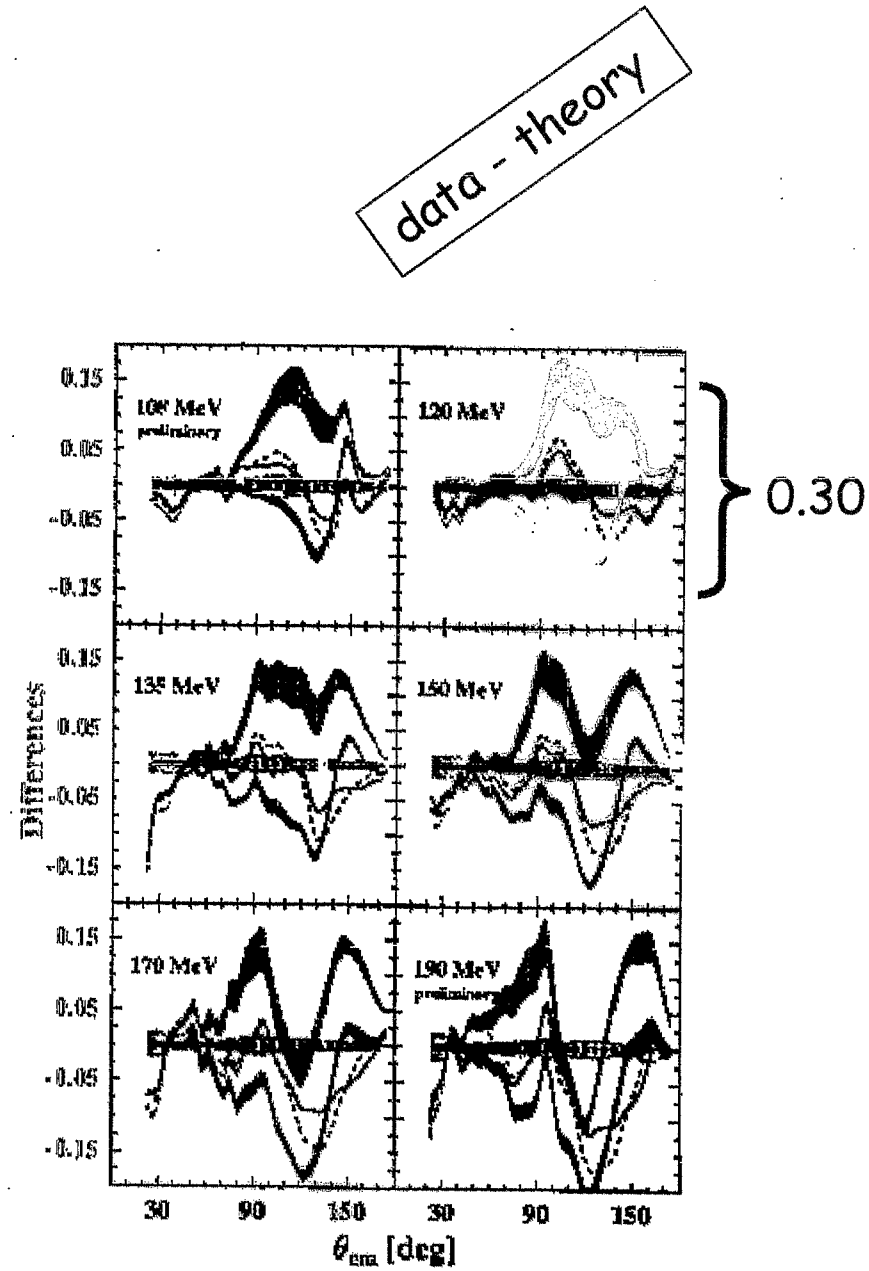
108, 120, 135, 150, 170, 190 MeV

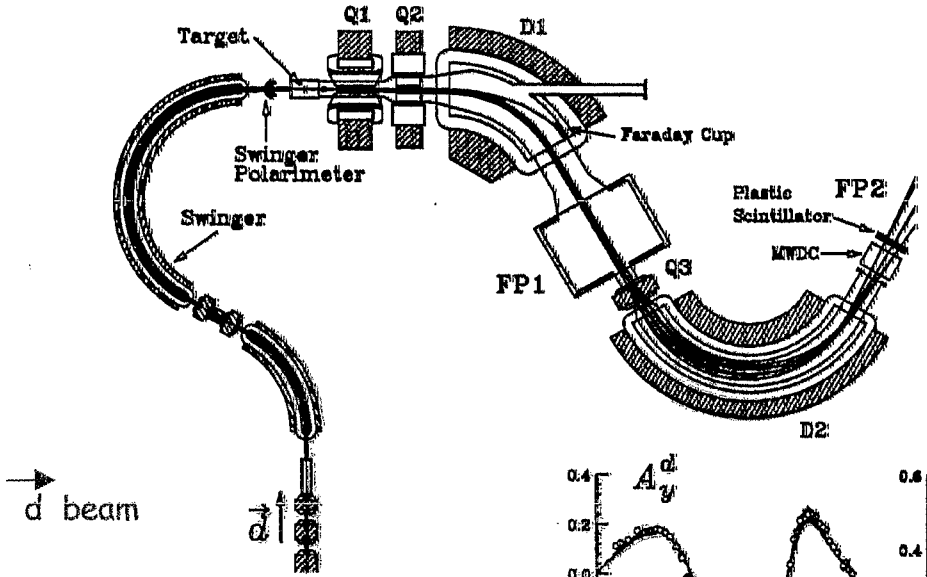
NN force predictions

NN predictions +TM3NF

AV18 + Urbana IX

CD-Bonn + TM'





K. Sekiguchi et al.

PRC 65 034003-1 (2002)

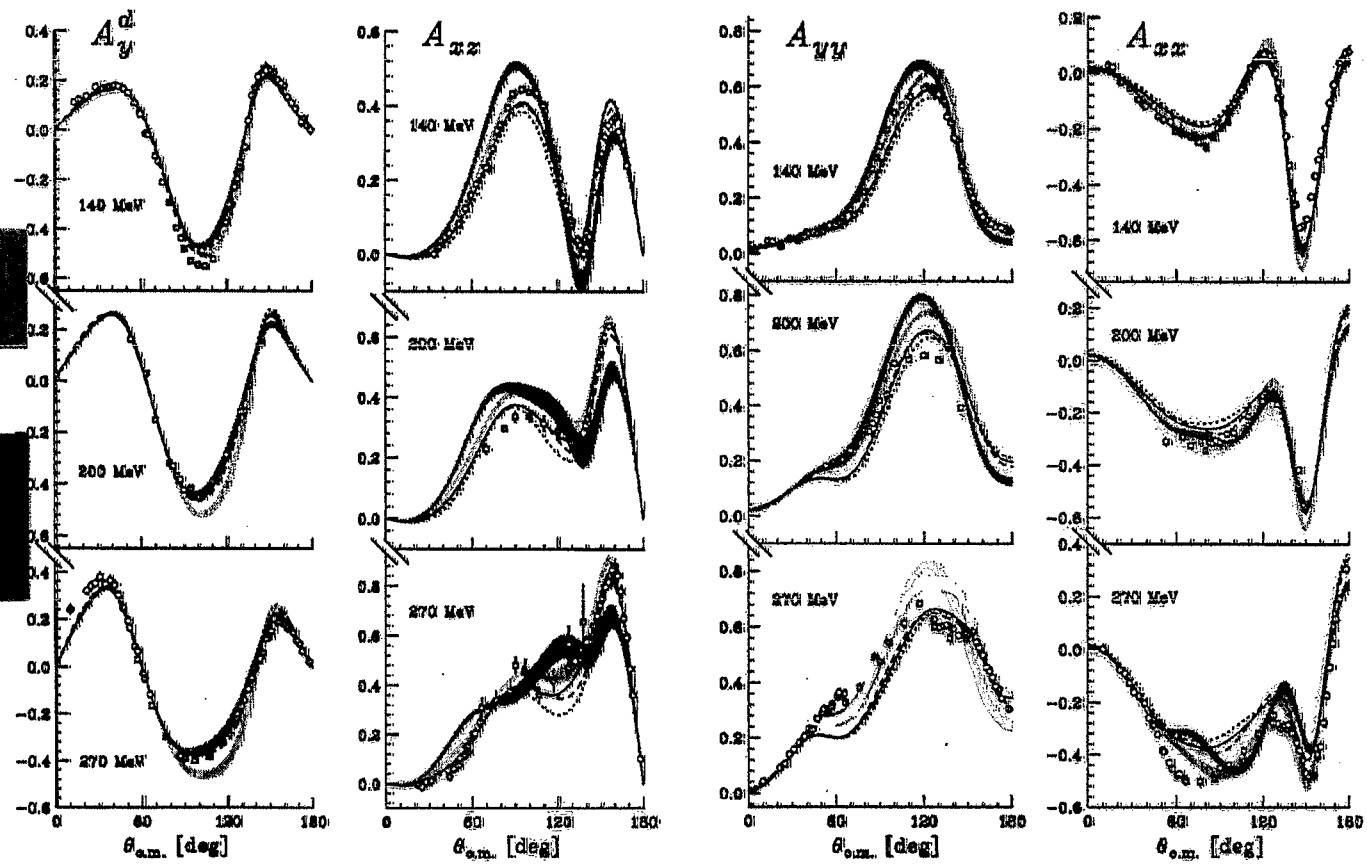
(RIKEN)

Tue, Sess. 5, 14:00

K. Hatanaka

NN force predictions:
AV18, CD-Bonn, Nijm I,II,'93

NN predictions + TM3NF
^{3}H binding energy adjusted
for each combination



AV18 + Urbana IX

CD-Bonn + TM'

AV18 + Urbana IX + phenomenol. spin-orbit 3NF

+ cross section

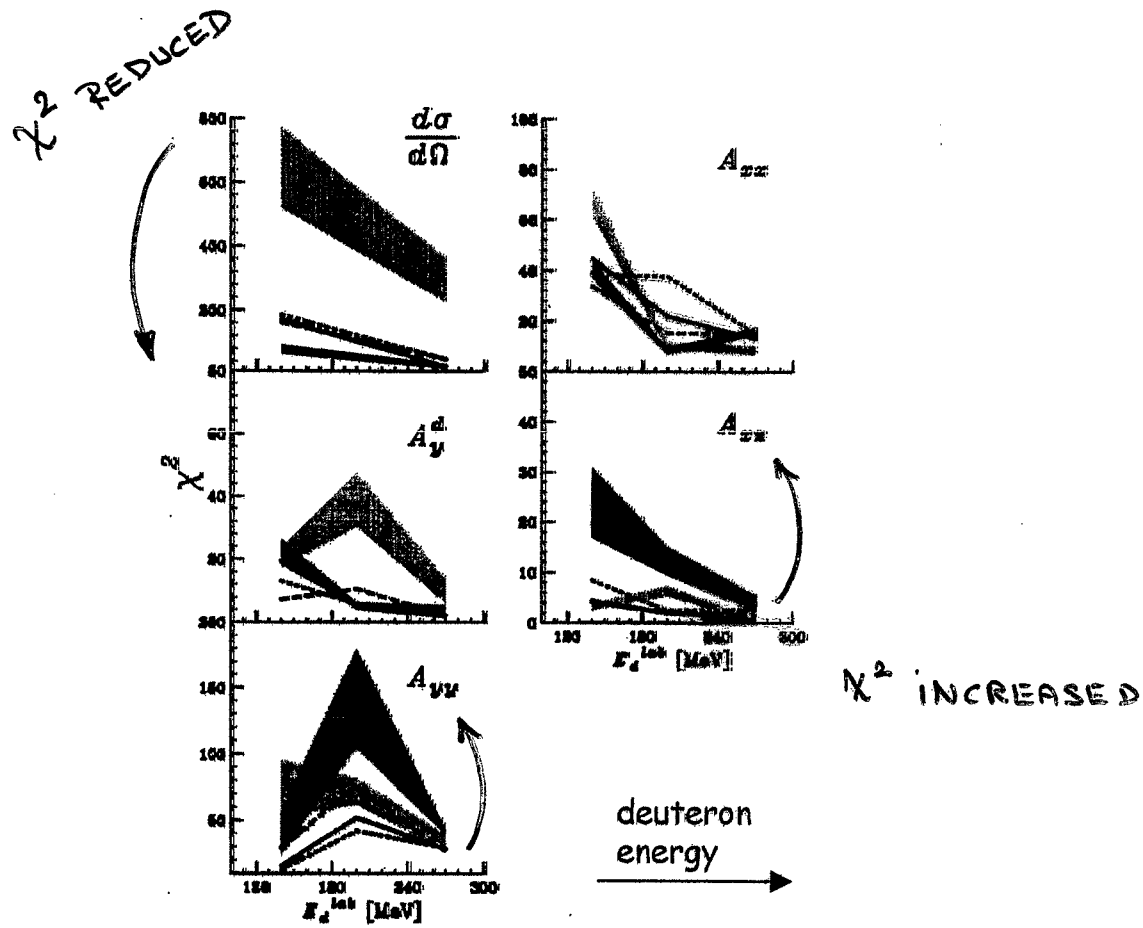
NN force predictions:
AV18, CD-Bonn, Nijm I,II,'93

[redacted]

AV18 + Urbana IX

CD-Bonn + TM'

AV18 + Urbana IX + phenomenol. spin-orbit 3NF



tensor analyzing powers present a challenge !

(effect of inclusion of Urbana IX and TM' mostly opposite of traditional TM3NF)

Calculations also fail to reproduce $K_{ij}^{y'}$ and $P^{y'}$ (H. Sakai et al. PRL 84 (2000) 5288)

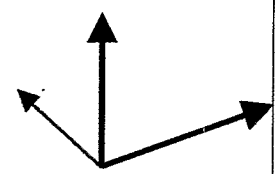
Tue, Sess. 5, 14:30

K. Sekiguchi

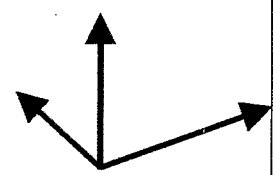
iucf

D(p,p)D elastic scattering

beam: $\vec{p}$, 135 MeV, 200 MeV

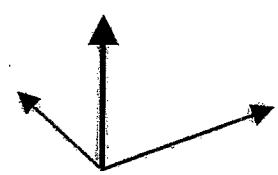


target: $\vec{d}$, pure vector, tensor

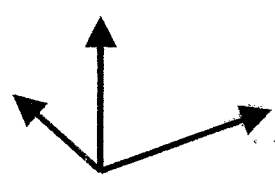


D(p,pp)n break-up reaction

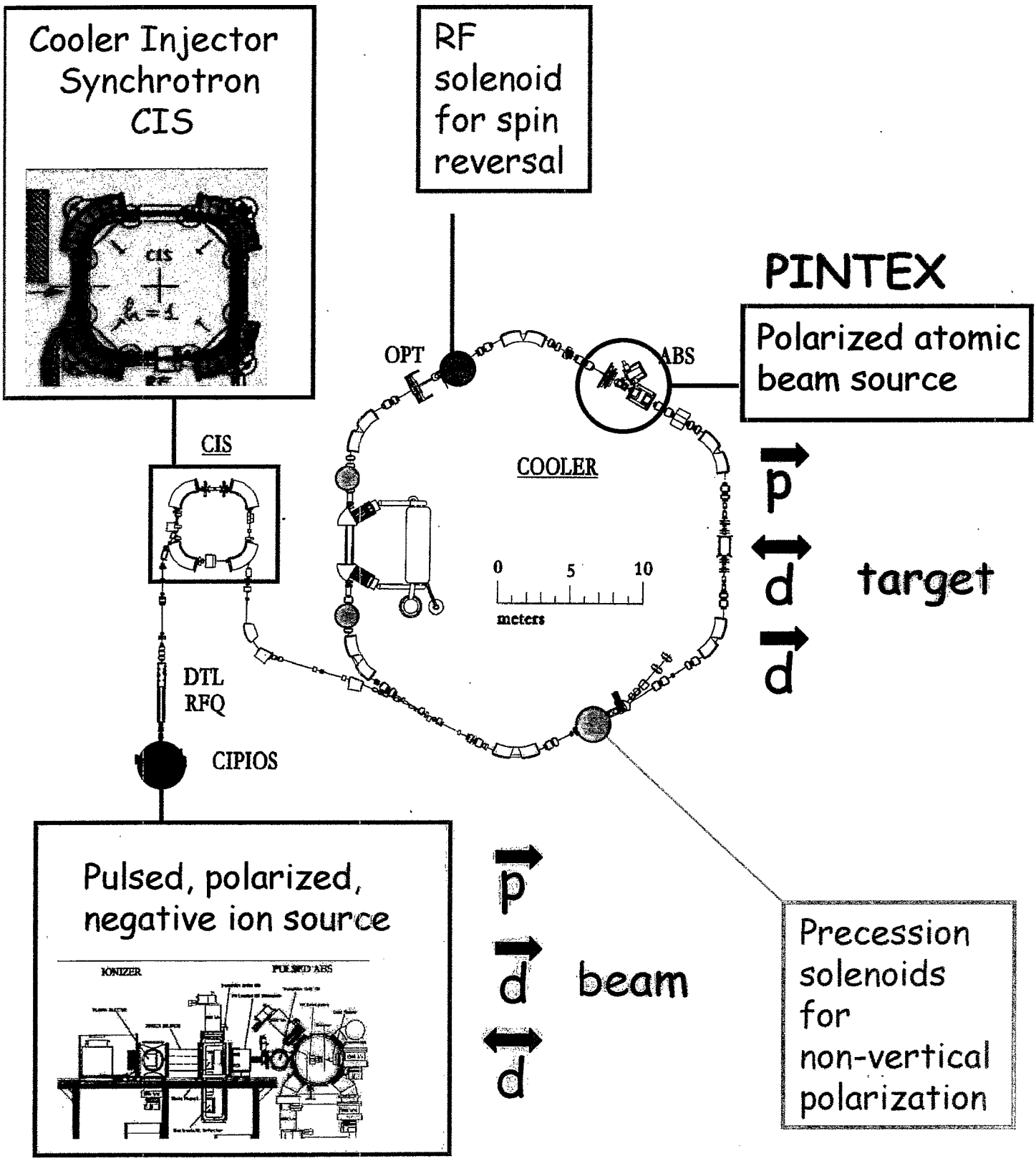
beam: $\vec{d}$, 270 MeV, vector, tensor, unpolarized



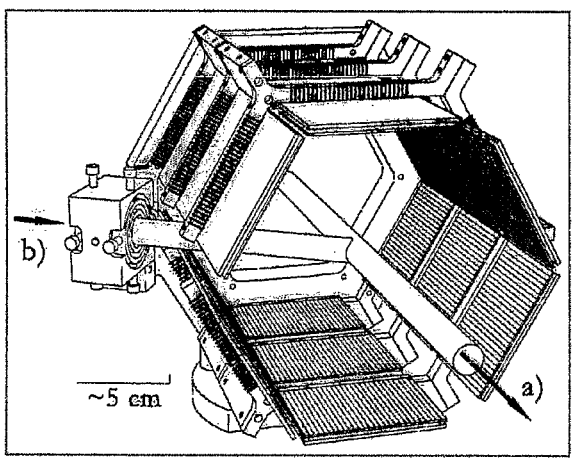
target: $\vec{p}$

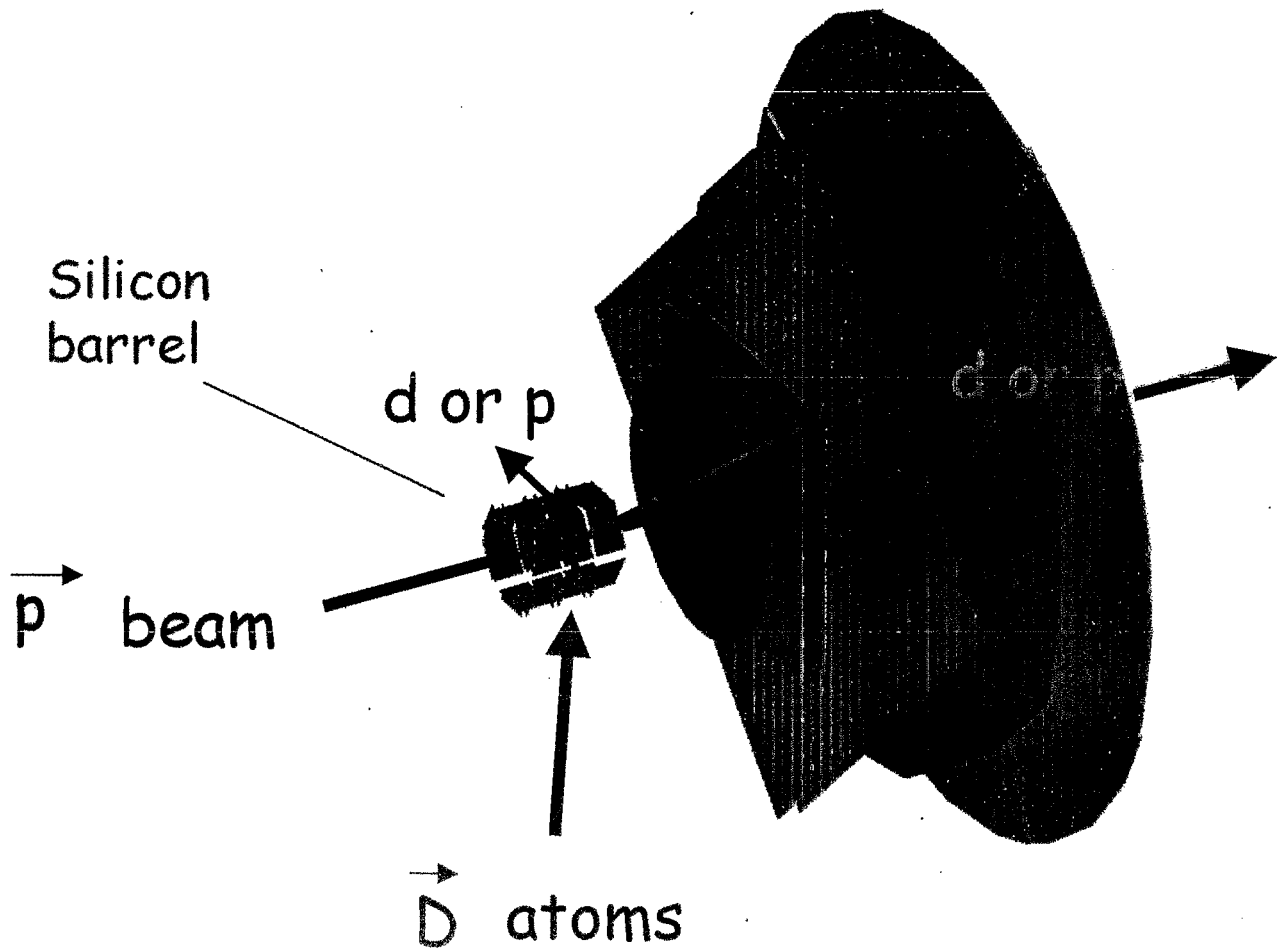


Indiana Cooler (1988 - 2002): Polarized Beam & Polarized Target



pd scattering: detector





Fri, Sess. 8, 18:05
BvP

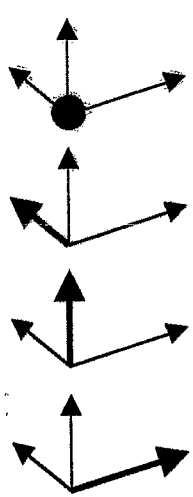
spin-½ on spin-1 observables

vector polarization

(two-body final state)

Beam (p)

Target (d)



	0	x	y	z
0	σ_0		A_y^p	
x		C_{xx}		C_{zx}
y	A_y^d		C_{yy}	
z		C_{xz}		C_{zz}

forbidden (parity conserv.)

redundant (rot. z-axis)

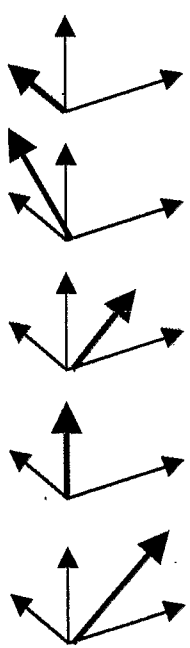
7 observables

spin-½ on spin-1 observables

tensor polarization

5 tensor moments

target (d)



beam (p)

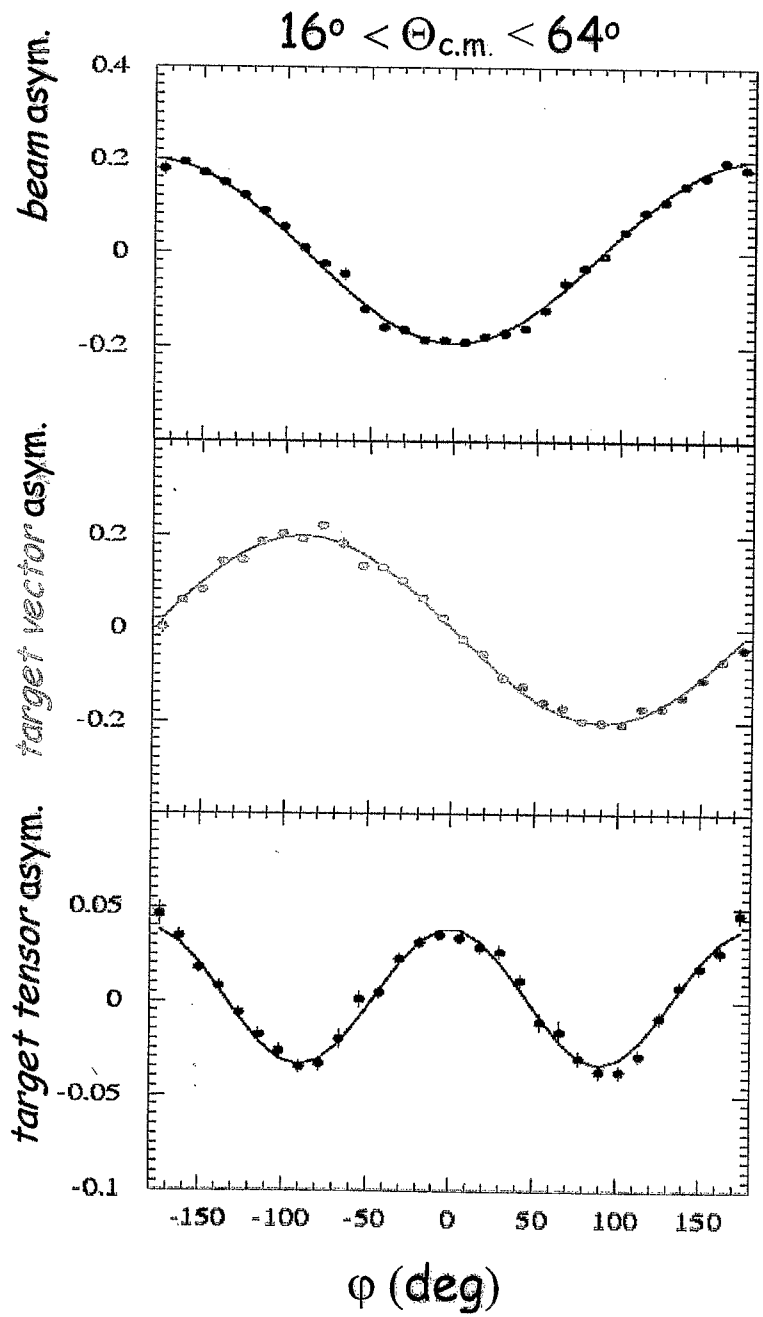
	0	x	y	z
xx	A_{xx}		$C_{xx,y}$	
xy		$C_{xy,x}$		$C_{xy,z}$
xz	A_{xz}		$C_{xz,y}$	$C_{xz,z}$
yy	A_{yy}		$C_{yy,y}$	
yz		$C_{yz,x}$		

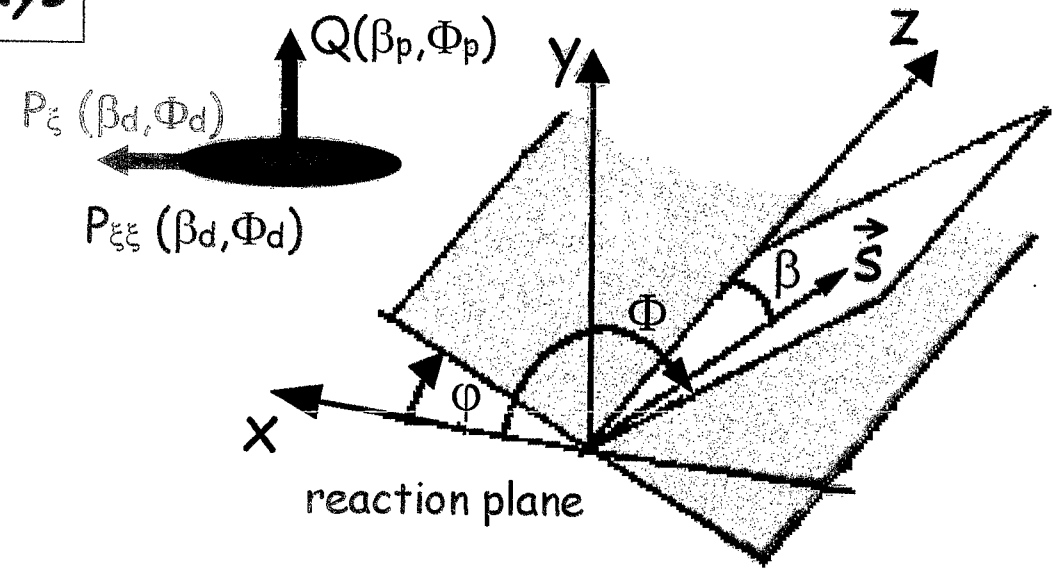
forbidden (parity conserv.)

redundant (rot. z-axis)

10 observables

proton *up* & deuteron *sideways*





$T_{20}=1/\mathrm{sqrt}(2)\ A_{zz}$

$T_{21}=-1/\mathrm{sqrt}(3)\ A_{xz}$ $\qquad A_{\Delta}= A_{xx}-A_{yy}$

$T_{22}=-1/2/\mathrm{sqrt}(3)\ A_{\Delta}$ $\qquad -A_{zz}= A_{xx}+A_{yy}$

$iT_{11}=\mathrm{sqrt}(3)/2\ A_y^d$ $\qquad C_{xx,y}+C_{yy,y}+C_{zz,y}=0$

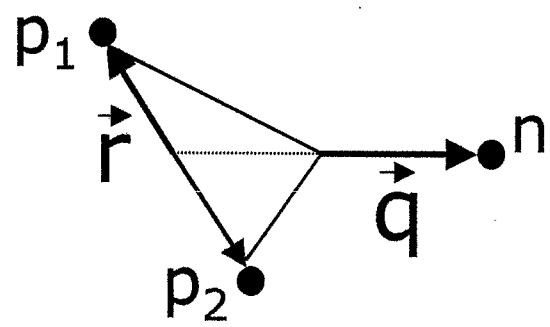
$$\sigma=\sigma_o(1+QA_y^p\cos\varphi-3/2P_\xi A_y^d\sin\varphi+1/4P_{\xi\xi}\cos2\varphi$$
$$-1/4P_{\xi\xi}A_{zz}+3/4P_\xi Q(C_{x,x}-C_{y,y})\sin2\varphi$$
$$-1/2P_{\xi\xi}QC_{xy,x}\sin\varphi\sin2\varphi-1/4P_{\xi\xi}QC_{zz,y}\cos\varphi$$
$$+1/4P_{\xi\xi}Q(C_{xx,y}\ C_{yy,y})\cos\varphi\cos2\varphi)$$

and more ...

absolute normalization

- Beam polarization (P_B) relative to existing A_y^p data at 135 and 200 MeV
- Target polarization (P_T) relative to existing A_y^d data at 135 MeV → transport normalization to 200 MeV (target polarization does not change during ramp)
- Spin correlation data are normalized to $P_B * P_T$

Break-up observables



Evaluate observables
for specified regions of phase space

Comparison to Faddeev calculations
needs strong theoretical support

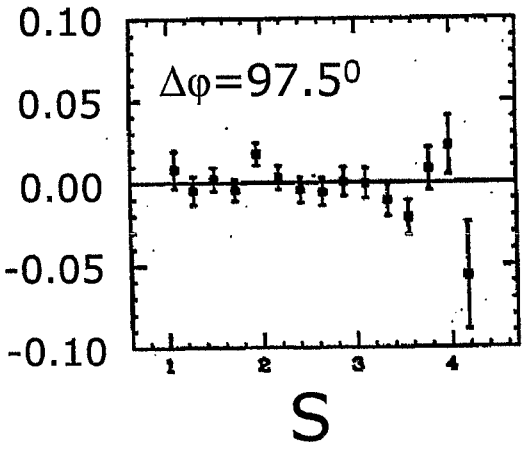
axial observables

Knutson (PRL 73, 3062 (1994)):
- "Axial" observables are sensitive to spin operators that occur in 3N potentials but not in 2N potentials

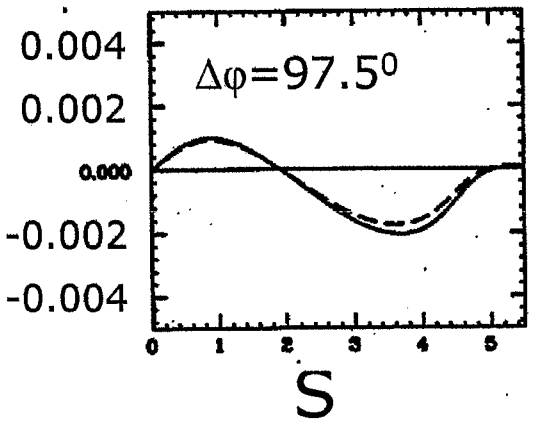
example: **longitudinal analyzing power A_z**

A_z has been measured at 9 MeV (E.A. George et al., PR C54, 1523 (1996)

Experiment:



Faddeev calculation



A_z predicted to be ~0.1 at T_d = 270 MeV

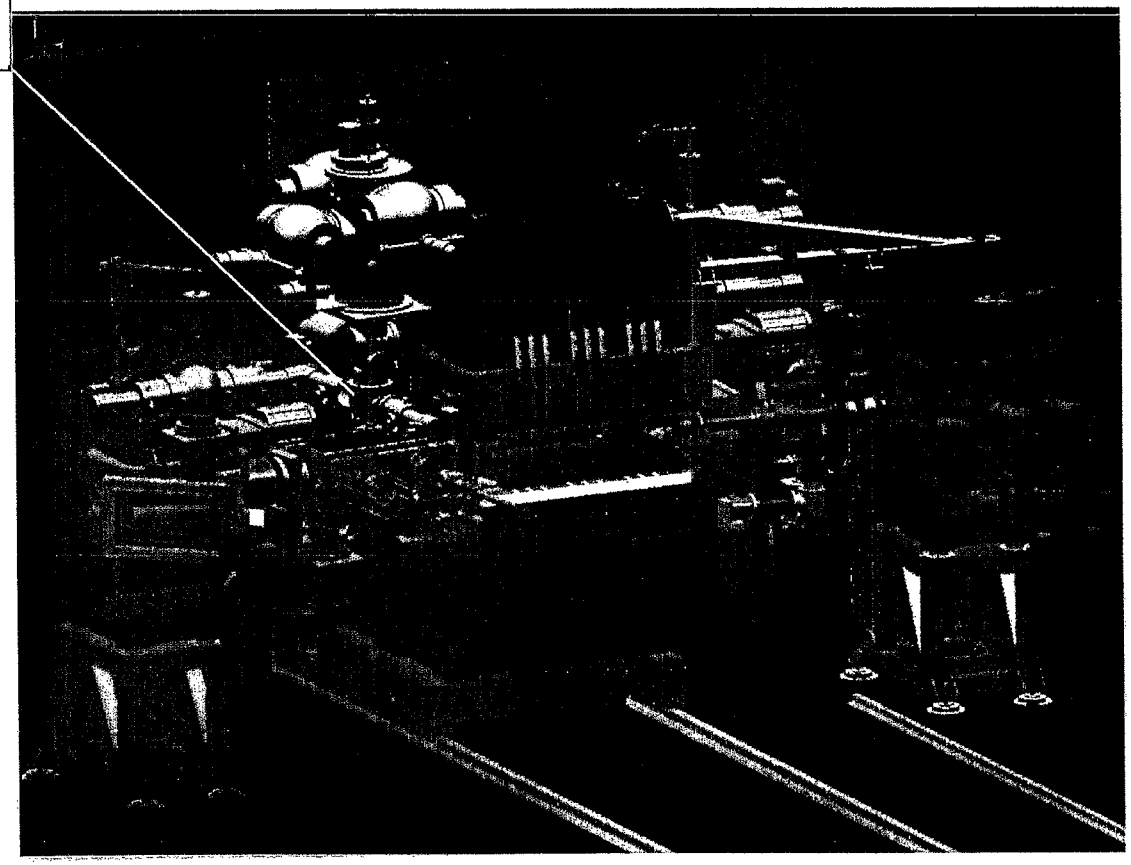
Future: Polarization Experiments at COSY

p+d break-up at GeV energies:
Reaction mechanism

ANKE spectrometer at COSY

Polarized
ABS target

Fri, Sess. 8, 14:00
F. Rathmann



Mo, Sess. 3, 17:25
F. Rathmann

conclusions

- advanced experimental techniques have resulted in precise data
- Faddeev calculations are feasible thanks to modern computers
- a large body of high quality data between a few MeV and up to the pion production threshold is available
- none of the existing calculations (NN or NN + 3NF) describe the data