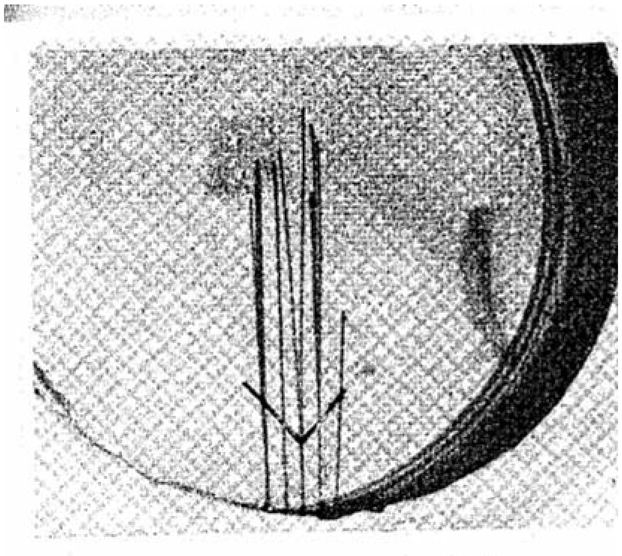
Spin physics in NN interactions at intermediate energies

B. von Przewoski
Spin 2004
Trieste, Oct 13 2004

Scattering of High Energy Protons in Hydrogen
M.G. White, PR 49



Cloud chamber

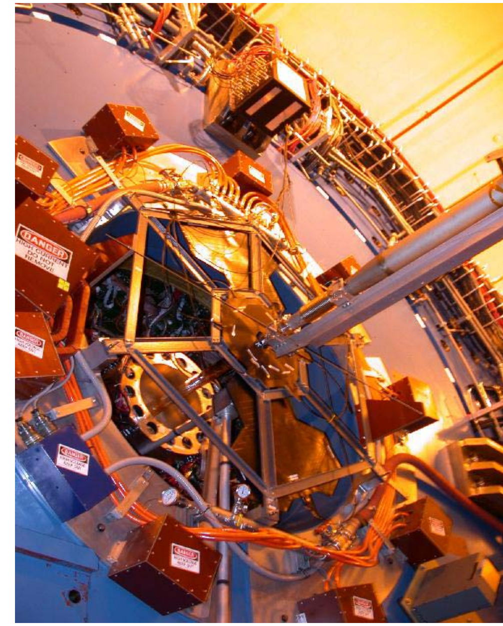
1935

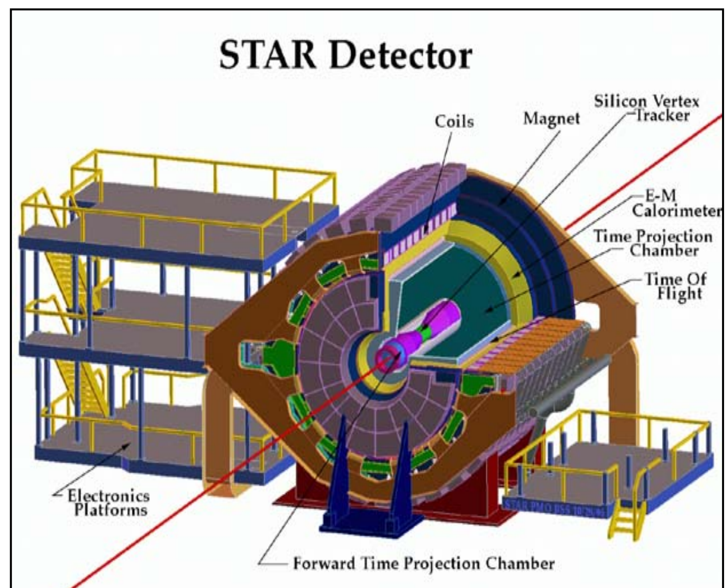
600 keV

In between: nucleon-nucleon scattering at intermediate energies

50-500 GeV

2004



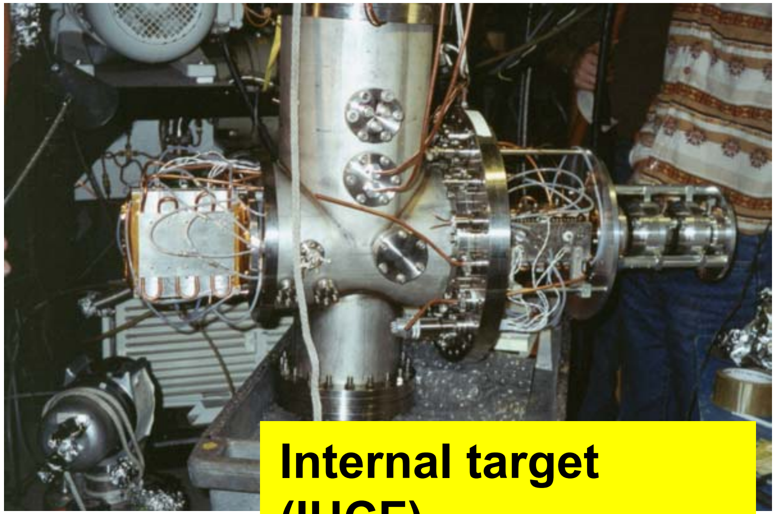


intermediate energies

- Issues NN scattering interm energies
- phenomenology (PSA)
  meson exchange, chiral perturbation theory
- pp elastic scattering
- IUCF
- EDDA (COSY)
- meson production
- IUCF
- ANKE(COSY), COSY-11
- np elastic (spectator model)
- ANKE (COSY)
- Breakup
- IUCF
- outlook

tools

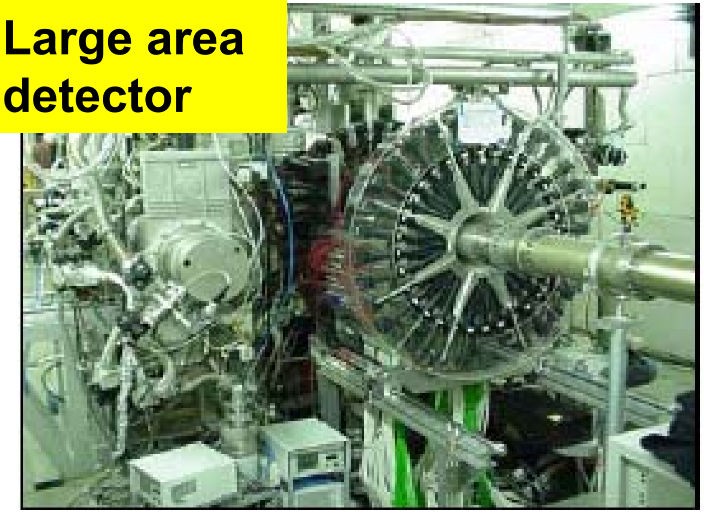
Storage ring (COSY)



Internal target (IUCF)

Spin manipulation

Large area detector

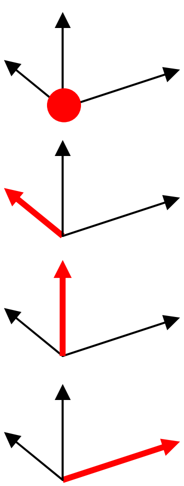


p+p elastic scattering:
improvement of phenomenology
(phase shift analyses)

spin-½ on spin-½ with two-body final state

beam

target



	0	x	y	z
0	σ_0		A_y^b	
x		C_{xx}		C_{zx}
y	A_y^t		C_{yy}	
z		C_{xz}		C_{zz}

forbidden (parity conserv.)

redundant (rot. z-axis)

blue: redundant (ident. particles)

IUCF Cooler 1988-2002

RF solenoid for spin reversal

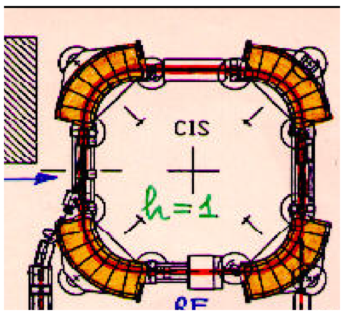
PINTEX

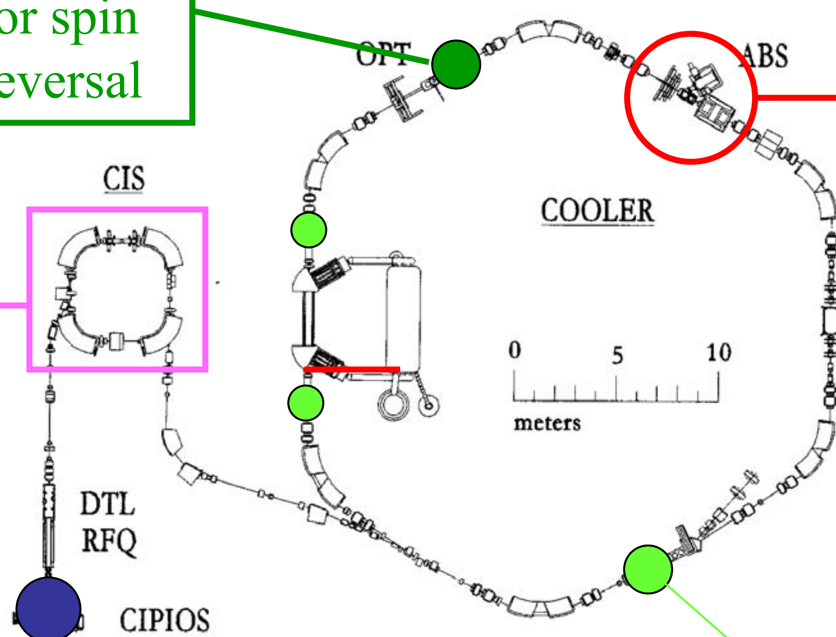
Polarized atomic beam source

$\vec{p}$

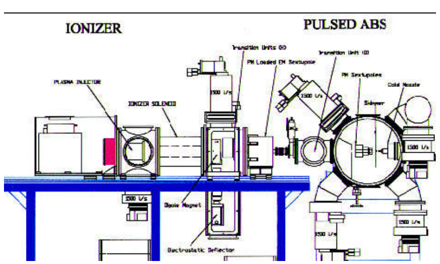
$\overleftrightarrow{d}$ target

$\vec{d}$





Pulsed, polarized, negative ion source



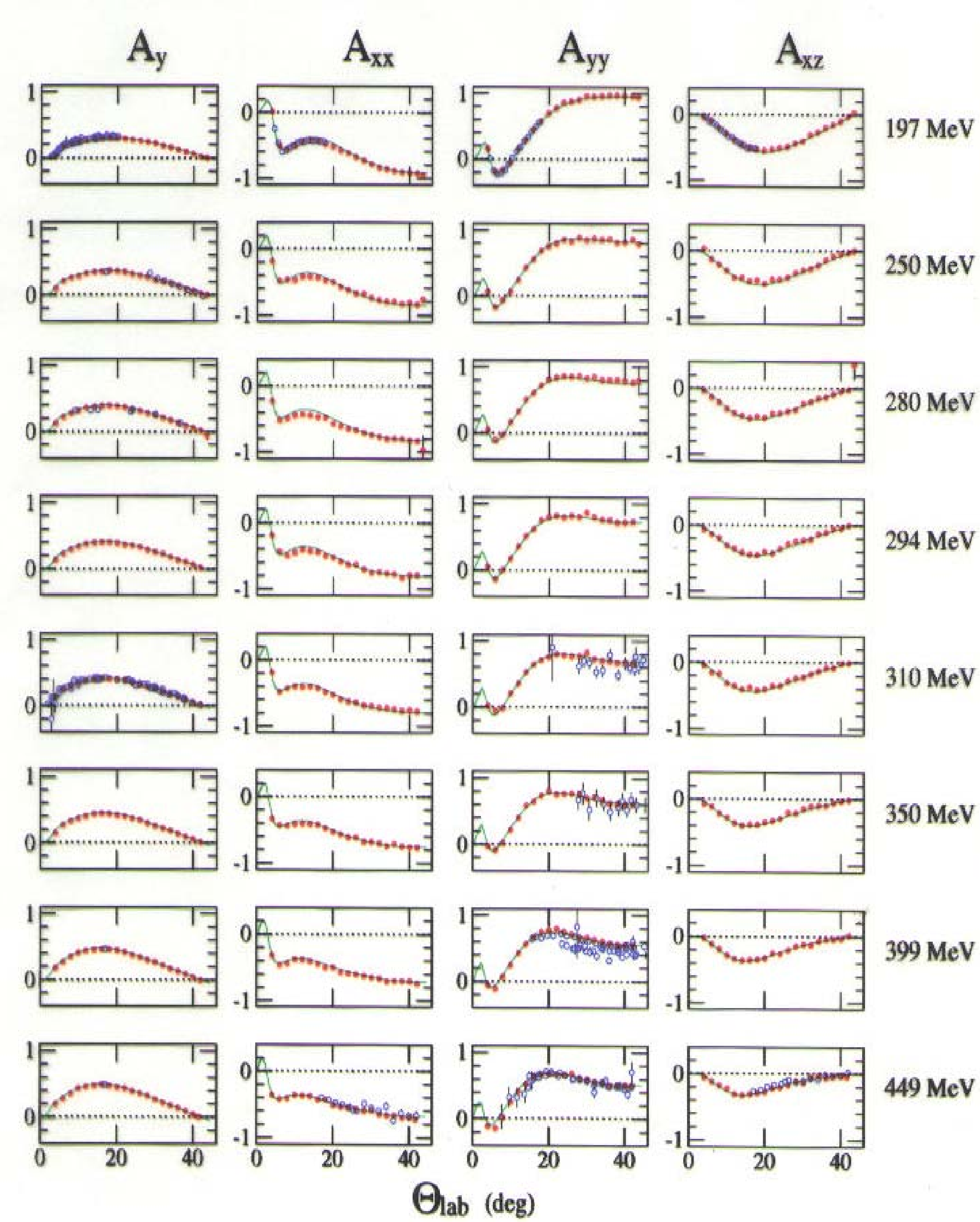
$\vec{p}$

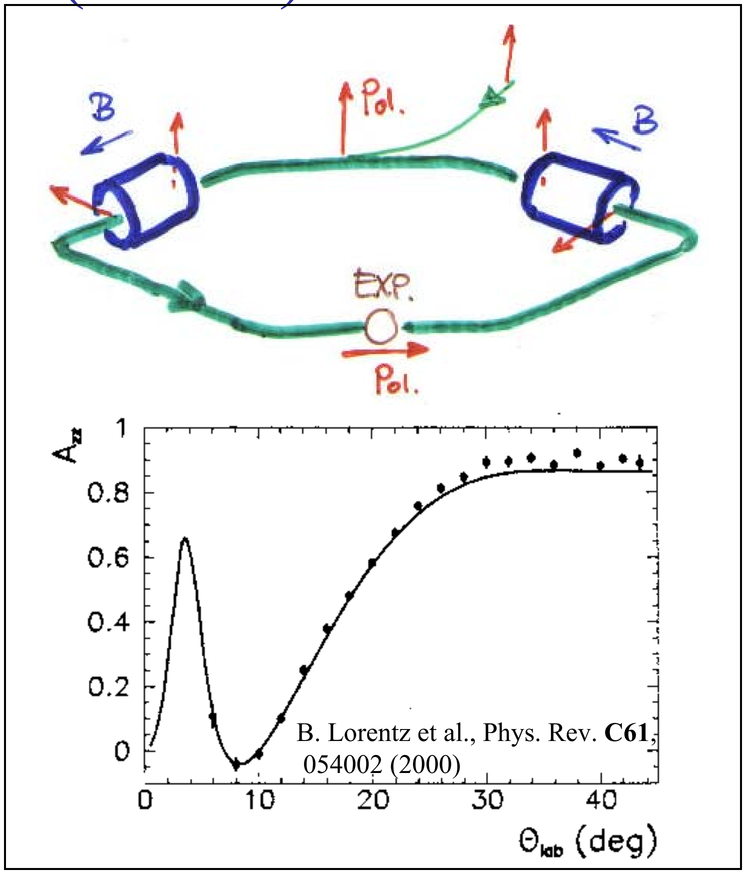
$\vec{d}$ beam

$\overleftrightarrow{d}$

Precession solenoids for non-vertical polarization

$\vec{p}\vec{p}$ elastic scattering (IUCF)

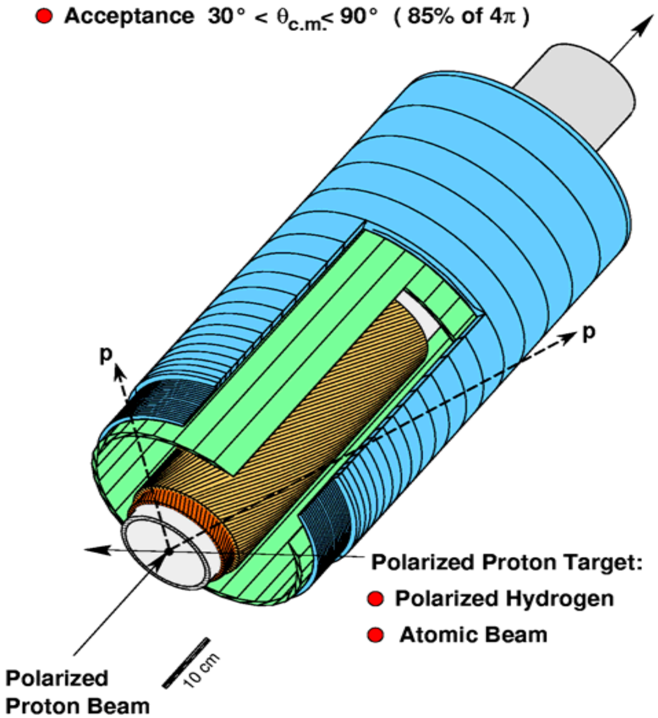


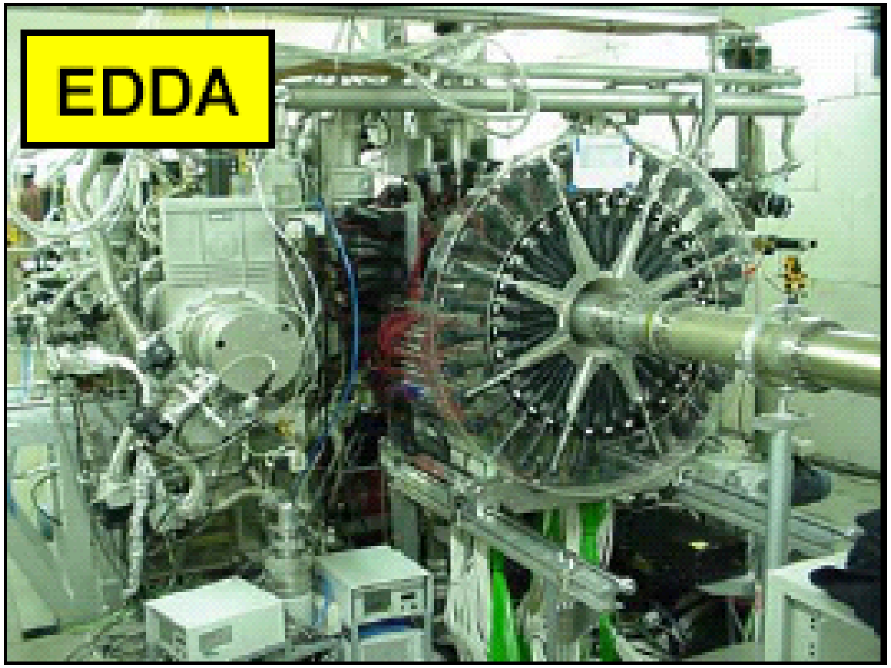


B. v. Przewoski et al., Rev. Sci. Instr. **67**, 165 (1996)
W. Haeberli et al., Phys. Rev. **C55**, 597 (1997)
R.E. Pollock et al., Phys. Rev. **E55**, 7606 (1997)
H.O. Meyer, Phys. Rev. **C56**, 2074 (1997)
F. Rathmann et al., Phys. Rev. **C58**, 658 (1998)
B. v.Przewoski et al., Phys. Rev.**C58**, 1897 (1998)

pp scattering: 0.5-2.6 GeV

COSY/EDDA



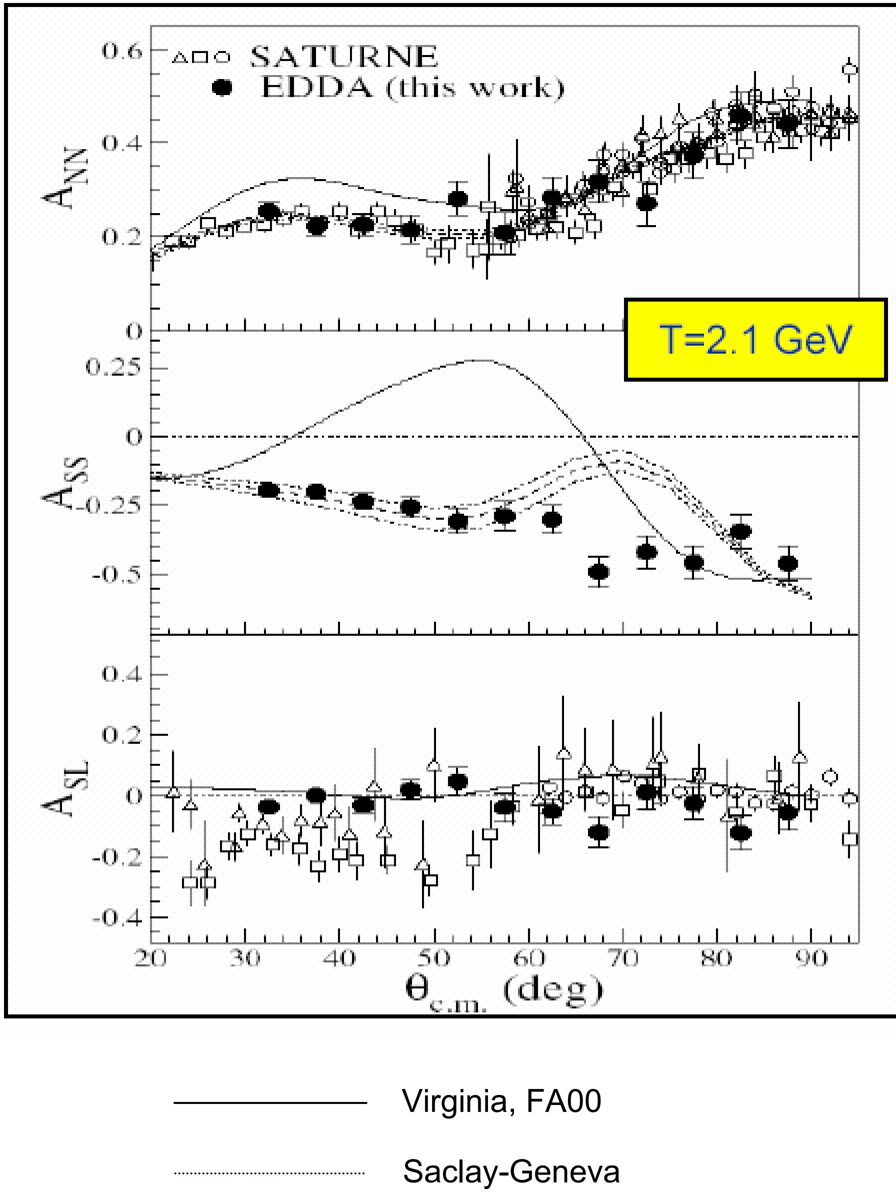


Polarized, internal target
Polarized, stored beam

Elastic $\vec{p}\vec{p}$ scattering (EDDA)

- Characterization of NN-interaction:
  - Large kinematical range:
    - 1.0 - 3.3 GeV/c, 30° - 90° [c.m.]
  - High precision data
    - Unpolarized, single, double polarized
    - Large impact on pp PSA >500 MeV
- Further Results:
  - No Evidence for dibaryons
  - Polarimetry for the pp system
- Future of EDDA:
  - Time Reversal Invariance Study

F. Bauer et al., PRL 90, 142301 (2003)



Dibaryons

- color singlet states

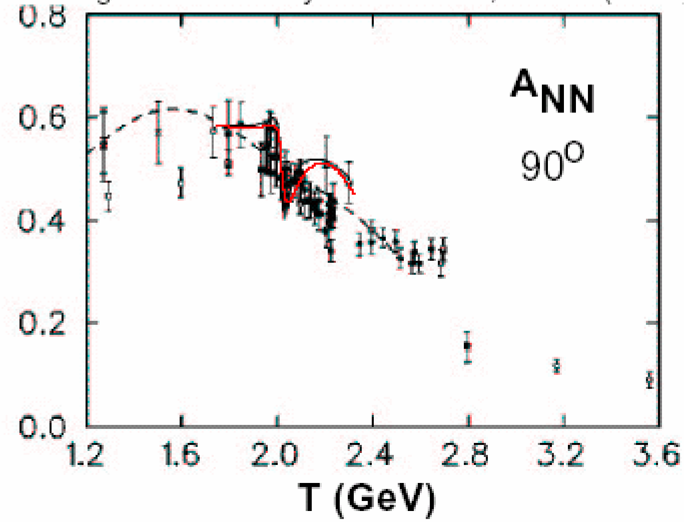
	Baryons	Mesons	
Why are	q q q	q $\bar{q}$	observed
but not	q q q q $\bar{q}$ q q q q q q	q q $\bar{q}$ $\bar{q}$	??

- numerous theoretical predictions
  for I=1 ,S=0 : $W_R \approx$ 2.1 ... 2.7 GeV
  Γ = 10...150 MeV

  no experimental evidence !

NN@Saturne

Allgower et al. Phys. Rev. C 64, 34003 (2001)



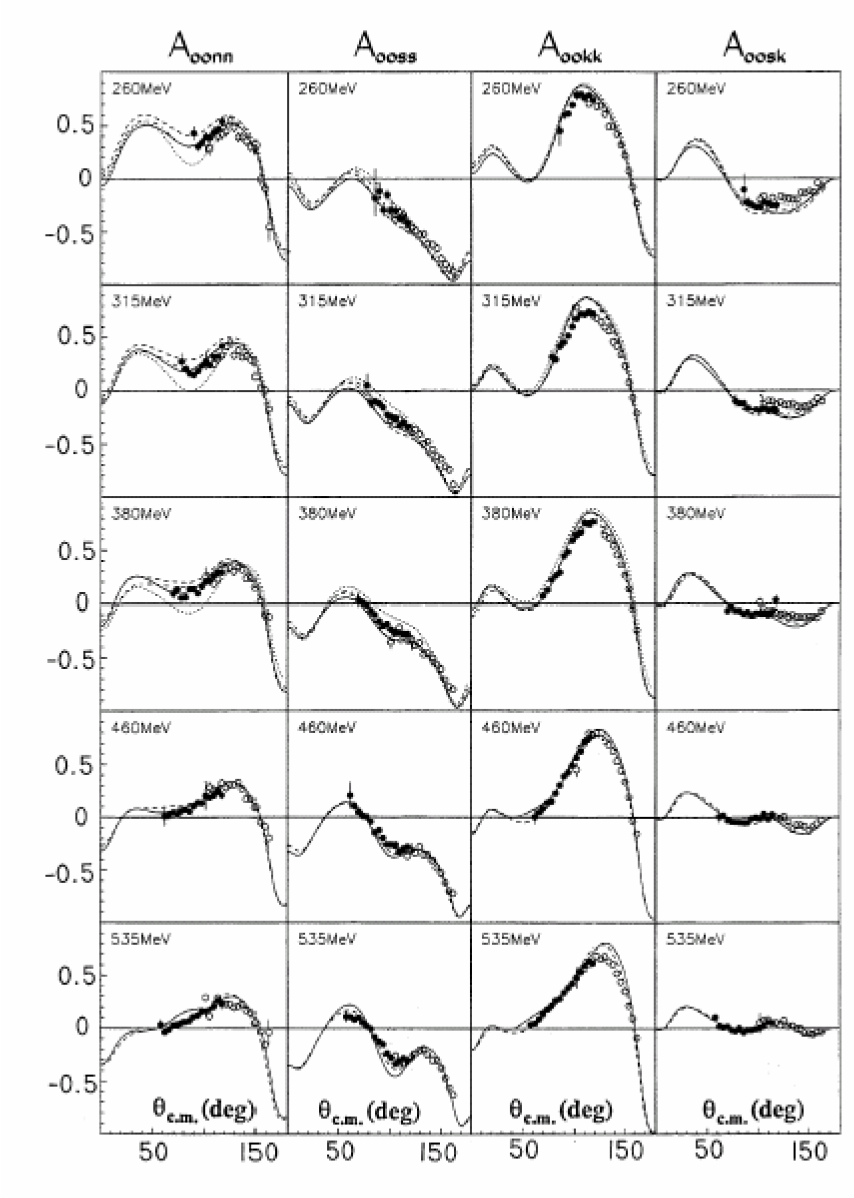
EDDA@COSY

upper limits for $\eta_{el} = \Gamma_{el} / \Gamma_{tot}$

W_R = 2.2 ... 2.8 GeV
Γ = 10 ... 100 MeV

η_{el} >	0.09	($^1S_0$)
	0.05	($^1D_2$)
	0.10	($^3P_0$)
	0.03	($^3P_1$)
	0.06	($^3F_3$)

excluded with
99%
confidence level



polarized np @ PSI

$\vec{n}\vec{p}$ 260-535 MeV

(External beam)

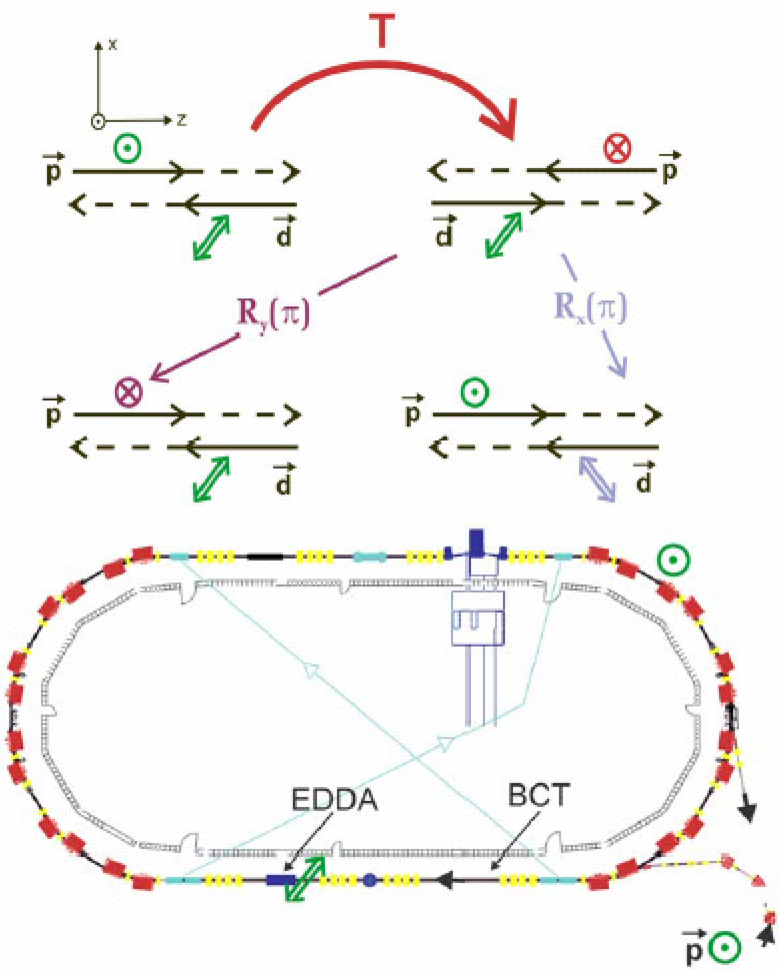
J. Arnold et al.
Eur. Phys. J. C 17, 67 (2000)

Additions since ~1990 to NN database

internal	external
• PINTEX @ IUCF Cooler $\vec{p}\vec{p}$ 200-450 MeV storage cell • EDDA @ COSY $\vec{p}\vec{p}$ 300-2500 MeV DAQ during acceleration	• polarized np @ PSI $\vec{n}\vec{p}$ 260-535 MeV • NN program at Saturne II $\vec{n}\vec{p}$ 300-1150 MeV $\vec{p}\vec{p}$ 600-2700 MeV
pure H targets $\frac{d\sigma}{d\Omega}$ A_N A_{NN} A_{SL} A_{SS} A_{LL}	double scattering observables total cross sections σ_{tot} A_N A_{ij} D_{ij} K_{ij} N_{ijk}

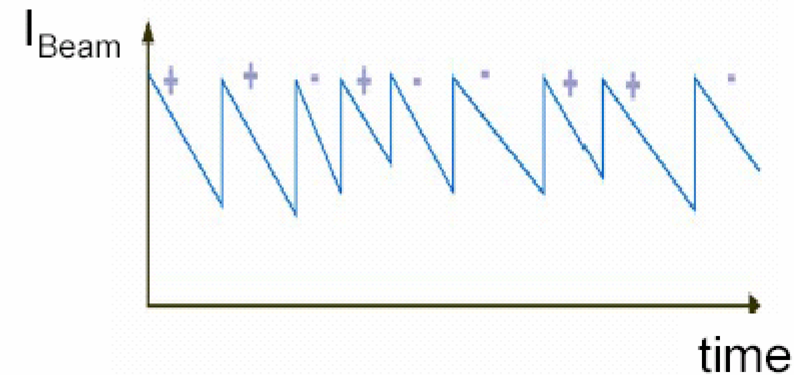
future (COSY): double scattering experiments?

Principle of the Experiment

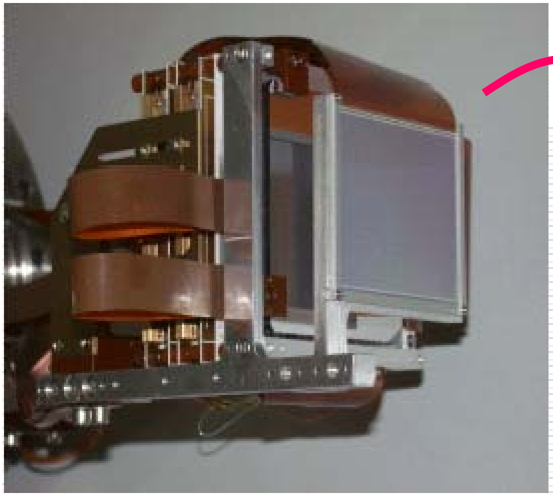


COSY used as accelerator and detector:

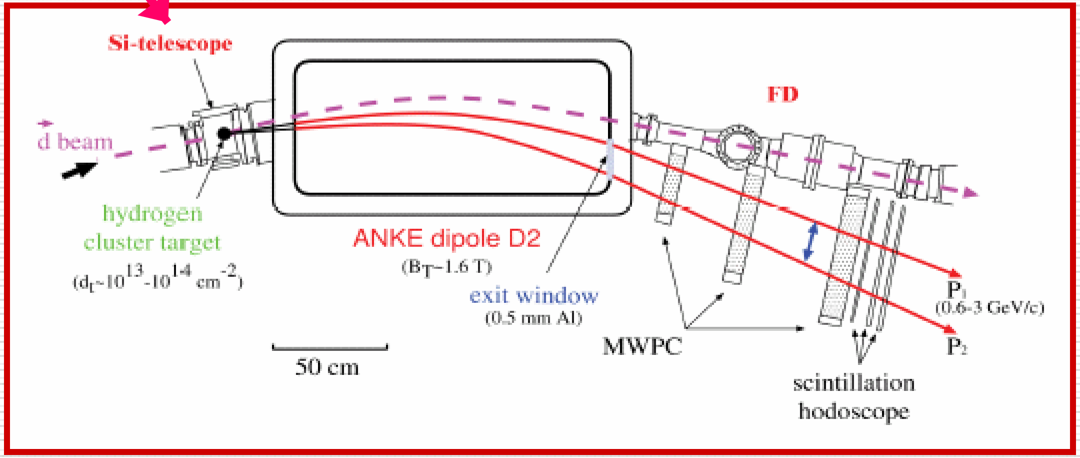
Total polarization correlation coefficient $A_{y,xz}$ leads to relative difference of current slopes



- Milestone:
  Operation of Precision BCT



ANKE @ COSY JUELICH

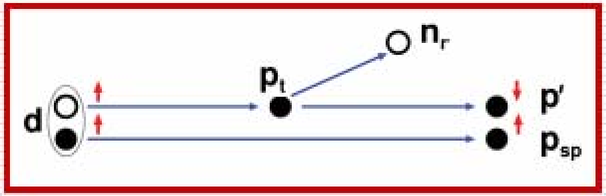


1. charge-exchange breakup $\vec{d}\vec{p} \to (pp)_{^1S_0}\, n$
2. np elastic scattering $\vec{p}\vec{d} \to p_{sp}(pn)$
3. Deuteron breakup $\vec{p}\vec{d} \to (pp)_{^1S_0}\, n$
4. Additional ideas (η meson, Parity of Θ^+, …)

A. Kacharava et al.

Motivation: *NN* Interaction

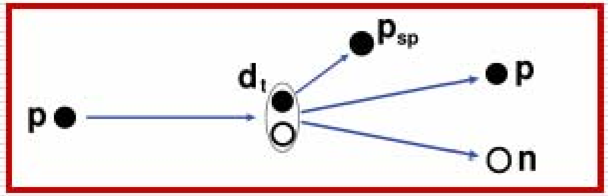
- Spin structure of $np \rightarrow pn$ reaction amplitudes
  - Method: CE break-up



$\vec{d}p \rightarrow (pp)_{^1S_0}\, n$

$\vec{d}\vec{p} \rightarrow (pp)_{^1S_0}\, n$

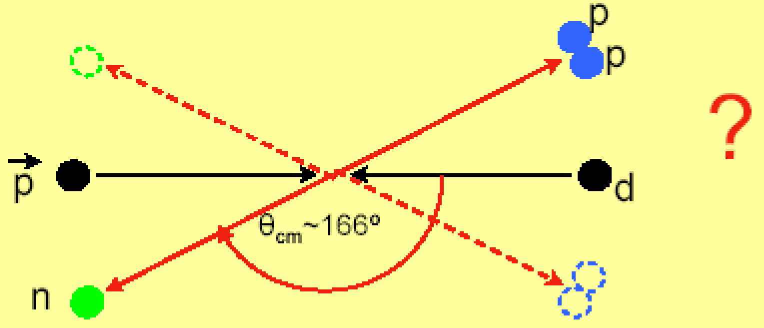
- Next Step: Measurement of spin observables for *pn* system up to 3 GeV
  - Method: Spectator technique



$\vec{p}\vec{d} \rightarrow p_{sp}\,(pn)$

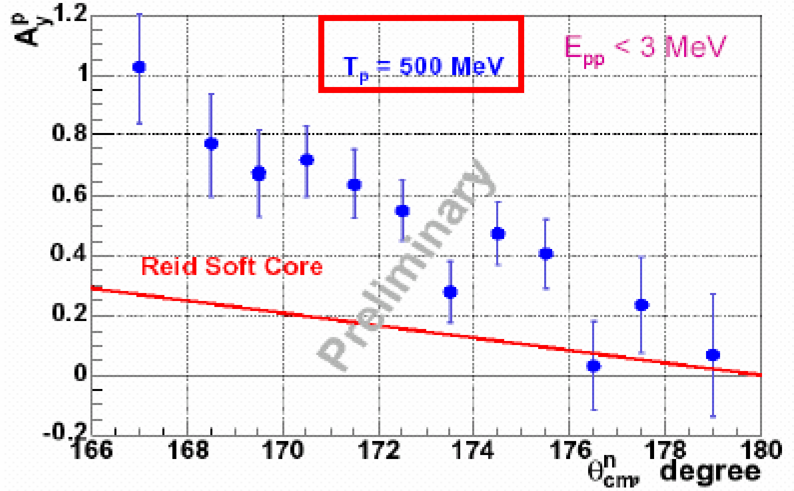
pd dynamics at high momentum transfer

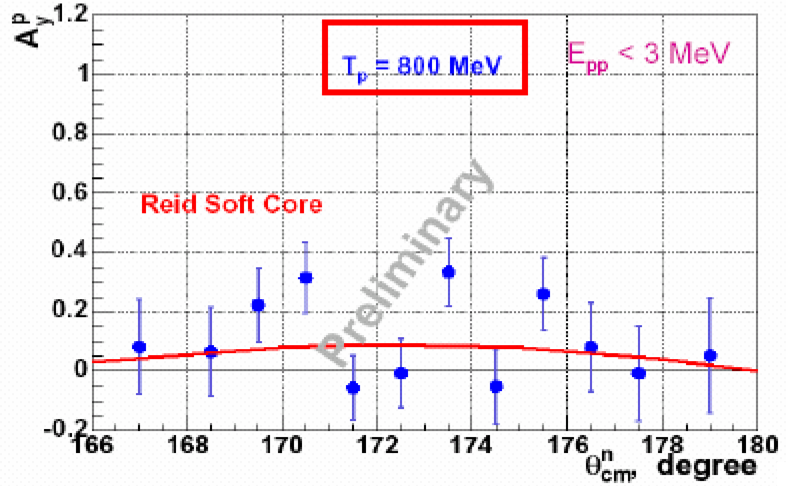
- pd → $(pp)_s$ n
- Kinematics like pd backward elastic
  - → S-wave pp-pairs
  - → Suppression of Δ
- Progress
  - cross sections (✓)
  - Analyzing Power A_y^p (✓)
  - Future: Polarized target
    - Analyzing Power T_{20}
    - Spin-Correlation Parameters



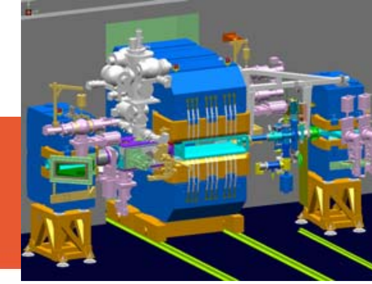
Effect shows strong energy dependence

Surprisingly large A_y^p in pd → $(pp)_s$ n





Future Experiments: Parity of θ⁺ (1540)



ANKE

COSY is perfectly suited to determine the parity free of any model!

How to measure the parity of the Θ^+ in $\vec{p}\vec{p}$ collisions

C. Hanhart[1], M. Büscher[1], W. Eyrich[2], K. Kilian[1], U.-G. Meißner[1,3], F. Rathmann[1], A. Sibirtsev[1], and H. Ströher[1]

[1]Institut für Kernphysik, Forschungszentrum Jülich GmbH, D–52425 Jülich, Germany

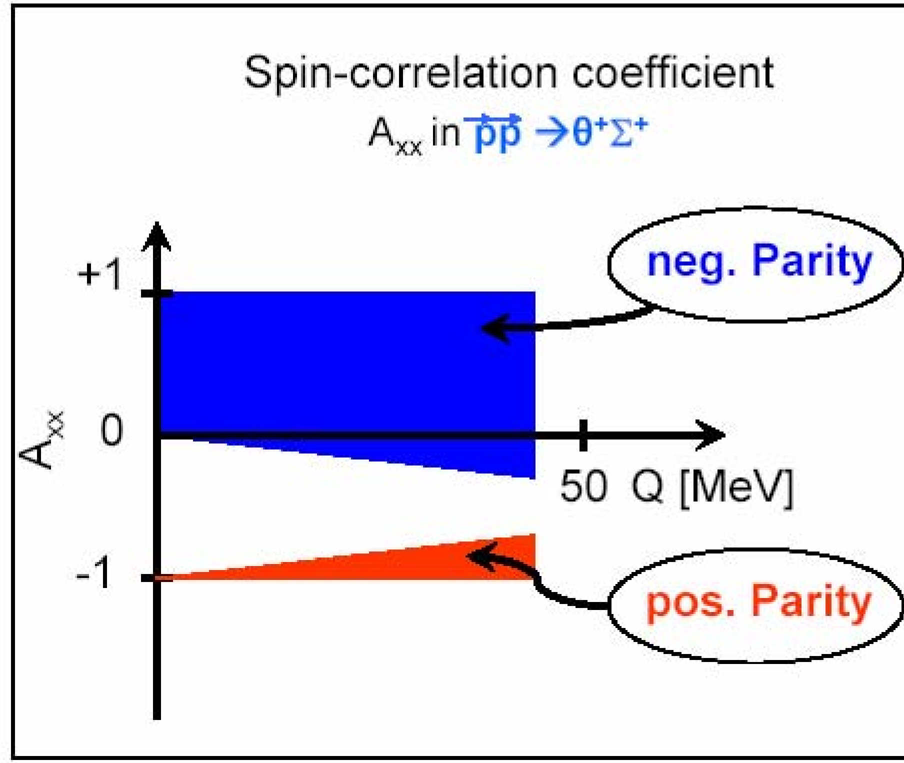
[2] Physikalisches Institut, Universität Erlangen, Erwin-Rommel-Str. 1, D–91058 Erlangen, Germany

[3]Helmholtz-Institut für Strahlen- und Kernphysik (Theorie), Universität Bonn Nußallee 14-16, D–53115 Bonn, Germany

accepted for publication in PLB

Abstract

Triggered by a recent paper by Thomas, Hicks and Hosaka, we investigate which observables can be used to determine the parity of the Θ^+ from the reaction $\vec{p}\vec{p} \to \Sigma^+\Theta^+$ near its production threshold. In particular, we show that the sign of the spin correlation coefficient A_{xx} for small excess energies yields the negative of the parity of the Θ^+. The argument relies solely on the Pauli principle and parity conservation and is therefore model–independent.



meson production near threshold:
study of fundamental πNN system,
meson-nucleon interaction

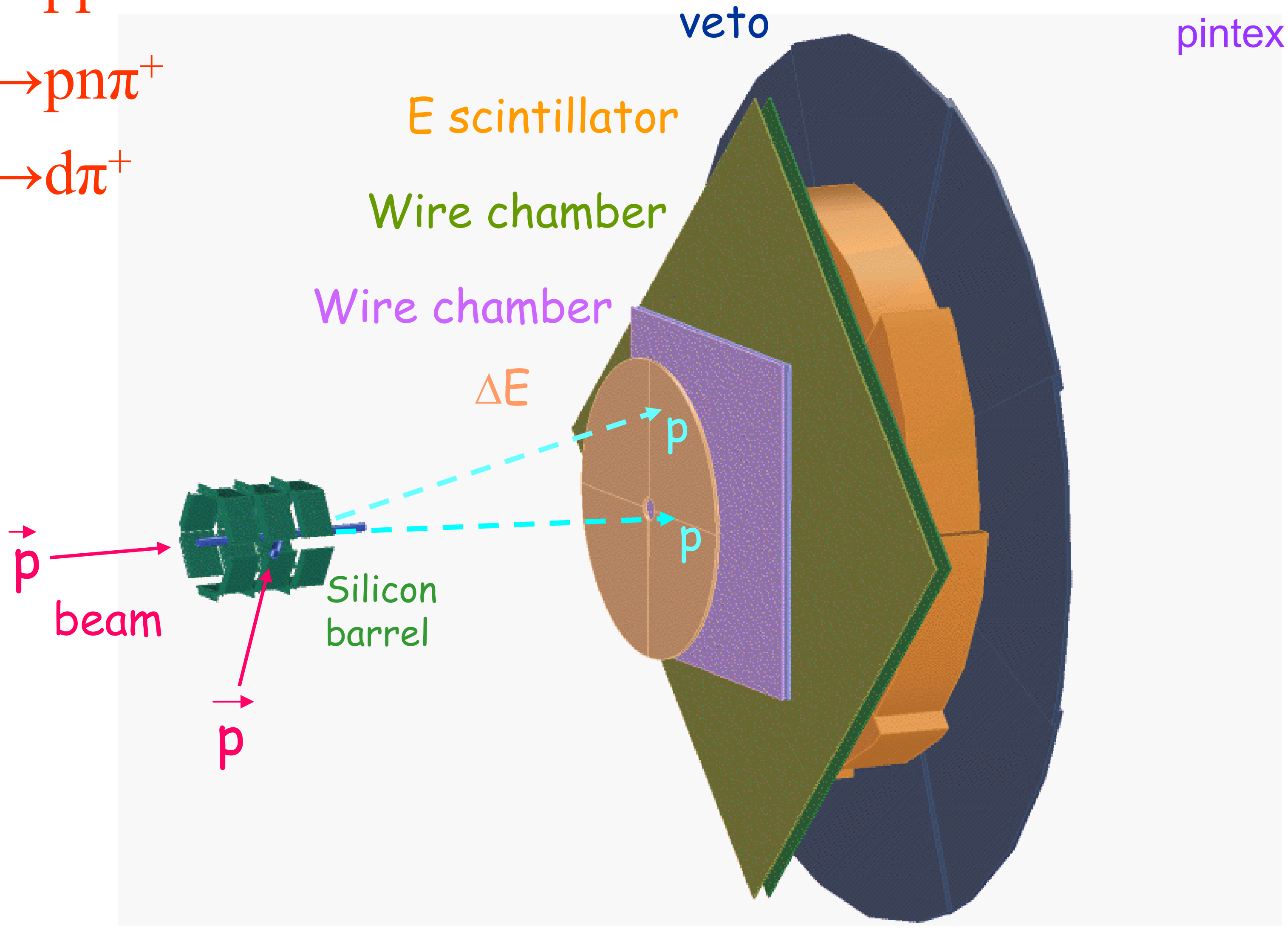
$\vec{p}\vec{p} \to pp\pi^0$

$\vec{p}\vec{p} \to pn\pi^+$

$\vec{p}\vec{p} \to d\pi^+$

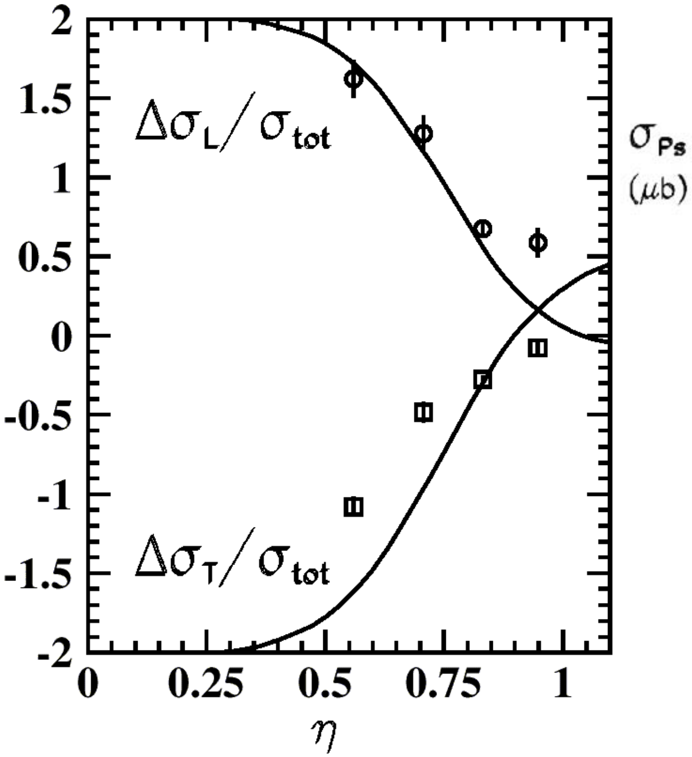
iucf

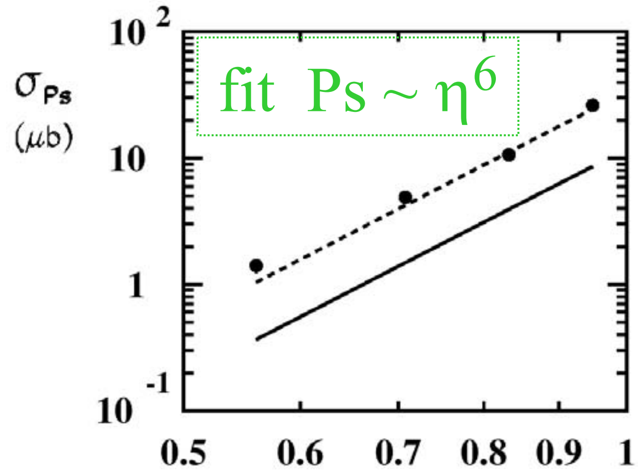
pintex

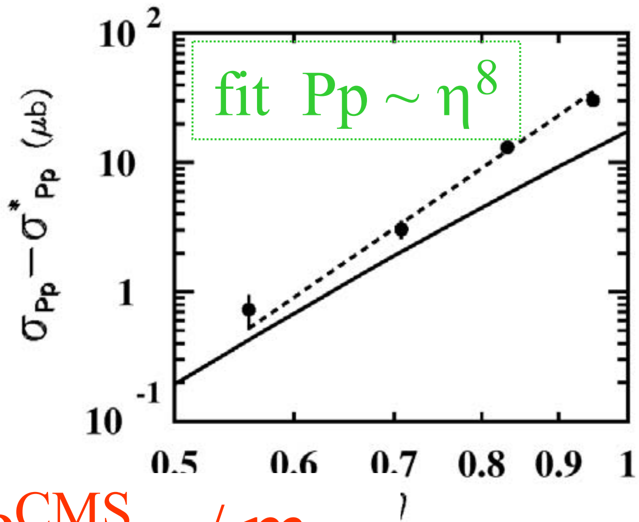


$\vec{p}\,\vec{p} \rightarrow pp\,\pi^o$ measured PW contributions

H.O.Meyer et al., Phys. Rev. Lett. 83, 5439,1999







$\eta = \max P^{CMS}_{\pi 0} / m_{\pi 0}$

solid lines: Jülich model

dotted lines : phase space

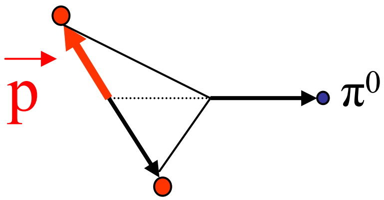
labeled with final L_{NN}, l_π

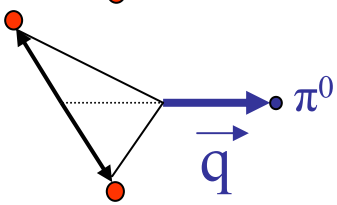
$$\begin{cases} \sigma_{TOT} = \sigma_{Ss} + \sigma_{Ps} + \sigma_{Pp} \\ \Delta\sigma_T = \sigma(\uparrow\downarrow) - \sigma(\uparrow\uparrow) = 2(\sigma_{Ps} - \sigma_{Ss} + \sigma^*_{Pp}) \\ \Delta\sigma_L = \sigma(\overset{\leftarrow}{\rightarrow}) - \sigma(\overset{\rightarrow}{\rightarrow}) = 2(\sigma_{Ss} + \sigma_{Ps} - \sigma_{Pp} - 2\sigma^*_{Pp}) \end{cases}$$

$$\frac{\sigma_{Ps}}{\sigma_{TOT}} = \frac{1}{4}\left(1 + \frac{\Delta\sigma_T}{\sigma_{TOT}} + \frac{1}{2}\frac{\Delta\sigma_L}{\sigma_{TOT}}\right)$$

Ps-cross section directly measured

spin-½ on spin-½ with three-body final state





Make cuts through 5-dim. phase space

polar angle:
θ_p or θ_q

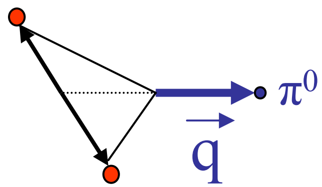
azimuth dependences
φ_p, φ_q, $\varphi_p+\varphi_q$, $2\varphi_p-\varphi_q$

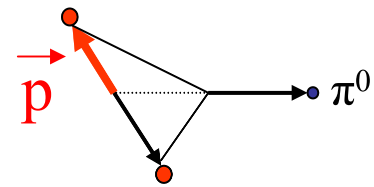
$\Delta\varphi = \varphi_p - \varphi_q$

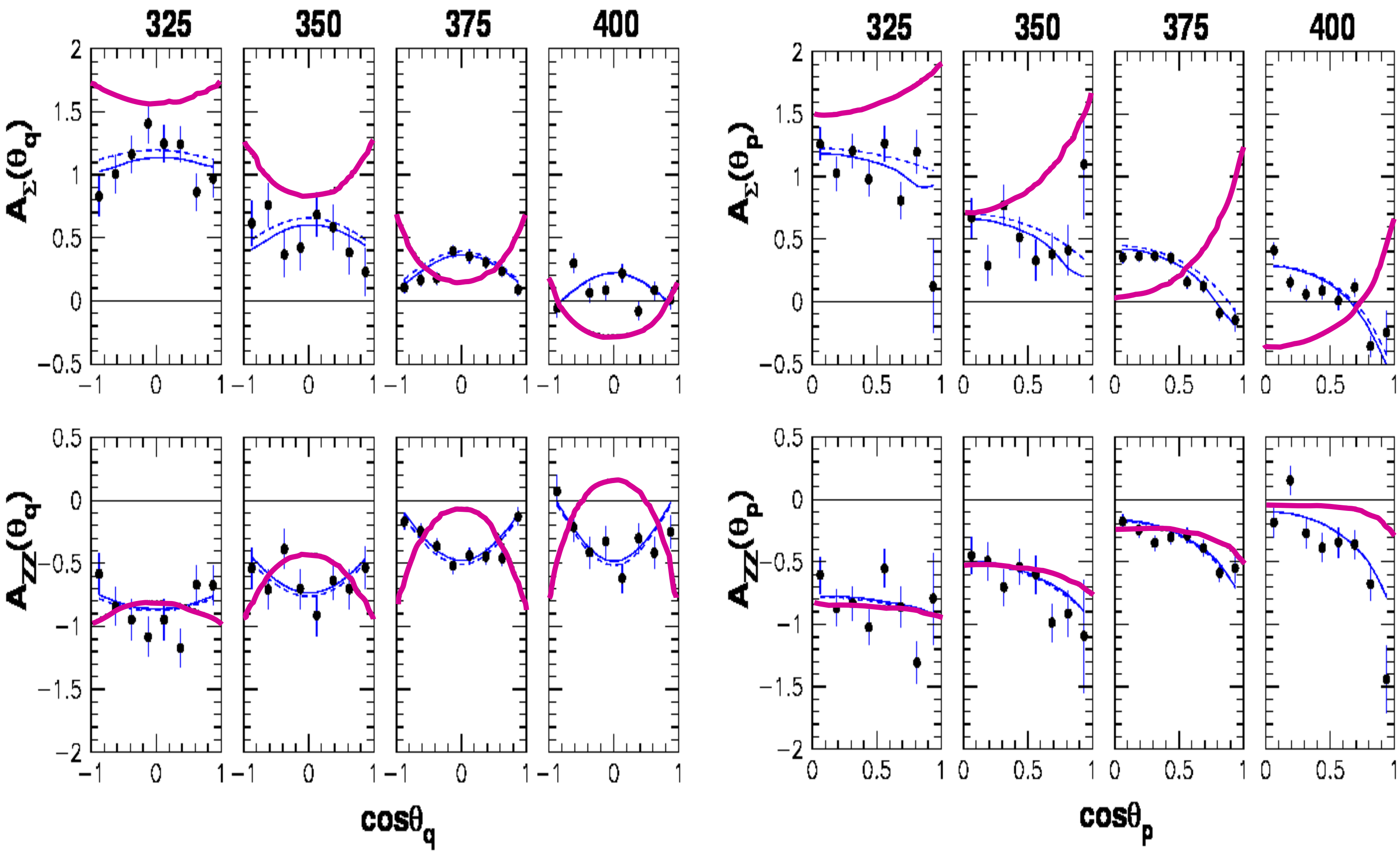
+ dependence on energy sharing parameter $\boldsymbol{\varepsilon}$

lots of observables, but also lots of information !
(complete mapping of phase space)

$\vec{p}\vec{p} \rightarrow pp\pi^0$, $A_{yy}+A_{xx}$ and A_{zz}





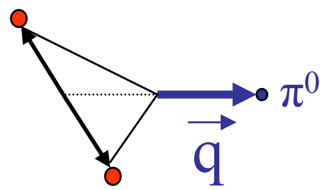


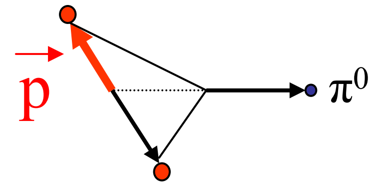
Partial-wave Fit with/without hole correction

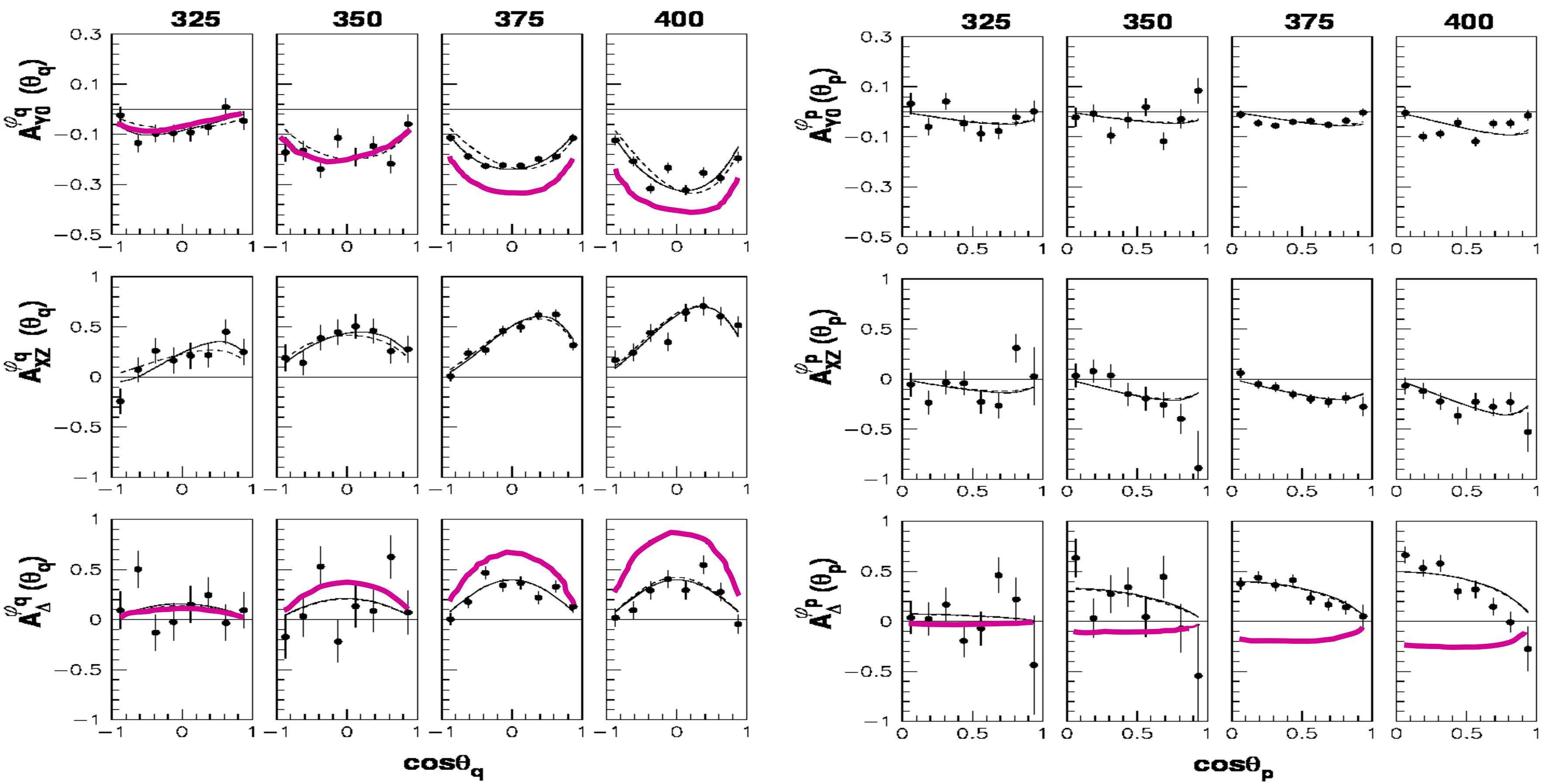
Ss, Ps, Pp

C. Hanhart et al., PRC42,064008 (2000) (Jülich model)

$\vec{p}\vec{p} \to pp\pi^0$, A_y, A_{xz} and A_{yy}-A_{xx}







Theory: C. Hanhart et al., PRC42, 064008 (2000) (Jülich model)

Chiral Symmetry

- a symmetry of QCD: $m_u = m_d = 0$ ... $m_\pi = 0$
- broken: $m_\pi \neq 0$, but small ($m_\pi \ll M$)

Chiral Perturbation Theory (χPT)

expand amplitude in terms of Q/M (Weinberg, 1979)

- applied to meson-baryon systems (1990)
- organize terms, power counting (Weinberg, 1992)
- applied to $pp \to pp\pi^0$

  (Cohen et al., Park et al. 1996 → tree-level up to D=1)

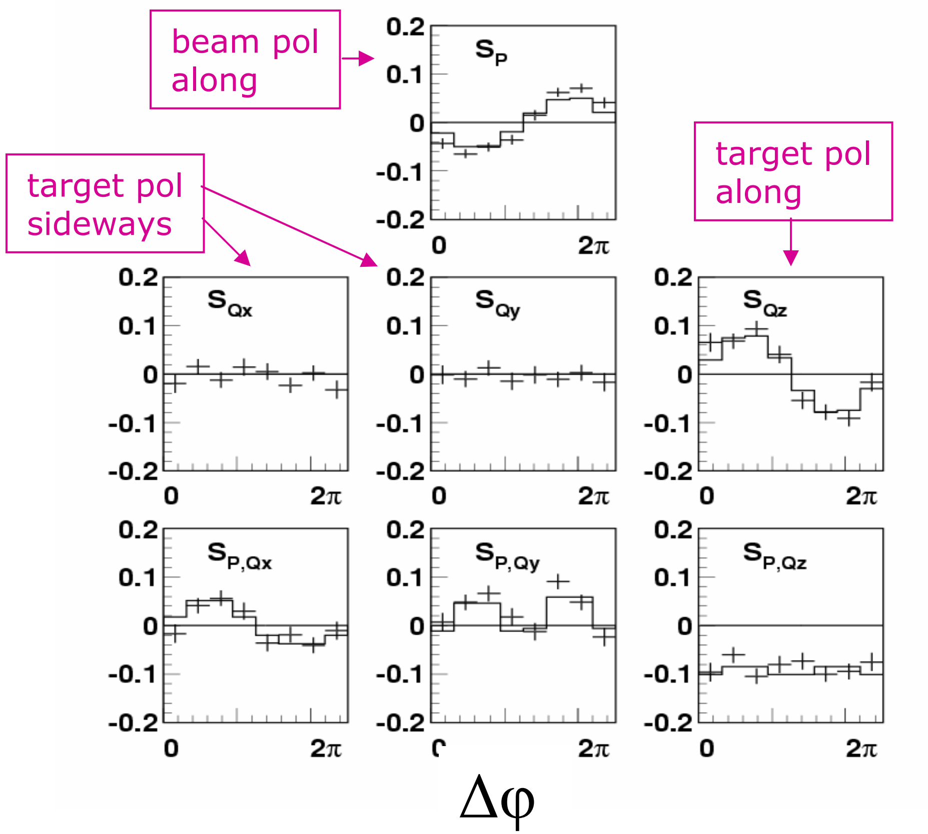
  (Gedalin et al., 1998 → loops up to D=2)

issues:
- convergence ($Q < (m_\pi M)^{1/2} < 0.4$)
- final-state interaction
- relativity

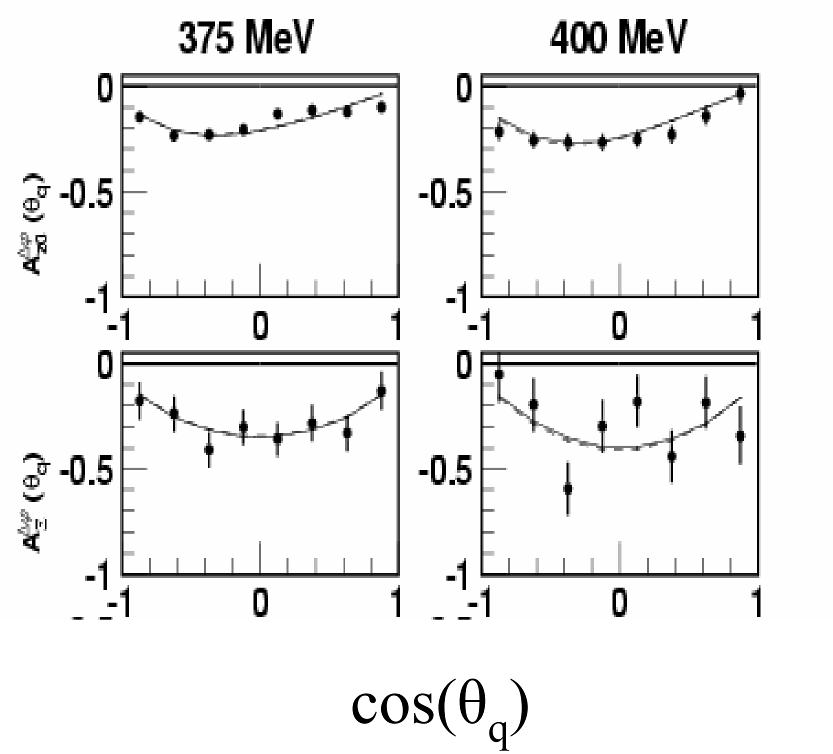
$\vec{p}\vec{p}\rightarrow pp\pi^0$, A_z and A_{xy}-A_{yx}

(Observables that are **forbidden** by parity conservation in reactions with two-body final state)

dependence on $\Delta\varphi=\varphi_\pi-\varphi_{pp}$
('coplanarity' angle)

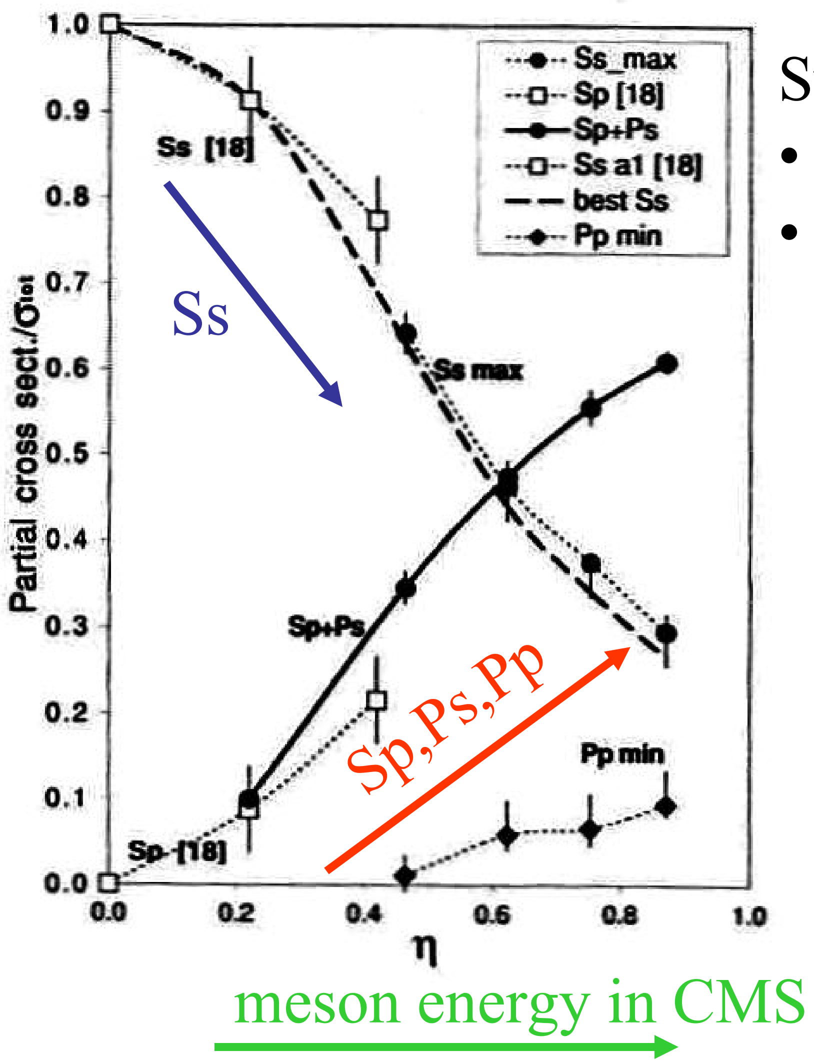


Axial observables



$\vec{p}\,\vec{p} \rightarrow pn\,\pi^+$ measured PW contributions

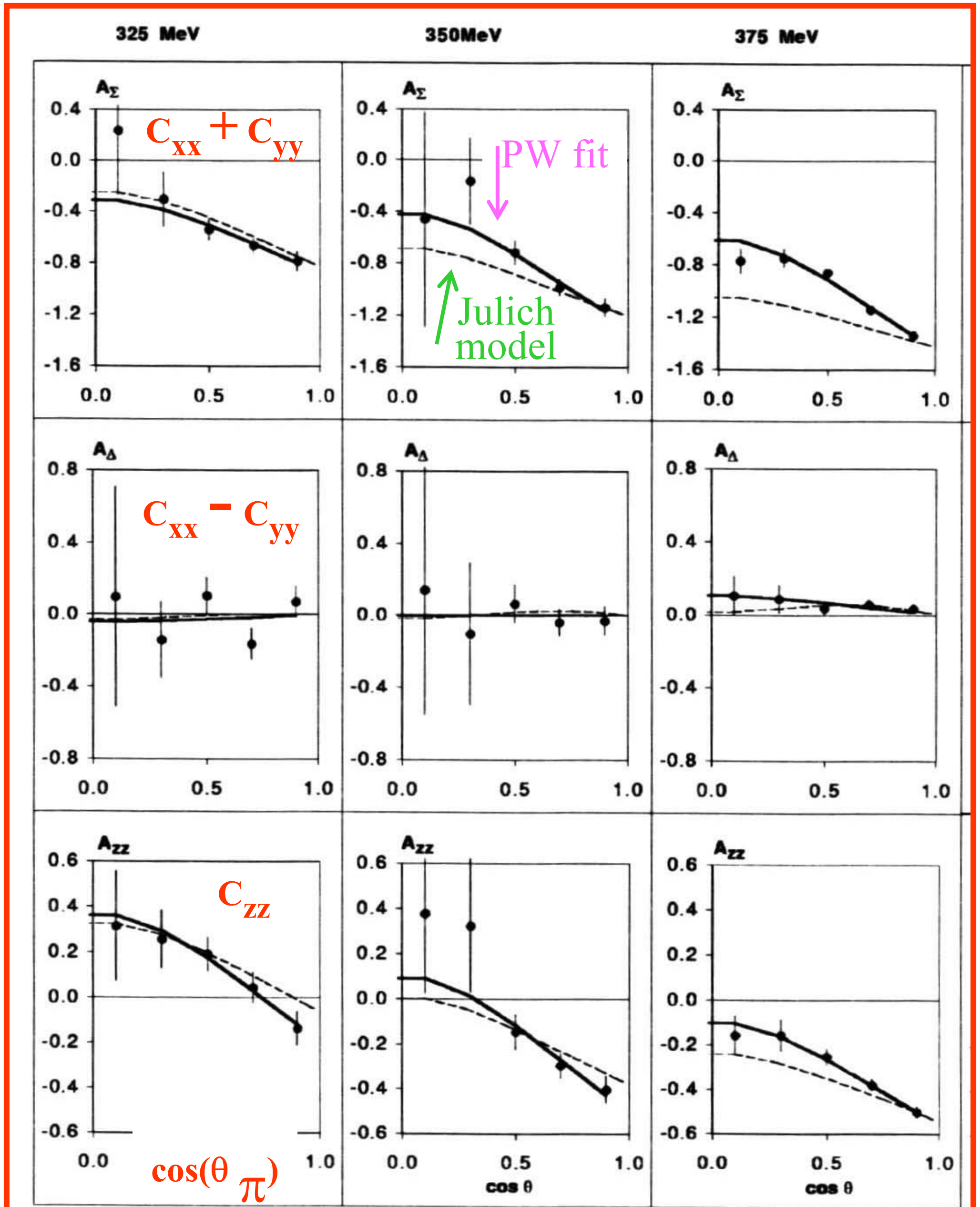
W.W.Daehnick et al., Phys. Rev. C. 65, 024003,2002

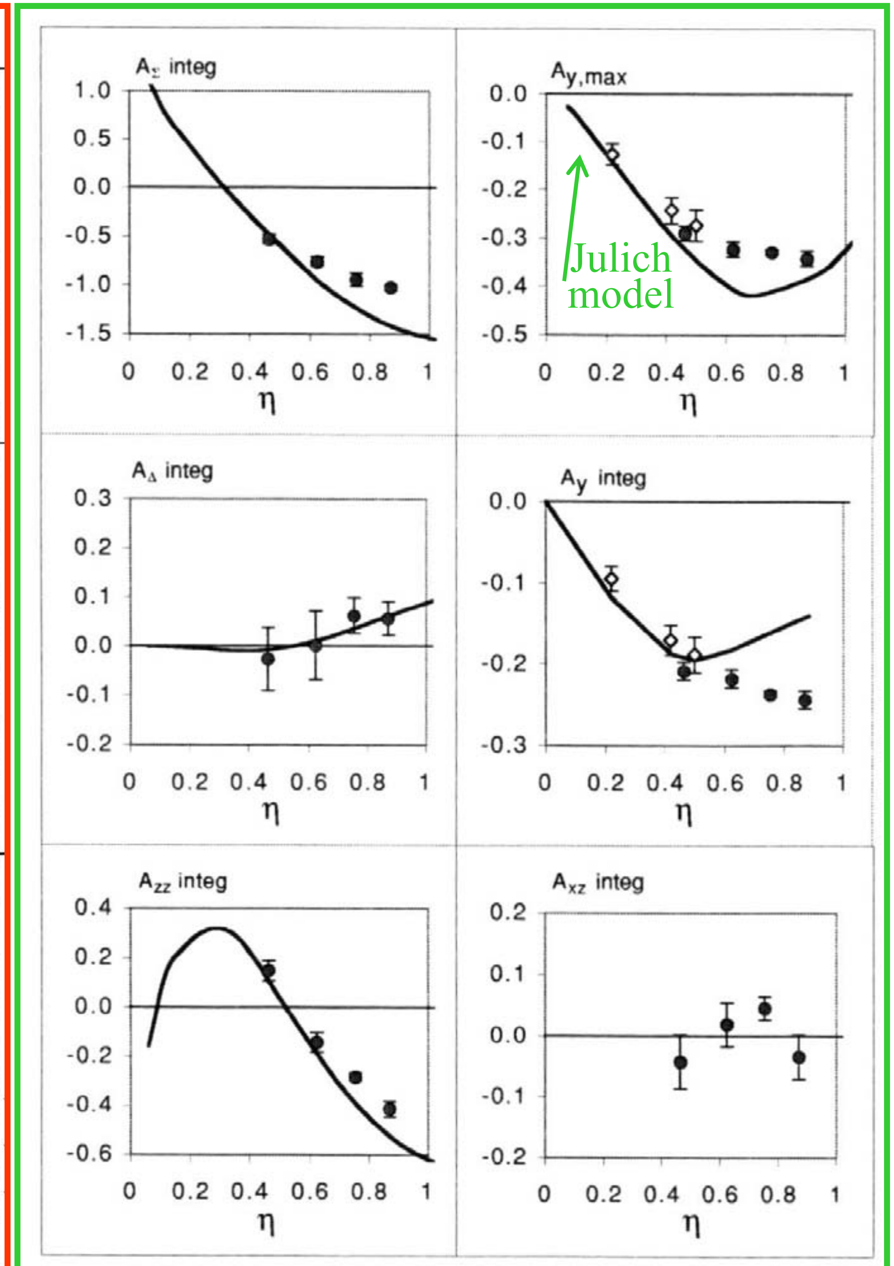


Summary plot

- individual amplitudes fitted to the data
- lines connect summed Ss, Sp+Ps, and Pp amplitudes

$\vec{p}\,\vec{p} \to pn\,\pi^+$ angular and energy dependence





W.W.Daehnick et al., Phys. Rev. C 65, 024003,2002

pp→meson +X

Indiana Cooler: spin correlation data

$\vec{p}\vec{p} \to d\pi^+$ B. v. Przewoski et al., *Phys. Rev.* **C61**, 064604 (2000)

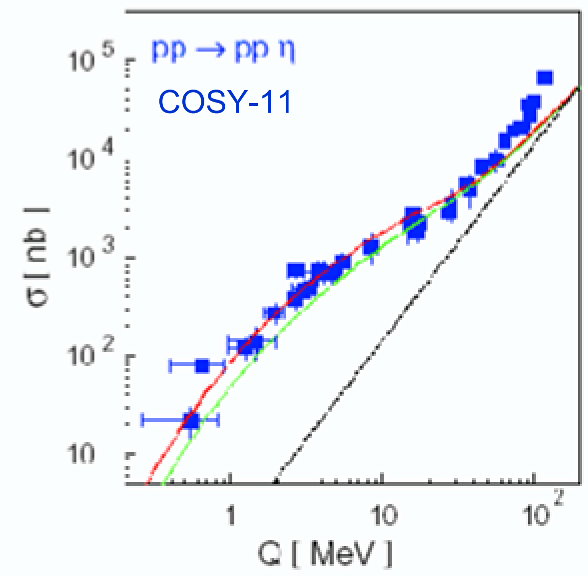
$\vec{p}\vec{p} \to pn\pi^+$ Swapan K. Saha et al., *Phys. Lett.* **B461**, 175 (1999)
W.W. Daehnick et al., *Phys. Rev.* **C65**, 024003 (2002)

$\vec{p}\vec{p} \to pp\pi^0$ H.O. Meyer et al., *Phys. Rev. Lett.* **81,** 3096 (1998)
H.O. Meyer et al., *Phys. Rev. Lett.* **83**, 5439 (1999)
H.O. Meyer et al., *Phys. Rev.* **C 63**, 064002 (2001)

COSY: heavy meson production with polarized beam

Future:

$\vec{p}p \to pp\eta$ Q=40 MeV, COSY-11 group



Theory: polarization in NN meson production **not** understood

few-nucleon reactions

add another nucleon
Reaction mechanism
3 nucleon forces (?)

Axial Observables

- anti-symmetric under parity operation.
  →forbidden in coplanar final states, e.g. longitudinal analyzing power Az

- A 3NF contains some axial operators that can not be constructed with pair wise NN forces.

- These axial operators couple strongly to unnatural parity states (i.e. $(-1)^{L+1}$; where $L=l_p+l_q$)

- Axial observables make it easier for the expected small unnatural-parity states to contribute via interference with large natural-parity states. Knutson (PRL 73, 3062 (1994))

Axial Observables in dp Breakup **(IUCF)**

Faddeev calcs, Witala et al.

-at 9 MeV: A_z is vanishingly small

experiment confirms this (George et al.)

-at 135 MeV: A_z is 100 times larger!

- **Possible axial observables**

$$A_z^p$$

$$A_z^d$$

$$C_{y,x} - C_{x,y}$$

$$C_{xz,x} - C_{yz,y}$$

$$C_{zz,z}$$

- **Measured axial observables**

$$A_z^p$$

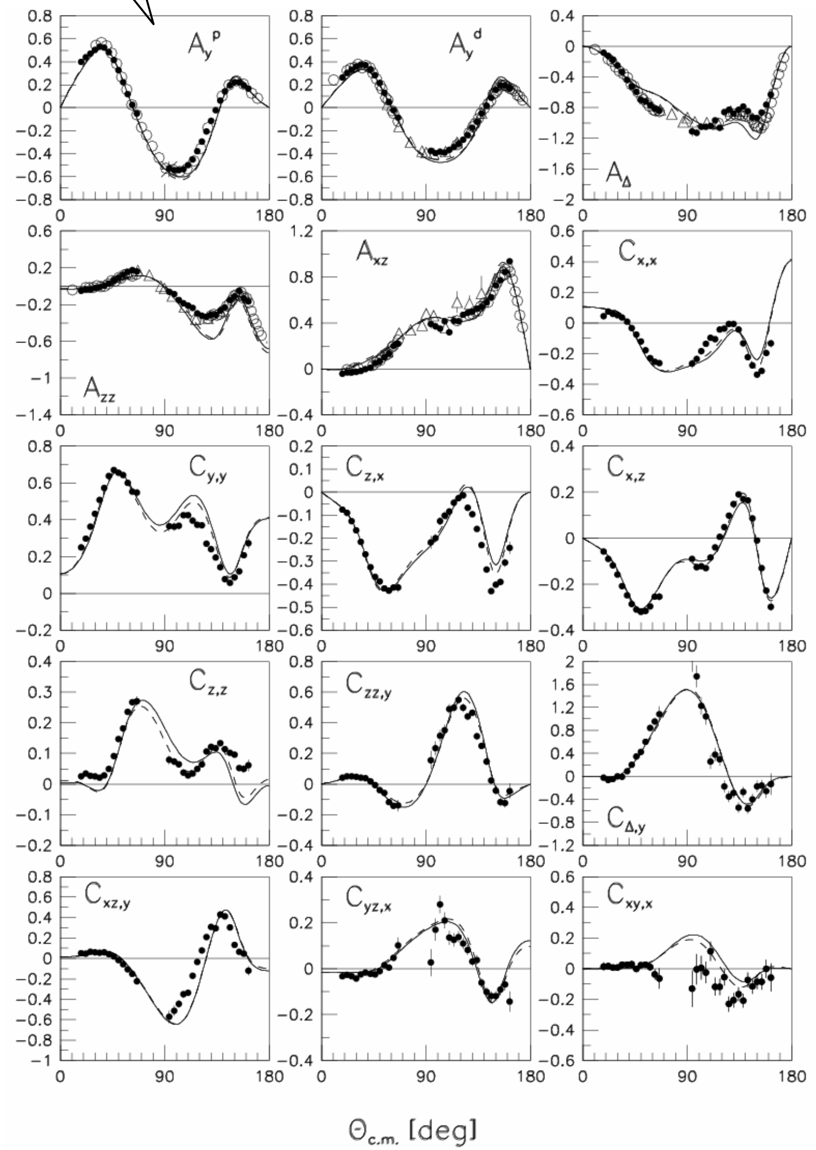
$$C_{y,x} - C_{x,y}$$

$$C_{zz,z}$$

Require longitudinal beam pol! (applies to A_z^d and $C_{xz,x} - C_{yz,y}$)

Normalize breakup data to pd elastic scattering

target



beam

pd→ pd, 135 MeV
v.Przewoski et al.

Polarized hydrogen target

Polarization of Beam States

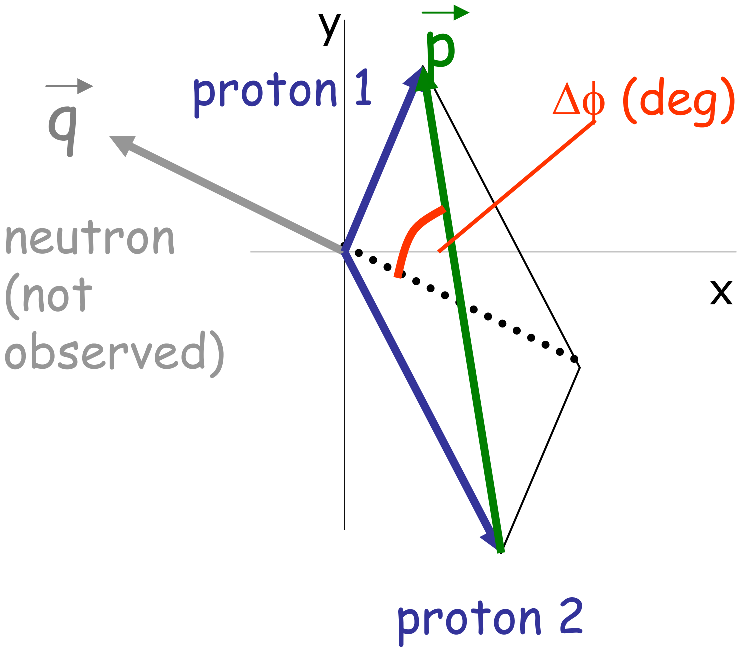
	Vector		Tensor	
Beam State	Hyp. states	Pol	Hyp. States	Pol
1	1-6	0	1-6	0
2	3,6	+1	3,6	+1
3	2,5	-1	2,5	+1
4	3,4	0	3,4	+1
5	1,6	0	1,6	-2

Description of Phase Space

- **The final state for breakup is described by three momentum vectors**
  - **9 degrees of freedom**
  - **4 are constrained by conservation laws**
  - **Thus, 5 parameters are needed to identify an event**

- **We chose, θ_p, θ_q, ϕ_p, ϕ_q, and $|\vec{p}|$**

- **The axial observables are invariant under rotations about the z-axis; thus can only depend on $\Delta\phi = (\phi_p - \phi_q)$**



Faddeev calculations with experimentally realistic constraints

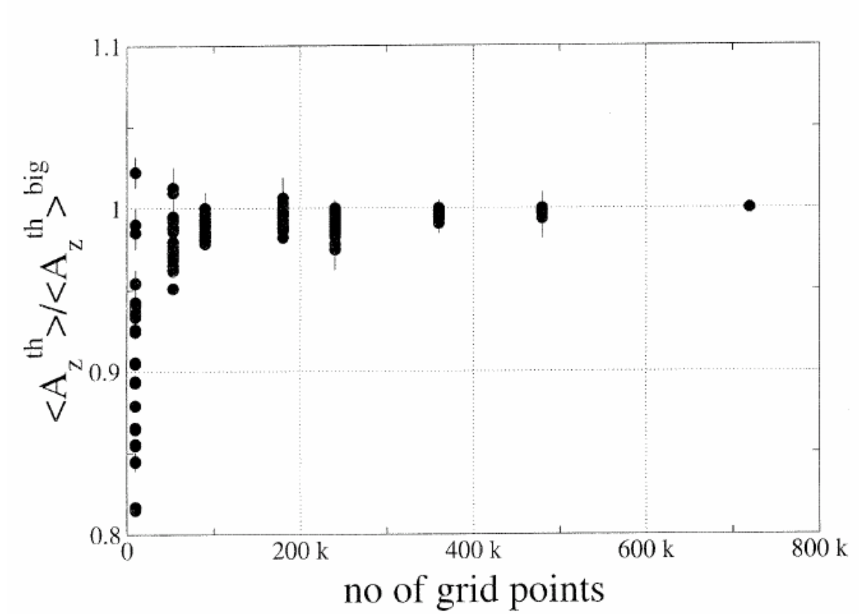
J. Kuros-Zolnierczuk et al., Few Body Systems 34, 259 (2004)

1) Average over true experimental acceptance
2) No need for Monte Carlo calculations
3) Applicable to kinematically complete experiments

Average over theoretical observables weighted by the density in phase space (~ cross section, detector efficiency and polarization asymmetry) of the actual events

Calculate observables on a grid from Faddeev amplitudes and interpolate between grid points by multidimensional linear interpolation

Difference between observables from amplitudes directly and observables from interpolation <.003



$\vec{d}\vec{p} \rightarrow ppn$, 270 MeV

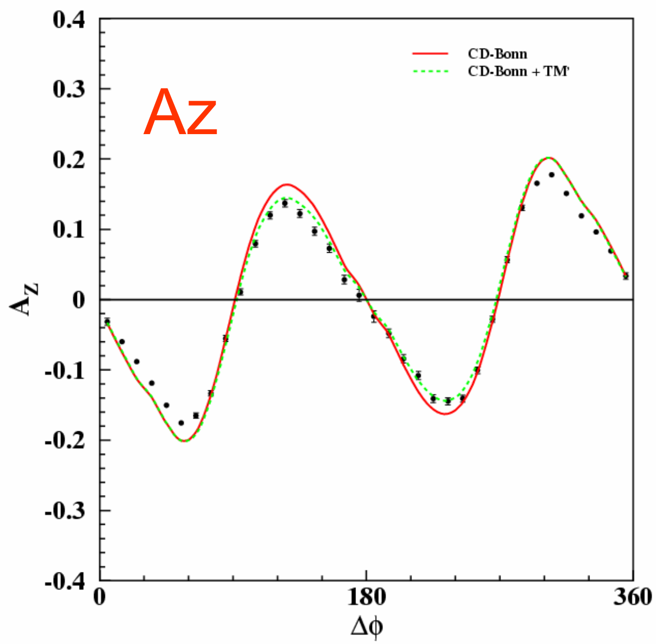
H.O. Meyer et al., PRL 93, 112502 (2004)

CD-Bonn

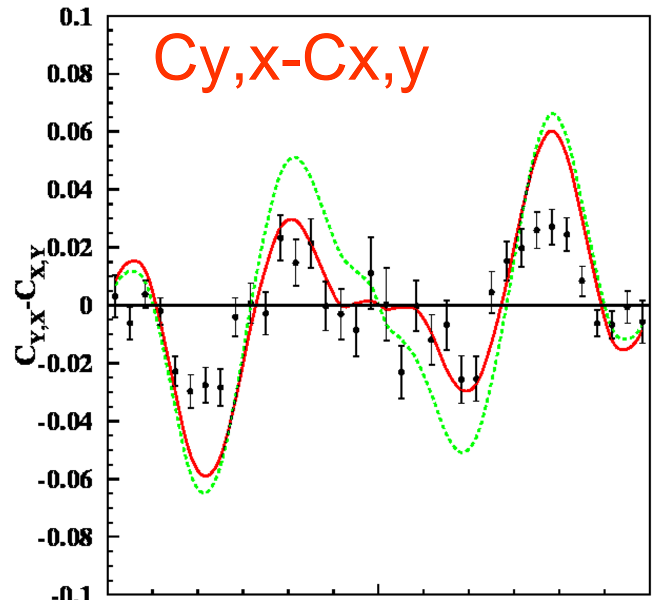
CD-Bonn+TM’

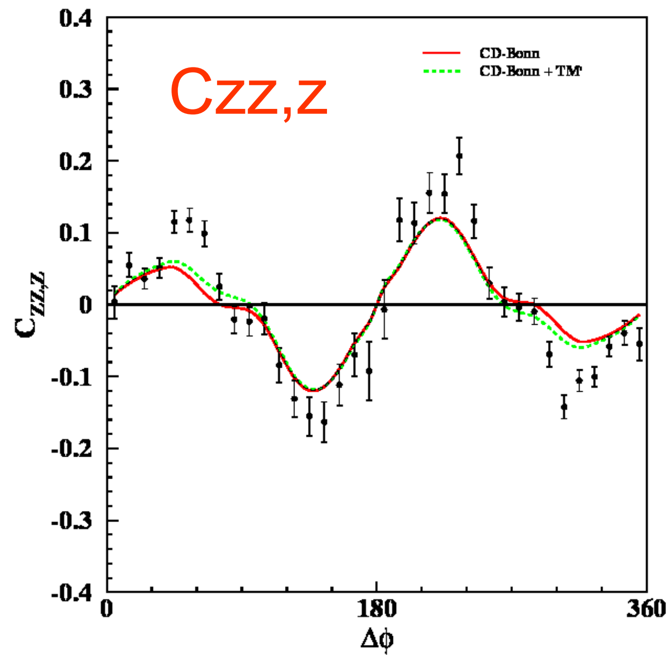
Addtl’ physics?

Longitudinal analyzing power



Spin correlation coefficients





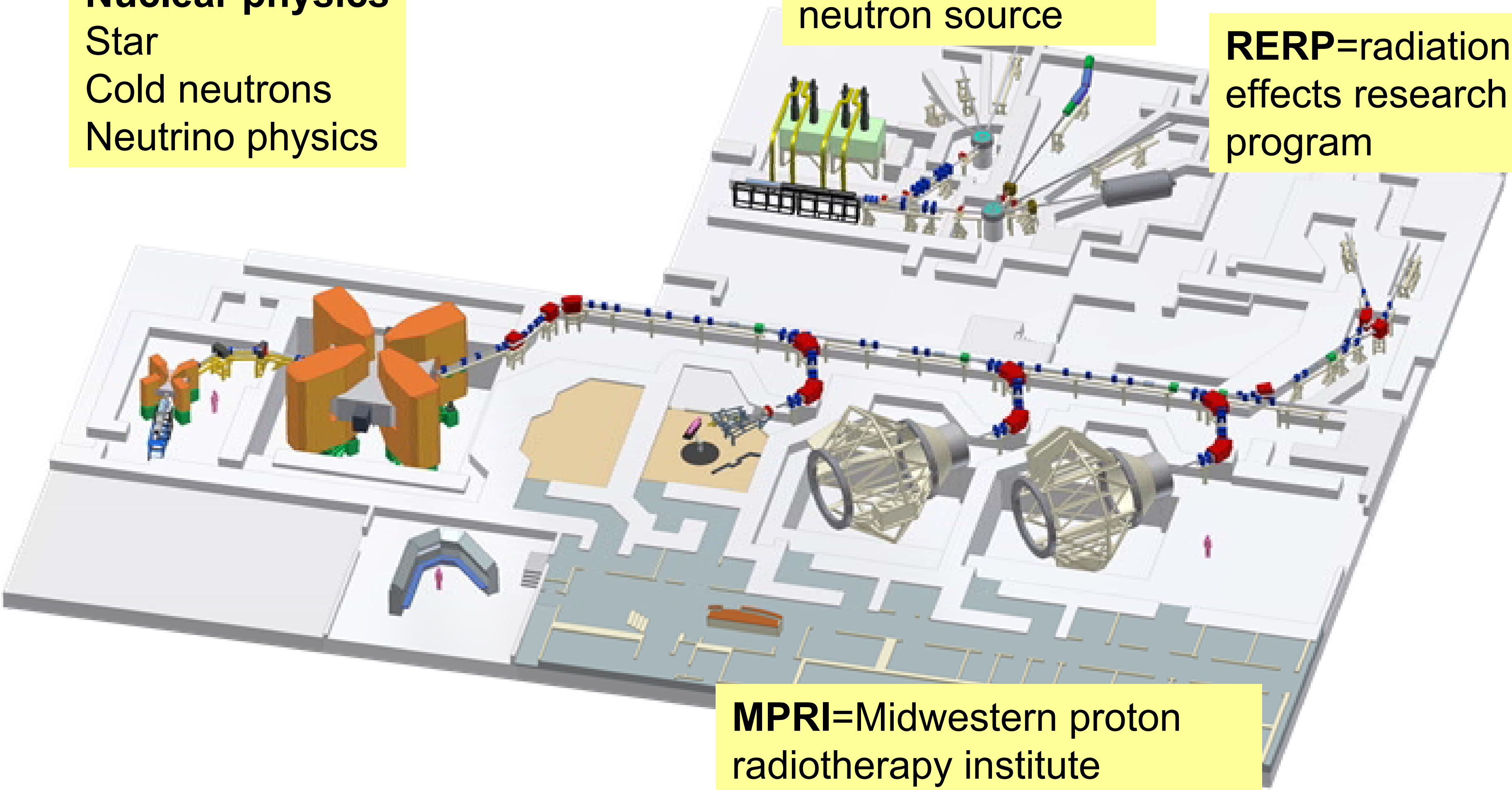
Q: Is there a 3NF?

A: maybe. There is no convincing signal to date

- -- **Axial observables are reasonably well described by the NN potential alone. The Axial observables measured turn out not to be sensitive to the 3NF**

- -- **inclusion of 3-nucleon forces in the Faddeev calculations sometimes does and sometimes does not improve agreement with the data (the same is true for elastic scattering)**

IUCF 2004 and beyond



Nuclear physics
Star
Cold neutrons
Neutrino physics

LENS=low energy neutron source

RERP=radiation effects research program

MPRI=Midwestern proton radiotherapy institute