PAX Ferrara workshop 2007

Realistic experimental constraints in the analysis of few-body reactions

The sampling method – how to integrate predictions from a theoretical model for true comparison with experiment

Pia Thörngren Engblom

Outline

- The Sampling Method –
  - motivation & derivation
- Application to 3nucleons –
  - dp breakup

Three bodies in the final state EXPERIMENT and THEORY

- **Problems:**
  1) What observable to analyze as function of what independent variable?
  2) How to ”correct” the experimental data with respect to the true acceptance and variations of detection efficiencies?
- **Solutions:**
  1) Use *The Sampling Method* to investigate phase space
  2) DON’T!

J.Kuros-Zolnierczuk, P.Thörngren, H.O. Meyer et al., FBS 34, 259 (2004), nucl-th/0402030

The Sampling Method (i)

– Define a set of parameters needed to completely describe the kinematics of a given reaction:

$$x = \{\alpha_1, \ldots., \alpha_m, \ldots.\}$$

- A typical polarization observable affects the unpolarized cross section σ_0 according:

$$\sigma(x) = \sigma_0(x)\left(1 + PO(x)\right)$$

where P is the polarization and O is the observable

The Sampling Method (ii)

To measure $O(x) \rightarrow$ Two measurements with $P_{\pm}$

The yields are given by

$$N_{\pm}(x) = L_{\pm}\varepsilon(x)\sigma_0(x)\left(1 \pm P_{\pm}O(x)\right)$$

where $P_{\pm}$ are the magnitudes of the polarizations

$L_{\pm}$ the time integrated luminosities

$\varepsilon(x)$ is the detection efficiency

-Assume $L_{+} = L_{-} = L/2$ and $P_{+} = P_{-} = P$

We get $N(x) = N_{+} + N_{-} = L\varepsilon(x)\sigma_0(x)$

for the total # of events

The Sampling Method (iii)

Using the previous results we arrive at

$$O(x) = \frac{1}{P}\left[\frac{N_+ - N_-}{N_+ + N_-}\right]$$

This holds for ANYpoint x in phase space-

impractical in a 5-dimensional space

- **In practise: One single independent parameter $\alpha_m \rightarrow$ ignoring (=integrating) all others**
- **For each bin of α_m one evaluates O(γ) in a region of phase space, where γ denotes the range for each of the ignored parameters**

The Sampling Method (iv)

The theoretical calculation provides us with a value $O^{th}(x)$ at any point in phase space. For comparison with experiment we have to average over the region γ

$$O^{th}(x) = \frac{\int \sigma_0(x)\varepsilon(x)O^{th}(x)dx}{\int \sigma_0(x)\varepsilon(x)dx} = \frac{\sum N(x_i)O^{th}(x_i)}{\sum N(x_i)}$$

Here $N(x_i)$ is the # of events collected in element x_i irrespective of polarization. Since we are free to choose the size of x, we decrease it until all N(x_i) are either 0 or 1

- ➲ The # of occupied x_i elements = the total # of events collected in the region γ during the experiment ⇒
- ➲ The list of x_i's = the list of phase space coordinates for all collected events!!!

A Simple Recipe: The Sampling Method

➲ For a kinematically complete experiment: The correctly averaged theoretical value is the mean

$$O^{th}(\gamma) = \langle O^{th} \rangle = \frac{\sum O^{th}(x_k)}{N(\gamma)}$$

➲ The error, the standard deviation that arises from the randomness of the experimental phase space points, is

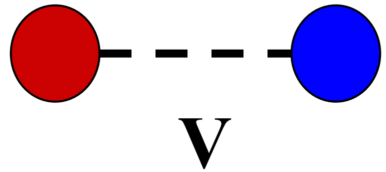
$$\partial O^{th}(\gamma) = \sqrt{\frac{\langle {O^{th}}^2 \rangle - \langle O^{th} \rangle^2}{N(\gamma) - 1}}$$

Few Body Syst. 34, 259 (2004), nucl-th/0402030

Three nucleons – 3NucleonForce?

- Objective – Probing the spin dependence of pd reactions at intermediate energies
- The PINTEX dp breakup experiment
  - Experimental set-up
  - Analysis tools – The sampling method

3NF - What is it ?

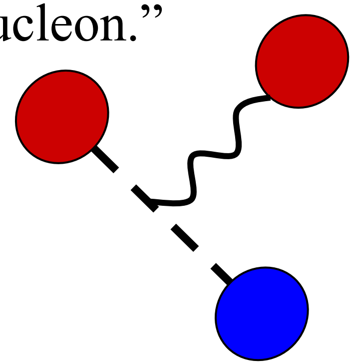


- IUCF Workshop Sep 1998 - Working Session II:
  - *Question: What do we mean by 3NF, and where is the best place to look for experimental evidence?*
- H. Witala (working session notes):
  - "In a pragmatic view, with nucleon DOF only

    $H=T + \sum V_{ij} + V_{1,2,3}$

    where the second term is all pairwise i.a. summed over the 3N.

    The rest is 3NF and takes into account any distorsion of NN potential energy caused by the presence of the third nucleon."



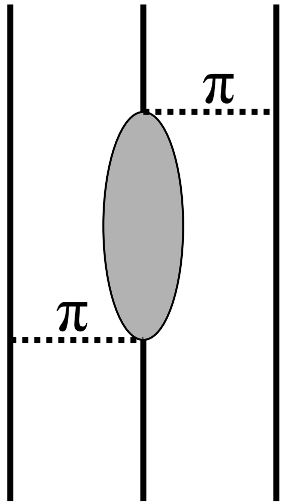
Size of the 3NF interaction:

$\Delta V \approx V^2/Mc^2 \rightarrow 0.5 - 1$ MeV

Models for 3NF

- Tucson –Melbourne (TM)
  - 2π exchange process, full off-shell πN scattering amplitude

S. Coon and W. Glöckle, PRC 23, 1790 (1981)

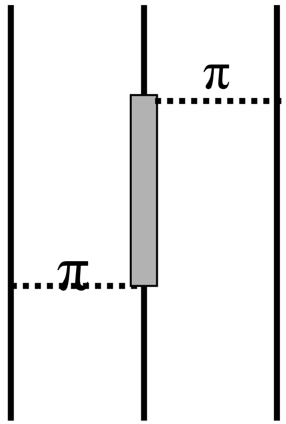


- TM modified (TM’)
  - Drop one term and modify another to comply with chiral symmetry

D. Hüber et al., Few-Body Syst. 30, 95 (2001)

- Urbana IX force
  - FM approach + phenomenological spin and isospin independent short-range part

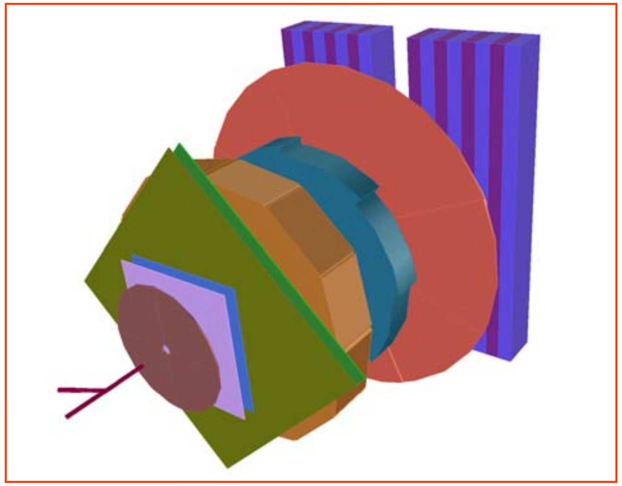
J. Carlson et al., Nucl. Phys. A401, 59 (1983)

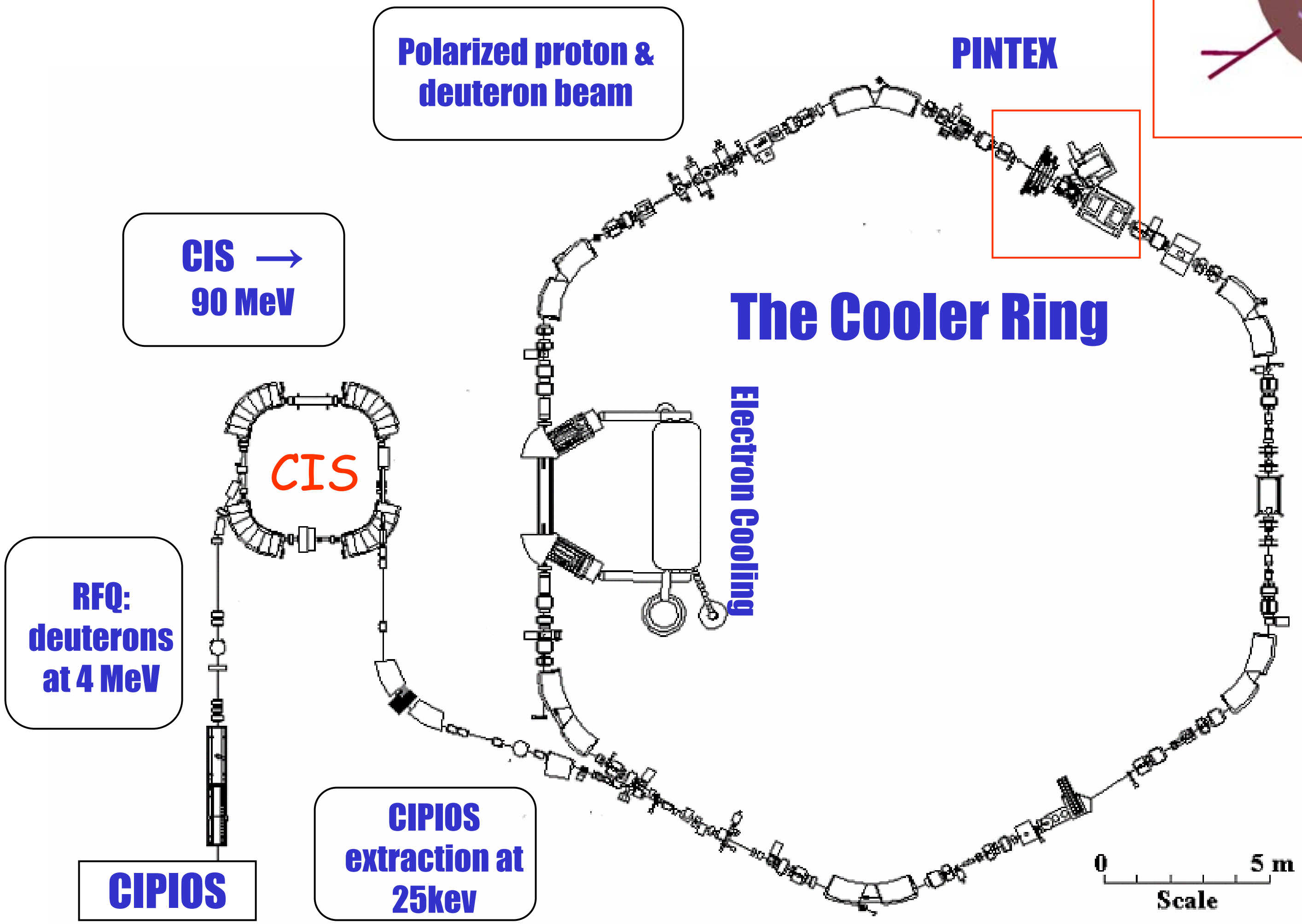


Spin dependence of dp breakup

- The PINTEX dp breakup experiment
  - Experimental set-up
  - Analysis tools – The grid method
  - Some results
    - Axial observables
    - Tensor analyzing powers

IUCF Indiana University Cyclotron Facility





in operation until 2002

Polarized deuteron beam

Beam state	Sextu pole 1	MFT	Sextu pole 2	WFT	SFT	Hyper fine s.	$\sim \mathbf{Q}_{\zeta}$	$\sim \mathbf{Q}_{\zeta\zeta}$
1	1,2,3	3→4	1,2		2→6	1,6	**+ 0.8**	**+ 0.7**
2	1,2,3	1→4	2,3	2→4		3,4	**– 0.6**	**+ 0.7**
3	1,2,3	1→4	2,3		2→6	3,6		**+ 0.8**
4	1,2,3	1→4	2,3		3→5	2,5		**– 1.6**

One beam state was unpolarized

Target storage cell

- Front view

25 cm long, Ø 12 mm

0.025 mm aluminum

Teflon coated

Target thickness

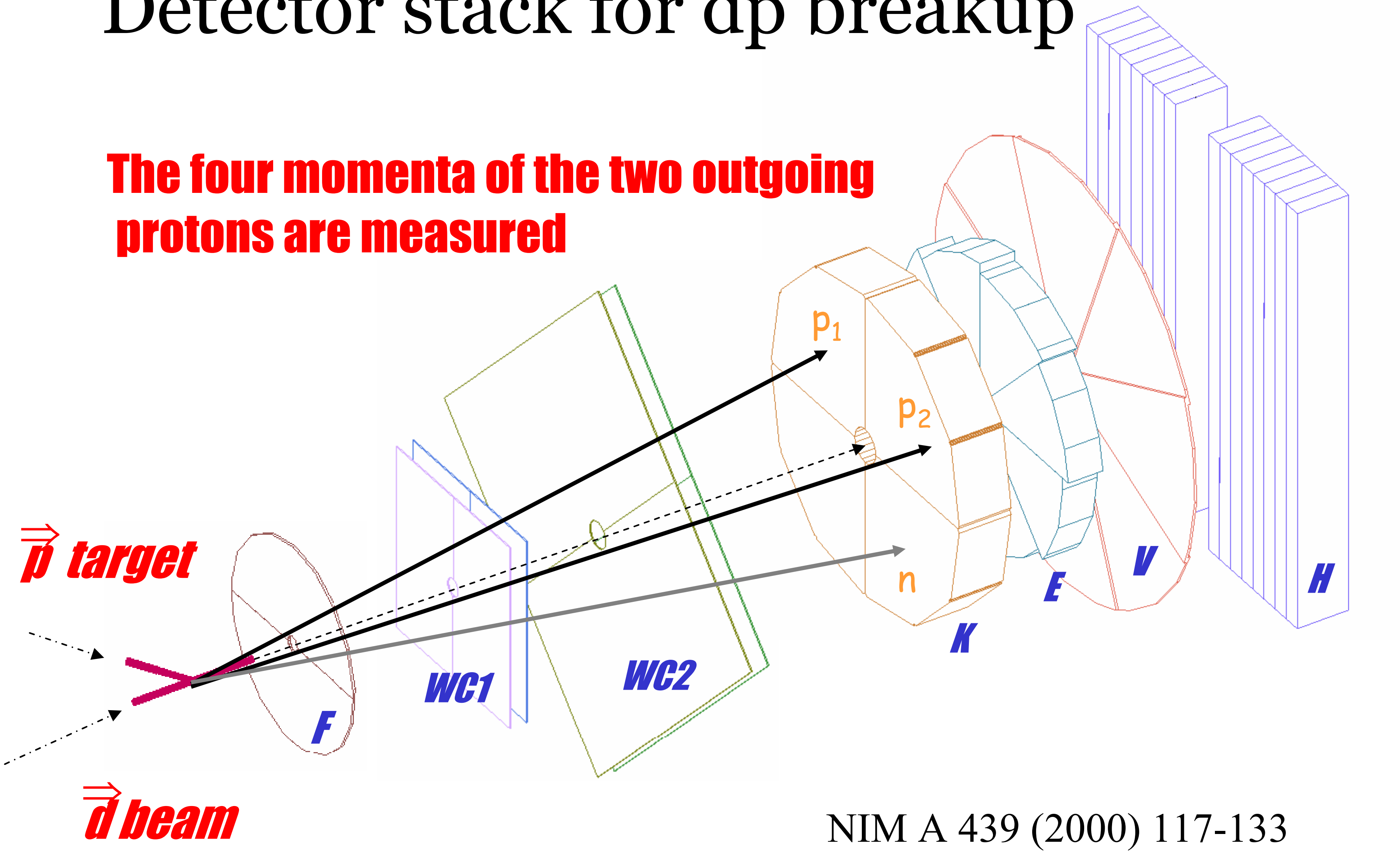
$\sim 10^{13}$ atoms/cm^2

Polarization ~0.6

±x, ±y, ±z directions

Detector stack for dp breakup

The four momenta of the two outgoing protons are measured

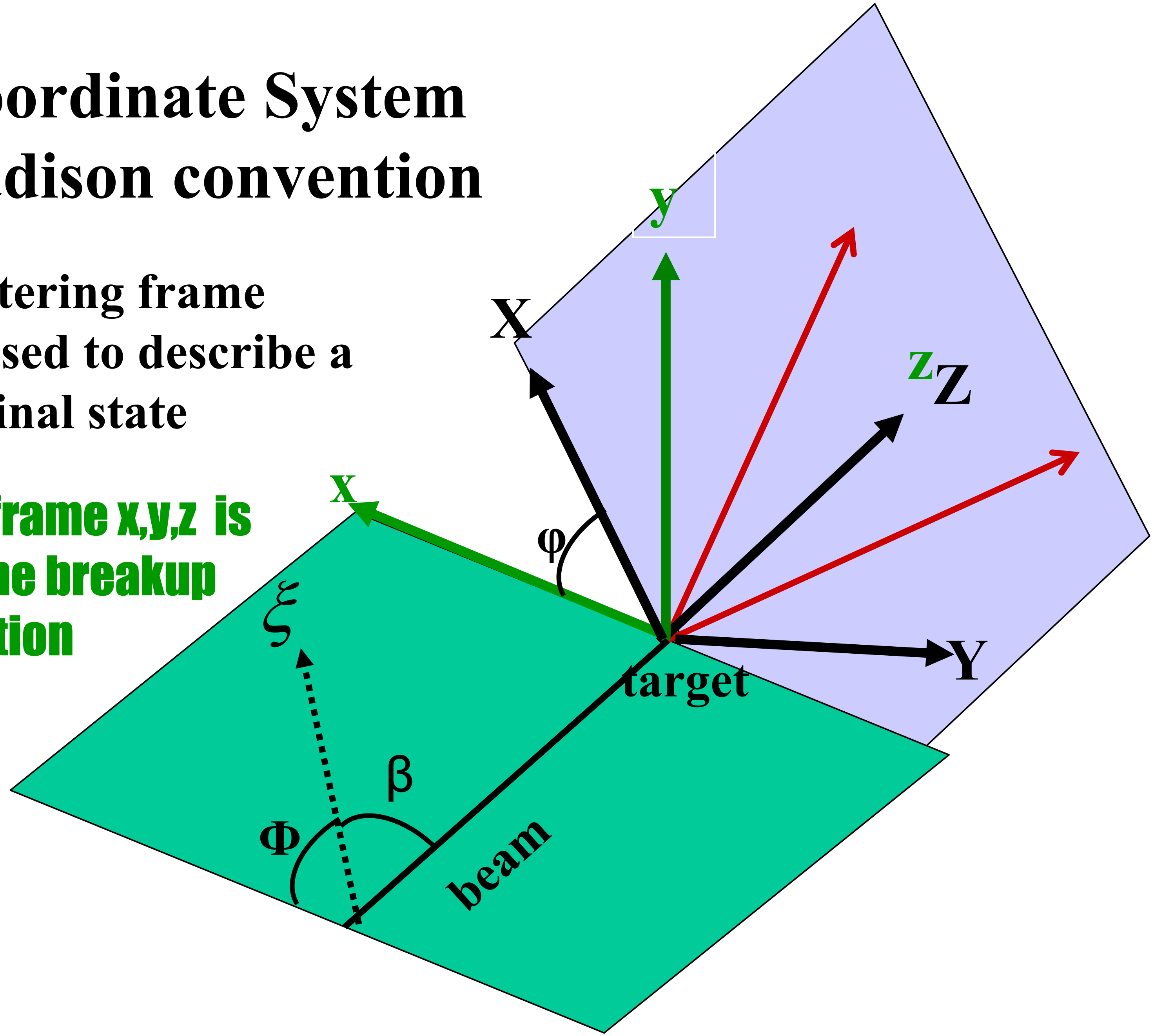


NIM A 439 (2000) 117-133

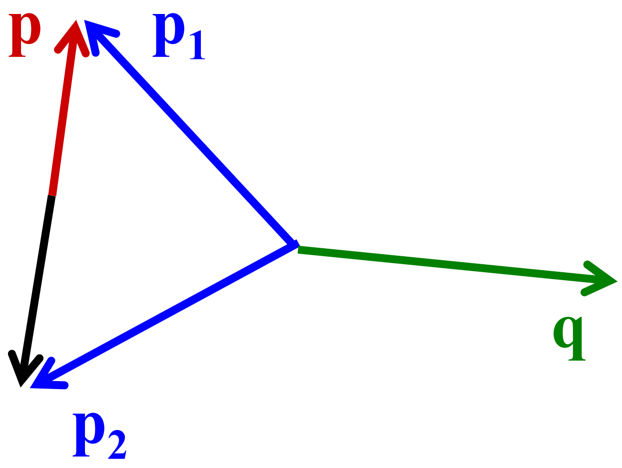
Coordinate System
Madison convention

The scattering frame X,Y,Z used to describe a 2-body final state

The fixed frame x,y,z is used for the breakup configuration



Three-body final state



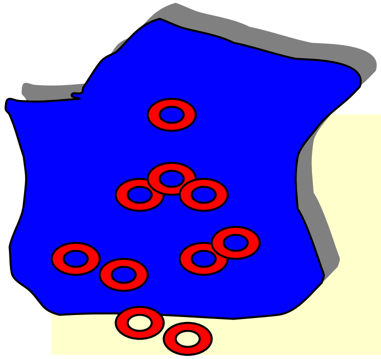
Jacobi momenta

$\mathbf{p} = \frac{1}{2}(\mathbf{p}_1 - \mathbf{p}_2)$

$\mathbf{q} = -(\mathbf{p}_1 + \mathbf{p}_2)$

$\Delta\varphi = \varphi(\mathbf{p}) - \varphi(\mathbf{q})$

- 3 particles ⇒ five-dimensional phase space
- 4 angles and energy: $\theta_p, \theta_q, \varphi_p, \varphi_q + \varepsilon(\text{energy})$
- Azimuthal symmetry ⇒ $\theta_p, \theta_q, \Delta\varphi + \varepsilon(\text{energy})$
- Task: find relevant observables !



The Sampling Method

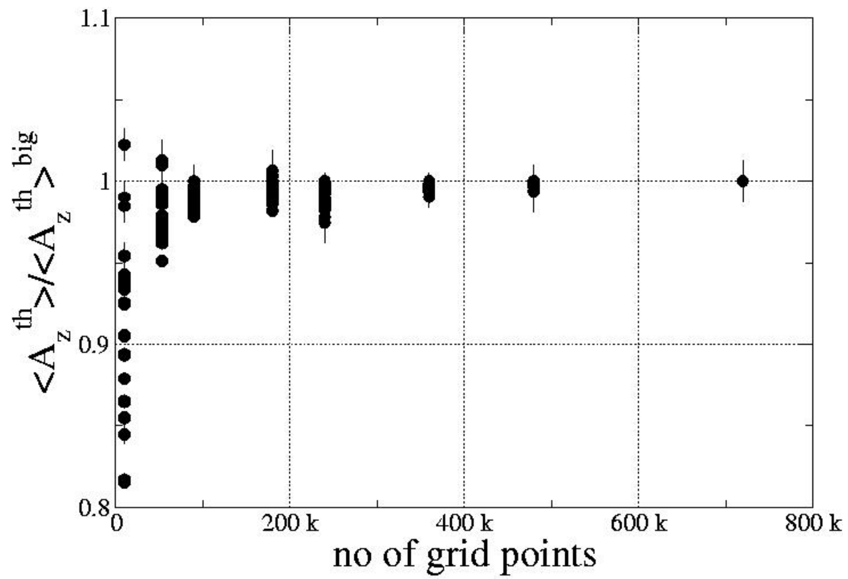
J.Kuros-Zolnierczuk, P.Thörngren, H.O. Meyer et al., FBS 34, 259 (2004), nucl-th/0402030

- For any 3b final state known with complete kinematics – 'sample' the theoretical value for each event in γ = (detected) region of phase space

$$O_{th}(\gamma) = \frac{\int \sigma_0(x)\,\varepsilon(x)\,O_{th}(x)\,dx}{\int \sigma_0(x)\,\varepsilon(x)\,dx} = \frac{\sum_x N(x_i)\,O_{th}(x_i)}{\sum_x N(x_i)}$$

The Sampling Method Using a Grid and Multidimensional Interpolation (i)

Few Body Syst. 34, 259 (2004), nucl-th/0402030



- ❑ Requirement:
  - ➢ Calculate a theoretical value for each event

  Drawback: X time consuming
- ❑ Solution:
  - ➢ Construct a grid covering phase space
  - ➢ Use multidimensional interpolation

Four-dimensional

2^4=16 corners / grid cell

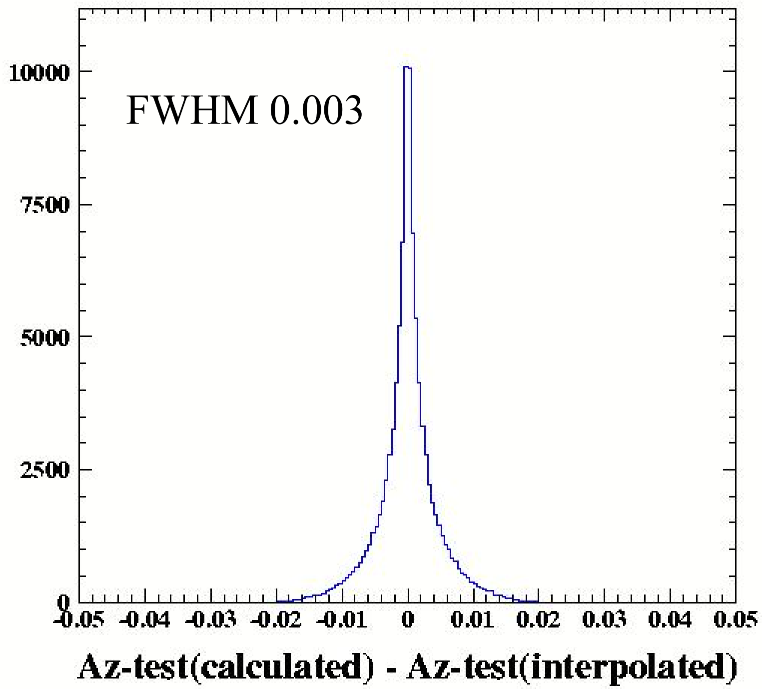
Five-dimensional:

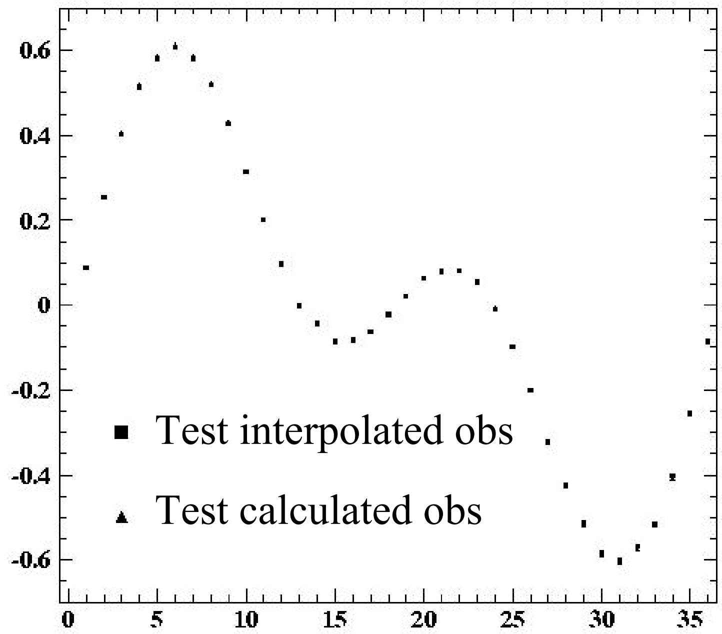
2^5=32 corners / grid cell

Grid behaviour

Few Body Syst. 34, 259 (2004), nucl-th/0402030

- Test: Construct a ’fake’ observable with similar angular dependencies

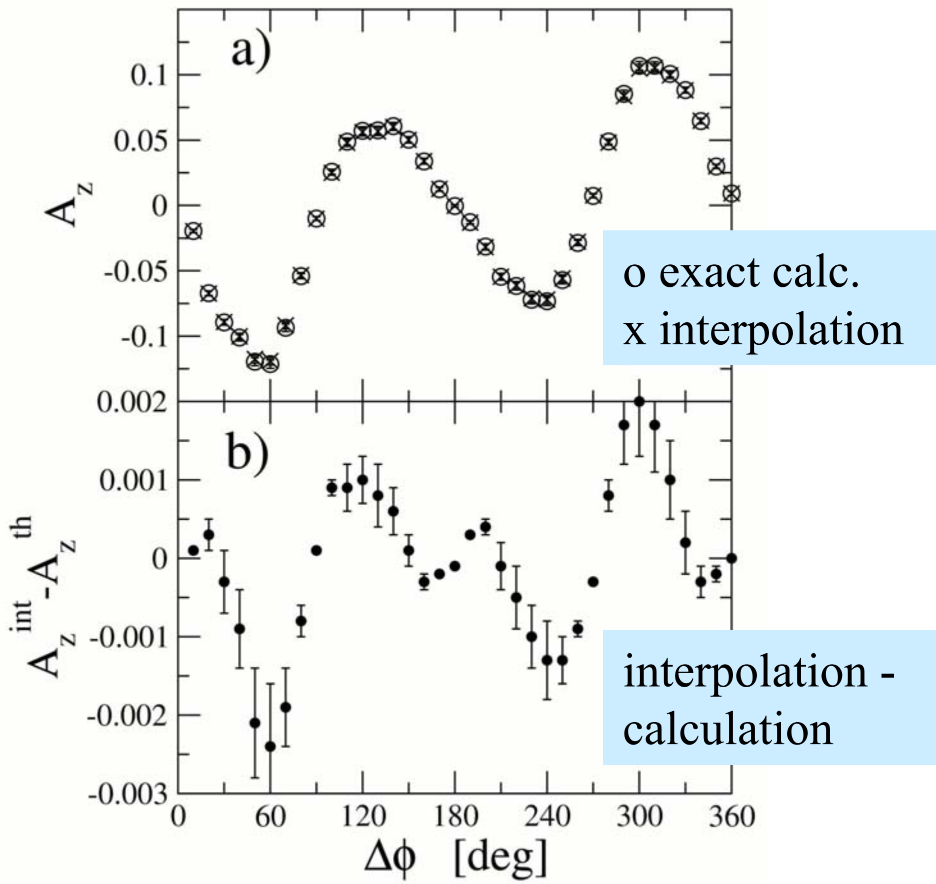




The Sampling Method Using a Grid and Multidimensional Interpolation (ii)

Few Body Syst. 34, 259 (2004), nucl-th/0402030

- Test of accuracy:
  - Compare single-shot exact calculation and interpolation
- Conclusion
  - **The Sampling Method** eliminates the necessity of monte carlo simulations and reflects the true detector acceptance and efficiency. Using a theoretical grid and interpolation reduces the computing time.



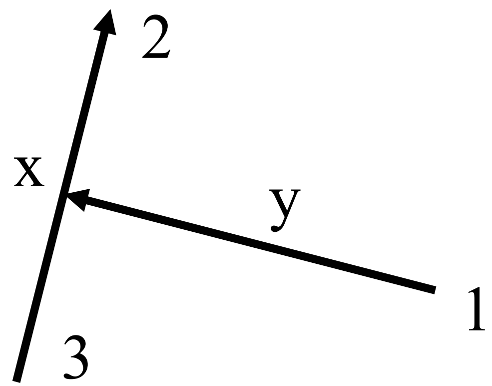
Axial observables in dp breakup

- Axial observables are required to be zero for coplanar events due to parity conservation. BUT - This is not the case in a breakup reaction.
- Axial observables measured: Azp, Cy,x-Cx,y, Czz,z (Azd, Cxz,x-Cyz,y possible with longitudinal beam)
- There are operators that are unique to axial observables that would vanish if there were no 3NFs. It is suggested that the axial operators might enhance the axial observables.

$$O\ (2\pi - 3N) = (\sigma_2 \cdot x)(\sigma_3 \cdot y) - (\sigma_2 \cdot y)(\sigma_3 \cdot x)$$

$$= (\sigma_2 \times \sigma_3) \cdot (x \times y)$$

L.D. Knutson PRL 73 (1994) 3062

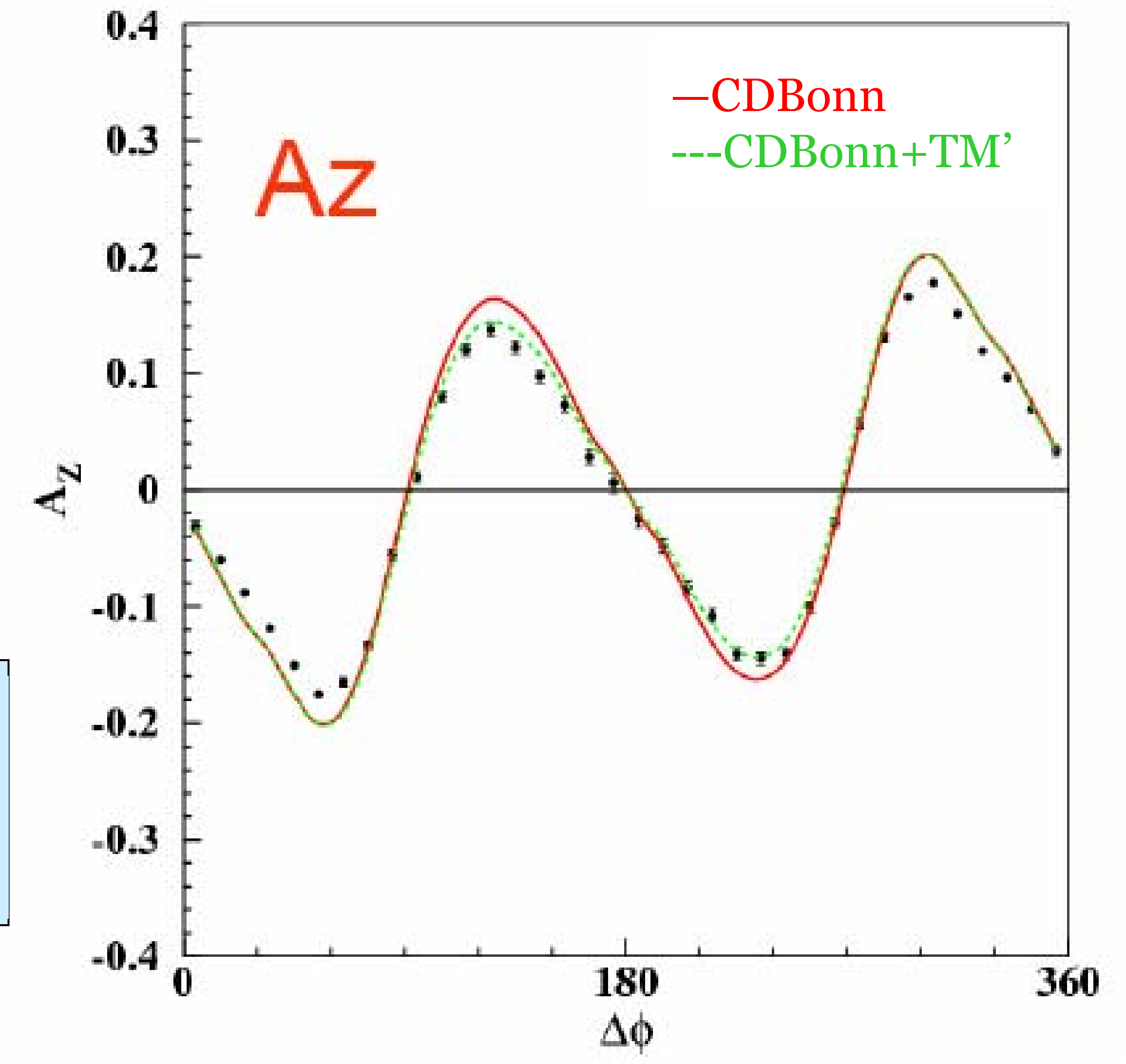


H.O. Meyer et al., PRL vol 93 nr 11, T.J. Whitaker PhD thesis, IUCF

A_z vs $\Delta\varphi$

Data using all five beam states and ±z target

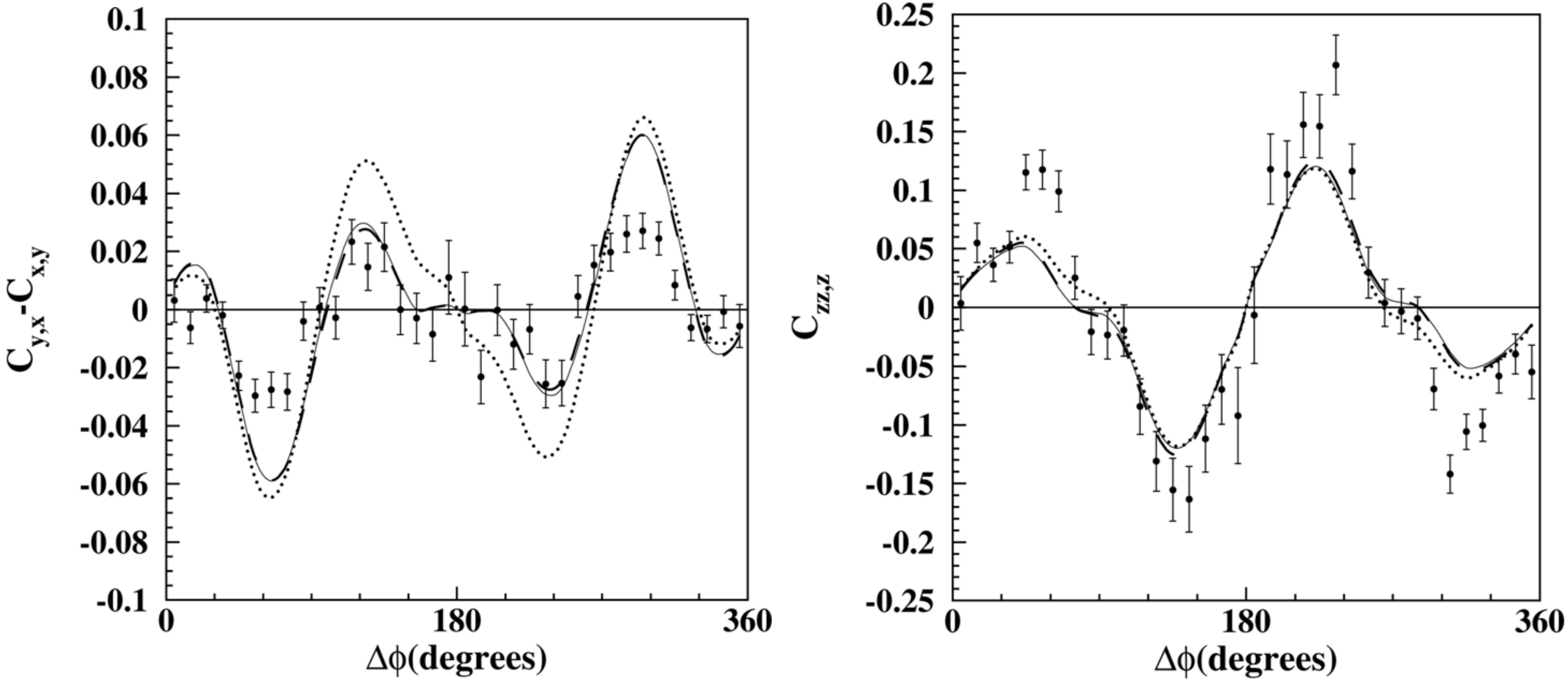
solid line: CD-Bonn
dashed: AV18
dotted: CD-Bonn+TM´



H.O. Meyer et al., PRL vol 93 nr 11,
T.J. Whitaker PhD thesis, IUCF

solid line: CD-Bonn
dashed: AV18
dotted: CD-Bonn+TM´

$C_{y,x}$-$C_{x,y}$ and $C_{zz,z}$ as a function of $\Delta\varphi$

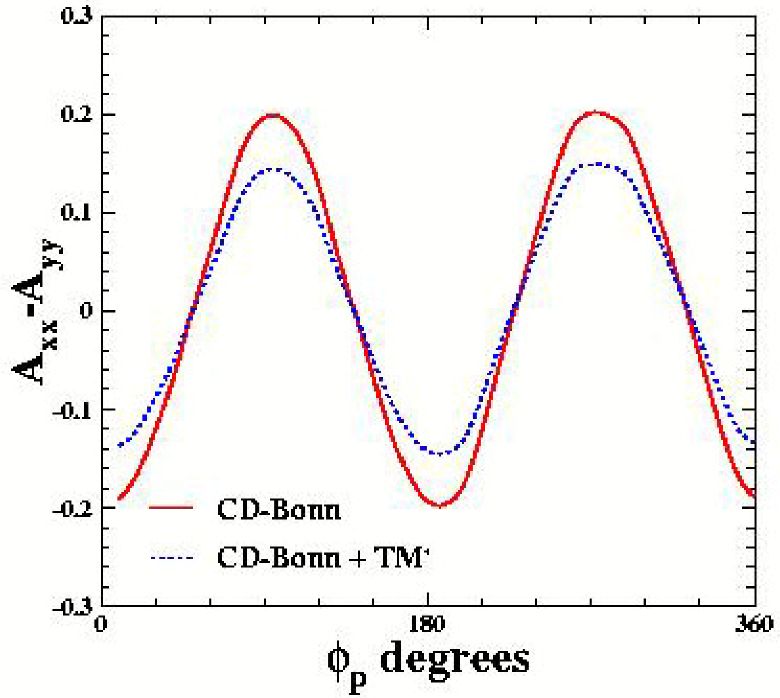


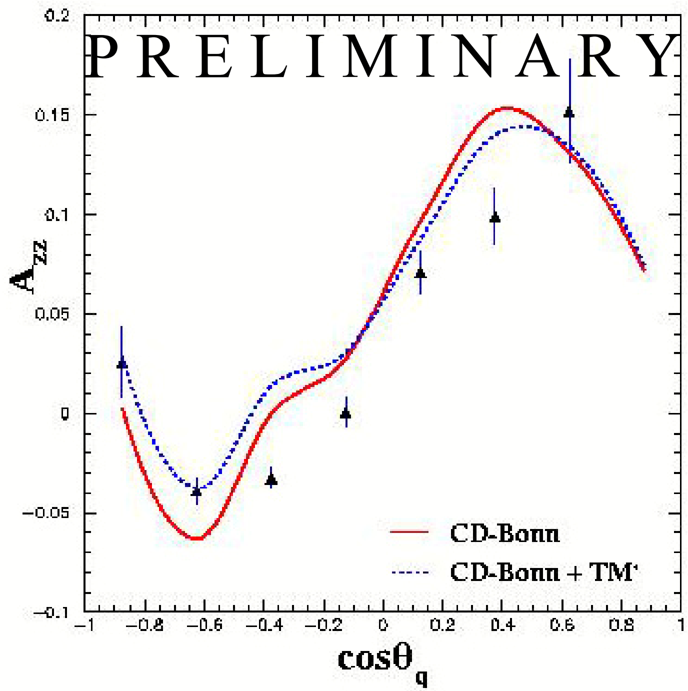
In progress: Tensor analyzing powers

P. T.E. et al., nucl-ex/0410006

- **Using the tensor polarized beam states and summing over all target polarization:** σ (tensor) =

$$\sigma_0 \left(1 - \frac{1}{4} QQ \cos(2\phi)(Axx - Ayy) - \frac{1}{4} QQ\, Azz \right)$$





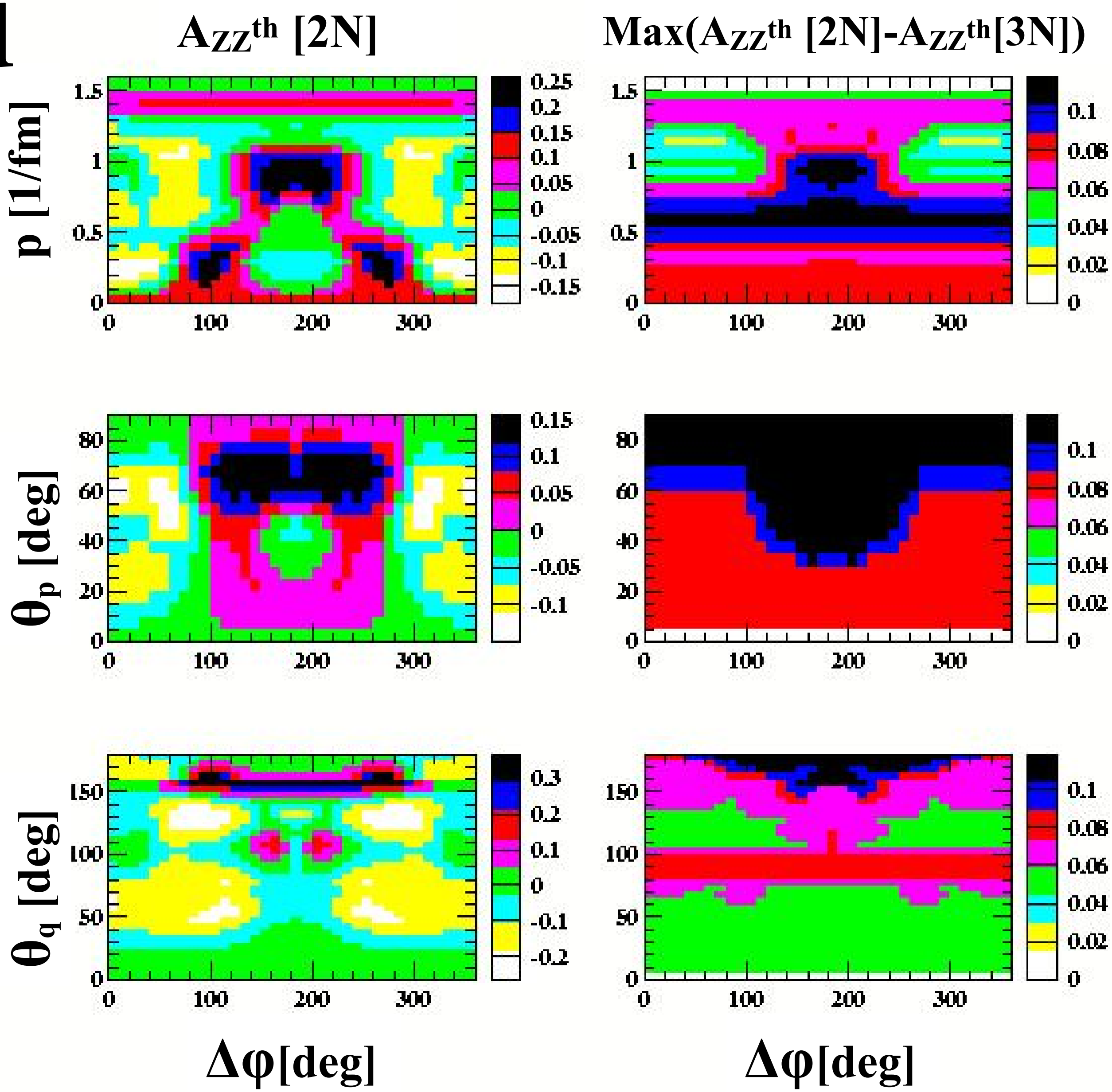
Using the grid

To investigate theoretical predictions –

J. Kuros-Zolnierczuk

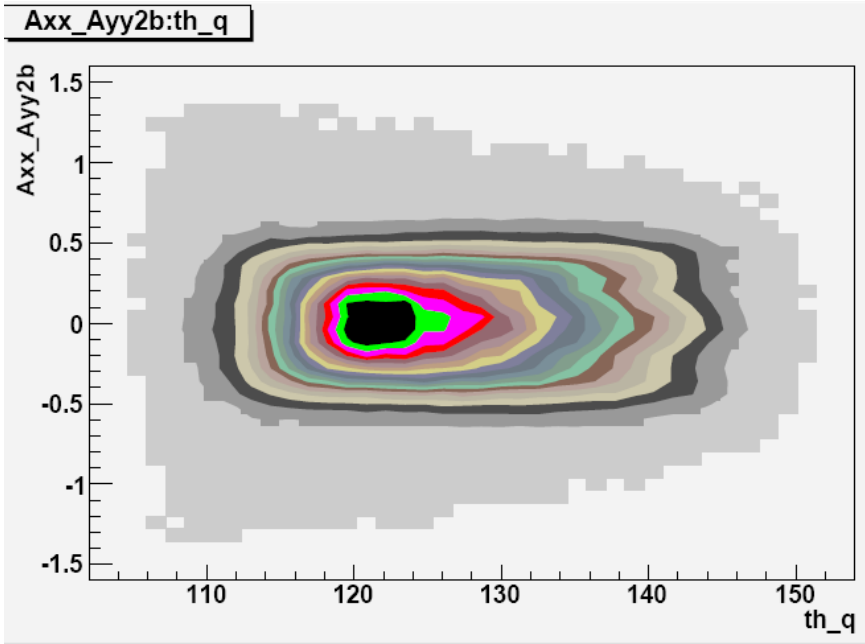
Krakow-Bochum group

Faddeev in momentum space: Glöckle et al., Phys. Rep. 274 (1996)

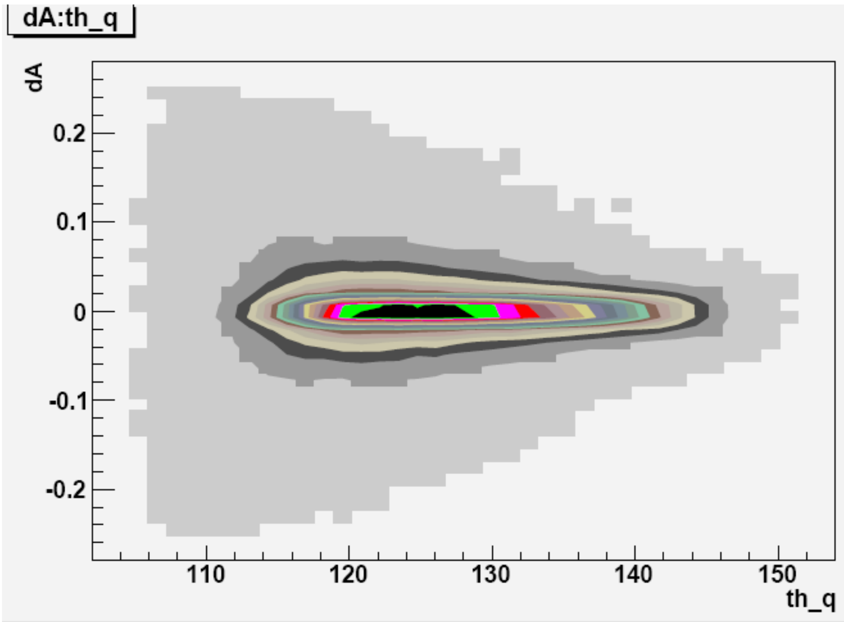


Theory grid investigation
Axx-Ayy as fcn of θq

Axx-Ayy (2NF) vs θq

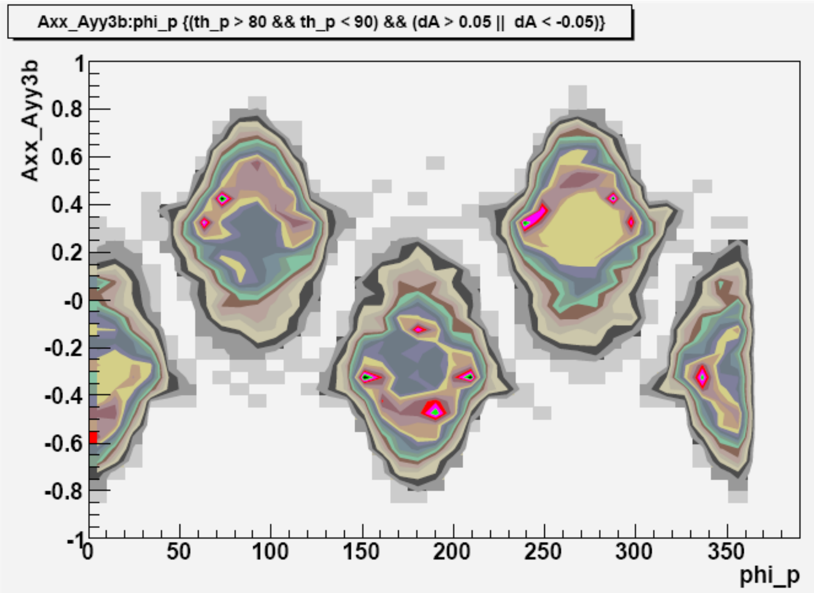


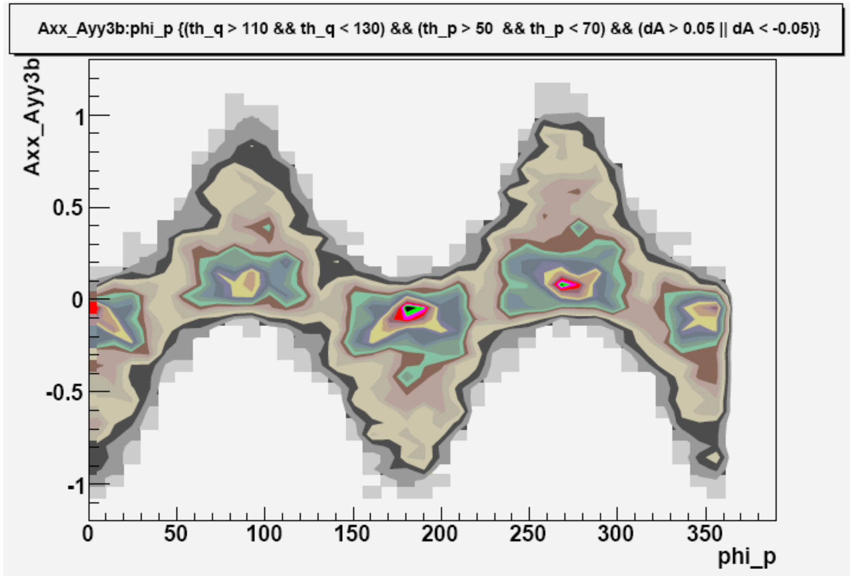
2NF-3NF

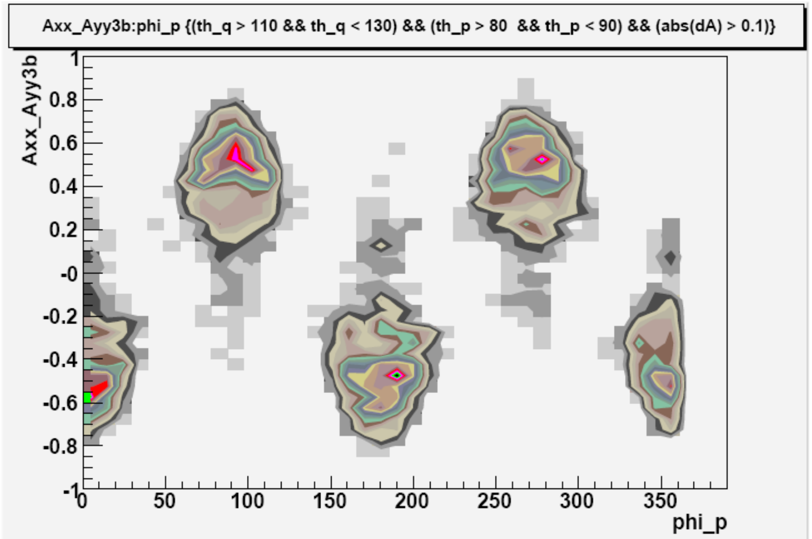


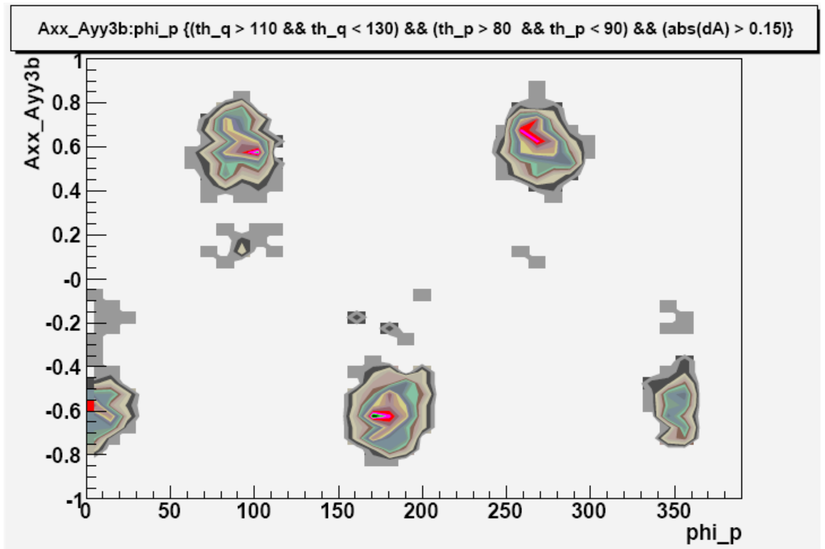
Theory grid investigation

Axx-Ayy(3NF) as fcn of φ_p



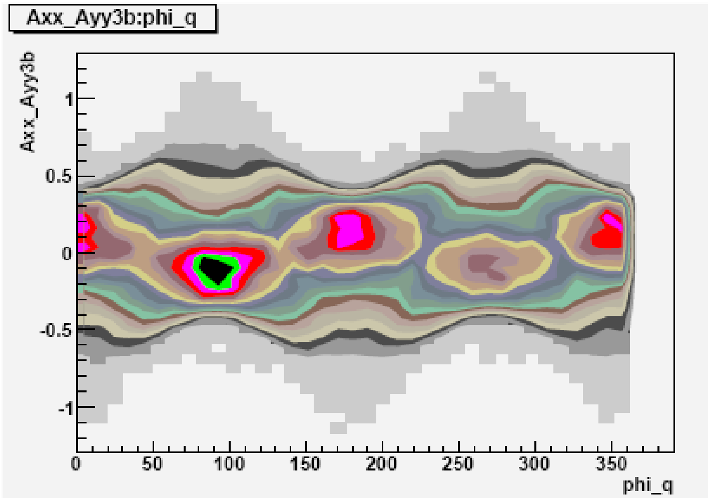


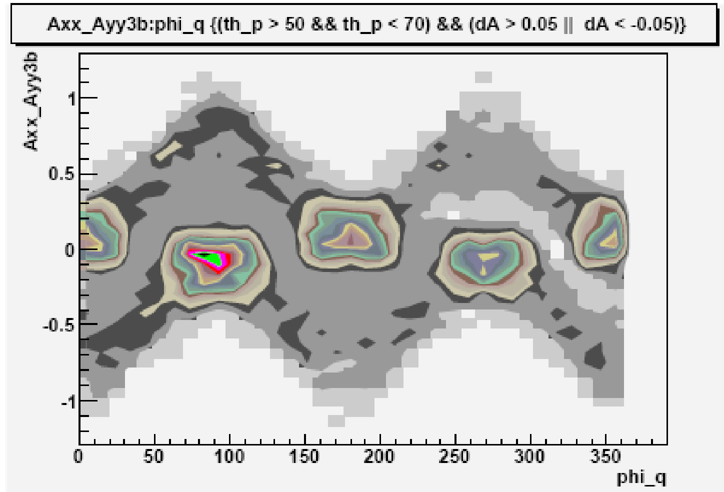


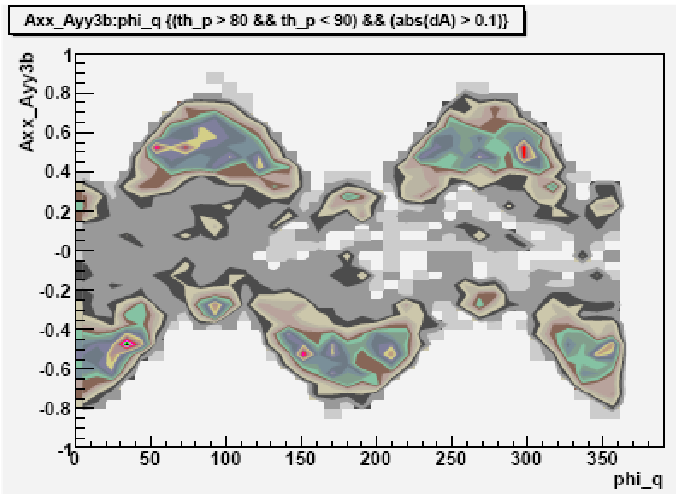


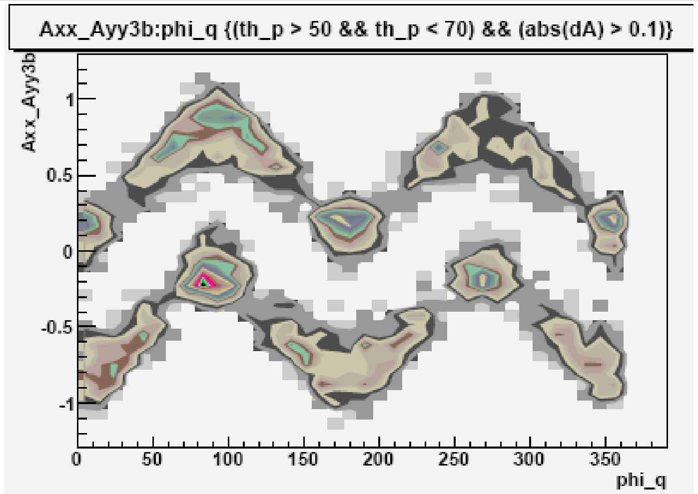
Theory grid investigation

Axx-Ayy(3NF) as fcn of φ_q



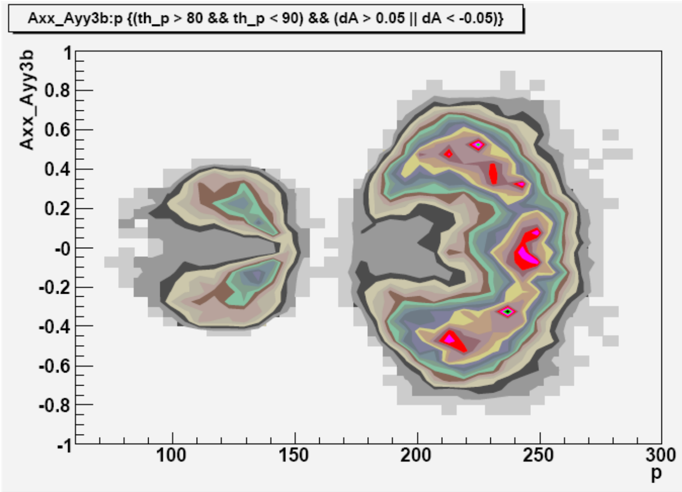


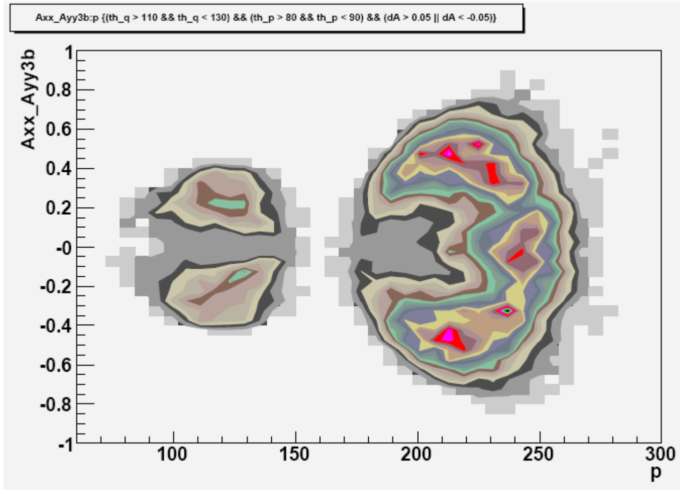


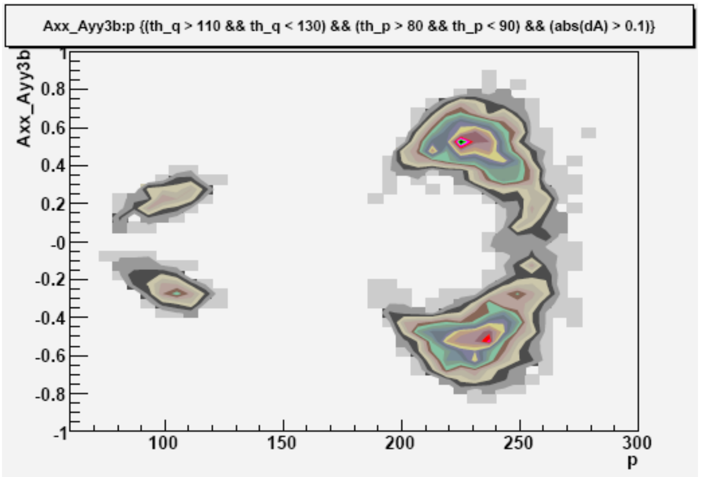


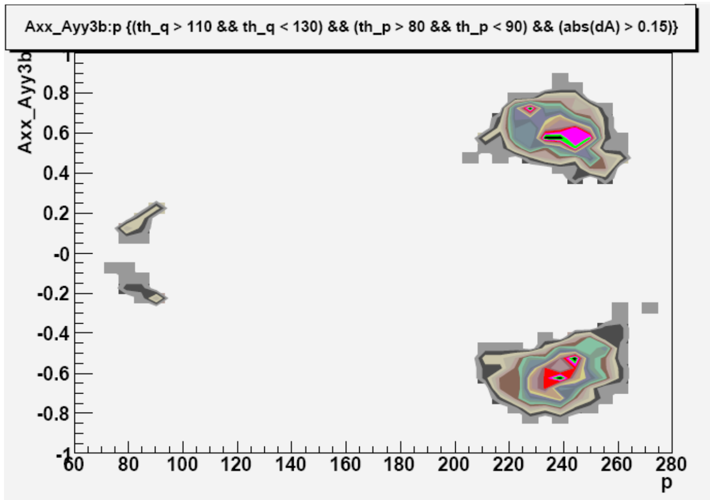
Theory grid investigation

Axx-Ayy(3NF) as fcn of p



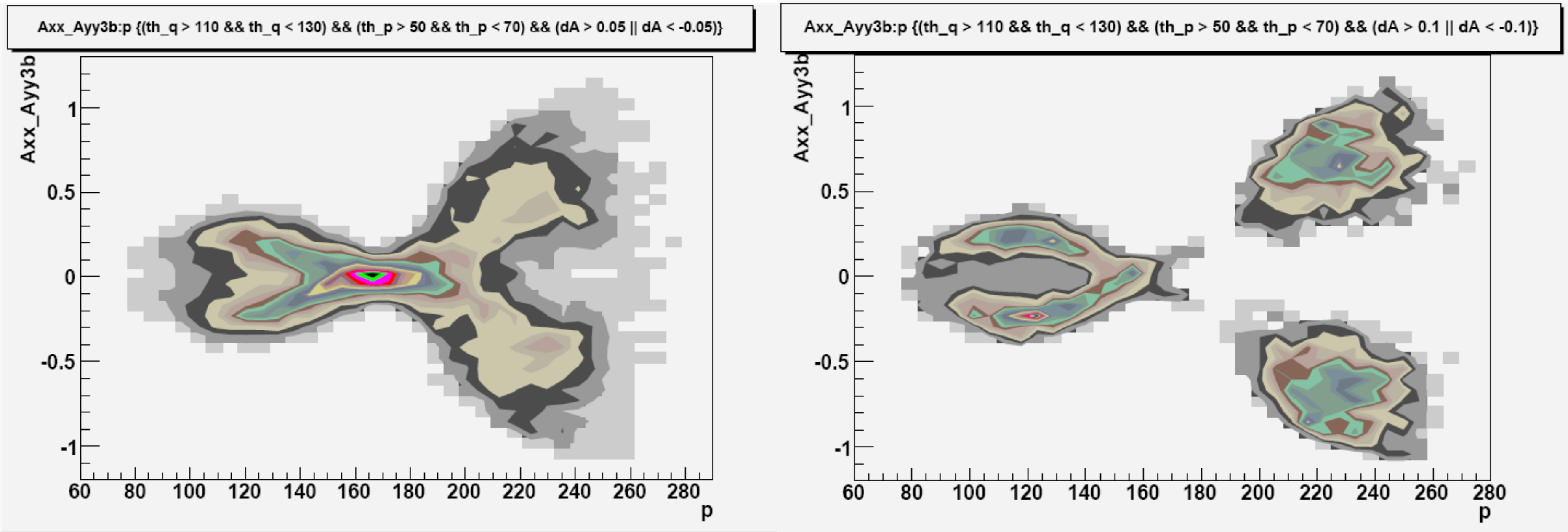






θp[80,90] & θq [110,130]

Theory grid investigation
Axx-Ayy(3NF) as fcn of *p*



θp[50,70] & θq [110,130]

Observables measured in dp breakup

- d+p breakup at T_d=270MeV
- Measured in this experiment:

(deuteron spin alignment was always +y)

- Analyzing powers: A_y^p, A_z^p , A_y^d , A_{zz} , $(A_{xx} - A_{yy})$
- Vector-vector correlation coefficients:

$(C_{x,x} - C_{y,y})$ $(C_{x,x} + C_{y,y})$ $C_{x,z}$ $(C_{y,x} - C_{x,y})$

- Tensor-vector correlation coefficients

$(C_{xx,y} - C_{yy,y})$ $C_{xy,x}$ $C_{xy,z}$ $C_{zz,y}$ $C_{zz,z}$

Summary and outlook

- A new method has been developed for the analysis of three particle final states → true comparison to theory that makes monte carlo simulations unnecessary
- The axial observables $\mathbf{A_z}$ **,** $\mathbf{(C_{y,x} - C_{x,y})}$**,** $\mathbf{C_{zz,z}}$ in dp breakup measured for the first time – they do not show any consistently sensitivity to TM´3NF, the analysis of tensor analyzing powers is in progress
- Future: Compare with predictions for 2N & 3N from n3lo chiral effective field theory [Entem & Machleidt, PRC 68, 041001 (2003)], [Epelbaum, Glöckle & Meissner, NPA 747 (2005) 362, PRC66,064001(2002)],
- Questions: 3nf – relativistic effects [Witala PLB 634 (2006), Skibinski nucl-th/0604033] – Coulomb [Kistryn nucl-ex/0607002]
- Meanwhile: Apply the sampling method to ……
  - ANKE data, e.g. dp→(pp)n

Implications and Possibilities...

- Drawbacks…
- Potential…

Polarized Internal Target EXperiements

- The **PINTEX** collaboration: H.O. Meyer, J.T.Balewski, J.Doskow, W.W.Daehnick, W.Haeberli, R.Ibald, J.Kuros-Zolnierscuk, B.Lorentz, P.Pancella, R.E. Pollock, B.v.Przewoski, F. Rathmann, T. Rinckel, Swapan K. Saha, P. Thörngren Engblom, A.Wellinghausen, T.J. Whitaker,T.Wise
- Krakow-Bochum theory group: W.Glöckle, H.Witala, J.Golak, H.Kamada, A.Nogga, R.Skibinski

Experimental studies of spin dependence in few-body systems

PINTEX collaboration@IUCF

Pia Thörngren Engblom
Uppsala University

RHIC seminar

PINTEX timeline

• **pp elastic @ 200-450 MeV – Ay, Axx, Ayy, Axz**

phase shift analyses
phenomenology

• **single pion production in pp @ 325-400 MeV –**

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

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

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

Meson-exchange model,
partial wave analyses, ChPT

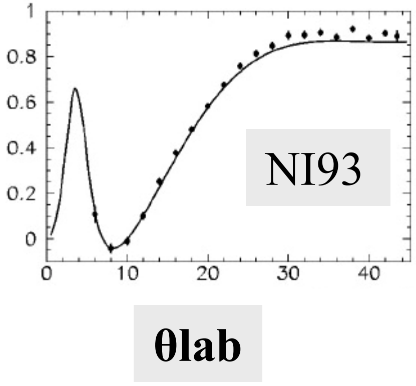
• **pd elastic @ 135 and 200 MeV – 15 of 17 spin observables measured**

nn potentials
three nucleon forces

• **dp breakup @ Td = 270 MeV**

nn potentials
three nucleon forces
……ChPT (N3LO)

Azz

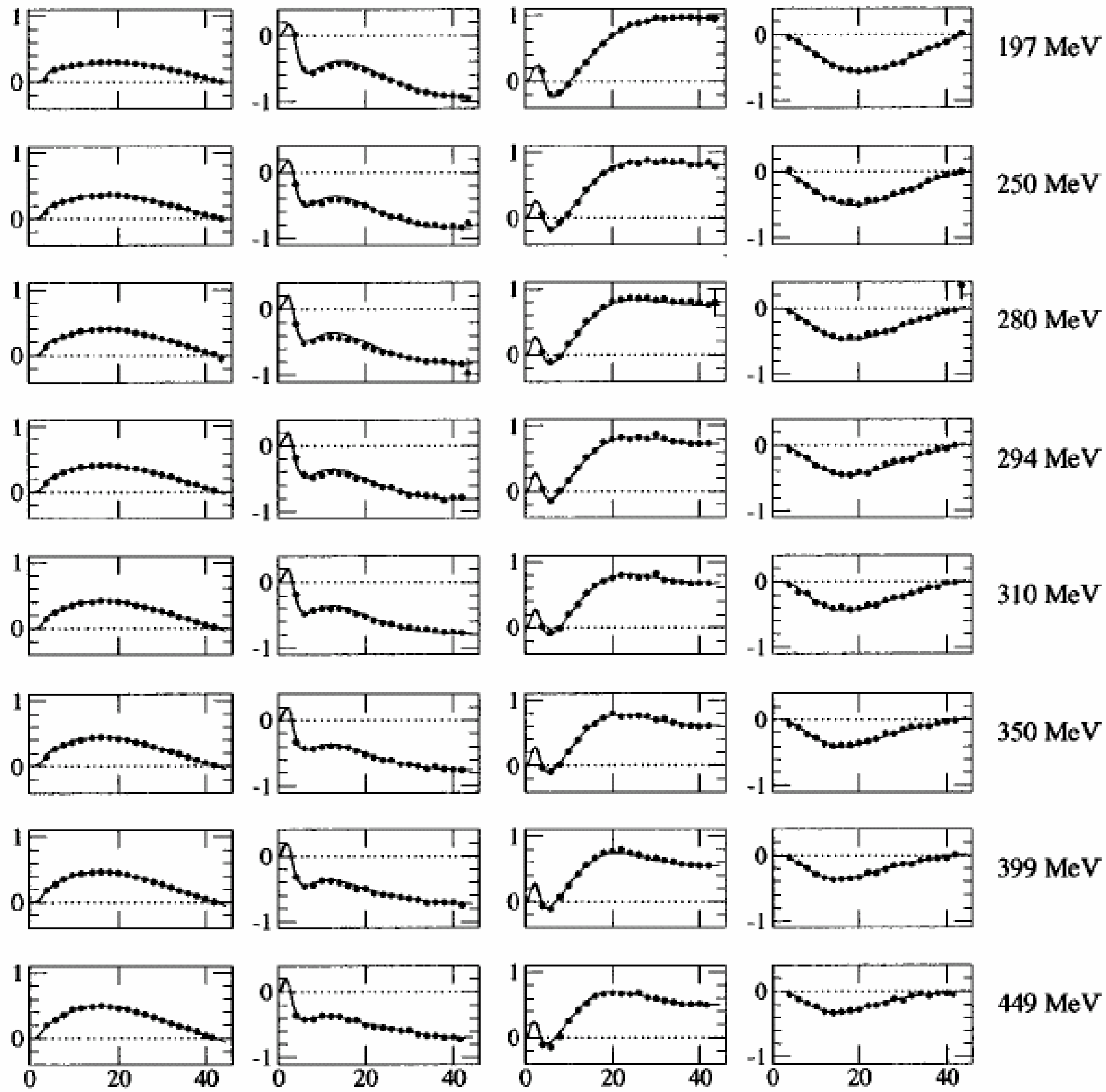


$$\vec{p}\vec{p} \to pp$$

@ 200-450 MeV

Haeberli & al, PRC55, 597 (1997)
Pollock & al., PRE55, 7606 (1997)
Meyer & al., PRC56, 2074 (1997)
Rathmann & al.,PRC58, 658 (1998)
Przewoski & al.,PRC58, 1897(1998)
Lorentz & al., PRC61, 054002(2000)

Ay Axx Ayy Axz



Solid line: phase shift analyses SM97

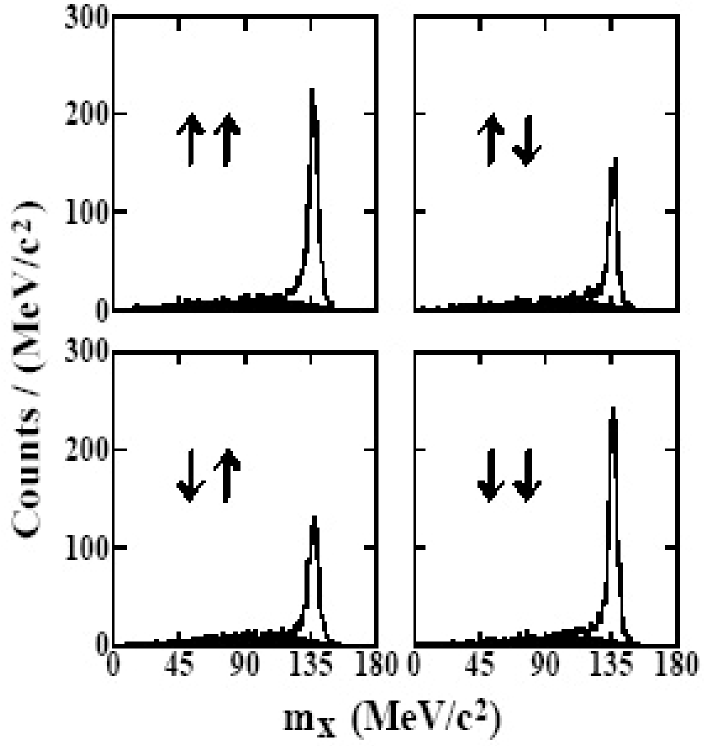
H.O. Meyer et al., PRL 83, 5439 (1999)

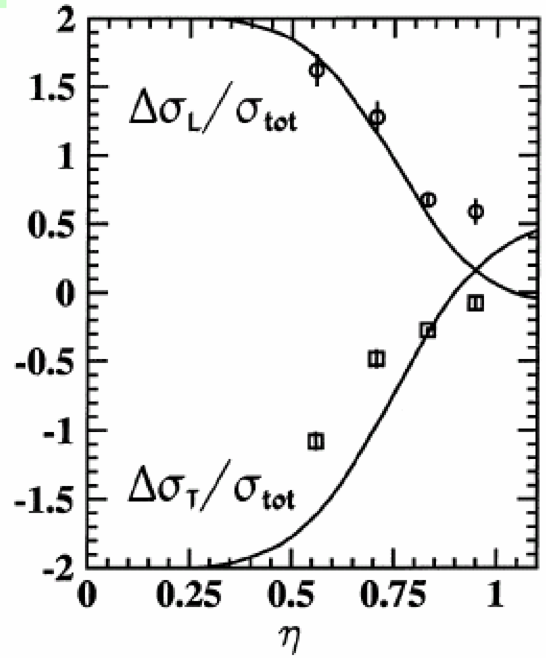
Spin-dependent cross sections

Transverse(T), Longitudinal(L) σ

$$\Delta\sigma_{T(L)} = \sigma(\uparrow\downarrow + \downarrow\uparrow) - \sigma(\downarrow\downarrow + \uparrow\uparrow)$$

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





— Theory:
C. Hanhart et al., PLB 444, 25 (1998)

Spin ½ on spin ½ ➔

$^{2S+1}\sigma_{m_s}$

- Near threshold there are only a limited # of partial waves in the final state: **L**$_{\mathbf{NN}}$≤1 and **l**$_{\boldsymbol{\pi}}$ ≤1 ➔ only Ss, Ps, Pp remains and one single partial wave can be obtained ➔

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

- ❑ Parity, isospin and angular momentum conservation ➔

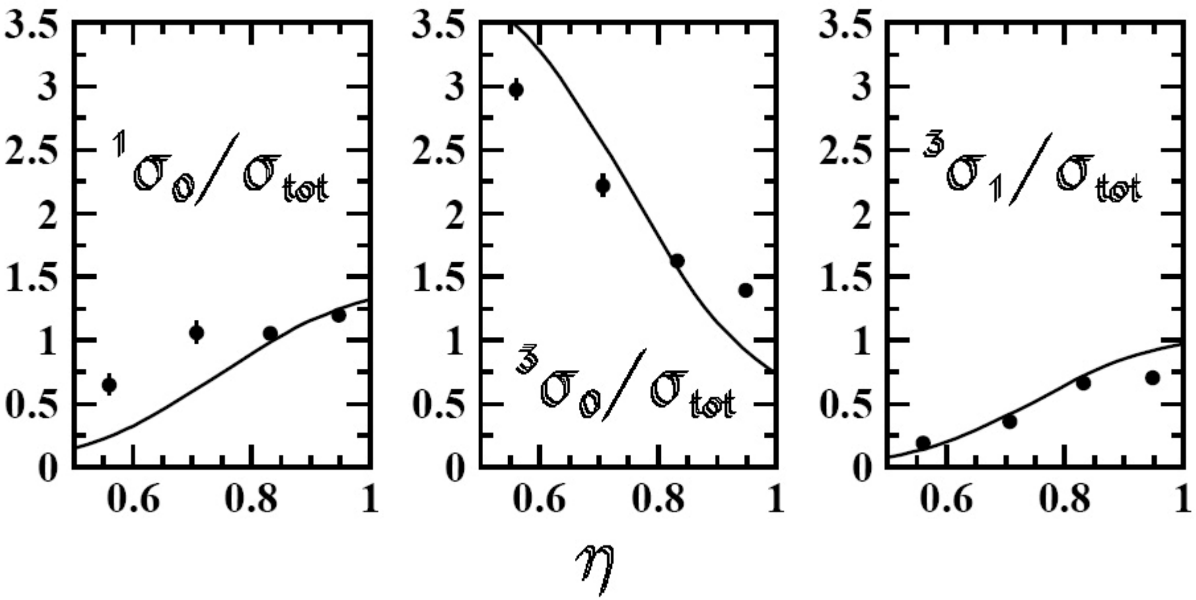
$$\frac{{}^1\sigma_0}{\sigma_{tot}} = 1 + \frac{\Delta\sigma_T}{\sigma_{tot}} + \frac{1}{2}\frac{\Delta\sigma_L}{\sigma_{tot}}$$

$$\frac{{}^3\sigma_0}{\sigma_{tot}} = 1 - \frac{\Delta\sigma_T}{\sigma_{tot}} + \frac{1}{2}\frac{\Delta\sigma_L}{\sigma_{tot}}$$

$$\frac{{}^3\sigma_1}{\sigma_{tot}} = 1 - \frac{1}{2}\frac{\Delta\sigma_L}{\sigma_{tot}}$$

Initial singlet and triplet spin contributions to $\vec{p}\vec{p} \rightarrow pp\pi^0$

P.Thörngren Engblom et al., Nucl. Phys.A663-4, 447c (2000)



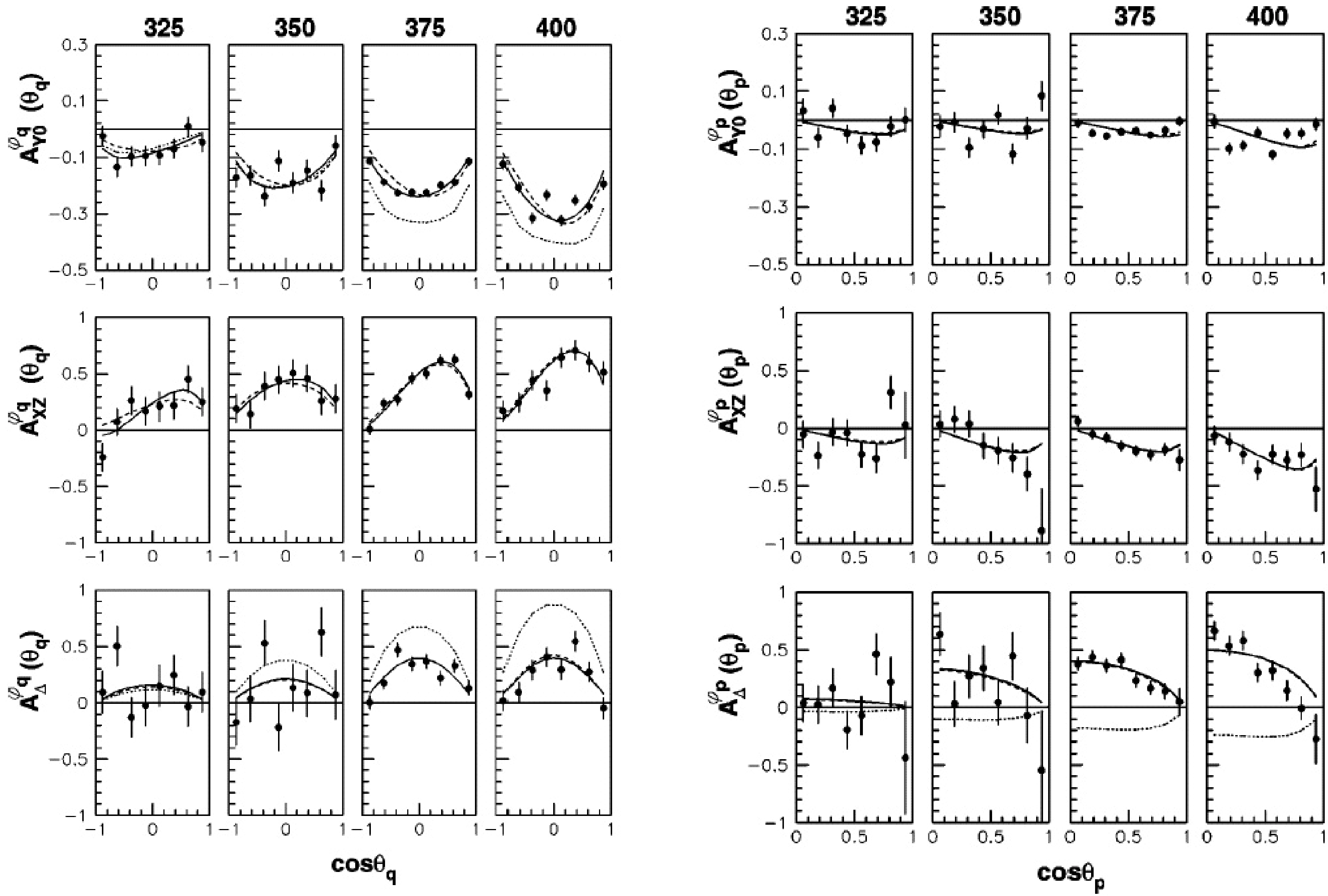
$^{2S+1}\sigma_{m_S}$

$\eta = \max(p_\pi)/m_\pi$

Theory: ——
C. Hanhart et al., PLB 444, 25 (1998)

- Irreducible tensor analysis → theoretical estimates for differential cross sections: $^1d\sigma_0, {}^3d\sigma_0, {}^3d\sigma_{\pm1}$

Deepak & Ramachandran, PRC 65, 027601 (2002)



H.O.Meyer et al., PRC63, 064002 (2001)

..... Theory: C. Hanhart et al., PRC61, 064008 (2000)

H.O.Meyer et al., PRC63, 064002 (2001)

Analysis of $\vec{p}\vec{p} \rightarrow pp\pi^0$

- **2 analyzing powers & 5 independent spin correlation parameters measured**
- **Partial wave formalism ➔ describe 3body final state**
- **Expansion of the spin observables into a complete set of angular functions for 3body final state with two initial spin ½ particles**
- **Use the dependencies of the observables on azimuthal functions and two polar angles to define and extract the observables in a 5dimensional phase space.**
  ➔ 25 independent observables are obtained
- **Recent partial wave analyses also by P.N. Deepak, J. Haidenbauer, C. Hanhart, hep-ph/0503228**
- **Theory review: C.Hanhart, PhysRep 397 (2004) 155 hep-ph/0311341**
- **NLO ChPT V.Lenksy et al., nucl-th/0609007**

PINTEX refereed journals since 1997

1) Haeberli et al, PRC55, 597 (1997)
2) Pollock et al., PRE55, 7606 (1997)
3) Meyer et al., PRC56, 2074 (1997)
4) H.O. Meyer et al., PRE56, 3578 (1997)
5) Rathmann et al.,PRC58, 658 (1998)
6) Przewoski et al.,PRC58, 1897(1998)
7) Lorentz et al., PRC61, 054002(2000
8) H.O. Meyer, Annu. Rev. Nucl. Part. Sci. (1997) 47:235-271
9) B.v.Przewoski et al., Review of Sci. Instr. 69, 3146 (1998)
10) T. Rinckel et al., NIM A 439, 117-133 (2000)
11) H. O. Meyer et al., PRL 81, 3096 (1998)
12) Meyer et al., PRL 83, 5439 (1999)
13) Swapan K. Saha, PLB 461, 175 (1999)
14) B.v.Przewoski et al., PRC 61, 064604, (2000)
15) H.O. Meyer et al., PLB480, 7 (2000)
16) Meyer et al., PRC63, 064002 (2001)
17) W. W. Daehnick et al., PRC65, 024003 (2002)
18) T. Wise et al., PRL 87, 042701 (2001)
19) B.v.Przewoski, PRE68, 046501 (2003)
20) B. v.Przewoski et al., PRA68, 042705 (2003)
21) B.v. Przewoski et al., acc. for publ. PRC, nucl-ex/0411019
22) J.Kuros-Zolnierczuk et al., FBS 34, 259
23) H.O. Meyer et al., PRL 93,112502 (2004)

Cross section for spin 1 on spin 1/2

- The most general case:

$$\sigma = \sigma_0 \Big(1 + py\,Ayp + pz\,Azp + \frac{3}{2} qy\,Ayd + \frac{3}{2} qz\,Azd + \frac{1}{6}(qxx - qyy)(Axx - Ayy) + \frac{1}{2} qzz\,Azz + \frac{2}{3} qxz\,Axz$$

$$+ \frac{3}{4}(qx\,px + qy\,py)(Cx\_x + Cy\_y) + \frac{3}{4}(qx\,px - qy\,py)(Cx\_x - Cy\_y) + \frac{3}{4}(qy\,px - qx\,py)(Cy\_x - Cx\_y)$$

$$+ \frac{3}{2} qx\,pz\,Cx\_z + \frac{3}{2} qz\,px\,Cz\_x + \frac{3}{2} qz\,pz\,Cz\_z + \frac{1}{6}(qxx - qyy)\,py\,(Cxx\_y - Cyy\_y) + \frac{1}{2} qzz\,pz\,Czz\_z + \frac{1}{2} qzz\,py\,Czz\_y$$

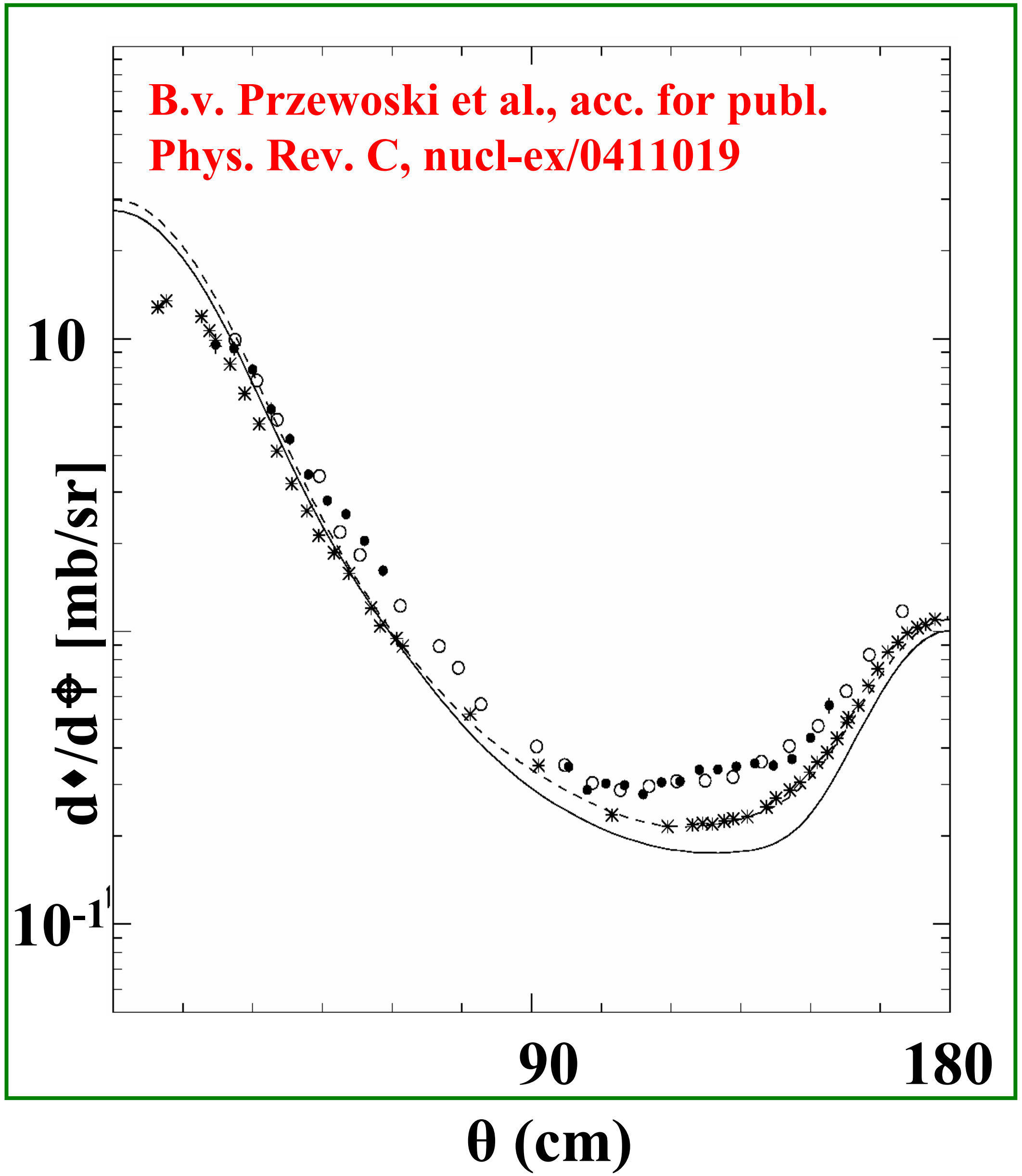
$$+ \frac{2}{3} qxy\,px\,Cxy\_x + \frac{2}{3} qxz\,py\,Cxz\_y + \frac{2}{3} qyz\,px\,Cyz\_x + \frac{2}{3} qxy\,pz\,Cxy\_z + \frac{2}{3} qyz\,pz\,Cyz\_z$$

$$+ \frac{1}{3}(qxz\,px + qyz\,py)(Cxz\_x + Cyz\_y) \Big)$$

Differential cross section

p+d elastic scattering at 135 MeV

- o **K. Ermisch et al., PRC 68, (2003) 051001, PhD thesis, KVI Groningen, ISBN:90-9016528-2**
- • **PINTEX-IUCF present data (normalized to Ermisch et al.)**
- * **K. Sekiguchi et al., Phys. Rev. C65 (2002) 034003**
- — **CD Bonn, R. Machleidt, PRC63, 024001 (2001)**
- **--- CDBonn + TM 3NF**

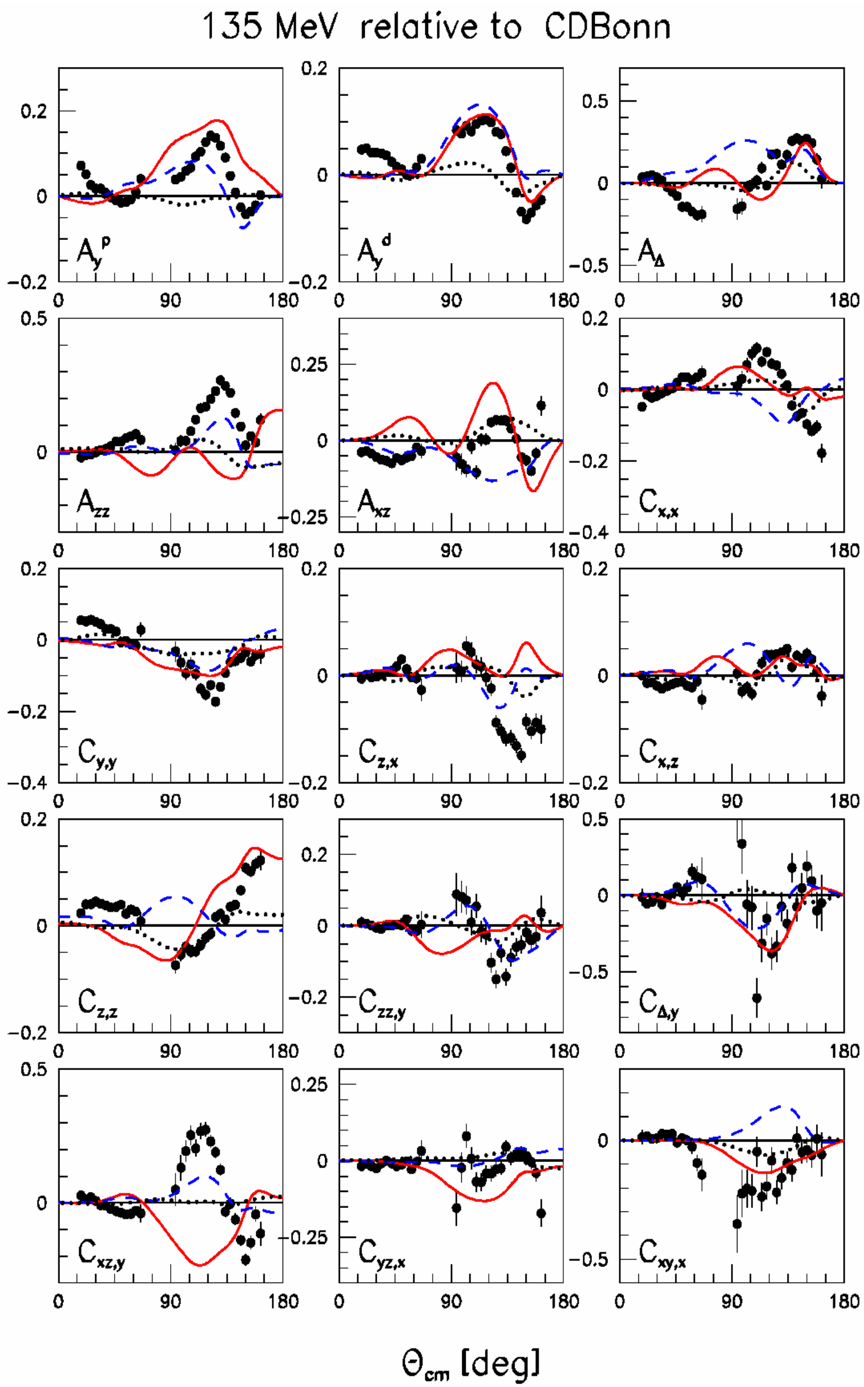


Data – CDBonn

Spin observables for p+d elastic scattering at Tp=135 MeV

- • Data-CDBonn NN
- —— Including TM 3NF
- ----- Including TM' 3NF
- . . . AV18-CDBonn NN

Statistical errors

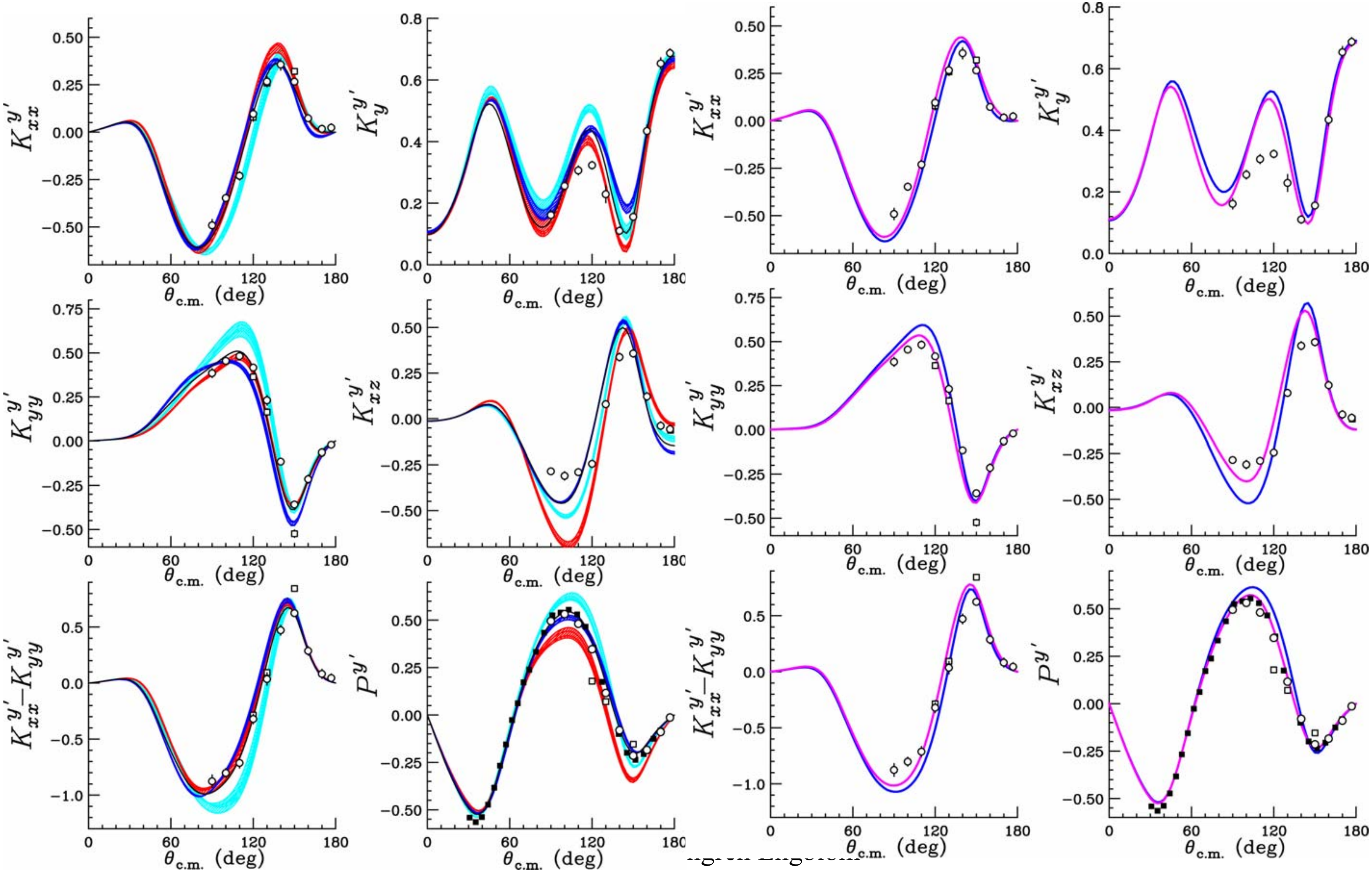


B.v. Przewoski et al., acc. for publ. PRC, nucl-ex/0411019

K. Sekiguchi et al. PRC 70, 014001(2004).

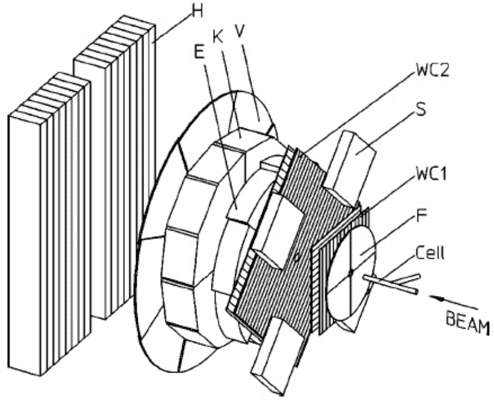
RIKEN DATA

Polarization transfer coefficients at 135 MeV/u



H.O. Meyer et al., PRL 83, 5439 (1999)

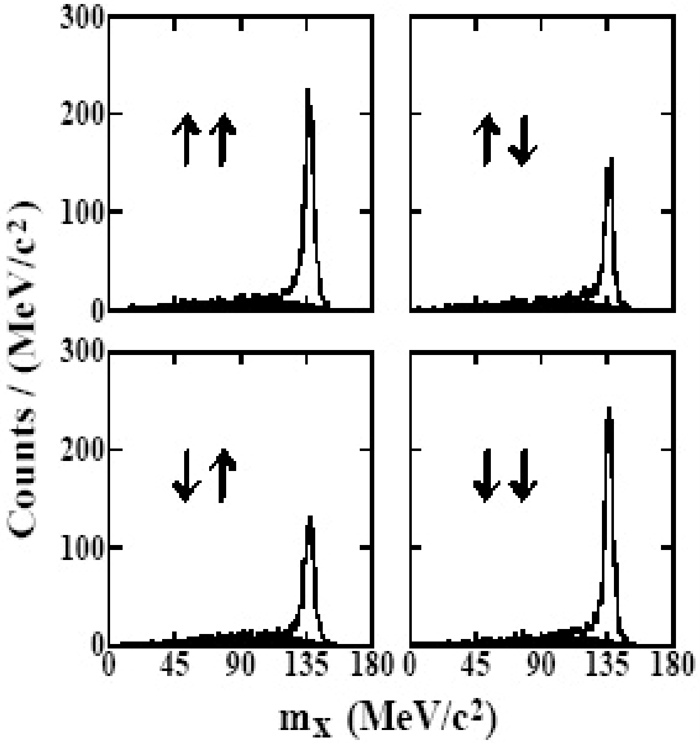
Spin-dependent cross sections

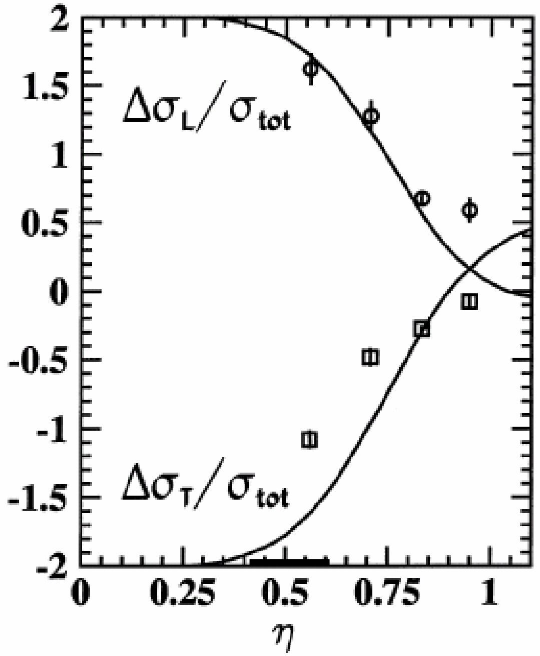


$$\Delta\sigma_{T(L)} = \sigma(\uparrow\downarrow + \downarrow\uparrow) - \sigma(\downarrow\downarrow + \uparrow\uparrow)$$

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

Theory: C. Hanhart et al., PLB 444, 25 (1998)

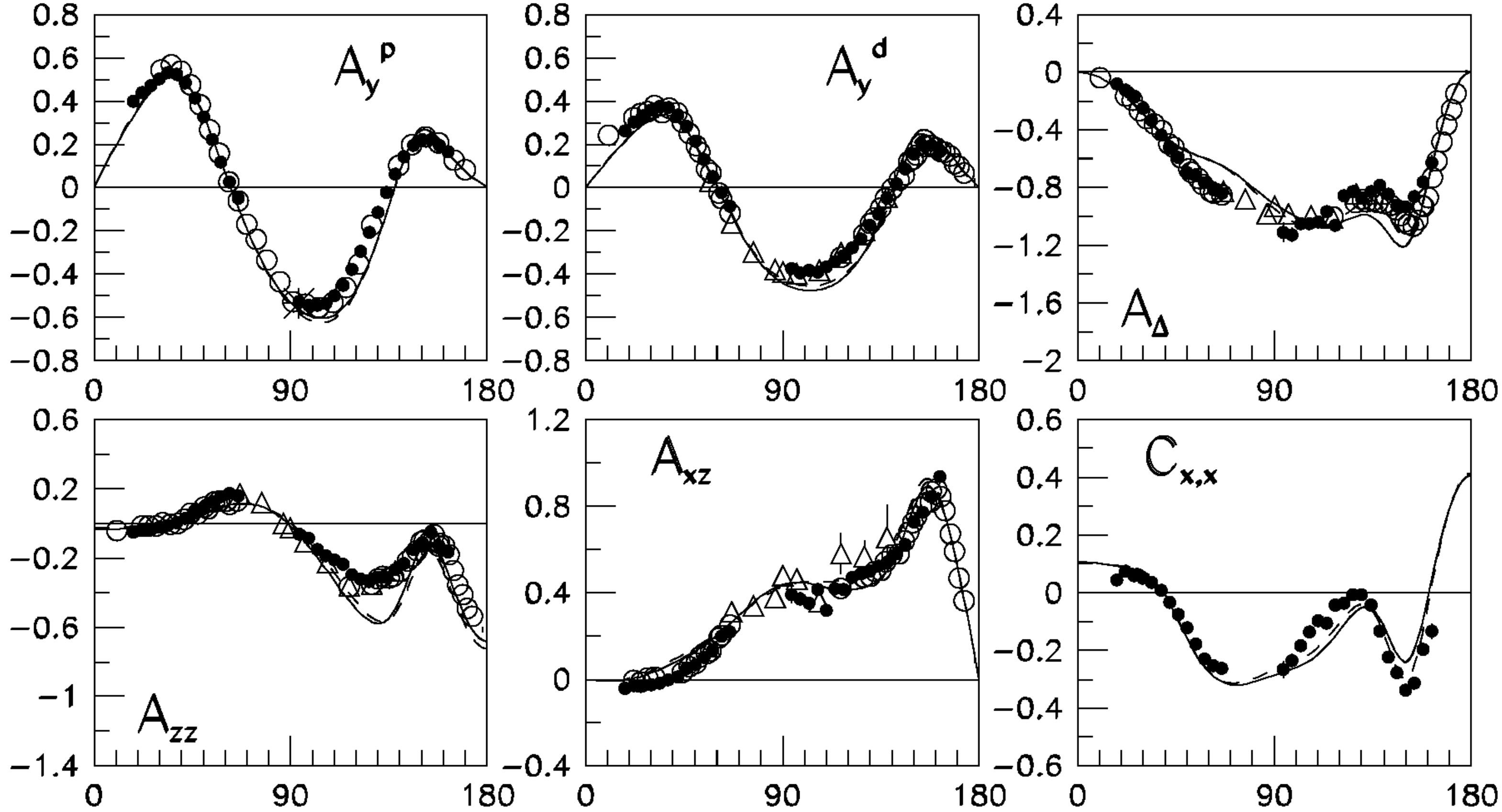




Spin observables for pd elastic scattering

●This experiment
°Δ Previous meas.
——CDBonn NN, Machleidt, PRC63, 024001 (2001)
- - - - AV18 NN, Wiringa, PRC51(1995)

135 MeV

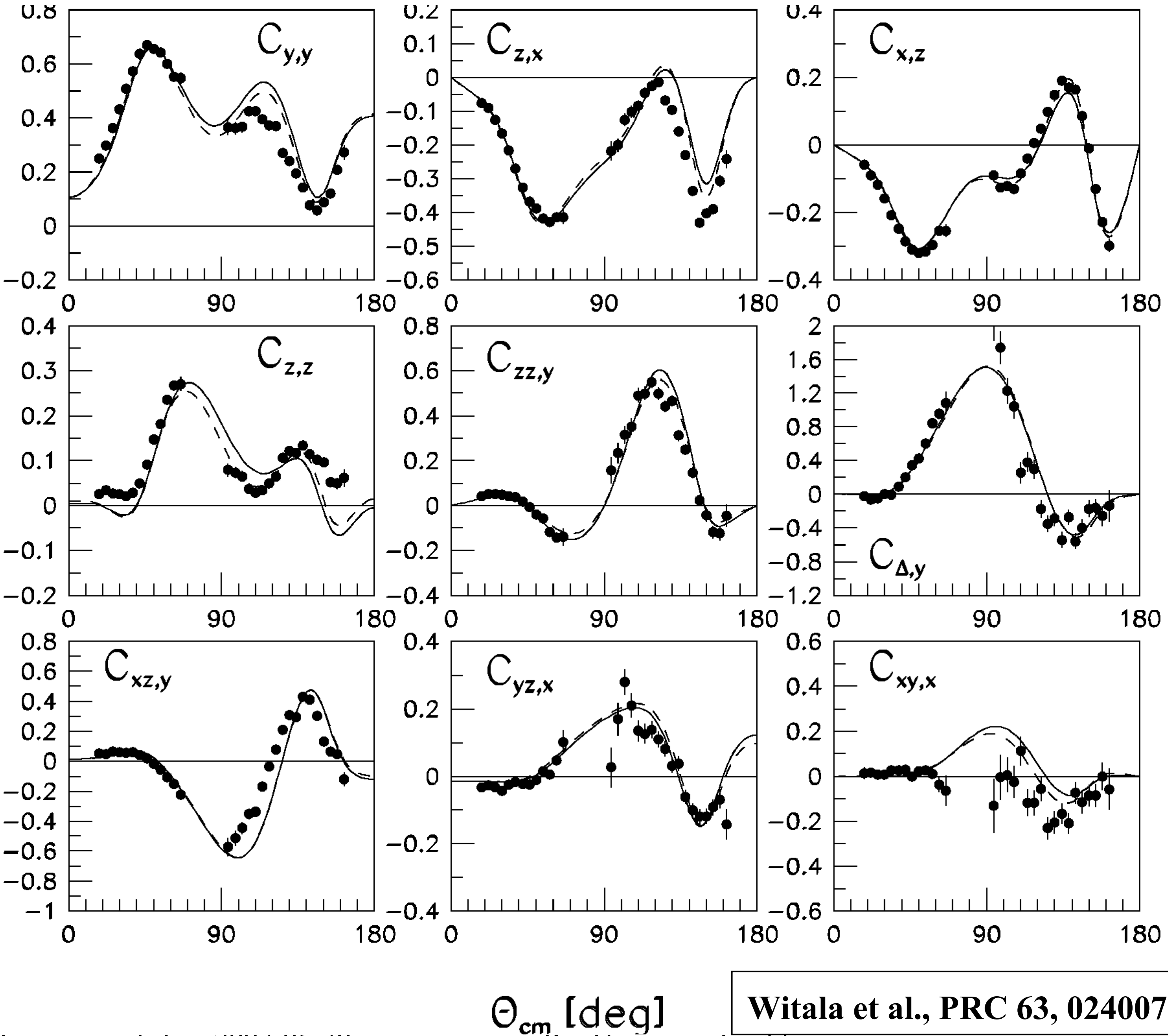


θ_{cm}[deg]

B.v. Przewoski et al., acc. for publ. PRC, nucl-ex/0411019

Ermisch et al., PRL 86, 5862 (2001)
Adelberger&Brown, PRD5,2139 (1972)
Wells et al., NIM A325, 205 (1993

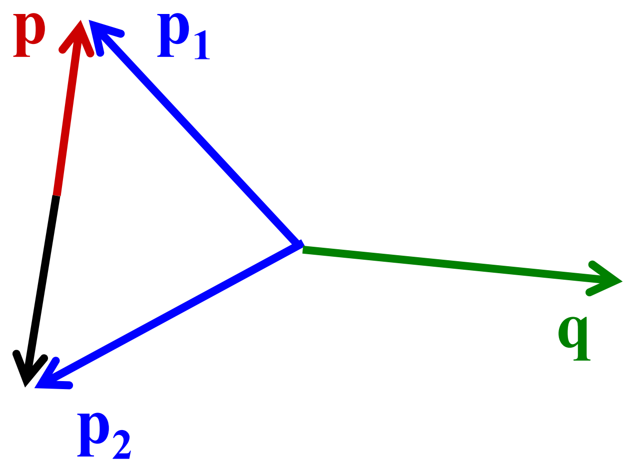
Stephenson PRC60, 061001 (1991) Bieber PRL 84, 606 (2000) Sakamoto PLB367, 60 (1996) Sakai PRL 84, 5288 (2000) Sekiguchi PRC65, 034003 (2002)



B.v. Przewoski et al., acc. for publ. PRC, nucl-ex/0411019

Witala et al., PRC 63, 024007 (2001)

3N final states – Basic definitions



Jacobi momenta

$p = \frac{1}{2} (p_1 - p_2)$

$q = -(p_1 + p_2)$

$\Delta\varphi = \varphi(p) - \varphi(q)$

$d+p \rightarrow p + p + n$

- **Kinematically complete if the two protons are measured**
- **Define the jacobi momenta such: q is the momentum of the neutron in the cm p is the relative mometum in the pp-system**
- **If azimuthally symmetric the two φ dependencies reduce to $\Delta\varphi$**