Workshop on Hadron-Physics @COSY, Bad Honnef, July 9, 2003

Nucleon-Nucleon Elastic Scattering

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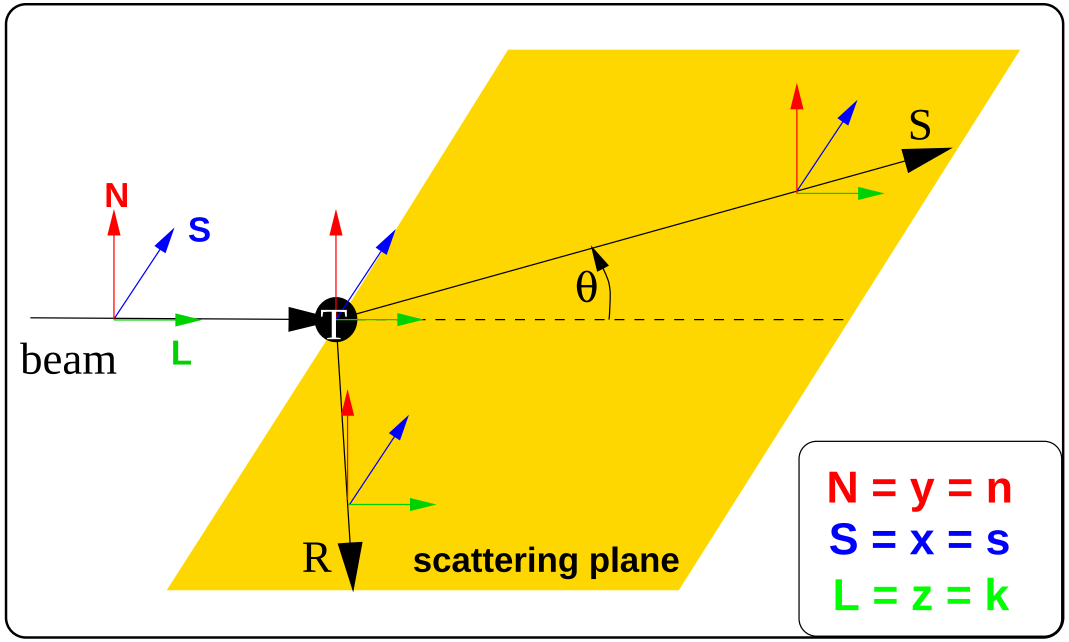
- **Introduction**
  - **Formalism, Observables**
  - **Phase Shift Analysis**
- **Status of Experiments**
  - **Database (recent additions)**
- **Status of Theory**
- **Where can COSY contribute?**

NN - formalism



4x4=256 experiments

↓

symmetries:

parity, TRI

↓

5 complex amplitudes

9 real functions (T_N, θ)

helicity-amplitudes:

$\phi_1 = \langle ++|T|++\rangle \quad \phi_2 = \langle ++|T|-- \rangle \quad \phi_3 = \ldots \quad \phi_4 = \ldots \quad \phi_5 = \ldots$

Isospin:

$$T(pp \rightarrow pp) \equiv T(nn \rightarrow nn) \equiv T_1$$

$$T(pn \rightarrow pn) \equiv T(np \rightarrow np) = \frac{1}{2}(T_1 + T_0)$$

$$T(pn \rightarrow np) = T(np \rightarrow pn) = \frac{1}{2}(T_1 - T_0)$$

Pauli-principle

Isospin0	Isospin1
$\phi_1(\pi-\theta) = -\phi_1(\theta)$	$\phi_1(\pi-\theta) = \phi_1(\theta)$
$\phi_2(\pi-\theta) = -\phi_2(\theta)$	$\phi_2(\pi-\theta) = \phi_2(\theta)$
$\phi_3(\pi-\theta) = \phi_4(\theta)$	$\phi_3(\pi-\theta) = -\phi_4(\theta)$
$\phi_5(\pi-\theta) = \phi_5(\theta)$	$\phi_5(\pi-\theta) = -\phi_5(\theta)$

Phase-Shift Analysis (PSA)

- partial-wave decomposition

  $S_J = e^{2i\delta_J}$; $\vec{J} = \vec{L} + \vec{S}$

- include known physics

  $L > L_{max}$: OPE

  Coulomb

- inelasticities for T > 300 MeV

  ➜ δ_J complex

- VPI/GWU (SAID)

  pp : 0-3.0 GeV : 24 000 data points

  np : 0-1.3 GeV : 13 000 data points

- Saclay-Geneva

  pp : mainly fixed energy

- Hiroshima

  pp/np : fixed energies 0-11 / 0.5-1.1GeV

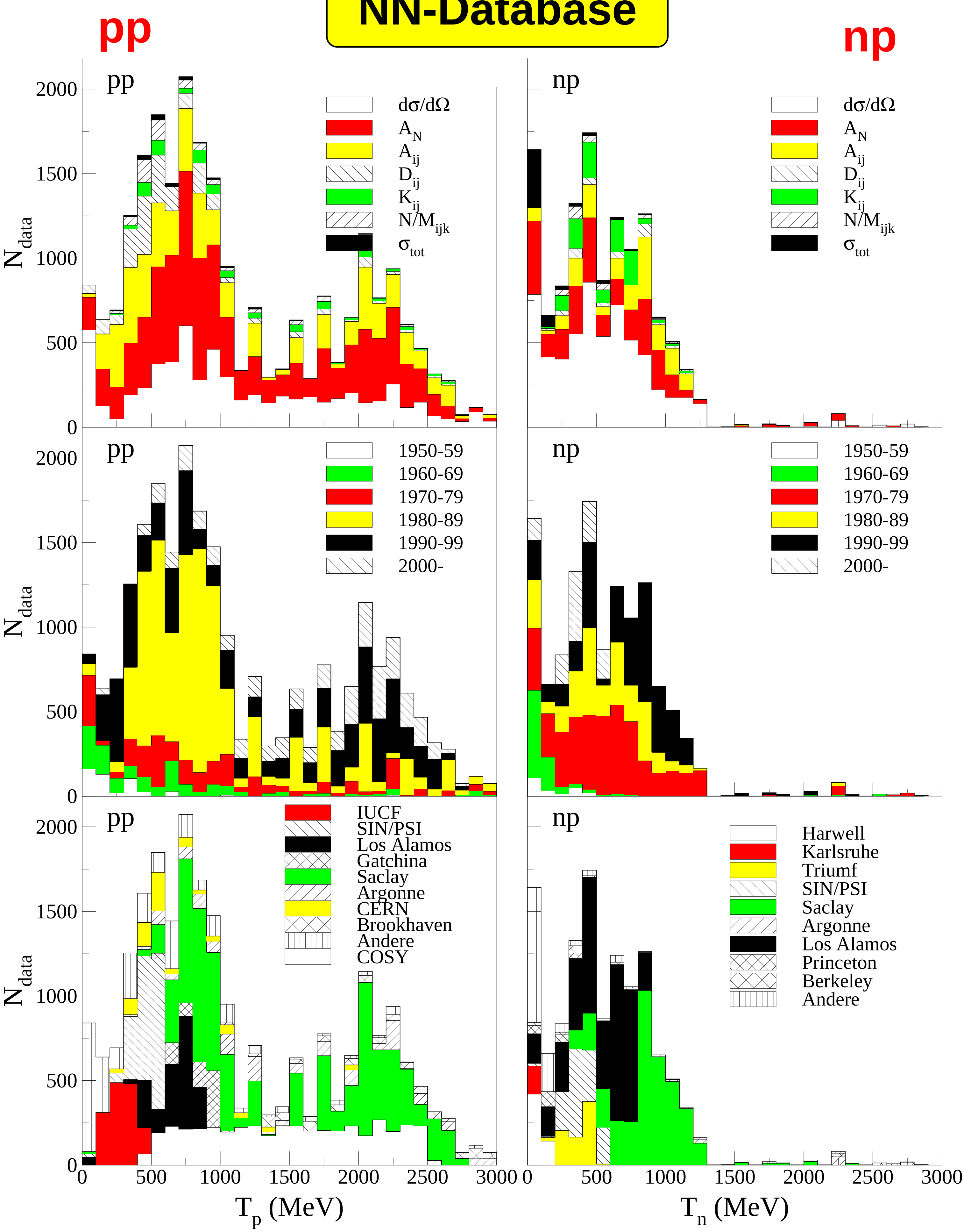
- Nijmegen

  pp/np : 0-350 / 0-500 MeV

➜ predicitive power !!

⟷ Theorie

NN-Database



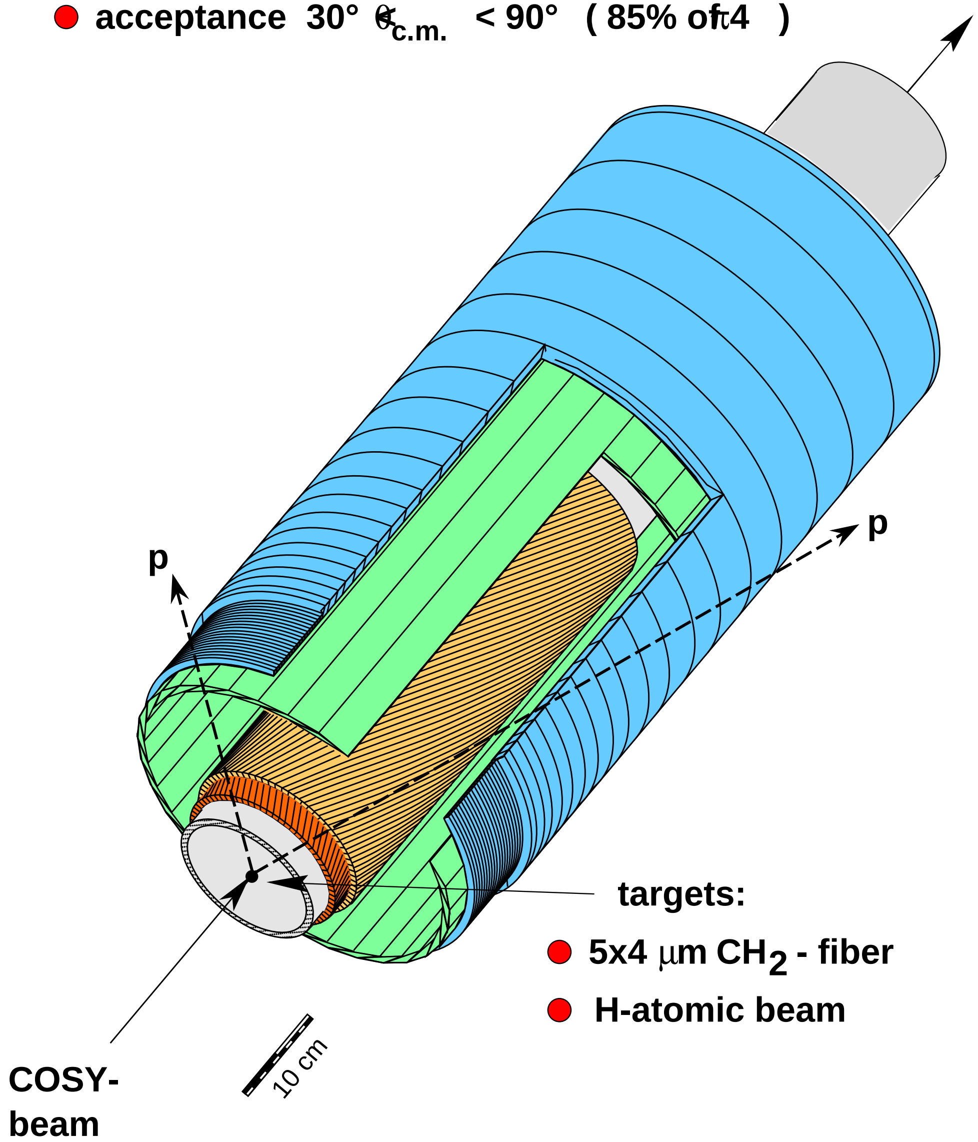
pp
np
pp
N_{data}
dσ/dΩ
A_N
A_{ij}
D_{ij}
K_{ij}
N/M_{ijk}
σ_{tot}
np
1950-59
1960-69
1970-79
1980-89
1990-99
2000-
IUCF
SIN/PSI
Los Alamos
Gatchina
Saclay
Argonne
CERN
Brookhaven
Andere
COSY
Harwell
Karlsruhe
Triumf
SIN/PSI
Saclay
Argonne
Los Alamos
Princeton
Berkeley
Andere
T_p (MeV)
T_n (MeV)

Recent Additions to the 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}

EDDA@COSY

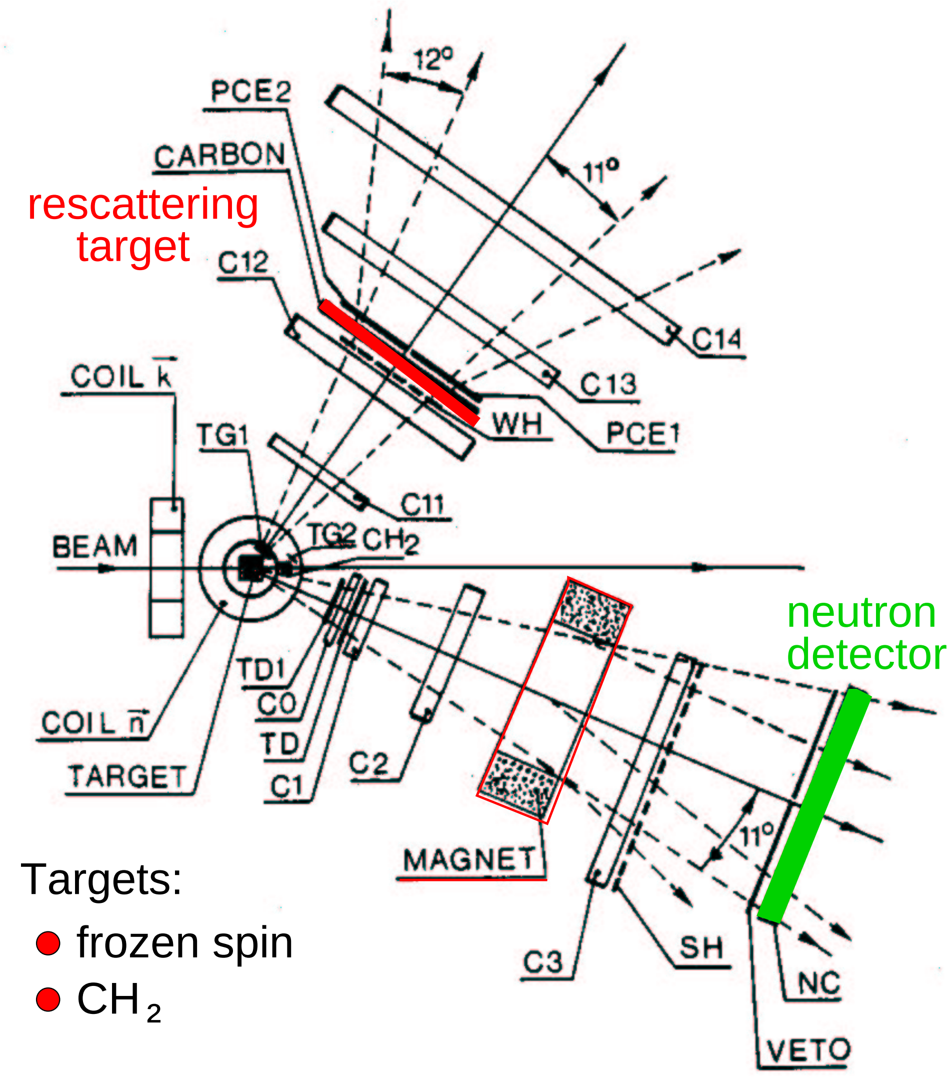
- acceptance $30^\circ < \theta_{c.m.} < 90^\circ$ (85% of 4π)



targets:

- $5 \times 4\ \mu m\ CH_2$ - fiber
- H-atomic beam

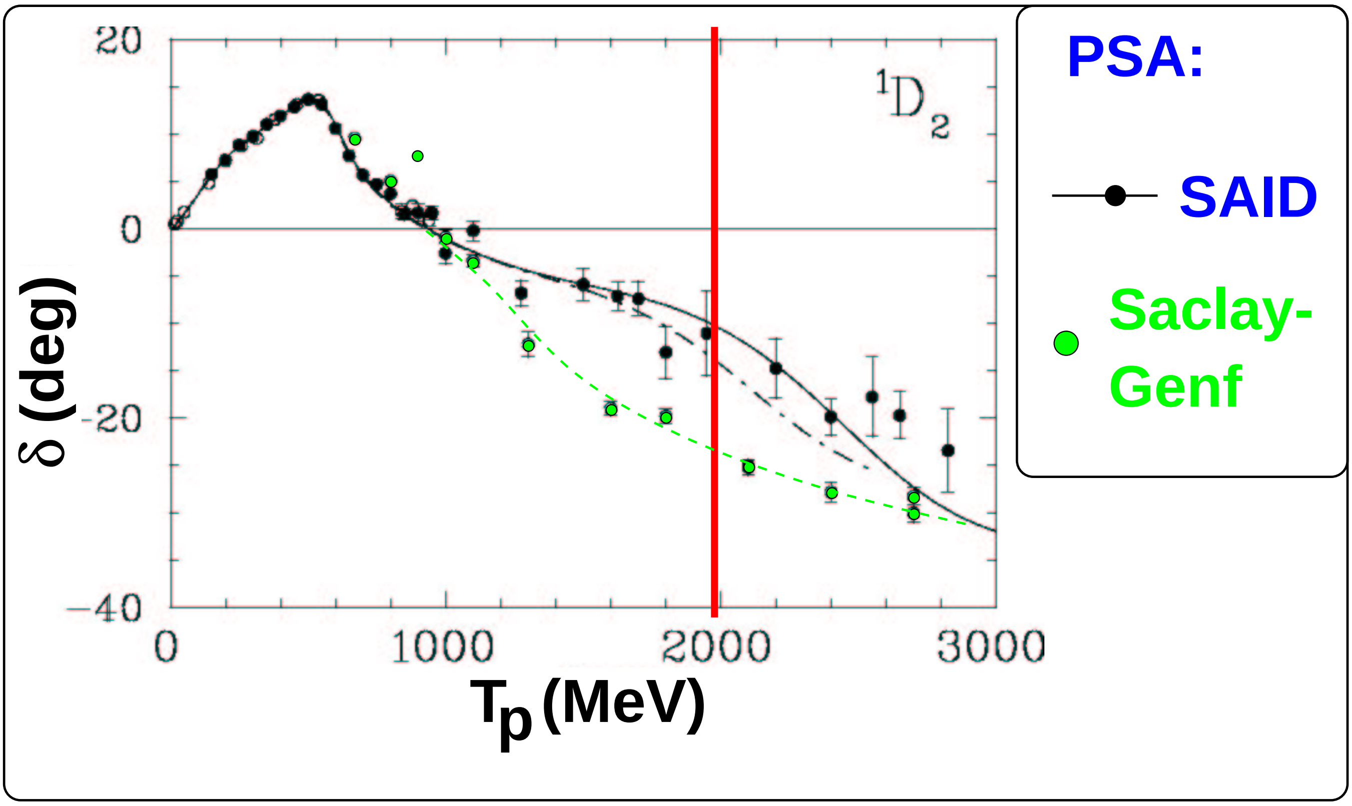
NN@Saturne II



Targets:

- frozen spin
- CH_2

ambiguities in phase shifts

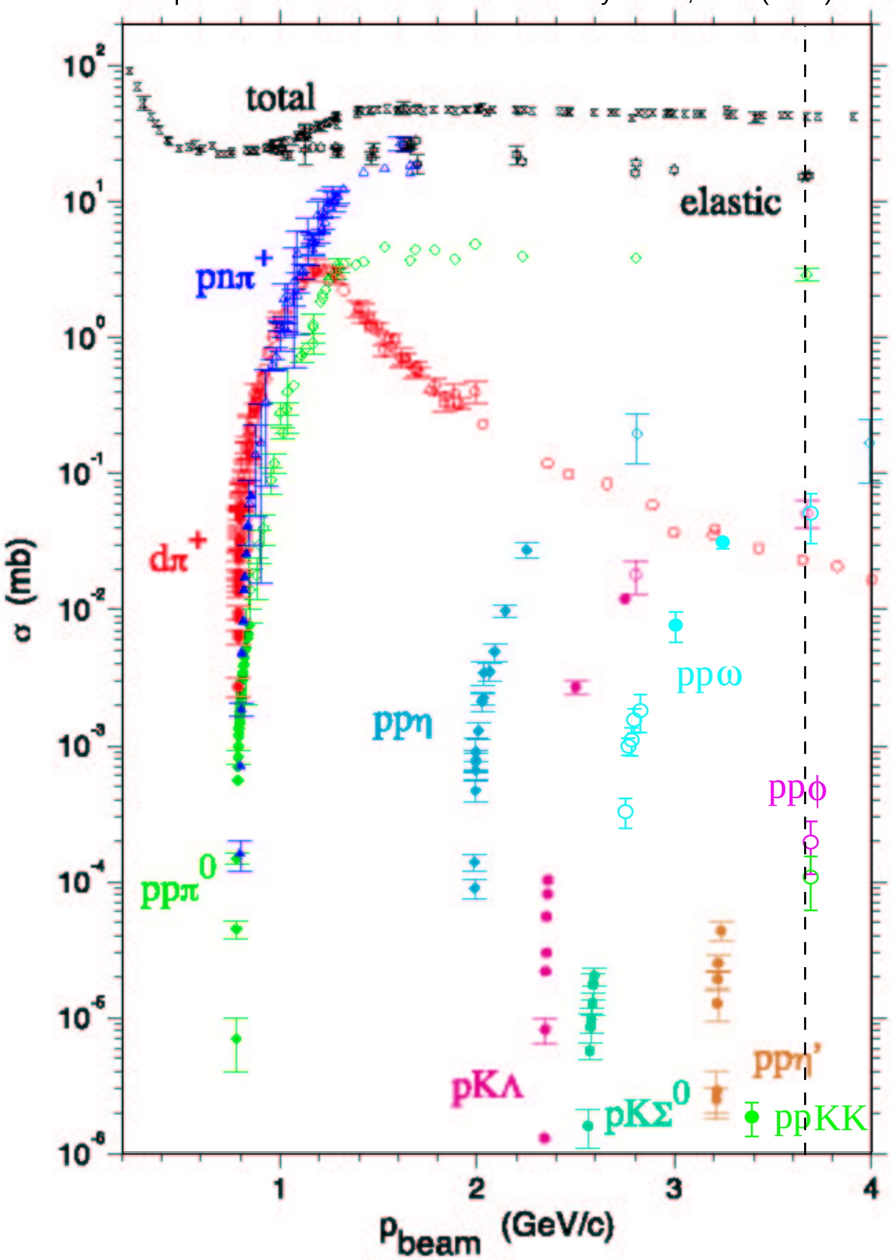


Bystricky, Lechanoine-Leluc, Lehar Eur. Phys. J. C4, 607 (1998)

Arndt, Strakovsky, Workman, Phys. Rev. C62, 034005 (2000)

Meson Production

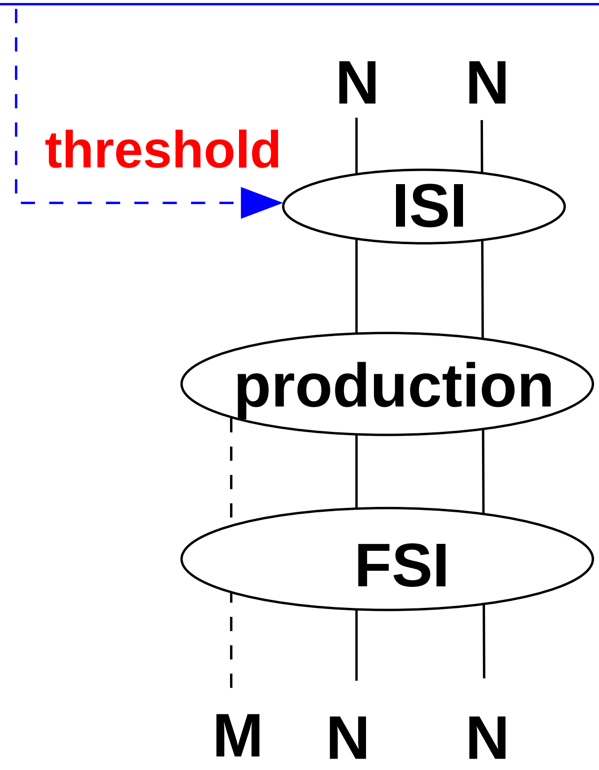
adopted from Machner&Haidenbauer J.Phys.G 25,R231 (1999)



T=1:

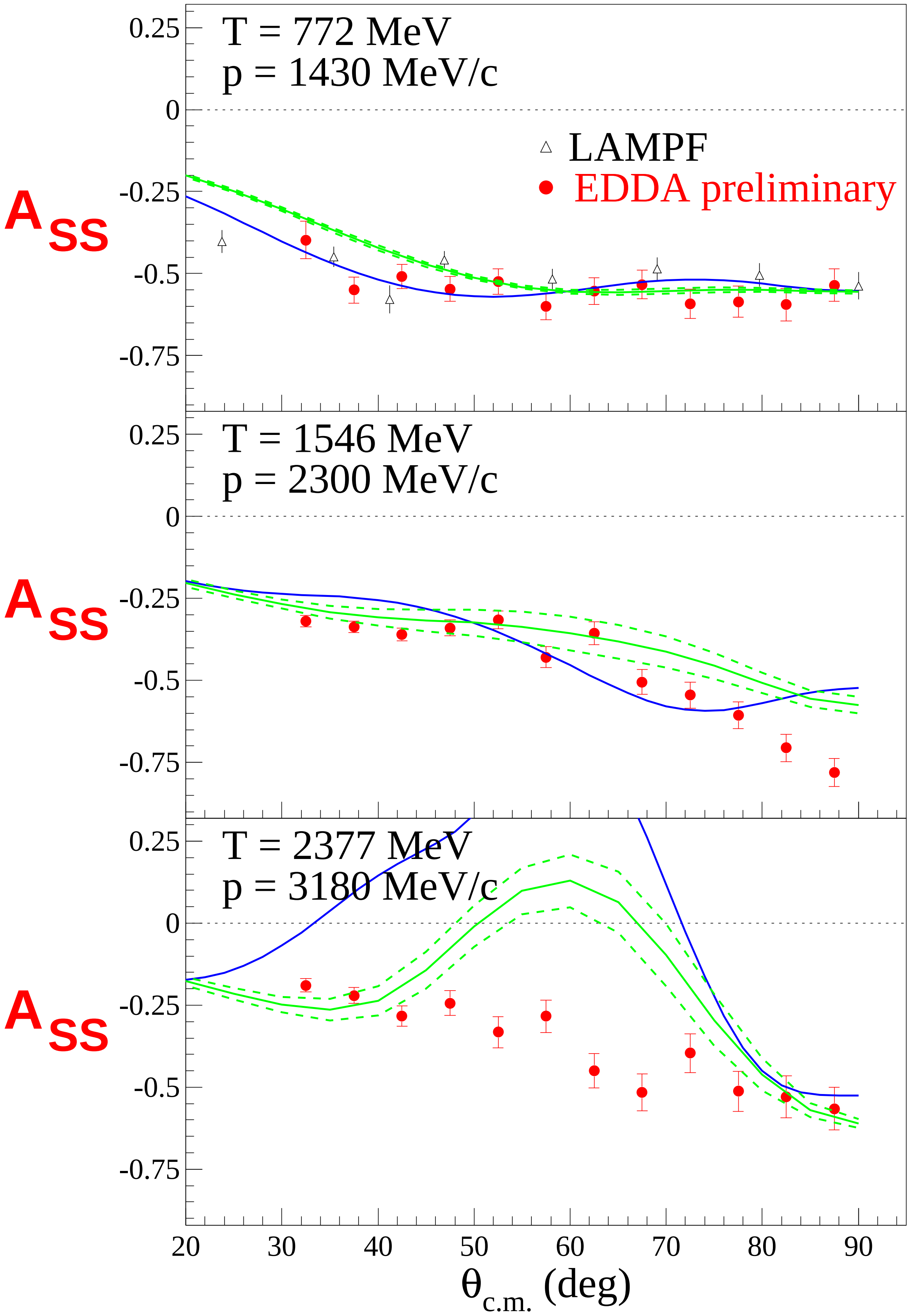
pseudoscalar: $^3P_0$

vector: $^3P_1$



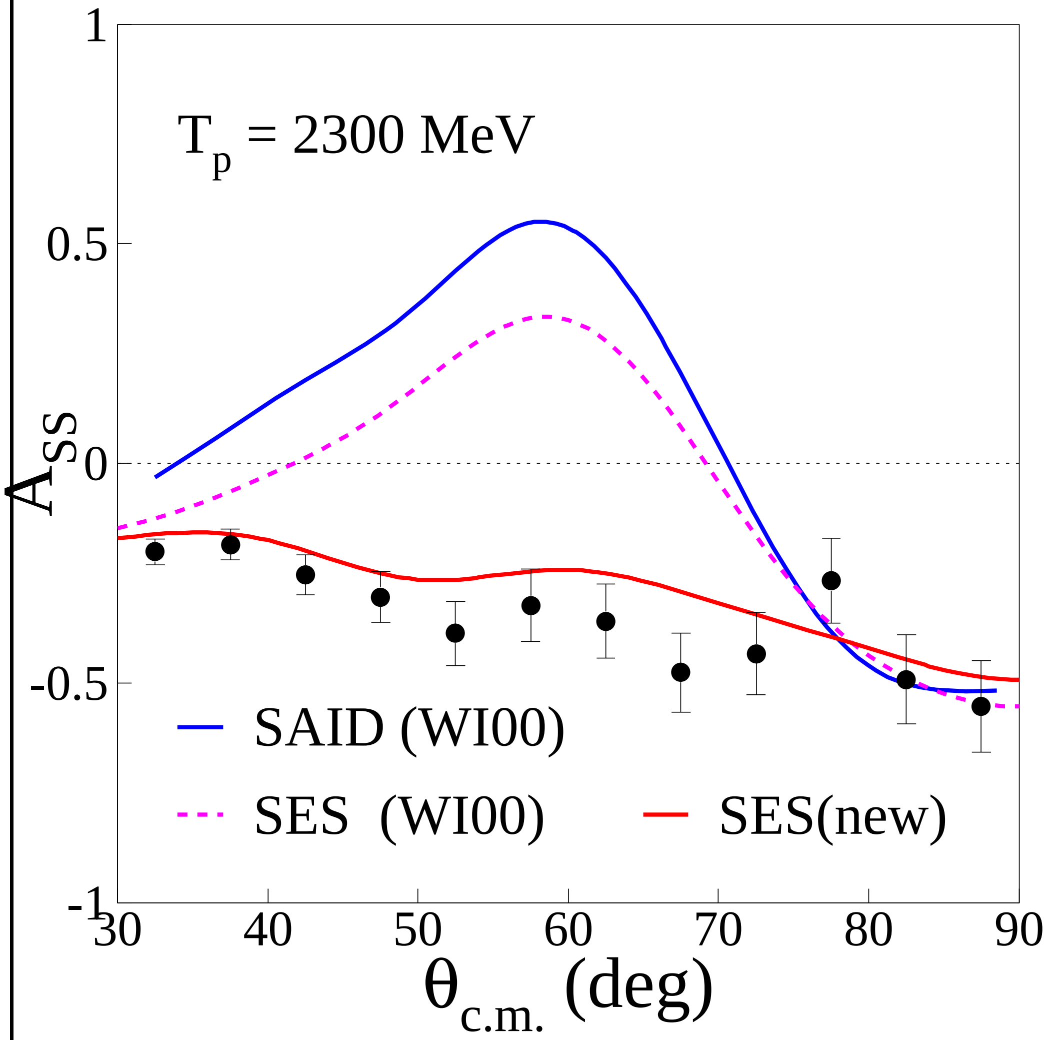
e.g. Hanhart &Nakayama Phys. Lett B 454, 176 (1998)

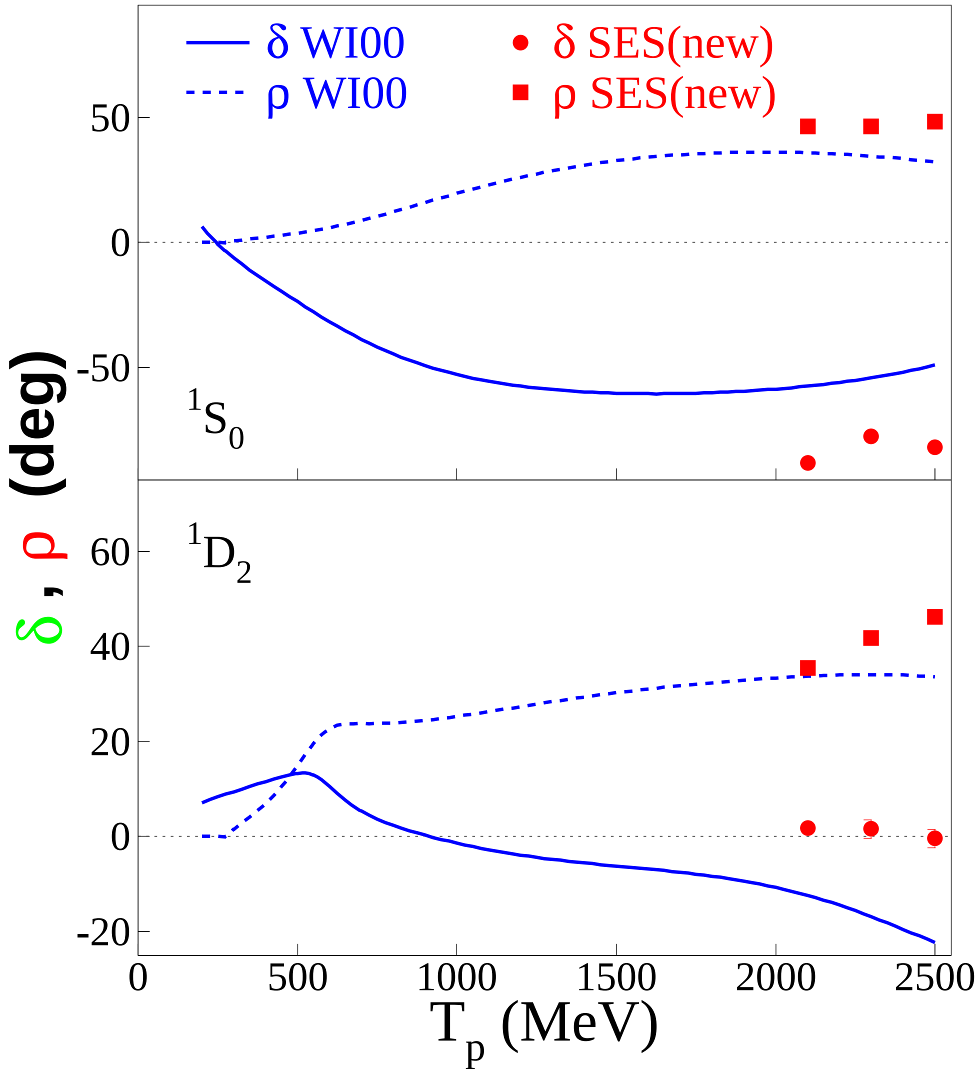
Spinkorrelationsparameter



PSA: SAID(SM00) Saclay-Genf

A_{SS} : Influence on PSA



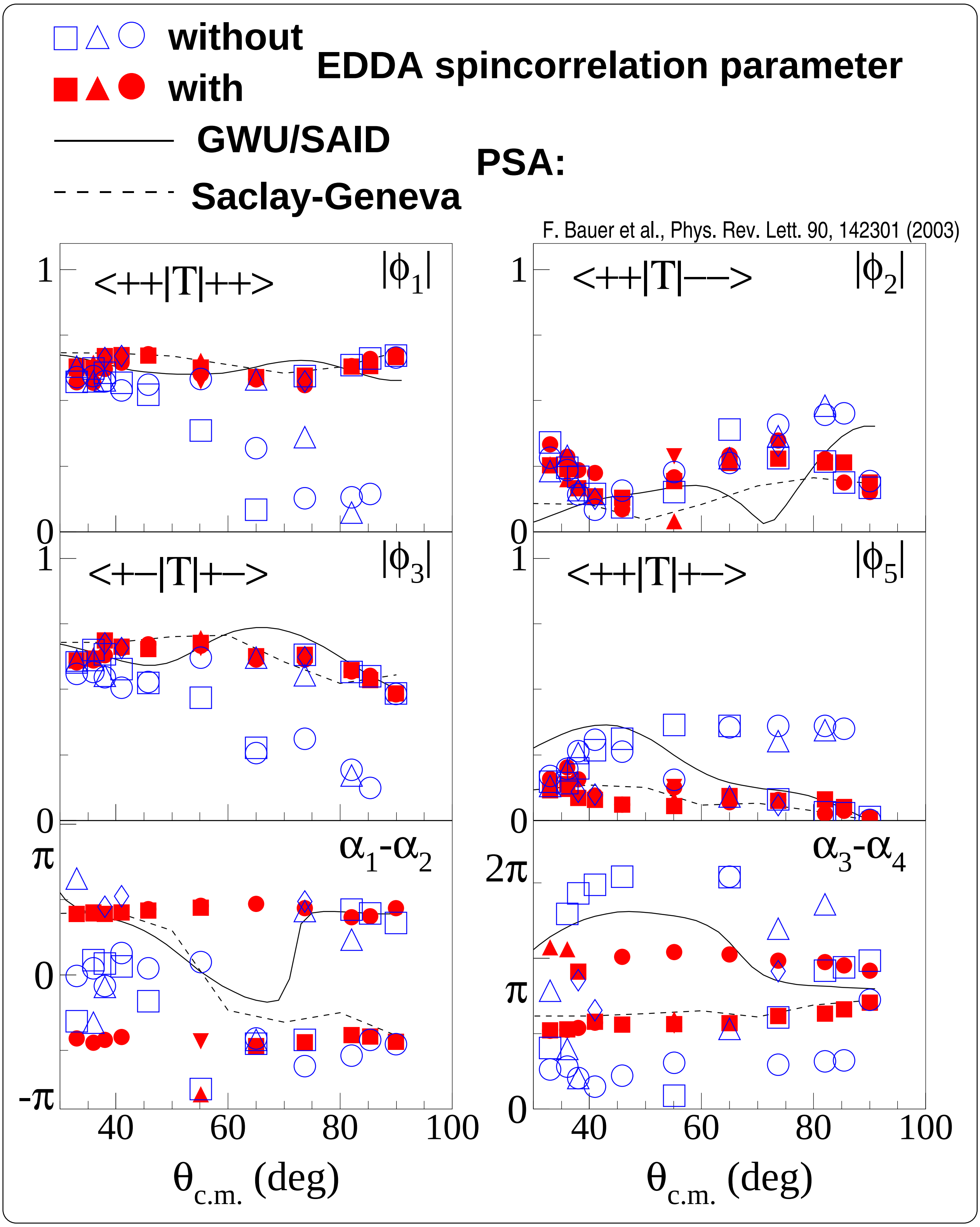


Amplitude Reconstruction

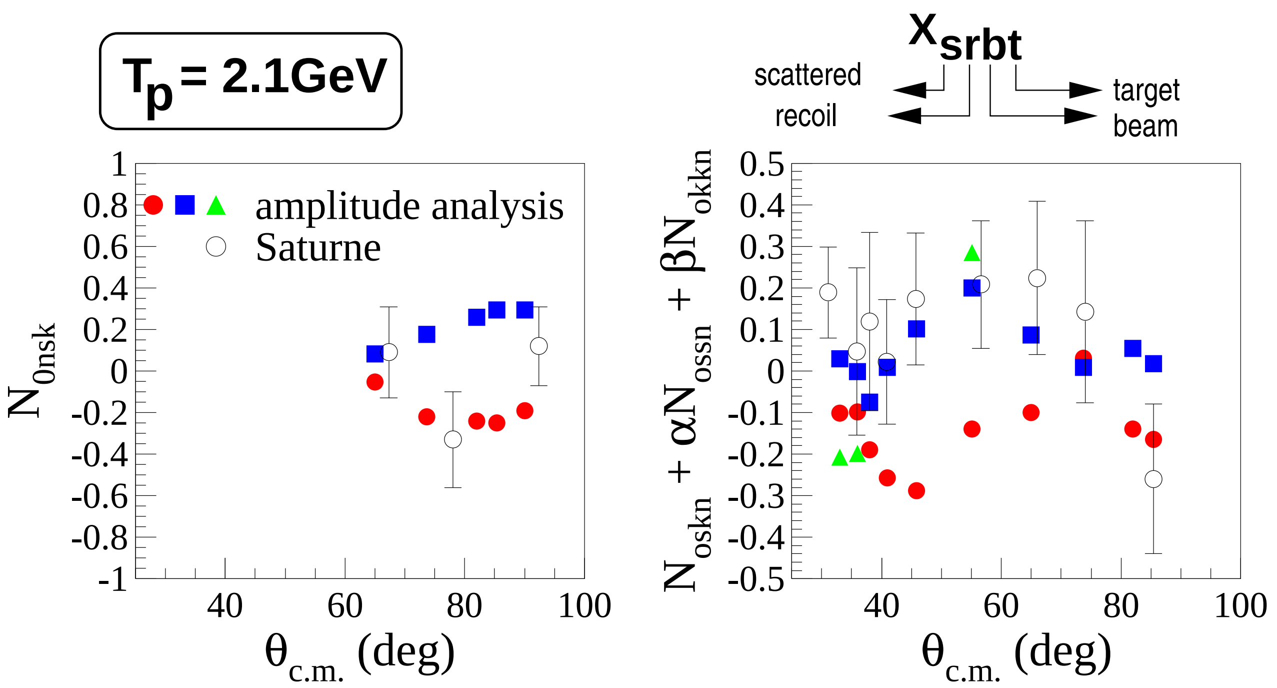
Helicity-amplitudes: $\phi_k = |\phi_k|\, e^{i\alpha_k}$

Observables: e.g.

$$A_{SS}\sigma_0 = |\phi_1||\phi_2|\cos(\alpha_1 - \alpha_2) + |\phi_3||\phi_4|\cos(\alpha_3 - \alpha_4)$$



What should we measure at COSY?

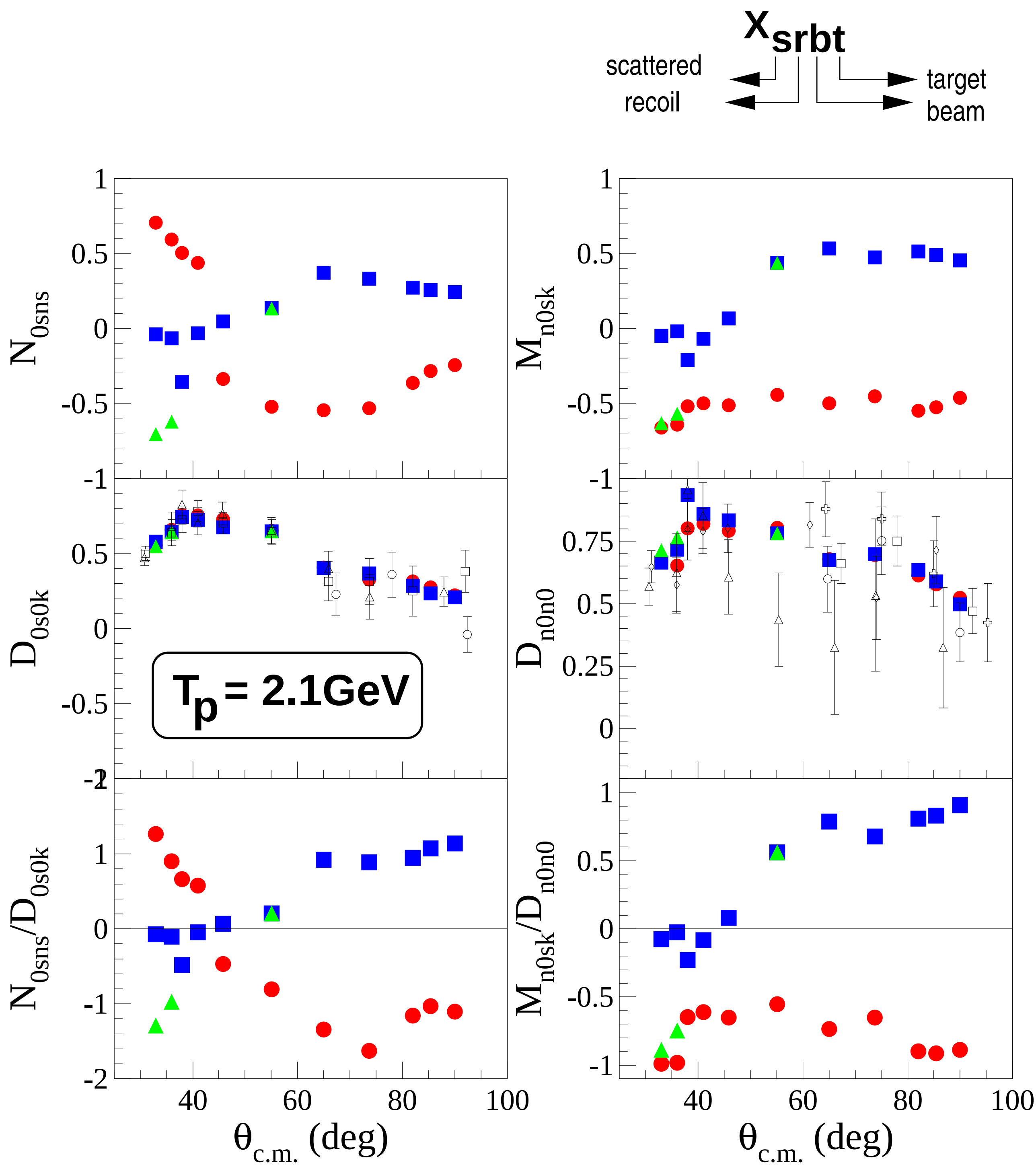


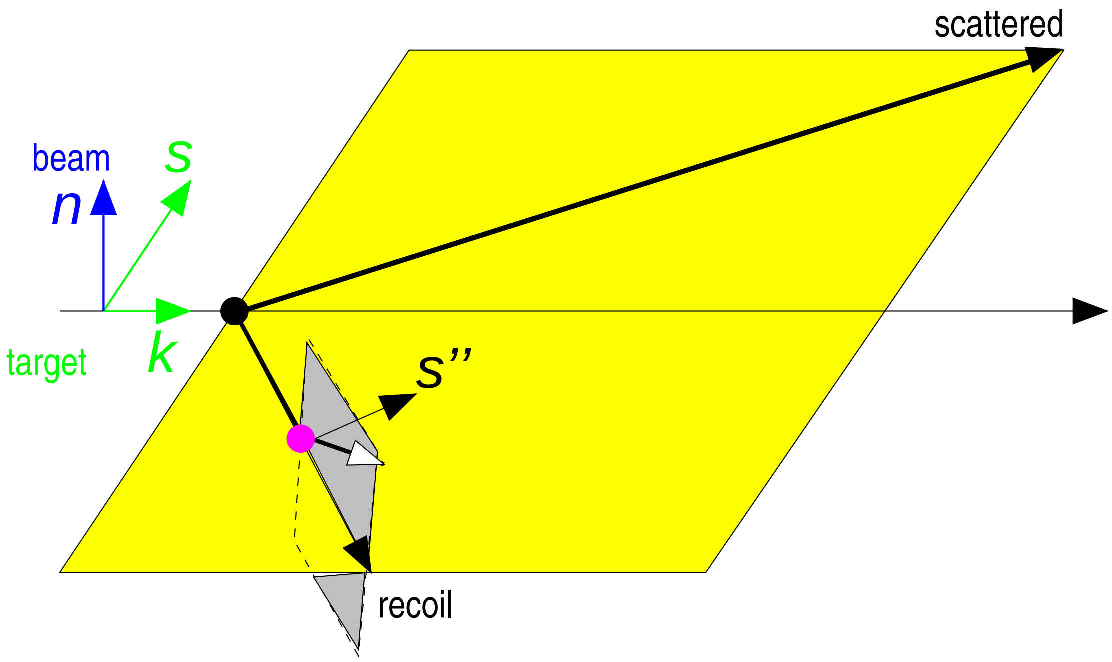
To resolve remaining ambiguities:

⇒ **measure triple-spin observables!**

Double-scattering experiments.

⇒ **very challenging!**


X srbt
scattered
recoil
target
beam
N 0sns
D 0s0k
N 0sns /D 0s0k
M n0sk
D n0n0
M n0sk /D n0n0
T p = 2.1GeV
θ c.m. (deg)
θ c.m. (deg)


scattered
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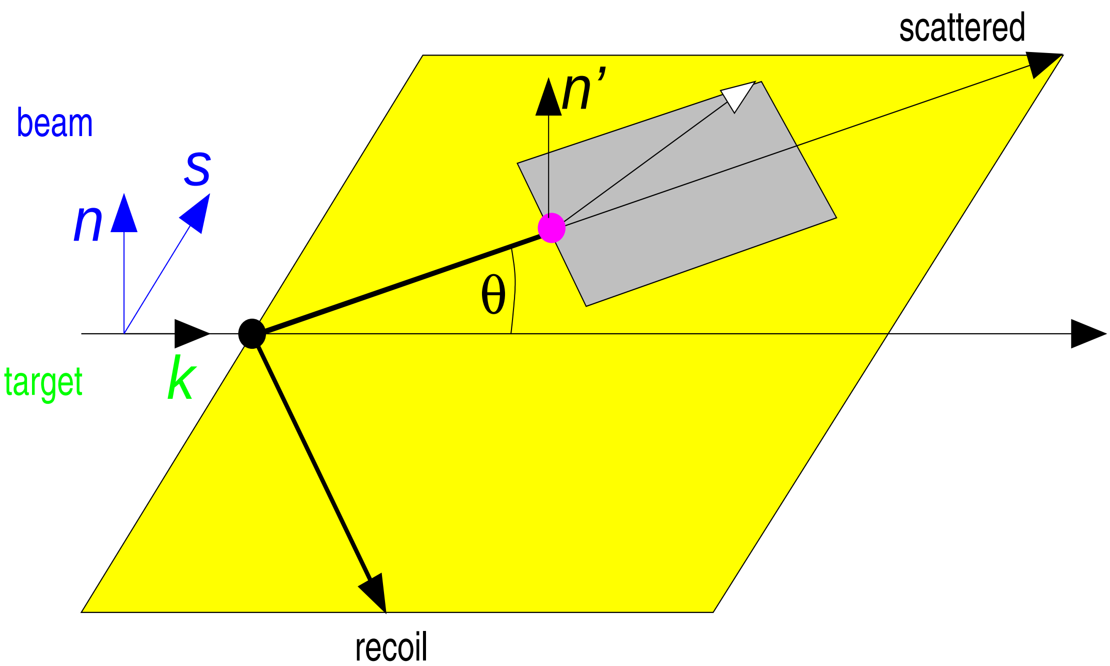

scattered
n'
beam
s
n
θ
target
k
recoil

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	$q\,q\,\bar{q}\,\bar{q}$	??

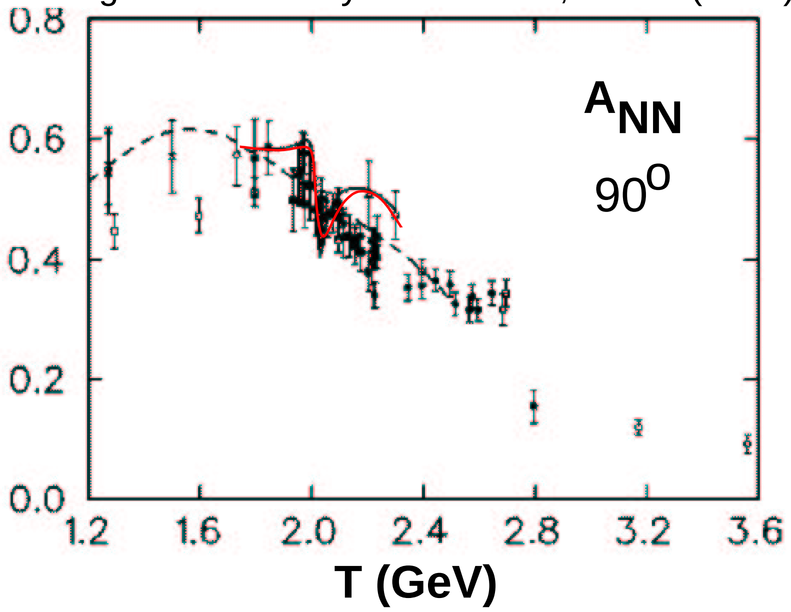
- numerous theoretical predictions for **I=1 ,S=0** : $W_R \approx$ **2.1 ... 2.7 GeV**

  $\Gamma =$ **10...150 MeV**

  no experimental evidence !

NN@Saturne

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



EDDA@COSY

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

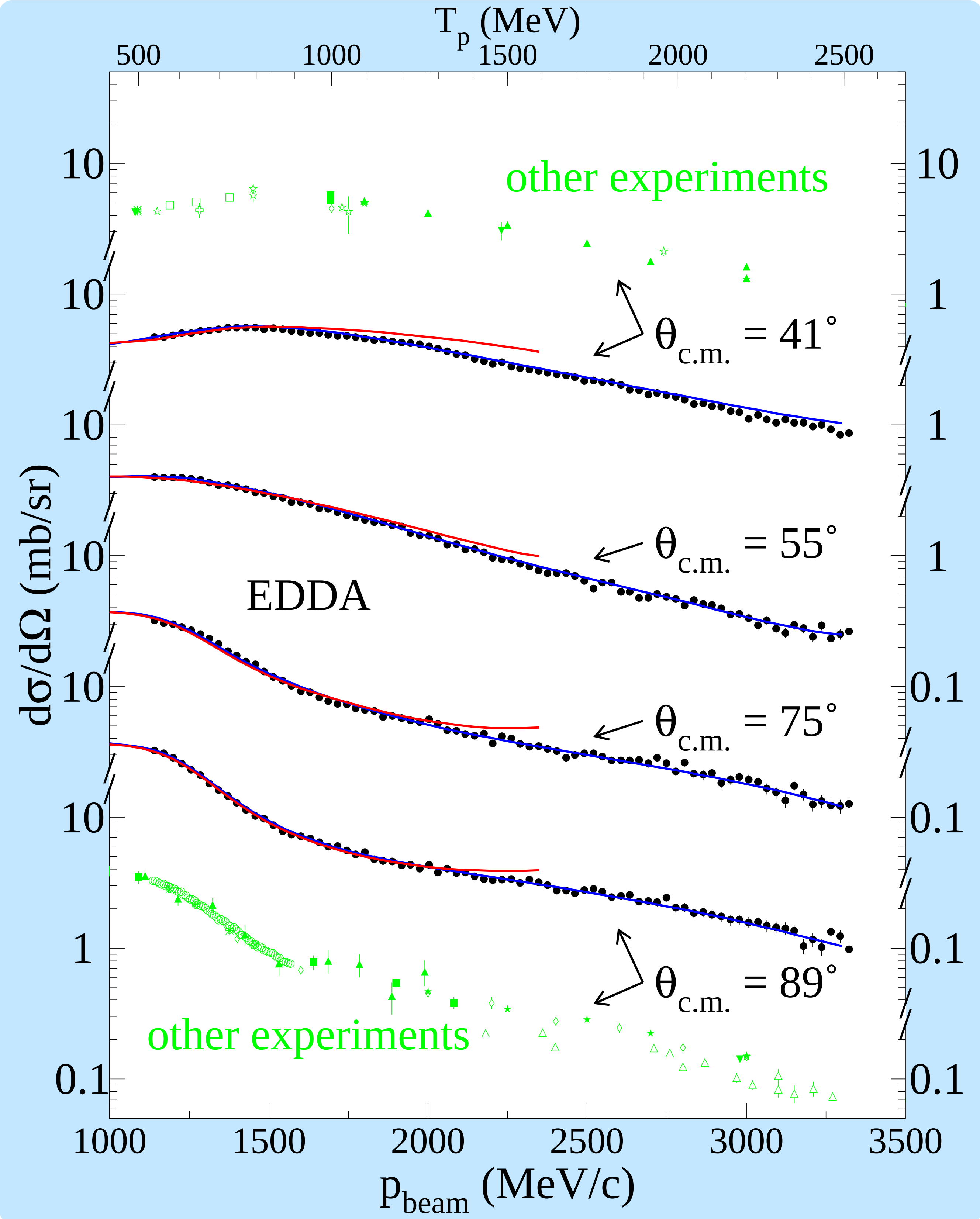
W_R = 2.2 ... 2.8 GeV
Γ = 10 ... 100 MeV

$\eta_{el} >$	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

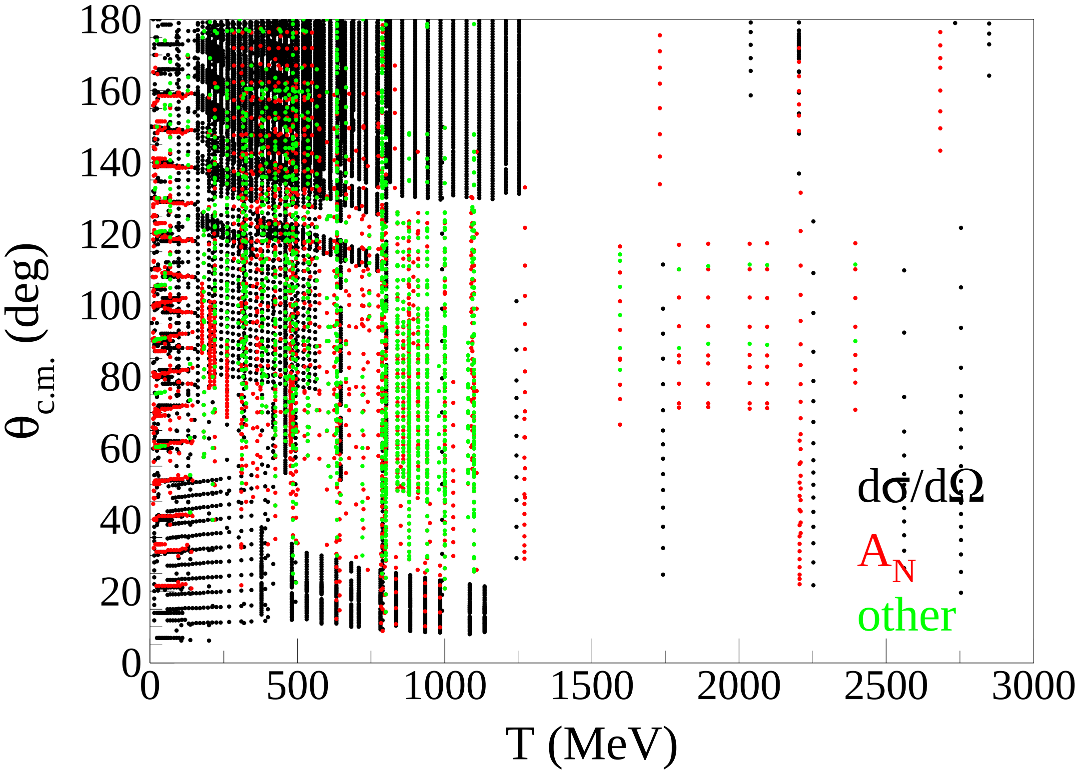
EDDA Results: $\frac{d\sigma}{d\Omega}$

D.Albers et al. *Phys. Rev. Lett.* **78**, 1652 (1997)



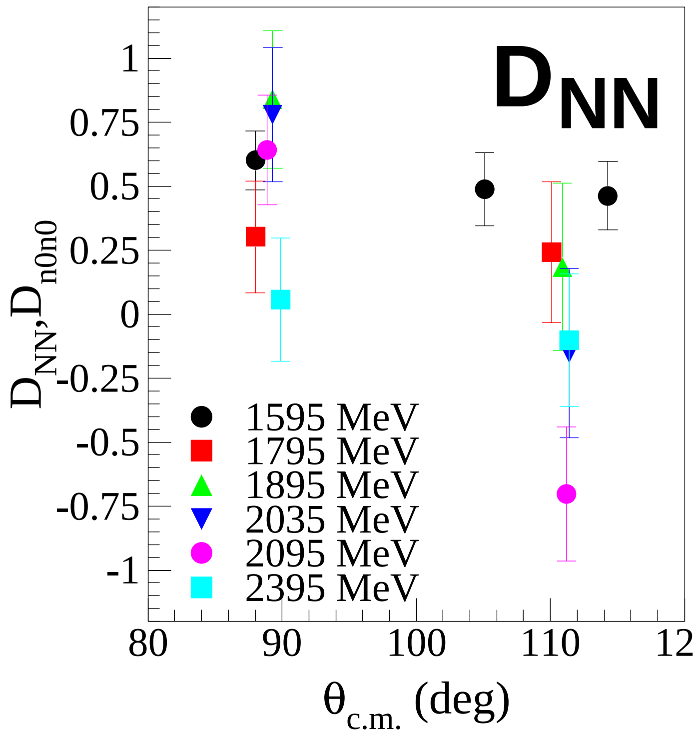
SAID PSA: SM94, SM97

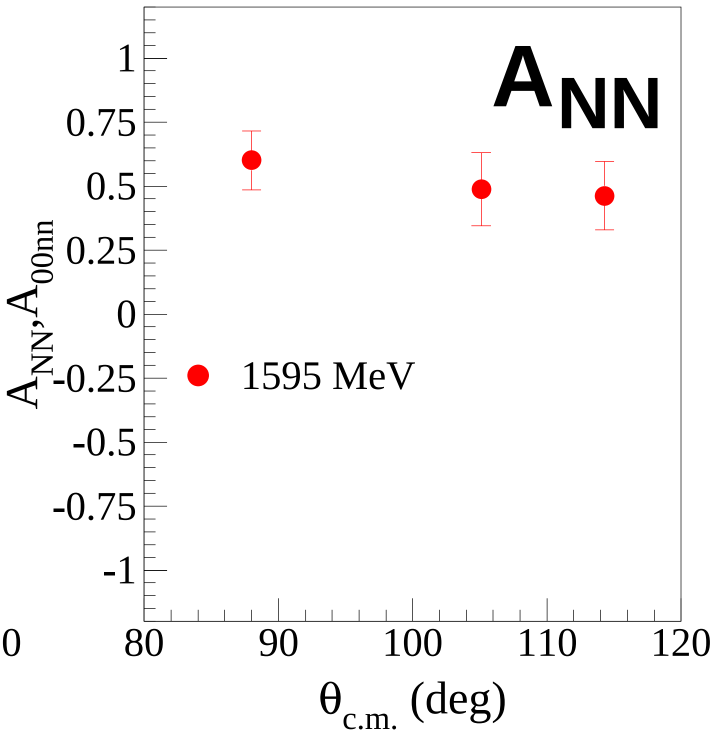
np-Observables



double-spin observables: T > 1.1GeV :

de Lesquen et al. Eur.Phys.J. C11, 69 (1999)





Polarized Neutrons

- deuteron-breakup (Saturne II)

  $3\ 10^{11}\ \vec{d}$ ⇒ 20cm Be — $1.3\ 10^{6}\ \vec{n}/cm^2$ (60% pol.)

  $T < 1.15$ GeV

- (p,n) reactions

  $\vec{p} + d$ ⇒ $\vec{n} + X$ (Triumf, LAMPF) $< 5\ 10^{5}\ \vec{n}/cm^2/s$ (40-60% pol.)

  $\vec{p} + C$ ⇒ $\vec{n} + X$ (PSI) $< 5\ 10^{6}\ \vec{n}/cm^2/s$ (40-50% pol.)

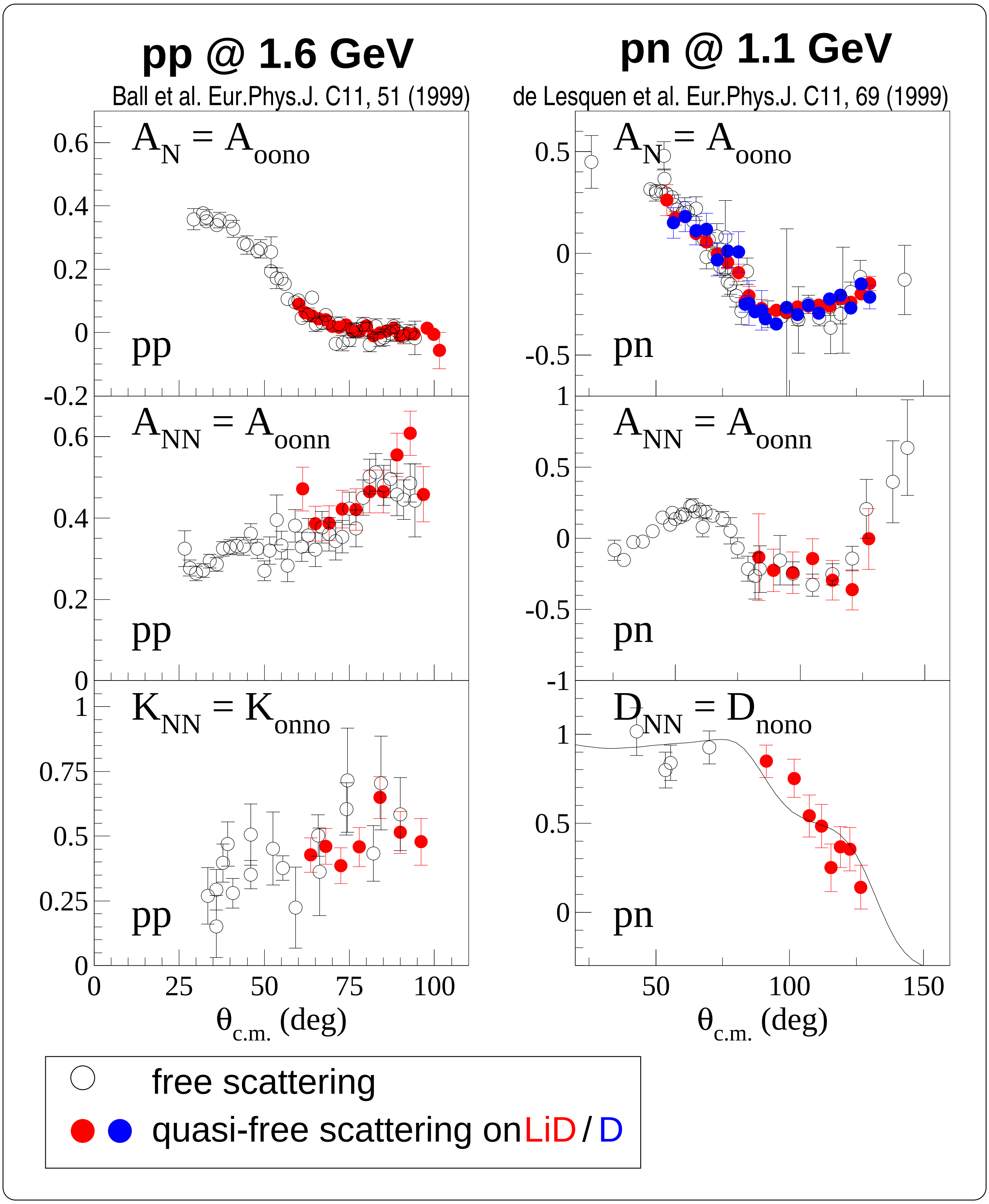
- quasi-free scattering $\vec{p}\ \vec{d} \rightarrow p_{sp}\ p\ n$

  LiD (Saturne II) $P_n = P_p = P_d\ (1-1.5 w_D)$

  d-atomic beams → < 2/3 purely vector polarized

quasi-free pN scattering

LiD -targets at Saturne II



Quasi-Free Meson Production

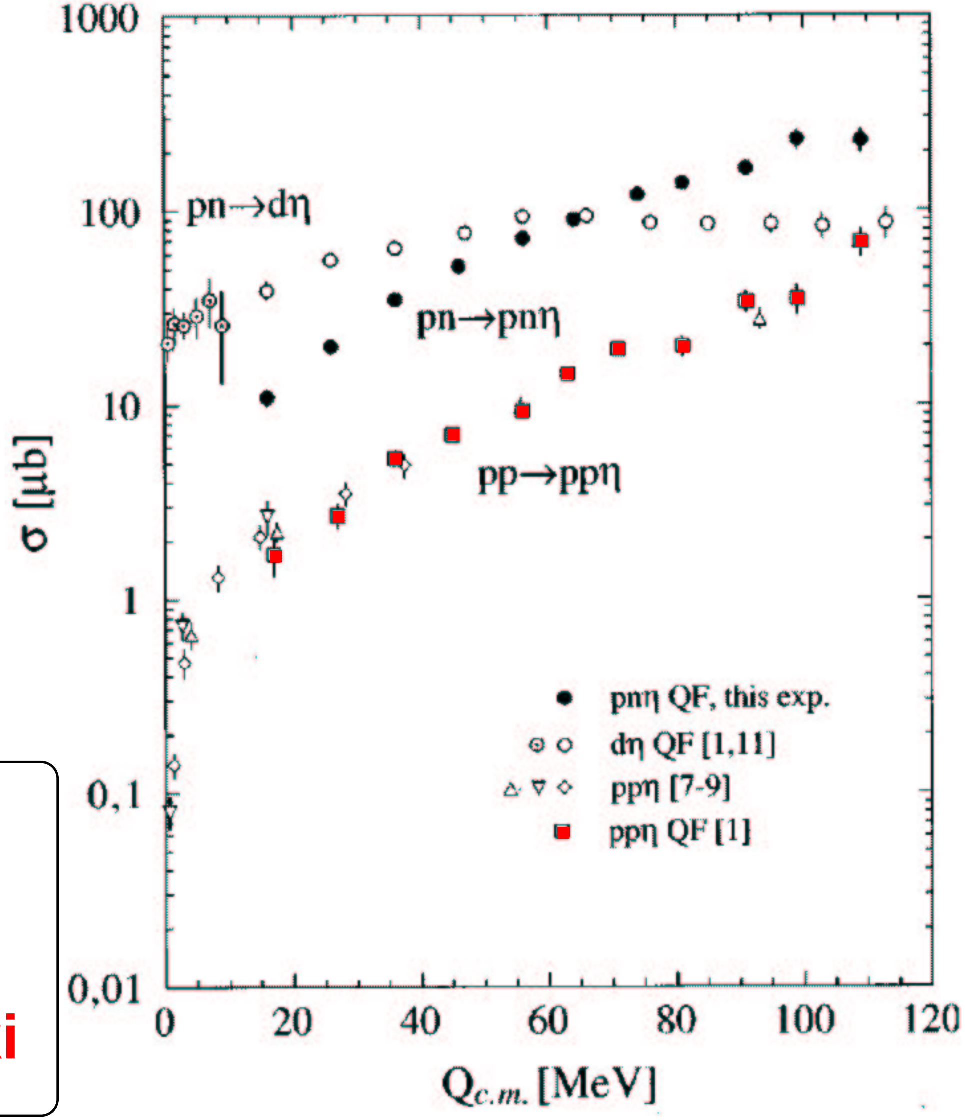
$p + d \rightarrow p_{sp} + p + n + M$

$\rightarrow n_{sp} + p + p + M$

$\rightarrow p_{sp} + d + M$

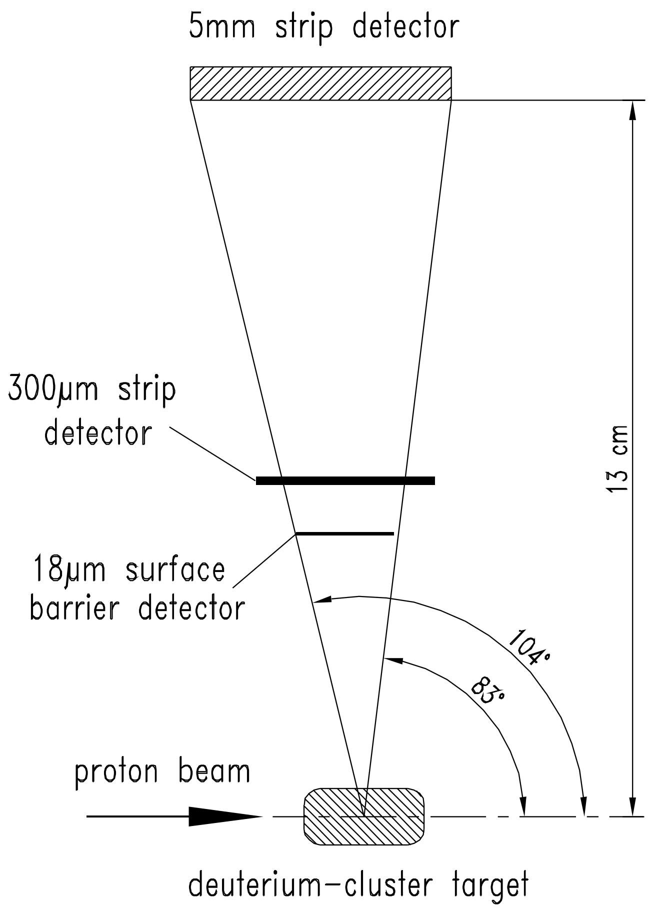
e.g: M = η

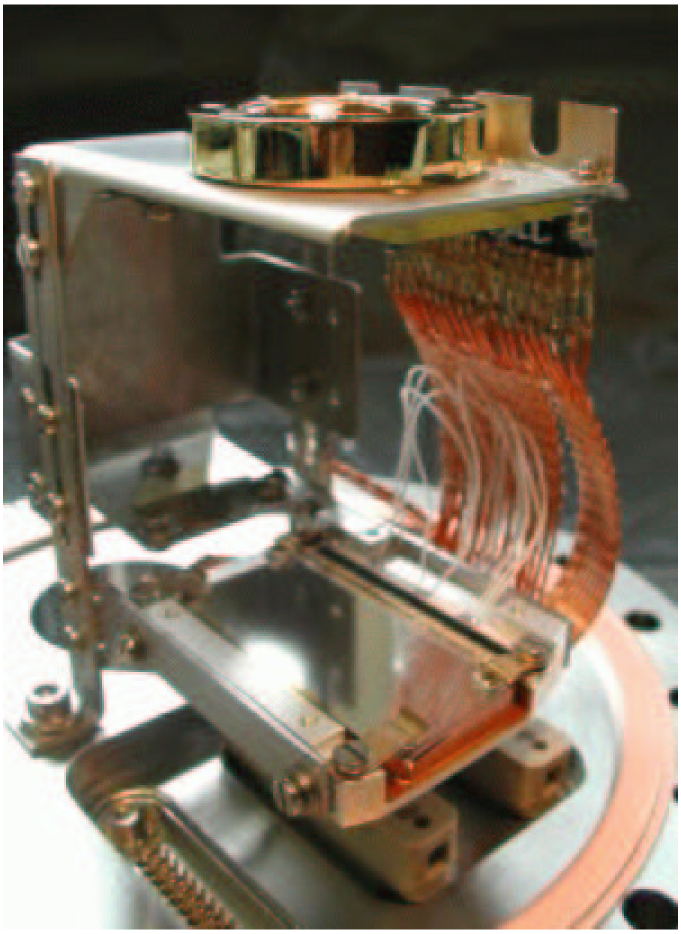
Calen et al. Phys. Rev. C. 58, 2667 (1998)



session on
pn-induced reactions
talks by: Vadim Baru
Jerzy Smyrski

Spectator-proton detection @Anke





Talks: I. Lehmann pn → d ω

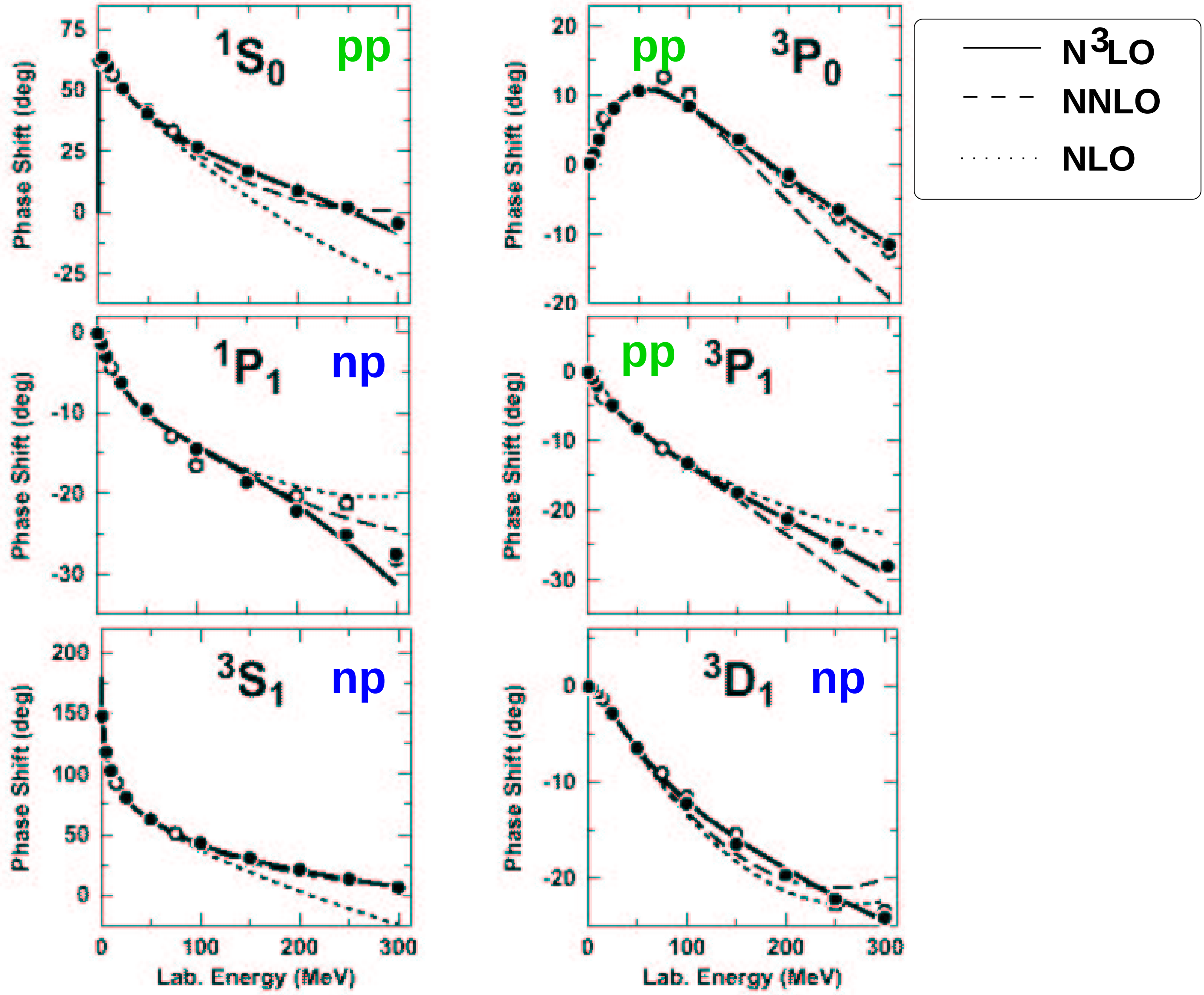
R. Schleichert

F. Rathmann

→ **Session on pn-induced reactions**

chiral perturbation theory

Entem &Machleidt nucl-th 0304018



Bin (MeV)	# of data	N^{3}LO	NNLO	NLO	AV18
0–290	2402	1.10	10.1	36.2	1.04

np

Bin (MeV)	# of data	N^{3}LO	NNLO	NLO	AV18
0–290	2057	1.50	35.4	80.1	1.38

pp

E. Epelbaum *et al.*, Eur. Phys. J. **A15**, 543 (2002).
R. B. Wiringa *et al.*, Phys. Rev. C **51**, 38 (1995).

Status of Theory

Low Energy 0-300 (500) MeV

- phenomenological potentials
- meson exchange (e.g. Bonn,Paris) **80s**
- effective field theory (χPT) **> 1990**

? **COSY-Energies 0.5 -2.5 GeV** ?

inelastic channels
resonances
short-range

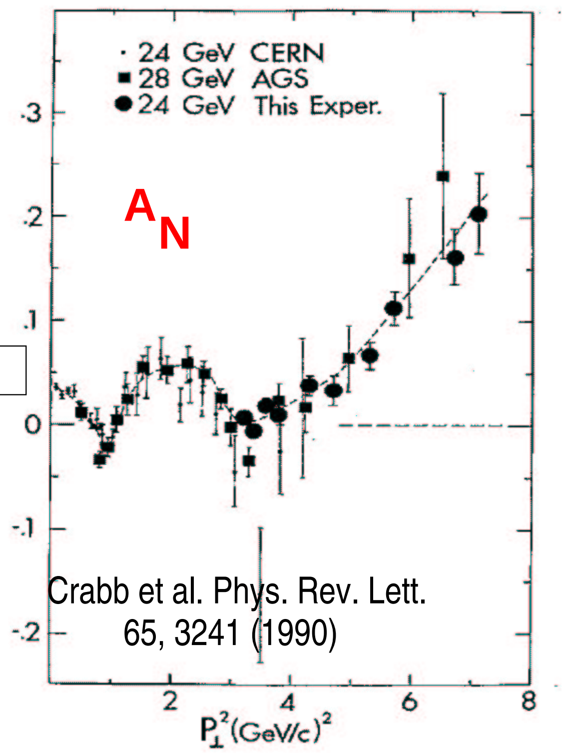
High Energy >> 10 GeV

- Regge-theory
- pQCD (s,t ⟶ ∞)

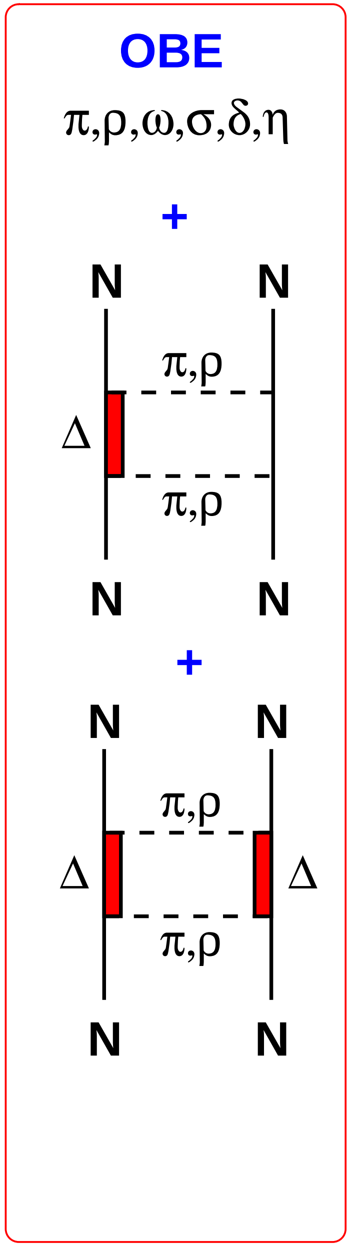
$$d\sigma/dt \propto F(\theta)/s^{10}$$

$$\phi_5 = <++|T|+-> = 0$$

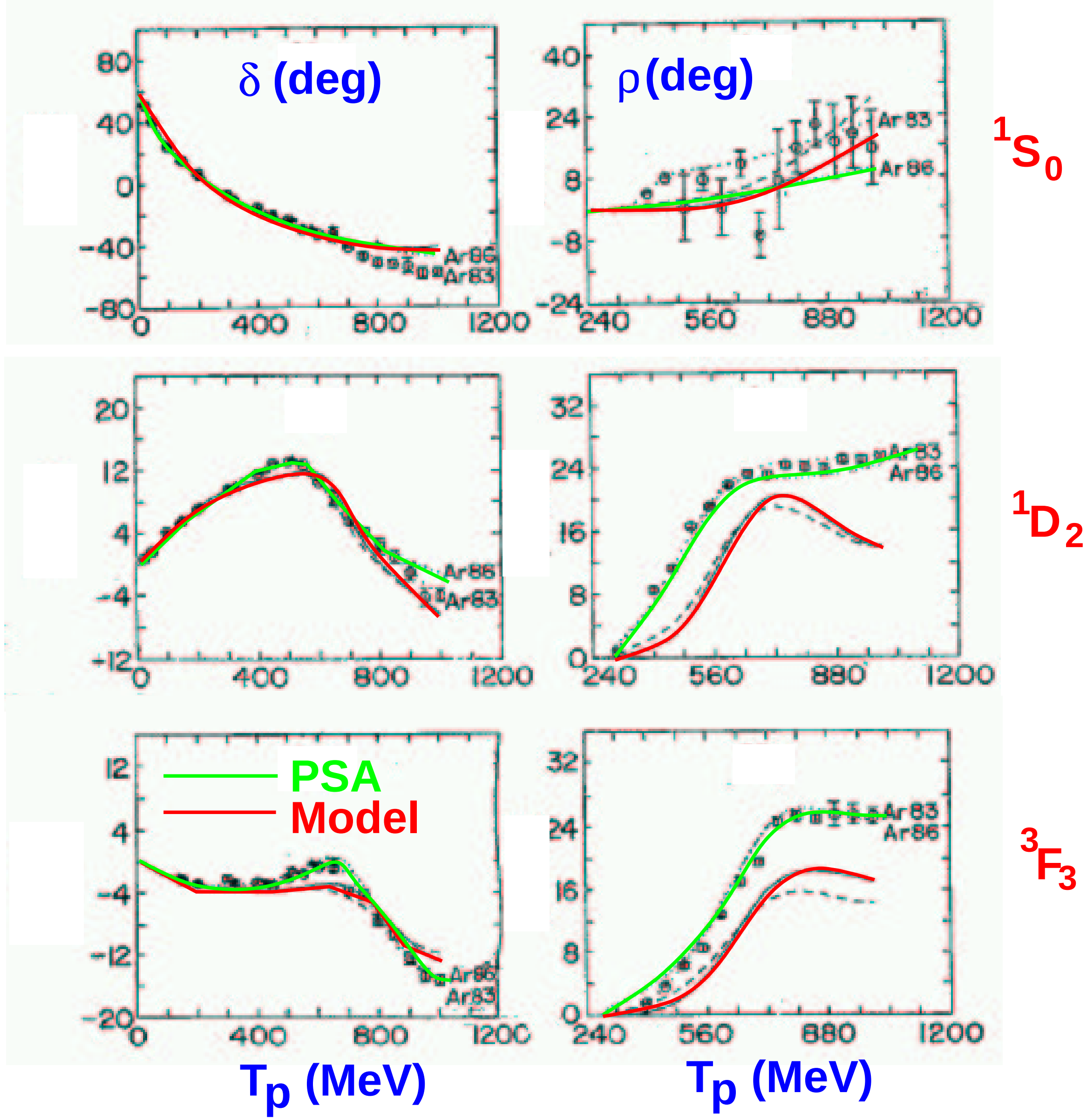
⇒ $A_N = 0$



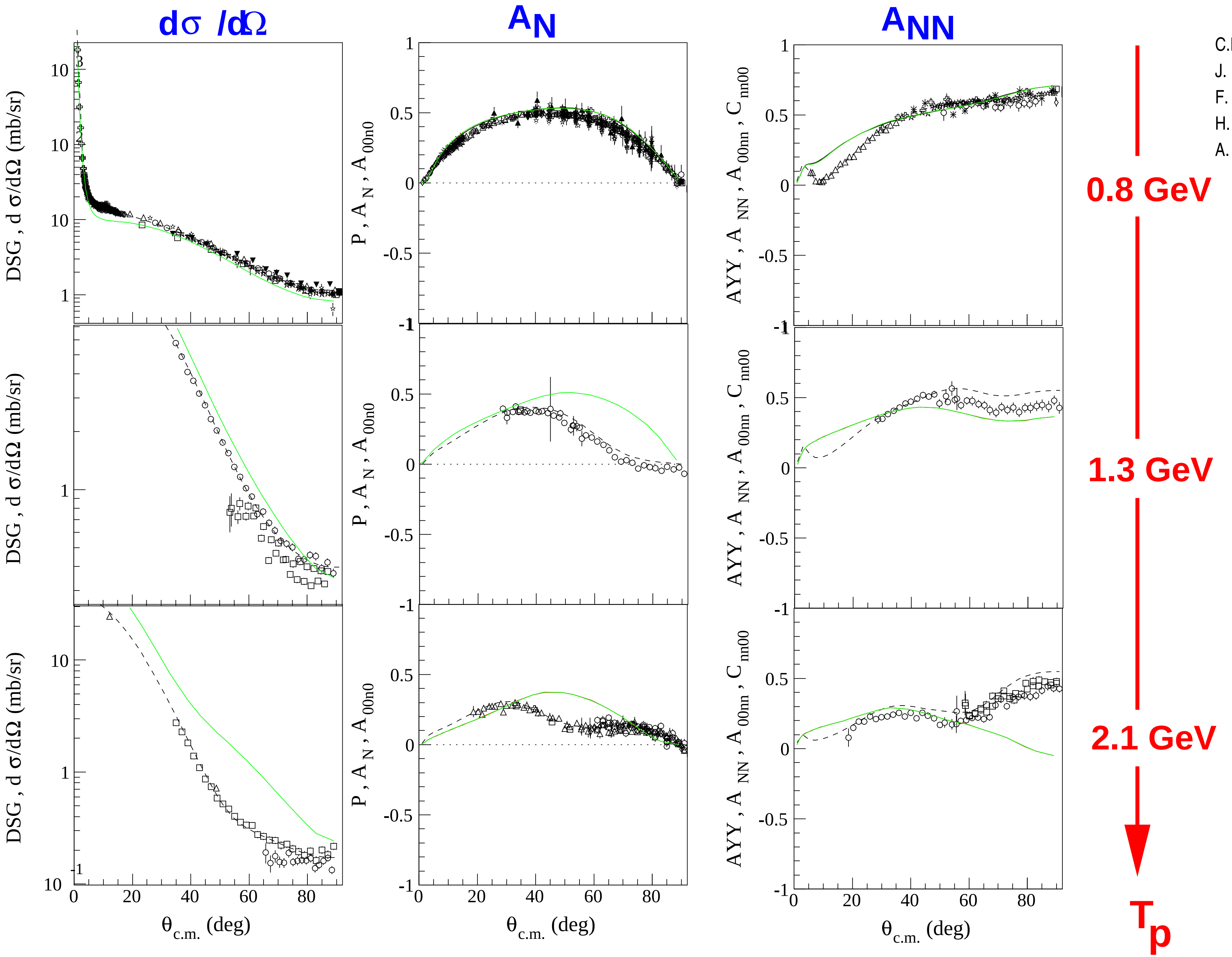
Meson Exchange Model



Elster/Holinde/Schütte/Machleidt Phys.Rev.C38, 1828 (1988)



C.Elster
J. Haidenbauer
F. Hinterberger
H. Rohdjess
A. Sibirtsev



Conclusion

- **Status of exp. data / PSA**
  - **pp : up to 1.2 GeV** ✓ **2.5 GeV** (✓)
  - **np : up to 1.1 GeV** ✓
- **Dibaryons? (T=1, S=0)**
  - ~~**strong coupling to NN**~~
- **Theory**
  - **Effort needed for T > 1GeV**
- **What can be done at COSY?**
  - **pp: triple-spin observables**
  - **polarized np for T > 1.1 GeV**