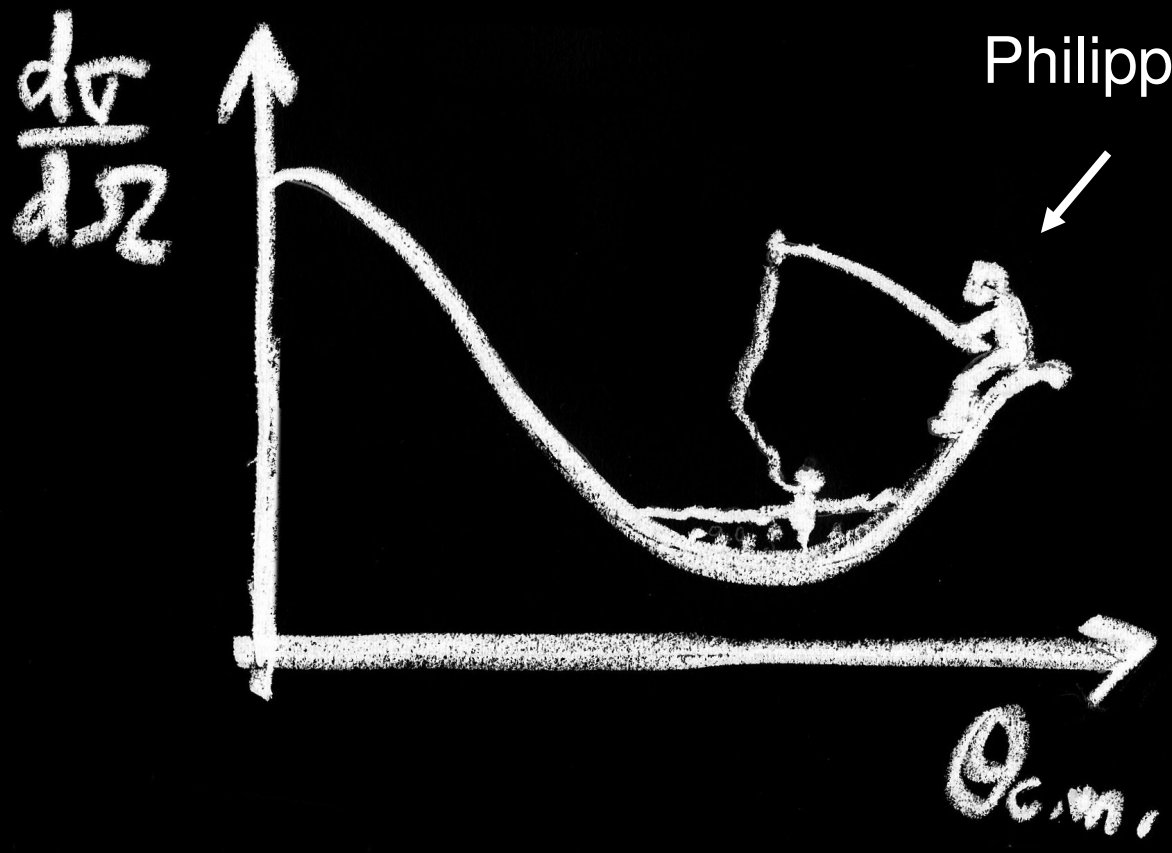
Three-body forces in neutron-deuteron scattering

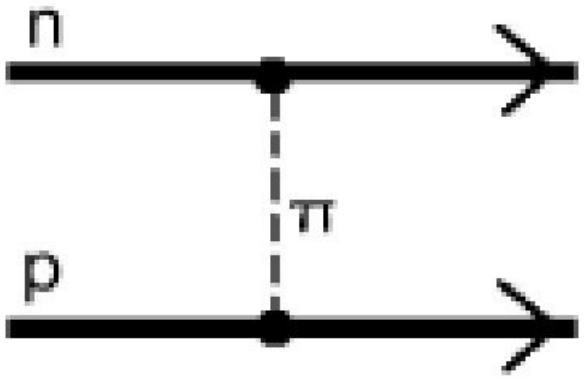


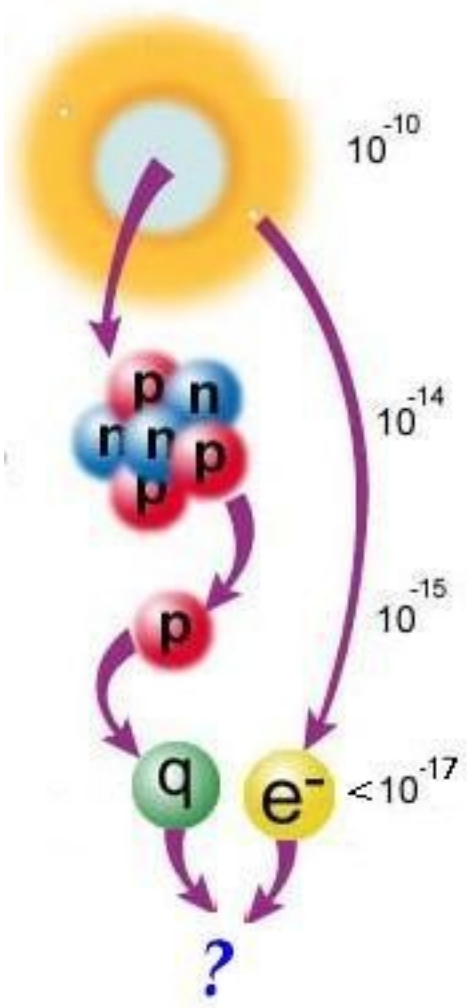
Philippe Mermod

Particle physics seminar, October 2007

Physics regime

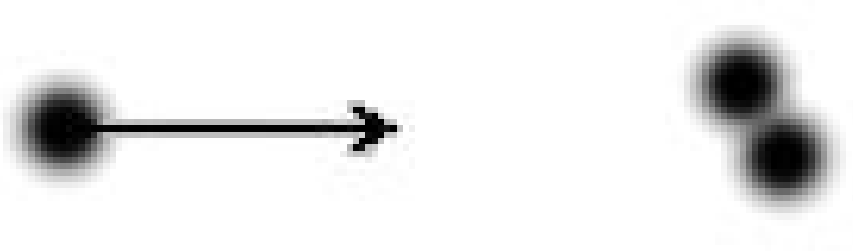
- Intermediate energies
- Nuclear forces
  - meson-exchange picture
  - effective “fundamental” theories



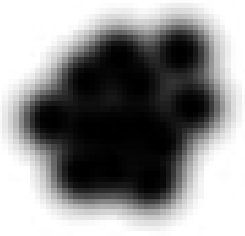


Motivations

- Advances in nuclear physics
  - New, high-accuracy NN potentials (CDBonn, AV18)
  - Exact calculations in 3N systems (Faddeev equations)
  - Time is ripe to explore **three-body nuclear forces**

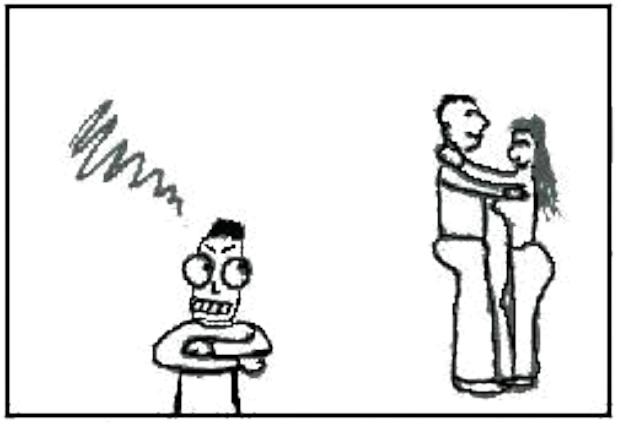


- *Ab initio* calculations
  - Consistent description of nuclear phenomena
  - Now possible for light nuclei up to carbon

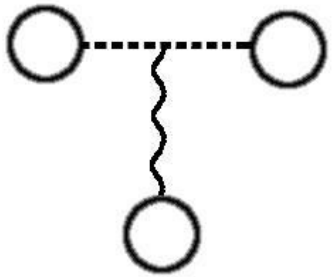


Three-body forces

- Expected in most fundamental interactions: strong, gravitational, human…



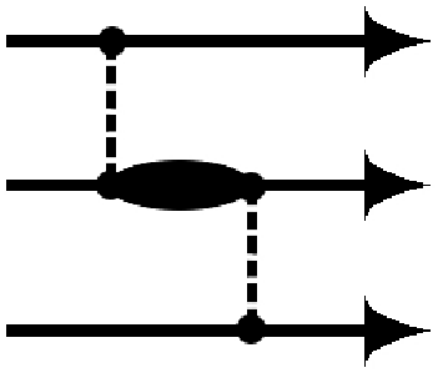
- Basic mechanism: an interaction with the interaction

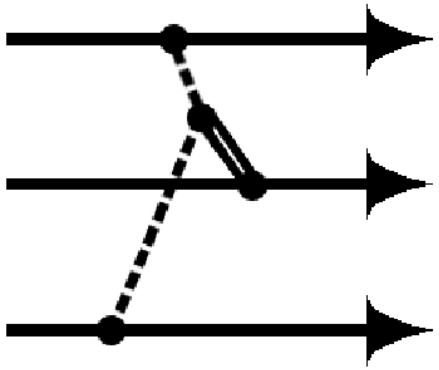


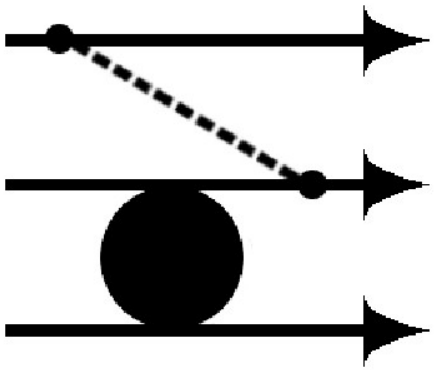
- Play often a negligible role compared to pairwise forces

Main types of three-nucleon forces

- Two-pion exchange
- Scalar/vector exchange
- In-flight correlation

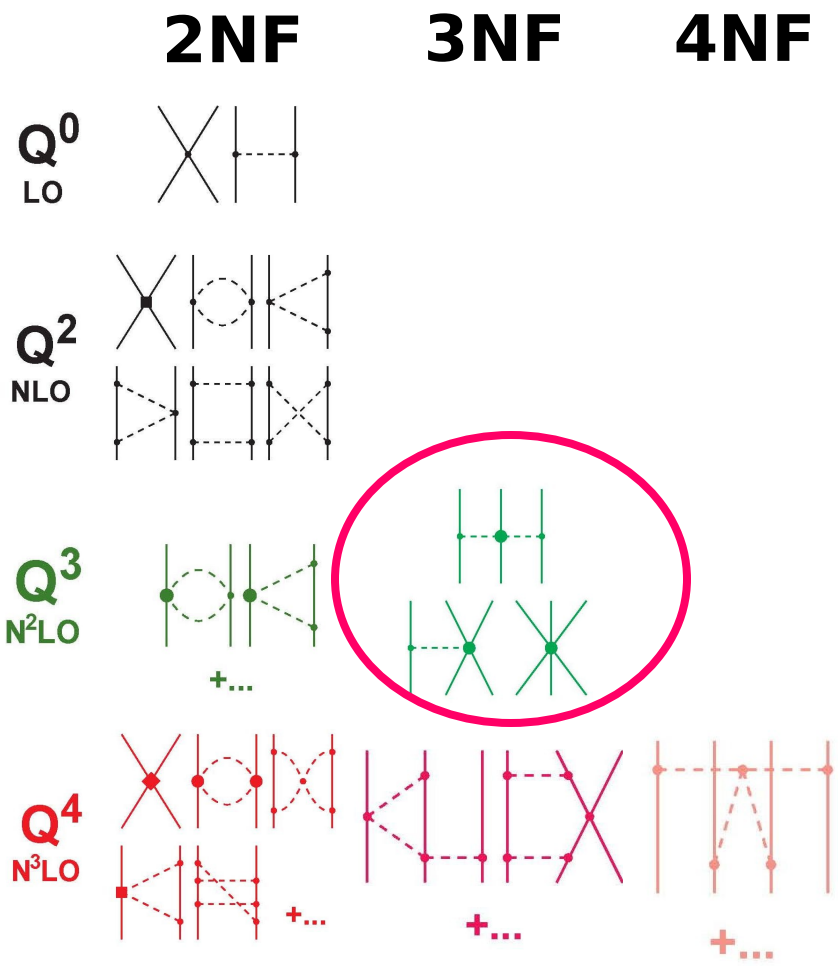






Chiral effective field theory

- Lagrangian consistent with the symmetries of QCD
- Perturbation techniques
- πN + NN contact terms
- 2NF, 3NF, ... are derived in a consistent way
- Hierarchy :
  2NF > 3NF > 4NF
- The first 3NF appears at NNLO

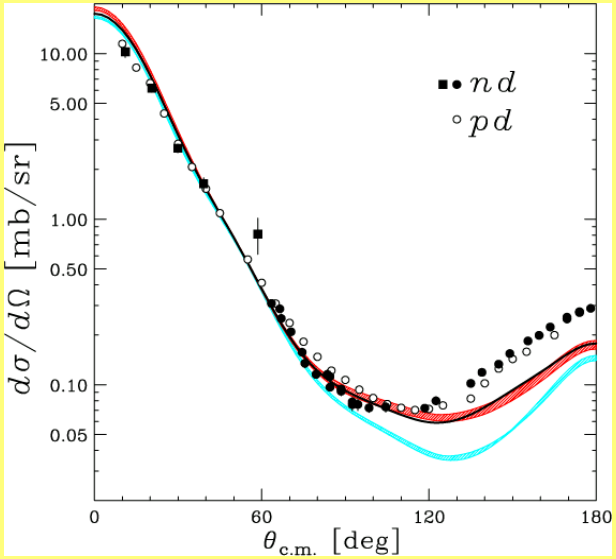


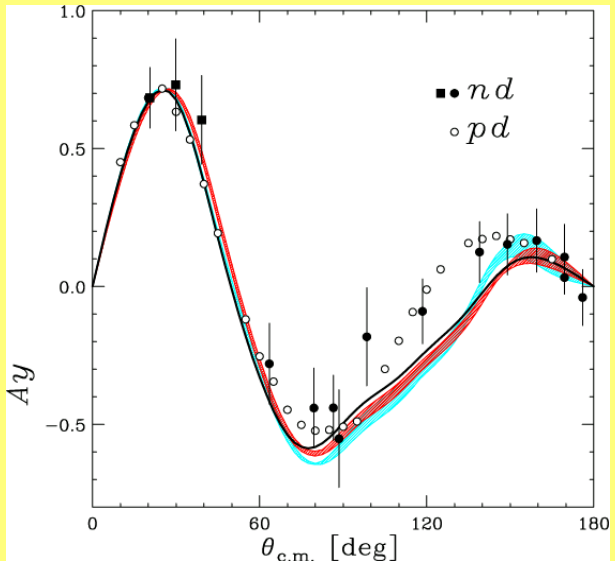
Three-nucleon force observables

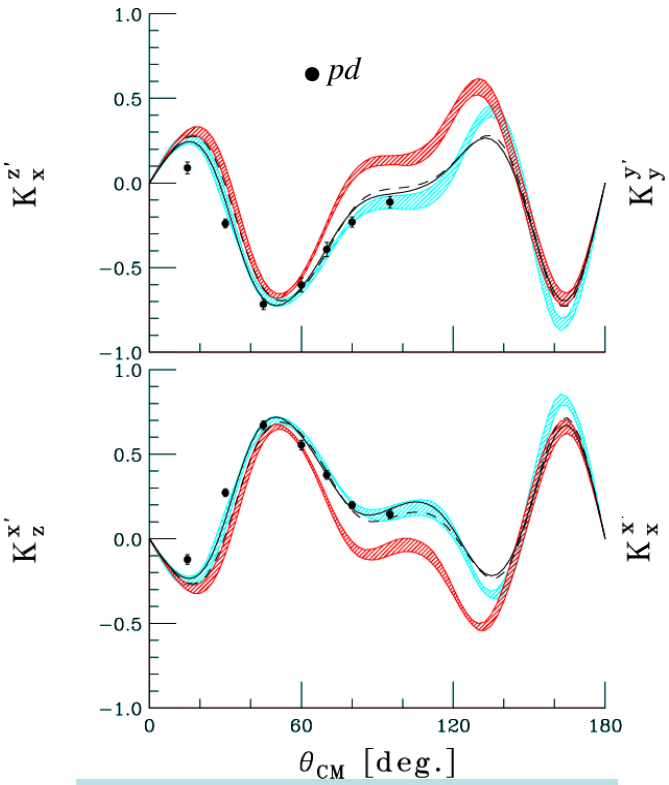
- The triton binding energy
  - 3.5 % discrepancy to pairwise forces only
  - Fix the strength of 3N forces
- Nucleon-deuteron scattering
  - Scattering length
  - Deuteron breakup
  - Spin observables
  - **Elastic scattering angular distribution at intermediate energies**

Nd elastic scattering at 250 MeV

- *pd* (K. Hatanaka *et.al*, PRC**66**(2002)044002) & *nd* (Y. Maeda *et al.*, PRC7**6**(2007)014004)

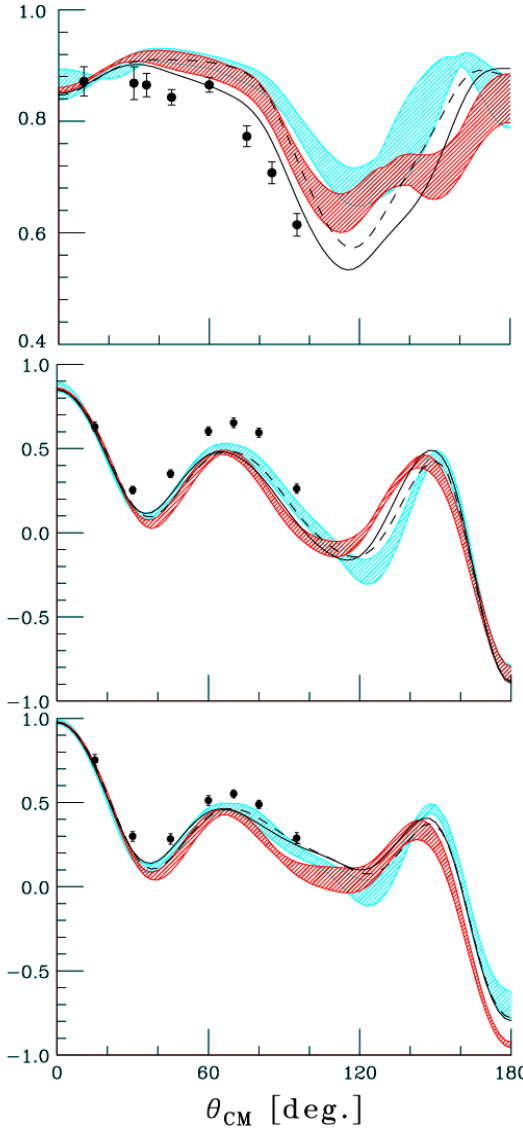






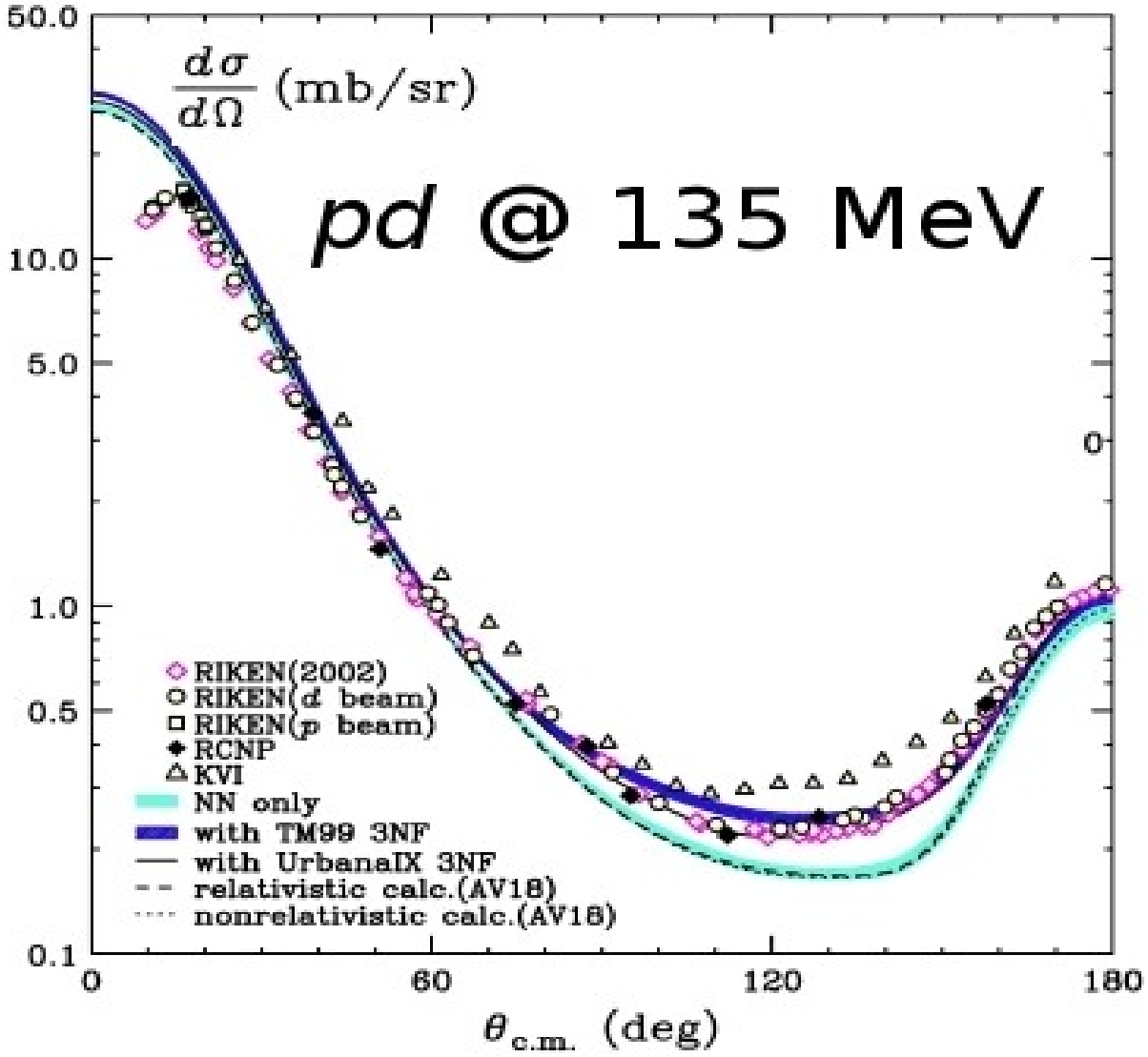
: *NN* only
: *NN* with TM-3NF
: AV18+UrbanaIX-3NF
: CD-Bonn+TM'-3NF

Calculations by H. Kamada



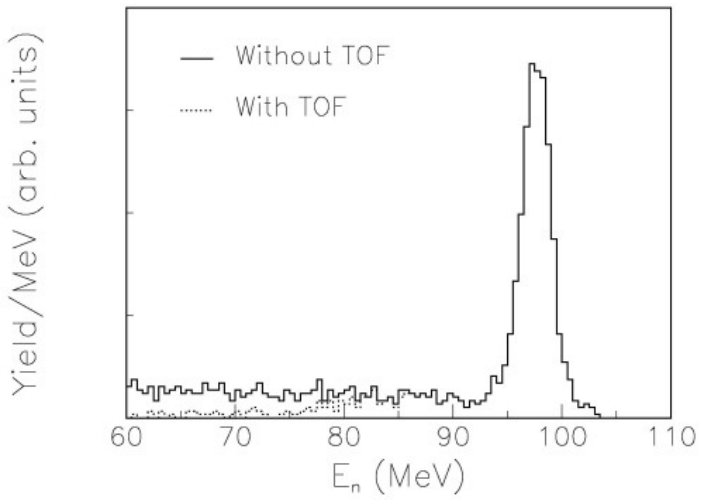
The 100 MeV region

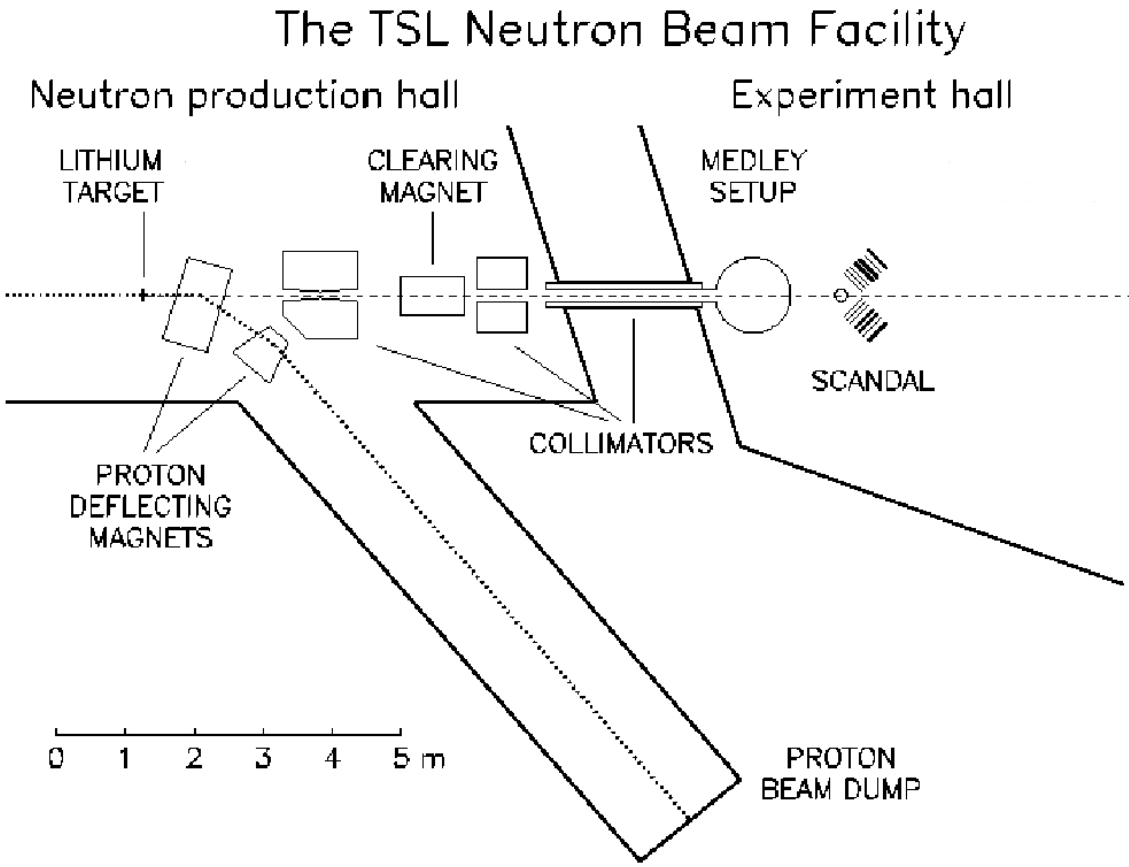
K. Sekiguchi *et al.*, Phys. Rev. Lett. 95, 162301 (2005)



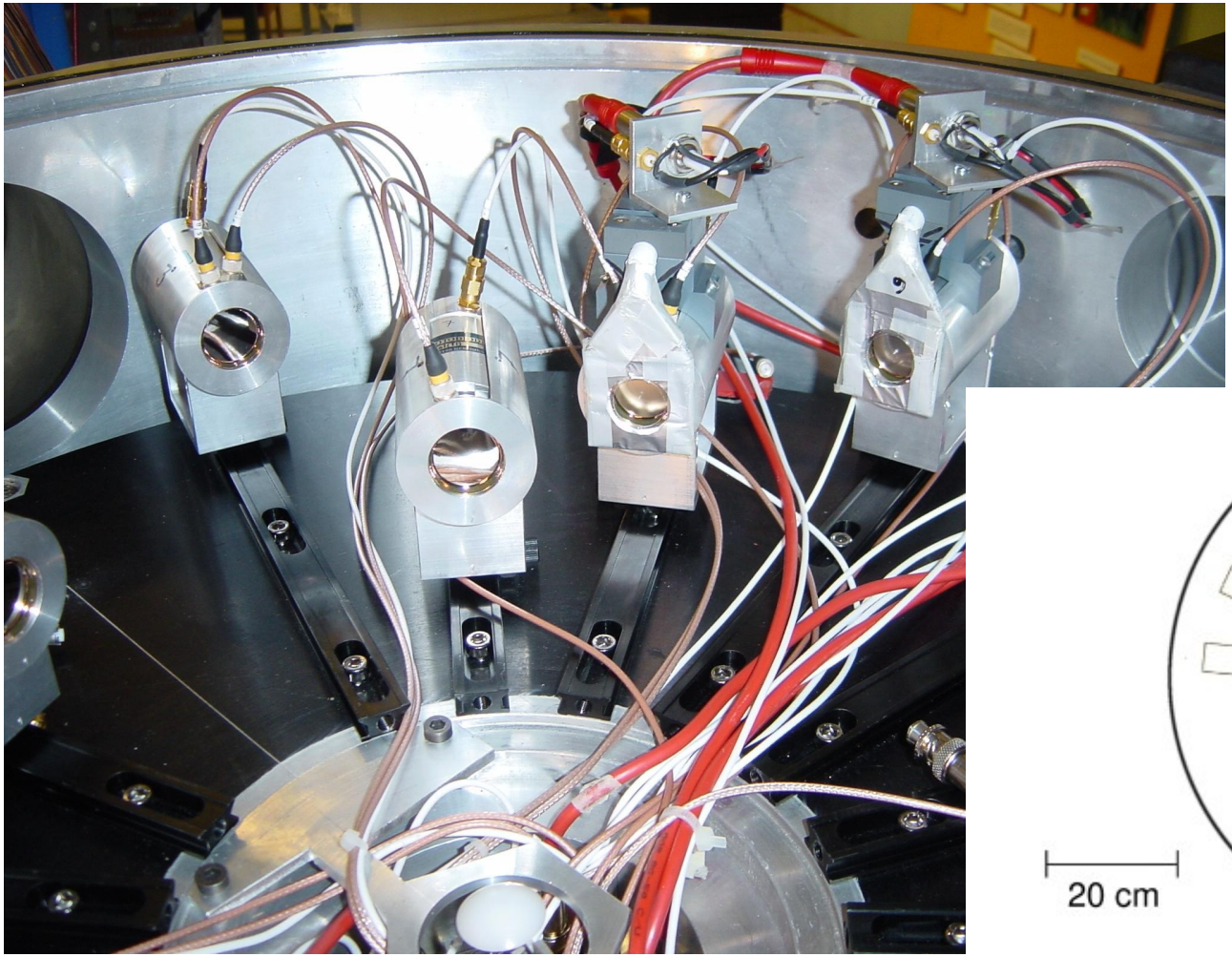
- No significant relativistic effects
- Coulomb effects in pd
- **nd @ 95 MeV** measured in Uppsala

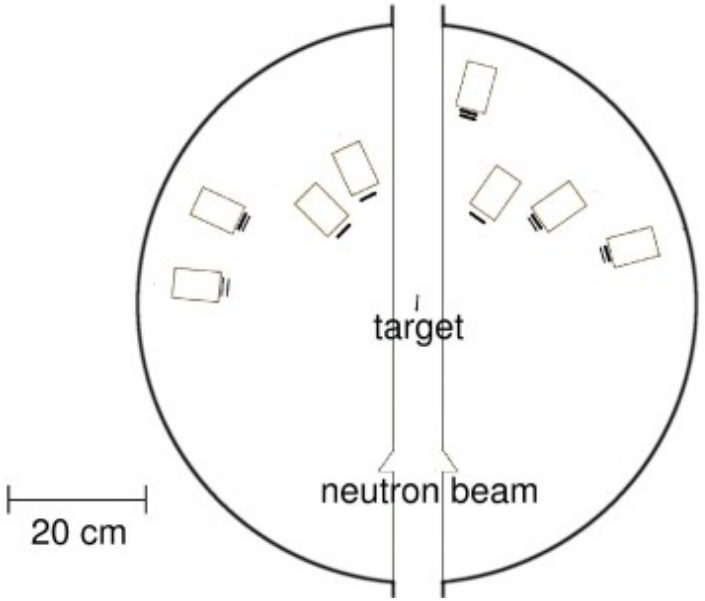
TSL neutron beam: 95 MeV



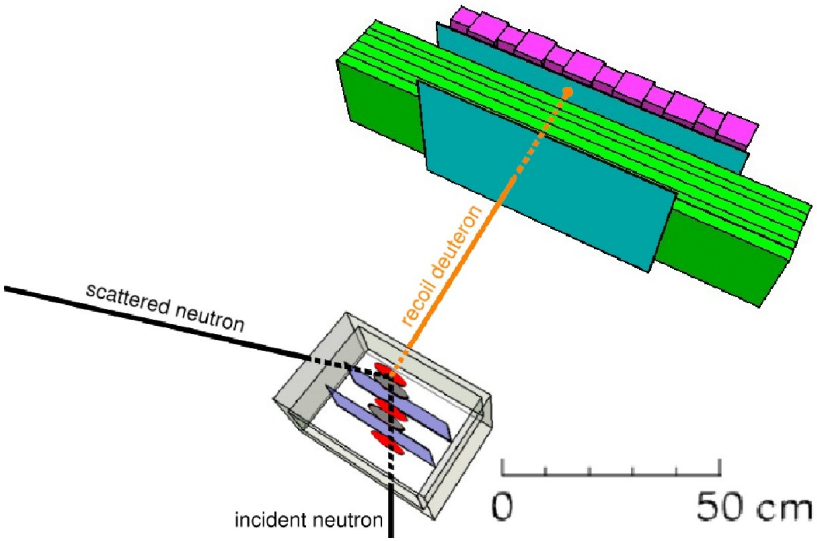


The MEDLEY setup

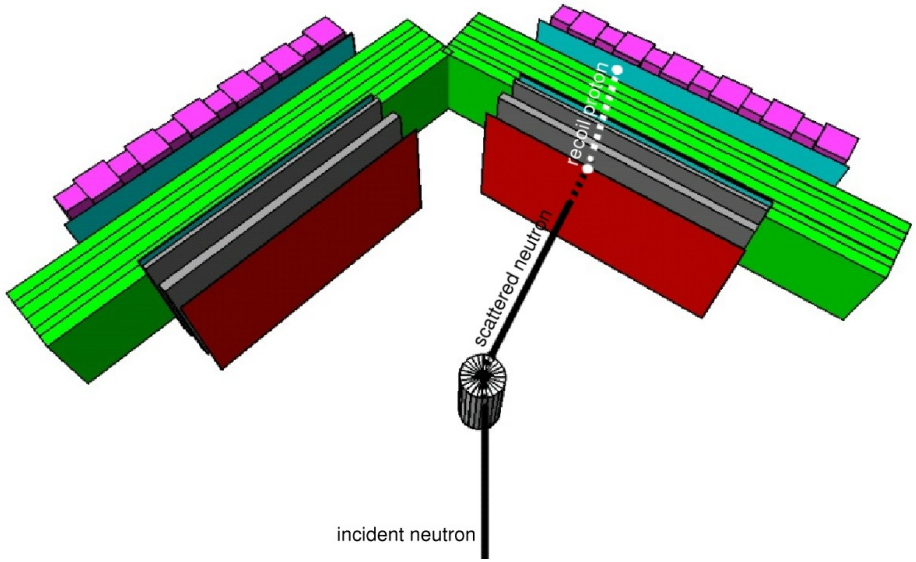




The SCANDAL setup



… in **deuteron** detection mode…



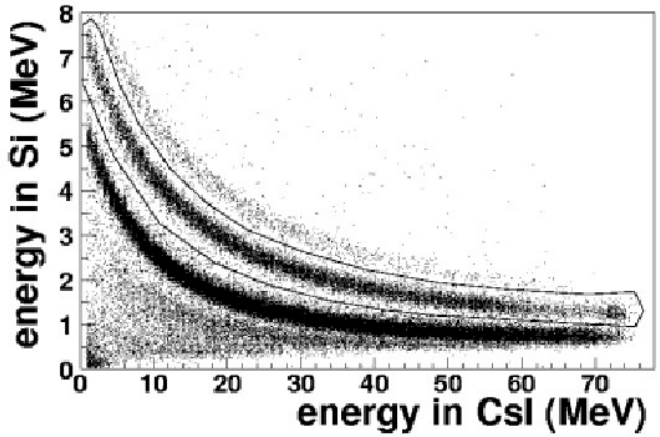
… or in **neutron** detection mode.

The three *nd* experiments

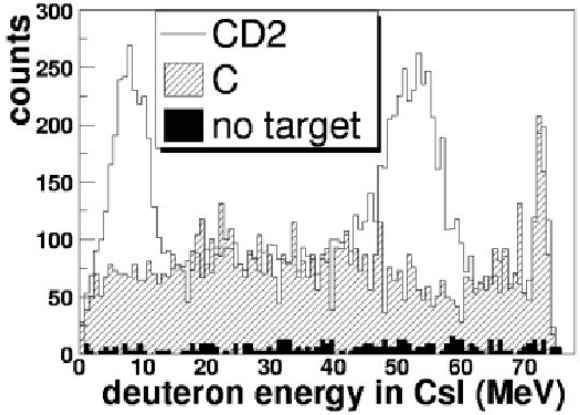
Detect **deuterons** with MEDLEY	Detect **deuterons** with SCANDAL	Detect **neutrons** with SCANDAL
CD_2, CH_2 and C thin sheets	CD_2, CH_2 and C thicker sheets	D_2O, H_20 and C cylinders
whole angular distribution	backward angles (minimum region)	forward angles
Normalization: *np* scattering	Normalization: *np* scattering	Normalization: C(n,n)
losses at large angles	MTGT efficiency	deuteron break-up

Data analysis (deuteron mode)

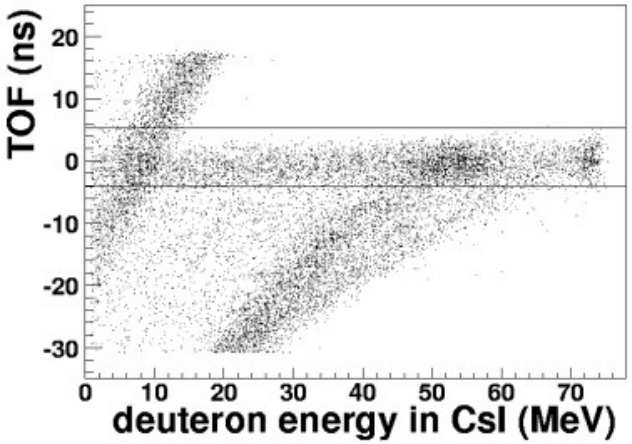
- Particle identification



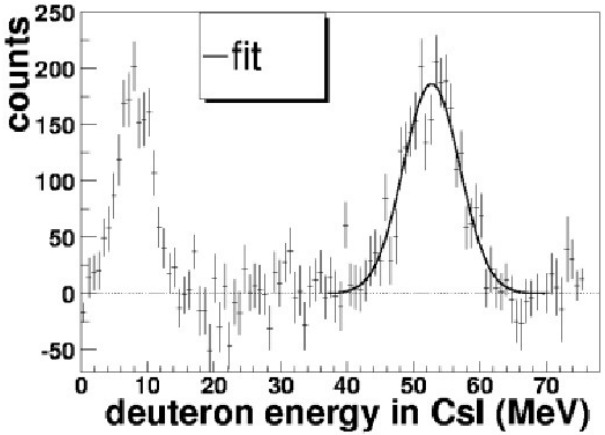
- Carbon Background



- Time-of-flight

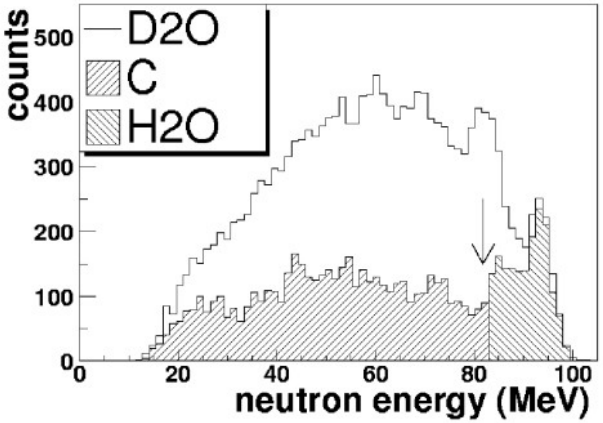


- Elastic peak

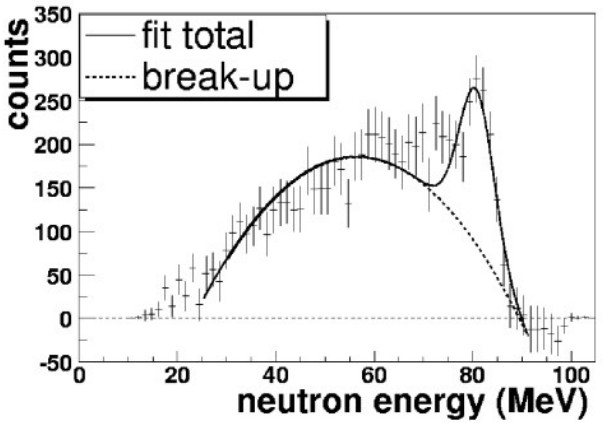


Data analysis (neutron mode)

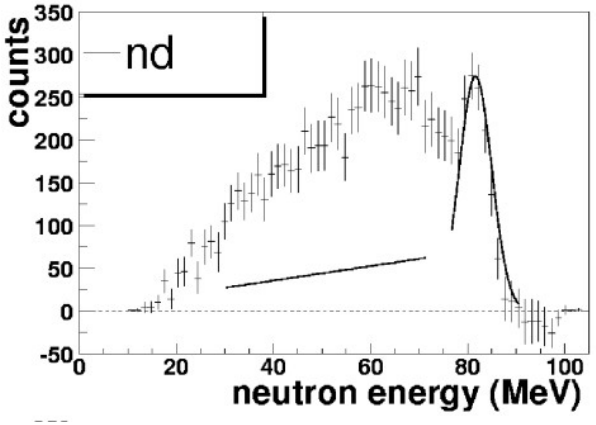
- Oxygen background



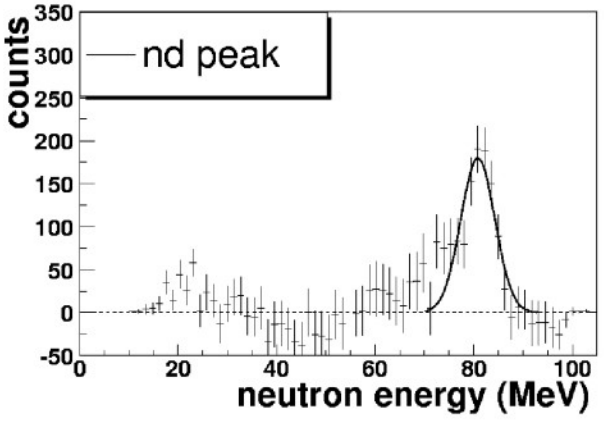
- Deuteron break-up



- Conversion in Carbon



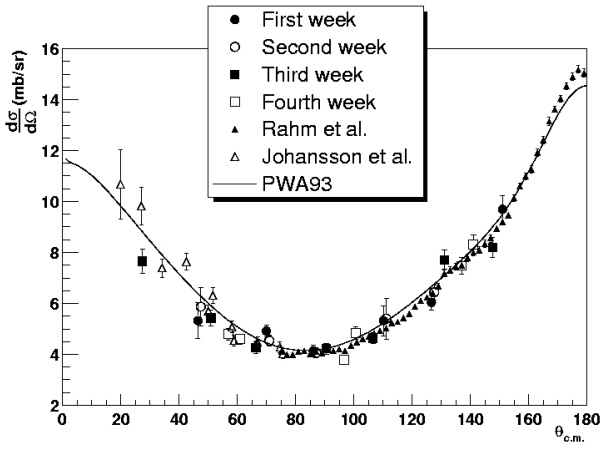
- Elastic peak



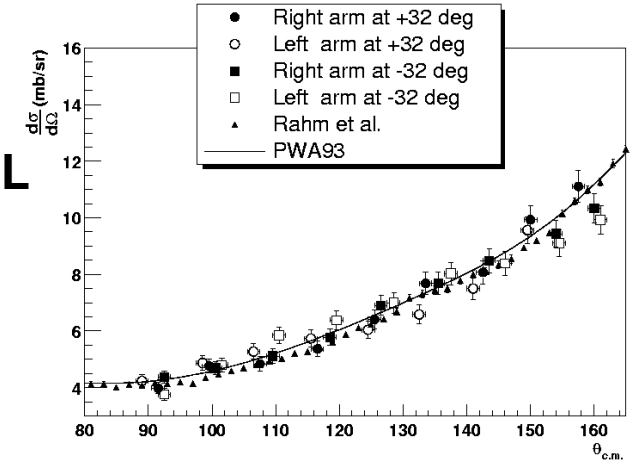
Normalization

- In **deuteron** mode: versus *np* scattering

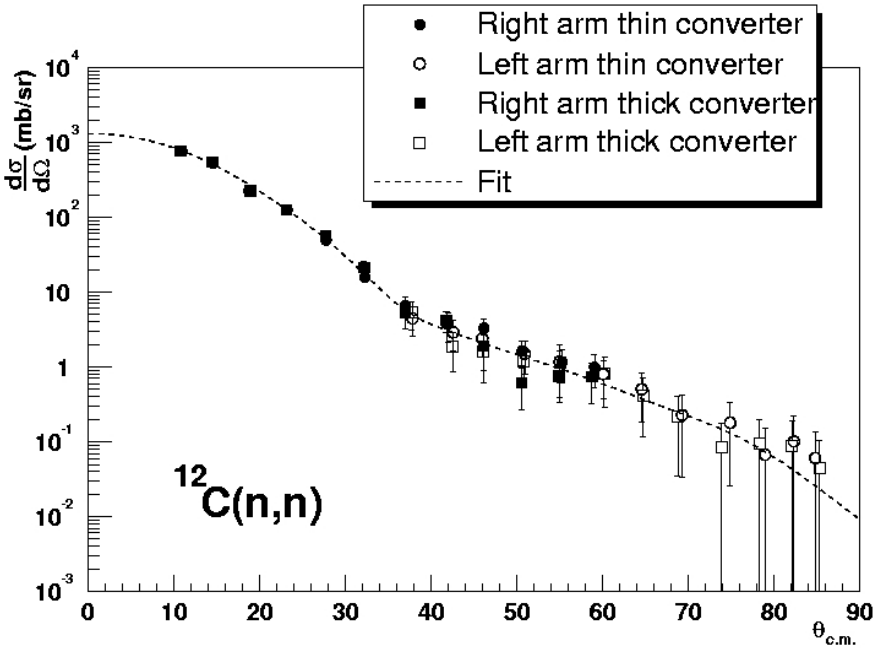
MEDLEY



SCANDAL

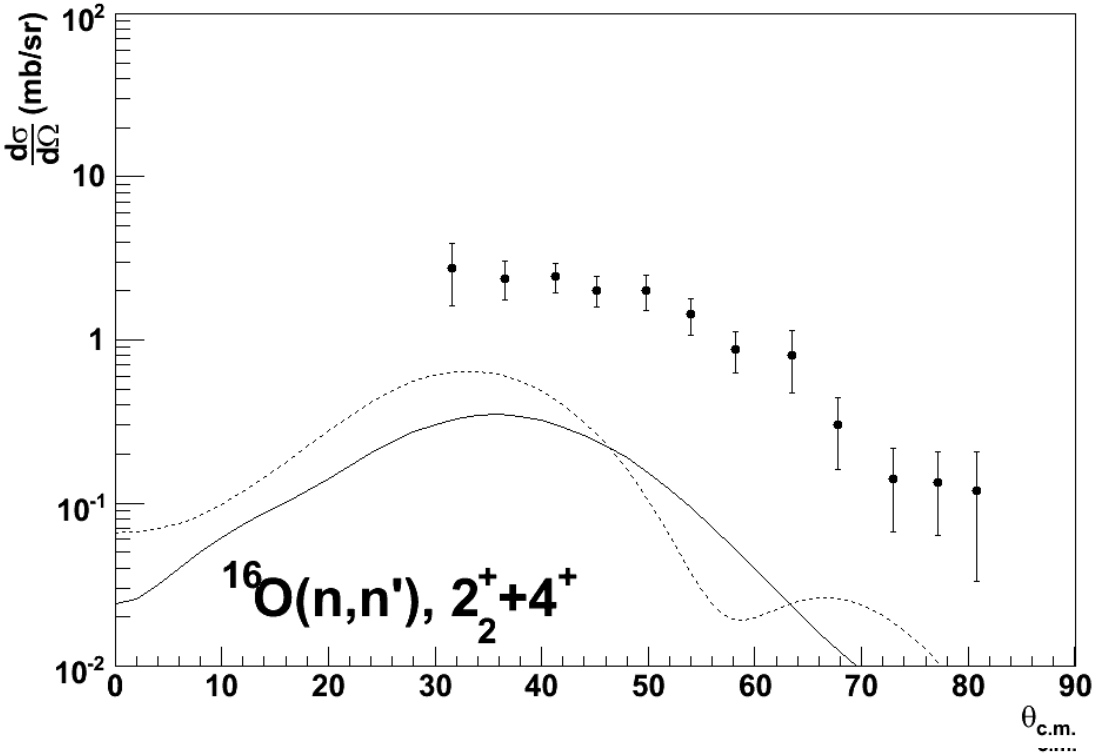


- In **neutron** mode: versus the total elastic scattering cross section on carbon



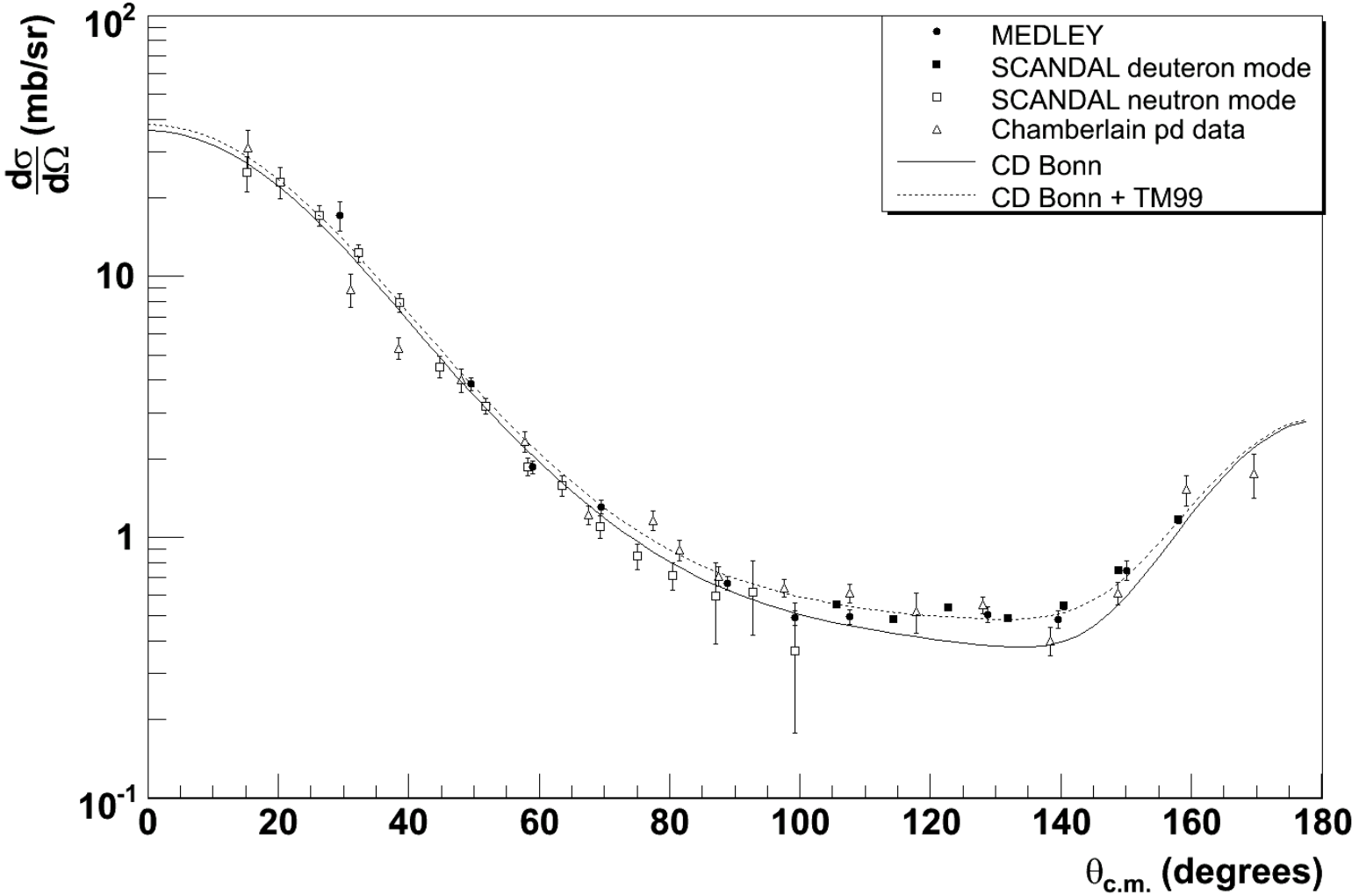
Spin-off effects: carbon and oxygen

- Elastic and inelastic scattering
  - ✓ New data at 95 MeV

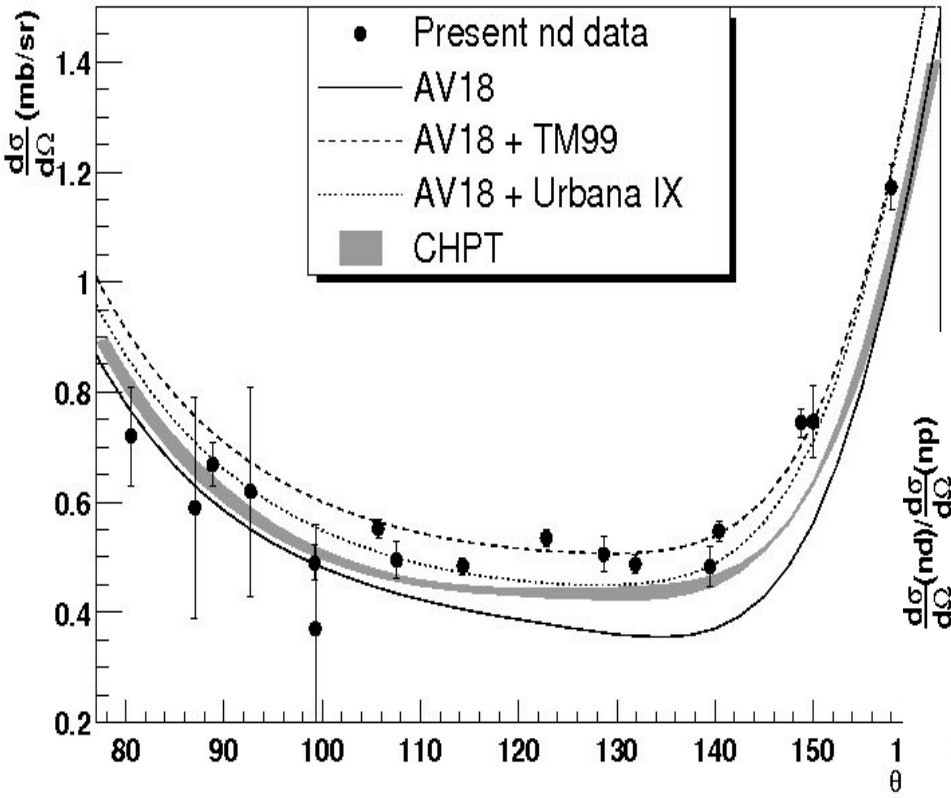


- Applications
  - ✓ Transmutation of nuclear waste
  - ✓ Fast neutron cancer treatment
  - ✓ Single-event effects in electronics

Results for *nd* scattering

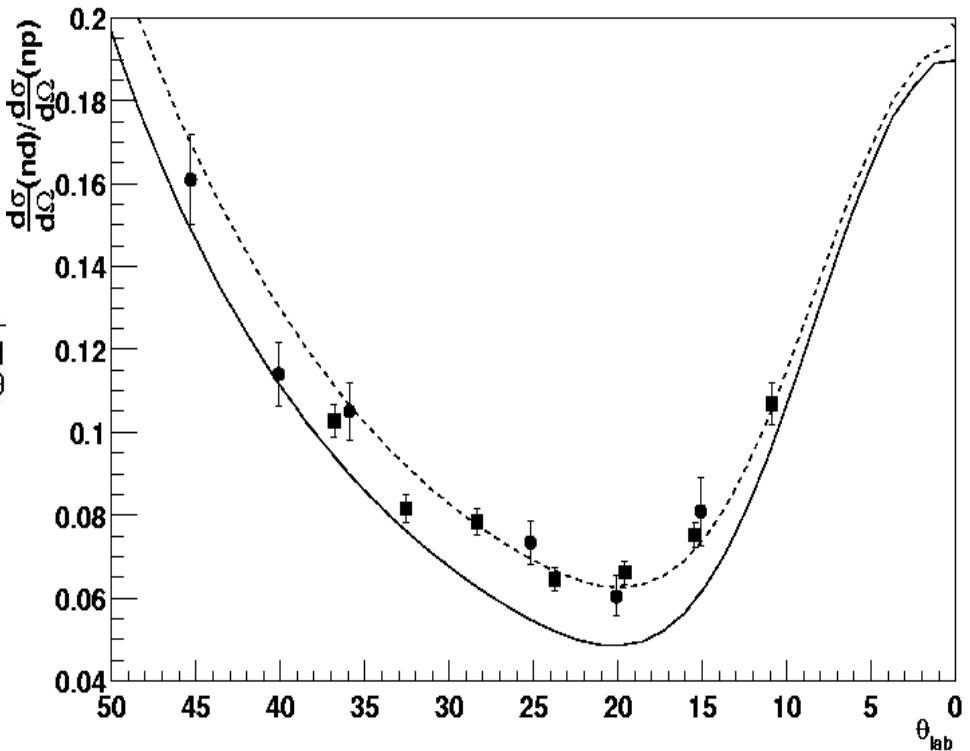


In the minimum



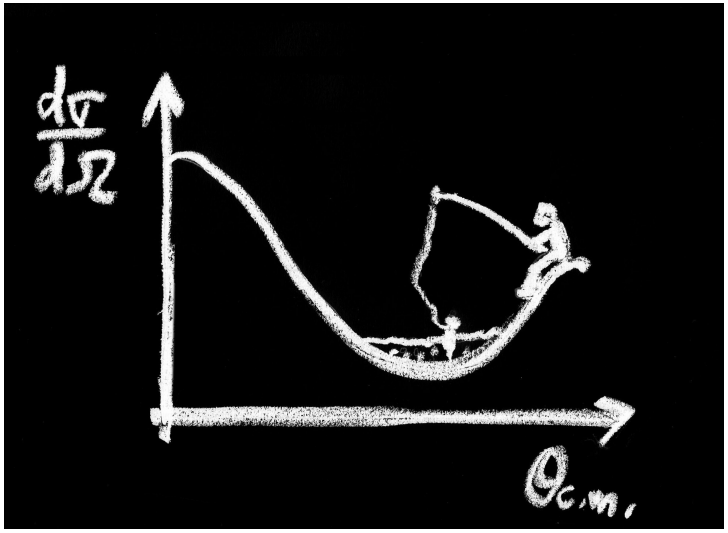
χ^2 (diff. cross sect.)

NN potential	Without 3*N*	TM99 [9]	Urbana IX [11]
AV18 [2]	25	2.3	3.5
CD Bonn (1996) [3]	21	2.1	–
CD Bonn (2001) [4]	18	2.2	–
Nijm1 [5]	21	3.2	–
Nijm2 [5]	25	2.4	–



Summary

- Nucleon-deuteron scattering around 100 MeV provides signatures of *3N* forces
- Differential cross sections are well reproduced when introducing *3N* forces
- The detailed structure of the *3N* forces is still not well understood
  - Polarized beams
  - Breakup
  - Refine 3N potentials
  - CHPT



We've caught a *3N* fish!