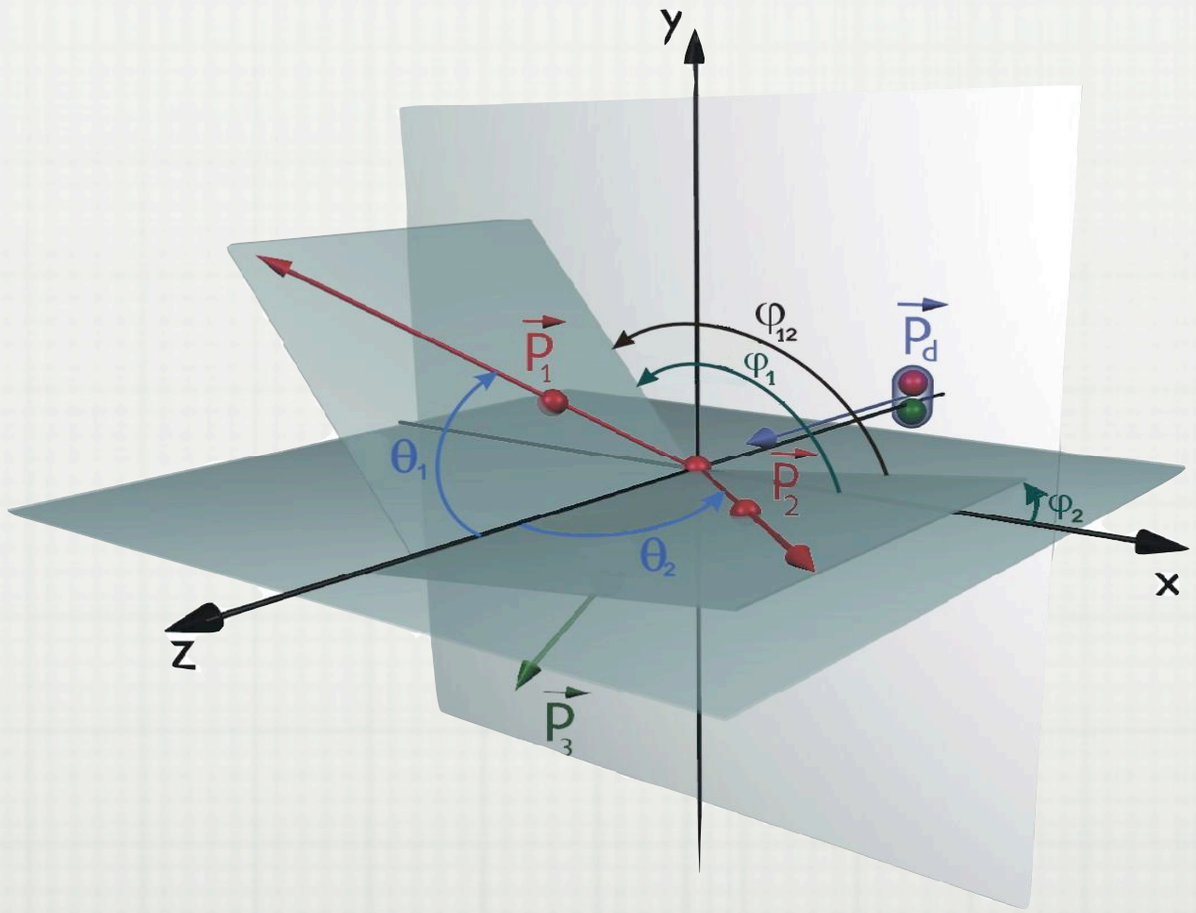
FEW-NUCLEON SCATTERING EXPERIMENTS



KVI

university of groningen

JOHAN MESSCHENDORP,

CD2009, JULY '09, BERN

FEW-NUCLEON SCATTERING?

ONE, TWO, ... A FEW!

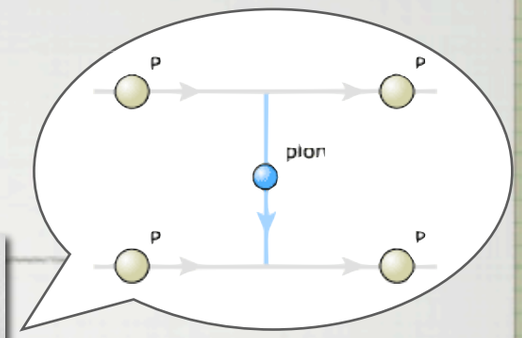
THIS TALK?

AT INTERMEDIATE ENERGIES: 50-200 MEV/NUCLEON

TWO-NUCLEON SYSTEMS

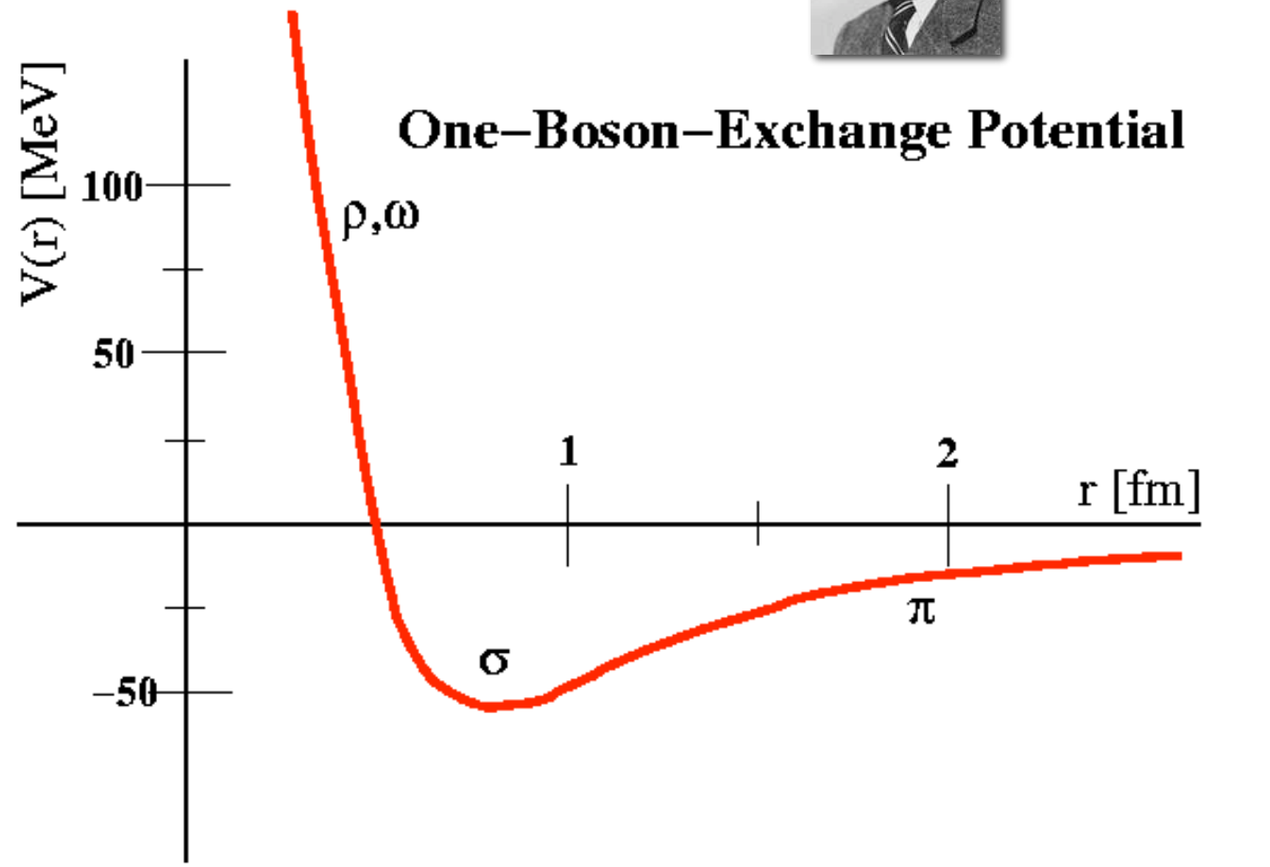
"PRECISION, SYSTEMATICS, AND PWAS"

TWO-NUCLEON POTENTIAL



Modern phenomenological NN potentials:

- Nijmegen I
- Nijmegen II
- Reid 93
- CD-Bonn
- Argonne V18
- ...



Comparison with experimental np&pp database gives:
χ^2/data ~ 1

TWO-NUCLEON POTENTIAL

NN INTERACTION

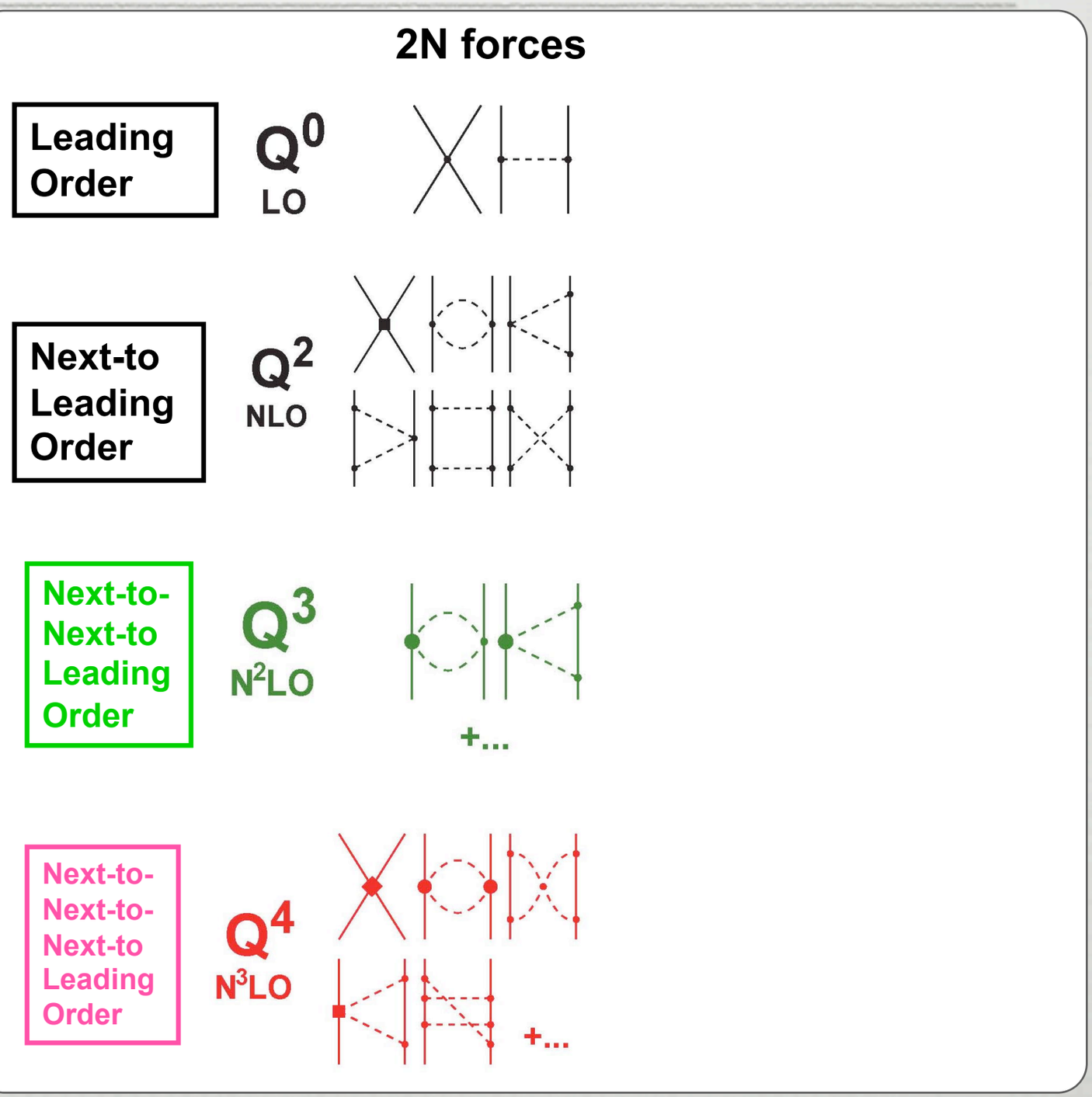
BASED ON CHPT

TWO-NUCLEON POTENTIAL

NN INTERACTION BASED ON CHPT

- DEVELOPED BY WEINBERG
- COUPLING OF PIONS AND NUCLEONS IN EFT
- A FUNDAMENTAL APPROACH: LOW-ENERGY QCD
- SELF-CONSISTENT APPROACH
- (ONLY) WORKS AT RELATIVELY LOW ENERGIES

Epelbaum and others...
Idaho/Bochum-Juelich

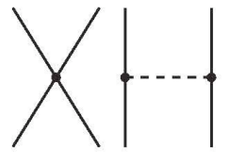
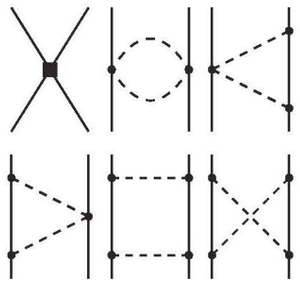
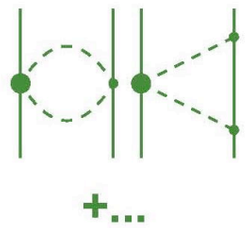
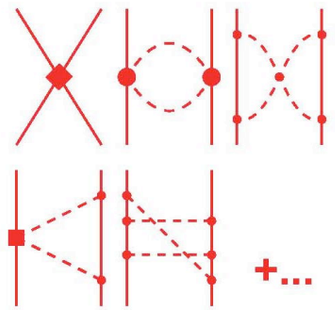


TWO-NUCLEON POTENTIAL

NN INTERACTION BASED ON CHPT

- DEVELOPED BY WEINBERG
- COUPLING OF PIONS AND NUCLEONS IN EFT
- A FUNDAMENTAL APPROACH: LOW-ENERGY QCD
- SELF-CONSISTENT APPROACH
- (ONLY) WORKS AT RELATIVELY LOW ENERGIES

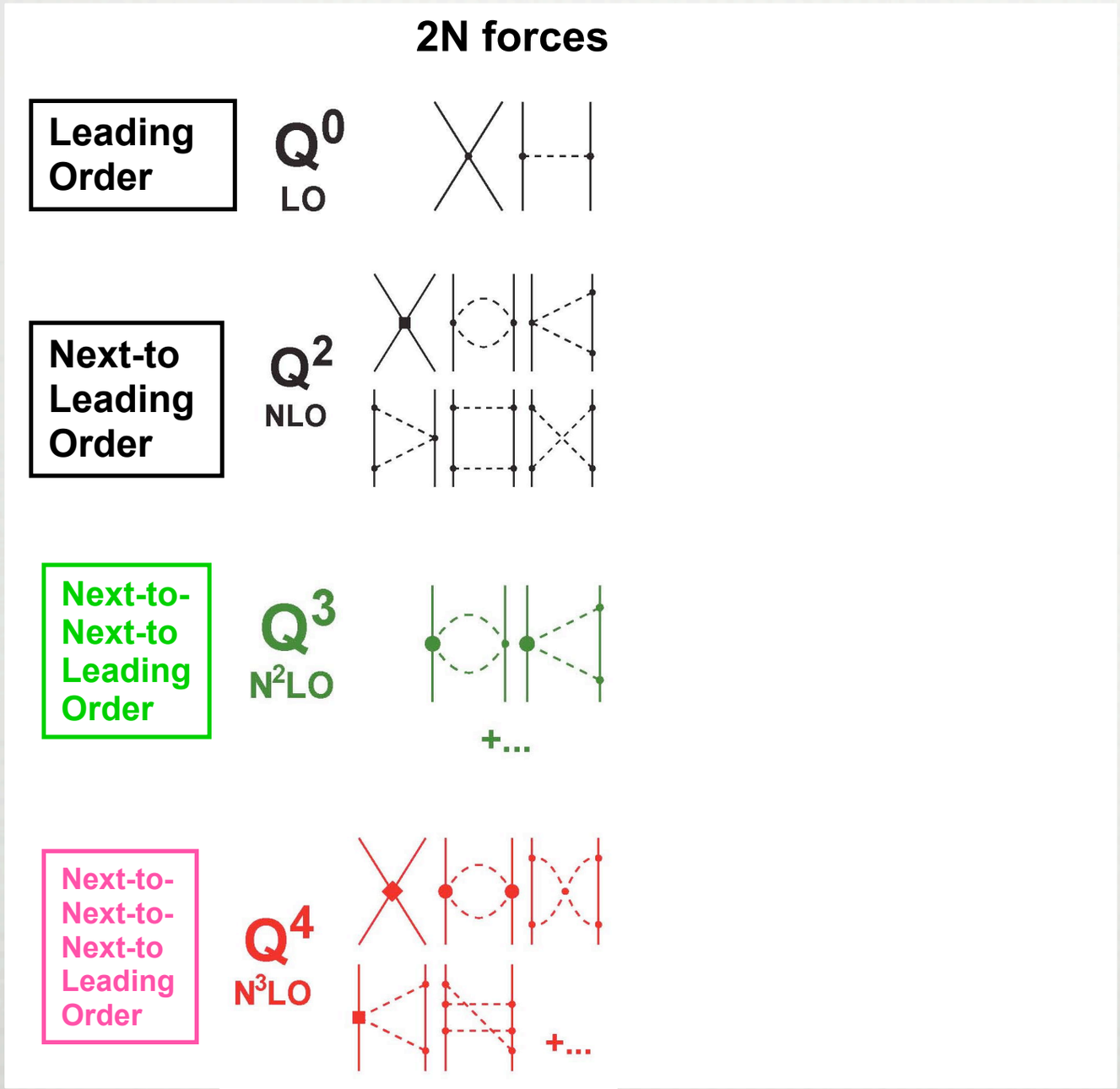
Epelbaum and others...
Idaho/Bochum-Juelich

		2N forces	χ^2/datum (0-200 MeV)
Leading Order	Q^0 LO		
Next-to Leading Order	Q^2 NLO		~ 100
Next-to-Next-to Leading Order	Q^3 N^2LO	 +...	~ 10
Next-to-Next-to-Next-to Leading Order	Q^4 N^3LO	 +...	~ 1 (24 PARS)

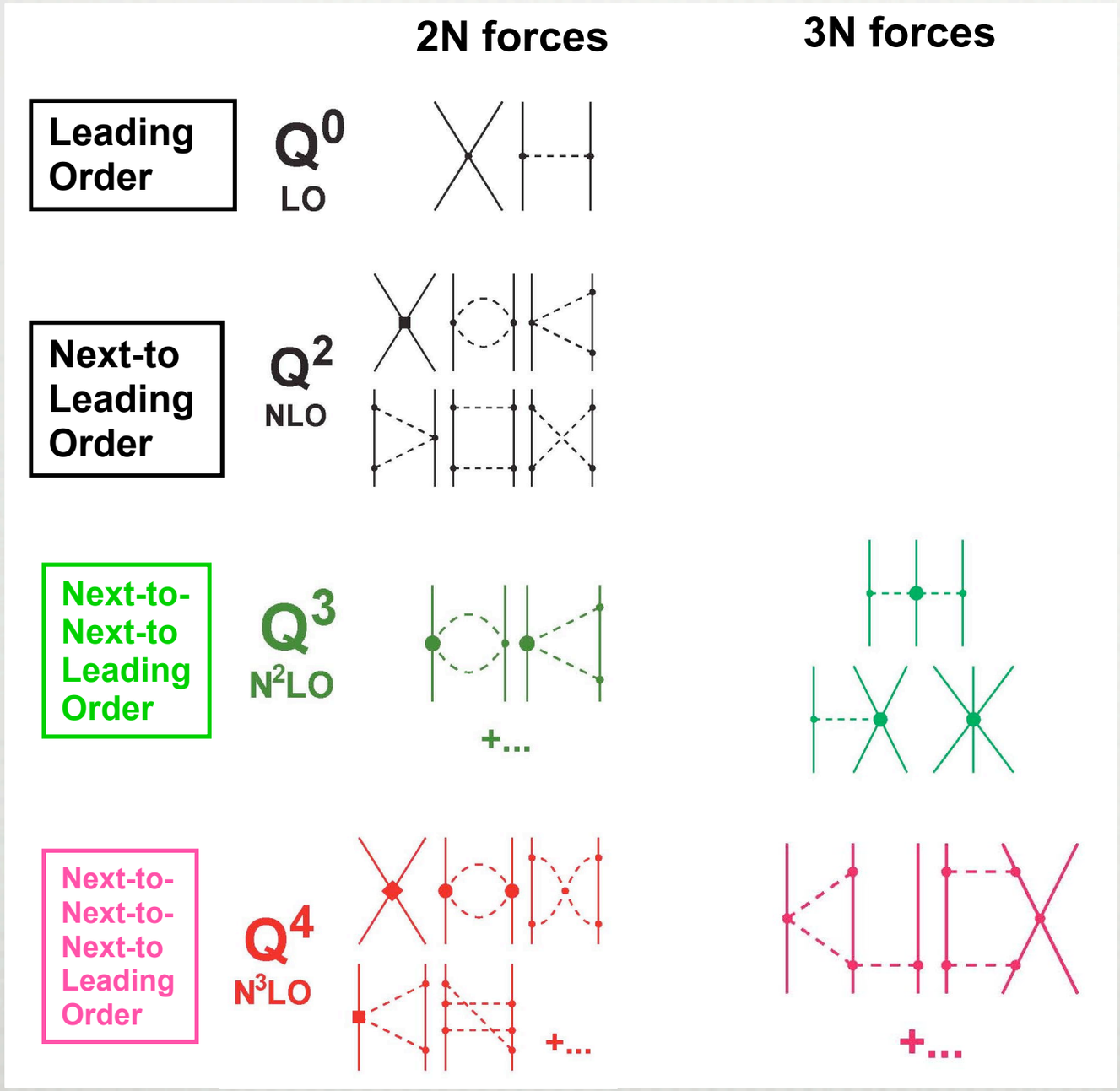
THREE-NUCLEON SCATTERING

"THE HUNT FOR THREE-NUCLEON FORCE EFFECTS"

THREE-NUCLEON FORCES



THREE-NUCLEON FORCES



ChPT predicts that 3NF effects show up at N^2LO and higher

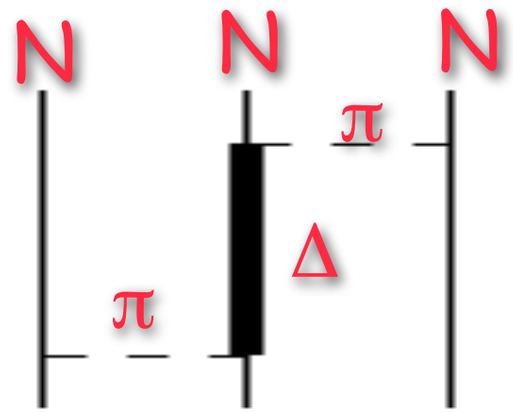
3NF<<2NF

Experimental challenge!

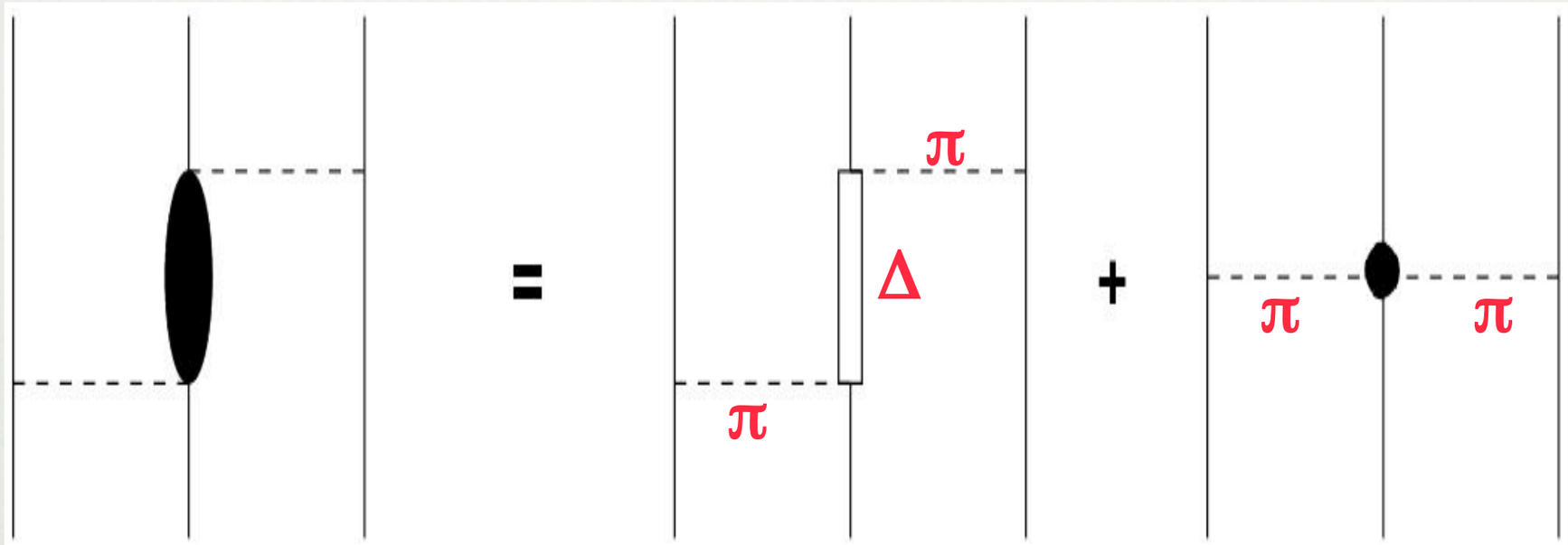
PHENOMENOLOGICAL 3 NUCLEON FORCES

PHENOMENOLOGICAL 3 NUCLEON FORCES

Fujita-Miyazawa
3NF

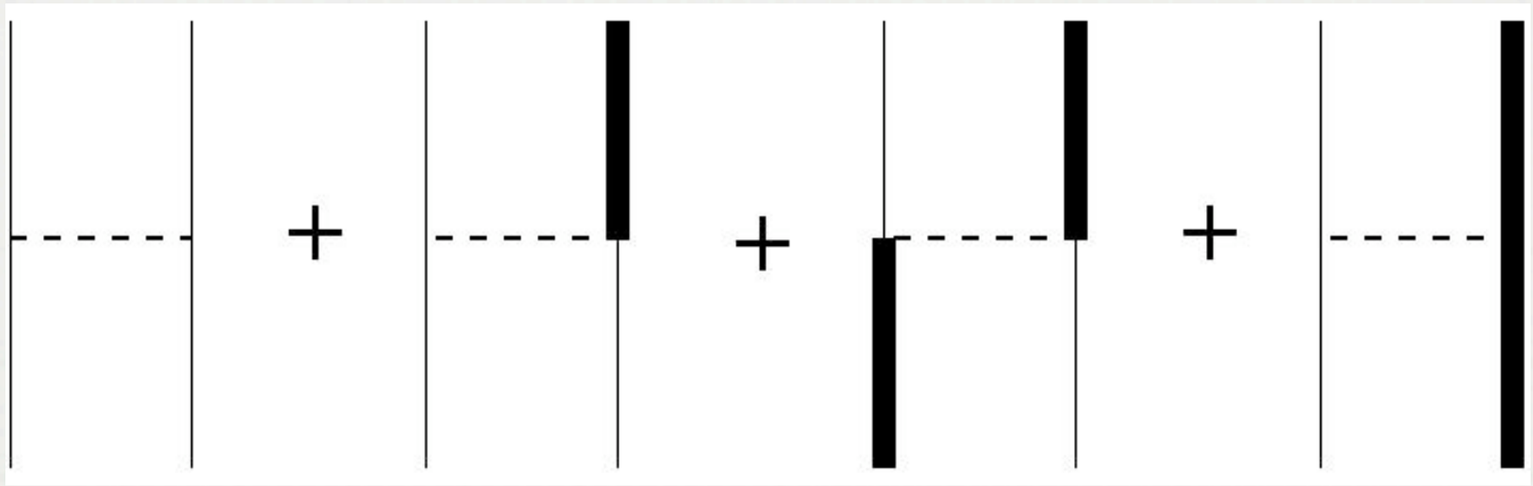


PHENOMENOLOGICAL 3 NUCLEON FORCES

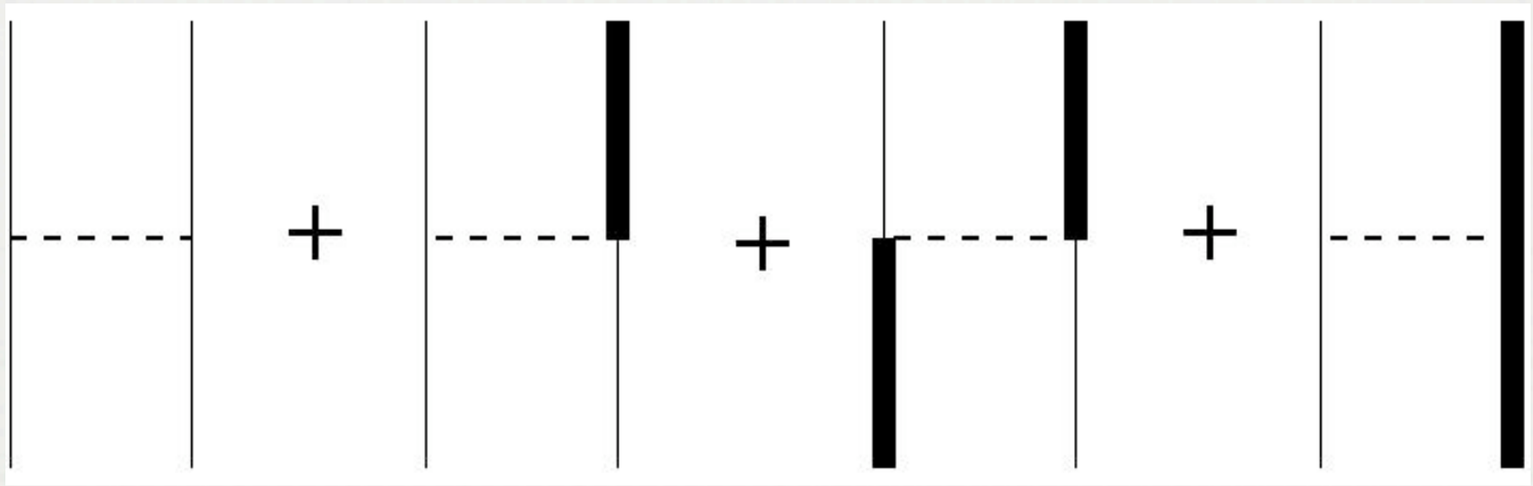


- parametrization of Fujita-Miyazawa force + 2π rescattering + higher-order interactions
- Added to 2N potential as correction
- Tucson-Melbourne, Urbana IX, Illinois, …
- Alternative approaches: Hannover/Lisbon

SELF-CONSISTENT 3 NUCLEON FORCES



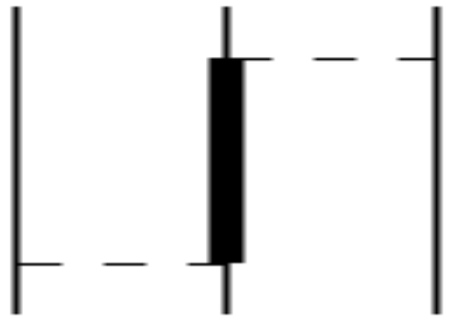
SELF-CONSISTENT 3 NUCLEON FORCES



- Approach by Hanover group (CD-Bonn+)
- Virtual Δ-isobar mediates the 3NF
- Self-consistent model which generates Fujita-Miyazawa 3NF, π-ring type 3NF, $\pi\rho$, $\rho\rho$ exchanges
- Incorporates Coulomb effect as well

SELF-CONSISTENT 3 NUCLEON FORCES

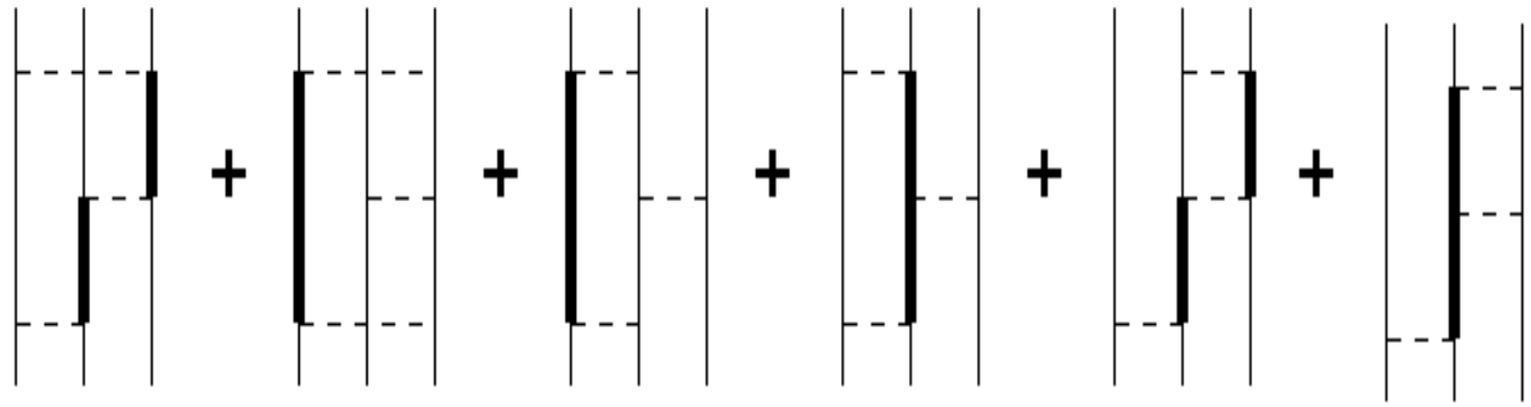
Fujita-Miyazawa
3NF



- Approach by Hanover group (CD-Bonn+)
- Virtual Δ-isobar mediates the 3NF
- Self-consistent model which generates Fujita-Miyazawa 3NF, π-ring type 3NF, $\pi\rho$, $\rho\rho$ exchanges
- Incorporates Coulomb effect as well

SELF-CONSISTENT 3 NUCLEON FORCES

π-ring type forces



- Approach by Hanover group (CD-Bonn+)
- Virtual Δ-isobar mediates the 3NF
- Self-consistent model which generates Fujita-Miyazawa 3NF, π-ring type 3NF, πρ, ρρ exchanges
- Incorporates Coulomb effect as well

THREE-NUCLEON SCATTERING

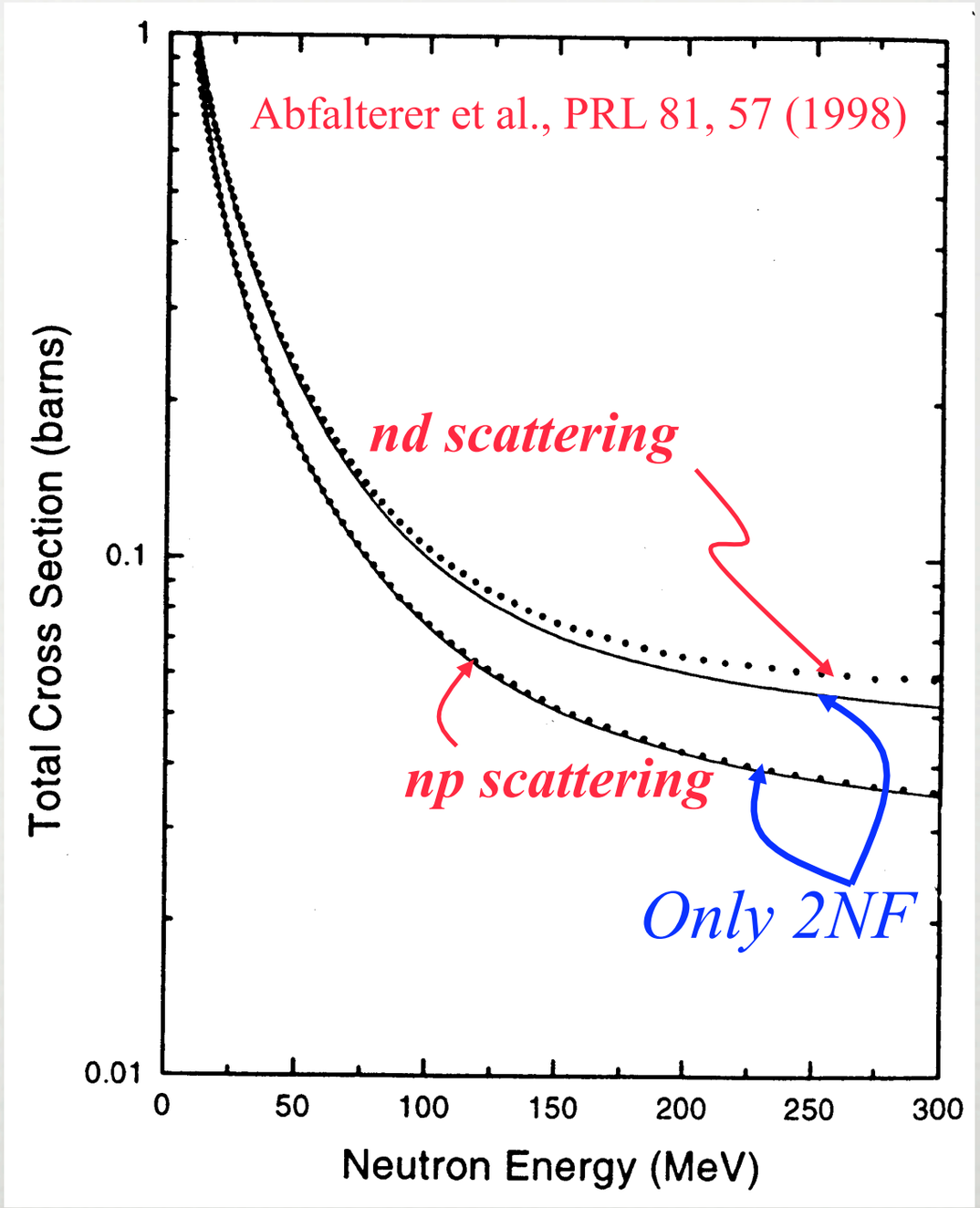
<u>Inclusive</u> np+nd scattering data

Faddeev calculation, rigorous solution of 3N dynamics

nd data reveals effects <u>beyond</u> two-nucleon forces

<u>precision</u> mandatory

Look for <u>sensitivity</u> in <u>exclusive</u> data and other <u>observables</u>

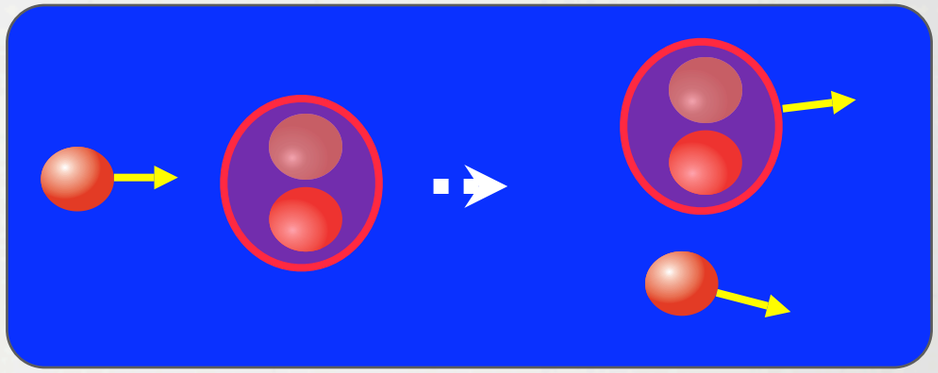


THREE-NUCLEON SCATTERING
(BELOW PION-PRODUCTION THRESHOLD)

THREE-NUCLEON SCATTERING
(BELOW PION-PRODUCTION THRESHOLD)

Elastic N+d scattering

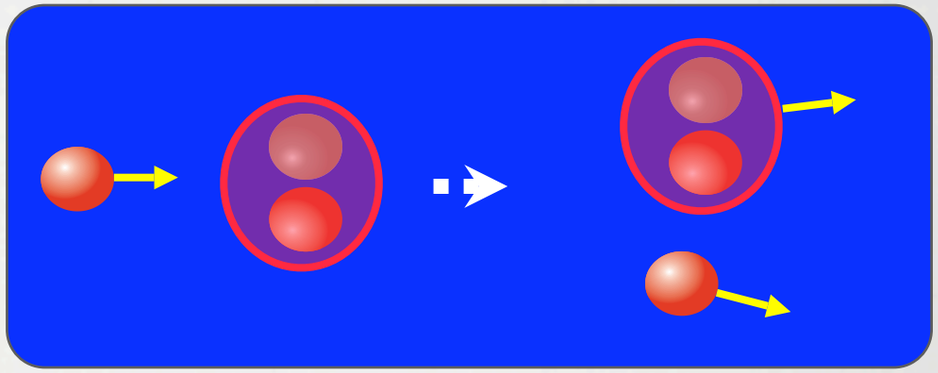
* pros: relatively easy experimentally
* cons: limited in "phase space"
* facilities: BONN/COLOGNE/IUCF/KVI/LANSCE/RCNP/RIKEN/TUNL



THREE-NUCLEON SCATTERING
(BELOW PION-PRODUCTION THRESHOLD)

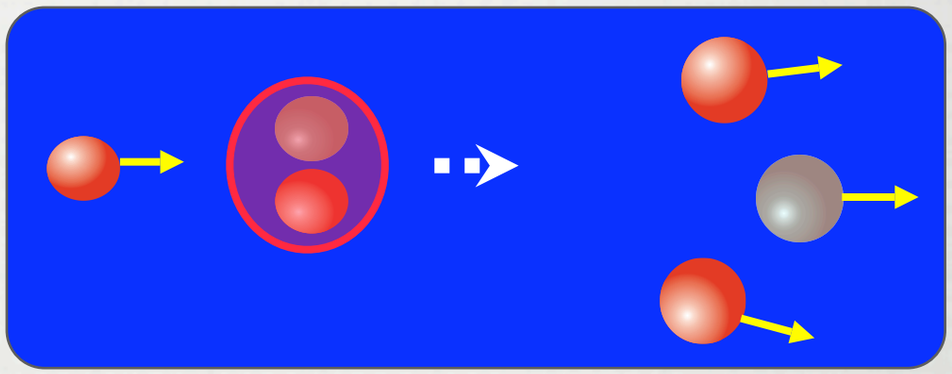
Elastic N+d scattering

* pros: relatively easy experimentally
* cons: limited in "phase space"
* facilities: BONN/COLOGNE/IUCF/KVI/LANSCE/RCNP/RIKEN/TUNL



N+d break-up

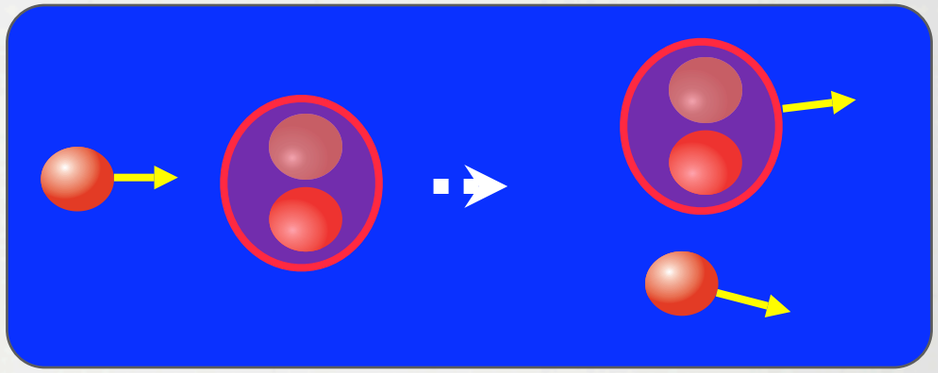
* pros: very rich "phase space"
* cons: experimentally harder
* facilities: BONN/COLOGNE/COSY/KVI/PSI



THREE-NUCLEON SCATTERING
(BELOW PION-PRODUCTION THRESHOLD)

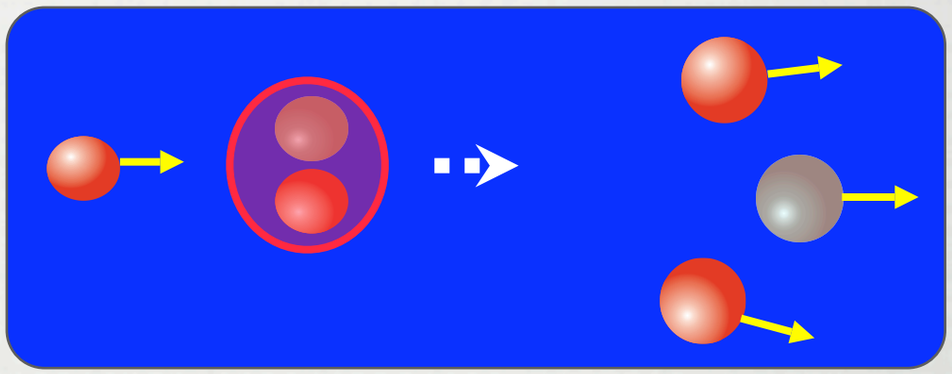
Elastic N+d scattering

* pros: relatively easy experimentally
* cons: limited in "phase space"
* facilities: BONN/COLOGNE/IUCF/KVI/LANSCE/RCNP/RIKEN/TUNL



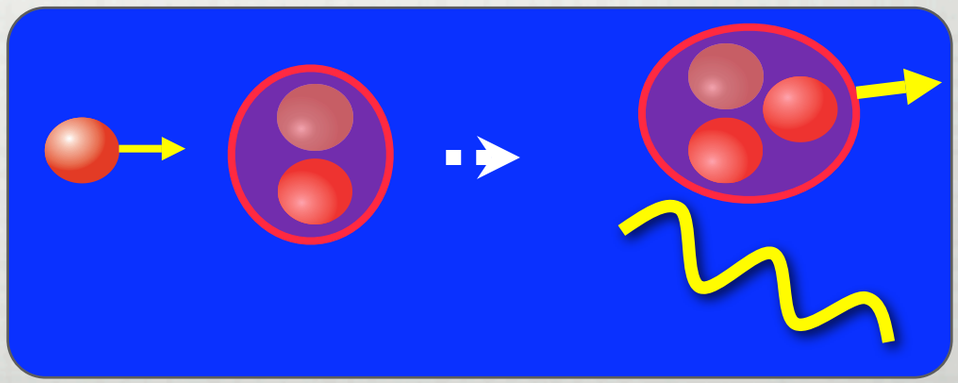
N+d break-up

* pros: very rich "phase space"
* cons: experimentally harder
* facilities: BONN/COLOGNE/COSY/KVI/PSI



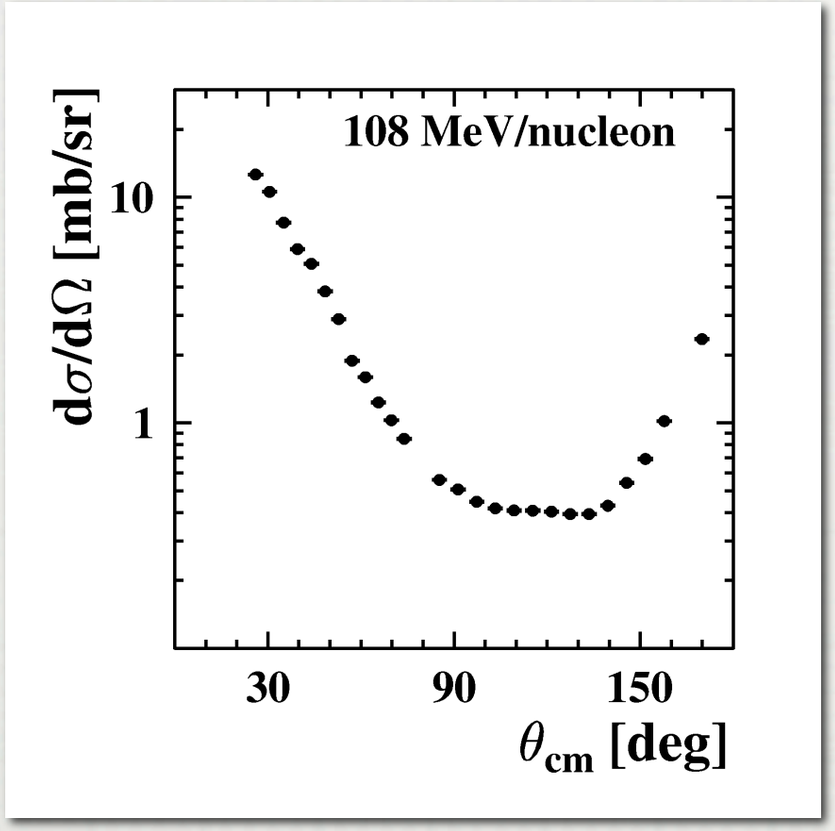
N+d radiative capture

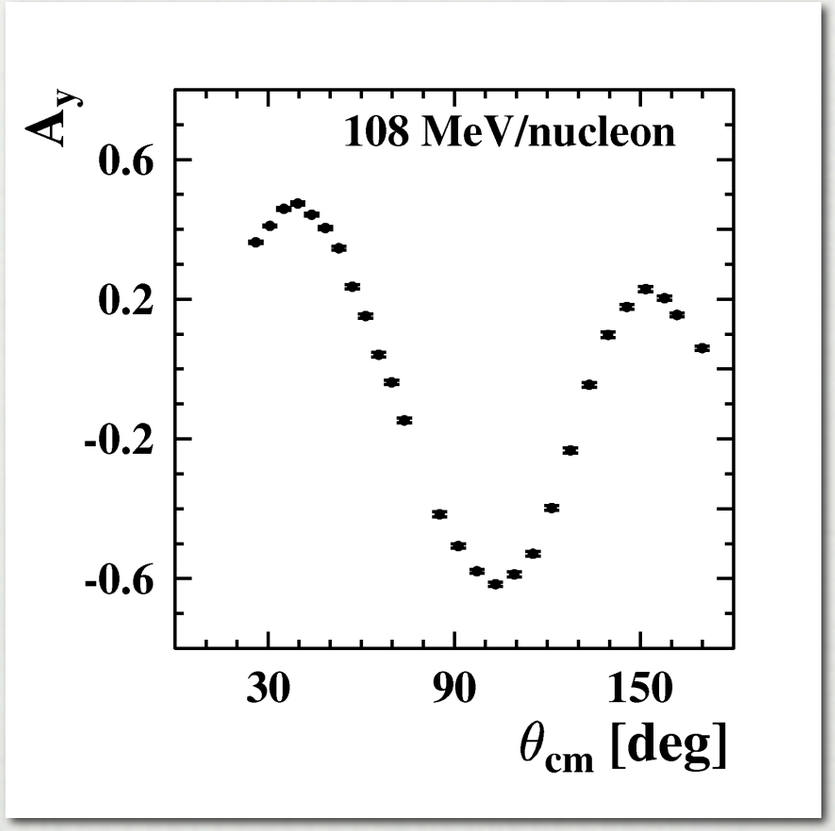
* pros: sensitive to electromagnetic currents
* cons: sensitive to electromagnetic currents
* facilities: IUCF/KVI/RCNP/TRIUMF/TSL



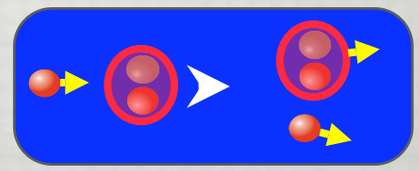
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)



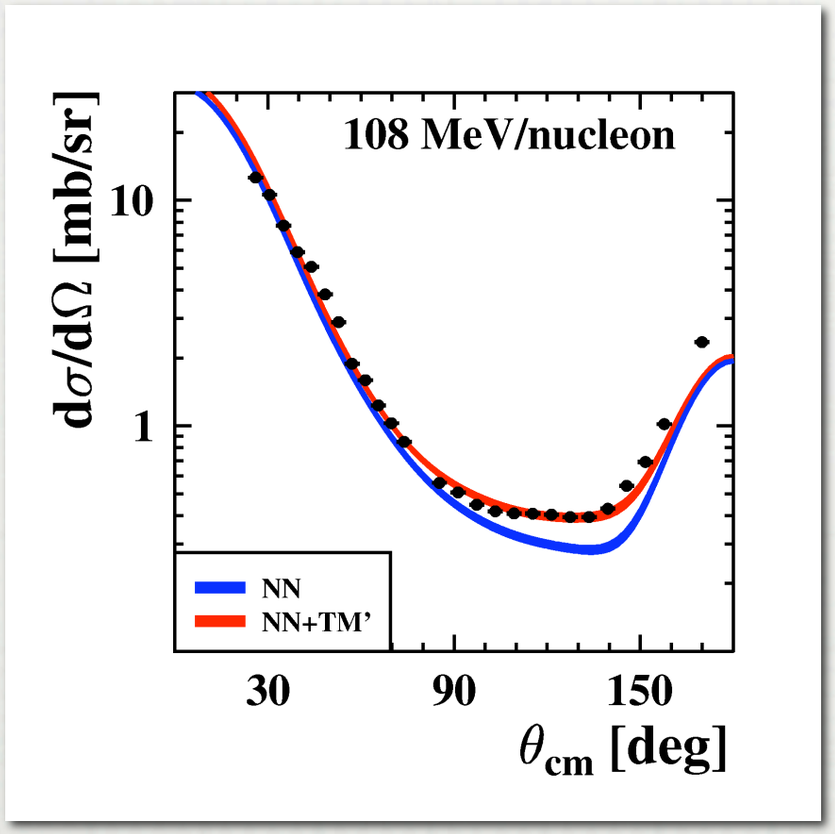


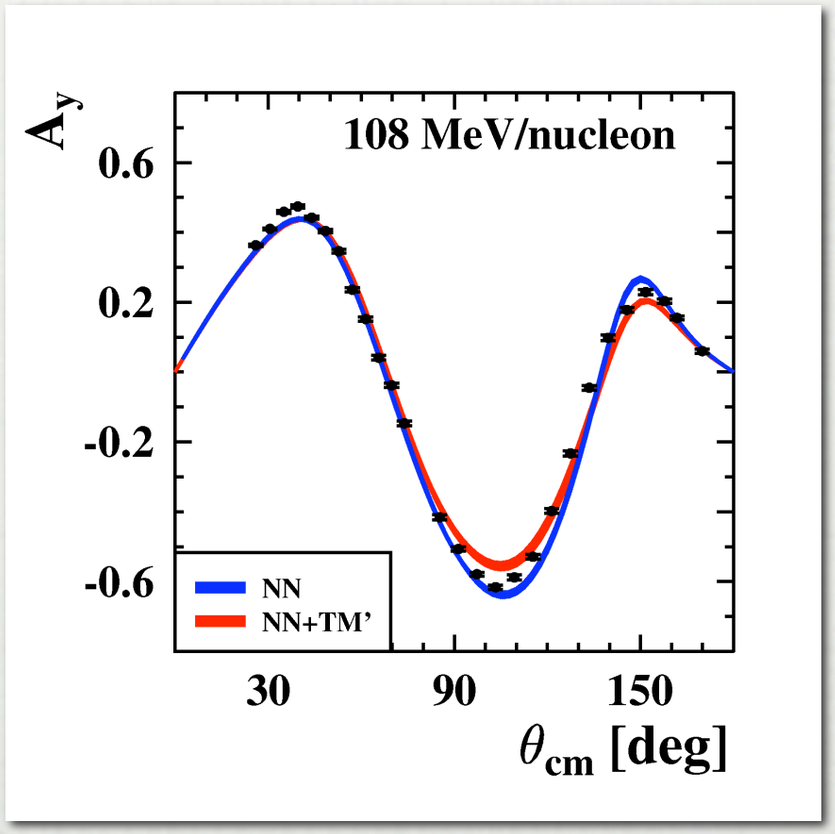
High-precision data (KVI,BBS)



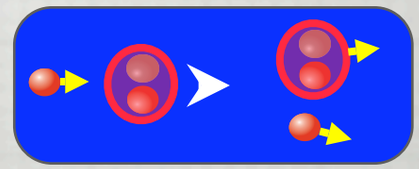
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)



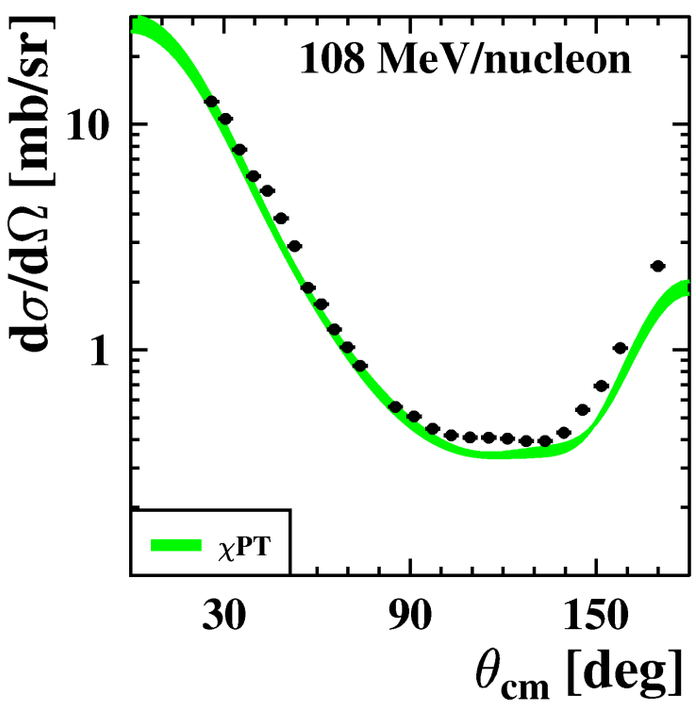


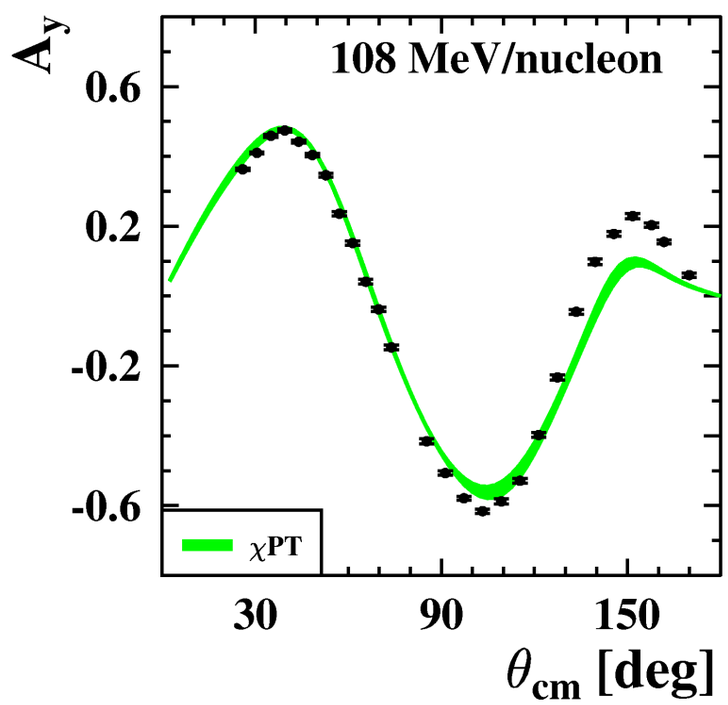
Calculation Bochum/Cracow
(Faddeev, 2NF+TM'-3NF)



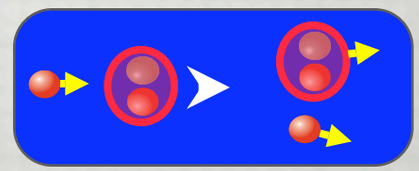
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)



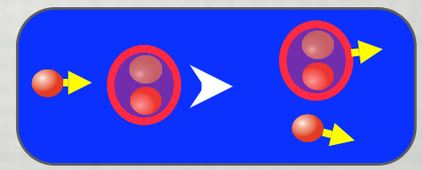


2NF and 3NF derived from χPT (N²LO) (Epelbaum et al.)



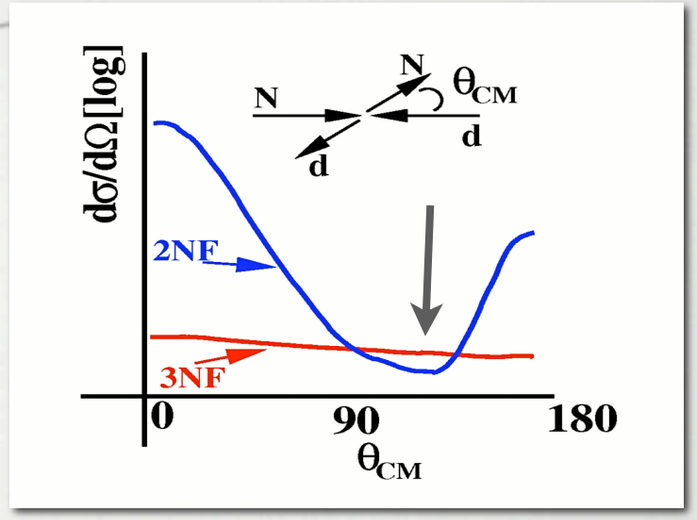
ELASTIC PD SCATTERING

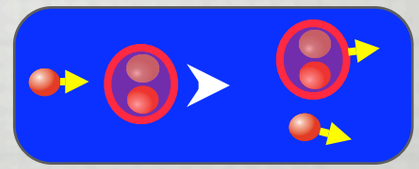
EXPERIMENT - THEORY (IN %)



ELASTIC PD SCATTERING

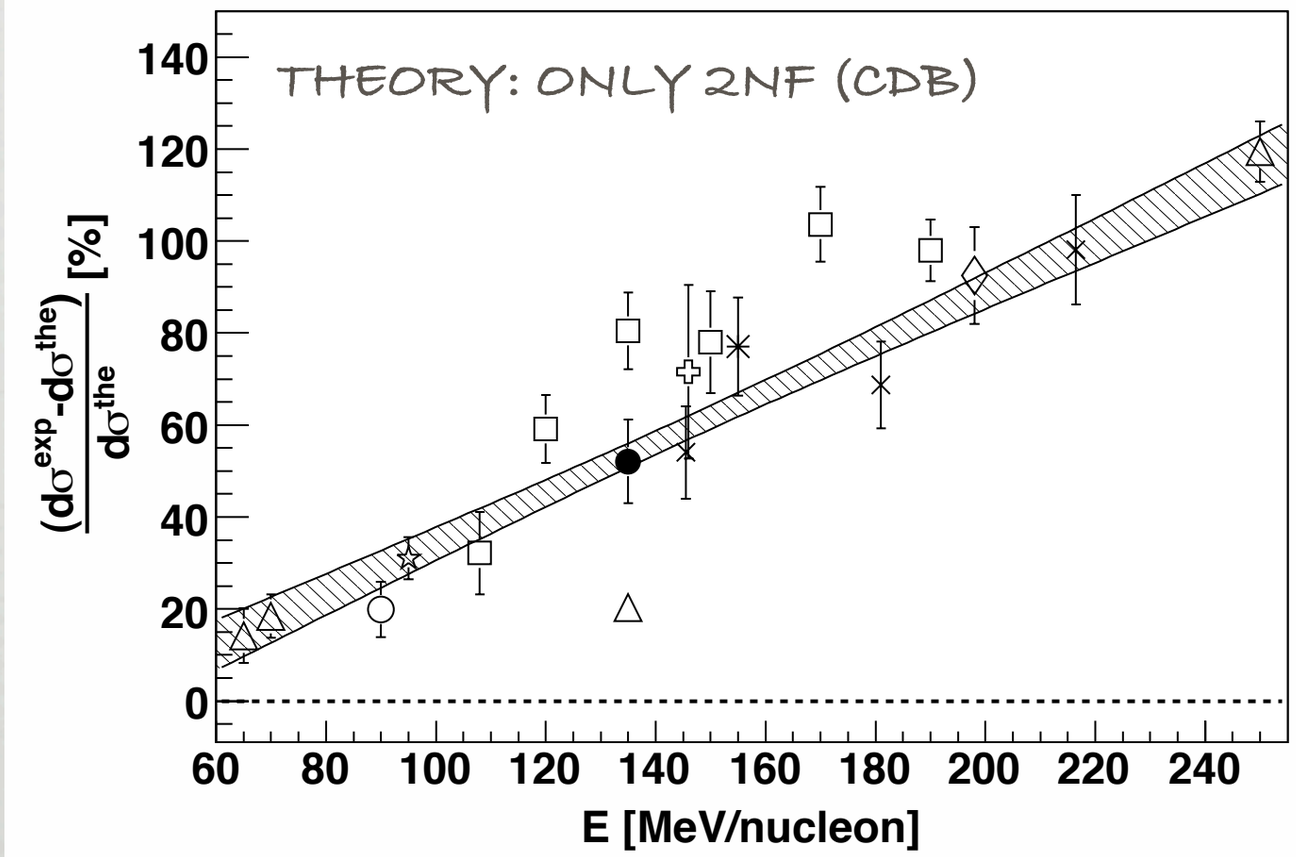
EXPERIMENT - THEORY (IN %)

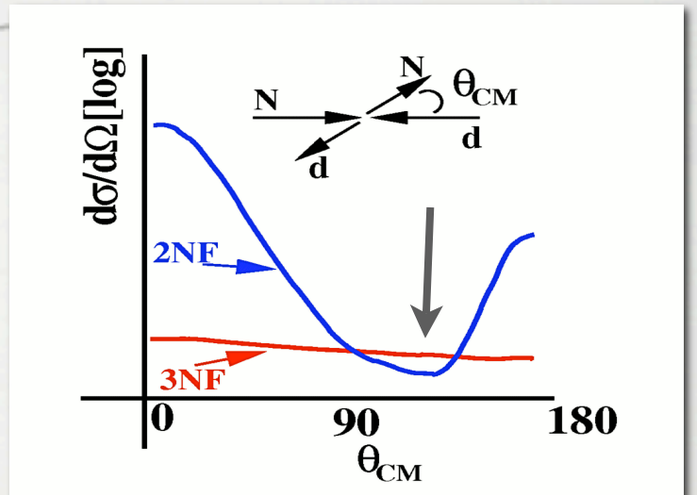




ELASTIC PD SCATTERING

EXPERIMENT - THEORY (IN %)



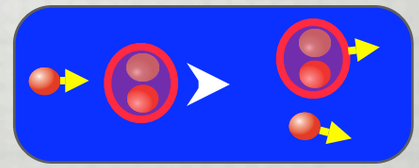


Data taken around the minimum of the differential cross section

HUGE discrepancy towards higher incident energies with 2NF

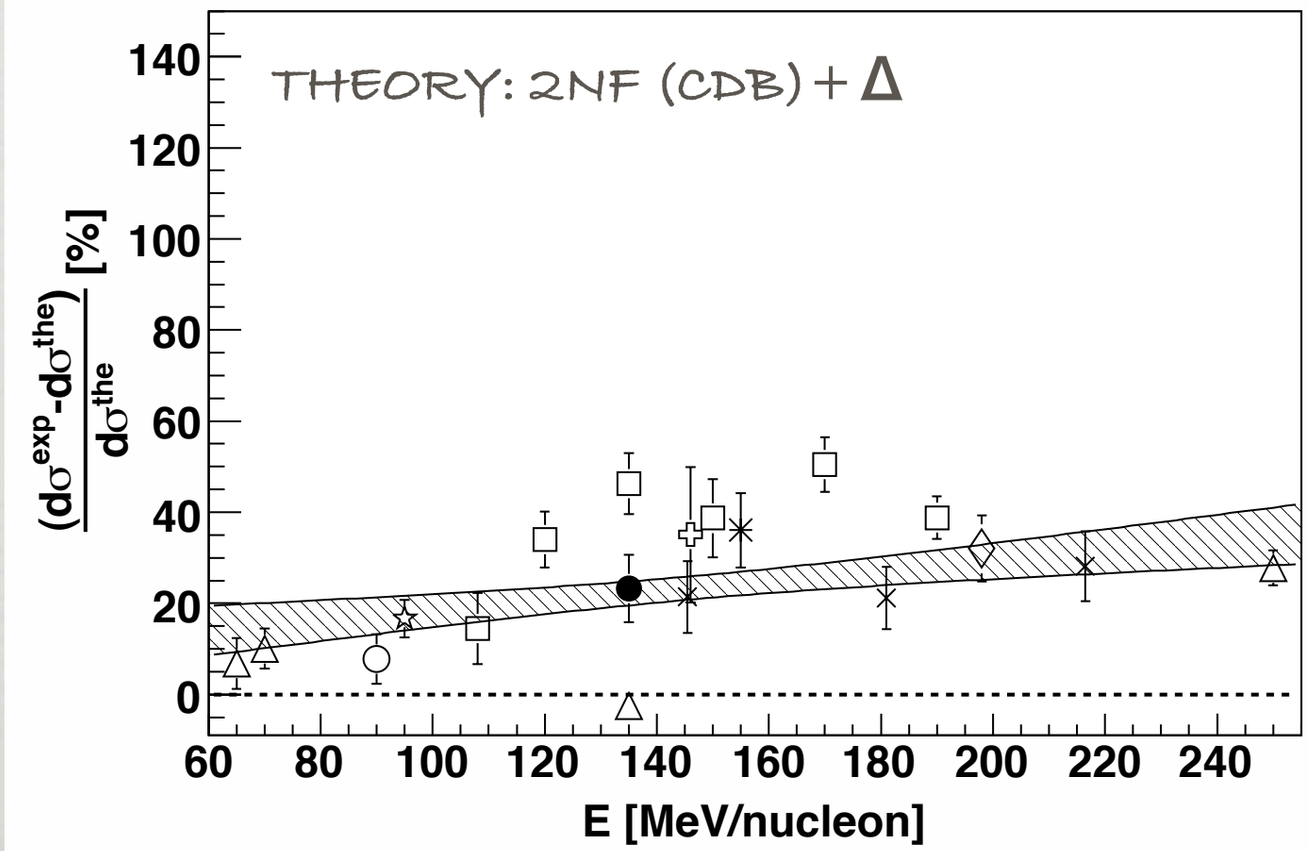
...for large part resolved by incorporating dynamic Δ

...discrepancies remain sizeable (in comparison to NN database!)

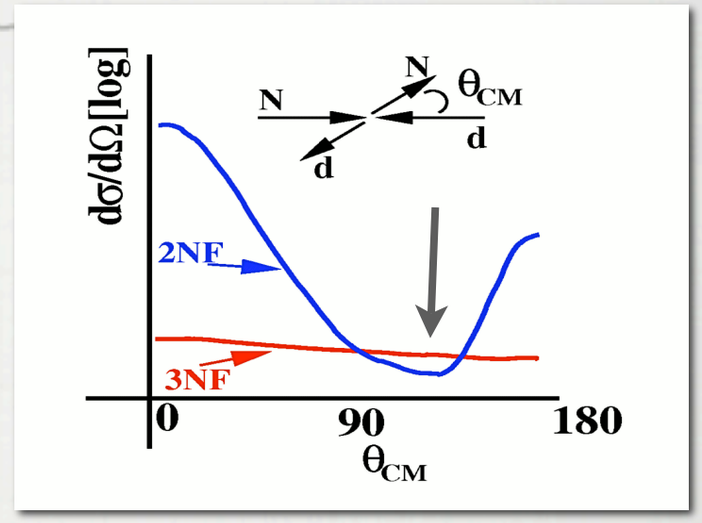


ELASTIC PD SCATTERING

EXPERIMENT - THEORY (IN %)



A. Ramazani-Moghaddam-Arani et al., PRC78, 014006 (2008)

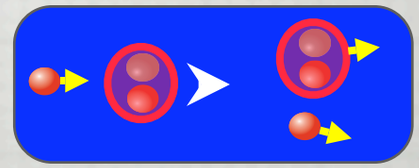


Data taken around the minimum of the differential cross section

HUGE discrepancy towards higher incident energies with 2NF

...for large part resolved by incorporating dynamic Δ

...discrepancies remain sizeable (in comparison to NN database!)



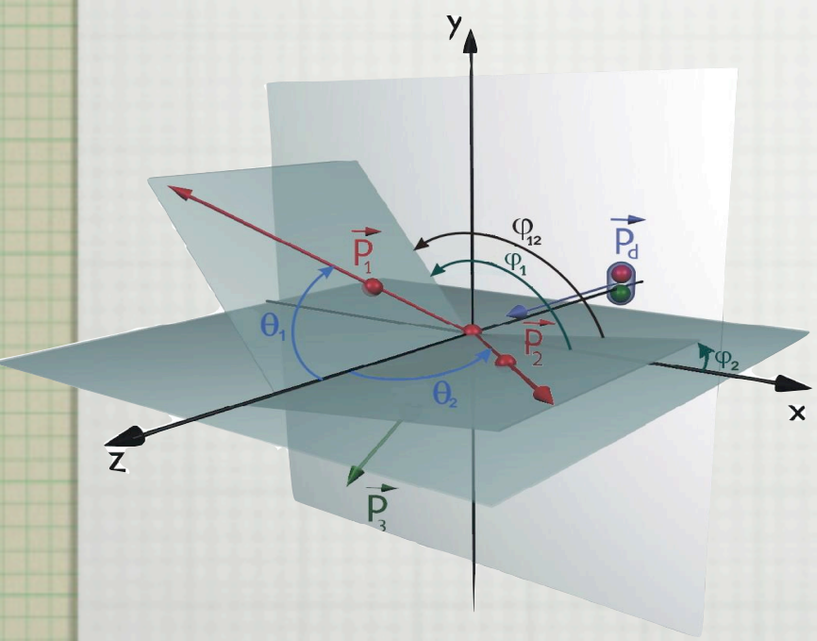
PROTON-DEUTERON BREAK-UP

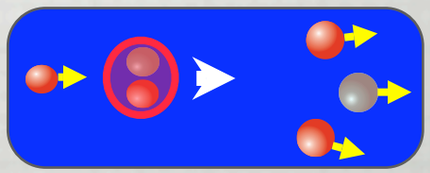
pros:

* very rich "phase space" (5 dimensions)
* detailed roadmap of 2N+3NFs

cons:

* experimentally challenging
* detector with large acceptance!





PROTON-DEUTERON BREAK-UP

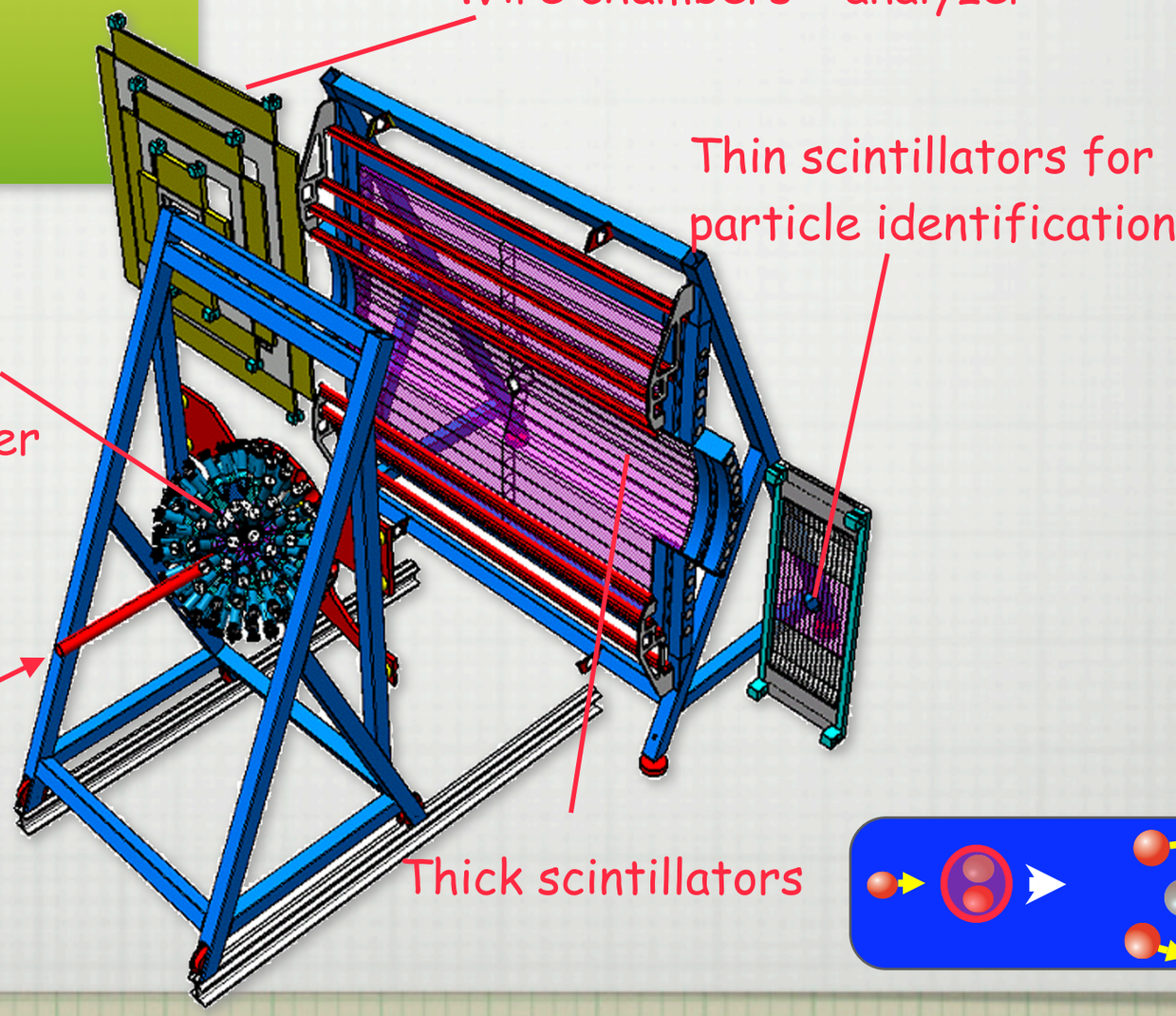
pros:

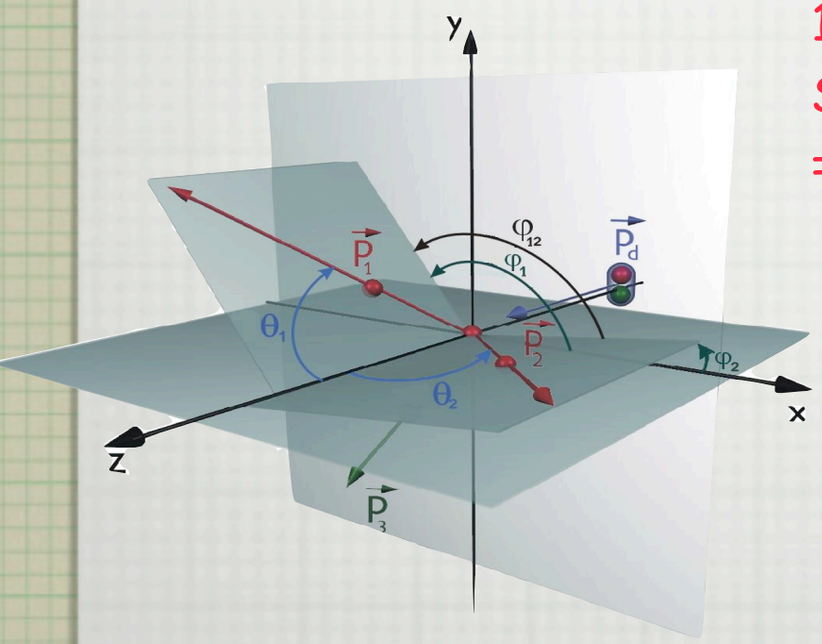
* very rich "phase space" (5 dimensions)
* detailed roadmap of 2N+3NFs

cons:

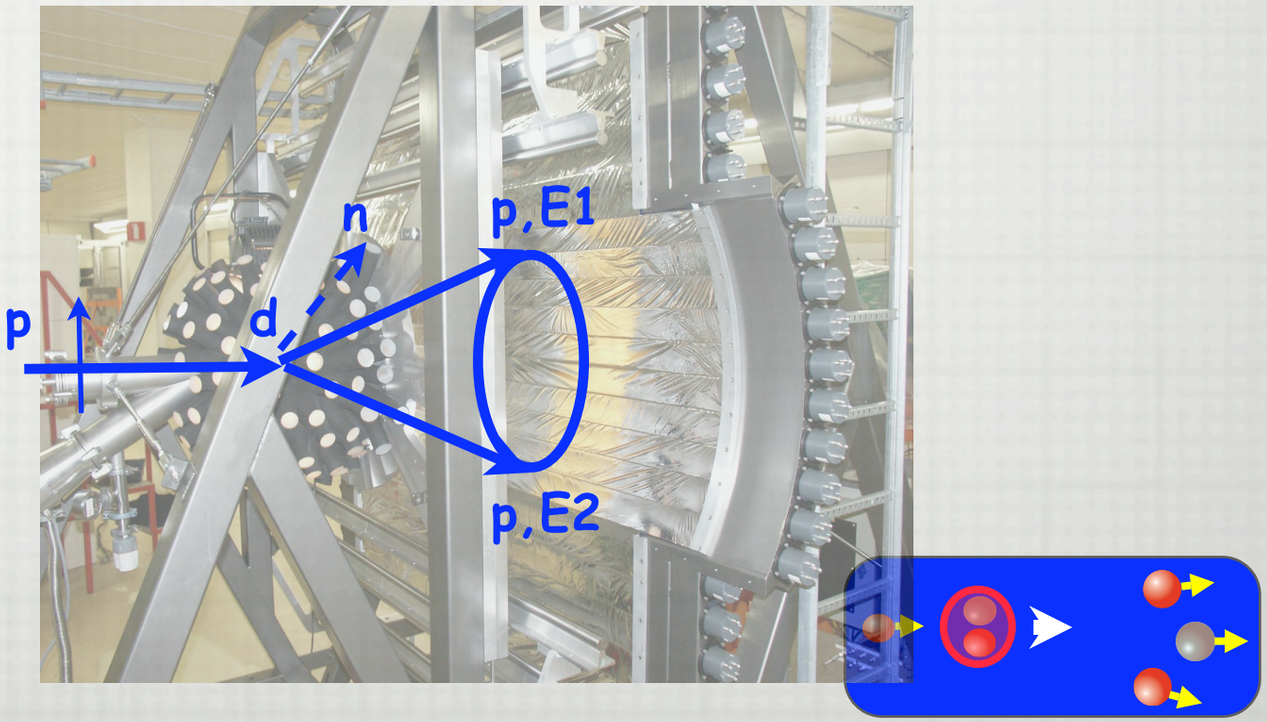
* experimentally challenging
* detector with large acceptance!

"BIG INSTRUMENT FOR POLARIZATION ANALYSIS" (BINA)



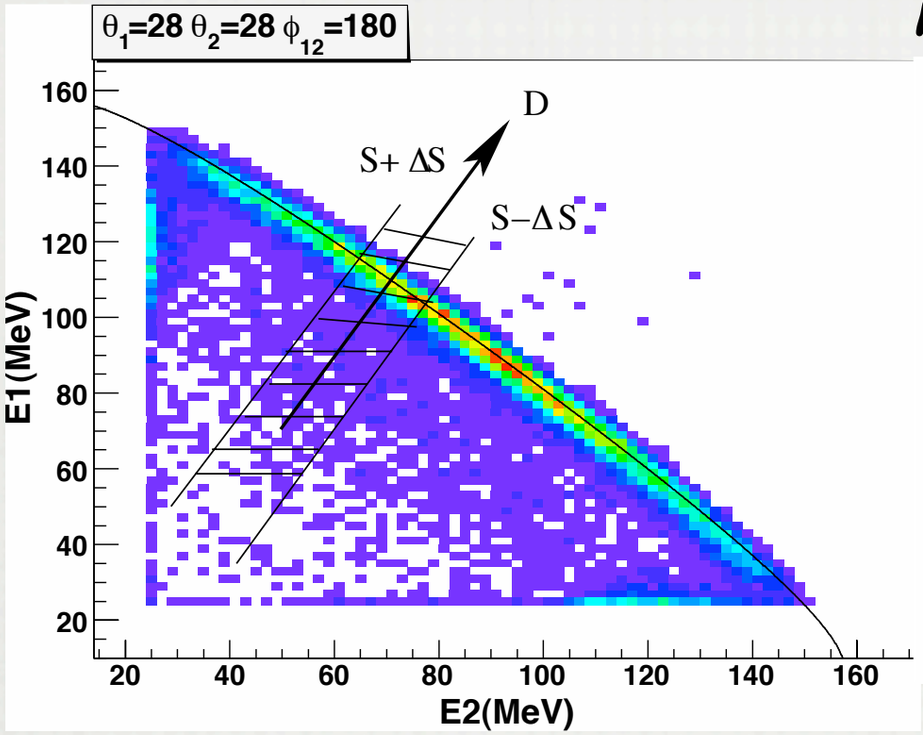


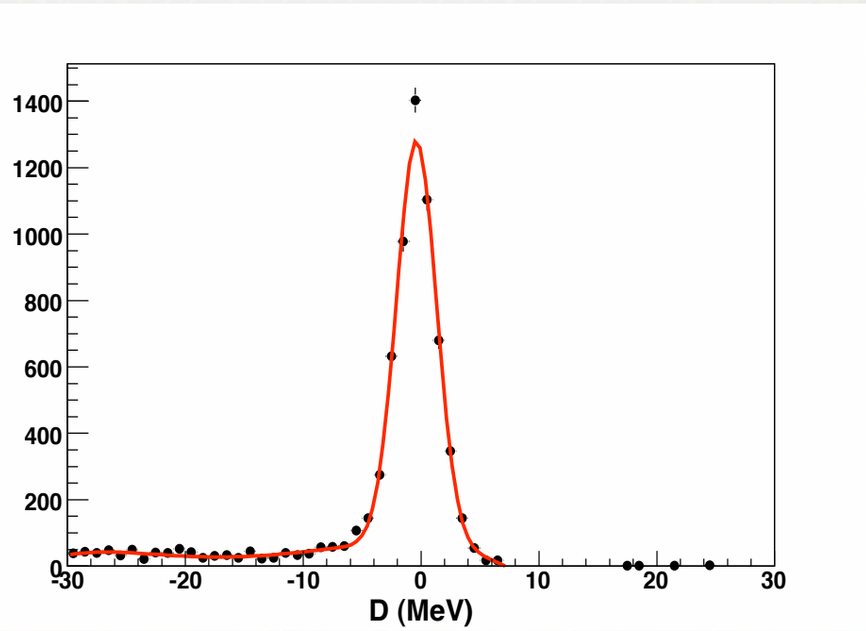
PROTON-DEUTERON BREAK-UP

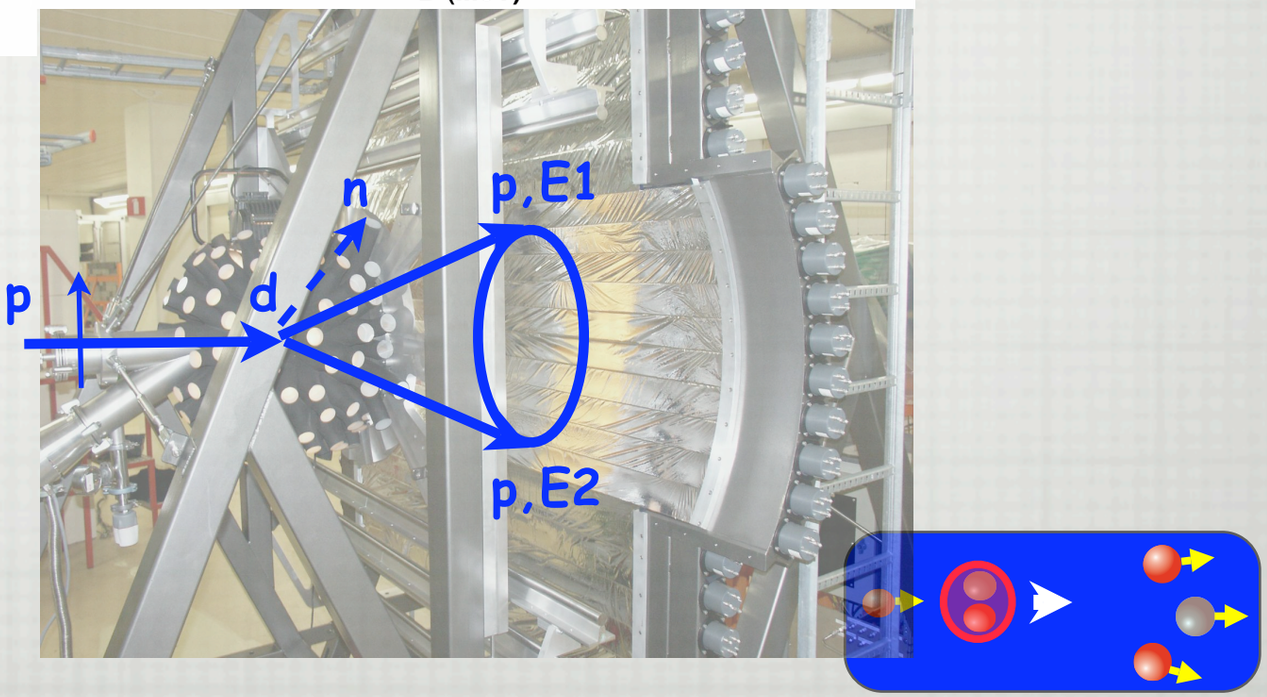


PROTON-DEUTERON BREAK-UP

M. Eslami-Kalantari, H. Mardanpour

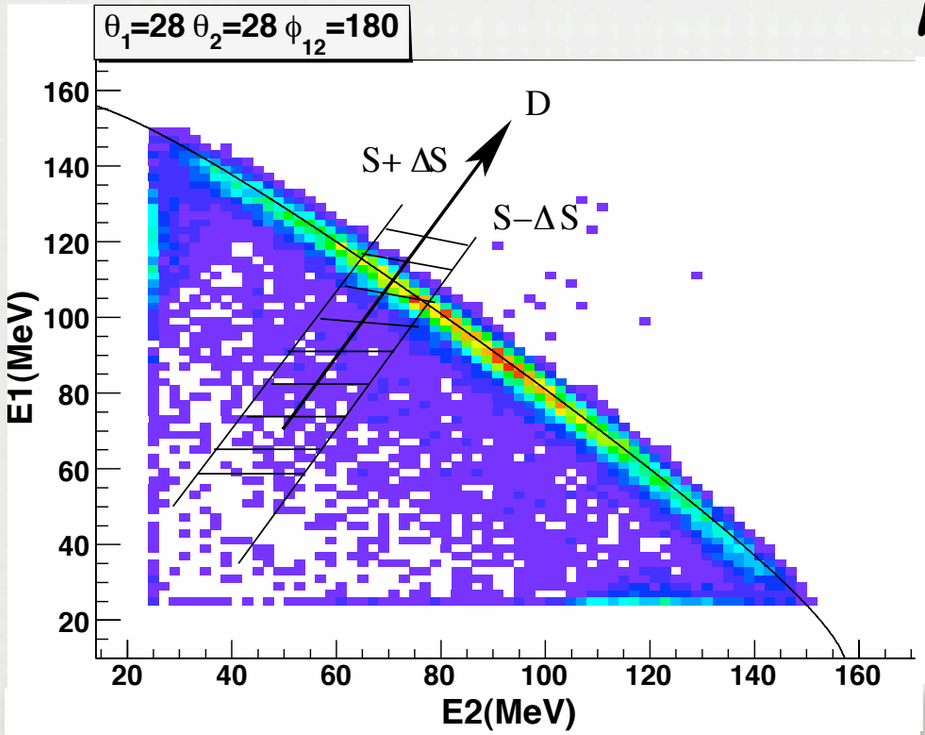


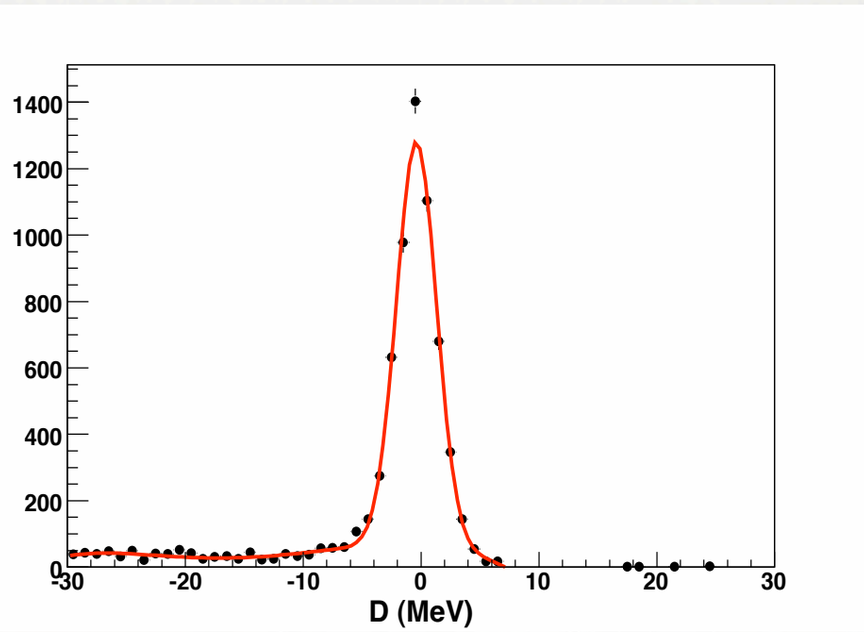


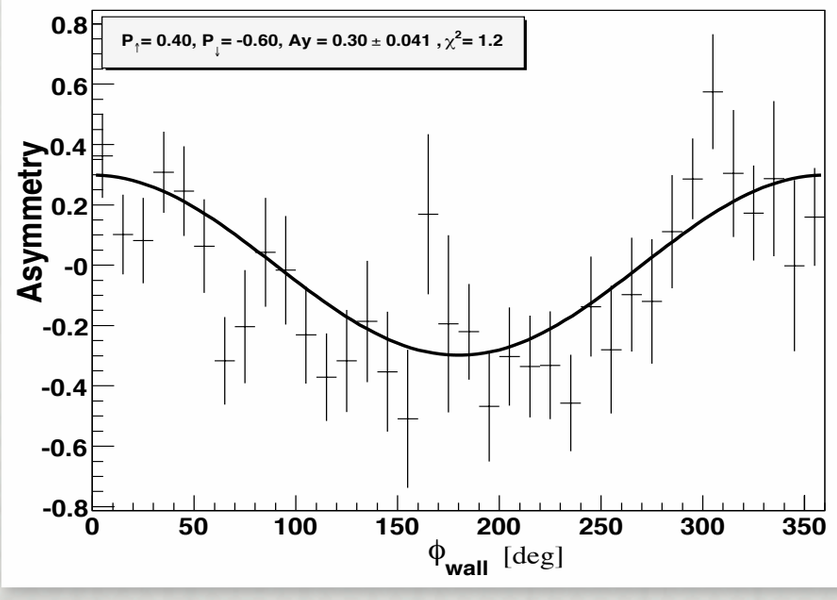


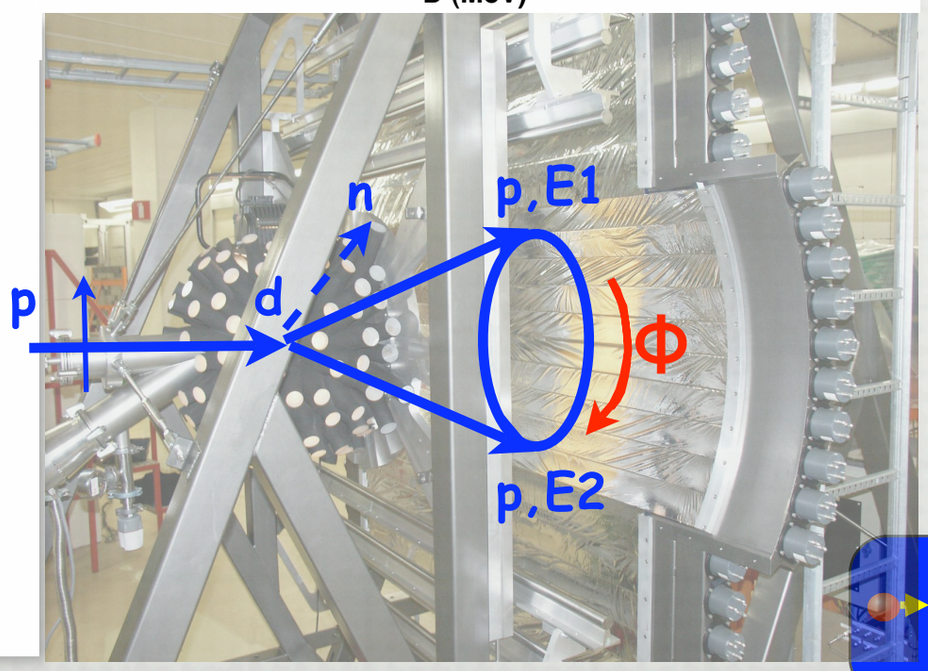
PROTON-DEUTERON BREAK-UP

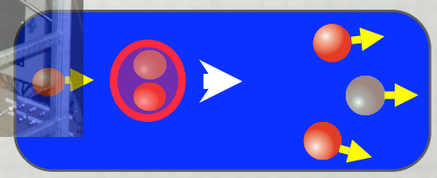
M. Eslami-Kalantari, H. Mardanpour





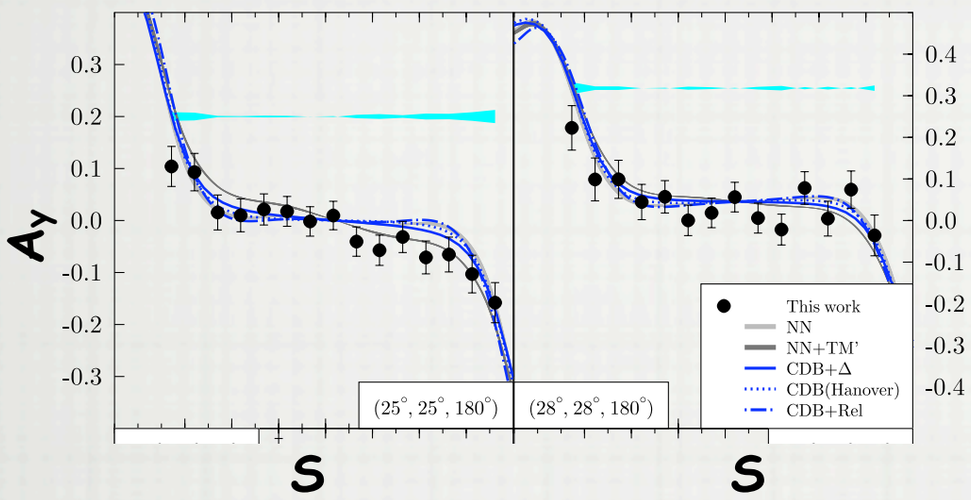


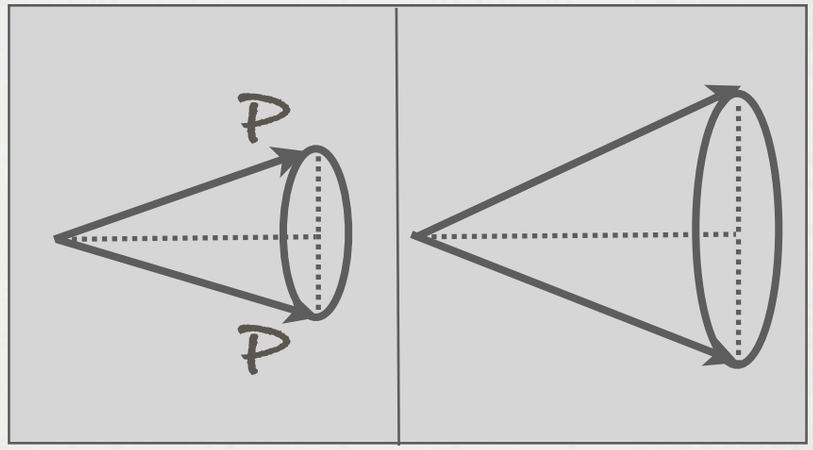


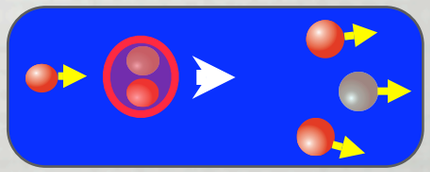


SPIN OBSERVABLES IN PD BREAK-UP

(@190 MEV)

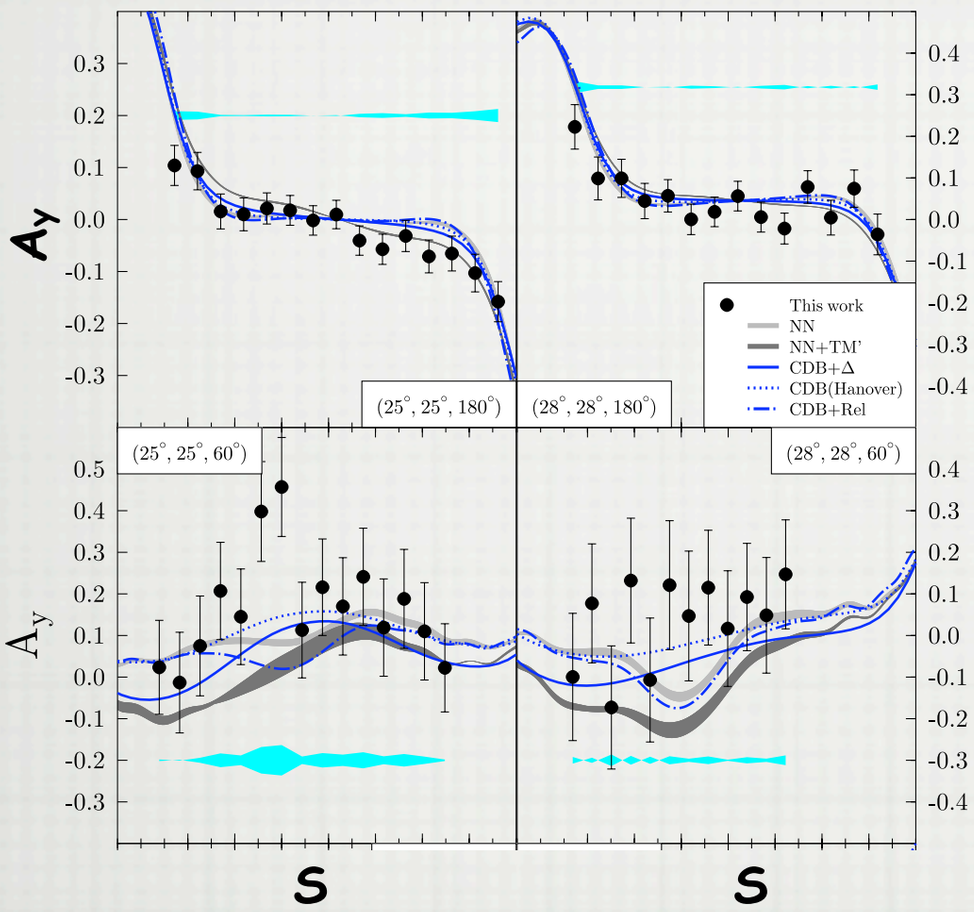


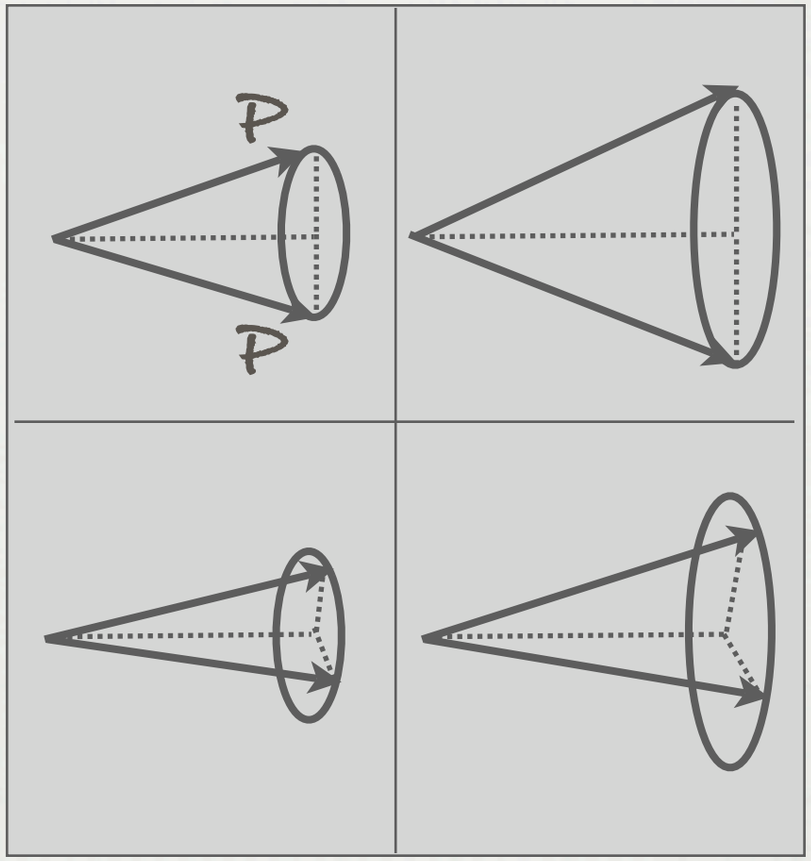


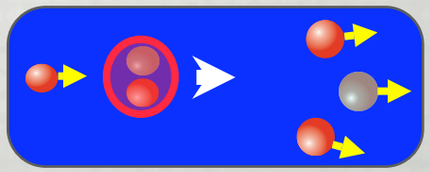


SPIN OBSERVABLES IN PD BREAK-UP

(@190 MEV)

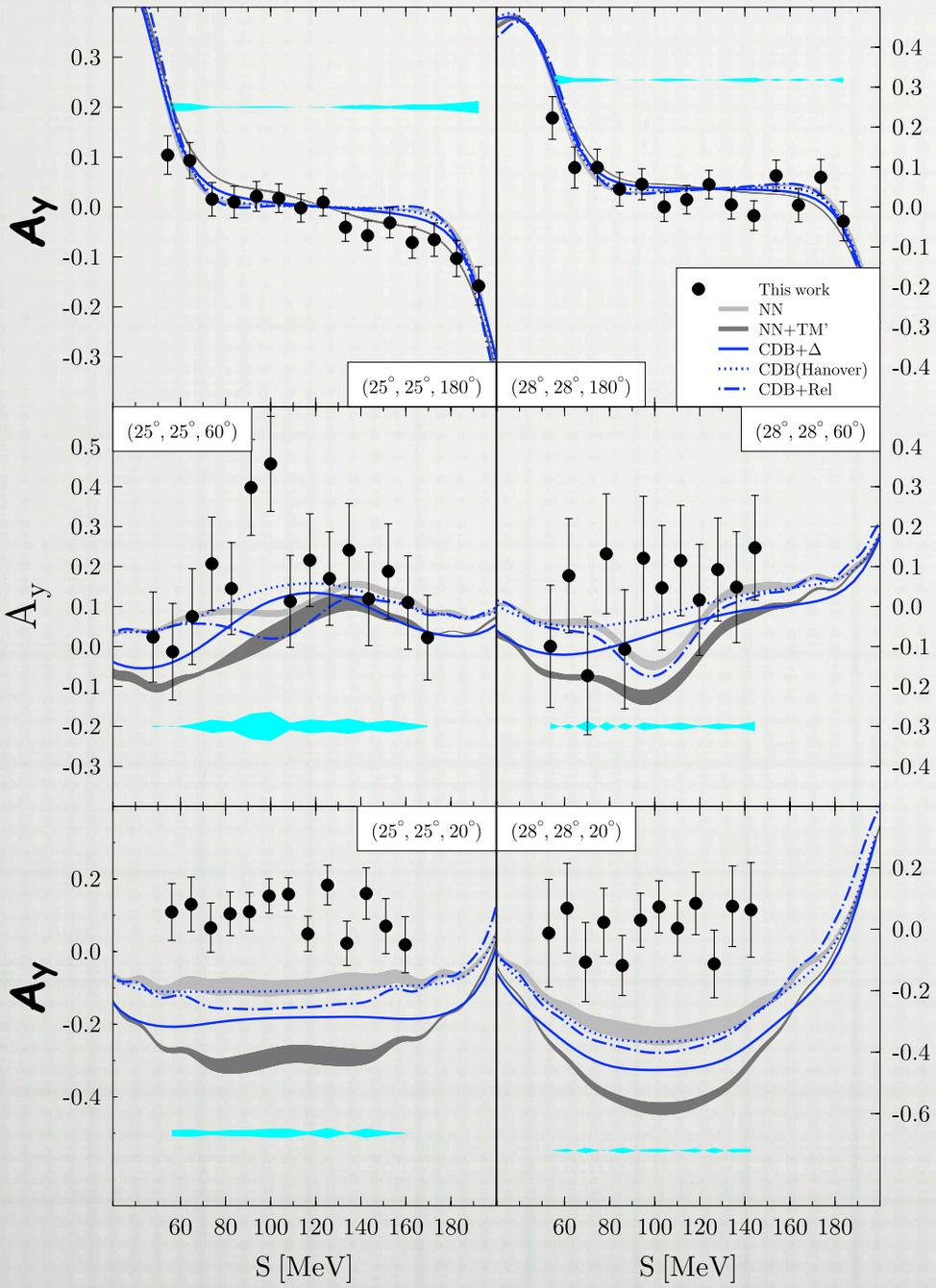


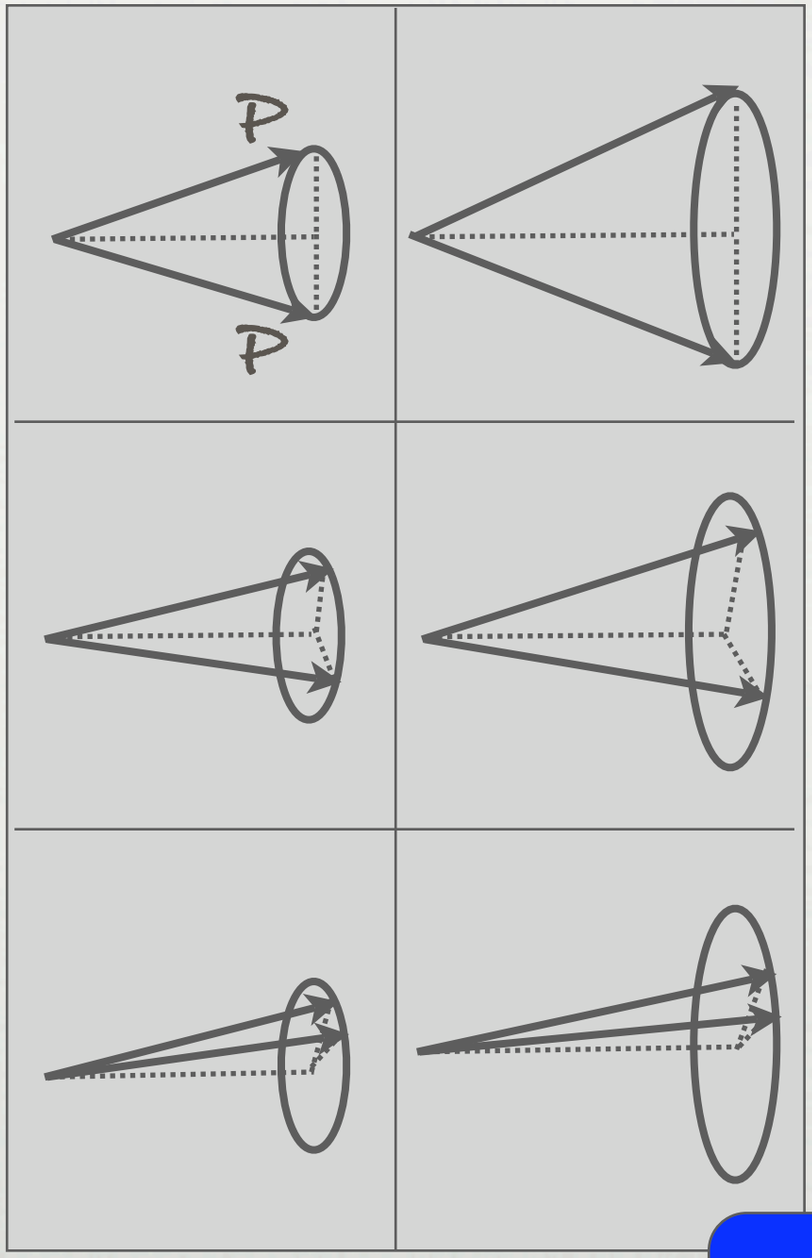


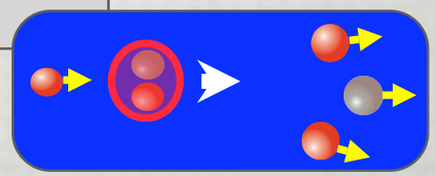


SPIN OBSERVABLES IN PD BREAK-UP

(@190 MEV)

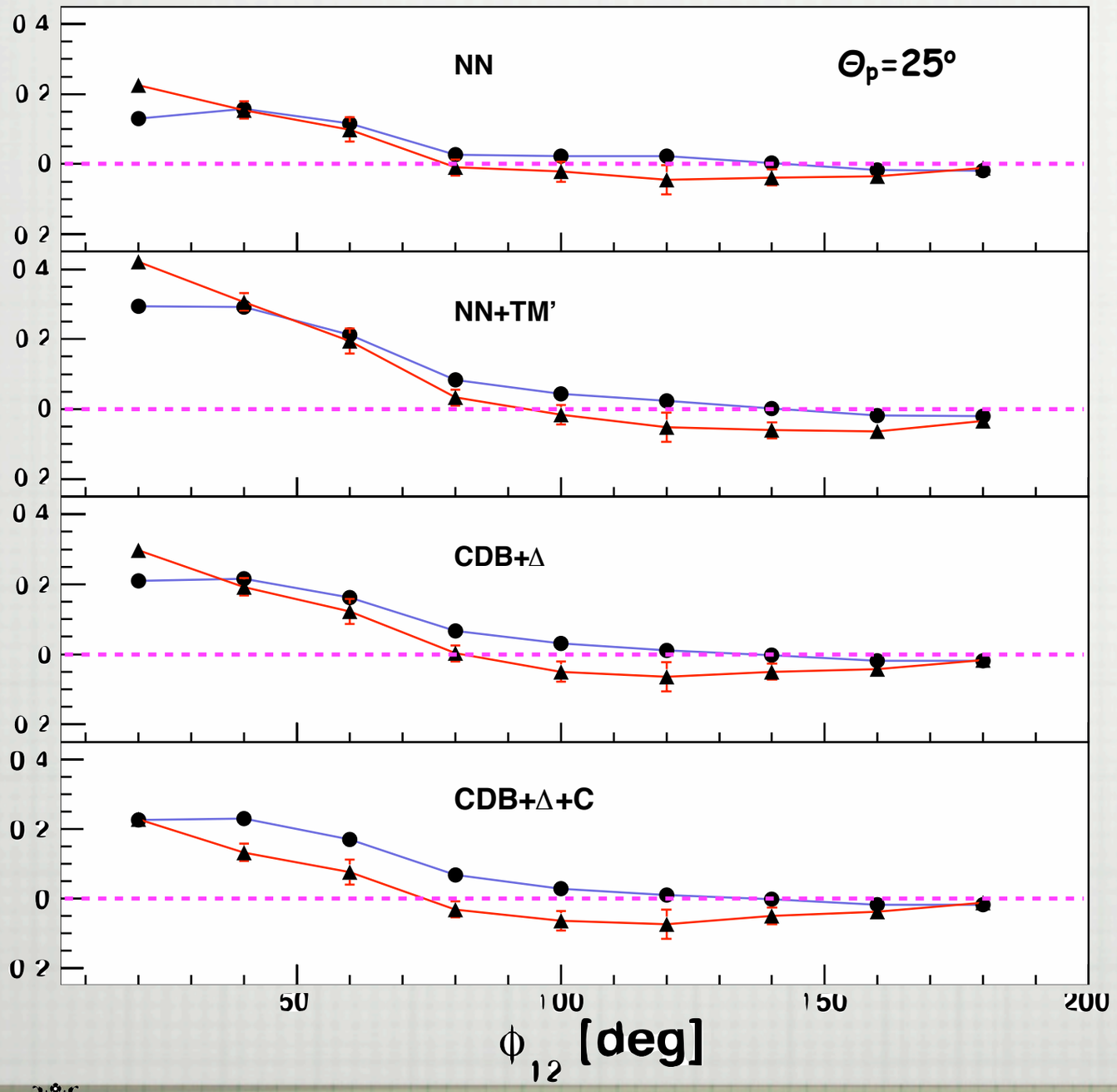






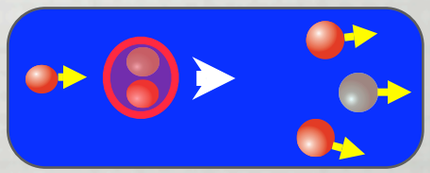
SPIN OBSERVABLES IN PD BREAK-UP

averaged A_y: **experiment-theory**



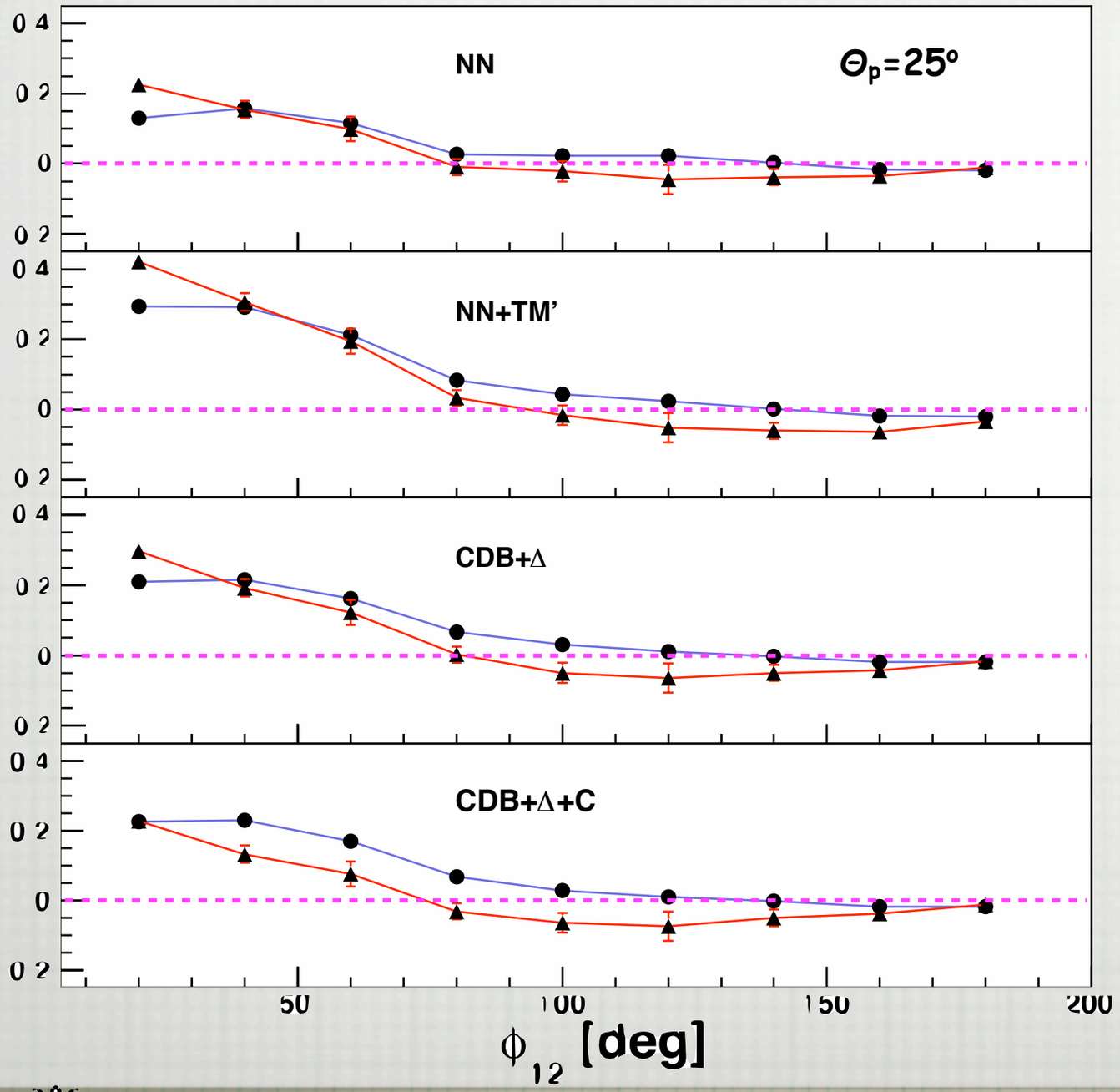
190 MeV

135 MeV



SPIN OBSERVABLES IN PD BREAK-UP

averaged A_y: **experiment-theory**

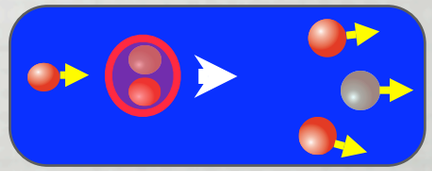


Discrepancy persists at different energies

<u>data</u>: BINA

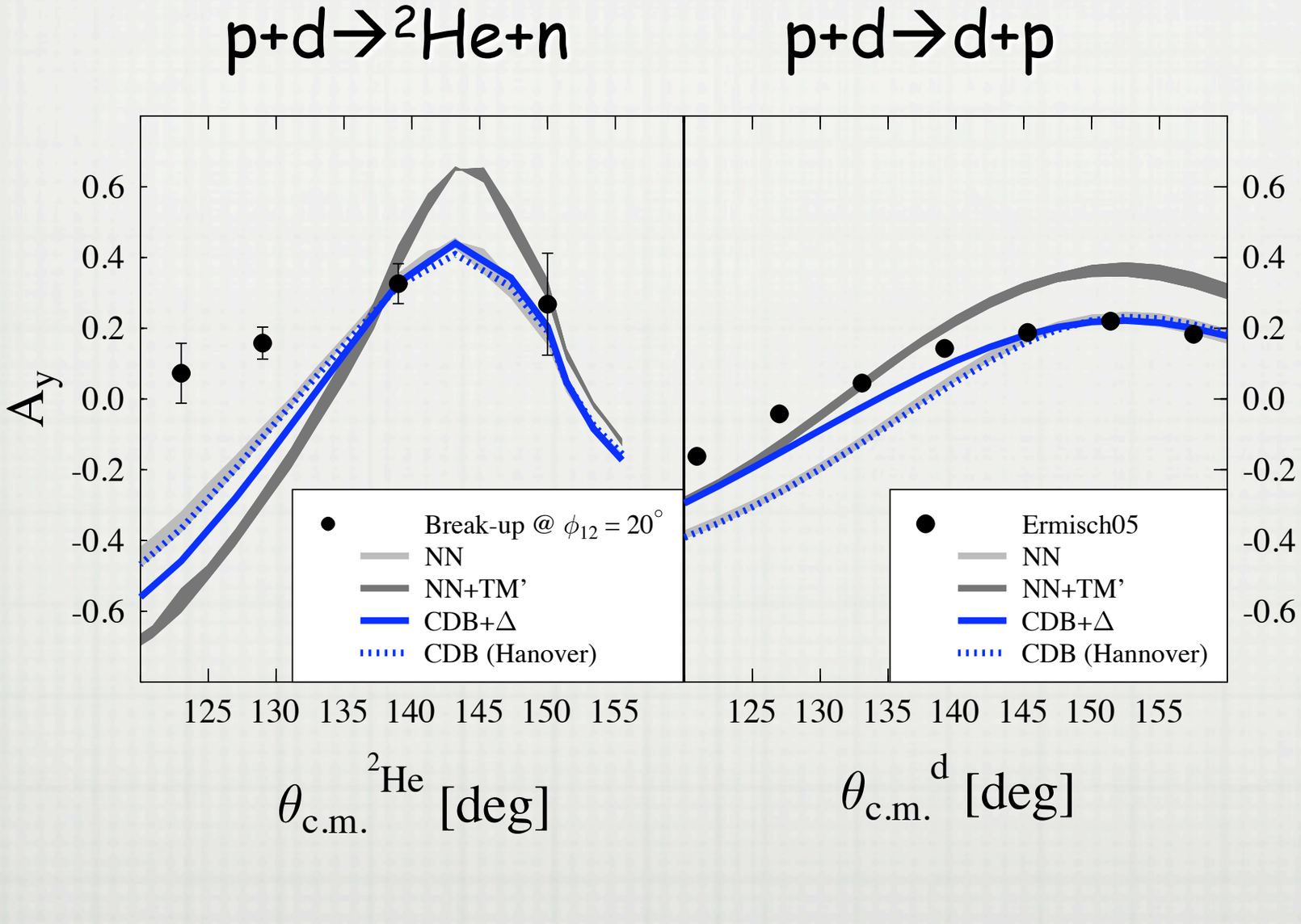
<u>theory</u>: Bochum-Cracow/ Hannover-Lisbon

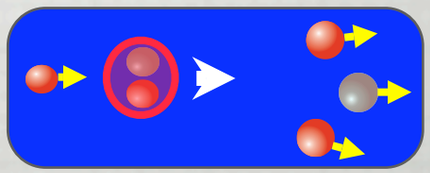
190 MeV
135 MeV



SPIN OBSERVABLES IN PD BREAK-UP

(@190 MEV)

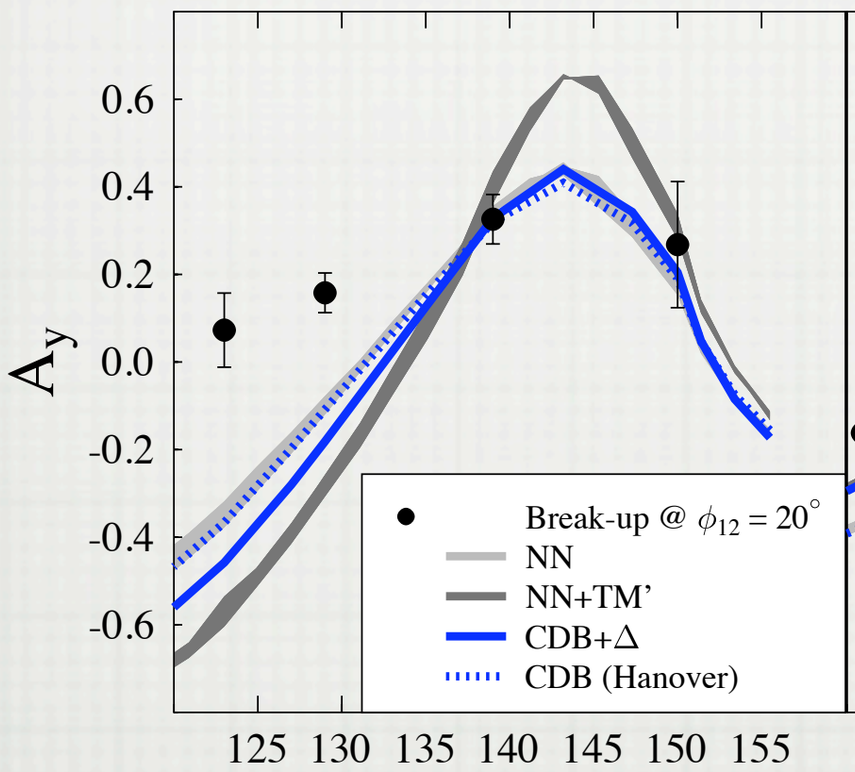




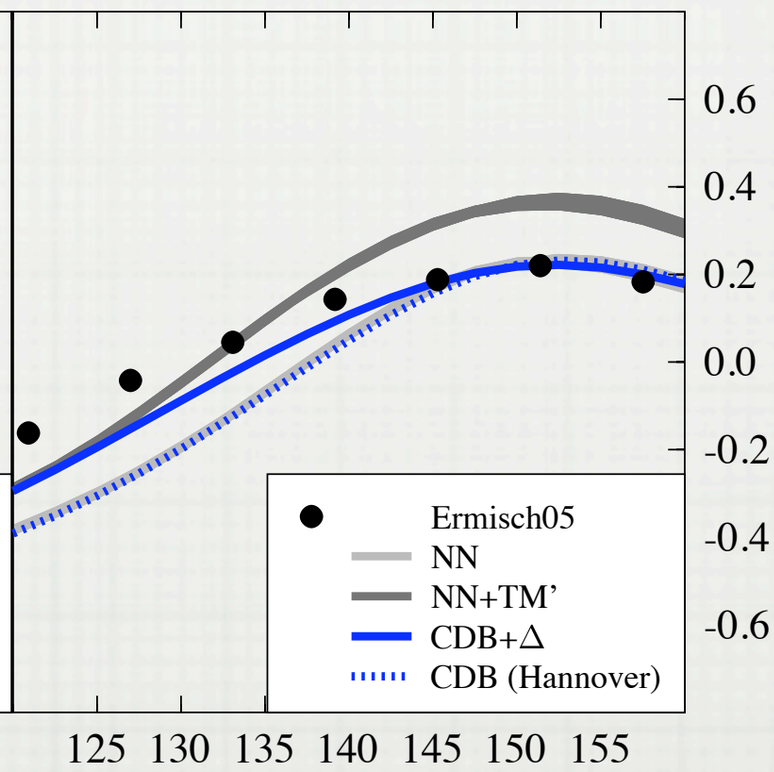
SPIN OBSERVABLES IN PD BREAK-UP

(@190 MEV)

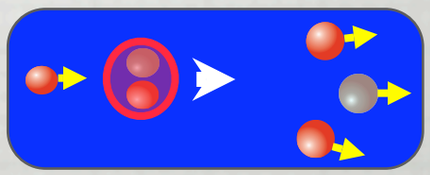
p+d→^{2}He+n



p+d→d+p

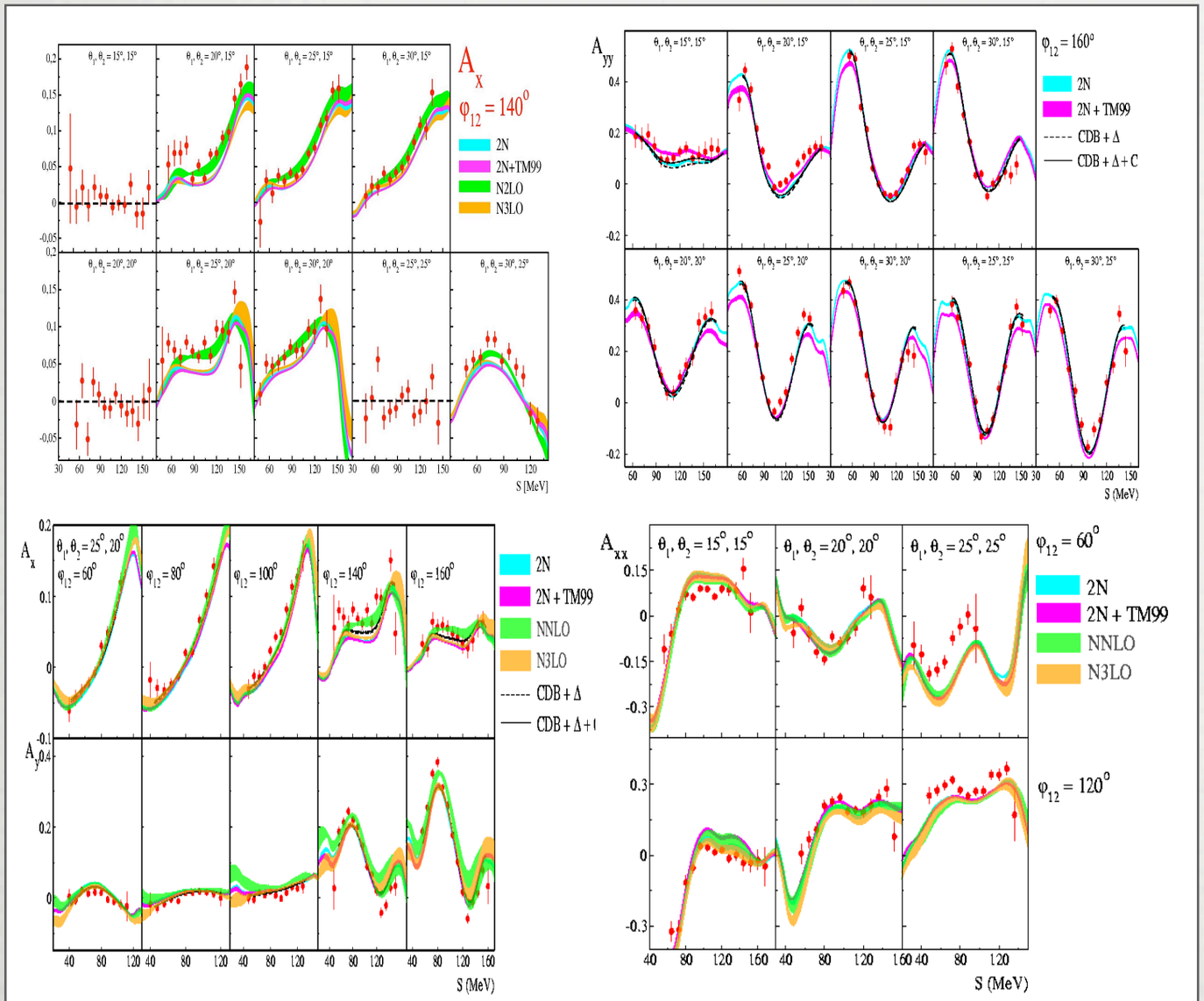


spin-isospin selectivity ?

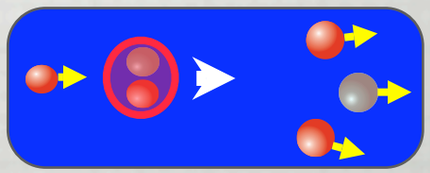


DP BREAK-UP @ 65 MEV/NUCLEON

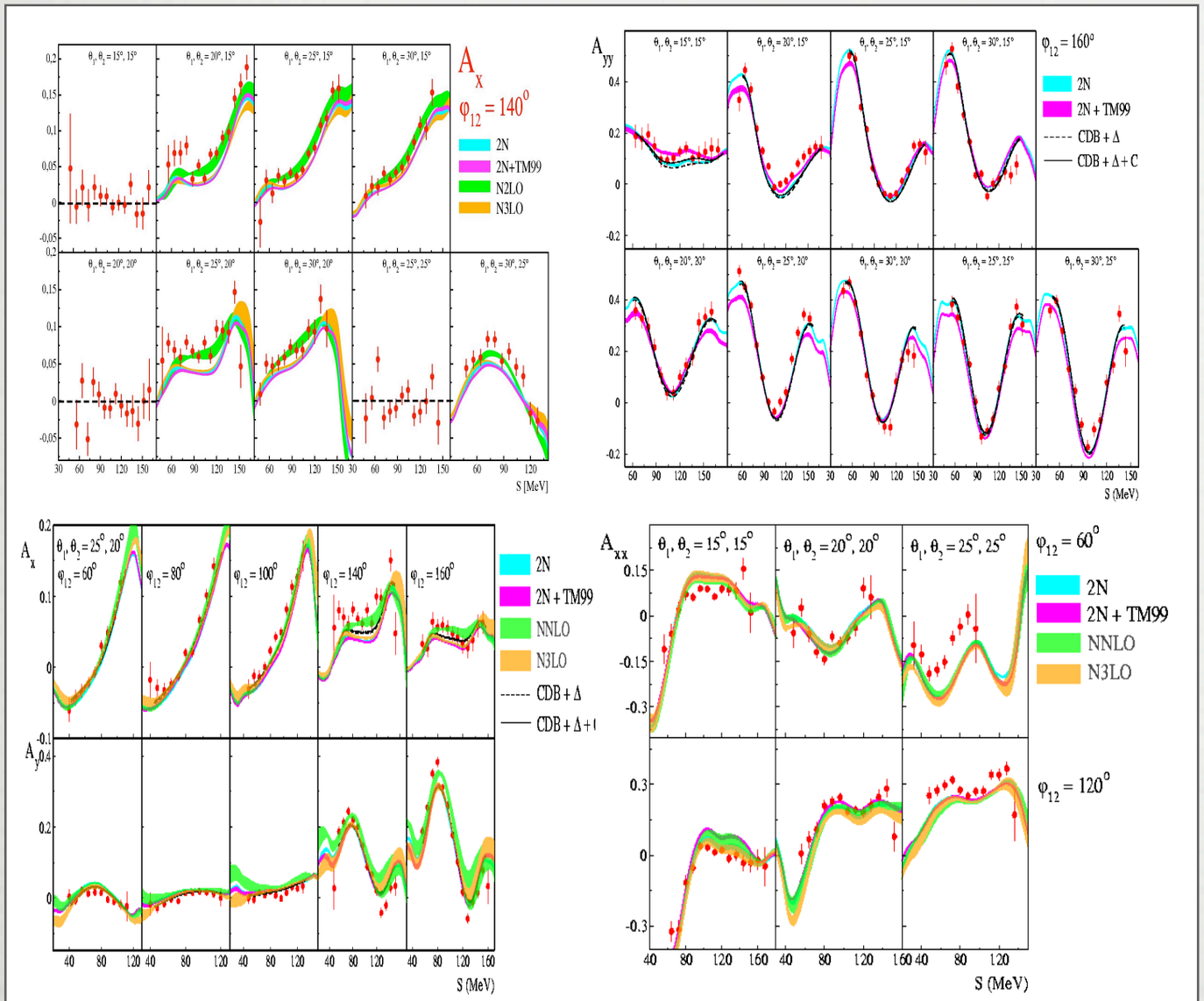
Stephan et al., PRC76, 057001 (2007)



...and many more configurations!!
(~1000 points per observable)



DP BREAK-UP @ 65 MEV/NUCLEON



...and many more configurations!!
(~1000 points per observable)

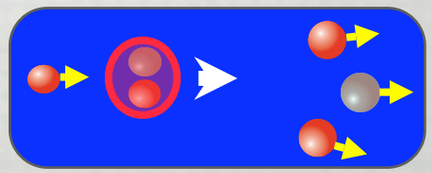
Stephan et al., PRC76, 057001 (2007)

Chi-square analysis of a huge data set in the break-up reaction at 65 A MeV

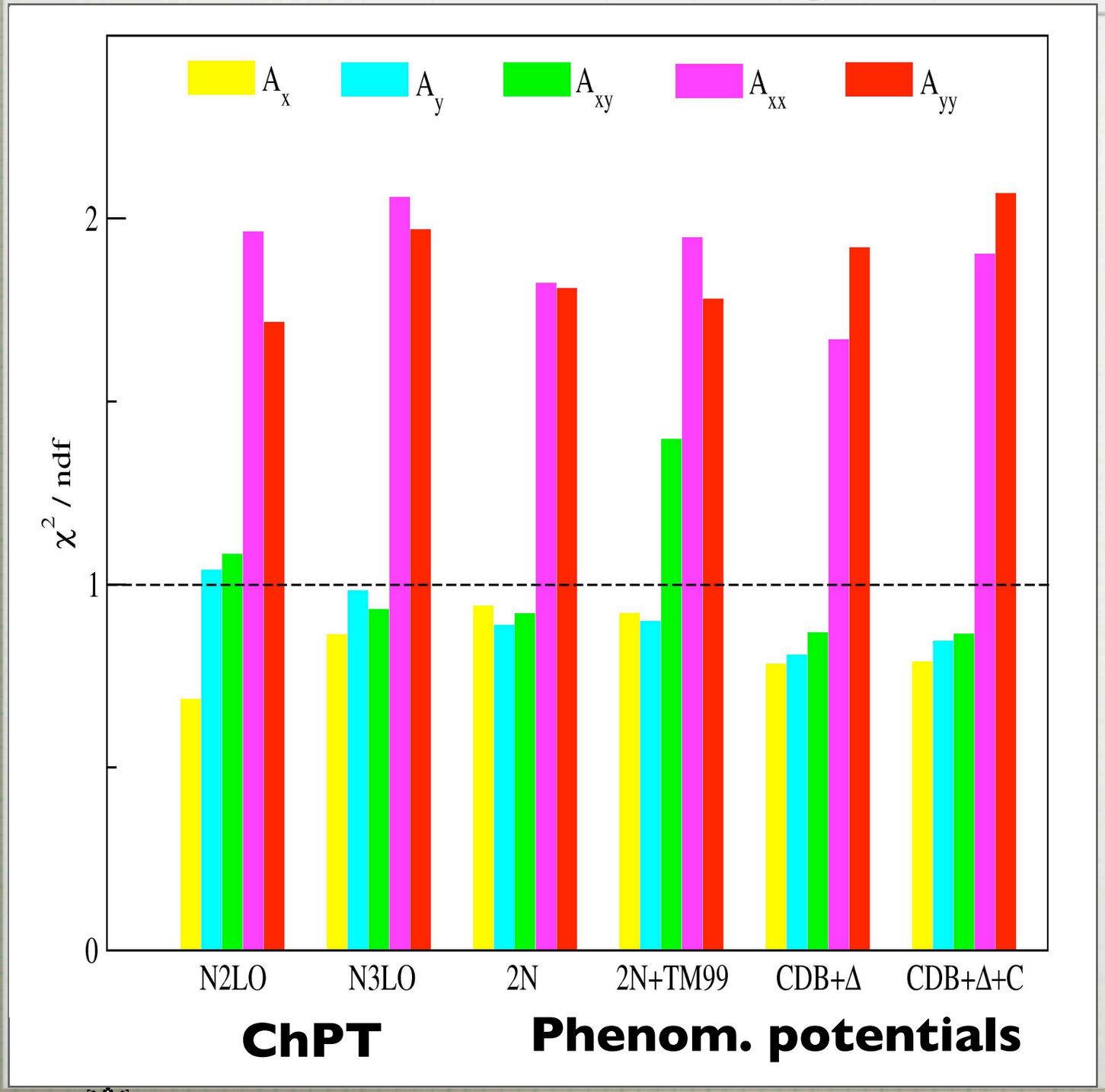
Persistent discrepancies for tensor analyzing powers

<u>data</u>: SALAD (Cracow-Katowice-KVI)

<u>theory</u>: Bochum-Juelich/ Bochum-Cracow/ Hannover-Lisbon



DP BREAK-UP @ 65 MEV/NUCLEON



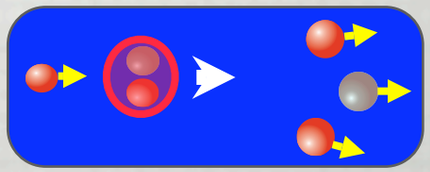
Stephan et al., PRC76, 057001 (2007)

Chi-square analysis of a huge data set in the break-up reaction at 65 A MeV

Persistent discrepancies for tensor analyzing powers

data: SALAD (Cracow-Katowice-KVI)

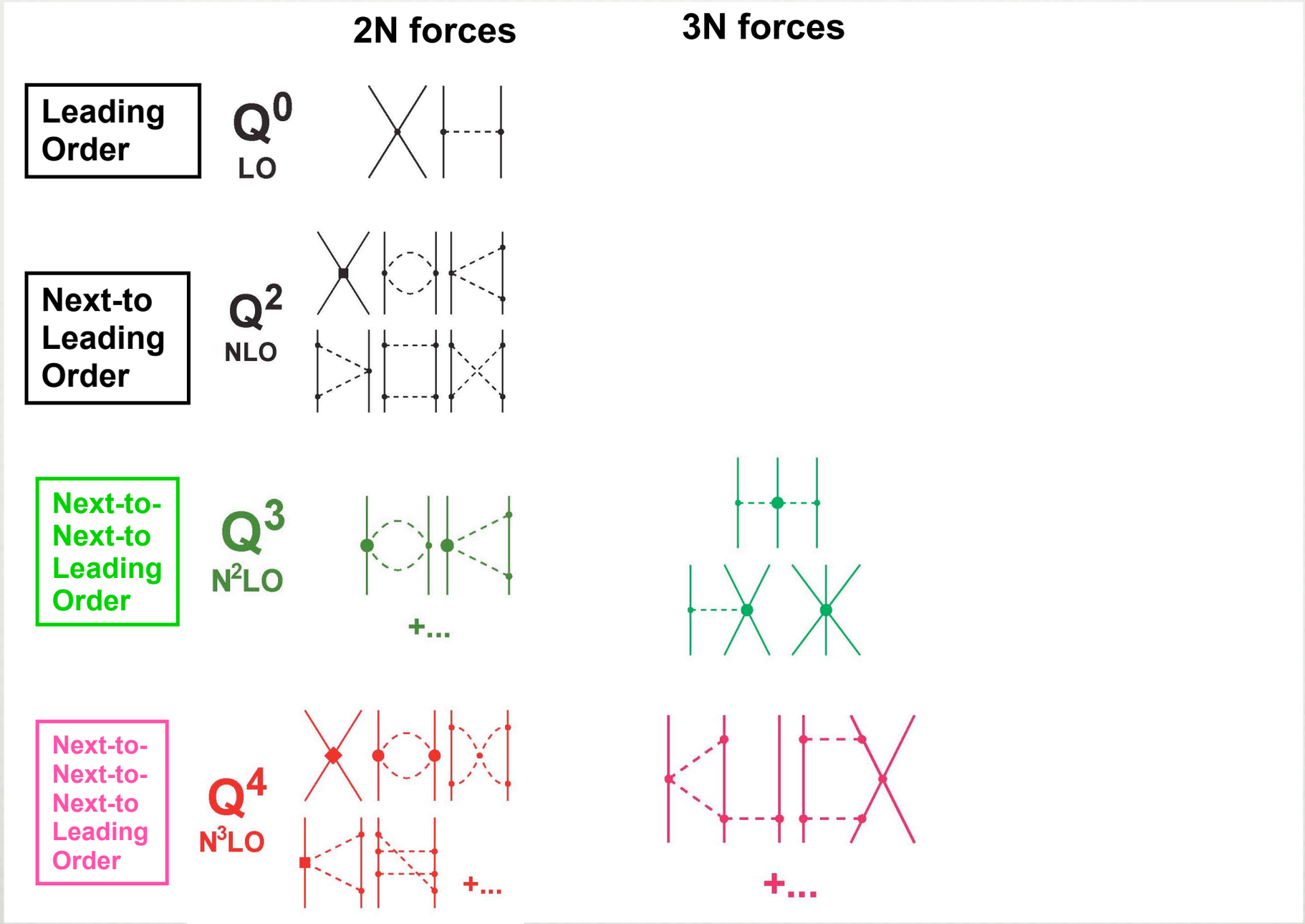
theory: Bochum-Juelich/ Bochum-Cracow/ Hannover-Lisbon



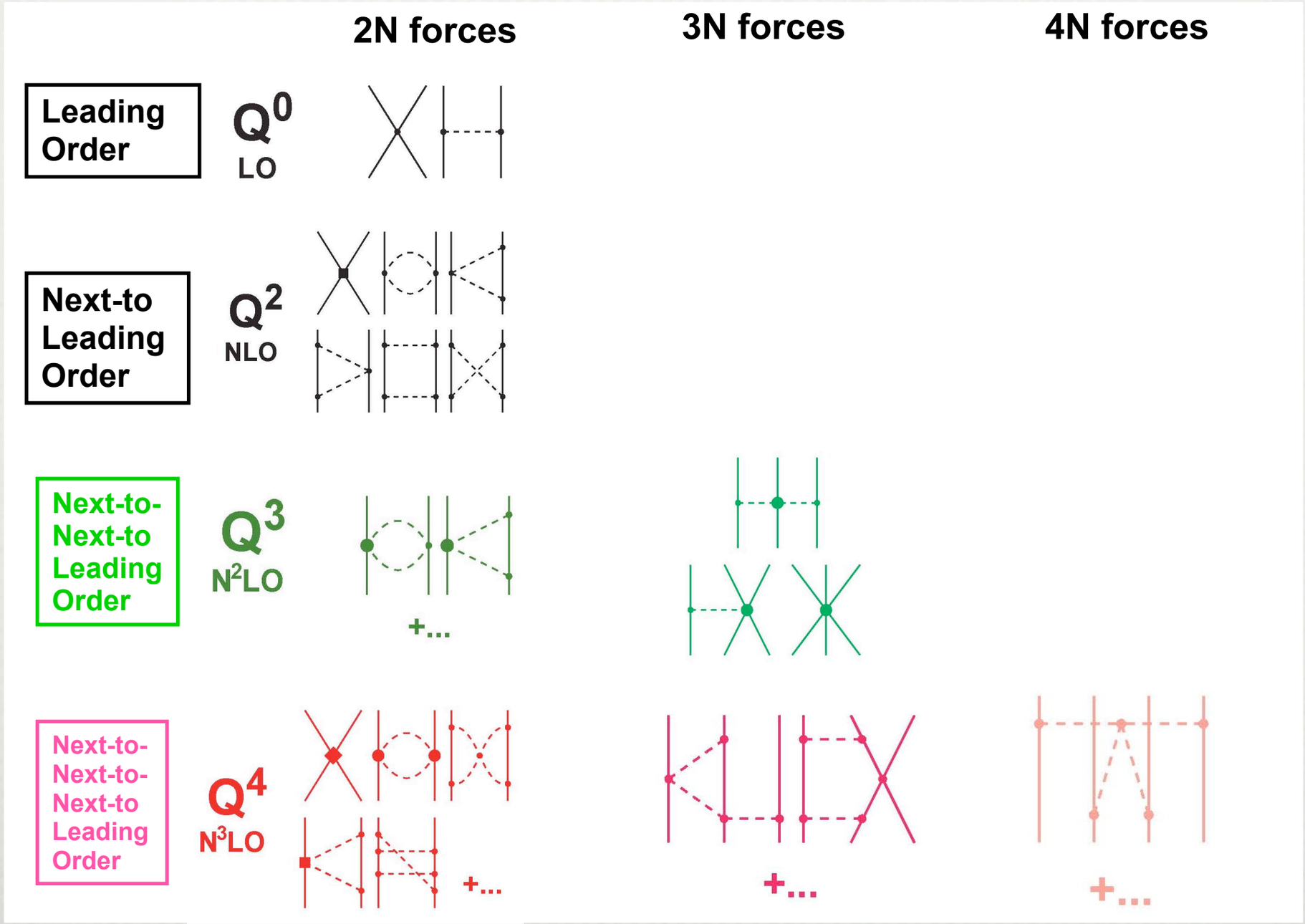
FOUR-NUCLEON SYSTEMS

"THE NEXT CHALLENGE..."

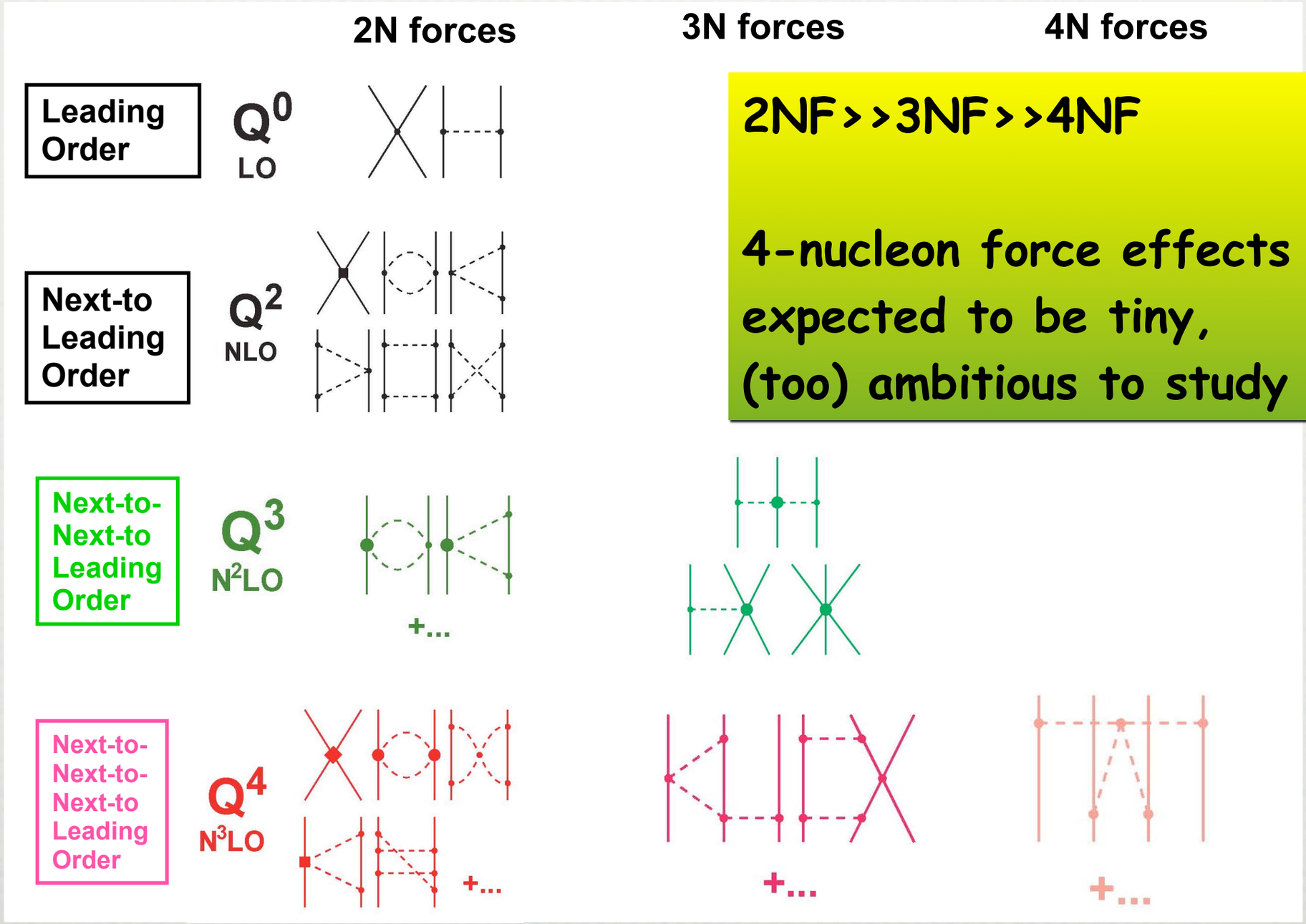
4NF EFFECTS?


2N forces
3N forces
Leading Order
Q^0
LO
Next-to Leading Order
Q^2
NLO
Next-to-Next-to Leading Order
Q^3
N^2LO
+...
Next-to-Next-to-Next-to Leading Order
Q^4
N^3LO
+...
+...

4NF EFFECTS?


2N forces
3N forces
4N forces
Leading Order
Q^0
LO
Next-to Leading Order
Q^2
NLO
Next-to-Next-to Leading Order
Q^3
N^2LO
+...
Next-to-Next-to-Next-to Leading Order
Q^4
N^3LO
+...
+...
+...

4NF EFFECTS?



2NF>>3NF>>4NF

4-nucleon force effects are expected to be tiny, (too) ambitious to study

WHAT TO LEARN FROM A 4-NUCLEON SYSTEM?

WHAT TO LEARN FROM A 4-NUCLEON SYSTEM?

Three-nucleon force effects! But magnified!

Increase in sensitivity with larger A expected

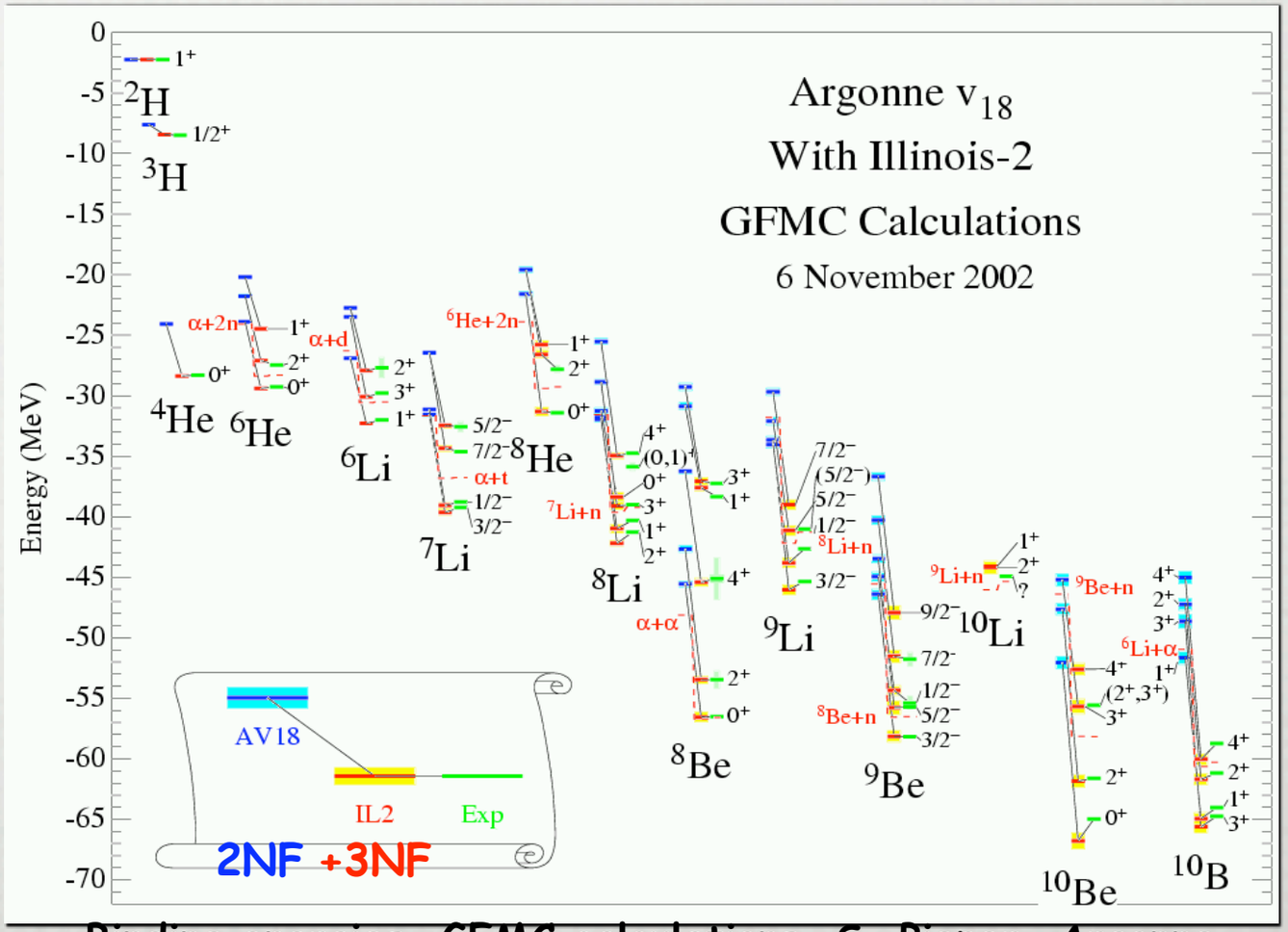
Unexplored territory at intermediate energies!!!

WHAT TO LEARN FROM A 4-NUCLEON SYSTEM?

Three-nucleon force effects! But magnified!

Increase in sensitivity with larger A expected

Unexplored territory at intermediate energies!!!



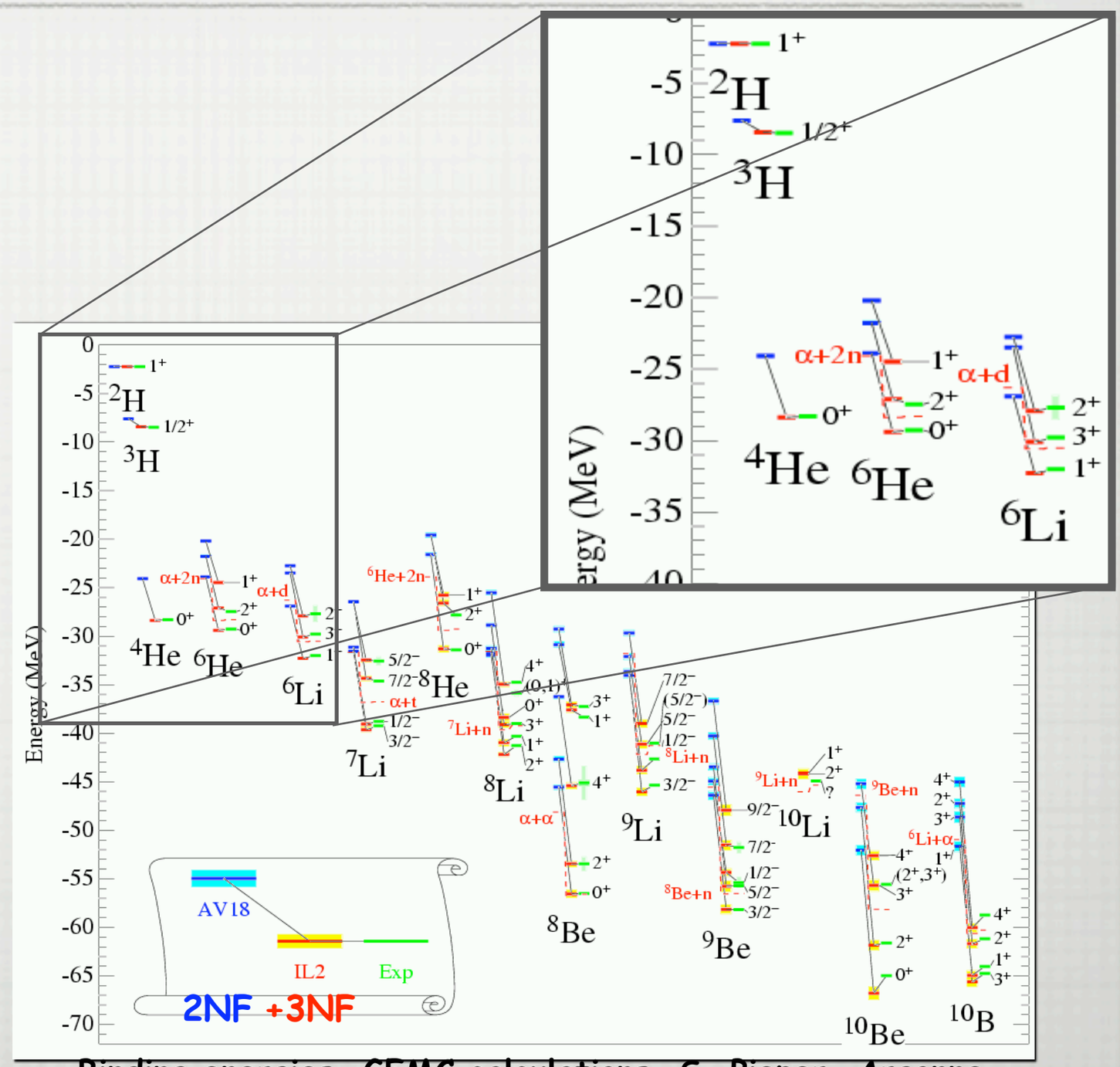
Binding energies, GFMC calculations, S. Pieper, Argonne

WHAT TO LEARN FROM A 4-NUCLEON SYSTEM?

Three-nucleon force effects! But magnified!

Increase in sensitivity with larger A expected

Unexplored territory at intermediate energies!!!



Binding energies, GFMC calculations, S. Pieper, Argonne

D+D SCATTERING AT 65 MEV/NUCLEON

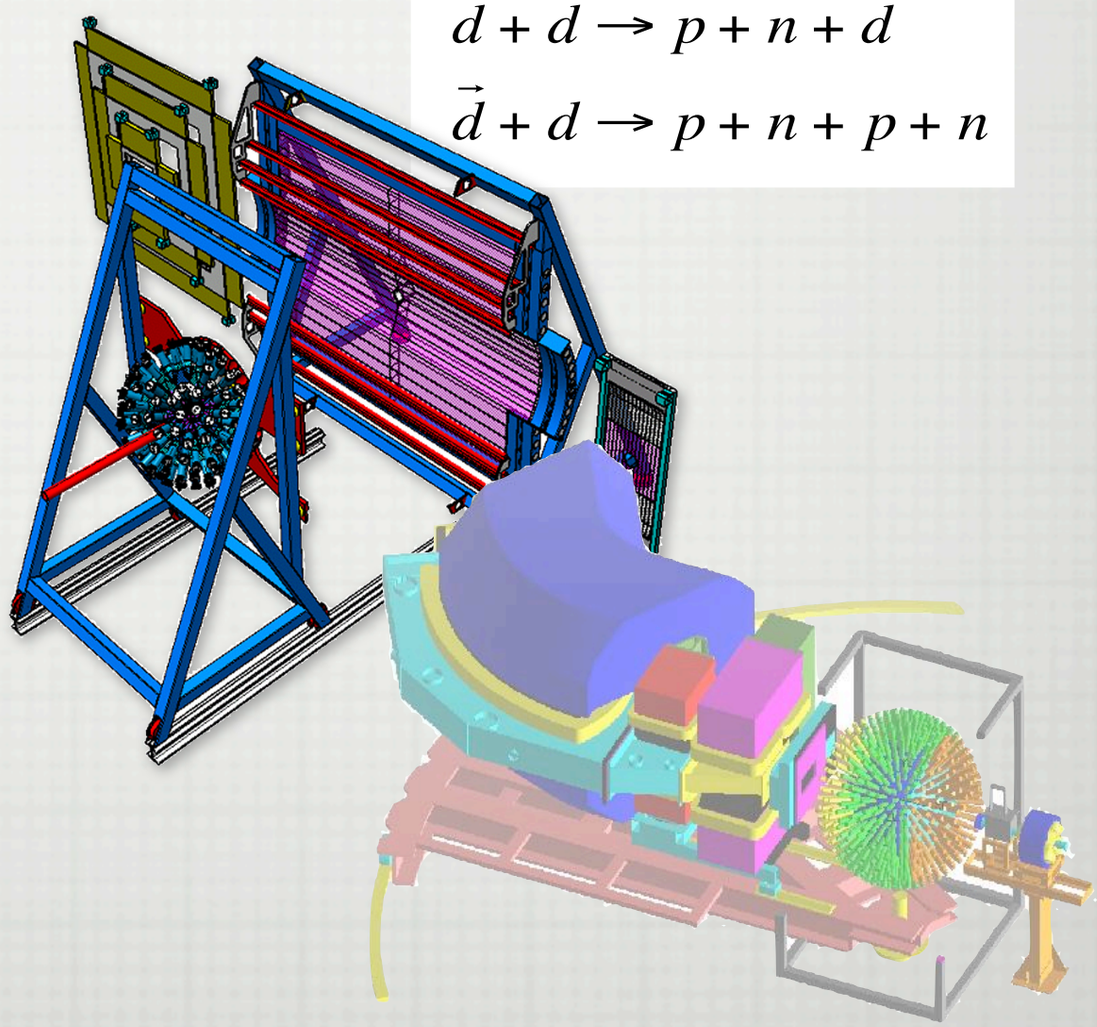
$$\vec{d} + d \rightarrow d + d$$

$$\vec{d} + d \rightarrow n + {}^{3}\mathrm{He}$$

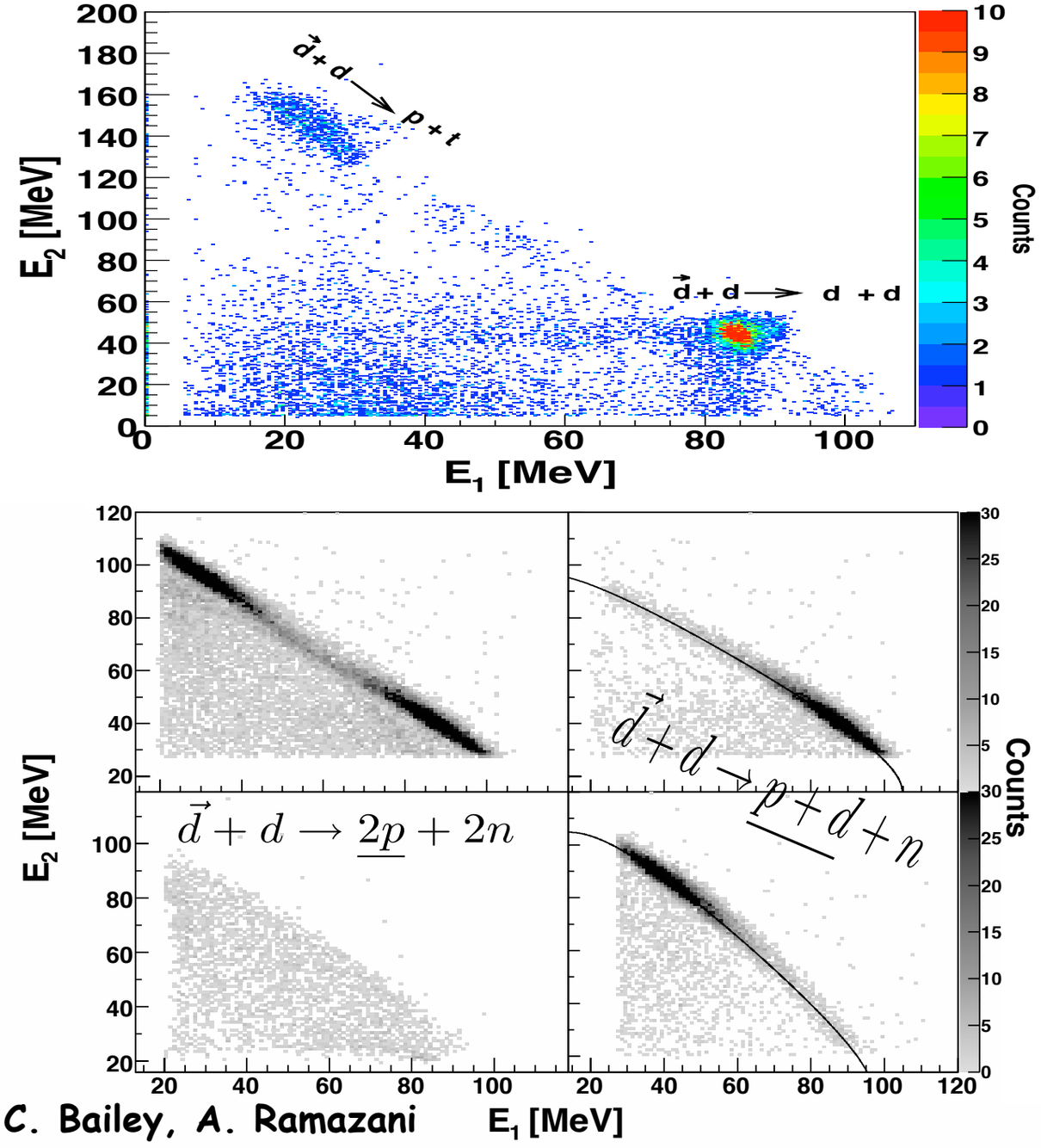
$$\vec{d} + d \rightarrow p + t$$

$$\vec{d} + d \rightarrow p + n + d$$

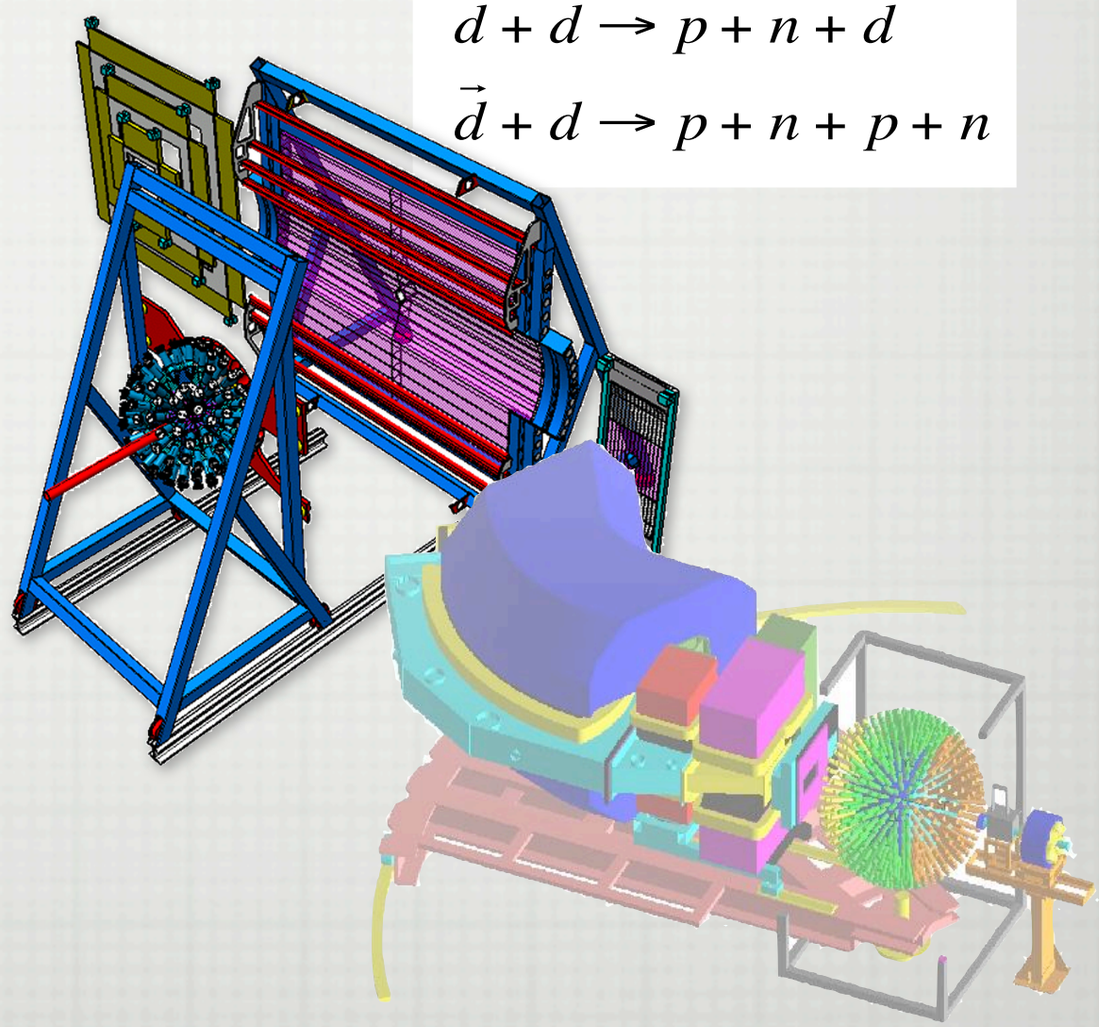
$$\vec{d} + d \rightarrow p + n + p + n$$



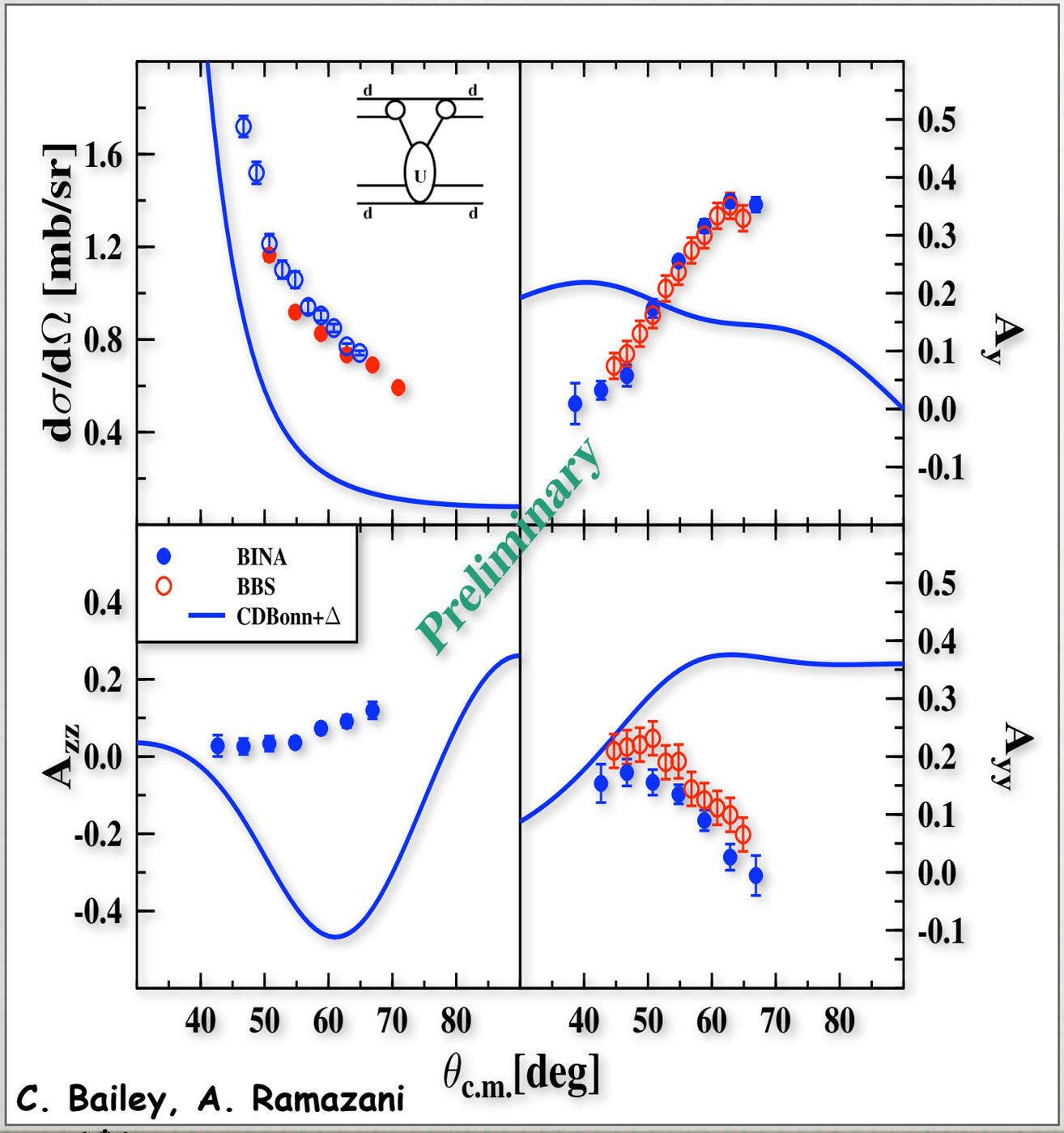
D+D SCATTERING AT 65 MEV/NUCLEON



$$\vec{d} + d \rightarrow d + d$$
$$\vec{d} + d \rightarrow n + {}^3\mathrm{He}$$
$$\vec{d} + d \rightarrow p + t$$
$$\vec{d} + d \rightarrow p + n + d$$
$$\vec{d} + d \rightarrow p + n + p + n$$



D+D SCATTERING AT 65 MEV/NUCLEON



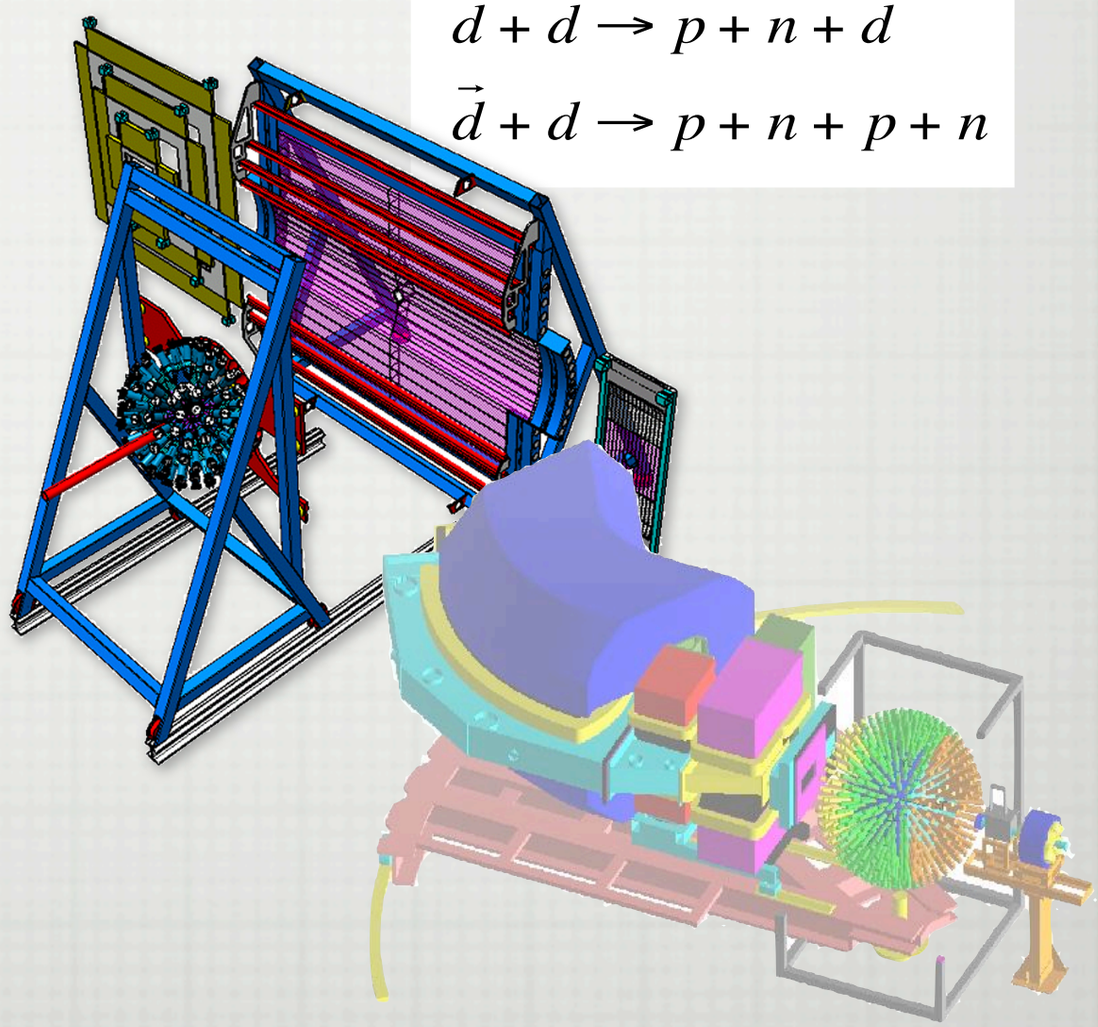
$$\vec{d} + d \rightarrow d + d$$

$$\vec{d} + d \rightarrow n + {}^{3}\mathrm{He}$$

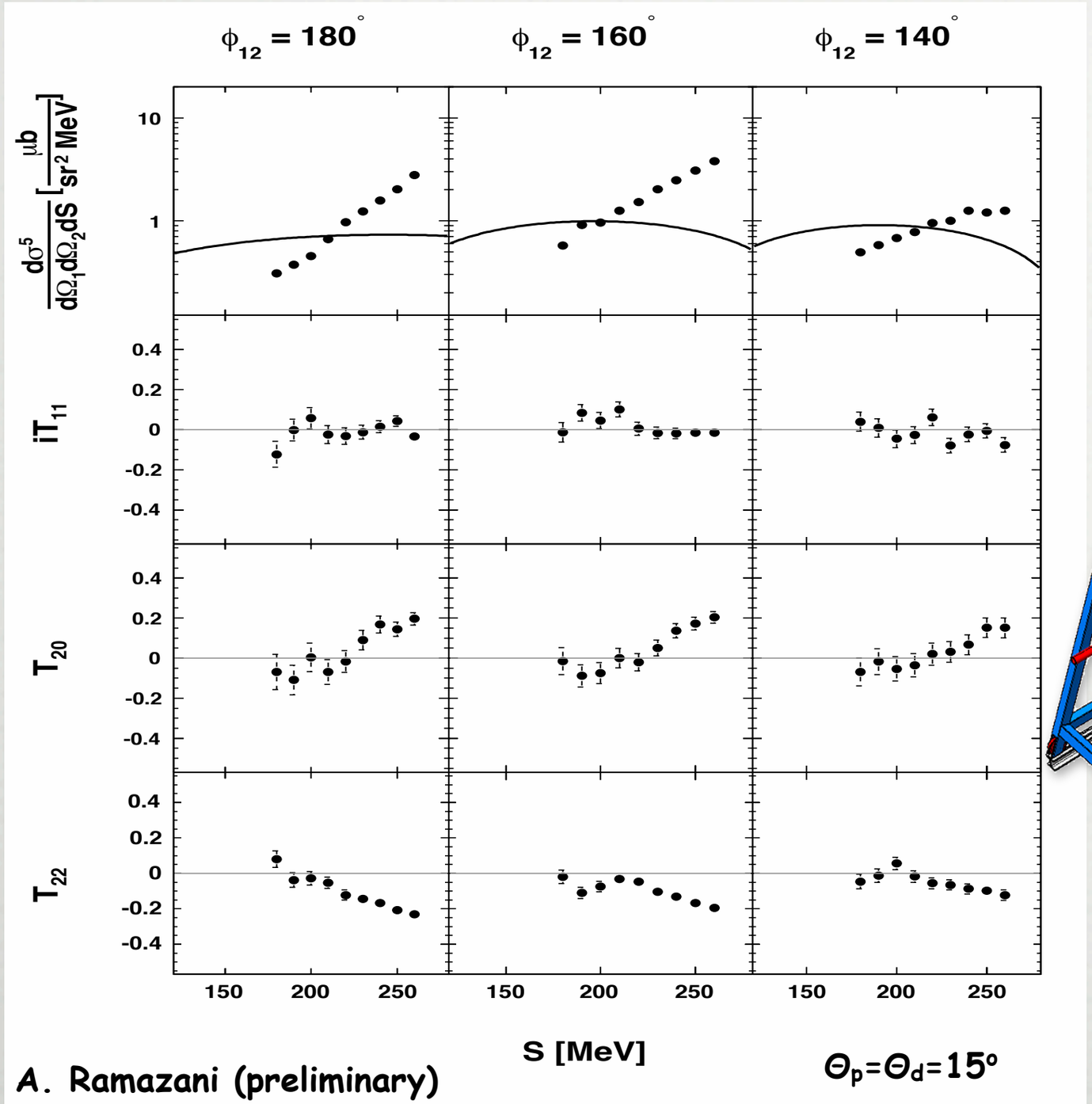
$$\vec{d} + d \rightarrow p + t$$

$$\vec{d} + d \rightarrow p + n + d$$

$$\vec{d} + d \rightarrow p + n + p + n$$



D+D SCATTERING AT 65 MEV/NUCLEON



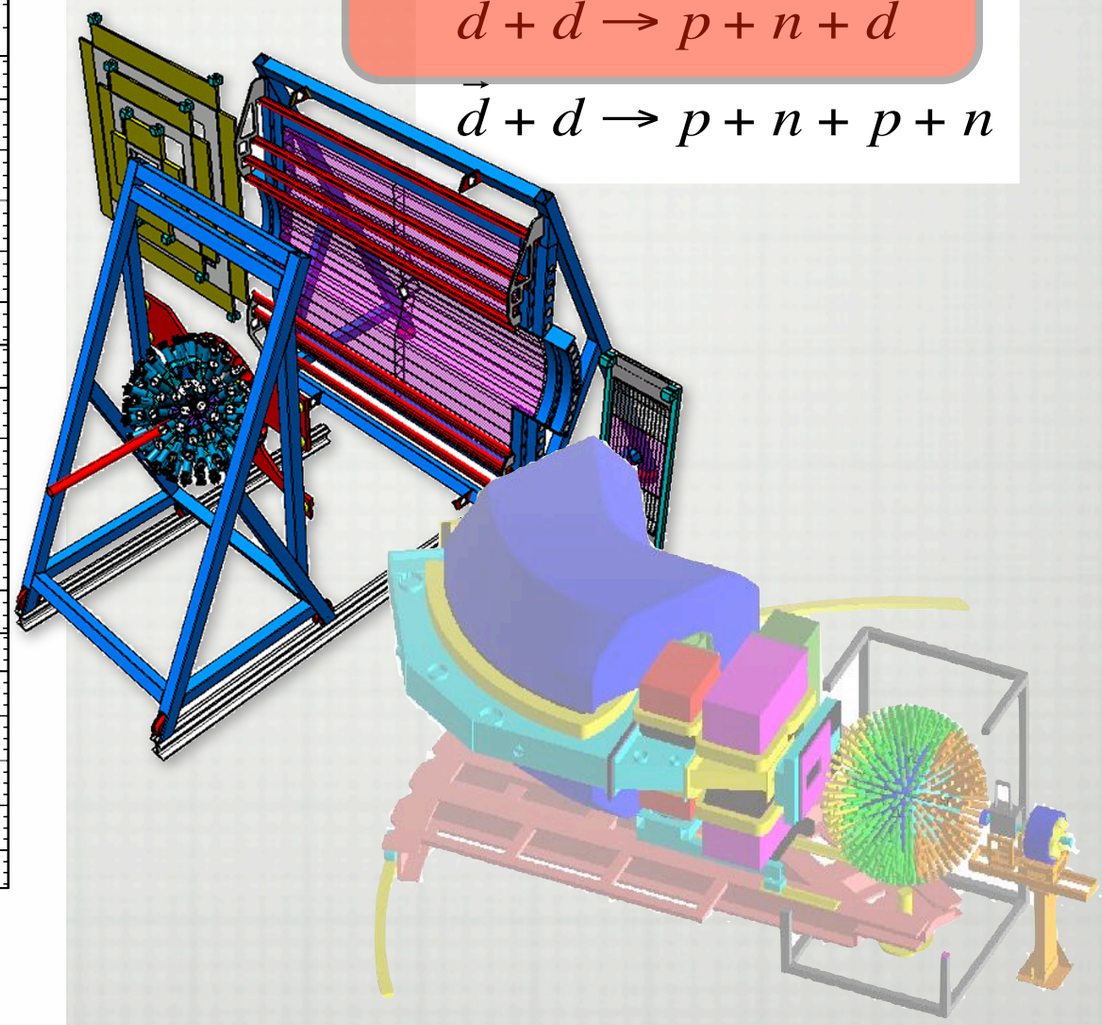
$$\vec{d} + d \rightarrow d + d$$

$$\vec{d} + d \rightarrow n + {}^3\mathrm{He}$$

$$\vec{d} + d \rightarrow p + t$$

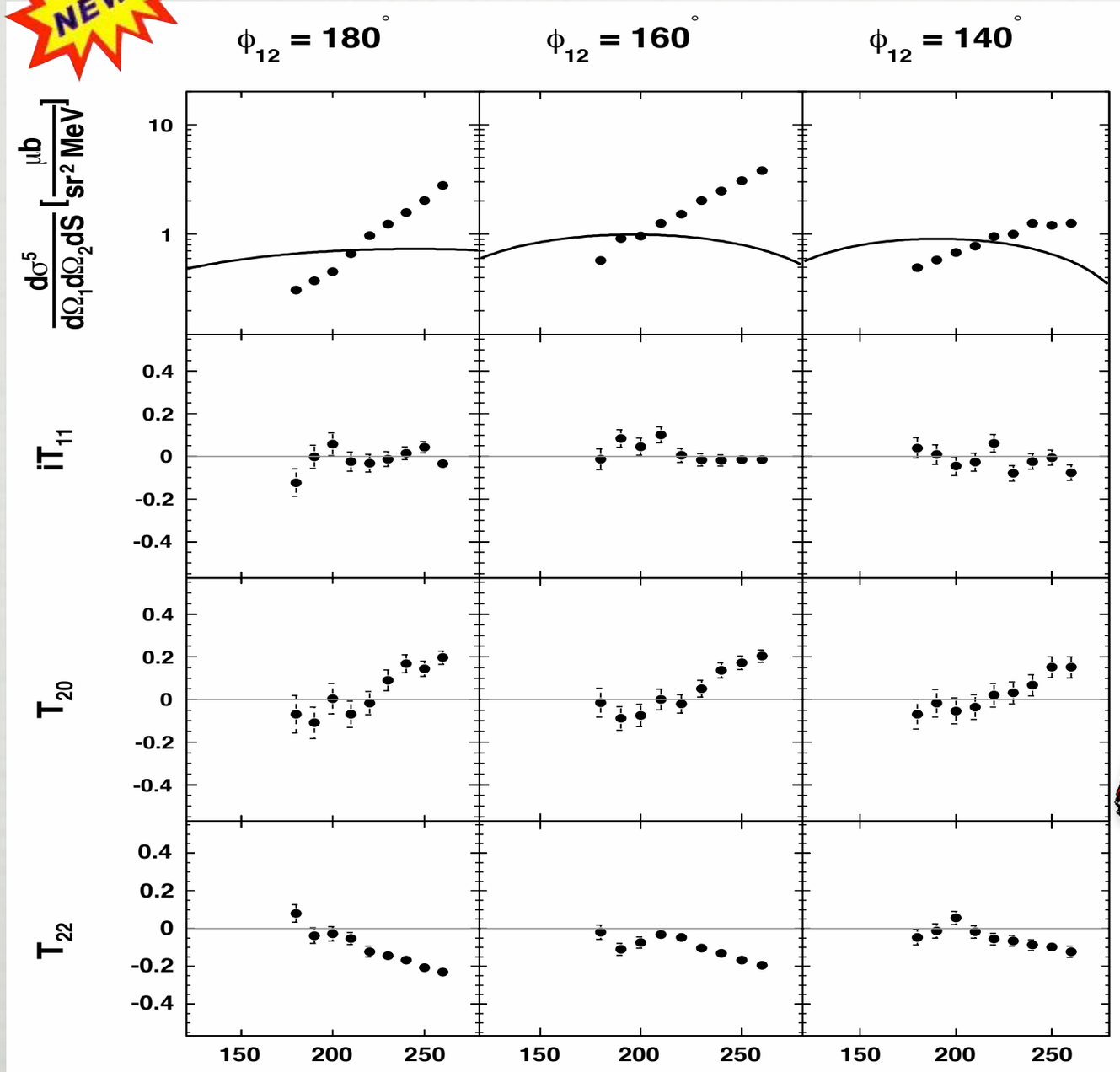
$$\vec{d} + d \rightarrow p + n + d$$

$$\vec{d} + d \rightarrow p + n + p + n$$



D+D SCATTERING AT 65 MEV/NUCLEON

NEW!



A. Ramazani (preliminary)

$\Theta_p = \Theta_d = 15^\circ$

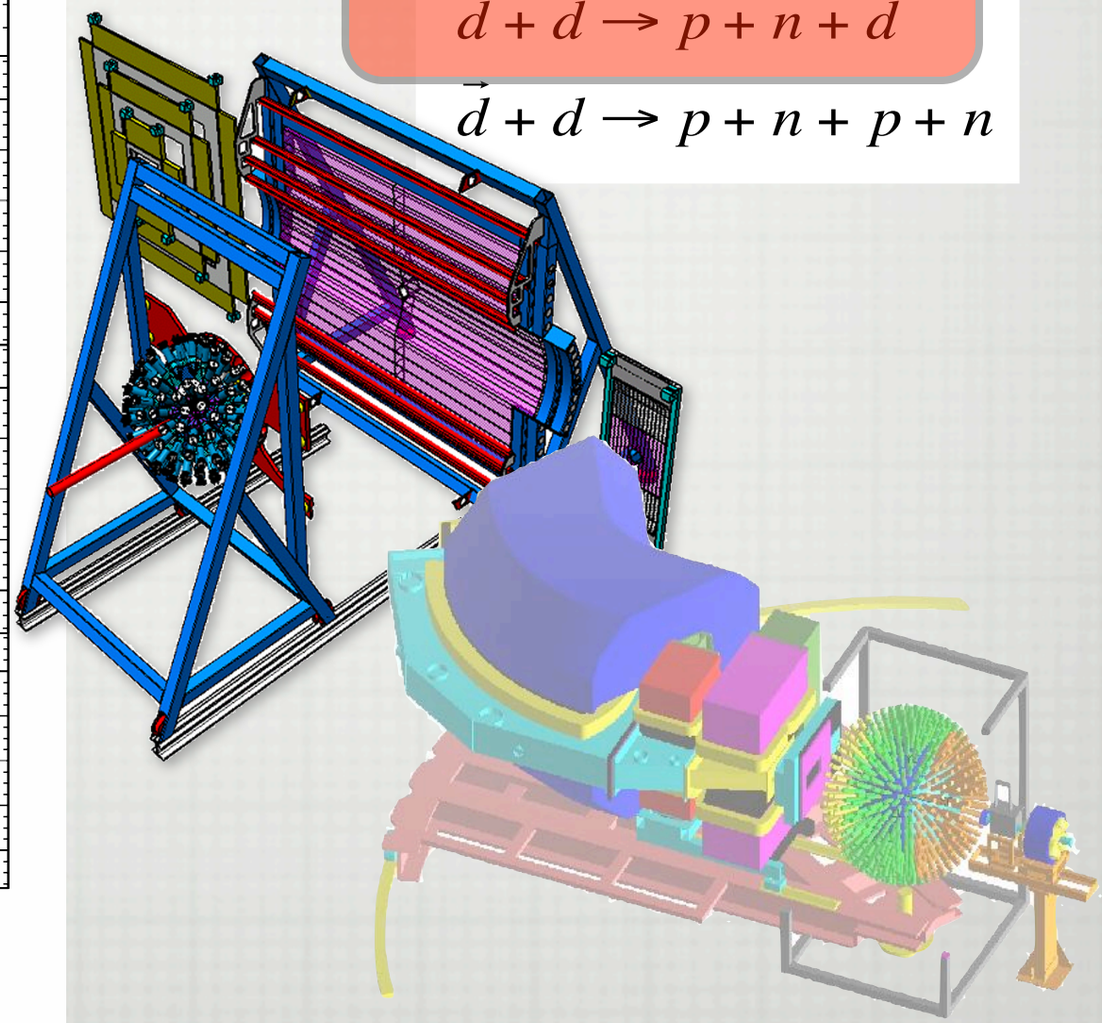
$\vec{d} + d \rightarrow d + d$

$\vec{d} + d \rightarrow n + {}^3\mathrm{He}$

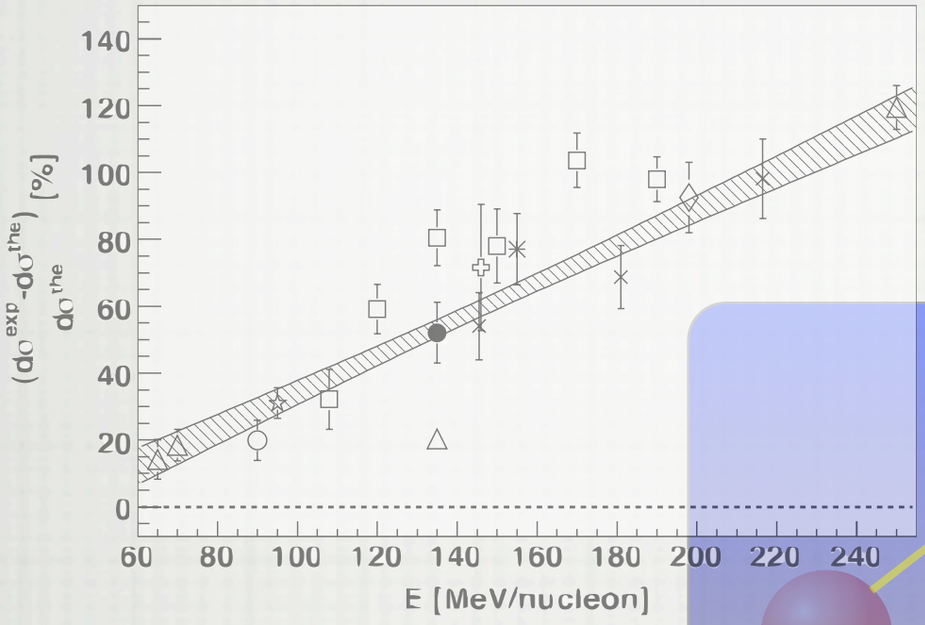
$\vec{d} + d \rightarrow p + t$

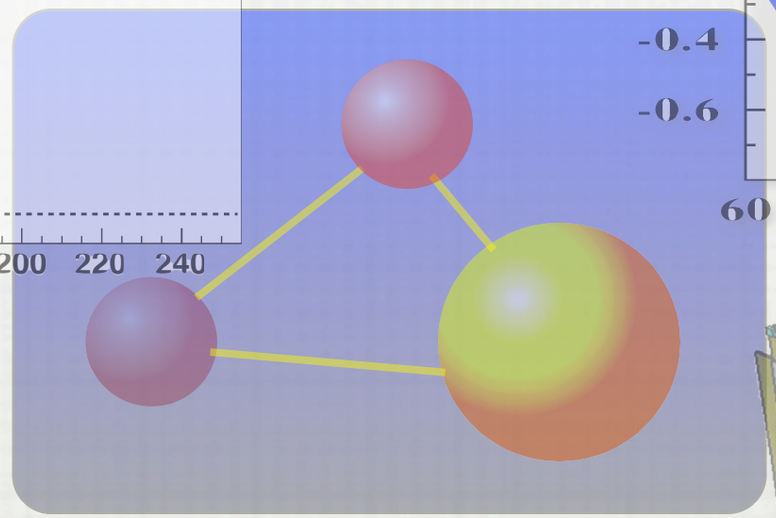
$\vec{d} + d \rightarrow p + n + d$

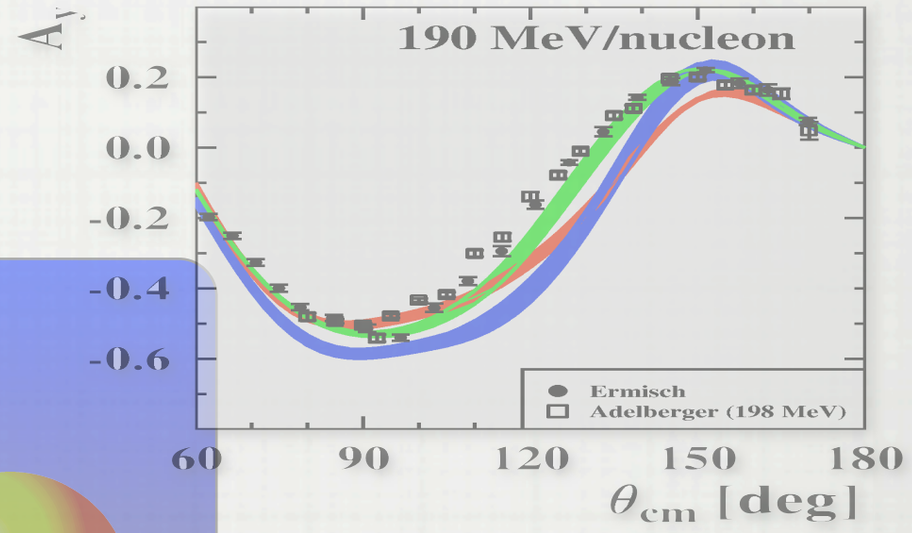
$\vec{d} + d \rightarrow p + n + p + n$

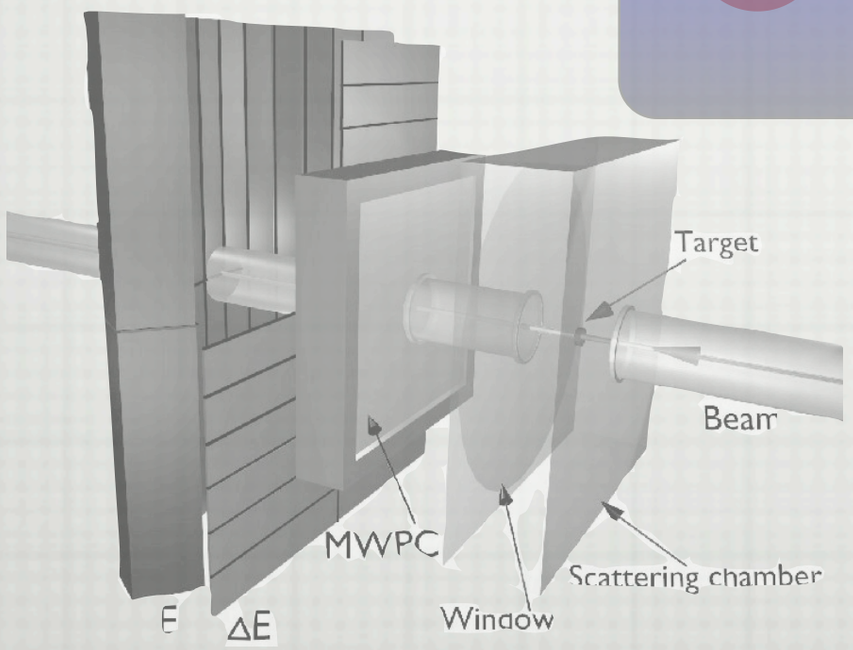


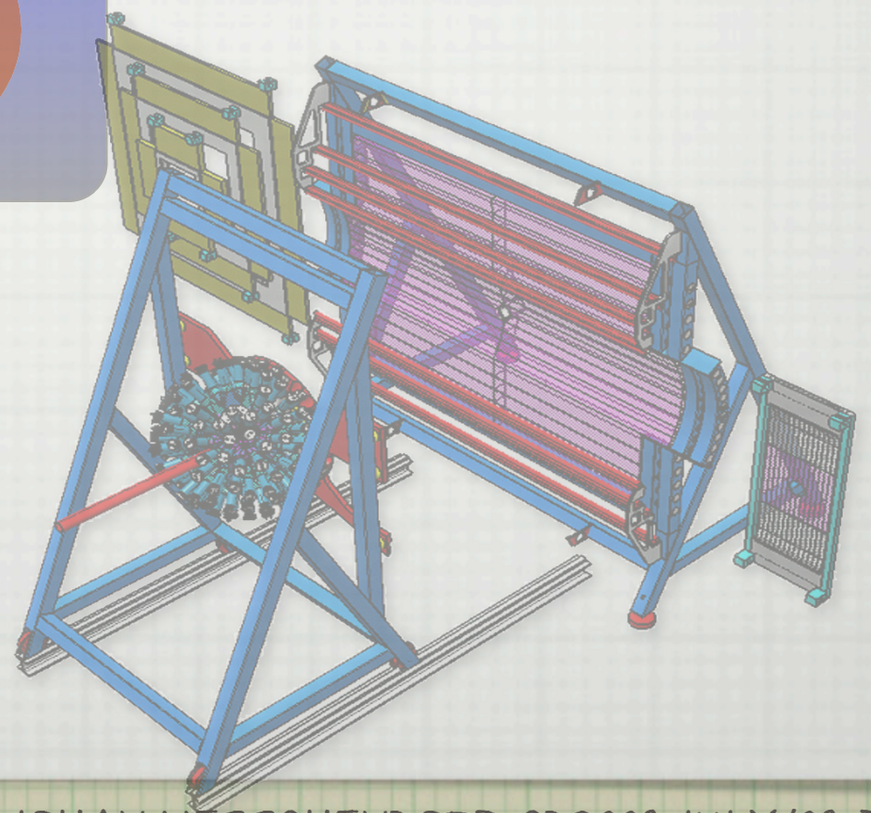
(2,3,4)-NUCLEON SCATTERING AT INTERMEDIATE ENERGIES





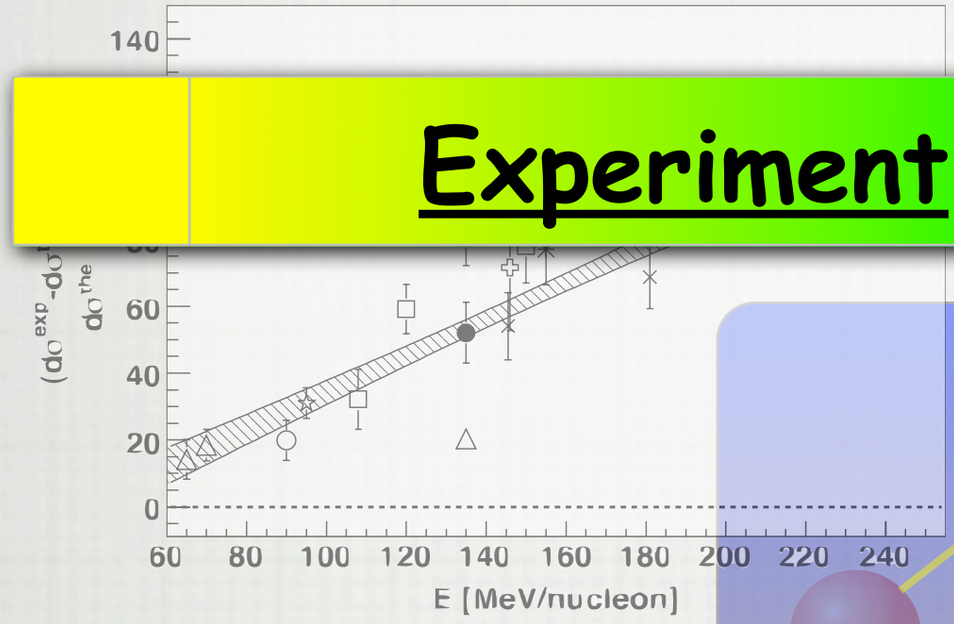


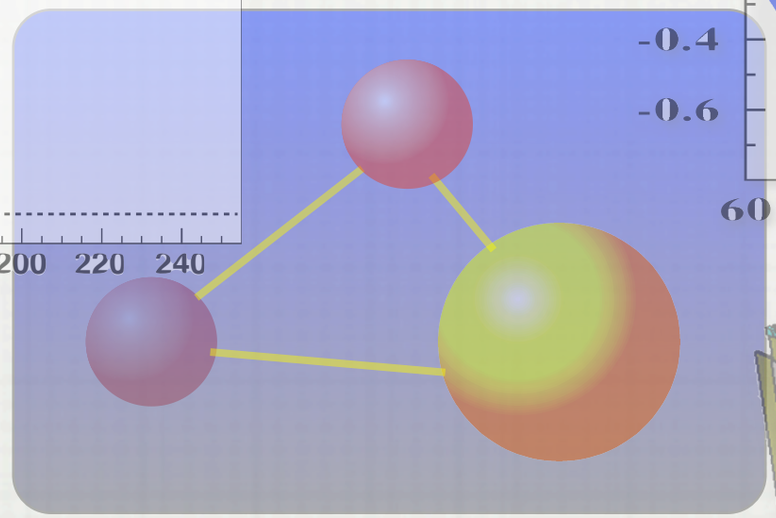


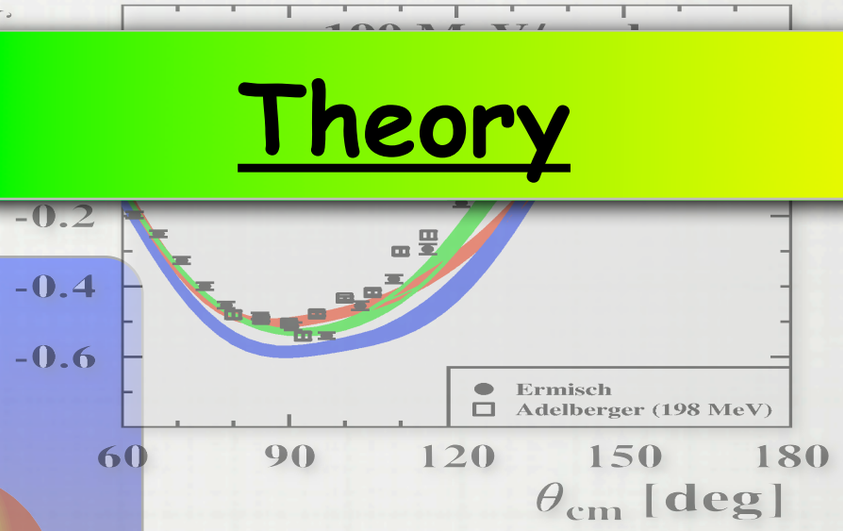


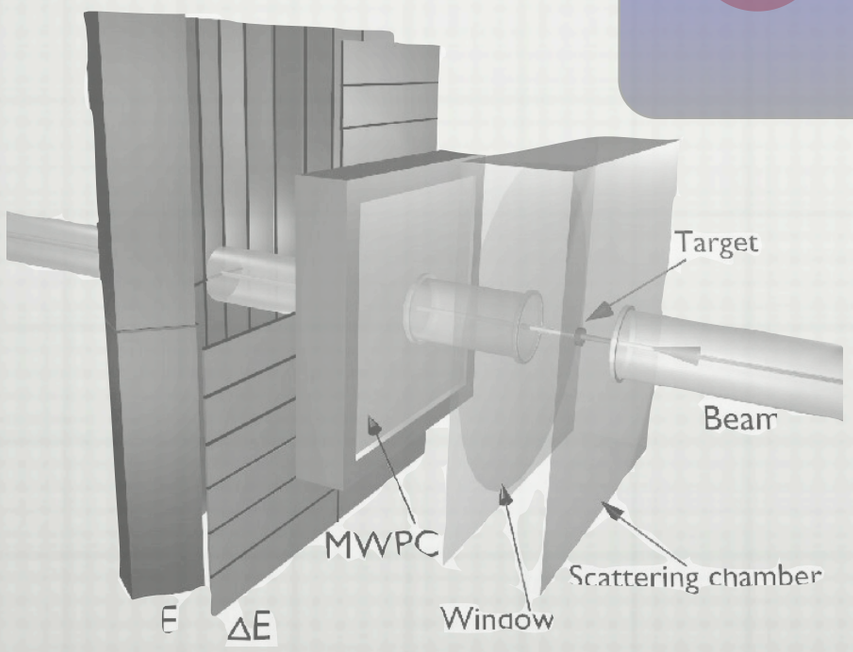
(2,3,4)-NUCLEON SCATTERING AT INTERMEDIATE ENERGIES

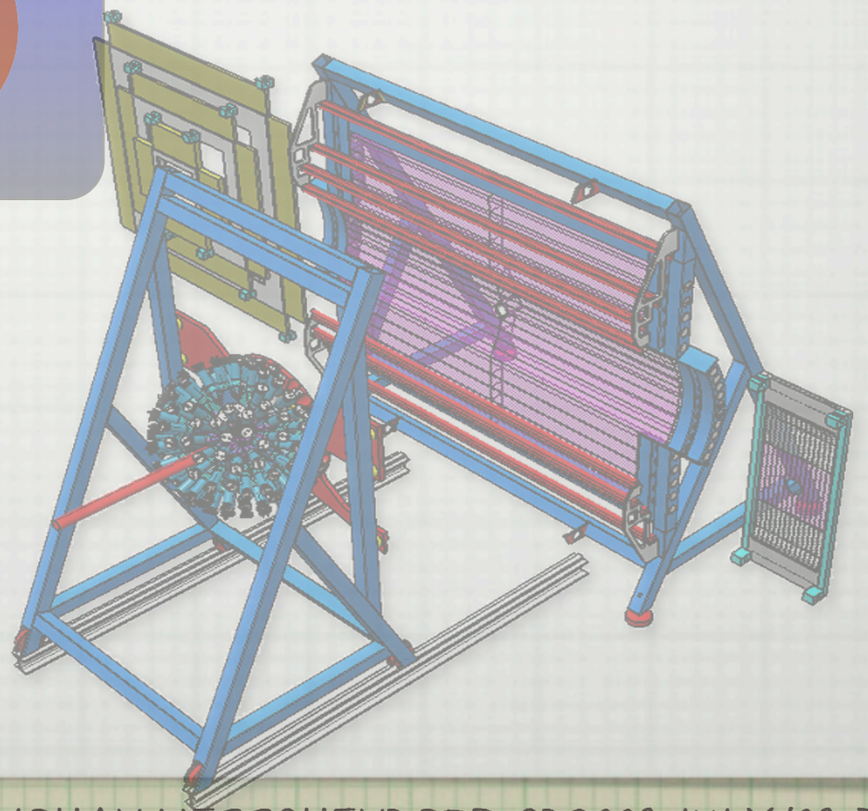
Experiment | **Theory**





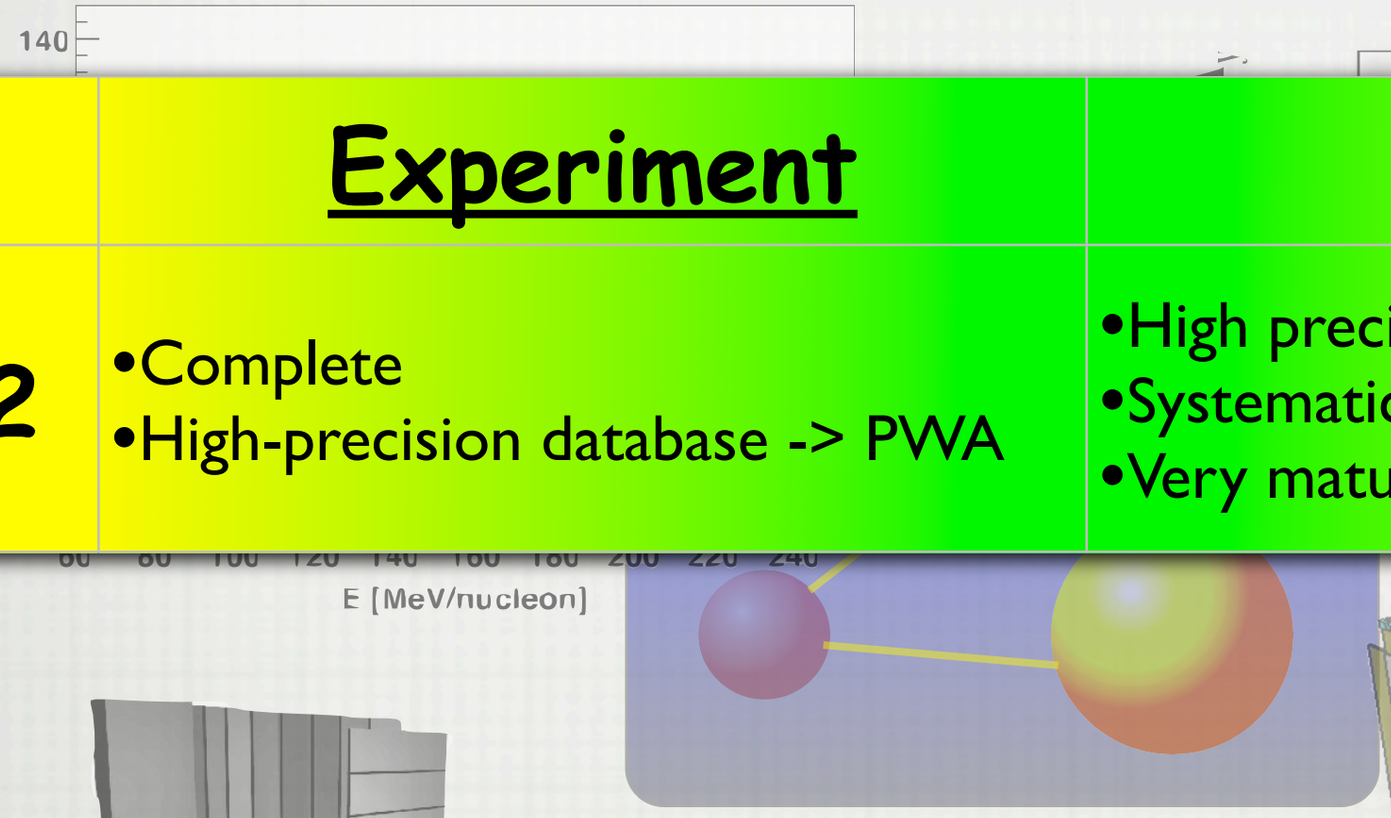


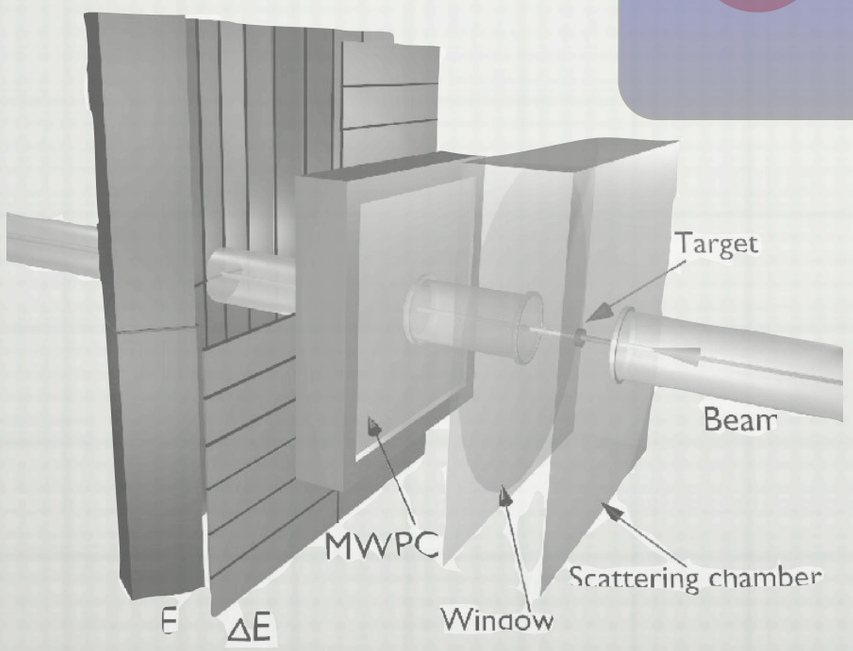


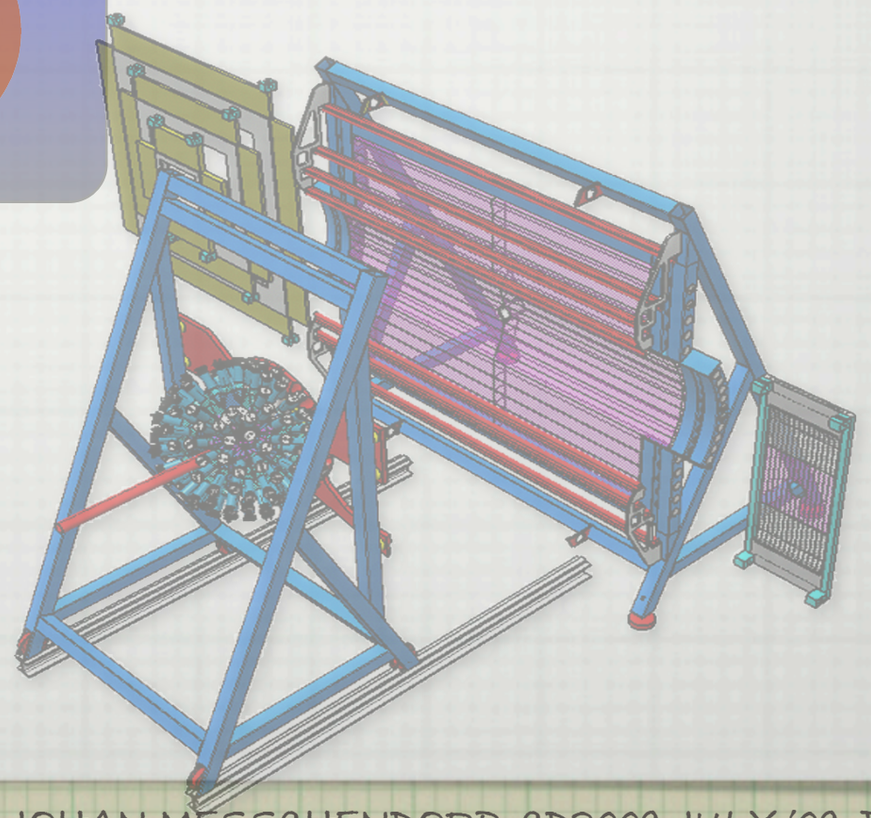


(2,3,4)-NUCLEON SCATTERING AT INTERMEDIATE ENERGIES

	Experiment	Theory
2	•Complete •High-precision database -> PWA	•High precision OBE & PWA •Systematic EFT based on ChPT •Very mature

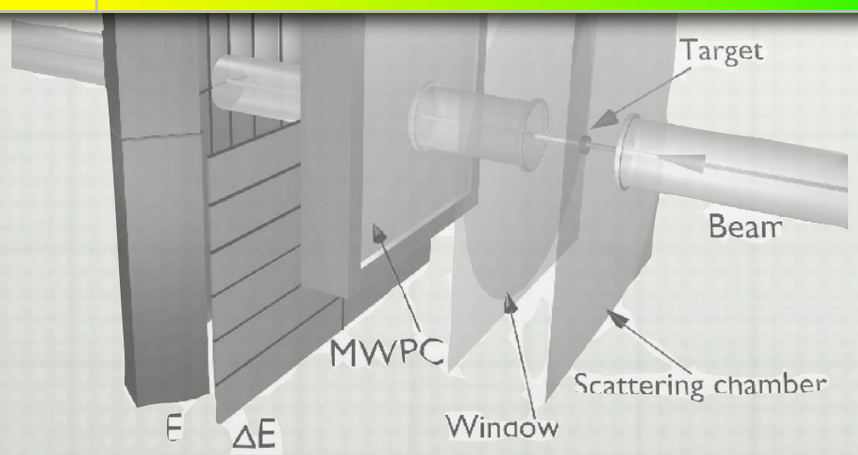






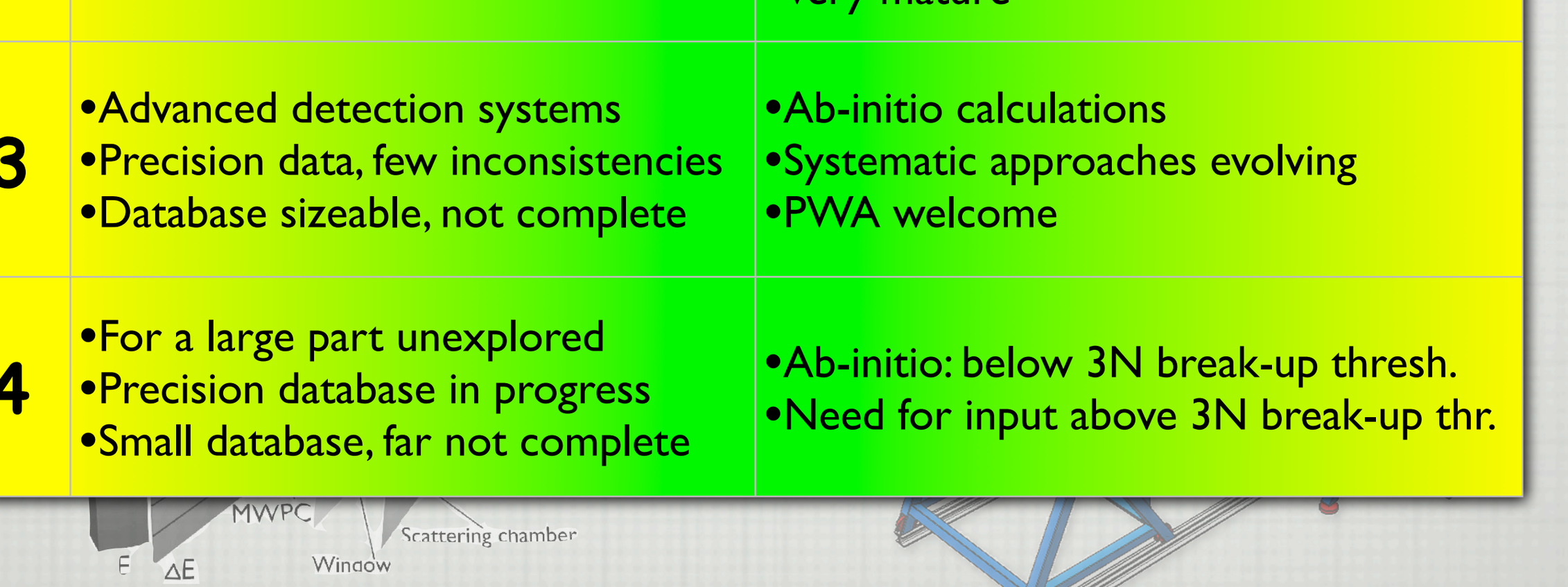
(2,3,4)-NUCLEON SCATTERING AT INTERMEDIATE ENERGIES

	Experiment	Theory
2	•Complete •High-precision database -> PWA	•High precision OBE & PWA •Systematic EFT based on ChPT •Very mature
3	•Advanced detection systems •Precision data, few inconsistencies •Database sizeable, not complete	•Ab-initio calculations •Systematic approaches evolving •PWA welcome



(2,3,4)-NUCLEON SCATTERING AT INTERMEDIATE ENERGIES

	Experiment	Theory
2	•Complete •High-precision database -> PWA	•High precision OBE & PWA •Systematic EFT based on ChPT •Very mature
3	•Advanced detection systems •Precision data, few inconsistencies •Database sizeable, not complete	•Ab-initio calculations •Systematic approaches evolving •PWA welcome
4	•For a large part unexplored •Precision database in progress •Small database, far not complete	•Ab-initio: below 3N break-up thresh. •Need for input above 3N break-up thr.



THANKS TO...

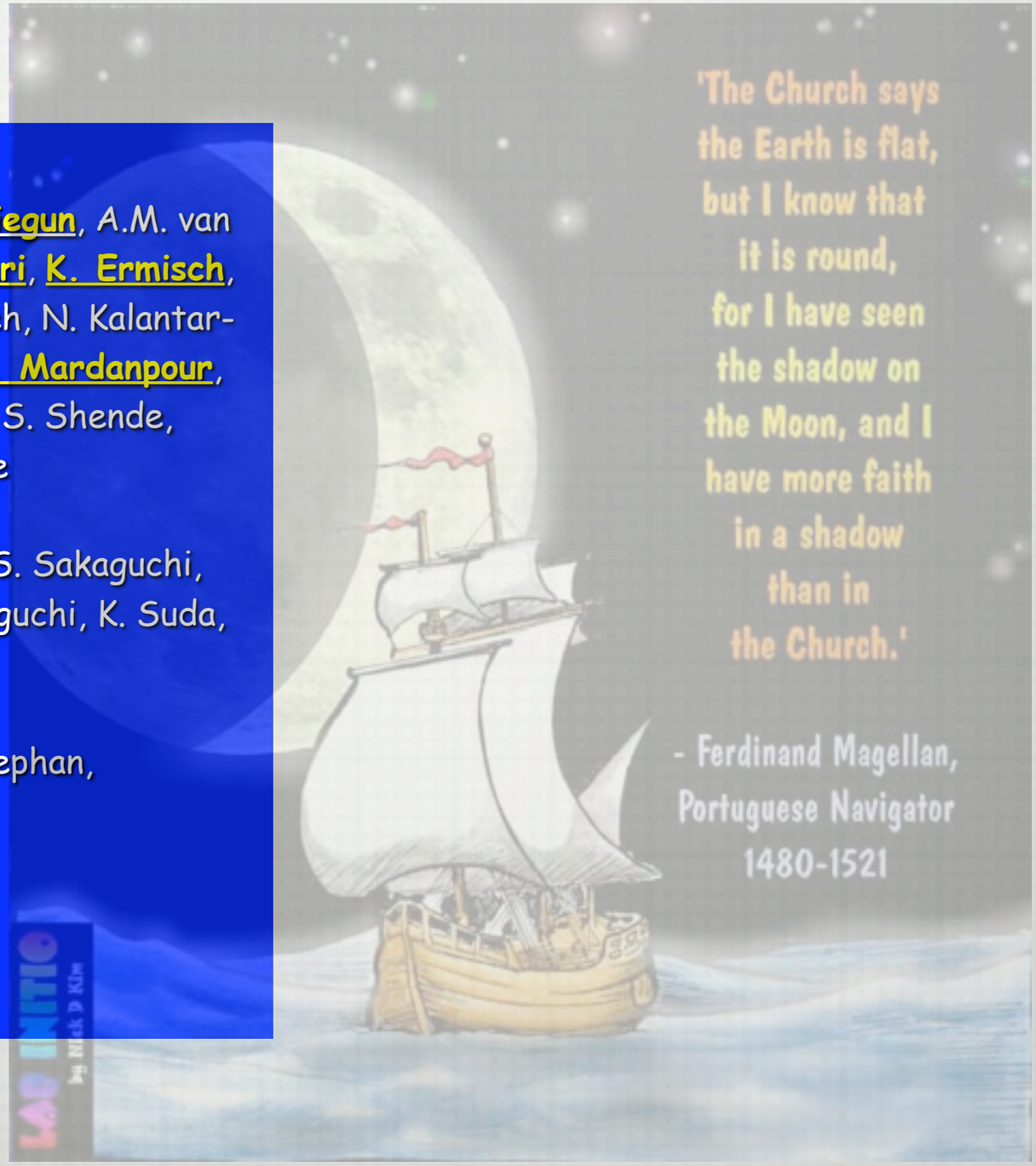
KVI Group: H. Amir Ahmadi, J.C.S. Bacelar, R. Benard, **A. Biegun**, A.M. van den Berg, R. Castelijns, L. Dieperink, **M. Eslami-Kalantari**, **K. Ermisch**, E. van Garderen, I. Gasparic, M. Harakeh, L. Joulaeizadeh, N. Kalantar-Nayestanaki, M. Kis, H. Loehner, M. Mahjour-Shafiei, **H. Mardanpour**, A. Mehmandoost, H. Moeini, **A. Ramazani**, O. Scholten, S. Shende, R.G.E. Timmermans, S.Y. van der Werf, and H. Woertche

Japanese Group: K. Itoh, T. Kawabata, H. Kuboki, Y. Maeda, S. Sakaguchi, H. Sakai, N. Sakalmoto, Y. Sasamoto, M. Sasano, K. Sekiguchi, K. Suda, Y. Takahashi, T. Uesaka, and K. Yako

Polish Group: K. Bodek, St. Kistryn, A. Mischerdzinska, E. Stephan, **R. Sworst**, J. Zejma, and W. Zipper

IUCF Group: A.D. Bacher, **C.D. Bailey**, and E. Stephenson

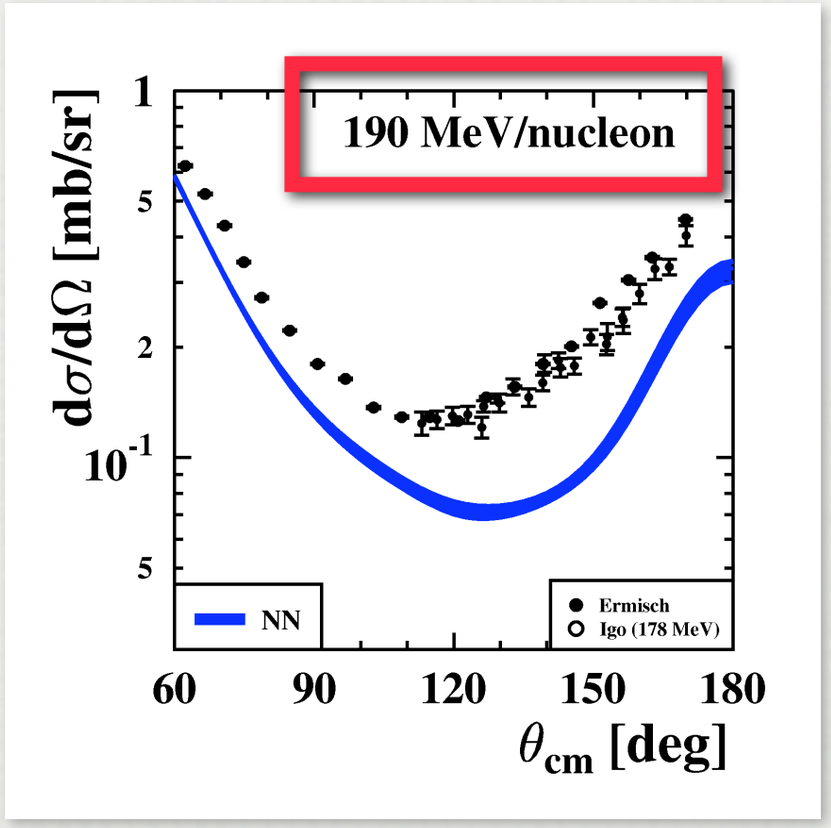
Bochum-Cracow and **Hanover-Lisbon Theory Groups**

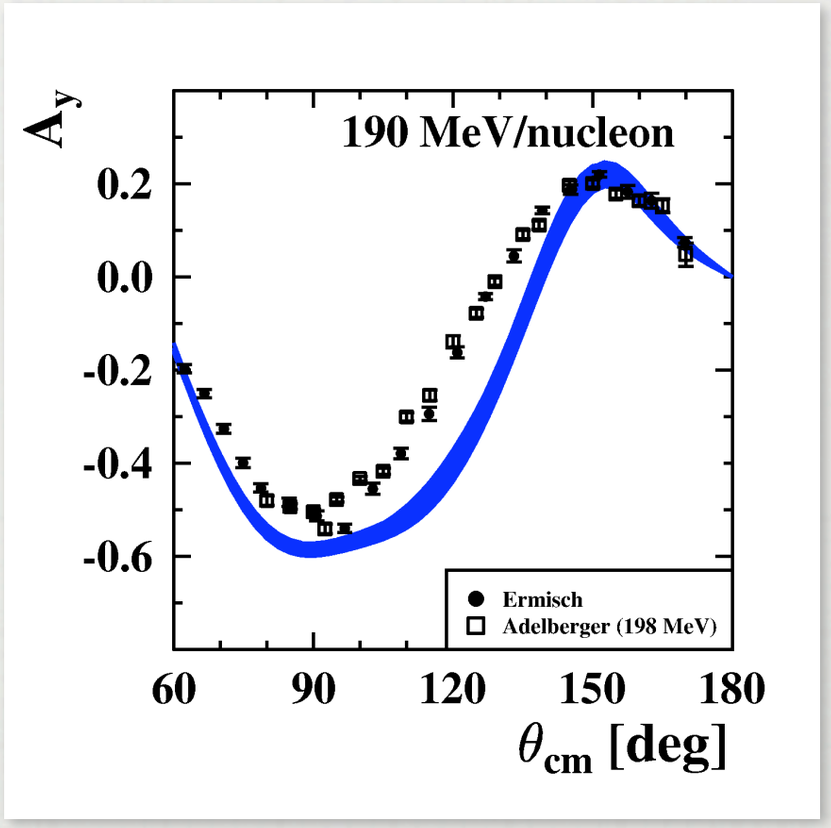


BACKUP

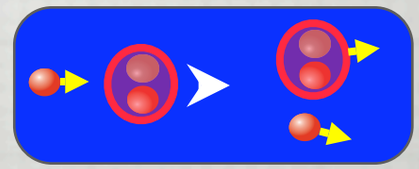
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)



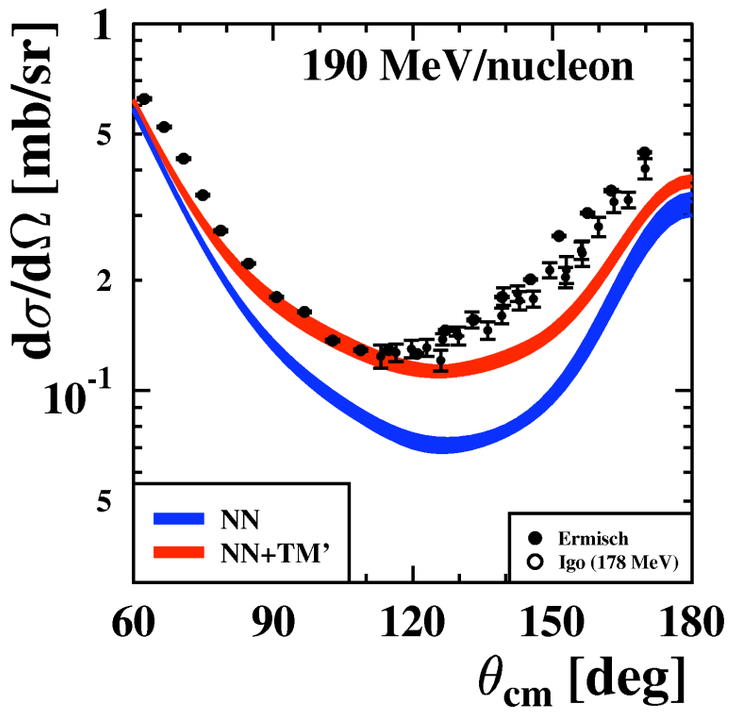


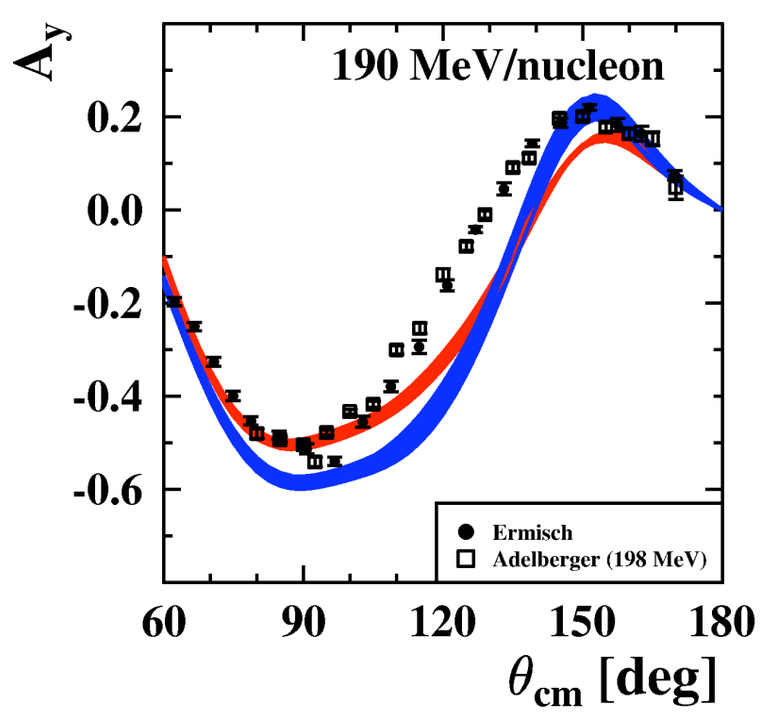
Discrepancies at higher energies:
Large 3NF effects?



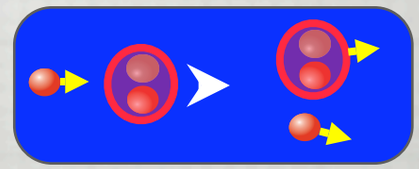
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)



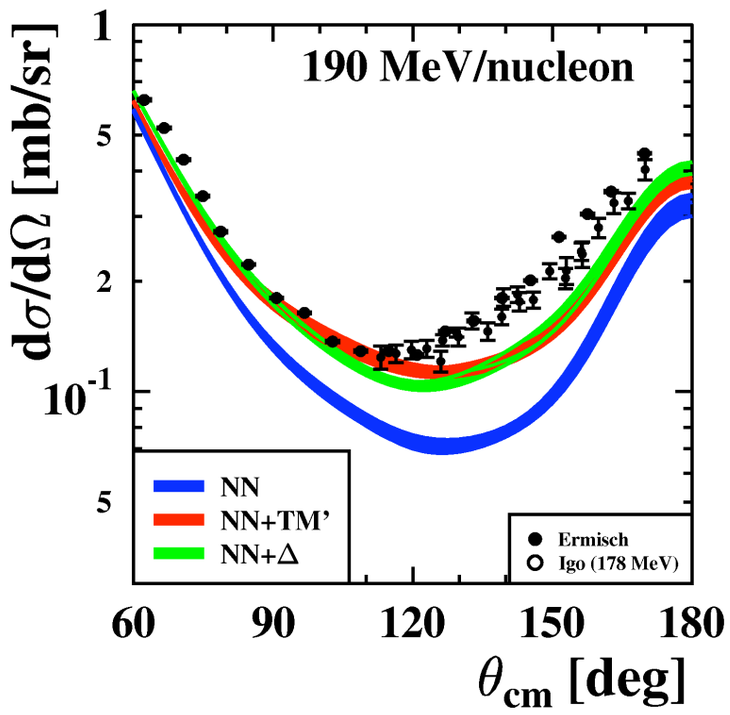


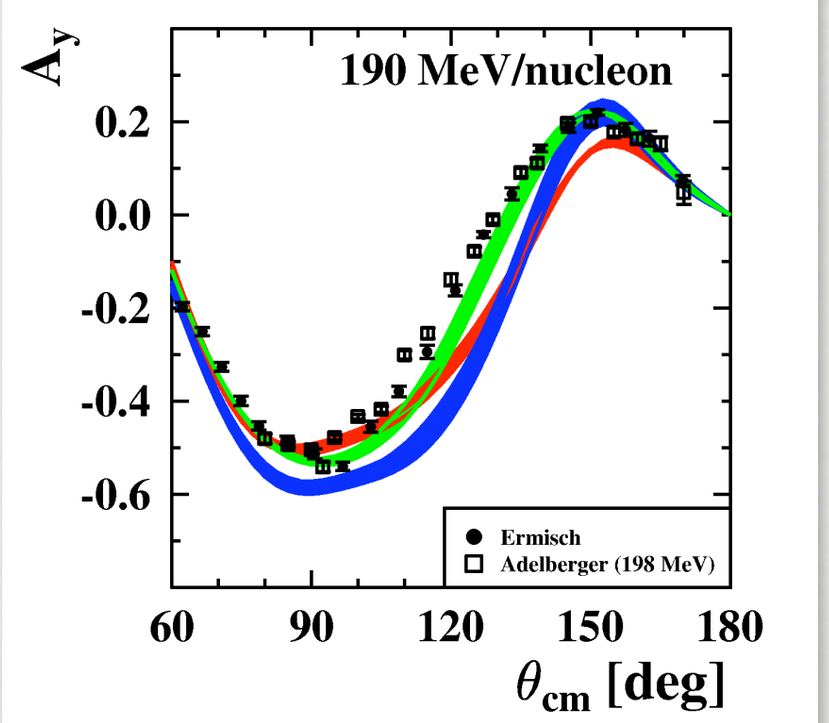
Phenomenological 2π-exchange 3NF not sufficient



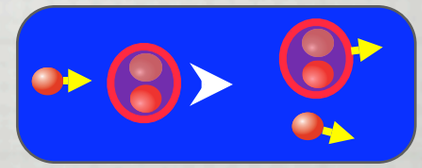
ELASTIC PD SCATTERING

Ermisch et al., PRL86, 5862 (2001); PRC68, 051001 (2003), PRC71, 064004 (2005)





Faddeev calculation by Hanover group
with dynamical Δ and πρ/ρρ contributions



AB-INITIO 4-NUCLEON CALCULATIONS

Data:

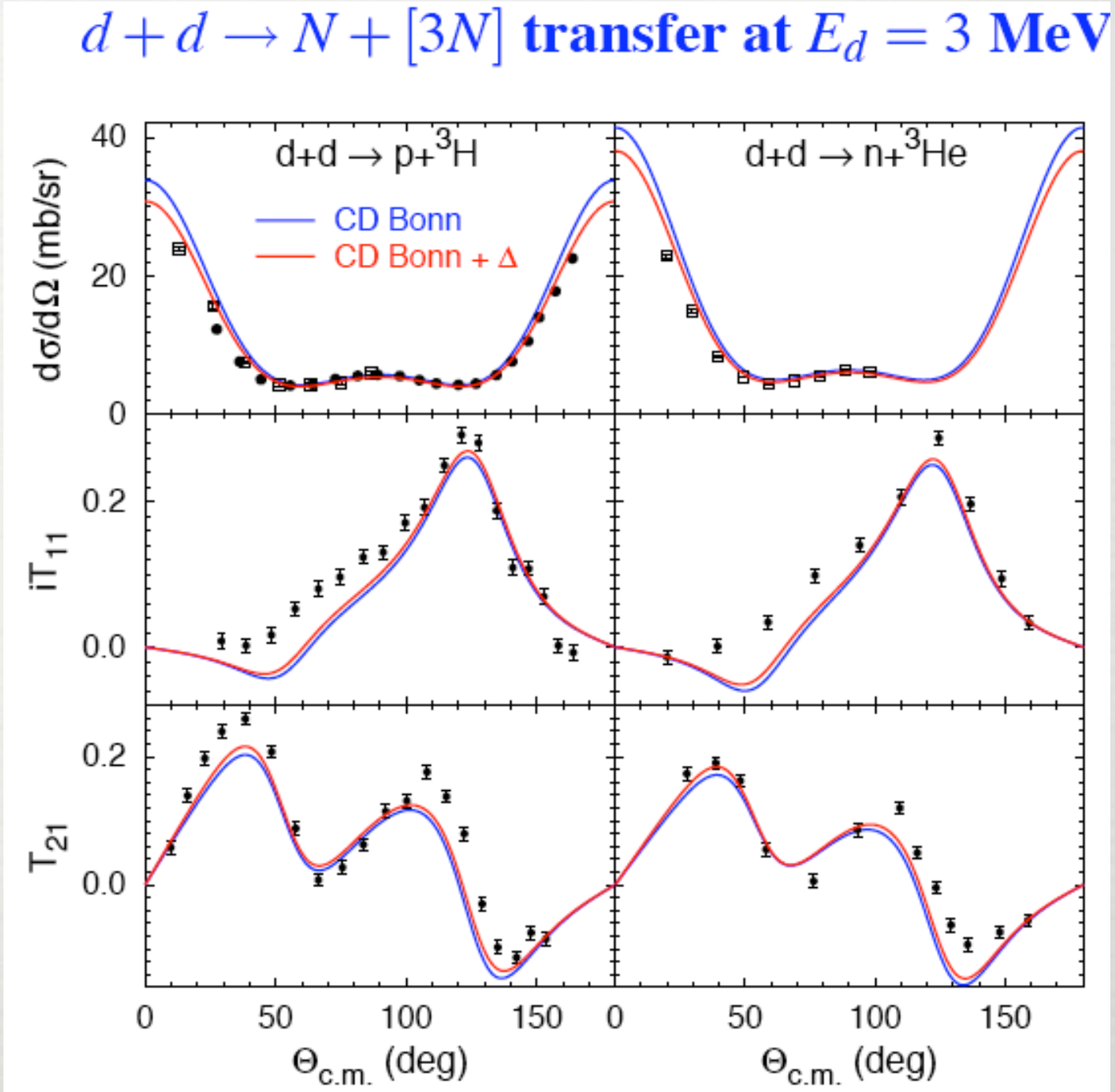
Blair et al, PR74, 1599 (1948)
Gruebler et al., NPA193, 129 (1972)
Dries et al., PL 80B, 176 (1979)

Calculation:

Ab-initio 4N calc:

Deltuva, Fonseca, Sauer, PLB660, 471 (2008)/ nucl-th/0801.4489

…including effective 3N and 4N forces via the Δ in a self-consistent approach



AB-INITIO 4-NUCLEON CALCULATIONS

Data:

Blair et al, PR74, 1599 (1948)
Gruebler et al., NPA193, 129 (1972)
Dries et al., PL 80B, 176 (1979)

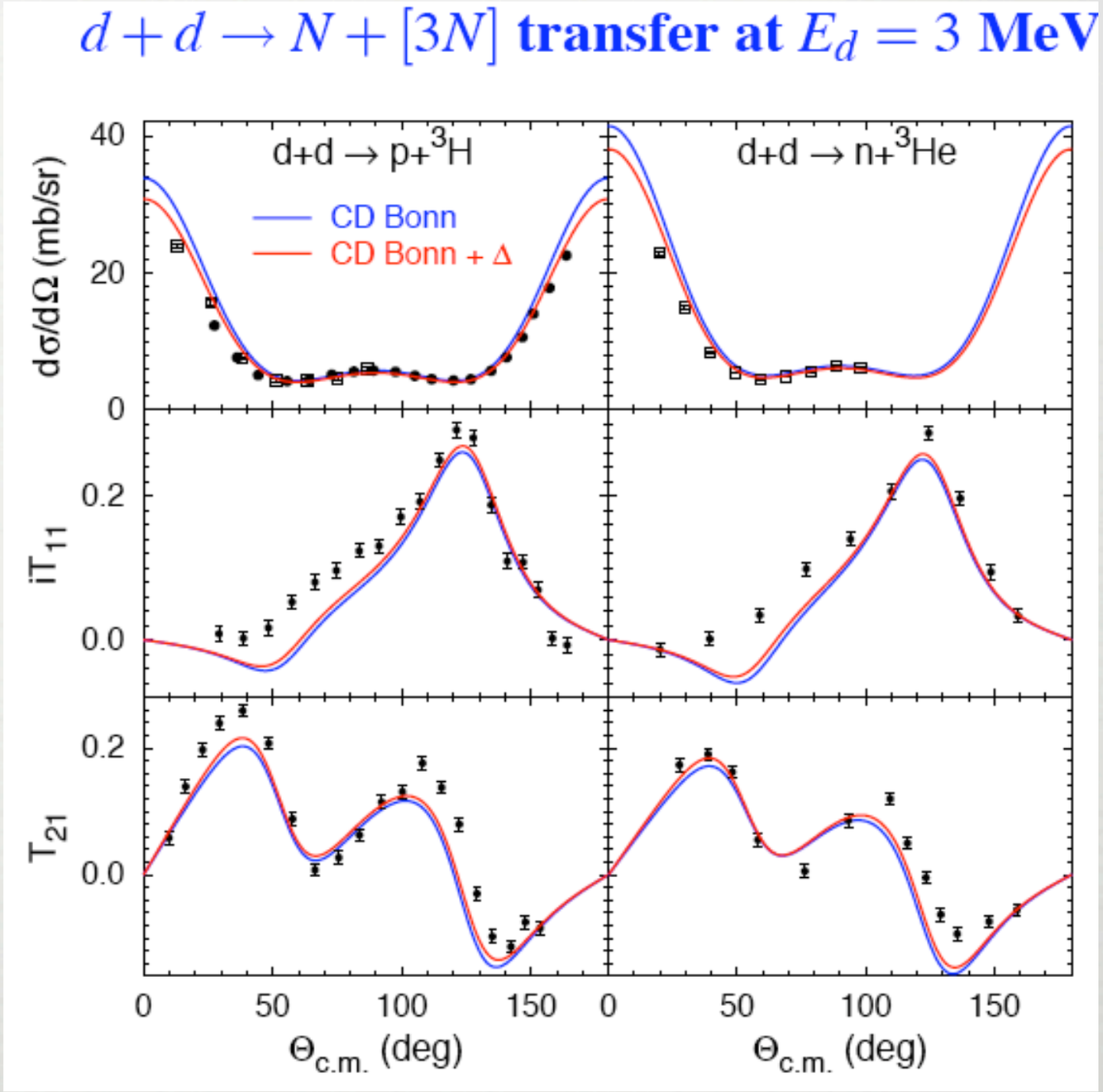
Calculation:

Ab-initio 4N calc:

Deltuva, Fonseca, Sauer, PLB660, 471 (2008)/ nucl-th/0801.4489

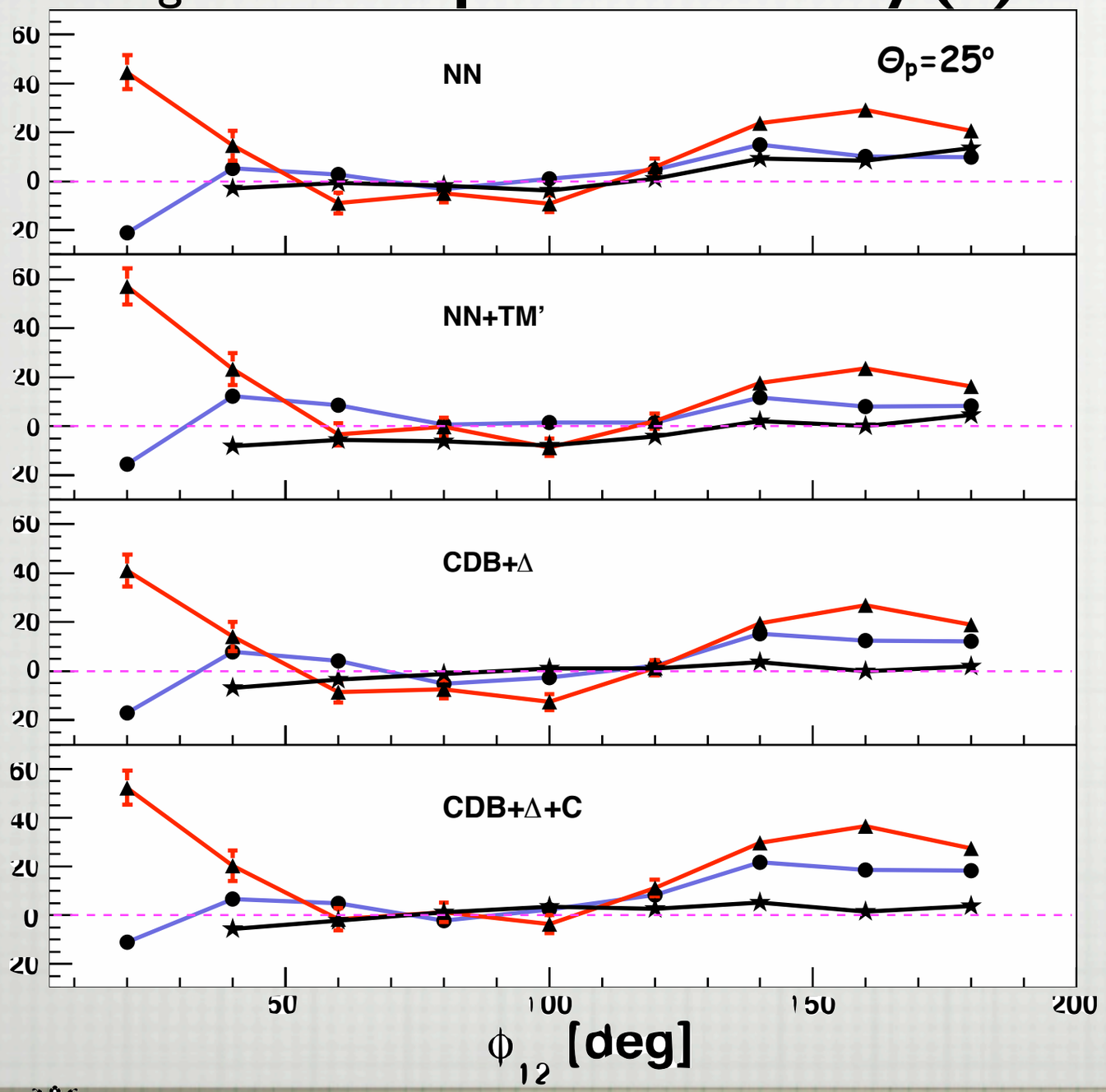
…including effective 3N and 4N forces via the Δ in a self-consistent approach

Theoretical framework advanced below 3-body break-up threshold



CROSS SECTIONS IN PD BREAK-UP

averaged xsecs: **experiment-theory (%)**



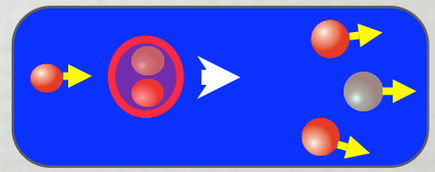
Large discrepancies in cross sections: deteriorate with increasing incident energy

Inclusion of 3NF effects does not improve comparison

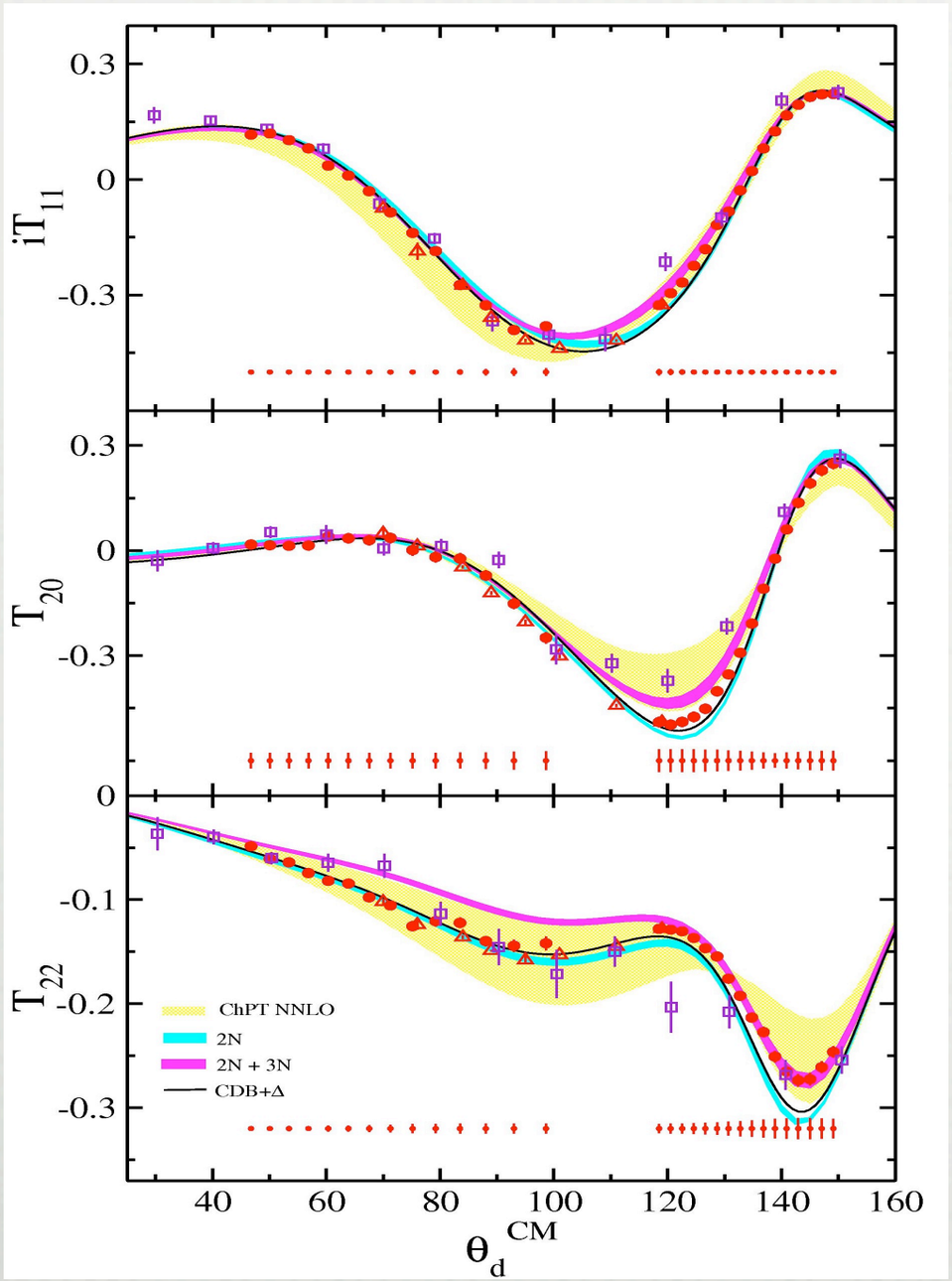
<u>data</u>: BINA

<u>theory</u>: Bochum-Cracow/ Hannover-Lisbon

190 MeV
135 MeV
65 MeV



PD ELASTIC



Analyzing powers of elastic scattering

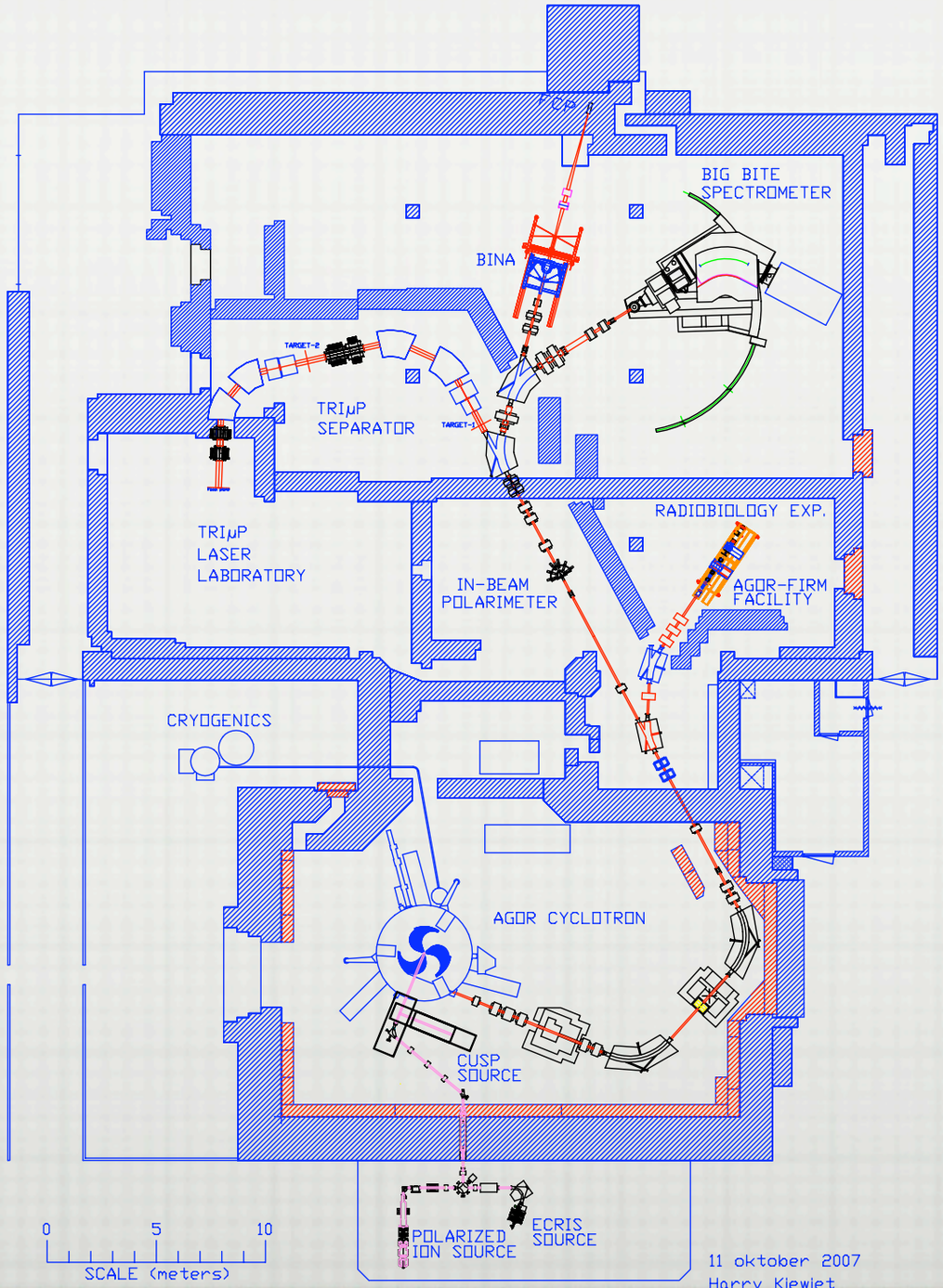
● $^1H(\vec{d},d)p$
$^1H(\vec{d},dp)$

E. Stephan et al.,
Phys. Rev. C 76, 057001 (2007)

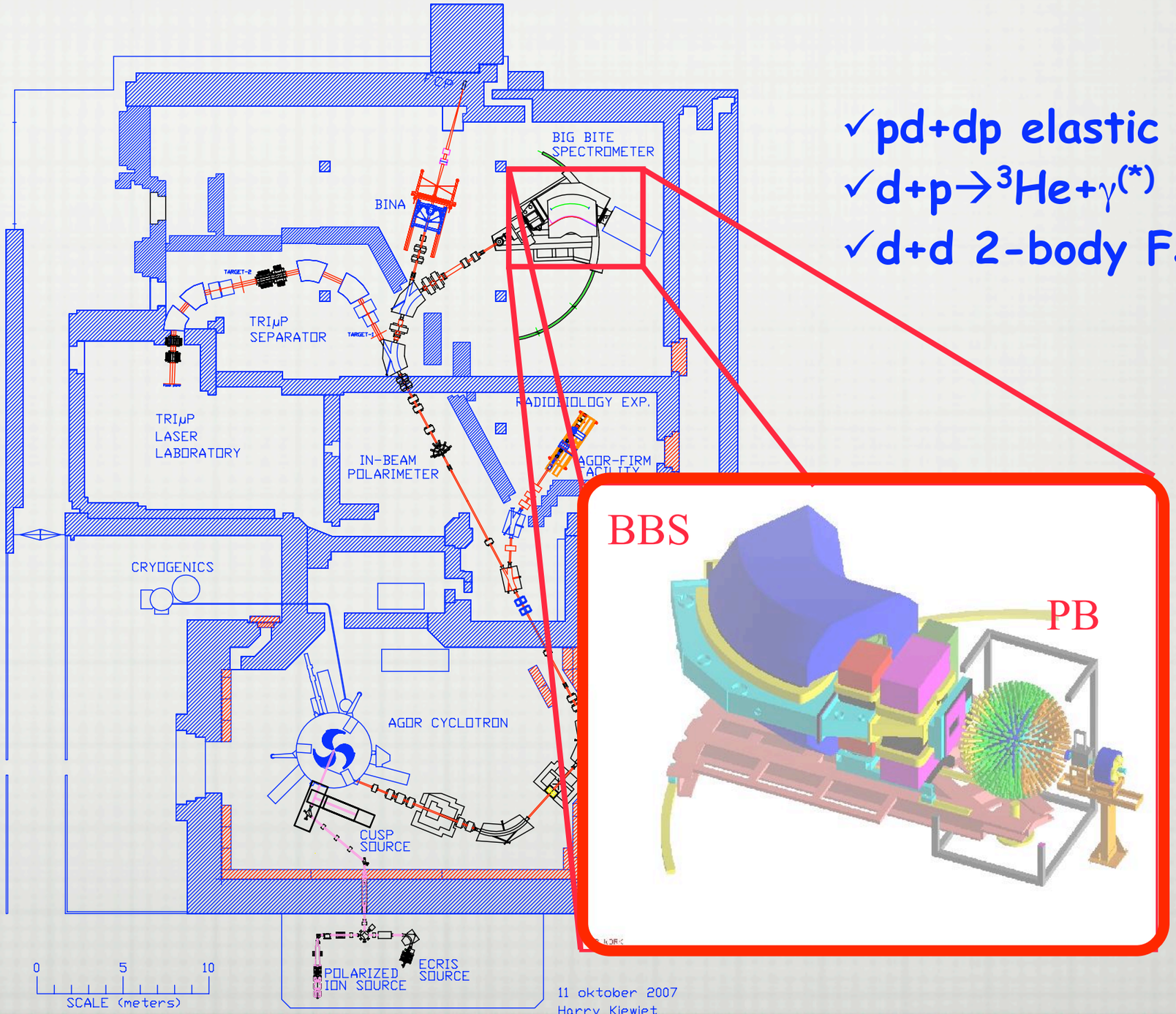
△ H. Mardanpour et al.,
Eur. Phys. J. 31, 383 (2007)

□ H. Witała et al.,
Few-Body Systems 15, 67-85 (1993)

FEW-BODY PROGRAM @ KVI



FEW-BODY PROGRAM @ KVI

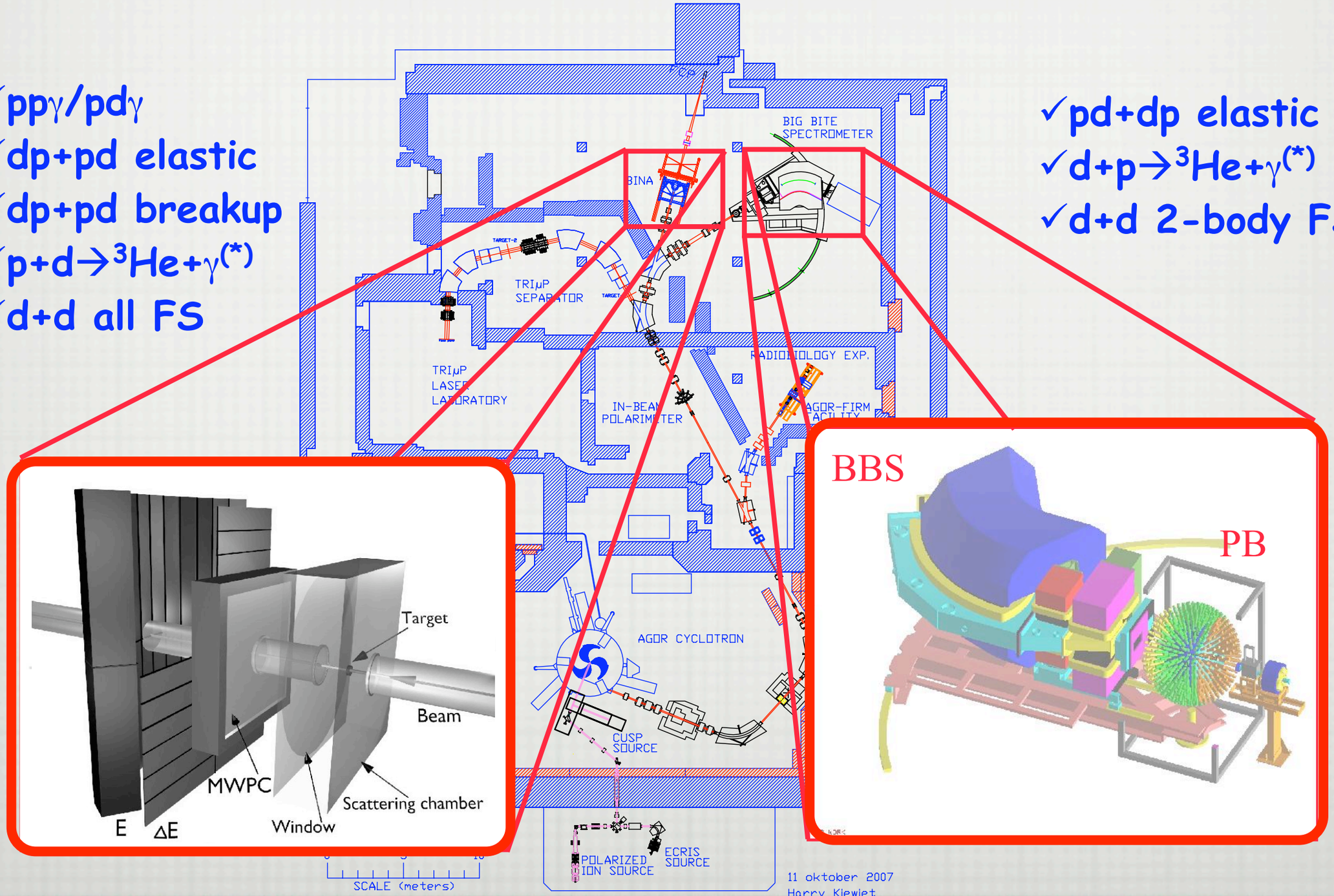


- ✓pd+dp elastic
- ✓d+p→^{3}He+$\gamma^{(*)}$
- ✓d+d 2-body FS

FEW-BODY PROGRAM @ KVI

- ✓ppγ/pdγ
- ✓dp+pd elastic
- ✓dp+pd breakup
- ✓p+d→^{3}He+γ$^{(*)}$
- ✓d+d all FS

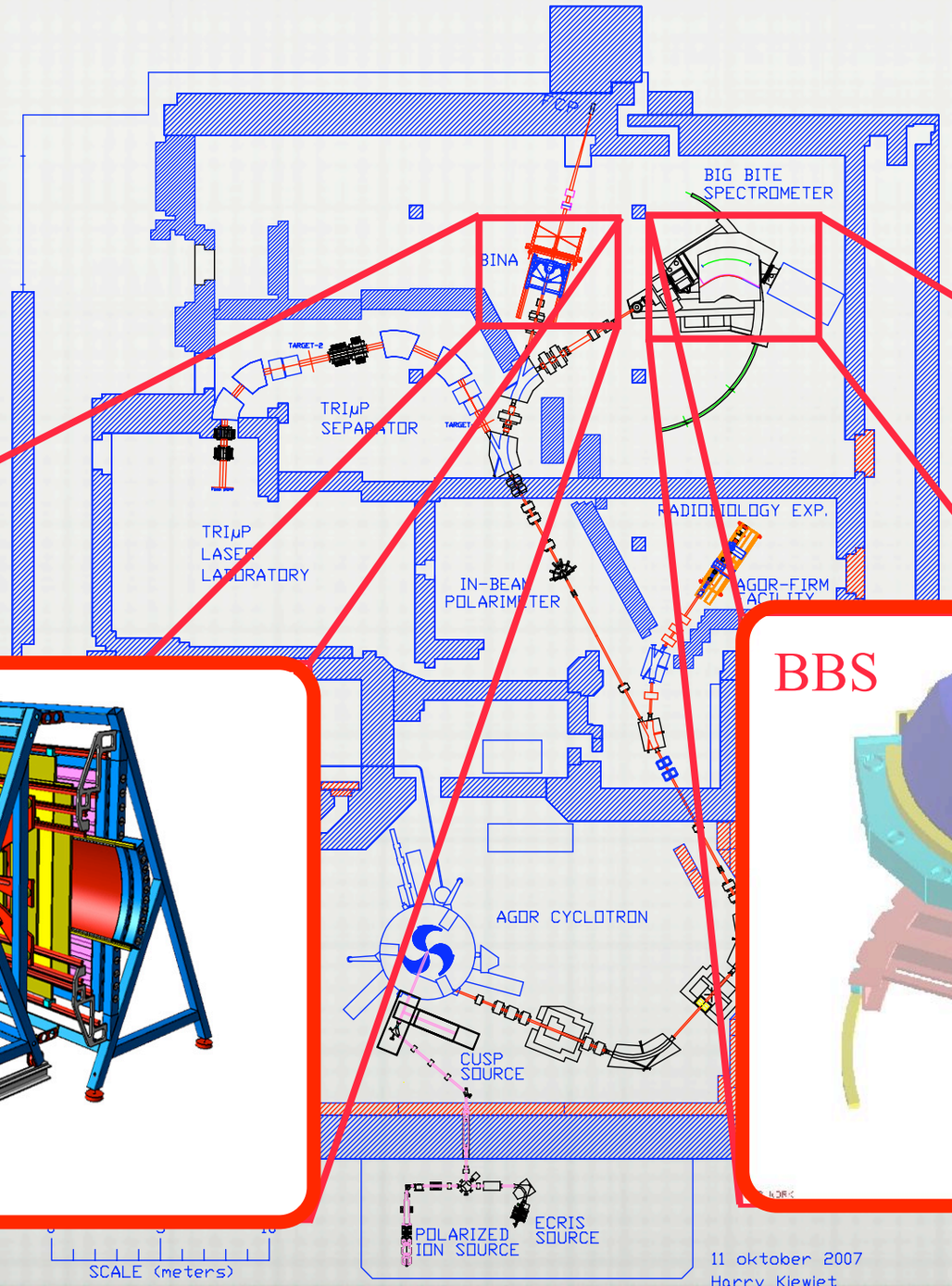
- ✓pd+dp elastic
- ✓d+p→^{3}He+γ$^{(*)}$
- ✓d+d 2-body FS



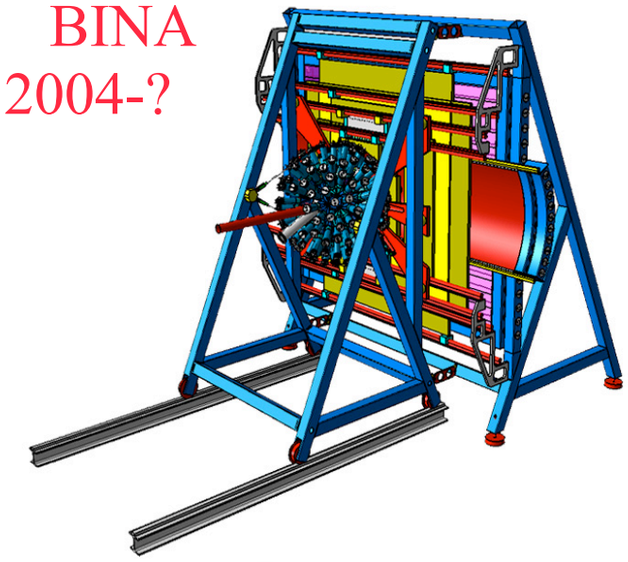
FEW-BODY PROGRAM @ KVI

- ✓ppγ/pdγ
- ✓dp+pd elastic
- ✓dp+pd breakup
- ✓p+d→^{3}He+γ$^{(*)}$
- ✓d+d all FS

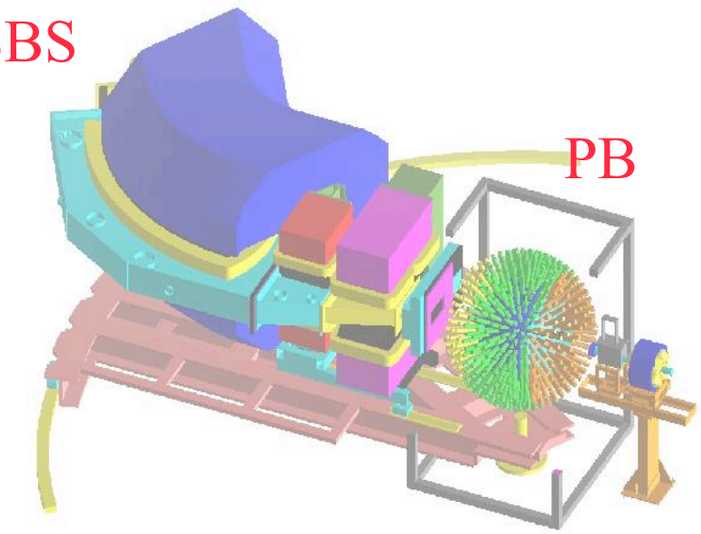
- ✓pd+dp elastic
- ✓d+p→^{3}He+γ$^{(*)}$
- ✓d+d 2-body FS



BINA
2004-?



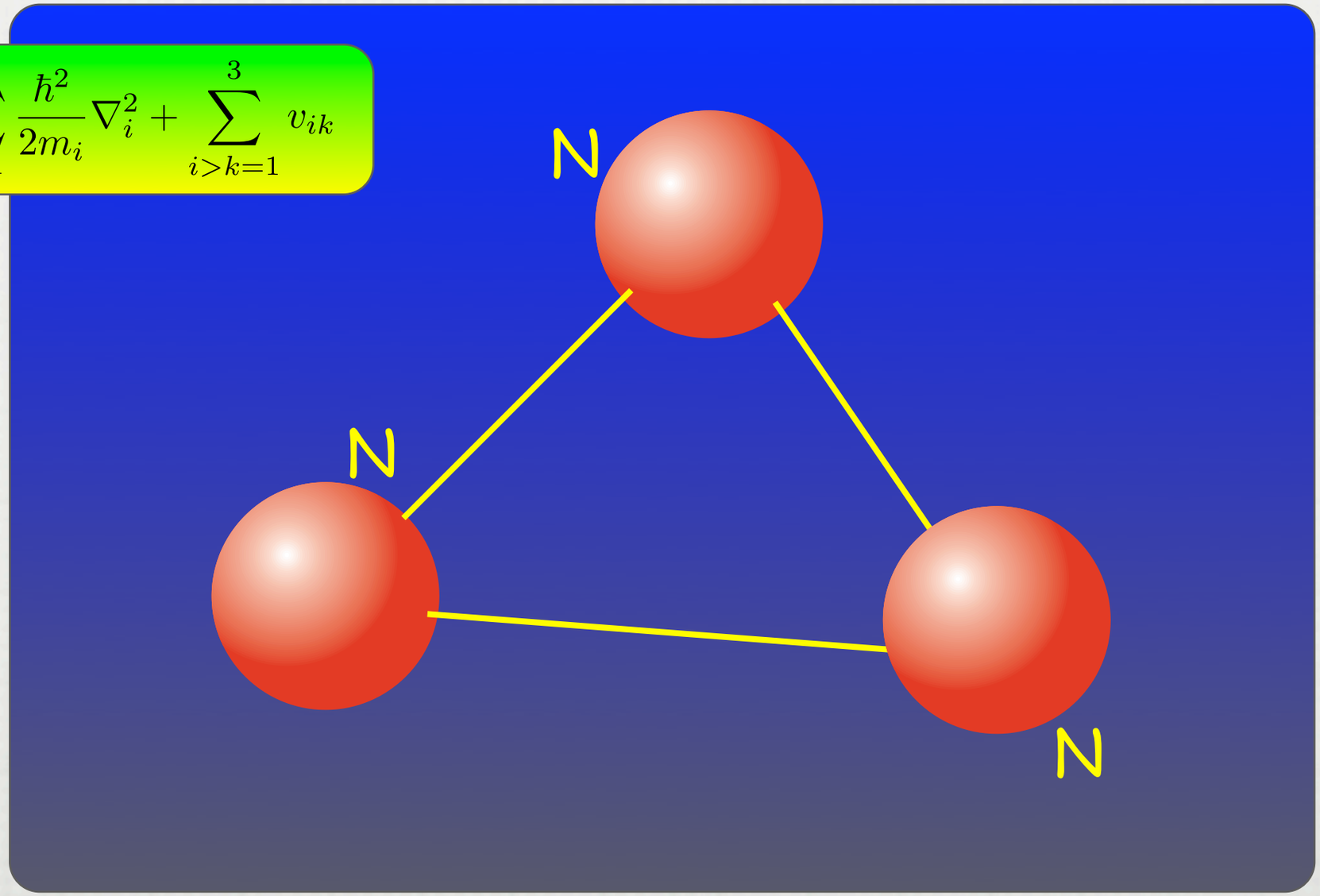
BBS



PB

THREE-NUCLEON FORCES

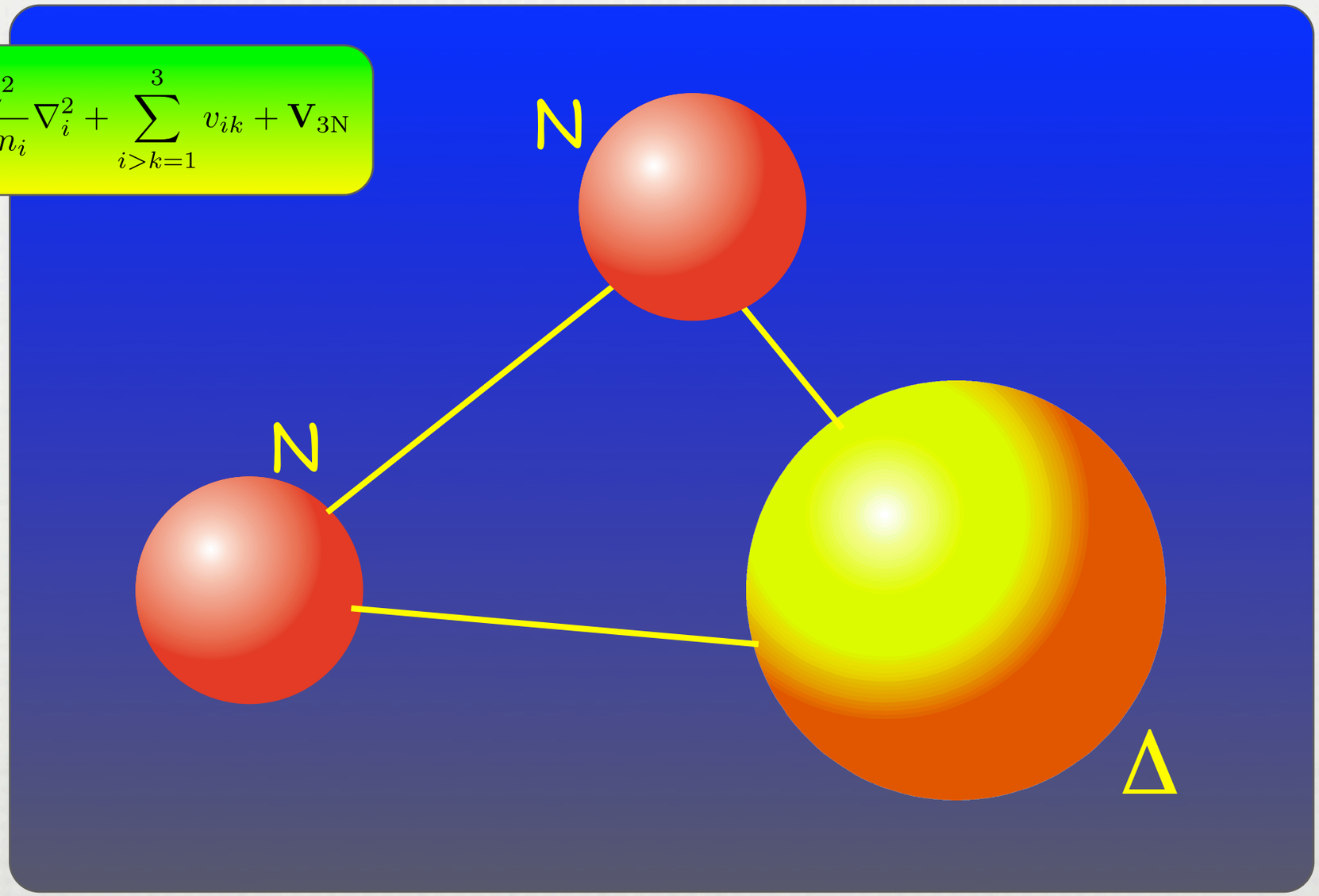
$$H = -\sum_{i=1}^{3} \frac{\hbar^2}{2m_i} \nabla_i^2 + \sum_{i>k=1}^{3} v_{ik}$$



"A POORMAN'S POINT-OF-VIEW"

THREE-NUCLEON FORCES

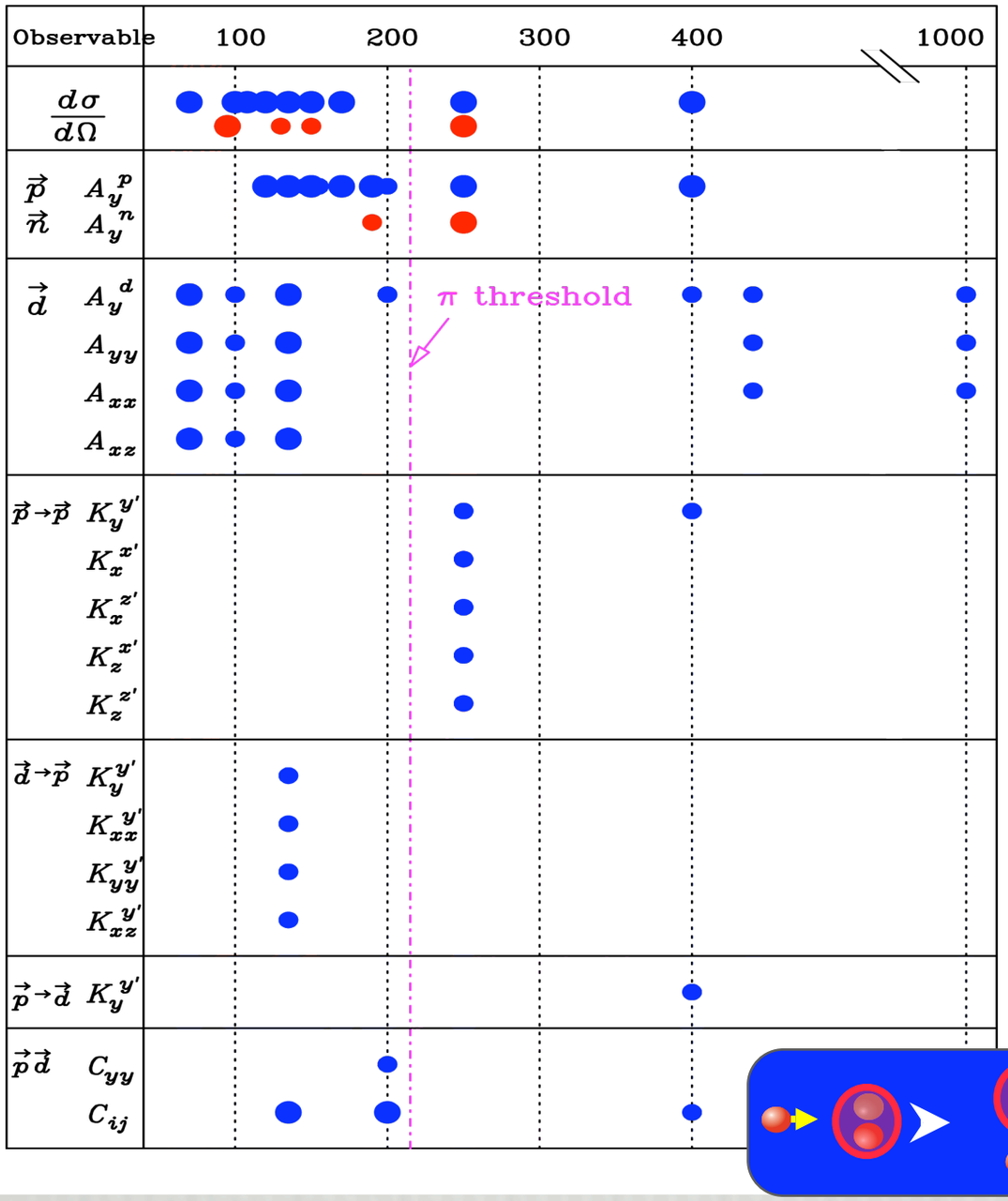
$$H = -\sum_{i=1}^{3} \frac{\hbar^2}{2m_i} \nabla_i^2 + \sum_{i>k=1}^{3} v_{ik} + \mathbf{V}_{3\mathrm{N}}$$



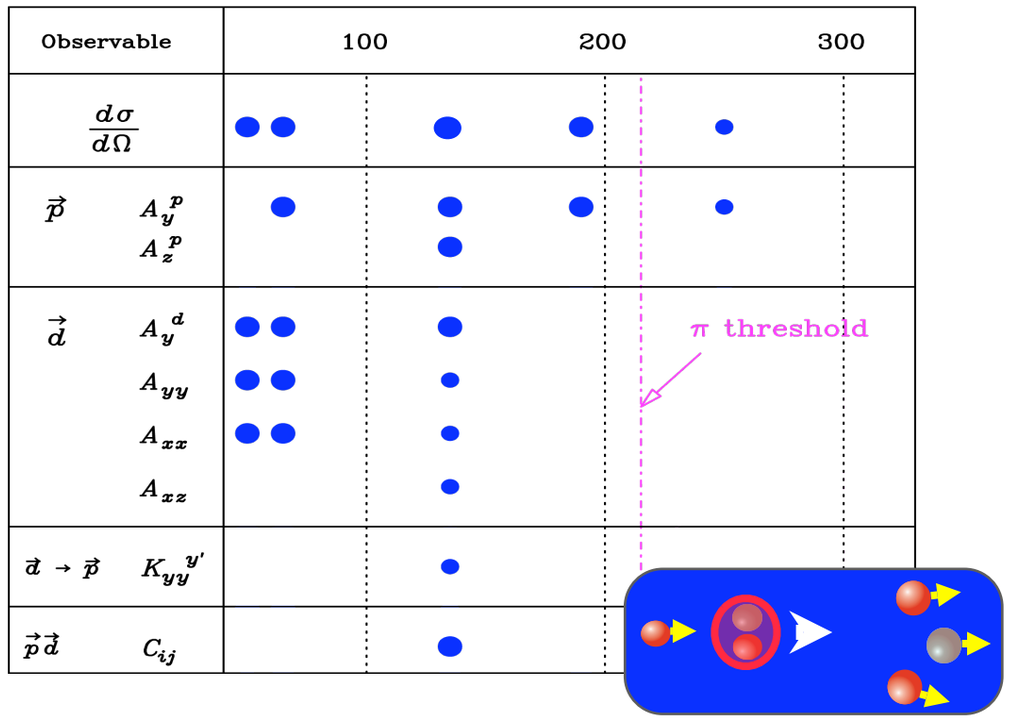
"A POORMAN'S POINT-OF-VIEW"

NUCLEON-DEUTERON SCATTERING

pd and nd Elastic Scattering at 65–1000 MeV/A



pd Breakup Reaction at 50–250 MeV/A



dp capture at 50–200 MeV/A