Four-nucleon Systems in Experiment and Theory

Adam Kozela

for PolHel3 Collaboration

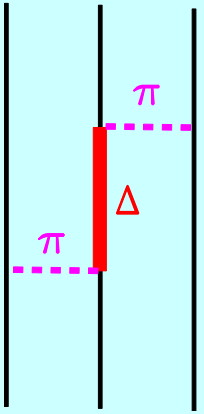
Outline

- 3-nucleon force (3NF) – very short intro
- 3NF in 4-nucleon systems – why interesting?
- Selected results of ***dd*** scattering – BINA@KVI
- New proposal for ***p^{3}He*** experiment – CCB, Kraków

High precision nucleon-nucleon potentials

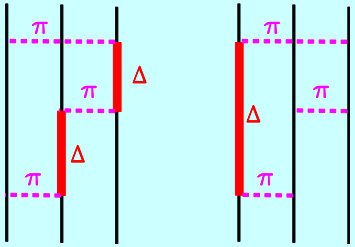
	# parameters	χ^2/ndf pp	χ^2/ndf np	^{3}H Eb [MeV]
CD Bonn	45	1.01	1.02	8.00*)
Nijm I	41	1.03	1.03	7.72
Nijm II	47	1.03	1.03	7.62
Av18	~40	1.35	1.07	7.62
Reid93	~40	1.02	1.03	7.63
Experiment		~3000 points	~3000 points	8.48

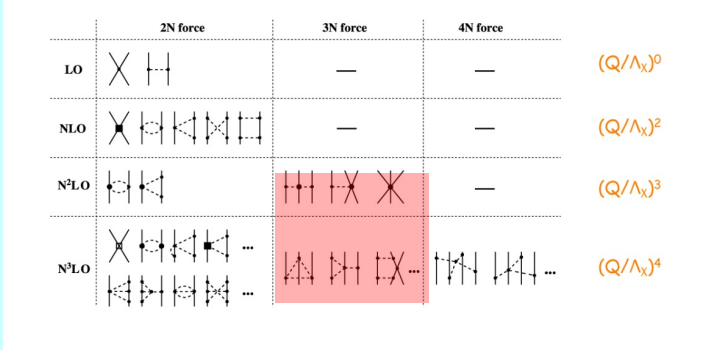
3-nucleon force



- J.Fujita, H.Miyazawa, Prog. Theor. Phys. **17** (1957) 360

- Tucson-Melbourne (TM)
- Urbana IX
- CD Bonn + Δ
- Illonois
- **C**hiral **P**erturbation **T**heory

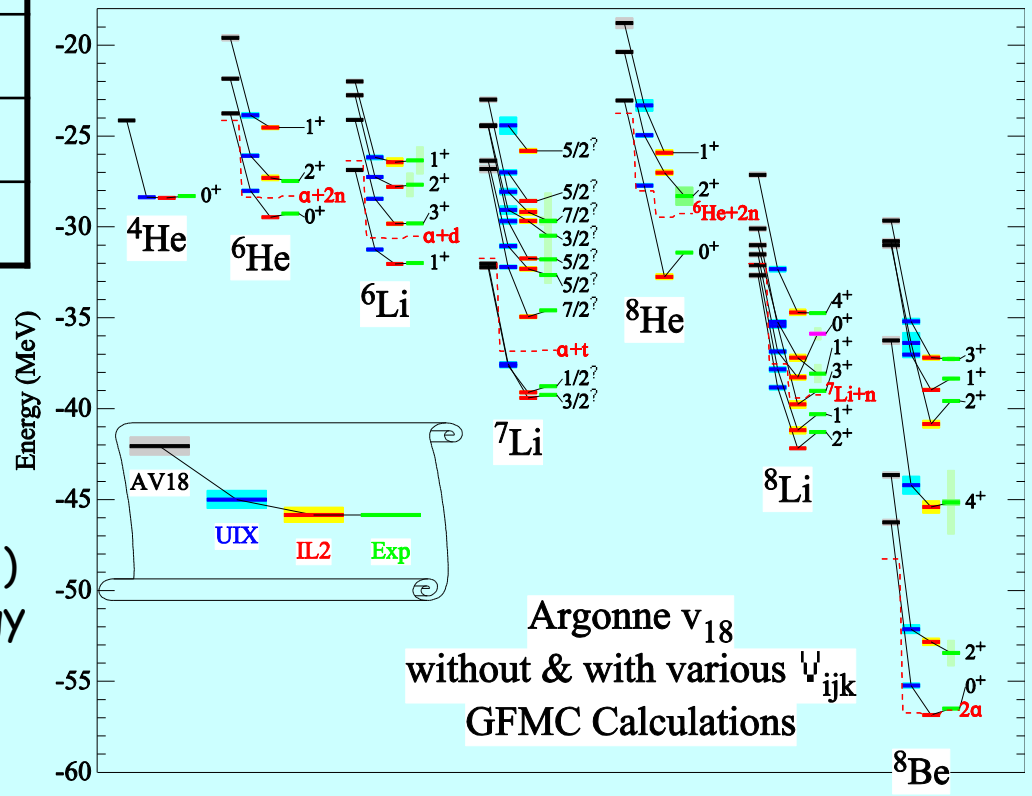




3-nucleon force in action – binding energy

EB [MeV]	^{3}H	^{3}He	^{4}He
Potencjały NN	7.62	7.07	24.2
CD Bonn + Δ	8.36	7.64	28.4
Nijm II + TM99	8.48	7.72	28.5
Av18 + TM99	8.48	7.76	28.8
CPT, NNLO (+3NF)	8.68	7.81	29.9
Experiment	8.48	7.72	28.4

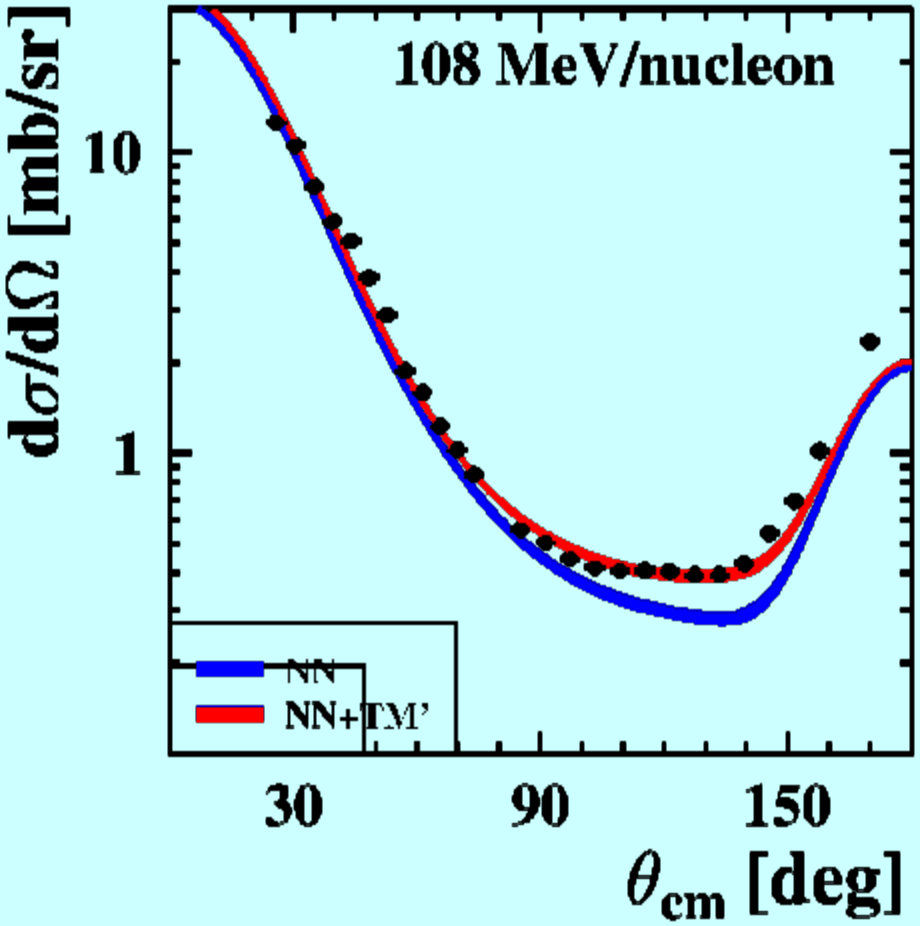
Binding of t and He-isotopes perfectly reproduced – no need for 4-nucleon force



Combination of Av18 and 3NF (ILL2) give good description of many energy levels of nuclei up to ^{12}C

S. Pieper Nucl.Phys. A751, 516c (2005)

3-nucleon force in action - elastic scattering



Realistic potentials NN fail in description of differential cross section for elastic scattering d(p,p)d.

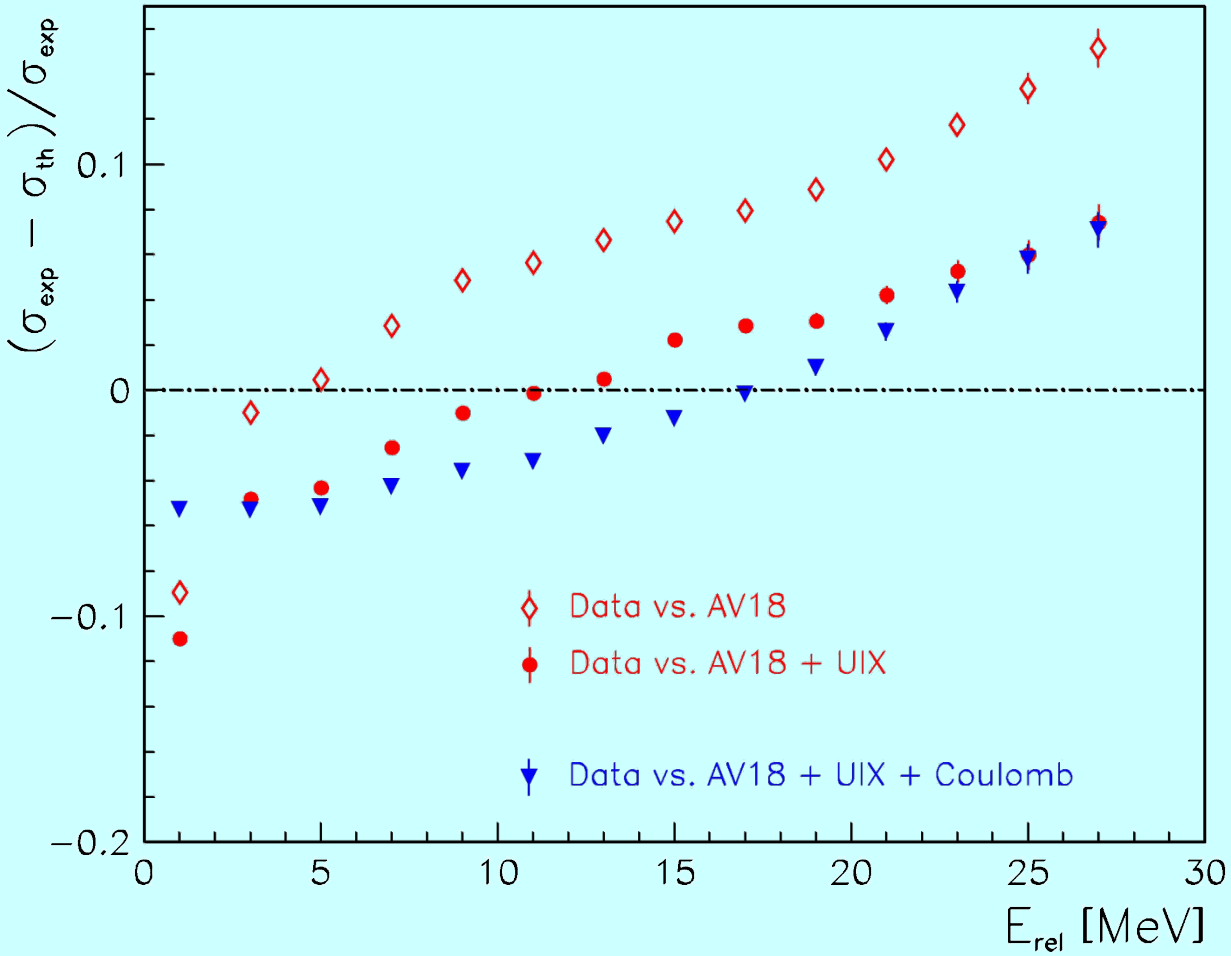
Supplemented with 3NF (TM) perform much better.

p(d,pp)n breakup reaction at 130 MeV

Cross Section Results – 3NF & Coulomb Effects

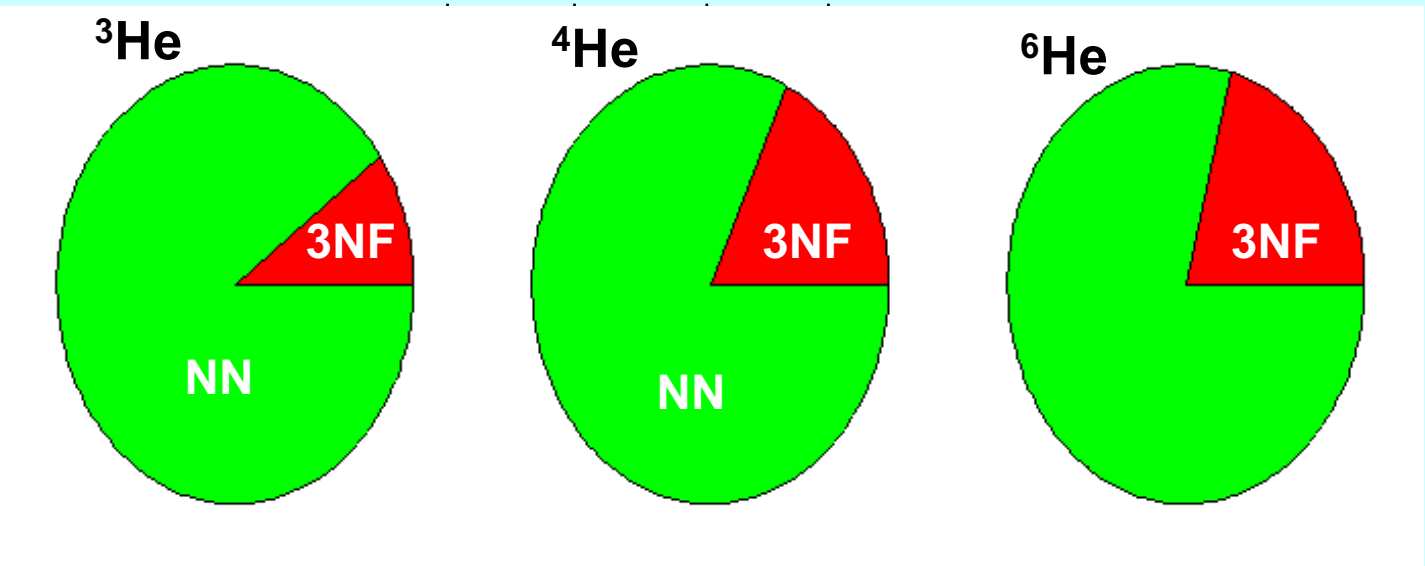
Including **3NF** effects improves the agreement with the data at low E_{rel} values

The best agreement is reached when both, the Coulomb force and the **3NF** are taken into account !



Four-nucleon system relevance to 3NF

- higher sensitivity (than in 3N systems) for 3NF



- many input and output channels
- chance for investigation of isospin dependencies (T=3/2)
- role of 4NF ?

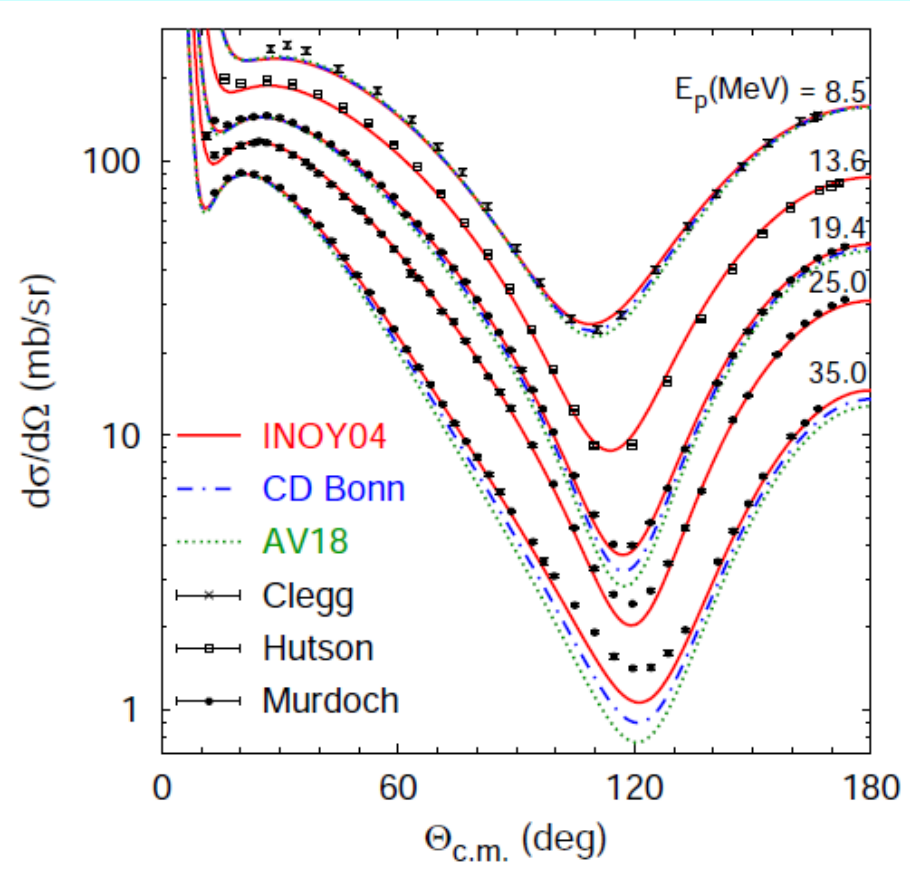
2NF>>3NF>>4NF

- nt -> nnnp
- p ^{3}He -> pppn

Four-nucleon system relevance to 3NF

p ^{3}*He* elastic scattering

- In 3N system effects of 3NF observed at 60 MeV
- In 4N system already at about 30 MeV



A. Deltuva and A. C. Fonseca, Phys. Rev. C 87, 054002, 2013

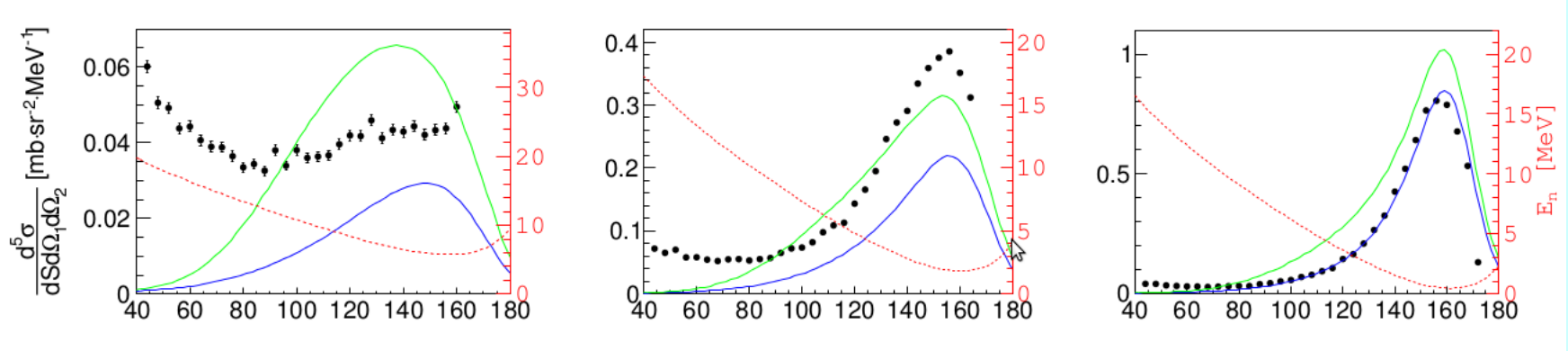
dd → dpn breakup at 135 and 160 MeV

BINA@KVI

- data at 135 MeV – good agreement for analyzing power but confusing results for differential cross section – normalization ?

- Sample results for 160 MeV, ϑ_p=20°, ϑ_n=22°:

φ_{rel} : 140° 160° 180°



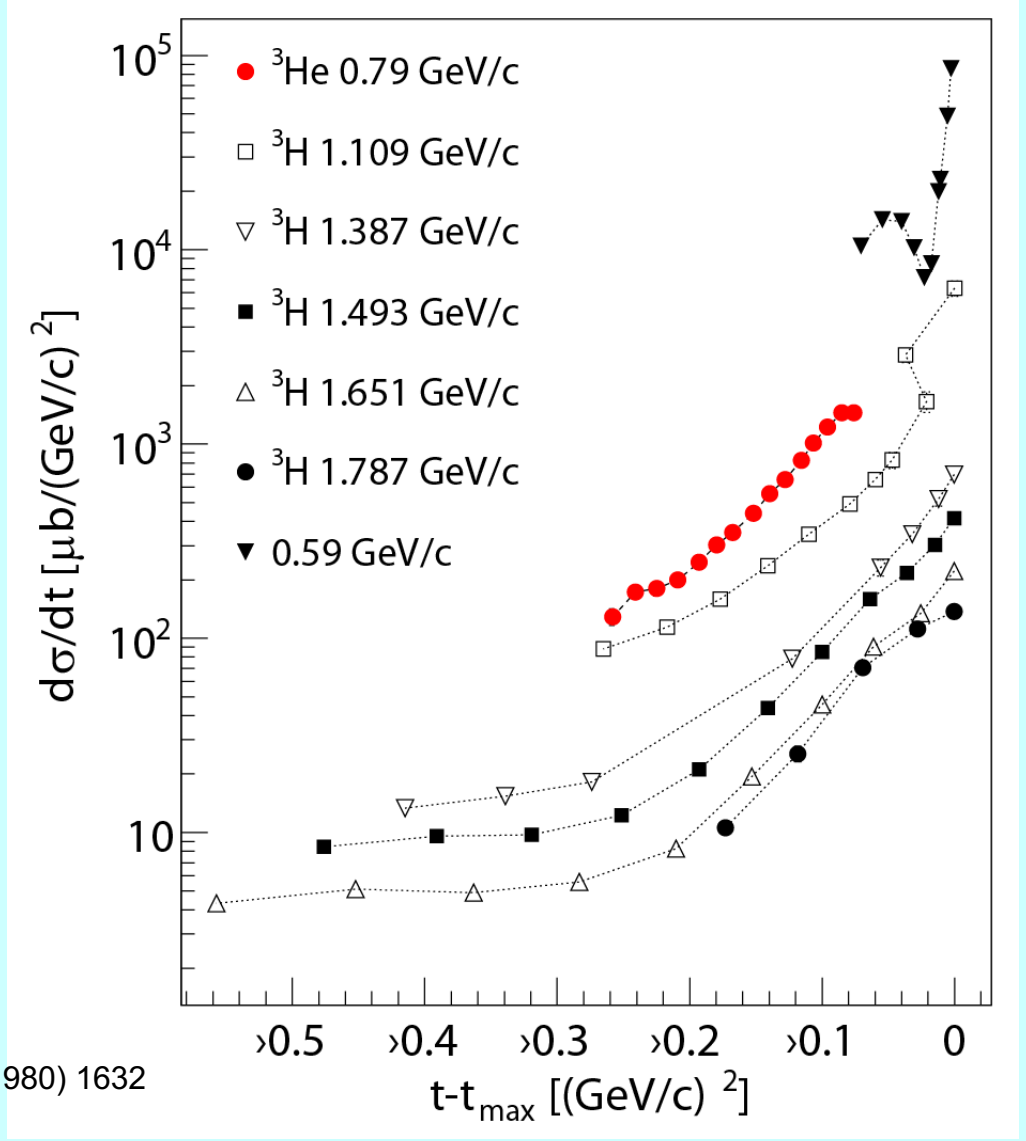
G.Khatri, PHD (2015)

- dp-QFS regime
- Calculations within Single Scattering Approximation

  A. Deltuva, A.C. Fonseca Phys.Rev.C 044001 (2016)

dd → ^{3}He n
Proton transfer reaction at 160 MeV

- Relative normalization to the elastic scattering data
- Good agreement with existing measurement
- No theory available



J. Kuboś, MSc Thesis 2017

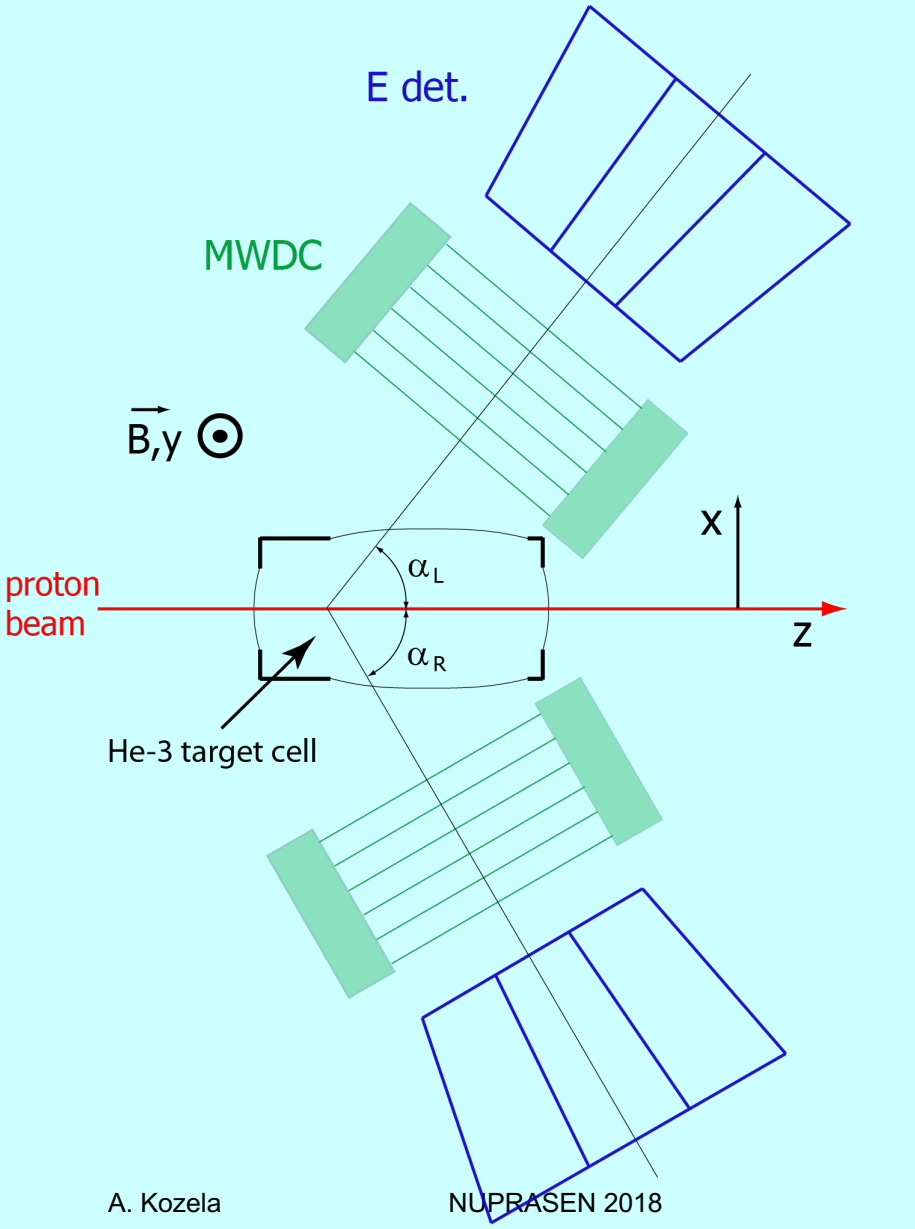
G.Bizard at al. Phys Rev C 22 (1980) 1632

New project for p^{3}He experiment - main goal

Precise, kinematically complete measurement of vector analyzing powers and differential cross sections for the p + ^{3}He elastic scattering and breakup reactions with the use of the polarized Helium-3 target, in a wide range of phase-space and proton energy range of 60 – 230 MeV.

Planned for Cyclotron Center Bronowice, Kraków

Experimental principle



Channels available for exclusive experiment

p ^{3}He → p ^{3}He

p ^{3}He → p d n

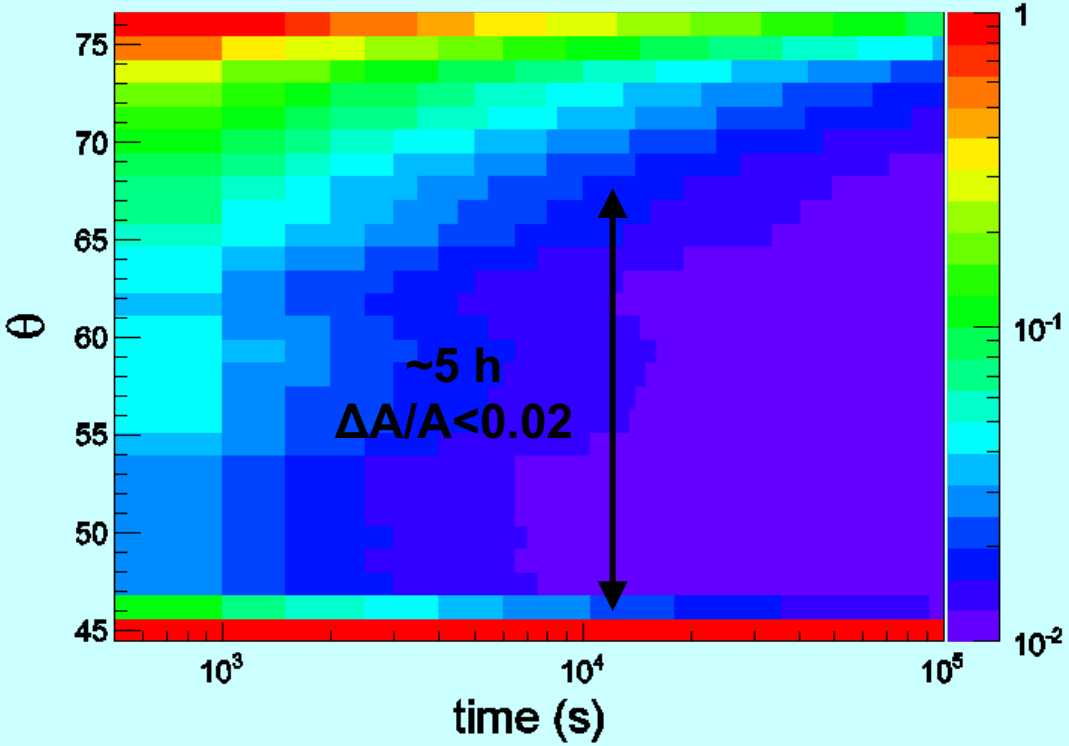
p ^{3}He → p p p n

Counting rate estimate for elastic scattering at

- Real cross section and symmetric geometry ($\alpha_L = \alpha_R = 55°$)
- Reaction kinematics
- ^{3}He detection energy threshold 20MeV
- CCB beam distribution ~100pA
- Binning in polar angle: $\Delta\vartheta = 1°$

$$\frac{\Delta A}{A} = \sqrt{\frac{1}{N} + \left(\frac{\Delta P}{P}\right)^2}$$

where $\Delta p/p \approx 0.01$



Ongoing activities and beam time request

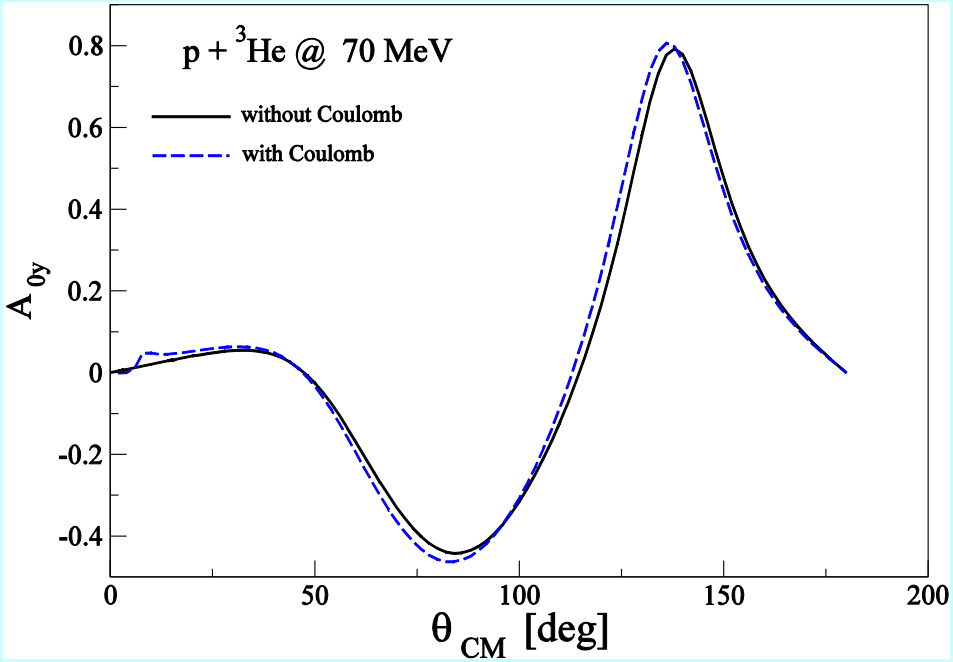
- Mechanical tests of scattering cell and different window foils

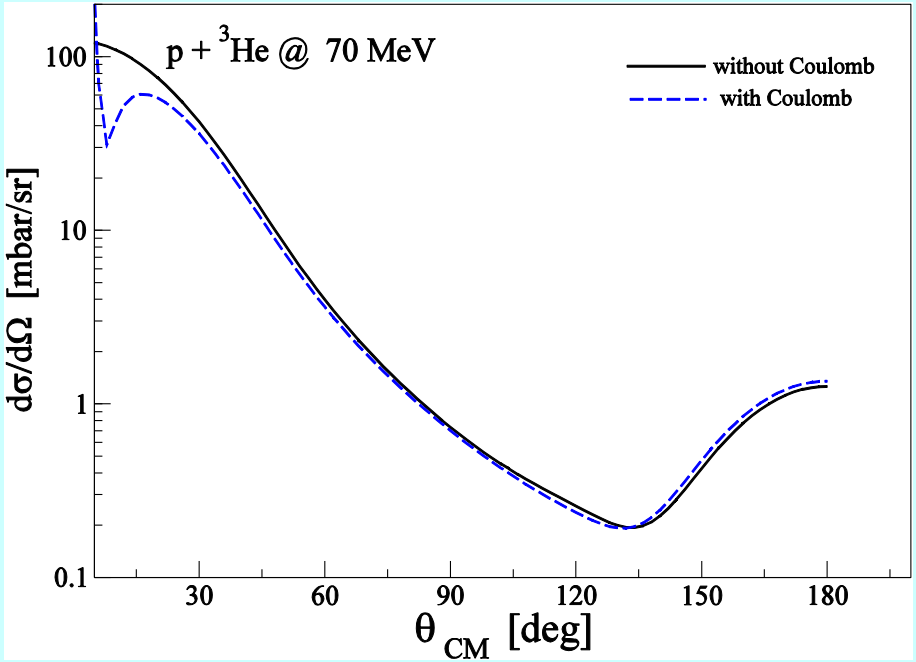
- Tests of polarizing cell

- Fabrication and tests of prototype drift chamber

THANK YOU

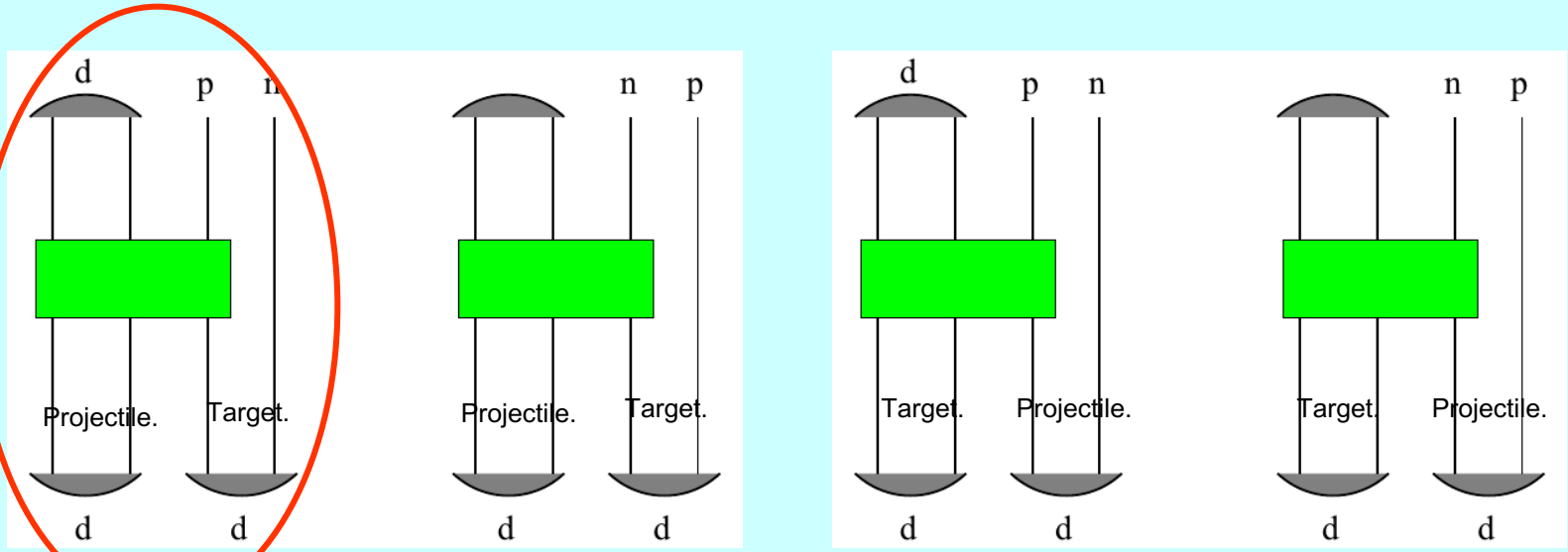
p-^{3}He elastic scattering Calculations at 70 MeV





A. Deltuva private communications

Single Scattering Approximation

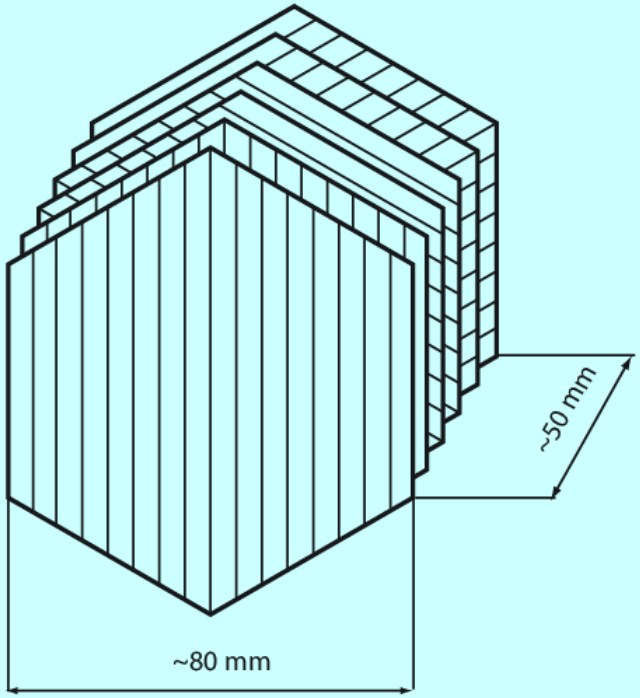


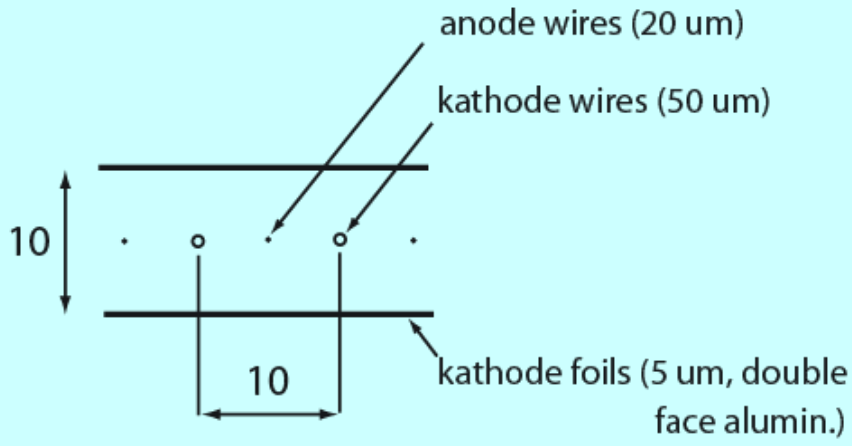
Previous slide case

- Lowest order term in the Neumann series expansion of Alt, Grassberger, Sandhas (AGS) equation
- Full 3N dynamic in dp system and not interacting spectator
- Different force models applicable (CD Bonn, CD Bon+Δ, AV18)
- Also valid for elastic scattering

Multiwire Drift Chambers

- As thin as possible
- 6 measuring planes with 3 directions of wires – full 3D reconstruction
- Position resolution < 200 μm
- Energy loss information
  - time over threshold
  - signal integral
- High rate capable (short drift distance)





Polarized ^{3}He target