ARUNA: Ohio University

Carl Brune

ARUNA

Association for Research
at University Nuclear Accelerators

Department of
physics + astronomy
OHIO UNIVERSITY

Ohio University: Athens, Ohio

Google Maps

Strong nuclear presence in the Department of Physics and Astronomy. Besides Low Energy Experiment, we have:

Nuclear Theory:
- Charlotte Elster
- Daniel Phillips
- Madappa Prakash

Intermediate Energy Expt:
- Justin Frantz
- Ken Hicks
- Julie Roche

Low Eergy Experiment

Faculty

- Carl Brune (Prof.)
- Steve Grimes (Prof. Emeritus)
- David Ingram (Prof.)
- Tom Massey (Res. Prof.)
- Zach Meisel (Ast. Prof.)
- Alexander Voinov (Res. Prof.)

Graduate Students

- Shamim Akhtar
- Nadyah Alanazi
- Kristyn Brandenburg
- Sushil Dhakal
- Rekam Giri
- Som Paneru
- Cody Parker
- Andrea Richard

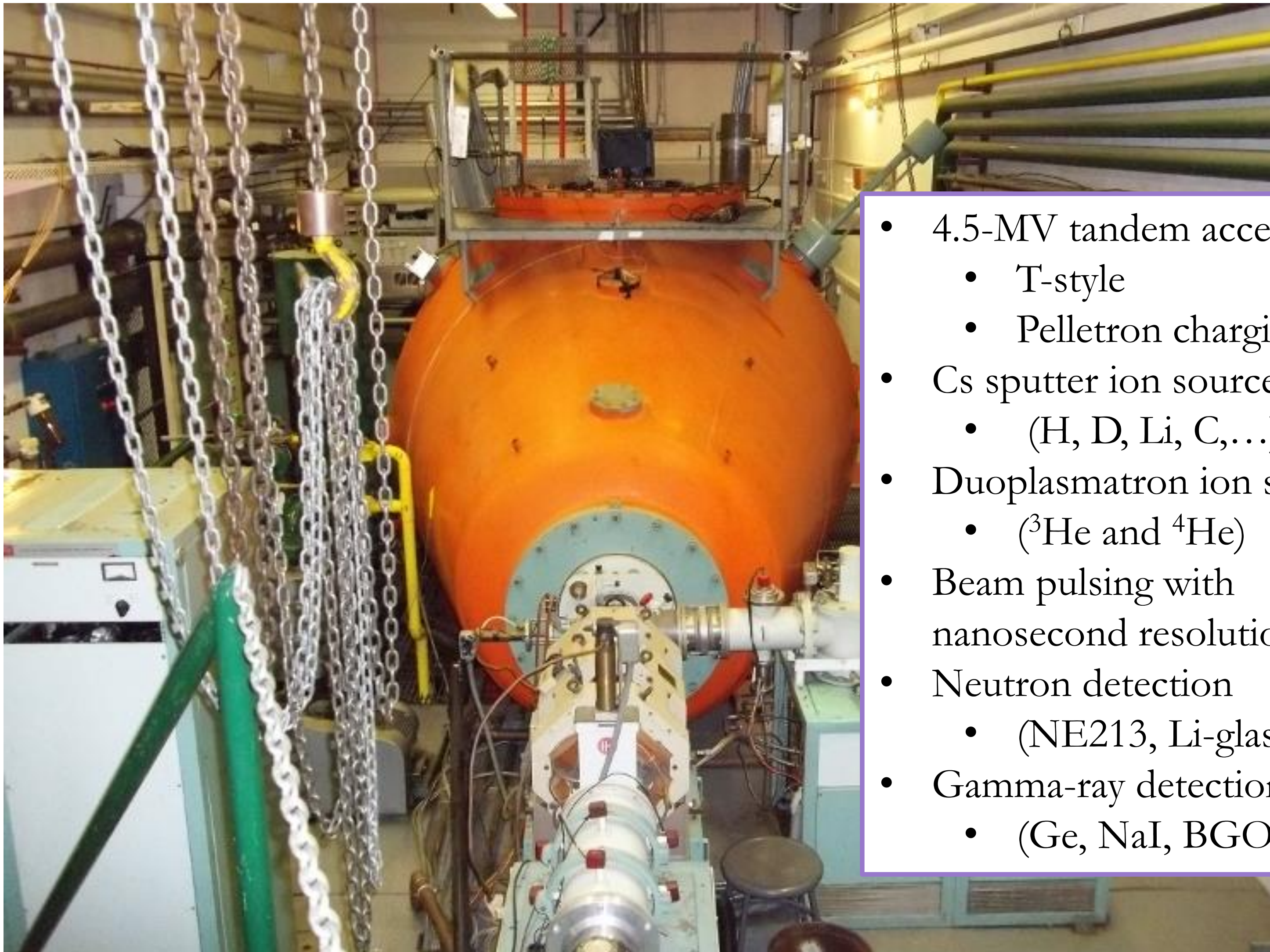
Research Staff

- Don Carter
- Devon Jacobs

Undergraduate Students

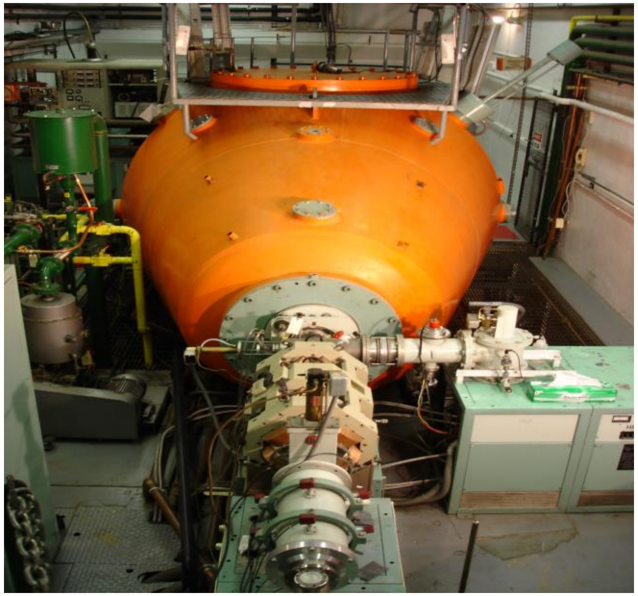
- Alex Carroll
- Colton Feathers
- David Overton (to TAMU)

The Edwards Accelerator Laboratory

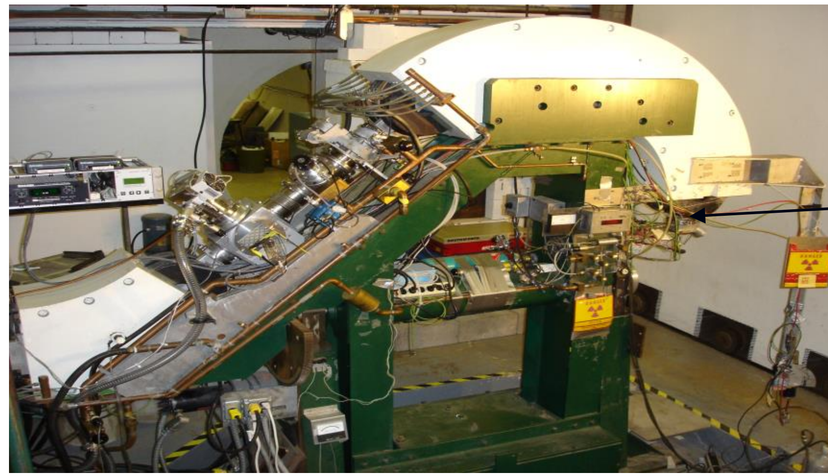


- 4.5-MV tandem accelerator
  - T-style
  - Pelletron charging
- Cs sputter ion source
  - (H, D, Li, C,…)
- Duoplasmatron ion source
  - (^{3}He and ^{4}He)
- Beam pulsing with nanosecond resolution
- Neutron detection
  - (NE213, Li-glass,…)
- Gamma-ray detection
  - (Ge, NaI, BGO, LaBr)

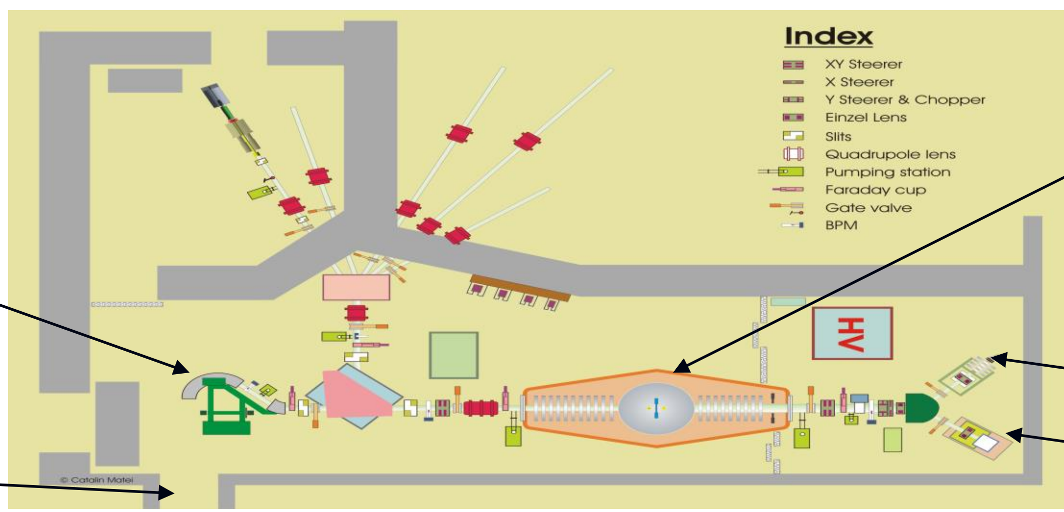
Edwards Accelerator Laboratory at Ohio University



Beam Swinger Facility



Target chamber



4.5-MV T-type tandem

Swinger Magnet ($-4° \le \theta_{lab} \le 158°$)

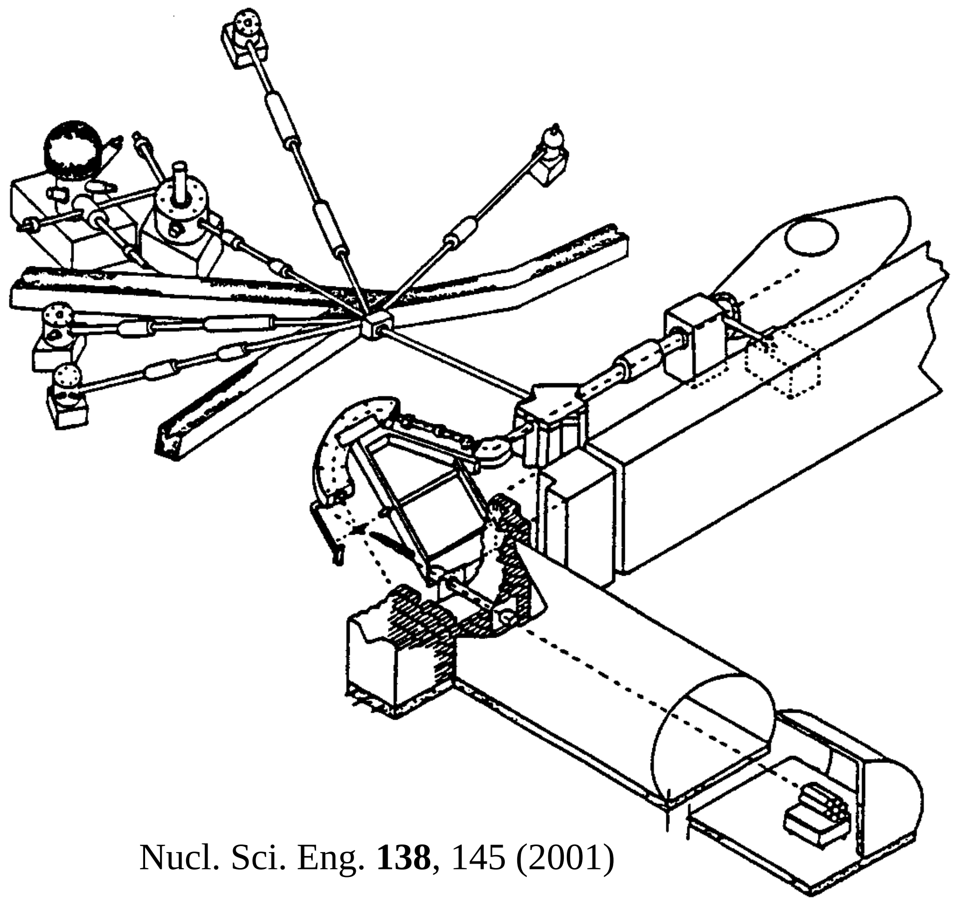
Cs Sputter Source

Duoplasmatron He Source

30-meter TOF Tunnel

Laboratory Layout

- **Beam swinger**
  - **Rotates to angles from 0° to 155°, and backward to 180°**
- **Well-shielded 30-m tunnel for neutron time-of-flight (TOF) measurements**
- **Charged-particle scattering chamber (RBS)**
- **Charged-particle time-of-flight spectroscopy with up to 2-m flight paths**
- **W.M. Keck Thin Film Analysis Facility**
- **6 instrumented beamlines**



Nucl. Sci. Eng. **138**, 145 (2001)

http://inpp.ohiou.edu/~oual/facility/oual-clickable/edwards.html

Research Areas

- Nuclear Astrophysics
  - transfer reactions
- Nuclear Structure: Statistical Nuclear Physics
- Applications
  - inertial confinement fusion
  - materials science
  - radiation damage,…
- Substantial outside program
  - user facilities, other ARUNA labs, NIF, international

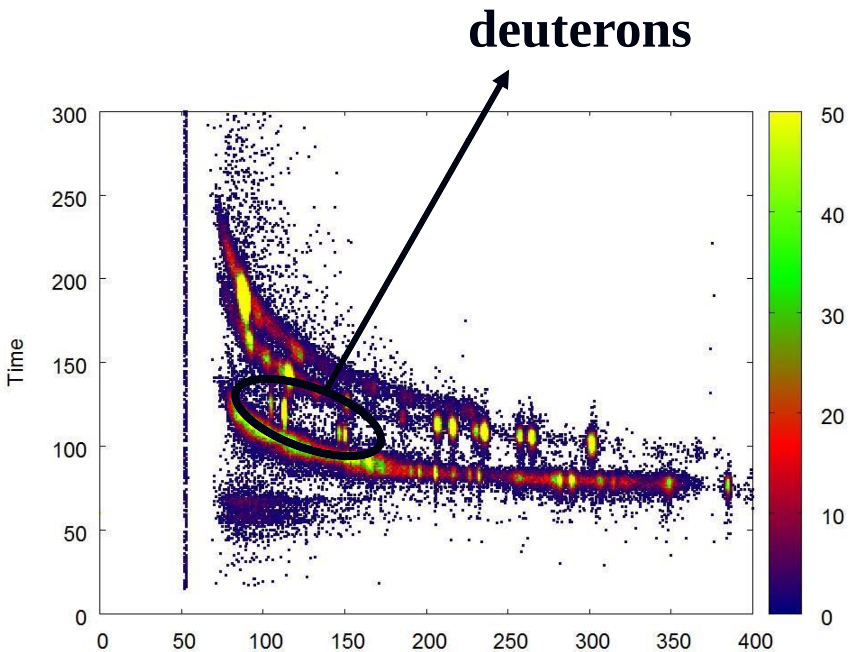
Management and Funding

- Operated by Ohio University
- Research support provided by
  - DOE/Office of NP, DOE/NNSA, LLNL
- Significant number of external users

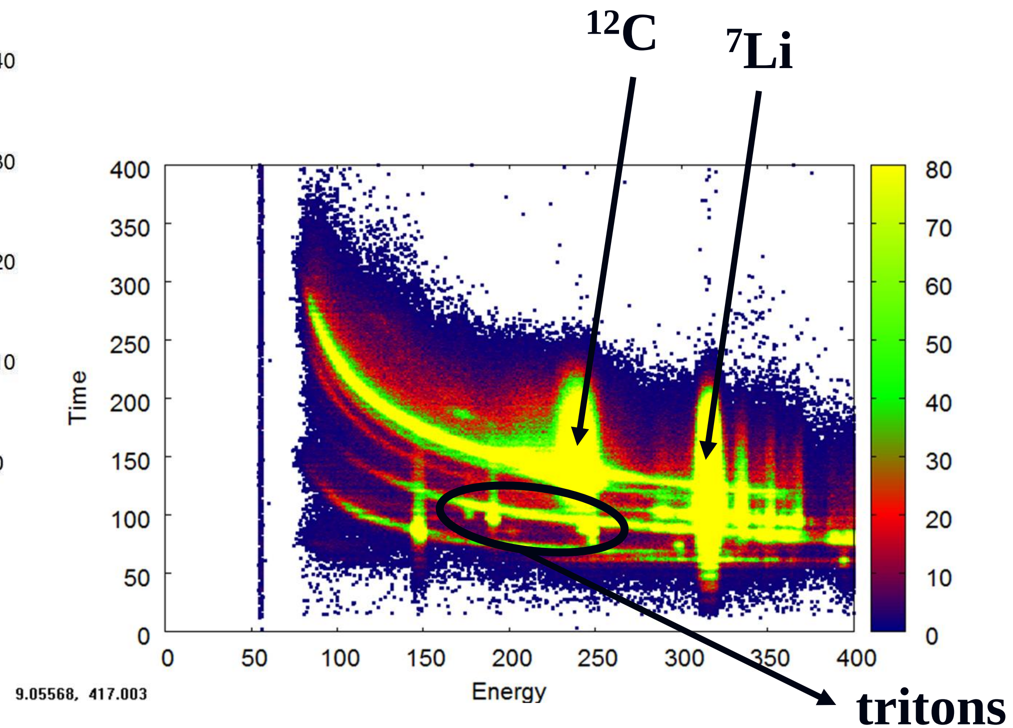
$^{12}C(\alpha,\gamma)$ via $^{12}C(^{6}Li,d)$ and $^{12}C(^{7}Li,t)$

- Asymptotic Normalization Constants (ANCs) or reduced α widths of bound states are essential for understanding the cross section at astrophysical energies
- These quantities can be reliably extracted from measurements of α transfer at sub-Coulomb energies
- Our approach: pulsed Li beams, TOF for particle ID
- Builds on previous work: Brune et al., PRL 83, 4025 (1999) and Avila et al., PRL 114, 071101(2015)
- Focus: experimental precision and evaluation of model (DWBA) uncertainties
- Ph.D. project of Shamim Akhtar

E-TOF Spectra

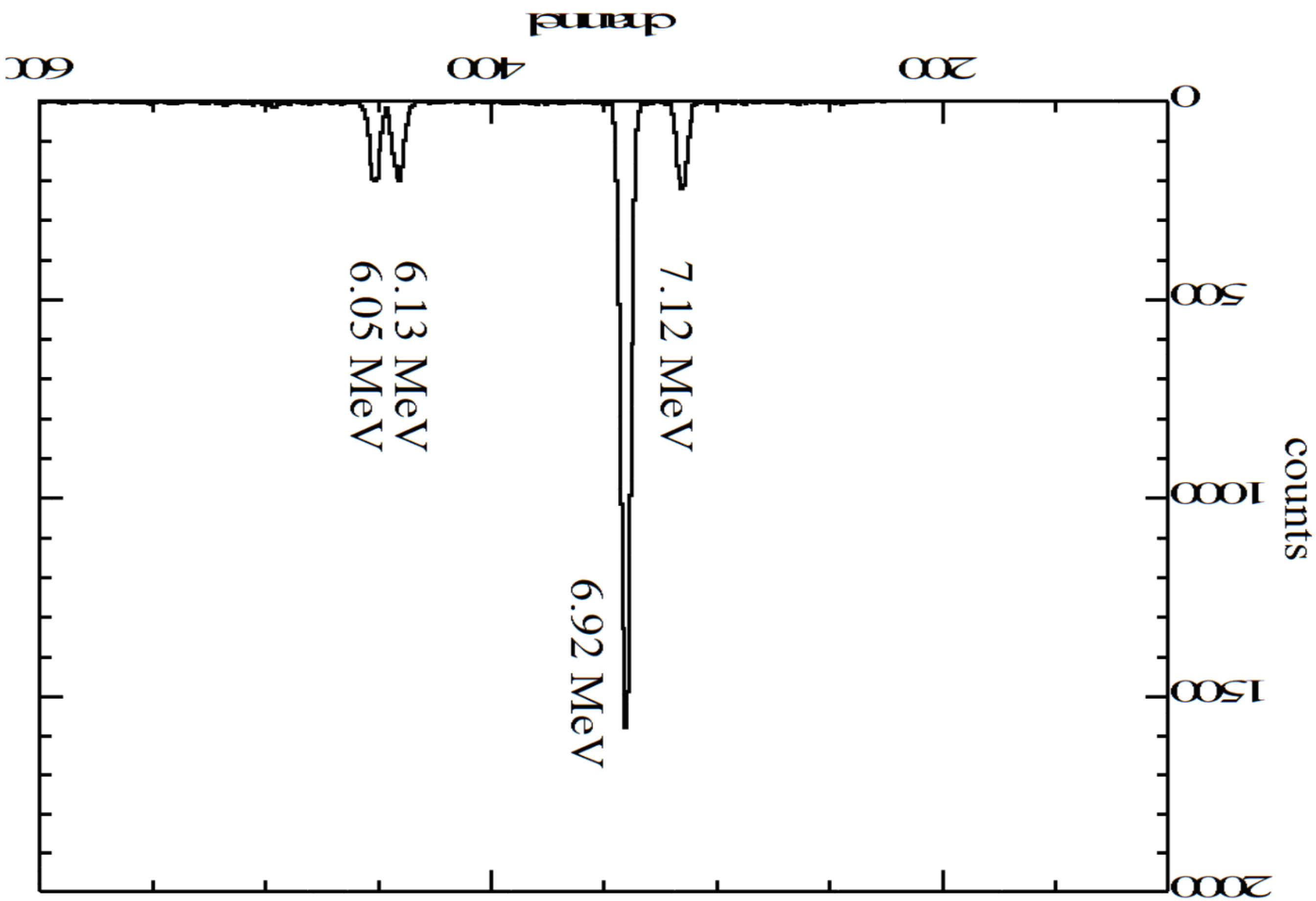


$^{12}C(^{6}Li,d)^{16}O$: E-TOF spectrum at 5-MeV
for 21-μg/cm^2-thick ^{12}C foil at 142.5^0



$^{12}C(^{7}Li,t)^{16}O$: E-TOF spectrum at 6-MeV
for 30-μg/cm^2-thick ^{12}C foil at 37.5^0

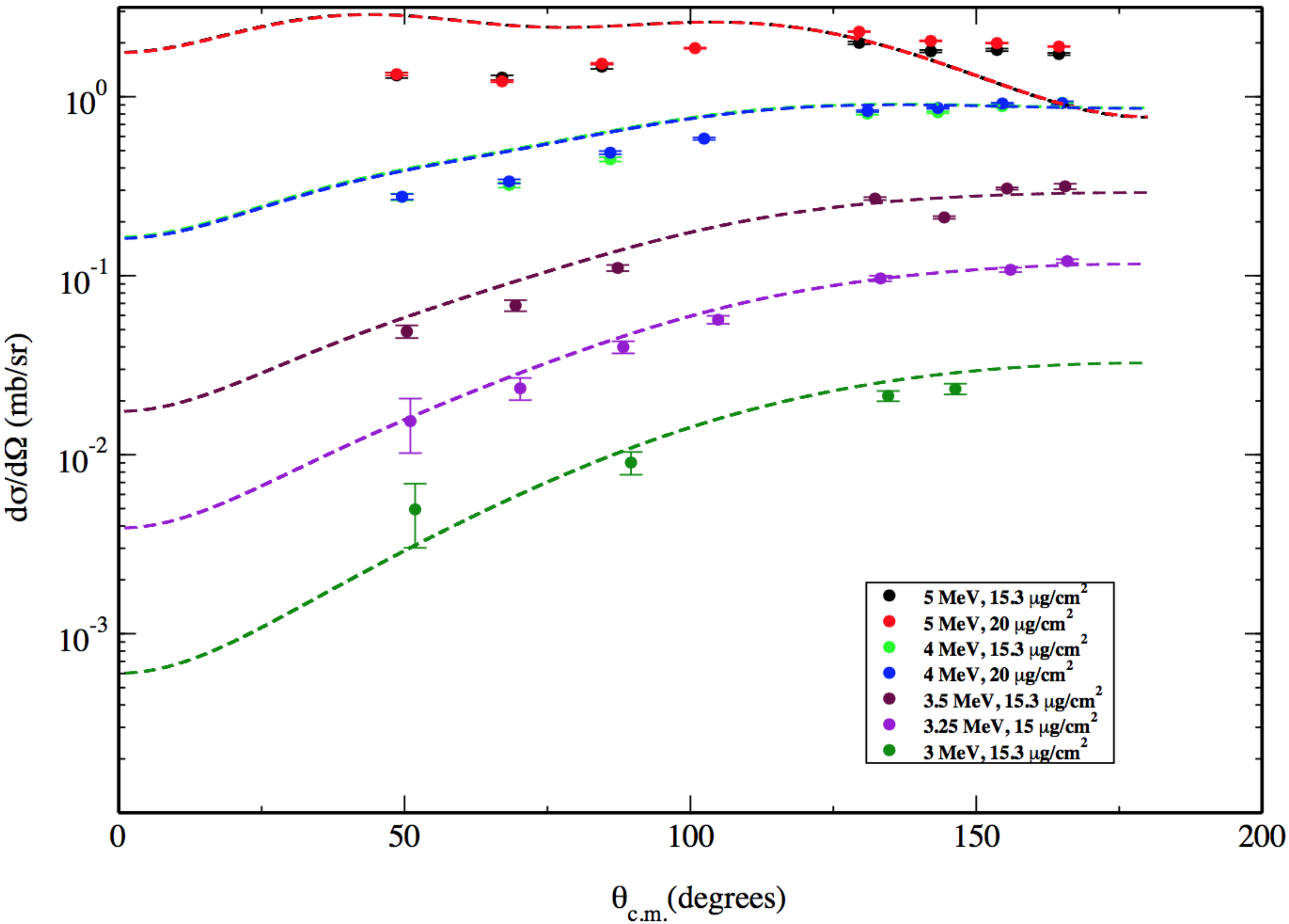
Resulting Deuteron Spectrum



E[6Li]= 5.0 MeV, θ_L=142.5 degrees

Experimental Cross Sections and DWBA Fits

$J^{\pi}=1^{-}$ E_x=6.92-MeV state of ^{16}O



Neutron Time-of-Flight Technique

$$^{24}Mg + {}^{3}He \rightarrow {}^{26}Si(*) + n$$

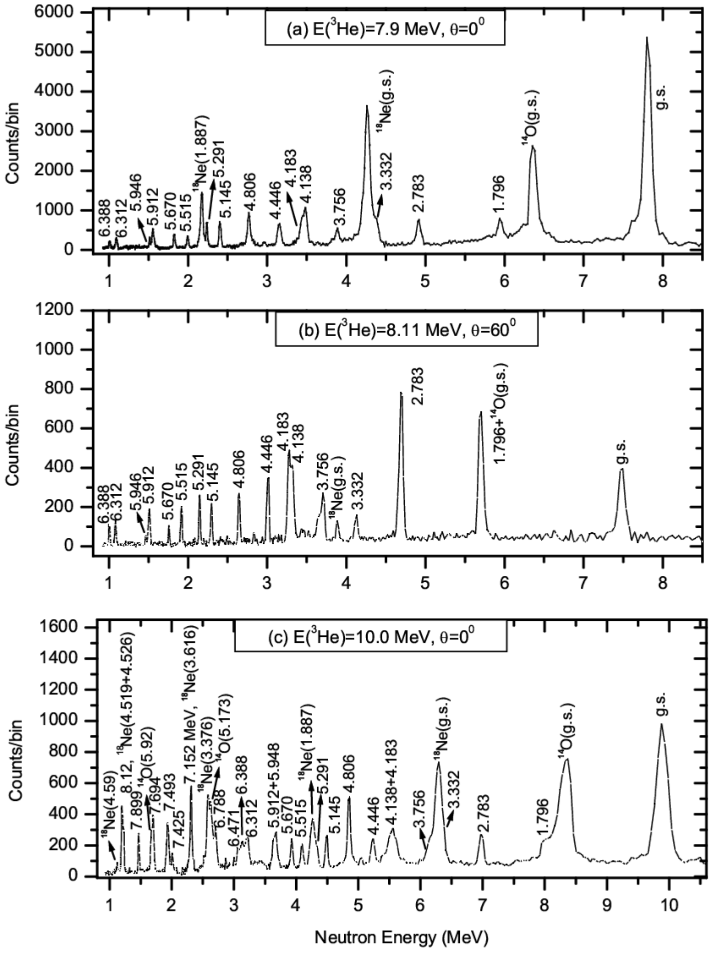
- time of flight → neutron energy
- kinematics → E_x in ^{26}Si
- $\Delta t \approx$ 2 ns
- long flight path, low E_n desirable
- NE-213 scintillator → neutron / gamma discrimination

Excellent energy resolution achievable (10 keV) !

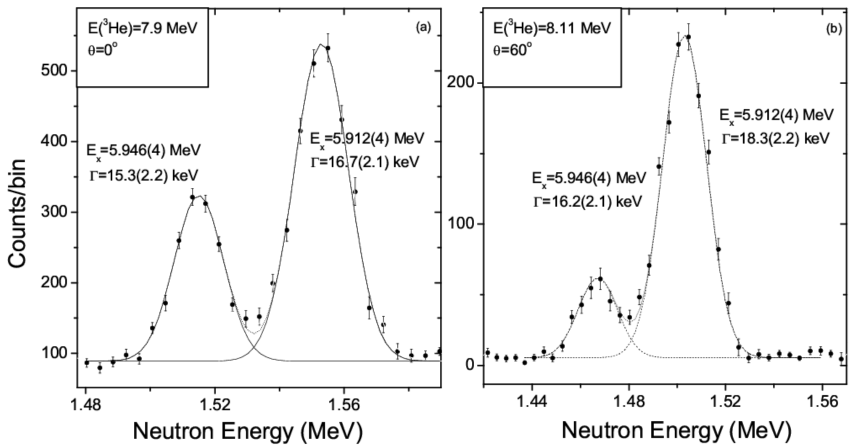
Neutron Energy Spectra

[Y. Parpottas et al., PRC 70, 065805 (2004)]

full spectra



$^{24}Mg(^{3}He,n)^{26}Si(*)$

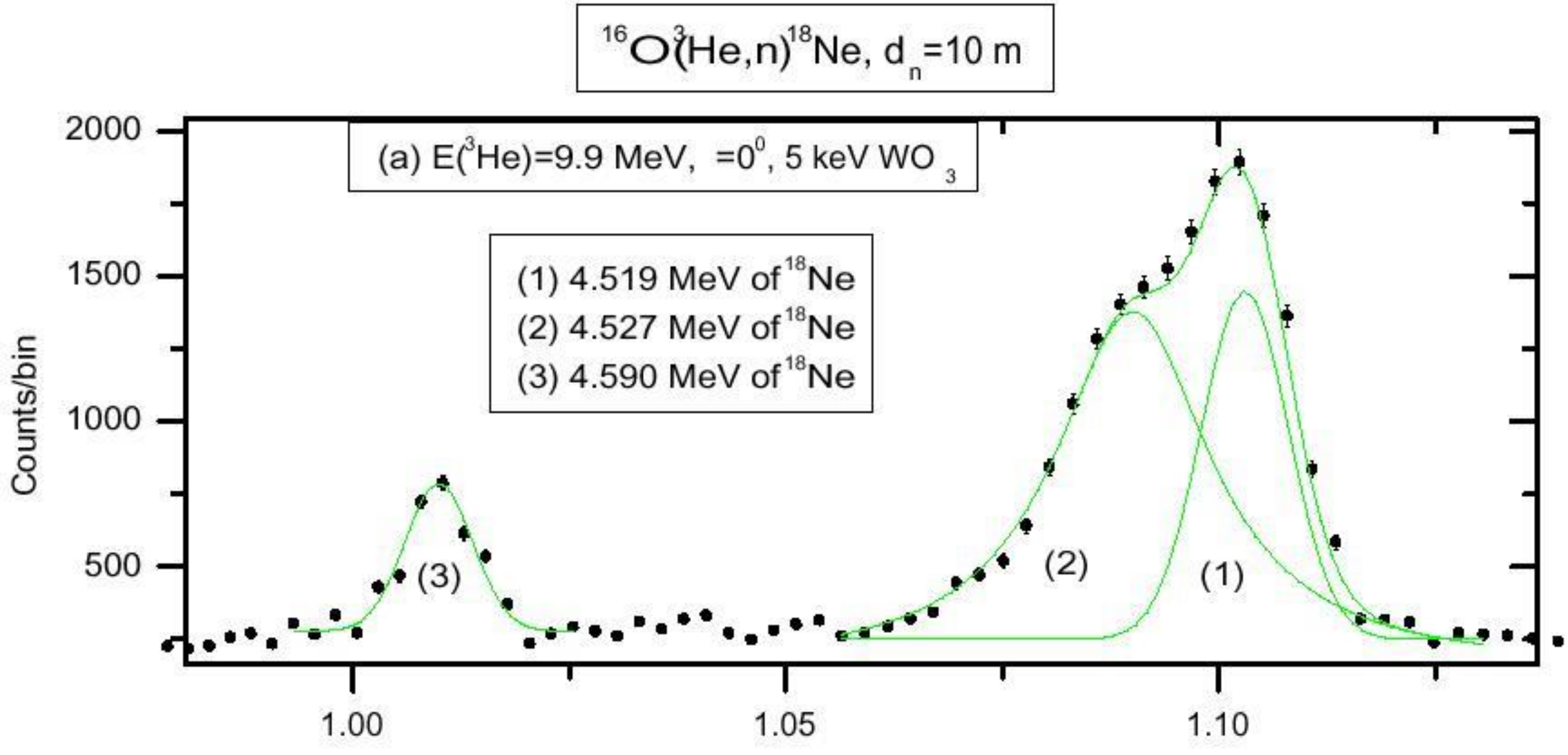


Key Result

Mirror nucleus leads us to expect 3^{+} and 0^{+} in this region.

$^{16}O(^{3}He,n)^{18}Ne$
(Y. Parpottas)

$\Gamma(4.527) = 17(4)$ keV



Neutron Energy (MeV)

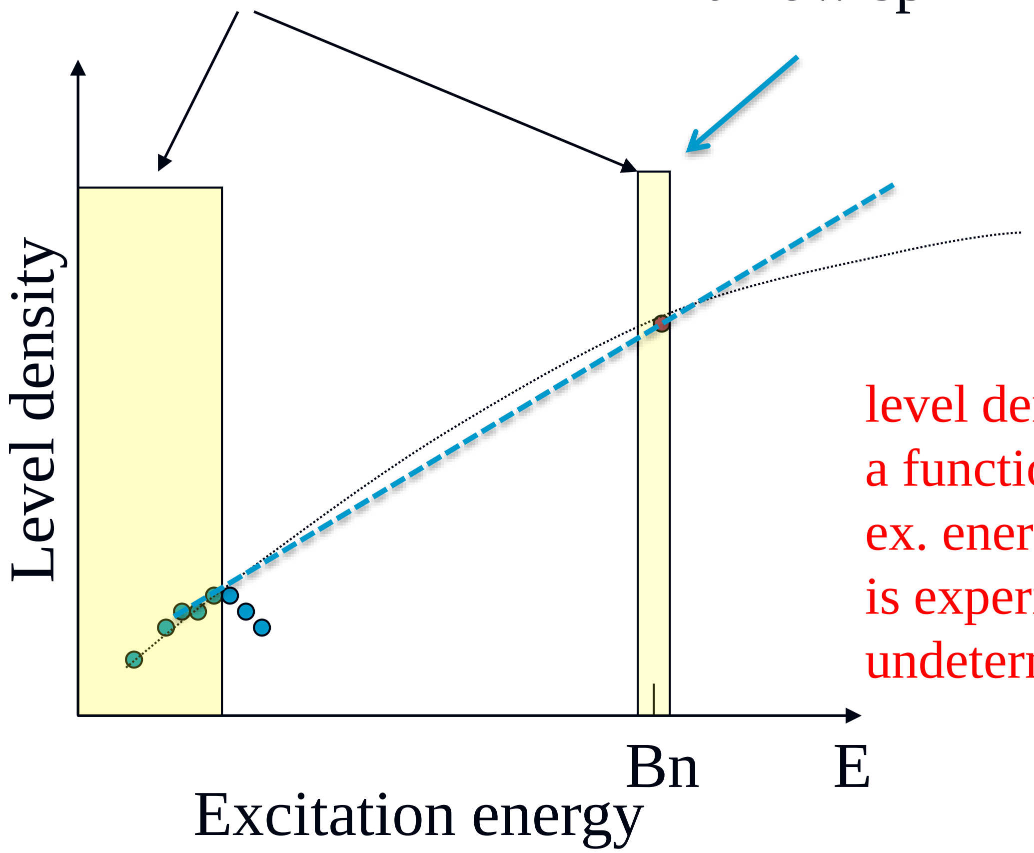
Statistical Nuclear Physics

Research program led by A. Voinov and S. Grimes

Example: Level Densities

Level density is known
for most of the stable nuclei

narrow spin interval



level density as
a function of
ex. energy and spin
is experimentally
undetermined !!!

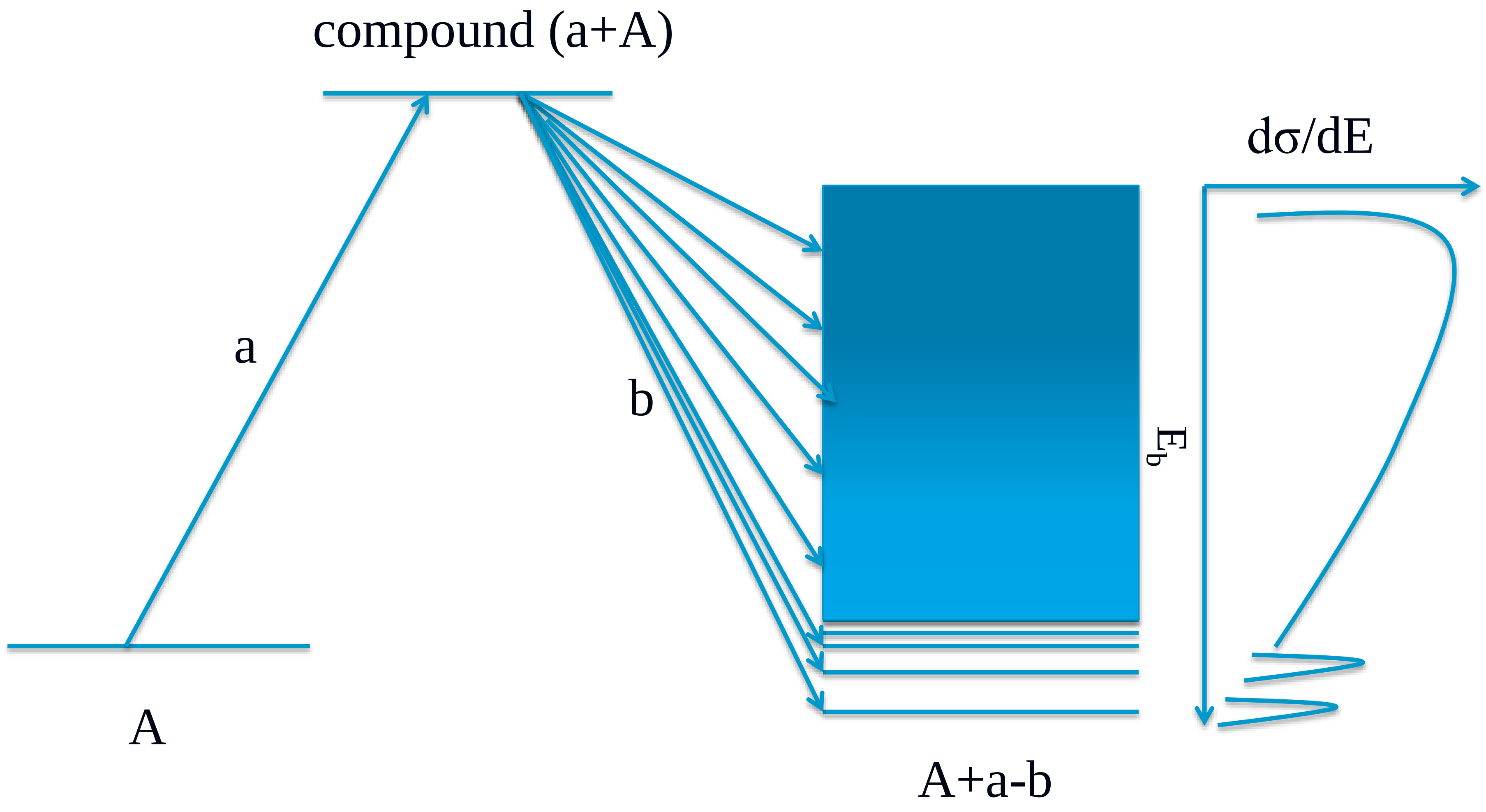
Level density as a function of excitation energy can be obtained experimentally from particle spectra of compound nuclear reactions

The concept:

$$\frac{d\sigma(E)}{dE} \sim \sigma_C(E)\frac{T_{out}(E')\rho_f(E^*)}{\sum_i T_{out\ i}}$$

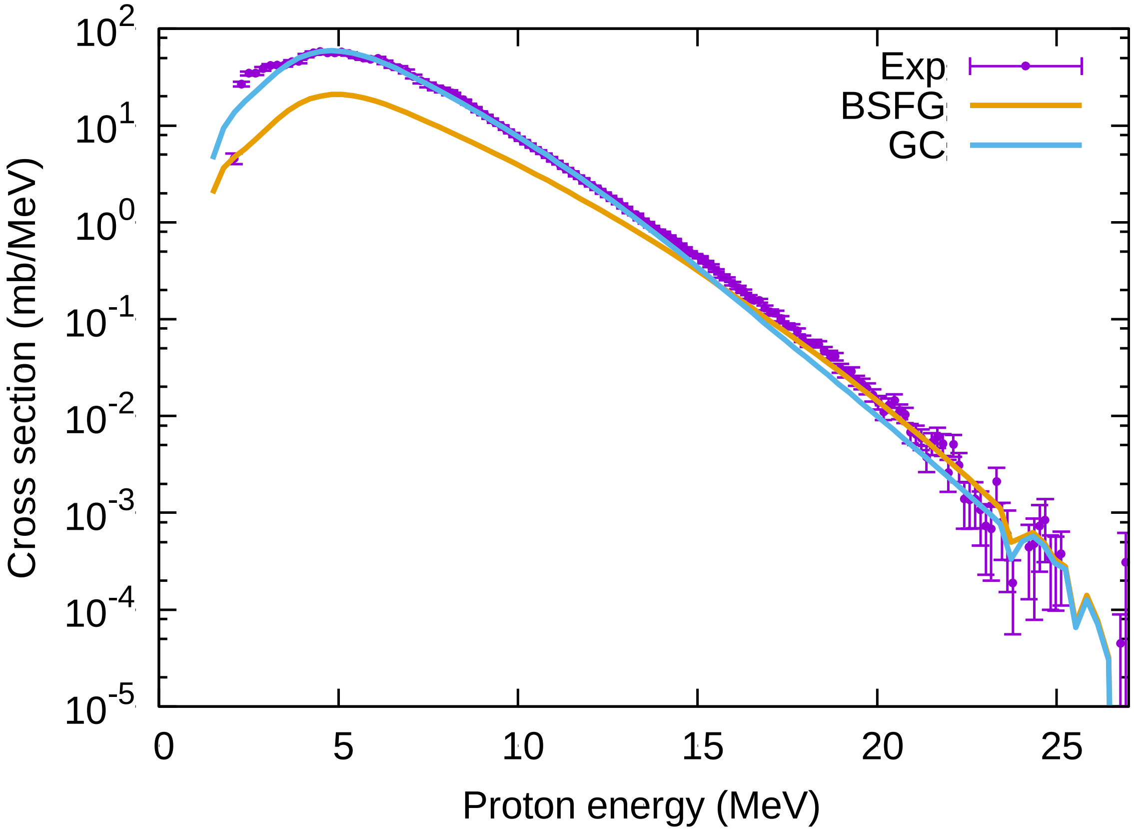
Make sure that the compound reaction mechanism dominates.

1. Select appropriate reactions (beam species, energies, targets).
2. Measure the outgoing particles at backward angles
3. Compare reactions with different targets and incoming species leading to the same final nuclei


compound (a+A)
a
b
dσ/dE
E_b
A
A+a-b

Results from ^{7}Li induced reactions
$E[^{7}Li]$=15 MeV

$^{7}Li + ^{54}Fe \rightarrow ^{60}Ni + p$

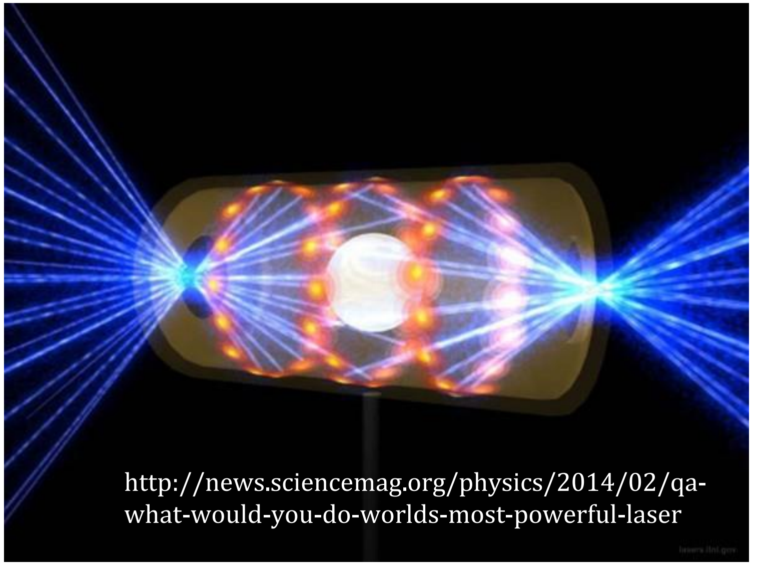


Back shifted Fermi-gas Model (BSFG)
Gilbert and Cameron Model (GC)

} parameters from RIPL3

The $^3H(d,\gamma)^5He$ Reaction

- Inertial confinement fusion studies at the National Ignition Facility
  - γ-rays useful for diagnostic purposes
    - $^3H(d,\gamma)/^3H(d,n)$ branching ratio – detected γ-rays can be used to determine the number of fusions
    - Roughly 1 γ-ray for 10,000 neutrons
- Understanding of the properties of the unbound ^5He nucleus
  - Broad 1st excited state overlaps with ground state above α+n



http://news.sciencemag.org/physics/2014/02/qa-what-would-you-do-worlds-most-powerful-laser

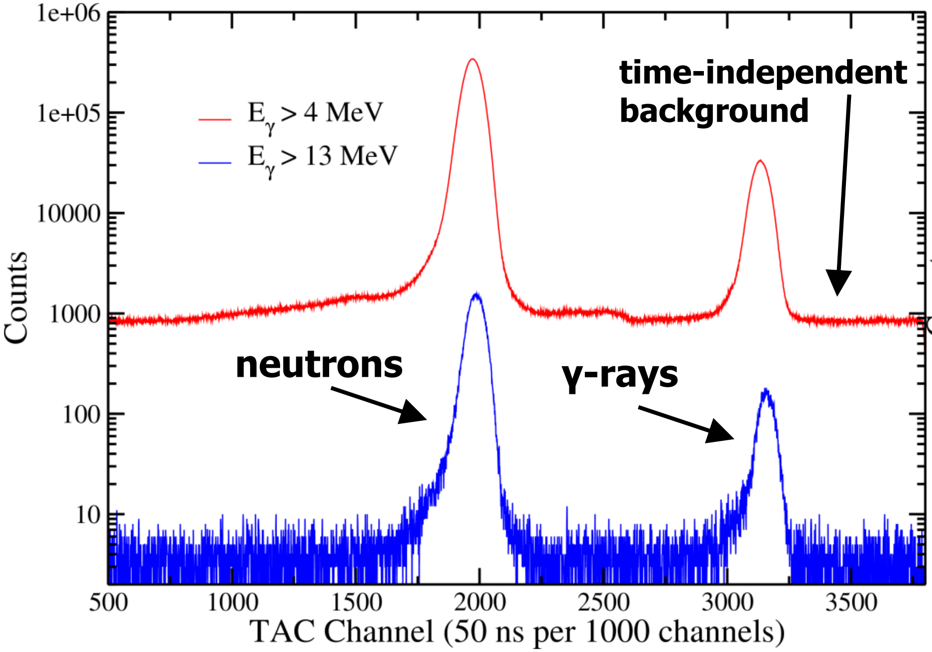
$^{3}H(d,\gamma)^{5}He$ - Experiment

- Pulsed & bunched 500-keV deuteron beam
- Swinger beamline and concrete-shielded tunnel
  - Lead bricks at tunnel entrance
  - Swinger angles of 90°, 45°, 135°
- Solid tritium target
  - ^{3}H:Ti ratio ≥ 1.5
- BGO for γ-rays
  - TOF technique
  - 3.9-meter flight path
- Silicon for α's
  - Inside target chamber
- Stilbene and NE-213 for neutrons
  - TOF & PSD
- Ph.D. project of Cody Parker

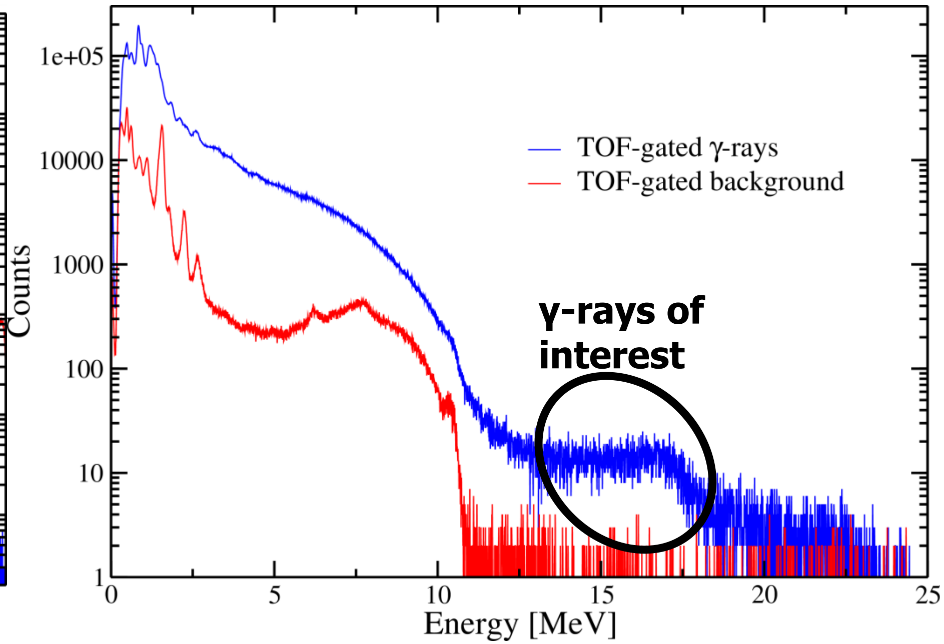
Swinger and tunnel entrance

$^{3}H(d,\gamma)^{5}He$ - BGO Spectra for 90°

TOF gated by energy



Energy gated by TOF



Recent Outside Users

Date(s)	PI	Institution – Project
June-July 2012; July 2013	S. Padalino, M. Yuly	SUNY Geneseo, Houghton College $\sigma(E)$, $^{12}C(n,2n)^{11}C$
March 2014; May 2016	A. Enqvist, *et al.*	University of Florida, University of Michigan Detector Calibration
Sept. 2014	J. Hall, D. Bleuel	Lawrence Livermore National Laboratory (d,n) on ^{9}Be, B, and ^{13}C
Feb. 2015; April 2015	A. McEvoy	Los Alamos National Laboratory $^{13}C(n,n'\gamma)$
May 2015	B. Wilson, T. Blue	Ohio State University Radiation Damage
Jan. 2016	A.C. Larsen, S. Liddick, *et al.*	Oslo University, Michigan State University Level Density Studies
April 2016	T. Ahn, *et al.*	Michigan State University Neutron Detector Calibration using D(d,n)
August 2016	M. Hogsed	Air Force Institute of Technology Radiation Damage

To Summarize

- Edwards Accelerator Laboratory at Ohio University:

  4.5-MV tandem accelerator

- Research:

  Nuclear Astrophysics, Nuclear Structure, Applications

- Complimentary to NSCL, ATLAS, TRIUMF, NIF,…

- Thanks for your attention!