A Brief History

of

EBs @ ND

from

1936 – 2022

J.J. Kolata
Exotic Beam Summer School
University of Notre Dame
June 7, 2022

Accelerator History

1930 Cockroft-Walton (Cavendish Laboratory)

1931 Converted X-ray tube (Caltech) (C.C. Lauritsen)

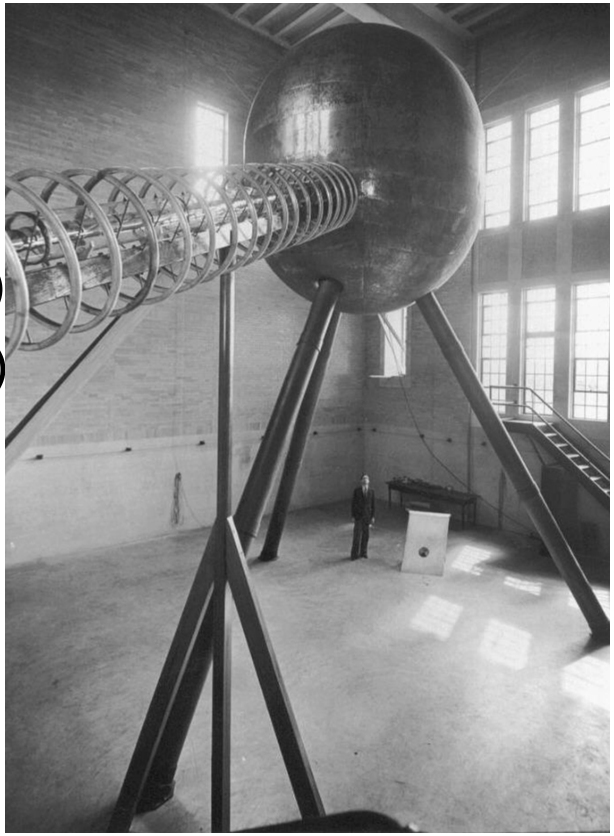
1931 Electrostatic Generator (MIT) (R. Van de Graaff)

1932 Cyclotron (UC Berkeley) (T.H. Lawrence)

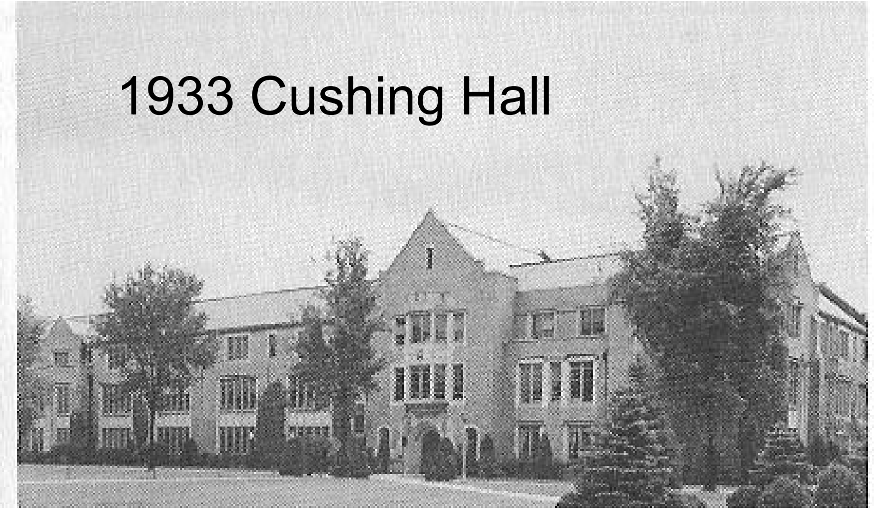
1933 Electrostatic Generator (Carnegie) (M.A. Tuve)

1935 Electrostatic Generator (Carnegie) (R.G. Herb)

1936 Electrostatic Generator (Notre Dame)



The 6th accelerator laboratory in the world!



First RNB Apparatus (1988)

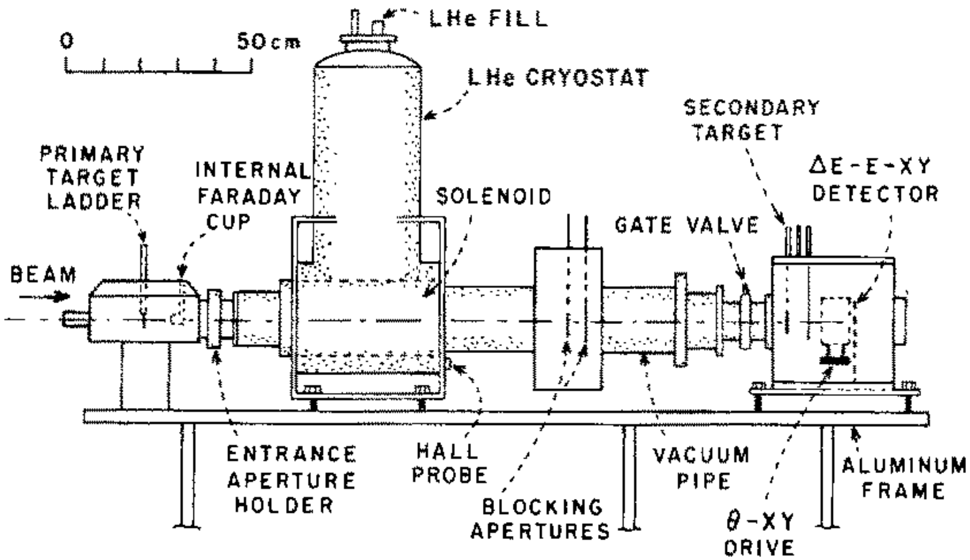


Fig. 1. Experimental apparatus for radioactive beam production.

Collaboration: J.J. Kolata (Notre Dame)
F.D. Becchetti (Michigan)

Typical Beam Parameters (^{8}Li):

Primary Beam: ^{7}Li ; 17 MeV ; 100 enA
3^{+} Charge State ; Spot Size 2 mm dia.
Primary Target: ^{9}Be ; 2.3 mg/cm^{2}

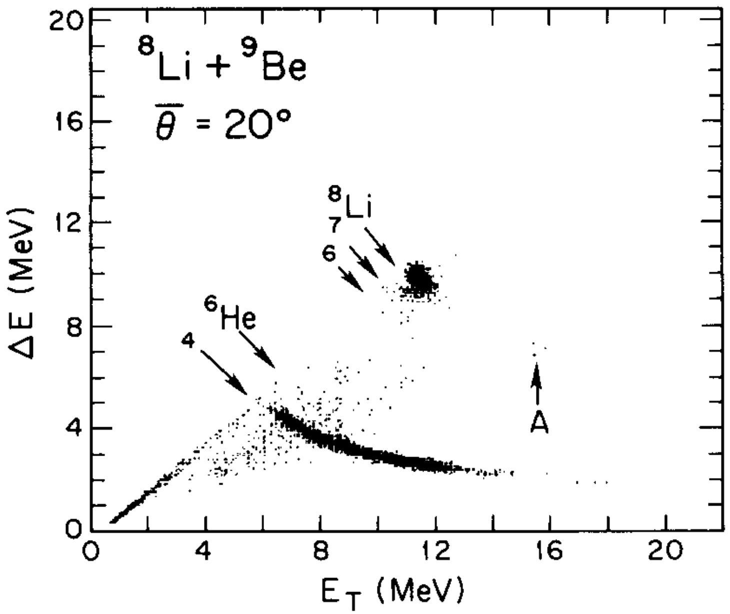
Secondary Beam: ^{8}Li ; 14.3 MeV
Resolution 600 keV FWHM
Rate: 5×10^{4}/s ; Spot Size 5 mm dia.
Divergence: ±4°

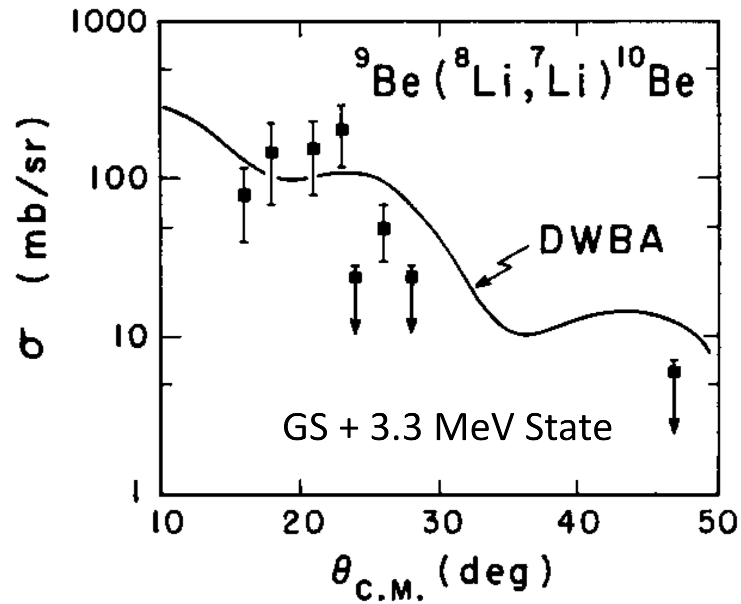
Solenoid: 3.5 T ; 20 cm bore ; 40 cm length

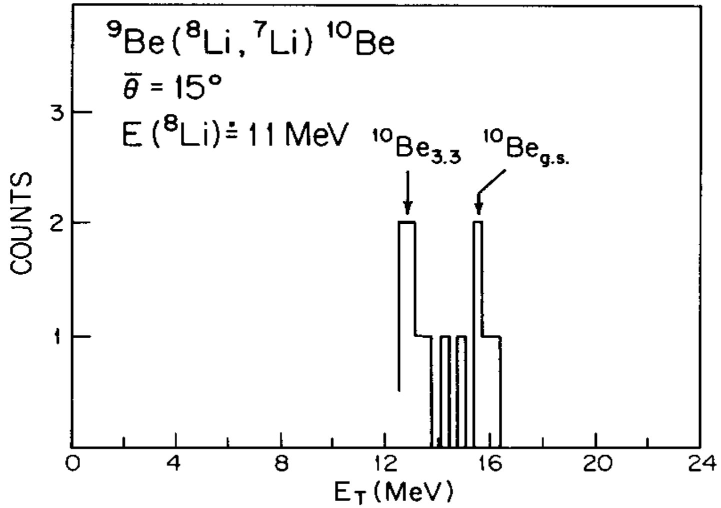
Beams: “3-stage” VdG at Notre Dame

Nucl. Inst. Methods B40/41, 503 (1989)

Early Experiments: Transfer Reactions





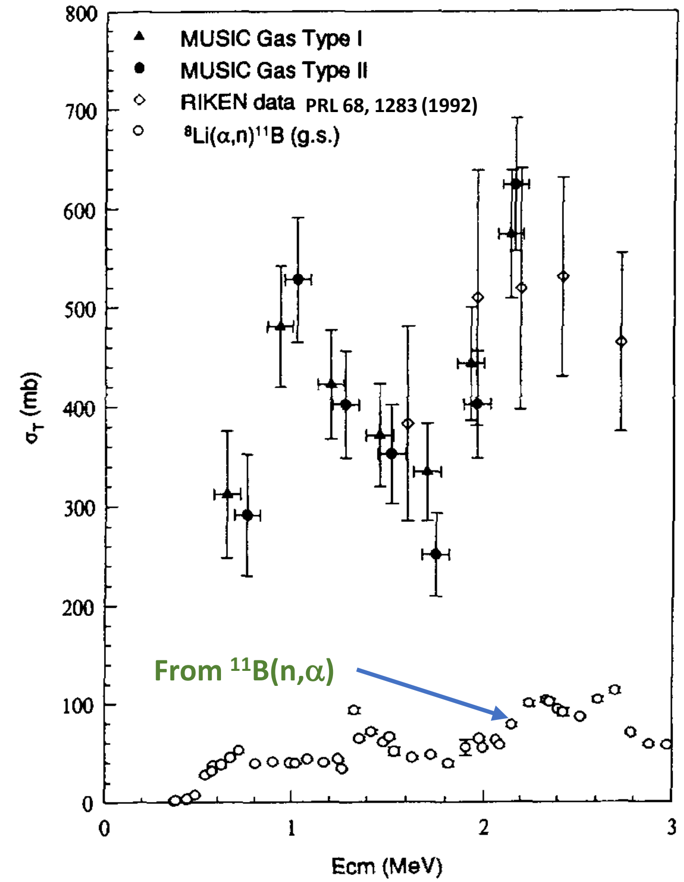


Phys. Rev. C40, R1104 (1989)

First-Ever Successful Transfer-Reaction Measurement with a Radioactive Beam (apart from ^{3}H).

Early Experiments: Nuclear Astrophysics

The $^{8}Li\ (\alpha,n)^{11}B$ reaction and primordial nucleosynthesis ; Phys. Lett. B343, 31 (1995)



Collaboration:

Ohio State
Notre Dame
Univ. of Michigan
Kyushu Univ.
RIKEN (Japan)
Lawrence Berkeley Lab.
Ball State Univ.

Method:

Parallel Plate
Avalanche Counter
(PPAC)

Multi-sampling Ion
Chamber (MUSIC)

^{4}He gas with 2%
Isobutane (Type I) or
Methane (Type II)

Details:

^{8}Li Energy of 7.1 MeV upon entry to the MUSIC chamber
Energy width: 0.1 MeV ; Uncertainty in the mean: 0.2 MeV

Early Experiments: Nuclear Astrophysics

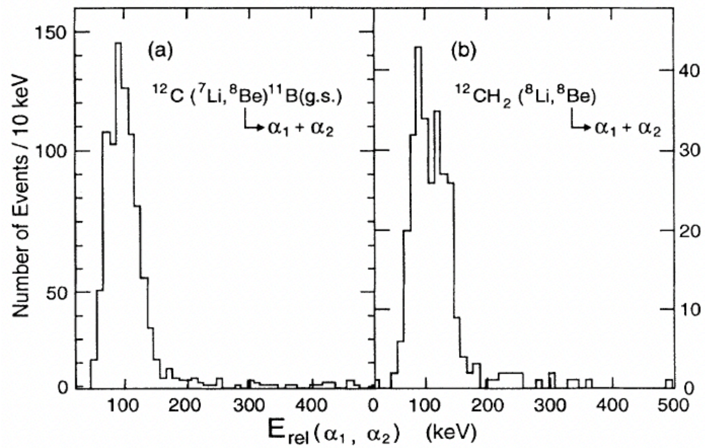
The ^{8}Li (p,n)^{8}Be$_{gs}$ reaction at E_{cm}=1.5 MeV ; Phys. Rev. C47, 387 (1993)

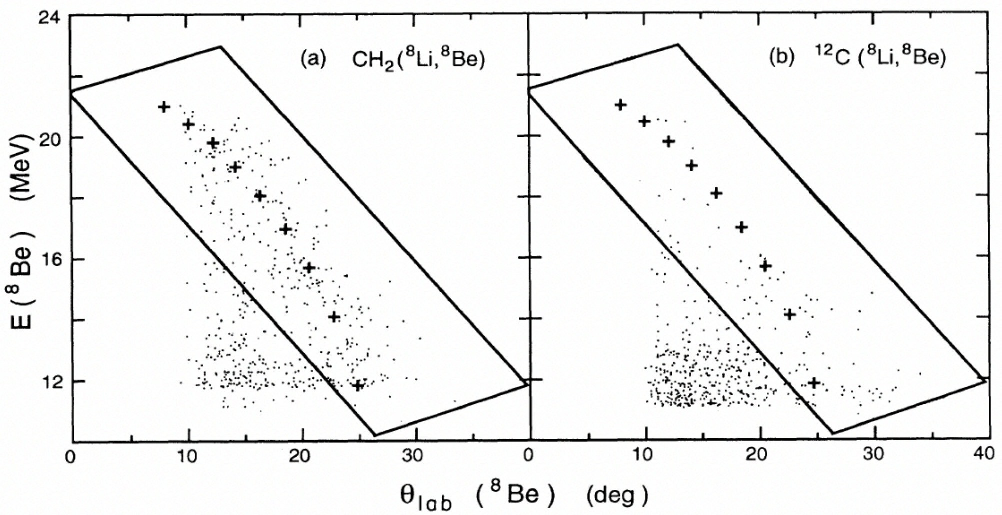
Collaboration:

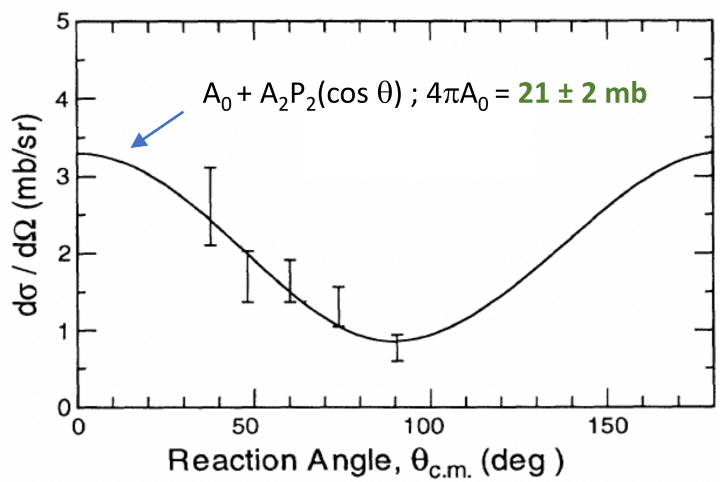
Florida State
Notre Dame
Univ. of Michigan
Univ. of North Florida

Method:

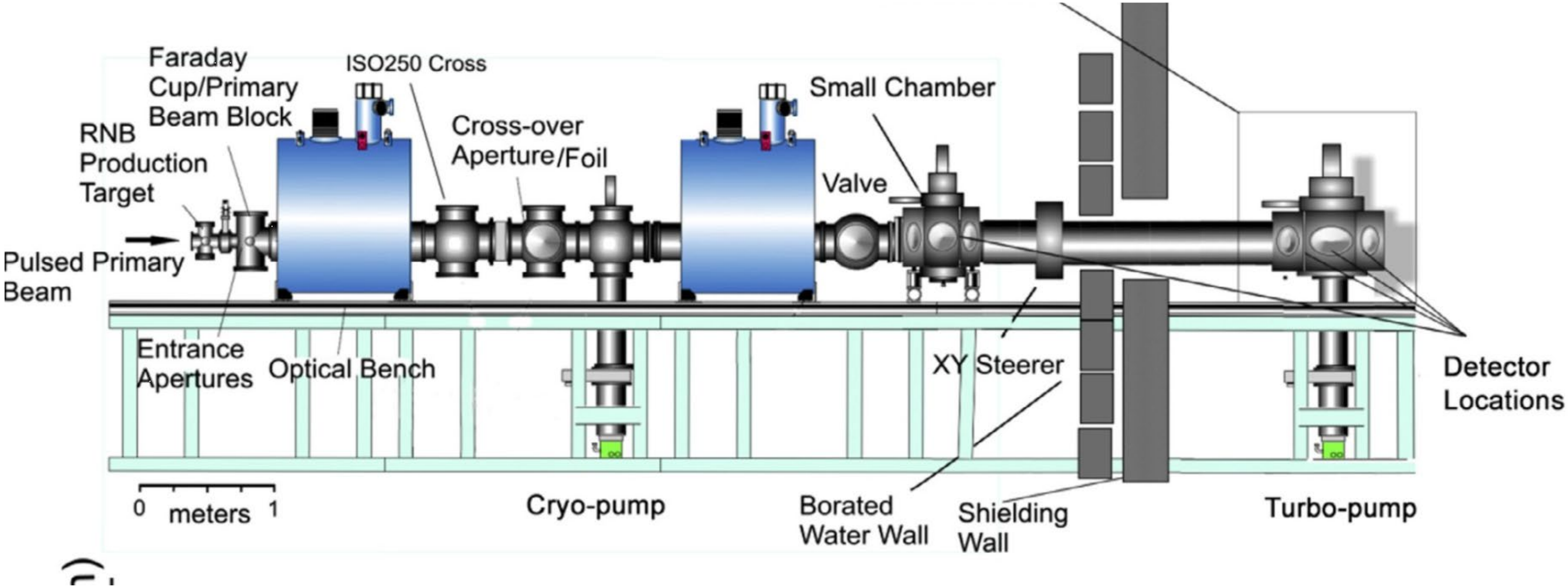
α-particle coincidences between stacked 5 cm long Si strip detectors.







New Facility: *TwinSol* (1998)



Solenoids: 6T ; 30 cm warm bore ; 1 m long

AIP Conf. Proc. 392, 397 (1997)

Sub-Barrier Fusion with Exotic Beams

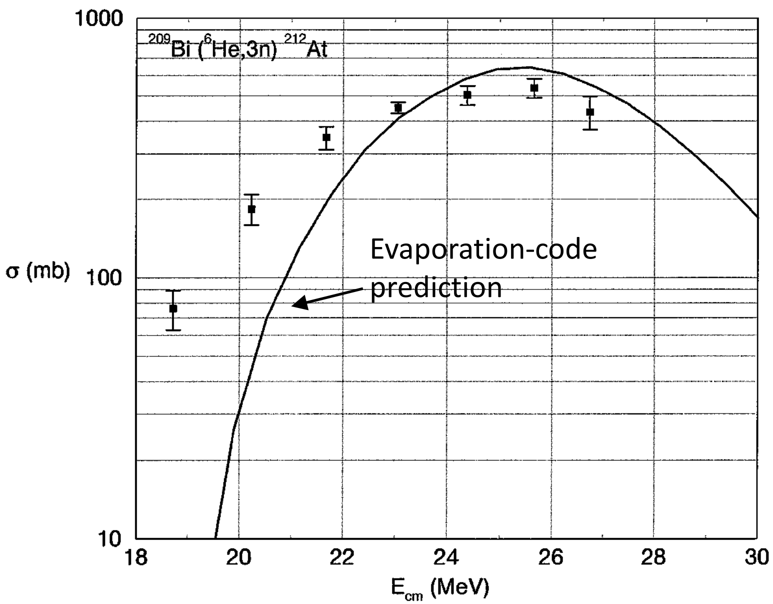
Questions to answer:

Is fusion suppressed due to breakup of ^{6}He?

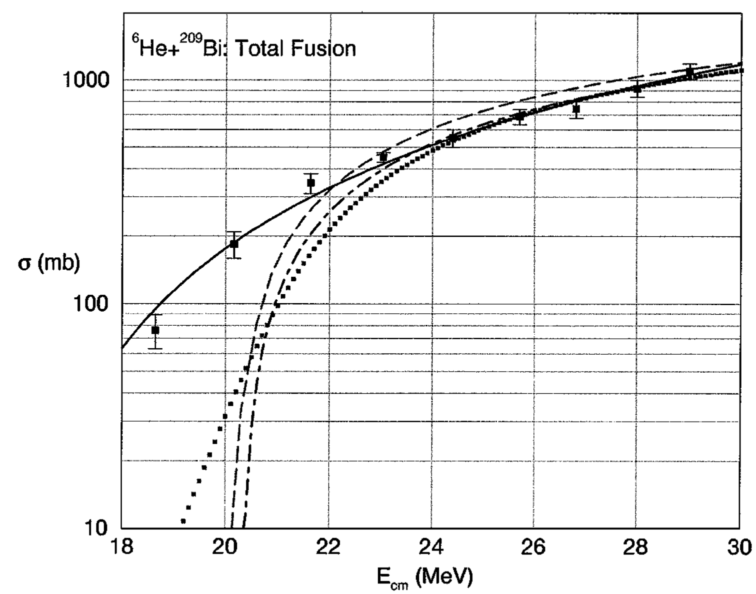
Is fusion enhanced due to neutrons at large radius?

Method:

^{6}He incident on ^{209}Bi.
Radiochemical: Stacked foils with degraders in-between.
Off-line detection of delayed alphas arising from evaporation residues.



^{212}At Production



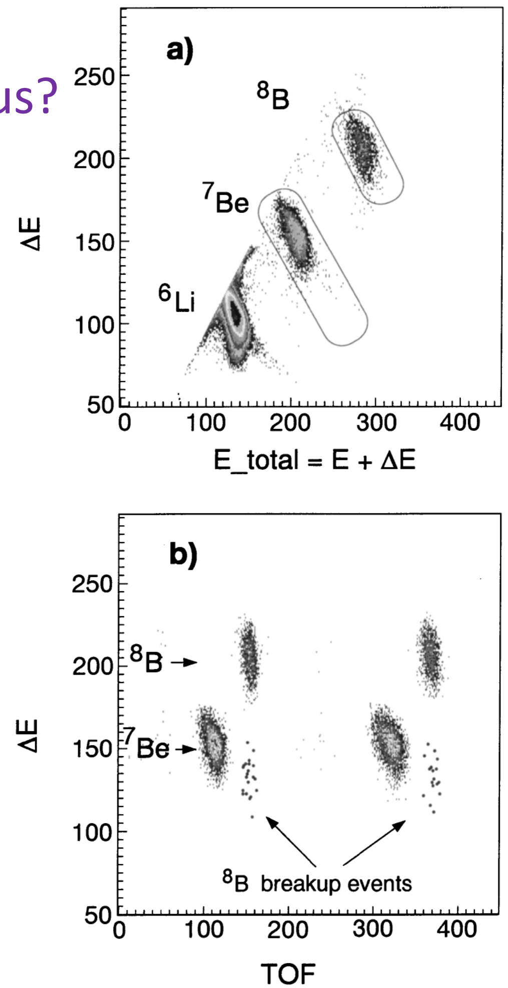
Total Fusion

Phys. Rev. Lett 81, 4580 (1998); 300 references (incl. mention in CERN Courier)

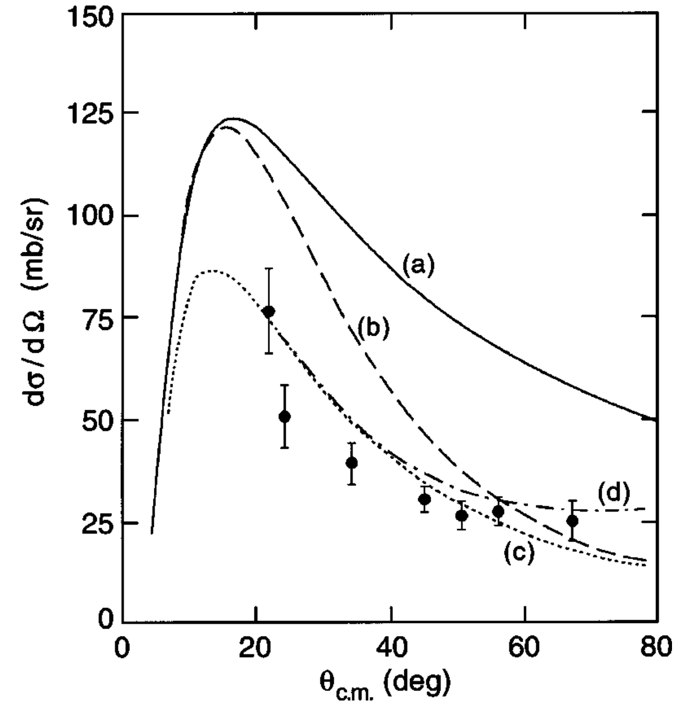
Breakup of ^{8}B on ^{58}Ni

Question: Is ^{8}B a 1p halo nucleus?

Method: Add Time-of-Flight using a 2 ns FWHM pulsed beam to tag the "cocktail" beam.



PRL84, 1862 (2000)



PRC66, 044609 (2002)
Esbensen and Bertsch

Results:

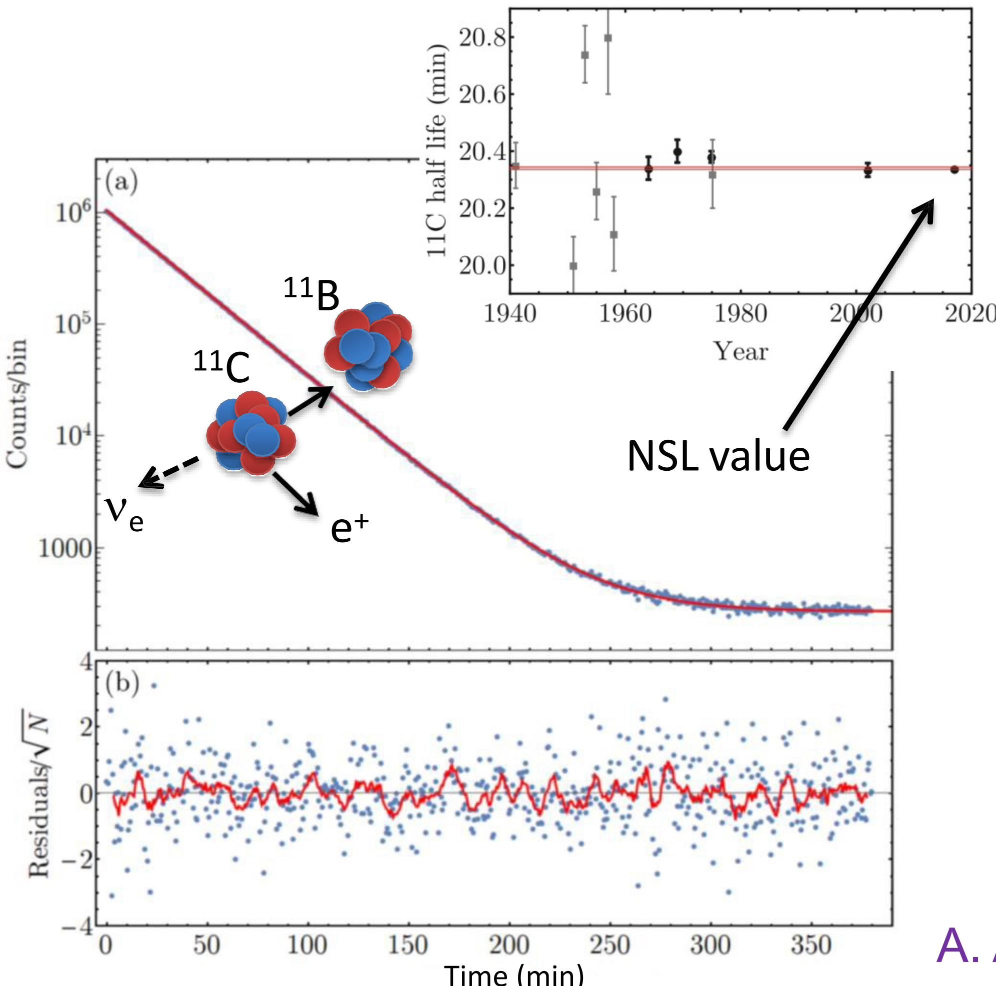
(a) First-order Coulomb excitation assuming the usual "far-field" approximation.

(b) Corrected for close and distant collisions due to Coulomb polarization of the ^{8}B proton halo state (shielding effect).

(c) Dynamic Coulomb dissociation of the halo state.

(d) Nuclear effects included. Transfer process greatly suppressed due to prior breakup.

^{11}C half-life measurement at the NSL



- Superallowed mixed mirror decays → precision tests of Standard Model via V_{ud}
- Measurement of ^{11}C $t_{1/2}$ @ ND → most precise of all SA mixed decays
- Lightest of all mirror transitions to test CVC
- Measurement of mixing ratio with the future St. Benedict ion trap is planned to extract V_{ud}.

A. A. Valverde *et al.*, PRC **97** 035503 (2018)

Shown by Alena Opper (NSF) at the 2019 NSAC meeting

TriSol Exotic Beam Facility

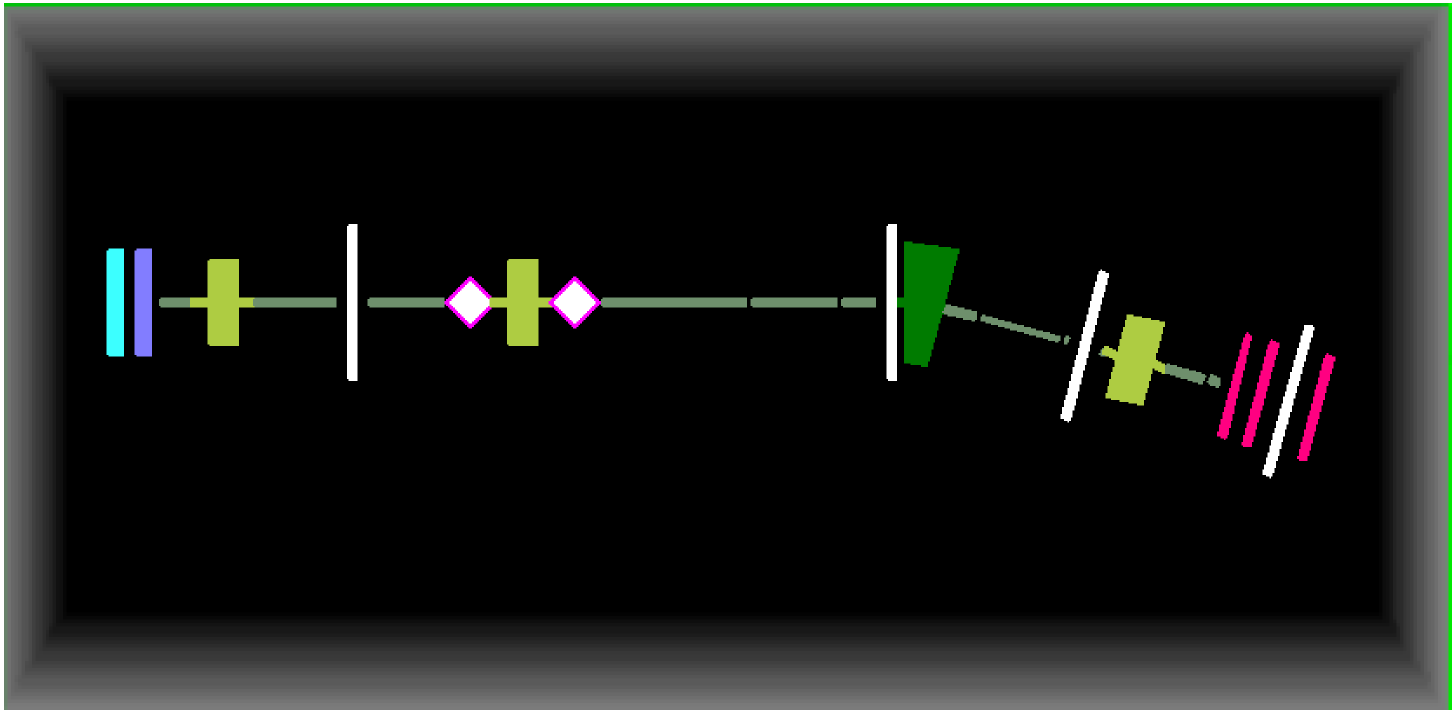
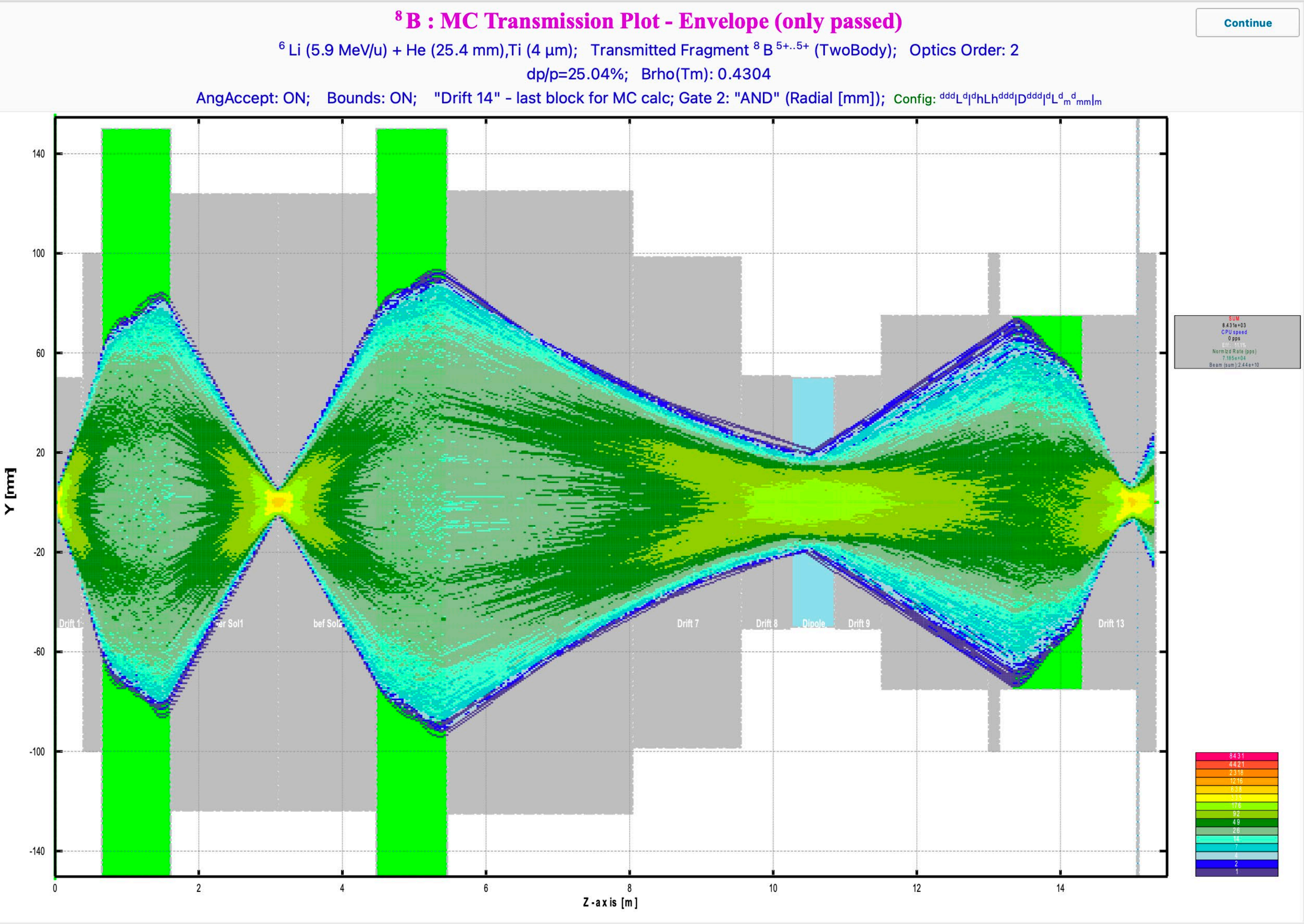
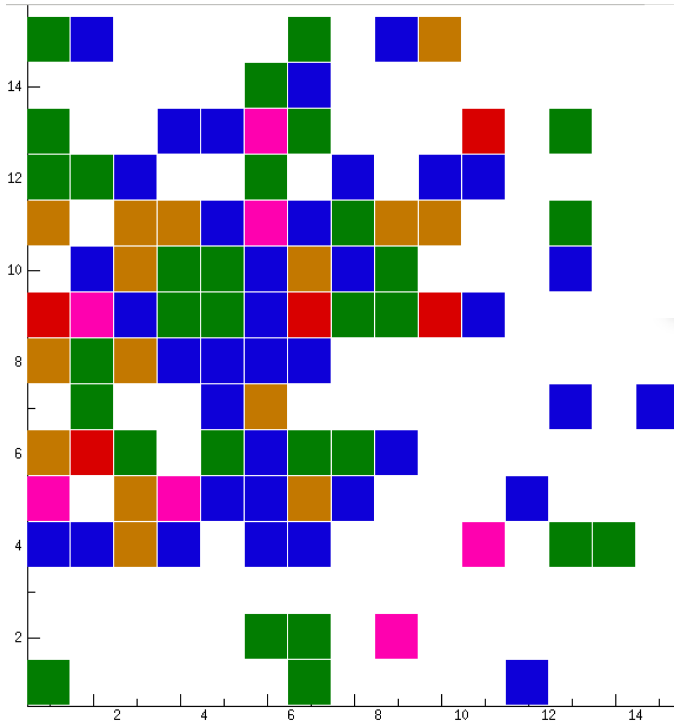


Diagram from a LISE^{++} Calculation

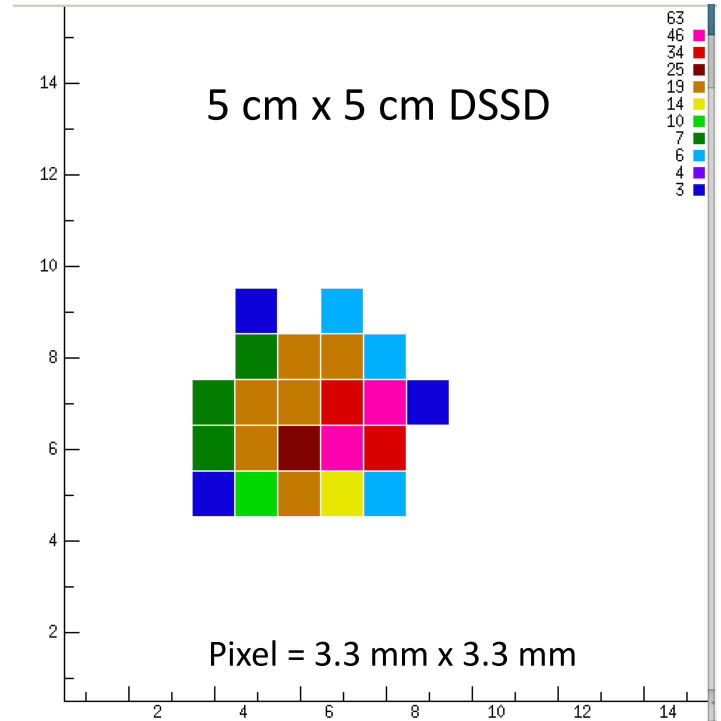


8 B : MC Transmission Plot - Envelope (only passed)
Continue
6 Li (5.9 MeV/u) + He (25.4 mm),Ti (4 µm); Transmitted Fragment 8 B 5+..5+ (TwoBody); Optics Order: 2
dp/p=25.04%; Brho(Tm): 0.4304
AngAccept: ON; Bounds: ON; "Drift 14" - last block for MC calc; Gate 2: "AND" (Radial [mm]); Config: dddLd|dhLhddd|Dddd|dLdmdmm|m
Y [mm]
140
100
60
20
-20
-60
-100
-140
Drift 1
er Sol1
bef Sol2
Drift 7
Drift 8
Dipole
Drift 9
Drift 13
0
2
4
6
8
10
12
14
Z-axis [m]
SUM
8.431e+03
CPU speed
0 pps
Eff: 11.1%
Normlzd Rate (pps)
7.185e+04
Beam (sum):2.44e+10
8431
4421
2318
1216
638
335
176
92
49
26
14
7
4
2
1

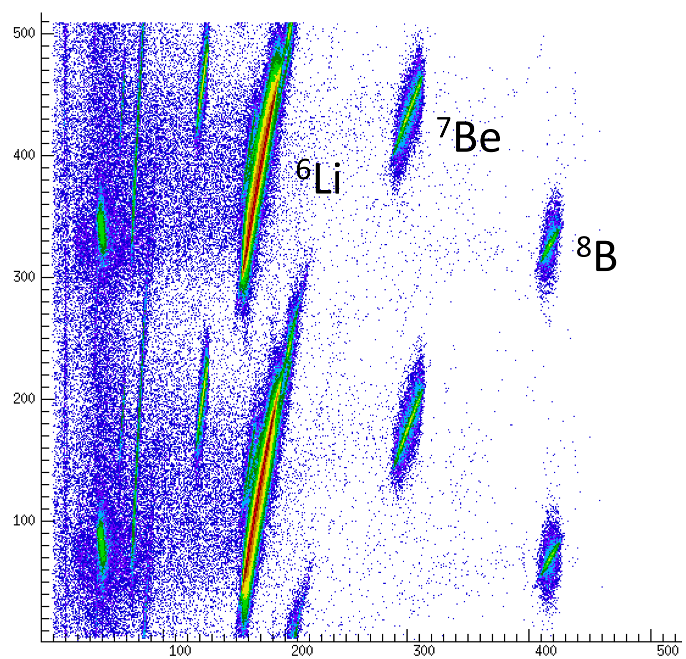
Sol3 = 0



Sol3 = 22 A



Time-of-Flight vs. Energy



Small, University Based Accelerator Laboratories --- Past and Future

Ubiquitous in the 1960's but Nearing Extinction in the 2020's

But, still able to carry out interesting, important, world-class research.

Advantages: Short Turn-Around Time for Innovative Experiments.
Ability to Dedicate Long Blocks of Time for Important Work.
Hands-on Experience with All Aspects of an Experiment.

Opportunities Exist in Nuclear Astrophysics, Fundamental Interactions, and even Reactions of Exotic Beams.

Find your niche and exploit it!