A SOLENOIDAL TRANSPORT DEVICE FOR TRANSFER REACTIONS IN INVERSE KINEMATICS

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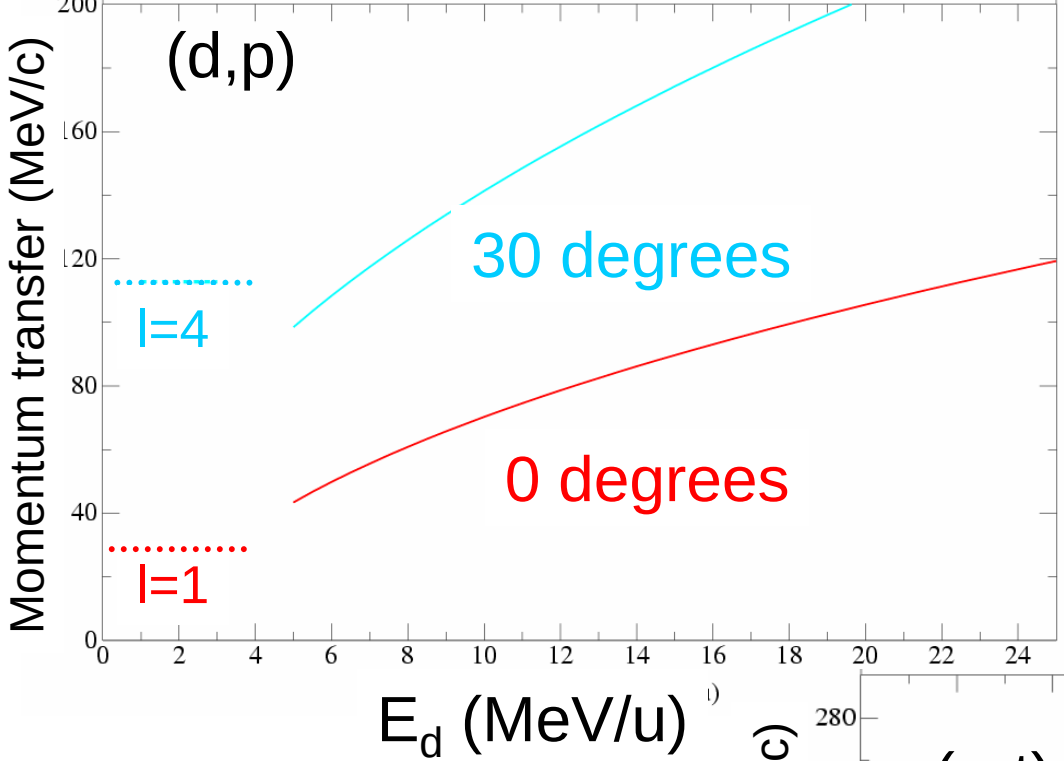
Outline

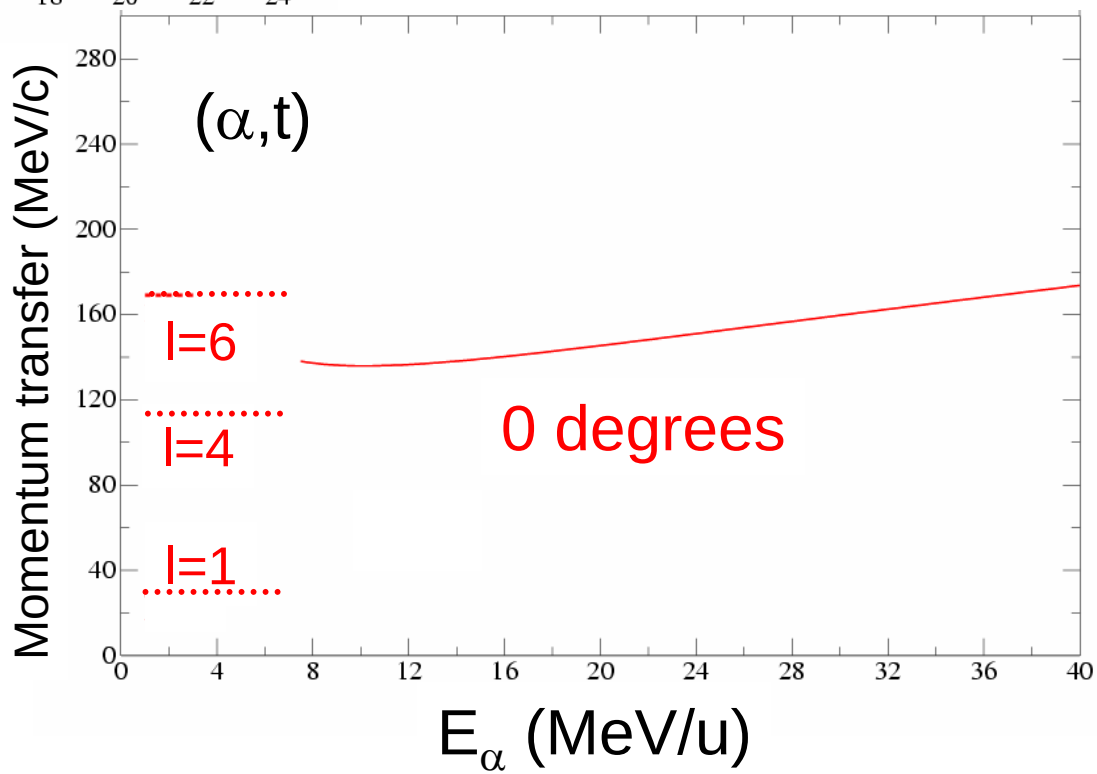
- General considerations for studies of few-particle transfer reactions in inverse kinematics.
- Experimental challenges – what makes such studies difficult?
- A possible solution – the solenoid alternative.
- Some advantages and disadvantages.

Transfer reactions at RIA

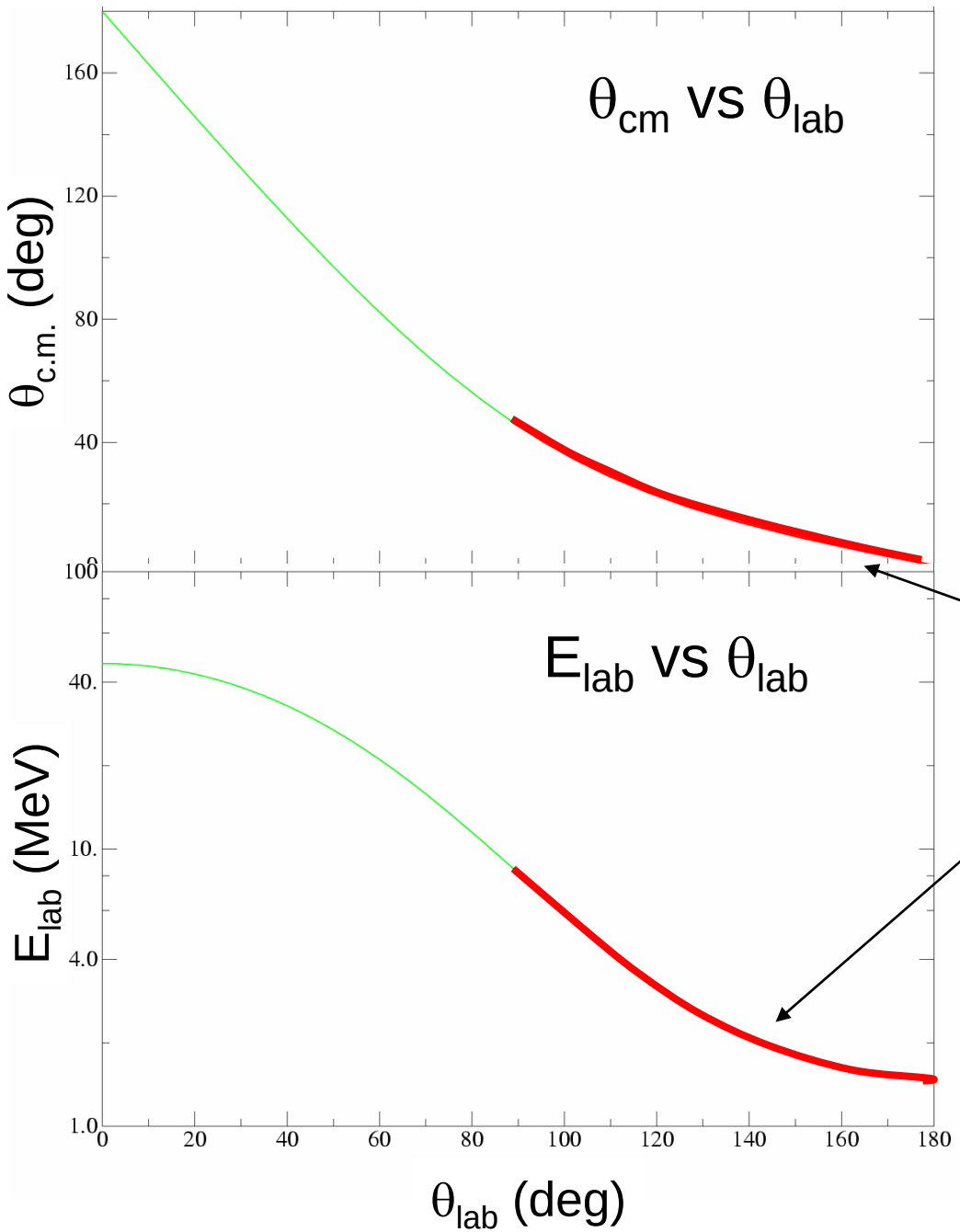
- Single particle structure in exotic nuclei, *e.g.* 1n or 1p states outside a ^{132}Sn core
- Study with single nucleon transfer reactions such as (d,p) (1 neutron) or (α,t), (^{3}He,d) (1 proton)
- Our poster child will be ^{132}Sn(d,p)^{133}Sn
- But – such transfer reactions on exotic nuclei must be performed in inverse kinematics…



Momentum transfer for (d,p) at Q=0 MeV and (α,t) at Q=-10 MeV



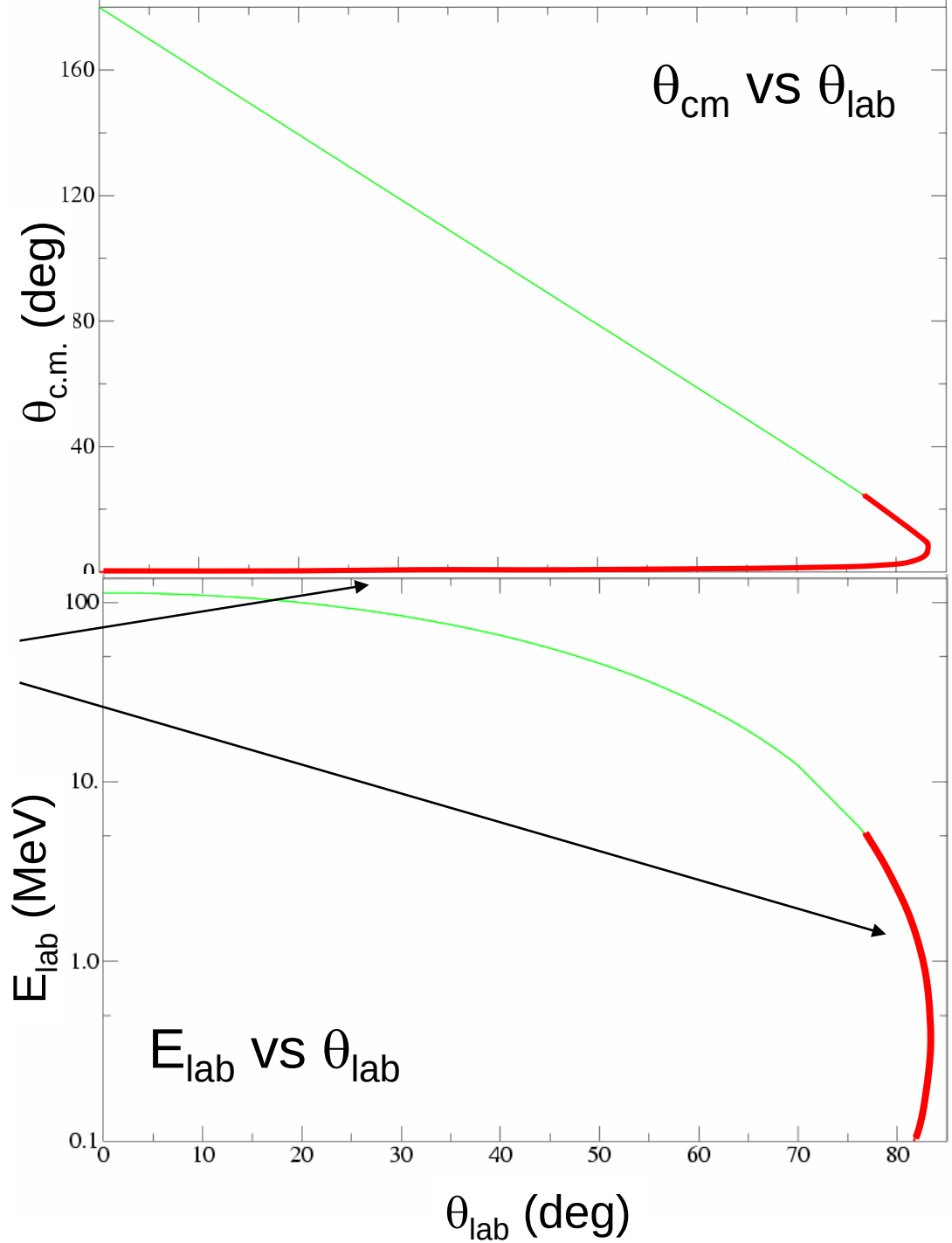
$d(^{132}Sn,p)^{133}Sn$ kinematics



Forward c.m. angles

$\alpha(^{132}Sn,t)^{133}Sb$ kinematics

Forward c.m. angles



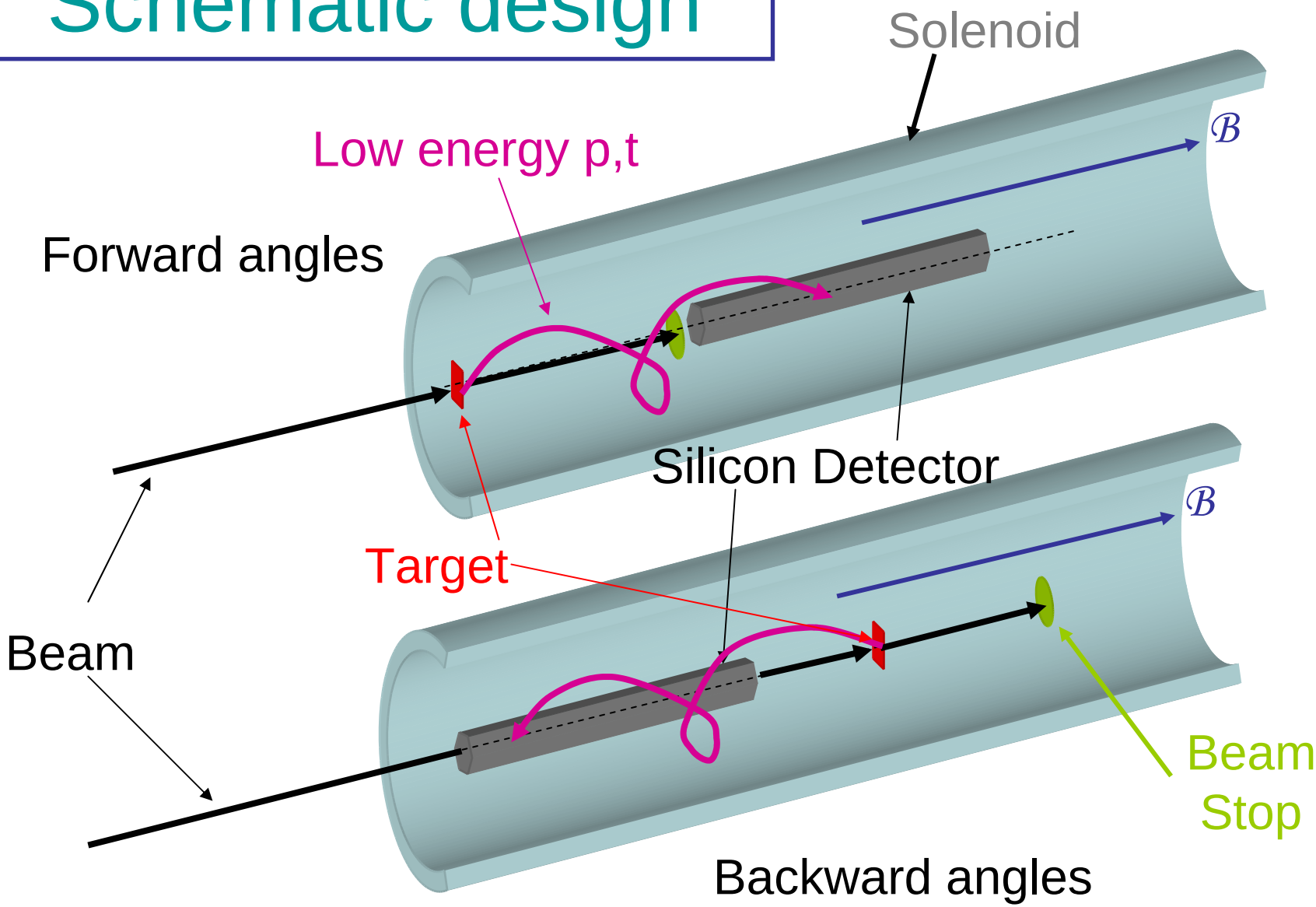
How to do this?

- Need good energy resolution and particle identification
- dE/dx measurements are not feasible at low energies – time of flight?
- Large solid angle is essential (2π hemisphere) with relatively small detector
- “Silicon ball” a possibility, but would be complex and could have difficulties with low-energy particles in a (high?) background environment
- Magnetic spectrograph would provide PID and resolution, but possesses small solid angle

The Solenoid alternative

- Use a solenoid to transport particles below a given momentum to the axis, where a detector is located.
- Use position-sensitive silicon detector: provides good energy resolution, and TOF sufficient to determine the cyclotron period (ΔT~few ns), necessary for particle ID.
- Length of the axial detector determines fractional momentum bite
- Angle is determined from energy, axial position, and TOF information ($\Delta\theta$ ~5-10°)

Schematic design



Cyclotron period for different particles (B=2T)

Particle	T(Cyclotron)
p	32.8 ns
d	65.6 ns
t	98.4 ns
^{3}He	49.2 ns
^{4}He	65.6 ns

$$T(cyc) = \frac{2\pi m}{qB}$$

T(cyc) is <u>independent</u> of energy and angle!

Some numbers

For d(^{132}Sn,p)

Proton energy range	1 - 8 MeV
Corresponding to lab angles of	180°-100°
Solenoid (r=25 cm)	~1-3 T
Detector length	~ 30 cm
Time of flight	~ 20-60 ns

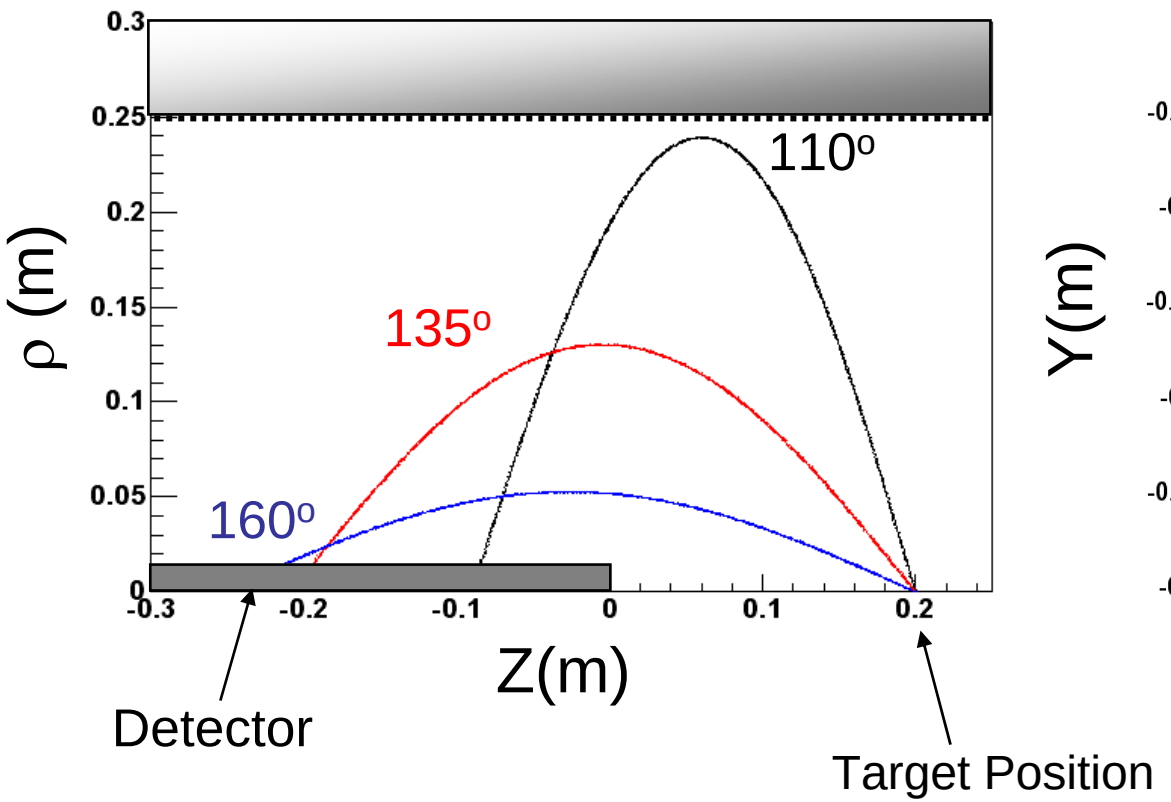
For α(^{132}Sn,t)

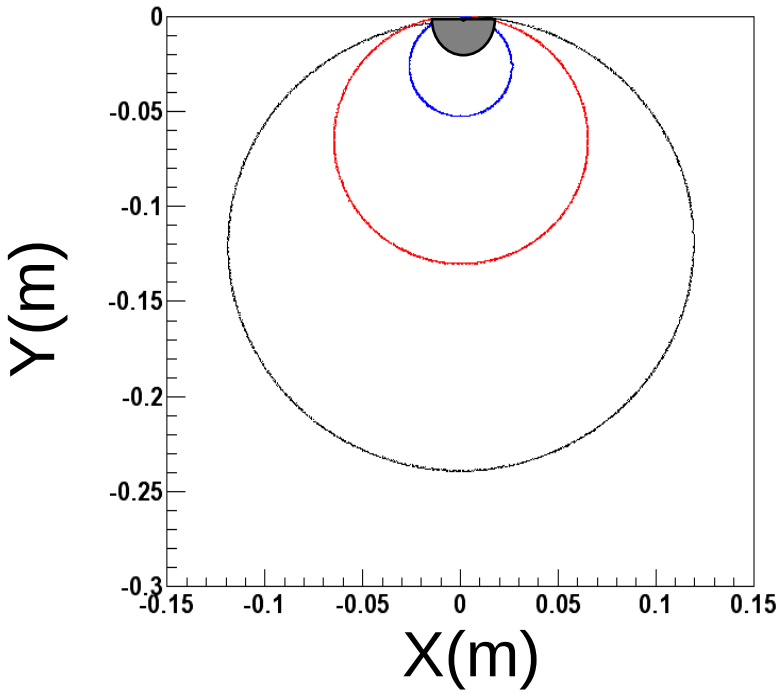
Triton energies	0.5-5 MeV
Corresponding to lab angles of	80$\pm$3°
Solenoid (r=25 cm)	~ 1-5 T
Detector length	~ 25 cm
Time of flight	~ 20-100 ns

Proton trajectories for $d(^{132}Sn,p)^{133}Sn_{g.s.}$

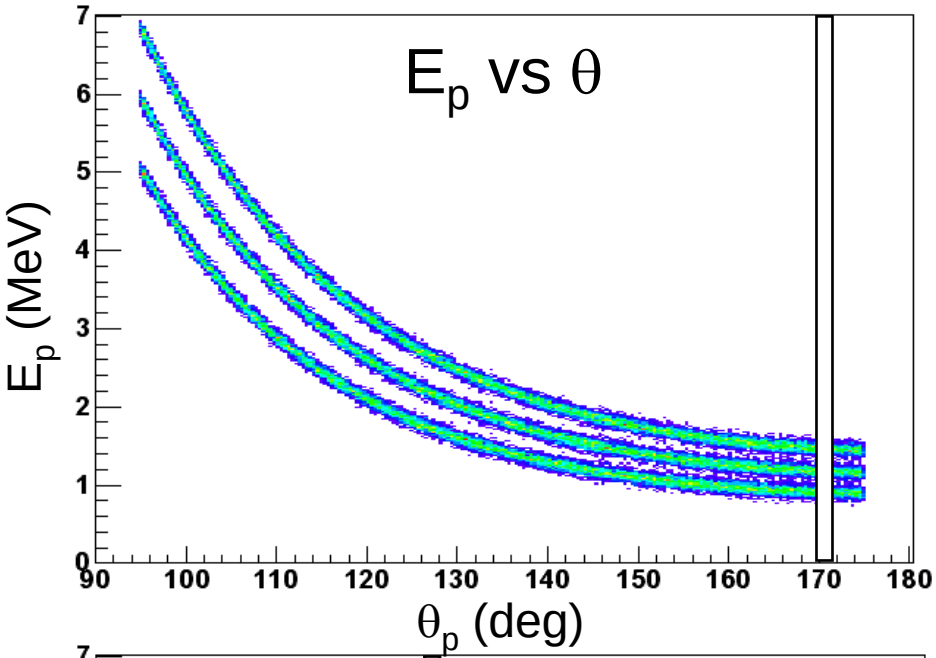
E(^{132}Sn)=8 MeV/u
B = 2.36 T

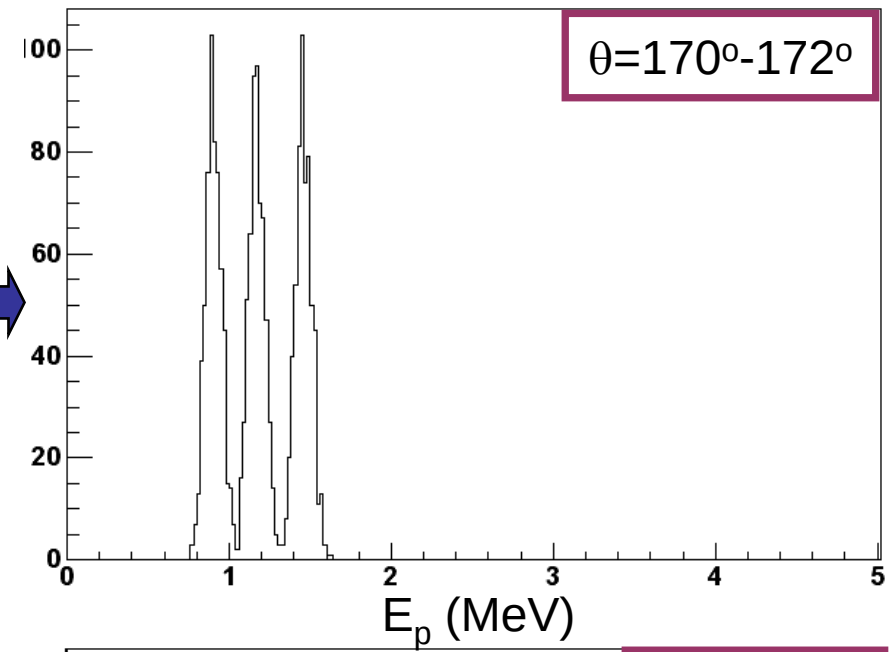
Solenoid inner radius = 0.25 m
Solenoid length = 1.50 m

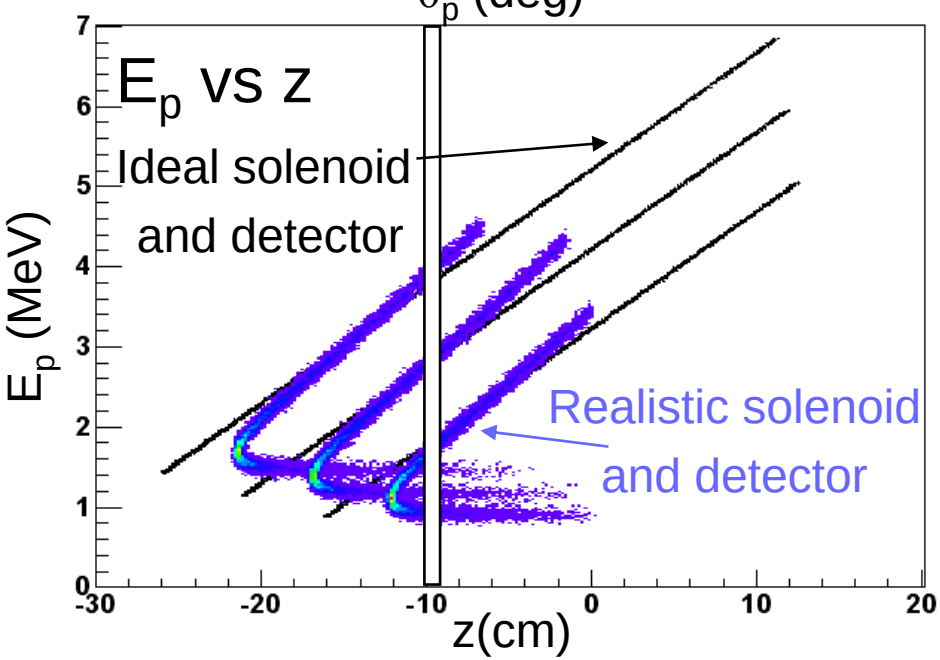


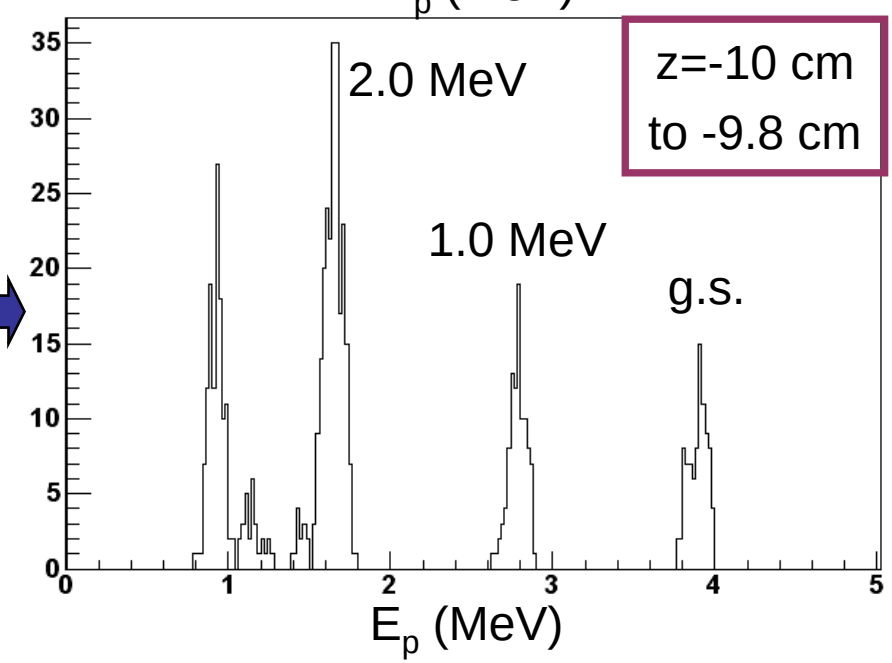


Transport and “kinematic compression”









Advantages and disadvantages

- Suppression of background
- Simple Particle ID
- Clarification of kinematics (excited states are separated in position as well as energy)
- High efficiency ($\Omega \sim 2\pi$)
- Simple detector (few segments)
- Need a large superconducting solenoid (~$500k, concerns with large stray fields)
- Target, detector, other mechanics more challenging

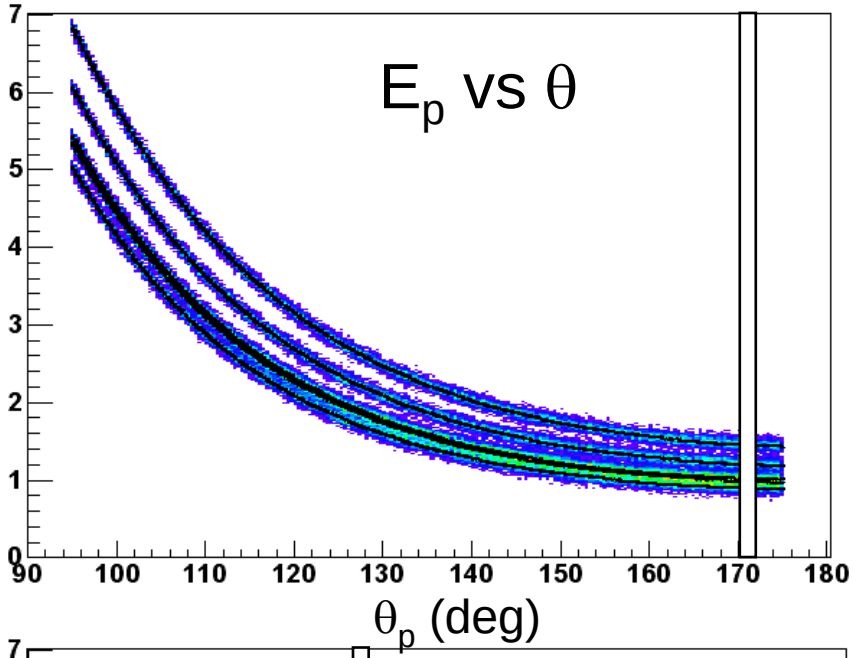
Conclusions

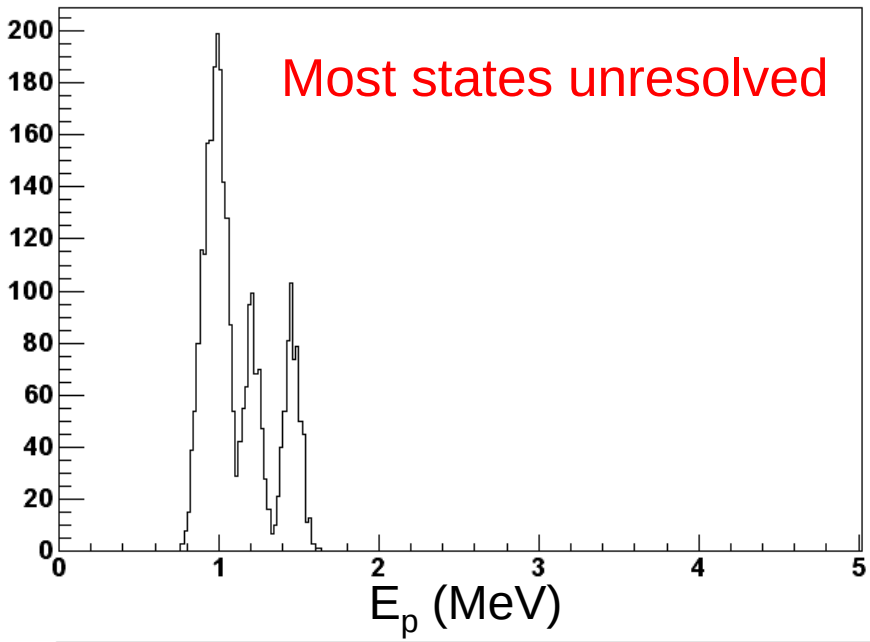
- A large superconducting solenoid can be a useful tool for studying few-particle transfer reactions in inverse kinematics
- This scheme has a number of advantages over more conventional methods.
- No significant technical obstacles
- Many applications – transfer reactions, proton inelastic scattering…

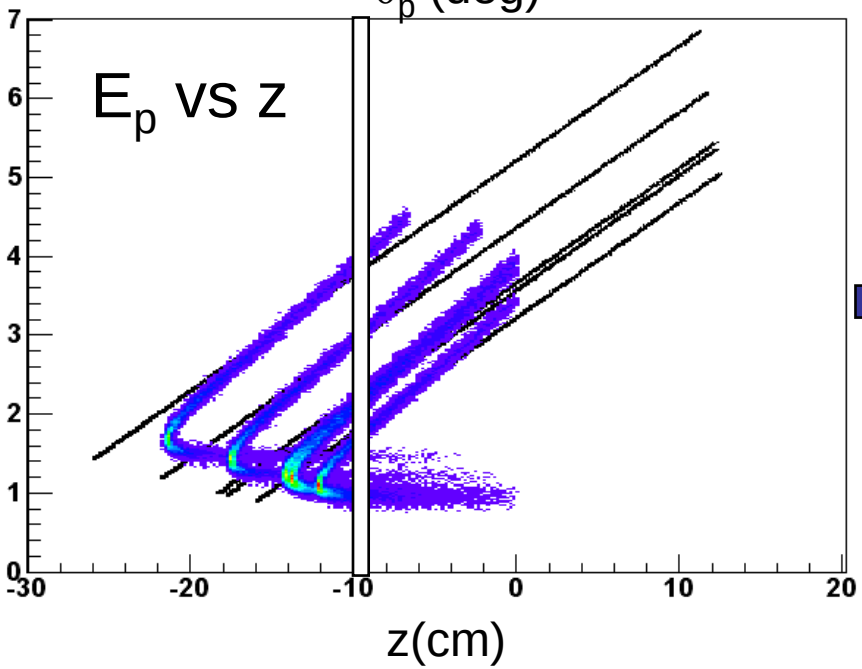
(Picture from Cryogenic Ltd. UK)

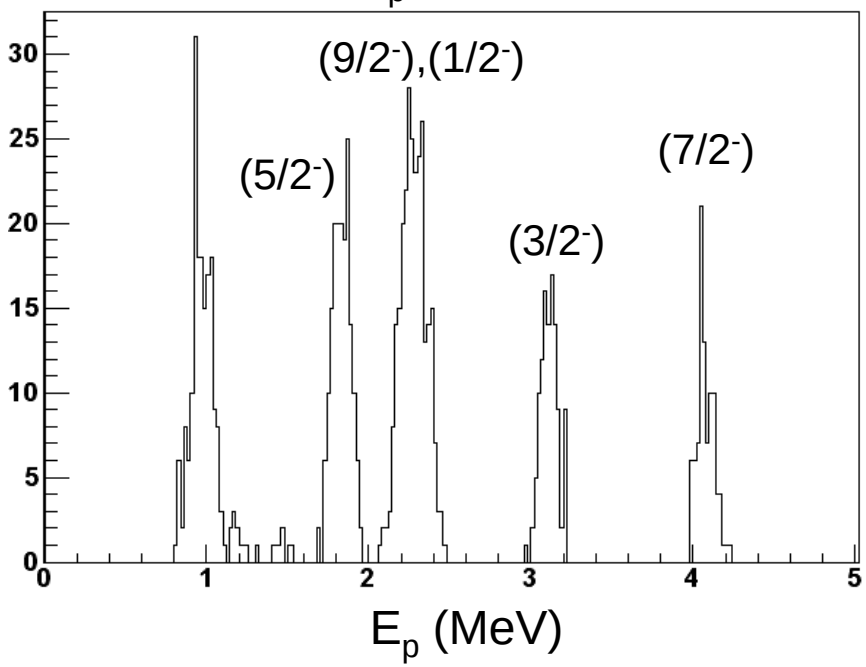
Supplementary Slides…

Real states in ^{133}Sn

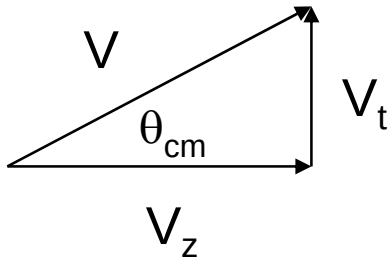








Why it works…

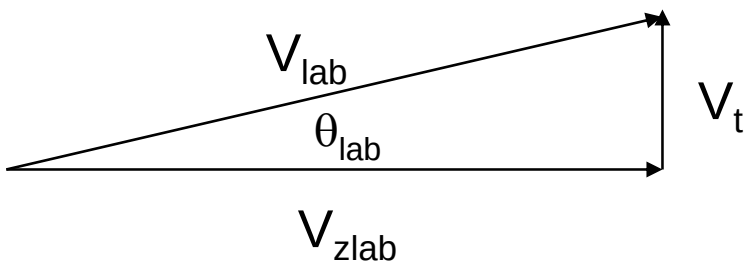


$V_z = V \cos\theta_{cm}$

$V_t = V \sin\theta_{cm}$

$V \sim (E_{c.m.} + Q - E_x)^{1/2}$

Center of mass



$V_{zlab} = V_z + V_{CM}$

$V_{tlab} = V_t$

$E_{lab} \sim V_{lab}^2 = V^2 + V_{CM}^2 + 2V_z V_{CM}$

Laboratory

Since: $T = T_{cyc}$, if two groups arrive at the same Z,

then $V_{zlab1} = V_{zlab2}$ and $V_{Z2} = V_{Z1}$

$$\Delta E_{lab} \sim V_{2lab}^2 - V_{1lab}^2 = (V_2^2 + V_{CM}^2 + 2V_{Z2}V_{CM}) - (V_1^2 + V_{CM}^2 + 2V_{Z1}V_{CM})$$

$$= (V_2^2 - V_1^2) + 2V_{CM}(V_{Z2} - V_{Z1})$$

But $V_{z2} = V_{z1}$! So: $\Delta E_{lab} = V_2^2 - V_1^2 \sim E_{X1} - E_{X2}$!

THE

PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics Established by E. L. Nichols in 1893

VOL. 49, NO. 8 APRIL 15, 1936 SECOND SERIES

Radioactive Argon

ARTHUR H. SNELL,* *Radiation Laboratory, Department of Physics, University of California*

(Received February 28, 1936)

When bombarded with high speed deuterons, argon gas is found to yield a radioactive product which emits negative electrons, and decays with a period of 110 ± 1 minutes. Chemical tests show that the activity is due to an isotope of argon, and the reaction involved is doubtless $A^{40} + H^2 = A^{41} + H^1$. Absorption measurements of the β-particles indicate that their maximum energy is about 1.1 MV. This is in satisfactory agreement with the results of a cloud chamber study of their distribution curve made by Kurie, Richardson and Paxton, which shows a strong group with an upper limit at 1.5 MV, and apparently

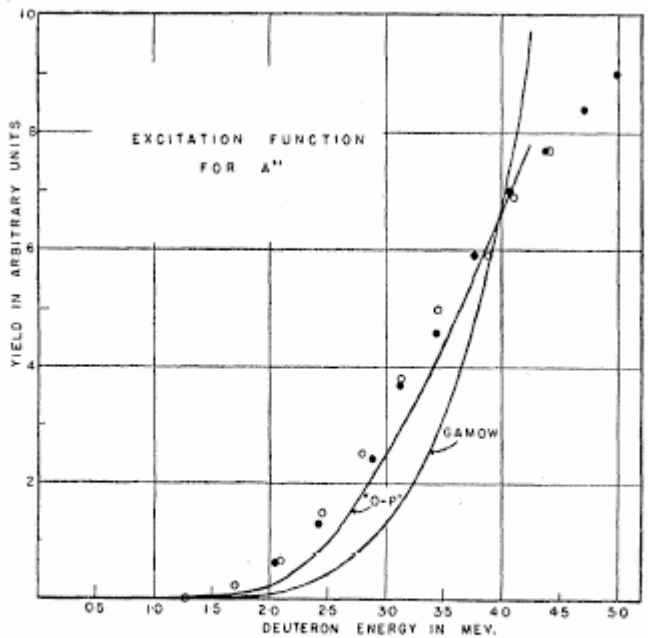


FIG. 4. The excitation function for radioactive argon-experimental points and two theoretical curves.

First (d,p) reaction

I can find in *Phys. Rev.*,

$^{40}Ar(d,p)^{41}Ar$

More history…

Angular Distributions of Protons and Tritons from Deuteron-Induced Reactions on Be^9†

H. W. Fulbright, J. A. Bruner, D. A. Bromley, and L. M. Goldman
University of Rochester, Rochester, New York
(Received July 29, 1952)

The angular distributions and absolute cross sections for the reactions $Be^9(d,p)Be^{10}$, $Be^9(d,p)Be^{10*}$ (3.37 Mev), and $Be^9(d,t)Be^8$ have been determined with 3.6-Mev deuterons. Both proton distributions have shapes characteristic of $l_n=$ [illegible] d for these reactions are 3.1±0.6 and 4.5±0.9 mb/s[illegible] ed at 0°. Its cross section at 5° is 15.5±3 mb/steradi[illegible]

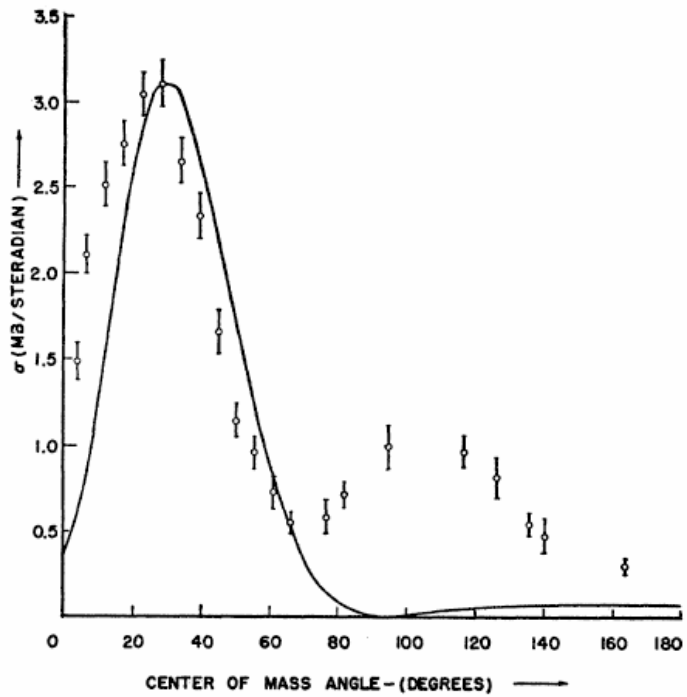


Fig. 2. Angular distribution of ground-state proton group. Curve is Butler theory prediction for 3.6-Mev deuterons, with $r_0=4.5\times10^{-13}$ cm and $Q=4.59$ Mev.