Polarized Targets for EURISOL

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Polarized Targets

Physics case

Technical solutions

Unpolarized Targets

why a polarized target ?

efficient way to learn about spin-orbit properties in exotic nuclei

study isospin dependence of the spin-orbit mean field

shell structure far from stability through transfer reactions

- evolution of spin-orbit partner splitting different in non-relativistic and relativistic mean field approaches

  transfer reactions: suitable tool to locate the two partners

- isospin dependence of SO potential — study mirror nuclei
  but coulomb corrections needed

- exotic nuclei have low bounding energies → important coupling to the continuum
  analyzing powers sensitive to these couplings → study reaction mechanisms — transfer, breakup

- (p,n) charge exchange reaction to the Isospin Analog State (IAS)

  if non-zero, analyzing power dominated by $V_{SO}(n) - V_{SO}(p)$

  neutron emssion similar to (p,p) elastic scattering
  neutron-target interactions very small → thicker target
  neutron insensitive to magnetic field

  but low neutron detection efficiency
  very primitive theoretical tools to be developed

Spectroscopy with polarized target

study of the shell strucutre of exotic nuclei

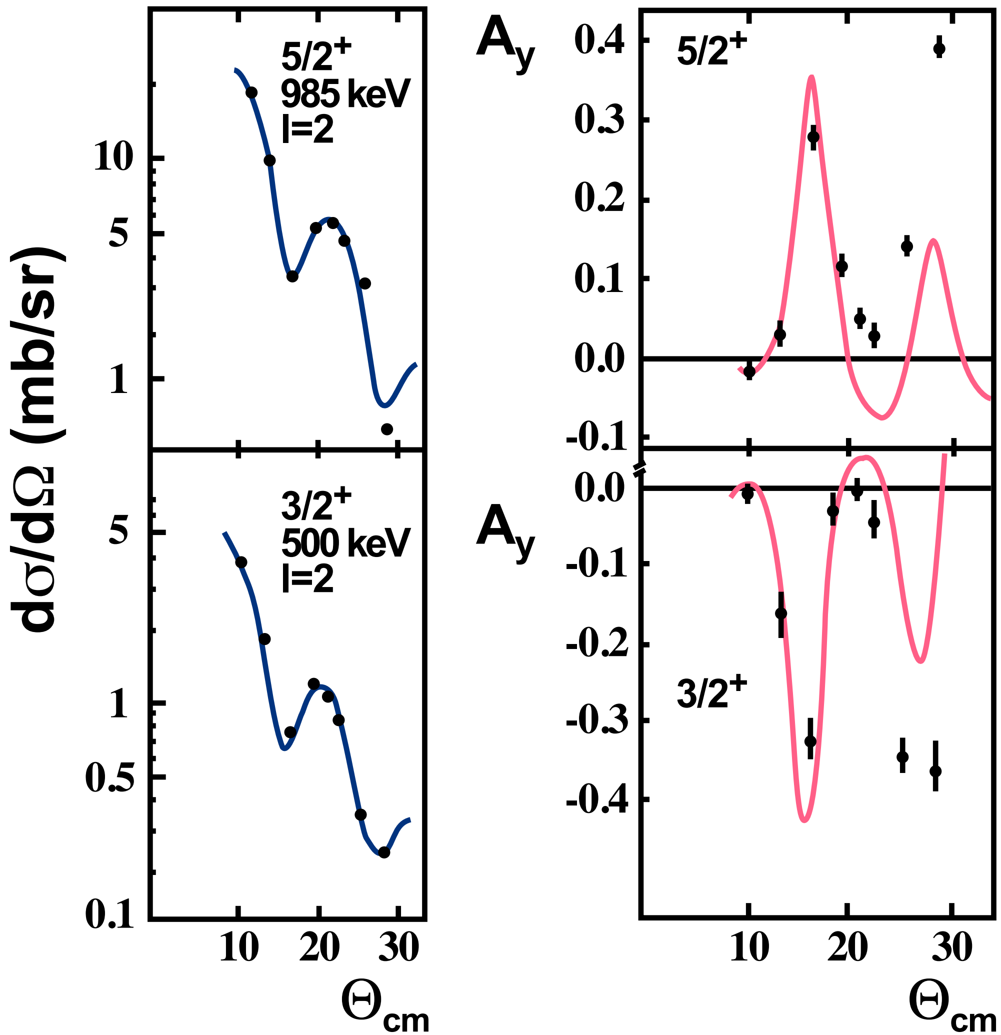
- cross section only
  sensitive to the transferred
  momentum

- vector analyzing power
  sensitive to final state spin

$A_y \sim l$ for $j=l+1/2$ and $A_y \sim -l(l+1)$ for $j=l-1/2$

powerful spectroscopic tool

$^{116}Sn(\vec{d},t)\,^{115}Sn$, E_d = 40 MeV



G. Perrin et al., Nucl. Phys. A356, 61 (1981)

Rates for transfer reactions with exotic beams and polarized targets

Polarized p,d beams (stable)

direct kinematics

Beam intensity = 10^{10-12} pps

target thickness = 1 mg/cm^2

E = 15-80 MeV

$d\sigma/d\omega$ = 1-10 mb/sr

A_y = -0.3 to +0.3

Polarization ~ 60%

Ω = 1 msr

Rate = 2-20 counts/sec

Accuracy ~1%

1-2 days of beam time

Exotic beams + Polarized targets

inverse kinematics

Beam intensity = 10^7 pps

target thickness = 1-10 mg/cm^2

E = 15-80 MeV/A

$d\sigma/d\omega$ = 1-10 mb/sr

A_y = -0.3 to +0.3

Polarization ~ 50%

Ω = 50 msr

Rate = 5 10^{-3} counts/sec

Accuracy ~10%

1 week of beam time (minimum)

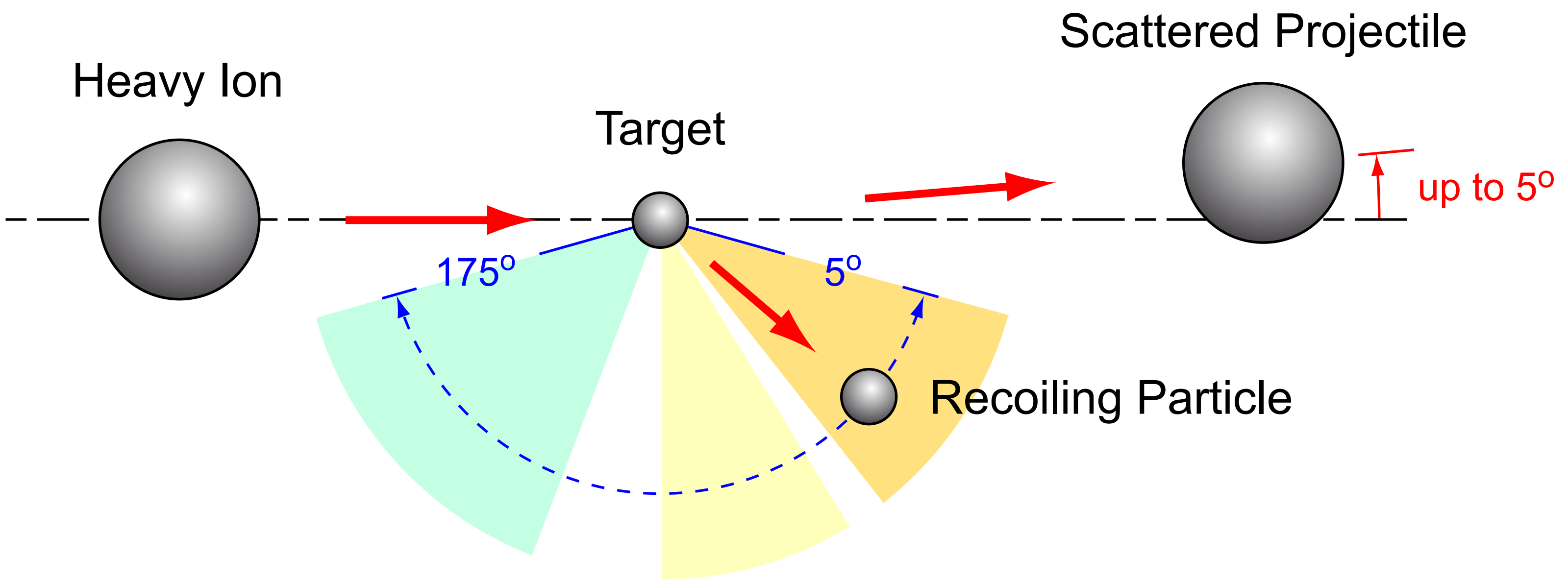
Selected cases only

Experiments with RIB
(inverse kinematics)

Goal: **get reaction kinematics**

- detection of heavy outgoing projectile — possible eventually for light projectile; otherwise limited by small emission cone

- detection of the recoiling particle — light charged particles; method of choice, more flexible



Experiments with RIB
(inverse kinematics)

mass 50 beam			beam energy	recoiling energy	and angle
scattering	(p,p)	(p,p')	40-70 MeV/A	0-25 MeV	65-90^o
transfer reactions			10 MeV/A		
neutron pickup	(p,d)	(d,t)		2-10 MeV	0-50^o
	(^{3}He,α)			0-20 MeV	70-180^o
proton pickup	(d,^{3}He)			7-15 MeV	0-20^o
neutron stripping	(d,p)			2-10 MeV	100-180^o
proton stripping	(^{3}He,d)	(d,n)		3-12 MeV	110-180^o

low recoiling energy from 50 keV up to 25 MeV — energy losses; energy and angular straggling

charged particle — trajectory in magnetic field

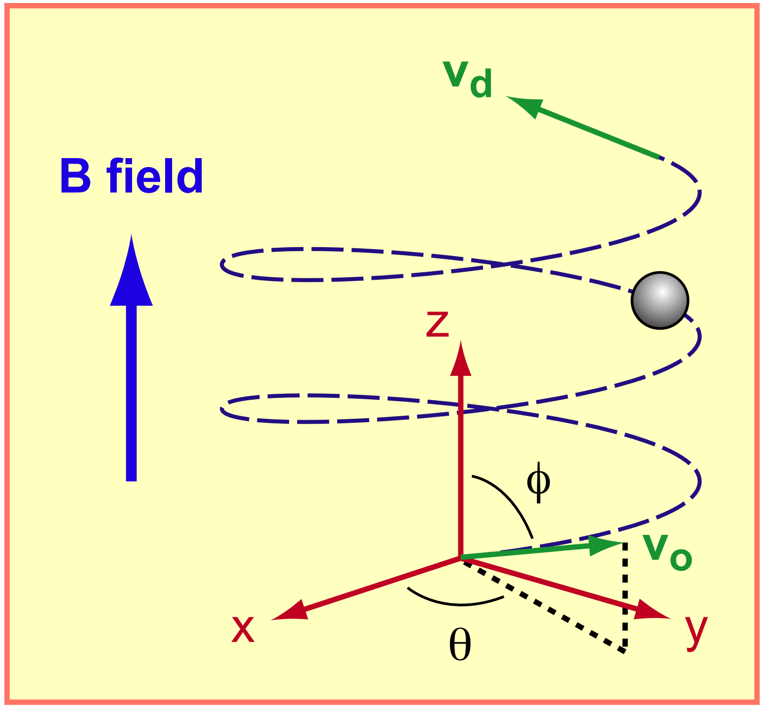
important issues to limit deterioration of kinematics:

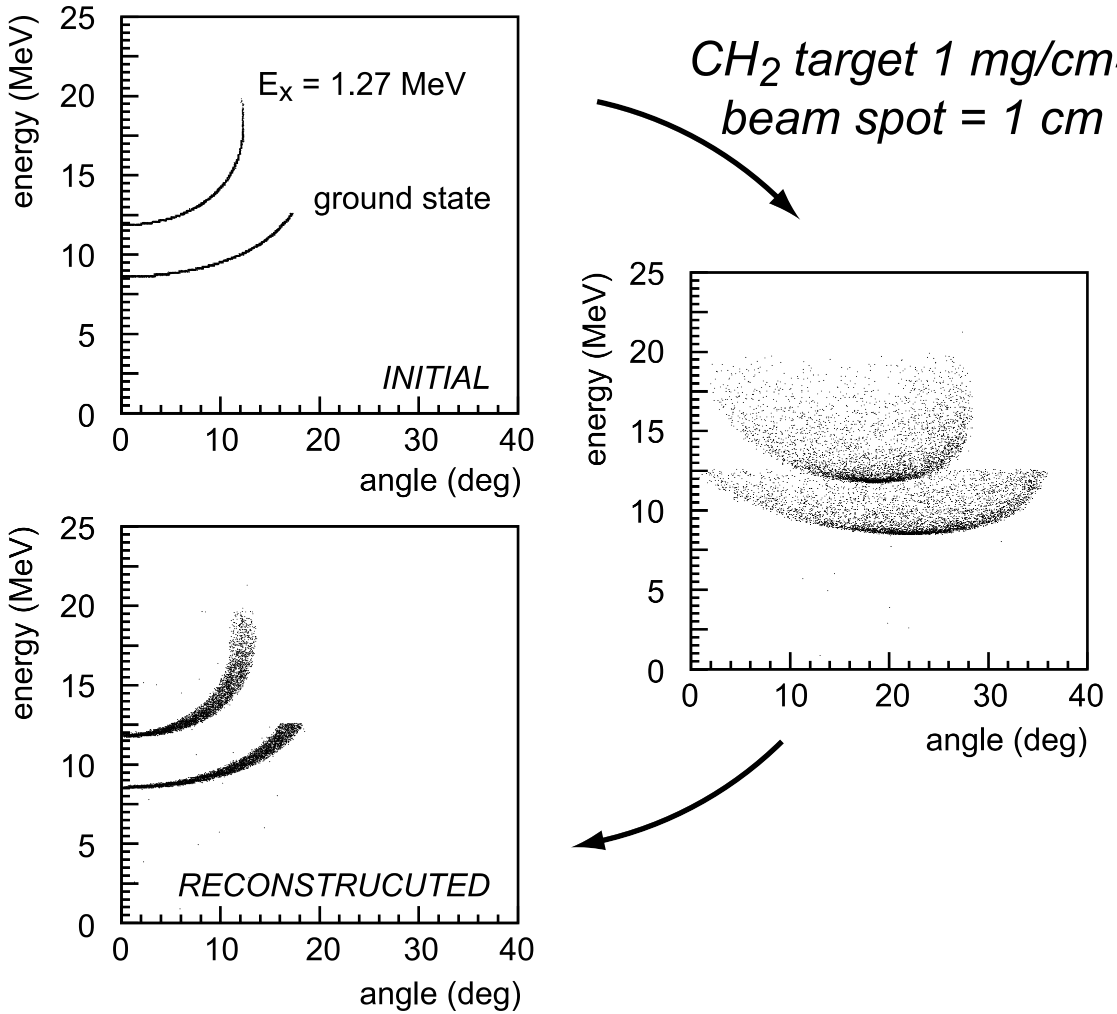
target thickness   target materials   window materials   B field intensity

B Field Issue

$^{40}Ar(p,d)^{39}K$
10 MeV/A
B=1.5 T

CH_2 target 1 mg/cm^2
beam spot = 1 cm





equation of movement

$$\frac{d\vec{p}}{dt} = q\vec{v} \wedge \vec{B}$$

v_{ox}	functions of qB/m	
v_{oy}		x_d, y_d and z_d
v_{oz}		v and t

localization and identification of the particle
knowledge of B to some extent
measurement of energy and time of flight

Magnetic field is not a problem if known vertex

Target Parameters

Technique	Nucleus	Operational Environment	Typical Polarization	Typical Thickness	Advantages	Disadvantages
DNP	p d	1 T, 0.5 K	P_p ~ 90% P_d ~ 40%	~ 10^{25} at/cm^2	P rate	logistics cryogenics thickness
Internal Target	p d ^{3}He	200 G, 70 K 50 G, 50 K	P_p ~ 70% P_d ~ 80% P_{3He} ~ 50%	~ 10^{14} at/cm^2	Purity P rate p, d, ^{3}He	logistics thickness
Gas Target	^{3}He	50 G, 300 K	P_{3He} ~ 35%	~ 10^{20} at/cm^2	temperature relaxation time	P rate windows cell volume
Pentacene	p	300 G, 77 K	P_p ~ 30%	~ 10^{23} at/cm^2	thickness temperature	P rate relaxation time
Plastics	p d	2 T, 100 mK	P_p ~ 70% P_d ~ 40%	~ 10^{21} at/cm^2	P rate thickness	cryogenics

many of the targets are working but need developments to fit with RIB experiments

→ necessary developments

most suitable targets for radioactive beam experiments at EURISOL → **CNS, PSI**

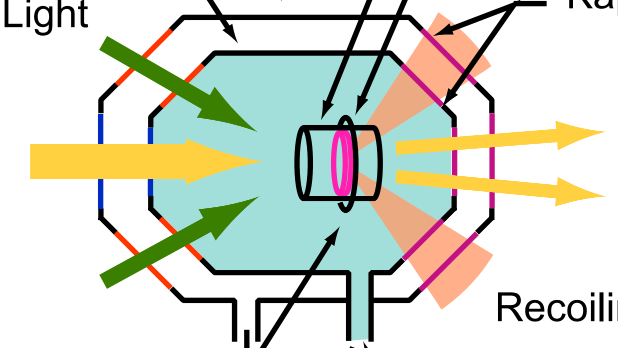
Solid Proton Target (CNS type)

polarization technique: microwave-induced optical nuclear polarization

crystals of naphtalene doped with pentacene (0.01 mol%)

2-step process: electron polarization via laser optical pumping

polarization transferred to protons via microwaves (integrated solid effect)



Relatively high temperature (> 77 K)
Low magnetic field (< 3 kG)

P_p ~ 40% @ 100 K and 3 kG

expected maximum polarization: 60%

test experiment p+^{4}He at 80 MeV/A
first experiment p+^{6}He at 70 MeV/A

necessary research and developments

minimum thickness ? 100 μm ?

target environment ? compatibilty with transfer reactions

relaxation time ?

buildup time: 2 hours
relaxation time: 20 hours (3 kG, 100 K)
thickness: 1 mm

Solid Proton Target (PSI type)

polarization technique: dynamic nuclear polarization

2-step process: (1) electron polarization via thermal equilibrium (2) polarization transferred to protons via RF transitions

Very low temperature (~ 100 mK)
High magnetic field (2.5 T)

P_p ~ 85% @ 100 mK for 5 mm

P_d ~ 40% @ 100 mK for 5 mm

P_p ~ 70% @ 100 mK for 70 μm

sample in mixing chamber

buildup time: 1-2 hours

relaxation time: 150 hours

thickness: 5 mm blocks,
20, 40 and 70 μm foils

scintillation
- detection of recoil in the target
- trigger signal
- no angle, no energy, no identification

→ standard CH_2, CD_2 plastic films
better dilution factor

necessary research and developments

thin windows — sample outside m.c.

→ RF cavity, cooling ...

CNS target

2005: 1st experiment p+^{6}He at 71 MeV/A

e = 1 mm

B field: 0.08 T Temp: 100 K

estimated polarization: 21%

microscopic folding model analysis
phenomenological model analysis

2007: 2nd experiment p+^{6}He at 71 MeV/A

more statistics

average polarization: 14%

2007: 1st polarization data for p+^{8}He

data analysis in progress

PSI target

2006: 1st test experiment p+^{12}C at 3.2 MeV/A (elastic resonant scattering)

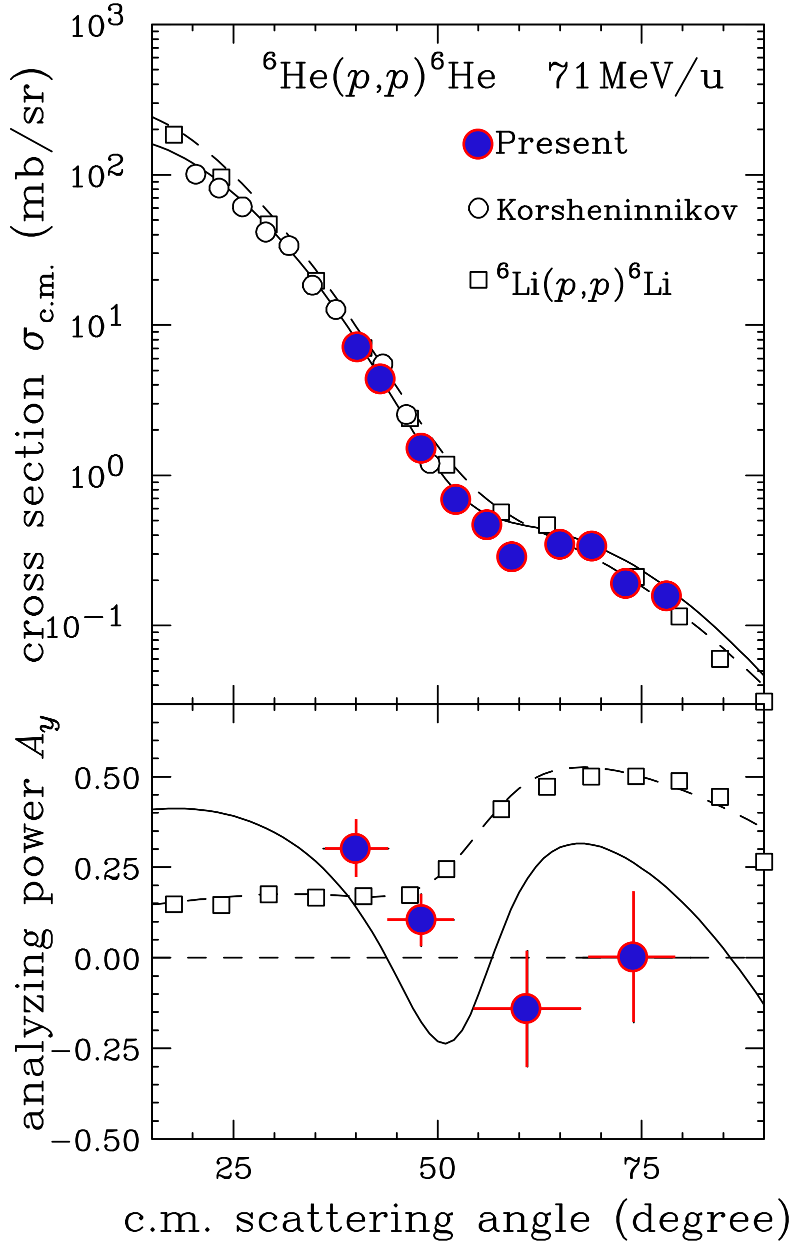
e = 14 mg/cm^2

stable beam delivered at HRIBF

test of experimental setup (target + detection)

no polarization data

p+^{6}He at 71 MeV/A



M. Hatano et al., Eur. Phys. J. A 25, 255 (2005)

Unpolarized targets ?

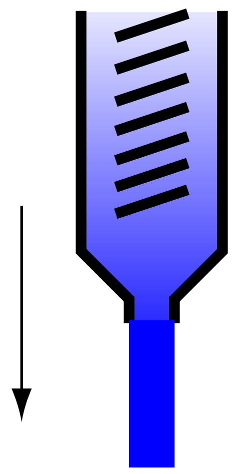
- cryogenic targets

Advantages: higher density than CH_2 or CD_2 polymer foils
Disadvantages: large thickness (1 mm or higher) and windows

→ CHYMENE (cible d'hydrogène mince pour l'étude des noyaux exotiques)
CEA/Saclay

small thickness variable (thinner than 200 μm)
windowless (*i.e.* no carbon contamination)

production by extrusion of an hydrogen iced film
(patented technique by PELIN in St Petersburg)



necessary research and developments

minimum thickness ? 100 μm ?
online thickness measurement

target environment ? cooling, vacuum
integration w/ detection system

disposal of film ?

- "tritium" targets

charge exchange reaction (t,^{3}He)

Conclusions

- Polarized targets → strong nuclear physics case

  spin observables sensitive to: total transferred momentum ($j = l \pm 1/2$)
  coupling to inelastic channels

  → very powerful spectroscopic tool

- few working techniques very promising

  R&D in progress for improvements

  important to comply with experimental needs (detection systems)

  thickness of target sample and windows

  effects of magnetic field on detector electronics ?

  ultra low temperature issues ?

  in-beam effects (depolarization)

- Other possibilities → polarized ^{3}He gas target

  thickness of glass cell

  determination of vertex for kinematics reconstruction

  low density

- Unpolarized targets → windowless solid proton target and “tritium” target