HELIOS at ATLAS
An incomplete retrospective
Prehistory: A very different experiment
Circa long, long ago... (Early 1990s)
4.3 Very Large Acceptance Options – Phase II

There are other possible geometries for magnetic spectrographs that are quite different from the conventional ones considered above. These alternative geometries provide the possibility for acceptances in the steradian range; i.e., about an order of magnitude more than the conventional designs. The two basic types of these very large-acceptance devices that have been used to some extent in the past are based on solenoidal and toroidal geometries. No detailed design studies for either of these classes of spectrograph have been carried out for charged-particle reaction studies at ISOL facilities. The possibilities of such devices in this context appear to be quite interesting and they are worthy of further study.

a) Solenoidal Geometry

A magnetic solenoid with its axis oriented along the beam direction could serve as a very large-acceptance magnetic spectrograph for low-energy light particles from inverse reactions such as $d(^{132}\text{Sn},p)^{133}\text{Sn}$. In this case the protons of interest are emitted in the backwards hemisphere with energies of 1-10 MeV. The particle energy measurements are done via silicon detector barrels surrounding the beam axis. This type of magnetic spectrograph deserves further study.
What do we need to Establish the Single-Particle Structure of Exotic (Neutron-Rich) Nuclei

John Schiffer
Argonne Nat’l. Lab
&
Alan Wuosmaa
Western Michigan University

RIA Equipment Workshop
ORNL March 19, 2003
The early concept
Solenoid transport for $d(^{132}\text{Sn},p)$

$E(^{132}\text{Sn}) = 7 \text{ MeV/u}$
$B = 2T$

$E_x = 0.0 \text{ MeV}$
$E_x = 2.0 \text{ MeV}$

Something interesting!
Particle transport in a solenoid

Measured: $E_{lab}, z, TOF$
Deduced: $E_{CM}, \theta_{CM}$

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

$z \propto \cos \theta_{CM}$

$E_{lab} = E_{CM} - A + Bz$

$\Delta E_{lab} = \Delta E_{CM}$

For a given state
For two states at fixed $z$
Interlude

• ANL Workshop (June 2004)
• Proposal to DOE (October 2004)
• No response from DOE
• ANL LDRD support (2005)
• An acronym is chosen (2006)
• And then...
HELIOS: From Scanner to Spectrometer

Tübingen, Germany
November 2006

Argonne, USA
December/January 2007
Field mapping

Measurements every 10 degrees, every 5 cm in radius, every 5 cm in axial position – 21,600 points!
Students hard at work...
HELIcal Orbit Spectrometer - HELIOS

$B_{\text{MAX}} = 2.85 \text{ T}$

2.35 m

0.9 m

Beam

Silicon Array

Target

Laser rangefinder

X-Y-\(\theta\) positioning stage


J. C. Lighthall et al, NIMPRA 622, 97 (2010)
$^{28}\text{Si}(d,p)^{29}\text{Si}$ commissioning

Residual $\alpha$ source background

protons from $^{28}\text{Si} + ^{12}\text{C}$

$E_{\text{proton}}$ (MeV)

$Z_{\text{proton}}$ (mm)

August 2008

J. C. Lighthall et al, NIMPRA 622, 97 (2010)
$^{28}\text{Si}(d,p)^{29}\text{Si}$ Excitation-energy spectrum

Typical resolution $\sim 120$ keV FWHM
Best resolution $\sim 80$ keV FWHM

J. C. Lighthall et al, NIMPRA 622, 97 (2010)
What was the physics?

- Experiment #1: $^{132}\text{Sn}(d,p)^{133}\text{Sn}$
- High-resolution measurements of single-particle states outside doubly-magic $^{132}\text{Sn}$
- Populate with $(d,p)$ (small $L$ transfer); $(\alpha,^3\text{He})$ or $(\alpha,t)$ (large $L$ transfer)
- We still want to do this!!
- Other transfer studies to nuclei where the density of states makes it challenging to work in inverse kinematics.
What *is* the physics?

- Have done some stable-beam \((d,p)\) near \(N=50\) \(^{86}\text{Kr}\) and \(Z=50, N=82\) \(^{136}\text{Xe}\)

- Much more done with light RIBs produced “In-Flight”

- Single-particle states in \(p-sd\) shell nuclei – evolution of shell-model orbitals, configuration mixing, residual interactions, etc.

- Multi-nucleon correlations in light nuclei

- Astrophysics

- Ab-Initio calculations
Reactions studied to date (a partial list)

- $^{10}\text{B}(p,p')^{10}\text{B}^*$
  - ($ab$-initio calculations for $^{10}\text{B}$)
  - (many beams A=12-136, single-particle structure)

- $^{14,15}\text{C}(d,^3\text{He})^{13,14}\text{B}$
  - (nucl. structure $^{14,15}\text{C},^{13,14}\text{B}$)

- $^{27}\text{Al}(d,t)^{26}\text{Al}$
  - (test/demonstration)

- $^{14,15}\text{C}(d,\alpha)^{12,13}\text{B}$
  - (“stretched” states in $^{12,13}\text{B}$)

- $(\alpha,p)$
  - (gas target – various beams, nuclear astrophysics)

- $(^3\text{He},d)$
  - (gas target – various beams, nuclear astrophysics)

- $(^6\text{Li},d)$
  - (various, cluster structure and nuclear astrophysics)

- $^{15}\text{C},^{12}\text{B}(t,p)^{17}\text{C},^{14}\text{B}$
  - (coming soon with $^3\text{H}$ target)

(13 journal publications to date)
Heavy stable beams: $^{86}$Kr and $^{136}$Xe

Particle energy versus position for $d(^{136}$Xe,$p$)$^{137}$Xe

$d(^{86}$Kr,$p$)$^{87}$Kr


B. P. Kay et al, PRC 84, 024325 (2011)
$(d,p)$ with in-flight ATLAS RIBs

PRL 105, 132501 (2010)

$^{15}\text{C}(d,p)^{16}\text{C}$

$^{2^+_1/3^+_1}$

$^{0^+_1}$

$^{12}\text{B}(d,p)^{13}\text{B}$

$^{0^+_2}$

PRL 104, 132501 (2010)

$^{19}\text{O}(d,p)^{20}\text{O}$

$^{4^-}(2.08)$

$^{4^-(1.38)}$

$^{3.57}\text{MeV}$

$^{4.07}\text{MeV}$

$^{4.46}\text{MeV}$

$^{4.99}\text{MeV}$

$^{5.23}\text{MeV}$

PRC 85, 054318 (2012)

S. Bedoor et al., PRC 88, 011304 (2013)

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PRC 85, 054318 (2012)

S. Bedoor et al., PRC 88, 011304 (2013)
$^{15}\text{C}(d,^3\text{He})^{14}\text{B}$

S. Bedoor PRC 93, 044323 (2016)

$^{14}\text{B}(\gamma)$

S. Kuvin, C. J. Lister

$^{10}\text{B}(p,p')$

S. Bedoor PRC 93, 044323

$^{14}\text{C}(d,^3\text{He})^{13}\text{B}$

B. Kay

$^{28}\text{Si}(d,t)^{27}\text{Si}$

B. Kay

$^{14,15}\text{C}(d,\alpha)^{12,13}\text{B}$

B. Kay

$^{28}\text{Si}(d,^3\text{He})^{27}\text{Al}$

B. Kay

PRC 90, 061301 (2014)
Angular distributions with light RIBs

$^{15}\text{C}(d,p)^{16}\text{C}$
$10^6$ pps

$^{17}\text{N}(d,p)^{18}\text{N}$
$2 \times 10^4$ pps

$^{14,15}\text{C}(d,^3\text{He})^{13,14}\text{B}$
$5 \times 10^5$ pps $^{15}\text{C}$

$\theta_{\text{c.m.}}$ (deg)


S. Bedoor et al, PRC 93, 044323 (2016)
Additions and upgrades

See Later Talks!
Conclusions

• HELIOS has proved to be a very useful device and serves an active and growing physics program.
• The approach is versatile and the applications have grown far beyond the original motivating physics.
• You will hear about recent developments in other physics and instrumentation.
• Prospects for new physics at FRIB with reaccelerated beams are promising – that is what we are here to discuss!
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