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SOLARIS

The SOLARIS spectrometer

Ben Kay, Argonne National Laboratory

ISOLDE Solenoidal Spectrometer Workshop, 2019

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357

Overview

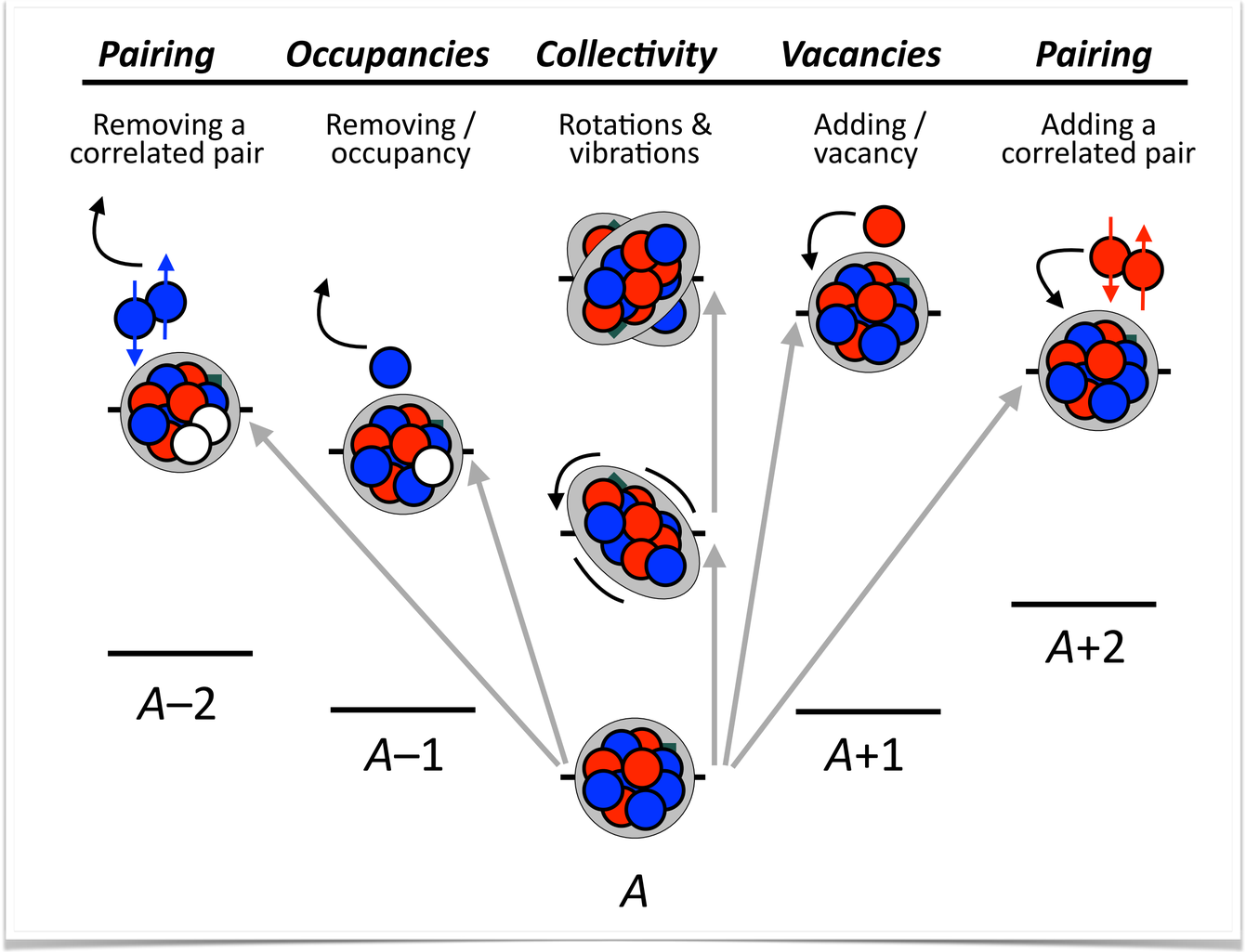
- Direct reactions, ReA
- What is the SOLARIS spectrometer?
- The AT-TPC (and PAT-TPC, AT3PC, etc)
- SOLARIS at ReA …
- … status, timelines

Direct reactions

~10 MeV/u (3-20 MeV/u), >10^4 pps (stable and radioactive)

Reactions used as a tool for nuclear structure and astrophysics:

- Selectively populate states, determine E, j^π
- Inelastic, single-nucleon, two-nucleon
- Cross sections → rates
- Cross section → overlaps

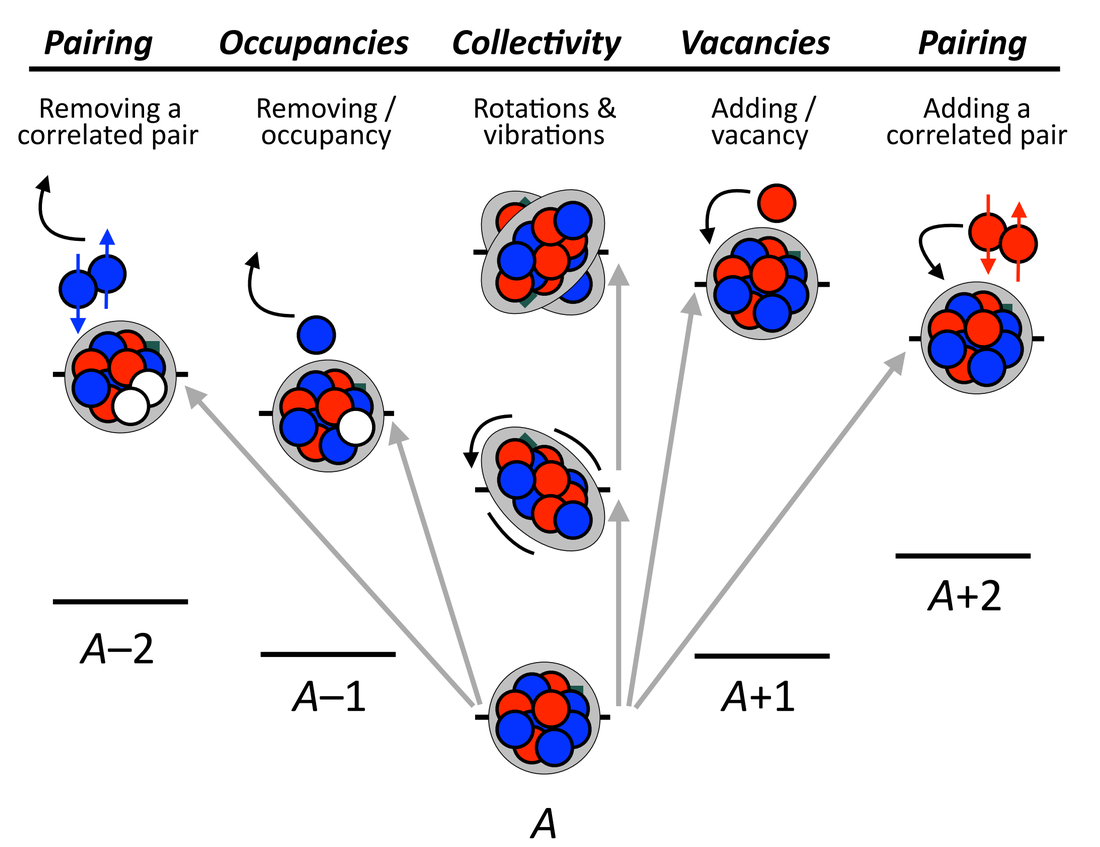


Nuclear physics with light-ion reactions

~few-15 MeV/u

Science drivers from NRC RISAC

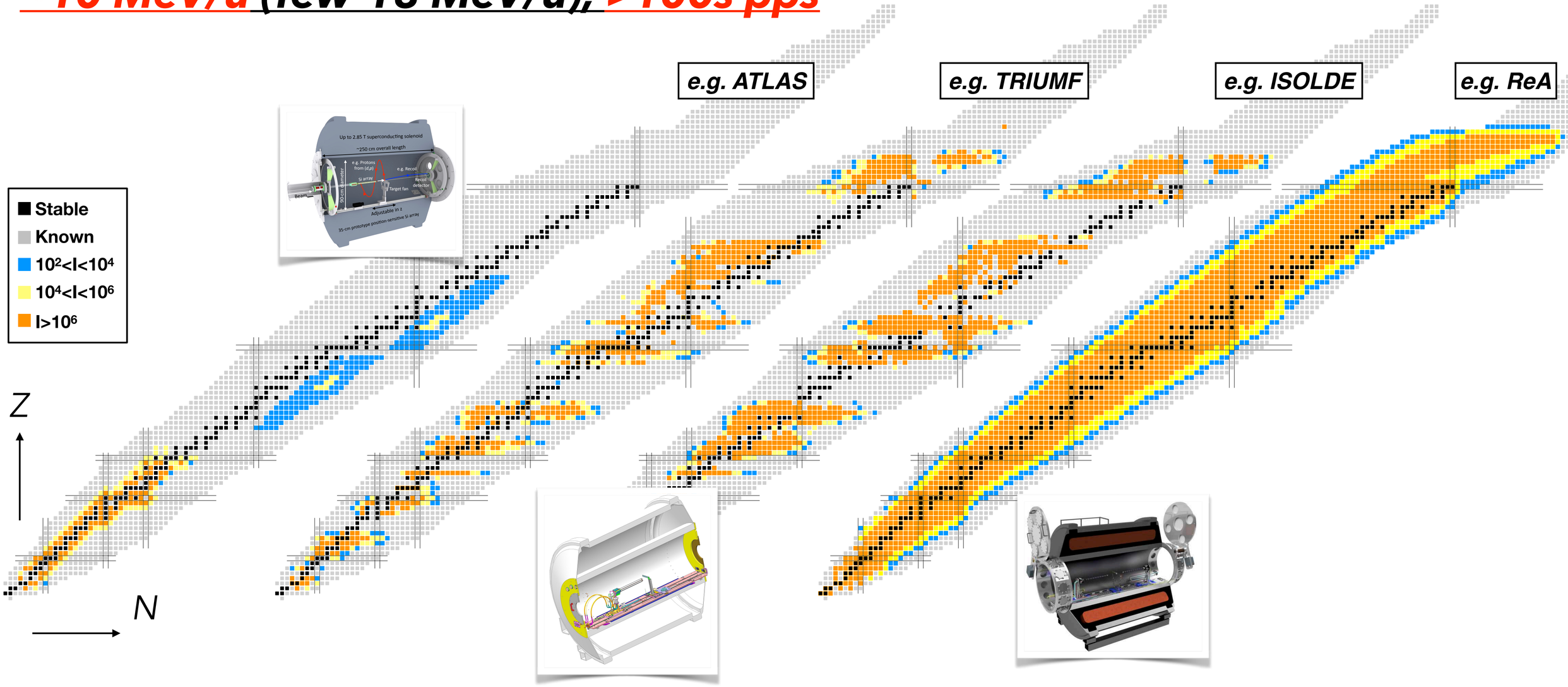
Nuclear Structure	Nuclear Astrophysics	Tests of Fundamental Symmetries	Applications of Isotopes
Overarching questions to be answered by rare-isotope research			
- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? - What is the origin of simple patterns in complex nuclei?	- What is the nature of neutron star and dense nuclear matter? - What is the origin of the elements in the cosmos? - What are the nuclear reactions that drive stars and stellar explosions?	- Why is there now more matter than antimatter in the universe?	- What are new applications of isotopes to meet the needs of society?
17 benchmarks programs to answer overarching questions			
1. Shell structure 2. Super heavy elements 3. Skins **4. Pairing** **5. Symmetries** **13. Limits of stability** **14. Weakly bound nuclei** 15. Mass surface	**6. Equation of state** **7. r-Process** 8. $^{15}O(\alpha,\gamma)$ 9. ^{59}Fe s-process 15. Mass surface **16. rp-Process** **17. Weak interactions**	**12. Atomic electric dipole moment** 15. Mass surface **17. Weak interactions**	10. Medical **11. Stewardship**



The Science of FRIB, https://www.frib.msu.edu/_files/pdfs/frib_scientific_and_technical_merit_lite_0.pdf

… RI beams

~10 MeV/u (few-18 MeV/u), >100s pps



(Beam rates are very crude estimates from various sources, illustrative, likely ~1-2 orders of mag. off

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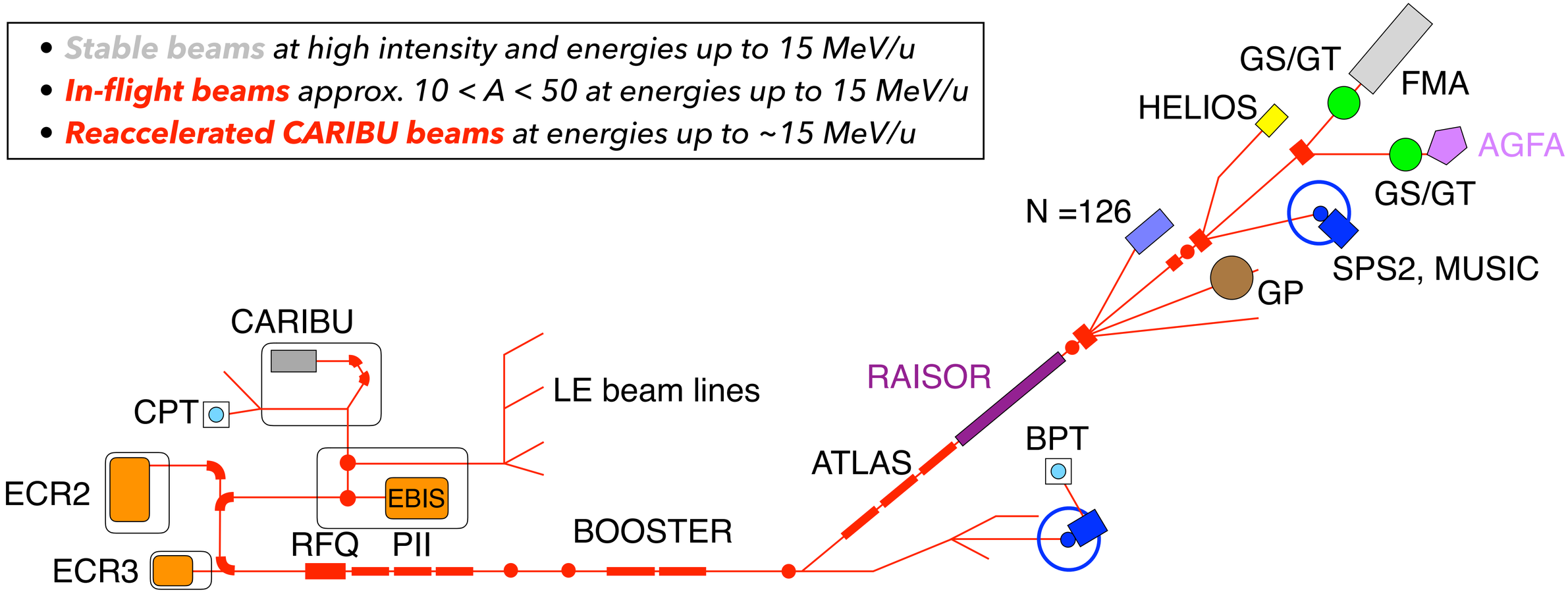
ATLAS & HELIOS

An excellent combination for direct-reaction studies for nuclear structure and astrophysics

- *Stable beams at high intensity and energies up to 15 MeV/u*
- ***In-flight beams** approx. 10 < A < 50 at energies up to 15 MeV/u*
- ***Reaccelerated CARIBU beams** at energies up to ~15 MeV/u*



ATLAS & HELIOS

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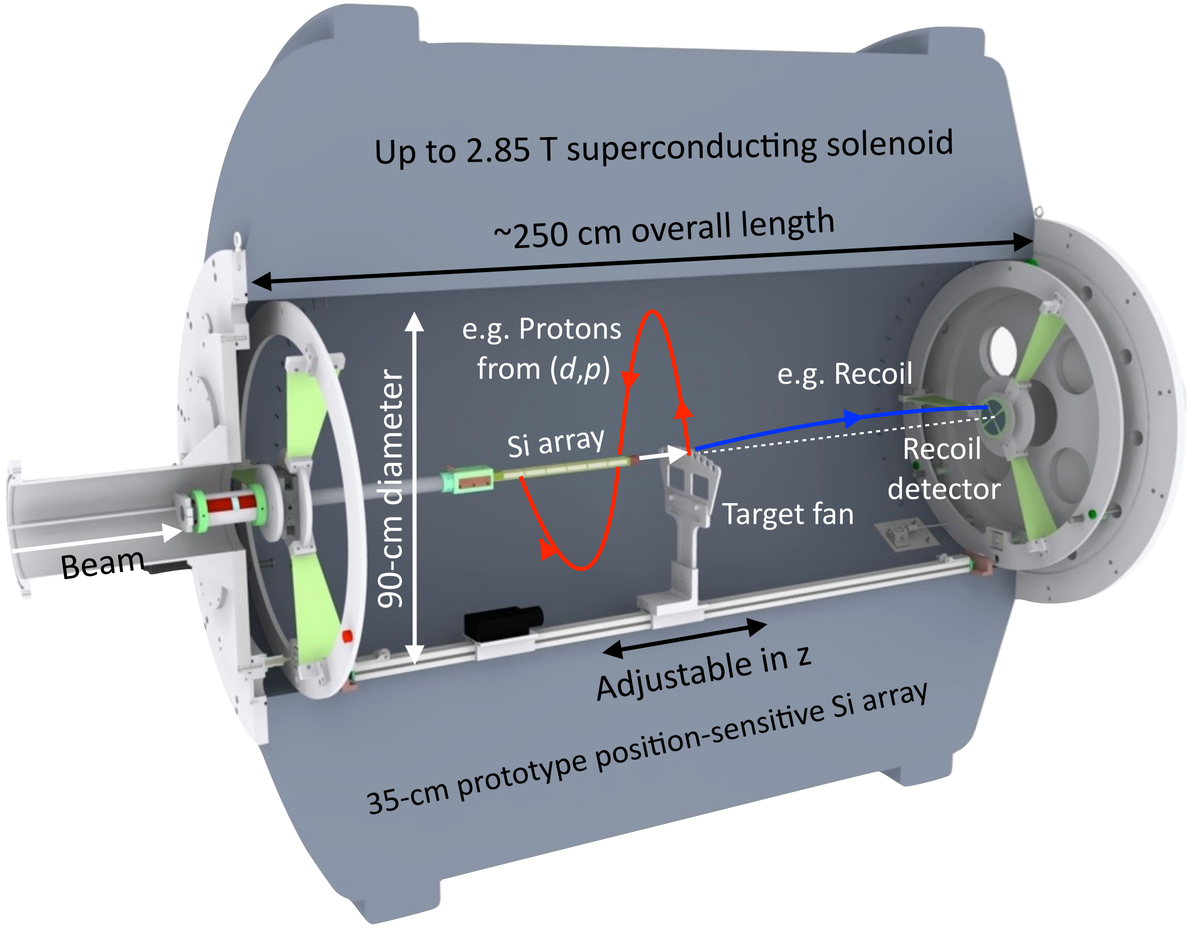

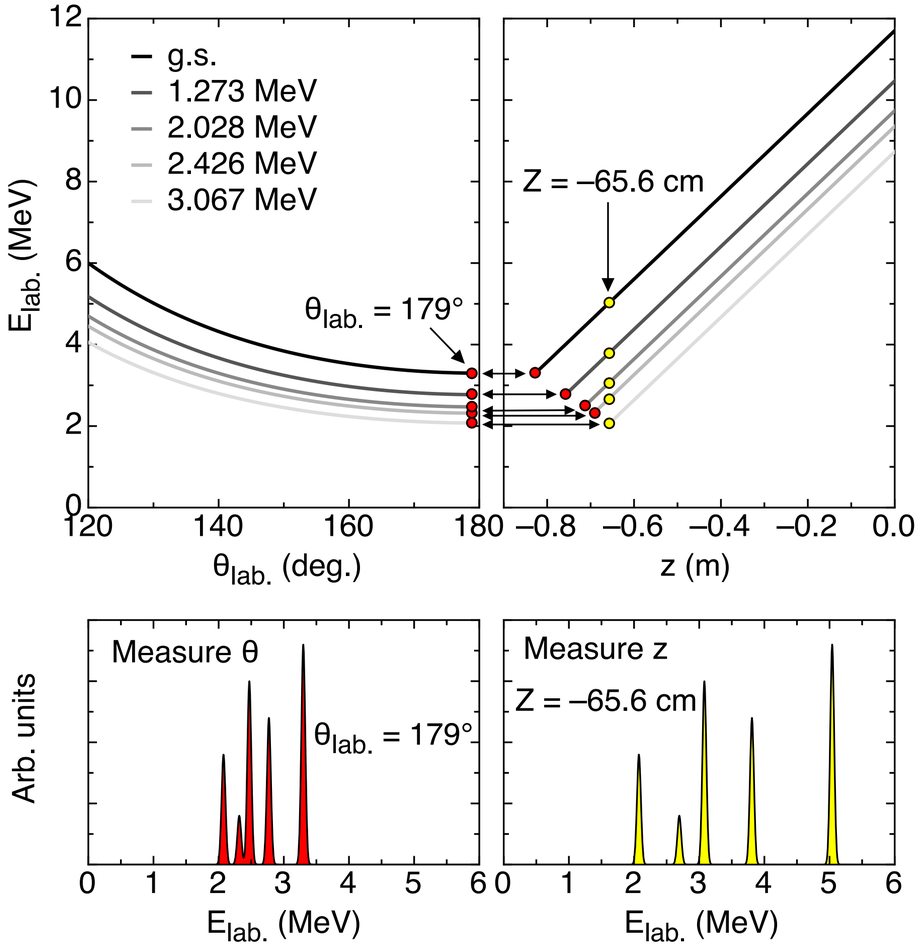

www.anl.gov/atlas

https://www.anl.gov/phy/helical-orbit-spectrometer

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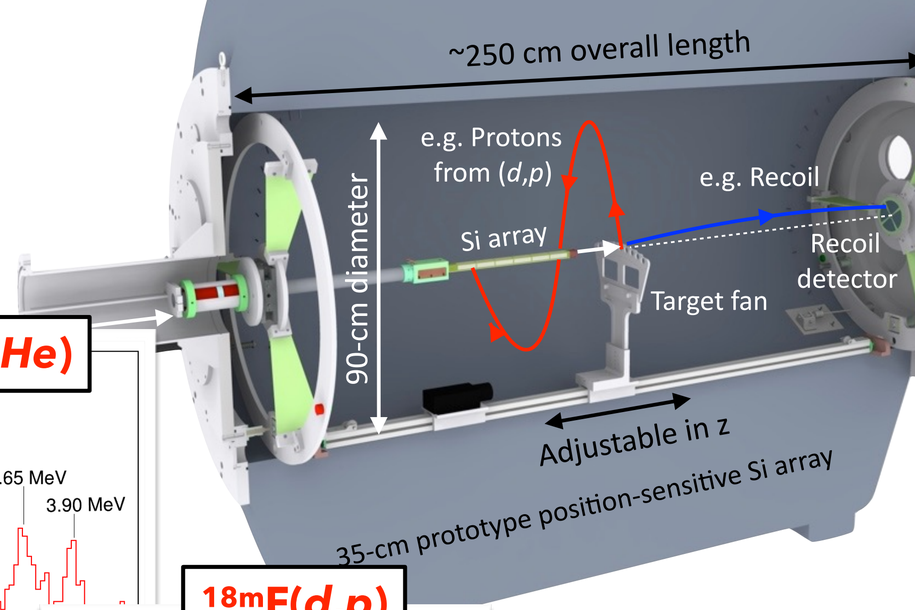
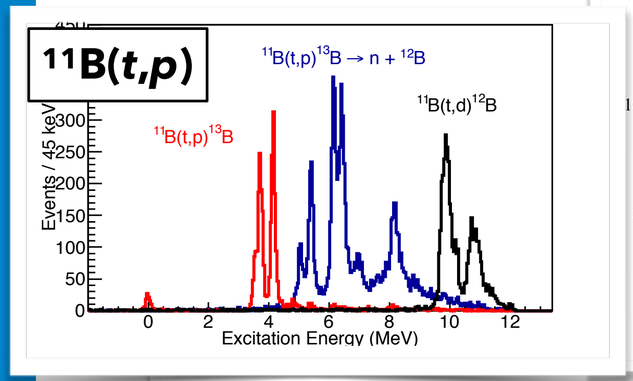
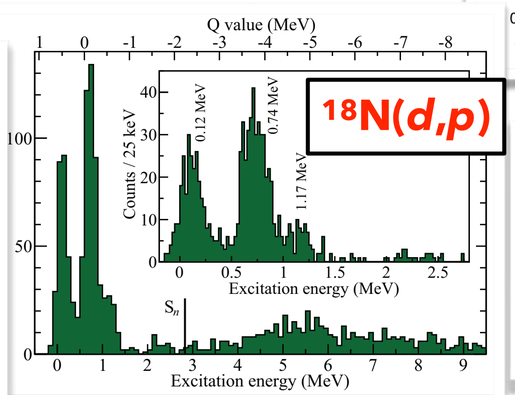
Buoyed by the success of ATLAS

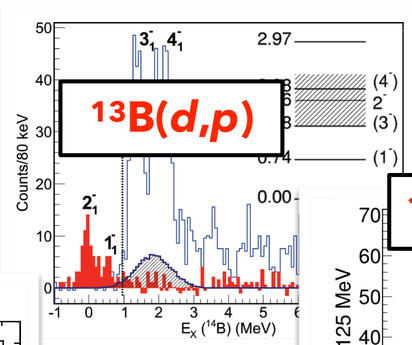
A highly versatile instrument

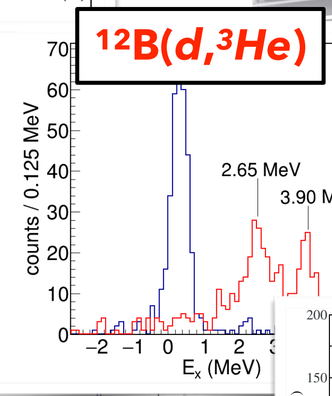
Apollo, gas target, ion chamber, backwards, forwards, tritium target, … all routine

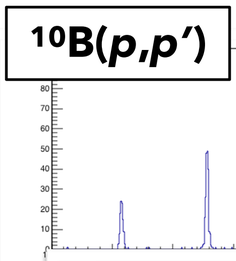


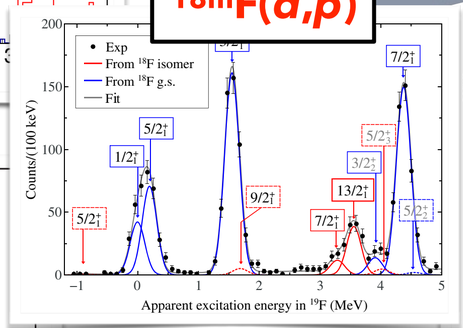


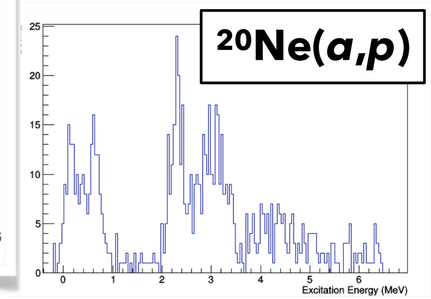


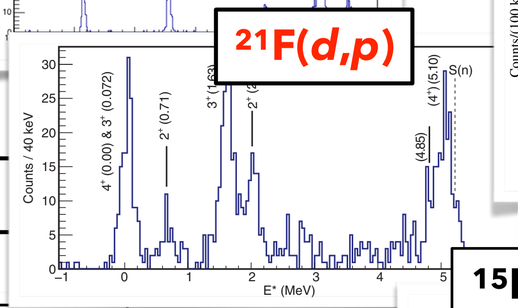


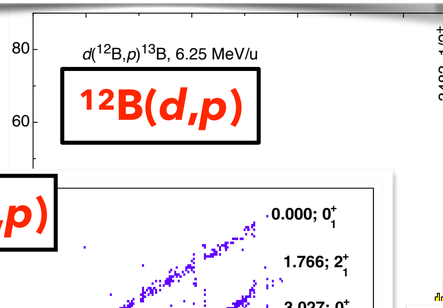


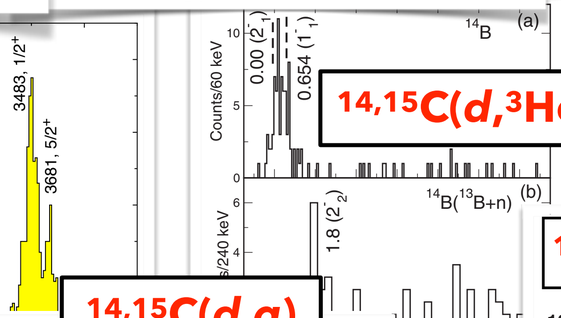


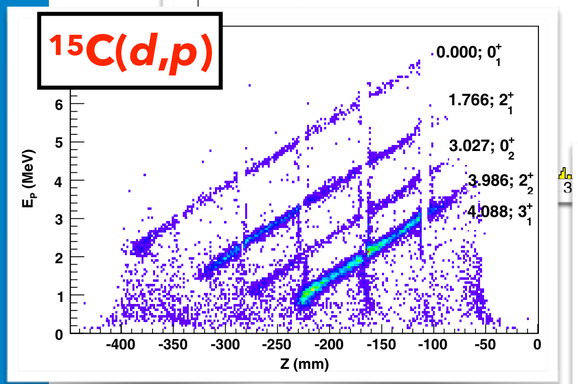


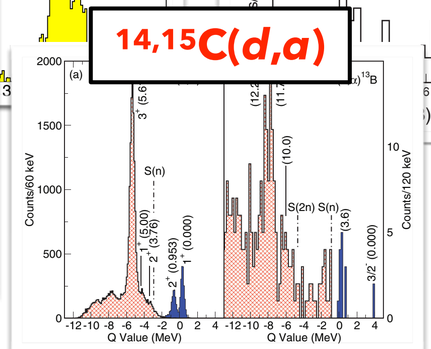


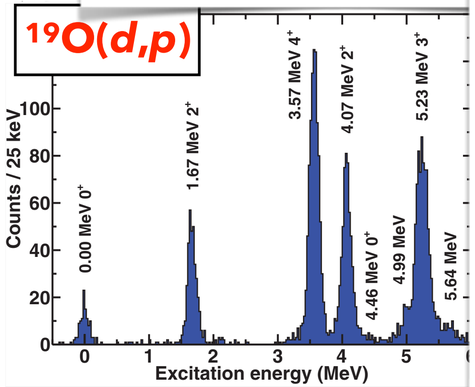


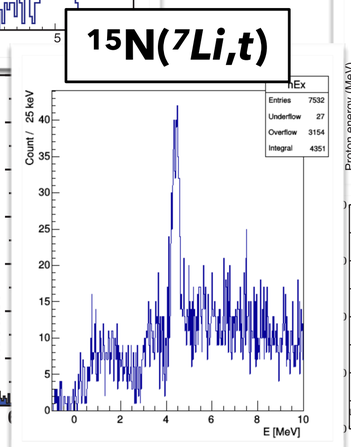


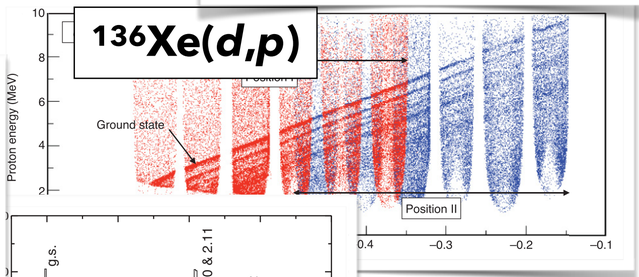


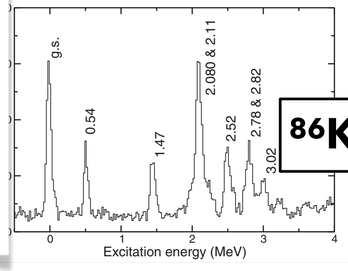












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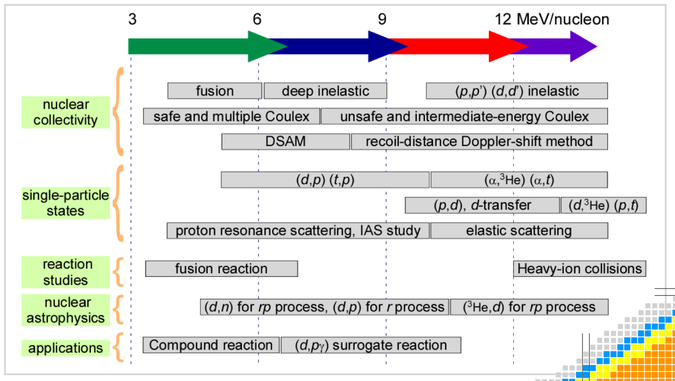
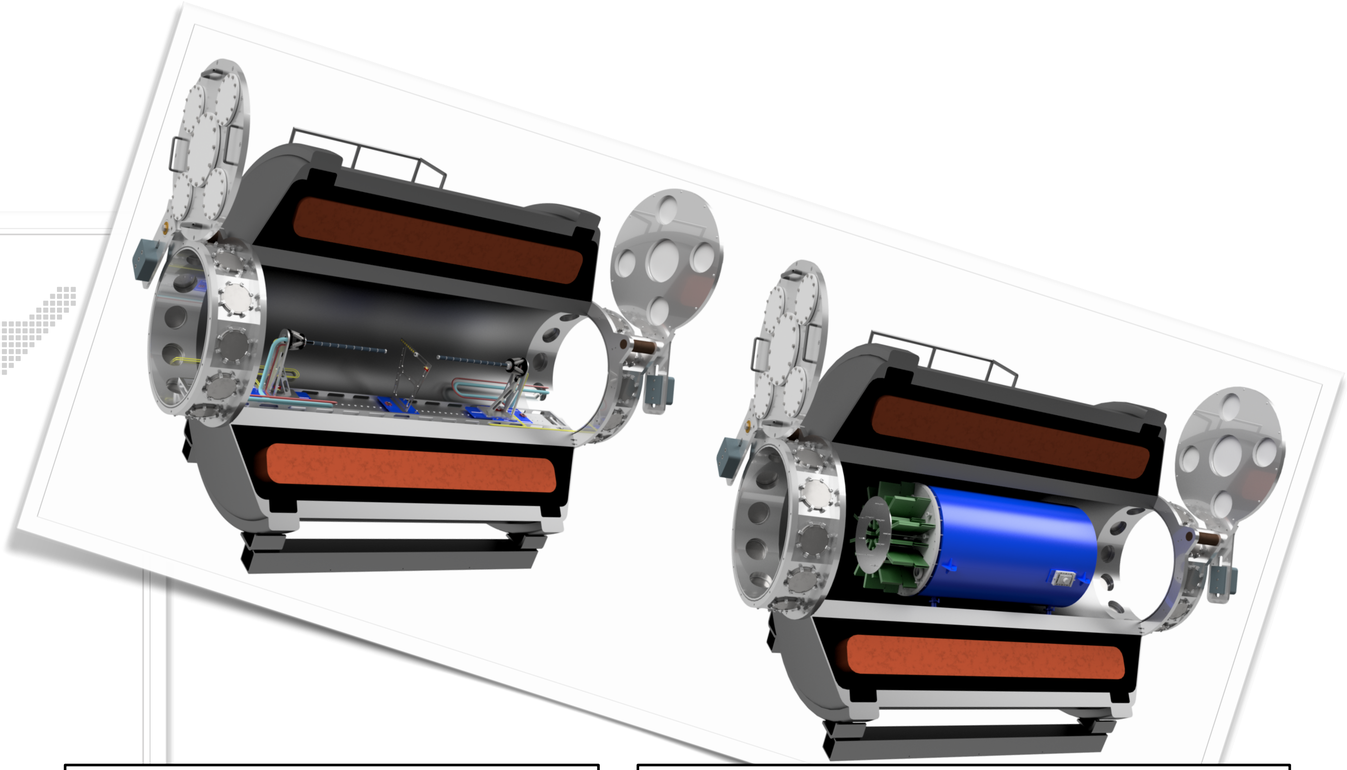
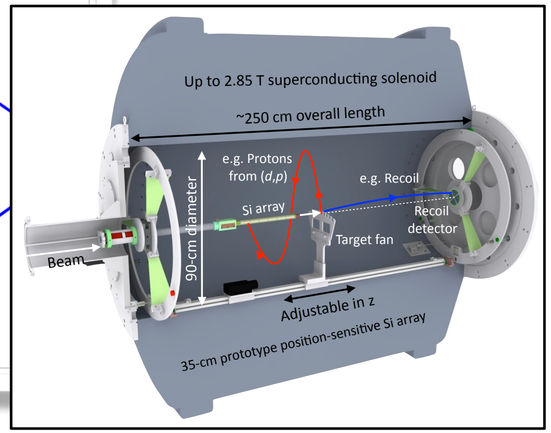
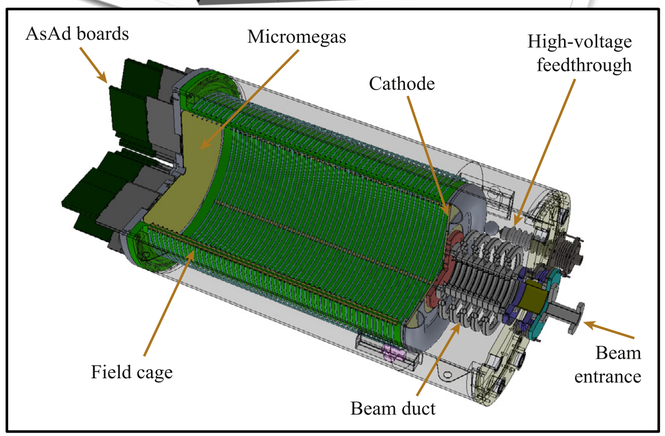
What is SOLARIS?









A dual-mode solenoidal spectrometer to exploit the full dynamic range of the ReA facility at FRIB

https://www.anl.gov/phy/solaris

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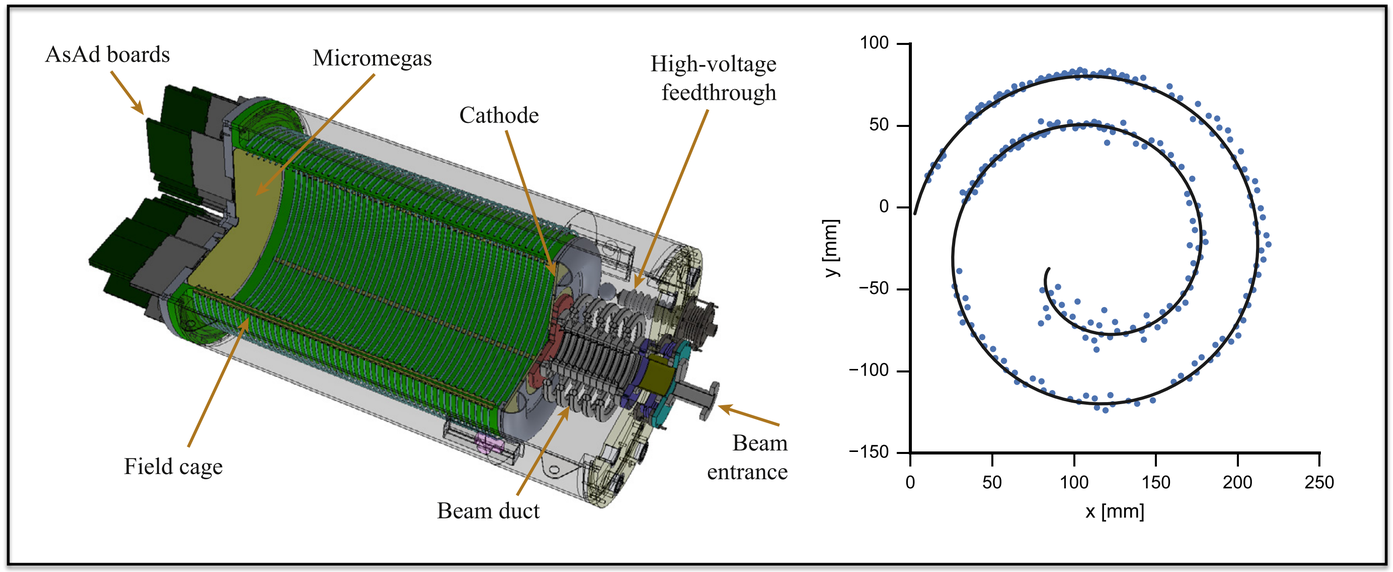
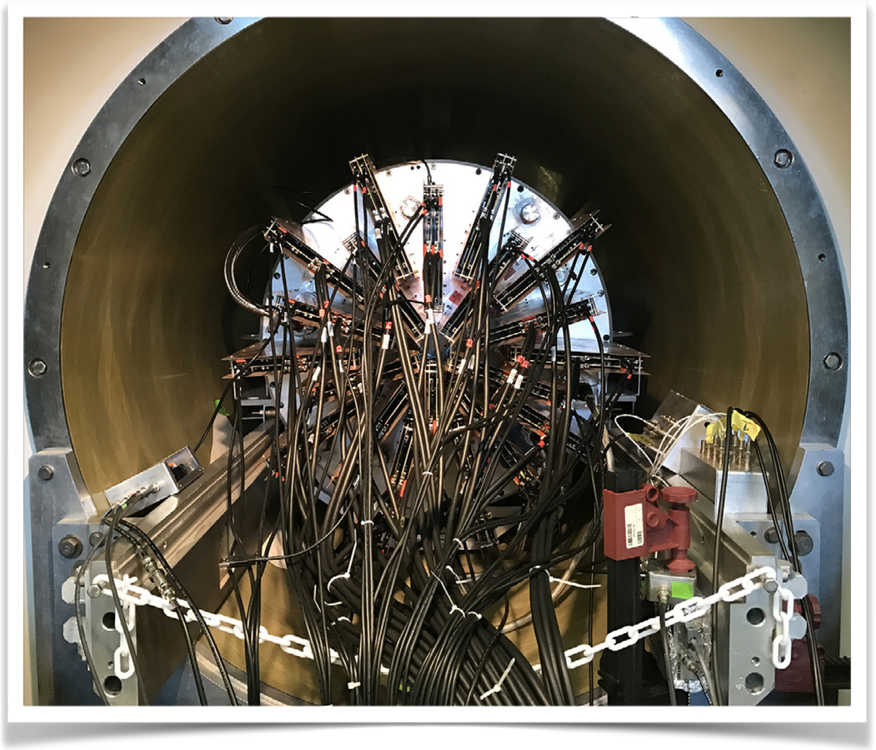
The AT-TPC …





Highly versatile *approach to studying nuclear reactions*

… weak beams, 'complex' final states, ***excitation functions****, pure targets, …, etc.*

~10^2 pps and above, all masses, energies

J. Bradt et al. Nucl. Instrum. Methods Phys. Res. A ***875****, 65 (****2017****)*

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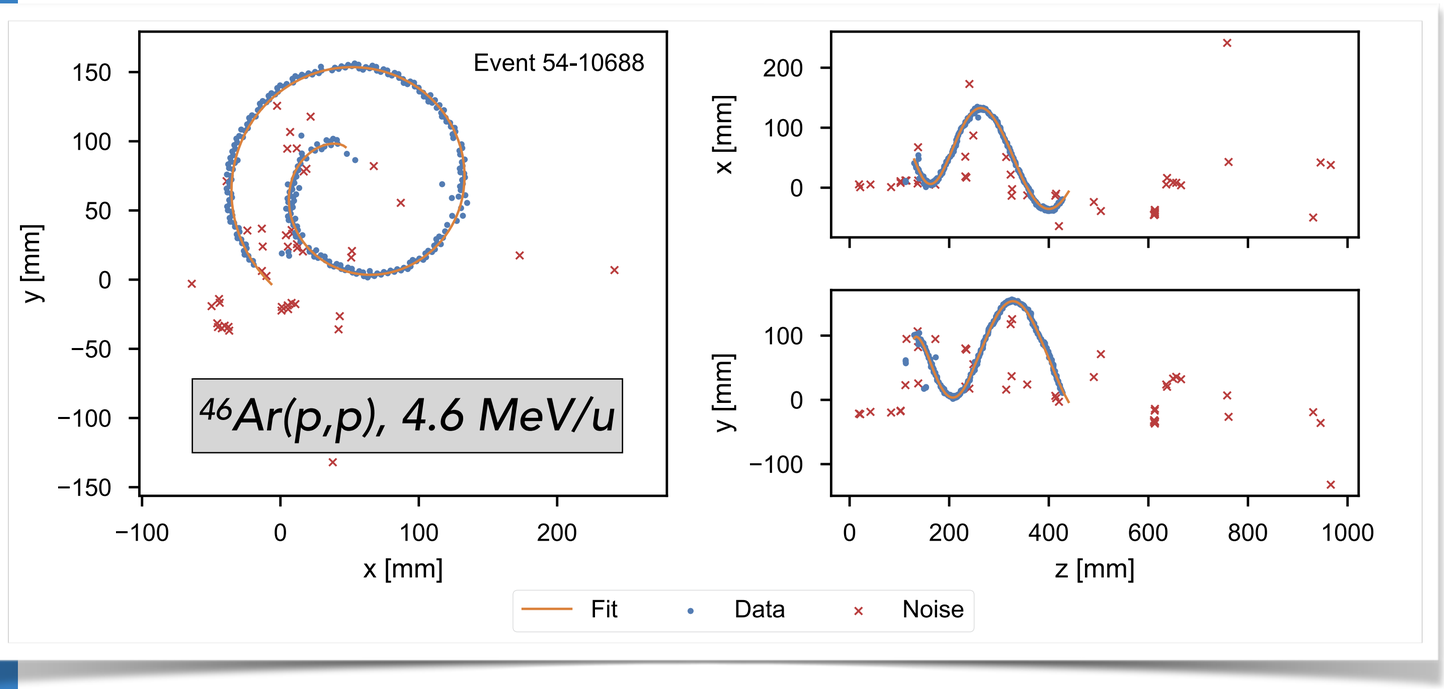
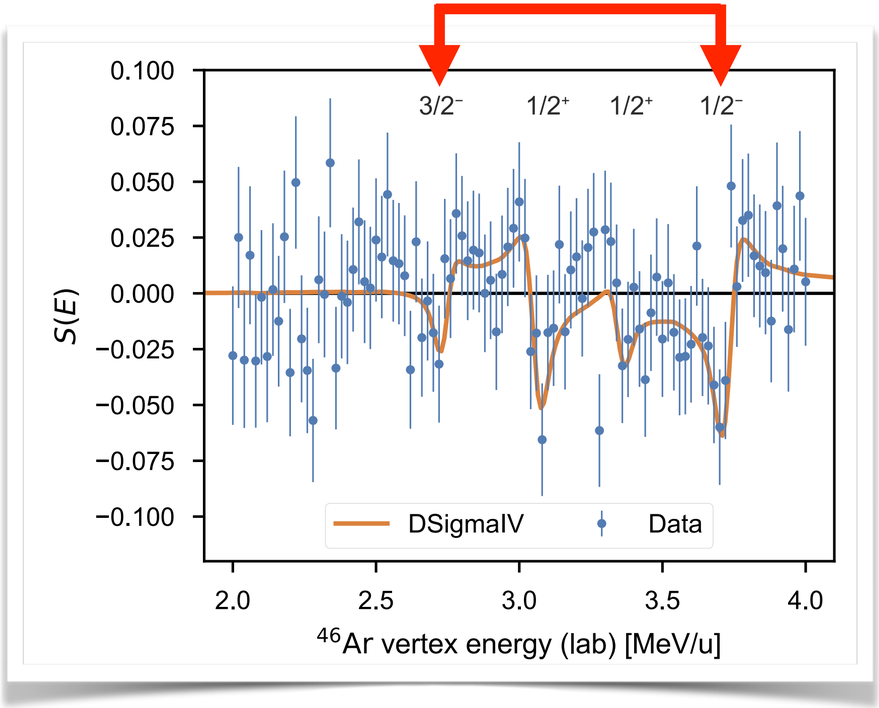
… commissioned in style



v1p states



$E_{\mathrm{res}}^{\mathrm{CM}}$ (keV)	E_x (keV)	J^π	T_z	S	Γ (keV)	Γ_p (keV)
$2680 \pm 108 \pm 20$	$0 \pm 91 \pm 28$	$3/2^-$	$11/2$ (^{47}Ar)	$0.27 \pm 0.03\ ^{+0.21}_{-0.13}$	15(10)	4.3(4)
$2990\ ^{+117}_{-124} \pm 20$	$310\ ^{+91}_{-92} \pm 28$	$1/2^+$	$9/2$ (^{47}K)	$0.027 \pm 0.006\ ^{+0.013}_{-0.007}$	30(10)	20(2)
$3280\ ^{+125}_{-127} \pm 20$	$600\ ^{+92}_{-93} \pm 28$	$1/2^+$	$9/2$ (^{47}K)	$0.008 \pm 0.002\ ^{+0.005}_{-0.006}$	18(10)	8.0(8)
$3650\ ^{+137}_{-147} \pm 20$	$970\ ^{+95}_{-99} \pm 28$	$1/2^-$	$11/2$ (^{47}Ar)	$0.42 \pm 0.05 \pm 0.09$	34(10)	24(2)

Allows for extraction of neutron spectroscopic factors, offering several advantages for studies with RI beams

*J. Bradt et al. Phys. Letts. B **778**, 155 (**2018**)*

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… and this

PHYSICAL REVIEW LETTERS **123,** 082501 (2019)

Editors' Suggestion

August 22, 2019

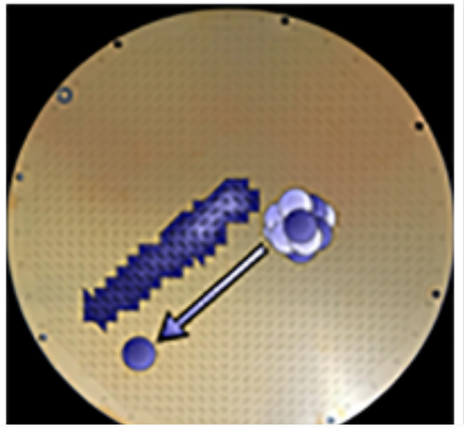
Direct Observation of Proton Emission in ^{11}Be

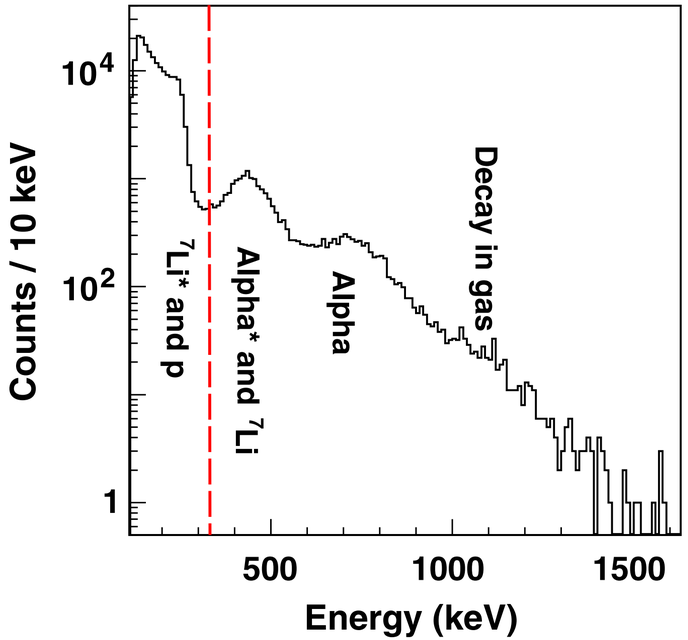
Y. Ayyad,[1,2,*] B. Olaizola,[3] W. Mittig,[2,4] G. Potel,[1] V. Zelevinsky,[1,2,4] M. Horoi,[5] S. Beceiro-Novo,[4] M. Alcorta,[3] C. Andreoiu,[6] T. Ahn,[7] M. Anholm,[3,8] L. Atar,[9] A. Babu,[3] D. Bazin,[2,4] N. Bernier,[3,10] S. S. Bhattacharjee,[3] M. Bowry,[3] R. Caballero-Folch,[3] M. Cortesi,[2] C. Dalitz,[11] E. Dunling,[3,12] A. B. Garnsworthy,[3] M. Holl,[3,13] B. Kootte,[3,8] K. G. Leach,[14] J. S. Randhawa,[2] Y. Saito,[3,10] C. Santamaria,[15] P. Šiurytė,[3,16] C. E. Svensson,[9] R. Umashankar,[3] N. Watwood,[2] and D. Yates[3,10]

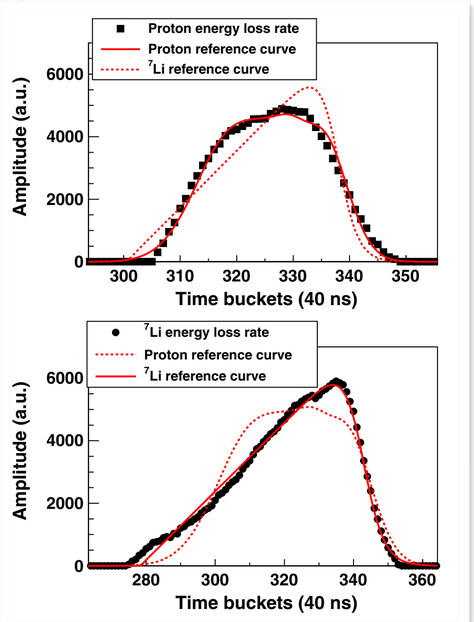
[1]*Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA*

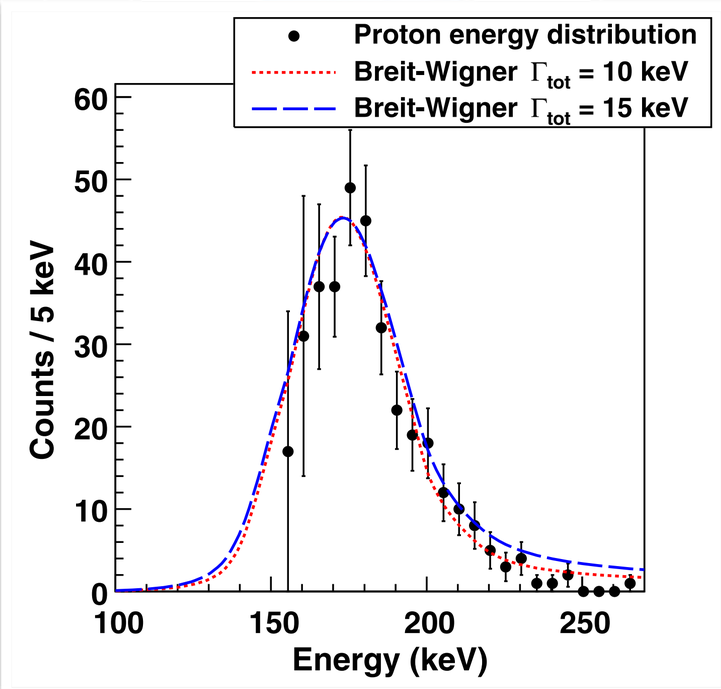
[2]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*

[3]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*









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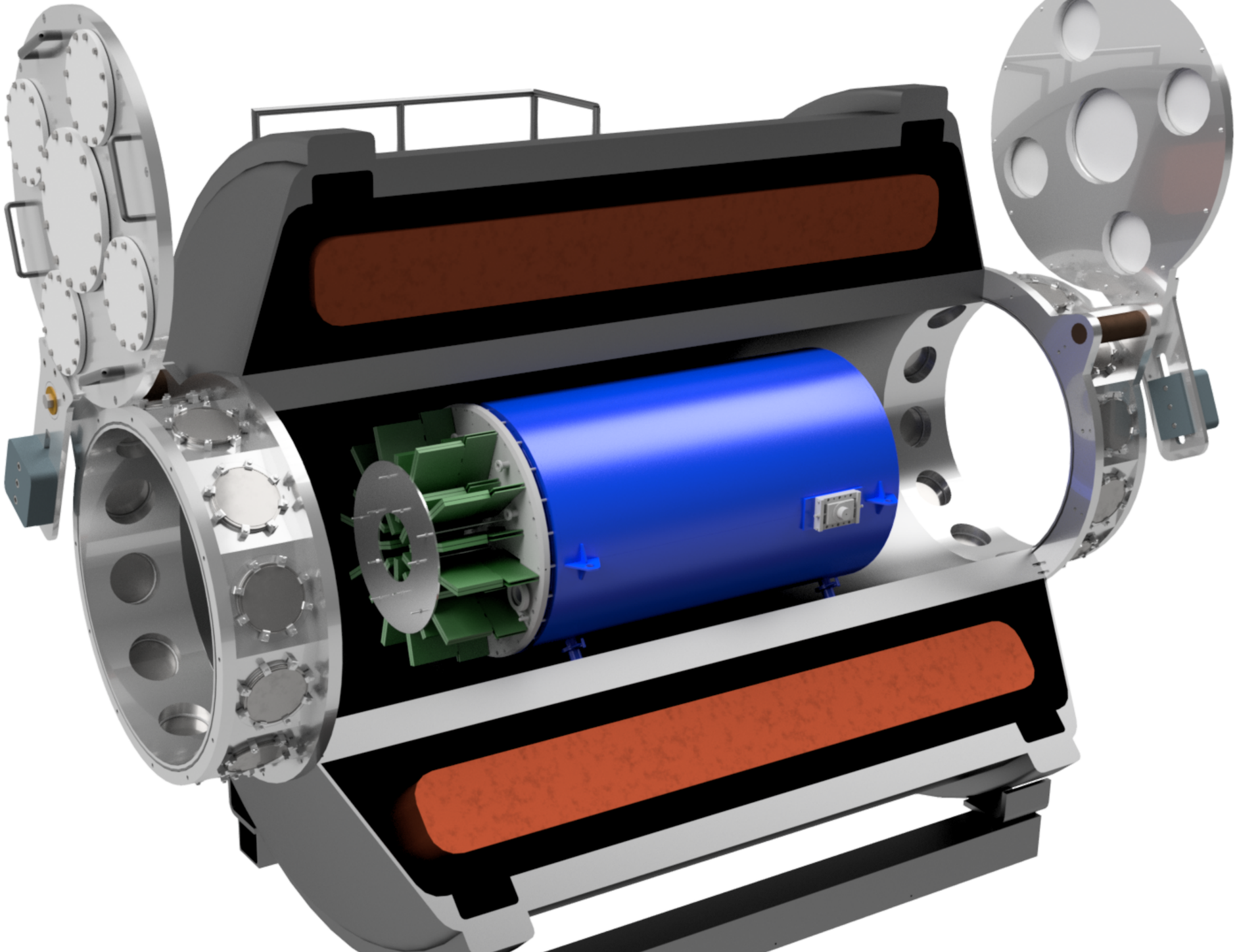

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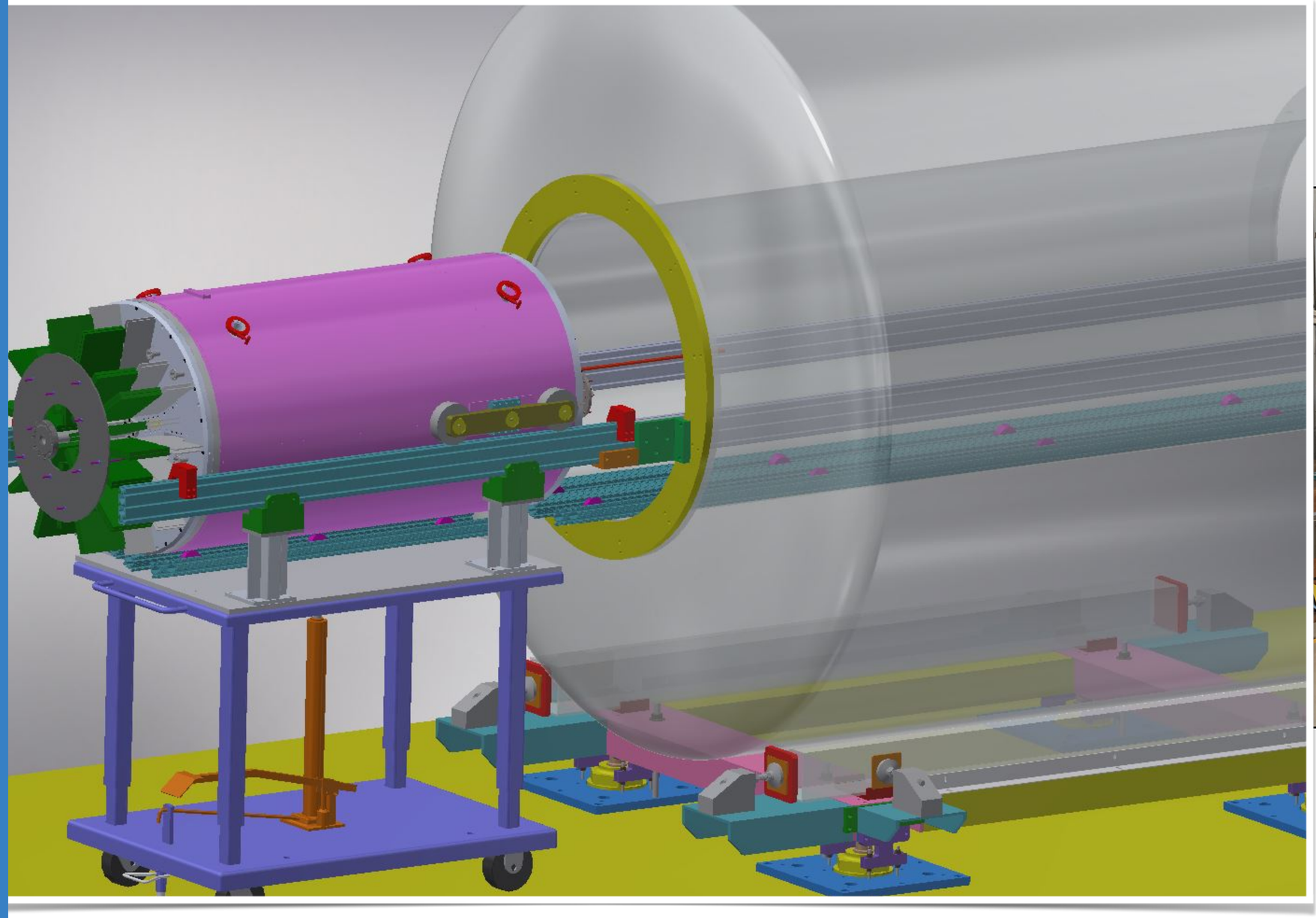
Pre-SOLARIS activities



AT-TPC support, Al Barcikowski (ANL) and SOLARIS team

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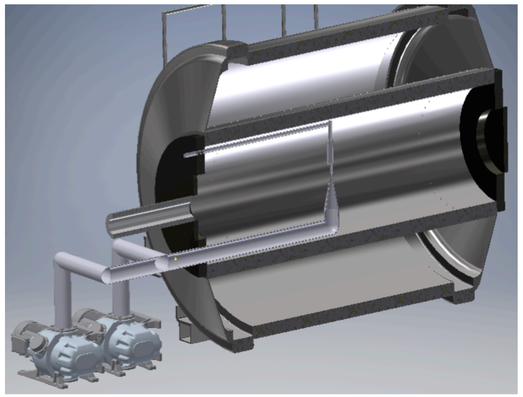
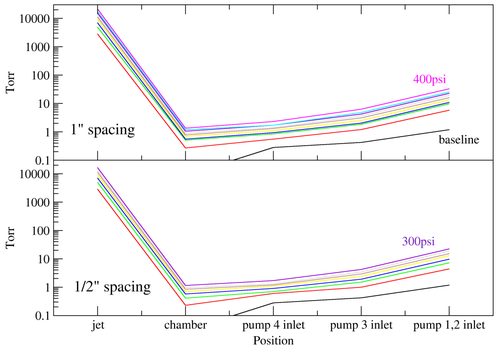
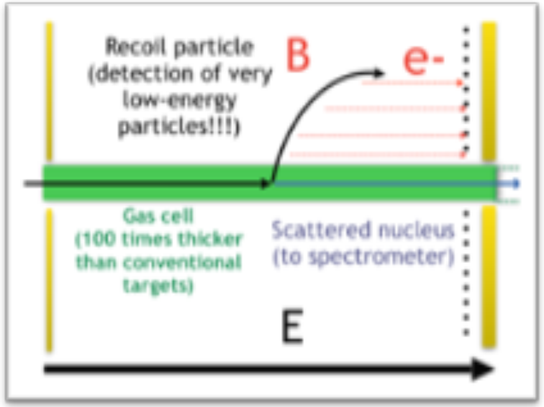
Pre-SOLARIS activities

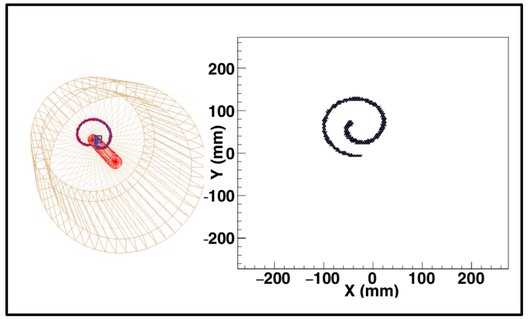
- *Consideration being given to using a JENSA-like gas-jet target system inside a solenoid*
- *Different TPCs can be used, such as the existing AT-TPC, the PAT-TPC, and the newly designed AT3PC (active tritium target time project chamber)*



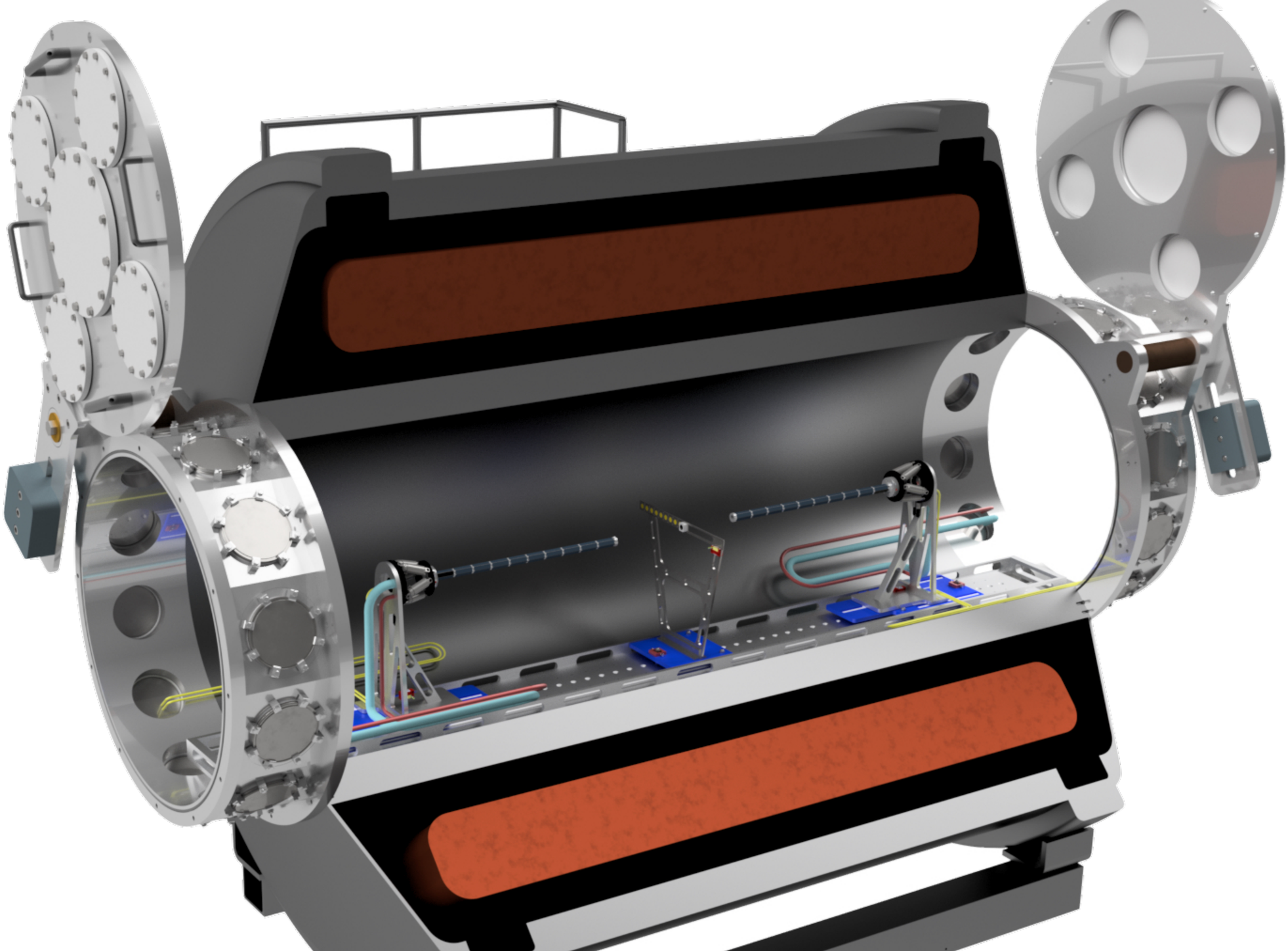


<u>*Gas-jet target*</u>: DOE early-career award. Test with HELIOS, possible use with SOLARIS





<u>*AT3PC*</u>: e.g. for the study of (*t*,*p*) reactions in SOLARIS



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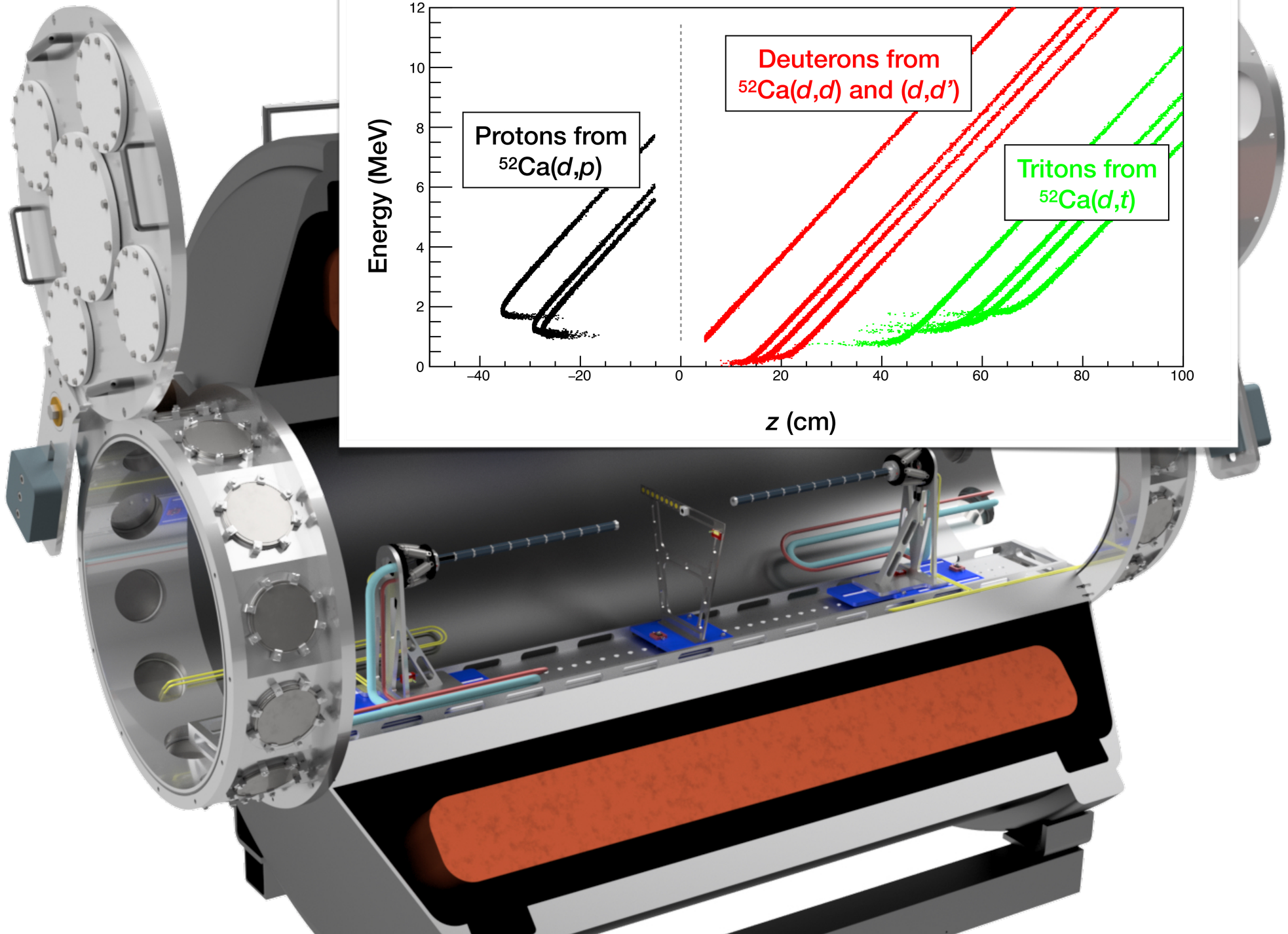
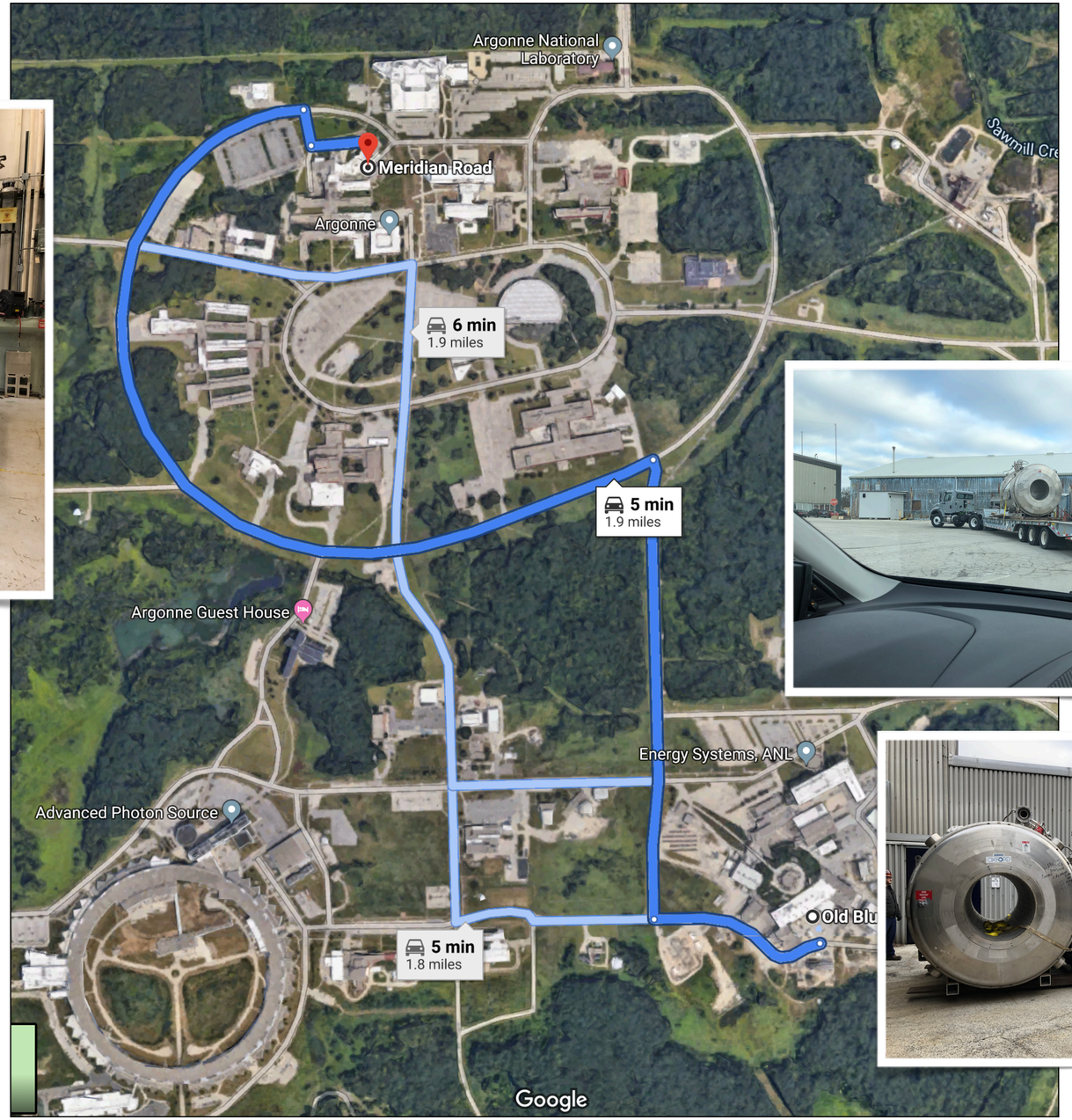

Energy (MeV)
z (cm)
Protons from
52Ca(d,p)
Deuterons from
52Ca(d,d) and (d,d')
Tritons from
52Ca(d,t)
0
2
4
6
8
10
12
−40
−20
0
20
40
60
80
100

January 2019



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February 2019

... paperwork/emails ...


March 2019
ABELL-HOWE
FOREST PARK ILLINOIS
1
TON
WARNING
ACHTUNG
(9,000 liters of LN2, 7,000 liters of LHe ...)
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May 2019

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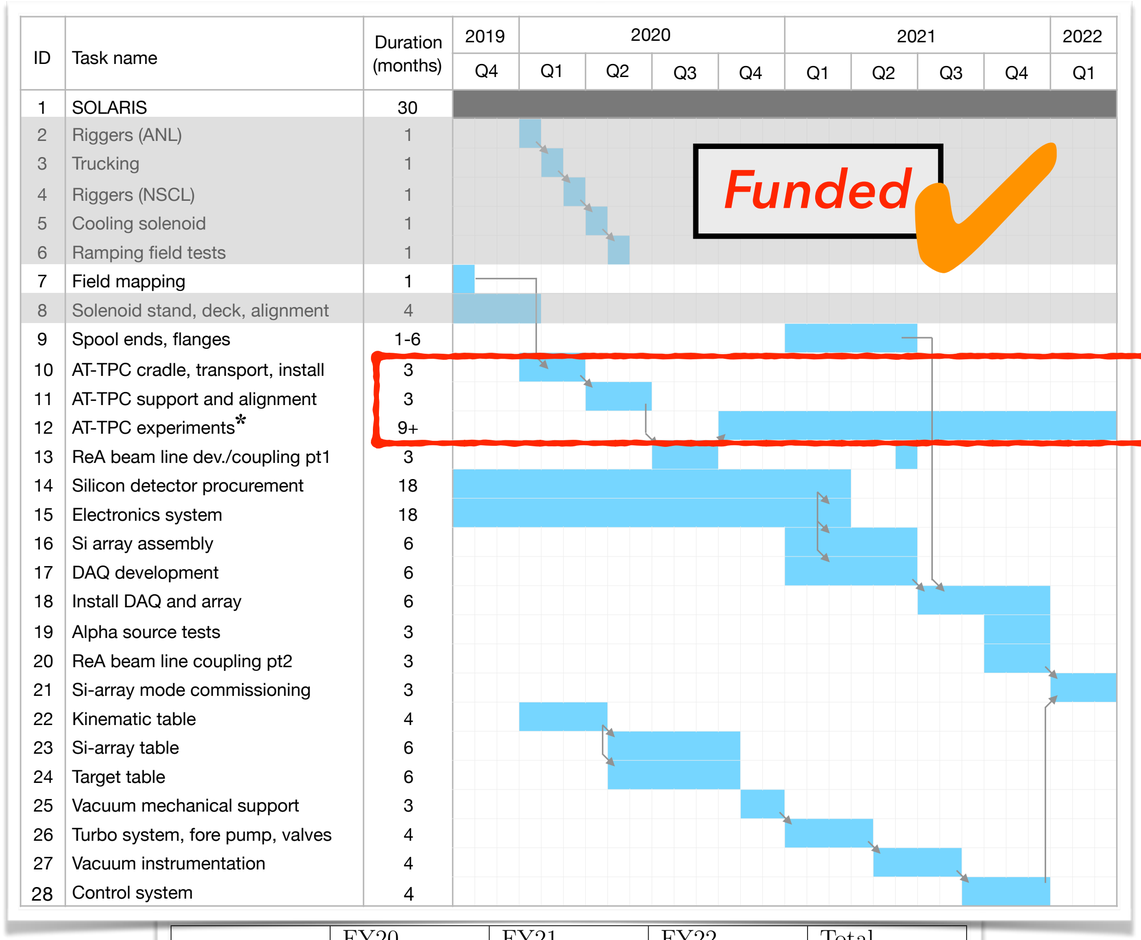
Status, timelines, budget

- 2009-2017: Planning "HELIOS for FRIB"
- March 2017: SOLARIS workshop @ ANL
- March 2018: **White Paper**
- May 2018: **Proposal #1 to DOE**
- September 2018: Prep. funds
- March 2019: Prep. done
- May 2019: Solenoid to NSCL
- June 2019–October 2020: AT-TPC install, commissioning
- August 2019: **Proposal #2 to DOE**

ID	Task name	Duration (months)
1	SOLARIS	30
2	Riggers (ANL)	1
3	Trucking	1
4	Riggers (NSCL)	1
5	Cooling solenoid	1
6	Ramping field tests	1
7	Field mapping	1
8	Solenoid stand, deck, alignment	4
9	Spool ends, flanges	1-6
10	AT-TPC cradle, transport, install	3
11	AT-TPC support and alignment	3
12	AT-TPC experiments*	9+
13	ReA beam line dev./coupling pt1	3
14	Silicon detector procurement	18
15	Electronics system	18
16	Si array assembly	6
17	DAQ development	6
18	Install DAQ and array	6
19	Alpha source tests	3
20	ReA beam line coupling pt2	3
21	Si-array mode commissioning	3
22	Kinematic table	4
23	Si-array table	6
24	Target table	6
25	Vacuum mechanical support	3
26	Turbo system, fore pump, valves	4
27	Vacuum instrumentation	4
28	Control system	4



	FY20	FY21	FY22	Total
Pre-R&D	–	–	–	–
R&D	237	–	68	305
CDR	146	–	–	146
PED	194	405	105	705
Construction	–	1180	1176	2356
Pre-Ops	–	–	105	105
TEC	194	1585	1281	3061
OPC	383	–	174	556
TPC	577	1585	1455	3617

Above: timeline and budget (as proposed)

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In the context of three solenoid set ups

Various stages of HELIOS program and links to other facilities

***SOLARIS at ReA**, estimated beam intensities, energy limited for foreseeable future to 8 MeV/u for Pb, competition with the fast beam program*

preFRIB

***The ISOLDE Solenoidal Spectrometer**, access to ISOL beams, limited operations hours, chemistry dependency, access through collaboration*

LS2

08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28

"The (d,p) machine" ... exploiting the simple in-flight beams

Dominantly sd-shell nuclei, over 5 years led to physics program on weak-binding, bubble-nucleus arguments, etc.

Develop new techniques/ capabilities in prep. for RAISOR beams, next generation devices

New complex reactions, gas targets, photon detection, recoil detection, new DAQ, new array

CERN, HELIOS @ ISS

RAISOR exploitation ...but this time with all the tools, development of more ambitious probes, such a (d,d') on heavy systems, consider AT-TPC sharing ... the "astrophysics machine" ..., use ***dual arrays***, re-vamp controls systems, add ***beam tracking***, gas-jet target with SOLSTISE

nuCARIBU exploitation, the definitive studies of nuclei around ^{132}Sn in terms of effective interactions, essential for informing calculations in the region, access to some astrophysically relevant cross sections

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Summary

Solenoidal spectrometers, a technology pioneered at ANL in anticipation of new RI beam facilities, and active-target TPCs, are now established as key instruments for direct-reaction studies with RI beams as demonstrated by HELIOS@ANL, ISS@ISOLDE, and the AT-TPC@NSCL

Capitalizing on these two technologies, the AT-TPC and HELIOS, SOLARIS will be the ideal tool to exploit the capabilities of ReA

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- *Support of Brad Sherrill and MSU/NSCL in sourcing cryogens and championing SOLARIS*
- *Support of the Michael Kelly of the Accelerator Development and Test Facility (ATDF) at ANL for giving us a home for the tests*
- *Support of the DOE for FY18 funds to test the solenoid, and for their continued support of SOLARIS*

White paper available at URL, hardcopy on demand, support, collaboration welcome

https://www.anl.gov/phy/solaris

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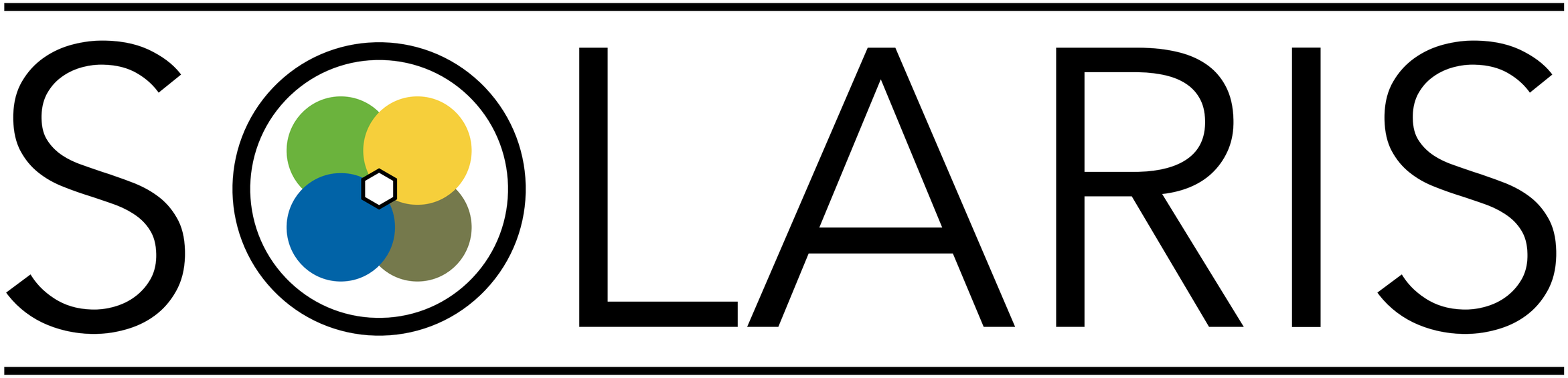
SOLARIS