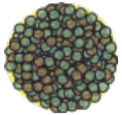
FRIB Day 1 Science Summary

Heather Crawford (LBNL) for the FRIBUEC

Agenda

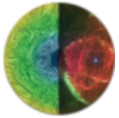
Time	Topic	Speaker	Time Breakdown	Slides
	FRIB Status and Overview: Chair: Kelly Chipps (ORNL)			
1:00pm	Workshop Goals	FRIBUEC	10"	pdf
1:10pm	FRIB Facility Overview	Thomas Glasmacher (FRIB)	30" + 10"	pdf
1:50pm	FRIB Equipment	Georg Bollen (FRIB)	30" + 10"	pdf
2:30pm	Break			
	Physics Session I: Chair: Carl Brune (OU)			
3:00pm	Astrophysics	Melina Avila (ANL) and Rebecca Surman (ND)	30"	Avila-pdf Surman-pdf
3:30pm	Reactions	Bob Charity (WashU) and Charlotte Elster (OU)	30"	pdf
4:00pm	Break			
	Physics Session II: Chair: Filomena Nunes (MSU)			
4:15pm	Structure	Mitch Allmond (ORNL) and Ragnar Stroberg (TRIUMF)	30"	Allmond-pdf Stroberg-pdf
4:45pm	Fundamental Symmetries	Jaideep Singh (MSU) and Jon Engel (UNC)	30"	pdf
5:15pm	Applications	Greg Severin (MSU)	15"	pdf
5:30pm	Discussion -- Chair: Lee Sobotka (WashU)		30"	
6:00pm	Adjourn			

FRIB – Big Science Themes



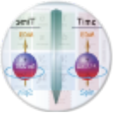
Properties of atomic nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.



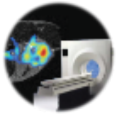
Astrophysics: What happens inside stars?

- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars



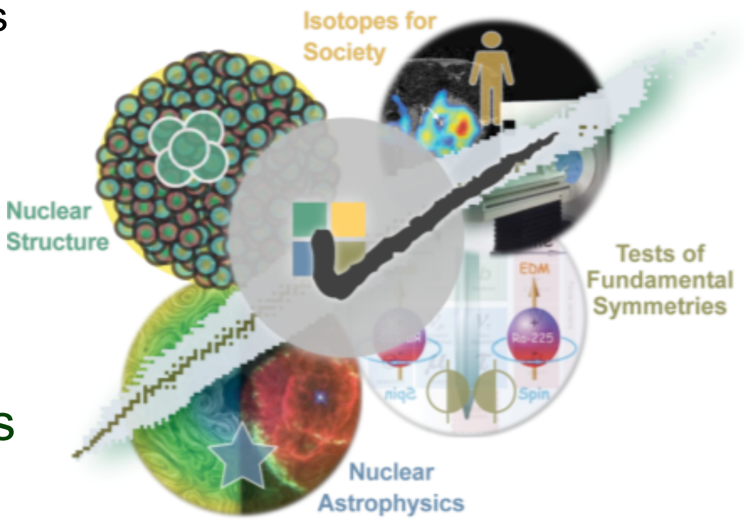
Tests of laws of nature

- Effects of symmetry violations are amplified in certain nuclei

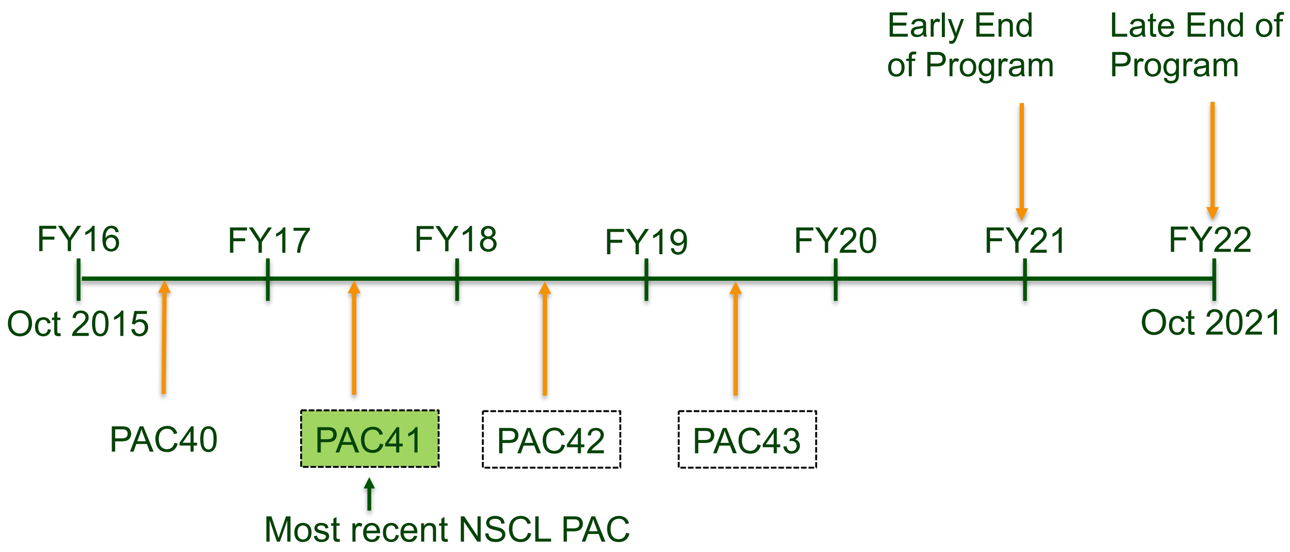


Societal applications and benefits

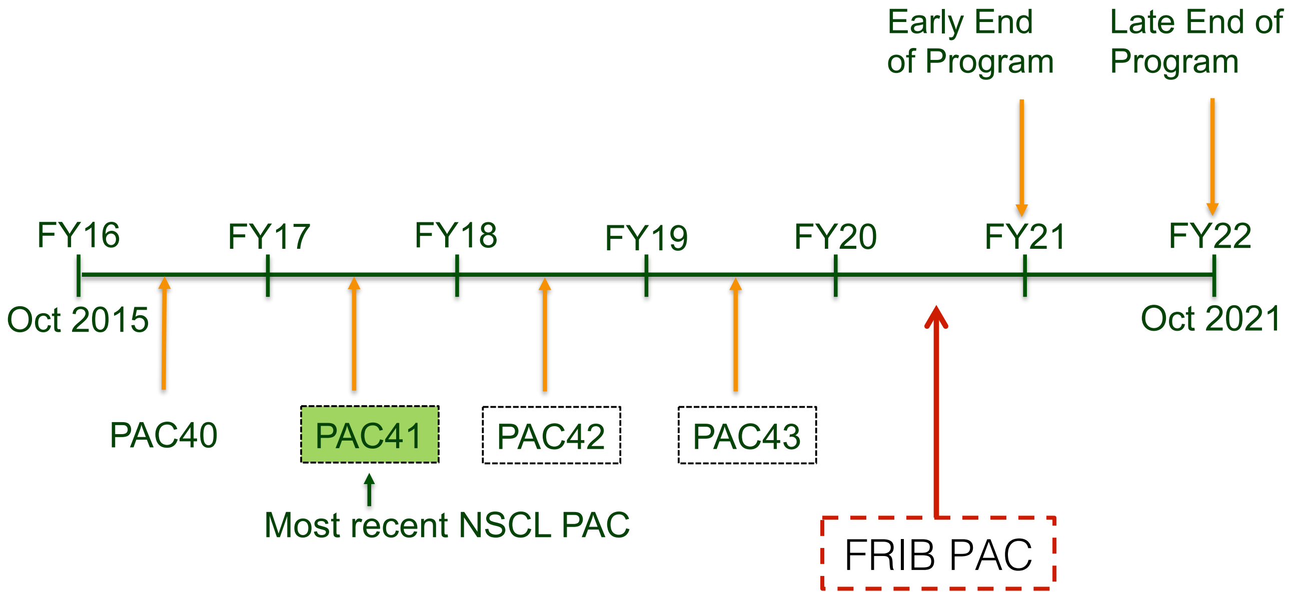
- Medicine, energy, material sciences, national security



Timeline to Day 1 Science

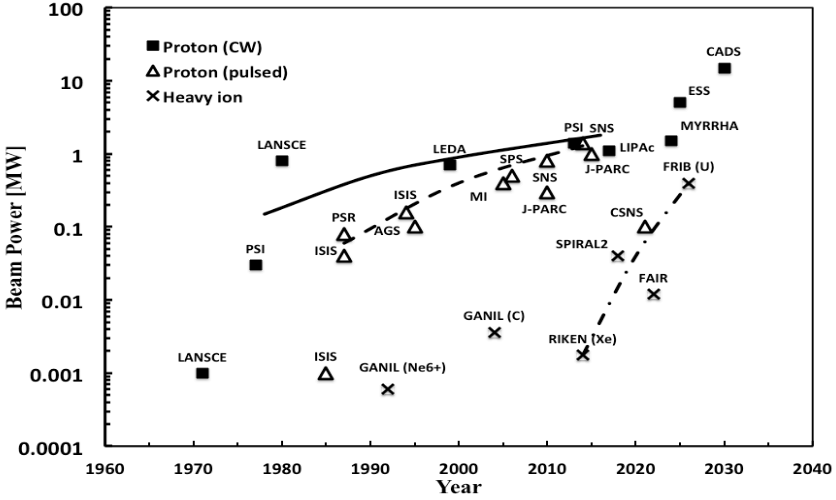


Timeline to Day 1 Science



T. Glasmacher, FRIB

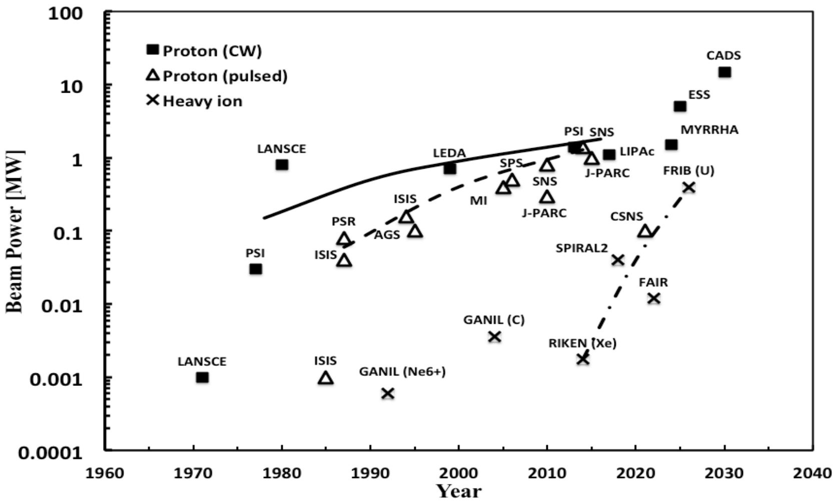
Optimizing Day 1 Science



Things to keep in mind…

- FRIB is hard! Thomas *et al*., just make it look easy…

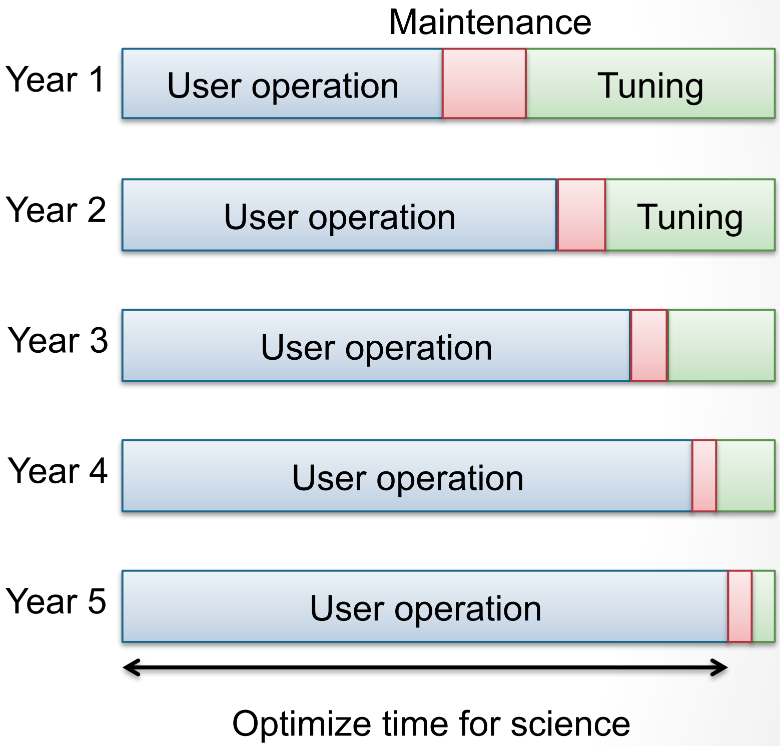
Optimizing Day 1 Science



Things to keep in mind…

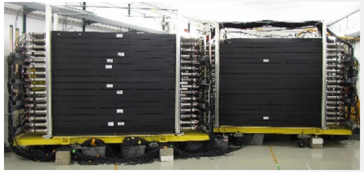
- FRIB is hard! Thomas *et al.*, just make it look easy…
- There will be a balance between development and user science time

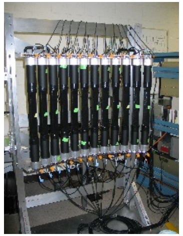
Tentative Operation Cycle

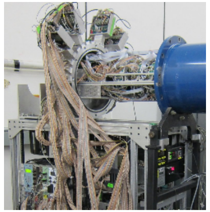


T. Glasmacher, FRIB

Day 1 Ingredients: Equipment







Spectrometers/Beam Line:
- S800, Sweeper Magnet, RFFS, SECAR, 92-inch chamber,

γ Detection:
- SeGA, CAESAR, SuN/MTAS, Gammasphere, GRETINA

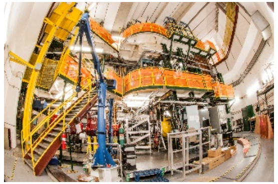
Neutron Detection:
- MoNA-LISA, Neutron Walls, NERO/3HeN, LENDA/VANDLE

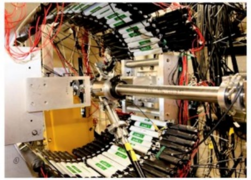
Charged Particle Detection:
- BCS, HiRA/LASSA, Diamond Detectors, JANUS, superORRUBA, CHICO-X, ORISS, CFFD

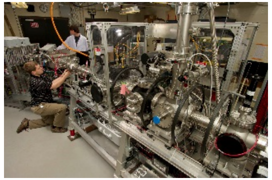
Active Targets/Advanced Targetry:
- AT-TPC, ANASEN, MUSIC, Liquid H-target, JENSA, TriPLEX

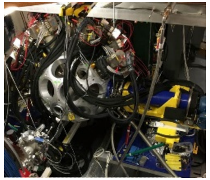
Stopped Beam Equipment:
- Beta-NMR, BECOLA, LEBIT

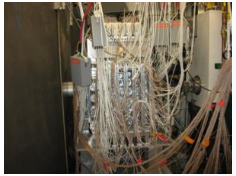
G. Bollen, FRIB











Day 1 Science Ingredients: Beams

Year One

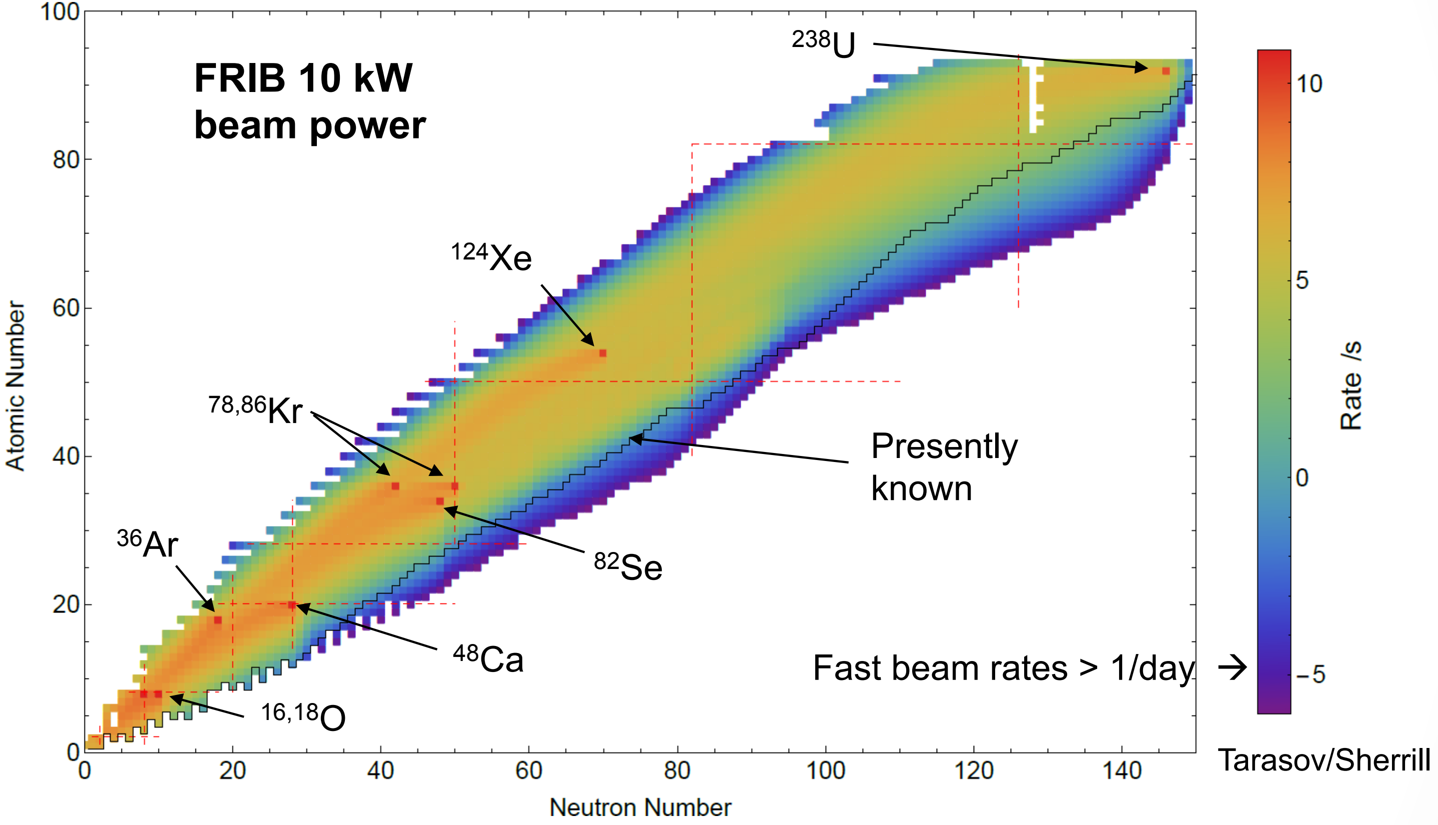
Beam	Notional Weeks/ Year	RISAC Bench-marks
^{238}U	12	7,10,12,15
^{48}Ca	6.34	2,14
^{82}Se	5.25	1,3,4,5,6, 13,14,15
^{78}Kr	2.21	3,8,9,16,17
^{124}Xe	1.3	1,11,17
^{18}O	0.86	2,8
^{86}Kr (CD-4)	0.63	1,3,4,6, 14,15
^{16}O	0.44	2,8
^{36}Ar (CD-4)	-	8
Total	23.8	

Year Two

Beam	Notional Weeks/ Year	RISAC Bench-marks
^{92}Mo	2.45	1,3,9,11,16, 17
^{58}Ni	1.64	1,3
^{22}Ne	0.54	2
^{64}Ni	0.5	1,13,14
Total	10.4	

- *This is not set in stone (except blue beams) – speak up if you want to see a different prioritization*
- *Link to fragment rates online; LISE++ version update coming for FRIB (purity estimations etc. will be possible)*

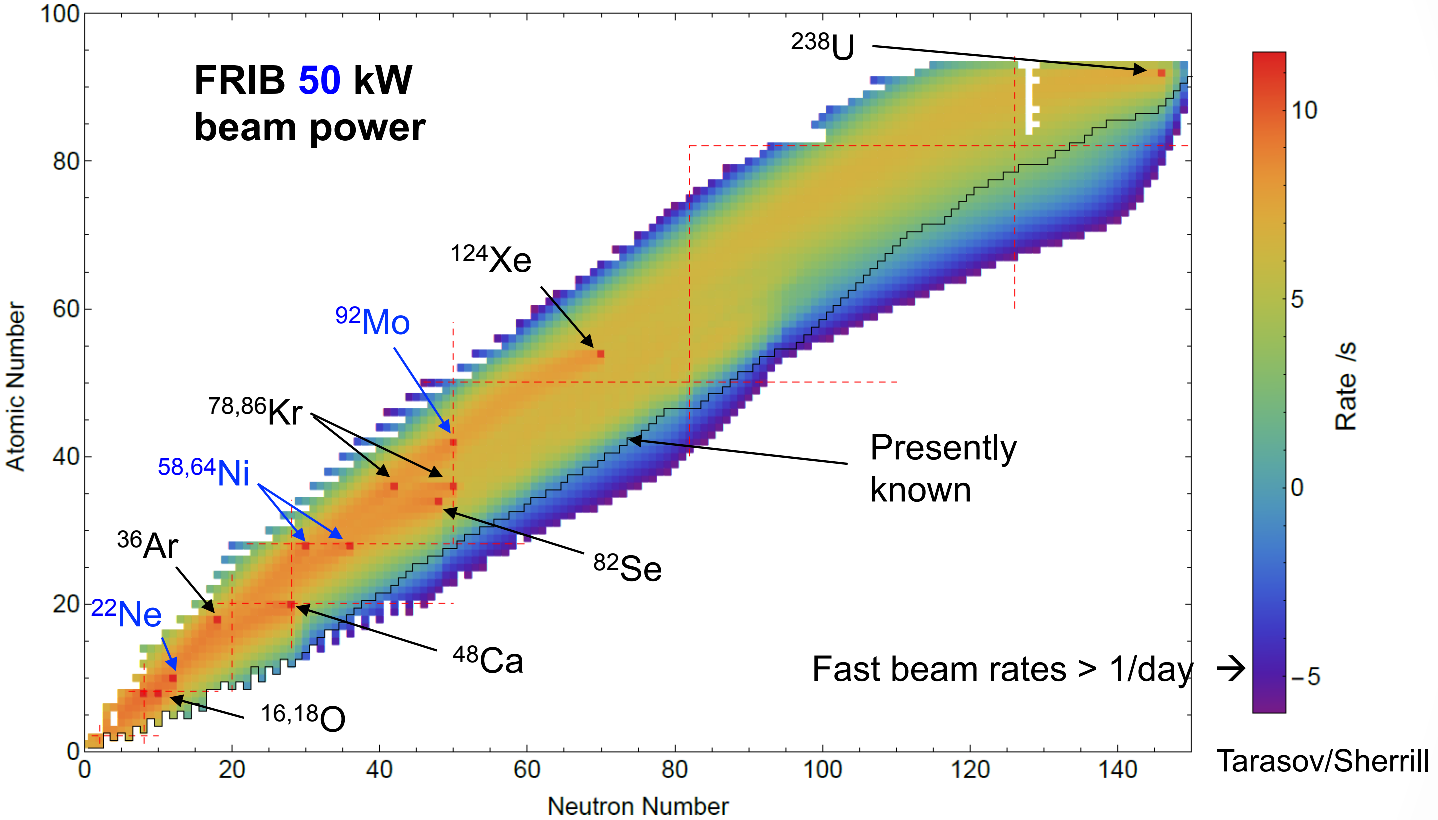
Day 1 Science Ingredients: Beam



Year-1 FRIB rates exceed rates at other facilities in many areas

G. Bollen, FRIB

Day 1 Science Ingredients: Beam



Year-2 FRIB provides access to ~600 more isotopes with rates > 1/day

G. Bollen, FRIB

Nuclear Astrophysics

Nuclear Astrophysics Experiments

Equipment:

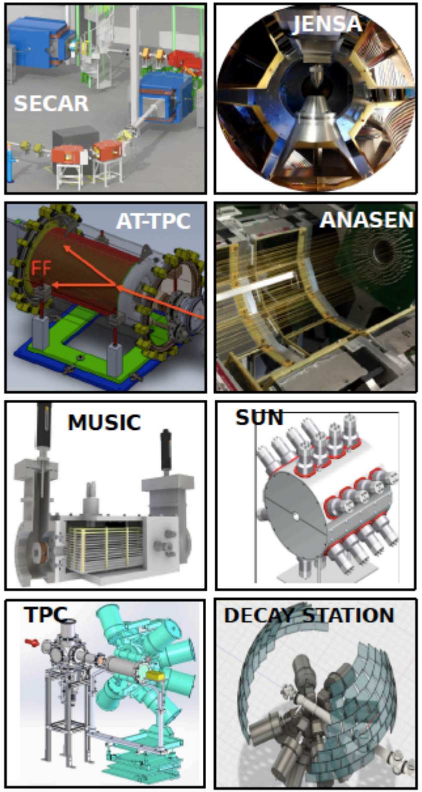
- SECAR, JENSA, AT TPC,ANASEN, MUSIC, SUN, DECAY STATION, HRS , ISLA, HELIOS, GRETINA/GRETA, HR AT TPC S800

Beams:

- ReA3 beams – ^{30}P, ^{18}F, ^{22}Mg, ^{26}Si, ^{30}S, ^{34}Ar, ^{56}Ni, ^{59}Cu, ^{45}V, ^{38}K, ^{8}B, ^{9}C, ^{13}O, ^{14}O , ^{18}Ne
- ReA6 – ReA12 beams – ^{18}F, ^{30}P, ^{38}K, ^{45}V, ^{59}Cu
- Fast beams – ^{15}O
- Stopped beams – near N=82 and N=126, Uranium

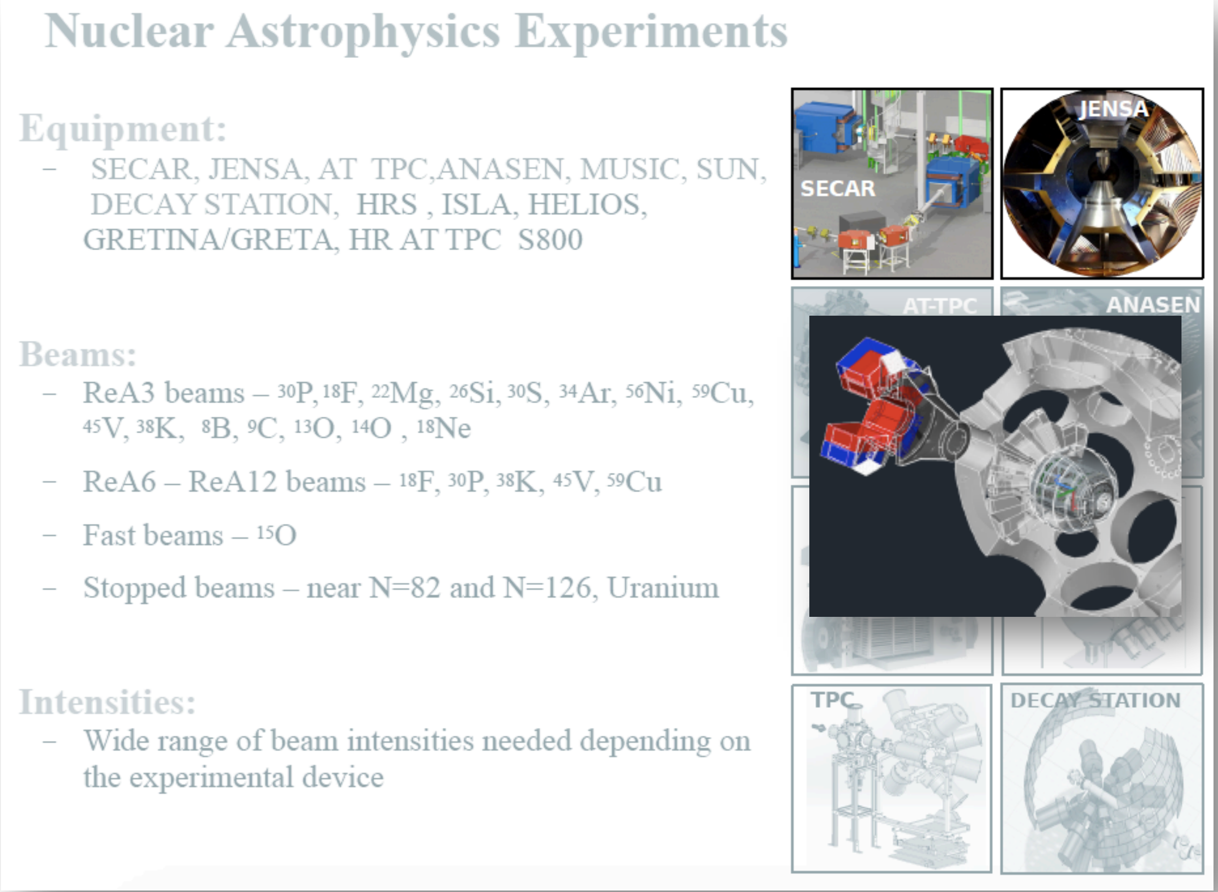
Intensities:

- Wide range of beam intensities needed depending on the experimental device



M. Avila, ANL

Nuclear Astrophysics


Nuclear Astrophysics Experiments

Equipment:
- SECAR, JENSA, AT TPC,ANASEN, MUSIC, SUN, DECAY STATION, HRS , ISLA, HELIOS, GRETINA/GRETA, HR AT TPC S800

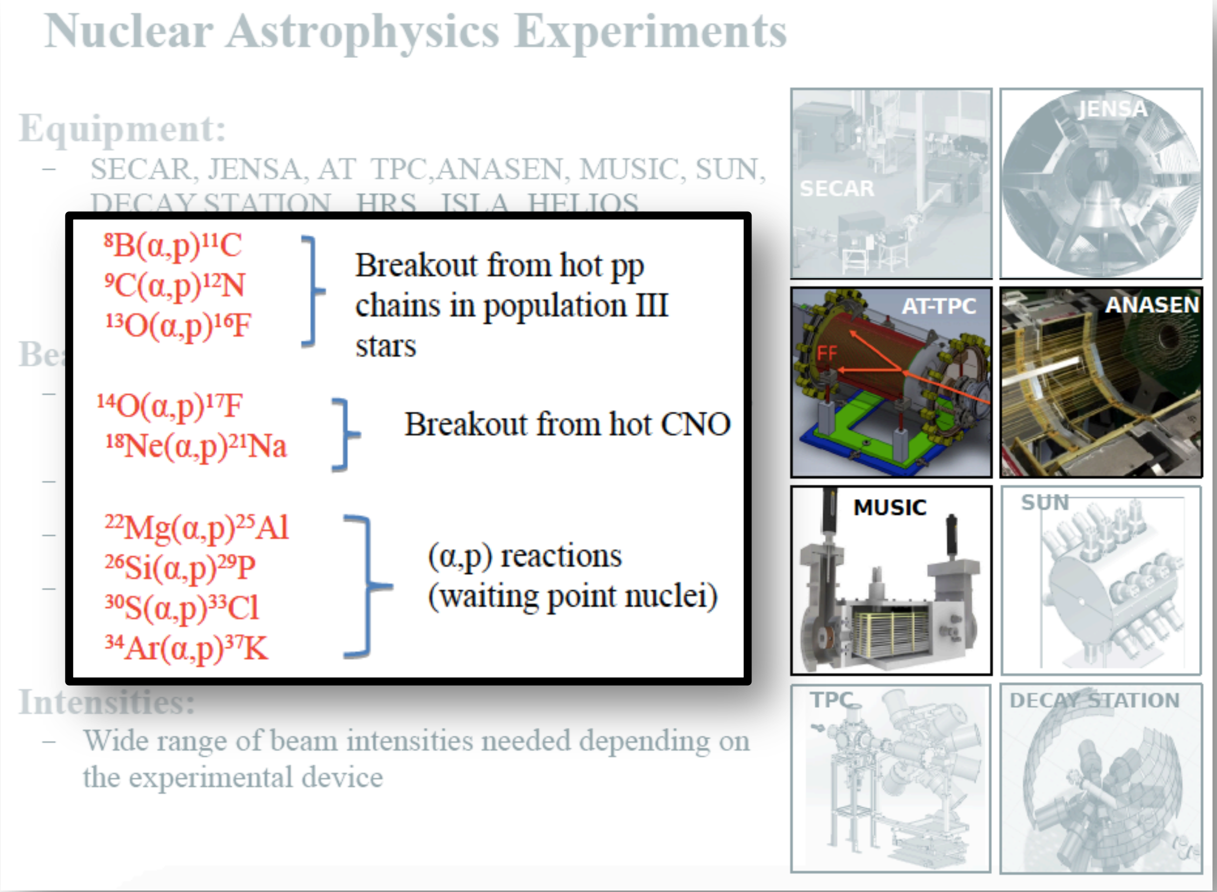
Beams:
- ReA3 beams – ^{30}P, ^{18}F, ^{22}Mg, ^{26}Si, ^{30}S, ^{34}Ar, ^{56}Ni, ^{59}Cu, ^{45}V, ^{38}K, ^{8}B, ^{9}C, ^{13}O, ^{14}O , ^{18}Ne
- ReA6 – ReA12 beams – ^{18}F, ^{30}P, ^{38}K, ^{45}V, ^{59}Cu
- Fast beams – ^{15}O
- Stopped beams – near N=82 and N=126, Uranium

Intensities:
- Wide range of beam intensities needed depending on the experimental device

- Combination of SECAR+JENSA provides unique opportunity with FRIB ReA beams
- Day 1: Some direct (p,γ) measurements, but other valuable reactions such as (d,n), (d,p), (α,p) will be key
- Other equipment is ready also for other transfer rxns

M. Avila, ANL & R. Surman (ND)

Nuclear Astrophysics



- Active target systems, also with ReA beams, are planned to have vibrant (α,p) measurement programs
- Experiments may possible with as little as ~ 500/s with MUSIC

M. Avila, ANL

Nuclear Astrophysics

Nuclear Astrophysics Experiments

Equipment:

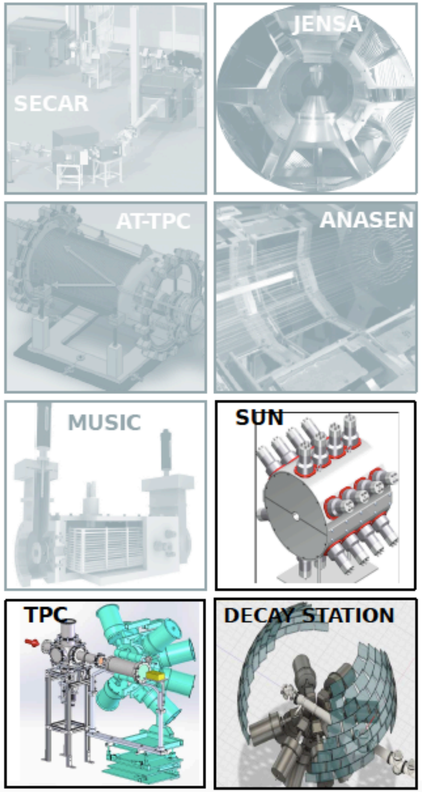
- SECAR, JENSA, AT TPC,ANASEN, MUSIC, SUN, DECAY STATION, HRS , ISLA, HELIOS, GRETINA/GRETA, HR AT TPC S800

Beams:

- ReA3 beams – ^{30}P, ^{18}F, ^{22}Mg, ^{26}Si, ^{30}S, ^{34}Ar, ^{56}Ni, ^{59}Cu, ^{45}V, ^{38}K, ^{8}B, ^{9}C, ^{13}O, ^{14}O , ^{18}Ne
- ReA6 – ReA12 beams – ^{18}F, ^{30}P, ^{38}K, ^{45}V, ^{59}Cu
- Fast beams – ^{15}O
- Stopped beams – near N=82 and N=126, Uranium

Intensities:

- Wide range of beam intensities needed depending on the experimental device



- For the most exotic nuclei, most relevant for r-process, at the lowest rates (down to << 1pps) decay techniques will be powerful for Day 1
- Decay spectroscopy, Total Absorption spectroscopy and β-Oslo yield key information
- Decay TPC for (β,p), (β,α) etc.

M. Avila, ANL & R. Surman (ND)

Nuclear Astrophysics

astrophysical conditions
dense matter properties
neutrino physics

nuclear physics inputs:
masses, halflives, reaction rates,
fission yields

Neutron stars
Astrophysics

astrophysical
simulations
+
nuclear network
calculations

contributions from
Nuclear structure
Medium mass nuclei
Heavy nuclei
Reactions

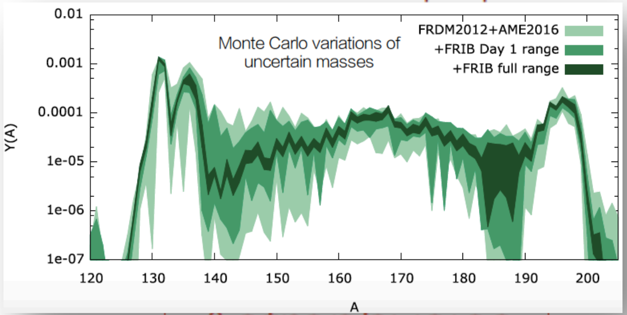
abundance pattern predictions

comparison to astrophysical
observables

R. Surman, ND

Nuclear Astrophysics

astrophysical conditions
dense matter properties

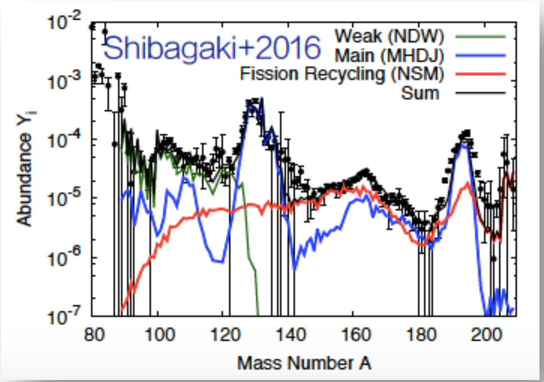


Astrophysics

nuclear physics inputs:
masses, halflives, reaction rates,
fission yields

astrophysical
simulations
+
nuclear network
calculations

contributions from
Nuclear structure
Medium mass nuclei
Heavy nuclei
Reactions



abundance pattern predictions

comparison to astrophysical
observables

R. Surman (ND)

Nuclear Astrophysics

astrophysical conditions
dense matter properties
neutrino physics

nuclear physics inputs:
masses, halflives, reaction rates,
fission yields

Neutron stars
Astrophysics

astrophysical
simulations
+
nuclear network
calculations

Unify nuclear structure and reactions; quantified beta-decay, neutron capture reactions

abundance pattern predictions

comparison to astrophysical
observables

R. Surman, ND

Nuclear Astrophysics

astrophysical conditions
dense matter properties
neutrino physics

nuclear physics inputs:
masses, halflives, reaction rates,
fission yields

astrophysical
simulations

FIRE
Fission In R-process Elements
The FIRE collaboration explores the role of fission in the rapid neutron capture or r-process of nucleosynthesis

N3AS

SciDAC proposal: TEAMS
lead P.I. R. Hix/ORNL

JINA-CEE
Center for the Evolution of the Elements

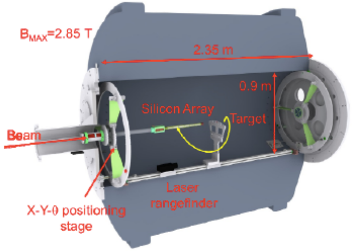
Unify nuclear structure and reactions; quantified beta-decay, neutron capture reactions

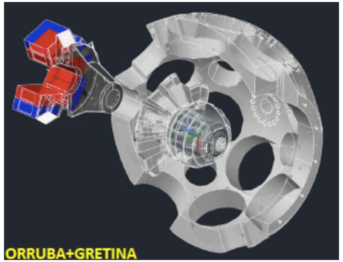
abundance pattern predictions

comparison to astrophysical observables

R. Surman, ND

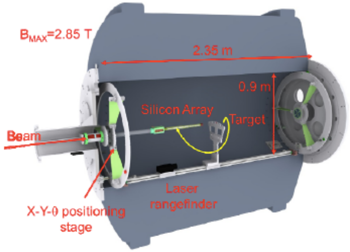
Reactions

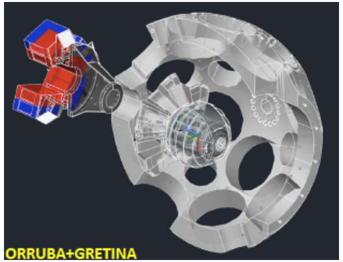




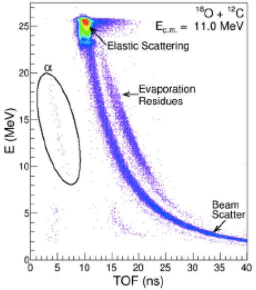
Transfer reactions with both ReA and with fast beams are of interest – i.e. (d,p) in astrophysically relevant cases.

Reactions





Transfer reactions with both ReA and with fast beams are of interest – i.e. (d,p) in astrophysically relevant cases.

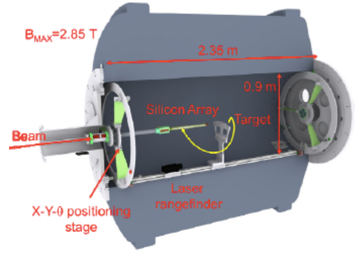


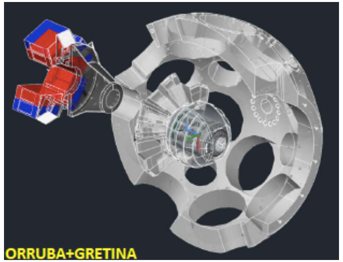
Light ion fusion at ReA3 with beam rates as low as 10^3 pps

^{16}O STABLE	^{17}O STABLE	^{18}O STABLE	^{19}O 26.88 s	^{20}O 13.51 s	^{21}O 3.42 s	^{22}O 2.25 s	^{23}O 97 ms	^{24}O 72 ms
← Reaccelerated beam →			3×10^6	2×10^6	7×10^6	1.5×10^5	1×10^4	1×10^3

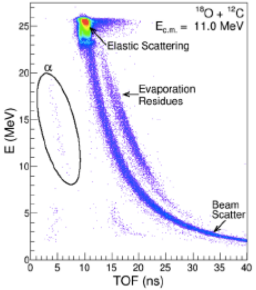
B. Charity (WashU)

Reactions

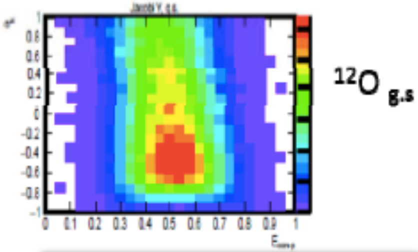




Transfer reactions with both ReA and with fast beams are of interest – i.e. (d,p) in astrophysically relevant cases.



Light ion fusion at ReA3 with beam rates as low as 10^3 pps

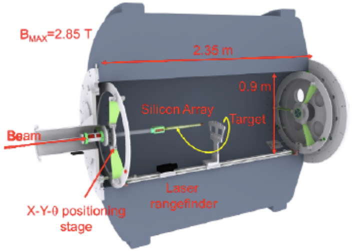


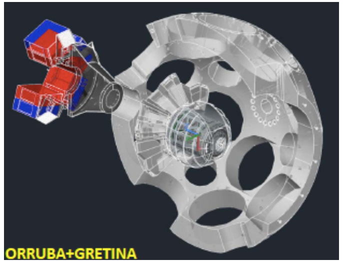
2p decay at the dripline with HIRA – use of ^{36}Ar beam!

^{16}O STABLE	^{17}O STABLE	^{18}O STABLE	^{19}O 26.88 s	^{20}O 13.51 s	^{21}O 3.42 s	^{22}O 2.25 s	^{23}O 97 ms	^{24}O 72 ms
Reaccelerated beam			3 x 10^6	2 x 10^6	7 x 10^6	1.5x10^5	1 x 10^4	1 x 10^3

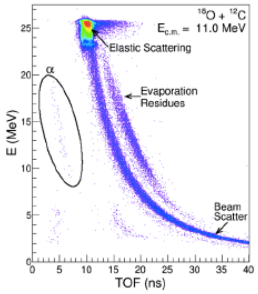
B. Charity (WashU)

Reactions



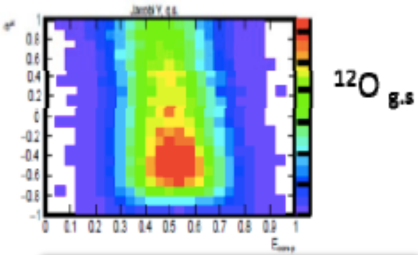


Transfer reactions with both ReA and with fast beams are of interest – i.e. (d,p) in astrophysically relevant cases.



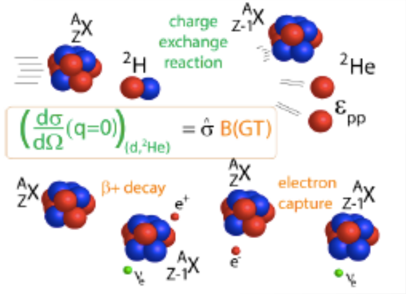
Light ion fusion at ReA3 with beam rates as low as 10^3 pps

^{16}O	^{17}O	^{18}O	^{19}O	^{20}O	^{21}O	^{22}O	^{23}O	^{24}O
STABLE	STABLE	STABLE	26.88 s	13.51 s	3.42 s	2.25 s	97 ms	72 ms
Reaccelerated beam			3 x 10^6	2 x 10^6	7 x 10^6	1.5x10^5	1 x 10^4	1 x 10^3



2p decay at the dripline with HIRA – use of ^{36}Ar beam!

CE with radioactive ions, with (d,^{2}He) in AT-TPC

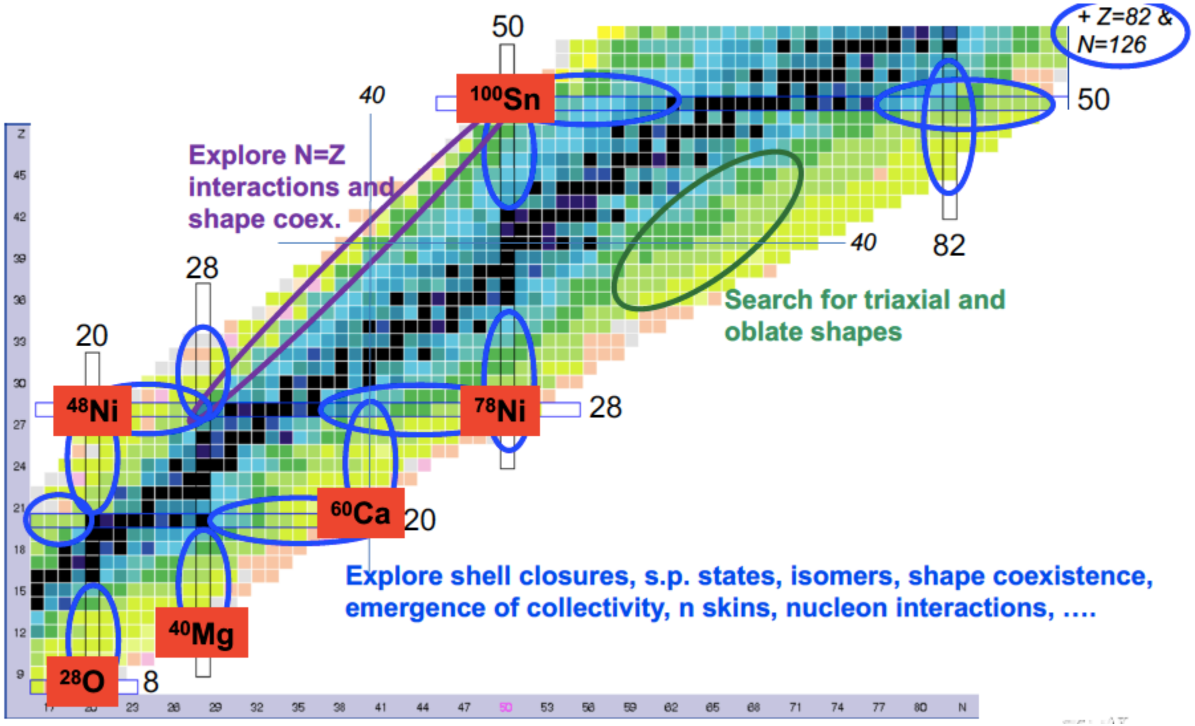


B. Charity (WashU)

Reactions

- Microscopic models are not well equipped to describe light-ion fusion – missing key ingredients like pairing – a lot of room for development
- NCSM is promising, but is still for lightest nuclei – maybe up to Ca by FRIB Day1?
- Reaction theory approaches often differ, and understanding differences between theories may provide insight
- Consistency between structure and theory calculations are needed
- Reaction theory is undermanned, and workforce is not growing at present
- To develop certain theories may require specific measurements

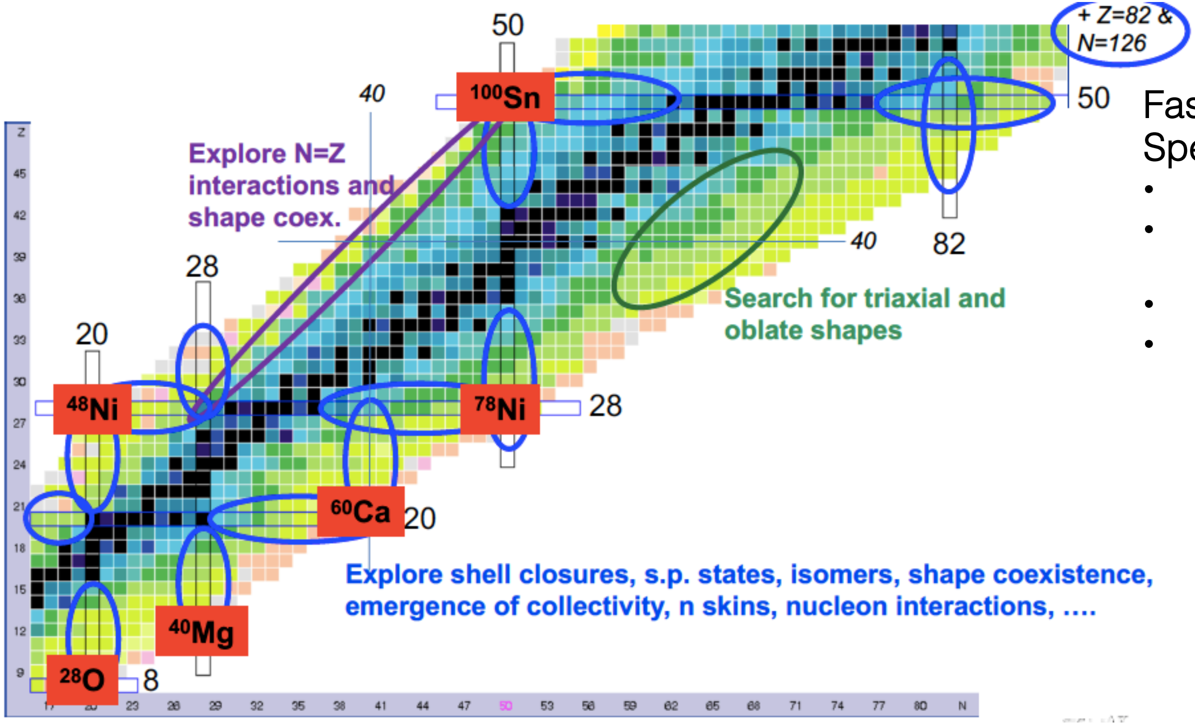
Structure



Questions of Shapes, Shape Coexistence and Shell Closures Toward the Limits

J. M. Allmond (ORNL)

Structure



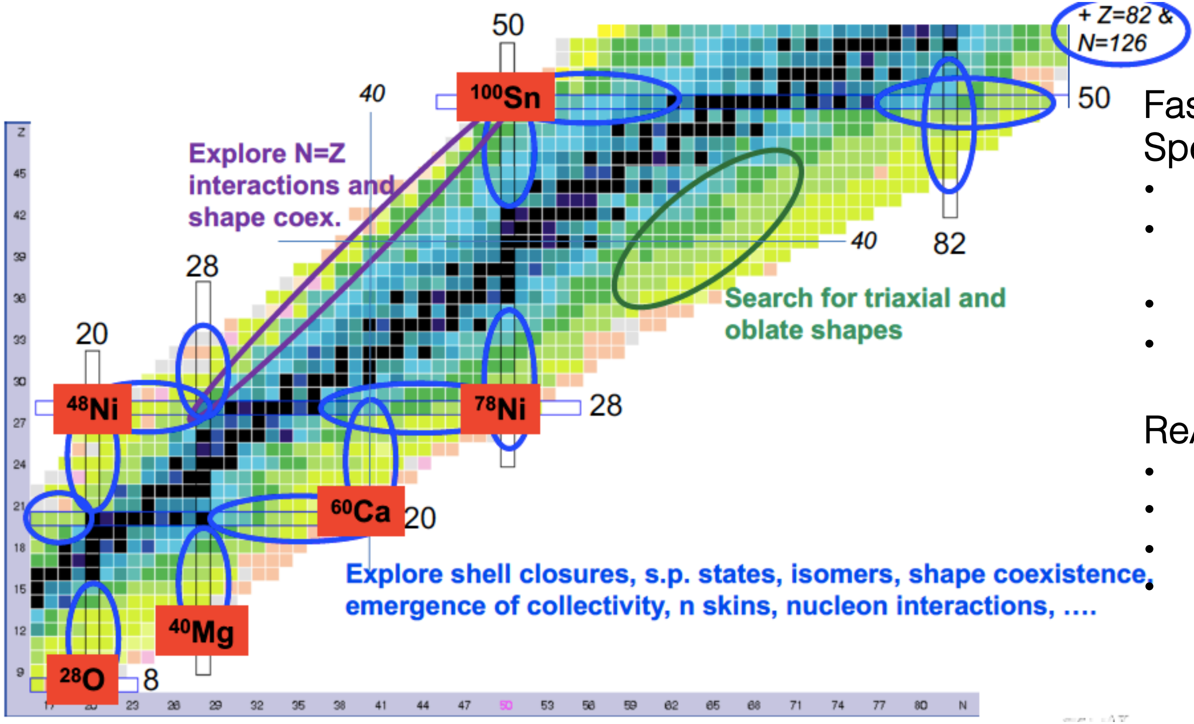
Fast Beams and In-Beam Spectroscopy

- 1n/2n knockout in ^{34}Mg, $^{29-31}Ne$
- 1p/2p knockout, Coulex for $^{52-54}Ca$ and Sc/K neighbours
- 1p/2p knockout around ^{78}Ni
- Coulex of ^{102}Sn

Questions of Shapes, Shape Coexistence and Shell Closures Toward the Limits

J. M. Allmond (ORNL)

Structure



Fast Beams and In-Beam Spectroscopy

- 1n/2n knockout in ^{34}Mg, $^{29-31}$Ne
- 1p/2p knockout, Coulex for $^{52-54}$Ca and Sc/K neighbours
- 1p/2p knockout around ^{78}Ni
- Coulex of ^{102}Sn

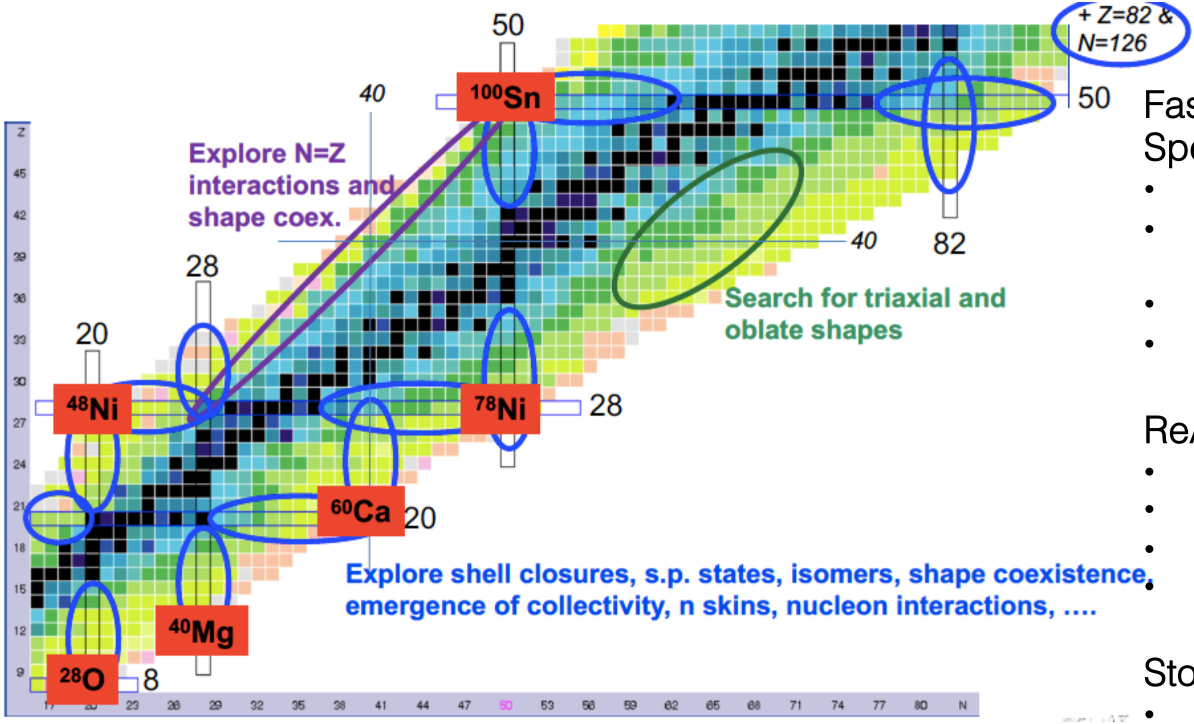
ReA Beams

- Coulex in IoI at N=20
- Transfer (t,p) on ^{31}Mg
- Coulex to ^{50}Ca; (d,p) transfer
- Coulex of neutron-deficient Sn

Questions of Shapes, Shape Coexistence and Shell Closures Toward the Limits

J. M. Allmond (ORNL)

Structure



Questions of Shapes, Shape Coexistence and Shell Closures Toward the Limits

Fast Beams and In-Beam Spectroscopy

- 1n/2n knockout in ^{34}Mg, $^{29-31}Ne$
- 1p/2p knockout, Coulex for $^{52-54}Ca$ and Sc/K neighbours
- 1p/2p knockout around ^{78}Ni
- Coulex of ^{102}Sn

ReA Beams

- Coulex in IoI at N=20
- Transfer (t,p) on ^{31}Mg
- Coulex to ^{50}Ca; (d,p) transfer
- Coulex of neutron-deficient Sn

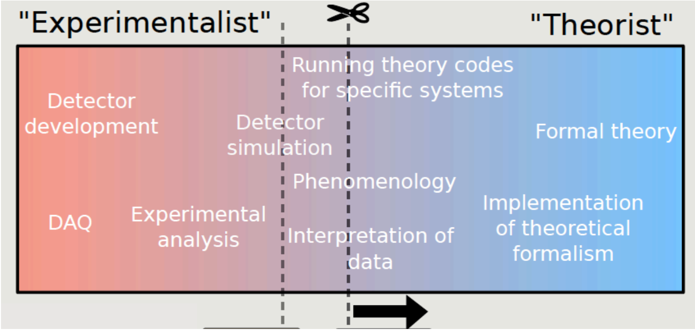
Stopped

- Decay spectroscopy in all regions
- Laser spectroscopy (hyperfine splitting, moments)
- Mass measurements

J. M. Allmond (ORNL)

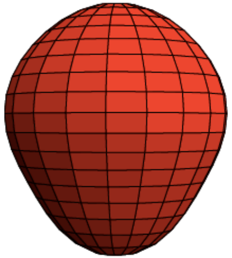
Structure

- *Quantified Theoretical Uncertainties and Consistency!*
- Comparison to experiment without uncertainties isn't necessarily informative
- To fully interpret data, (i.e. knockout or transfer) need a consistent framework for bound state, resonance structure and reactions
- Consistency in single-particle and collective excitation descriptions



S. R. Stroberg (TRIUMF/Reed)

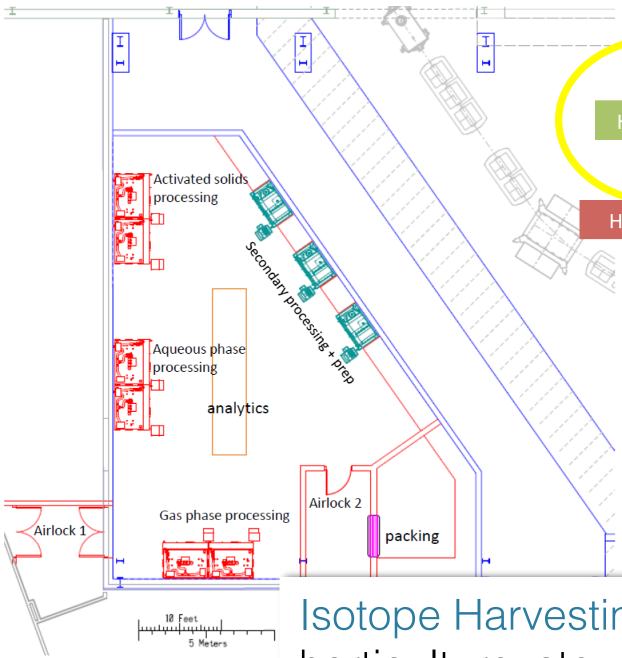
Fundamental Symmetries

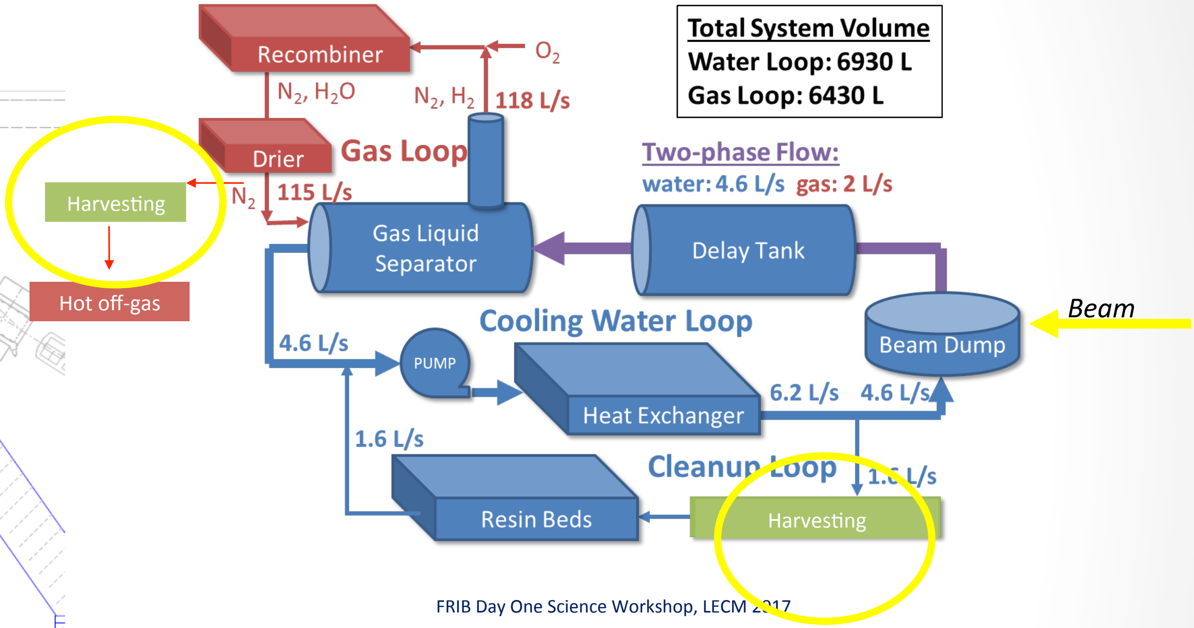


- FRIB can both potentially make directly relevant measurements and provide data to support theory for interpreting other experiments
- EDM searches require nuclear structure knowledge – i.e. constrain matrix elements in ^{225}Ra, or other candidate nuclei as input to theory
- Theory must also develop, focus on ab-initio β-decay matrix elements, Schiff and anapole moments etc.
- Directly, FRIB with Isotope Harvesting may provide other EDM candidates – ^{229}Pa
- Day 1 will allow characterization nuclear structure measurements on candidates and development of experimental techniques

J. Singh (MSU) & J. Engel (UNC)

Applications





Isotope Harvesting will provide a mechanism for applications (medicine, horticulture, stewardship etc.) and a resource to basic research.

^{211}At is a compelling case where FRIB can enable critical applied research for therapeutic use.

G. Severin (MSU)

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS

⇒ "Experiments can fail because of physics, not because of technical issues"

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS
  - ⇒ "Experiments can fail because of physics, not because of technical issues"
- We are not alone; there is international effort in low-energy nuclear physics, and we should consider what is likely to be done, or is better done at another facility.

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS
  - ⇒ “Experiments can fail because of physics, not because of technical issues”
- We are not alone; there is international effort in low-energy nuclear physics, and we should consider what is likely to be done, or is better done at another facility.
- Beam lines are not unlimited. We should be planning to move equipment around the facility as necessary.

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS
  - ⇒ "Experiments can fail because of physics, not because of technical issues"
- We are not alone; there is international effort in low-energy nuclear physics, and we should consider what is likely to be done, or is better done at another facility.
- Beam lines are not unlimited. We should be planning to move equipment around the facility as necessary.
- ReA3, ReA6 (and even beyond) beams are clearly going to be in demand, and fast beams present unique opportunities for FRIB Day 1

A Few Observations

- Much of the equipment for Day 1 is well-established, but a few newer devices were highlighted, e.g. SECAR, SOLARIS
  - ⇒ "Experiments can fail because of physics, not because of technical issues"
- We are not alone; there is international effort in low-energy nuclear physics, and we should consider what is likely to be done, or is better done at another facility.
- Beam lines are not unlimited. We should be planning to move equipment around the facility as necessary.
- ReA3, ReA6 (and even beyond) beams are clearly going to be in demand, and fast beams present unique opportunities for FRIB Day 1
- Change in sociology needed? *This might be happening naturally…*

A Few (More) Observations

- A consistent framework for structure and reaction theory will benefit multiple experiment types interpretation and maximize physics

A Few (More) Observations

- A consistent framework for structure and reaction theory will benefit multiple experiment types interpretation and maximize physics
- Theoretical uncertainties are a priority

A Few (More) Observations

- A consistent framework for structure and reaction theory will benefit multiple experiment types interpretation and maximize physics
- Theoretical uncertainties are a priority
- Theory requires, or may require in the future, specific measurements to address certain hurdles – need to determine a way to prioritize such experiments

A Few (More) Observations

- A consistent framework for structure and reaction theory will benefit multiple experiment types interpretation and maximize physics
- Theoretical uncertainties are a priority
- Theory requires, or may require in the future, specific measurements to address certain hurdles – need to determine a way to prioritize such experiments

Thank you all for a constructive workshop!

This was a great step in planning for optimizing FRIB Day 1 Science, let's not lose momentum!