Argonne **I**n-Flight **R**adioactive **I**on **S**eparator

AIRIS

www.phy.anl.gov/airis

B. B. Back, C. Dickerson, C. R. Hoffman, B. P. Kay, **B. Mustapha**,
J. A. Nolen, P. Ostroumov, R. C. Pardo, K. E. Rehm, G. Savard,
J. P. Schiffer, D. Seweryniak – Argonne National Laboratory

S. Manikonda, M. Alcorta – Former Collaborators

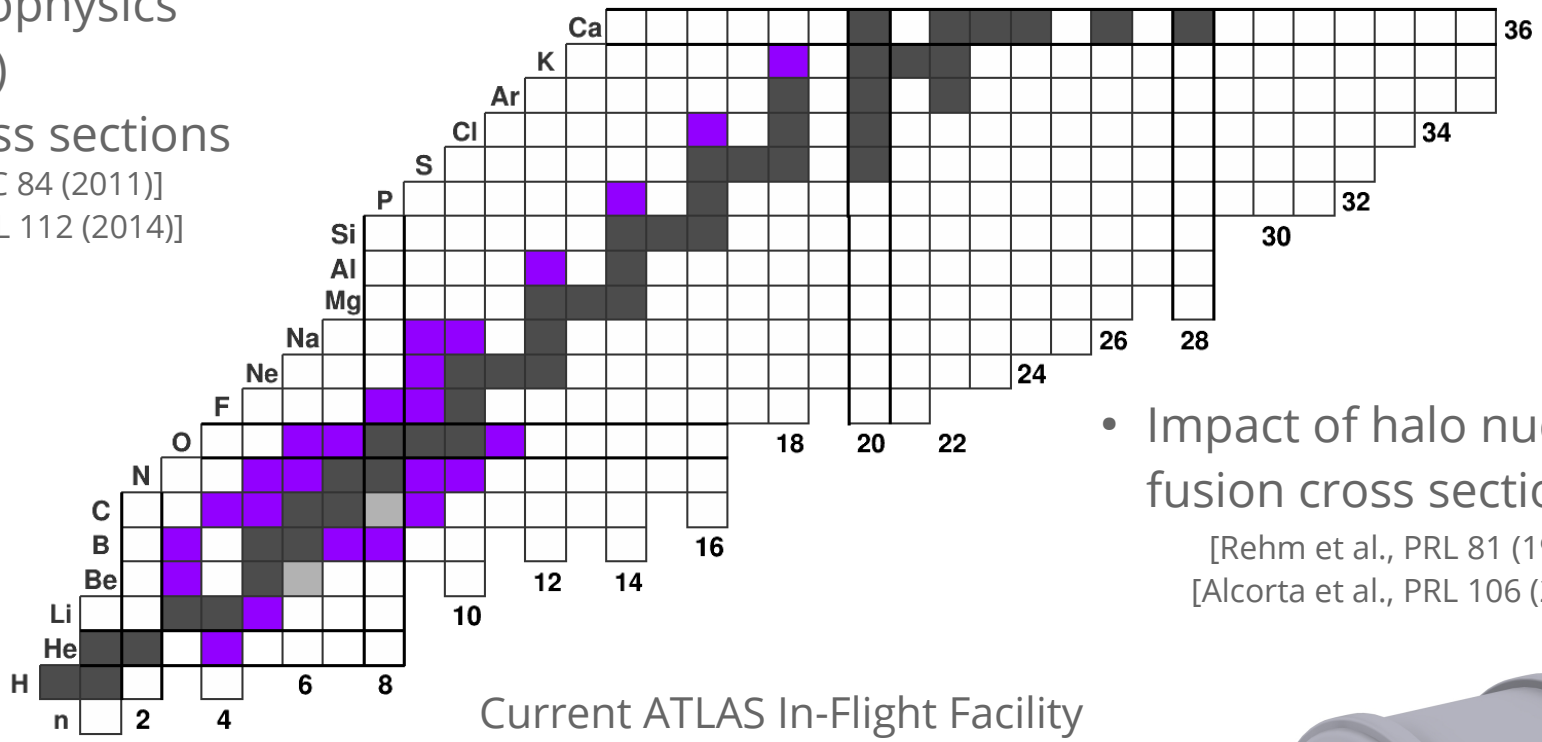
U.S. DEPARTMENT OF ENERGY | Office of Science

Argonne NATIONAL LABORATORY | Physics Division

ATLAS In-Flight Radioactive Beam Program

- Nuclear astrophysics
  - (α,p) & (p,γ)
  - Fusion cross sections

[Deibel et al., PRC 84 (2011)]
[Carnelli et al., PRL 112 (2014)]



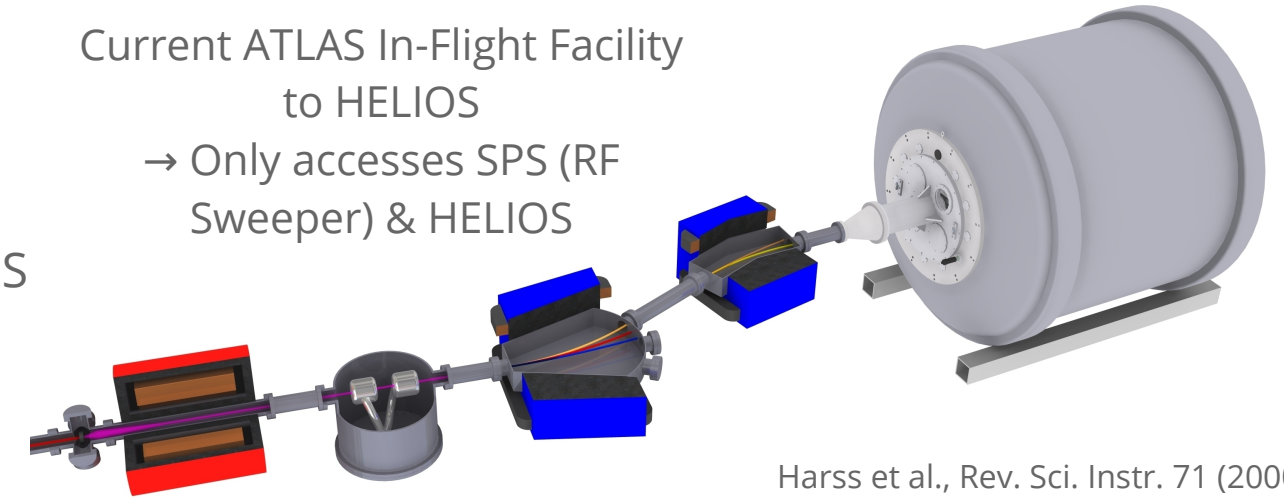
- Impact of halo nuclei on fusion cross sections

[Rehm et al., PRL 81 (1998)]
[Alcorta et al., PRL 106 (2011)]

- Single-particle structure
  - (d,p) & (d,^{3}He), etc. w/ HELIOS

[Back et al., PRL (2010)]
[Bedoor et al., PRC (R) (2013)]

Current ATLAS In-Flight Facility to HELIOS
→ Only accesses SPS (RF Sweeper) & HELIOS



Harss et al., Rev. Sci. Instr. 71 (2000)

Figure: DiGiovine

Motivation for ATLAS Separator Upgrade

- The community has presented strong support for the expanded availability of intense radioactive ion beams at appropriate energies for certain classes of measurements
  - 2007 NSAC Long Range Plan, The Science of the Rare Isotope Accelerator (RIA) Brochure, recommendation from the most recent ATLAS review committee, etc.

- Enhance the physics reach of ATLAS for a modest investment
  - Build upon current success of ATLAS In-Flight programs
  - Impact many aspects of nuclear physics → astrophysics, single-particle structure, reactions, pairing, collective structures etc.
  - Complementary to measurements with more exotic beams at higher energies e.g. varying reaction mechanisms & techniques

- Research based on these radioactive beams at low-energy will provide a clear path for the physics and technical developments leading to reaccelerated beams at FRIB

Answering Questions of Limitation

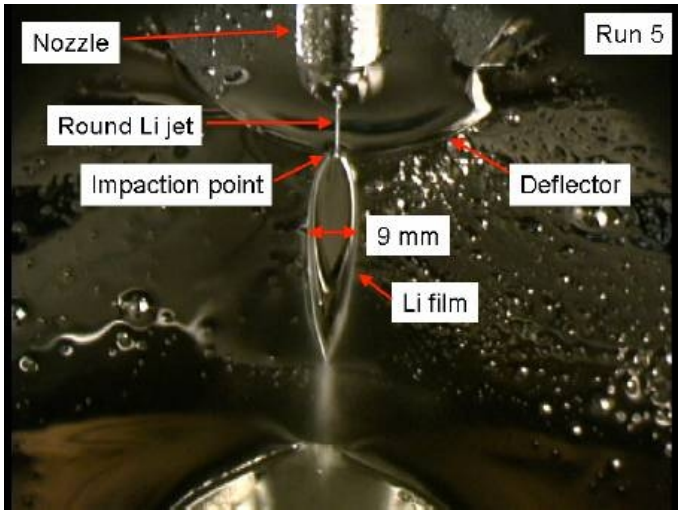
Accessibility

- Limited to the HELIOS and SPS experimental areas → Placement of dedicated separator (AIRIS) before switching magnet(s)

Intensity

- Transmission → Dedicated separator – AIRIS (Magnetic chicane and buncher/rebuncher cavity)
- ATLAS intensity upgrade → Completed!
- Durable targets → Liquid film & rotating targets

Liquid Film Target

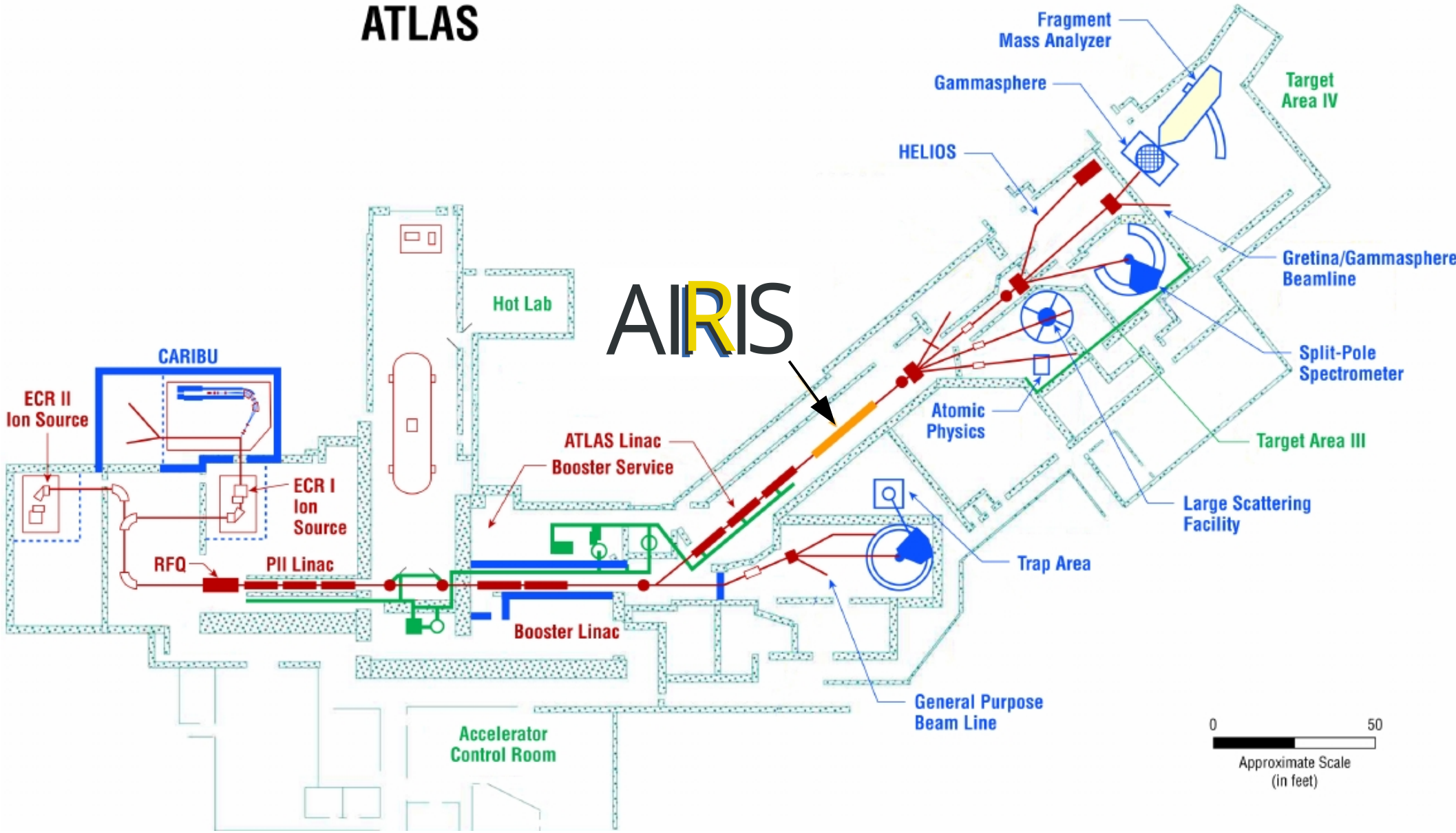


Nolen et al.,

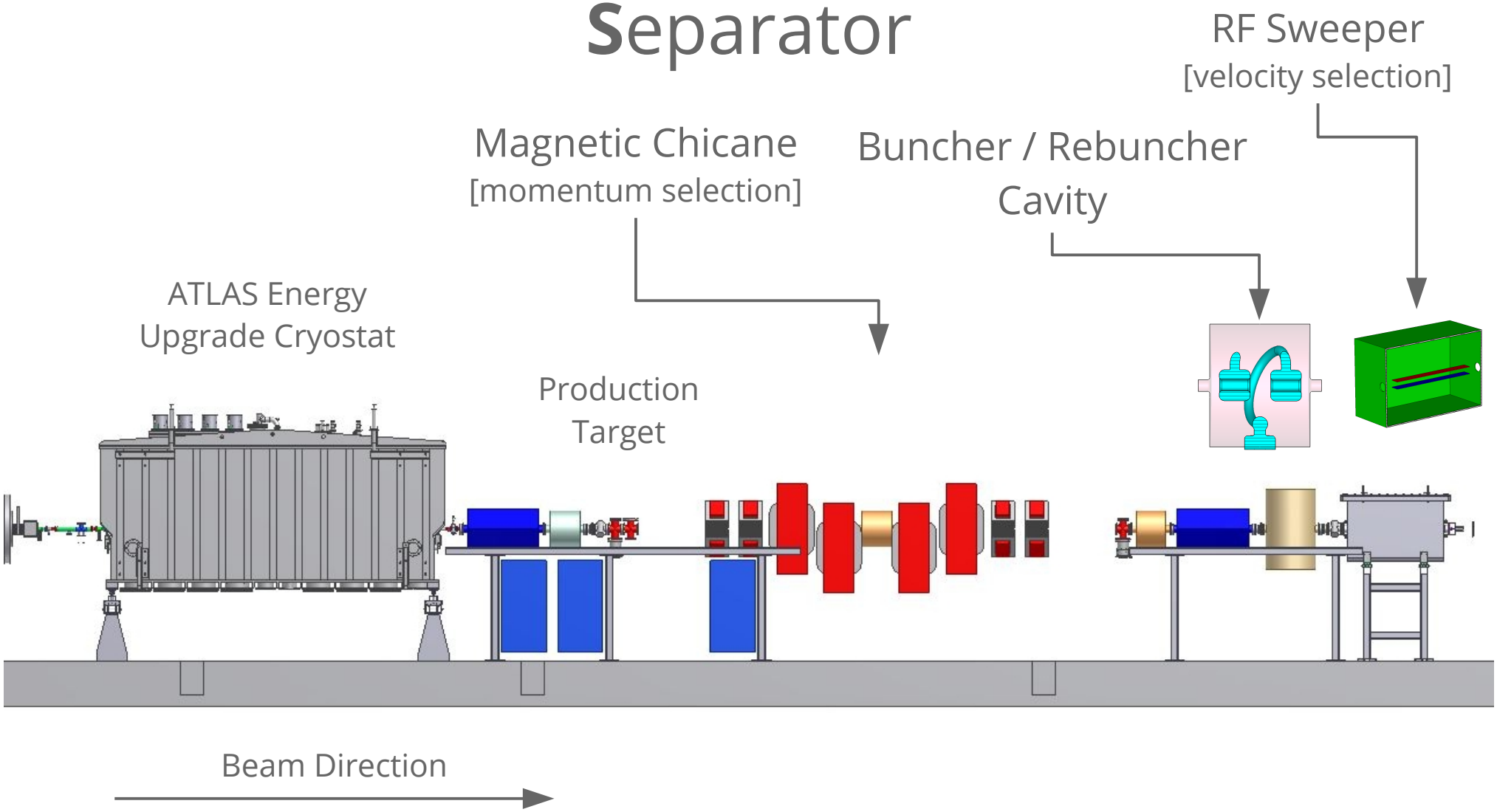
Selection & Reach

- Extend reach of in-flight beams by mass and N/Z ratio → AIRIS (Magnetic chicane, buncher/rebuncher and RF Sweeper)
- Removal of contaminants in secondary in-flight beams → AIRIS (Magnetic chicane and RF sweeper)

ATLAS


Fragment
Mass Analyzer
Gammasphere
Target
Area IV
HELIOS
Gretina/Gammasphere
Beamline
AIRIS
Hot Lab
CARIBU
ECR II
Ion Source
Split-Pole
Spectrometer
Atomic
Physics
ATLAS Linac
Booster Service
Target Area III
ECR I
Ion
Source
Large Scattering
Facility
RFQ
PII Linac
Trap Area
Booster Linac
General Purpose
Beam Line
Accelerator
Control Room
0
50
Approximate Scale
(in feet)

AIRIS – **A**rgonne **I**n-Flight **R**adioactive **I**on **S**eparator



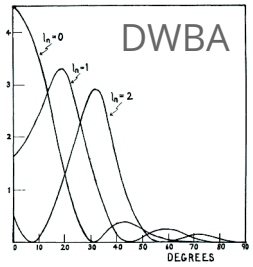
www.phy.anl.gov/airis/design.html

Figures: Al, Brahim, and others.

AIRIS Design & Transmission Calculations

Focus on largest recoil transmission while highly suppressing (>10^{-6}) unreacted and scattered primary beam

A(b,c)D +



→ LISE++ → Energy, Angle, Position

Tarasov & Bazin

<u>Reactions</u>

- ~15 secondary beams from various types of reactions
- ~5 different targets, ~10-15 MeV/u beam energies

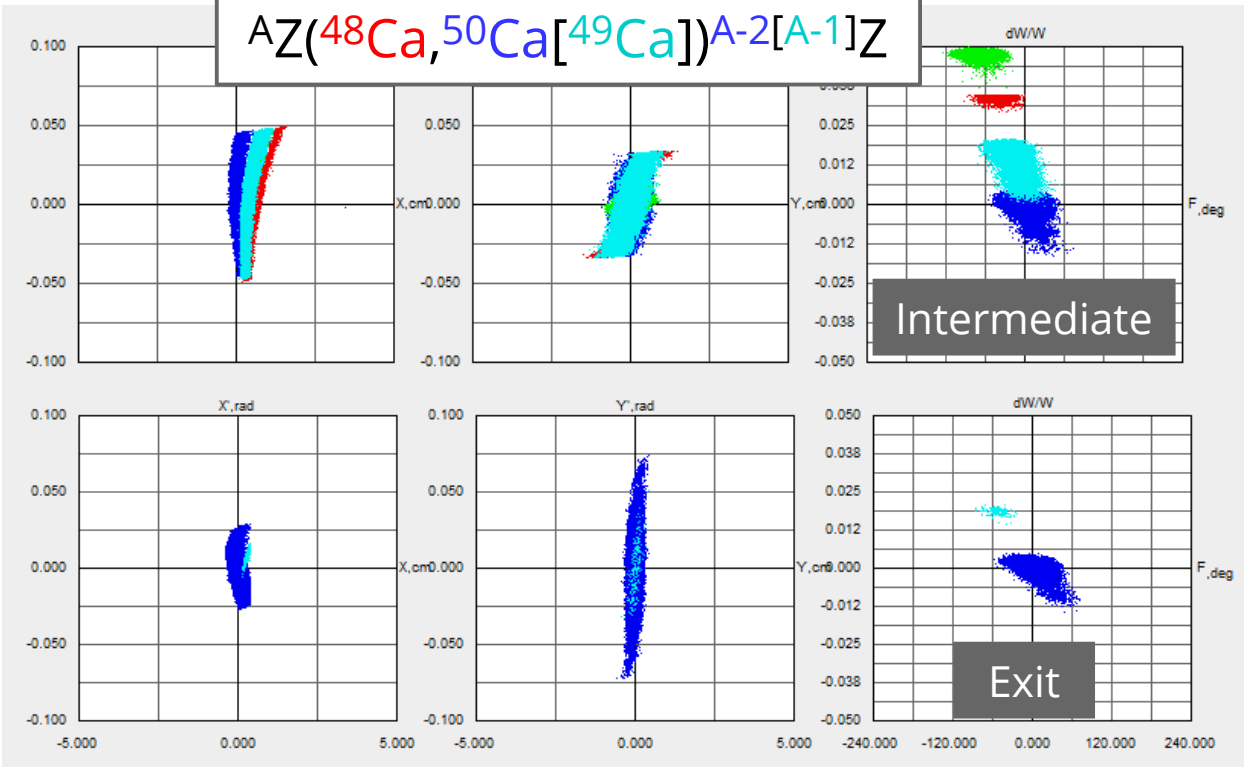
<u>Kinematics Calculations</u>

- Target scattering & straggling

<u>Beam Optics in TRACK</u>

- high-order beam optics calculations
- Checks w/ realistic 3-D fields
- Includes rebuncher and RF sweeper

$^{A}Z(^{48}Ca,^{50}Ca[^{49}Ca])^{A-2}[^{A-1}]Z$



Mustapha

See PTOLEMY, LISE++, TRACK web sites on final slide

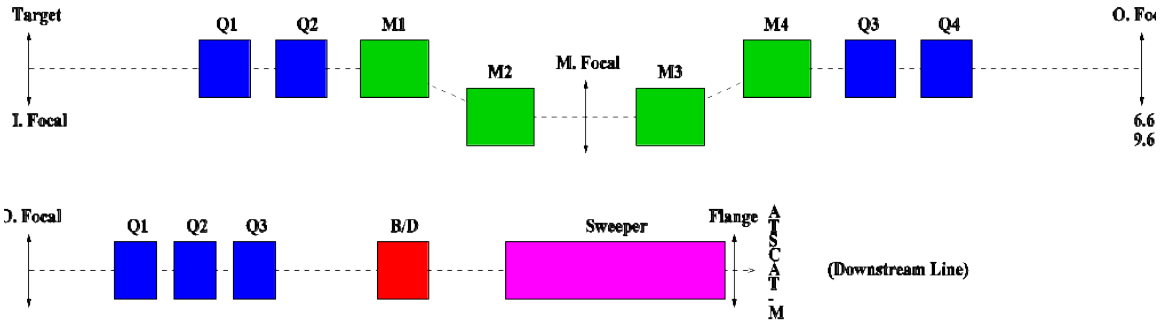
AIRIS Design & Transmission Calculations

Momentum Chicane Parameters		
Dipole Bend Angle	22.5	deg
Dipole Maximum Rigidity	1.75	Tm
Dipole Full Gap	8	cm
Quad Length	30	cm
Quad Maximum Field	1	T
Quad Full Aperture	15	cm

AIRIS General Parameters		
Total Length	~11	m
Angular Acceptance	75	mrad
Dispersion at midplane	1.2	mm/%
Magnification at midplane	< 1	
Momentum Acceptance	<20	%

Buncher / Rebuncher Parameters (Slit-Ring)		
Aperture	3.8	cm
Frequency	97	MHz
Maximum Voltage	1.5	MV

RF Sweeper Parameters		
Electrode length	1	m
Frequency	6.0625	MHz
Maximum Voltage	70	kV

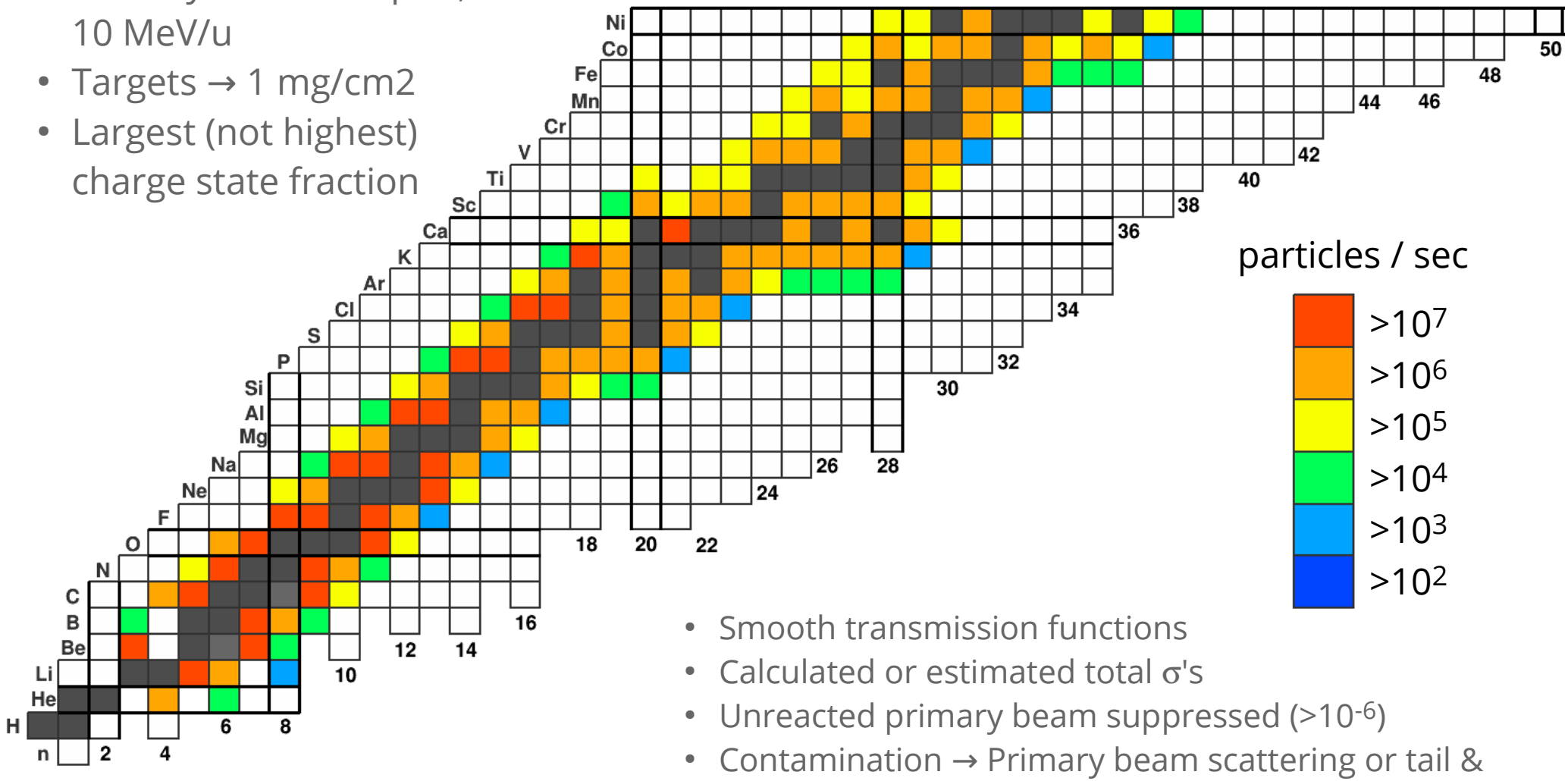


www.phy.anl.gov/airis/design.html

Estimated Beam Rates at AIRIS Exit

- Primary beam → 1 puA, 10 MeV/u
- Targets → 1 mg/cm2
- Largest (not highest) charge state fraction

Up to x10 uncertainty in rate estimates

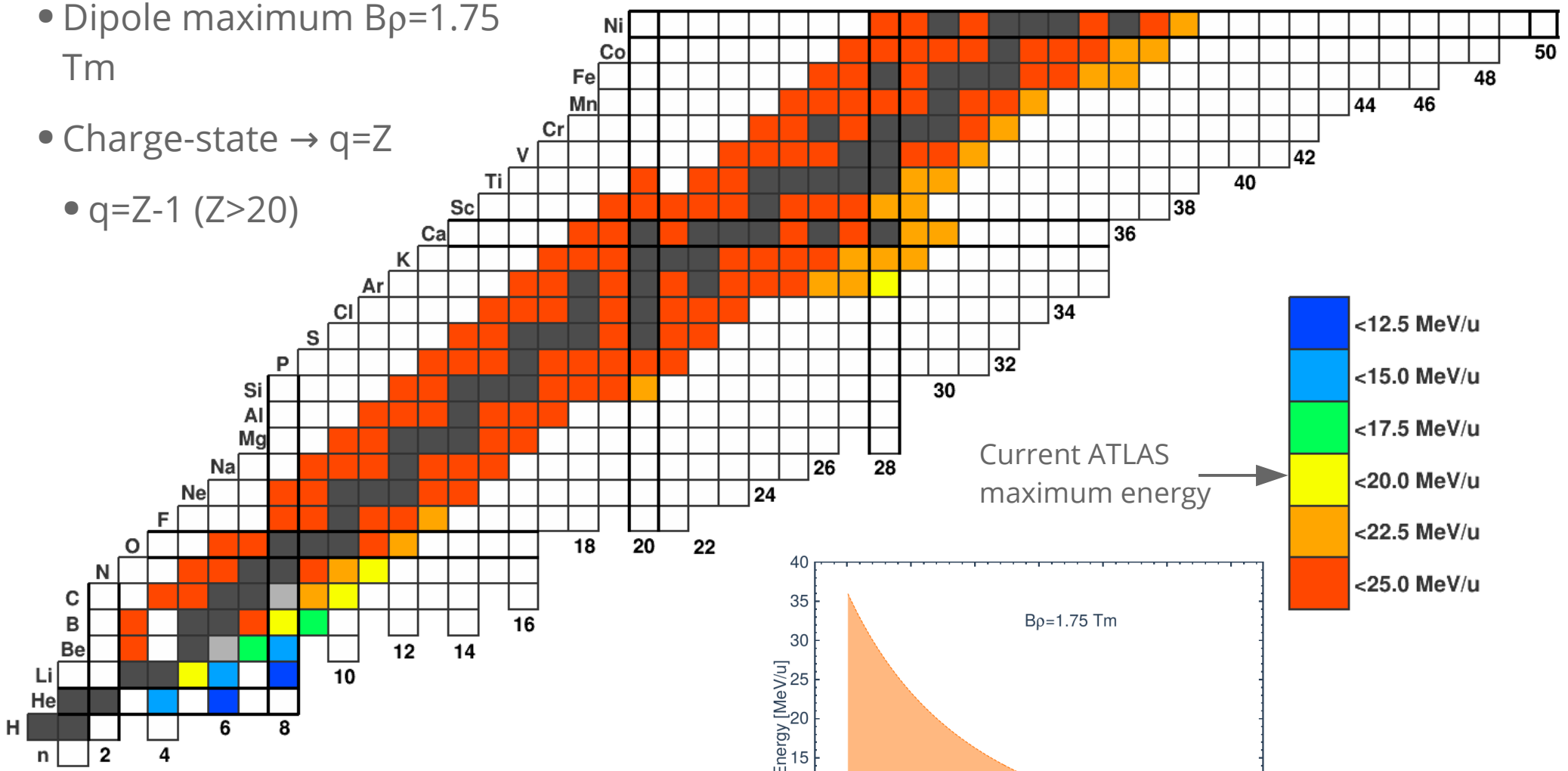


- Smooth transmission functions
- Calculated or estimated total σ's
- Unreacted primary beam suppressed (>10^{-6})
- Contamination → Primary beam scattering or tail & other reaction channels
- > 25% transported to experimental areas

www.phy.anl.gov/airis/rates.html

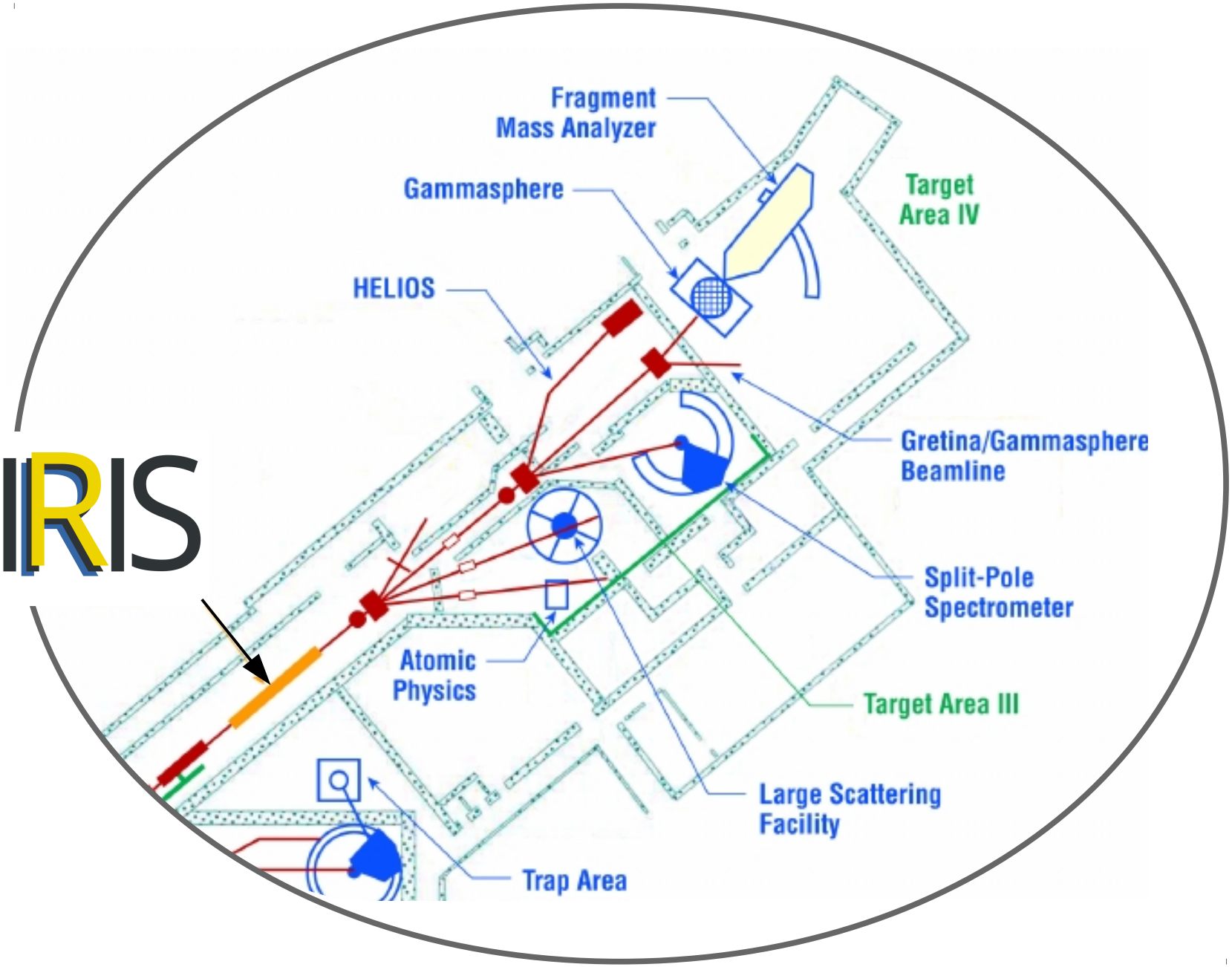
Maximum Recoil Energies Available

- Dipole maximum Bρ=1.75 Tm
- Charge-state → q=Z
  - q=Z-1 (Z>20)



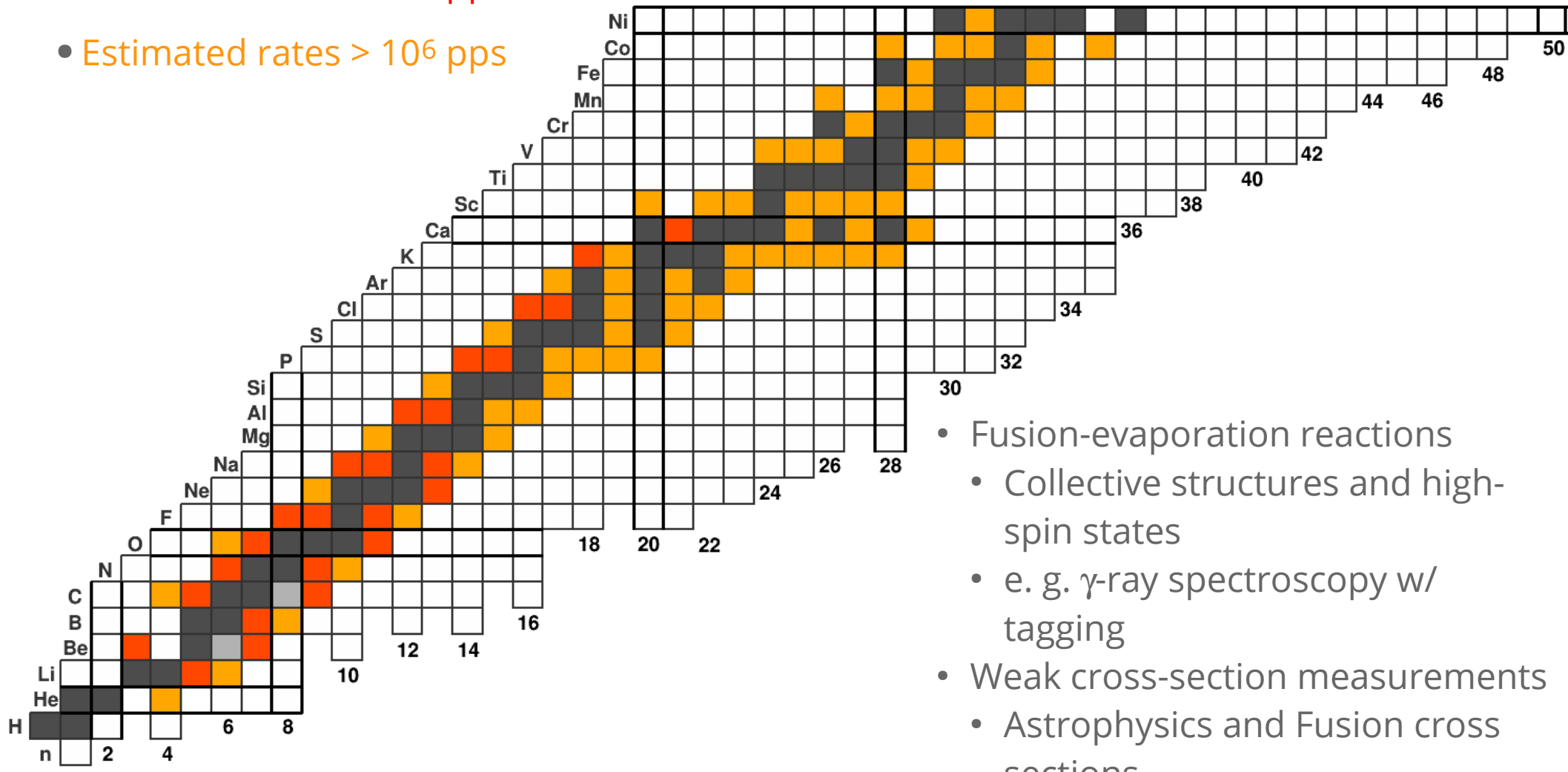
Current ATLAS maximum energy

AIRIS


Fragment
Mass Analyzer
Gammasphere
HELIOS
Target
Area IV
Gretina/Gammasphere
Beamline
Split-Pole
Spectrometer
Atomic
Physics
Target Area III
Large Scattering
Facility
Trap Area

Physics Opportunities with AIRIS Beams

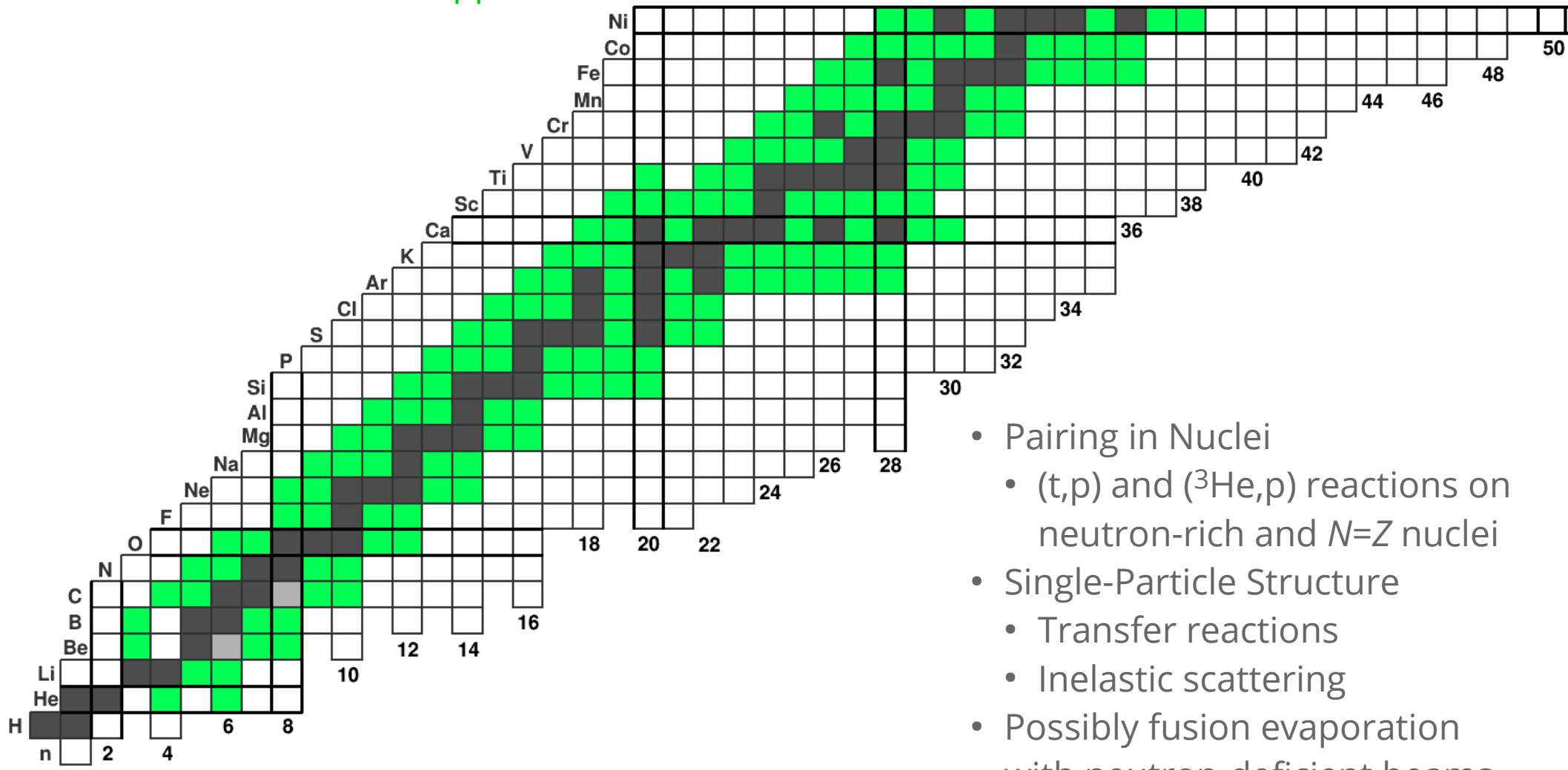
- Estimated rates > 10^7 pps
- Estimated rates > 10^6 pps



- Fusion-evaporation reactions
  - Collective structures and high-spin states
  - e. g. γ-ray spectroscopy w/ tagging
- Weak cross-section measurements
  - Astrophysics and Fusion cross sections
  - Transfer and fusion reactions

Physics Opportunities with AIRIS Beams

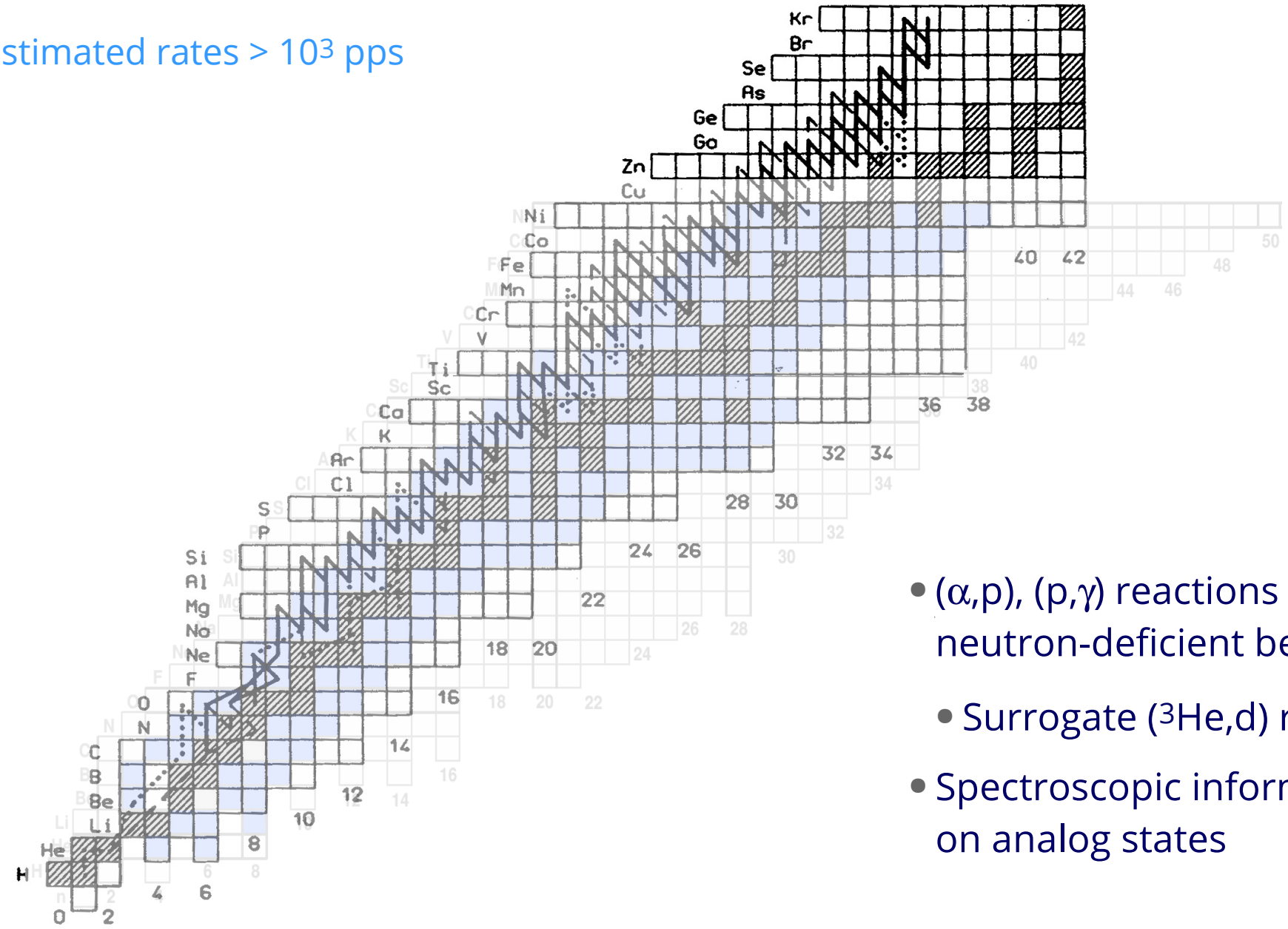
- Estimated rates > 10^4 pps



- Pairing in Nuclei
  - (t,p) and (^{3}He,p) reactions on neutron-rich and *N*=*Z* nuclei
- Single-Particle Structure
  - Transfer reactions
  - Inelastic scattering
- Possibly fusion evaporation with neutron-deficient beams
  - ^{38}Ca, ^{42}Ti, ^{56}Ni, (^{60}Zn) etc.

Astrophysics Opportunities with AIRIS

- Estimated rates > 10^3 pps

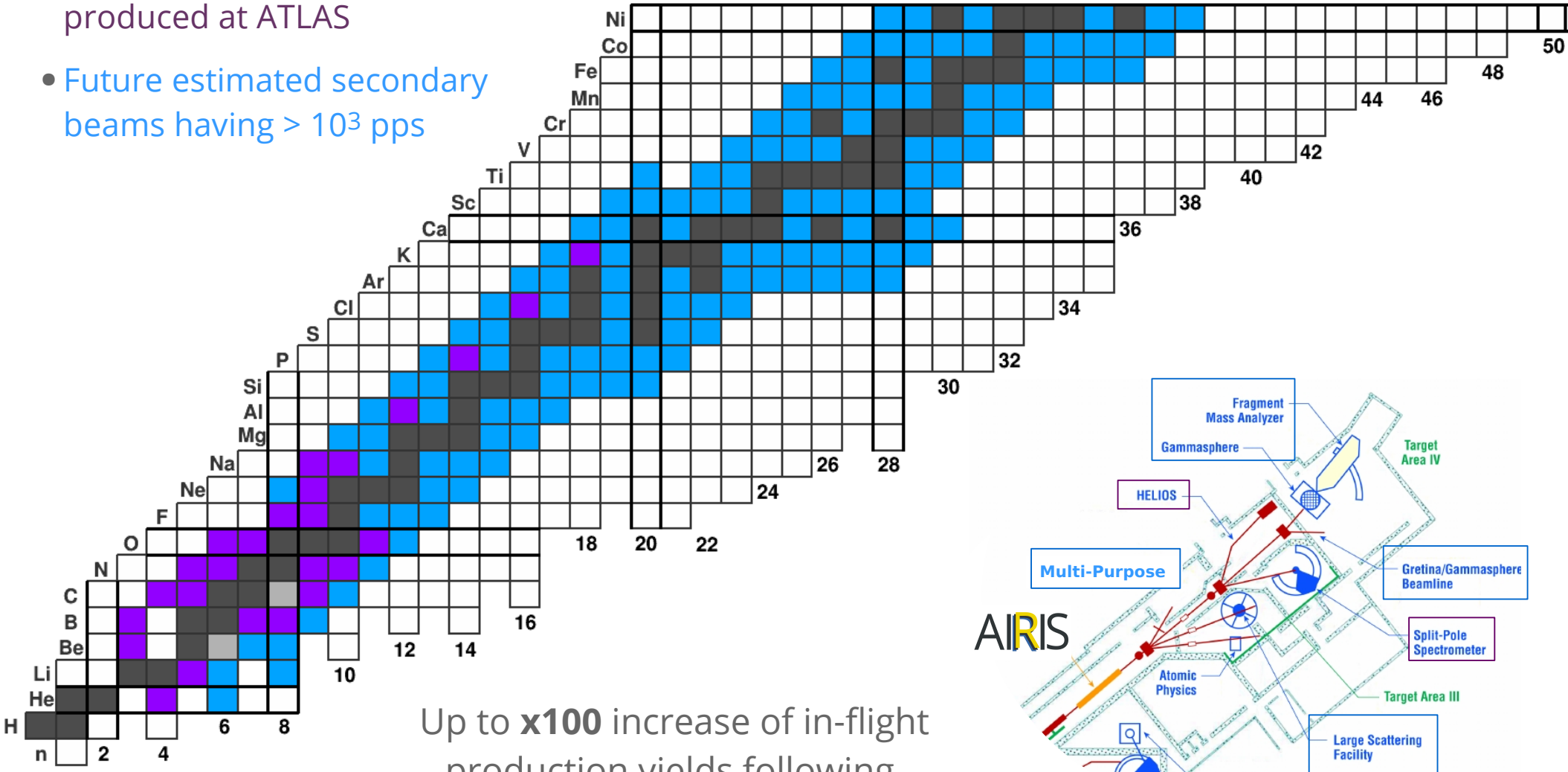


- (α,p), (p,γ) reactions on neutron-deficient beams
  - Surrogate (^{3}He,d) reaction
- Spectroscopic information on analog states

Schatz et al.,(1998, 1999, 2001), Jose et al., NPA 777 (2006), Hale et al., Phys. Rev. C 70 (2004)

Expansion of ATLAS In-Flight Program

- In-Flight beams previously produced at ATLAS
- Future estimated secondary beams having > 10^3 pps



Up to **x100** increase of in-flight production yields following facility upgrades

Conclusions

- AIRIS provides an excellent opportunity to expand the availability of radioactive in-flight beams in an energy region of great interest to the nuclear physics community
  - Improves and extends the Accessibility, Intensity, Selection & Reach of ATLAS In-Flight Radioactive Beams

Project Outline

- Proposal: Under preparation, and will be strongly guided by input from Users Meeting
- Project completion goal: 2016 – 2017
- Cost: ~$2 Million

- **Need input from the LE community!**
  - **What are the beam species, energies, and purities that are needed?**
  - **What experimental equipment needs to be made accessible?**
  - **Other comments, questions, or thoughts…**

Points of Contact & Information

- Web site: www.phy.anl.gov/airis
- Contacts: www.phy.anl.gov/airis/contacts.html
- Email: Calem Hoffman – crhoffman@phy.anl.gov

AIRIS

- PTOLEMY: www.phy.anl.gov/theory/ptolemy
- LISE++: lise.nscl.msu.edu
- TRACK: www.phy.anl.gov/atlas/TRACK