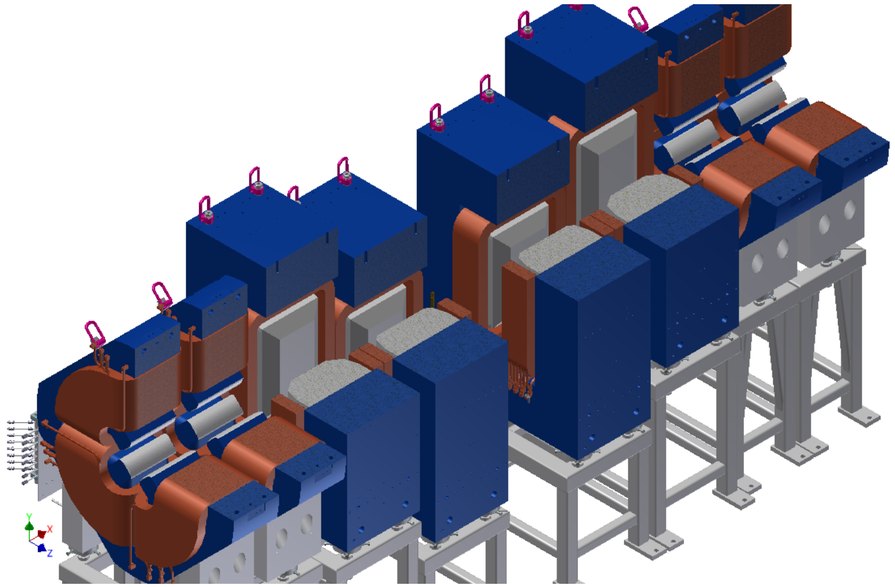

CHARACTERISTICS OF AVAILABLE AND EXPECTED IN-FLIGHT BEAMS WITH RAISOR

CALEM R HOFFMAN
Physics Division
Argonne National Laboratory
crhoffman@anl.gov

ACKNOWLEDGEMENTS

An encompassing project / operation intertwining numerous areas of expertise

RAISOR experimental support: **Gemma Wilson**, Ryan Tang, Jie Chen

Melina Avila, Martin Alcorta, Birger Back, Al Barcikowski, Bob Bertrand, Ben Blomberg, Grant Bilbrough, Glenn Cherry, Andrew Cravatta, **Clay Dickerson**, Bela Erdelyi, Alex Grabenhoffer, Arnold Germain, Matt Gott, John Greene, Matt Hendricks , Mark Hetherington, Calem Hoffman, Bill Jansma, Ben Kay, Tony Krupa, Ling-Ying Lin, Yong Luo, Sashi Manikonda, AJ Mattillion, Brahim Mustapha, Jerry Nolen, Peter Ostroumov, Richard Pardo, Nick Pastore, Chris Peters, Maria Power, Ernst Rehm, John Rohrer, Daniel Santiago, Guy Savard, John Schiffer, Derek Seweryniak, Sergey Sharamentov, Eric Swanson, Gary Zinkann, Gavin, Nicole, Lee, Dan, Jason, Ivan

- SCIENTIFIC RESEARCH STAFF
- ATLAS OPERATIONS
- TECHNICAL SUPPORT MEMBERS
- USER COMMUNITY INPUT

DOE OFFICE OF SCIENCE NP

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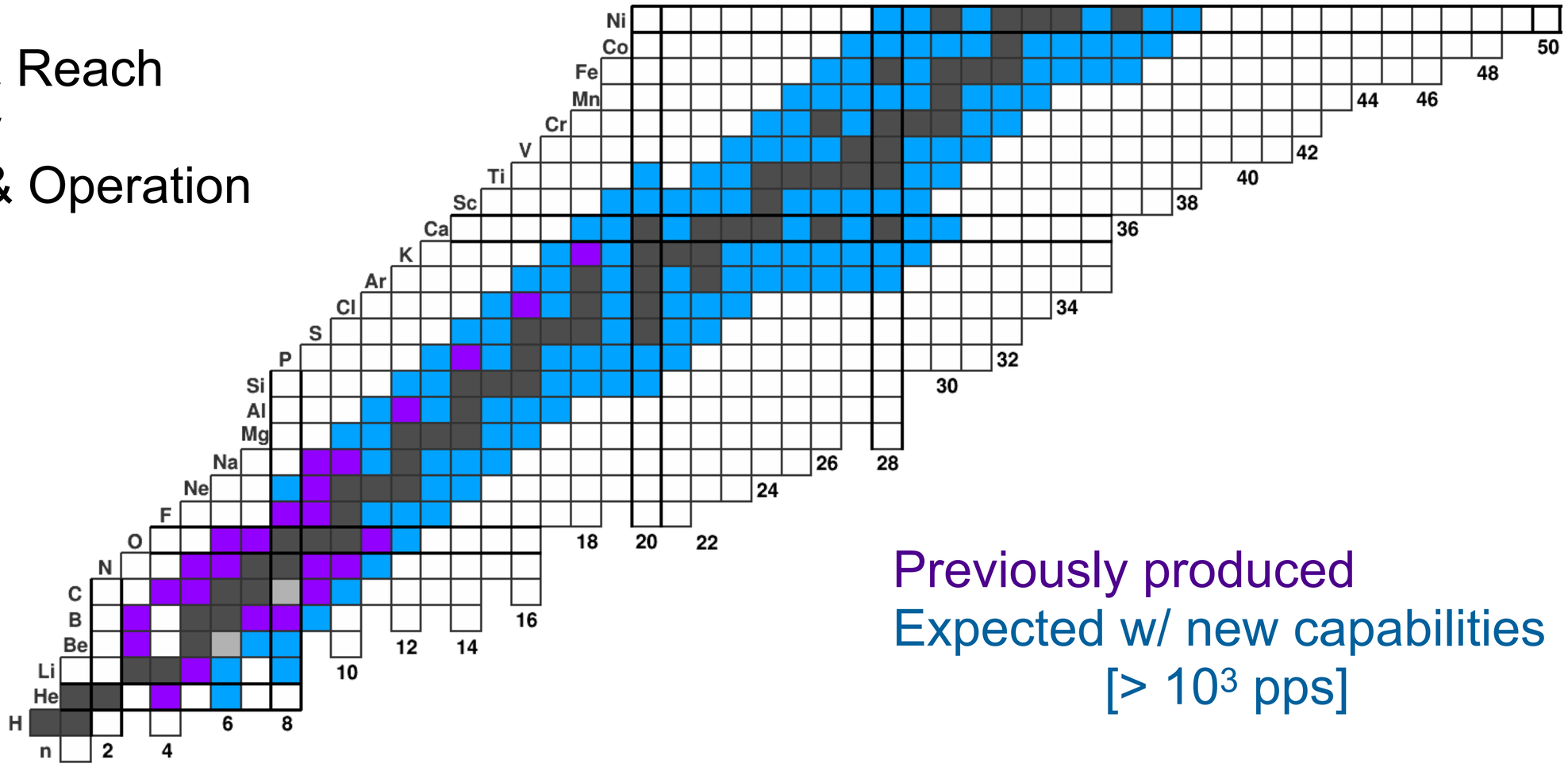
UPGRADING THE IN-FLIGHT CAPABILITIES AT ATLAS

Leverage the facilities experience & past successes

Improvement in numerous areas:

- Intensity
- Selectivity & Reach
- Accessibility
- Integration & Operation



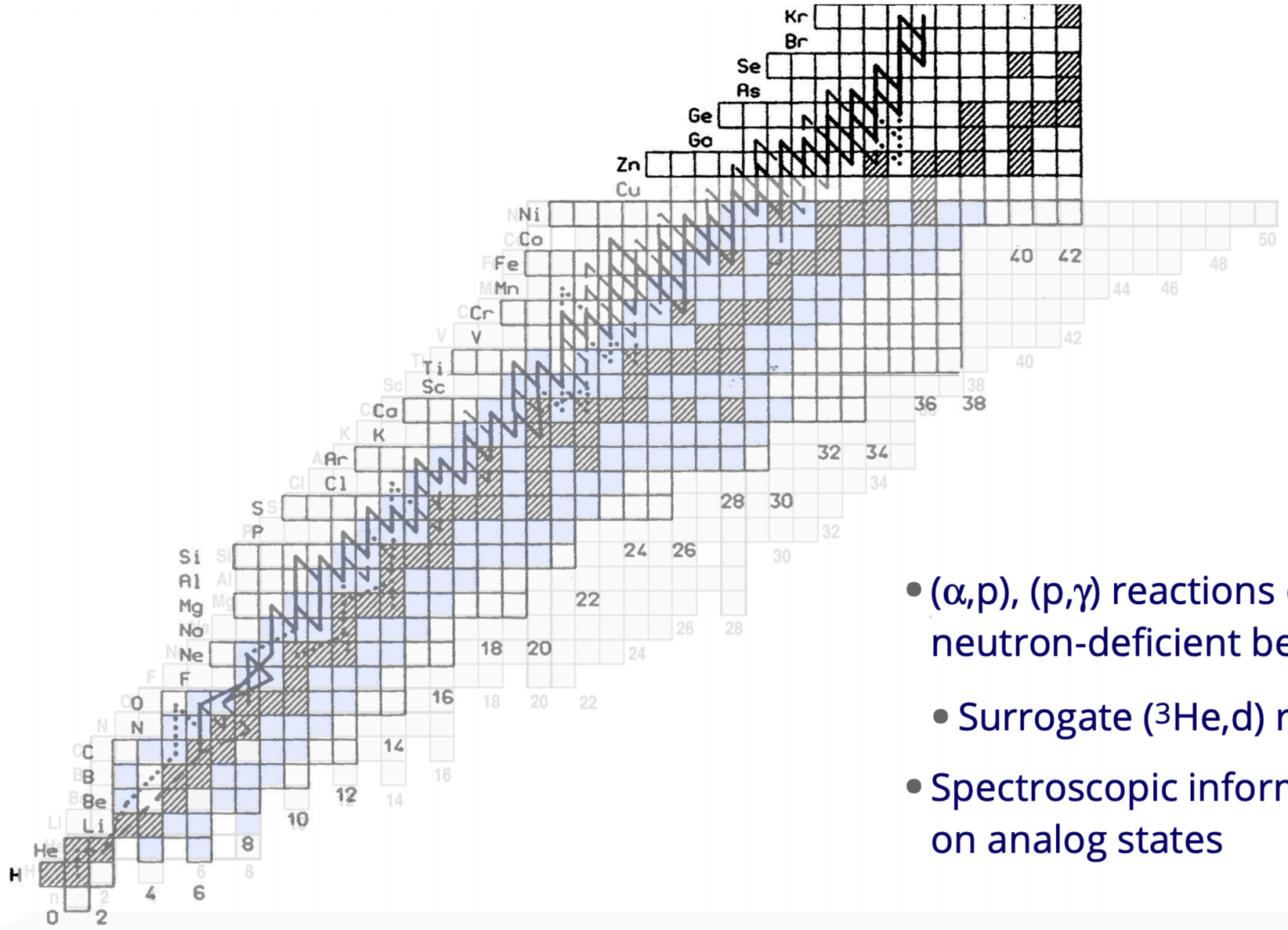
Previously produced

Expected w/ new capabilities

[> 10^3 pps]

NUCLEAR ASTROPHYSICS OPPORTUNITIES

In addition to reactions, structure, fundamental symmetries, etc.



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

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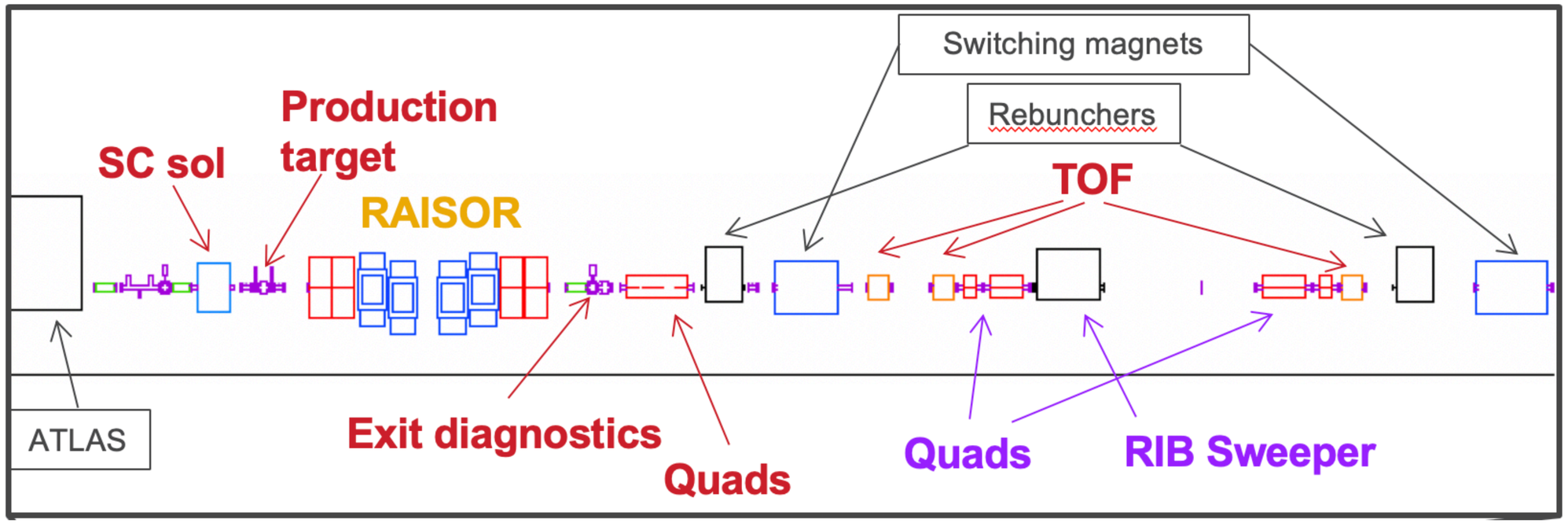
RAISOR DESIGN LAYOUT AND FEATURES

Multiple key design features considered

- Achromatic magnetic chicane
  - Momentum selection & stopping of primary beam current
- RF Sweeper / rebunchers
  - Further beam purification through velocity selection
- Upstream of all high-energy experimental areas



RAISOR DESIGN LAYOUT AND FEATURES

Multiple key design features considered

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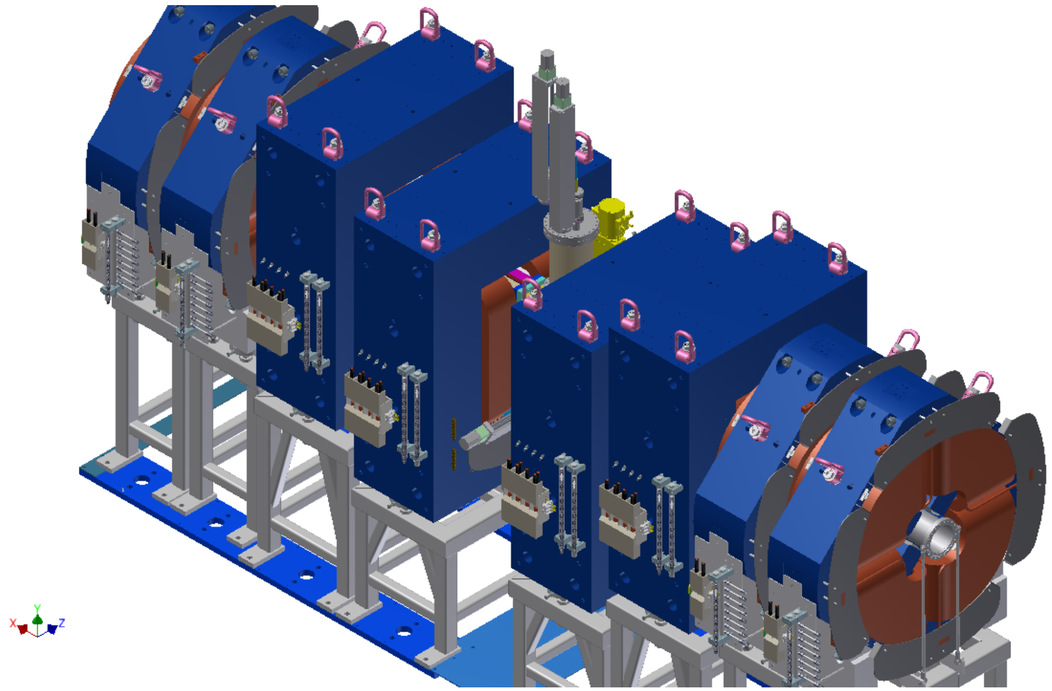
  - Further beam purification through velocity selection
- Upstream of all high-energy experimental areas

Total length	6.6 m
Angular acceptance	75 mrad
Dispersion at midplane	1.3 mm/%
Beam offset	30 ± 5 cm
Dipole gap	8 cm
Max dipole field	1.75 T
Dipole field integral	0.73 T-m
Dipole effective length	41.9 cm
Quadrupole aperture	16 cm
Quadrupole length	30 cm
Maximum pole tip field	1 T



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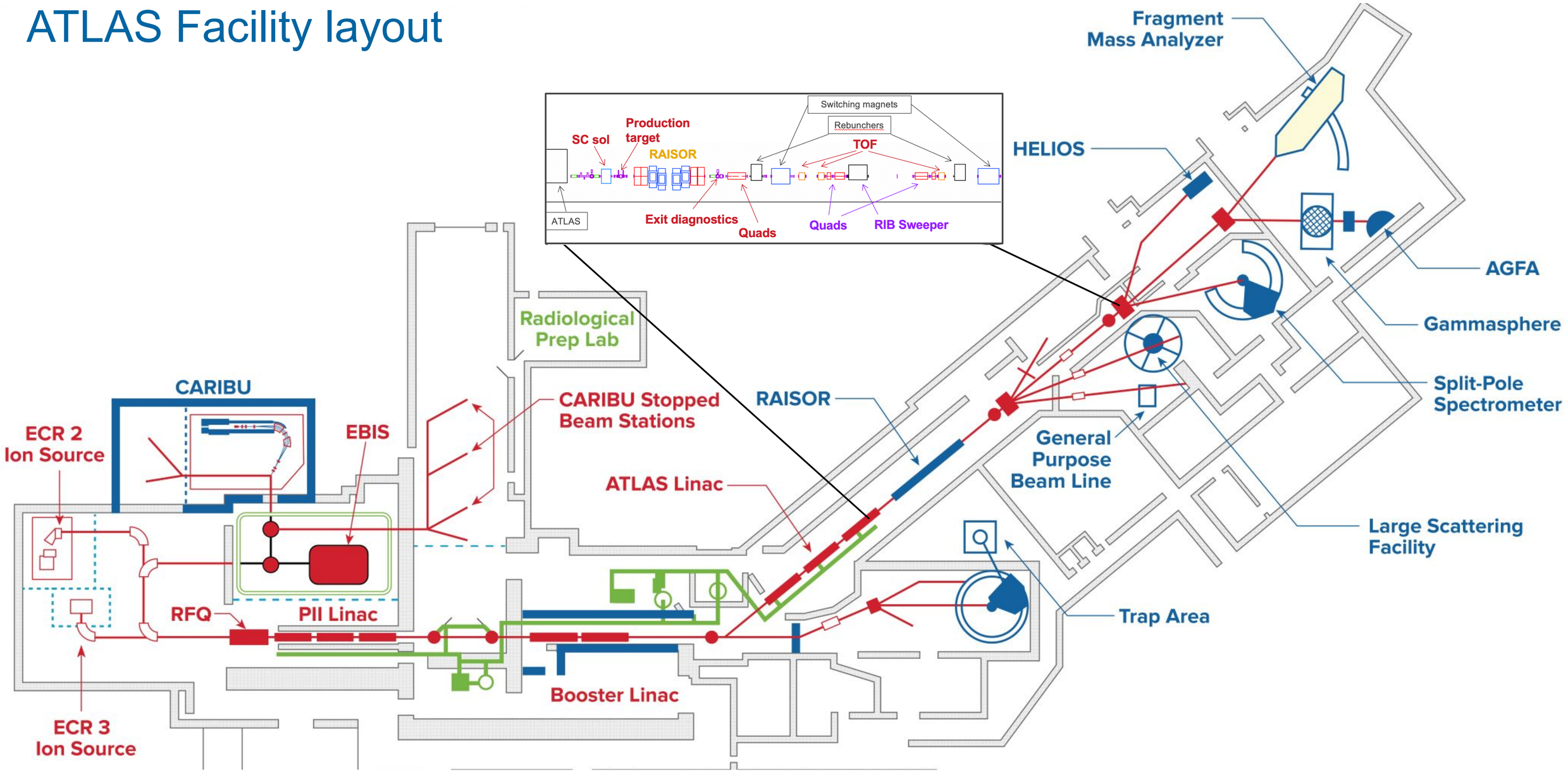
RAISOR INSTALLATION

ATLAS Facility layout



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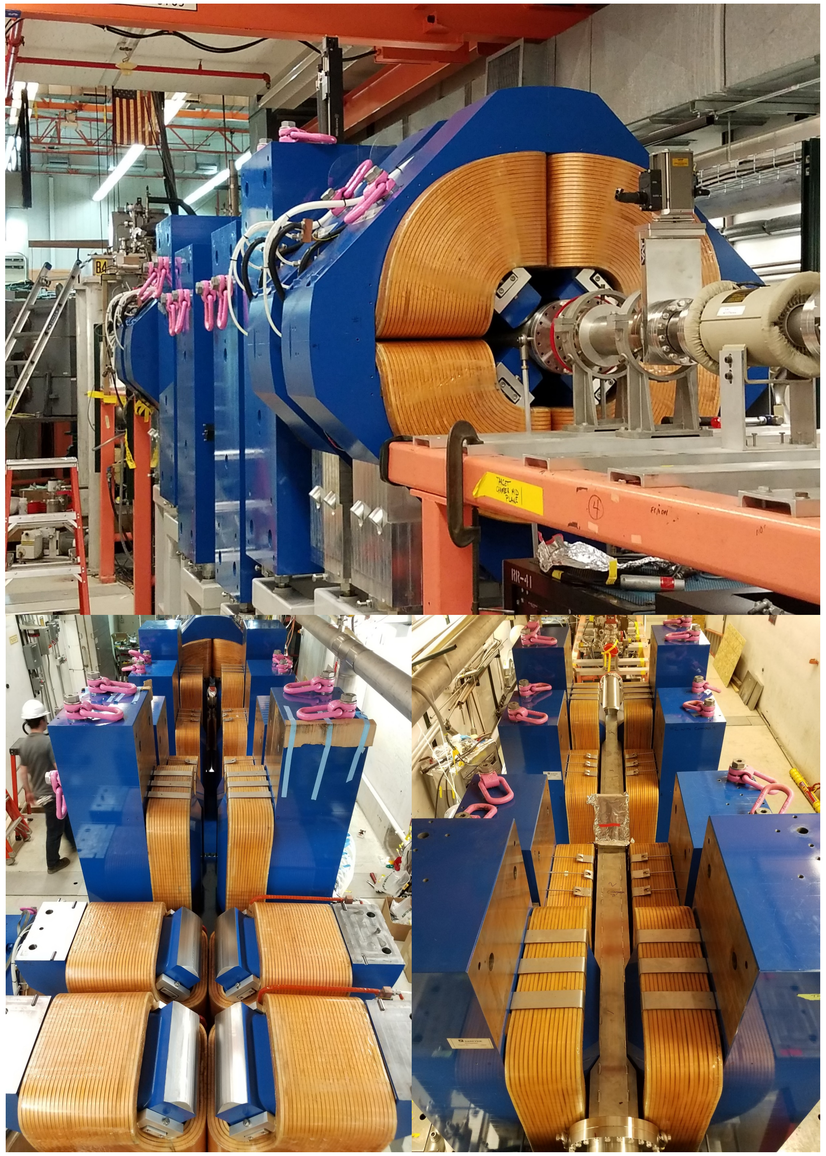
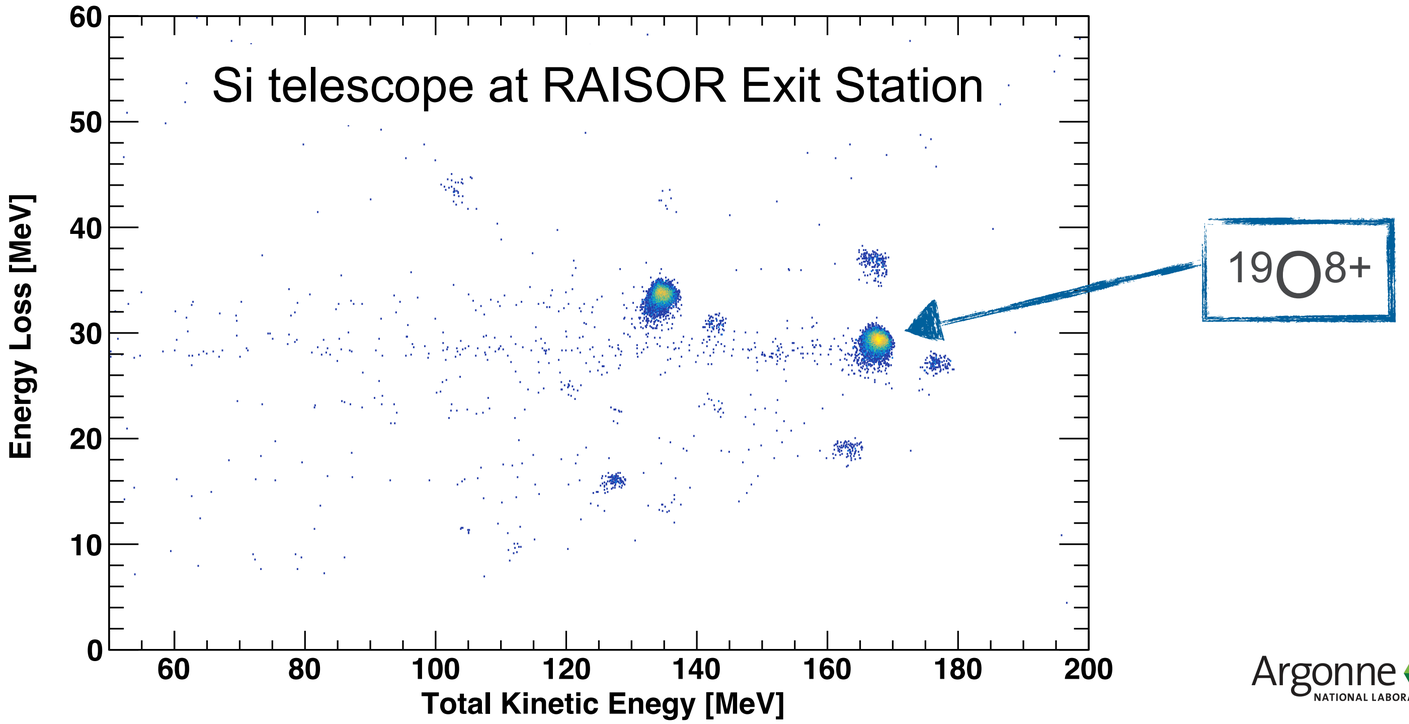
RAISOR COMMISSIONING AND OPERATING PRINCIPLES

AIRIS project complete fall 2018, RAISOR operating since Dec. 2018



- Primary beam transported through AIRIS at 0 cm midplane offset (March 2018)
- Primary $^{18}O^{5+}$ 180 MeV transported at a -32 cm midplane offset w/ >99% efficiency
- Degraded $^{18}O^{8+}$ at ~172 MeV transported at a -32 cm midplane offset w/ >95% efficiency
  - 2% & full open ΔP/P slit settings



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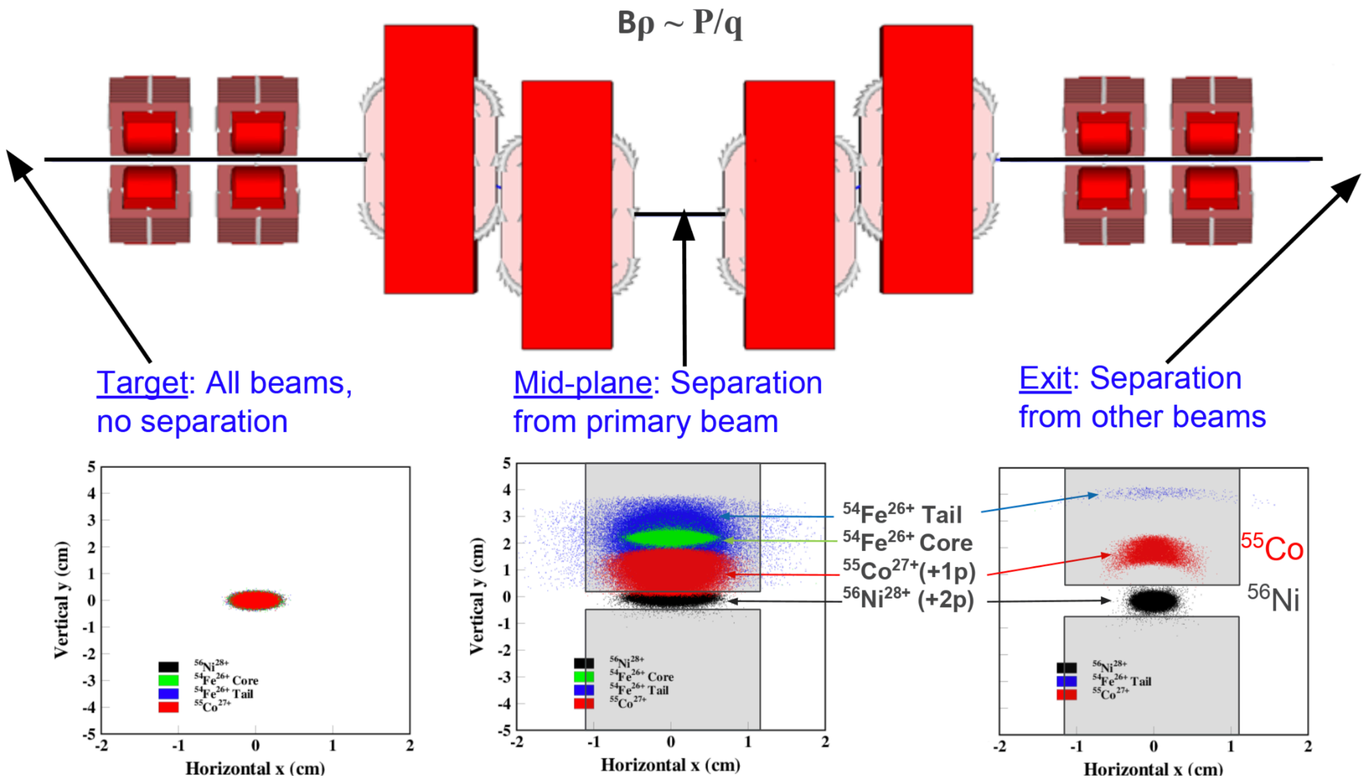
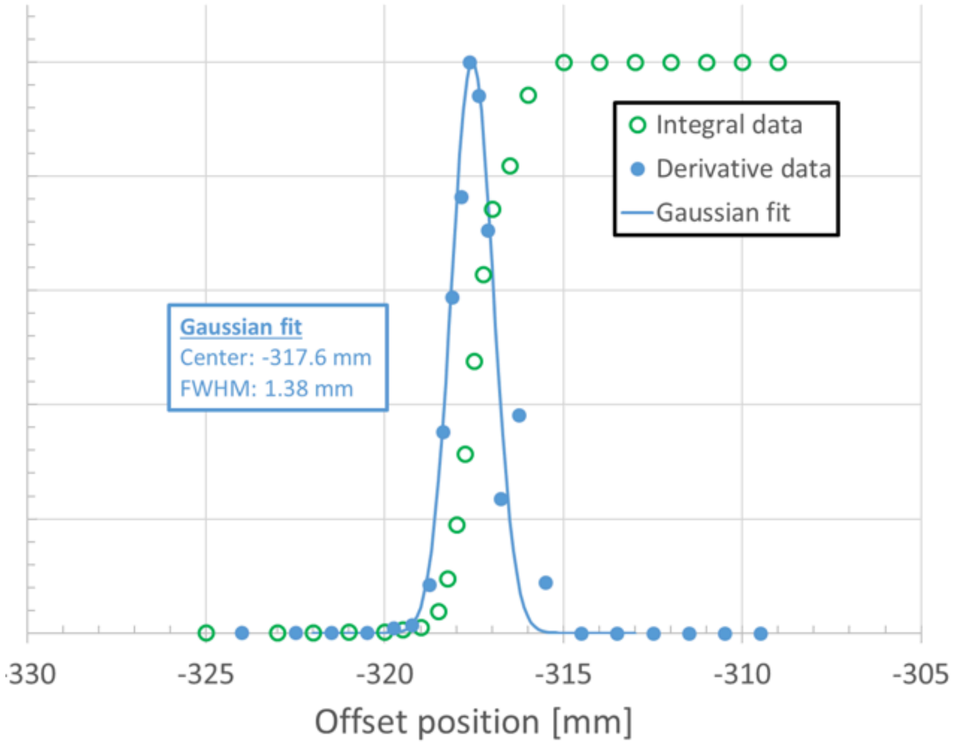
OPERATING PRINCIPLES

Scan beam at the mid plane, vertical slits block primary beam



$^{18}O^{8+}$ dispersive plane beam scan at the midplane



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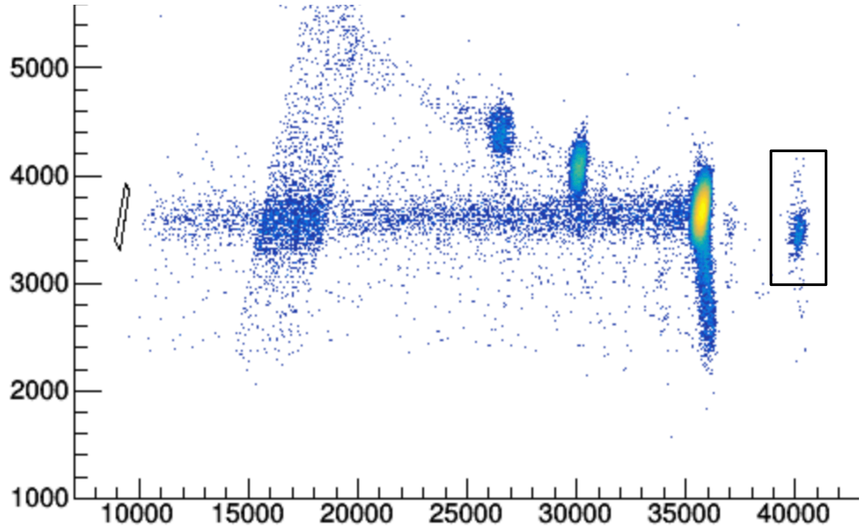
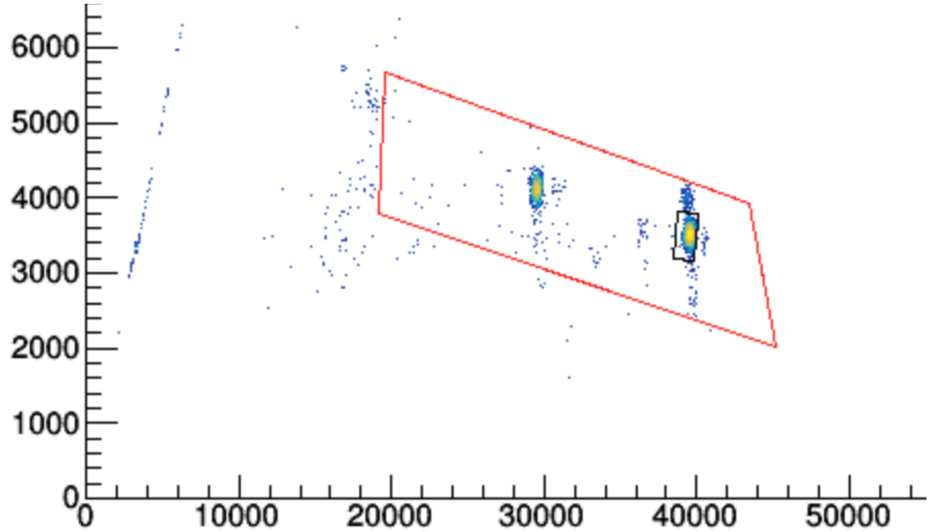
OPERATING PRINCIPLES

Use of the RF Sweeper to further clean the secondary beams (~x100 improvement) w/ 70-80% transmission of beam of interest

Before RF Sweeper Optimizations



After

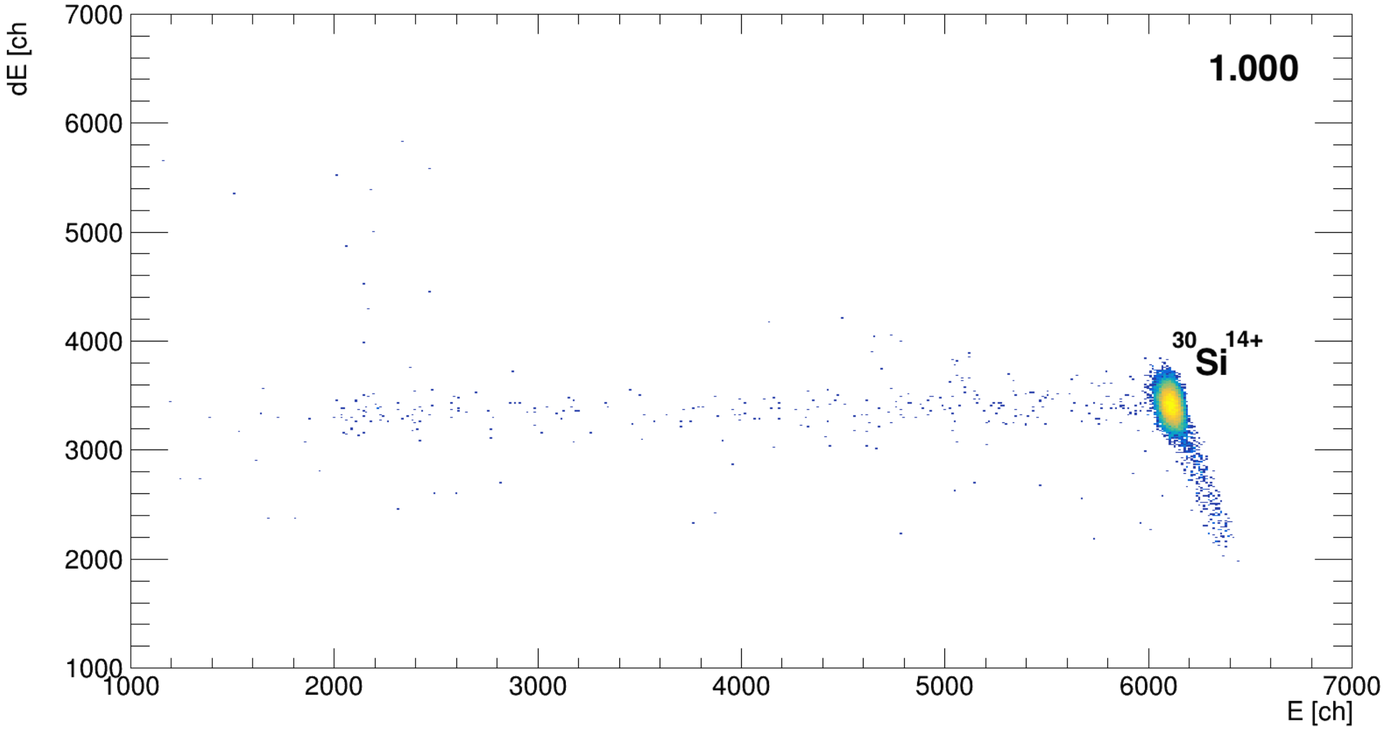


RF Sweeper Parameters		
Electrode length	1	m
Frequency	6.0625	MHz
Maximum Voltage	70	kV

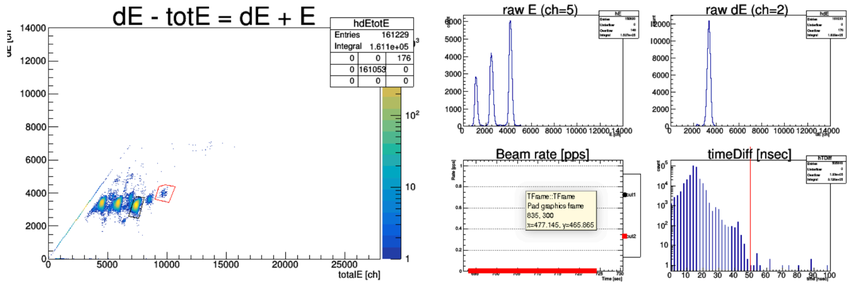
TOOLS FOR IDENTIFICATION / DELIVERY OF IN-FLIGHT BEAMS

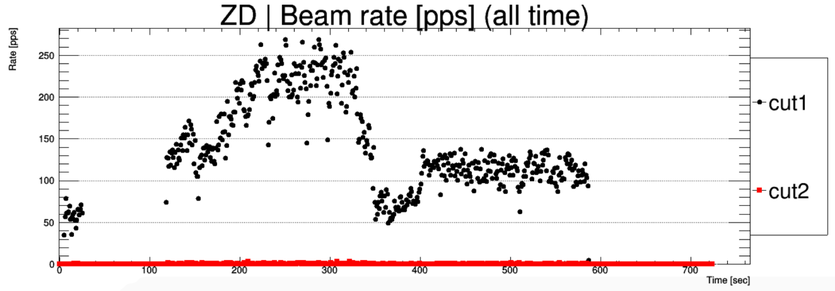
Development & implementation of tools

Visualizing rigidity scanning



courtesy of G. L. Wilson





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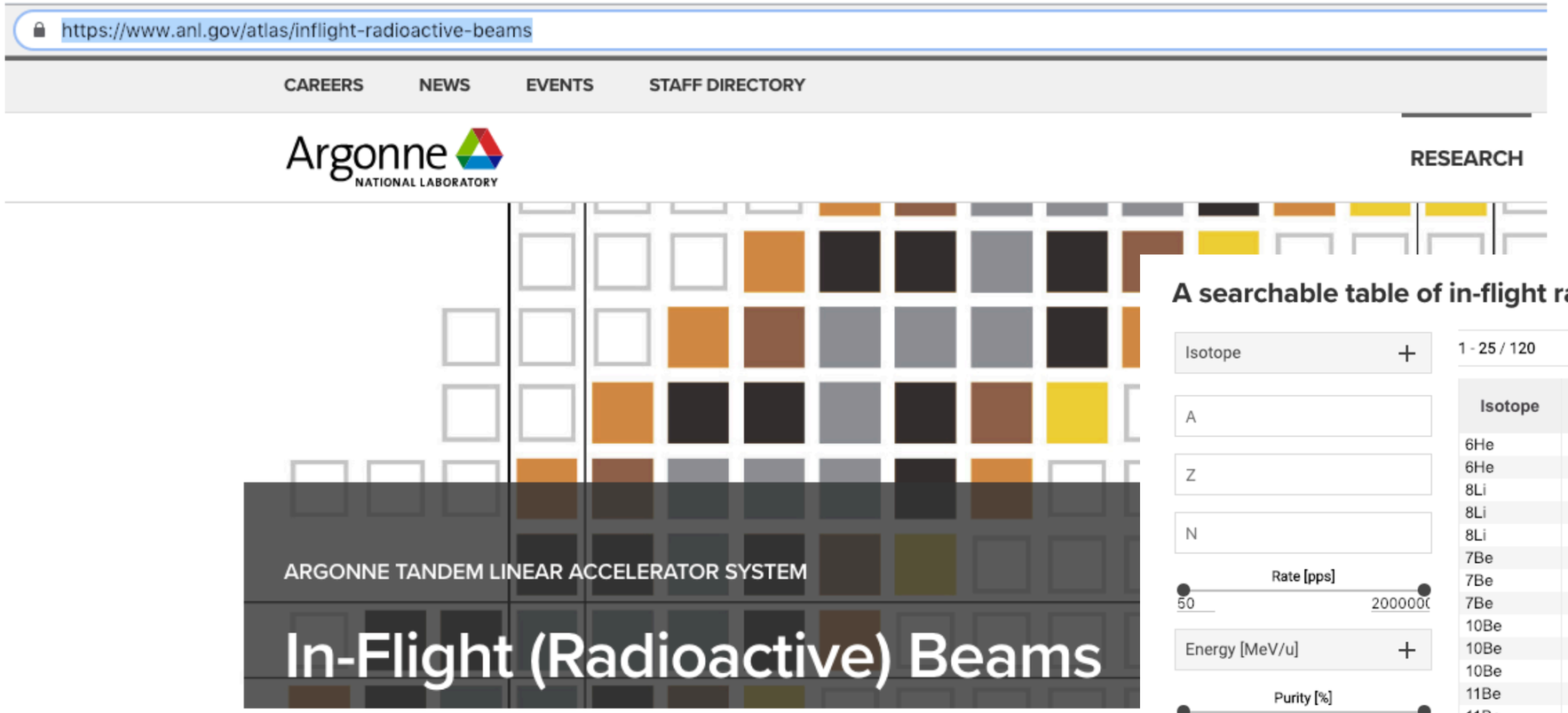
IN-FLIGHT PROGRAM AND PRIORITIES



A searchable table of in-flight radioactive ion beams

Isotope +
A
Z
N
Rate [pps]
50 2000000
Energy [MeV/u] +
Purity [%]
2 50
Designation +
More actions...

1 - 25 / 120

Isotope	Rate [pps]	Energy [MeV/u]	Purity [%]	Designation
6He	1.00E+04	10	5	Expected
6He	2.00E+04	14	5	Expected
8Li	5.00E+04	6	5	Expected
8Li	5.00E+04	10	10	Available
8Li	1.00E+04	14	10	Expected
7Be	1.00E+04	6	10	Expected
7Be	5.00E+03	10	20	Available
7Be	1.00E+03	14	20	Expected
10Be	1.00E+05	6	50	Available
10Be	1.00E+05	10	50	Available
10Be	2.00E+04	14	50	Expected
11Be	2.00E+02	10	50	Expected
11Be	1.00E+03	14	50	Expected
12Be	2.00E+02	10	50	Expected
12Be	1.00E+03	14	50	Expected
12B	2.00E+06	6	20	Available
12B	1.00E+06	10	50	Available
12B	2.00E+05	14	50	Available
13B	2.00E+04	10	20	Available
13B	5.00E+04	14	50	Available
11C	1.00E+06	6	10	Available
11C	5.00E+05	10	20	Available
11C	1.00E+05	14	20	Available
15C	2.00E+06	6	50	Available
15C	1.00E+06	10	50	Available

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- **Program / priorities set in Fall 2018**
  - Initiate physics program early 2019
  - Targeted developments late 2019
- **Generate beam list for Users** -spring 2019 PAC
- **Continually evaluate program priorities** - community input

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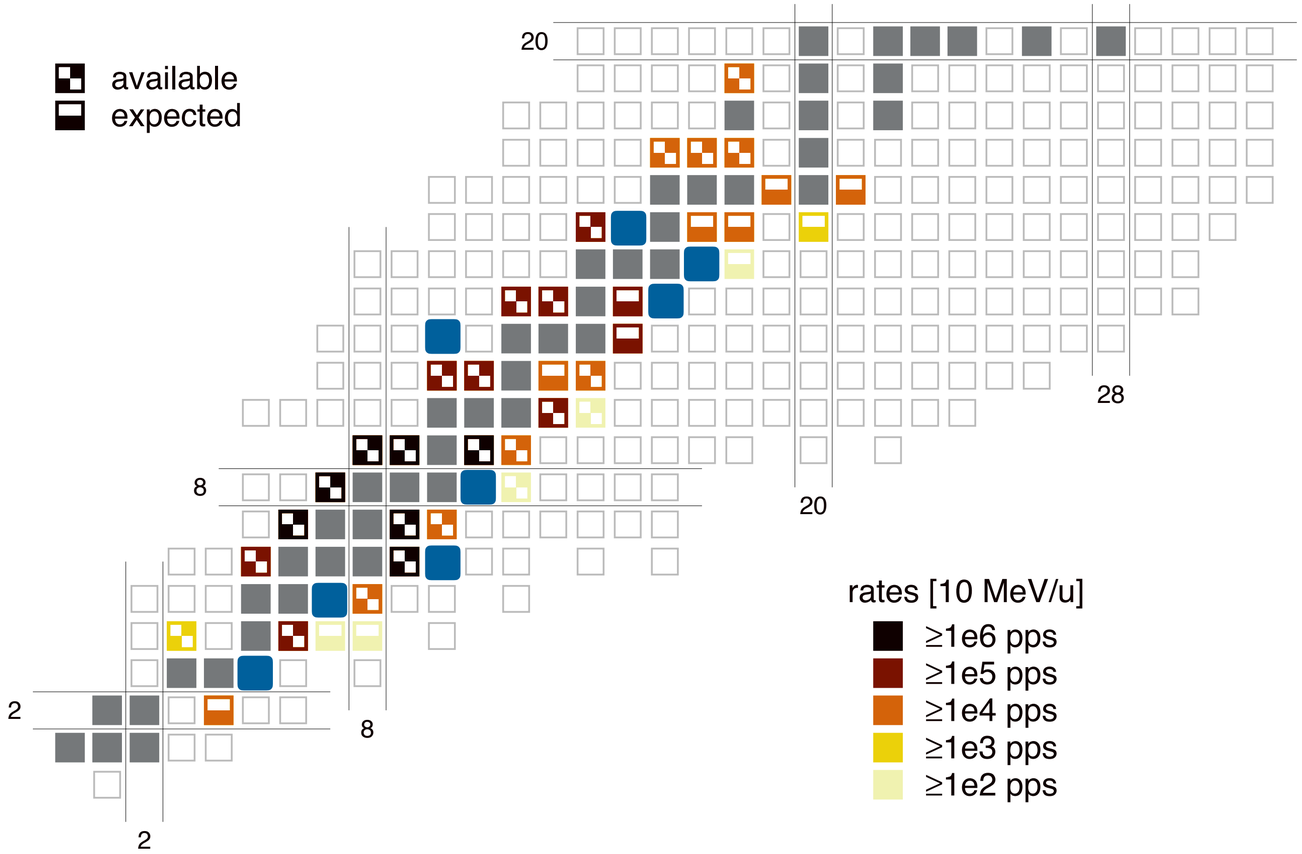
IN-FLIGHT BEAMS PRODUCED

Eight beams & six measurements took (taking) place

- $^{19}O^{8+}$ - commissioning measurement at ATSCAT
- $^{16}C^{6+}$ - Fusion cross sections @ MUSIC [LSU (Hood) / ANL (Santiago)]
- $^{30}P^{15+}$ - ^{30}P(d,p) with GODDESS [ORNL (Pain)]
- $^{12}B^{5+}$ - ^{12}B(t,p) @ HELIOS - UCONN (Wuosmaa)
- $^{8}Li^{3+}$ - ^{8}Li(t,p) @ HELIOS - UCONN (Wuosmaa)
- $^{31}Si^{14+}$ - ^{31}Si(d,p) @ HELIOS - LSU/ANL (Wilson)
- ^{22}Mg - Development of a ^{22}Mg beam at ~50 - 60 MeV @ MUSIC - ANL (Avila)
- $^{29}Al^{13+}$ - ^{29}Al(d,p) @ HELIOS - Manchester (Sharp)



- >80 days of in-flight beam requested by Users in 2019 PAC
- 4 approved experiments in ’19 (+6 previously approved)
- ~30-35% of ATLAS beam time in CY19

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IN-FLIGHT BEAMS PRODUCED

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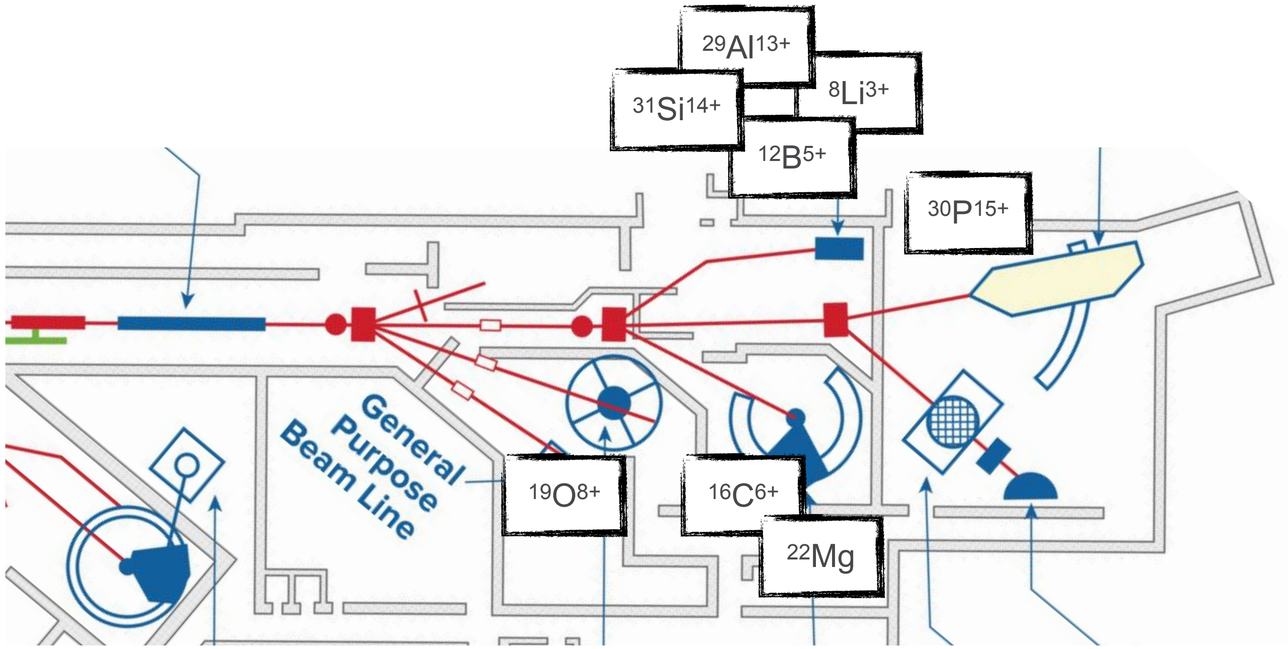

- >80 days of in-flight beam requested by Users in 2019 PAC
- 4 approved experiments in ’19 (+6 previously approved)
- ~30-35% of ATLAS beam time in CY19

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CHARACTERISTICS OF IN-FLIGHT BEAMS

Values taken from final “production” configurations in most cases

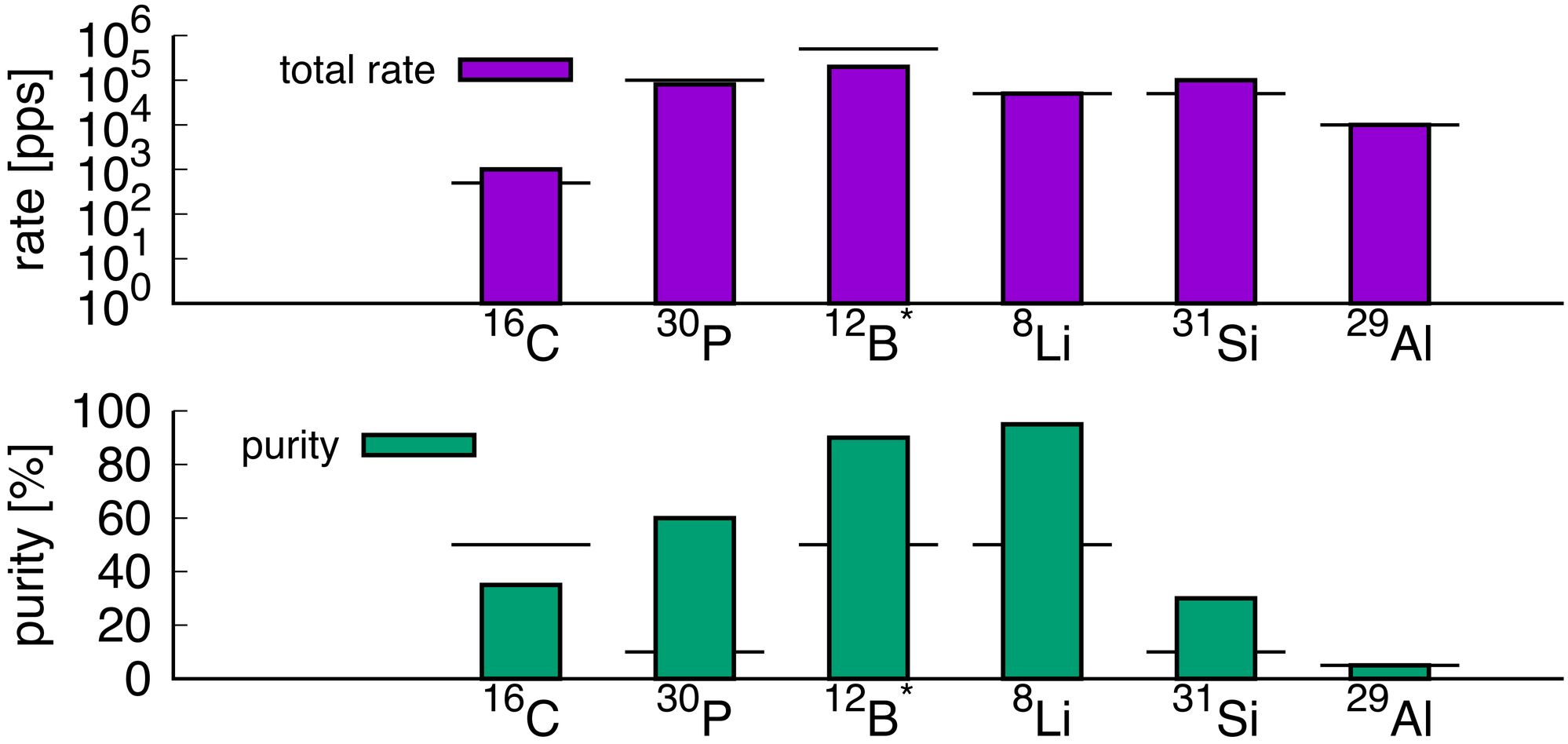
Beam	Energy [MeV/u]	Rate [pps]	Purity [%]	Reaction	Primary beam intensity [pnA]	Target	Spot size [fwhm]
$^{19}O^{8+}$	8.8	2E+05	60	$^{18}O(d,p)$	50	Warm D_2 gas	< 6 mm
$^{16}C^{6+}$	14.0	1E+03	35	$^{18}O(^{9}Be,-2p)$	150	12 mg/cm^2 Be	< 7 mm
$^{30}P^{15+}$	8.3	8E+04	60	$^{29}Si(d,n)$	40	Cold D_2 gas	~5 mm
$^{12}B^{5+}$	7.2	2E+05	90	$^{11}B(d,p)$	200	Cold D_2 gas	< 8 mm
$^{8}Li^{3+}$	9.2	5E+04	95	$^{7}Li(d,p)$	150	Cold D_2 gas	< 8 mm
$^{31}Si^{14+}$	10.0	1E+05	30	$^{30}Si(d,p)$	20	Cold D_2 gas	< 8 mm
$^{22}Mg^{11+}$	2.7	1E+03*	-	$^{20}Ne(^{3}He,n)$	100*	Warm ^{3}He gas	-
$^{29}Al^{13+}$	10.7	1.5E+04	5	$^{30}Si(^{9}Be,-1p)$	120	4 mg/cm^2 Be	< 8 mm

- RAISOR momentum acceptance typically 2-4% as defined by mid-plane slits
- Beams < 10 mm in spot size at RAISOR focal plane

*Assuming 100 pnA on target, Note: Cold = liquid nitrogen temperature; Upper limits on spot size estimated by slit settings

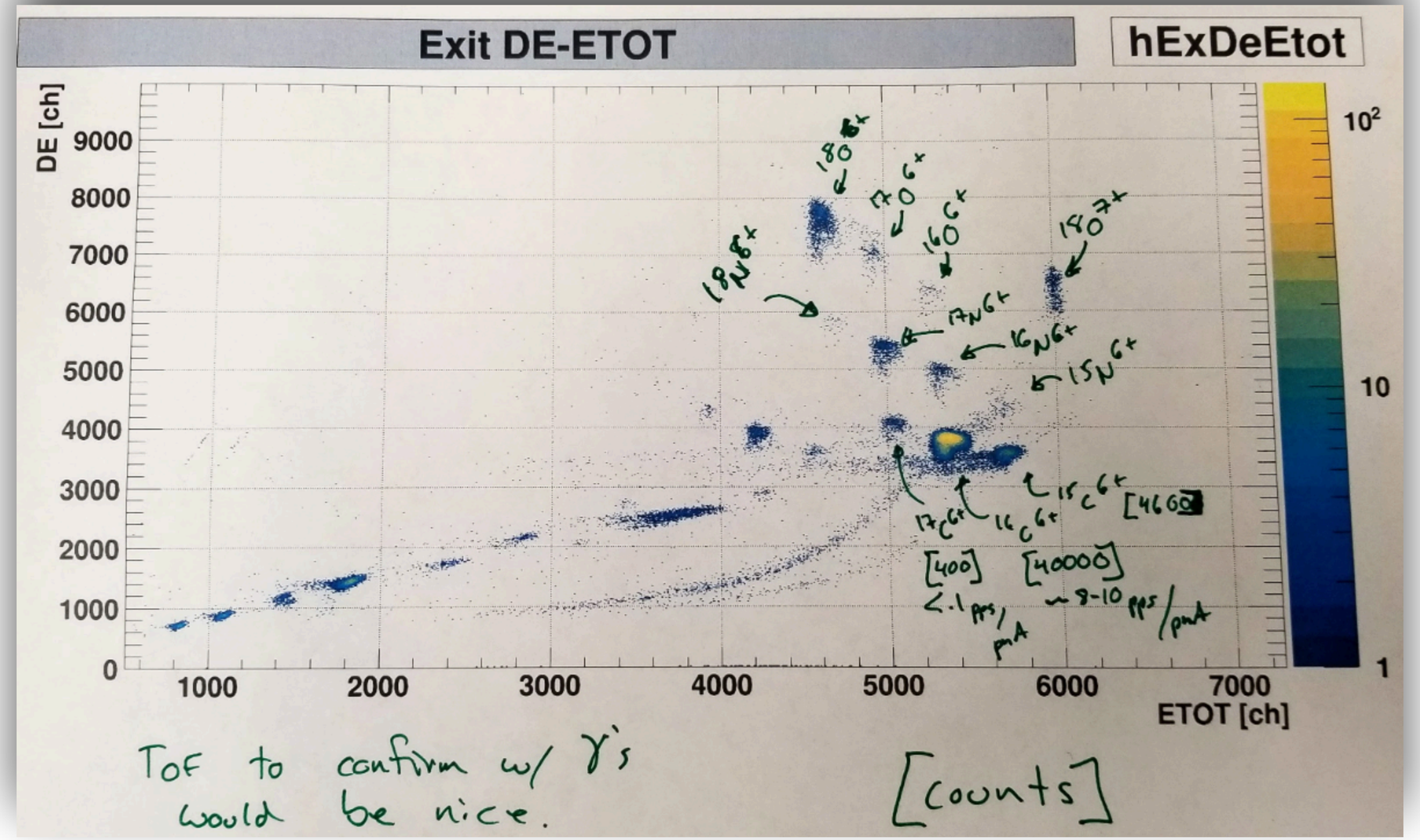
CHARACTERISTICS OF IN-FLIGHT BEAMS

Comparisons with expectations delivered for previous PAC



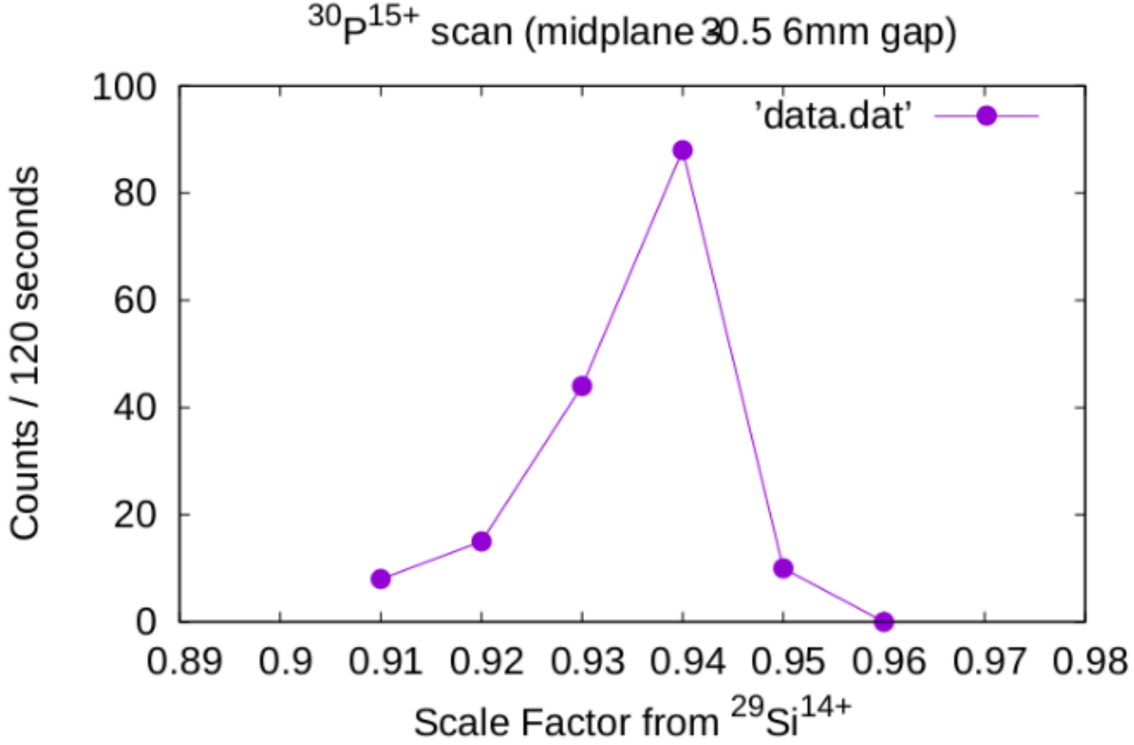
FURTHER DETAILS ON A FEW CASES: $^{16}C^{6+}$

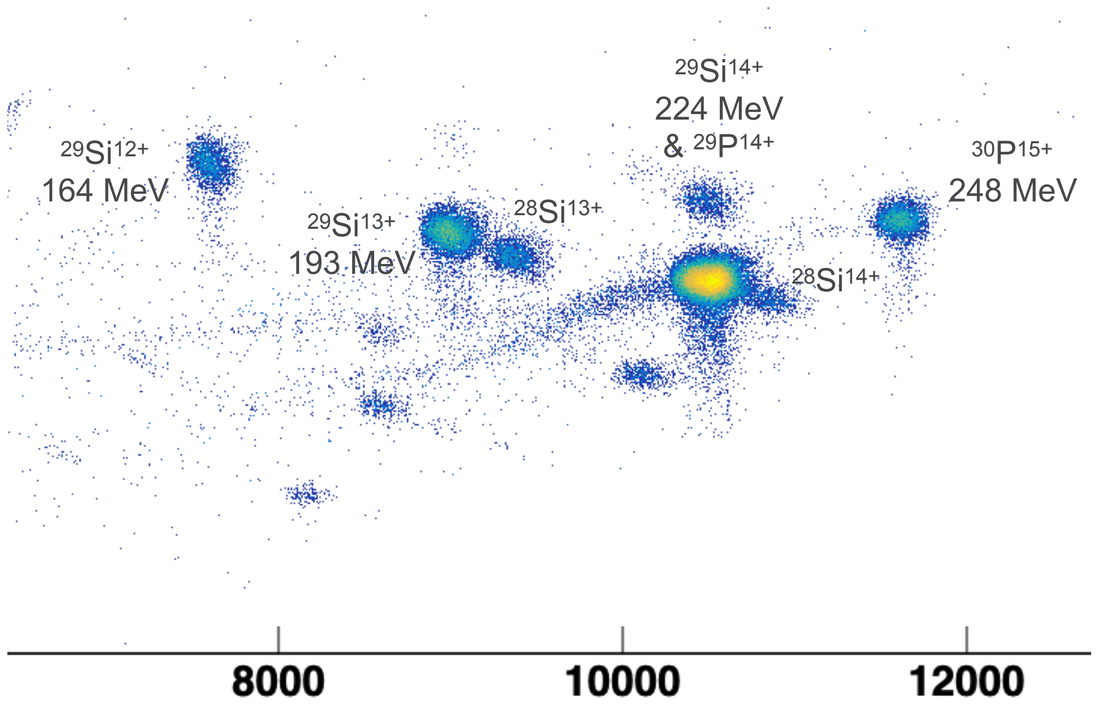
Highlight: greater than x10 increase in intensity delivered over previous facility



FURTHER DETAILS ON A FEW CASES: $^{30}P^{15+}$

Highlight(s): First in-flight beam delivered down FMA beam line, and first beam to use the full facility including the newly placed RF Sweeper





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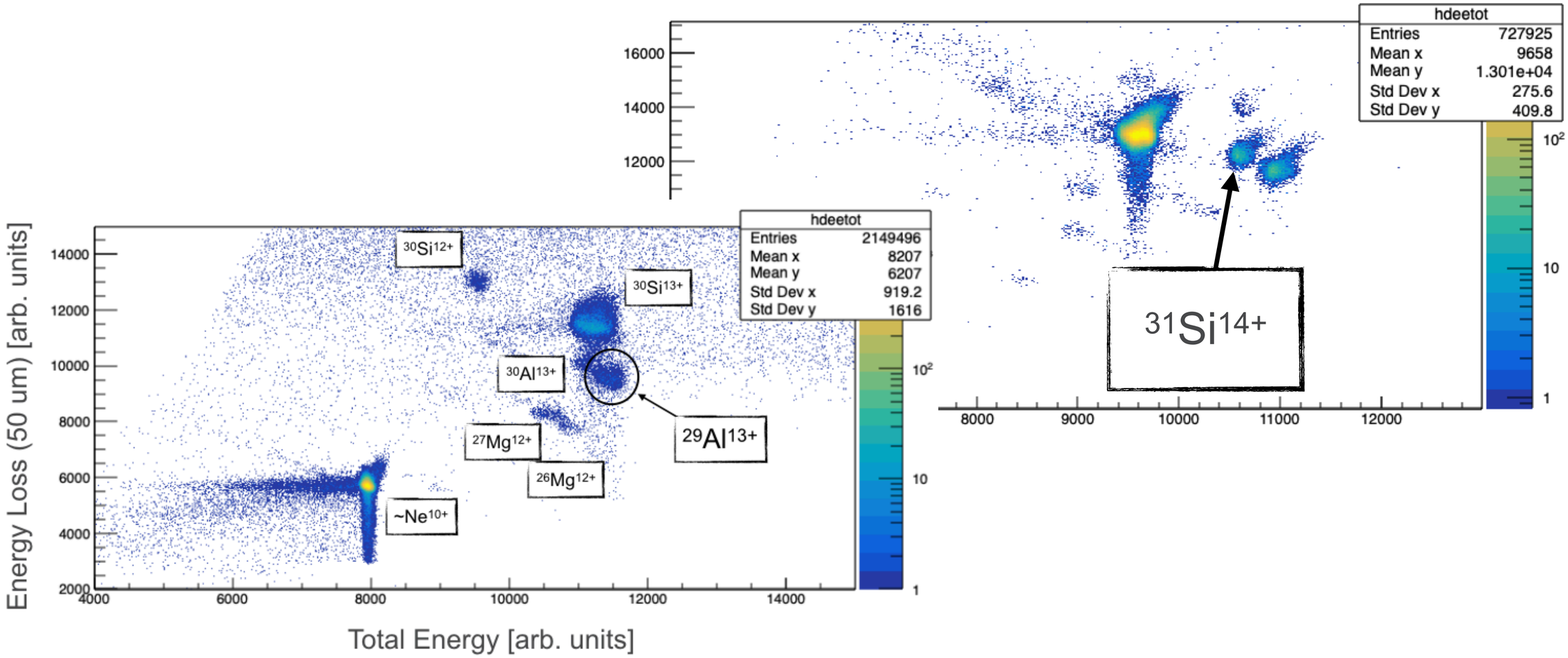
FURTHER DETAILS ON A FEW CASES: $^{31}Si^{14+}$, $^{29}AL^{13+}$

Highlight: Heaviest neutron-rich beams (by 10 mass units) produced at ATLAS, w/ $^{31}Si^{14+}$ separated from $^{30}Si^{14+}$ by only 1.5% in rigidity



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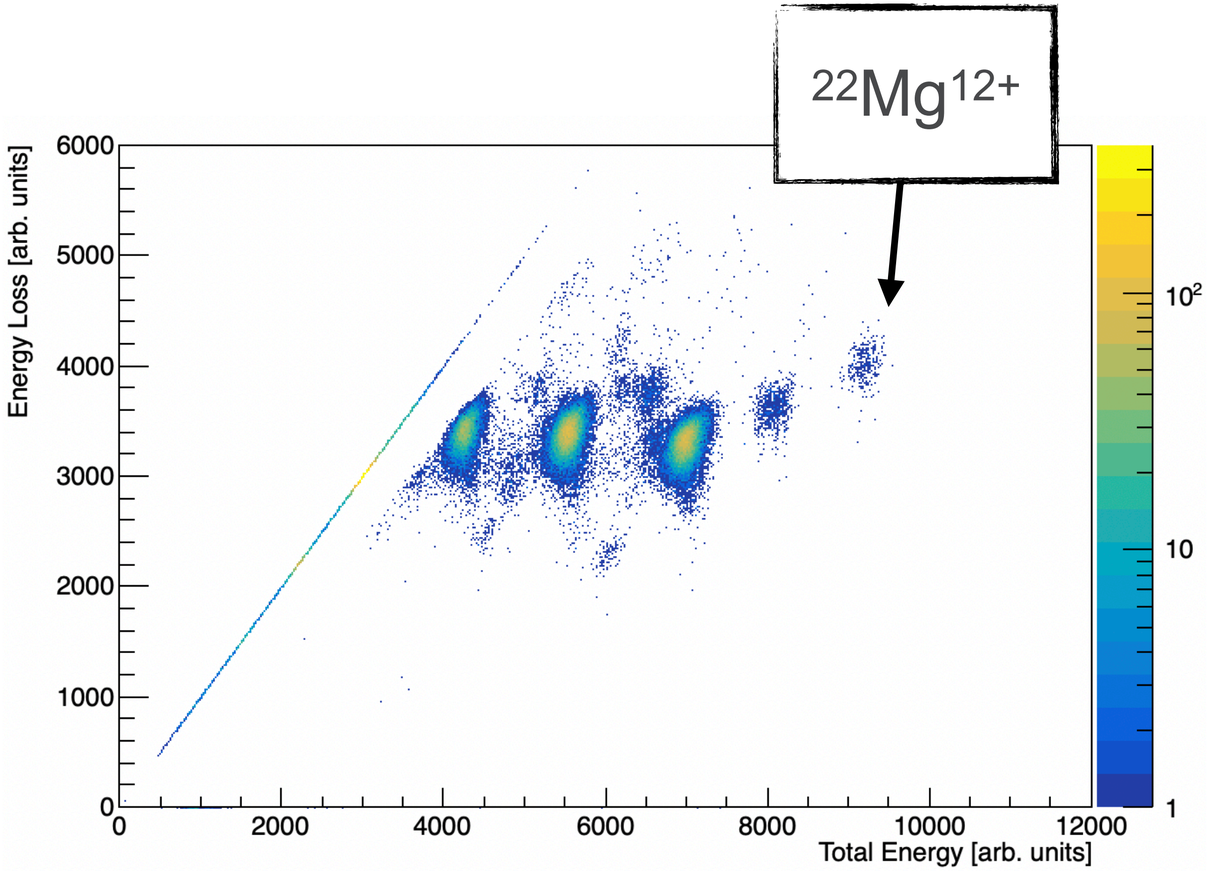
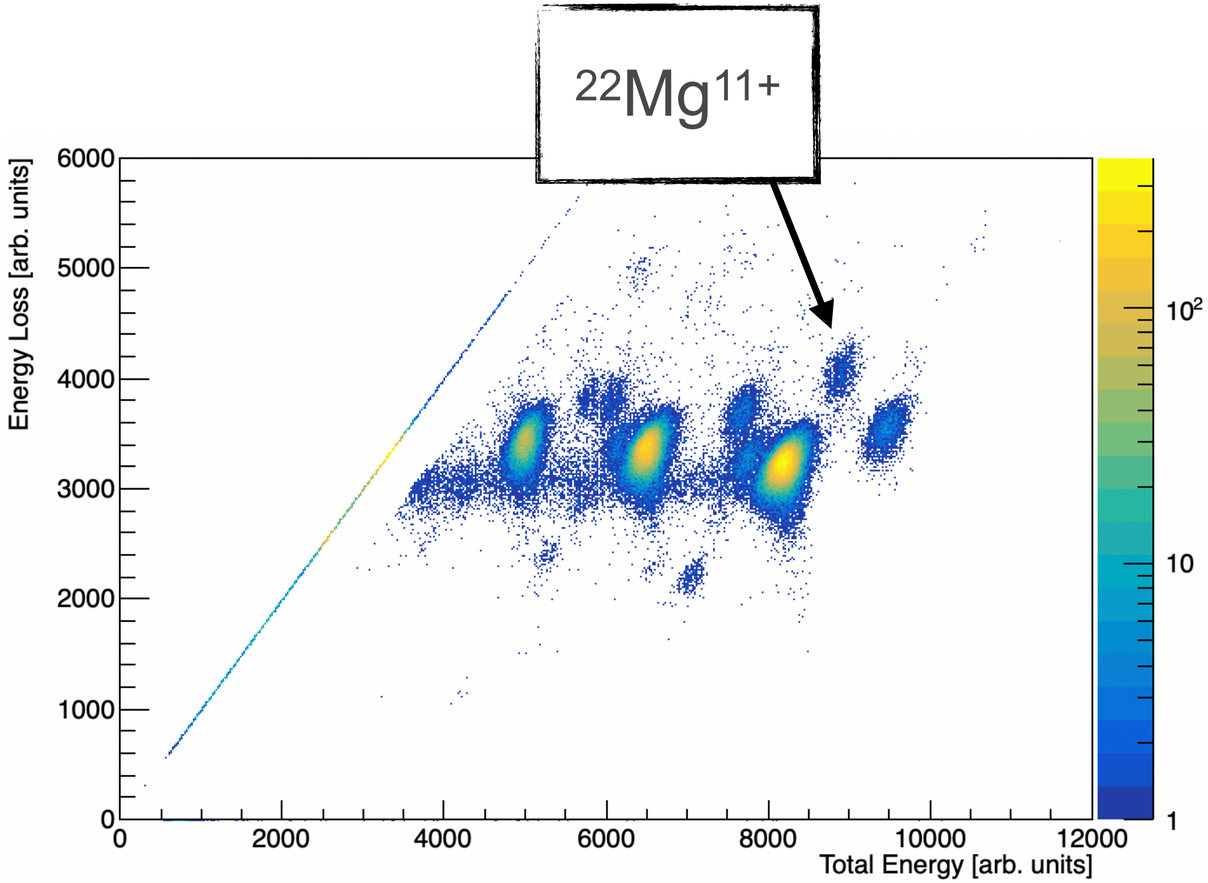
FURTHER DETAILS ON A FEW CASES: ^{22}MG

Highlight(s): Lowest energy beam attempted, new reaction type explore (^{3}He,n), ability to identify, optimize for and deliver beam with q < Z [11^{+}]





- Scale factors of 0.8 and 0.88 in rigidity from degraded ^{20}Ne^{10+} beam
- ~x3.5 improvement of q=11^{+} over 12^{+} in this energy regime

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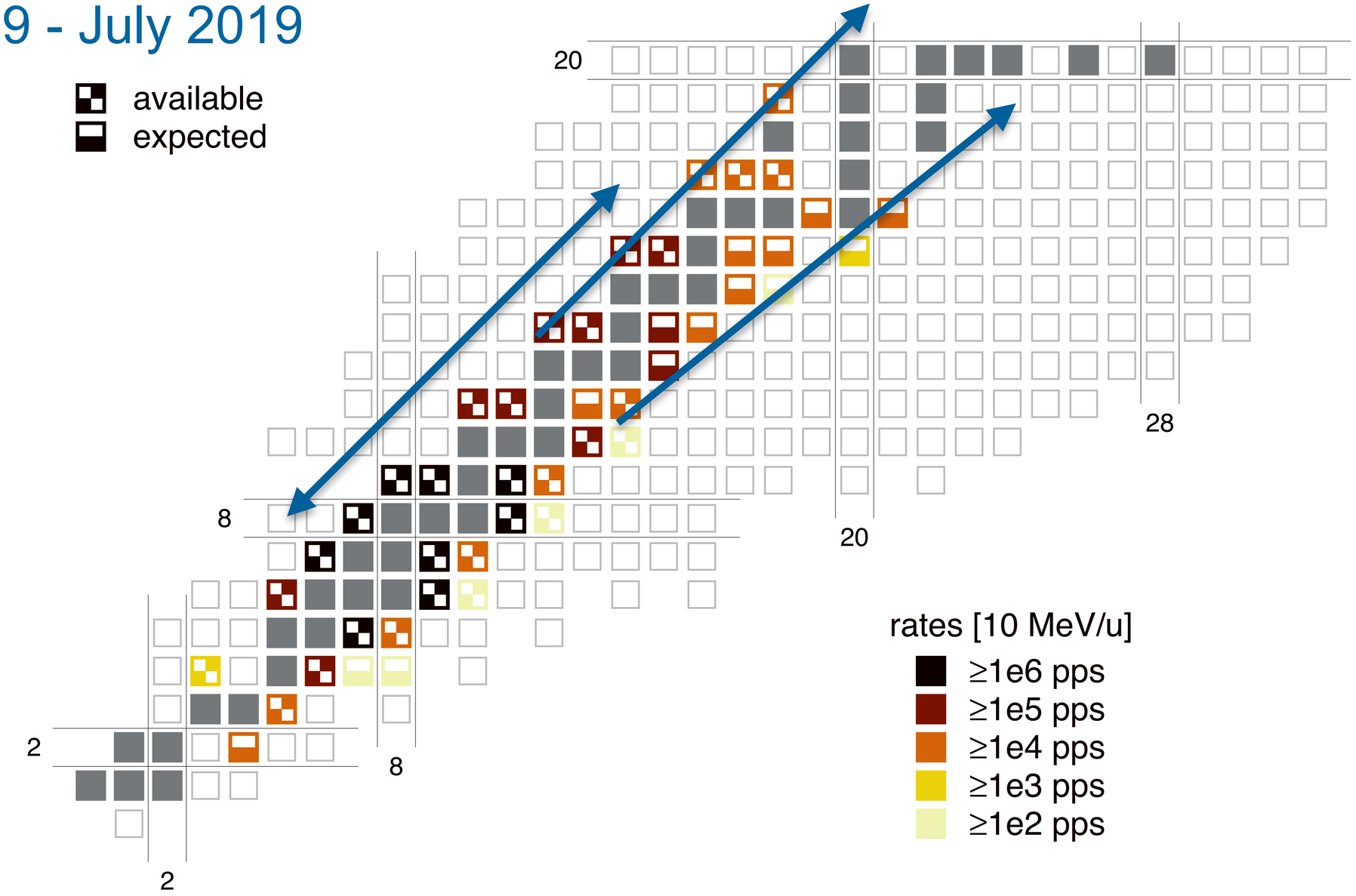
SUMMARIZING / CURRENT STATUS OF BEAMS

Jan. 2019 - July 2019

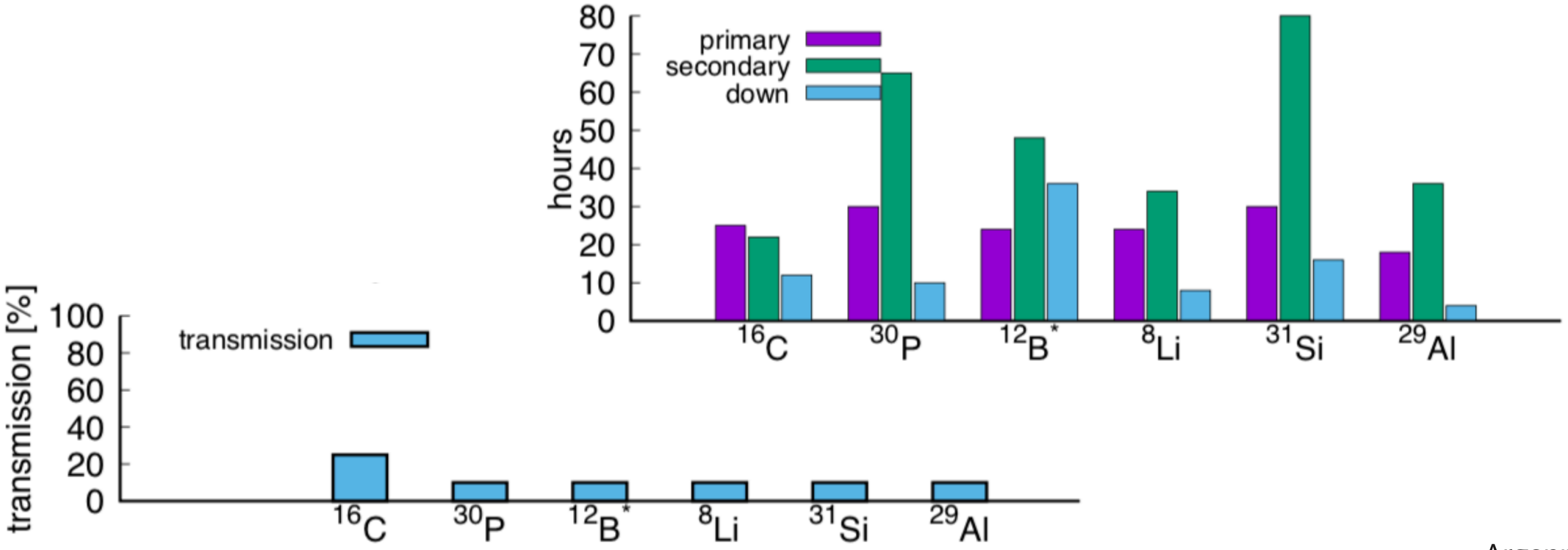


+ a number of planned developments this coming Fall

FOCUS IN THE NEAR FUTURE

Continued execution of FY19 plan & formulation of priorities for 2020 this fall

- Increase the number of beams available & strive towards energies / purities demanded by the community
- Evaluate and address current limitations
  - Transmission, delivery times, targets, shielding



PARTICULARS FOR IN-FLIGHT PROPOSALS

https://www.anl.gov/atlas/inflight-radioactive-beams

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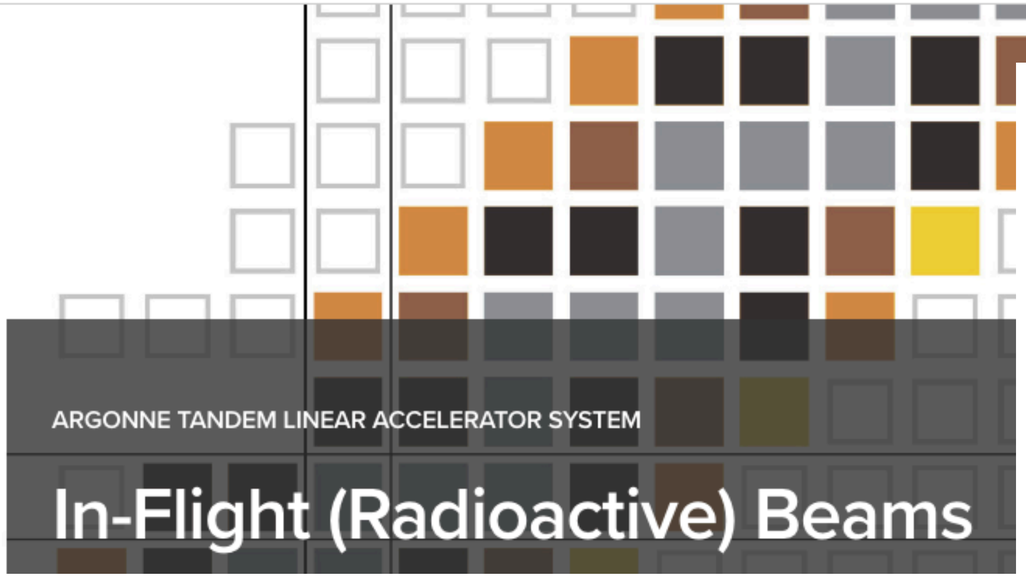
RESEARCH



A searchable table of in-flight radioactive ion beams

Isotope +

A

Z

N

Rate [pps]

50 2000000

Energy [MeV/u] +

Purity [%]

2 50

Designation +

More actions...

1 - 25 / 120

Isotope	Rate [pps]	Energy [MeV/u]	Purity [%]	Designation
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12Be	1.00E+03	14	50	Expected
12B	2.00E+06	6	20	Available
12B	1.00E+06	10	50	Available
12B	2.00E+05	14	50	Available
13B	2.00E+04	10	20	Available
13B	5.00E+04	14	50	Available
11C	1.00E+06	6	10	Available
11C	5.00E+05	10	20	Available
11C	1.00E+05	14	20	Available
15C	2.00E+06	6	50	Available
15C	1.00E+06	10	50	Available

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Beam Designations

- **Available** - schedule experiments w/ out developments
- **Expected** - development required before scheduling experiment
- **Absent from list** - development before experiment can be approved

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INPUT FOR FUTURE DIRECTION PLANNING

What are the priorities for the nuclear astrophysics community

- Species, rates, purity, energies
- …all the above?

Please fill out the questionnaires

Reach out to anyone on the RAISOR team

Thank you!