Status of the Rare Isotope ReAccelerator Facility ReA

D. Leitner
on behalf of the ReA team at
Michigan State University

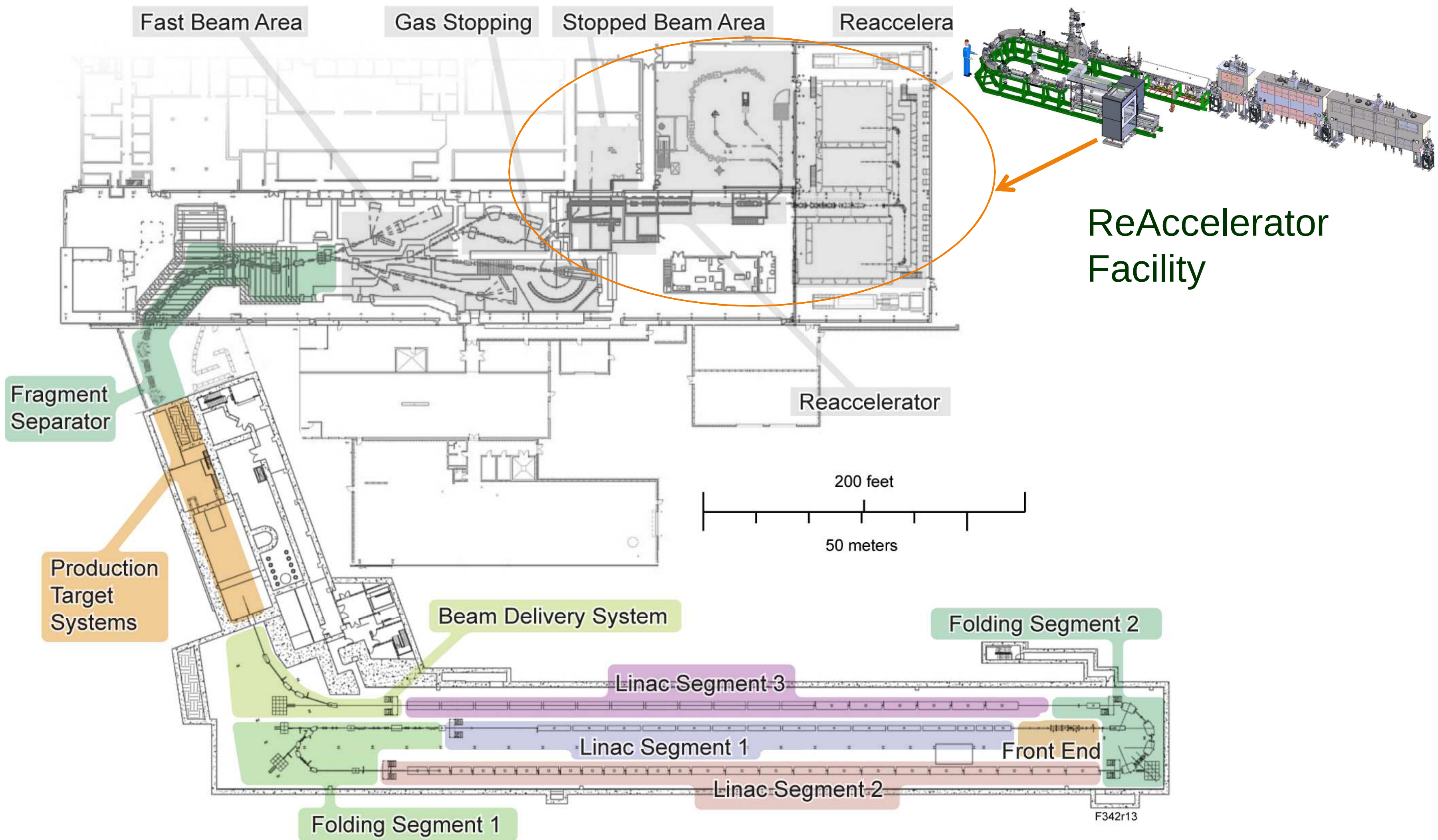
Outline

NSCL/FRIB Laboratory

- Introduction
- ReAcclerator facility
- Commissioning Results and Status
- First radioactive ion beam delivery

NSCL FRIB
U.S. Department of Energy Office of Science
National Science Foundation
Michigan State University

FRIB Accelerator Complex Subsystems

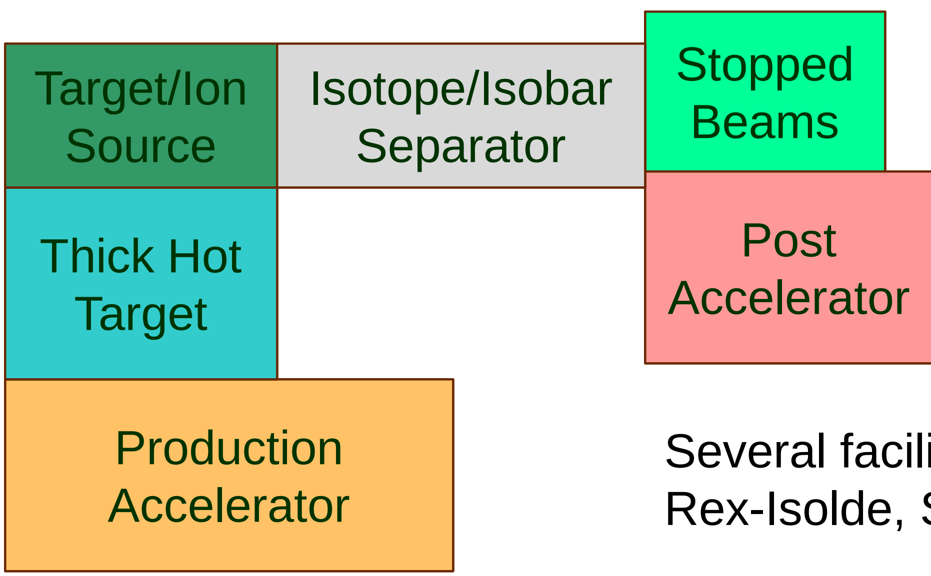


Isotope production reaction mechanisms [1]

Most post accelerator facilities are based on

ISOL –Isotope Separator On-Line (target “spallation”or fission)

– Light ion-induced “spallation” or fission of heavy targets
– Isotopes must diffuse from hot targets and effuse to an ion source
– Typical beams ~100-1000 MeV protons; typical targets Ta & UC
– Photofission using high power electron linac

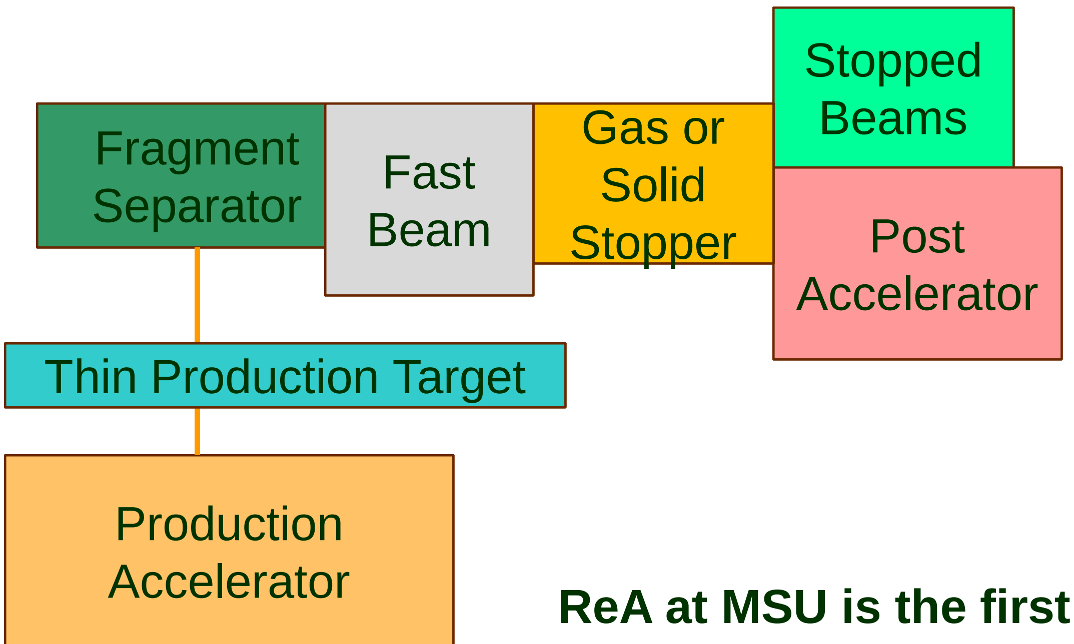


- Very intense beams of many elements, especially noble gases and alkalis
- Weak beams of refractory and chemically active elements

Several facilities around the world:
Rex-Isolde, Spiral, ISAC, EXYPT, SPES,EURISOL …

Isotope production reaction mechanisms [2]

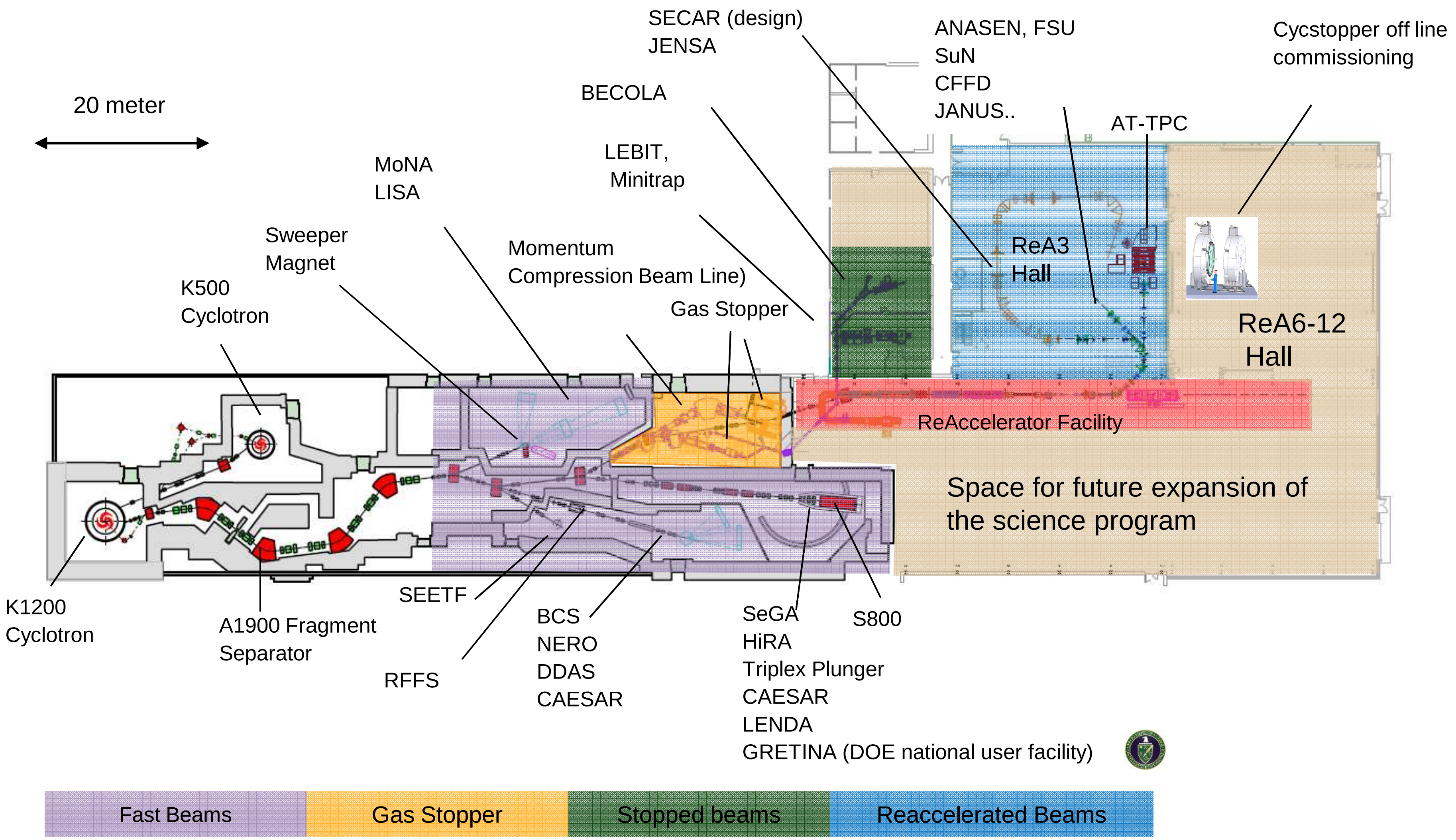
- **In-flight heavy-ion fragmentation or fission on a light target**
  - Fragments of the beam are kinematically forward directed at ~beam velocity
  - Rare isotopes are separated physically; no chemical dependence
  - Typical heavy ion beams are ^{18}O- ^{238}U at 200-2000 MeV/u; typical targets Be or C



- Separated beams of any species including refractory and chemically active elements and isotopes with very short half-lives, even isomers
- Needs gas catcher or solid stopper for post acceleration

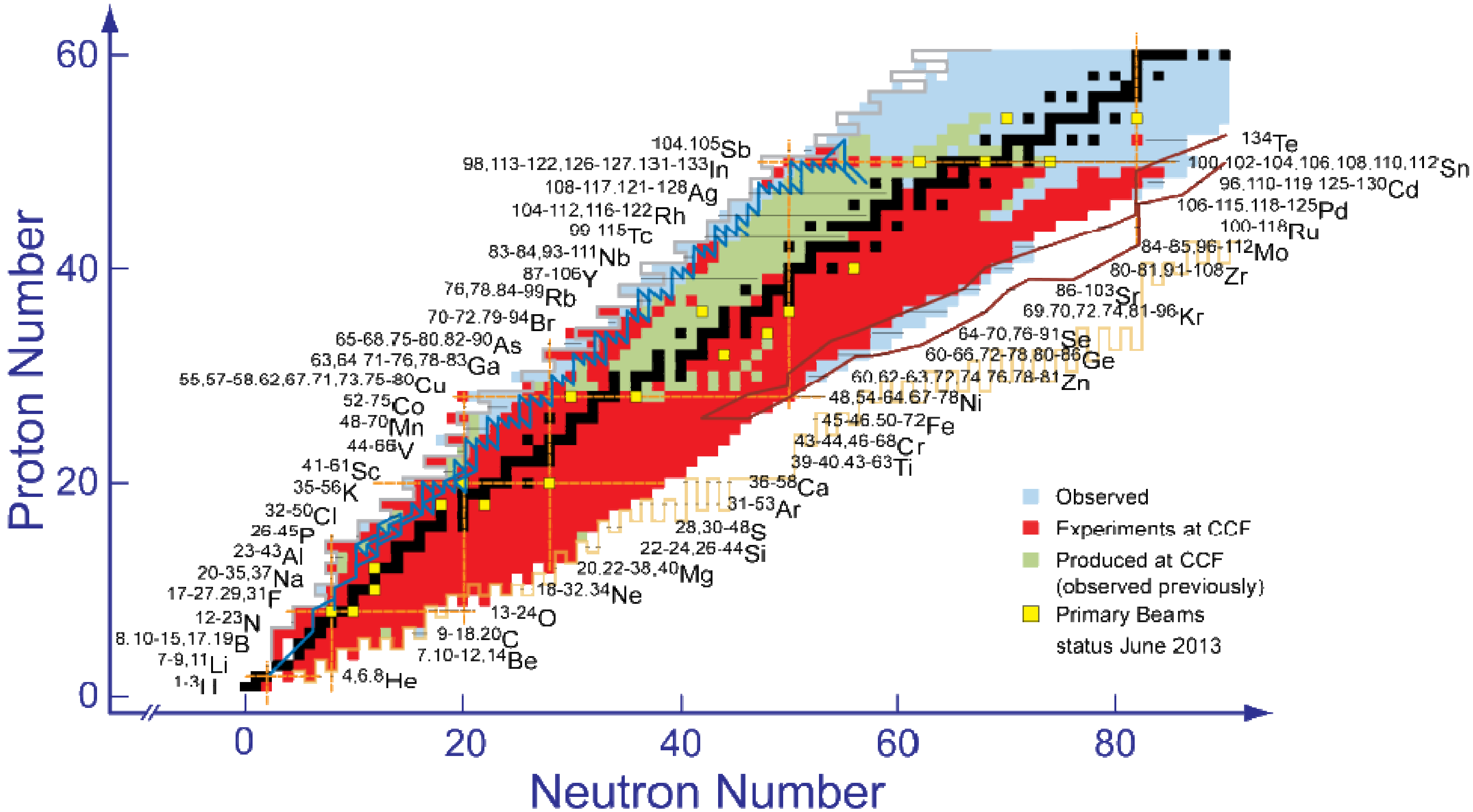
ReA at MSU is the first post-accelerator coupled to a fragmentation facility

CCF Is The Only Facility In The World That Provides Fast, Stopped, And Reaccelerated Beams Of Rare Isotopes



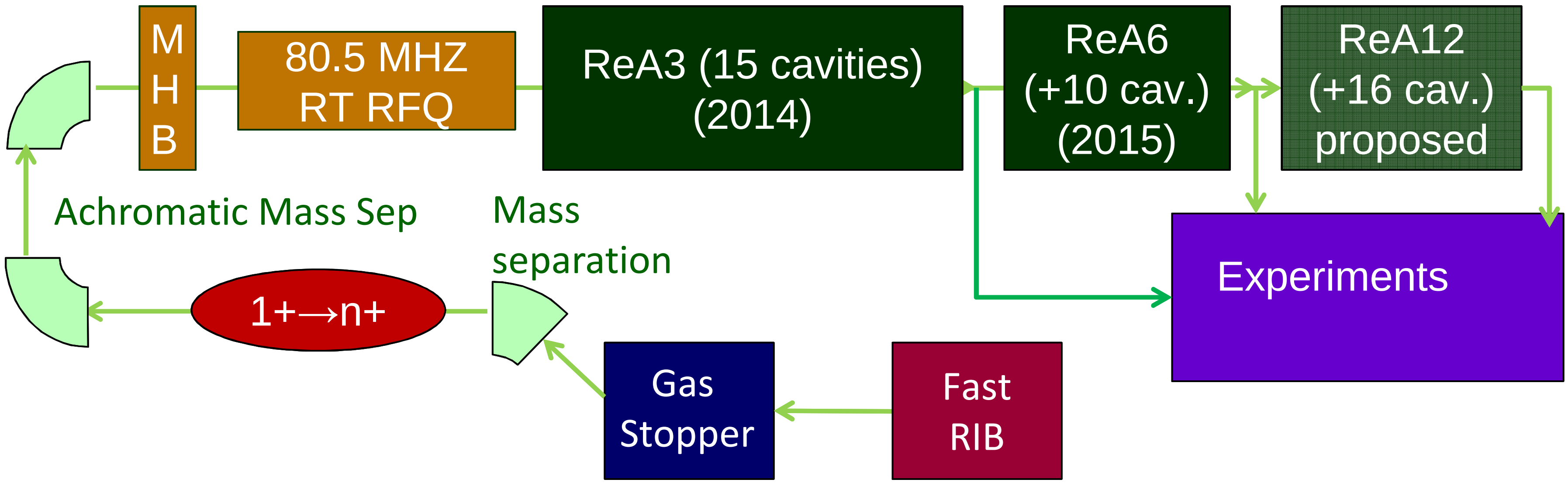
In-flight Fragmentation Offers A Wide Variety Of Rare Isotopes

At the Coupled Cyclotron Facility at MSU (≈10 years of operations) more than 1000 RIBs have been produced and more than 870 RIBs have been used in experiments with > 90% availability



Average experiment: primary beam 120 hrs, several secondary RIB beam changes

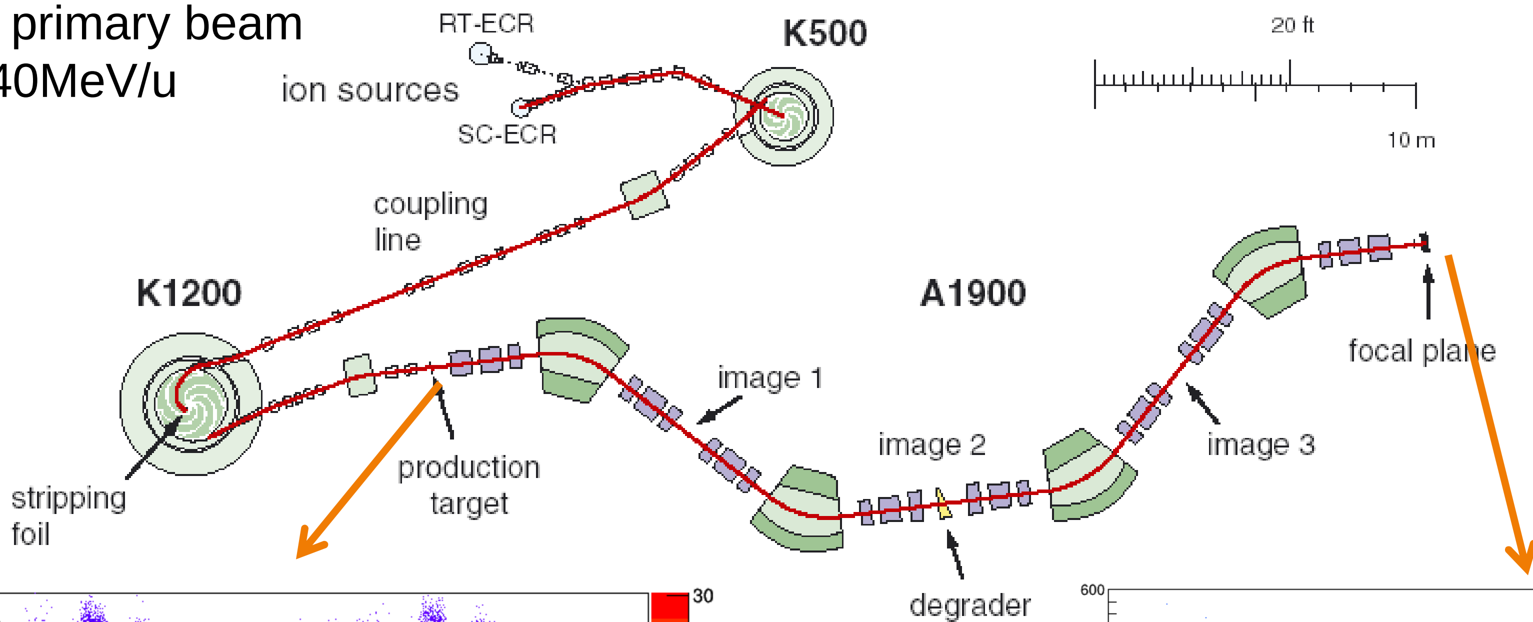
ReA SC Post-Accelerator – 3 stages
(41 SC SRF cavities)

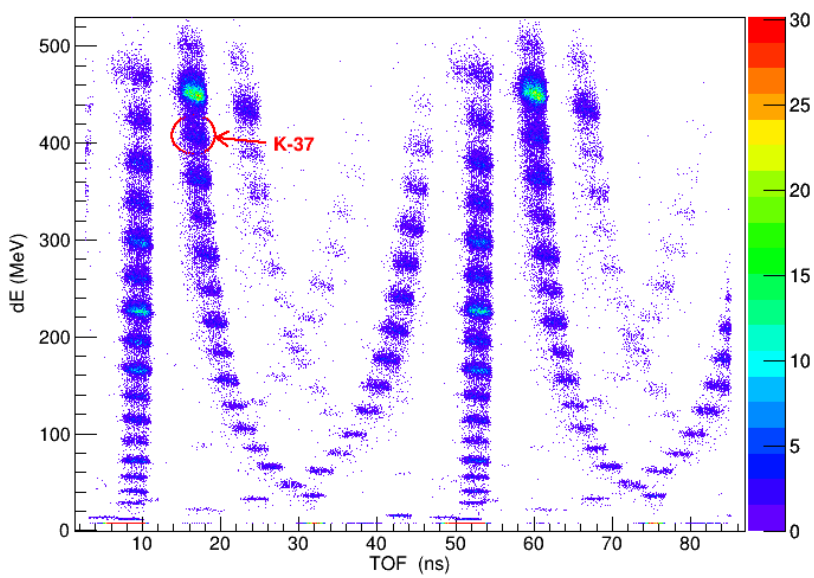


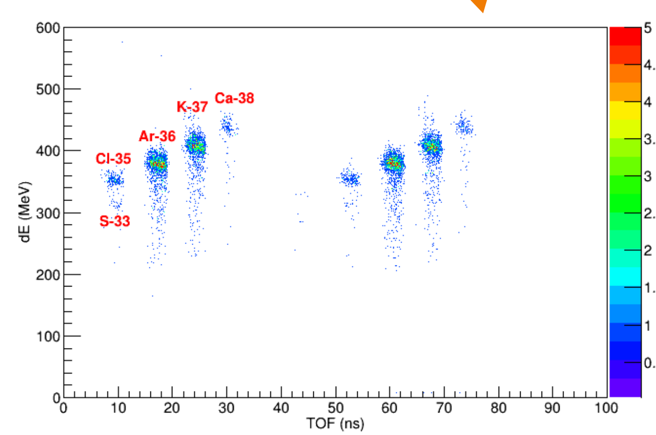
Requirements : Variable energies 300keV/u – 12MeV/u		
Ionization efficiency for all elements	> 20 %	EBIT charge breeder + high efficiency linac
Beam rate capabilities	10^8 ions/sec	Hybrid EBIS/T charge breeder
High beam purity		A1900, EBIT CB, Q/A
Low energy spread, short pulse length	1keV/u, 1nsec	Multiharmonic external buncher and tight phase control in SRF linac

Rare Isotope Beam Production

^{40}Ca primary beam
At 140MeV/u



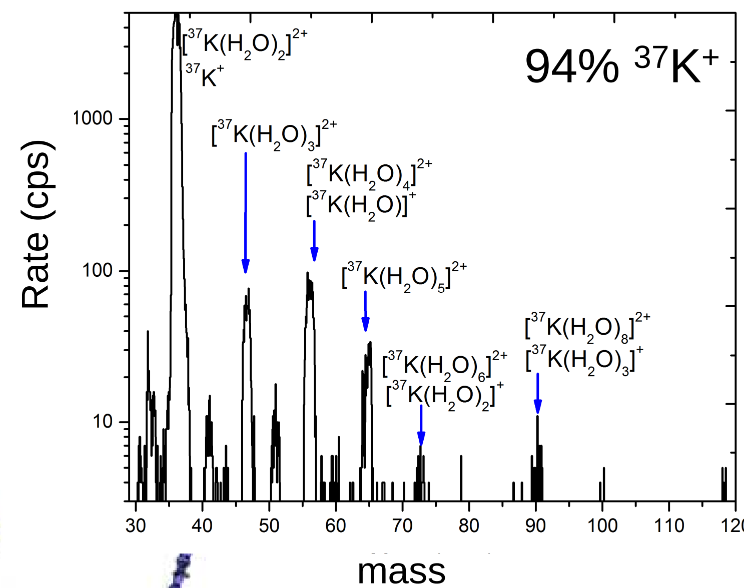




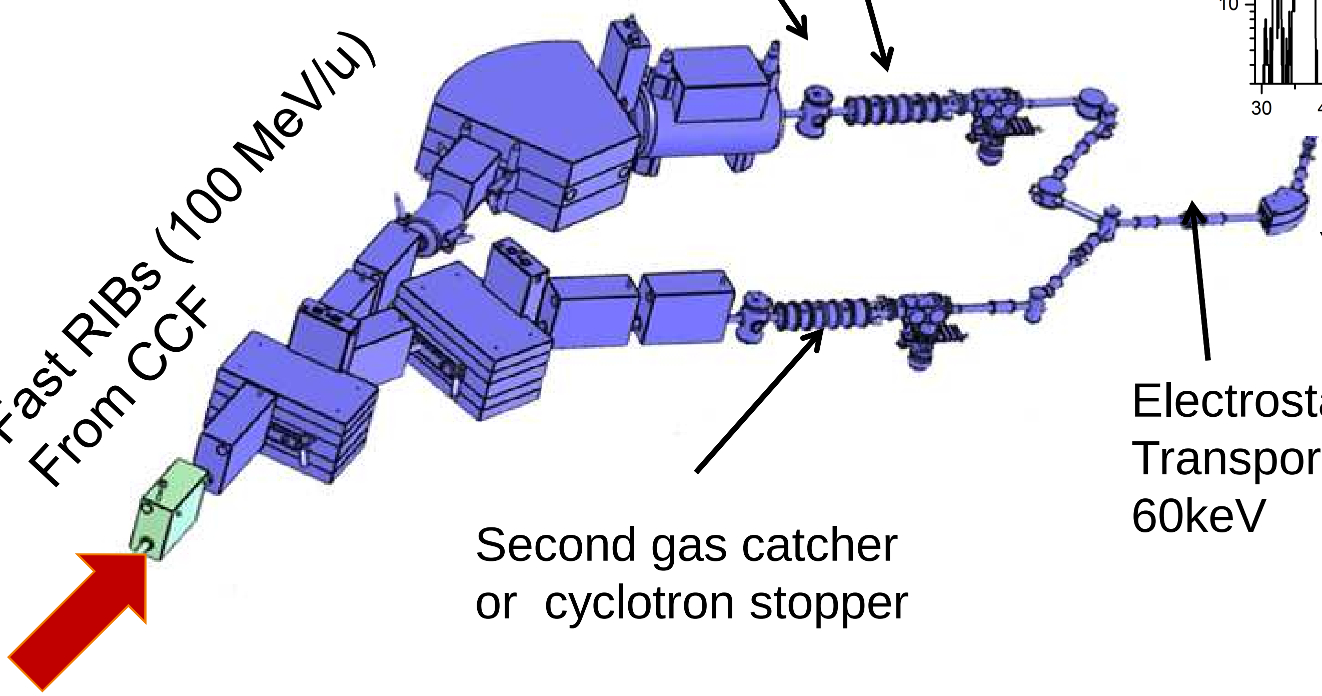
Production rate ~1.3E5 PPS/pnA,
Purity for K-37 ~ 50%
dp/p = 0.5%

Rare Isotope Beam Thermalization: RIB Beams Gets Further Purified

ANL 1.2 m long linear gas cell
High purity helium: ~ 90 Torr, -5^{0}C
Thermalizes RIB ions to < 1eV
Singly and doubly charged



Variable degrader and wedge for further purifying the beam



Analyzing Magnet

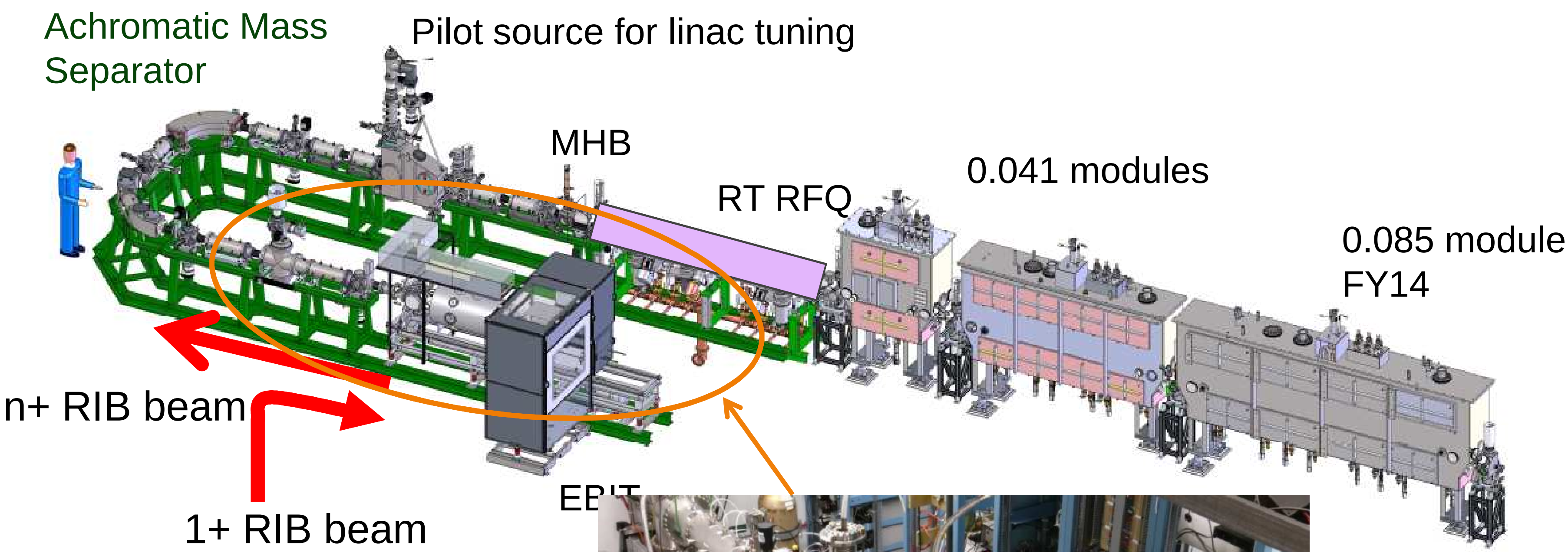
Electrostatic Transport Line at 60keV

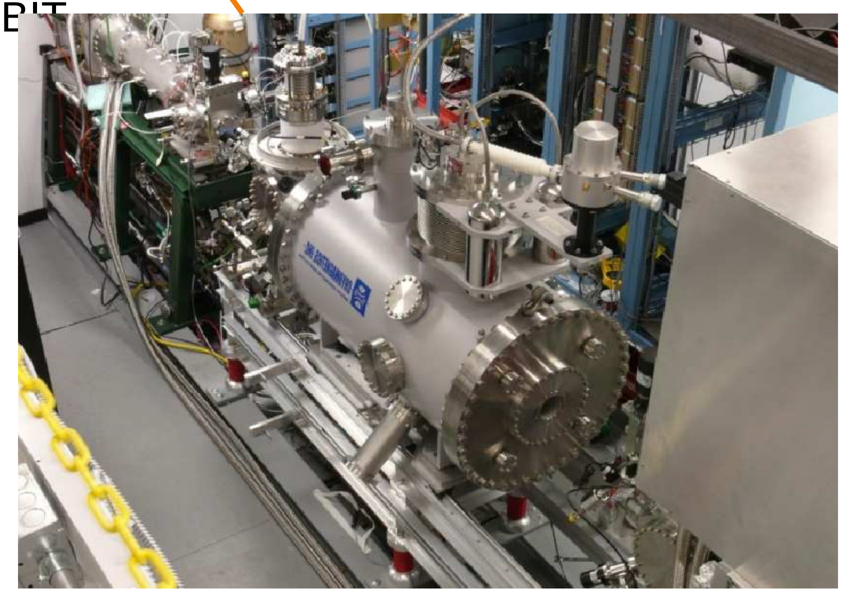
Second gas catcher or cyclotron stopper

MOPMA07, J.A. Rodriguez et al, “The D-Line Project at MSU”

Rare Isotope Beam Thermalization Station

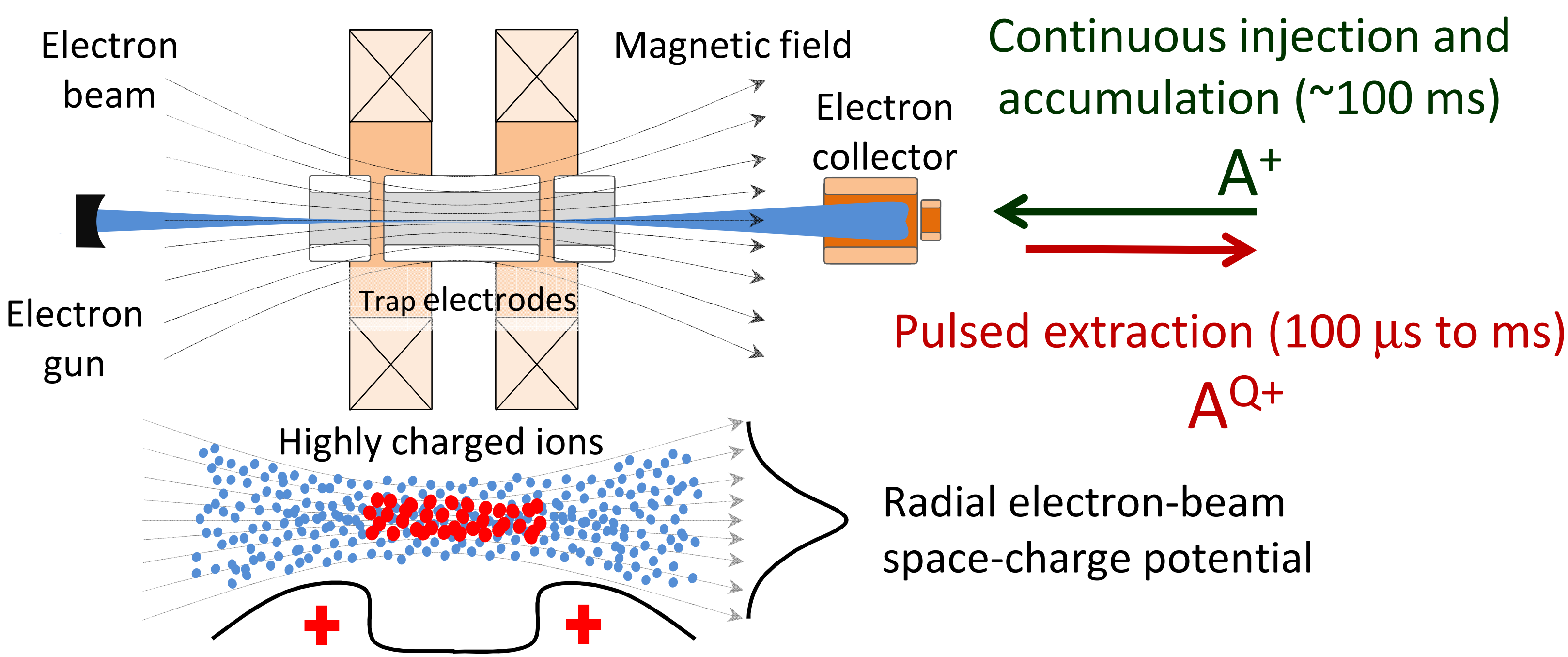
ReA Design Choices: EBIT Charge Breeder





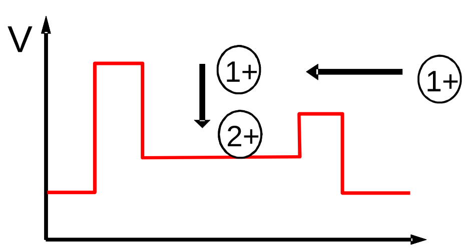
EBIT:
- Short breeding time
- High ionization efficiency
- Charge state flexibility
- Low beam contamination
- $0.5 \geq Q/A \geq 0.2$

Charge Breeding In The EBIT Source



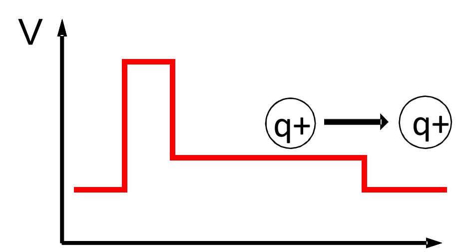
Axial potential well from the trap electrodes

Over-the-potential barrier injection



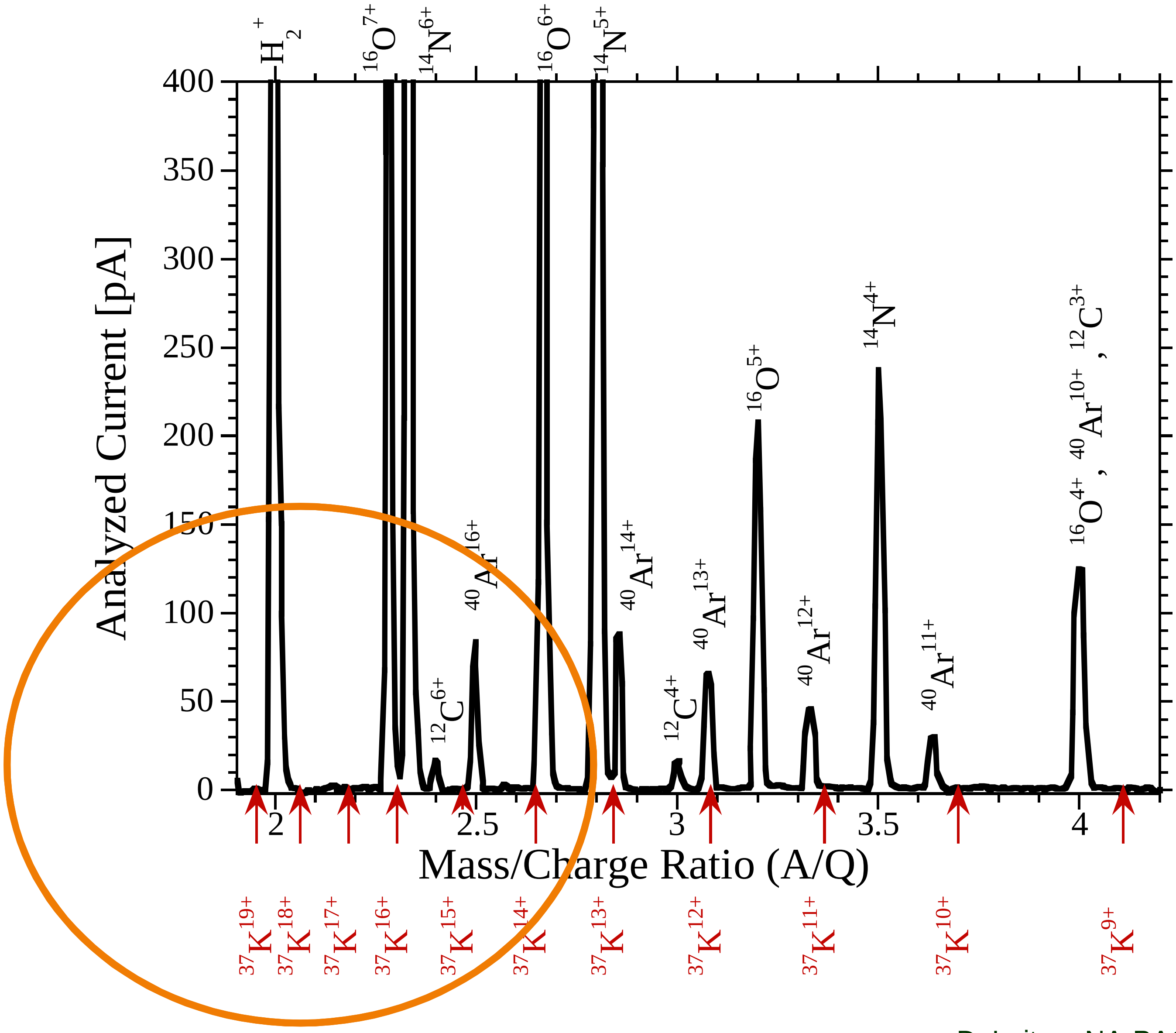
Continuous injection

Lower-the-barrier extraction

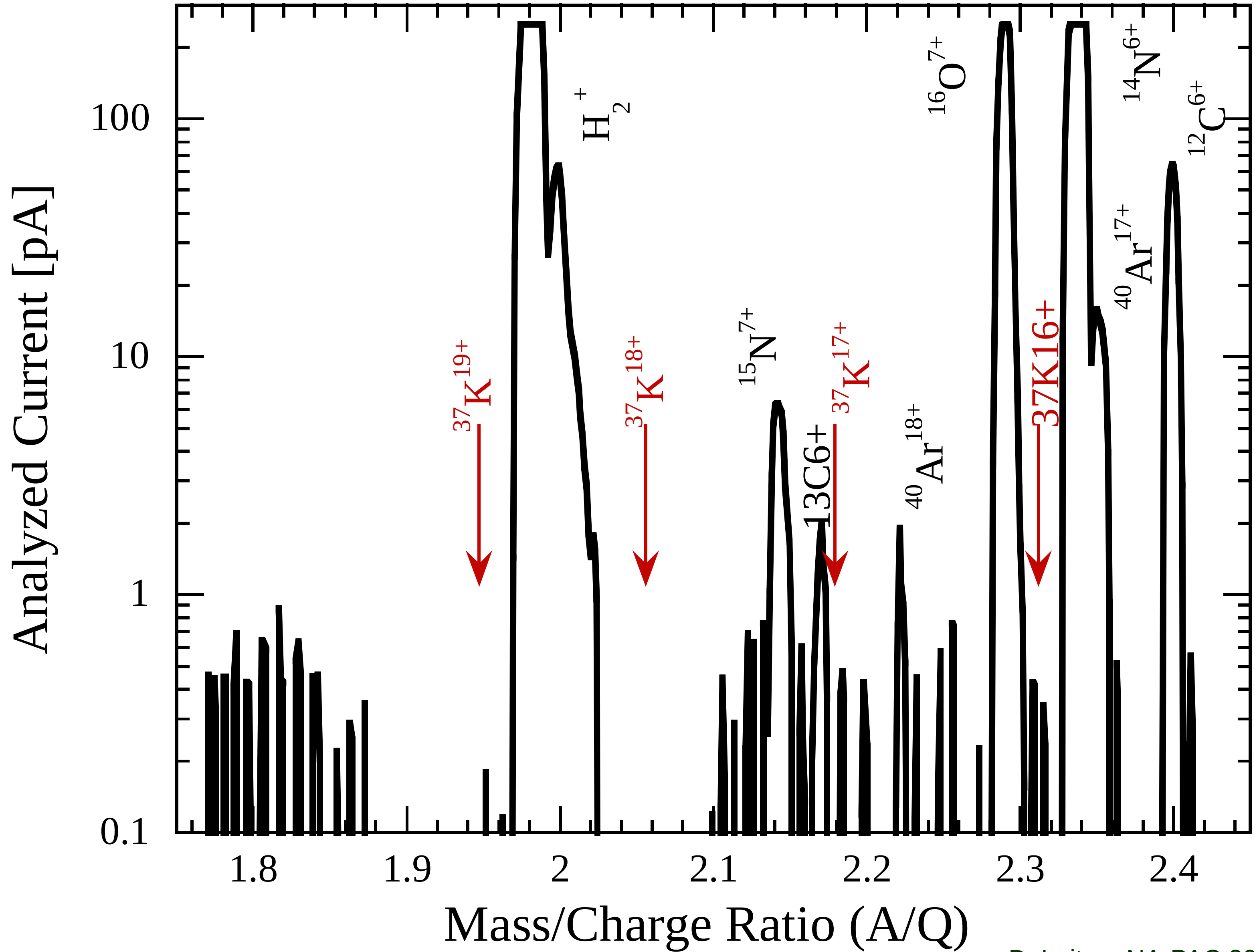


Pulsed extraction

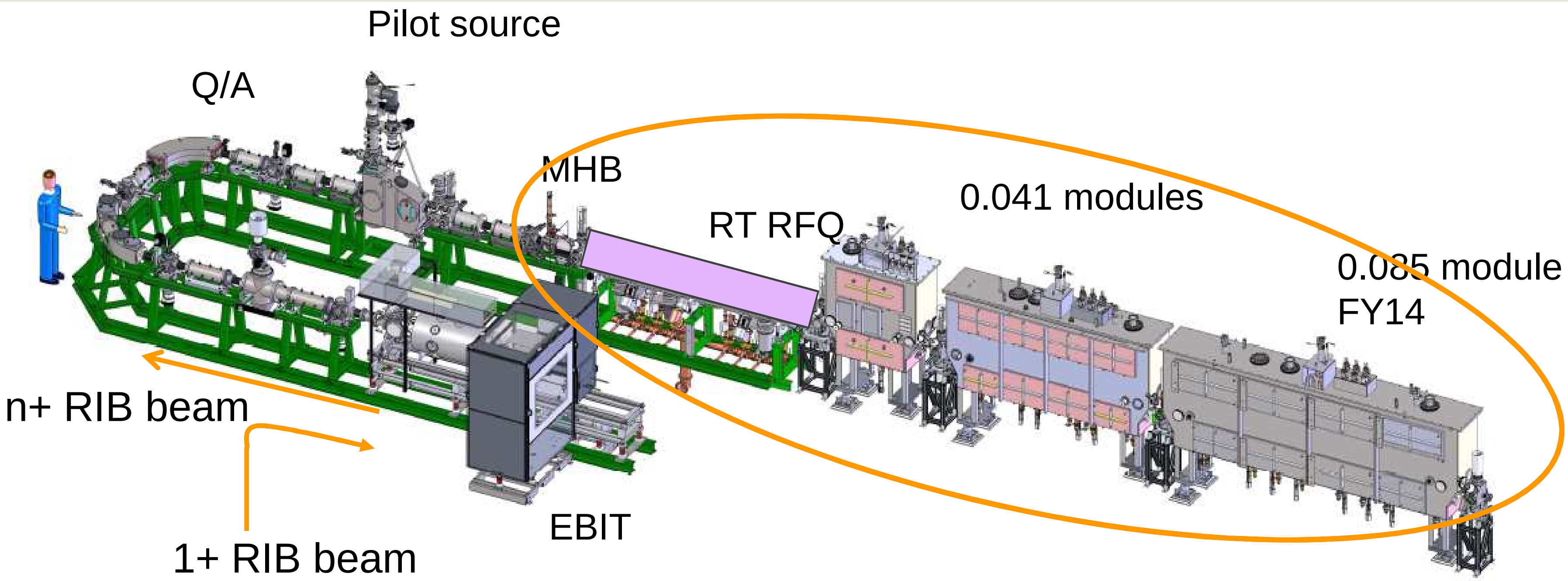
EBIT Background Spectrum And Selection Of ^{37}K Charge States



Background ion intensities from the charge breeder in the region of interest are less than 1 pA



ReA Design Choices: RT-RFQ With External Buncher And High Efficiency SC-Linac

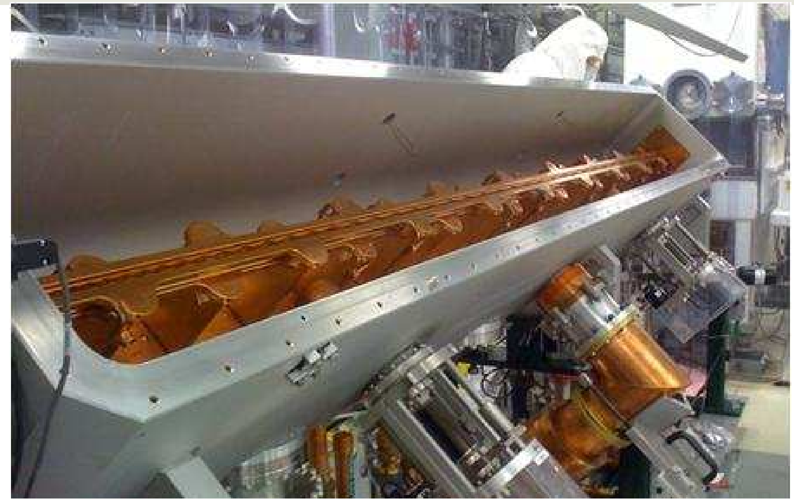


SRF LINAC

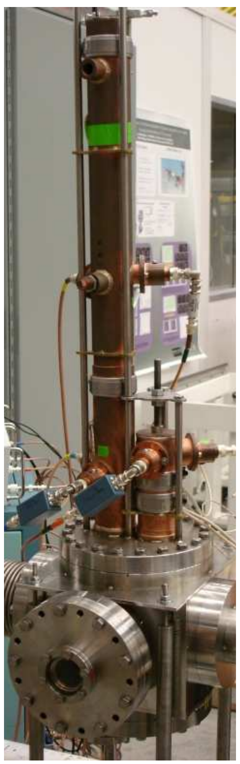
- 80.5 MHz RF frequency
- Flexible energy range (deceleration 300keV/u to maximum linac energy in small steps
- External multi harmonic buncher to minimize the longitudinal emittance

Room Temperature Radio Frequency Quadrupole (RFQ)

- Pulsed operation (160kW, 25%)
- Energy Boost: 12 keV/u - 600 keV/u
- 4-rod structure, 92 cells, 3.3 m long
- Buncher : 80.5MHz, 161MHz, (241.5 MHz)
- Nom 82 % beam capture measured

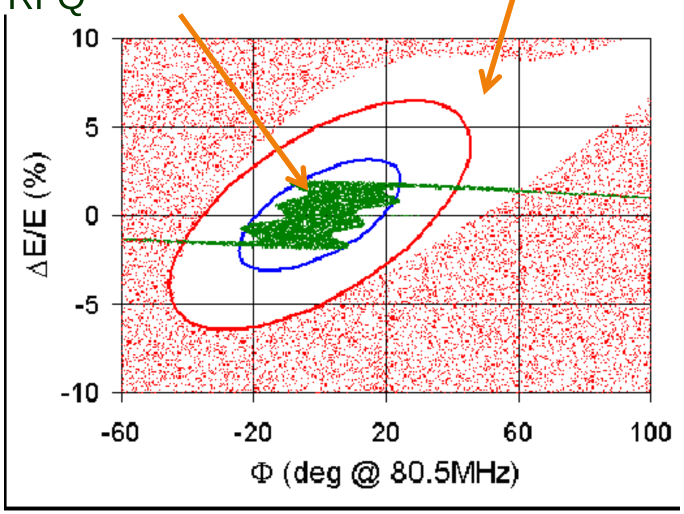


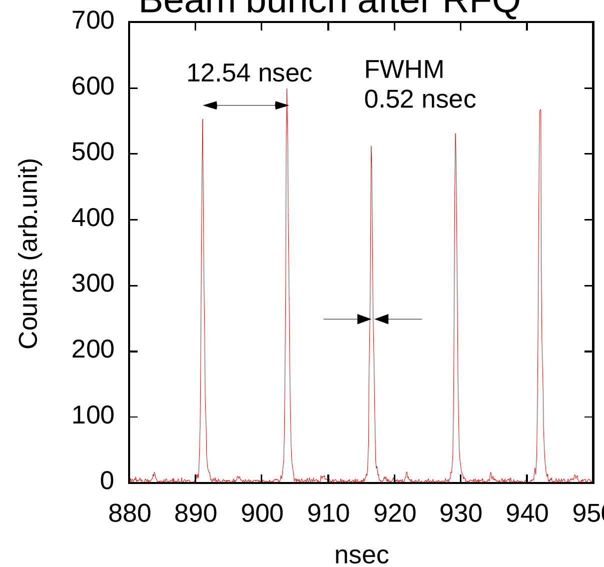
MHB



Longitudinal acceptance (white area)

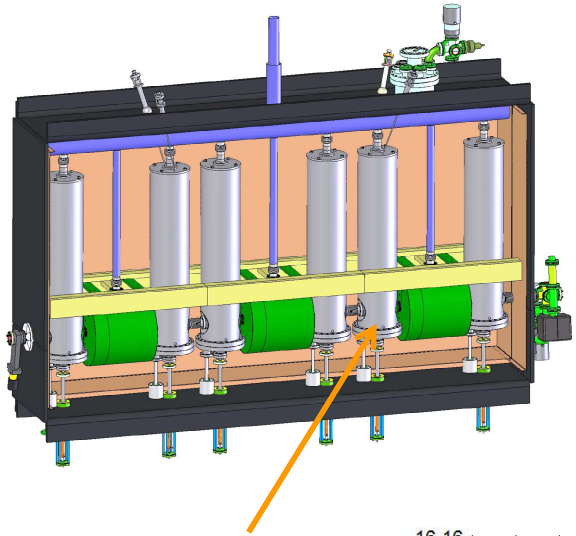
Beam at the entrance of RFQ



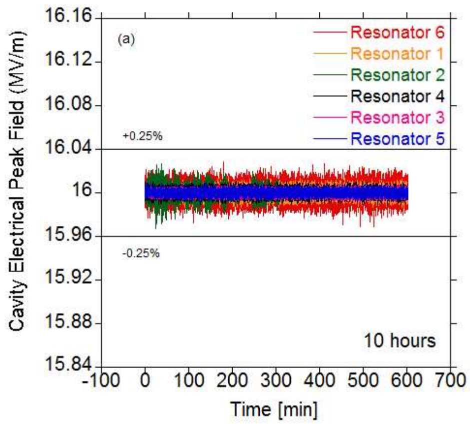


Q. Zhao et al., PAC'07; D. Leitner et al, PAC'11; W. Wittmer et al., NA-PAC'13 (MOPSM07)

Compact Superconducting Linac With 2 Types Of Quarter Wave Resonators



- 7 β=0.041 cavities are in operation since 2010 with excellent performance and stability
- Routinely operated at 160% of the specified gradient



Measured Phase and Amplitude Stability		
Cavity	Phase Std dev (deg)	Amplitude Std dev (%)
82	0.149	0.025 %
84	0.207	0.009 %
85	0.043	0.018 %
88	0.14	0.013 %
89	0.06	0.020 %
91	0.248	0.046 %

D. Leitner et al., SRF'2011

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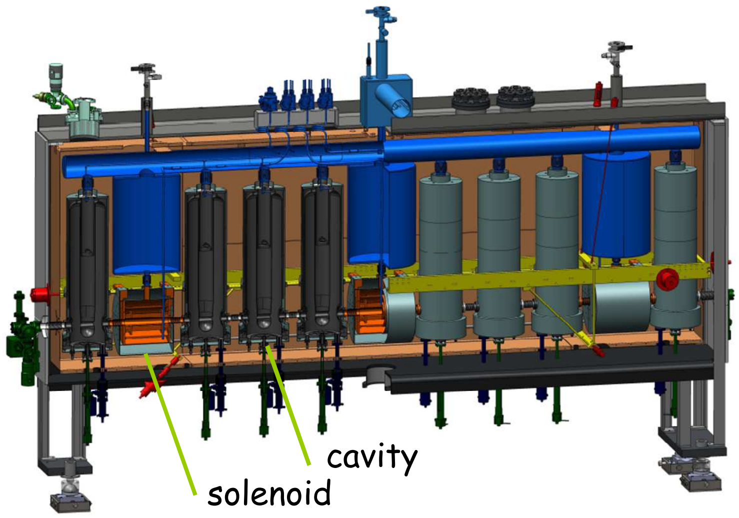
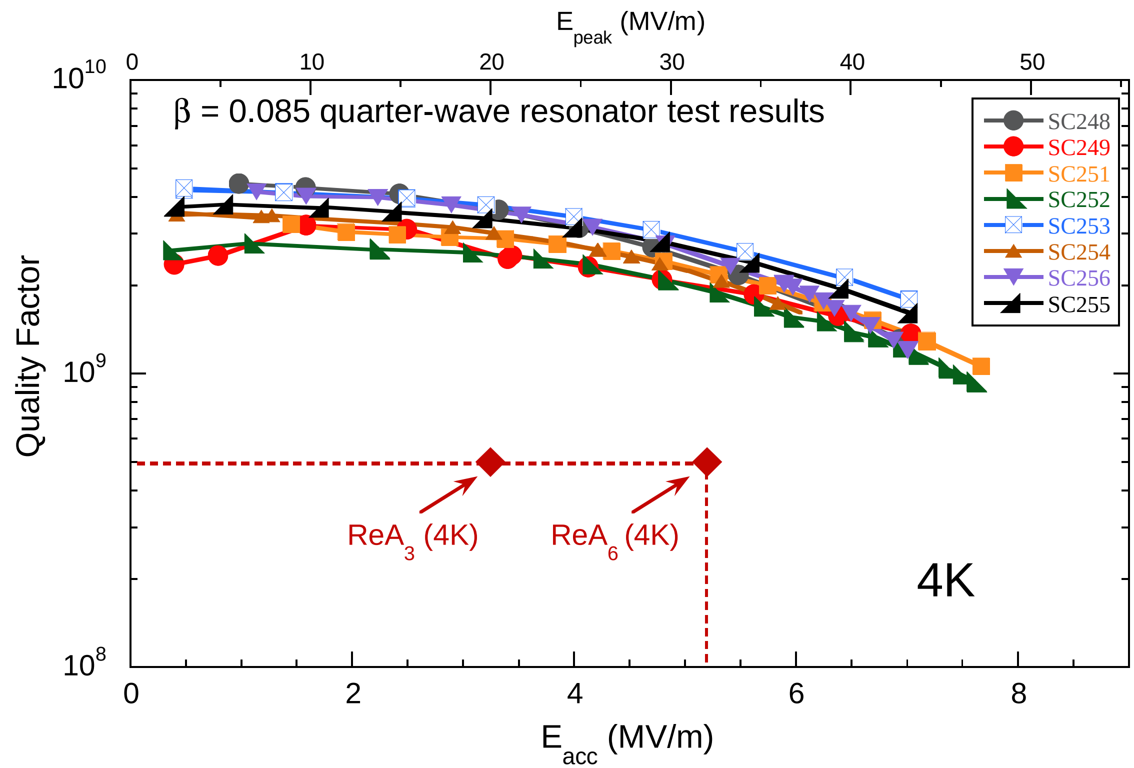


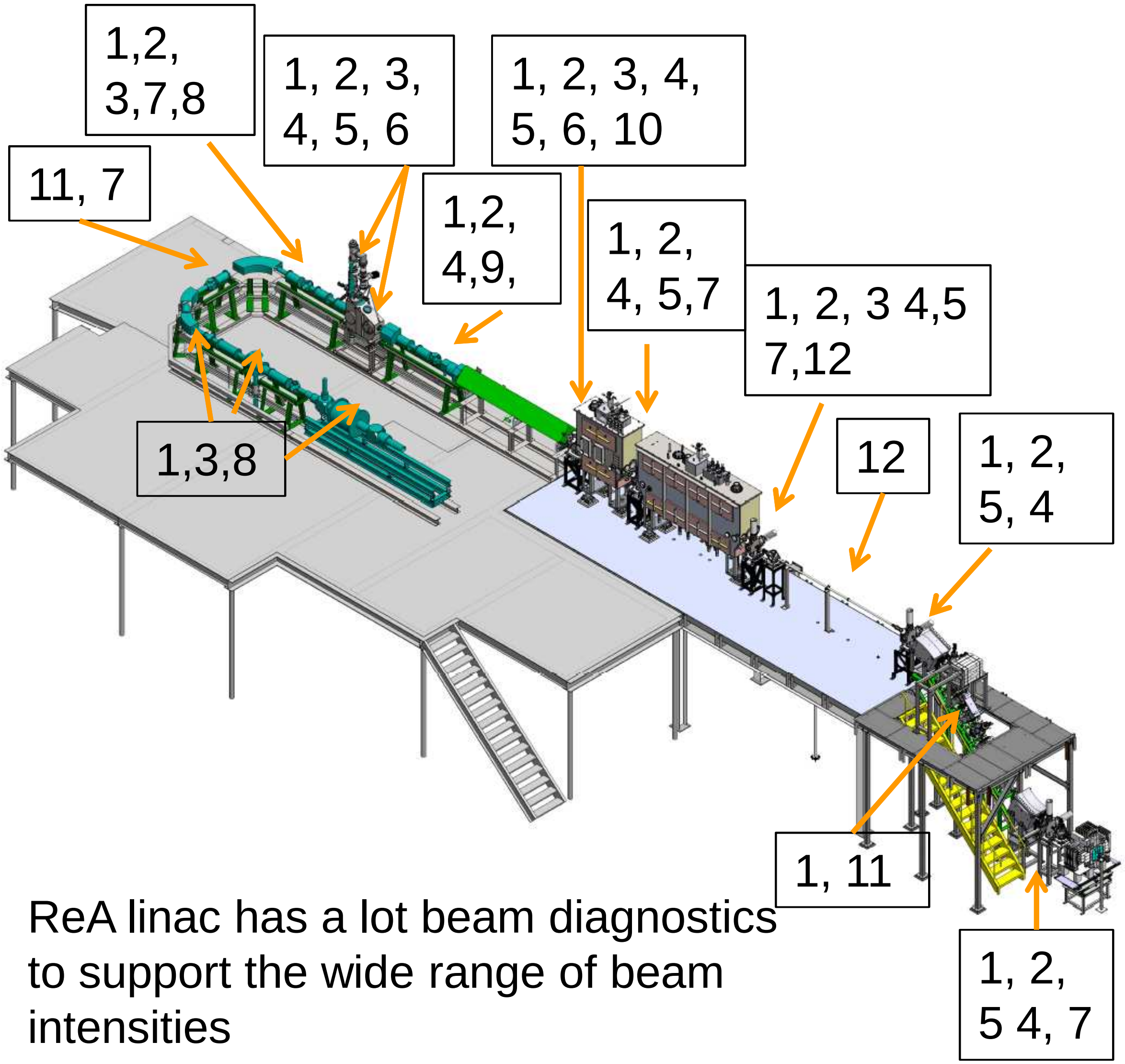
- Cryomodule 3 will be installed and commissioned in the in 2014
- β=0.085 cavities were redesigned to reliably provide high gradient acceleration fields



- Eleven β=0.085 cavities have been tested (all tested well above specifications)
- CM4 (FRIB prototype) 2015, novel bottom up design

FRYBA1, J. Wei et al, "Progress towards the Facility for Rare Isotope Beams"
A. Facco et al., IPAC'2012

Diagnostic Systems Are Very Challenging For RIB Post-accelerators (Dynamic Range 10 pps To 10^{12} pps)

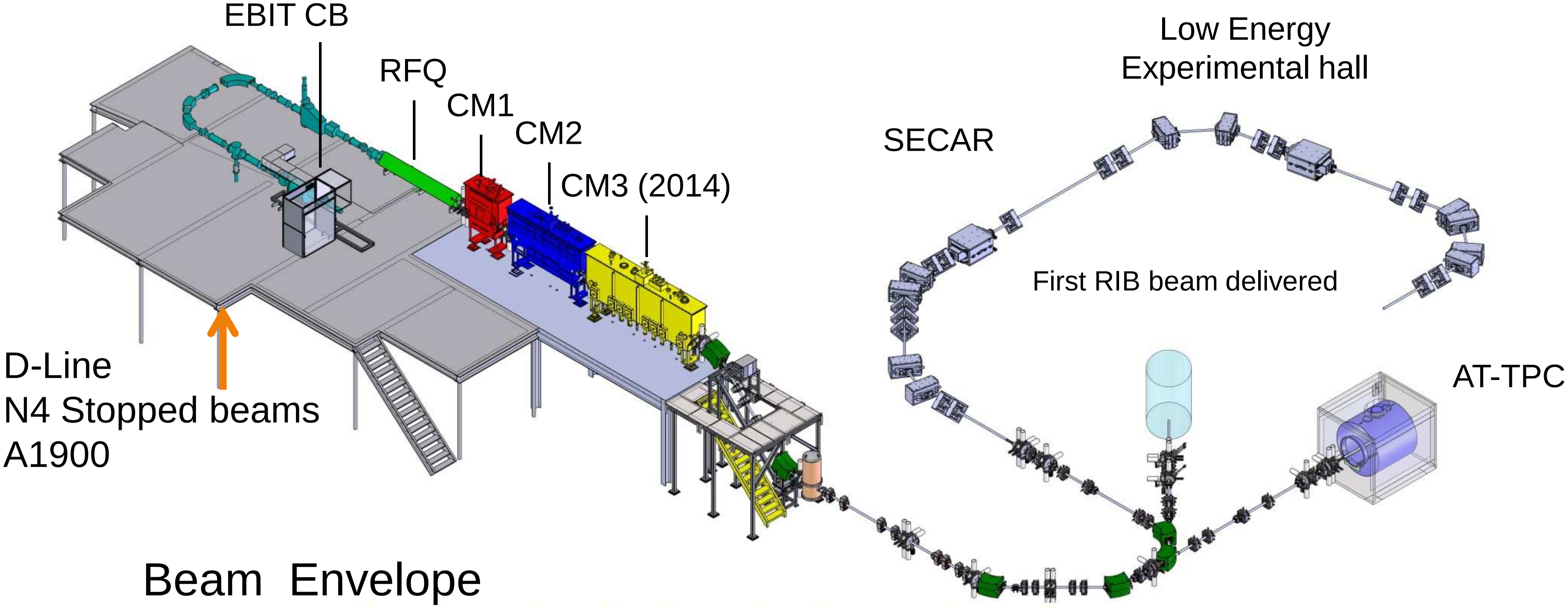


ReA linac has a lot beam diagnostics to support the wide range of beam intensities

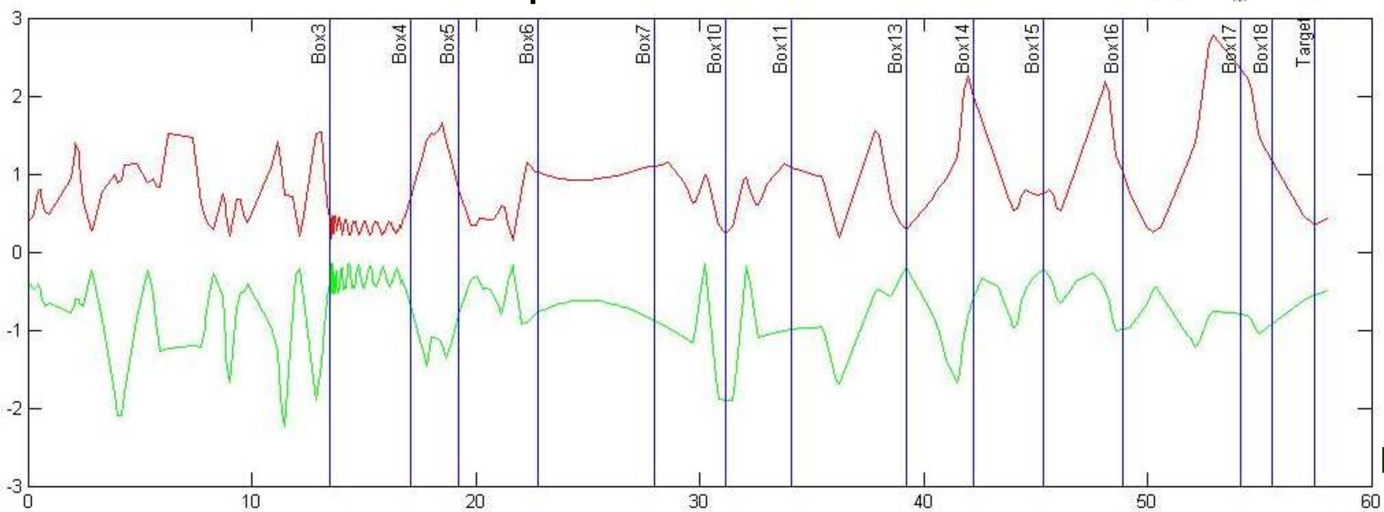
	Diagnostics
1	FC
2	Slit profile monitor
3	Viewer, MCP or crystals
4	Bunch lengths, timing
5	Slits, aperture
6	Attenuators
7	Detectors (decay, scattering, in beam)
8	MCP, TOF
9	Pepperpot
10	Emittance Scanner
11	Energy defining slits
12	BPM

ReA Beam Line Is Well Understood

Design compares well with the actual tuning parameters of the beam line



Beam Envelope

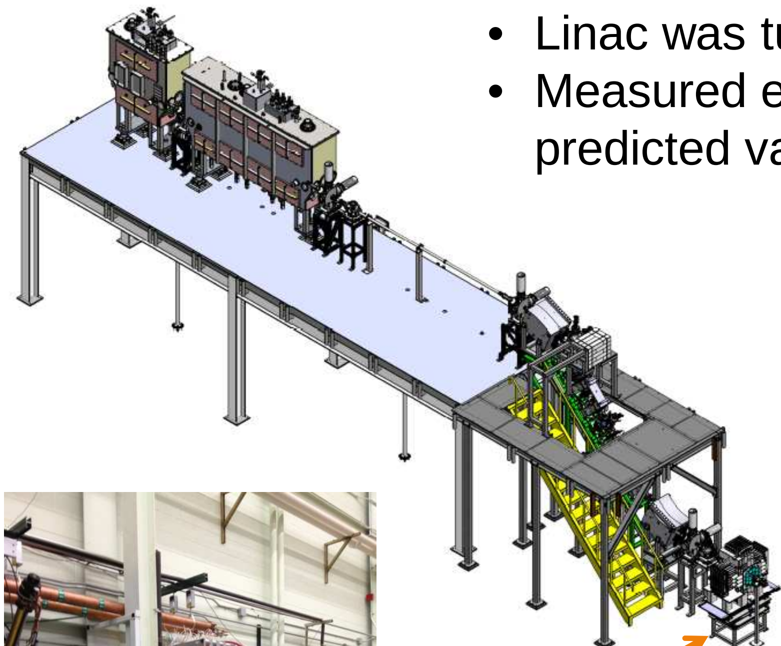


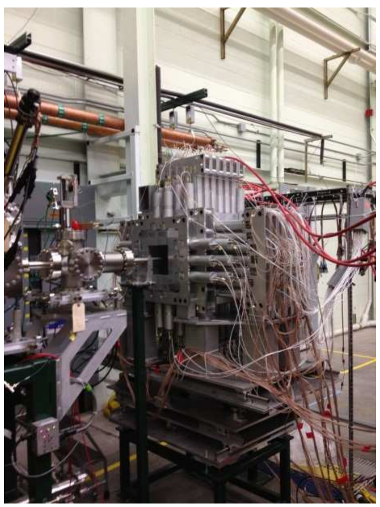
Linac transmission
RIB beams
≈ 70%

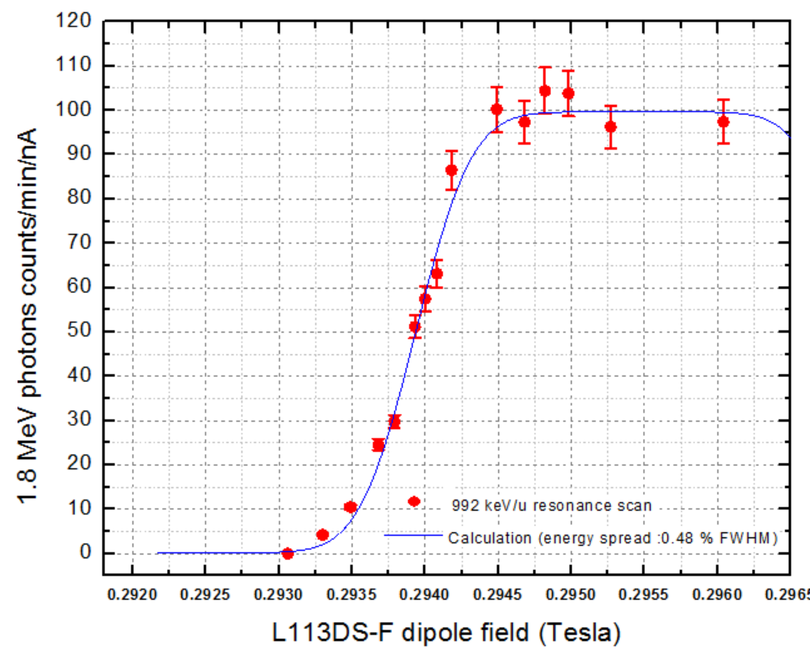
MOPSM07, W. Wittmer et al.

The ReA Linac (CM1+CM2) Was Characterized Using Stable Beams

- Absolute energy calibration of ReA using 992 keV Al(p,γ) resonance
- Linac was tuned in 2keV energy steps
- Measured energy spread of 0.5% FWHM is close to predicted value



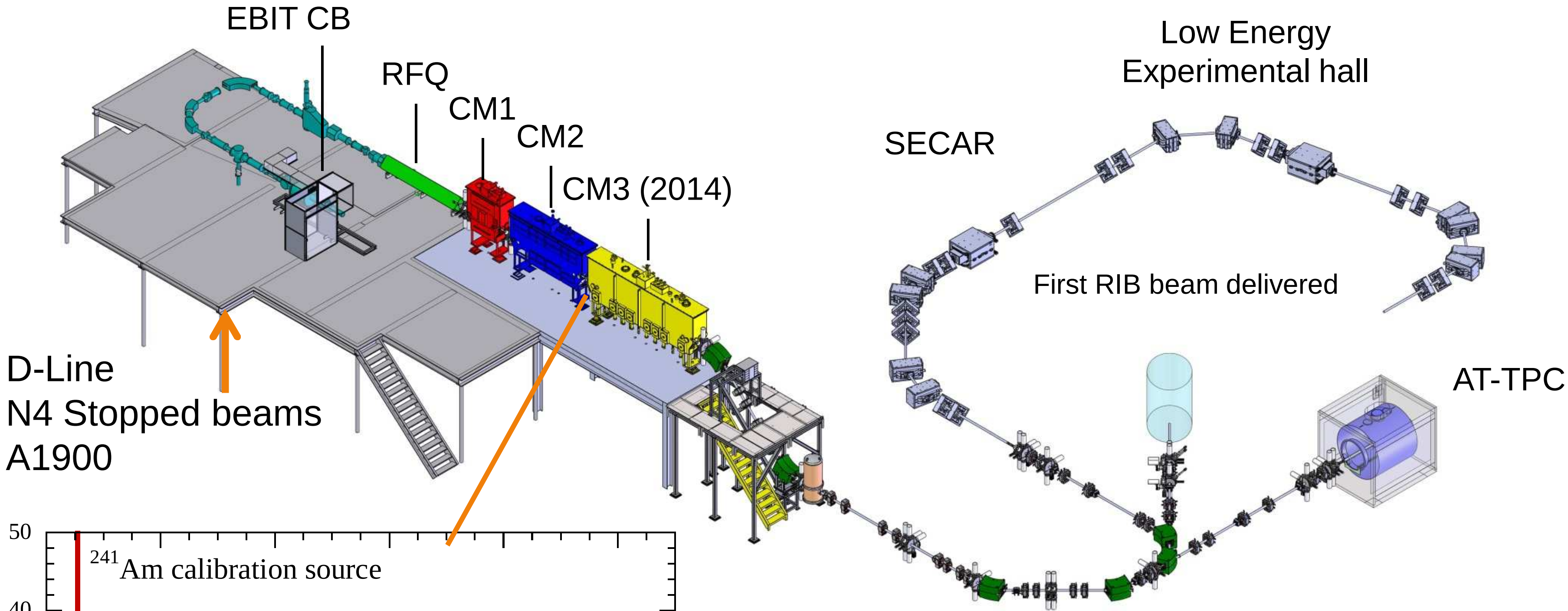


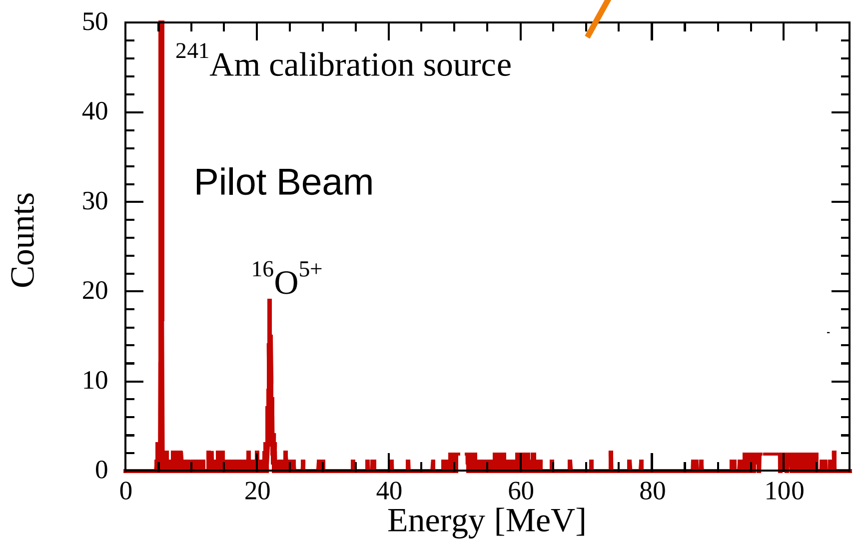


CAESAR Detector Array

L. Ling-Ying et al., manuscript under preparation

For Rare Isotope Beam Operations Pilot Beams Are Used To Pre-tune The Linac





MOPSM07, W. Wittmer et al.

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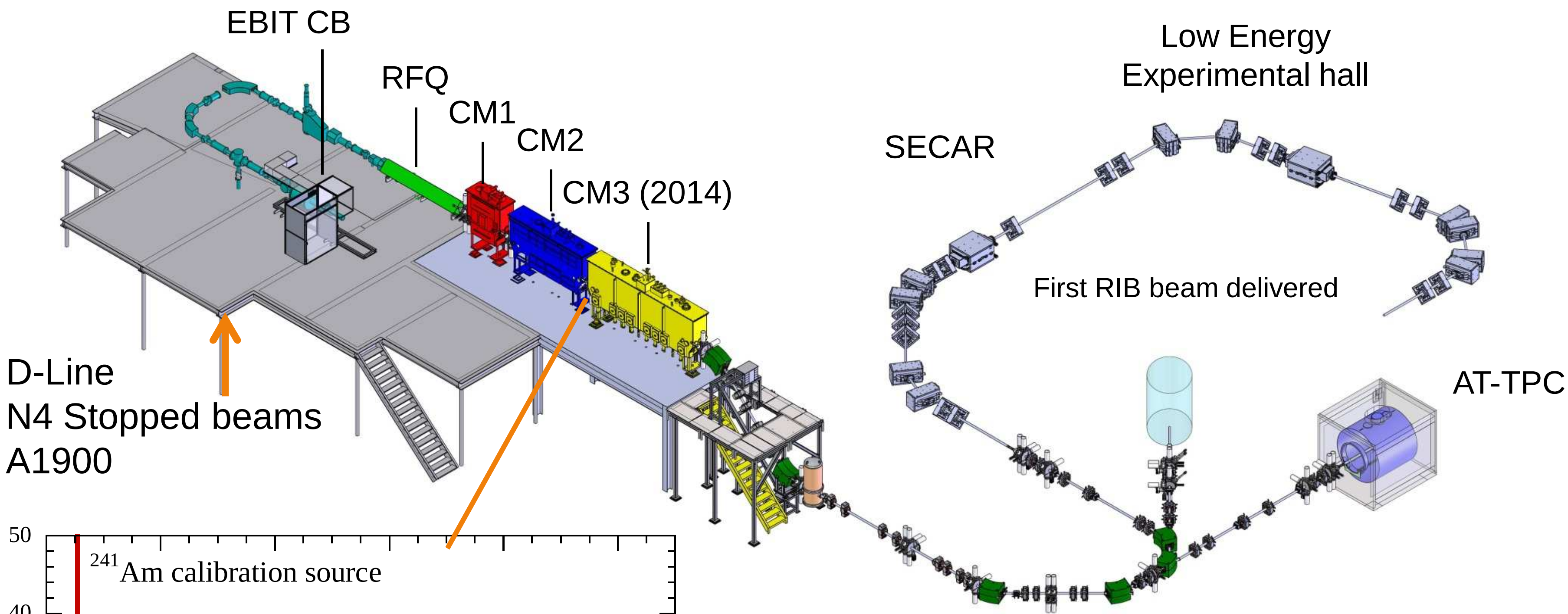

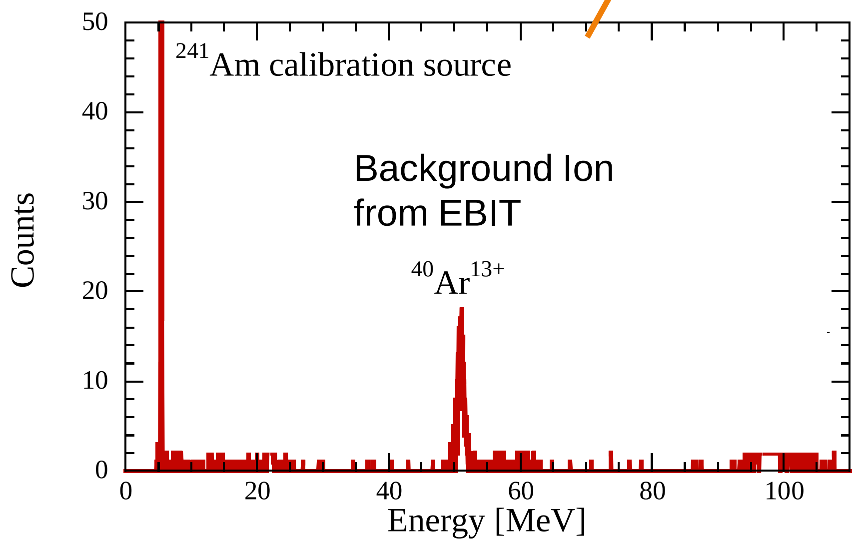

MOPSM07, W. Wittmer et al.

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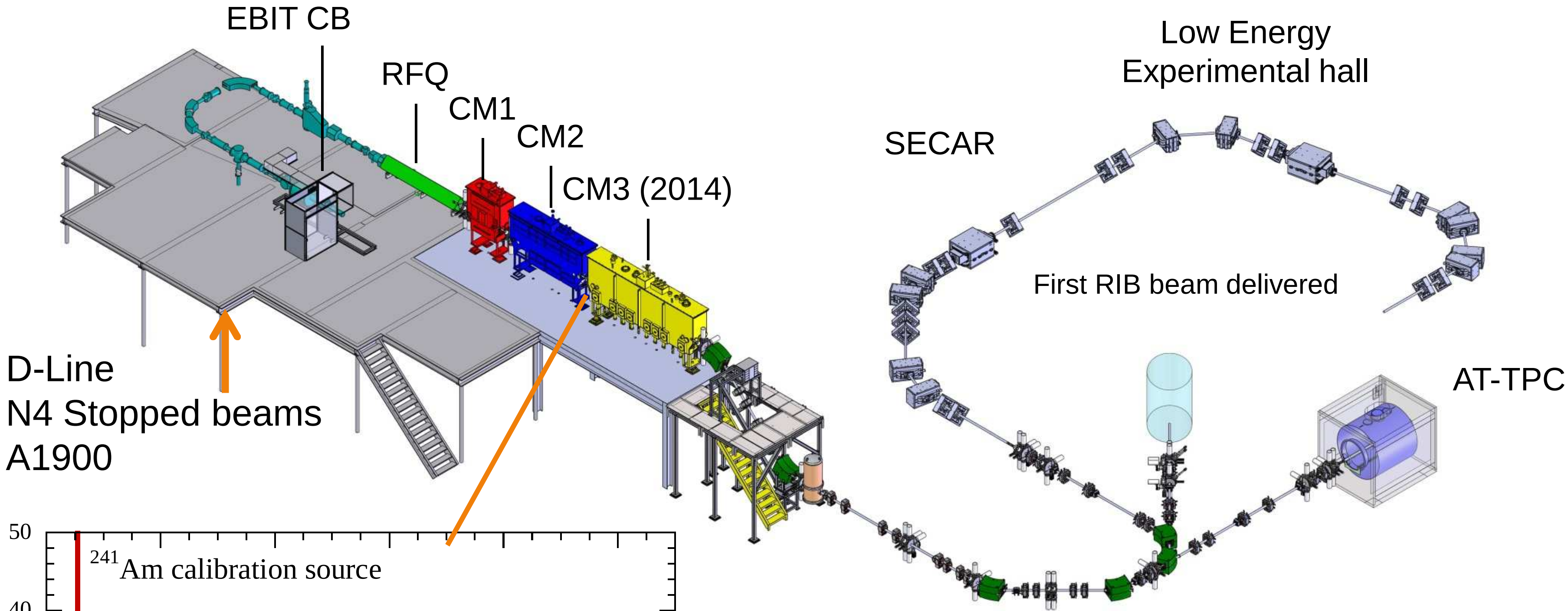

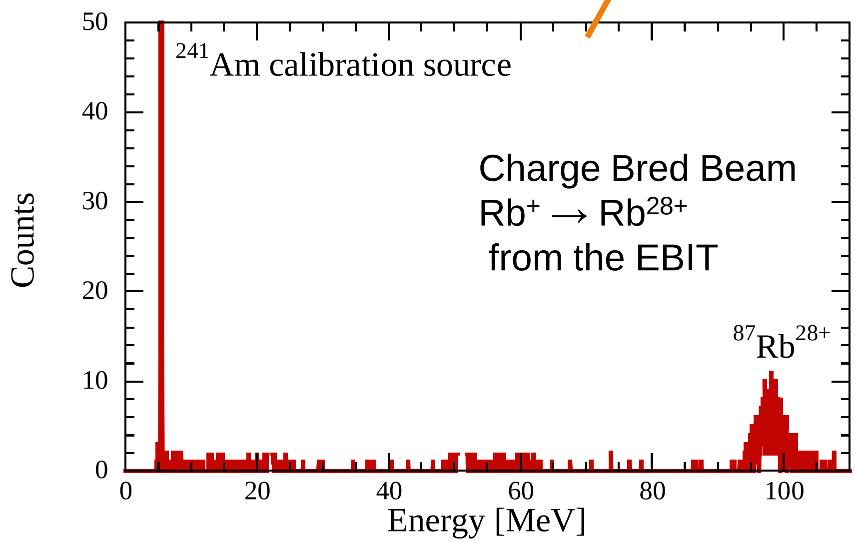

MOPSM07, W. Wittmer et al.

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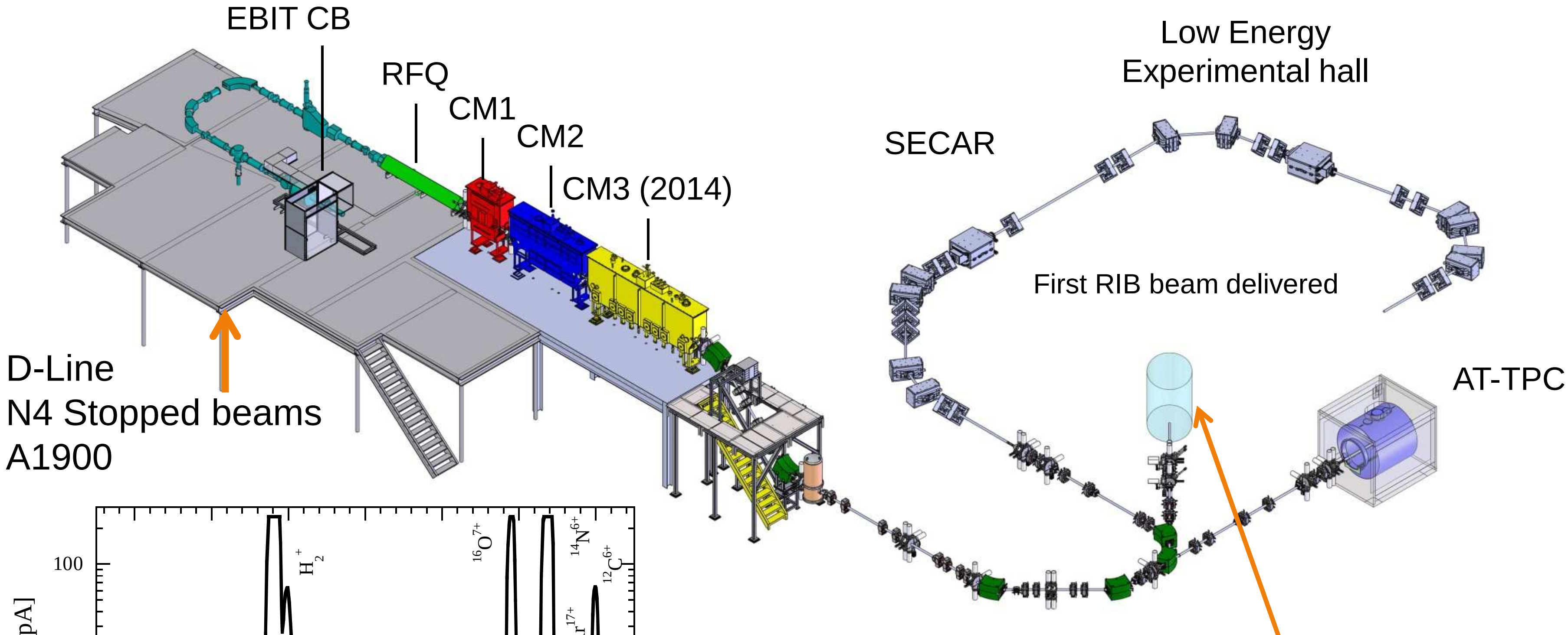

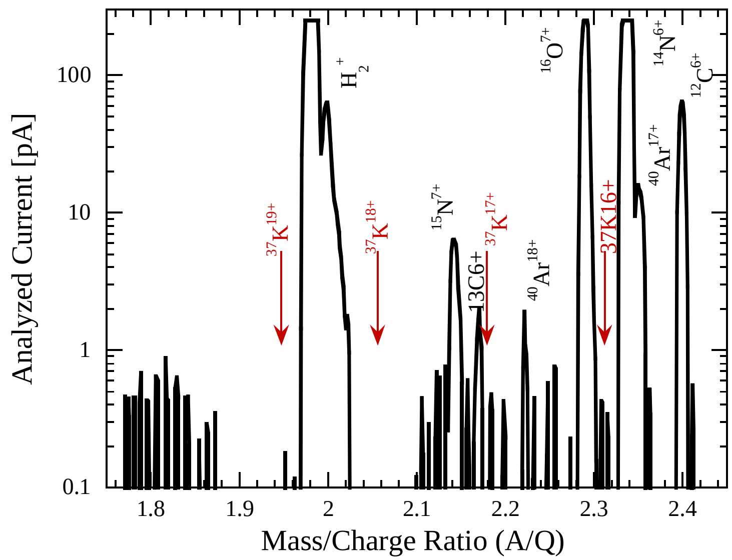

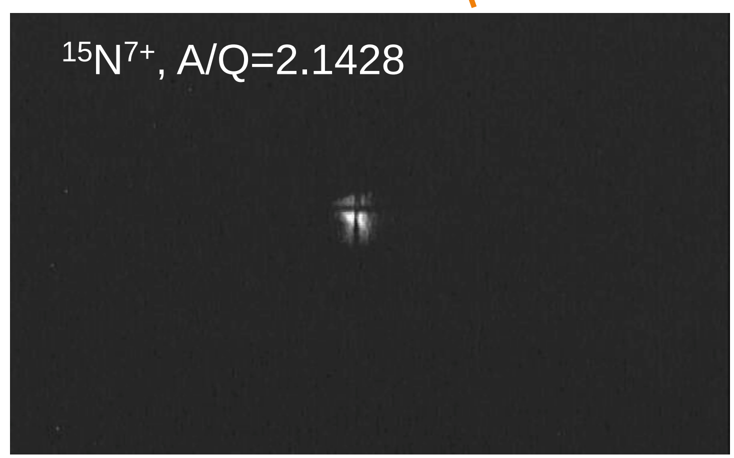

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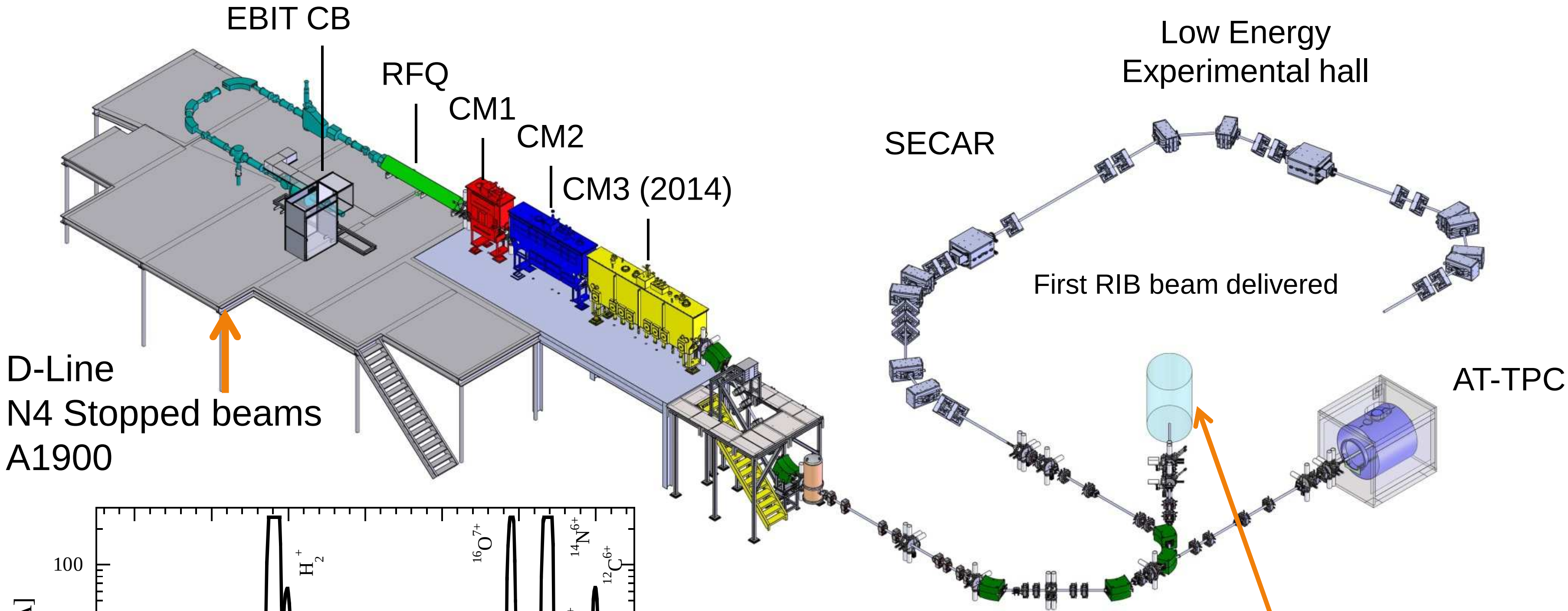
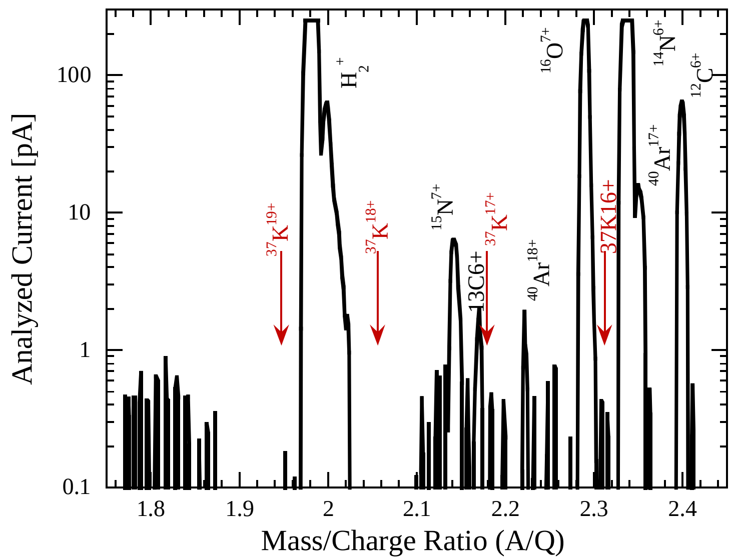
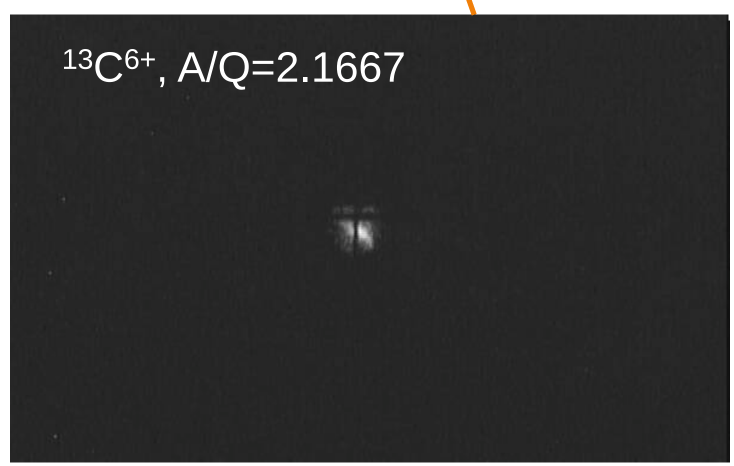
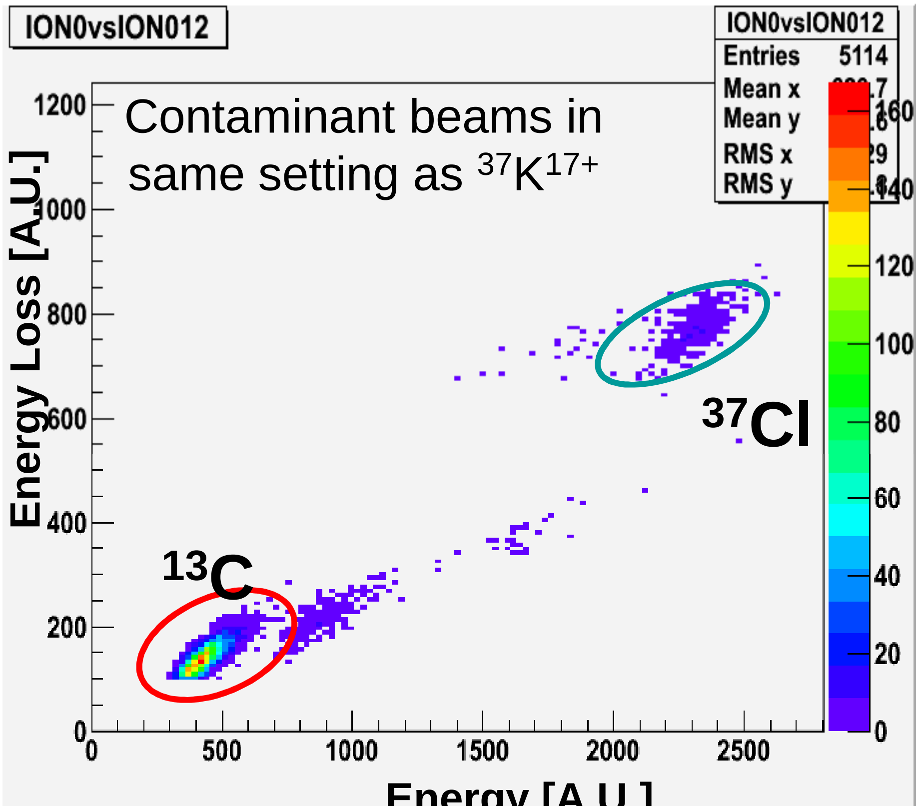


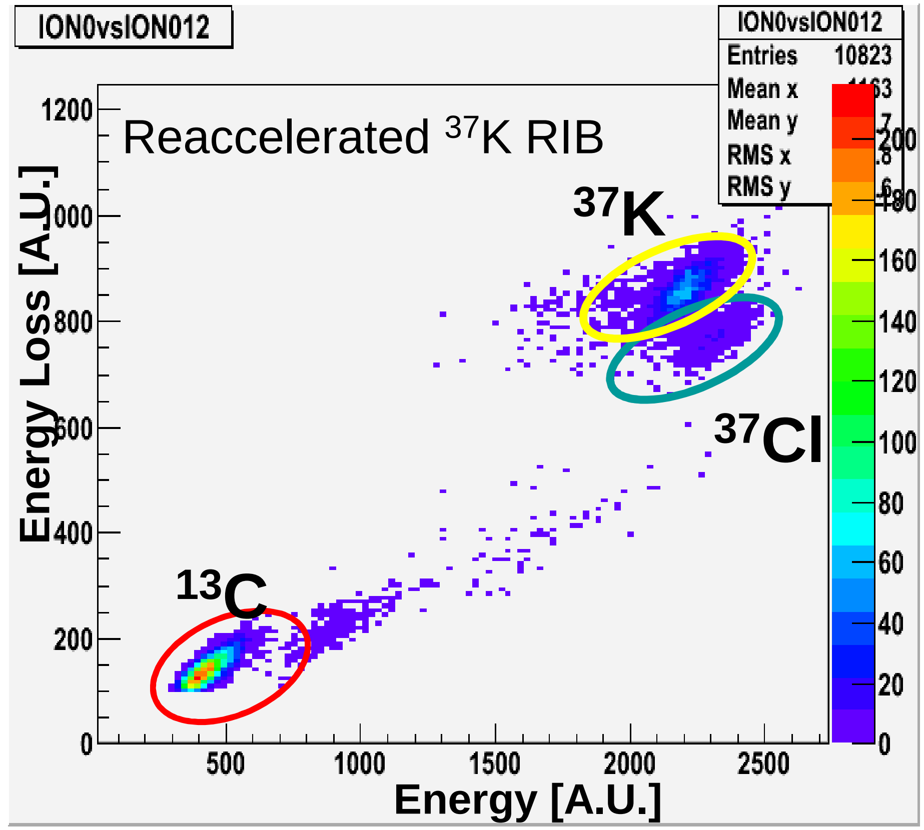




MOPSM07, W. Wittmer et al.

Radioactive Ion Beam Measured In The ANASEN Ionization Chamber





First radioactive ion beam delivery to user 8/20/2013!

Summary

- ReA is the first post-accelerator coupled to a fragmentation facility
- The EBIT charge breeder provides high purity beams
- The SC cavities perform above specification and have been operated reliably since 2010
- Commissioning and final installations are progressing well, RIB beams below or close to the Coulomb barrier(light ions) will available for users in 2014
- The first radioactive ion beam was delivered to users in August of 2013
- ReA will serve as post accelerator for FRIB

Co-authors

D. Leitner[1,2], D. Alt[2], T. M.Baumann[2], C. Benatti[2], B. Durickovich[1], K. Kittimanapun[2], A. Lapierre[2], L. Ling-Ying, S. Krause[2], F. Montes[2], D. Morrissey[2], S. Nash[2], R. Rencsok[2], A. Rodriguez[1], C. Sumithrarachchi[2], S. Steiner[2], S. Schwarz[2], M. Syphers[2], S. Williams[2], W. Wittmer[1], X. Wu[1]

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

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