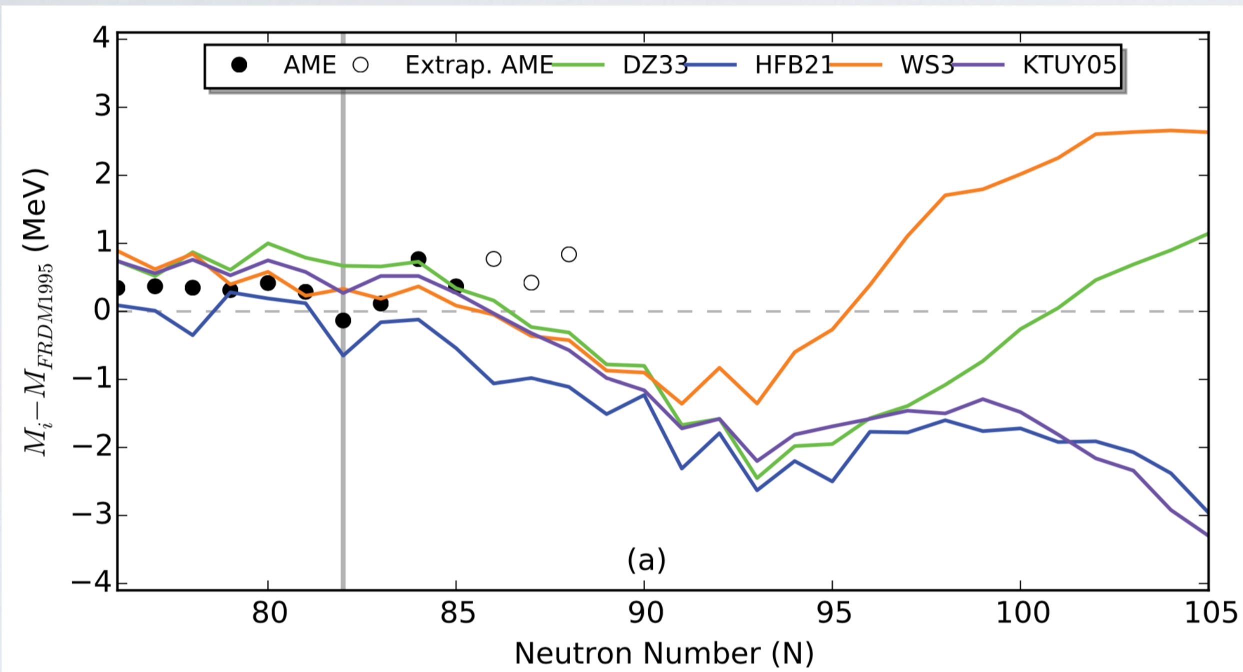
MR-TOF DEVELOPMENT AT THE UNIVERSITY OF NOTRE DAME

James Kelly

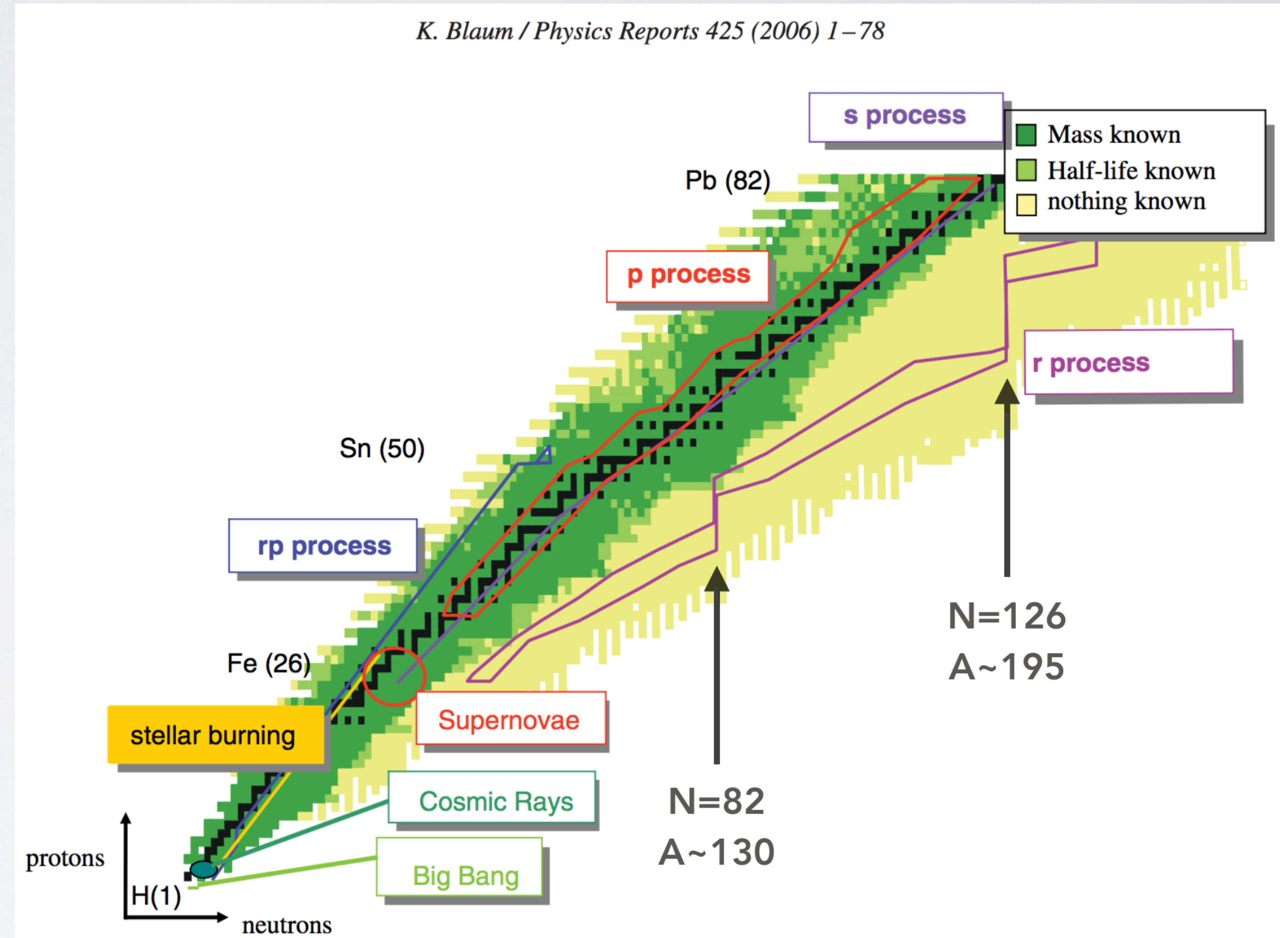
CS Workshop, GSI
21-24 March, 2016

OUTLINE

- Rapid neutron capture process
- N=126 factory at Argonne
- Notre Dame MR-TOF
- Control system



R. Surman, "The sensitivity of r-process nucleosynthesis…" (2013)



WHY MEASURE MASS?

Deformation
Shell structure evolution

R-process
Unrefined models

Limits of stability
Halos

R-PROCESS ABUNDANCES

- New paths blazed in neutron-richness - N capture outpaces photodissociation

- stellar nucleosynthesis abundance peaks seen around magic numbers

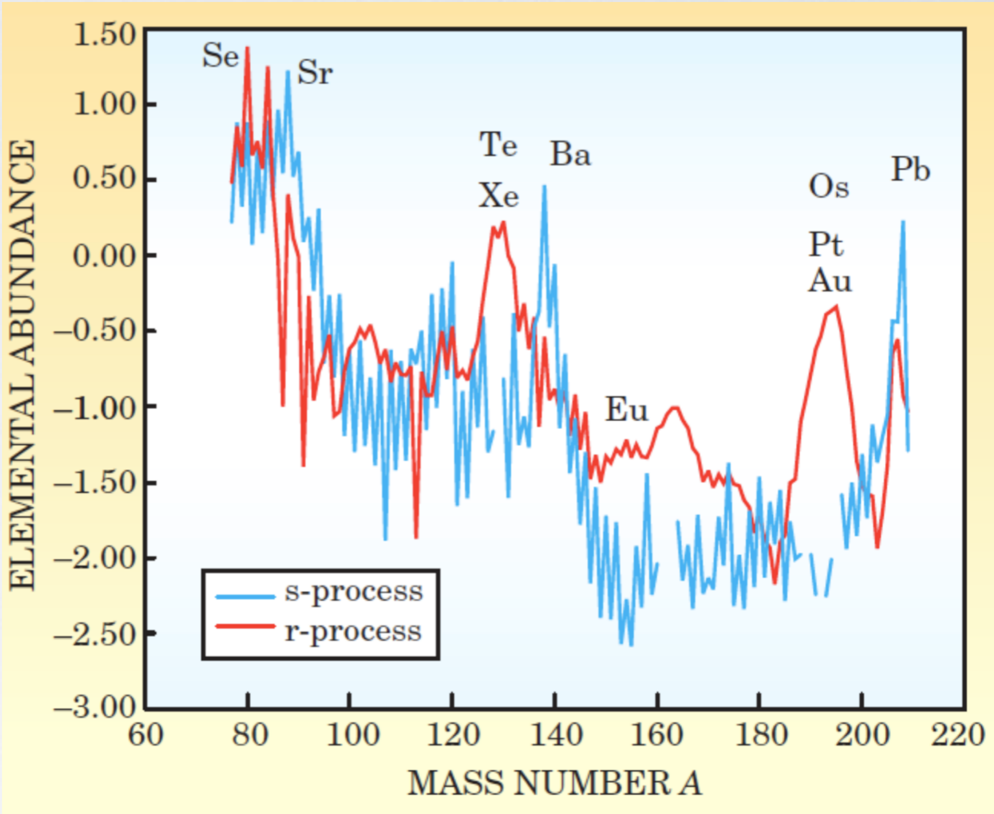
  - N=50 (A≈80): Se, Ge

  - N=82 (A≈130): Te, Xe

  - N=126 (A≈195): Os, Ir, Pt

- Waiting point nuclei have (n,γ)<->(γ,n) equilibrium

- Nuclei at these bottlenecks are short-lived (10s of ms or less)



Mario A. Riquelme, Princeton Astro Theory Seminar 2009

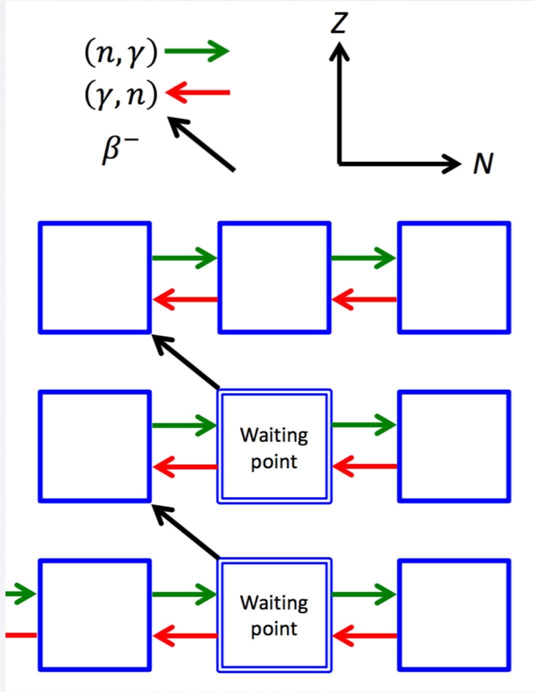
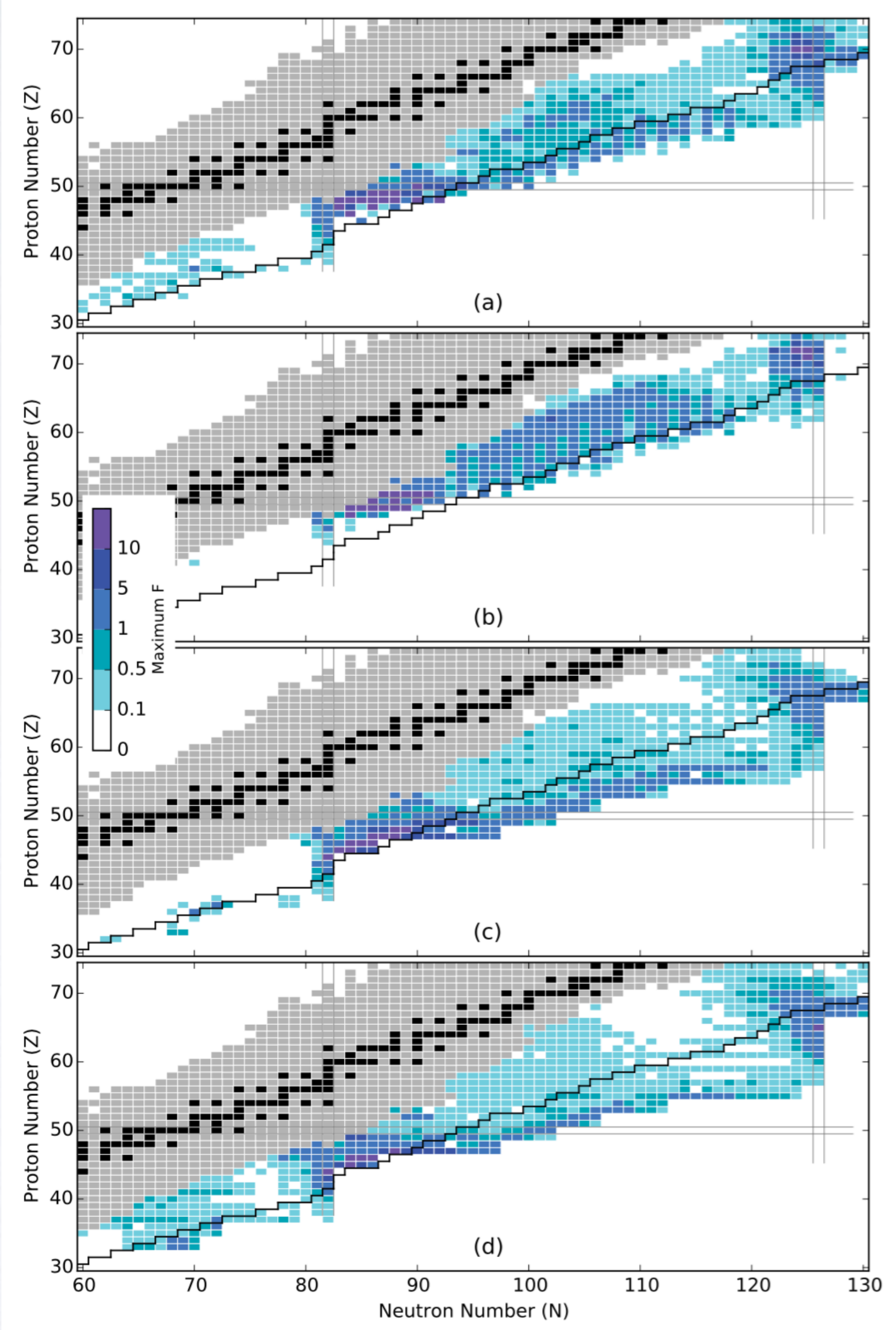


Figure: Courtesy of B.E. Schultz

SENSITIVITY STUDIES

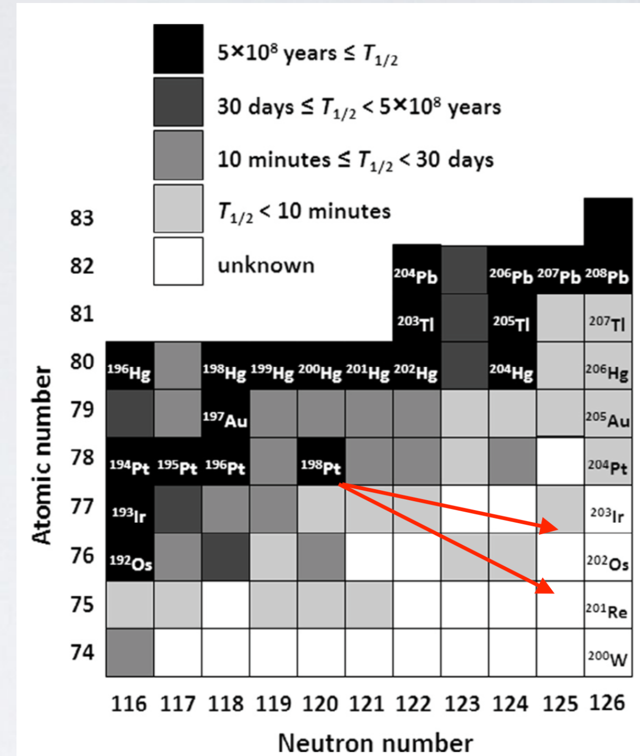
- Compare a baseline simulation to thousands of others, each with one piece of nuclear data varied.
    - mass, N capture cross section, ß-decay rates, ß-delayed N emission, etc.
- Mass has greatest impact on isotopic abundances.
    - especially so around closed shells due to their higher abundances.



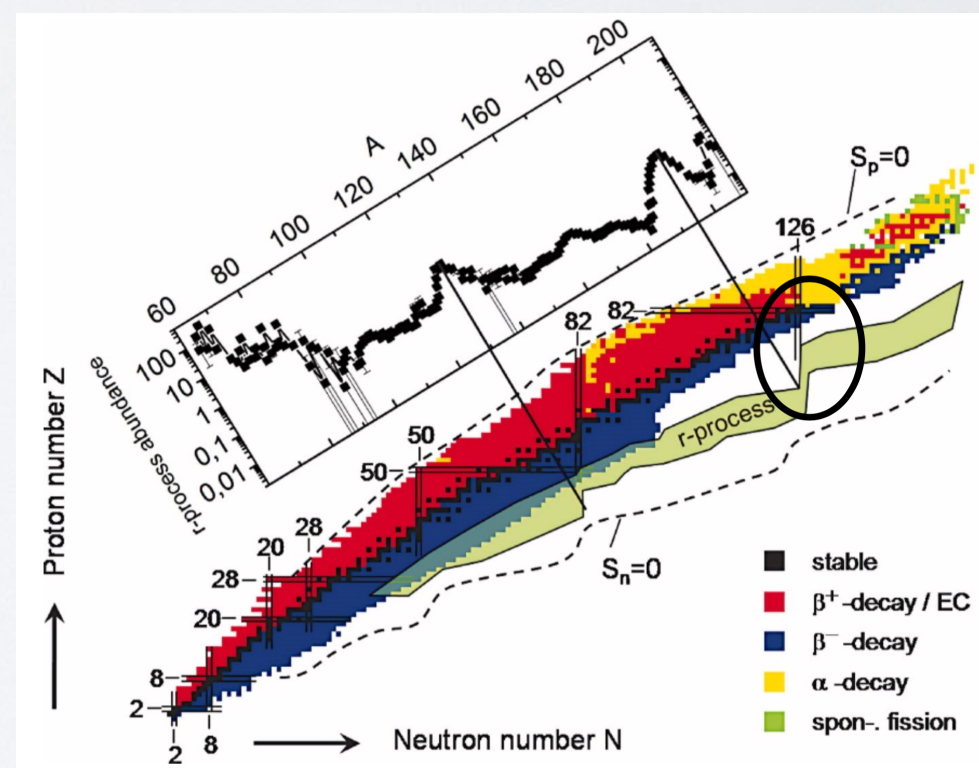
R. Surman, “The sensitivity of r-process nucleosynthesis…” (2013)

N=126 FACTORY USING ATLAS

- Argonne National Lab will house the MRTOF as part of a new facility to access N=126 nuclei.
- Produced by multi-nucleon transfer reactions (deep inelastic collisions)
  - fragmentation difficult
  - fusion, fission impossible
- 136Xe on 198Pt at <10 MeV/A shows promise… produce nuclei about which nothing is known!

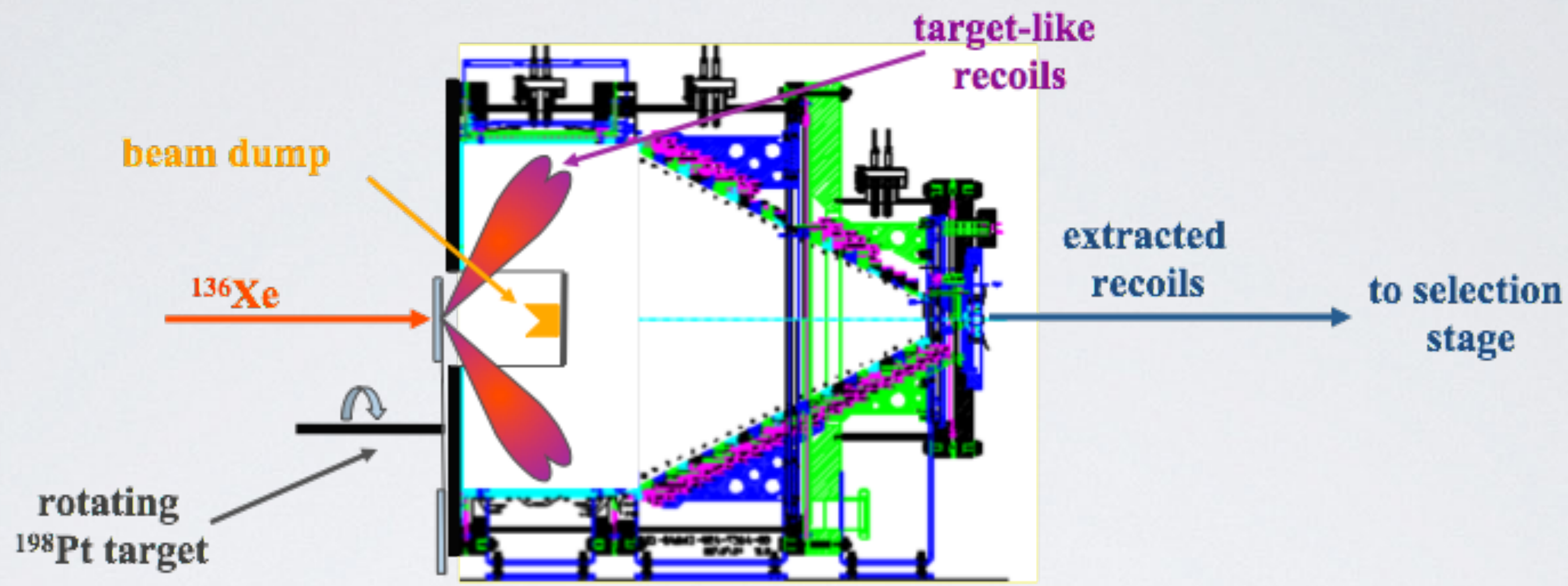


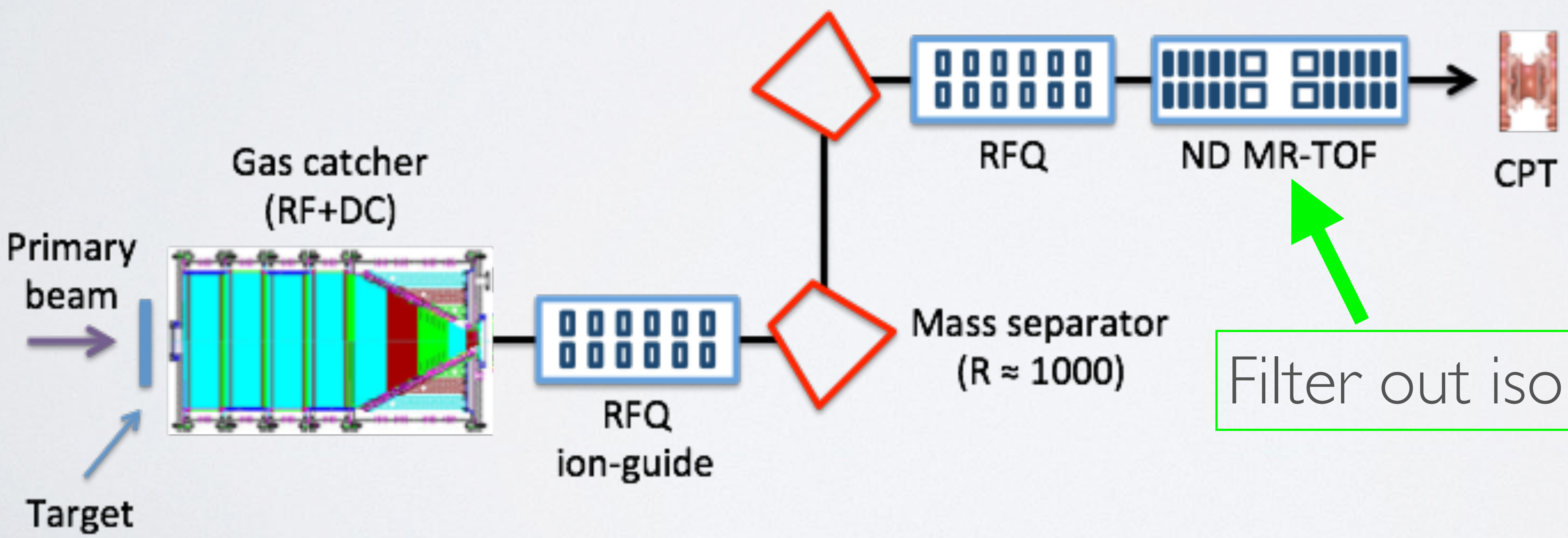
Y.X. Watanabe et. al., NIM B 317 (2013)



R. Krücken, Contemp. Phys. **52** 101(2011)

ACCESSING N=126 AT ARGONNE





Filter out isobaric contaminants

MR-TOF PRINCIPLES

- Separates species (including isobars/isomers) by mass/charge ratio.
- Hundreds of rounds trips, measurement time ~10 ms.
- R > 10^5 possible.

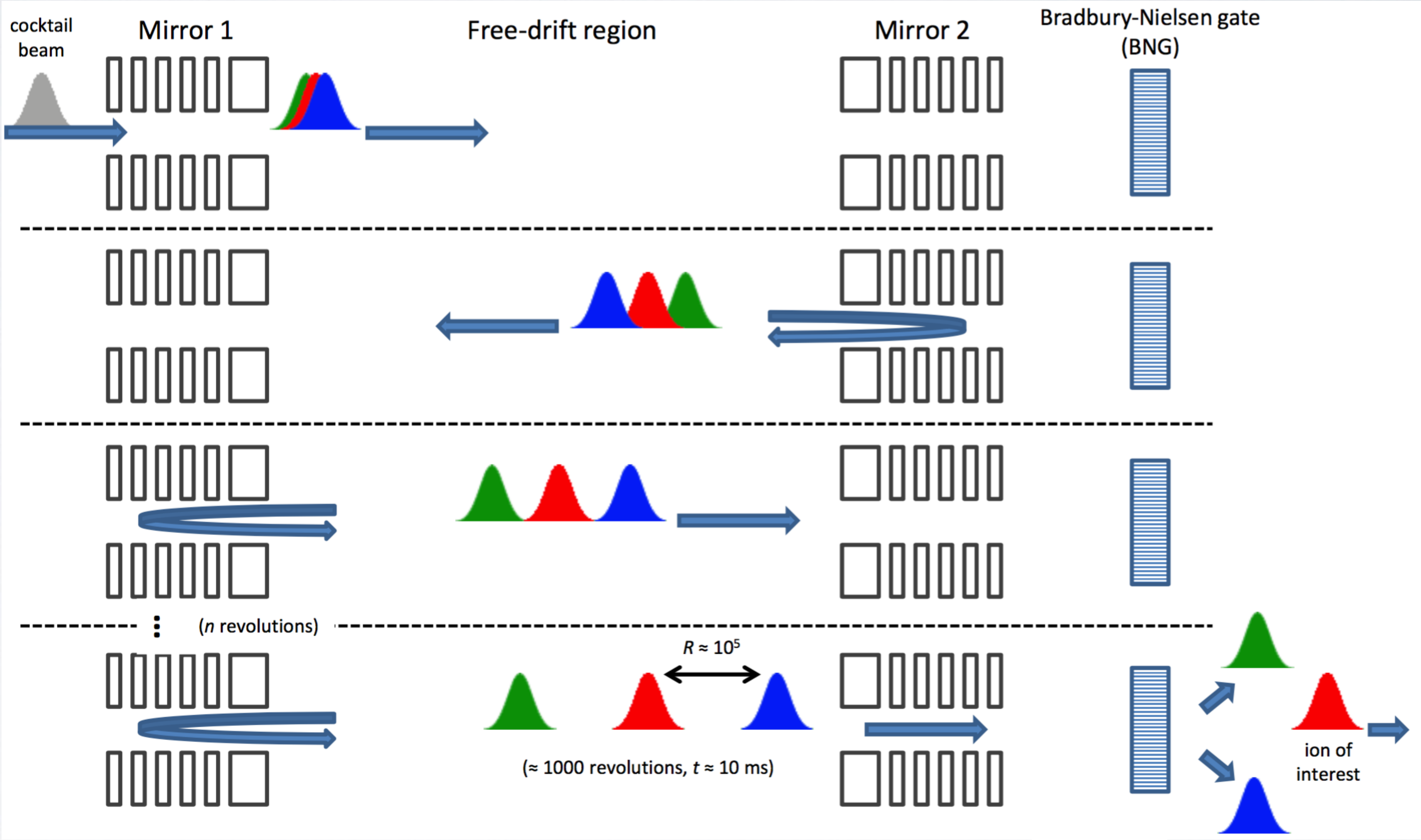
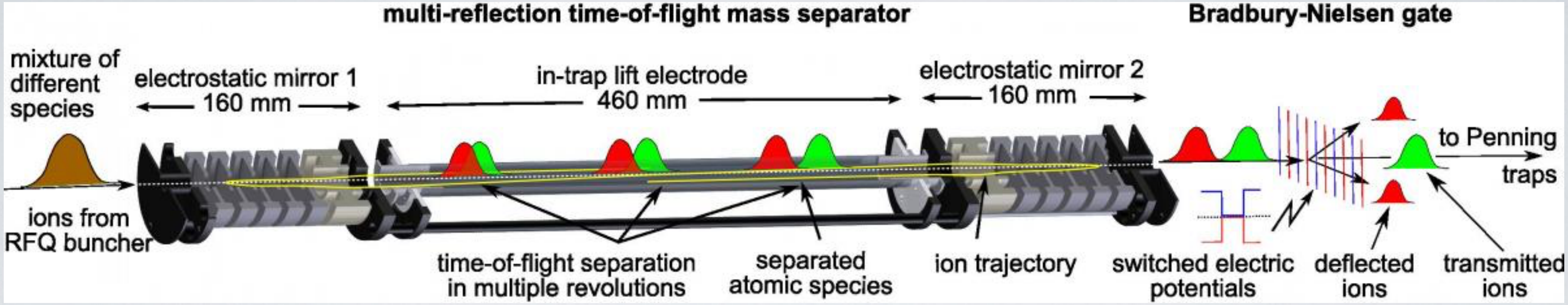


Figure: Courtesy of B.E. Schultz



CERN PH Newsletter (Mar 23, 2013)

- **Trapping: In-trap lift method**
  - No switching of end mirrors, which would negate the inherent precision and speed of the system.
  - Trapped energy is independent of Injection energy, and so can be tuned.

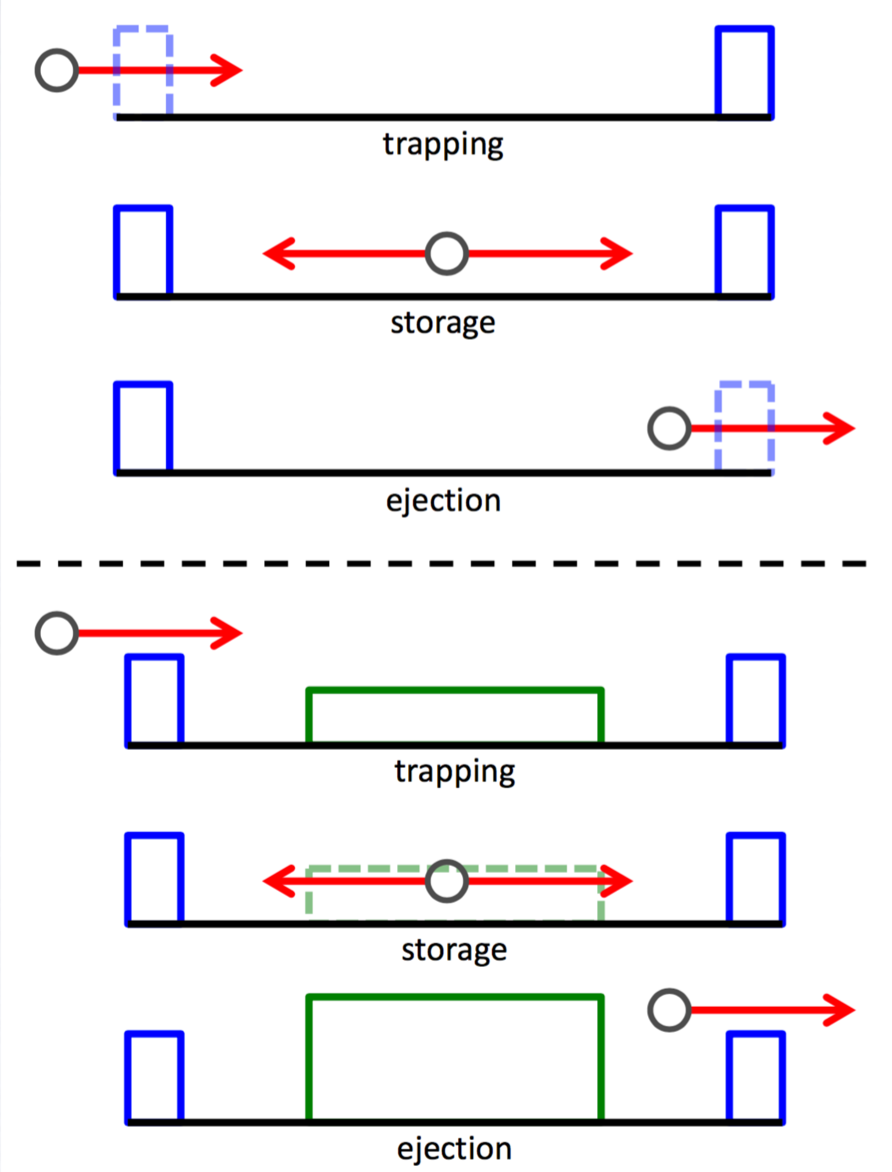
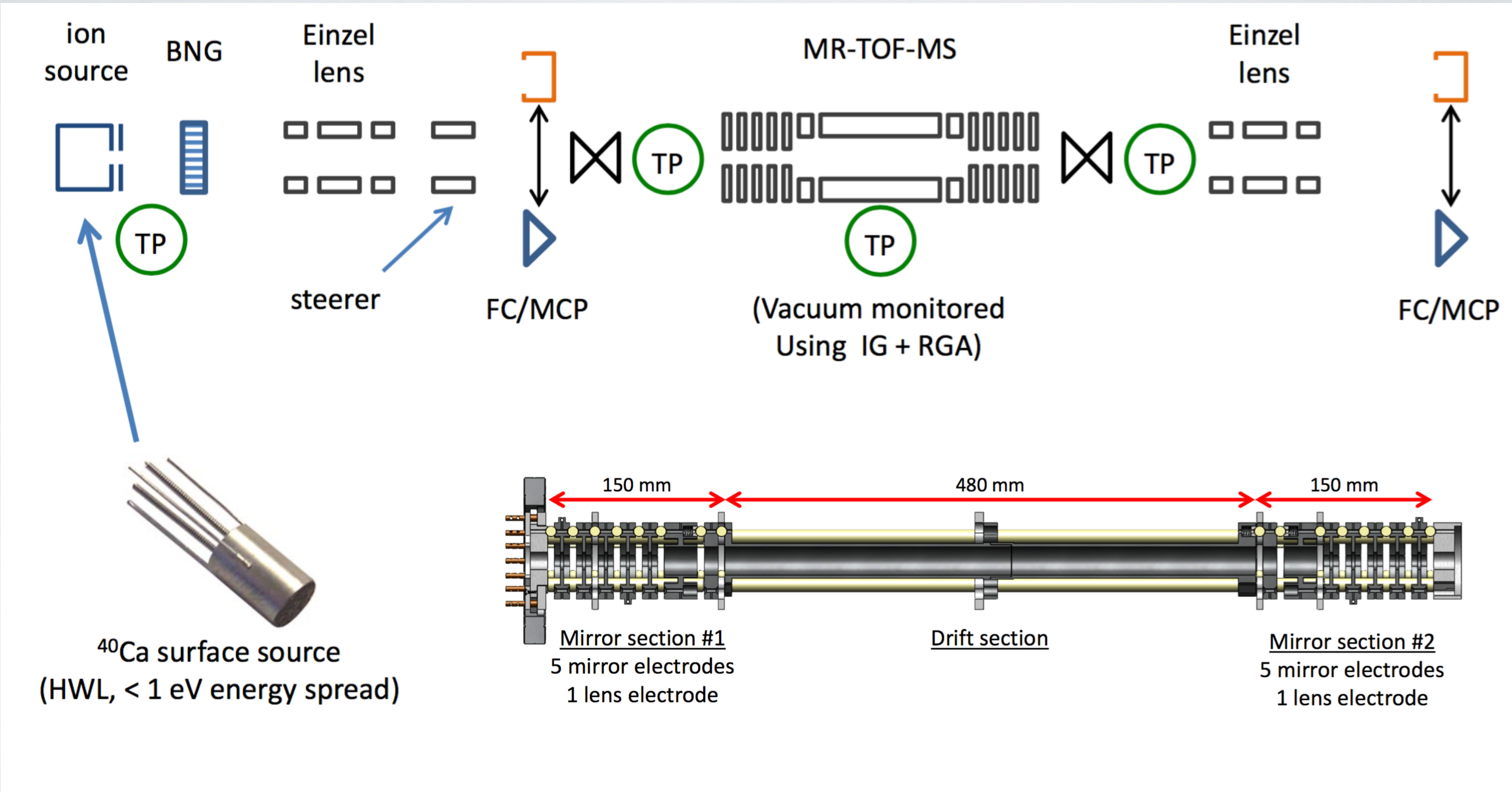


Figure: Courtesy of B.E. Schultz

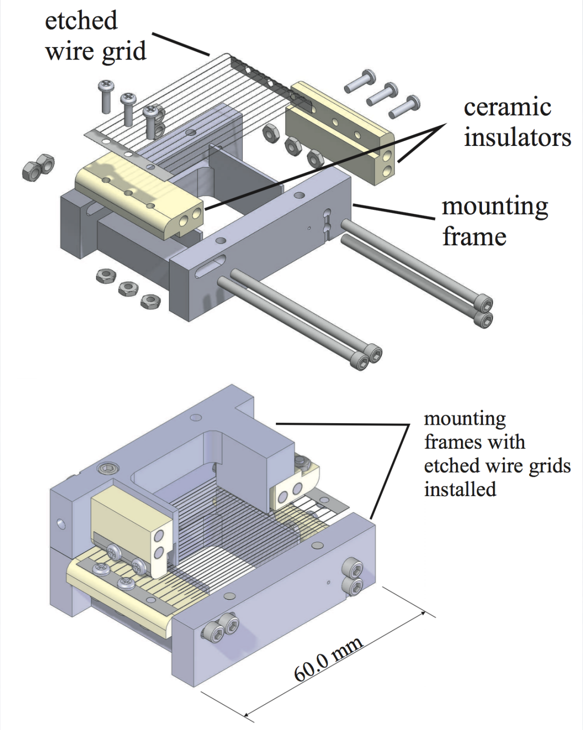
OFFLINE TEST SETUP

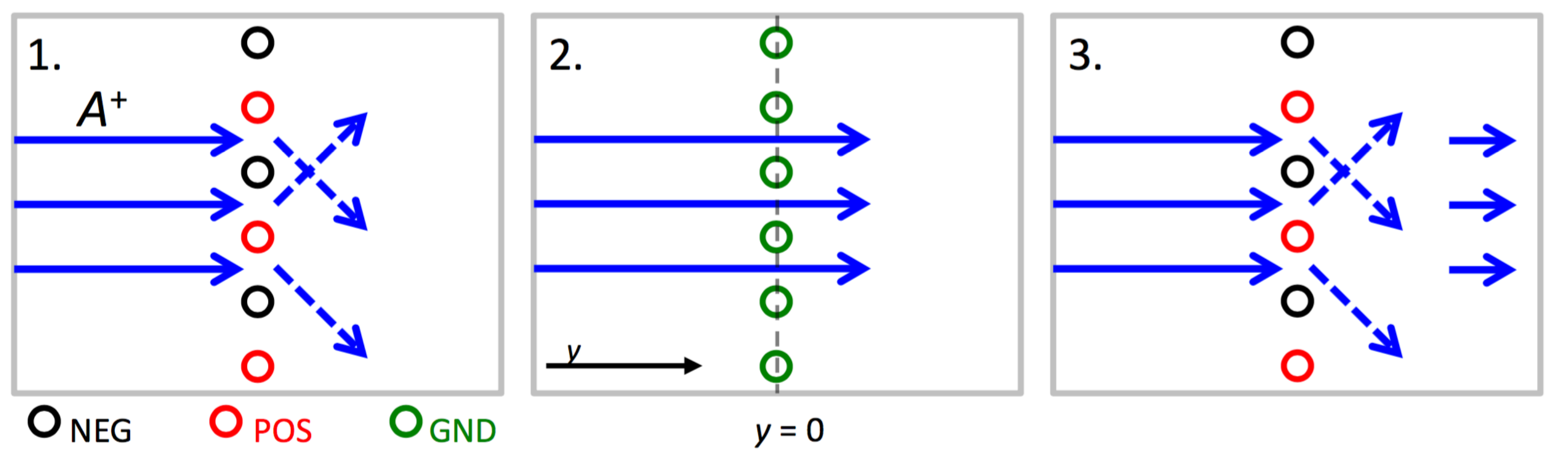


Figures: Courtesy of B.E. Schultz

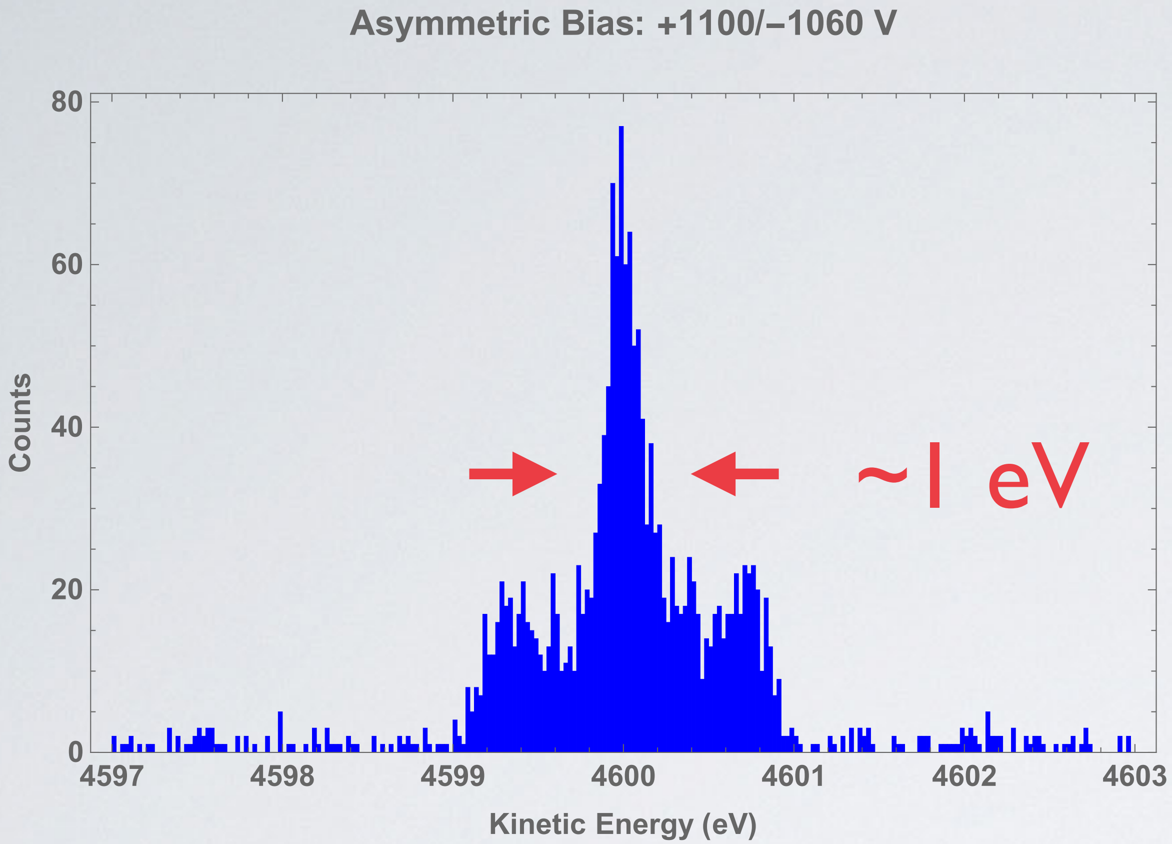
SIMULATIONS AND OPTIMIZATION

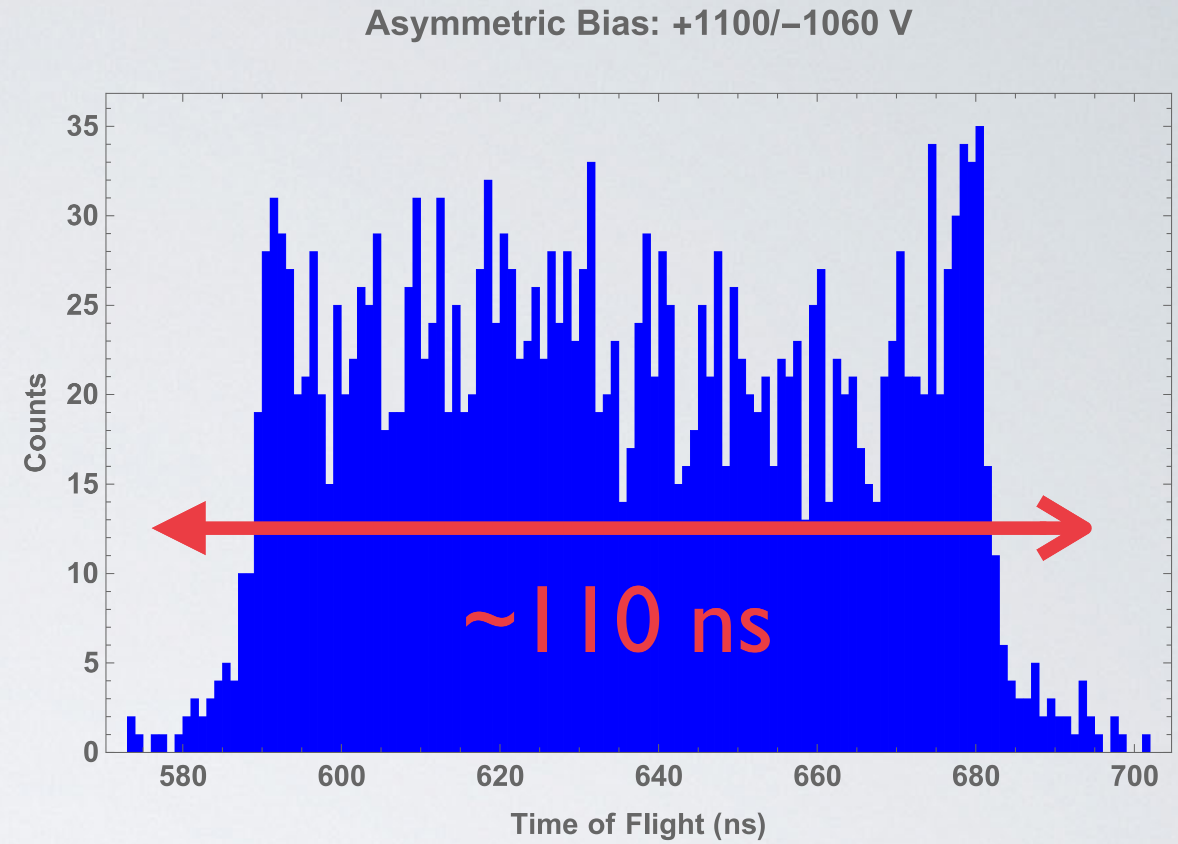
- **Ion bunch creation using Bradbury-Nielsen Gate**
  - SIMION 8.1
  - A = 40, q = +1, E = 4600 +/- 0.3 eV (typical spread of surface ion source), 3mm beam radius
  - 100 ns bunch chopped out of "continuous" beam



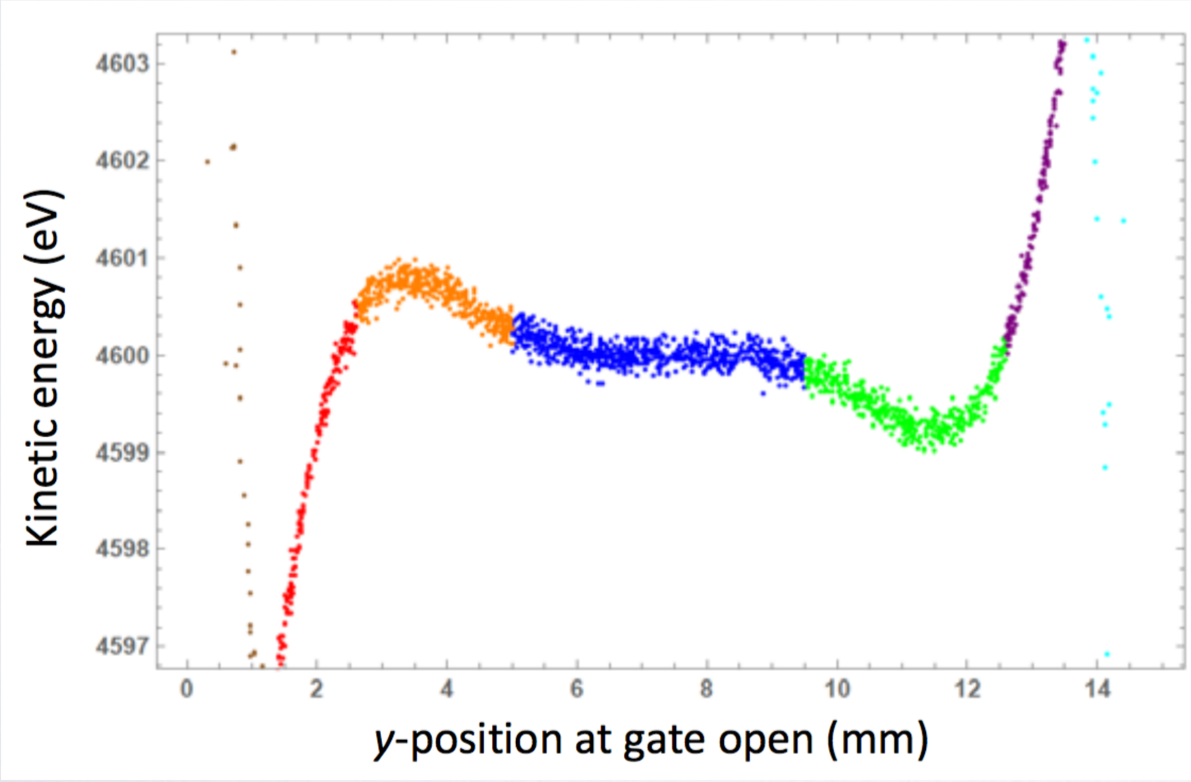


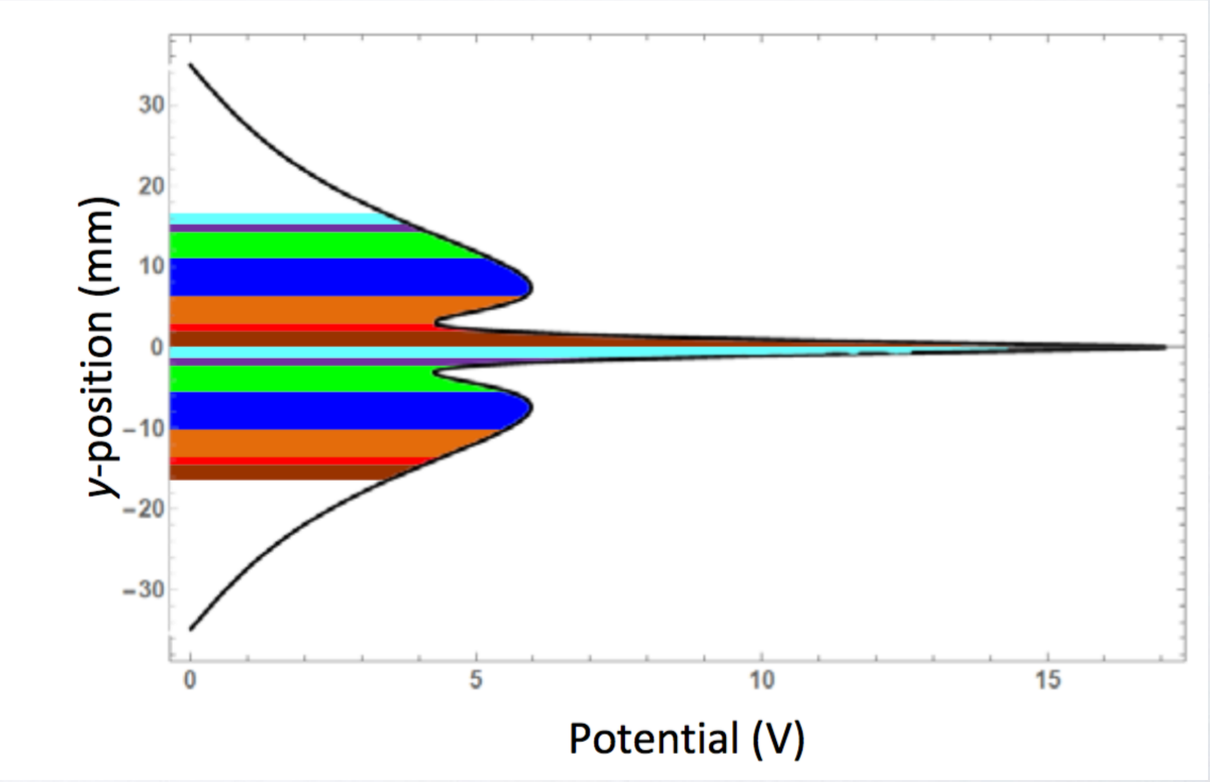
$$\tan\alpha = \frac{\pi}{2\,\ln\left(\cot\left(\frac{\pi}{2}\frac{R}{d}\right)\right)}\,\frac{V_{wire}}{E_{kin}/q}.$$

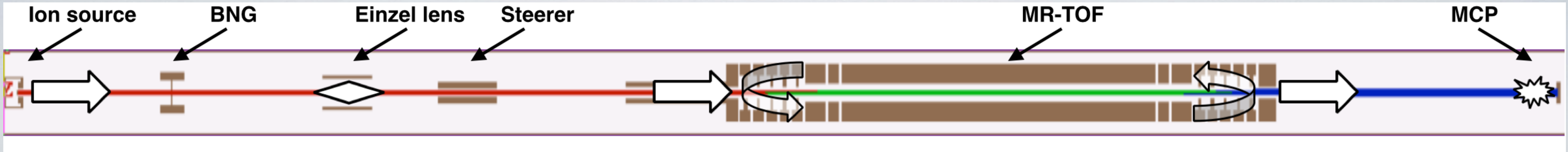




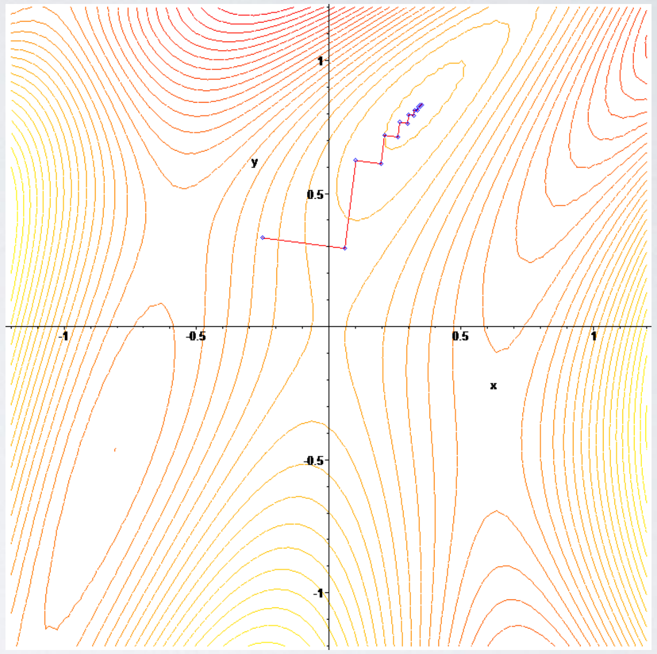
Bunches have low energy spread, and are sharply defined.







- **Offline test setup simulation and MR-TOF optimization**
  - adding injection and optics builds on earlier sims which started ions at MR-TOF center.
  - "gradient ascent" procedure written in lua automates the optimization process.



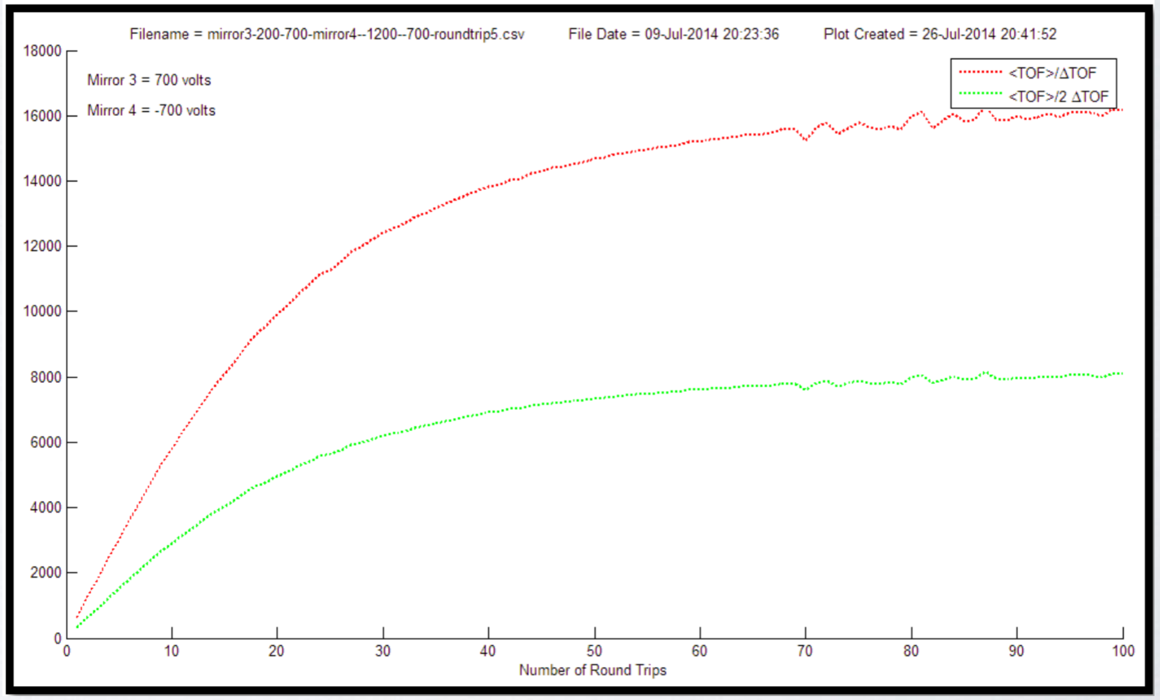
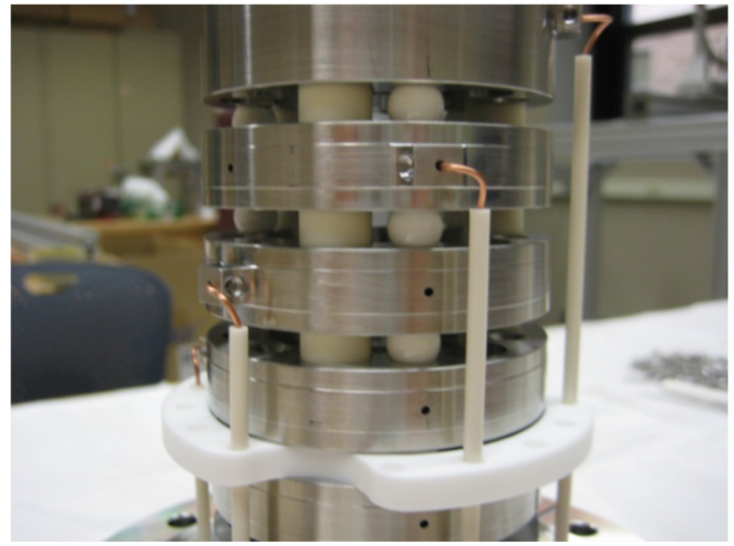
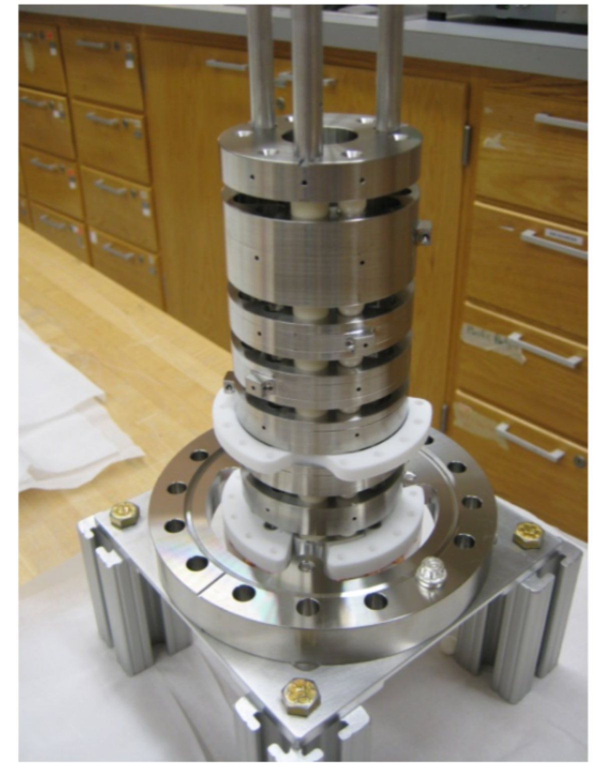
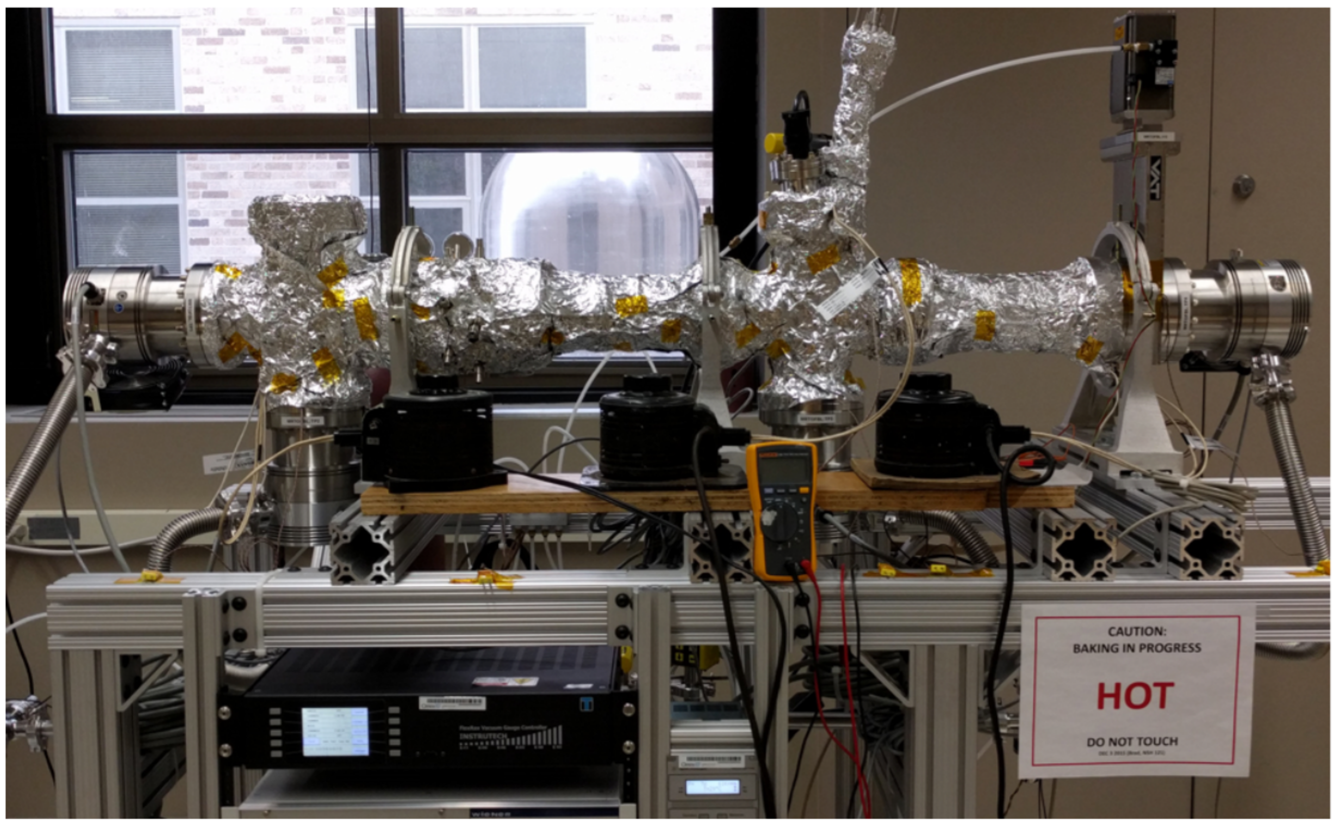


Figure: Courtesy of C. Nicoloff







- All components designed, cleaned and assembled for UHV compatibility

CONSTRUCTION

CONTROL SYSTEM & DAQ

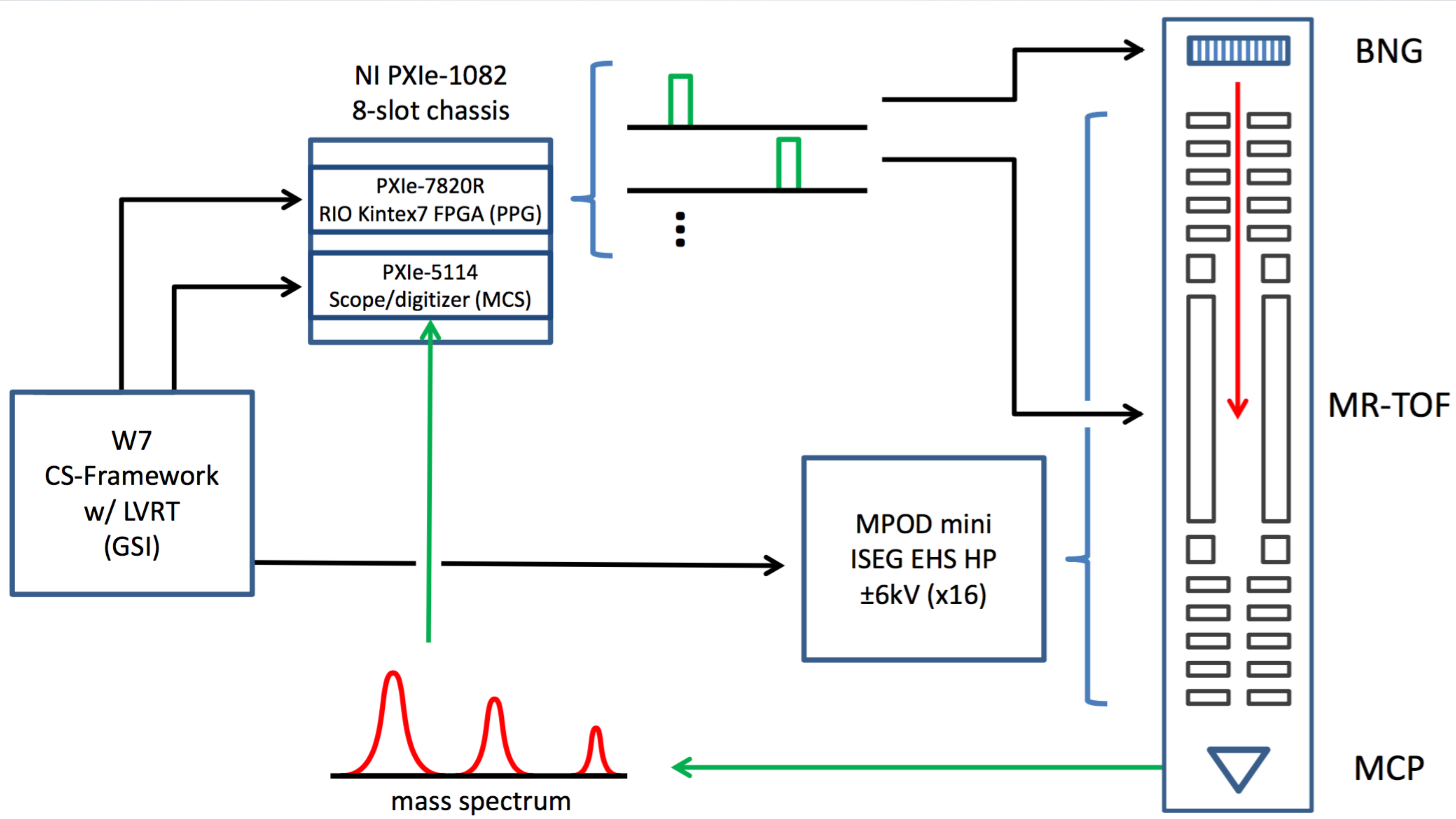


Figure: Courtesy of B.E. Schultz

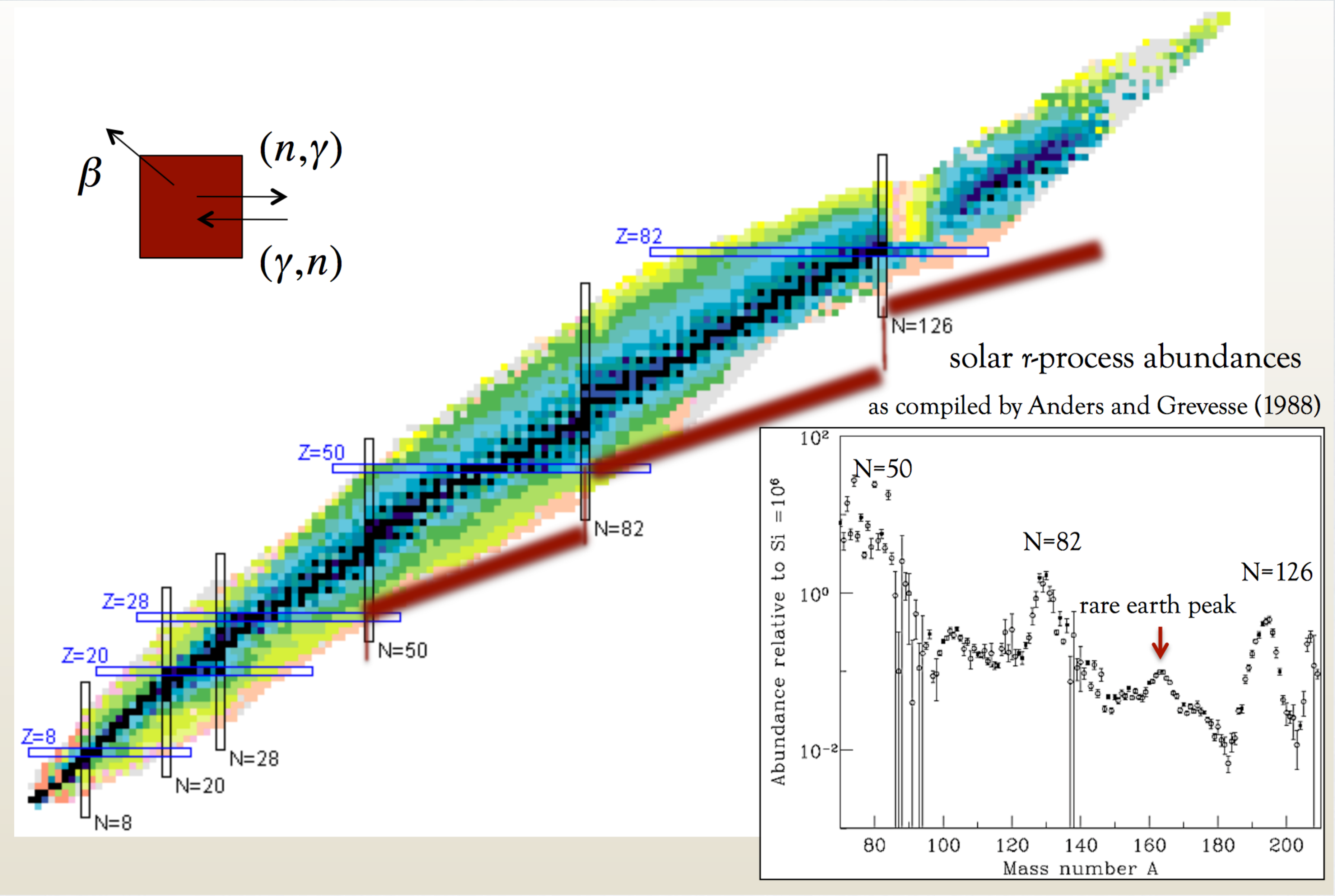
SUMMARY AND OUTLOOK

- R-process produces half of the elements heavier than iron, yet is poorly understood
- N=126 factory at Argonne National Lab will permit new measurements with the help of our MR-TOF.
- MR-TOF assembled.
- Simulations to optimize its performance are ongoing.
- HV power supplies on order. Control systems in development…
- Offline commissioning this summer. Move to ANL at beginning of 2017.

ACKNOWLEDGEMENTS

- Maxime Brodeur (Notre Dame)
- Brad E. Schultz (Notre Dame)
- Catherine Nicoloff (Wellesley College)
- Dennis Neidherr (GSI)
- Ryan Ringle (NSCL)
- Martin Eibach (NSCL)

Extra Slides



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Production rate for N=126 nuclei

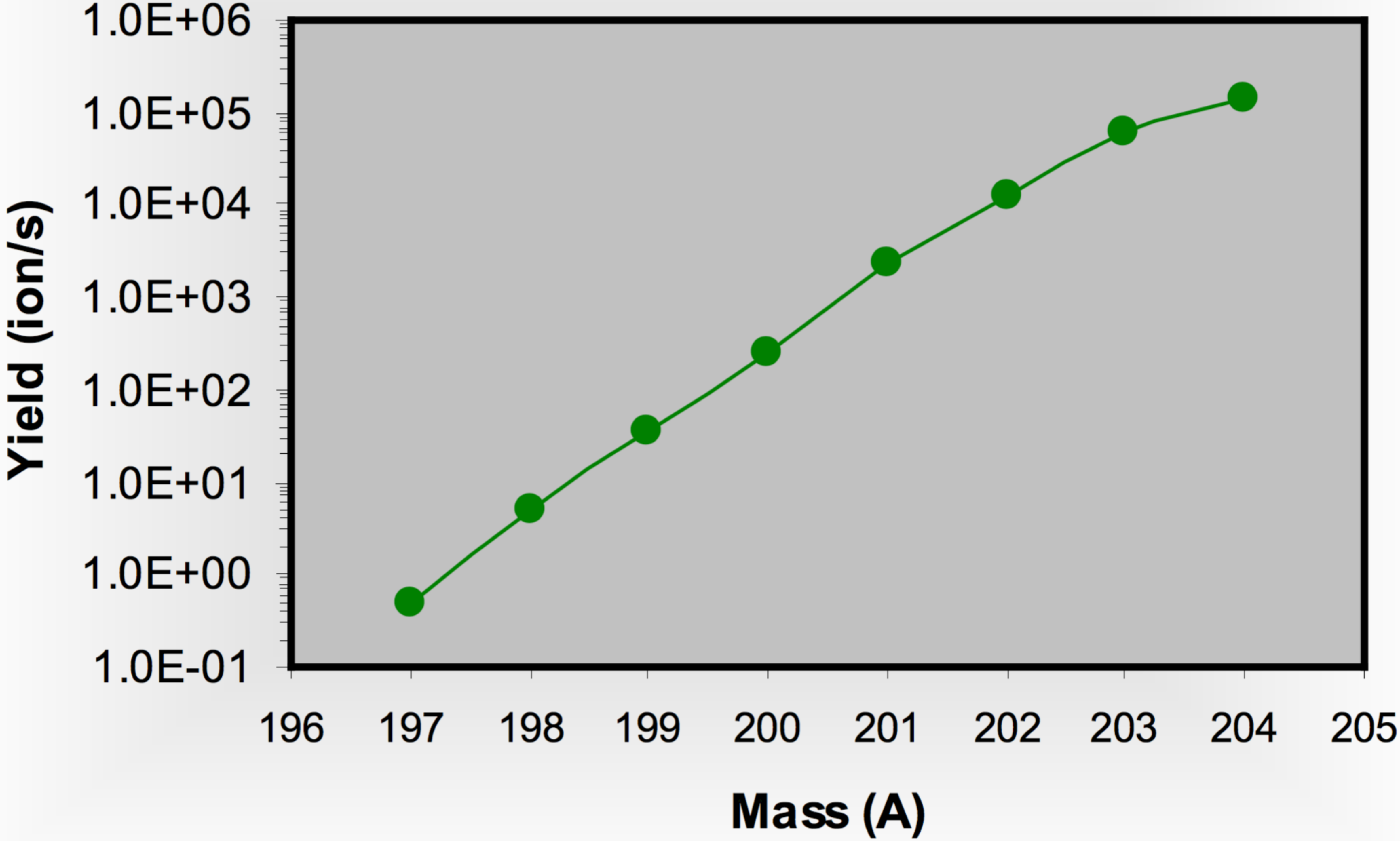
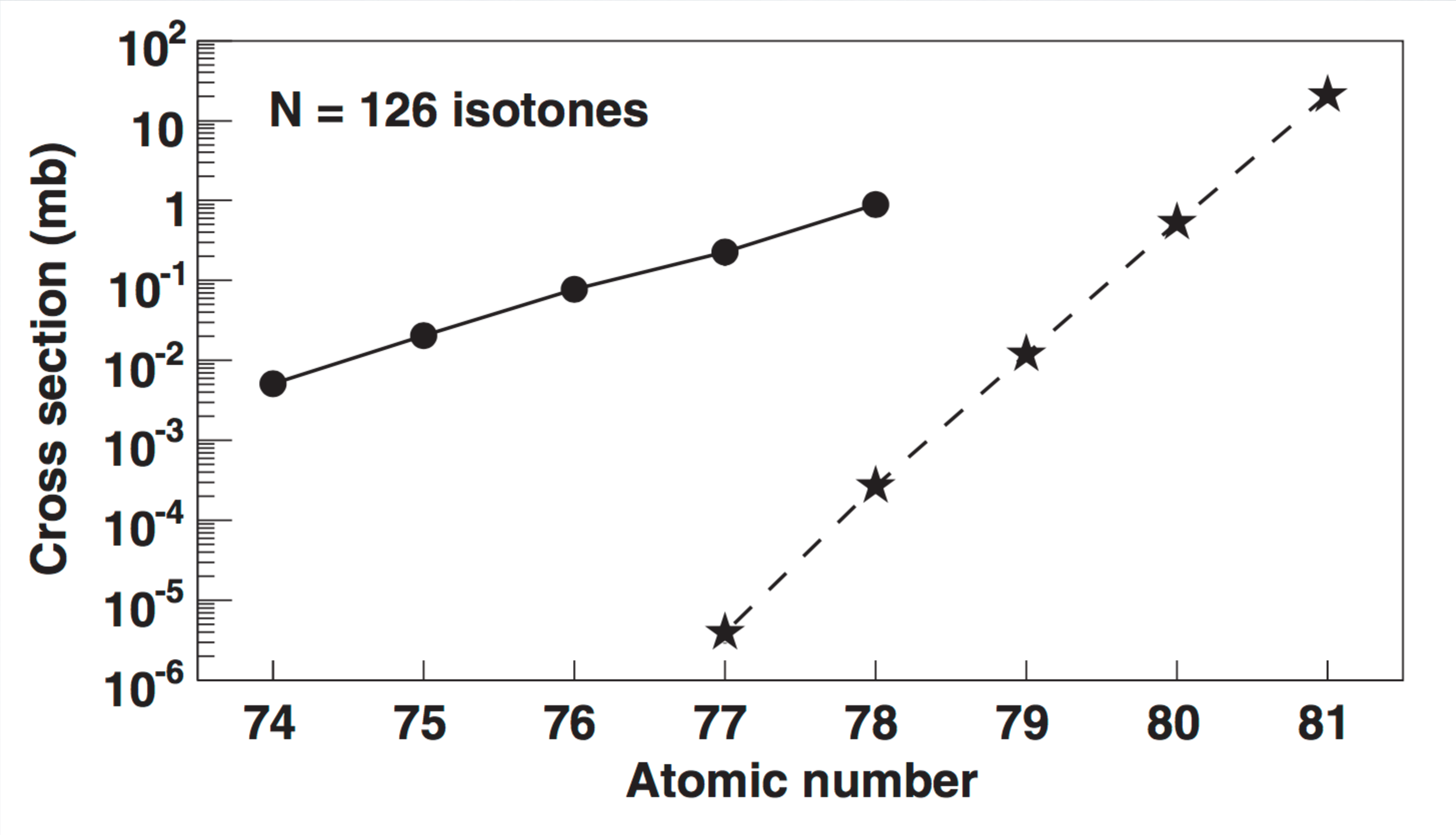


Figure courtesy of G. Savard.



N = 126 isotones
Cross section (mb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
74
75
76
77
78
79
80
81
Atomic number

MERITS OF MULTI-REFLECTION TIME-OF-FLIGHT MASS SPECTROGRAPH

- Used for measurement, diagnostics, beam purification, bunching.
    - Short measurement times (~ms) and large mass range (better than Penning trap mass spec.).
    - Requires very few ions (hundreds).
- Produces pure samples out of contaminated beam.
    - More accepting of large, contaminated bunches than Penning traps. Measure multiple species in single spectrum.
    - Accepts larger energy spread in incoming bunches due to high cycling rate.
- Extends time-of-flight (TOF) indefinitely while remaining small in size.
    - high sensitivity and resolving powers ($R=m/\Delta m \geq 10^{-5}$). Comparable uncertainties to PTMS.
    - better than dipole separators ($R < 5000$) and HRS ($R \approx 20{,}000$)
- Resolves isobars & isomers.