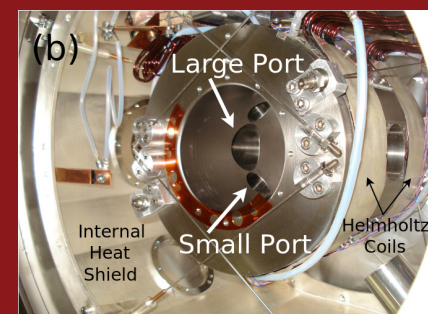
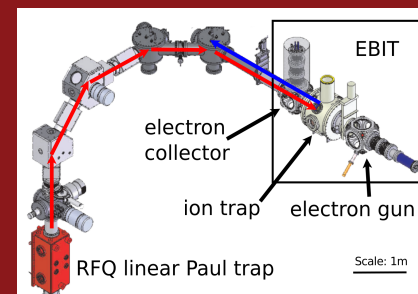
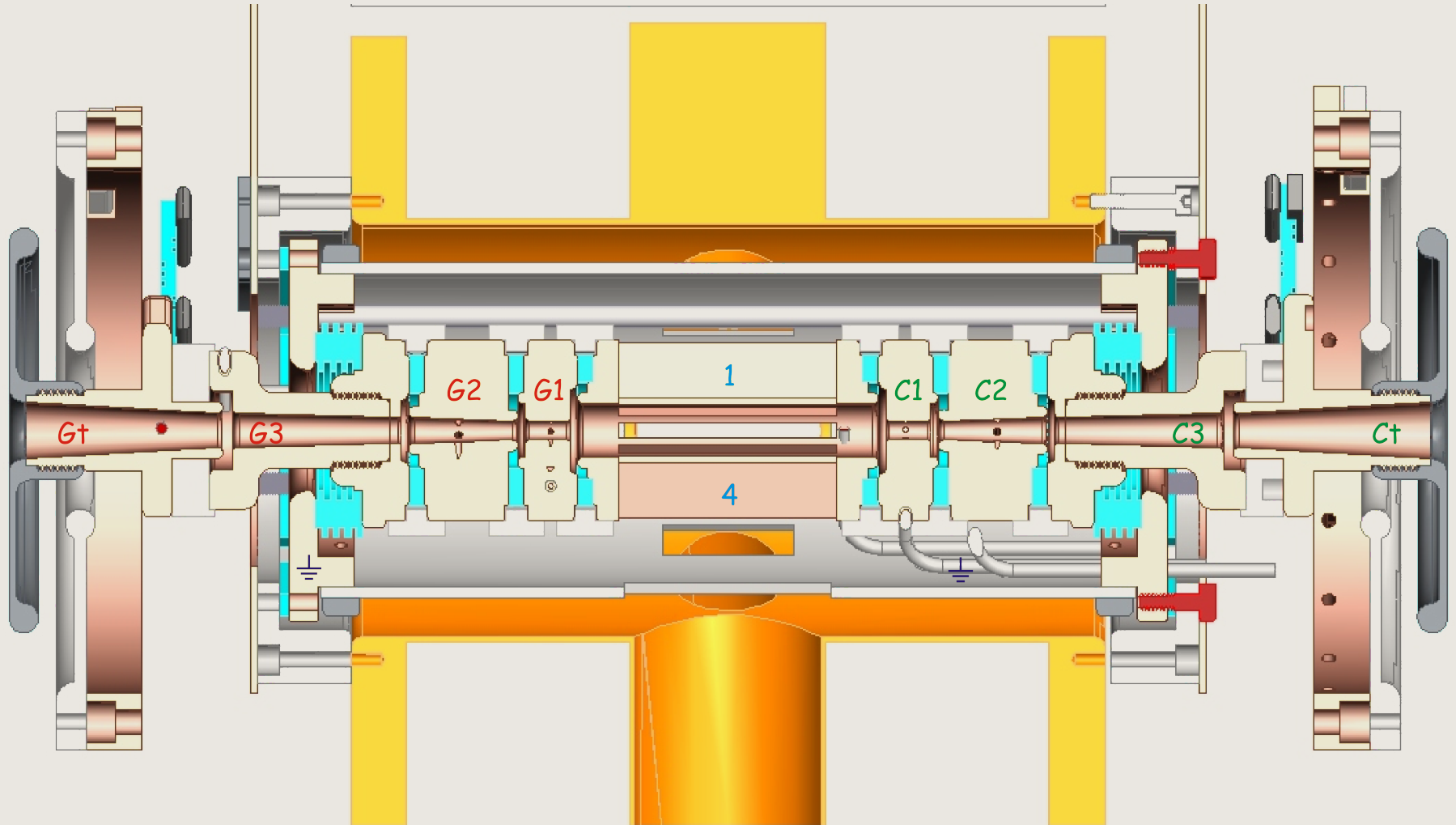


# In-Trap Decay Spectroscopy with the TITAN Facility at TRIUMF

Kyle G. Leach | TITAN | TRIUMF and SFU

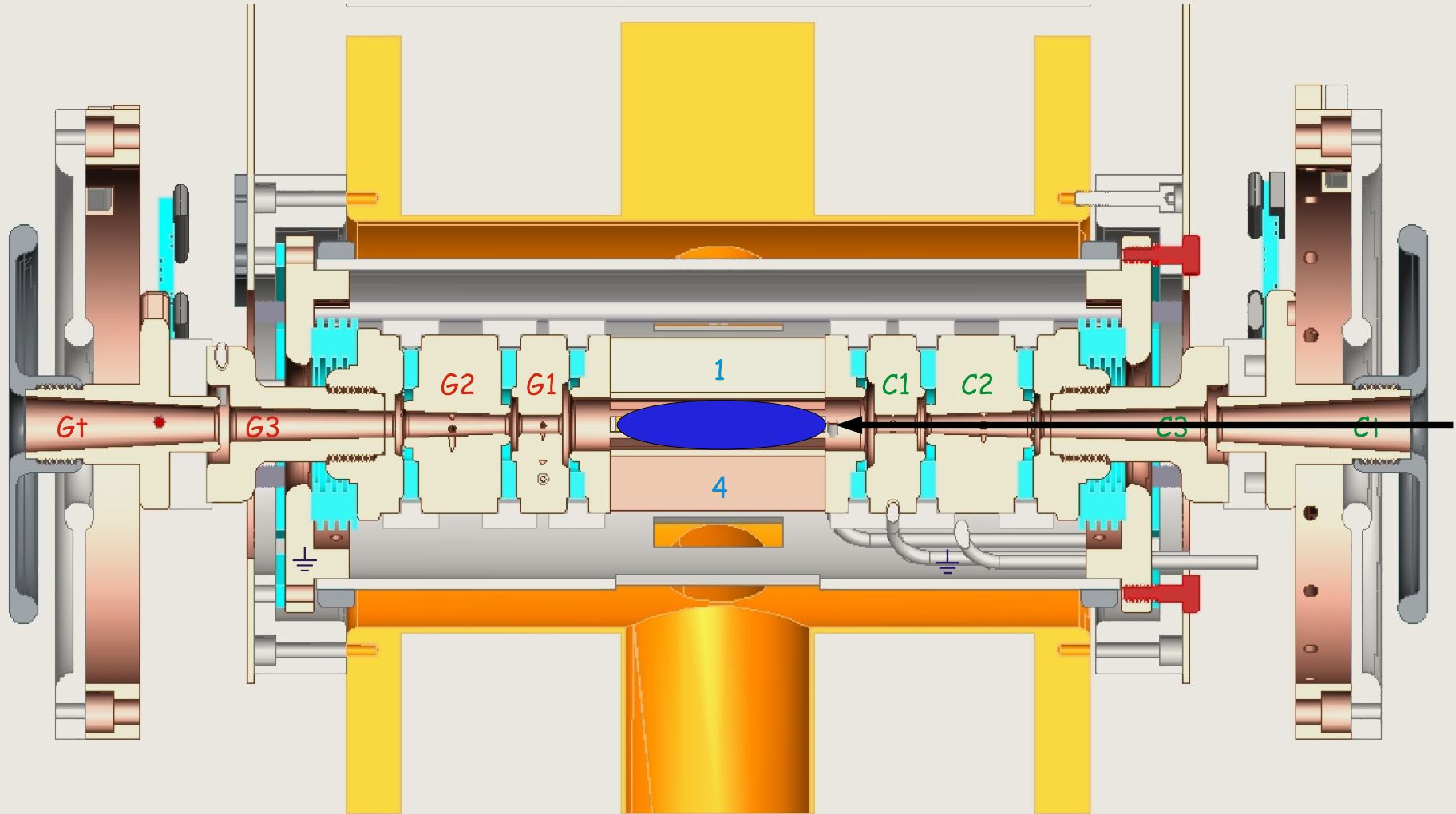


# “Capture” Gamma Spectroscopy

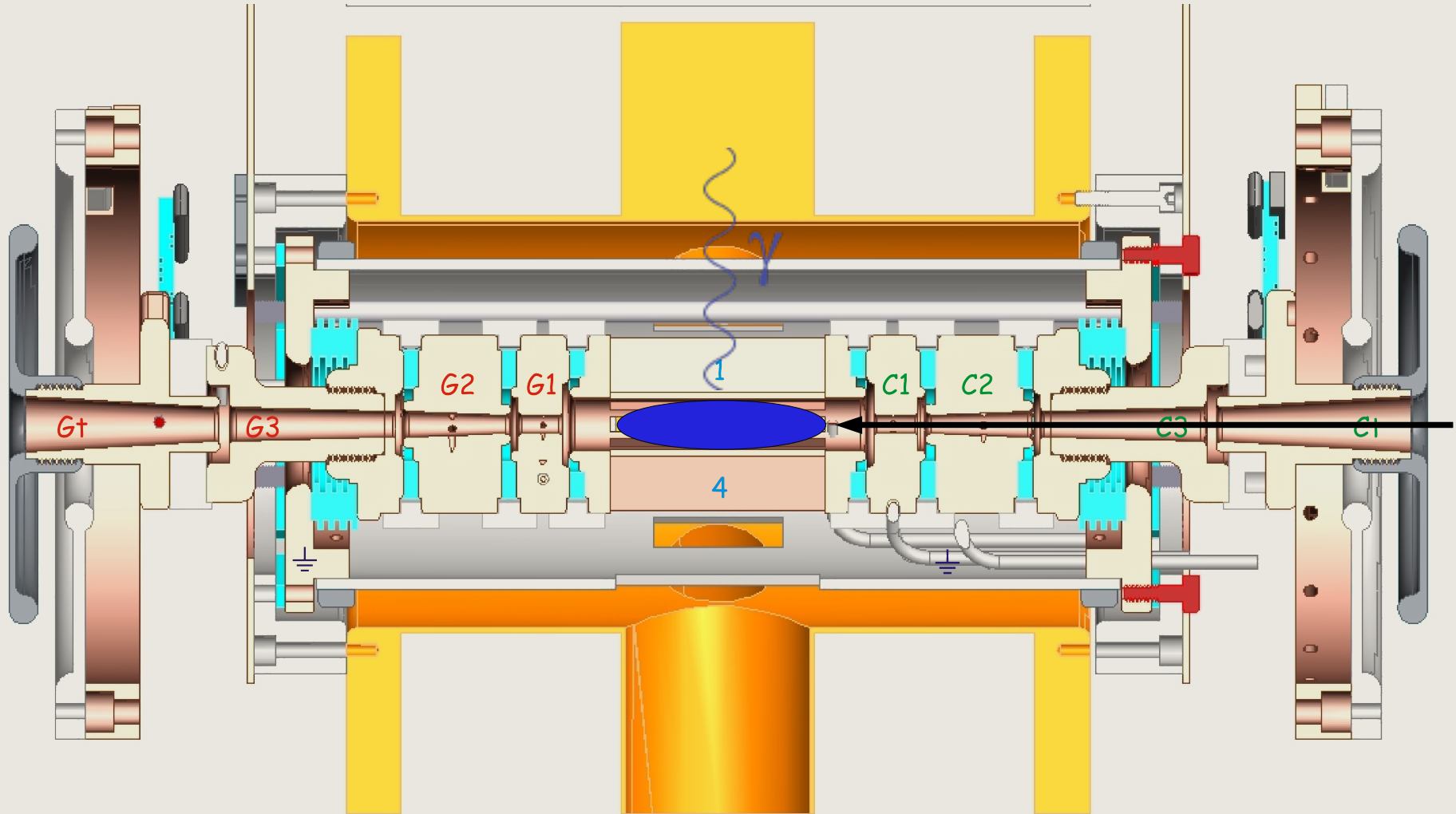




# “Capture” Gamma Spectroscopy



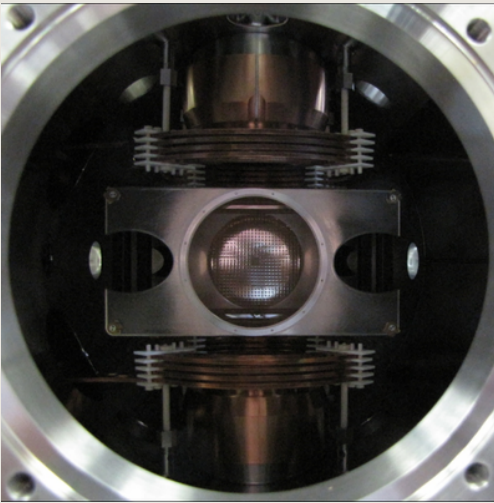
# “Capture” Gamma Spectroscopy



# Low Background Nuclear Spectroscopy

- With increasing experimental access to unstable nuclei, high-sensitivity studies on physically interesting systems are becoming more relevant
- Tests of the Standard Model
  - Superaligned Fermi beta decay
  - Beta-neutrino angular correlations
  - Neutrinoless double beta decay
- These studies require high precision and high accuracy

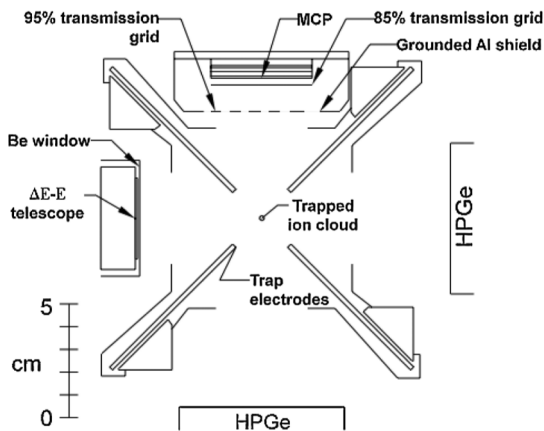
# In-Trap and Trap Assisted Decay Spectroscopy



TRINAT @ TRIUMF



JYFLTRAP

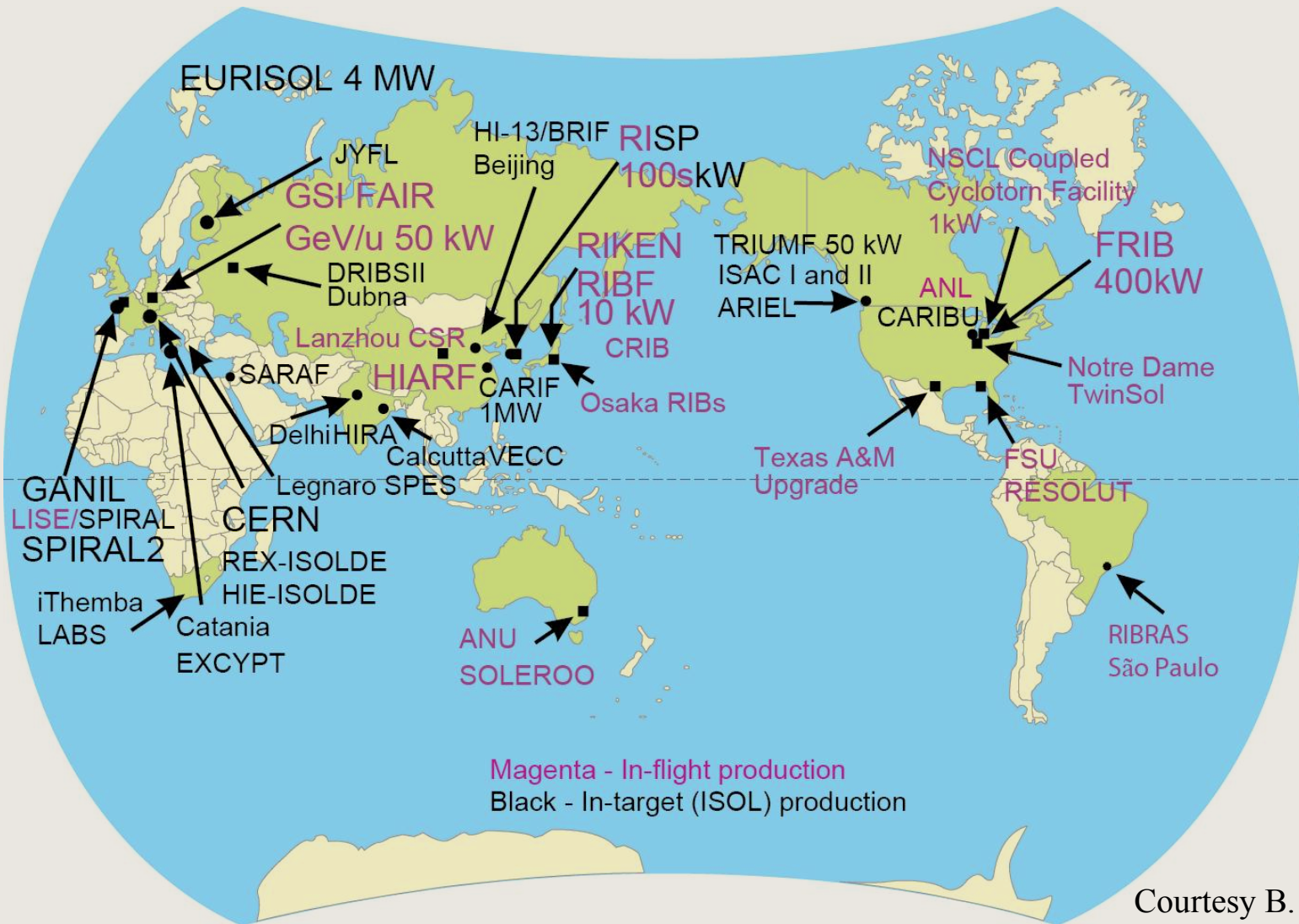


- Isobaric purification
- Indirect neutron and neutrino measurements
- High-precision and high-sensitivity studies
- Greater control over the decay environment

R.M. Yee *et al.*, Phys. Rev. Lett. **110**, 092501 (2013)



# Worldwide RIB Production



Courtesy B. Sherrill



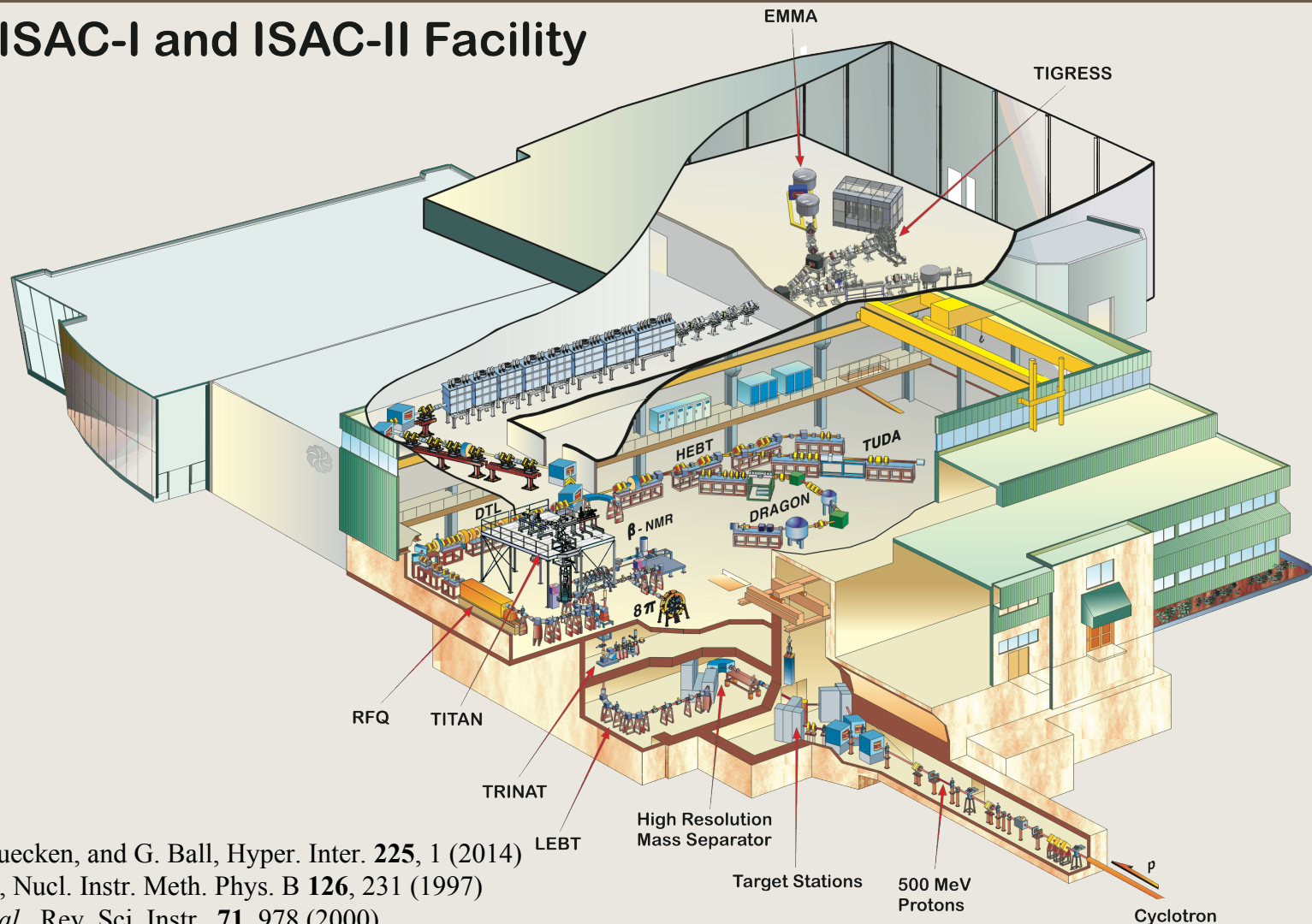


- ISOL-type facility with the highest-intensity primary beam in the world --  $100\ \mu\text{A}$  of 500 MeV protons
- Highest power ISOL facility in the world: 50 kW
- Low-, intermediate-, and high-energy experimental halls (ISAC-I and II)
- Nuclear structure, astrophysics, symmetry tests, condensed matter, medical isotopes



# The TRIUMF-ISAC Facility

## ISAC-I and ISAC-II Facility



J. Dilling, R. Kruecken, and G. Ball, *Hyper. Inter.* **225**, 1 (2014)

P. Bricault *et al.*, *Nucl. Instr. Meth. Phys. B* **126**, 231 (1997)

M. Domsbysky *et al.*, *Rev. Sci. Instr.* **71**, 978 (2000)

# TRIUMF's Ion Trap for Atomic and Nuclear Science (TITAN)

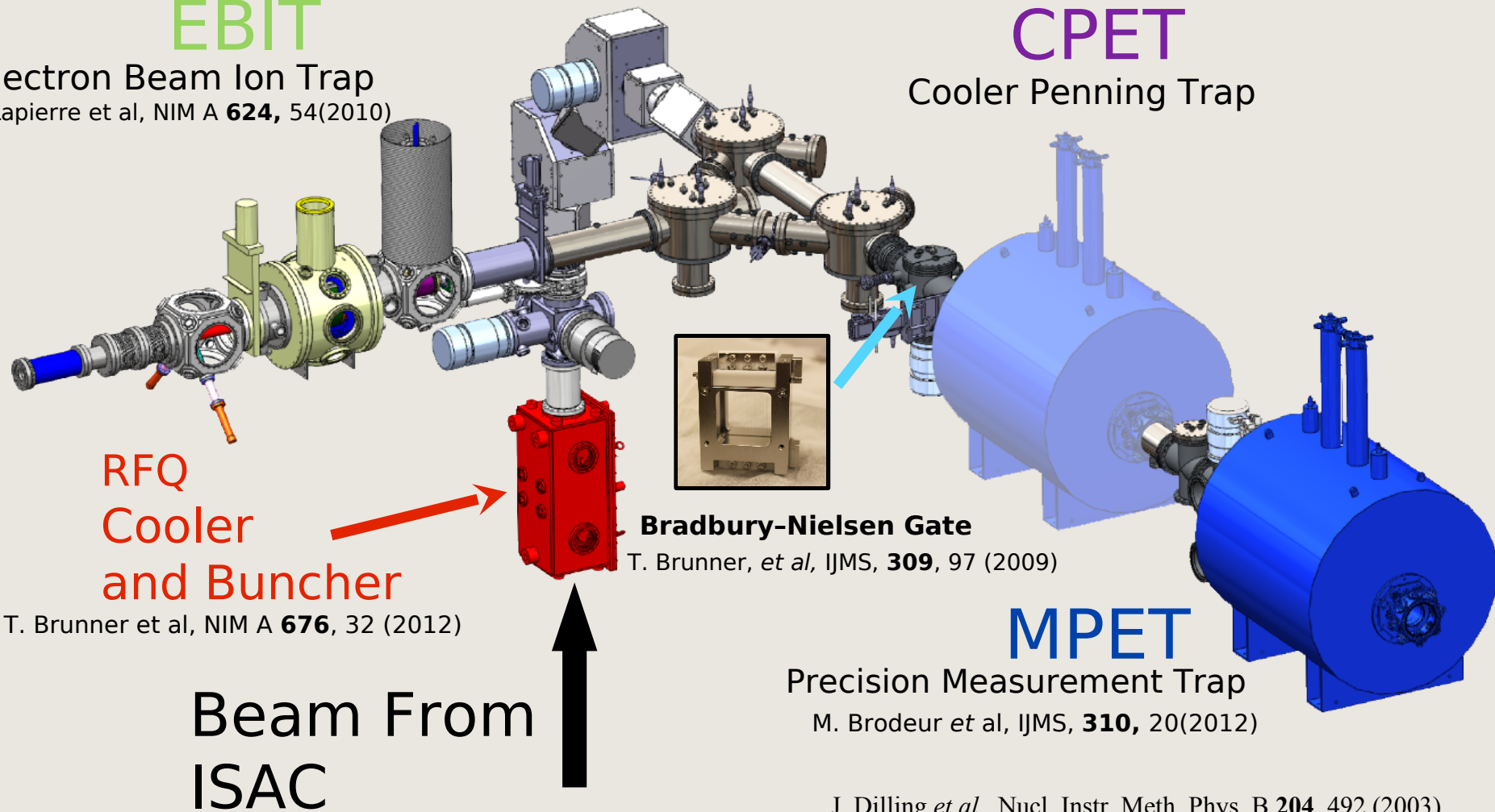
EBIT

Electron Beam Ion Trap

A. Lapierre et al, NIM A **624**, 54(2010)

CPET

Cooler Penning Trap



RFQ  
Cooler  
and Buncher

T. Brunner et al, NIM A **676**, 32 (2012)

Bradbury-Nielsen Gate

T. Brunner, et al, IJMS, **309**, 97 (2009)

MPET

Precision Measurement Trap

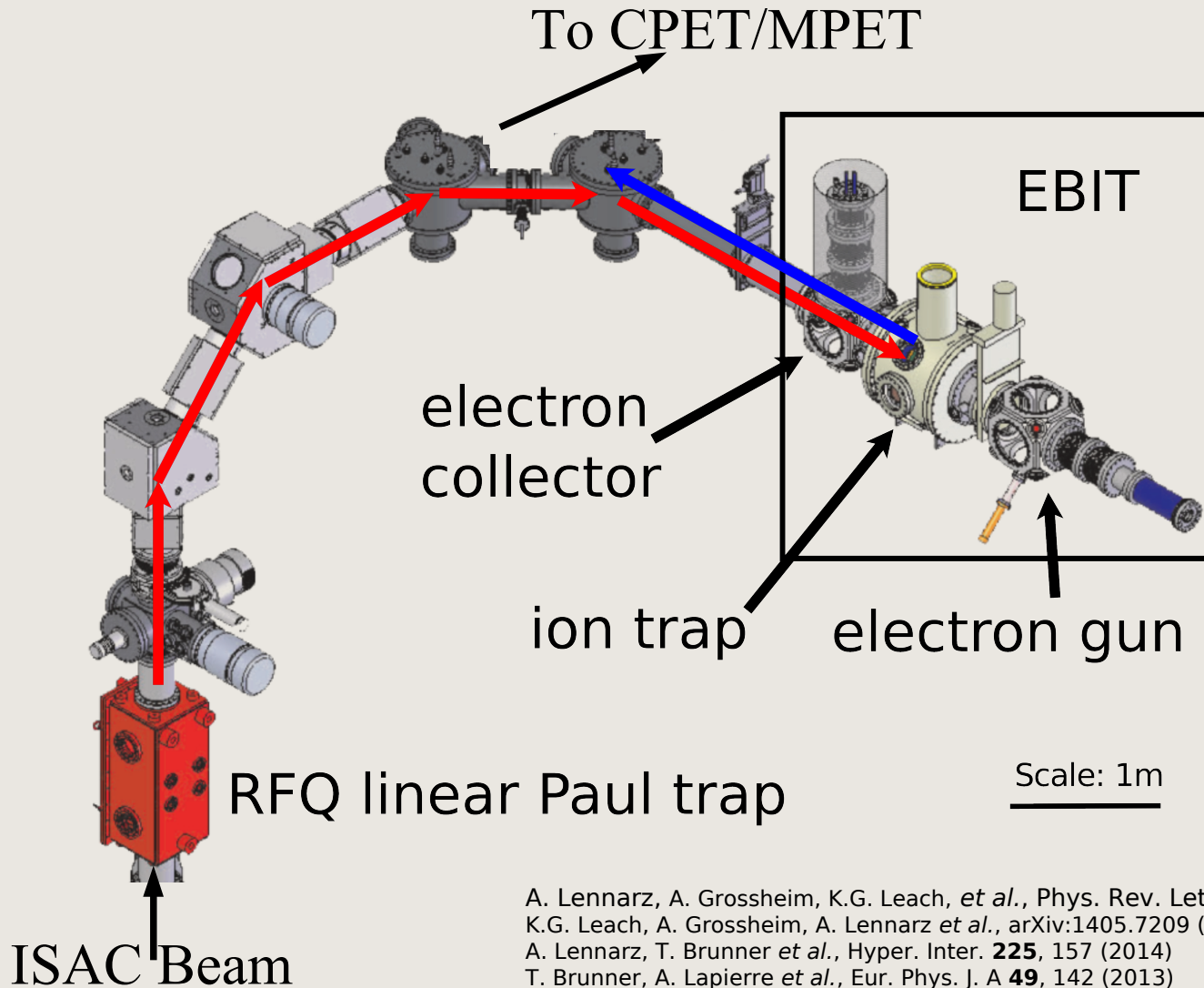
M. Brodeur et al, IJMS, **310**, 20(2012)

J. Dilling et al., Nucl. Instr. Meth. Phys. B **204**, 492 (2003)

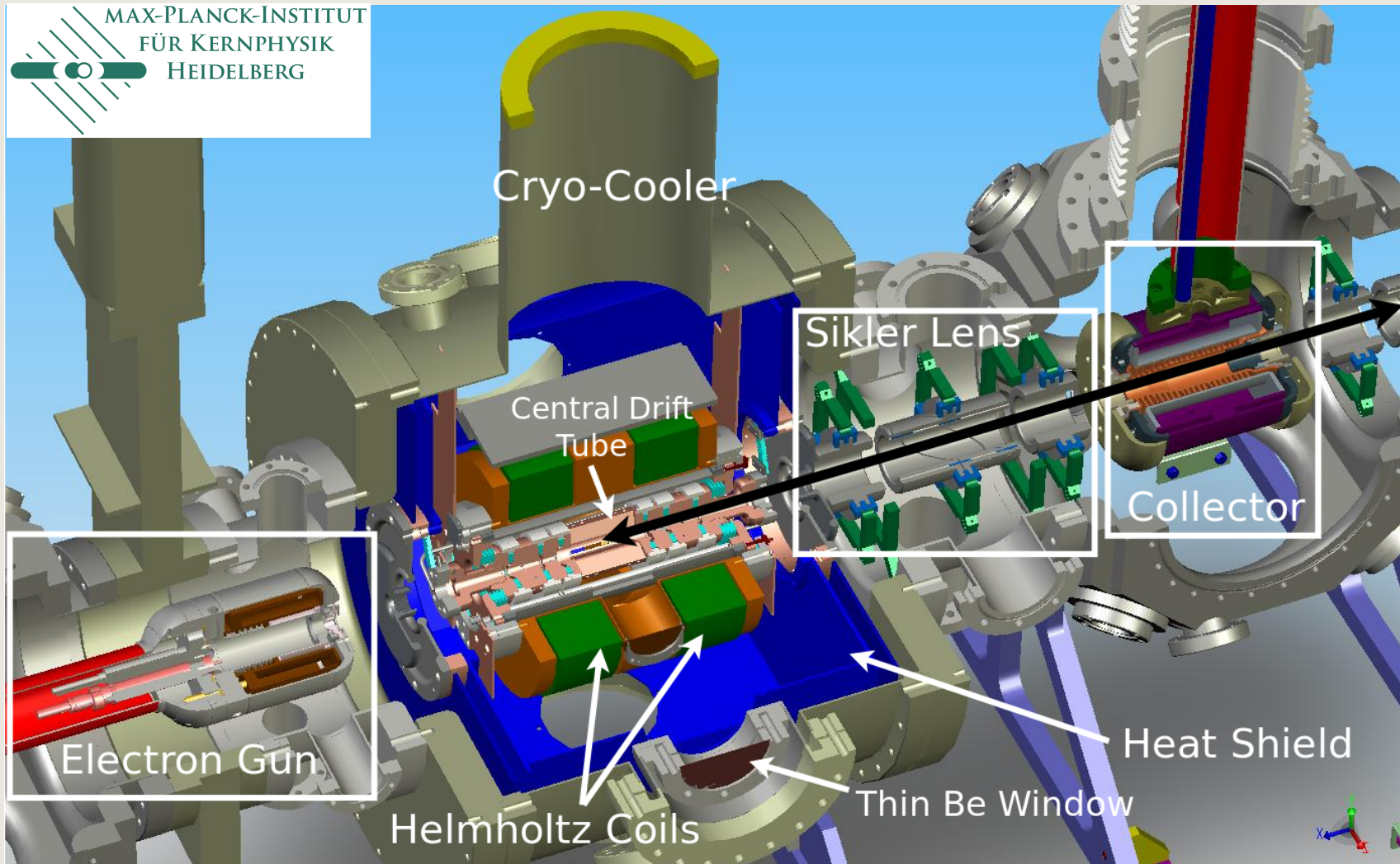
J. Dilling et al., Int. Journ. Mass Spec. **251**, 198 (2006)



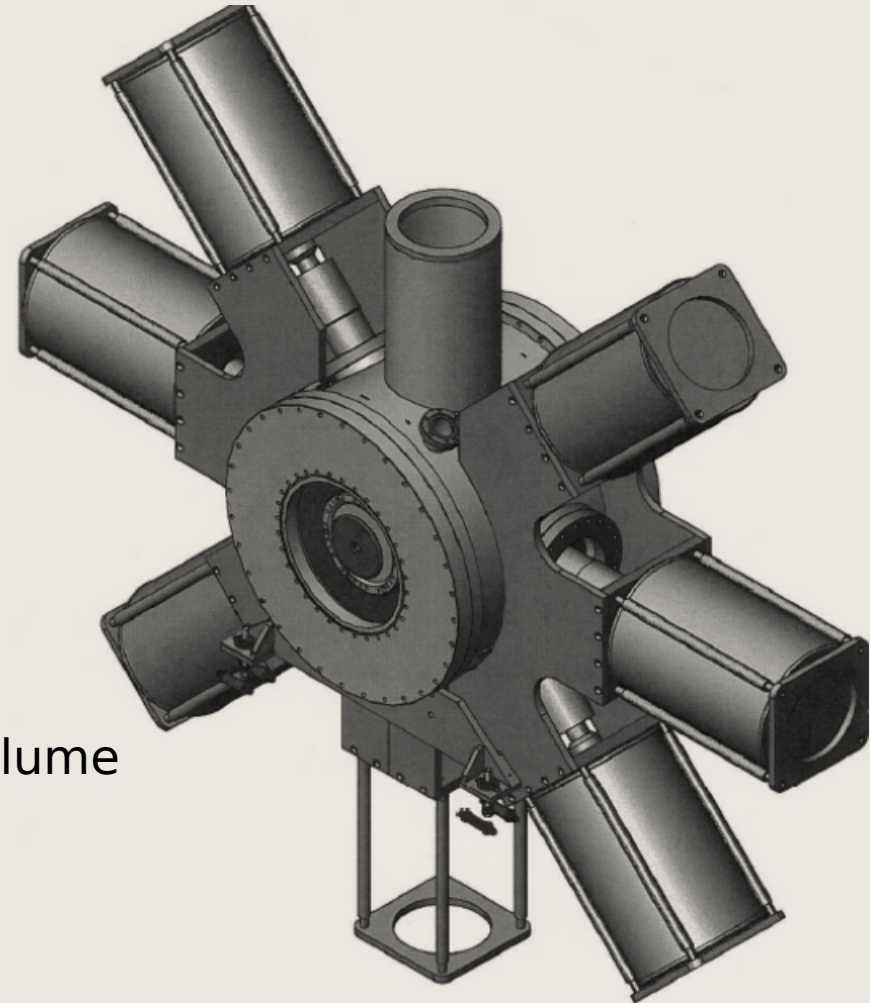
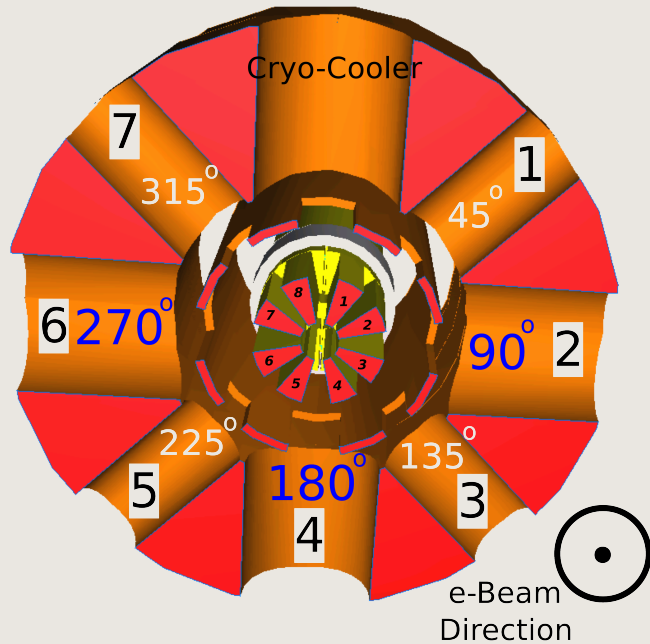
# Decay Spectroscopy with TITAN



# Decay Spectroscopy with TITAN



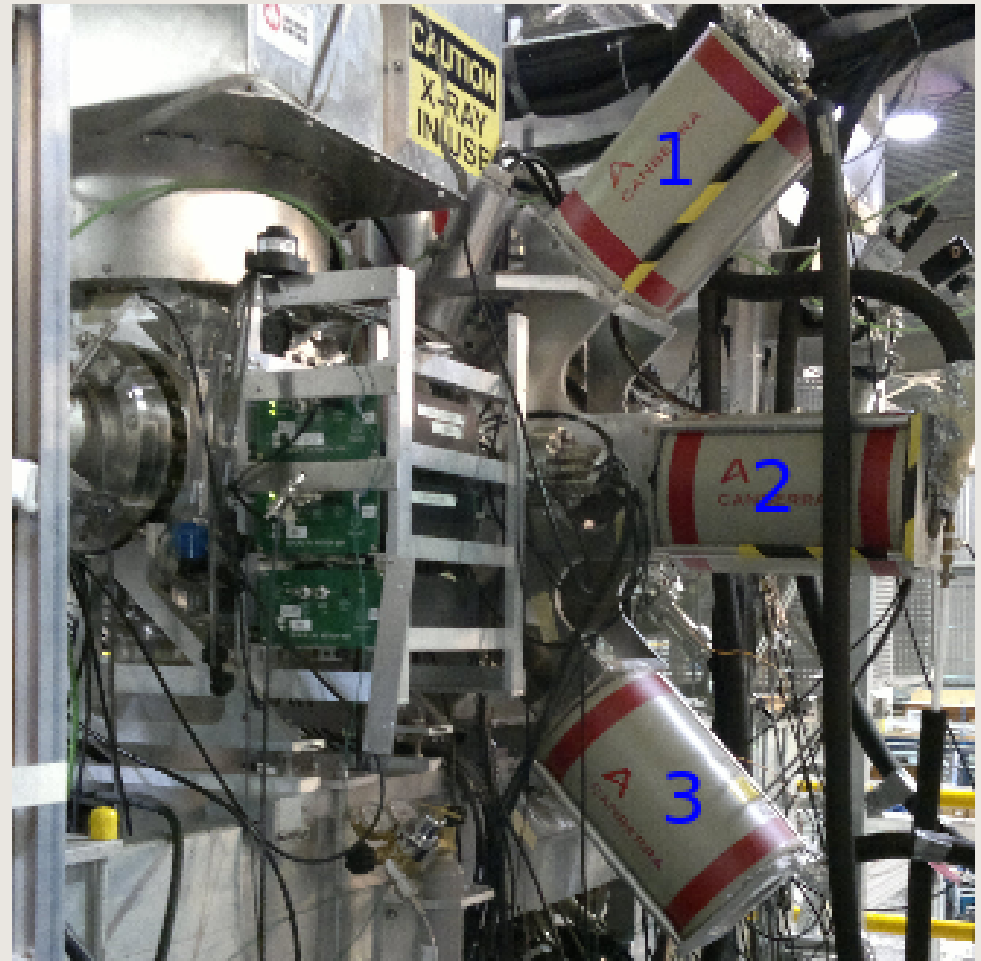
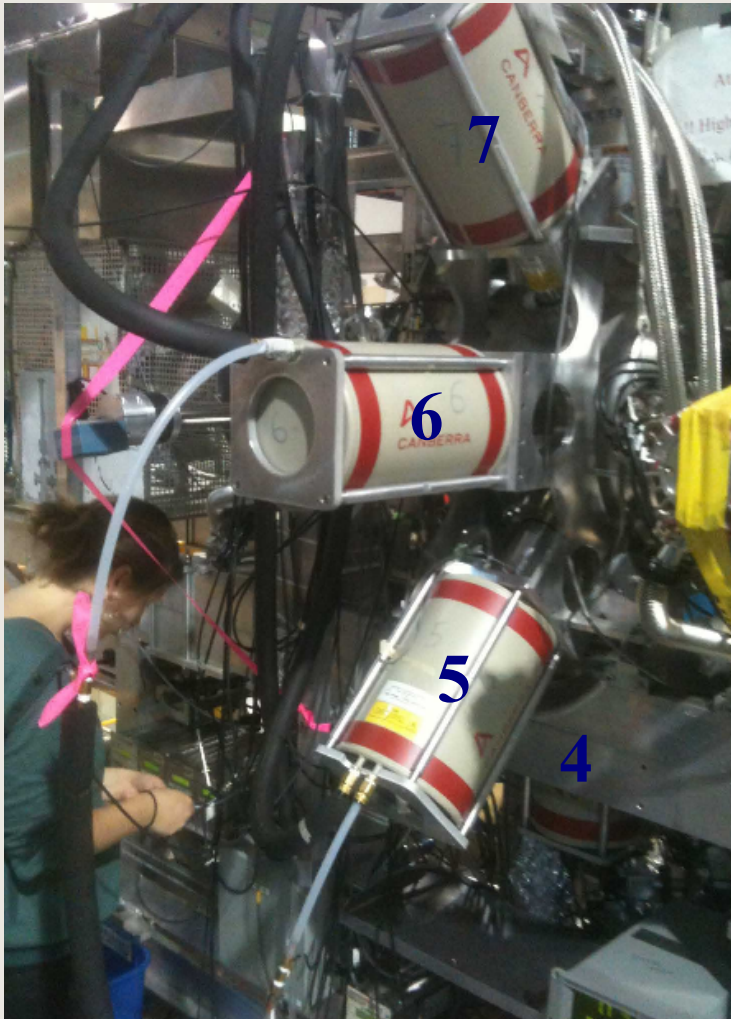
# Decay Spectroscopy on Trapped Radioactive Ions



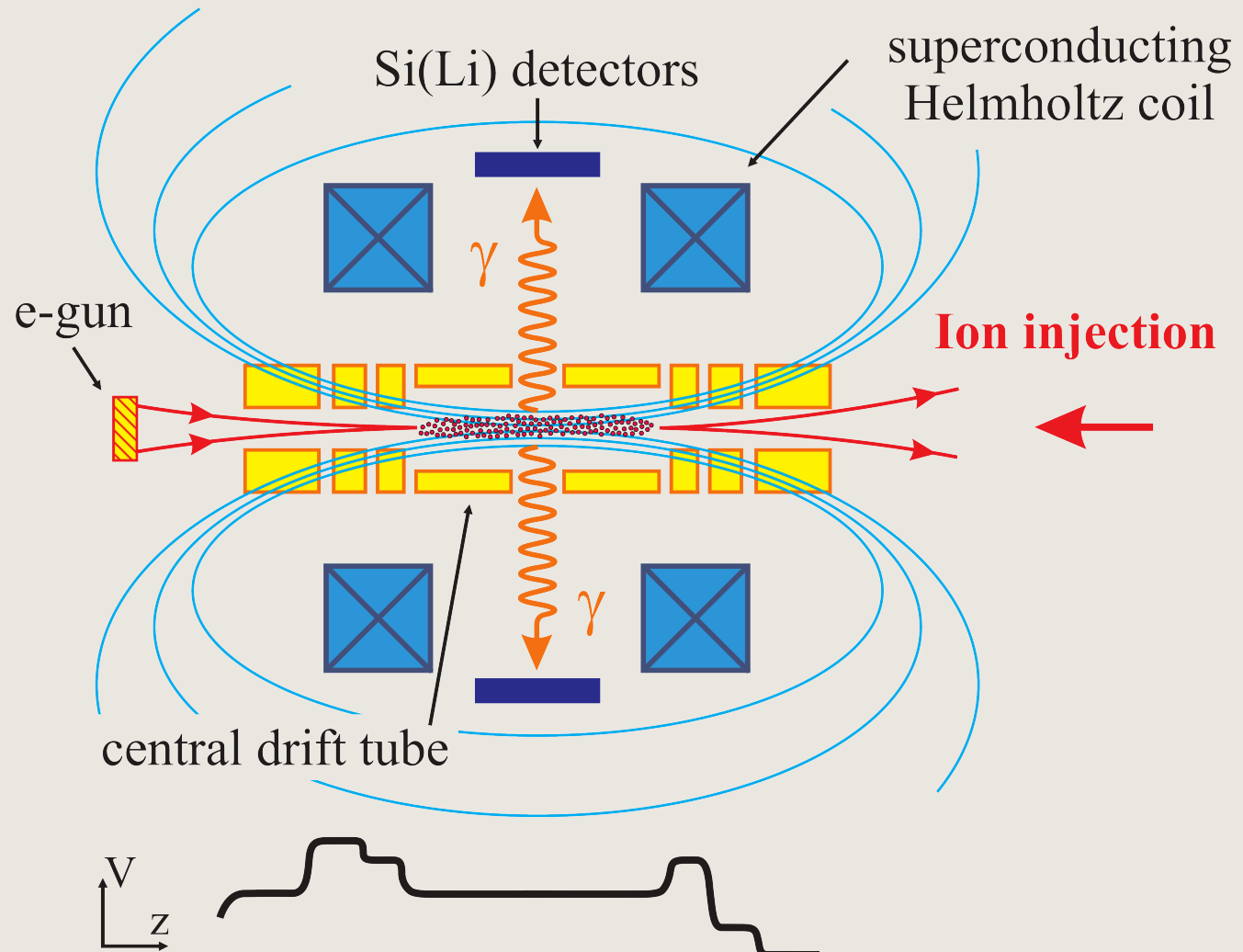
- Up to 6 T field with a 7 cm trapping volume
- Up to 500 mA e-beam
- 7, 5 mm thick Si(Li) detectors
- 1 LeGe detector for monitoring



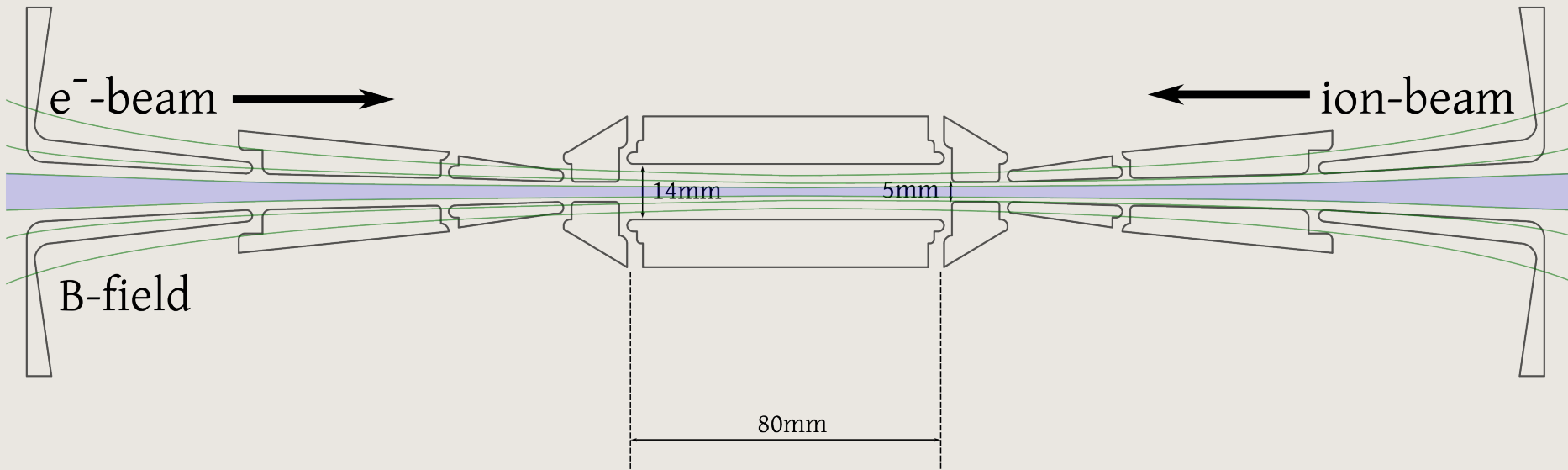
# Decay Spectroscopy on Trapped Radioactive Ions



# Ion-Bunch Confinement



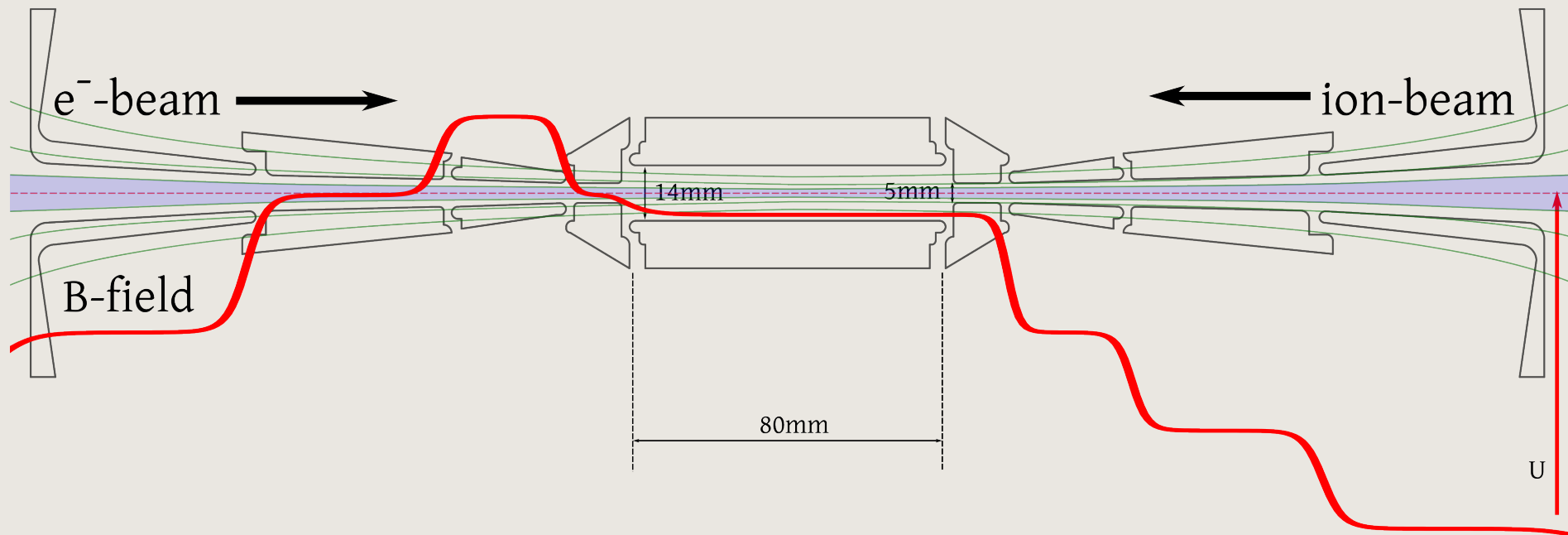
# EBIT Ion-bunch Injection



Courtesy R. Klawitter

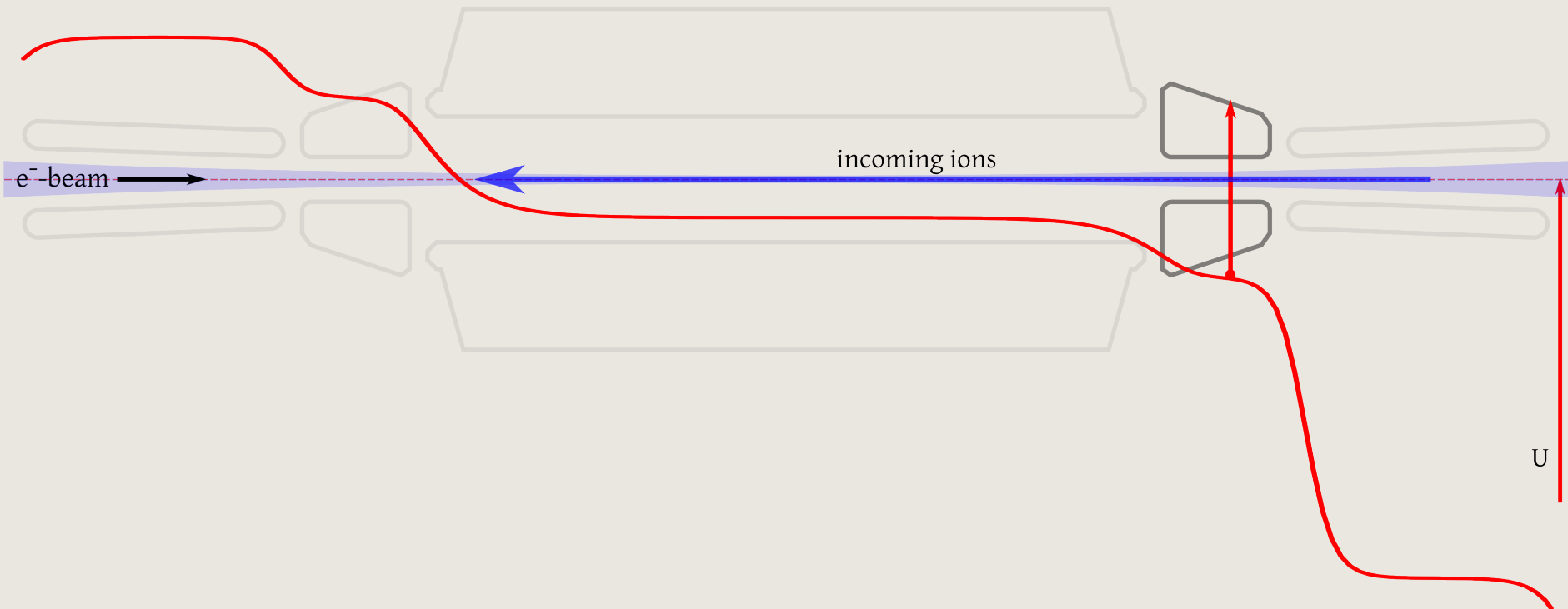


# EBIT Ion-bunch Injection



Courtesy R. Klawitter

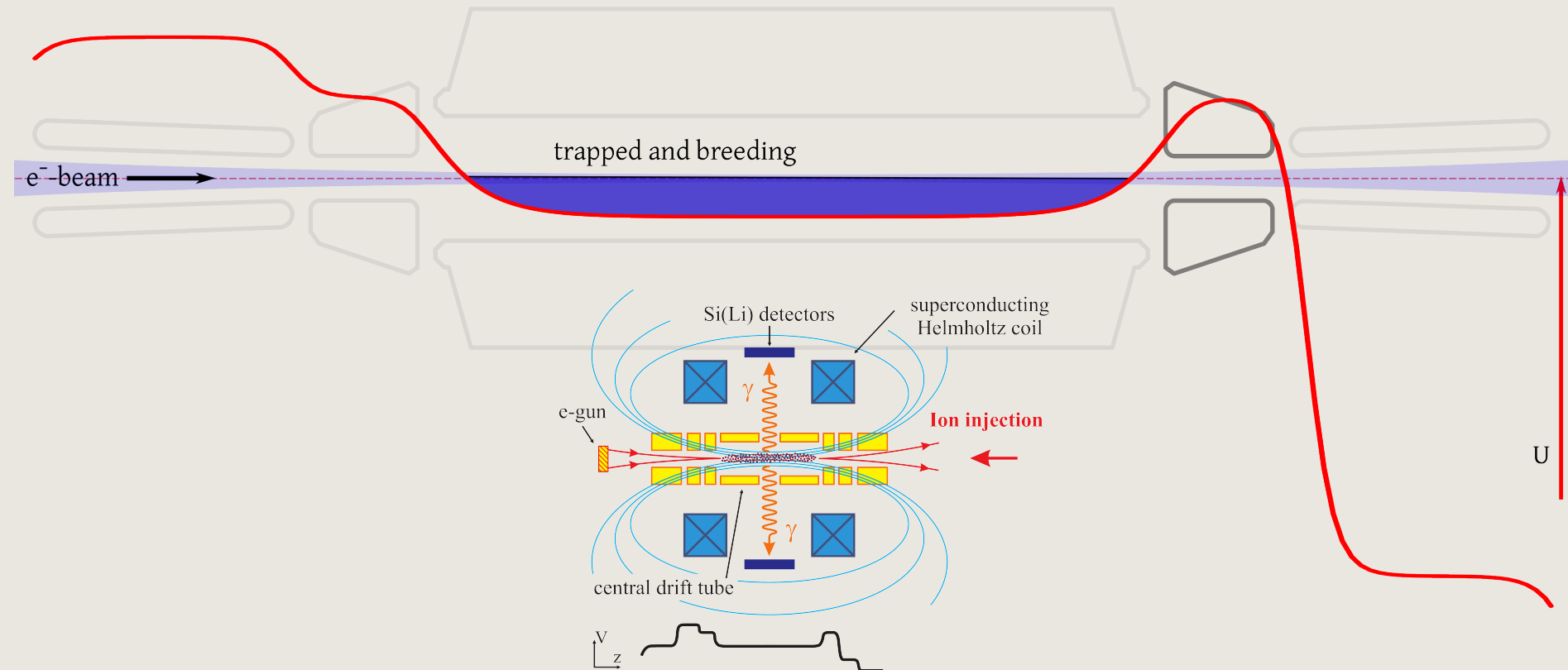
# EBIT Ion-bunch Injection



Inner-most collector side electrode potential is lowered for injection

Courtesy R. Klawitter

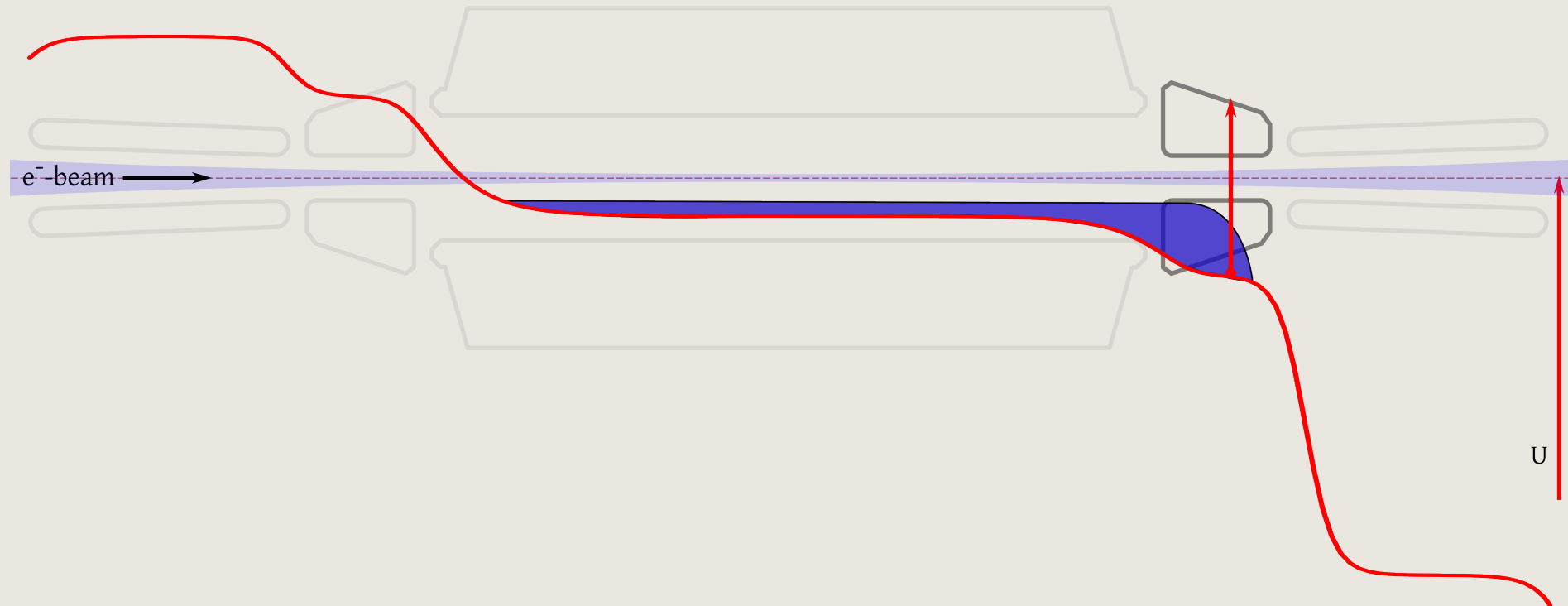
# EBIT Ion-bunch Injection



Inner-most collector side electrode potential is raised for axial confinement of the ion bunch

Courtesy R. Klawitter

# EBIT Ion-bunch Injection



Inner-most collector side electrode potential is lowered again,  
and bunch is removed from the trap

Courtesy R. Klawitter



# A=124 On-Line Commissioning

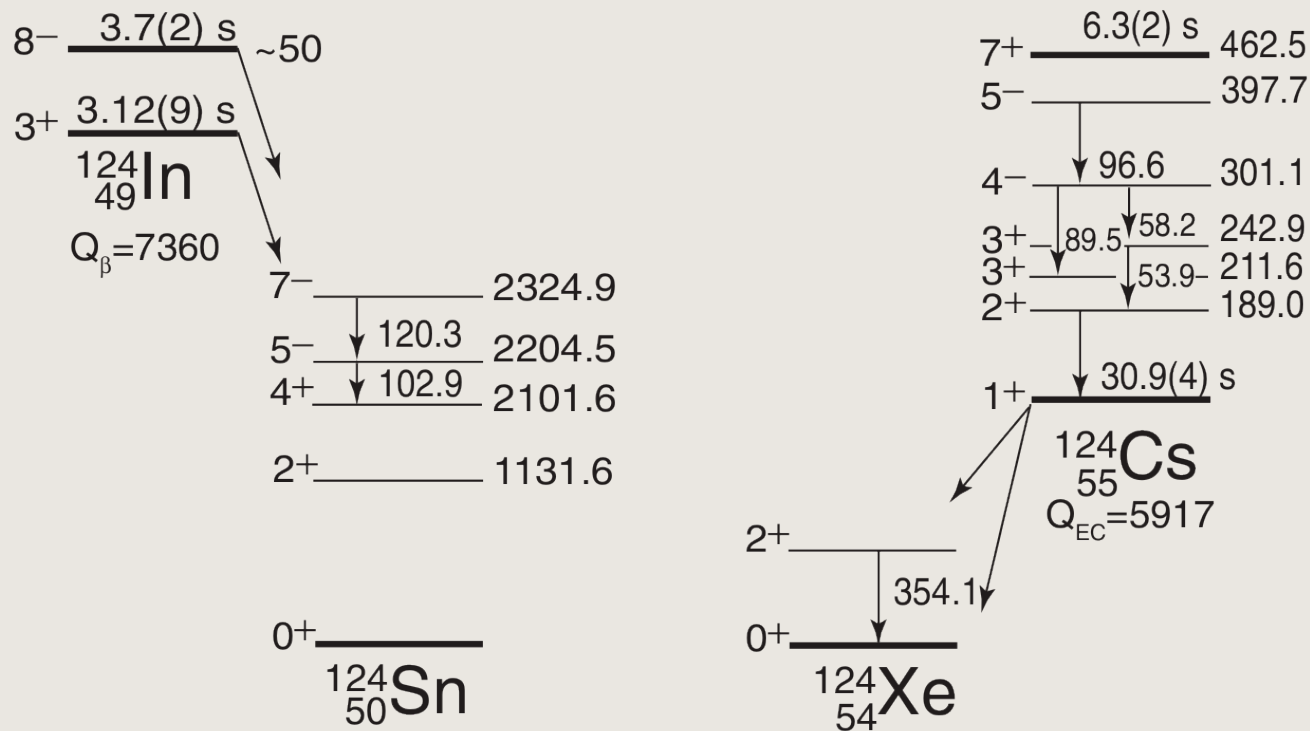
PRL **113**, 082502 (2014)

PHYSICAL REVIEW LETTERS

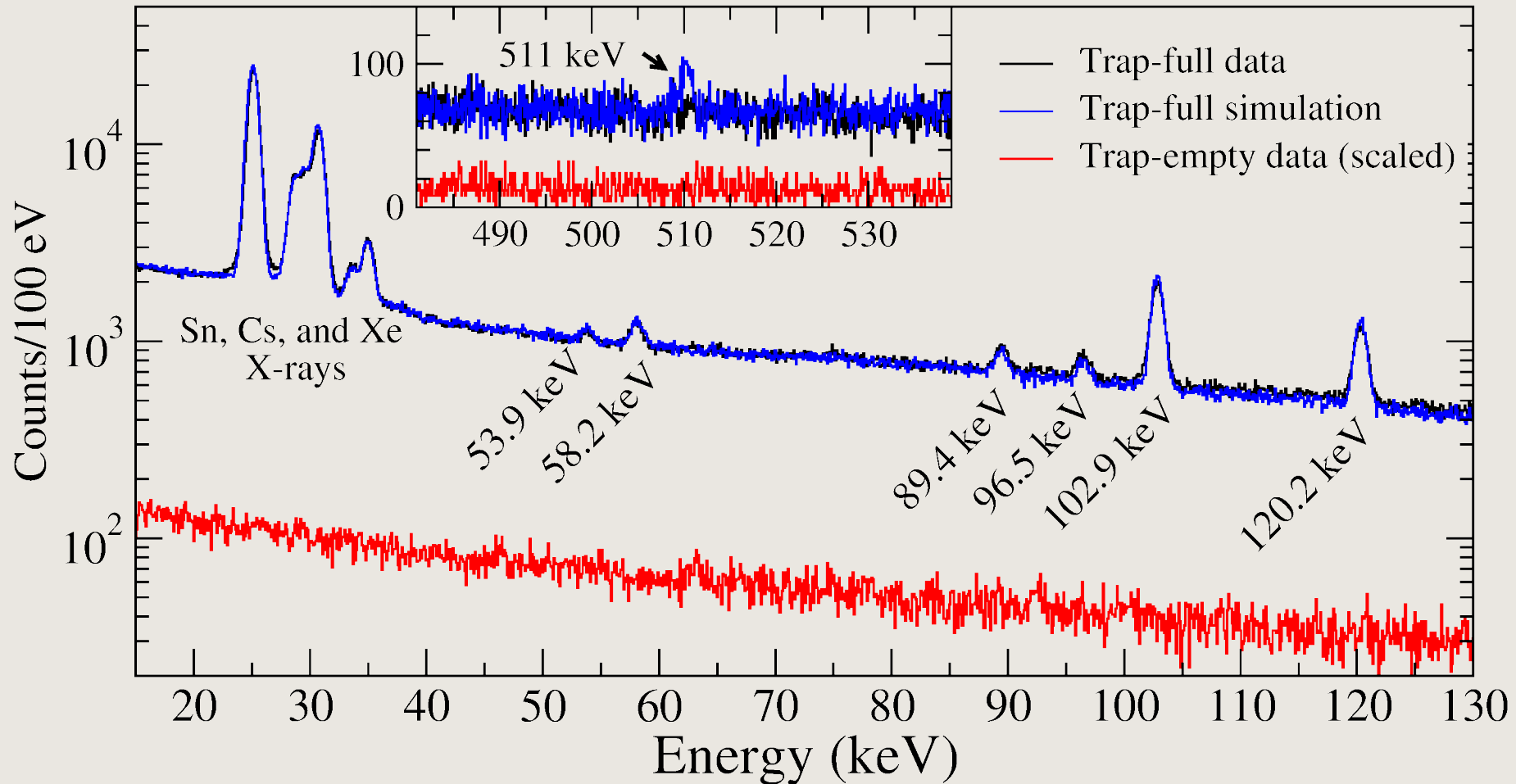
week ending  
22 AUGUST 2014

## In-Trap Spectroscopy of Charge-Bred Radioactive Ions

A. Lennarz,<sup>1,2</sup> A. Grossheim,<sup>2,3</sup> K. G. Leach,<sup>2,3</sup> M. Alanssari,<sup>1</sup> T. Brunner,<sup>2,†</sup> A. Chaudhuri,<sup>2</sup> U. Chowdhury,<sup>2,4</sup>  
J. R. Crespo López-Urrutia,<sup>5</sup> A. T. Gallant,<sup>2,6</sup> M. Holl,<sup>1</sup> A. A. Kwiatkowski,<sup>2</sup> J. Lassen,<sup>2</sup> T. D. Macdonald,<sup>2,6</sup>  
B. E. Schultz,<sup>2</sup> S. Seeraji,<sup>3</sup> M. C. Simon,<sup>2</sup> C. Andreoiu,<sup>3</sup> J. Dilling,<sup>2,6</sup> and D. Frekers<sup>1,\*</sup>

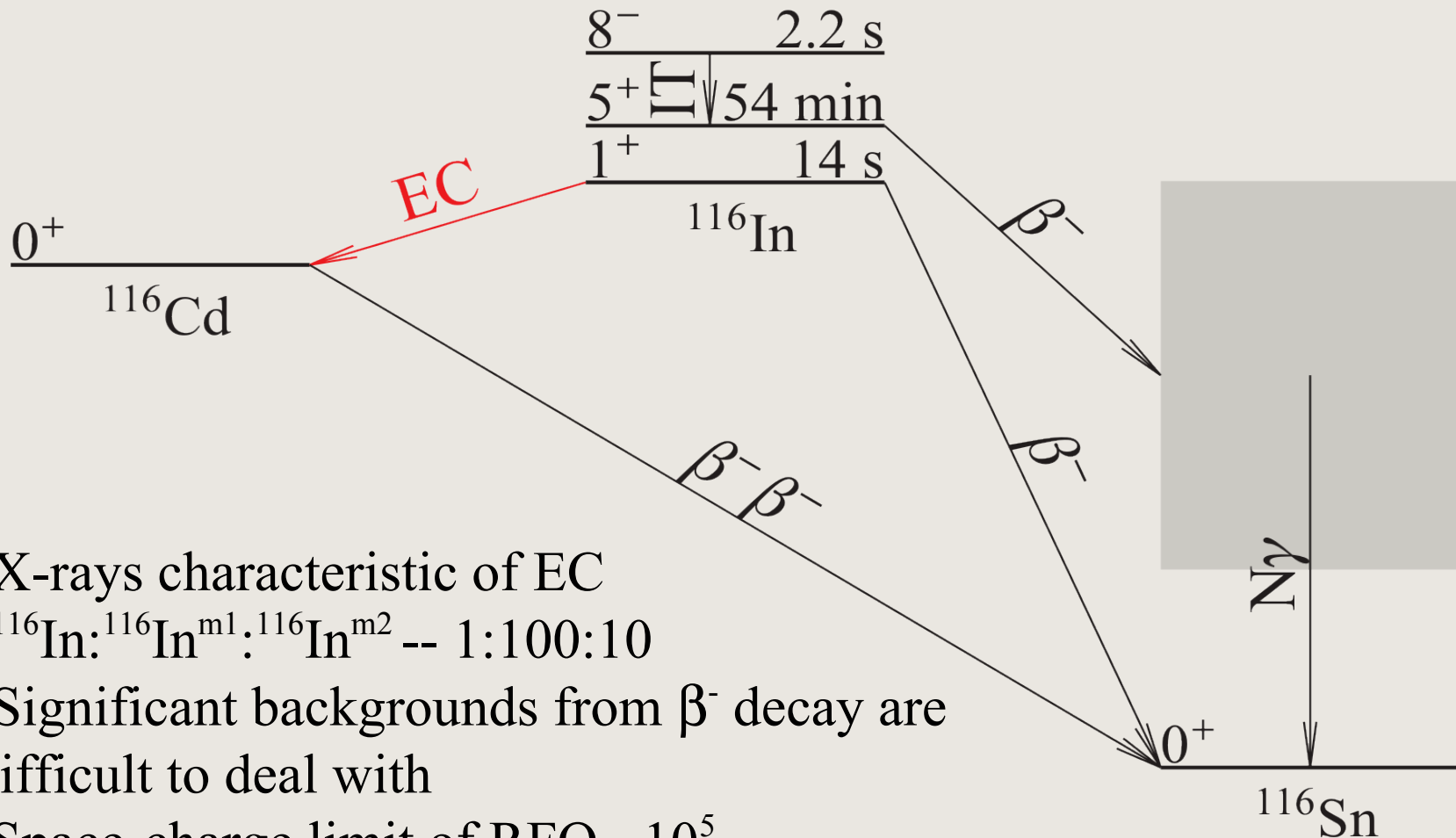


# A=124 On-Line Commissioning



A. Lennarz *et al.*, Phys. Rev. Lett. **113**, 082502 (2014)  
 K.G. Leach *et al.*, arXiv:1405.7209[nucl-ex] (2014)

# $^{116}\text{In}$ On-Line Commissioning



- X-rays characteristic of EC
- $^{116}\text{In}$ :  $^{116}\text{In}^{\text{m1}}$ :  $^{116}\text{In}^{\text{m2}}$  -- 1:100:10
- Significant backgrounds from  $\beta^-$  decay are difficult to deal with
- Space-charge limit of RFQ  $\sim 10^5$

C. Wrede *et al.*, Phys. Rev. C **87**, 031303(R) (2013)

# Multiple Ion-bunch Stacking

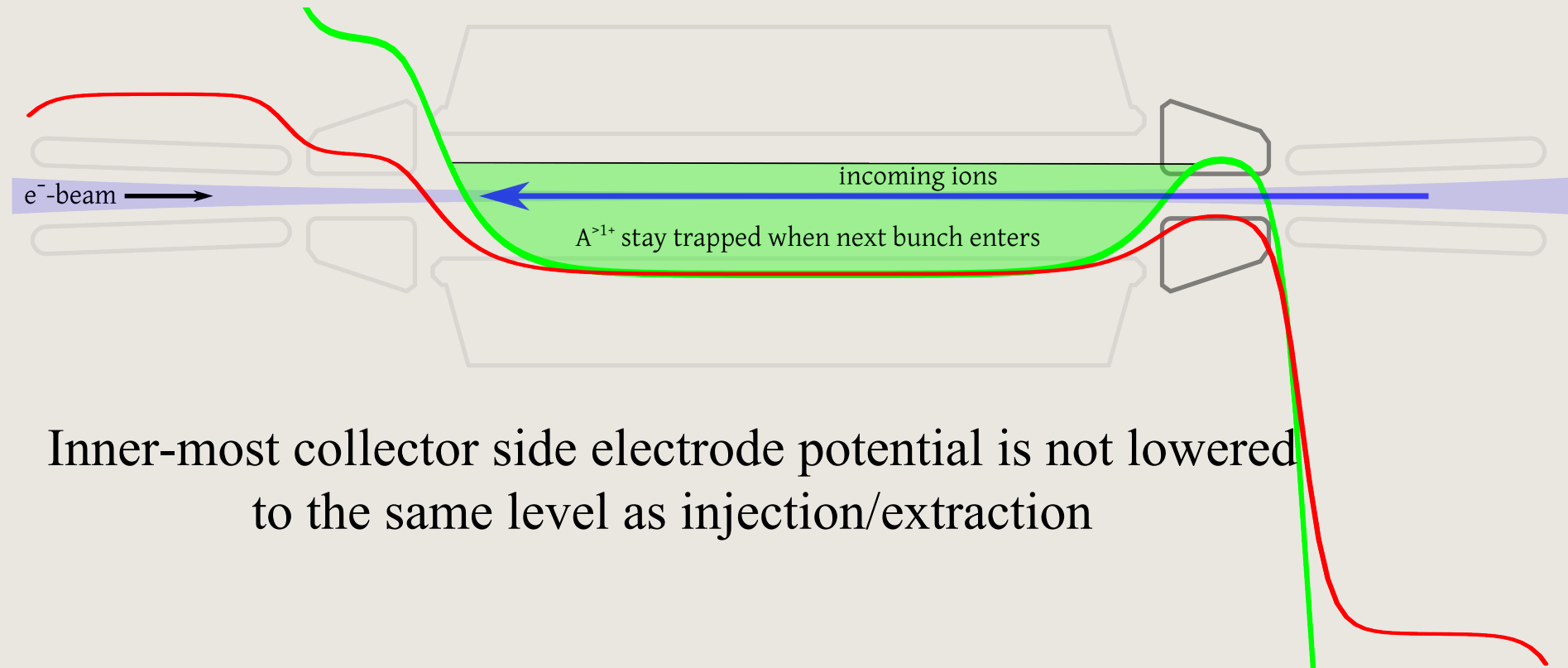


Ions are trapped, and in charge-state  $q > 2+$

Courtesy R. Klawitter



# Multiple Ion-bunch Stacking

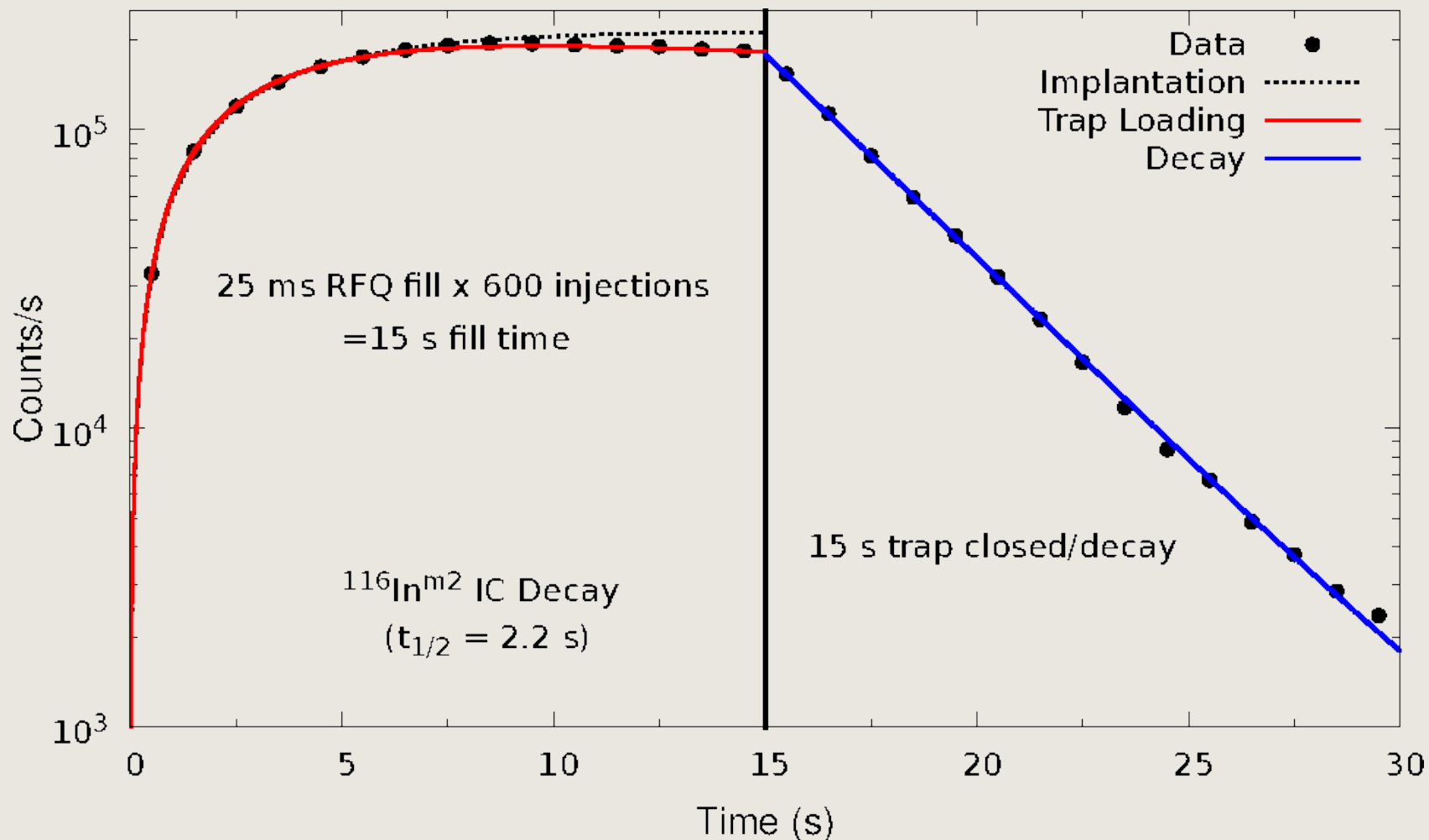


Inner-most collector side electrode potential is not lowered to the same level as injection/extraction

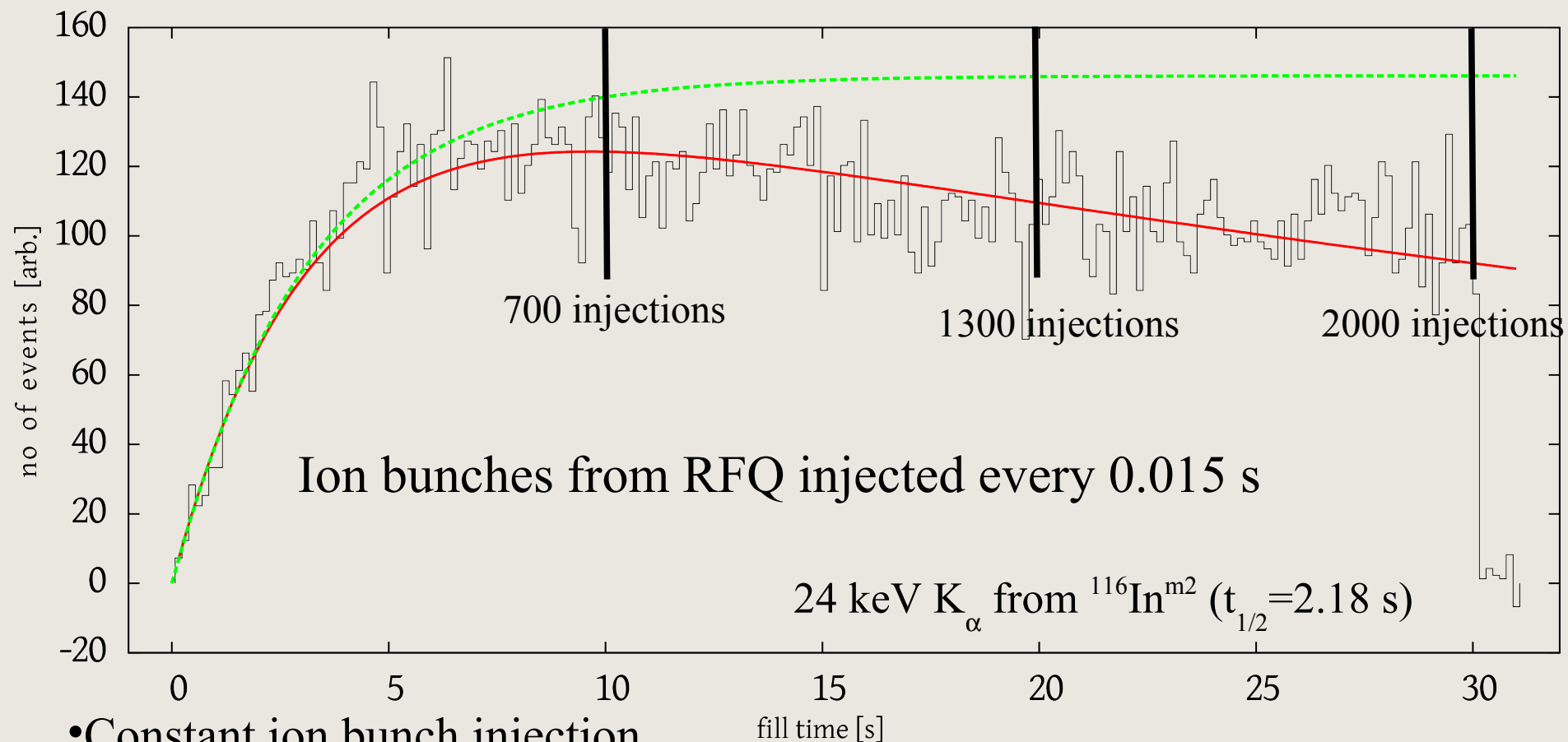
Subsequent ion bunches are rapidly injected, where they are quickly Charge-bred, and remain trapped

Courtesy R. Klawitter

# $^{116}\text{In}$ Decay Spectroscopy

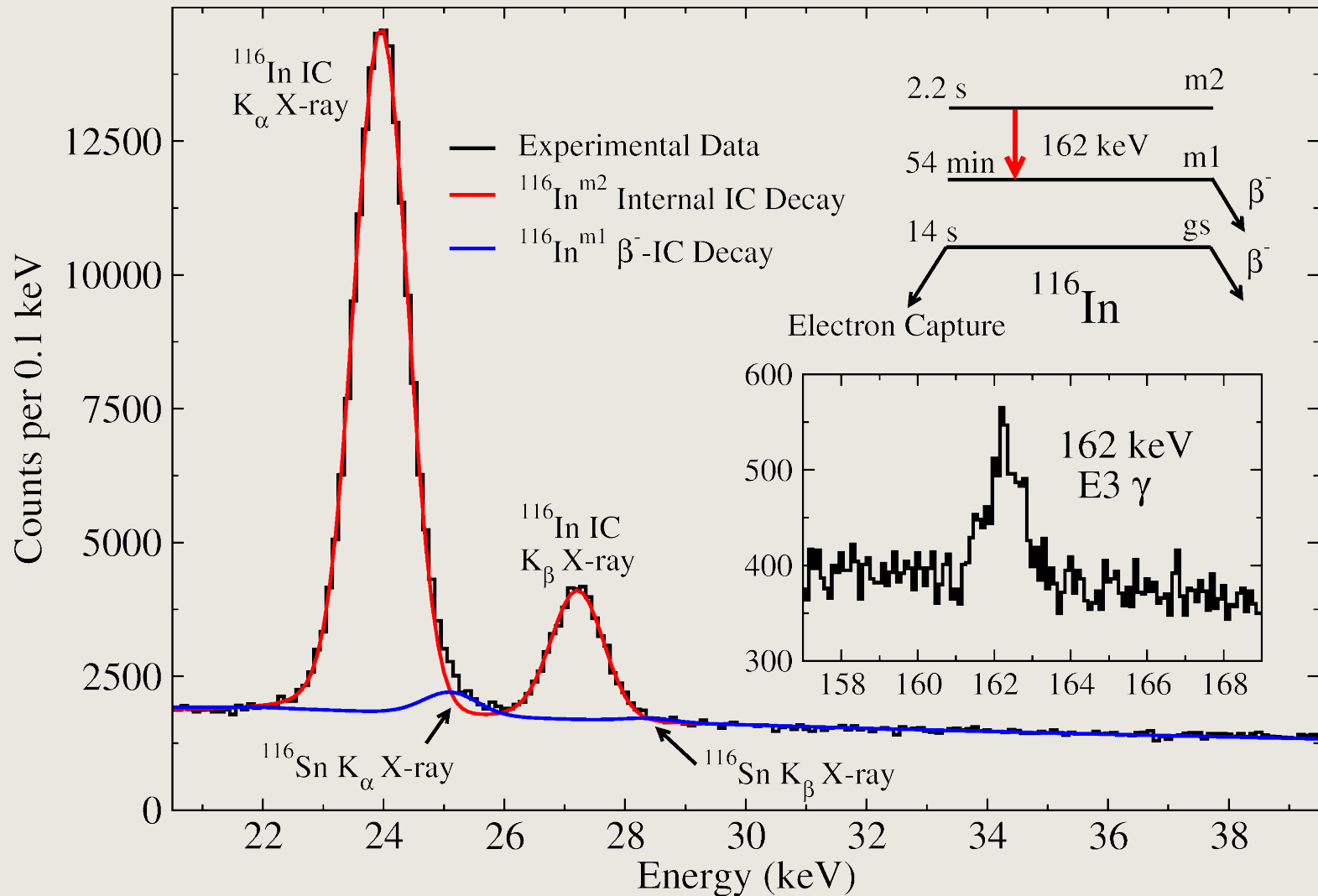


# Multiple Ion-bunch Stacking



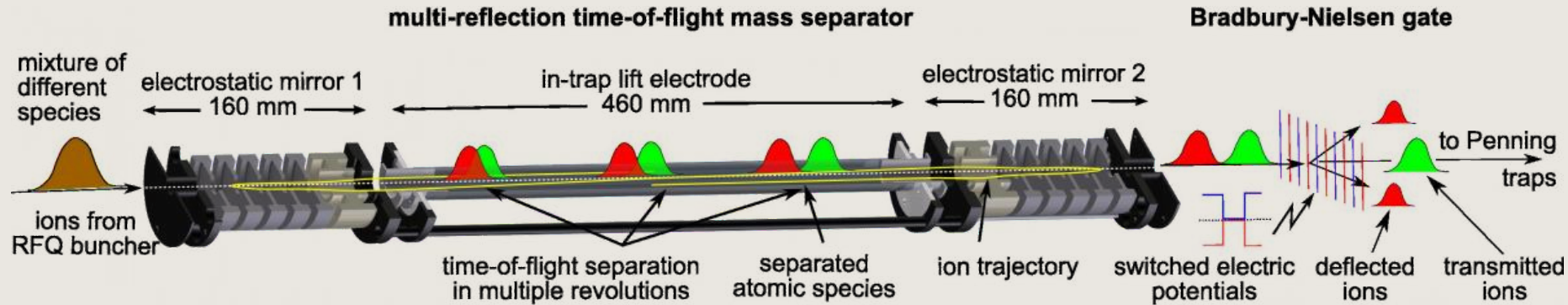
- Constant ion bunch injection
- Max after 700 bunches ( $\sim 10^6$ - $10^7$  ions, for RFQ space charge of  $<10^5$ )
- e-beam: 100 mA, 1.7 keV - space charge limit is about  $10^9 e$

# $^{116}\text{In}$ Decay Spectroscopy



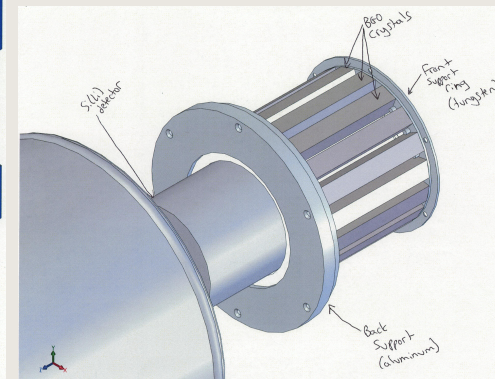
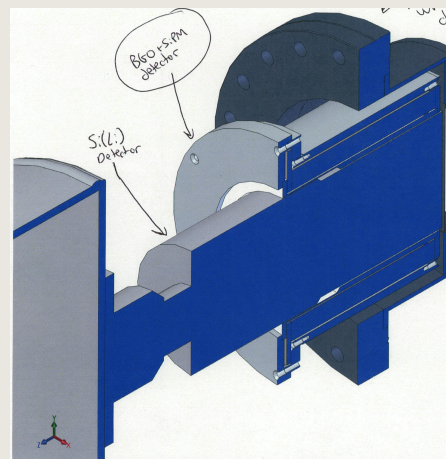
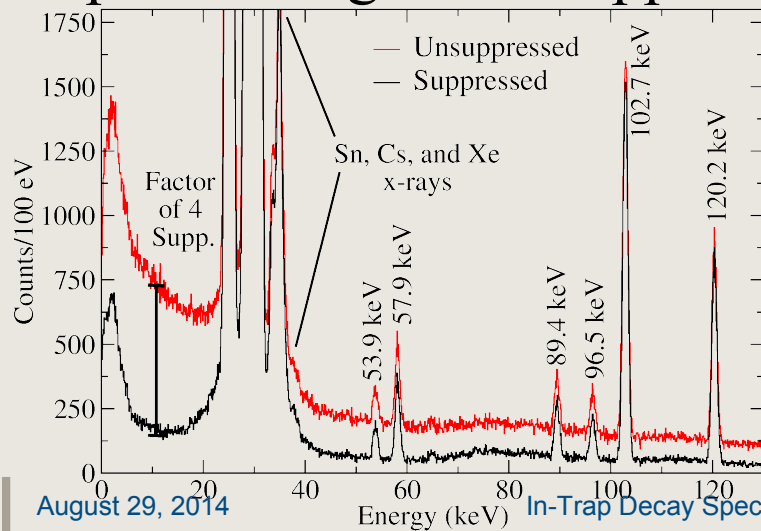
# Future Sensitivity Increases

## Multi-reflection time-of-flight:



R. N. Wolf *et al.*, PRL **110**, 041101 (2013)

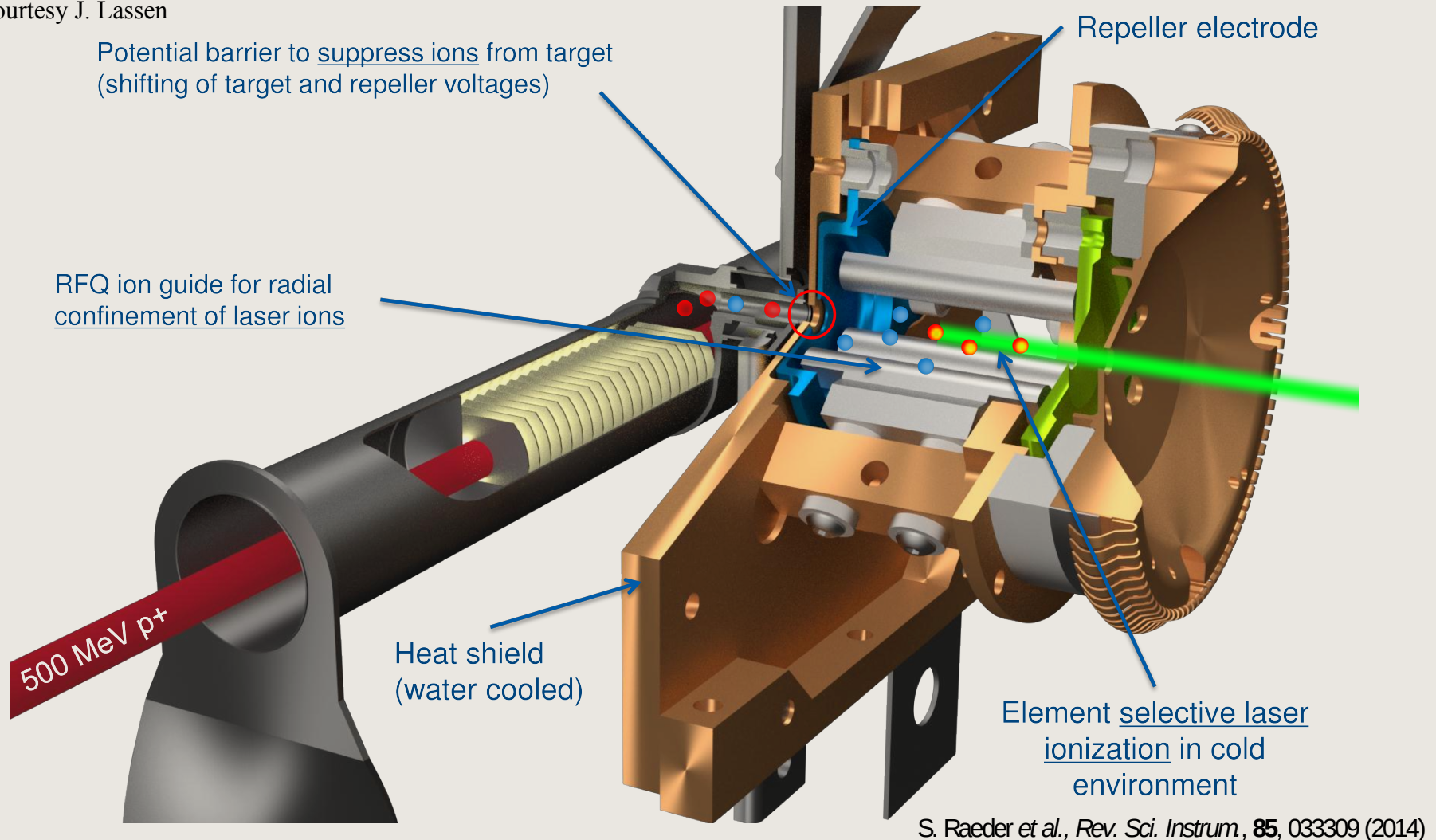
## Compton Background Suppression:



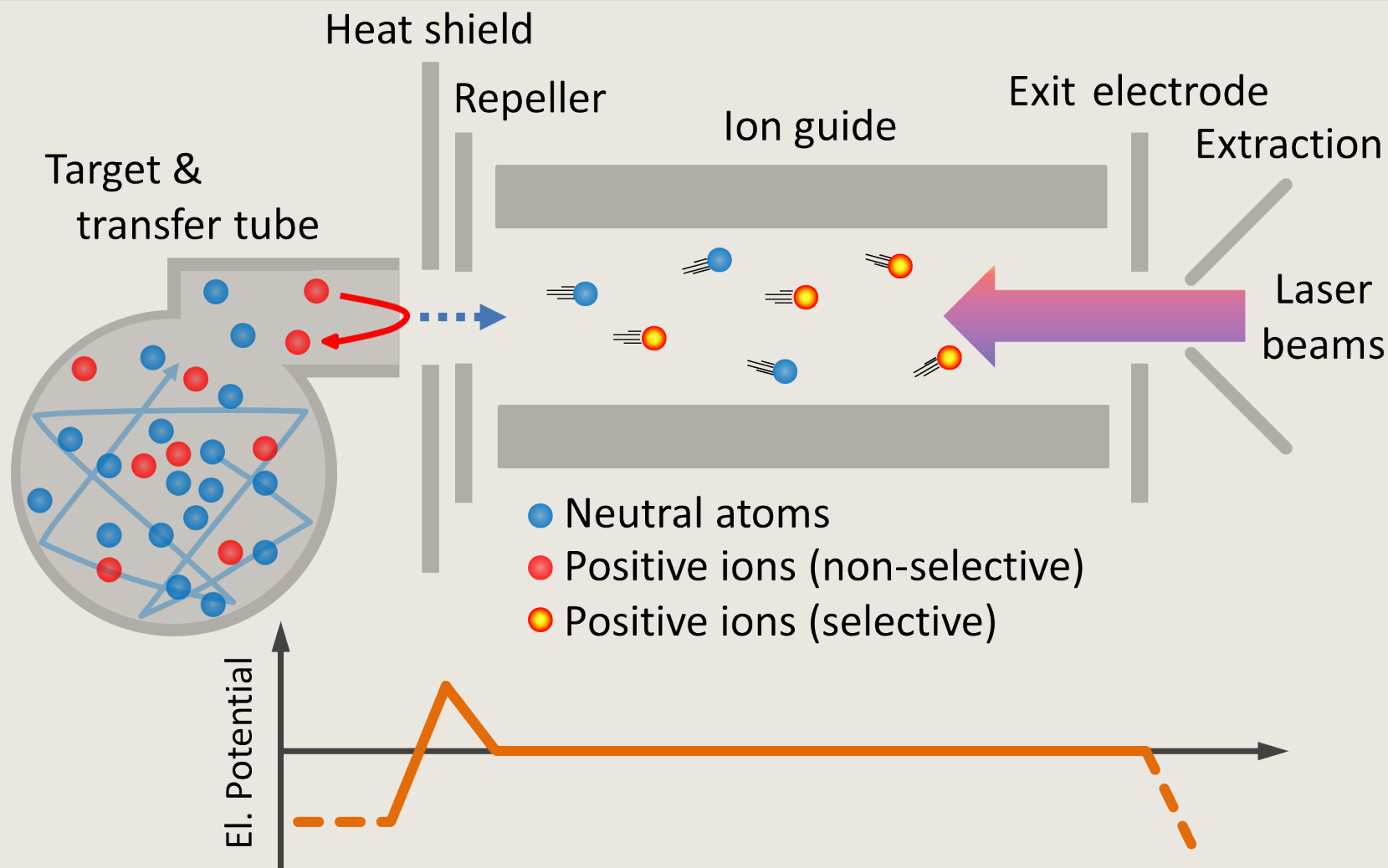


# The Ion-Guide Laser Ion Source (IG-LIS)

Courtesy J. Lassen

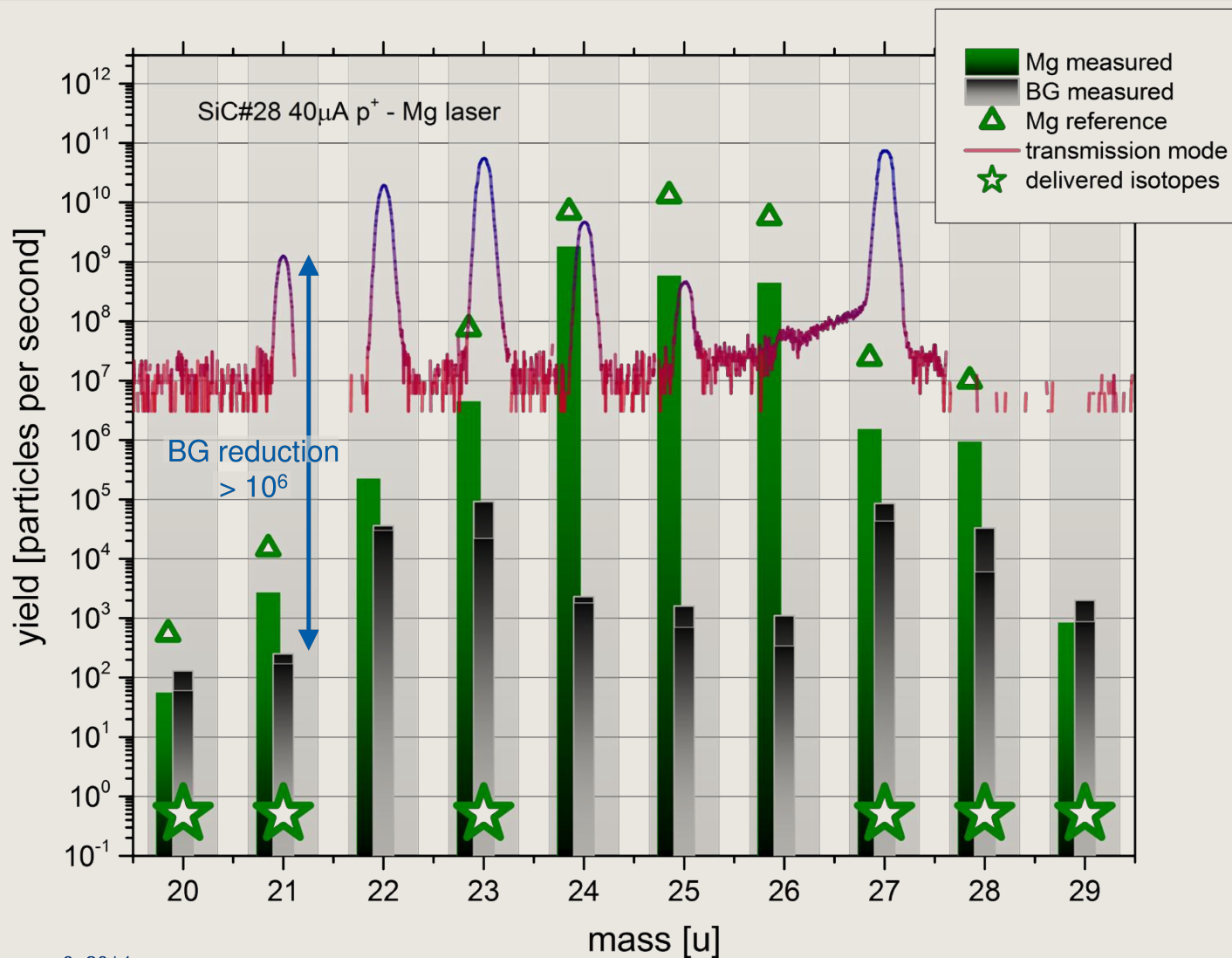


# The Ion-Guide Laser Ion Source (IG-LIS)



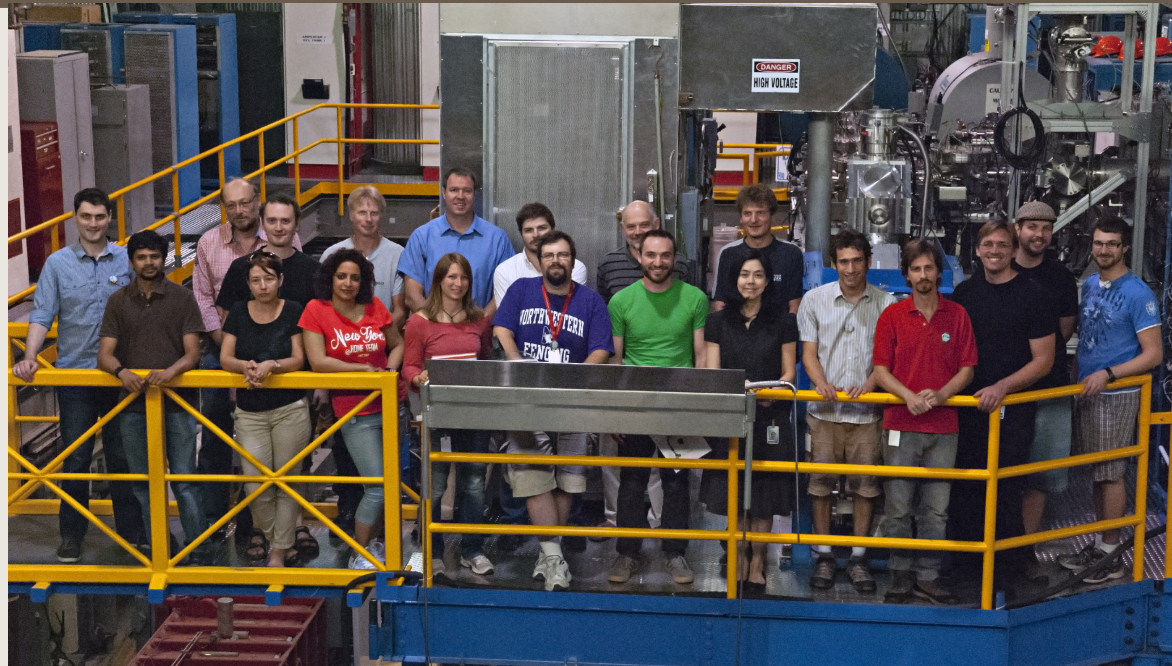
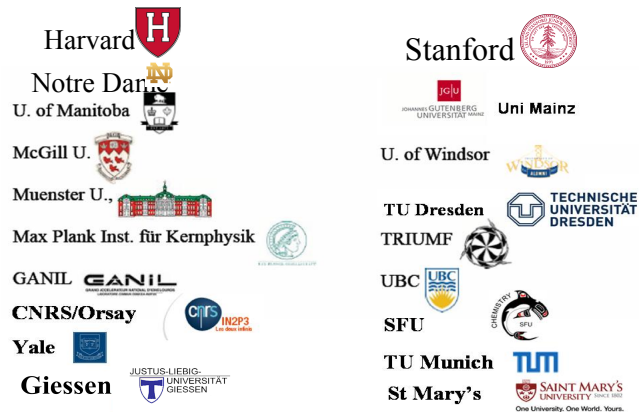
A.T. Gallant *et al.*, Phys. Rev. Lett. **113**, 082501 (2014)

# Rare-Isotope Beam (RIB) Purity



# Conclusions

- An ion-trap decay spectroscopy tool has been constructed and commissioned with TITAN at TRIUMF
- Consists of:
  - Up to 6 T open-access ion trap
  - 500 mA  $e$ -gun
  - Seven 5mm thick planar Si(Li) detectors
- Have achieved trapping times of minutes with no ion losses
- Demonstrated multiple-injection technique
- Sensitivity increases will provide access to experiments which were not previously possible



# Thank You!

# Merci!

Contact TRIUMF :

4004 Wesbrook Mall | Vancouver BC | Canada V6T 2A3 | Tel 604.222.1047 | Fax 604.222.1074 | [www.triumf.ca](http://www.triumf.ca)



# $^{116}\text{In}$ Decay Spectroscopy

Counts/bin

25ms RFQ, 600 Injections  
= 15 s Fill

15 s Trapping/Decay

