Nuclear Excitation via Electron Capture with TITAN

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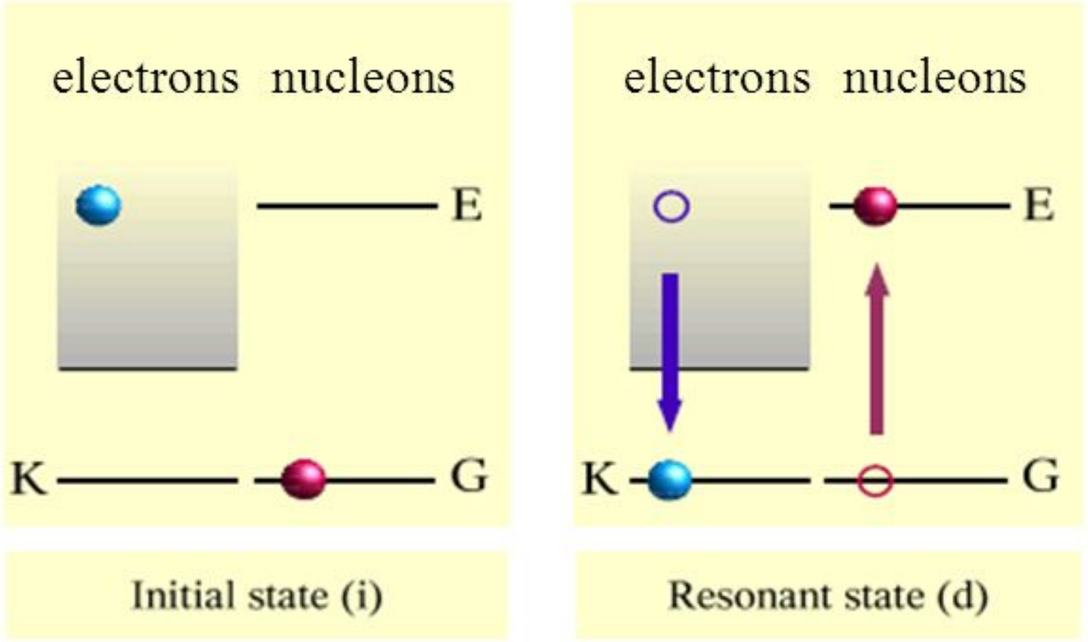
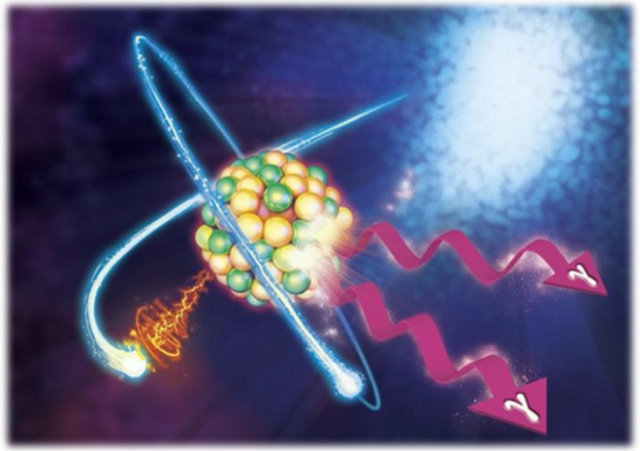
NEEC: Nuclear Excitation via Electron Capture

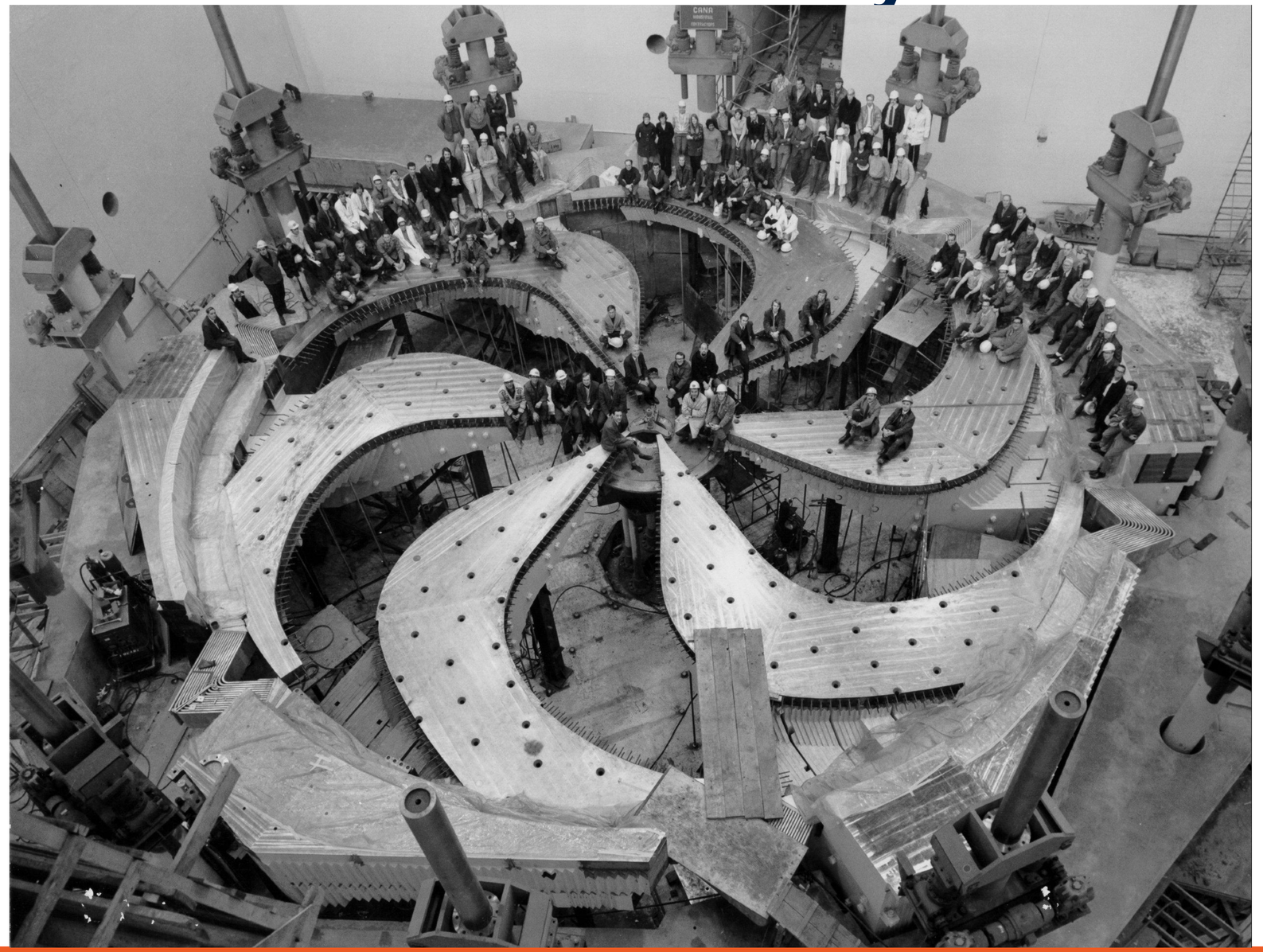
- In the resonant process of NEEC, a free electron is captured into a highly charged ion with the simultaneous excitation of the nucleus
- Atomic electron is captured into a vacancy of a highly charged ion causing energy to be transferred to the nucleus via a resonant process
- Resonance energy = binding energy of atom + kinetic energy of electron
- NEEC was recently reported for the first time in 2018 via in beam measurement at Argonne National Laboratory in ^{93}Mo
- The claimed observation disagrees with theoretical calculations by 9 orders of magnitude, and thus more controlled stimulation techniques are being explored
- By considering unstable nuclei for NEEC in ion traps, the number of suitable cases is increased dramatically.



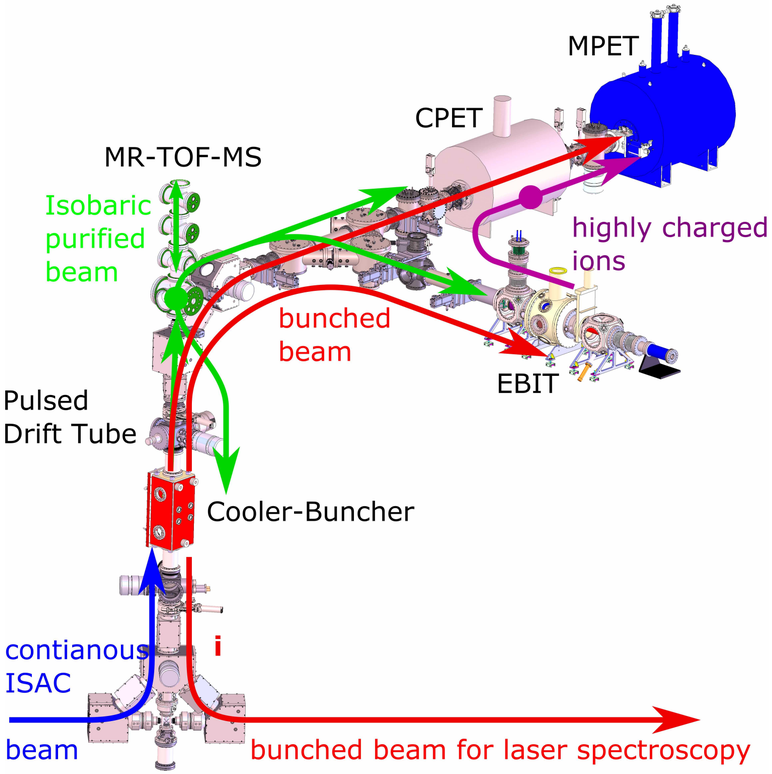


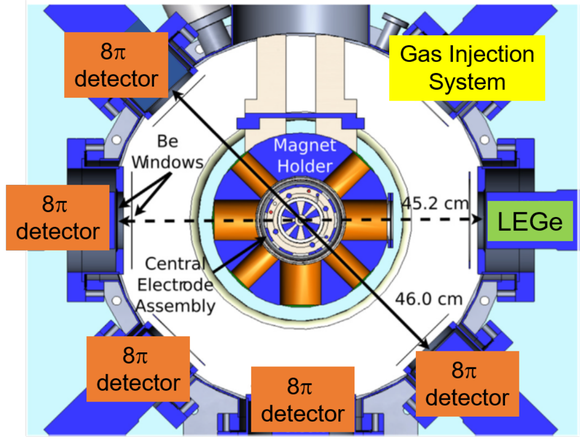
A. Palffy et al., Phys. Rev. Lett. 99, 172502 (2007)
C. J. Chiara et al., Nature 554, 216-218 (2018)
Y. Wu, C.H. Keitel, and Adriana Pálffy, Phys. Rev. Lett. 122, 212501 (2019)

TRIUMF - 520MeV Cyclotron

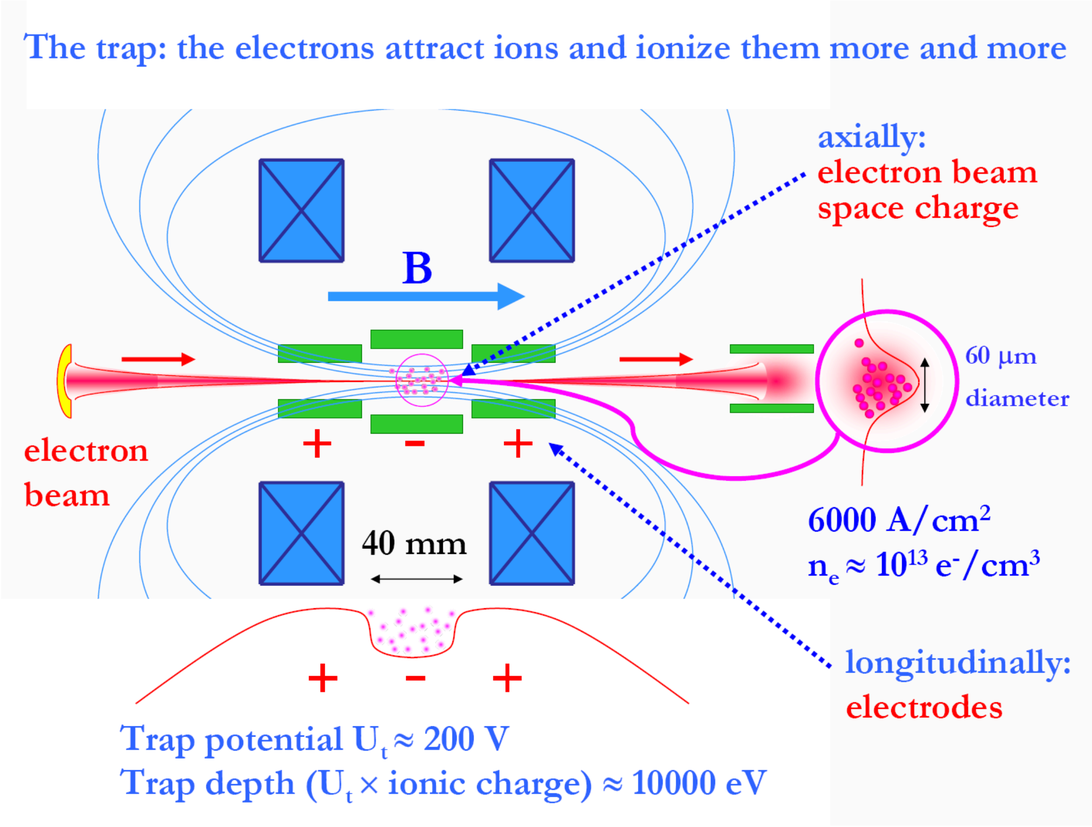


TITAN EBIT @ TRIUMF





*EBIT constructed and designed in Heidelberg.

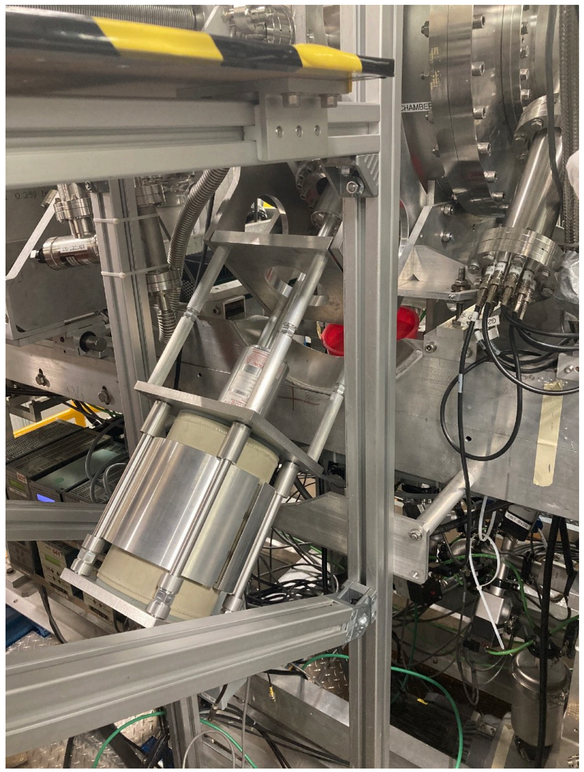


- **TITAN - TRIUMF's Ion Trap for Atomic and Nuclear Science**
- **7 access ports to house 5 HPGe's & 1 ULE-HPGe detector**
- **Geometric acceptance is ~ 2% of 4pi**

A. Lennarz, et al., Phys. Rev. Lett. 113, 082501 (2014)
K.G. Leach et al. NIM A 780, 91-99 (2015)
K.G. Leach et al. Atoms 5, 14 (2017)

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

High Purity Germanium Detectors



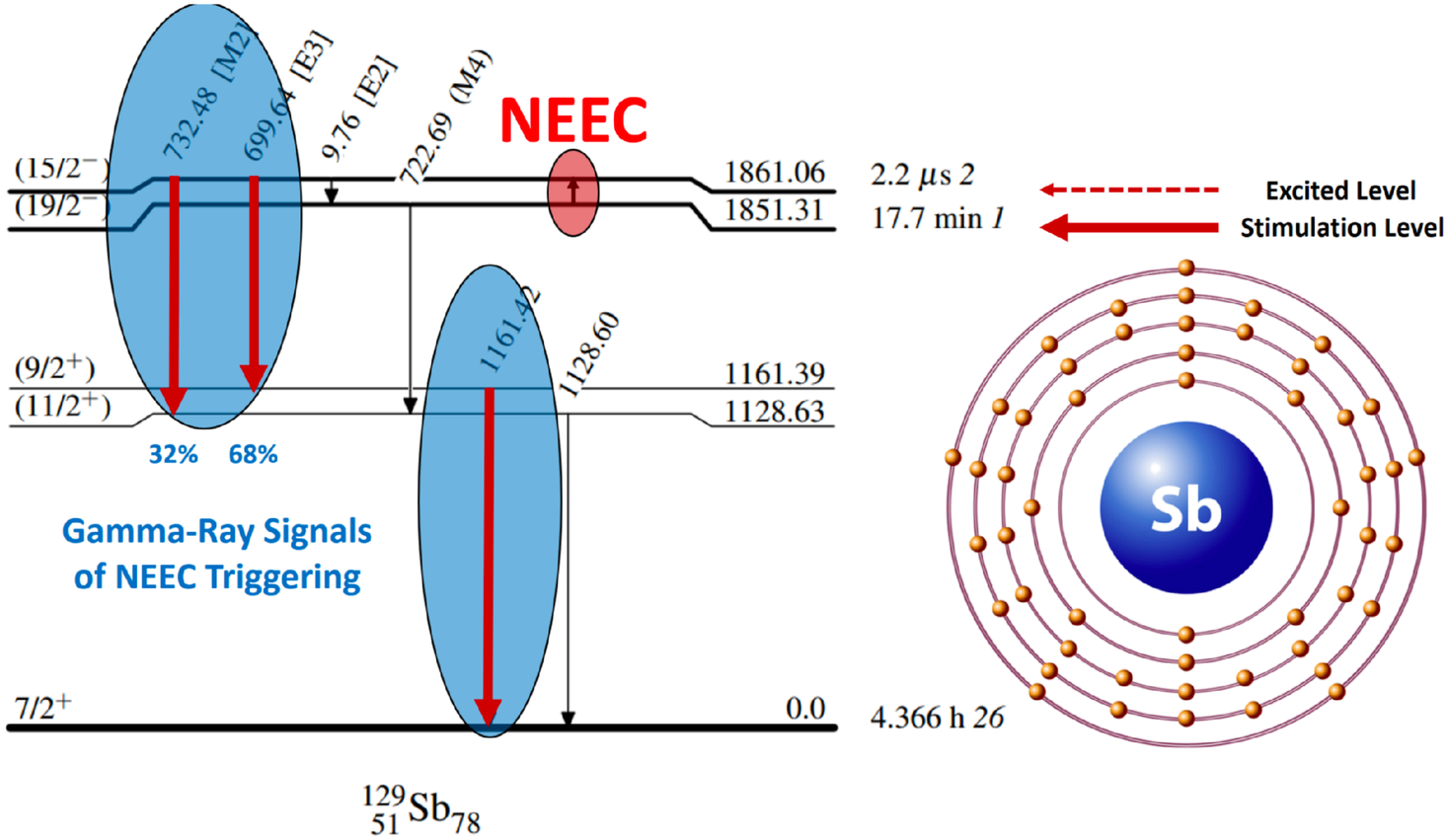
High Energy HPGe

- **Sensitive to nuclear gamma rays (100 keV-> 2 MeV)**
- **Used to observe NEEC characteristic gamma rays**

Ultra Low Energy HPGe

- **Sensitive to atomic x-rays (1 keV -> 100 keV)**
- **Used to determine current charge state in EBIT**

NEEC of $^{129m1}Sb$

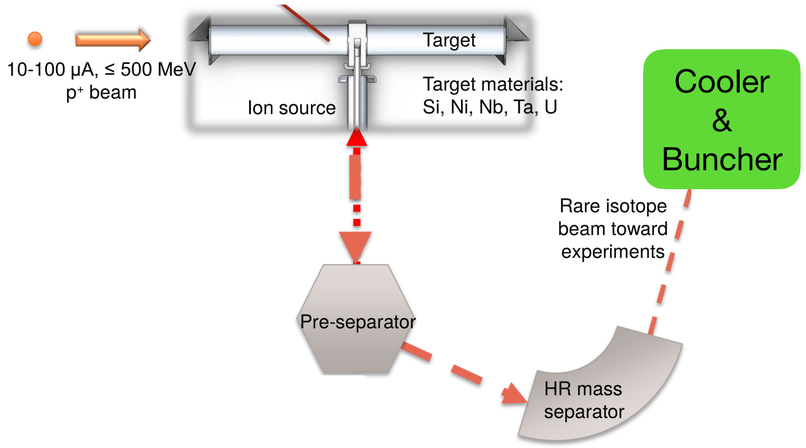


He-like case : L-shell atomic vacancy - Recombination x-section : $1.6x10^{-3}b \cdot eV$

Ne-like case : M-shell atomic vacancy - Recombination x-section : $3.0x10^{-5}b \cdot eV$

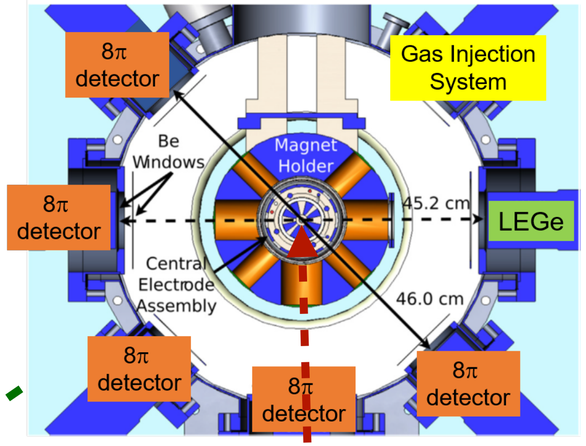
A. Palffy, Private Communication (2018)

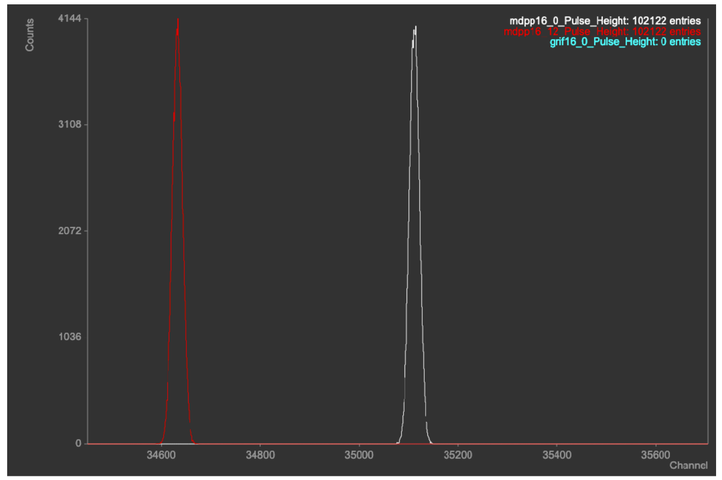
Controlled Stimulation of NEEC in an EBIT



Cooler & Buncher

Rare isotope beam toward experiments



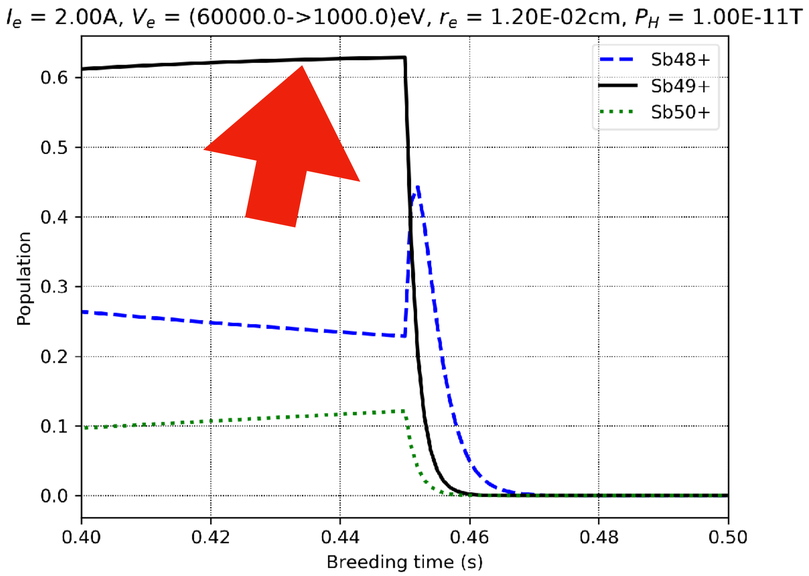


Output as timestamped energy spectrum

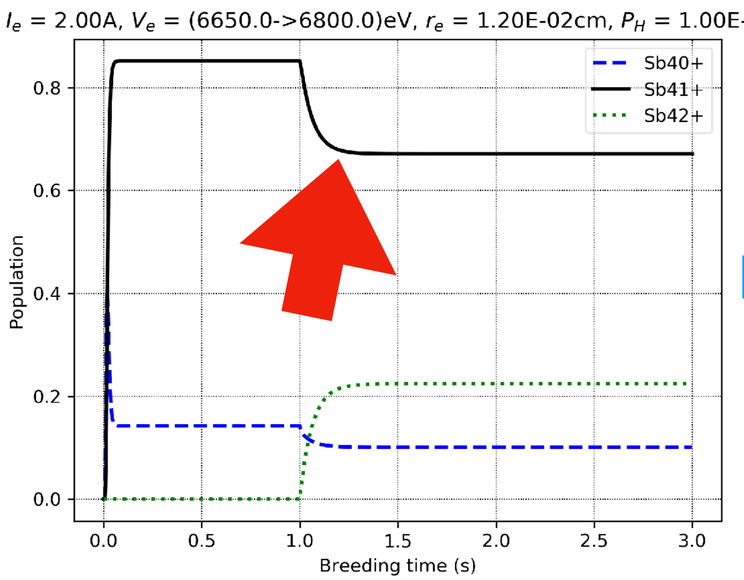
Variable Energy Electron Gun :
For further ionization & generation of electrons at resonance energy

Simulation of charge breeding w/ Electron beam ramping

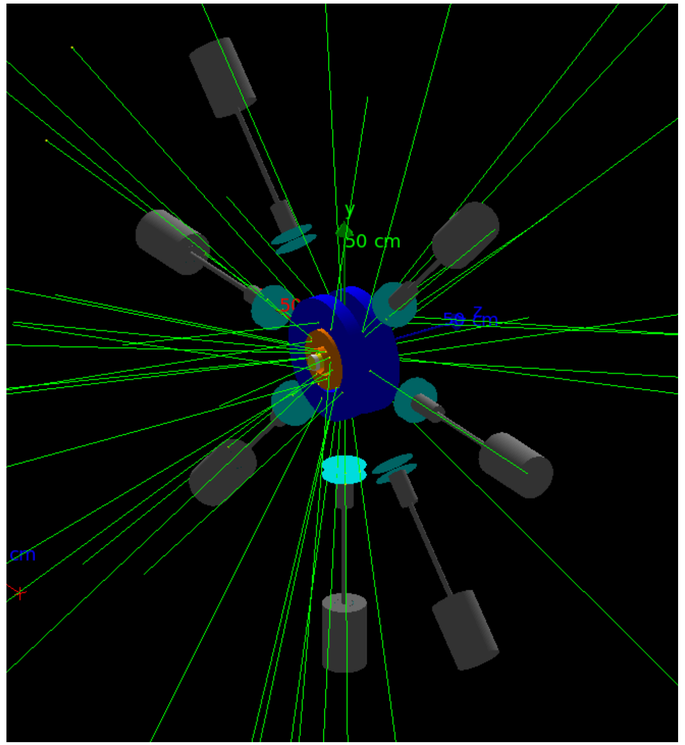
Antimony - 129Sb



He-like (Sb49+)



Ne-like (Sb41+)

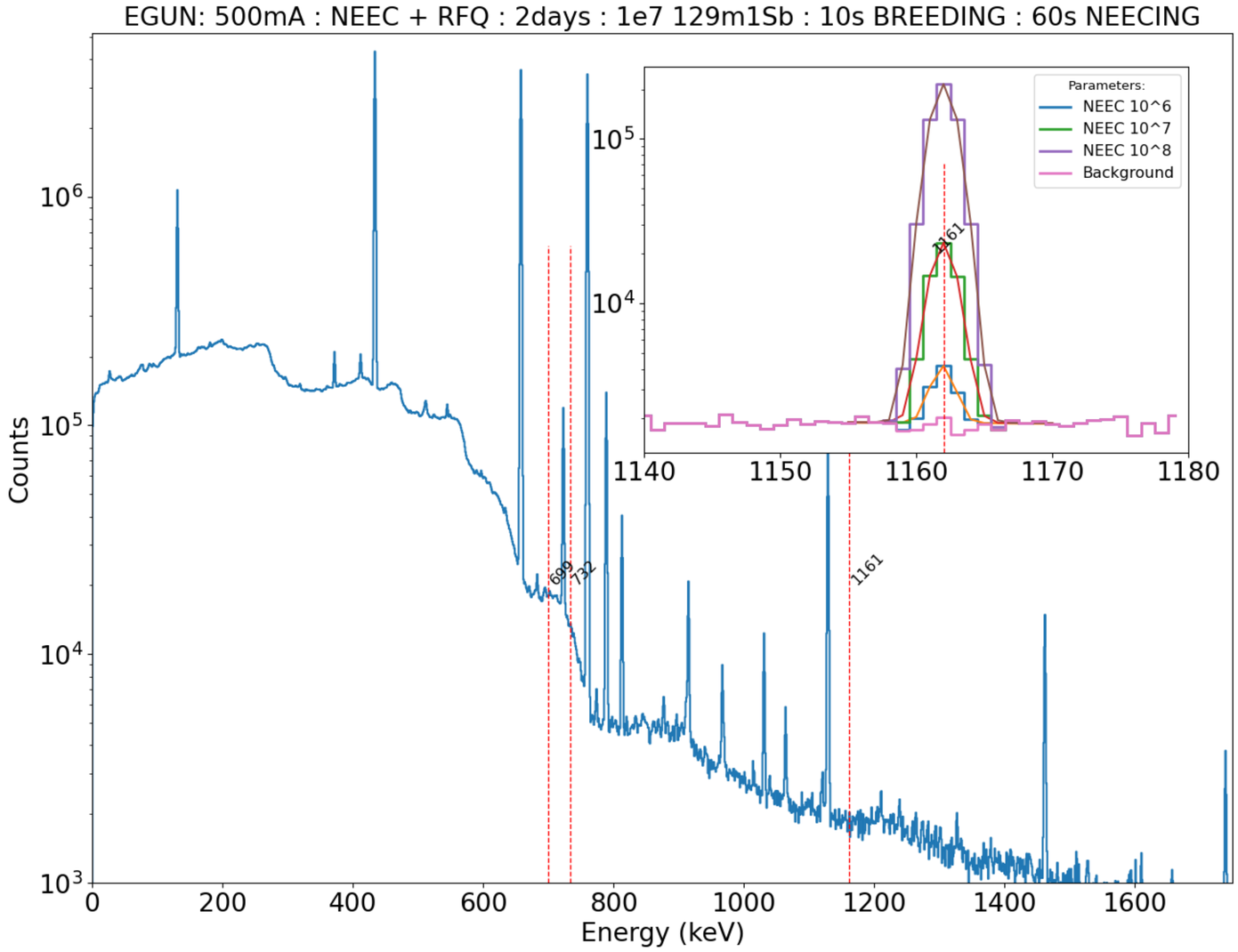


GEANT4 Simulation

Spectrum Simulation with Ion Stacking

- RFQ Space Charge Limit: 1e6
- EBIT Space Charge Limit: 1e8
- Ions trapped in EBIT: 1e7
- Trap Ion Stacking Cycles: 10
- NEECing time: 1min

Resolve up to 3 orders of magnitude difference between theory and Argonne experiment.



Conclusions - work in progress

- Beam Time: Oct 10-12 2021
- In the TITAN EBIT we have been able to perform decay measurements of highly charged ions
- This setup is ideally suited to perform controlled measurements of the NEEC process on a wide variety of stable and unstable cases
- DAQ is setup and shown to function properly
- Simulations have been completed for each step of the experiment
- HPGe's and ULGe have been setup and are waiting to be installed on the EBIT
  - LN2 cooling & mounting brackets
- Upgrades to the electron beam to reach higher currents
  - With the new electron gun currents of near 500 mA should be achievable (previous ~200mA)
- Electron beam energy ramping is being explored

TITAN Collaboration

TRIUMF
www.triumf.ca

@TRIUMFLab

Discovery, accelerated

Acknowledgements

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Grazie!
Thank you!

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Ania Kwiatkowski			Zachary Hockenbery	Jon Ringuette

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Canada

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Available code

EBIT Charge state simulator :
https://github.com/mineselectroweakgroup/ebitsim

EBIT Charge state simulator VAGRANT instance:
https://github.com/mineselectroweakgroup/ebitsim_vagrant

GEANT4 Simulation of EBIT + HPGe's :
https://github.com/TITANCollaboration/decayspec_8pi_geant4sim

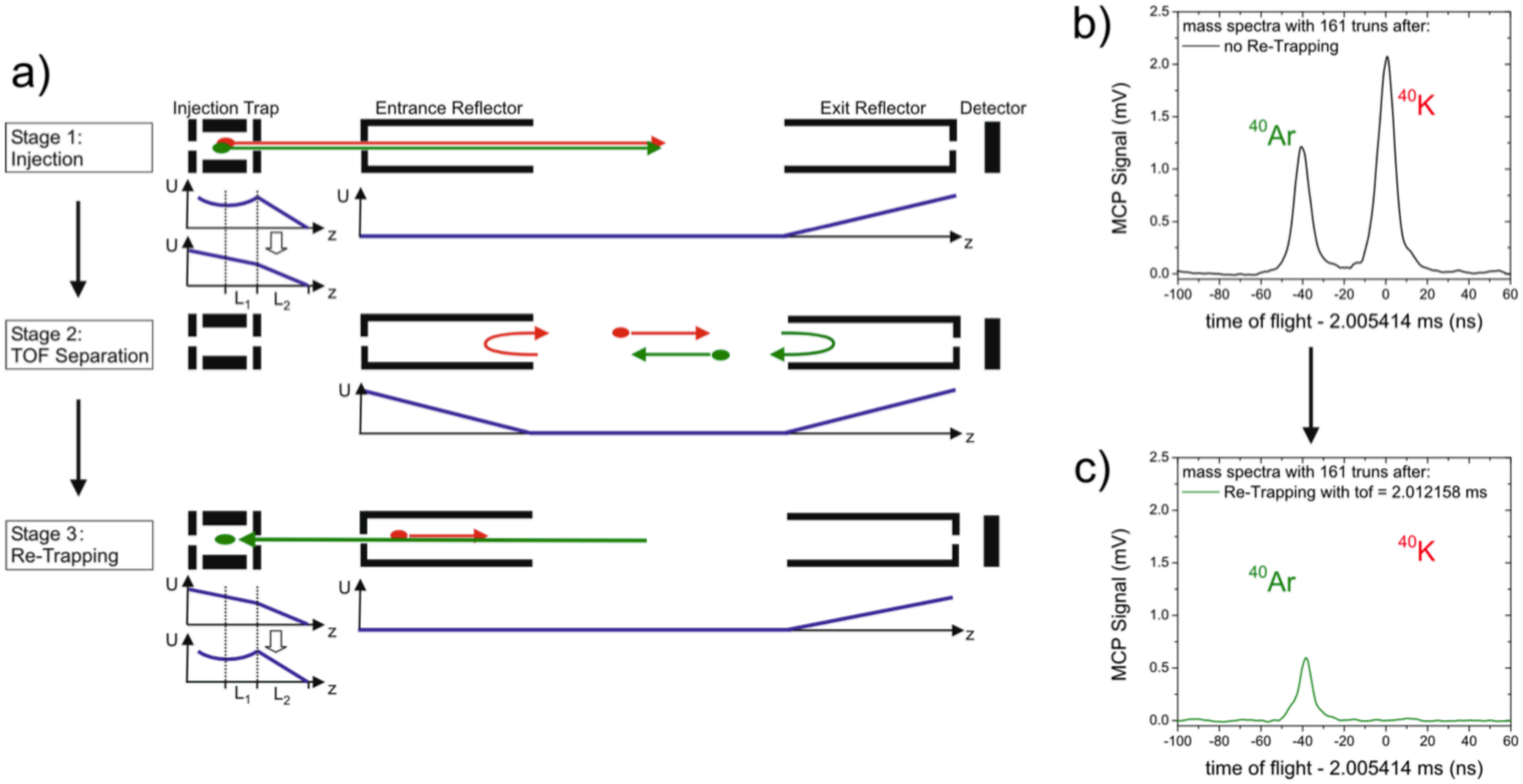
GEANT4 Cluster software for parallel runs :
https://github.com/TITANCollaboration/Geant4ClusterMacroRunner

DAQ decoder and event sorter :
https://github.com/TITANCollaboration/decayspec_midas2root

EXTRA SLIDES TO FOLLOW

MR-TOF-MS

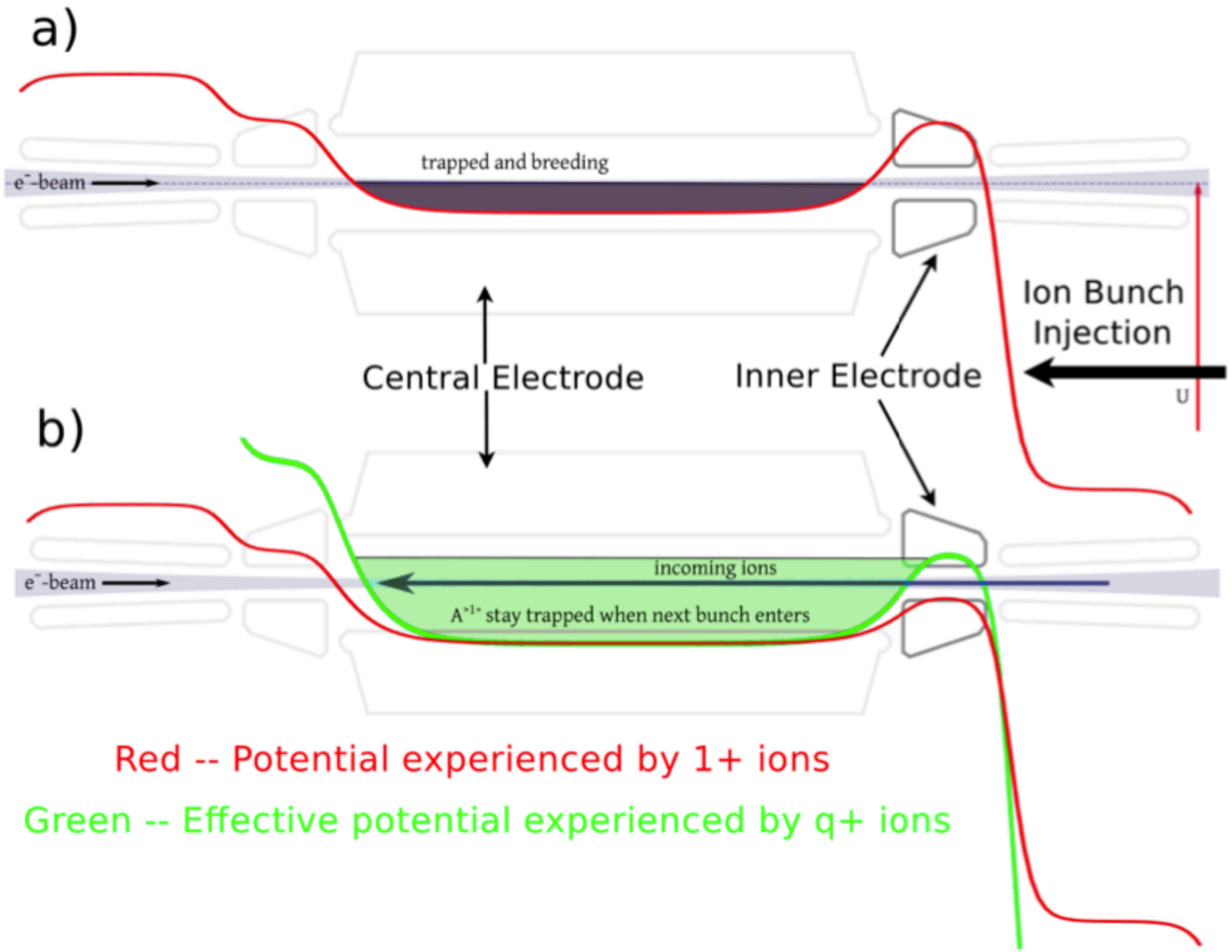
Helps clean up initial ion beam before injection into EBIT



- K G. Leach et al., TRIUMF EEC Lett. of Intent **1865** (2019)

Filling the EBIT to space charge limit

Space-charge density : ~10^9 (for select cases)



- K.G. Leach et al., NIM A 780, 91 (2015) and A. Lennarz et al. Phys. Rev. Lett. 113, 082502 (2014)