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The TITAN EBIT: Status & Research Plans

A. Lapierre, T. Brunner, C. Champagne, P. Delheij, and J. Dilling

for the TITAN collaboration

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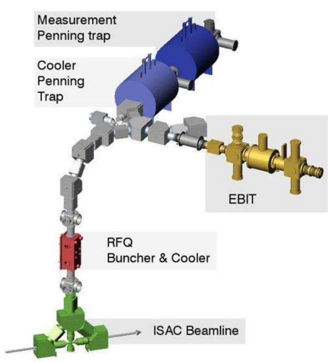
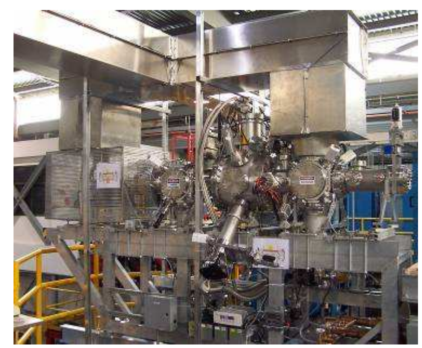
Canada's National Laboratory for Nuclear and Particle Physics,
Vancouver, British Columbia, Canada





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Outline

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- TITAN Facility @ TRIUMF: High-Precision Mass Measurements.
- TITAN EBIT.
- Role of the EBIT in Mass Measurements.
- Status…
- Trap & Beam Physics –Plans and Ideas.
- Nuclear & Atomic Physics –Plans and Ideas.
- Summary.

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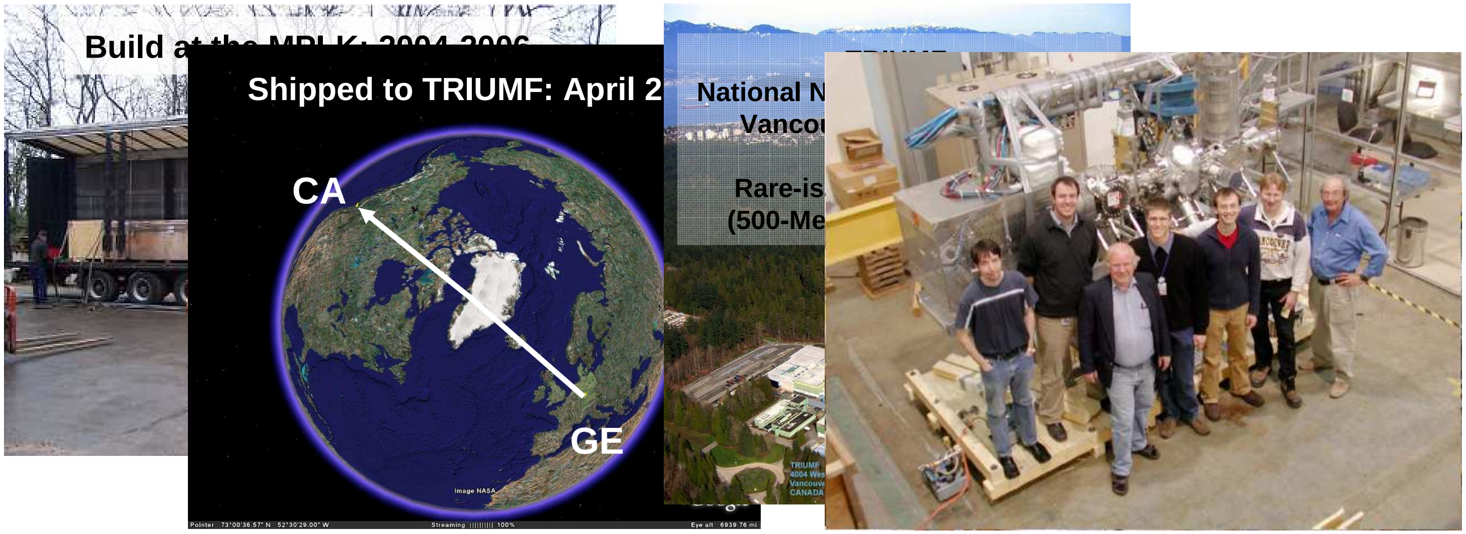
First…a Bit of History



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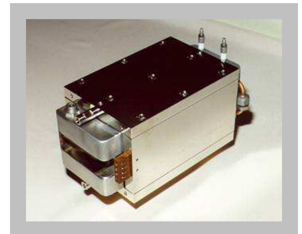
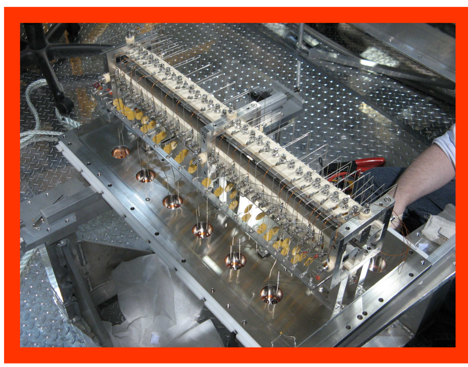
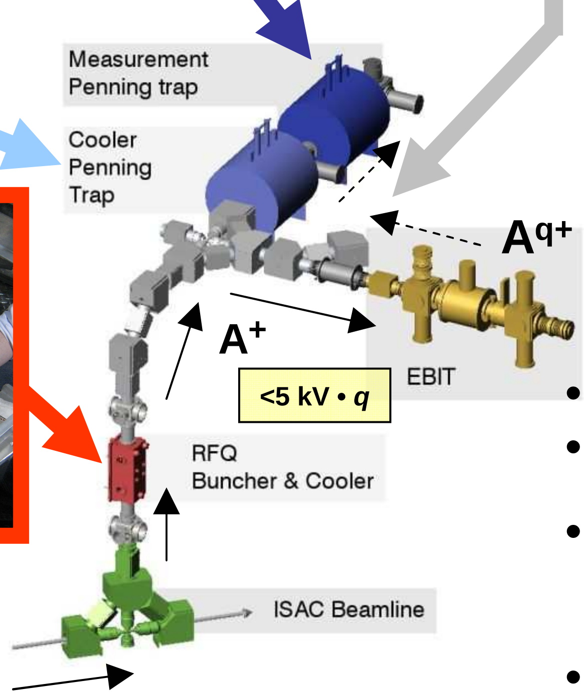
TITAN Facility



2 Wien filters: q/m selection

Under development *(proton cooling)*

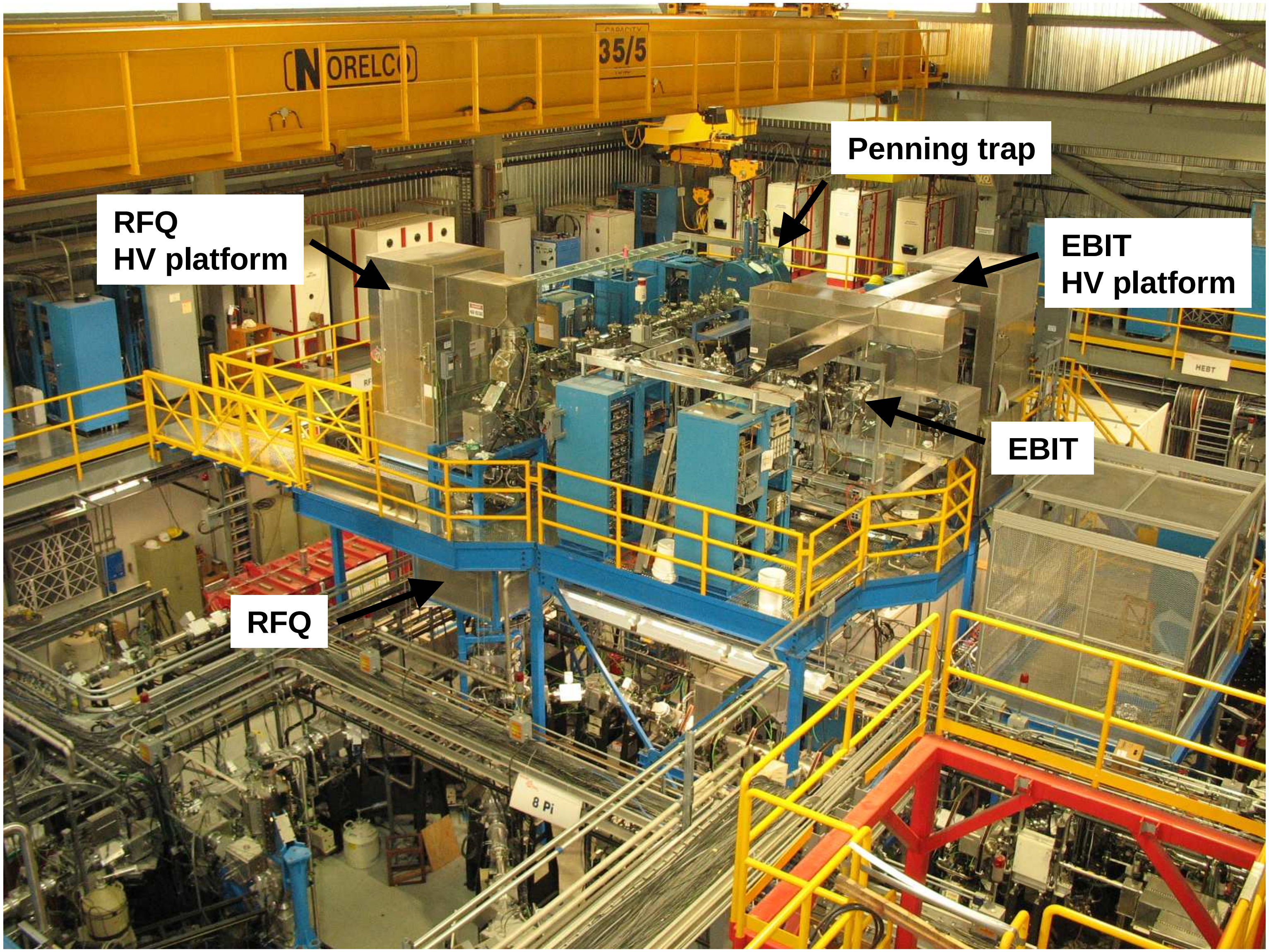




Short-lived isotopes from an Isotope Separator and Accelerator (ISAC).

- EBIT is a part of the TITAN facility.
- **TITAN:** TRIUMF's Ion Trap for Atomic and Nuclear Physics.
- **Motivation:** High-precision mass measurements of **short-lived isotopes** ($T_{1/2}$~10 ms) **for nuclear physics** ($\Delta m/m<10^{-8}$).
- Consists of 4 ion traps.
- EBIT is used as a **charge breeder for higher precision of mass measurement.**

TITAN Platform!



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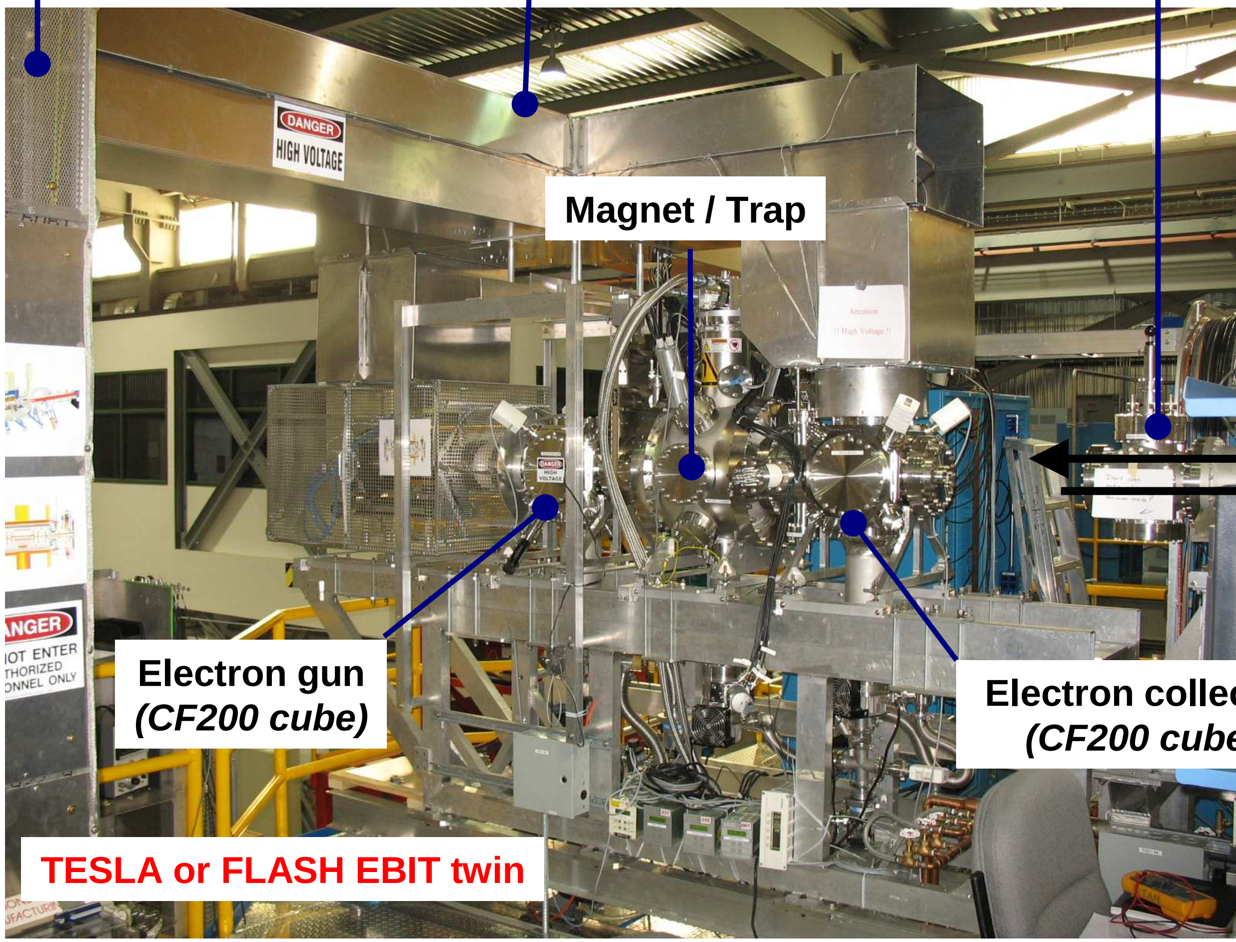
TITAN EBIT

High-voltage platform

60 kV high-voltage duct

Beam line under construction



Injection

Extraction

3 m

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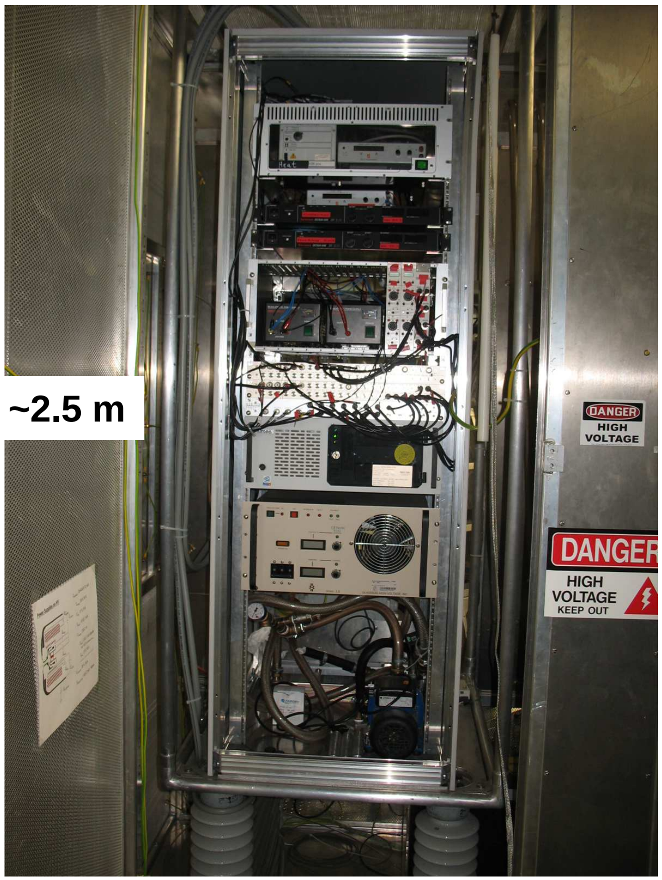
High-voltage platform



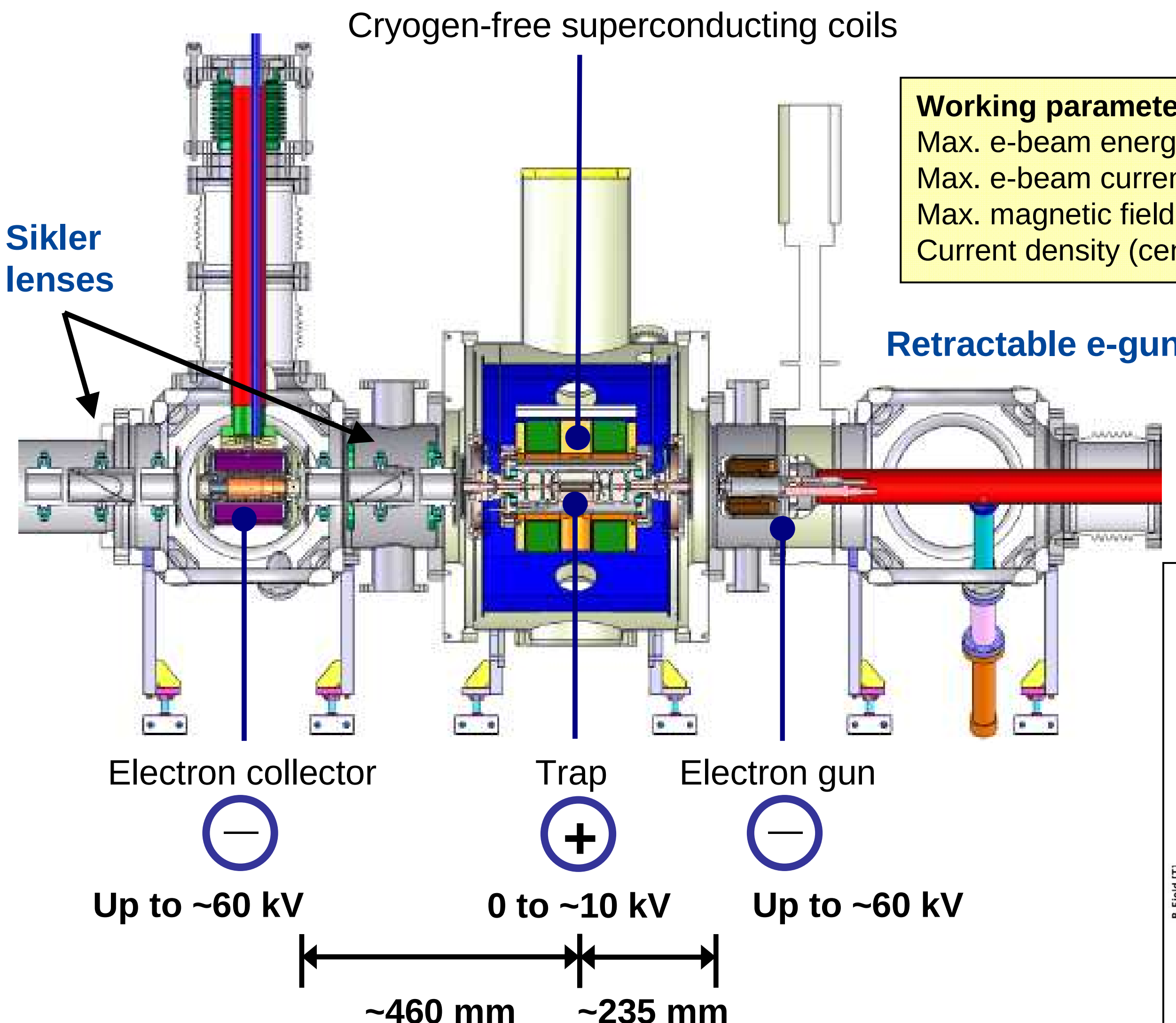
~2.5 m

~1 m

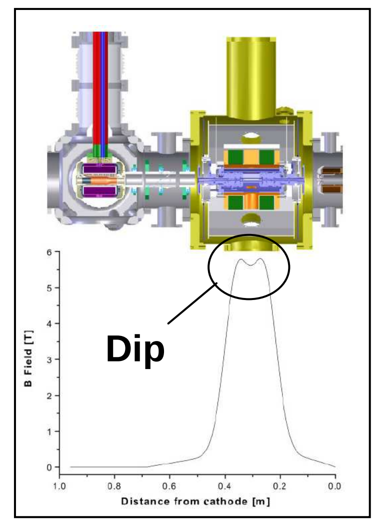
High-voltage cage

Cut of TITAN EBIT

Working parameters:
Max. e-beam energy: ~70 keV
Max. e-beam current: 500 mA **(up to 5 A)**
Max. magnetic field strength: 6 T
Current density (center): 10^4 - 10^5 A/cm^2



Magnetic-field distrib.



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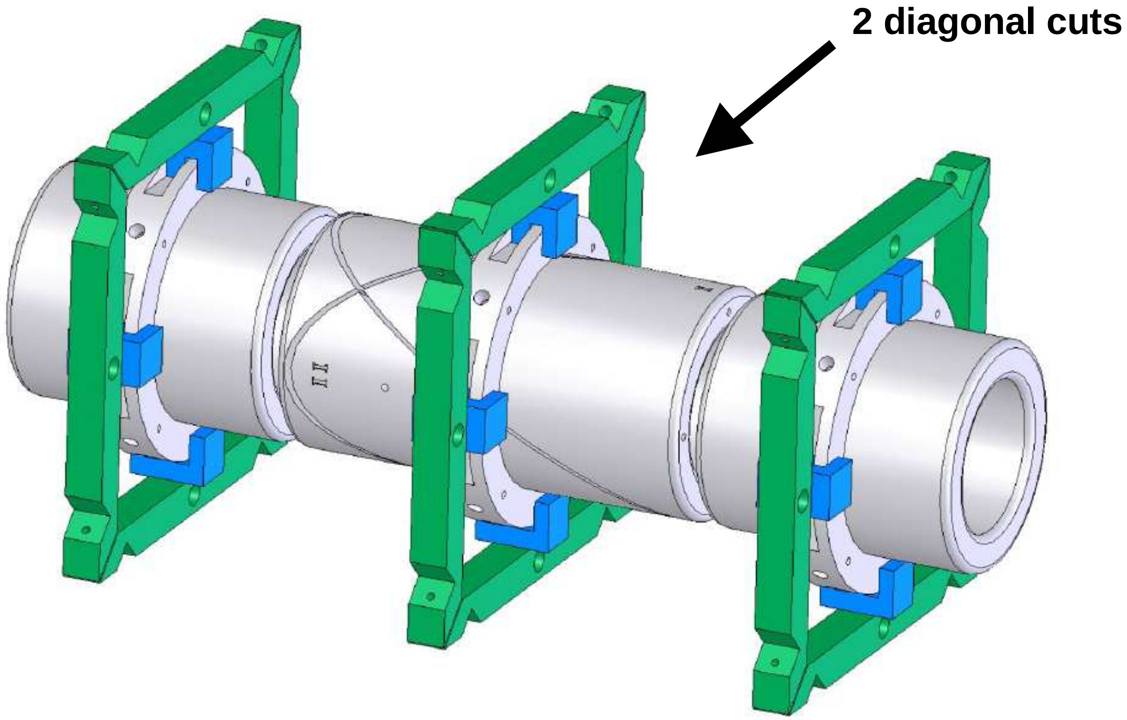
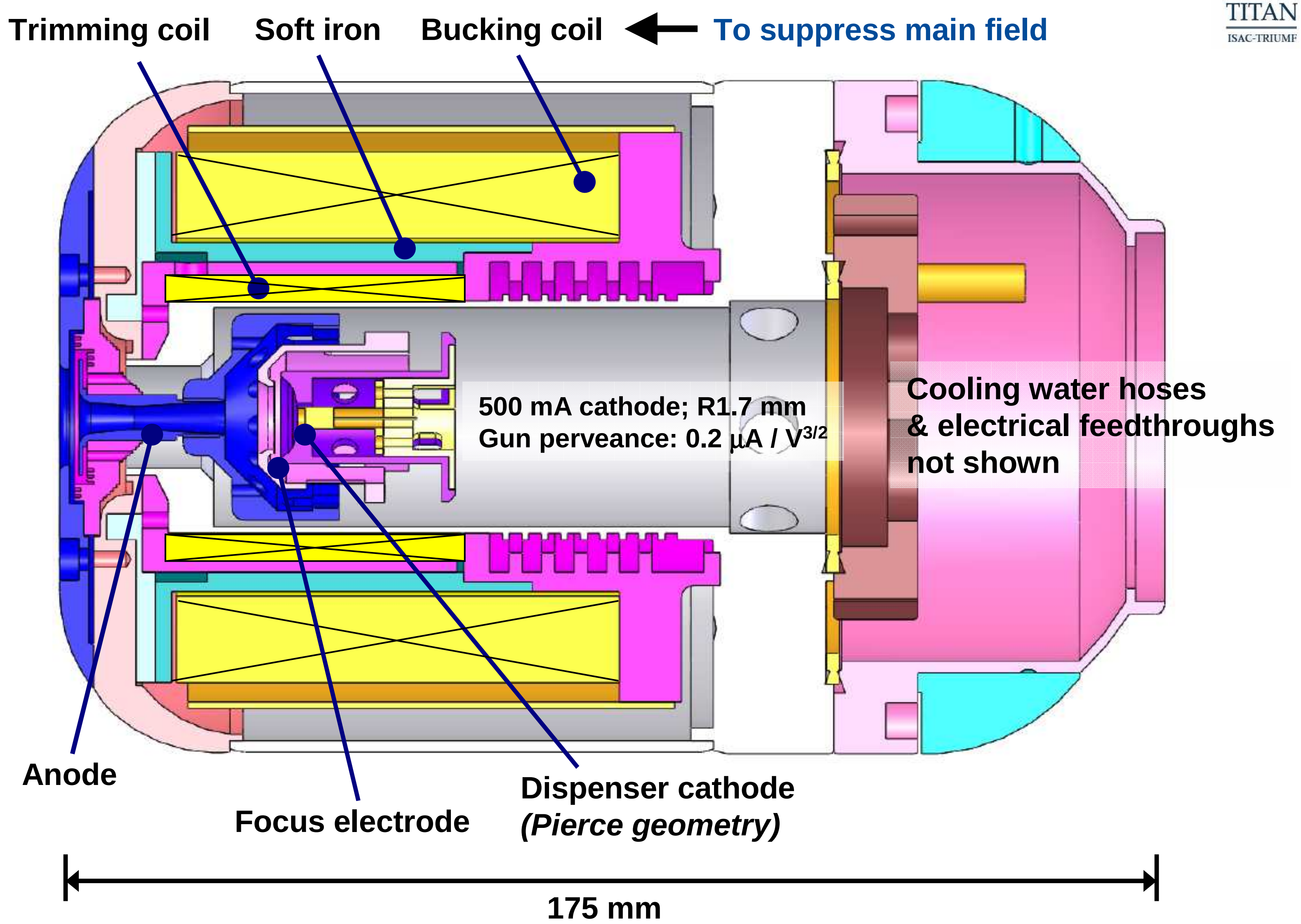
Sikler lens

A Sikler lens is an Einzel lens whose central electrode is segmented into 4 electrodes to steer the beam.



Electron Gun



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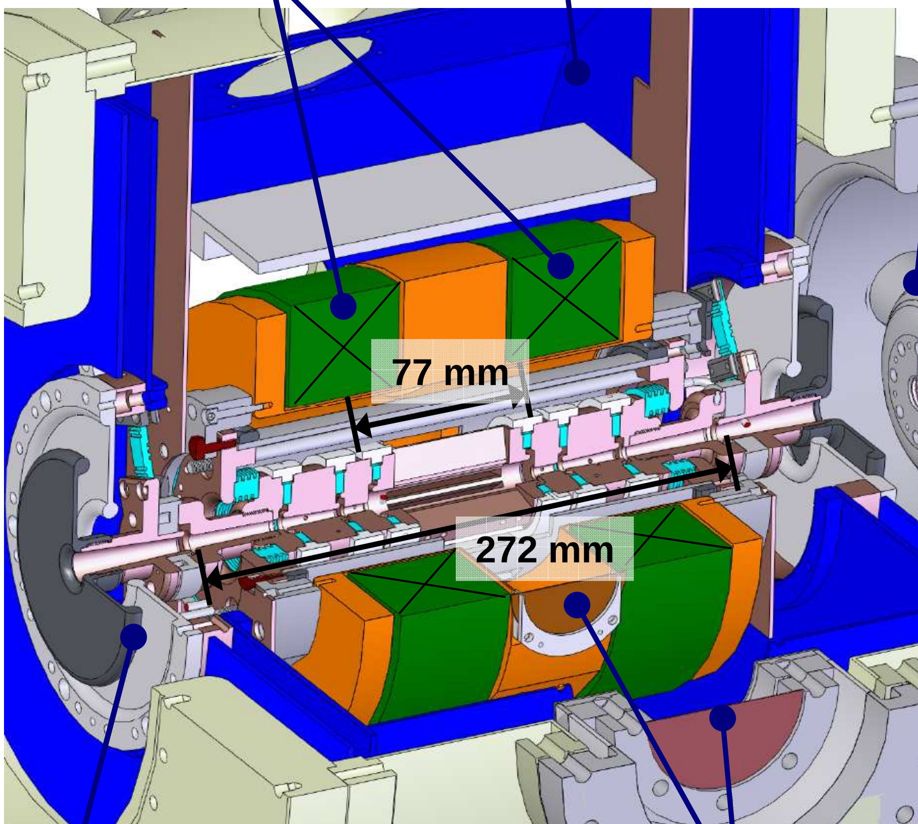
Trap

Thermal shield @ ~30 K

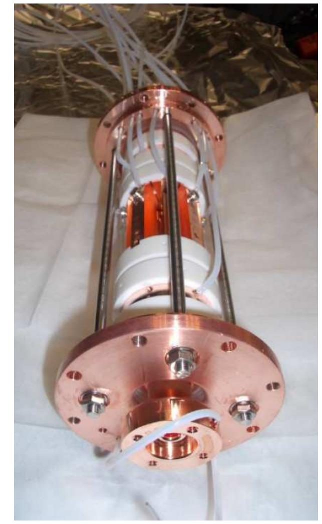
Coils ($NbSn_3$) @ ~4 K

Electron gun



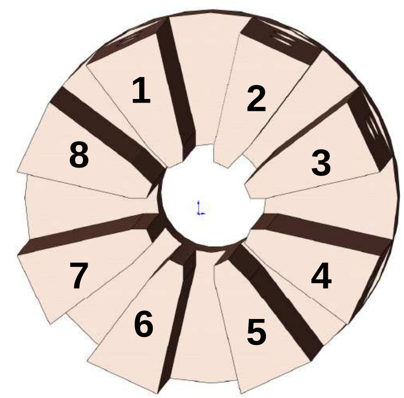
Trap made of 9 drift tubes

Be windows
(7 access viewports)



Center electrode segmented into 8 independent sections:

- Rotating-wall cooling
- Side-band cooling
- Ion Cyclotron Resonance



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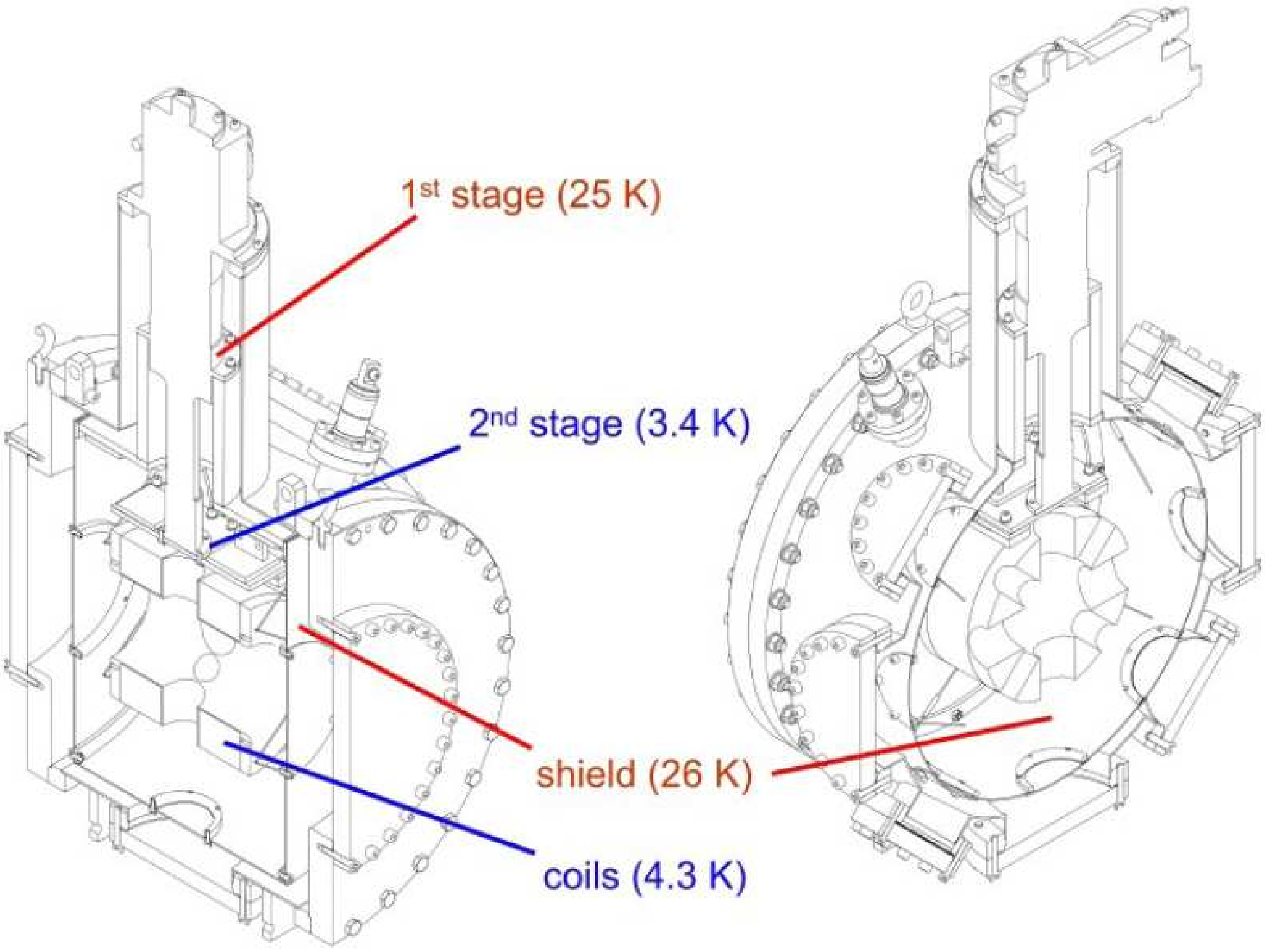
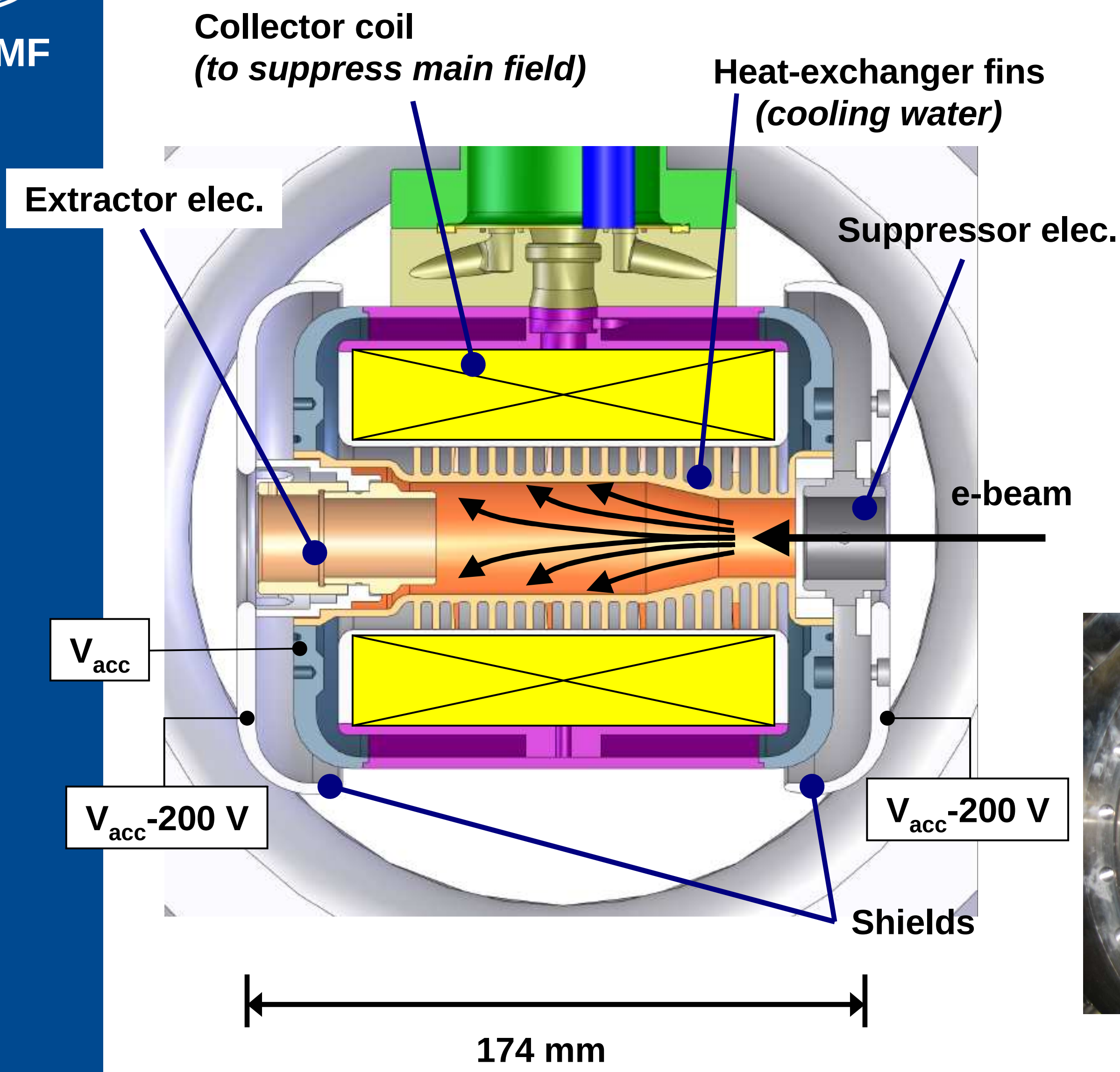
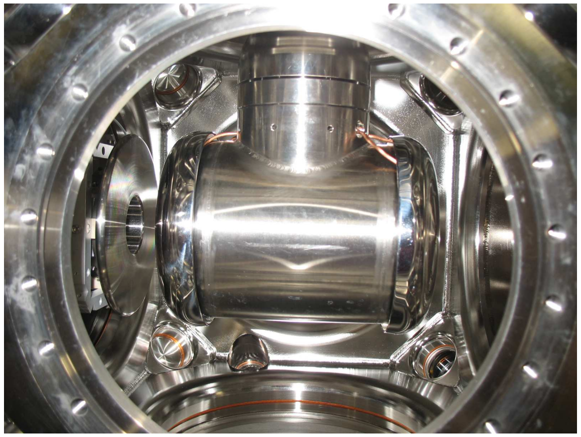
Cryogen-Free Superconducting Magnet



Electron Collector





Gas Injection

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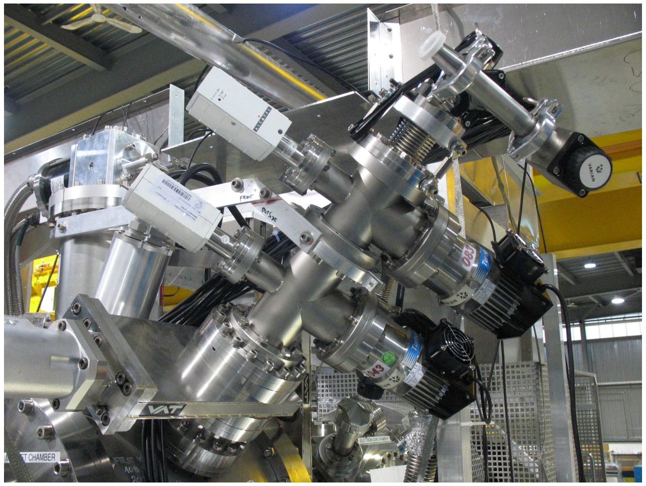
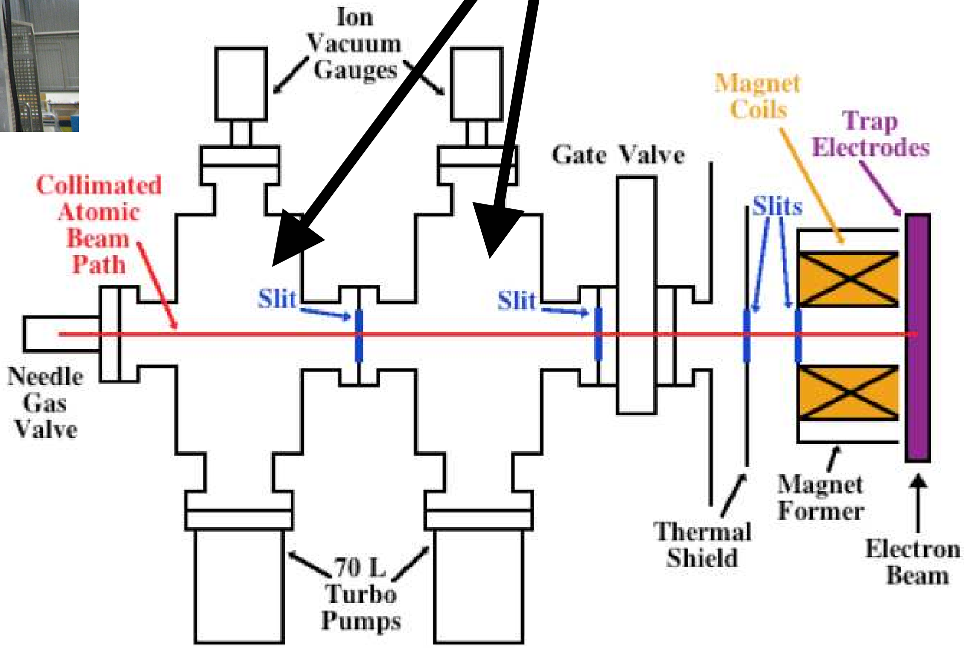


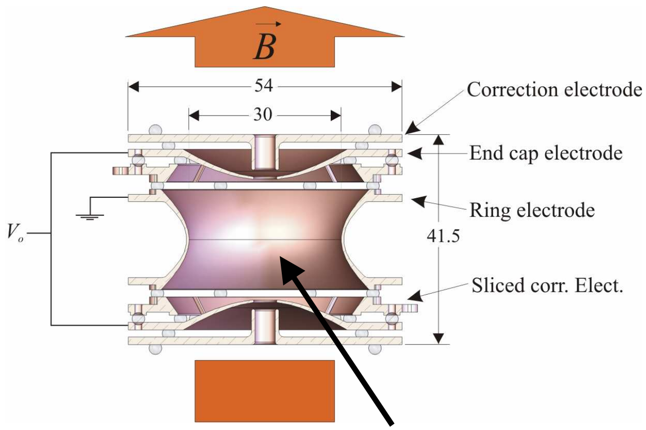
2 differentially pumped chambers



Mike Froese Master's thesis

Role of the EBIT in Mass Measurements

- TITAN Penning trap:



3 hyperbolic electrodes producing a quadrupole potential well.

- Mass measurements in a Penning trap are performed by measuring ion cyclotron frequencies.

$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

- Hence, the precision of mass measurements is a function of the ion charge state, *q*.

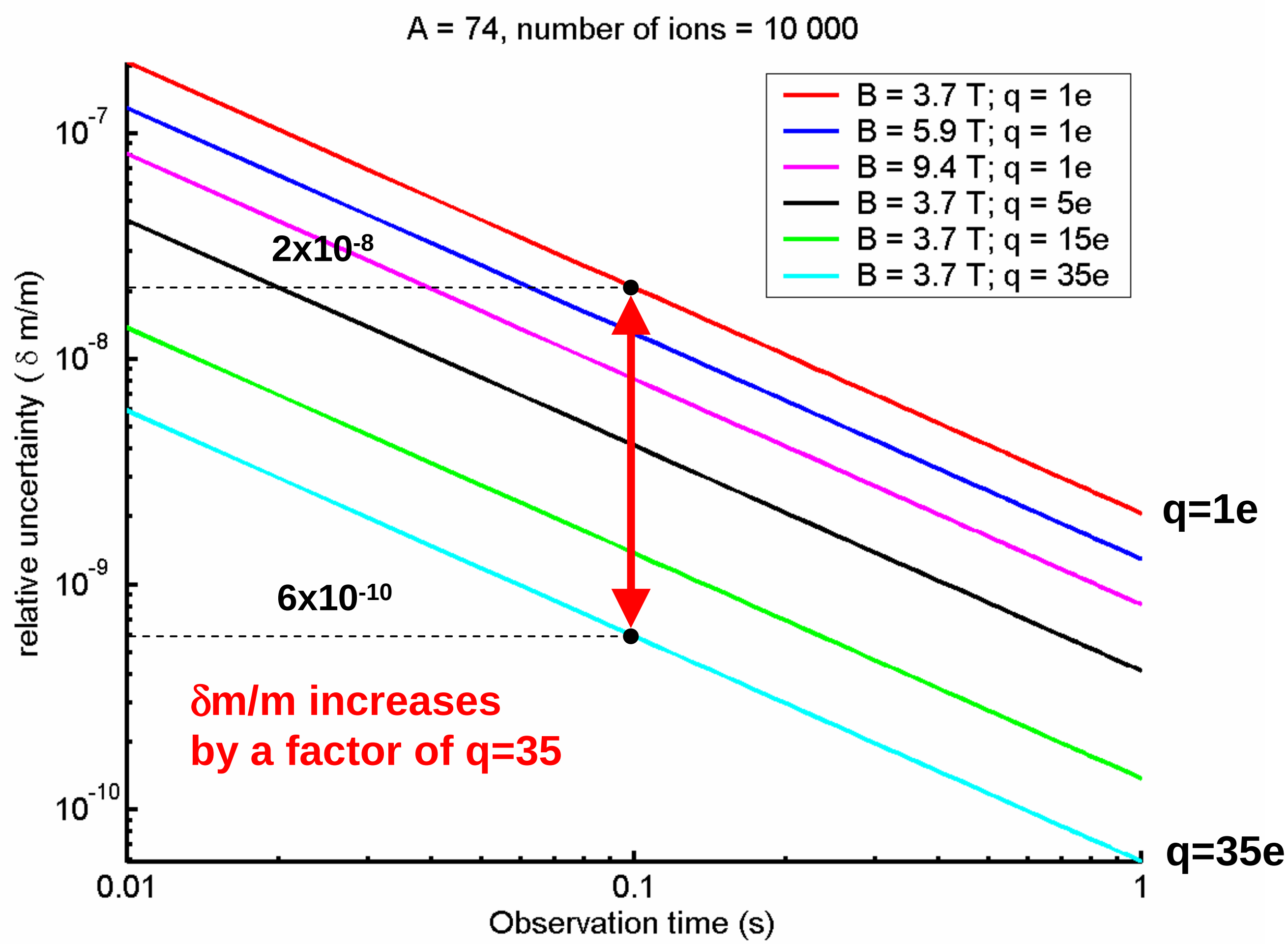
$$\frac{\delta m}{m} \propto \frac{m}{T_{obs} q B \sqrt{N}}$$

- Conclusions:

  For a fixed observation time, mass measurements with higher charge states are more accurate.

EBIT is used as a charge booster!

As an Example…He-like ^{74}Rb ($T_{1/2}$=65 ms)



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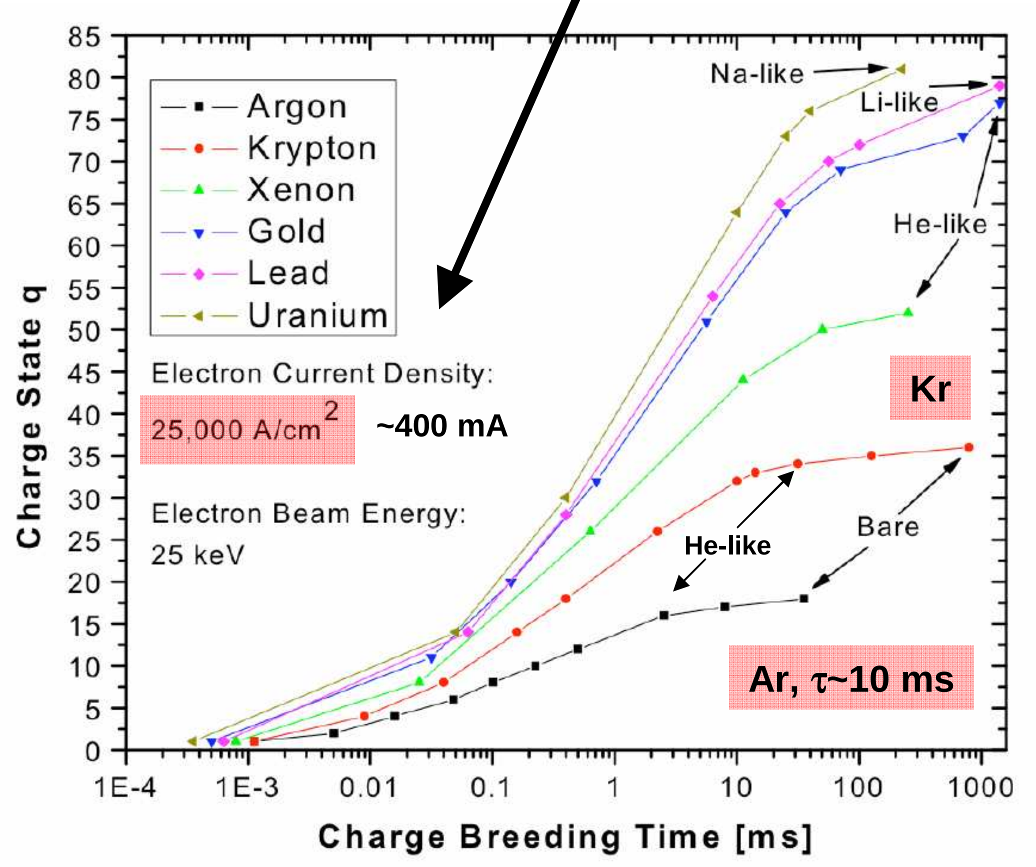
Charge Breeding Time

Reacheable TITAN EBIT Parameters



- **For mass measurements on short-lived isotopes, a rapid production of HCI is crucial!**
- **CB time < Half Life of Nuclei**

^{74}Rb half-life: 65 ms
He-like ^{74}Rb CB time:~10 ms
Bare ^{74}Rb CB time: ~100 ms

With a 5-A cathode, bare ^{74}Rb could be produced within ~10 ms

Mike Froese Master's thesis
(Becker's SUK program)

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TITAN EBIT Status

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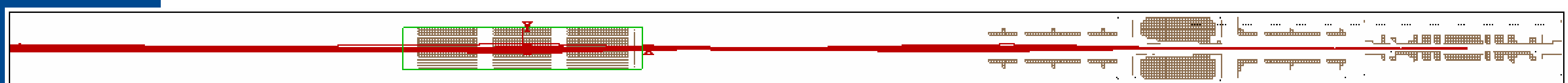
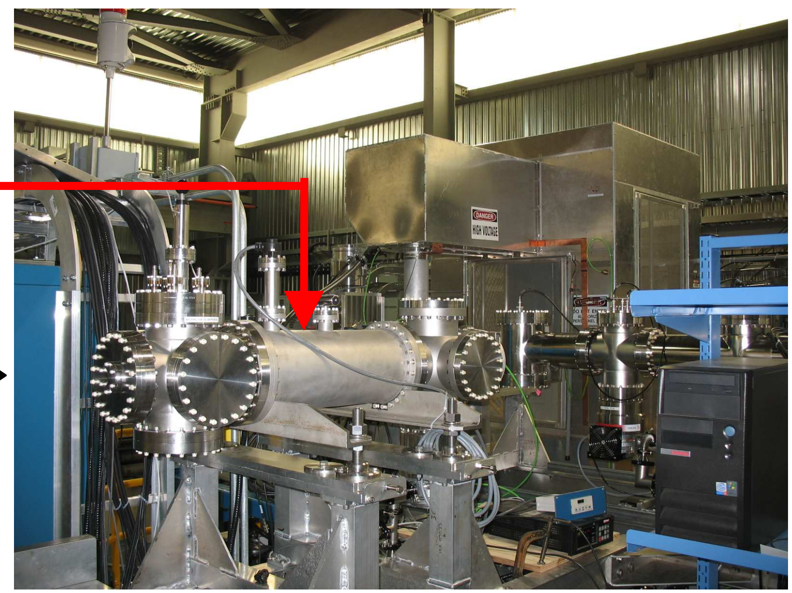
- **Sep. 2006:** Reached a beam current ~400 mA (~7 keV) & energy of ~20 keV (~172 mA).
- **Sep. 2006:** Collector shorted.
- **Nov. 2006:** Received a spare collector from Jose.
- **June 2007:** New collector just installed!
- **Meanwhile…building an injection/extraction beam line based on SIMION simulations.**



Instances from S. Schwarz

Quadrupole triplet

Beam line under construction

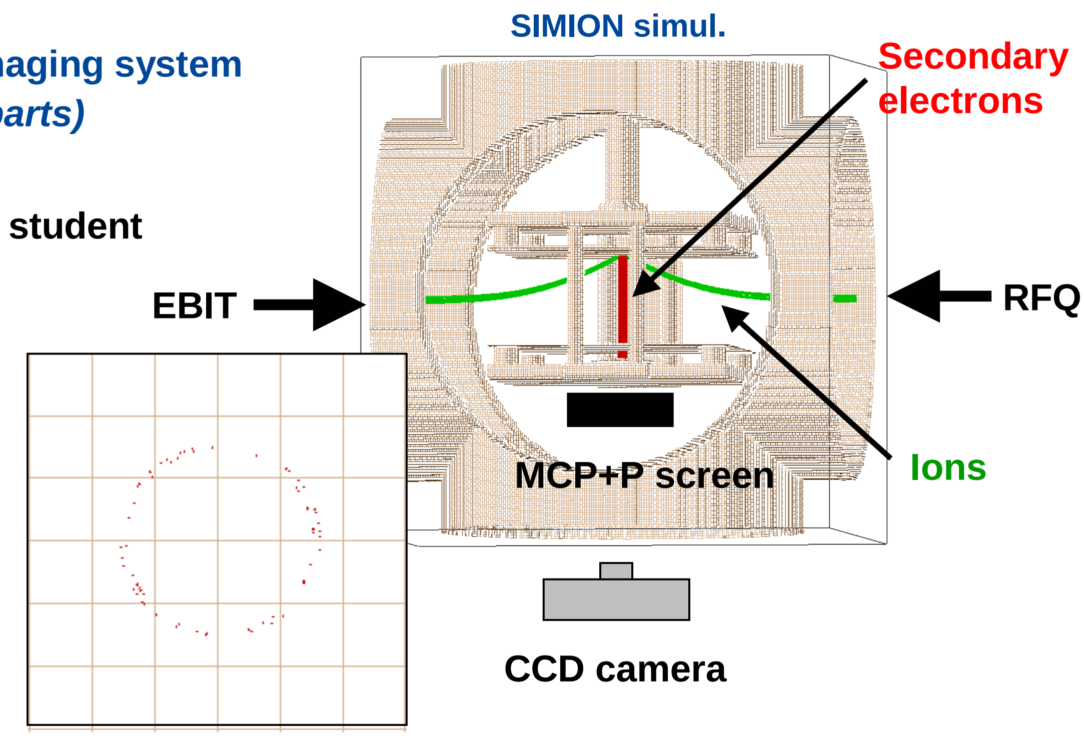


Present Work

- Installation of an injection/extraction beam line.
- Installation of a ion source for injection.
- Remote control of all vacuum systems and EBIT power supplies: MIDAS & EPICS
- Installation of an event-mode DAQ system.

2-way Daly-type beam imaging system
(w/ no moving parts)

C. Leung,
Undergrad. summer student



Good representation of ion beams!

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Research Plans: Trap & Beam Physics

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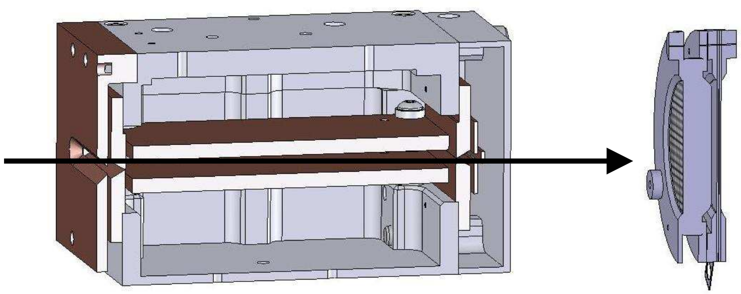
Emittance measurements and optimization

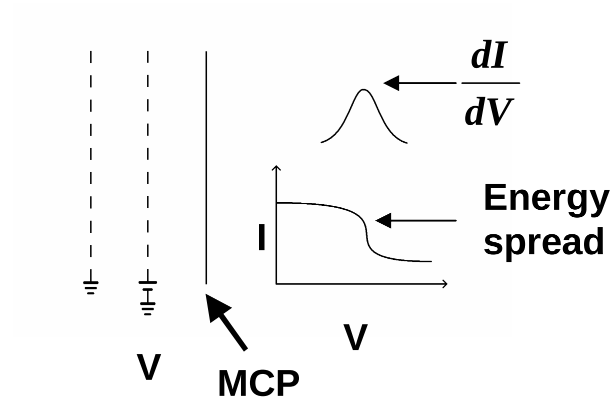
Transverse emittance

$$\varepsilon_t = \pi\, r\, r' \,[\text{mm mrad}]$$



Longitudinal emittance

$$\varepsilon_l = \Delta E\ \Delta T\,[\text{eV s}]$$



C. Champagne, MSc candidate

Studies and optimization of charge breeding, extraction, and injection…

Research Plans: Electron Capture Branching Ratios

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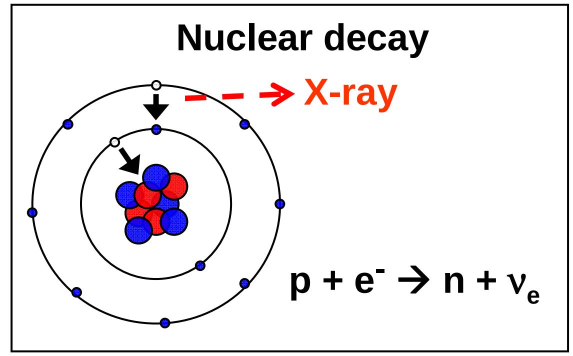
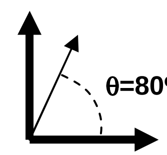
Measurements of electron capture branching ratios of nuclei in singly charged ions through x-ray detection.

- ***Radioactive singly charged ions trapped in the Penning-trap mode: no electron beam used!***
- EC branching ratios used to evaluate double β – and neutrinoless double β – decay nuclear matrix elements.
- If 0νββ decay is observed, EC branching ratios can be used to infer the neutrino mass.

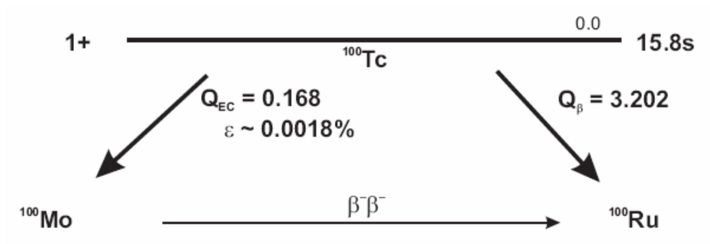


β-decay electrons are used to monitor trapped radioactive ions.

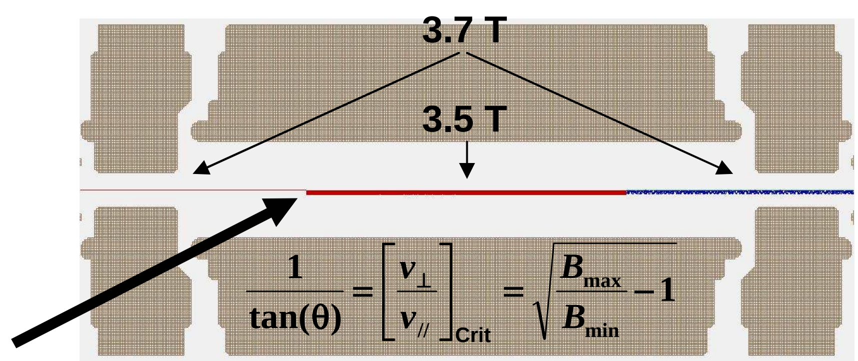
3-MeV electrons of an emission pitch angle >80º are trapped.



First candidate… Technetium-100



T. Brunner, PhD candidate



Trapped electrons

SIMION simul.

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Research Plans: EBIT for AMS

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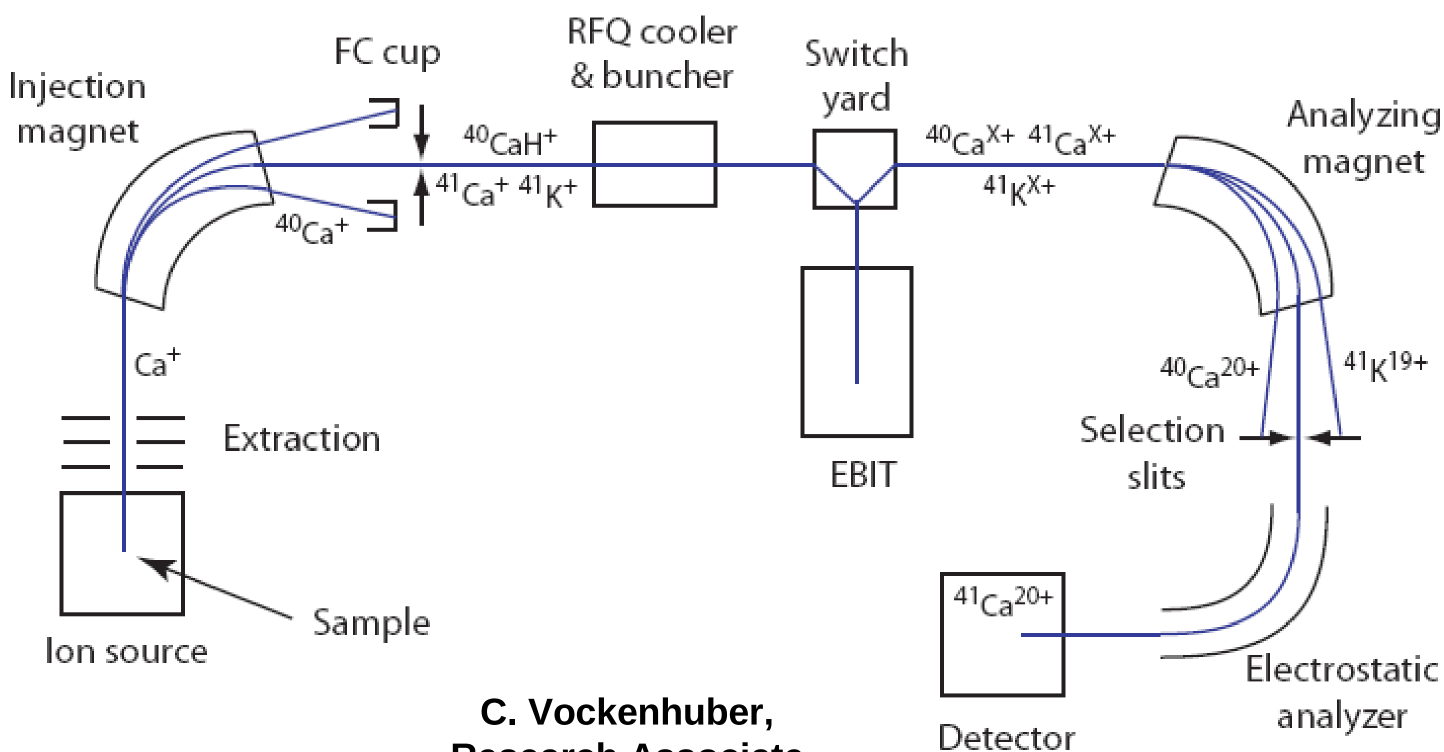
AMS: Accelerator Mass Spectrometry

Use HCIs for isobar separation

Example with bare ions: **Bare Ca-41: q/m=+20/41**
Bare K-41: q/m=+19/41



C. Vockenhuber, Research Associate

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Future Plans & Ideas

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Isotope shift measurements of transition energies in highly charged ions

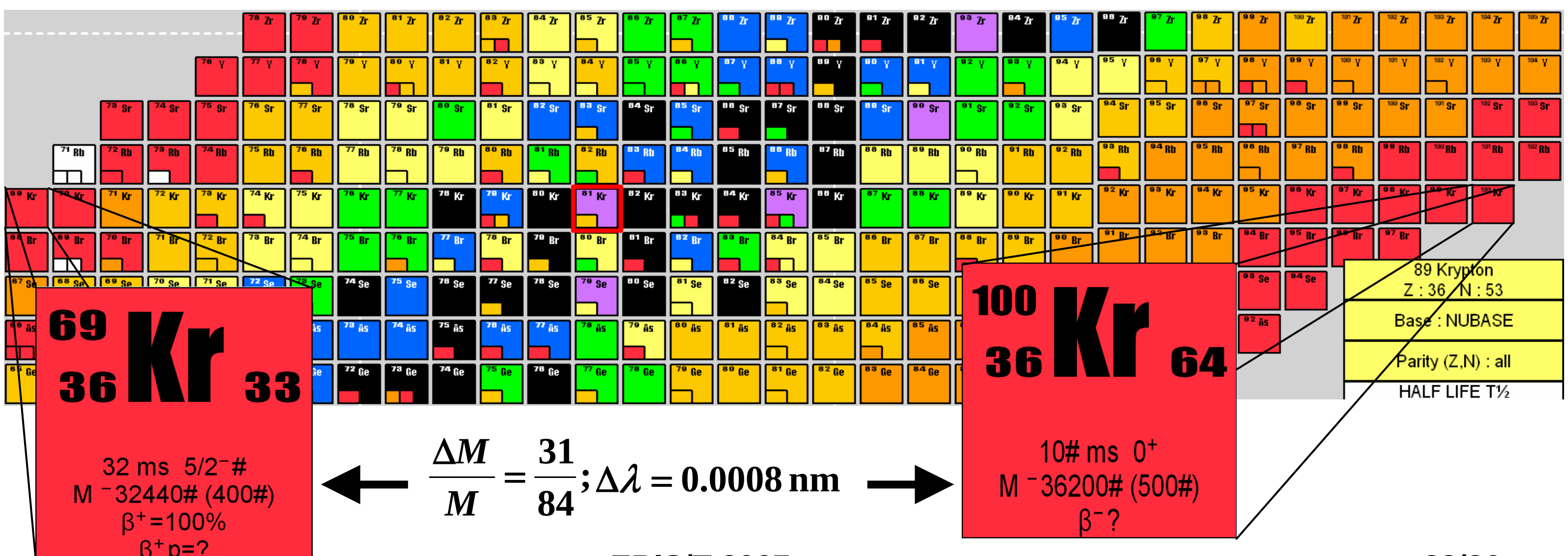
TABLE IV. Energies of forbidden transitions for Ar and Kr ions and the isotope shifts in ^{40}Ar: ^{36}Ar and ^{86}Kr: ^{84}Kr.

Ion	Transition	Theory [22,23] λ (nm, air)	Theory [1], this work λ (nm, air)	Experiment [1] λ (nm, air)	Isotope shifts (nm)
Ar^{13+}	$2s^2 2p^1\ {}^2P_{1/2}$-${}^2P_{3/2}$	440.99	441.16(27)	441.2559(1)	0.00126
Ar^{14+}	$2s^1 2p^1\ {}^3P_1$-${}^3P_2$	593.88	594.24(30)	594.3880(3)	0.00136
Kr^{22+}	$3s^2 3p^2\ {}^3P_1$-${}^3P_2$		383.70(65)	384.1146(2)	0.00005

$$\frac{\Delta M_{Ar}}{M_{Ar}} = \frac{4}{40}$$

$$\frac{\Delta M_{Kr}}{M_{Kr}} = \frac{2}{84}$$

ISAC produces a wide range of exotic isotopes



$$\frac{\Delta M}{M} = \frac{31}{84};\Delta\lambda = 0.0008\ \text{nm}$$

Future Plans & Ideas

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Isotope shift measurements in singly charged ions to investigate systematic effects on astrophysical measurements of the fine-structure constant variation.

Atomic spectroscopy and the search for variation of fundamental constants

J. C. Berengut, V. A. Dzuba, V. V. Flambaum, M. G. Kozlov[1], M. V. Marchenko, M. T. Murphy[2], and J. K. Webb

School of Physics, University of New South Wales, Sydney 2052, Australia

[1]*Petersburg Nuclear Physics Institute, Gatchina, 188300, Russia*

[2]*Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, U.K.*

We urgently need accurate laboratory measurements of atomic transition frequencies to search for variation of the fine structure constant, by comparison of these frequencies with those in quasar (QSO) absorption spectra. Theories unifying gravity with other interactions suggest spatial and temporal variation of fundamental "constants" in the Universe. A change in the fine structure constant, $\alpha = e^2/\hbar c$, could be detected via shifts in frequencies of atomic transitions in QSO systems. We previously studied three independent samples of data containing 143 absorption systems spread from 2 to 10 billion years after the Big Bang. All three data samples hint that α was smaller 7 – 11 billion years ago.

To continue this study we need accurate laboratory wavelengths for E1 transitions to the ground state in a variety of atoms and ions. The wavelengths range from around 900 – 6000 Å, and require an accuracy of better than 10^{-4} Å.

Isotope shift measurements for these transitions are also needed in order to resolve systematic effects in the st[...] s clouds sa m[...] ntify these al[...] the ea[...] stars.

Isotope shifts ~1 ppm

Fe II	1608.450	62171.63	0.058000	$3d^5 4s4p\ ^6P^o_{7/2}$	-1300 (300)	isotope shift
	1611.200	62065.53	0.001360	$3d^6 4p\ ^4F^o_{7/2}$	1100 (300)	isotope shift
	2249.877	44446.88	0.001821	$3d^6 4p\ ^4D^o_{7/2}$		isotope shift
	2260.780	44232.51	0.002440	$3d^6 4p\ ^4F^o_{9/2}$		isotope shift
	2344.212	42658.24	0.114000	$3d^6 4p\ ^6P^o_{7/2}$	1210 (150)	isotope shift
	2367.589	42237.06	0.000212	$3d^6 4p\ ^6F^o_{7/2}$	1904	A
	2374.460	42114.83	0.031300	$3d^6 4p\ ^6F^o_{9/2}$	1590 (150)	isotope shift
	2382.764	41968.06	0.320000	$3d^6 4p\ ^6F^o_{11/2}$	1460 (150)	isotope shift
	2586.649	38660.05	0.069180	$3d^6 4p\ ^6D^o_{7/2}$	1490 (150)	isotope shift
	2600.172	38458.99	0.238780	$3d^6 4p\ ^6D^o_{9/2}$	1330 (150)	isotope shift

Researchers who are interested in doing these measure[...]

Victor Flambaum flambaum@phys.unsw.edu.a[...]

Julian Berengut jcb@phys.unsw.edu.au

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Summary

TITAN
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- TITAN facility @ TRIUMF: High-precision mass measurements.
- TITAN EBIT is used as a charge breeder to boost the precision of mass measurements.
- Current EBIT max. energy & current are ~70 keV & ~500 mA.
  - ***Trap on-line short-lived isotopes.***
  - ***Cryogen-free superconduction magnet.***
  - ***9 drift tubes: short and long trap configurations***
  - ***Segmented central drift tube in 8 indep. electrodes.***
- In the future, the cathode will be upgraded to 5 A.
- EBIT won’t be limited to charge breeding…
- X-ray / Visible / Laser spectroscopy of **exotic isotopes**.

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Members / Collaborators

TITAN
ISAC-TRIUMF

M. Brodeur, T. Brunner, A. Bylinkii, C. Champagne, J. Dilling, P. Delheij, M. Good, A. Lapierre, C. Leung, C. Marshall, R. Ringle, V. Ryjkov, M. Smith, for the TITAN collaboration.

U. of Manitoba

McGill U.

Muenster U.

MPI-K

GANIL

U. of Calgary

U. of Windsor

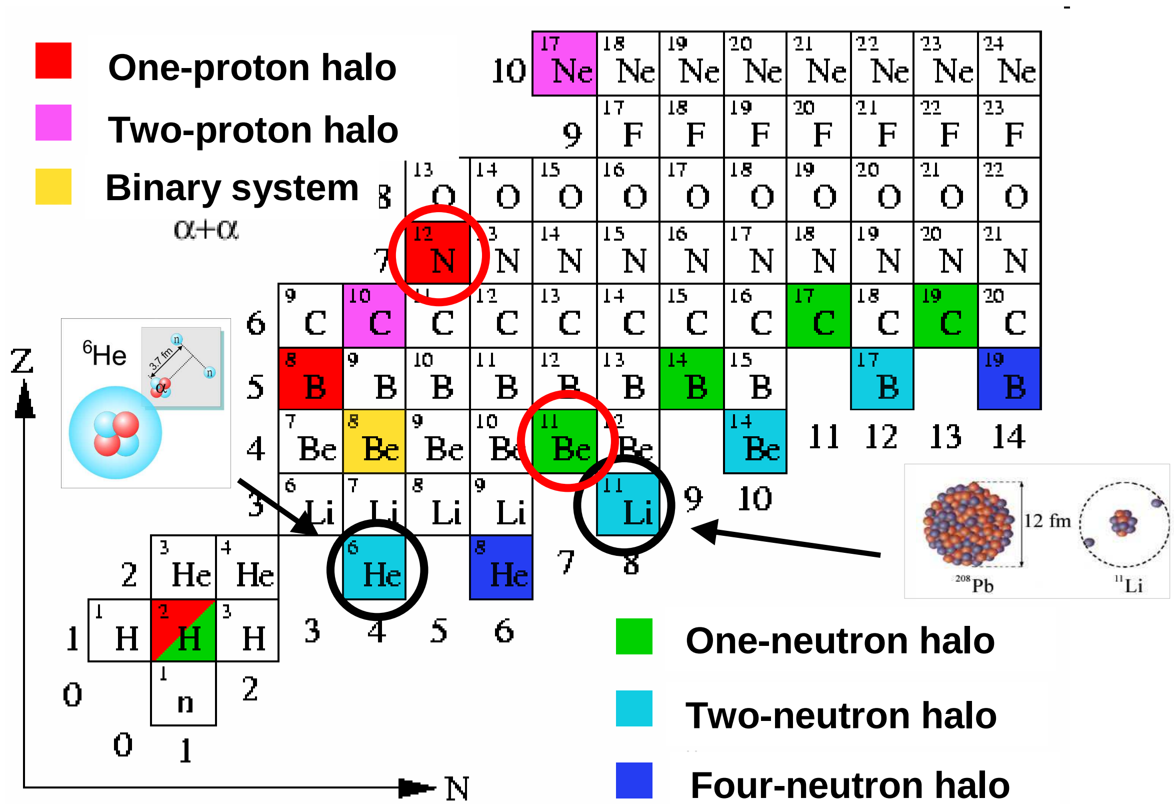
Colorado School of Mines

UBC

Everybody's welcome…

Thanks !

Future Plans & Ideas



Future Plans & Ideas

Model-independent measurements of nuclear charge radii of halo nuclei by laser spectroscopy in He-like $^{11,12}N$ ions

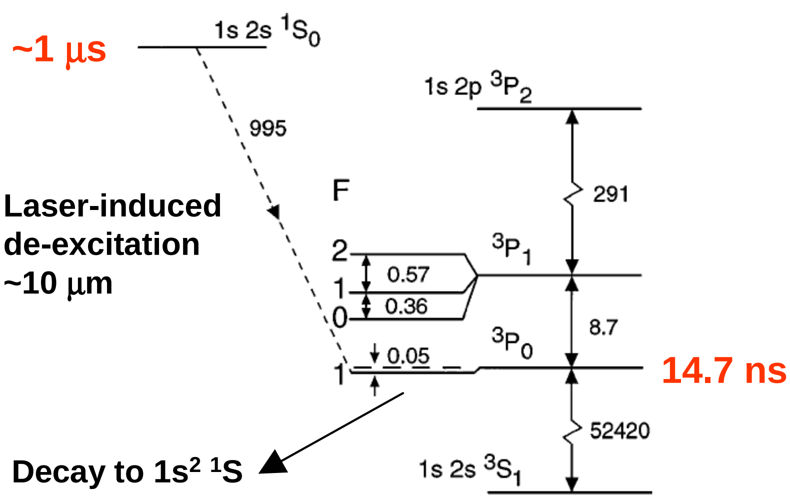


FIG. 1. Schematic of the energy levels of $^{14}N^{5+}$ relevant to the experiment. The hyperfine induced transition is indicated. Approximate spacings are given in units of cm^{-1}.

Myers *et al.*, PRL, **76** 4899 (1996)

Nuclear size effect: $\Delta\lambda/\lambda$~5×10^{-7} (14 *vs* 12)
Distinguish diff. models: $\Delta\lambda/\lambda$~5×10^{-8}

Linewidth: $\Delta\lambda/\lambda$~2×10^{-7} ;
$\Delta\lambda/\lambda$~2×10^{-8} with high stat.

$\Delta f/f$~8×10^{-9} (200-kHz tunable CO_2 laser bandwidth)

$\Delta\lambda/\lambda$~ 2×10^{-8} Dopplerwidth
(Excitation @ 90 deg.;
~10 π mm mrad transverse emittance)

Long shot!!!!