RECENT ACTIVITIES AT THE ORNL MULTICHARGED ION RESEARCH FACILITY (MIRF)*

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Abstract

Recent activities at the ORNL Multicharged Ion Research Facility (MIRF) are summarized. A brief summary of the MIRF high voltage (HV) platform and floating beam line upgrade is provided. An expansion of our research program to the use of molecular ion beams in heavy-particle and electron collisions, as well as in ion-surface interactions is described, and a brief description is provided of the most recently added **I**on **C**ooling and **C**haracterization **E**nd-station (ICCE) trap. With the expansion to include molecular ion beams, the acronym MIRF for the facility, however, remains unchanged: "M" can now refer to either "Multicharged" or "Molecular."

THE MIRF UPGRADE PROJECT AND RECENT FACILITY ACTIVITIES

In order to enhance the capabilities of on-line experiments of the MIRF [1], a facility upgrade project was undertaken to add an all permanent magnet ECR source on a new 250 kV HV platform, and to modify the existing CAPRICE ECR source to inject a new floating beam line, from which beams could be decelerated into grounded end stations with final energies as low as a few eVxq, where q is the charge state of the analyzed beam [2][3][4]. An electrostatic trap end station was also added to the facility, for multi-second confinement of metastable-multicharged or hot-molecular ions to reduce their degree of internal excitation either for lifetime or subsequent cold collision studies [5].

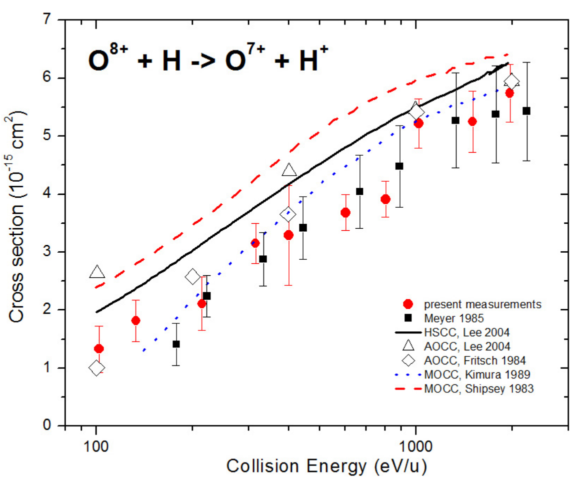

Figure 1: Results for O^{+8} – H electron capture [7].

Table 1: Performances of the MIRF ECR sources [6]

Ion		CAPRICE 10 GHz	Platform ECR source
Xe	+20	35 μA	52 μA
	+26	9	24
	+29	--	3
Ar	+8	500	510
	+11	70	90
O	+6	400	650
	+7	50	90

The new permanent magnet ECR source was designed and built at CEN-Grenoble, and has been previously described [6]. Table 1 summarizes typical multicharged ion performances for the CAPRICE and the new permanent magnet ECR sources injecting the low-energy and high-energy MIRF beam lines, respectively.

To illustrate the increased experimental capabilities made possible by the facility upgrade, Figure 1 shows recent results for electron capture by fully stripped oxygen ions from atomic hydrogen obtained with the upgraded ion-atom merged beams experiment. For these measurements, a well-collimated, small-cross section O^{8+} beam was merged with a fast ground-state atomic hydrogen beam produced by photodetachment, and the protons resulting from charge exchange collisions between the two fast beams monitored.

The present MIRF layout is shown in Figure 2. The facility is comprised of 5 on-line experiments fed by the new HV platform ECR source, and 3 on-line experiments injected from the new low-energy floating beam line.

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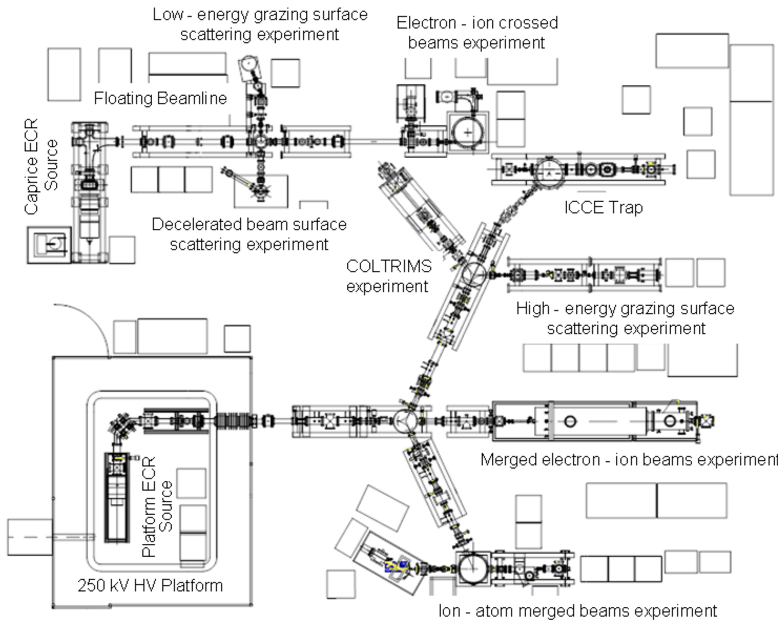

Figure 2: Present configuration of the ORNL Multicharged Ion Resarch Facility. A total of eight on-line experiments studying electron- and heavy-particle collisions, and ion-surface interactions utilize ion beams from either the new permanent magnet ECR ion source on the 250 kV HV platform or from the existing CAPRICE ECR ion source injecting the new floating beam line (see above).

Molecular ion beams

In addition to their well documented capability of highly charged ion production, both ECR sources in the MIRF have recently found increasing use for production

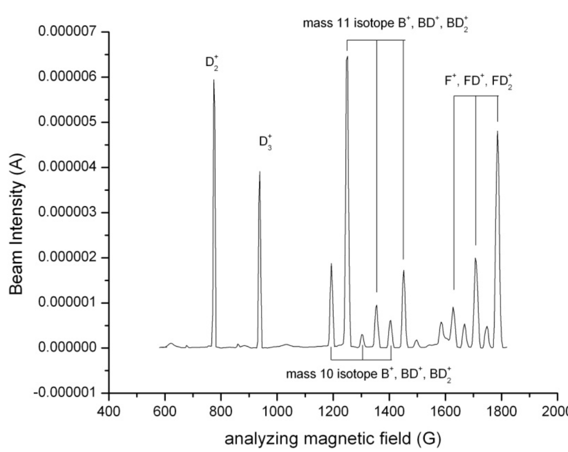

Figure 3: B and F mono- and di-hydride beam production by CAPRICE ECR gas mixing of BF3 and D2 at a total source pressure of 1x10-4 Torr and 4 W forward rf power.

of molecular ion beams as well, due to the increased programmatic focus of our research activities on the atomic collision and surface interactions occurring in the cool edge of magnetic fusion devices, and on electronic driven process in systems of increasing chemical complexity. Figure 3 illustrates synthesis of B and F mono- and di-hydride molecular ion beams in the CAPRICE ECR source plasma using a mixture of BF_3 and D_2 source gases that can be optimized by a combination of high source pressure and low rf power. These beams were required for exploration of electron impact dissociation of such molecular ions along iso-

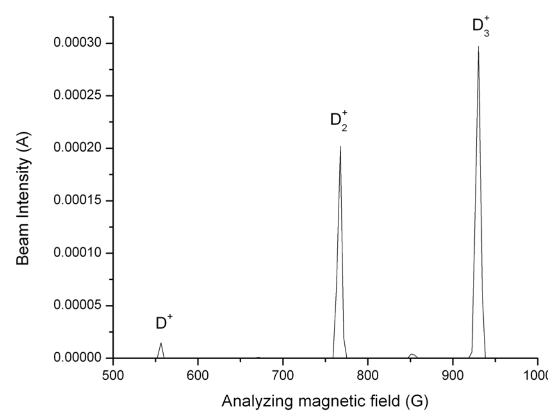

Figure 4: CAPRICE ECR D beams for a source pressure of 5x10-5 Torr and 10 W forward rf power.

electronic sequences. Figure 4 illustrates synthesis of D_3^+ ions, again in the CAPRICE ECR source, from D_2 source gas at very high source pressures and low rf powers. Such beams, decelerated to a few eV, are used in our studies of low-energy chemical sputtering of C materials. Intense beams of molecular ions have been obtained using the all-permanent magnet HV platform ECR source as well [8]. However, extraction region discharges due to the poorer extraction region pumping of the permanent magnet source limit its high-source-pressure operation. The D_3^+ beams from the platform ECR source are typically lower in intensity than those produced with the CAPRICE, and, unlike Figure 4, can't be tuned to exceed the D_2^+ current.

ICCE Trap

The final element of the MIRF upgrade project was the development and installation of the **I**on **C**ooling and **C**haracterization **E**nd-station (ICCE) trap. This electrostatic trap is side-injected by a combination of 32° and 13° pulsed parallel plate deflectors, simplifying HV

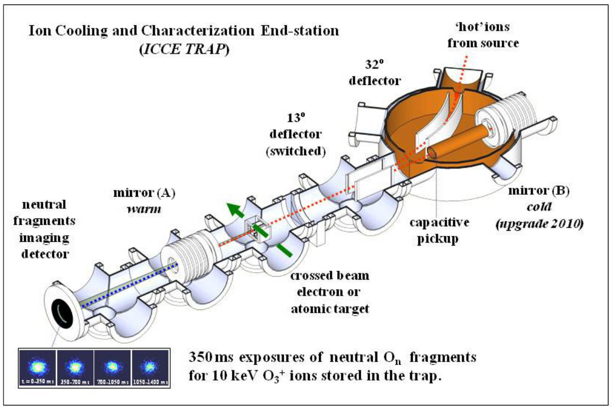

Figure 5: Schematic diagram of the ICCE trap [5].

switching and permitting DC operation of the two electrostatic end mirrors [5]. A neutral fragment imaging detector located outside one of the end mirrors is implemented to permit analysis of kinetic energy release during electron- or heavy-particle-induced dissociation of the trapped molecular ions. Figure 5 shows a schematic of the ICCE trap. Recently multi-second trapping of CO^+ ions has been achieved. In-situ electron and gas jet targets are being used to study electron and heavy-particle collisions of molecular ions as function of trapping times, i.e., as function of the degree of internal cooling of the trapped ions.

Plasma potential measurements

An issue of continuing interest is the determination of the ECR source plasma potential and the energy spread of extracted ions. These parameters impact the magnitude and uncertainties of impact energies of decelerated beams used in our low energy ion surface interaction studies [9] and thus must be known. In addition, knowledge of these parameters may improve fundamental insights into the ECR plasma dependences on pressure, microwave power, confinement magnetic fields, and elucidate the basis of the gas mixing effect. In-situ Langmuir probe measurements of MIRF CAPRICE plasma potentials have been reported in [10]. More recently, complementary measurements of plasma potentials based on retardation analysis of extracted ion beams [11] have been carried out, which are generally consistent with the in-situ probe measurements. A typical plasma potential and ion energy spread result from analysis of external beam deceleration is shown in Figure 6.

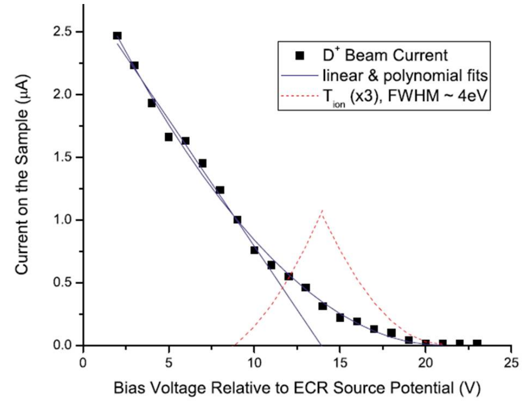

Figure 6: CAPRICE ECR plasma potential (~13.8 eV) and ion energy spread (~4 eV) deduced from retardation analysis of a D^+ ion beam extracted at a source pressure of $2x10^{-6}$ Torr and 6 W forward rf power [11].

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Recent activities at the ORNL Multicharged Ion Research Facility (MIRF)

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Physics Division
Oak Ridge National Laboratory

XIXth International Workshop on ECR Ion Sources
23-26 August, 2010, Grenoble

UT-BATTELLE
OAK RIDGE NATIONAL LABORATORY

Timeline of the Multicharged Ion Research Facility (MIRF)

- *ORNL ECR ion source, since 1984, dedicated to atomic collisions physics, MIRF established*

- *CAPRICE ECR ion source, since 1992*

- MIRF upgrade project

Extend upper energy limit to 250xq keV by placing new all permanent magnet ECR ion source on 250 kV high voltage platform

- *expands capabilities of present experiments*
- *opens door to new areas of study*
- completed 2005

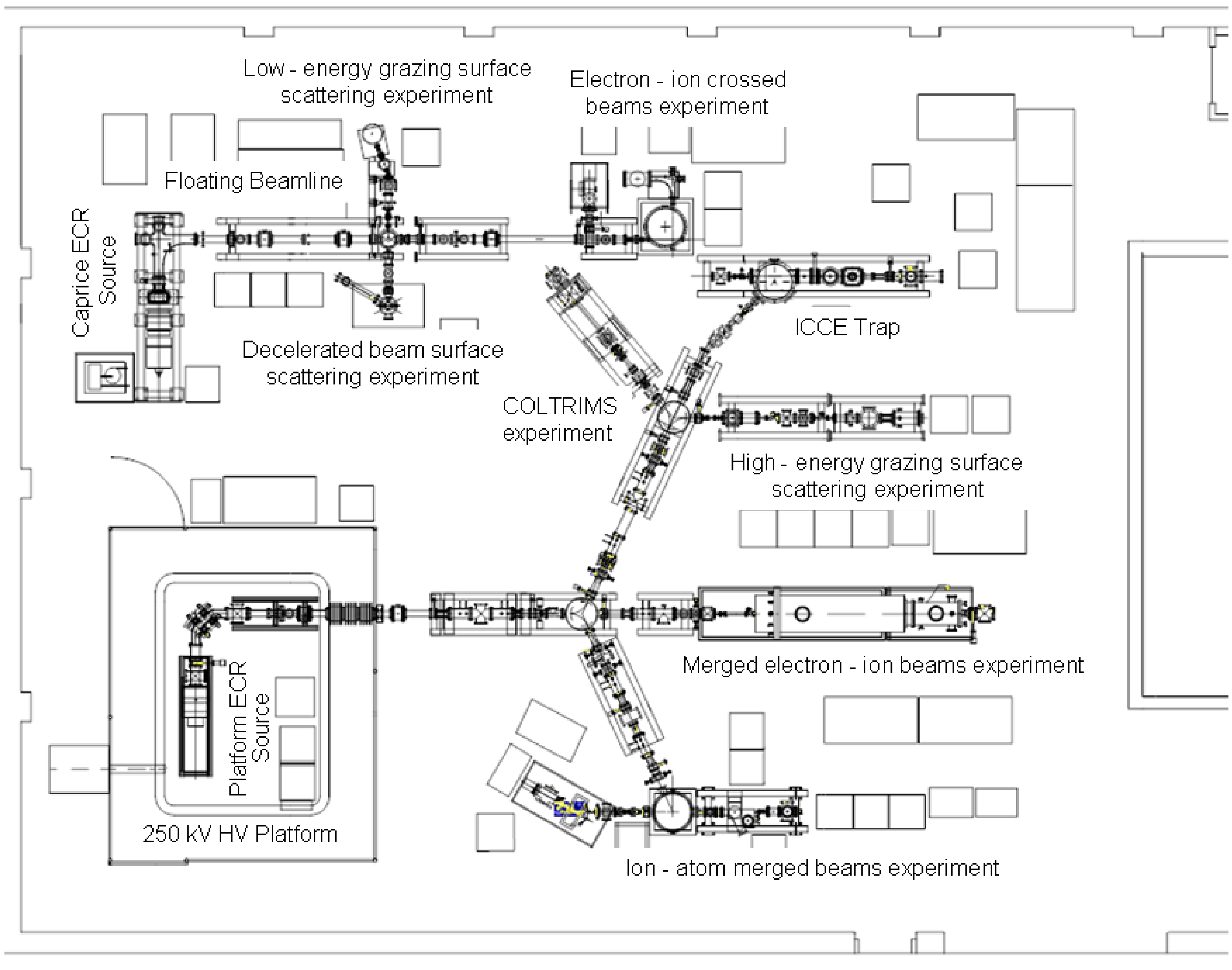
Extend lower energy limit to few eVxq by injecting CAPRICE beams into a floating beamline

- *efficient extraction and beam transport with subsequent deceleration at experimental end station*
- *simplifies present decelerated beams surface scattering experiment*
- *makes possible new experiments at very low energies*
- completed 2007

Develop linear electrostatic trap end station

- *fragmentation imaging for in-situ collisions of cold molecular ions with electrons and neutrals*
- Multisecond trapping lifetimes achieved Oct 2009

Present MIRF layout



Atomic Collision Studies at MIRF

Electron Collisions (Electron X-beam, MEIBEL, ICCE)

- Excitation and ionization of atomic ions
- Dissociation and ionization of molecular ions
- Ion beam excited state populations
- Dielectronic recombination of atomic ions
- Dissociative recombination of molecular ions
- Collisions with cooled ions (fragment imaging)

Heavy Particle Collisions (Merged beam , ICCE, COLTRIMS)

- Charge exchange between neutral atoms and molecules and atomic and molecular ions
- Very low relative velocities for heavy projectiles
- X-ray emission measurements of low energy CEX by HCI
- Highly charged ion neutralization during large angle projectile scattering
- Projectile excited state characterization
- Molecular dissociation
- Collisions with cooled ions (fragment imaging)

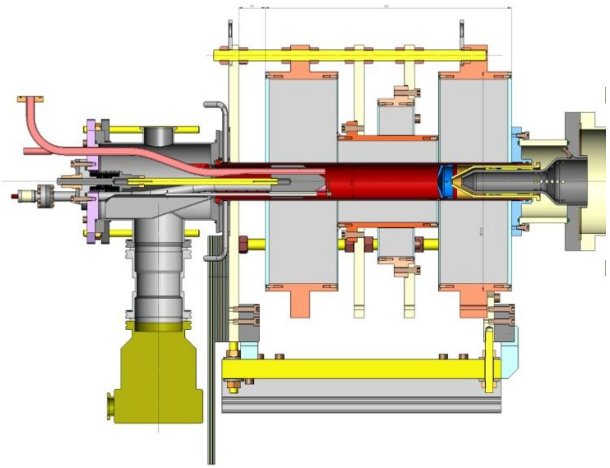
Low Energy Ion-Surface Scattering

- Chemical sputtering of graphite by low-energy D ions
- Neutralization of highly-charged ions in interactions with conducting and insulating crystals
- Charge-state distributions of scattered ions and neutrals
- “Soft” Molecular dissociation
- C-14 Detection

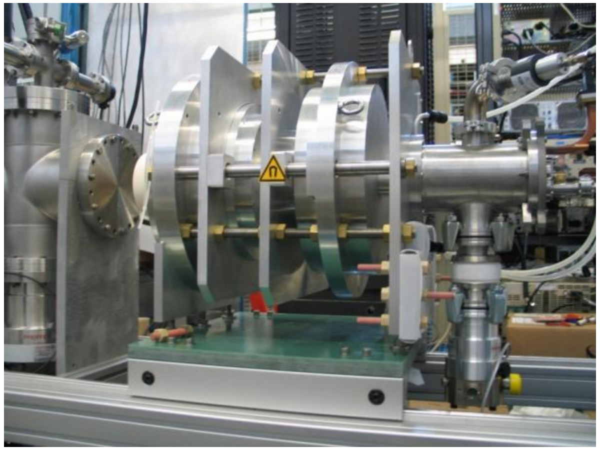
High Energy Ion-Surface Scattering

- Multicharged ion transmission/neutralization in nanocapillaries
- Multicharged projectile neutralization in grazing surface interactions
- Projectile excitation during grazing interactions with periodic (insulator) lattices
- Molecular dissociation interactions

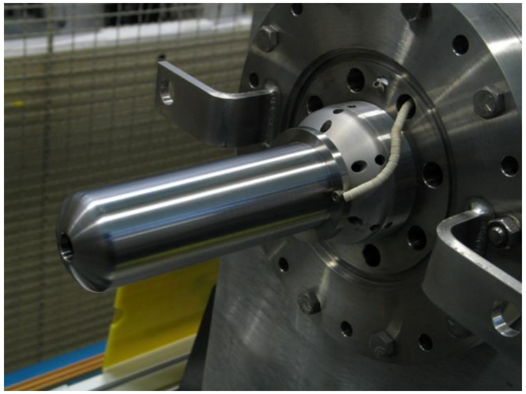
HV platform permanent magnet ECR ion source (Denis Hitz & Grenoble group)



0.9 T Tesla hexapole
1.8 Tesla w/ iron plug
12.5 – 14.5 GHz
750 W TWT
Ar: 8+ 510 μA; 11+ 90 μA
Xe: 20+ 25 μA; 30+ 1 μA
O: 1-3+ 700 μ A; 7+ 90 μA

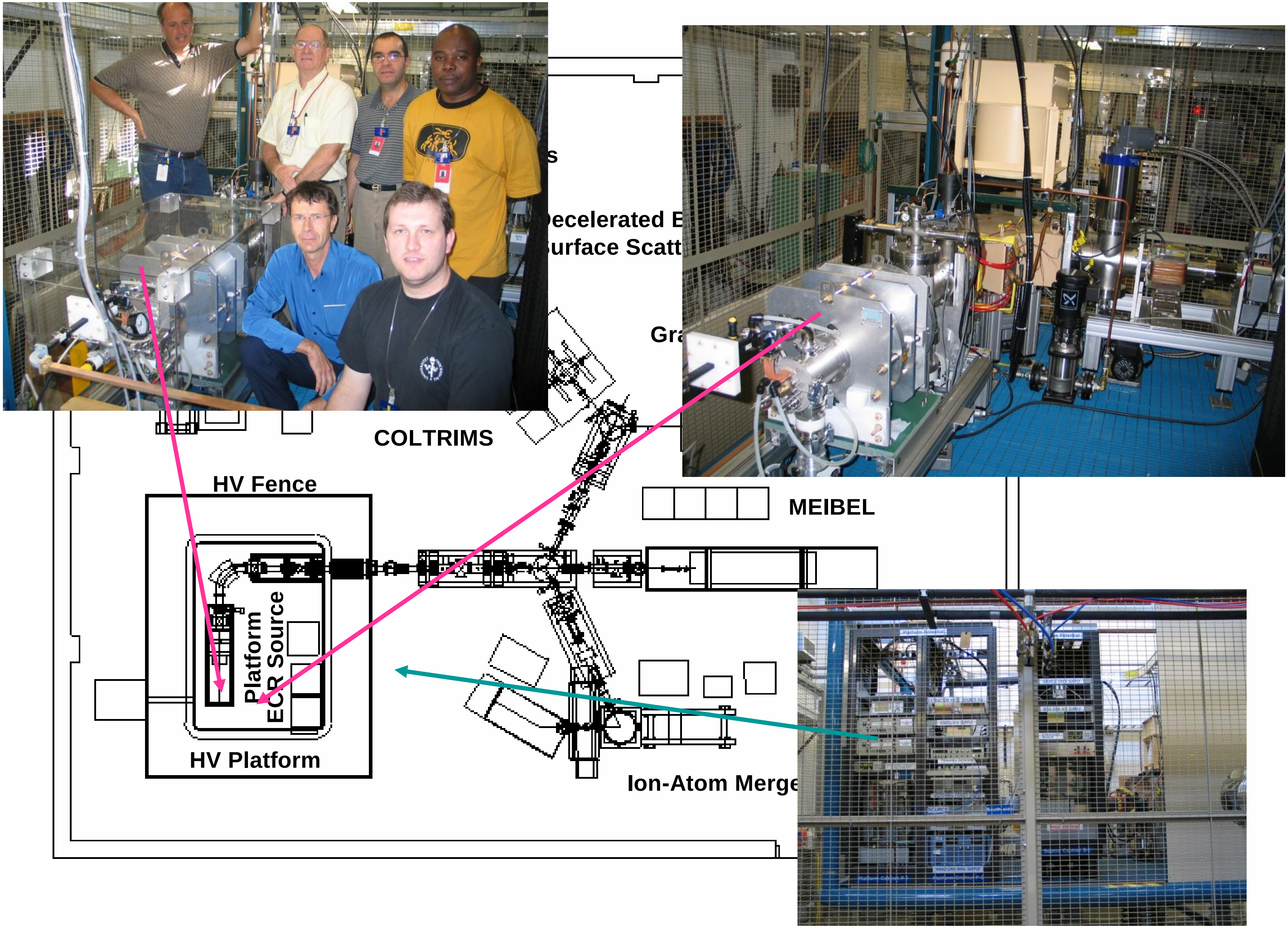


Relocation of TP
to reduce B field

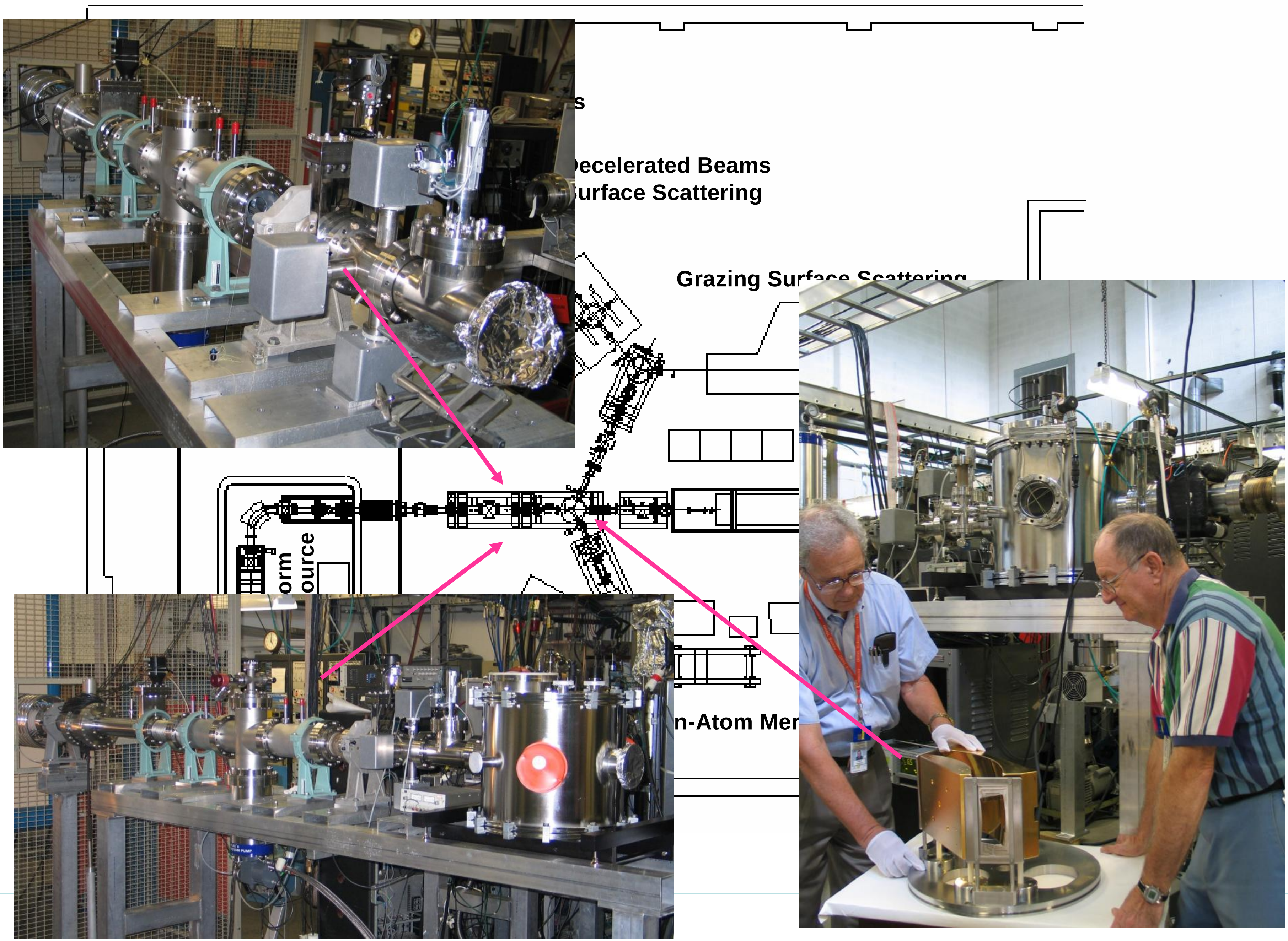


Modified Pierce geometry puller
to reduce insulator sputtering

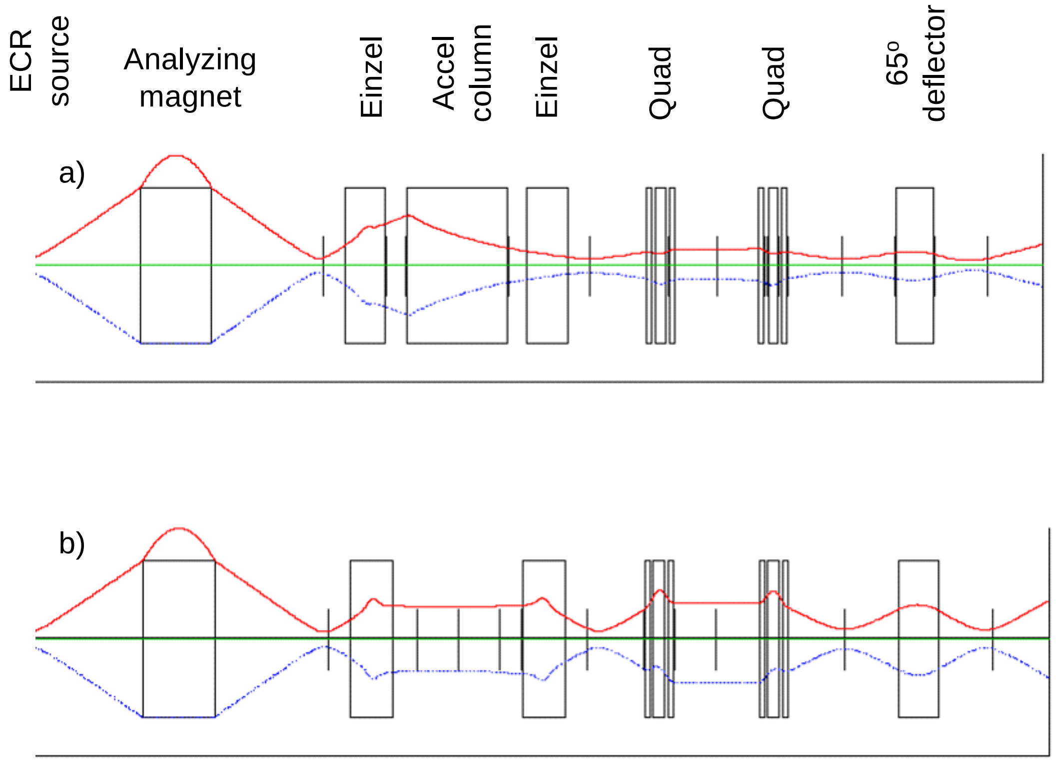
High voltage platform layout



High energy beam line elements



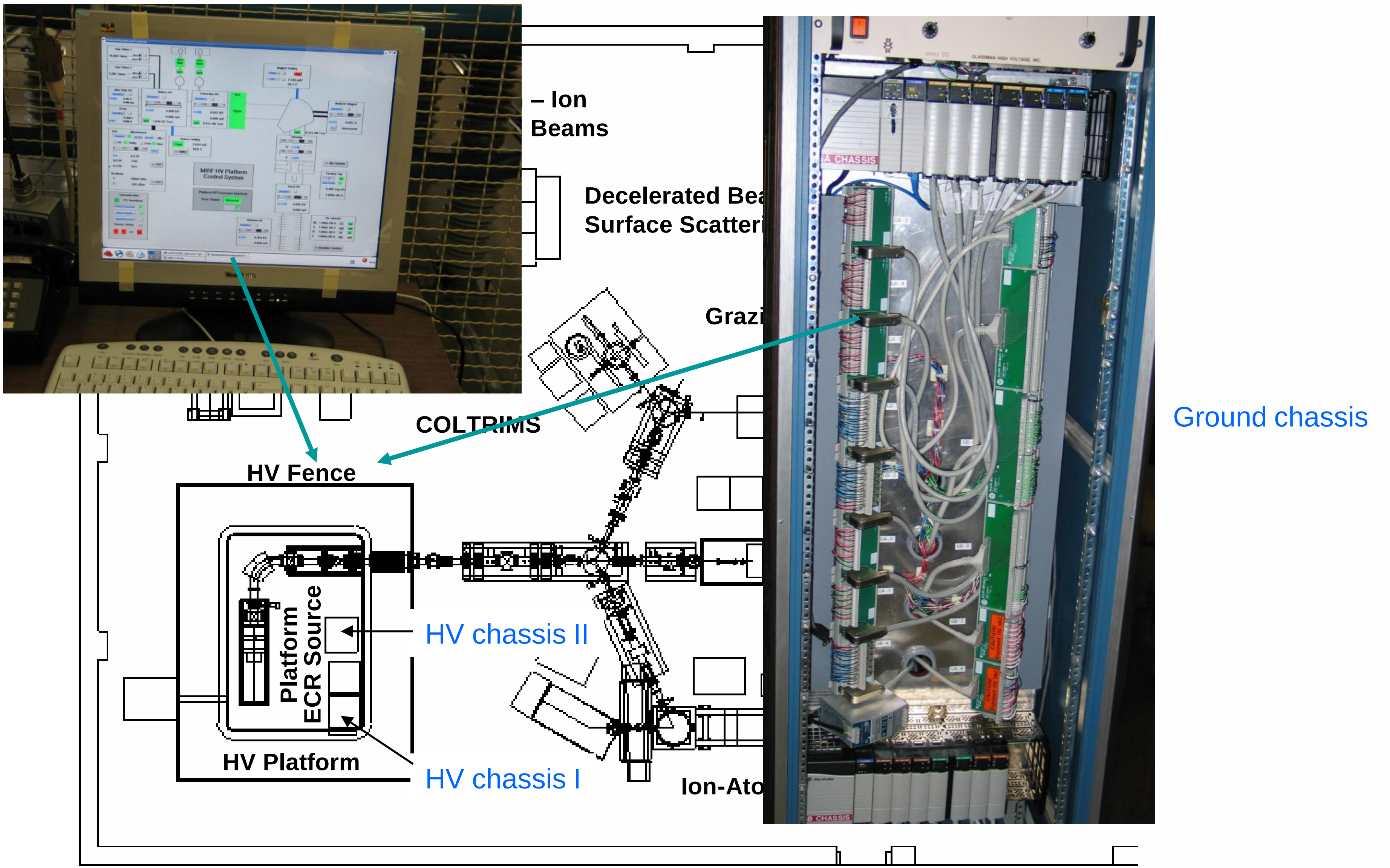
>90% transmission to end stations from 20 – 270 kV



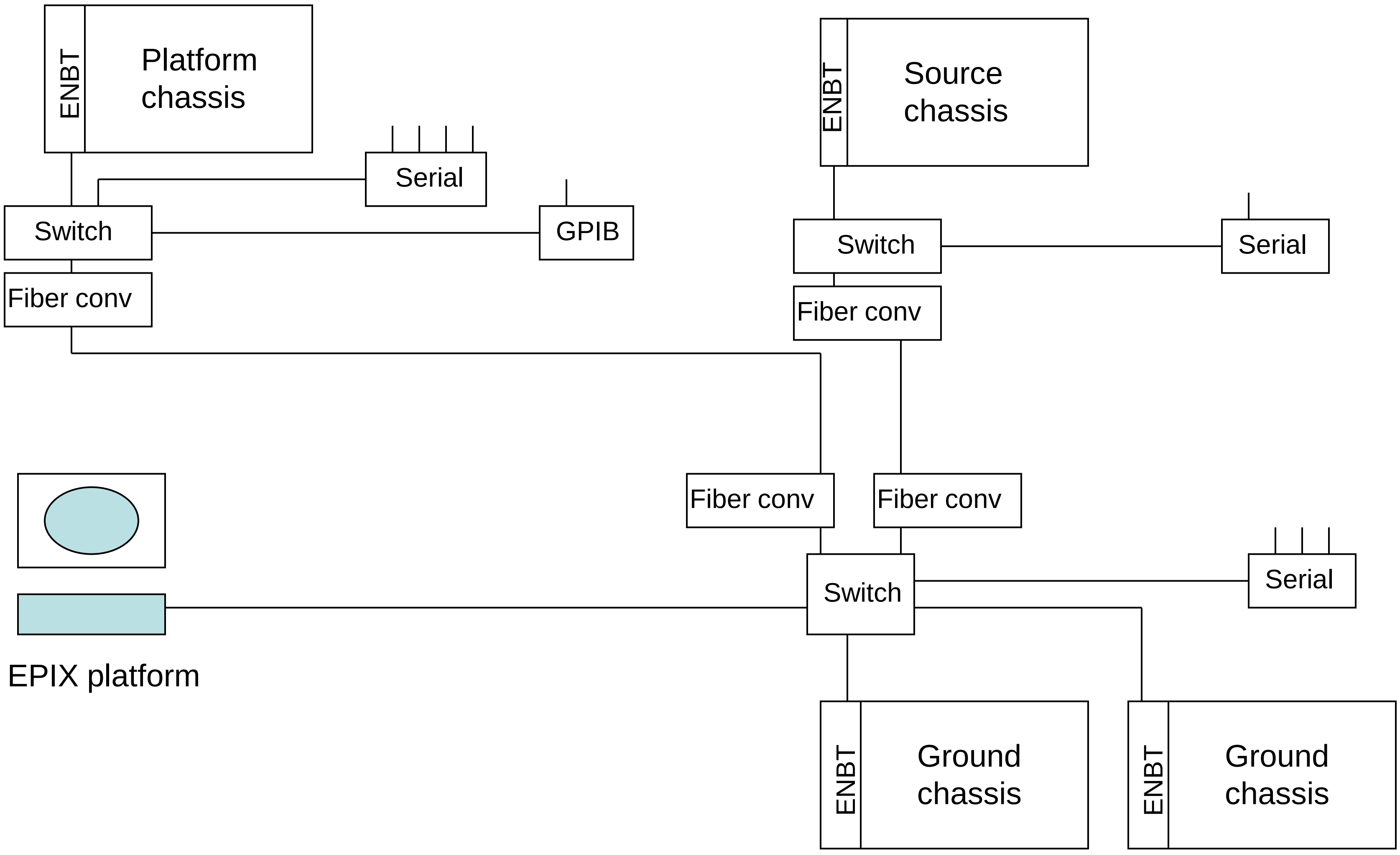
High energy beam envelope:
- accel column provides main focusing strength for waist to waist beam transport

Low energy beam envelope:
- 2 einzel lenses provide waist to waist beam transport

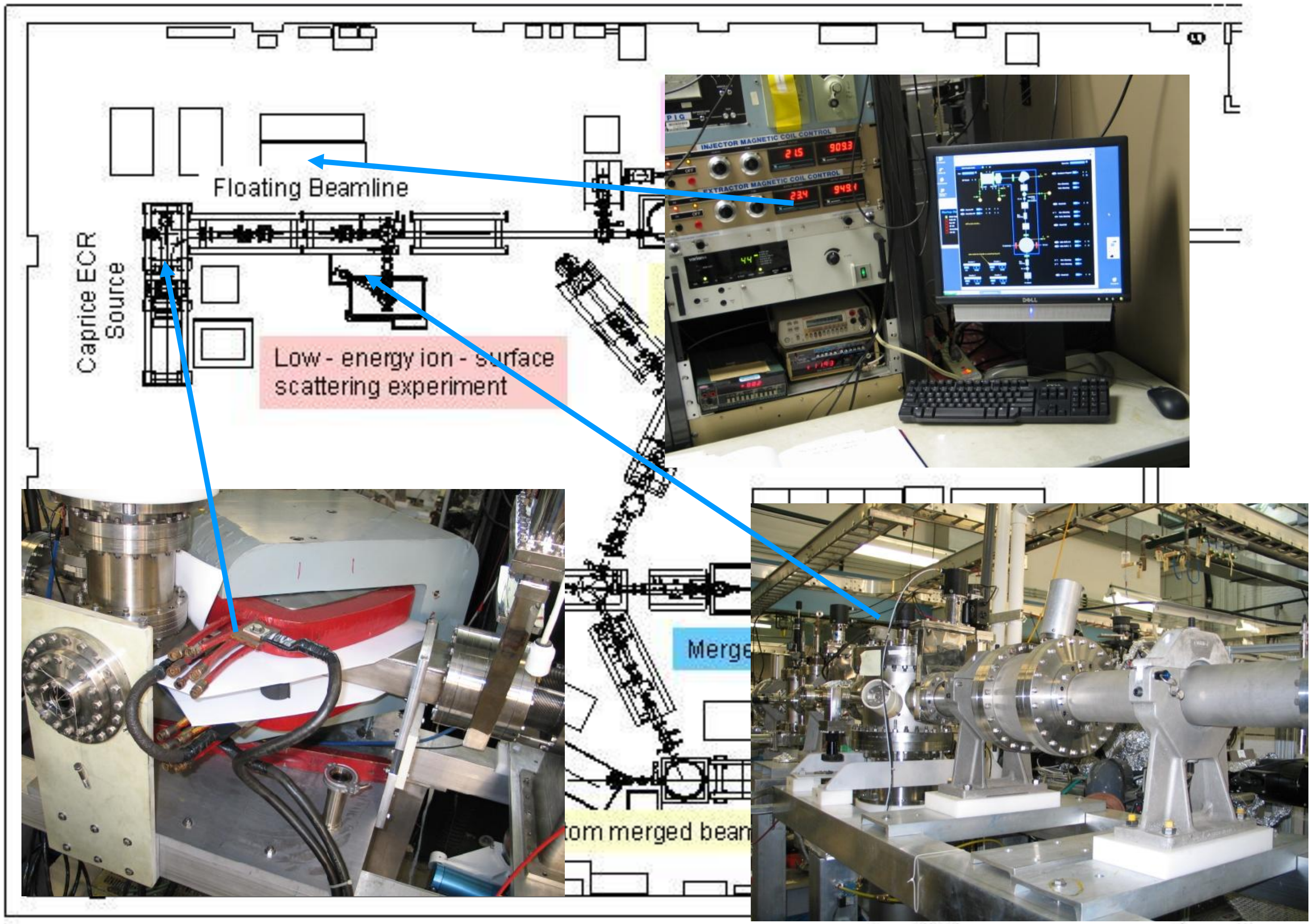
Platform and high energy beam line control system (A-B ControlLogix/EPICS)



Ethernet bridges among ControlLogix Chassis and to EPIX PC

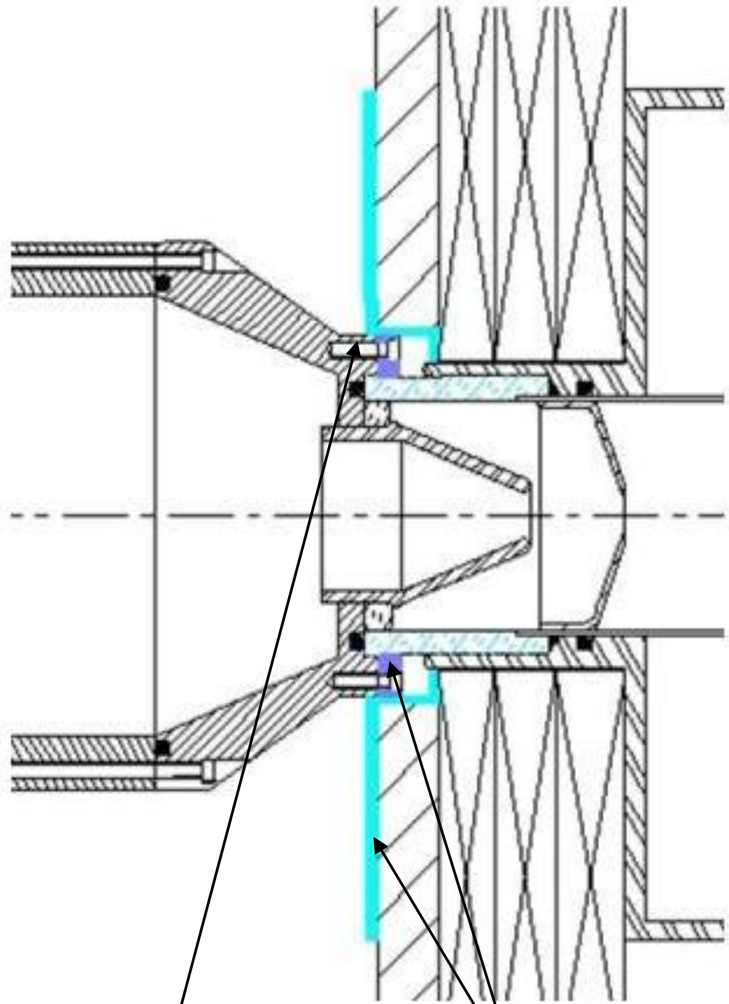


The floating beam line injected by CAPRICE



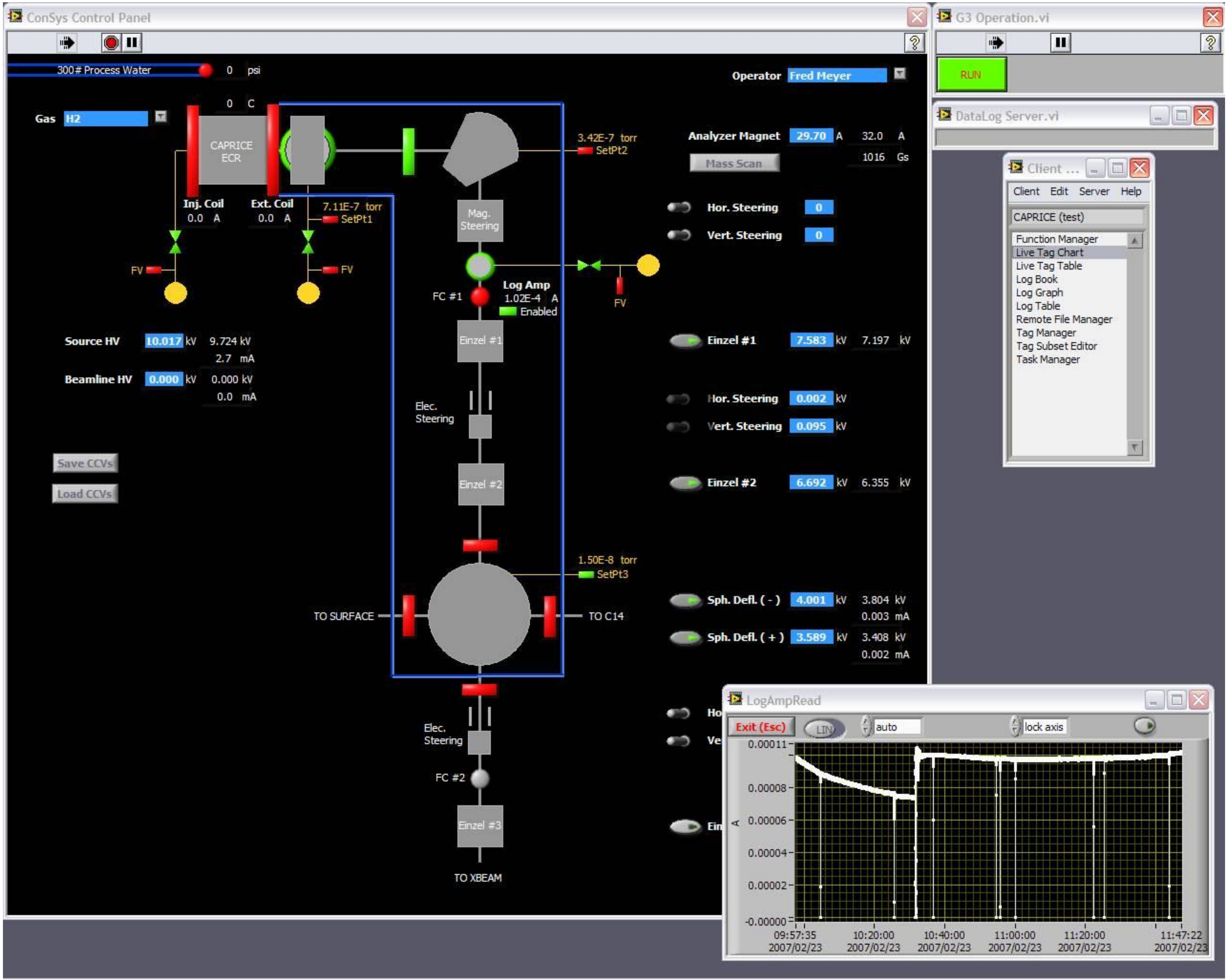
Low energy floating beam line HV isolation details

- Beamline supports on insulating Delrin blocks
- All pumps (1 DP, 1 TP, and 2 cryopumps) and ion gauges at ground potential, isolated from beamline HV by Delrin DC breaks
- All vacuum gate valves at HV: valve solenoids at ground potential
- 3.2 mm thick Teflon sheet between vacuum box and magnet for HV isolation

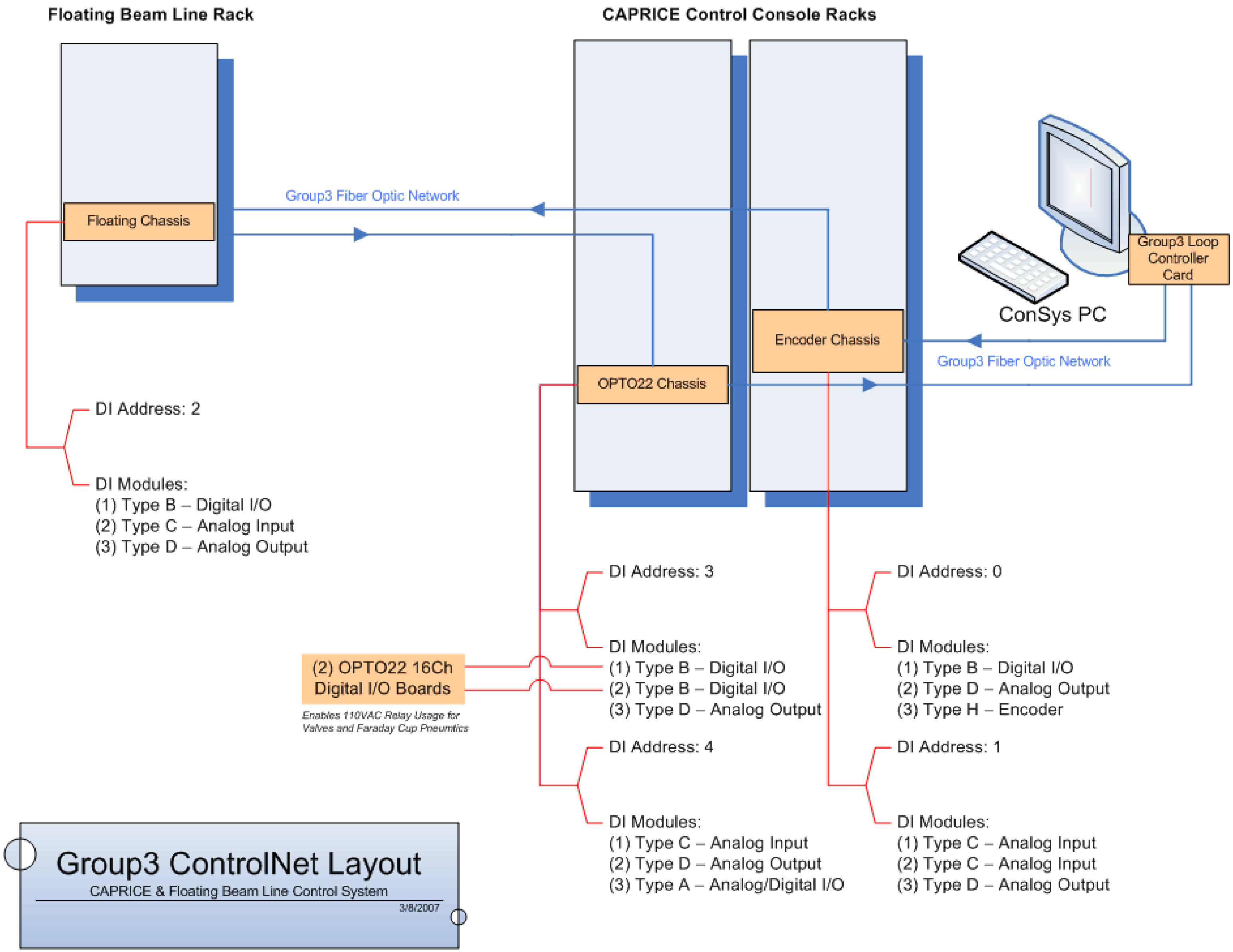


HV insulation of the ECR source extraction region enhanced by two added Delrin insulators, and nylon bolts

Floating beam line and ion source control screen with charting feature enabled



CAPRICE / Floating Beam Line Control System Network Diagram

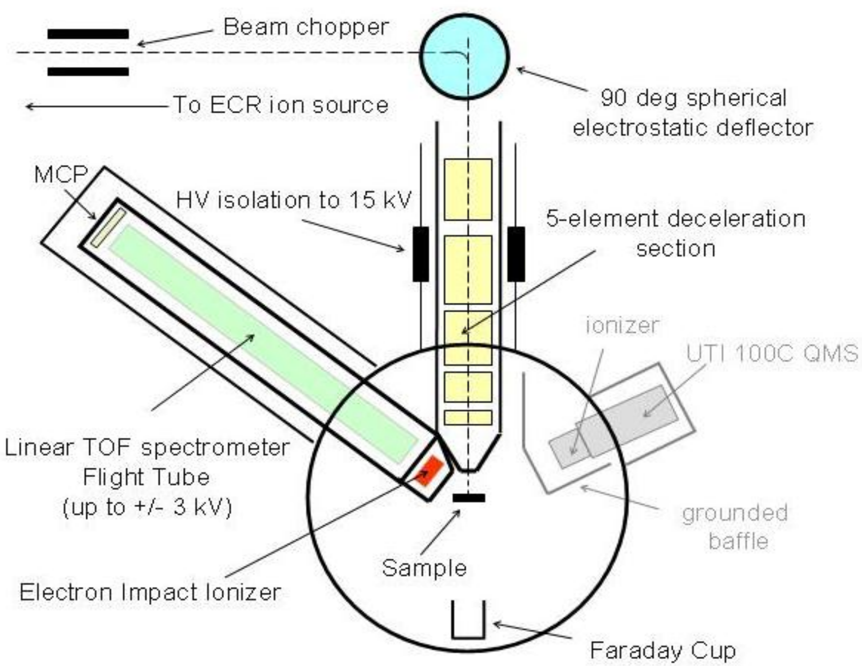


Low energy beam line - Control System Features

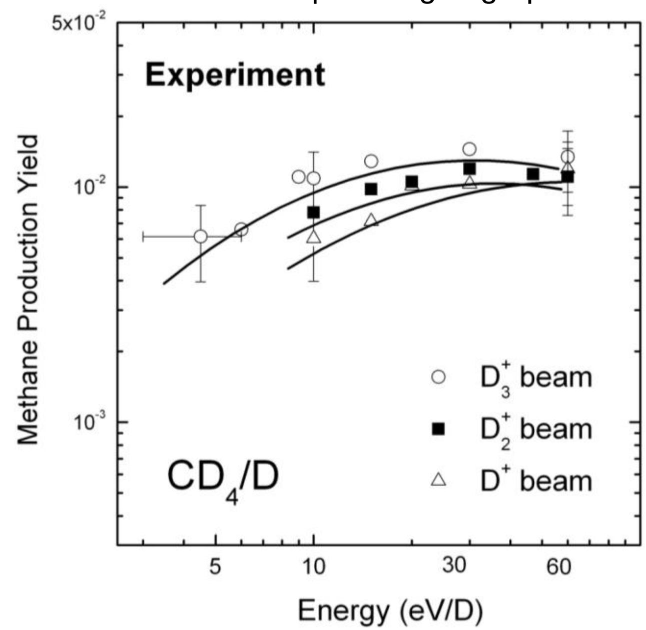
- Group3 ControlNet fiber-optically-linked distributed control system
- Small intelligent outstations (Device Interfaces or DI's) contain I/O boards
- A Loop Controller (LC) card handles communications on the fiber loop
- Group3 virtual instruments (VI) for LABVIEW handle all set-up tasks, and access all I/O data in LC
- Implements open source LuaVIEW data logging package

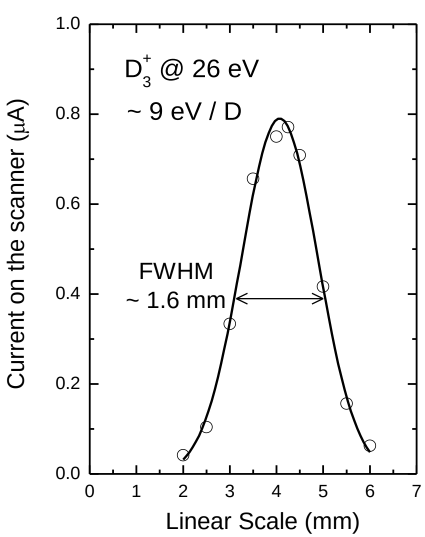
  process variables (tags) logging using time-, event-, or threshold-based algorithms
  alarms or warnings if limit values are exceeded
  mass scan utility
  charting functions
  control variable save and restore functions

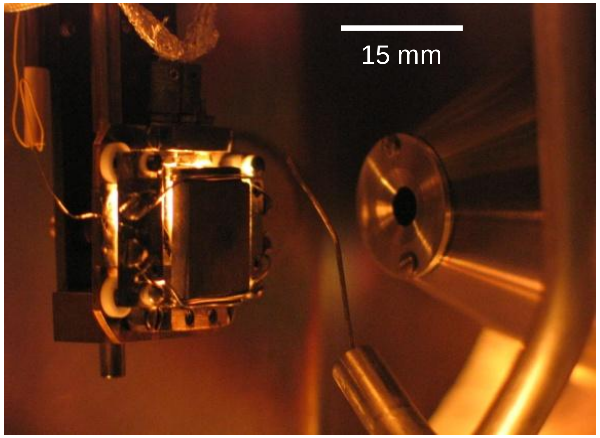
Low energy sputtering experiment needs well characterized, intense molecular ion beams



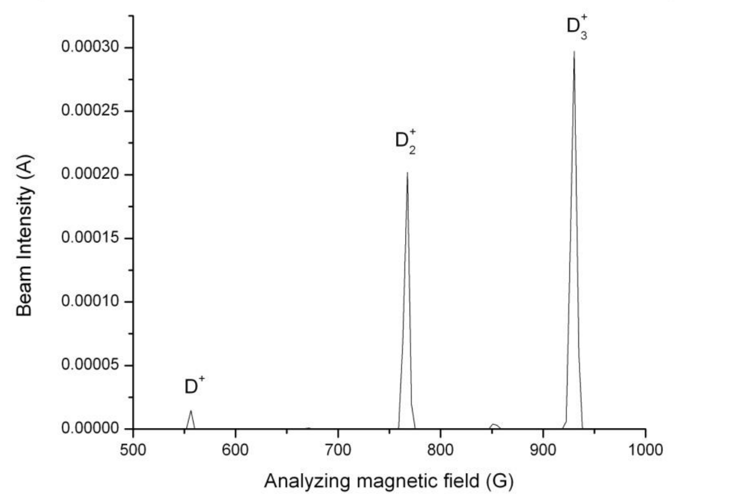
Chemical sputtering of graphite



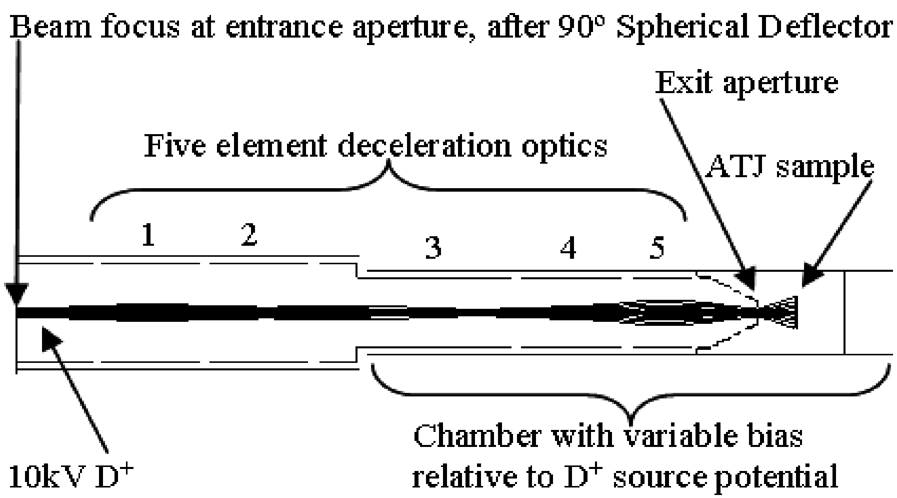




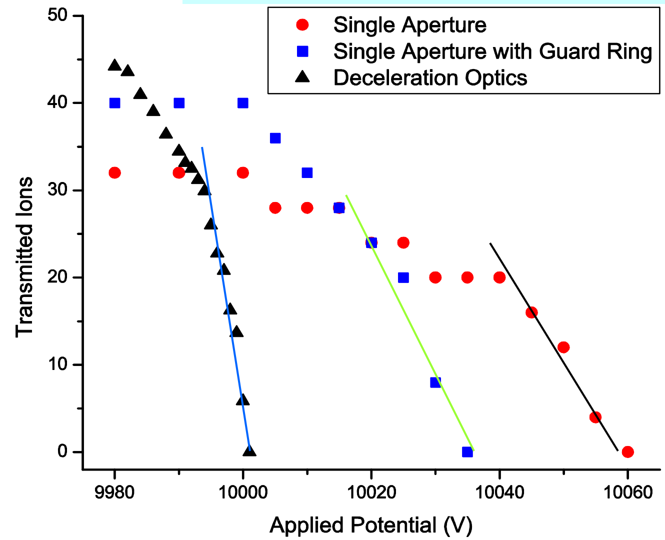
At high source pressure D_3^+ beam from CAPRICE dominates

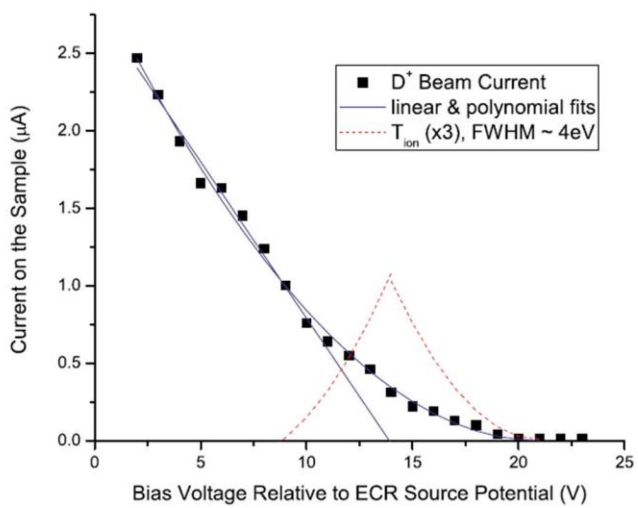


Correction for the ECR plasma potential is crucial for low energy experiments



Deceleration of 10 keV ion beam



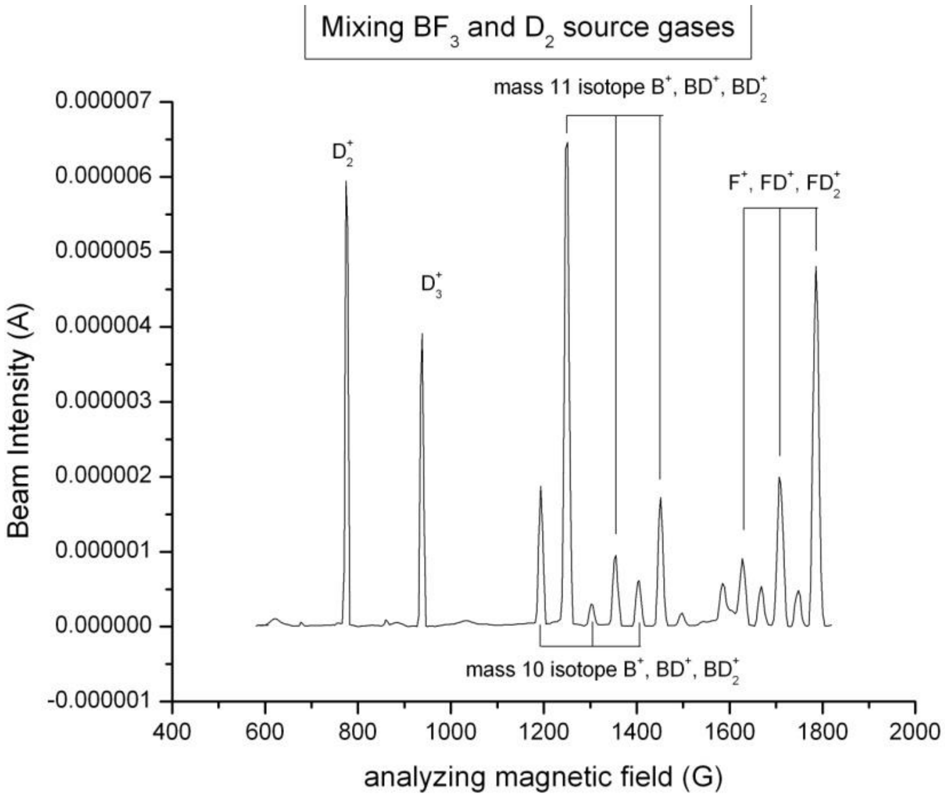


Abscissa intercept of linear region gives plasma potential estimate of *13.5 V*; difference between linear fit and actual retardation curve gives ion energy spread estimate of *4 V FWHM*

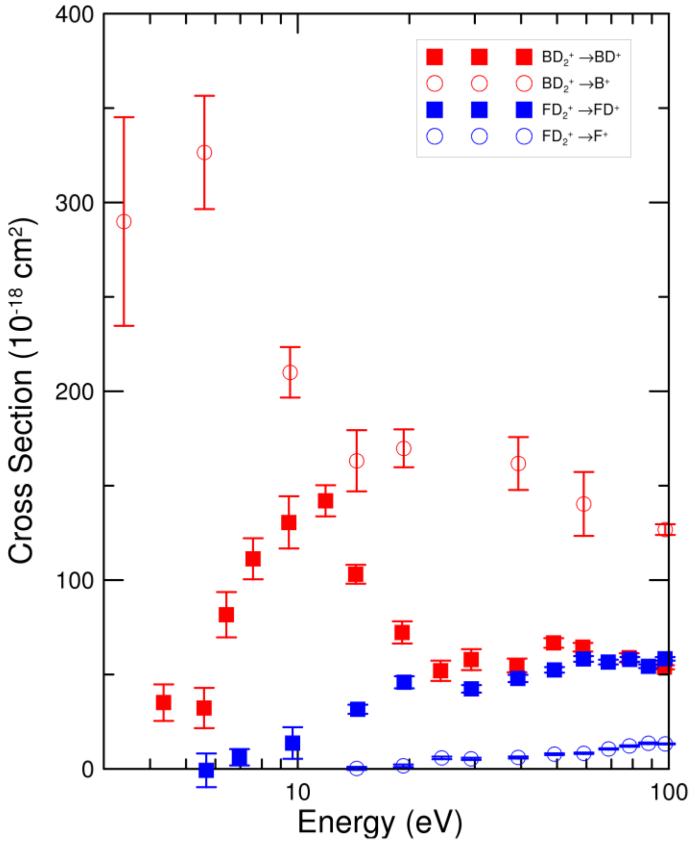
Values depend on source conditions !

ECR source chemistry produces molecular ion species for Electron X-beam Experiment

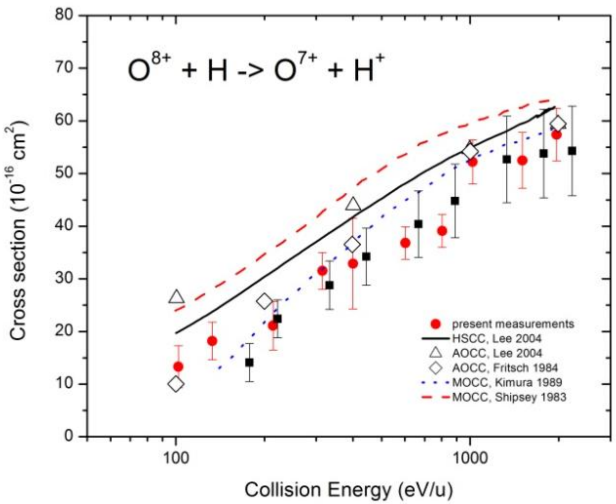
CAPRICE ECR source

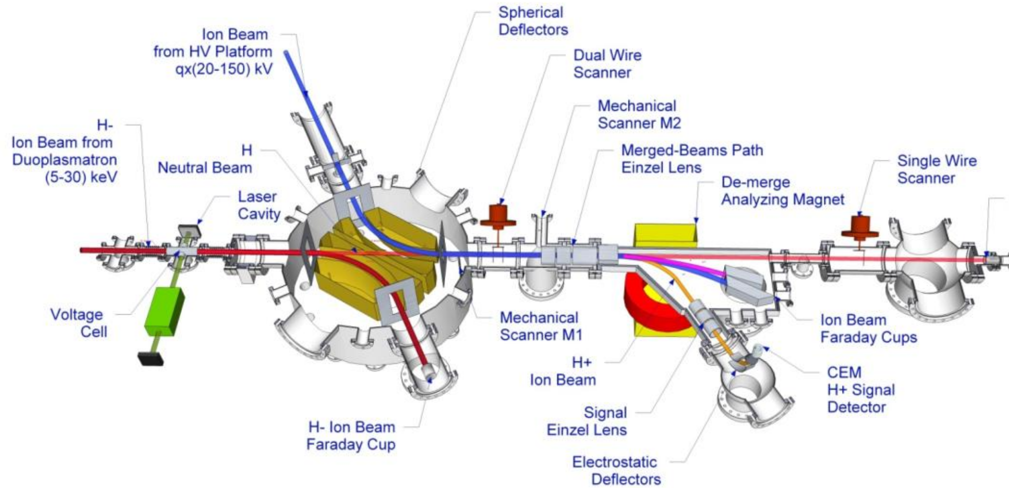


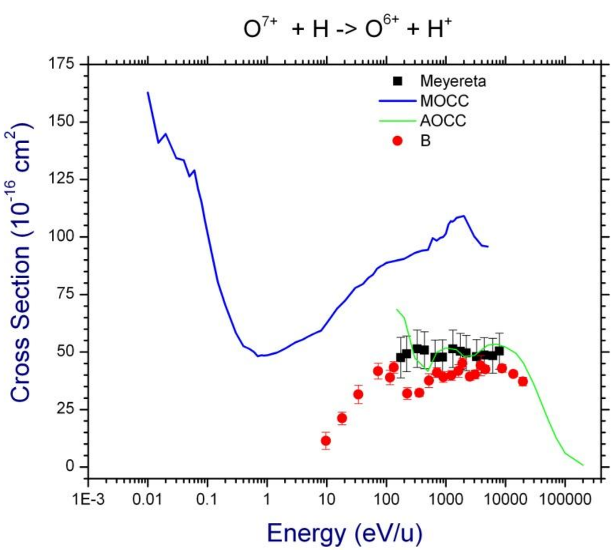
Electron impact dissociation of BD_2^+, FD_2^+

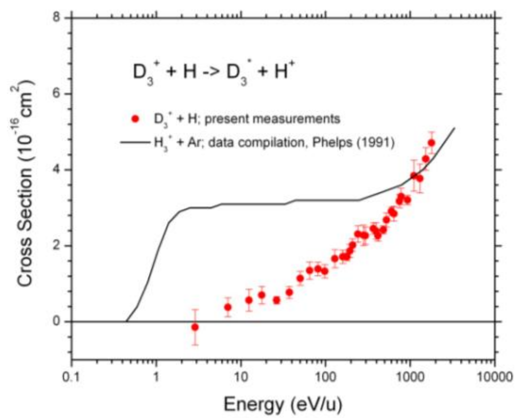


Ion-atom Merged Beams Experiment uses multi-charged as well as molecular ion beams

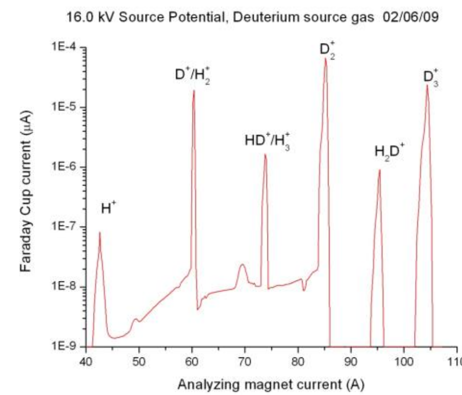








Platform ECR source



Discharge in extraction region limits max source pressure, and therefore max D_3^+ current

*The new **I**on **C**ooling and **C**haract**E**rization (ICCE) Trap End Station*

- *lifetime studies of excited molecular and multi-charged ions*
- *neutral fragment imaging*
- *studies of dissociative recombination and capture of molecular ions*