Status of the SNS H^- Ion-Source and Low-Energy Beam Transport System

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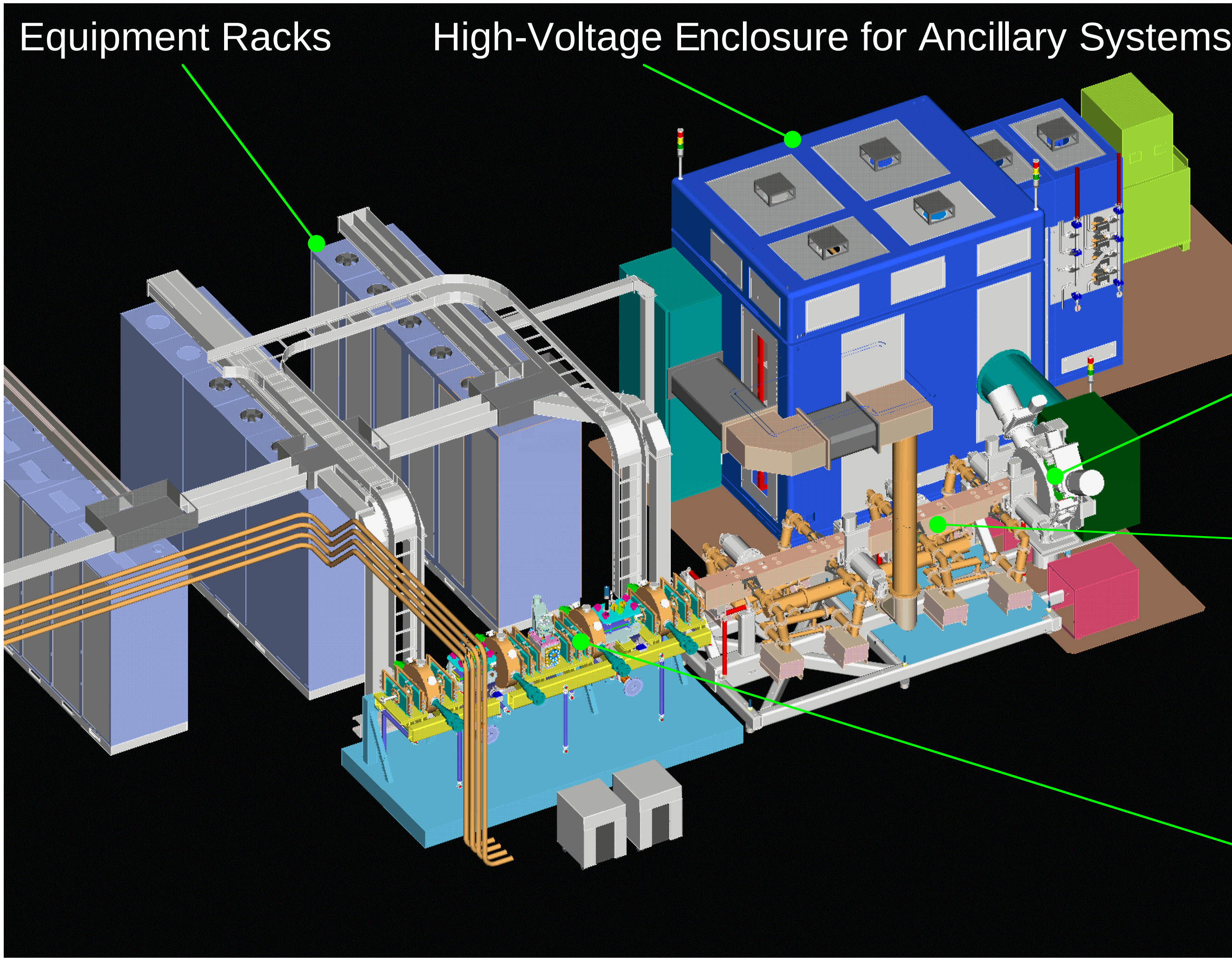
Outline of Talk

- SNS Front-End Overview
- Ion Source design
- LEBT design
- Beam measurements
- Summary

SNS Front-End Systems: Function



Ion Source/LEBT

Create ~50-mA H^- ion beam

RFQ

Accelerate beam to 2.5 MeV

LEBT/ MEBT

Chop beam into mini-pulses

MEBT

Match 38-mA beam into DTL

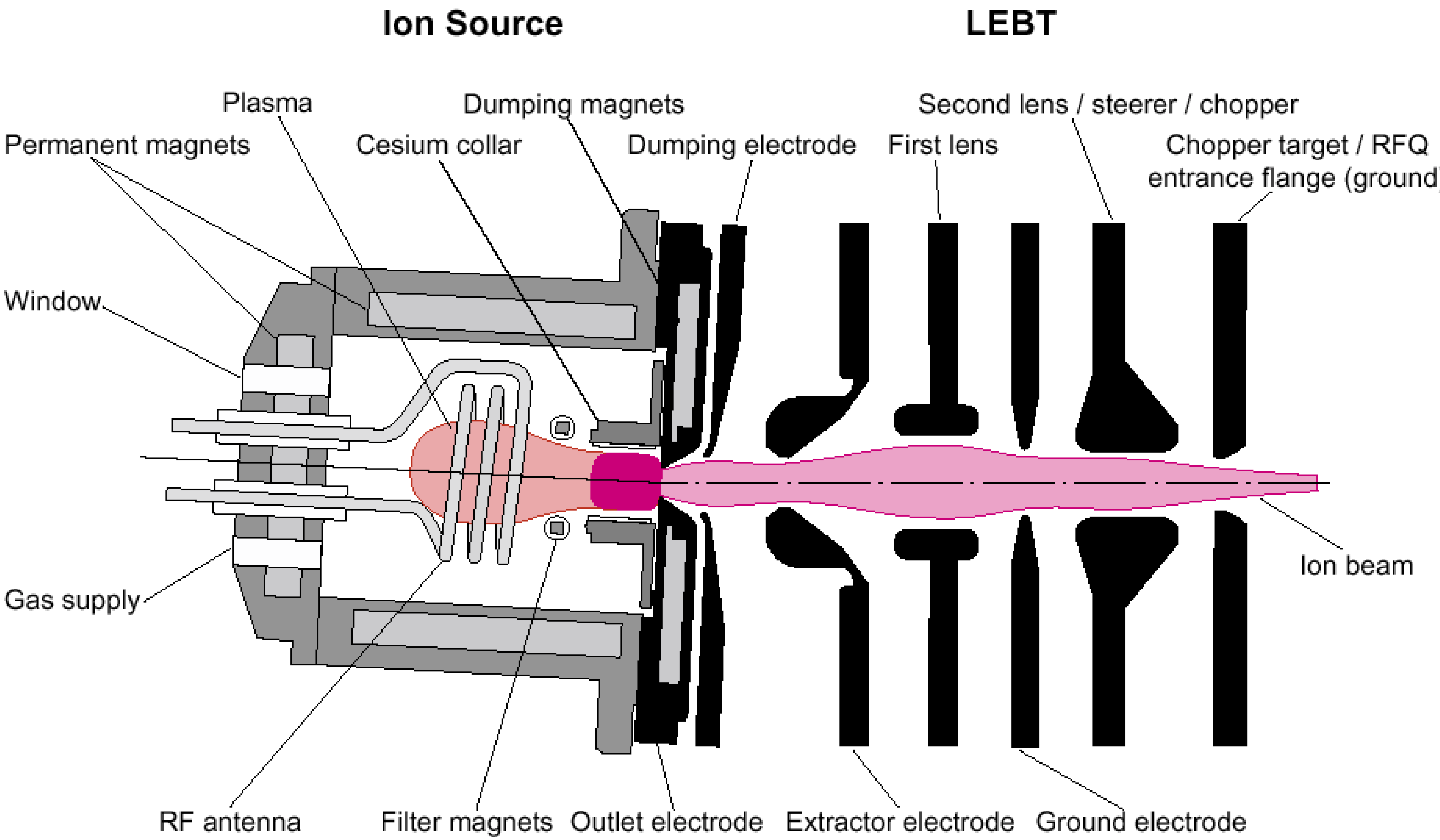
SNS Front-End
Key Performance Parameters

Ion species	H^-
MEBT output energy (keV)	2500
LEBT output energy (keV)	*65*
H^- peak current	
MEBT output (mA)	38
Nominal ion-source output (mA)	*50*
Output normalized transverse rms emittance (π mm mrad)	0.27
Output normalized longitudinal rms emittance (π MeV deg)	*0.126*
Macro pulse length (ms)	1
Duty factor (%)	6
Repetition rate (Hz)	60
Chopper system:	
LEBT rise, fall time (ns)	50
MEBT rise, fall time (ns)	10
Off/on beam-current ratio	*10^{-4}*

SNS Front-End Technical Characteristics

- Multi-cusp, rf-driven (volume-production) cesium-enhanced H^- Ion Source
  - Minimal amount of cesium
- Electron removal from beam ('dumping') at low energy
- All-electrostatic LEBT
  - No space-charge compensation
- 4-vane RFQ with π-mode stabilizers
  - Copper/GlidCop hybrid structure
- Beam chopping in LEBT (power) and MEBT (speed)
- Elaborate MEBT
  - Chopper and anti-chopper pair
  - 14 quadrupole magnets and 4 rebunchers
  - Beam diagnostics

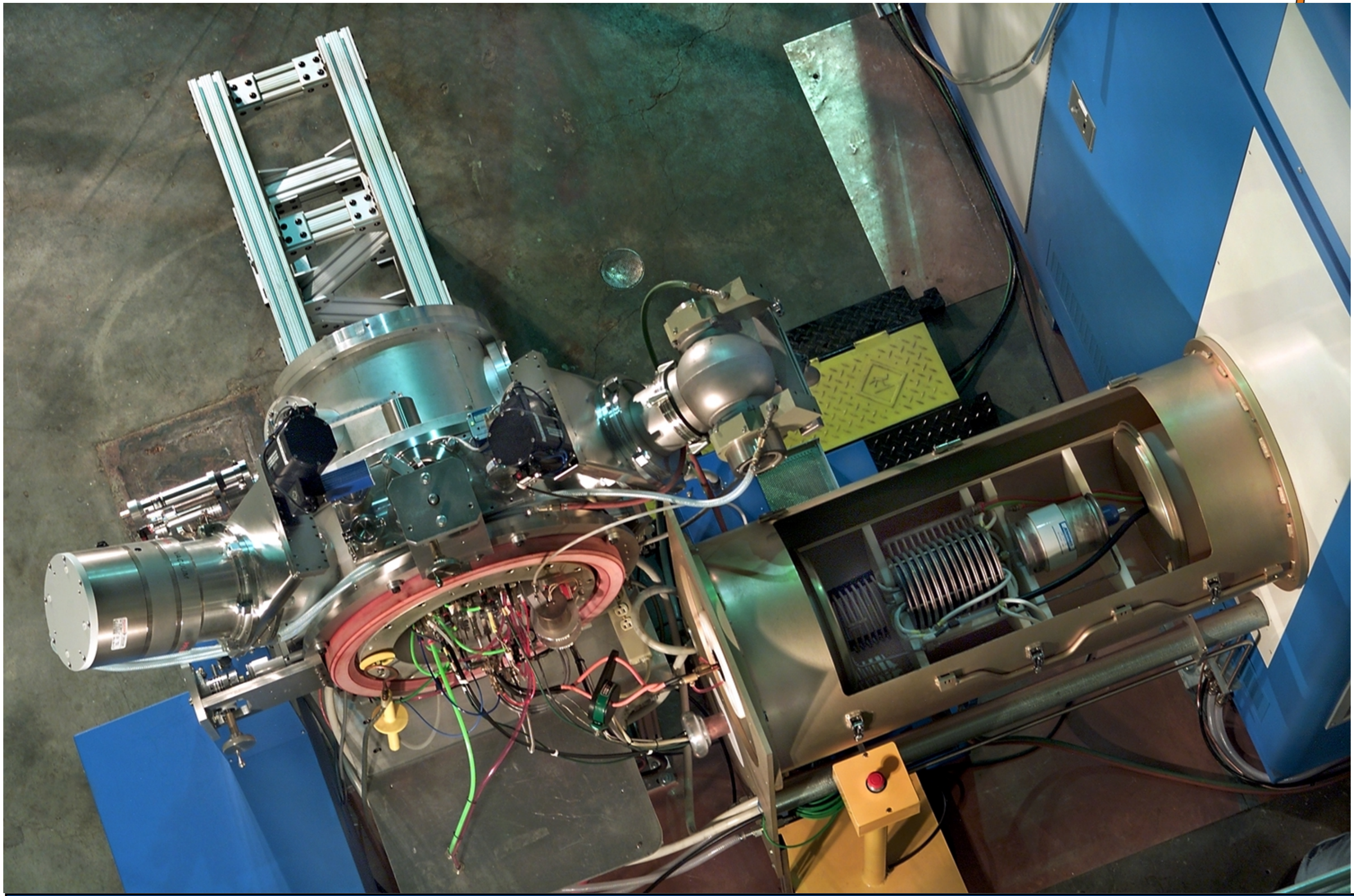
Ion Source and LEBT Layout



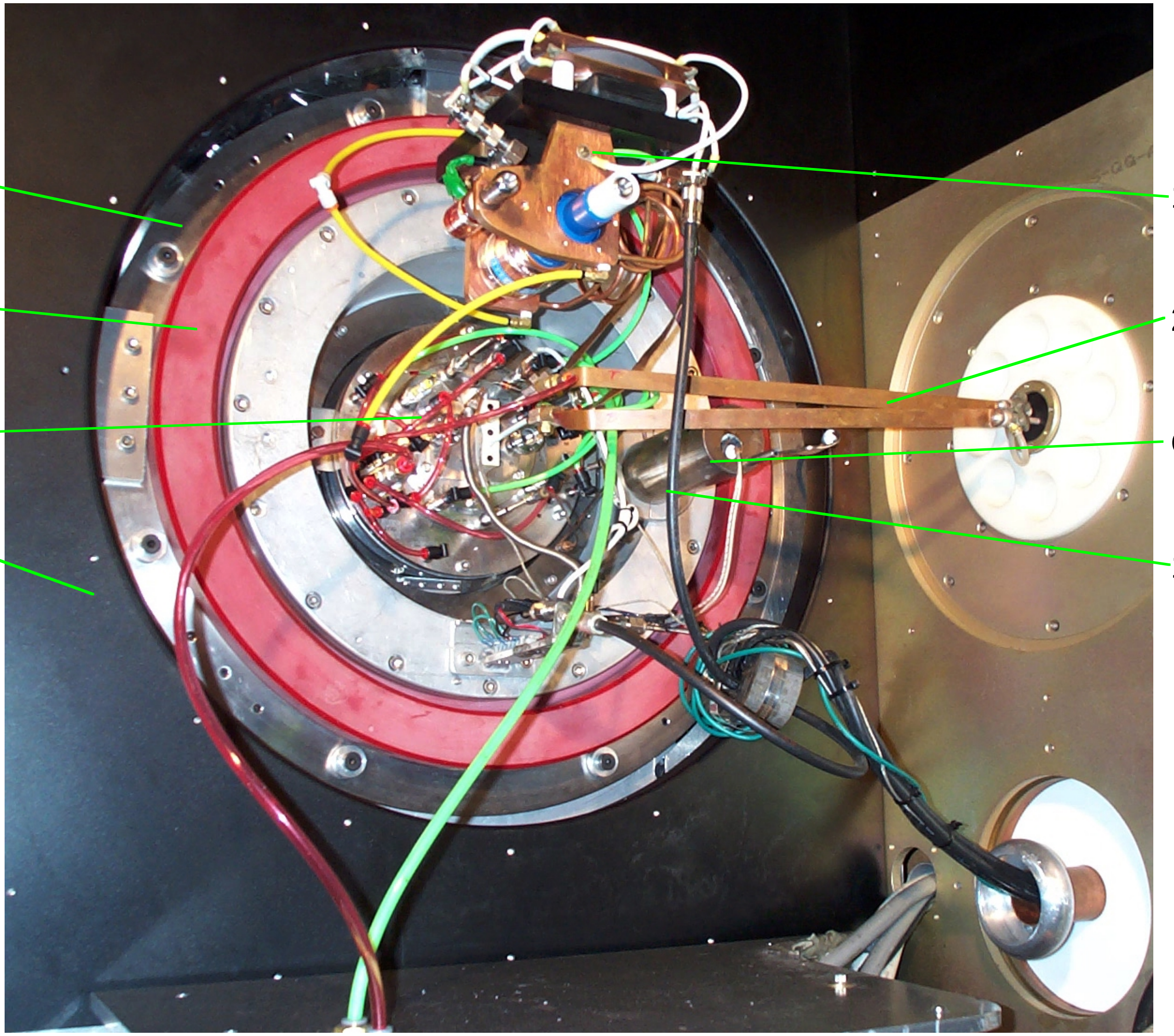
Plasma Generation Using RF Power

- Dual-frequency technique to ignite/sustain discharge
- Power input from pulsed 2-MHz and cw 13.56-MHz amplifiers merged on antenna feed-through
  - Significant improvement of ignition reliability with only 20 W cw power
  - No filament or UV light needed to facilitate ignition
- Transformer-based (inductive) impedance matcher
  - Proven suitability for ion source, but rather low efficiency
  - Used with 2-MHz main rf pulse
- Capacitive impedance matcher
  - High-Q, high efficiency
  - Used with 13.56-MHz cw rf power
- Plasma density is proportional to rf power
  - ~ 0.9 mA beam current per kW of rf power

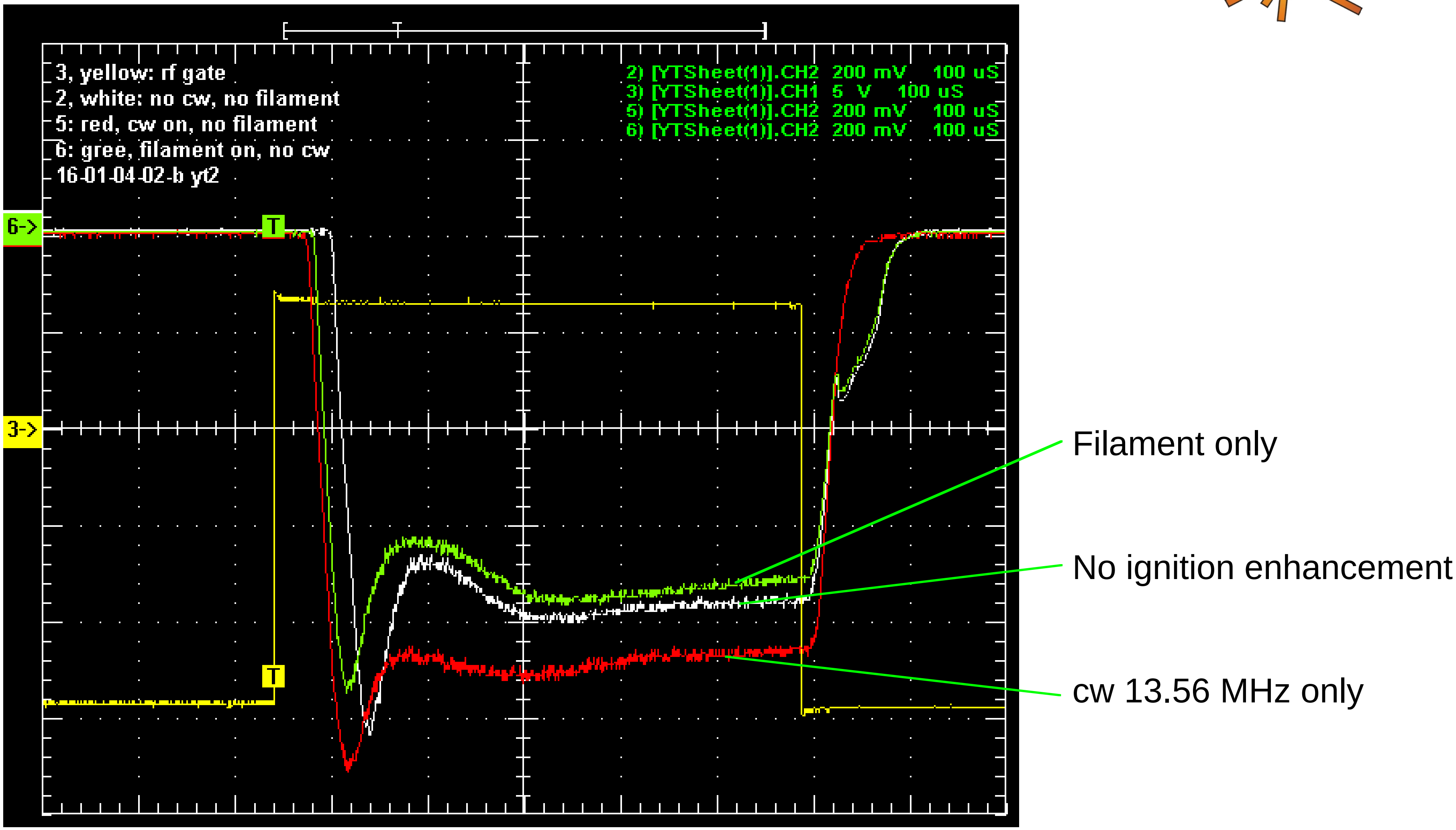
Ion Source, LEBT, and Infrastructure



Ion Source and LEBT Installation

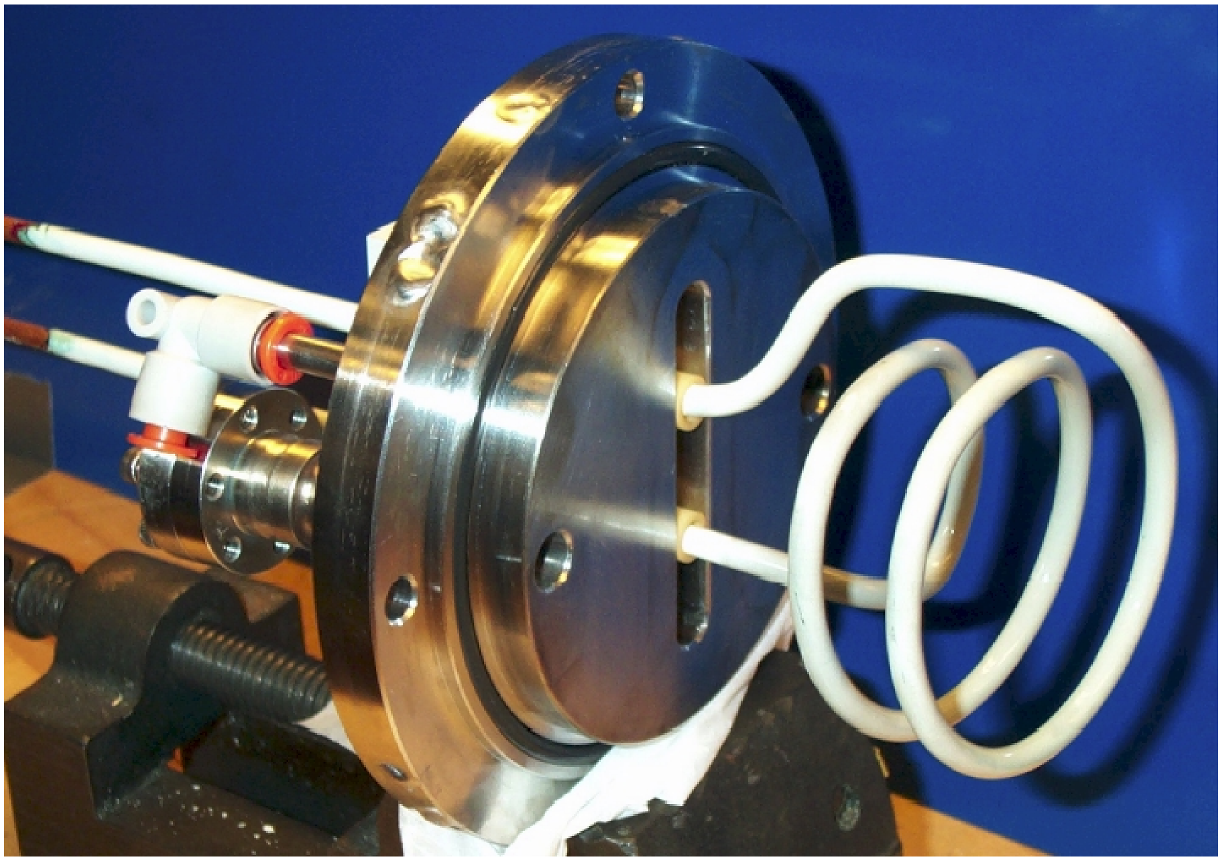


Discharge-Ignition Enhancements



100 µs per major division

RF-Antenna



- Porcelain-coated, water-cooled copper tubing
- Significantly improved reliability compared to earlier versions
  - Analyzed causes for reliability problems
  - New porcelain mixture and thicker multi-layer structure
  - Lifetime of latest version not yet measured; sure to exceed 100 hrs

Cesium management

- Established facts
  - About 1/2-monolayer coating of collar surface is optimal
  - Achieving good coating within ~15 min
    by initially heating collar to > 500 °C
  - Getting highest beam current around 280°C operating temperature
  - Cesium-enhanced source operation can be resumed after venting to air, even without cleaning
- Open issues
  - Duration of cesium charge in dispensers
    - Expected to last several months
  - Persistence of optimal coating inside collar
    - Expected to last ~ 1 day
  - Possibility of refreshing cesium layer during beam production
    - Requires duty factor close to 6%

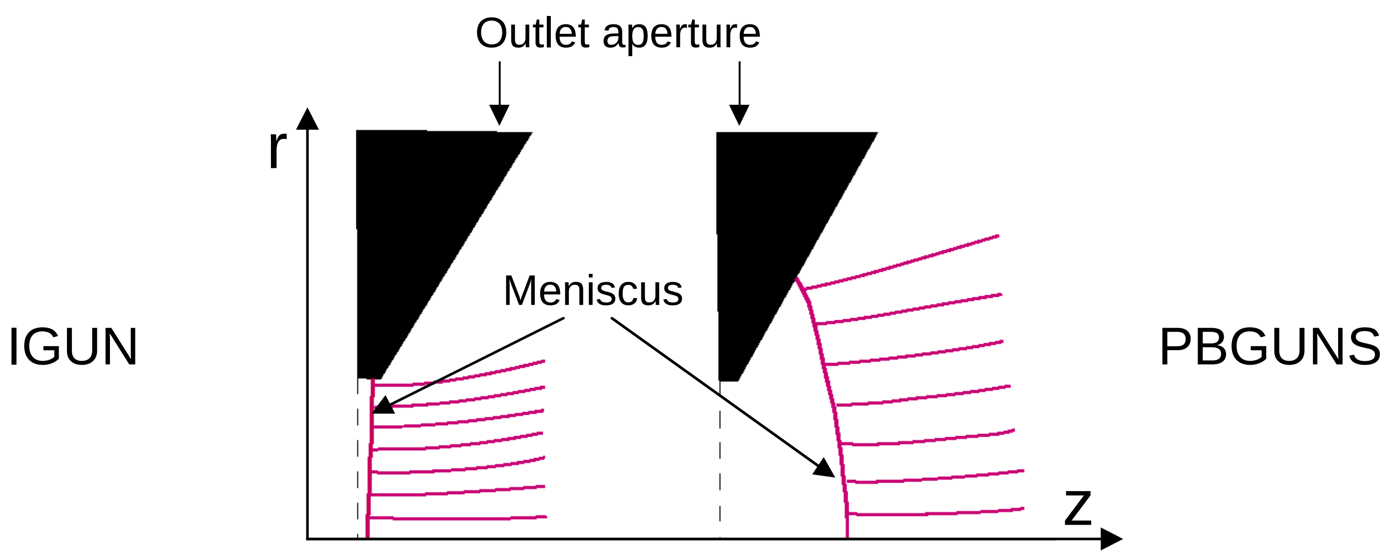
Electron Dumping and Beam Formation

- Status
  - Dumping of extracted electrons at low energy works well in principle
    - Some 65 keV electrons are deposited on extractor support
    - Installed water-cooled shield
  - Low-energy electrons with asymmetric distribution might deteriorate ion-beam emittance
  - Beam production for SNS commissioning and early operations is assured in any case

- Ongoing work
  - 2-d simulations (PBGUNS) of negative-ion beam formation
  - 3-d simulations (SIMION) of ion and electron transport including measured magnetic dipole field
  - Integrated cesium-collar/outlet-aperture to be tested soon

Beam-Formation and LEBT Simulations

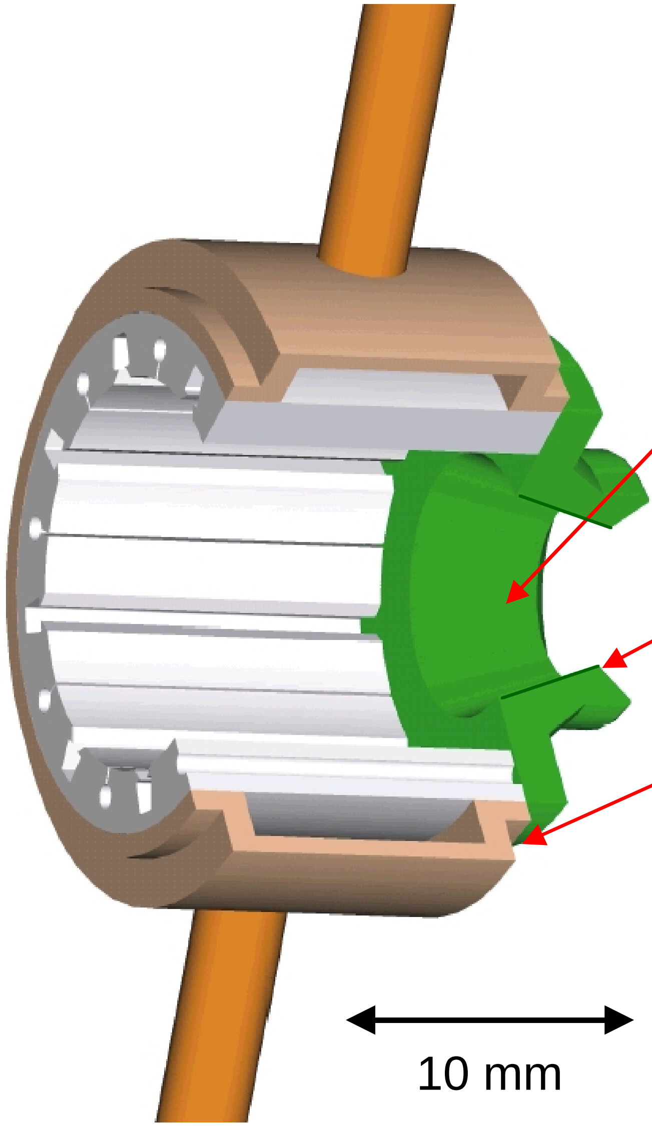
- Initially used positive-ion code IGUN
  - Found novel way of including finite ion temperatures
  - Fair representation of LEBT properties
  - Problems with modeling beam formation (meniscus location)
- Began using negative-ion version of PBGUNS
  - Appropriate treatment of beam formation



- Modified outlet-aperture contour based on PBGUNS simulations

Ion-Source

Integrated Cesium Collar/Outlet Electrode Design



Offers hot, cesiated ionization surface close to plasma meniscus

(2-mm mean free path length)

Improved outlet electrode shape based on PBGuns simulations

Isolated from outlet plate by ceramic ring

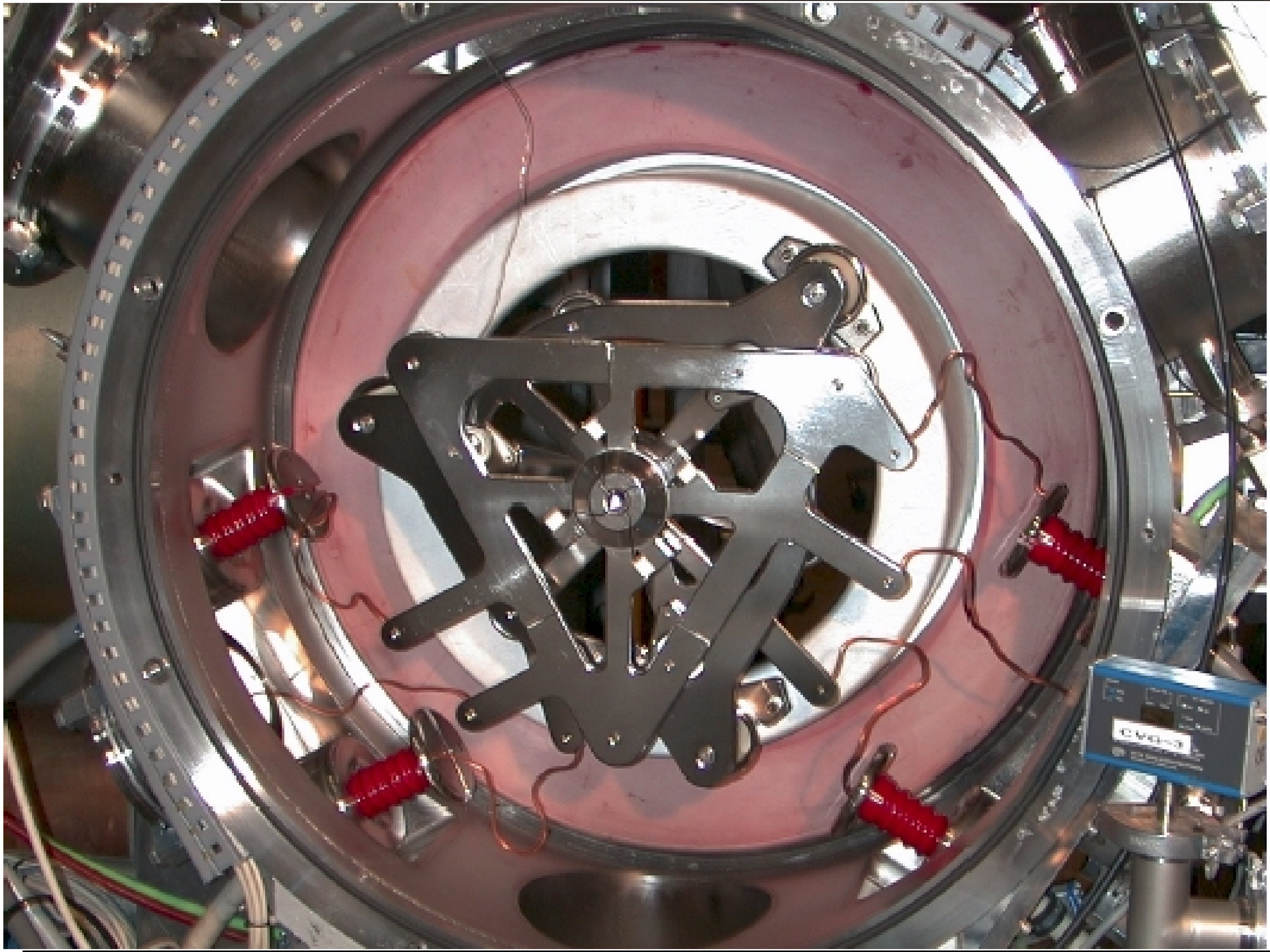
- Can be biased to apply optimum voltage for beam production
- Provides alignment with respect to outlet plate aperture

LEBT Features

- Fully electrostatic, no space-charge compensation
- Extractor electrode from ferromagnetic steel
  - Clips electron-dumping field of ion source
- Two einzel lenses
  - Center electrode of second lens is split into four quadrants
    - Electrostatic steering
    - Beam chopping
- Last LEBT electrode has several functions
  - Ground electrode for second lens
  - Target for chopped beam
  - Indicates beam position through time-dependent current measurement
  - RFQ entrance electrode
- LEBT / ion source system can be mechanically offset against RFQ entrance-electrode for steering purposes
- Electrodes designed for efficient gas pumping

LEBT Assembly in Vacuum Tank

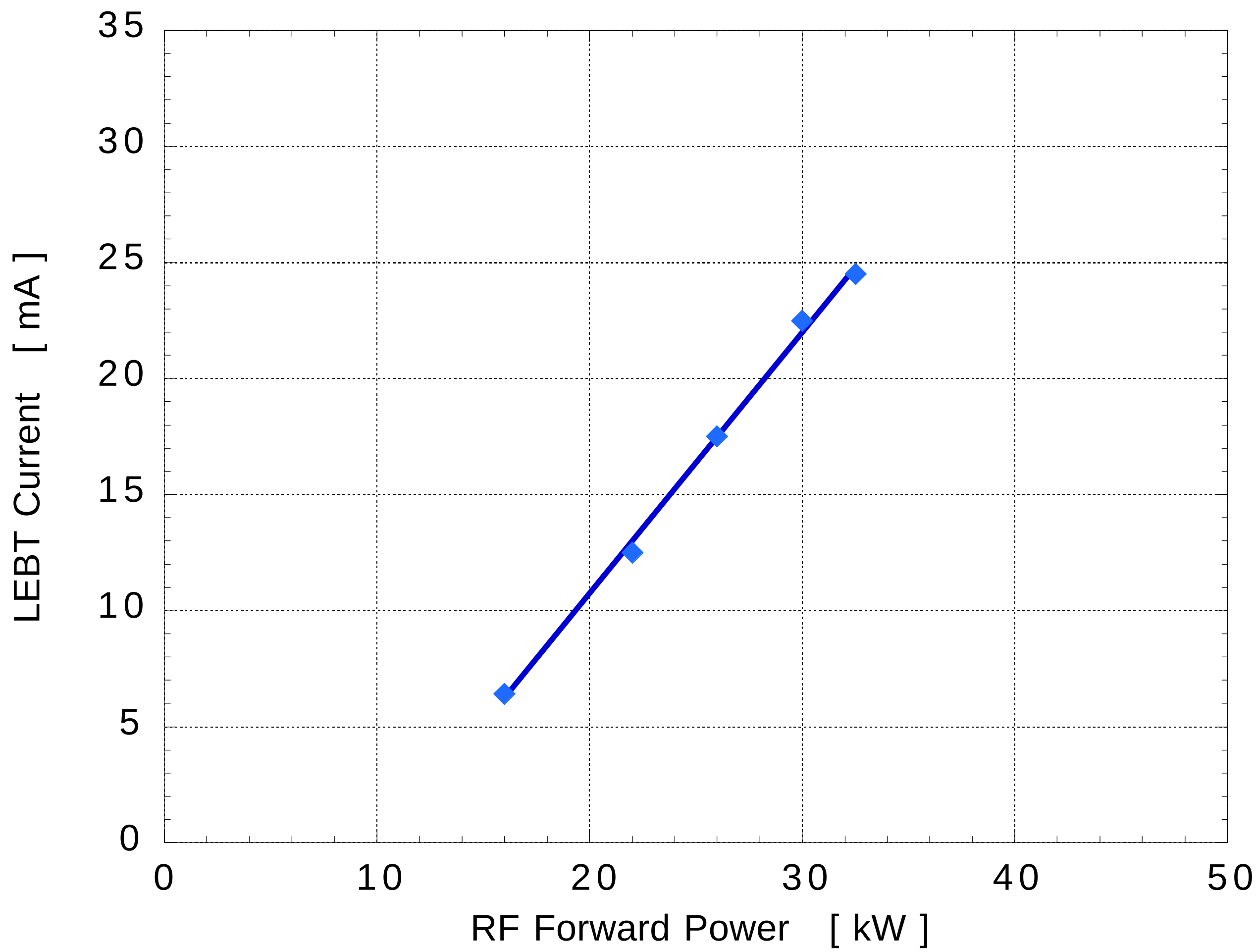
seen from downstream side



LEBT Status

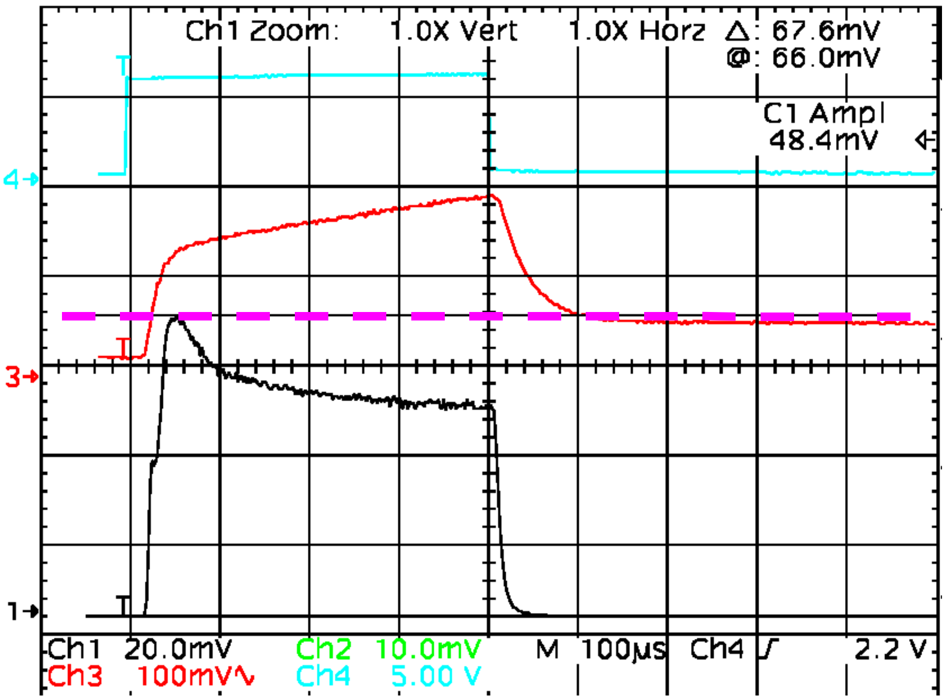
- Main functions tested with ion beam
  - Operation at nominal voltages
    - 65 keV beam energy
  - Lens-tuning matrix
  - Electrical and mechanical steering
  - Chopping
    - Measured 25-ns beam rise/fall time with RFQ attached
    - Twice faster than specified
- Produced 36-mA beam for RFQ commissioning
  - 33 mA transmitted through RFQ
- Ready to produce beam for MEBT commissioning

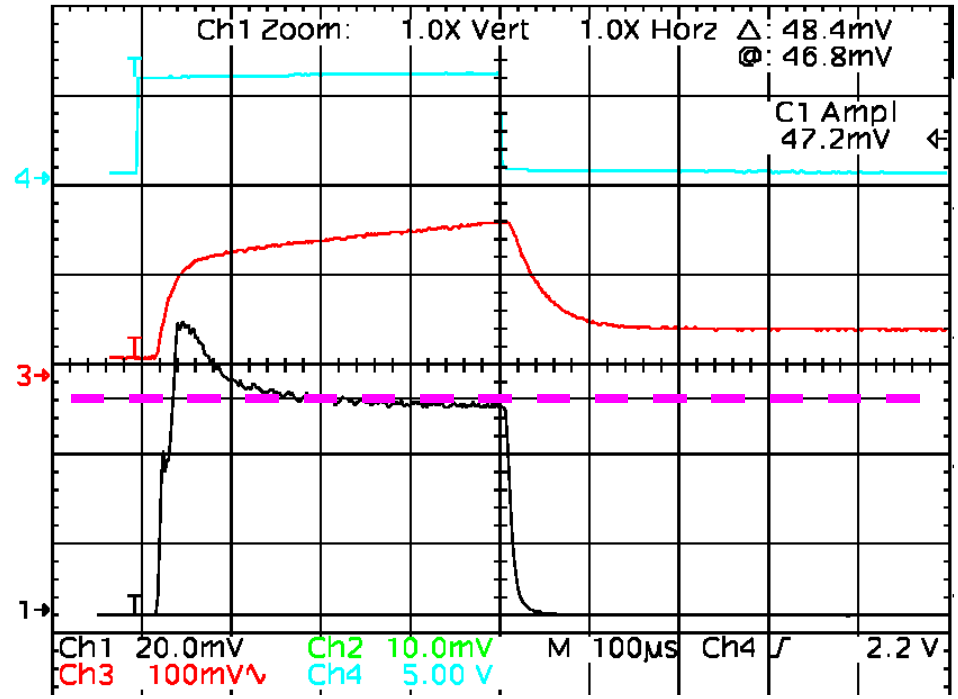
Effect of Ion-Source rf Power on Beam Current



Note: cesium coating was not optimized for these measurements

Ion-Source/LEBT Beam Current



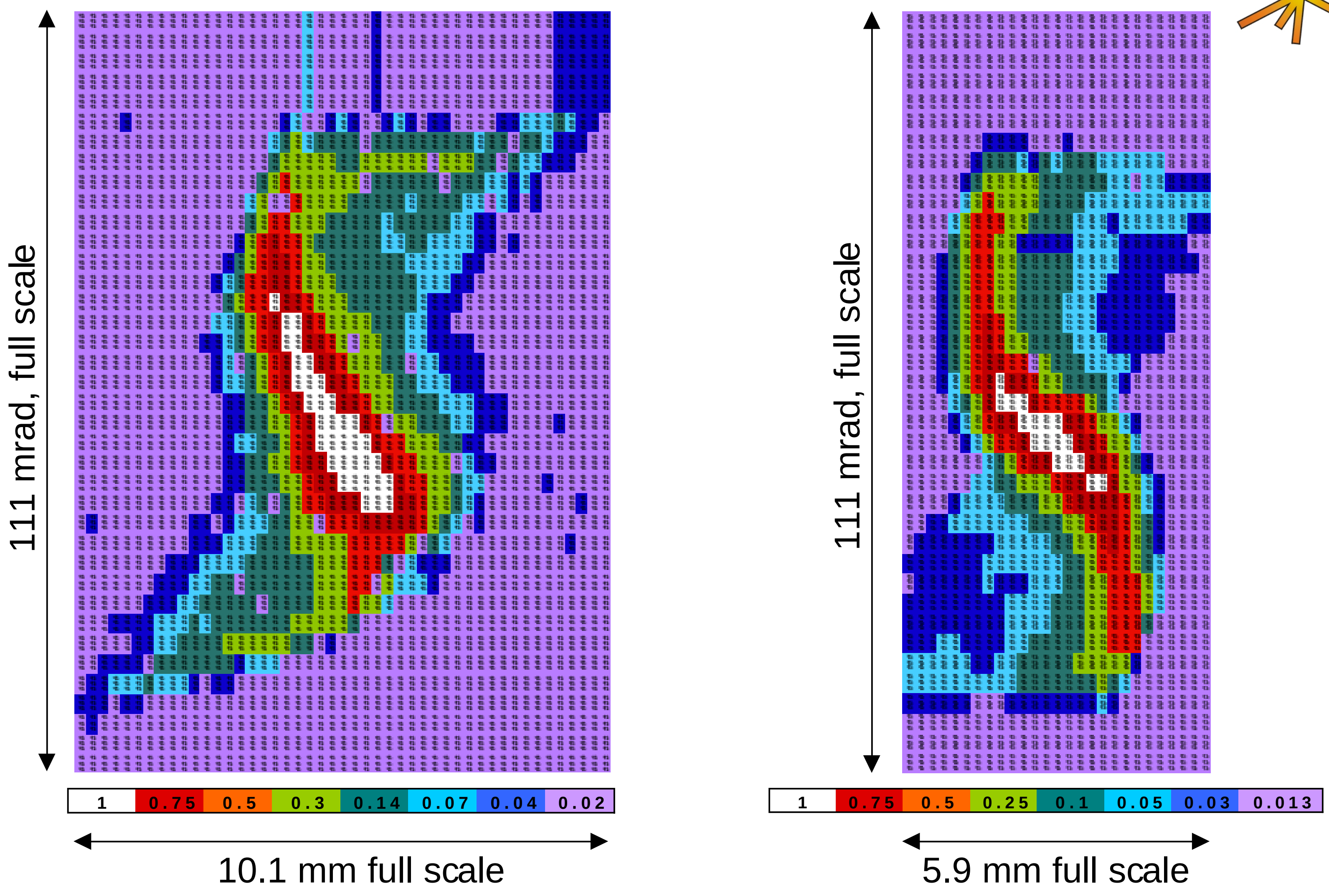


68 mA peak current

50 mA average current

Measured 33-mA Beam RMS Emittances

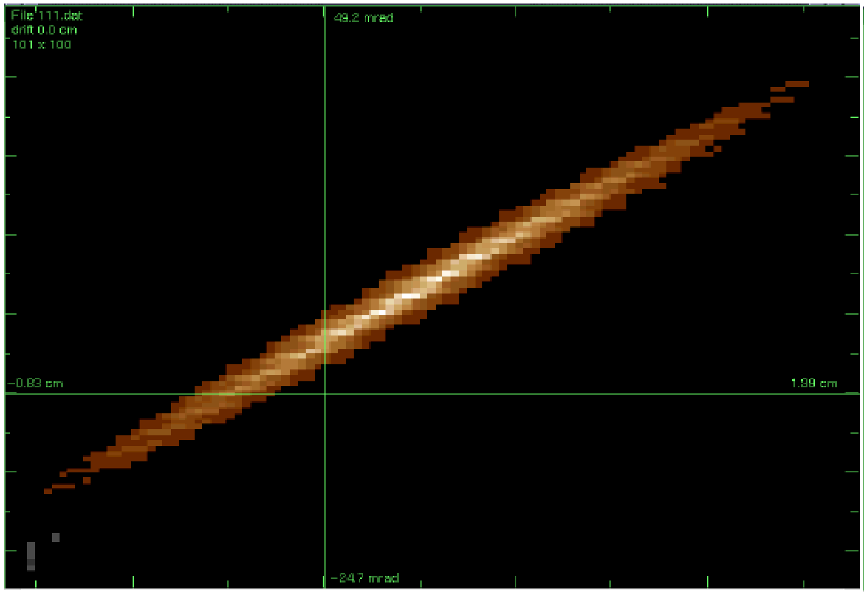
Thresholded at 2.1% (hor.) and 1.3% (vert.) of maximum

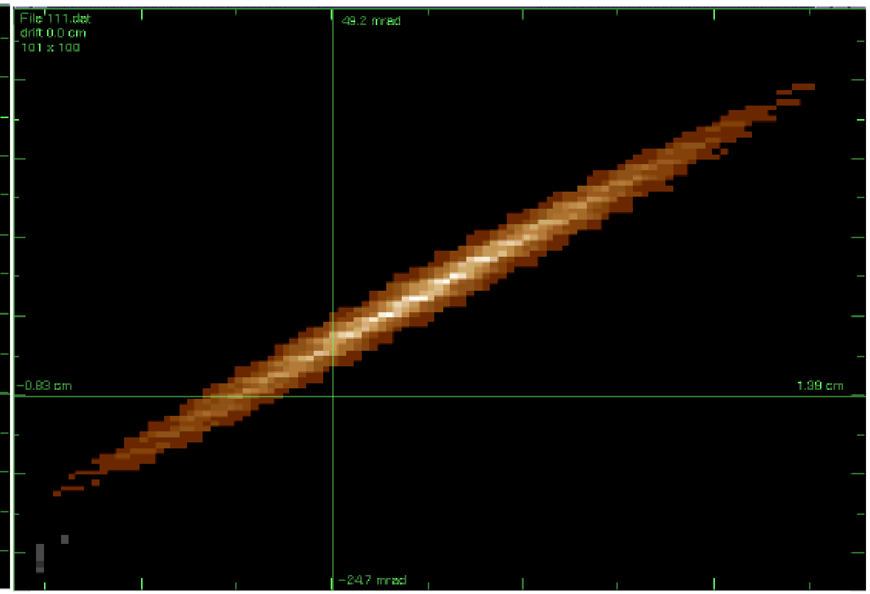


Horizontal, 0.22 π mm mrad

Vertical, 0.15 π mm mrad

RFQ Emittances with 22-mA Beam





Horiz.: 0.27 π mm mrad rms Vertical: 0.29 π mm mrad

Summary

- Ion Source produces required H^- density
  to satisfy SNS operational need for 38 mA into Linac
  - 50 mA average pulse current measured at LEBT exit
    with 6% duty factor
    - Lifetime not precisely known—so far exceeds 100 hrs
    - Improvements to electron dumping in preparation
    - Planning effort underway to further enhance lifetime/reliability
- LEBT delivers matched 65-keV beam to RFQ
  - Viability of all-electrostatic focusing method demonstrated
  - Measured emittances within design goal of 0.2 π mm mrad
  - Further improvements in beam formation process envisaged
- Very encouraging beam tests with full RFQ
  - Better than 90% transmission at 35 mA level
  - RFQ clips emittance distortions

SNS Front End
with Staff, Feb. 2002