Status of the new SNS injector and external antenna ion source

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- **The Spallation Neutron Source**
- **Motivation for replacing the SNS 2.5 MeV linac injector**
- **Description of the new injector and Beam Test Facility (BTF)**
- **Injector performance: Beam current, persistence, emittance and energy measurements**
- **Timeline, status and outlook**

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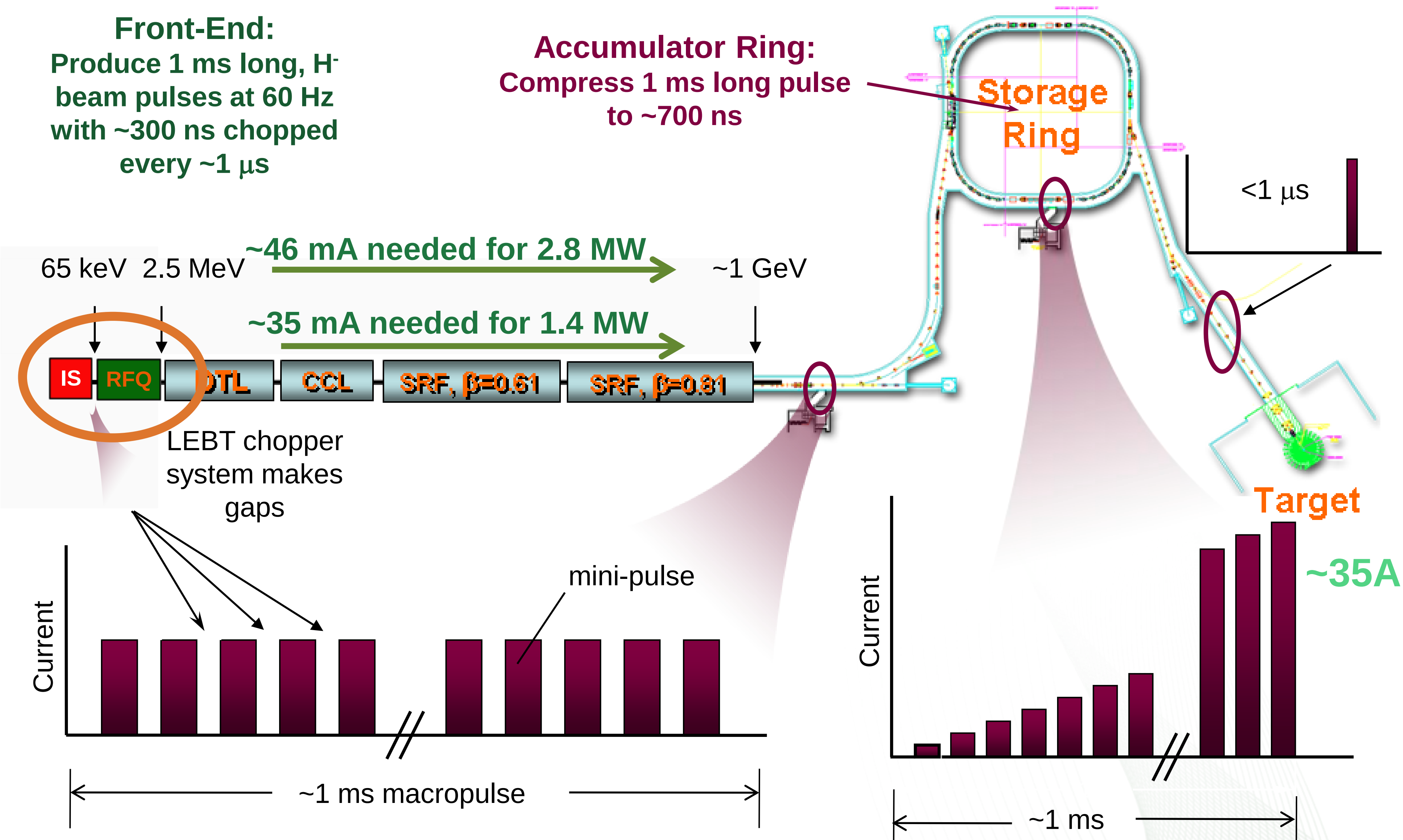
The Spallation Neutron Source

ORNL hosts the worlds most powerful accelerator-based neutron source and the highest flux reactor-based research neutron source in the United States. More than 1000 users per year conduct experiments physics, chemistry, biology, material science and engineering.

Currently the SNS operates at 1.2 MW with near term plans to run continuously at 1.4 MW and later up to 2.8 MW to simultaneously support a second target station

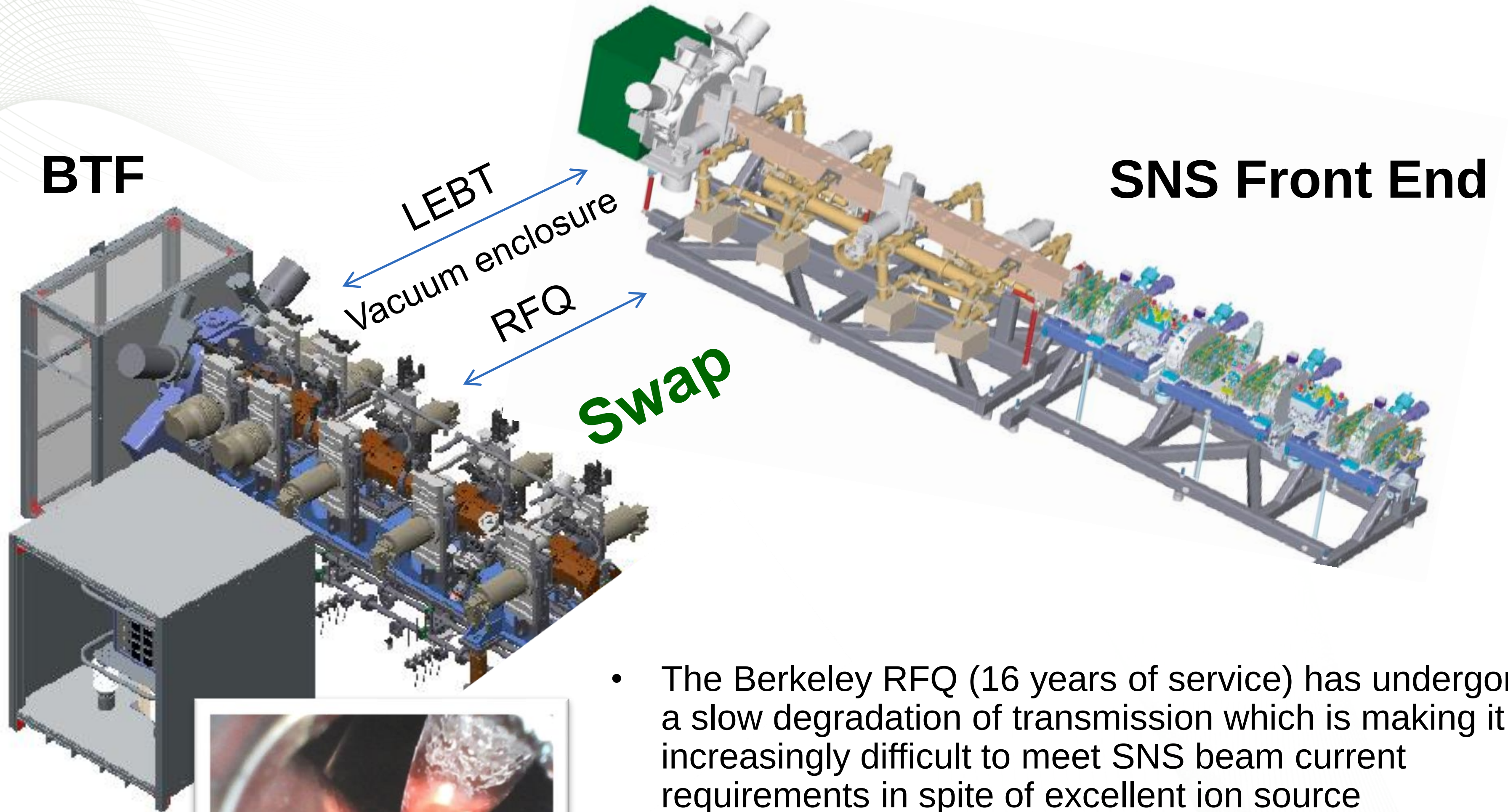
	1.4 MW Operation	PPU & STS Upgrade
Energy (GeV)	0.94	1.3
Macro-pulse length (ms)	0.97	0.97
RFQ output beam current (mA)	~35	~46
Macro-pulse un-chopped fraction	0.78	0.82

The SNS accelerator system overview



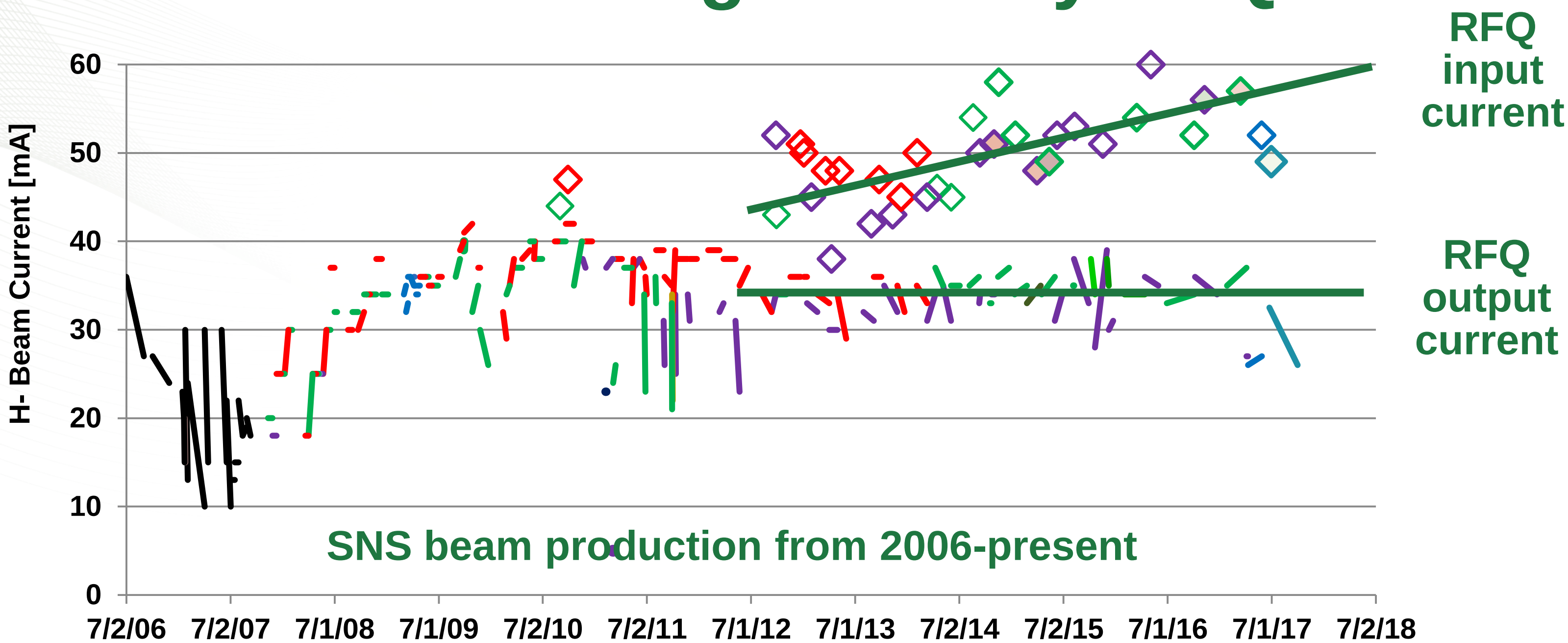
The multi-turn charge exchange injection and clean extraction of the accumulator ring requires chopped H^- beam from the linac.

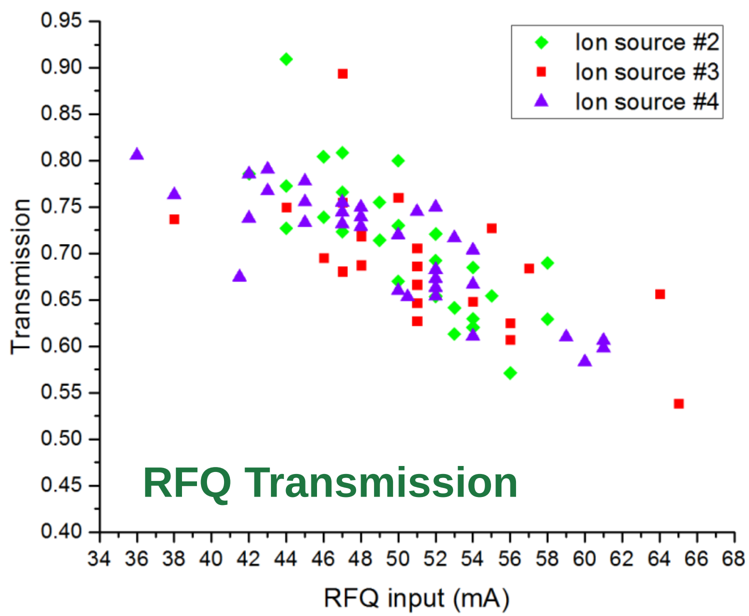
Why replace the Berkeley RFQ?



- The Berkeley RFQ (16 years of service) has undergone a slow degradation of transmission which is making it increasingly difficult to meet SNS beam current requirements in spite of excellent ion source performance.
- Several unexplained detuning events and shifts in the RFQ field distribution have motivated us to procure a spare RFQ accelerator and build the **BTF** to test it.

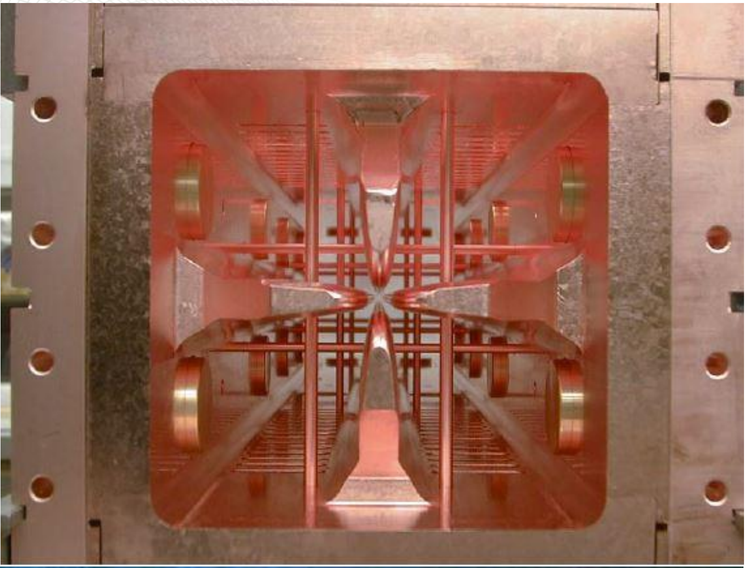
Issues with the existing Berkeley RFQ





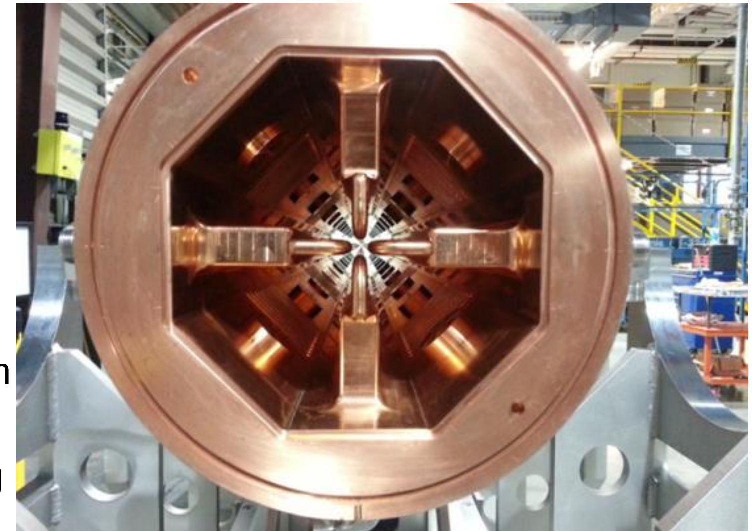
- Over the years we had had to improve source performance to compensate for decreased RFQ transmission, which is now typically 60-75%.
- RFQ Task Force: Poor transmission results from not being able to run at full design field most likely caused by degradation in structural integrity either due to brazed joints shifting or surface coating / erosion. Also we found that the internal RFQ cooling system cannot maintain resonance under some conditions
- **Decision: Replace the RFQ in 2018 Spring outage**

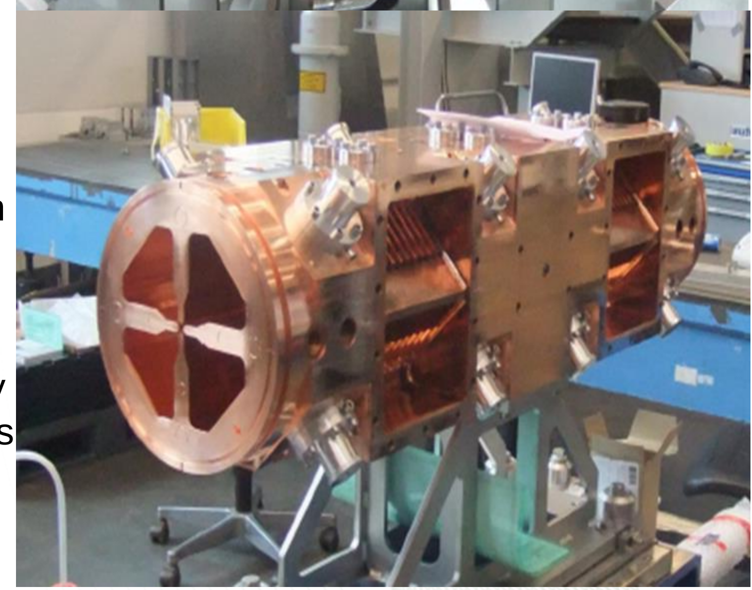
The new RFQ accelerator



Manufactured by Research Instruments, GmbH

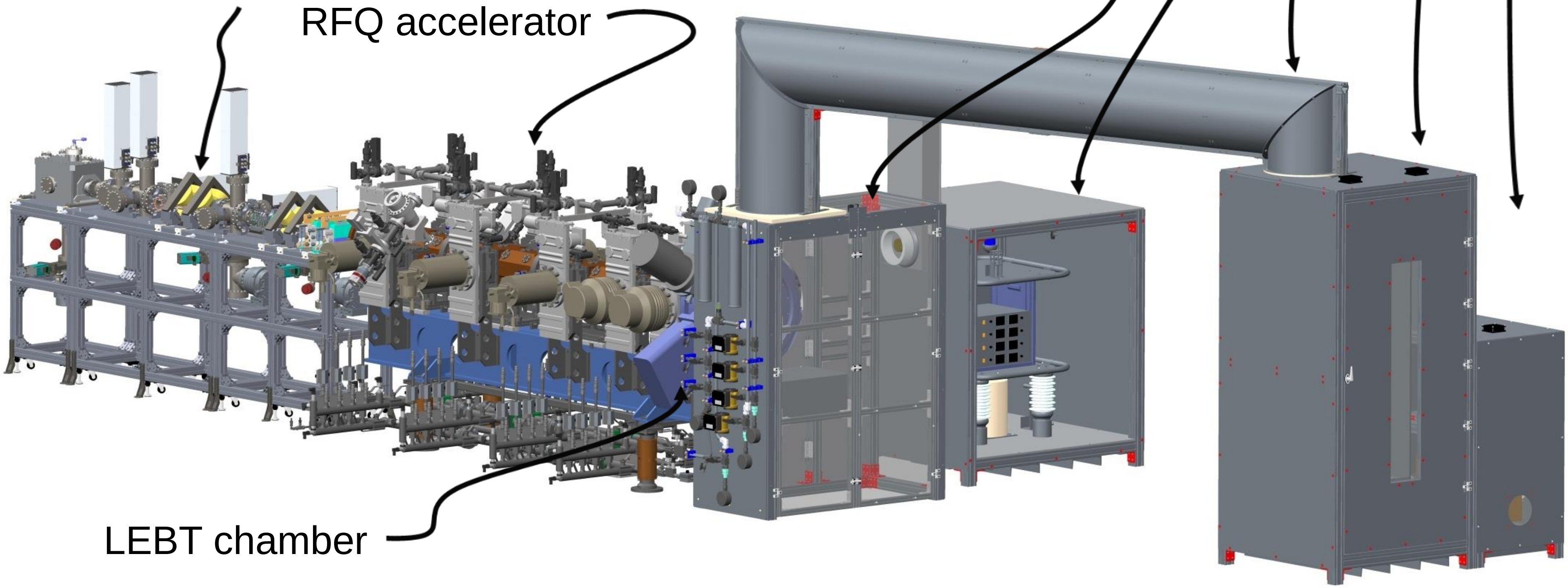
- Mechanical & RF structures designed at ORNL using the Berkeley physics design $\therefore$ same beam dynamics
- Much better pumping
- No brazed joints (solid Cu) vacuum deformation: -18 vs -119 kHz
- Octagonal shape can provide better vacuum quality and mechanical strength (RF efficiency slightly decreases, but losses by stabilizers are much smaller)
- **RFQ needs to be tested at ORNL: BTF**





The Beam Test Facility

- **Designed to first validate the new RFQ and**
- **Serve as a stand alone research accelerator using both RFQs to conduct accelerator and ion source R&D**



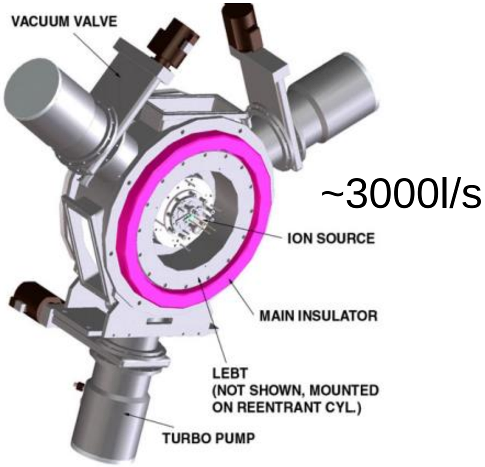
RF generator, ground rack 04 (not shown)

The ion source systems of the BTF

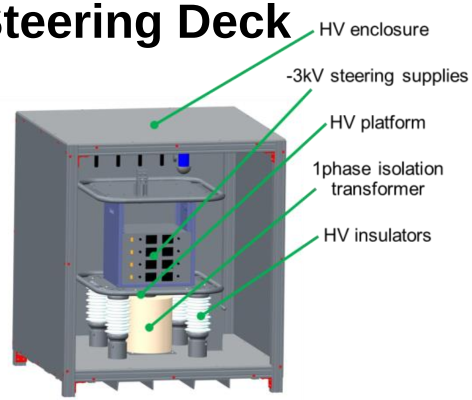
Designed and built at ORNL giving the BTF the same operational functionality as the SNS front end (no chopping) as well as similar personal & equipment safety features

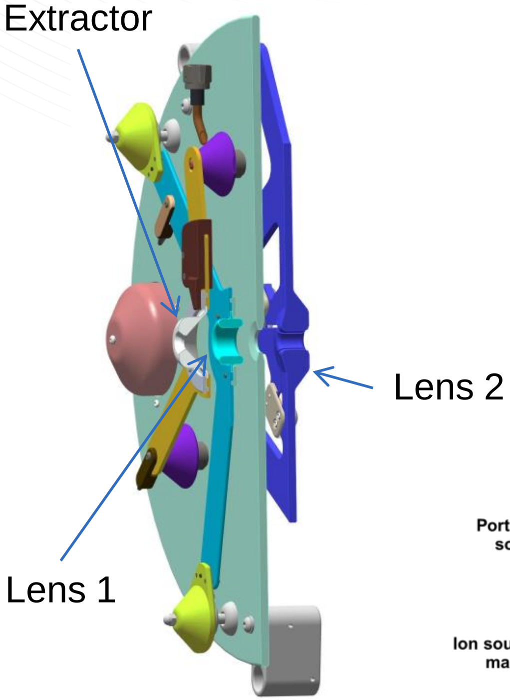
Isolation transformers 19kVA

LEBT tank

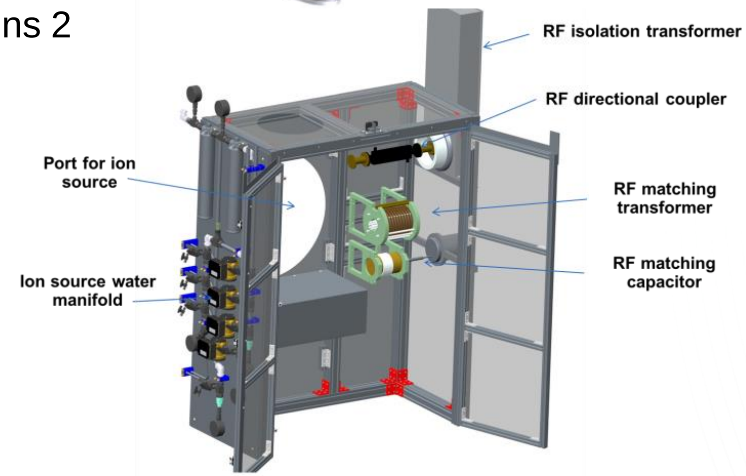


Steering Deck



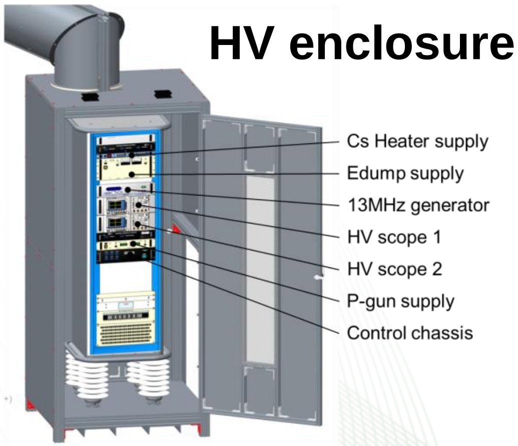


LEBT electrodes



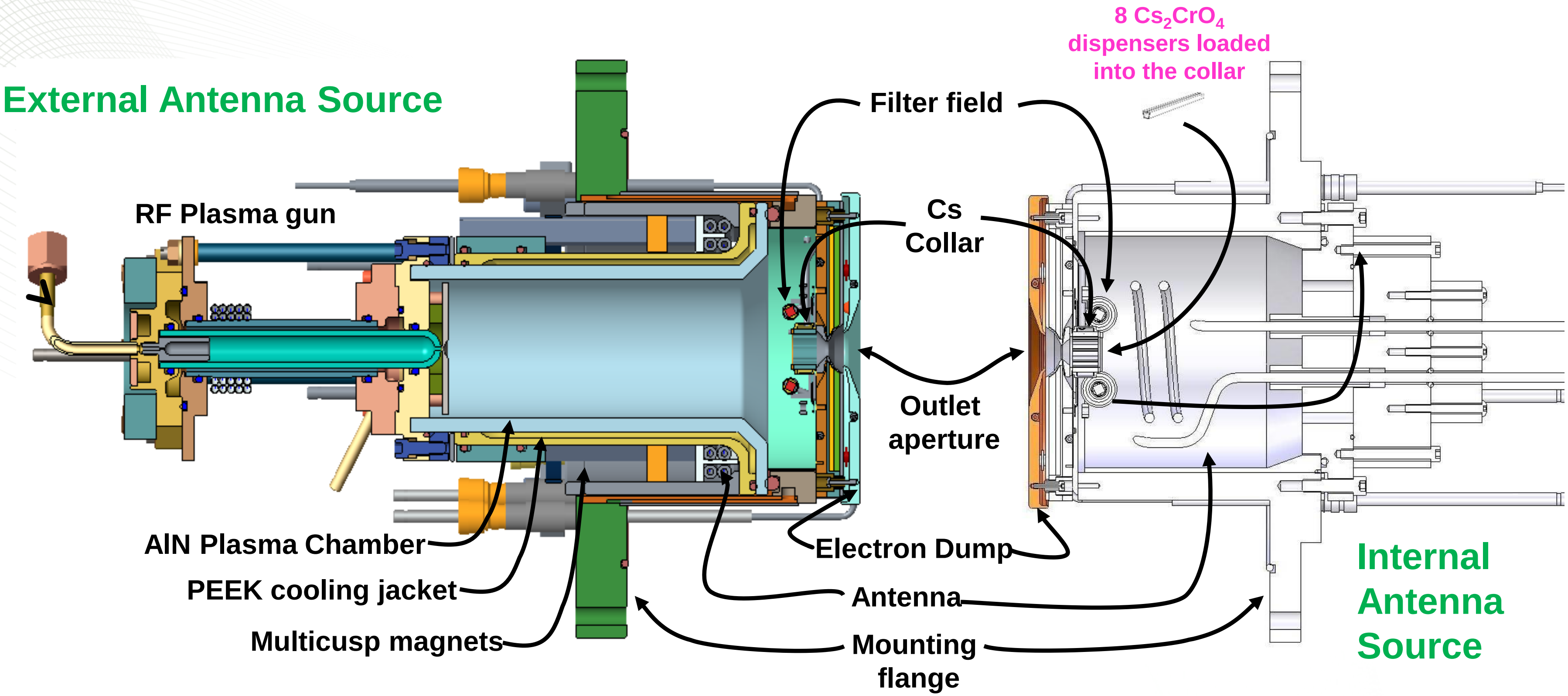
Ion Source Cage

HV enclosure



All HV structures have a min of 6” gaps (2.5x FOS)

The SNS ion sources

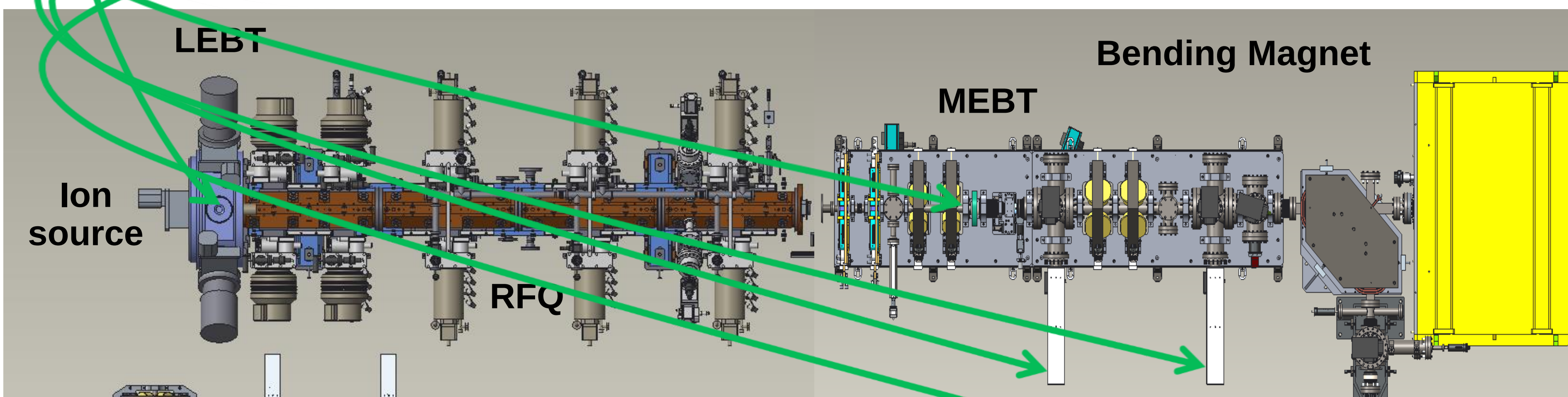


- **SNS ion sources**: baseline source #2,3,4,5,6,7 & external antenna sources x3, x4 can be installed interchangeably on the **SNS, BTF and Ion Source Test Stand (ISTF)**
- **External antenna source** – highly developed, routinely runs on ISTS makes persistent **50-60 mA beams**, usually tested for weeks on test stand, See **RSI 87, 02B146 (2016)**
- Nearly identical electrostatic **Low Energy Beam Transports** (LEBT) are also installed in each facility

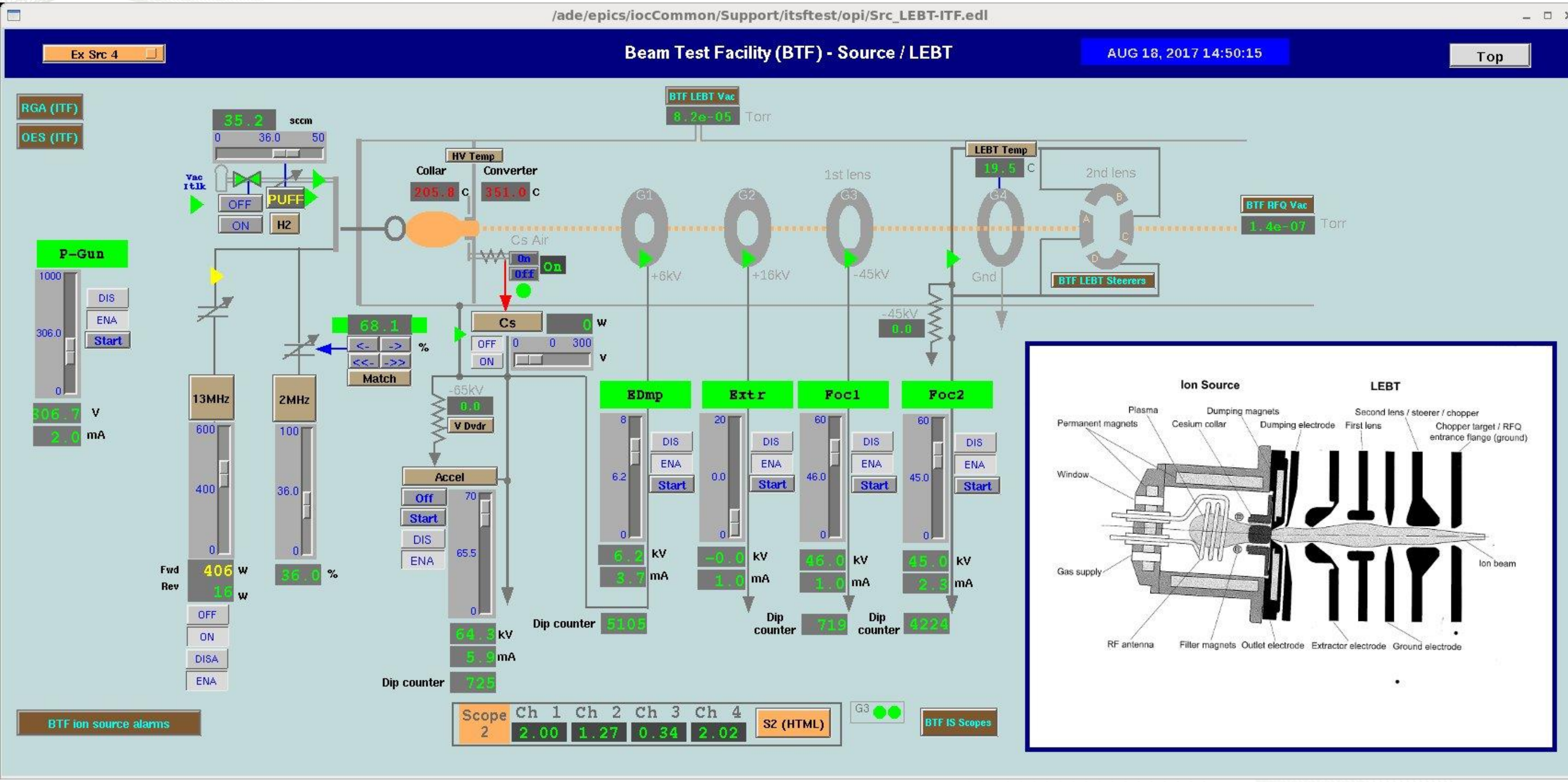
Performance of the new injector tested on the BTF

- LEBT current measurements at 65kV
- MEBT current measurements at 2.5 MeV
- Beam persistence
- Transverse Emittance: Slit-Slit scans
- Longitudinal Emittance: dipole / bunch shape scans
- Beam energy: TOF phase scans

(First three items:) RFQ transmission measurements

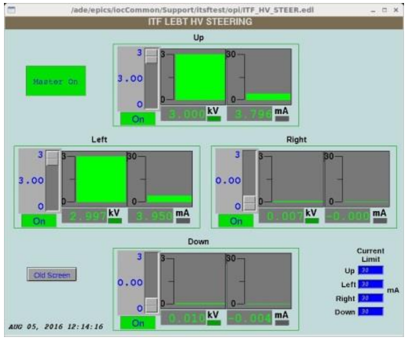


Typical external antenna run parameters

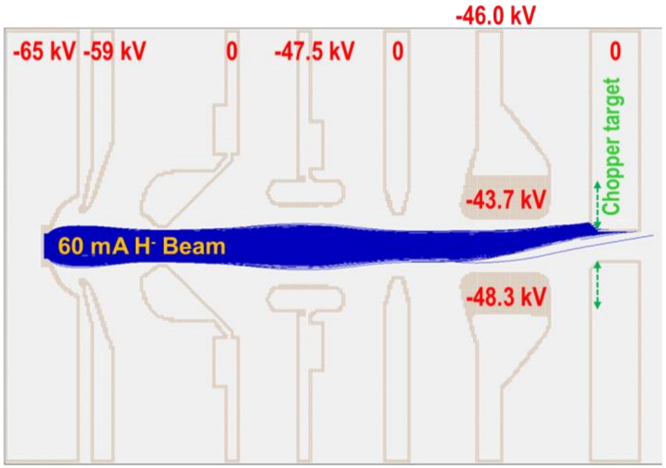


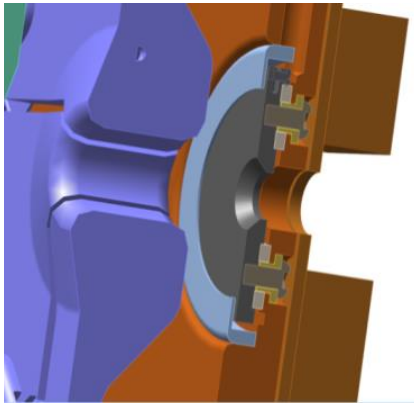
LEBT beam current measurements

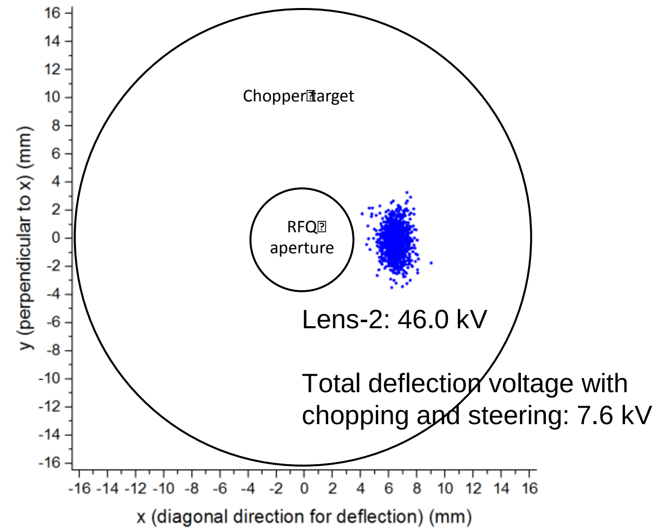
- BTF does not have a beam chopping capability like the SNS
- LEBT beam current measurements therefore require a dedicated +6kV (1-10 us, 10 Hz) pulsed power supply, deflecting beam to chopper target
- Full deflection will also require steering



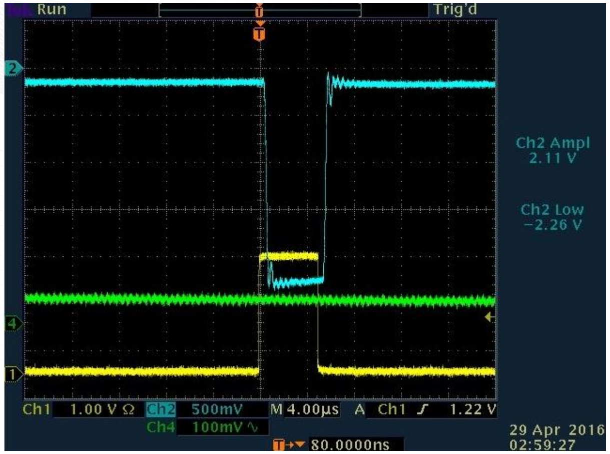
- SNS LEBT beam current measurements: ΔV=4.6kV (chopper) + 3kV (steering) = ~7.6 kV
- BTF LEBT beam current measurements: ΔV=6kV (pulser) + 2-3kV (steering) = ~8-9 kV

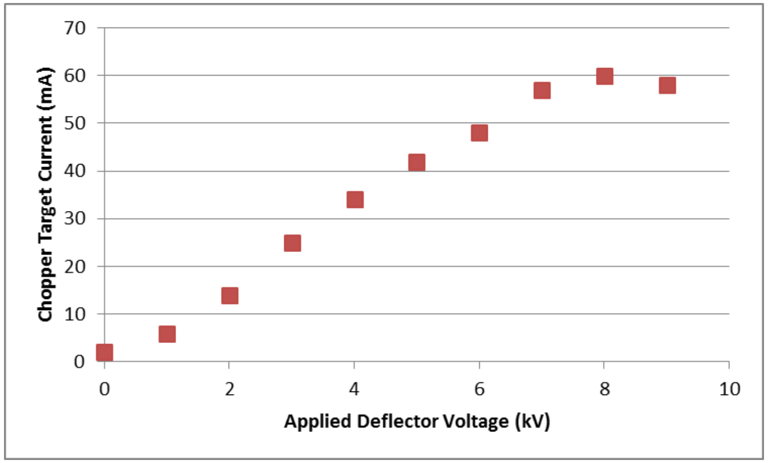




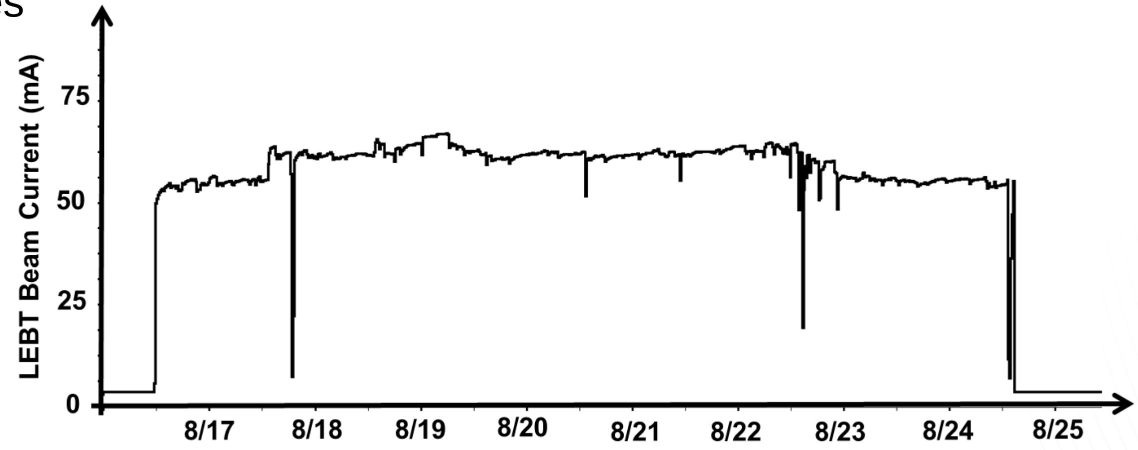


Typical LEBT beam current measurement





- RFQ was off during these measurements
- LEBT beam currents typically 60mA range have been measured at the BTF for baseline source #6 with an 2MHz set point of ~60%
- Source #6 was also tested ~60 mA for multiple days of continuous running with no significant issues



- Demonstration of continuous operation of source #6 on the BTF making about 60mA for 1 week.

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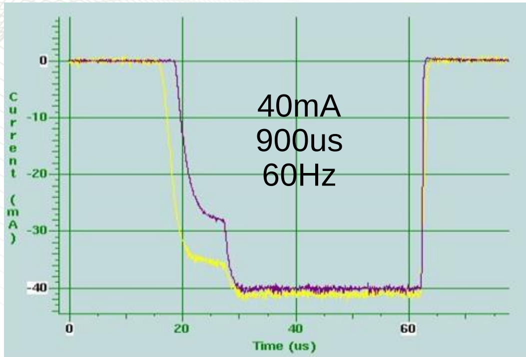
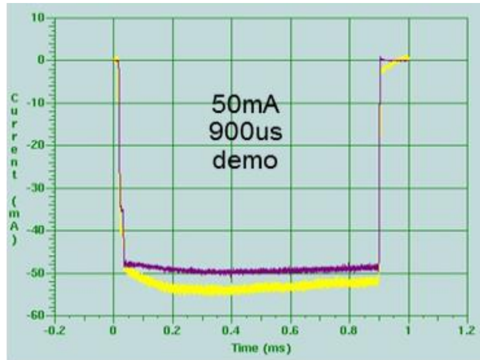
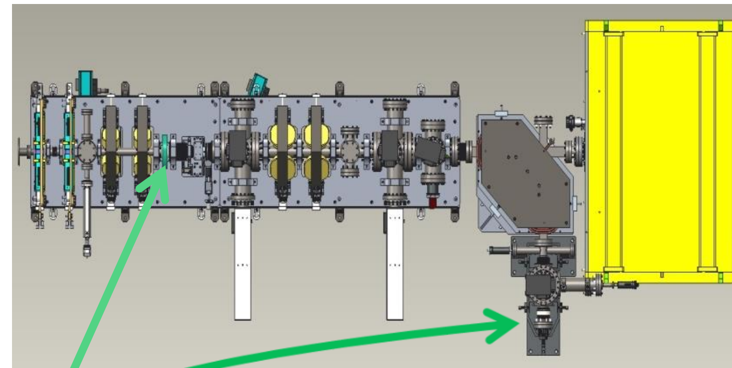
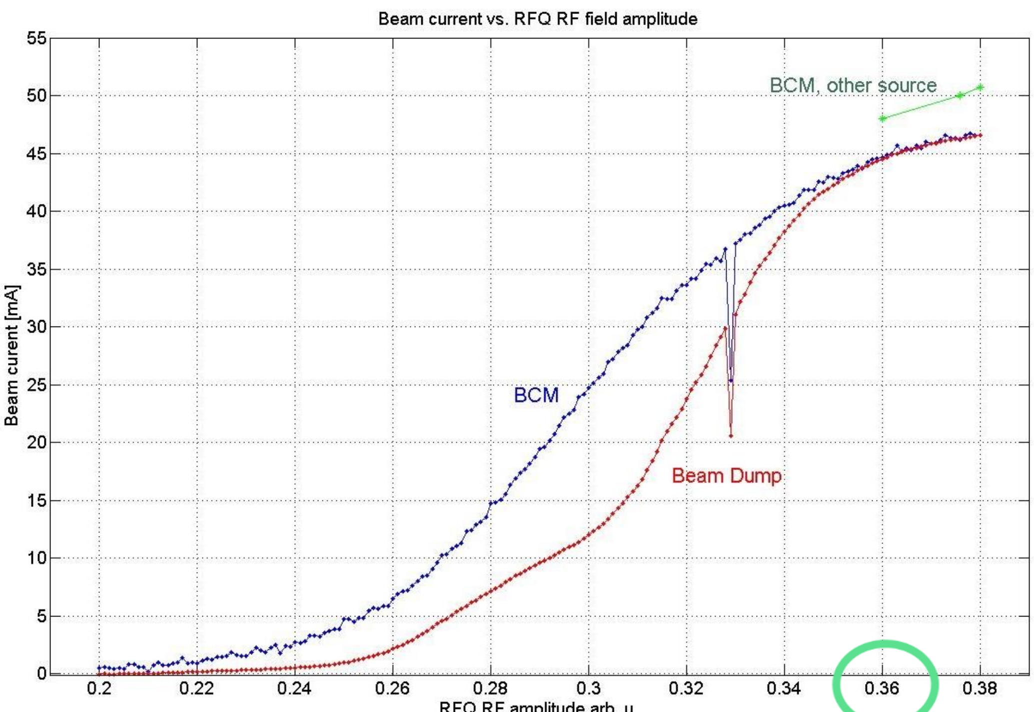
MEBT beam current measurements





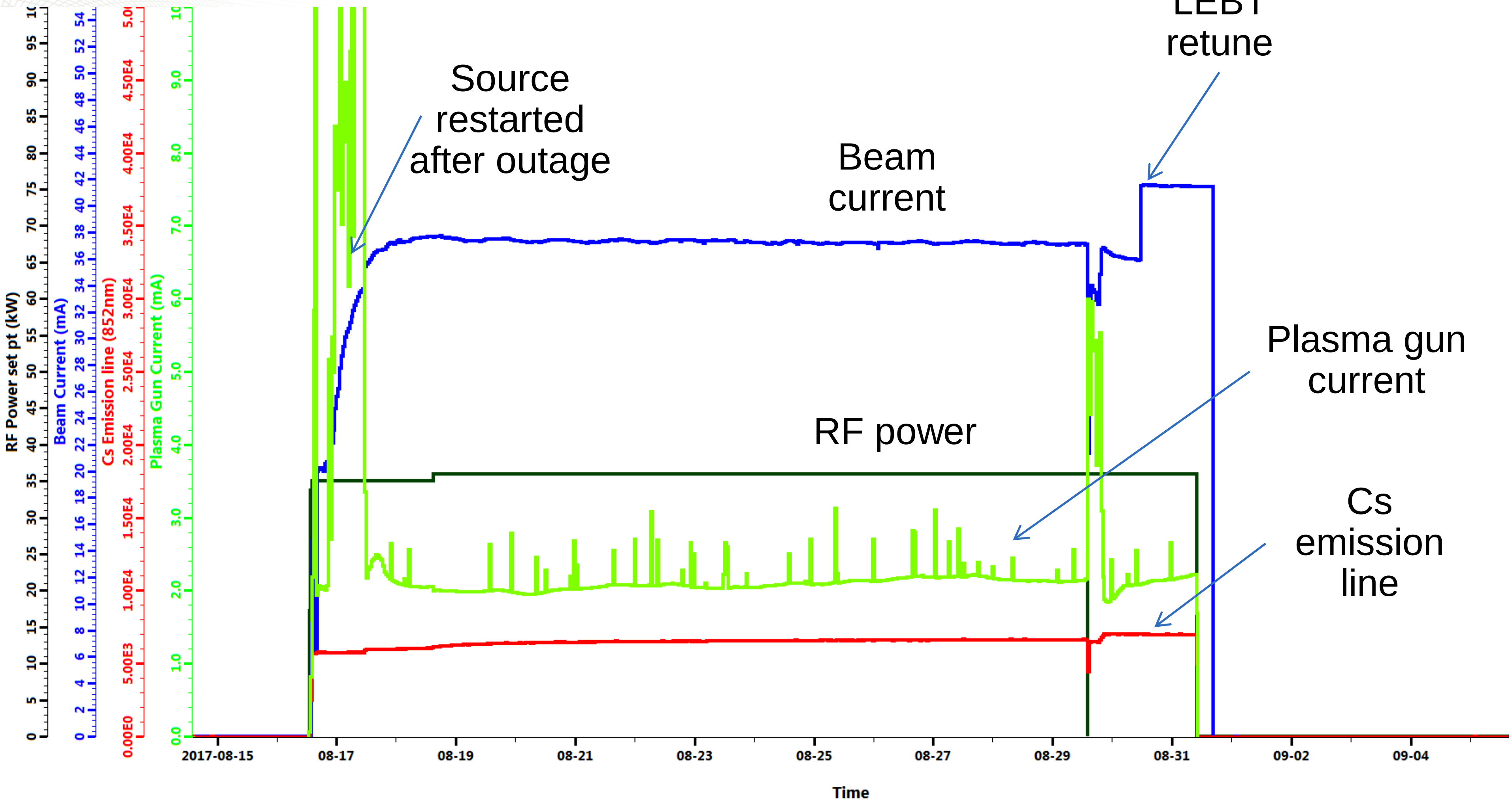




Design

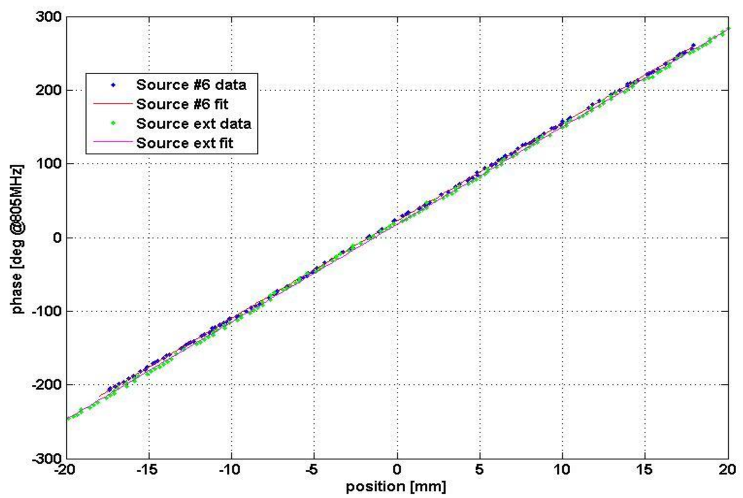
- Beam Current Monitor (BCM)
- Faraday cup
- RFQ design inter-vane voltage of 83kV achieved at RFQ drive parameter of **0.36** (x-ray cut off technique)
- All RFQ measurements made at this value.
- Typical RFQ transmission: **88%** @44mA out of RFQ
- Sources **x3, x4**, #3, #5 & #6 all produced **> 40mA!**

External antenna Sources (x3, x4) delivered persistent beams on the BTF

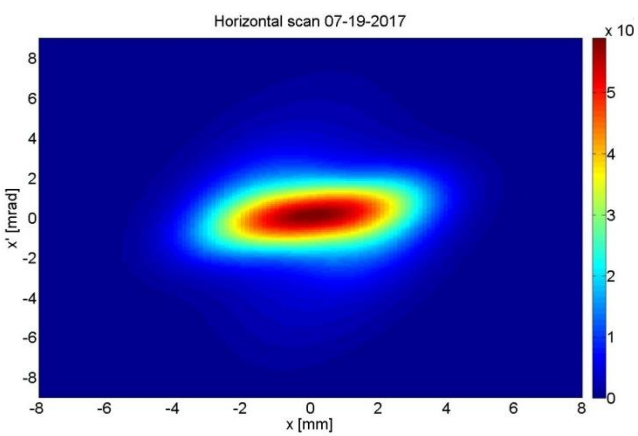


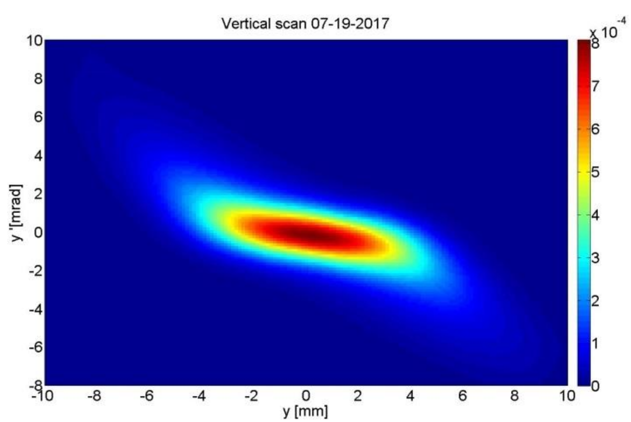
RFQ periodically turned off / ion source runs, long outages

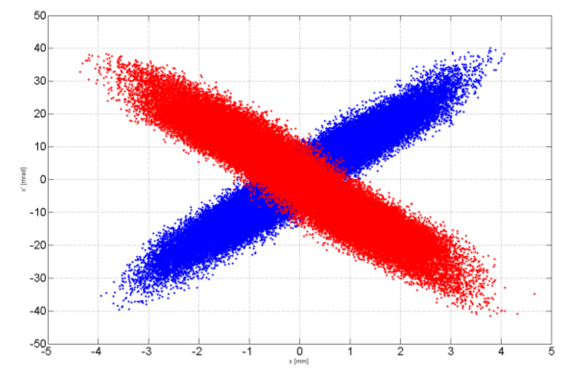
Beam energy and emittance measurements



- TOF phase & dipole magnetic energy scans show RFQ output energy: **2520 ± 20 keV**
- **Transverse beam emittance** was measured using a slit-slit scan and found to be the same as on SNS: **0.25-0.35 π mm mrad** normalized and essentially the same between baseline & external antenna sources
- **Longitudinal emittance** was measured using the dipole magnet and bunch shape monitor and found to the same as on SNS **~0.25 π MeV Deg**







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Summary of ion sources tested on the BTF

Source	installed	removed	Days tested	RF set point	LEBT beam current	MEBT beam current	Issues
#6	Aug 2014	Aug 24, 2016	~14 days	~60 kW	~60 mA	na	Edump dips (end of run) thin walled insulator
#6	Aug 29, 2016	Oct 11, 2016	~2 days	~60 kW ~30 kW ~35 kW ~40 kW	~60 mA ~13 mA ~22 mA ~33 mA	Na 8 mA 18 mA 26 mA	Struggled with alignment, extractor heating
#6	Oct 14, 2016	Nov 25, 2016	~10 days	~50 kW ~55 kW ~70 kW	~45 mA ~50 mA C. Target failure	~32 mA ~44 mA ~50 mA	Aligned with dummy source, o-ring unloaded, full power RFQ operation test, bend mode, lost chopper target
x3	Nov 28, 2016	Dec 9, 2016	~11 days	~36 kW ~35 kW ~43 kW		~40 mA ~44 mA ~50 mA	5D measurements no explicit Cesiation!, source removed to test production source
#3	Dec 14, 2016	Jan 25, 2017	~25 days	~53 kW ~44 kW ~43 kW		~46 mA ~40 mA ~29 mA	Edump struggles, beam decay, 2 min Cs partially recovered beam
x4	Jan 25, 2017	Feb 17	~18 days	~32 kW	~40mA	~40mA	Lens 2 conditioning, plasma ignition, Cs collar inlet air leak caused replacement a QA issue (scratch on tube)
#5	Feb 20	May 1	~34	~57 kW	NA	30-40mA	Lens 2 voltage dips, limited BC to 30mA during run, lens-2 supply upgraded Mar 29 final performance: ~32mA/60kW
x3	May 1	June 16	~29	~38 kW	NA	40-45mA	Extractor feedthrough resistors failed, arcing in sagging isolation transformer cable, 13 MHz supply swap, source replaced due to antenna loop bleed resistor failure
x4	Jun 16	Present	50+	~35 kW	NA	40mA	P-gun cable failure, used for low intensity beam studies, high gas, spikes on p-gun current

RFQ installation schedule

RFQ SWAP

DISMANTLE SNS RFQ IN BTF

DISMANTLE BERKELEY RFQ IN FRONT END

- *Shutdown Berkeley RFQ in Front End*
- *Transport Berkeley RFQ to BTF*

REPLACE CRYO MODULE #17

- *Move Existing Cryo Module #17 out of LINAC*
- *Install New Cryo Module #17 in LINAC*

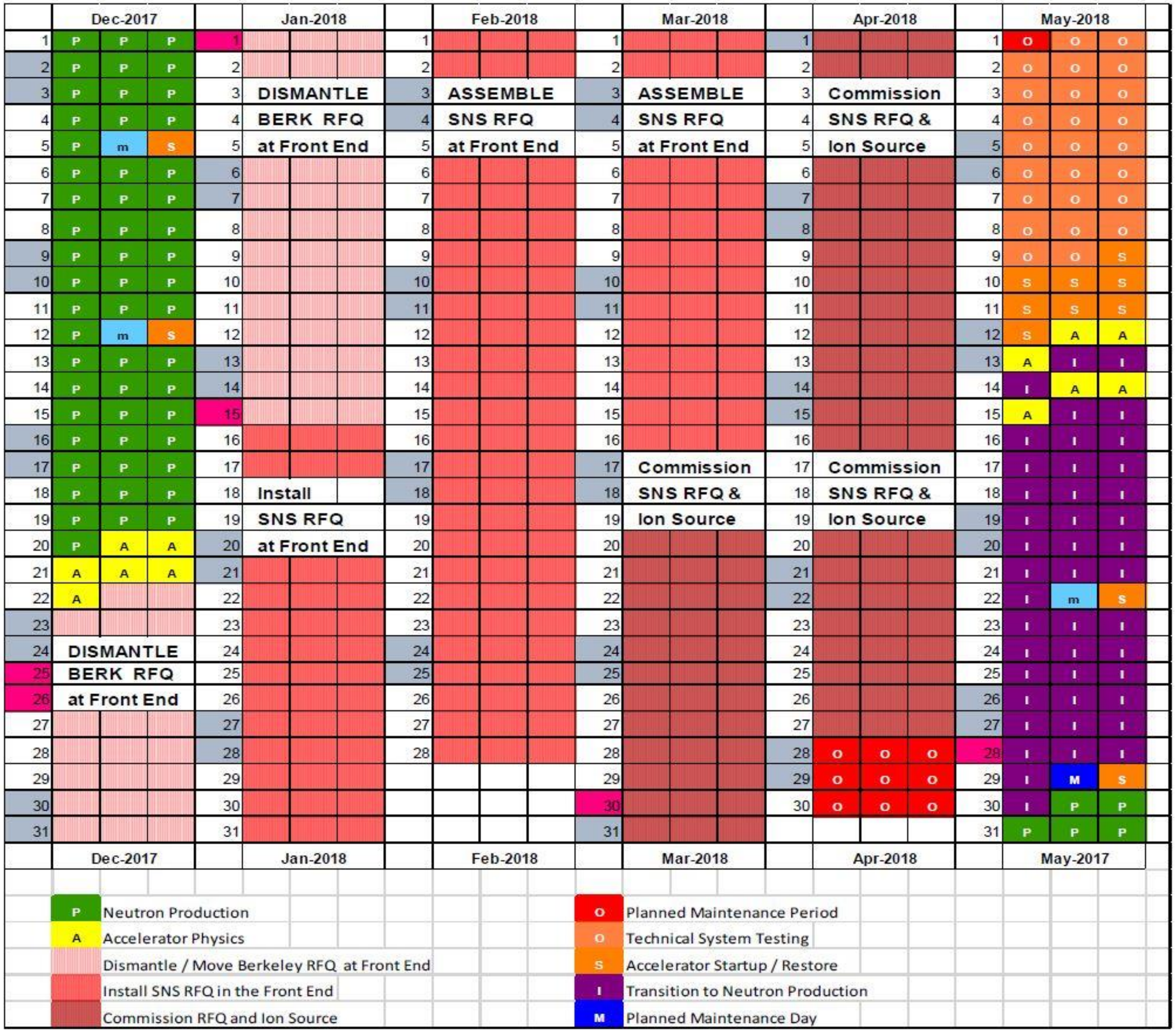
INSTALL SNS RFQ IN FRONT END

- *Assembly of Technical Systems*
- *Upgrade & Commission RFQ Water Systems PLC_EPICs*
- *Upgrade & Commission RFQ Vacuum System PLC_EPICs*

PPS Front End Certified with new LINAC PPS Door.

RFQ is ready for Front End Only Mode to test Ion Source

RFQ and Ion Source Commissioning complete



Conclusion and outlook

- The new RFQ on the BTF have been extensively tested with beam for over a year.
- Beam current, beam persistence, longitudinal and transverse emittance and energy were all measured and found to meet the SNS requirement with each source producing > 40mA when requested.
- The clear performance benefit of the new injector as well as the risk of continued degradation of the old RFQ justify installation on the SNS.
- Installation will begin on Dec 2017 be completed & recommissioned in April 2018
- BTF performance was sufficiently stable to allow multi-day 6D phase space measurements
- The new injector will be commissioned with both internal and external ion sources, the total testing time of external antenna sources on the BTF is ~2500 hours with internal antenna sources ~1650 hours.