A Multi-Mode RFQ for Dual-Species and Short-Pulse Beam Production

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The project team would like to very much thank Spallation Neutron Source at Oak Ridge National Laboratory for direct contributions to LAMP ion source technology.

U.S. DEPARTMENT of ENERGY

NNSA National Nuclear Security Administration

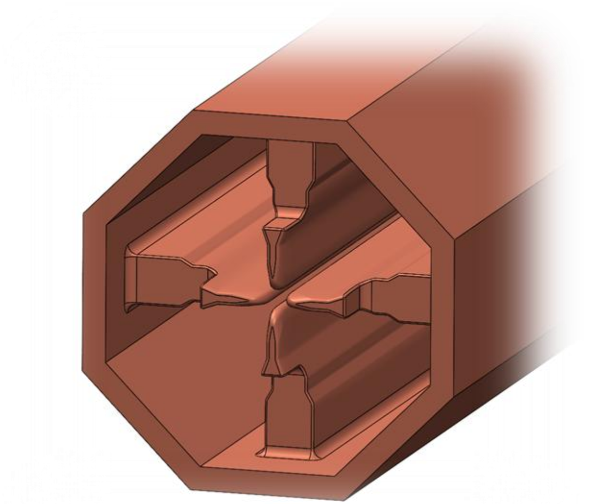
LANSCE Los Alamos Neutron Science Center

OAK RIDGE National Laboratory

SNS SPALLATION NEUTRON SOURCE

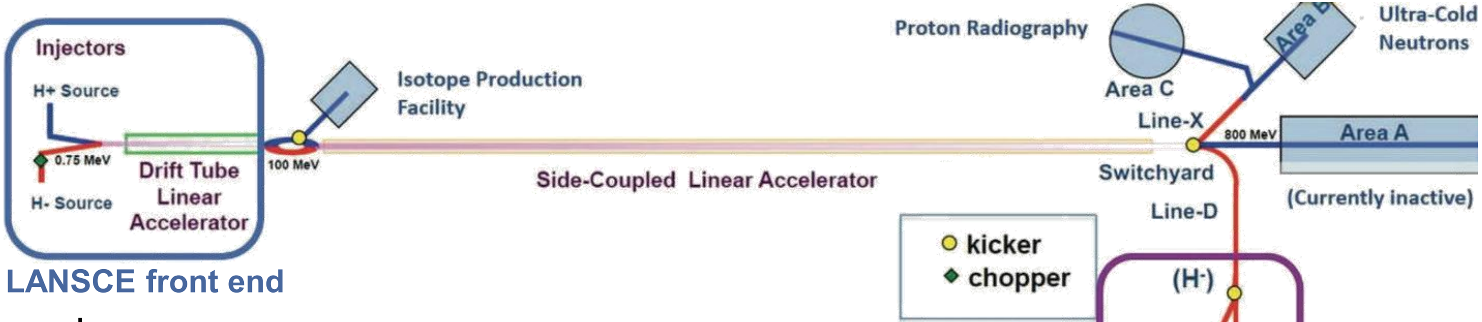
Outline

- LAMP: LANSCE Accelerator Modernization Project
- LAMP LEBT-RFQ Design Basis 1
- LAMP LEBT-RFQ Design Basis 2
- Short-pulse beam performance comparison
- Conclusions



Beam-entrance end of the LAMP Conceptual Design RFQ model for RF validation, built in SolidWorks.

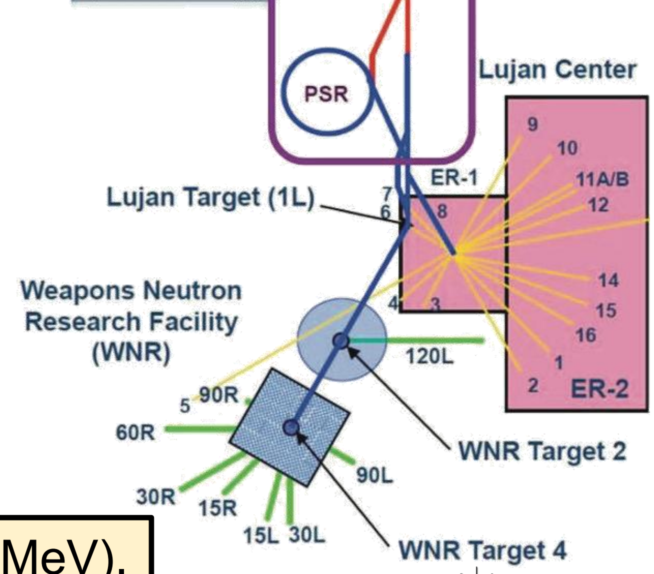
LANSCE: Los Alamos Neutron Science Center



LANSCE front end

LANSCE front end:
- Cockcroft–Walton (CW, 0.75 MeV)
- Drift-Tube Linac (DTL, 0.75–100 MeV)

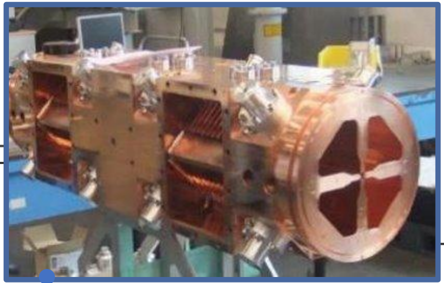
LANSCE experimental areas:
- Lujan Center
- Weapons Neutron Research Facility
- Proton Radiography
- Ultra-Cold Neutrons
- Isotope Production Facility



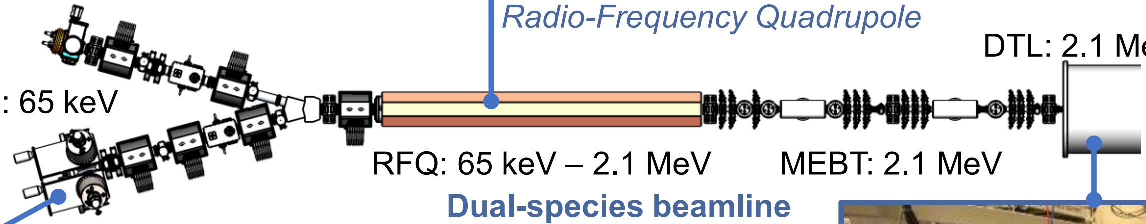
LAMP scope ends at end of DTL (100 MeV).

LAMP: LANSCE Accelerator Modernization Project

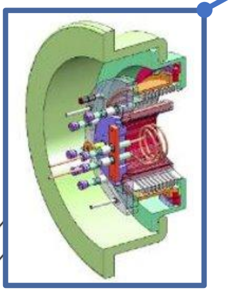
LANSCE Sector J layout: Design Basis 2



Radio-Frequency Quadrupole



Dual-species beamline



SNS-style H⁻ ion source

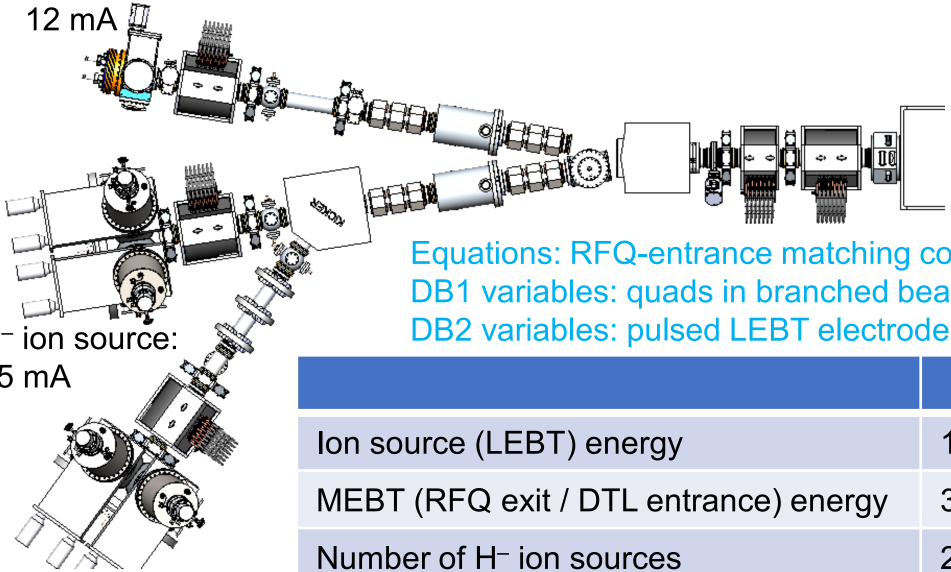
LAMP upgrades LANSCE's CW-DTL layout to LEBT-RFQ-MEBT-DTL.

Drift-Tube Linac

LAMP LEBT: DB1 vs. DB2

Design Basis 1 (DB1)

H^+ ion source:
12 mA

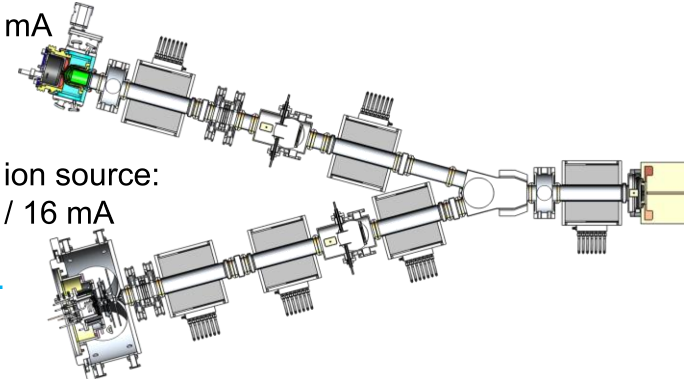


H^- ion source:
35 mA

H^- ion source:
16 mA

Design Basis 2 (DB2)

H^+ ion source:
12 mA



H^- ion source:
55 / 16 mA

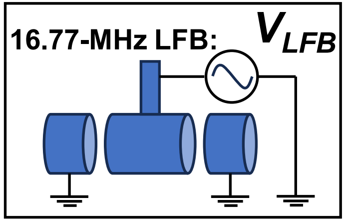
Equations: RFQ-entrance matching conditions.
DB1 variables: quads in branched beamlines;
DB2 variables: pulsed LEBT electrodes.

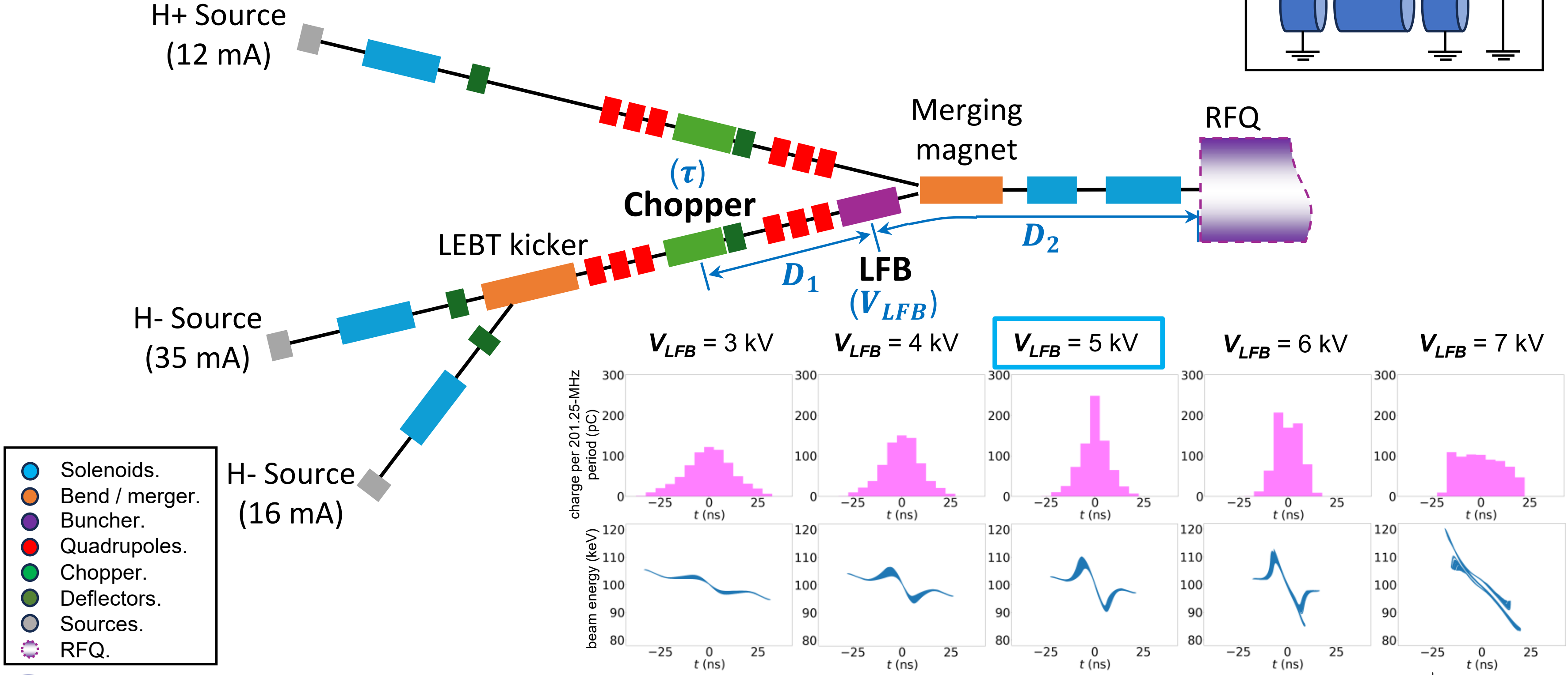
	DB1	DB2
Ion source (LEBT) energy	100 keV	65 keV
MEBT (RFQ exit / DTL entrance) energy	3.0 MeV	2.1 MeV
Number of H^- ion sources	2	1 (dual-mode)
Transverse beam focusing	solenoids & quad triplets	solenoids only
High-charge H^- bunch formation	chopper & low-frequency buncher	two choppers

DB1 to DB2: risk mitigation and cost reduction

Short-Pulse Beam Production: LAMP DB1

LEBT chopper and **low-frequency buncher** (LFB).
Maximize RFQ-exit bunch charge by varying D_2 and V_{LFB}.

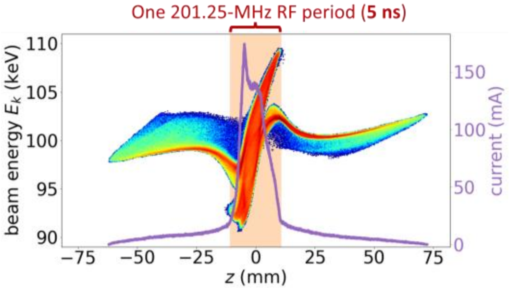


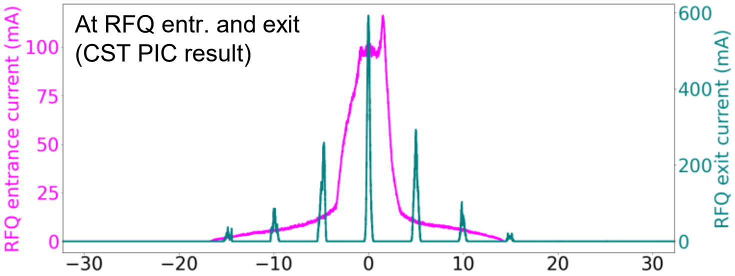


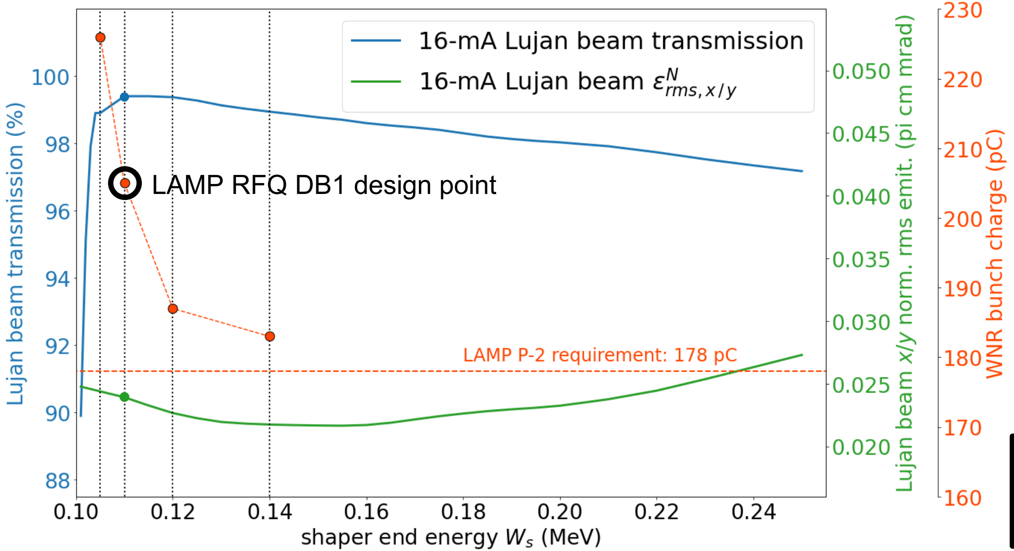
Short-Pulse Beam Production: LAMP DB1

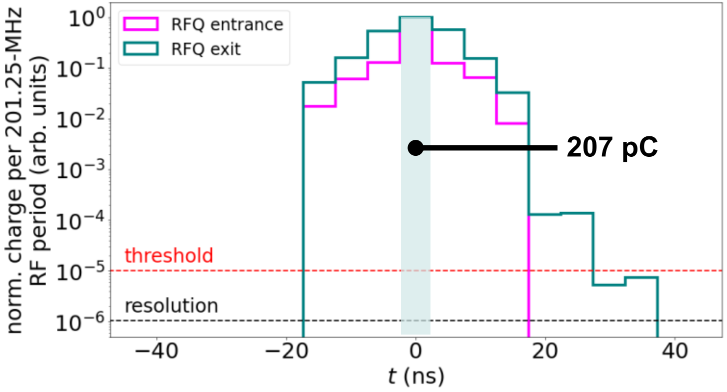
Challenge: High energy spread at RFQ entrance.

Solution: Shortened shaper section of RFQ.







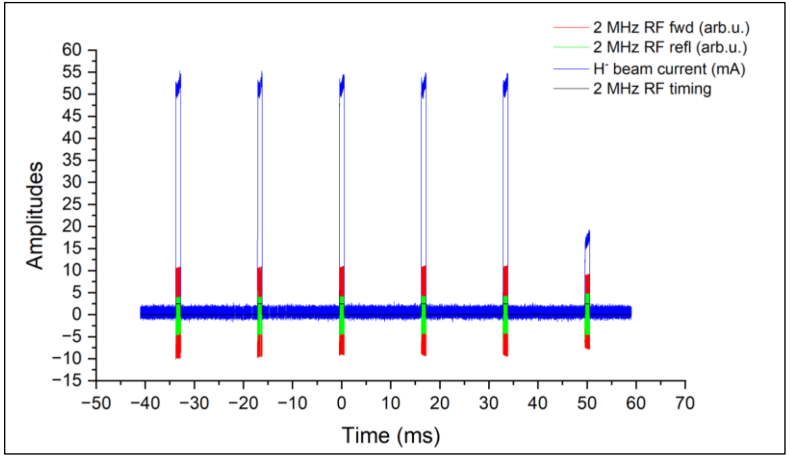


DB1: LEBT ballistic bunching, shortened RFQ shaper section, chopping satellites in MEBT.

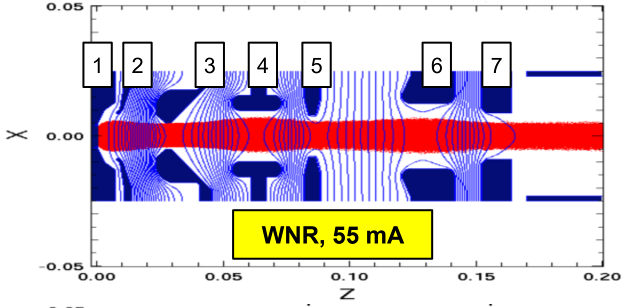
Short-Pulse Beam Production: LAMP DB2

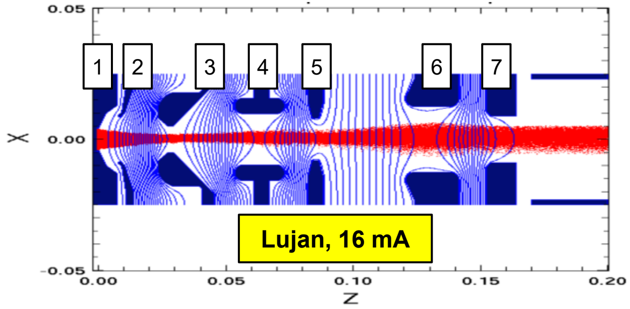
Dual-mode H⁻ ion source and **two choppers**.

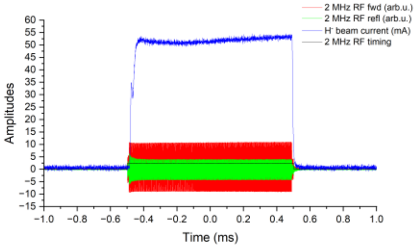
SNS test data for LAMP: dual-mode H⁻ ion source (60 Hz).

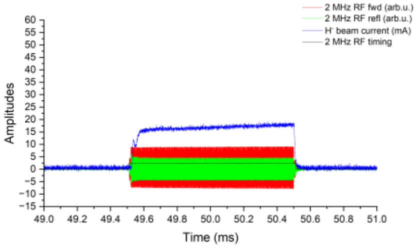


#	WNR [kV]	Lujan [kV]
1	-65.0	-65.0
2	-58.8	-58.8
3	+6.0	+6.0
4	**-41.0**	**-48.0**
5	0.0	0.0
6	**-42.3**	**-45.3**
7	0.0	0.0









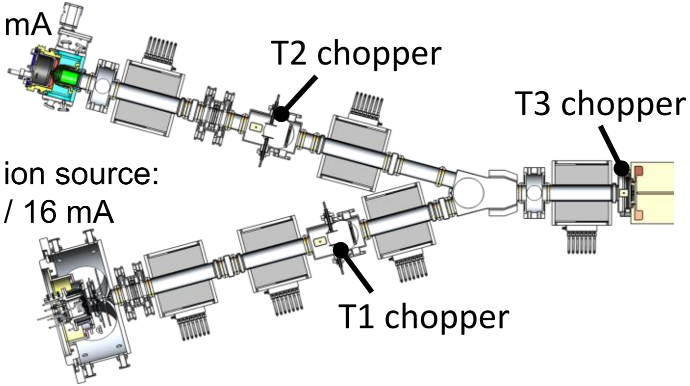
Ion beam current adjusted by RF antenna power.

Challenge: Matching different beam currents in one beamline (different space charge conditions).

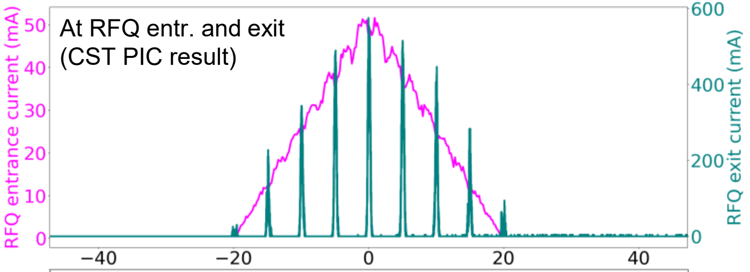
Solution: Pulsing einzel lens at different voltages.

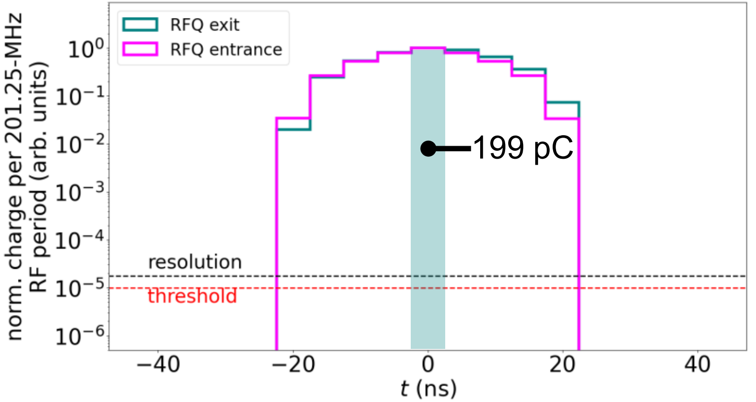
Los Alamos NATIONAL LABORATORY

Short-Pulse Beam Production: LAMP DB2

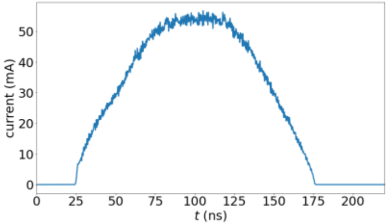


T1 chopper: Produce a 100-ns H⁻ pulse every 1.8 µs.
T2 chopper: Produce H⁺ beam when T1 chopper is chopping.
T3 chopper: Allow only the central slice (~40 ns) of the H⁻ pulse produced by T1 chopper to enter the RFQ.





H⁻ pulse lengthening (over ~1.7 m):
At T1 chopper: 100 ns (square pulse),
55 mA
At T3 chopper: 150 ns (total),
53.6 mA (peak)



H⁻ pulse current at T3 chopper

DB2: Dual-mode H⁻ ion source, two-chopper pulse formation, chopping satellites in MEBT.

Short-Pulse Beam Performance

At RFQ exit:

Parameter	LAMP DB1 RFQ exit	LAMP DB2 RFQ exit	Unit
short-pulse bunch charge	207	199	pC
beam energy	3.0	2.1	MeV
fractional rms energy spread	1.12	0.93	%
$\epsilon^N_{rms,x}$ / $\epsilon^N_{rms,y}$	0.0807	0.0375	pi·cm·mrad
$\epsilon^N_{95,x}$ / $\epsilon^N_{95,y}$	0.557	0.230	pi·cm·mrad
$\epsilon^N_{rms,z}$	0.267	0.138	pi·deg·MeV
$\epsilon^N_{95,z}$	1.92	0.923	pi·deg·MeV

At DTL exit (TR entrance):

<u>LAMP requirement (P-2)</u>: 128 pC
LAMP DB1: 170 pC
LAMP DB2: 192 pC*

Short-pulse beam quality of DB2 is significantly improved.

Summary

LANSCE Accelerator Modernization Project (LAMP) will upgrade the LANSCE front end, extending from the ion sources through the drift-tube linac.

LAMP must support distinct beam-current requirements and pulse-timing structures across the LANSCE experimental areas.

- The most demanding requirement is producing a high-charge, single-bunch H^- beam.

LAMP designs of high-current, short-pulse H^- beam production

- LAMP Design Basis 1 used RF bunching: a low-frequency buncher with a drift space.
- LAMP Design Basis 2 used a dual-mode H^- ion source and a two-chopper scheme.
- LAMP MEBT chopper removes satellite bunches.

LAMP low-energy beam transport design evolution from Design Basis 1 to 2 significantly improved the short-pulse H^- beam quality.