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Multi-Beam Operation of LANSCE Accelerator Facility

Yuri Batygin

Los Alamos National Laboratory, NM 87545, USA

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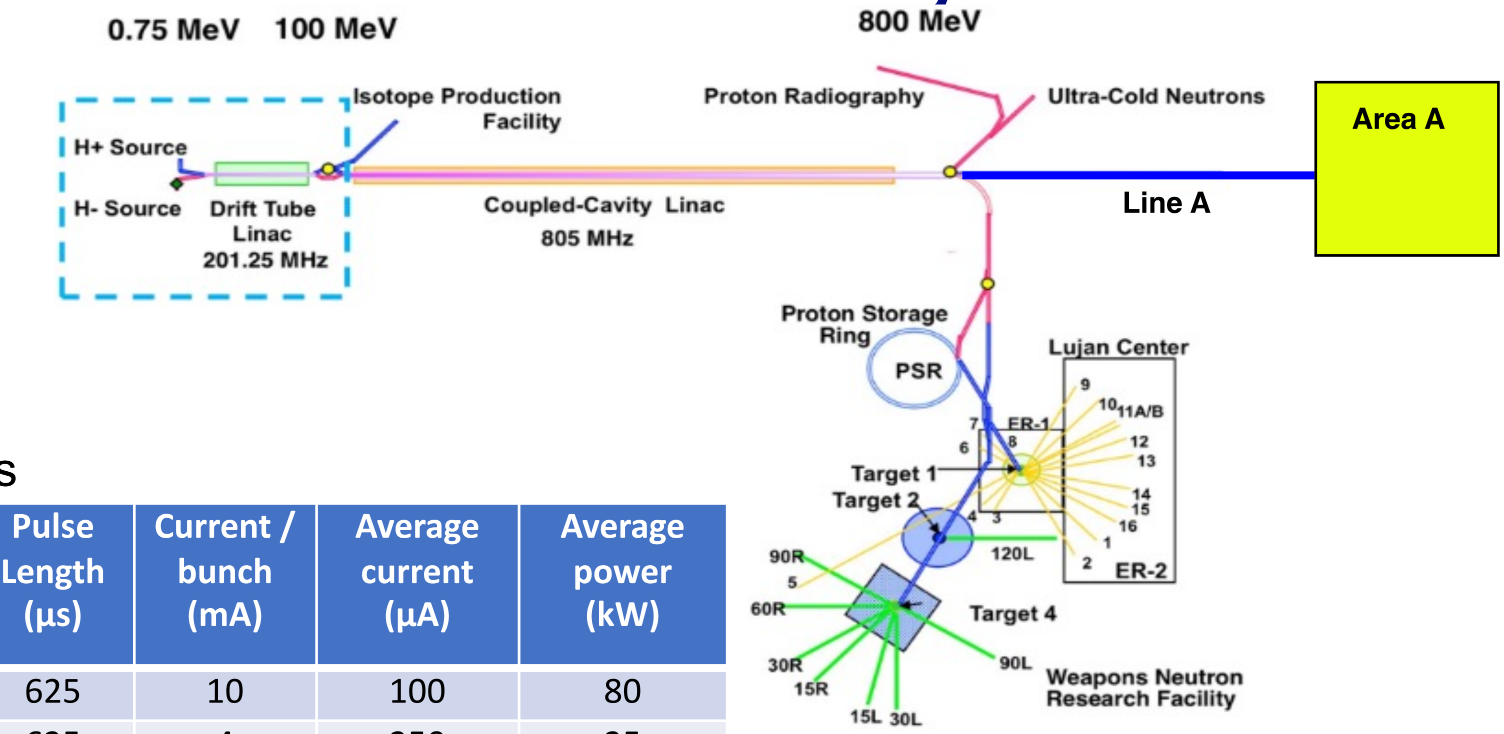
LA-UR-23-31117

LANSCE Accelerator Facility

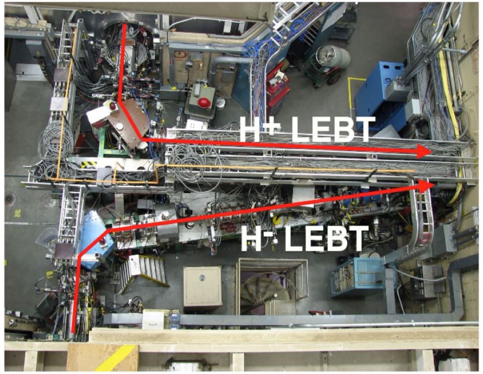


Beam Parameters

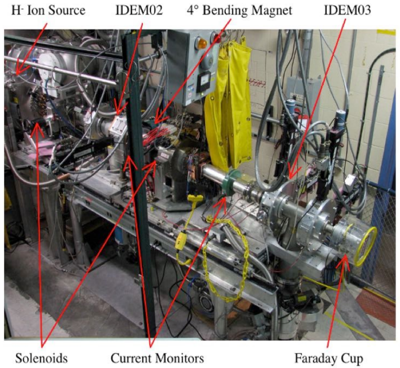
Area	Rep. Rate (Hz)	Pulse Length (µs)	Current / bunch (mA)	Average current (µA)	Average power (kW)
Lujan	20	625	10	100	80
IPF	100	625	4	250	25
WNR	100	625	25	4.5	3.6
pRad	1	625	10	<1	<1
UCN	20	625	10	10	8

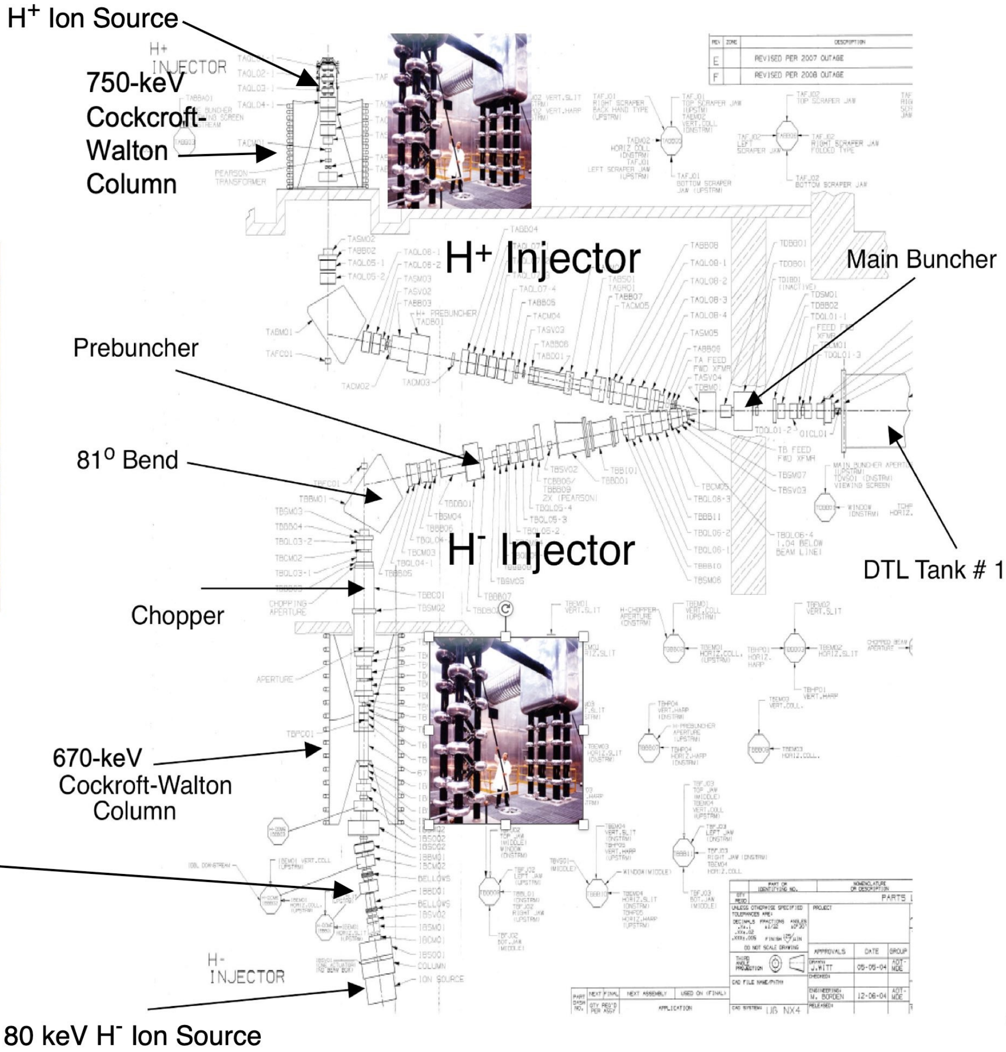
750 keV LANL Injector of H+ / H- Beams

750 keV
H+/H- Beams
Transport



80 keV H-
Beam
Transport





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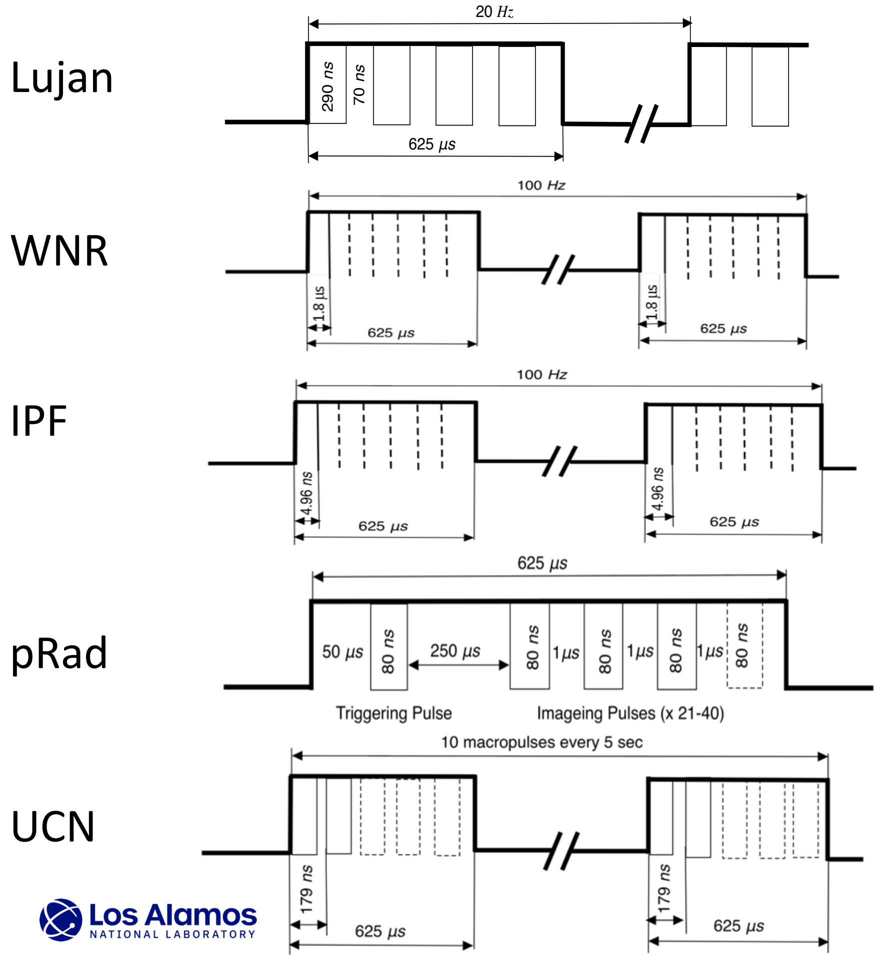
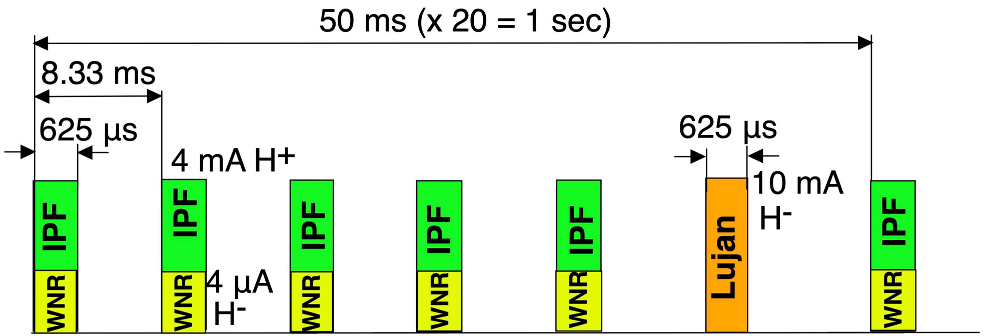
Time Structure of LANSCE Beams





Layout of Lujan/WNR/IPF beams.
Beams delivered to pRad or UCN facilities "steal" their time cycles from WNR beam.

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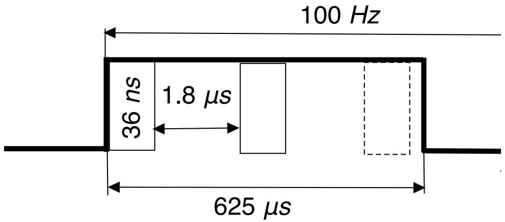
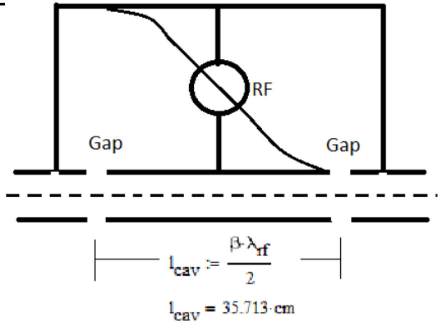
Formation of Multi Beam Structure

LANSCE slow-wave chopper

Chopper short pulse mode for H^- WNR beam

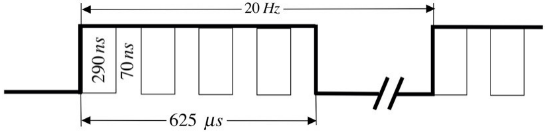


Low Frequency Buncher (16.77 MHz)

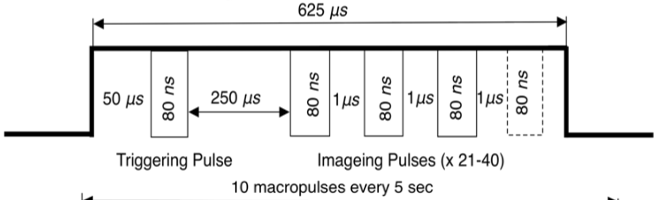


Chopper long pulse mode for H^- beams

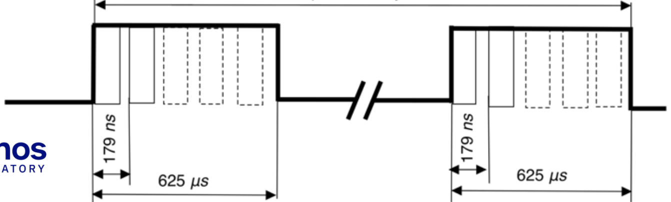
Lujan

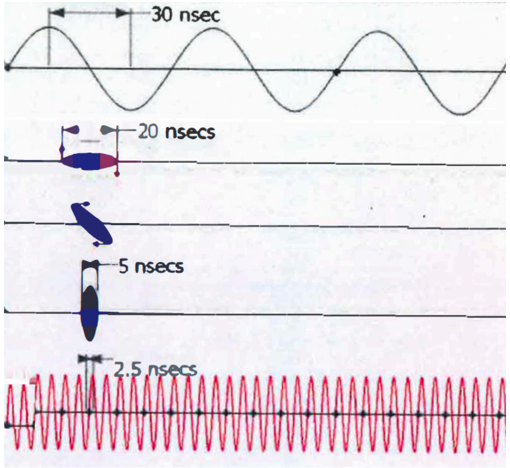


pRad



UCN





16.77 MHz Low Frequency Buncher

Short Chopper Pulse

Drift Space

WNR Bunch

201.25 MHz Drift Tube Linac

Formation of a high-charge single WNR bunch

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Beam Current Plots

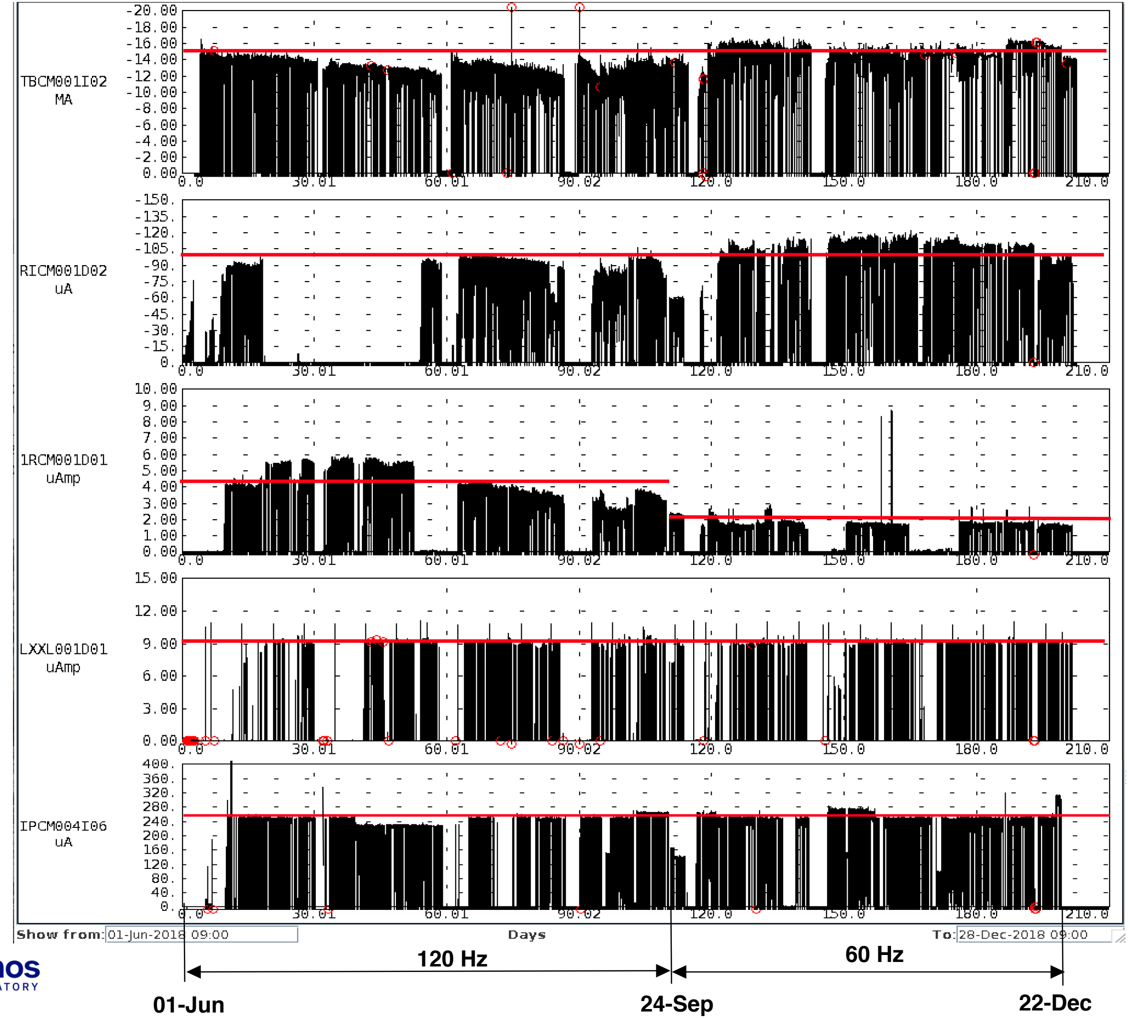
H- Source

Lujan

WNR

UCN

IPF



Planned average beam current

Operation schedule

Maintenance: 4 months

Tune-up: 1.5 months

Operation : 6 months

Number of operation hours: ~ 3500 /year

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Beam Emittance Growth in LANSCE Linear Accelerator

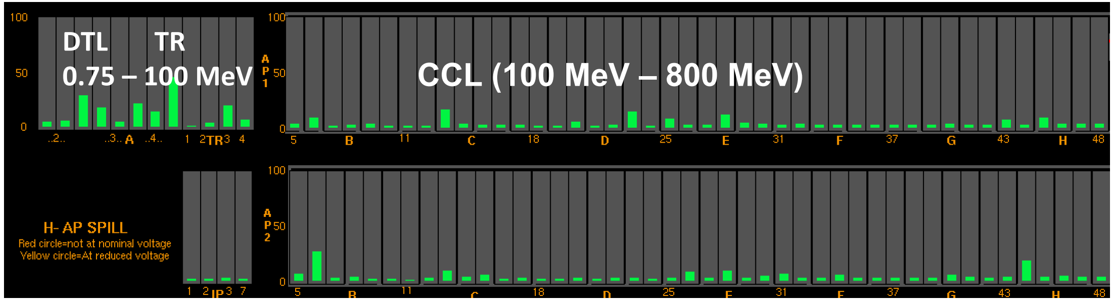
Beam (Facility	Source	0.75 MeV	100 MeV	800 MeV	Charge/ bunch (pC)	Emittance growth in linac, ε_f / $\varepsilon_{0.75}$
H^-(Luj/pRad/UCN)	0.018	0.022	0.045	0.07	50	**3.2**
H^- (WNR)	0.018	0.027	0.058	0.124	125	**4.6**
H^+(IPF), DTL only	0.003	0.005	0.026		20	**5.2**
H^+(Area A, 1995)	0.005	0.008	0.030	0.07	82	**8.7**

Normalized transverse rms beam emittance (π cm mrad), charge per bunch (pC), and emittance growth in linac.

Beam Loss in Linac and HEBT

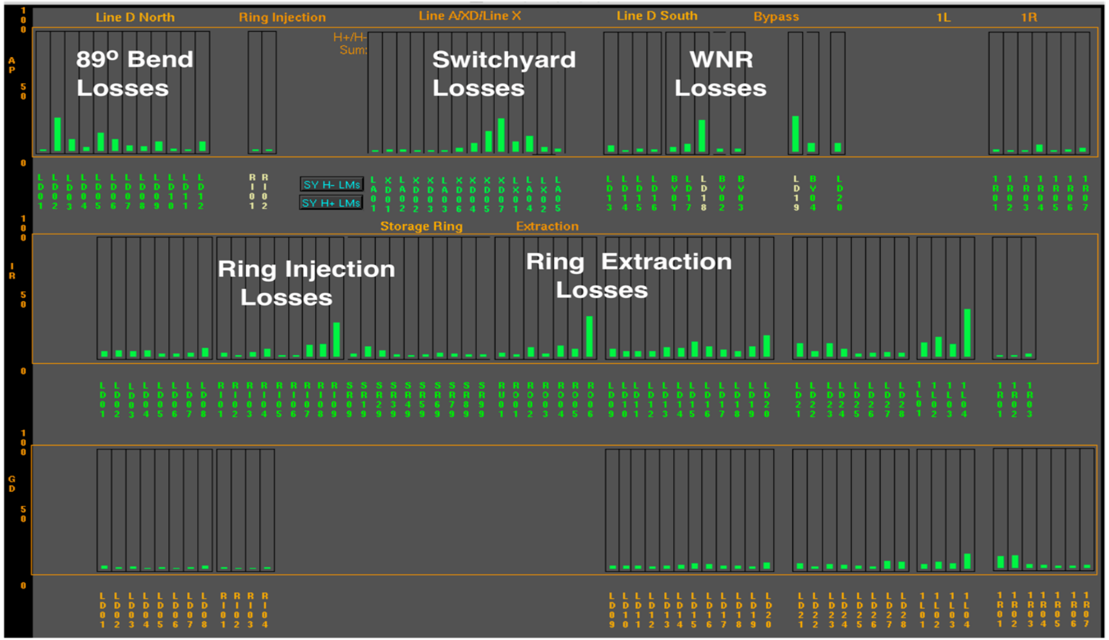
Activation Protection (AP) scintillation detector

Ion Chamber (IR) and Gamma Detector (GD)



Average beam loss in CCL linac:

3×10^{-6} m^{-1}
~ 0.2 W/m



Average beam loss in high-energy beamlines:

2×10^{-5} m^{-1}
~ 1.6 W/m

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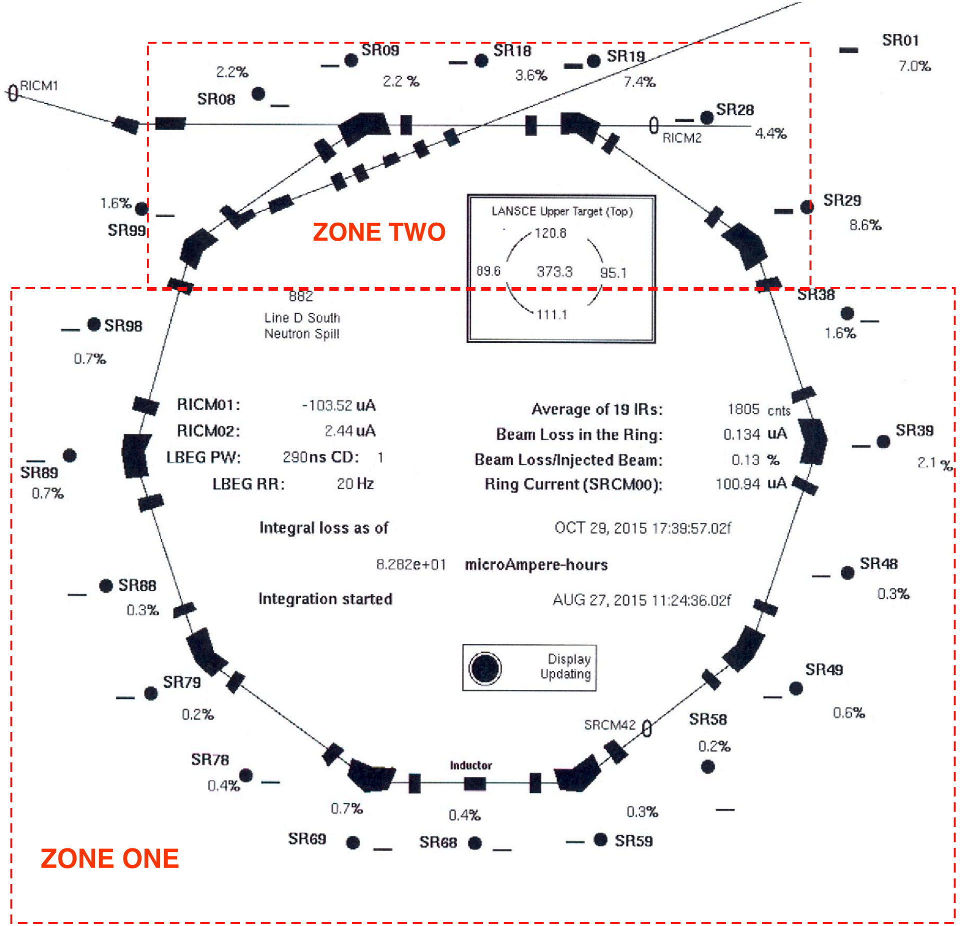
Beam Loss in Proton Storage Ring (PSR)



Year	PSR Beam Losses (%)
2022	0.30
2021	0.28
2020	0.35
2019	0.14
2018	0.39
2017	0.32

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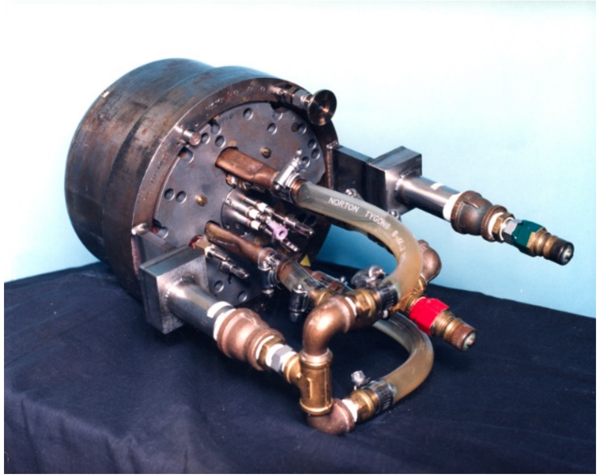
Sources of Beam Emittance Growth and Beam Loss in LANSCE Linear Accelerator

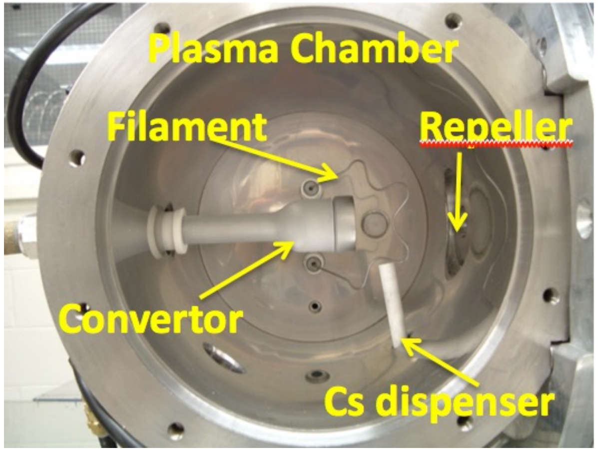
🔴 Significant 🟡 Moderate 🟢 Insignificant

Source	0.75 MeV LEBT	100 MeV DTL	800 MeV CCL	800 MeV HEBT
Misalignments of accelerator channel components	🟡	🟡	🟡	No Data
Transverse-longitudinal coupling in RF field	🟡	🟡	🟢	N/A
H^- beam stripping on residual gas, intra-beam stripping	🟢	🟡	🔴	🔴
Nonlinearities of focusing and accelerating elements	🟢	🟢	🟢	🟢
Space-charge forces of the beam	🟢	🔴	🔴	🔴
Mismatch of the beam with accelerator structure	🔴	🔴	🔴	🔴
Instabilities of accelerating and focusing field	🔴	🔴	🔴	🔴
Beam energy tails from un-captured particles	🔴	🔴	🔴	🔴
Dark currents from un-chopped beam	🟡	🟡	🟡	🟡
Excitation of higher-order RF modes	🟢	🟢	🟢	N/A

H^+ and H^- Ion Sources



Side view of assembled LANSCE duoplasmatron proton ion source.



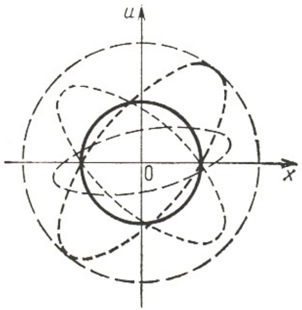
Cesiated, multicusp-field, surface-production H^- ion source

Beam	Current, *I* (mA)	Normalized Emittance, ε_{rms} (π cm mrad)	Normalized Beam Brightness, $B = I / (8 \pi^2 \varepsilon^2_{rms})$ A/(π m mrad)^2
H^+	10 - 30	0.003 - 0.005	20
H^-	14 - 20	0.016 - 0.018	0.6

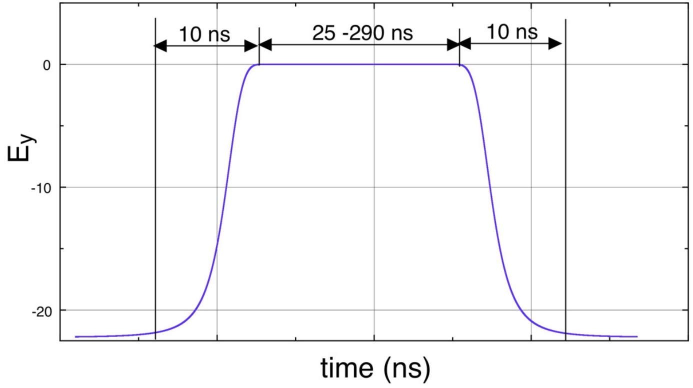
Beam Emittance Growth in 750-keV Beam Transport

RF Bunching

Beam	Emittance Growth $\varepsilon_{RF}/\varepsilon$
H^-	1.1 – 1.2
H^+	1.9 – 2.2

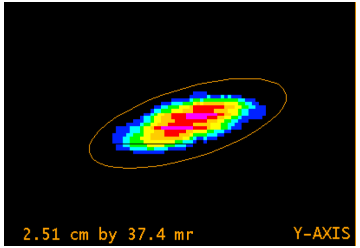


H^- Beam Chopping

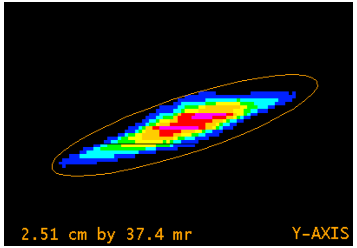


H^- Chopper Pulse	Emittance Growth $\varepsilon_{Ch}/\varepsilon$
290 ns	1.1
36 ns	1.3

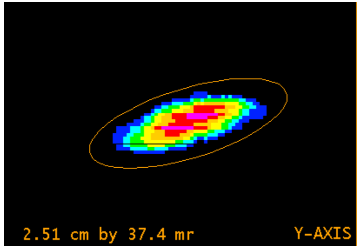
Bunchers Off



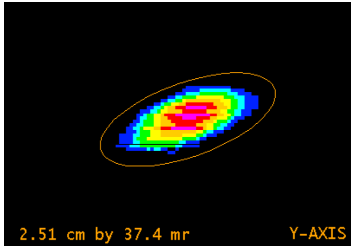
Bunchers On



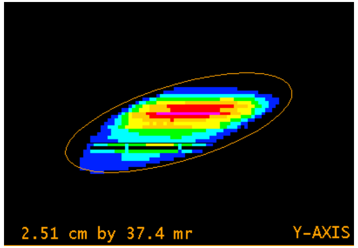
Chopper Off



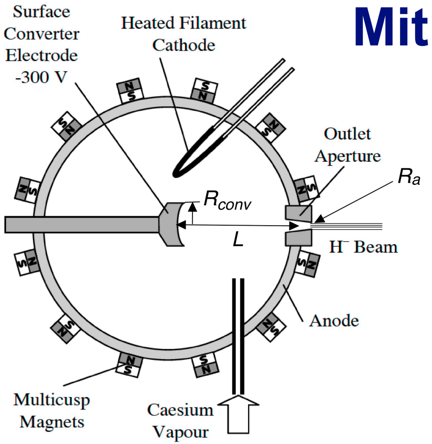
Chopper pulse 290 ns



Chopper pulse 36 ns

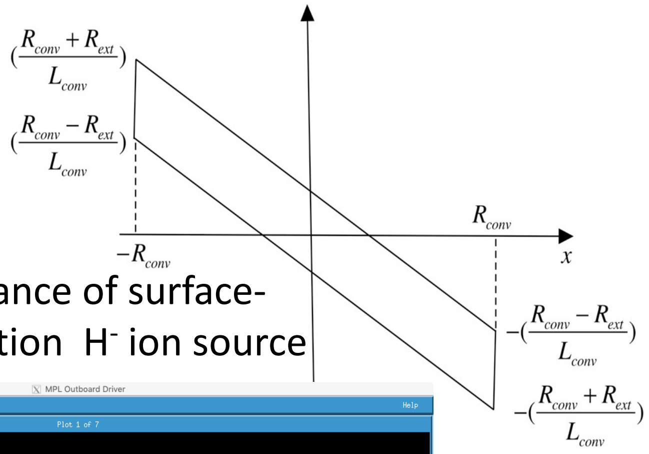


Mitigation of H⁻ Beam Loss via Adjustment of H⁻ Source



Normalized acceptance (admittance) of surface-production H⁻ ion source:

$$\varepsilon = \frac{4}{\pi}\sqrt{\frac{2eU_{conv}}{mc^2}}\frac{R_{conv}R_a}{L}$$



Acceptance of surface-production H⁻ ion source

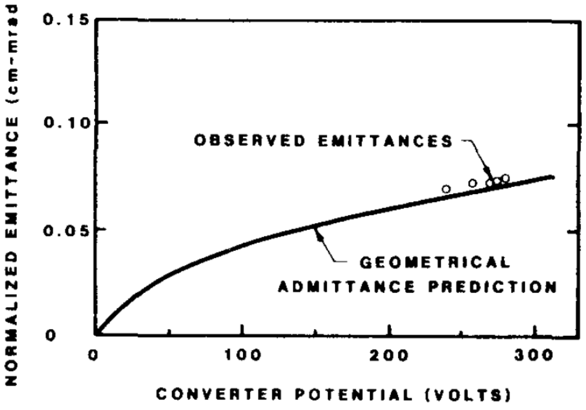
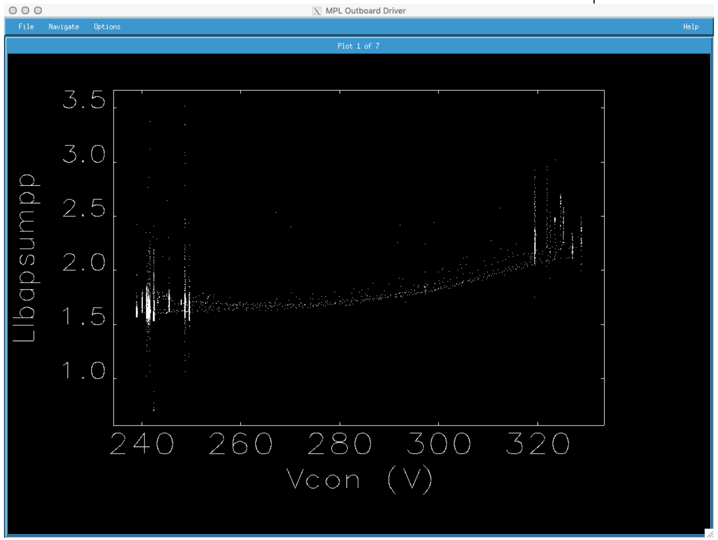


Fig. 3 Normalized emittance vs converter voltage

H⁻ beam emittance versus converter voltage (R. Stevens et al, Proc. LINAC 1984, p. 226).



Summed beam loss in CCL versus reduction of H⁻ source convertor voltage (courtesy of Larry Rybarcyk, 2019).

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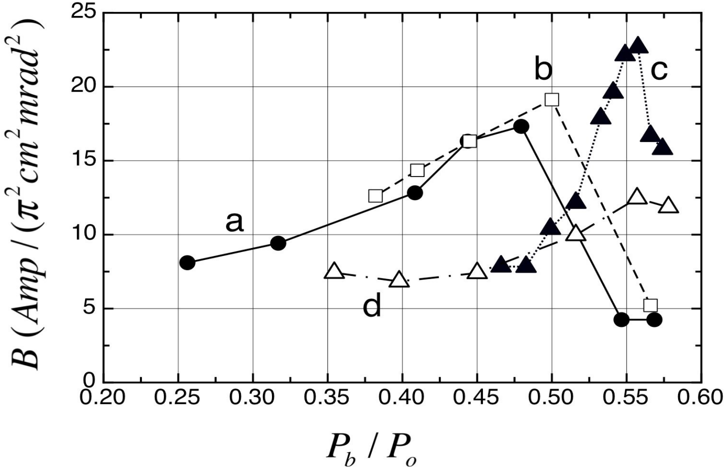
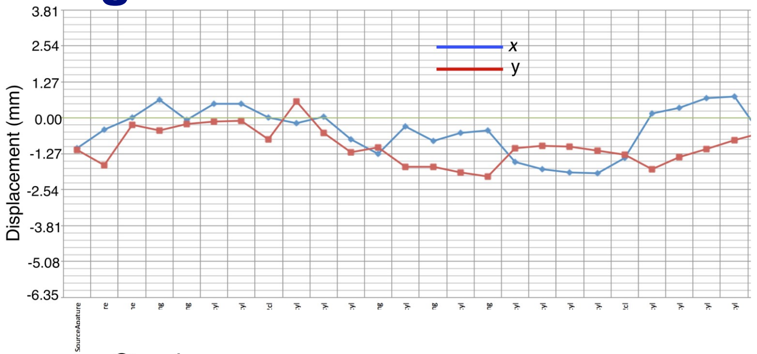
Maximization of H^+ Beam Brightness and Beam Based Alignment

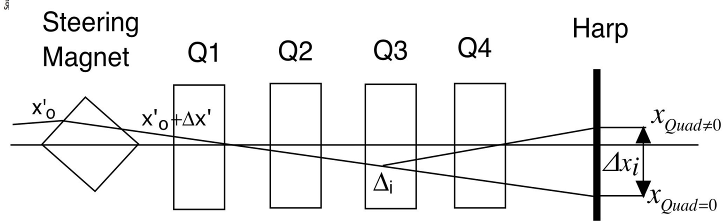


H+ beam brightness as function of ratio of beam perveance to Child-Langmuir perveance

$$\eta = \frac{P_b}{P_o} = \frac{9}{\sqrt{2}S^2}\frac{I}{I_c}\left(\frac{mc^2}{qU_{ext}}\right)^{3/2}$$



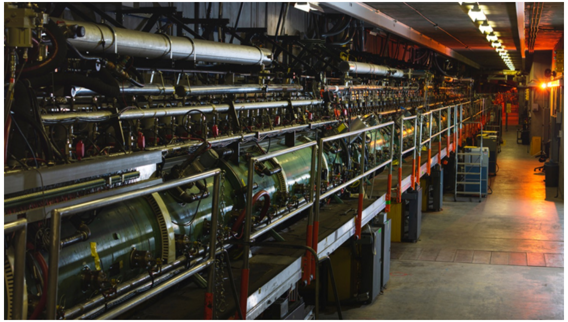
750-keV H^+ LEBT misalignments

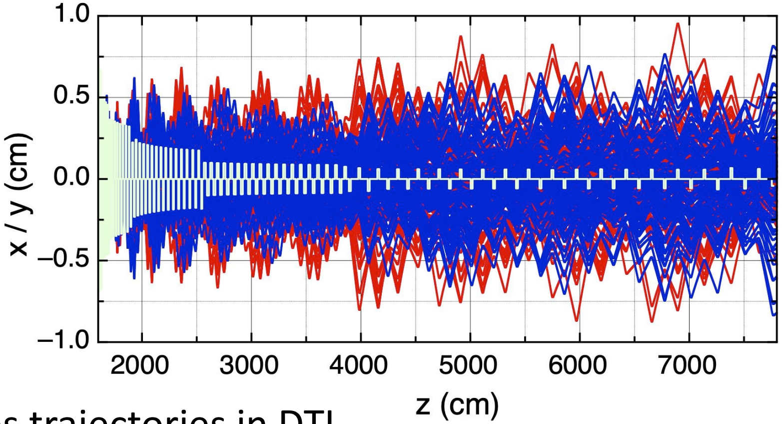


Minimization of beam offset in a sequence of quadrupoles

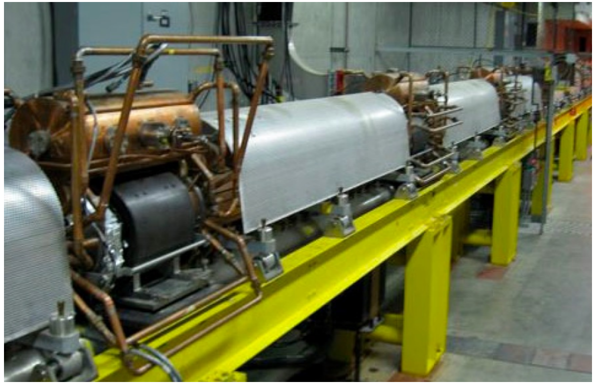
750-keV RMS Beam Emittance Before Alignment, π cm mrad (Initial/Final)	750-keV RMS Beam Emittance After Alignment, π cm mrad (Initial/Final)
0.002/ 0.007	0.002/ 0.004

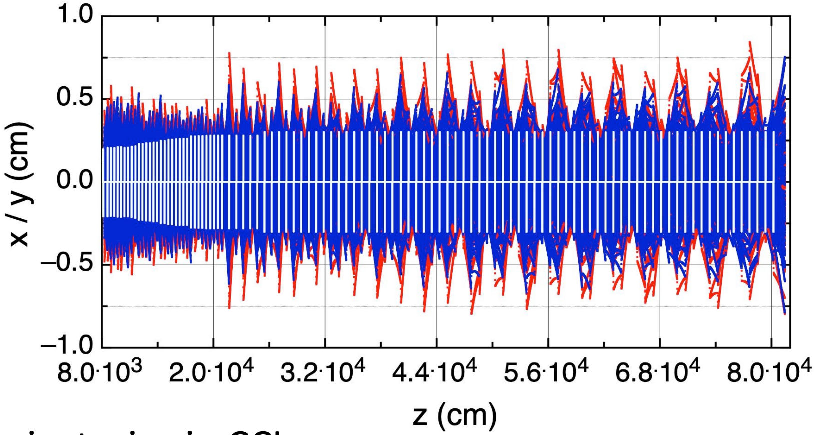
Beam Mismatch in Linear Accelerator





Mismatched particles trajectories in DTL.





Mismatched particle trajectories in CCL.

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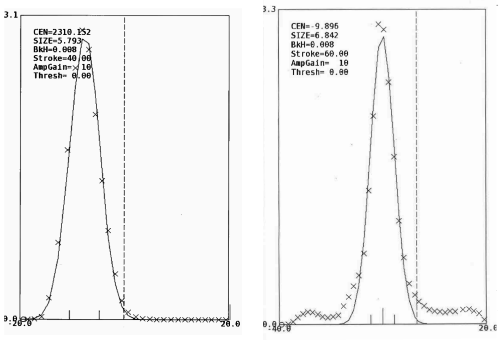
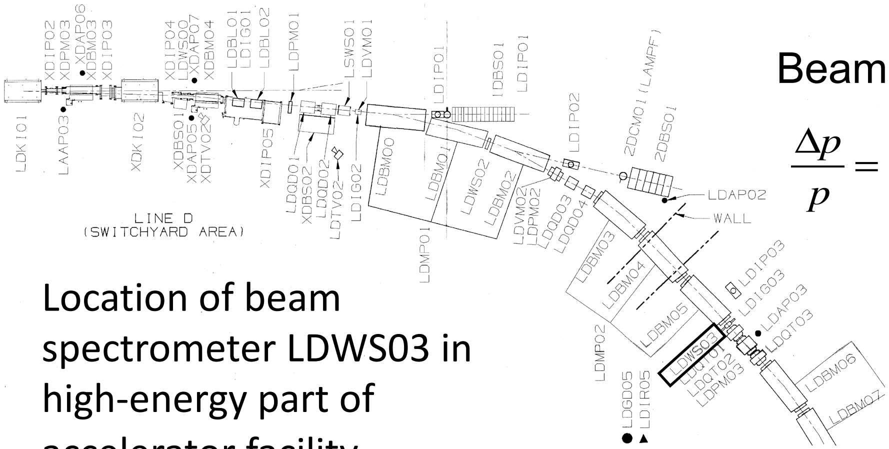
Low-Momentum Beam Spill in High-Energy Beamlines



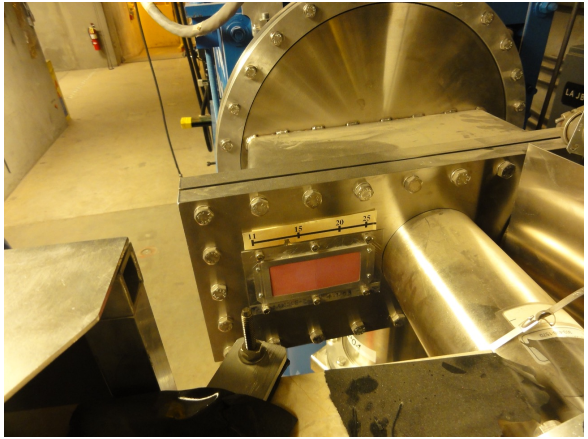
Measurement of momentum spread of the beam: (left) properly tuned beam, (right) beam with momentum tails due to improper tune.

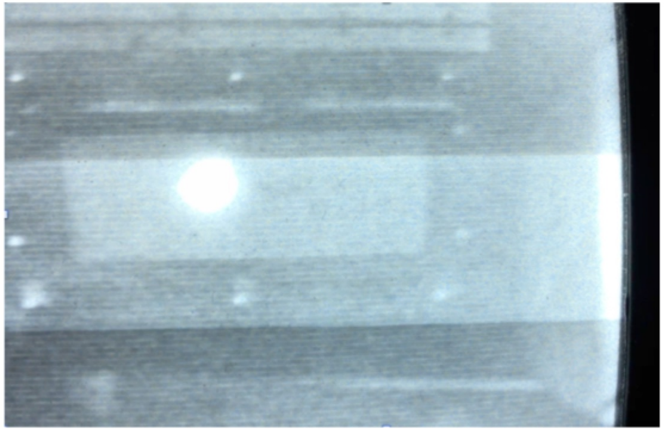


Location of beam spectrometer LDWS03 in high-energy part of accelerator facility

Beam Momentum Spread

$$\frac{\Delta p}{p} = \frac{\sqrt{R_x^2 - \beta_x(4\,\varepsilon_{x\_rms})}}{\eta} = 8 \cdot 10^{-4}$$





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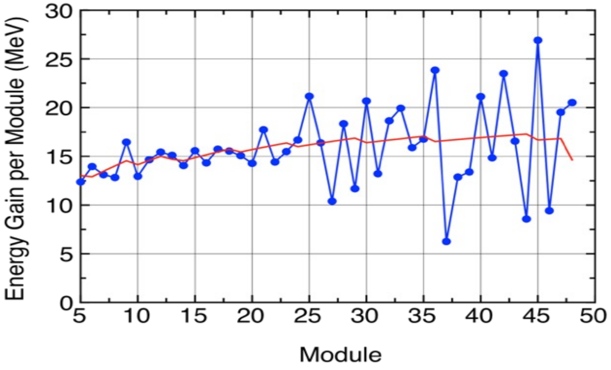
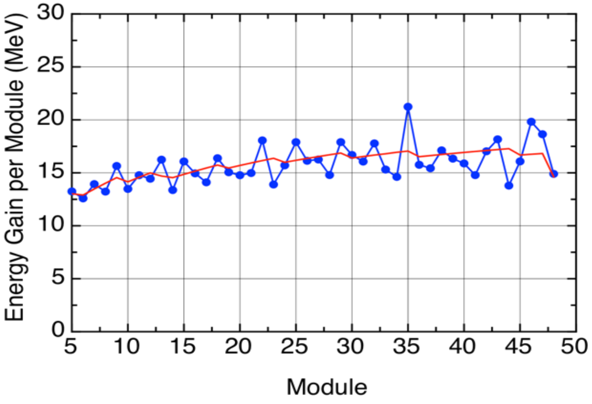
Phosphor screen in 800 MeV beamline and observation of low-momentum beam spill.

Mitigation of Beam Loss in HEBT

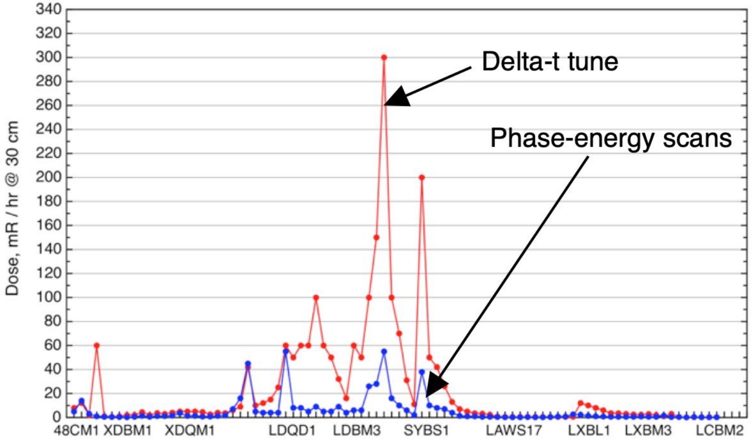
(a)



(b)



Energy gain per module: (a) after delta-t tune, (b) after phase-energy scans tune, (red line – design).



Switchyard radiation survey after different CCL tunes.

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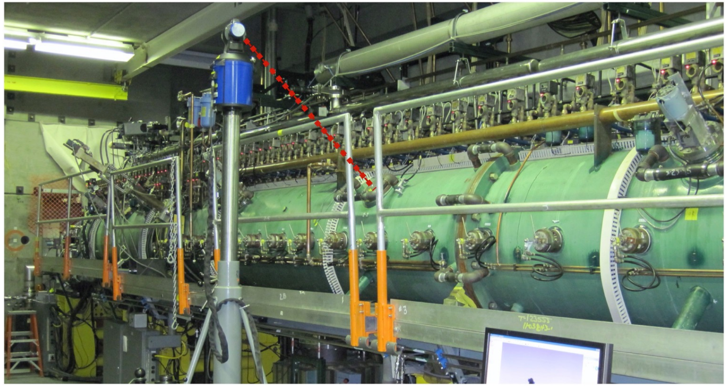
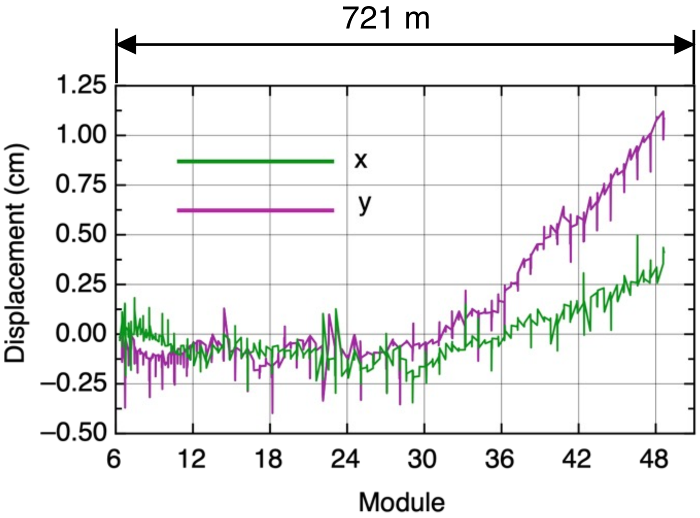
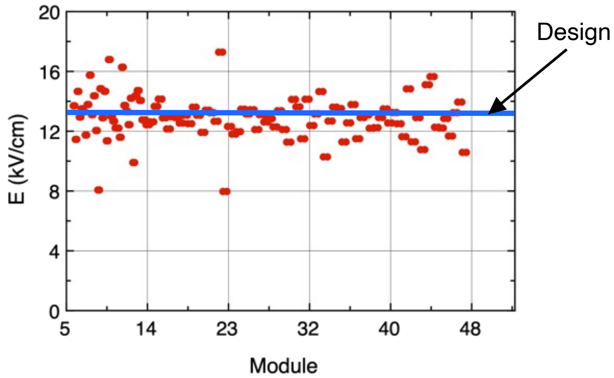
Effect of Lattice Misalignment and RF Field Variation on Beam Parameters



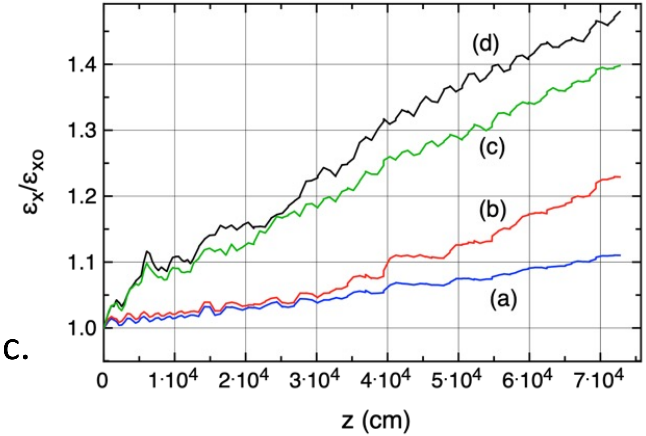
Measurement of DTL linac misalignment.



805 MHz CCL Misalignment Data

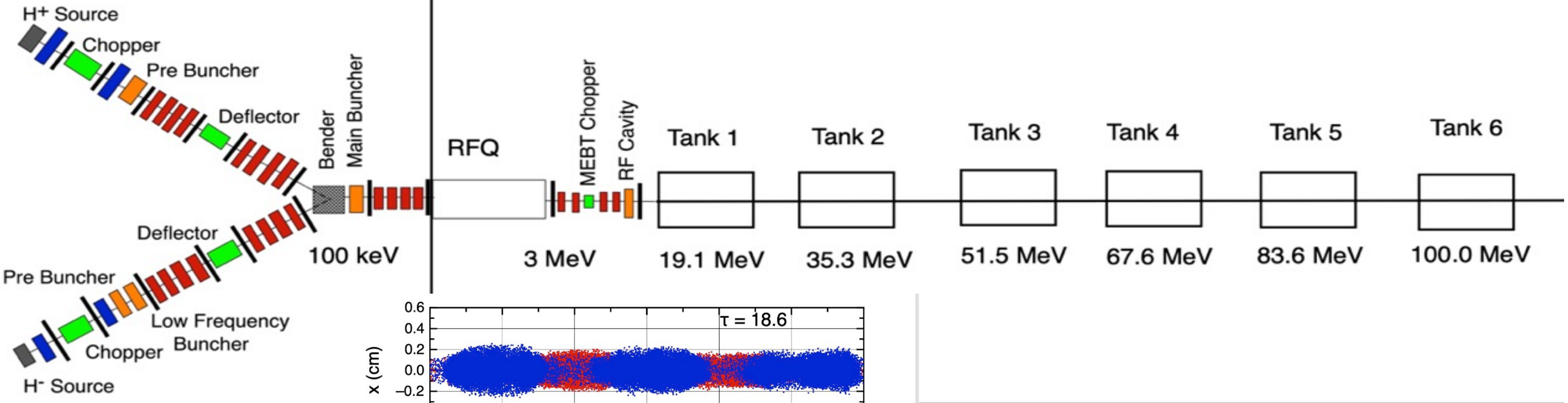


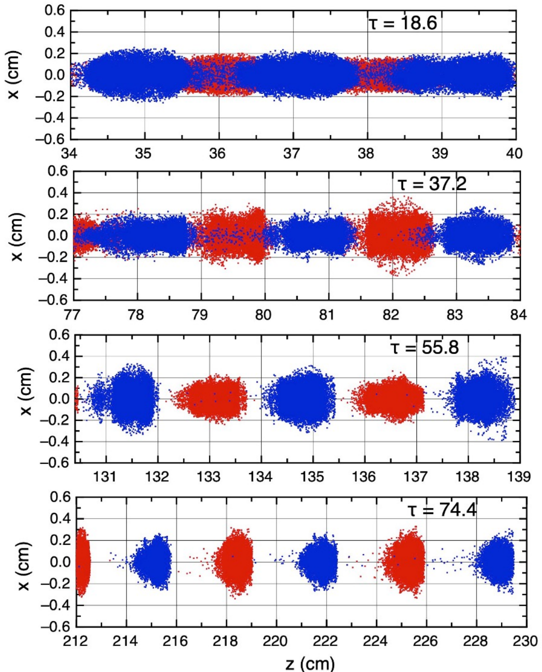
Measured RF Field Amplitudes in CCL Linac.



Beam emittance growth along CCL linac: (a) ideal structure (b) structure with misalignment (c) structure with misalignment, and beam space charge, (d) structure with misalignments, beam space charge, and RF field variation.

Novel 100 MeV LANSCE Front End





Formation of the two-component beam in RFQ: (red) H^+ beam, (blue) H^- beam.

Parameters of injector

Ions	H^+/H^-
Ion sources extraction voltage	100 keV
RF Frequency	201.25 MHz
RFQ energy	3 MeV
Repetition rate	120 Hz
Max beam peak current	32 mA
Average current	1 mA
Beam pulse	625-1000 μs
Number of RFQ cells	187
RFQ Length	4.2 m

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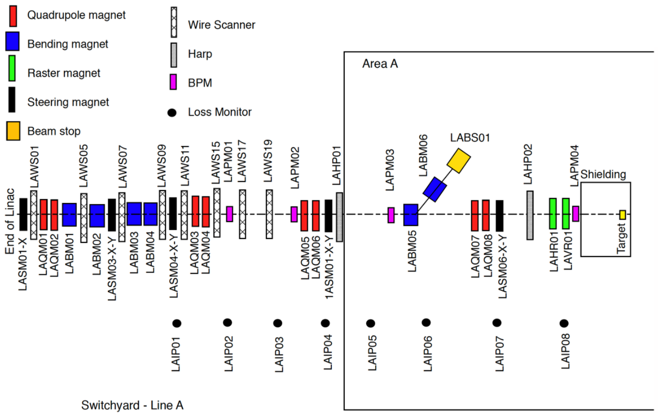
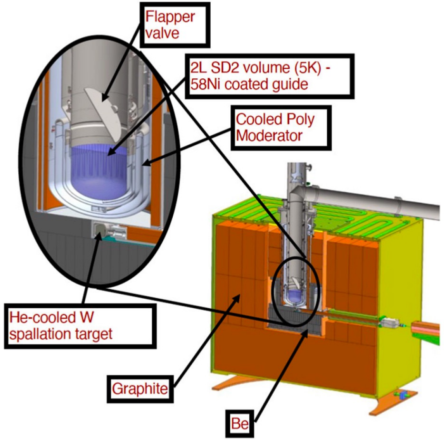
Future Plans and Upgrade of LANSCE

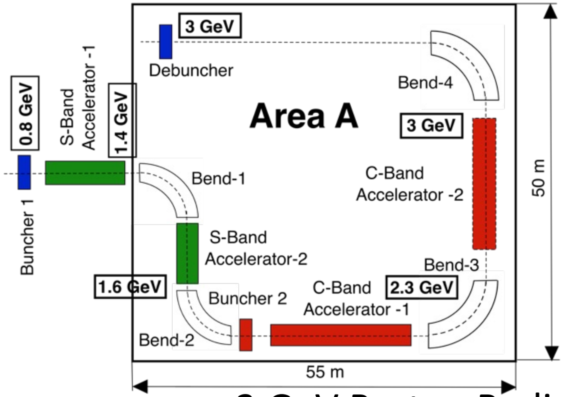


Restore 1 MW proton beam for Fusion Prototypic Neutron Source (LA-UR-19-32216)

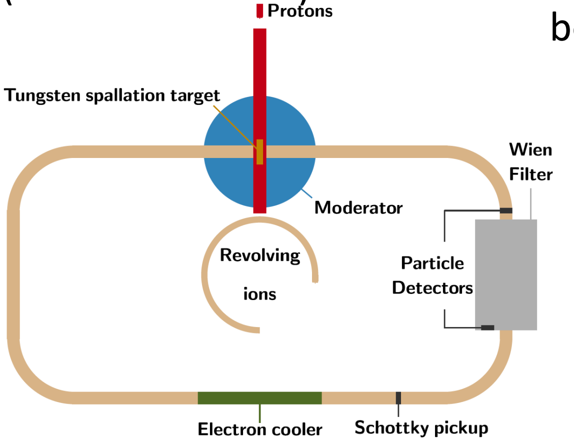


Upgrade of UCN Facility (LA-UR-21-31223)

Experimental Area A has not been used since 1999.



3 GeV Proton Radiography (NAPAC22)



Neutron target for heavy ion physics study (LA-UR-21-31223)

Summary

1. The unique feature of the LANSCE accelerator facility is multi-beam operation, simultaneously delivering beams to five experimental areas.

2. Multi-beam operation requires compromises in beam tuning to meet beam requirements at the different targets while minimizing beam losses throughout the accelerator.

3. The near - term plans are to replace obsolete systems of the LANSCE linear accelerator with modern 100-MeV Front End with significant improvement of beam quality.