Presentation of the LINAC2010 invited talk on Design of Proton Drivers.(Draft as of September 9, 2010)

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APC Seminar

September 9, 2010

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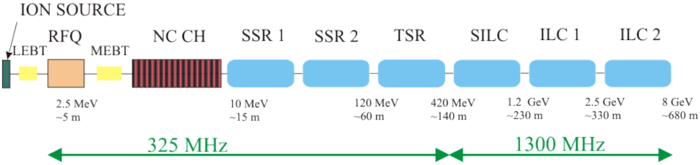
Multi-GeV Proton and H- Linacs Overview

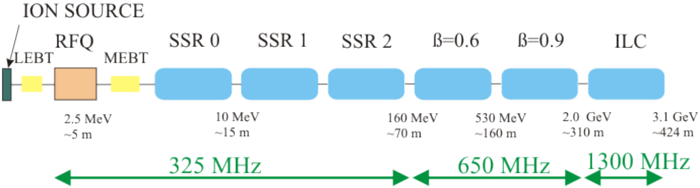
Project	E [GeV]	I_{av} [mA]	Power [MW]	Application	Status
FNAL 8-GeV Pulsed	8	25	2	neutrinos	proposed
FNAL 3-GeV CW	3	1	3	neutrinos kaons, muons	proposed
CERN LP-SPL	4	0.05	0.2	LHC upgrade	proposed
CERN HP-SPL	5	0.8	>4	neutrinos, RIB	proposed
ESS1 (EU)	1.334	3.75	5	neutrons	proposed
ESS2 (EU)	1.334	7.5	10	neutrons	proposed
ORNL SNS1	1	26	1.4	neutrons	in operation
ORNL SNS2	1.3	42	3	neutrons	proposed

FNAL 8-GeV Pulsed / 3-GeV CW Linacs Layout

- FNAL 8-GeV Pulsed Linac

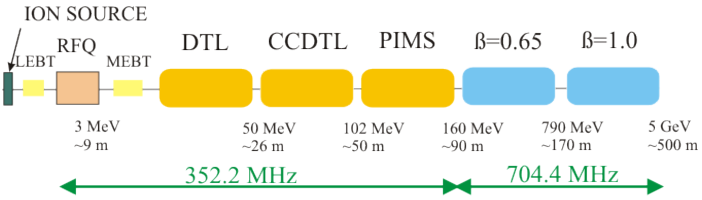


- FNAL 3-GeV CW Linac

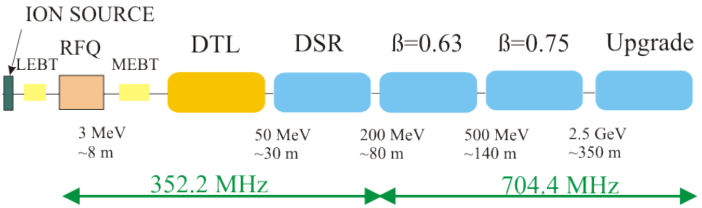


CERN SPL / ESS Linacs Layout

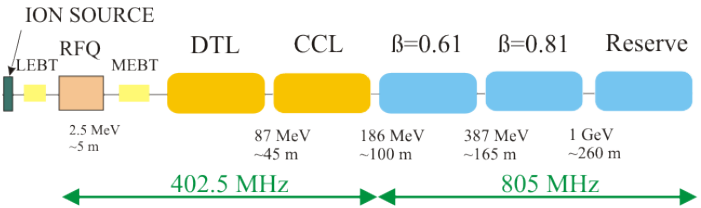
- CERN SPL Linac



- ESS Linac



ORNL SNS Linac

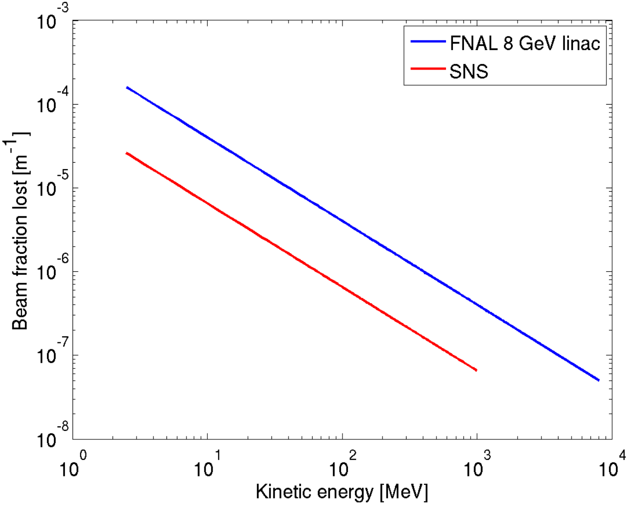


Tolerable Beam Loss in High-Intensity Linacs: 1W/m

- Beam loss in accelerators lead to beamline component activation
- Maintenance Restriction (for example LANSCE, Los Alamos Guidelines)
  - Limited access time: 100 μSv/h to 1 mSv/h, 30 cm from the component surface
  - Very limited controlled: 1 mSv/h to 100 mSv/h
  - Remote maintenance required: >100 mSv/h
- Experience from Asia, Europe and US on high-energy accelerators AND calculation results from three different codes (`LAHET` (Los Alamos), `HETC/MCNP/ORIHET` (ORNL) and `MARS` (FNAL)) lead to the basic result:

$$\boxed{1 \text{ mSv/h} \Longleftrightarrow \sim 1\text{W/m}} \tag{1}$$

Permissible Beam Loss Fraction to achieve 1 W/m



Zero-Current Design

Considerations

- The zero current phase advance of transverse and longitudinal oscillations should be kept below 90° per focusing period to avoid parametrically-excited instabilities at high-current.
- The transverse and longitudinal wavenumbers k_{T0} and k_{L0} must change adiabatically along the linac to minimize the potential for mismatch and assure a current independent lattice

$$k_{T0} = \frac{\sigma_{T0}}{L_f}, \qquad k_{L0} = \frac{\sigma_{L0}}{L_f} \tag{2}$$

where σ_{T0} and σ_{L0} are the zero current transverse and longitudinal phase advances per focusing period L_f

- Avoid the $n = 1$ parametric resonance between the transverse and longitudinal motion.

High-Current Design

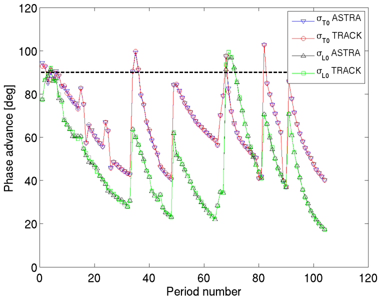
Considerations

- Avoid energy exchange between the transverse and longitudinal planes via space-charge resonances by:
  - providing beam equipartitioning. Emittance ratio close to one
  - avoiding instable areas in Hofmann's stability charts
- Provide Longitudinal-to-transverse emittance ratios close to one ($0.5 < \epsilon_l/\epsilon_t < 2$) and a tune depression > 0.5 provide larger stable areas in the stability charts
- Provide proper matching in the lattice transitions to void appreciable halo formation
- Keep a ratio aperture-to-rms-beam-size > 10, if possible

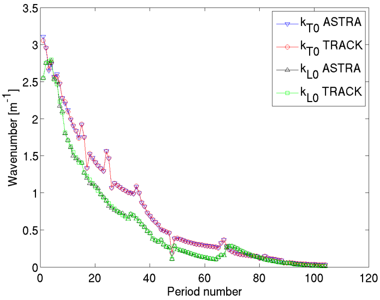
Zero-Current design

FNAL 8-GeV Pulsed Linac

Phase advance



Wavenumber



Zero-Current design

FNAL 8-GeV Pulsed Linac

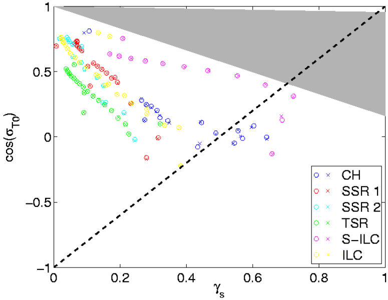
- the condition of occurence of an n-th order transverse motion parametric resonance is

$$\sigma_{T0} = \frac{n}{2}\sigma_{L0}$$

- the strongest resonance occur if for $n = 1$ (grey area)
- the defocusing factor γ_s is defined as

$$\gamma_s = \frac{\pi}{2}\frac{1}{(\beta\gamma)^3}\frac{L_f^2}{\lambda}\frac{eE_m sin(\phi_s)}{m_0 c^2}$$

Kapchinskiy Stability Chart

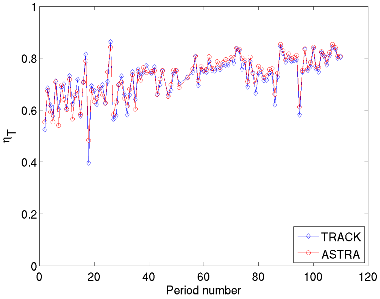


$\gamma_s < 0.7 \Leftrightarrow$ stability

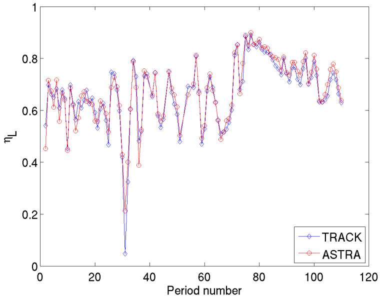
High-Current design

FNAL 8-GeV Pulsed Linac

Transverse Tune Depression



Longitudinal Tune Depression

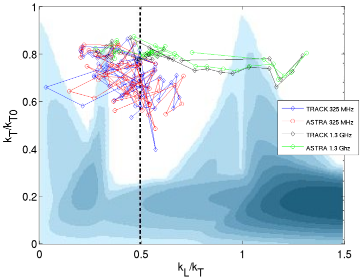


High-Current design

FNAL 8-GeV Pulsed Linac

- core-core resonance
- the shadded area indicate regions where non-equipartioned beams are subject to space-charge coupling resonances that are expected to cause emittance transfer between transverse and longitudinal planes
- the vertical dash line show the condition for equipartition

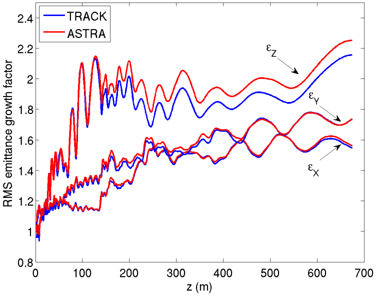
Hofmann Stability Chart



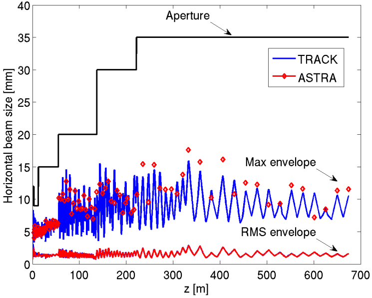
$$\epsilon_L/\epsilon_T = 2$$

High-Current design
FNAL 8-GeV Pulsed Linac

RMS Emittance Growth



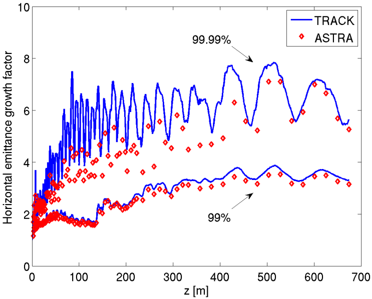
Max. and RMS Hor. Beam Size



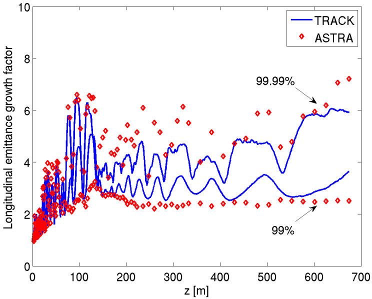
High-Current design

FNAL 8-GeV Pulsed Linac

99% & 99.99% Hor. Emittance Growth



99% & 99.99% Long. Emittance Growth



Beam Losses

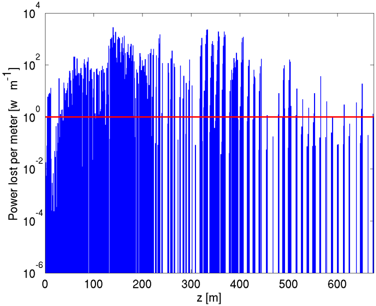
Errors in the FNAL 8-GeV Linac

Beam Parameter		Error Value	Distribution
Solenoid Displacement (x and y)	[mm]	0.5	Uniform
Solenoid Rotation (x and y)	[mrad]	2	Uniform
Solenoid Field Jitter	[%]	0.5	Gaussian
Quadrupole Displacement (x and y)	[mm]	0.5	Uniform
Quadrupole Rotation (x and y)	[mrad]	2	Uniform
Qaudrupole Field Jitter	[%]	0.5	Gaussian
Cavity Displacement (x and y)	[mm]	0.5	Uniform
Cavity Rotation (x and y)	[mrad]	2	Uniform
Cavity Field Jitter	[%]	1.0	Gaussian
Cavity Phase Jitter	[%]	1.0	Gausssian

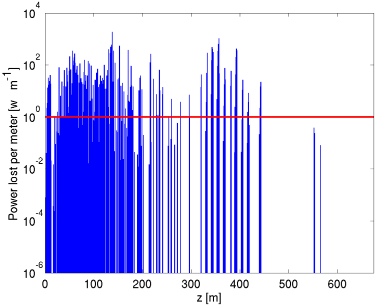
Beam Losses

Errors FNAL 8-GeV Pulsed Linac

Loss Pattern from TRACK



Loss Pattern from ASTRA



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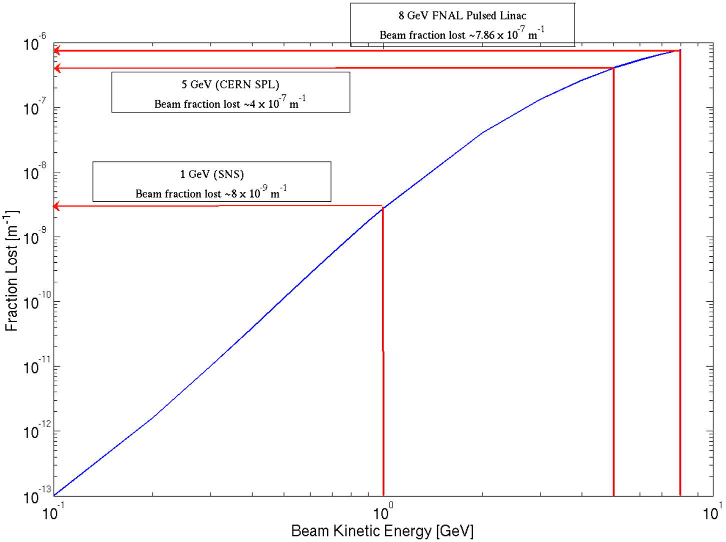
Beam Losses

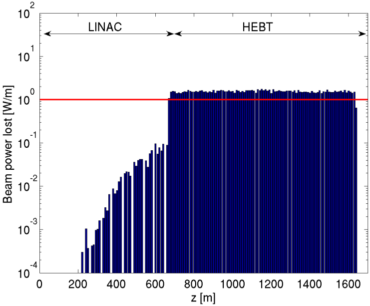
Blackbody Radiation



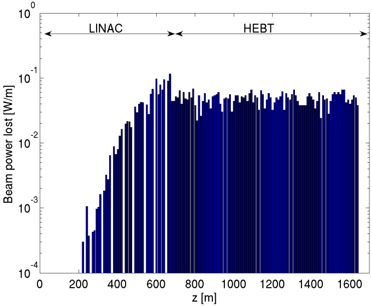
Blackbody Stripping

FNAL 8-GeV Pulsed Linac

HEBT at 300 K



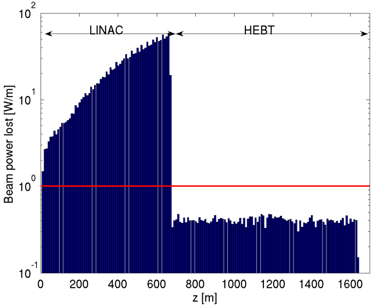
HEBT at 150 K



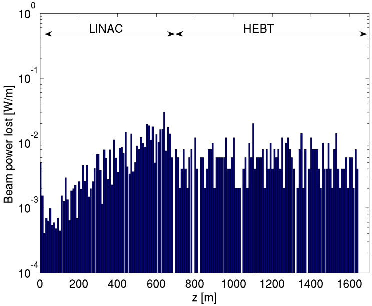
Residual Gas Stripping

FNAL 8-GeV Pulsed Linac

HEBT at 300 K



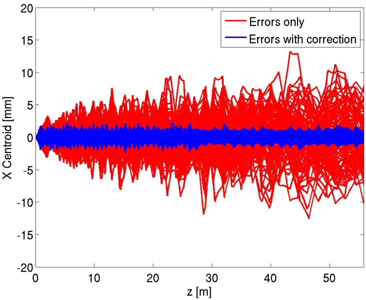
HEBT at 150 K



One-to-one correction algorithm

Errors + Correction FNAL 8-GeV Linac

Hor. Beam Centroid Motion (from TRACK)



Loss Pattern (from TRACK)