High-Gradient Booster for Enhanced Proton Radiography at LANSCE

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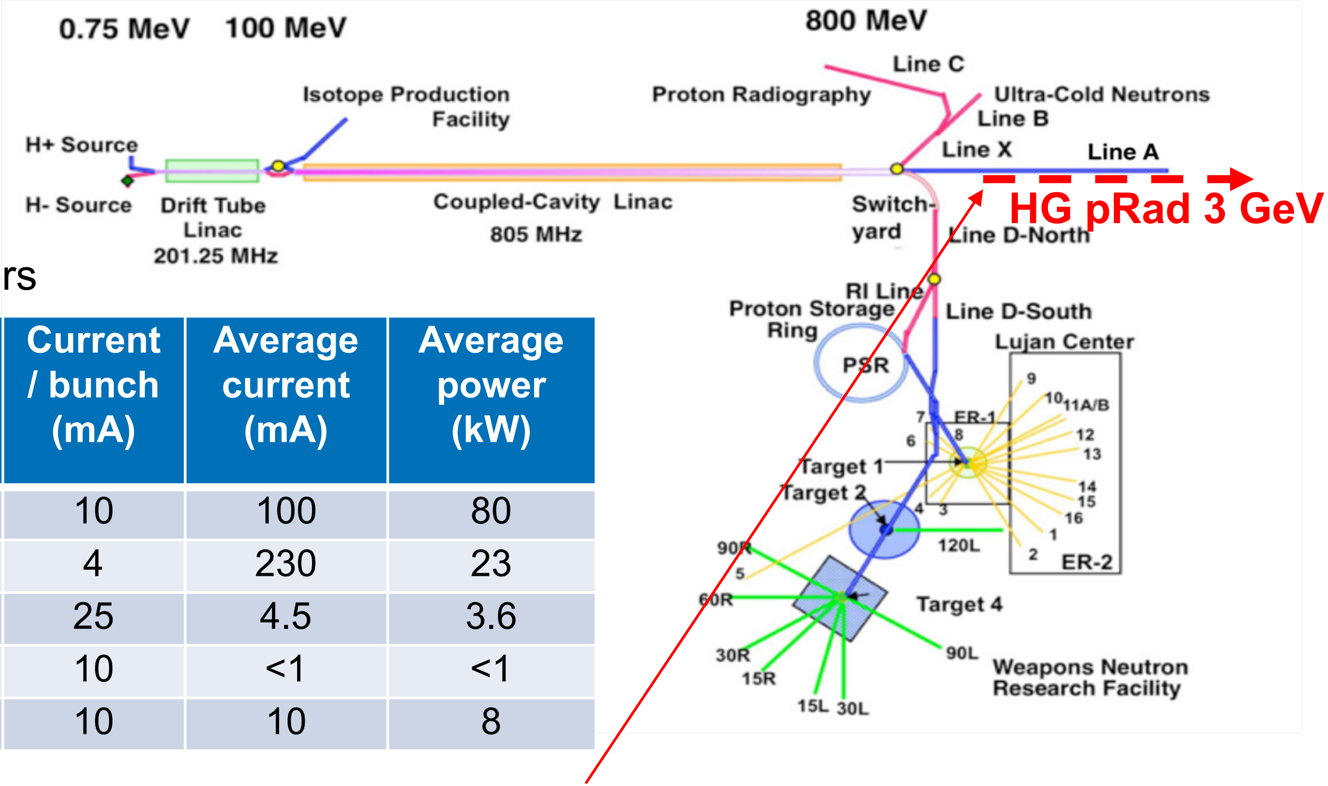
Abstract

Increasing energy of proton beam at LANSCE from 800 MeV to 3 GeV improves radiography resolution ~10 times. We propose accomplishing this energy boost with a compact cost-effective linac based on cryo-cooled normal conducting high-gradient (HG) RF accelerating structures. HG structures exceeding 100 MV/m have been developed for electron acceleration and operate with short RF pulse lengths below 1 us. Though such parameters are unusual for typical proton linacs, they fit perfectly for proton radiography (pRad) applications. The pRad limits contiguous trains of beam micro-pulses to less than 80 ns to prevent blur in images.

For a compact pRad booster at LANSCE, we develop a staged design: a section to capture and compress the 800-MeV proton beam is followed by the main HG linac. Our beam dynamics study addresses the beam magnetic focusing and minimizing its energy spread, which are challenging in high-gradient structures but very important for successful pRad operation.

Los Alamos Neutron Science Center (LANSCE)



LANSCE Beam Parameters

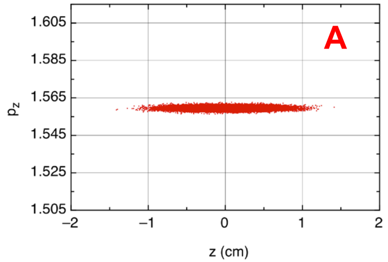
Area	Rep. Rate (Hz)	Pulse Length (ms)	Current / bunch (mA)	Average current (mA)	Average power (kW)
Lujan	20	625	10	100	80
IPF	100	625	4	230	23
WNR	100	625	25	4.5	3.6
pRad	1	625	10	<1	<1
UCN	20	625	10	10	8

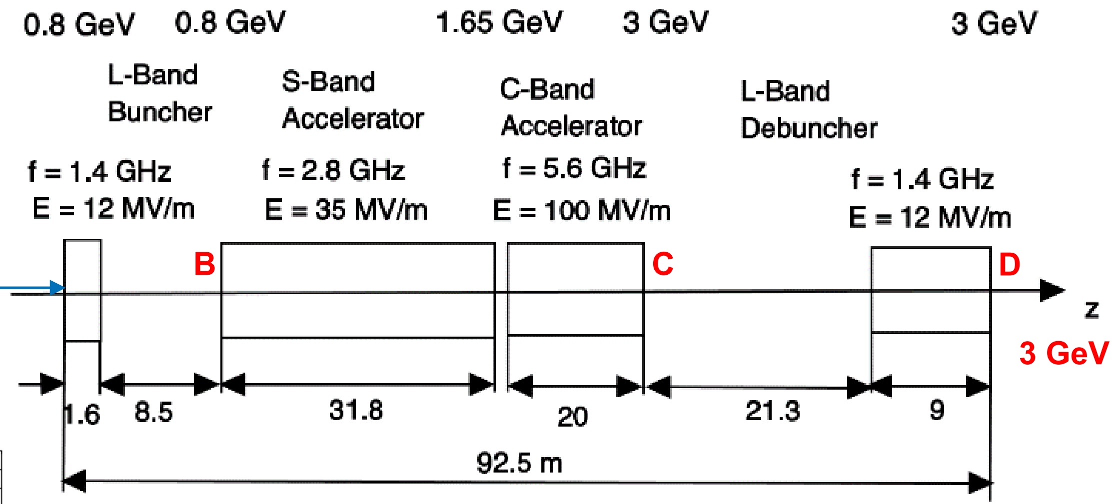
Potential Location of High-Gradient pRad booster to 3 GeV at LANSCE

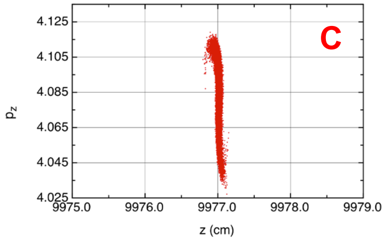
High-Gradient (HG) pRad Booster

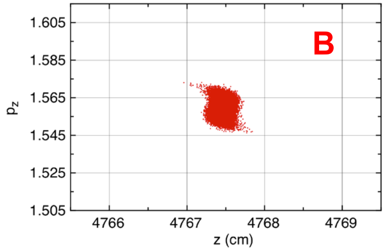
- HG cavities for pRad booster at LANSCE have to be modified to cover proton beam velocities from $\beta = v/c = 0.84$ at 800 MeV to $\beta = 0.97$ at 3 GeV. We plan to use cryo-cooled copper standing-wave structures with distributed coupling [S. Tantawi *et al. PRAB* 2020].
- The booster must capture and compress the 800-MeV proton (H^-) beam from the LANSCE linac. Important requirement: the relative momentum spread $\Delta p/p = 8.8 \cdot 10^{-4}$ at the exit of the 800-MeV linac should be reduced as $1/p$, to $3.4 \cdot 10^{-4}$ at 3 GeV, which is essential for pRad image quality.
- This leads to a modified booster design compared to a simple 2-stage scheme [SK et al. Linac16, p.280]. We add an L-band buncher at 1408.75 MHz (=7*201.25). The captured beam is accelerated to 3 GeV in a high-gradient linac consisting of S- (2817.5 MHz) and C-band (5635 MHz) structures. After that an L-band de-buncher is used to reduce the momentum spread of the 3-GeV beam.
- Beam dynamics study with Beampath [YB, *NIM*, 2005] defines beam magnetic focusing and minimal required cavity apertures in the booster.

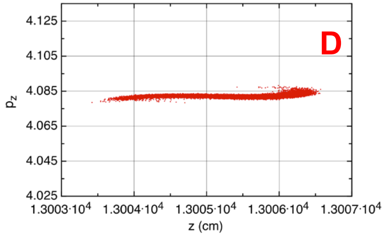
High-Gradient (HG) pRad Booster – modified design







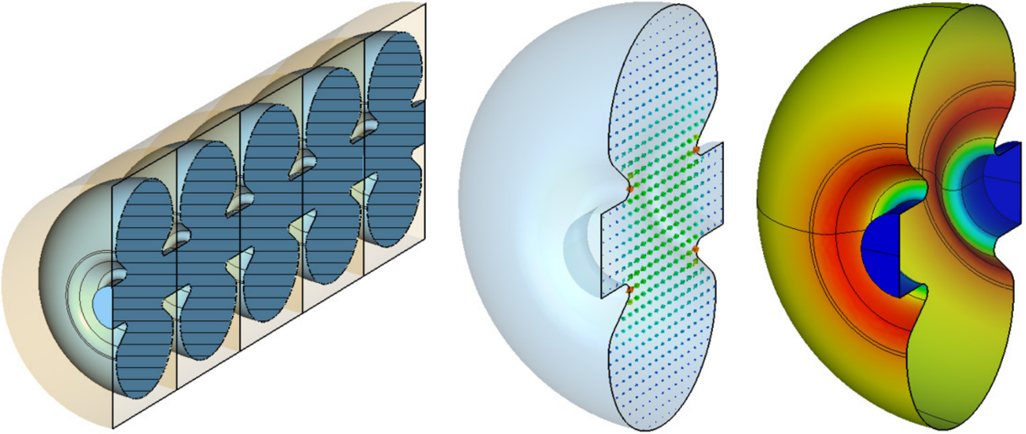




Layout of modified HG pRad booster and longitudinal phase-space snapshots of the simulated beam at locations A, B, C, and D

HG RF Structures for pRad Booster

We consider re-entrant cavity shapes (to be optimized)



S-band structure for β=0.84: 5-cell structure section (left); electric field within a cell; current distribution on the cell inner surface.

Cavity Parameters at Gradient E

f	β	a, mm	E, MV/m	E_{max}/E	Z', MΩ/m	P', MW/m
L	0.84	8	18	4.3	68.6	4.7
S	0.84	8	36	4.23	69.9	18.5
S	0.93	6.5	36	4.1	83.4	15.5
C	0.93	6.5	80	3.63	76.9	83.2
C	0.97	5	80	3.63	96.9	66
L	0.97	5	18	4.6	77	4.2

Summary

- We developed a preliminary design of HG pRad booster at LANSCE. It captures and compresses the 800-MeV proton (H^-) beam from the LANSCE linac using an L-band buncher. The captured beam is accelerated to 3 GeV in a high-gradient linac consisting of S- and C-band structures. After that an L-band de-buncher is used to reduce the relative beam momentum spread of the 3-GeV beam below its value at the exit of 800-MeV linac. Beam dynamics study with Beampath addresses the beam magnetic focusing and cavity apertures. It also demonstrates the required relative momentum reduction for the accelerated beam, which is very important for successful pRad operation.