Acceptance Calculation and Study of Fault Scenarios in the PIP-II Linac

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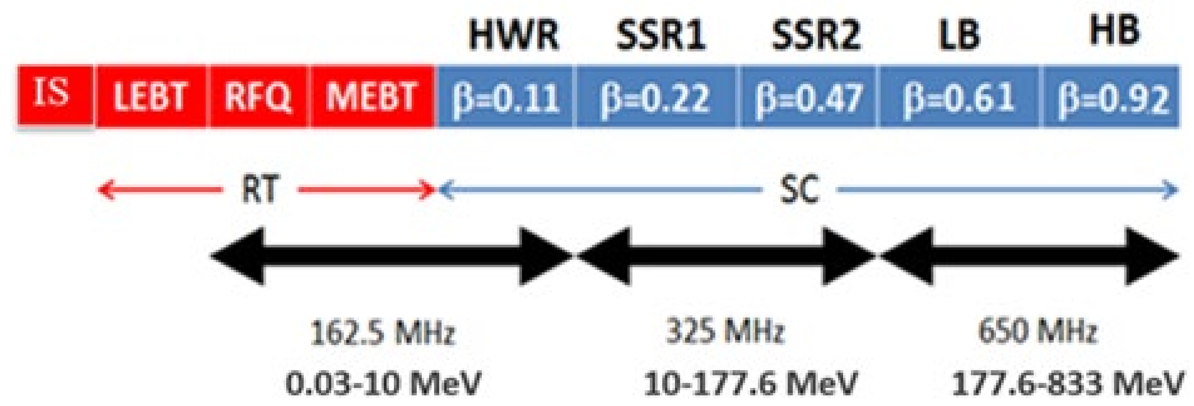
Introduction

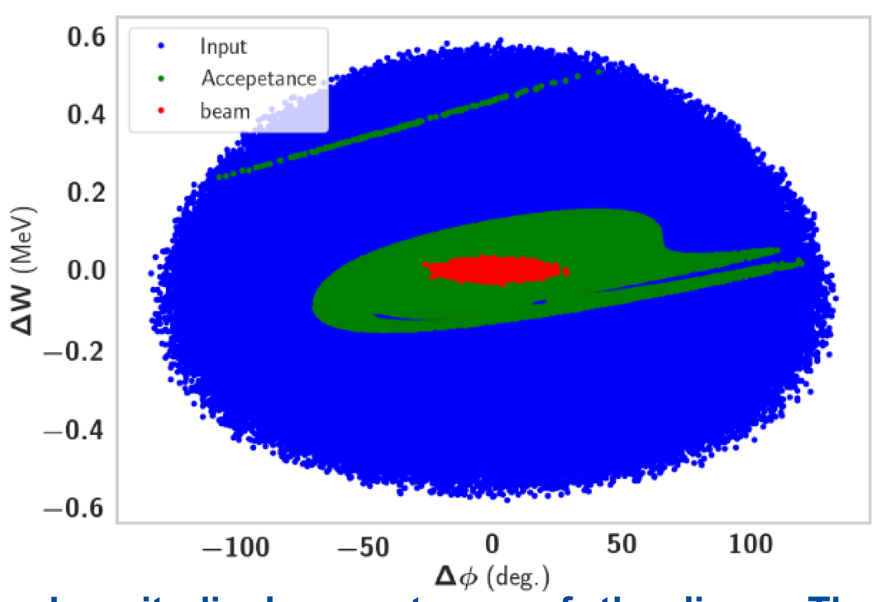
- **Acceptance**: The maximum size of the beam which can be transported through the linac without beam loss [3].
- Acceptance calculation is essential because of following reasons,
  - ❑ Beam loss has to be restricted within 1W/m.
  - ❑ Shrinkage in acceptance area has to be estimated at the location where frequency transition in the linac [4].
- For PIP-II SRF linac, acceptance calculations were done using TraceWin [4] for **(a) Longitudinal** and **(b) Transverse** planes.



Block diagram representation of the PIP-II linac [1][2]. Red coloured blocks represent warm sections whereas blue painted blocks showed superconducting sections operating at 2 K. Acceptance calculations were carried out for the superconducting part of the linac starting from HWR section.

Longitudinal Acceptance

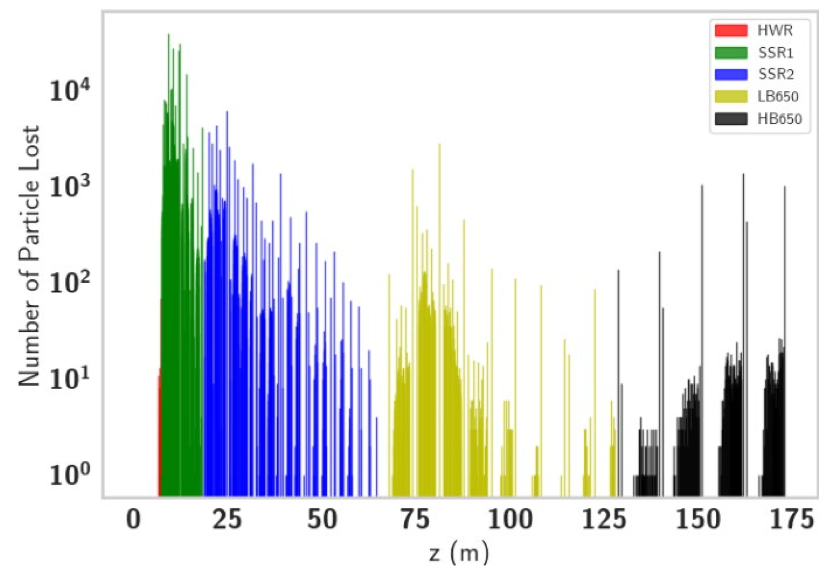
- Nominal optics without any misalignment errors was used.
- An artificial beam with large number of macro particles (~7x10^5) was created by setting initial longitudinal emittance very high in comparison with the nominal emittance.
- Transverse emittance was kept at minimum to avoid any loss in the transverse plane.
- Particle distribution at linac entrance was plotted on a phase space and surviving particles were identified and highlighted with a different color to show the acceptance area.



Longitudinal acceptance of the linac. The beam falls well within the acceptance region.

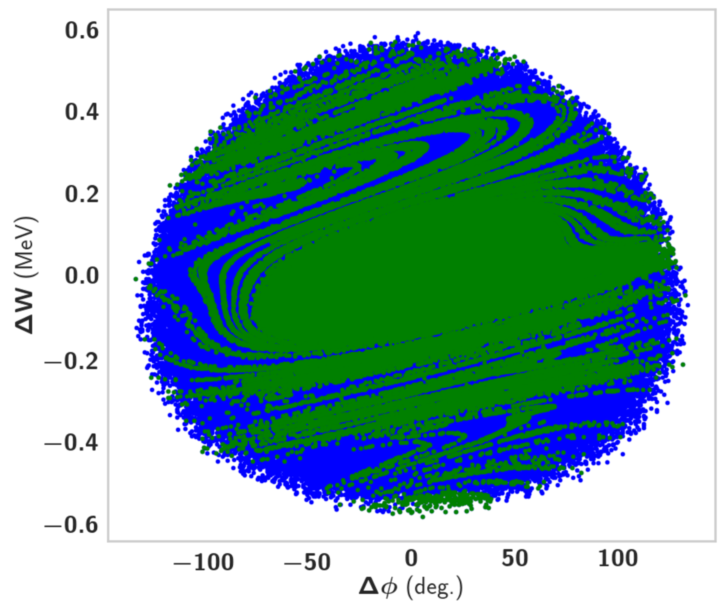
Particle Loss along the Linac

The minimum loss occurs in the HWR section (~0.02%) while maximum loss happens in the SSR1 section (~82.8%). A significant amount ~14.3% of the beam is also lost in SSR2 section. Very small (~1.5%) beam is lost in LB650 and HB650 sections.

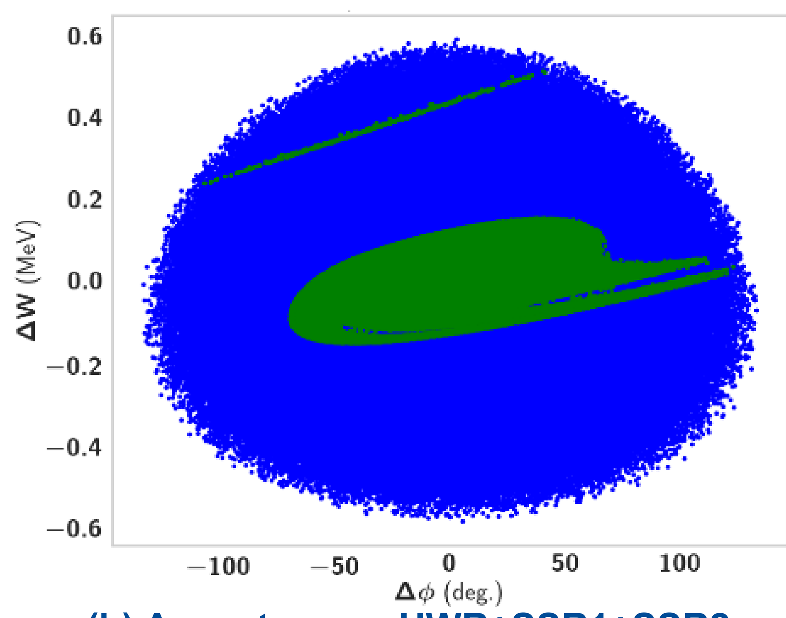


Evolution of Acceptance Area in phase space through the linac

- acceptance of the linac shrinks rapidly due to SSR1 section.
- When the linac is modified to include SSR2 section along with HWR and SSR1, the acceptance region shrinks further more as shown in the Fig (b).
- LB650 and HB650 sections have very small effect on the acceptance area.



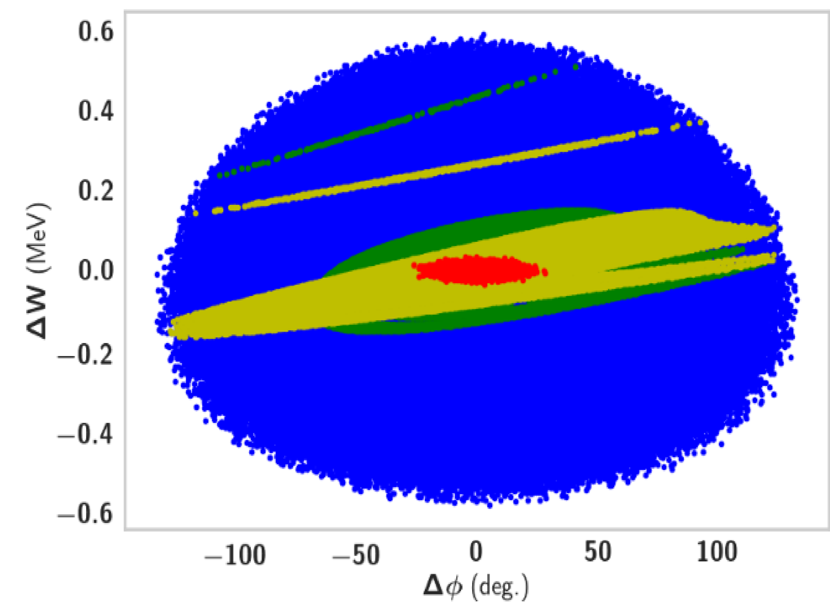
(a)Acceptance – HWR+SSR1 Section



(b) Acceptance – HWR+SSR1+SSR2 Section

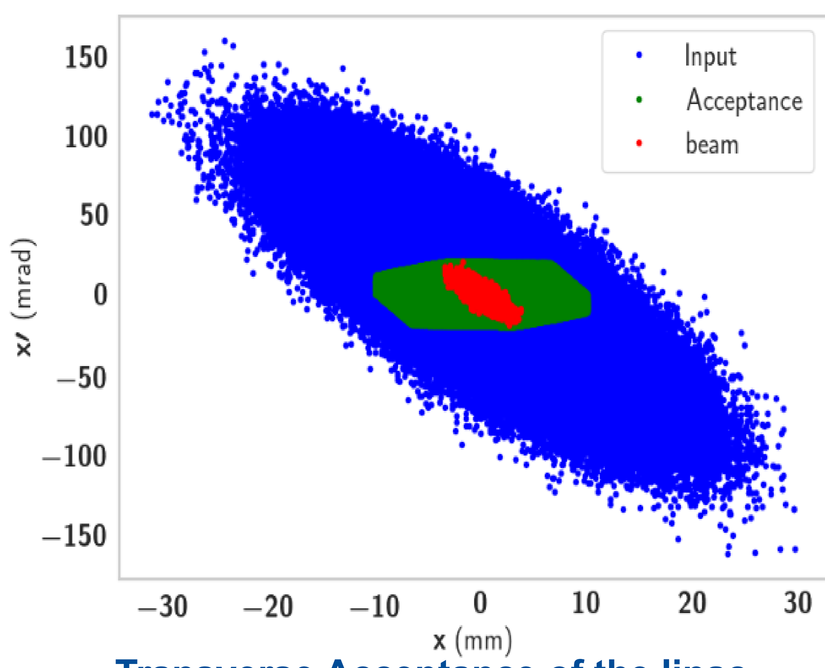
Effect of 1st Cavity failure in HWR Section

Longitudinal acceptance of the linac gets disturbed when first cavity of the HWR section is failed. It should be noted that acceptance with cavity failure (yellow) has distorted shape in comparison to the acceptance without any failure (green). The beam (red) still falls within the new acceptance area.



Transverse Acceptance

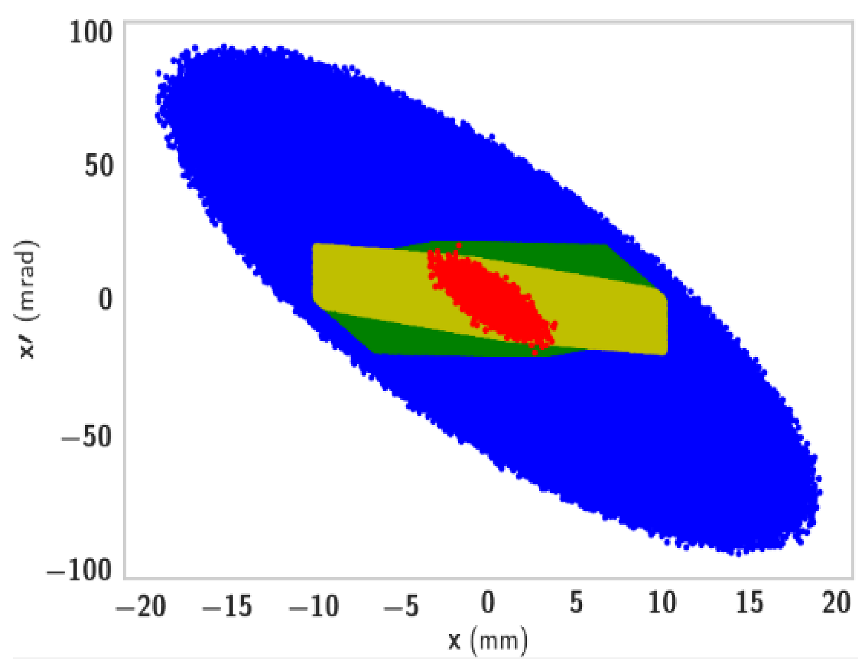
- Transverse acceptance reflects the beam restrictions in the transverse plane.
- For the calculations, the artificial beam was created with very high transverse emittance and small longitudinal emittance.
- Acceptance area is plotted in the following figure and it can be observed that the beam is located within the acceptance area.



Transverse Acceptance of the linac.

Effect of 1st Solenoid failure in HWR Section

Effect of solenoid failure on the transverse acceptance. Nominal acceptance is shown in green and acceptance after 1st sol. failure is shown in yellow. The acceptance are rotates in the plane yet the beam still resides inside it.



Conclusions

- In the phase space plots, the beam falls within the acceptance region for both cases - longitudinal and transverse.
- SSR1 and SSR2 are the most sensitive area of the linac where acceptance shrinkage happens.
- Failure of beamline element (cavity and solenoid) has adverse impact on the acceptance region.
- The acceptance area is still sufficient to transport the beam without loss.

References

[1] The DUNE Collaboration, "CDR Volume 1: The LBNF and DUNE Projects," tech. rep., 2015.
[2] PIP-II Conceptual Design Report, 2017.
[3] Martin Reiser, "Theory and Design of Charged Particle" WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2008
[4] http://irfu.cea.fr/dacm/logiciels/
[5] A. Saini et al., "Calculation of Acceptance of High Energy Superconducting Proton Linac for Project-X", in FERMILAB-CONF-11-123-APC.

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