Progress on the Multi-Ion Injector Linac Design

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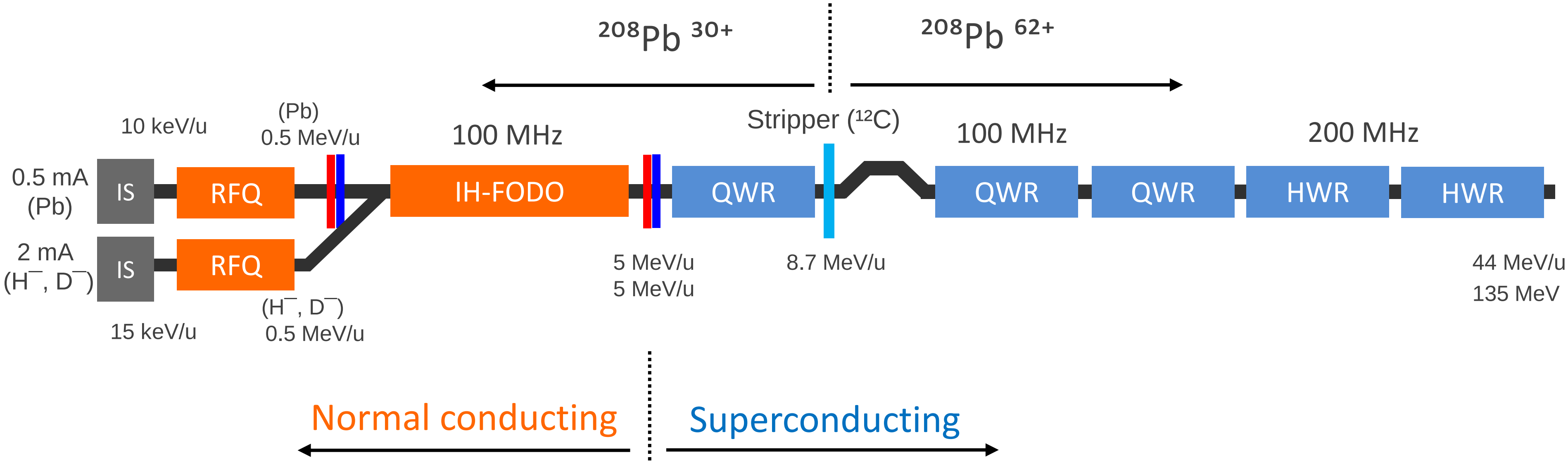
Outline

- Recent Updates to the Ion Linac Design
  - Two RFQs: One for light ions & one for heavy ions
  - IH-DTL: No frequency jump & FODO lattice instead of triplets
  - Two LEBTs designed for light & heavy ion beams

- Design of Different Linac Sections
  - LEBTs
  - RFQs
  - IH-FODO
  - SRF Linac

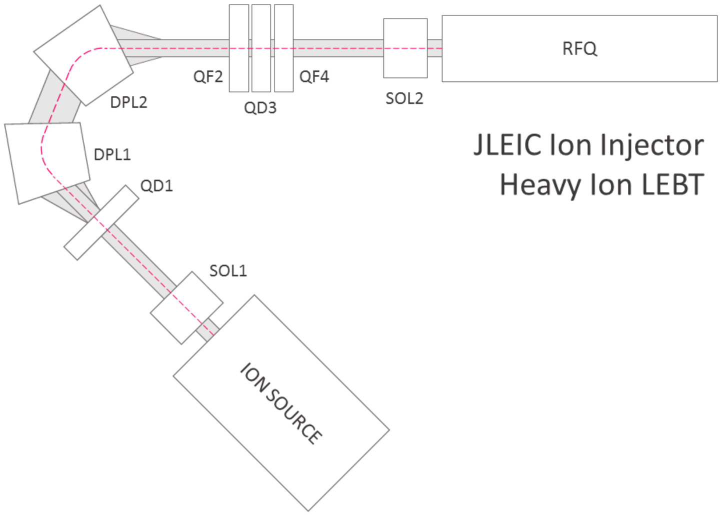
- Very Preliminary: Alternative Options for the JLEIC Ion Complex
  - Compact 3 GeV Booster (Octagonal or Race-Track)
  - Electron Ring as Ion Booster: 3 Possible Scenarios/Energies
  - Possible Collider Staging: 60 GeV with RT to 200 GeV with SC magnets

Updated Linac Design & Layout



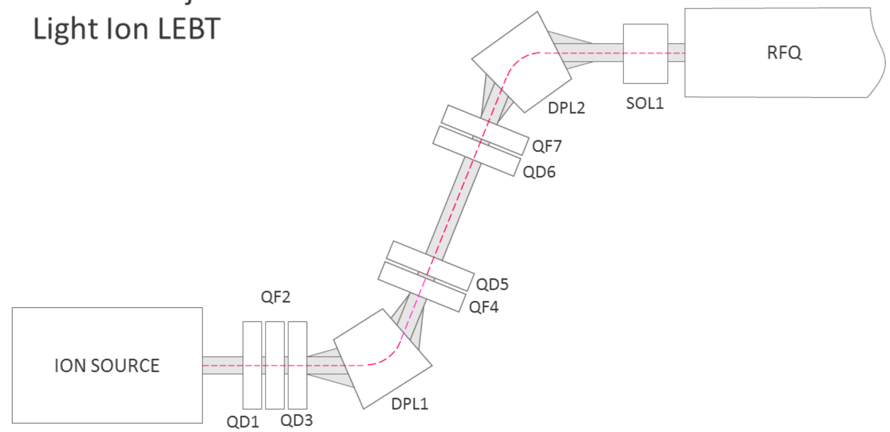
- Two RFQs: For light ions (q/A ~ 1/2) and for heavy ions (q/A ~ 1/7)
  - Different emittances and voltage requirements for polarized light ions and heavy ions
- Selected RT Structure: IH-DTL with FODO Lattice instead of Triplets
  - No Frequency jump & FODO focusing → Significantly better beam dynamics
- Separate LEBTs and MEBTs for light and heavy ions
- Stripper and SRF section are the same

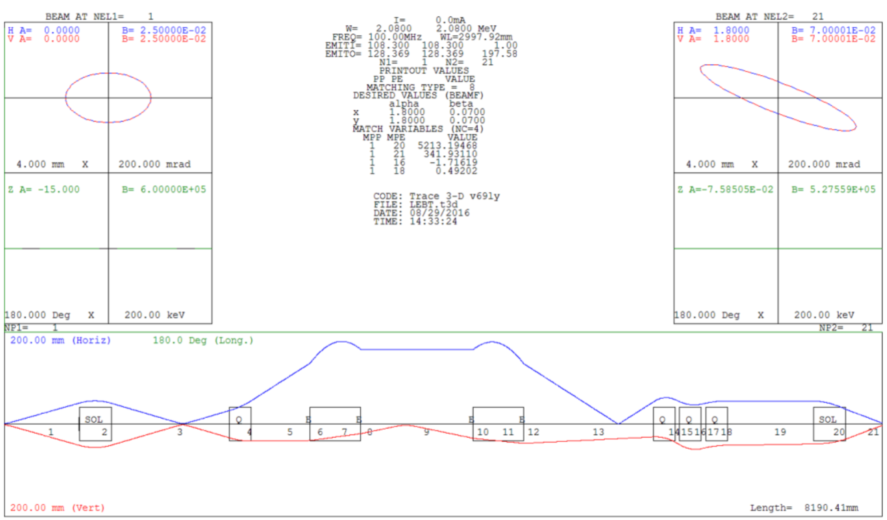
LEBTs: From Ion Sources to the RFQs

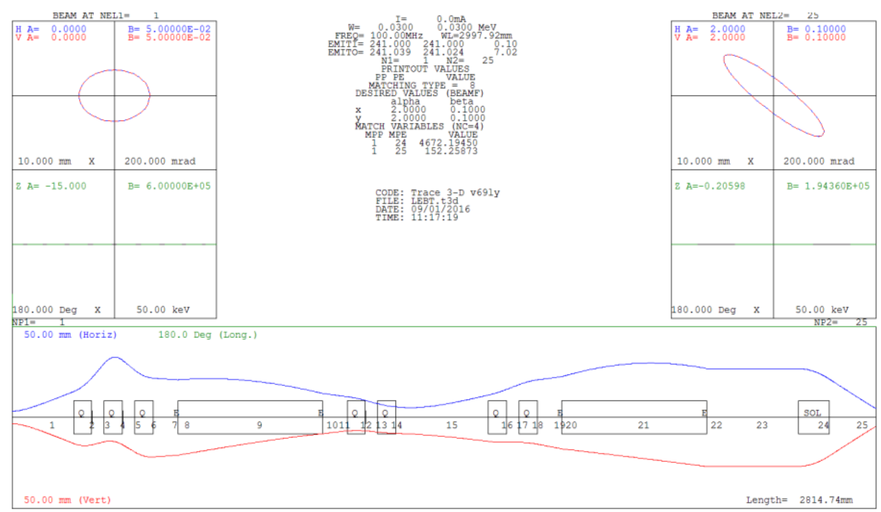


JLEIC Ion Injector
Heavy Ion LEBT

JLEIC Ion Injector
Light Ion LEBT



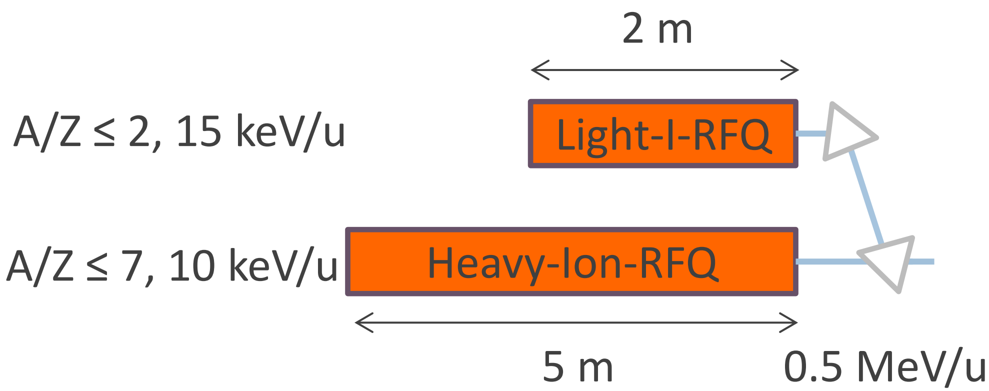




Similar to CERN Linac3 LEBT

Similar to BNL LEBT

Two Separate RFQs for Light Ions and Heavy Ions

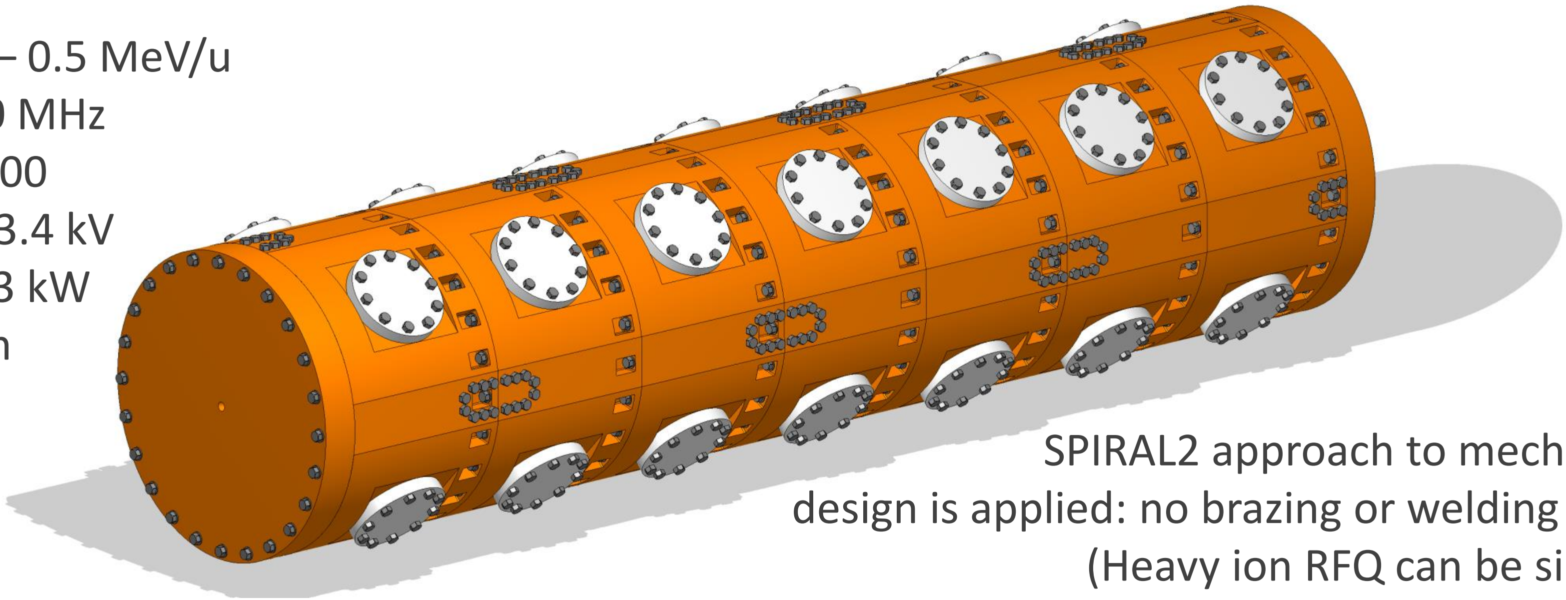


- ✓ Light-Ion RFQ is designed for polarized beams with **2 π** mm mrad normalized transverse emittance
- ✓ Heavy-Ion RFQ is designed for ion with Z/A ≤ 7 with **0.5 π** mm mrad normalized transverse emittance

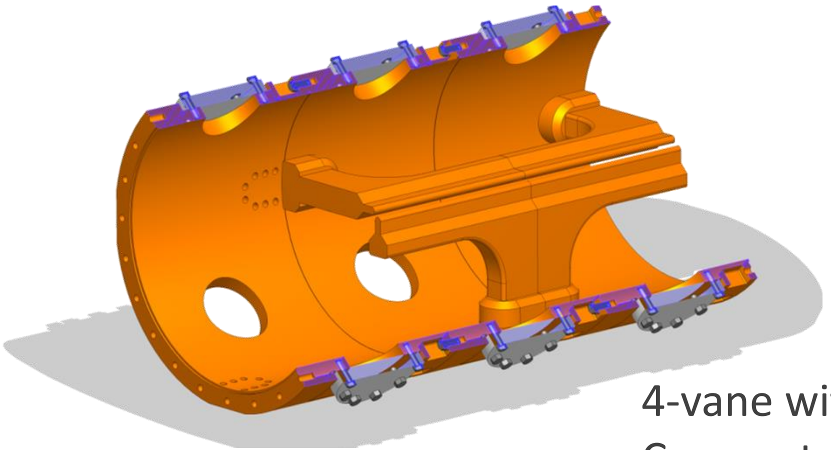
Parameter	Heavy ion	Light ion	Units
Frequency	100		MHz
Energy range	10 - 500	15 - 500	keV/u
Highest - A/Q	7	2	
Length	5.6	2.0	m
Average radius	3.7	7.0	mm
Voltage	70	103	kV
Transmission	99	99	%
Quality factor	6600	7200	
RF power consumption (structure with windows)	210	120	kW
Output longitudinal emittance (Norm., 90%)	4.5	4.9	π keV/u ns

Light Ion RFQ: Proposed Structure

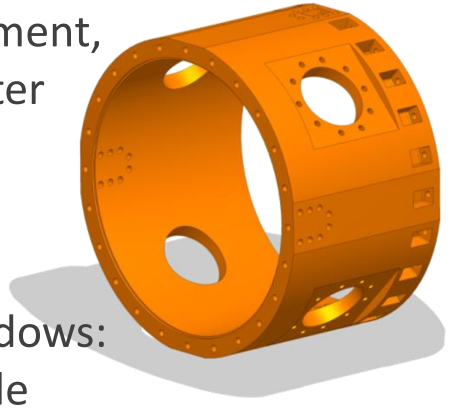
0.015 – 0.5 MeV/u
f = 100 MHz
Q = 9700
V = 103.4 kV
P = 113 kW
L = 2 m



SPIRAL2 approach to mechanical design is applied: no brazing or welding joints (Heavy ion RFQ can be similar)



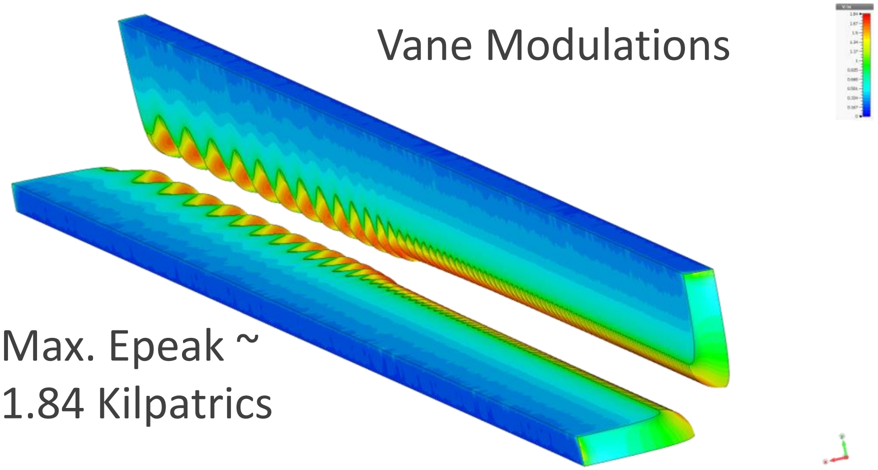
One RFQ segment, 40 cm diameter



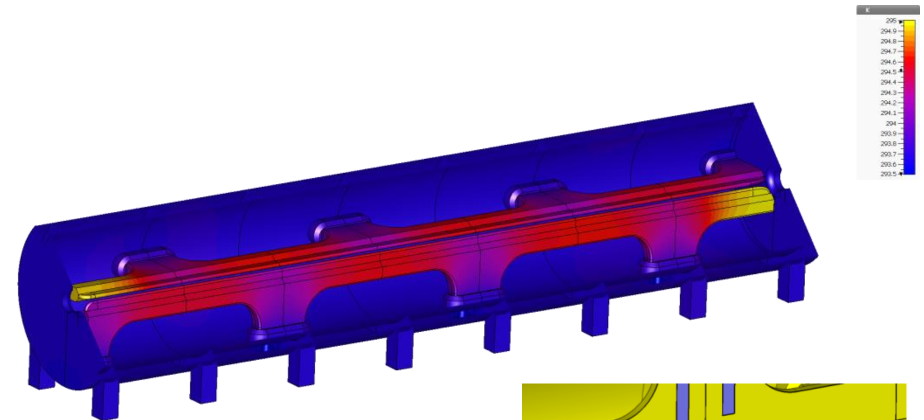
4-vane with magnetic coupling windows: Compact & Suitable for pulsed mode

Light Ion RFQ: 3D Modeling and Multi-Physics Analysis

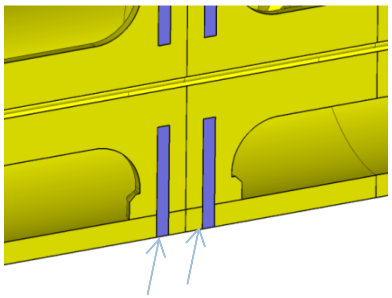
Vane Modulations



Max. Epeak ~ 1.84 Kilpatrics

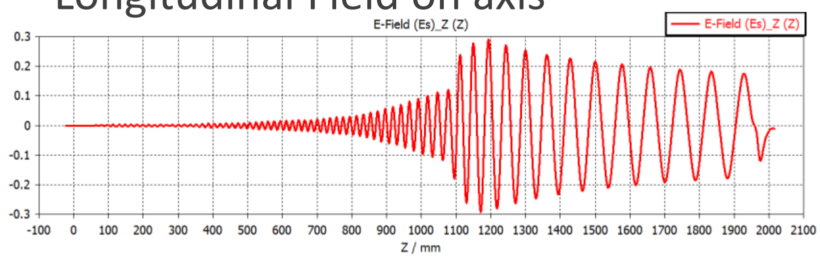


Temperature gradient is 1.5°C

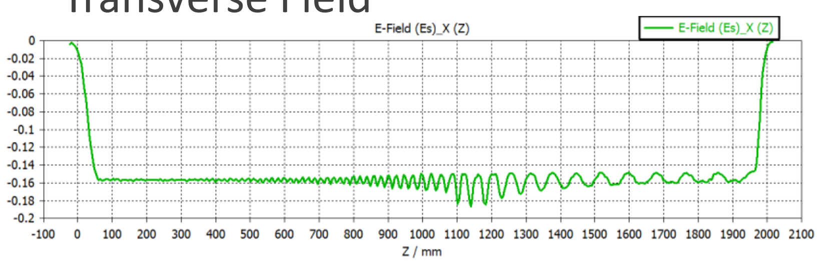


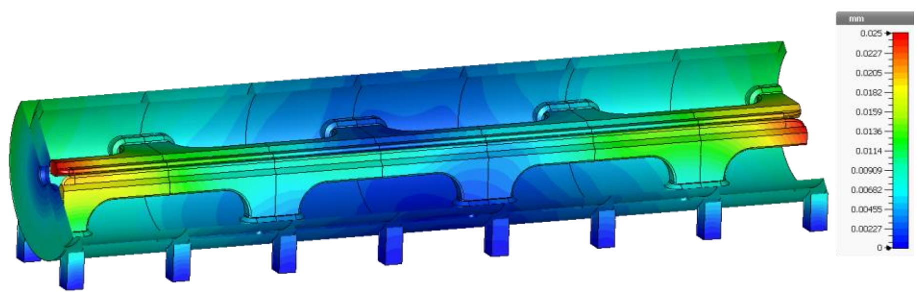
Cooling channels

Longitudinal Field on axis



Transverse Field

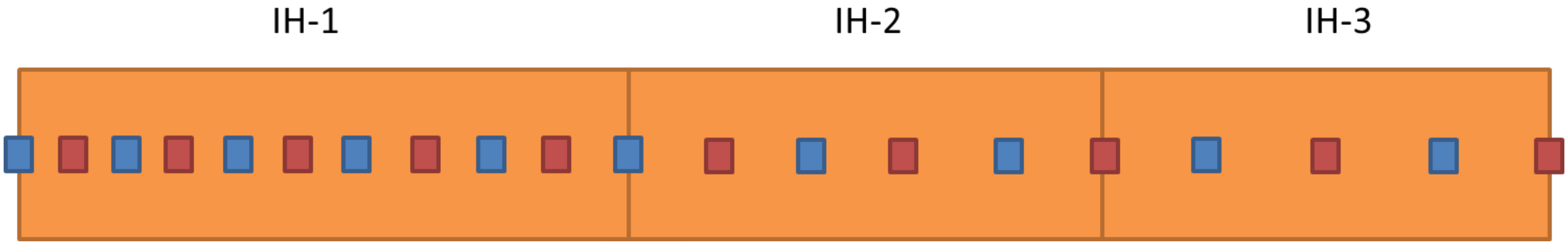


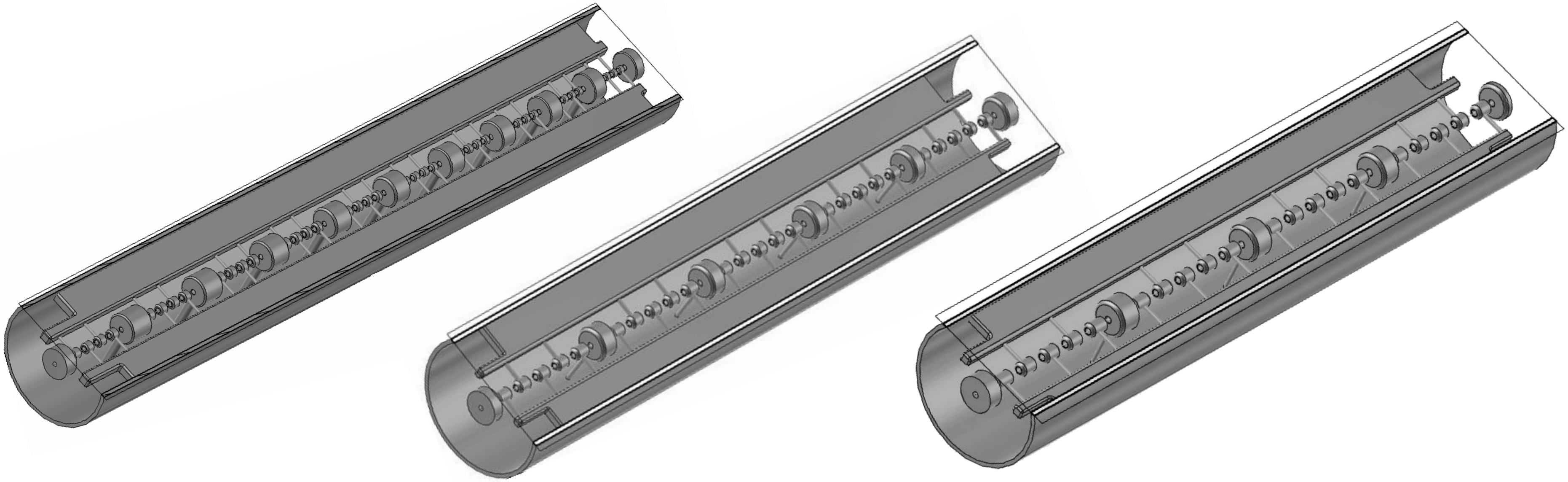


Deformation doesn't exceed 25 µm (includes gravity, atmospheric pressure and heating)

IH-DTL with FODO Focusing Lattice

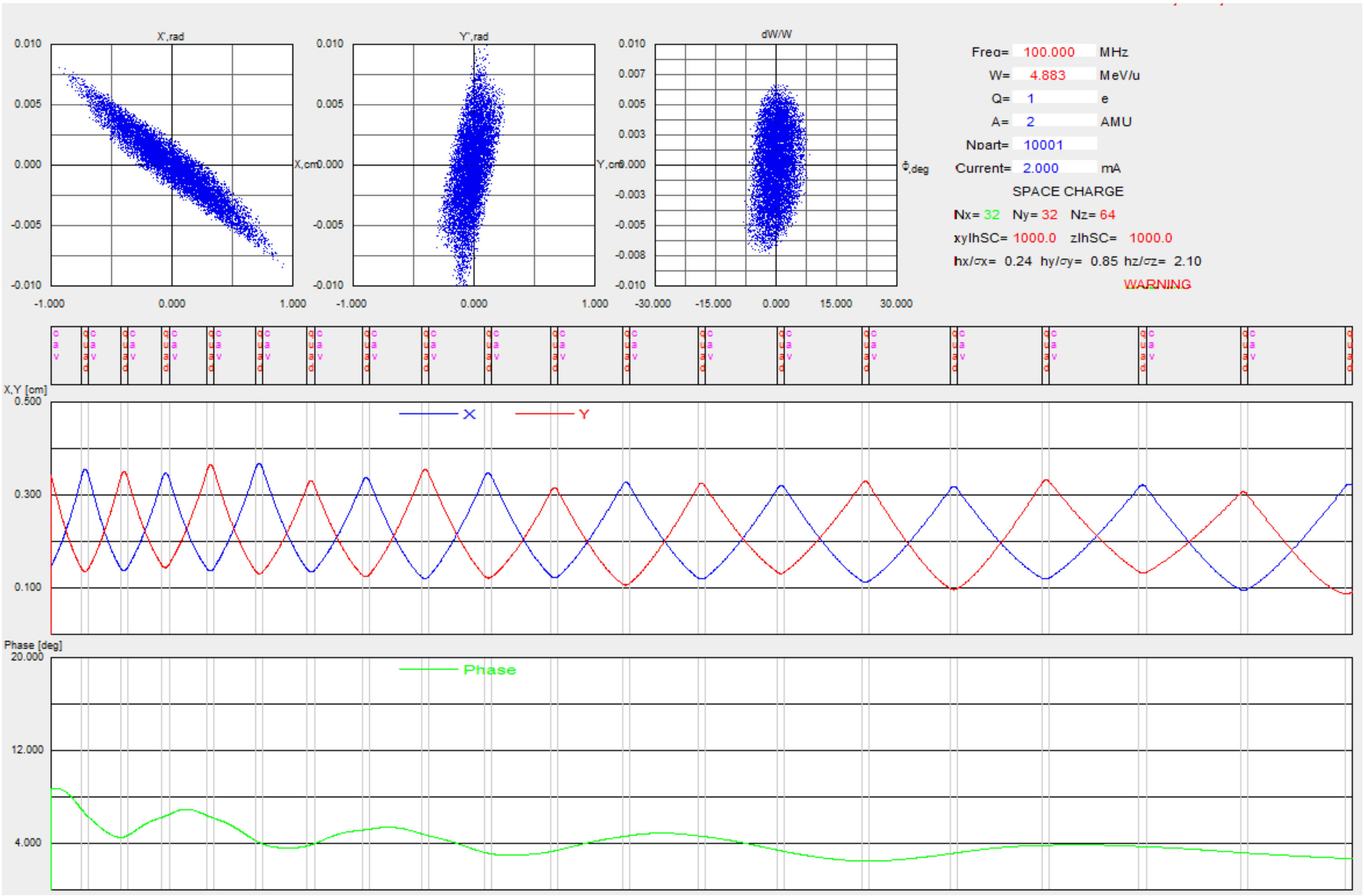
- ✓ 3 Tanks – 20 Quadrupoles in FODO arrangements





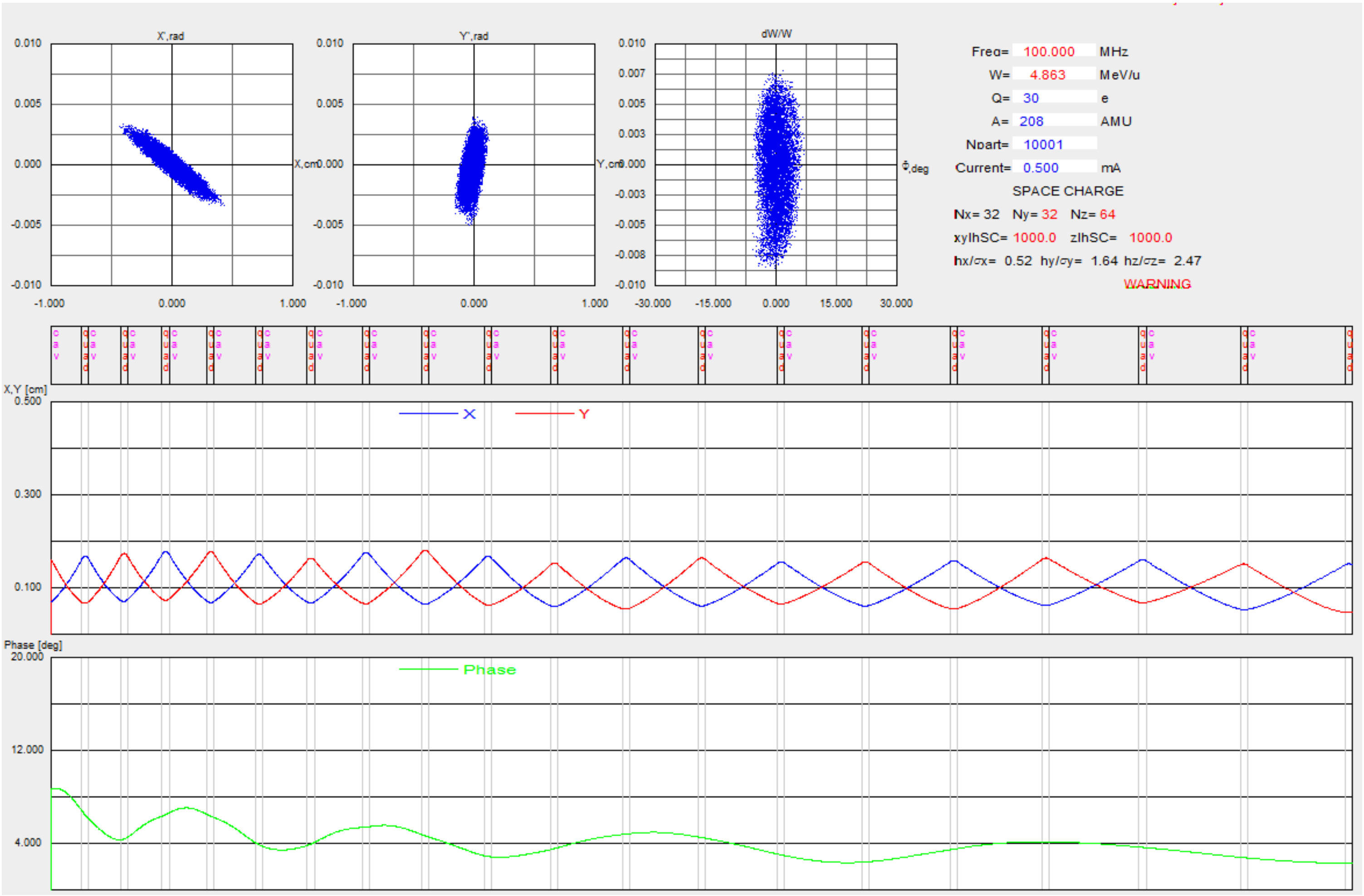
- ✓ Energy gain: 0.5 – 4.9 MeV/u = 30.5 MeV
- ✓ Total length: 4.3 + 3.5 + 3.4 m = 11.2 m
- ✓ Real-estate accelerating gradient: 2.72 MV/m
- ✓ RF Power losses: 280 + 400 + 620 = 1.3 MW

Light Ion Beam Dynamics in the IH-DTL



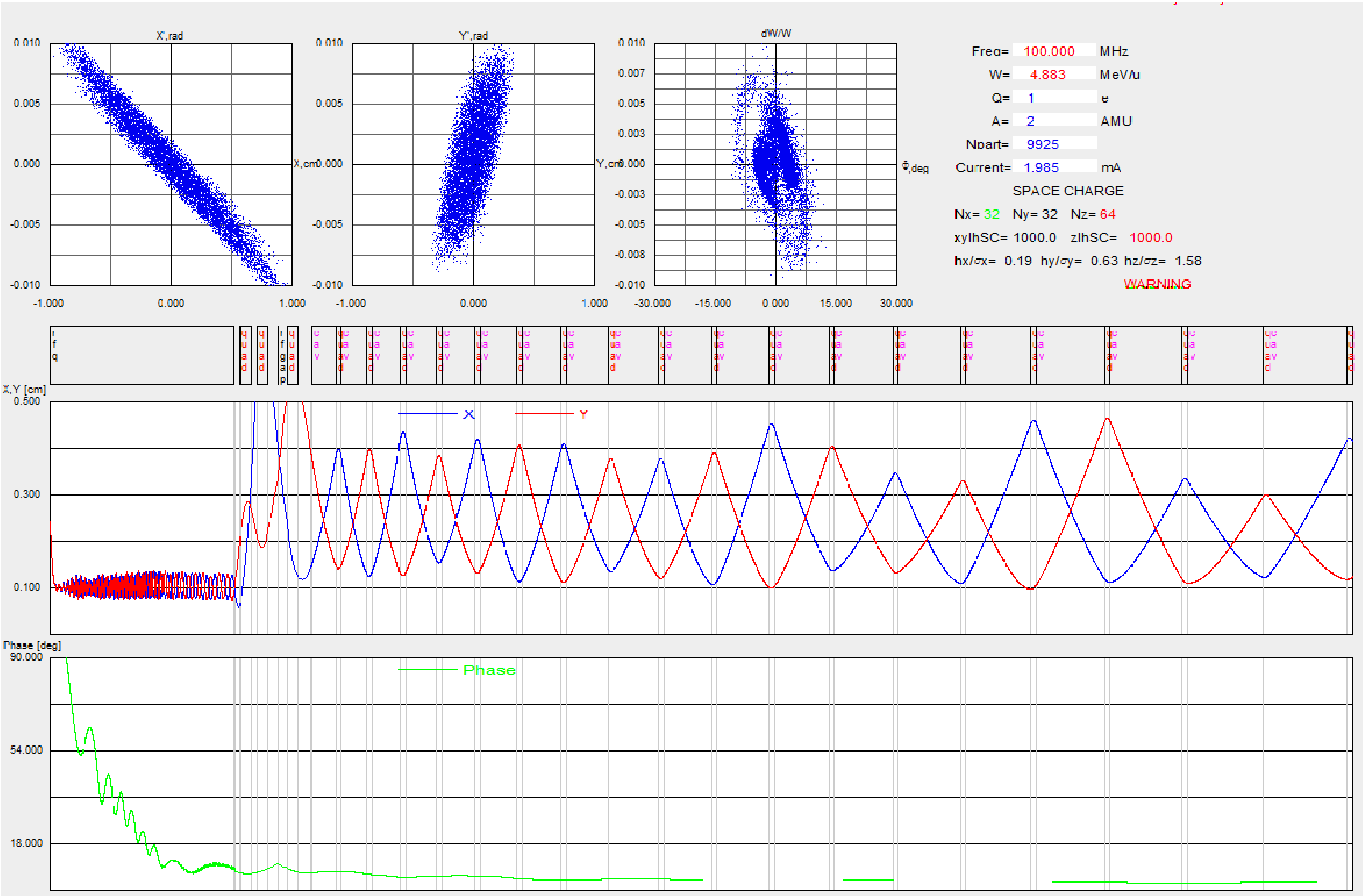
- ✓ Input beam: 0.5 MeV/u, polarized deuterons, 2 π.mm.mrad and 2 mA
- ✓ Output beam: ~ 5 MeV/u, 13% Transverse emittance growth – 0% Longitudinal

Heavy Ion Beam Dynamics in the IH-DTL

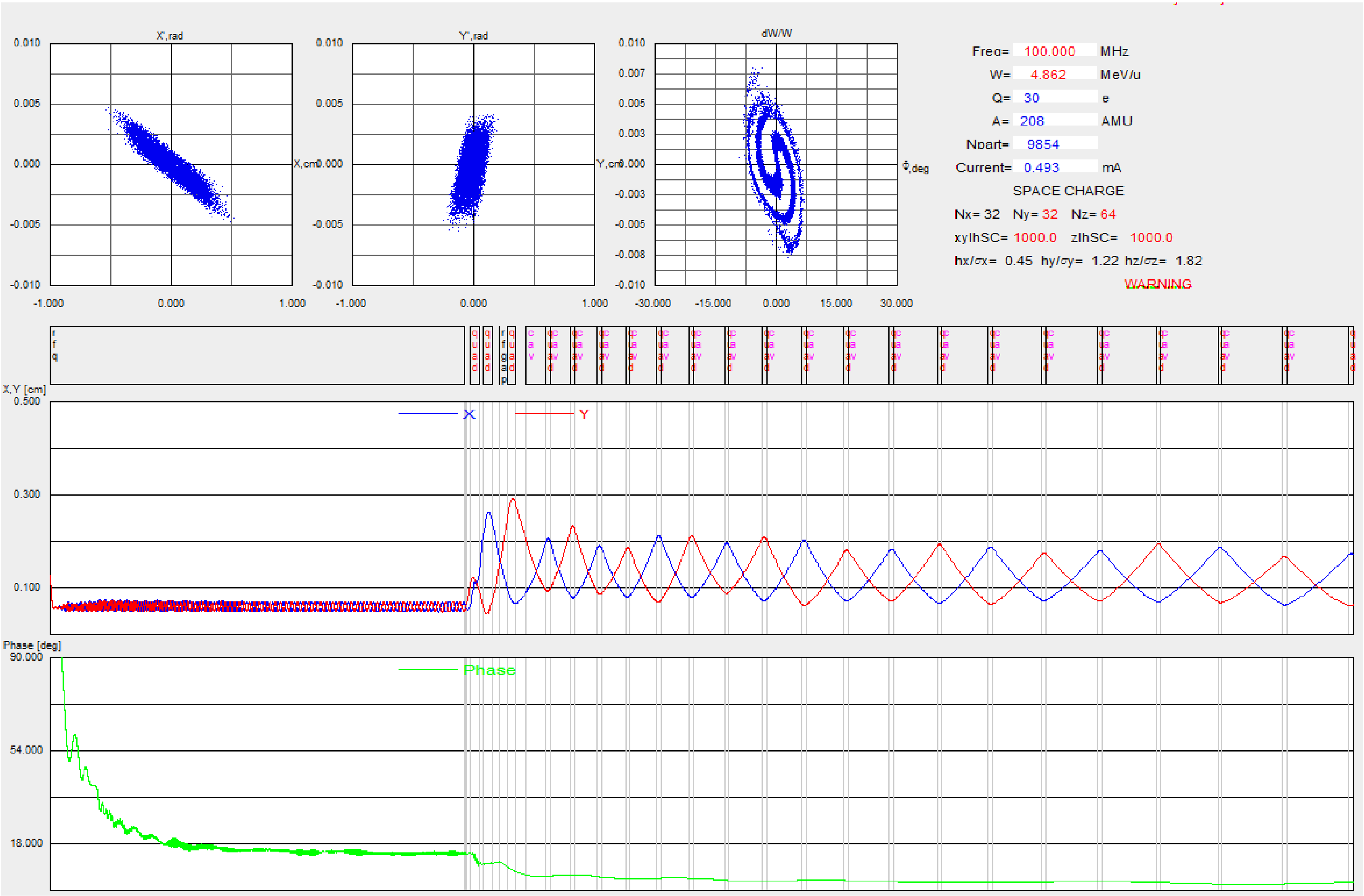


- ✓ Input beam: 0.5 MeV/u, lead ions, 0.5 π.mm.mrad and 0.5 mA
- ✓ Output beam: ~ 5 MeV/u, 10% Transverse emittance growth – 0% Longitudinal

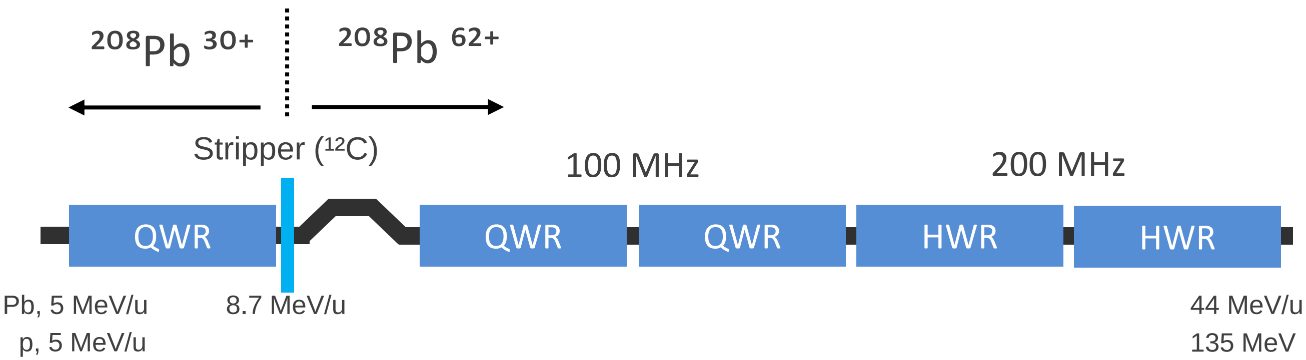
Deuterons Beam Dynamics in the RFQ + IH-DTL



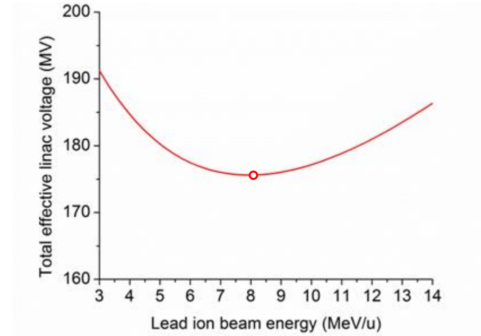
Lead Beam Dynamics in the RFQ + IH-DTL



Stripper and SRF Linac Section



Stripping Energy & Charge



QWR Module

HWR Module

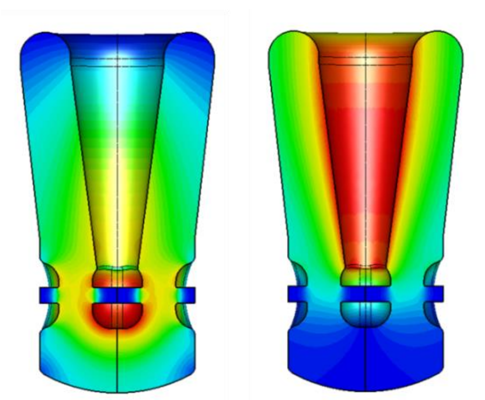
Horizonal orientation of cavities

@ 8.7 MeV/u: 30+ → 62+ → 44 MeV/u

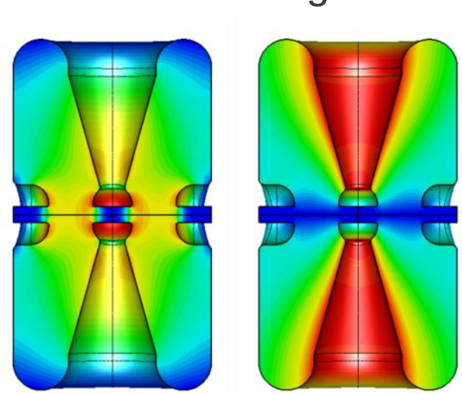
@ 13.3 MeV/u: 30+ → 67+ → 40 MeV/u

Parameter	QWR	HWR	Units
β_{opt}	0.15	0.30	
Frequency	100	200	MHz
Length (βλ)	45	45	cm
E_{PEAK}/E_{ACC}	5.5	4.9	
B_{PEAK}/E_{ACC}	8.2	6.9	mT/(MV/m)
R/Q	475	256	Ω
G	42	84	Ω
E_{PEAK} in operation	**57.8**	**51.5**	**MV/m**
B_{PEAK} in operation	**86.1**	**72.5**	**mT**
E_{ACC}	**10.5**	**10.5**	**MV/m**
Phase (Pb)	-20	-30	deg
Phase (p/H^-)	-10	-10	deg
No. of cavities	21	14	

QWR Design



HWR Design

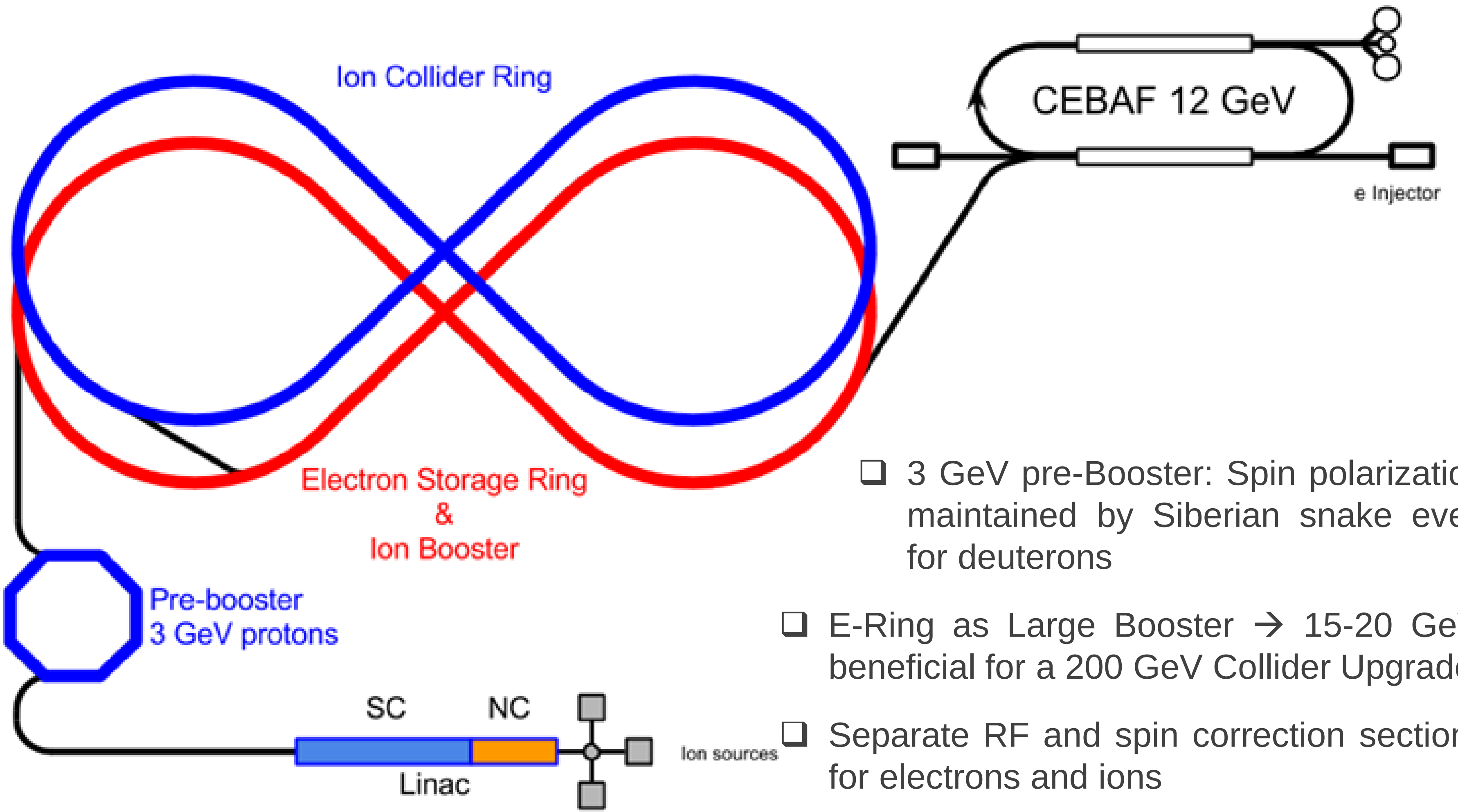


Very Preliminary: Alternative Options for the JLEIC Ion Complex

Motivations / Driving Forces

- Reduce the footprint of the Ion Complex → Potential cost saving
  - Compact ring as pre-booster (3 GeV, RT, no figure-8 required)
  - Consolidate: Use electron ring as large ion booster (10-20 GeV)
- Lower the risk of the project by using proven technology of room-temperature or fully superconducting magnets
- Possible Staging of the project
  - First Stage: 60 GeV Collider with RT magnets only (Cost effective)
  - Second Stage: Upgrade to 200 GeV with fully superconducting

Layout of A Possible Alternative …



- ❑ 3 GeV pre-Booster: Spin polarization maintained by Siberian snake even for deuterons
- ❑ E-Ring as Large Booster → 15-20 GeV, beneficial for a 200 GeV Collider Upgrade
- ❑ Separate RF and spin correction sections for electrons and ions

- The Electron Storage Ring and Ion Collider Ring are stacked vertically in one tunnel
- Ion injection from the booster (e-ring) to the ion collider ring is a vertical bend

Electron Ring As Large Booster: 3 Scenarios

PEP-II Magnets

Proton energy ~ 11 GeV
Lead energy ~ 3.8 GeV
Proton above transition
in collider ring, ions NOT

Limited by dipole field
(0.36 T for PEP-II Magnets)

…

New Magnets for low-emittance version

Proton energy ~ 15 GeV
Lead energy ~ 5.4 GeV
Proton above transition
in collider ring, ions NOT

Limited by RT quad gradient
(20-25 T/m for RT)

…

New Magnets for higher ions energy & low emi.

Proton energy ~ 20 GeV
Lead energy ~ 7.5 GeV
Proton above transition
in collider ring, Lead NOT

Similar or shorter dipoles than
low-emittance option for higher γ_{tr}

Requires ~ 25% longer or
25% smaller RT quad aperture

Consequences on electrons …

✓ In all of these options, ion beams remain below transition in the e-ring = large ion booster

Possible Staging with RT than SC Magnets

- First Stage: Fully RT Magnets → 60 GeV Collider, possible with
  - 130 MeV Linac
  - 3 GeV Pre-Booster
  - 11 GeV Large Booster (E-ring with PEP-II Magnets)
  - 60 GeV Ion Collider Ring

- Second Stage: SC Magnets in Collider Ring → 200-250 GeV Collider
  - 130 MeV Linac
  - 3 GeV Pre-Booster
  - 15-20 GeV Large Booster (E-ring with New RT Magnets)
  - 200-250 GeV Ion Collider Ring with SC Magnets

Summary & Future Work

- Significant progress has been made in the design of the Injector Linac
- Two separate RFQs are use for light and heavy ions
- IH-DTL structure with FODO focusing lattice produced very good beam dynamics both longitudinally and transversely
- Just started investigating possible alternative options for the JLEIC Ion Complex
- First order: E-ring could be used as large booster for the ions … more detailed work needed …
- Possibility of Staging with first RT than SC magnets in Collider Ring