DESIGN AND BEAM DYNAMICS STUDIES OF A MULTI-ION LINAC INJECTOR FOR THE JLEIC ION COMPLEX

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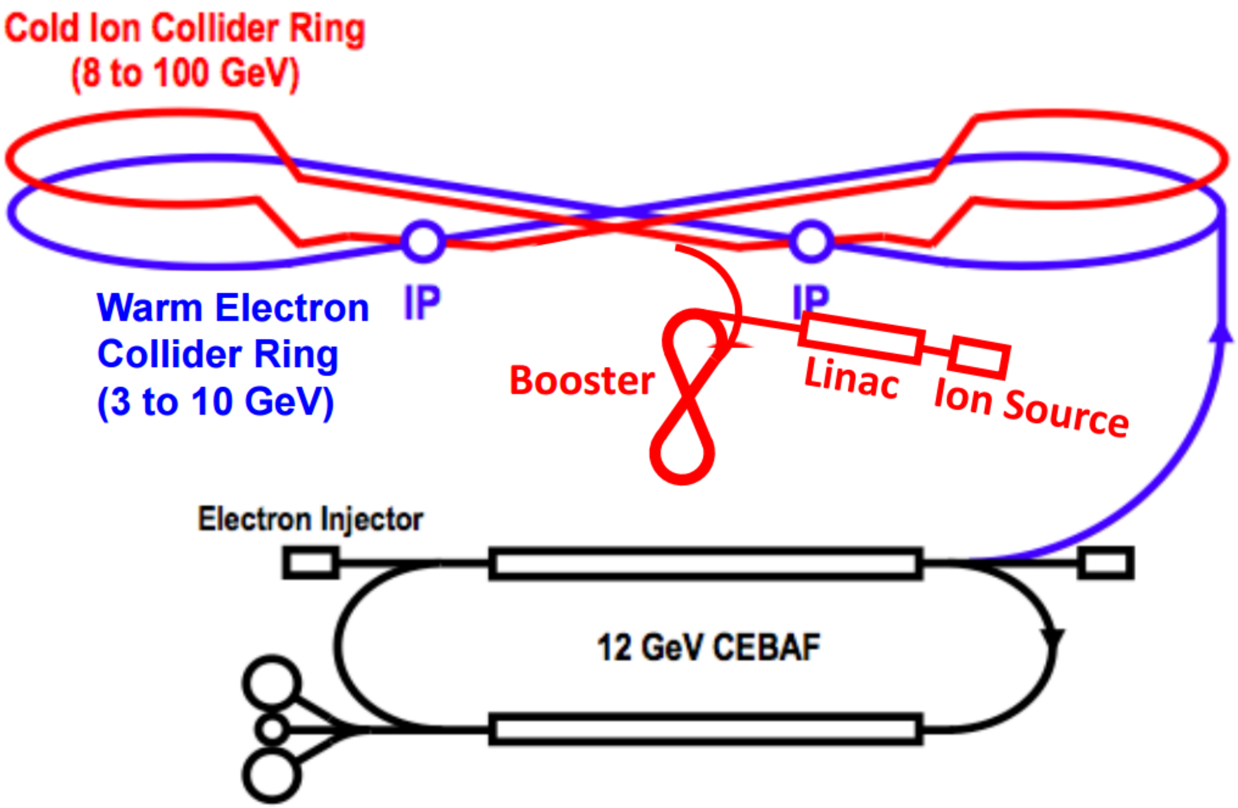
Outline

- JLAB-based Electron Ion Collider
- Multi-ion pulsed injector Linac
- Key Linac Components
  - Heavy-ion source
  - Polarized light ion sources
  - Normal Conducting RFQ
  - IH Structure / RF Focusing Structure
  - High Performance Superconducting QWRs and HWRs
  - Optimized Stripping Energy & Charge State
- End-to-End Beam Dynamics

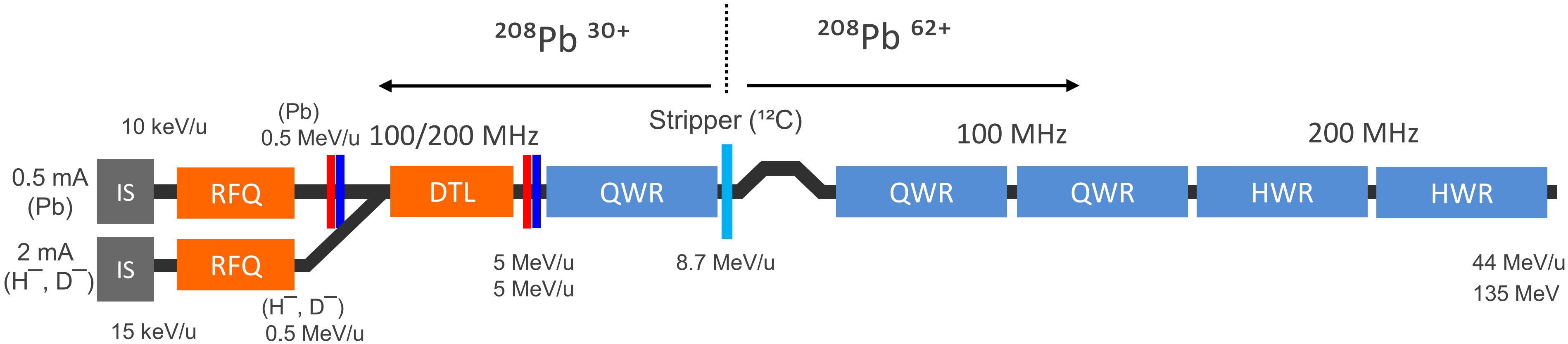
JLAB-Based Electron-Ion Collider



CEBAF is a full energy injector.

(Courtesy of F. Pilat)

Linac Design: Layout & Key Components



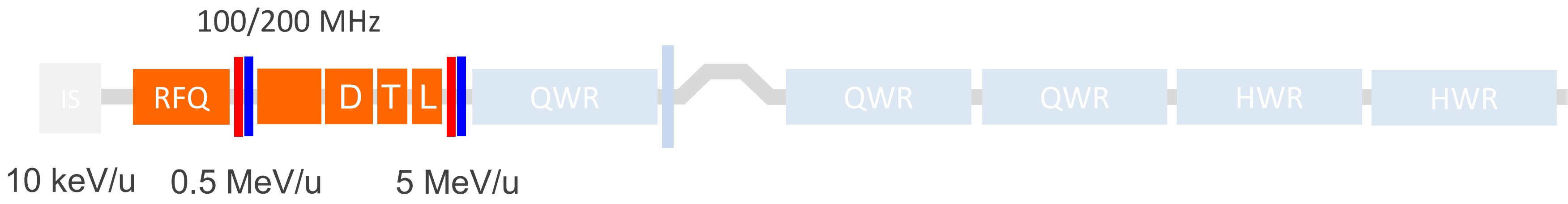
Normal conducting | Superconducting

QWR

HWR

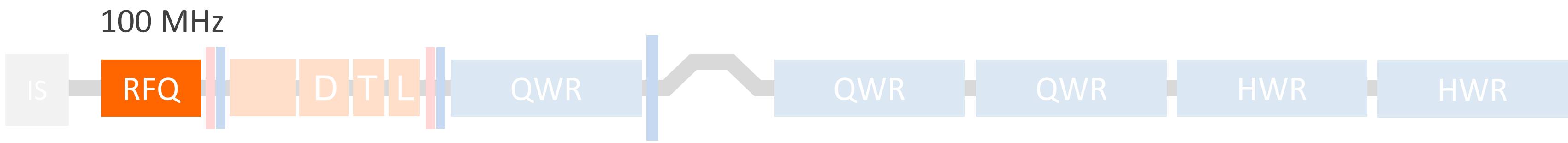
Horizonal orientation of cavities

- A stripper for heavy ions for more effective acceleration: $Pb^{30+ \rightarrow 62+}$
  - An option of stripping to Pb^{67+} is also investigated
  - H^- and light ions will be polarized
- Repetition rate: 10 Hz (Pb) and 5 Hz (H^-)
- Total linac length is ~ 50 m



RT section

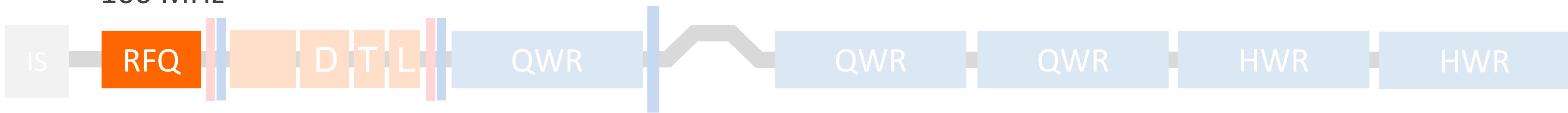
Normal Conducting Front-End: RFQs



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

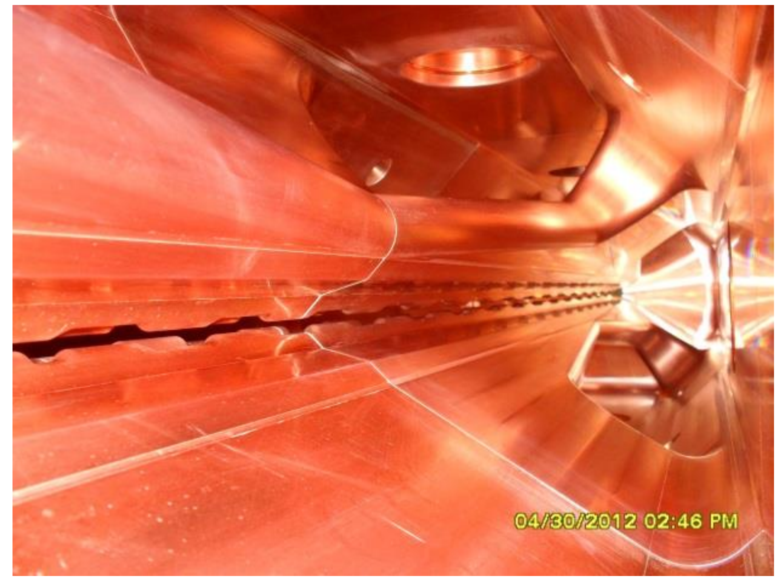
Normal Conducting Front-End: RFQ

100 MHz



✓ 4-vane with coupling windows

4-rod



(Courtesy of J. Alessi)

Maximum A/Q:	~ 7
Frequency:	100 MHz
Energy:	10 – 500 keV/u
Voltage:	70 kV
Average radius:	3.7 mm
Length:	5.6 m
Power consumption:	210 kW

BNL's Heavy Ion 4-Rod RFQ

- Designed and built by Alvin Schempp
- 300 keV/u, A/Q=6

(Courtesy of J. Alessi)

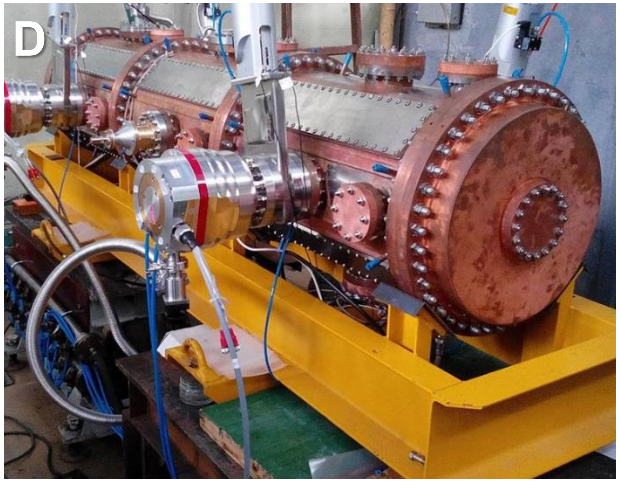
Examples of Operating 4-vane Window-Coupled RFQs

The structure is proven by operation of several linacs:

ATLAS CW RFQ, 60 MHz, A/Q=7 (ANL, USA)

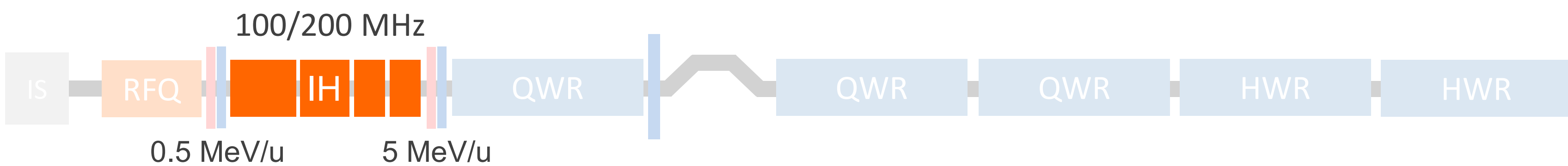
Heavy Ion Prototype, 27 MHz, A/Q=60 (ITEP, Moscow)

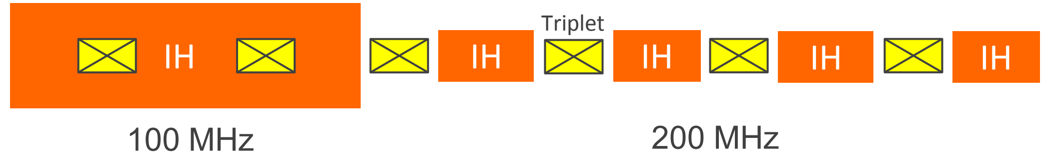
Heavy Ion Injector, 81 MHz, A/Q=3 (ITEP, Moscow)



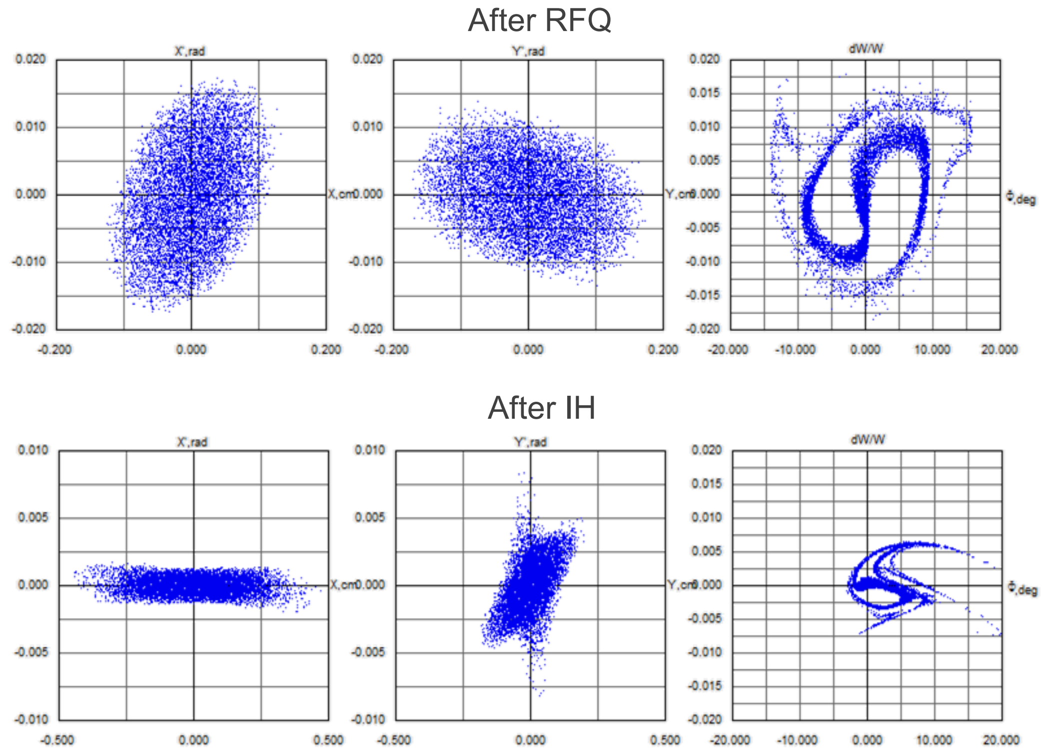
Light Ion Injector, 145 MHz, A/Q=3 (JINR, Dubna)

Normal Conducting Front-End: IH Structure



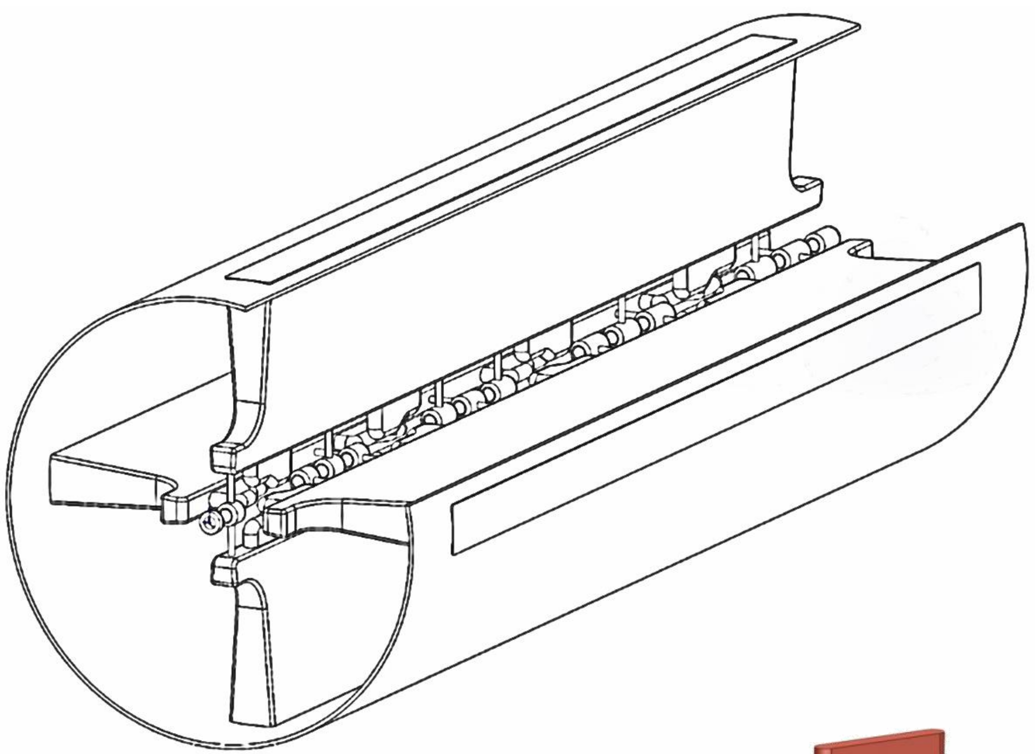


BNL EBIS Injector 100 MHz IH Structure
(Courtesy of J. Alessi)

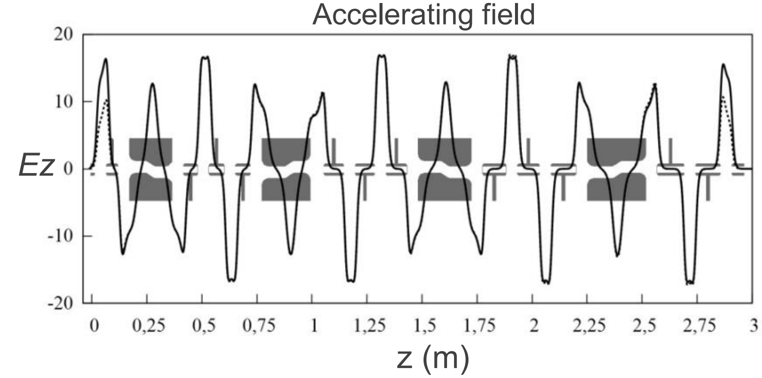


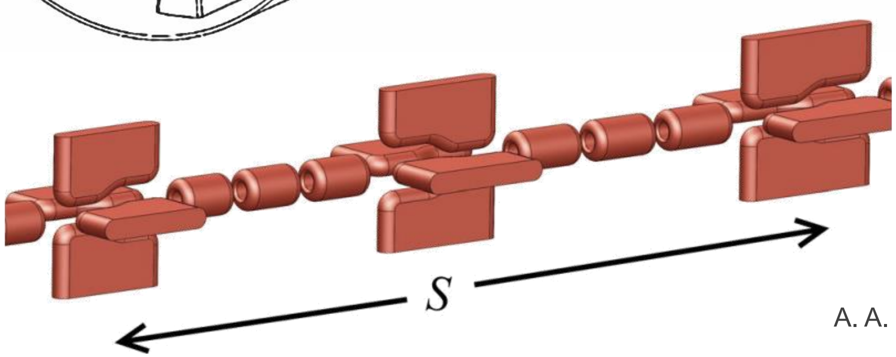
RF Focusing Structure: Alternative Option to IH-DTL

Spatially Periodic RF Quadrupole Linac



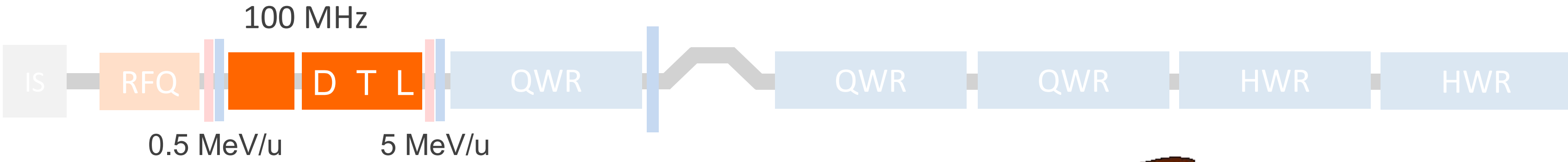
- In this velocity range, focusing by RF fields is very efficient
- Conventional longitudinal beam dynamics can be applied
- Real-estate accelerating gradient can be high as in IH structure
- Beam quality is better than in IH structure
- The resonator is 4-vane type as in a conventional RFQ

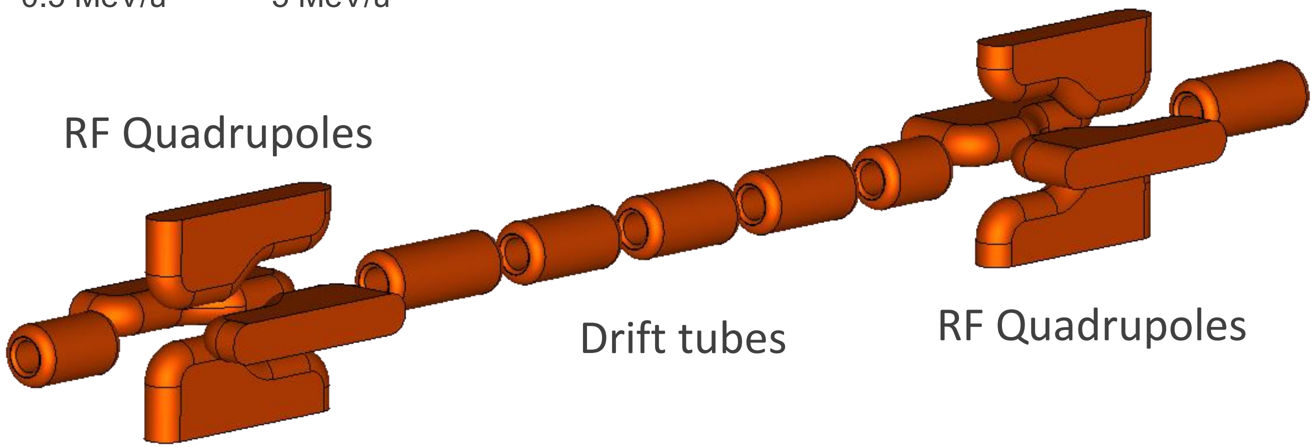




Spatially periodic radio-frequency quadrupole focusing linac
A. A. Kolomiets and A. S. Plastun, Phys. Rev. ST Accel. Beams **18**, 120101

Normal Conducting Front-End: RF Focusing Structure

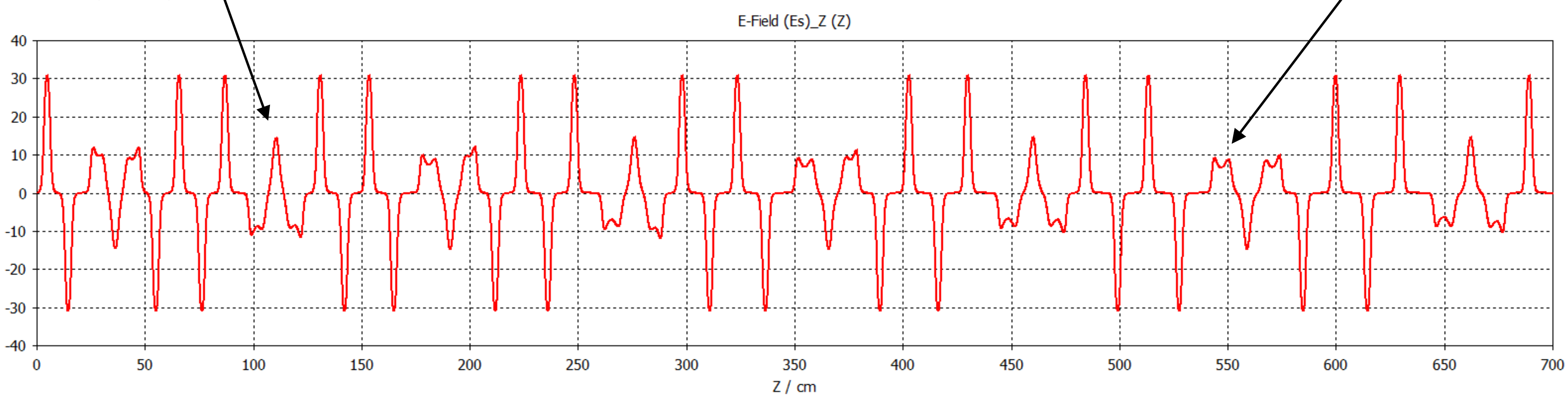


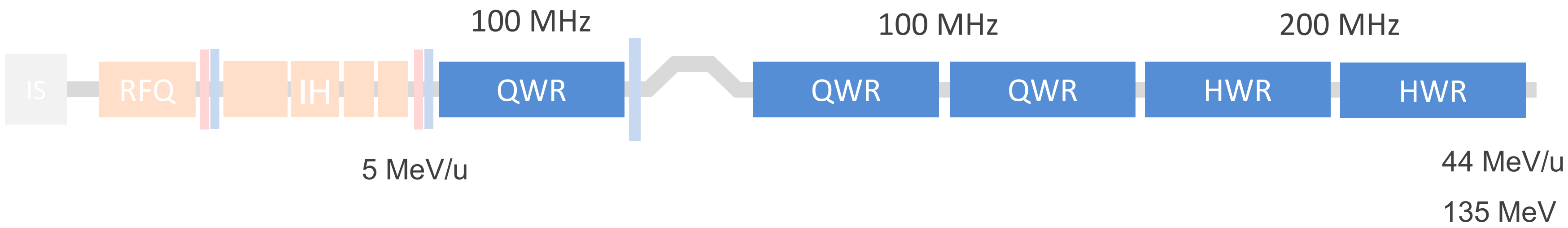


Accelerating field inside RF quadrupole

Accelerating field distribution

Accelerating field between RF quadrupole and drift tube





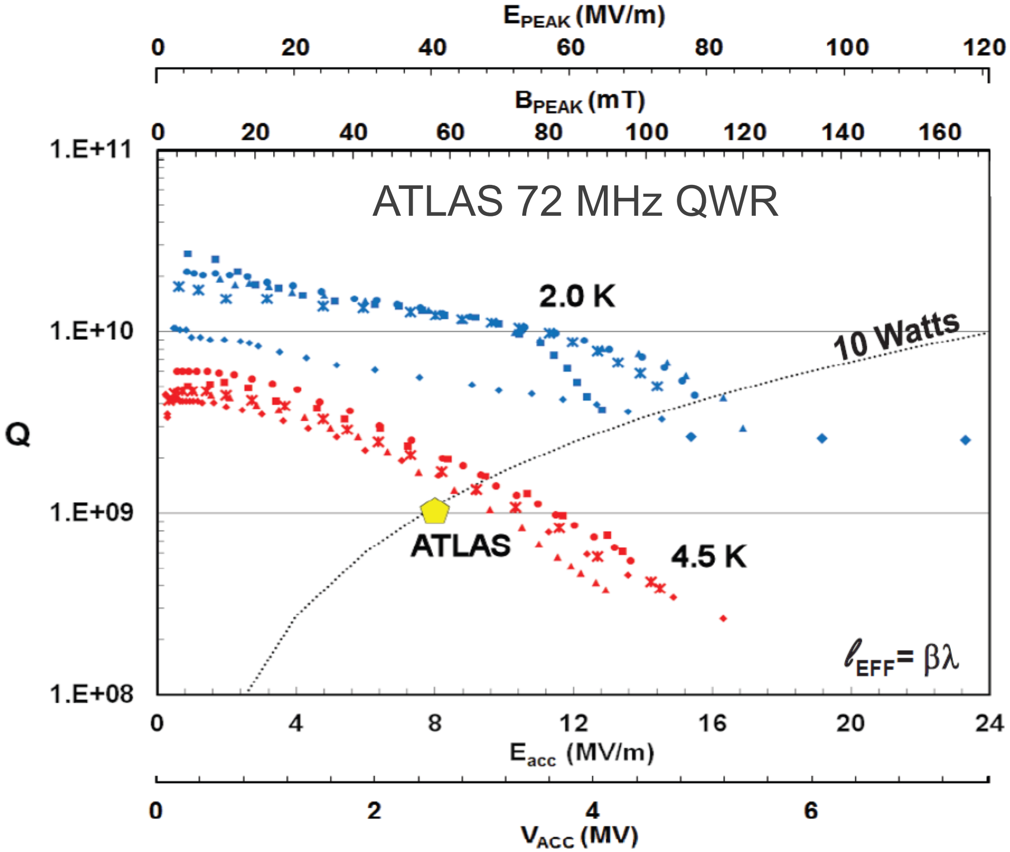
SC section

will operate at 4.5K in pulsed mode

High-Performance QWRs Developed at ANL

ATLAS
72 MHz QWR

SC section will operate at 4.5K in pulsed mode

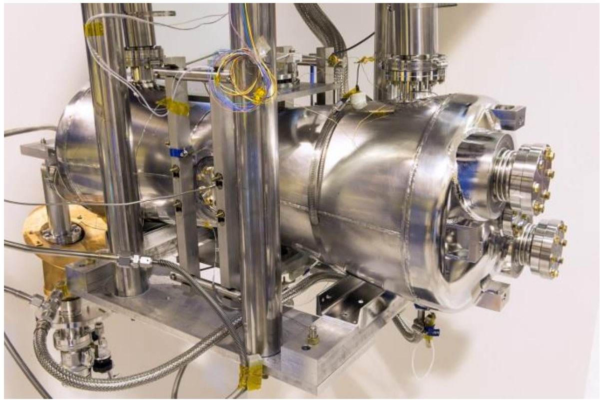


A single 72 MHz β=0.077 QWR is capable of delivering 4 MV voltage @ E_{peak} ~ 64 MV/m and B_{peak} ~ 90 mT in CW mode which corresponds to 5.6 MV @ 100 MHz and βopt = 0.15.

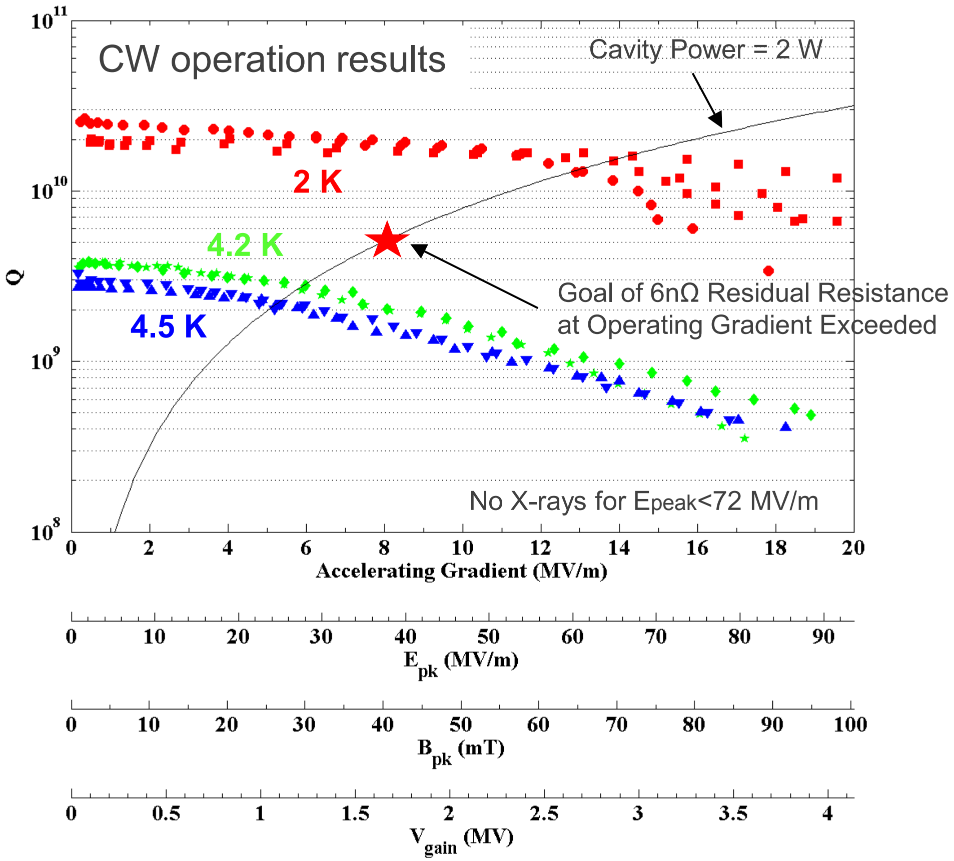
We propose to operate 100 MHz β=0.15 QWRs in pulsed mode to produce 4.7 MV per cavity

High-Performance HWRs developed at ANL

FNAL - 162 MHz HWR



SC section will operate at 4.5K in pulsed mode

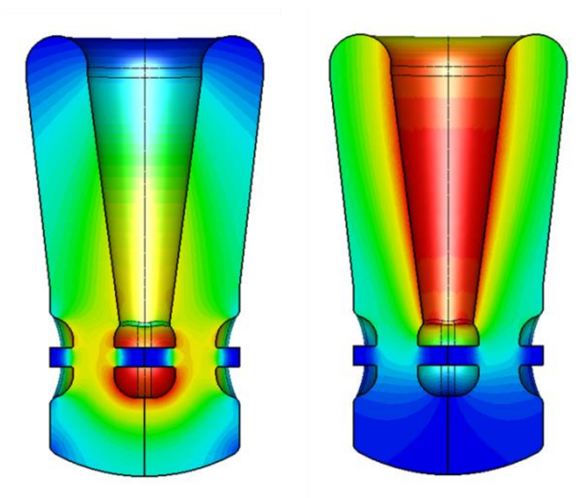


A single 162 MHz β=0.11 HWR is capable of delivering 3 MV voltage @ E_{peak} ~ 68 MV/m and B_{peak} ~ 72 mT in CW mode which corresponds to 6.6 MV @ 200 MHz and βopt = 0.3.

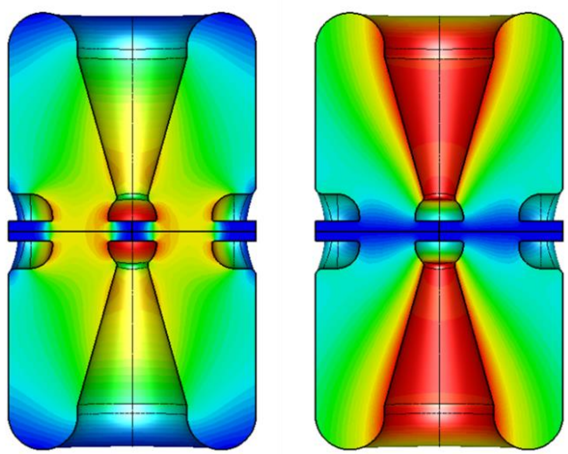
We propose to operate 200 MHz β=0.3 HWRs in pulsed mode to produce 4.7 MV per cavity

Preliminary QWR and HWR Design for JLEIC Linac

JLEIC QWR Design



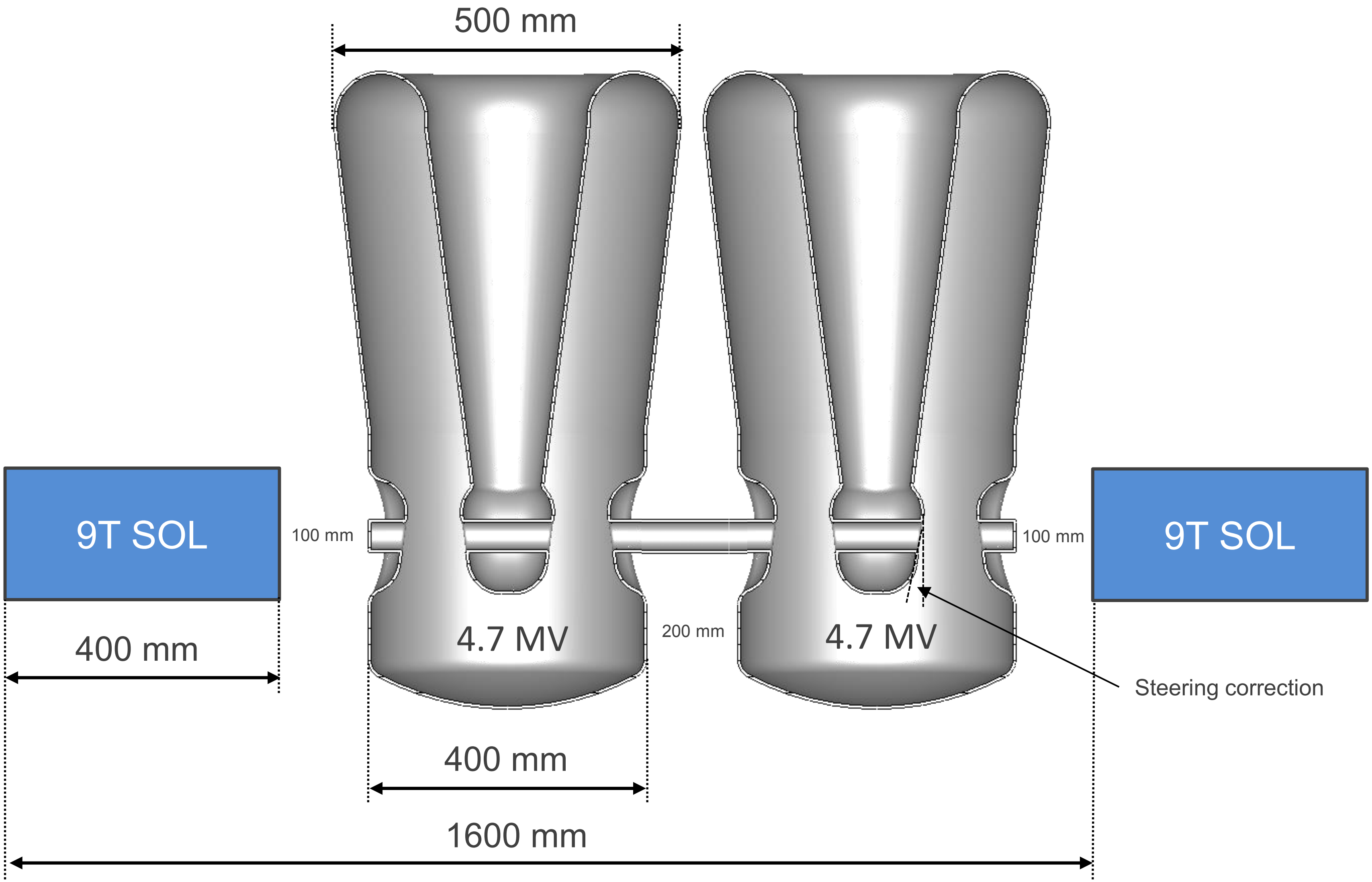
JLEIC HWR Design



Parameter	QWR	HWR	Units
β_{opt}	0.15	0.30	
Frequency	100	200	MHz
Length ($\beta\lambda$)	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	-15	deg
No. of cavities	21	14	

Period Structure in SRF Section

QWRs are optimized to compensate beam transverse RF steering by tilting the drift tube faces

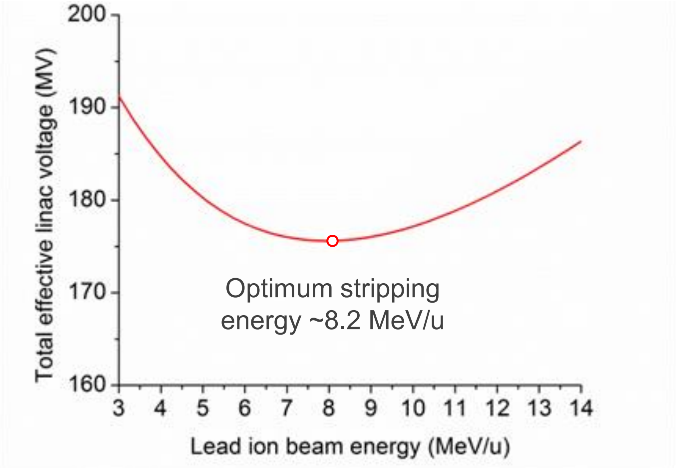


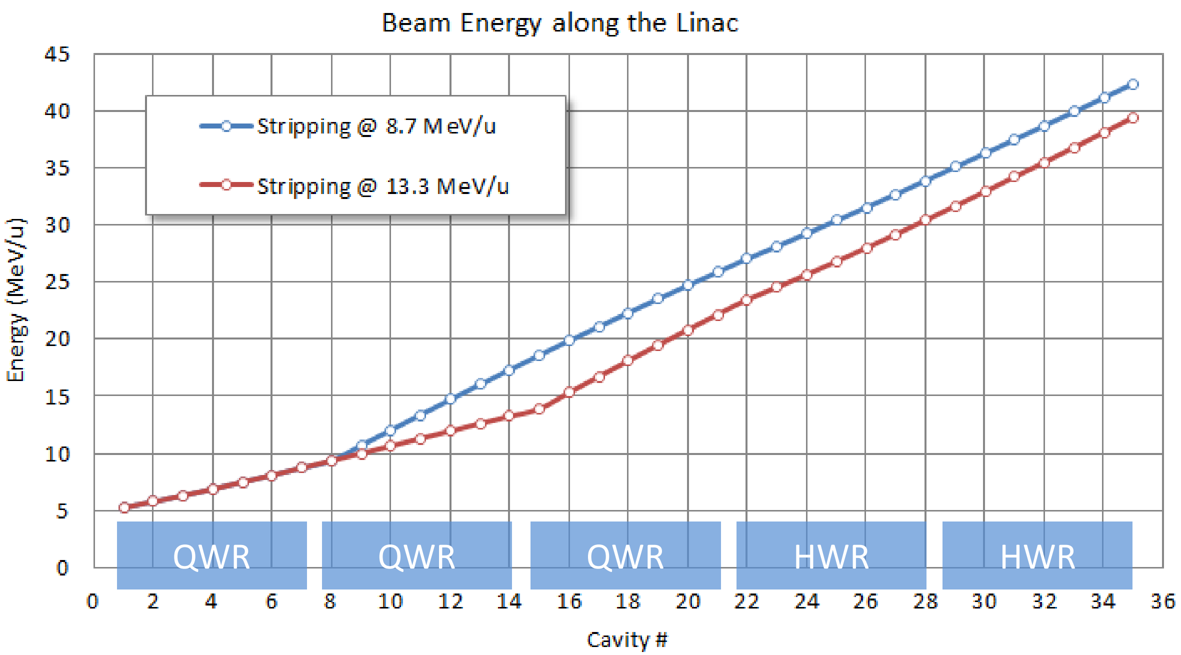
Optimized Stripping Energy & Charge State

Stripping efficiency:
(30+) → (62+) : 17.5% @ 8.7 MeV/u
(30+) → (67+) : 22% @ 13.3 MeV/u

$$U_{total} = \frac{\Delta W_1}{Q_1} + \frac{\Delta W_2}{Q_2}$$

1 – before stripping, 2 – after stripping

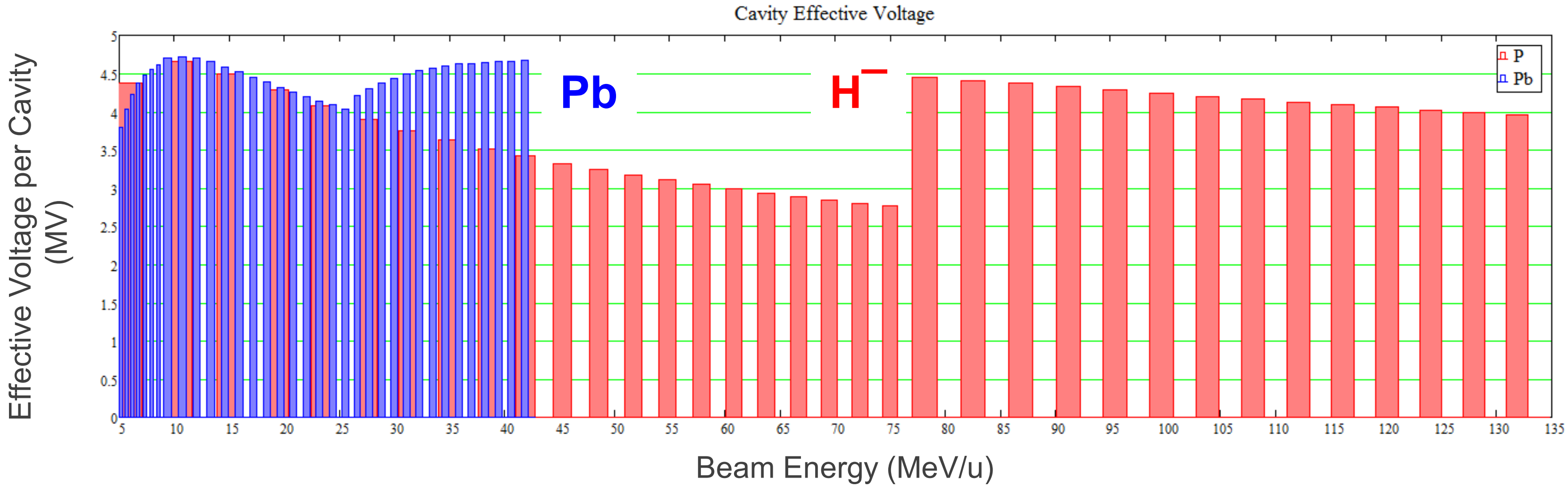




44 MeV/u (62+)

40 MeV/u (67+)

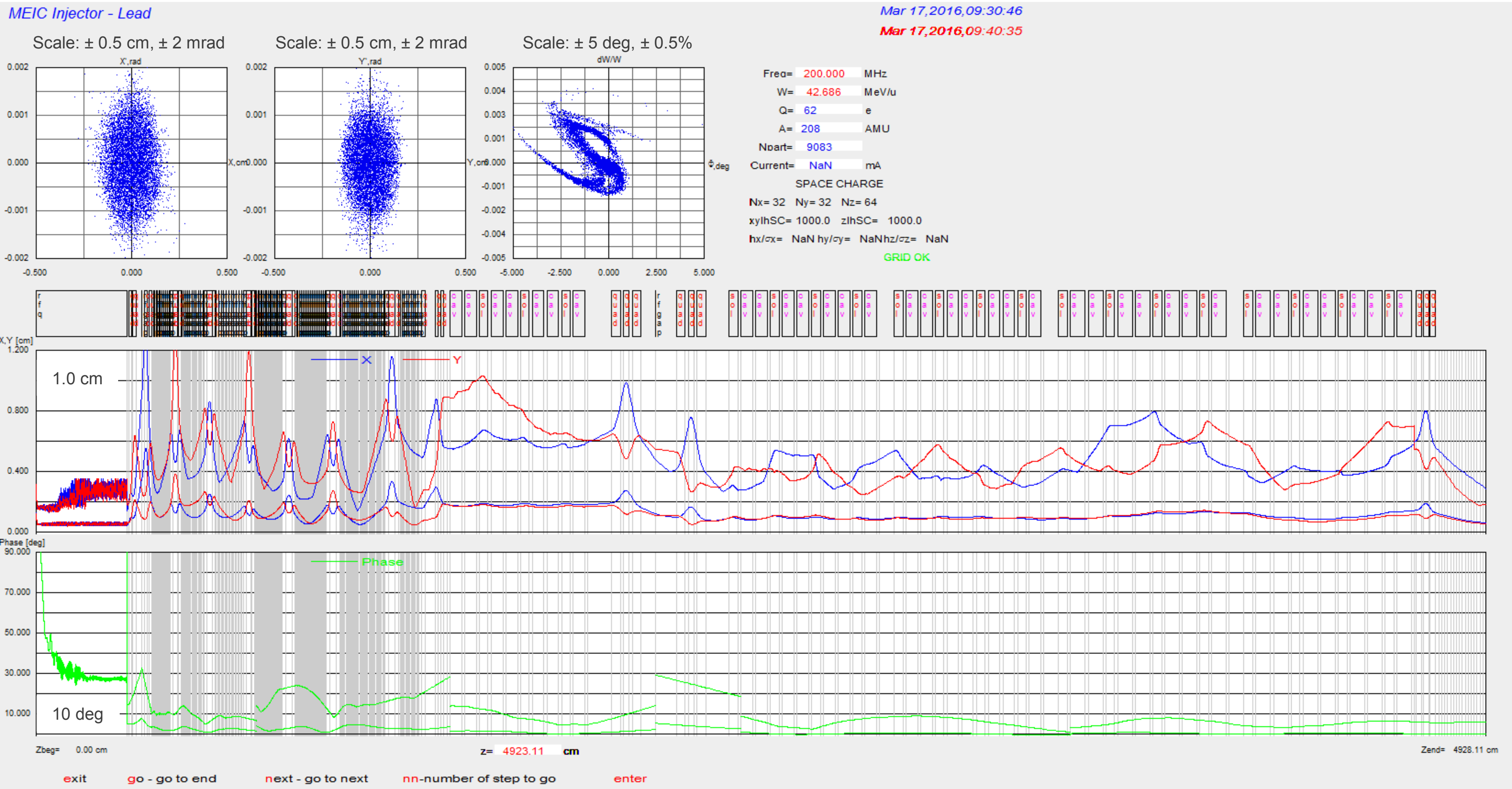
Voltage Profile & SRF Performance



- SC Cavity Voltage profile optimized for both lead ions and protons/H^-
- SC Cavity re-phasing produces much higher energy for protons/H^-
- SC linac will operate in pulsed mode to reduce dynamic cryogenics load
  - 10% duty cycle during the booster filling time, SC cavities will be equipped with fast tuners to compensate for Lorentz detuning
  - 4.5K operation temperature
  - Total ~75 Watts of static load for 5 cryomodules
  - Can be used for other applications during the collider operation
    - Booster beam to fixed target experiments
    - Isotope production, for example, molibdenium-99

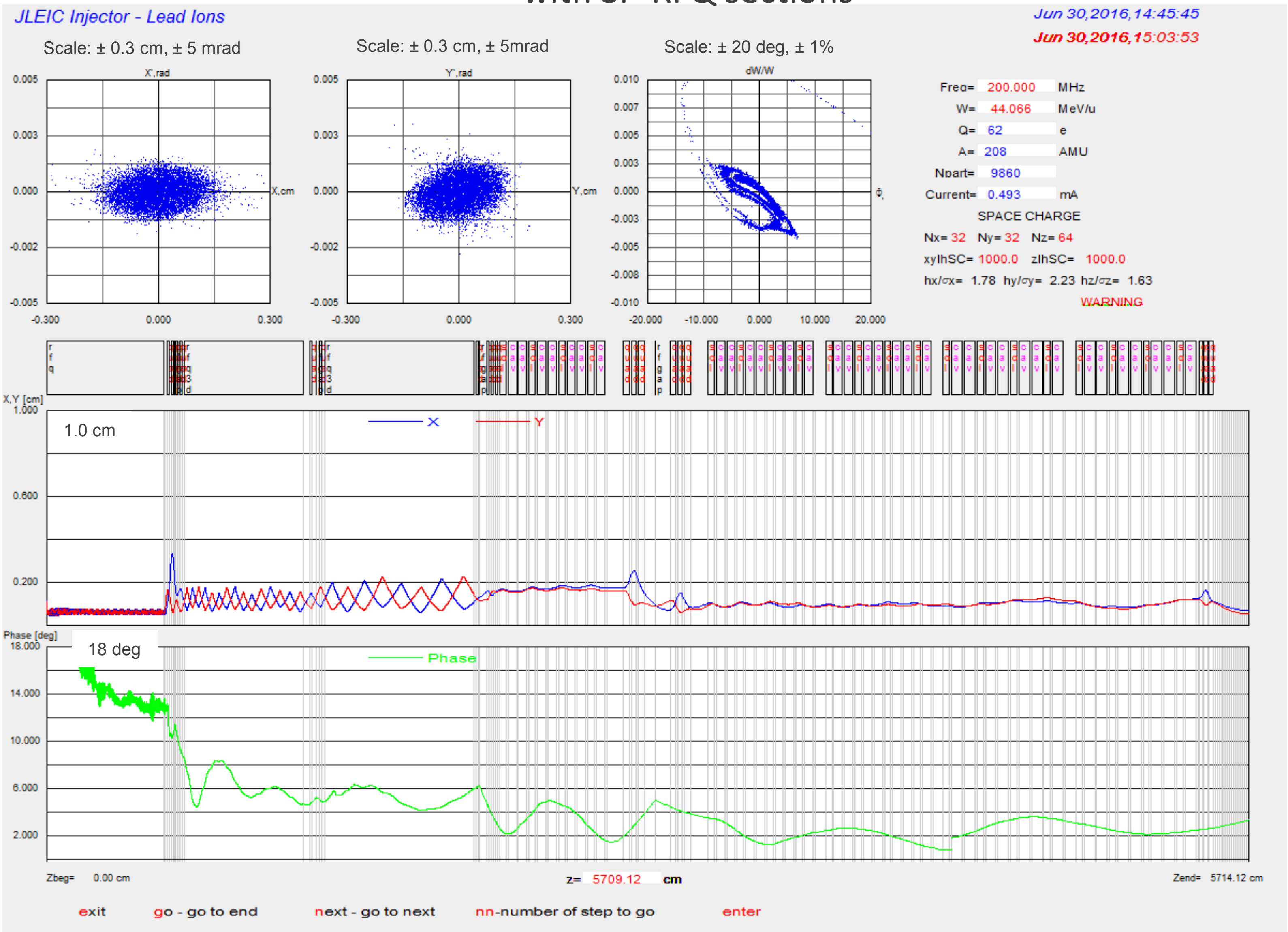
End-to-End Beam Dynamics Simulation – Lead Ions

with IH-DTL sections



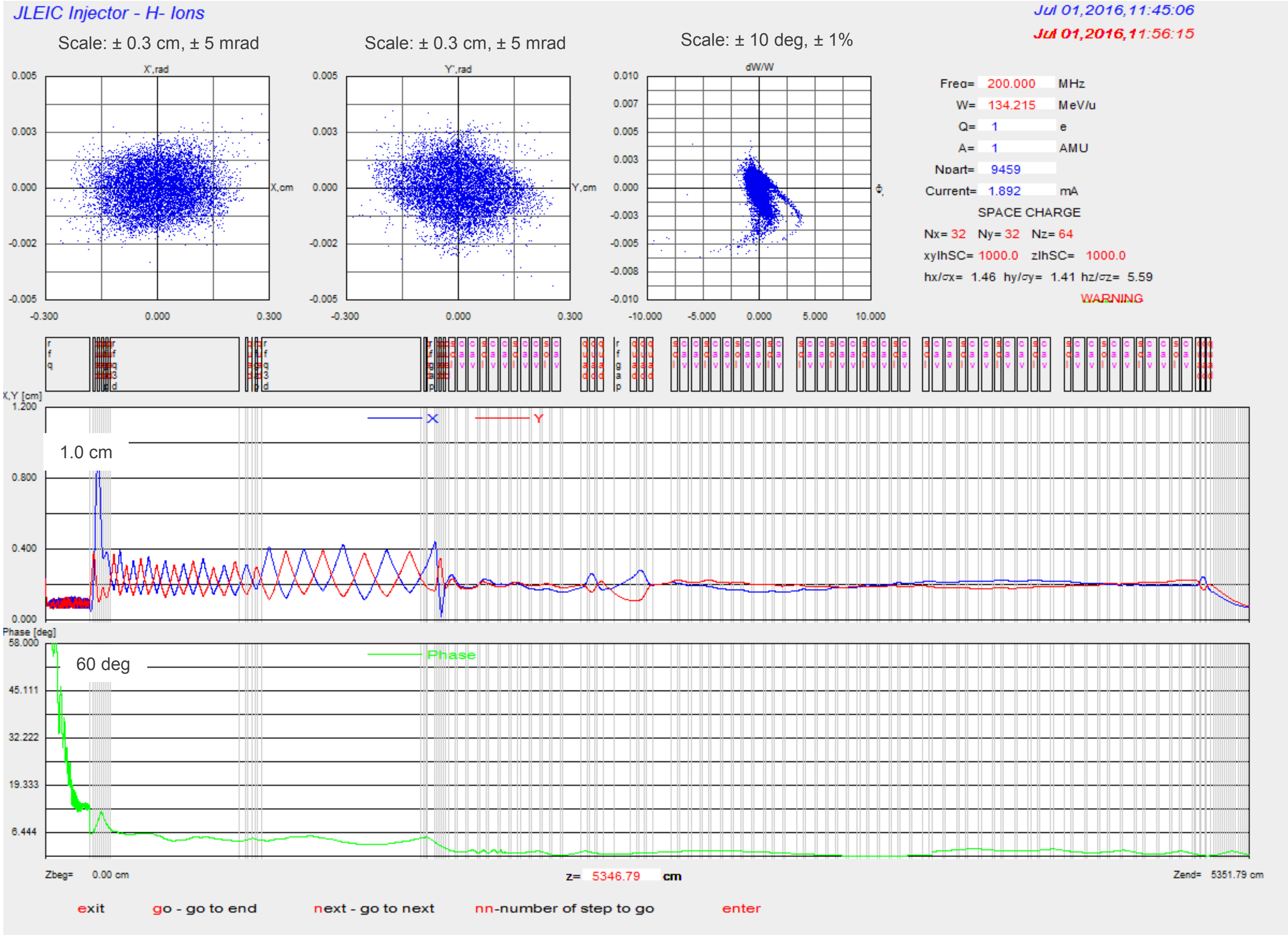
End-to-End Beam Dynamics Simulation – Lead Ions

with SP-RFQ sections



End-to-End Beam Dynamics Simulation – Protons/H⁻

with SP-RFQ sections



Summary

- A pulsed multi-ion linac is based on 5 MeV/u normal conducting section and 5 cryomodules of SC cavities
  - 44 MeV/u lead ions
  - 135 MeV polarized H^-
- Capable to accelerate light polarized ions
- Stripping injection of polarized H^- and D^- in a single pulse
- Multi-pulse, multi turn injection of heavy ions with electron cooling in the booster between the pulses
- The goal of pre-conceptual design is to provide beam parameters for the design of the booster
- Linac requires detailed conceptual design with the following cost estimate