End-to-End Beam Simulations for MSU RIA Driver Linac

Xiaoyu Wu
NSCL
Michigan State University

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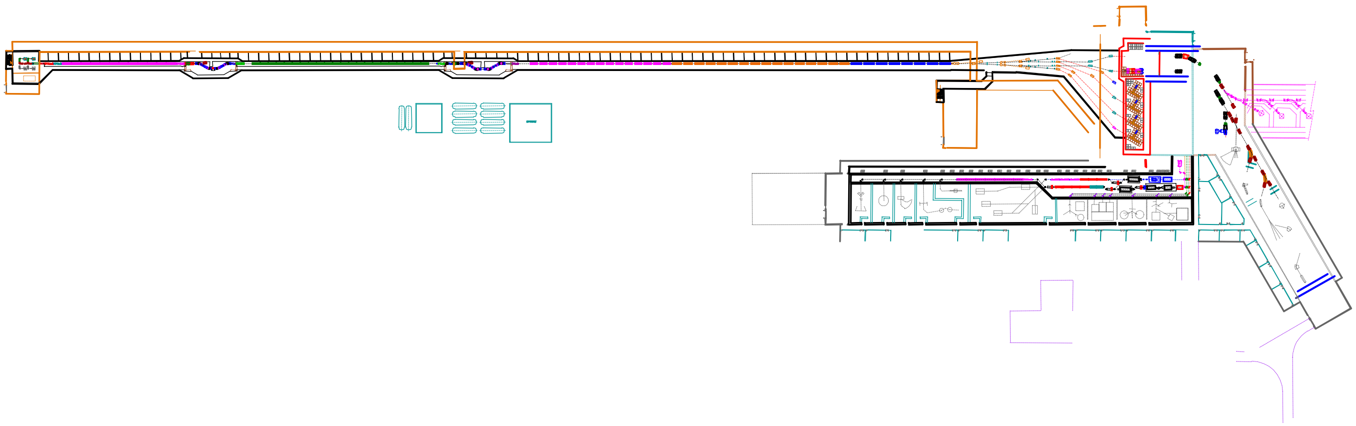
Beam Dynamics studies for RIA at MSU

- **Established 10th sub-harmonic (80.5 MHz) RIA driver linac design option**
  - **Beam power: 400 kW**
  - **Uncontrolled beam loss: 1W/m**
  - **Adequate acceptances and limited emittance growths**
- **Beam simulations for all sub-systems of MSU RIA driver linac design**
- **End-to-end beam simulation studies**
  - **Realistic input beams**
  - **Alignment and dynamic rf errors through all segments of RIA driver linac**
  - **Charge-stripping foil model**

Beam Simulation Tools

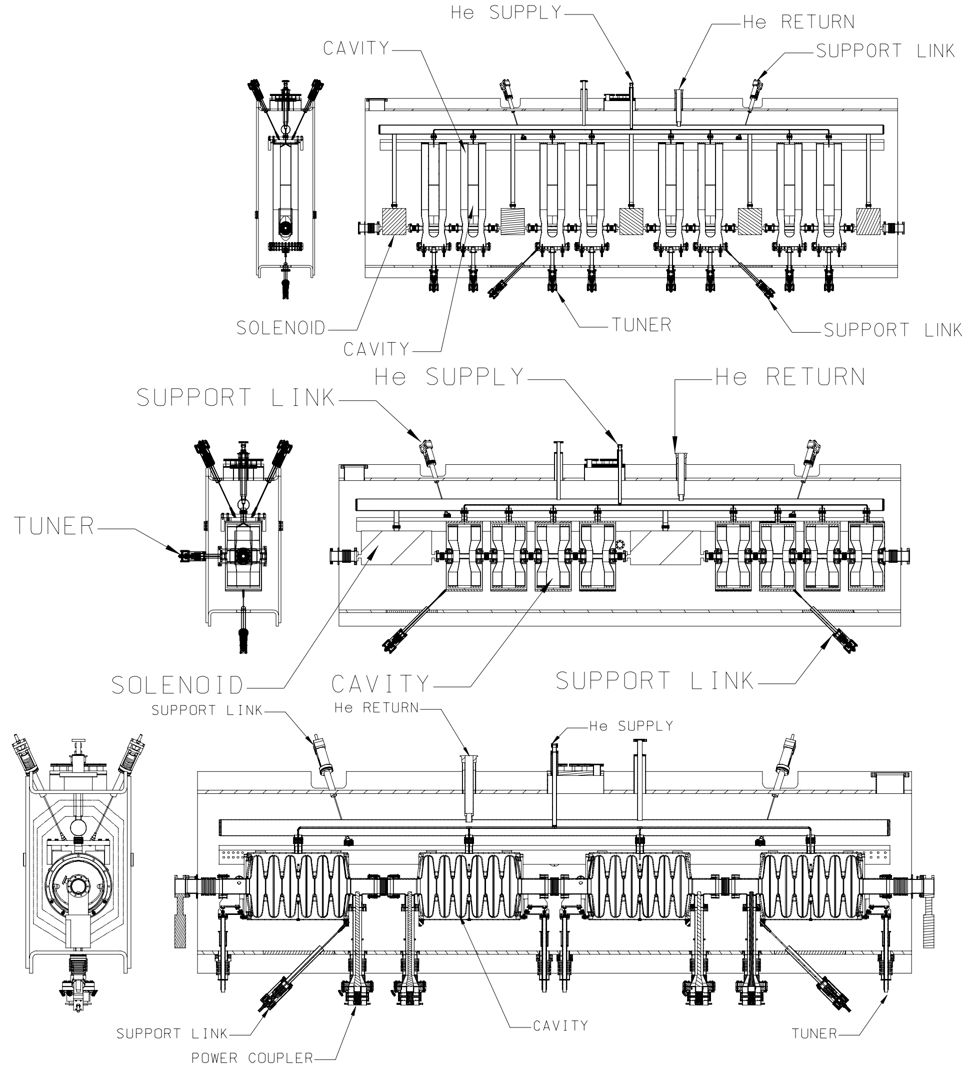
- RIA front end:
  - PARMELA – beam transport with space charge
  - PARMTEQ – RFQ beam dynamics
- Driver linac segments and charge-stripping sections
  - LANA – end-to-end 3-D simulations
  - DIMAD – transverse focusing lattice, misalignment and correction scheme
  - COSY INFINITY – high order aberrations and corrections
  - TRIM – Charge-stripping foil modelling
- In progress
  - PARMTEQm + IMPACT – end-to-end simulations

RIA Layout at NSCL/MSU



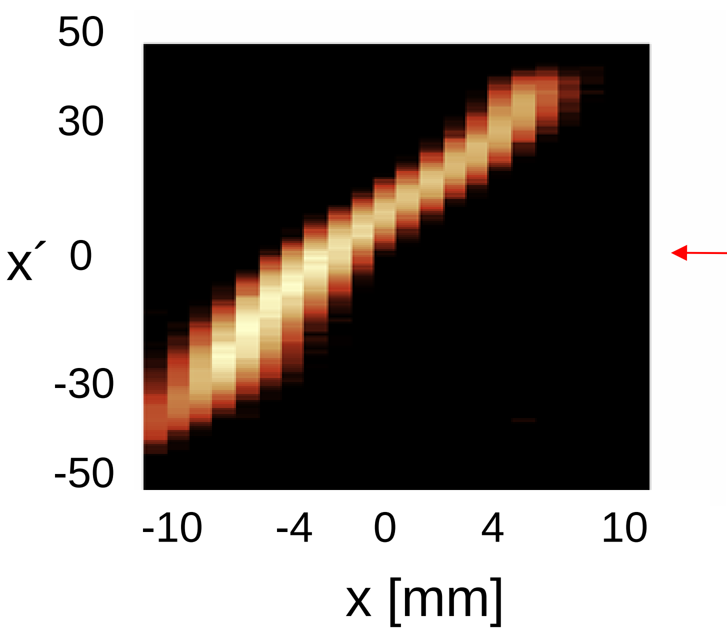
RIA Driver linac Lattice

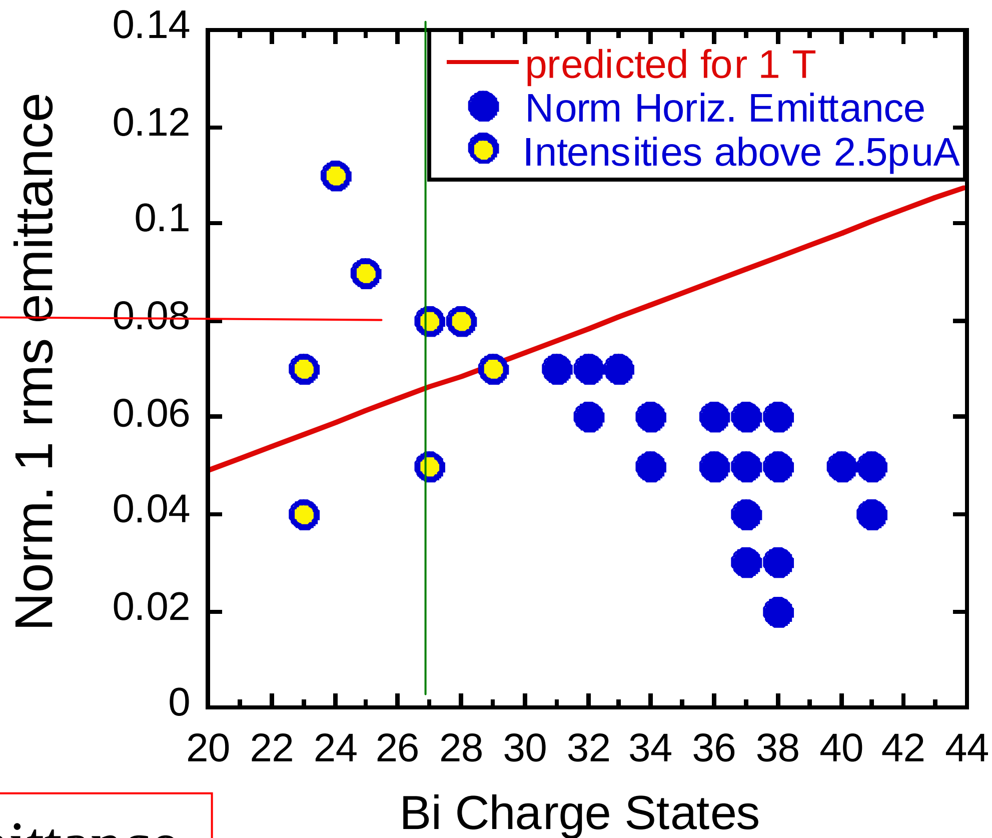
- **Segment I: 0.292 – 11.8 MeV/u**
  - 80.5 MHz (0.041, 0.085) SRF QWC, 30 mm aperture
  - SC solenoid magnets, L=0.1 and 0.2 m
- **Segment II: 11.6 – 88.9 MeV/u**
  - 322 MHz (0.285) SRF HWC, 30 mm aperture
  - SC solenoid magnets, L=0.5 m
- **Segment III: 83.8 – 400 MeV/u**
  - 805 MHz (0.49, 0.63, 0.83) 6-cell elliptical cavities, 77 mm aperture
  - Room-temperature quadrupole magnets, L=0.25 m
- THP70 – T.L. Grimm, "Experimental Study of an 805MHz Cryomodule for the Rare Isotope Accelerator"



VENUS Source (LBNL)
Bismuth Emittance Measurements

3 pμA Bi^{27+}





Measured Bi^{27+} RMS emittance

~ 0.08 π-mm-mrad

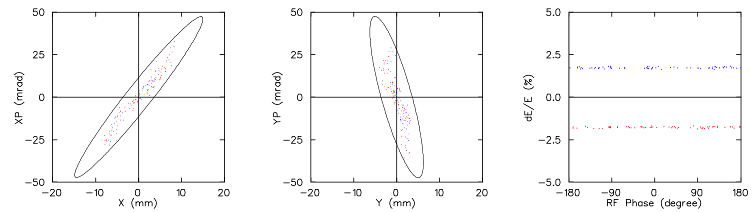
Courtesy of D. Leitner

RIA Front End Simulation Results

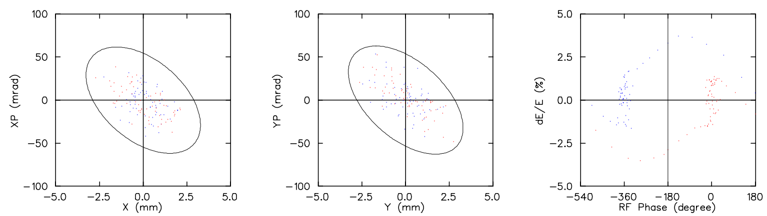
- **Two charge-state U^{238} beam acceleration**
- **Beam intensity: 8 pμA**
- **100kV high voltage platform**
- **Phase spaces based on LBNL emittance measurement**
- **Small transverse emittance growth**
- **Beam emittance at SCL entrance**

$\varepsilon_{n,T}$ **(rms)**	**~0.09 π mm-mard**
$\varepsilon_{n,T}$ **(99.5%)**	**~0.9 π mm-mard**
$\varepsilon_{n,L}$ **(rms)**	**~0.1 π keV/u-ns**
$\varepsilon_{n,L}$ **(99.5%)**	**~1.2 π keV/u-ns**

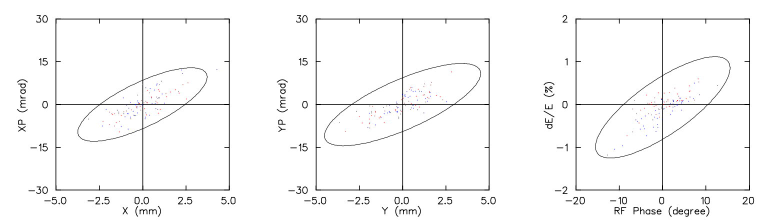
Beam phase spaces at the entrance of LEBT



Beam phase spaces at the entrance of RFQ



Beam phase spaces at the exit of Front end



Misalignment and rf Errors

RIA Driver Linac	Misalignment $\sigma_{x,y}$ [mm]		Maximum rf Errors for SRF Cavity*	
	SRF Cavity	Focusing Element	Phase [deg]	Amplitude [%]
Segment I	1.0	0.5	±0.25	±0.25
Segment II	1.0	0.5	±0.50	±0.50
Segment III	1.0	1.0	±0.50	±0.50

- Gaussian distribution with a cut-off at 2σ for mislaignment
- Uniform distribution for rf errors

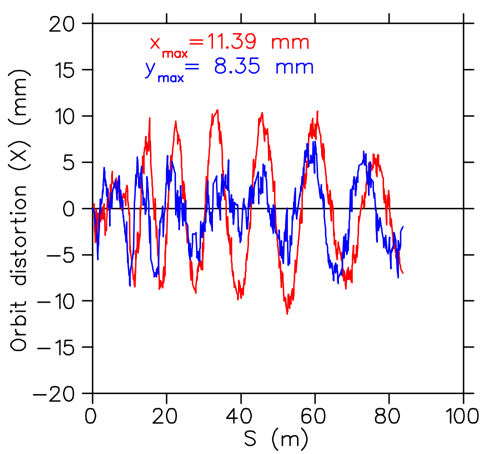
*A. Facco, “High Gradient Locking of Beam Loaded QWRs”, presented at *RIA Driver Workshop II*, May 2002, ANL.

*THP66 – T.L. Grimm, “Measurement and Control of Microphonics in High Loaded-Q Superconducting RF Cavities”

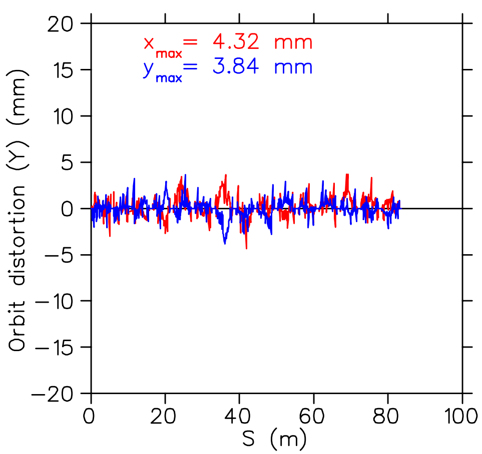
*TUP76 – T.Kandil, “Adaptive Feedforward Cancellation (AFC) of Sinusoidal Disturbances in Superconducting RF (SCRF) cavities”

Alignment Correction Scheme

- Segments I, II – Horizontal/vertical dipole windings for each focusing solenoid magnet
- Segment III – Warm dipole correctors beside focusing quadrupole doublet
- All BPMs in the warm region between cryomodules
- Central orbit distortions limited within ± 5mm after corrections in all three segments of driver linac



Before corrections



After corrections

Charge-Stripping Foils

- Stripping foil model
  - Based on simulation results from code TRIM
  - Elastic and inelastic scattering
  - Energy loss and straggling
- Small transverse beam spot (~3mm) and Short bunch length (~8°) achieved on both foils
- Carbon foils* used in simulation
- Foil thickness variation : ± 5%

Stripping Foil	Stripping Energy	Thickness	Emittance Growth Transverse/Longitudinal
1st	11.87 MeV/u	1.78 μm	~21%, ~64%
2nd	83 MeV/u	64 μm	~45%, ~103%

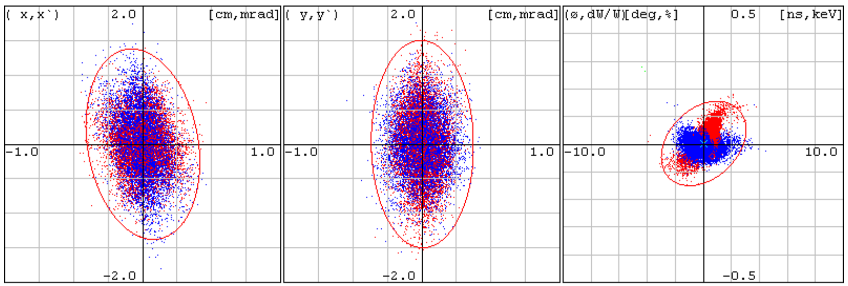
*Charge-stripping foil experiments at MSU

Simulation Results: Segment I

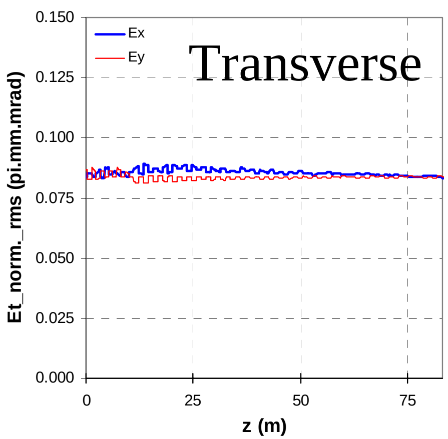
- **Segment I lattice without errors**

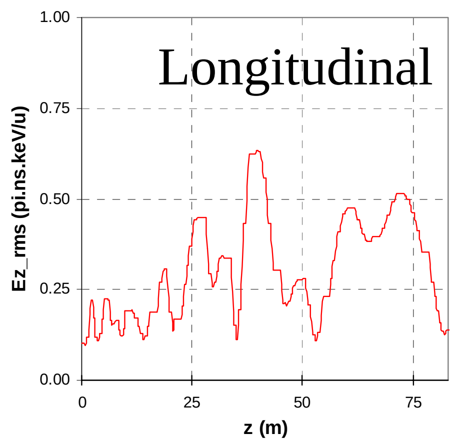
Beam phase spaces at the end of Segment I

U$_{28+}$
U$_{29+}$



Beam transverse and longitudinal rms emittances in Segment I



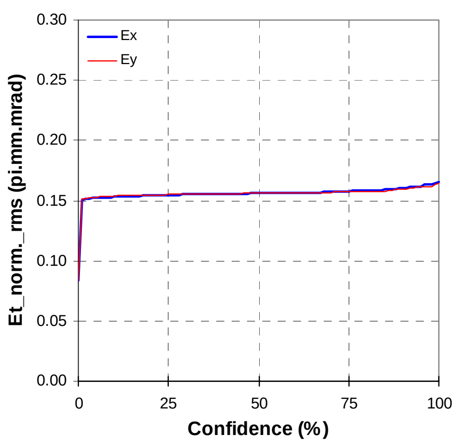


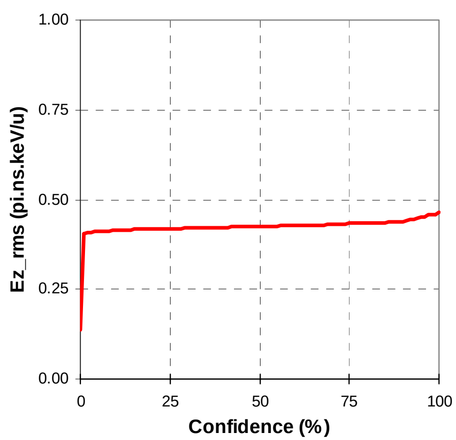
No transverse rms emittance growth
Small longitudinal rms emittance growth

Simulation Results: Segment I

- **Segment I with misalignment and rf errors**
  - **Alignment correction applied**
  - **100 random seeds**
  - **No beam loss observed in simulations**
  - **Transverse and longitudinal emittance growths**

Confidence plots of Beam rms emittances at the end of Segment I





- **Beam continued through charge-stripping sections and Segment II and III with errors**

End-to-End Simulations Summary

- **No beam loss observed**
- **Transverse and longitudinal emittance growths acceptable**

Transverse emittances and acceptances comparison

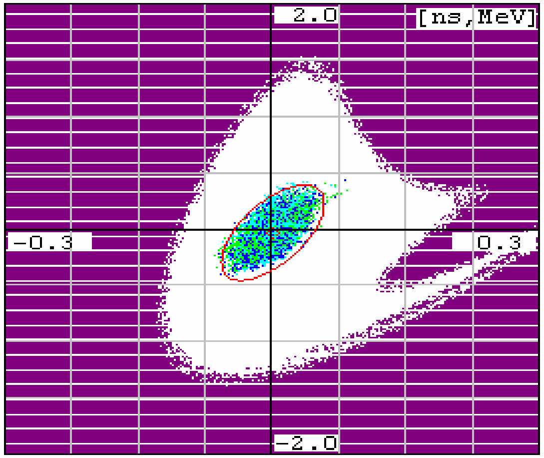
	Segment I Entrance	Segment II Entrance	Segment III Entrance	Segment III Exit
ε_T (rms) (π mm-mrad)	0.09	0.16	0.24	0.25
ε_T (99.5%) (π mm-mrad)	0.9	1.4	2.4	2.5
Rmax (mm)	10.4	9.6	12.1	
Radial Aperture (mm)	15.0	15.0	25.0 (38.5)	
Aperture/Rmax	1.4:1	1.6:1	2.1:1 (3.2 :1)	

End-to-End Simulations Summary

Longitudinal emittances and acceptances comparison

	Segment I Entrance	Segment II Entrance	Segment III Entrance	Segment III Exit
ε_L (rms) (π keV/u-ns)	0.10	0.64	1.8	2.2
ε_L (99.5%) (π keV/u-ns)	1.2	6.2	20.2	25.8
Acceptance (π keV/u-ns)	3.5	20.0	113	
Acceptance/ ε_L (99.5%)	2.9:1	3.2:1	5.6:1	

Longitudinal acceptance for 805 MHz 6-cell elliptical cavity lattice



Conclusions

- End-to-end beam simulations for RIA
  - Experimentally based input beams
  - Misalignment and rf errors
  - Charge-stripping foil model
- 10^{th} sub-harmonic (80.5 MHz) RIA driver linac option proposed by MSU has adequate transverse and longitudinal performance for multi-charge state beam acceleration

Current and future beam dynamics studies

- **Equipment loss scenarios – accelerating structures, focusing & steering elements**
- **Developing an automated SRF cavity tuning procedure for multi-charge beam acceleration**
- **Introducing PARMTEQm + IMPACT tools for beam simulations using supercomputers**

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