No Beam-Loss Quadrupole Scan for Transverse Phase Space Measurements

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U.S. DEPARTMENT OF ENERGY | Office of Science

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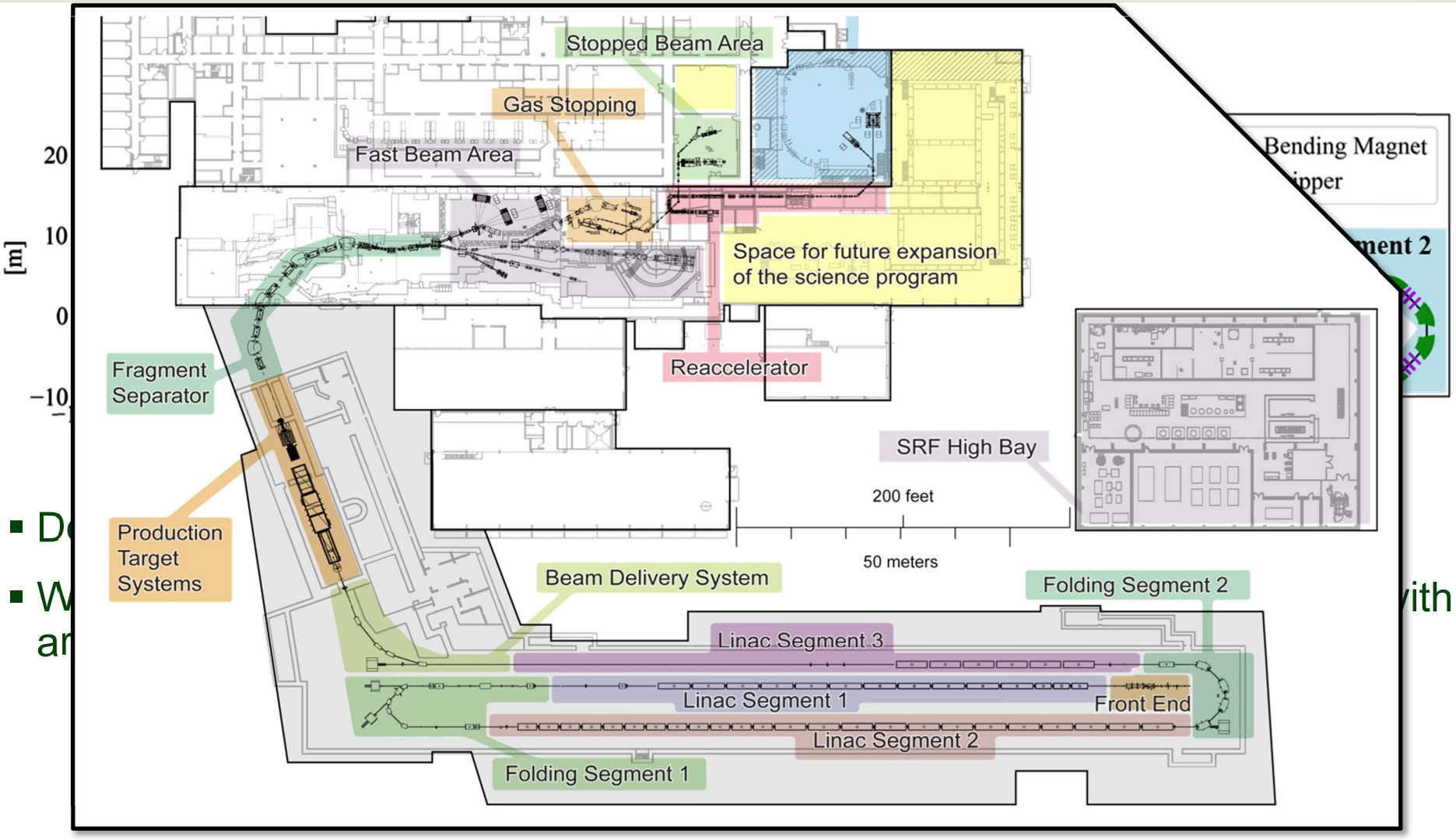
FRIB (Facility for Rare Isotope Beams)

Exploring new, unexplored regions of the nuclear chart



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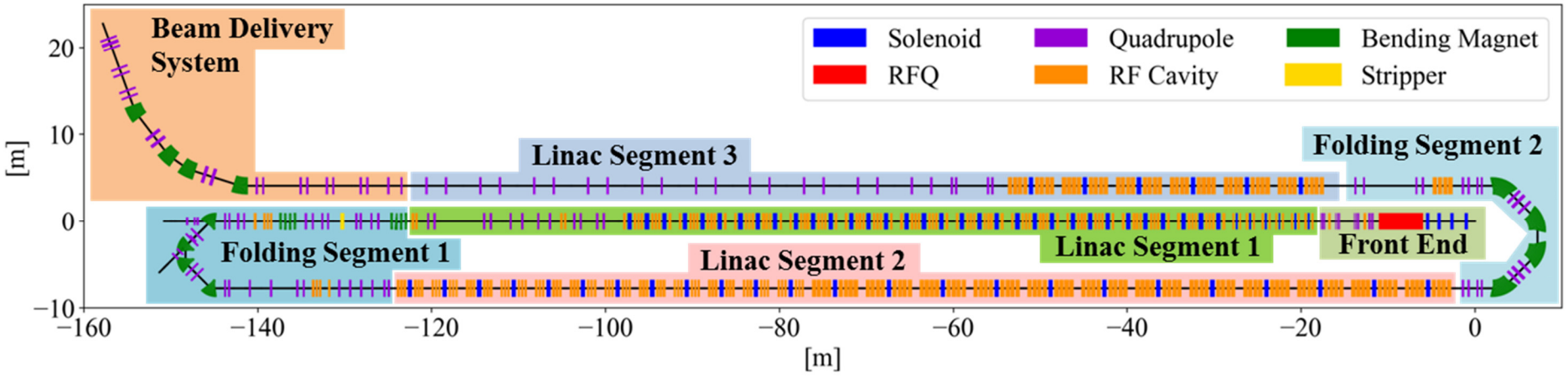
- **FRIB Driver Linac Layout**



- Designed to accelerate all stable ions above 200 MeV/u

[1] T. Glasmacher, “The Facility for Rare Isotope Beams Project: Motivation, Status, and Technical Challenges”, Opening session in Monday

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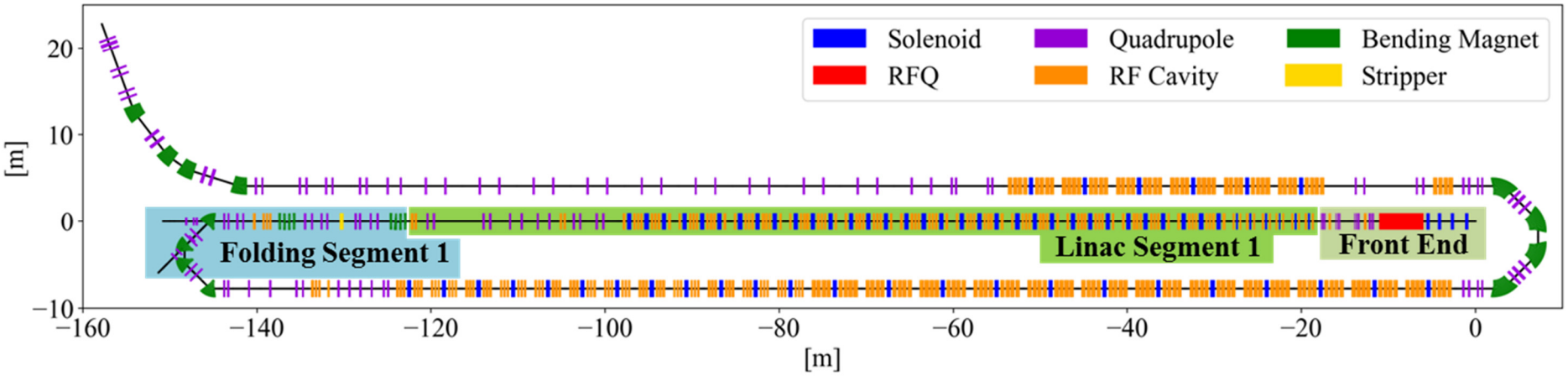

- Designed to accelerate all stable ions above 200 MeV/u
- Working on the beam commissioning from Front End to FS1 beam dump with argon and other ion species (Ne, Kr, Xe) beam up to 20.3 MeV/u

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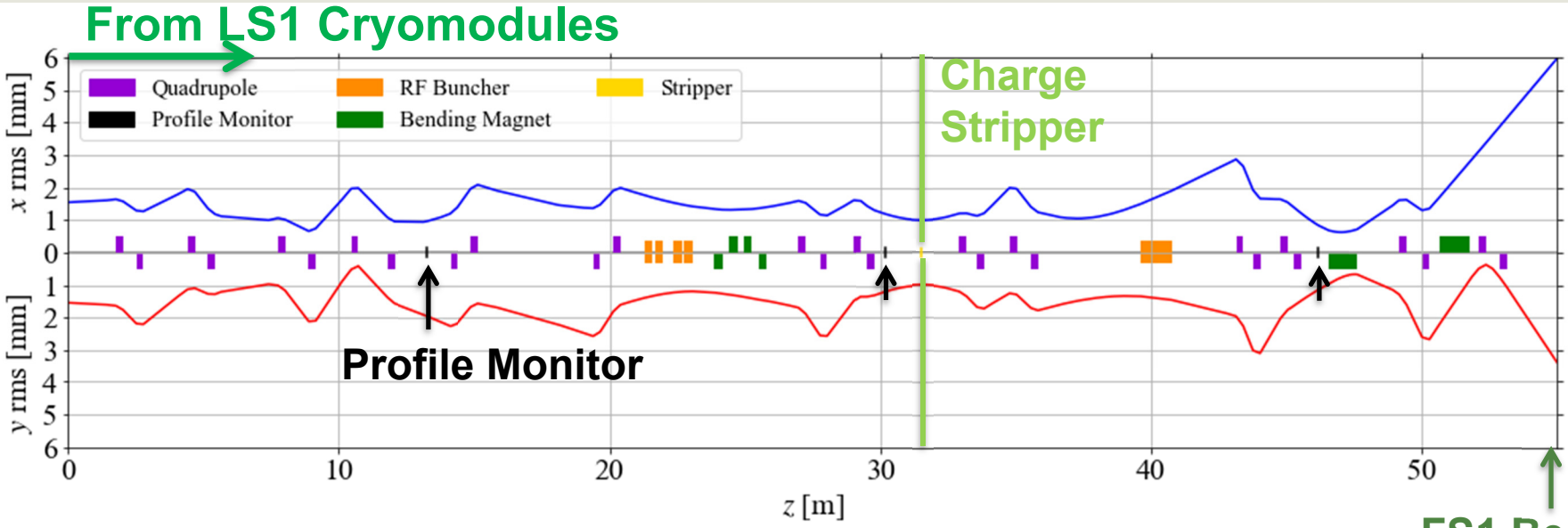
Design RMS Beam Envelope in FS1



Design Beam Parameter @ LS1 cryo exit

Ion specie	Ar9+	
Beam energy [MeV/u]	20.3	
	x	y
Normalized rms emittance [π mm-mrad]	0.10	0.10
Twiss parameter β [m]	5.0	5.0
Twiss parameter α	0.0	0.0

Aperture in Diameter [mm]

Quadrupoles	**50**
RF buncher	**34**
Bend (chicane)	40x40 (rectangle)
Bend (Arc)	40x100 (rectangle)

Most Beam Tuning Activities Performed with FLAME

FLAME code features:

- Envelope calculation by transfer matrix
  - Support multiple charge states simulation
- Simulate FRIB-linac beam envelope in millisec time scale
- Caching transfer matrix for iterative running
- Native Python interface (C++ python extension)
  - include Jupyter-notebook
- User documentation

Performance Benchmark	1st run	iterative run (matrix cached)
LS1 (2 charge states)	**28.3 ms**	**6.5 ms**
LS1+FS1 (2 to 5 charge states with charge stripper)	**39.2 ms**	**8.2 ms**

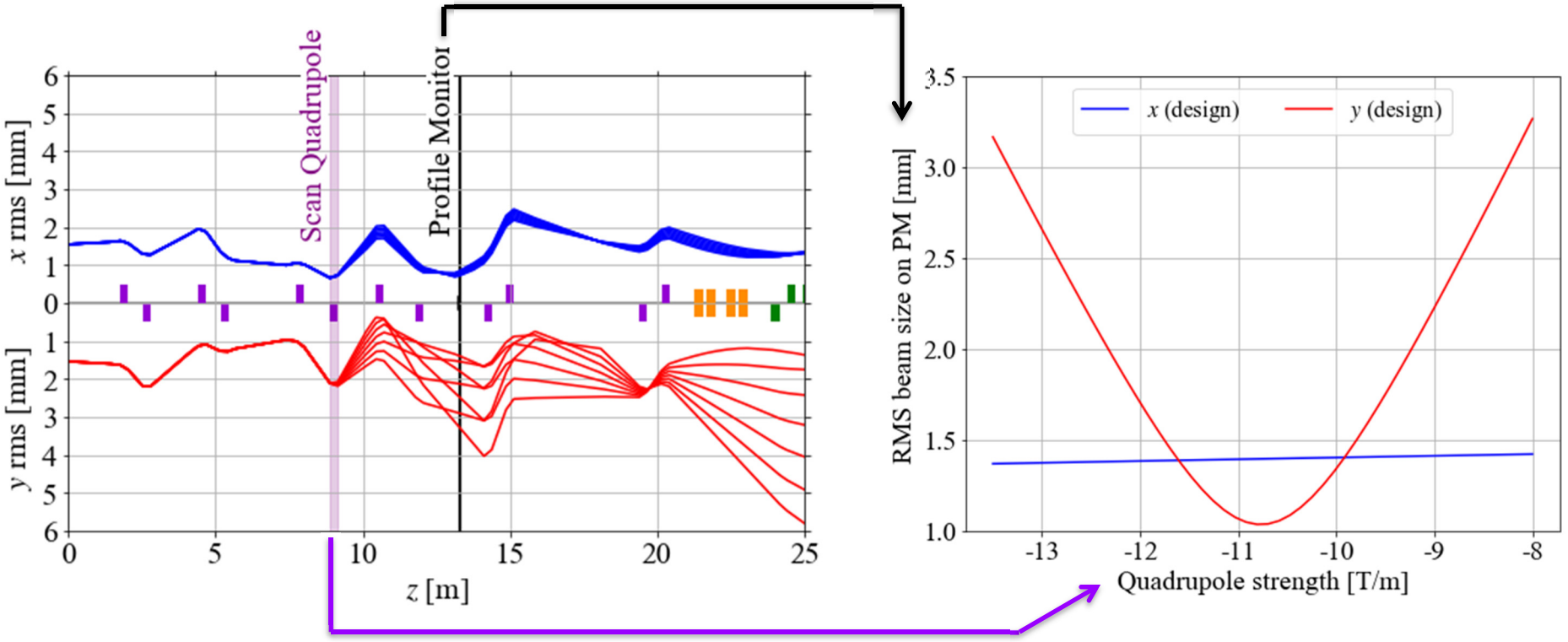
Running on Intel(R) Core(TM) i7-6820HQ CPU @ 2.70GHz with 1 core

✓ **Millisec time scale simulation cycle enables to complete more than tens of multivariate optimization in few seconds**

[2] Z. He et al, Computer Physics Communications **234**, pp. 167-178 (2019).

Quadrupole Scan in Simulation

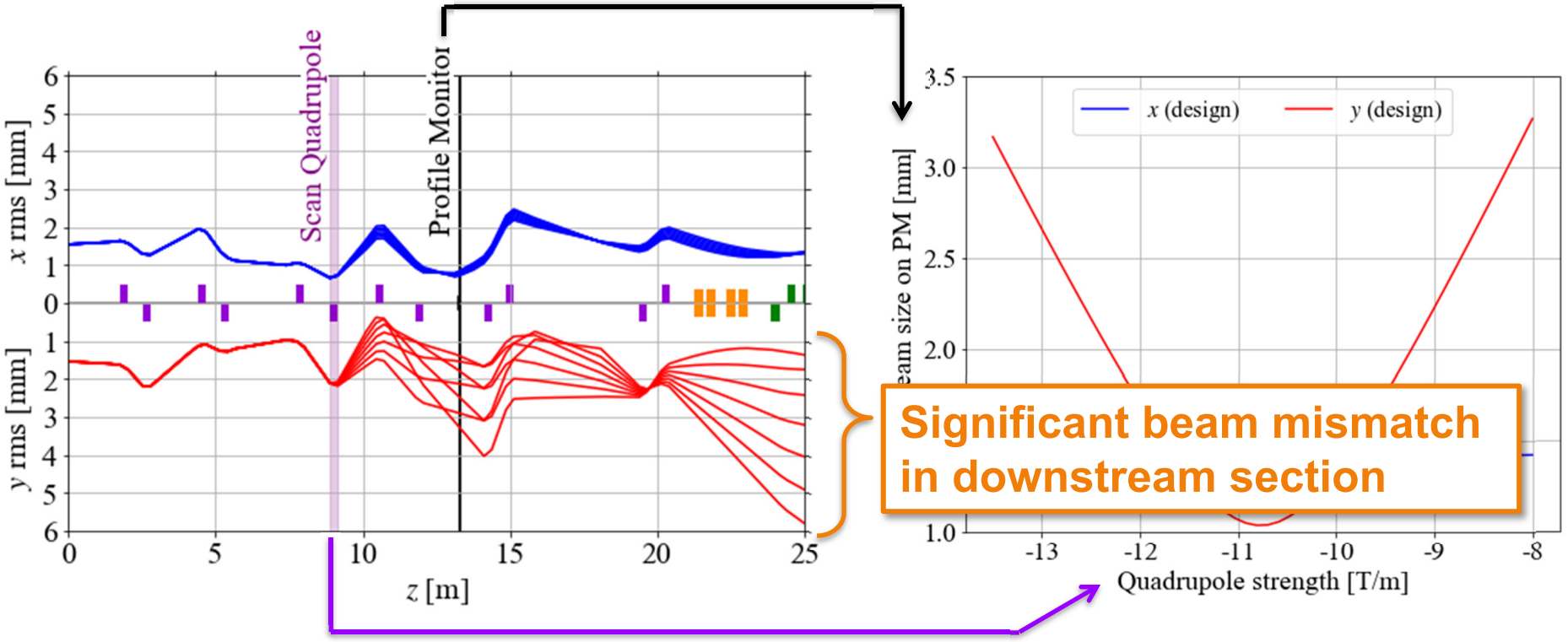
Obtain σ-matrix by fitting the measured rms size



The above Q-scan setting is most suitable for the measurements in vertical (y) plane. Similarly, the measurements can be performed in other phase space plane with high accuracy by scanning another quadrupole.

Quadrupole Scan in Simulation

Obtain σ-matrix by fitting the measured rms size



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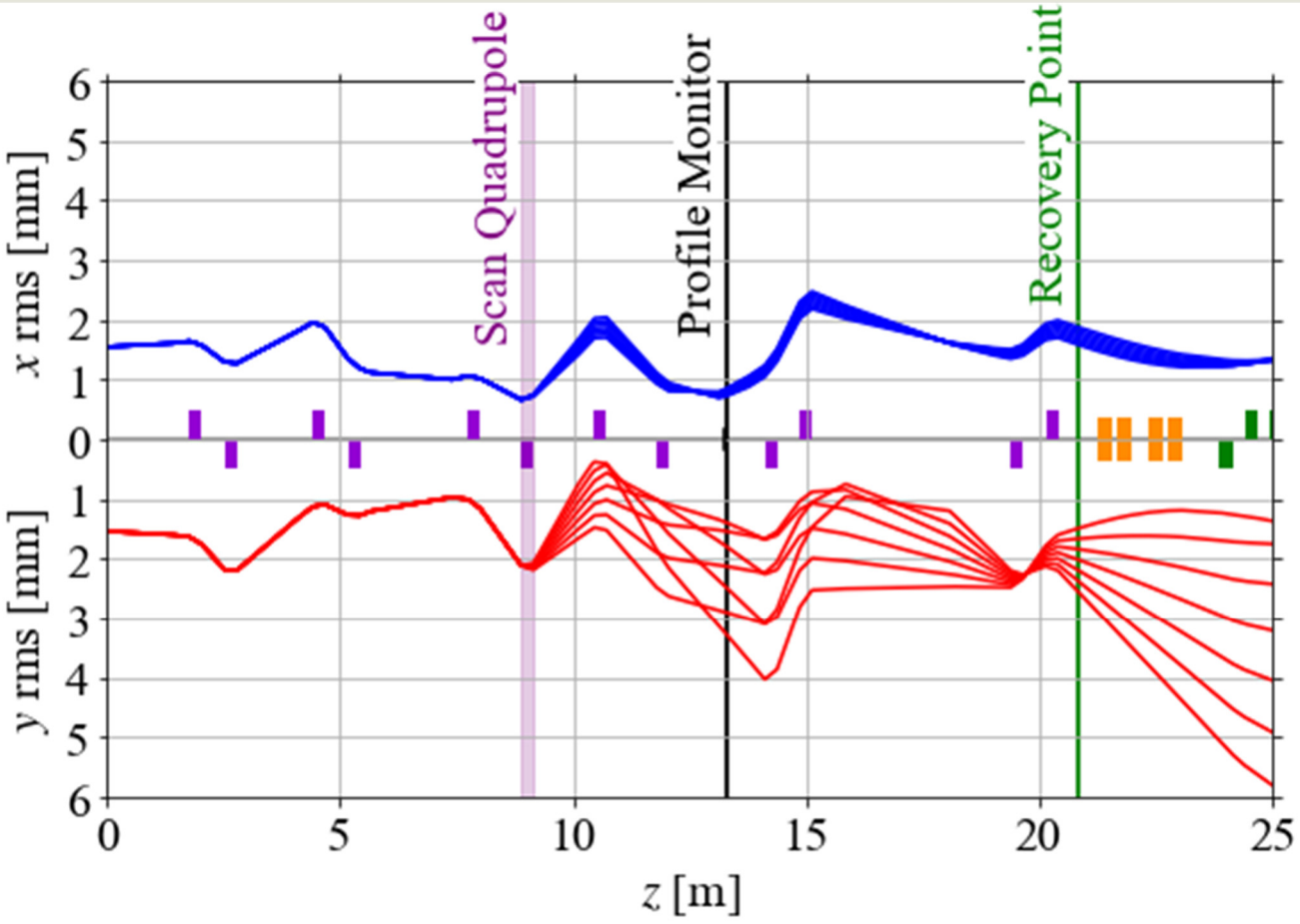
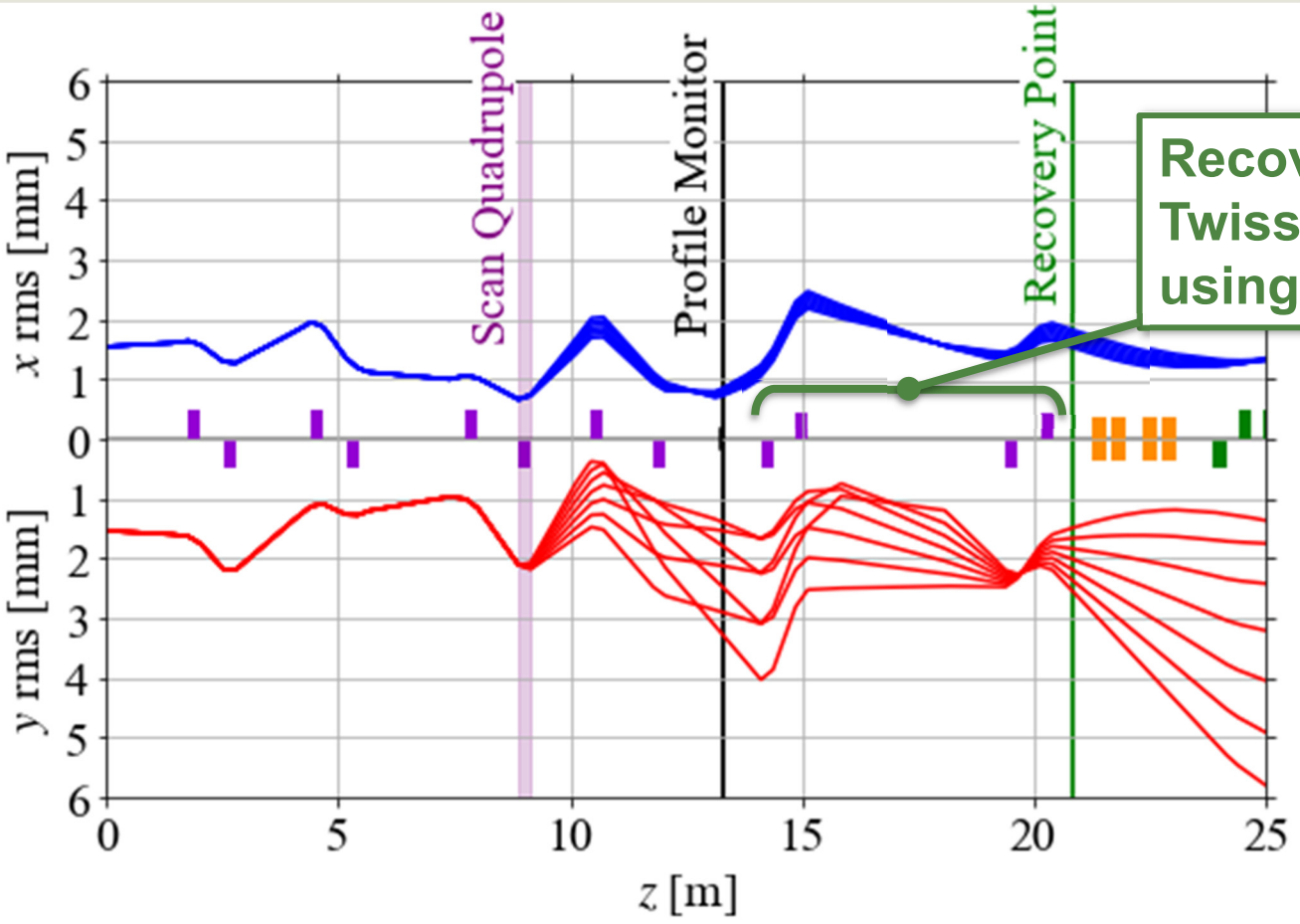
Conventional Quadrupole Scan



cf. Aperture in Diameter	
Quadrupoles	**50 [mm]**
RF buncher	**34 [mm]**

- ✓ Conventional q-scan can produce beam losses
- ✓ We developed “Twiss recovery method” to avoid beam losses during q-scan

Conventional Quadrupole Scan



Recover original Twiss parameter by using these 4 quads

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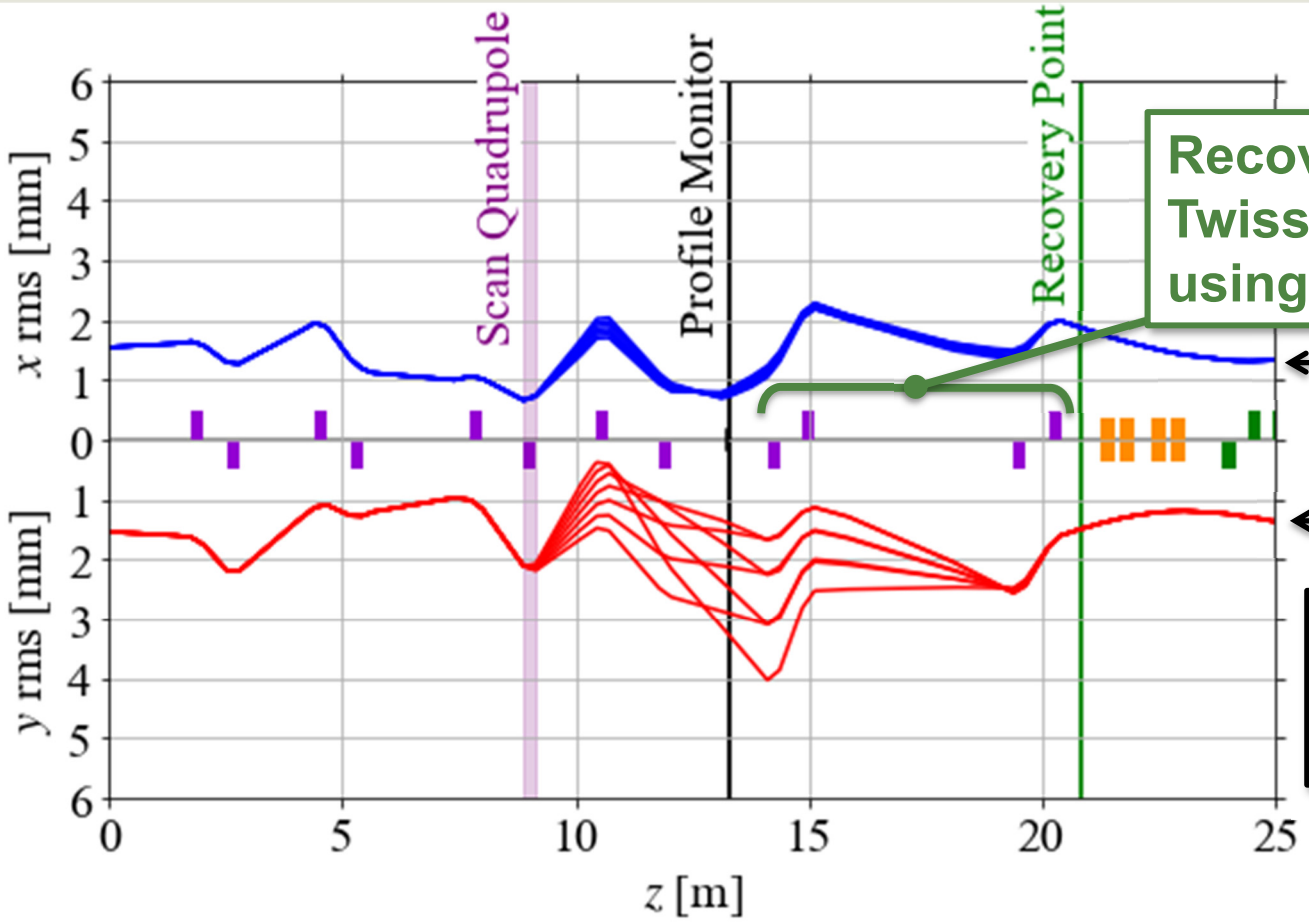
Twiss Recovery Procedure

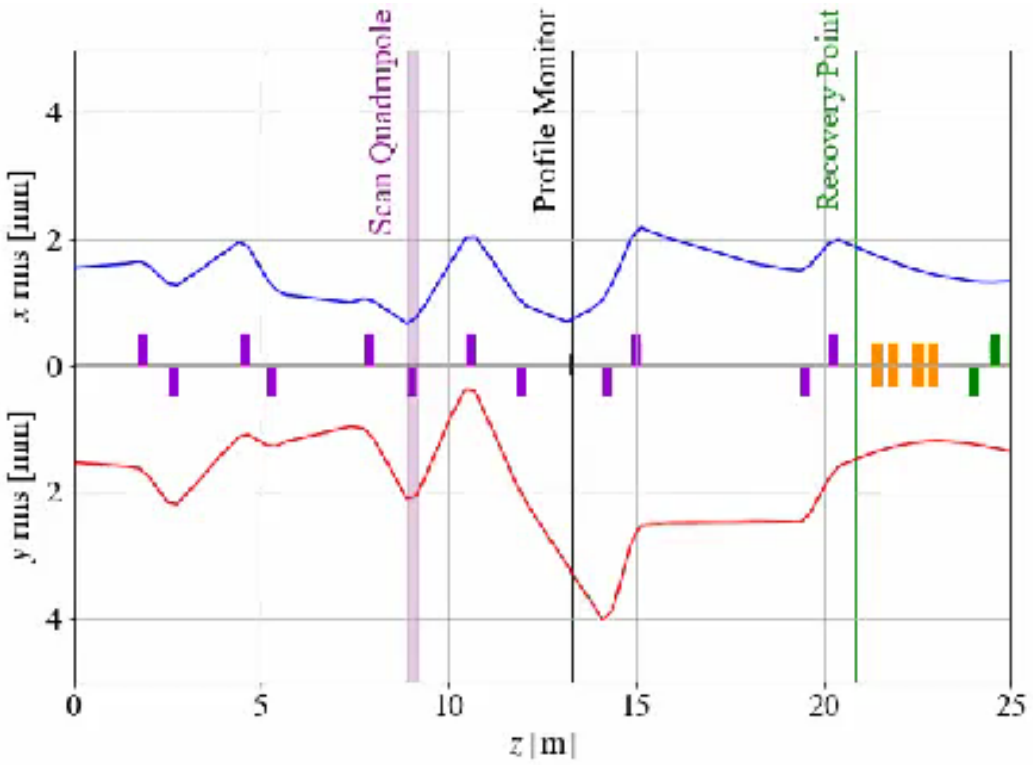


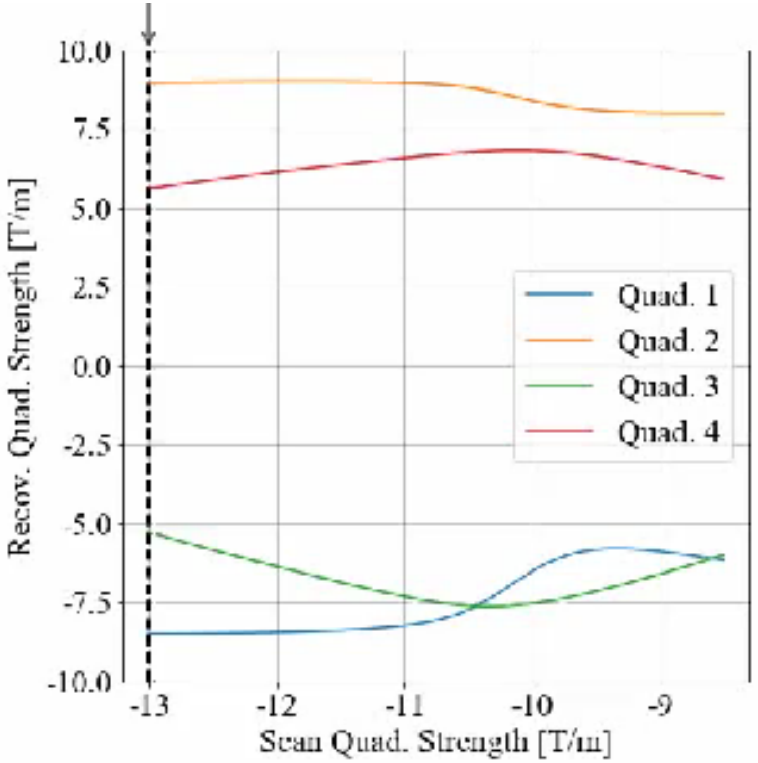
Recover original Twiss parameter by using these 4 quads

Downstream envelopes are come back to the original envelope

Quads Settings for Twiss Recovery

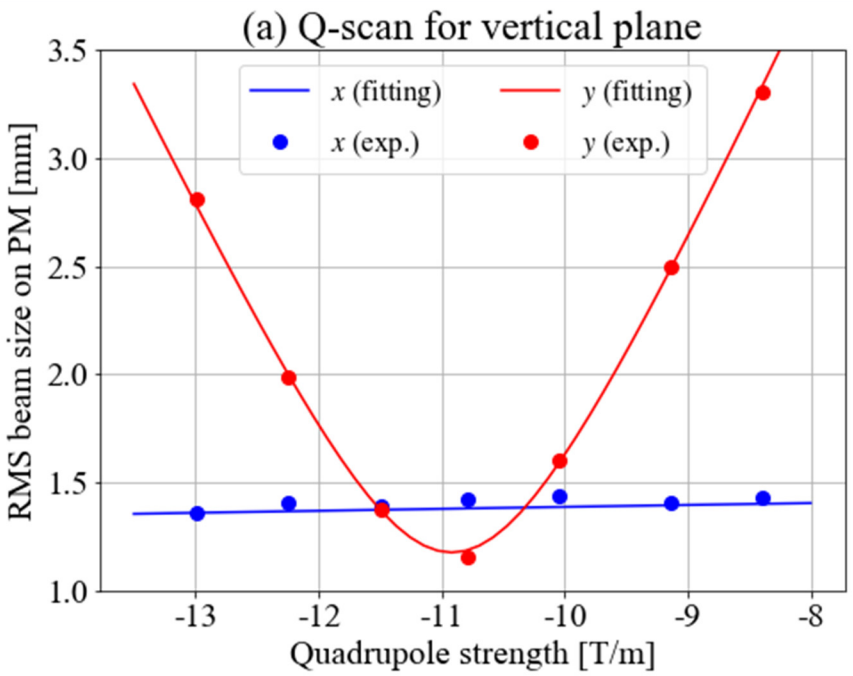
- **RMS Beam Envelope with Twiss recovery** **--- Operating point**

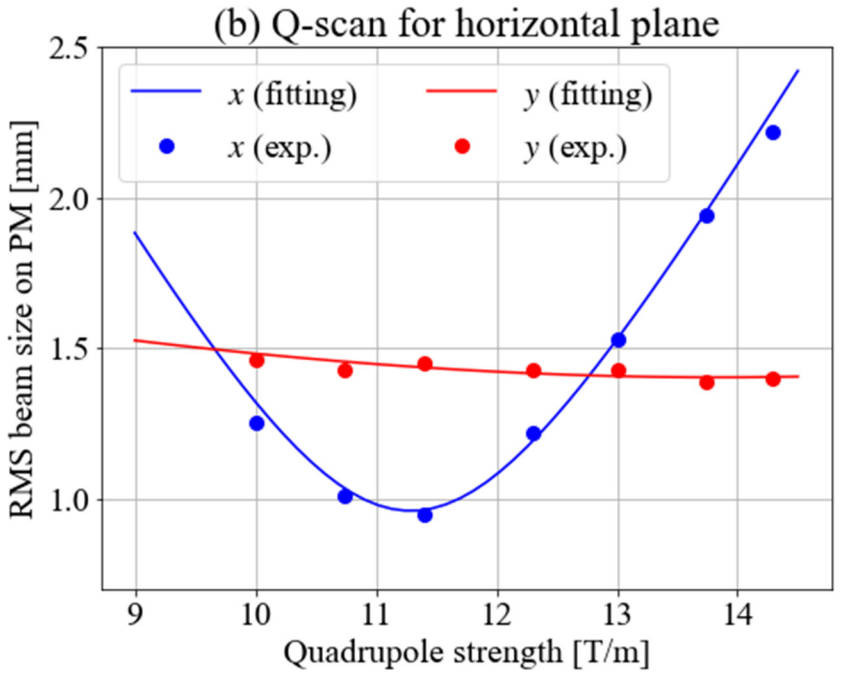




✓ **By using FLAME, the calculation time for the optimization of 4 quadrupoles setting for each profile measurement is approximately 0.1 s.**

Experimental Result of Q-Scan





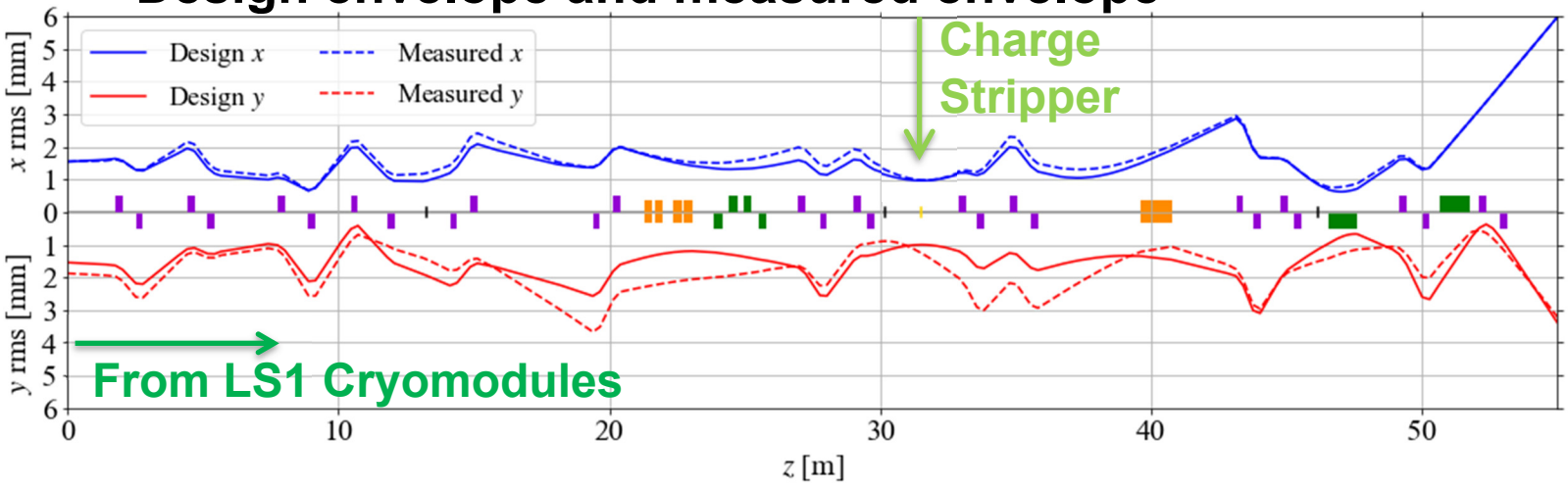
Measured Beam Parameter

	x	y
Normalized rms emittance [π mm-mrad]	0.13	0.13
Twiss parameter β [m]	4.0	5.9
Twiss parameter α	0.13	-0.02

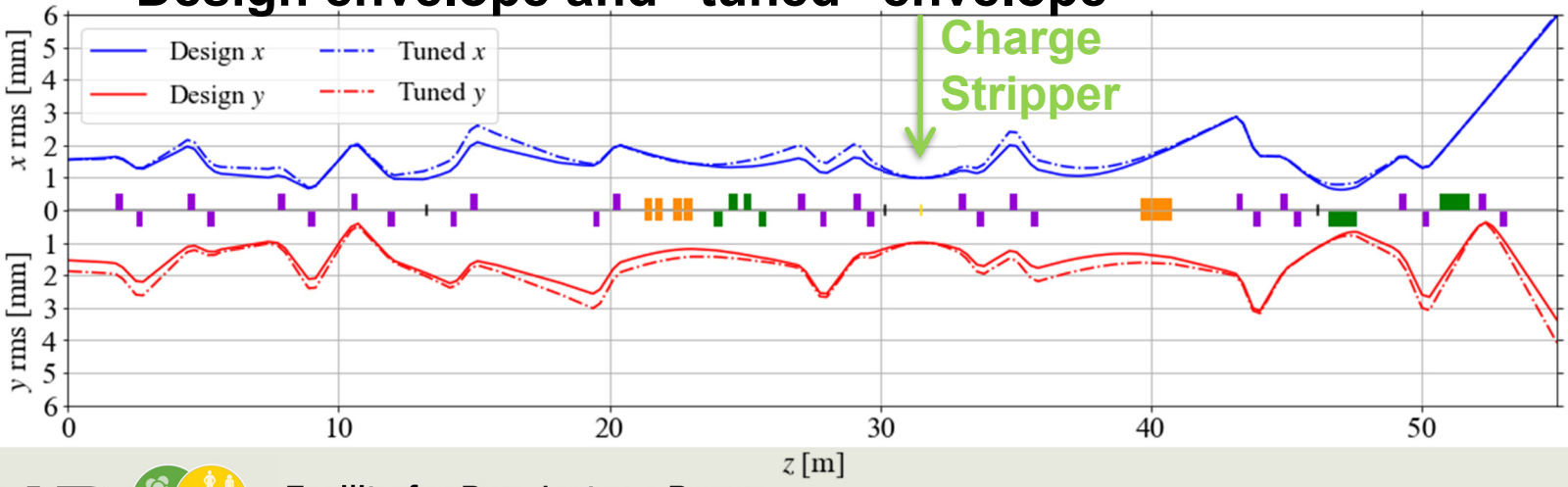
✓ **By fitting both scan results simultaneously, the transverse 2nd order moments including the coupling terms are evaluated**

Measured RMS Beam Envelope in FS1

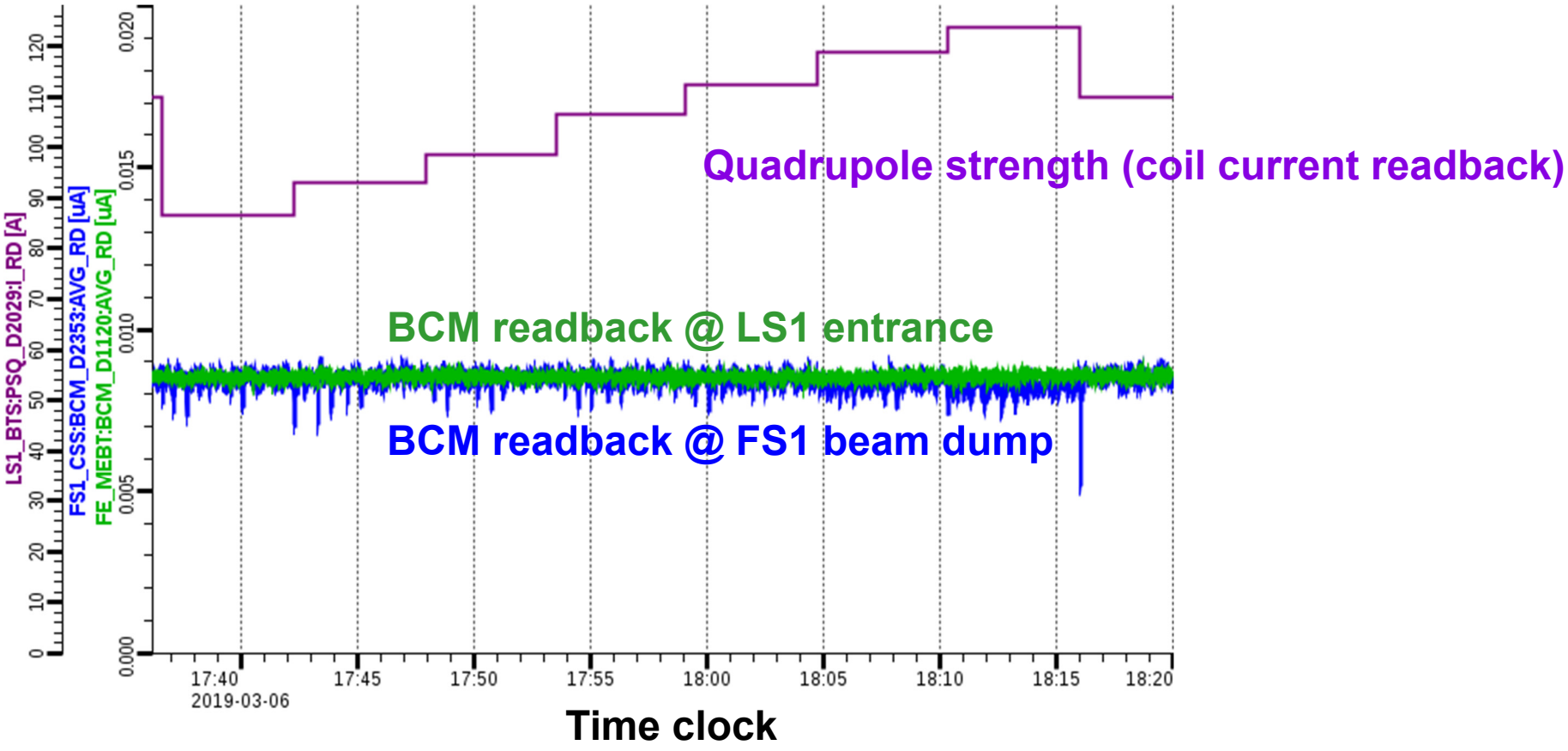
- **Design envelope and measured envelope**



- **Design envelope and "tuned" envelope**

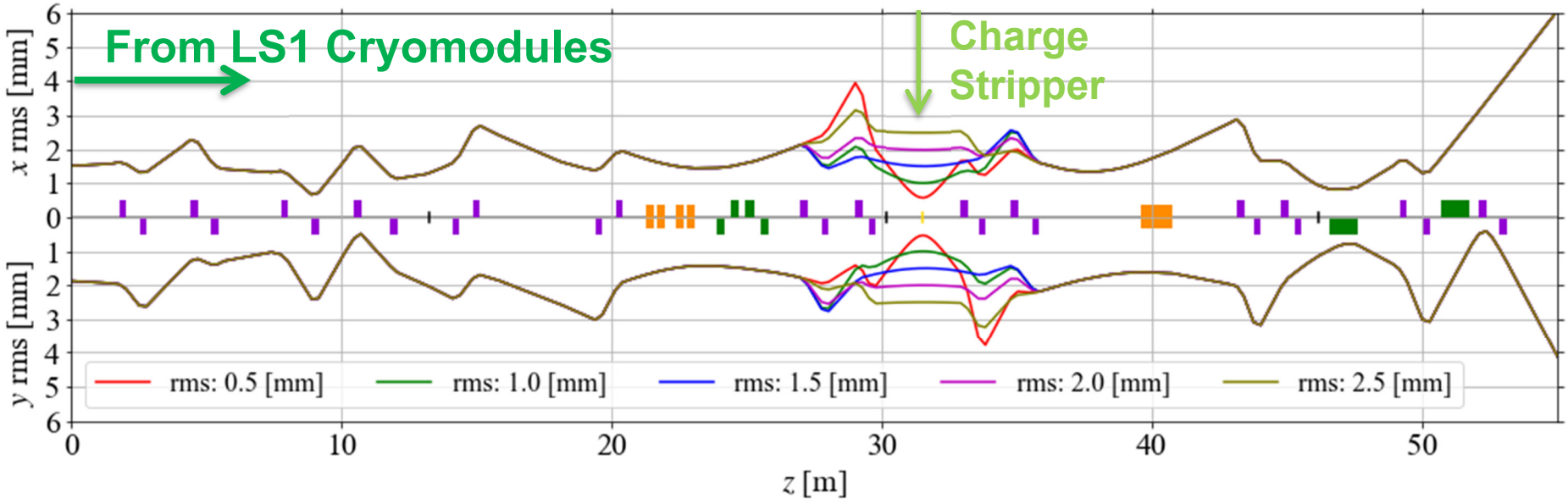


BCM Signal During the Q-Scan



- ✓ Bothe BCM signals are overlapped during the Q-scan with Twiss recovery procedure
- ✓ Spike noises in blue line are caused by the wire insertion of the profile monitor

Beam Size Control on Charge Stripper



- ✓ By using similar procedure, we can control the rms beam size on the charge stripper (carbon foil) by changing **upstream 4 quadrupoles**, and the Twiss parameters are recovered by using **downstream 4 quadrupoles**.

Summary

- In FS1 section of the FRIB linac, the transverse Twiss parameters and rms emittances were measured without any beam losses by using Q-scan with Twiss recovery procedure.
- The experimental results are consistent with FLAME simulation, and this fast optimization routine is useful for beam tuning.
- The Twiss recovery procedure is a very useful method to avoid unnecessary beam losses and activation of the accelerator equipment during Q-scan measurements.

* Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.