

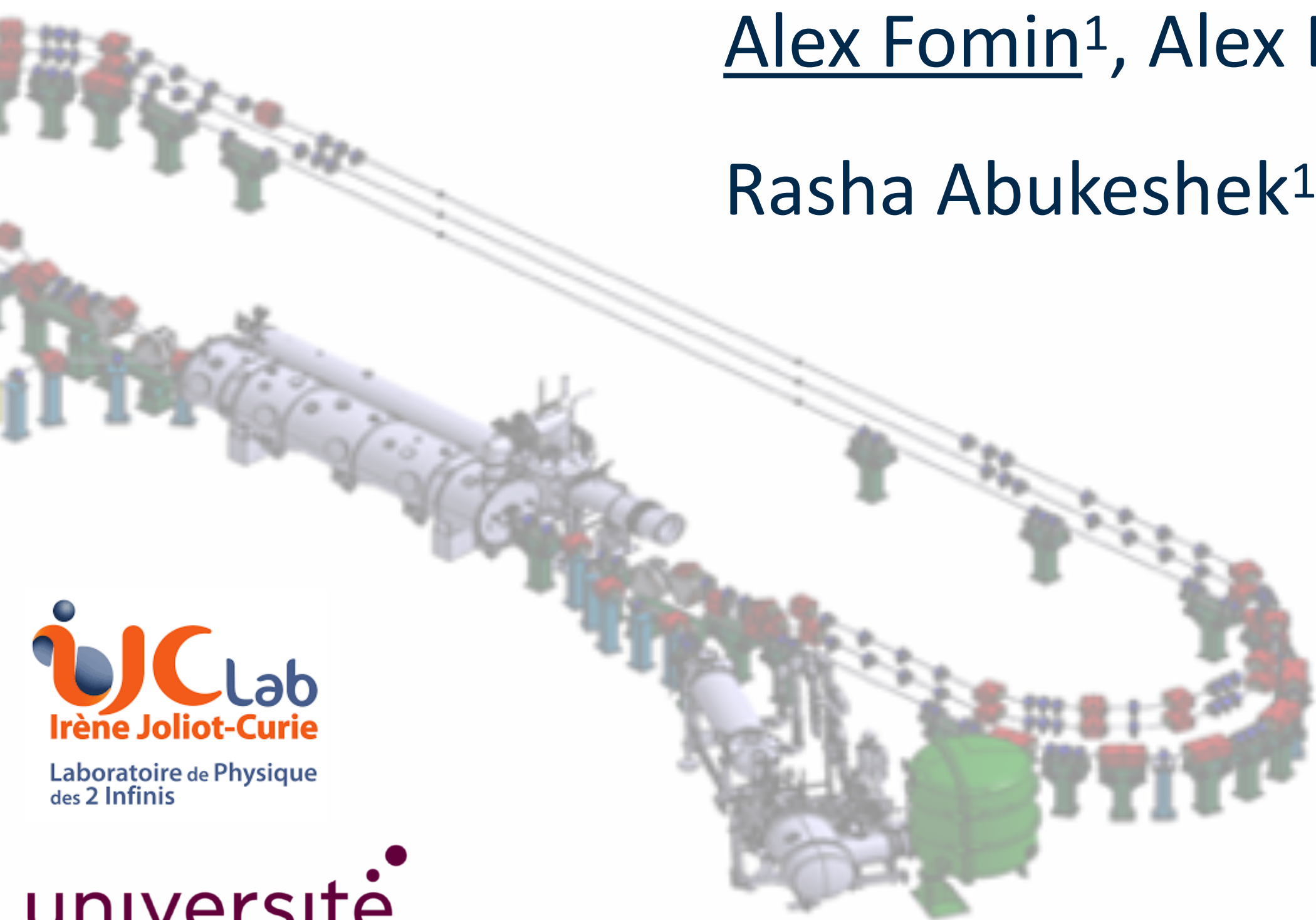


PERLE design and beam dynamics studies

Alex Fomin¹, Alex Bogacz², Julien Michaud¹, Luc Perrot¹, Coline Guyot¹,
Rasha Abukeshek¹, Connor Monaghan^{1,3}, Walid Kaabi¹, Achille Stocchi¹

- (1) Université Paris-Saclay, CNRS/IN2P3, IJCLab (Orsay, France)
- (2) Jefferson Lab, CASA (Newport News, USA)
- (3) Cockcroft Institute (Warrington, United Kingdom)

Special thanks to: Ben Hounsell, Kirsten Deitrick, Raphael Roux, Frederic Bouly,
Hayg Guler, Denis Reynet, Sylvain Brault et al.





Lattice design

Optics

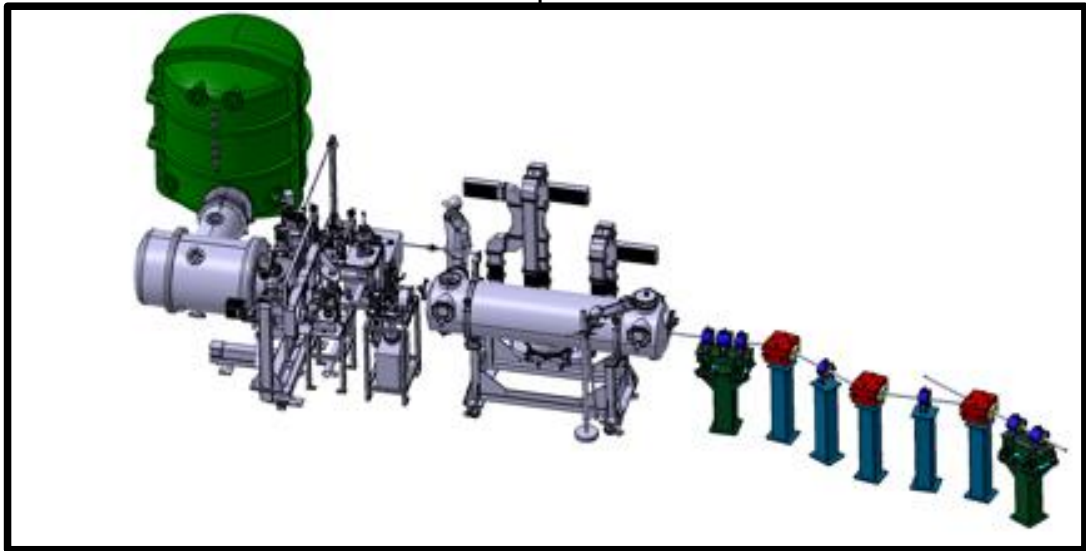
Beam dynamics

Outlook

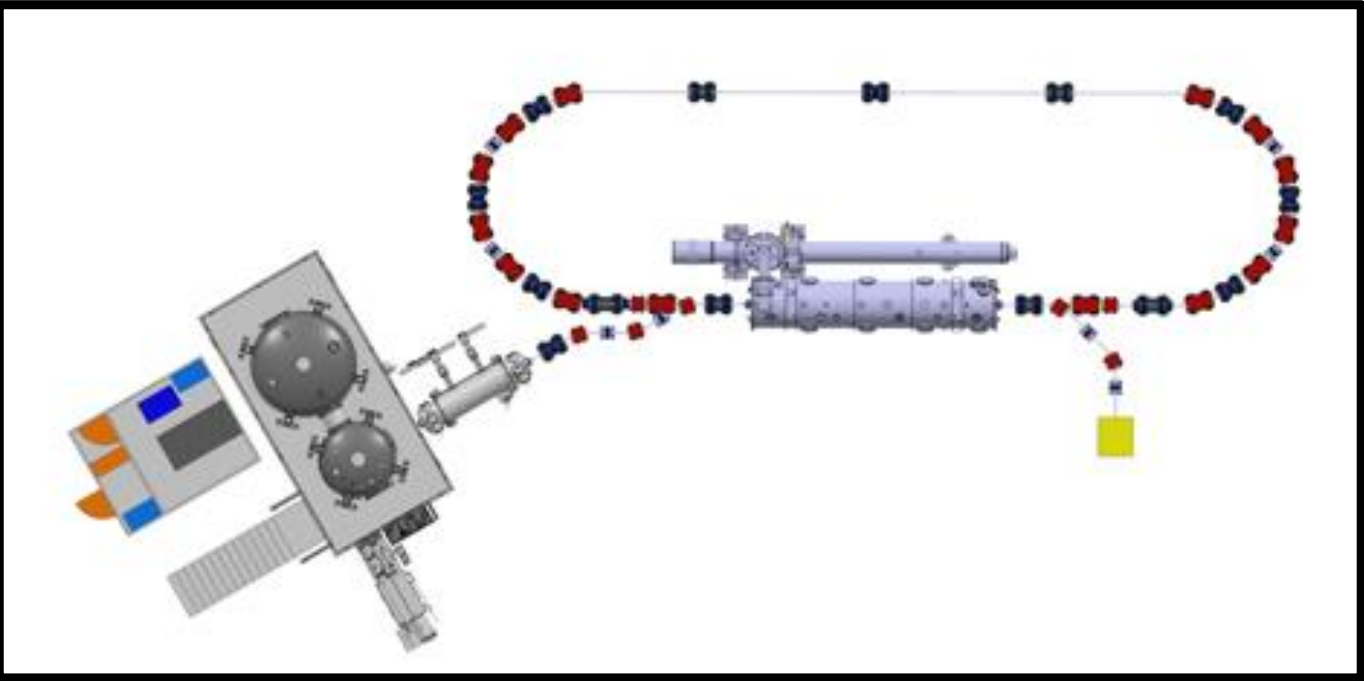


TDR and prototyping

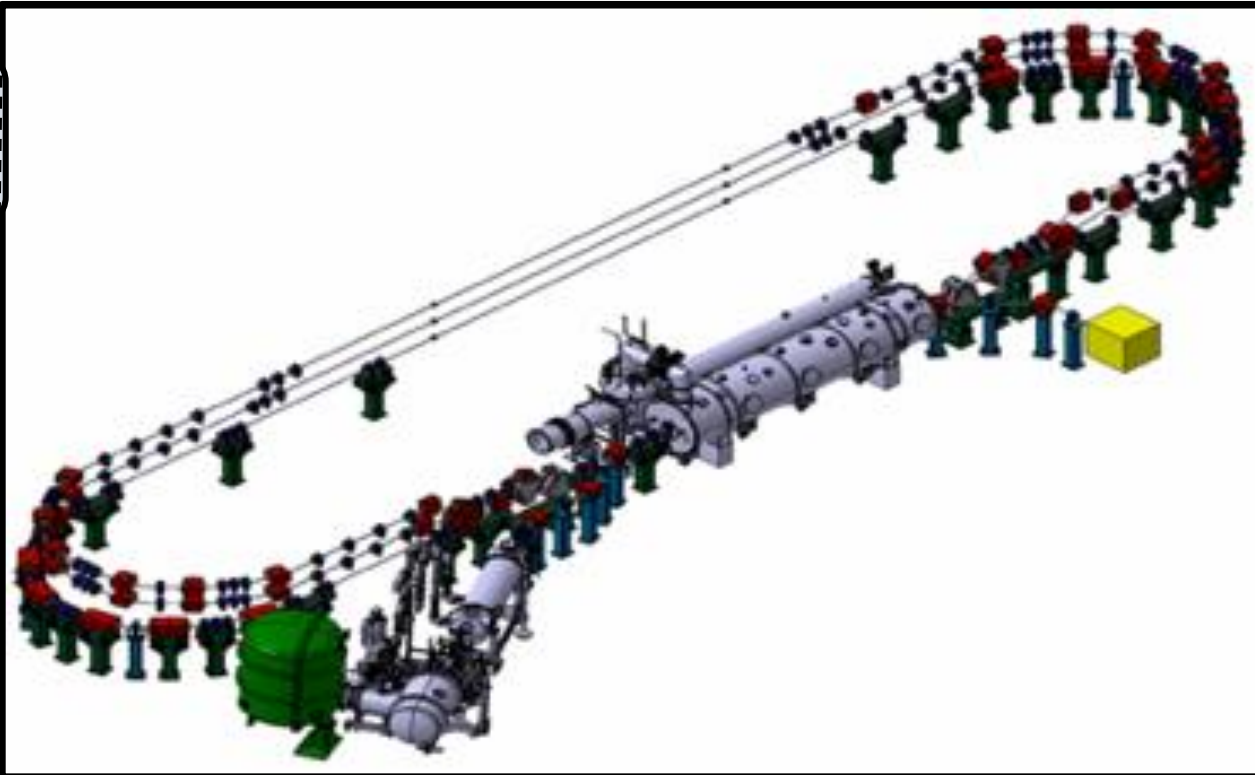
Phase 1: Injection line



Phase 2: PERLE 1 tour



Phase 2: PERLE 250 MeV



Phase 3: PERLE 500 MeV

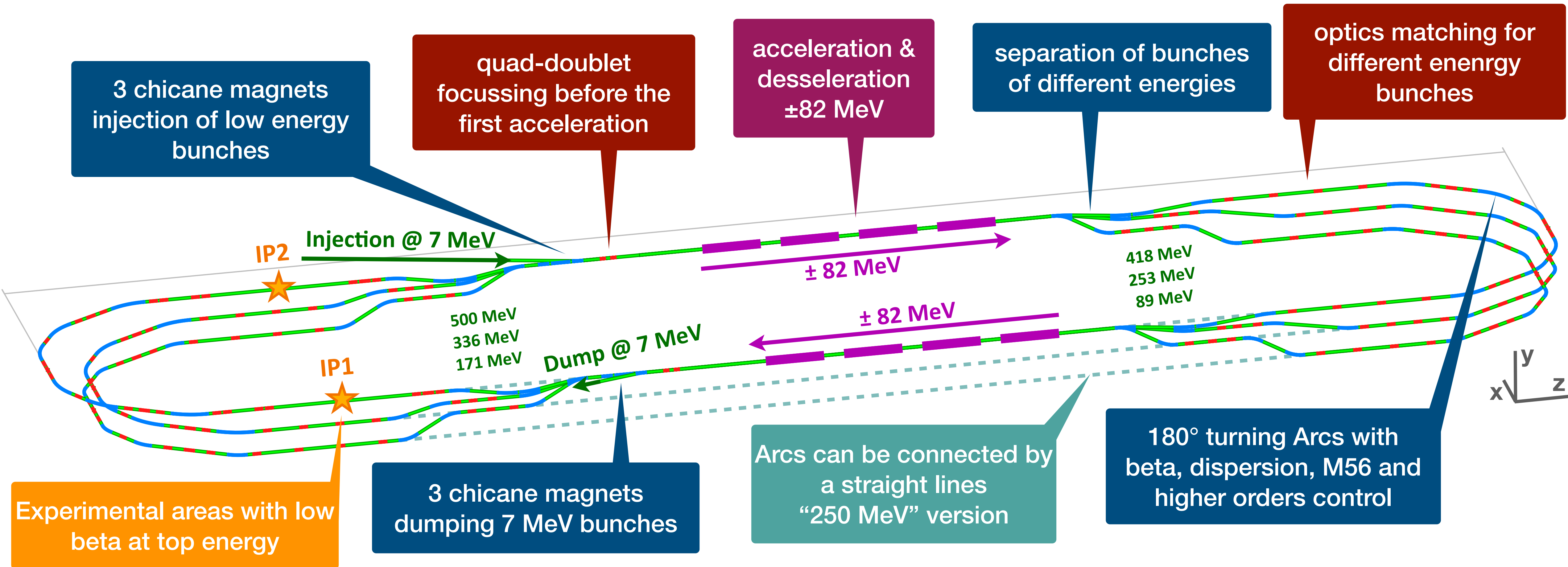


Lattice design — 500 MeV version of PERLE



Initial lattice design made by Alex Bogacz (recent paper: [DOI: 10.1103/PhysRevAccelBeams.27.031603](https://doi.org/10.1103/PhysRevAccelBeams.27.031603))

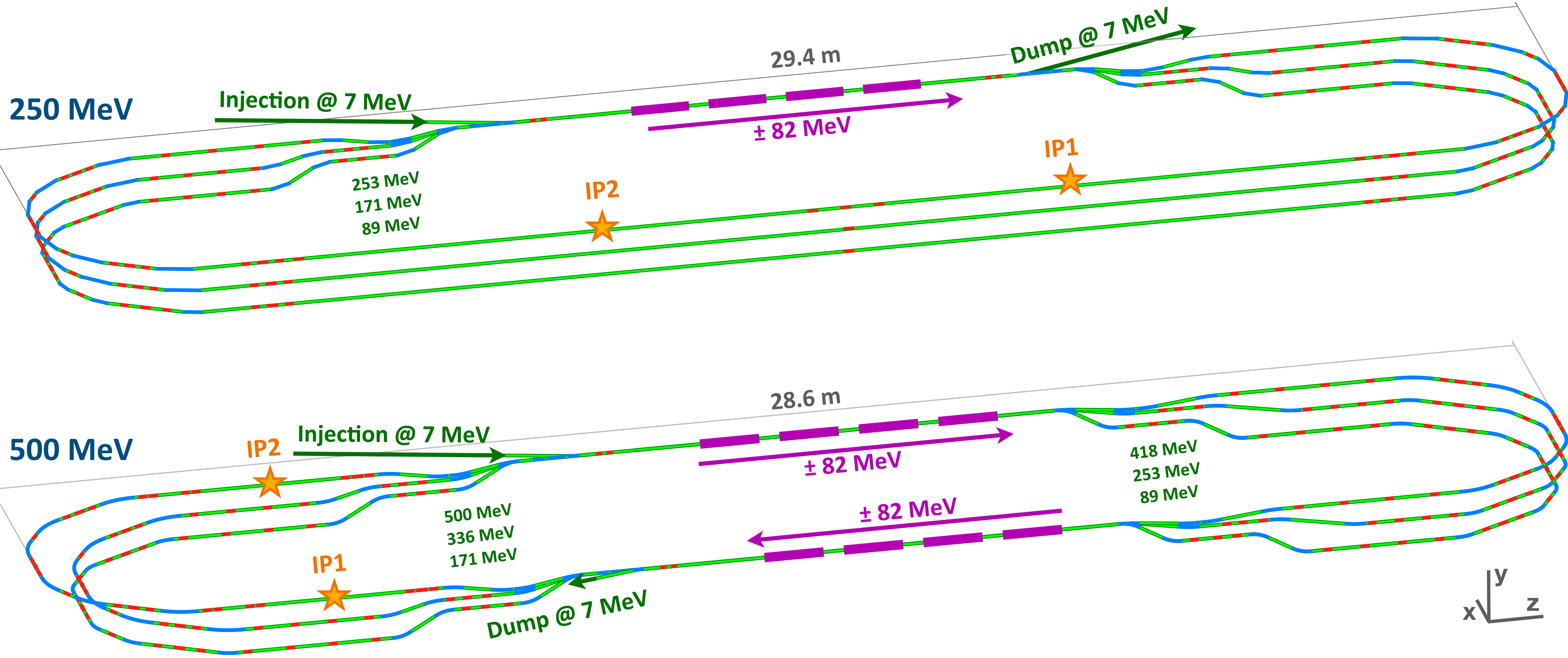
→ racetrack topology with **3 accelerating & 3 decelerating passes through linacs** placed on both sides of the machine



footprint ~ 30 m × 5.5 m



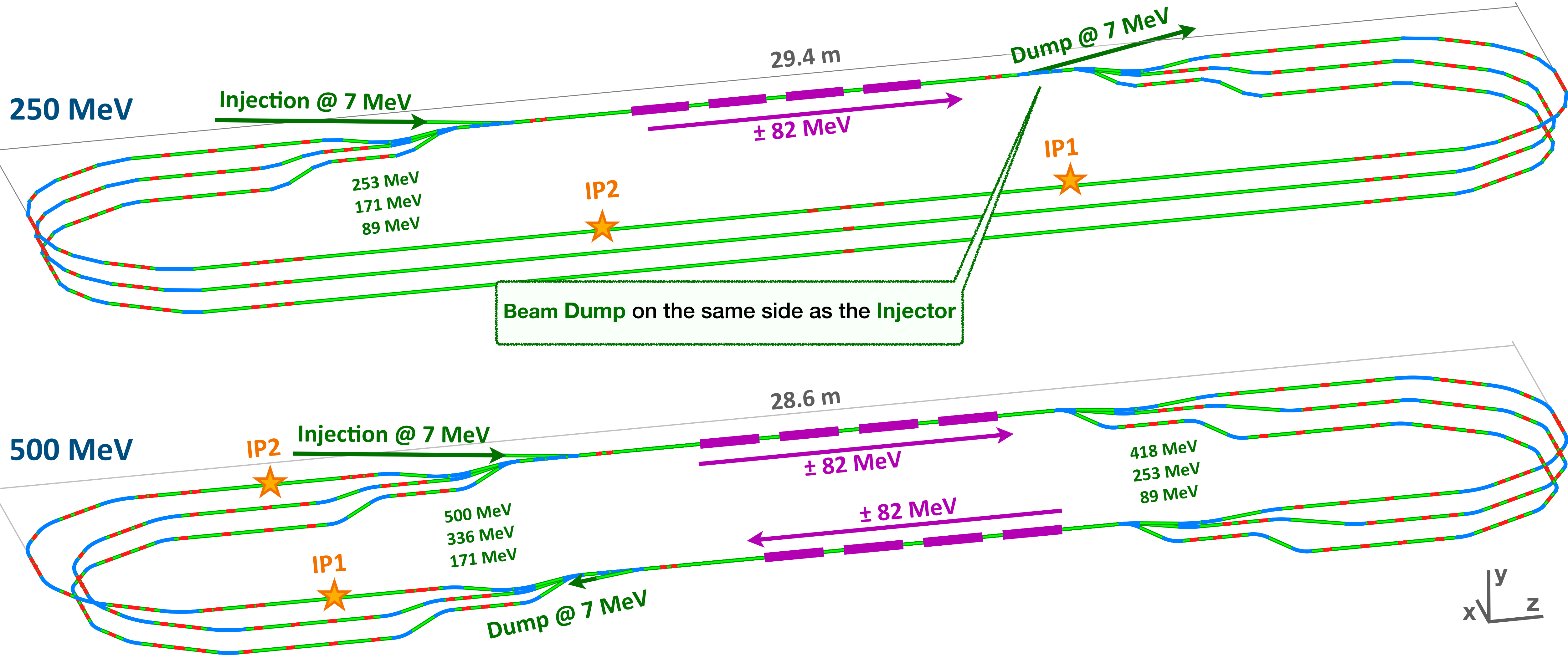
Lattice design. 250 MeV & 500 MeV versions



All main elements should be reused in 500 MeV version of PERLE



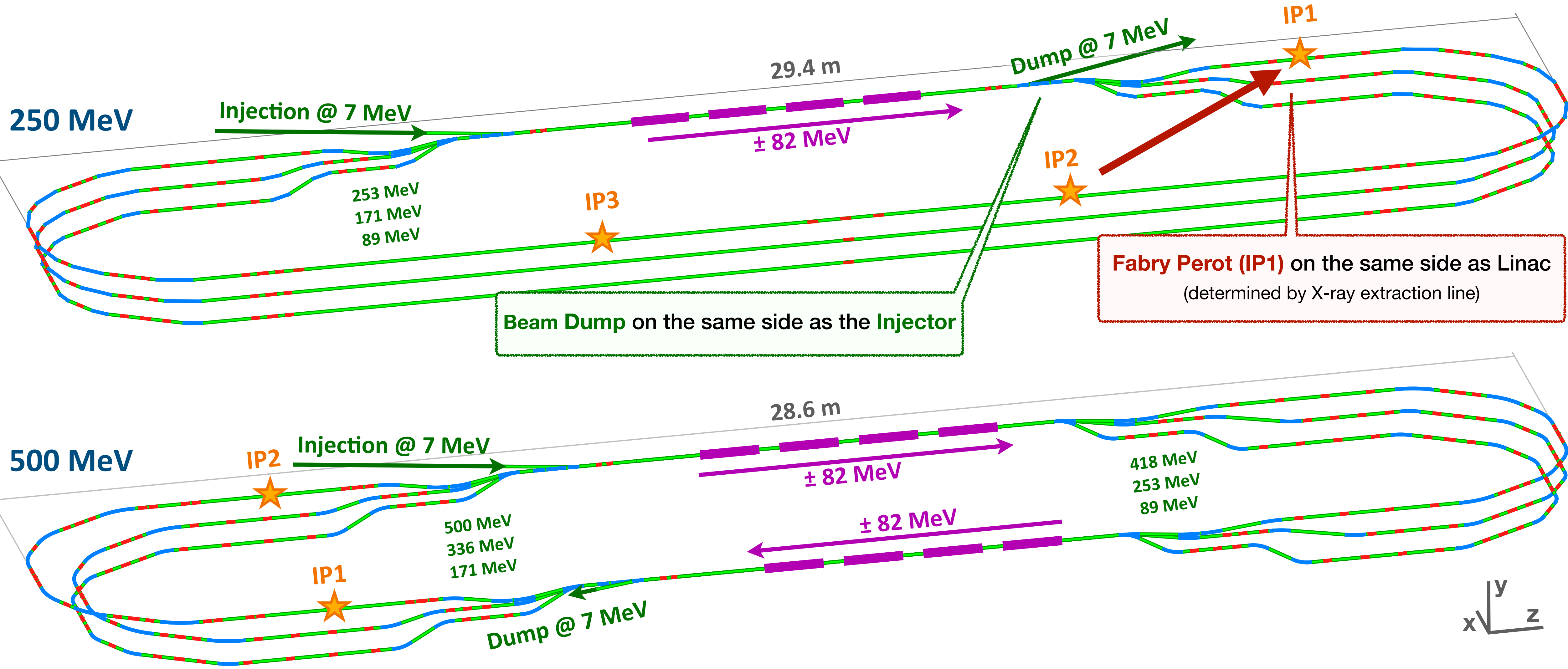
Lattice design. 250 MeV & 500 MeV versions



All main elements should be reused in 500 MeV version of PERLE



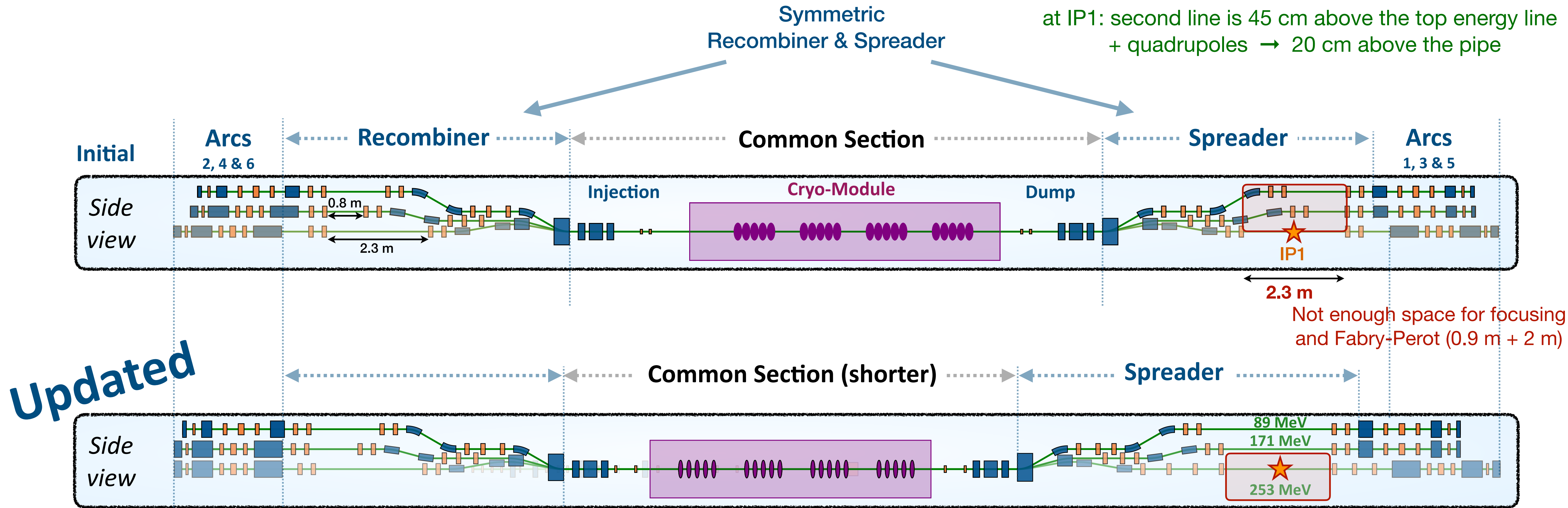
Lattice design. 250 MeV & 500 MeV versions



All main elements should be reused in 500 MeV version of PERLE



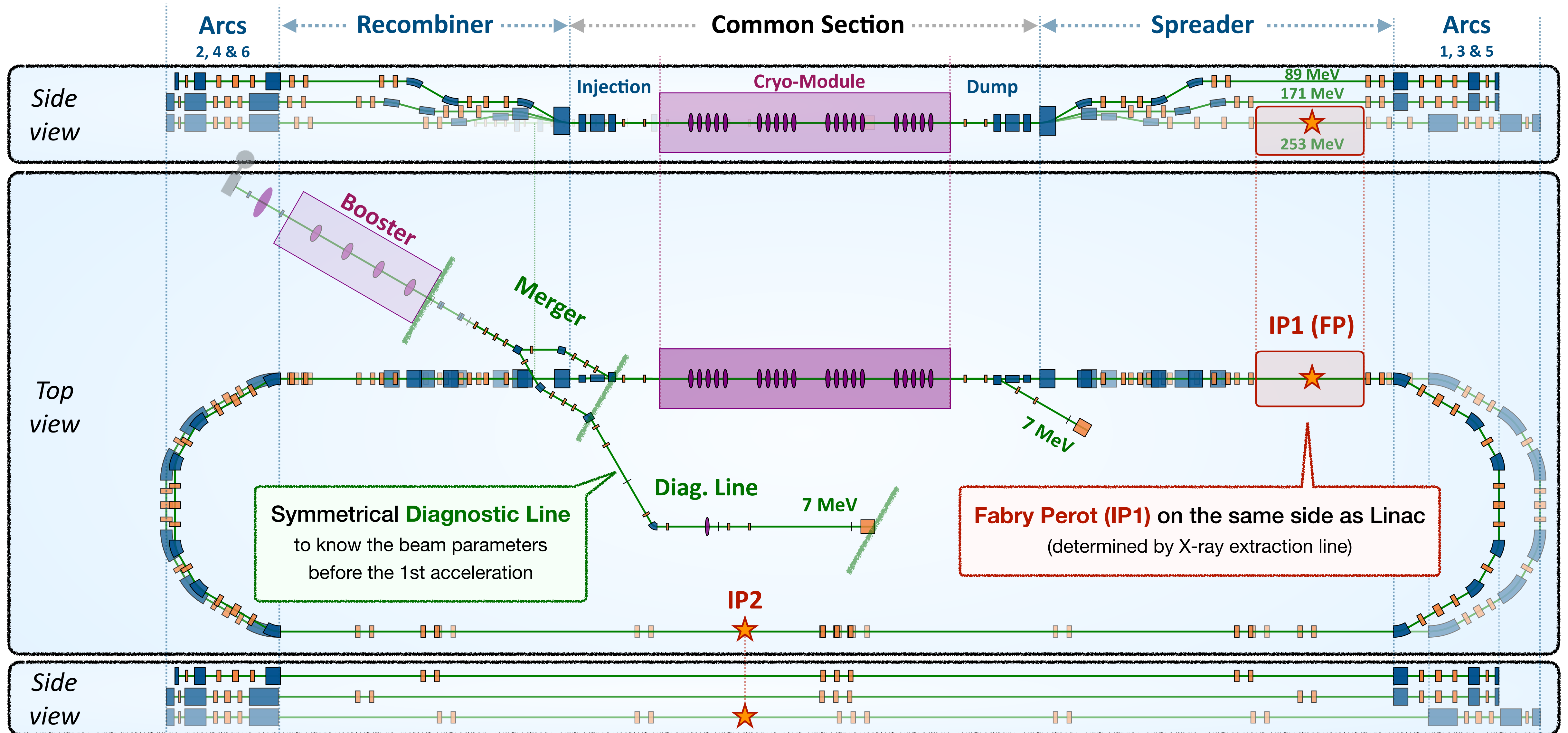
250 MeV Lattice update: Fabry-Perot in the Spreader section



- Recombiner & Spreader and not symmetric
- Spreader section increased ← Common section reduced

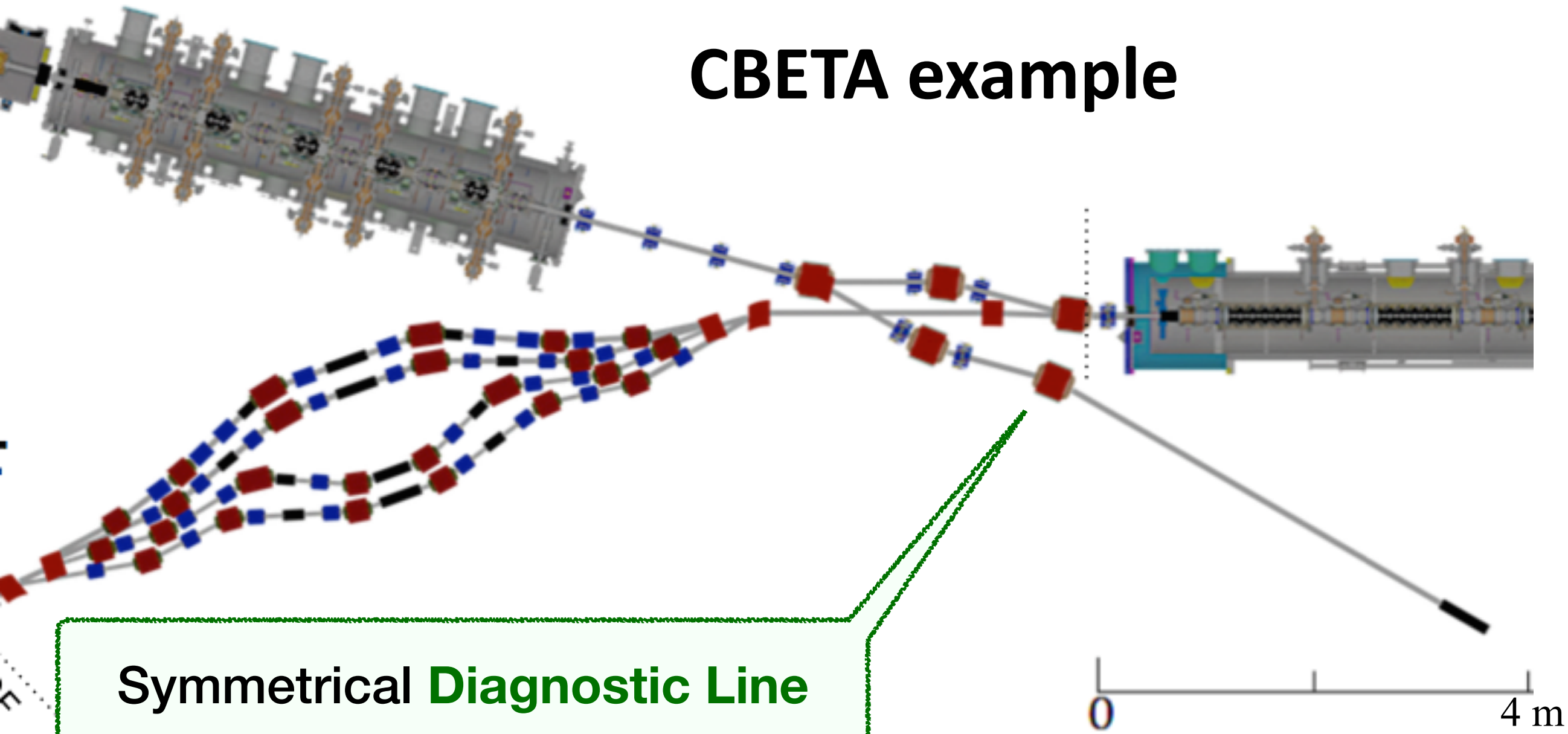


Updated PERLE Lattice 250 MeV version





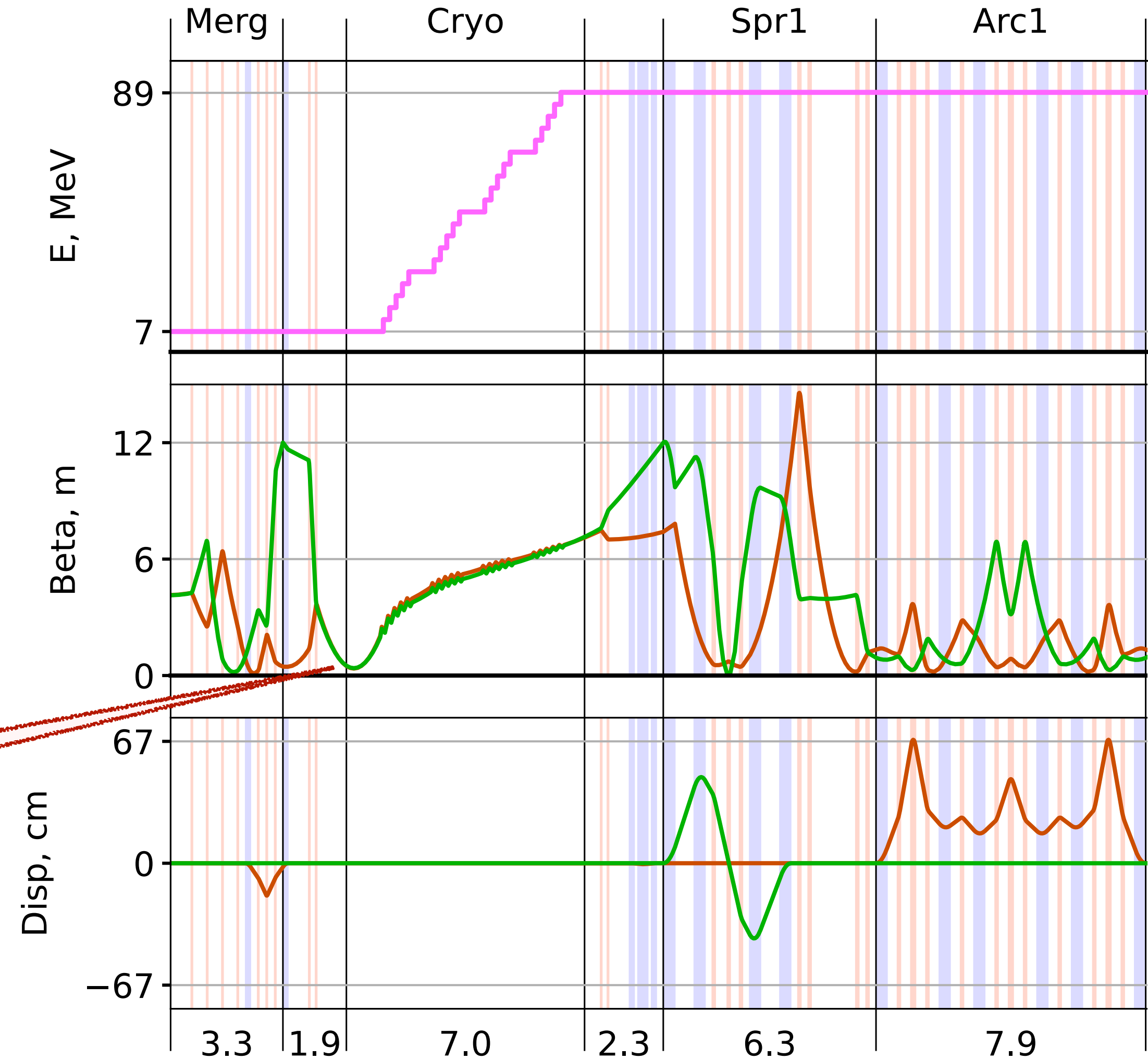
3 Dipole Merger: CBETA Design



Symmetrical **Diagnostic Line** to know the beam parameters before the 1st acceleration

Unavoidable **over-focusing** before the 1st acceleration of Space-Charge dominated beam

PERLE optics

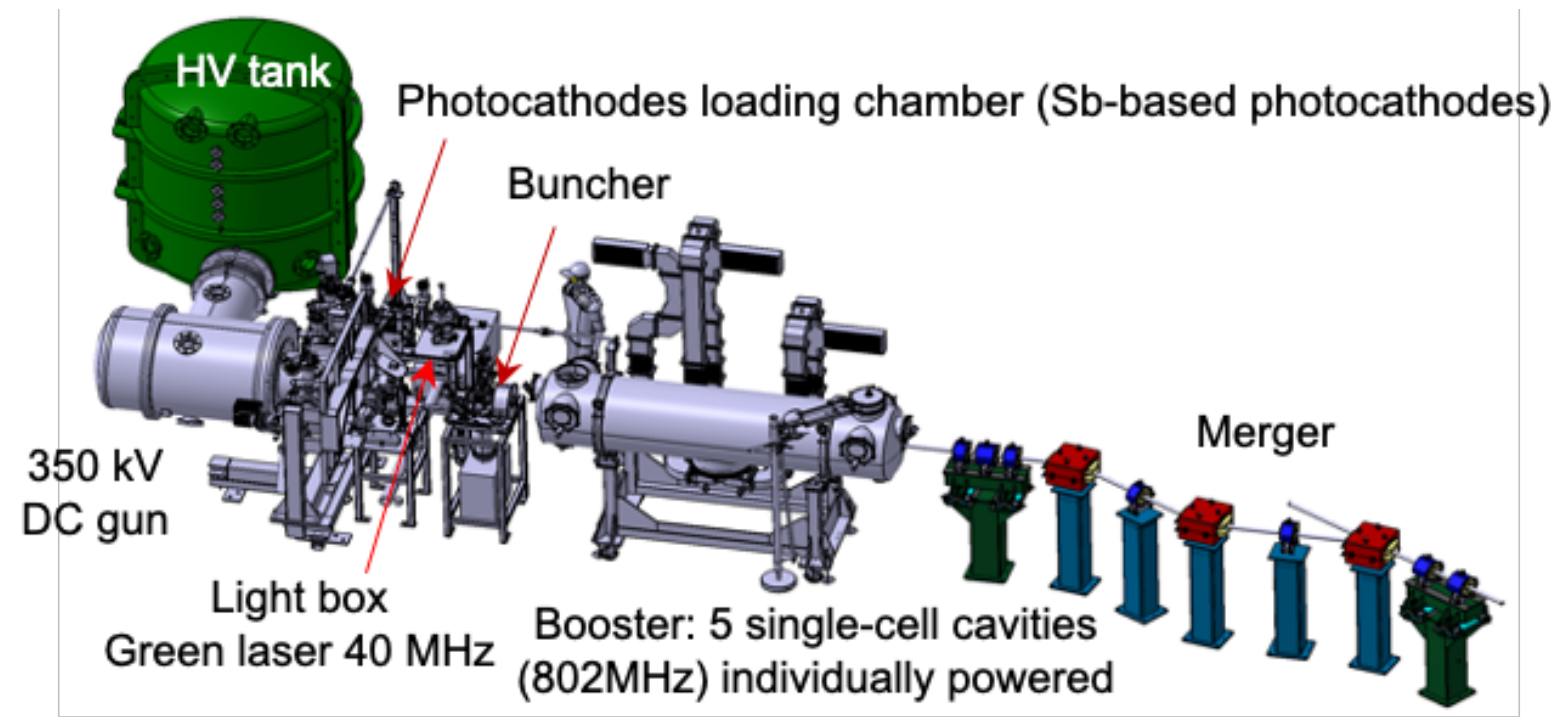




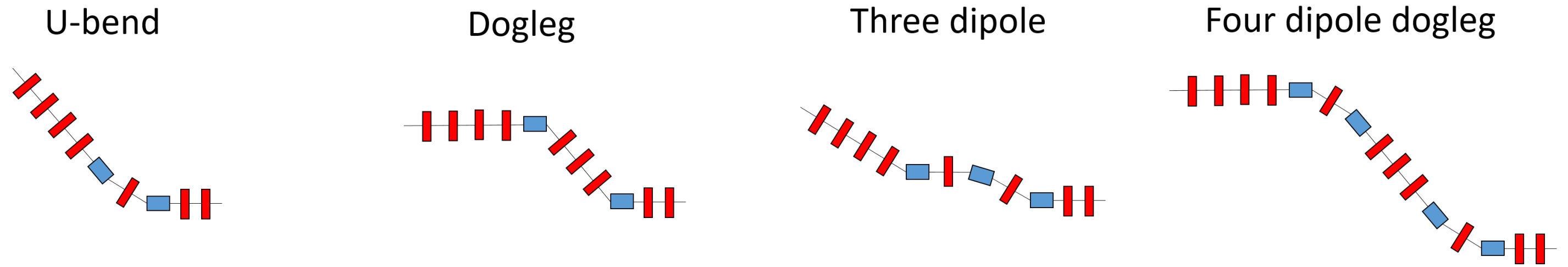
Injector/merger design and initial space-charge studies



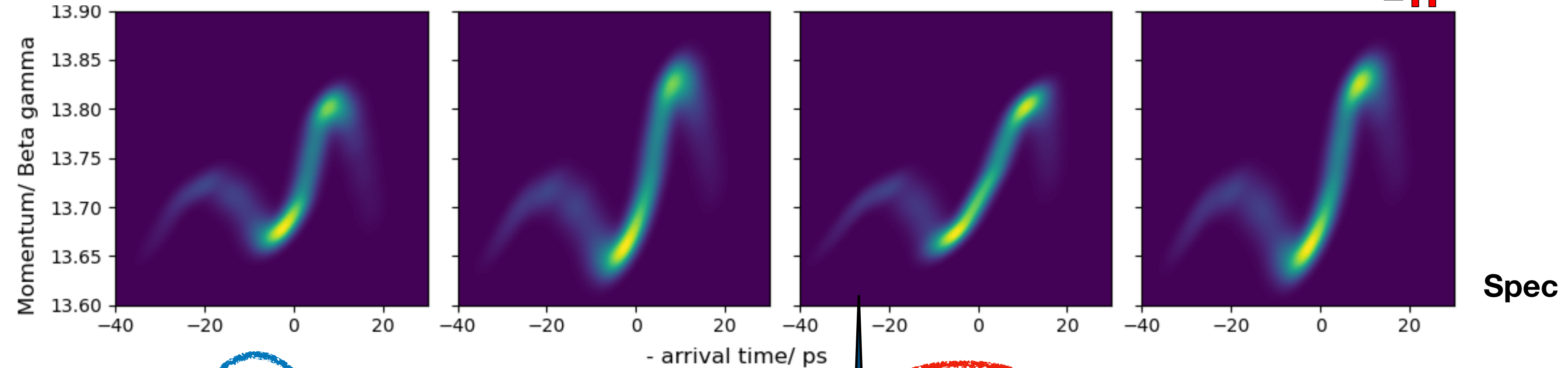
(PhD of B. Hounsell)



Four merger schemes



A conceptual design of the PERLE injector was made within a collaboration between AsTeC-Daresbury, UoL and IJCLab.



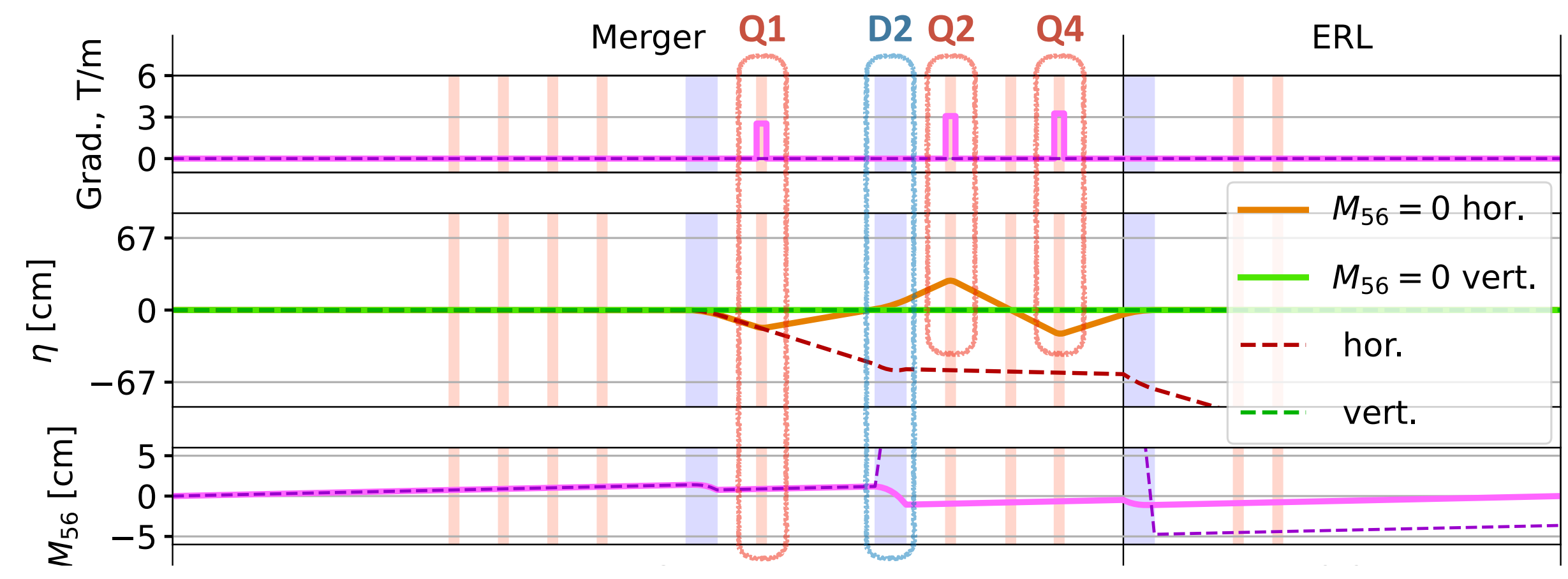
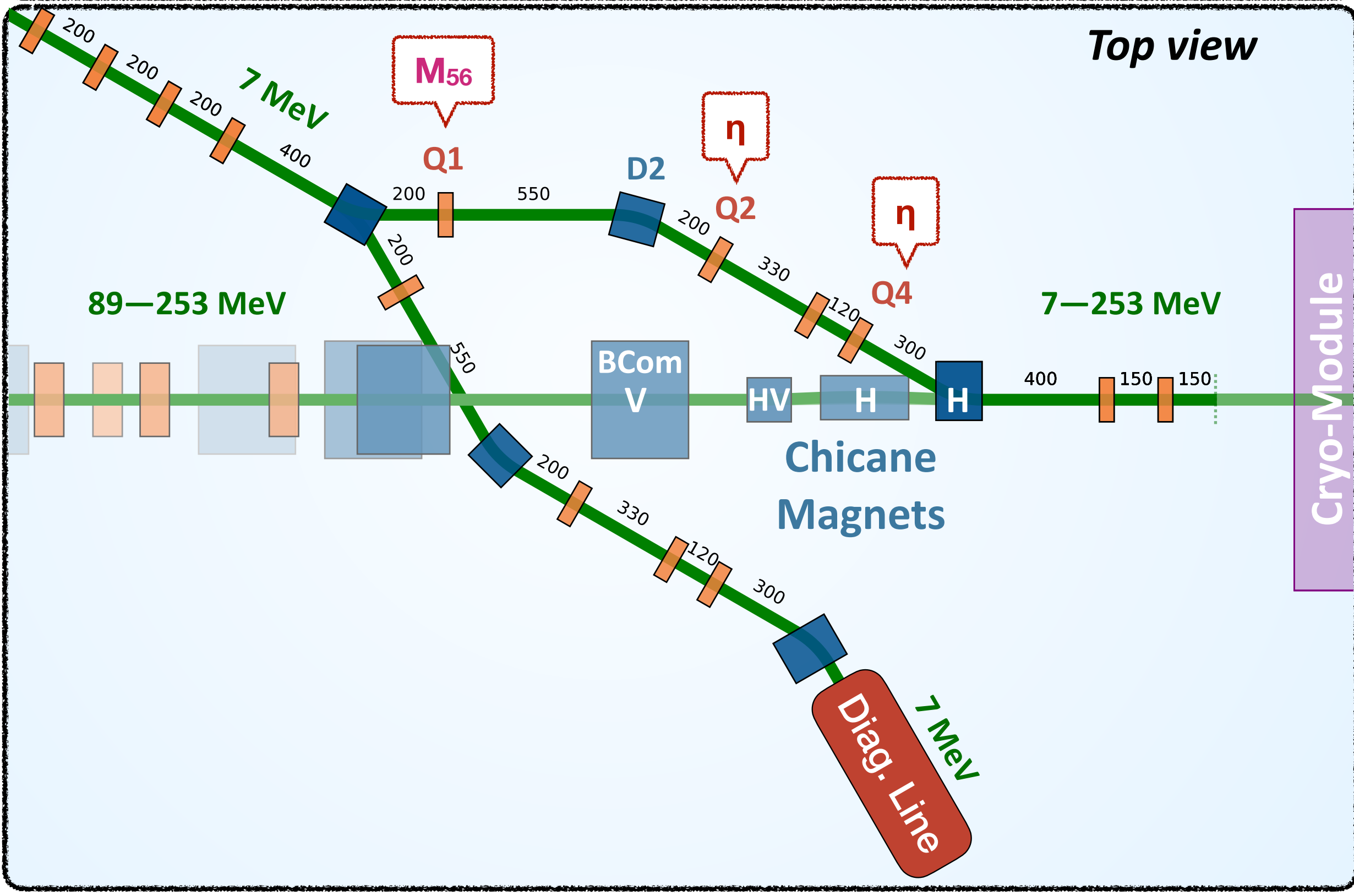
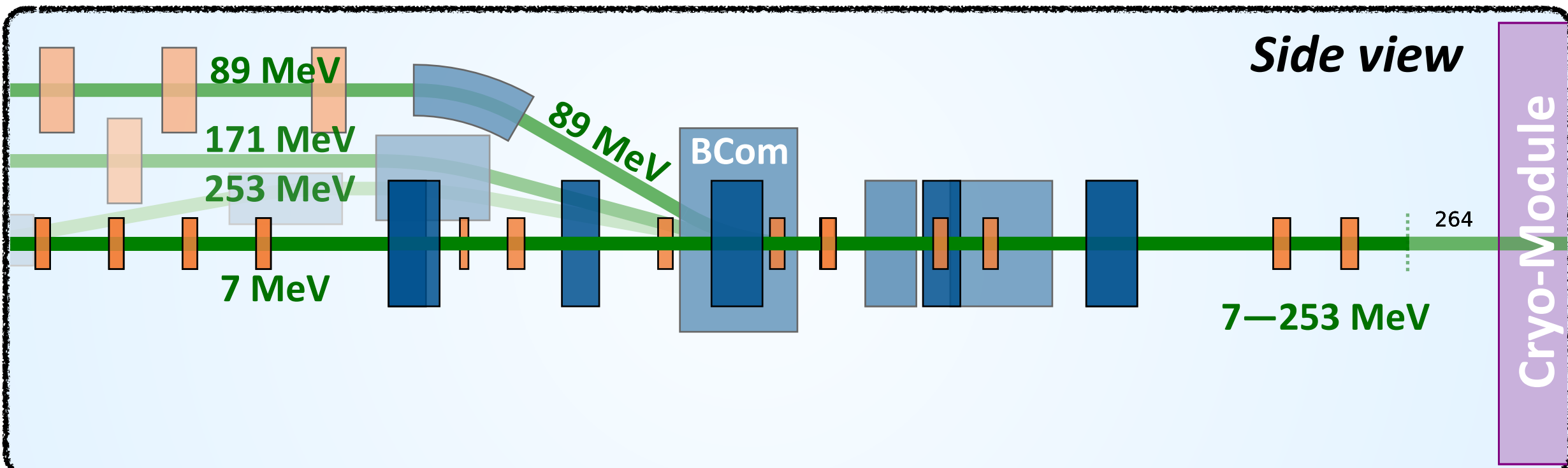
	U-bend	Dogleg	Three dipole	Four dipole dogleg	Spec
$\epsilon_x / \text{mm}\cdot\text{mrad}$	4.3	5.2	5.9	4.7	< 6
$\epsilon_y / \text{mm}\cdot\text{mrad}$	4.4	4.5	3.2	7.0	< 6
Mismatch factor	0.014	0.72	0.05	0.11	0
R56/ m	0.023	0.0185	-0.155	0.031	0

Initially preferred scheme

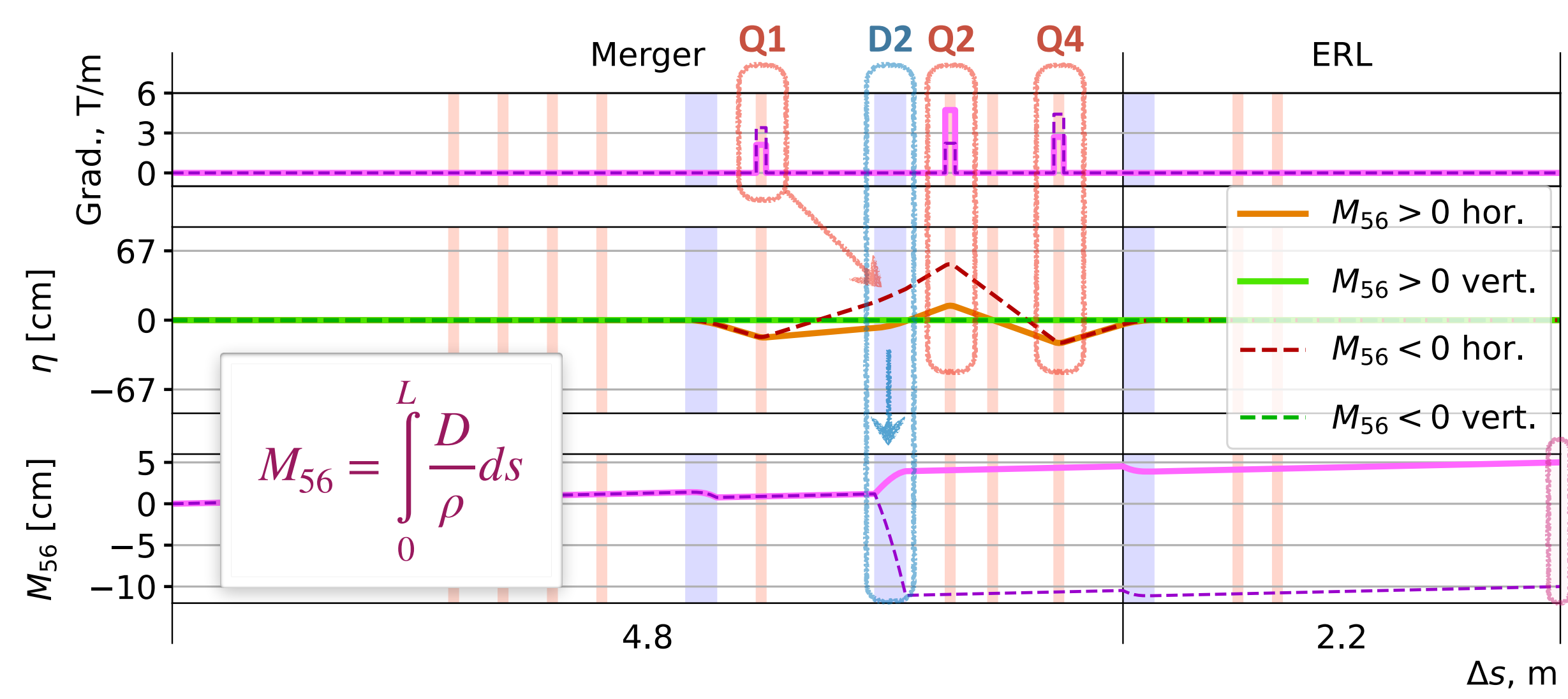
CBETA choice



3 Dipole Merger: Tuning M56 & closing dispersion bump

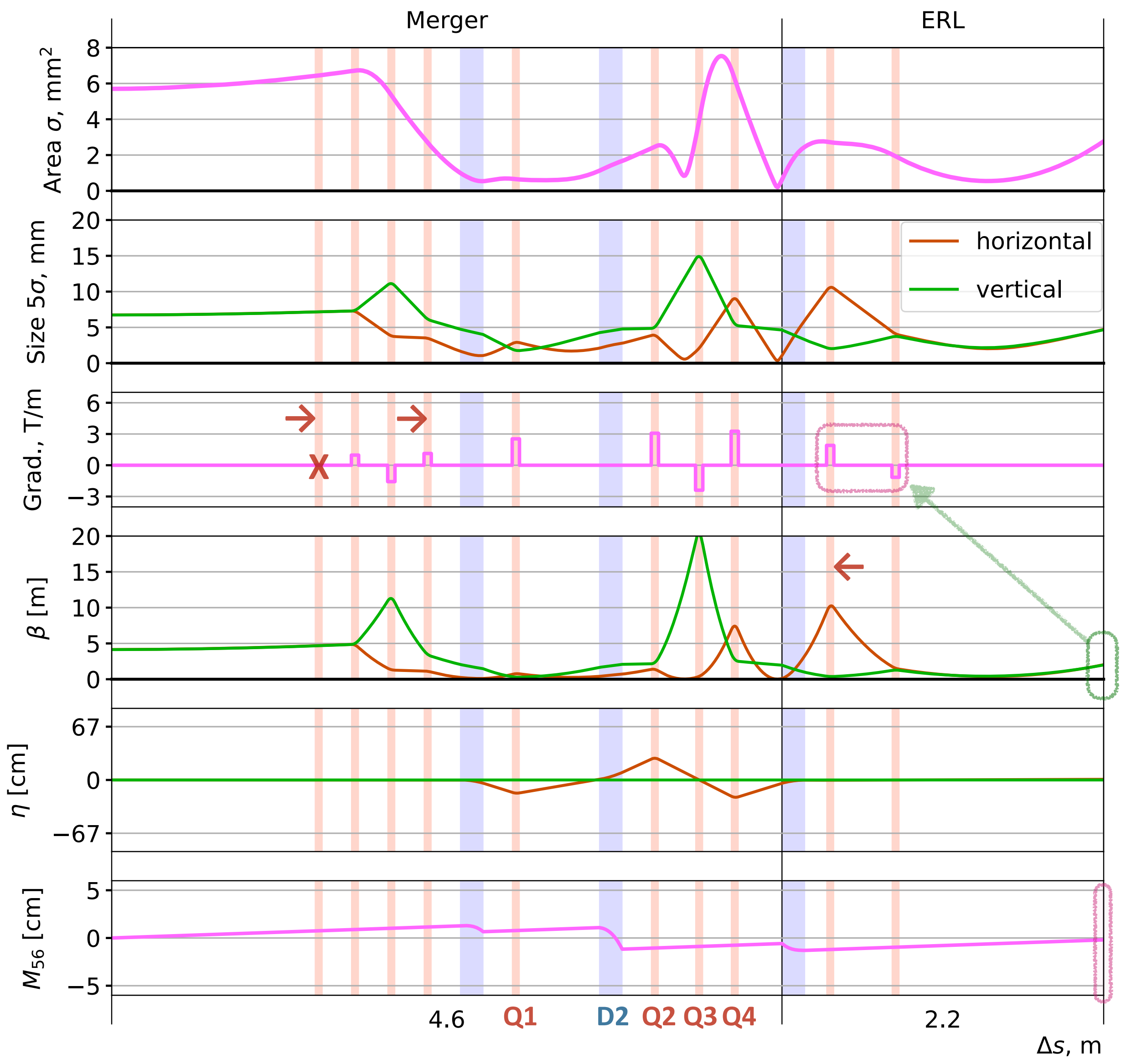
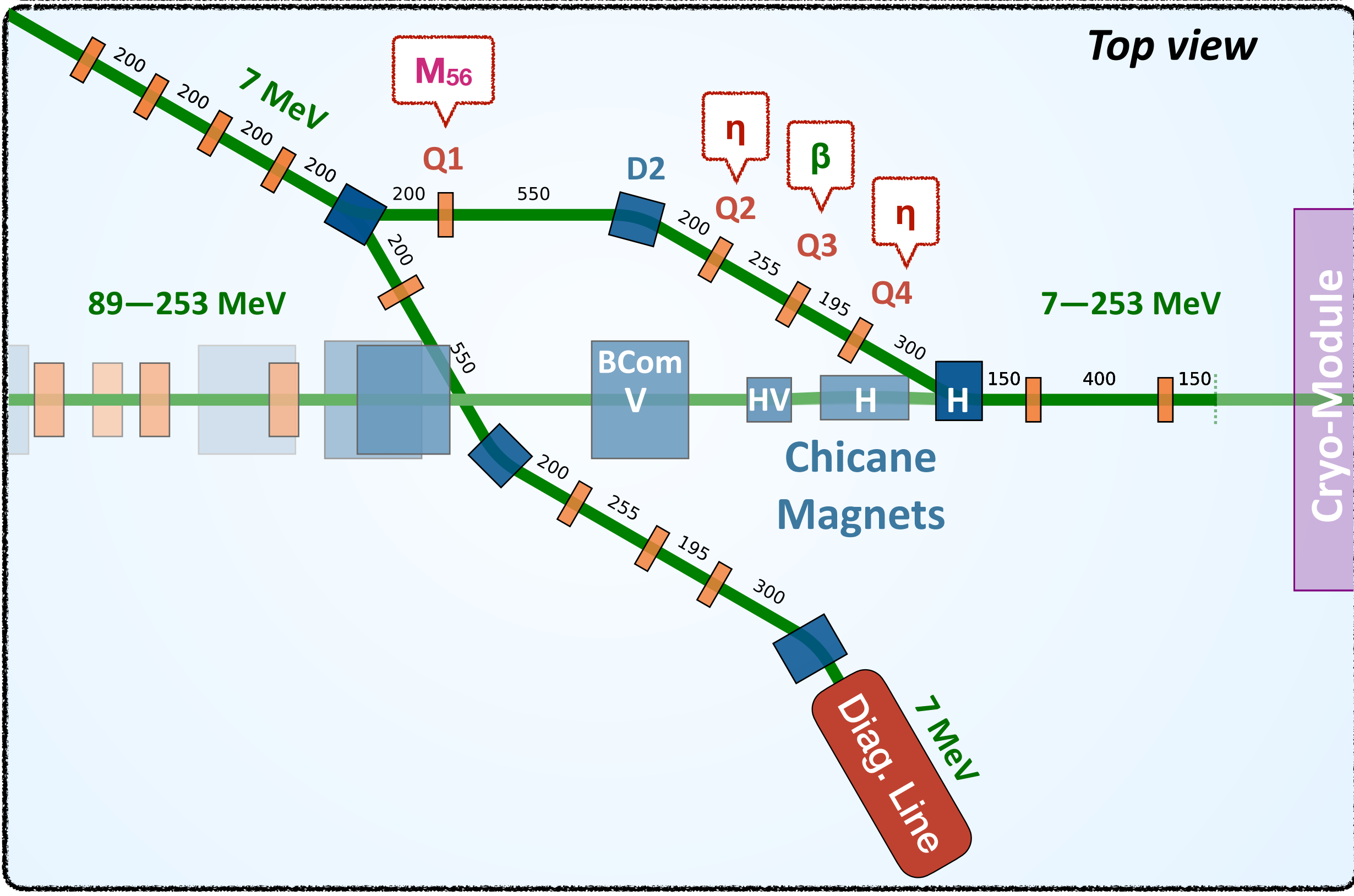
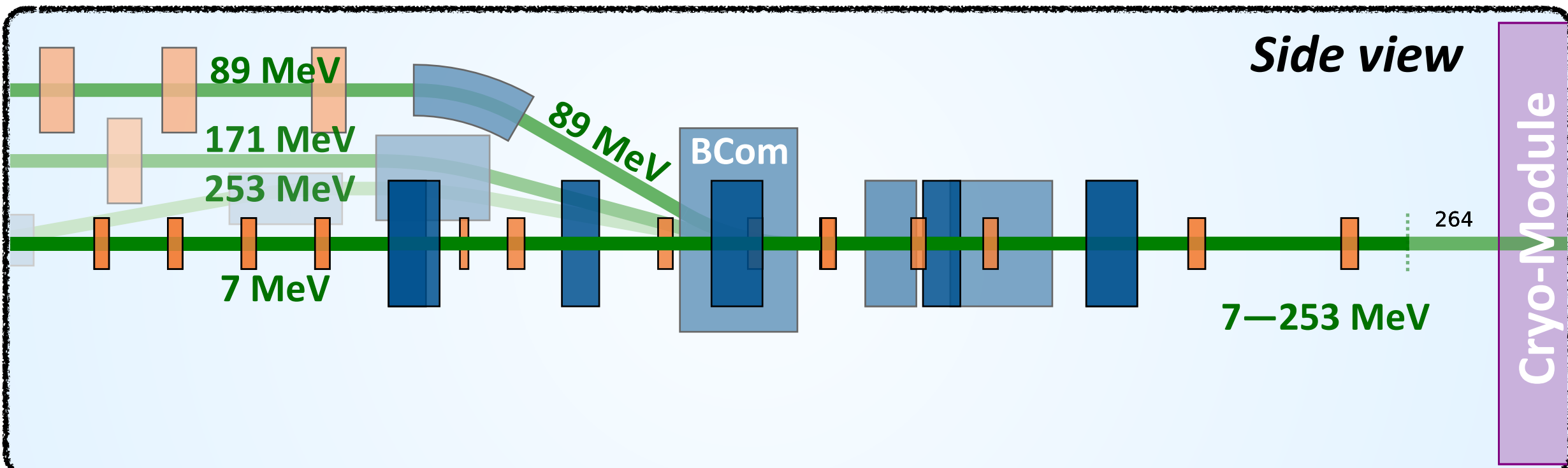


Tuning M56 at Dog-Leg Merger: Q1 → tune the dispersion at D2 → control $M_{56} \in [-10, 5]$ cm
 Q2 & Q4 → closes the dispersion bump ($dx, dp_x = 0$)



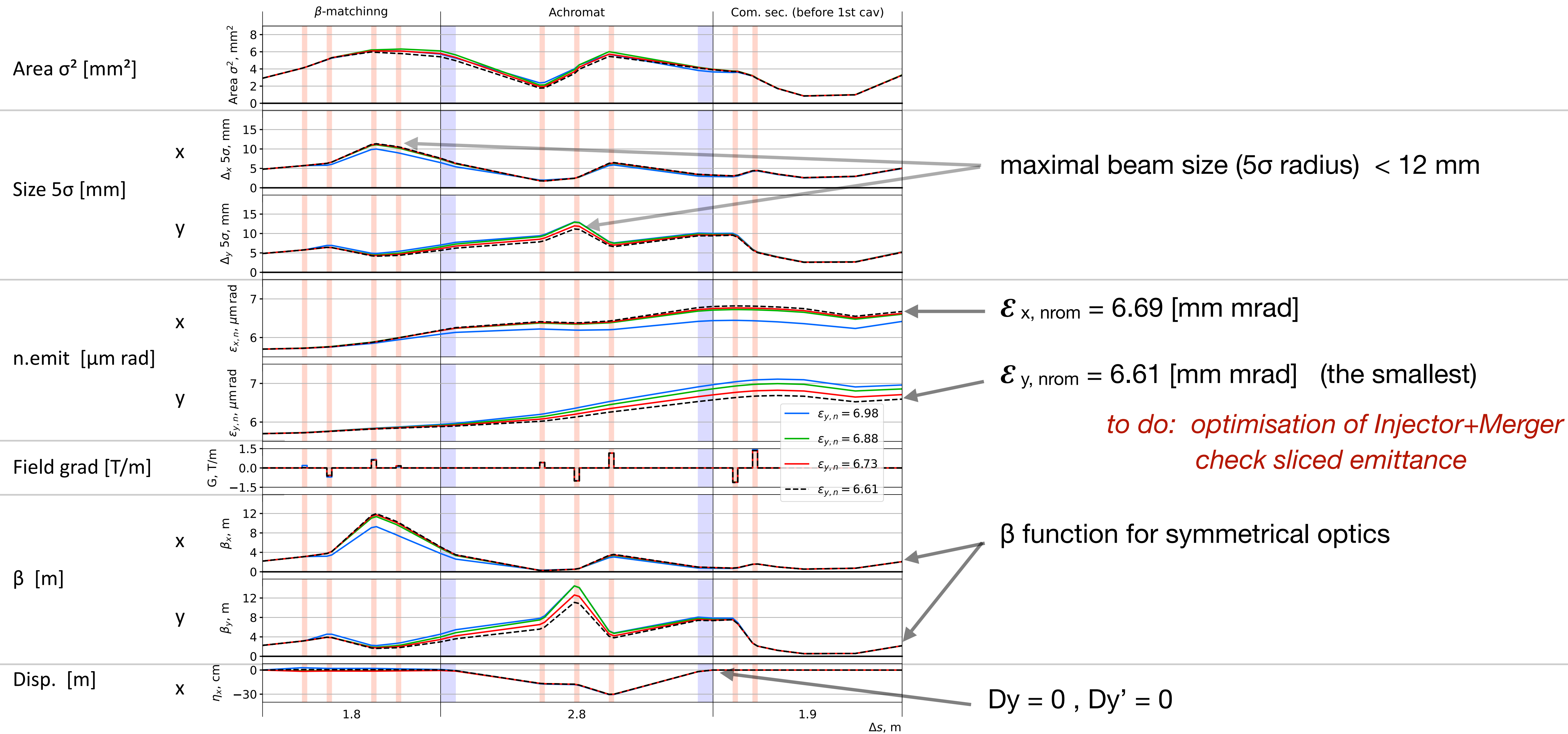


3 Dipole Merger: Controlling the beam size, dispersion & M56



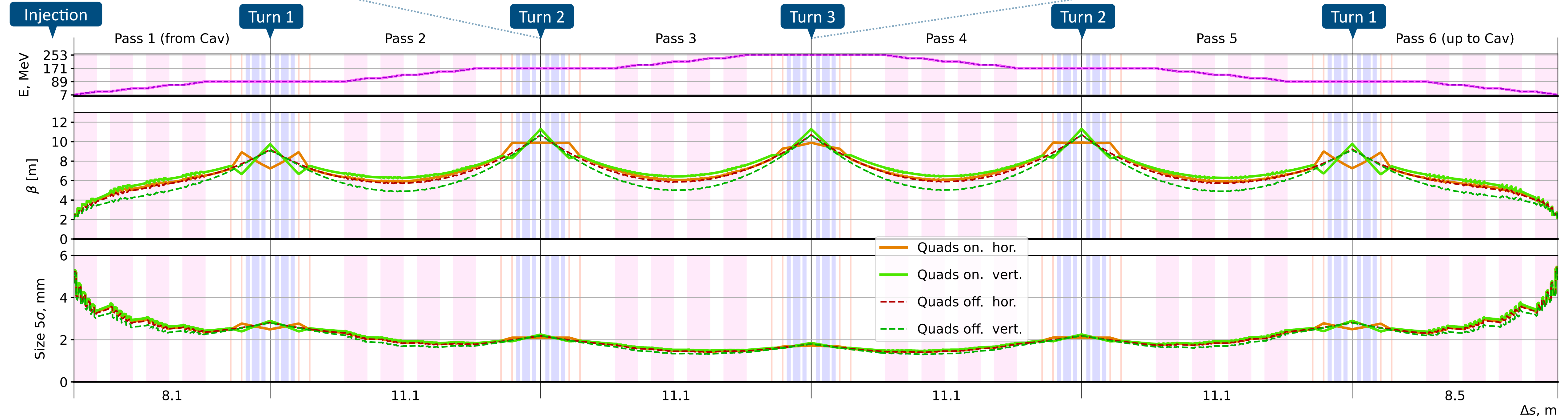
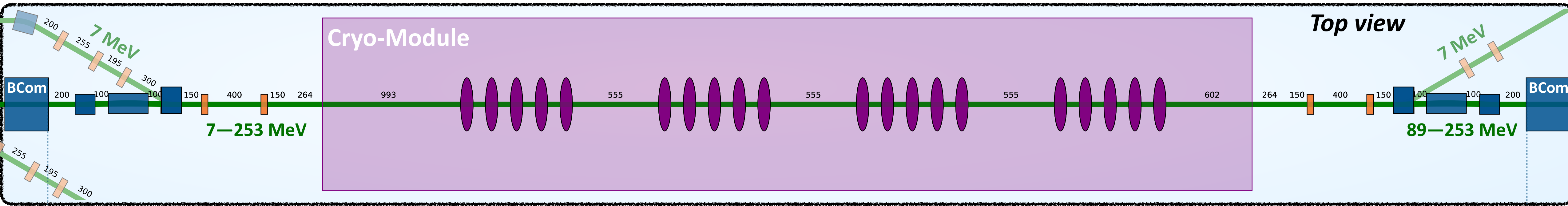


Matching of merger with SC (BMAD tracking)



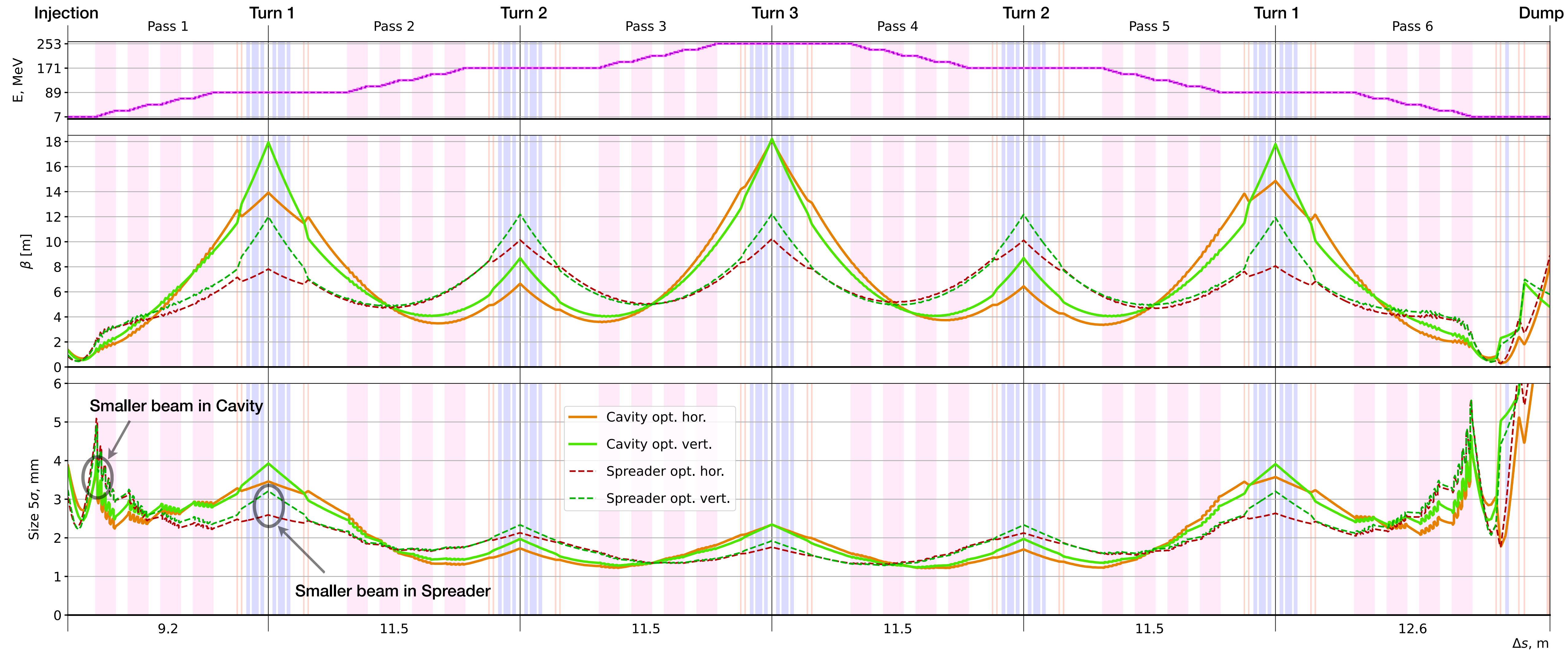


Common section (between Recombiner and Spreader)





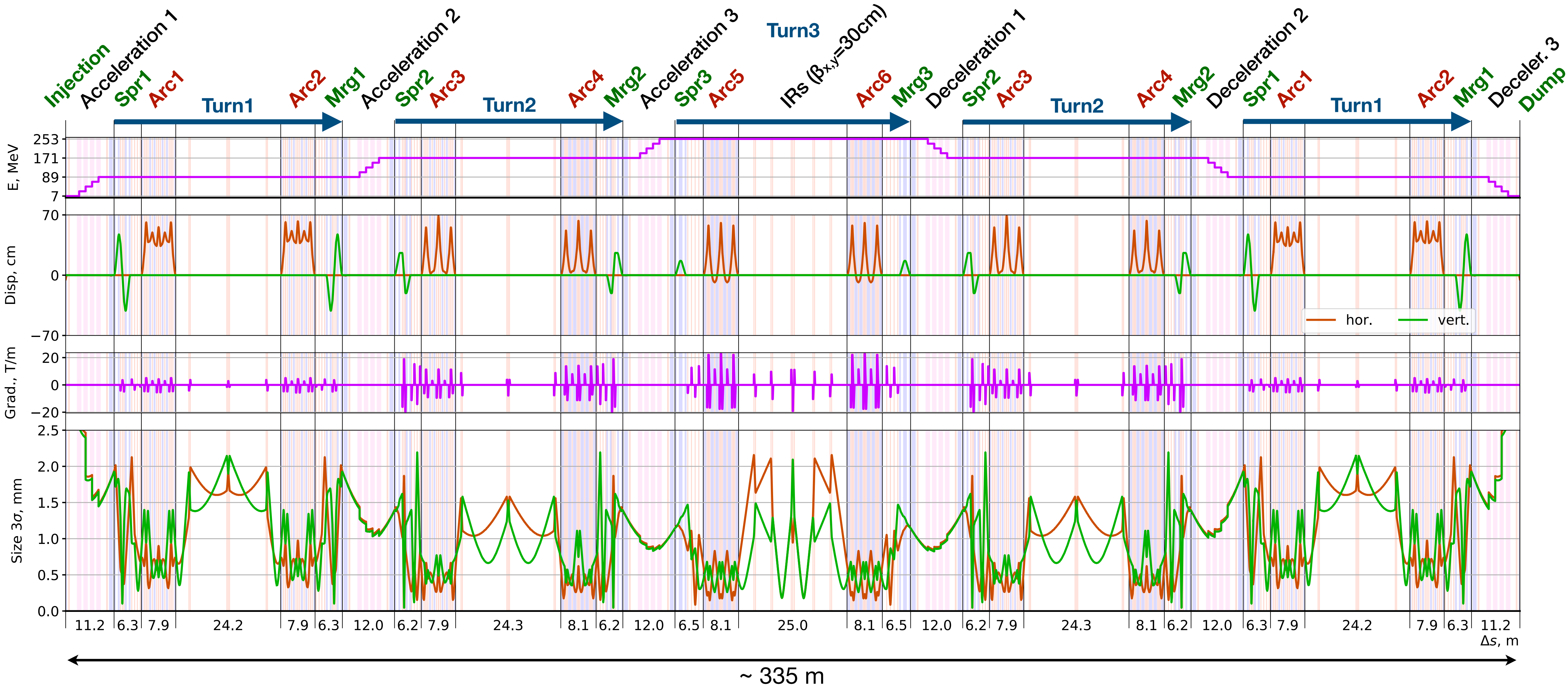
Tuning the beam size (Cavity vs Spreader)



Tuning the twiss parameters at injection → beam size optimisation in the Cavities or in the Spreader



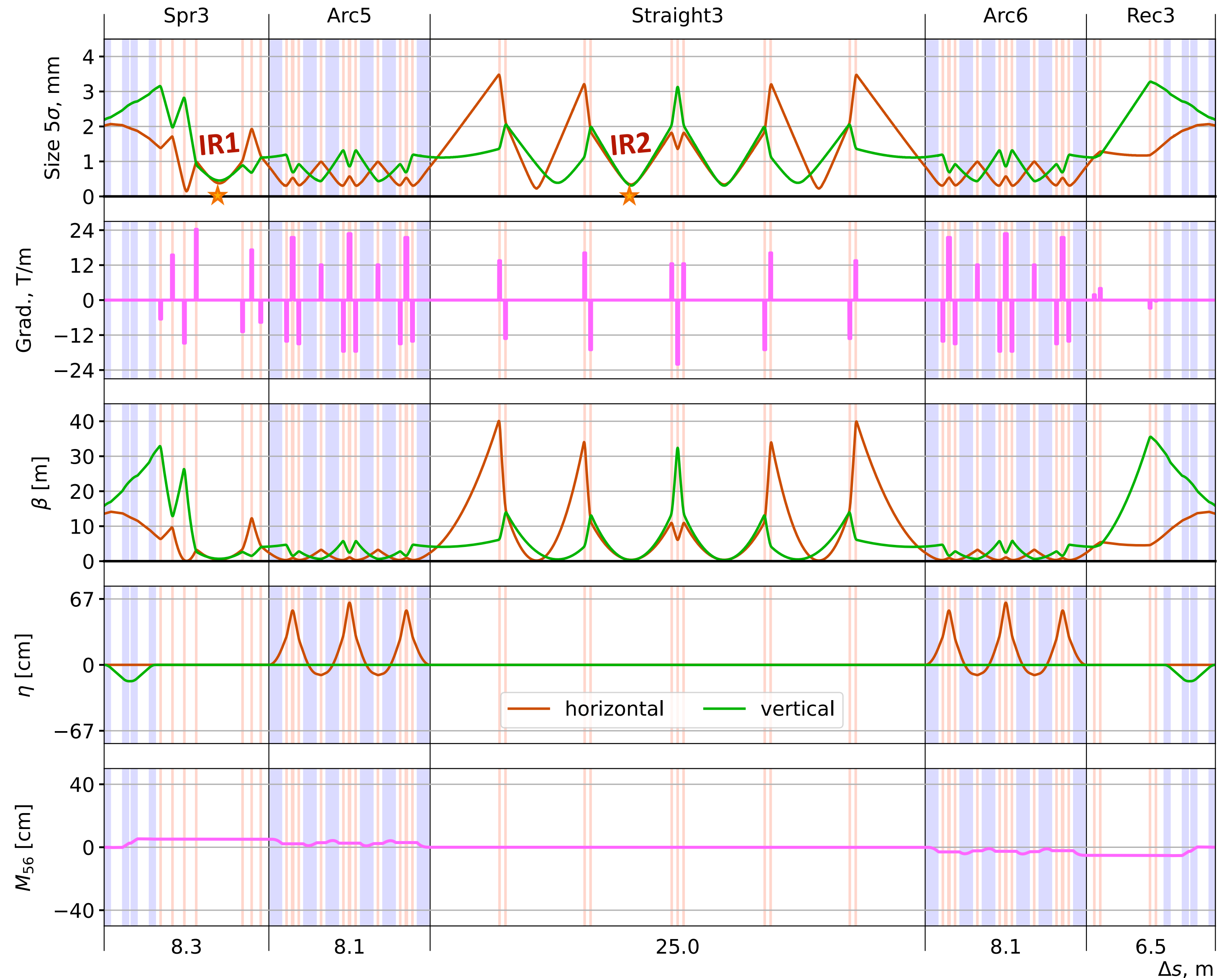
PERLE Optics: from Injection to Dum (250 MeV version)





Optics of the 3rd Turn (updated)

- Spreader and Recombiner are not symmetric
- Quadrupoles in Arcs close the dispersion and compensate M_{56} of Spreader and Recombiner
- Low beta ($\beta=30\text{cm}$) regions for experiments
 - ➔ IR1: Fabry Perot (2m) in the Spreader section (on the same side as Linac, determined by X-ray extraction line)
 - ➔ IR2: scattering on unstable ions (in the straight section)
- Beam size (5σ) under 4 mm
- Maximal gradient of quadrupole magnets $< 24 \text{ T/M}$



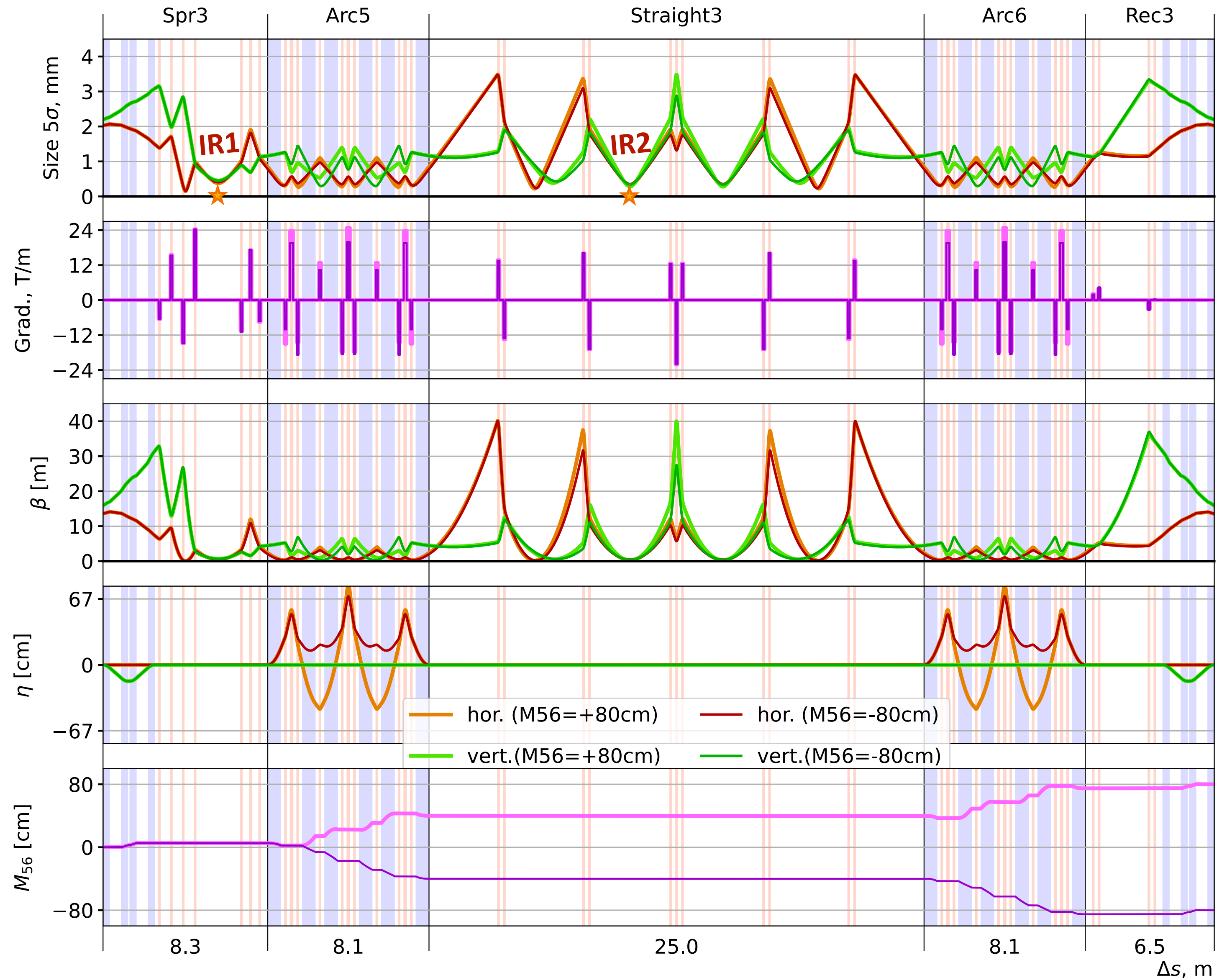


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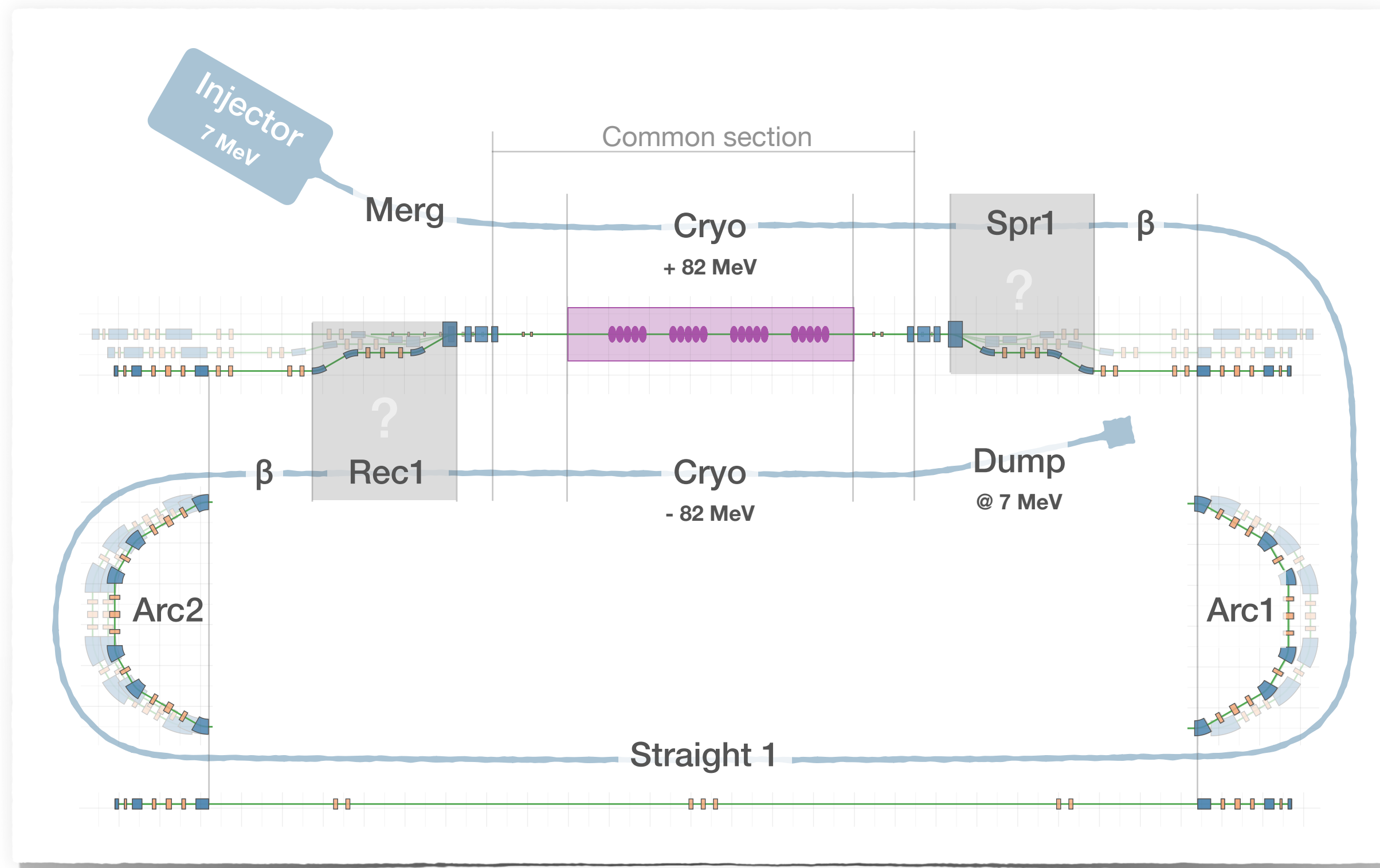
Tuning M56 in the Arcs

- Possible to gain $M_{56} = \pm 80 \text{ cm}$ with minor change of beam properties or introduce a local bump of $M_{56} = \pm 40 \text{ cm}$ (probably more — ongoing studies)



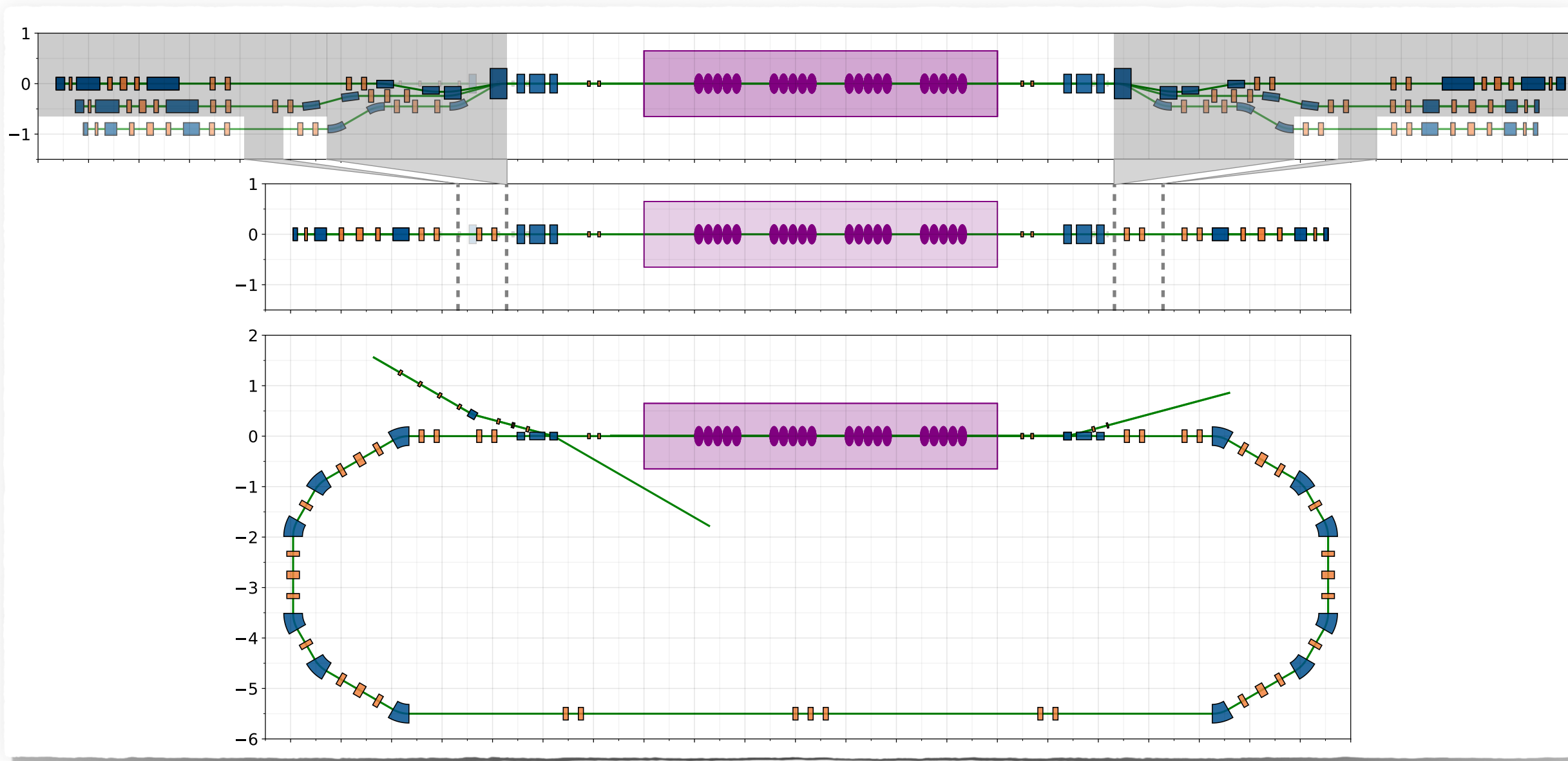


PERLE: Single-Turn version

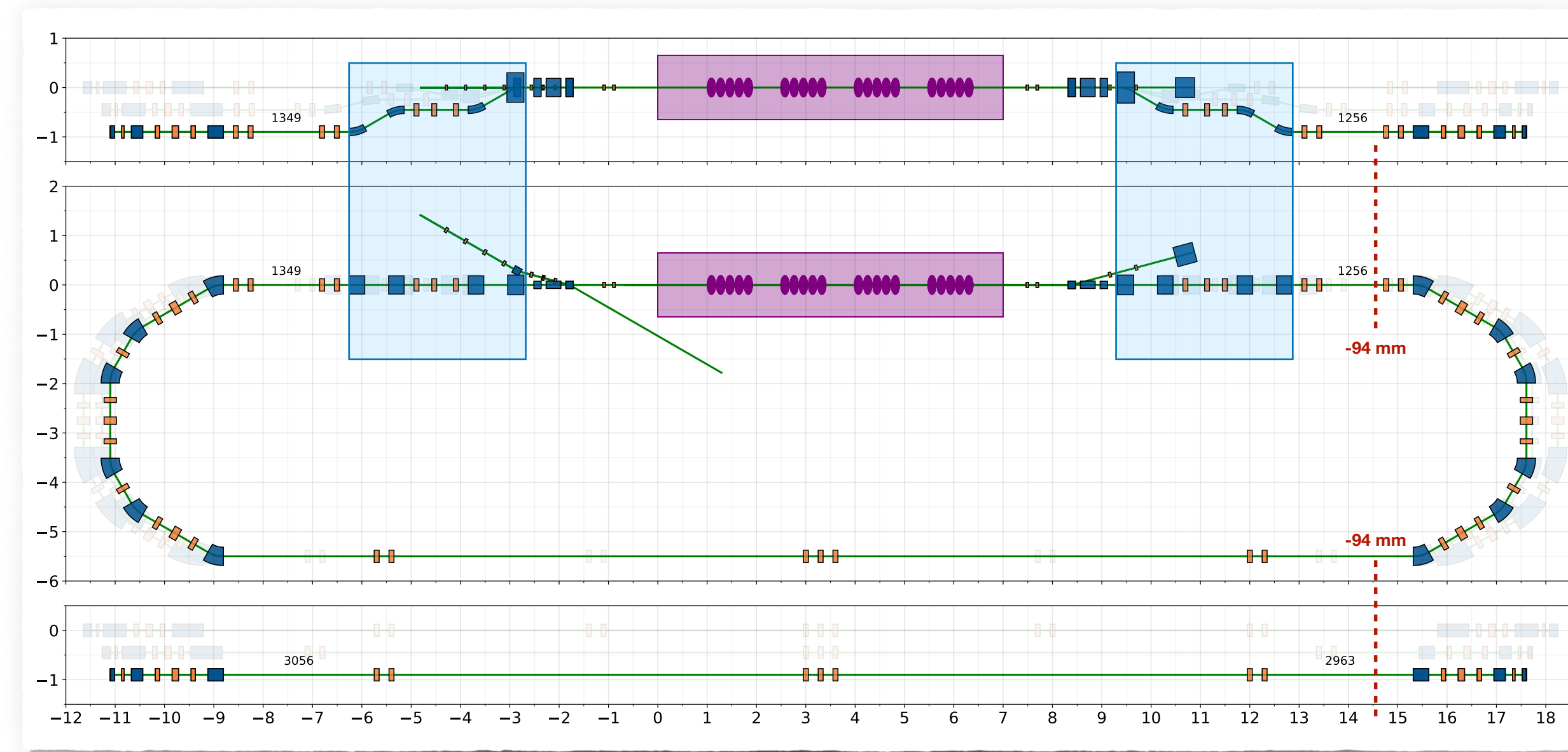




Single-Turn “Simple”



Single-Turn “with B-Coms”



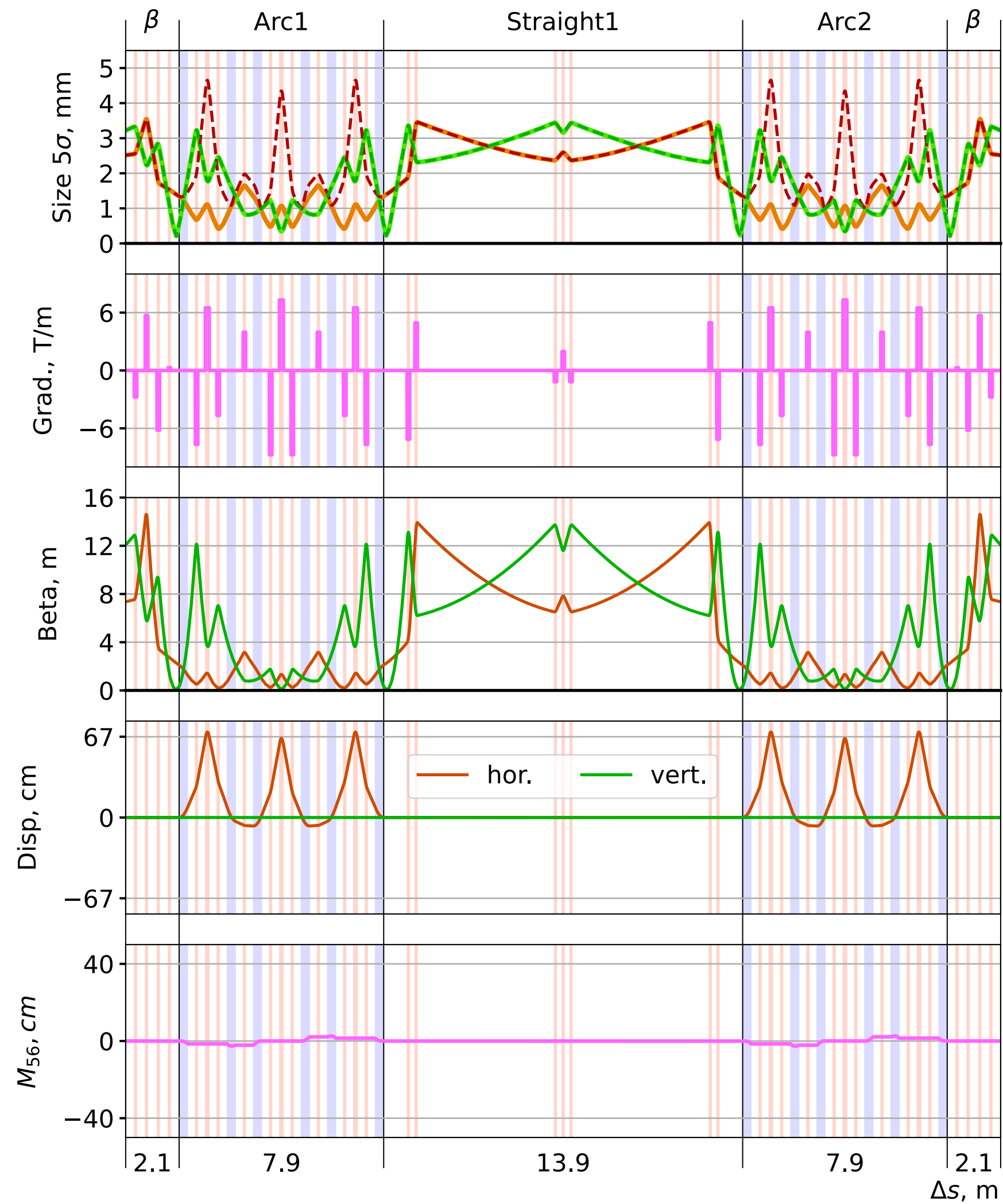
- The simplest design to test the performance of cavities in ERL mode
 - minimal number of element (magnets, diagnostics)
 - 12 S-Bends of 33cm, 30° horizontal (**0.472 T** with 6 (of 12) upgradable to **0.907 T** (for 500 MeV version))
 - 2 R-Bends of 15cm, 15° horizontal deflection (**0.040 T**)
 - 2 R-Bends of 30cm, 30° horizontal deflection (**0.040 T**)
 - smaller footprint: 21 m (vs 30 m)
- Requires more for 250 MeV upgrade
 - Both Arcs would have to be relocated horizontally (by a few meters) and vertically (by 90 cm)

- Would require less for 250 MeV upgrade
 - one Arc has to be shifted by $\lambda_{RF}/4 \approx 9.4$ cm
 - higher energy lines could be attached on top at the B-Com magnet
- Is bigger than simple Single-Turn, with more complicated optics (+ vertical plane)
 - +16 m to the path length
 - +2 B-Com magnets of 33 cm, **0.451 T** (vertical) with 1 (of 2) upgradable to **0.866 T** (for 500 MeV version)
 - +6 S-Bends of 33cm, **0.472 T** (vertical deflection) with 3 (of 6) upgradable to **0.907 T** (for 500 MeV version)
 - +6 quadrupoles (< 7 T/m)

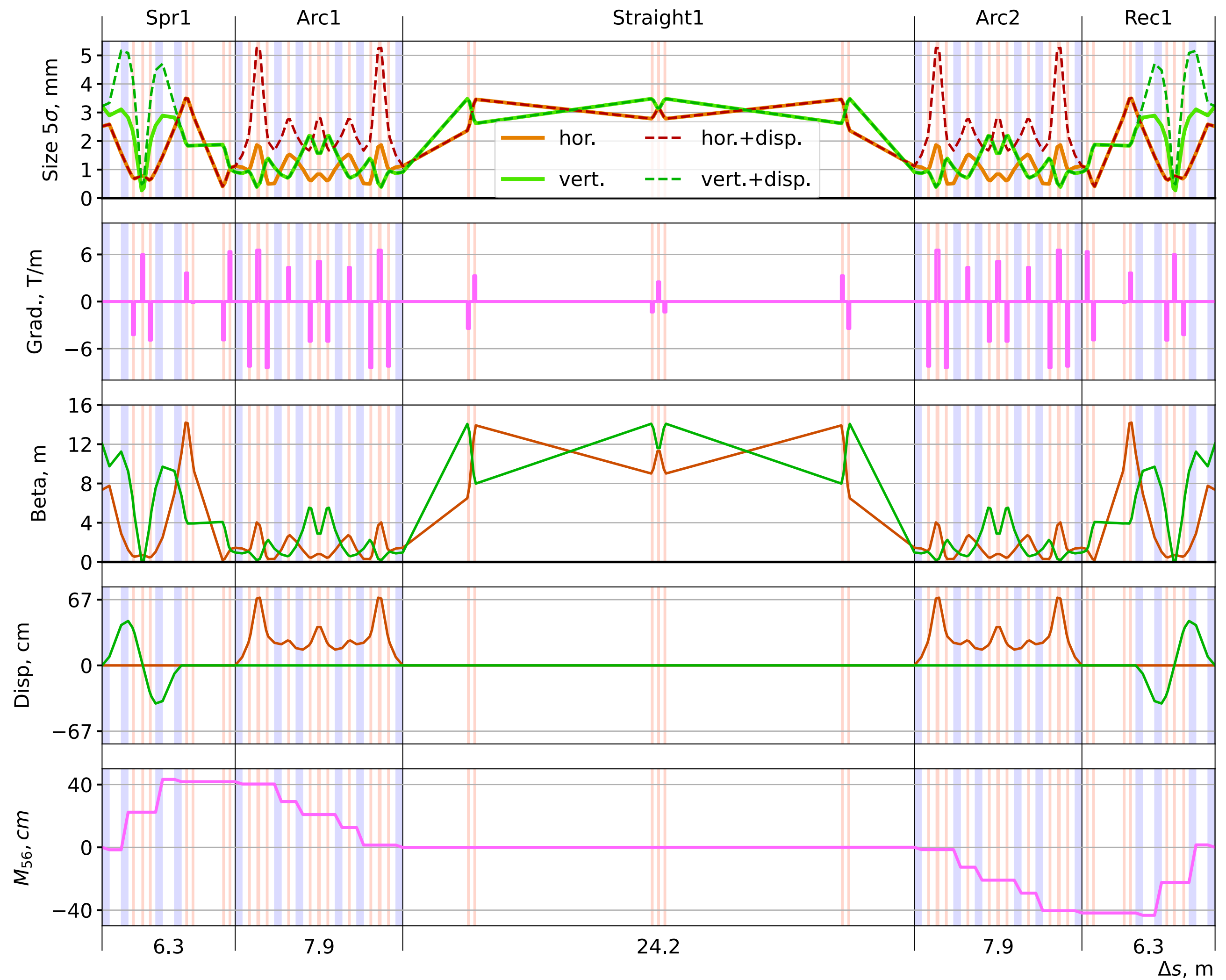


PERLE Single-Turn version optics: "Simple" → "with B-Com"

Single-Turn "Simple"



Single-Turn "with B-Coms"

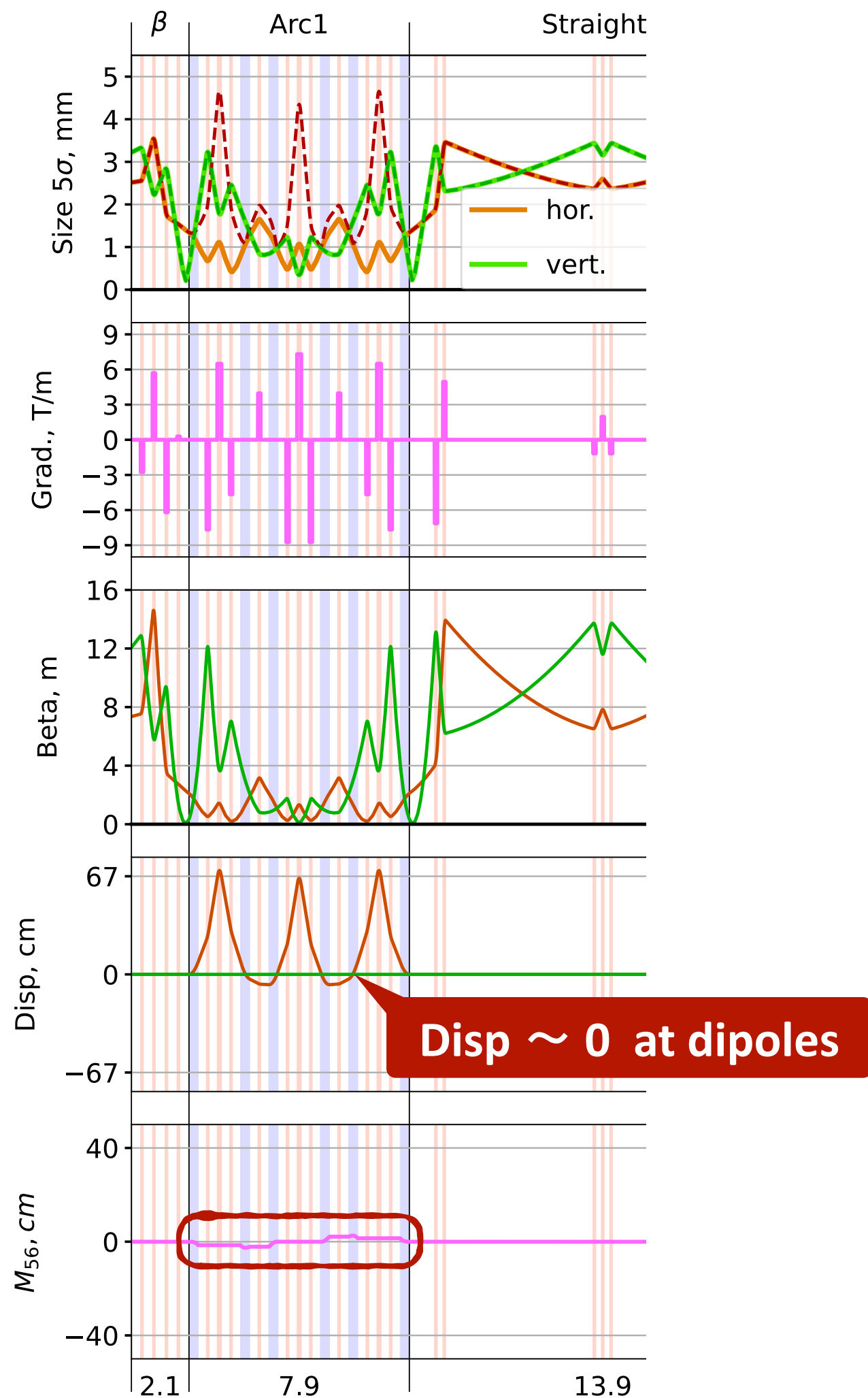




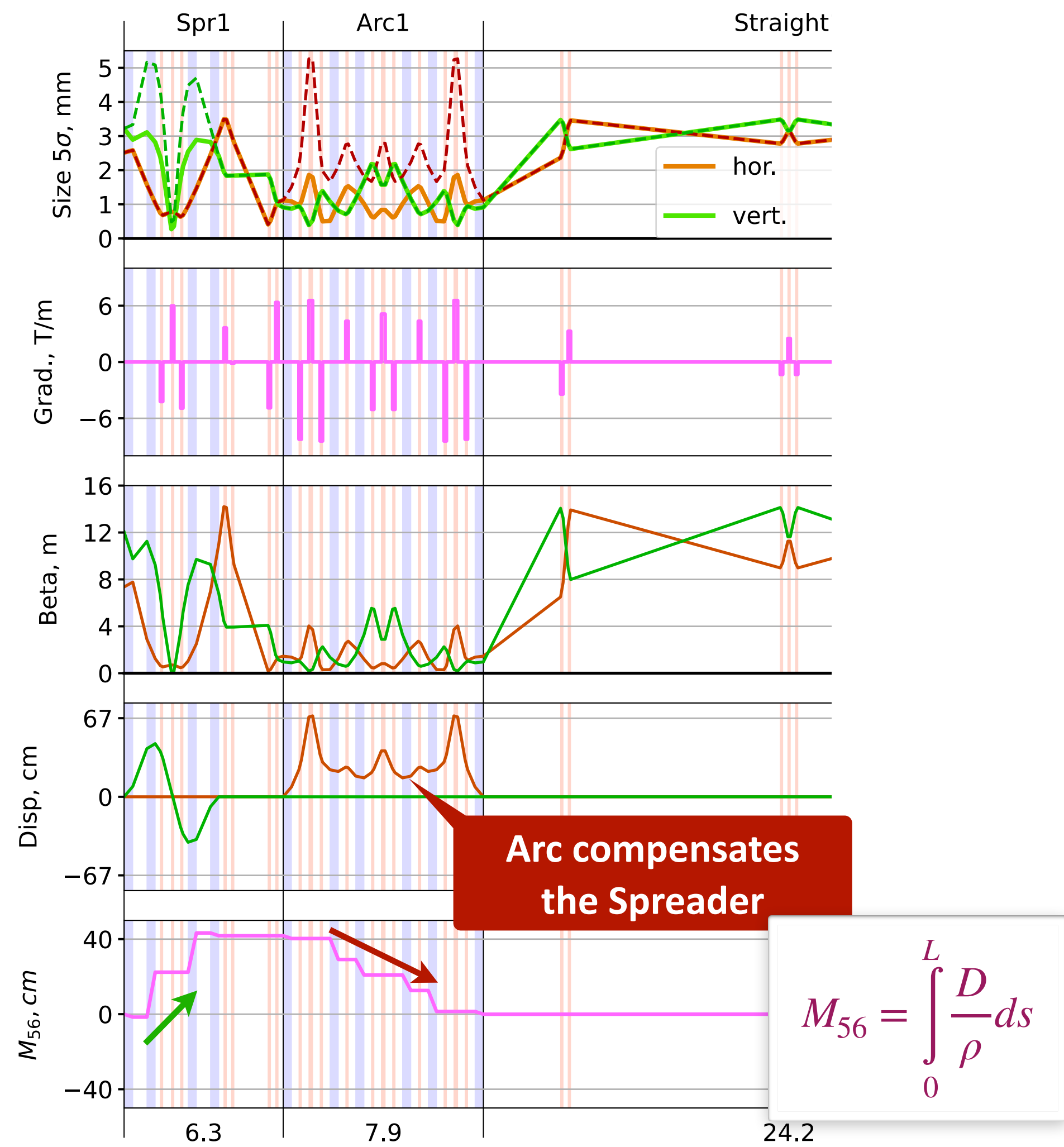
PERLE Optics: M56 compensation in the Arc (ST vs 250 & 500 MeV)



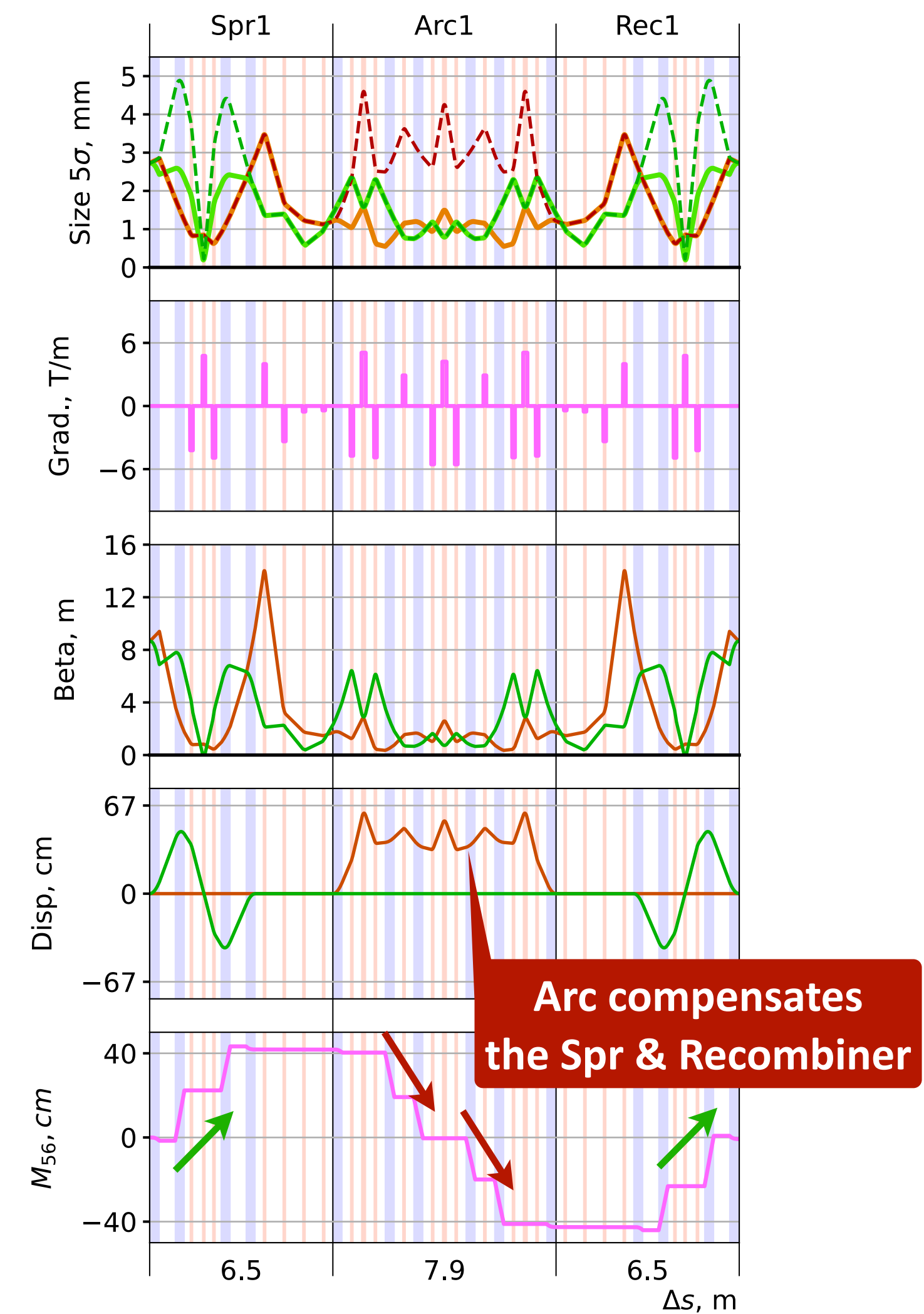
Single-Turn "Simple"



250 MeV version (Arc1)

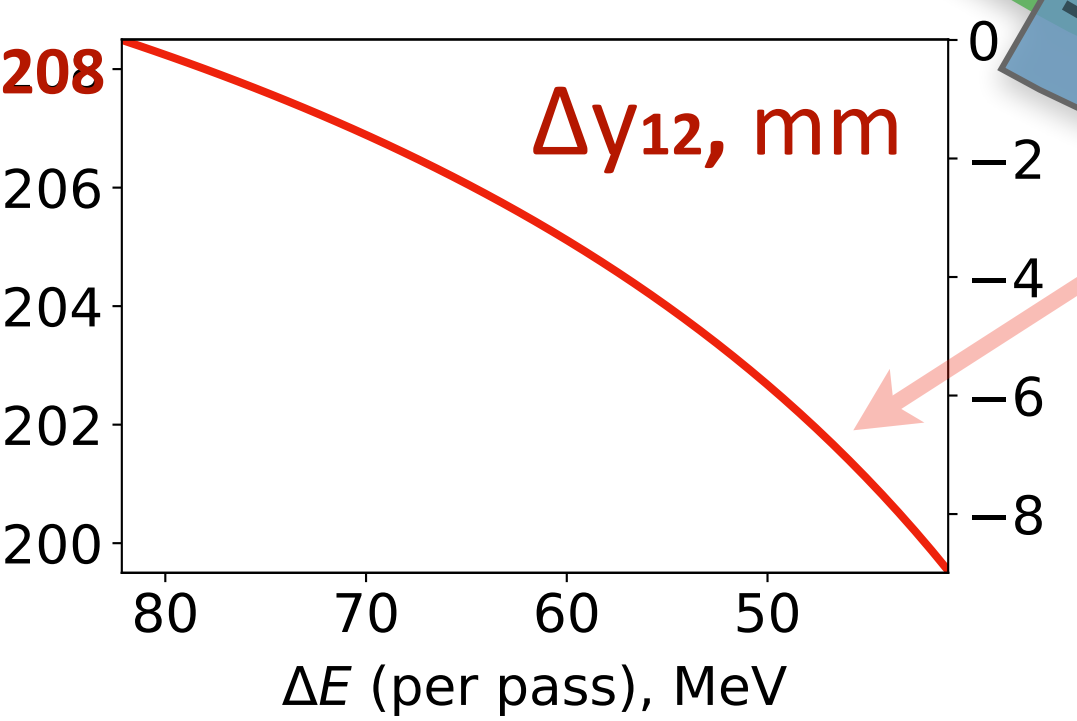
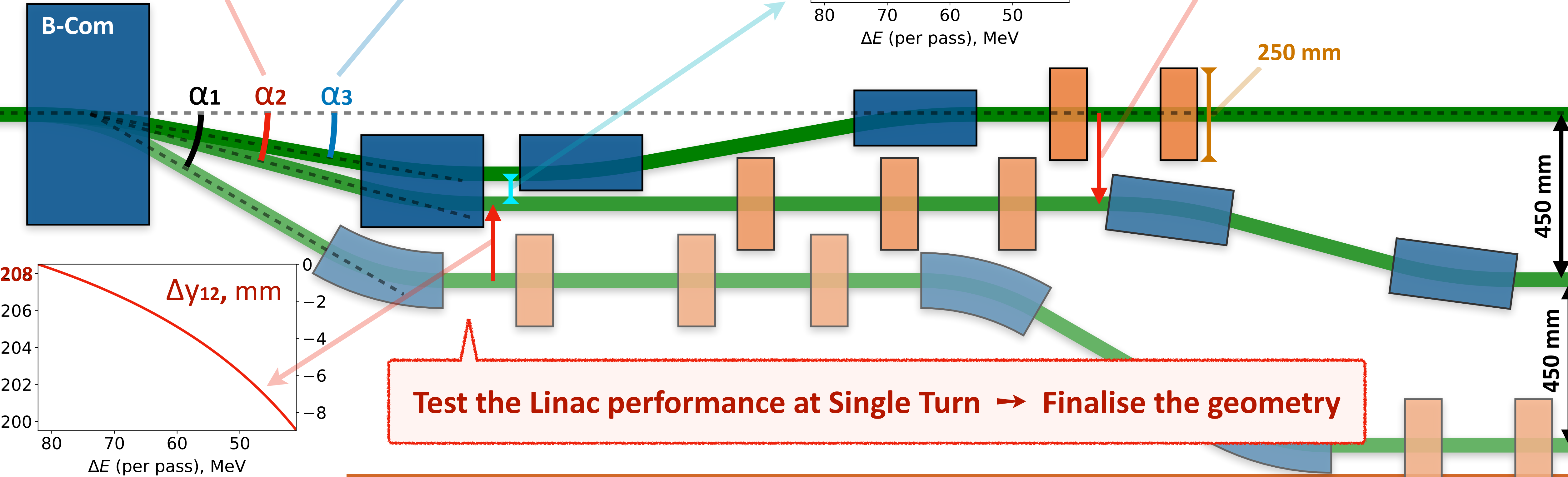
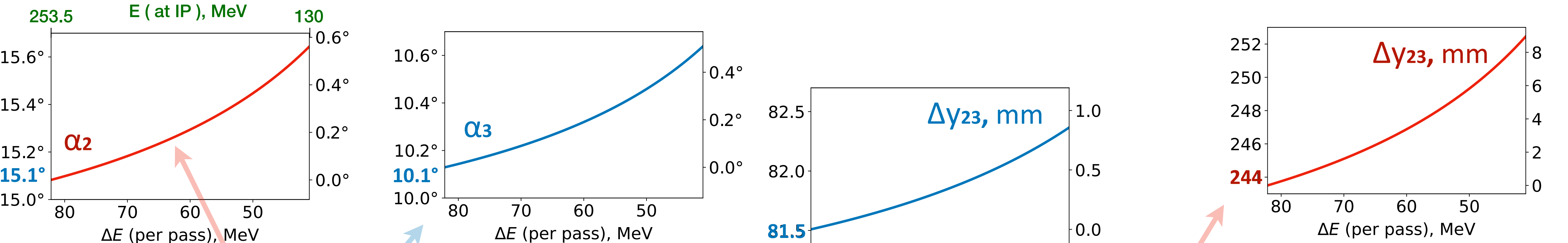


500 MeV version (Arc1)





Switchyards: Geometry vs Cavity boost (82 → 41 MeV / pass)



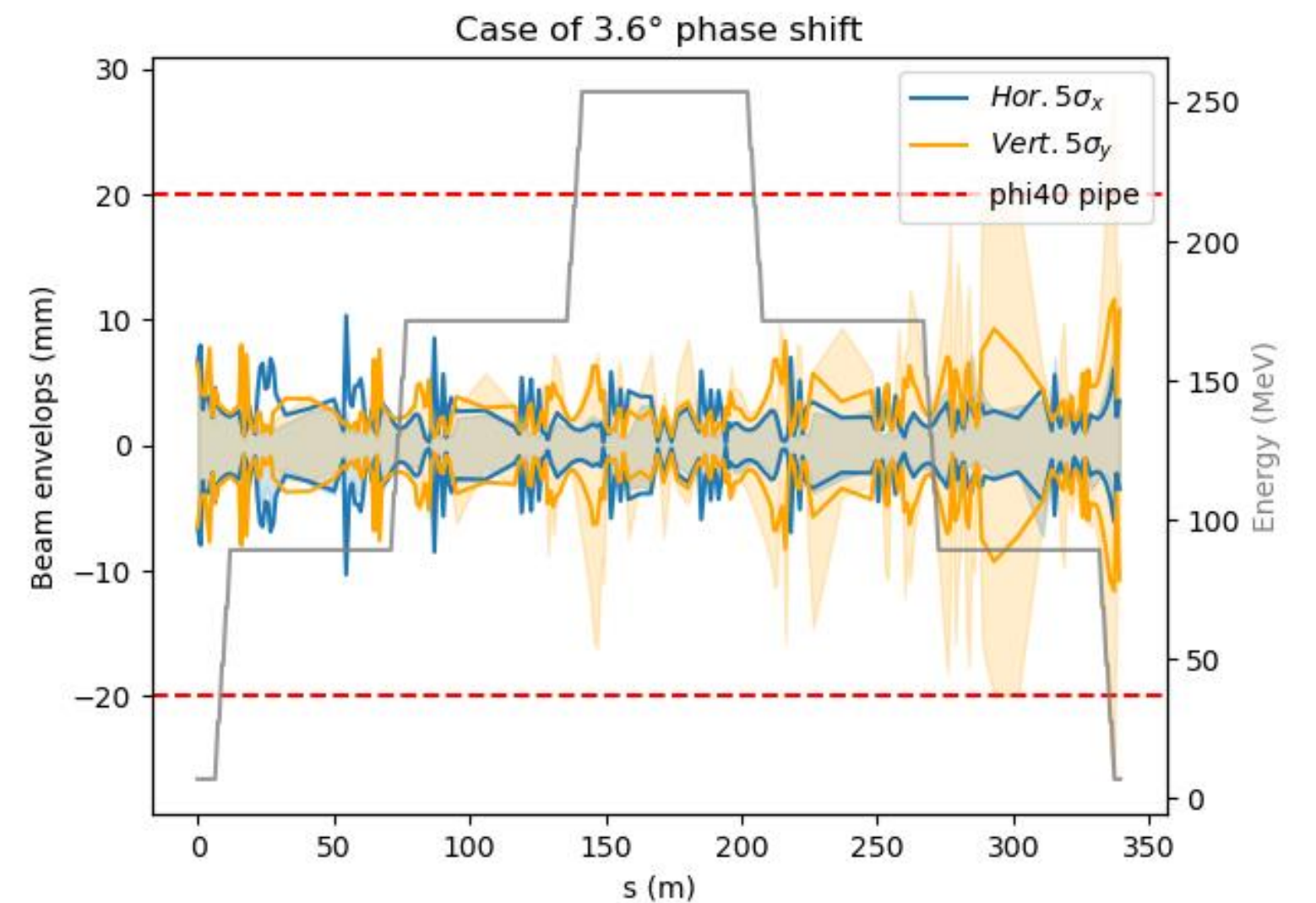
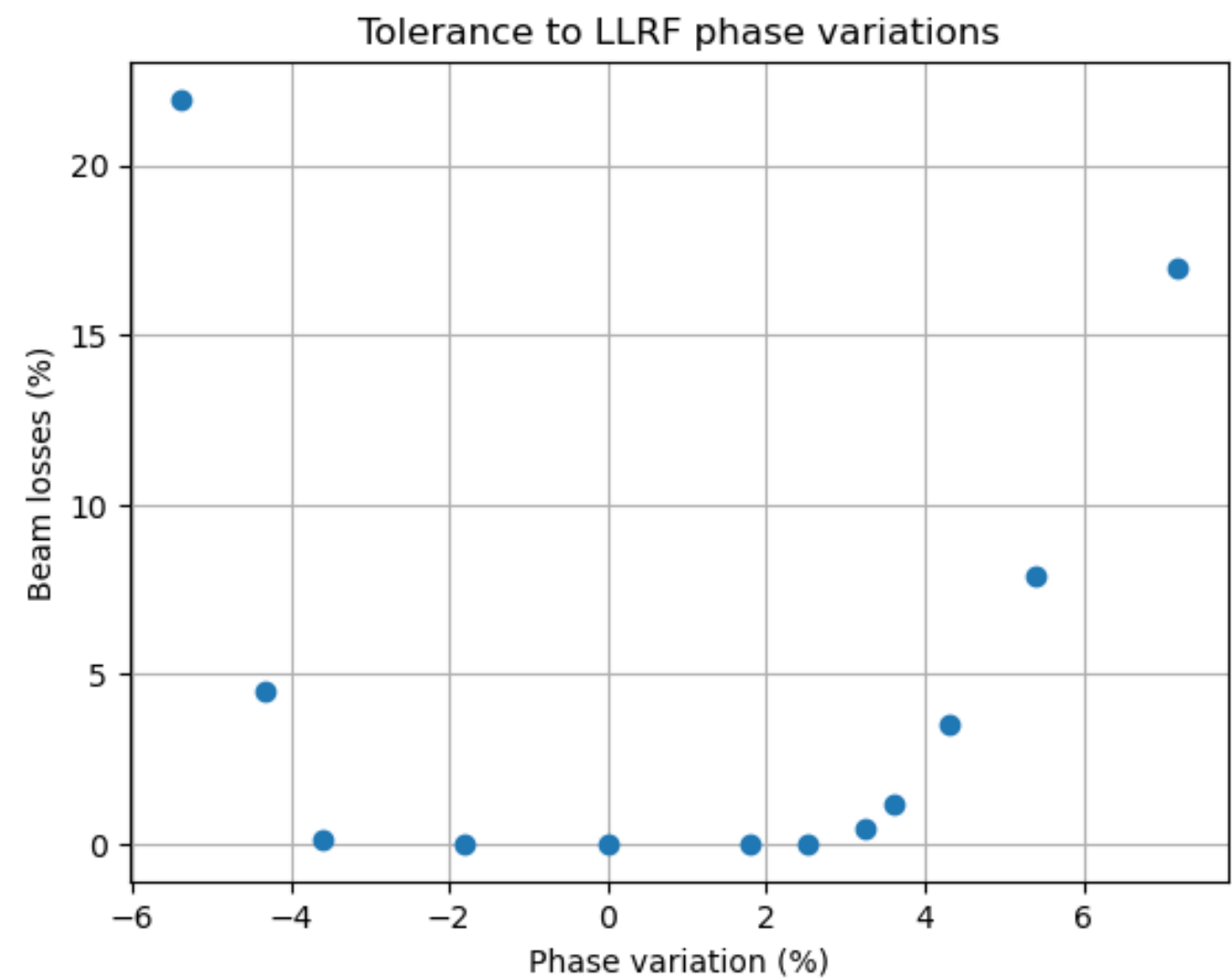
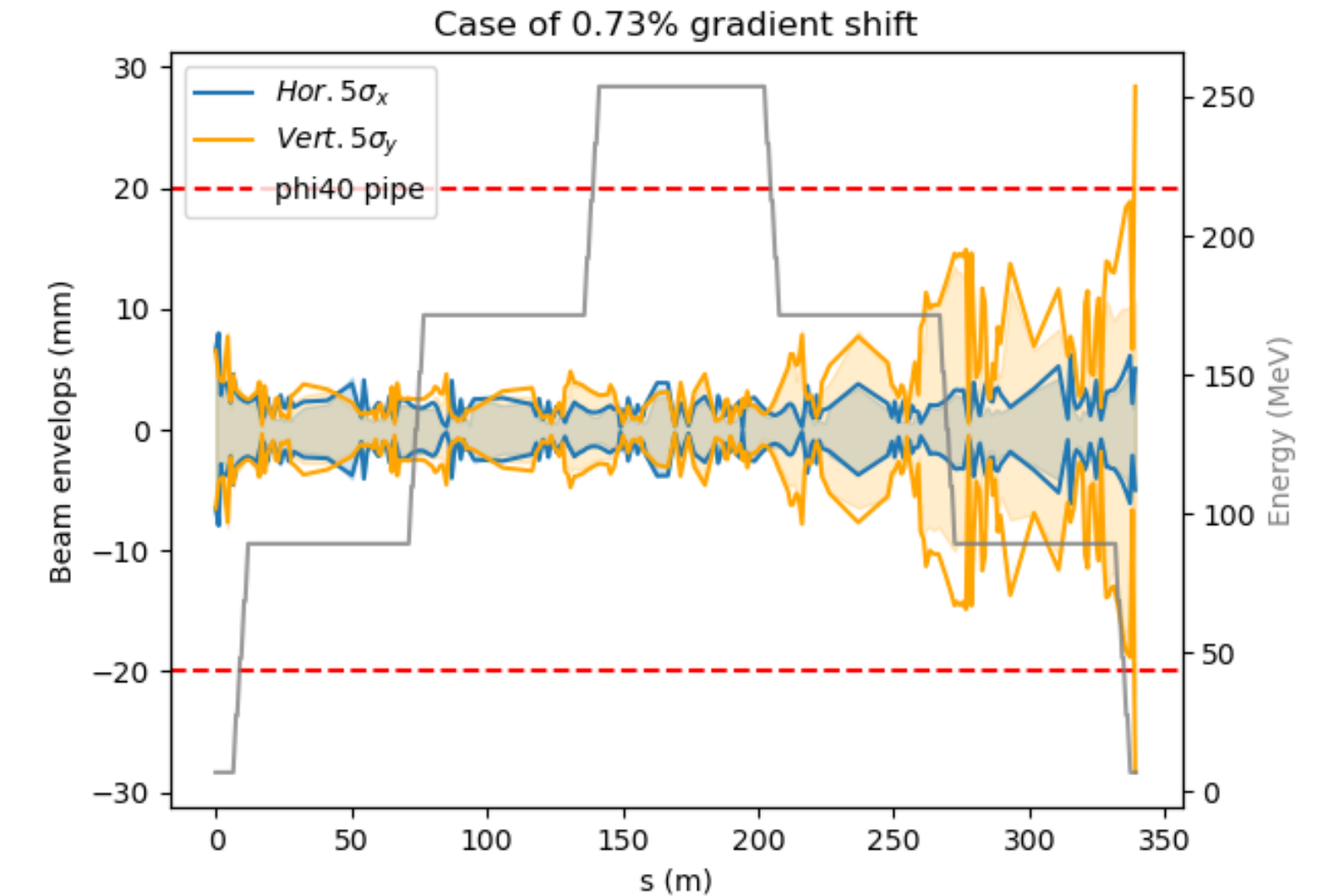
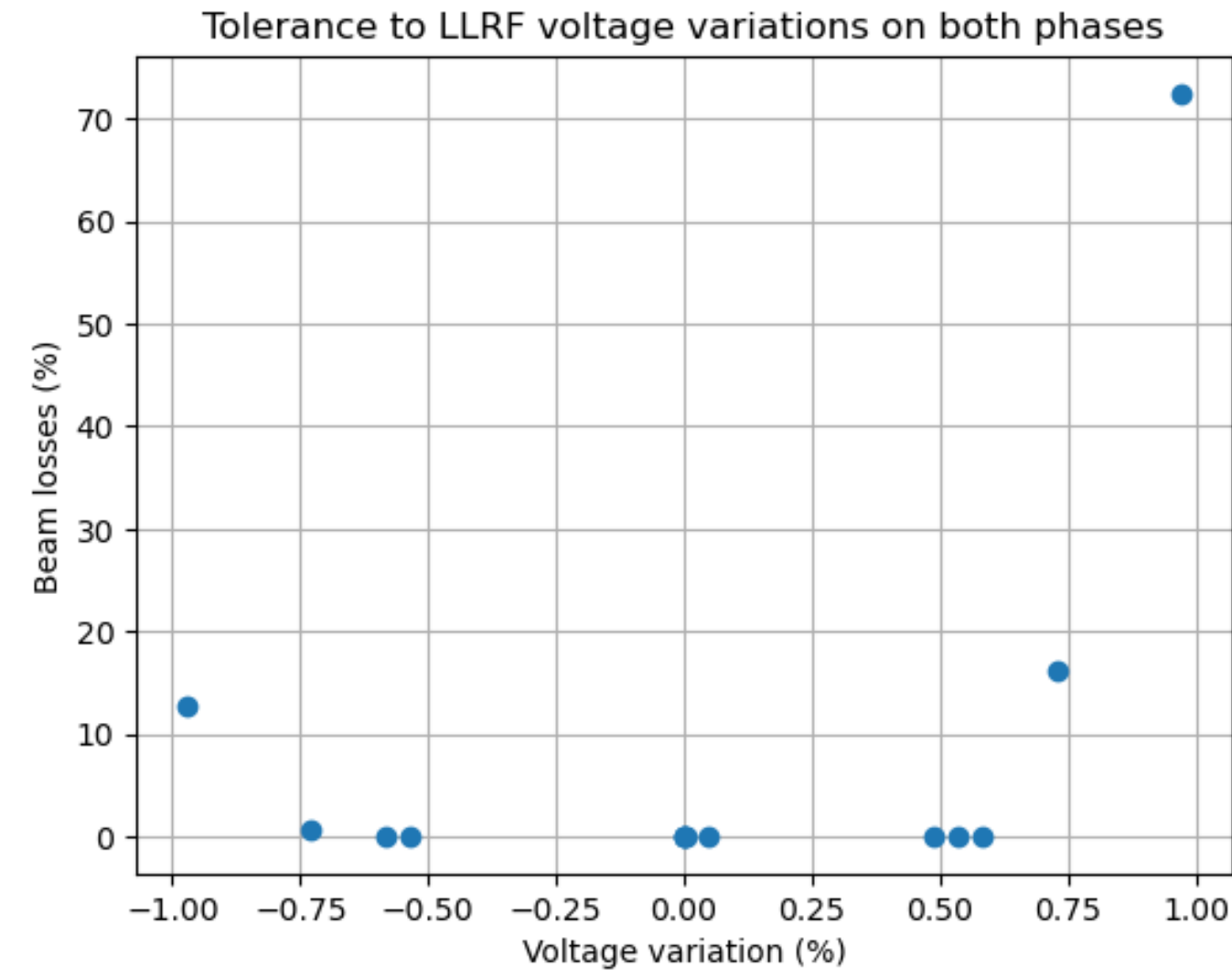


Cavity voltage variations

- BMAD simulation
- Acceptance is $\pm 2,5$ degrees for all cavities
(worst case scenario: 4 cavities detuned)

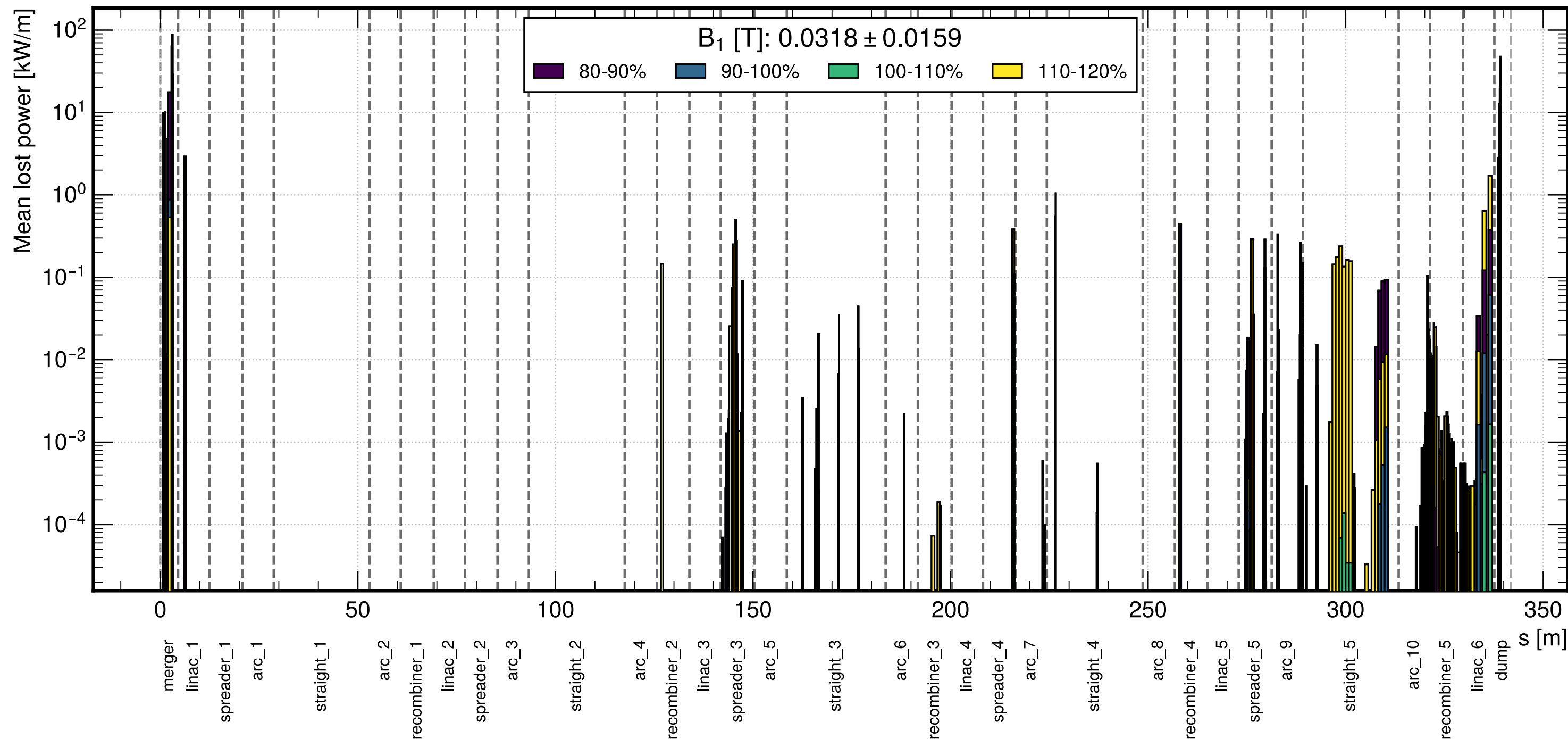
LLRF phase variations

- Acceptance is $\pm 0,5\%$ (≈ 120 kV)
(worst case scenario: 4 cavities detuned)





- Effect of field errors and laser offset in the injector on the losses in ERL
- Simulation ASTRA + BMAD
- 5% field errors → significant losses
- major losses found in the merger — layout should be optimised



Thesis submitted with the goal of achieving a masters degree in Physics

BEAM LOSS AND HALO SIMULATION STUDIES FOR PERLE

Lode Vanhecke

2023-2024

Promotor: Prof. Dr. Jorgen D'Hondt
Co-promotor: Dr. Hayg Guler (CNRS/IN2P3 - IJCLab)

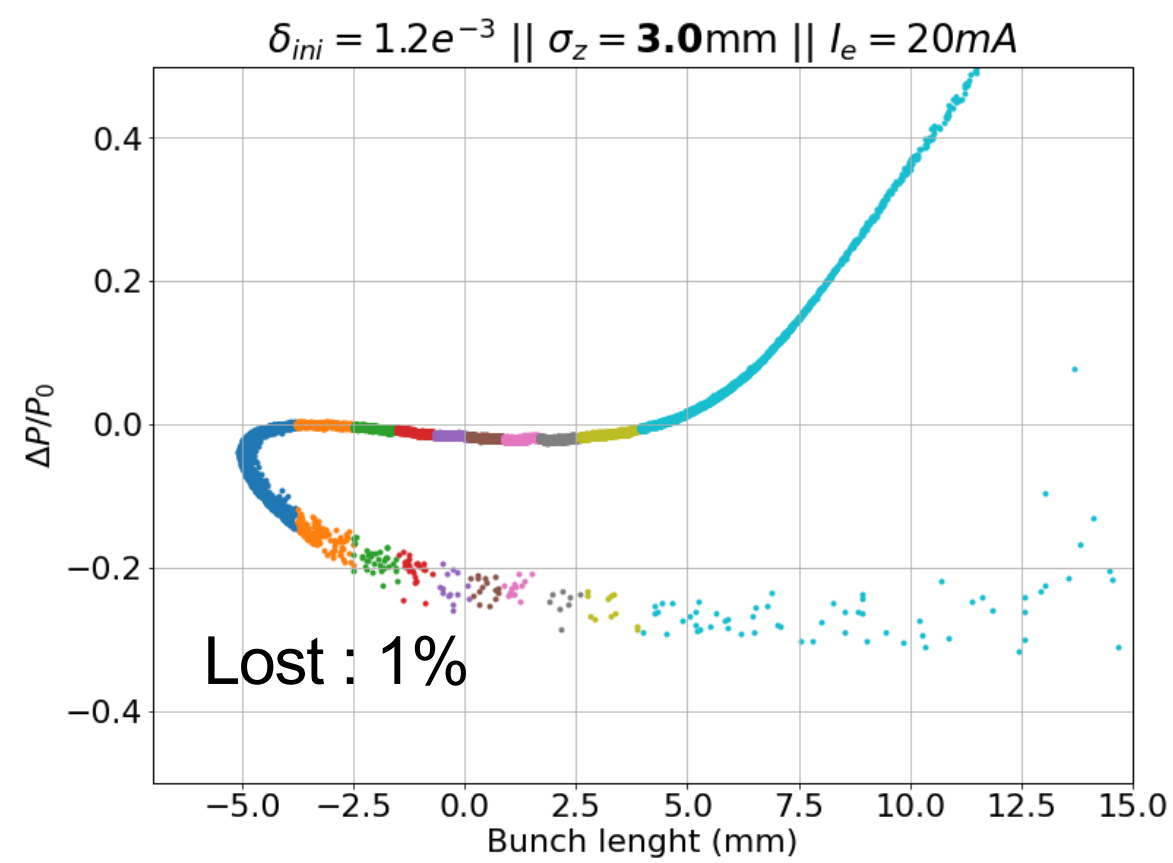
Sciences and bioengineering sciences



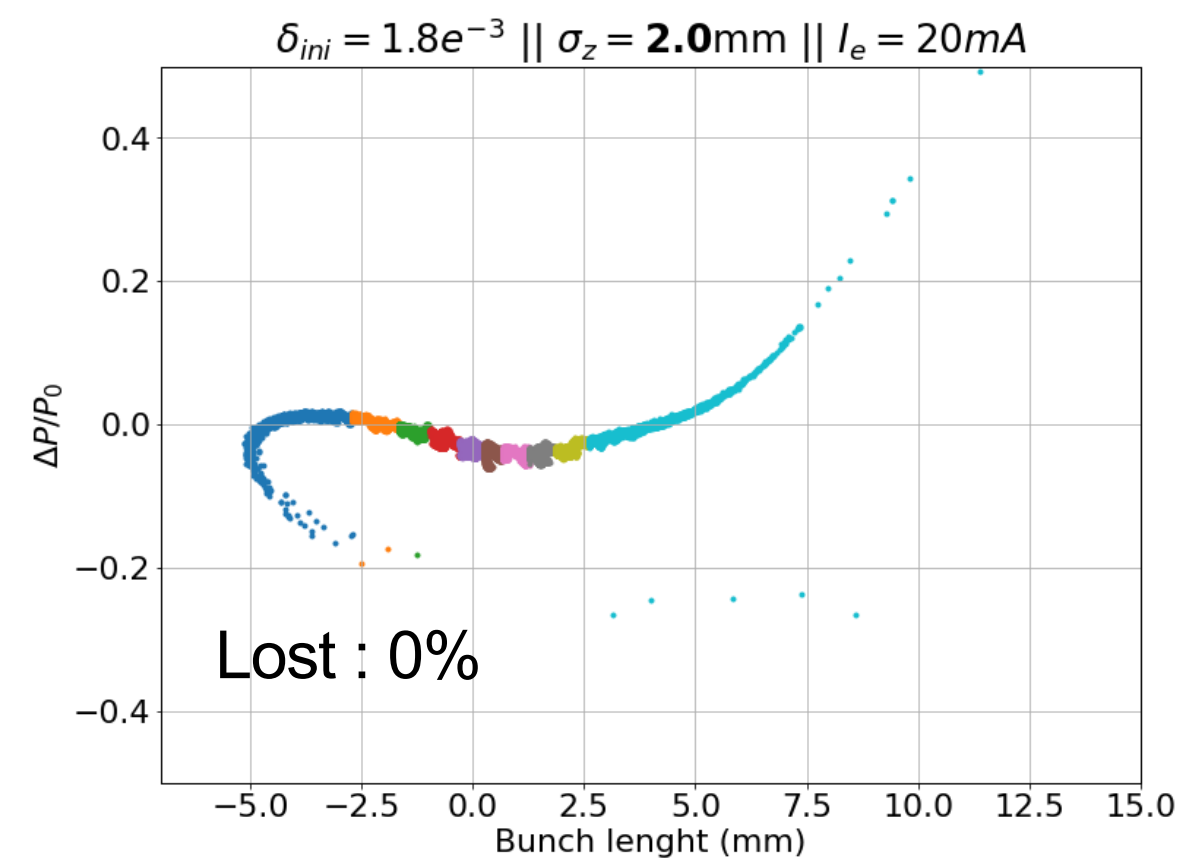
RF curvature vc CSR (work by K. André and J. Michaud)



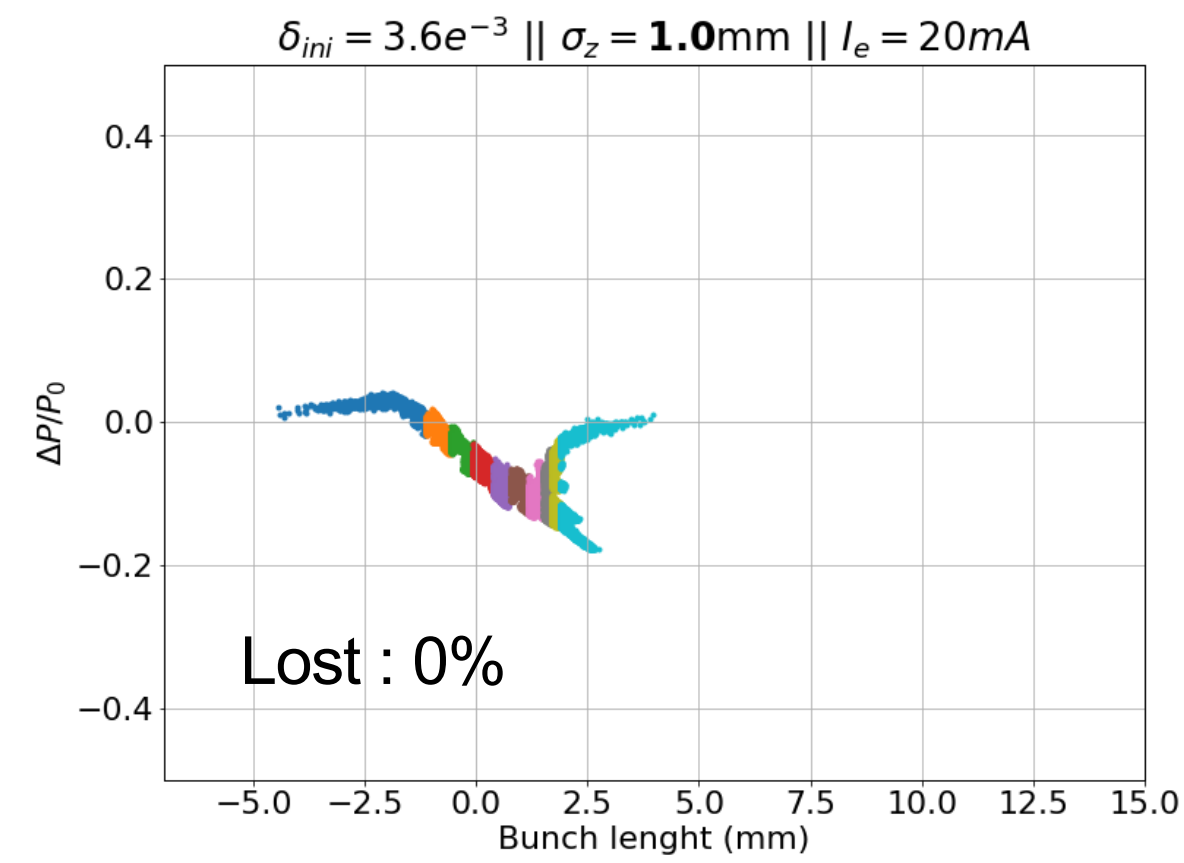
**3 mm
bunch length**



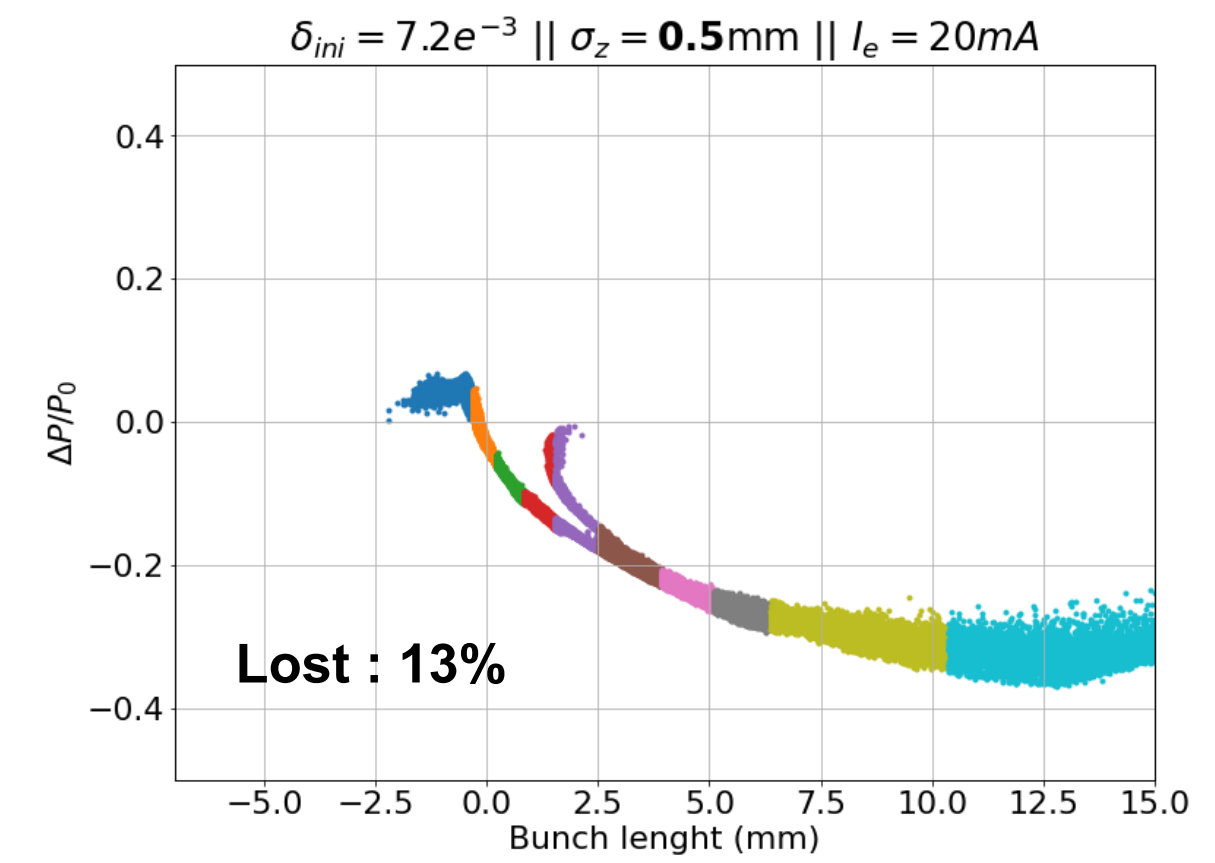
**2 mm
bunch length**



**1 mm
bunch length**



**0,5 mm
bunch length**



RF curvature dominated

CSR dominated



Update on lattice design

- Fabry-Perot cavity on the same side as the main Linac (250 MeV version of PERLE)
- Three dipole merger
- Single turn phase

PERLE optics studies

- Optimisation of beam size at injection energy (7 MeV)
- Control of momentum compaction factor (M56) at the merger and in the arcs

Beam dynamics studies

- Sensitivity to instabilities (J. Michaud)
- Beam loss and halo formation (L. Vanheche)
- Optics misalignments ([see poster by R. Abukeshek](#))

Outlook

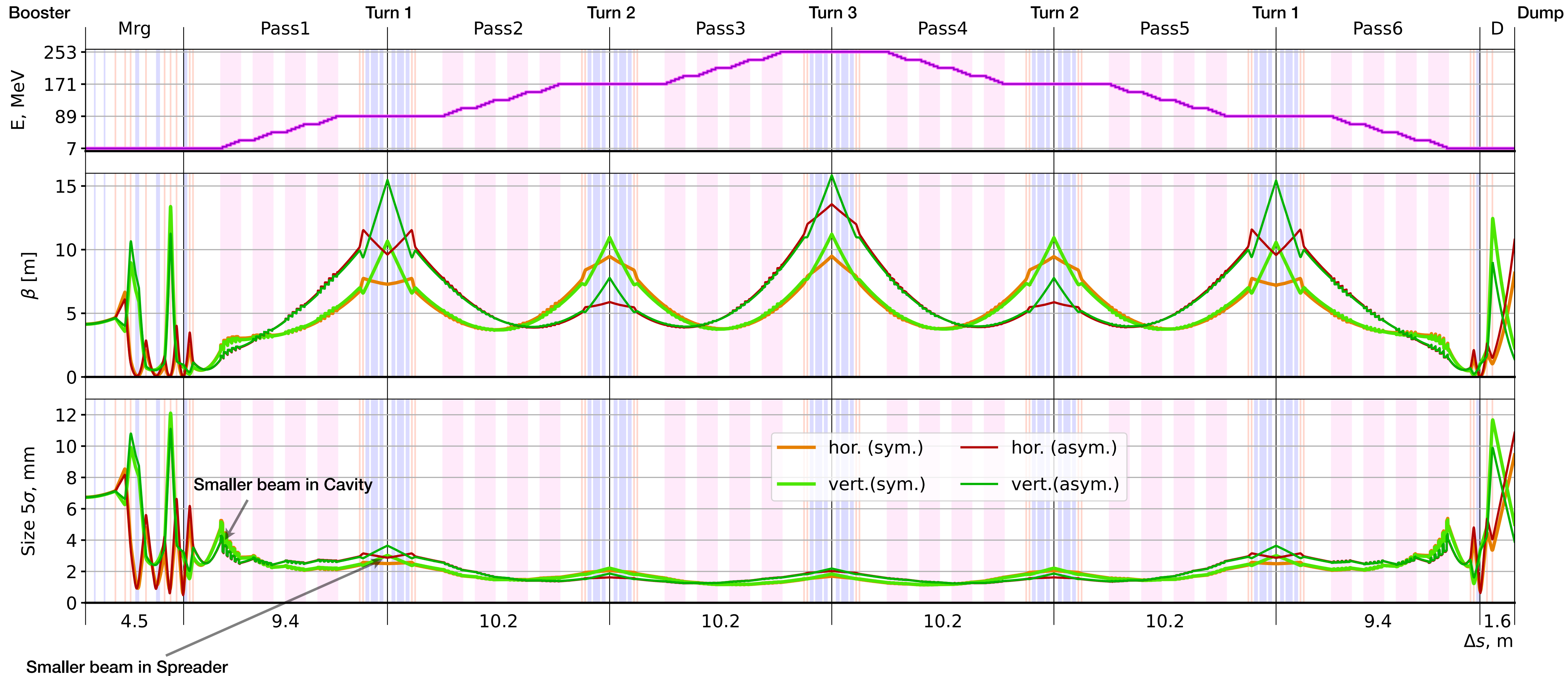
- Longitudinal match ([see poster by J. Michaud](#))
- Simulations for beam diagnostic at injection energy (7MeV)



Thank you !



Tuning the beam size (Cavity vs Spreader)



Tuning the twiss parameters at injection → beam size optimisation in the Cavities or in the Spreader



Dipoles for PERLE v2.1 Types of dipoles (for ERL only)

Types of dipoles for PERLE defined by geometry and size

Type	Name	Plane	Number				Function	Geometry	L, cm	B , T		I, mA
			ST	ST+BC	v.250	v.500				min	max	
1	Chicane 15cm	hor.	4	4	4		Injection and Dump merger/correctors/spreader	R-Bend	15	0.040		120
2	Chicane 30cm	hor.	2	2	2		corrector with double length and inverted field (w.r.t. Type 1)	R-Bend	30	0.040		120
3	B-Com 3-lines	vert.	0	2	2	4	spreaders/mergers for 3 energy lines (for all Arcs)	R-Bend	33	0.451	0.866	120
4	B-Com 2-lines	vert.	0	0	2	4	spreaders/mergers for 2 energy lines (for Arcs 3, 5 & 4, 6)	R-Bend	33	0.451	0.866	80
5	R-Bend 33cm	vert.	0	0	8	16	spreaders (one energy line) for Arcs 3, 4, 5 & 6	R-Bend	33	0.451	0.873	40
6	S-Bend 33cm	vert.	0	6	6	12	spreaders (one energy line) for Arcs 1 & 2	S-Bend	33	0.472	0.907	40
		hor.	12	12		18	180° turn of the Arc 1, 2, 3 (6 dipoles per Arc)	S-Bend	33	0.472	1.342	40
7	S-Bend 66cm	hor.	0	0		18	180° turn of the Arc 4, 5, 6	S-Bend	66	<u>0.453</u>	<u>1.323</u>	40
Total			18	26	60	78						

Total number of dipole

- 19 dipoles for Single-Turn version (simple)
- 27 dipoles for Single-Turn version (with B-Coms)
- 61 dipoles for 250 MeV version
- 79 dipoles for 500 MeV version

There are 7 types of magnets defined by geometry and size

- the required **magnetic field might vary by the factor 2–3** within the same Type of dipole
- **“S-Bend 33cm”** at the Spreader/Merger sections is in **vertical** orientation and in **horizontal** at the Arcs — **Can it have the same dipole design?**