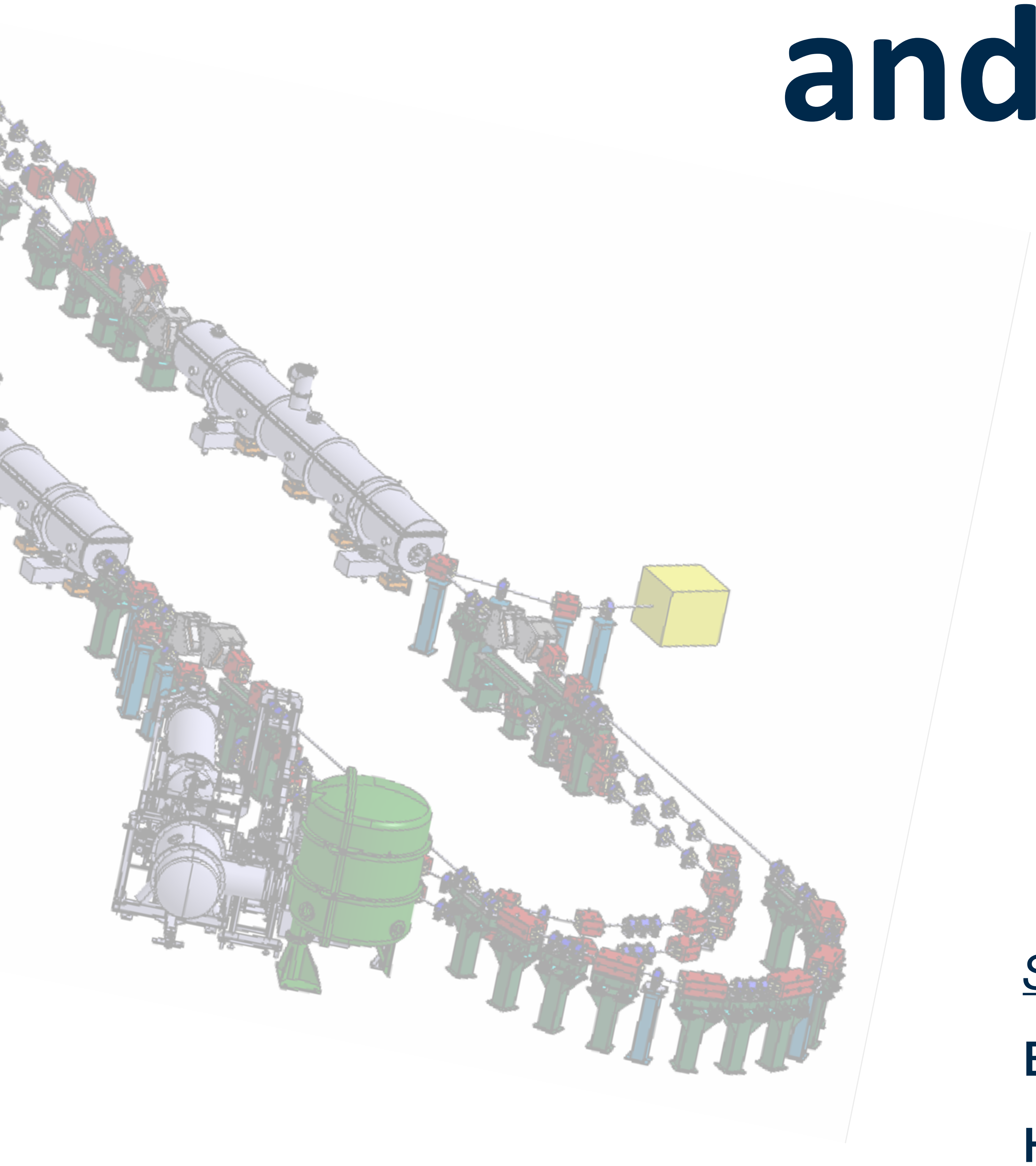
PERLE Lattice Update and Specifications of Magnets



Alex Fomin

Three Dipole Merger (symmetrical Diagnostic Line)

Fabry Perot (IP1) on the same side as Linac

Single Turn layout and optics

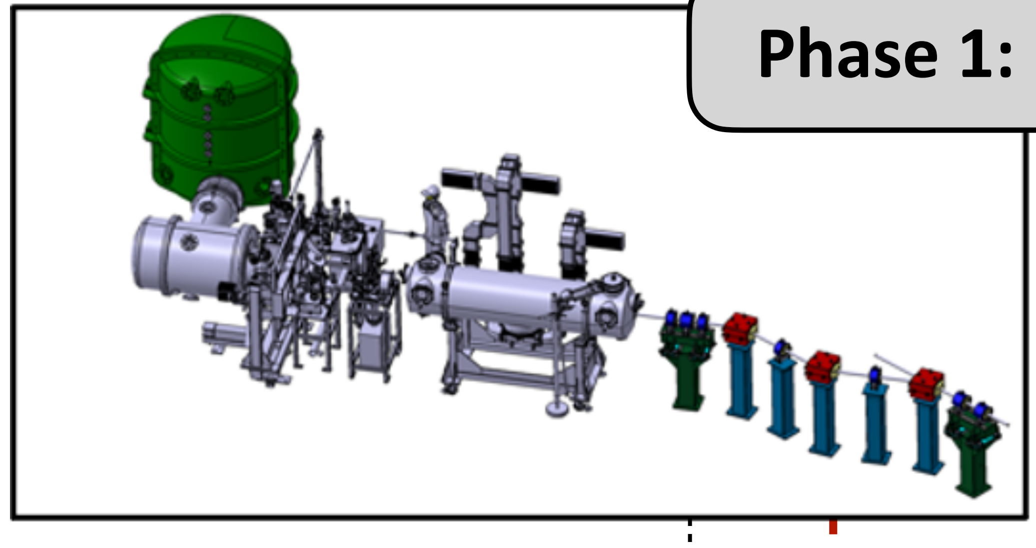
Special thanks to: Alex Bogacz, Luc Perrot, Julien Michaud, Rasha Abukeshek, Coline Guyot, Ben Hounsell, Kirsten Deitrick, Raphael Roux, Denis Reynet, Sylvain Brault, Mohammed Abdillah, Hayg Guler, Frederic Bouly, Connor Monaghan, Walid Kaabi, Achille Stocchi et al.

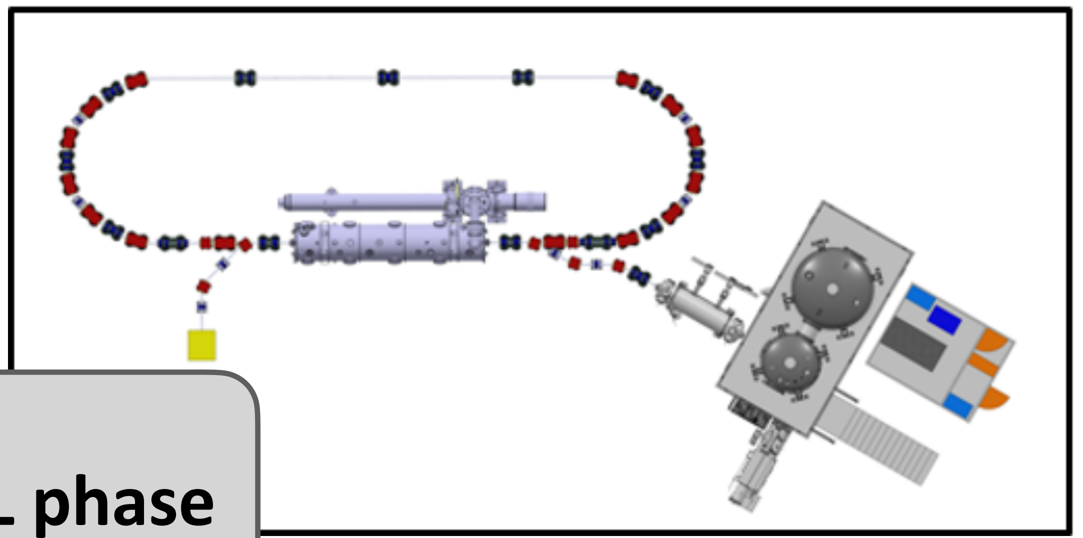
PERLE Timeline

Prepare to Build phase (P2B): TDR and prototyping

Installation phases

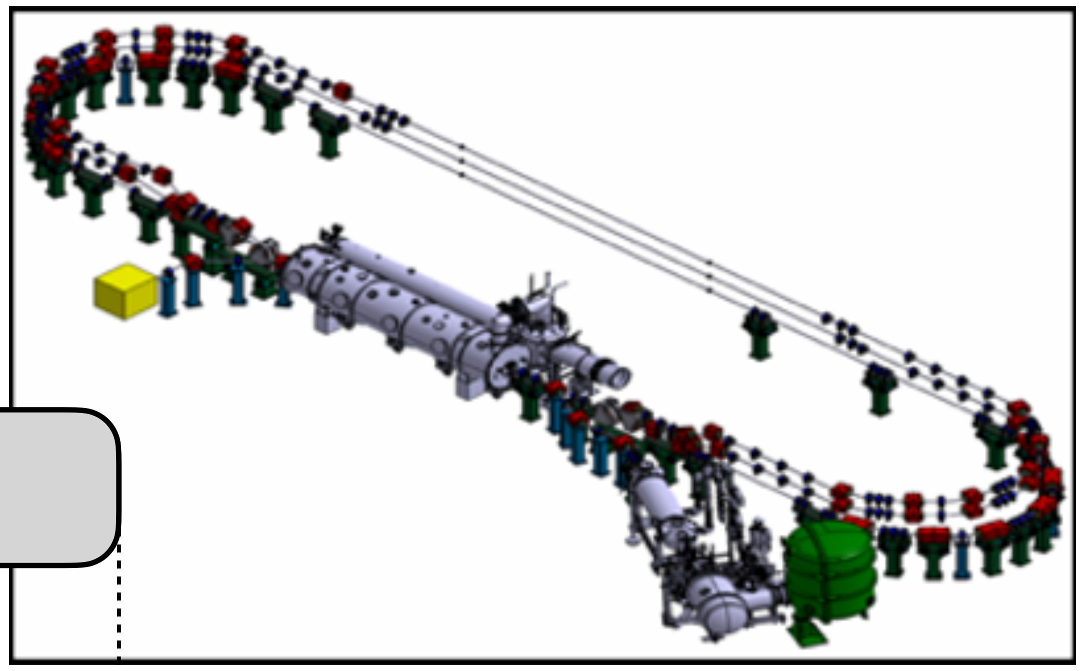
Phase 1: Injection line Installation



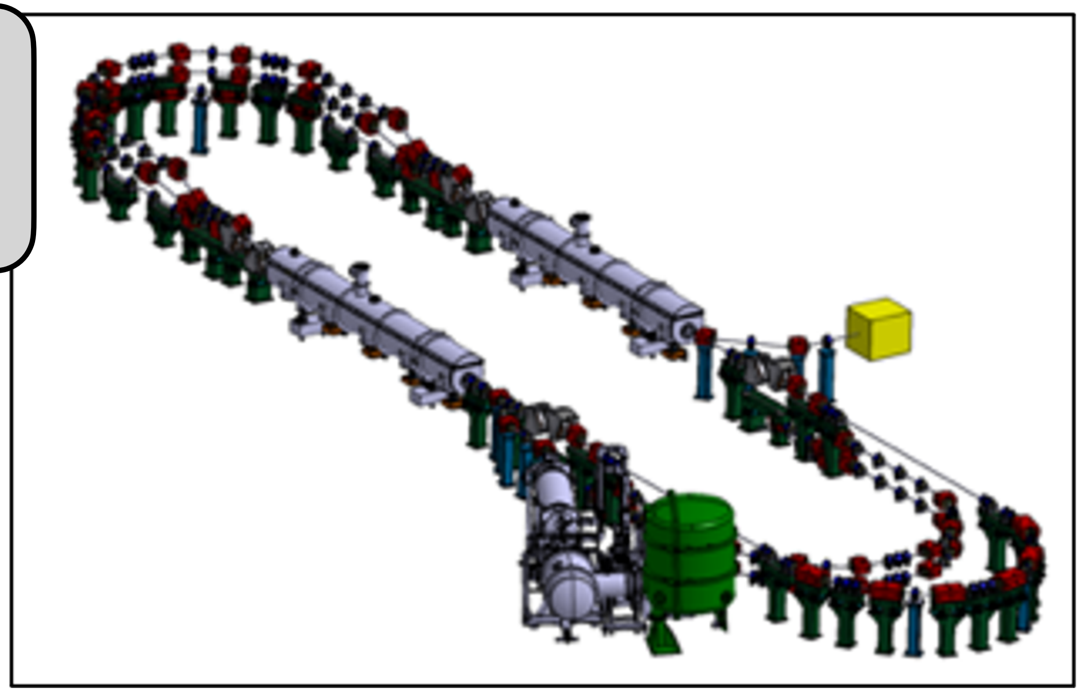


Possible Single turn ERL phase under evaluation → Phase 1 to be extended to 2028

Phase 2: PERLE 250 MeV version

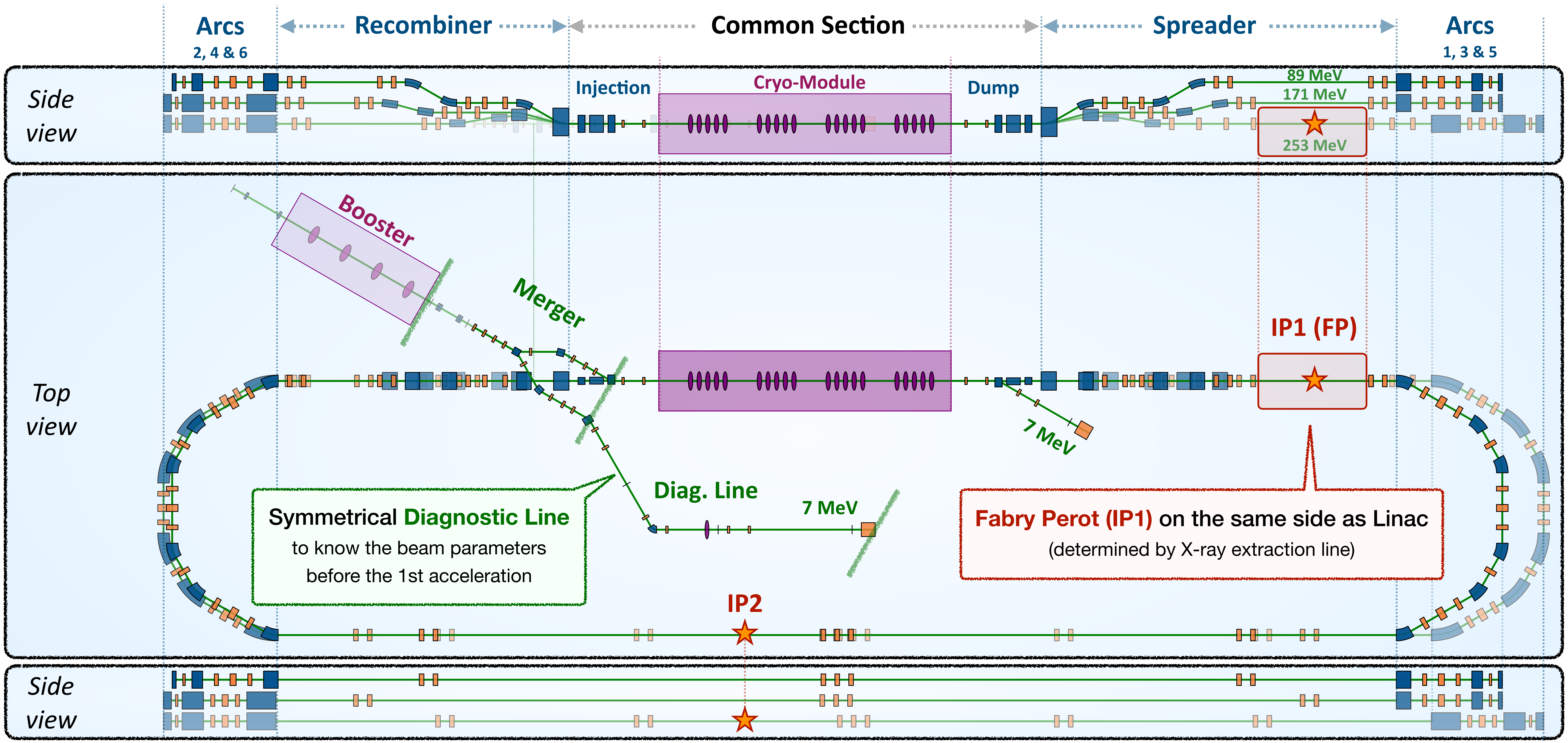


Phase 3: PERLE 500 MeV version

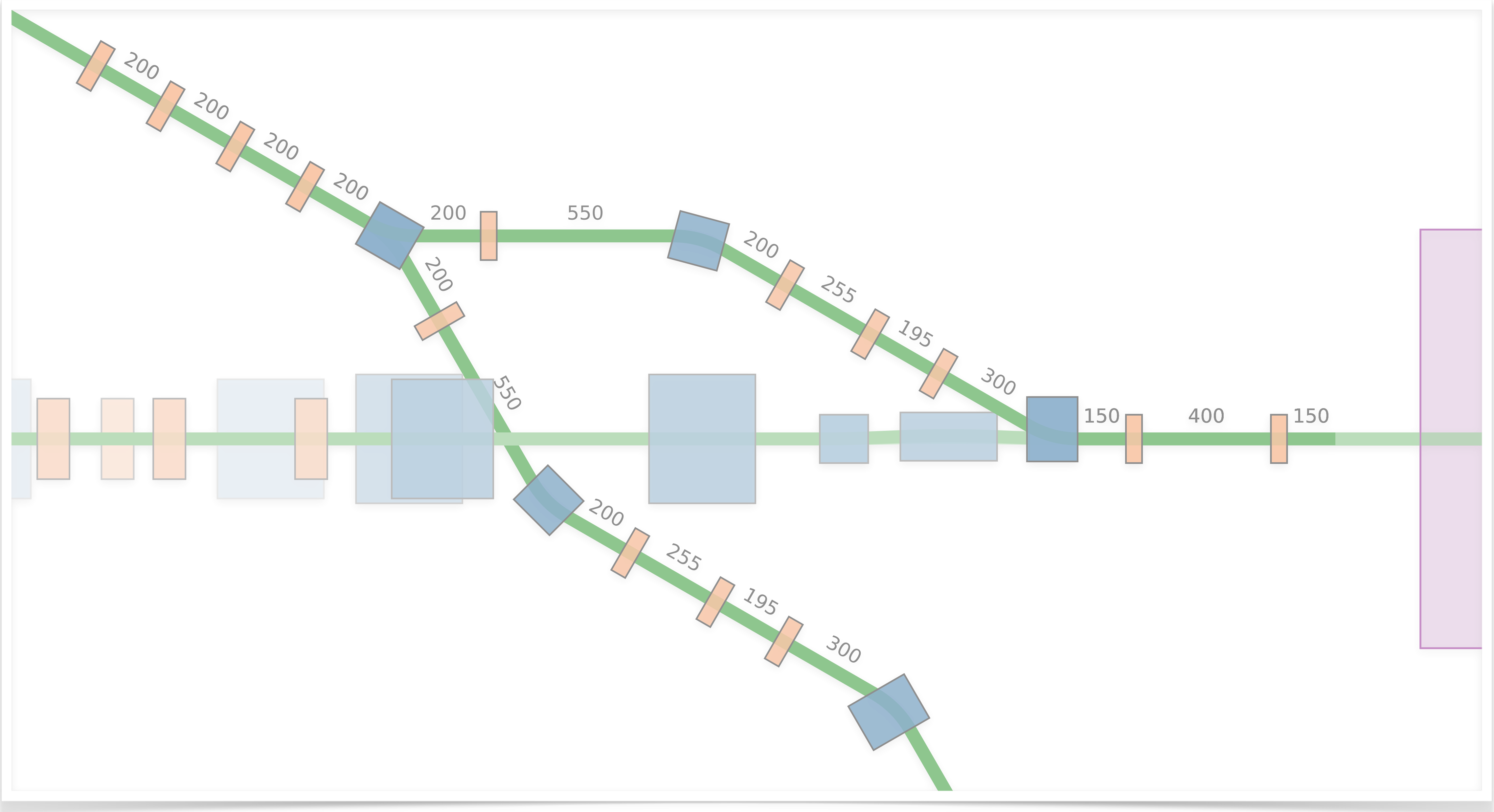


2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031

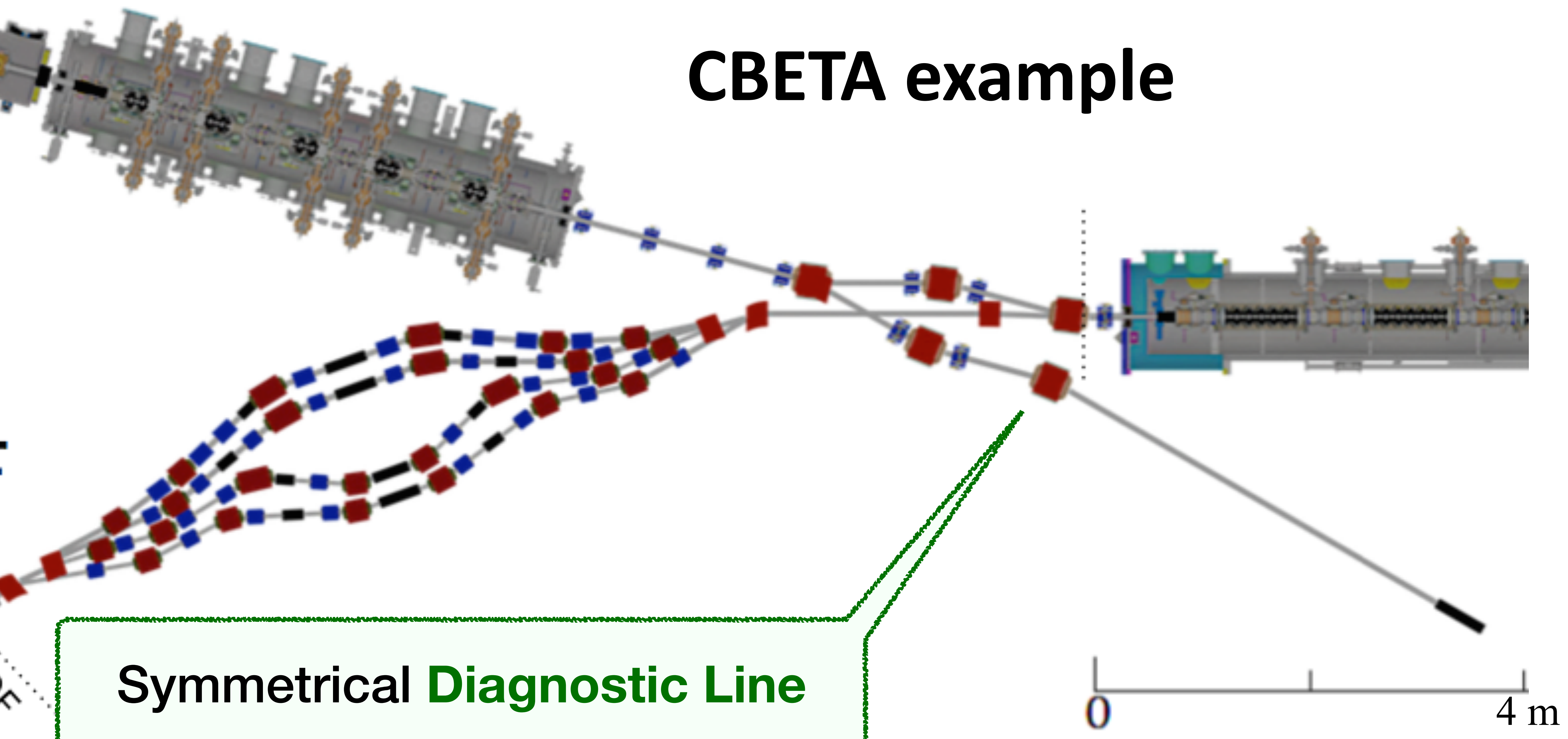
Updated PERLE Lattice 250 MeV version



Three Dipole Merger

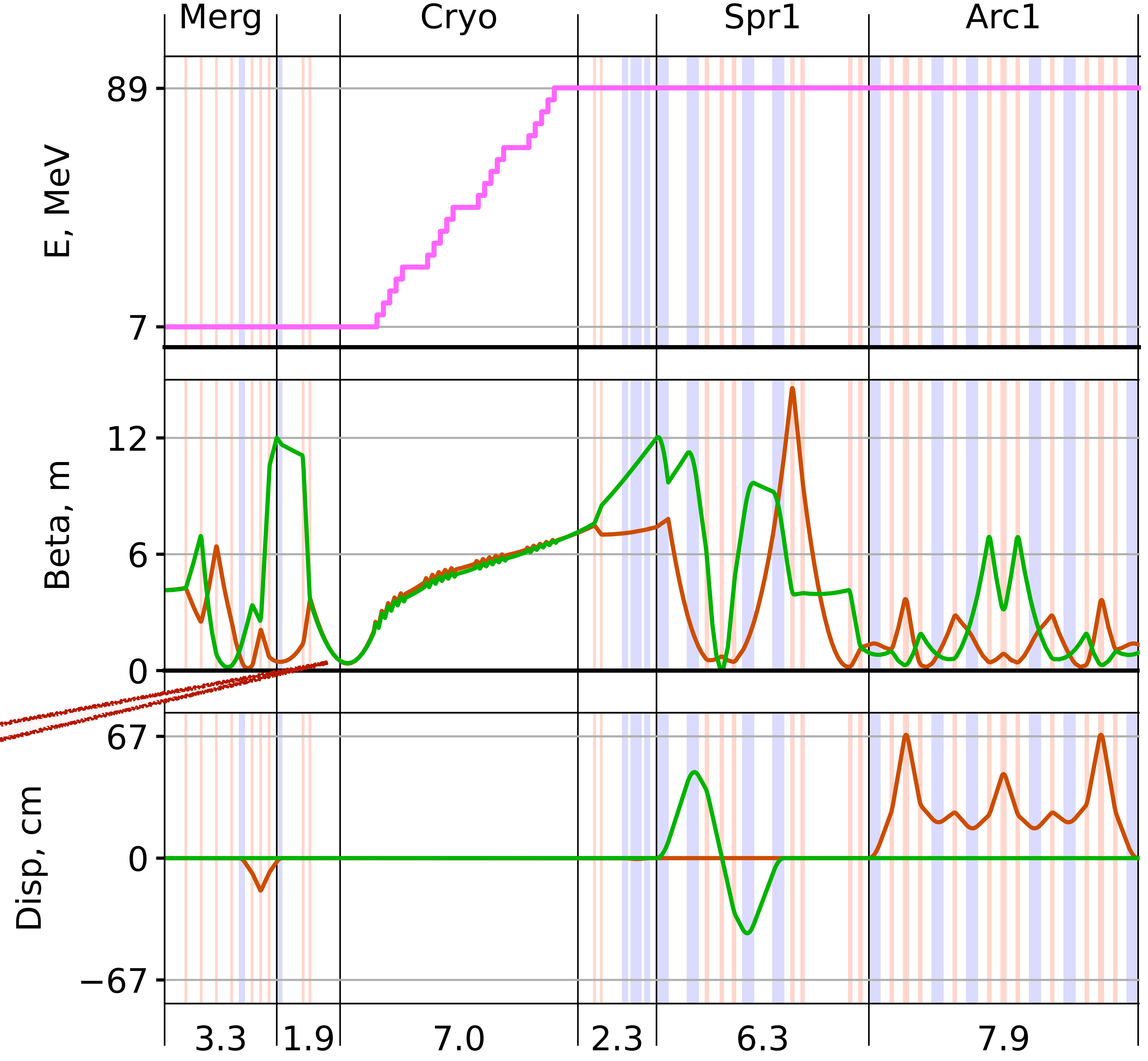


CBETA example



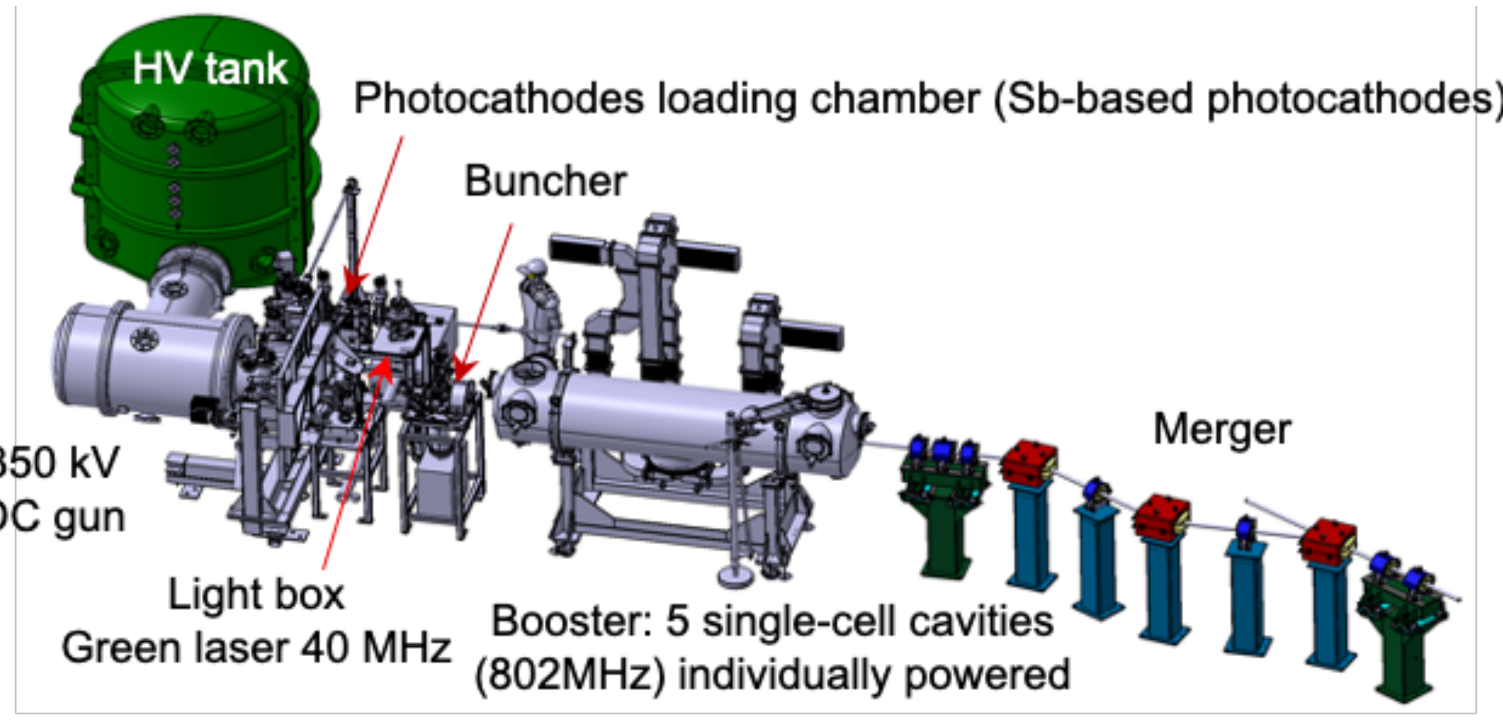
Symmetrical **Diagnostic Line** to know the beam parameters before the 1st acceleration

PERLE optics



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

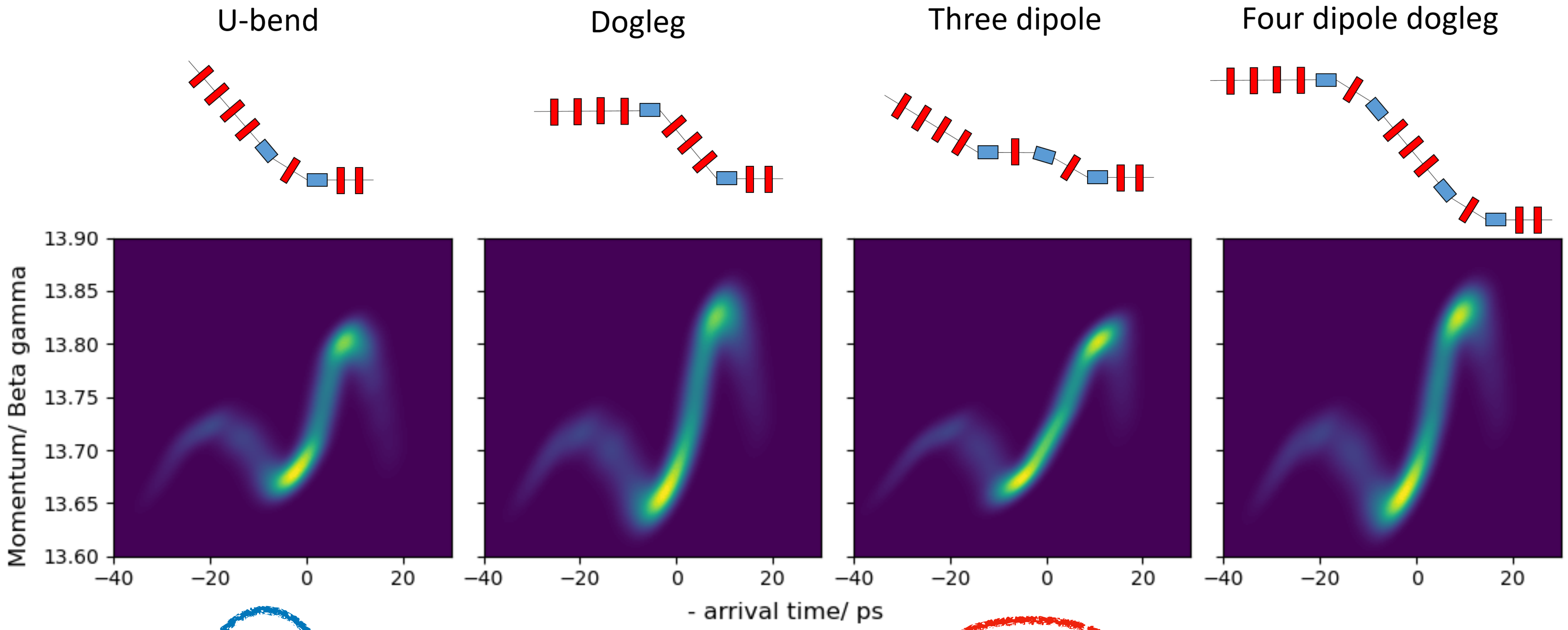
Injector/merger design and initial space-charge studies



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

(PhD of B. Hounsell)

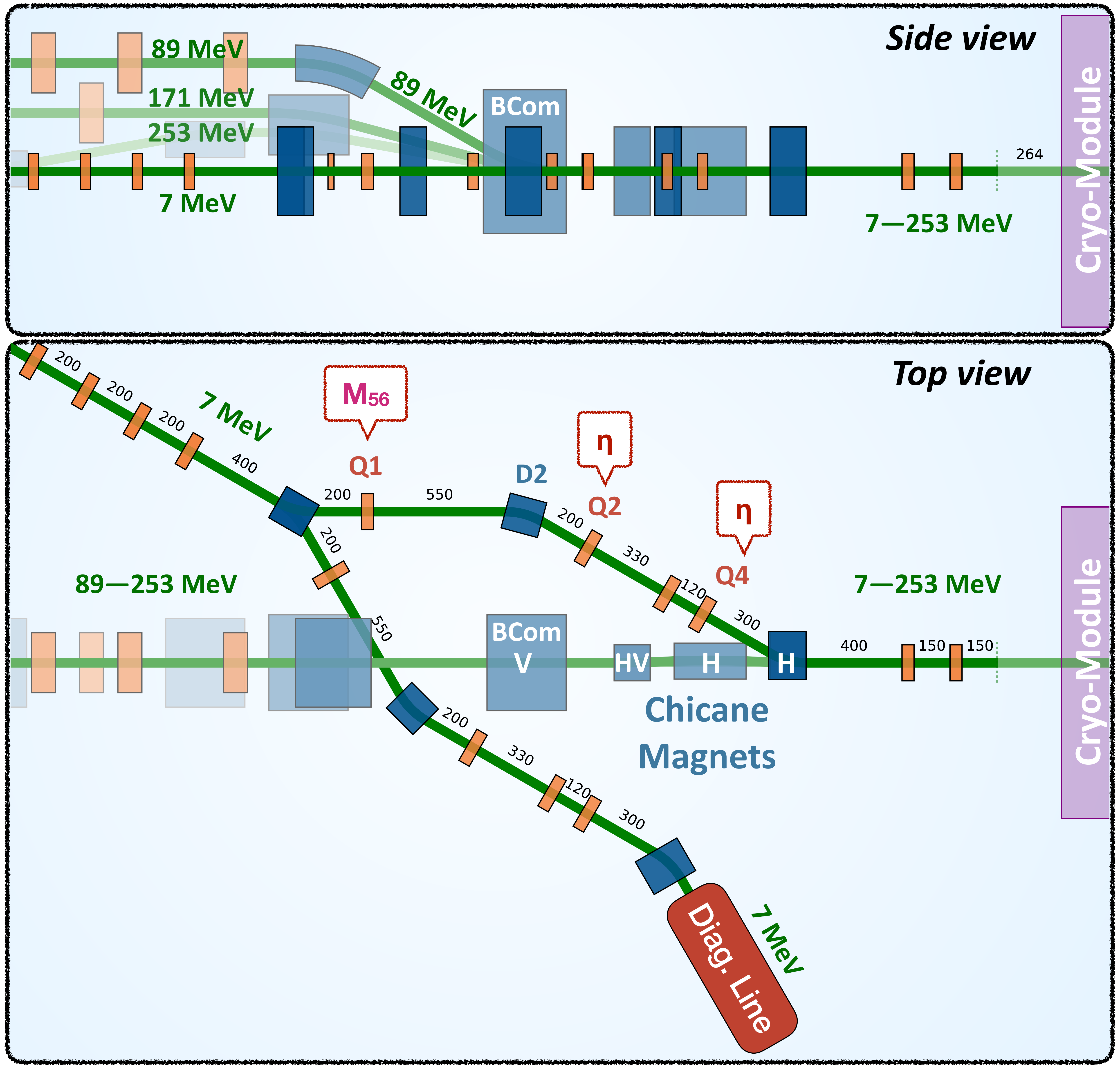
Four merger schemes

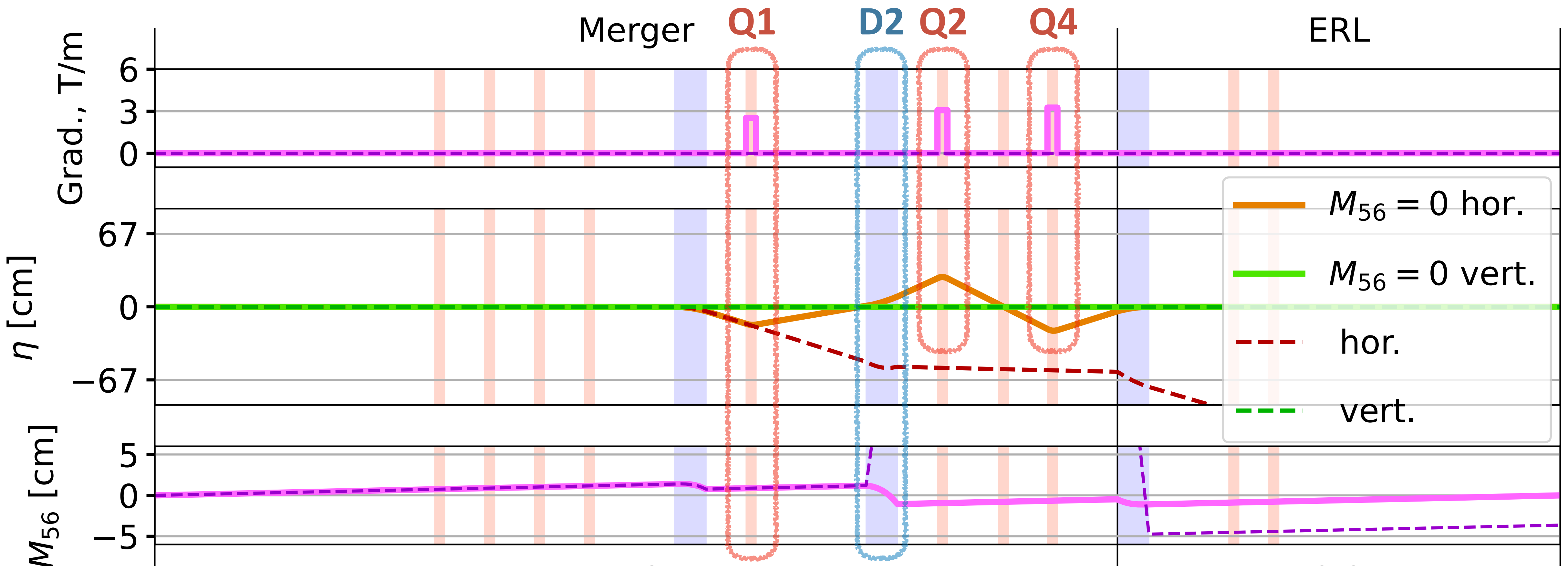


	U-bend	Dogleg	Three dipole	Four dipole dogleg	Spec
εx/ mm·mrad	4.3	5.2	5.9	4.7	< 6
εy/ mm·mrad	4.4	4.5	3.2	7.0	< 6
Mismatch factor	0.014	0.72	0.05	0.11	0
R56/ m	0.023	0.0185	-0.155	0.031	0

Initially preferred scheme

CBETA choice

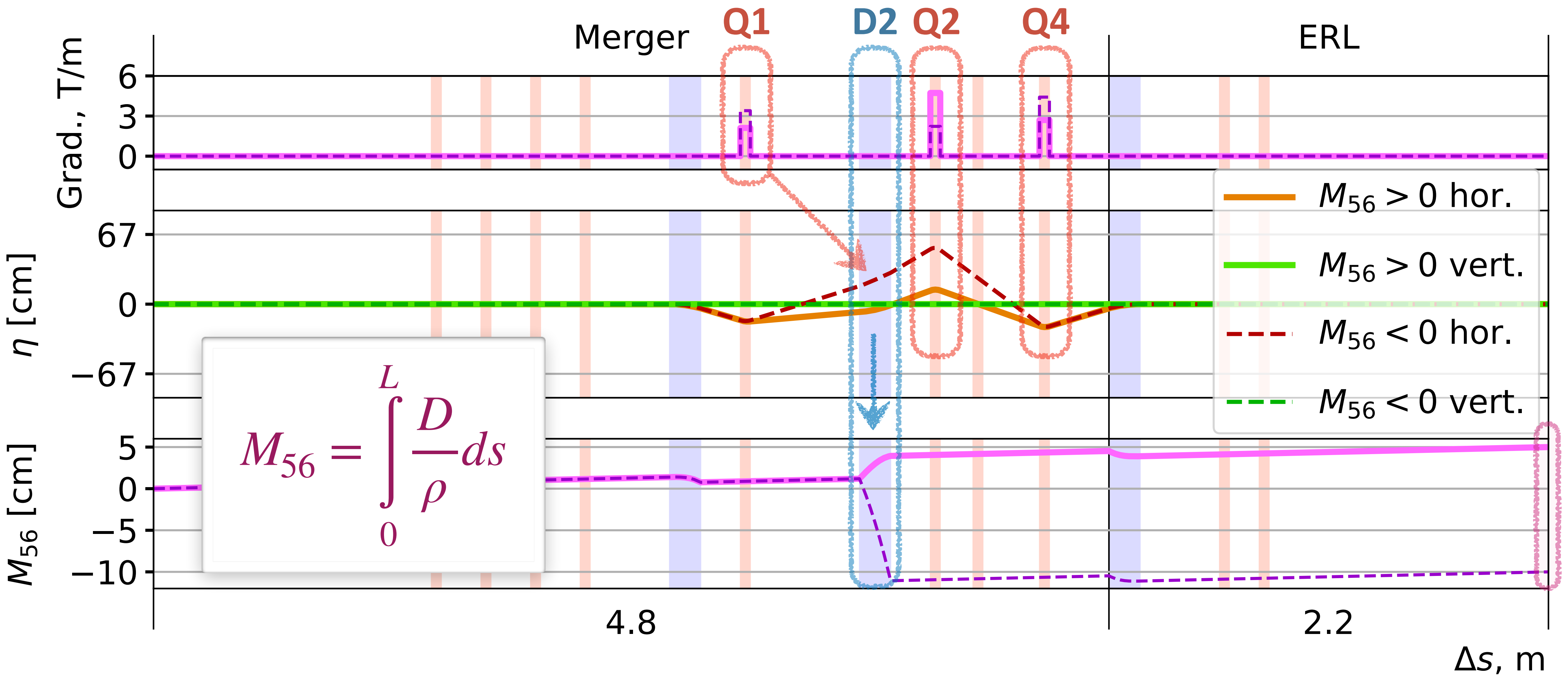




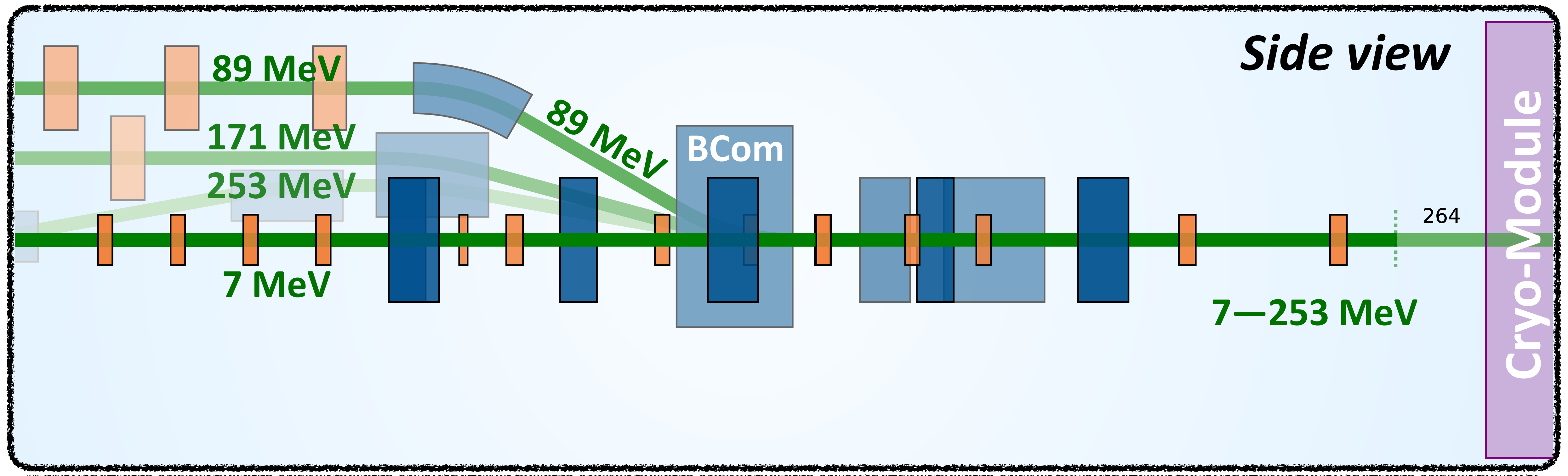
Tuning M56 at Dog-Leg Merger:

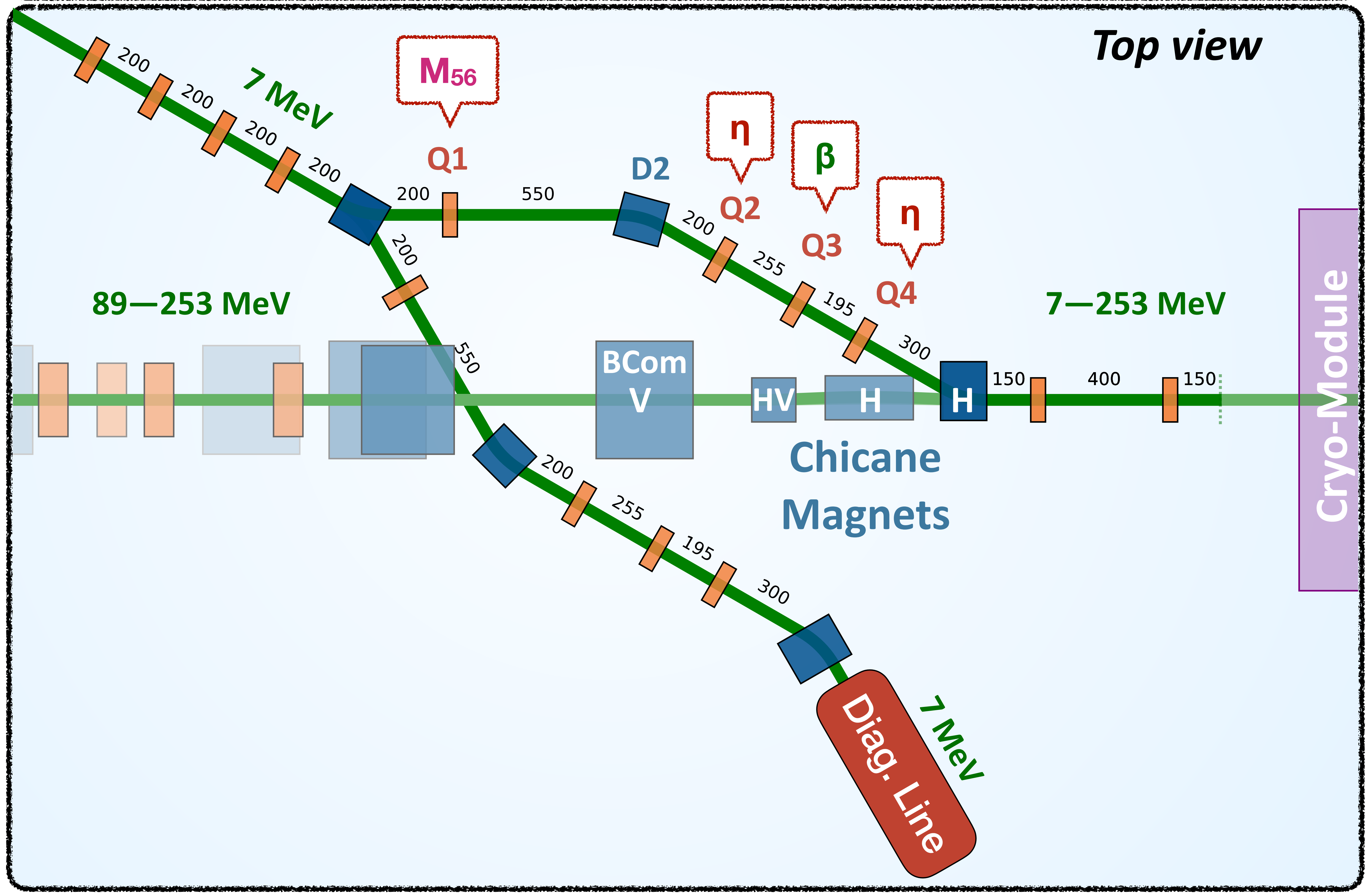
Q1 → tune the dispersion at **D2** → control **M56** ∈ [-10, 5] cm

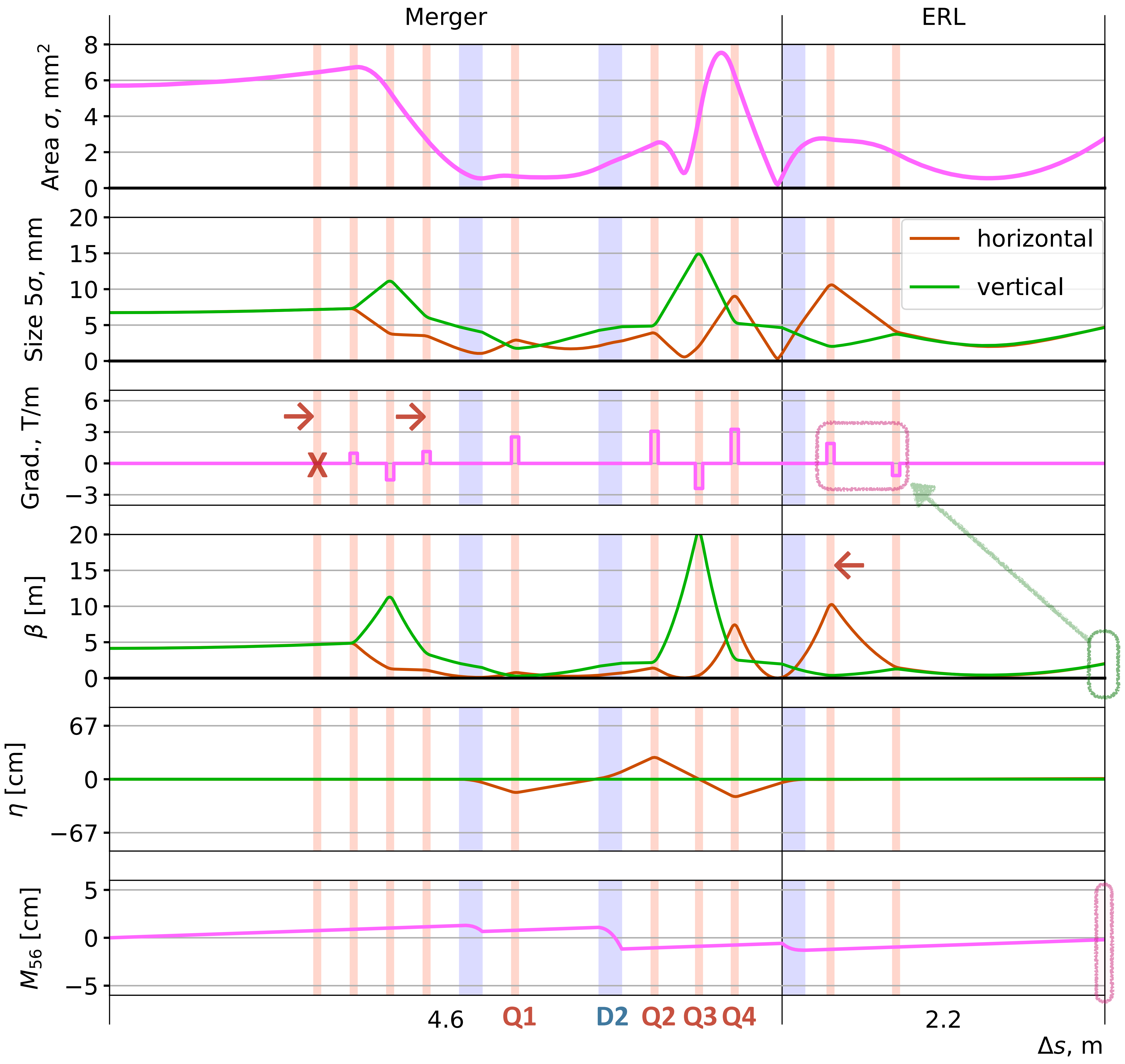
Q2 & **Q4** → closes the dispersion bump (dx, dpx = 0)



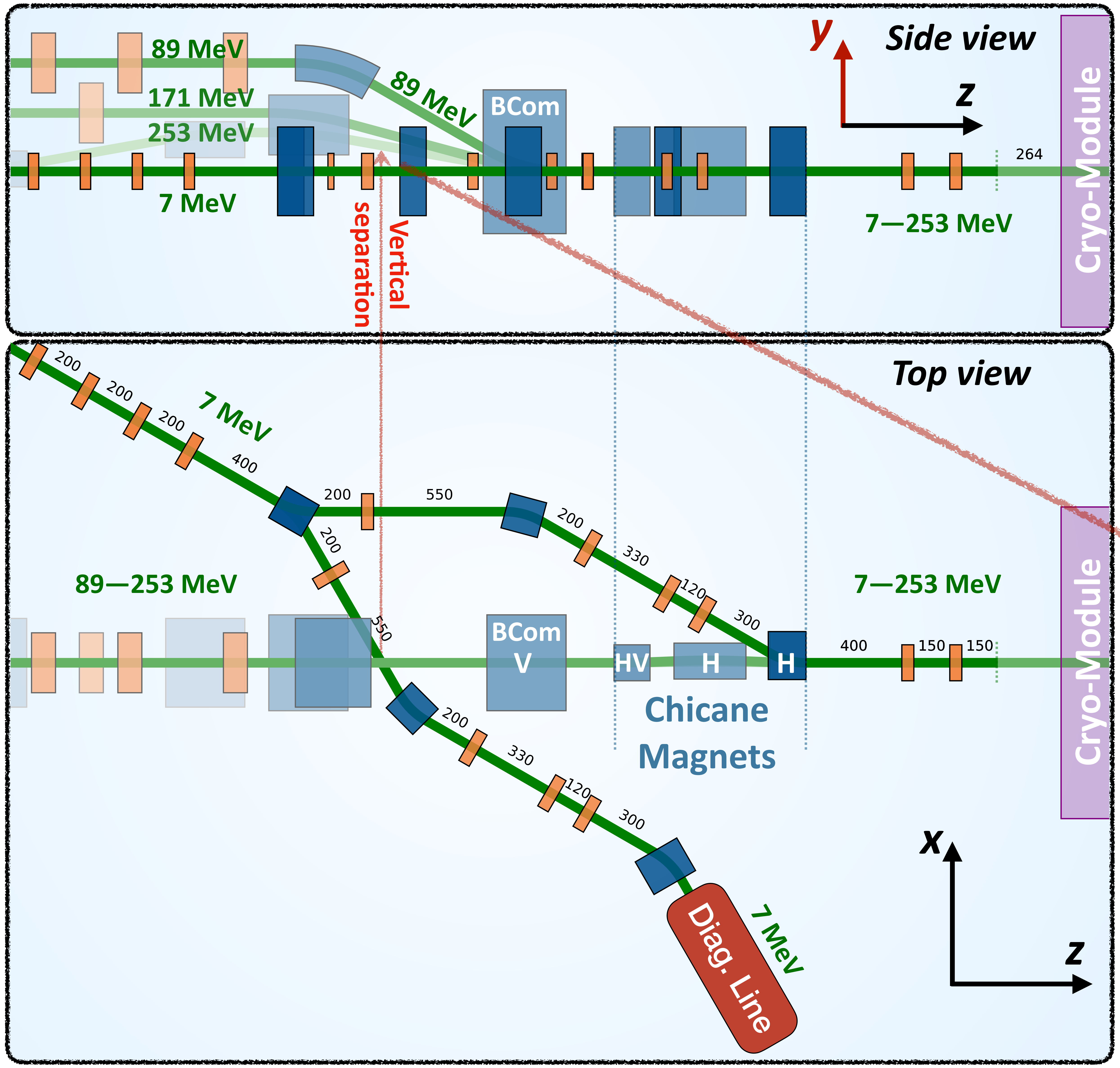
3 Dipole Merger: Controlling the beam size, dispertion & M56

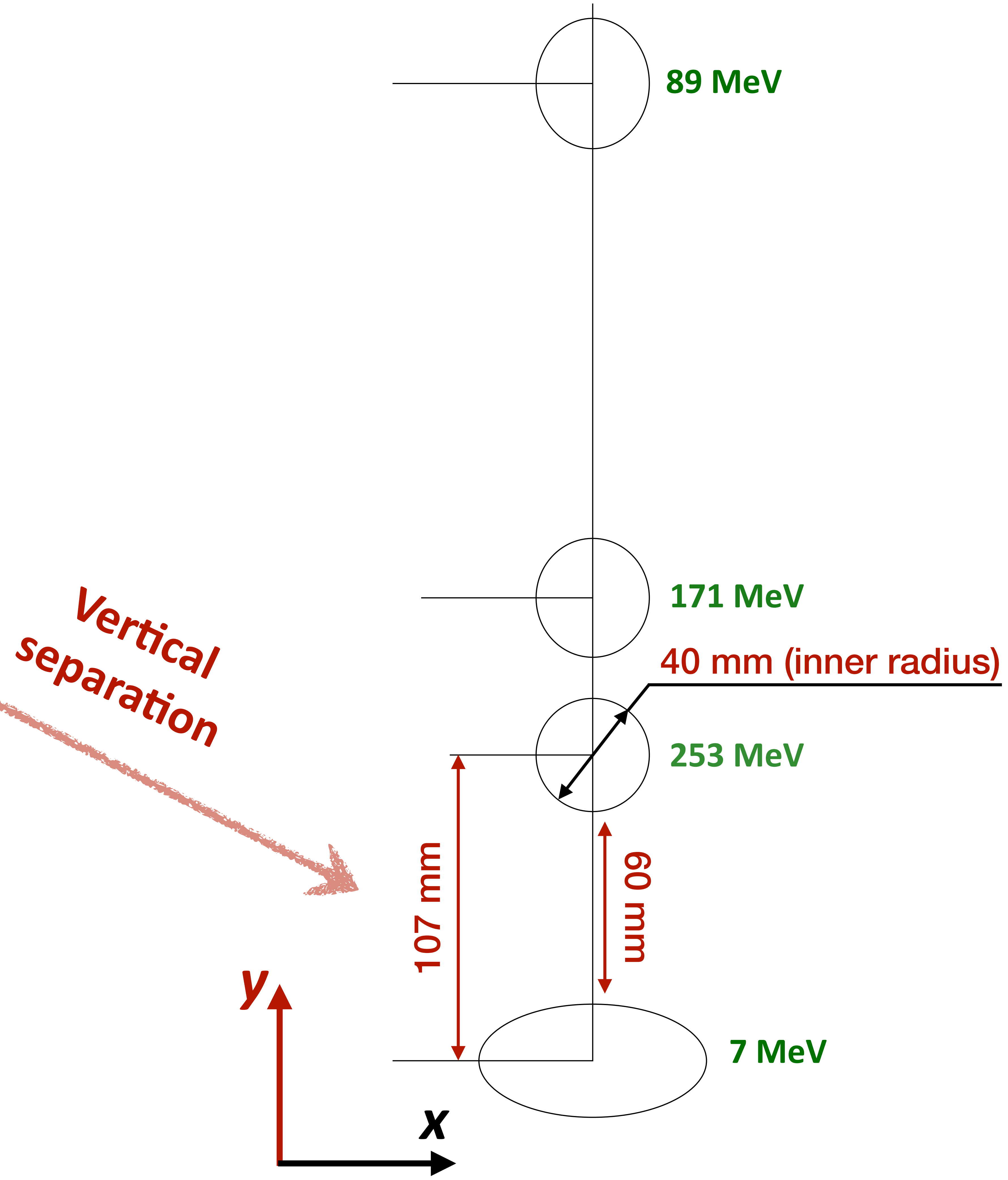




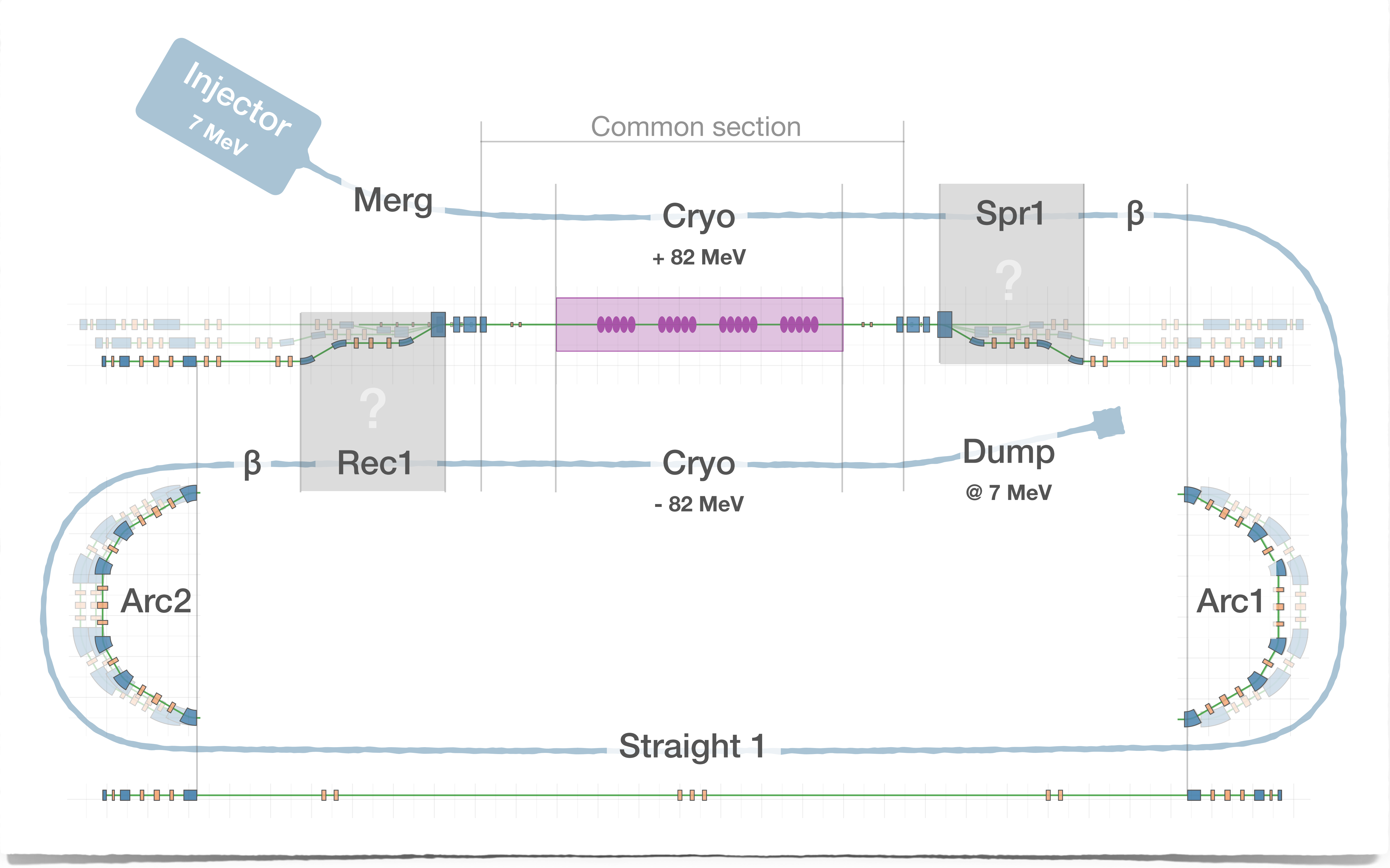


3 Dipole Merger: vertical separation (Diag. Line is under the ERL)

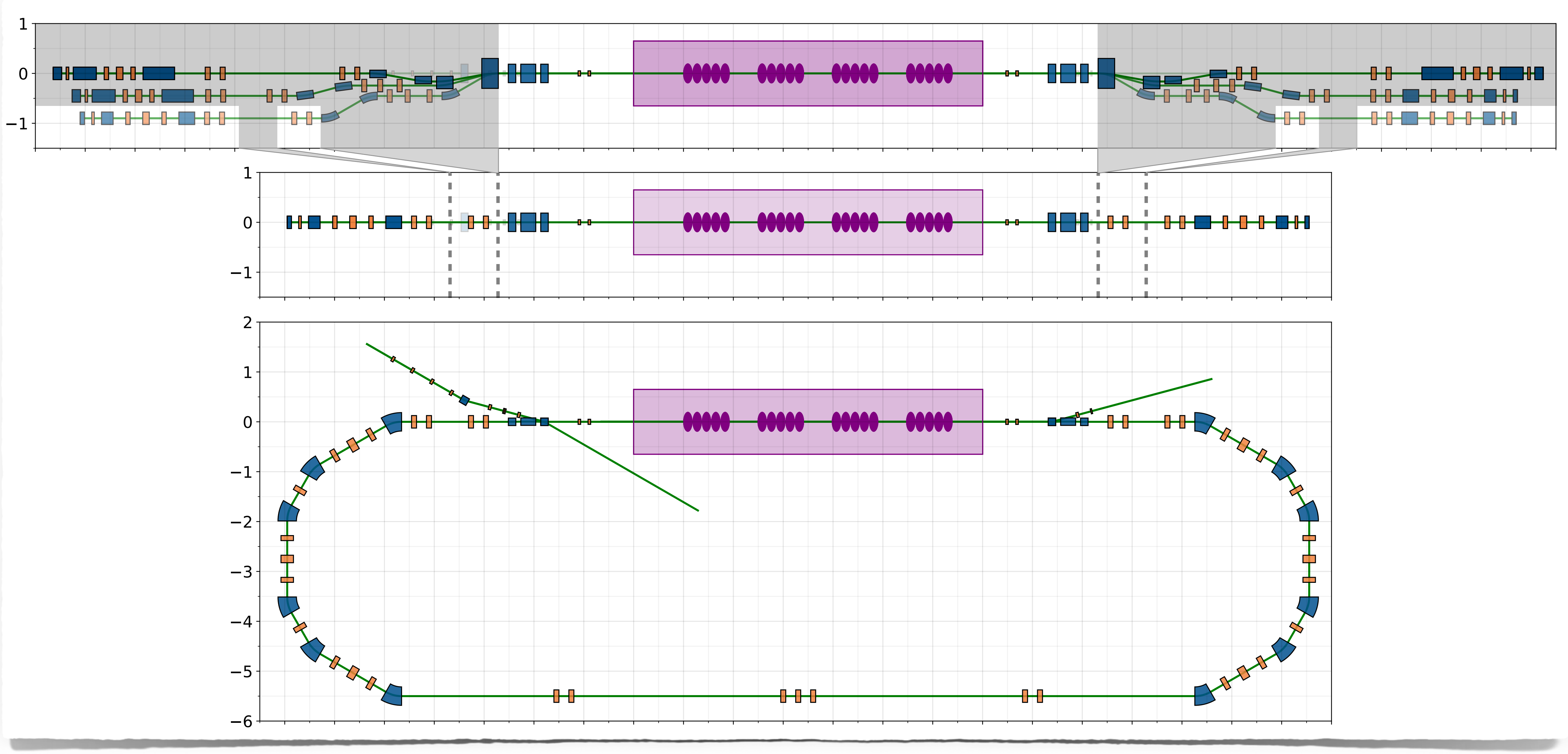




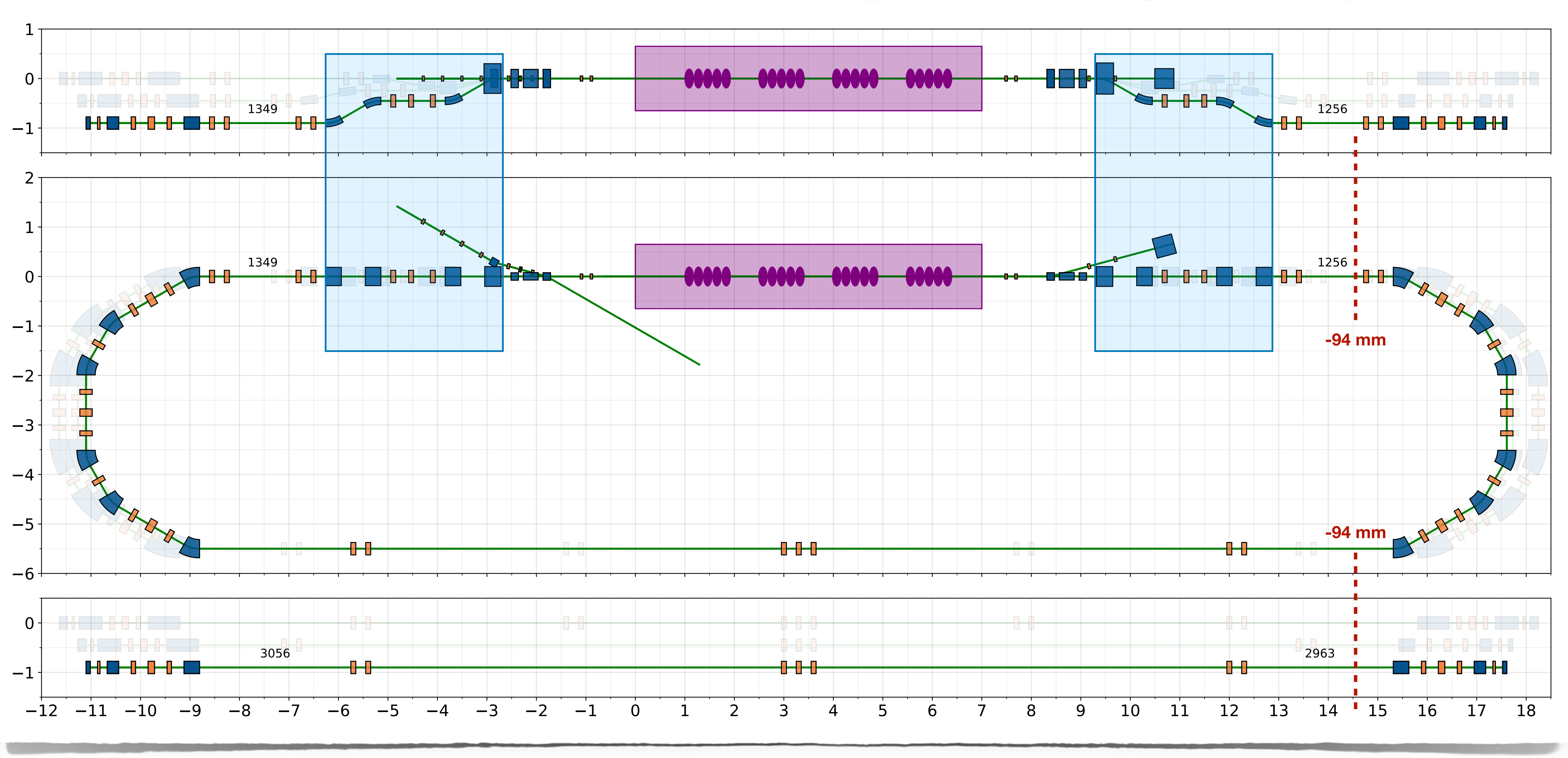
PERLE: Single-Turn version



Single-Turn "Simple"



Single-Turn "with B-Coms"

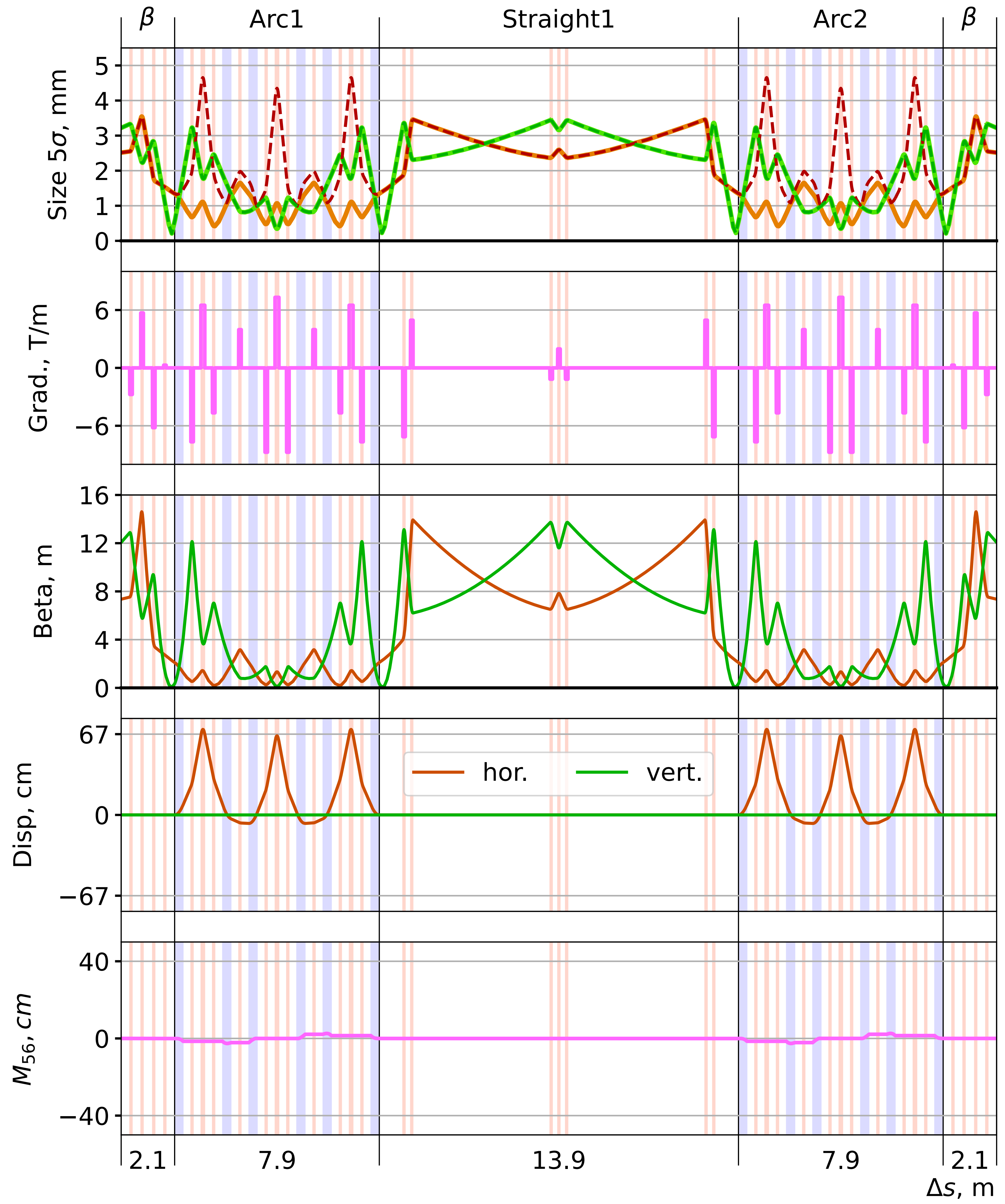


- **The simplest design to test the performance of cavities in ERL mode**
  - minimal number of element (magnets, diagnostics)
    - **12** S-Bends of 33cm, 30° horizontal (**0.472 T** with **6** (of 12) upgradable to **0.907 T** (for 500 MeV version)
    - **2** R-Bends of 15cm, 15° horizontal deflection (**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)

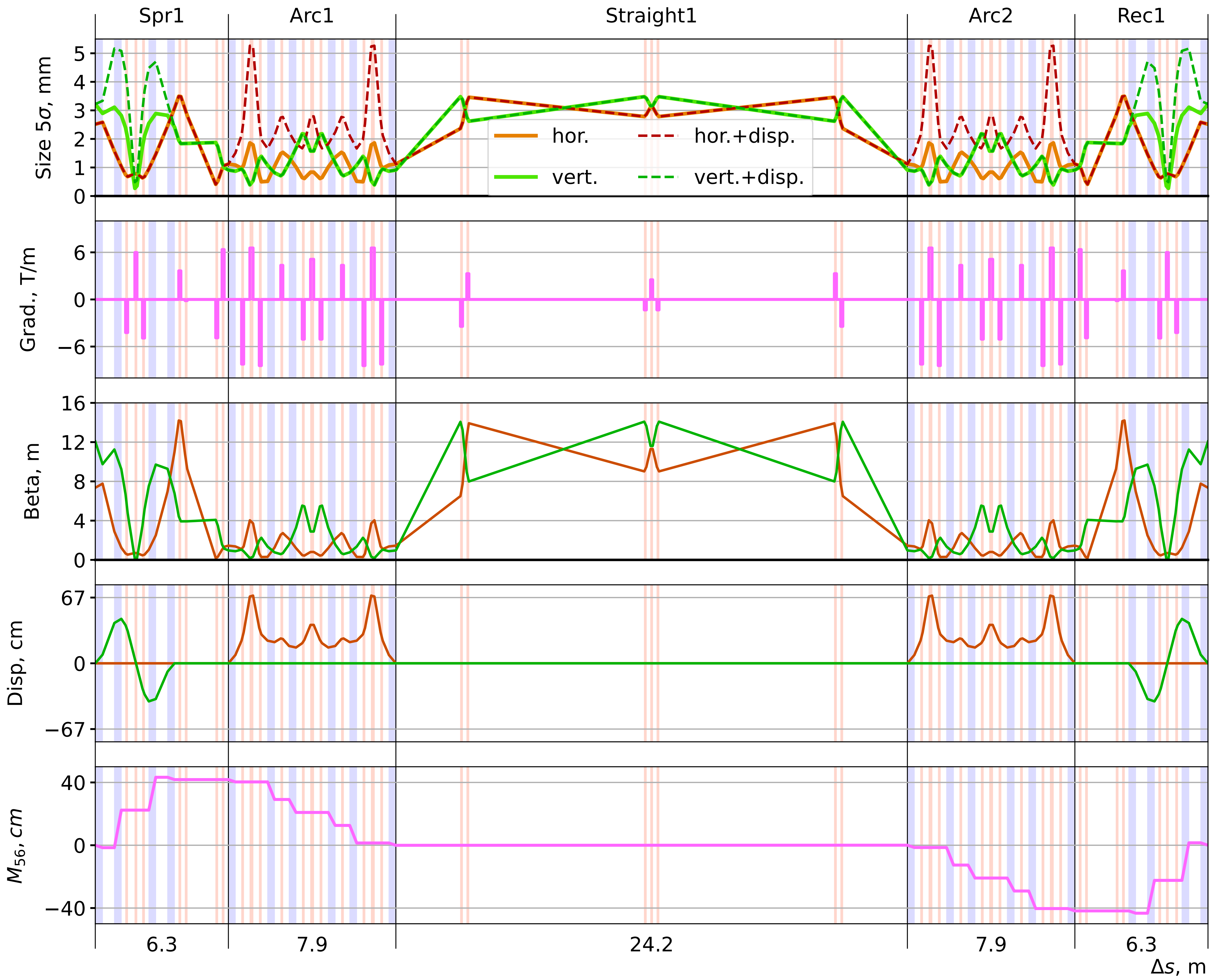
- **Would require less for 250 MeV upgrade**
  - one Arc has to be shifted by $\lambda_{RF}/4 \approx 9.4$ cm
  - higher energy lines could be attached on top at the B-Com magnet
- **Is bigger than simple Single-Turn, with more complicated optics (+ vertical plane)**
  - **+16 m** to the path length
  - **+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”

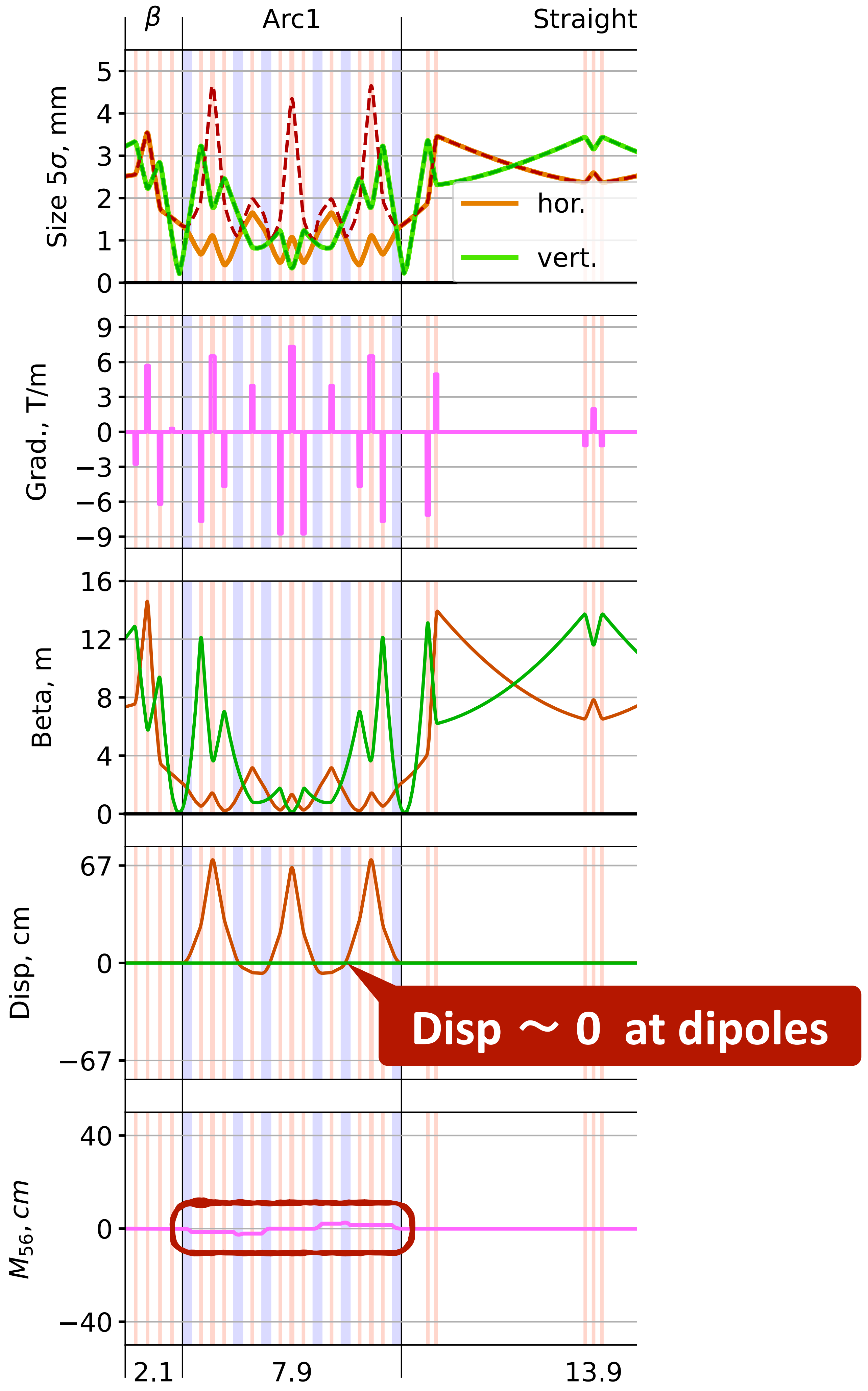


Single-Turn “with B-Coms”

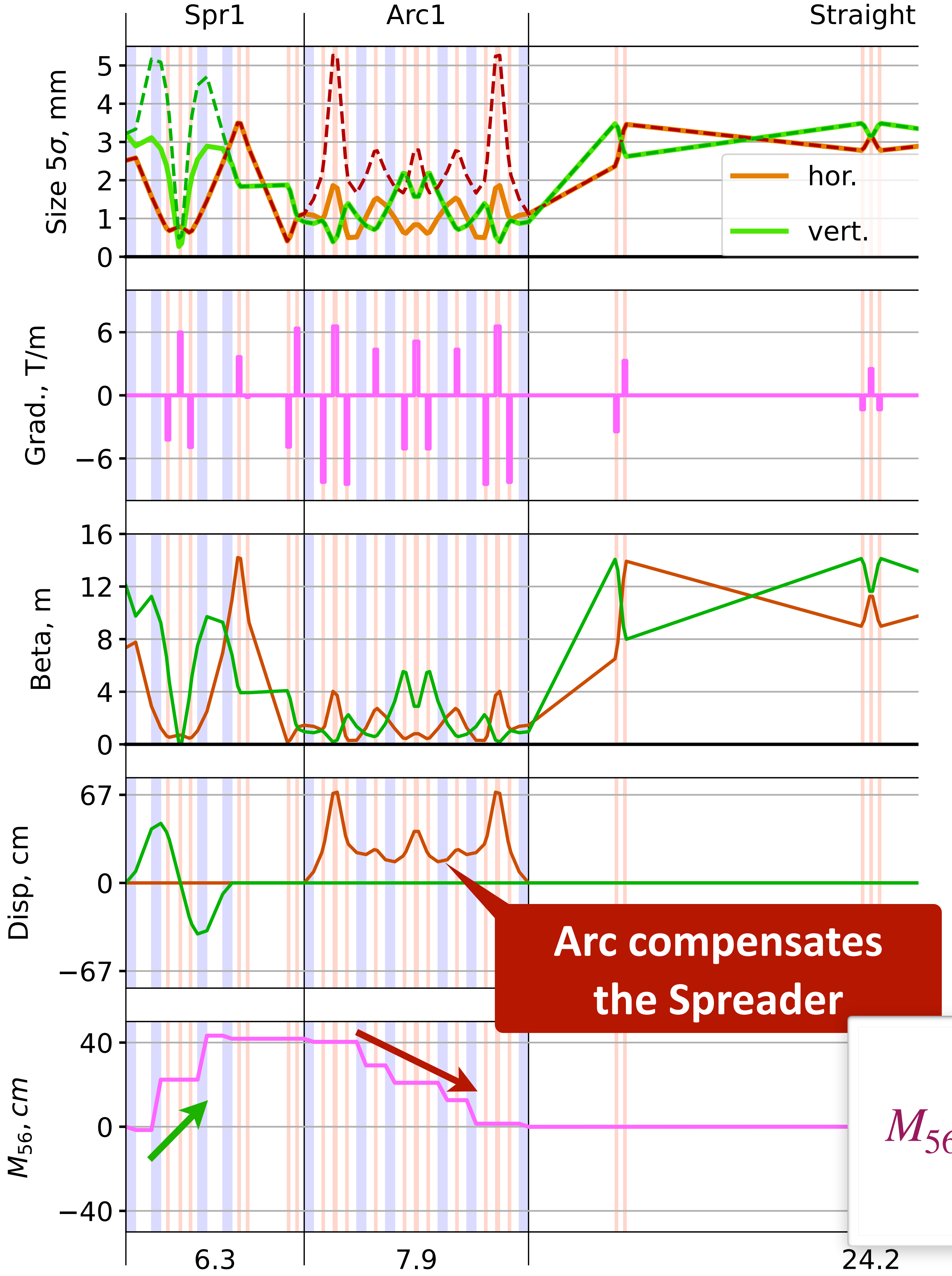


PERLE Optics: M56 compensation in the Arc (ST vs 250 & 500 MeV)

Single-Turn "Simple"

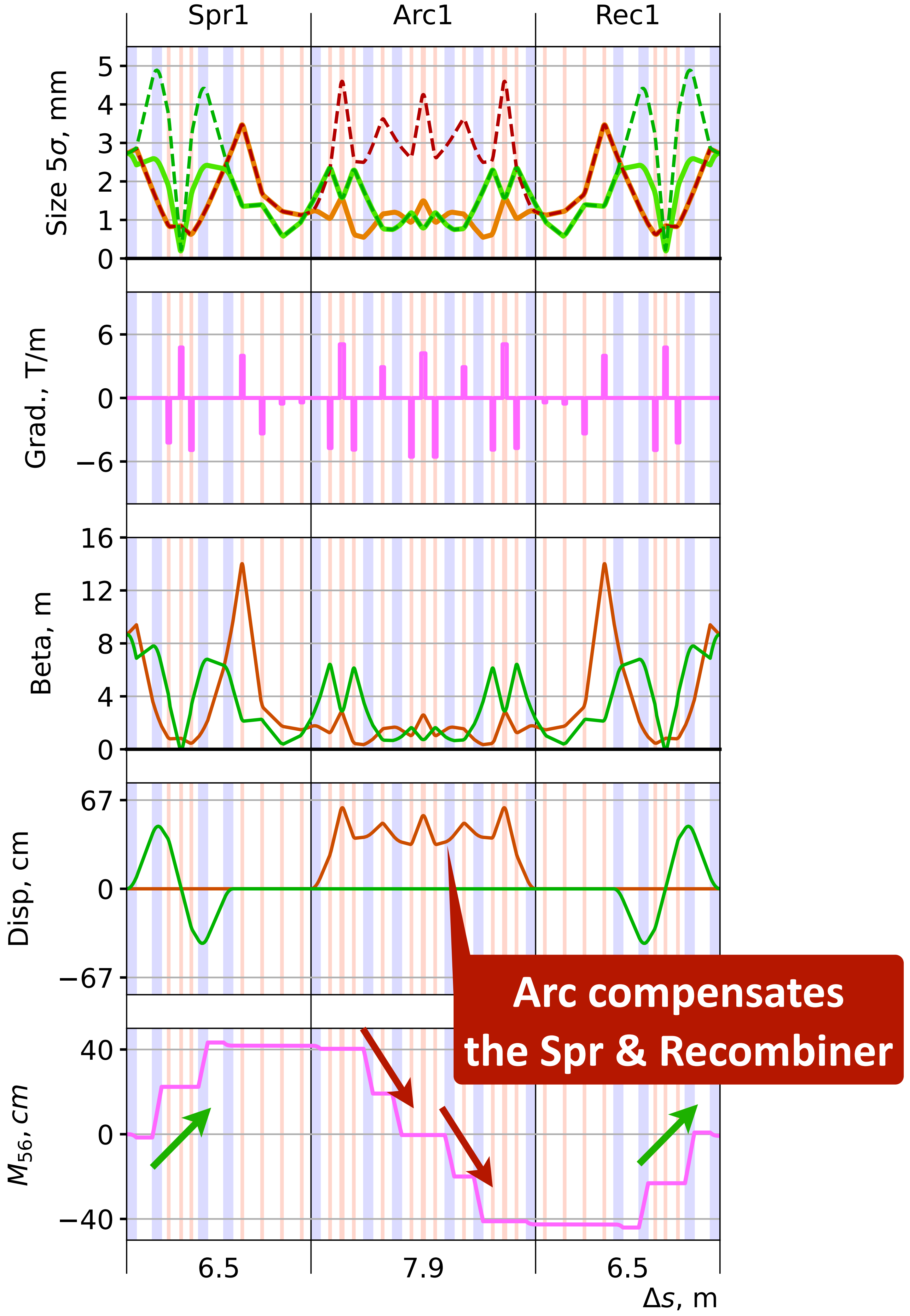


250 MeV version (Arc1)



$$M_{56} = \int_0^L \frac{D}{\rho} ds$$

500 MeV version (Arc1)

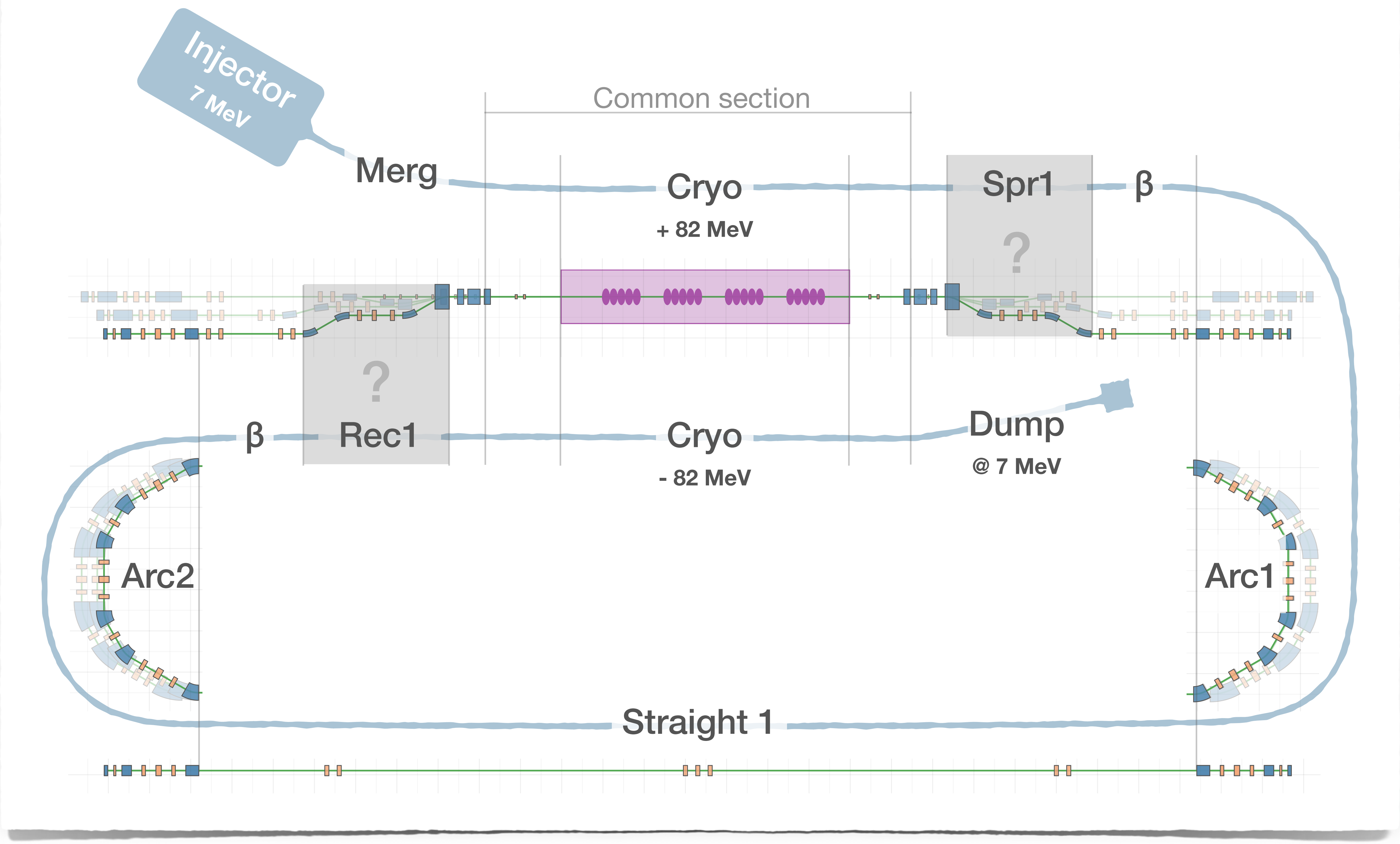


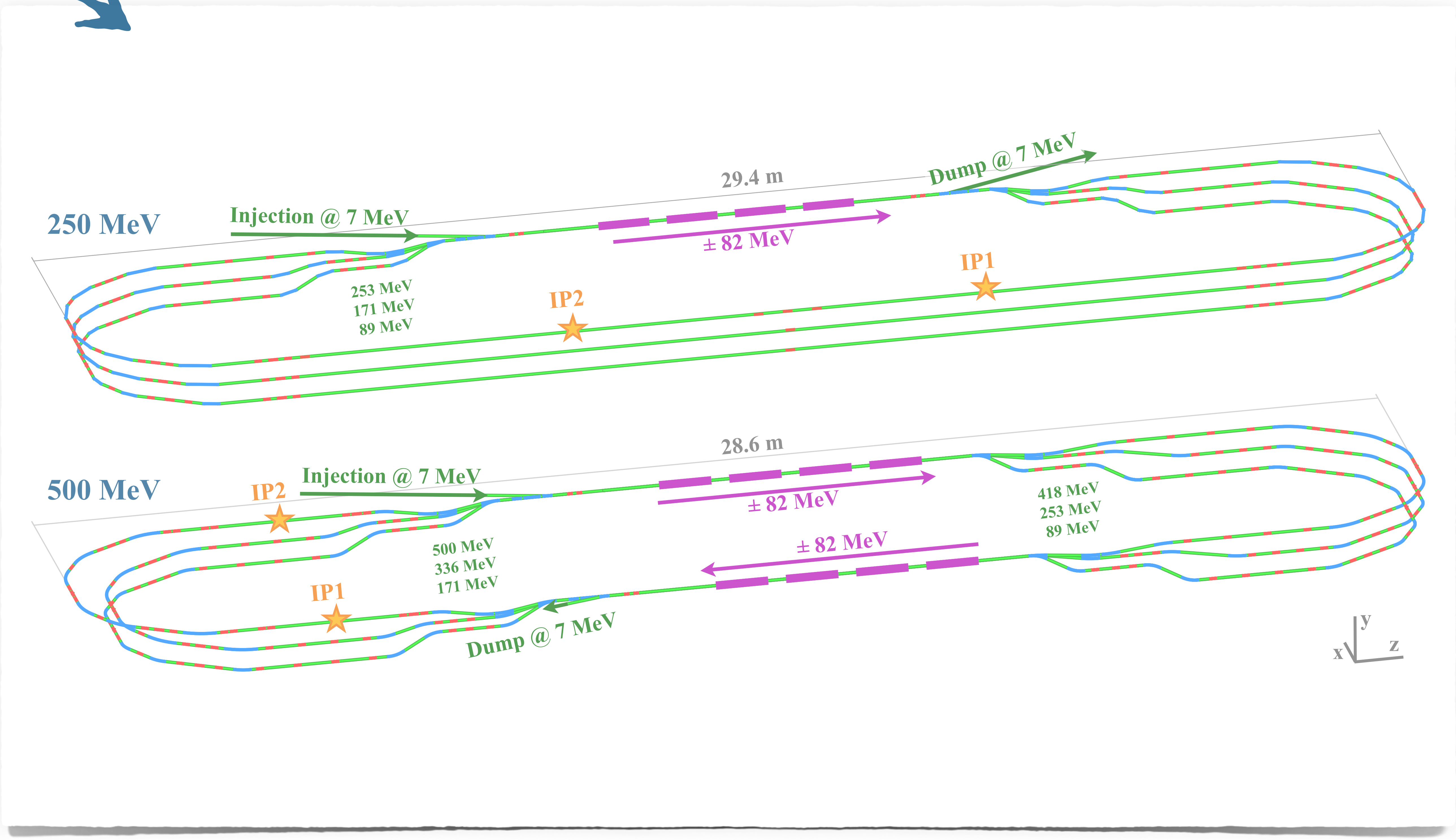
Switchyards: Geometry vs Cavity boost (82 ➞ 18 MeV / pass)

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

Test the Linac performance at Single Turn ➞ Finalise the geometry

Upgradability to 250 & 500 MeV





PERLE Upgradability for 500 MeV — Types and Number of Dipoles

Versions	Angle, pl.	30° hor.						15° hor.	30° hor.	30° vert.	30° vert.		…
	Type	S-Bend						R-Bend		B-Com	S-Bend		…
	Length	33 cm			66 cm			15 cm	30 cm	33 cm	33 cm		…
	Place	Arc1	Arc2	Arc3	Arc4	Arc5	Arc6	Inj & Dump chicane		Spreader	Spr. Arc1	Spr. Arc2	…
Single-Turn (simple)	Field, T	**0.47**	**0.47**										
Single-Turn (with B-Coms)		**0.47**	**0.47**							0.45	0.47	0.47	
250 MeV (3 turns, 1 cryo)		**0.47**	**0.47**	**0.91**	0.45	0.67	0.67	0.04		0.45	0.47	0.47	…
500 MeV (3 turns, 2 cryo)		**0.47**	**0.91**	**1.34**	0.89	1.11	**1.32**			**0.89**	0.47	**0.91**	**…**
		1.34			1.32						**0.91**		
Single-Turn (simple)	Number	12						5	2	0	0		0
Single-Turn (with B-Coms)		12						5	2	2	6		0
250 MeV (3 turns, 1 cryo)		18			18			5	2	2	6		…
500 MeV (3 turns, 2 cryo)		18			18			5	2	4	12		…

We propose to group S-Bend dipoles of the Arcs in 3 types:

- type 1: 18 dipoles (12 for Single-Turn), magnetic length: 33 cm, deflection angle: 30° **horizontal**, magnetic field range: 0.47–1.34 T
- type 2: 18 dipoles (0 for Single-Turn), magnetic length: 66 cm, deflection angle: 30° horizontal, magnetic field range: 0.45–1.32 T
- type 3: 12 dipoles (6 for Single-Turn with B-Com), L = 33 cm, deflection angle: 30° **vertical**, magnetic field range: 0.47–0.91 T

Is it worth combining the groups?

- type 1 + type 2: **45 cm**, 30°, with **wider field range**
- type 1 + type 3: 30 cm, 30°, same design for **hor. and vert.**

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	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	0.453	1.323	40
Total			**18**	**26**	60	78						

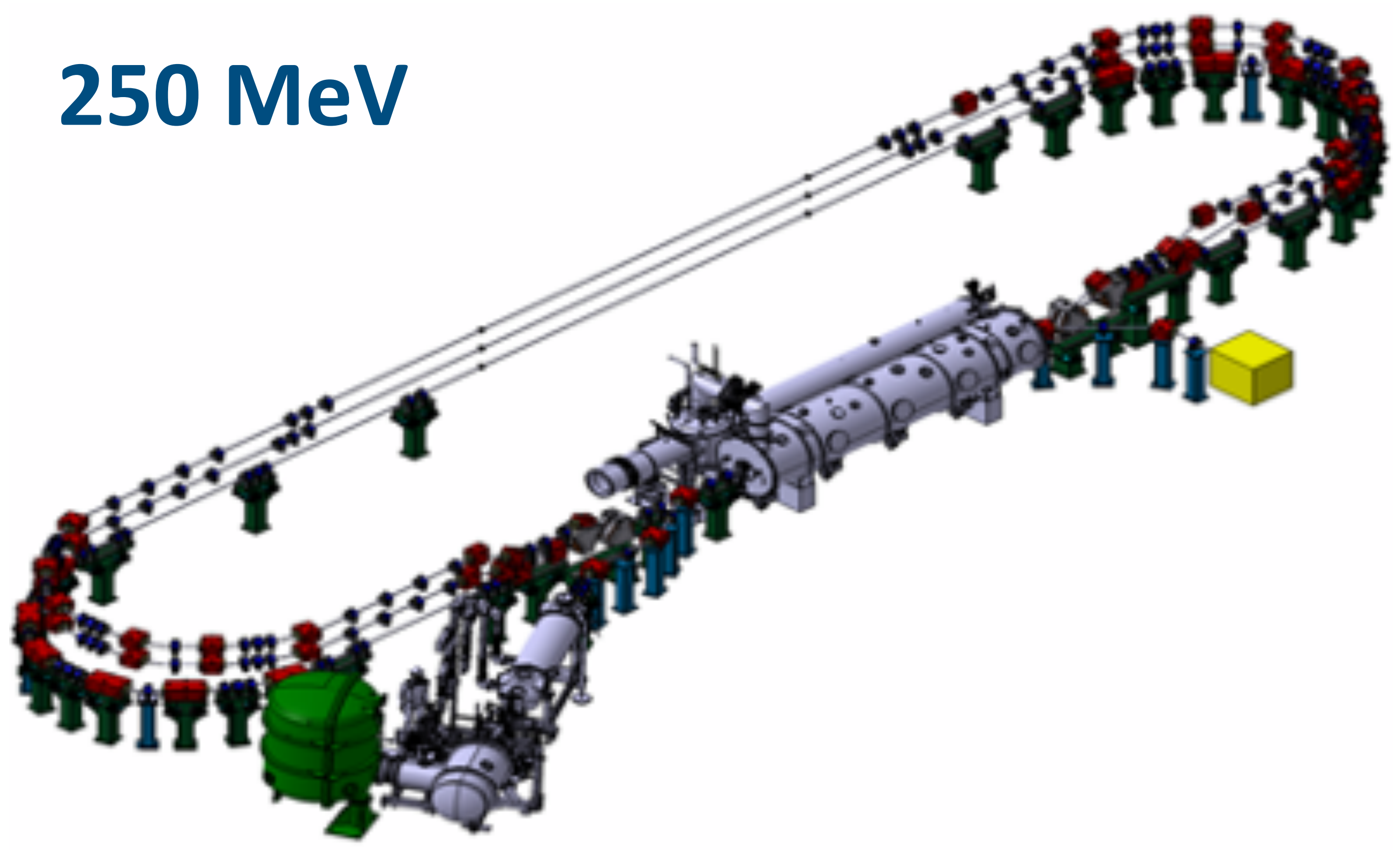
Total number of dipole

- 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

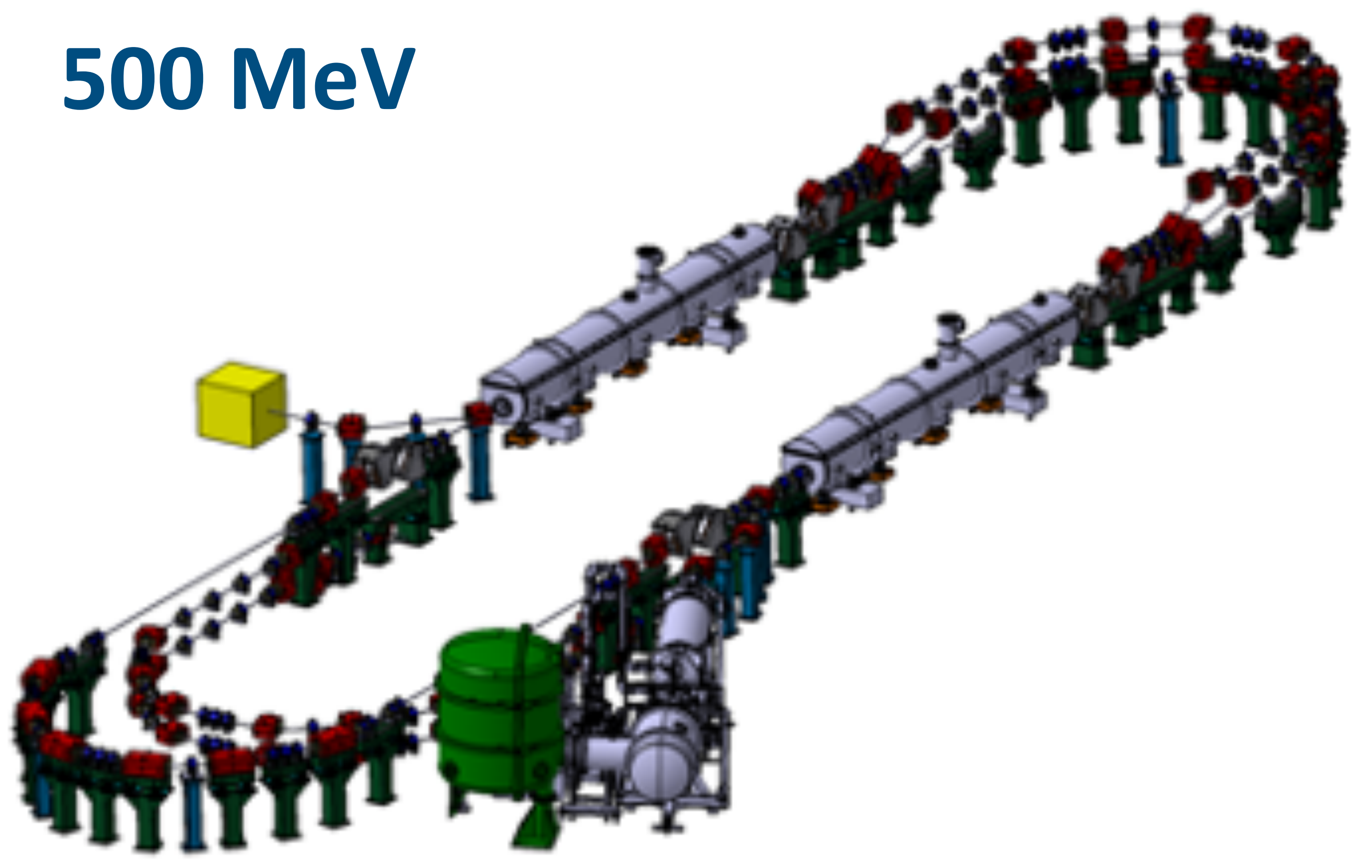
- the required magnetic field might vary by the factor 2—3 within the same Type of dipole
- "S-Bend 33cm" at the Spreader/Merger sections is in vertical orientation and in horizontal at the Arcs — Can it have the same dipole design?

250 MeV



T/m	0.2	2.6	6.4	8.2	19	23	total
7 MeV	15						
89 MeV	9	34					
171 MeV	2	9	6	26			
253 MeV			6	28	7		
All	26	43	12	54	7		*142*

500 MeV



T/m	0.2	2.6	6.4	8.2	19	23	43	56	total
7 MeV	15								
89 MeV	4	21							
171 MeV	4	4	4	13					
253 MeV		2	14		2	8			
336 MeV				12	2	12			
418 MeV				6	2	12			
500 MeV				2	2	12	10		
All	23	27	18	33	8	44	10		*163*

Air cooled quadrupoles

- Dimensions, cm: 15 x 15 x 15
- Gradient, T/m: 0.2 < … < 2.6
- number: **26** (for 250 MeV) and **23** (for 500 MeV)

Water cooled quadrupoles

- Dimensions, cm: 15 x 15 x 15
- Gradient, T/m: 2.6 < … < 6.4
- number: **43** (for 250 MeV) and **27** (for 500 MeV)
- if gradient of < 8.2 T/m is ok

➡ number of quads for 500 MeV is ***45***

from CBETA TDR:

Quad-Air 15x15x15	Quad-Water 15x15x15
44	20

PERLE project could use: **26** **20+**

Three Dipole Merger

- Symmetrical Diagnostic Line ➙ know the beam parameters before the 1st acceleration
- Possible to control compaction factor

Fabry Perot (IP1) on the same side as Linac

- Determined by X-ray extraction line
- Spreader is extended to host Fabry Perot (2.4m space available)
- Recombiner is shortened, Arcs are aligned (optimal space occupancy)

Single Turn layout and optics

- Arcs are tuneable (M56 compensation) for all version
- Test the Linac performance at Single Turn ➙ Finalise the geometry
- 67% less magnets needed

Ongoing

- Define the dimensions of Booster Cryo-Module

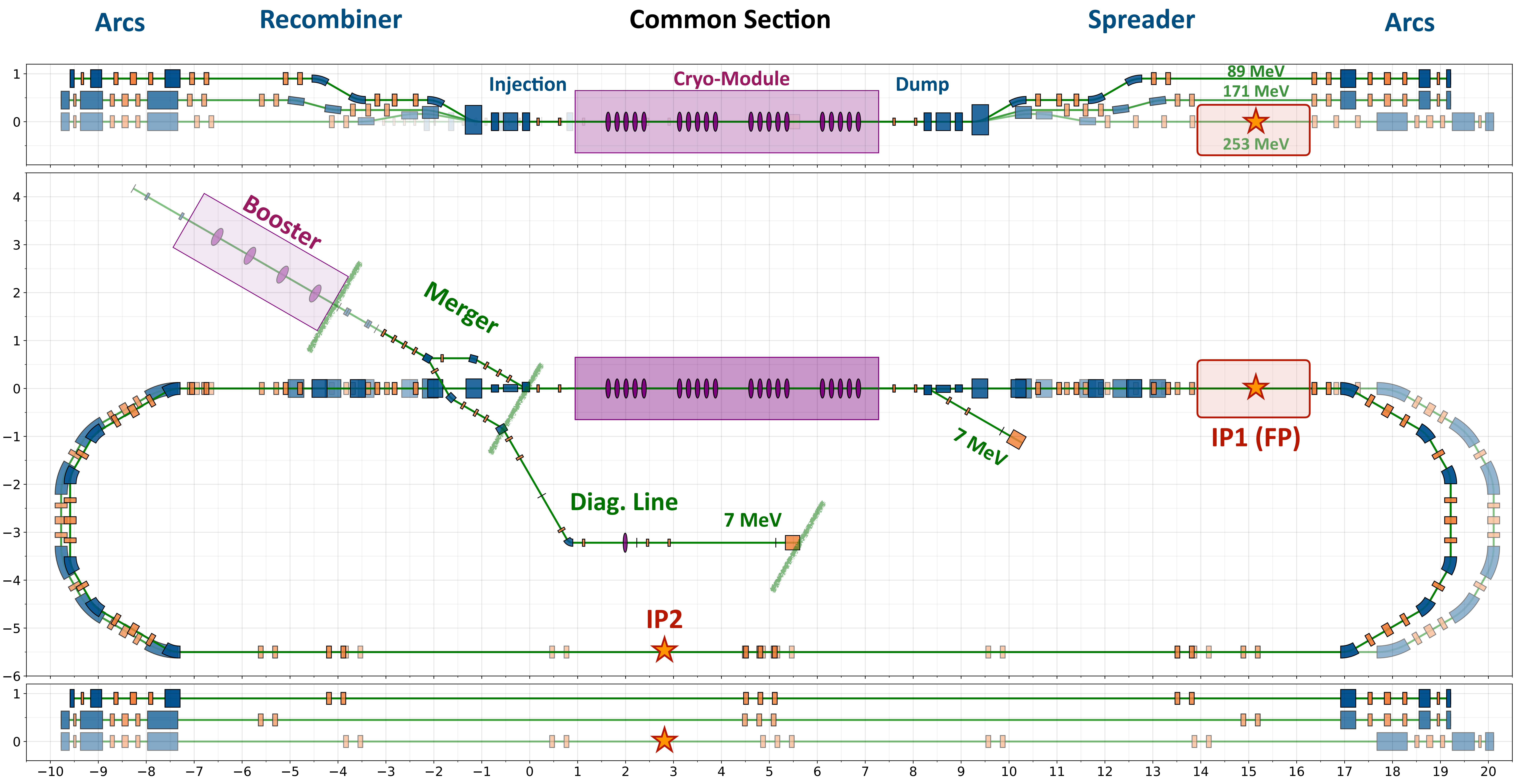
➡ adjust the lattice to fit in the IGLOO building

- Implementation of diagnostics to the lattice

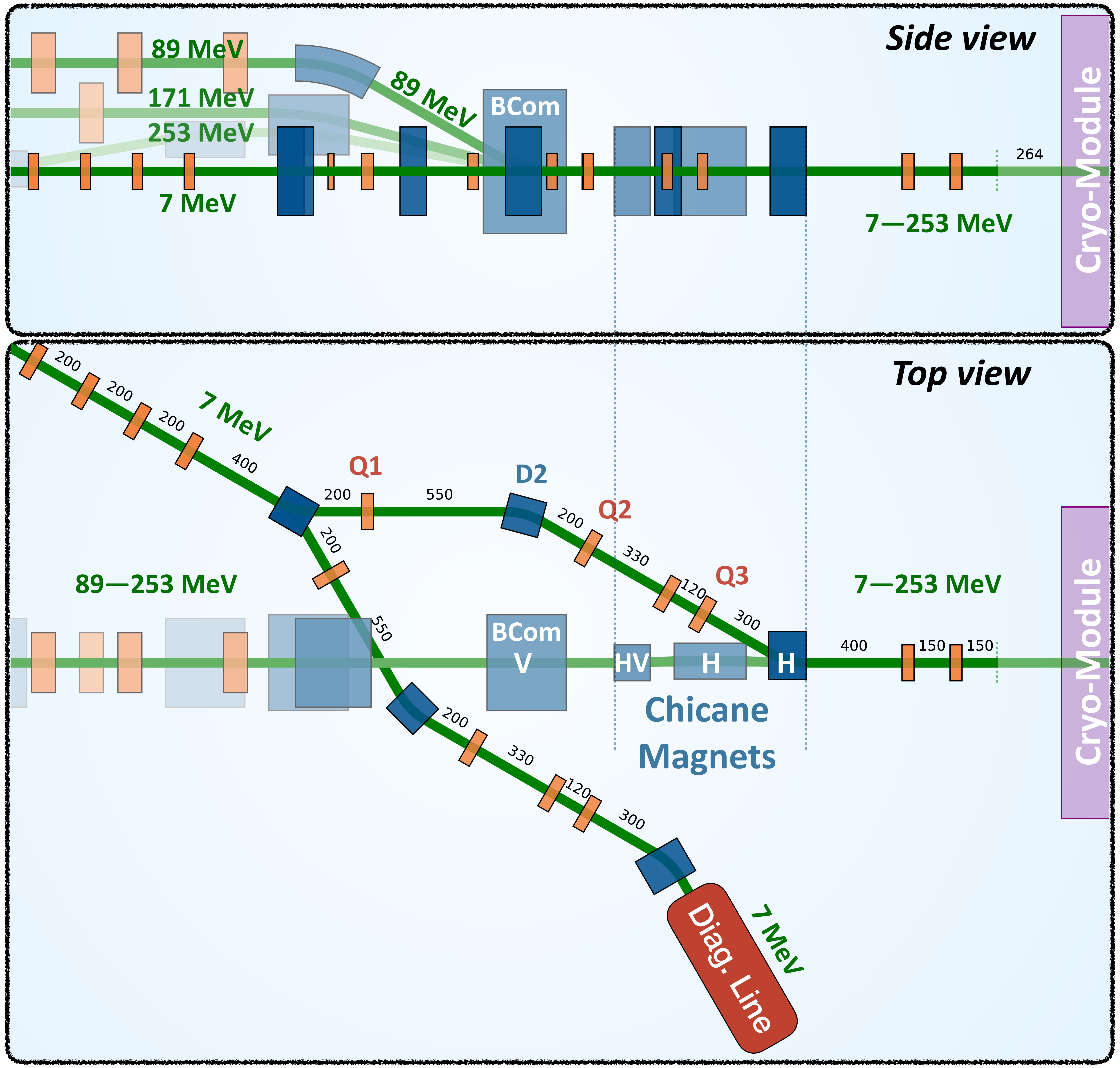
Thank you !

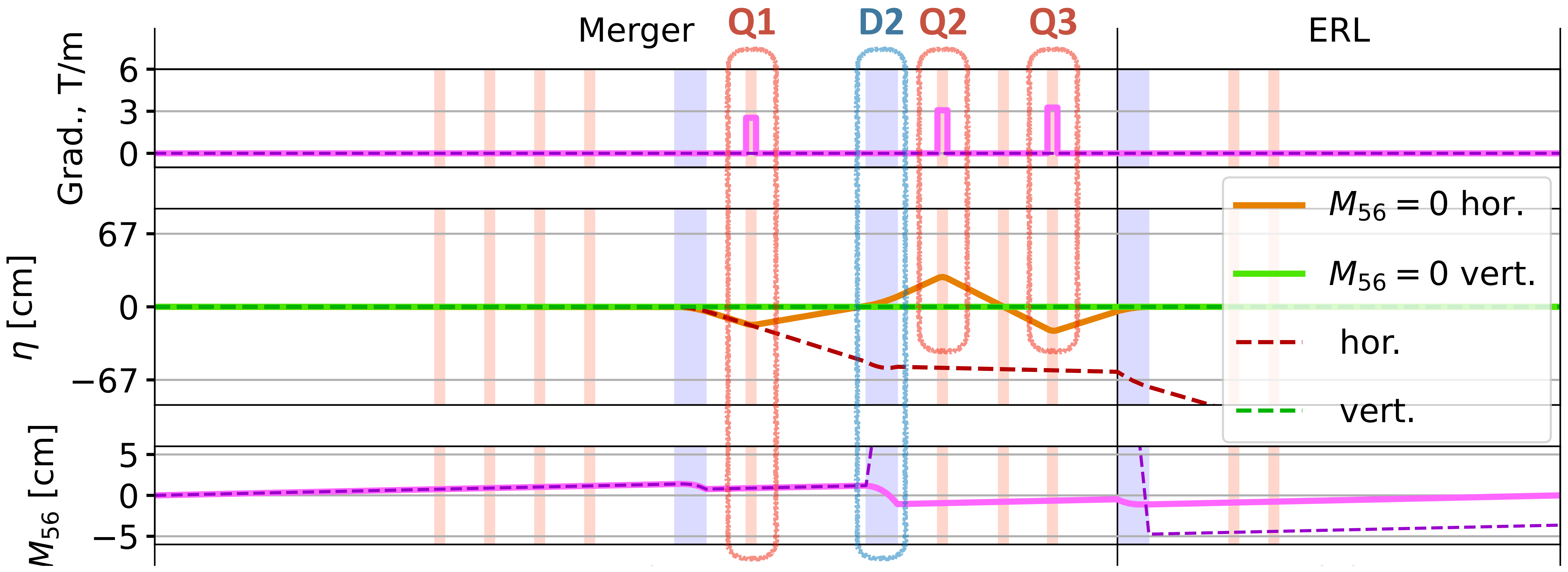
Back Up

PERLE Lattice with symmetrical Diagnostic Line & Fabry Perot (IP1)



Dog-Leg Merger: Tuning M56 & closing dispersion bump

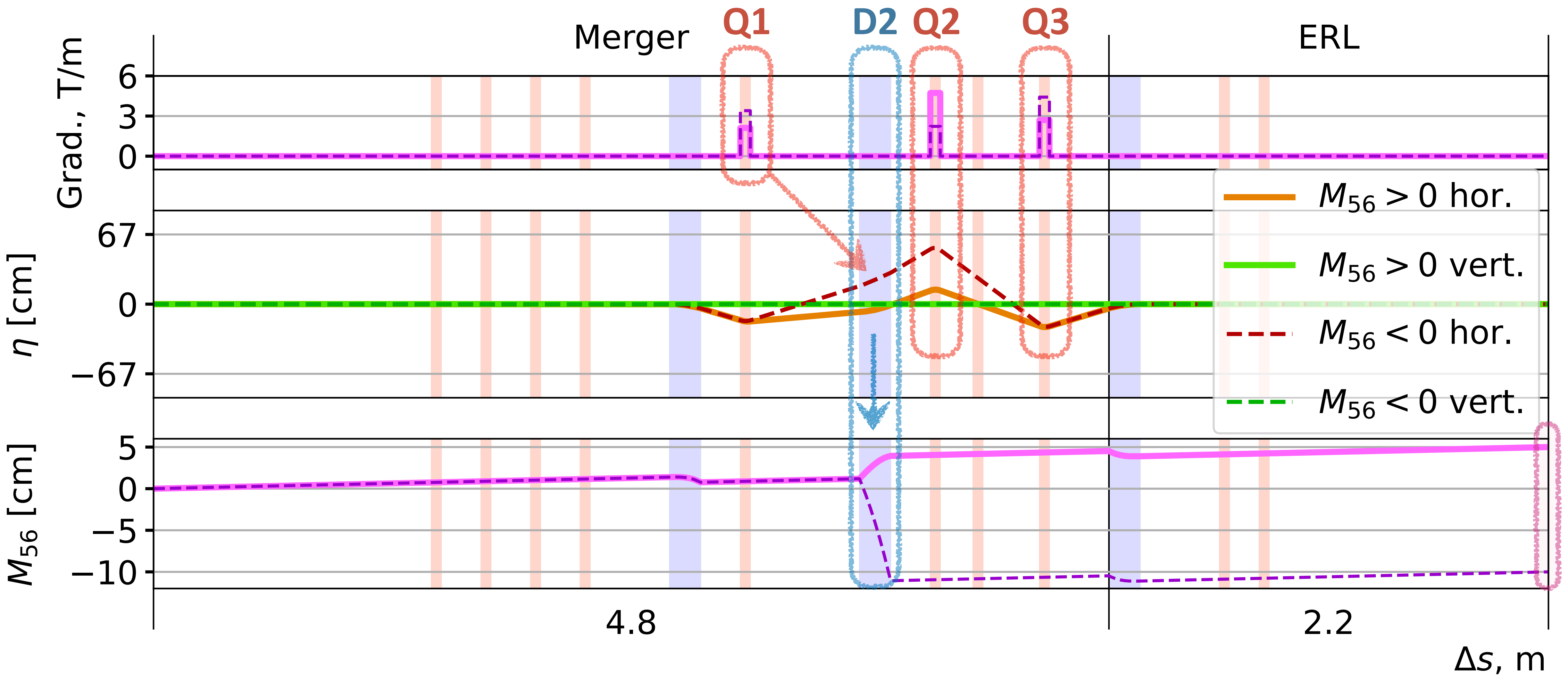




Tuning M56 at Dog-Leg Merger:

Q1 → tune the dispersion at **D2** → control **M56 ∈ [-10, 5] cm**

Q2 & **Q3** → closes the dispersion bump **(dx, dpx = 0)**



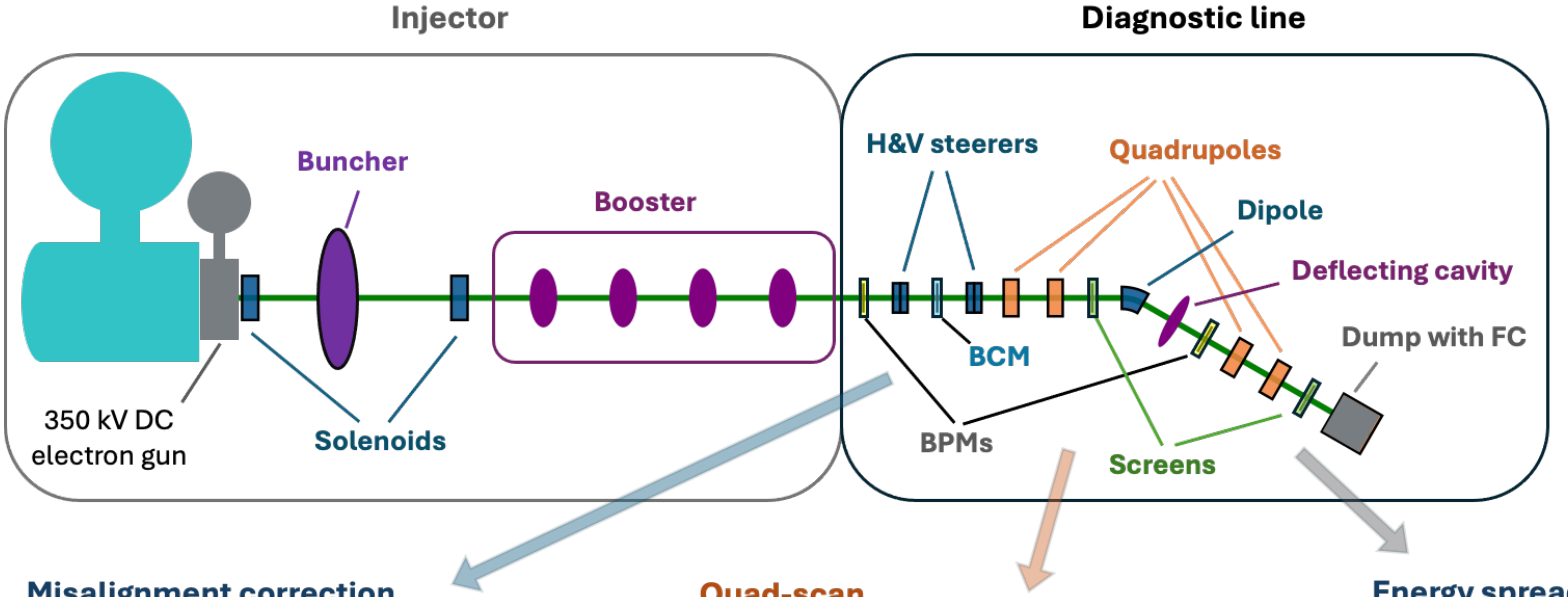
New labelling convention. Table: Section, Subsec. (objective), Name

Section		Subsection			E3	E2	E1	E0
Common	C1	A	Inj. chic.	x, px	bC1A1_#			
					bC1A2_#			
					bC1A3_#			
		B	2q	β	qC1B1_#			
					qC1B2_#			
		C	SRF	ΔE	cC1C1_#			
					cC1C2_#			
					cC1C3_#			
					cC1C4_#			
		D	2q	β	qC1D1_#			
					qC1D2_#			
		E	Dump chic.	x, px	bC1E1_#			
					bC1E2_#			
					bC1E3_#			
Spreader	S1 S2 S3	A	B-Coms	y	bS3A1_#			
					bS3A2_#		bS1A2	
		B	3q	dy		qS2B1	qS1B1	
						qS2B2	qS1B2	
						qS2B3	qS1B3	
		C	2b	y	bS3C1	bS2C1	bS1C1	
					bS3C2	bS2C2	bS1C2	
		D	4q	β	qS3D1	qS2D1	qS1D1	
					qS3D2	qS2D2	qS1D2	
					qS3D3	qS2D3	qS1D3	
					qS3D4	qS2D4	qS1D4	
		E	3q	IP	qS3E1			
					qS3E2			
					qS3E3			

Section		Subsection			E3	E2	E1
Odd Arcs	A1 A3 A5	A	b + 3q	x, dx, β, r56	bA5A1	bA3A1	bA1A1
					qA5A1	qA3A1	qA1A1
					qA5A2	qA3A2	qA1A2
					qA5A3	qA3A3	qA1A3
		B	b + q		bA5B1	bA3B1	bA1B1
					qA5B1	qA3B1	qA1B1
		C	b + 3q		bA5C1	bA3C1	bA1C1
					qA5C1	qA3C1	qA1C1
					qA5C2	qA3C2	qA1C2
					qA5C3	qA3C3	qA1C3
		D	b + q		bA5D1	bA3D1	bA1D1
					qA5D1	qA3D1	qA1D1
		E	b + 3q		bA5E1	bA3E1	bA1E1
					qA5E1	qA3E1	qA1E1
					qA5E2	qA3E2	qA1E2
					qA5E3	qA3E3	qA1E3
		F	b		bA5F1	bA3F1	bA1F1
Lines	L1 L2 L3	A	2q	β			
		B	3q				
		C	2q				
		D	2q	IP			

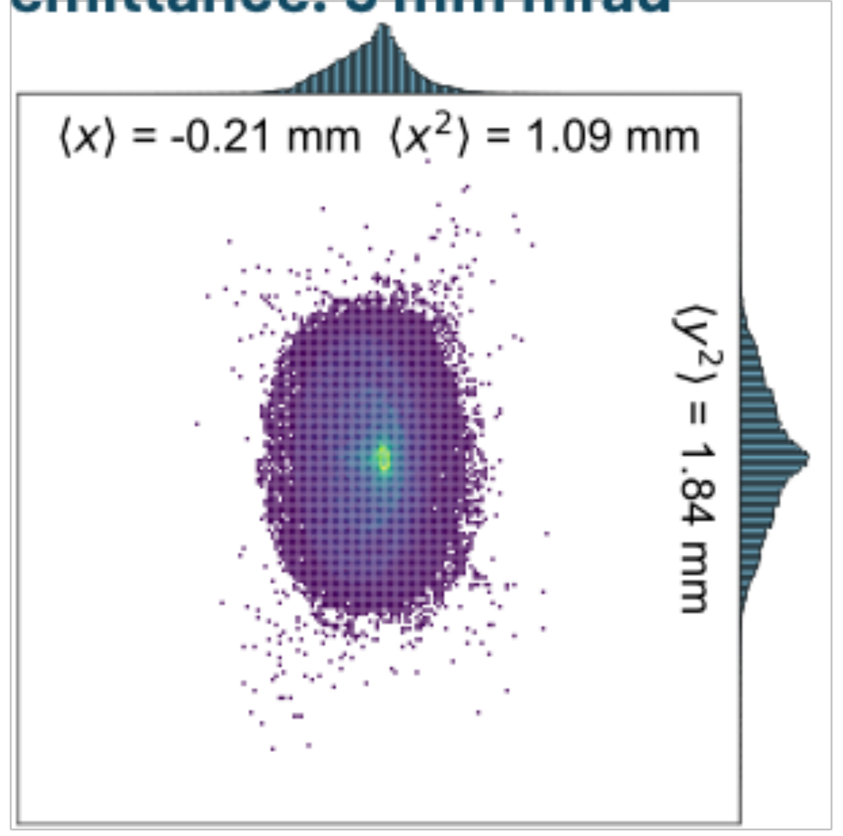
Section		Subsection			E3	E2	E1
Even Arcs	A2 A4 A6	A	b + 3q	x, dx, β, r56	bA6A1	bA4A1	bA2A1
					qA6A1	qA4A1	qA2A1
					qA6A2	qA4A2	qA2A2
					qA6A3	qA4A3	qA2A3
		B	b + q		bA6B1	bA4B1	bA2B1
					qA6B1	qA4B1	qA2B1
		C	b + 3q		bA6C1	bA4C1	bA2C1
					qA6C1	qA4C1	qA2C1
					qA6C2	qA4C2	qA2C2
					qA6C3	qA4C3	qA2C3
		D	b + q		bA6D1	bA4D1	bA2D1
					qA6D1	qA4D1	qA2D1
		E	b + 3q		bA6E1	bA4E1	bA2E1
					qA6E1	qA4E1	qA2E1
					qA6E2	qA4E2	qA2E2
					qA6E3	qA4E3	qA2E3
		F	b		bA6F1	bA4F1	bA2F1
Recombiner	R1 R2 R3	A	4q	β	qR3A1	qR2A1	qR1A1
					qR3A2	qR2A2	qR1A2
					qR3A3	qR2A3	qR1A3
					qR3A4	qR2A4	qR1A4
		B	2b	y	bR3B1	bR2B1	bR1B1
					bR3B2	bR2B2	bR1B2
		C	3q	dy		qR2C1	qR1C1
						qR2C2	qR1C2
						qR2C3	qR1C3
		D	B-Coms	y	bR3D1_#		bR1D1
					bR3D2_#		

Diagnostic Line after the booster



Beam parameters

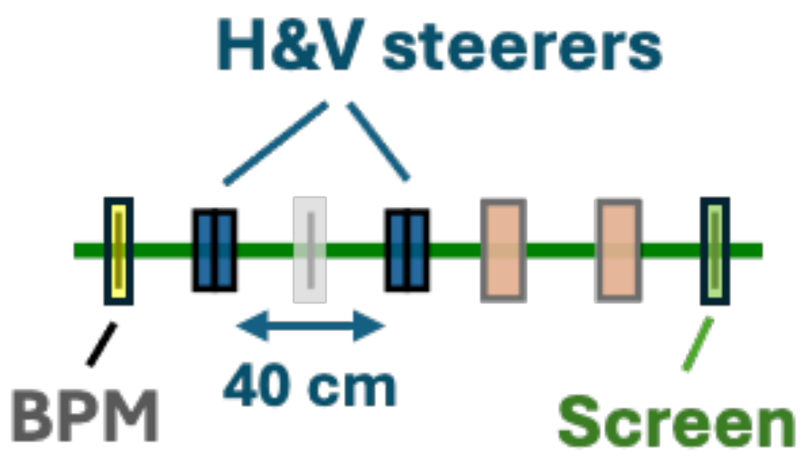
7 MeV electrons
up to 500 pC, 3mm bunches
emittance: 5 mm mrad



Misalignment correction

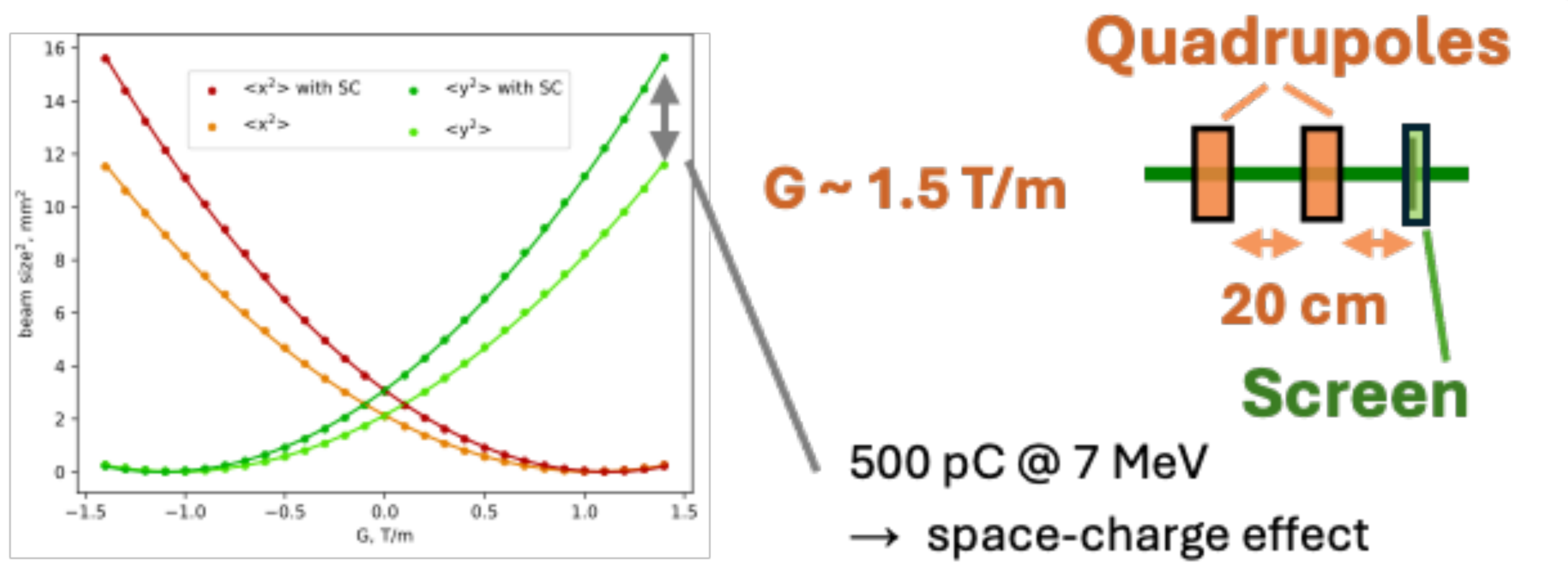
2 combined H&V steerers

placed after the Booster
drift between: 40 cm
magnetic length: 5 cm
deflection angle: 10 mrad

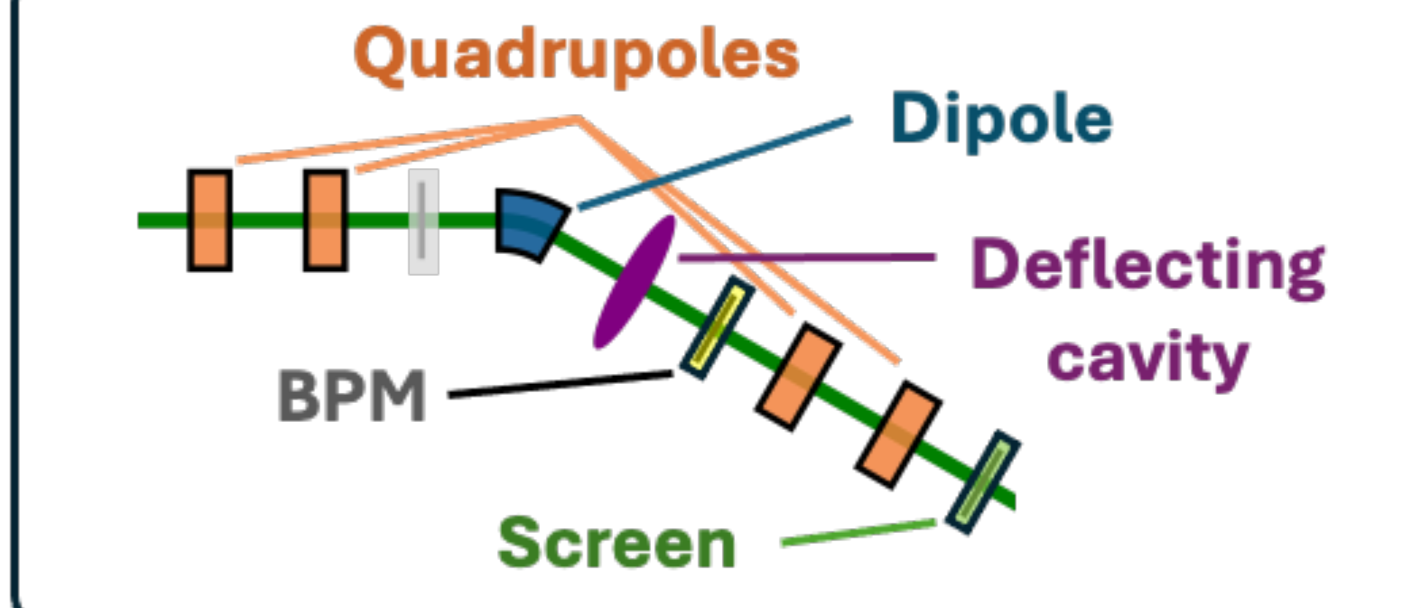


magnetic field: 5 mT → 4 mm correction in both planes

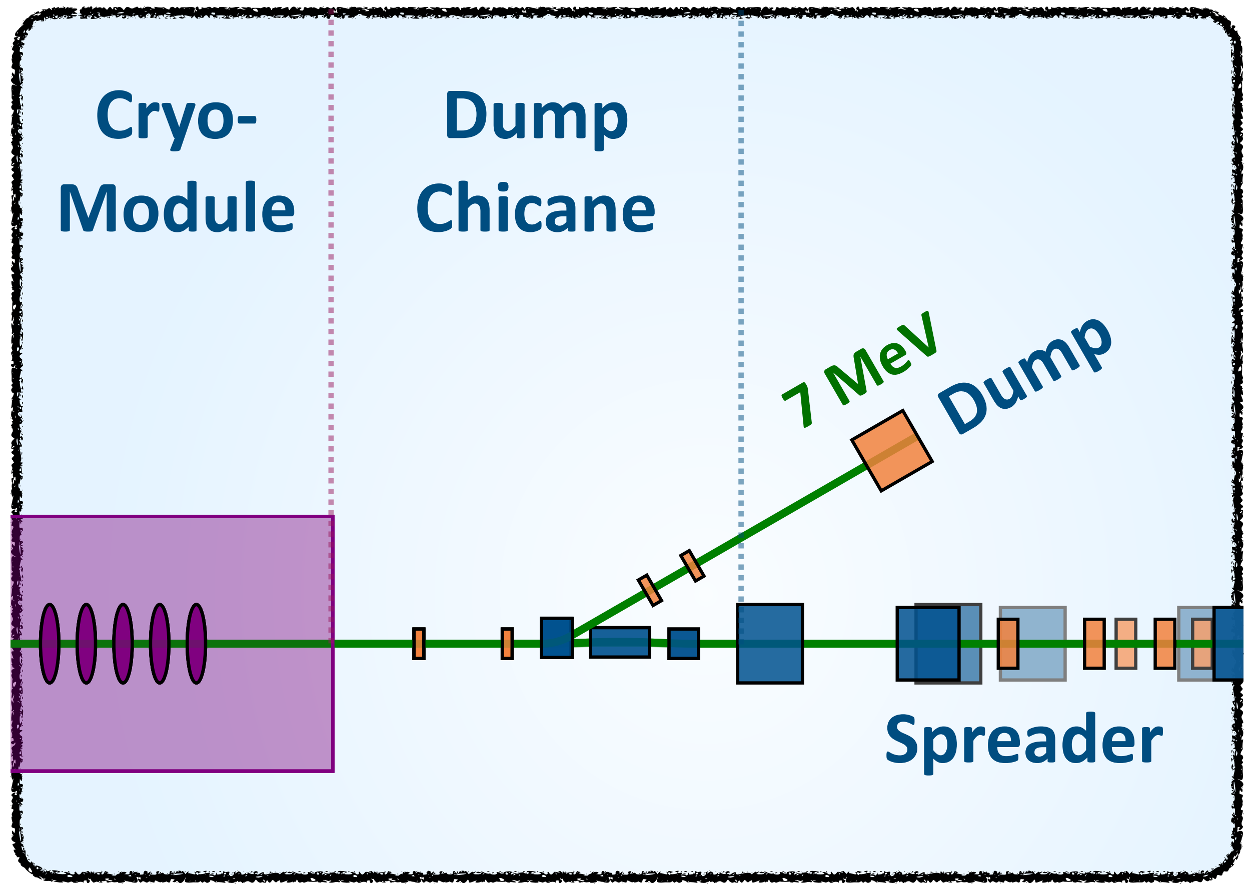
Quad-scan



Energy spread & longitudinal size

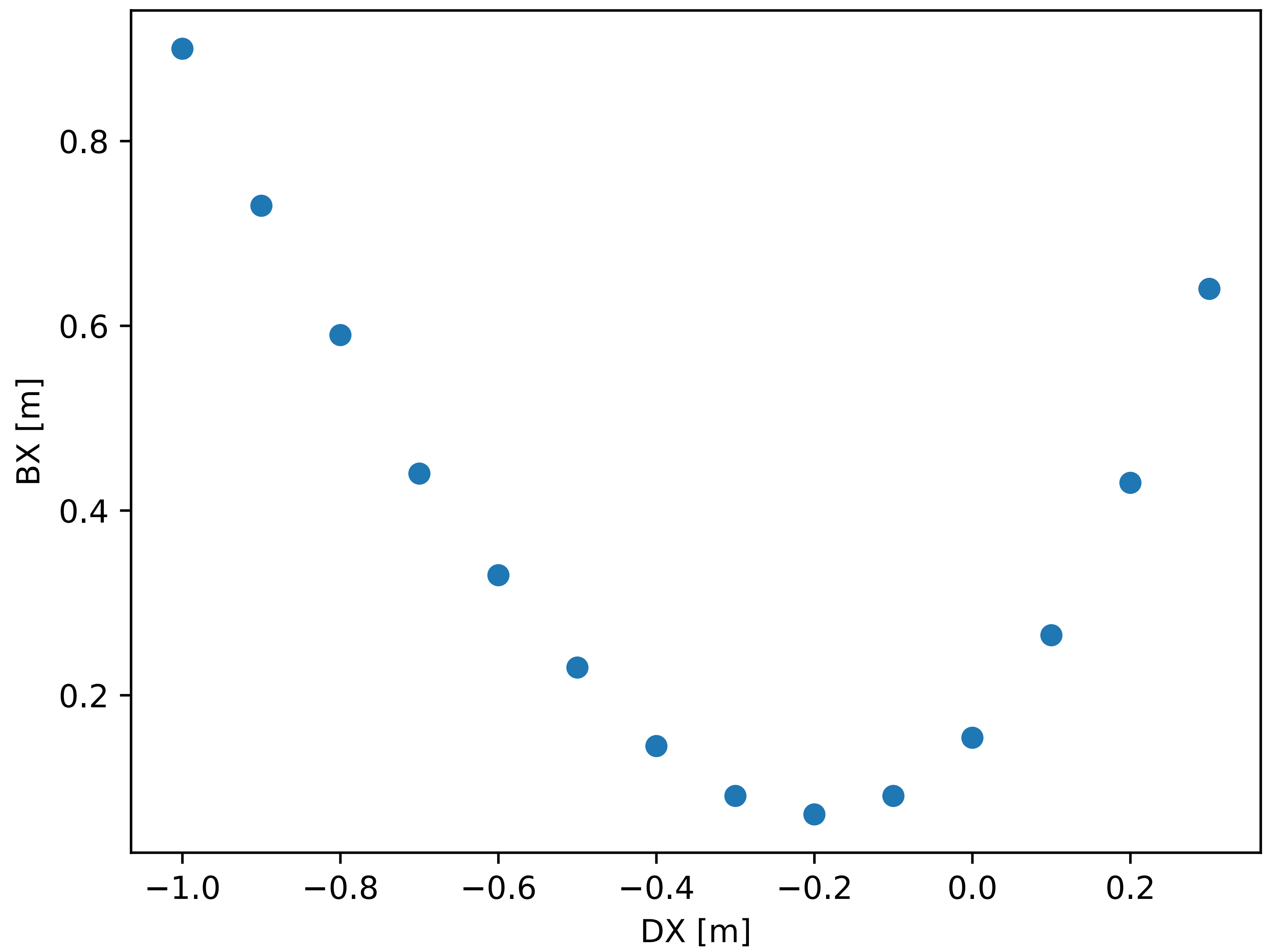


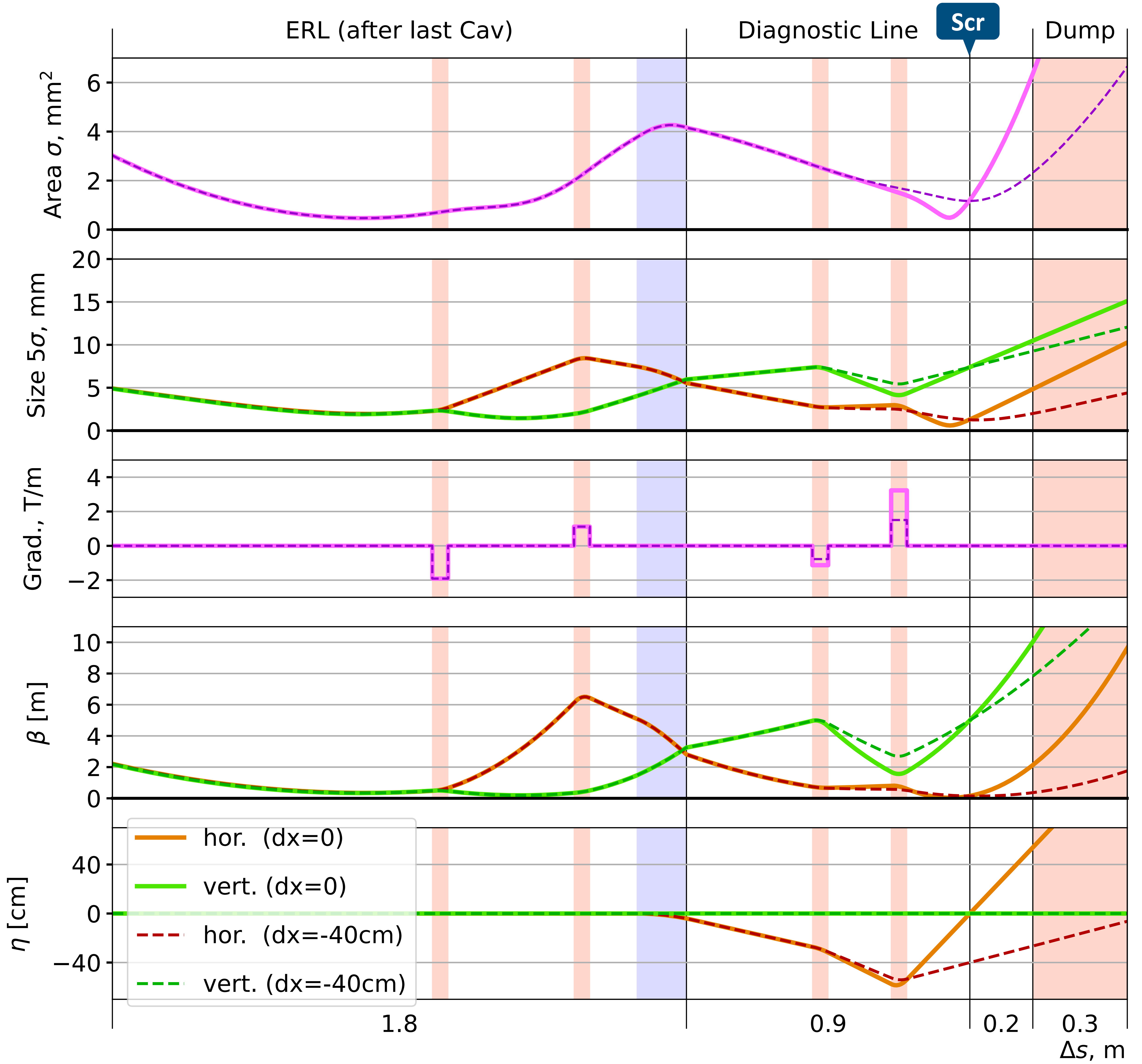
Diagnostic Line at the Dump.   Using chicane as Spectrometer



- quad-scan with quad-doublets after the chicane → measure transverse emittance and energy spread
- space charge (7 MeV)
- work in progress

Beta vs Dispersion (horizontal plane)





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