Alternating Phase Focusing Beam Dynamics for Drift Tube Linacs

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REQUIREMENTS FOR FAIR, THE "SHE"-PROGRAM, AND MATERIAL SCIENCE AT GSI

Facility for Antiproton and Ion Research (FAIR) requirements:

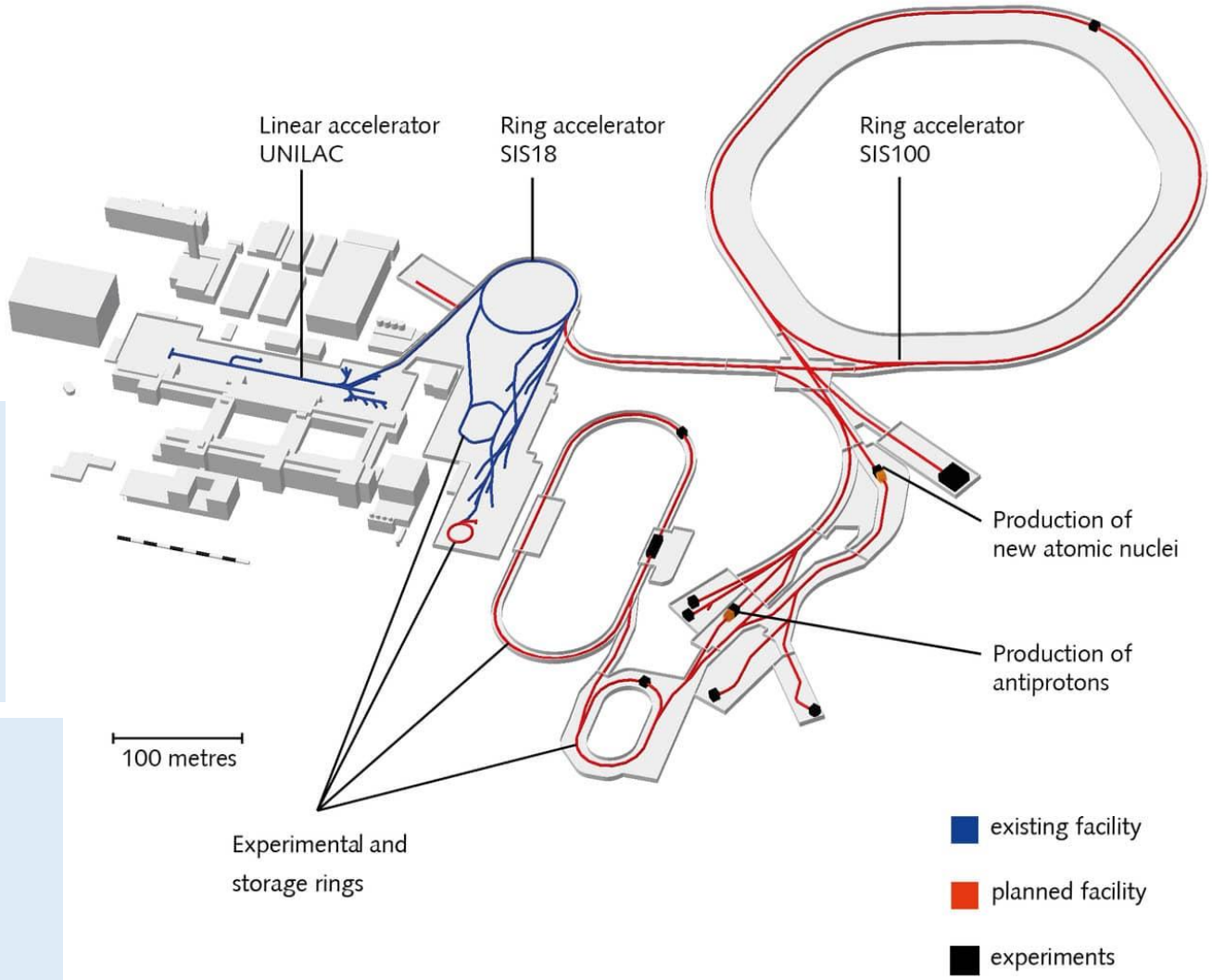
- High beam currents
- Low repetition rate (max. 3 Hz)
- Low duty factor

Super Heavy Element (SHE) requirements:

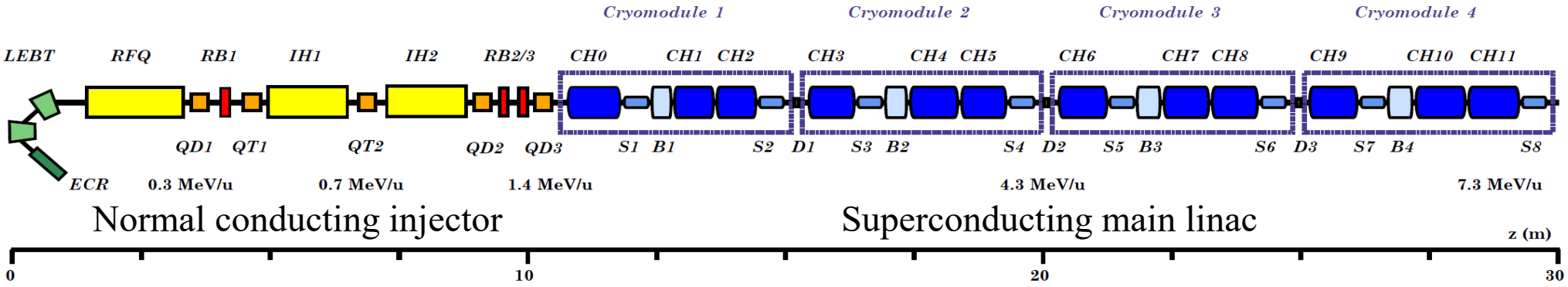
- Relatively low beam currents
- High repetition rate (50 Hz)
- High duty factor (100 %, pulse length up to 20 ms)

Material Science at GSI requirements

- Heavy ions (m > 200)
- Beam energy (up to 10 MeV/u)
- Smoothly variable beam energy (1.5 – 10 MeV/u)



A NEW ACCELERATOR FOR SHE RESEARCH



A new dedicated CW capable accelerator is under construction:

HElmholtz LInear Accelerator

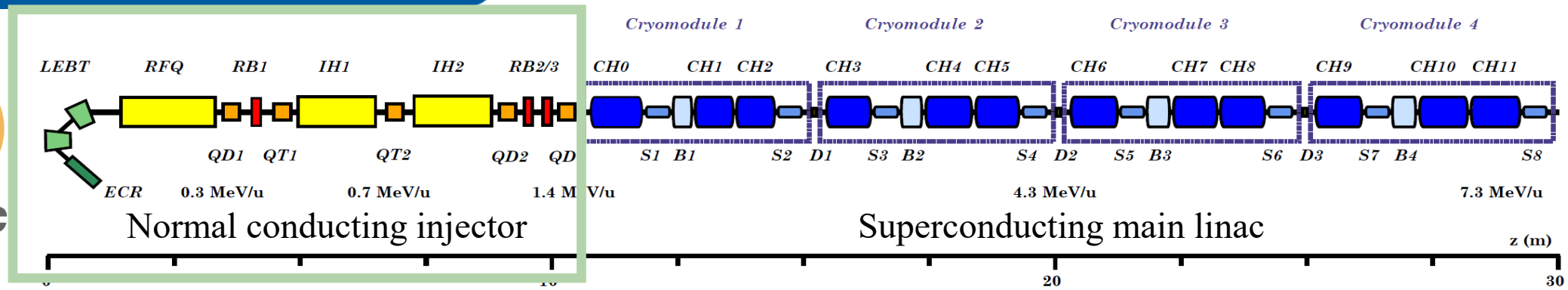
HELIAC
GSI DARMSTADT

Common project of HIM and GSI

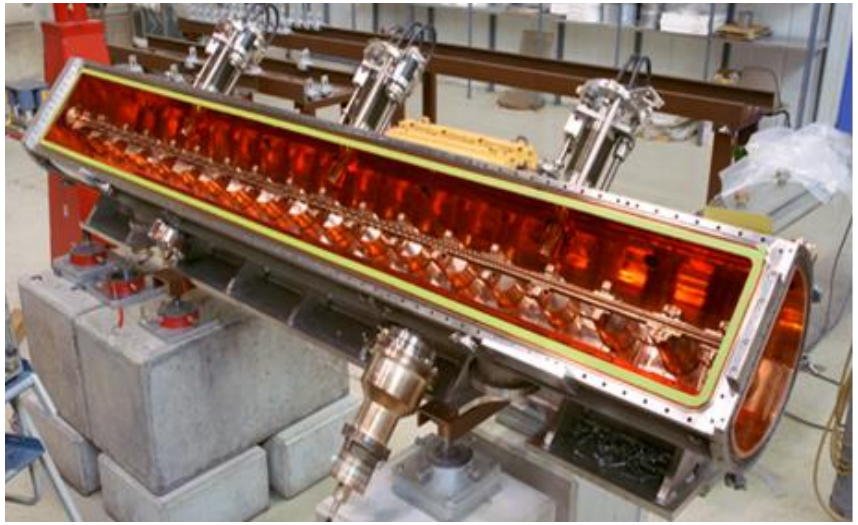
under key support of IAP

	Design Value
Mass-to-charge ratio	≤6
Frequency	108.408 (216.816) MHz
Injection energy	1.4 MeV/u
Output energy	3.5–7.3 MeV/u
Output energy spread	±3 keV/u
Max beam current	≤1 mA
Operation mode	continuous wave (CW)

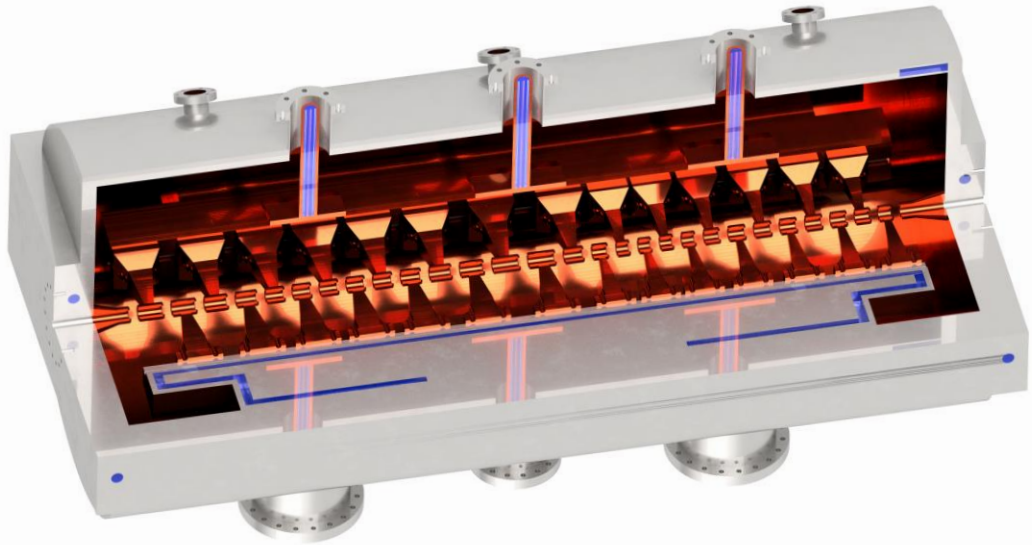
HELMHOLTZ LINEAR ACCELERATOR (HELIAC)



Radio Frequency Quadrupole

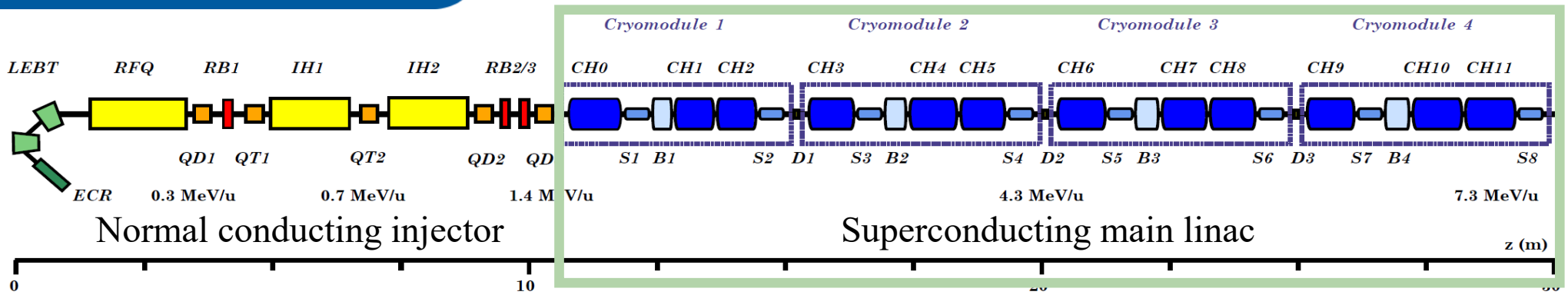


Normal Conducting APF Injector Cavity

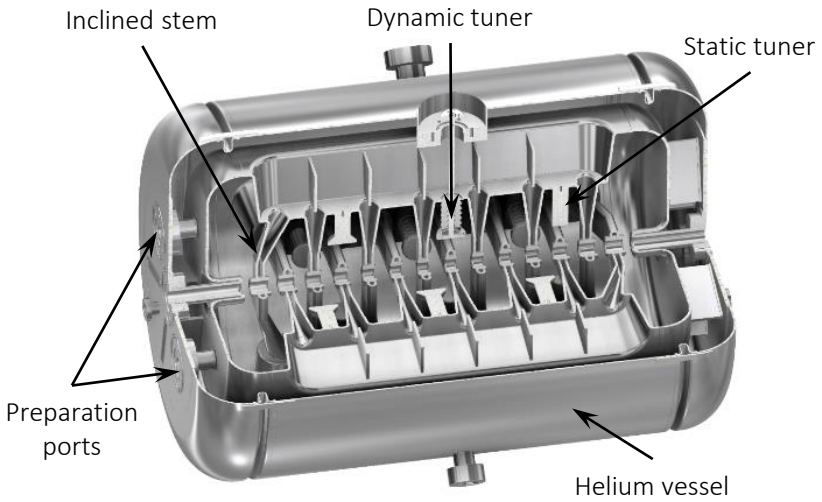


HELMHOLTZ LINEAR ACCELERATOR (HELIAC)

HELIAC
GSI DARMSTADT



Cavity CH0



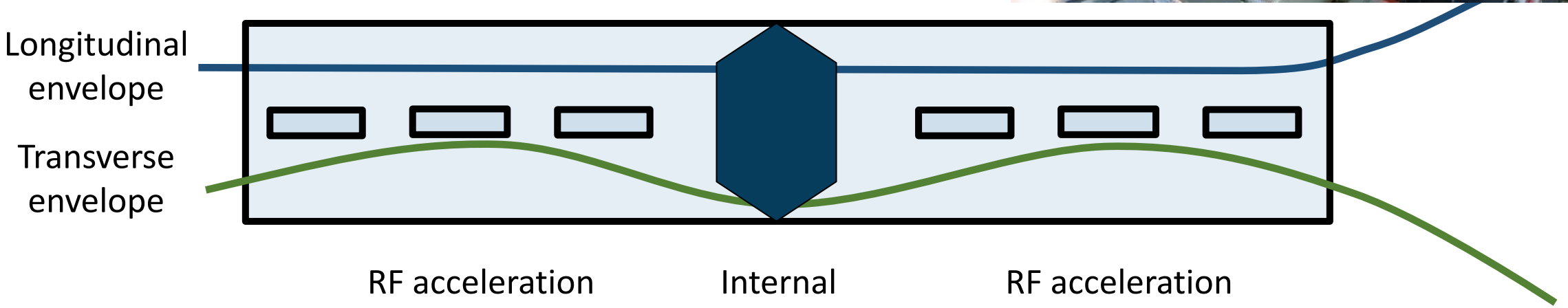
Cold string assembly Cryomodule 1

THEORY OF ALTERNATING PHASE FOCUSING

DRIFT TUBE LINAC CONCEPTS

Conventional* Heavy Ion Drift Tube Linac (DTL)

- Costly internal lenses of conventional DTLs

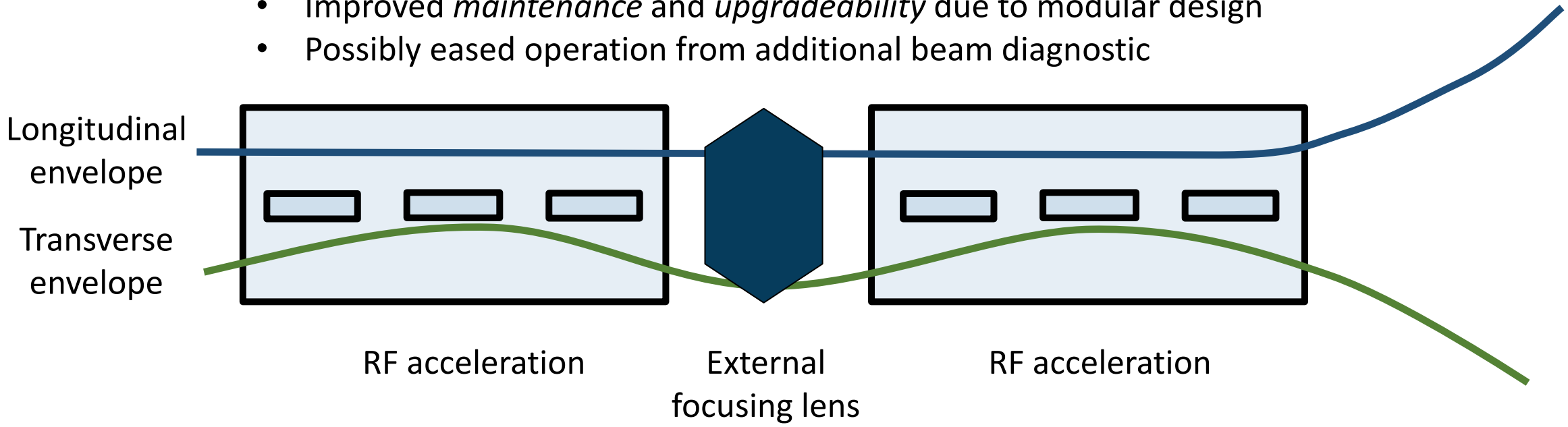


* -30° sync phase

DRIFT TUBE LINAC CONCEPTS

Short Cavities with external lenses

- Improved *maintenance* and *upgradeability* due to modular design
- Possibly eased operation from additional beam diagnostic

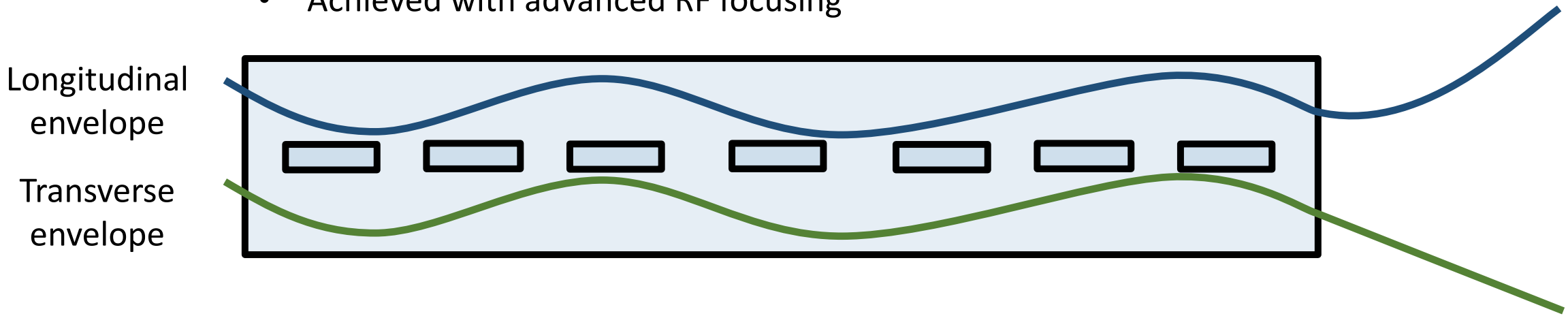


DRIFT TUBE LINAC CONCEPTS

Alternating Phase Focusing Cavity

(J. H. Adlam, 1953; M. Good, 1953, Y. Fainberg 1957)

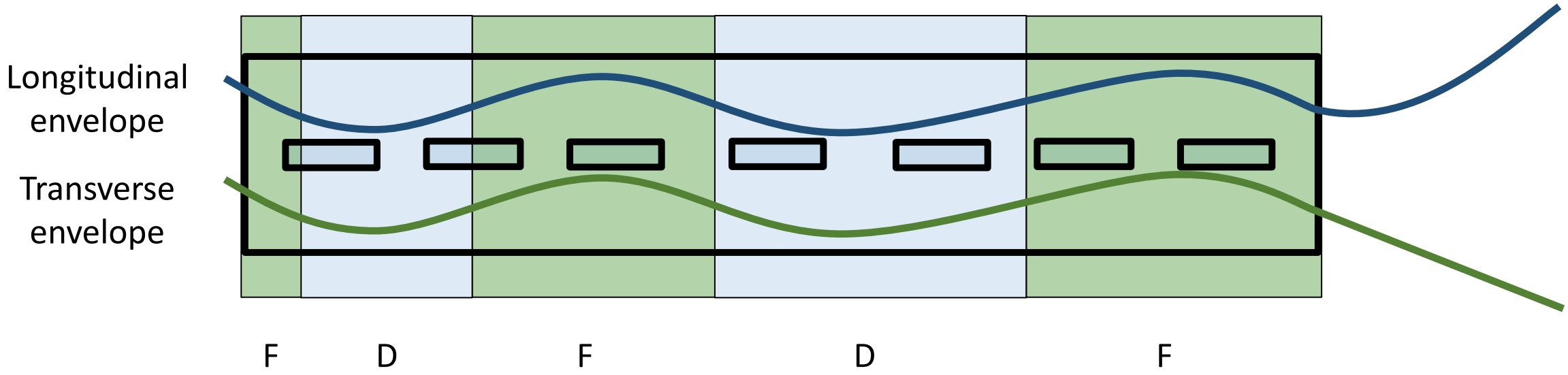
- ..Or even one RF cavity without additional focusing
- Achieved with advanced RF focusing



ALTERNATING PHASE FOCUSING

Alternating Phase Focusing Cavity

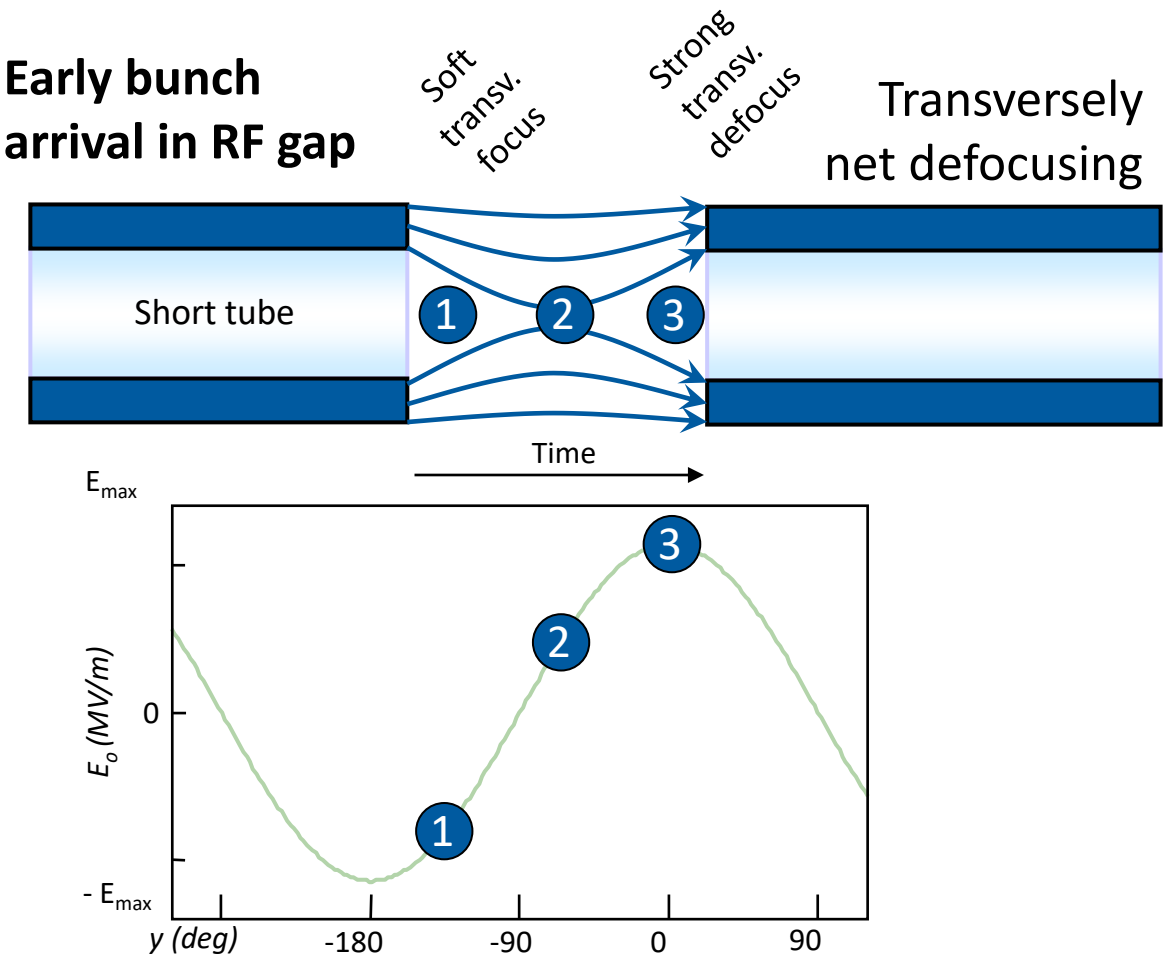
- Alternating focusing (F) and defocusing (D)
- Special timing of the bunch with respect to RF phase necessary



F: Focusing
D: Defocusing

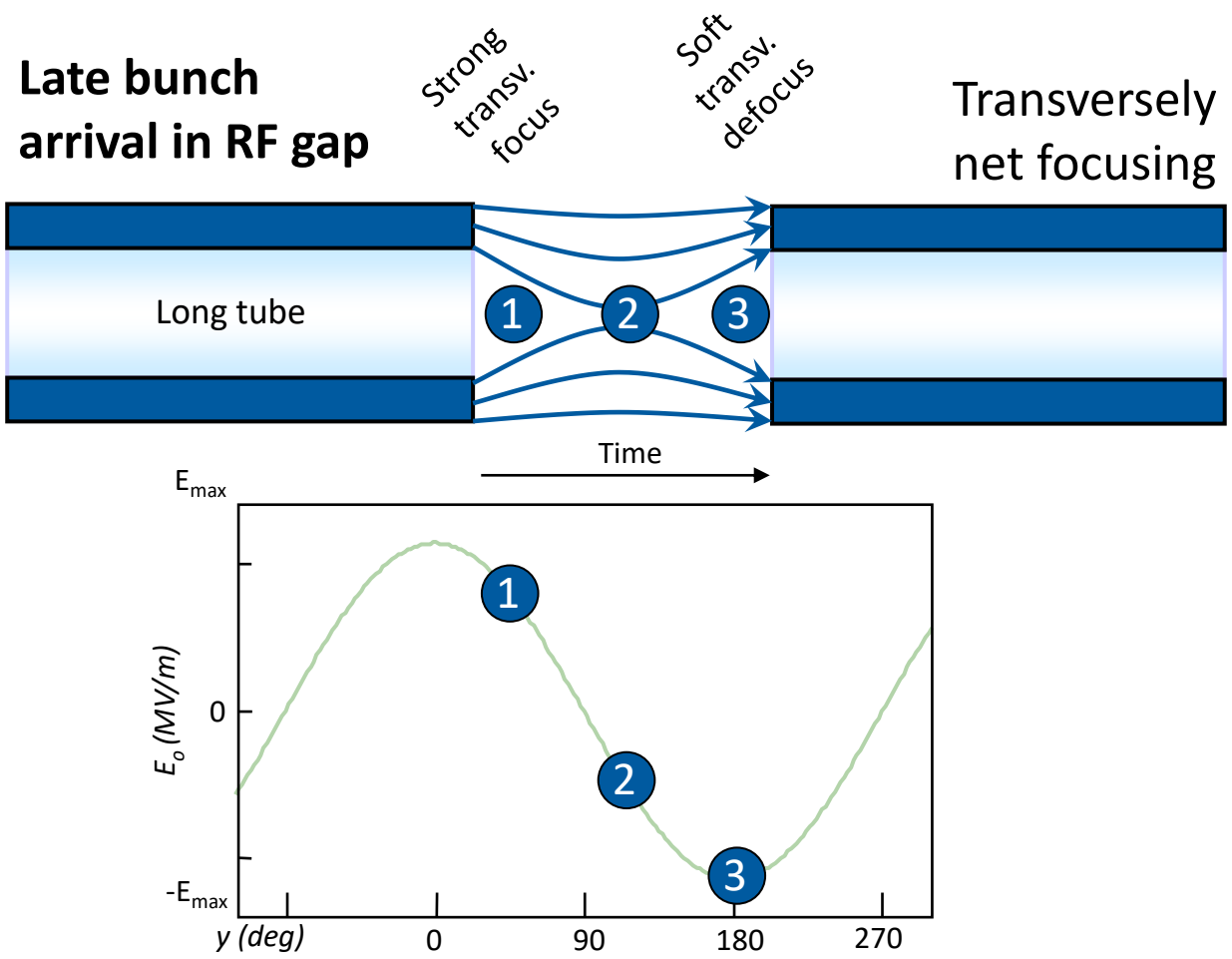
ALTERNATING PHASE FOCUSING

Early bunch arrival in RF gap



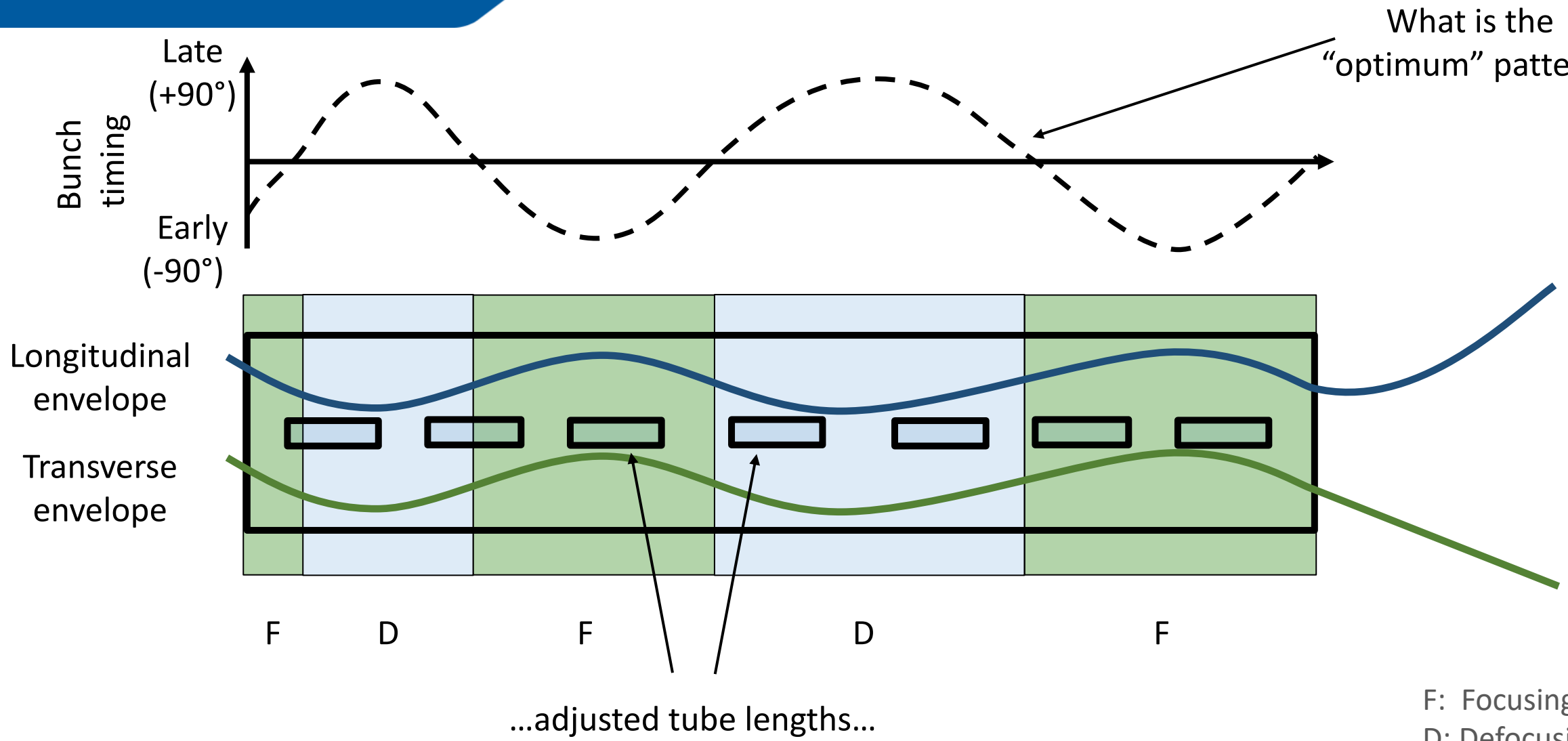
Longitudinal net focusing

Late bunch arrival in RF gap



Longitudinal net defocusing

ALTERNATING PHASE FOCUSING



F: Focusing
D: Defocusing

ALTERNATING PHASE FOCUSING

PROS

- Embedded transverse focusing
  - Highly reduced number of control parameter (retaining tank phase & voltage)
- No additional lenses necessary
- Reduced construction and operation costs (U. Ratzinger, 1999)
- Applicable for superconducting (SC) accelerators
  - Absence of internal focusing lenses required due to SC breakdown limits
- Applicable to other resonance accelerator systems, e.g., dielectric laser acceleration (U. Niedermayer, 2018)

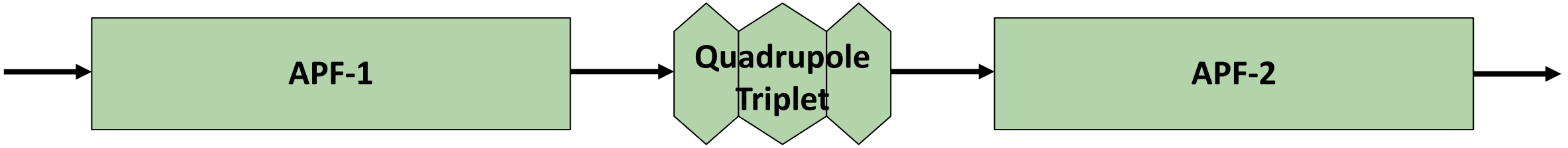
CONS

- High demand for expertise
- Modern beam dynamics solver is mandatory
- Increased R&D efforts
  - No consensus on optimum design
- Tight tolerance specifications (V. Kapin, 2004)
- Low experience in operating such linacs beyond HIMAC for medical treatment (Y. Iwata, 2006)

A NEW APF DTL FOR THE HELIAC INJECTOR LINAC

Advanced APF DTL design

as dedicated heavy ion injector linac



➔ from RFQ

to SC-HELIAC ➔

Hybrid approach incorporating APF focusing has been designed (S. Lauber, 2022)

- Two energy-efficient Interdigital H-Mode (IH) cavities
- For increased adaptability when operation with different ions (*A/Q* 1 to 6)
- Additional quadrupole triplet is installed

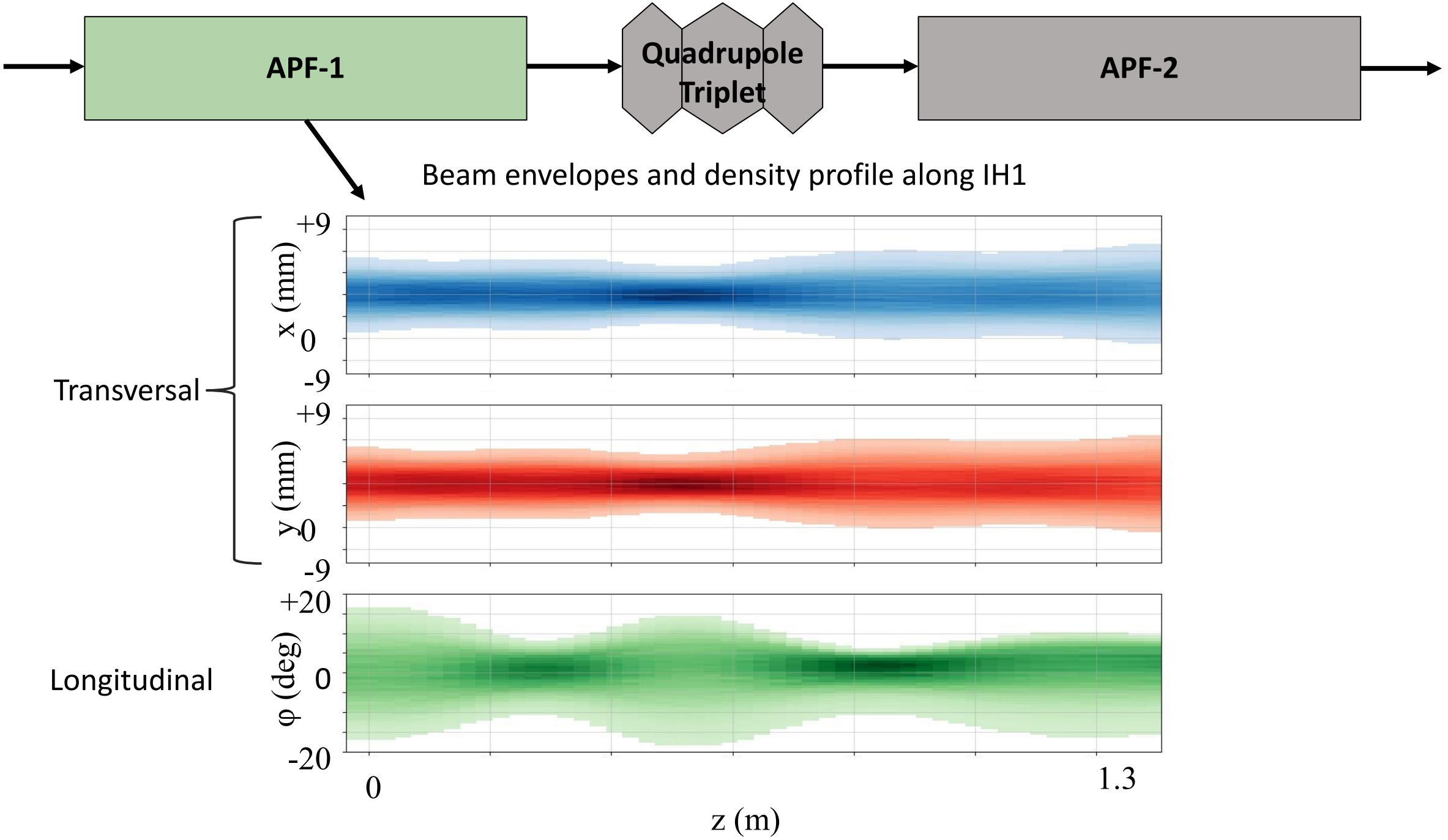
This solution with longer tanks is not available from conventional* beam dynamics

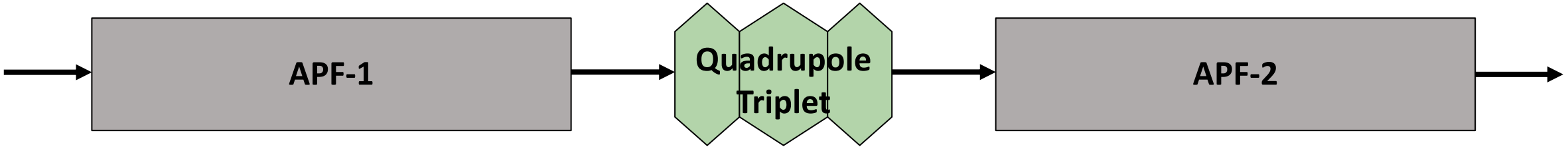
- Transverse RF defocusing demands more (quadruple) lenses

Design with two separate cavities offers:

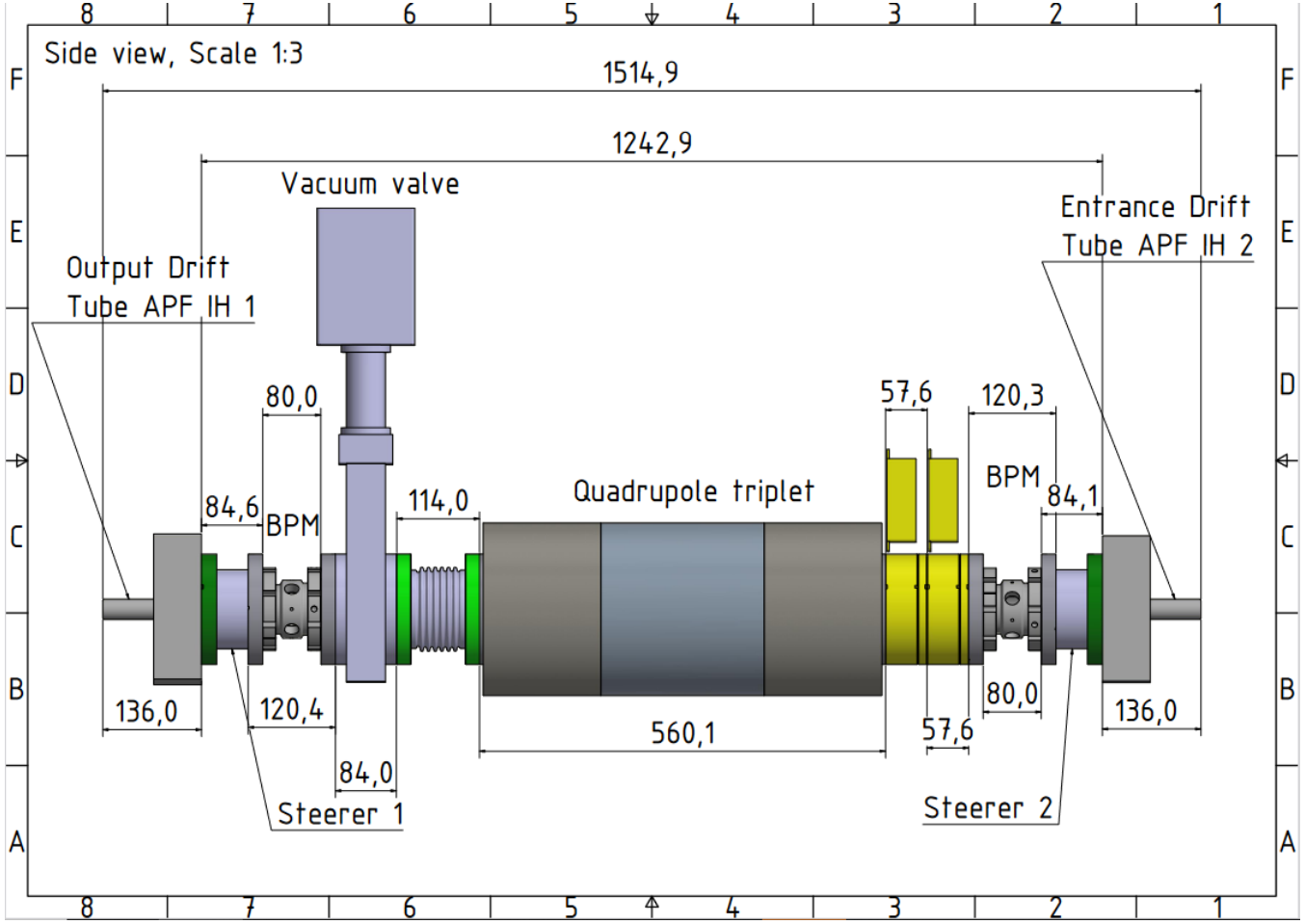
- Low emittance growth
- Reduced number of control parameters, yet flexible operation
- Cooling concept for continuous wave operation
- Additional beam diagnostics installed to the intertank

* -30° sync phase

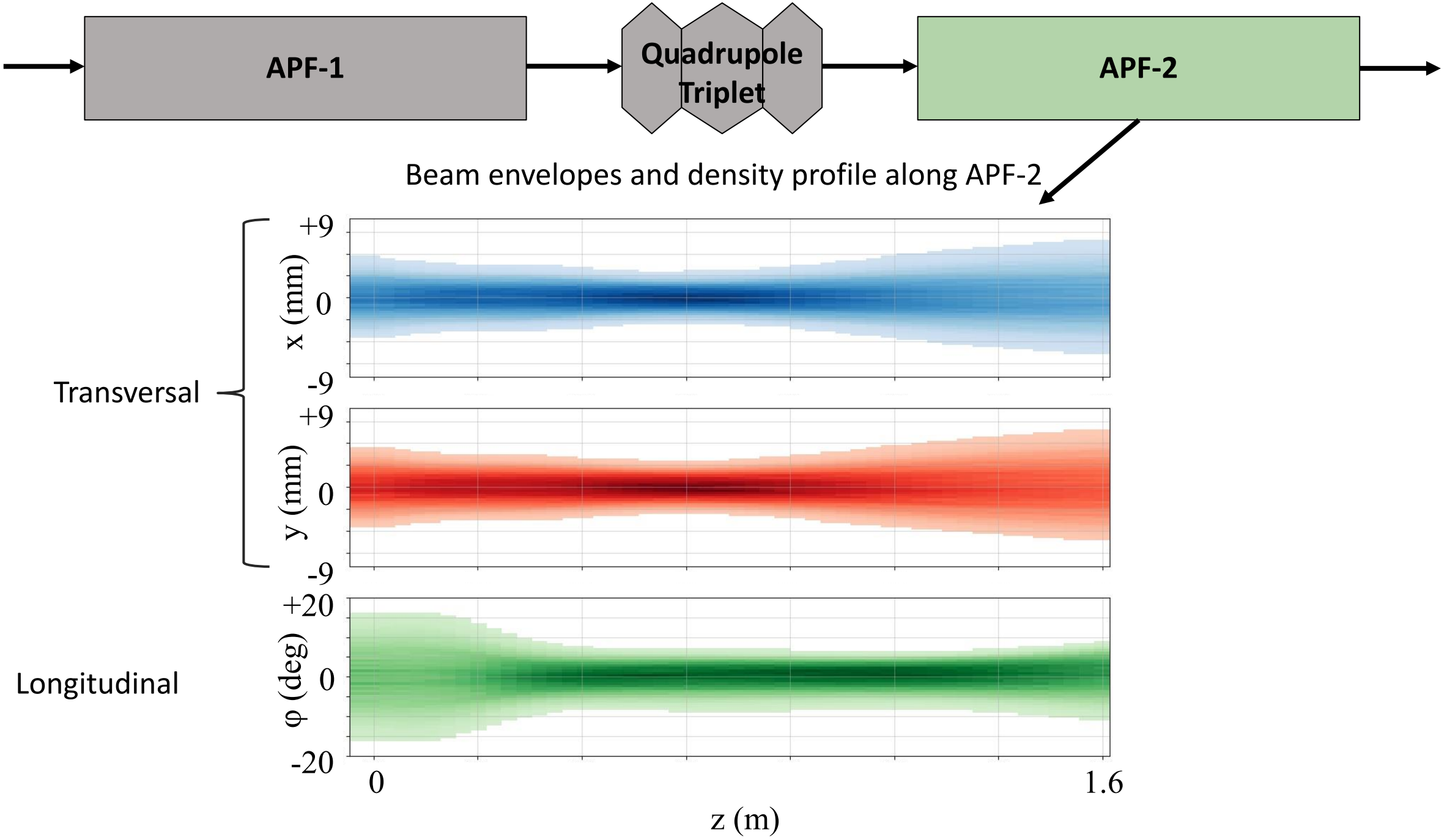

APF-1
Quadrupole Triplet
APF-2
Beam envelopes and density profile along IH1
Transversal
Longitudinal
x (mm)
y (mm)
φ (deg)
+9
0
-9
+20
0
-20
0
1.3
z (m)



Fully equipped intertank



(units in mm)

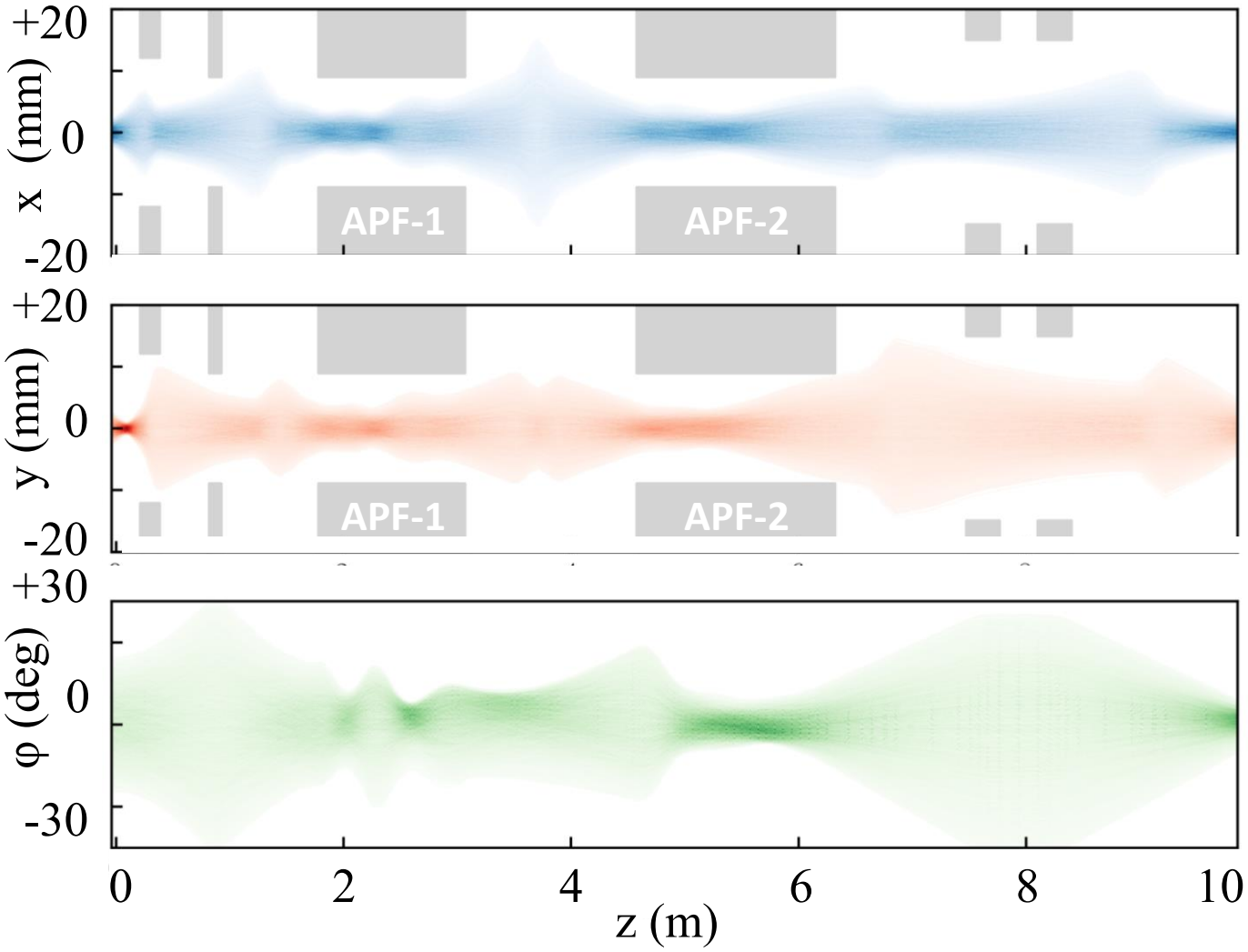

APF-1
Quadrupole Triplet
APF-2
Beam envelopes and density profile along APF-2
Transversal
Longitudinal
+9
x (mm)
0
-9
+9
y (mm)
0
-9
+20
φ (deg)
0
-20
0
1.6
z (m)

BEAM DYNAMICS DESIGN OF THE ENTIRE DTL SECTION

Transversal

Longitudinal

Beam envelopes and density profile along whole channel



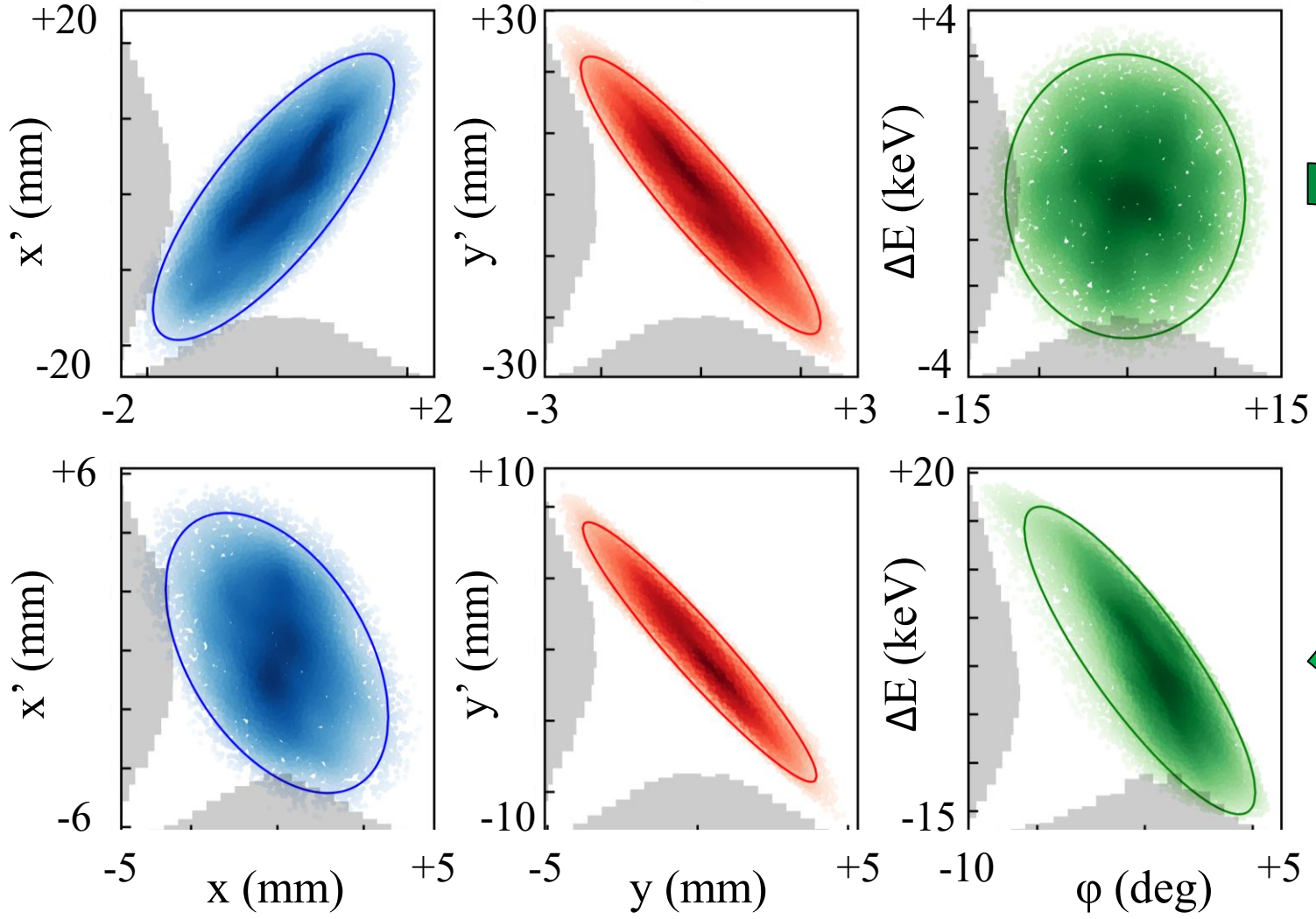
BEAM DYNAMICS DESIGN OF THE ENTIRE DTL SECTION

Beam input and output in three main phase planes

RFQ Output

~8% emittance growth without halo

IH2 Output



3% emittance growth without halo

CONCLUSION 1/2

APF DTLs are an attractive approach to deliver high beam quality

- Effective acceleration → compact
- Low number of control parameters
- Time-efficient commissioning
- Reliable operation
- Reduced construction costs

CONCLUSION 2/2

- Reliable operation at the medical accelerator HIMAC
- Continuous wave operation with various ion species at HELIAC
  - An IH Cavity with embedded APF beam dynamics designed
  - High beam quality
  - Full transmission

- Discovery of new superheavy elements with assistance of this new linac HELIAC
  - Fundamental physis research
  - Improving quantum-chemical model of atoms
  - Promoting for advanced chemical applications and material research

Thank you
for your attention!

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