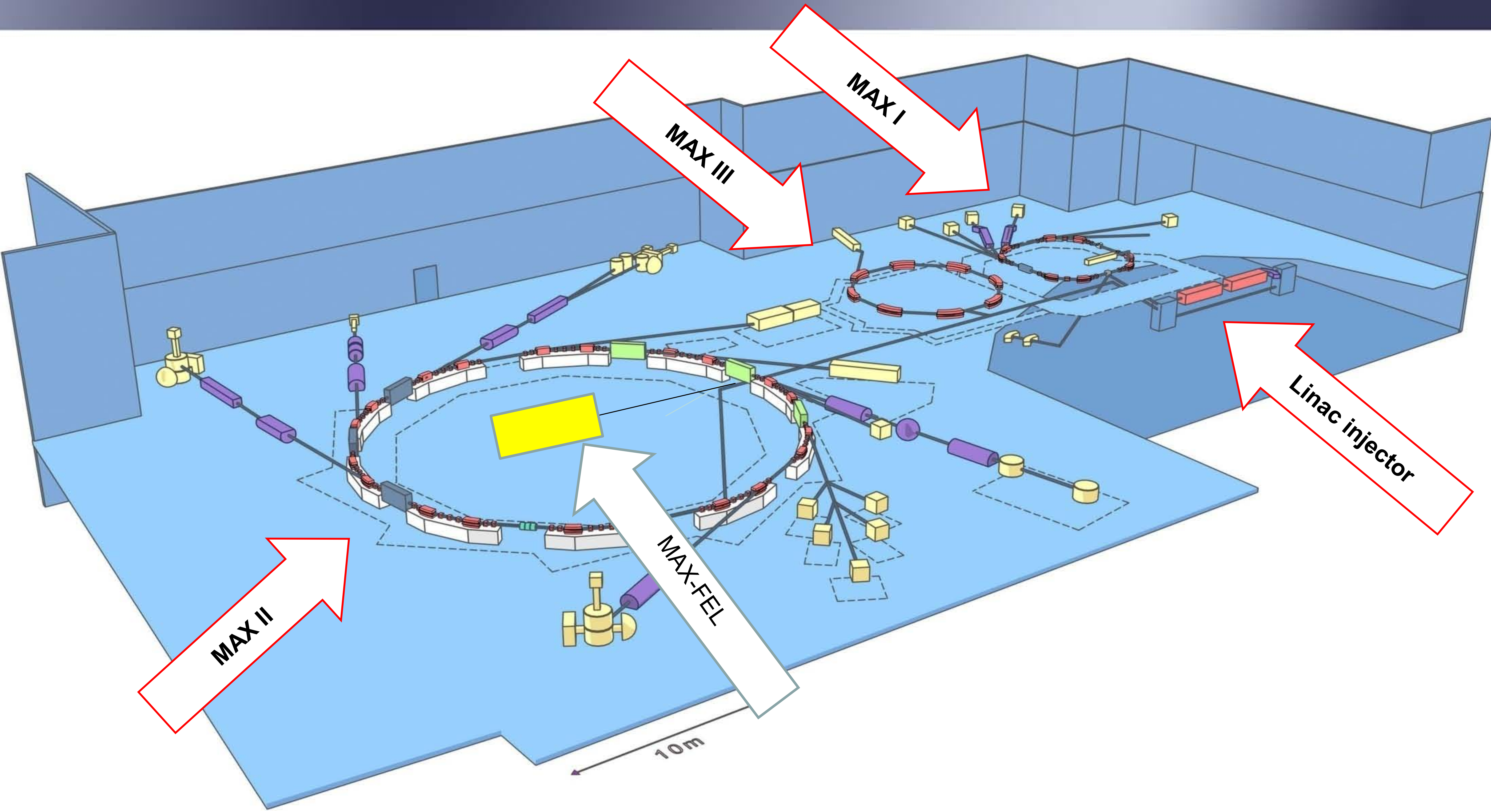
MAX IV, The World's Brightest Synchrotron Radiation Source
or
The design of Small Emittance Lattices

- Mikael Eriksson, MAX-lab

- Acknoledgement: MAX-lab staff
- +Bengt Anderberg (AMACC), Johan Bengtsson (NSLS II), Andeas Streun (PSI), Hamed Tarawne (SESAME) +….

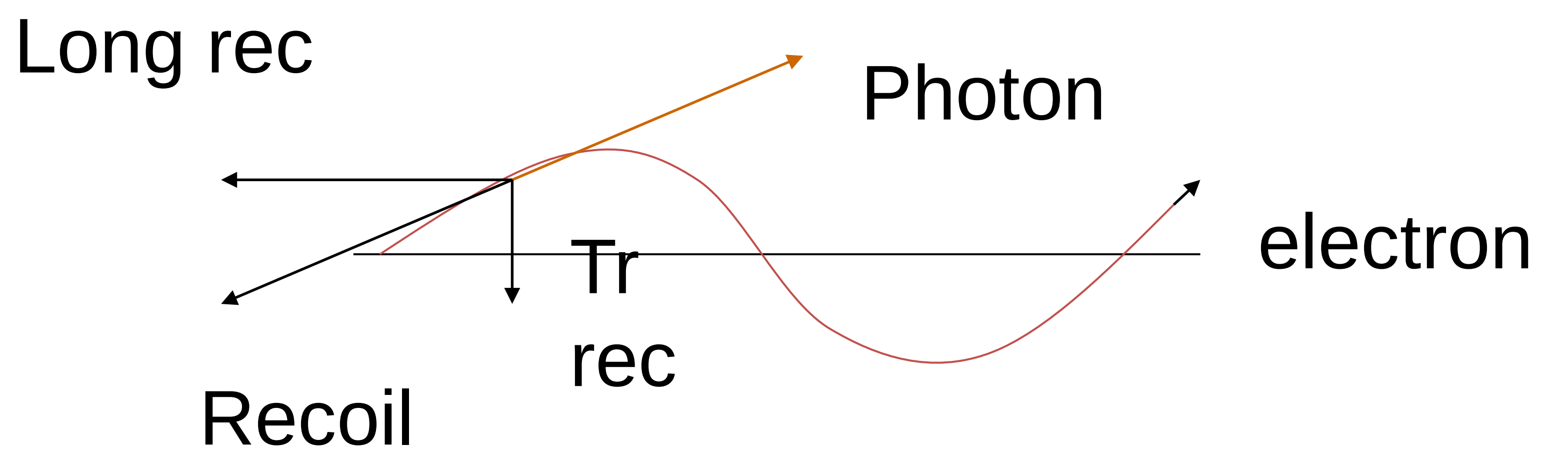
MAX-lab accelerators



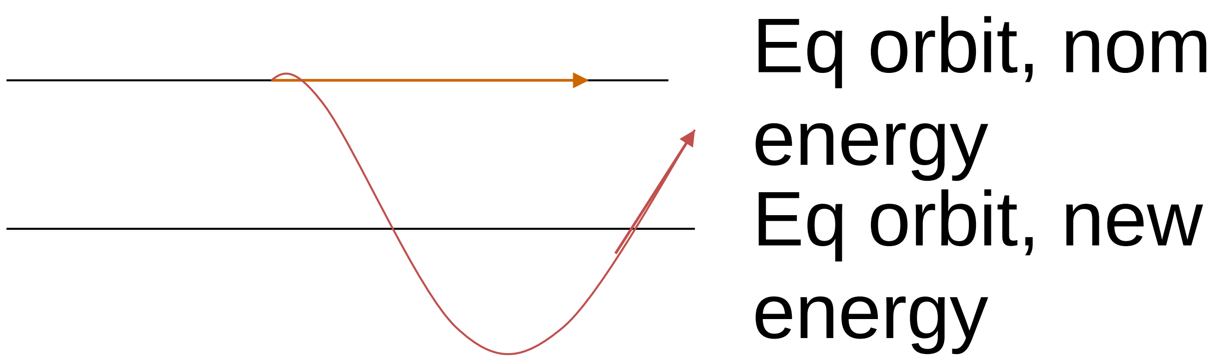
This talk:

- Synchrotron radiation fundamentals
- Stability (Dynamic Aperture)
- Touschek lifetime
- The MAX IV example

Radiation damping



Vertical direction

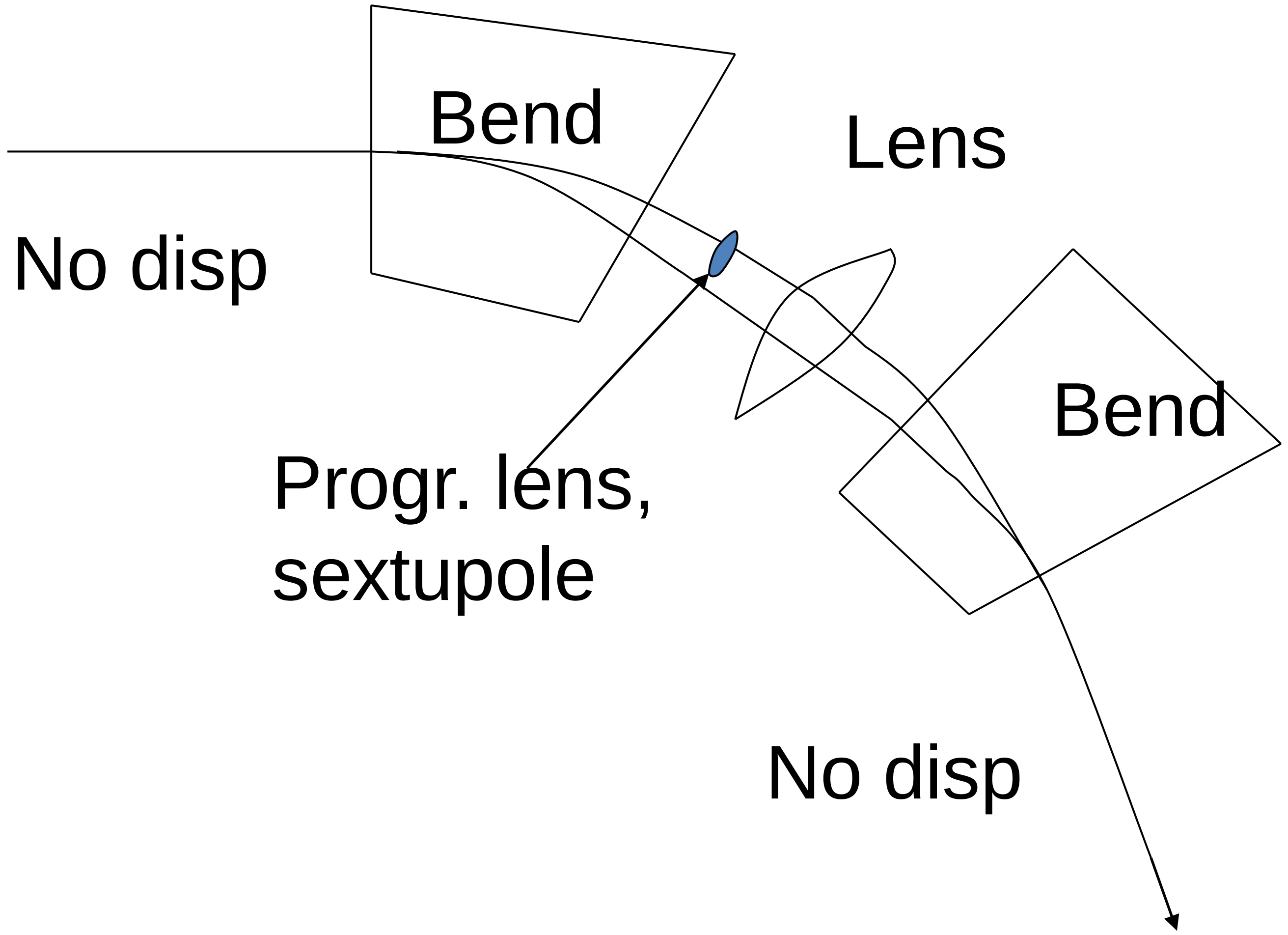


Hor. direction,finite dispersion

Radiation heating

Small dispersion =>less heating=>smaller eq beam size (emittance)

Dispersion in bending magnets

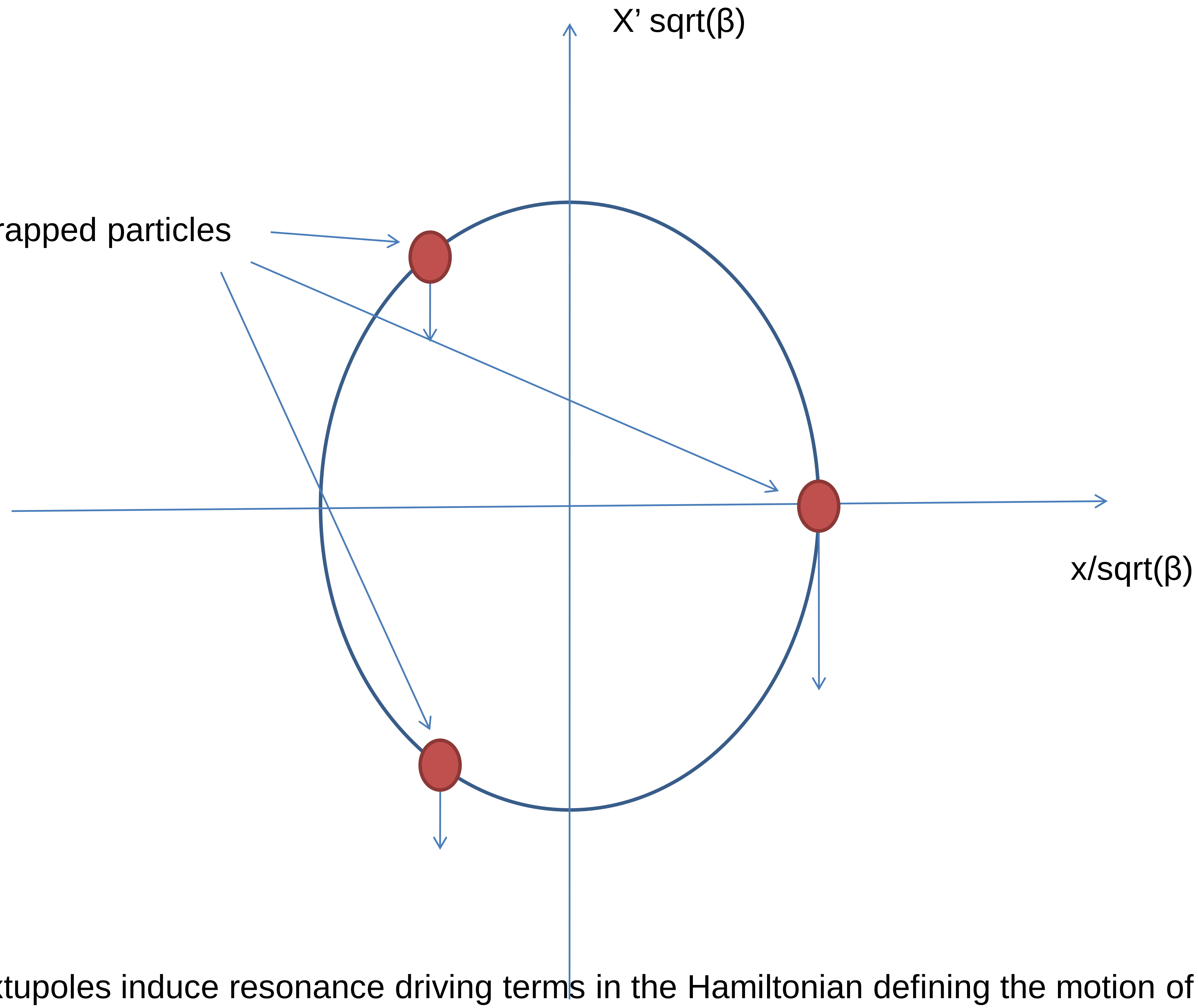


One unit cell consisting of two bending magnets and a focusing lens between.

The smaller the bend angle, the smaller the dispersion; smaller emittance means larger number of cells.

Small emittance=>many bends=>many magnet items=>big expensive rings.

Small emittance =>small dispersion=>strong sextupoles for chrom correction



The sextupoles induce resonance driving terms in the Hamiltonian defining the motion of the particles
You can optimize the sextupole distribution to minimize the driving terms
DBA or TBA gives fewer sextupole position and limits the possibility to minimize many driving terms simultanously
Multi-Bend Achromats offers the opportunity to introduce many sextupoles to minimize several of the driving terms

BUT:

There might be many sextupoles in an achromat in the MBA lattice and minimizing the driving terms is a complex affair

So: Use the code OPA developed by Andreas Streun (PSI) based on the mathematics by Johan Bengtsson (NSLS II)

Recipe for designing the lowest emittance ring in the world:

Remember: $$Brilliance \propto \frac{1}{\varepsilon^2} \qquad \varepsilon = C_q \frac{Energy^2}{N_{magnets}^{\;3}}$$

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1. Try to minimize C_q (Theoretical Minimum Emittance)
   But: Doesn't work, the ring gets unstable.

2. Increase the number of magnets.
   But: The ring will get a 2 km or so circumference.
   (PETRA, PEP)

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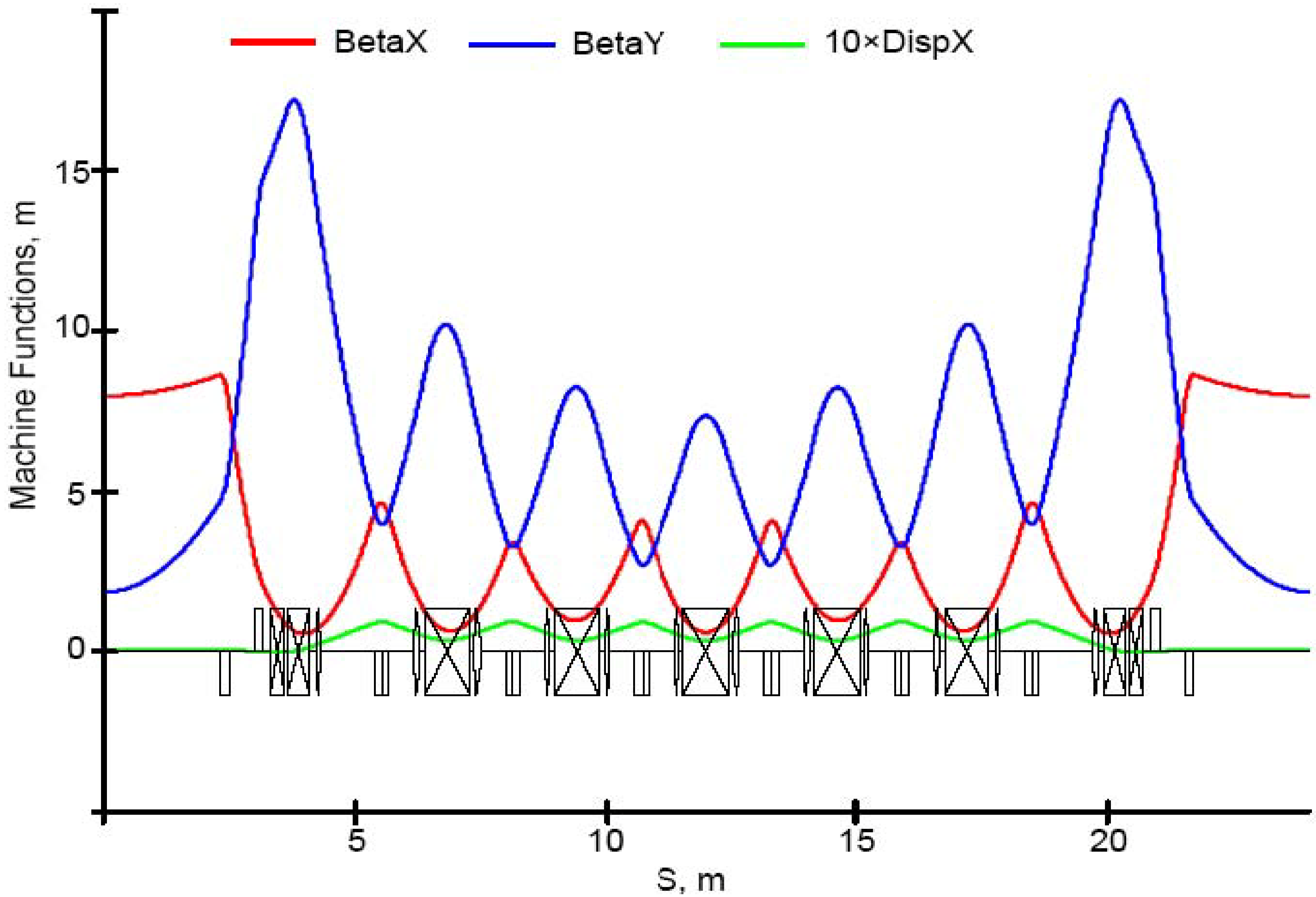
   So: We make the componenets small but keep a large number of magnets

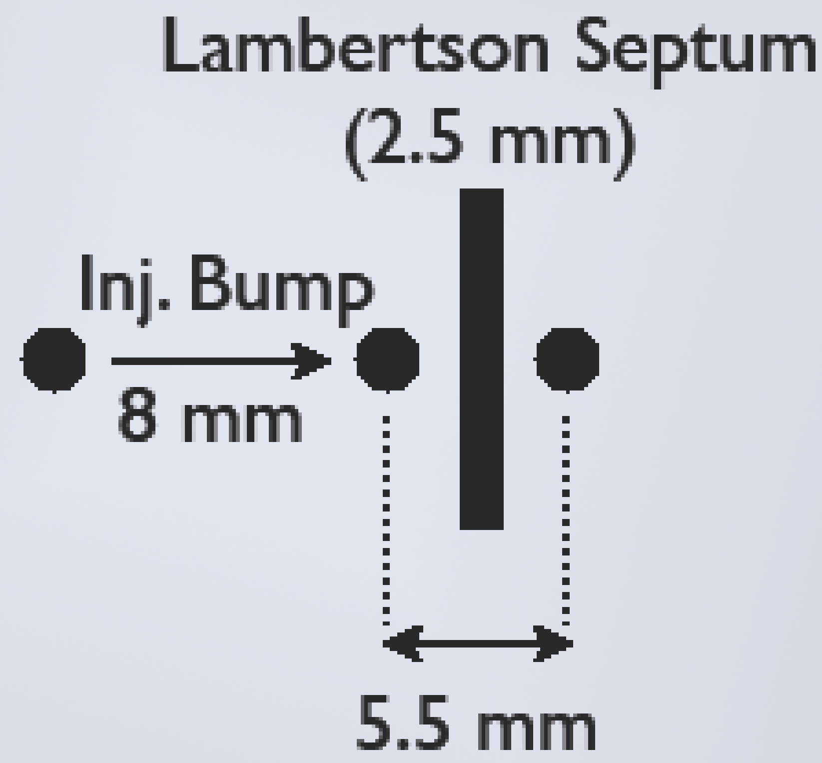
MAX IV lattice functions

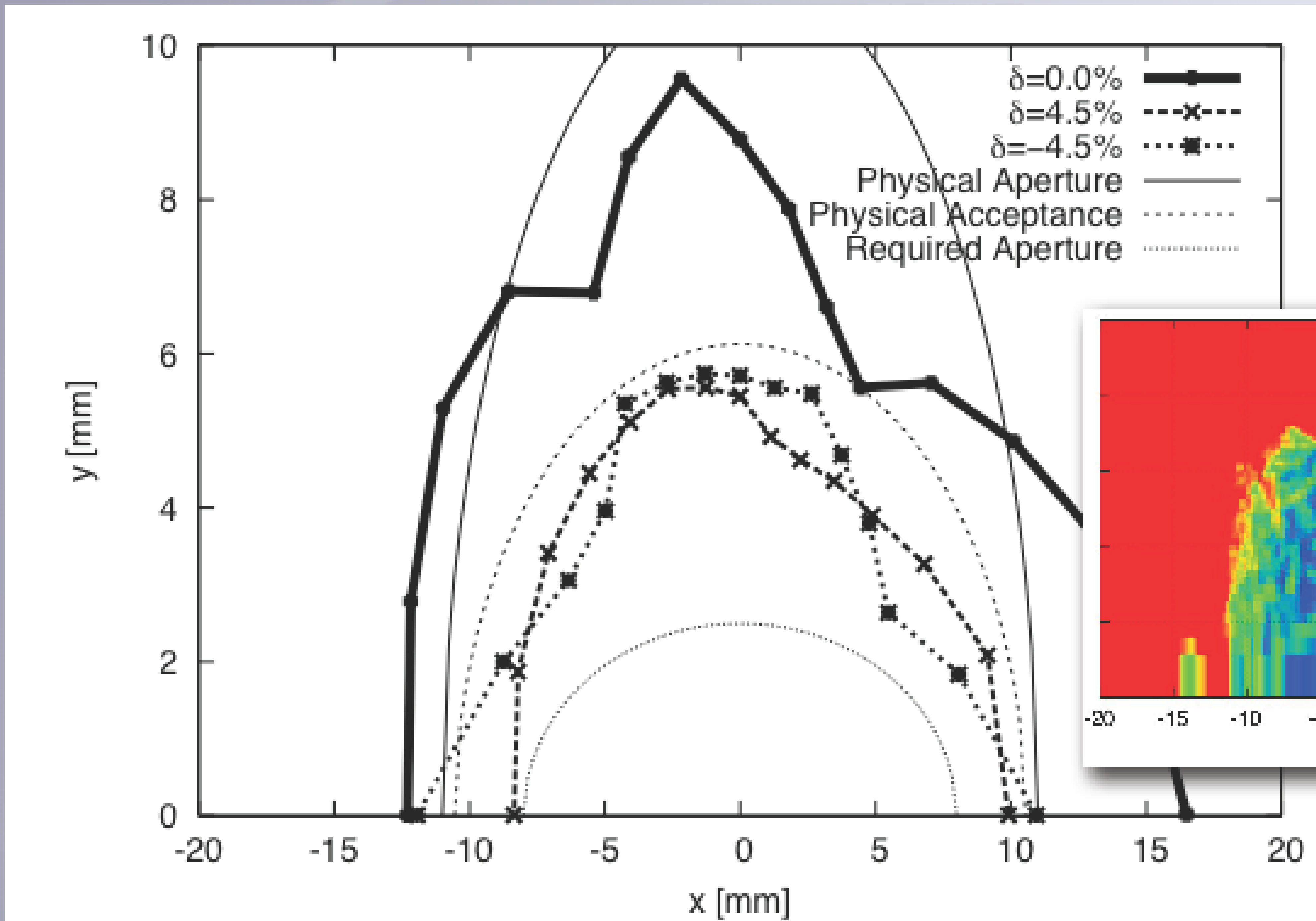


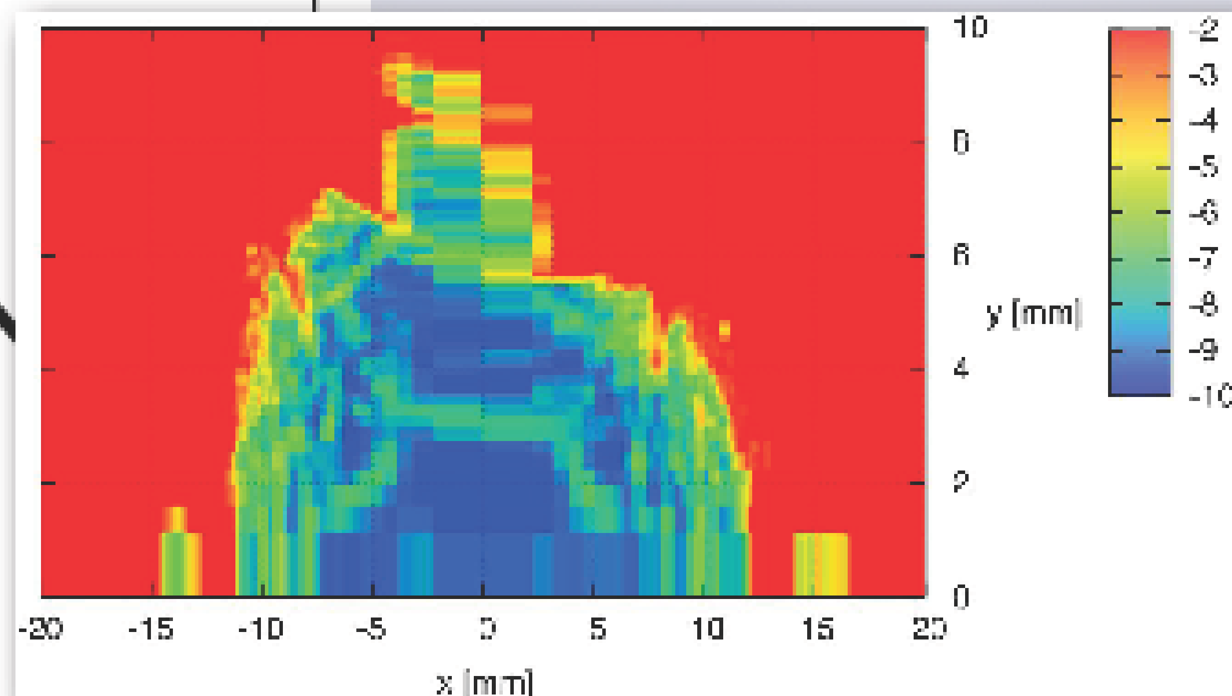
- Cromaticity brick wall:
- Sextupole magnets necessary for chromaticity correction, but they decrease the dynamic aperture.
- Conventional (DBA) lattices have few sextupoles=>can't minimize driving terms within cell
- 7-bend achromats have several sextupoles and we can.

Dynamic Aperture

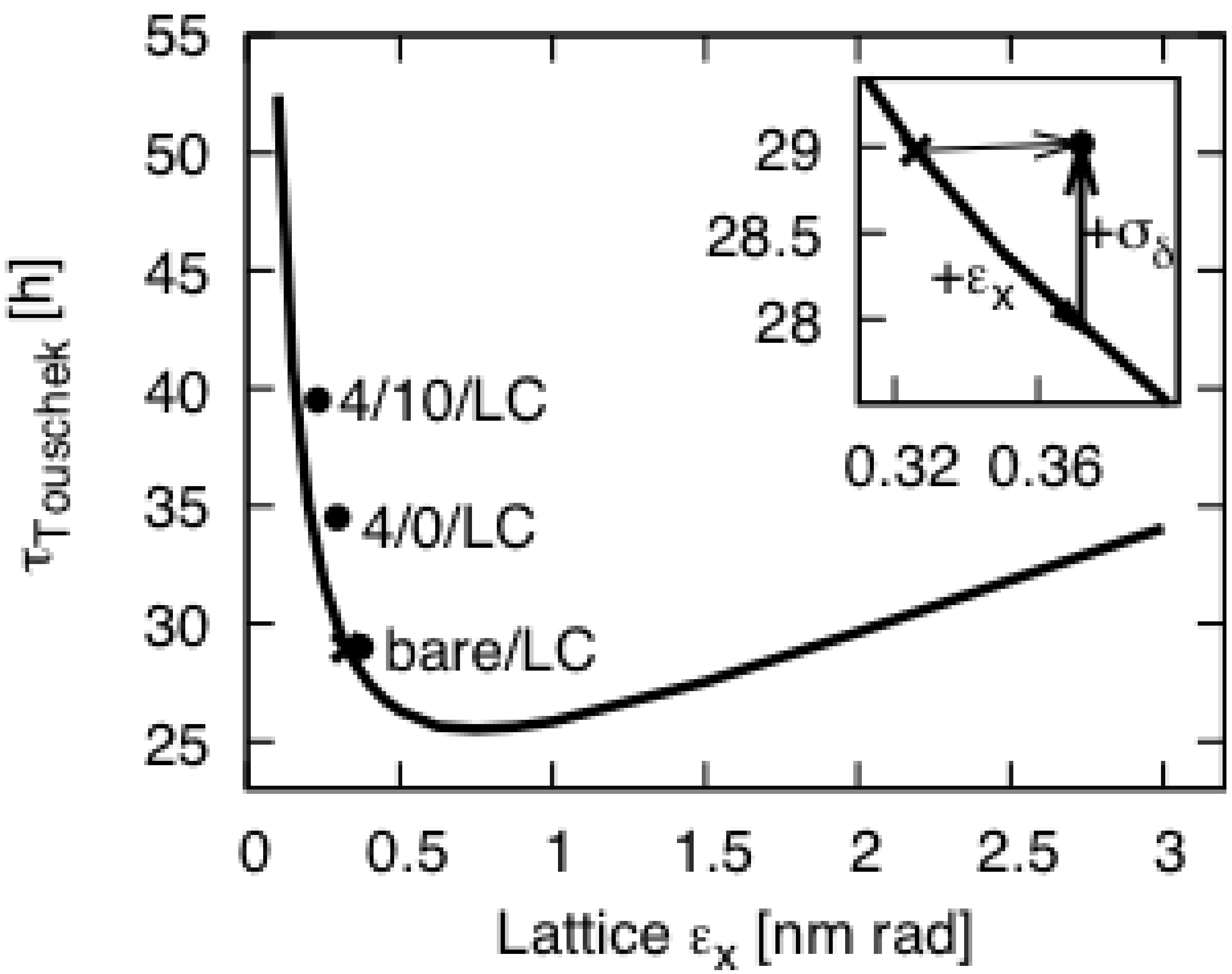
- Octupoles → minimize ADTS (first-order effect!)
- Injection requirement: 8 mm (2.5 mm safety margin)
- Vertical: in-vacuum IDs, 4 mm full-gap height



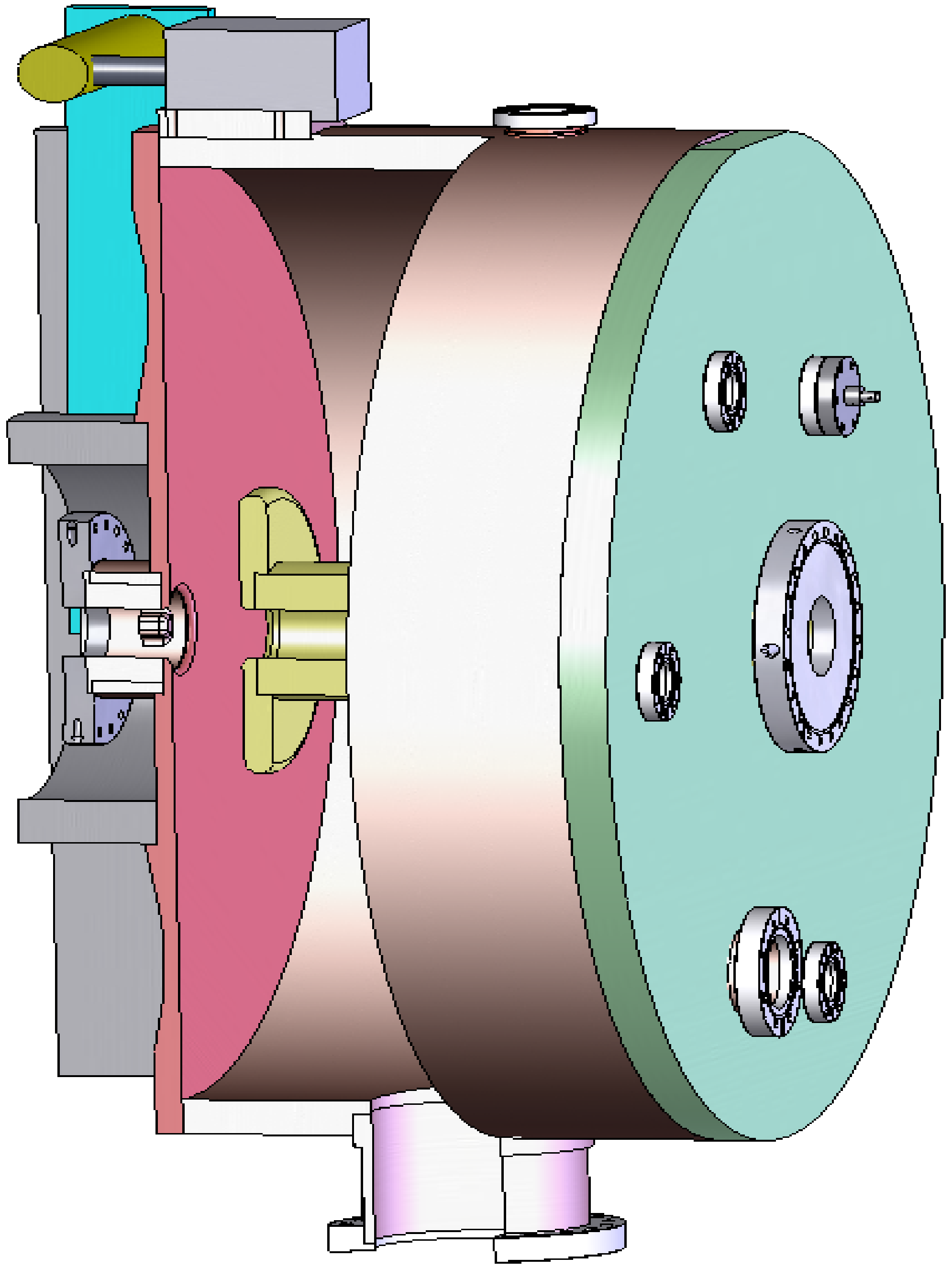


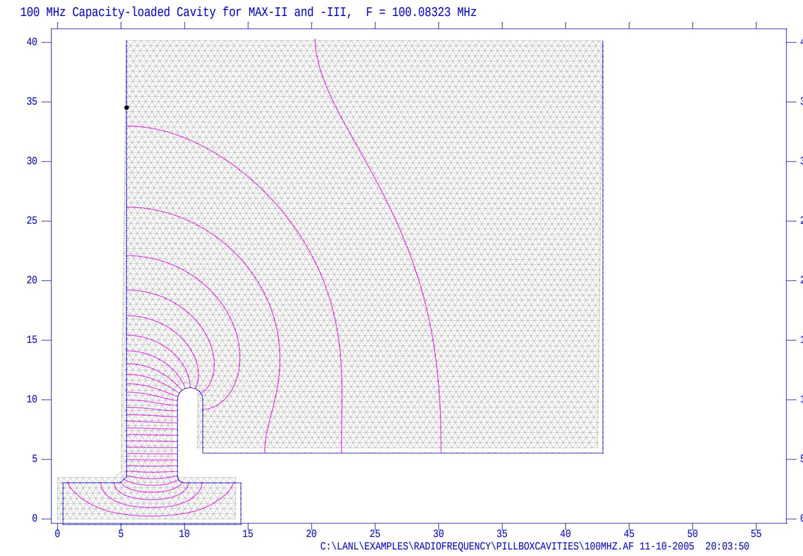


Touschek lifetime

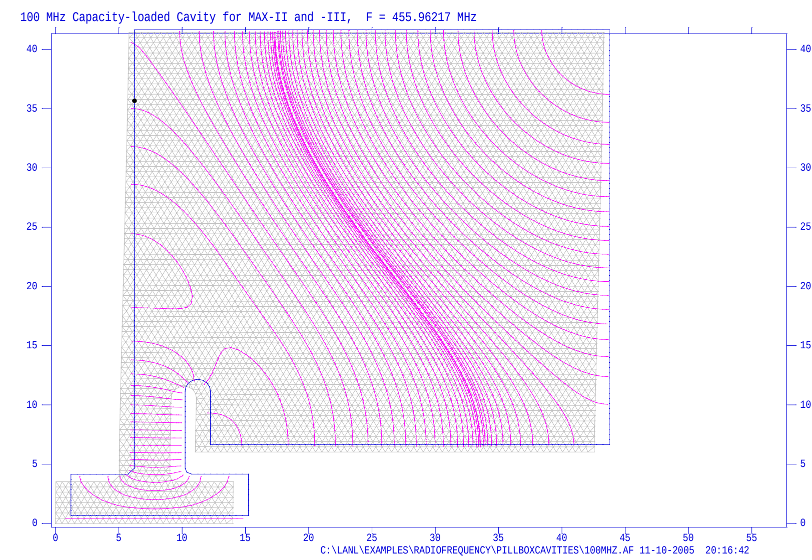


100 MHz cavity

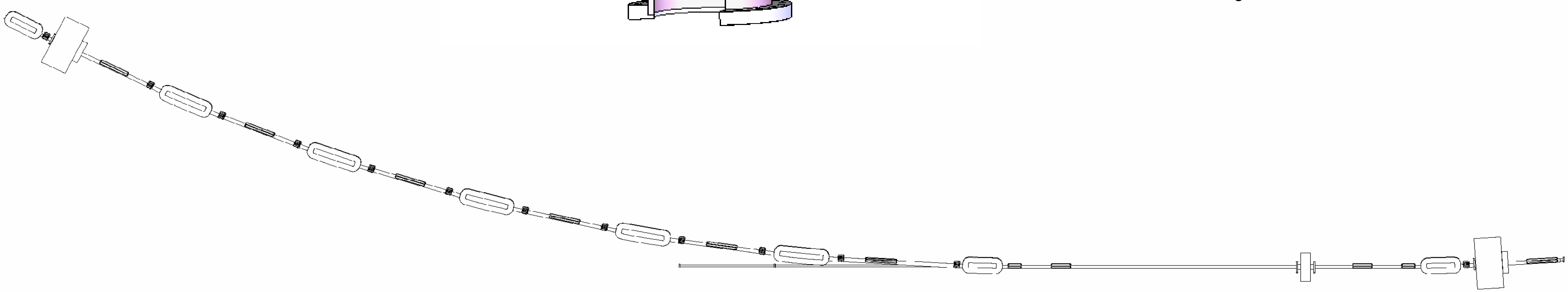




100 MHz cavity profile with fundamental mode E-field lines

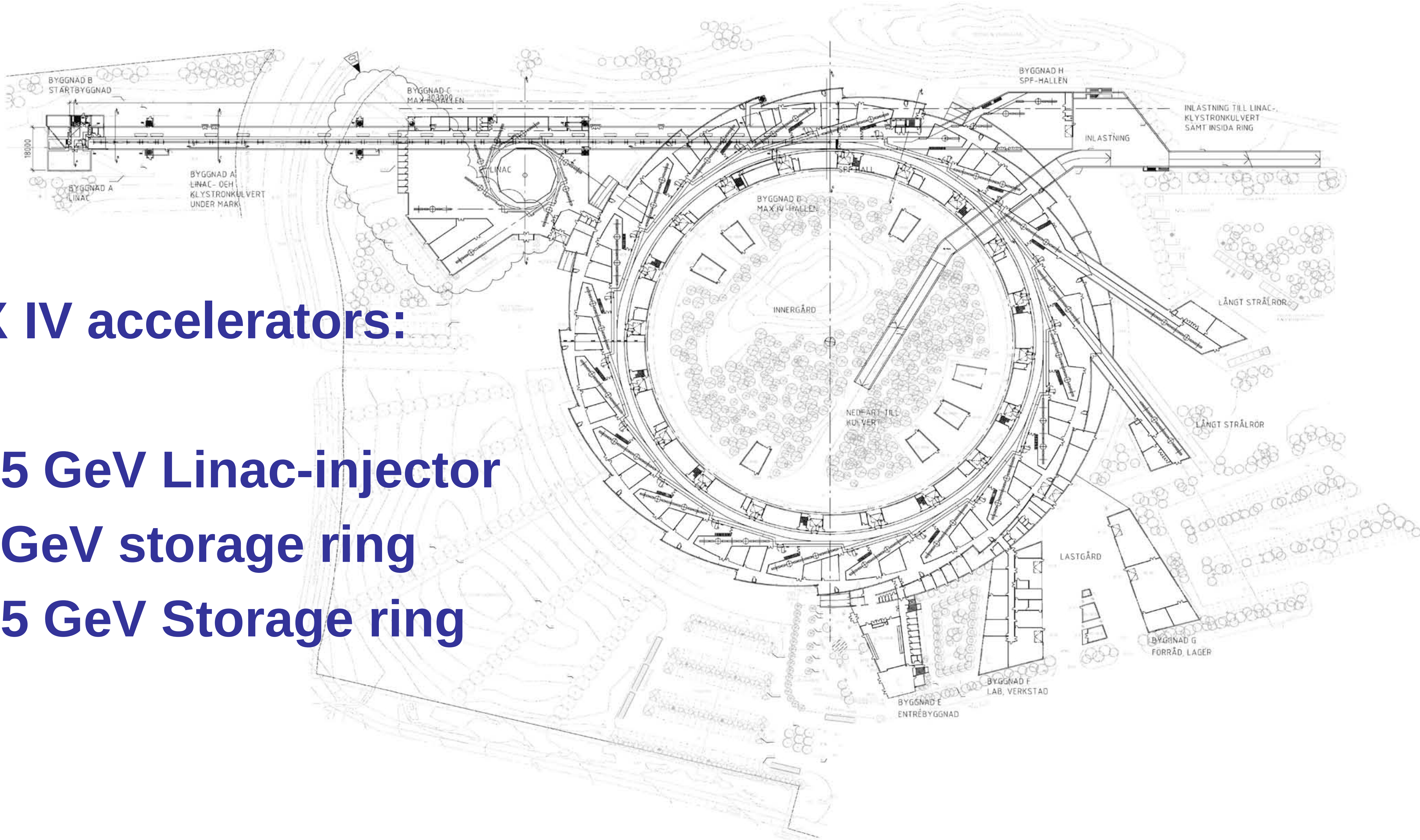


E-field lines of the high order mode at 456 MHz



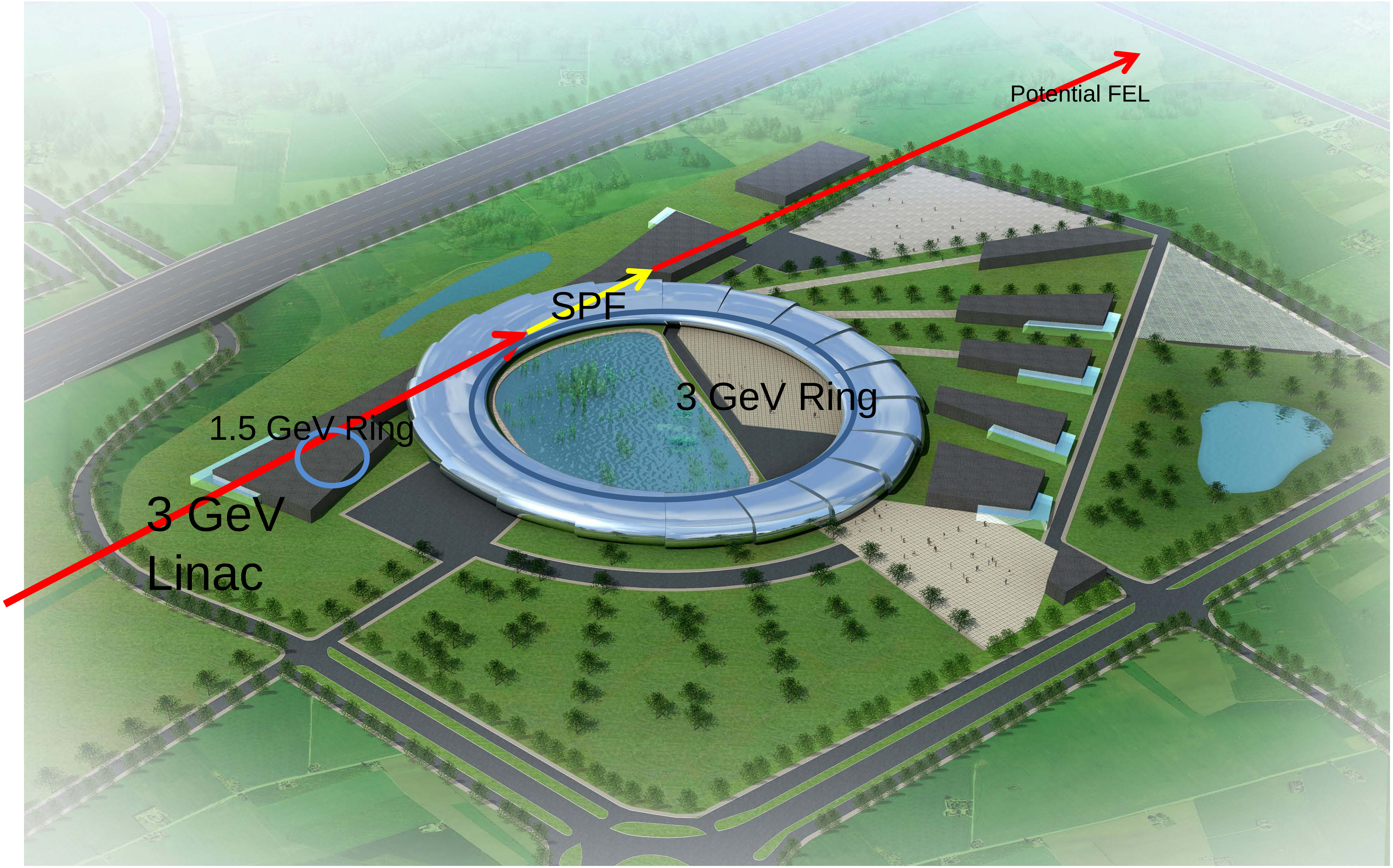

MAX IV + ESS

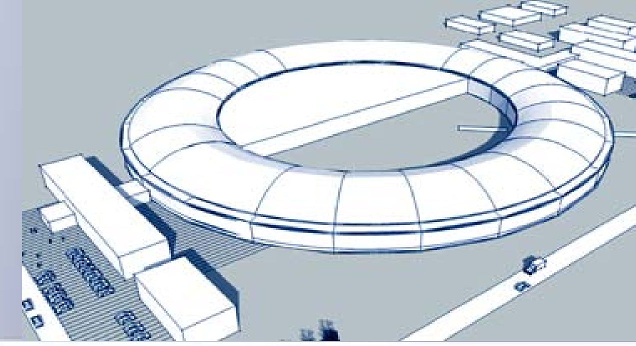
MAX IV layout



MAX IV accelerators:

- 3.5 GeV Linac-injector
- 3 GeV storage ring
- 1.5 GeV Storage ring

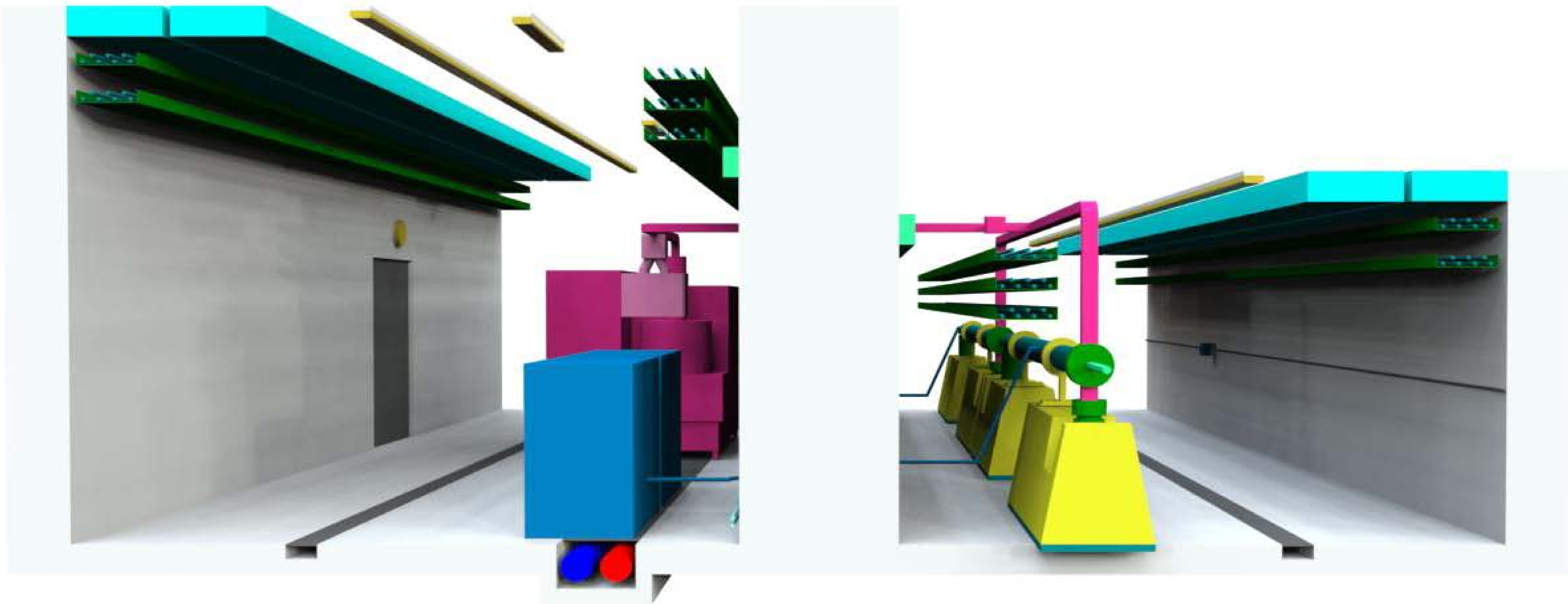

Potential FEL
SPF
3 GeV Ring
1.5 GeV Ring
3 GeV
Linac



Specifications Linac

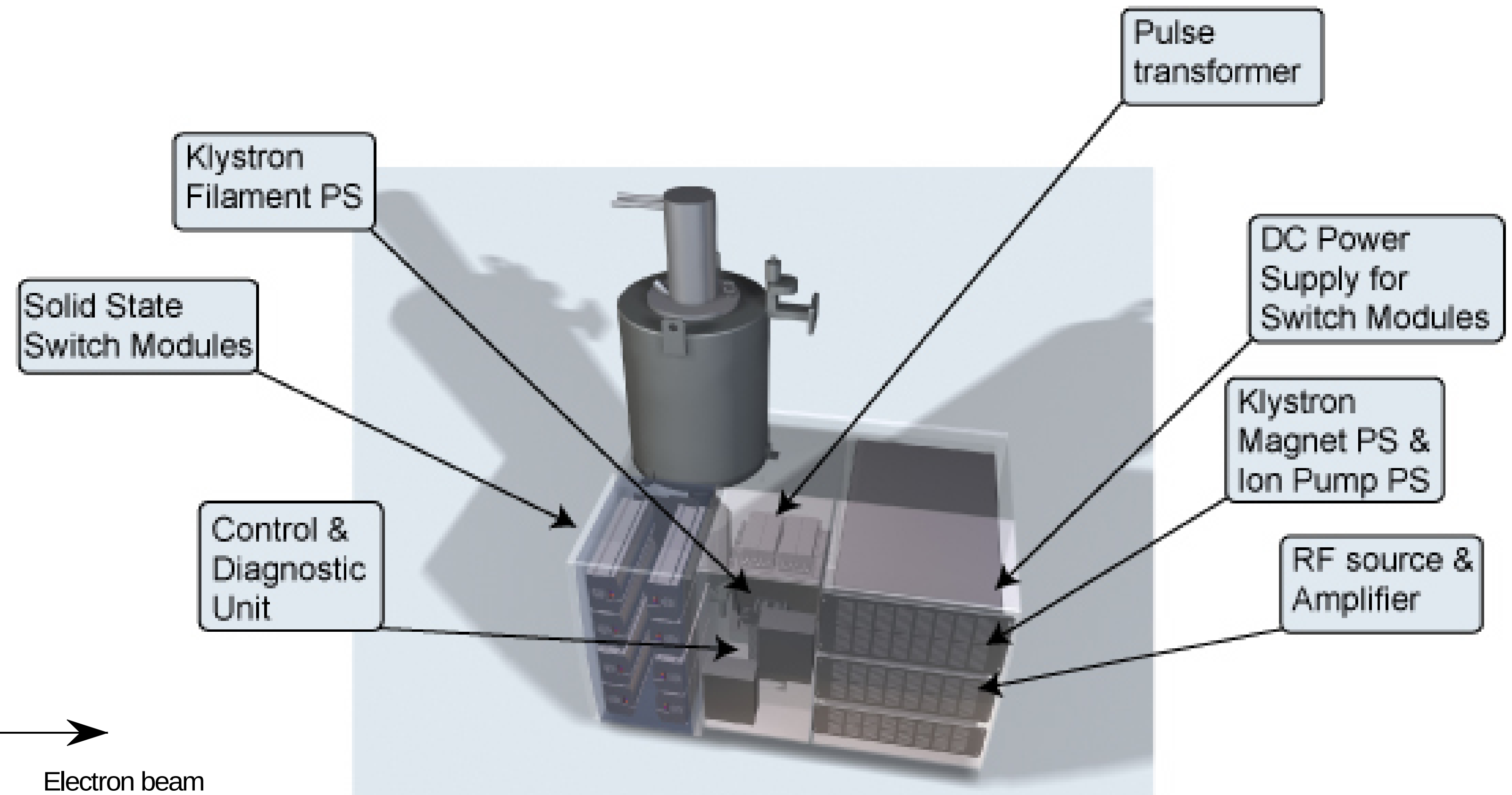
3 GHz warm Linac

	Injector	SPF
End Energy (GeV)	3.0	3.5
Charge/pulse (nC)	15*0.1	0.1
Bunch length (fs)	400	30-50
Rep Rate (Hz)	<10	100
Peak current (kA)		3
Emittance (mm mrad)	<10	0.4
Energy spread	$3*10^{-3}$	$3*10^{-3}$

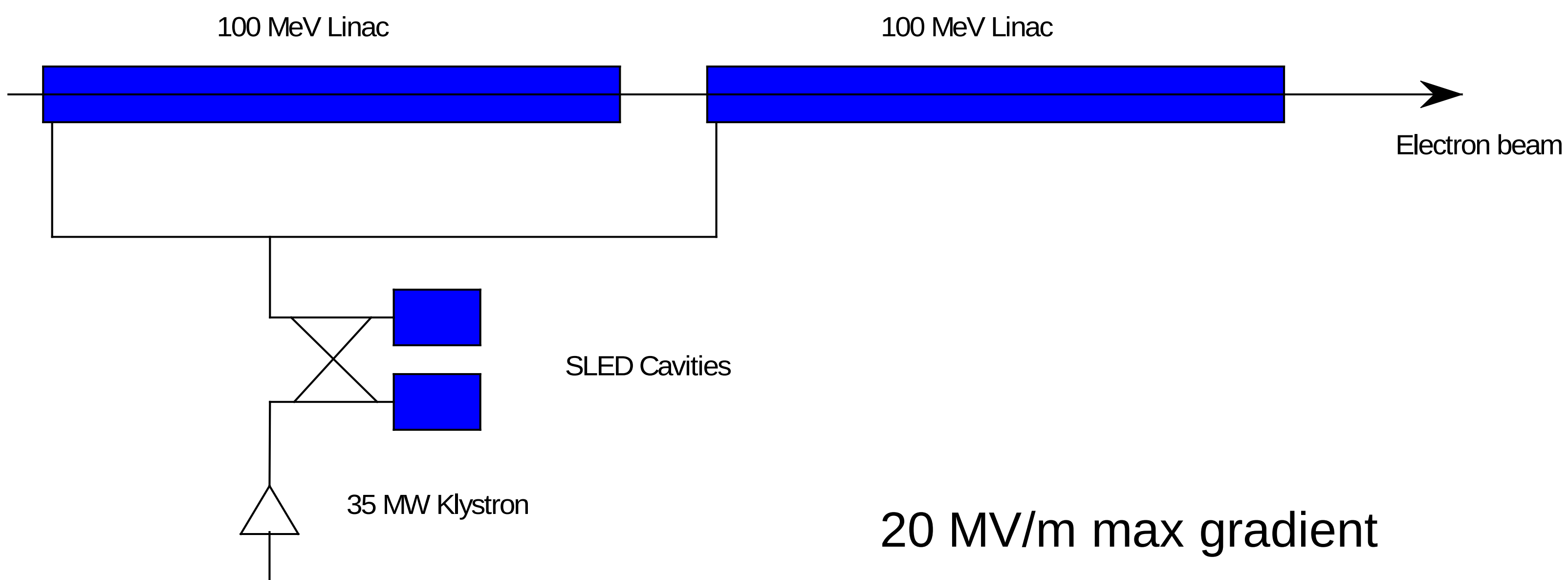


Klystron gallery & LINAC

MAX IV – linac



Linac Module (18 of them)



1 35 MW klystron

1 Pair of SLED cavities

2 pcs 5 m linac structures

20 MV/m max gradient

Max dutyfactor 0.001

Solid state modulators
=>variable pulse length

Status Linac

- Design for long and transv optics (incl compressors) almost finished.
- Tenders for linac structures, klystrons, SLEDs, modulators out (Red line)
- Parts for first electron gun finished.
- Linac tunnel defined
- Transport lines to rings (LRT) defined
- Work ongoing for intra-sections between linac

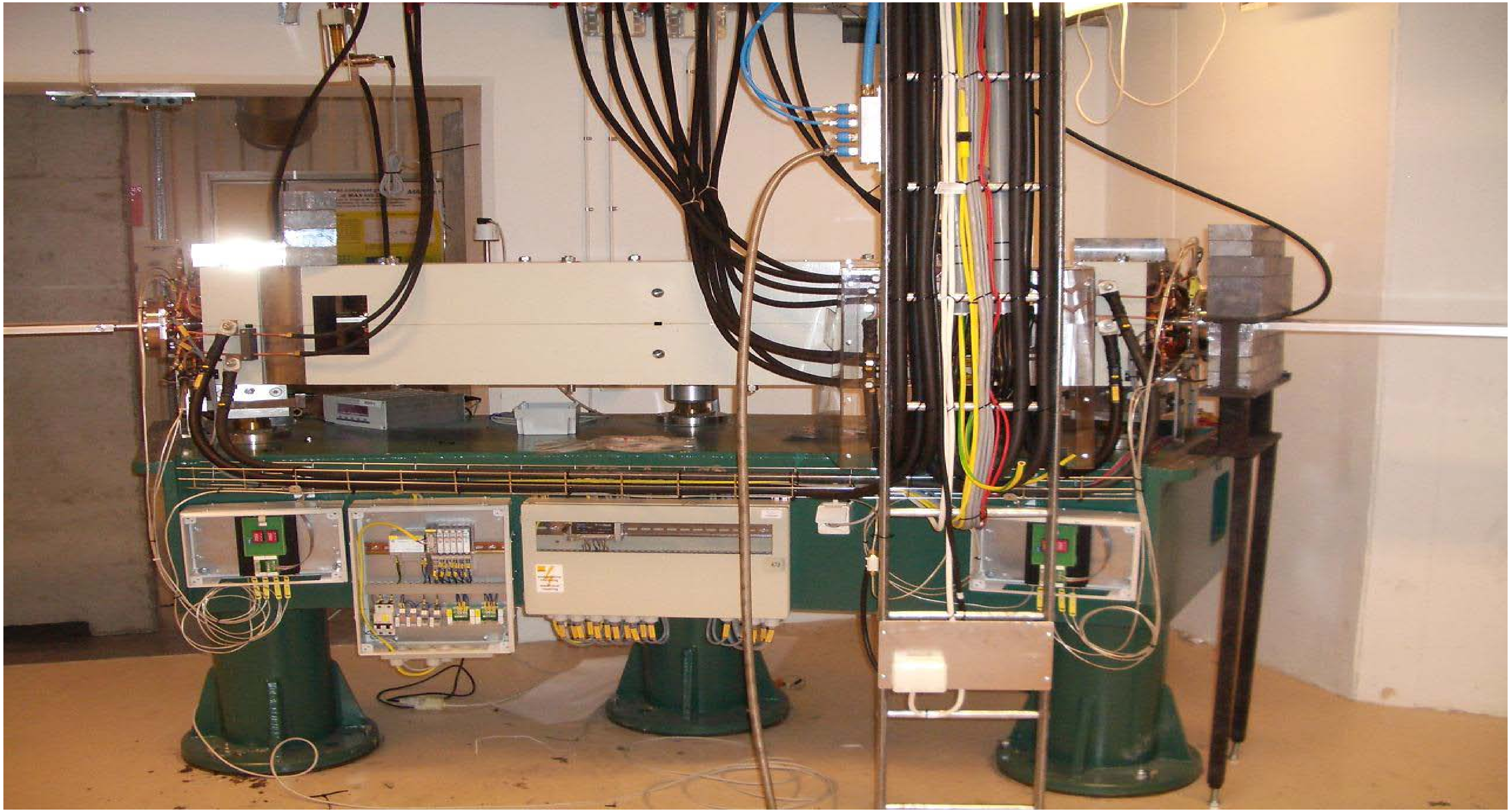
Specifications Storage Rings

Electron energy (GeV)	3	1.5
Circ current (mA)	500	500
Circumference (m)	527	96
Nr of long straights	20	12
Length (m)	5	3.5
Hor emittance (nm rad)	0.24	5.6
Hor RMS beam size (μm)	45	200
Vert RMS beam size (μm)	1-4	10
Beam life-time (h)	10	5

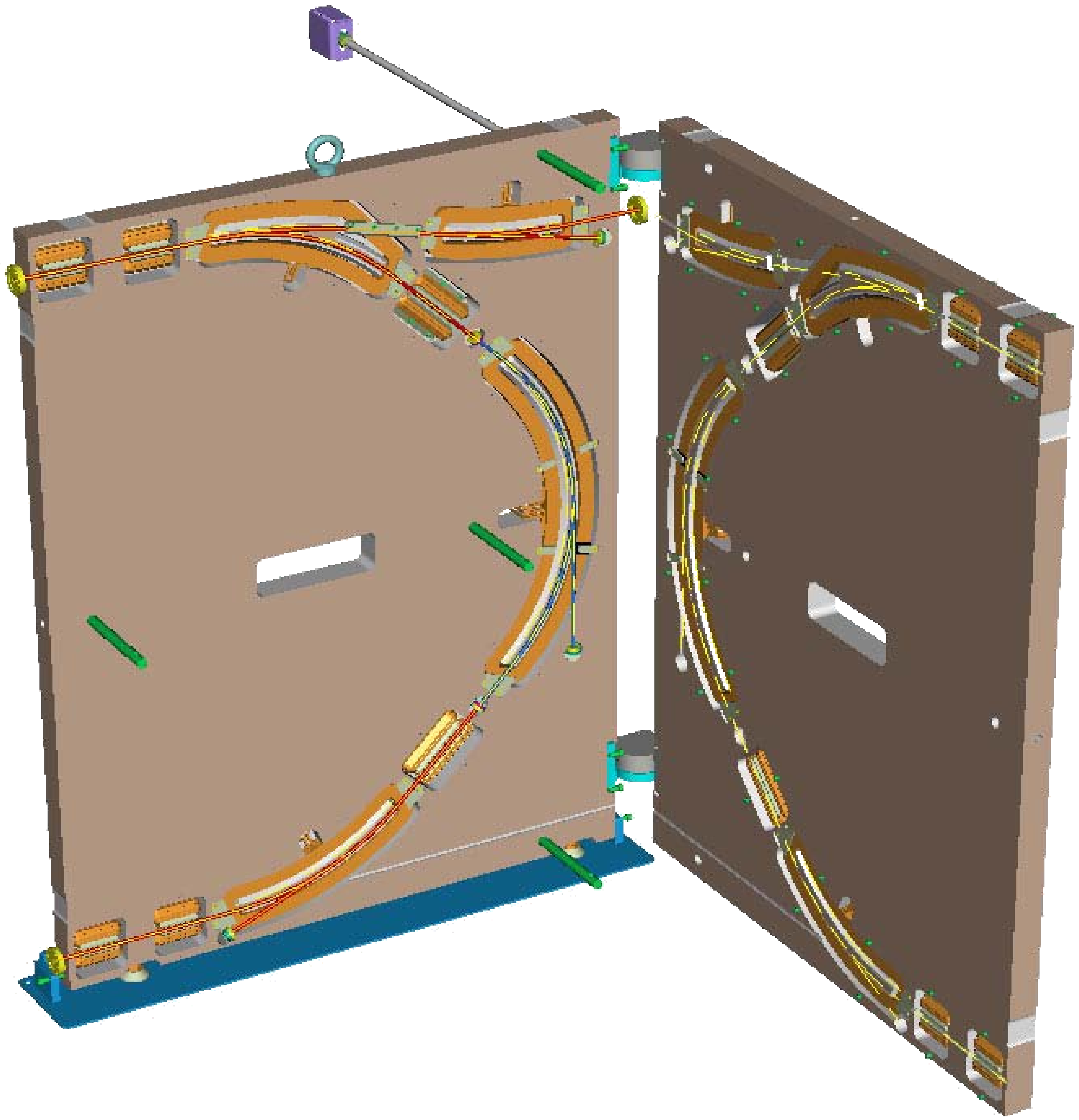
Top-up injection in both rings

Two 1.5 GeV rings will be built. One goes to Krakow (Polish Light Source)

MAX III cell (Proto for M IV)



180 degrees bends

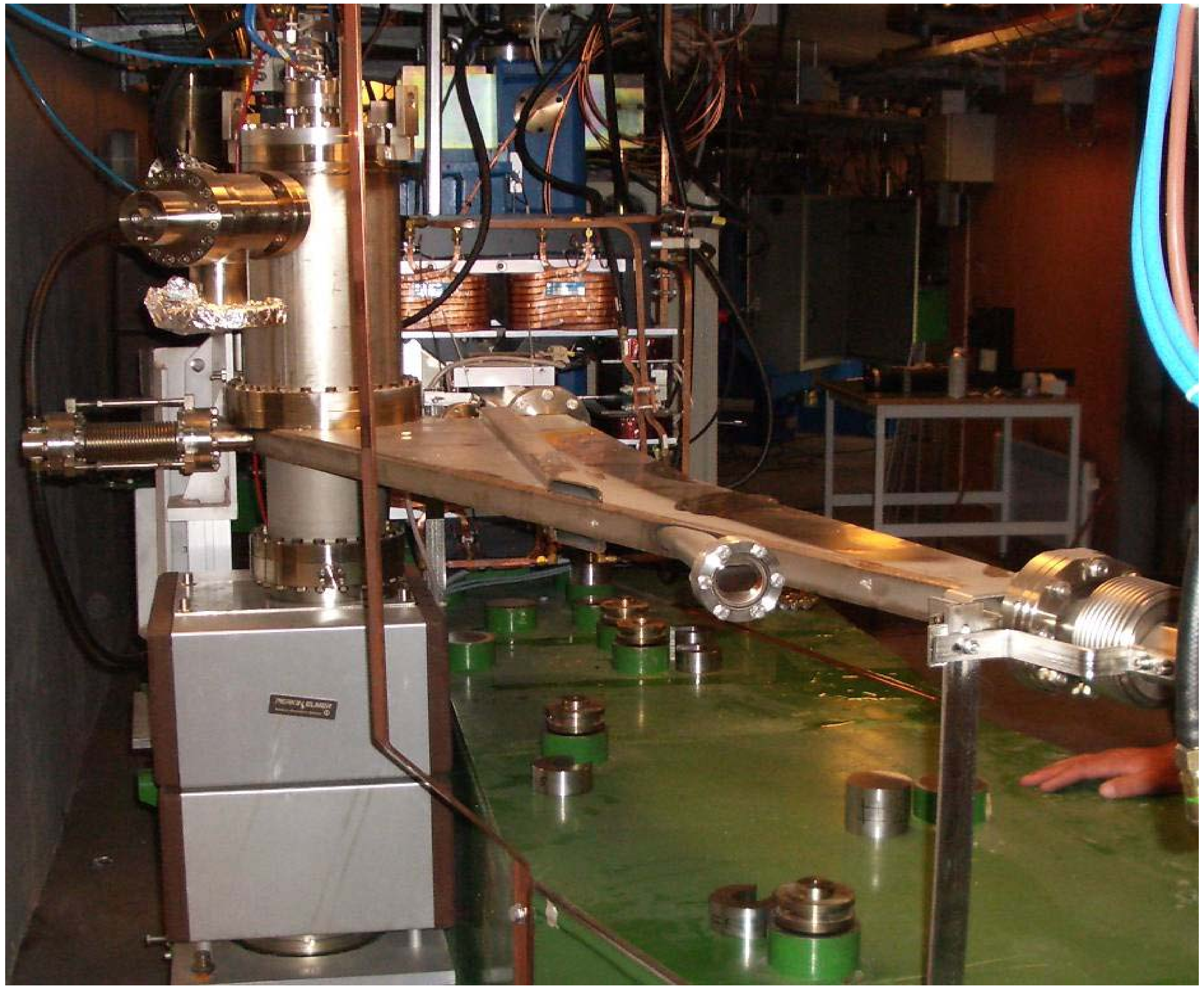


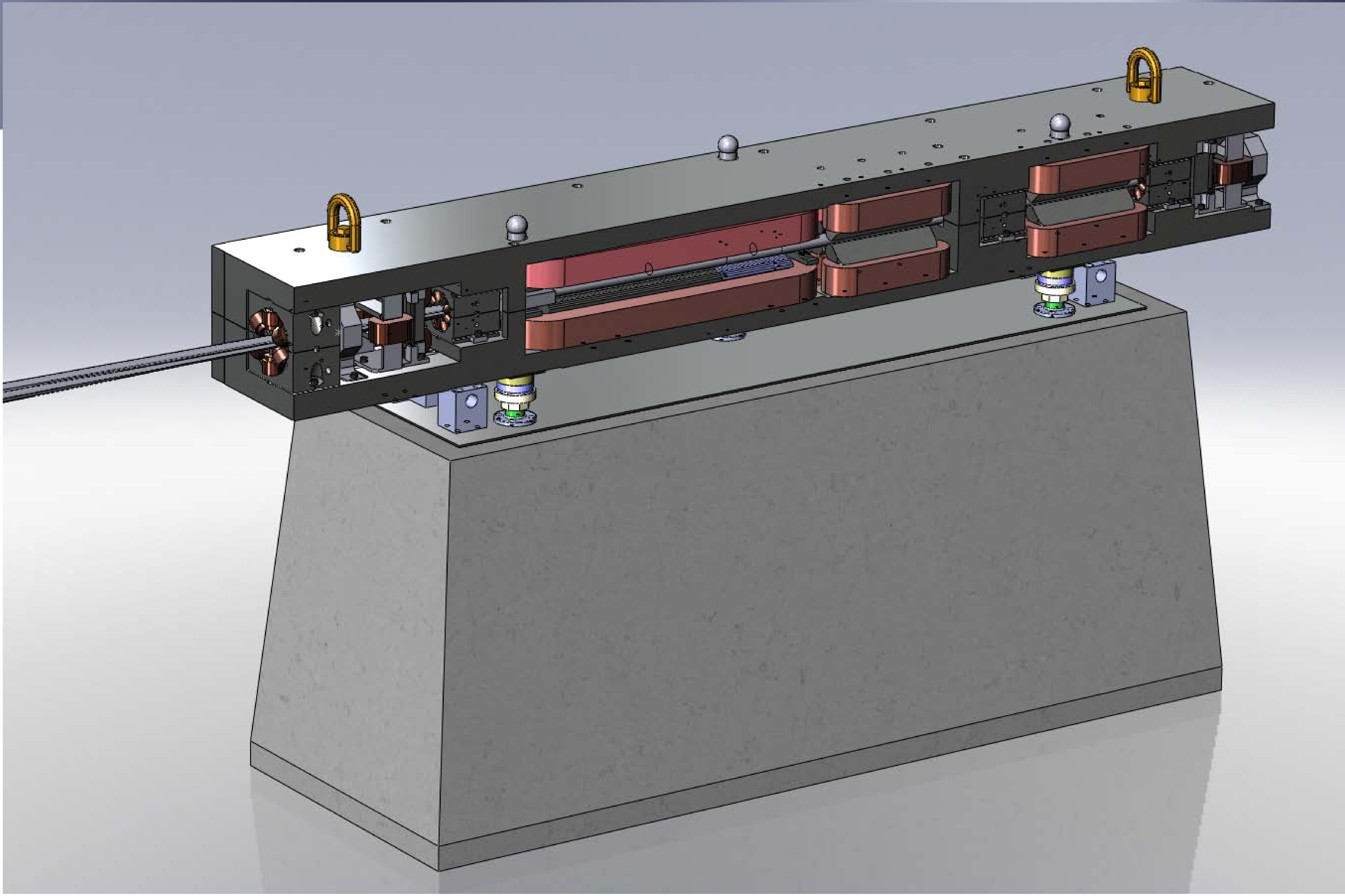
Two 5 m LINACs give 500 MeV using the SLED technique and a recirculator.

- Replacement of aging 100 MeV microtron
- Decoupled injection into all storage ríngs
- Possibility to use the LINAC for FEL research
- Higher energy regim for nuclear research

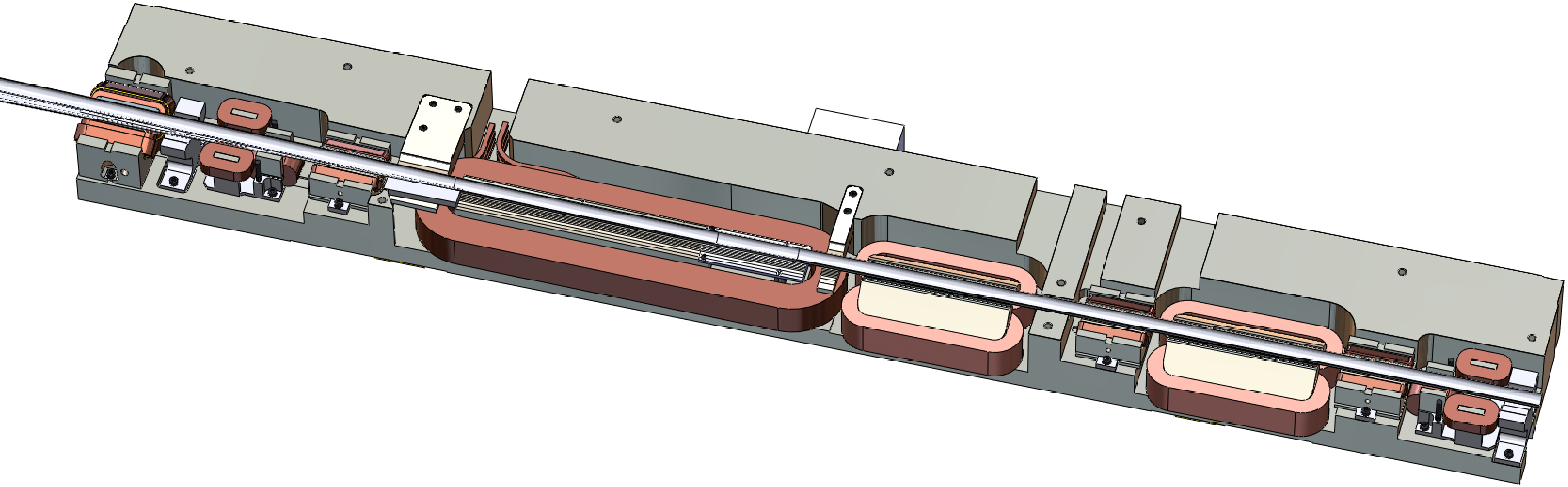
Standard MAX II dipole chamber made of stainless steel.

NEG coated dipole chamber of Cu to be tested in MAX II.

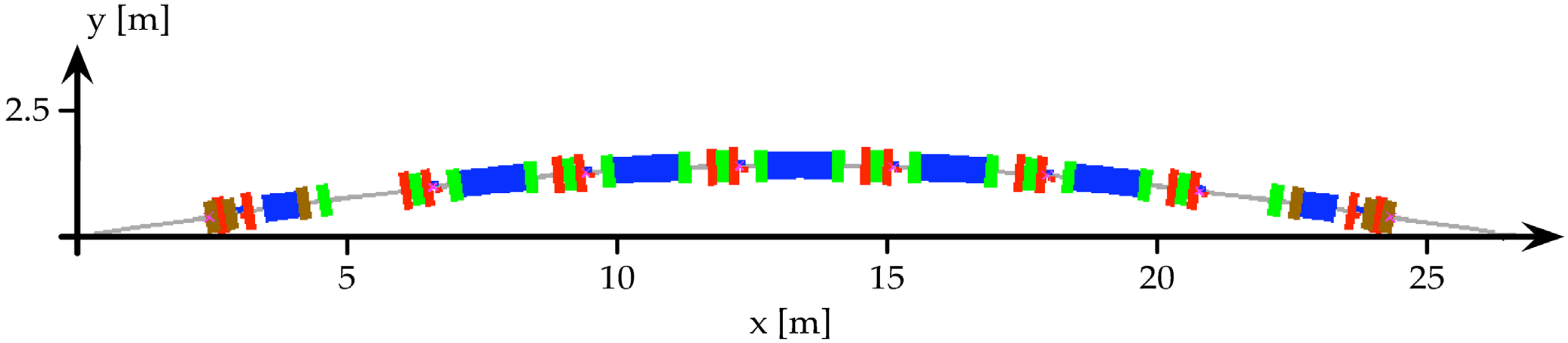




Magnet half



7-Bend Achromat



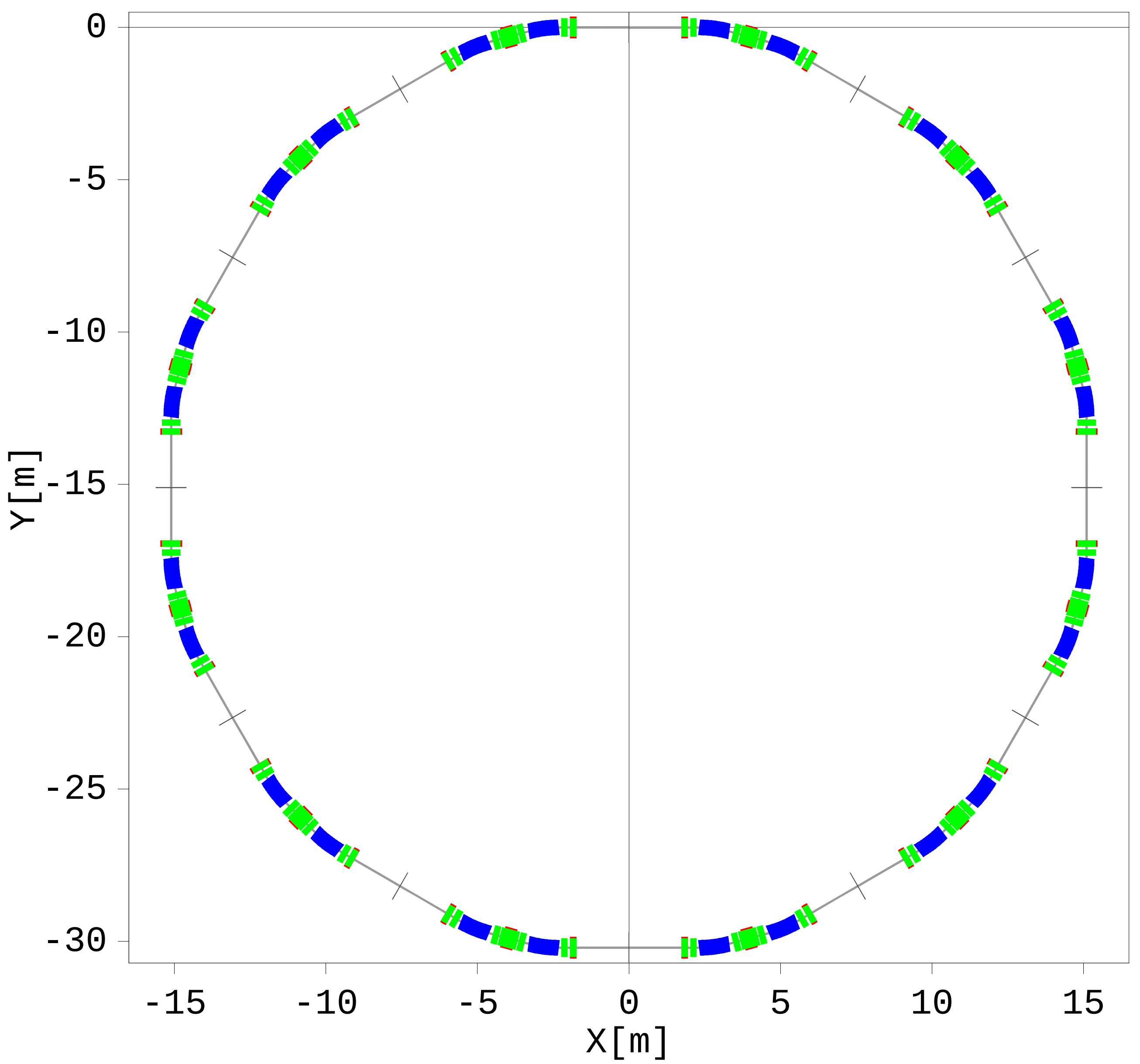
Status 3 GeV Ring

- Magnet iron bought now. One single batch.
- Magnet tender prepared. CFT released in Oct 2010
- Vacuum system defined. To be settled: Activation of NEG coating
- RF transmitter tender prepared. CFT in Oct 2010
- Cavity tender prepared. CFT in Oct 2010
- Remaining main tenders: Pulsed elements, diagnostics, IDs (to be defined)

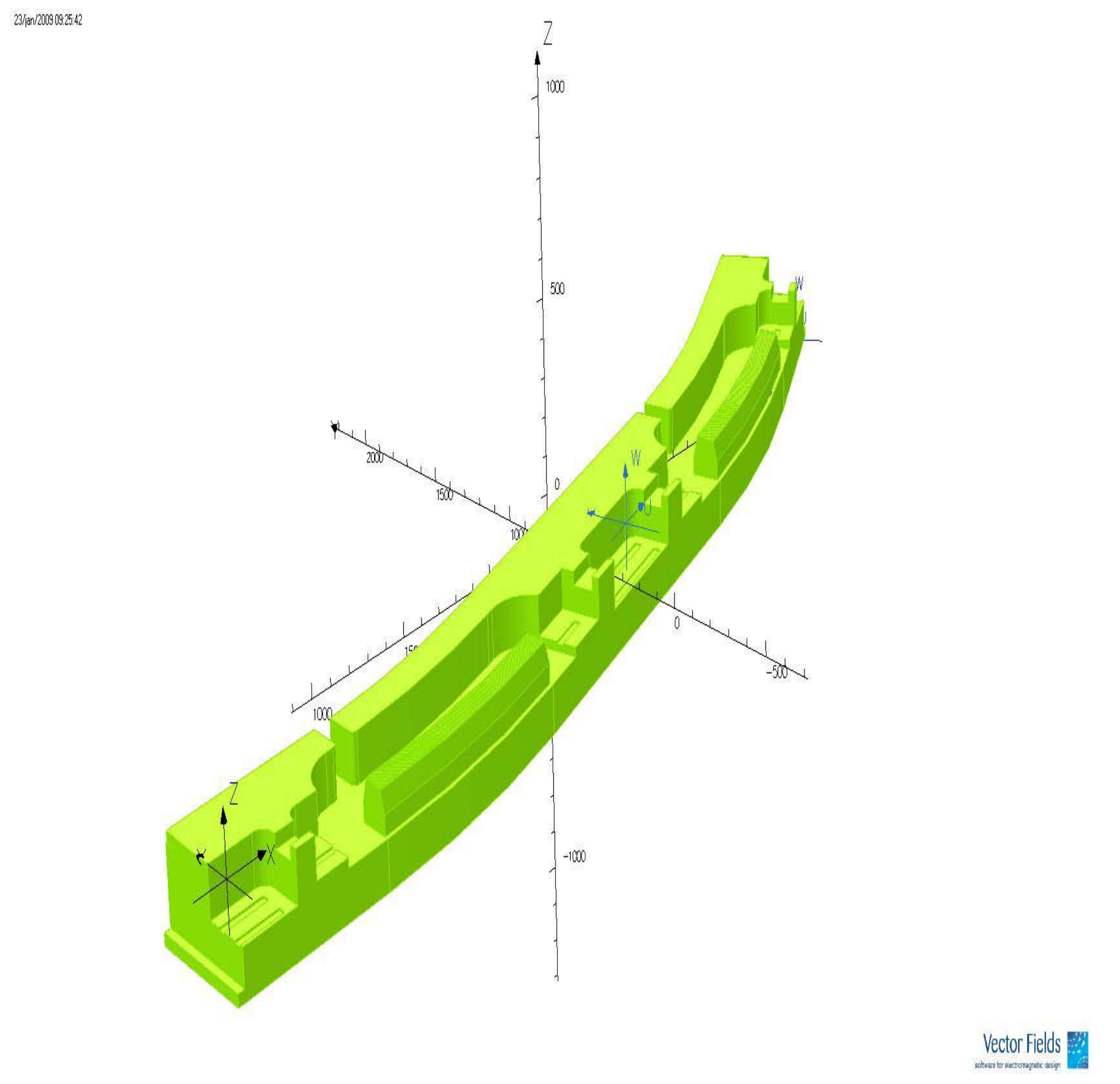
1.5 Gev Ring

Motivation: Extended spectral range with SR from optimized undulators
2 rings will be constructed, one for Krakow and one for us

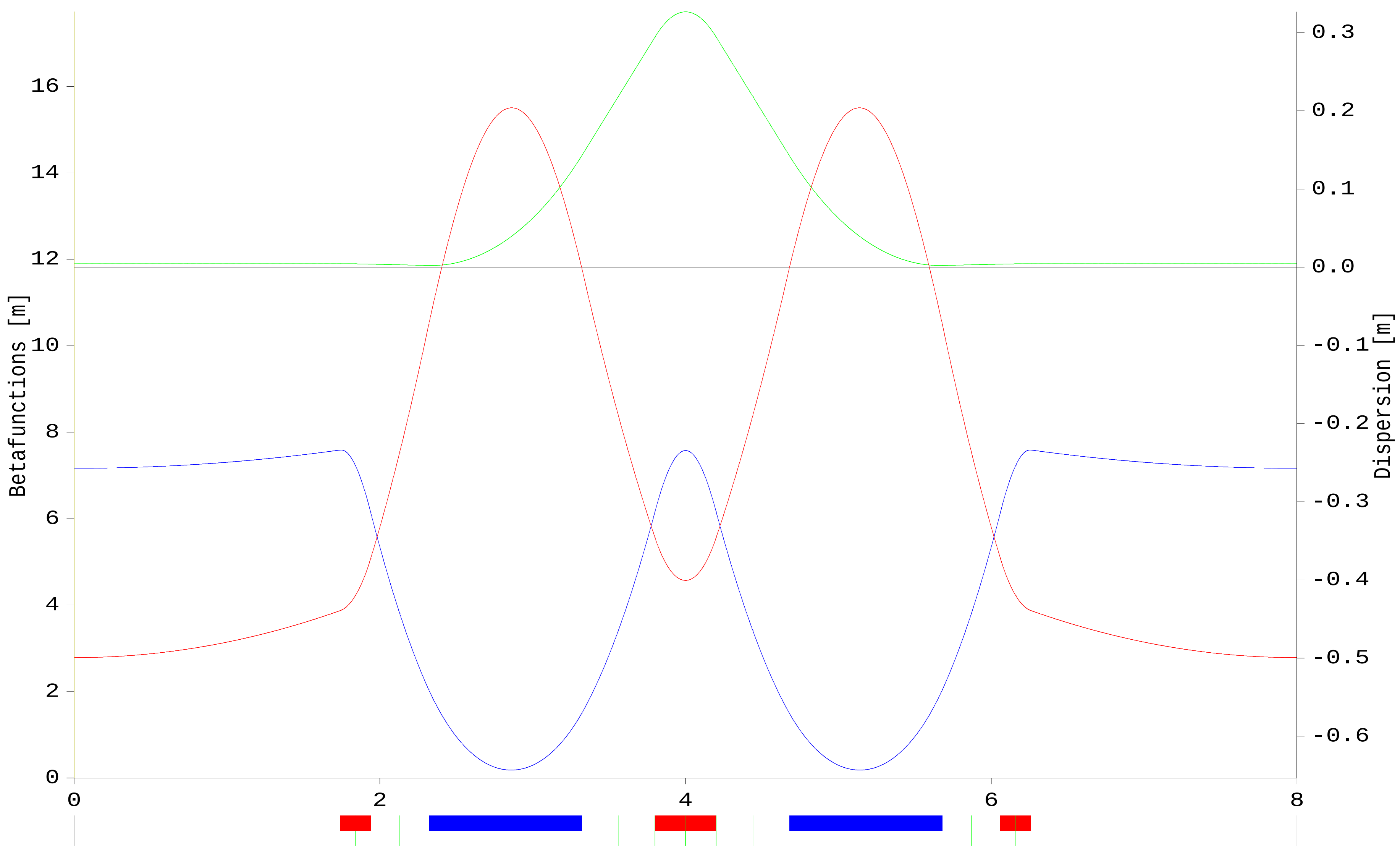
MAX IV 1.5 GeV lattice



Achromat

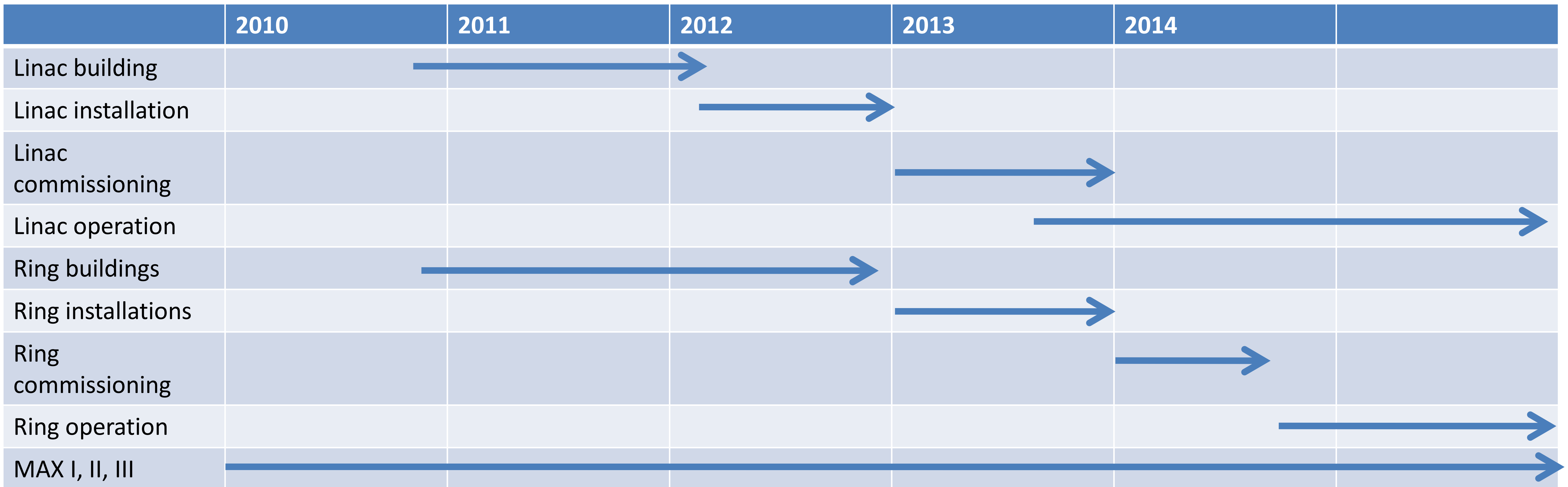


MAX IV 1.5 GeV

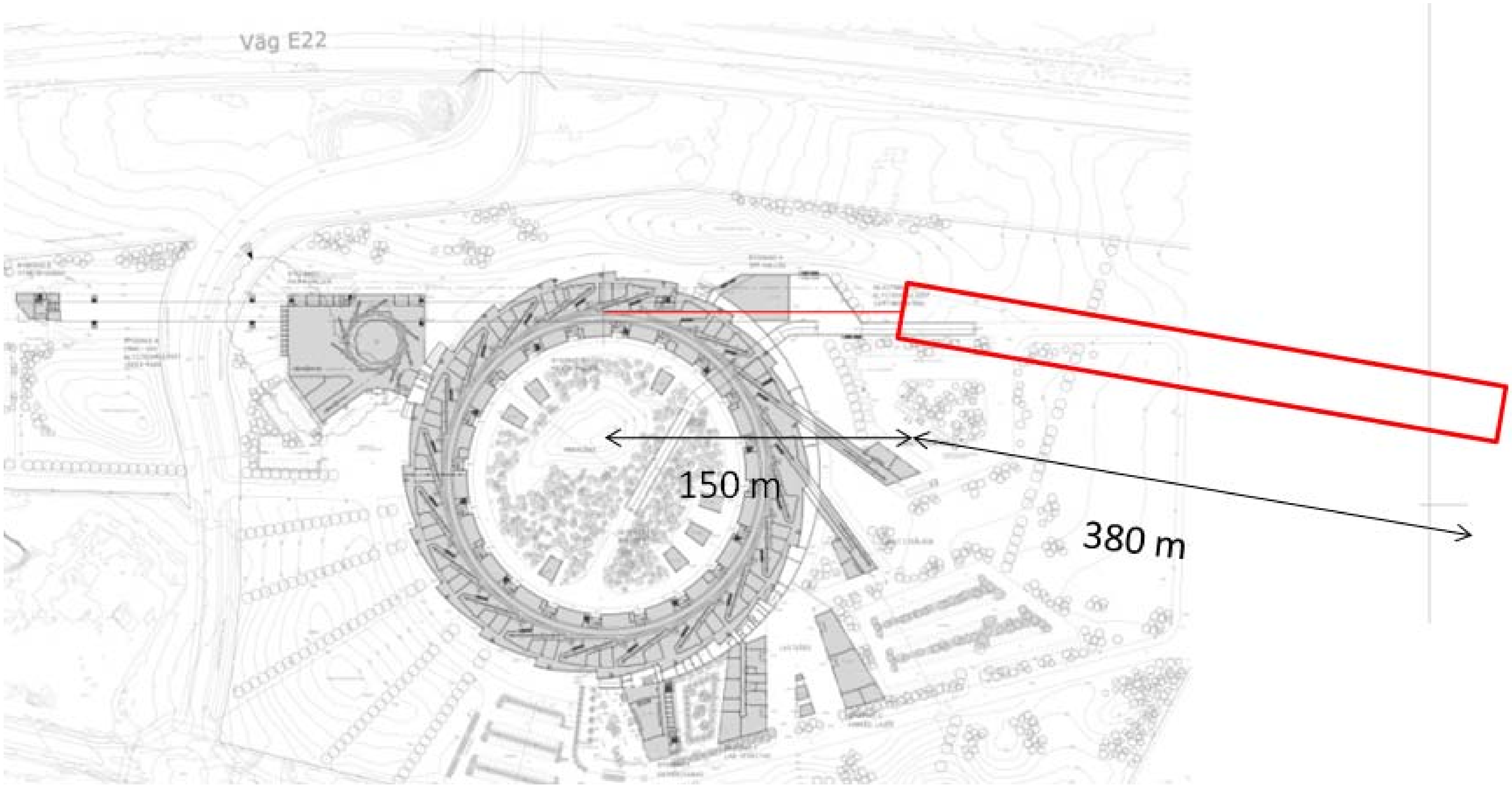


Energy	1.5 GeV
Circ current	0.5 A
Circumference	96 m
Hor emittance	5.6 nm rad
Achromat nr	12
Straight section	3.5 m
Hor RMS beam size	0.200 mm

Time schedule MAX IV



Possible X-FEL extension



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