Ultra-Low Emittance Light Source Ring having a Projected Torus-knot Lattice

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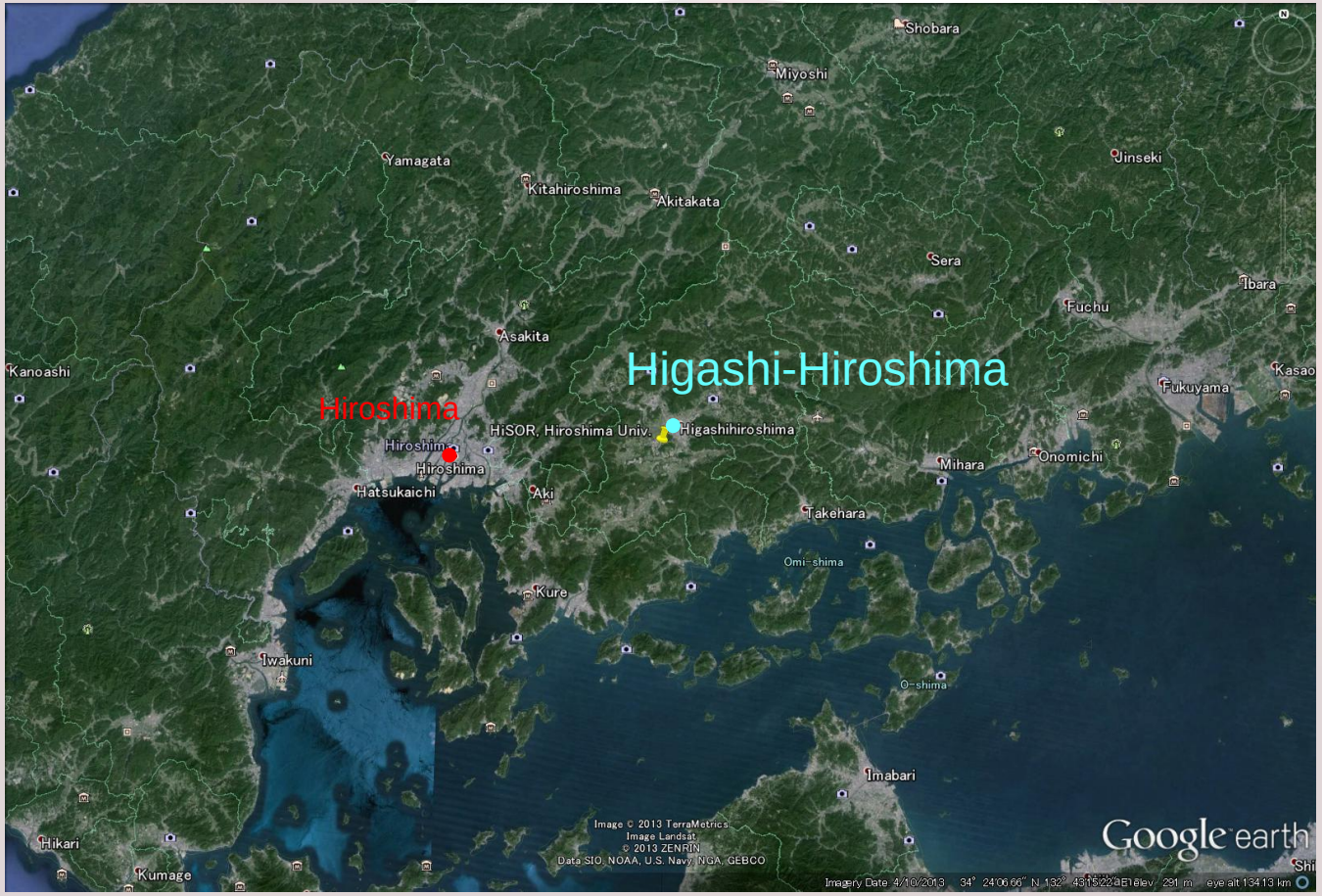
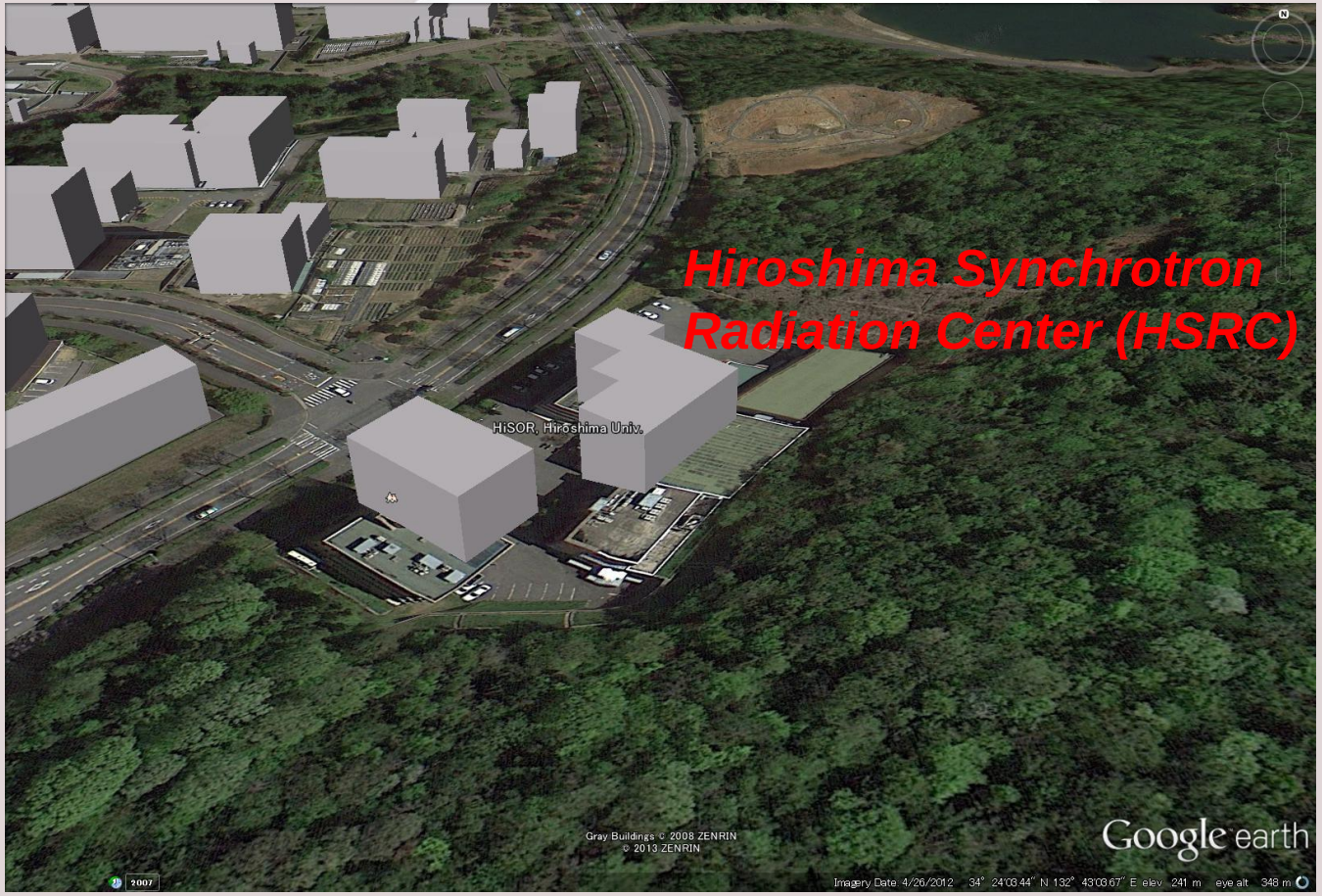
- **Hiroshima, Japan**
- **Hiroshima Synchrotron Radiation Center (HSRC)**



HSRC, Hiroshima University

- Hiroshima, Japan
- Hiroshima Synchrotron Radiation Center (HSRC)



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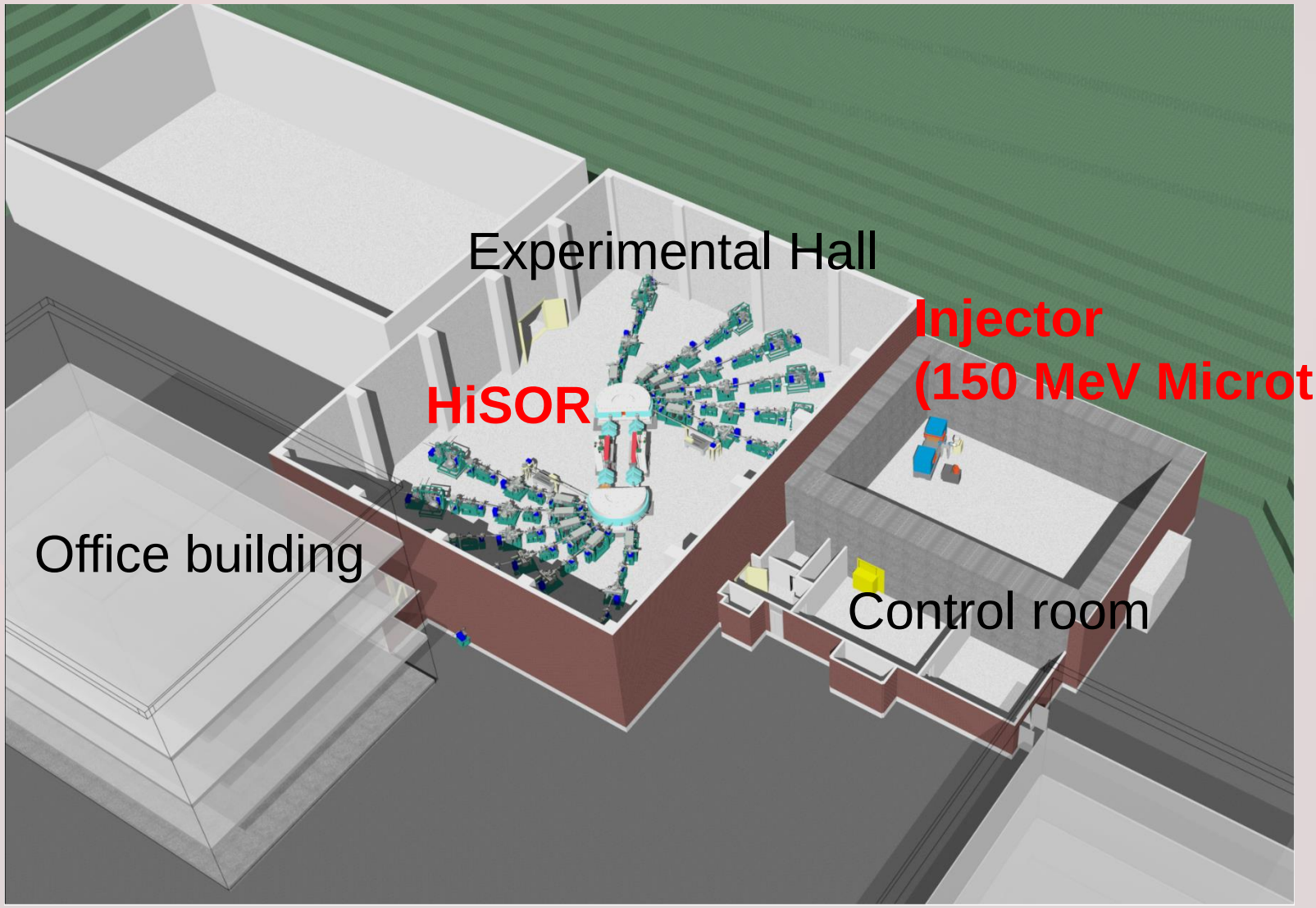
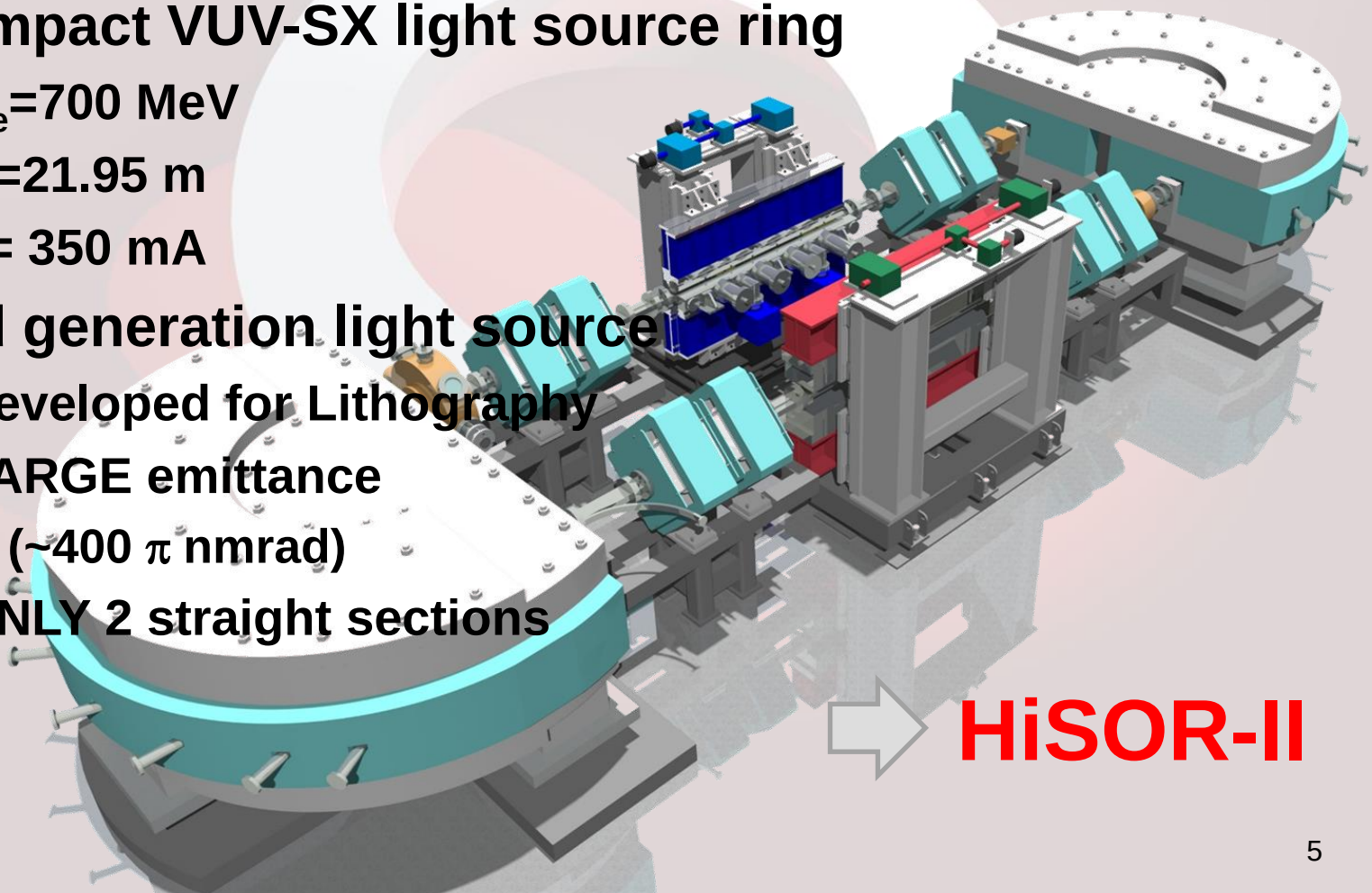


Compact SR ring 'HiSOR'

- HiSOR Storage ring
  - Built in 1996
  - Compact VUV-SX light source ring
    - E_e=700 MeV
    - C=21.95 m
    - I = 350 mA
  - 2nd generation light source
    - Developed for Lithography
    - LARGE emittance
      - (~400 π nmrad)
    - ONLY 2 straight sections



HiSOR-II

Future Plan ‘HiSOR-II’

- Concept of New SR ring ‘HiSOR-II’
  - Beam energy 700 MeV
    - VUV-SX light source ring
  - LOW emittance (<20 πnmrad)
  - Straight sections for IDs
  - Top-up injection
    - with Booster or Linac ?
  - Compact SR ring ! (C~50 m)

Theoretical Min. Emittance

$$\varepsilon_{TME} = \frac{C_q \gamma^2 \theta^3}{12\sqrt{15} J_x}$$

θ :Bending angle of one bend

J_x:Damping partition number ~1

Number of bends	4	6	8	10	12
ε_{TME} [nmrad]	60	18	7.5	3.8	2.2

700 MeV, ε<20 nmrad

6 or 8 bends required !

Lattice for low emittance ring

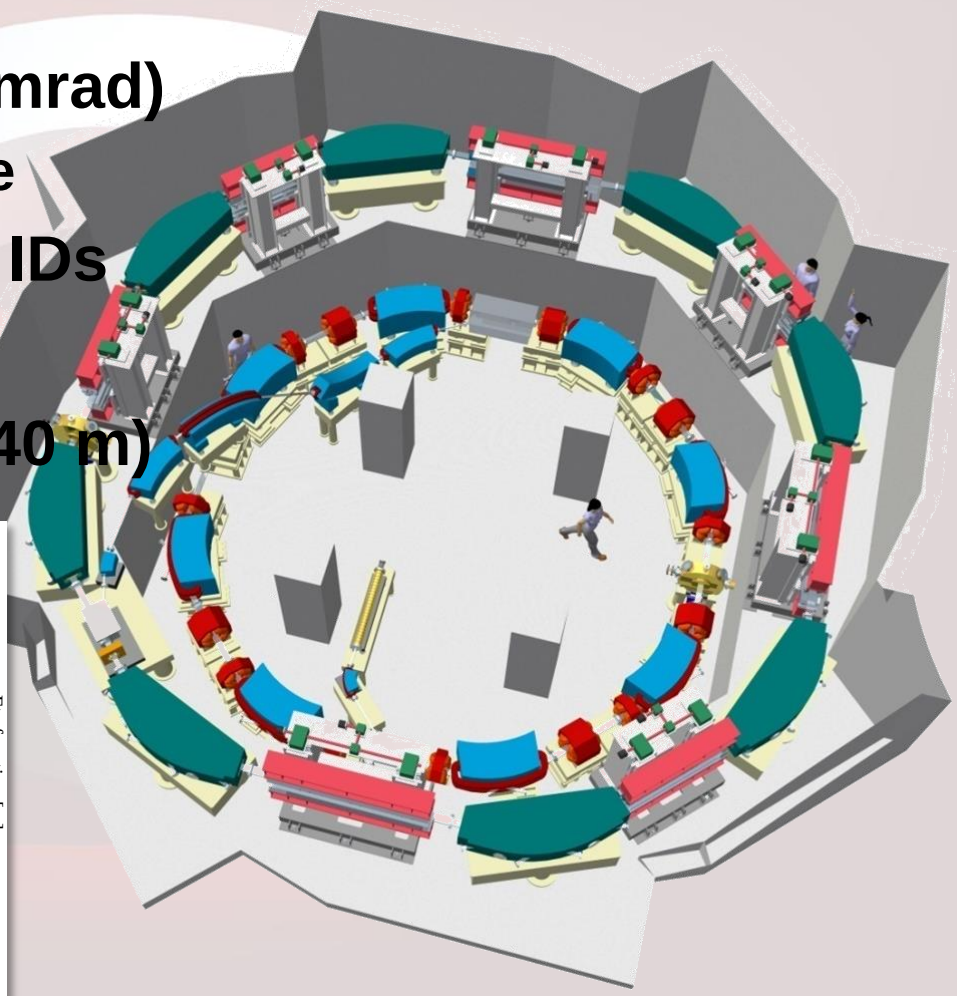
- **Double Bend Achromat**
  - **Dispersion free in straight section**
  - **Achromatic optics**

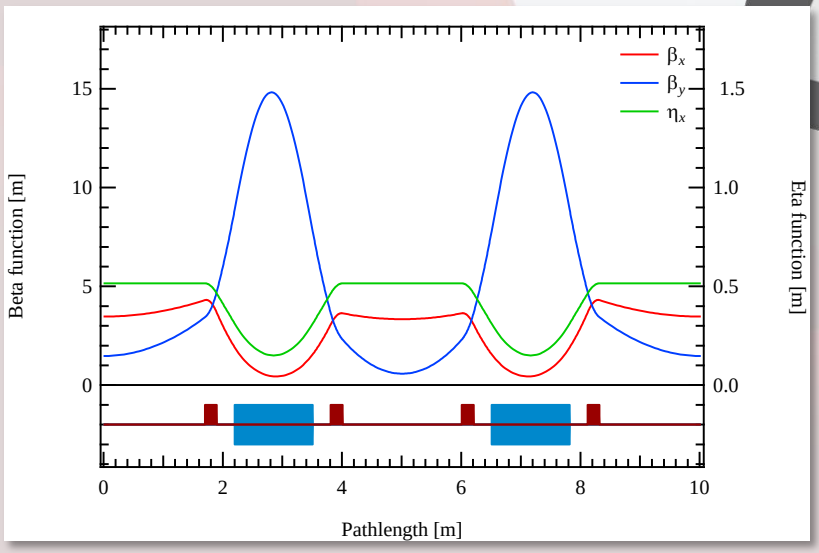
- **Extended DBA**
  - **Non-achromatic optics**
  - **Emittance is lower than DBA**

- **MAX-III type lattice**
  - **Super low emittance**
  - **Bending magnets have defocus quad. field**
    - **Required combined magnets**

Future Plan ‘HiSOR-II’

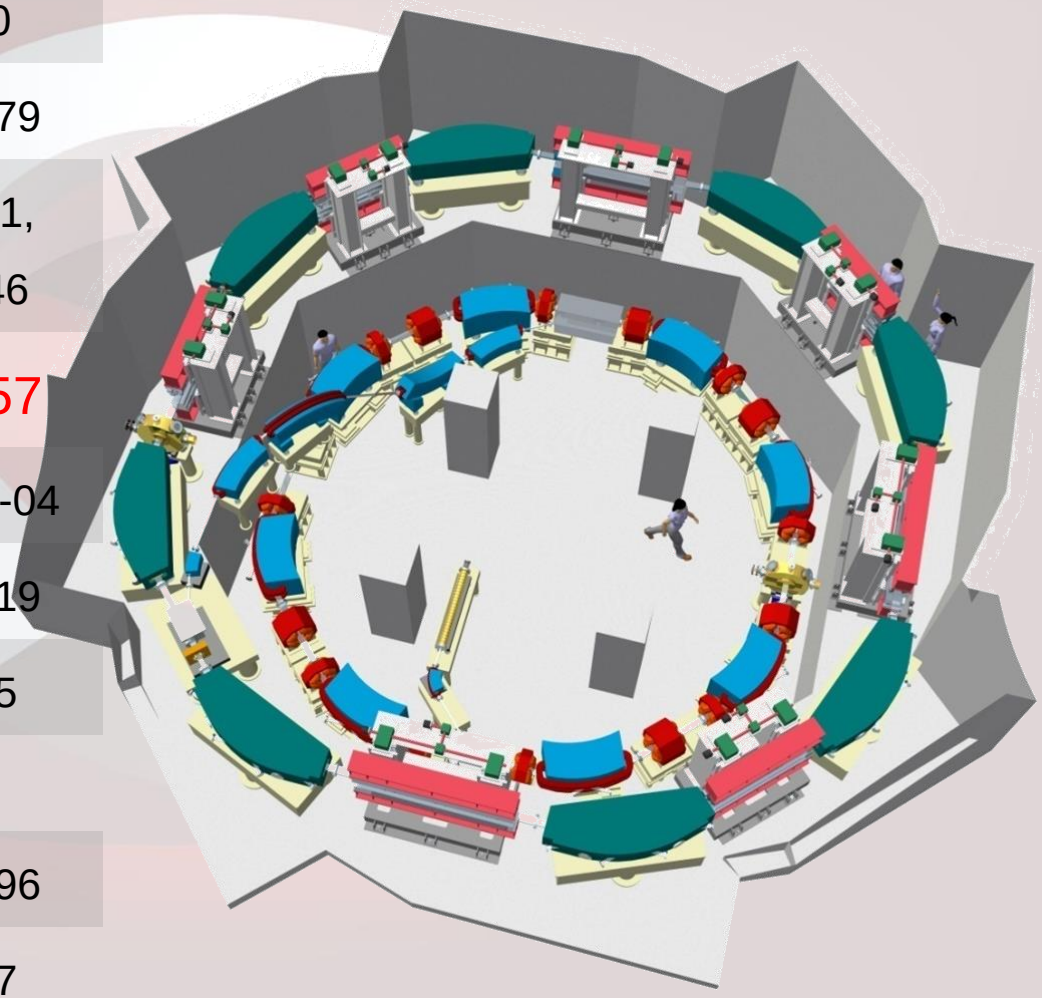
- New SR ring ‘HiSOR-II’
  - Low emittance (13.6 nmrad)
    - Based on MAX-III lattice
  - 8 straight sections for IDs
  - Top-up injection
  - Compact SR ring! (C~40 m)





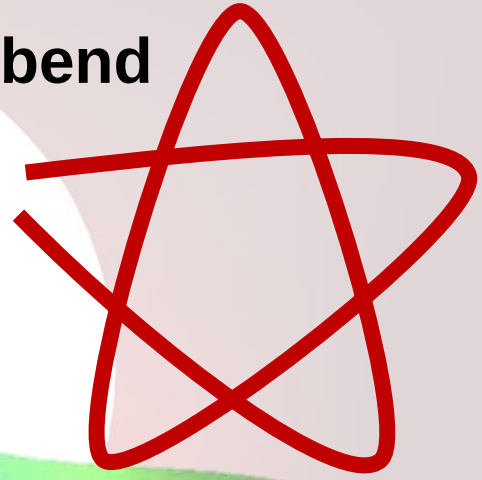
Future Plan ‘HiSOR-II’

Beam energy [MeV]	700
Circumference [m]	40.079
Betatron tune	3.761, 2.846
Natural emittance [nmrad]	13.57
Momentum spread	5.79e-04
Momentum compaction	0.0319
Bunch length [mm]	17.5
Harmonic number	27
RF frequency [MHz]	201.96
Touschek lifetime [min]	40.7
Straight sections	3.4 m×4 2.0 m×4



Compact SR ring

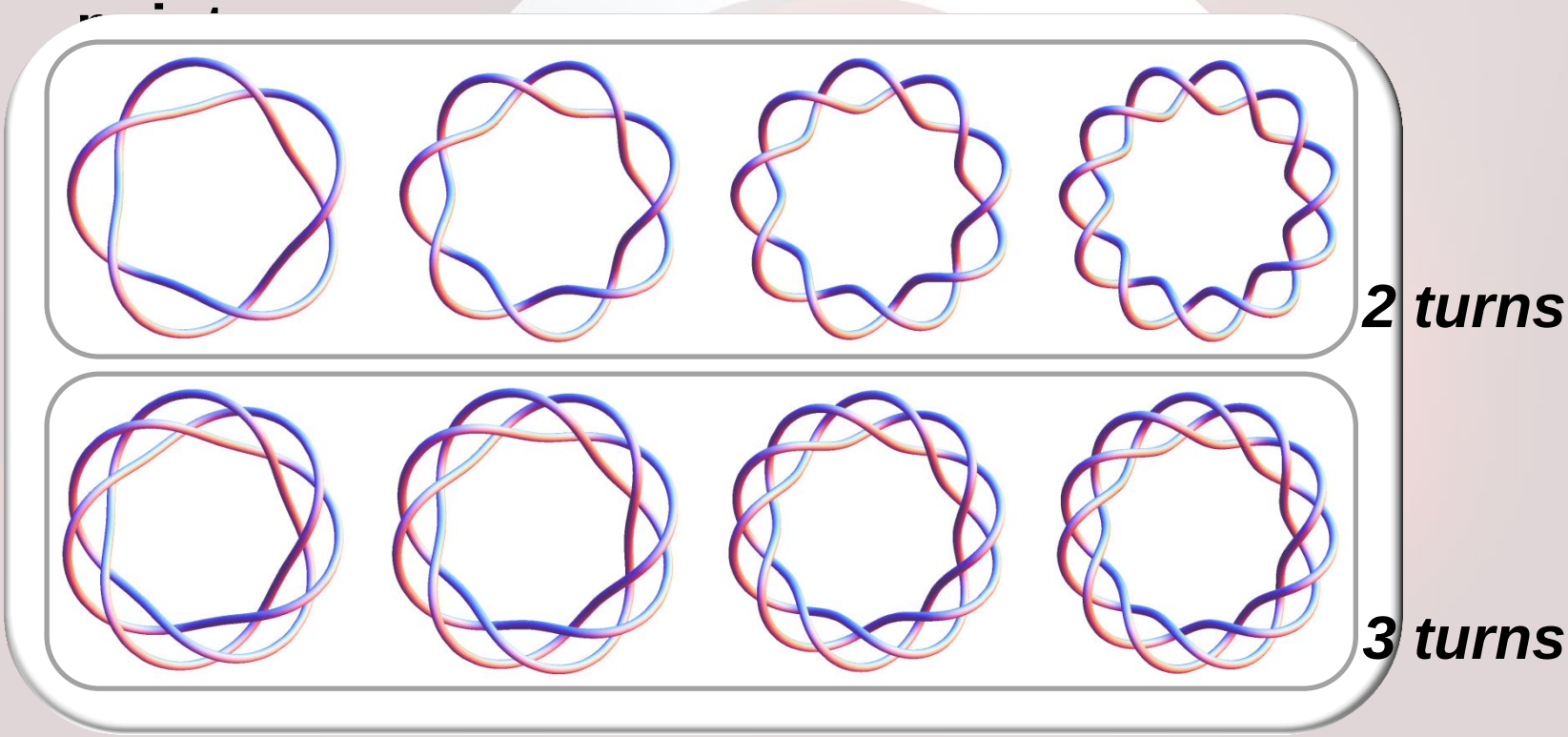
- Merit
  - Compact magnets and small radius of bend
  - Not required huge site
- Demerit
  - Only several straight sections for IDs
  - Short circumference
    - Long circumference for TOF (Time Of Flight) experiments



- What's a structure which is long but compact ?
  - Möbius strip
    - 2 turns around the ring before returning to start point
  - Star polygon

New idea for storage ring

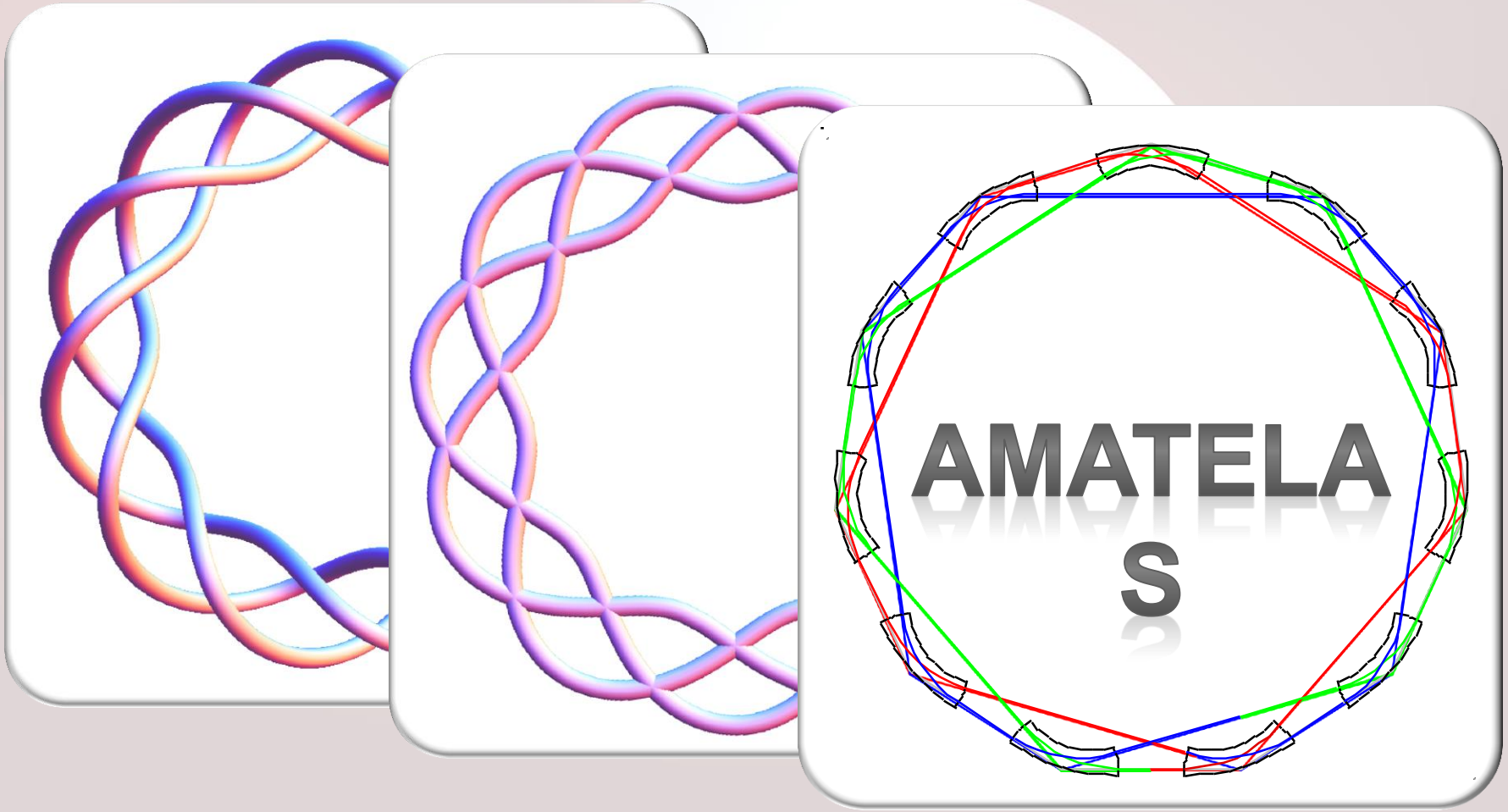
- **Torus knot**
  - **Multi-turn around the ring before returning to start**



Can we apply these shape to Particle Accelerators ?

Torus knot to accelerators

- **(3,11)-torus knot**



AMATELAS

- **AMATELAS is …**
  - **Architecture of**
  - **Multi-turn**
  - **Accumulator on**
  - **Torus-knot**
  - **Eccentric**
  - **Lattice**
  - **Accommodate with many**
  - **Straight sections**

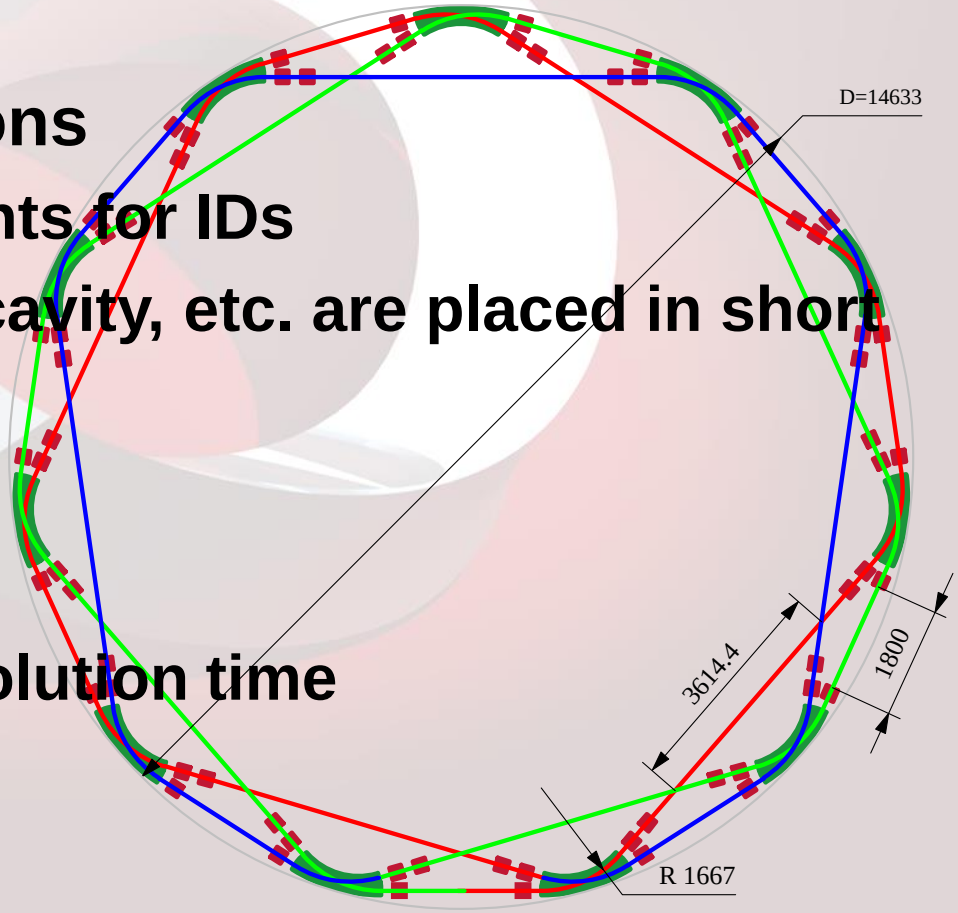
- **天照(Amaterasu)**
  - **Sun Goddess in the Japanese myth**

AMATELAS for HiSOR-II

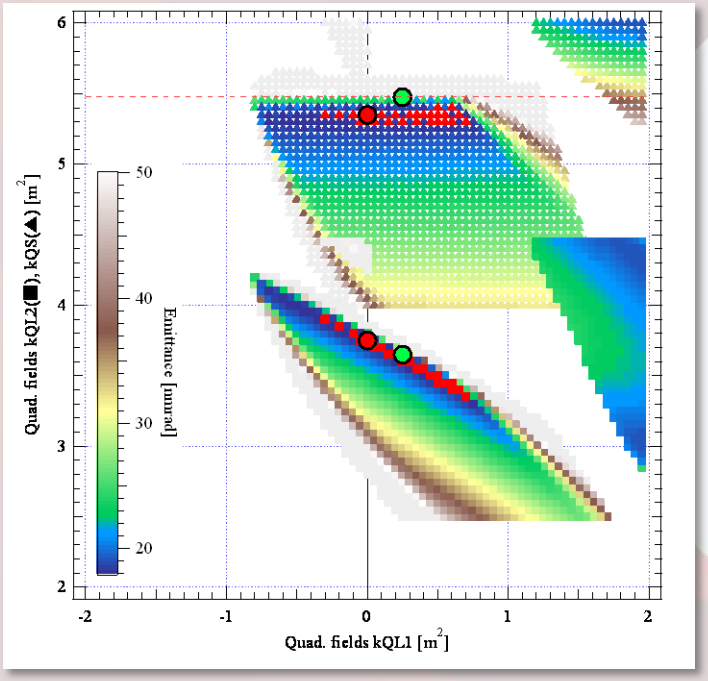
- **Lattice type**
  - **MAX-III / DBA**

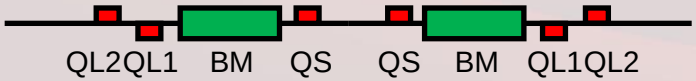
- **11 Long straight sections**
  - **Almost all long straights for IDs**
  - **Injection section, RF cavity, etc. are placed in short straights**

- **3-turn orbit**
  - **3 times long orbit/revolution time**

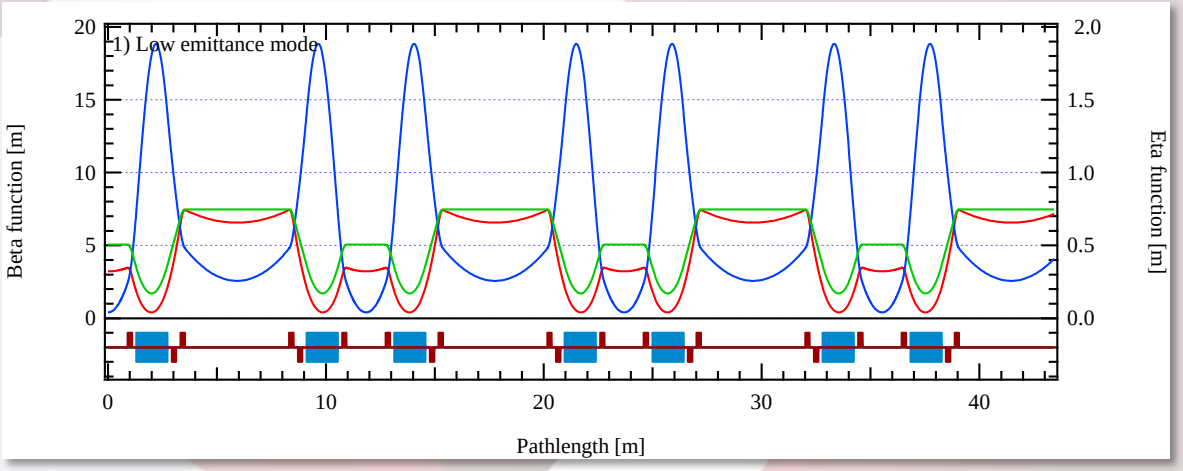


Operating point and optics

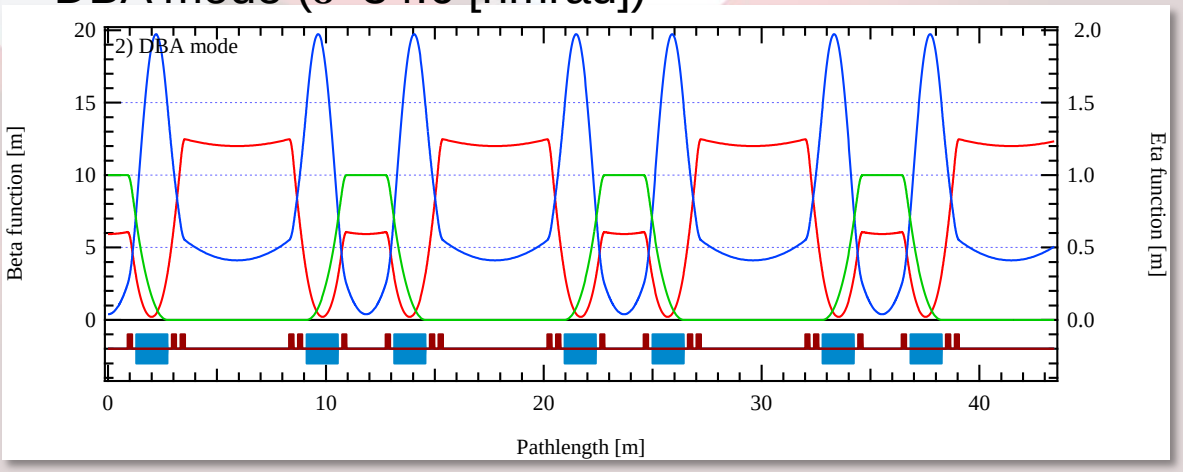




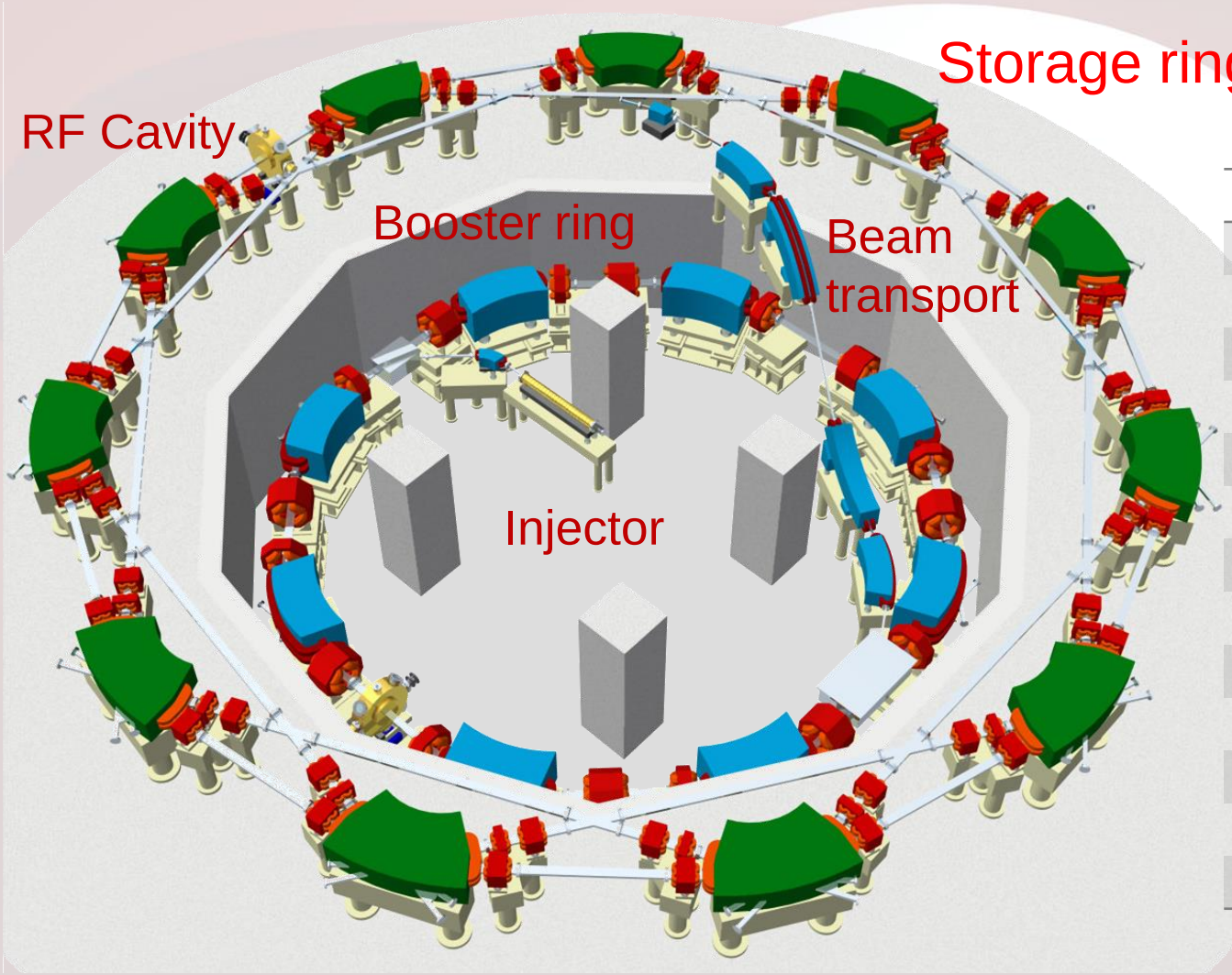
- Low emittance mode (ε=17.7 [nmrad])



- DBA mode (ε=34.6 [nmrad])



HiSOR-II with AMATELAS



AMATELAS - (3,11) torus knot	
Beam energy	700 MeV
Circumference	130.3 m
Diameter	14.6 m
Betatron tune	(10.54, 6.60)
(DBA mode)	(10,78, 6.92)
Emittance	17.7 nmrad
(DBA mode)	34.6 nmrad
Chromaticity	(+1.0, +1.0)
Straight sections	3.6 m×11
	1.8 m×11
Harmonic num.	88 ?
RF frequency	~200 MHz ?
Touschek life time	> 2 hours ?

Diffraction limited light

- Recent trend is ‘Diffraction limited light’
  - Multi bend lattice
    - Short bend and focusing quadrupole
    - Low dispersion function in the bending magnet
- Required emittance for VUV light source ring
  - Emittance $\varepsilon \leq \frac{\lambda}{4\pi}$
  - Photon energy Eγ ~ 10 eV
    - From typical undulator of HiSOR

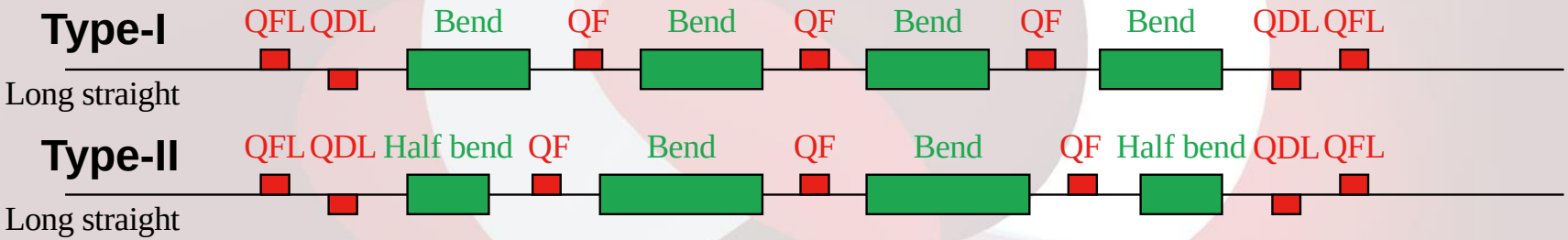
$$\varepsilon \leq 10\ [\mathrm{nmrad}]$$

It is not difficult !!

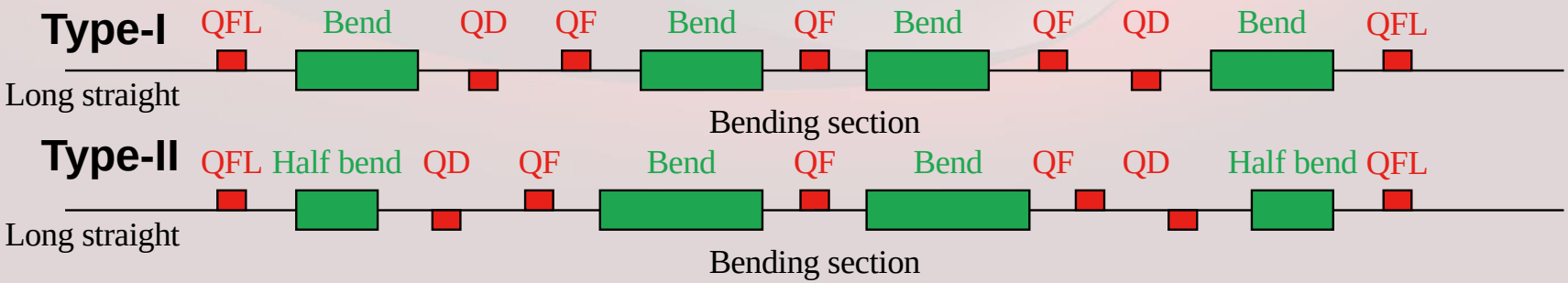
Multi-bend lattices

- **Double bend (Original)**

- **4 Bend (doublet is outside bending section)**



- **4 Bend (doublet is inside bending section)**



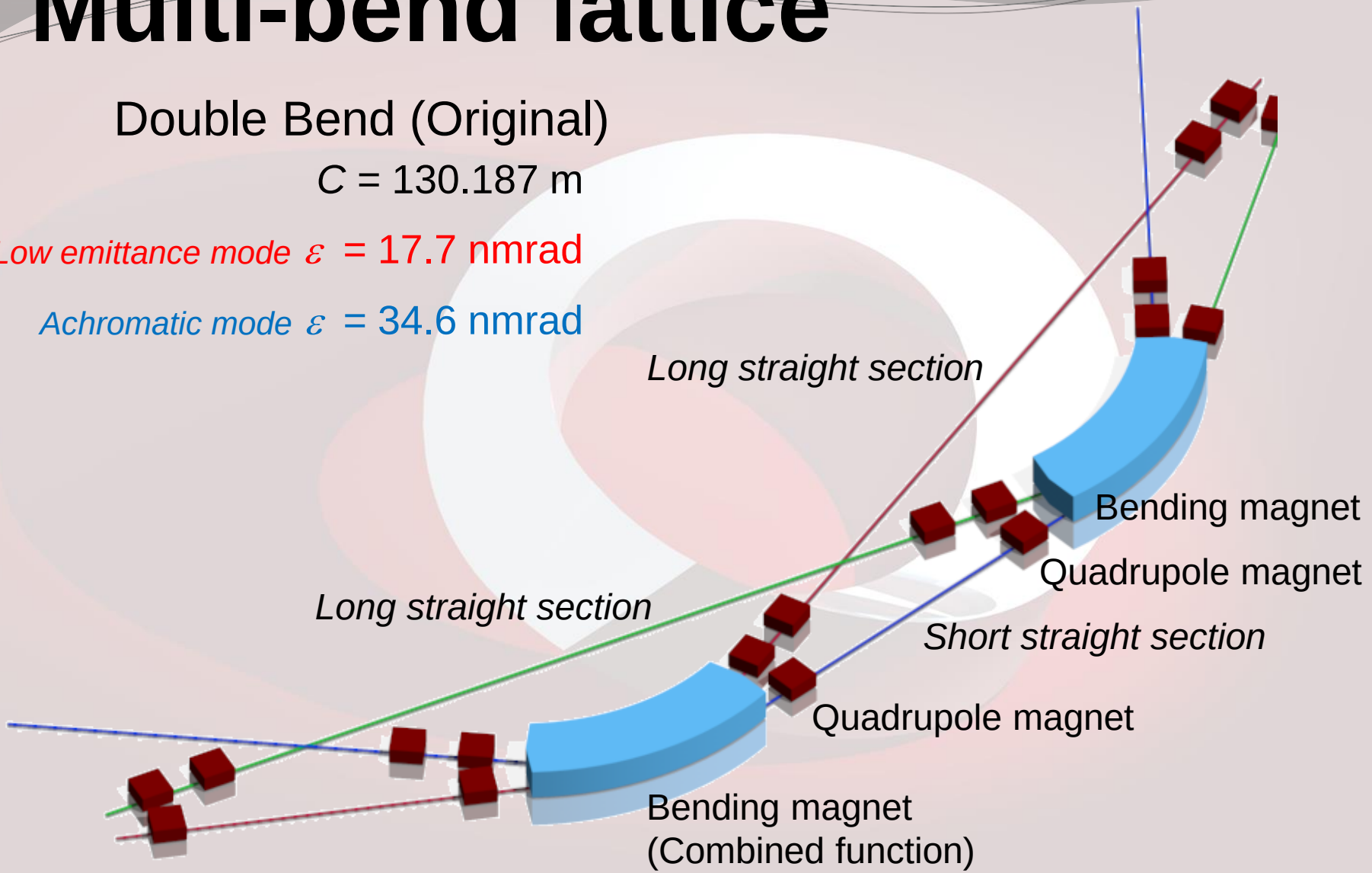
Multi-bend lattice

Double Bend (Original)

C = 130.187 m

Low emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad



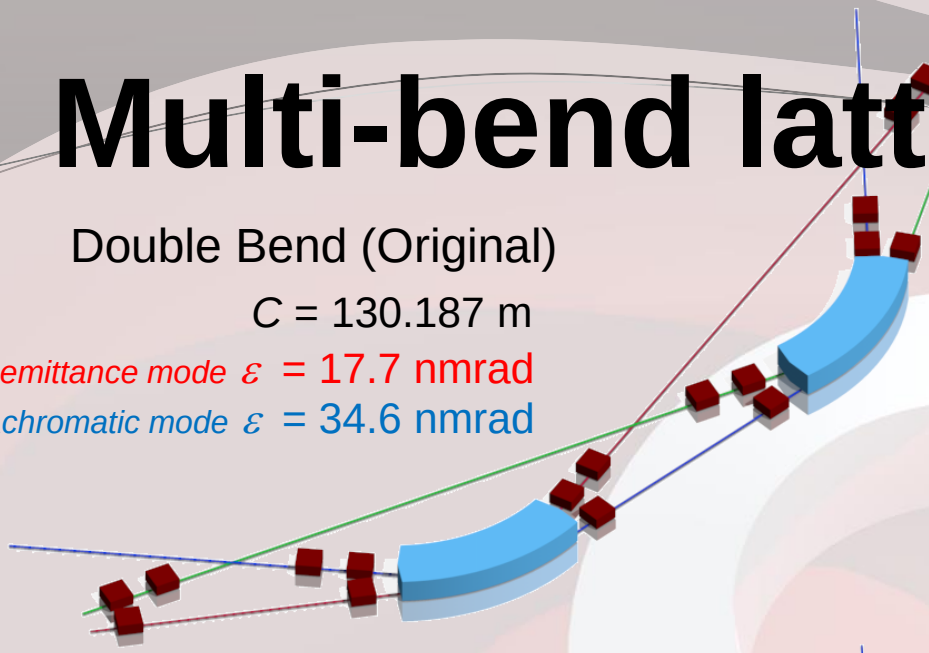
Multi-bend lattice (type-I)

Double Bend (Original)

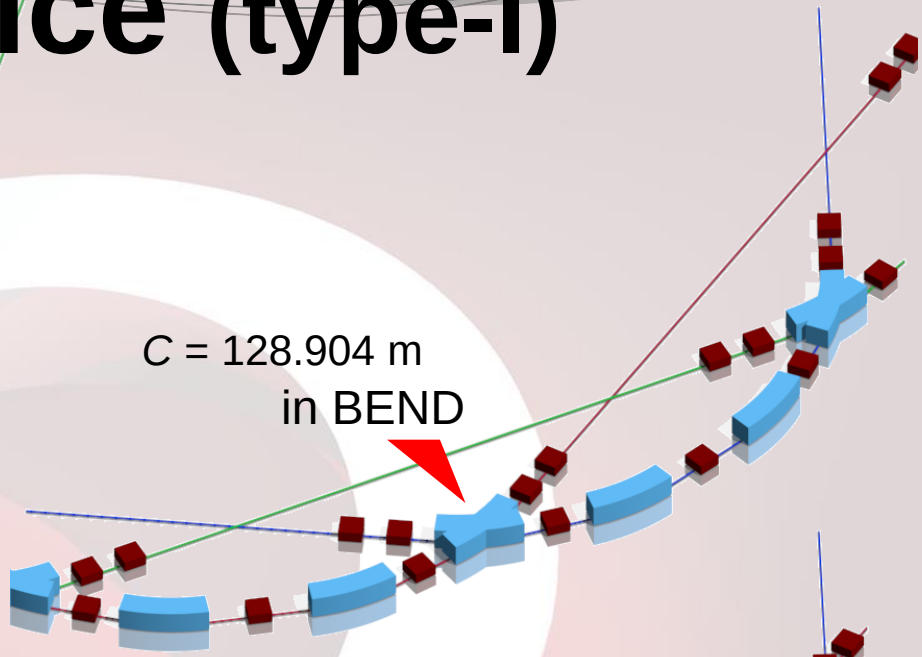
C = 130.187 m

ow emittance mode ε = 17.7 nmrad

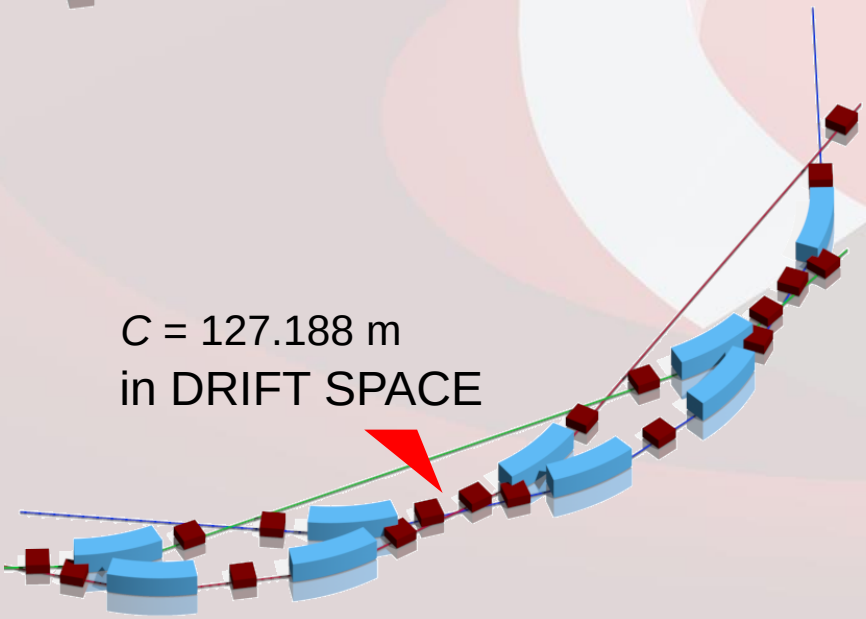
Achromatic mode ε = 34.6 nmrad



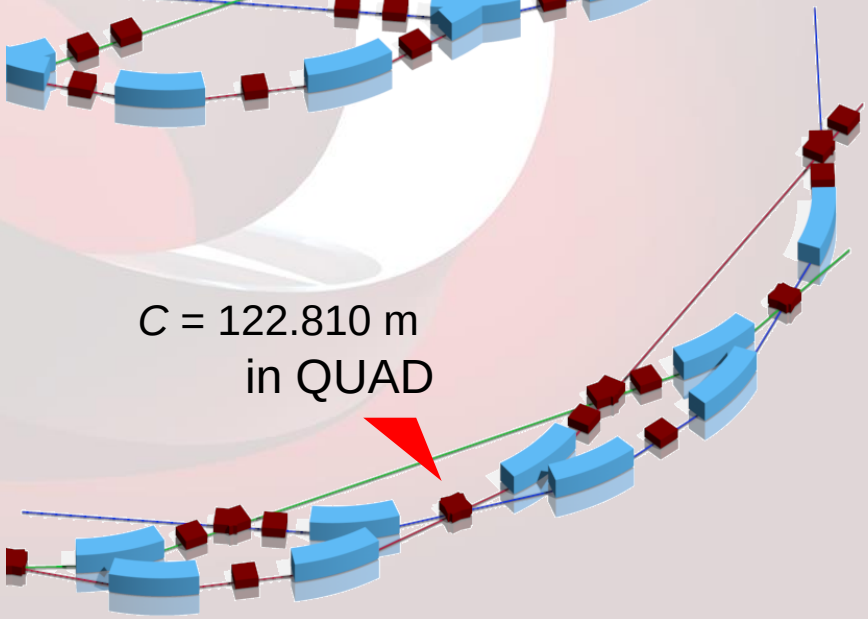
C = 128.904 m
in BEND



C = 127.188 m
in DRIFT SPACE



C = 122.810 m
in QUAD



Multi-bend lattice (type-I)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad

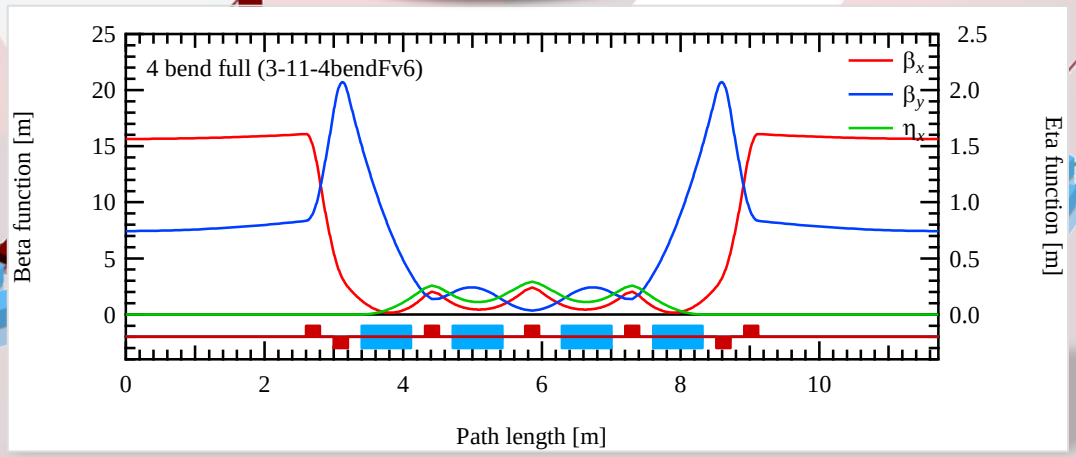
ε = 6.70 nmrad

C = 128.904 m

in BEND

C = 127.188 m

in DRIFT SPACE



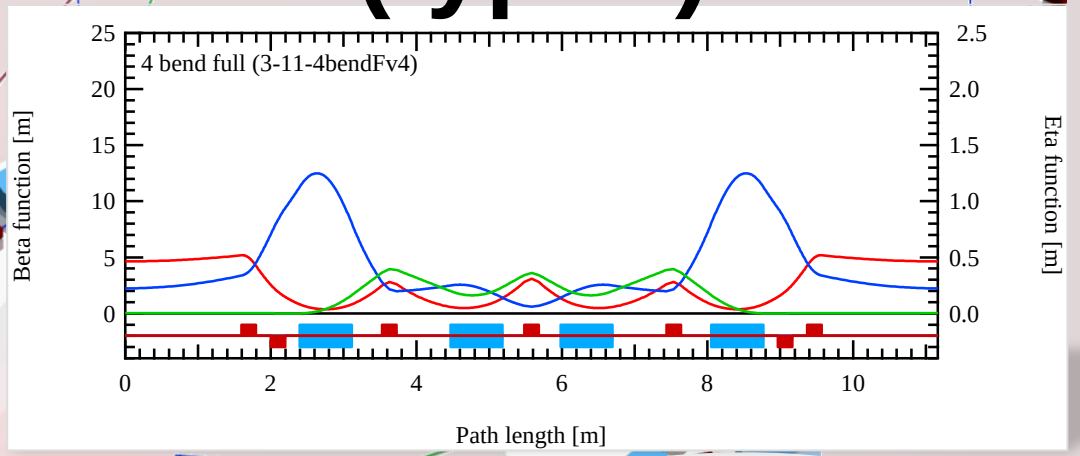
Multi-bend lattice (type-I)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad



ε = 10.47 nmrad

C = 122.810 m
in QUAD

C = 127.188 m
in DRIFT SPACE

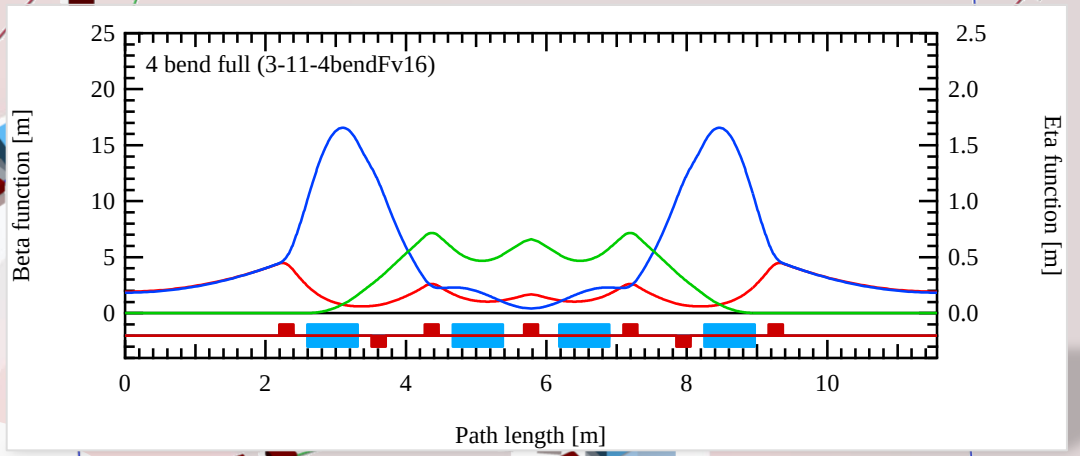
Multi-bend lattice (type-I)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad



ε = 25.80 nmrad

C = 127.188 m

in DRIFT SPACE

10.47 nmrad

C = 122.810 m

in QUAD

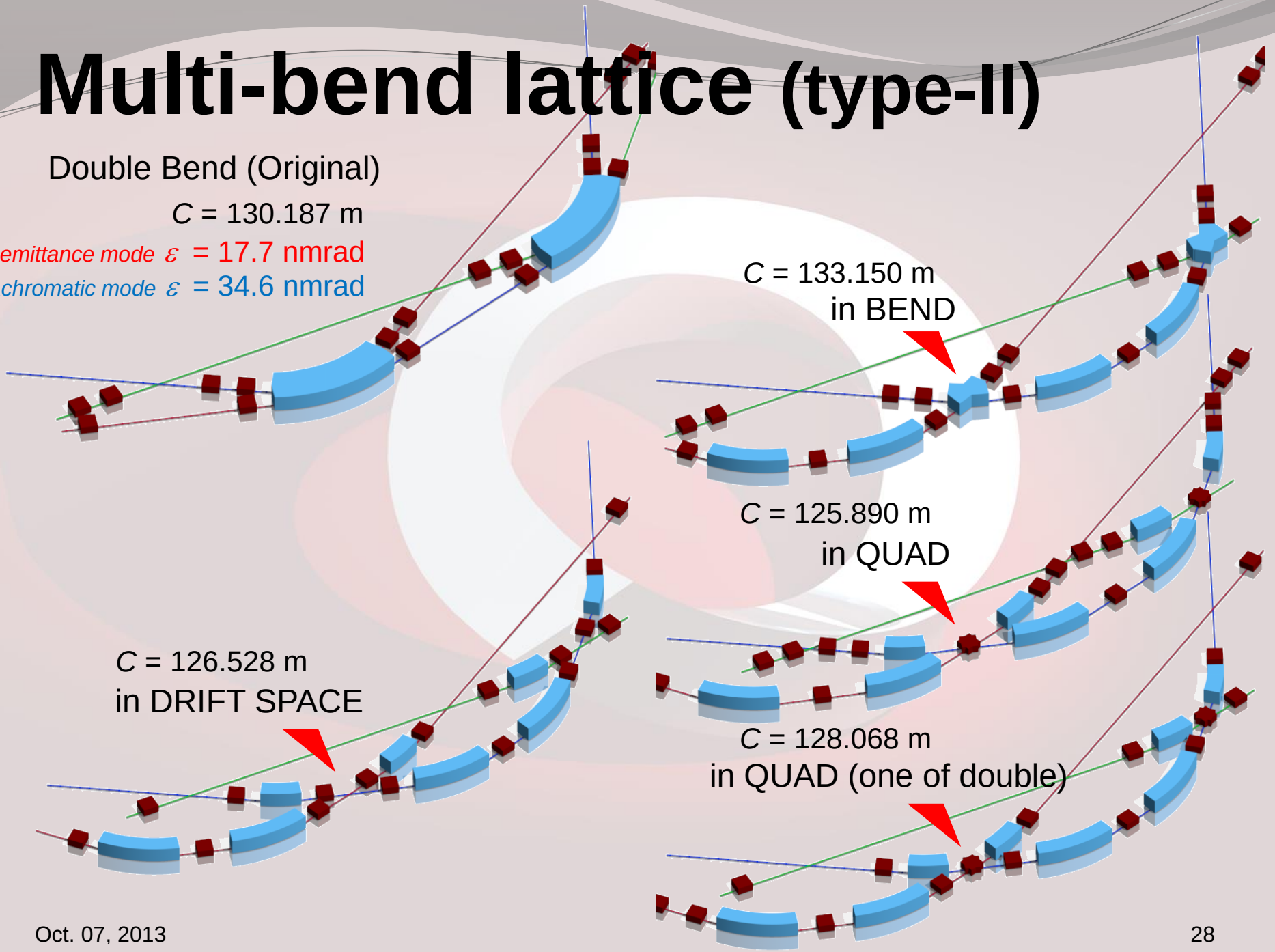
Multi-bend lattice (type-II)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad



Multi-bend lattice (type-II)

Double Bend (Original)

C = 130.187 m

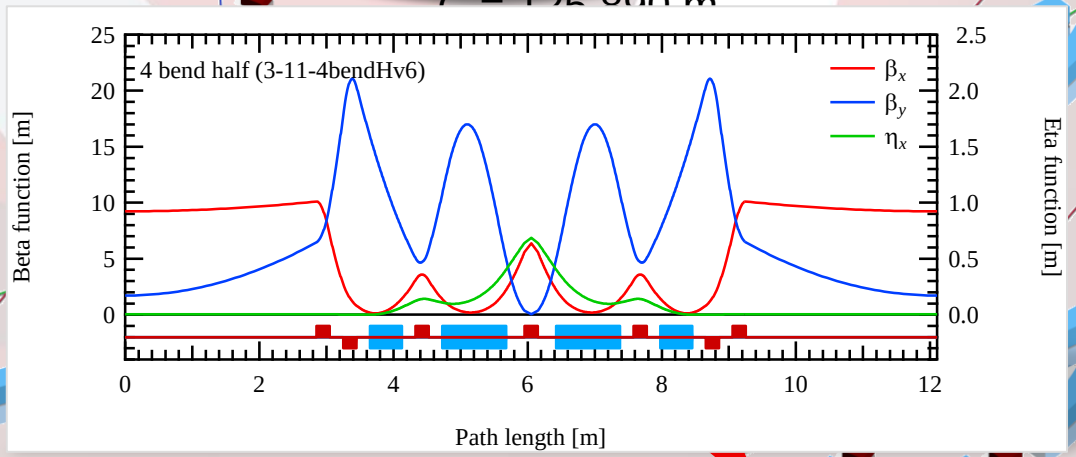
ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad

ε = 10.91 nmrad

C = 133.150 m
in BEND

C = 126.528 m
in DRIFT SPACE



Multi-bend lattice (type-II)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad

ε = 10.91 nmrad

C = 133.150 m

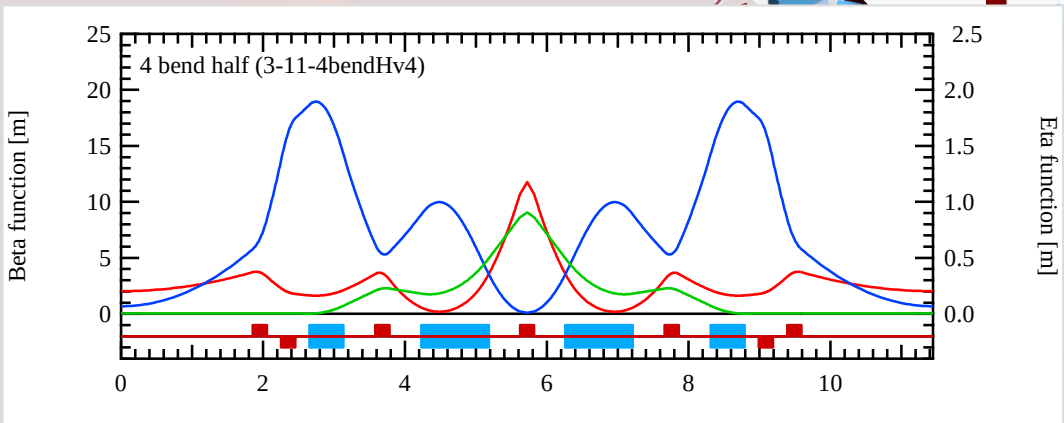
in BEND

ε = 22.97 nmrad

C = 125.890 m

in QUAD

C = 126.528 m



C = 128.068 m

in QUAD (one of double)

Multi-bend lattice (type-II)

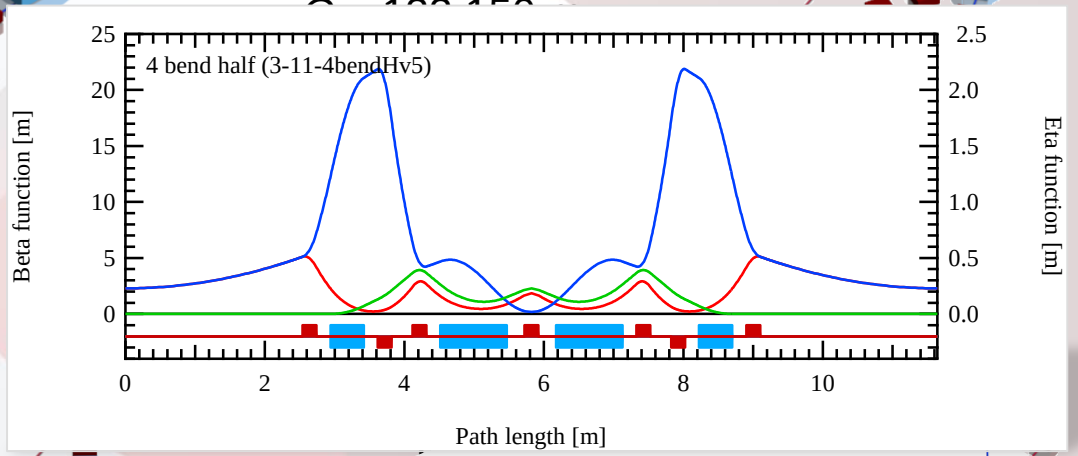
Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad

ε = 10.91 nmrad



C = 126.528 m
in DRIFT SPACE

ε = 9.32 nmrad

C = 128.068 m
in QUAD (one of double)

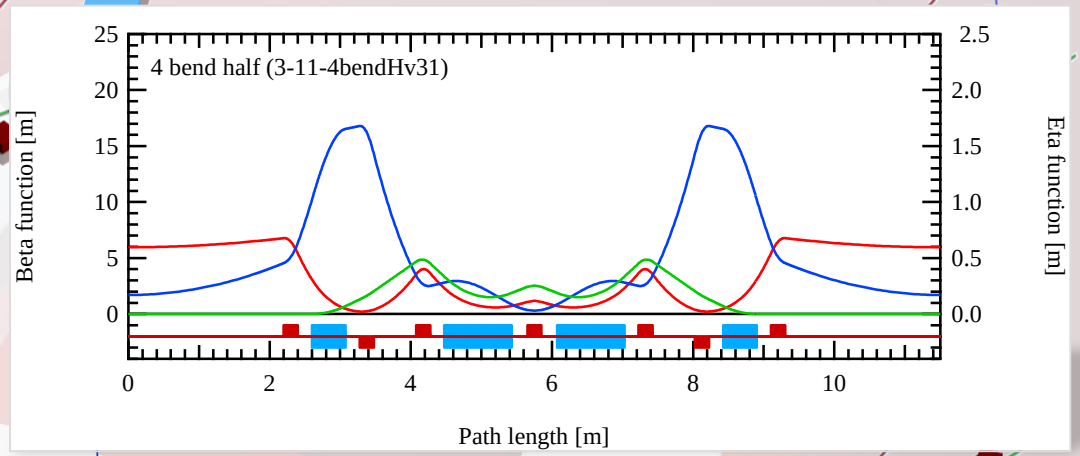
Multi-bend lattice (type-II)

Double Bend (Original)

C = 130.187 m

ow emittance mode ε = 17.7 nmrad

Achromatic mode ε = 34.6 nmrad



ε = 11.94 nmrad

C = 126.528 m

in DRIFT SPACE

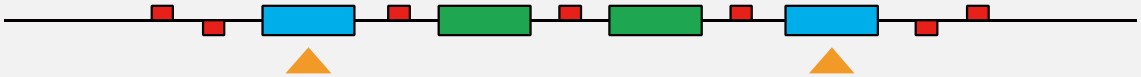
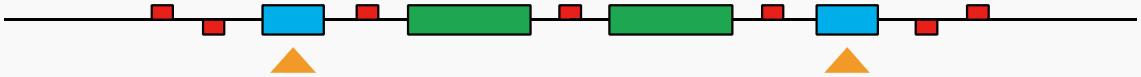
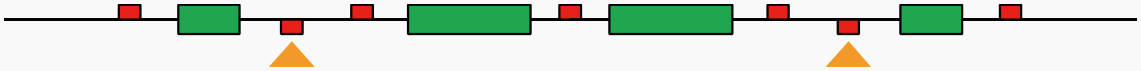
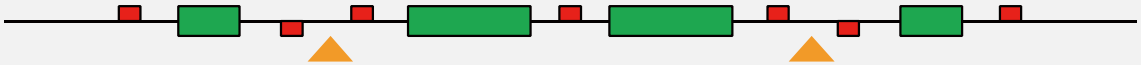
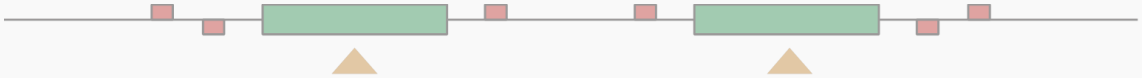
= 22.97 nmrad

in QUAD

ε = 9.32 nmrad

in QUAD (one of double)

Table of parameters

Lattice / Crossing point	Orbit length [m]	Emittance [nmrad]
	128.904	6.70
	122.810	10.47
	127.188	25.80
	133.150	10.91
	125.890	22.97
	128.068	9.32
	126.528	11.94
	130.187	34.6

Conclusion

- **We are designing a new ring for our future plan**
  - **Ultra-low emittance light source ring**
    - **Multi-bend lattice**
  - **Diffraction limited light**
    - **10 nmrad for photon energy of 10 eV**
  - **We have to consider about…**
    - **Chromaticity correction**
    - **Dynamic aperture**
    - **Injection scheme**
    - **etc.**

How about this idea for APS-U ?

Thank you for your attention!