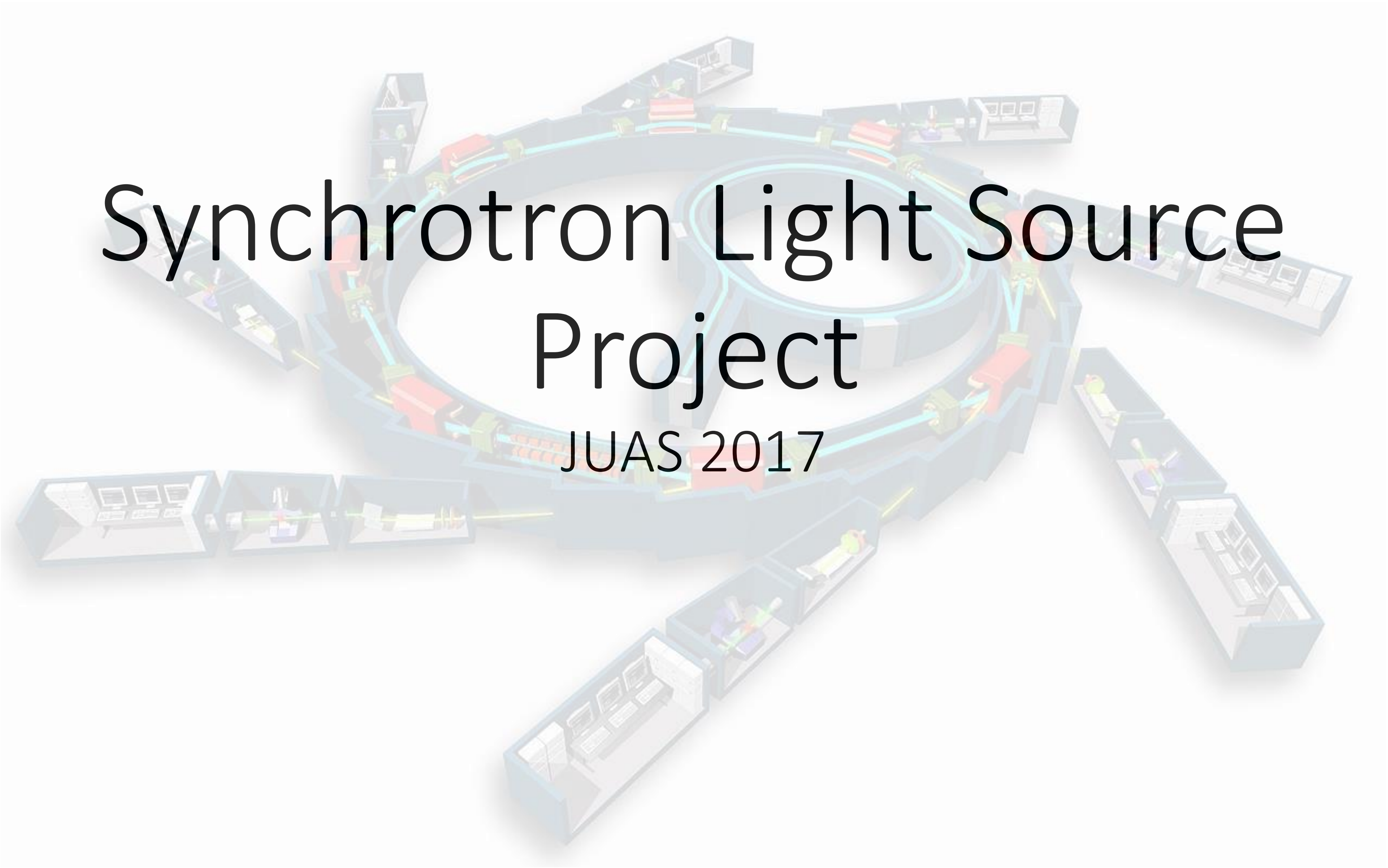
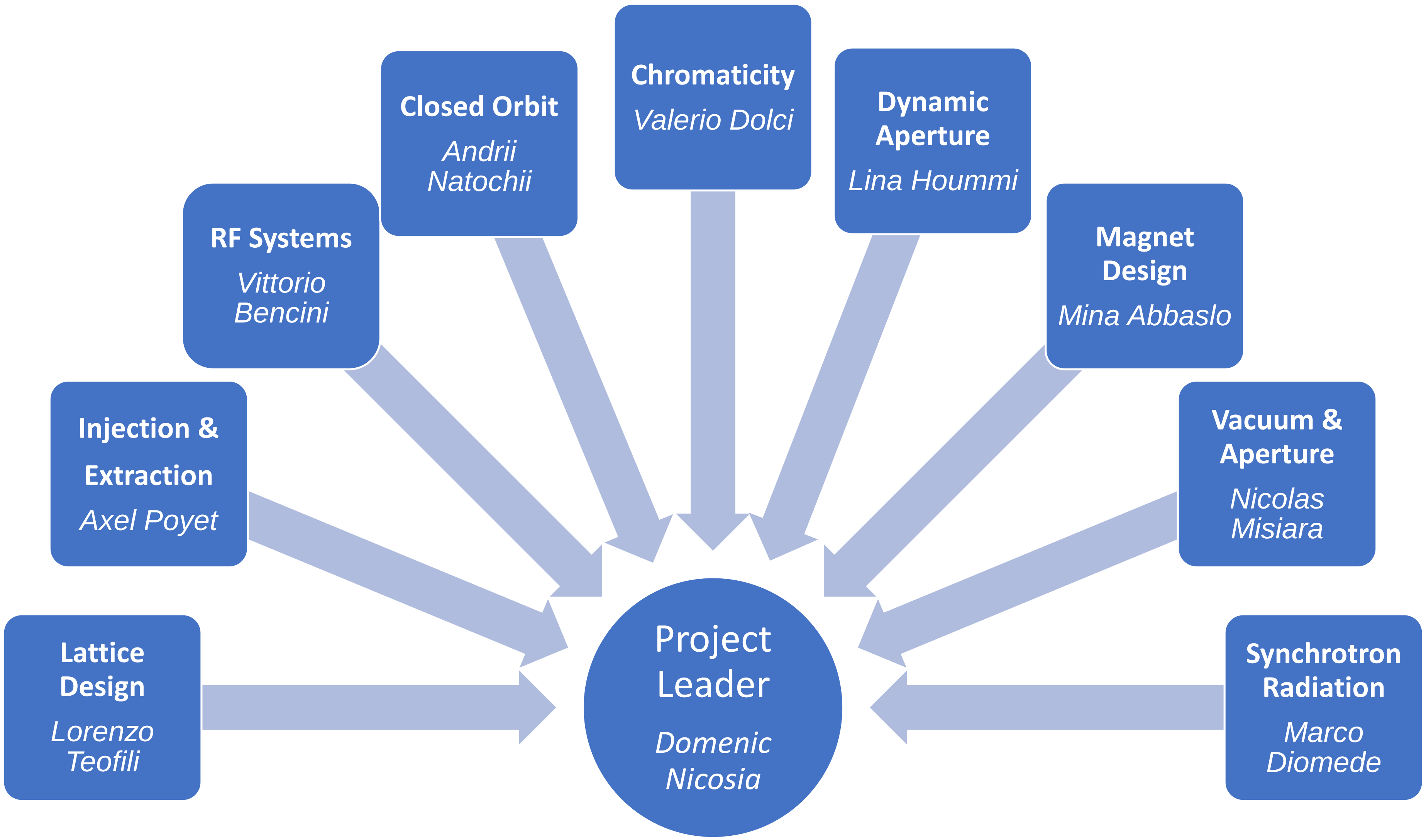
Synchrotron Light Source Project

JUAS 2017



juas
Joint Universities Accelerator School

Group Structure



juas
Joint Universities Accelerator School

Content

- Introduction
- Lattice design
- Injection/Extraction
- RF
- Closed orbit
- Chromaticity
- Dynamic Aperture & Resonances
- Magnet considerations
- Aperture & Vacuum considerations
- Synchrotron radiation

Aim

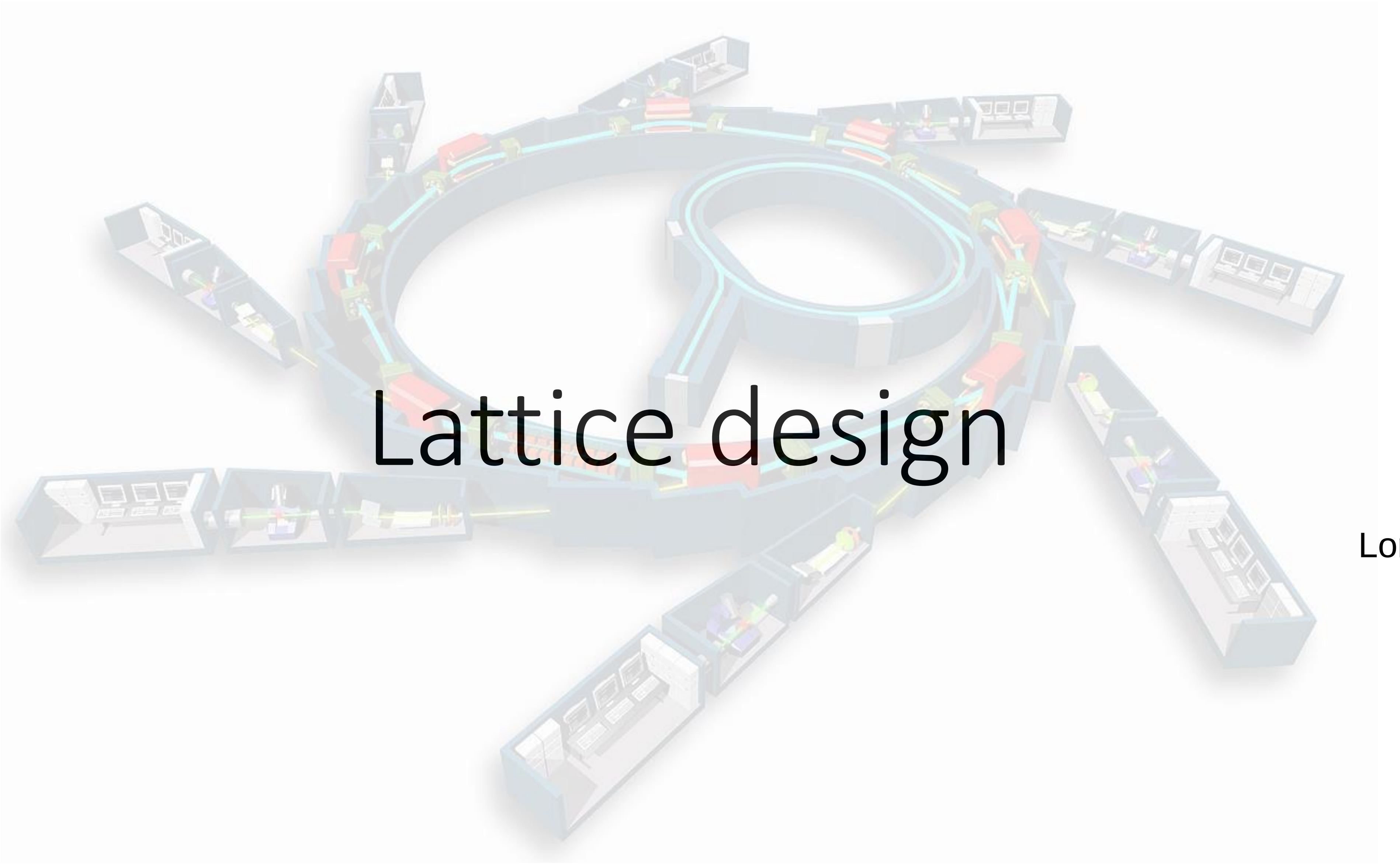
- To upgrade a synchrotron light facility with a new 3 GeV high-brightness ring, whilst keeping the existing 2GeV injector.

Requirements

- Maximum permitted circumference: 700m
- Lattice: 2 super periods connected by 2 dispersion-free regions
- Super period contains DBA 12 bending cells
- 500MHz RF system, 2GeV to 3GeV whilst compensating for radiative losses
- Smallest possible equilibrium horizontal emittance

Existing injector parameters

- Existing injector operates at 500MHz
- Single injector pulse contains 225 bunches, duty cycle of 5s
- Bunch length of 40ps (12mm)
- Bunch intensity of 4×10^{10} electrons per bunch
- 1-σ emittances of 0.15 π mm mrad for both in both H & V planes, $\frac{\Delta p}{p} = 10^{-3}$



Lattice design

Lorenzo Teofili,
Heidi
Giacomo
Riccardo
Antonia
Paul
Ángel
Ezgy
Antonio
Pang

Joint Universities Accelerator School

The lattice group

And Riccardo

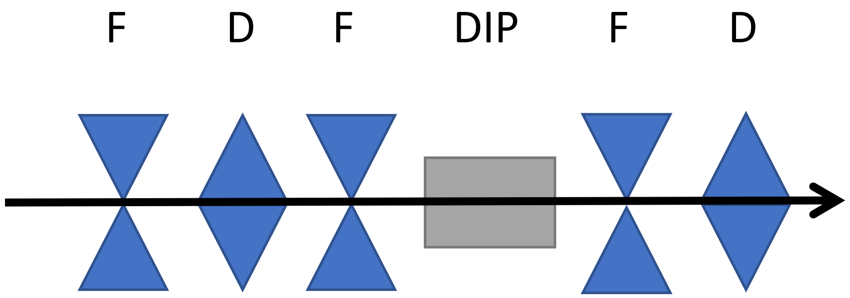
Lorenzo Teofili
Antonia Morabito
Riccardo Mirabelli
Ezgi Ergenlik
Heidi Ayse Rösch
Ángel Ferran Pousa
Paul Thrane
Antonio Paladino
Giacomo Mazzacano
Chengguo Pang

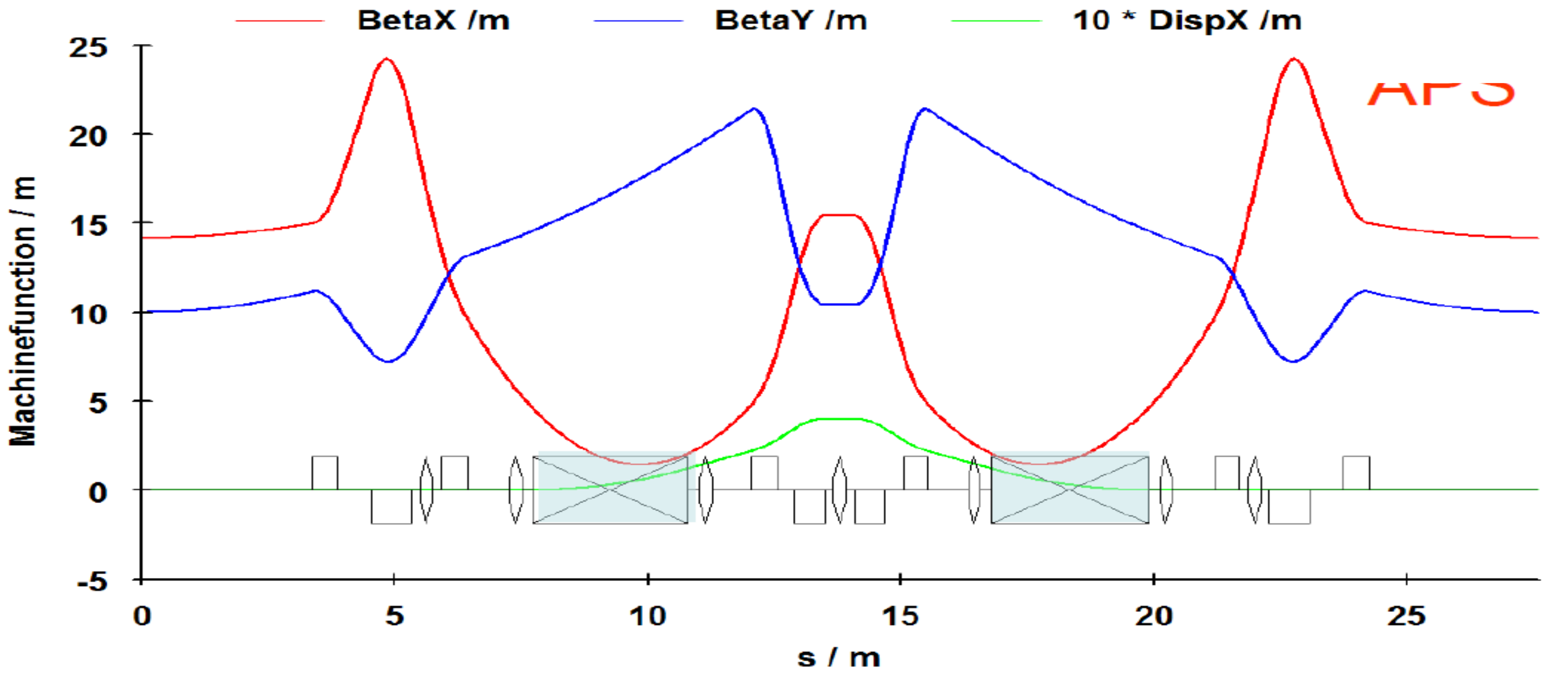
The main task

Improving the lattice of a 2° generation synchrotron light source lattice into a 3° generation one

The key parameter to do that is the emittance! Indeed, the performance of such a machine are optimized if the lattice keep the equilibrium emittance as lower as possible, however, having a reasonable cost!

Standard Cell Double Bend Achromat (DBA)





Cell optimization (Numerical)

Here it is our main Guest
The Equilibrium Emittance

$$E_{x,eq} = A\left[\frac{\int_{Dipole} H(s)ds}{L\rho_0 + 2\rho_0^{2}k\int_{Dipole} D_x(s)ds}\right]$$

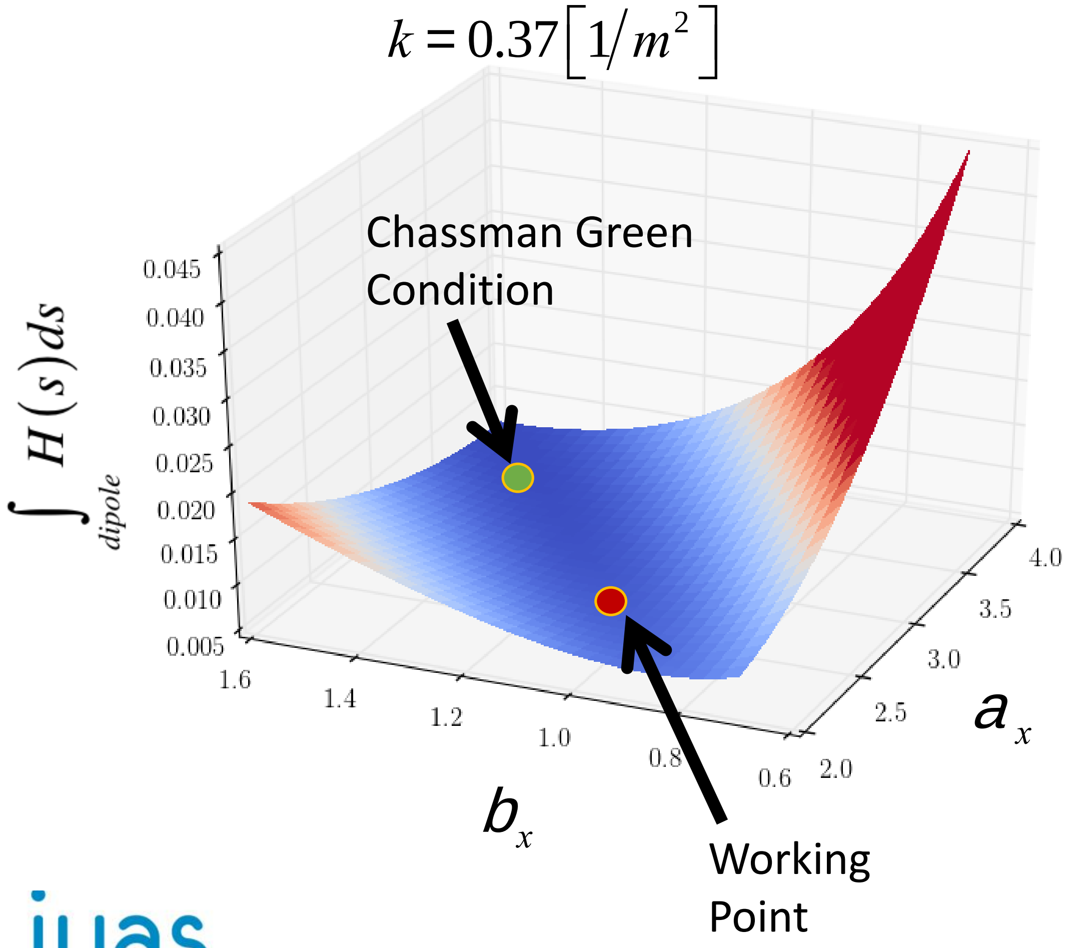
$$H(s) = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$$

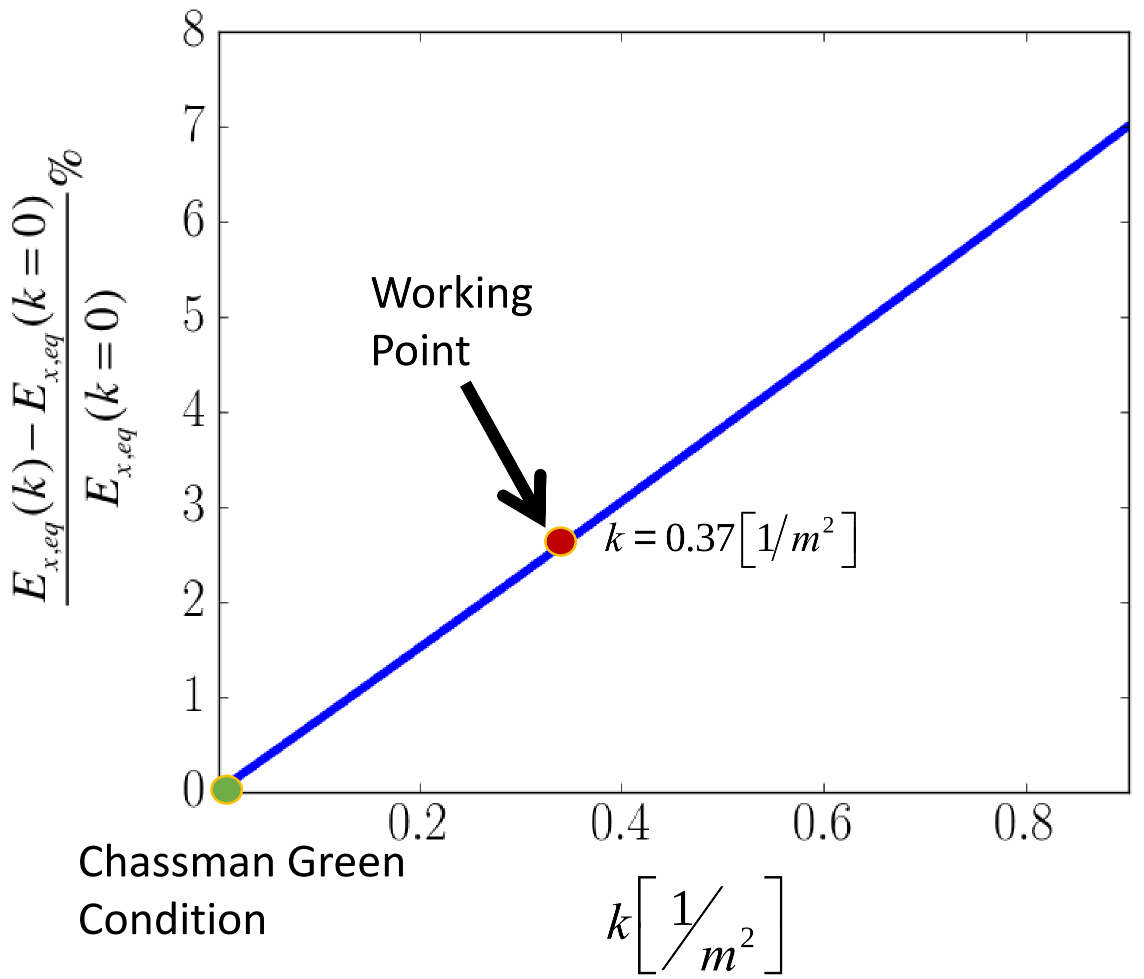
$$\begin{pmatrix}\beta\\ \alpha\\ \gamma\end{pmatrix}_S = \begin{pmatrix} t_{11}^{2} & -2t_{11}t_{12} & t_{12}^{2} \\ -t_{11}t_{21} & t_{11}t_{22}+t_{12}t_{21} & -t_{12}t_{22} \\ t_{21}^{2} & -2t_{21}t_{22} & t_{22}^{2}\end{pmatrix}\begin{pmatrix}\beta\\ \alpha\\ \gamma\end{pmatrix}_0$$

- **First Optimization: Chasman-Green**
  $\beta_x(0) = 1.549L$
  $\alpha_x(0) = 3.873$

- **"Super" Optimization Including the gradient**
  $\beta_x(0) = ?$
  $\alpha_x(0) = ?$

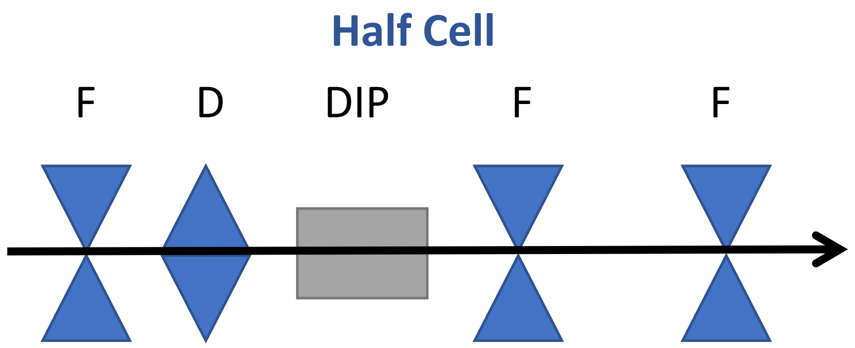
Cell optimization (Numerical)



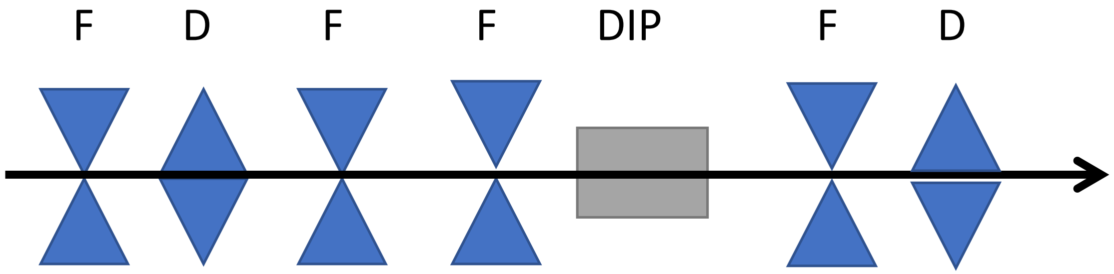


Three different cell designs

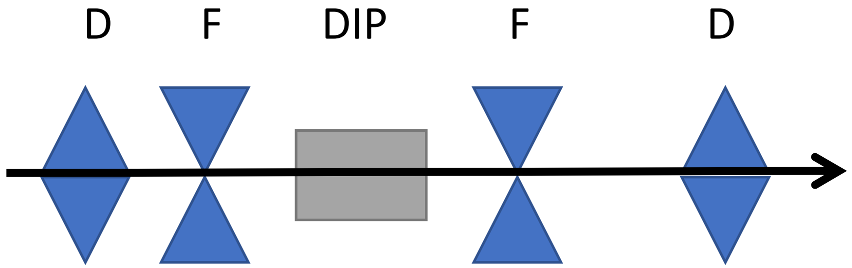
	Cell Values
Beam size (hor.) (mm)	1.28
Beam size (vert.) (mm)	1.90
Eq. Emittance (mm mrad)	0.026 π
Beta max horizontal (m)	20.08
Beta max vertical (m)	44.25
Maximum Disp. (vert.) (m)	0.59



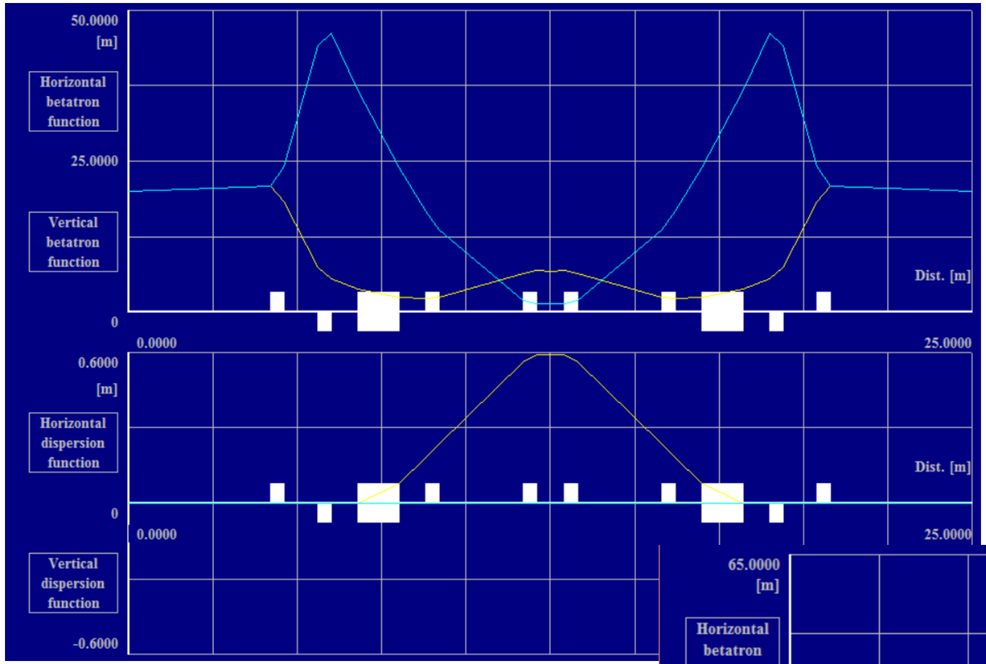
Beam size (hor.) (mm)	1.7
Beam size (vert.) (mm)	3.9
Eq. Emittance (mm mrad)	0.0014 π
Beta max horizontal (m)	33.65
Beta max vertical (m)	64.8
Maximum Disp. (vert.) (m)	0.23



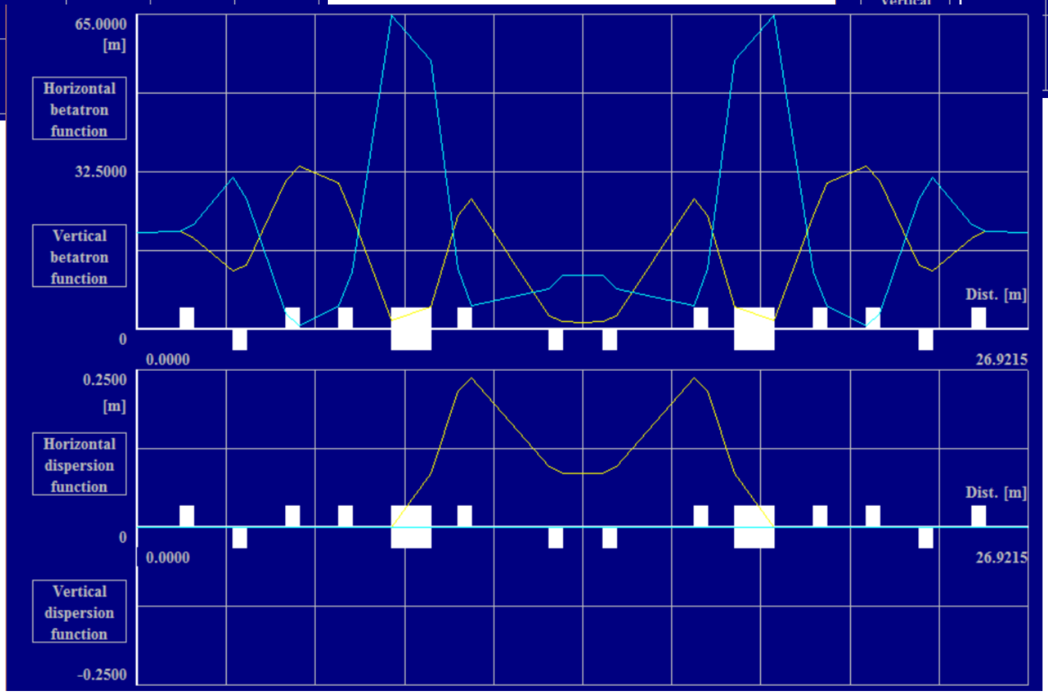
Beam size (hor.) (mm)	0.52
Beam size (vert.) (mm)	0.53
Eq. Emittance (mm mrad)	0.0026 π
Beta max horizontal (m)	25.08
Beta max vertical (m)	62.67
Maximum Disp. (vert.) (m)	0.3607



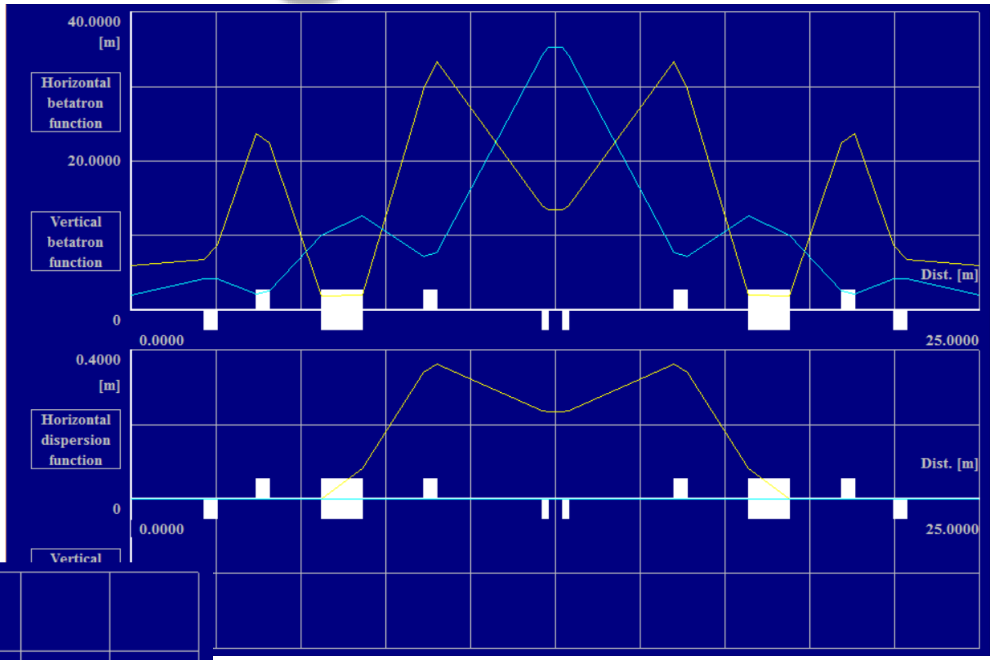
Three Different Cell Designs



Basic Cell



1° Optimized Cell



2° Optimized Cell

Joint Universities Accelerator School

Cost estimation

"Rough" estimation of components cost → Quadrupole ~ 15K$ Dipole ~ 20K$

- Basic Cell

Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	8	0.4

Total Cost:3840 K$

ε=0.0260 π mm mrad

εC=99.84 π mm mrad K$

- 1° Optimized Cell:

Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	12	0.4

Total Cost:5280 K$

ε=0.0014 π mm mrad

εC=7.795 π mm mrad K$

- 2° Optimized Cell:

Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	6 (+2)	0.4 (0.2)

Total Cost:3840 K$

ε=0.0026 π mm mrad

εC=9.98 π mm mrad K$

Cost estimation

"Rough" estimation of components cost → Quadrupole ~ 15K$, Dipole ~ 20K$

- Basic Cell

Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	8	0.4

Total Cost:3840 K$

ε=0.0260 π mm mrad

εC=99.84 π mm mrad K$

- 1° Optimized Cell:

NOT STABLE ☹

Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	12	0.4

Total Cost:5280 K$

ε=0.0014 π mm mrad

εC=7.795 π mm mrad K$

- 2° Optimized Cell:

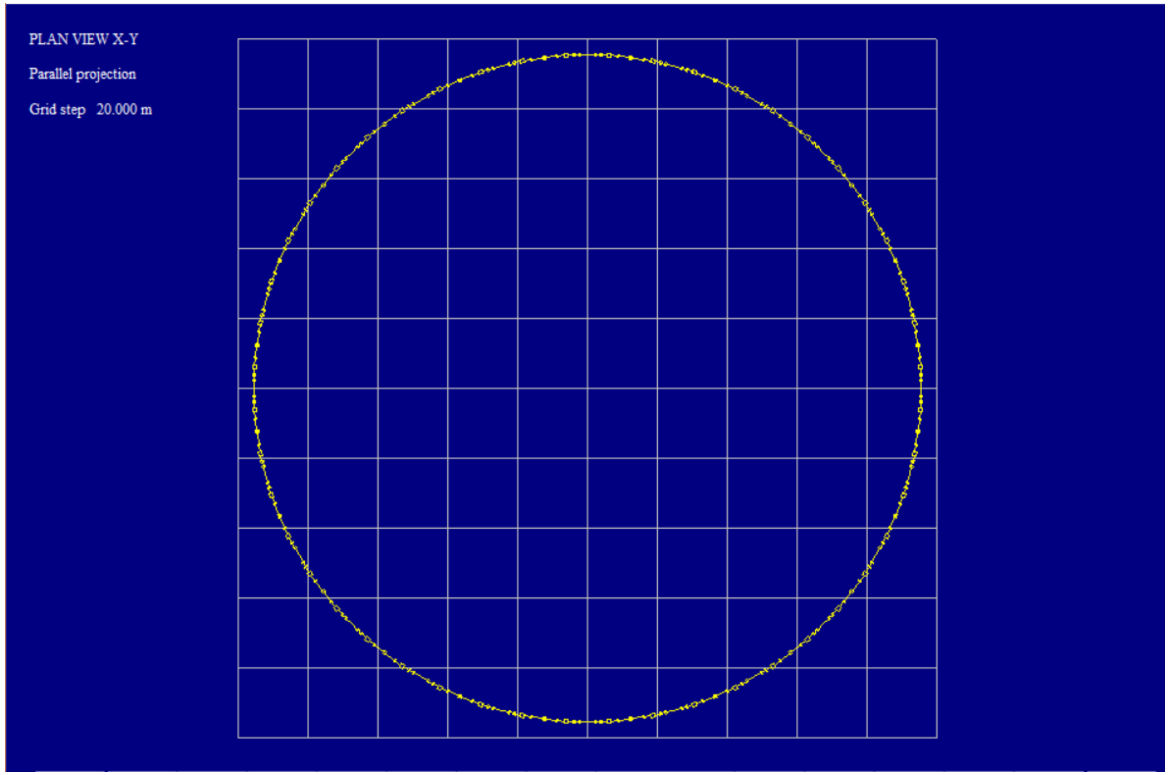
Element	Number	Lenght [m]
Dipole	2	1.2
Quadrupole	6(+2)	0.4 (0.2)

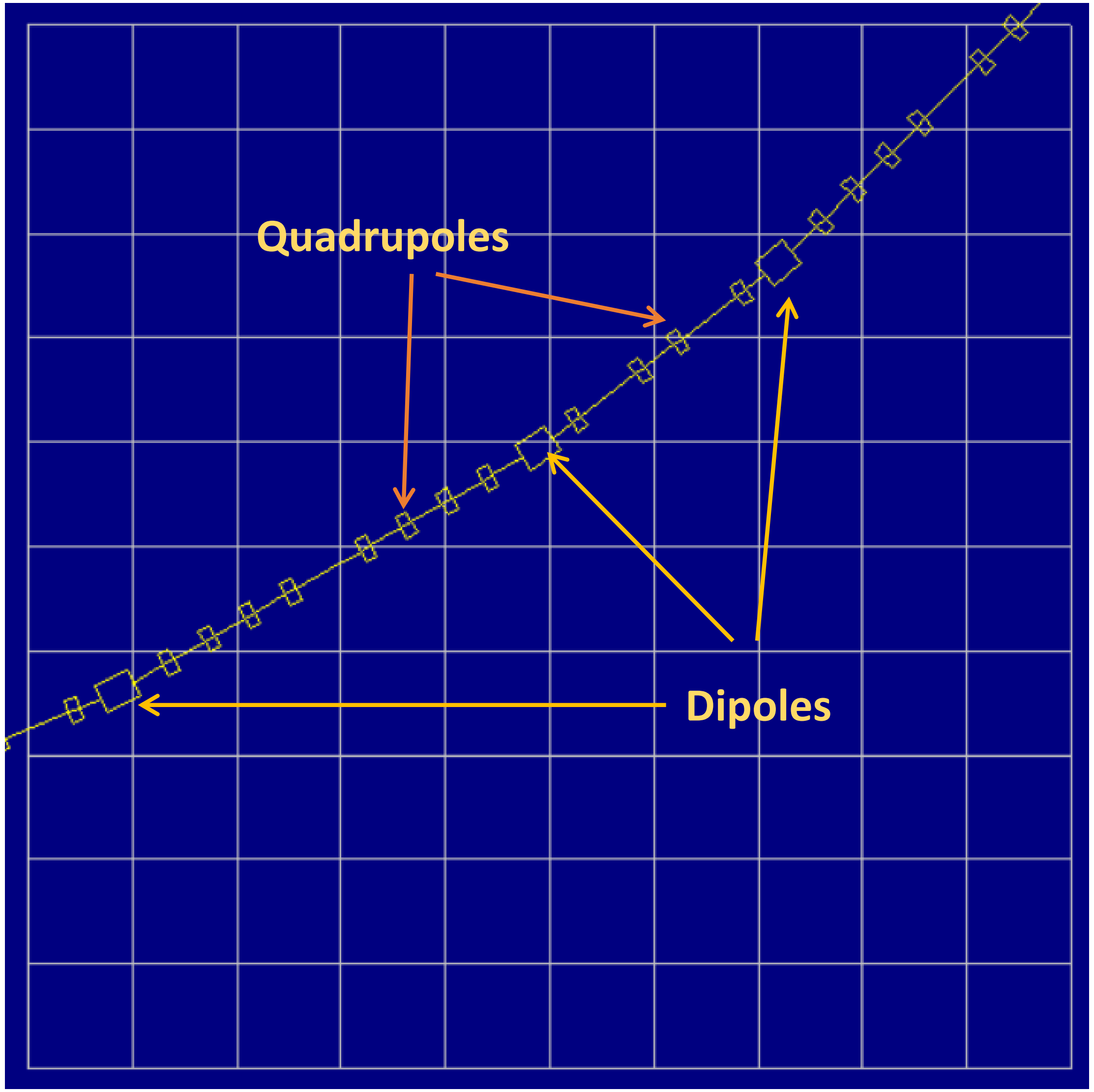
Total Cost:3840 K$

ε=0.0026 π mm mrad

εC=9.98 π mm mrad K$

Lattice design geometry



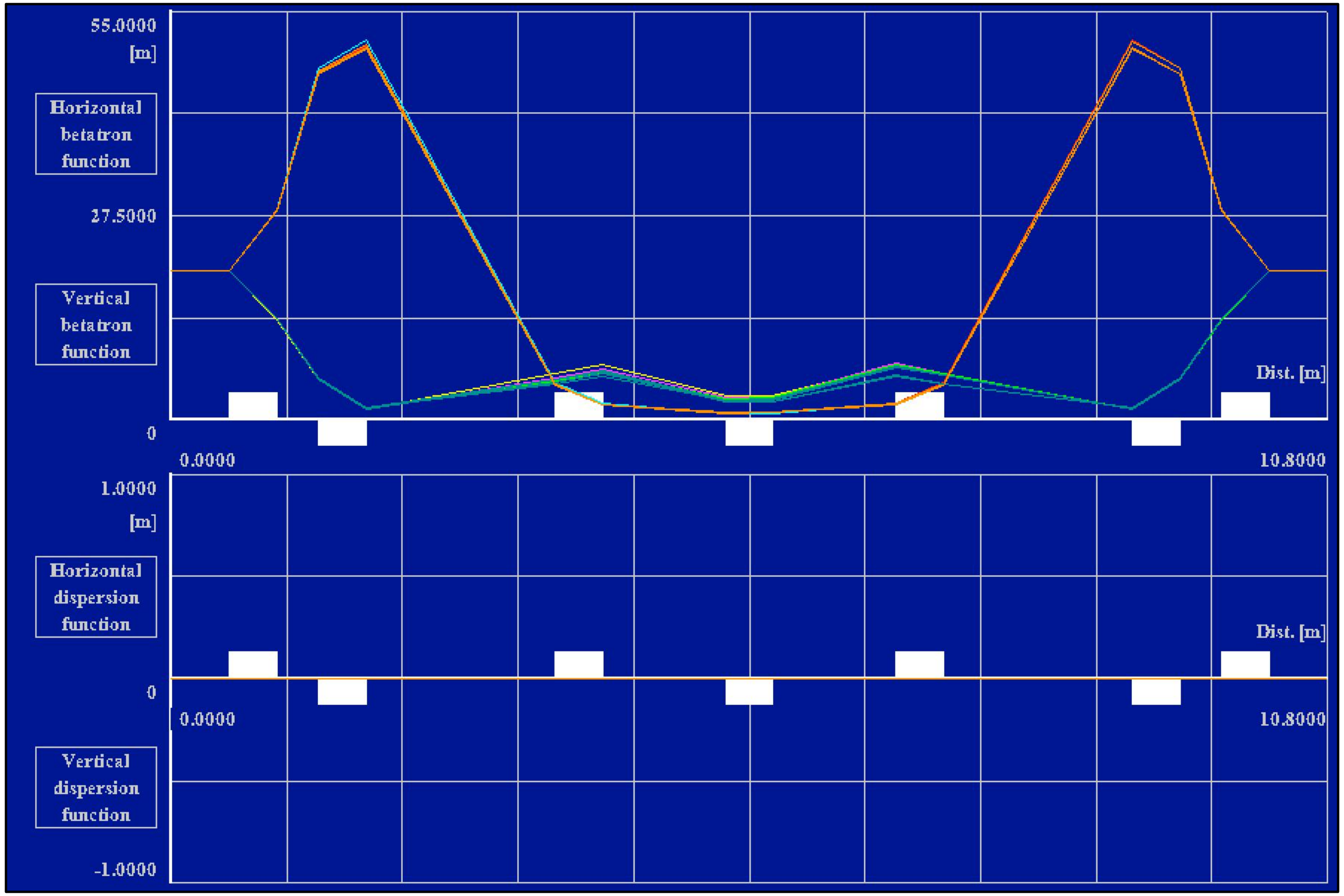


CENTRAL ORBIT
Circular machine

Circumference	[m] =	599.9993
Horizontal tune	Qx =	27.113570
Vertical tune	Qz =	17.747357
Horizontal chromaticity	dQx/dp/p =	-111.972
Vertical chromaticity	dQz/dp/p =	-33.531
Gamma transition	gamma tr =	59.61421

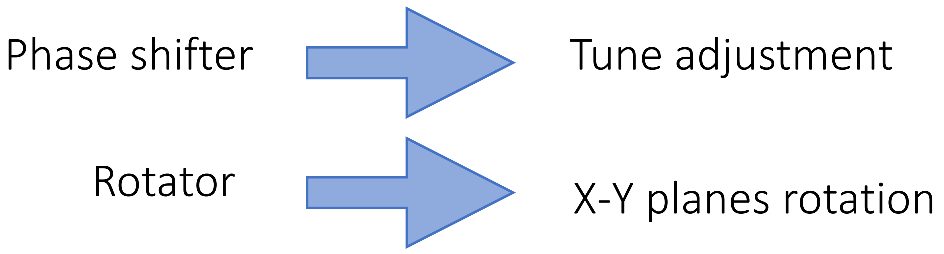
Phase shifter

- Change phase advance to find the best working point.
- Phase advance of the shifter changed from $\Delta\mu = 6.2832$ to $\Delta\mu = 6.40$ to explore a big range of phase shifts.
- 6 steps of phase shifts from $\Delta\mu = 6.30$ to $\Delta\mu = 6.40$
- To find the matching, 6 conditions were set, with 7 quadrupole gradients used as variables.

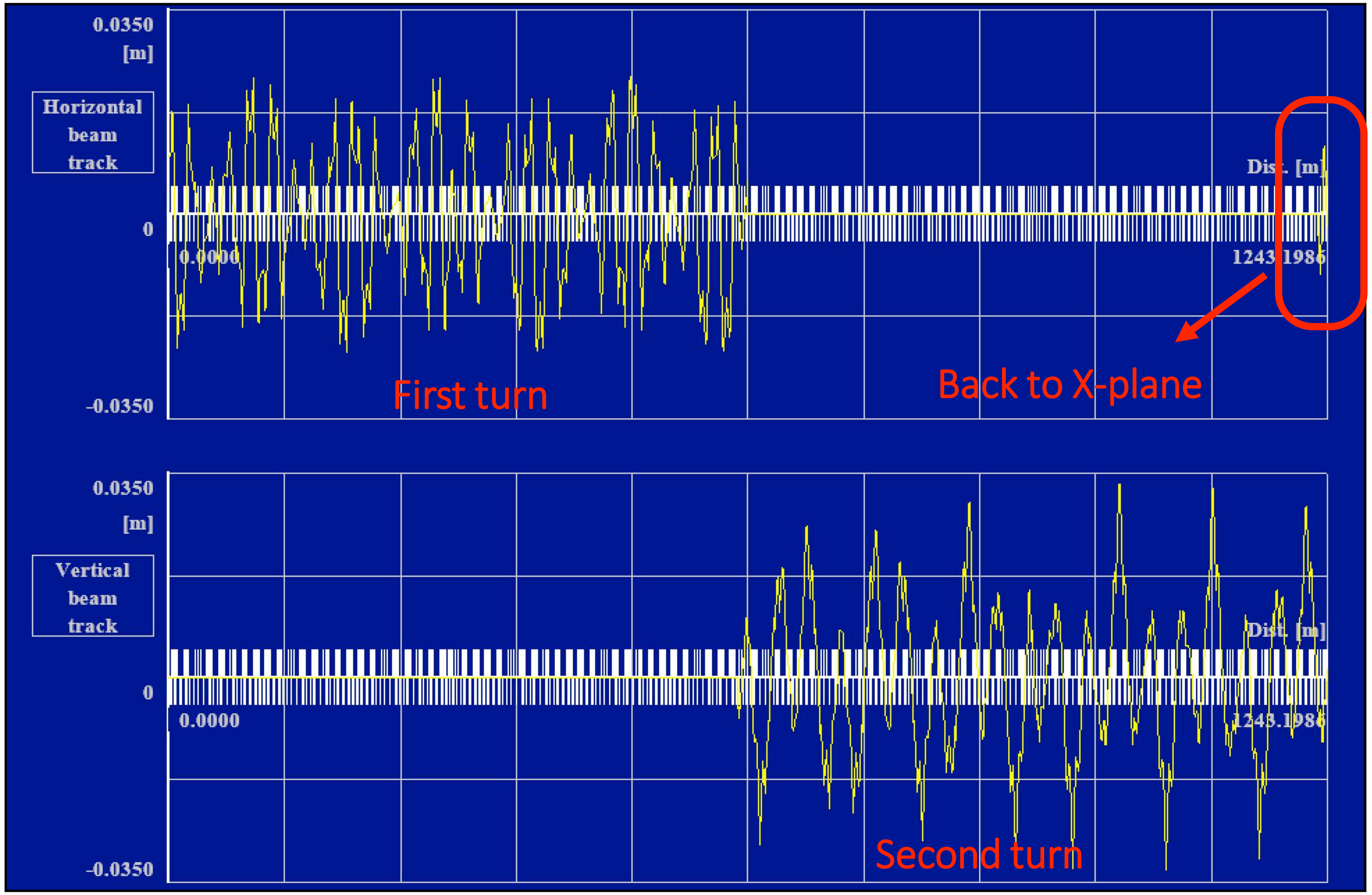


Möbius Ring

- Phase shifter and rotator added to the ring.



- Ring lattice replicated two times and run as a transfer line.
- Using single particle tracking:
  - during first turn the particle oscillates in X-plane;
  - during second turn the particle oscillates in Y-plane;
- Successful exchange of X-Y planes.



juas
Joint Universities Accelerator School

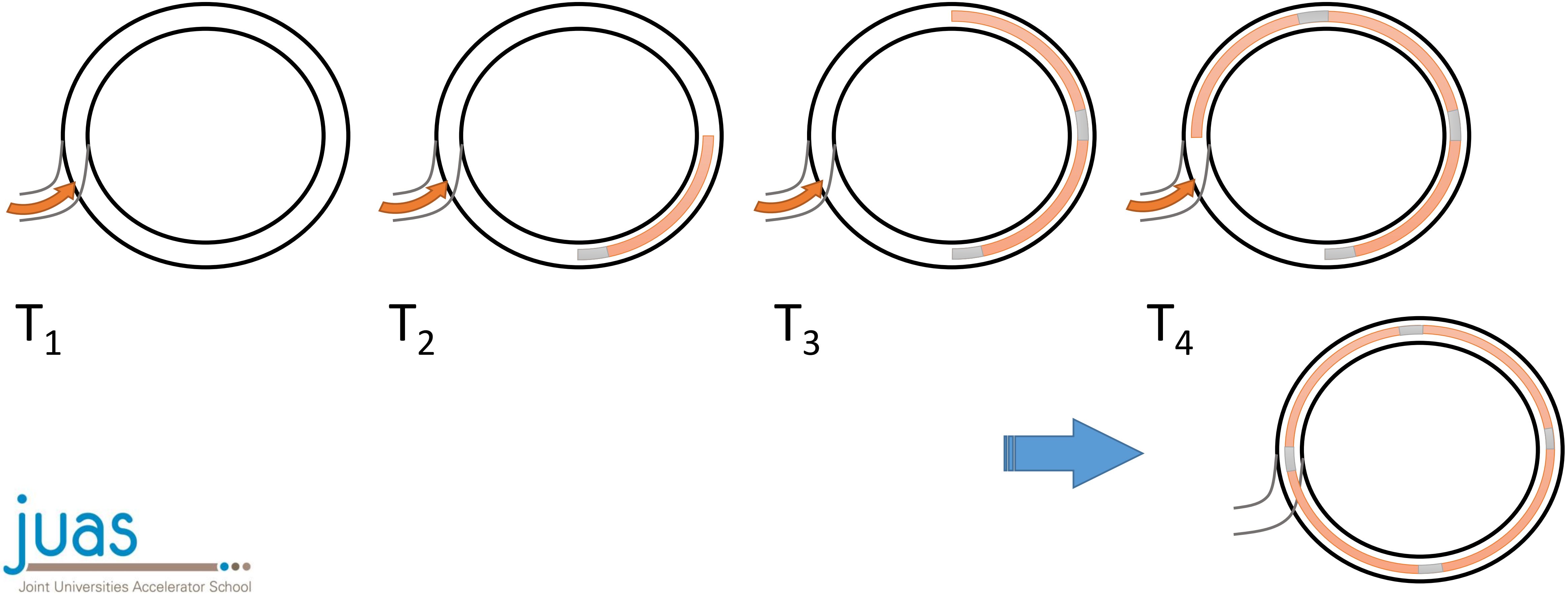
Injection/Extraction

Axel Poyet
Edgar
Jérémy
Félix,
Doru
Alexandru
Adrian
Volker Schramm

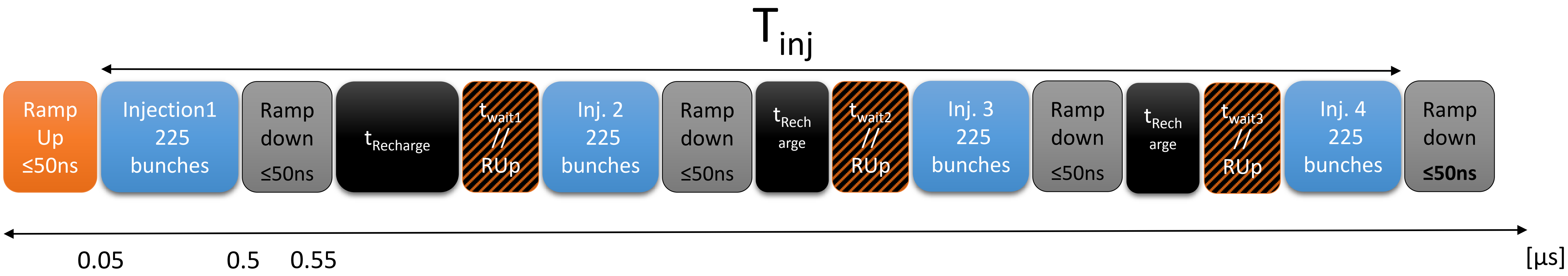
Injection Process

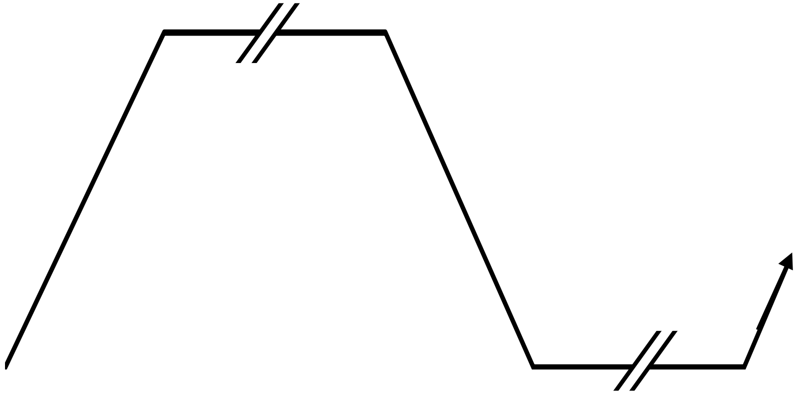
<u>1st approach (tricky solution):</u>

- Injection of 4 pulses (225 bunches) in 4 separate periods



Injection Process





- Flat top for 450ns to inject a pulse of 225 bunches
- Ramp up/down ≤50ns to keep a gap of 25 bunches

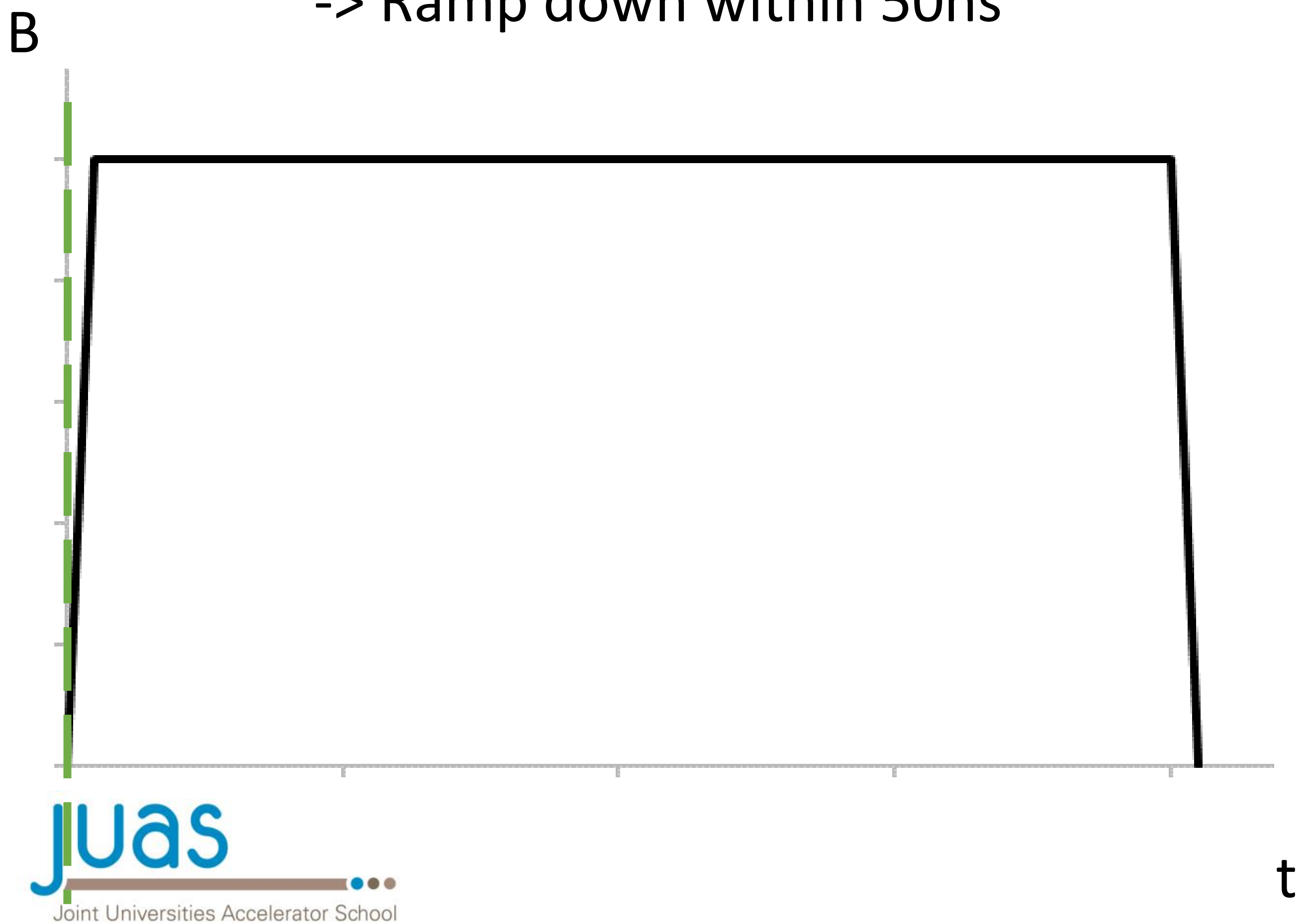
$t_{Ramp\ Up/Down}$	Available time to ramp the magnet
$t_{Recharge}$	Needed time to recharge capacitors (PS)
t_{wait}	Waiting time to place next pulse

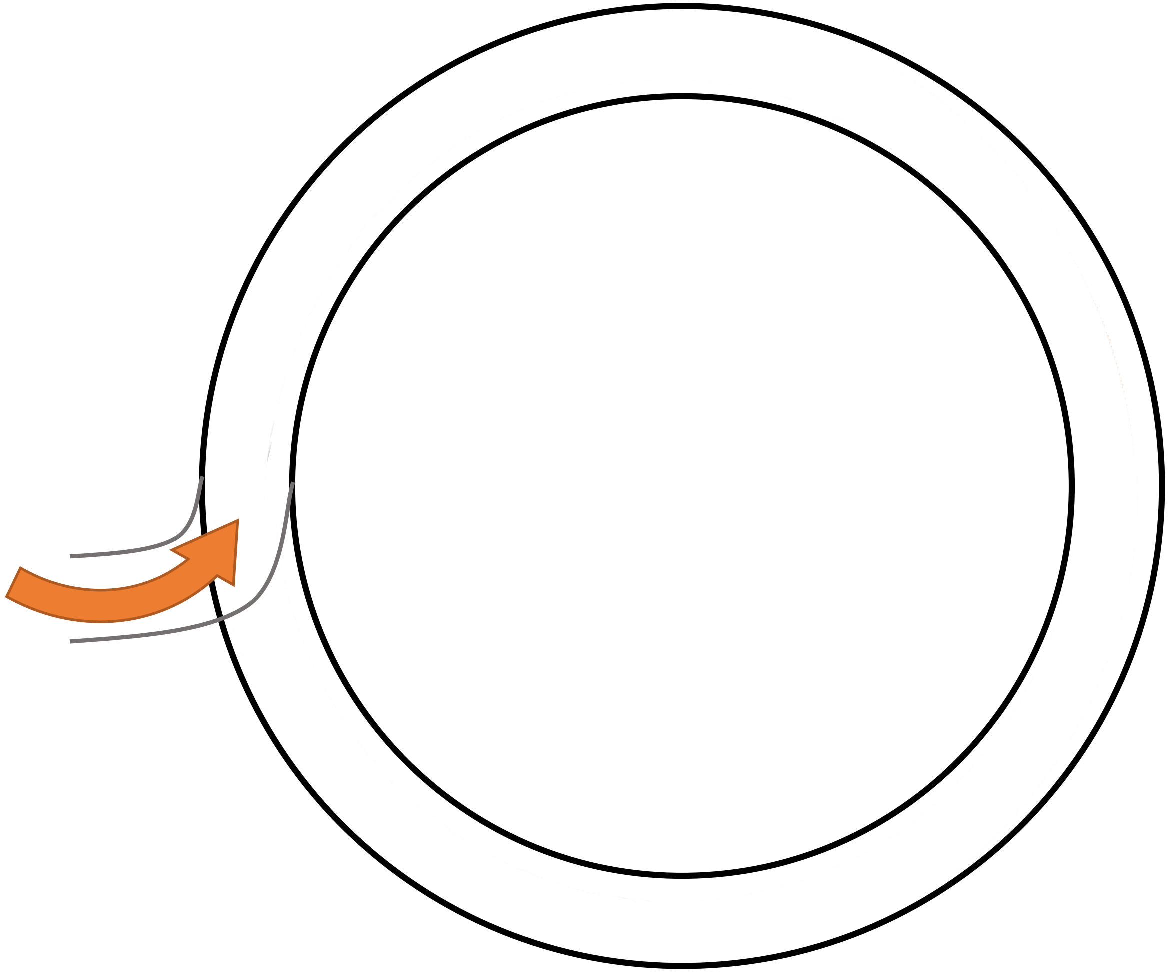
Injection Process

Simple solution:

-> Ramp up and inject all 4 pulses at once

-> Ramp down within 50ns

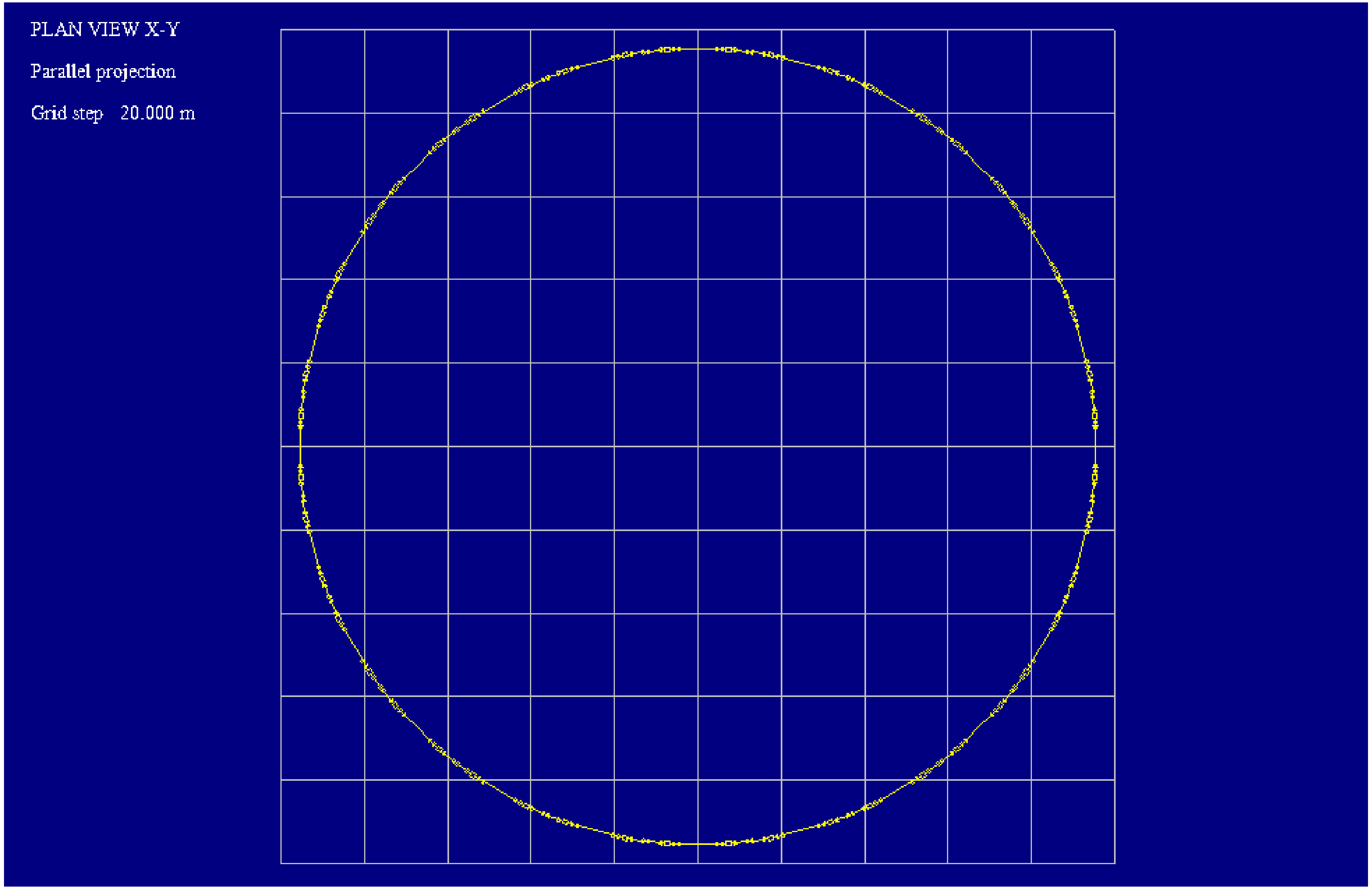




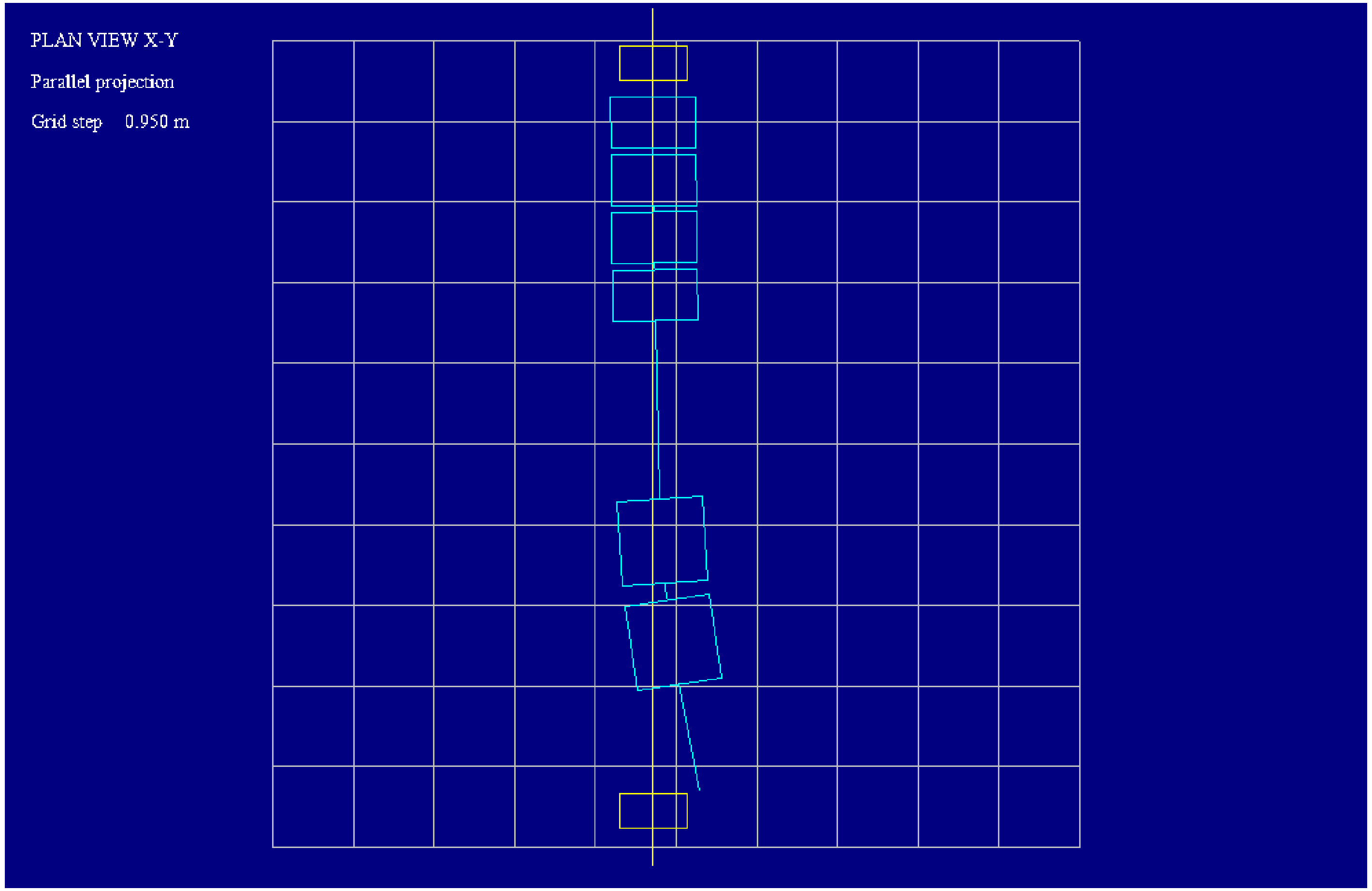
Extraction Process

- Ramp up extraction kicker within 50ns in the gap
- Complete extraction in one turn
- Dumping in a secure structure (steel)

Injection & Extraction – Basic Design



Injection – Basic Design

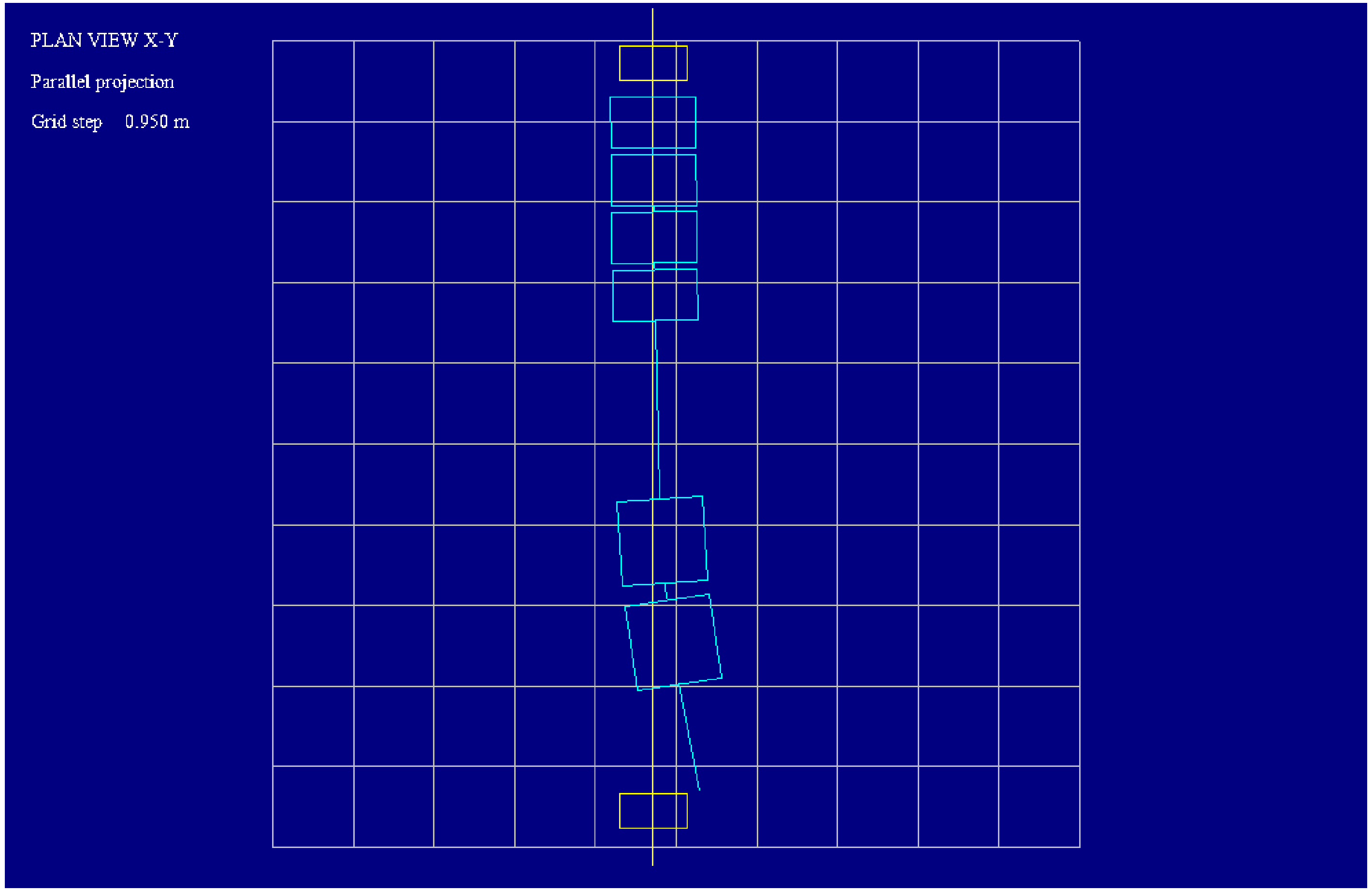


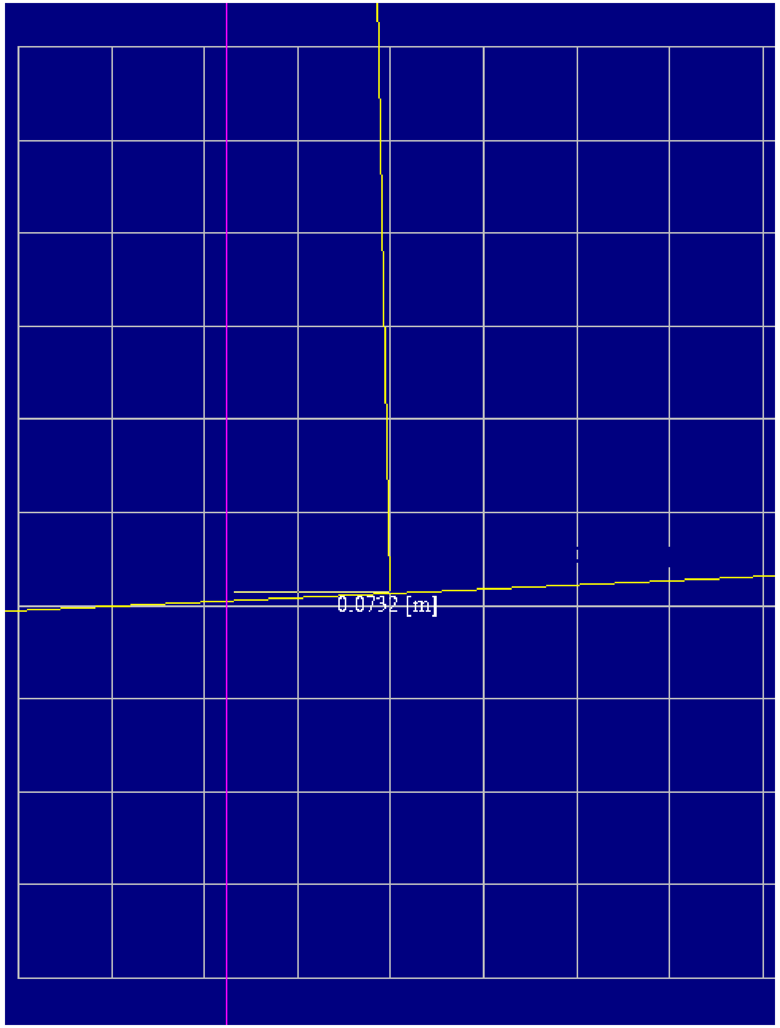
Parameters

- Particles at 2 GeV, 8.2 meters long.
- 2 septa at B = 0.55 T.
- 4 kickers at 0.06 T → θ = 5.4 mrad.
- Large space margin at the second septum exit (7.32 cm).

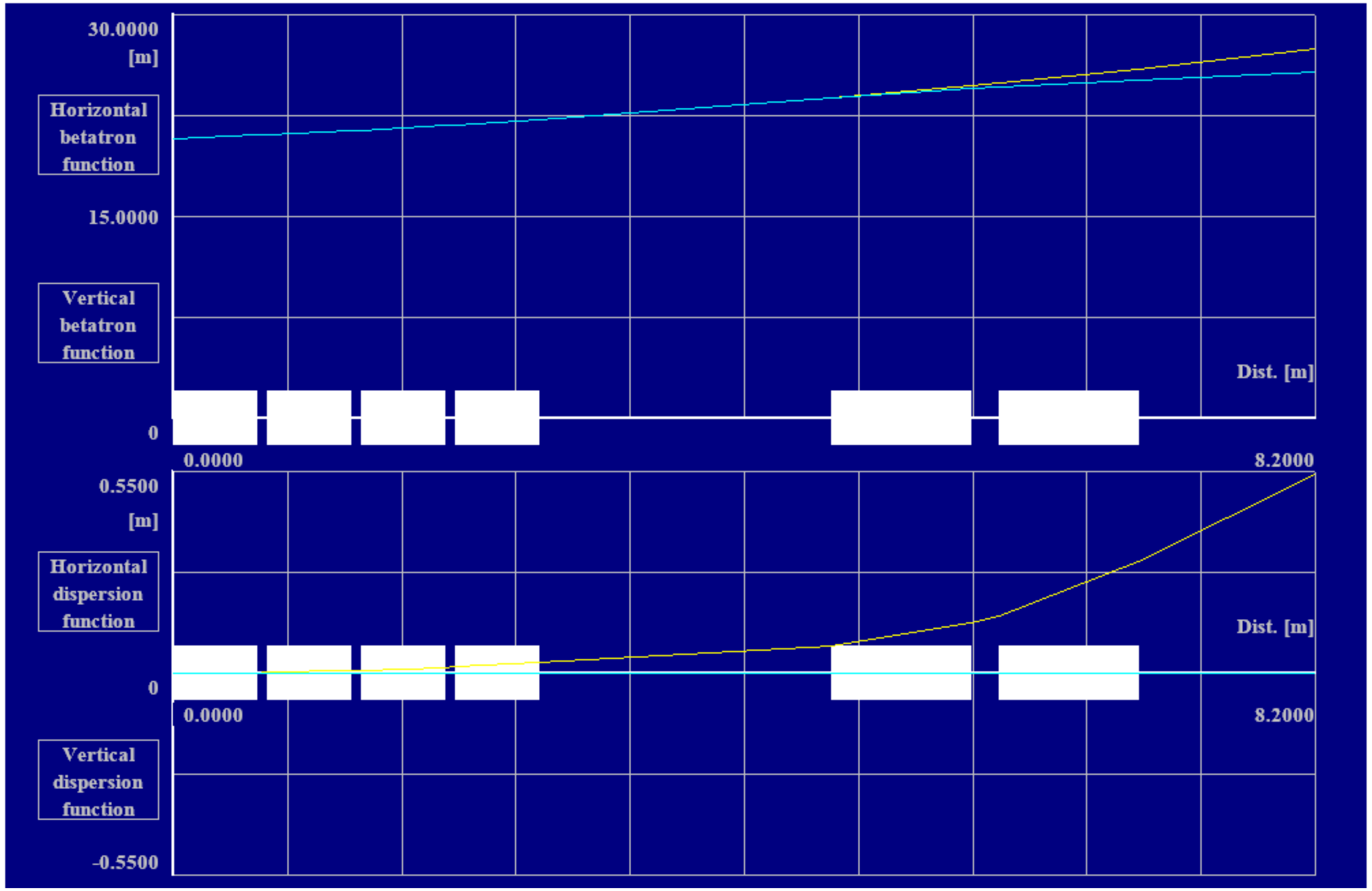
- Matching parameters at insertion point.
  - $\beta_x = \beta_z = 20.8$m; $\alpha_x = \alpha_z = -0.2$
  - $\varepsilon_x = \varepsilon_z = 0.1500$ pi.mm.mrad

Injection – Basic Design





Injection – Basic Design



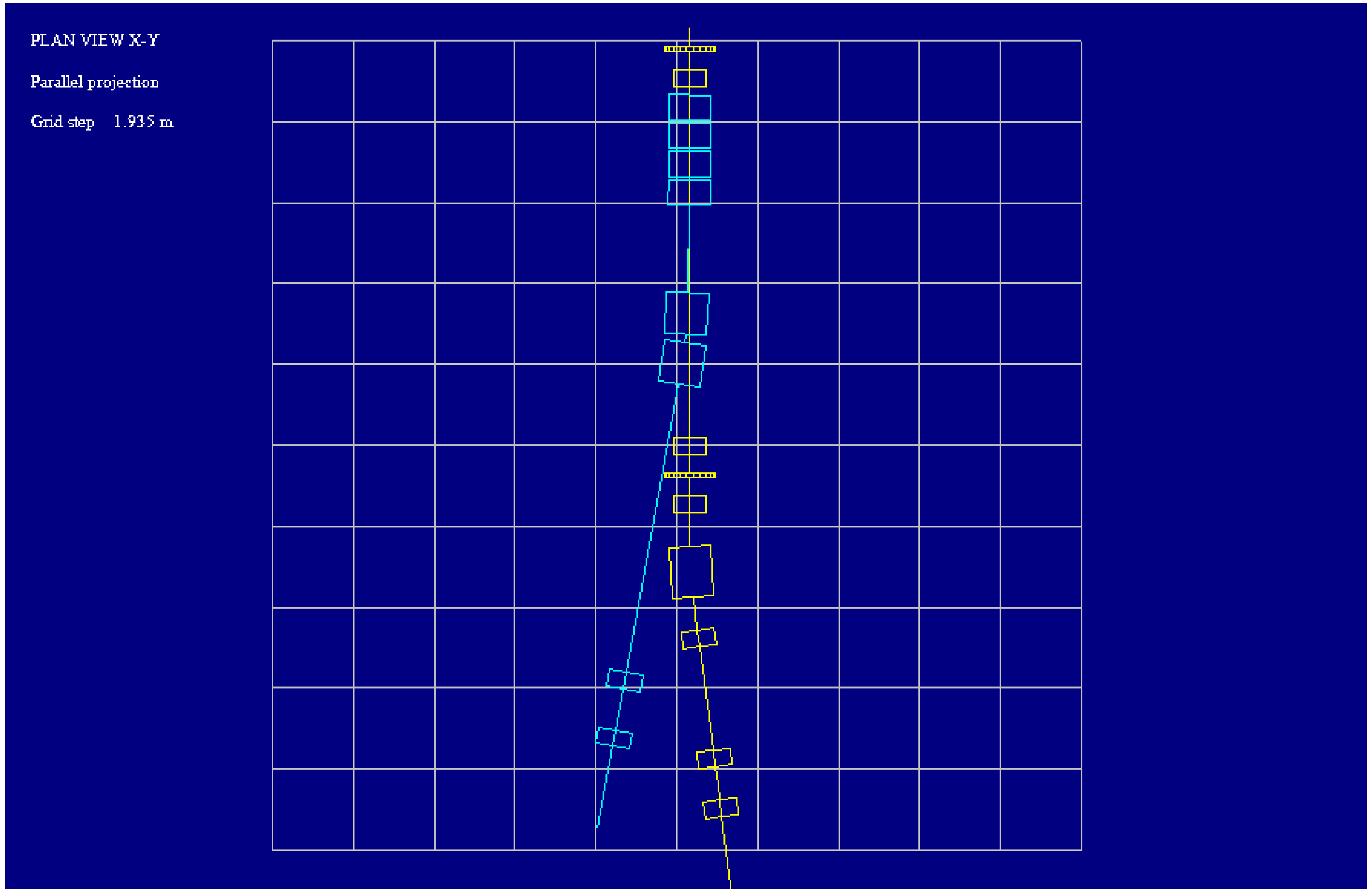
Main functions in the line

- Required conditions are matched.
- Prior to injection line, there will be :
  - 1 RF cavity
  - 6 quadrupoles (β_x, β_z, α_x, α_z, D_x, D_z)

- Functions don't get out of hand :
  - Dispertion is ok since we're out of an RF
  - Beta function will be easy to match

- No need for more elements. Keep cost as low as possible.

Extraction & Dump – Basic Design



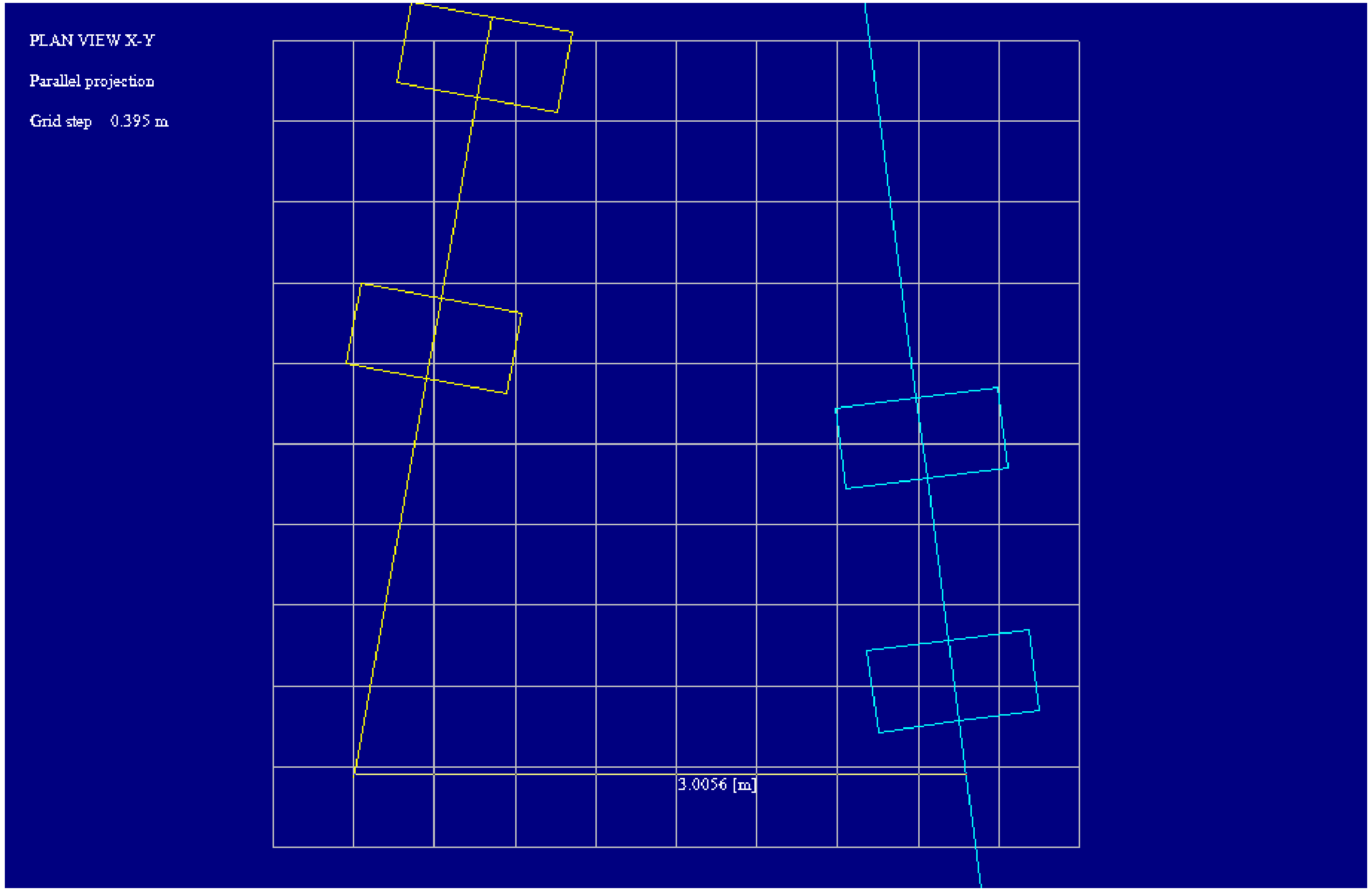
Parameters

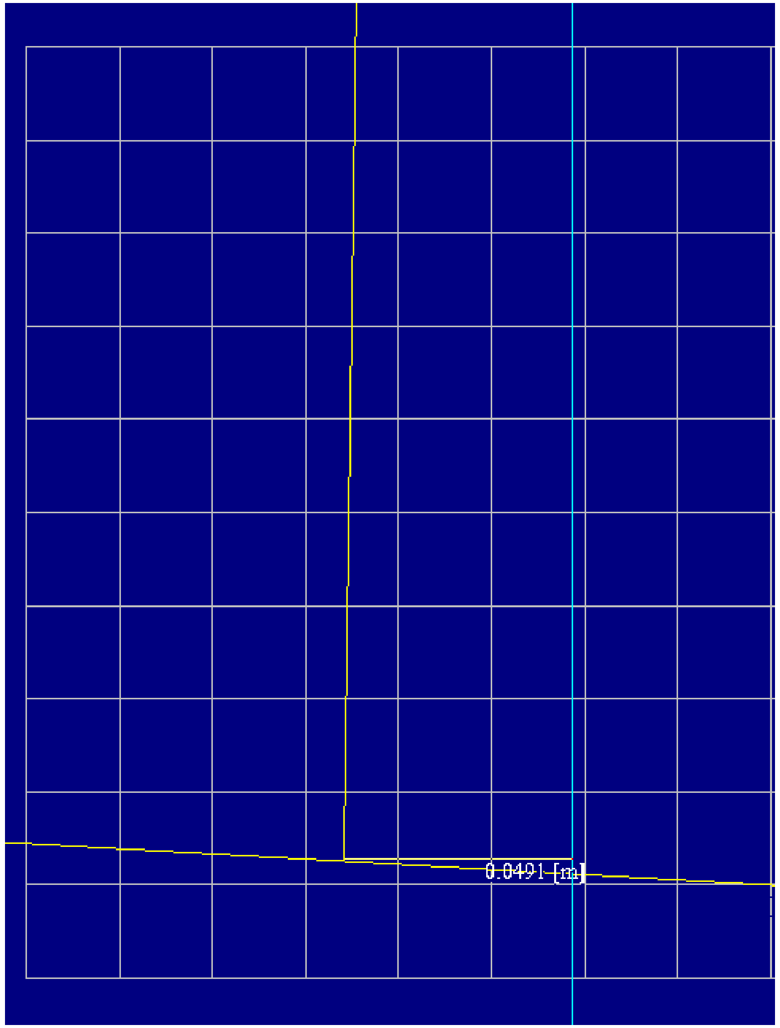
- Particles at 3 GeV, 17.725 meters long.
- 2 septa at B = 0.83 T
- 4 kickers at 0.06 T → θ = 3.6 mrad
- 2 defocusing quads spread the beam for dumping.

- Minimal space margin at the first septum entrance (4.91 cm).
- Dump structure is 3 meters away from ring.

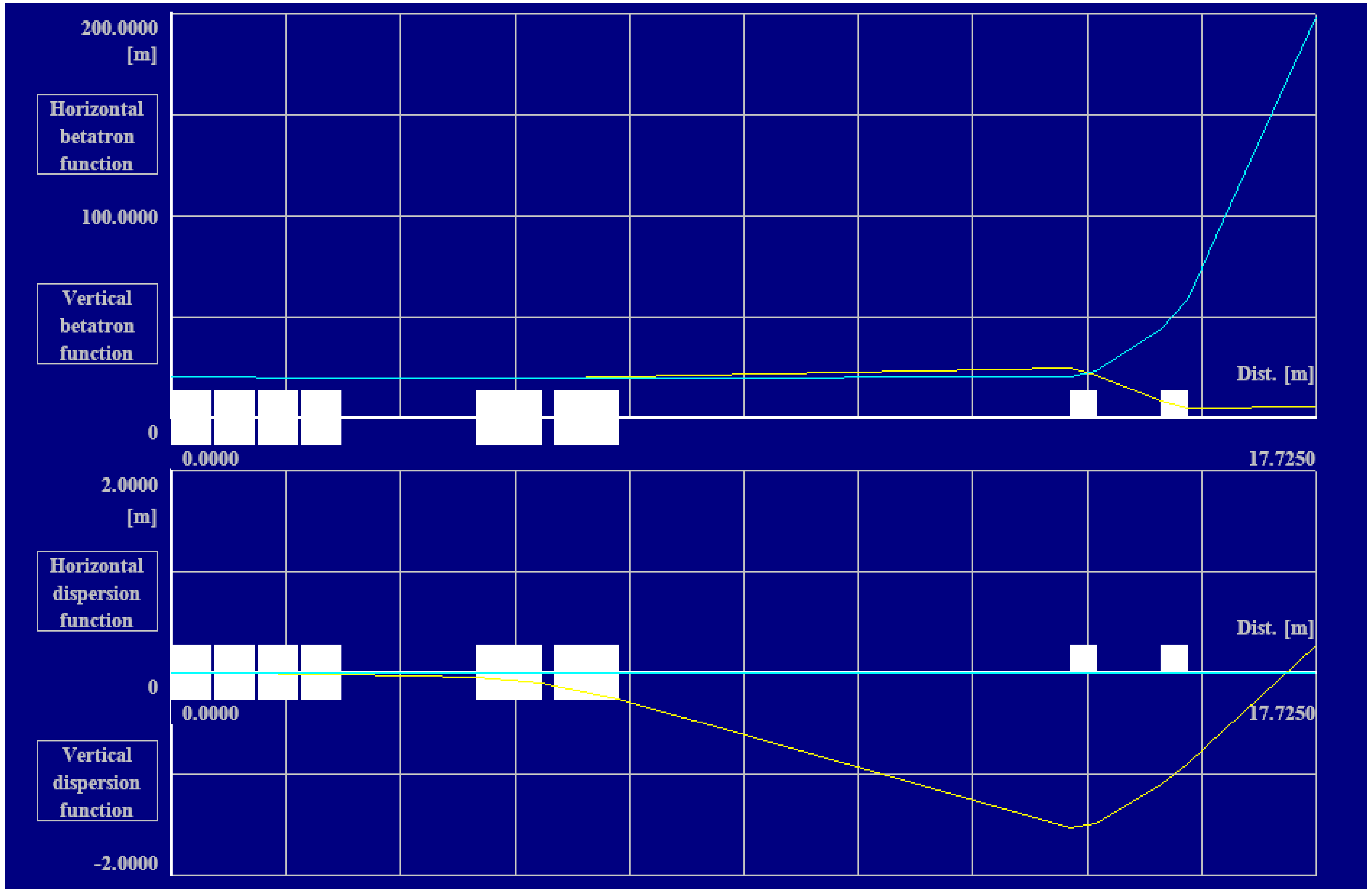
- Matching parameters at insertion point
  - $\beta_x = \beta_z = 20.8$m; $\alpha_x = \alpha_z = 0.2$
  - $\varepsilon_x = \varepsilon_z = 0.1500$ pi.mm.mrad

Extraction & Dump – Basic Design





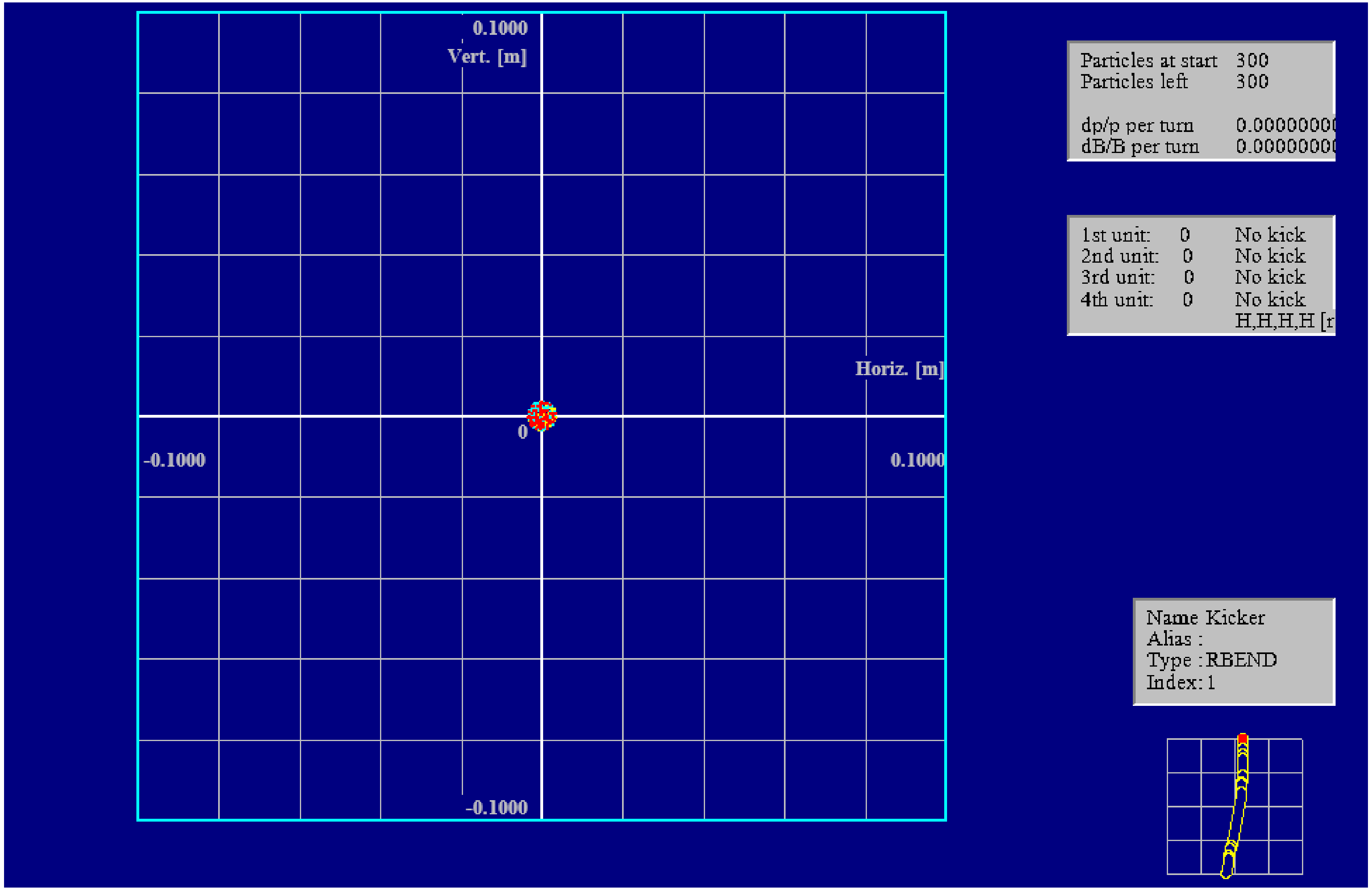
Extraction & Dump – Basic Design



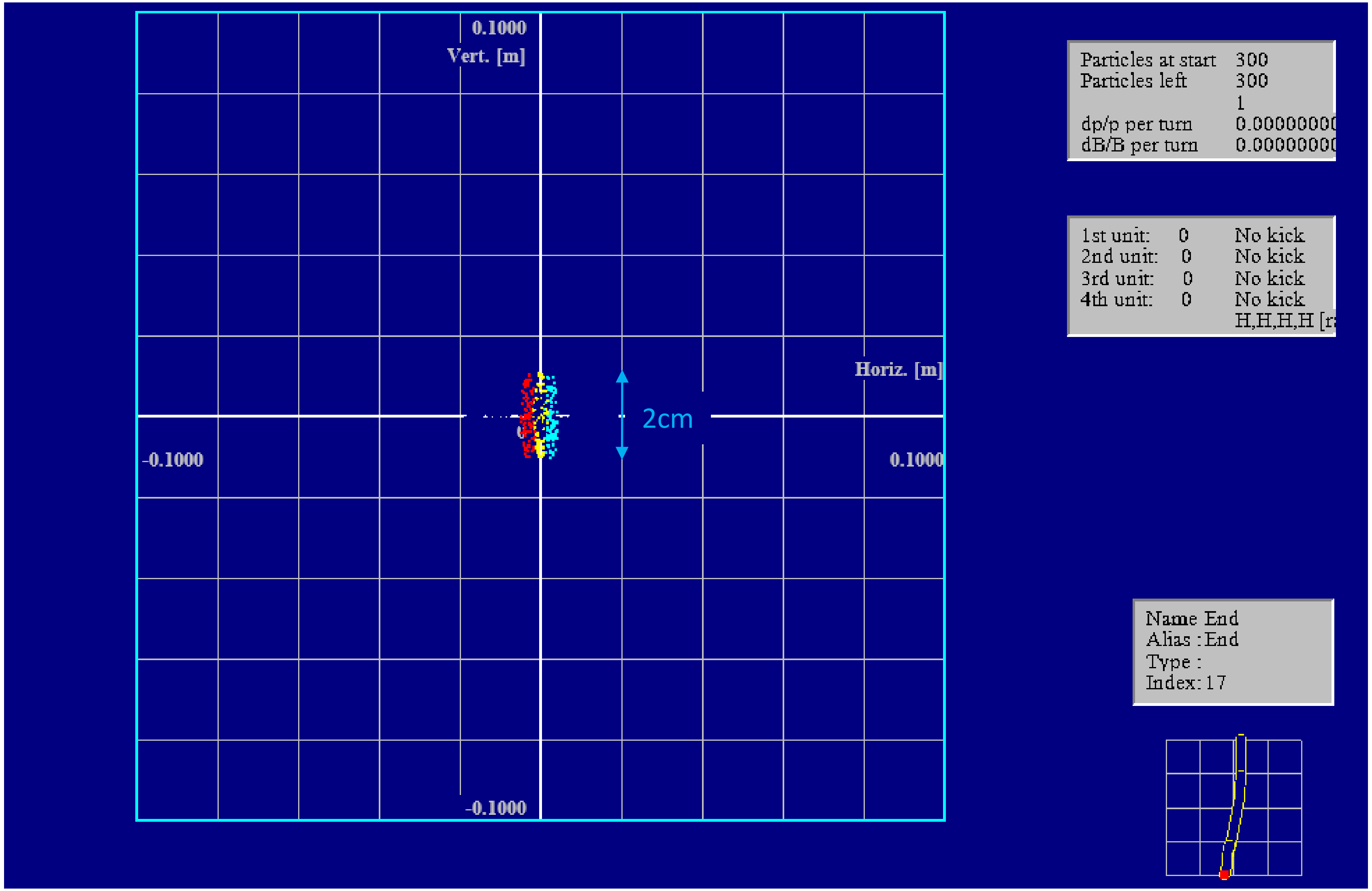
Main functions in the line

- Recquired conditions are matched.
- The quadrupoles are the same as the ring's ones :
  - Reduces cost and assembly complexity.
  - Can be plugged in series and left passive (no powering problem).
- Functions have a satisfying behavior :
  - Dispertion does not matter that much.
  - One very high beta is enough for dumping.

Extraction & Dump – Basic Design



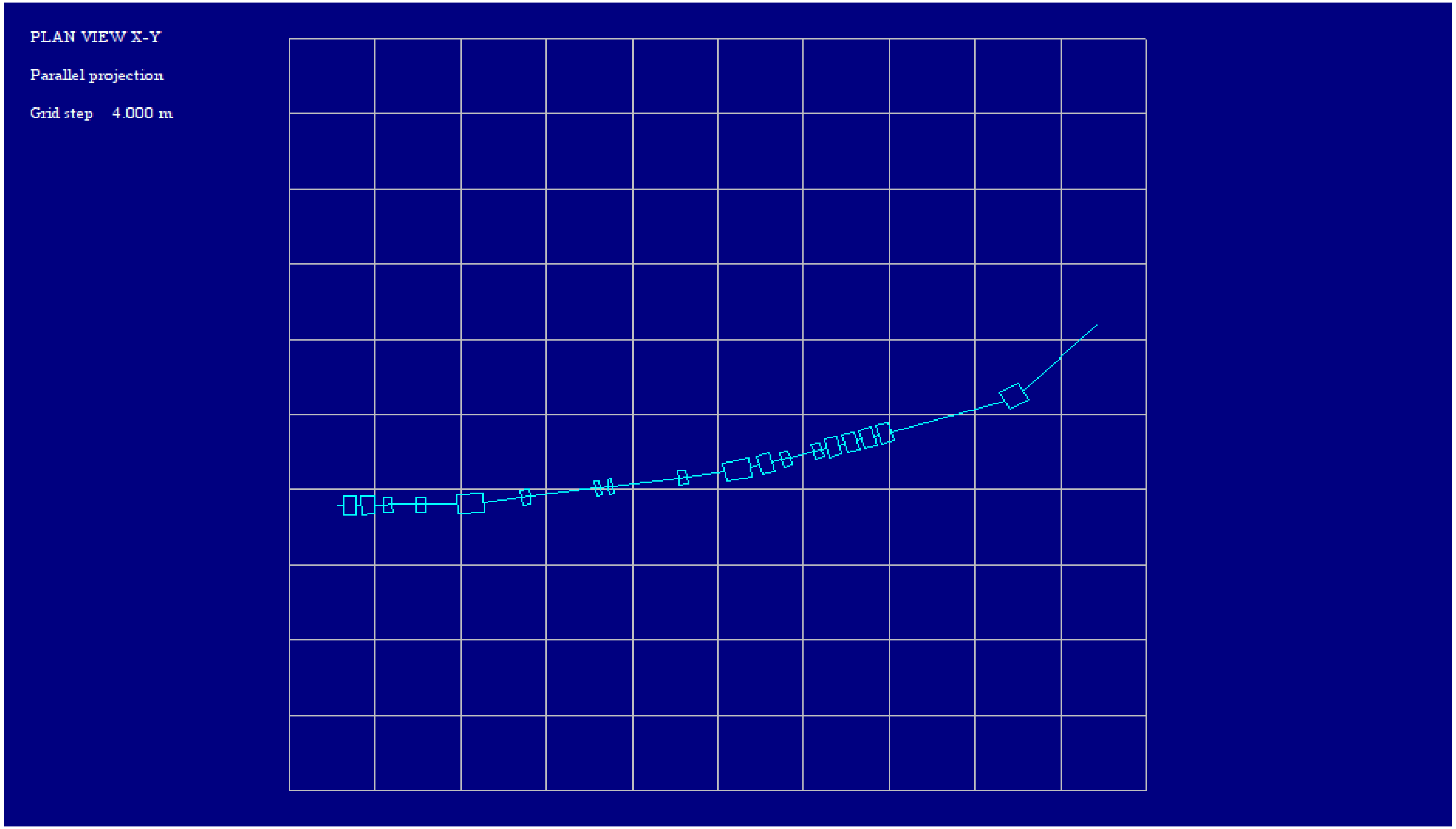
Extraction & Dump – Basic Design



Extraction Process

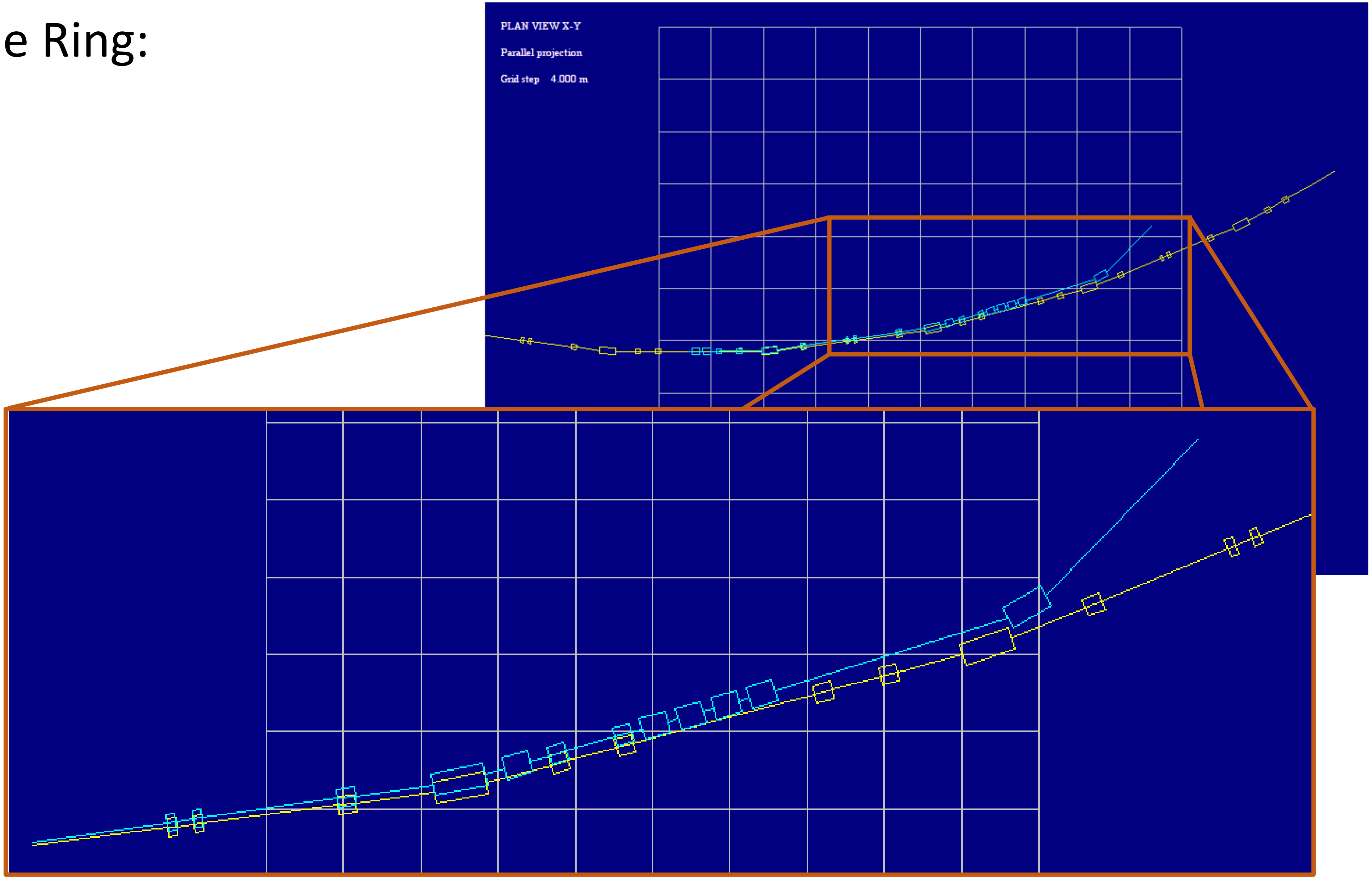
- Ramp up extraction kicker within 50ns in the gap
- Complete extraction in one turn

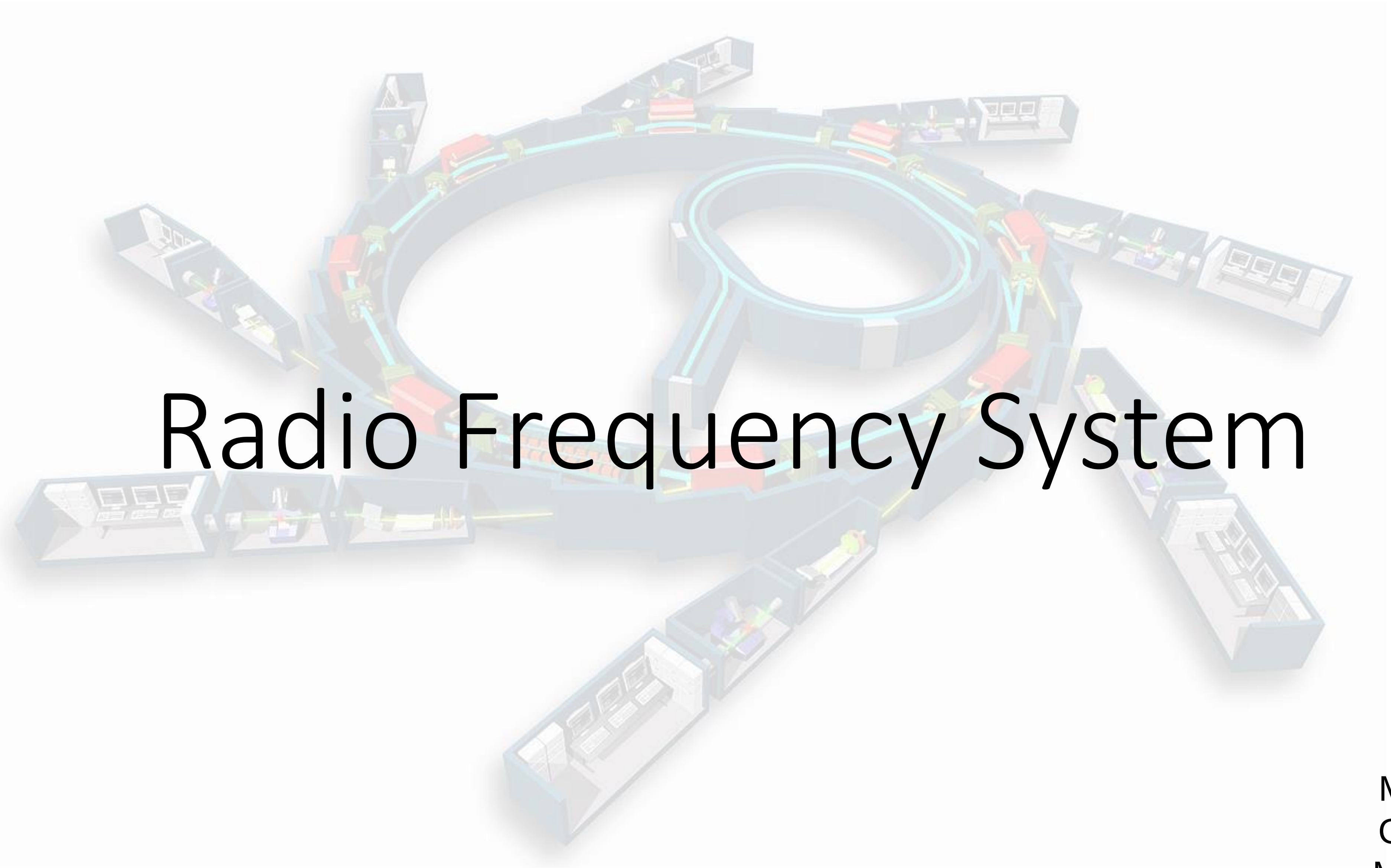
Extraction Line:



Extraction Process

Extraction Line Ring:





Radio Frequency System

Vittorio Bencini
Anna Pugelise
Marco Diomede
Gabriel Tuturcia
Mostafa Behtoei
Thomas Coldfix

Joint Universities Accelerator School

Requirements and design parameters

Requirements → Compensate losses due to synchrotron radiation

Requirements → Provide constant acceleration to the electrons to follow up the magnets ramp

Design parameter	Value
C ring [m]	600
R [m]	95.49
ρ [m]	9.17
σ_z bunch [m]	0.012
σ_e bunch [m]	0.001
$E_{injection}$ [GeV]	2
E_{final} [GeV]	3

RF modulation

In order to compute the V_{RF} needed to compensate the losses and accelerate the particle we have to consider

$$\frac{dB}{dt} = const \quad \Rightarrow \quad \Delta E_{ACC,turn} = \frac{dB}{dt} \times 2\pi R\rho = 1.084 KeV$$

So, taking into account the losses due to synchrotron radiation, it becomes

$$\Delta E_{RF,turn} = \Delta E_{ACC,turn} + \Delta E_{L,turn}$$

$$\Delta E_{L,turn}[KeV] = 88.46 \times \frac{E[GeV]^4}{\rho}$$

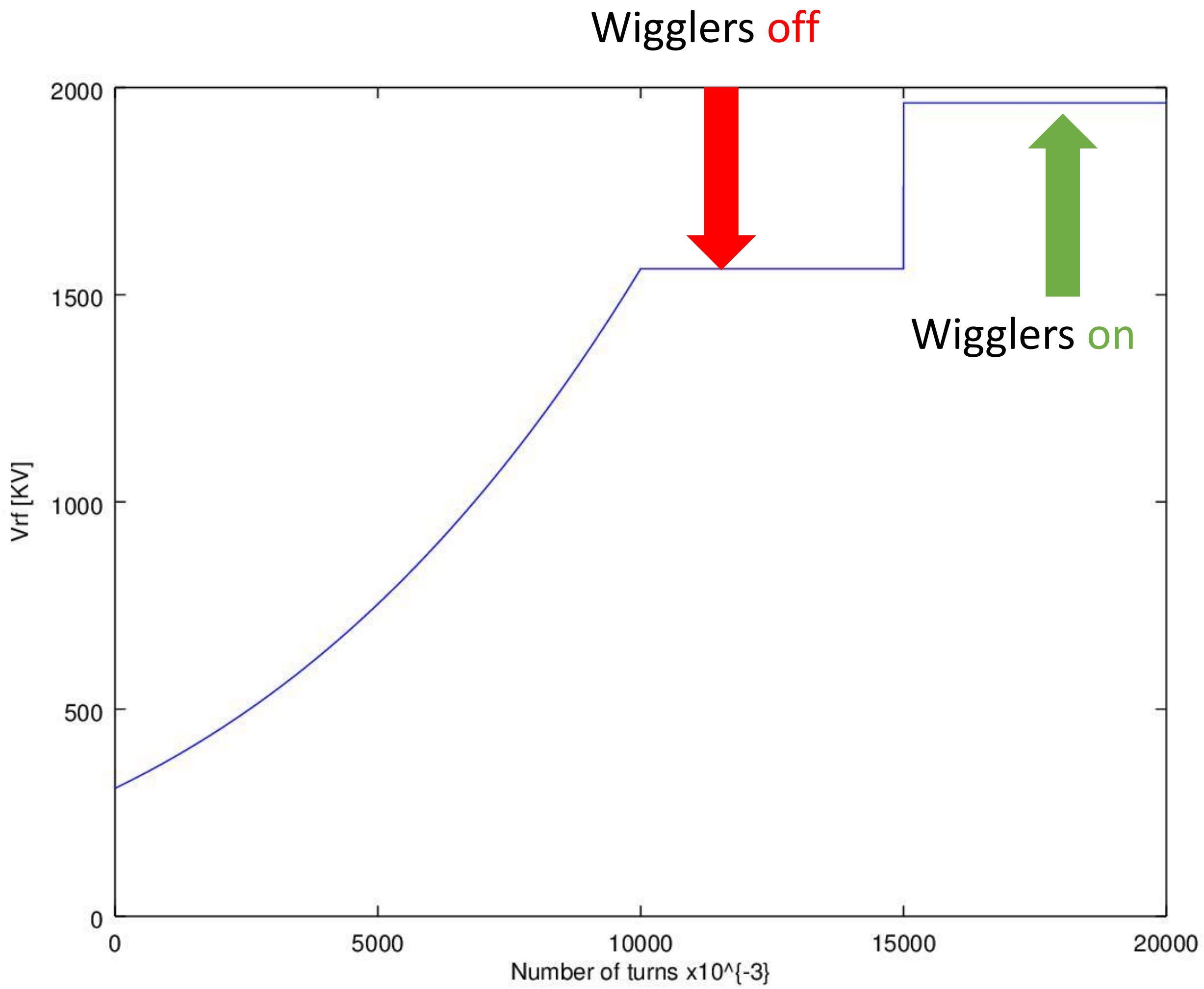
RF modulation

The energy gain is followed by modulating V_{RF} → $sin\varphi_s = 30° = const$

$$V_{RF,2\ GeV} = 308.7\ KV$$

$$V_{RF,3\ GeV} = 1562.8\ KV$$

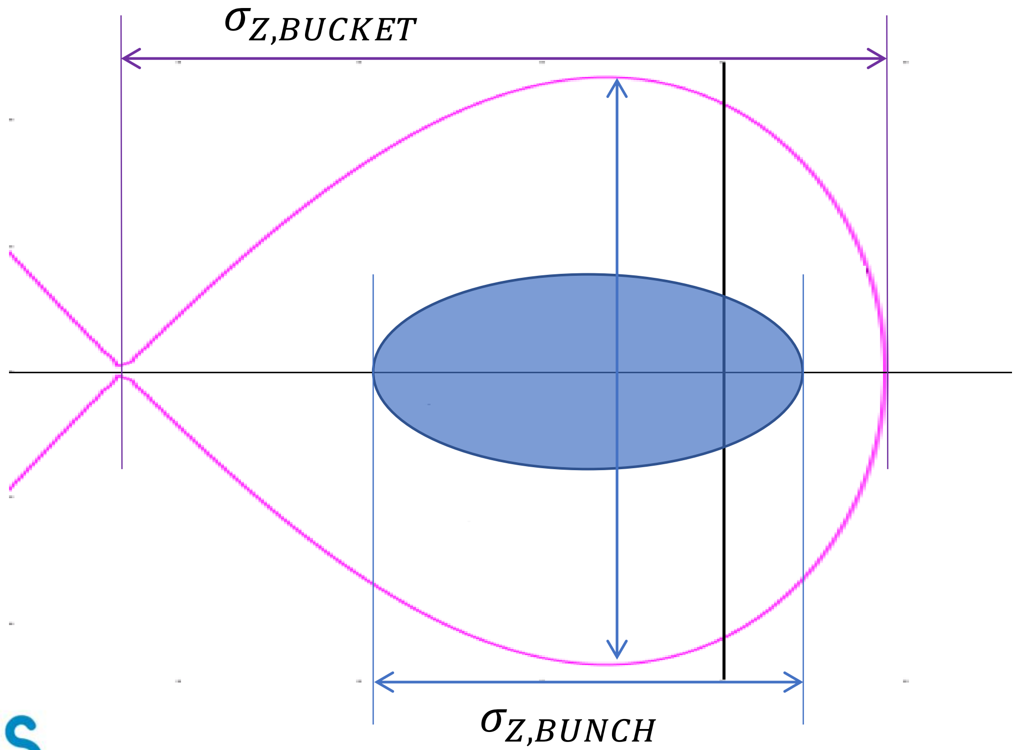
$$V_{RF,3\ GeV,W} = 1962.8\ KV$$

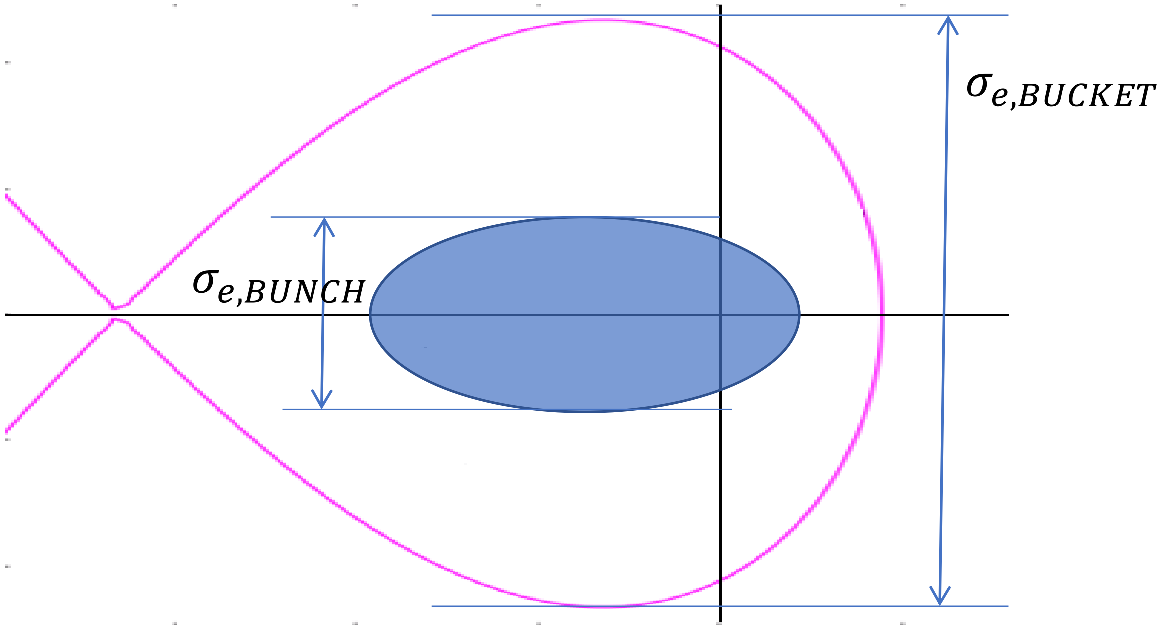


Matching at injection

The macthing condition is respected if the ratio between the axis of the bunch ellipse is similar to those of the bucket.

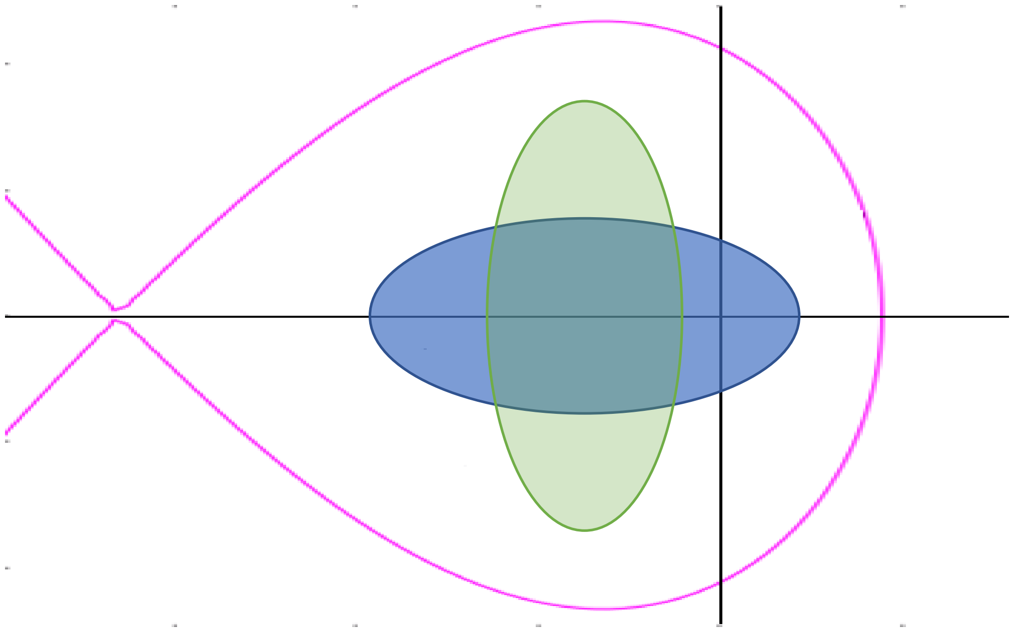
$$\left|\frac{\sigma_z}{\sigma_\varepsilon}\right| bunch \approx \left|\frac{\sigma_z}{\sigma_\varepsilon}\right| bucket$$





Matching at injection

Another condition is that, in case the first is not respected, the rotated ellipse still complitely fits into the bucket



$$\left|\frac{\sigma_z}{\sigma_\varepsilon}\right| bunch = 12$$

$$\left|\frac{\sigma_z}{\sigma_\varepsilon}\right| bucket = 14$$

OK!

RF cavity design

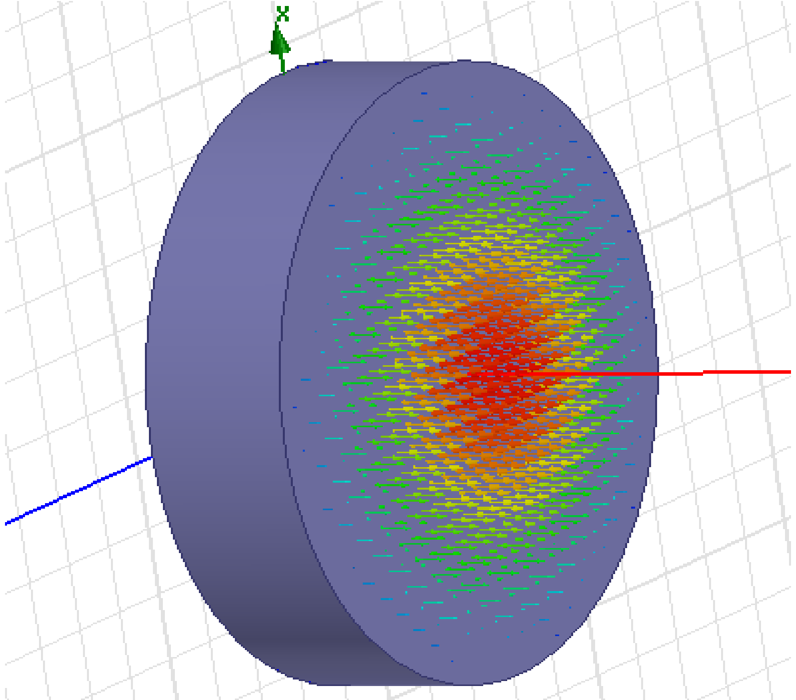
Cavity parameter	Value
$V_{RF,peak}$ [KV]	750 KV
φ_s (above transition) [deg]	150
Gap [mm]	100
R_0 [MΩ]	3.5
f_{res} [MHz]	500

From EM theory we know that the relationship between radius and frequency in TM_{01} mode is given by

$$R = \frac{2.405}{f_{res}} = 22.95\ cm$$

Using HFSS and CST simulation it was possible to confirm the radius and to compute the shunt impedance of the cavity

$$R = 23.08\ cm$$



RF power and cooling

At 3 GeV (wigglers on) the cavities have to be powered with

$$P = \frac{(V_{RF})^2}{R_0} = 1.1\ MW$$

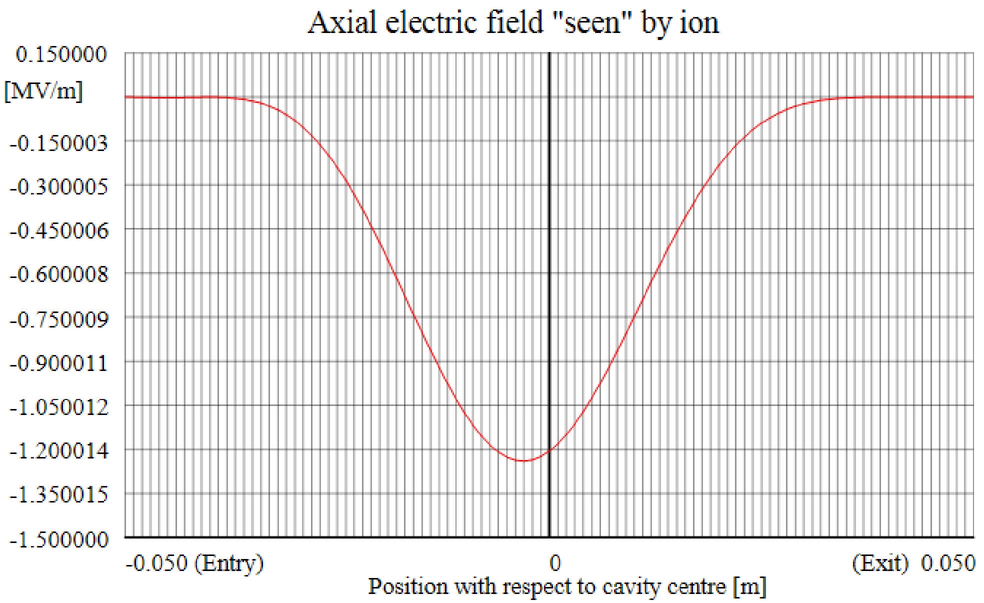
The efficiency between klystron and cavity is usually in the order of $\varepsilon = 0.85$

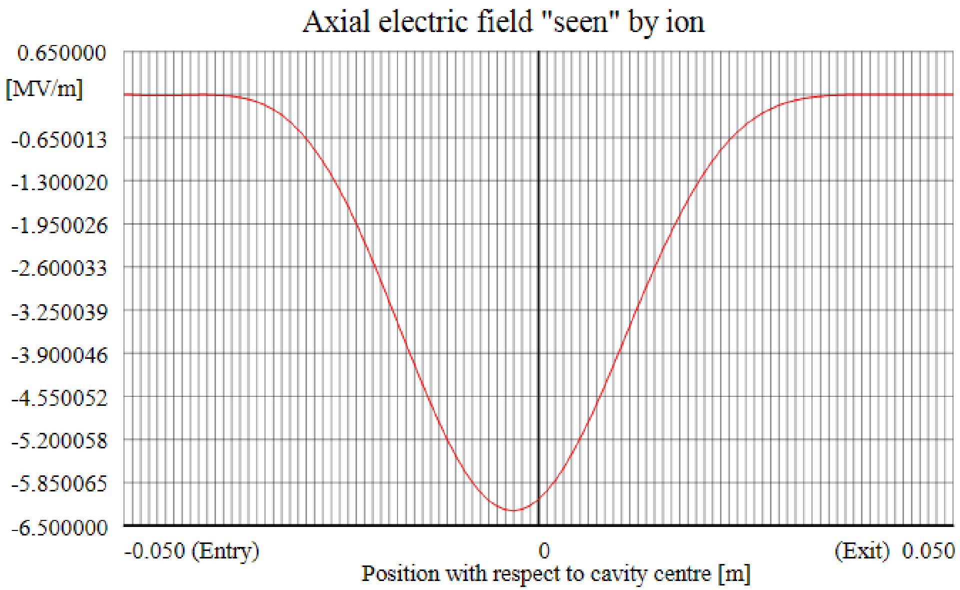
$$P_{tot} = P \times (2 - \varepsilon) = 1.27\ MW$$

Cooling:

- The power dissipated in the cavity walls induce a ΔT that could affect the performances of the cavities (resonance frequency shift, mechanical stress)
- Colling system is needed

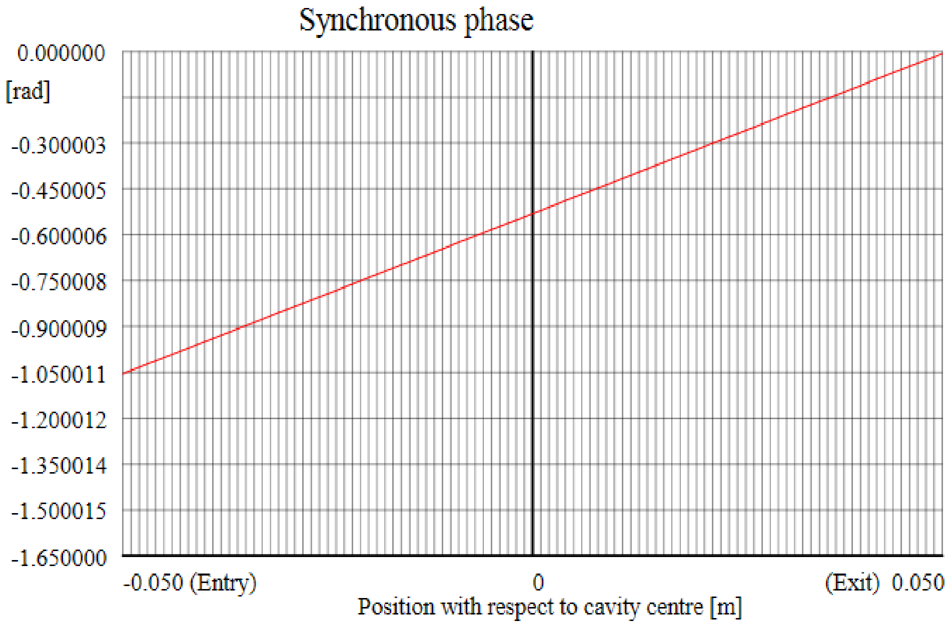
WinAGILE results





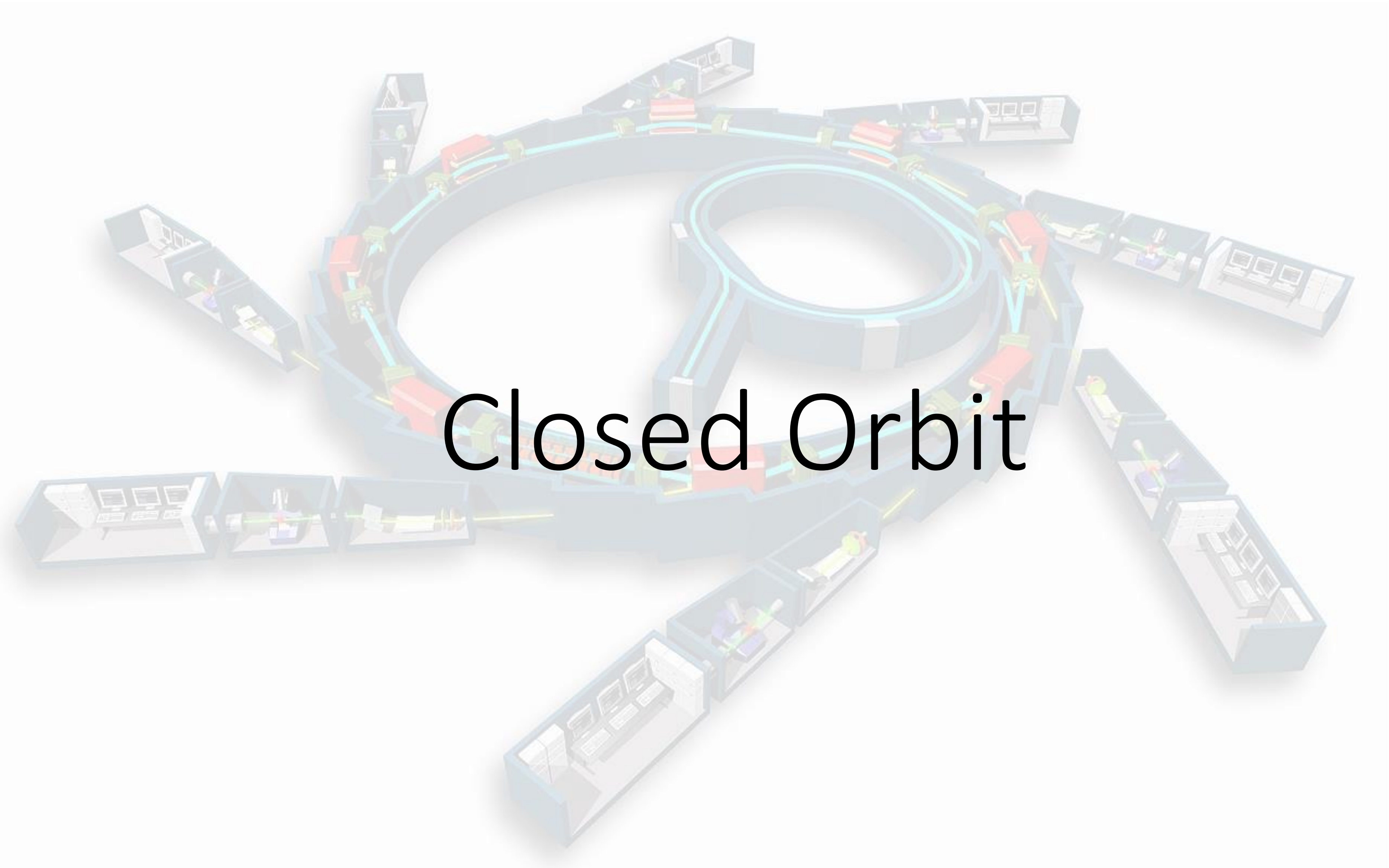
Putting the computed V_{RF} values at 2 and 3 GeV (wigglers off) we can see that

- The phase at the center of the cavity is exactly 150 deg (in the figure different reference system and negative phase)
- The E field has different amplitudes but the right shape



juas
Joint Universities Accelerator School

Closed Orbit

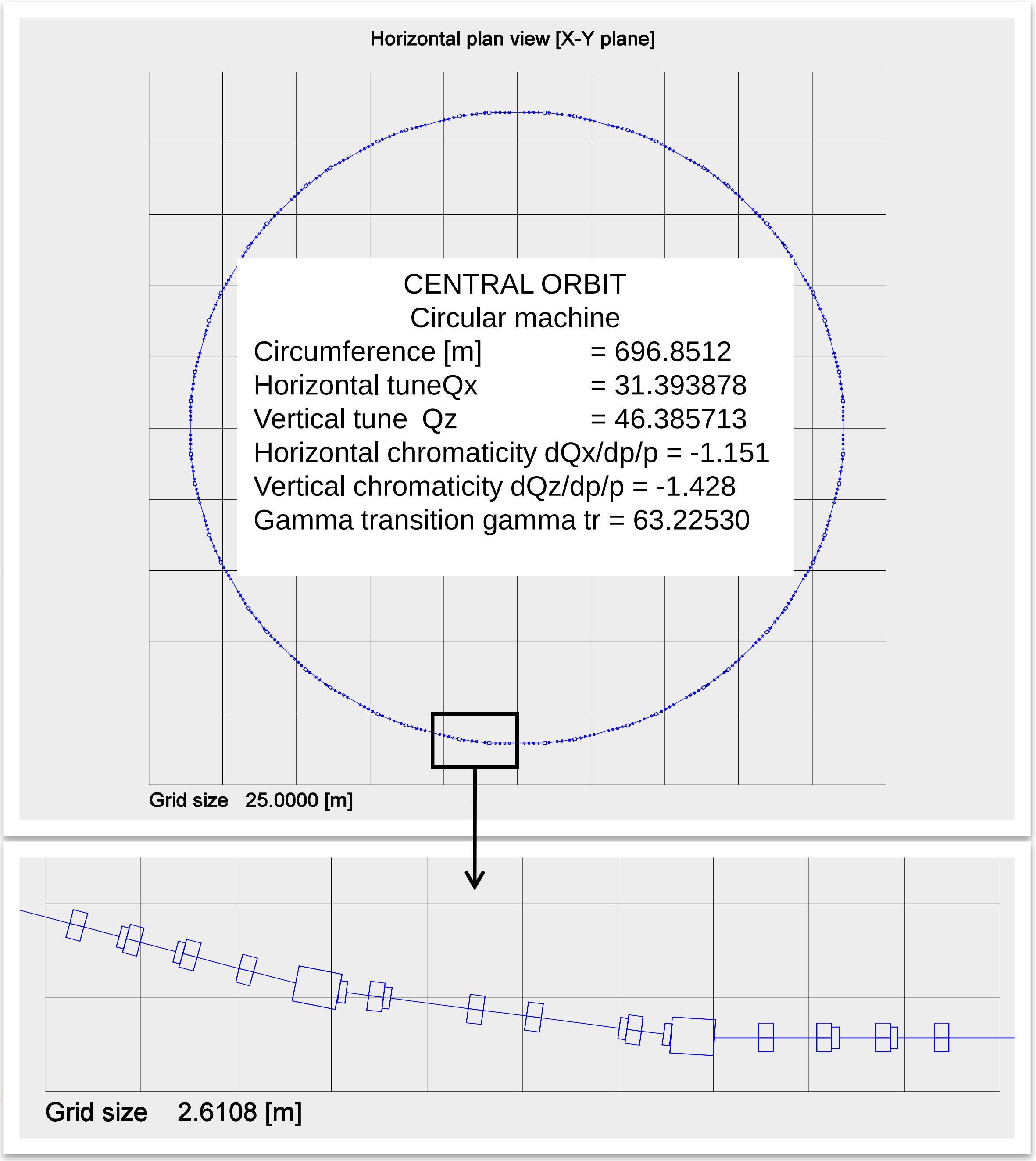


Andrii Natochii
Mirza Sajjad Hussain

Joint Universities Accelerator School

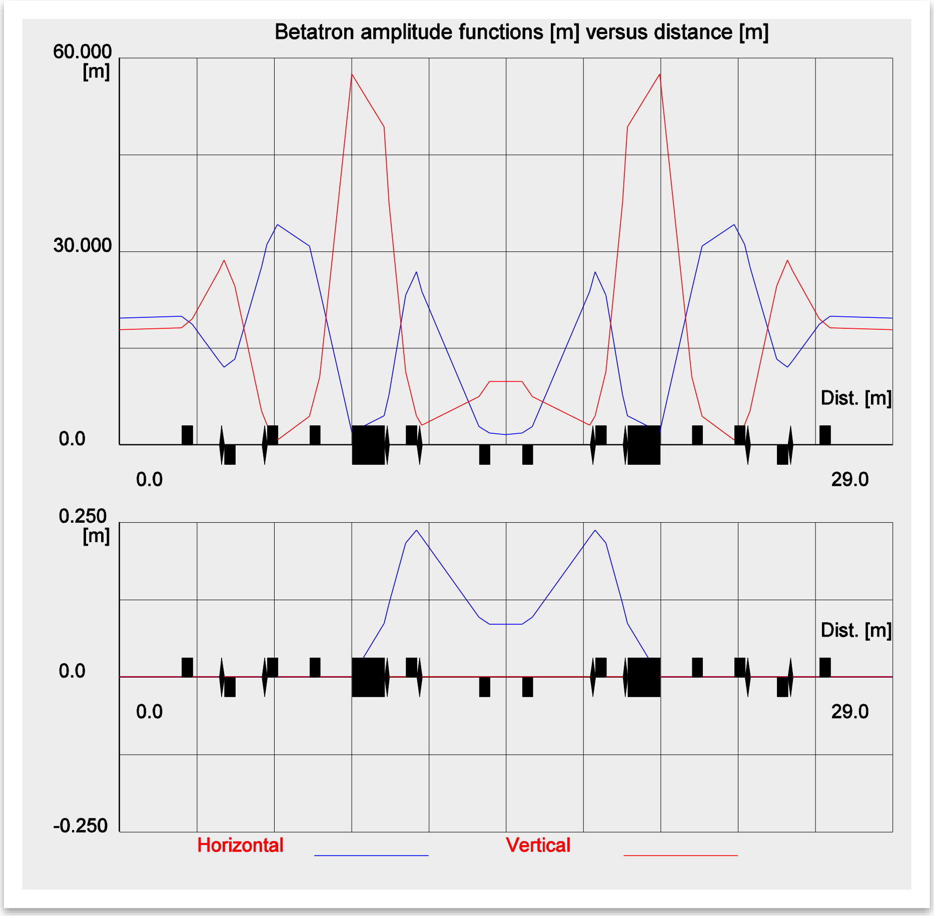
Closed Orbit

“Optimized_ring_SEXTU.lat” 3 GeV electrons



Closed-orbit correction is a compromise. The orbit is measured at only a finite number of positions and there is only a finite number of correctors.

Our goals:
→ Generate errors inside the machine
→ Choose correctors and monitors
→ Try to correct the orbit of the particle in closed orbit case



Machine errors

Random generated errors:

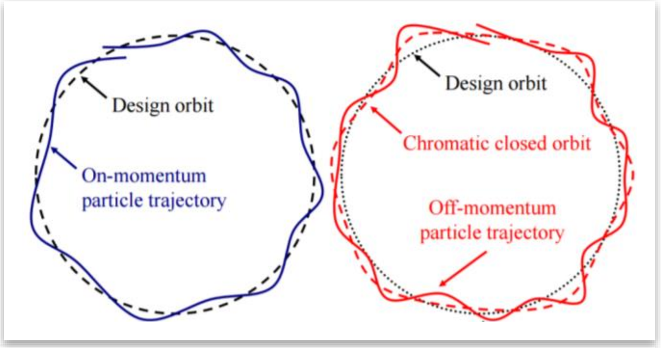
Distribution:Truncated gaussian (4.5 sigmas)

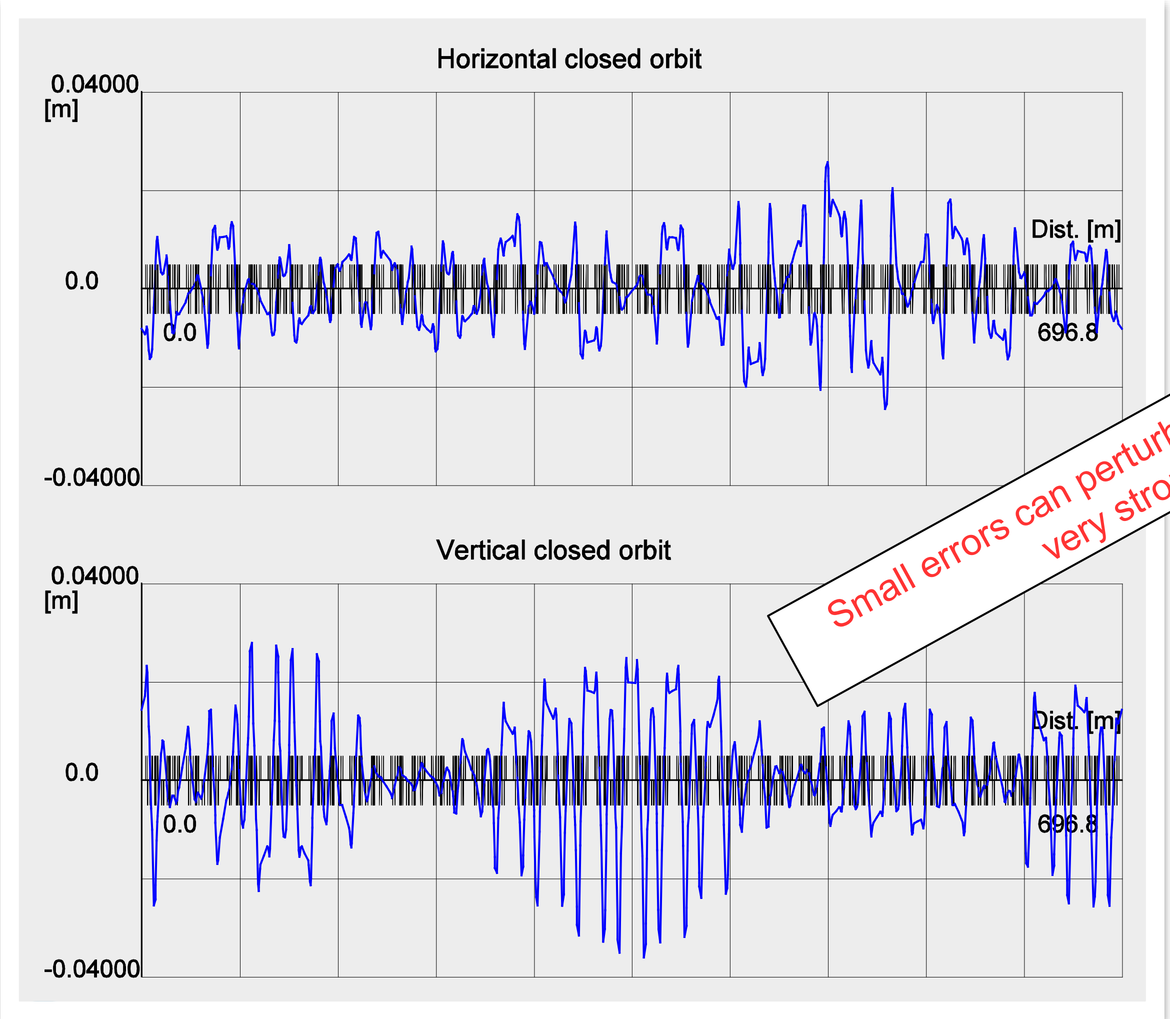
Axial shift of all dipoles [m] = 0.001

Tilts of all dipoles [rad] = 0.001

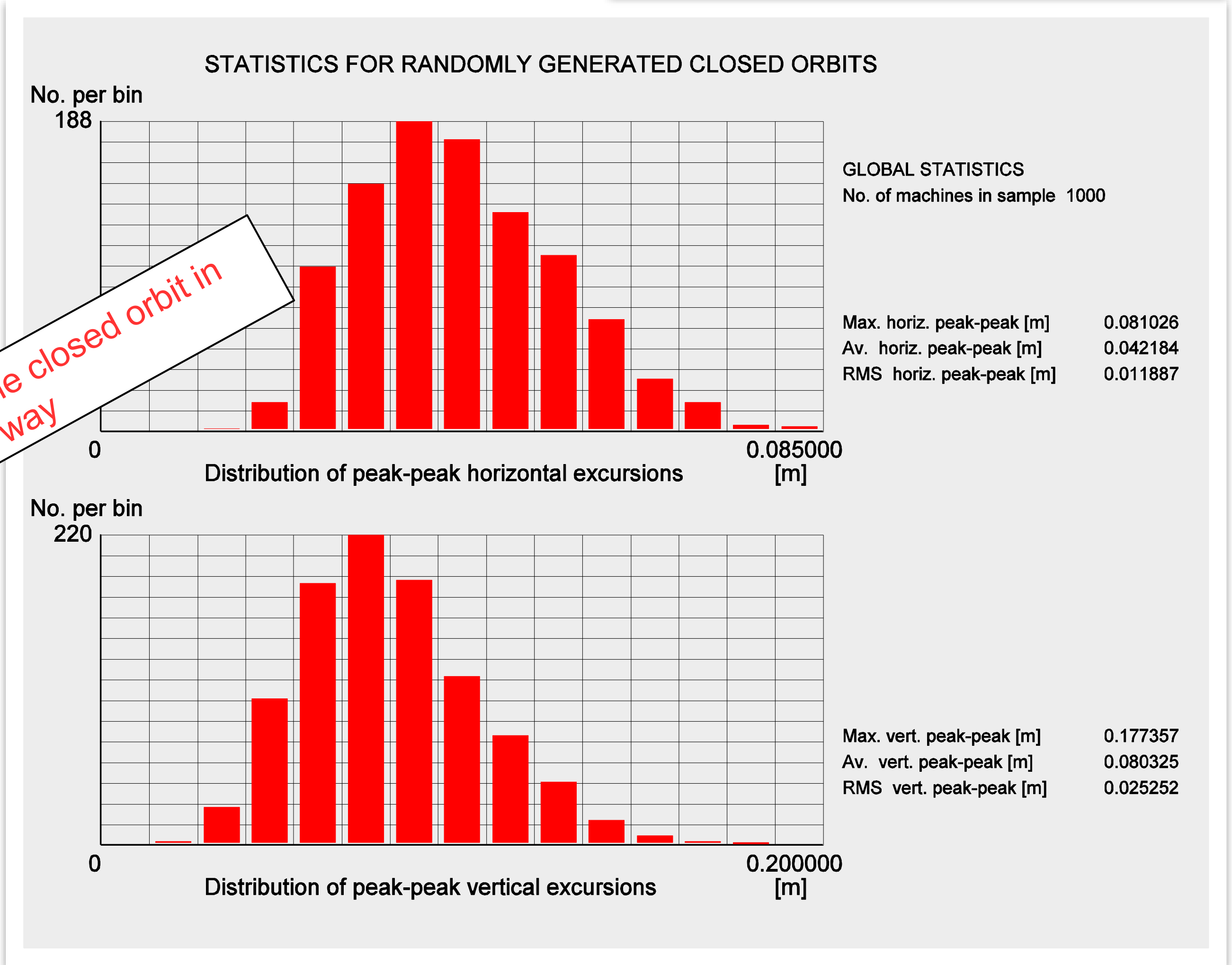
Trans. shifts of all quads.[m] = 0.0001 (H&V)

No. of machines in sample: 1000





Small errors can perturb the closed orbit in very strong way



Correctors/Monitors of the orbit

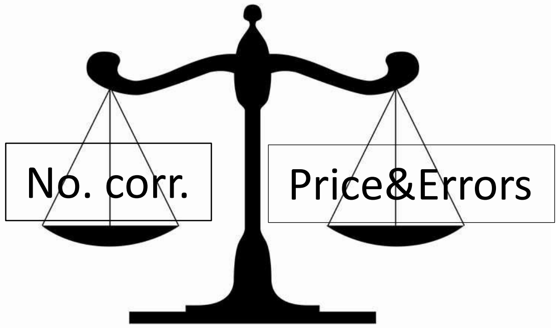
Initial values

# corr	Pk-Pk [m]	Mean [m]	RMS [m]
0	0.050201	-0.000036	0.008351
1	0.034230	-0.000152	0.004511
2	0.033369	-0.000166	0.004433
3	0.028876	-0.000184	0.004055
4	0.028863	-0.000171	0.004047
5	0.028869	-0.000167	0.004047
6	0.028859	-0.000170	0.004046
7	0.028921	-0.000181	0.004043
8	0.028974	-0.000189	0.004041
9	0.028984	-0.000192	0.004041
10	0.028978	-0.000191	0.004041
11	0.028899	-0.000179	0.004033
12	0.028816	-0.000165	0.004022
13	0.028557	-0.000141	0.003991
14	0.028347	-0.000119	0.003973
15	0.028218	-0.000142	0.003957
16	0.028200	-0.000149	0.003954
17	0.028180	-0.000158	0.003946
18	0.028099	-0.000205	0.003905
19	0.027895	-0.000171	0.003852
20	0.027693	-0.000134	0.003791
21	0.027624	-0.000110	0.003765
22	0.027534	-0.000082	0.003730
23	0.027509	-0.000054	0.003701
24	0.027508	-0.000032	0.003681

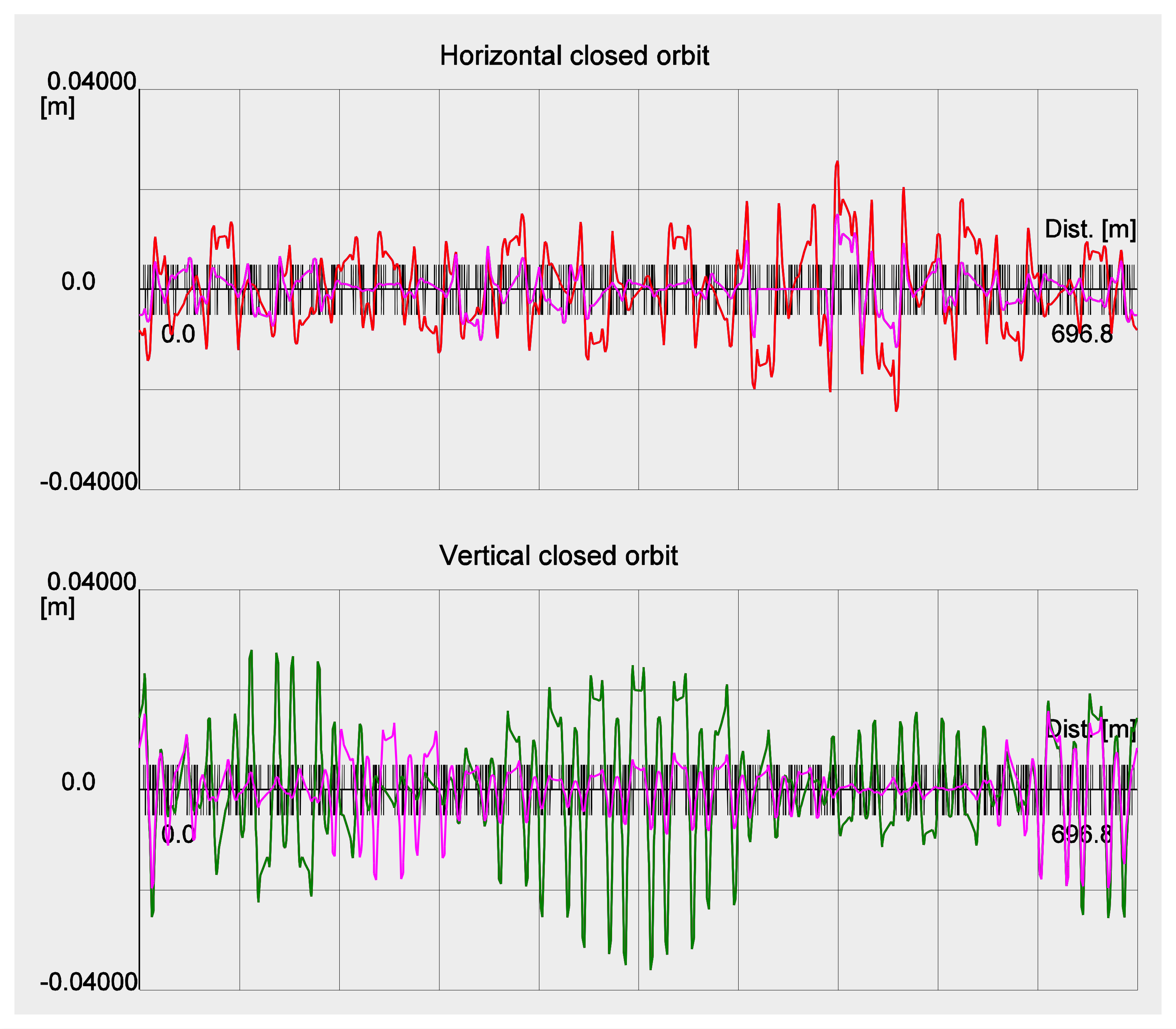
Horizontal plane

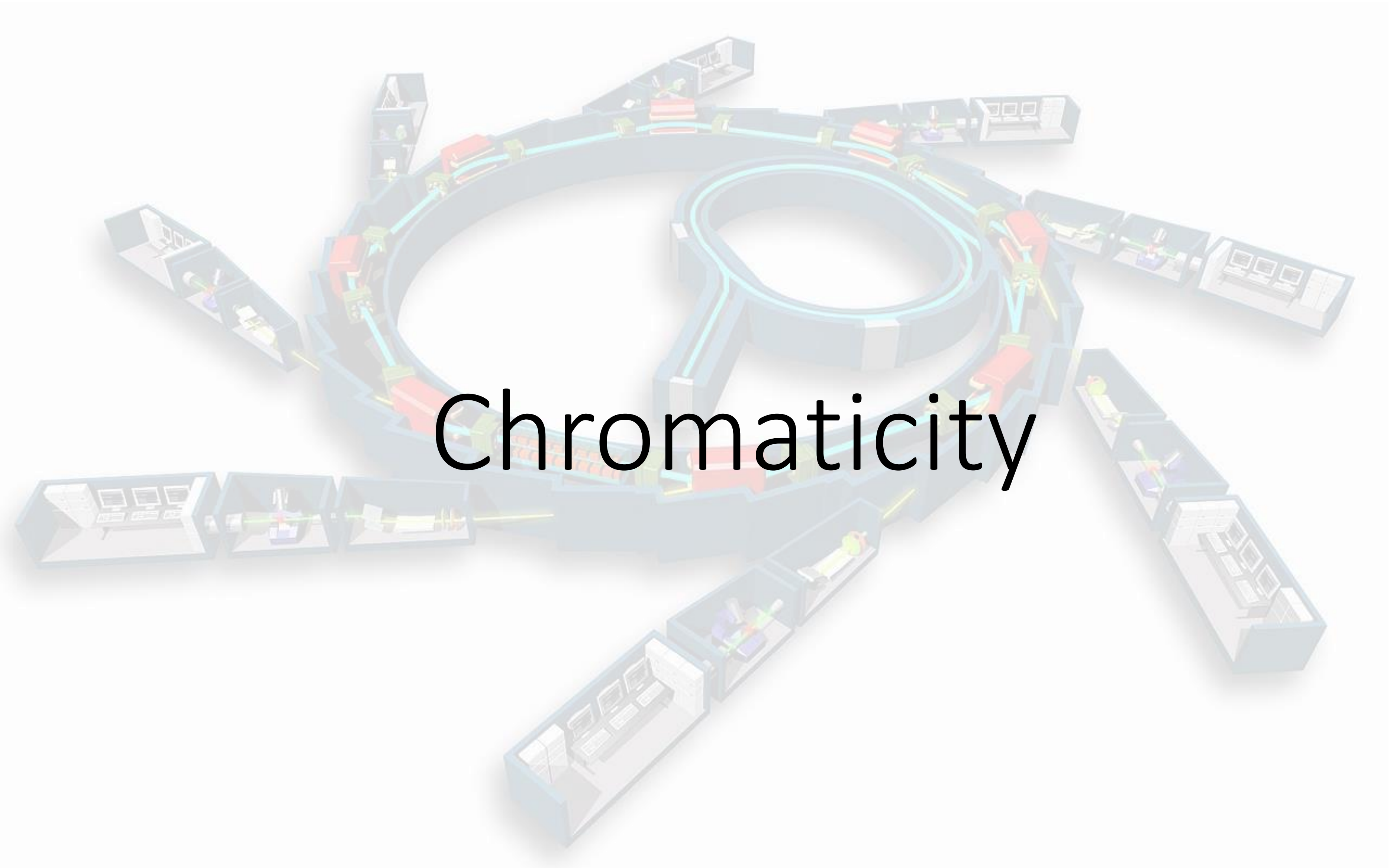
# corr	Pk-Pk [m]	Mean [m]	RMS [m]
0	0.064047	0.000189	0.011008
1	0.049571	0.000310	0.007059
2	0.051840	0.000321	0.007338
3	0.035442	0.000233	0.005486
4	0.035533	0.000224	0.005491
5	0.035597	0.000217	0.005496
6	0.035700	0.000238	0.005494
7	0.035736	0.000246	0.005496
8	0.035774	0.000242	0.005499
9	0.036114	0.000229	0.005523
10	0.036367	0.000220	0.005540
11	0.036565	0.000210	0.005552
12	0.036796	0.000198	0.005567
13	0.036798	0.000197	0.005567
14	0.036939	0.000215	0.005569
15	0.036990	0.000228	0.005570
16	0.037156	0.000219	0.005581
17	0.037299	0.000212	0.005590
18	0.037522	0.000236	0.005593
19	0.037600	0.000244	0.005597
20	0.037681	0.000239	0.005601
21	0.038402	0.000224	0.005643
22	0.038853	0.000214	0.005671
23	0.039191	0.000205	0.005693
24	0.039577	0.000195	0.005720

Vertical plane



Closed orbit (corrected)





Chromaticity

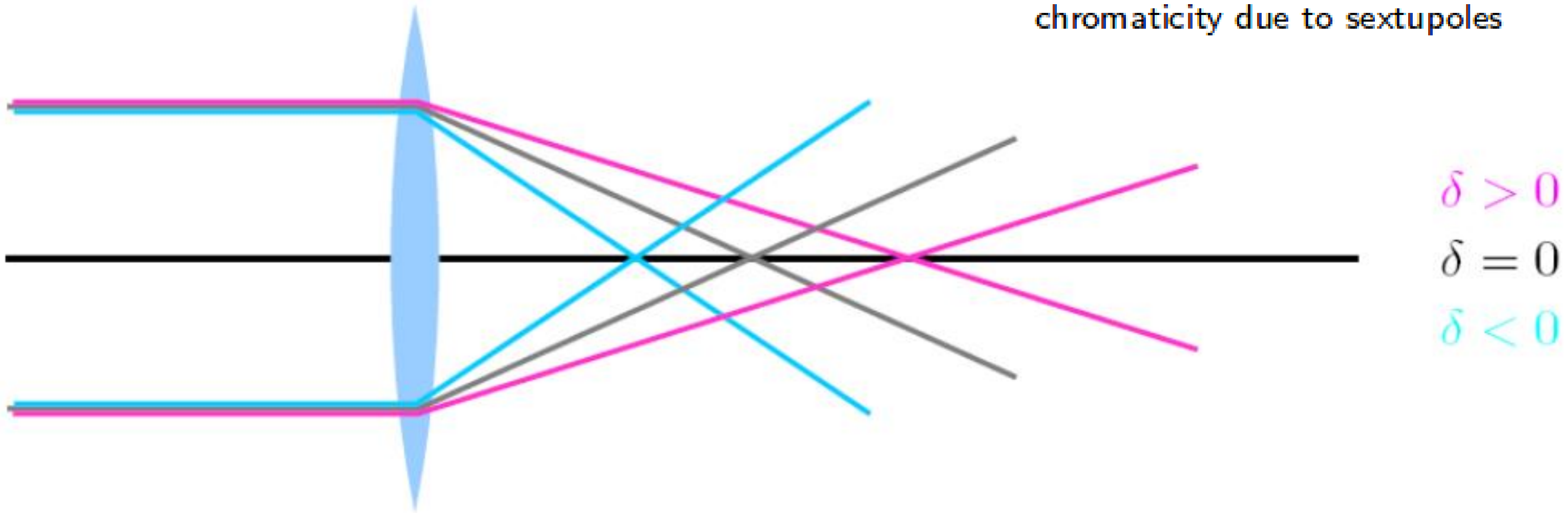
Valerio Dolci

Joint Universities Accelerator School

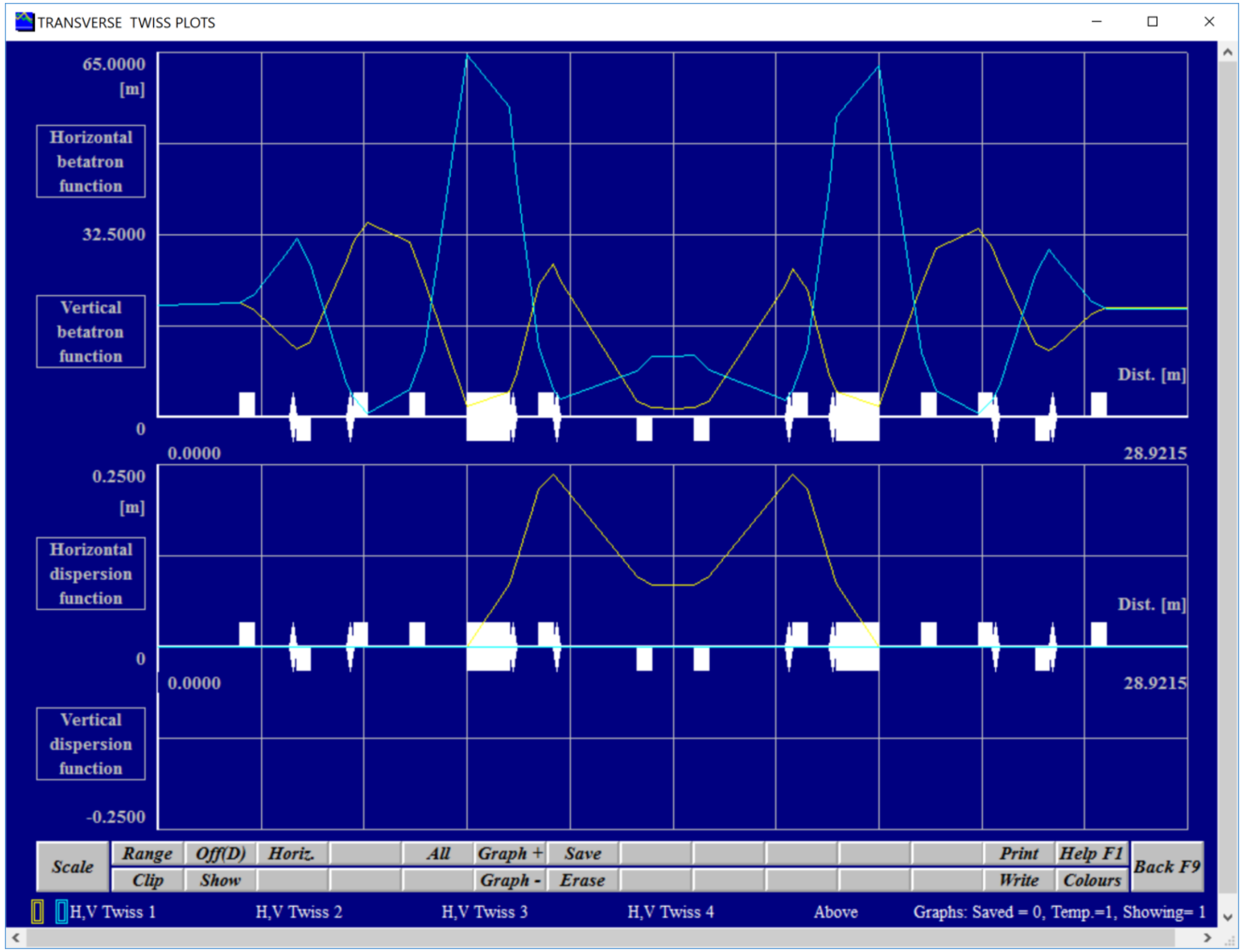
Theory of chromaticity

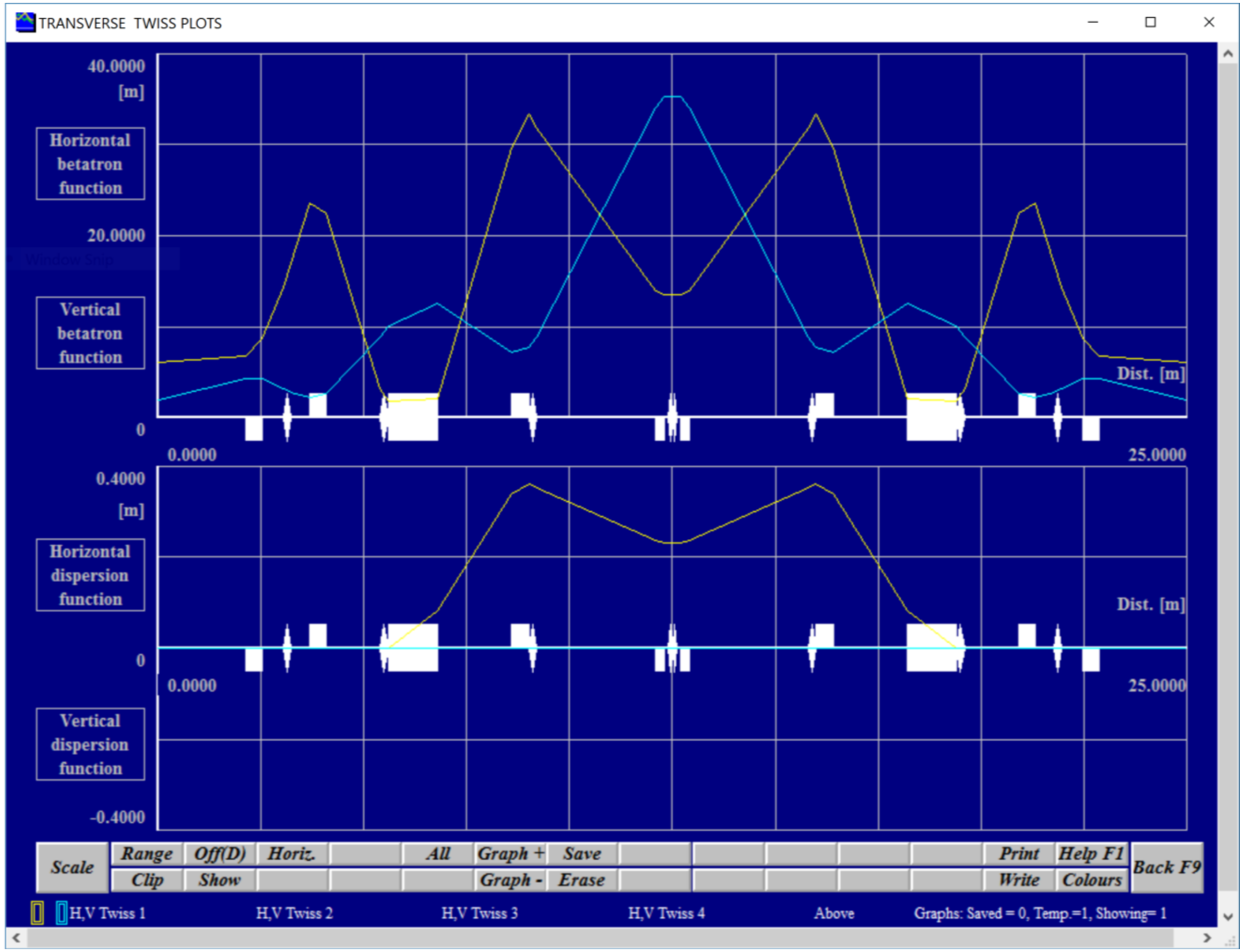
$$\varepsilon_{x,y} = \frac{\delta Qx_{y}}{\frac{\delta P'}{P}}$$

$$\xi = \underbrace{-\frac{1}{4\pi}\oint k(s)\,\beta(s)\,ds}_{\text{chromaticity due to quadrupoles}} + \underbrace{\frac{1}{4\pi}\oint k_2(s)\,D\beta(s)\,ds}_{\text{chromaticity due to sextupoles}}$$



Global chromaticity correction





K_2(sext1)=95,68861
K_2(sext2)=-46,42698

K_2(sext1)= 15,5725
K_2(sext2)= 21, 9066

Joint Universities Accelerator School

W-vector local correction

$$B = \frac{(\beta_1 - \beta_0)}{(\beta_0\beta_1)^{1/2}} \quad \text{and} \quad A = \frac{(\alpha_1\beta_0 - \alpha_0\beta_1)}{(\beta_0\beta_1)^{1/2}}$$

$$\psi = \frac{1}{2}(\mu_0 + \mu_1) \quad \text{and} \quad \Delta K = (K_1 - K_0)$$

$$\frac{\delta P}{P} = 0.001\%$$

$$a = \underbrace{\text{Limit}}_{\Delta p/p \to 0} \frac{A}{\Delta p / p} \quad \text{and} \quad b = \underbrace{\text{Limit}}_{\Delta p/p \to 0} \frac{B}{\Delta p / p}$$

$$\Delta K = \underbrace{\text{Limit}}_{\Delta p/p \to 0} \frac{-\Delta K}{\Delta p / p} \quad \text{and} \quad \psi \to \mu$$

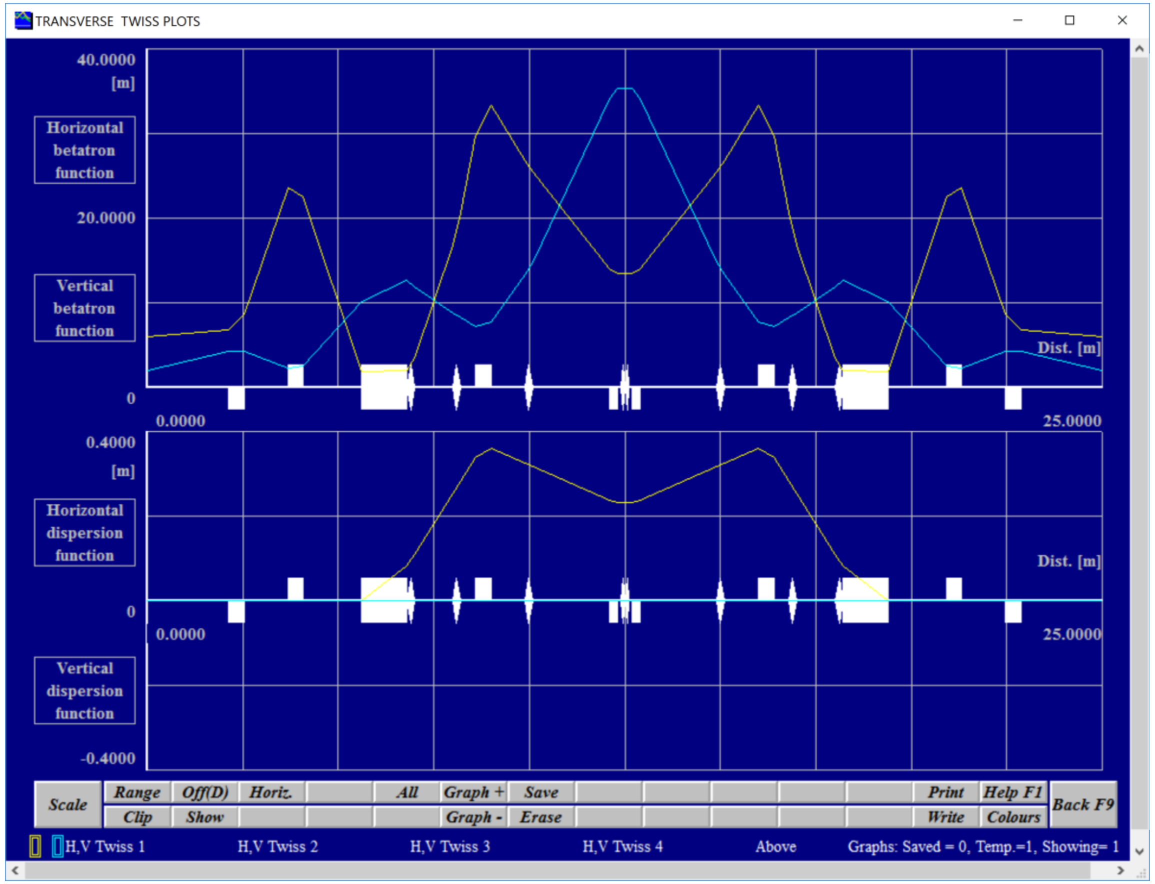
$$\boldsymbol{w} = (b + ja)$$

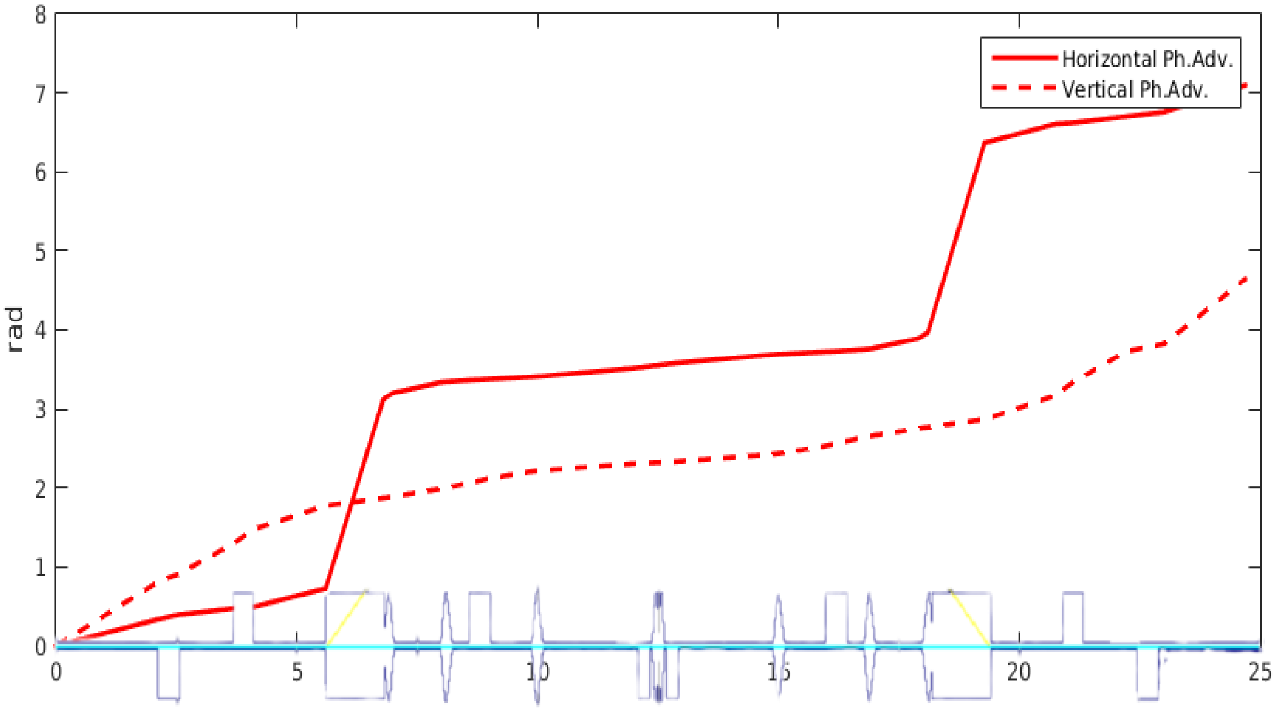
Thin lens approximation

$$\text{Quadrupole}: \Delta a(0) = -(\beta_0\beta_1)^{1/2} \Delta k \, \Delta s \approx \beta_0 k_0 \ell_{\text{q}}$$

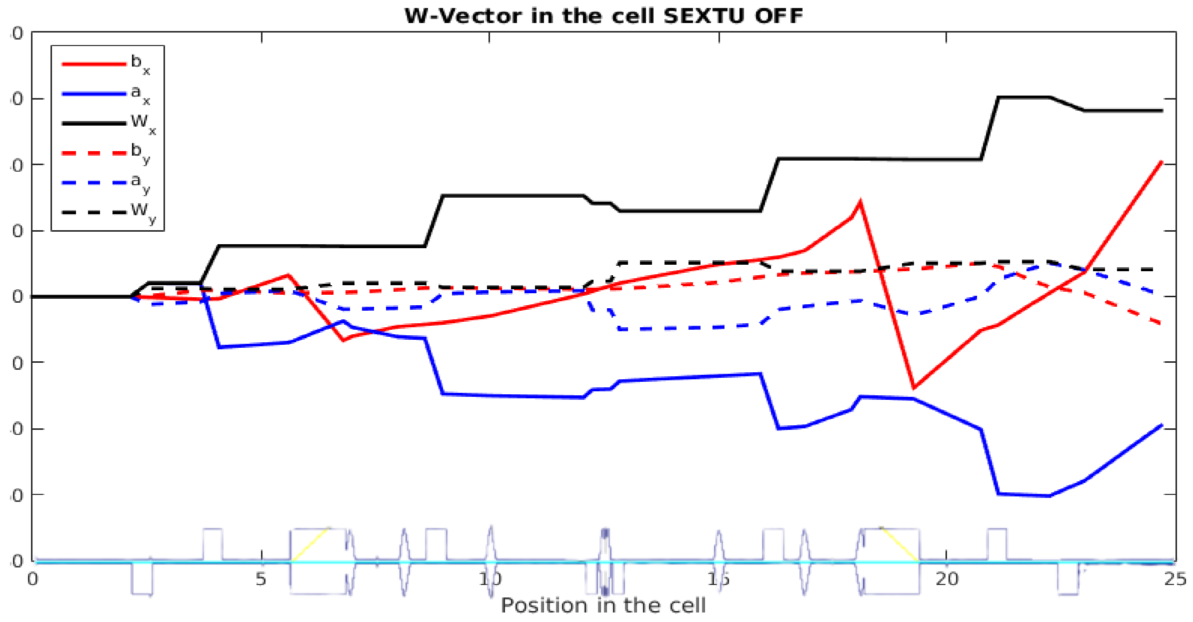
$$\text{Sextupole}: \quad \Delta a(0) = -(\beta_0\beta_1)^{1/2} \Delta k \, \Delta s \approx -\beta_0 D_x k_n^1 \ell_{\text{s}}$$

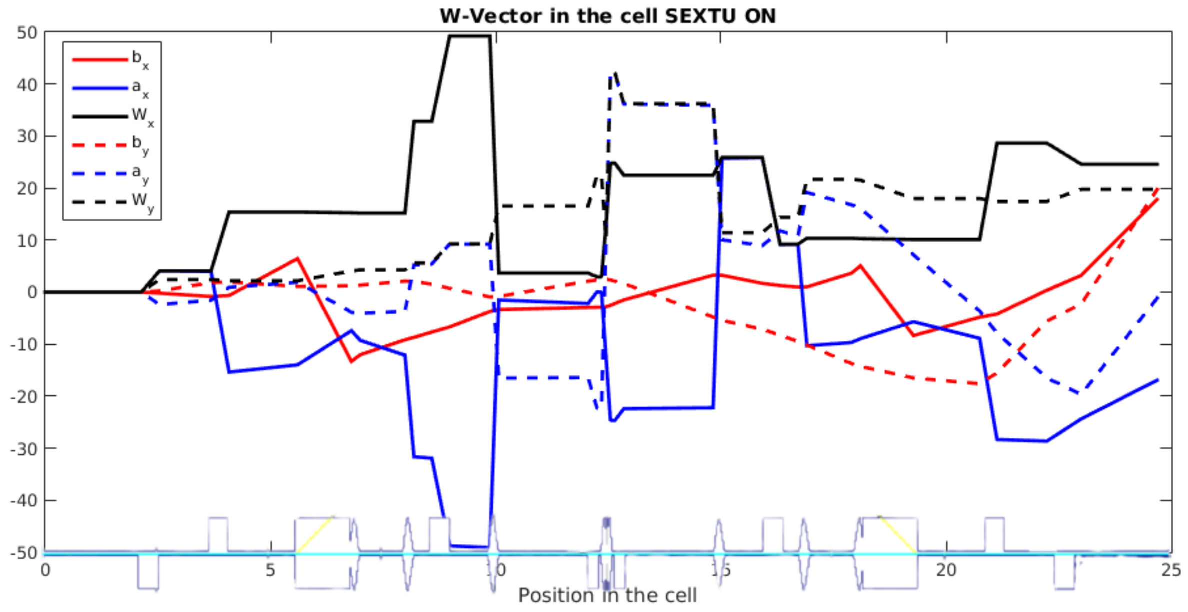
Local correction in optimized cell

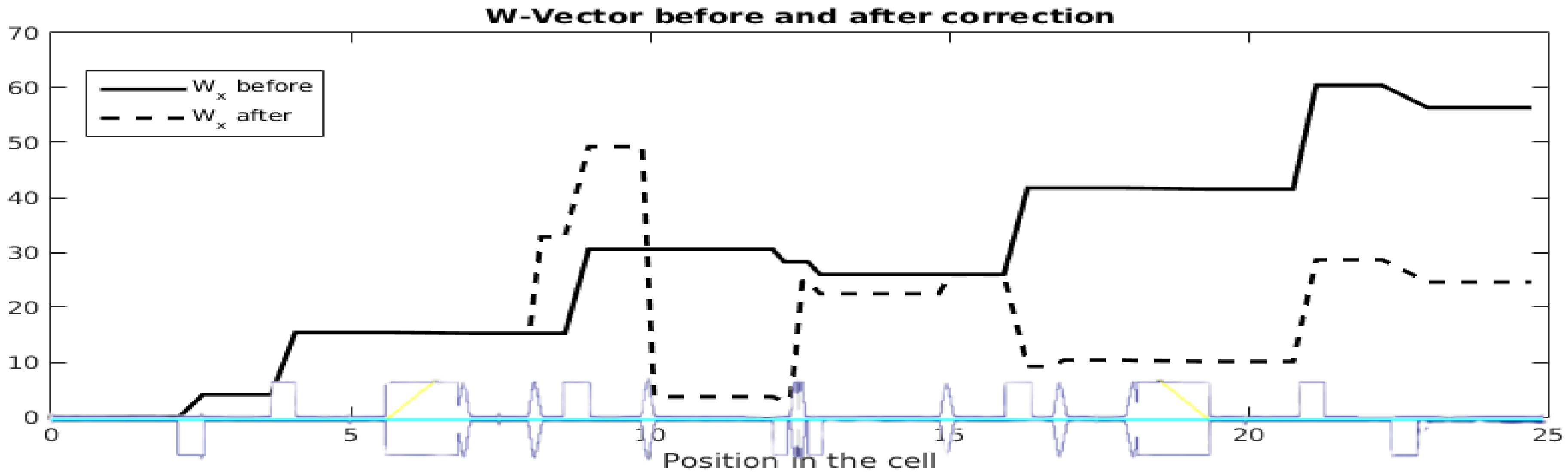


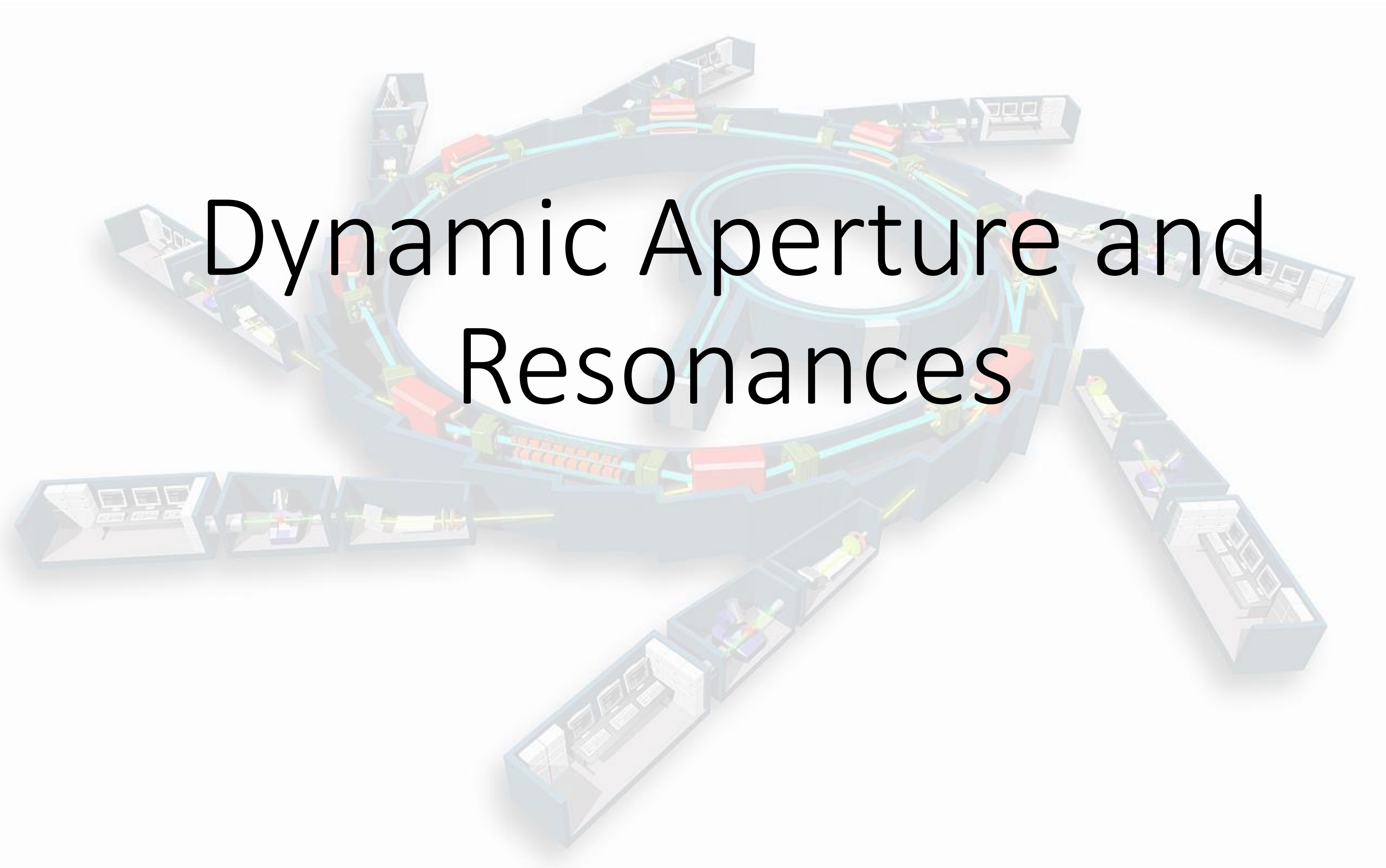


Result of local correction on W-vector









Dynamic Aperture and Resonances

Lina Hoummi
Sofia Kostoglou
Jean Cazabonne

Joint Universities Accelerator School

Summary

1) Introduction to dynamic aperture

2) Resonances

3) Dynamic aperture : First lattice cell.

4) Dynamic Aperture : New lattice.

5) Dynamic Aperture : Improvement.

Conclusion

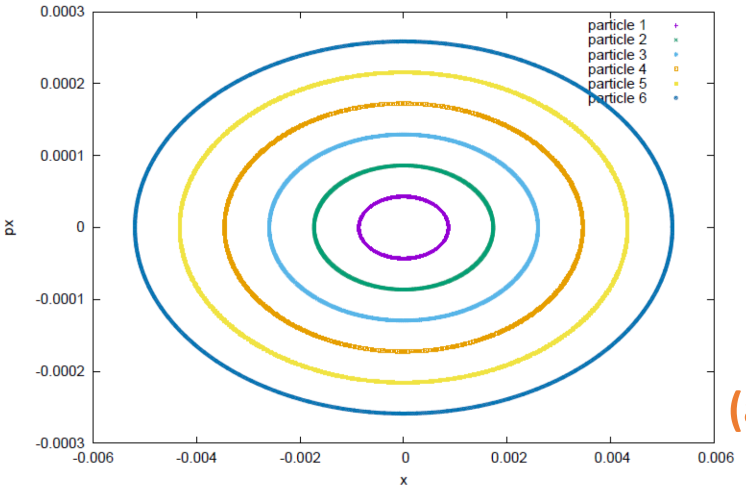
Introduction to dynamic aperture

Sextupoles create 2nd order magnetic fields:

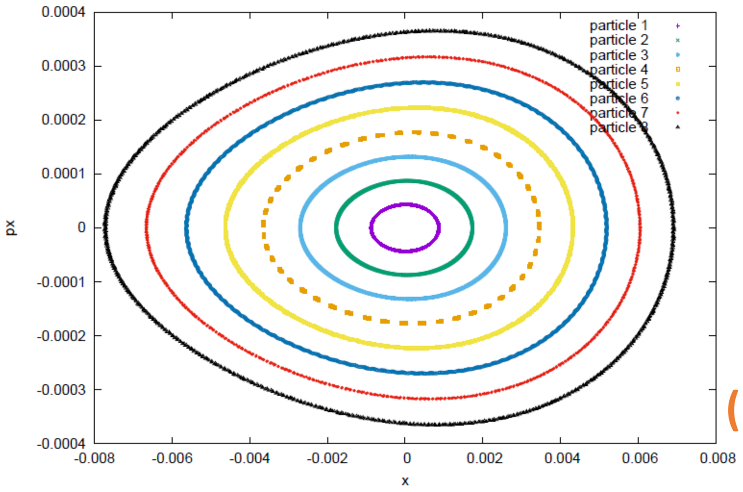
- => **non-linear** deformation of the field.
- => non-linear deformation of the **phase space**.
- => modes of **resonance**.

Resonances can dispel the beam in few turns.

Example: *transverse phase space for the ring with sextupoles switched off* **(a)** *and on* **(b)**.



(a)



(b)

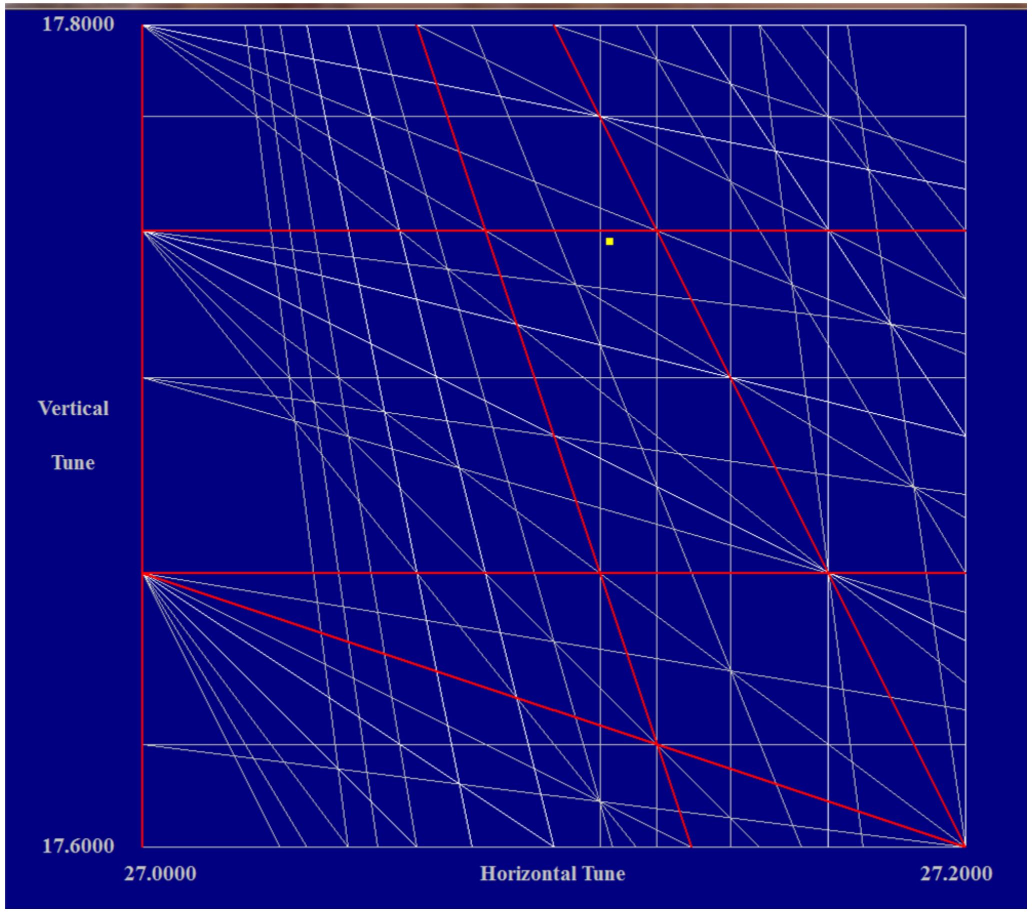
2) Resonances

Sextupoles:

- Correct the chromaticity.
- Do not change the **tune** BUT add resonance modes.

- Problem of **beam stability**.

*Tune diagram showing resonance modes for the optimized ring, from **WinAgile**.*



3) Dynamic aperture: First lattice cell

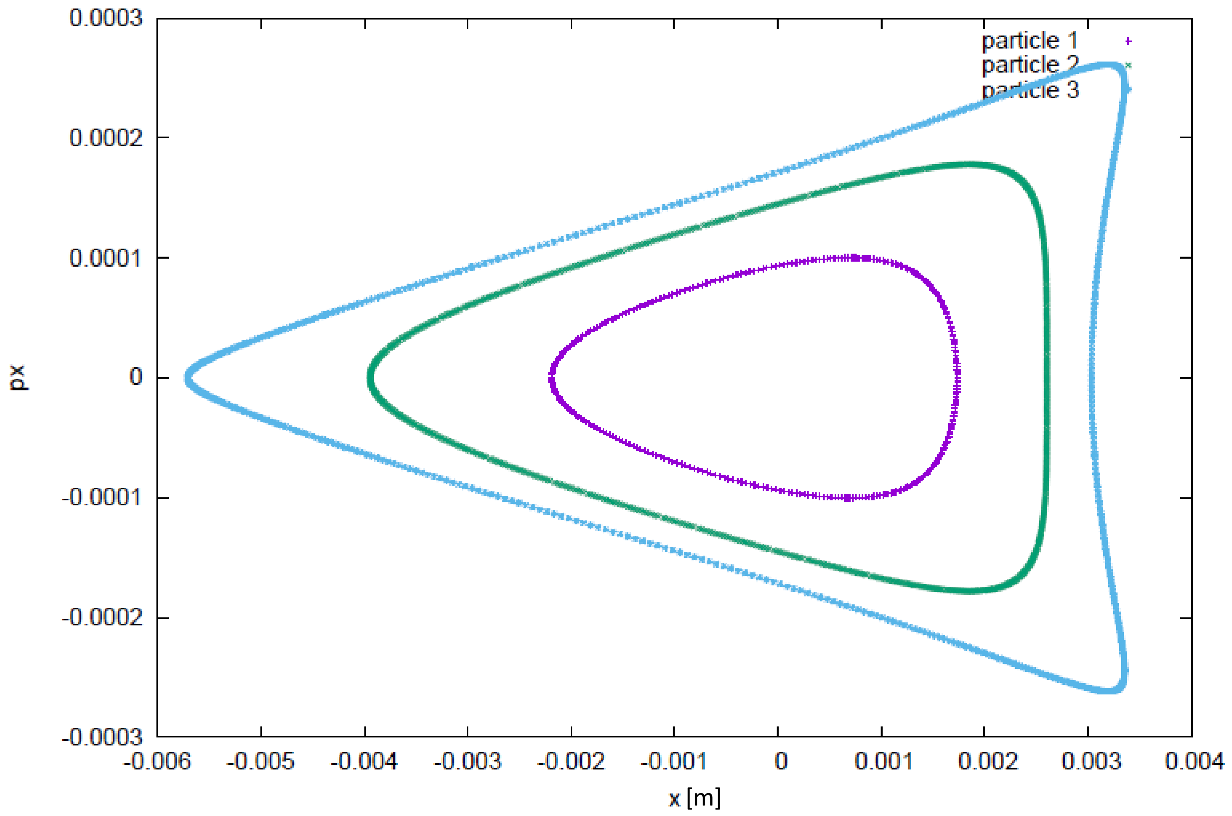
Tracking done with **MAD-X**.

<u>Problems</u>:

- High chromaticity => high **sextupoles strength**.
- => Particles lost after **1,75σ** only.

With:

$$\sigma_i = \sqrt{\beta_i \cdot \varepsilon_G} = 1{,}7 \text{ mm}$$



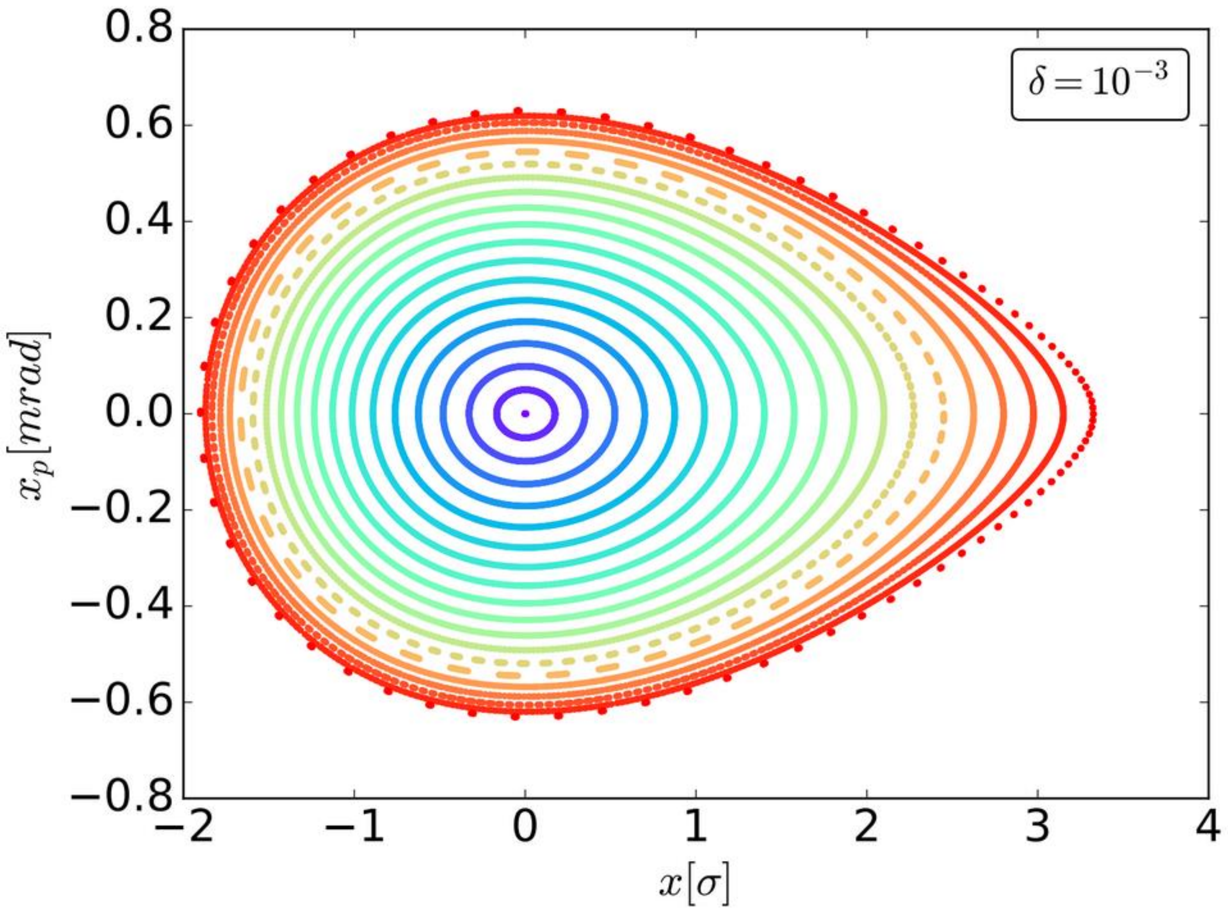
3) Dynamic aperture: New lattice cell

Natural chromaticity is lower than before:

- => lower sextupoles strength
- => Particles now lost after **3,65σ**.

<u>Note</u>:

All focusing and defocusing sextupoles have respectively the **same strength**.



3) Dynamic aperture: Improvement

Correction sextupoles are in:

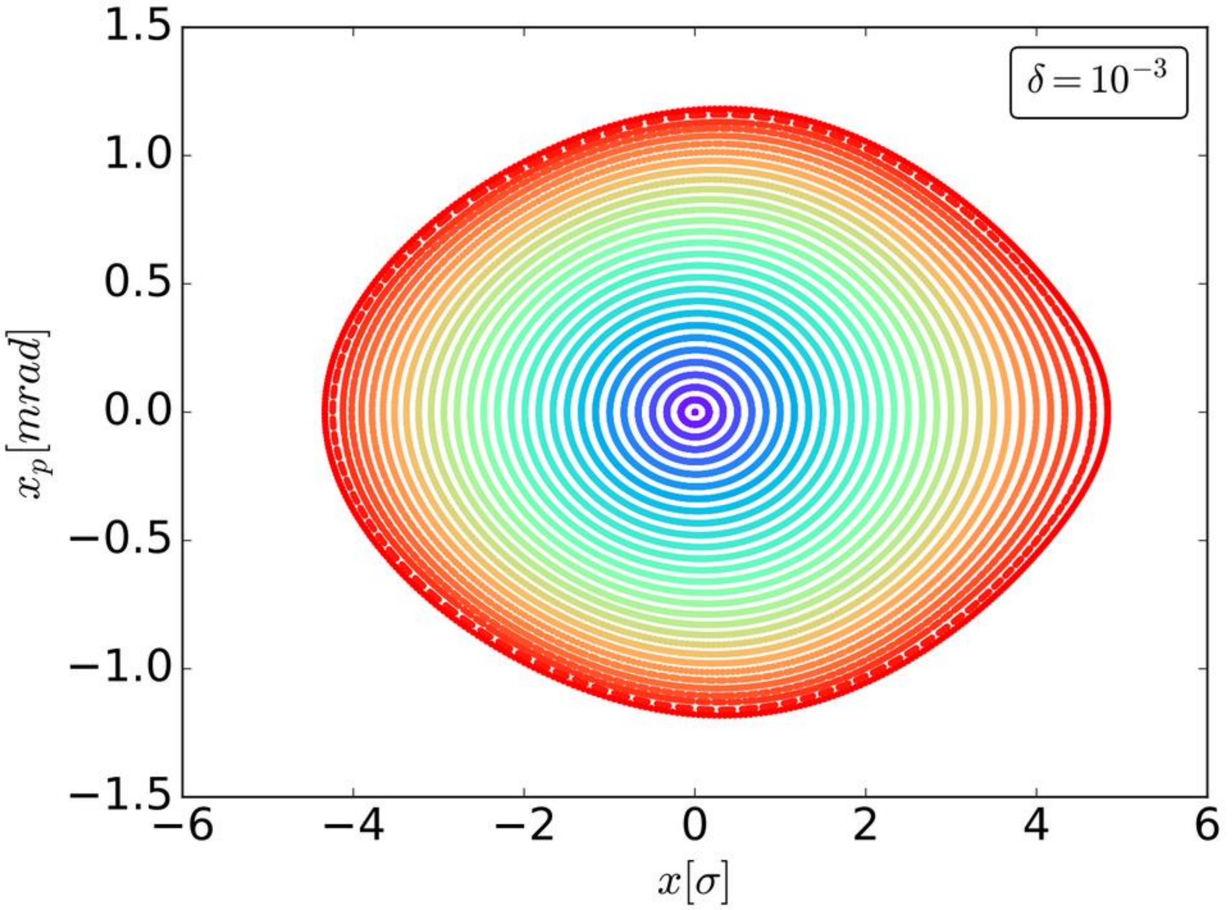
- Zero-dispersion zone.
- => do not affect chromaticity.
- => only compensate other sextupoles strength.

- Low-β zone.
- => need **more strength** to do the compensation.

With:

$$K_{corrector} = 2{,}5.\, K_{sextupole}$$

=> Reach **5σ**.



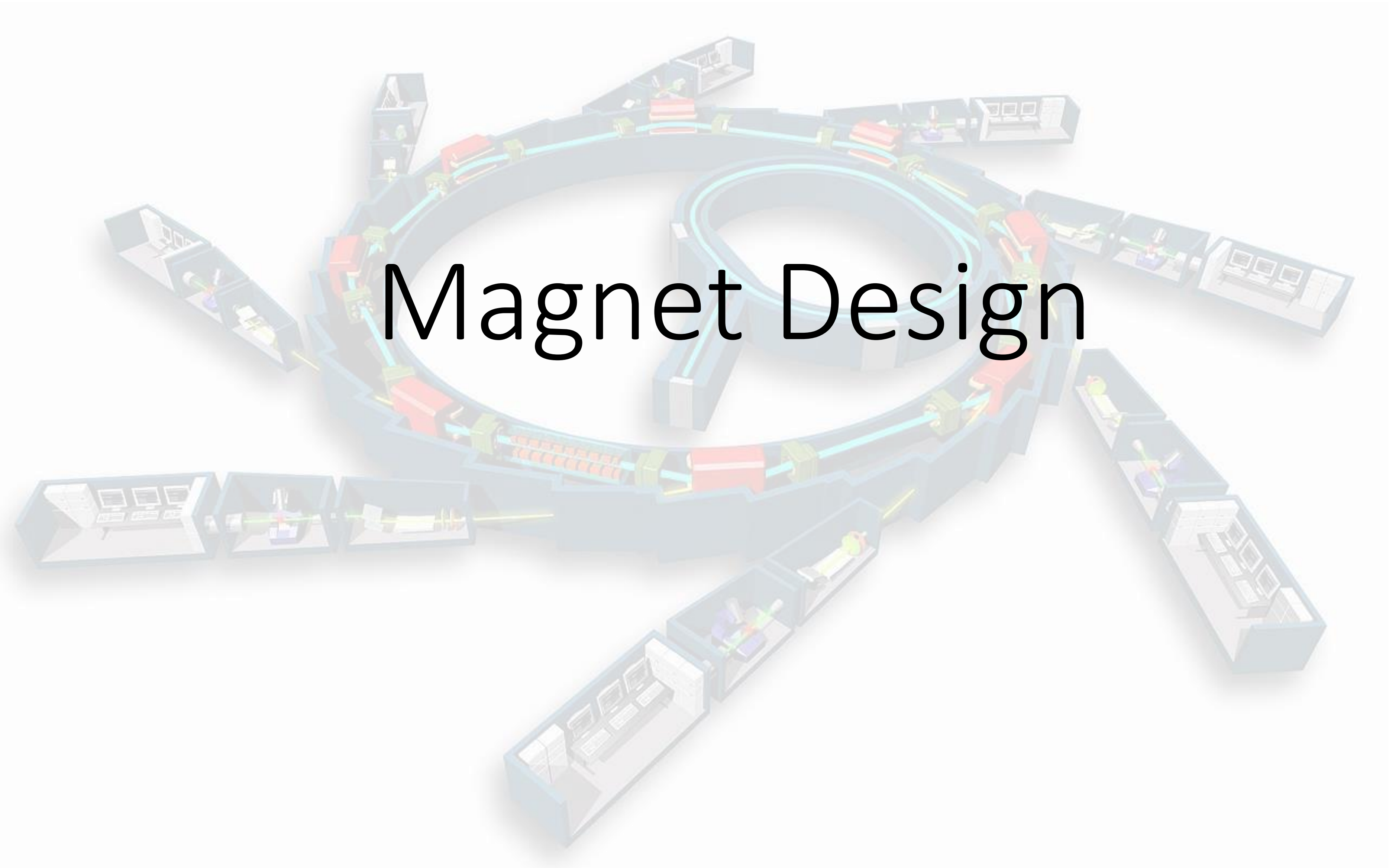
Conclusion

Dynamic aperture high enough to have a **stable beam**: 5σ (at least 3σ are required).

Due to:

- Lower natural chromaticity (lattice design, quadrupoles).
- So lower sextupoles strength to correct it.
- So less magnetic field deformations.

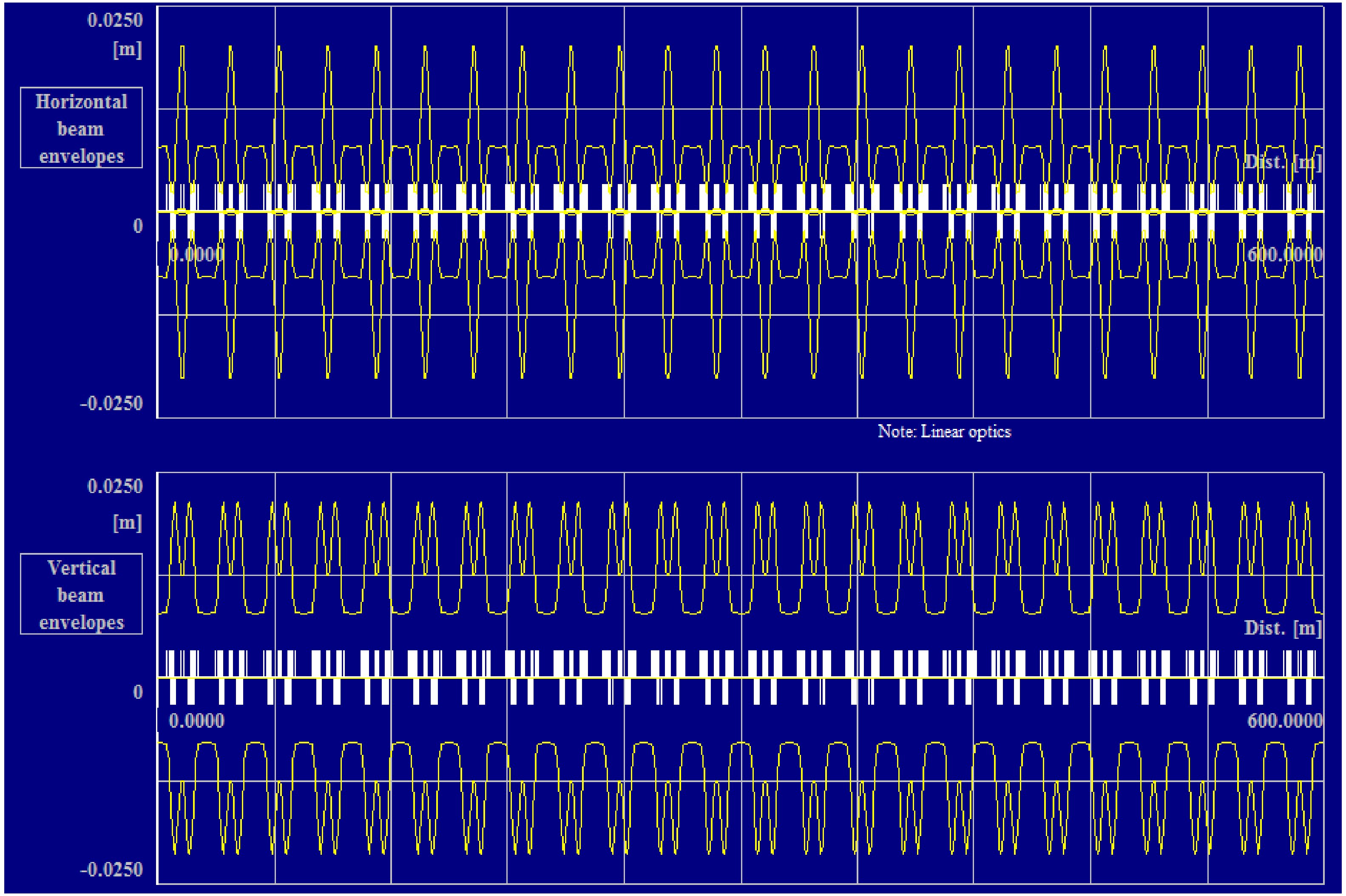
Close to resonances, but can be corrected by a **tune shifter**.



Magnet Design

Mina Abbaslo
Elham Salehi

Magnet Design



Main Specifications For Dipole

Bmax,[T]=1.0918

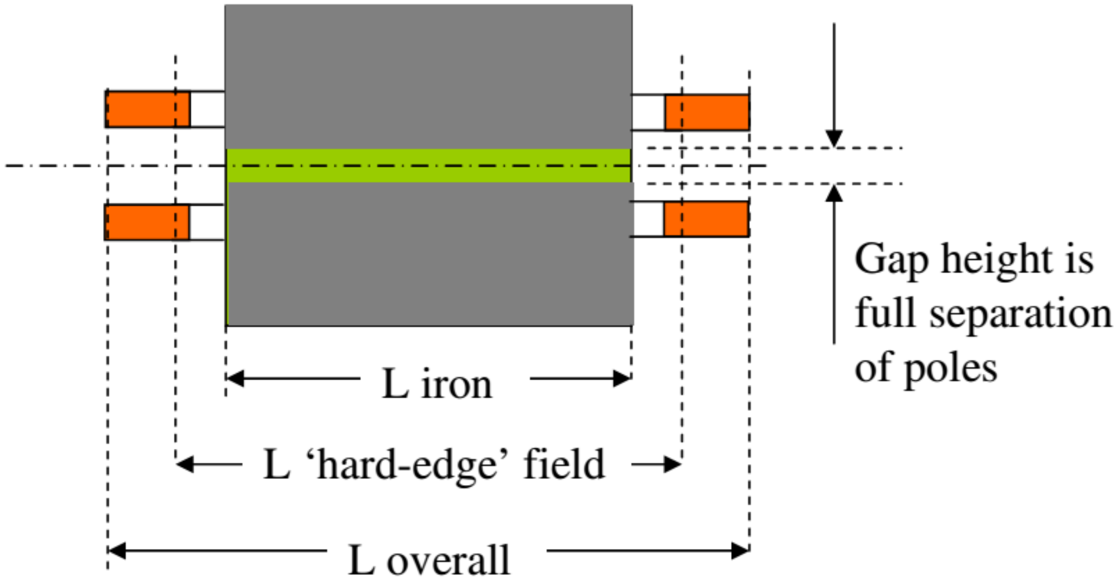
Bending Radius,[mm]=9160

Bending Angle,[˚]=0.1309

Magnet Length,[mm]=1200

Iron Yoke Specifications

Overall Length,[mm]=10*gap=560
Liron,[mm]=1166.9
Pole width ,[mm]=5*56=280
Overall width ,[mm]=13*56=728
Overal height ,[mm]=10*56=560



Coil Specifications

NI,[A]=24326.5245
Conductor dimensions,[mm]=12*12

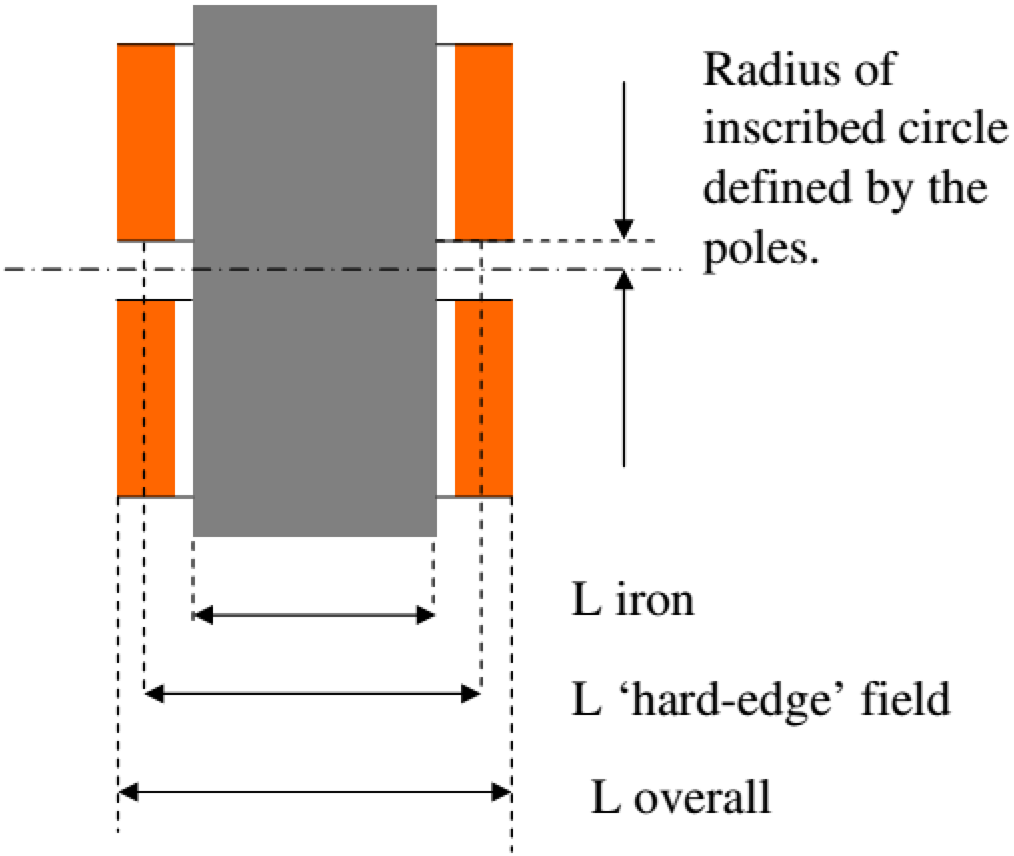
Gap height= 56mm (External beam pipe Diameter + Geometric alignment tolerance + Thermal insulation)

Dipole Eddy Current

Selected unit=10. Dipole1
Dipole half gap [m]= 0.028000
Left/lower wall [m]= -0.02850
Right/upper wall [m]=   0.02850
Wall thickness [m] =0.00150000
Resistivity [ohm m] =0.0000007200
Laminated yoke
Pole width [m] = 0.210000
Lamination thickness [m] =0.00100000
End plate thickness [m] =0.05000000
Lamination resistivity [ohm m] =0.0000001000
End plate resistivity [ohm m] =0.0000001000
Path length in iron [m] =   1.120000
Lamination: principal mode, T 1,1 = 0.00002496
End plate: principal mode, T 1,1 = 0.05906533

Main Specifications For Quadropole

- Magnet Length,[mm]=400
- Aperture diameter,[mm]=28
- Overall Length,[mm]=56.3720
- Liron,[mm]=0.3720
- Overal width,[mm]=7*28=196
- NI,[A]=16964.11

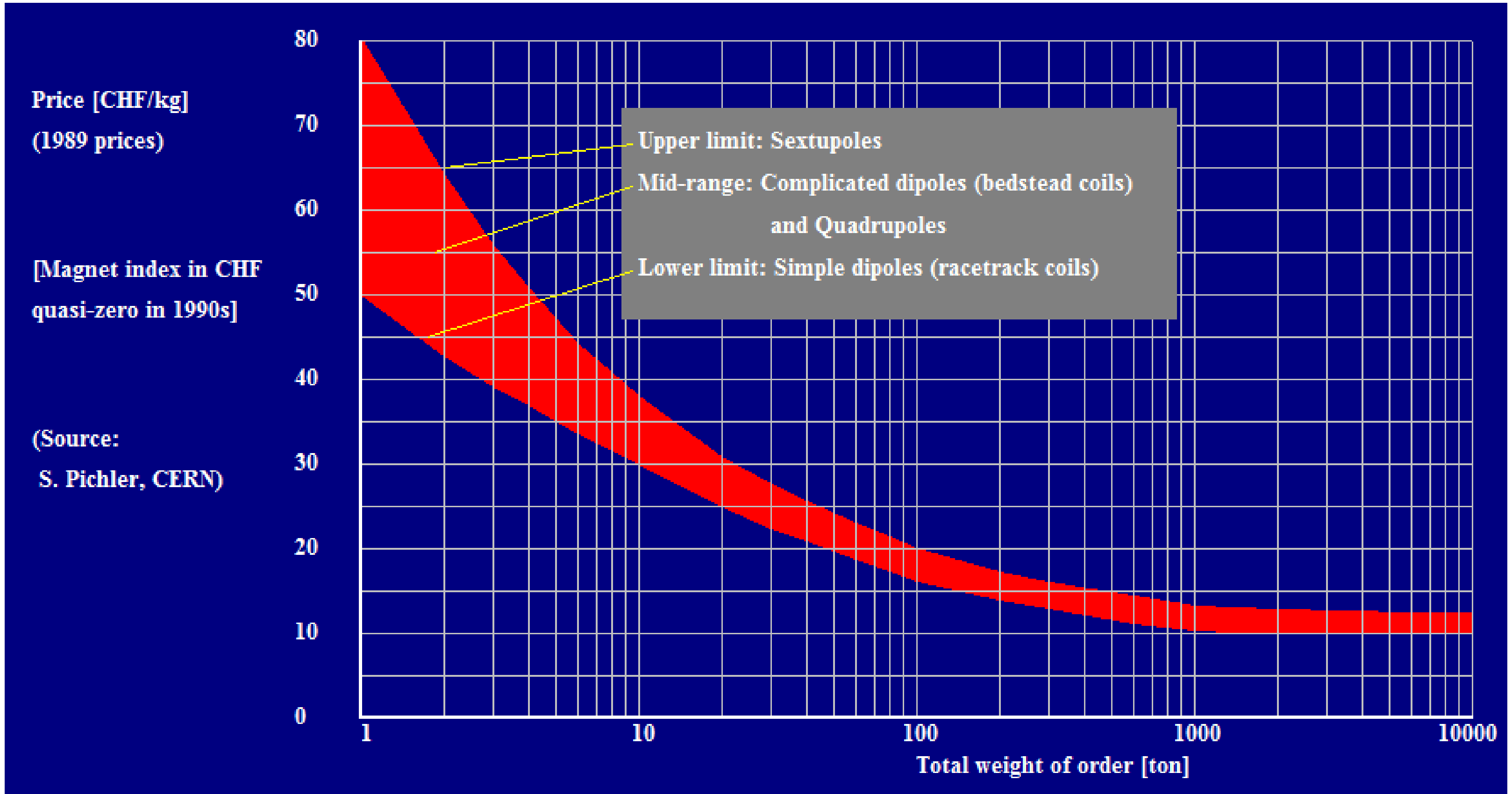


$$r_x \propto \sigma_x = \sqrt{\varepsilon_x \beta_x}$$

$$r_y \propto \sigma_y = \sqrt{\varepsilon_y \beta_y}$$

$$r = \max(r_x, r_y)$$

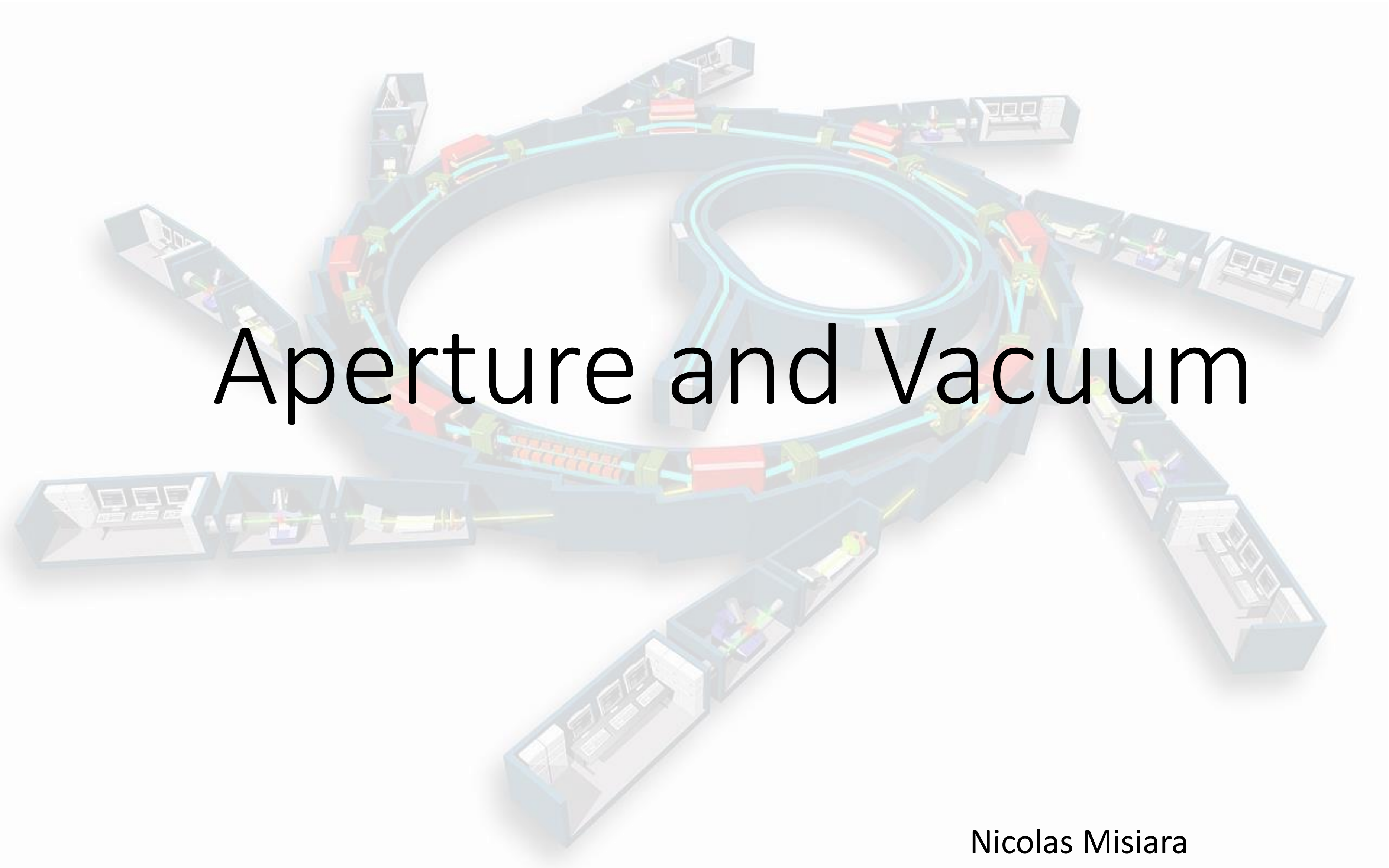
Magnet Cost



ALTERNATIVE FORMULA: (Source: M. Giesch, CERN)

For orders >500 ton. 1998 prices.

Iron: 5 CHF/kg.
Copper: 60 CHF/kg for racetrack coils.



Aperture and Vacuum

Nicolas Misiara

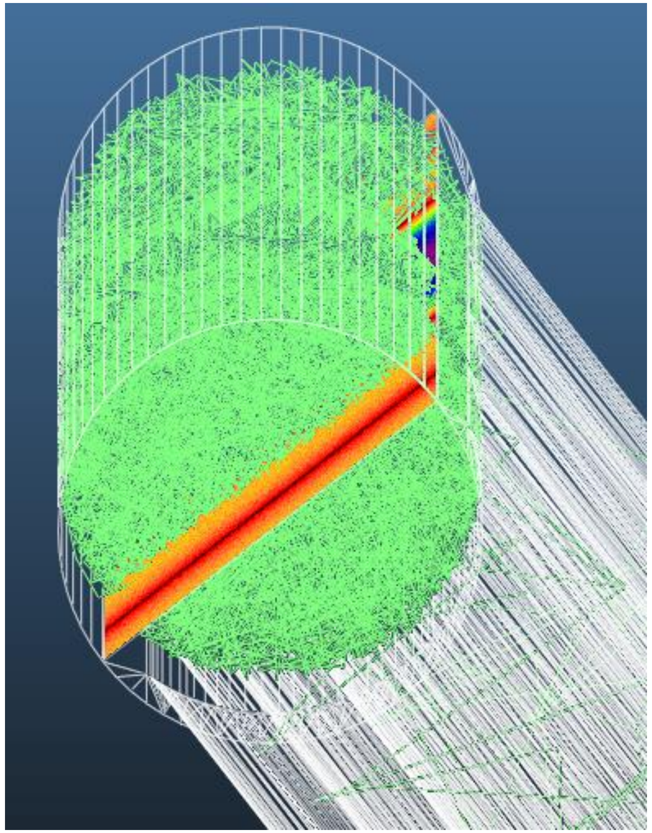
Joint Universities Accelerator School

Vacuum & aperture

- Input parameters
  - Base vacuum pressure : **$1{,}33.10^{-10}$ mBar** (10^{-10} torr)
  - Reference value of β function : **150m**
  - Induced 4,5σ minimum radius of the beam pipe : **21mm**

Vacuum & aperture

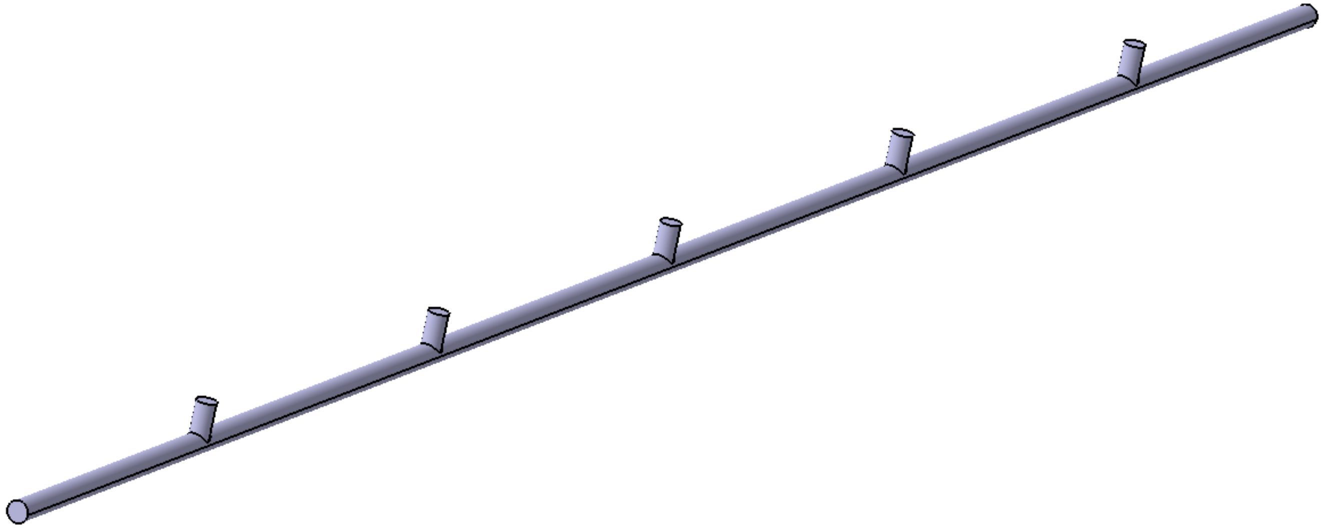
- Molflow (CERN) simulation software
  - Monte-Carlo statistical counting
  - Simulation without beam
  - No time-dependency



molflow.web.cern.ch

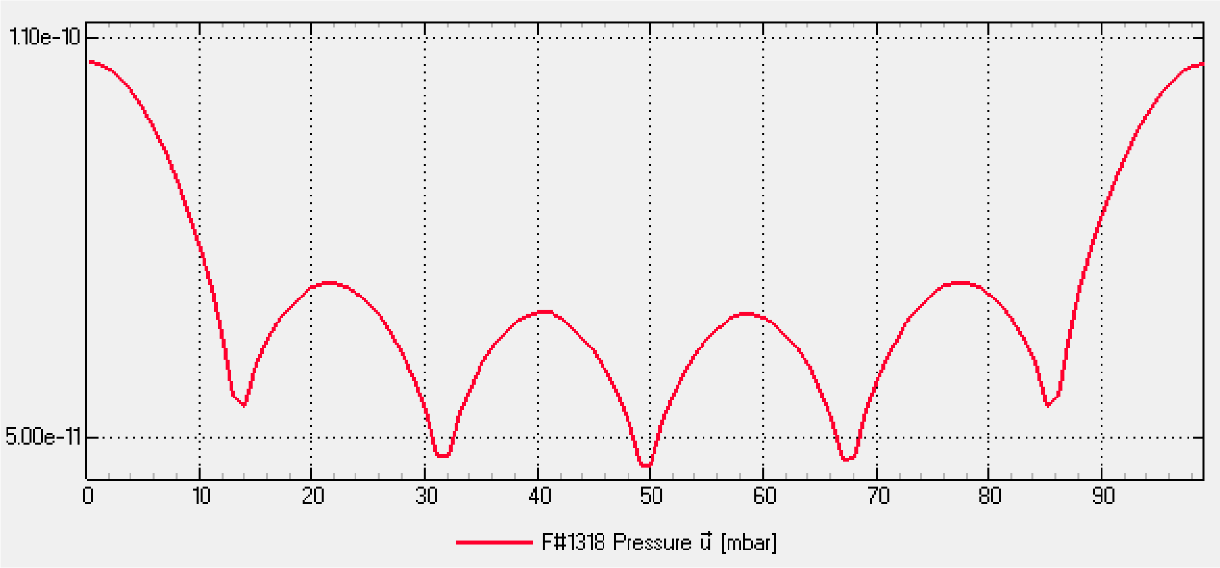
Vacuum & aperture

- Source of particle
  - Outgassing of the beam pipe (**$1{,}3.10^{-12}$ mBar.L/s/cm²** for stainless steel)
- Sink of particle
  - Pumping systems (50 – 100 L/s)
- 5m cell
- Constant Ø42mm
- Ø40mm ports every 0,9m

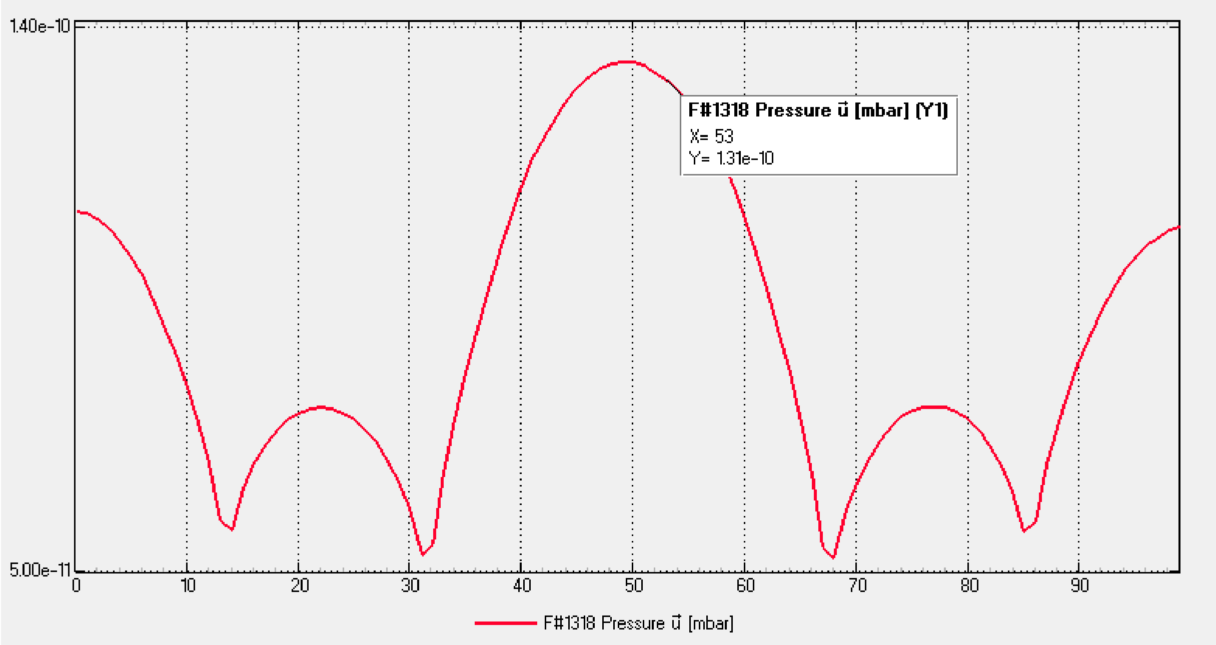


Vacuum & aperture

- 5 pumps every 0,9 m
- 50 L/s (50%)

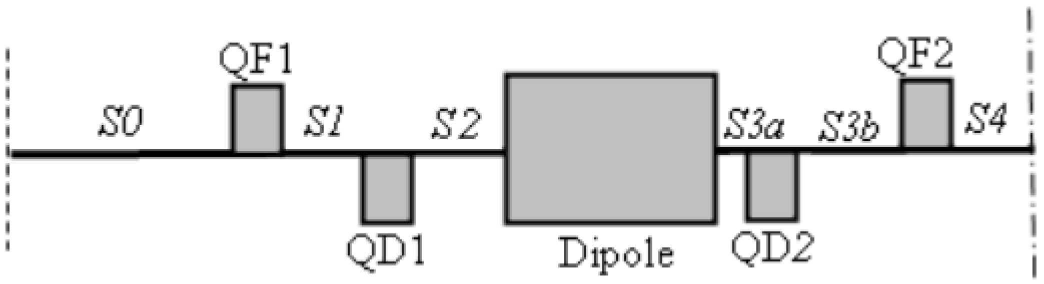


- 50 – 75 – 0 – 75 – 50 L/s
- 1,8 m

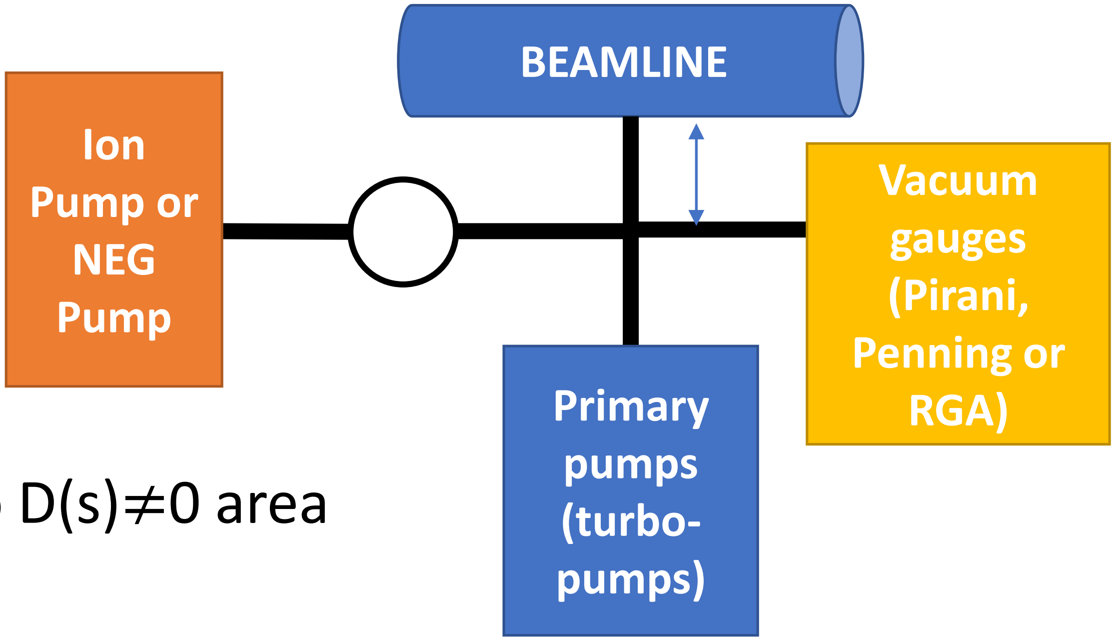


Joint Universities Accelerator School

Vacuum & aperture



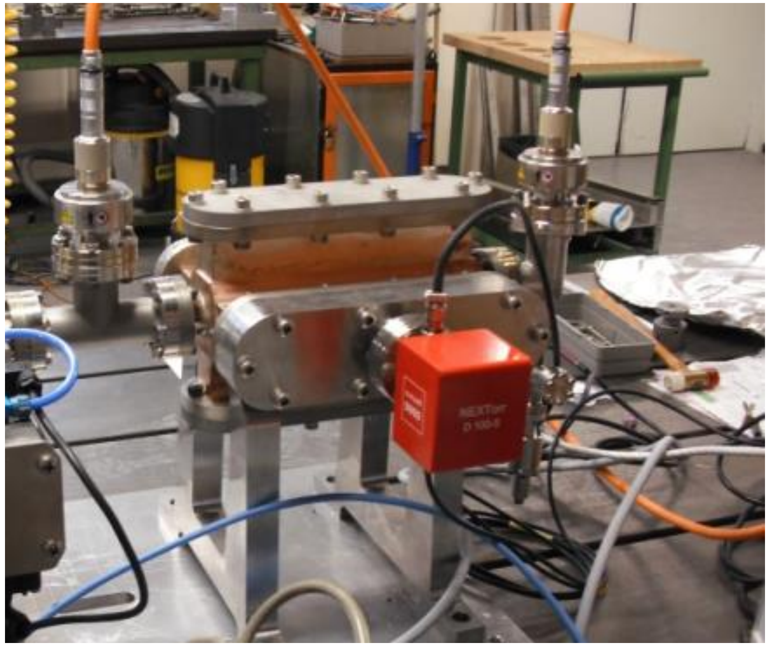
- Implantation on the beamline
  - Dipoles : 1,2 m long
- Pumping cell
  - MPS

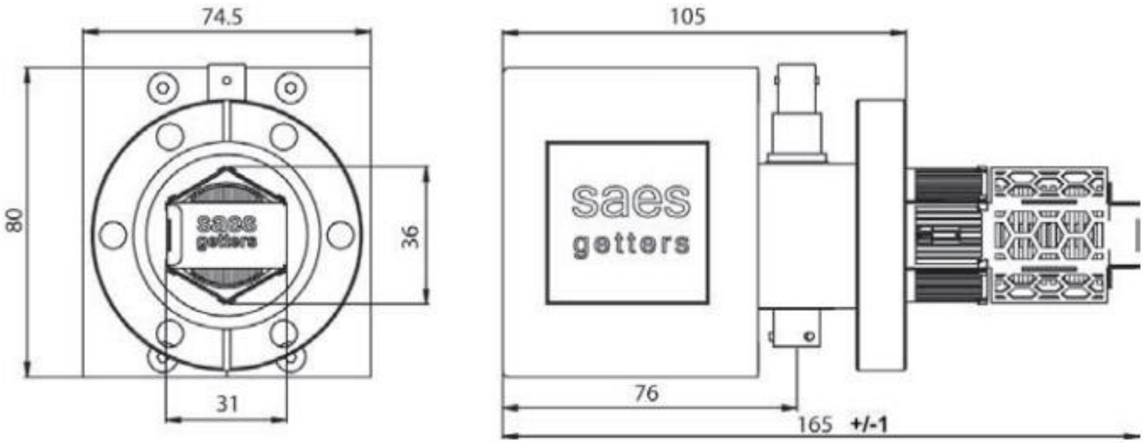


- Photodesorption
  - Placing the pumps close to D(s)≠0 area

Vacuum & aperture

- Ex : NEG pump : SAES Getters NexTorr
  - 100L/s





Synchrotron radiation

Marco Diomede
Anna Pugelise

Joint Universities Accelerator School

Goals

- Compute
  critical frequency of bending;
  energy loss per turn;
  total power radiated;

- Install IDs to reach **5 keV**;

- Compute
  tuning range;
  energy loss per turn;
  total power emitted by the IDs;

- Compute the **RF power** needed for 300mA;

- Install SCW for a UV wavelength.

Joint Universities Accelerator School

✓ Compute **critical frequency** of bending, **energy loss per turn**, **total power radiated**;

Bending Radius ρ (m)	Energy (GeV)	Lorentz Factor ϒ
9.167	3	5871

Critical Frequency

$$\omega_c = \frac{3}{2}\frac{c}{\rho}\gamma^3 = 9.93 \cdot 10^{18}\ \frac{rad}{s}$$

Critical Energy

$$\varepsilon_c = \hbar\omega_c = 6.5\ keV$$

Energy Loss per Turn per electron

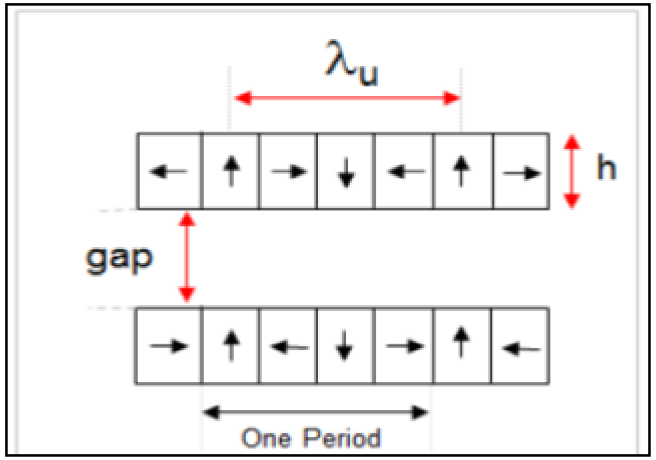
$$U_0(keV) = \frac{e^2\gamma^4}{3\varepsilon_0\rho} = 88.46\frac{E(GeV)^4}{\rho(m)} = 781\ keV$$

Total Power Radiated

$$P(kW) = \frac{e\gamma^4}{3\varepsilon_0\rho}I_b = 88.46\frac{E(GeV)^4 I(A)}{\rho(m)} = 235\ kW$$

✓ Install IDs to reach **5 keV**

TYPICAL VALUES FOR AN UNDULATOR	
Pole Tip Field Br (T)	**Undulator Period λ_u (mm)**
1.3	**20**



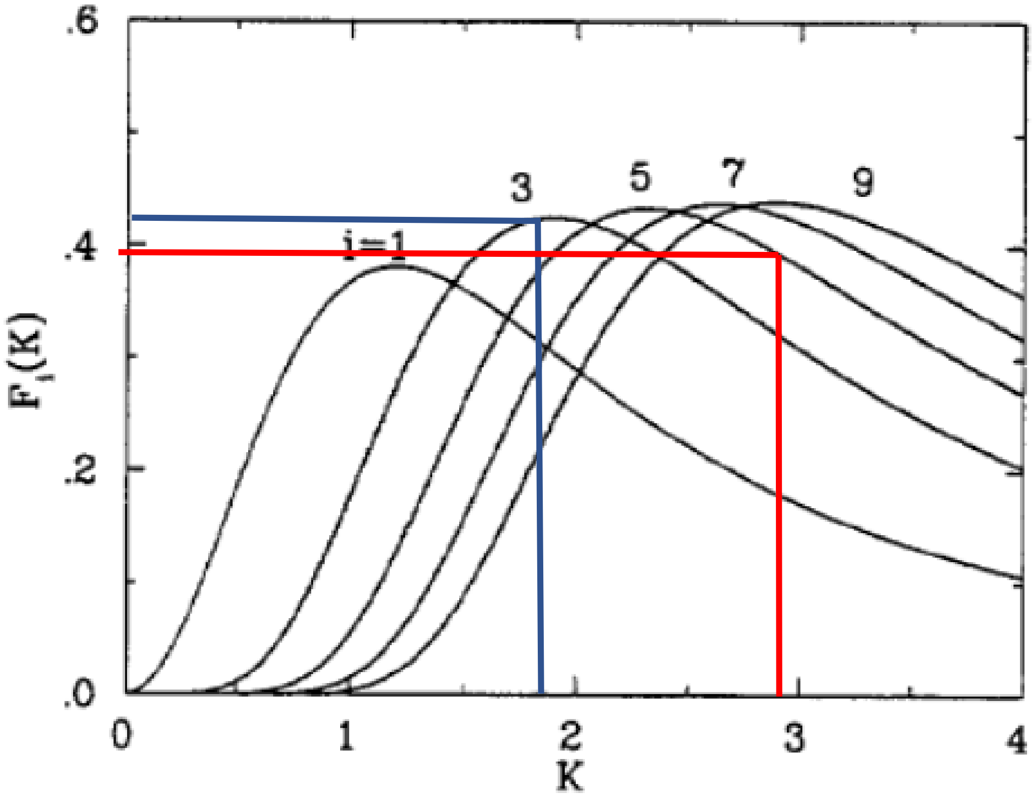
$$\varepsilon = \frac{hc}{\lambda} = 5\ keV \quad \Rightarrow \quad \lambda = 2.48 \cdot 10^{-10} m$$

$$\lambda_n = \frac{\lambda_u}{2\gamma^2 n}\left(1 + \frac{K^2}{2}\right) \quad \Rightarrow \quad \boxed{K = 1.77 \quad for\ n = 3}$$

$$K = 0.168\ B_r\ \lambda_u\ e^{-\frac{\pi\ Gap}{\lambda_u}} \quad \Rightarrow \quad Gap = 5.83\ mm > 4\ mm$$

$$(Limit\ for\ an\ undulator)$$

$$For\ \boxed{n = 5 \qquad K = 2,94} \qquad Gap = 2.55\ mm < 4\ mm$$



✓ Compute **tuning range**

$$K_{max}(Gap = 4mm) = 0.168\, B_r\, \lambda_u\, e^{-\frac{\pi\, Gap}{\lambda_u}} = 2.33$$

$$\lambda_n = \frac{\lambda_u}{2\gamma^2 n}\left(1 + \frac{K^2}{2}\right)$$

$$0.5 \le K \le 2.33 \quad \Rightarrow \quad \lambda_{@K=0.5} \le \lambda \le \lambda_{@K=2.33}$$

$n = 1$

$K = 0.5$

$K = 2.33$

$$\Rightarrow \begin{cases} \lambda_{@K=0.5} = 3.26 \cdot 10^{-10} m \\ \lambda_{@K=2.33} = 10.77 \cdot 10^{-10} m \end{cases}$$

$$3.26 \cdot 10^{-10} m \le \lambda \le 10.77 \cdot 10^{-10} m$$

$$\lambda = 2.48 \cdot 10^{-10} m$$

$n = 3$

$K = 0.5$

$K = 2.33$

$$\Rightarrow \begin{cases} \lambda_{@K=0.5} = 1.09 \cdot 10^{-10} m \\ \lambda_{@K=2.33} = 3.59 \cdot 10^{-10} m \end{cases}$$

$$1.09 \cdot 10^{-10} m \le \lambda \le 3.59 \cdot 10^{-10} m$$

$$\lambda = 2.48 \cdot 10^{-10} m$$

✓ Compute **energy loss per turn**, **total power emitted** by the IDs;

TYPICAL VALUES FOR AN UNDULATOR		
Pole Tip Field Br (T)	**Undulator Period λ_u (mm)**	**Undulator Length (m)**
1.3	**20**	**2**

$$E_u\,(\mathrm{eV}) = 0.07257\,\frac{E^2\,(GeV)\cdot K^2}{{\lambda_u}^2(m)}\,L_u(m) = 10\,keV$$

$$\#cells = 20$$

$$E_{u,tot} = \#cells\,\cdot E_u = 200\,keV$$

$$P_{u,tot} = E_{u,tot}\cdot I = 60\,kW$$

✓ Compute the **RF power needed** for 300mA;

$$P_{RF} = P_{tot} = P_{u,tot} + P_{syn\_rad} = 295\,kW$$

✓ Install **SCW** for a UV wavelength

TYPICAL VALUES FOR A WIGGLER		
Wiggler Parameter K	Wiggler Period λ_u (mm)	Wiggler Length (m)
20	40	2

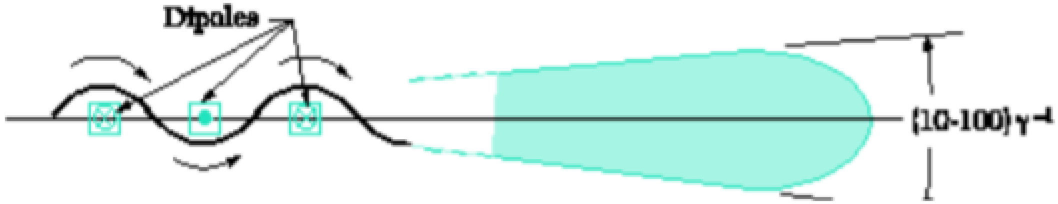
$$B_0 = \frac{K\, 2\pi\, mc}{e\lambda_u} = 5.35\ \mathrm{T}$$

$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) = 1.16 \cdot 10^{-7} m$$

$$E_w = 326\ keV$$

$$P_{w,tot} = E_{w,tot} \cdot I = \#cells \cdot E_w \cong 2.0\ MW$$

$$P_{tot} = P_{w,tot} + P_{syn\_rad} = 2.235\ MW$$

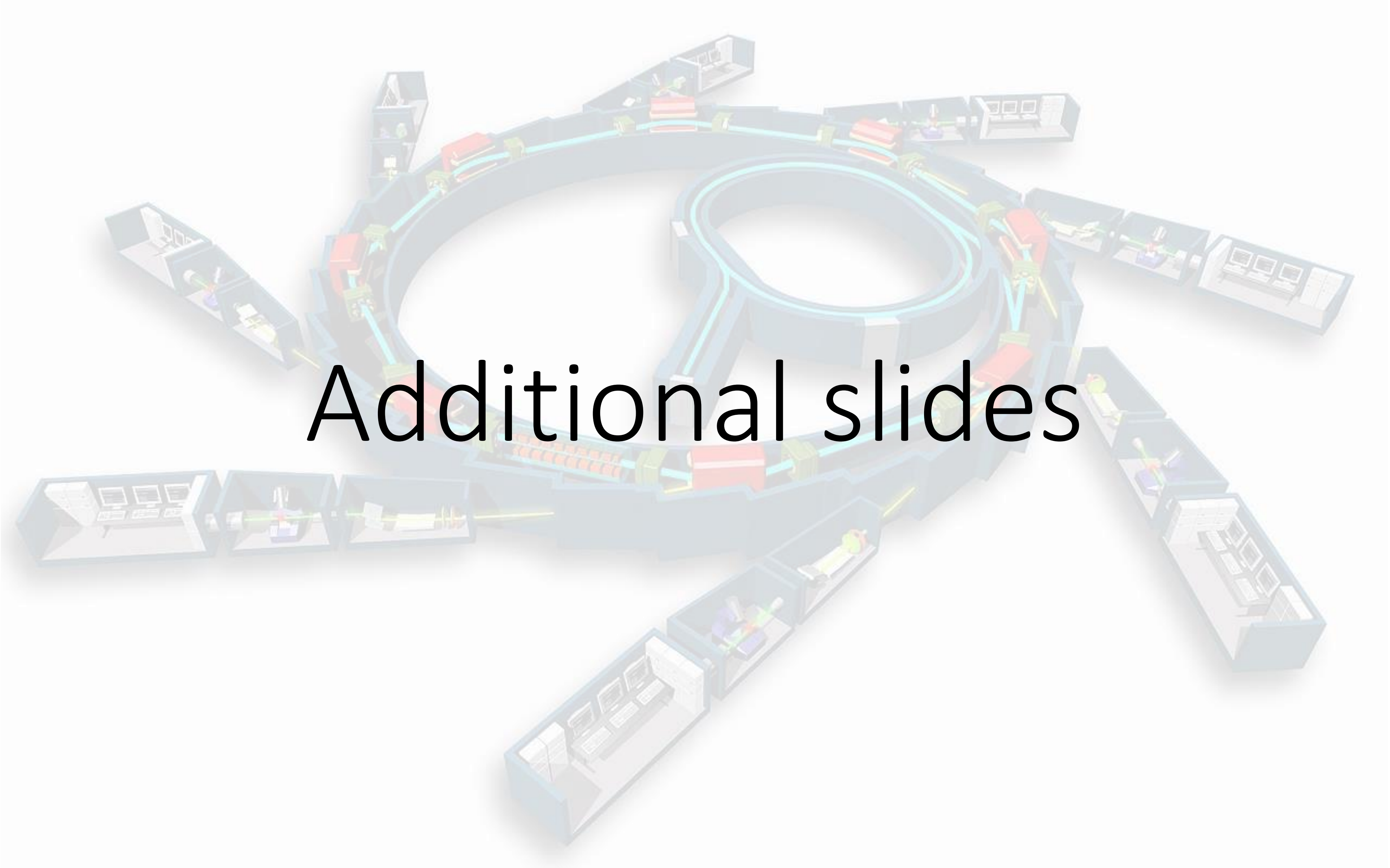


wiggler - incoherent superposition K > 1

Thank you for your attention

juas
Joint Universities Accelerator School

Additional slides



Phase shifter

Plotting the quadrupole strenght vs phase shift, we observe a discontinuity.