Review of the Budker Institute activity for CLIC damping ring design

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Main issues

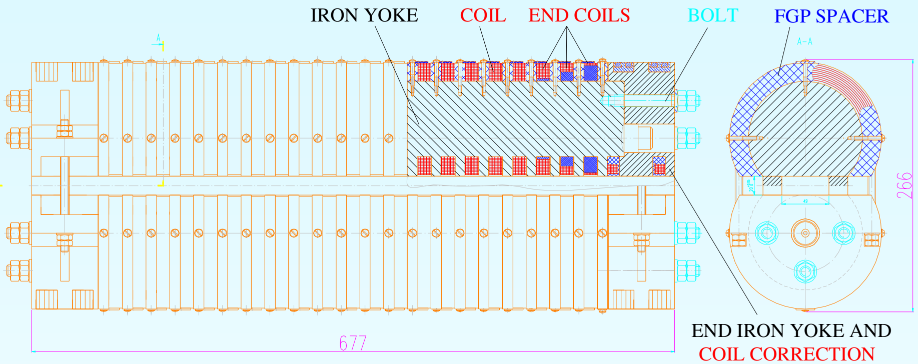
- *SC wiggler design fabrication and tests*
- *Proposals for DR structure*
- *Proposal for SR absorber system and results of simulation*
- *Some results of some simulation of the beam dynamics in case of fast damping*

Superconductive wiggler design

Main parameters of the wiggler

Period, mm	*50*
Magnetic field, B, T	*2.5*
Pole gap, mm	*20*
Vertical working aperture, mm	*12*
Wiggler length, mm	*500*
Stored energy, kJ	*56.5*
Number of coils in one half	*21*
Number of whole coils in one half (without end coil)	*15*

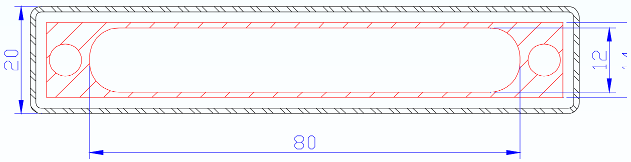
General view for BINP wiggler prototype



SC cable and coil parameters

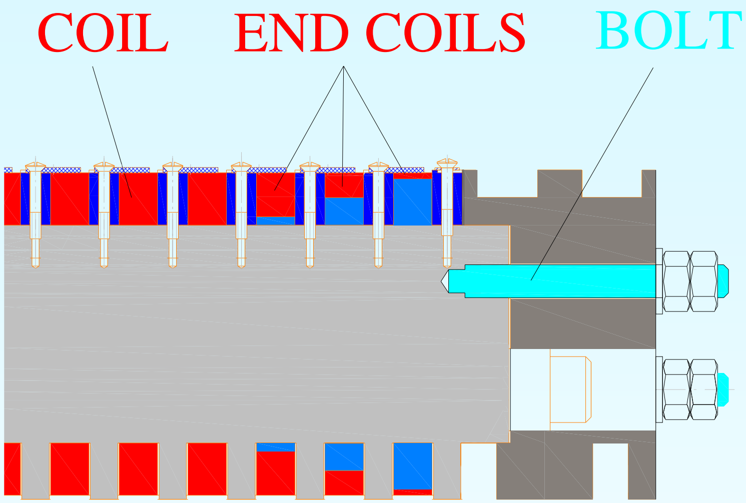
Cable type	*NbTi/Cu ~ 1.5/1*
Cable diameter, mm	*0.85*
Insulated diameter, mm	*0.91-0.92*
Design current – I_d, A (at 6 T)	*660*
Ratio I_d/I_c, %	*85*
Coil net size at the poles, mm	*14.6×20.5*
Number of turns in the whole (main) coil	*357 (23 layers per 16-15 turns)*
Number of turns in the three ends coils	*44, 179, 310*

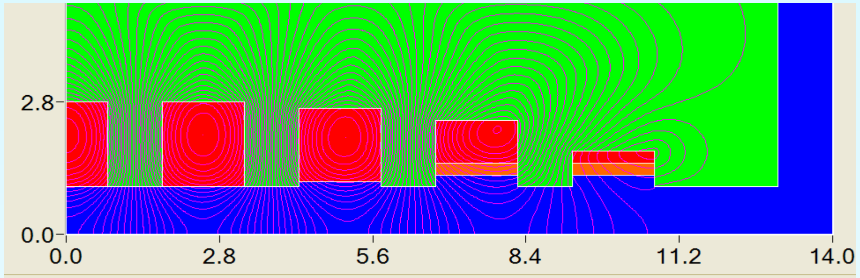
Internal Cu liner with LN temperature protects LHe elements from SR

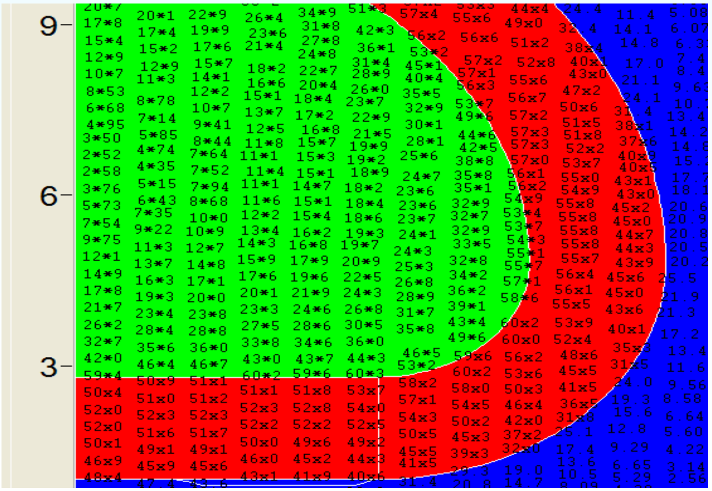


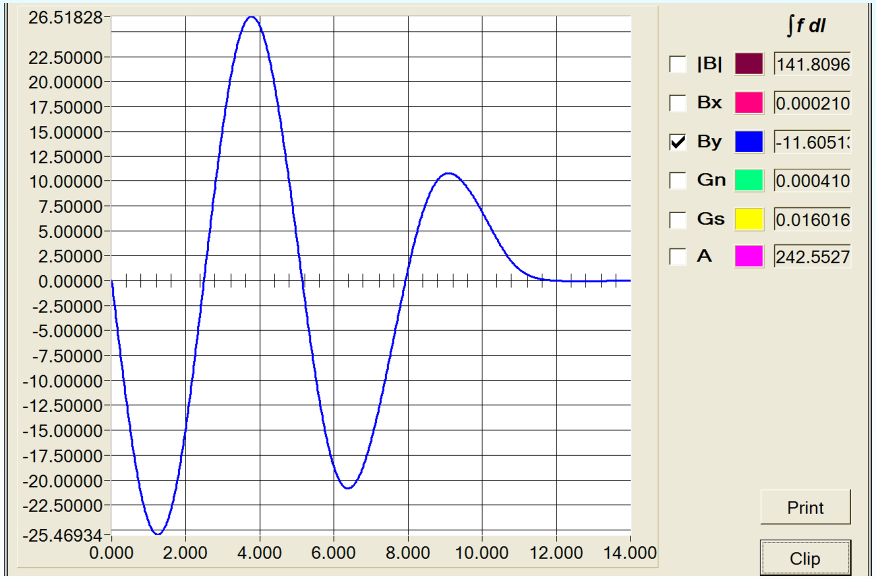
A cryogenic cooler SUMITOMO SRDK 408S2 permits evacuate up to 50 W power from 60 K liner.

Field calculations

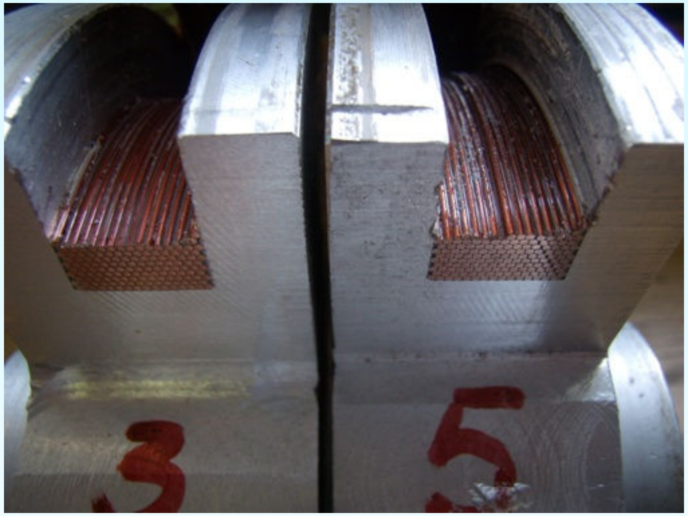


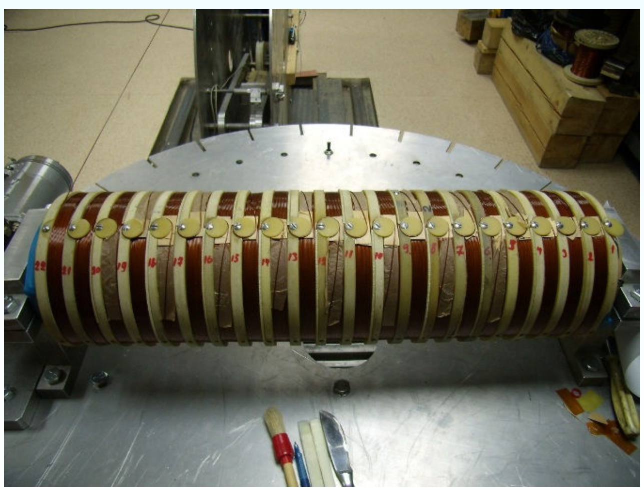


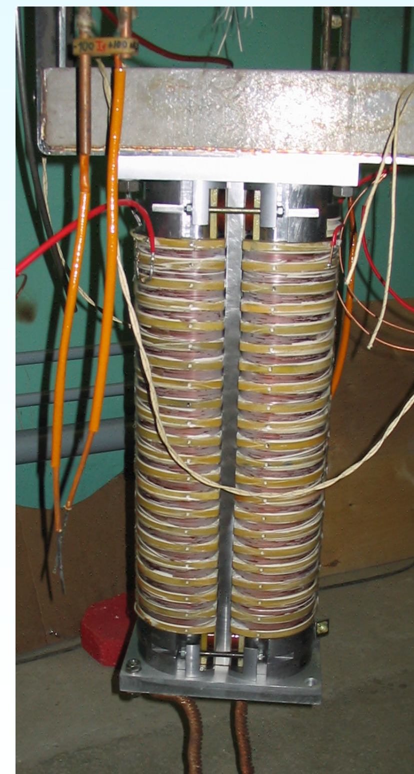




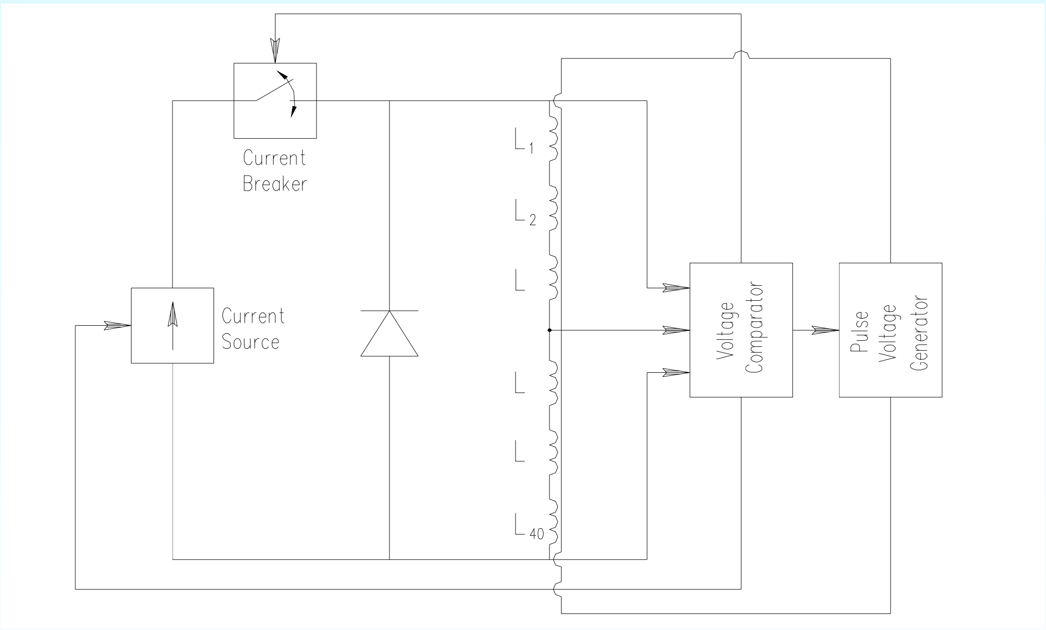
Wiggler fabrication

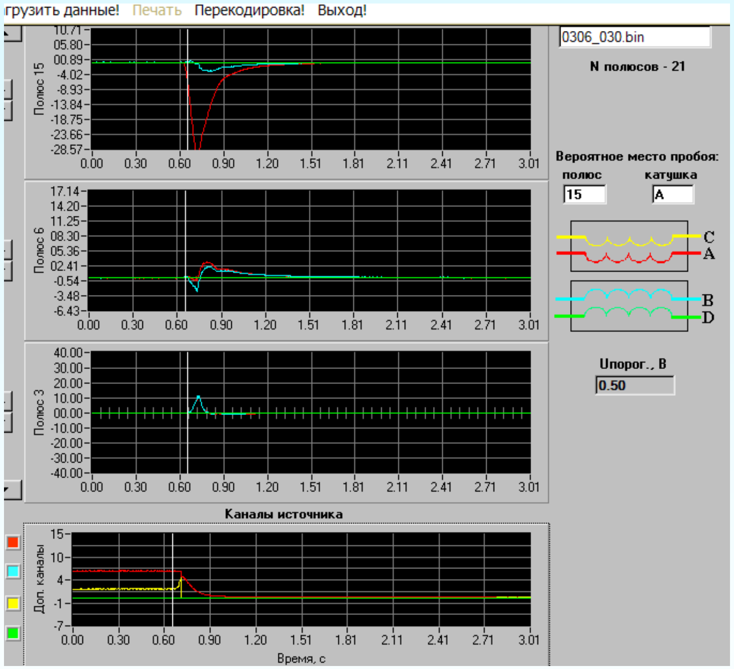




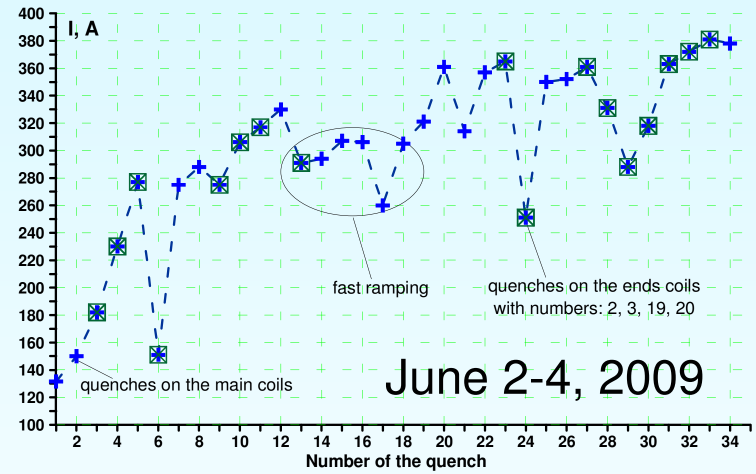


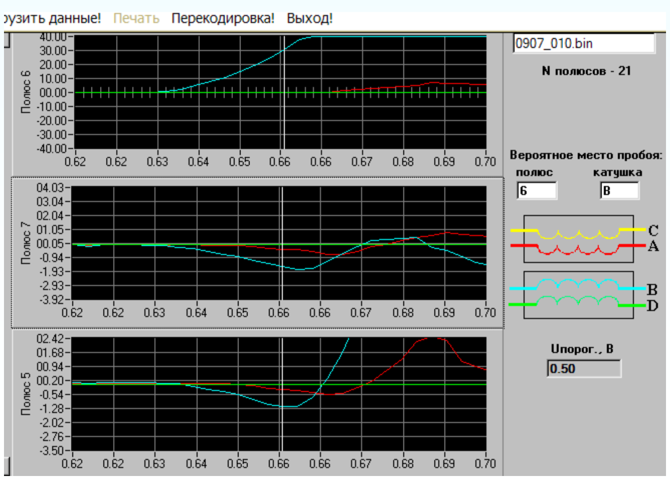
Active quench protected system

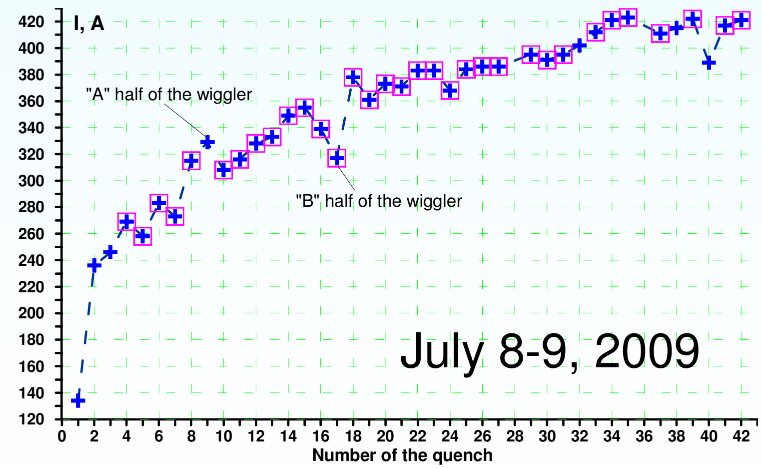




Wiggler testing

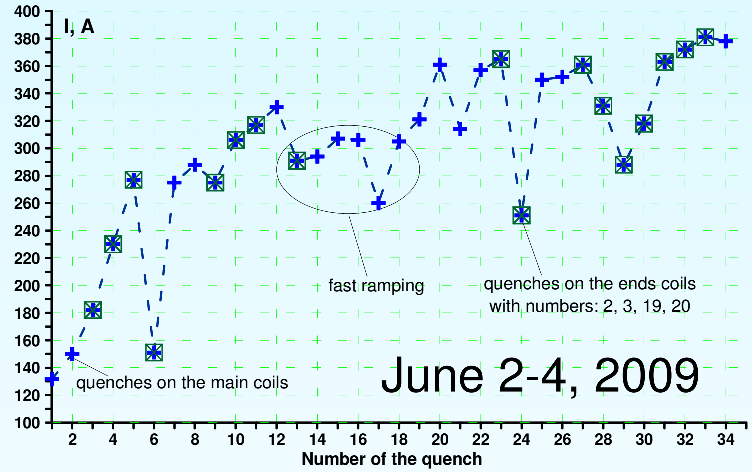


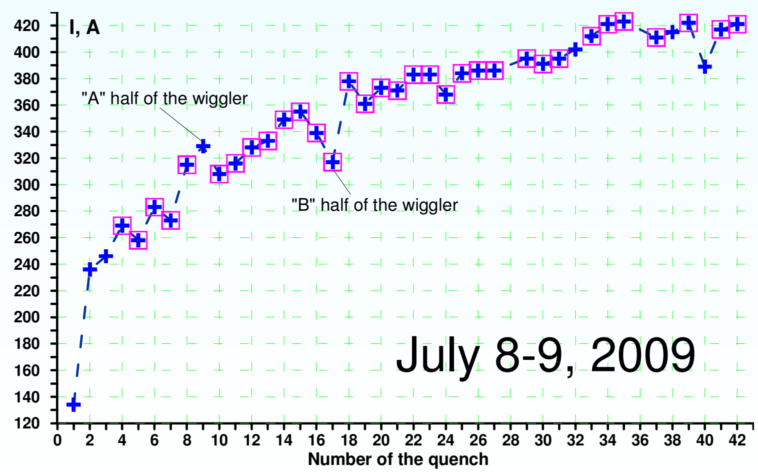




Conclusions on the tests

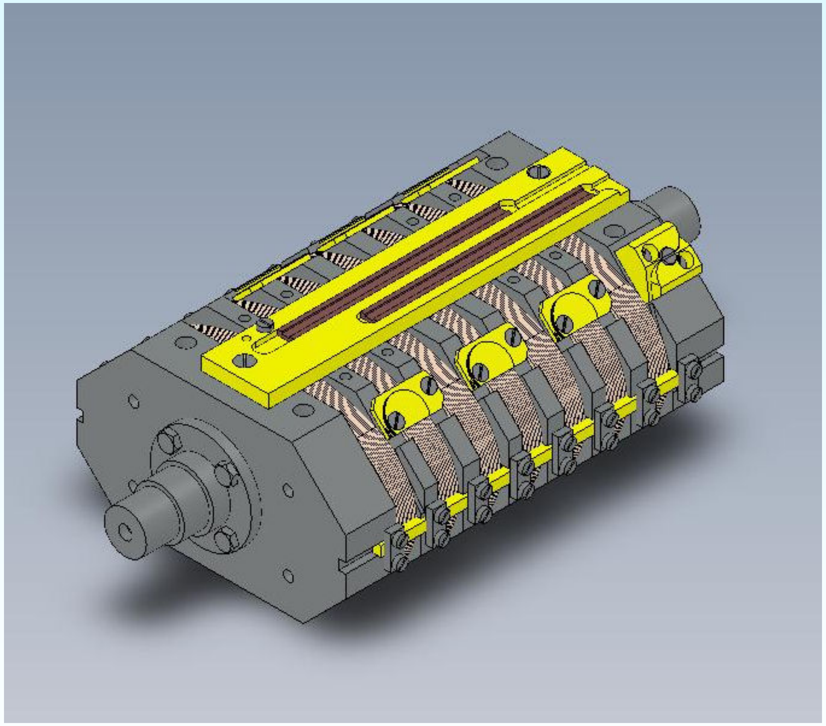
- *The training was too long. The 420 A current was achieved instead 661 A of the design current.*
- *The most quantity of quenches, 33 out of 40, was in one – the "B" half of the wiggler.*
- *The protection system worked well. The maximal voltage on the first quenched coil was about 100 V.*
- *The significant difference of the quantity of quenches between the two halves. One of the reasons of this may be the different epoxy impregnation: difference in epoxy mixtures, quantity of powder, etc.*
- *The use GFP spacers, of those thermal expansion coefficient is up to 6 times larger than for the iron, may only impair the imperfect epoxy impregnation. But we don't see the clear evidence that the reason of degradation lays on the spacers.*



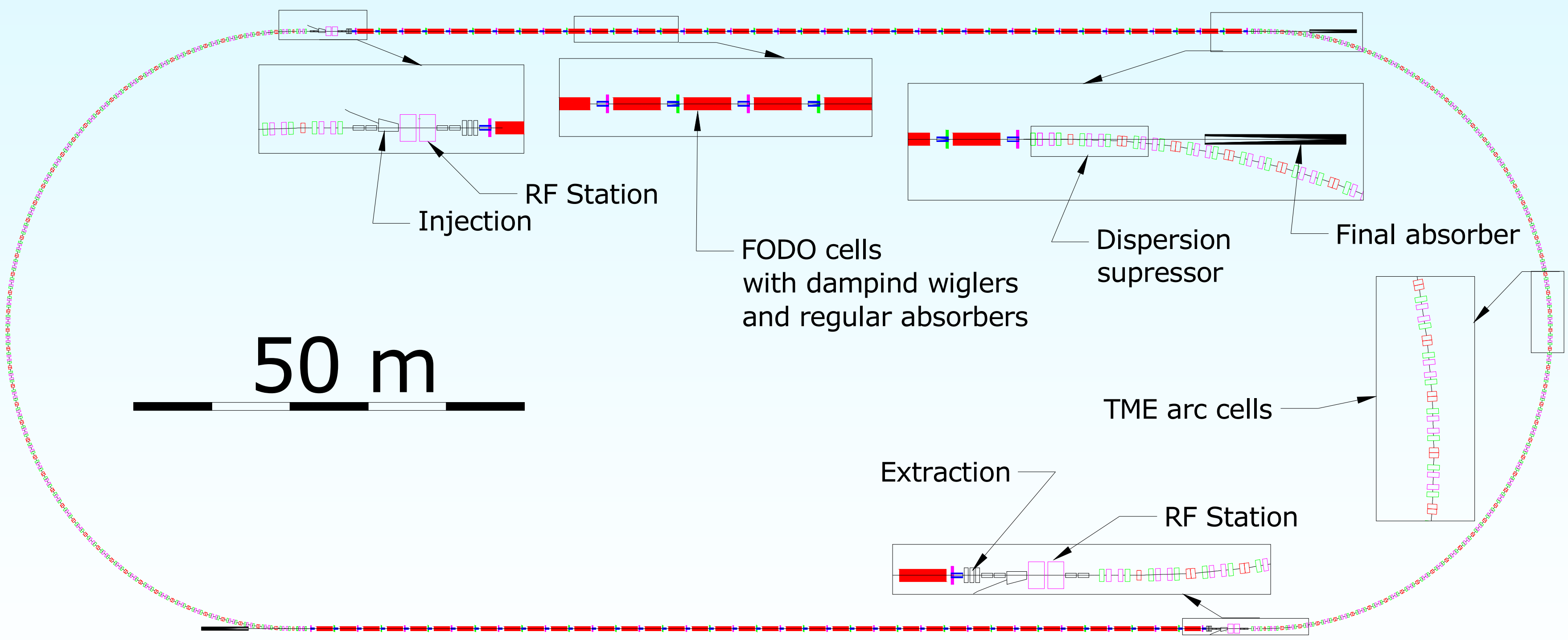


Proposals

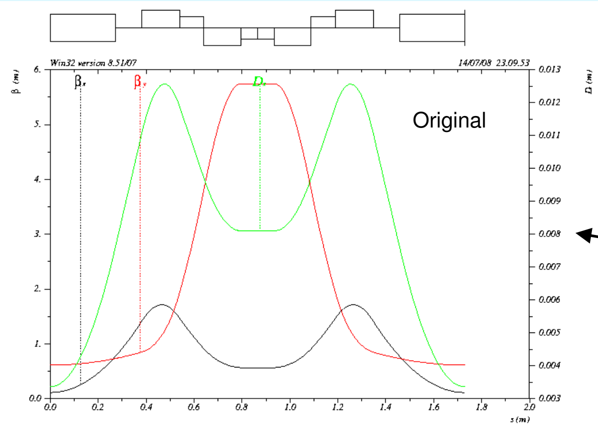
- *First approach is to make short wiggler prototype without use of the GFP elements. The manufacturing of this design will start in close days. The SC cable for this short prototype is available yet.*
- *The use of another type of epoxy could be very desirable. The Araldite MY740 is probably not perfect for our tasks.*
- *Another one is to make another test run (runs) to understand the quench behavior and to make magnet measurements.*

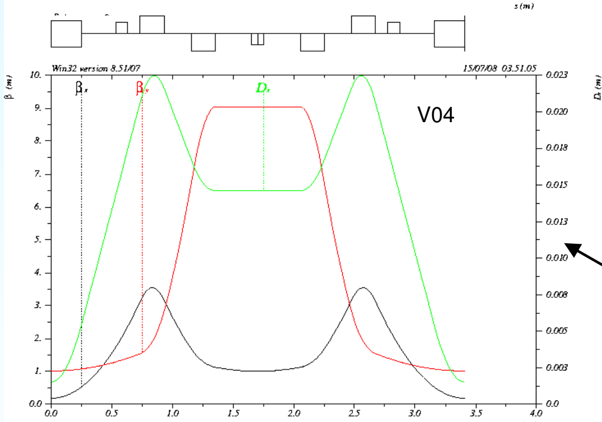


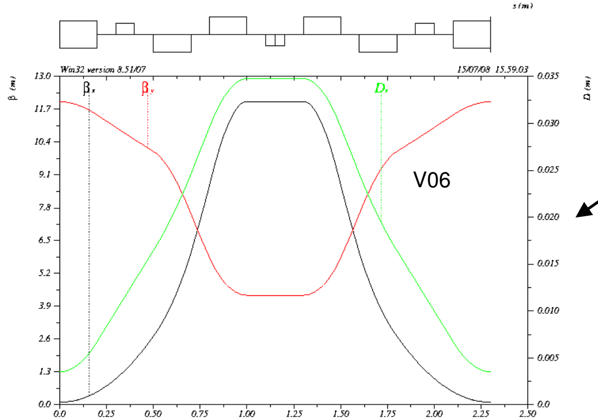
DR lattice design

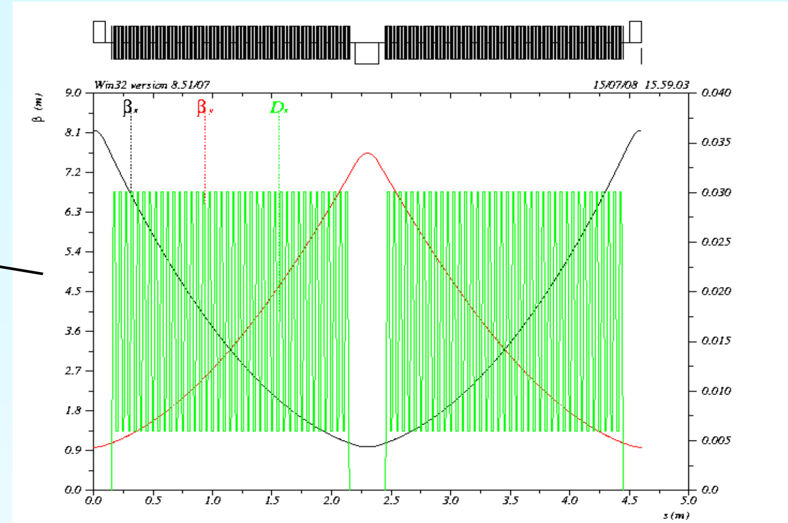


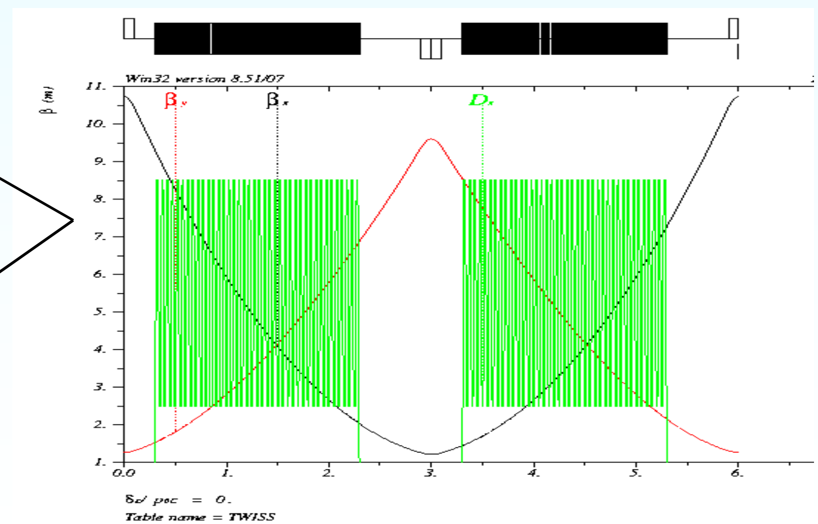
Arc and FODO cells structures



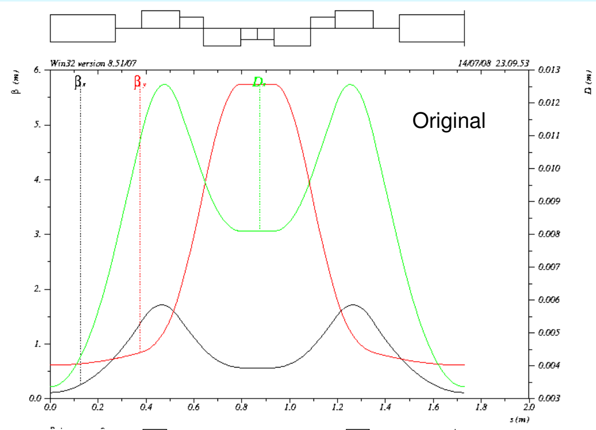


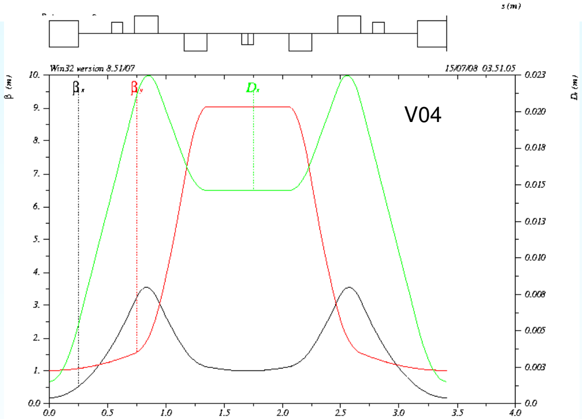


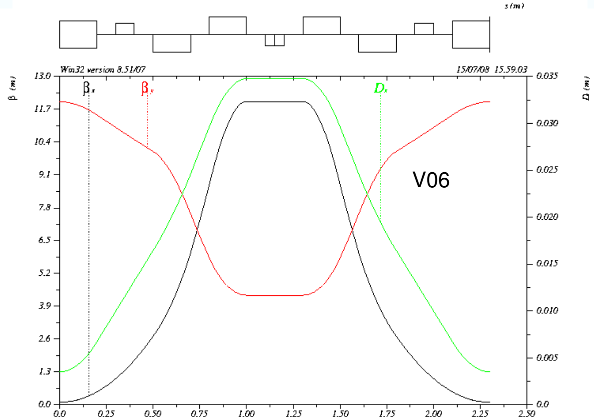




Arc cell structures

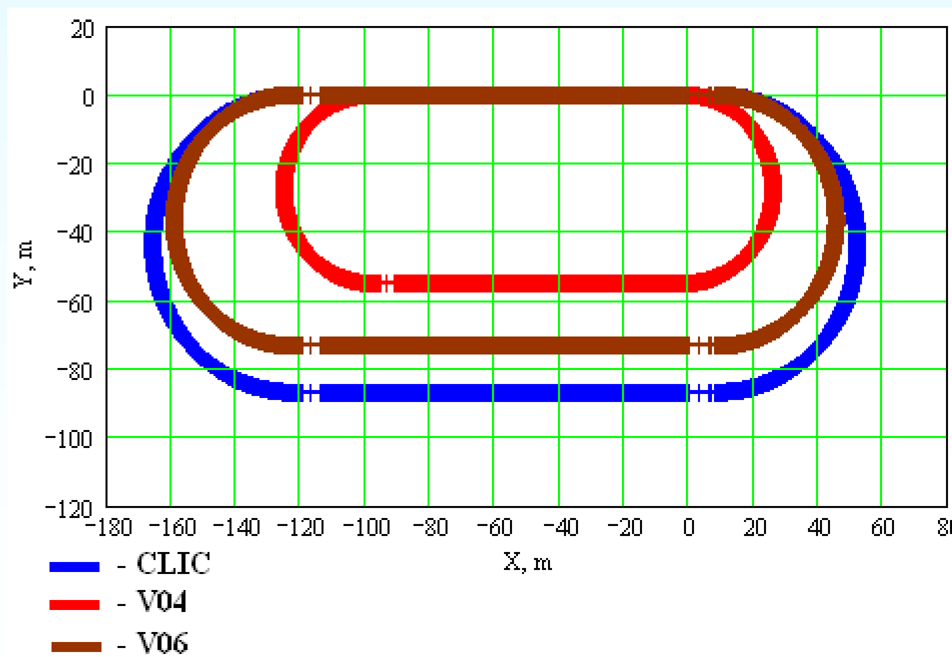




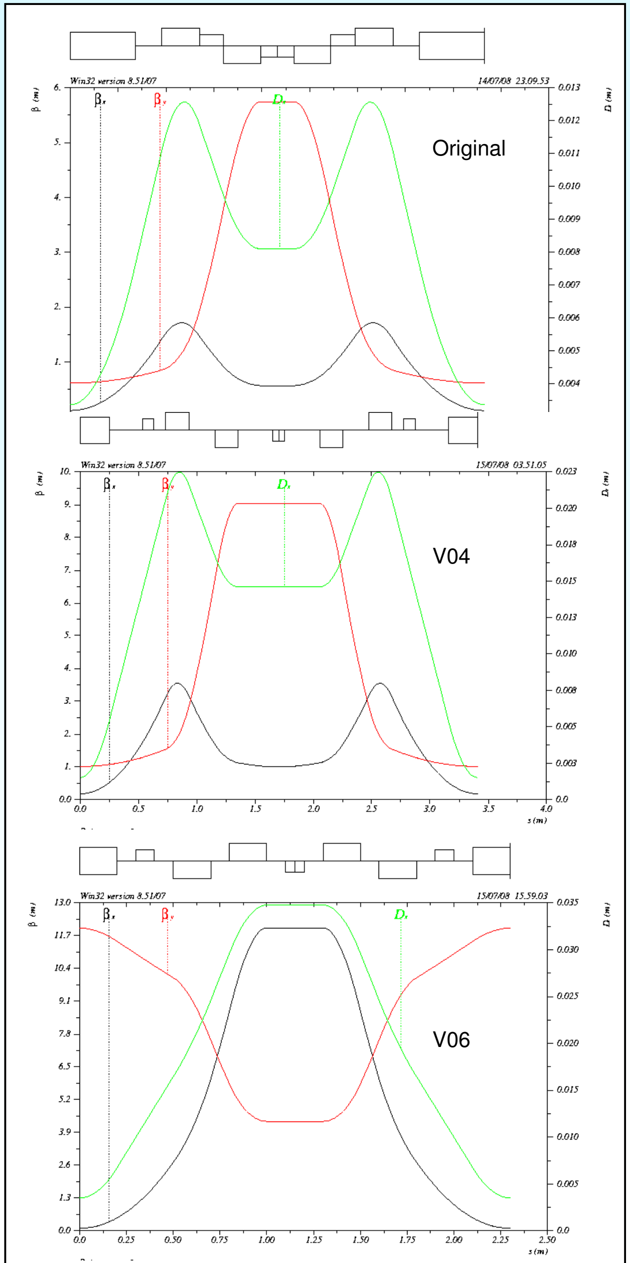


TME structures for CLIC-DR (Original and proposals)

Structure version	*Original*	*V04*	*V06*
Energy E [GeV]		*2.424*	
Circumference P [m]	*365.21*	*534*	*493.05*
*Emittance [nm*rad]*	*0.0182*	*0.0256*	*0.0312*
*Normalized Emittance [nm*rad]*	*86.3*	*121.44*	*148*
Dynamic aperture a/σ_{inj} x / y	*±3.5 / 6*	*±1.5 / 5*	*±12 / 50*



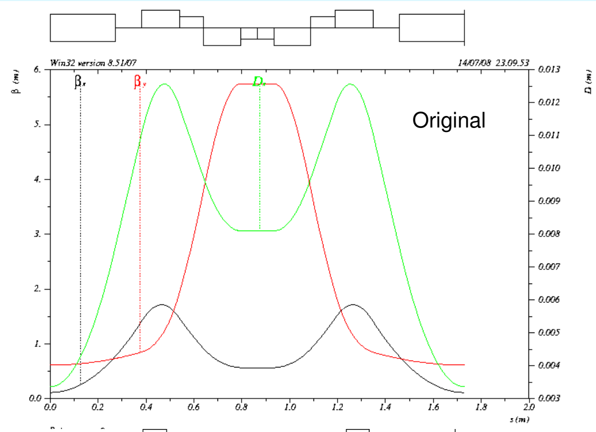
Arc cell structures

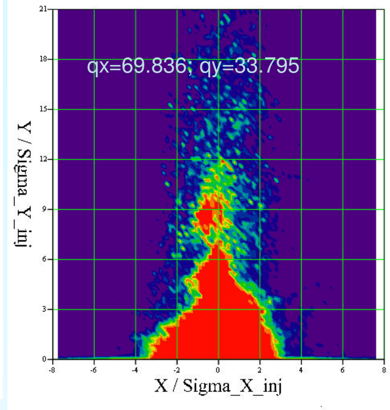


Arc cell parameters for CLIC-DR (Original and proposals)

Arc cell			
Structure version	*Original*	*V04*	*V06*
Bend field [T]	*0.93*	*1.27*	*1.27*
Bend gradient [1/m^2]	*0*	*0*	*-1.10*
Quad coefficient K1 [1/m^2]	*27.21 / -16.17*	*13.33 / -8.24*	*7.47 / -4.27*
Quad gradient [T/m]	*220 / -131*	*107.7 / -66.6*	*60.3 / -34.5*
Sextupole coefficient K2 [1/m^3]	*7700 / -9839*	*2985 / -2058*	*780 / -815*
Sextupole strength [T/m^2]10^3*	*62 / -80*	*24.1 / -16.6*	*6.30 / -6.59*
IBS			
Bunch current I, mA	*0.539*	*0.3681*	*0.399*
*Bunch population, N*10^9*	*4.1*	*4.1*	*4.1*
*Emittance [nm*rad] / IBS gain factor*	*0.0946 / 5.1831*	*0.0926 / 3.62*	*0.090 / 2.89*
*Normalized Emittance [nm*rad] ****	*449*	*439.26*	*428.4*
Energy spread / IBS gain factor	*1.571 / 1.402*	*1.620 / 1.45*	*1.551 / 1.38*
Bunch length [mm]	*1.402*	*1.450*	*1.380*
Longitudinal beam emittance [eV m]	*5339*	*5694*	*5188*

Arc cell structures

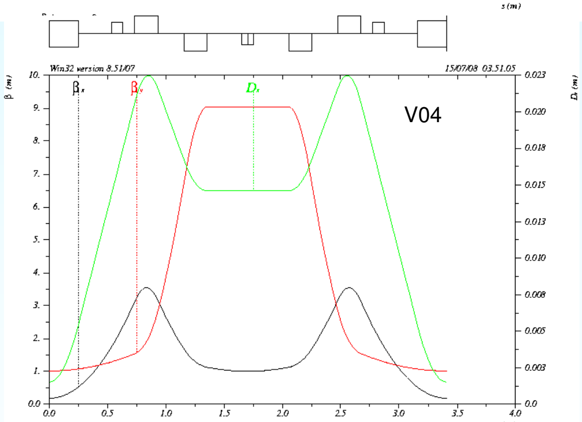


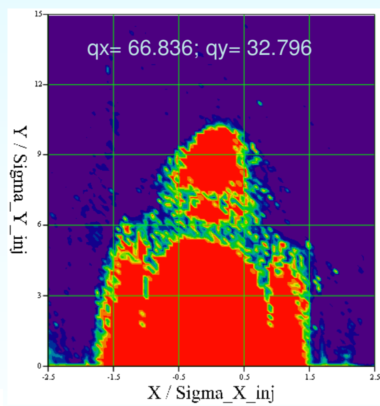


Summary

Compact and effective

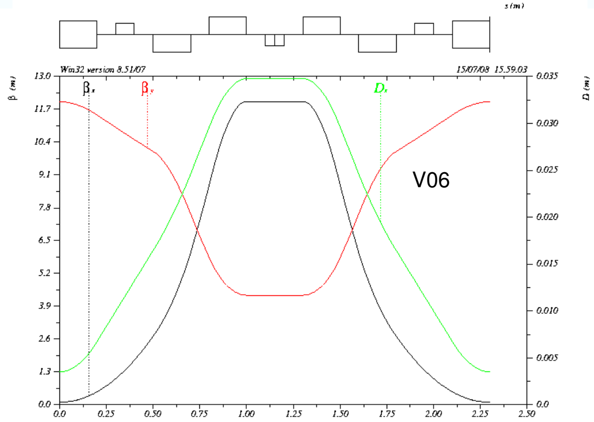
Extremely high lenses, non realistic design for conventional lens technology

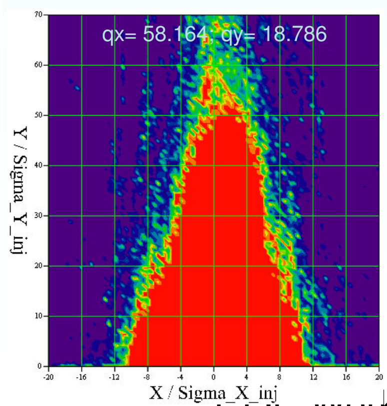




Realization

Big circumference



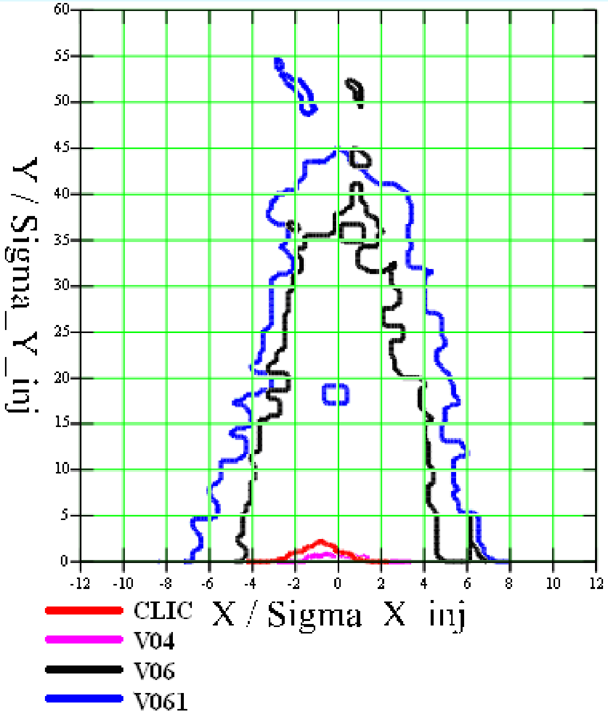


Small lenses gradient, big dynamic aperture

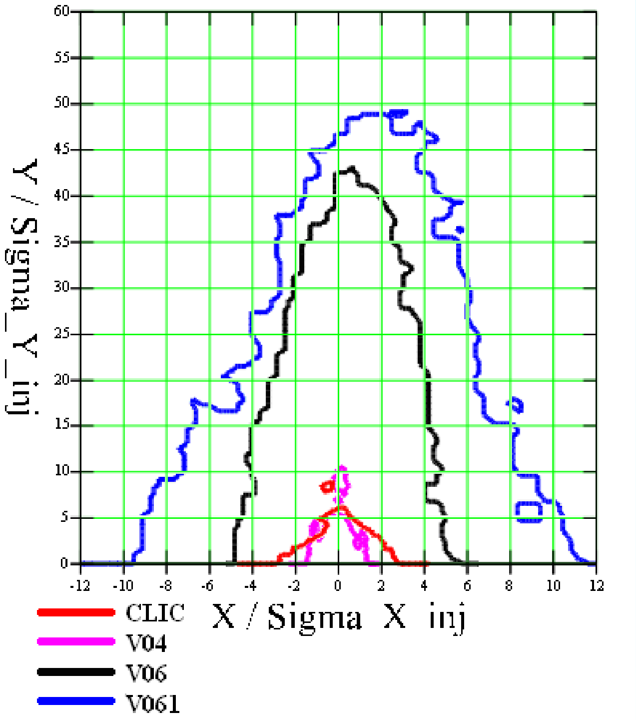
Gradient in bend dipoles, orbit correction dificulties

DA comparisson

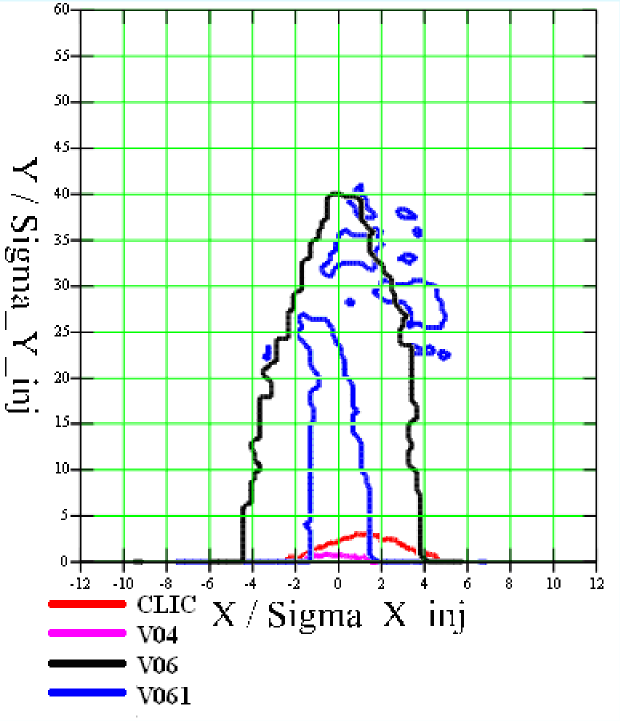
ΔP/P=-1%



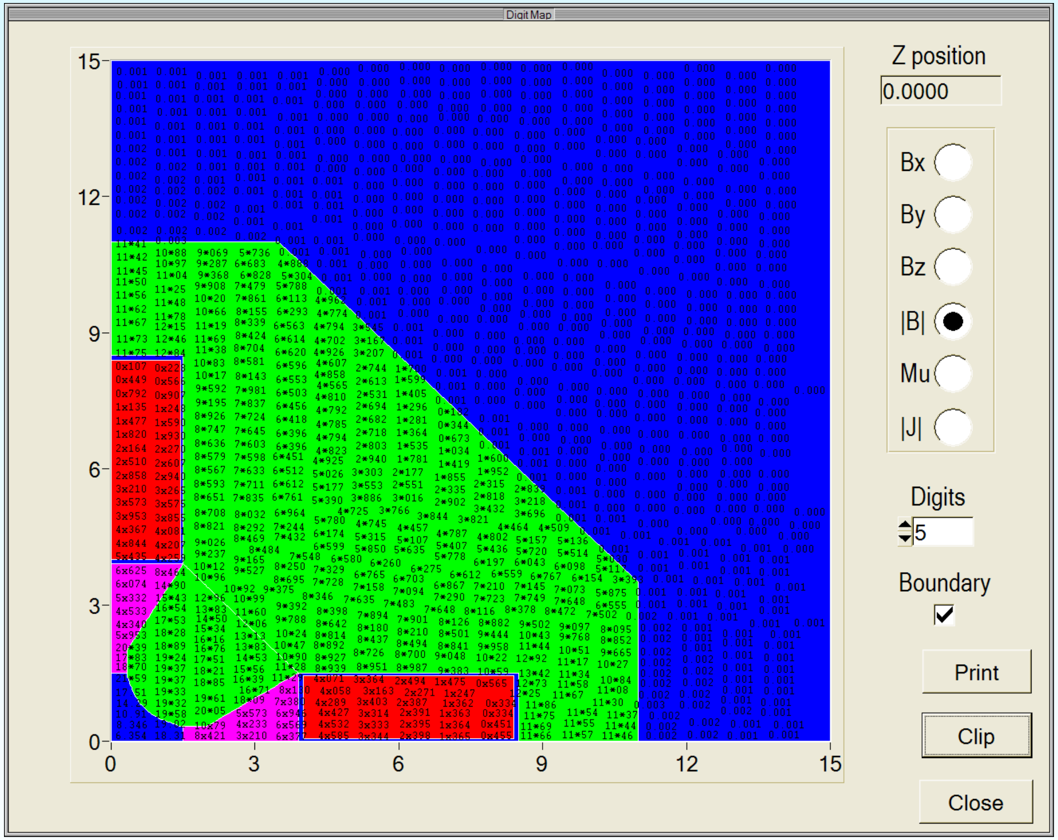
ΔP/P=0

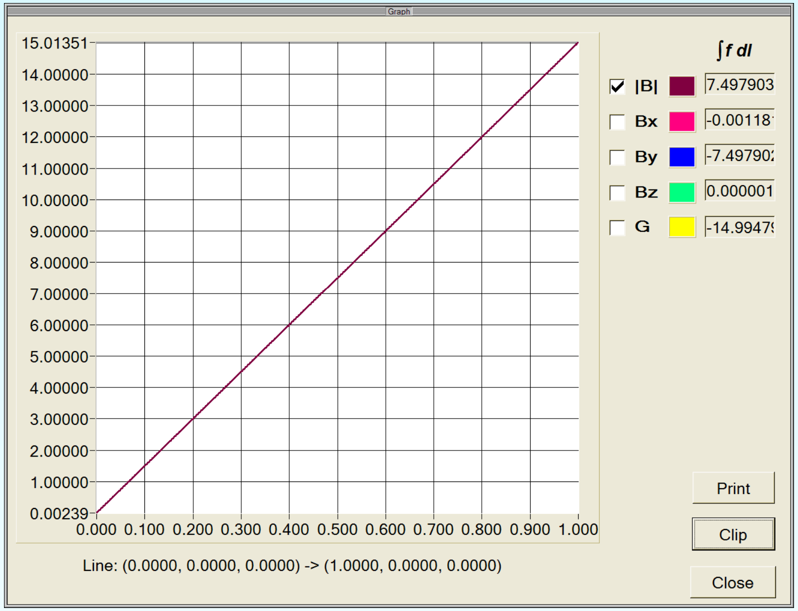


ΔP/P=+1%



Hybrid quadrupole (g = 150T/m, r = 10 mm)





Analysis

	An	Bn	an	bn
1	0.0000000	0.0000000	0.0000000	0.0000000
2	-11.9916170	0.0000000	-14.9895212	0.0000000
3	0.0000000	0.0000000	0.0000000	0.0000000
4	-0.0003470	0.0000000	-0.0040666	0.0000000
5	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0026118	0.0000000	-0.9564802	0.0000000
7	0.0000000	0.0000000	0.0000000	0.0000000
8	-0.0002582	0.0000000	-6.2064055	0.0000000
9	0.0000000	0.0000000	0.0000000	0.0000000
10	-0.0018051	0.0000000	4880.498717	0.0000000
11	0.0000000	0.0000000	0.0000000	0.0000000
12	-0.0000571	0.0000000	26536.388317	0.0000000
13	0.0000000	0.0000000	0.0000000	0.0000000
14	-0.0001068	0.0000000	092394.3096	0.0000000
15	0.0000000	0.0000000	0.0000000	0.0000000
16	-0.0000102	0.0000000	3240093.0887	0.0000000
17	0.0000000	0.0000000	0.0000000	0.0000000
18	0.0003577	0.0000000	23429825.78	0.0000000

Radius: 0.800000

Length: 0.000000

Angle: 90.0000

Print

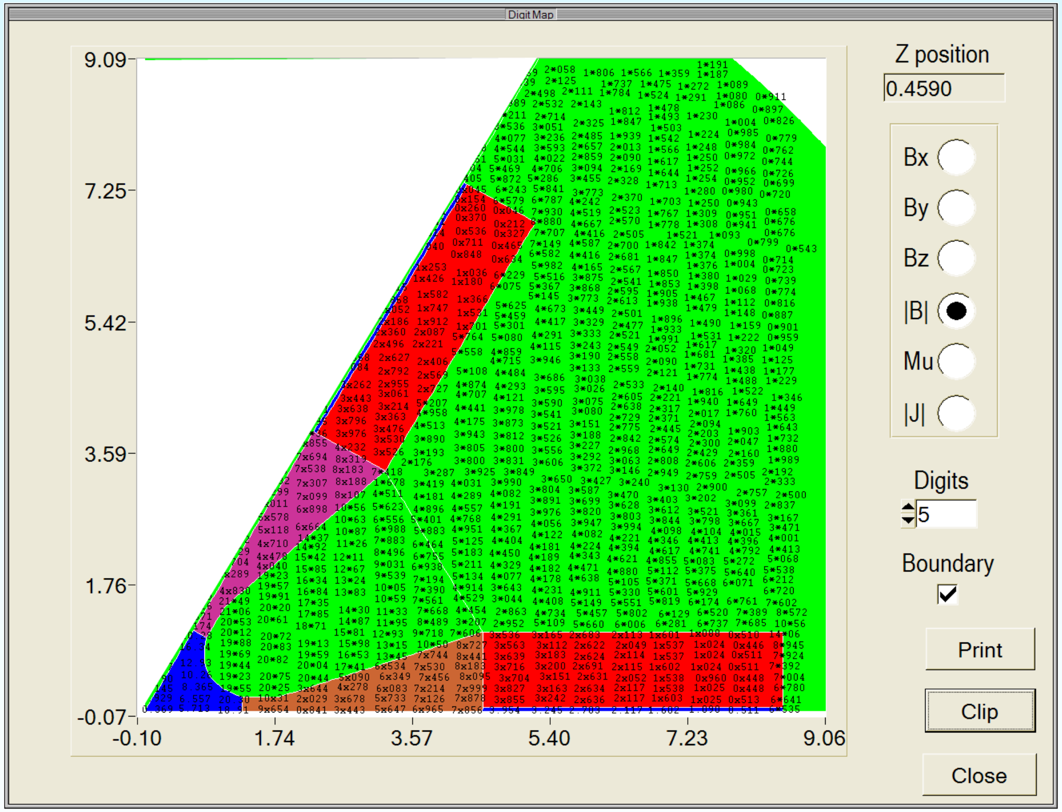
Clip

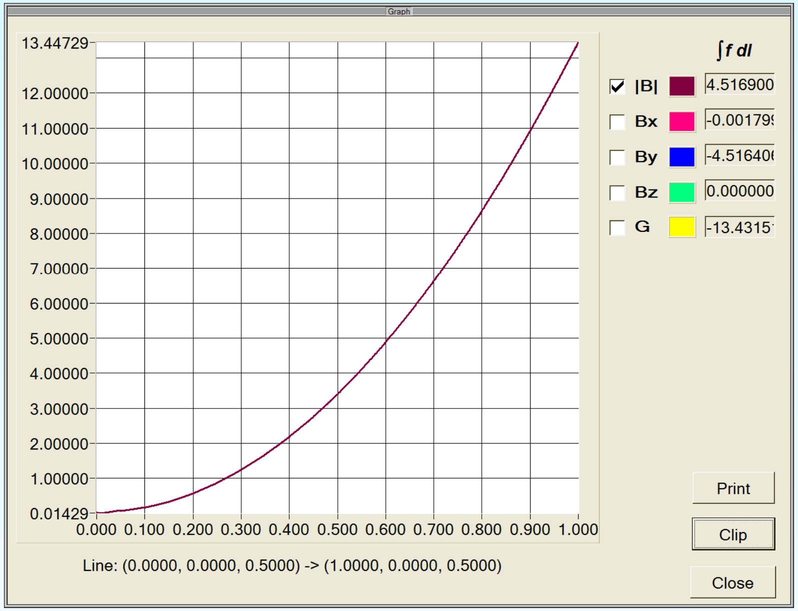
Close

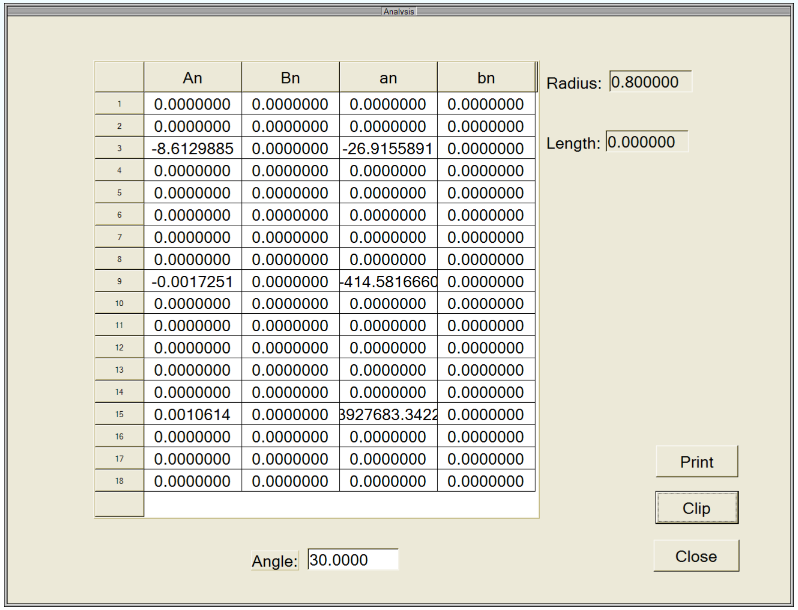
BINP Mermaid Magnetic code

Units at the plots – kG and cm

Hybrid sextupole (s = $26 \cdot 10^3$ T/m^2 , r = 10 mm)





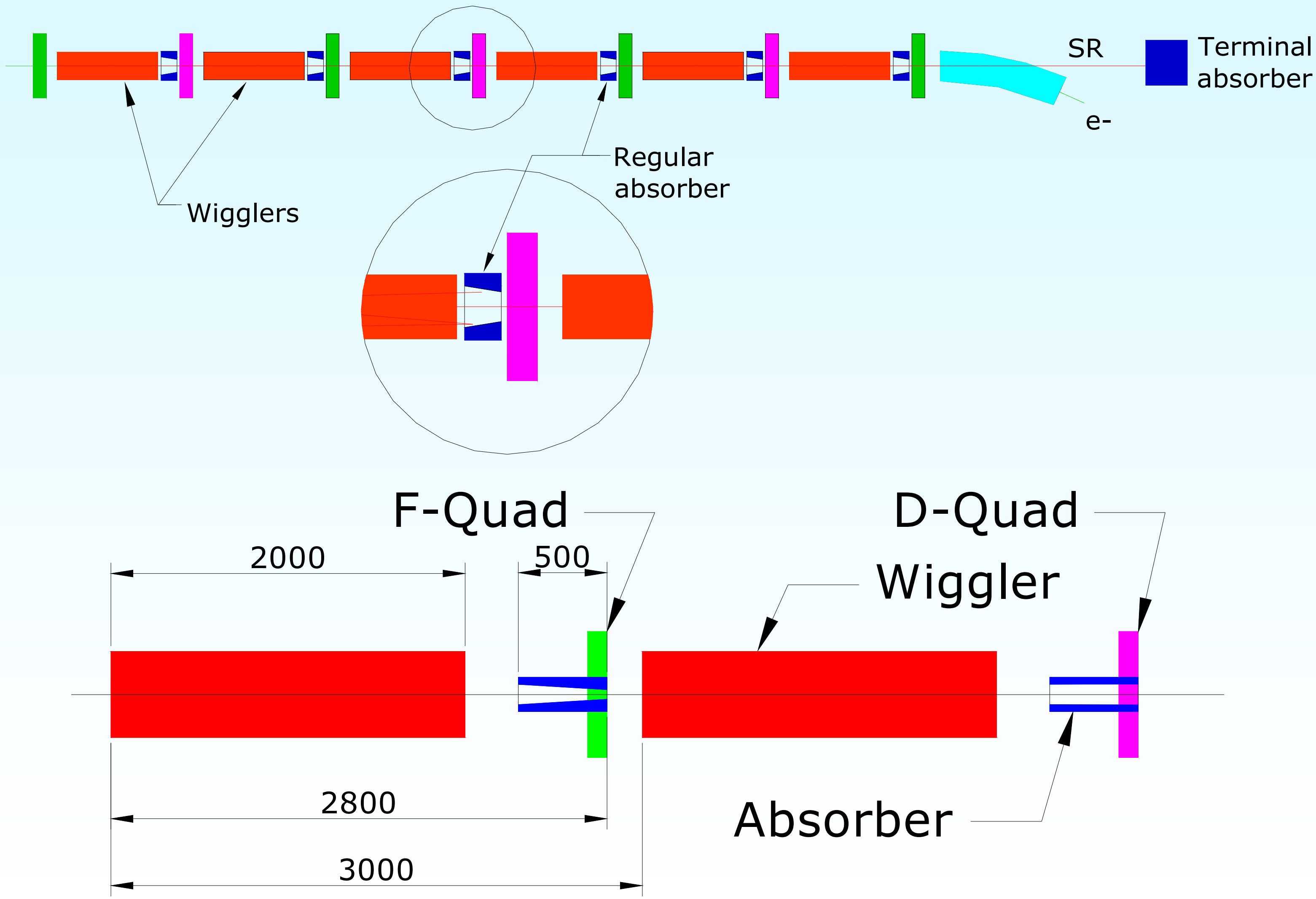


	An	Bn	an	bn
1	0.0000000	0.0000000	0.0000000	0.0000000
2	0.0000000	0.0000000	0.0000000	0.0000000
3	-8.6129885	0.0000000	-26.9155891	0.0000000
4	0.0000000	0.0000000	0.0000000	0.0000000
5	0.0000000	0.0000000	0.0000000	0.0000000
6	0.0000000	0.0000000	0.0000000	0.0000000
7	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000000	0.0000000	0.0000000	0.0000000
9	-0.0017251	0.0000000	-414.5816660	0.0000000
10	0.0000000	0.0000000	0.0000000	0.0000000
11	0.0000000	0.0000000	0.0000000	0.0000000
12	0.0000000	0.0000000	0.0000000	0.0000000
13	0.0000000	0.0000000	0.0000000	0.0000000
14	0.0000000	0.0000000	0.0000000	0.0000000
15	0.0010614	0.0000000	3927683.3422	0.0000000
16	0.0000000	0.0000000	0.0000000	0.0000000
17	0.0000000	0.0000000	0.0000000	0.0000000
18	0.0000000	0.0000000	0.0000000	0.0000000

BINP Mermaid Magnetic code

Units at the plots – kG and cm

SR power evacuation strategy



Code for calculation of SR power loads for SR absorbers

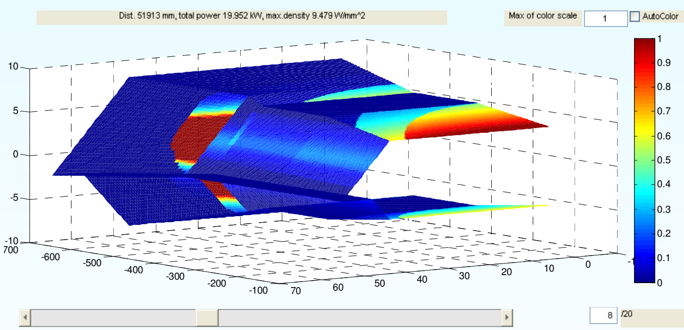
$$\frac{dP}{d\Omega} = \frac{d^2P}{d\theta\, d\psi} = P_T \frac{21\gamma^2}{16\pi K} G(K)\, f_K(\gamma\theta, \gamma\psi)$$

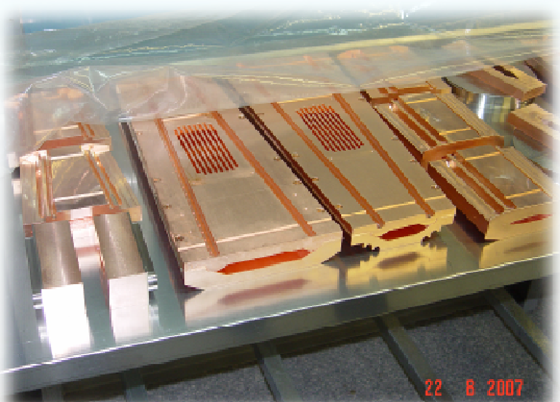
$$P_T[\mathrm{kW}] = 0.633 \cdot E_e^2[\mathrm{GeV}] \cdot B^2[\mathrm{T}] \cdot L[\mathrm{m}] \cdot I[\mathrm{A}]$$

$$f_K(\gamma\theta, \gamma\psi) = \sqrt{1 - \left(\gamma\theta / K\right)^2} \left\{ \frac{1}{\left(1+(\gamma\psi)^2\right)^{5/2}} + \frac{5(\gamma\psi)^2}{7\left(1+(\gamma\psi)^2\right)^{7/2}} \right\}$$

$$G(K) = K \frac{K^6 + \frac{24}{7}K^4 + 4K^2 + \frac{16}{7}}{\left(1+K^2\right)^{7/2}}$$

K.-J. Kim, Nucl. Instr. And Meth A246(1986)

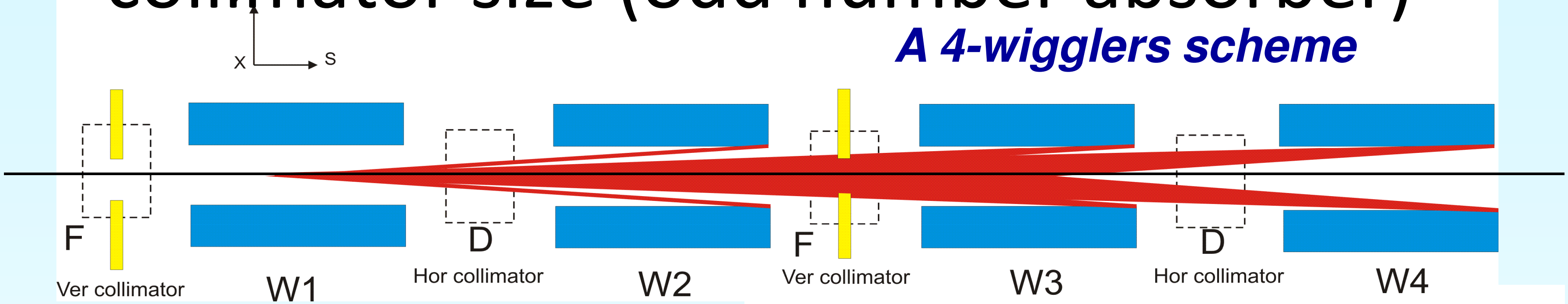


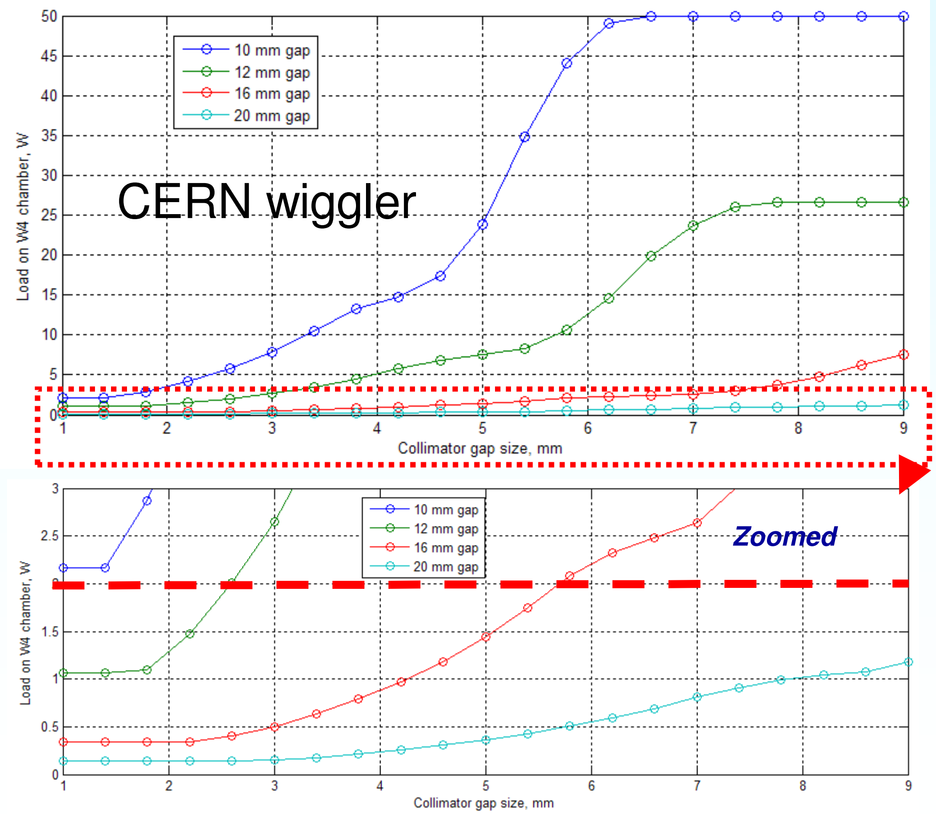


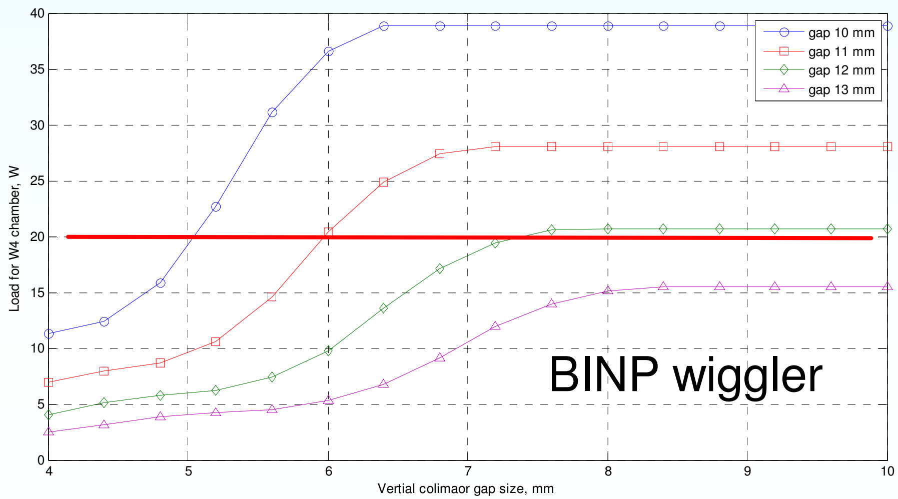
For design and optimization of Petra-III damping section a special codes were developed for SR power load simulations. The codes performs a following actions:

- *Ray tracing technique for accounting of absorber shadows*
- *Parametric optimization of absorber shape*
- *COD accounting*
- *3D modeling of complicated absorber shape*

Choice for wiggler gap and vertical collimator size (odd number absorber)

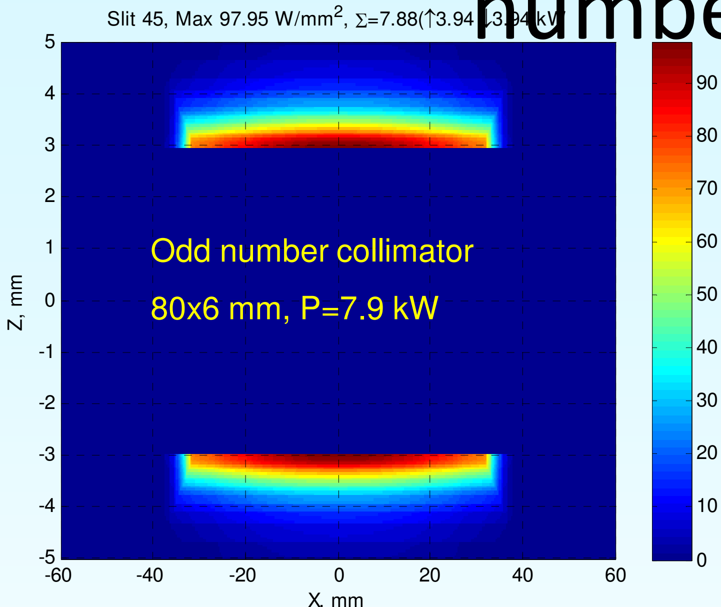


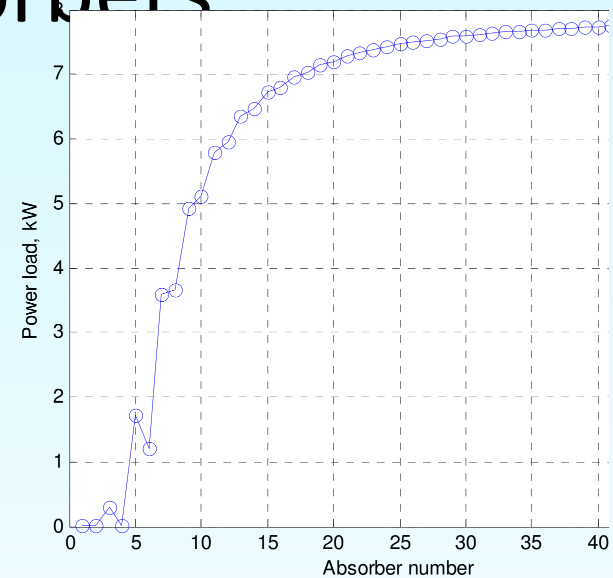


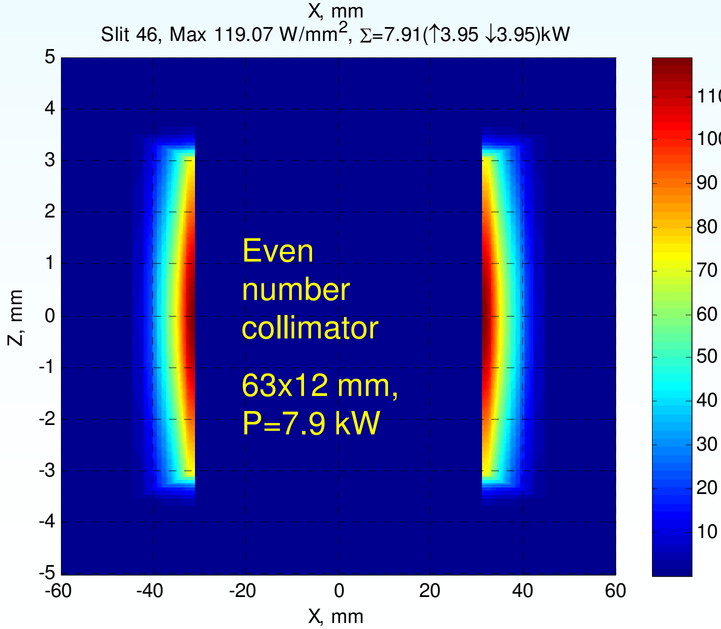


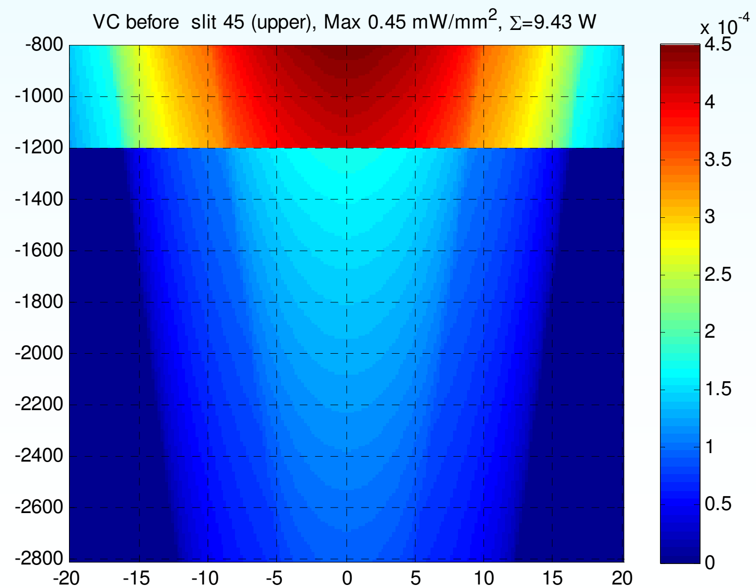
Choice for horizontal aperture for even number absorbers

BINP wiggler version

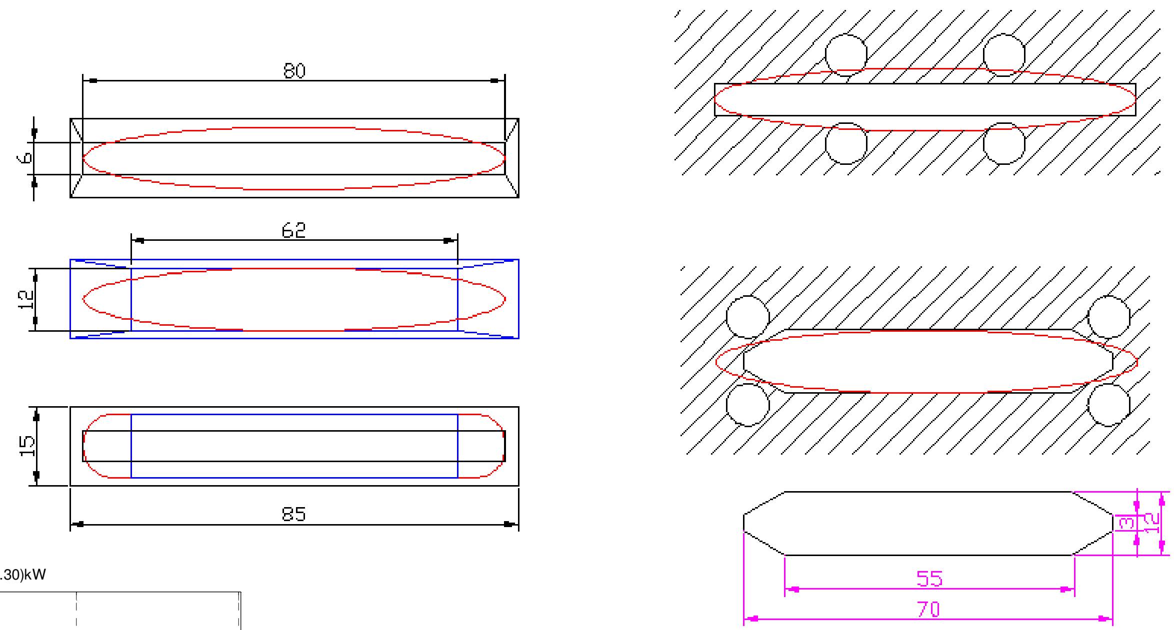


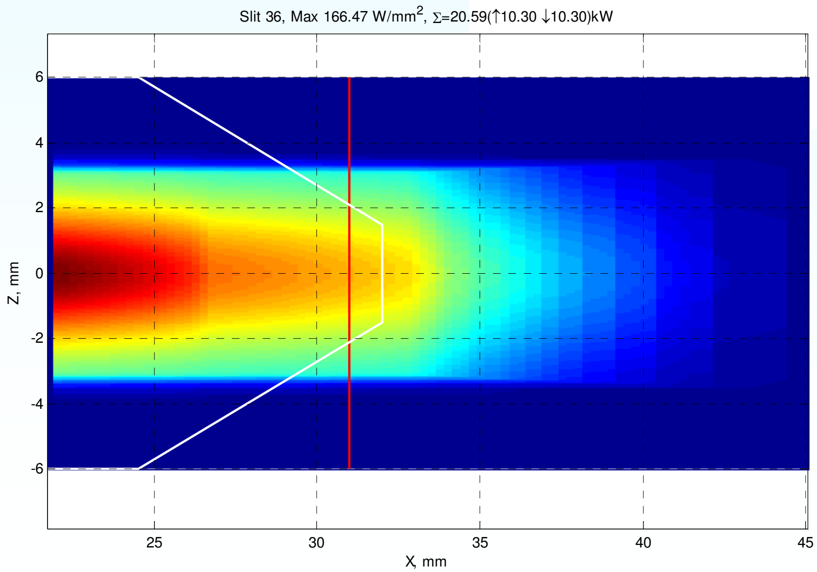




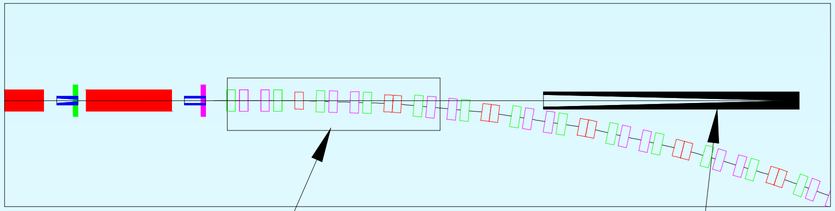


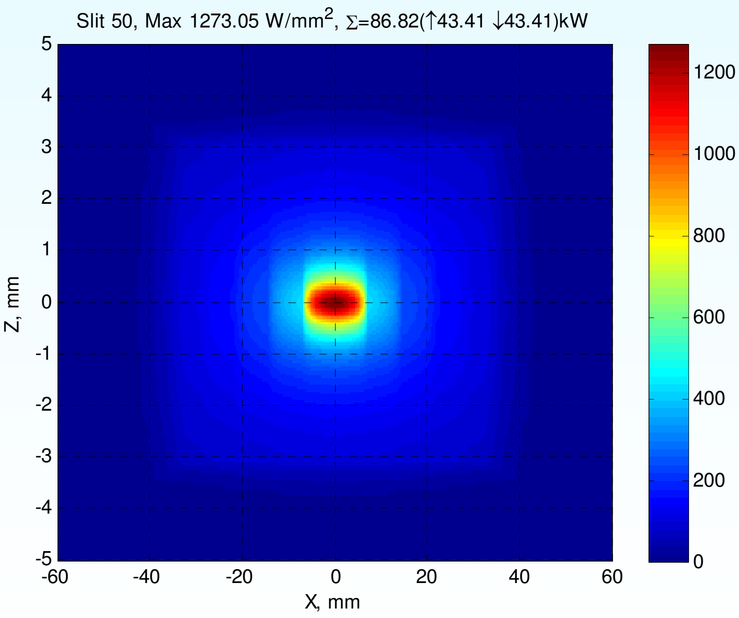
Even number wiggler VC load distribution, P=9.4 W

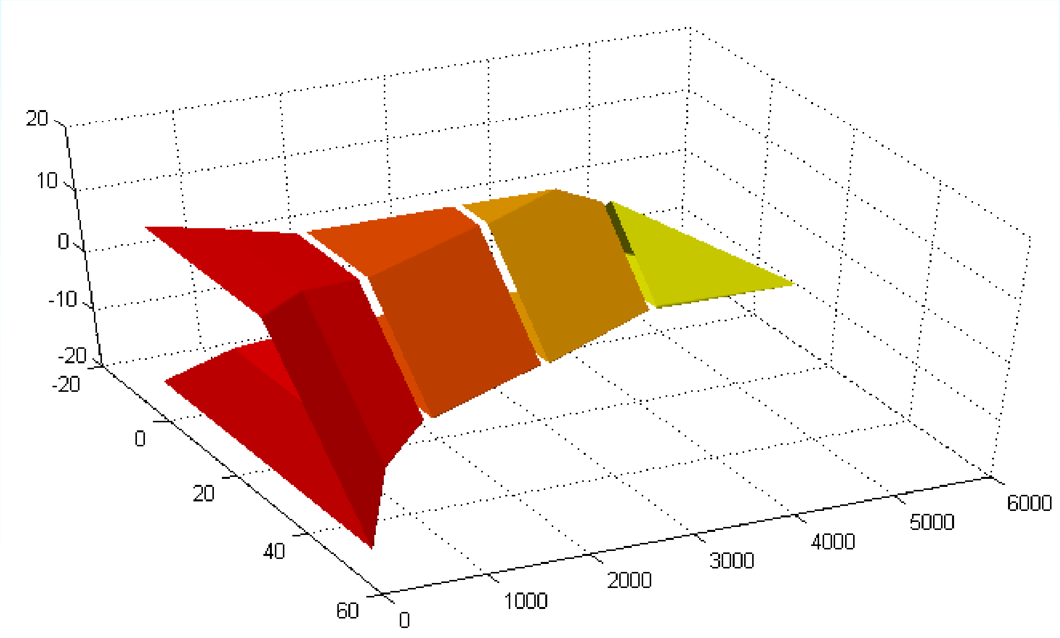

80
6
62
12
15
85
55
70
3
12


Slit 36, Max 166.47 W/mm2, Σ=20.59(↑10.30 ↓10.30)kW
Z, mm
X, mm
6
4
2
0
-2
-4
-6
25
30
35
40
45

Final absorber

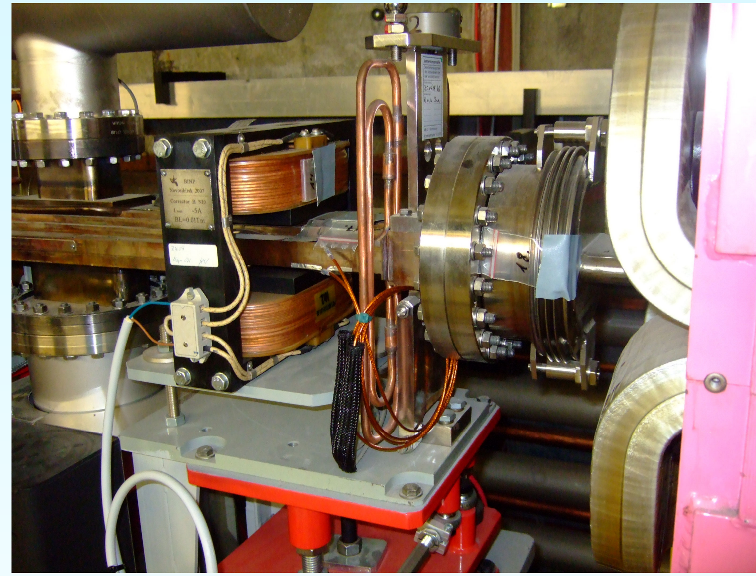


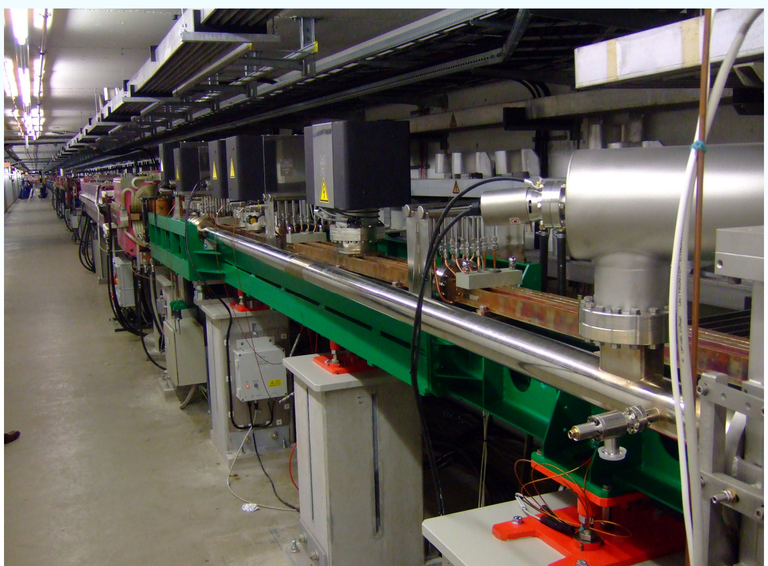


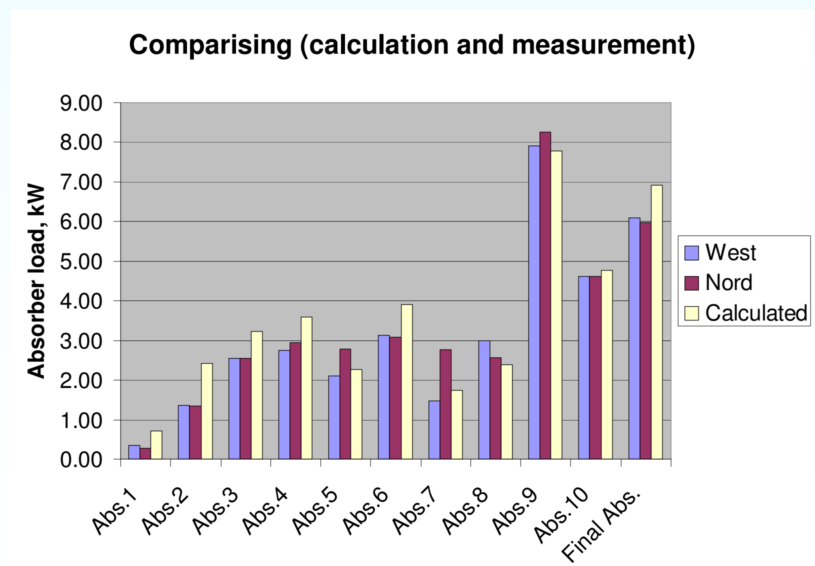


6 m length final absorber can absorb up to 170 kW of SR power

Petra-III DWS commissioning



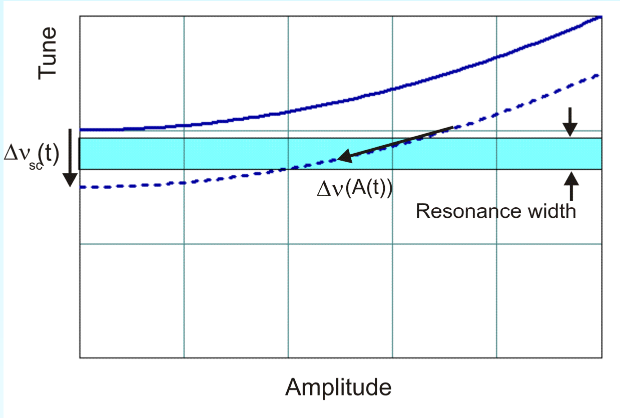


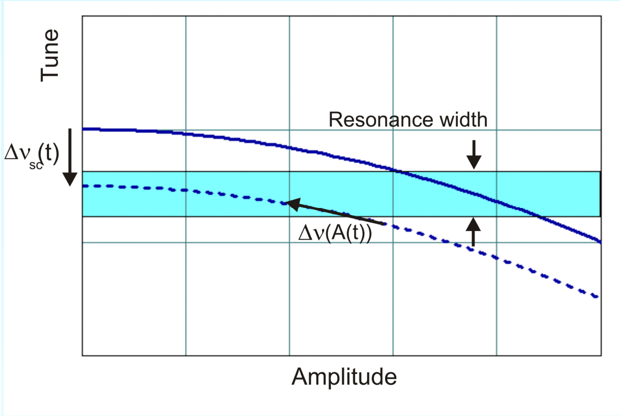


Nonlinear beam dynamics with strong damping in the CLIC damping ring

$$\nu(t) = \nu_0 + \Delta\nu_{sc}(t) + \Delta\nu\big(A(t)\big)$$

$$\Delta\nu_{sc}(t) \sim -\varepsilon^{-1}(t)$$





LIFERTAC – the beam-beam macroparticle simulation code
ACCELERATICUM – 6D nonlinear tracing code with dumping accounting

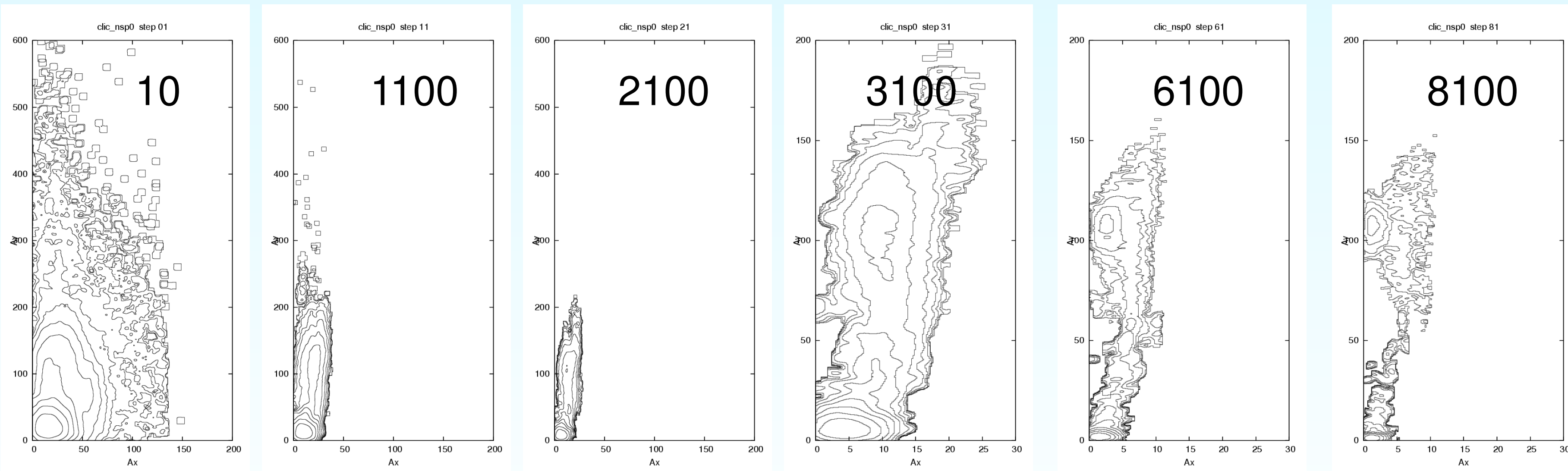
The main goals of this efforts:
•To establish and test a computer simulation of the evolution of particles distribution in presence of strong damping, space charge effects and realistic lattice including different nonlinearities (the strongest are the chromatic sextupoles)
•To understand if the fast damping under described circumstances may influence the CLIC DR performance

DR lattice version v.44 dated May, 2005

Space charge influence on the damping

DR lattice version v.44 dated May, 2005

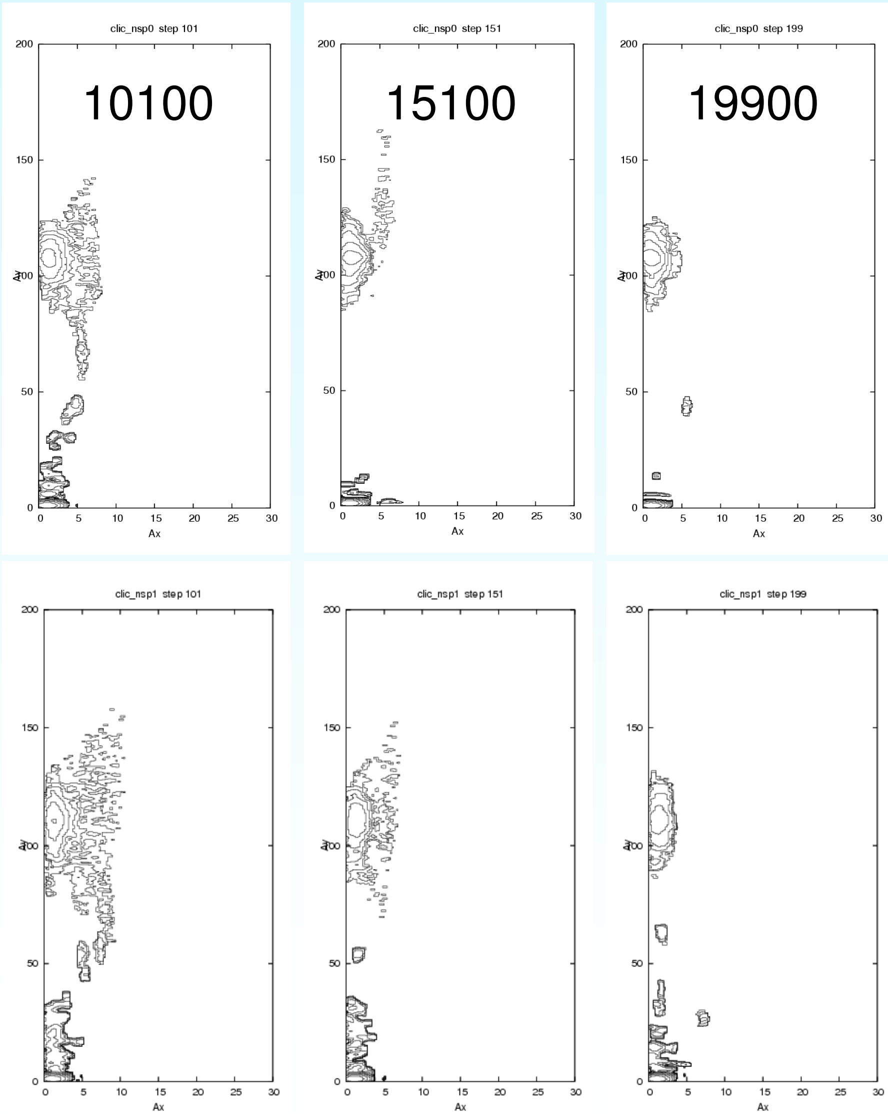
1000 particles, 19900 turns (~10 τ_{xy}), 30% particles were lost during first 400 turns

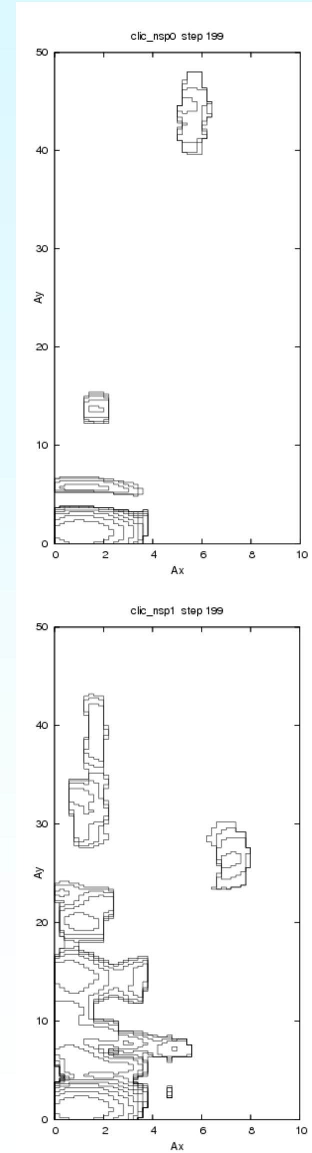


200 x 600 extraction σ

30 x 200 extraction σ

Space charge influence on the damping





Summary

- *The first short prototype of the SC wiggler was developed, fabricated and tested in BINP. In spite of some unsuccessful test, the main technological innovation can be used for next modifications. The new design of wiggler was developed and fabrication of the new version was started*
- *The two modifications of the classical DR lattice were proposed for more realistic design. Additional optimization of the proposed schemes is possible after final choice of the of DR parameters.*
- *SR absorption scheme was proposed for wiggler sections of DR. The special SR absorption simulating code can be used for design and optimization absorption system.*
- *The special approach for analysis of nonlinear beam dynamic in case of fast damping was proposed. The influence of space charge in the final stage of the damping. The method can be used for analysis of final lattice structure.*
- *The results of these issues can be included in the final CDR of CLIC DR in the next year.*

Thank you for attention