NICA Collider Lattice Optimization

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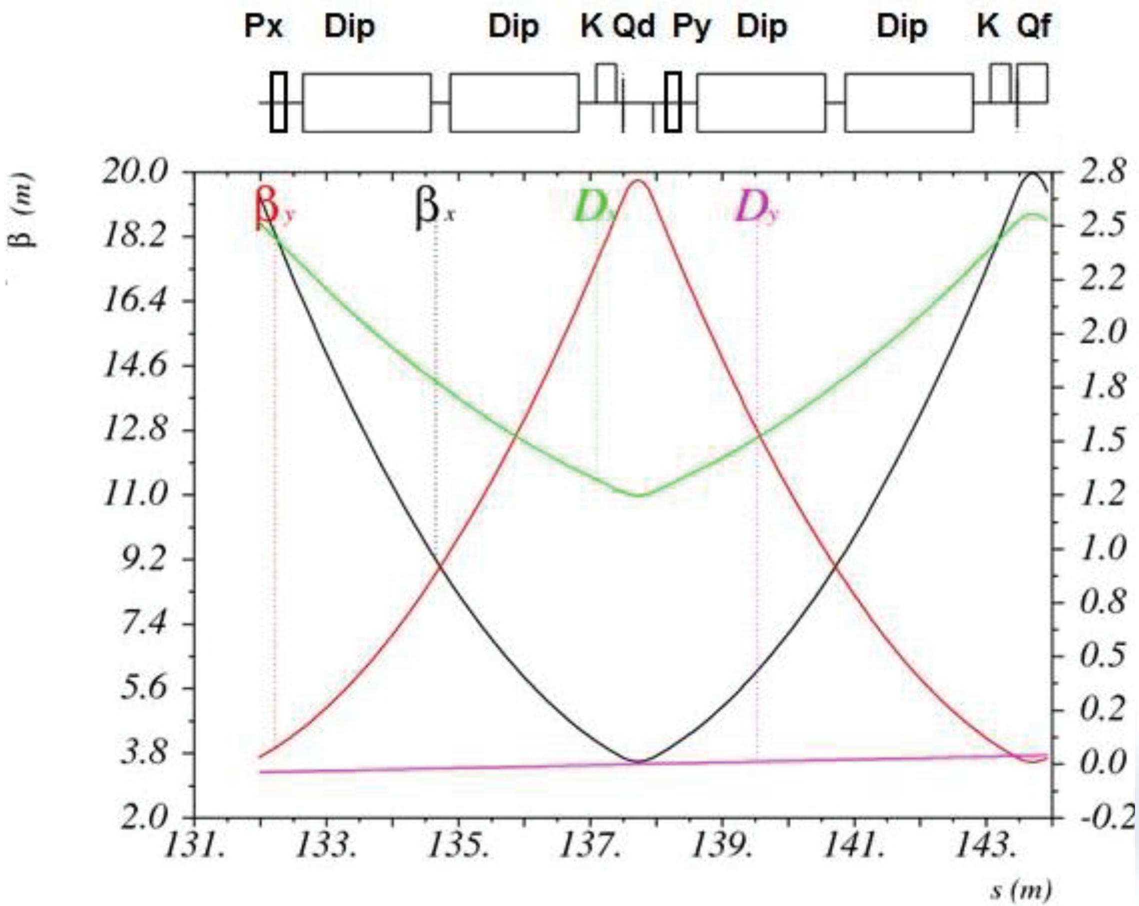
for the NICA team

Collider general parameters

Circumference, m	503.04		
Number of bunches	22		
Rms bunch length, m	0.6		
Beta-function at IP, m	0.35		
Betatron tunes, Qx / Qy	9.44 / 9.44		
Chromaticity, Q'x / Q'y	-33 / -28		
Ring acceptance, π·mm·mrad	40		
Long. acceptance, $\Delta p/p$	$\pm$0.010		
Gamma-transition, γ_{tr}	7.088		
Ion energy, GeV/u	1.0	3.0	4.5
Ion number per bunch	$2.0 \cdot 10^{8}$	$2.4 \cdot 10^{9}$	$2.3 \cdot 10^{9}$
Rms $\Delta p/p$, 10^{-3}	0.55	1.15	1.5
Rms beam emittance, hor/vert, (unnormalized), π·mm·mrad	1.1/ 0.95	1.1/ 0.85	1.1/ 0.75
Luminosity, $cm^{-2}s^{-1}$	$0.6 \cdot 10^{25}$	$1.0 \cdot 10^{27}$	$1.0 \cdot 10^{27}$
IBS growth time, sec	160	460	1800
Tune shift, $\Delta Q_{total} = \Delta Q_{SC} + 2\xi$	-0.050	-0.037	-0.011

Collider Optics

Periodic Cell

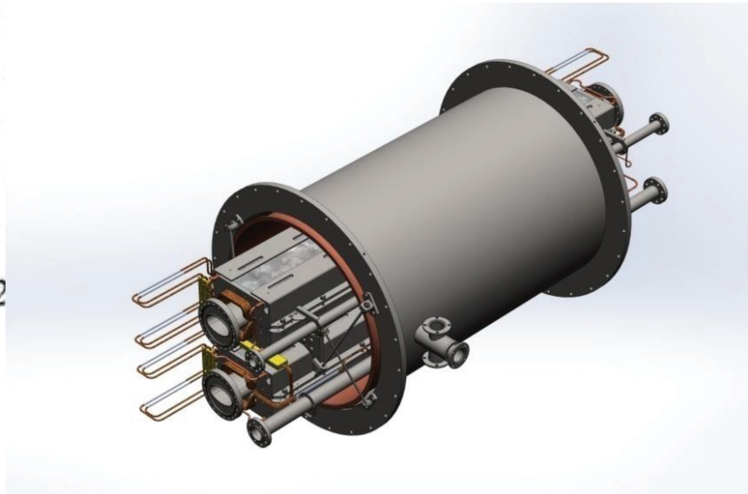


Lcell=11.96m

Ldip=1.94m Bmax=1.8T

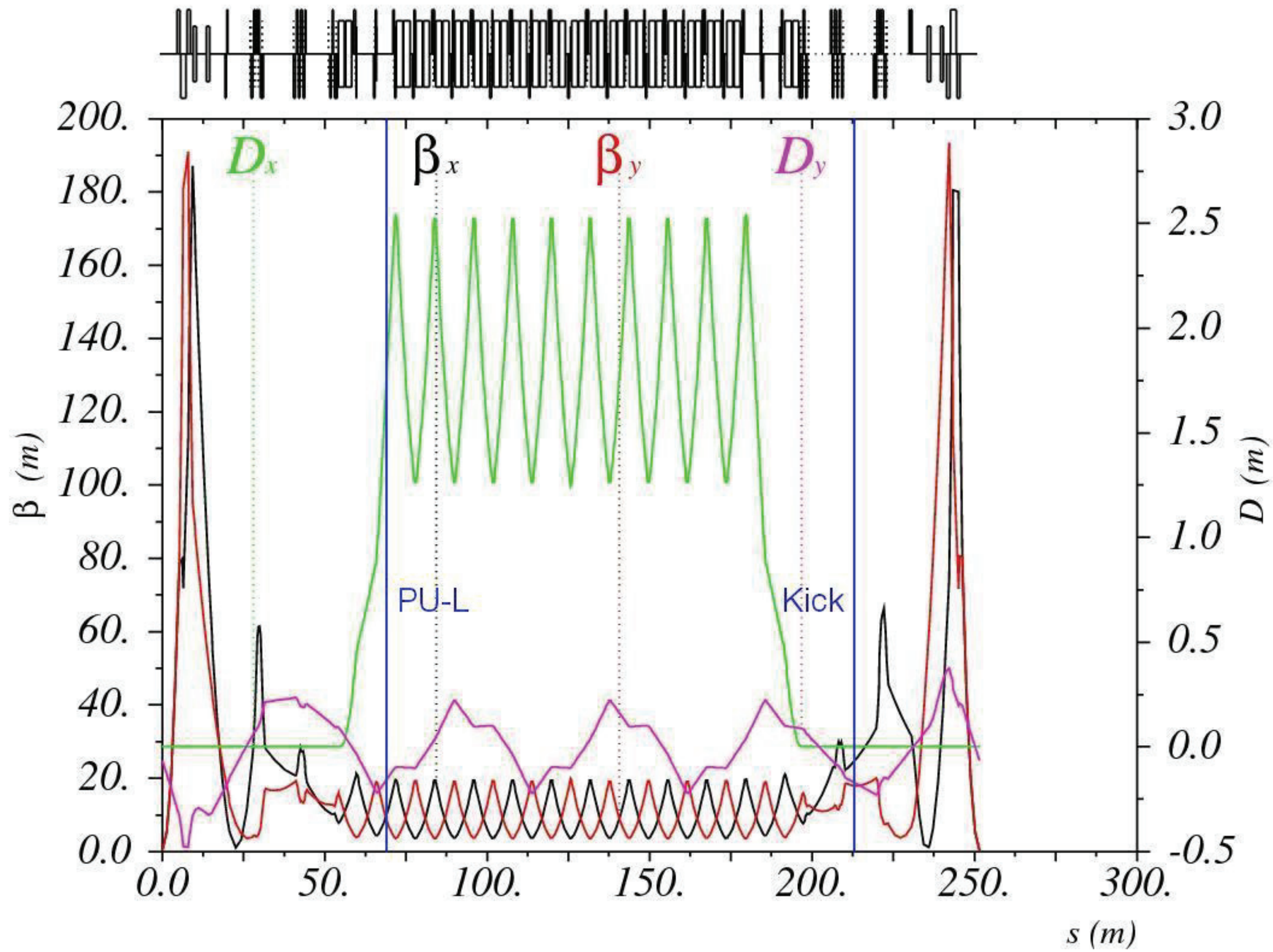
Lquad=0.47m Gmax=23T/m

Lcorr=0.30m (dipole,
quadrole, sextupole,
octupole windings)



Collider 2-Aperture Dipole

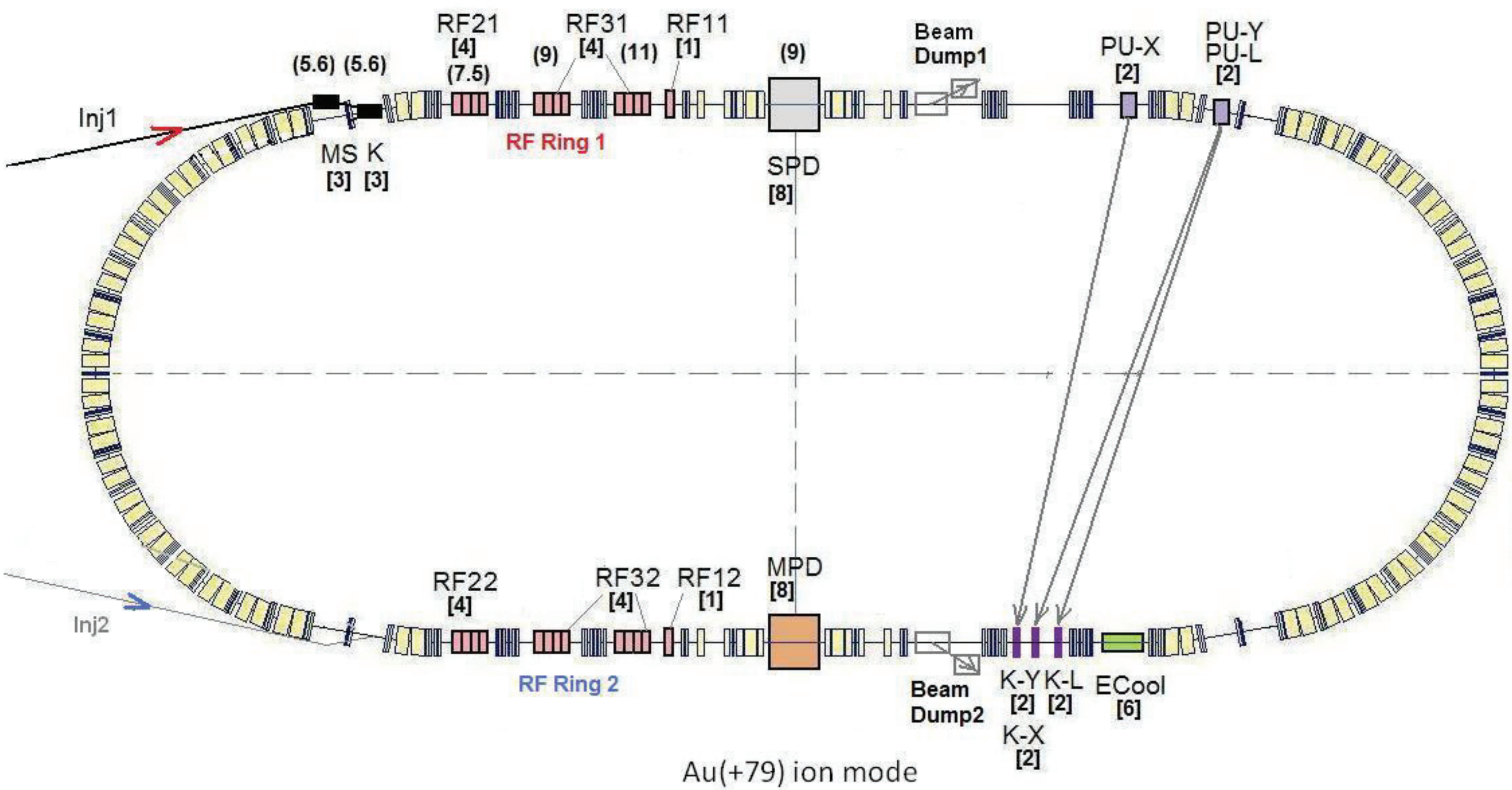
Collider Optics



Optics for both beams (Half of the Ring). ΔL(Triplet-IP)=5.25m

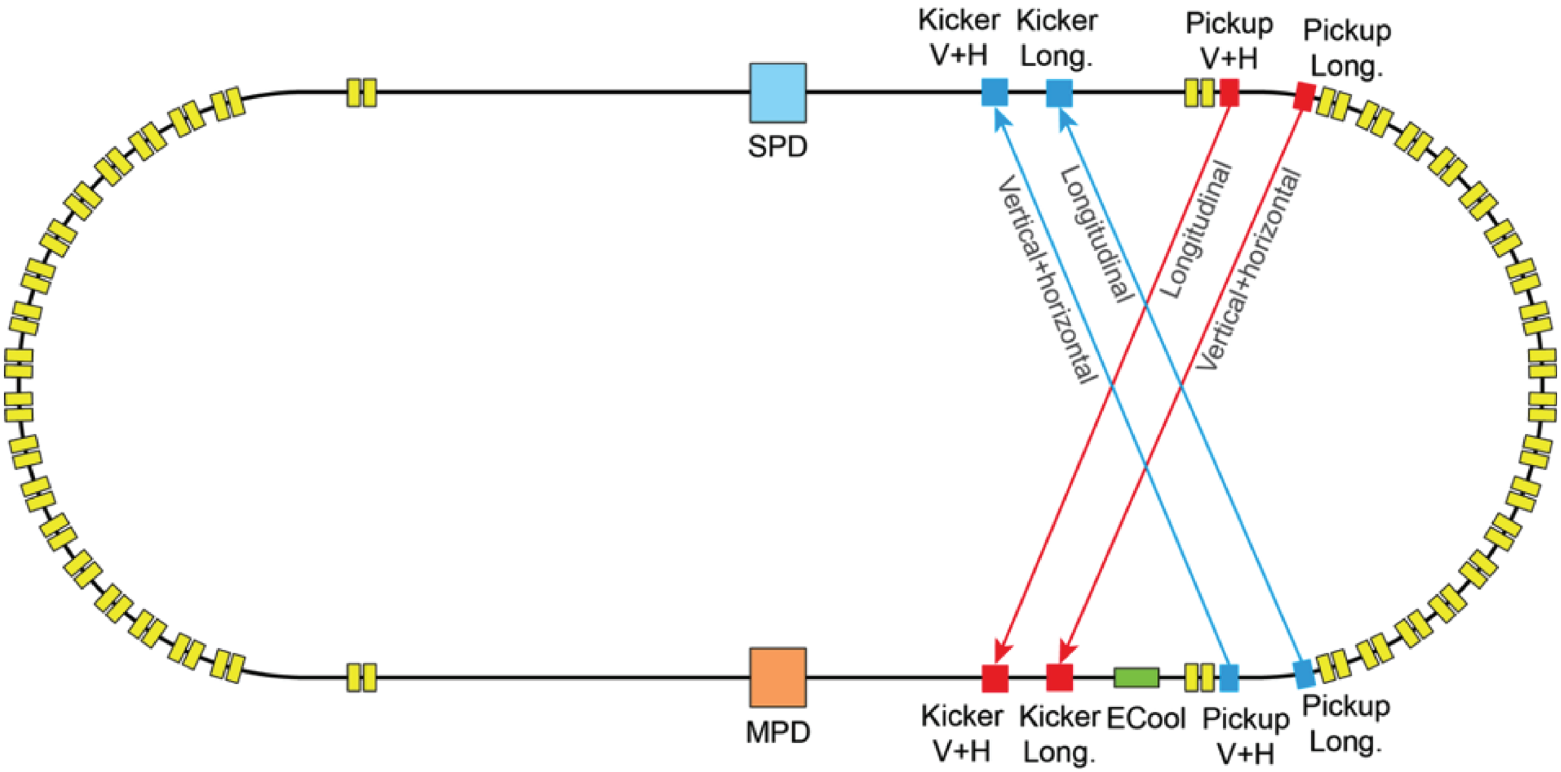
Dy not compensated

Collider Ring scheme & Layout, Ion Mode



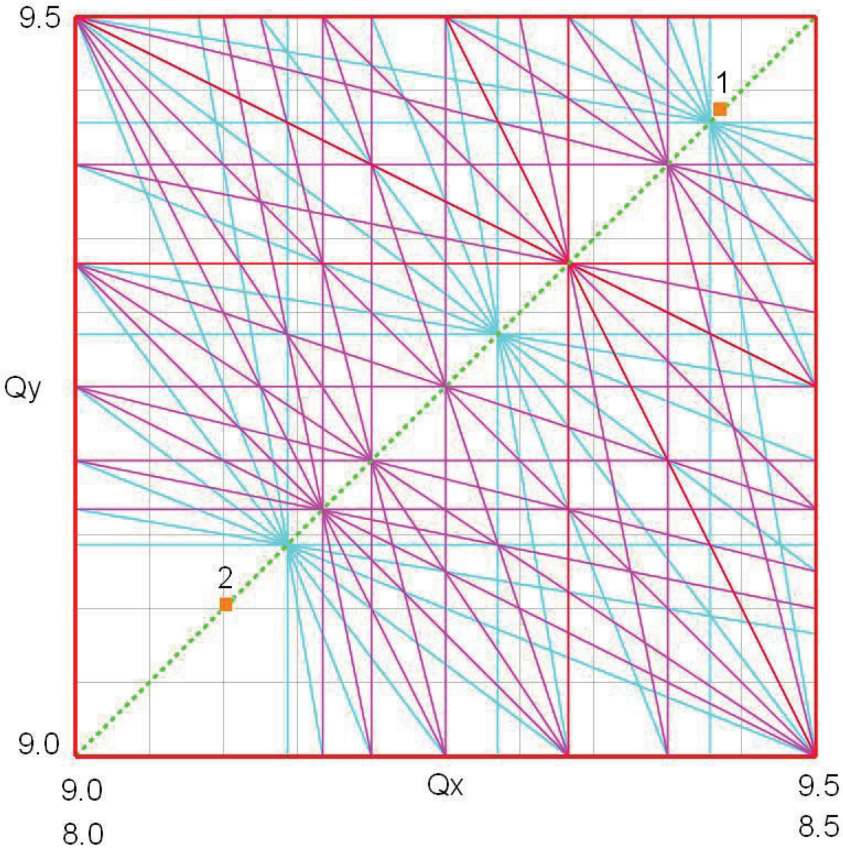
Collider Ring scheme & Layout, Ion Mode

Stochastic cooling systems layout in collider



SC system parameters:
W=2÷4 GHz, P= up to 500 W amplifier,
L_pickup=2m

Betatron tunes correction



Resonance diagram up to 7th order. Collider Working points

- **Betatron tunes Qx/Qy regulation:**
  1. Quadrupole correctors (trim-quads) in long straight sections (small regulation ΔQ =+/-0.1, and matching conditions), Imax=1kA ;
  2. Arc quadrupoles (strong change of tune, Q=8÷9.5), Imax=11kA ;
- **Nominal Betatron Tunes $\nu x=\nu y$=0.42÷0.44 require for effective Stochastic Cooling in Energy range 3÷4.5 GeV/u;**
- **Qx/Qy=9.10 – second possible working point: Ecool up to 3GeV/u, larger DA**

Dynamic Aperture calculation

- **Dynamic Aperture:** $A(x,y) = A_{x,y}(s, N_{turn})$

in optimal collider lattice: $A_{x,y}(s) > M_{x,y}(s)$, $M_{x,y}(s)$ **– vacuum chamber**

good reserve: $A_{x,y}(s) = 2M_{x,y}(s)$;

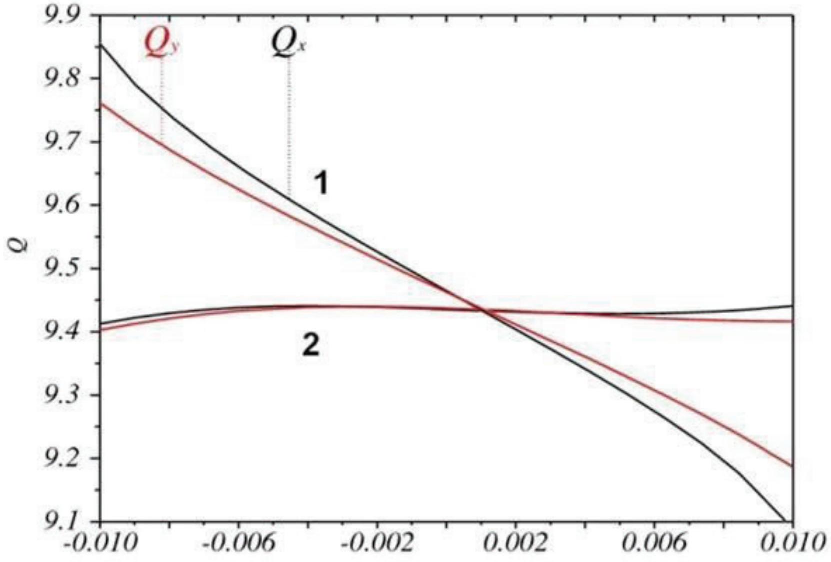
- **DA calculation methods:**

1. PTC - Polymorphic Tracking Code, (MAD-X):
- **Symplectic tracking;**
- **Nonlinearities of magnetic elements (chromaticity sextupoles, systematic/random errors in dipoles/quadrupoles);**
- **Fringe fields of all magnetic elements;**

2. Thin-lens tracking, (MAD-X):
Symplectic tracking also;
- **Beam-beam interactions in IPs;**
- **Space charge forces.**

Sextupole correction, Chromaticity of tune

- Cancellation of sextupole nonlinearity influence on DA : $\Delta\mu=180^0$ between correctors of one family (F/D)
- Sextupoles adjusted to minimaze tune variation: 4 families of sextupole correctors for second order chromaticity correction,



Tune spread over the momentum acceptance $\pm 4\sigma_p$ before (1) and after (2) correction

- Natural chromaticities: Q'x=-33, Q'y=-28 (ΔQ'x,y~20 from 2 IPs)
- Corrected chromaticities: Q'x=-1.5, Q'y=-1.5
- Ncorr=24, G'max=150T/m^2

Nonlinearities of the magnetic field

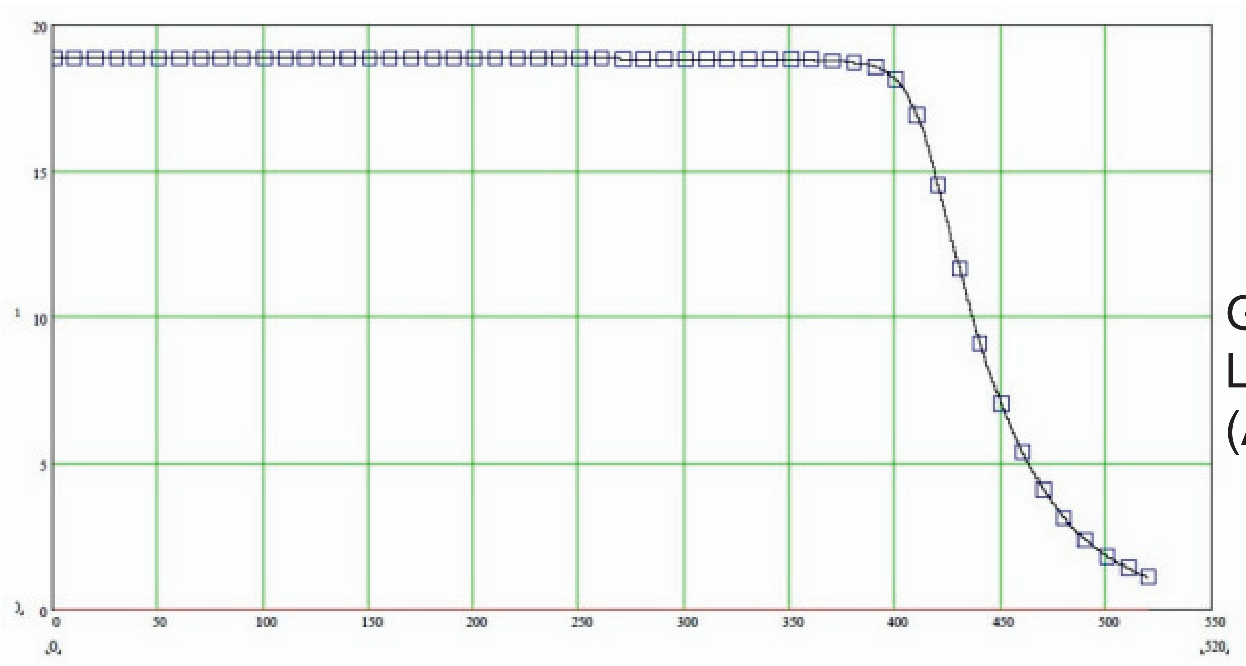
1. Dipole/Quadrupole harmonics (dipole shown):

b_2	b_4	b_6	b_8	b_{10}	b_{12}
-0.03	76.3	$-1.5\cdot10^{5}$	$-2.7\cdot10^{10}$	$-7.5\cdot10^{14}$	$-6.6\cdot10^{18}$

$$b_n = \frac{1}{B\rho}\left(\frac{d^n B_y}{dx^n}\right),\ м^{-(n+1)} syst.\ error$$

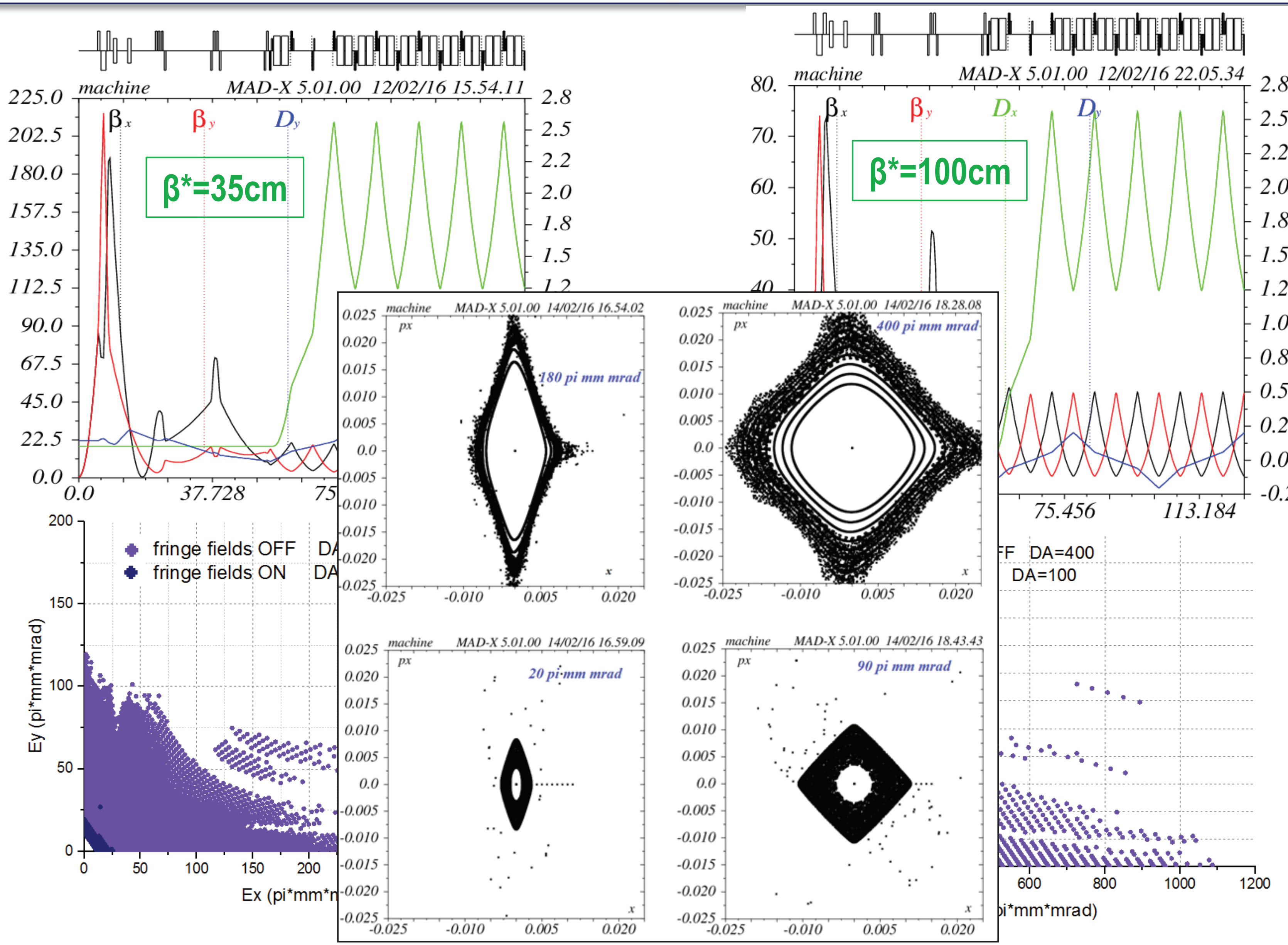
$$\sigma_n = 0.3 b_n,\ random\ error$$

2. Fringe Fields, Final Focus Quads in particular:

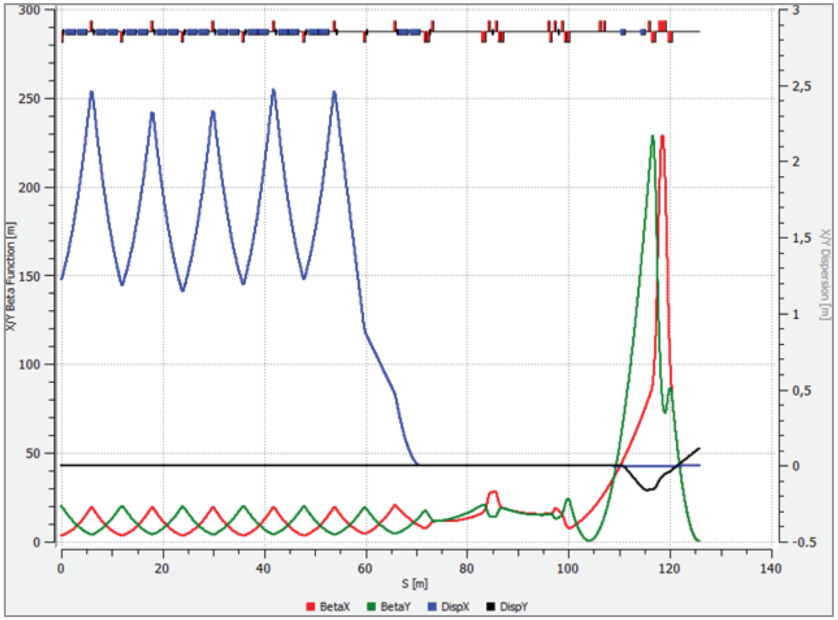


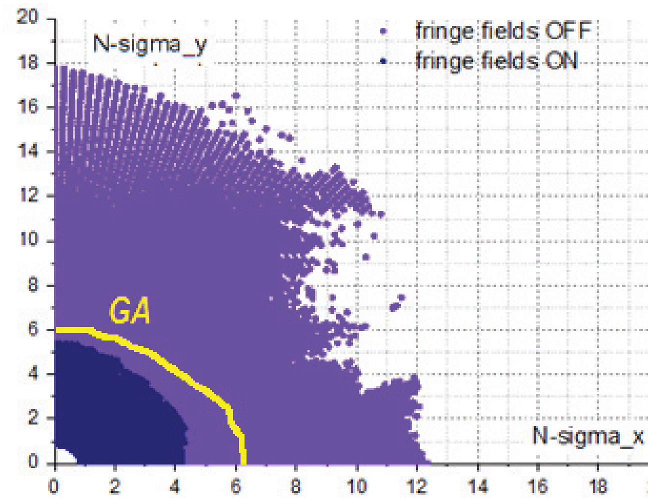
Gradient in QFF1 vs. Longitudinal coor. @ I=10.3kA (A.Getman calc.)

DA calculation results. DA optimization

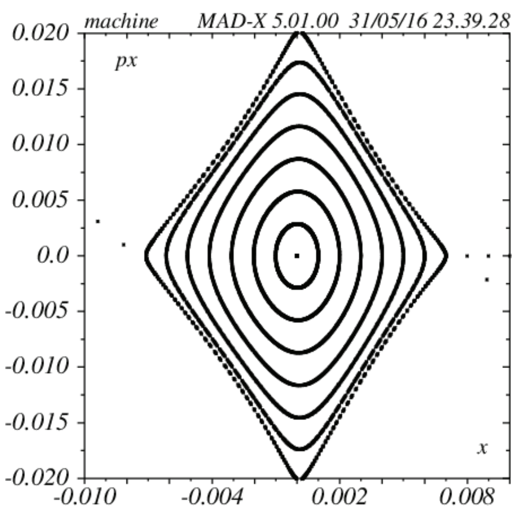


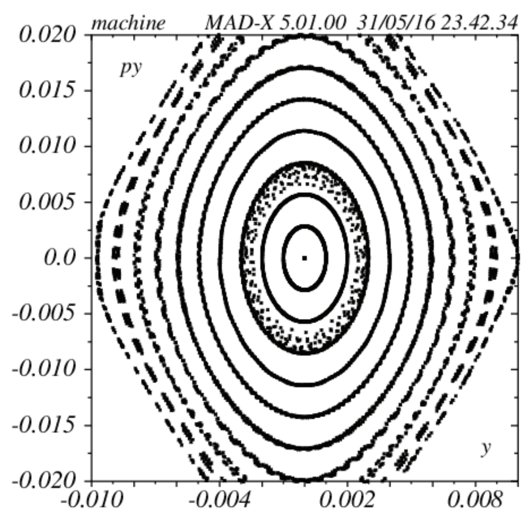
Qx=8.45
Qy=9.44
β*=35cm

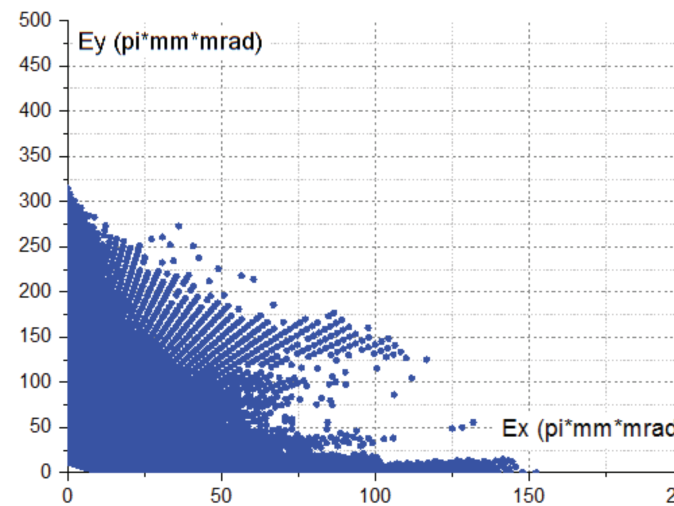




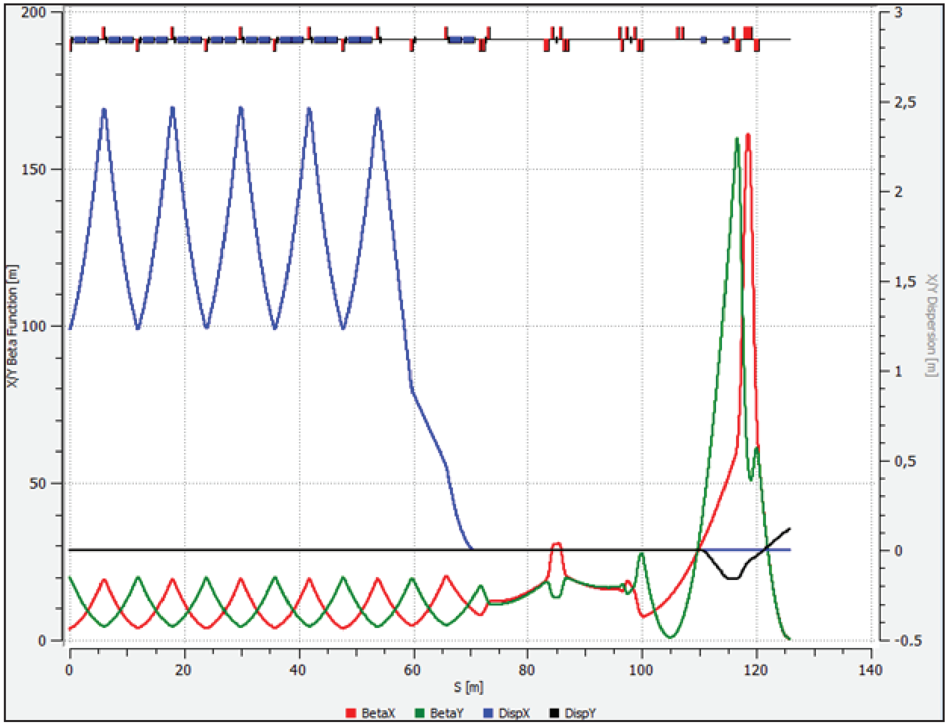
Fringe fields OFF, only Chrom sext.

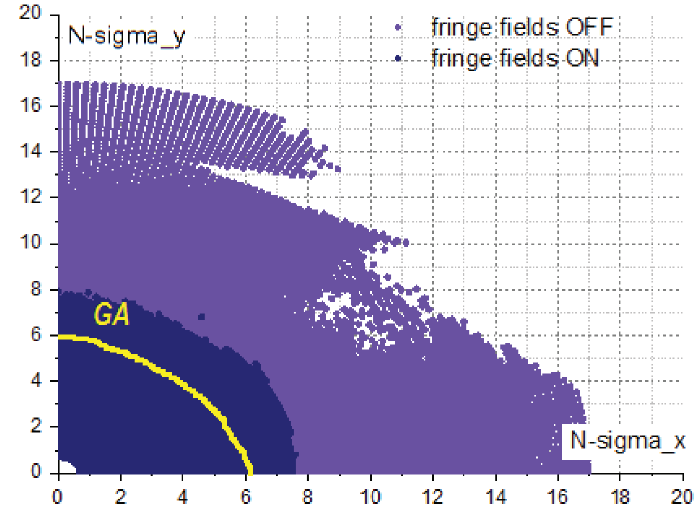




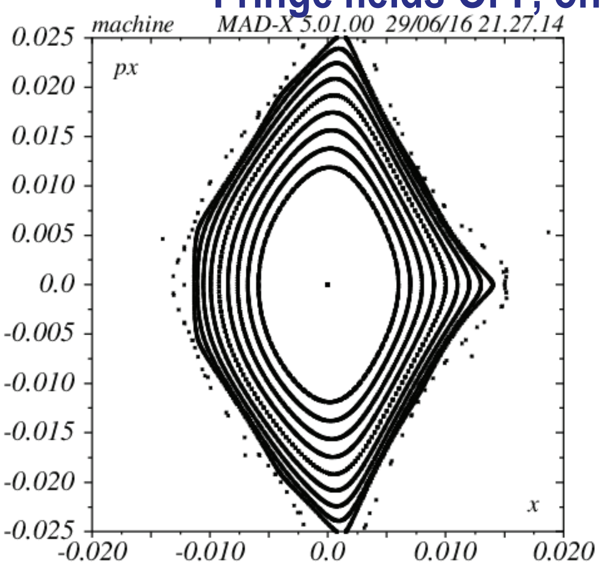


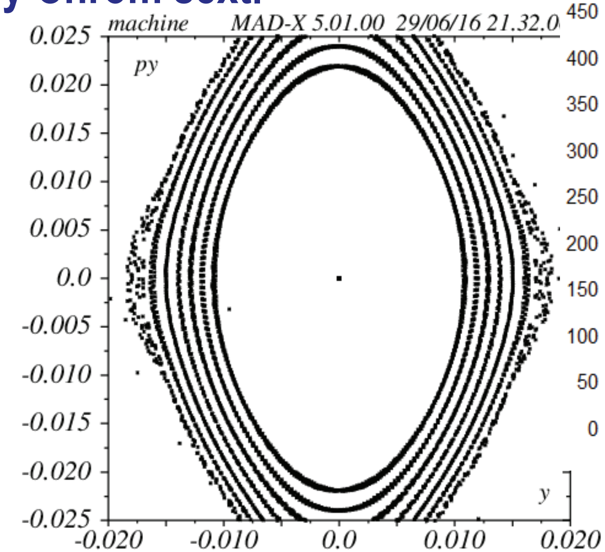
Qx=8.42
Qy=9.42
β*=50cm

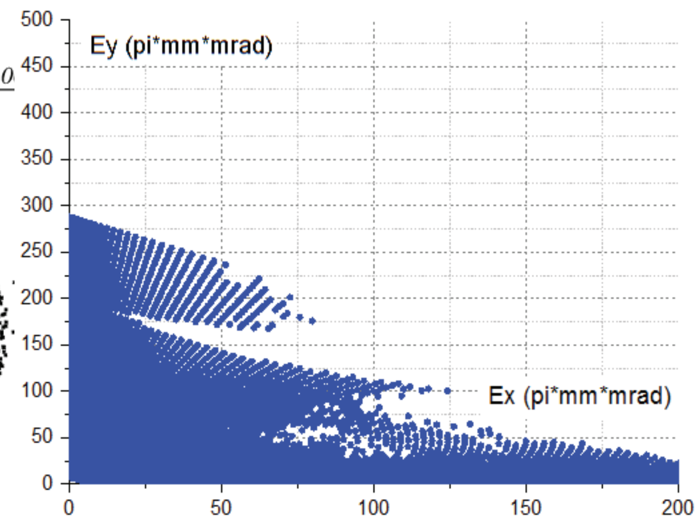




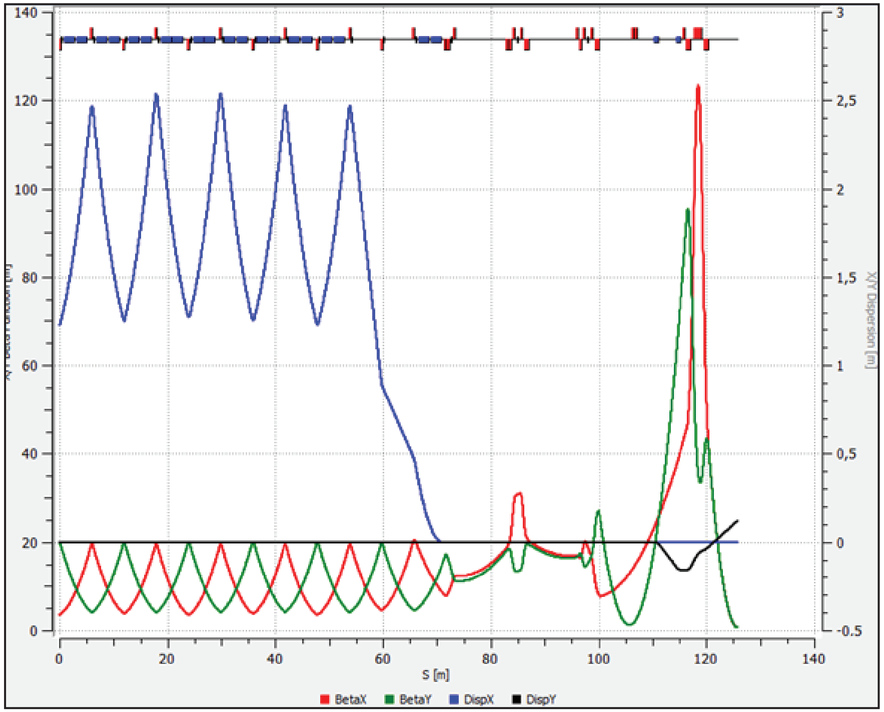
Fringe fields OFF, only Chrom sext.

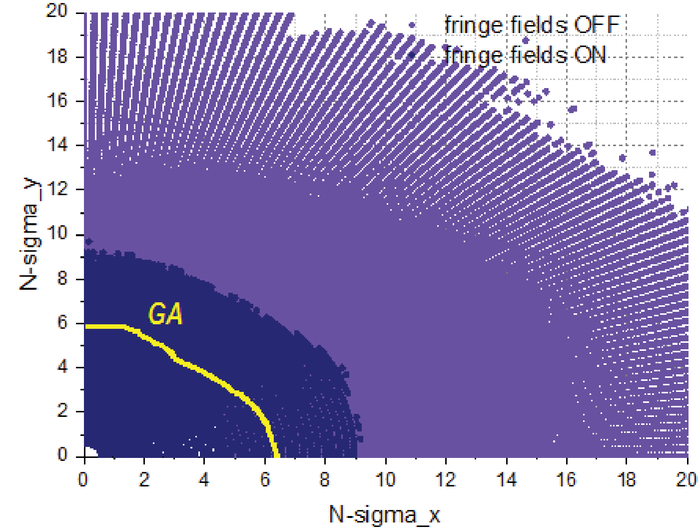




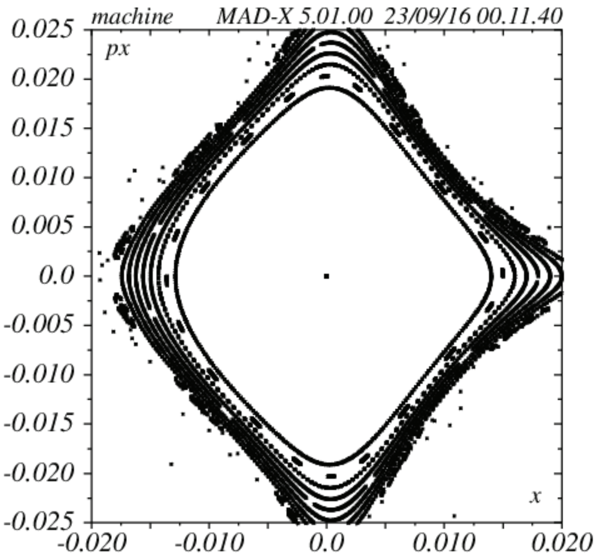


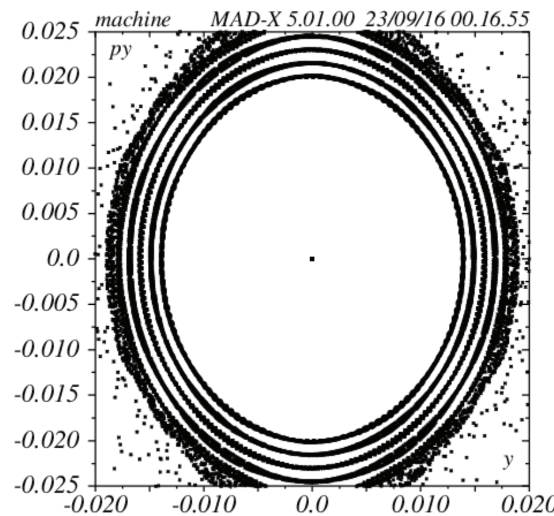
Qx=8.44
Qy=9.44
β*=70cm

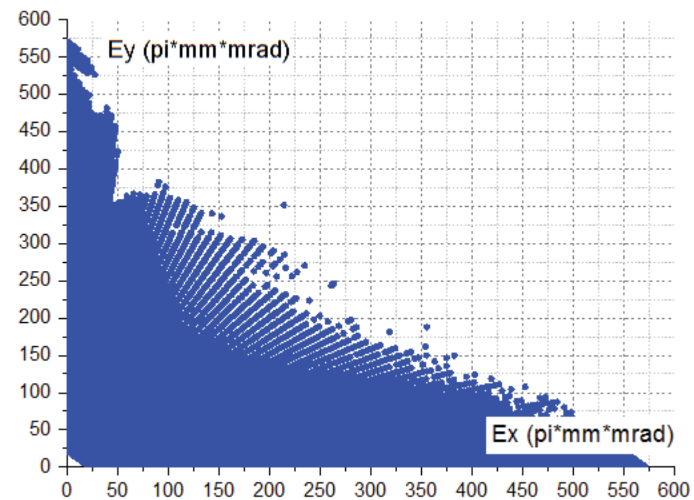




Fringe fields off, only chrom corr sextupoles



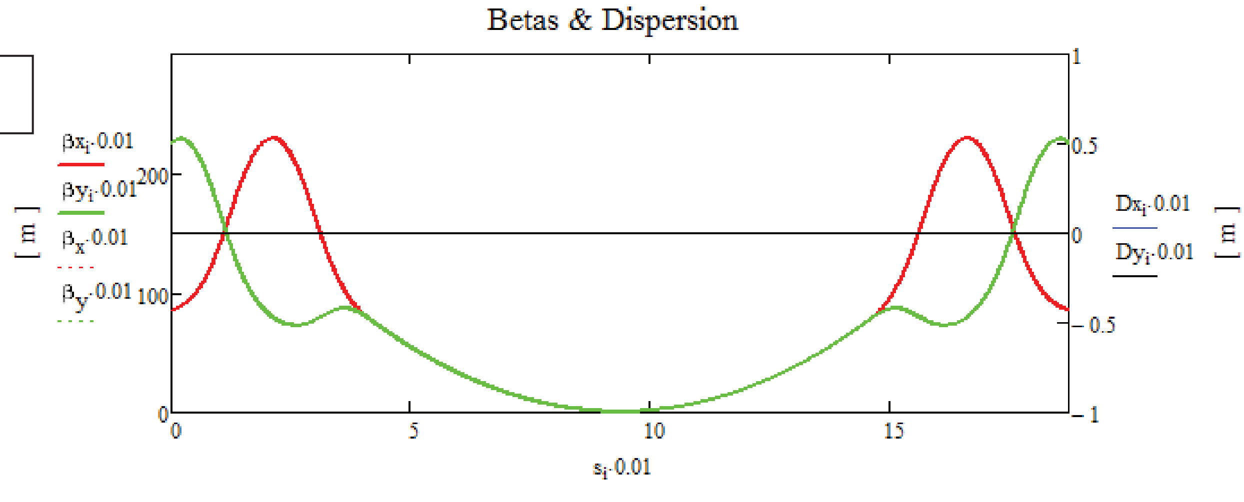




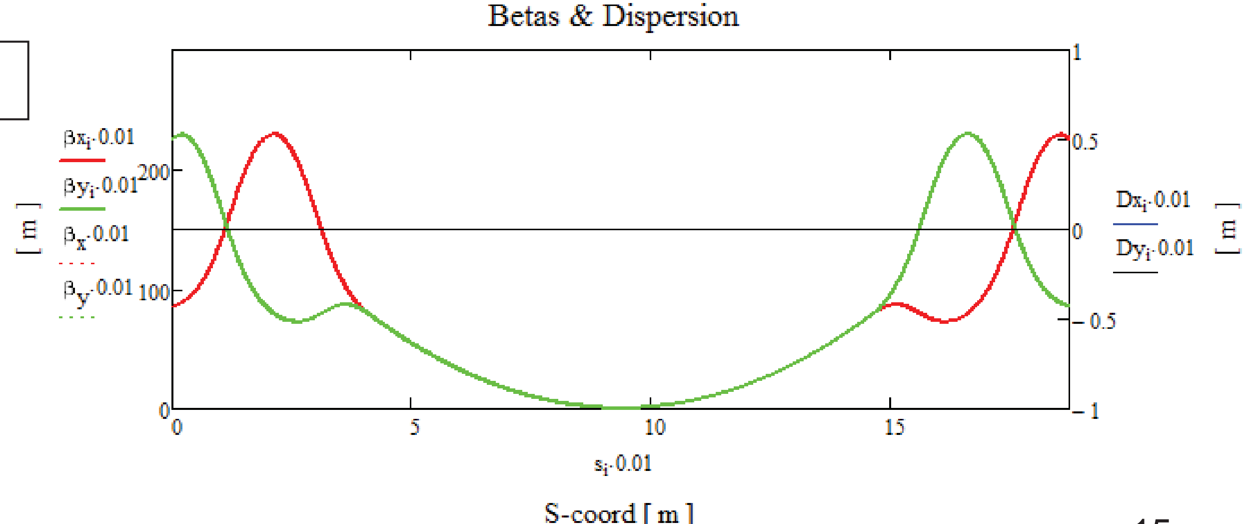
Fringe Fields of Final Focus Quads

β*=35cm

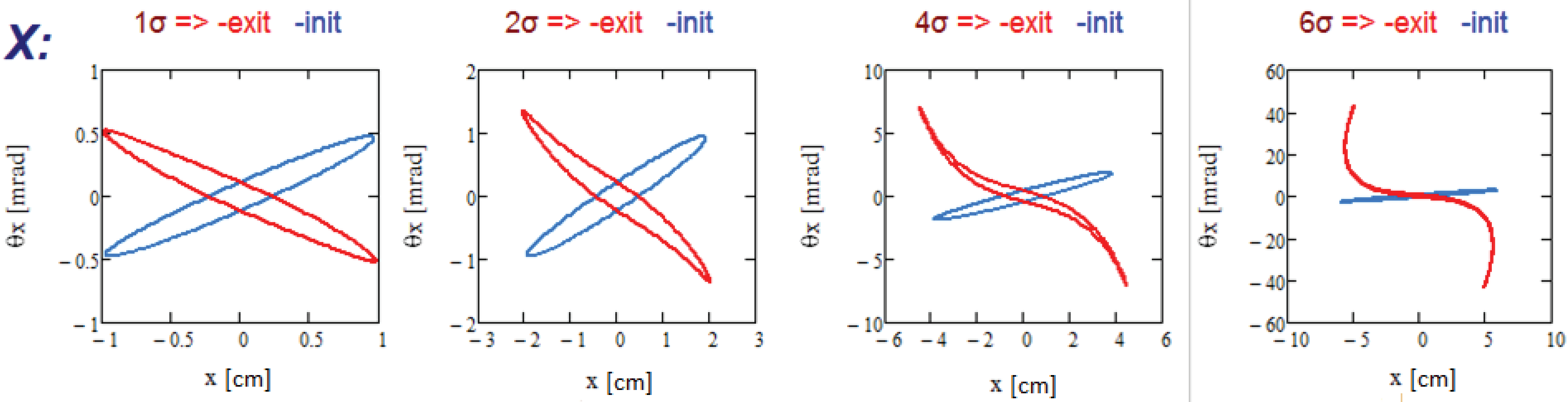
Symmetric (to IP) triplet



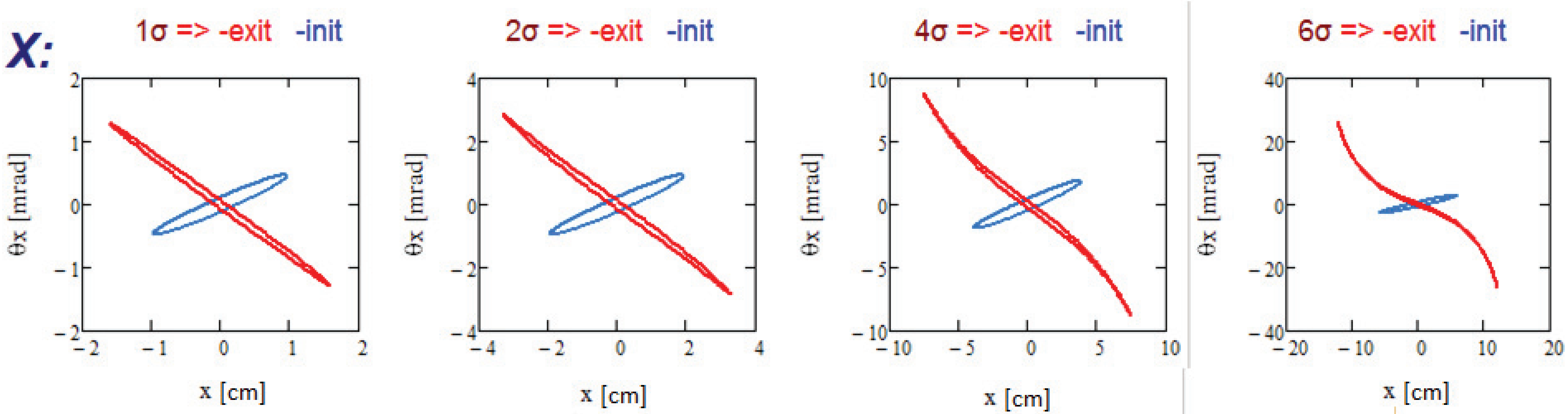
AntiSymmetric (to IP) triplet



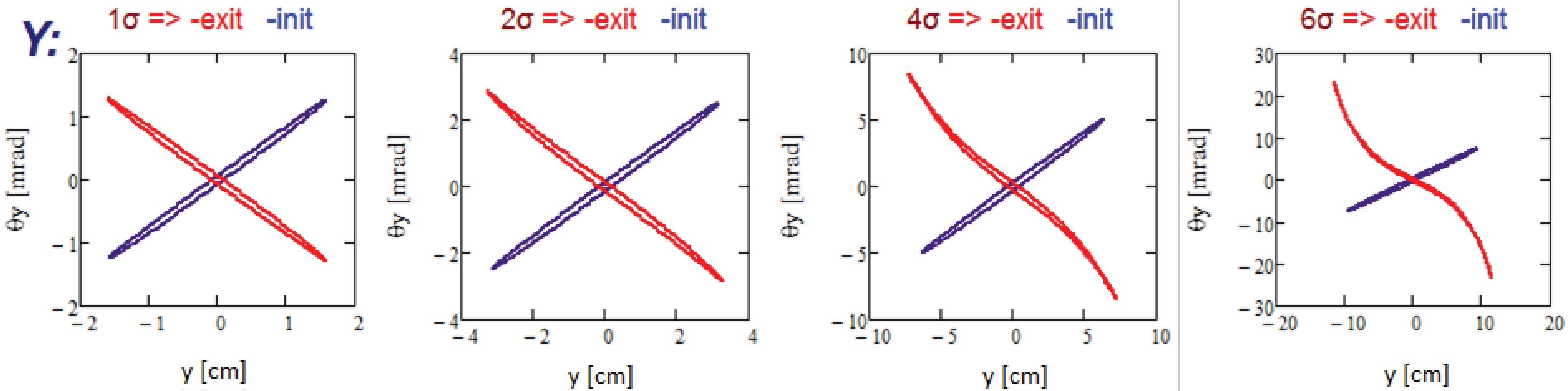
Symmetric



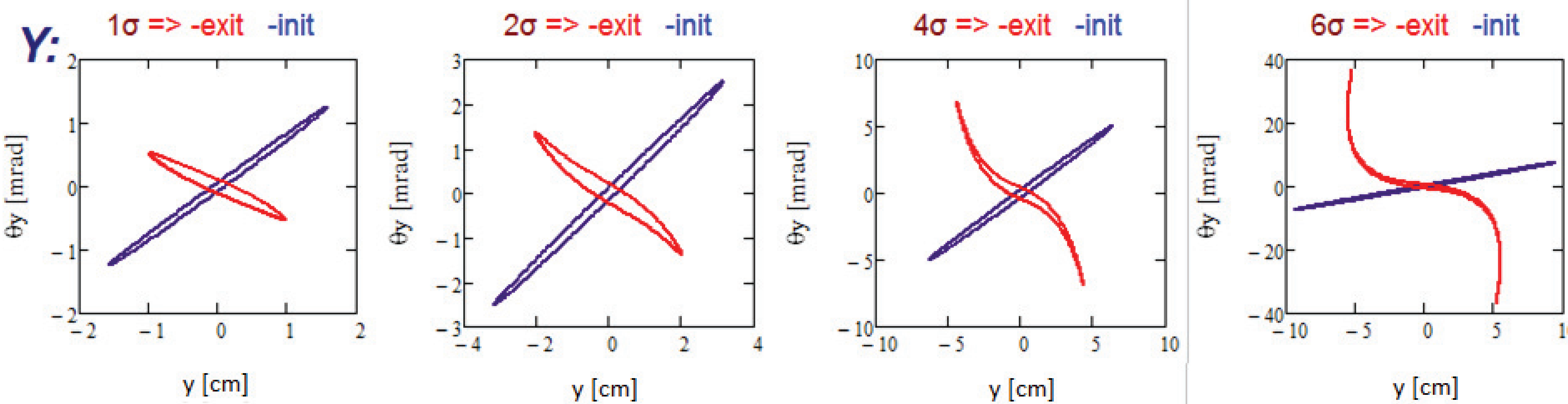
Antisymmetric



Symmetric

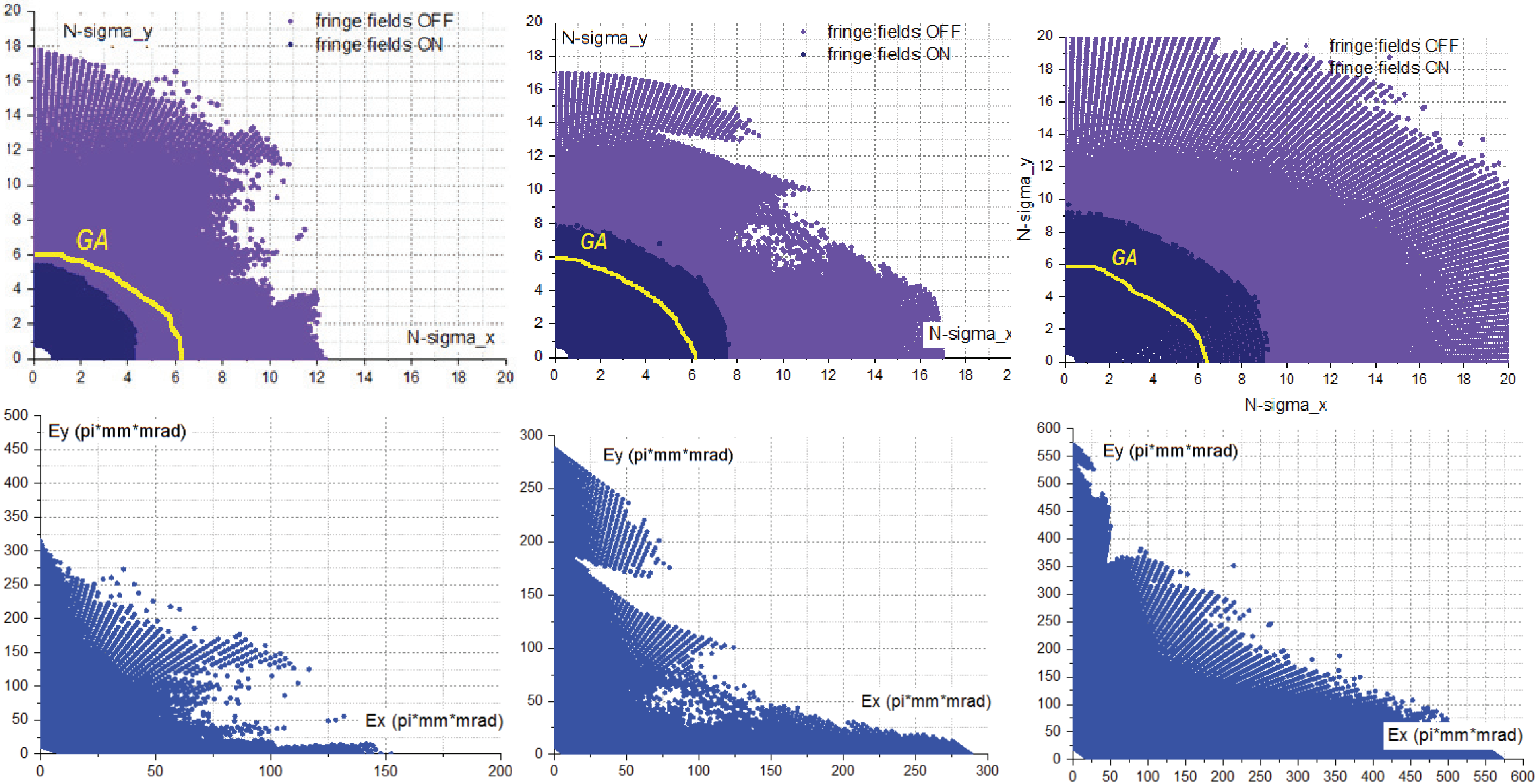


Antisymmetric



Qx=8.44 Qy=9.44

β*=35cm β*=50cm β*=70cm



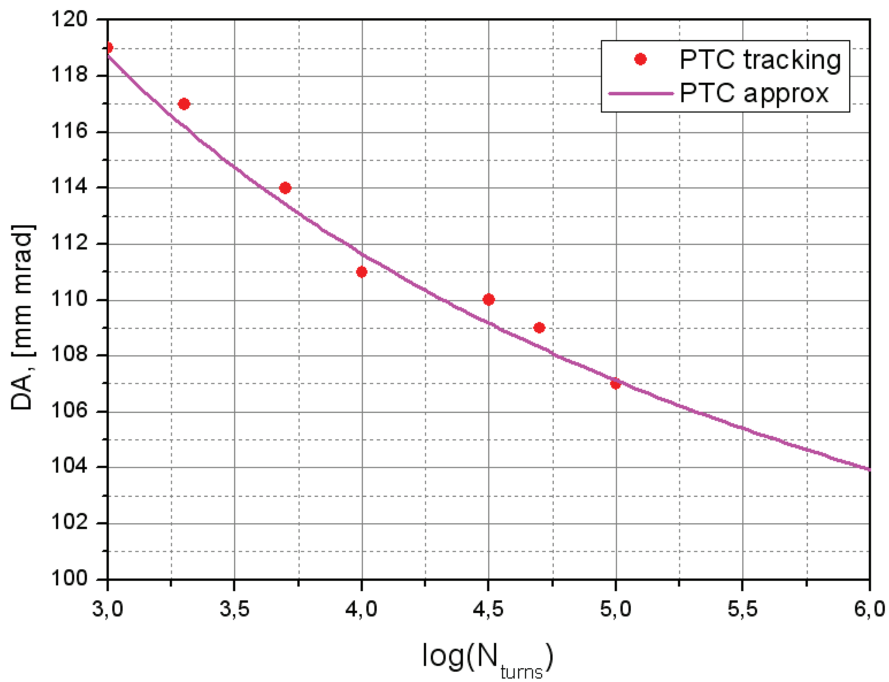
a) b) c)

Asymptotic DA

N=10^6 turns in collider correspond to time T=2 sec,
Experiment performance corresponds to T=n*hours.
DA approximation based on numerical results (M. Giovannozzi):

$$\sqrt{D(N)} = \sqrt{D_\infty}\left(1 + \frac{b}{[log(N)]^k}\right)$$

D_∞ - asymptotic DA, b,k-parameters obtained from fitting D(N).



D(∞)=80 pi мм мрад
b=0.44
K=0.65

Conclusions

- Collider lattices with the circumference of 503m and 12FODO cells in bending arcs are considered;
- Collider optic structure are checked for the following Working Points:
  Qx/Qy=9.44/9.44 (project values),
  Qx/Qy=8.44/9.44, Qx/Qy=8.10/9.10,
  β@IP = 0.35, 0.5, 0.7, 1.0m ;
  Global tunes are arranged by quadrupoles in arcs.
- Fringe Fields of the magnetic elements show severe influence on DA;
- DA calculations show that Fringe Field effects could be corrected or compensated by tuning the Ring: optics Qx/Qy=8.44/9.44, with more or less optimal Chrom. Correction scheme, Beta*=0.6m gives DA=2GA=80pi mm mrad. L(beta*=0.60m)/L(beta*=0.35m)=0.74 ;
- DA correction study with Octupoles in FFQ shows (preliminary) the effect of DA increase.

Thank you for your attention !