Status of Novosibirsk SCTF

A.Bogomyagkov (BINP)

IAS Program on High Energy Physics
18-21 January 2021

History of SCTF in Novosibirsk: 1995

- $E_{cm} = 700 - 2500$ MeV
- Round beams
  $L = 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Monochromatization
  $L = 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Longitudinal polarization
  $L \approx 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Transverse polarization for precise energy calibration

SCTF 2006 - 2011

- $E_{cm} = 2 - 5$ GeV
- Crab Waist collision
- Peak luminosity at 2 GeV of $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Longitudinal polarization of electron beam
- No transverse polarization. Energy calibration by Compton backscattering ($\sim 3 \times 10^{-5}$)
- Symmetric beam energy at collision
- No collision monochromatization
- Positron production rate $\geq 1 \times 10^{11}\mathrm{e}^{+}/\mathrm{s}$

A PROJECT OF

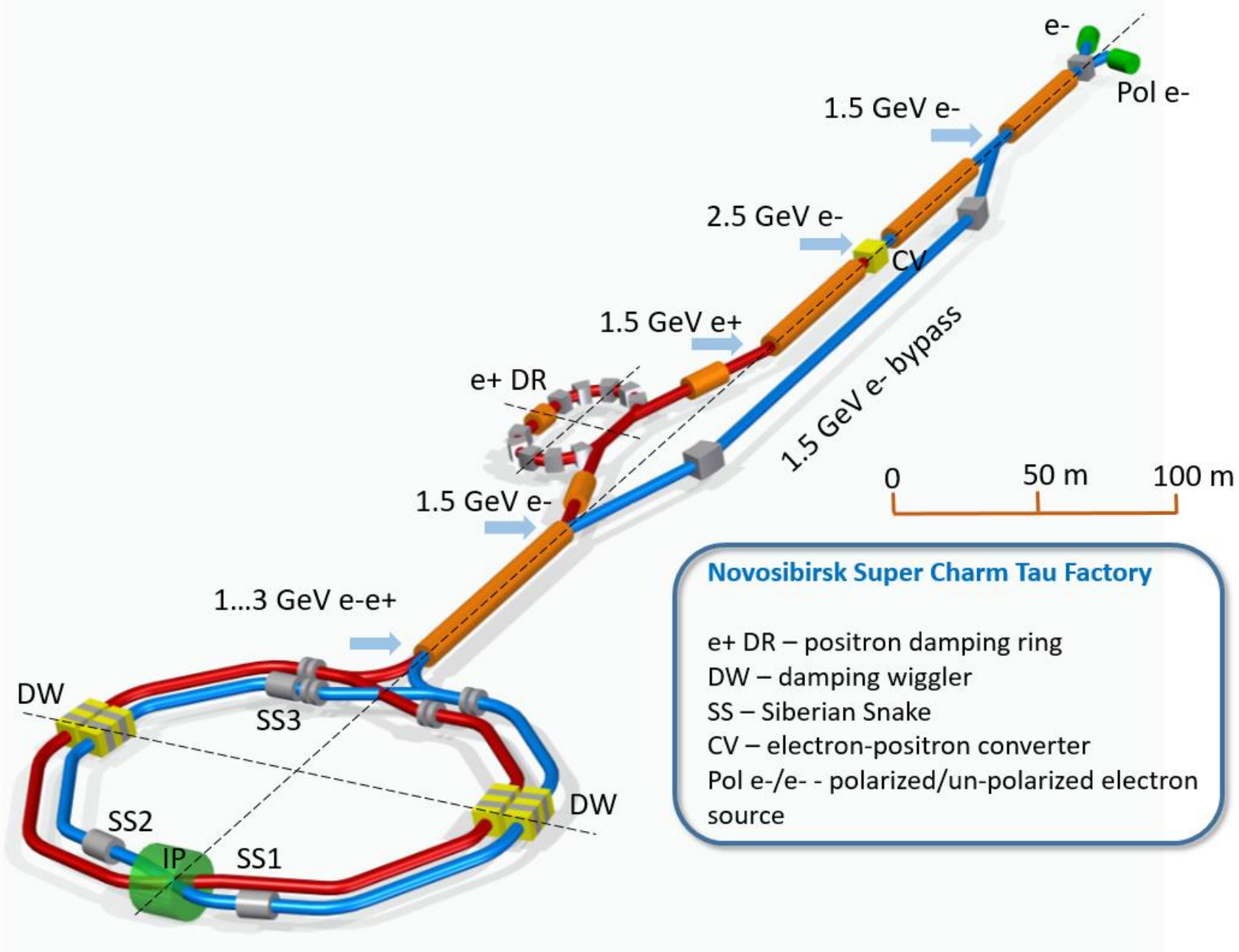
SUPER C-τ FACTORY

IN NOVOSIBIRSK

Budker Institute of Nuclear Physics

Novosibirsk - 2011

The whole facility



SCTF 2006 - 2011

Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	780 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	30/30/15 ms			
Bunch length	16 mm	11 mm	10 mm	10 mm
Energy spread				
Momentum compaction	$1.00 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$
Synchrotron tune	0.007	0.010	0.009	0.008
RF frequency				
Harmonic number	1300			
Particles in bunch	$7 \cdot 10^{10}$			
Number of bunches				
Bunch current	4.4 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.15	0.15	0.12	0.095
Luminosity	$0.63 \cdot 10^{35}$	$0.95 \cdot 10^{35}$	$1.00 \cdot 10^{35}$	$1.00 \cdot 10^{35}$

Unrealisticly strong wigglers

L*=0.6 too smal

Insufficient DA with CRAB sextupole ON

IP: β_y=0.8 mm, β_x=40 mm

Official Status

- SCTF was approved by Russian Government as one of the six mega-science projects.
- The Government requested final documents by the end of 2019 for the project financing.
- Preliminary Design Report, Conceptual Design Report, Civil Construction Design Report and Road Map are ready.
- SCTF officially supported by ECFA.
- European Commission Expert Group has supported SCTF (Russian Mega Science projects – evaluation of the potential for cooperation with Europe Experts meeting in Brussels 19 June 2013).
- MoUs with CERN, KEK, INFN, JINR, John Adams Institute, etc. are signed.

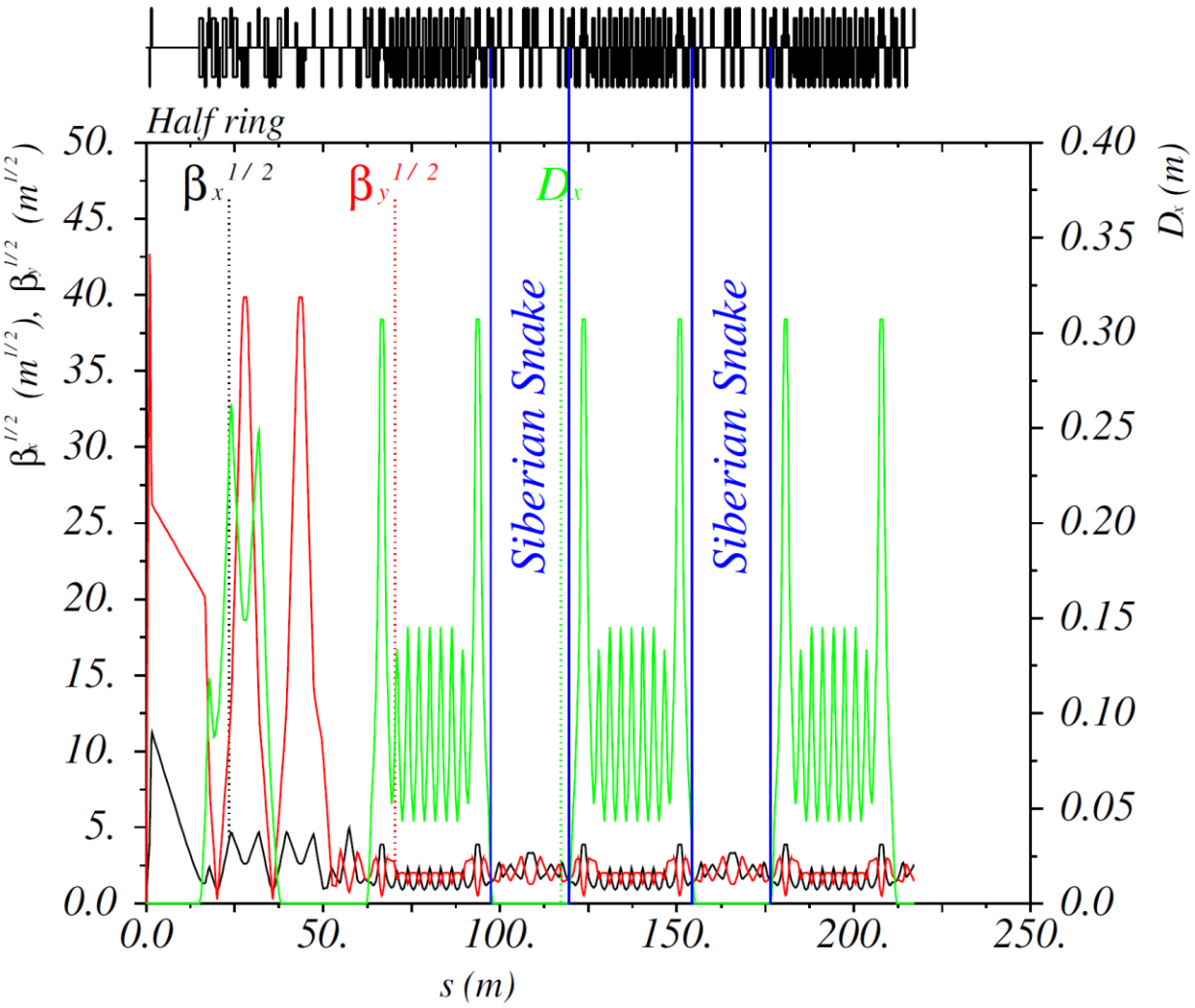
Never received funding

Progress continues

Super KEKB experience, new projects (FCC-ee, CEPC, HIEPA) with well developed light source technology give a basis for improvement of Novosibirsk SCTF performance.

- Beam energy increase at least up to 3 GeV
- Realistic design of the FF/MDI area $L^* = 0.6\ \mathrm{m} \rightarrow 0.9\ \mathrm{m}$
- 3d design of FF lens
- Short chromatic correction section (designed by Katsunobu Oide for FCC-ee)
- Damping wigglers removal (or reduction of their number)
- Change of parameters to enhance DA
- Realistic design of new injection facility ($2 \times 10^{11}\ e^+/s$)

SCTF 2018

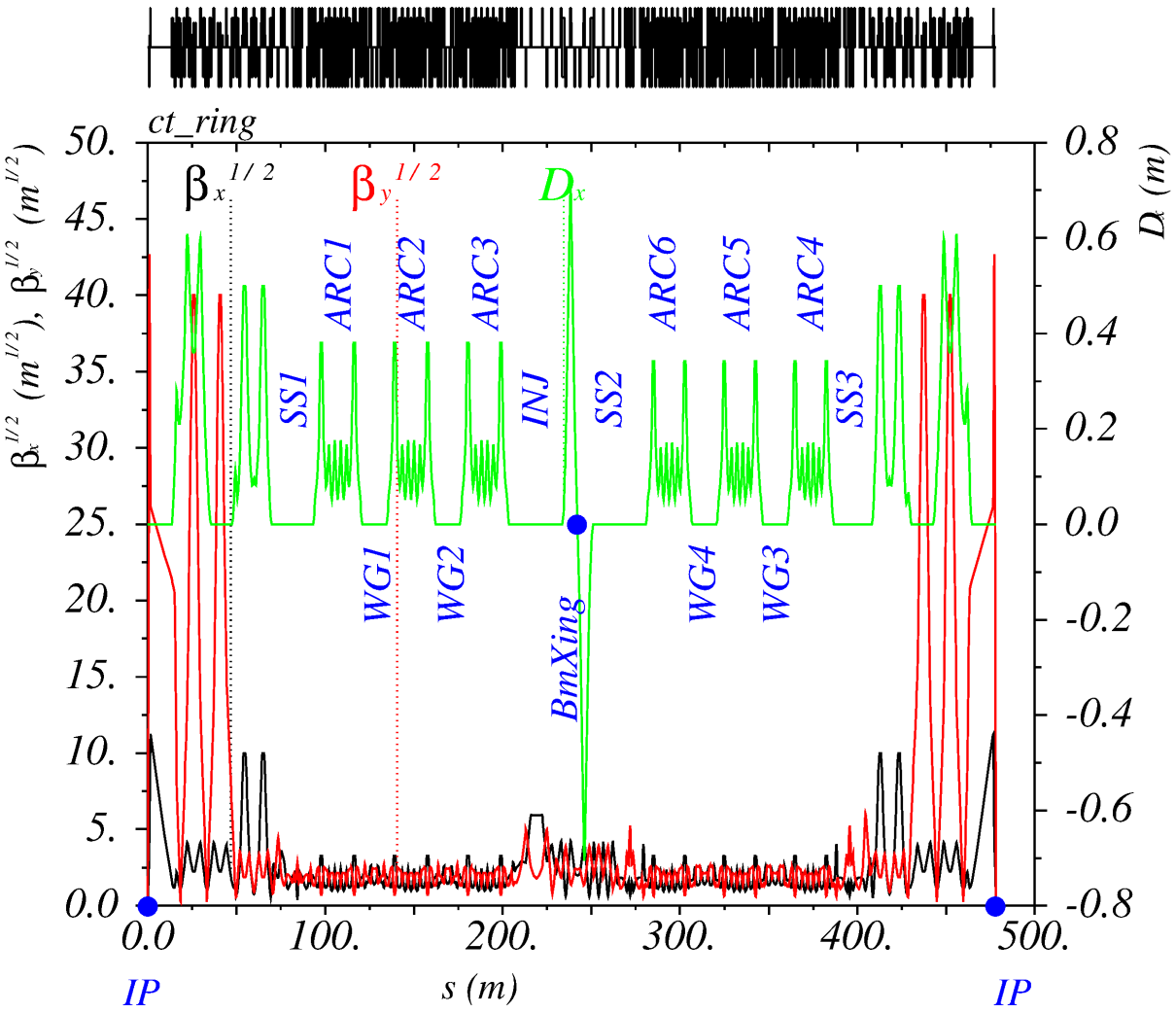


K.Oide's type of Interaction Region
6 HMBA cells in the arcs

E (MeV)	1000*)	1000	2000	3000
Π (m)	522.665			
F_{RF} (MHz)	351.034			
q	612			
θ (mrad)	±30			
$N_{e/bunch}\times10^{10}$	5.5	7	6.7	9
N_b	440	360	360	270
U_0 (keV)	11	11	176	894
V_{RF} (kV)	700	700	700	1600
$\nu_s\times10^{-3}$	6.1	6.1	4.3	4.9
δ_{RF} (%)	3.5	3.5	2	1.7
$\sigma_E\times10^{-3}$	0.3/2	0.3/1.8	0.6/0.93	0.93/0.96
σ_s (mm)	3.2/13	3.2/11	6.7/10	8.8/9.1
ε_x (nm)	0.5/10	0.5/15	2.1/4.3	4.8/5/0
$L_{HG}\times10^{35}$ ($cm^{-2}s^{-1}$)	0.9	0.7	2	2.8
HG (%)	78	73	86	85
$\xi_x\times10^{-3}$	5.8	4.3	4.2	4.6
ξ_y	0.12	0.1	0.12	0.11
ϕ	15	15	20	17
τ_L (s)	1900	2600	830	620

Insufficient momentum acceptance with CRAB sextupole ON

SCTF 2019



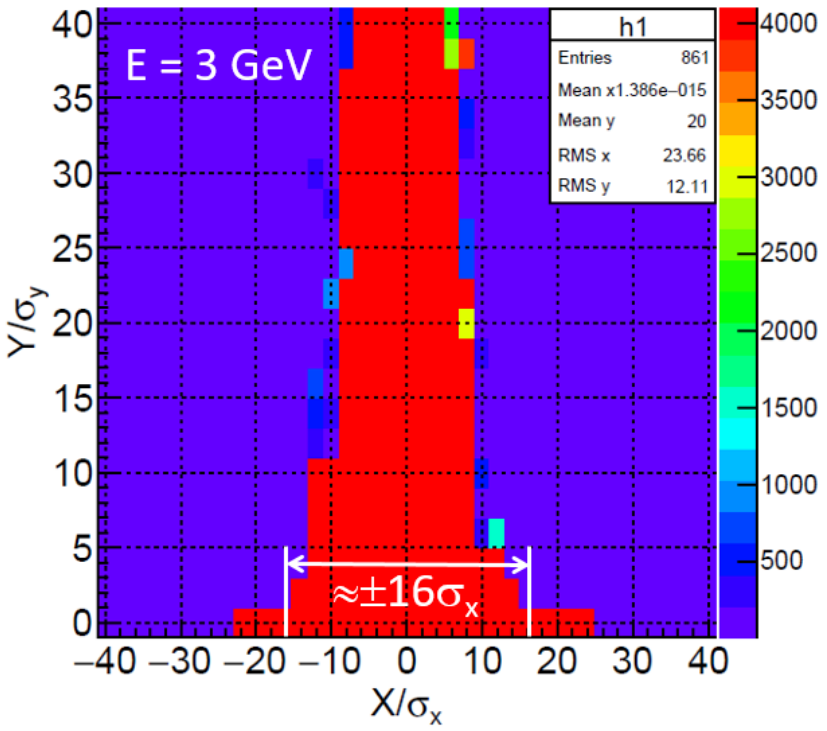
K.Oide's type of Interaction Region + CCSX

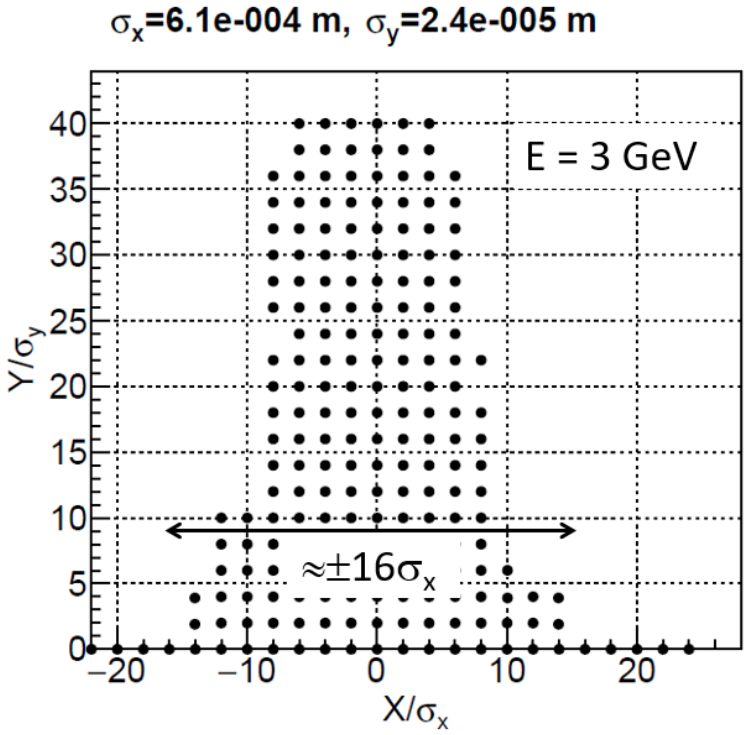
6 HMBA cells in the arcs

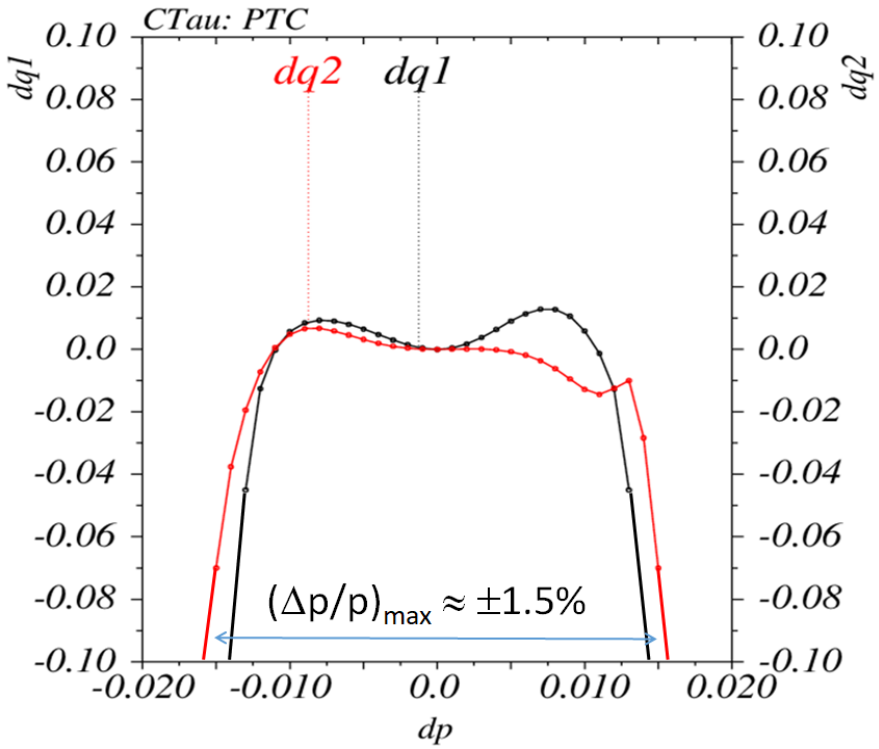
E(MeV)	1000*	1000	1500	2000	3000
Π(m)	478.092				
F_{RF}(MHz)	349.9				
q	558				
2θ(mrad)	60				
κ (%)	0.5				
β_x^*(mm)	50				
β_y^*(mm)	0.5				
I(A)	1	1	2.2	2.2	2
$N_{e/bunch} \times 10^{-10}$	2.1	2.1	4.5	5.2	7
N_b	500	500	490	420	290
U_0(keV)	11.7	11.7	59.3	187.4	948
V_{RF}(kV)	1000	1000	600	1000	2000
ν_s	0.0093	0.0093	0.0059	0.0065	0.0072
δ_{RF}(%)	3.4	3.4	2	2	1.7
$\sigma_e \times 10^3$	1	1.2	0.9	0.8	9.6
σ_s(mm)	7.9	9.5	11	8.8	10
ε_x(nm) with IBS	11.3	16.3	8.8	7	10.9
$L_{HG} \times 10^{-35}(cm^{-2}s^{-1})$	0.21	0.14	0.8	1.3	1.1
HG (%)	76	72	79	82	77
ξ_x	0.0042	0.0029	0.0031	0.0042	0.003
ξ_y	0.06	0.04	0.07	0.085	0.054
φ	10	10	16	14	13
τ_L (s)	3245	4968	1803	1080	1197

History of SCTF in Novosibirsk: 2019

$$\varepsilon_x = 10.7\ nm, \sigma_\delta = 1 \times 10^{-3}$$







Sufficient on momentum DA with CRAB sextupole ON
Better, but still not enough off momentum DA
Small number of sextupoles

Parameters 2020

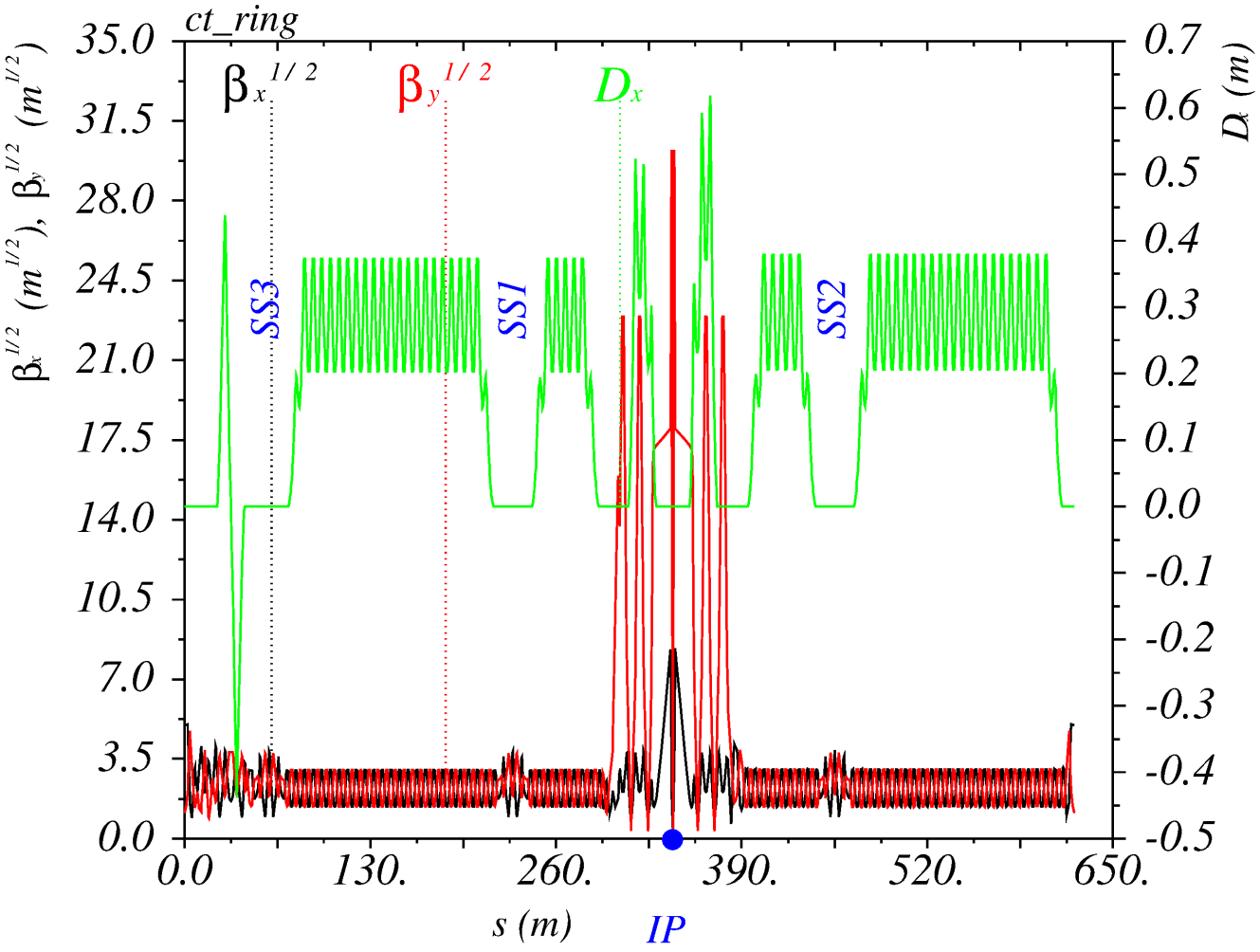
- Minimal energy increased to $E_{beam} = 1.5$ GeV
  - Relaxed lattice
  - $E_{beam} < 1.5$ GeV is possible, but not priority
- Increased, $\begin{cases} \beta_y^* = 0.5 \rightarrow 1mm \\ \beta_x^* = 5 \rightarrow 10cm \end{cases}$
- K.Oide's type of Interaction Region
- FODO 90° cells in the arcs
  - weaker sextupoles
  - more sextupoles

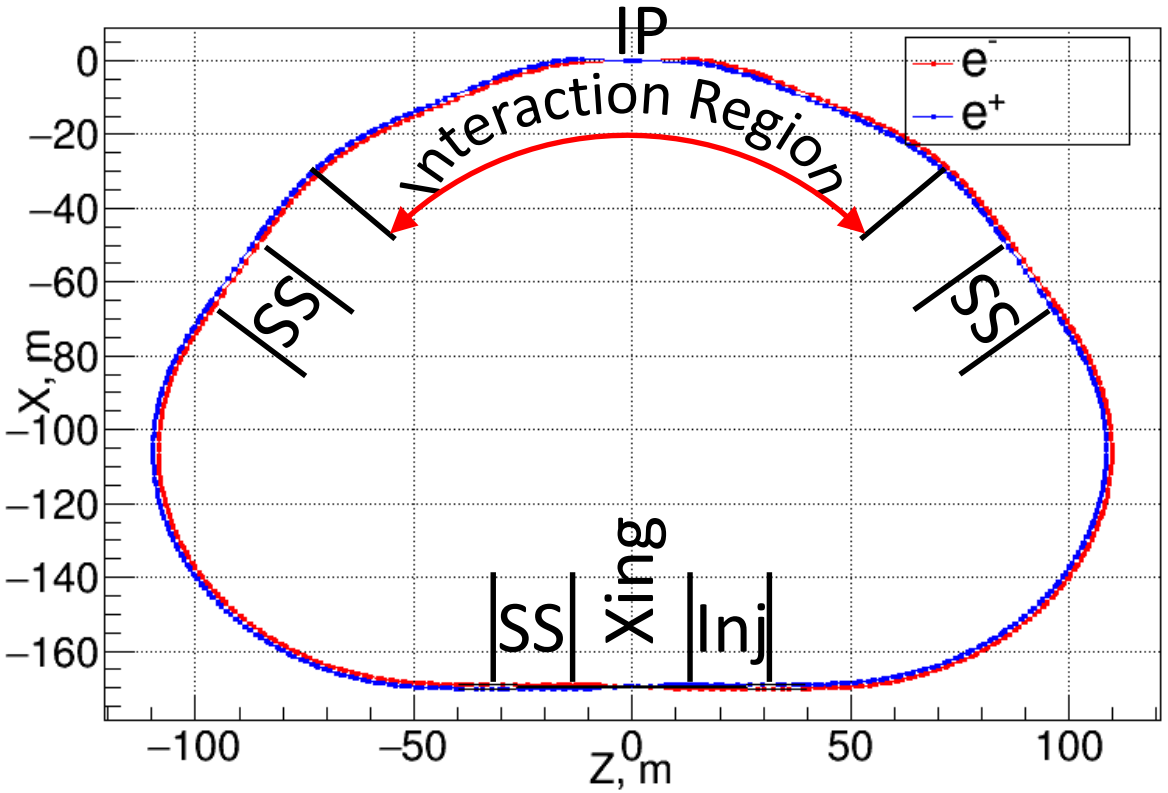
E(MeV)	1500	2000	3000
Π(m)	622.712		
F_{RF}(MHz)	350		
q	727		
2θ(mrad)	60		
$\varepsilon_y/\varepsilon_x$(%)	0.5		
β_x^*(mm)	100		
β_y^*(mm)	1		
α	2.5×10^3		
I(A)	2	2	2
$N_{e/bunch} \times 10^{-10}$	8	6	10
N_b	323	431	259
U_0(keV)	17	53	270
V_{RF}(kV)	1200	1200	2000
ν_s	0.0153	0.0132	0.0139
δ_{RF}(%)	1.6	1.4	1.4
$\sigma_e \times 10^3$ (SR/IBS)	0.27/0.9	0.4/0.7	0.5/0.6
σ_s(mm) (SR/IBS)	4/15	7/12.6	10/11
ε_x(nm) (SR/IBS)	3/22	6/12.8	12/13.7
$L_{HG} \times 10^{-35}(cm^{-2}s^{-1})$	0.4	0.5	1
ξ_x	0.005	0.005	0.007
ξ_y	0.08	0.072	0.09
τ_{Touschek} (s)	2800	2000	2600
τ_L (s)	4200	3200	1731

FODO cell comparison by detuning ($x_0 = 20\sigma_x, y_0 = 20\sigma_y$)

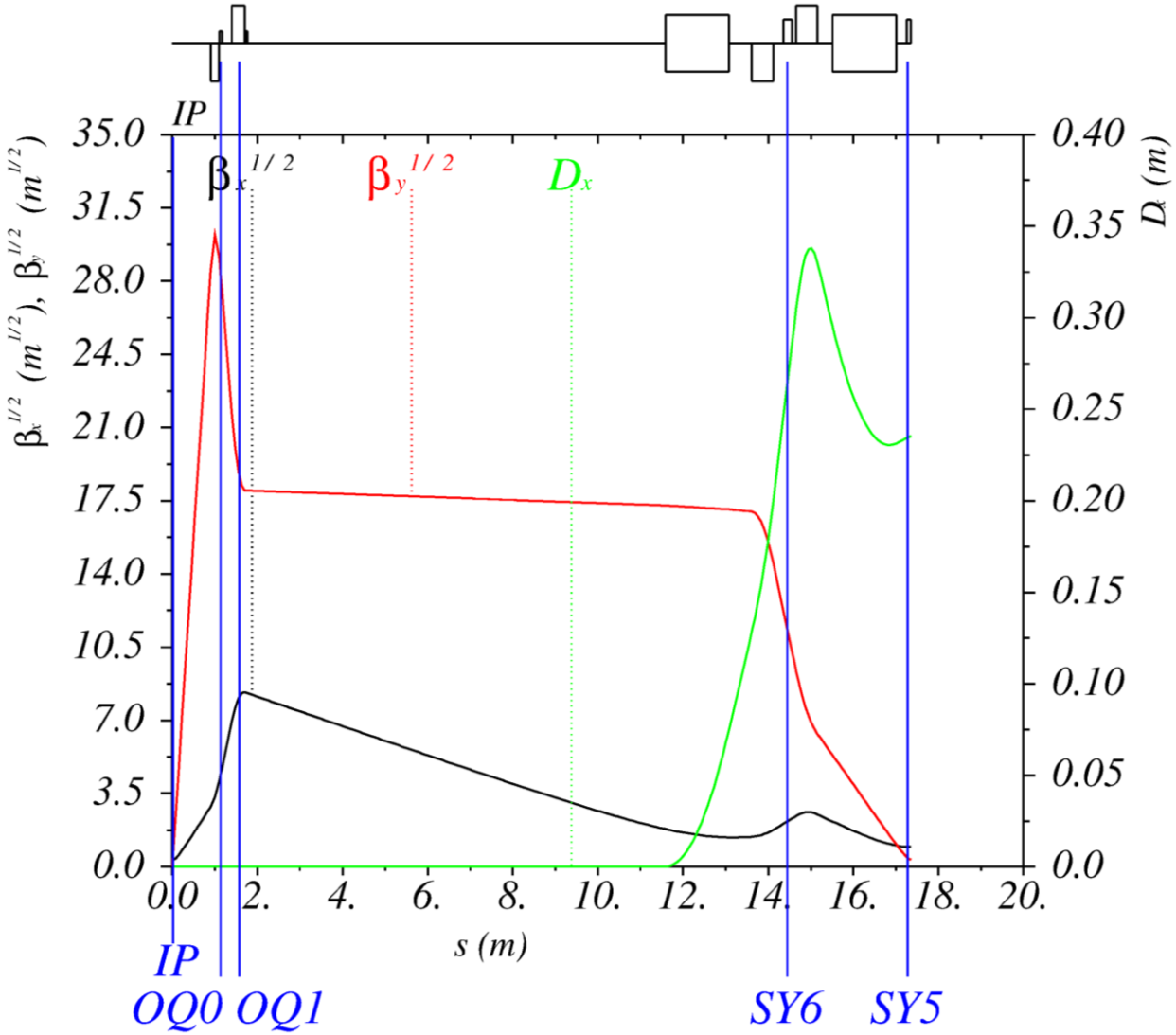
Lattice	Save/6	Save/8	Save/9
Cell μ_x/μ_y	$\frac{3}{4}\pi / \frac{1}{4}\pi$	$\frac{1}{2}\pi / \frac{1}{2}\pi$	$\frac{1}{2}\pi / \frac{1}{2}\pi$
N_{cell} per arc	16	20	20
E, GeV		1.75	
β_x^*/β_y^* (mm)	100 / 2	100 / 2	100 / 1
ε_x (m)	8.9×10^{-9}	11×10^{-9}	11×10^{-9}
$\Delta\nu_{xx}$ $\Delta\nu_{yx}$ $\Delta\nu_{xy}$ $\Delta\nu_{yy}$	$\Delta\nu_{\alpha\beta} = \frac{\partial\nu_\alpha}{\partial j_\beta} j_\beta$		
FRINGE OFF	9.2×10^{-4} 2.5×10^{-3} 1.3×10^{-5} 3.0×10^{-4}	1.1×10^{-3} 3.1×10^{-3} 1.6×10^{-5} 3.7×10^{-4}	1.1×10^{-3} 6.2×10^{-3} 3.1×10^{-5} 1.5×10^{-3}
FRINGE ON	6.5×10^{-3} 6.7×10^{-2} 3.3×10^{-4} 3.1×10^{-3}	7.8×10^{-3} 8.3×10^{-2} 4.1×10^{-4} 3.8×10^{-3}	7.8×10^{-3} 1.6×10^{-1} 8.2×10^{-4} 1.5×10^{-2}
+ CRAB ON	6.5×10^{-3} 6.7×10^{-2} 3.3×10^{-4} 3.0×10^{-3}	7.8×10^{-3} 8.3×10^{-2} 4.1×10^{-4} 3.8×10^{-3}	7.8×10^{-3} 1.6×10^{-1} 8.2×10^{-4} 1.5×10^{-2}
+ IR ON	6.5×10^{-3} 6.6×10^{-2} 3.3×10^{-4} 2.8×10^{-3}	7.8×10^{-3} 8.2×10^{-2} 4.1×10^{-4} 3.4×10^{-3}	7.8×10^{-3} 1.6×10^{-1} 8.1×10^{-4} 1.4×10^{-2}
+ ARC Y ON	6.4×10^{-3} 1.0×10^{-1} 5.0×10^{-4} 2.6×10^{-3}	7.5×10^{-3} 8.4×10^{-2} 4.2×10^{-4} 3.4×10^{-3}	7.5×10^{-3} 1.6×10^{-1} 8.2×10^{-4} 1.4×10^{-2}
+ ARC X ON	-7.4×10^{-2} 6.7×10^{-2} 3.3×10^{-4} 3.0×10^{-3}	5.2×10^{-3} 7.8×10^{-2} 3.9×10^{-4} 3.4×10^{-3}	5.0×10^{-3} 1.6×10^{-1} 7.9×10^{-4} 1.4×10^{-2}

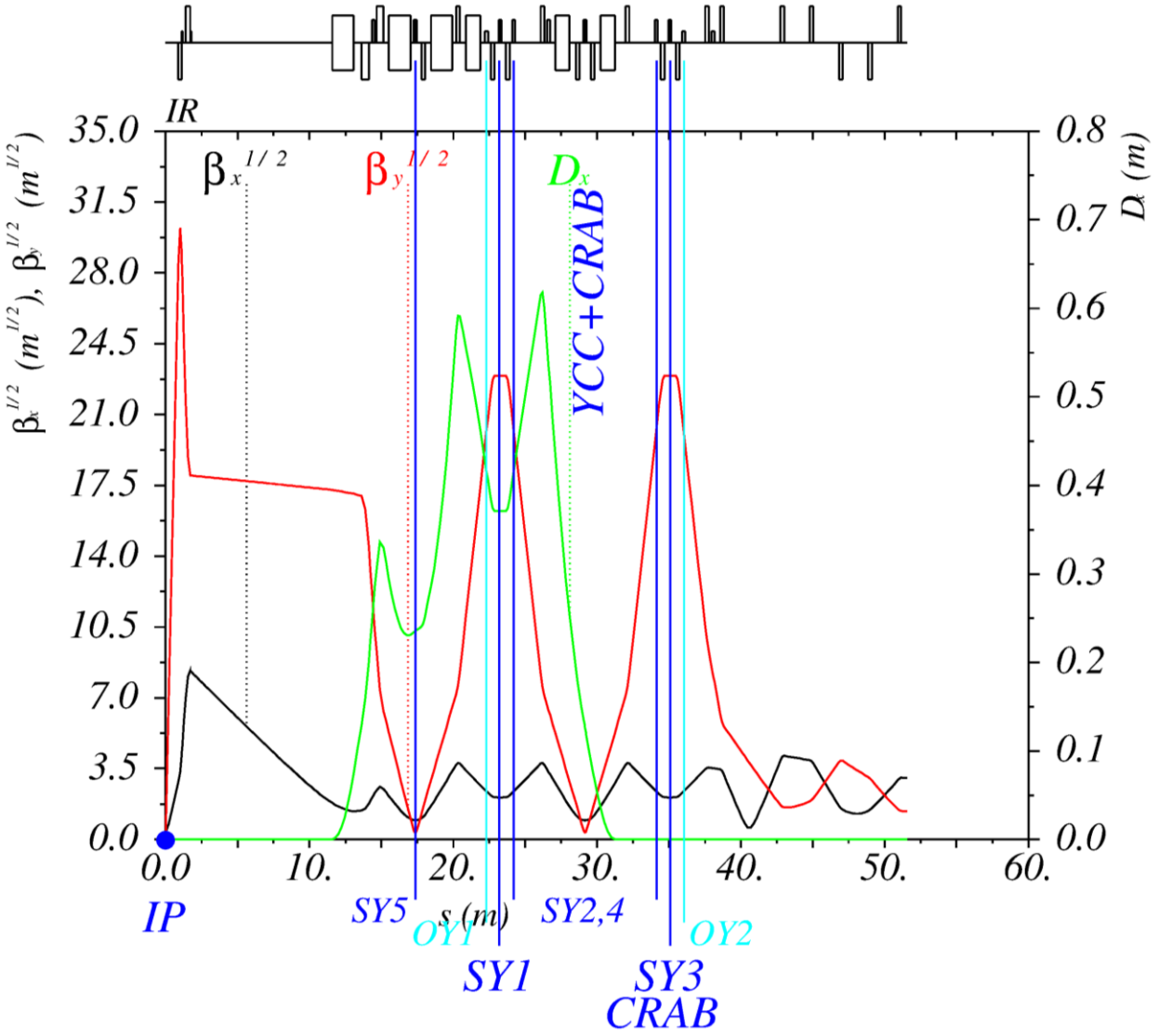
Lattice and layout





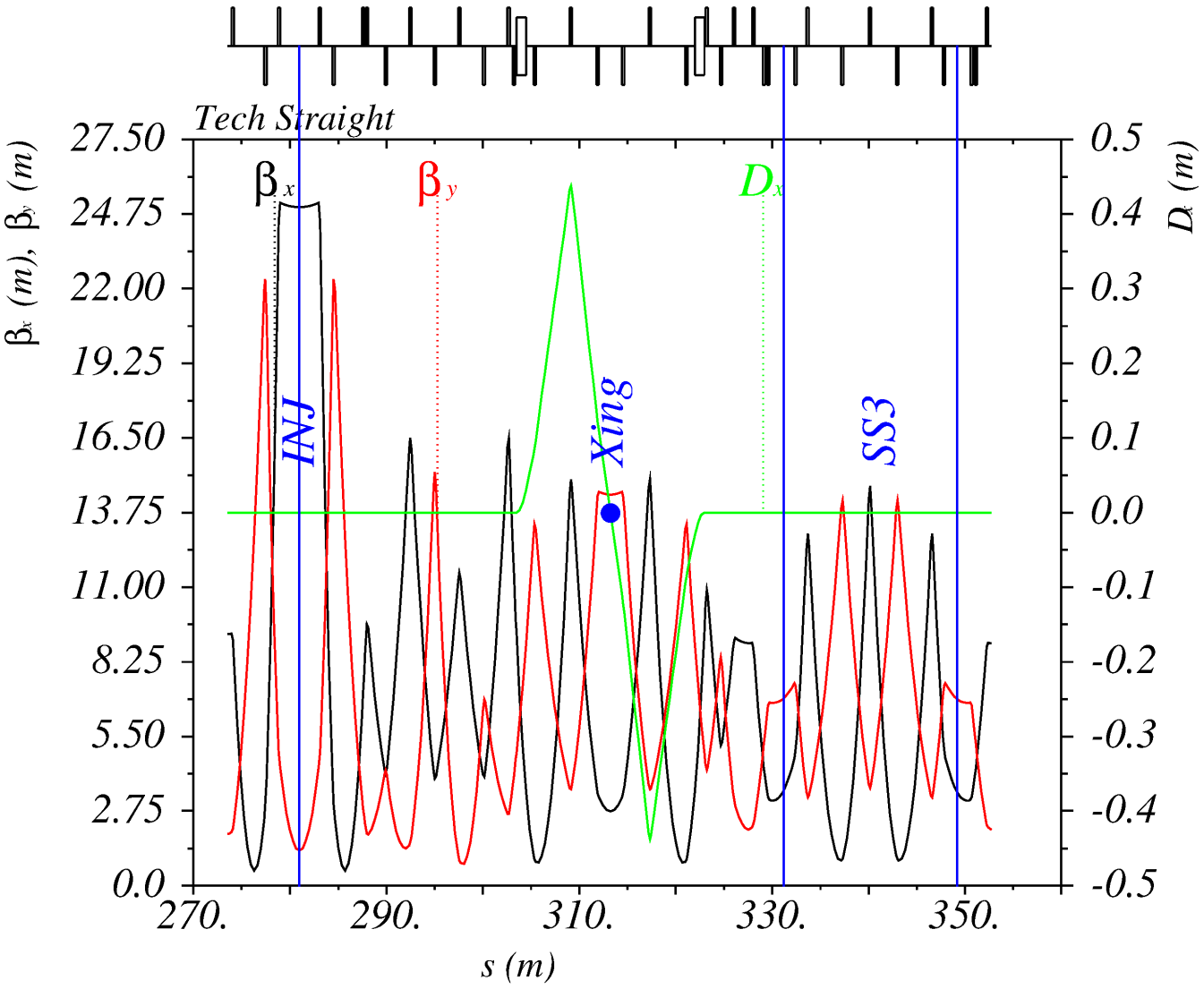
Interaction region



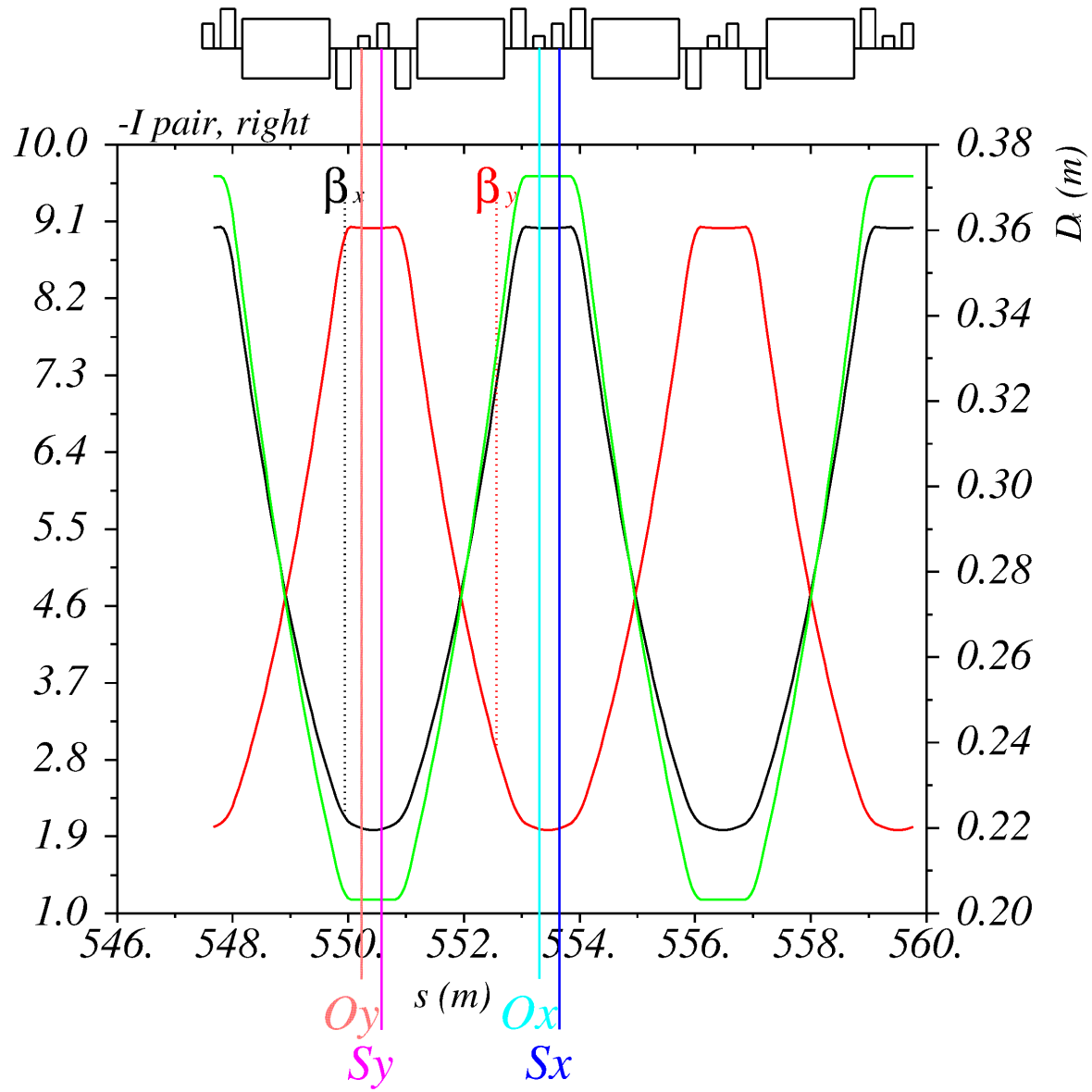


Straight and Arc sections

Straight

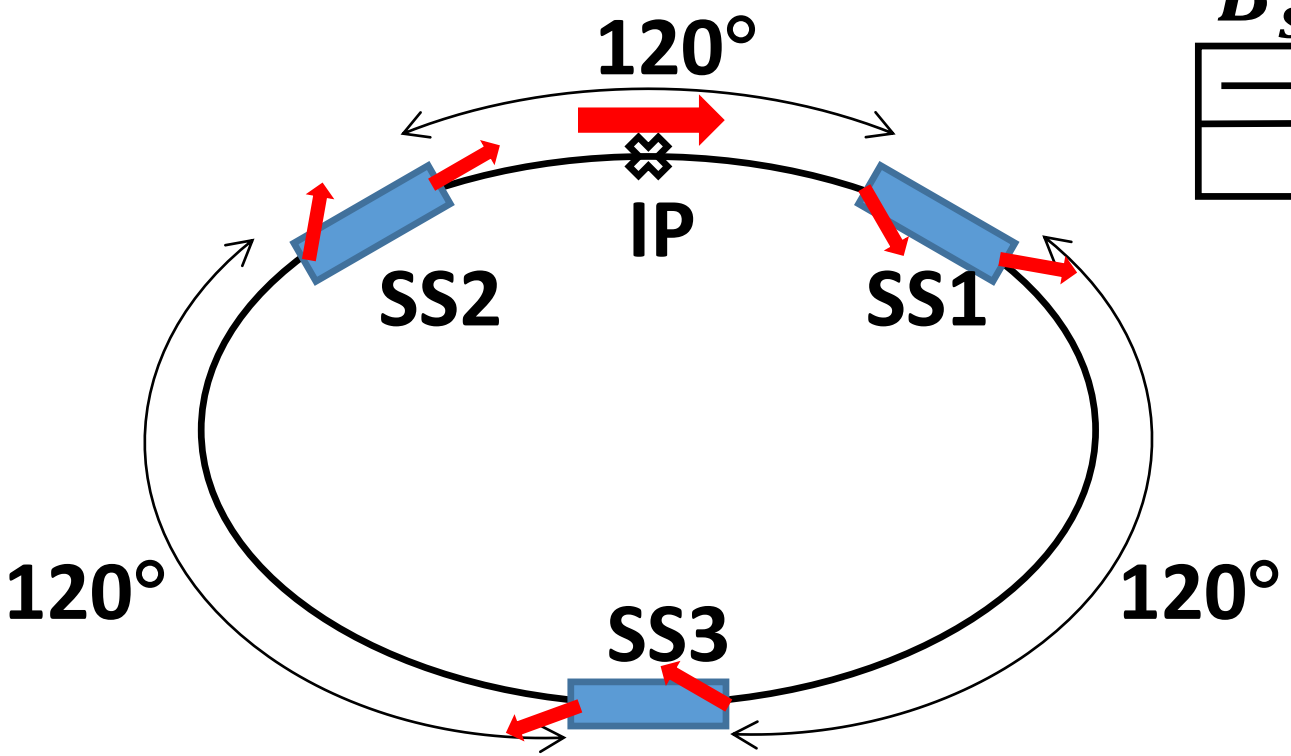


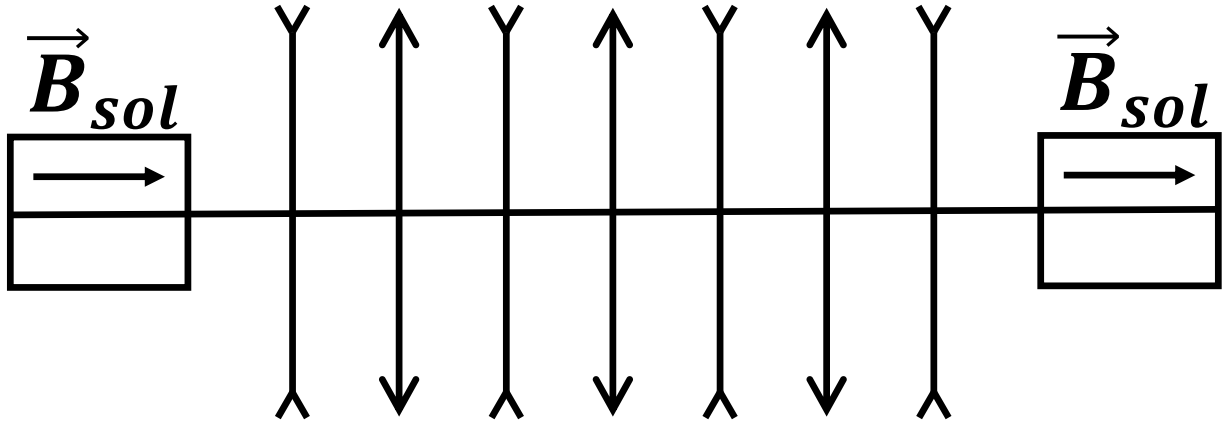
Arc: FODO 90° cells

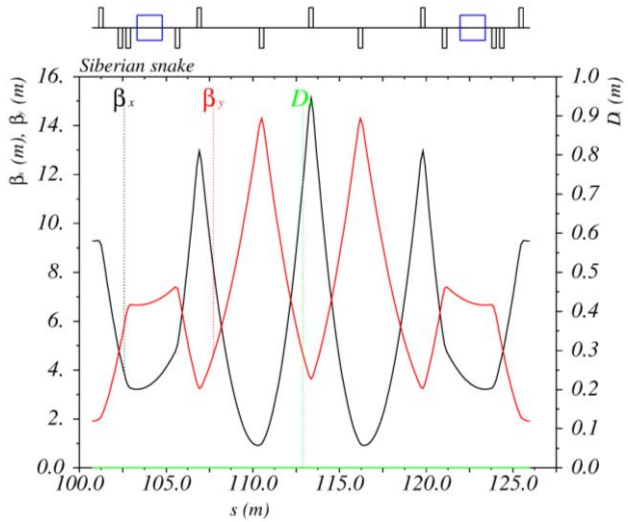


Siberian Snake

The goal is to provide longitudinal polarization at IP



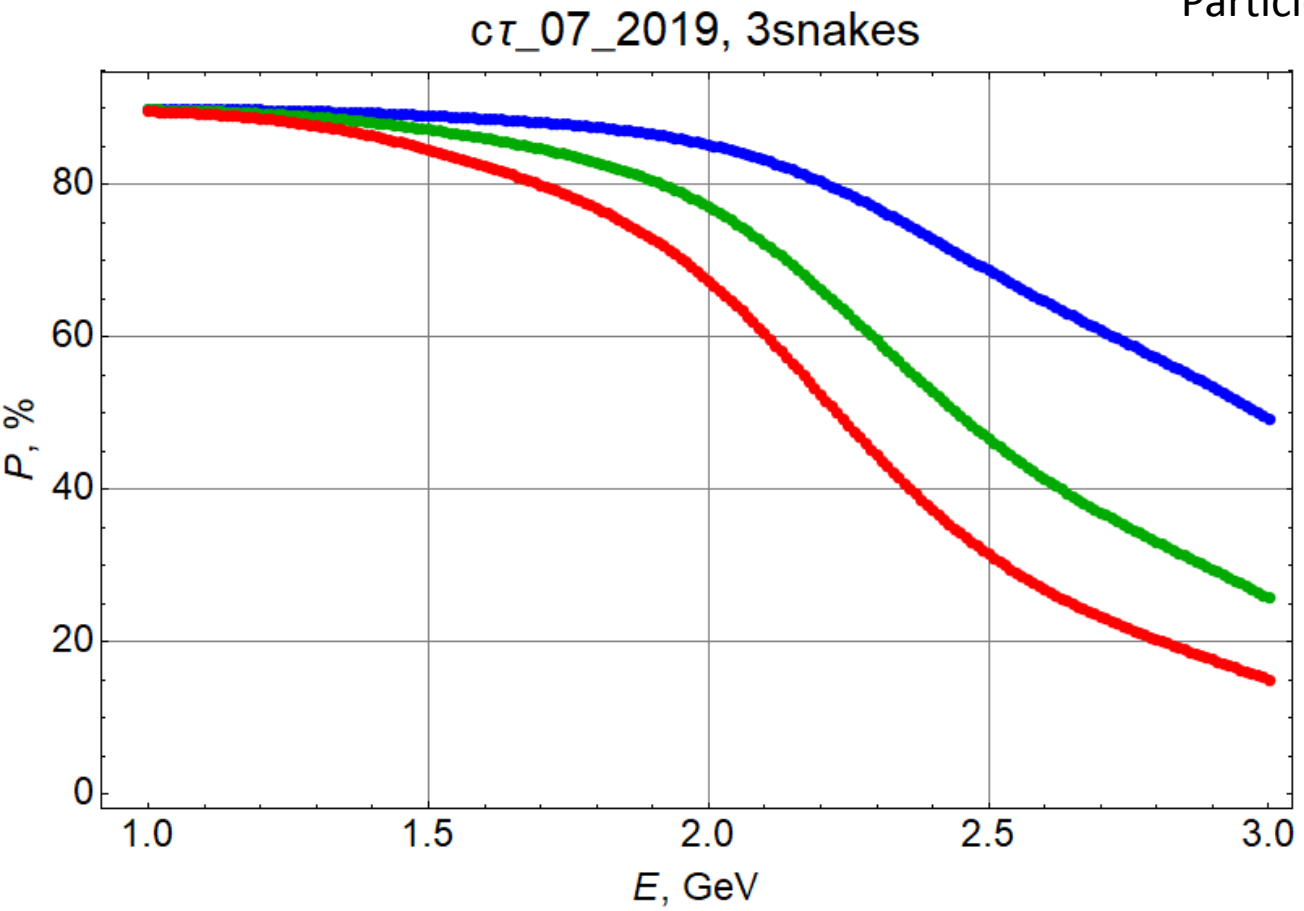




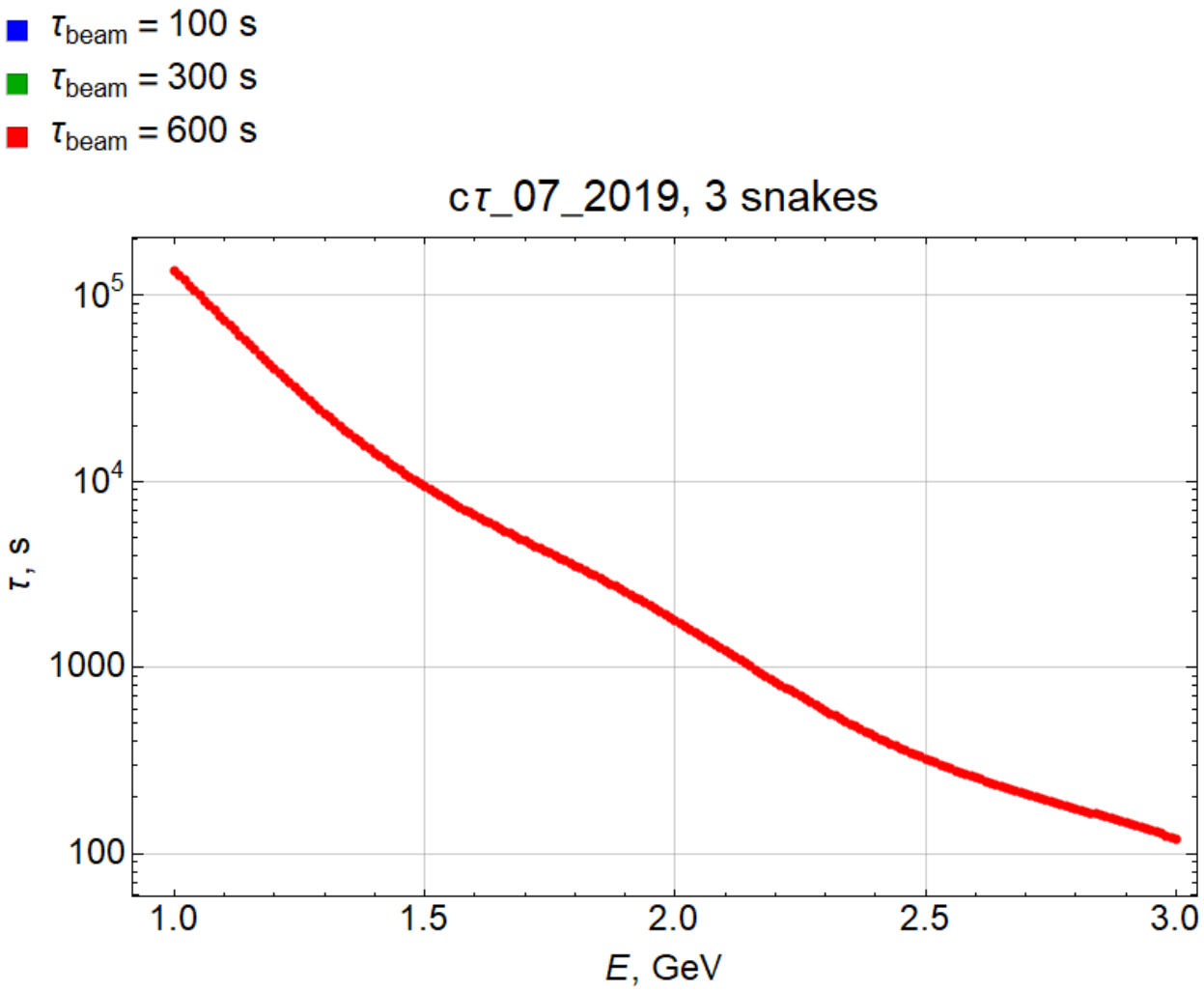
To decouple $R_x = -R_y$, 7 quadrupoles needed

Solenoid spin rotation angle is $\pi/2$ $B_{sol} = 7$ T at $E_{beam} = 3.5$ GeV, $L = 2.6$ m

Longitudinal Polarization (number of snakes)

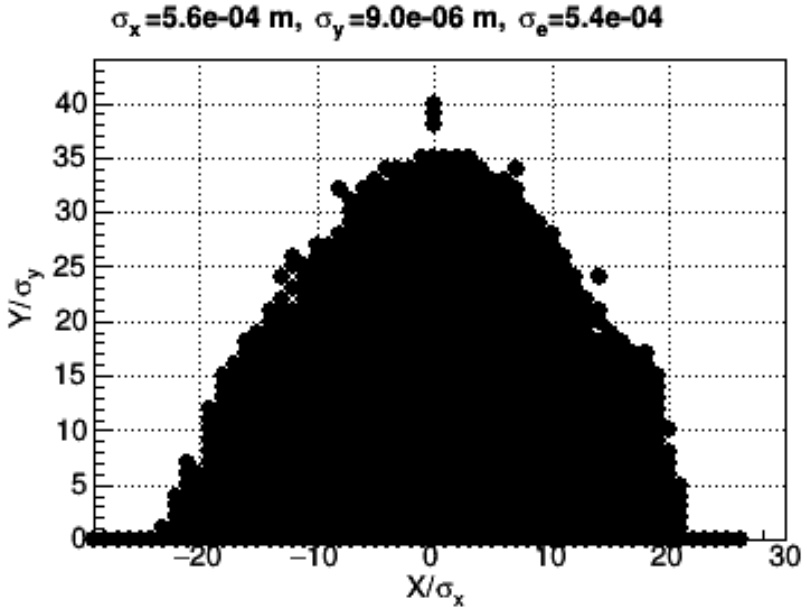


Particle replenishing time



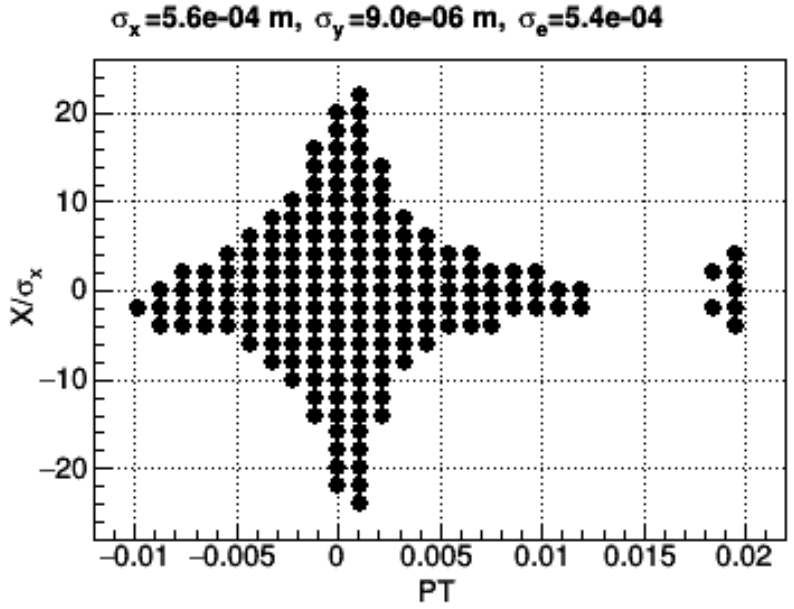
Nonlinear dynamics

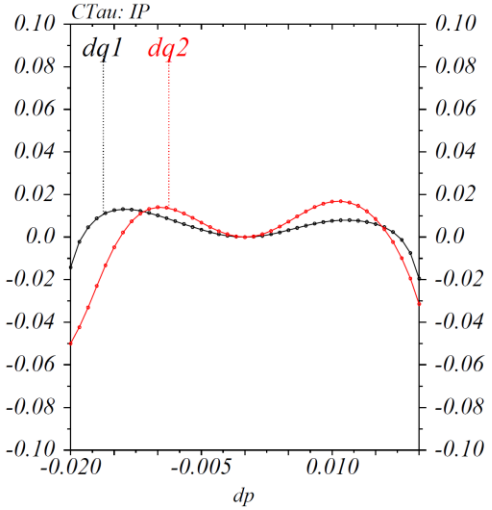
4d, on momentum



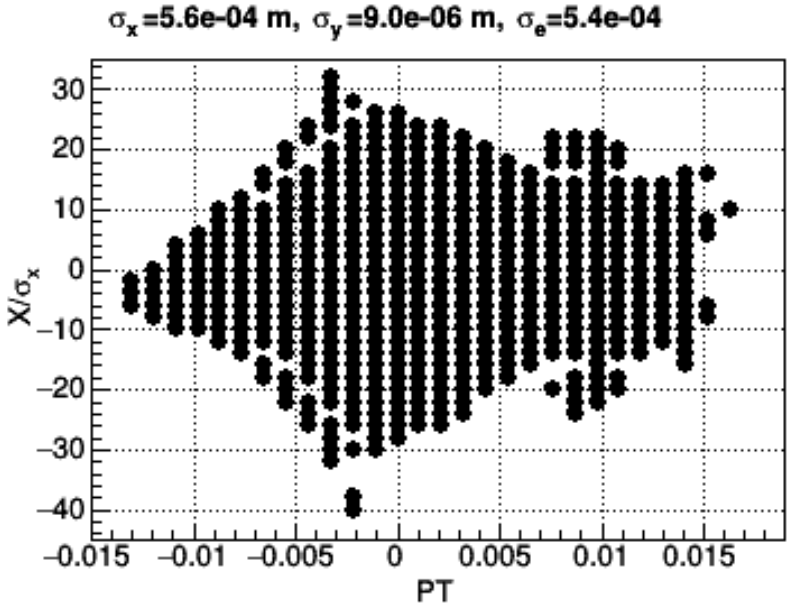
$\varepsilon_x = 12.4\ nm, \sigma_\delta = 0.5 \times 10^{-3}$

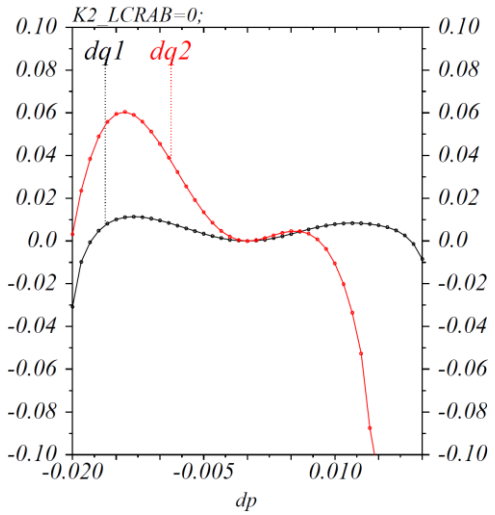
5d, $Y_0 = \sigma_y$, CRAB ON





5d, $Y_0 = \sigma_y$, CRAB OFF

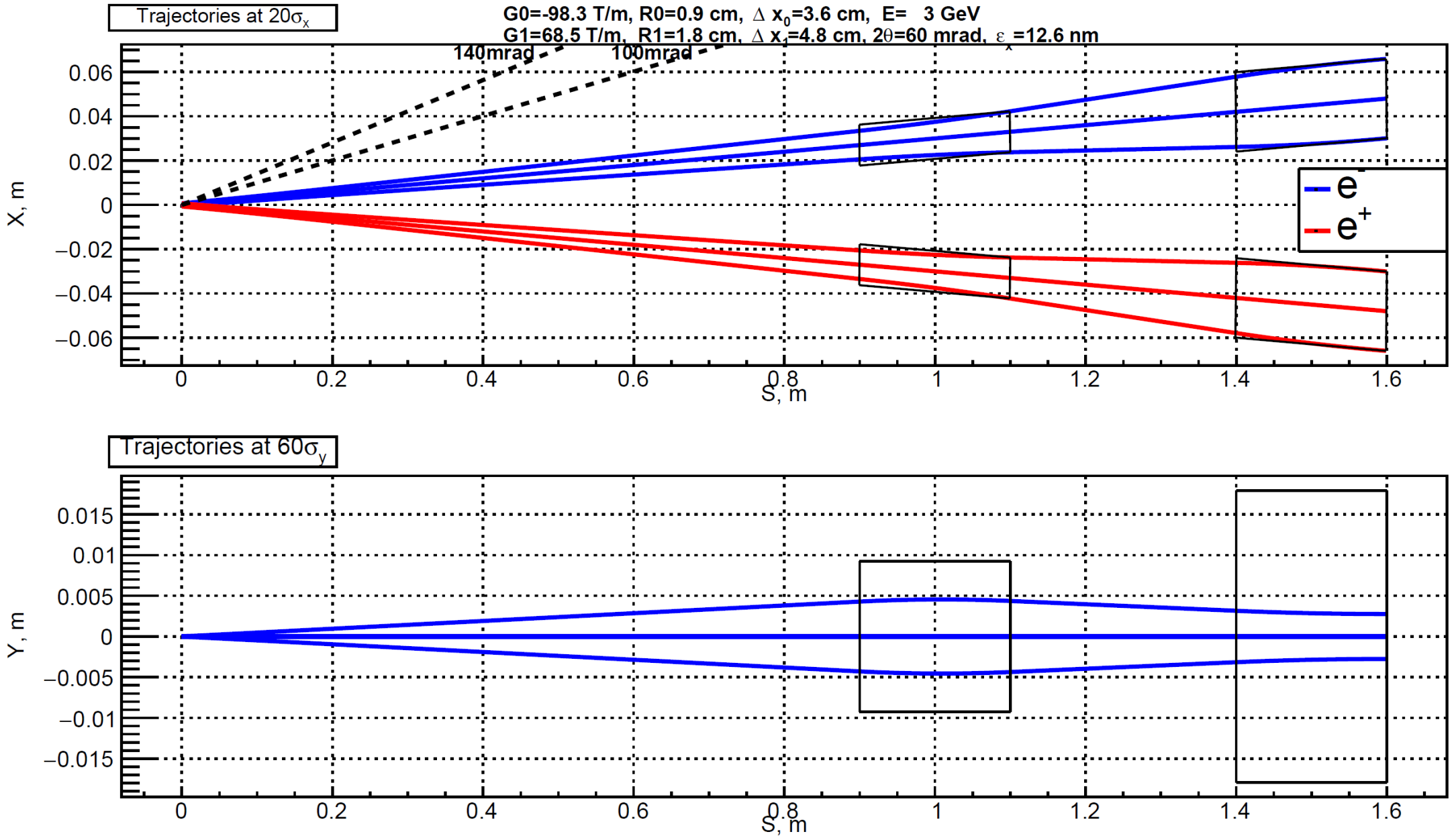




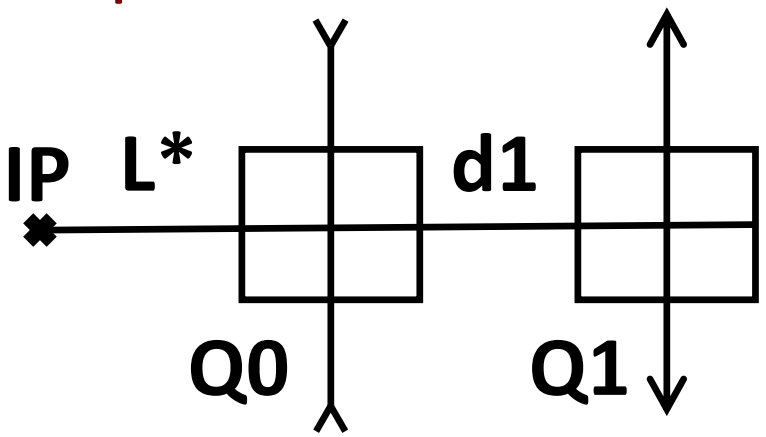
Detuning CRAB ON and OFF ($x_0 = 10\sigma_x, y_0 = 15\sigma_y, \delta = 1.5\%$)

	CRAB ON	CRAB OFF
$\Delta\nu_y = \frac{\partial^2 \nu_y}{\partial j_x \partial \delta} j_x \delta$	3.1×10^{-3}	-4×10^{-5}
$\Delta\nu_y = \frac{\partial^2 \nu_y}{\partial j_y \partial \delta} j_y \delta$	$\mathbf{-2.2 \times 10^{-2}}$	$\mathbf{-1.3 \times 10^{-3}}$
$\Delta\nu_y = \frac{3}{6} \frac{\partial^3 \nu_y}{\partial j_x \partial \delta^2} j_x \delta^2$	$\mathbf{1.18}$	$\mathbf{5.37 \times 10^{-2}}$

Final Focus trajectories



Optimization of the final doublet



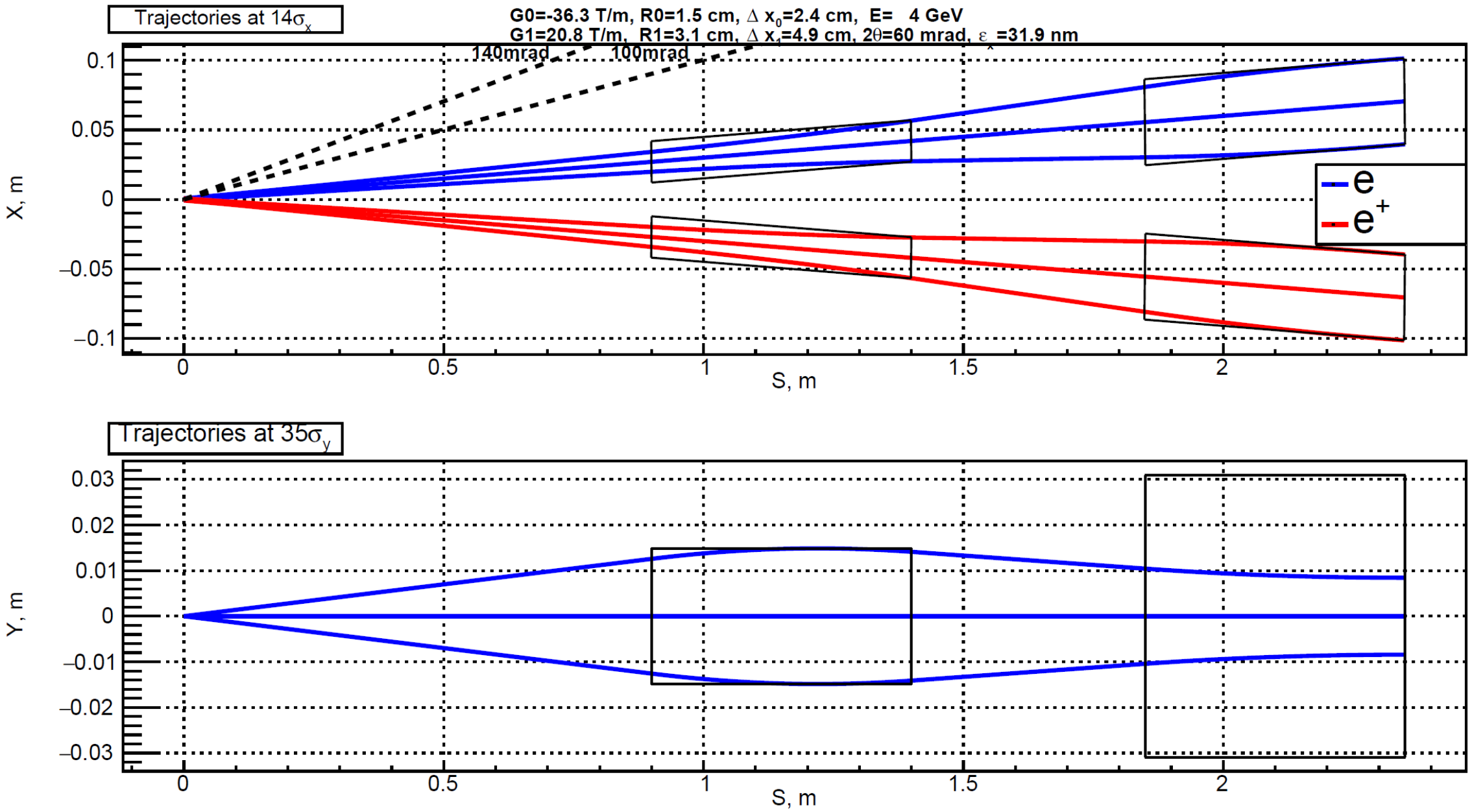
$$\Delta\nu_{yy} = \alpha_{yy} j_y \approx \frac{1}{\pi} \frac{L^{*3}}{\beta_{0,y}^2 L_q^2 \left(1 + \frac{2L^*}{L_q}\right)} \times \frac{n_y^2 \varepsilon_y}{2}$$

$$\Delta\nu_{yx} = \alpha_{yx} j_x \approx \frac{1}{\pi} \frac{L^*}{\beta_{0,x}\beta_{0,y}} \left(2 + \frac{L^*}{L_q}\right) \times \frac{n_x^2 \varepsilon_x}{2}$$

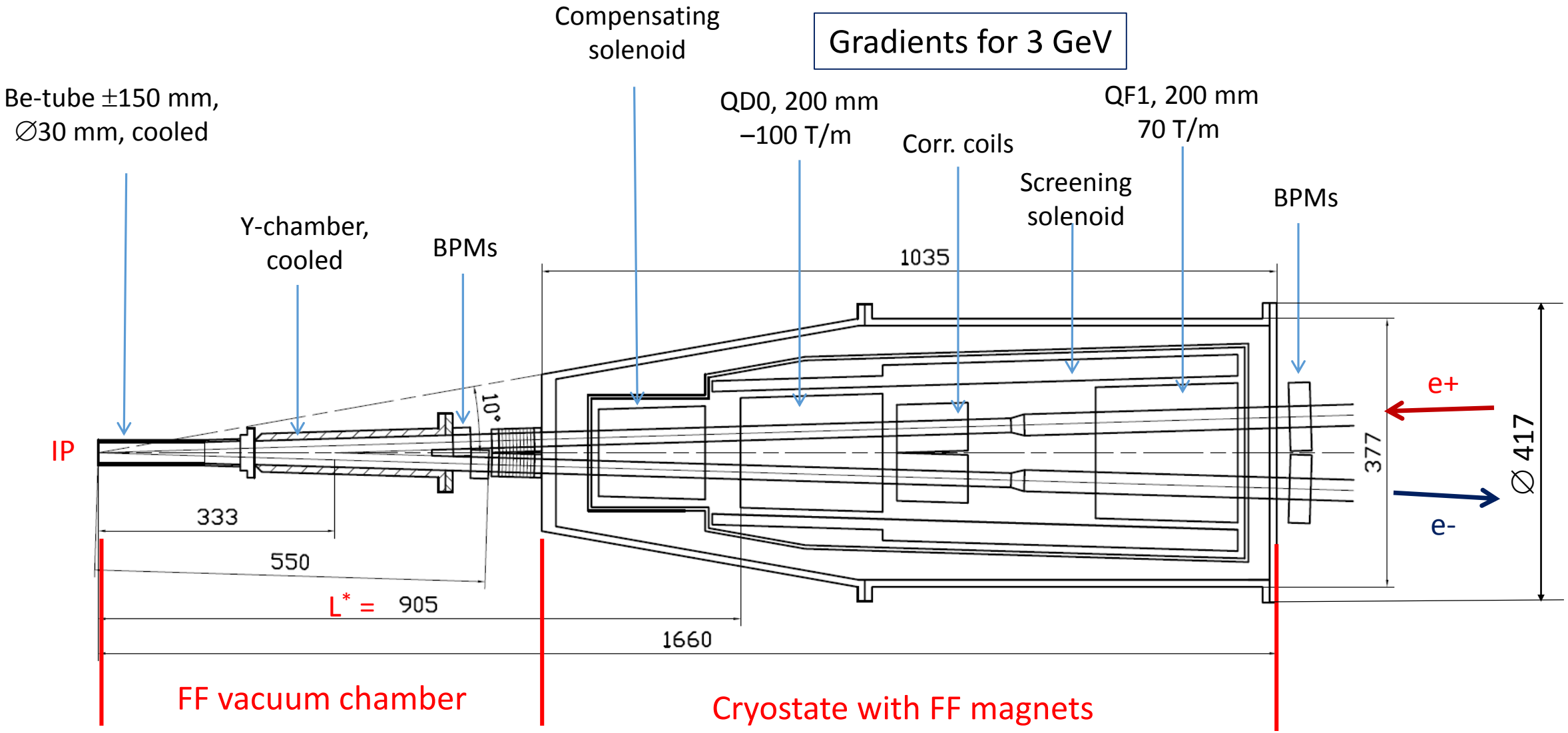
For first final focus quadrupole, with L_q increase $\alpha_{yy} \to 0$, $\alpha_{yx} \to const$

Lattice	49_5		52_1		54_1	
L(Q0,d1,Q1)	0.2, 0.3, 0.3		0.5, 0.44, 0.5		0.5, 0.45, 0.5	
A_x, A_y	20,20					
β_x^*/β_y^* (mm)	100 / 1					
$\varepsilon_{x,rad}$ (m)	12.4×10^{-9}		12.5×10^{-9}		10.6×10^{-9}	
$\Delta\nu_{xx}$ $\Delta\nu_{yx}$ $\Delta\nu_{xy}$ $\Delta\nu_{yy}$	$\Delta\nu_{\alpha\beta} = \frac{\partial \nu_\alpha}{\partial j_\beta} j_\beta$					
FRINGE OFF	1.1×10^{-3}	6.4×10^{-3}	1.7×10^{-3}	5.7×10^{-3}	1.5×10^{-3}	5.1×10^{-3}
	3.2×10^{-5}	1.6×10^{-3}	2.9×10^{-5}	1.0×10^{-3}	2.5×10^{-5}	1.3×10^{-3}
FRINGE ON	6.4×10^{-3}	$\mathbf{1.5 \times 10^{-1}}$	8.0×10^{-3}	9.4×10^{-2}	6.7×10^{-3}	$\mathbf{7.9 \times 10^{-2}}$
	7.4×10^{-4}	1.6×10^{-2}	4.7×10^{-4}	6.6×10^{-3}	3.9×10^{-4}	5.6×10^{-3}

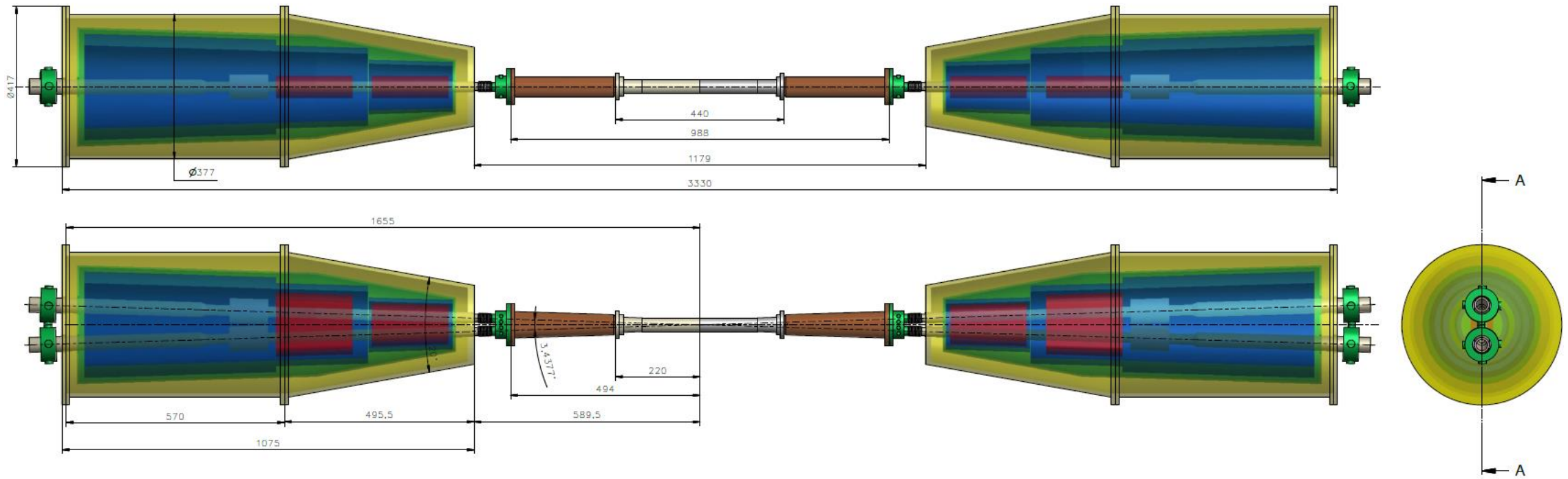
New Final Focus trajectories



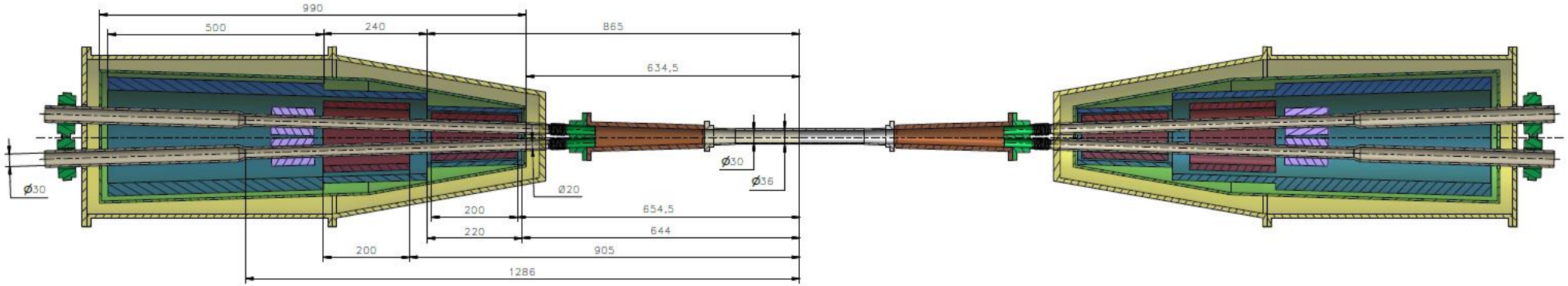
Machine-detector interface



Machine-detector interface



A-A (1 : 5)



Conclusion

- Increased maximum and minimum energies
- The linear lattice and parameters provide desired luminosity and polarization
- Two ring collider with $\Delta R = 1.14\ m$
- Siberian snakes sections are moved to optimized polarization levels
- On momentum dynamic aperture is sufficient for injection and beam-beam effects for 3 GeV, not sufficient for 1.5 GeV
- Off momentum dynamic aperture with CRAB ON is insufficient for Touschek lifetime at 1.5 GeV
- Detailed design of interaction region and MDI
- 3d design of FF lens
- Realistic design of new injection facility $2 \times 10^{11}\ e^{+}/s$