Interaction Region Design Options for eRHIC

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eRHIC

A high luminosity eA collider, consisting of one of the 250 GeV proton/100 GeV/u heavy ion RHIC rings, and a 10 GeV electron accelerator

Two design lines for the electron accelerator:

- a 10 GeV self-polarizing electron (positron) ring with full-energy injector linac and polarized electron source for 5 GeV operation

- a 10 GeV ERL with polarized electron source (no positrons)

IR design goals

- Beam separation

- Accomodation of synchrotron radiation generated by beam separation

- Beam focusing to small spot sizes to maximize luminosity

Three different IR design options:

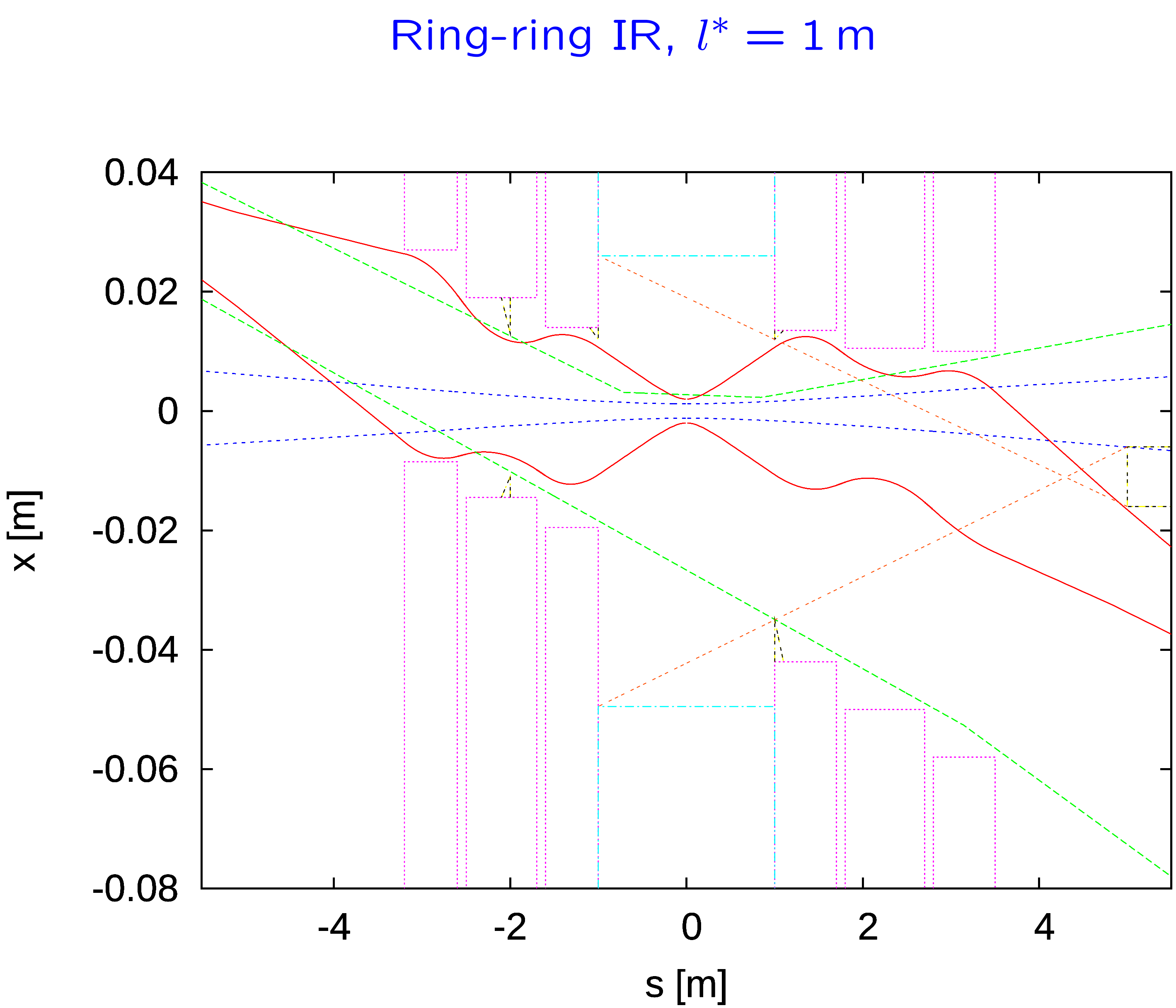
- Low-β quadrupoles inside the detector volume, starting at $l^* = 1\,\text{m}$ from the IP (ring-ring option). Beam separation by dipole windings in these quads.

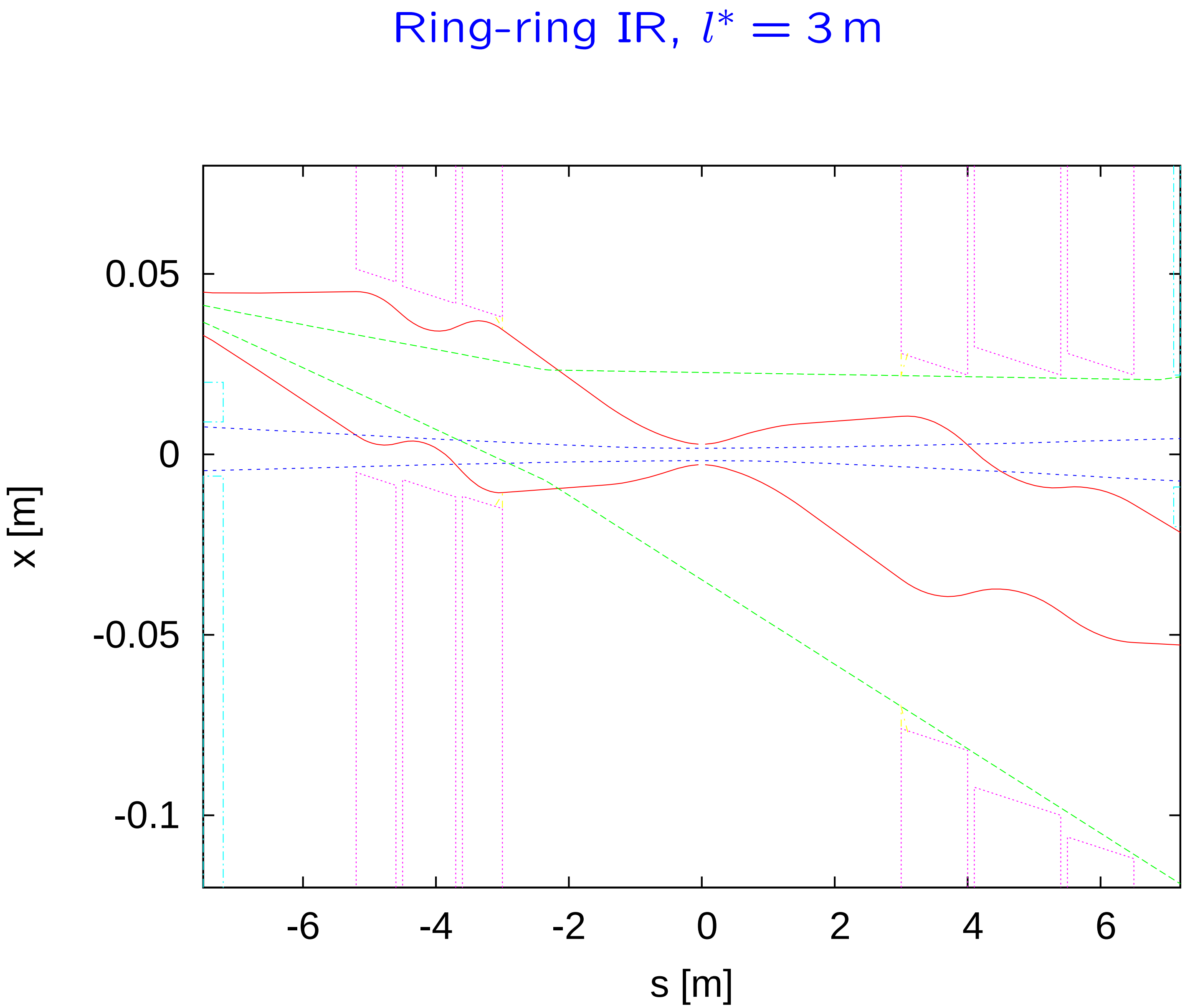
- Low-β quadrupoles outside the detector volume, starting at $l^* = 3\,\text{m}$ from the IP (ring-ring option). Beam separation by dipole windings on detector solenoid (detector-integrated dipole).

- Low-β quadrupoles outside the detector volume, starting at $l^* \geq 5\,\text{m}$ from the IP (linac-ring option). Beam separation by dipole windings on detector solenoid (detector-integrated dipole).

IR parameters for 10 GeV e on 250 GeV p

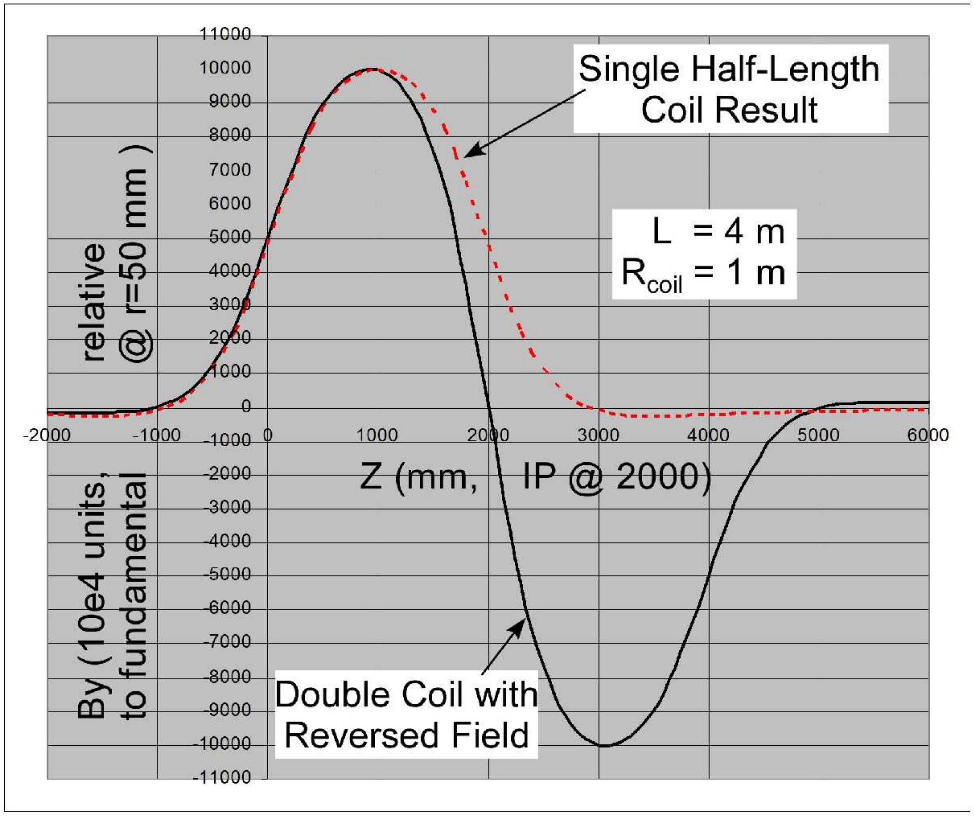
	ring-ring		linac-ring
	$l^* = 1\,\mathrm{m}$	$l^* = 3\,\mathrm{m}$	$l^* \geq 5\,\mathrm{m}$
ϵ_h [nm]	9.5		9.5
ϵ_e (x/y) [nm]	53/9.5		2.5/2.5
β_h (x/y) [m]	1.08/0.27	2.16/0.54	0.27/0.27
β_e (x/y) [m]	0.19/0.27	0.38/0.54	0.99/0.99
σ^* (x/y) [μm]	100/50	140/70	50/50
N_e/bunch [10^{11}]	1.0	1.0	1.4
N_p/bunch [10^{11}]	1.0	1.0	1.0. . . 2.0
ξ_h (x/y)	0.007/0.0035		0.007/0.007
ξ_e (x/y)	0.022/0.08		
$\mathcal{L}$ [$10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	0.44	0.22	1.25. . . 2.5


Ring-ring IR, $l^* = 1\,\mathrm{m}$
x [m]
s [m]
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-4
-2
0
2
4



Ring-ring IR, $l^* = 3\,\mathrm{m}$
0.05
0
-0.05
-0.1
x [m]
-6
-4
-2
0
2
4
6
s [m]

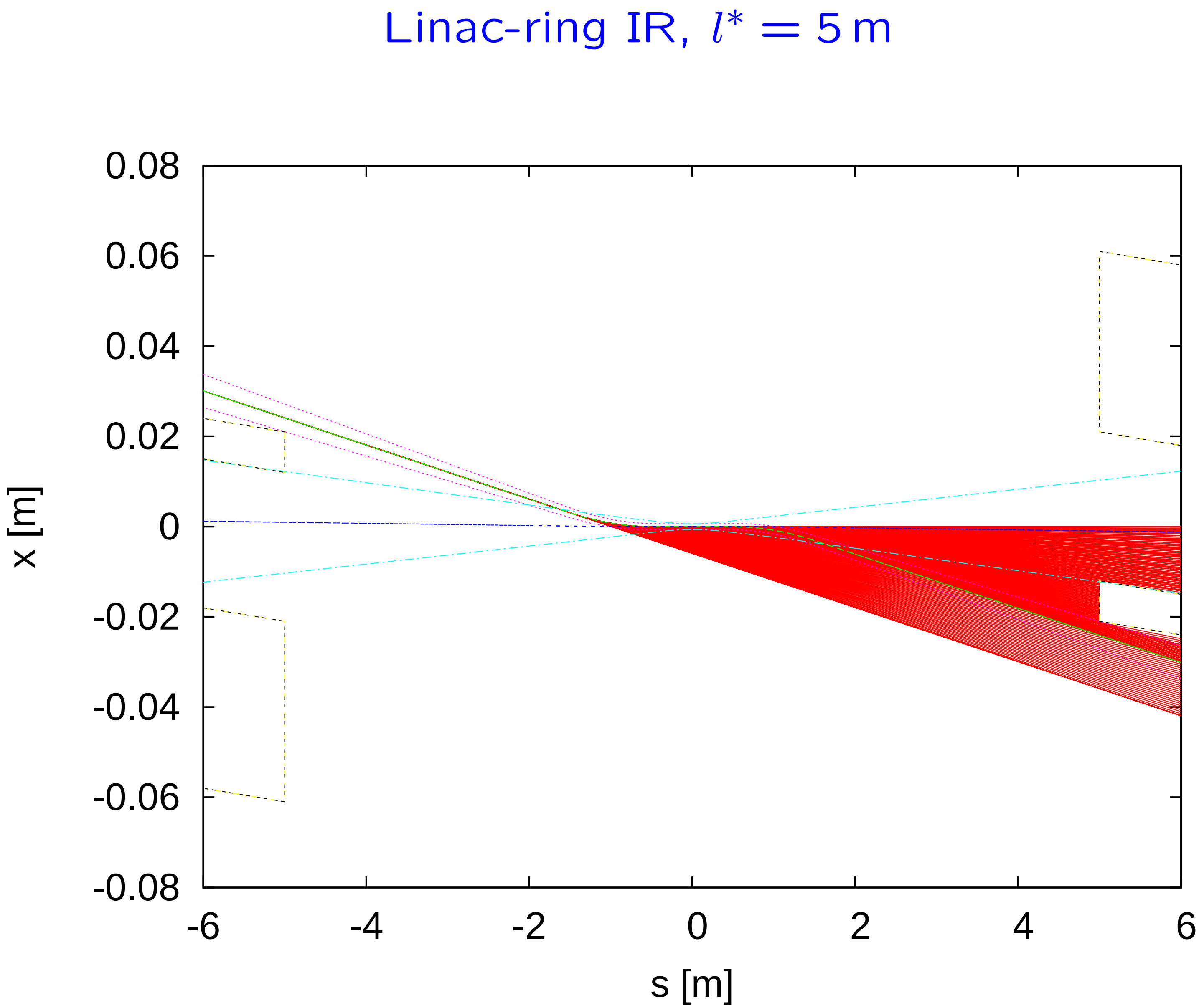
Separator dipole field superimposed on detector solenoid (Detector Integrated Dipole, DID)



Linac-ring IR

- Focusing elements can be far away from the IP ($l^* = 5\,\mathrm{m}$) due to tiny electron beam emittance and relatively large β^*

- Separation by Detector Integrated Dipole (DID)


Linac-ring IR, $l^* = 5\,\mathrm{m}$
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x [m]
-6
-4
-2
0
2
4
6
s [m]

Spare slides

Beam separation by a crossing angle

First hadron quadrupole (septum quad) starts approximately 5m from the IP

Required beam separation at septum:
$12\sigma_p + 20\sigma_e + d_{\text{septum}} \approx 25\,\text{mm}$

$\Rightarrow$ Required crossing angle to provide separation without additional dipoles:

$$\Theta \approx 5\,\text{mrad}$$

Large crossing angle reduces luminosity by factor ≈ 5 due to long hadron bunches

Crab Crossing

Required transverse deflecting voltage (according to KEKB design report):

$$V_{\perp} = \frac{cE \tan \Theta}{e\omega_{\text{RF}}\sqrt{\beta^* \beta_{\text{crab}}}}$$

250 GeV protons (or 100 GeV gold ions)
$\Theta = 5\,\text{mrad}$
$\beta_{\text{crab}} = 400\,\text{m}$
$\omega_{\text{RF}} = 2\pi \cdot 200\,\text{MHz}$

$$V_{\perp} = 30\,\text{MV}$$

For comparison: RHIC RF voltage is 2 MV, KEKB crab cavity voltage is 1.44 MV

Beam separation with zero crossing angle

Horizontal beam sizes at septum need to be kept small to minimize required beam separation

- hadrons:
  horizontal beam size at septum $\sigma_{x,h} \propto 1/\sqrt{\beta^*_{x,h}}$
  $\longrightarrow$ lower limit on $\beta^*_{x,h}$
  $\longrightarrow$ upper limit on luminosity

- electrons:
  horizontal beam size at septum $\sigma_{x,e} \propto \sqrt{\epsilon_{x,e}}$,
  but smaller $\epsilon_{x,e}$ requires larger $\beta^*_{x,e}$ to match beam sizes
  $\longrightarrow$ larger beam-beam parameter
  $\longrightarrow$ luminosity limitation for ring-ring design

Synchrotron radiation issues

Beam separation close to the IP to bring proton low-β quads as close as possible to the IP

$\longrightarrow$ Generation of synchrotron radiation close to the IP, inside the detector volume

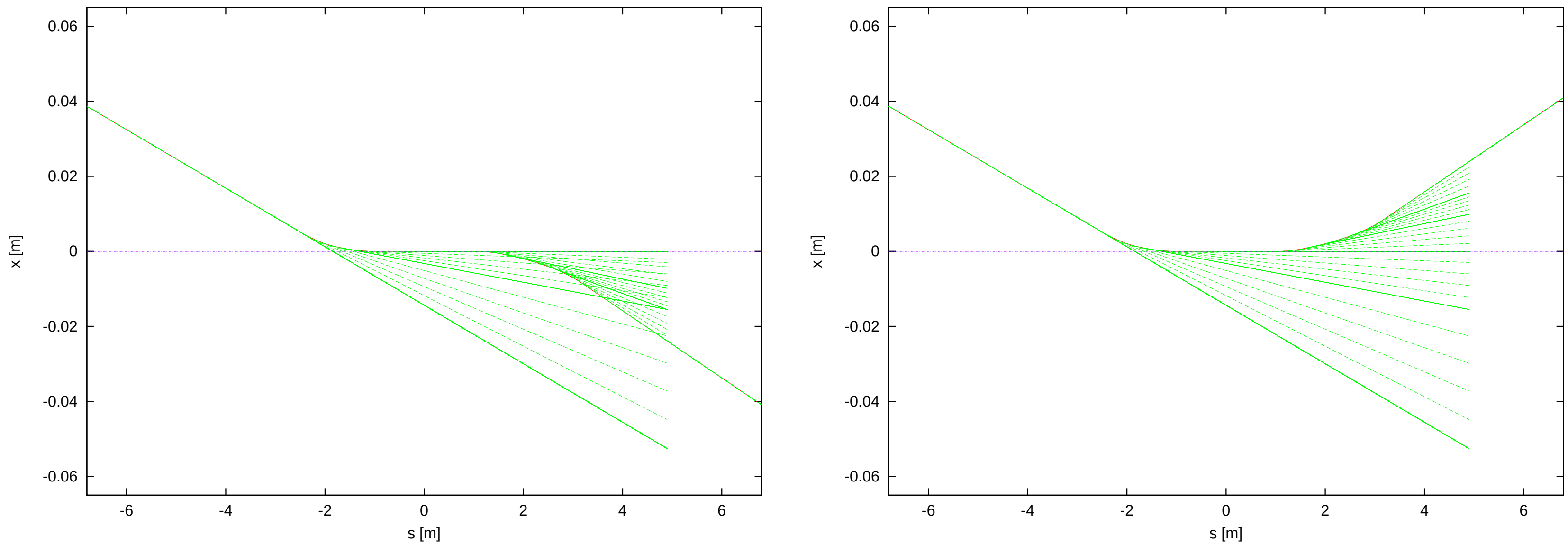
$\longrightarrow$ SR must be passed safely through the IP and the low-β electron quads

$\longrightarrow$ SR fan must be kept narrow to limit required quad aperture

$\longrightarrow$ separation as close as possible to the IP

$\longrightarrow$ S-shape IR preferred over C-shape

S-shape IR preferred over C-shape:



Low-β focusing

Low-β focusing is limited by hourglass effect:

$$\beta > \sigma_{p,s}$$

Hadron bunchlength $\sigma_{p,s}$ is limited by cryo load and IBS:

$$\sigma_{p,s} \approx 20\,\mathrm{cm}$$

Hadron transverse emittance is given by present RHIC

Keep beams at IP as round as possible to maximize luminosity and minimize beam-beam, but be aware of horizontal beam size at the septum

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	ring-ring		linac-ring
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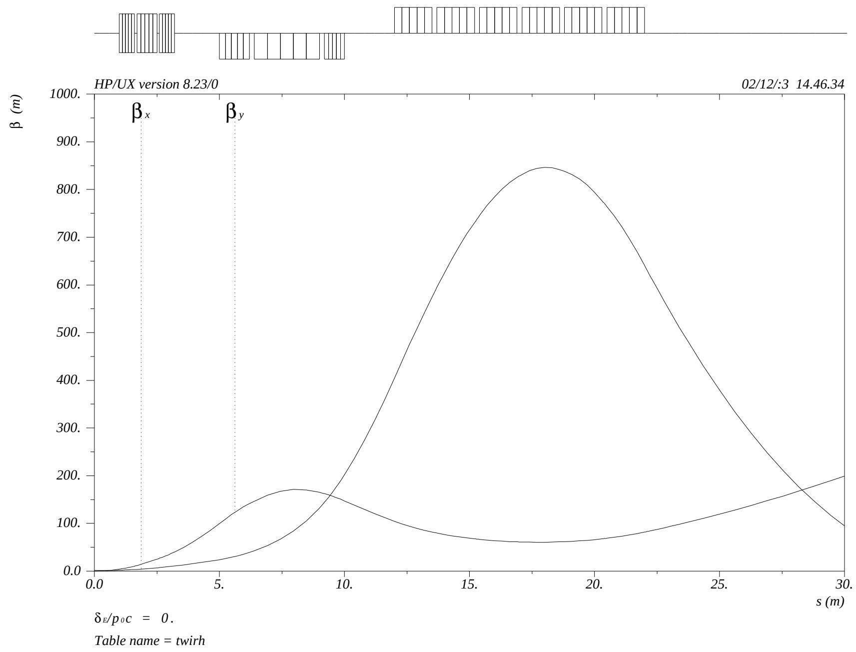
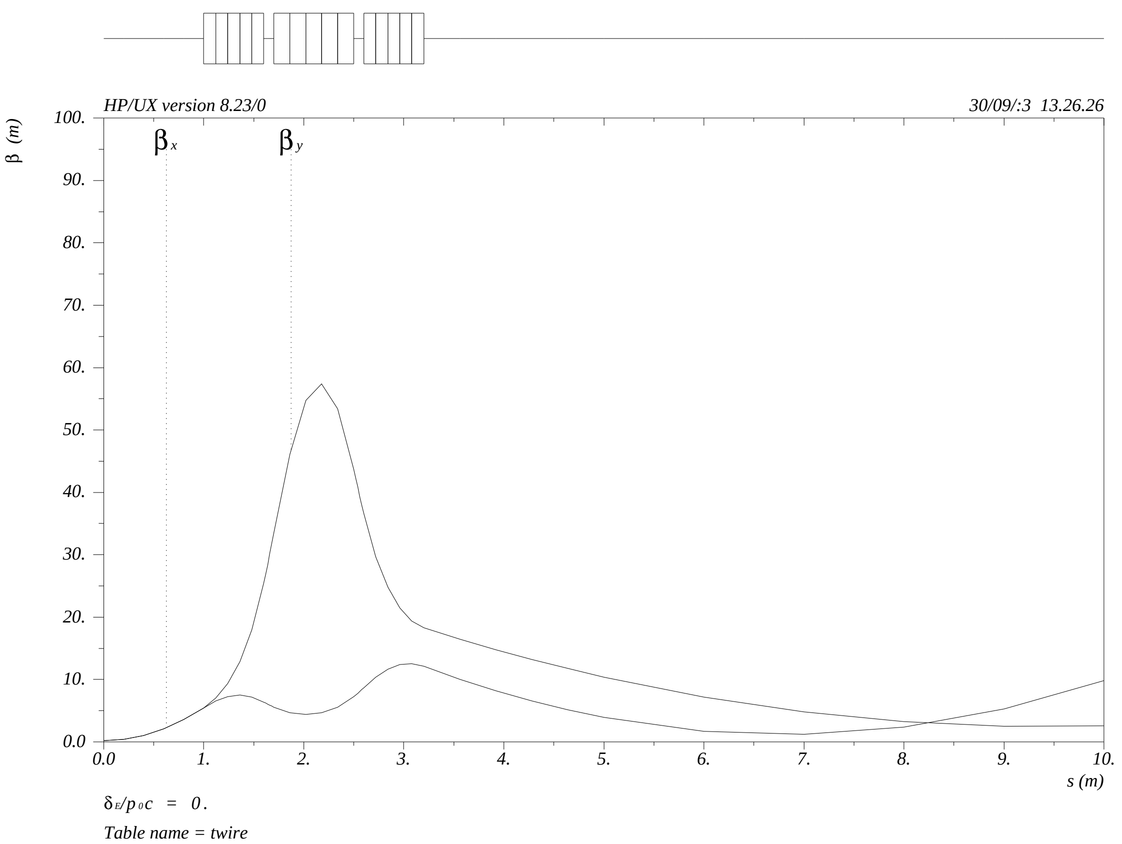
Ring-ring IR lattice, $l^* = 1\,\mathrm{m}$

Hadron doublet:

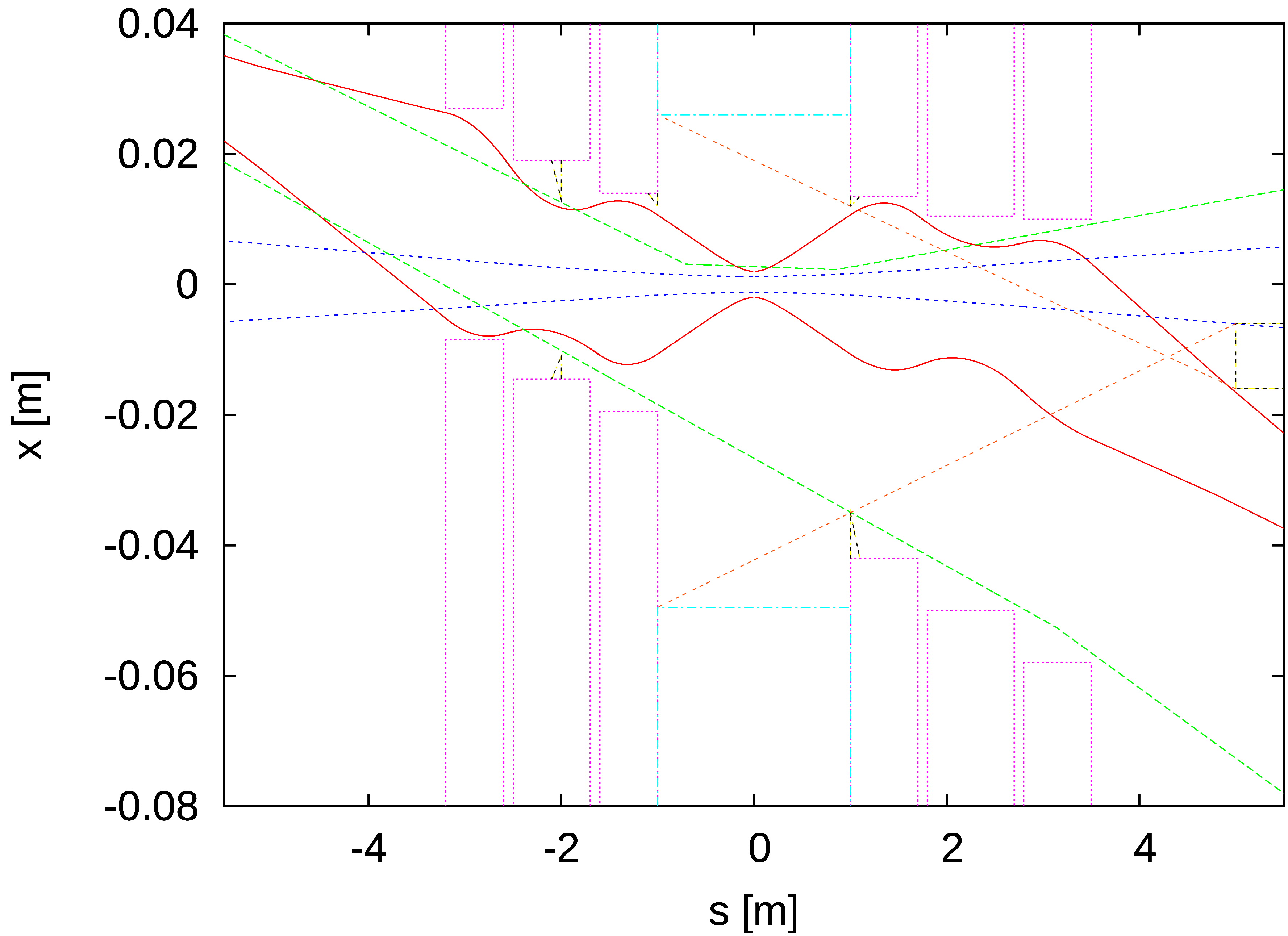


Pole tip fields: 1.0 Tesla, NC

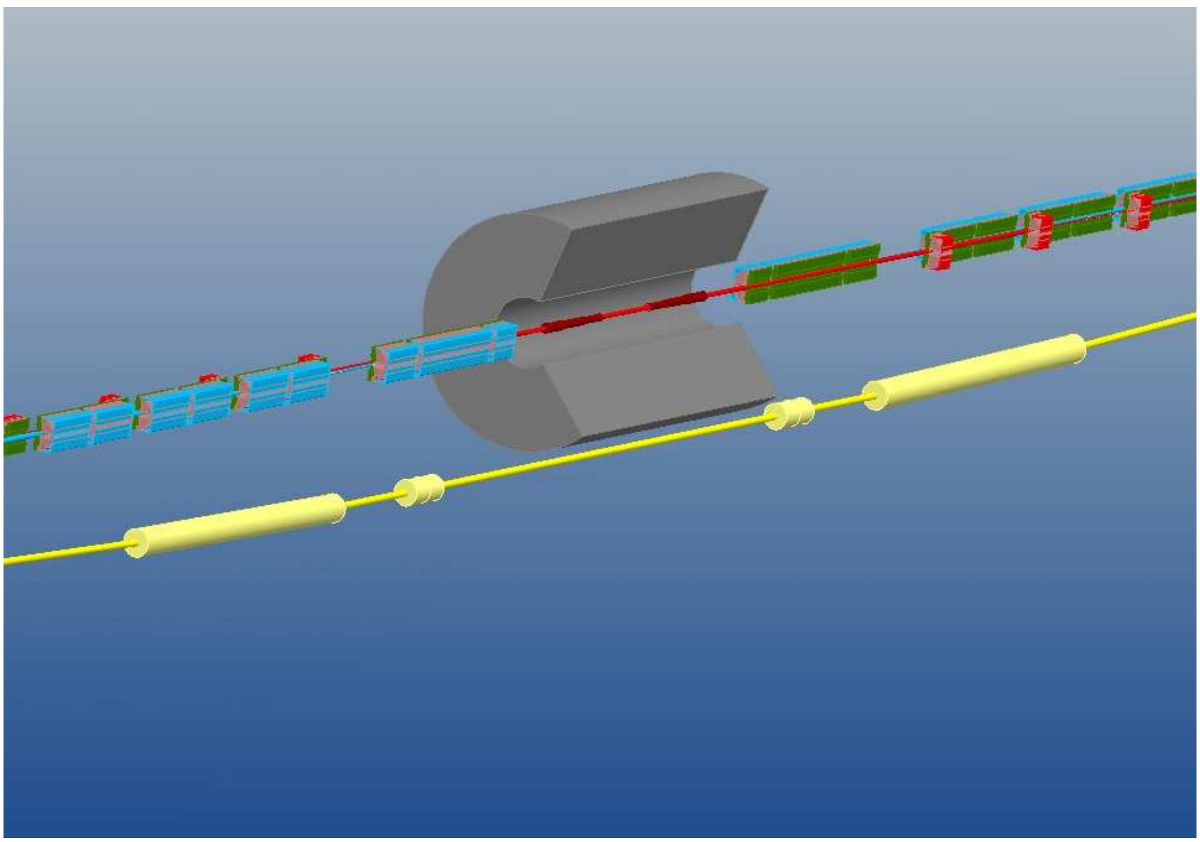
Electron triplet with dipole windings, inside detector:

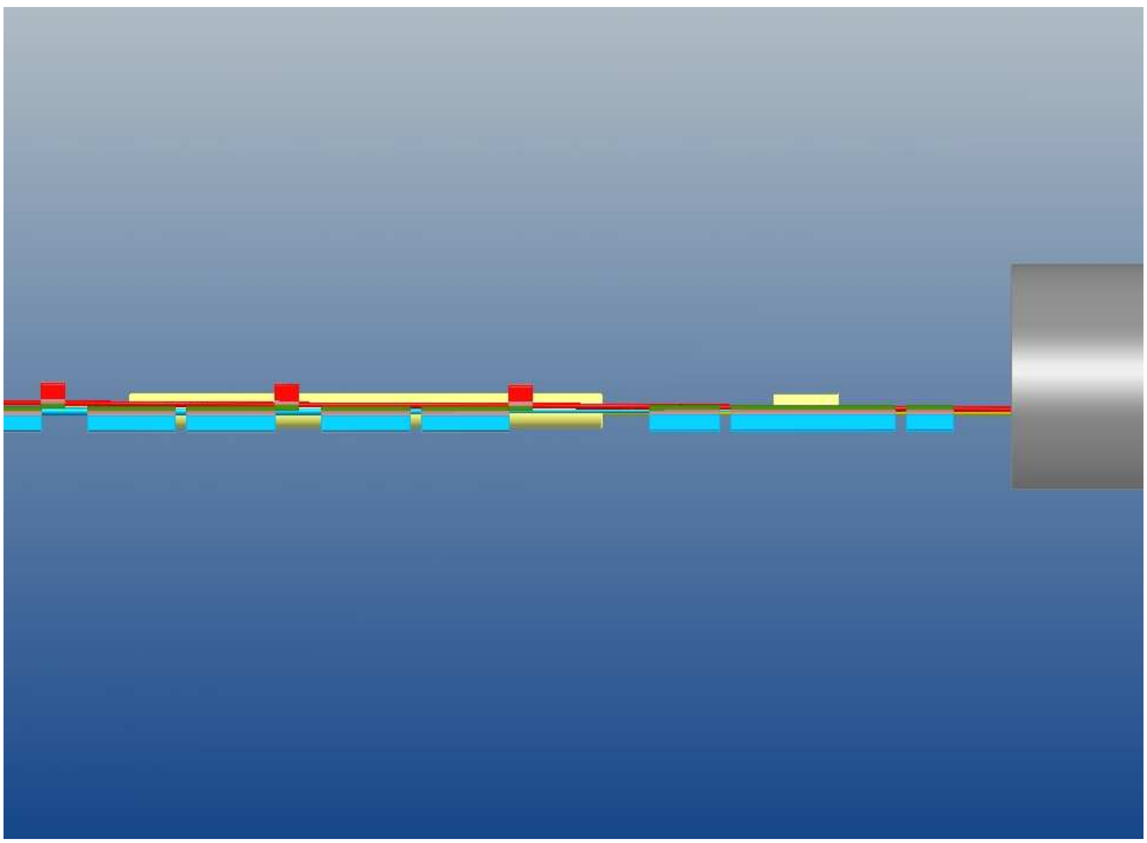


Quadrupole peak fields: 2 Tesla, SC



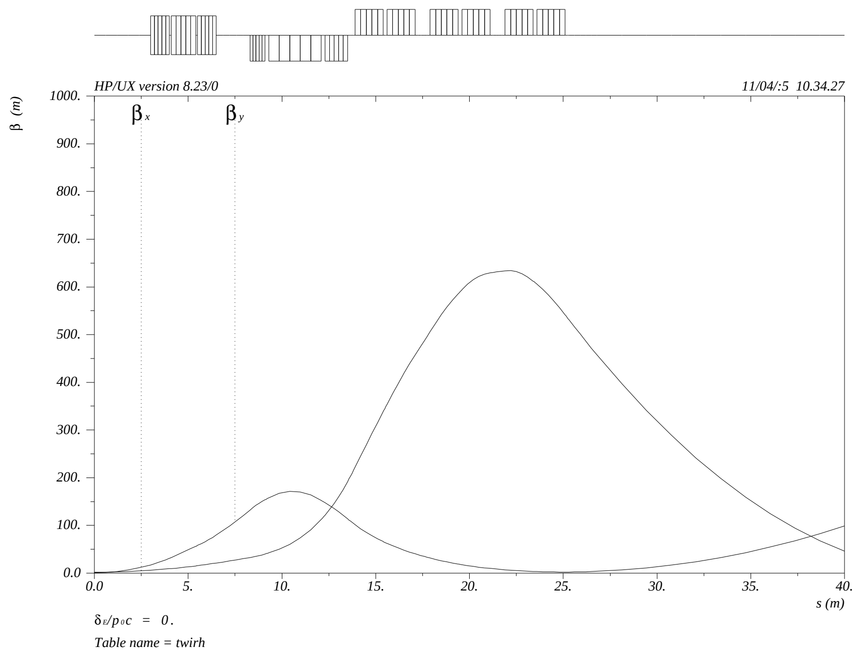
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x [m]
-4
-2
0
2
4
s [m]





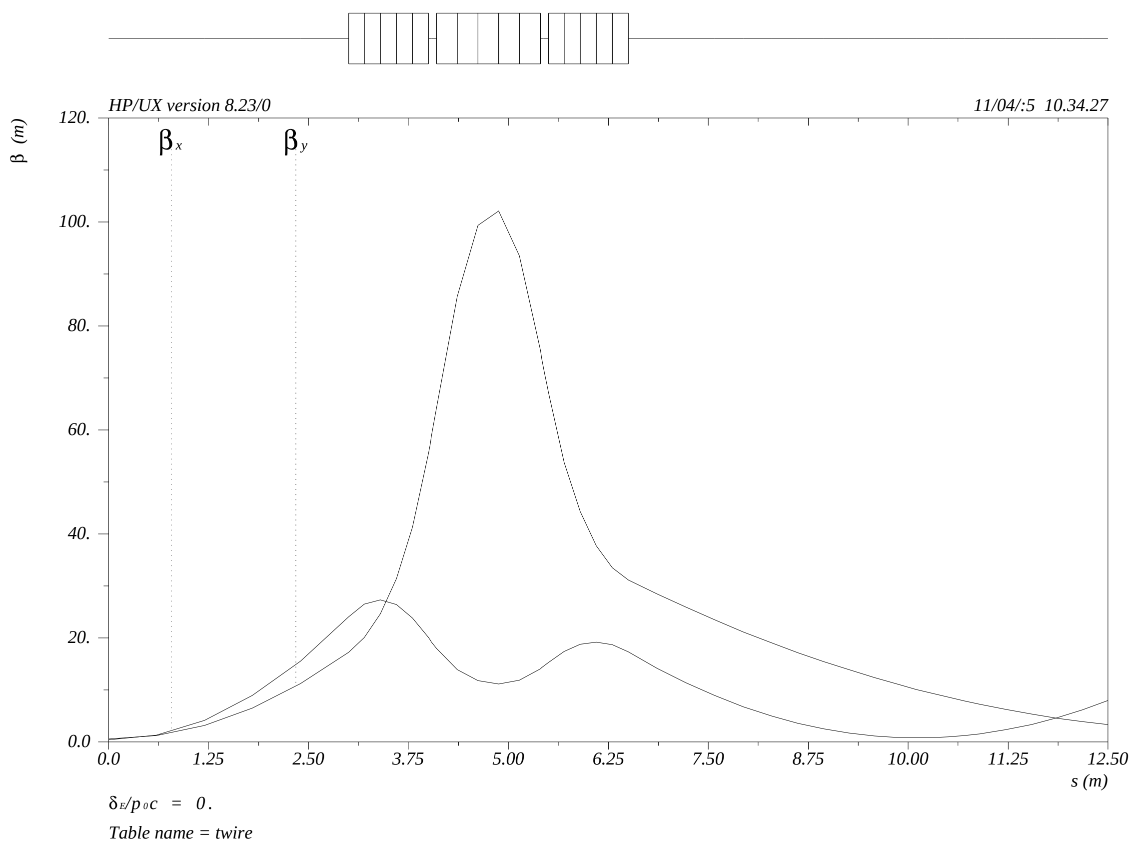
Ring-ring IR lattice, $l^* = 3\,\mathrm{m}$

Hadron doublet:



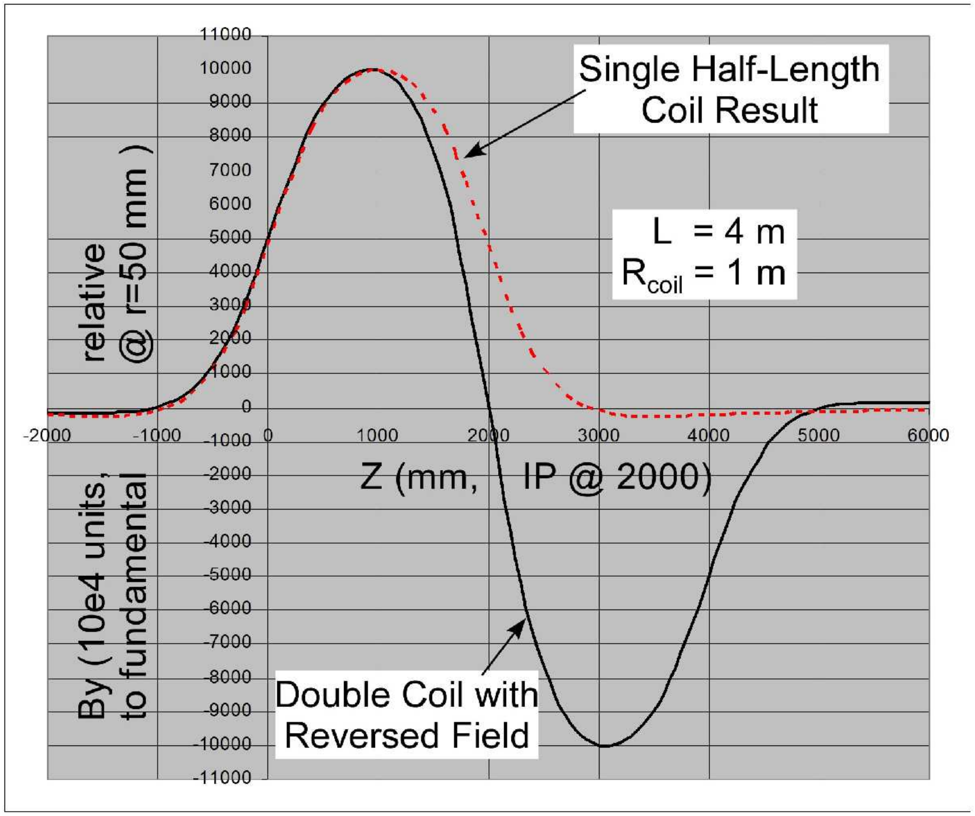
Pole tip fields: 1.0 Tesla, NC

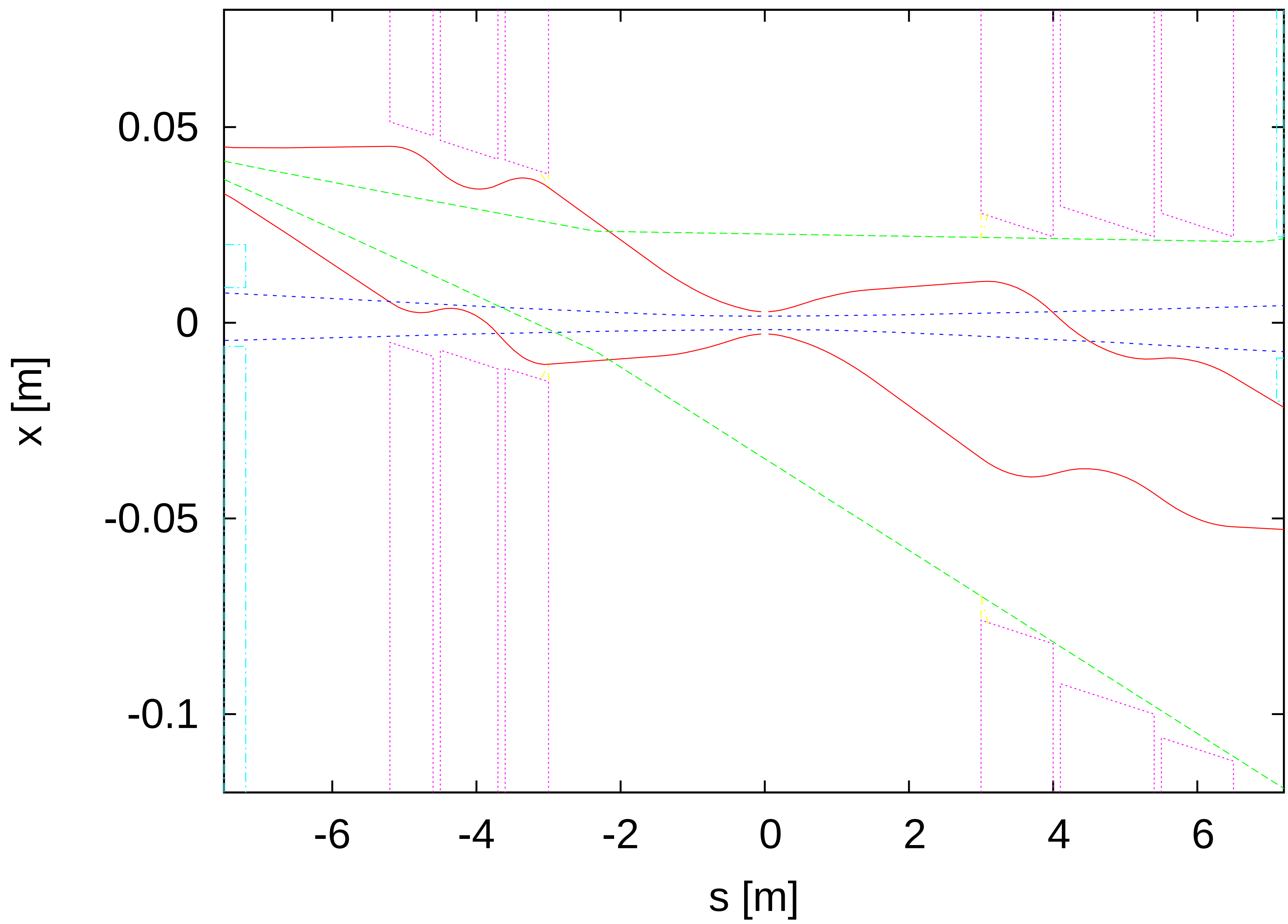
Electron triplet outside detector:



Quadrupole peak fields: 2 Tesla, SC

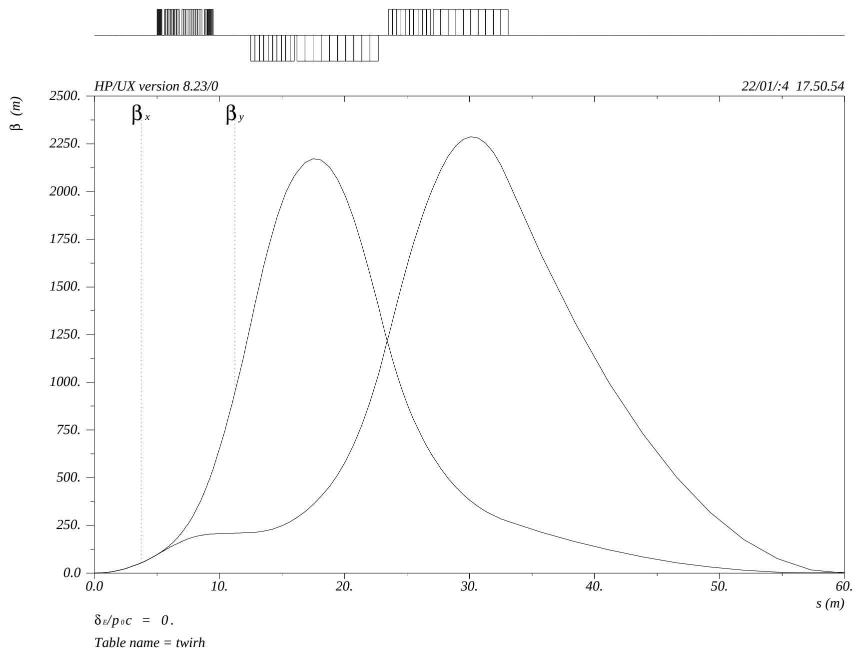
Separator dipole field superimposed on detector solenoid (Detector Integrated Dipole, DID)




0.05
0
-0.05
-0.1
x [m]
-6
-4
-2
0
2
4
6
s [m]

Linac-ring IR lattice

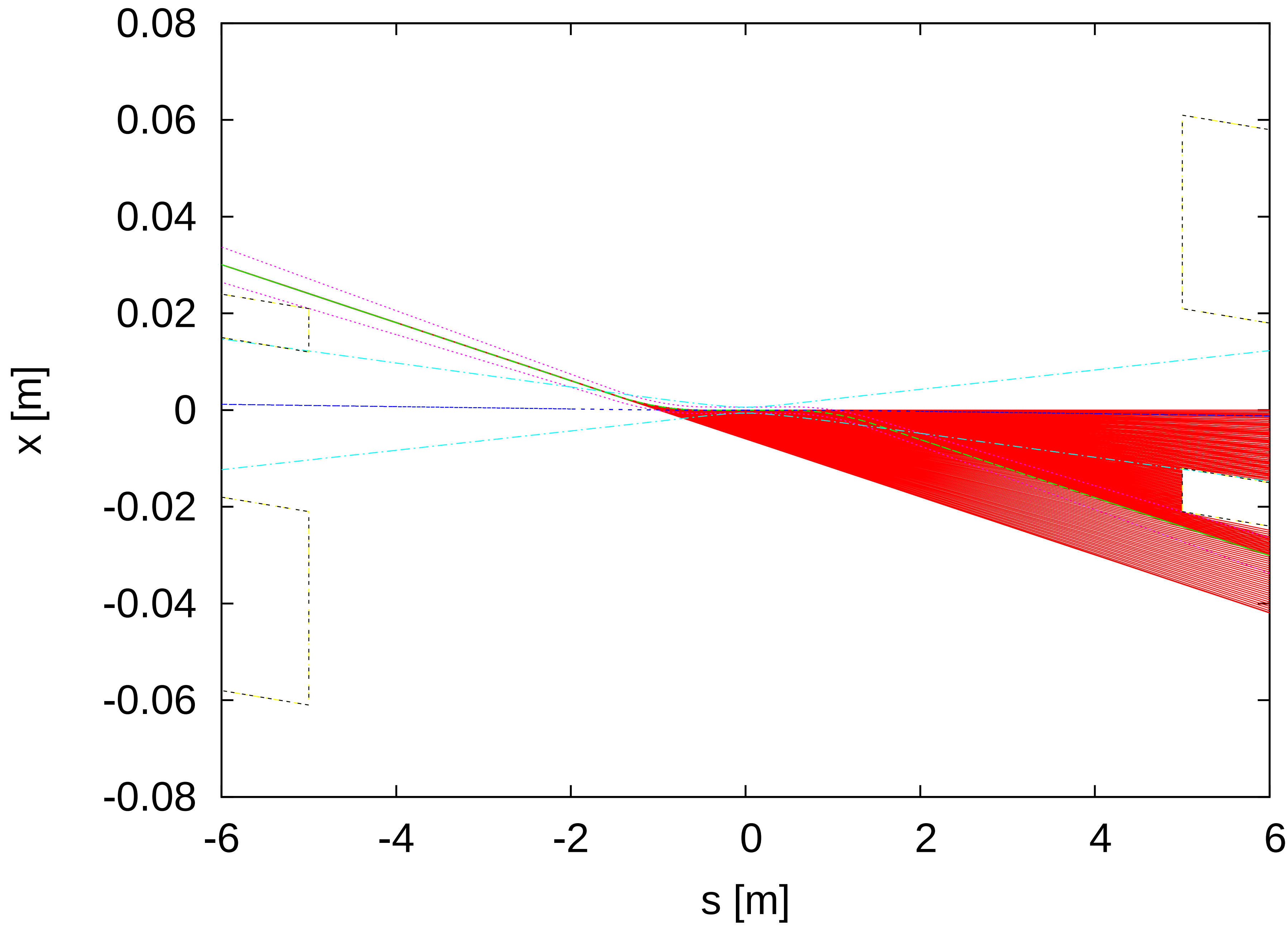
Hadron triplet:



Pole tip fields: 1.0 Tesla, NC

Electrons:

- Focusing elements can be far away from the IP ($\geq$ 10 m) due to tiny emittance and relatively large β^*
- Separation by Detector Integrated Dipole (DID)


0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
x [m]
-6
-4
-2
0
2
4
6
s [m]

Conclusion

- Design considerations and limitations for (eRHIC) electron-ion IR have been presented.
- IR design solutions for both ring-ring and linac-ring option of eRHIC exist.
- Linac-ring option provides significantly higher luminosity for 10 GeV e on 250 GeV p, but no positrons.
- SR background simulations being worked on.