14 mrad Extraction Line Optics for Push-Pull

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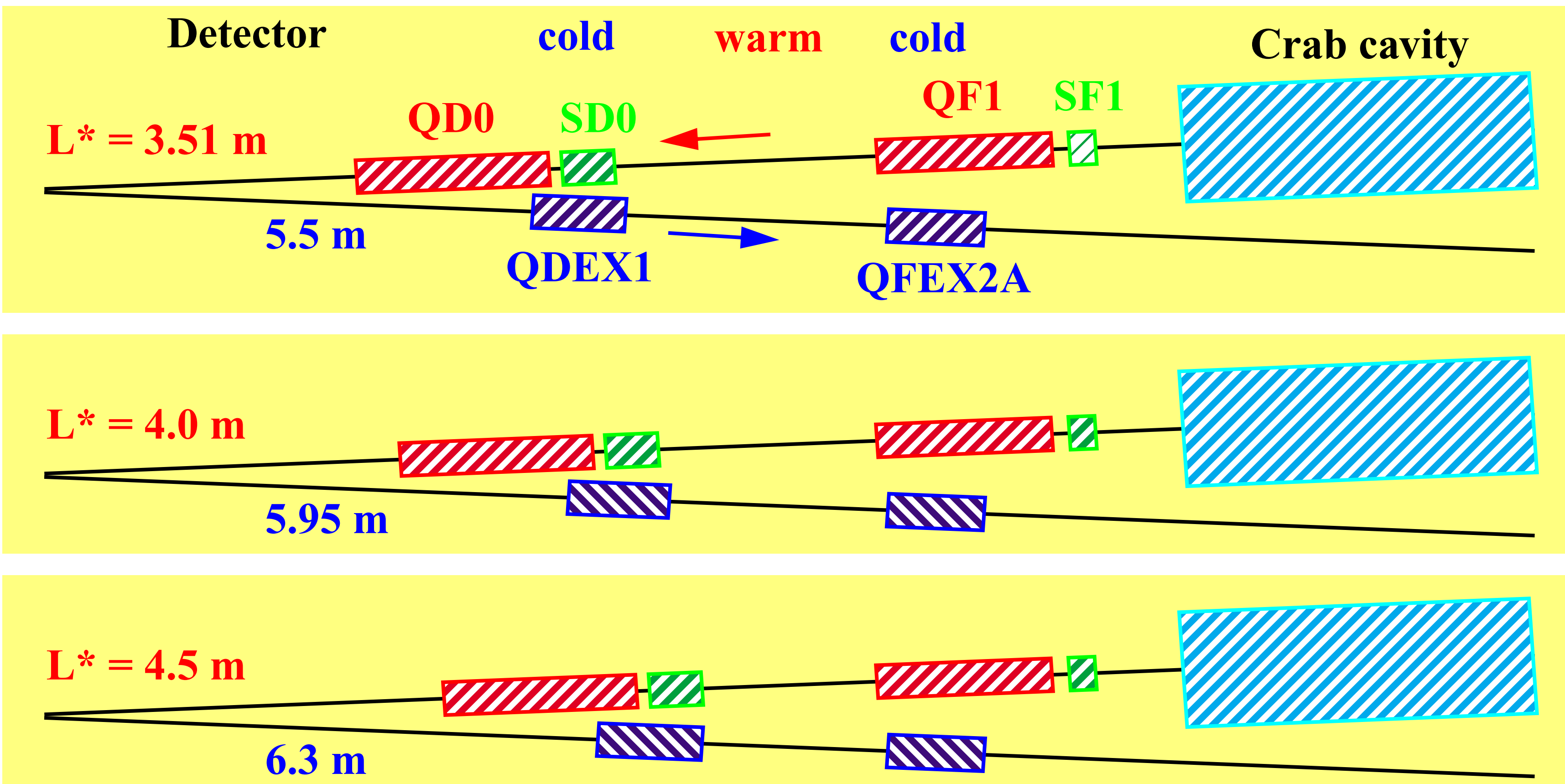
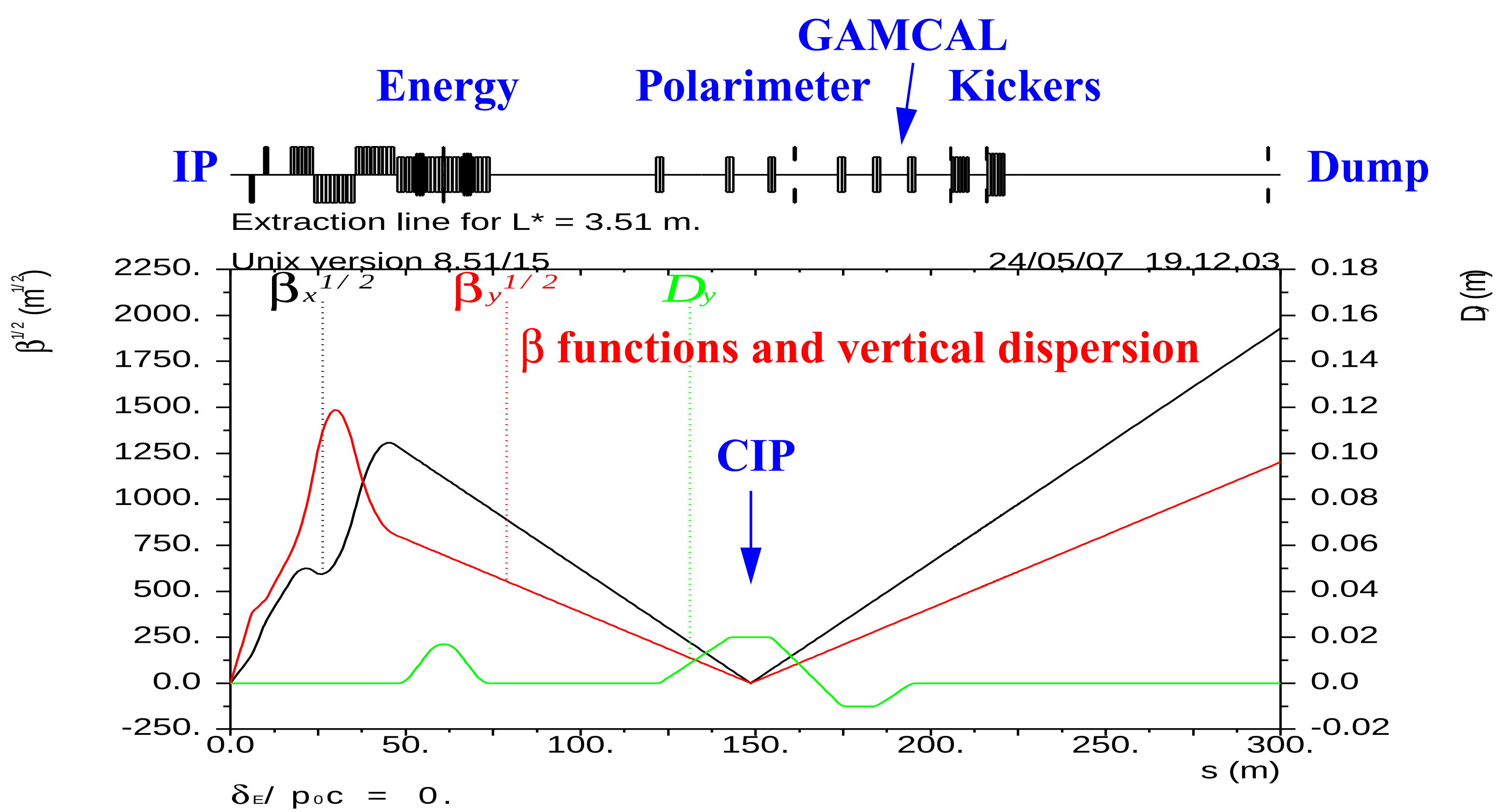
Magnet configuration near IP

- Distance between the 1st and 2nd SC quads after IP is increased to provide sufficiently long warm section for push-pull design.
- For three options of L* = 3.51 m, 4.0 m, 4.5 m, the SC extraction quad QDEX1 is placed at 5.5 m, 5.95 m and 6.3 m. The 2nd SC quad QFEX2A is at fixed position, 9.6 m from IP.
- A long drift after QFEX2A provides transverse space for crab-cavity. The downstream warm quads start at 17.19 m.



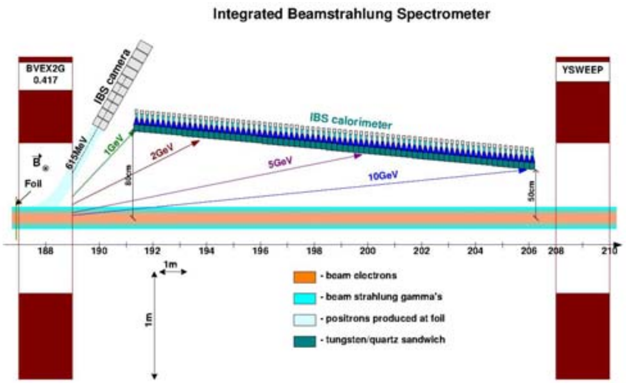
Extraction beam optics

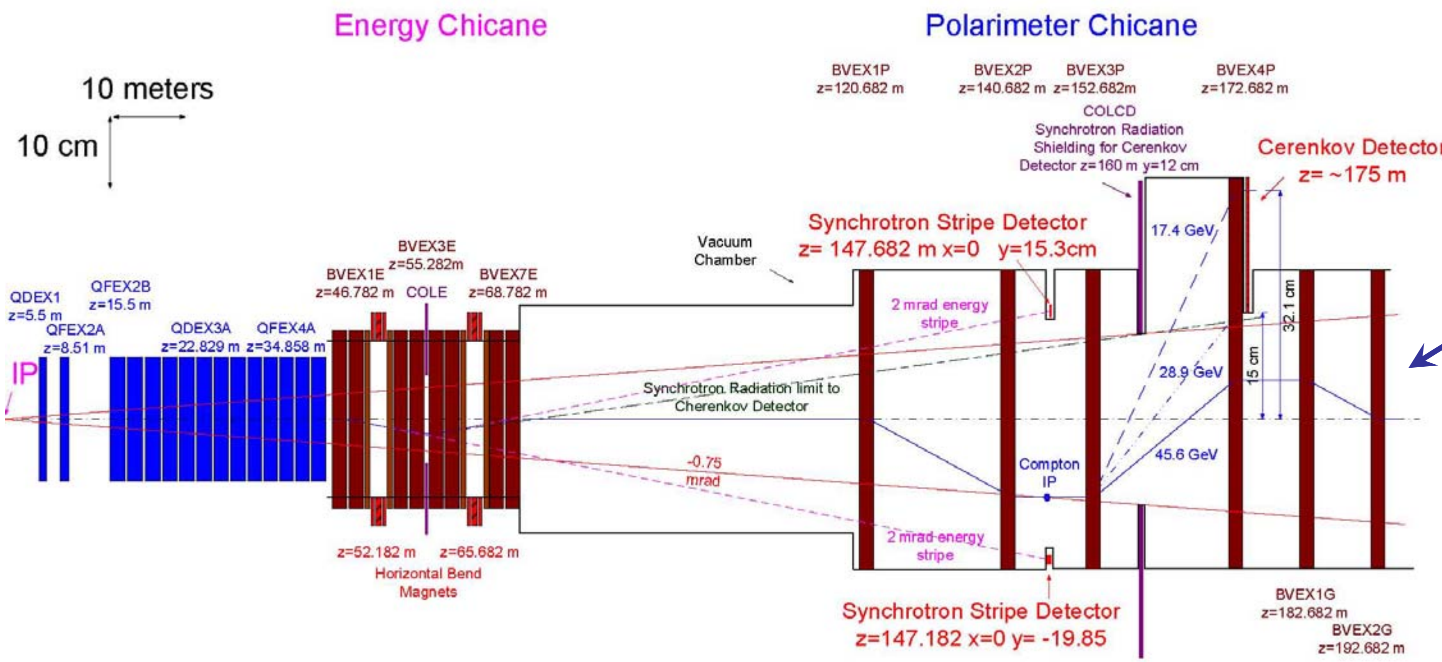
- The quads focus the beam to the 2nd focus at Compton IP with $R_{22} = -0.5$ transformation.
- The diagnostic contains energy and polarimeter chicanes, two proposed GAMCAL bends and the fast kickers for sweeping the beam on 3 cm circle at the dump window.
- Two collimators are included in the energy and polarimeter chicanes, and three collimators are in the final 100 m drift to protect the kickers and limit the beam size to within the R = 15 cm dump window.



Extraction diagnostics (K. Moffeit, B. Morse)

- The original 4-bend symmetric polarimeter chicane is modified to increase the strengths of the 3rd and 4th bends by 50% which improve acceptance of Compton backscattered electrons in the Cherenkov detector.
- The 5th and 6th bends are added to the polarimeter chicane which close the orbit bump and can be used by the proposed Gamma Calorimeter (B. Morse).
- Configuration of diagnostic vacuum pipe is designed in detail (K. Moffeit).

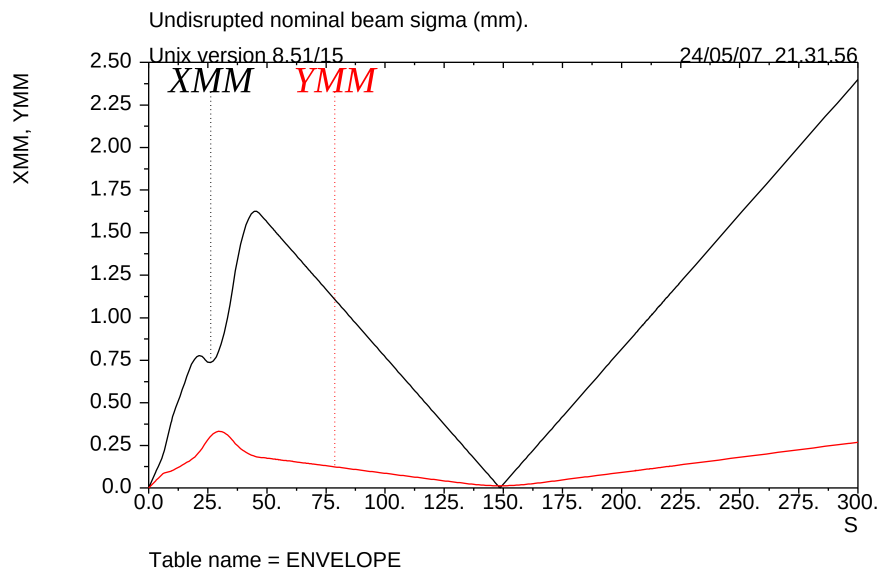




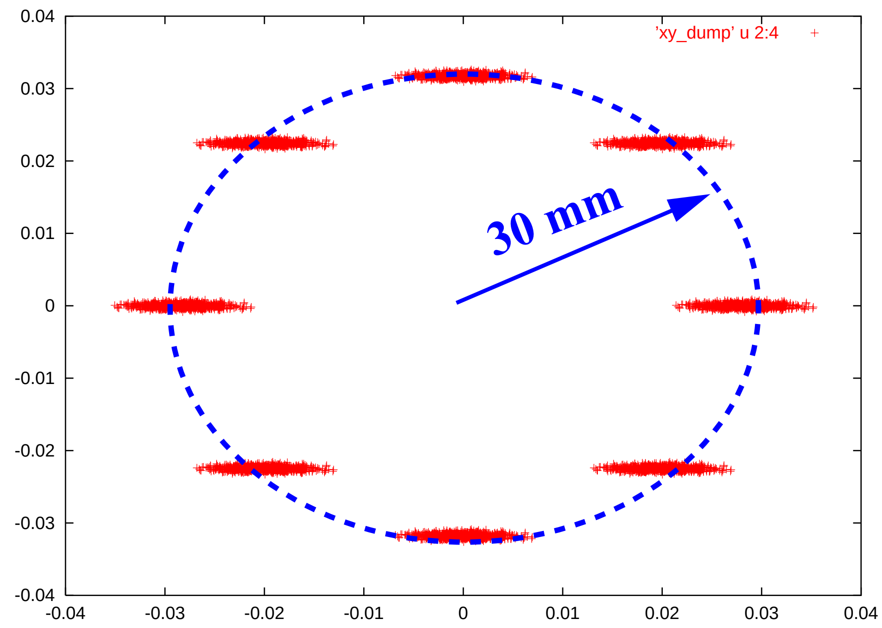
Fast sweeping kickers

- Without beam collision, the undisrupted nominal beam size is too small (2.42 x 0.29 mm^2) at the dump window.
- A system of 5 horizontal and 5 vertical fast kickers is included ~90 m before the dump. The rapidly oscillating x and y kicker field (~1 kHz) sweep the beam on 3 sm circle at the dump window. This was shown to be sufficient to protect the dump window and prevent water boiling in the dump vessel (L. Keller).

Undisrupted σ (mm)

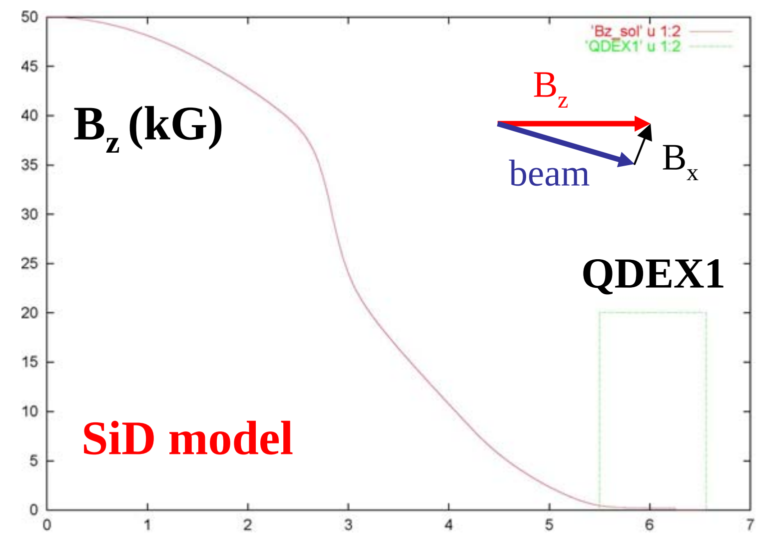


Undisrupted bunches at dump

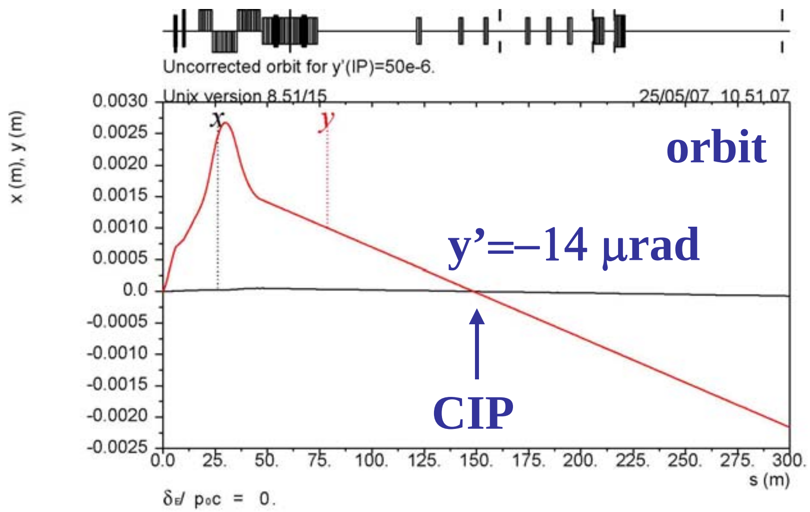


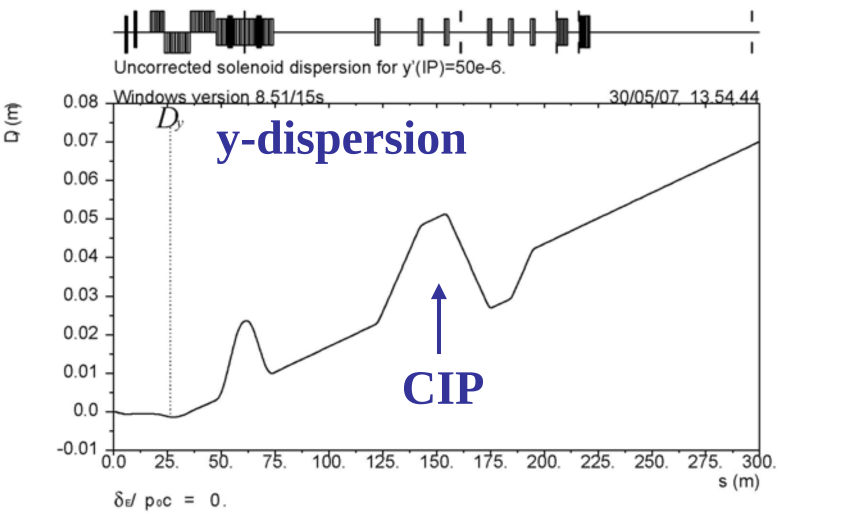
Effect of post-IP detector solenoid (5T SiD model)

• Post-IP solenoid field creates vertical orbit, coupling and focusing in the extraction line.
• The orbit is due to 7 mrad angle between the solenoid field and the beam. Additional orbit can be caused by uncompensated IP angle.
• Without orbit correction and with y' = 50 μrad IP angle, the extraction orbit is within 2.7 mm, but both y and y' are small at CIP. The y-dispersion at CIP is increased from 20 to 50 mm.
• Solenoid focusing shifts the s-position of vertical beam waist at CIP by ~4 mm.



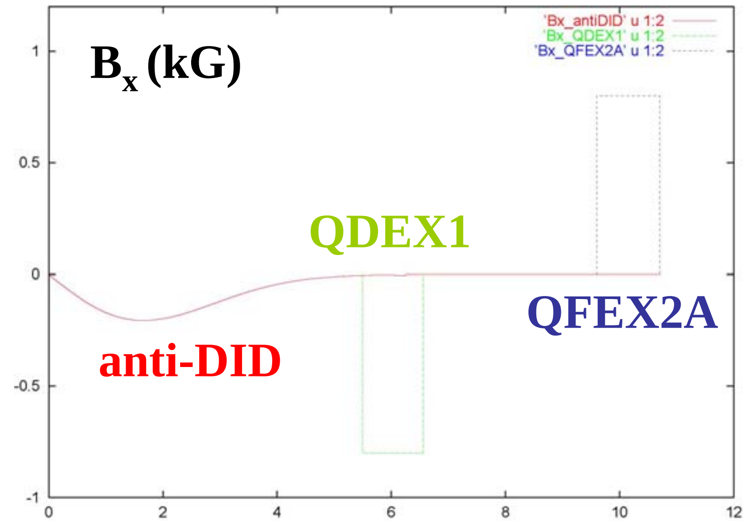
Uncorrected solenoid orbit and dispersion for y'= 50 μrad at IP, without anti-DID



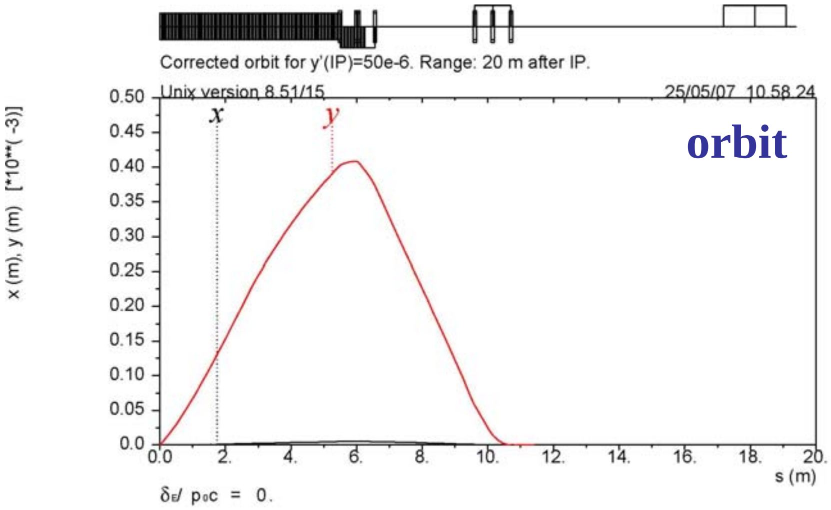


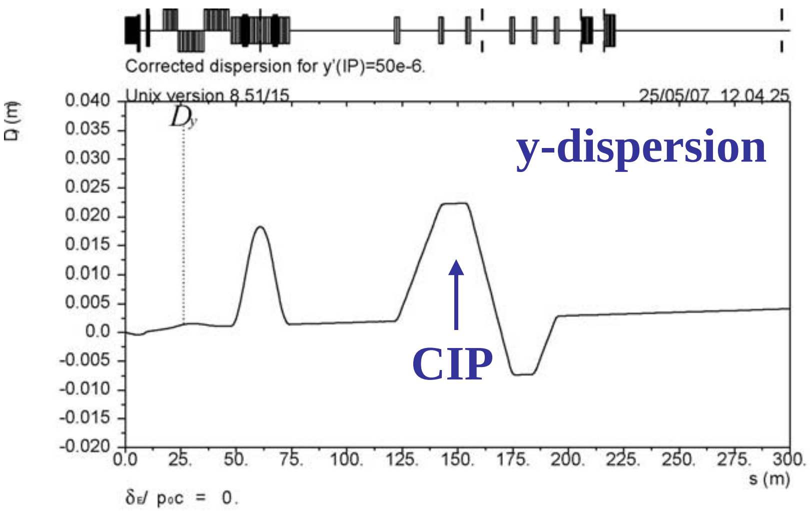
Correction of solenoid orbit and focusing

- Dipole and quadrupole correcting coils on QDEX1 and QFEX2A can correct the solenoid orbit and focusing. The anti-DID field helps to correct the extraction orbit.
- The under-corrected IP y-angle may significantly increase the required corrector field. For SiD solenoid with anti-DID and y' = 0 at IP, the correcting fields at QDEX1 and QFEX2A are -0.11 kG and 0.23 kG for L* = 3.51 m optics. For IP y' = 50 μrad the fields are -0.81 kG and 0.78 kG. These values increase ~20% for L* = 4.5 m.
- The orbit correctors also reduce the solenoid dispersion.



Corrected solenoid orbit and dispersion with anti-DID for y'= 50 μrad at IP





Quadrupole gradient (T/m), length (m) and aperture (mm) at 250 GeV

Quad	Qty	L* = 3.51 m			L* = 4.0 m			L* = 4.5 m		
		Grad	L	Aper	Grad	L	Aper	Grad	L	Aper
QDEX1 (SC)	1	98.00	1.060	15	89.41	1.150	17	86.39	1.190	18
QFEX2A (SC)	1	31.33	1.100	30	33.67	1.100	30	36.00	1.100	30
QFEX2B,2C,2D	3	11.12	1.904	44	11.27	1.904	44	11.36	1.904	44
QDEX3A,3B	2	11.39	2.083	44	11.37	2.083	44	11.36	2.083	44
QDEX3C	1	11.39	2.083	44	11.37	2.083	44	11.36	2.083	44
QDEX3D	1	9.82	2.083	51	9.81	2.083	51	9.80	2.083	51
QDEX3E	1	8.21	2.083	61	8.20	2.083	61	8.19	2.083	61
QFEX4A	1	7.05	1.955	71	7.04	1.955	71	7.04	1.955	71
QFEX4B,4C,4D,4E	4	5.89	1.955	85	5.88	1.955	85	5.88	1.955	85

- Only the QDEX1 quadrupole changes the position, length and aperture for different L*. The other magnets stay the same.
- The SC quads QDEX1 and QFEX2A are made short with a high gradient compatible with 250 GeV beam energy. They need to be replaced for 500 GeV upgrade.
- The warm quad parameters are compatible with up to 500 GeV beam energy.

Bend field (T), length (m) and aperture (mm) at 250 GeV

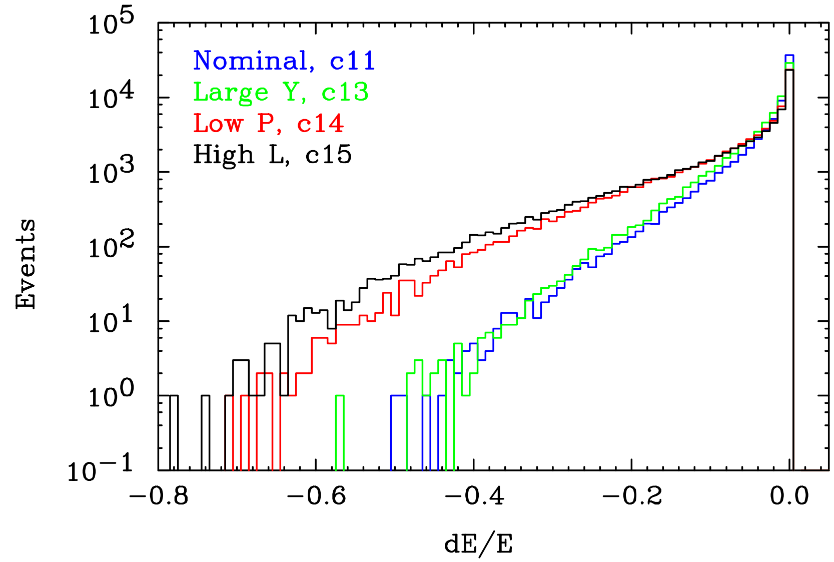
Bends and kickers	Qty	L (m)	B (T)	Half-gap (mm)	Diagnostics
BVEX1E,2E,...,8E	8	2.0	0.4170	85	Energy
BVEX1P,2P	2	2.0	0.4170	117	Polarimeter
BVEX3P	1	2.0	0.6254	117	
BVEX4P	1	2.0	0.6254	132	
BVEX1G,2G	2	2.0	0.4170	147	GAMCAL
XSWEEP	5	0.8	0.071	120	
YSWEEP	5	0.8	0.071	120	

- Diagnostic bends are compatible with 500 GeV beam energy. Polarimeter and GAMCAL bends do not change field with energy.
- Space is reserved to double the number of sweeping kickers at 500 GeV without raising their field.

ILC parameter options at 250 GeV beam energy

- Four disrupted beam options were studied: nominal (option c11), large Y emittance (c13), low power (c14) and high luminosity (c15).
- The beam in options c11 and c13 is less disrupted than in options c14 and c15.
- Additional disruption is caused by large vertical offset between beams at IP.
- Most beam loss occurs in the low energy tail due to overfocusing.

Disrupted energy spread



Maximum IP angles for disrupted electrons and beamstrahlung photons

Option	No beam offset at IP				Large vertical offset at IP			
	electrons		photons		electrons		photons	
	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)
Nominal, c11	529	253	369	212	474	685	366	537
Large Y, c13	956	492	768	396	716	668	573	586
Low P, c14	1104	580	668	344	1120	1190	684	918
High L, c15	1271	431	723	320	1280	1415	783	1232

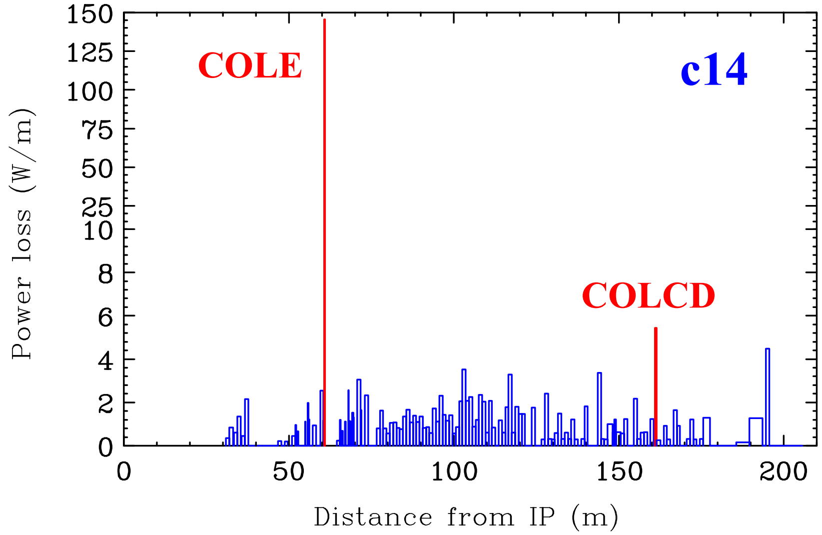
Beam power loss (kW) for optics with L* = 3.51 m without solenoid

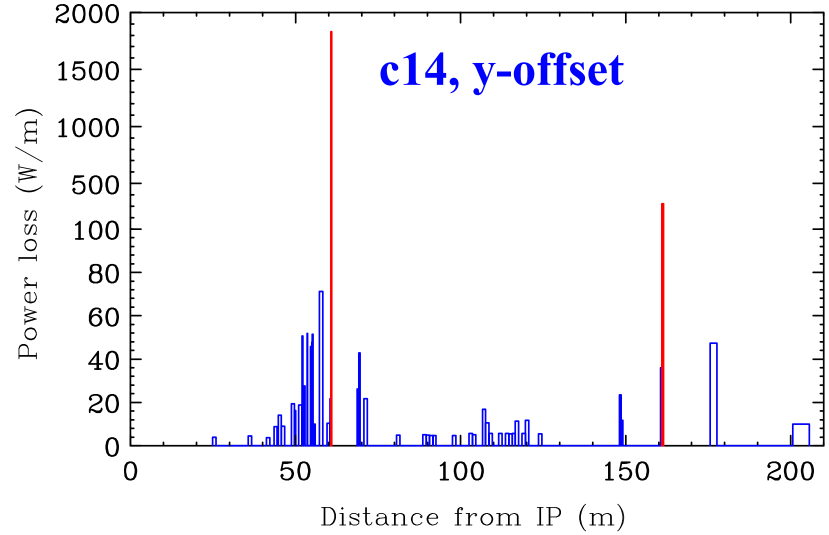
Option	Primary electrons						BS photons		
	Total on magnets and pipe	Diagnostic collimators		Dump collimators			Dump collimators		
		COLE	COLCD	COLW1	COLW2	COLW3	COLW1	COLW2	COLW3
c11	0	0	0	0	0	0.272	0	0	0
c11, y-offset	0.001	0.001	0.0003	1.12	2.59	11.2	0.0001	0.025	0
c13	0.007	0.001	0.0001	1.02	1.57	6.54	0.570	0.820	0
c13, y-offset	0	0.0001	0	1.08	1.76	9.05	0.138	1.82	0
c14	0.126	0.044	0.003	2.62	6.18	26.3	0.035	0.171	0
c14, y-offset	0.581	0.549	0.161	85.9	43.7	82.1	10.9	20.1	0
c15	1.020	0.308	0.011	10.1	21.1	77.5	0.142	0.443	0
c15, y-offset	7.127	3.371	5.360	356.9	122.0	215.4	35.0	51.0	0

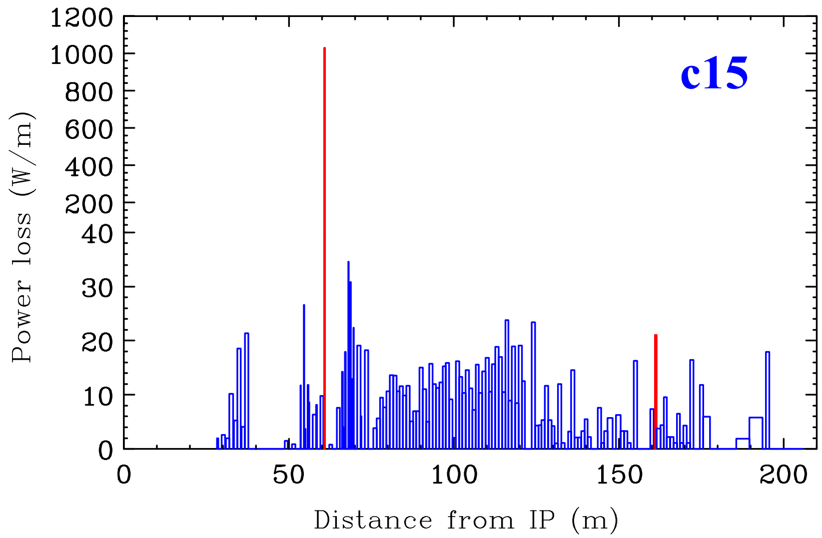
- Without solenoid, the beam loss is small in options c11 and c13, and manageable in option c14. The loss may be too high in option c15.
- It is expected that large y-offsets at IP will be efficiently corrected. A protection system should be considered to prevent beam running with large y-offset for a long time (few seconds, per L. Keller) in order to protect the collimators.

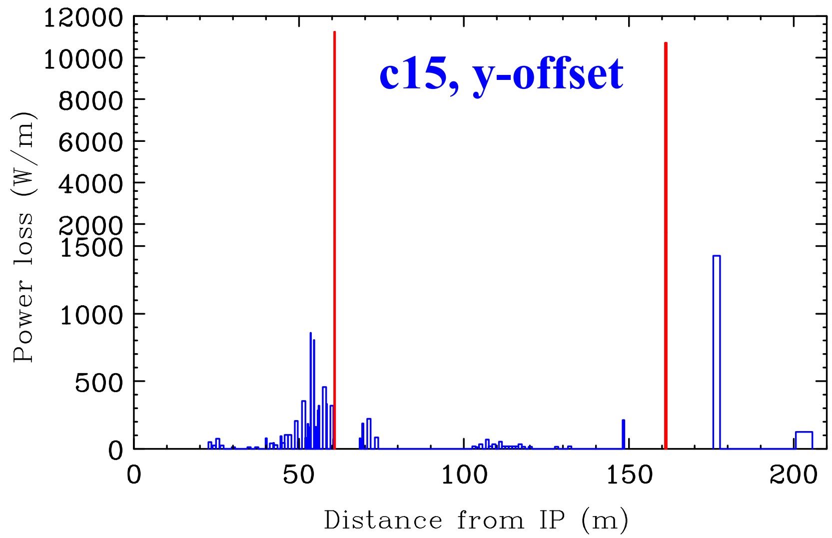
Primary loss density (W/m) for L* = 3.51 m without solenoid

- Losses are small in the nominal (c11) and large Y (c13) options.





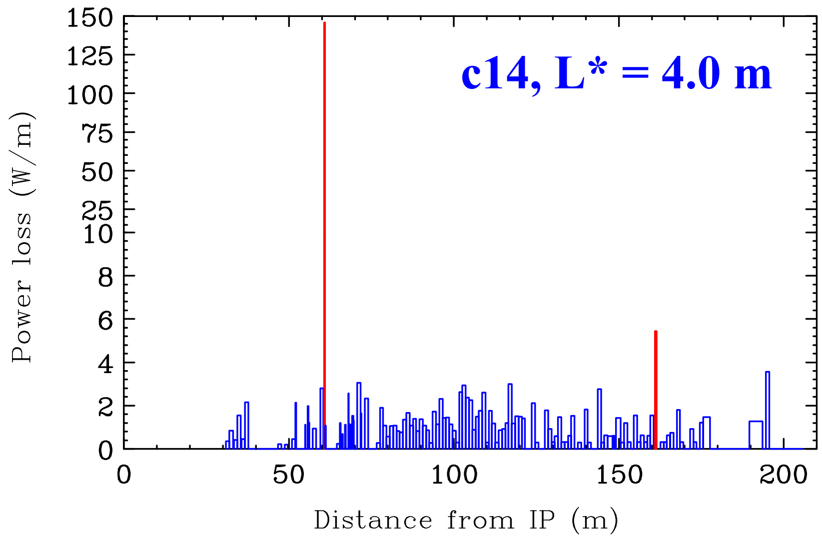


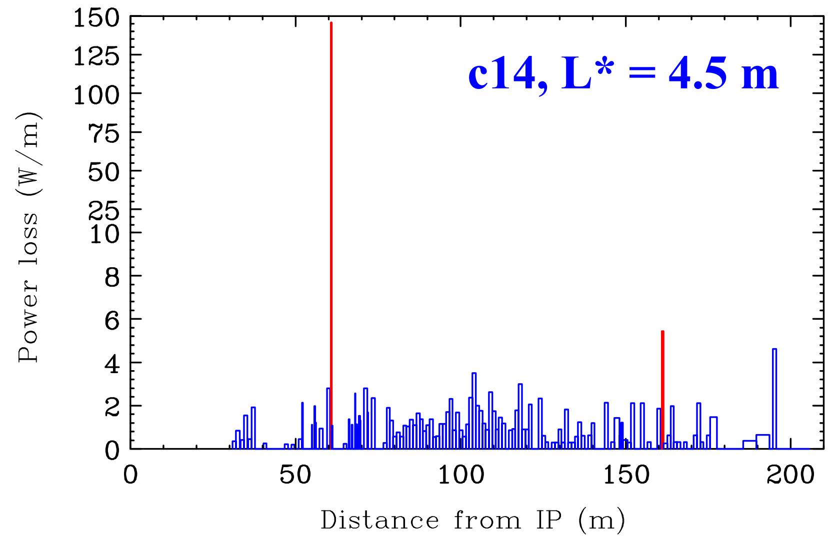


Comparison of power loss (kW) in versions L* = 3.51 m, 4.0 m and 4.5 m without solenoid and without y-offset, for option c14

L* (m)	Total on magnets and pipe	Diagnostic collimators		Dump collimators		
		COLE	COLCD	COLW1	COLW2	COLW3
3.51 m	0.126	0.044	0.003	2.62	6.18	26.3
4.0 m	0.125	0.044	0.003	2.62	6.22	26.3
4.5 m	0.123	0.044	0.003	2.71	6.18	26.3

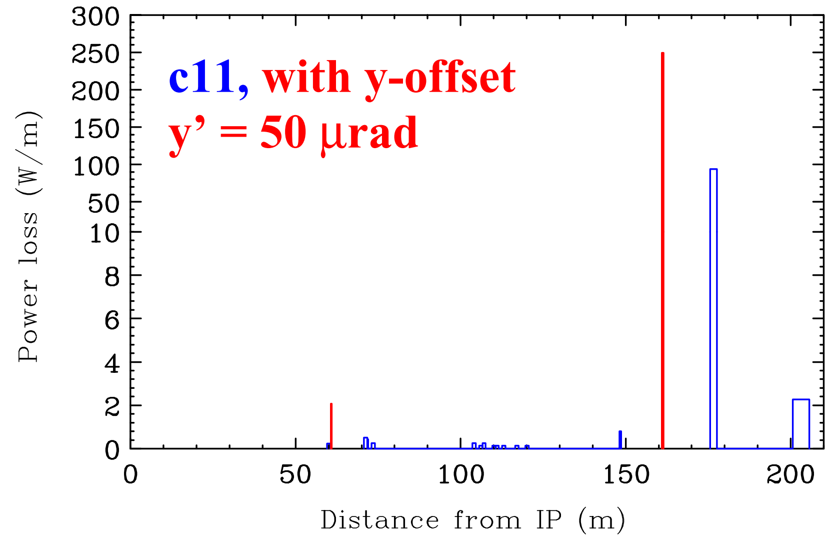
- Electron loss is very similar in the three L* versions.
- Beamstrahlung loss is the same because of the same magnet and collimator aperture.

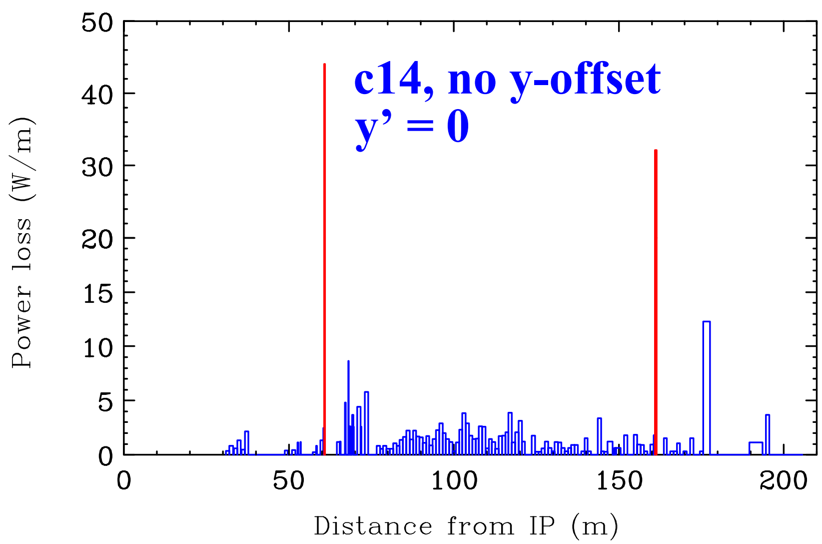


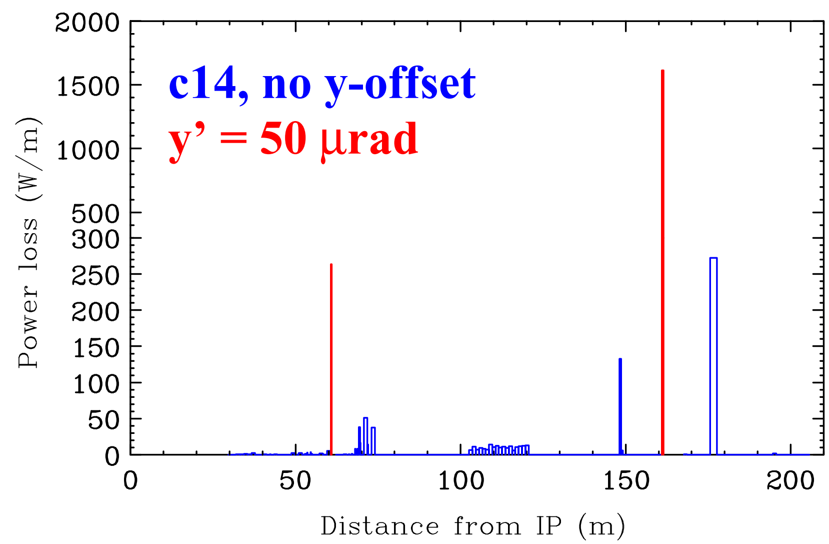


Power loss for L* = 3.51 m with 5T solenoid & orbit correction for cases with IP angle y’ = 0 or 50 μrad and IP y-offset

- The 5T solenoid with orbit correction for y’ = 0 at IP does not significantly increase beam loss.
- But there is a higher loss on diagnostic collimators and near Cherenkov detector for case with y’ = 50 μrad IP angle.

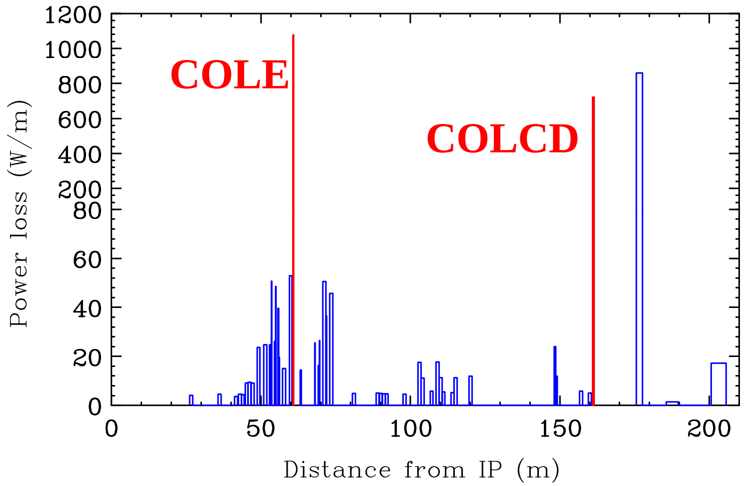




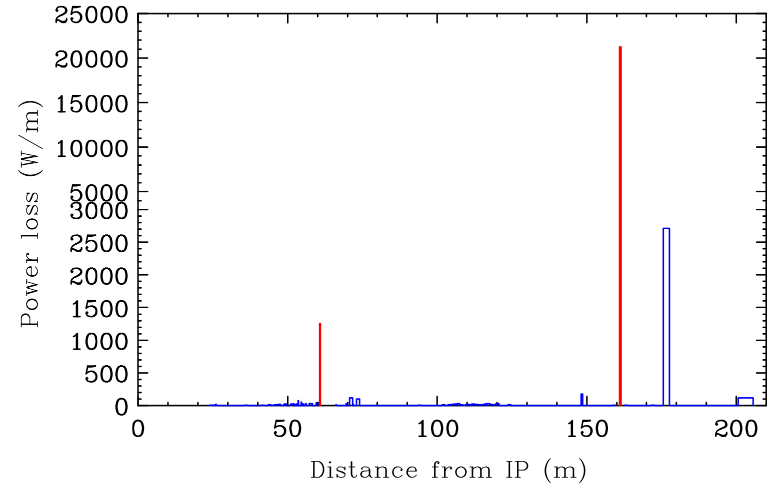


Power loss for L* = 3.51 m with 5T solenoid (cont'd)

c14, y' = 0 with y-offset at IP



c14, y' = 50 μrad with y-offset at IP



• Loss on magnets is still small or modest, but loss on diagnostic collimators may become high when both y-offset and y-angle at IP are large, particularly in high disruption options c14 (c15). Therefore, large IP orbit offsets need to be efficiently controlled. Further improvement of diagnostic collimation system should be studied.

• The source of the higher loss is the non-linear dispersion created by the corrector field. It increases the orbits of low energy electrons which may be consequently lost.

• In order to reduce the non-linear dispersion, the corrector fields need to be lowered and, possibly, brought closer to IP for more local correction. The following may be considered:

- The uncorrected IP y-angle is minimized,
- The anti-DID field is increased, so the correcting fields on the SC quads are reduced.

Summary

• 14 mrad extraction optics compatible with push-pull detector configuration for a range of L* from 3.51 m to 4.5 m is designed.
• Modifications are made to diagnostic polarimeter bends and two new bends are included which improve acceptance of Compton backscattered electrons in the Cherenkov detector and provide optics for the proposed Gamma Calorimeter.
• Fast kickers are included for reduction of the undisrupted beam power density at the dump to acceptable level.
• 5T post-IP solenoid including anti-DID field with orbit and focusing correction have been modeled. It is found that disrupted beam loss on magnets is still small in the nominal option and should be manageable in a large energy spread option (c14). However, a high loss may occur at diagnostic collimators when there is a very large y-offset and non-zero y-angle at IP, particularly in option c14. This loss is driven by non-linear dispersion from the dipole correctors. To reduce this effect, the following may be considered: a) the “design” IP y-angle is minimized, b) anti-DID field is increased, c) dipole corrector field is brought closer to IP. In machine operation, the beam running with large y-offsets at IP should be efficiently detected and prevented.