# ILC Extraction Line simulations with TDR parameters

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# Introduction

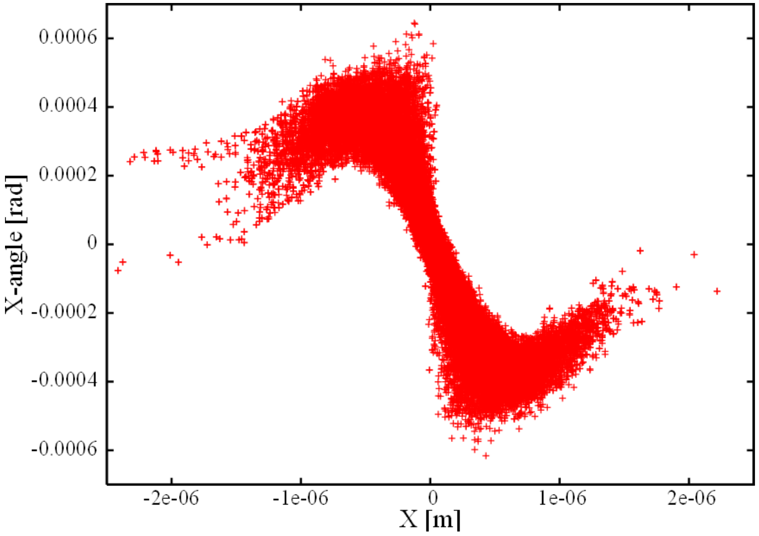
- The goal of the study is to evaluate the impact of the latest ILC beam parameters at IP (ILC TDR 2013) on beam loss in the extraction line, and compare the results to previously used parameter sets – the “nominal” and the so-called “low power” (low-P) options (ILC RDR 2007). These two sets are the closest to the TDR parameter set.
- The study was performed for the extraction line optics corresponding to L* = 4.5m.
- Beam collision at IP generates a disrupted beam with a very long low energy tail and large angular spread leading to beam loss in the extraction line.
- The disrupted beam particle data was generated using Guinea-Pig.
- The generated particles were tracked in the extraction line using DIMAD to determine the beam loss.
- A large number of particles needs to be generated (≥ several million) in order to obtain sufficient statistics in the low energy tail where most of the beam losses occur. Tracking this huge beam data not only would require a long cpu time, but would also pose a space problem on unix system. In practice, however, it is sufficient to track only the tail particles (~1% of the total beam) in order to determine the losses. Hence, the procedure was to generate the complete beam data on a PC, then extract the much smaller beam tail data for tracking.

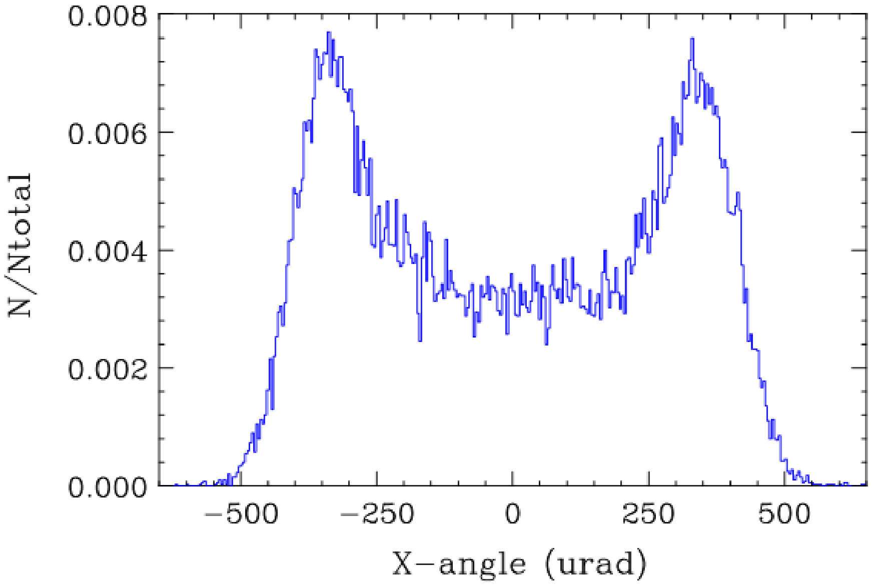
# IP beam parameters in the TDR 2013 and the RDR 2007 nominal and low-P options

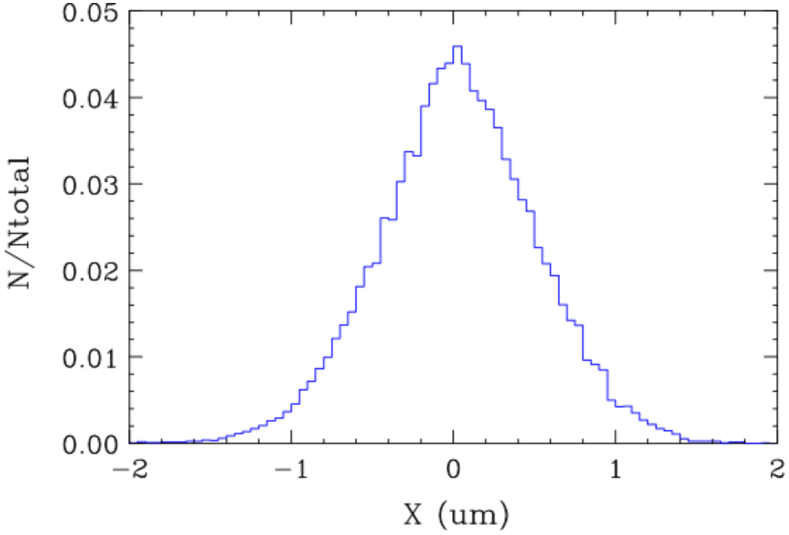
| | E GeV | Ne | Nb | fRF Hz | P MW | βx* mm | βy* mm | σz mm | γεx m·rad | γεy m·rad | Dx | Dy | δBS % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDR 2013 | 250 | $2\cdot10^{10}$ | 1312 | 5 | 5.25 | 11 | 0.48 | 0.3 | 10-5 | $3.5\cdot10^{-8}$ | 0.30 | 24.6 | 4.5 |
| Nominal | 250 | $2\cdot10^{10}$ | 2625 | 5 | 10.5 | 20 | 0.40 | 0.3 | 10-5 | $4.0\cdot10^{-8}$ | 0.17 | 19.4 | 2.4 |
| Low-P | 250 | $2\cdot10^{10}$ | 1320 | 5 | 5.29 | 11 | 0.2 | 0.2 | 10-5 | $3.6\cdot10^{-8}$ | 0.21 | 26.1 | 5.5 |

- Here, Ne is the number of particles per bunch, Nb – number of bunches per pulse, fRF – repetition rate, P – total beam power, β* – beta function at IP, σz – bunch length, γε – normalized emittance, Dx,y – the disruption parameter, and δBS – the fractional rms energy loss to beamstrahlung.
- The parameter δBS is an average fractional energy loss to beamstrahlung which correlates with the extent of the disrupted beam low energy tail. Based on the δBS values, it is expected that the extraction loss with the TDR 2013 parameters will be higher than in the RDR 2007 nominal option, but lower than in the low-P option.

# TDR disrupted X-phase space at IP (4·104 particles)



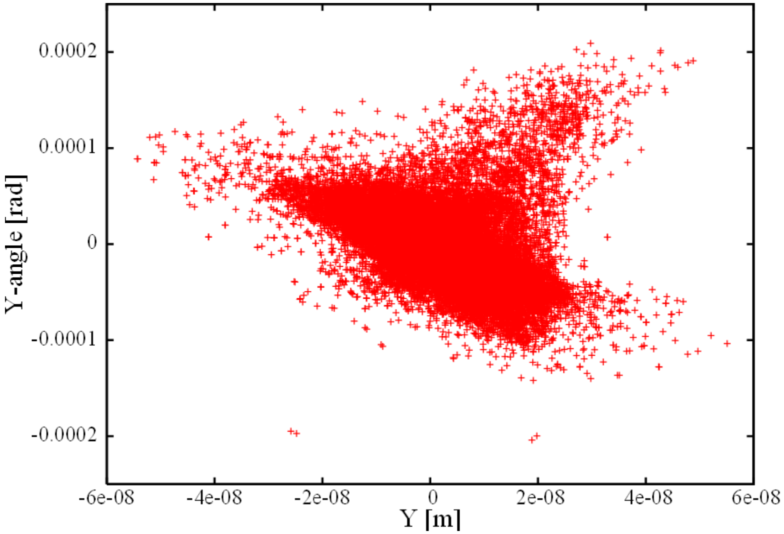


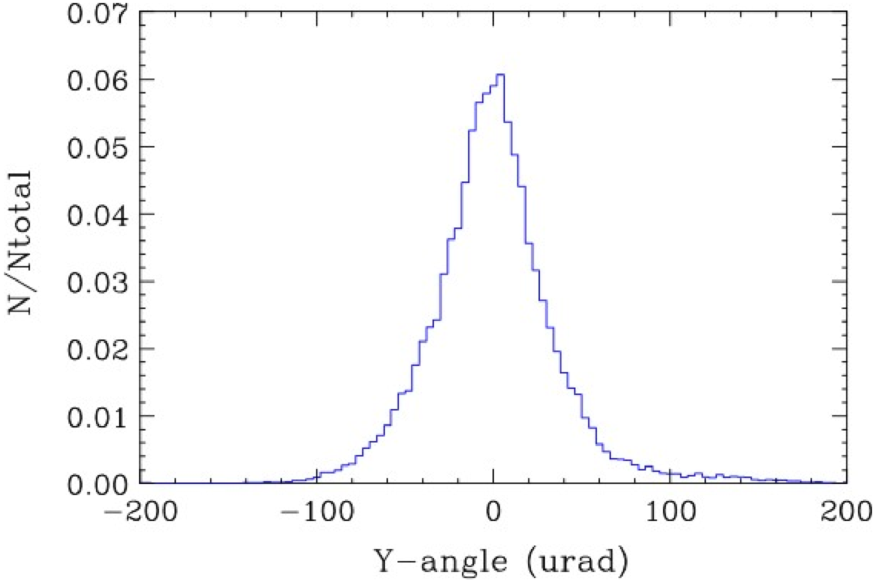


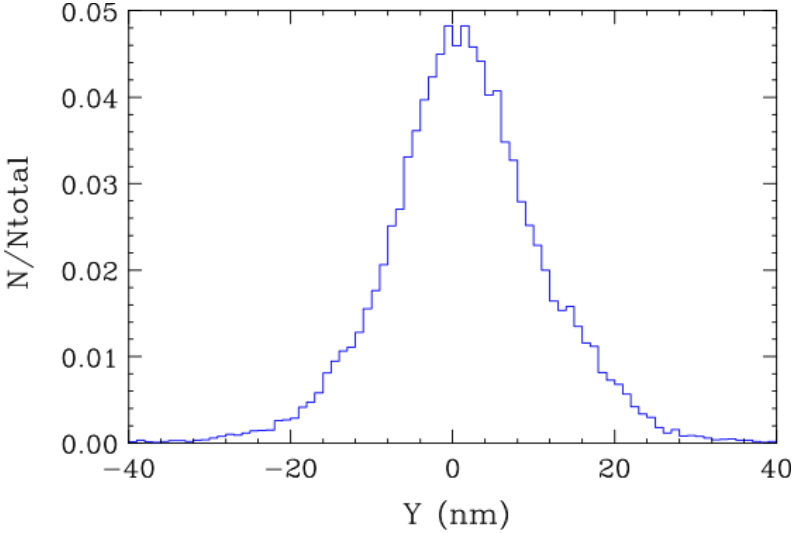
| at IP | σ*x | σ*x’ | γεx |
|---|---|---|---|
| undisrupted | 474 nm | 43 μrad | 1.0e-5 |
| disrupted | 493 nm | 284 μrad | 3.6e-5 |

A factor of 6.6 increase of X-angle spread

# TDR disrupted Y-phase space at IP (4·104 particles)





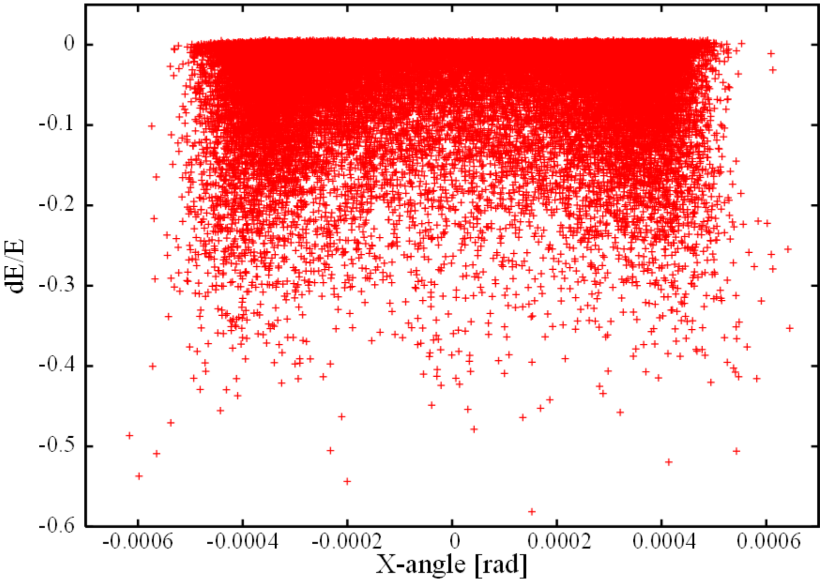


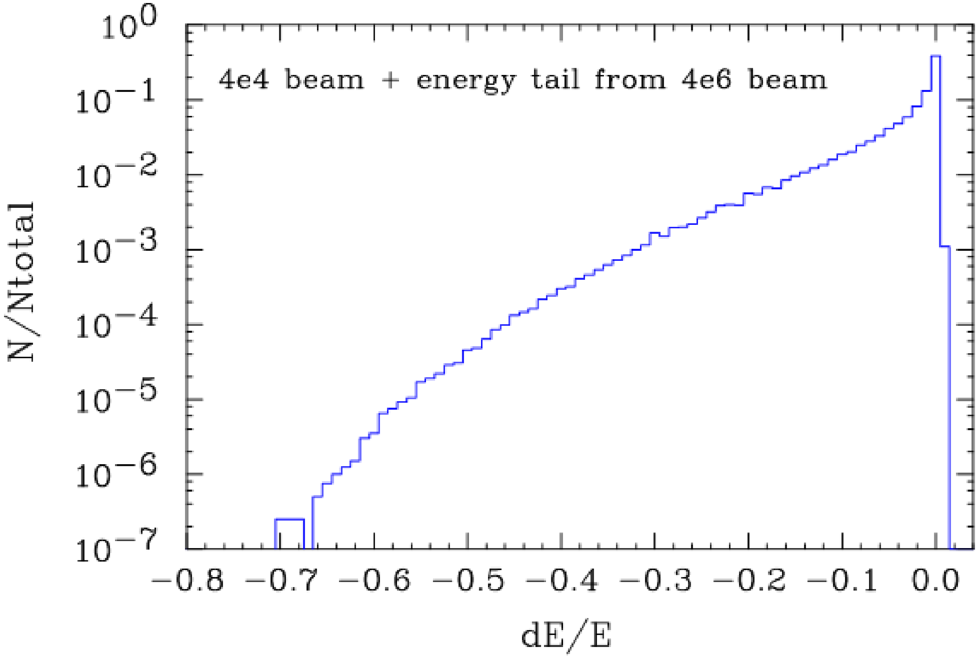
| at IP | σ*y | σ*y’ | γεy |
|---|---|---|---|
| undisrupted | 5.9 nm | 12.2 μrad | 0.35e-7 |
| disrupted | 9.9 nm | 36.2 μrad | 1.64e-7 |

A factor of 3 increase of Y-angle spread

# TDR disrupted energy spread at IP

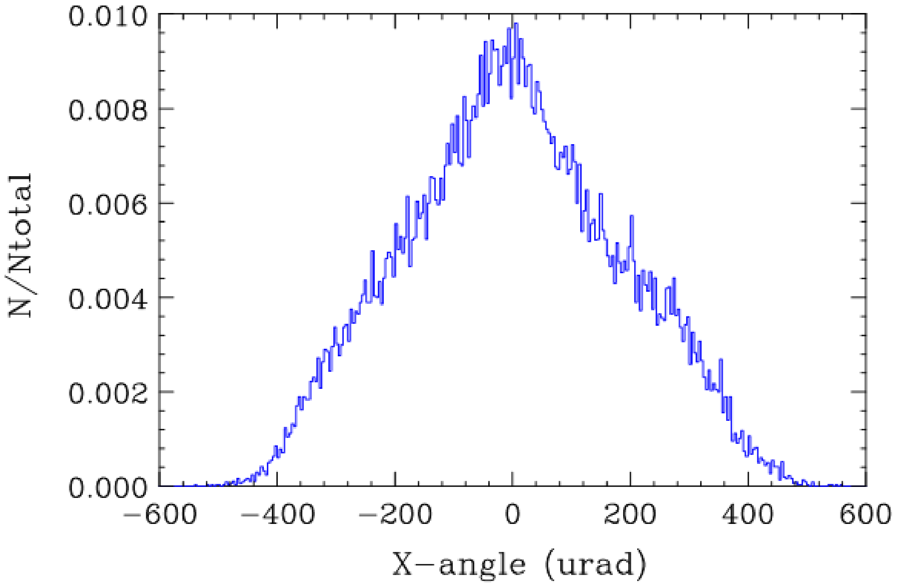
4·104 particles

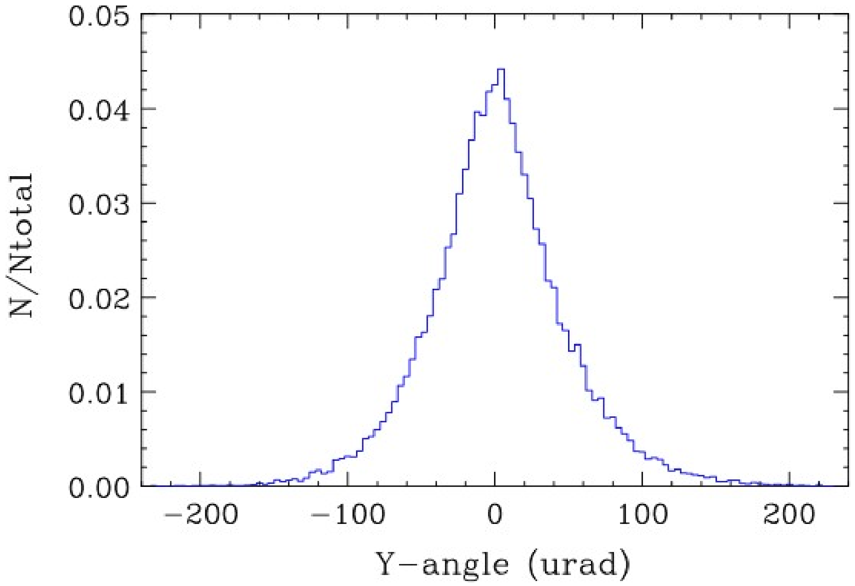




Low energy tail and large X-angles at IP in the disrupted beam are the main sources for extraction line beam loss.

# TDR beamstrahlung photons at IP (3.6·104)

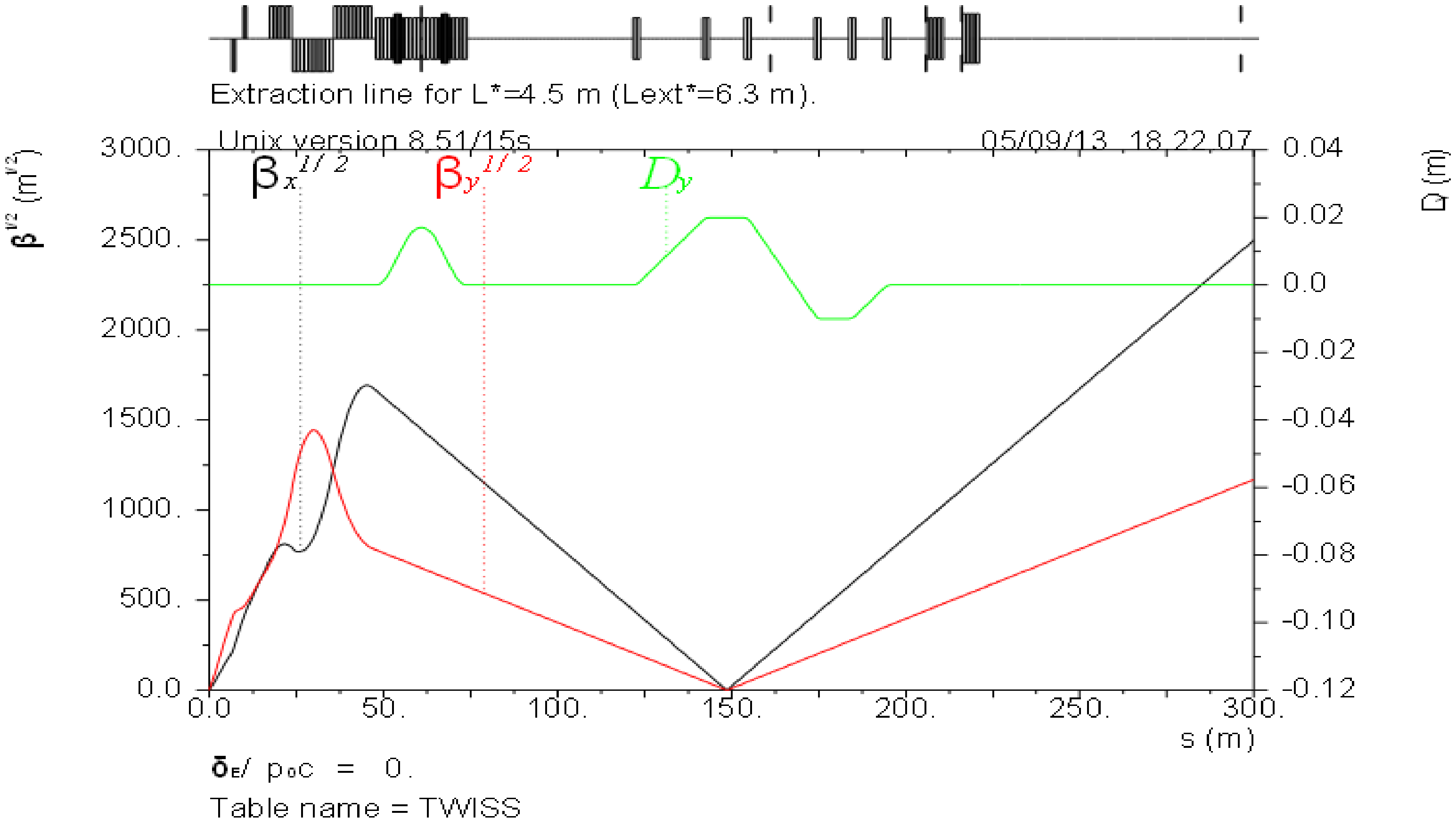




| σ*x’ | σ*y’ | x’max | y’max |
|---|---|---|---|
| 184 µrad | 47 µrad | 559 µrad | 308 µrad |

Photon trajectories are not affected by the extraction magnets, hence the photon loss is strictly determined by the photon X/Y angles at IP and aperture in the extraction line.

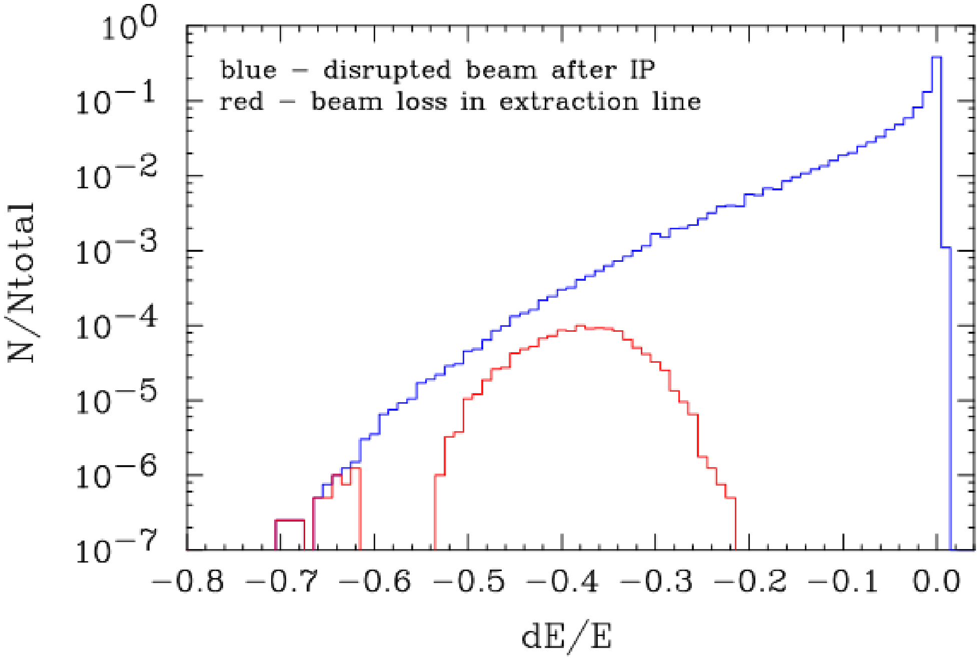
# Extraction line optics for L* = 4.5 m (L*ext = 6.3 m)

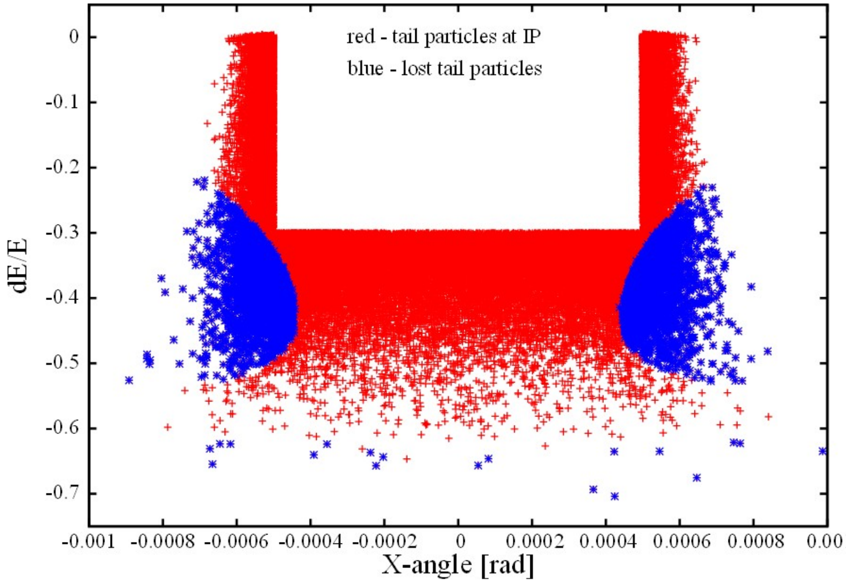


| at IP | β*x | α*x | β*y | α*y |
|---|---|---|---|---|
| undisrupted | 11 mm | 0 | 0.48 mm | 0 |
| disrupted | 3.29 mm | 1.609 | 0.294 mm | 0.386 |

# TDR disrupted beam loss in the extraction line without detector solenoid

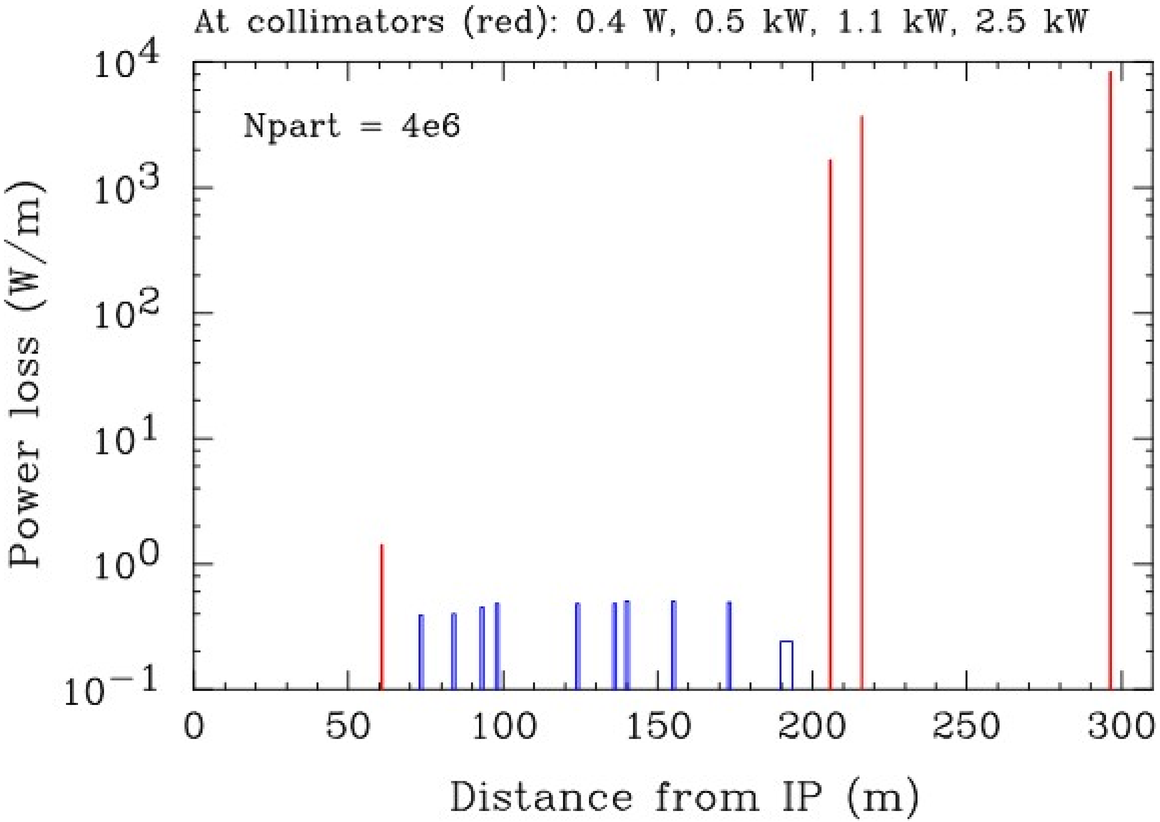
- Extraction beam loss may occur when particles have both low energy and large X-angle at IP.
- To determine the complete loss it is sufficient to track only the beam tail where E<0.7×E0 or IP X/Y angles >0.5 mrad (~1.3% particles of the total beam).
- A beam tail of 52289 particles (red area in the right-hand side figure) was extracted from the disrupted beam of 4·106 particles and tracked using DIMAD. The resulting beam loss amounted to 5062 particles. Their initial IP distribution is shown in blue in the right-hand side figure and in red in the left-hand side figure.





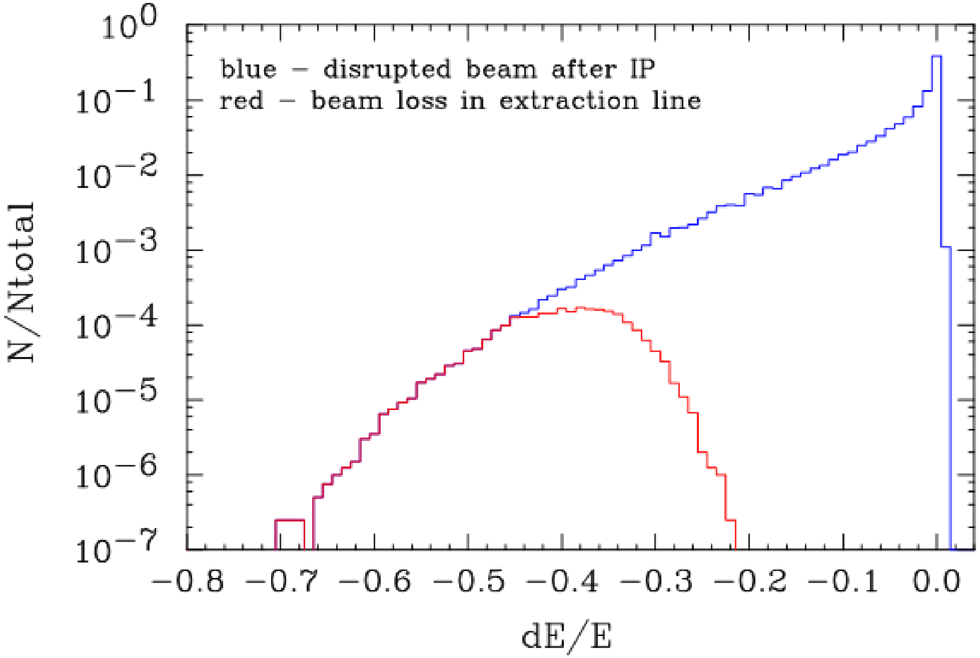
# TDR disrupted beam power loss in the extraction line without detector solenoid

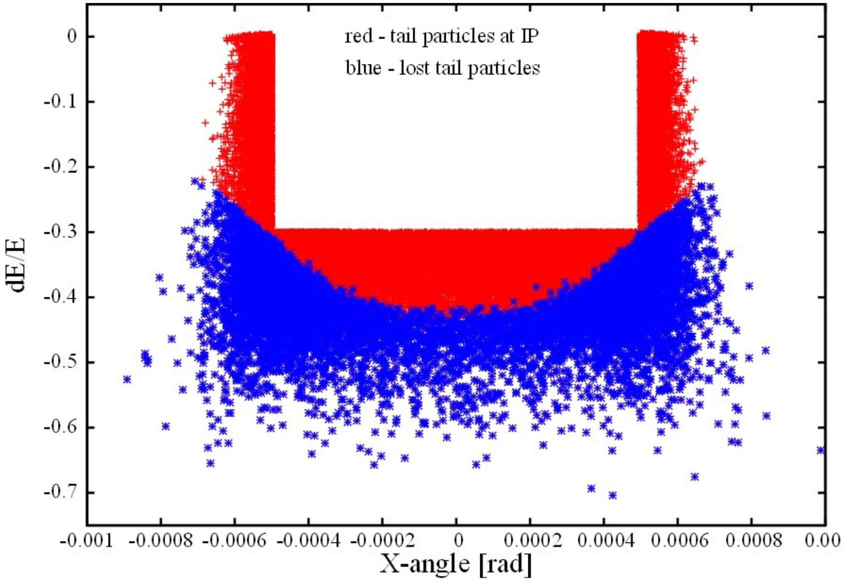
- The beam power loss is obtained by tracking the tail of the 4·106 beam.
- Most losses occur in the last three collimators (shown in red) which constrain the beam spot to the size of the dump window.
- Power loss in the warm magnets is ≤0.5 W/m which should be acceptable. There is no loss in the SC quadrupoles.



# TDR disrupted beam loss in the extraction line with detector solenoid

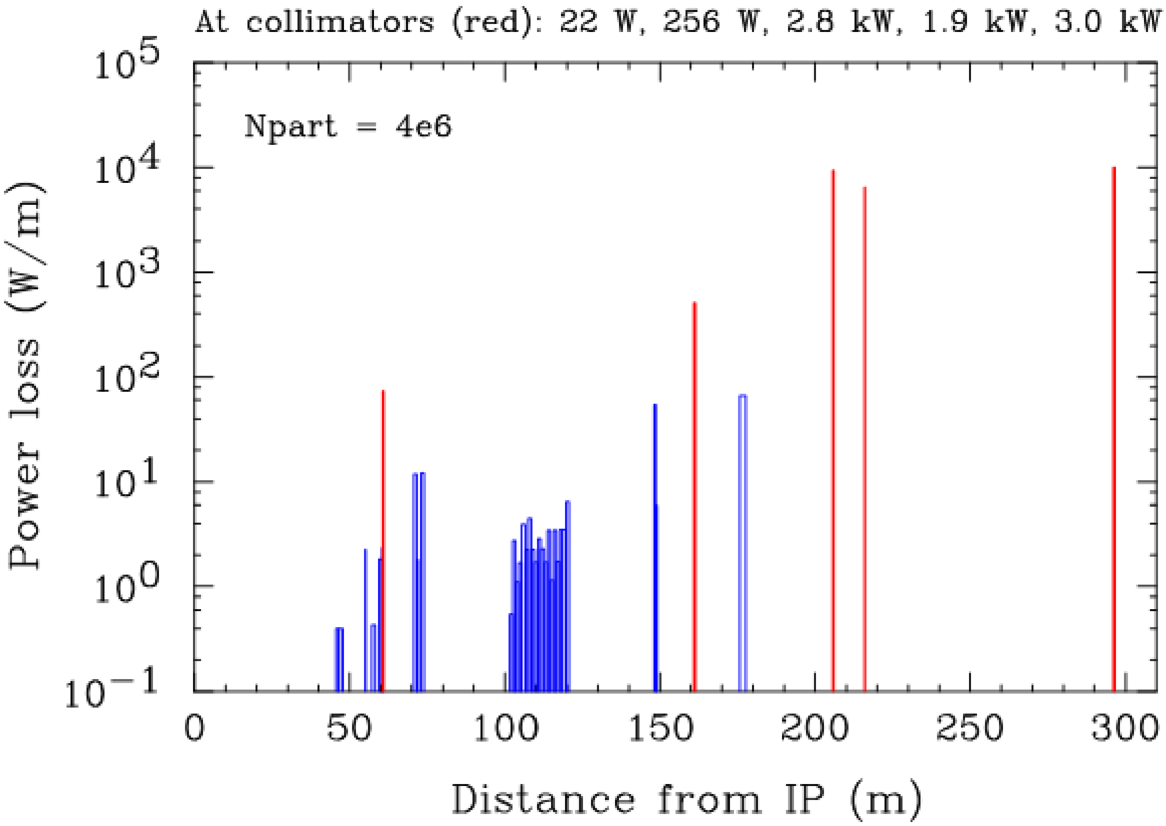
- SiD detector solenoid field model and the correcting anti-DID field are used. Residual orbit from the IP and from the solenoid is corrected by 4 extraction dipole correctors.
- It is assumed that incoming orbit at IP has non-zero Y-angle due to the effect of the upstream part of the solenoid. The extraction beam loss increases with the larger Y-angle. A conservatively large value of <Y'> = 100 μrad is used for the tracking.
- Extraction loss was obtained by tracking the same beam tail at IP as in the case without solenoid. The solenoid increases the total loss a factor of 2. This is due to residual dispersion from the solenoid resulting in losses of low energy particles with small IP angles. Compensation of incoming <Y'> at IP would reduce the losses.





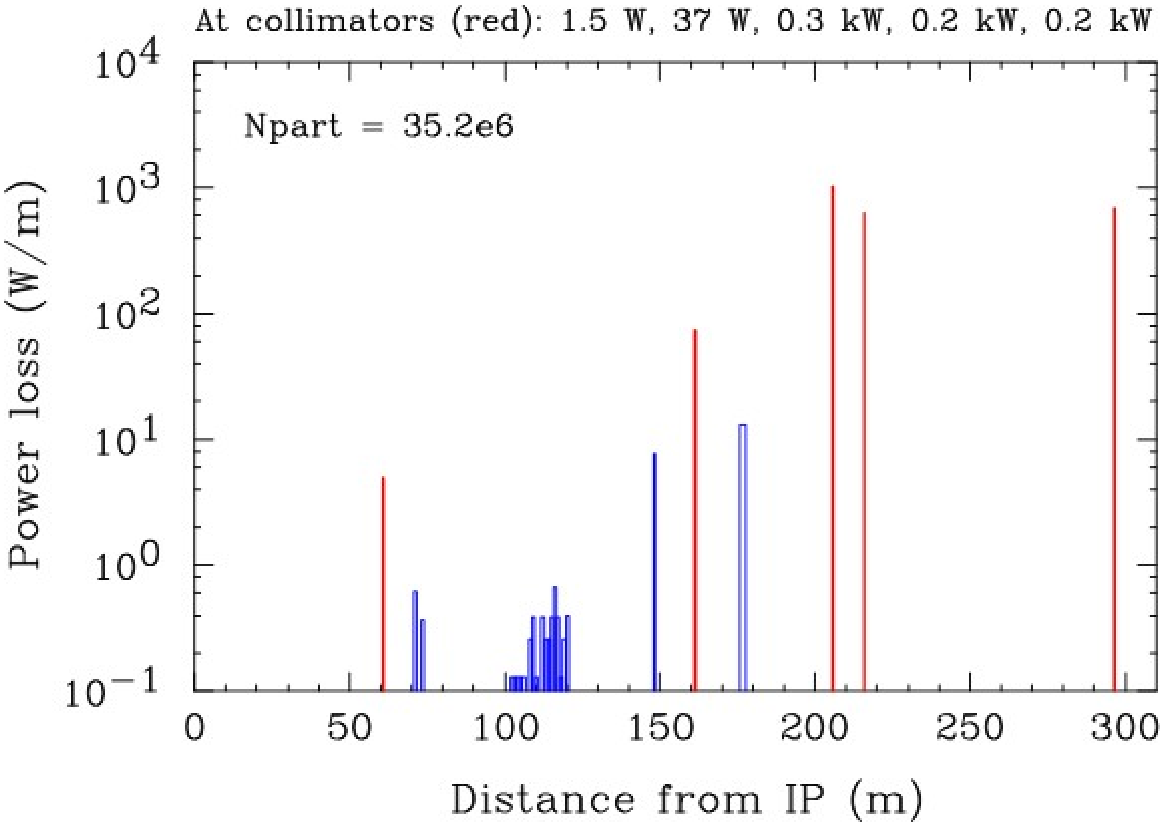
# TDR disrupted beam power loss in the extraction line with detector solenoid

- Most losses occur in the collimators (shown in red).
- Power loss in the warm magnets is ≤12 W/m which should be acceptable. There is no loss in the SC quadrupoles.



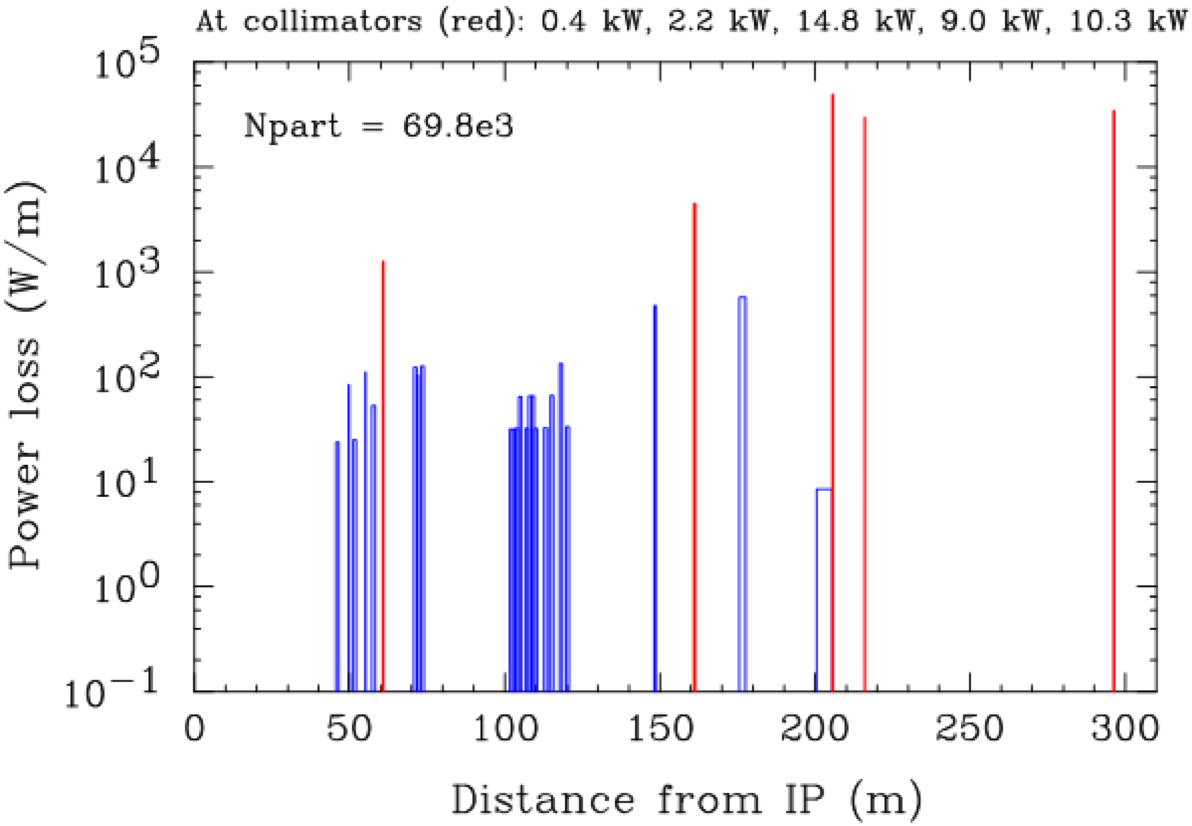
# Extraction beam power loss in the RDR 2007 nominal option with detector solenoid

- Tracking was performed using a low energy tail from 35·106 beam, and the same solenoid model and IP Y-angle = 100 μrad as in the TDR tracking.
- Power loss in the warm magnets is ≤0.6 W/m which should be acceptable. There is no loss in the SC quadrupoles.



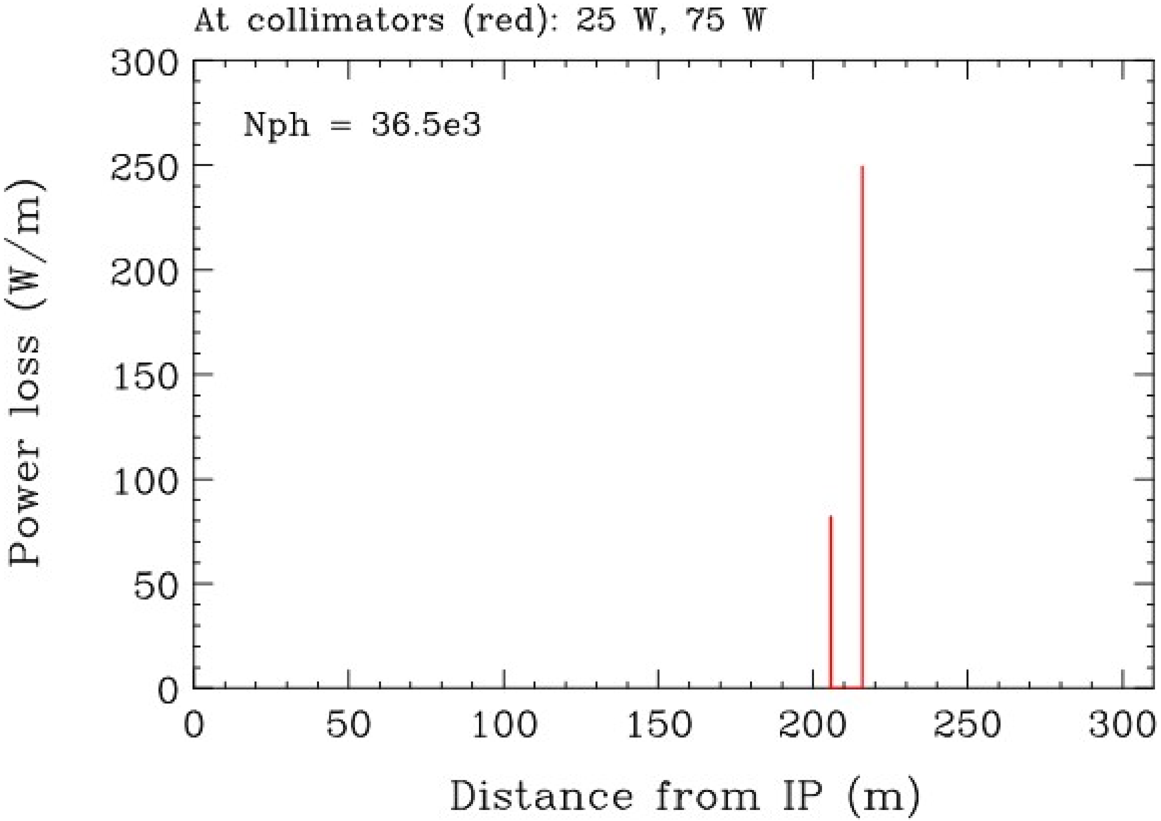
# Extraction beam power loss in the RDR 2007 low-P option with detector solenoid

- Tracking was performed using a full beam with 69.8·103 particles, and the same solenoid model and IP Y-angle = 100 μrad as in the TDR tracking.
- Power loss in the warm magnets is ≤130 W/m. There is no loss in the SC quadrupoles.



# TDR beamstrahlung photon power loss in the extraction line

- Photon loss is determined only by photon angles at IP and extraction aperture.
- Extraction acceptance for IP photons is ±0.75 mrad within the magnets and diagnostic (S = 0 to 200 m), and ±0.5 mrad in the dump collimators (S = 200 to 300 m).
- Tracking was performed for 36.5·103 photons corresponding to 20·103 electrons.
- Total photon loss is small (100 W) and occurs at two dump collimators.



# Summary of extraction loss and conclusions

| | Magnets | | Detectors | | Collimators | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SC | Warm (max) | Synchrotron | Cherenkov | Energy | Cherenkov | Dump-1 | Dump-2 | Dump-3 |
| TDR 2013 | 0 | 12 W/m | 30 W | 130 W | 22 W | 0.3 kW | 2.8 kW | 1.9 kW | 3.0 kW |
| Nominal | 0 | 0.6 W/m | 4 W | 26 W | 2 W | 37 W | 0.3 kW | 0.2 kW | 0.2 kW |
| Low-P | 0 | 130 W/m | 0.5 kW | 0.6 kW | 0.4 kW | 2.2 kW | 14.8 kW | 9.0 kW | 10.3 kW |

- Extraction losses with the TDR 2013 IP parameters are a factor of 10 higher than in the RDR 2007 nominal option, but a factor of 5 lower than in the low-P option.
- The TDR losses on magnets and collimators look acceptable. Losses on the Synchrotron and Cherenkov detectors may need an expert opinion to evaluate the impact of background.
- The TDR beamstrahlung photon losses are small.

Note: The calculations were done assuming ideal collision conditions. Non-ideal conditions, such as large vertical beam-to-beam separation at IP, will increase the disruption and the extraction beam loss. Evaluation of this effect requires a special study.