Design of Extraction Line Optics for 20 mrad and 2 mrad IRs

Y. Nosochkov (SLAC)
for SLAC-BNL-UK-France task group

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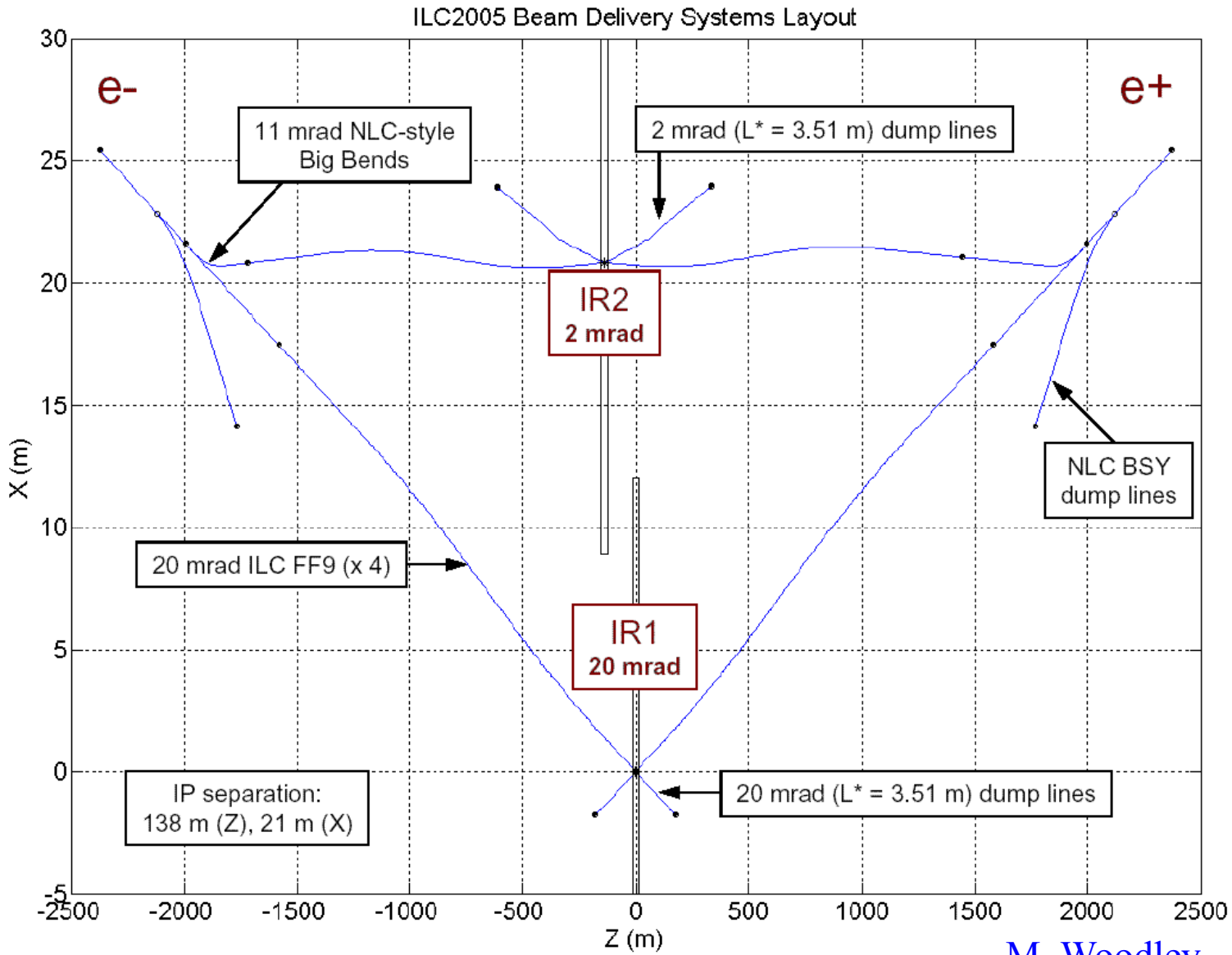
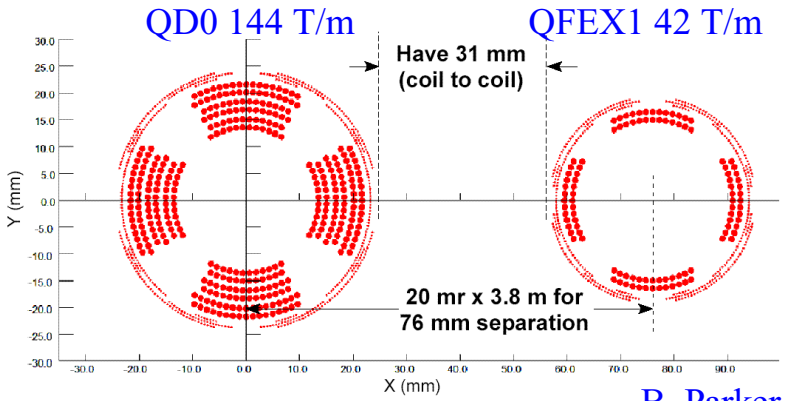
Layout of BDS with 20 mrad and 2 mrad IRs



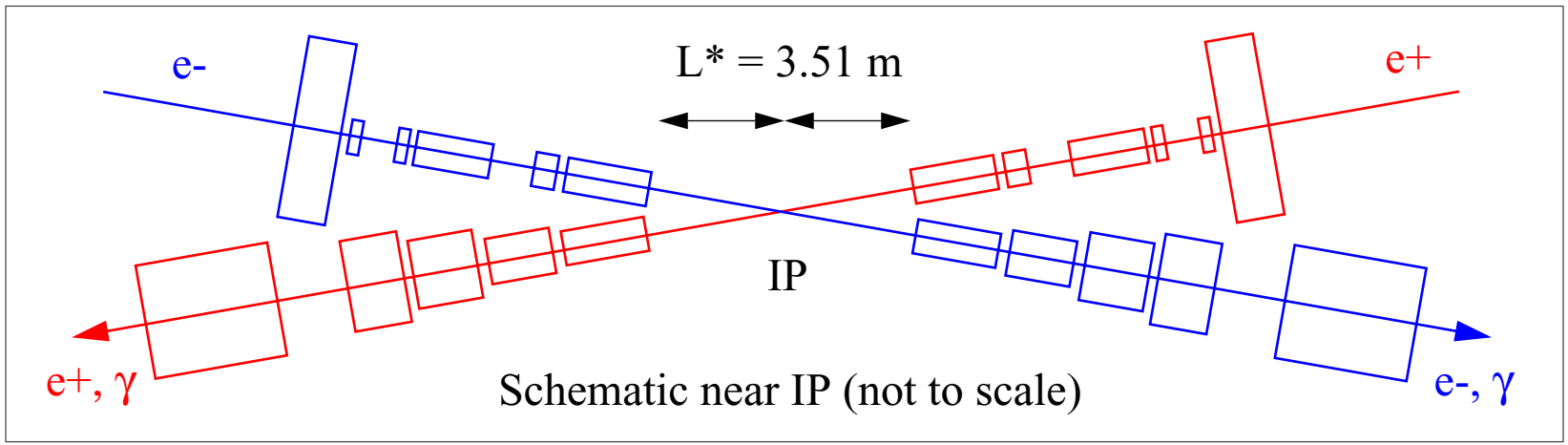
M. Woodley

20 mrad Extraction Design

- Extracted primary electron and photon beams share the same beam line and dump.
- Independent magnets in the extraction and incoming lines except detector solenoid.
- Dedicated vertical chicanes and 2nd focus for energy and polarization diagnostics.
- L* = 3.51 m for same position of the first extraction and FF incoming quads near IP (options with larger L* possible).
- SC quads with compact coils near IP where horizontal space is limited, then warm magnets downstream.
- Dump at ~180 m from IP.
- 500 and 1000 GeV cms energy.



B. Parker



20 mrad Extraction Optics

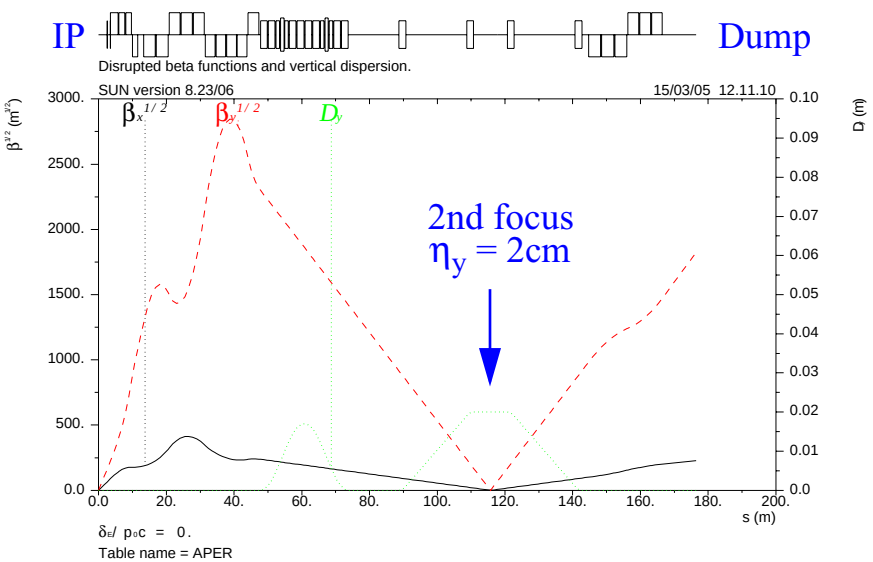
Option with first focusing quad

- Advantage - smaller beam loss at ideal IP collisions, when disrupted horizontal IP angles are larger.
- Disadvantage - 1) less favorable transformation from IP to 2nd focus: R_{22} = -0.137, R_{44}=-0.529; and 2) larger beam loss for IP collisions with large vertical offset between beams.
- Undisrupted σ_x / σ_y: 4.8 / 20 μm at 2nd focus, 0.28 / 0.41 mm at dump.

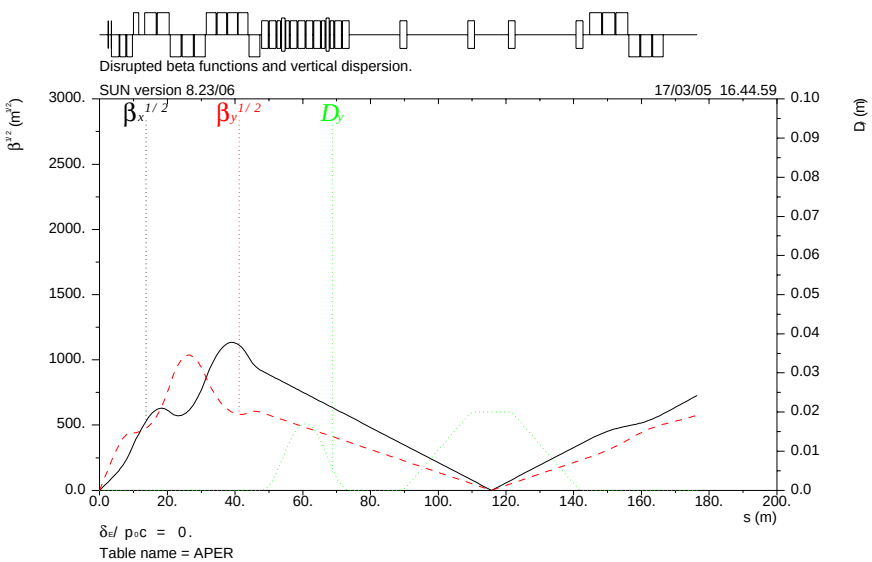
Option with first defocusing quad (all quad polarities reversed)

- Advantage - 1) more favorable transformation from IP to 2nd focus: R_{22} = -0.529, R_{44}=-0.137; and 2) smaller beam loss with large vertical offset between beams at IP.
- Disadvantage - larger beam loss at ideal IP collisions.
- Undisrupted σ_x / σ_y: 1.2 / 20 μm at 2nd focus, 0.89 / 0.13 mm at dump.

Energy Polarimeter



Same optics, but with quad polarities reversed



Extraction magnets for 20 mrad IR

Quad	L (m)	G (T/m) at 1 TeV	B (T) at pole	R (mm)
QFEX1A	2.2	41.667	0.5	12
QFEX1B	1.70742	70.588	1.2	17
QFEX1C	1.70742	50.000	1.2	24
QDEX2A	1.47516	-40.000	-1.2	30
QDEX2B,2C	3.47892	-27.907	-1.2	43
QFEX3A	3.27523	27.907	1.2	43
QFEX3B	3.27523	26.087	1.2	46
QFEX3C	3.27523	20.690	1.2	58
QDEX4A	2.84092	-16.901	-1.2	71
QDEX4B,4C,4D	2.84092	-15.584	-1.2	77
QFEX5	3.21911	16.901	1.2	71
QDEX6A,6B,6C	3.56313	-3.200	-0.8	250
QFEX7A,7B,7C	3.18724	3.200	0.8	250

- All chicane bends are L = 2 m long with B = 0.8339 T field at 1 TeV cms energy.

Disrupted Beam Parameters at IP

- IP parameters for recently proposed nominal and high luminosity options.
- Guinea-Pig disrupted beam distributions for ideal IP collisions and for collisions with large vertical offset between beams.

Maximum angles and lowest particle energy for disrupted beam at IP

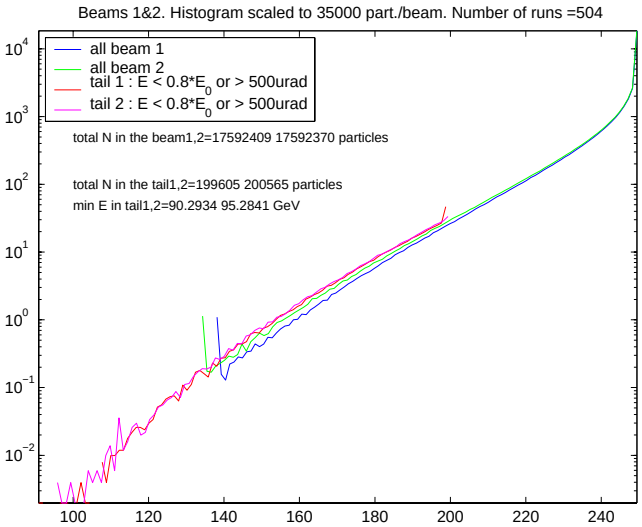
	Ideal collision at IP		
E_{cms} (GeV)	$\frac{E_{min}}{E_0}$	electron X'_{max} / Y'_{max} (μrad)	photon X'_{max} / Y'_{max} (μrad)
500 nominal	0.36	529 / 253	369 / 212
500 high lumi	0.17	1271 / 431	723 / 320
1000 nominal	0.20	496 / 159	271 / 148
1000 high lumi	0.063	2014 / 489	937 / 296

Large vertical offset Δy between beams at IP			
Δy (nm)	$\frac{E_{min}}{E_0}$	electron X'_{max} / Y'_{max} (μrad)	photon X'_{max} / Y'_{max} (μrad)
200	0.36	474 / 674	366 / 537
120	0.17	1280 / 1415	782 / 1232
100	0.19	423 / 566	279 / 408
80	0.062	1731 / 1592	974 / 1200

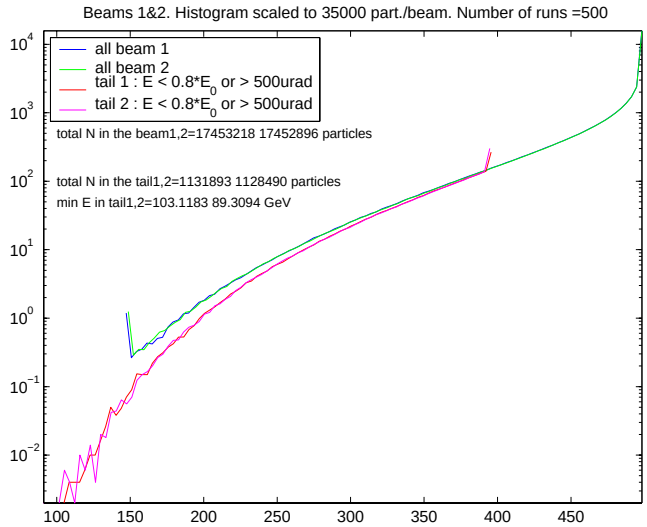
- Total extracted beam power is 11.29 MW for 500 GeV cms and 18.07 MW for 1000 GeV.

Disrupted Energy Spread

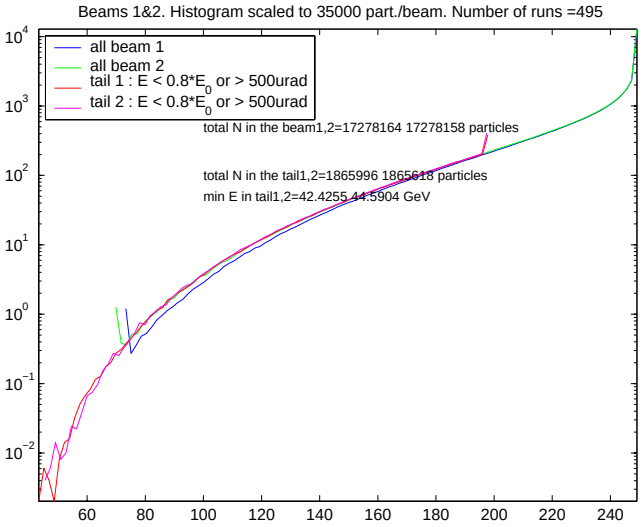
500 nominal



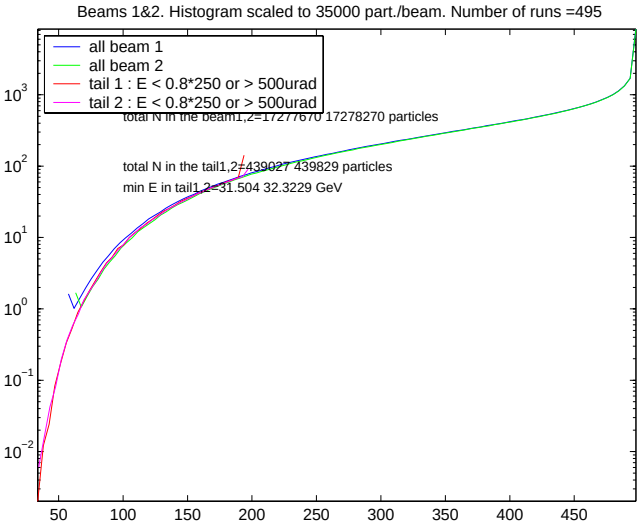
1000 nominal



500 high luminosity



1000 high luminosity



Tracking Beam Loss in 20 mrad Extraction Line

- Number of generated particles up to 35 million.
- Tracked only beam tail with <65% energy and >500 μrad IP angles.

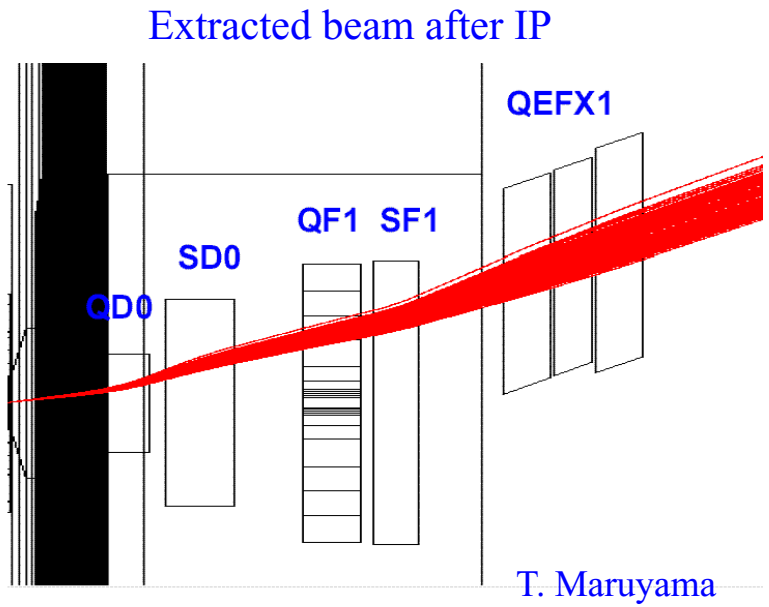
		Ideal collision at IP			Large vertical offset between beams at IP	
E_{cms} (GeV)	Quad option	Total loss (kW)	Max density (W/m)		Total loss (kW)	Max density (W/m)
500 nominal	F	0	0		6.4e-3	0.5 (all), 0.05 (QDEX4B)
	D	0.26e-3	0.13 (all), 0 (quad)		1.4e-3	0.3 (all), 0 (quad)
500 high lumi	F	1.76	90 (all), 60 (QFEX5)		14.3	400 (all), 520 (QDEX4A)
	D	3.54	90 (all), 95 (QDEX4A)		9.97	300 (all), 220 (QFEX5)
1000 nominal	F	0.117	6 (all), 4 (QFEX5)		3.89	160 (all), 45 (QDEX4A)
	D	0.456	10 (all), 3 (QDEX4A)		1.98	50 (all), 40 (QFEX5)
1000 high lumi	F	47.9	1300 (all), 4500 (QDEX4D)		325.4	10400 (all), 14600 (QFEX3C)
	D	49.2	900 (all), 4900 (QFEX3C)		274.4	6600 (all), 7000 (QFEX3C)

* In the table, "Q..." refers to quads between IP and 1st chicane, "all" to the rest of optics.

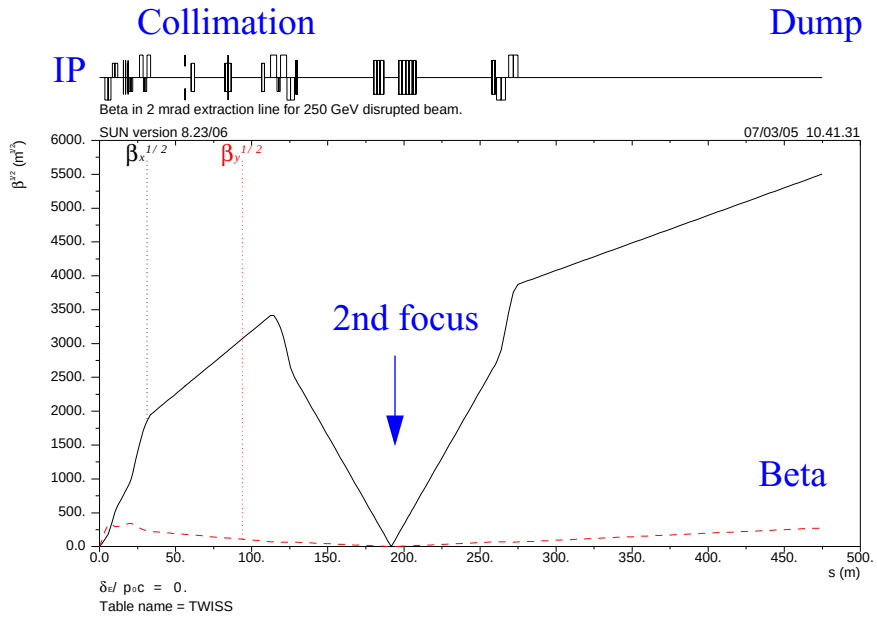
- Beam loss is acceptable in 500 GeV nominal case, may be acceptable in 1000 GeV nominal and 500 GeV high luminosity cases with warm magnets after ~20 m after IP, and unacceptable in 1000 GeV high luminosity case.

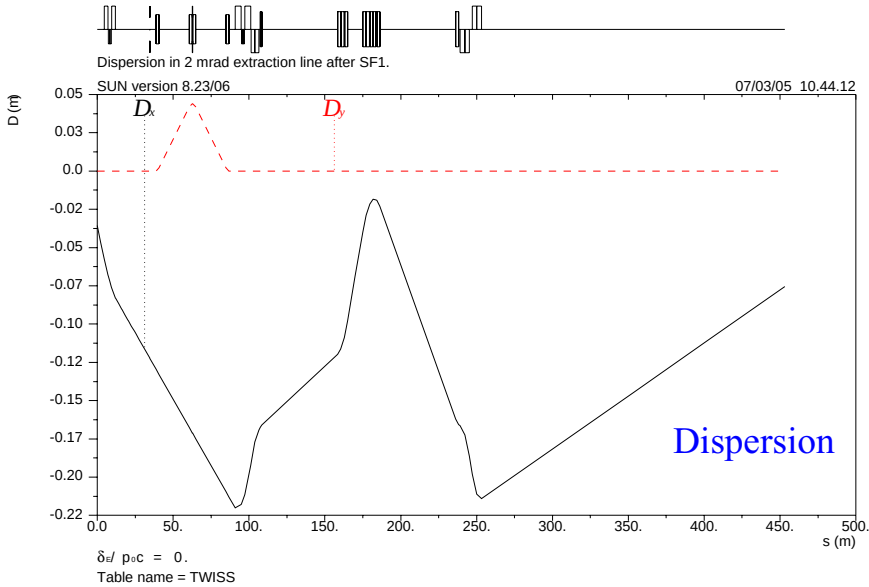
2 mrad Extraction Design

- In this version, extracted electrons and photons pass at x-angle through the aperture of the incoming QD0 quad and SD0, SF1 sextupoles, and through pocket aperture of QF1 quad.
- +/-0.5 mrad is assumed for the maximum photon angle at IP.
- Shared magnets need large aperture to accept both electron beams and photons.
- Parameters of the shared QD0, SD0, SF1, QF1 magnets are optimized using MAD and MATLAB for both the incoming optics and for minimum extracted beam size with large energy spread.
- Optimum polarity of SD0 field results in less favorable bending properties of the BDS.
- Separate extraction magnets are placed starting at 26 m after IP.
- SC super septum quad design and Panofsky septum quad design are under study for the first extraction quads where horizontal space is limited.
- Downstream optics includes vertical chicane for collimation of low energy tail, 2nd focus for diagnostics and horizontal bends for 2 mrad angle at the 2nd focus.
- Dump is at Z ~ 500 m from IP and at X ~ 3.5 m from the incoming beam.
- 500 GeV cms energy.



2 mrad Extraction Optics





At 2nd focus:

- Z = 191.7 m, 2 mrad x-angle, 10 m space
- η_x = -6.9 cm, R_{22} = -1.305, R_{44} = -0.016
- Undisrupted σ_x / σ_y : 69 / 0.3 μm

At dump:

- Undisrupted σ_x / σ_y : 6.7 / 0.053 mm

To achieve satisfactory optics conditions for diagnostics:

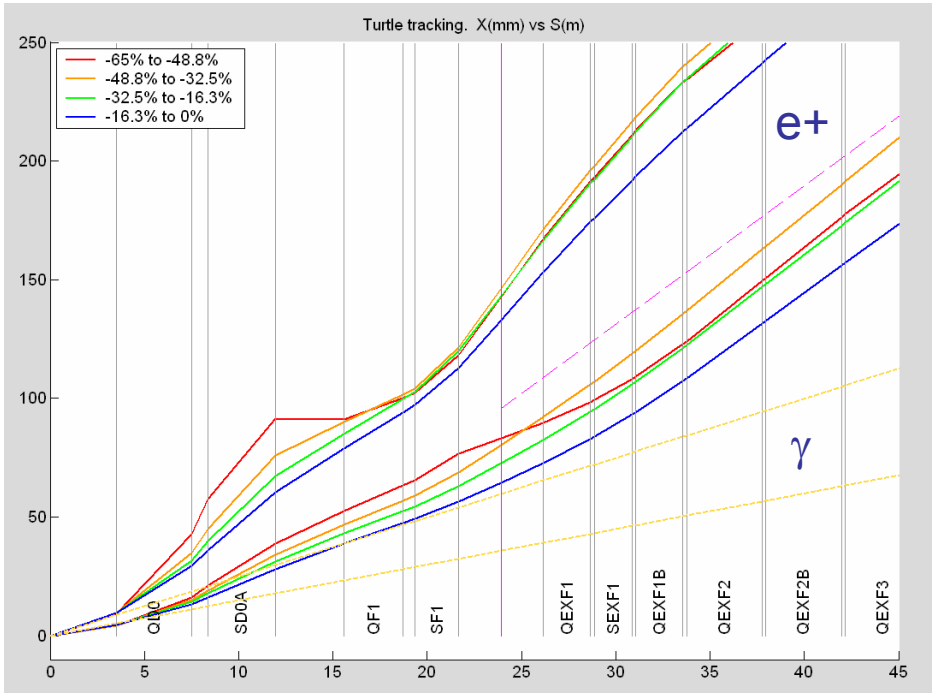
- A true chicane needs to be added around the 2nd focus, and
- Value of R_{22} should be adjusted closer to -0.5.

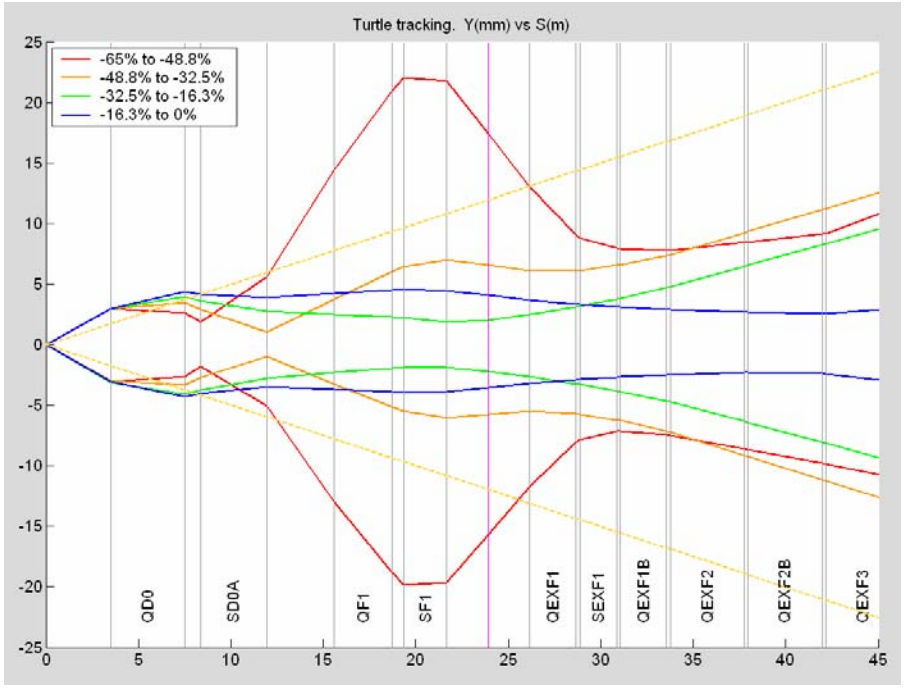
Extraction Magnets for 2 mrad IR and 500 GeV cms Energy

Name	Number	Length (m)	Dipole field (T)	dB_y/dx (T/m)	d^2B_y/dx^2 (T/m^2)	$Z-Z_{IP}$ (m)	$X-X_{IP}$ (m)
QEXF1	1	2.5	0	7.2849	0	26.161	0.109
SEXF1	1	2.0	0	0	-125.0865	28.861	0.125
QEXF1B	1	2.5	0	7.2849	0	31.061	0.138
BYCHIC	2	2.0	0.8339	0	0	60.360	0.310
BYCHICM	2	2.0	-0.8339	0	0	82.360	0.439
QEXF4	1	4.0	0	4.2156	0	112.459	0.615
SEXF2	1	2.0	0	0	-41.6955	116.659	0.640
QEXF4B	1	4.0	0	4.2156	0	118.859	0.653
QEXF5	1	5.0	0	-4.6006	0	123.059	0.677
BHEX2	1	1.0	-0.8339	0	0	129.059	0.713
BHEX3	3	2.0	0.6759	0	0	180.058	1.062
BHEX4	5	2.0	-0.7141	0	0	196.658	1.111
BHEX5	1	2.0	0.8339	0	0	257.855	1.710
QEXF6	1	6.0	0	-4.1210	0	260.855	1.737
QEXF7	1	6.0	0	4.3965	0	268.854	1.806

- Magnet parameters need more optimization.

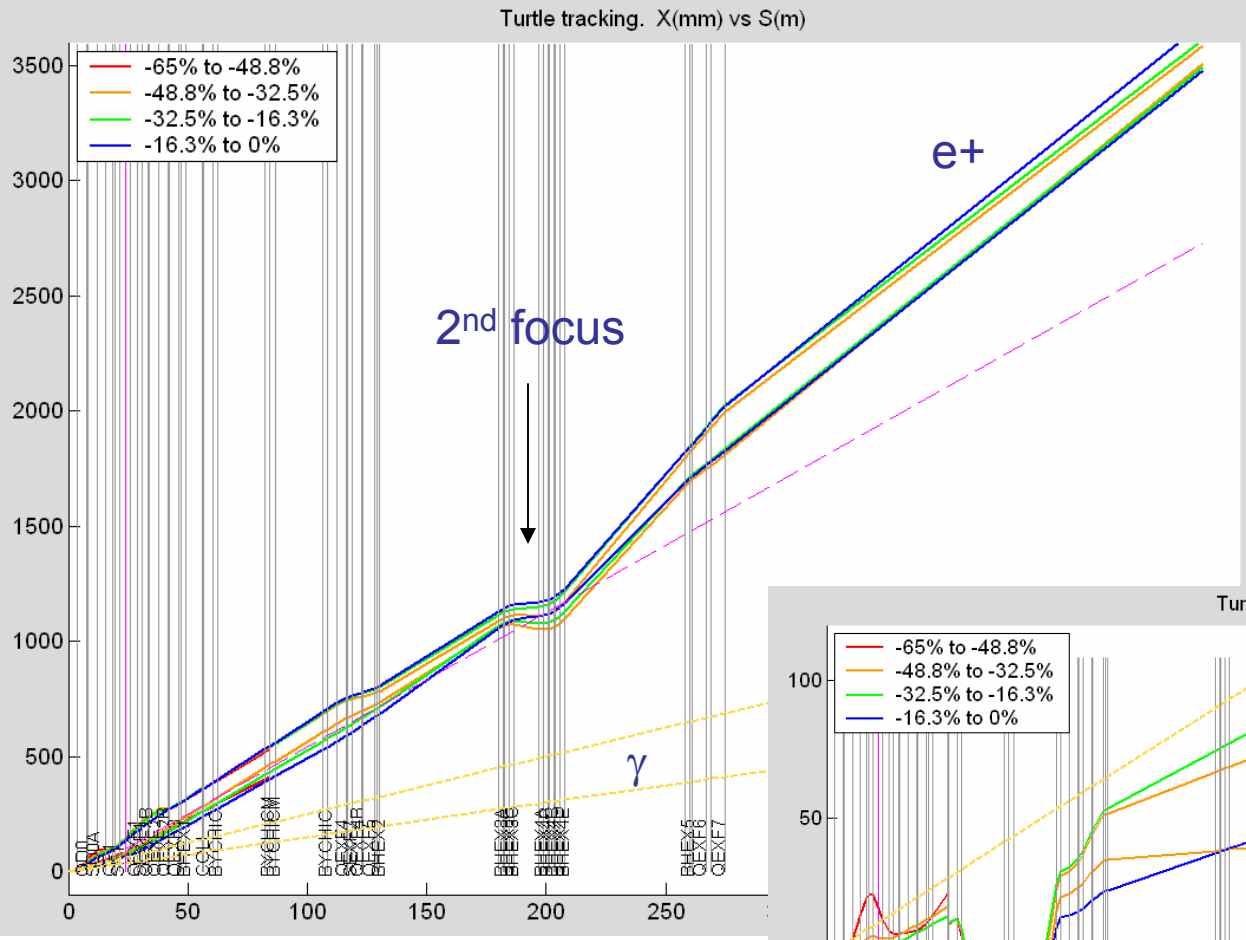
TURTLE tracking of disrupted beam in the beginning of 2 mrad extraction line

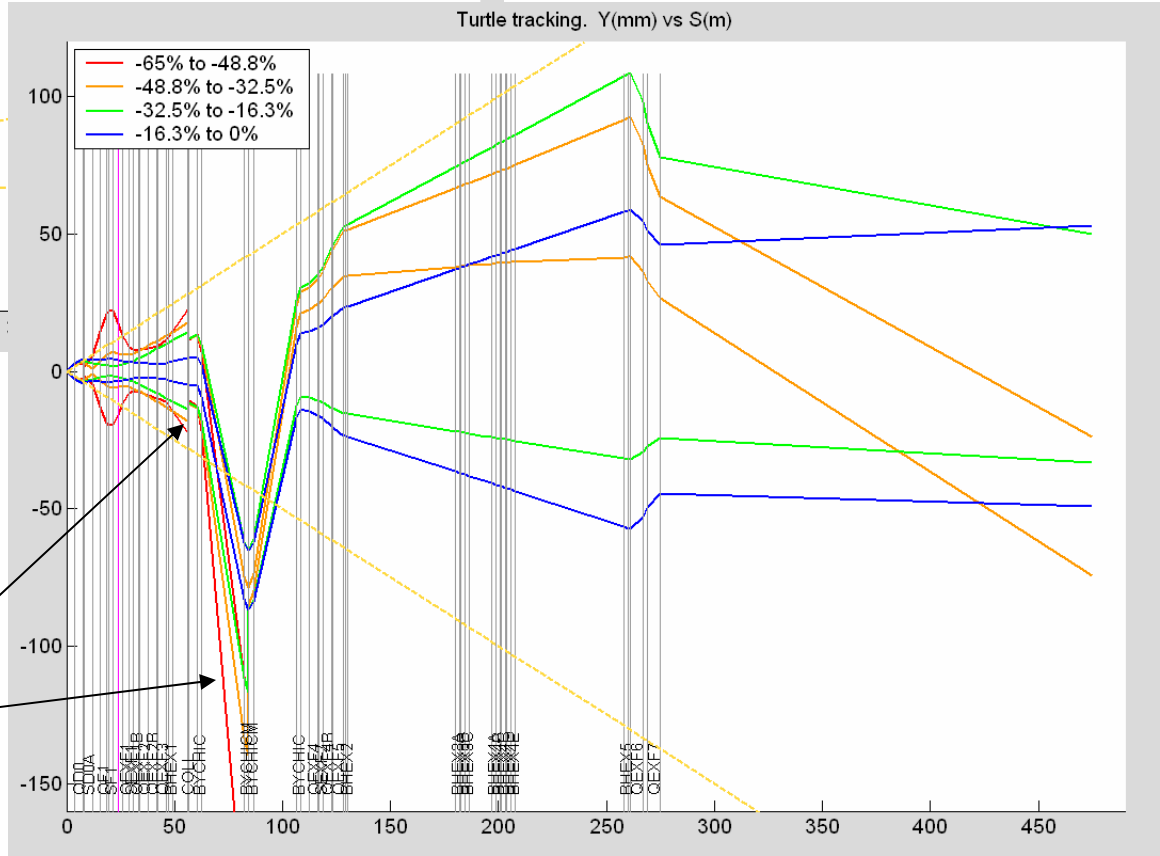




- 250 GeV beam with nominal IP parameters.

Tracking in the complete 2 mrad line





Tracking and beam loss in 2 mrad line with new IP parameters

- Nominal 500 GeV cms, dY=0 and dY=200nm
  - no losses on magnets*
  - collimated: N/N_0 = 2.9E-4 (1.3 kW) at 56m and 5.2E-3 (23 kW) at 84m from IP
- High luminosity 500 GeV cms
  - Loss on QD0: 5.6E-5 (250 W), on QEXF1: 1.1E-5 (50 W)
- High luminosity 500 GeV cms and dY=120nm
  - Loss on QD0: 7.9E-5 (350 W), on QEXF1: 9.3E-5 (400 W)
- Nominal 1 TeV cms and dY=100nm
  - no losses on magnets

* Losses on QF1 were not evaluated – a special QF1 pocket aperture needs to be included in the code.

Conclusion

- 20 mrad extraction design provides necessary optics for diagnostics and a low beam loss at 500 GeV cms nominal parameters. The beam loss may also be acceptable for high luminosity 500 GeV cms and nominal 1000 GeV cms options. In the high luminosity 1000 GeV cms option the disrupted beam energy tail and the corresponding beam loss are unacceptably large.
- First design of complete 2 mrad extraction line has been developed. The design provides the 2nd focus for diagnostics and a low beam loss at nominal 500 and 1000 GeV cms parameters, but unacceptable loss in QD0 in high luminosity 500 GeV cms option. In further optics development, a 'true' chicane is needed around the 2nd focus and R22 term should be adjusted closer to 0.5.
- Both 20 and 2 mrad designs will be further optimized according to developing magnet designs.