The small crossing angle layout - where are we and what do we do now?

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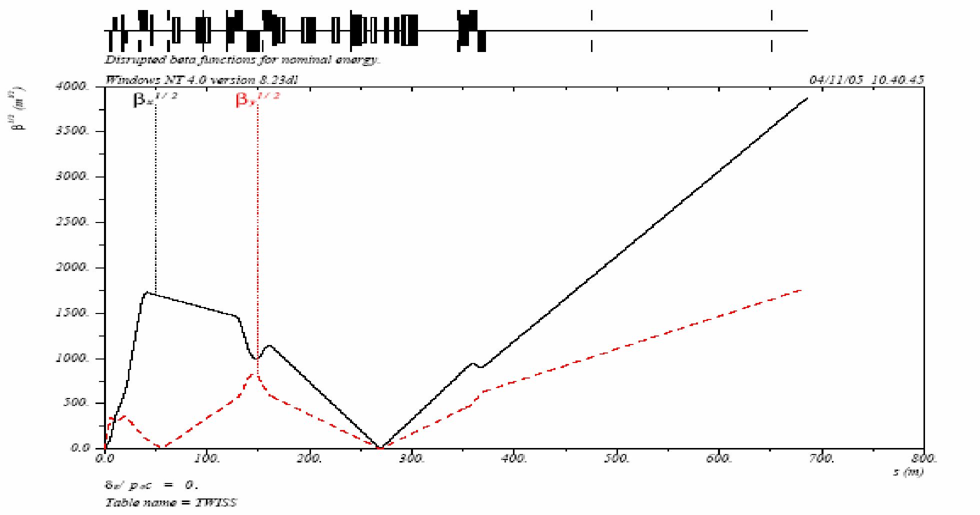
The small crossing angle layout

- Small crossing angle layout is favoured from a physics perspective, meaning we need to try to make it work
- The arguments leading to the 14mrad baseline need to be addressed
- Why is extraction difficult? The beamstrahlung tail (large energy spread) and large angular divergence of the beam causes over-focusing and stronger deflections (~ 1/E) increasing beam size and power losses (Large power means even small losses are bad). And need to accommodate beamstrahlung and charged beam in magnetic apertures
- The existing layout exhibits large losses, uncompetitive diagnostic performance and large, costly magnetic systems
- The FD region has already been redesigned (RBA and Bambade), exploiting new magnet technology
- Here, we extend this work to fully reoptimising the FD sextupoles and reduce the design complexity/cost by proposing a extraction line with no diagnostics

Work done by RBA (FD,XL), D. Toprek (FD), D. Angal-Kalinin (FD,XL), Bambade (FD,XL)

Snowmass layout

- Developed by 2mrad task force
- Final doublet is shared, and a drift gives beam separation before first extraction line quadrupole
- The line consists of three vertical chicanes, horizontal bends, collimators and quadrupoles
- Extraction line magnets and collimators optimised to reduce beam size
  - Bore sizes derived from beam “fit” + margin
  - Resulting apertures are large
  - Vertical collimation chicane and collimators in early part of line to remove extreme beamstrahlung tail



- FD region: large-bore SC sextupoles, QD0 with g=160 T/m
- Diagnostics (energy spec. and polarimeter)
- Length is long - almost 700m

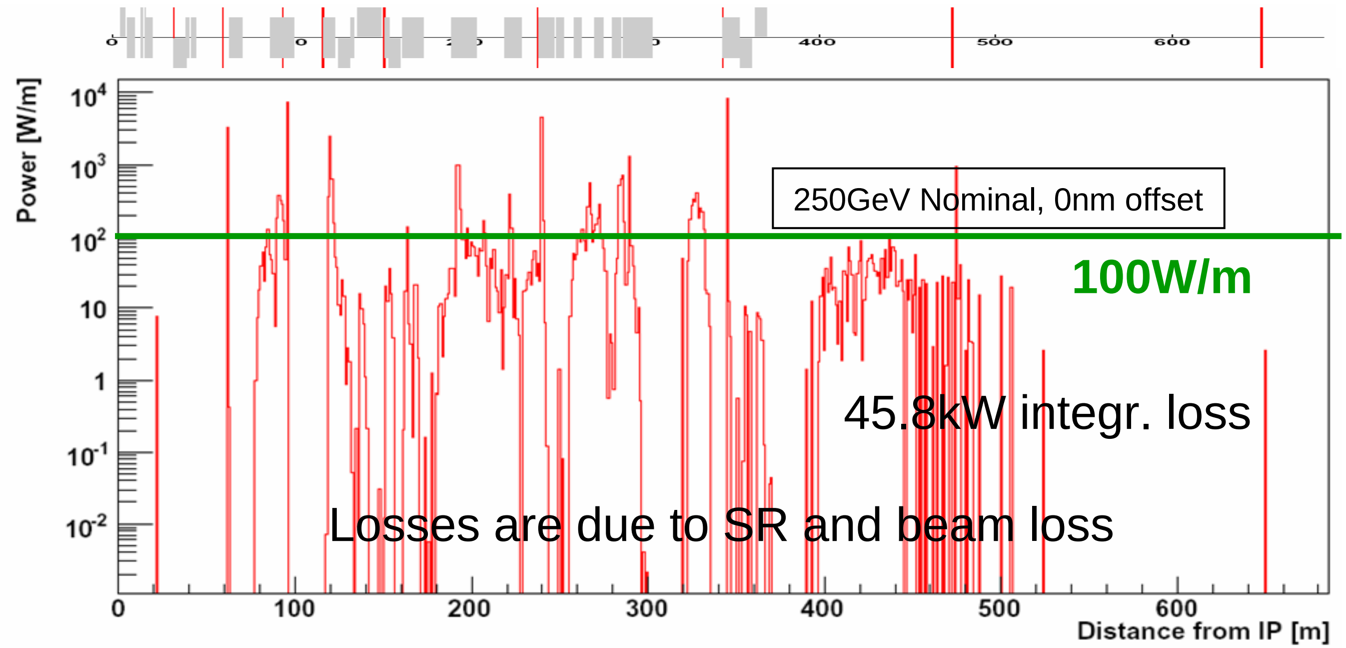
Diagnostic performance and losses

Comparisons for 250GeV/beam	20mr	2mr
Beam overlap with 100mm laser spot at Compton IP	48%	15%
Beam loss form IP to Compton IP	<1E-7	>2.6E-4
Beam SR energy loss from IP to middle of energy chicane	119MeV	854MeV
Variation of SR energy loss due to 200nm X offset at IP	< 5MeV (< 20 ppm)	25.7MeV (~100 ppm)
The need for SR collimator at the Cherenkov detector	yes	No

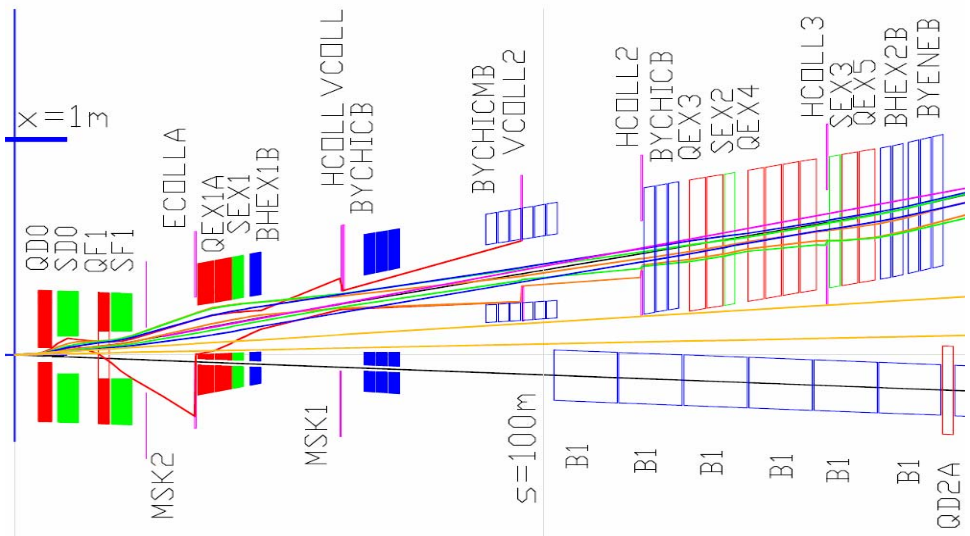
Losses are at 100W/m level for 500GeV CM and exceed this level at 1TeV

Radiation conditions and shielding to be studied

Localised losses exceed maximum tolerance, even in FD superconducting magnets

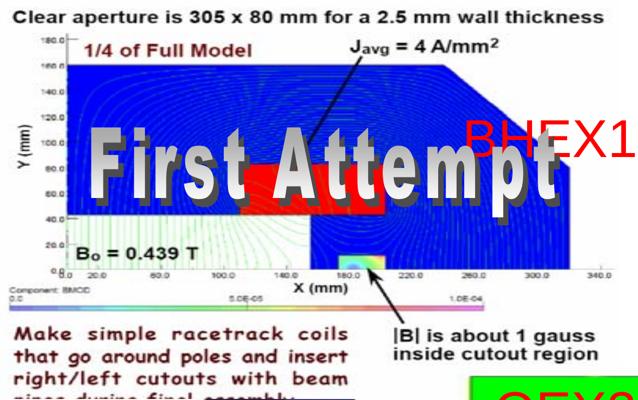


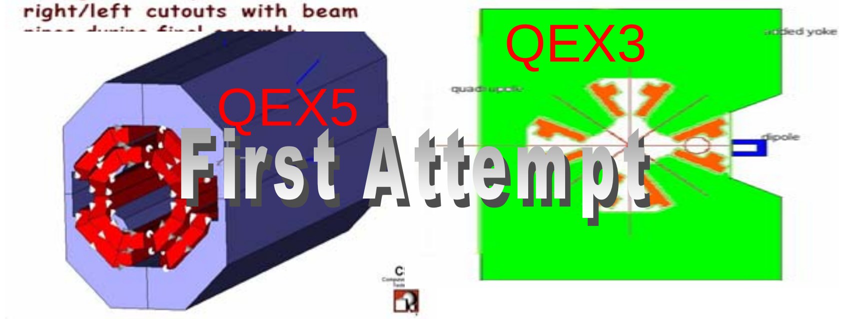
Magnets



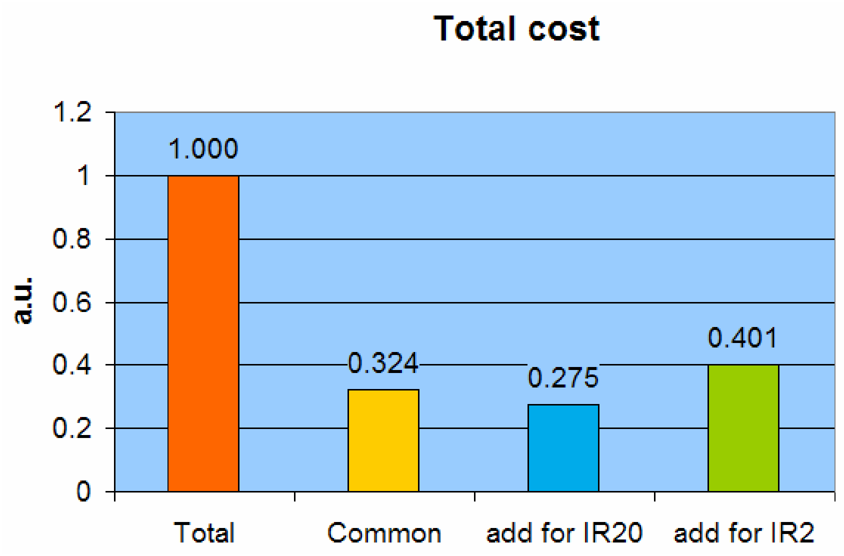
- Large apertures, high fields, beamstrahlung photons passing nearby, SR photons makes these magnets very challenging
- Power at 1TeV CM ~MW/magnet.
- There is interest from 3 regions - investigating the possibilities

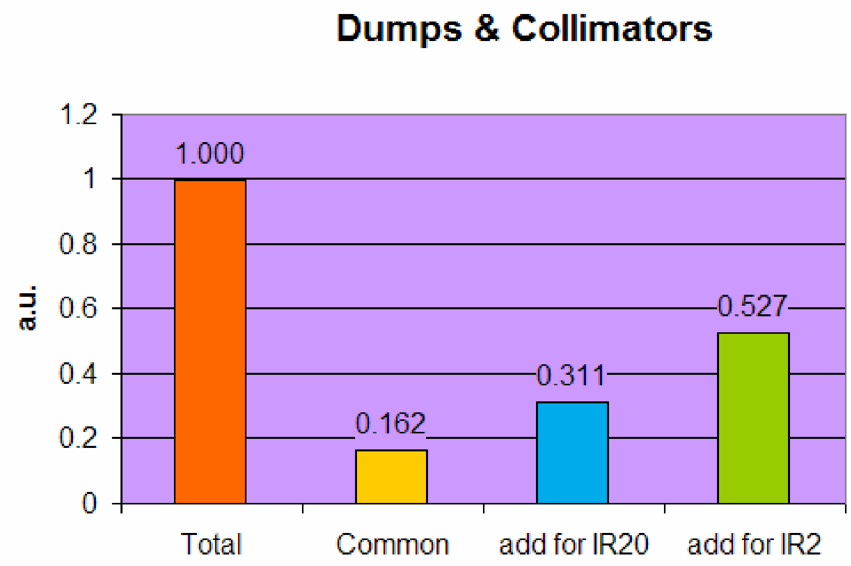
- There were a lot of recent work and ideas on the extraction line magnets
- Some of recent suggested designs did not take all constraints into account

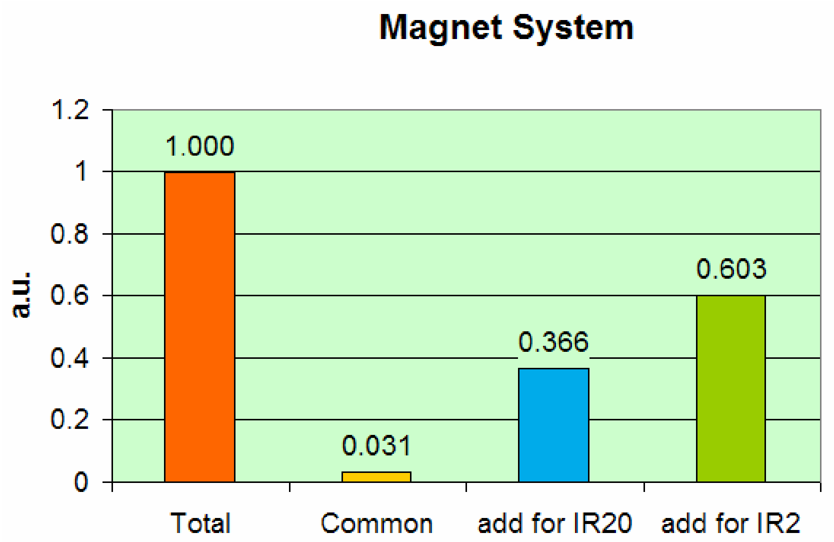


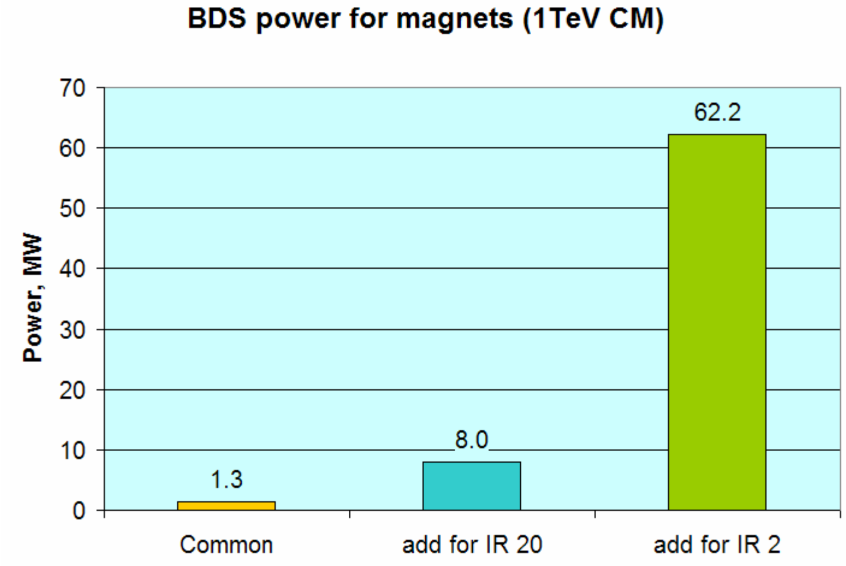


Cost of 2mrad line

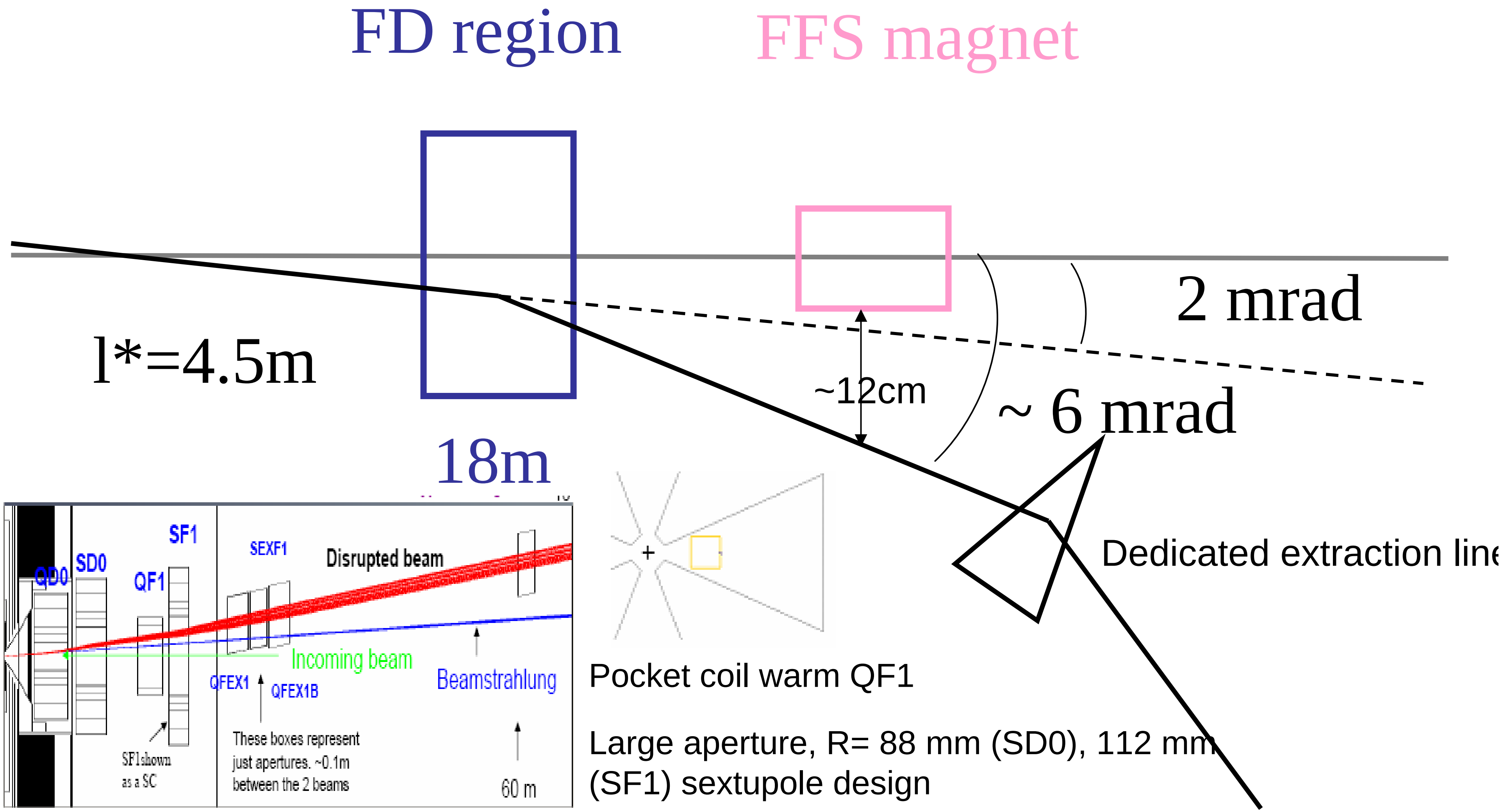








Separation of shared final doublet region from dedicated extraction line



Pocket coil warm QF1

Large aperture, R= 88 mm (SD0), 112 mm (SF1) sextupole design

Reoptimised FD region

- Redesign of final doublet region of small crossing angle scheme to produce acceptable beam losses, using
  - **NbTi** SC magnets with g=180 T/m (achievable now)
  - **Nb_3Sn** SC magnets with g=250 T/m (achievable later)
- This was achieved with an optimisation algorithm
  - Magnets optimised to meet optics goals and reduce charged beam (with IP offsets) and radiative Bhabhas power losses under beam transport
  - Localised loss studied and tolerance agreed with magnet people
  - Perfect for QD0
  - An approximation for the sextupoles
  - Assumptions made on magnet constraints
- Result is three new FD layouts at 500 GeV and 1 TeV, with losses in SC magnets mostly below tolerance, provided Tungsten liners are used.
- Appleby and Bambade EuroTeV report 2006-022
- Need to further reoptimised sextupoles - ongoing work at CI

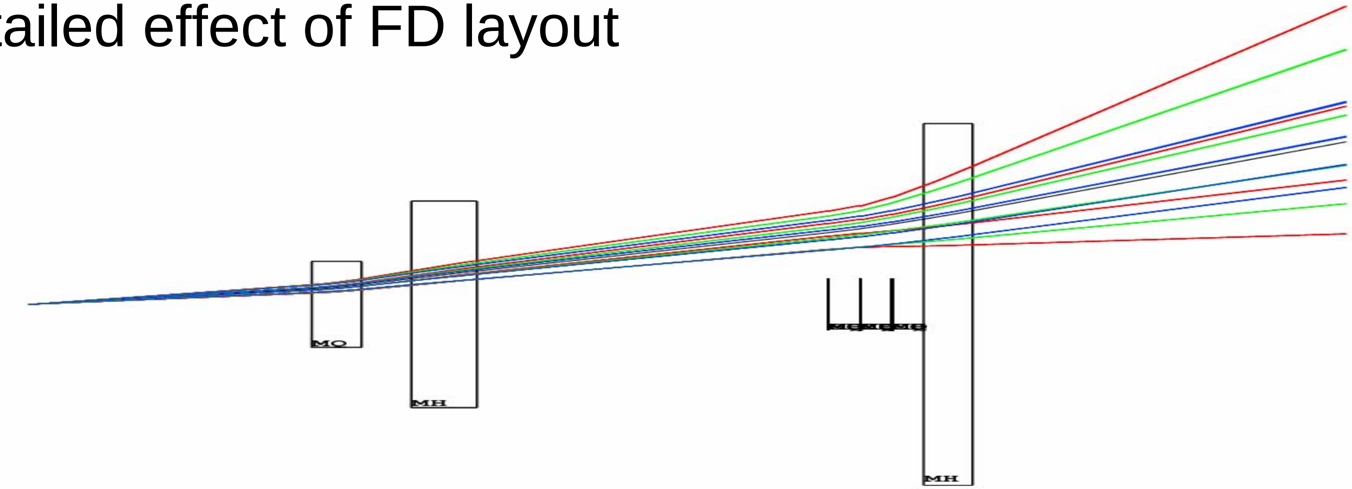
NbTi 500 GeV machine parameters and losses

Name	Length [m]	Strength	Radial aperture [mm]	Gradient [T/m]	Pole-tip field [T]
QD0	1.23	-0.1940 m^{-1}	39	162	6.3
SD0	2.5	1.1166 m^{-2}	76	-	2.69
QF1	1.0	0.0815 m^{-1}	15	70	1.02
SF1	2.5	-0.2731 m^{-2}	151	-	2.59

Beam	QD0 [W]	SD0 [W]	QF1 [W]	SF1 [W]
Low P (cb)	0	0	0	0
Low P (rb)	0.05	0.1	0	0
High L (cb)	0	4.1	11.6	0
High L (rb)	0.13	0.25	0.13	0

Fully reoptimised sextupoles

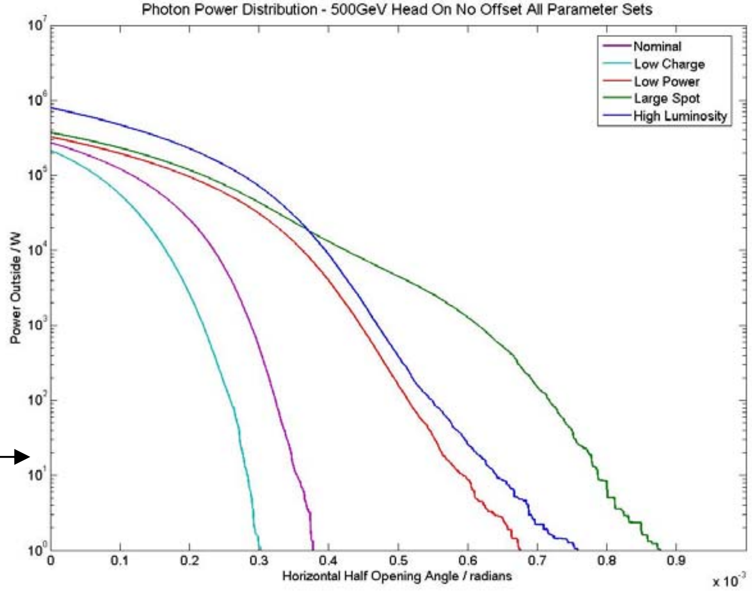
- Goal is to reoptimise sextupoles in FD, to reduce size and meet beam transport requirements. Both charged beam and radiative Bhabha losses are considered
- Work so far has focused on NbTi 500 GeV machine FD, and gives
  - SD0: L=1.037 m, r=60 mm, K_2=+2.691
  - SF1: L=0.777m, r=105 mm, K_2=-0.879
- Future work will extend to all FD parameter sets, and study detailed effect of FD layout



Beamstrahlung cones

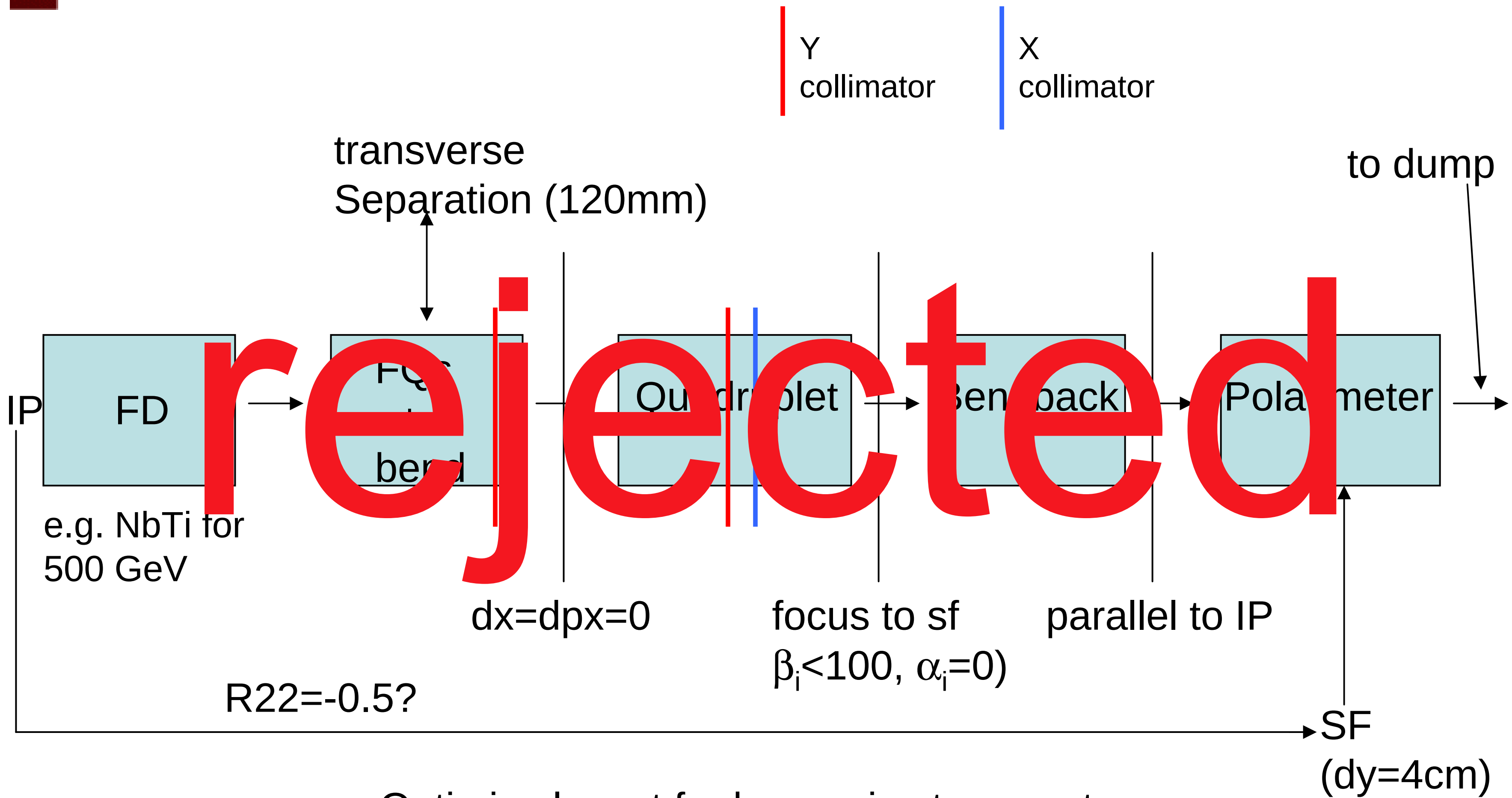
This is work done at Manchester by Daniel Smalley and Mark Briscombe, two MPhys students, with RBA (EuroTeV note to follow)

500 GeV horizontal cone



- The maximum beamstrahlung cones half opening angles, covering all parameter sets and energies are
  - 100 W excluded: 0.9mrad vertically and 0.7mrad horizontally
  - 10 W excluded: 0.8mrad vertically and 1.2mrad horizontally
  - 1 W excluded (full cone): 1.4mrad vertically and 1.0mrad horizontally
- Redefining 1W cone with Low Power and High Luminosity excluded gives 0.6mrad vertically and 0.9mrad horizontally.

Modular optics abstraction (with diag.)

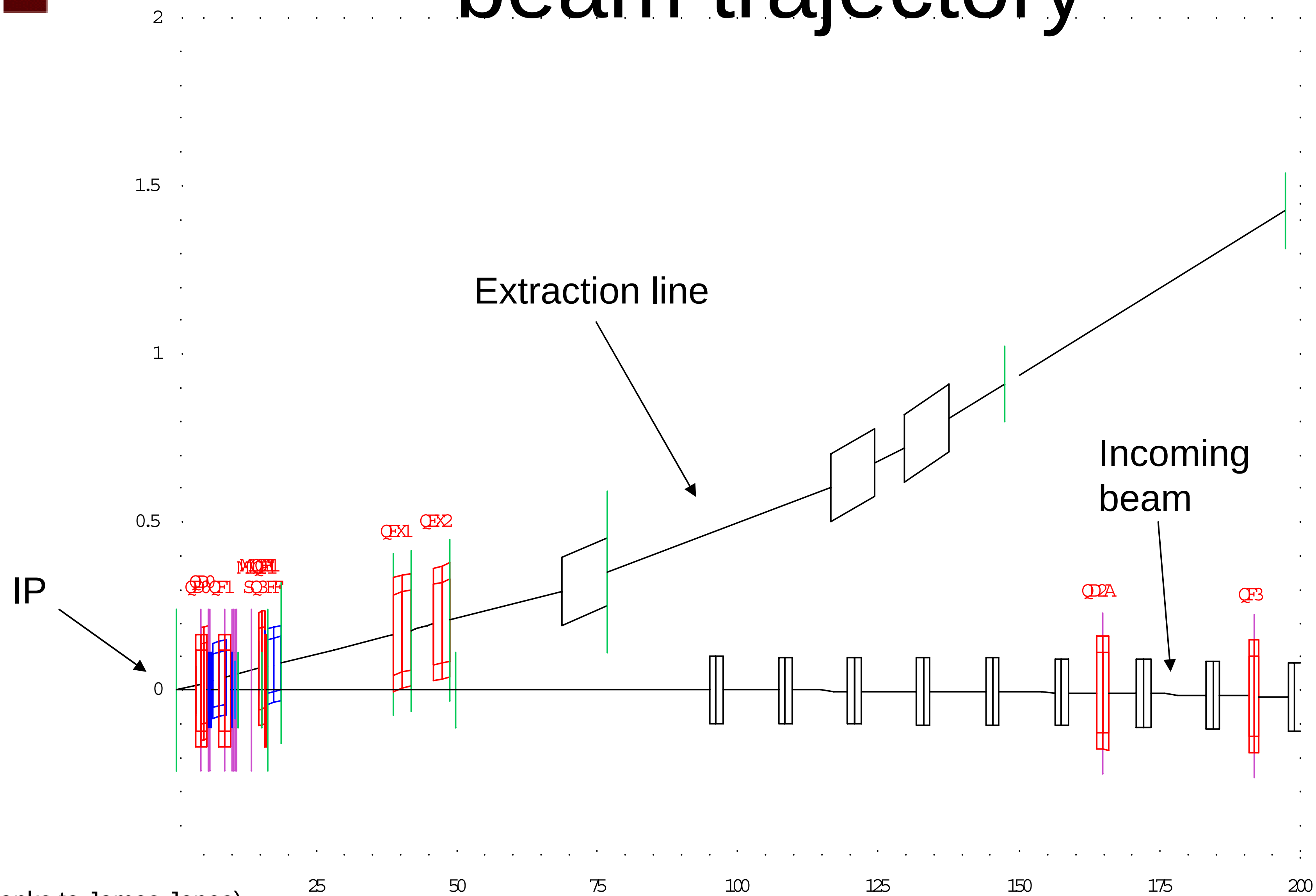


- Optimise layout for beam size transport
- Concerns are
  1) Transport of higher order dispersion
  2) Beam shape at the SF of polarimeter

Minimal extraction line

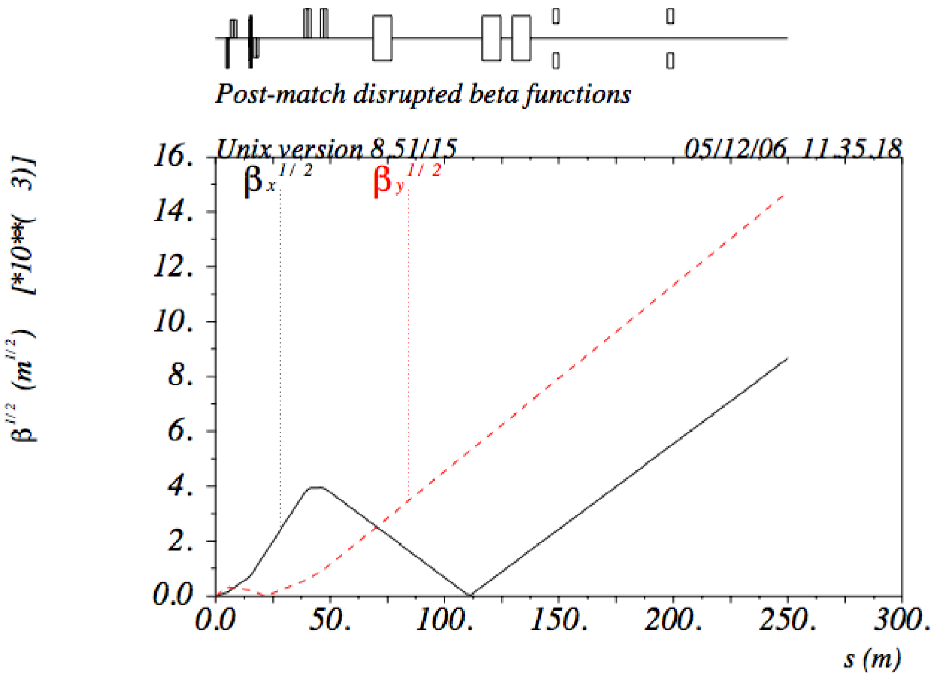
- Diagnostics and all chicanes removed
- Magnet complexity and number vastly reduced
- Attack power consumption through magnetic aperture, hence beam size, control. Simpler system allows this control
- Magnetic system after FD consists of two quadrupoles and a separating bend, followed by two big bends for extraction line separation from the incoming beam
- Several collimators provide protection and tail removal: specification is either solid Cu (15kW rated, radiatively cooled) or rotating Al balls in water (200 kW rated, actively cooled)
- Line length 250m, with 1.9m separation at dump
- Optimisation of magnets through beam transport
- FD is NbTi, 500 GeV, with a 15mm QF1 (with multipoles)
- A design with competitive cost and performance, with physics and machine benefits, will be a good choice for the future baseline

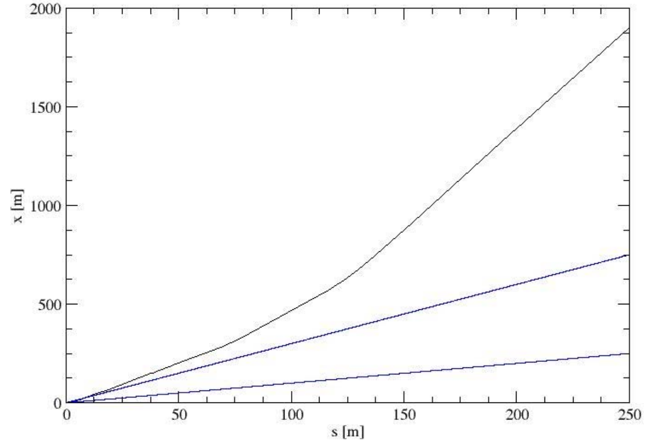
Incoming and outgoing beam trajectory

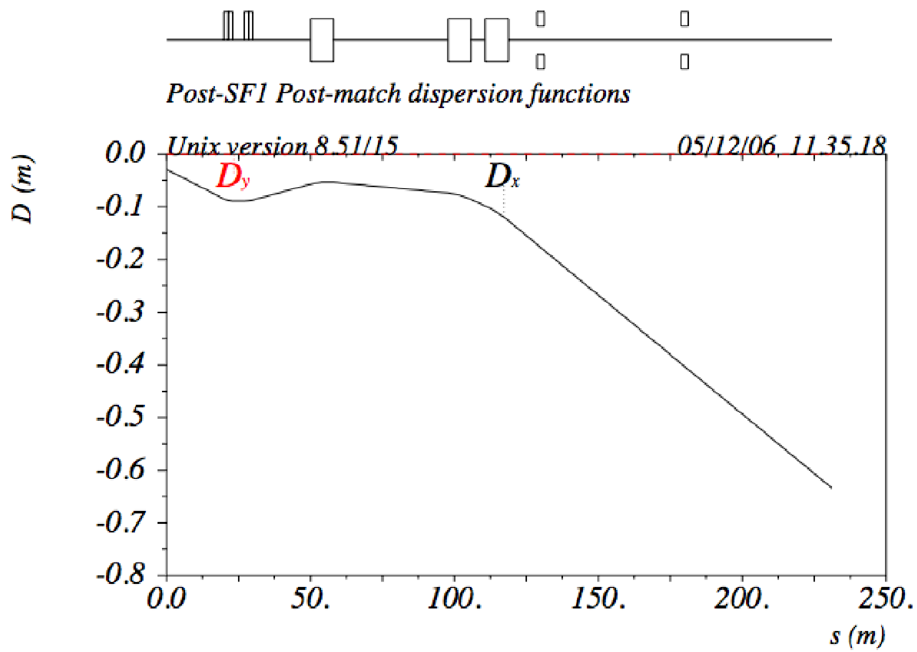


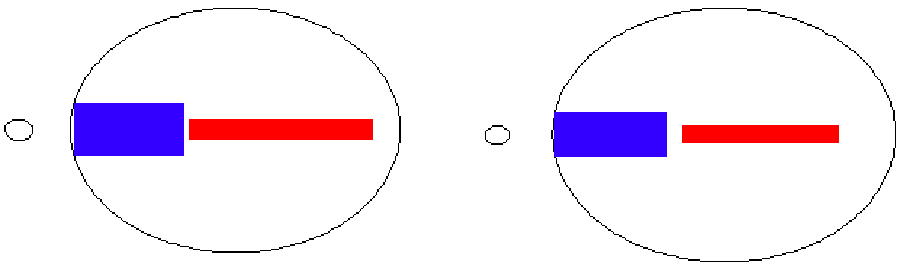
(Thanks to James Jones)

Optics and orbit









QEX1 QEX2

Beamstrahlung is blue, charged beam is red

Magnets and collimators

Parameter	QEX1	QEX2	BHEX1
S [m]	38.75	45.75	76.75
γ^{upper} [mm]	116.3	137.25	230.3
γ^{lower} [mm]	38.8	45.8	76.8
B^{upper} [mm]	97.4	92.8	17.3
B^{lower} [mm]	-32.5	-33.4	-19.0
Beam orbit [mm]	152	182.2	322.9

Collimator name	Position [m]	Length	Power load [kW]	X jaw [mm]	Material	Cooling
QEX1COLL	38.75	1.0	15	104	Cu	Radiative
QEX2COLL	45.75	1.0	15	95	Cu	Radiative
COLL1	150	2.5	205	116	Al (balls)	Active
COLL2	200	2.5	205	204	Al (balls)	Active

Magnet	Length	Strength/angle	Radial aperture [mm]	B [T]
QEX1	3.0	0.011 /m	116	1.04
QEX2	3.0	0.0056 /m	138	0.63
BHEX1	8.0	2.0 mrad	-	0.21
BB1	8.0	2.0 mrad	-	0.21
BB2	8.0	2.0 mrad	-	0.21

Work now focused on technical feasibility of these magnets

Two big bends, 8m with an angle of 2mrad, have been placed just before COLL1. The first bend is located at 116.5m and the second bend is located at 129.5m. The transverse separation from the incoming beam is 57.2cm and 63.1cm respectively. These magnets provide additional bending and achieve a dump separation of 1.9m after 250m.

Beam power losses

Beam	QEX1COLL [kW]	QEX1 [kW]	QEX2COLL [kW]	QEX2 [kW]	BHEX1 [kW]	COLL1 [kW]	COLL2 [kW]
Nominal	0	0	0	0	0	0.2	5.1
Nominal (dy=200nm)	0	0	0	0	0	0	2.9
Nominal (dx=1σ)	0	0	0	0	0	0.7	2.6
Low Power	2.8	0	1.3	0	0	65.3	50.0
Low Power (dy=120nm)	3.6	0	1.4	0	0	69.8	73.8
Low Power (dx=1σ)	1.4	0	0.7	0	0	34.5	19.3
High Lumi	12.3	0	4.4	0	0	202.1	131.9
High Lumi (dy=120nm)	14.8	0	4.5	0	0	200.0	195.8
High Lumi (dx=1σ)	8.3	0	2.8	0	0	101.9	49.1

Computed using GUINEA-PIG and DIMAD, for ILC parameter sets at machine energy of 500 GeV, with high statistics. Protection collimator jaws tuned to remove losses on magnets, and main collimator jaws tuned to loss specification of 200 kW

Conclusions

- The small (and zero) extraction line designs provide considerable technical challenges to beam and magnet physicists
- The Snowmass layout leaves several issues unresolved, including cost and technical feasibility
- Redesigned final doublets, exploiting new magnet technology, mitigates problems in this region
  - Ongoing work will fully complete the sextupole optimisation and exploitation of technology
  - Warm SF1 under study: removes need for big sextupole
- Removing the diagnostics will considerably reduce complexity and cost
  - Complete optics for 500 GeV machine, with NbTi FD
  - Work is focused now on magnet feasibility, including stray field on incoming beam and aperture requirements
  - Overall machine impact of no diagnostics needs to be assessed
  - Extension to 1 TeV layout follows completion of 500 GeV design