The 2mrad crossing angle alternative

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Motivation (why bother?)
The 2mrad design concept
Progress and the current design
Remaining issues and plans

Motivations for the scheme

- Large crossing-angle :

  1. Eases post-IP beam extraction & transport ➔ diagnostics

  2. But adds pre-IP constraints (crab-cavity control & tuning, non-axial solenoid + DID / anti-DID ➔ pre / post-IP trajectory bumps)

- Physics & detector advantaged by smaller crossing-angle IR : simpler forward geometries, better hermeticity, no (or less) DID / anti-DID

- Head-on IR a priori nicest ➔ needs large electrostatic separators

- 2 mrad scheme : no crab-cavity (initially…), no electrostatic separators and order-of-magnitude smaller pre / post-IP trajectory bumps (for example, no need to worry about integration of anti-DID coils in IR region)

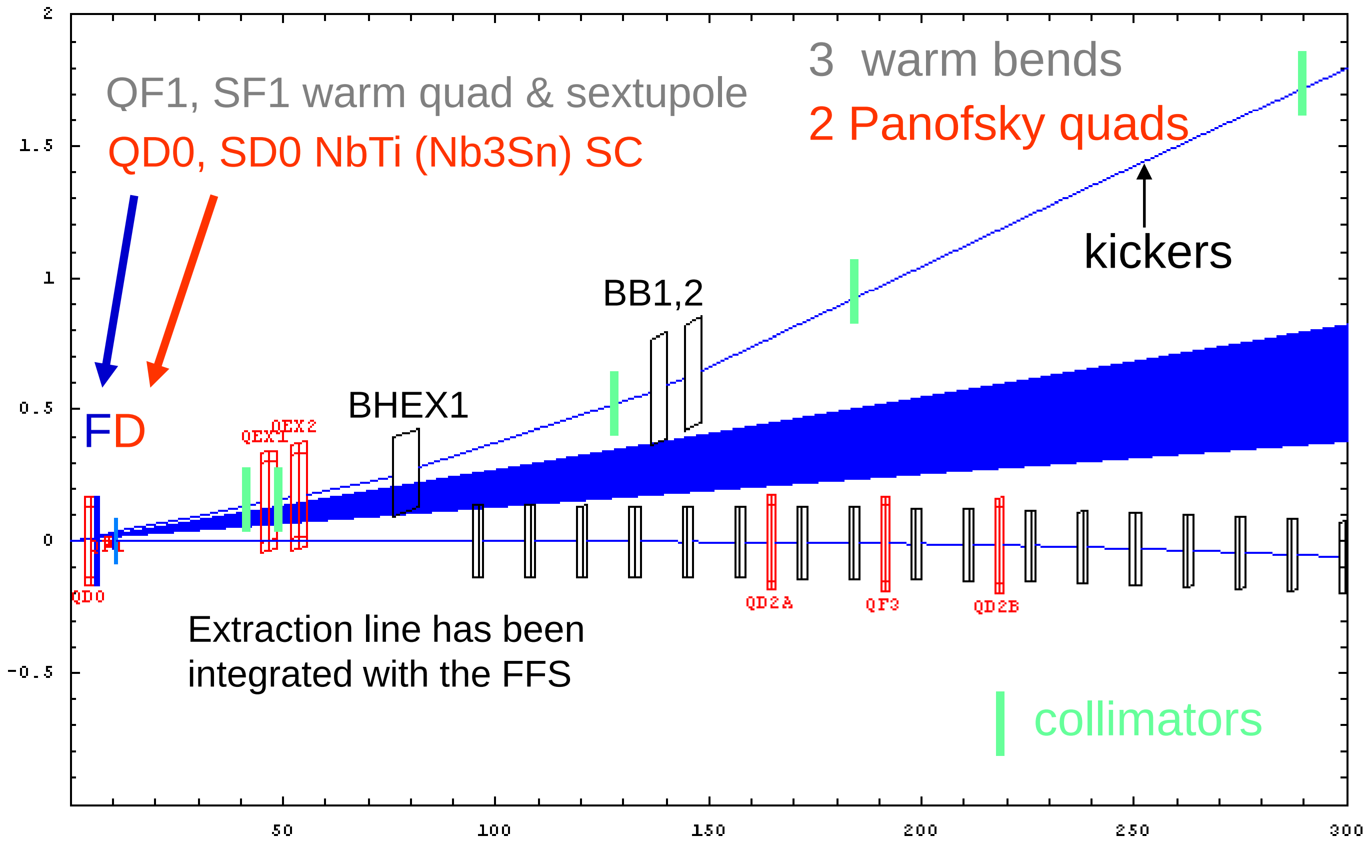
- Snowmass 2 mrad design unsatisfactory ➔ redesign with simpler concept aiming to be as short & economical as possible

  - Now, a viable alternative to the 14mrad baseline solution now seems both technically possible and cost-effective

    - And it's sensible to have viable alternatives

New “minimal” extraction line concept

➔ Explicit goals : short & economical, as few and feasible magnets as possible, more tolerant and flexible



dump(s): 0.5 m

3 m

Length ~ 300 m

Space exists for beam rastering kickers (to prevent water boiling and window damage)

Optimised compact final doublets

- Re-designed with acceptable losses and stay-clear for in / out charged & beamstrahlung beams ➔ EUROTeV-Memo-2007-001/JINST 1 P10005 (2006)
- Works for all proposed ILC beam parameter sets, including (new) "High Luminosity" at 1 TeV (GP++ large statistics at http://flc-mdi.lal.in2p3.fr/spip.php?rubrique17)
- Compact SC QD0,SD0 : NbTi LHC-like QD0 at 500 GeV, Nb_3Sn SLHC-like QD0 at 1 TeV, NbTi 60 mm radius SD0
- Standard warm QF1 & SF1, with 20 and 30 mm radius
- Outgoing beam subject to non-linear pocket fields of QF1 and SF1

Table 1: The 500 GeV final doublet parameters.

Parameter	QD0	SD0	QF1	SF1
Length [m]	1.059	1.469	1.596	0.75
Strength	-0.270 m^{-2}	2.969 m^{-3}	0.0786 m^{-2}	-2.044 m^{-3}
radial aperture [mm]	28	60	20	30
gradient [T/m]	225	-	65	-

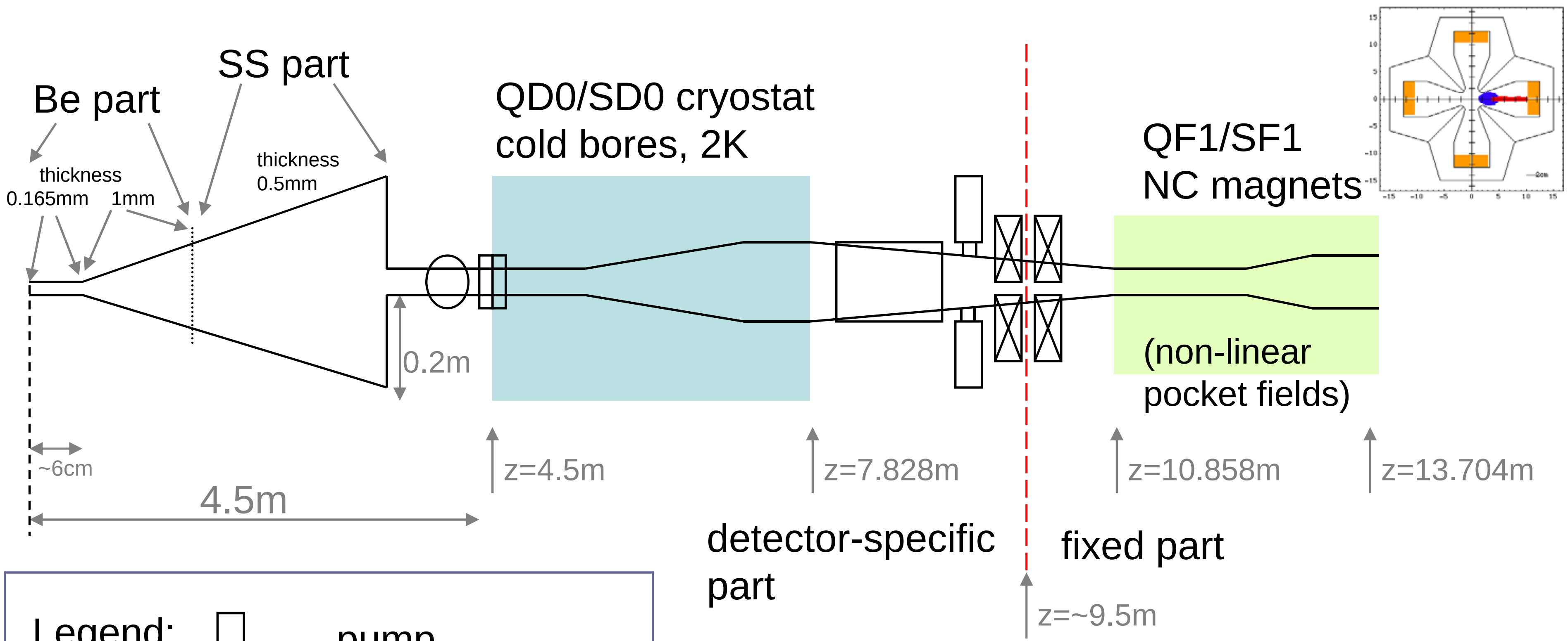
Parameter set	QD0	SD0
High Luminosity CB [W] 500 GeV	<1	<1
High Luminosity RB [W] 500 GeV	0.46	0.2
High Luminosity CB [W] 1 TeV	<1	<1
High Luminosity RB [W] 1 TeV	0.82	0.04

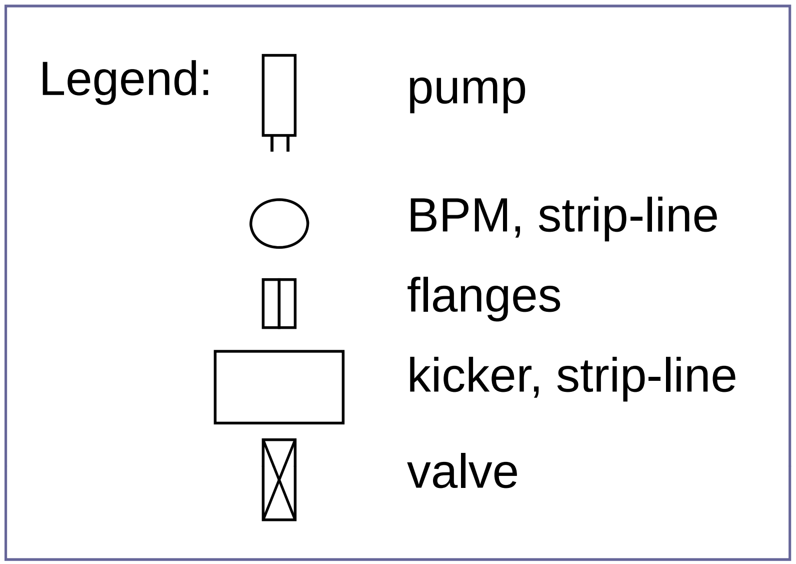
Table 4: The 1 TeV final doublet parameters.

Parameter	QD0	SD0	QF1	SF1
Length [m]	1.352	2.5	3.192	1.5
Strength	-0.210 m^{-2}	1.502 m^{-3}	0.0394 m^{-2}	-0.943 m^{-3}
radial aperture [mm]	25	59	20	30
gradient [T/m]	350	-	66	-

	500 GeV	1 TeV
l* [m]	4.5	4.5
QD0-SD0 [m]	0.8	0.8
SD0-QF1 [m]	3.03	2.05
QF1-SF1 [m]	0.5	0.5

2mrad beampipe layout in IR region





Tapering apertures between shared beamline elements

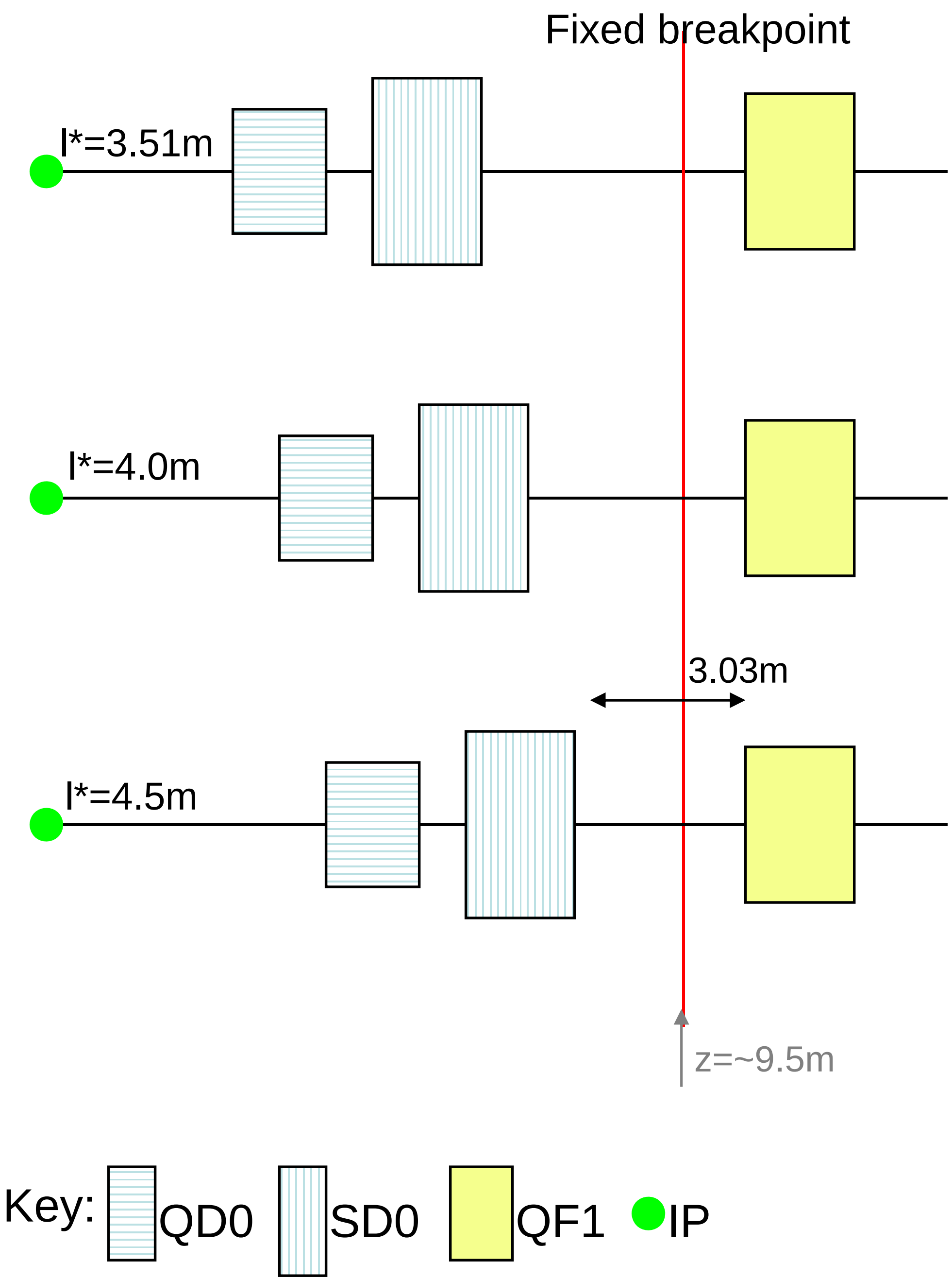
Breakpoint between SD0 and QF1

No FD cryostat needed for QF1/SF1

QD0/SD0 outer sizes, cryostat design/size, support for integration and detector opening procedure?

Modified from 14mrad drawing by Andrei

Variable l* IR layout



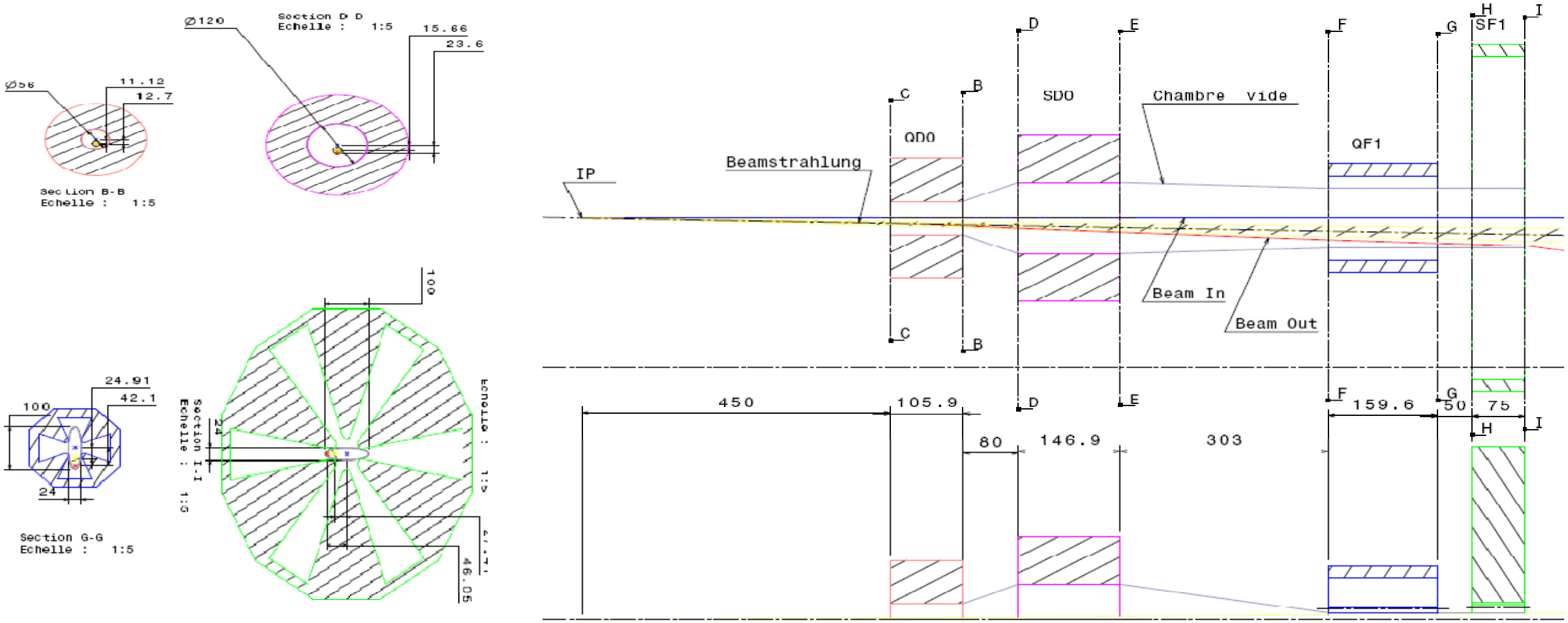
Optics design exist for l*=4.5m. Variable l* achieved by

- Fixed breakpoint located between SD0 and QF1
- Optics refitted by varying SD0-QF1 distance to obtain sufficient beam separation and minimum losses
- Some impact on beam power losses and beam separation

Keep physical size of FD magnet constant (change currents)

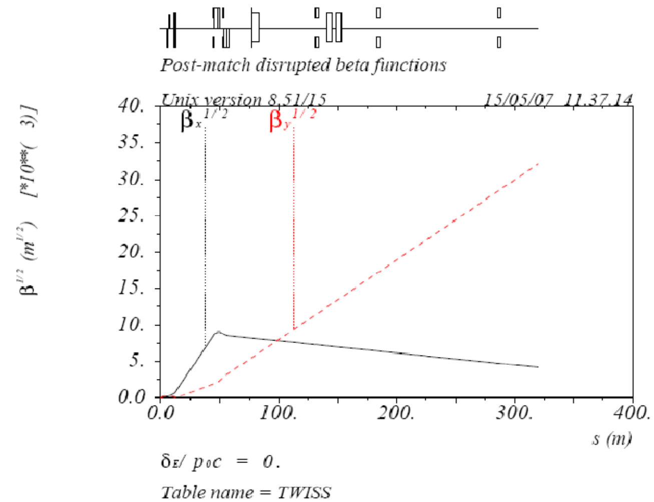
Variable l* of detector gives varying downstream orbit. Correct using corrector dipoles

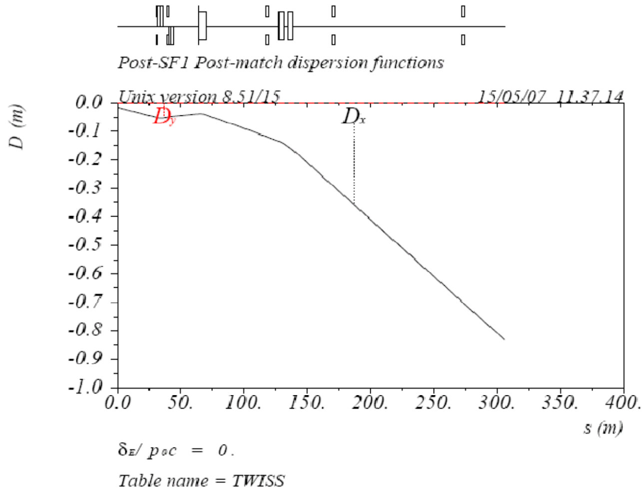
Beampipe in FD region

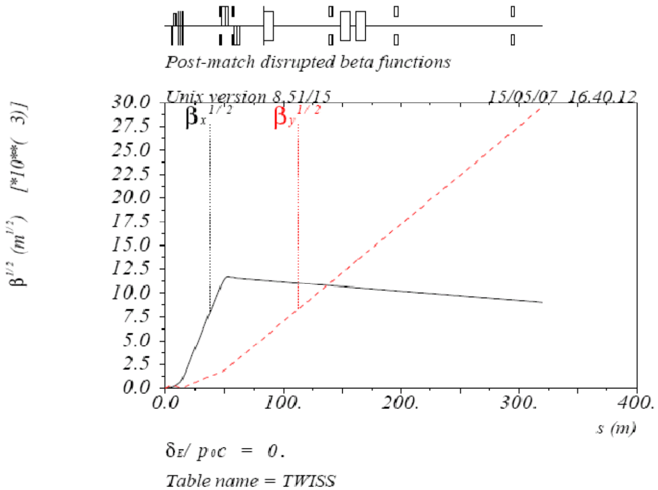


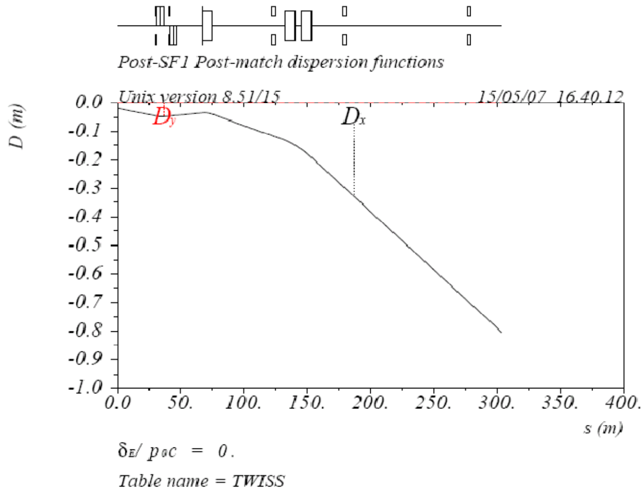
- Separating the incoming beam from the outgoing beam and beamstrahlung in the shared region from the FD to QEX1,2
- Separation of beamstrahlung after BHEX1

Optics for 500 GeV and 1 TeV









Magnets and collimators in the rest of the line

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

- Designed proof-of-principle optics with reasonable QEX1,2, BHEX1 and BB1,2 apertures & strengths and acceptable losses on dedicated collimators at both 500 GeV and 1 TeV
- Can be adjusted depending on best choice of dump arrangement
- Flexibility : magnet + beam pipe designs $\rightarrow$ final parameters

EUROTeV-Memo-2007-004

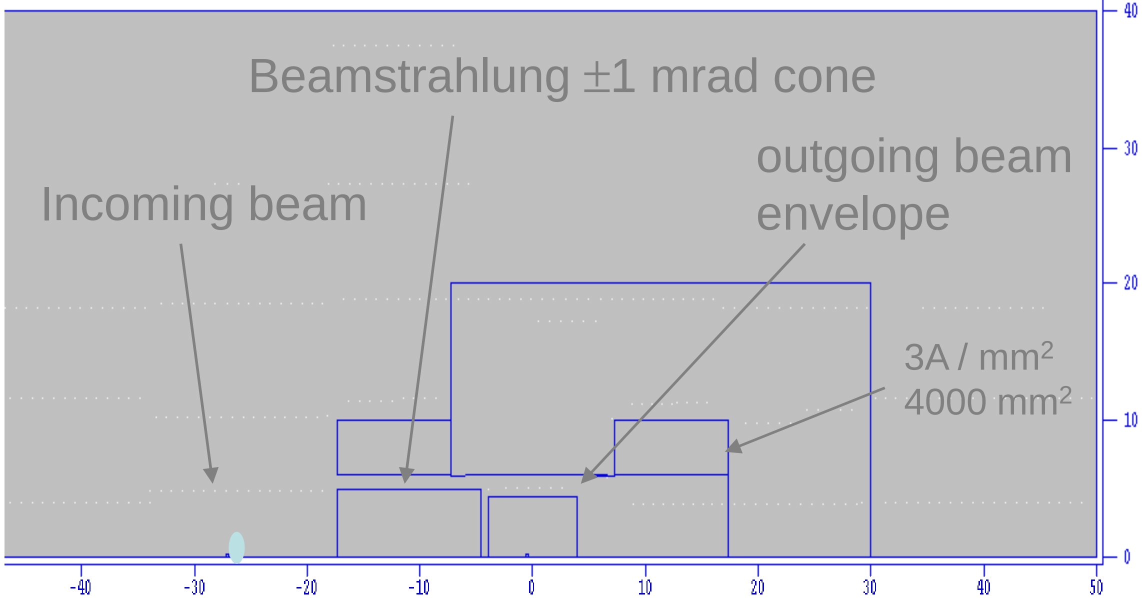
Beam power losses

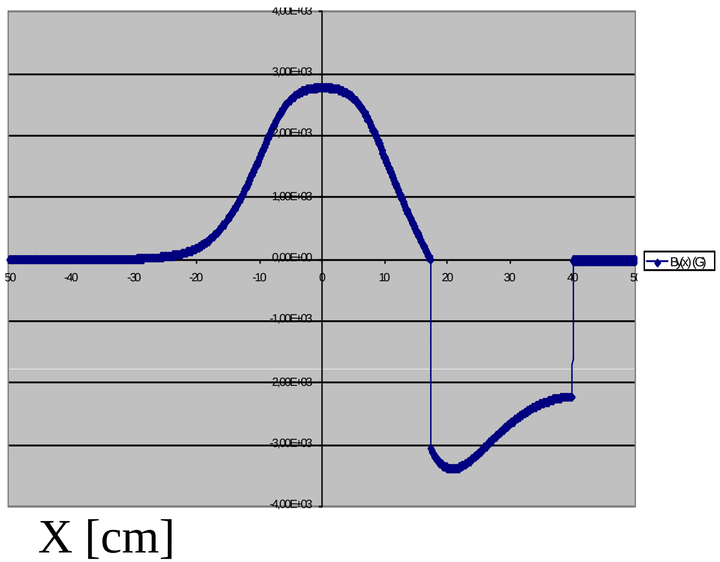
Beam	QEX1COLL [kW]	QEX1 [kW]	QEX2COLL [kW]	QEX2 [kW]	BHEX1 [kW]	COLL1 [kW]	COLL2 [kW]
Nominal	0	0	0	0	0	0.2	5.1
Nominal (dy=200nm)	0	0	0	0	0	0	2.9
Nominal (dx=1σ)	0	0	0	0	0	0.7	2.6
Low Power	2.8	0	1.3	0	0	65.3	50.0
Low Power (dy=120nm)	3.6	0	1.4	0	0	69.8	73.8
Low Power (dx=1σ)	1.4	0	0.7	0	0	34.5	19.3
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 and beam size on dump window.

BHEX1 (C-dipole)

- The bend BHEX1, designed as a C-magnet to accommodate the beamstrahlung, outgoing beam and proximity of incoming beam, has been studied using the field solver POISSON





- $B_y(x)$ homogeneity < 4% (with shims) within outgoing beam envelope (checked and okay)
- Residual B_y on incoming beam ~ 1%. use corrector
- Residual $B_x(y)$ dependence on incoming beam
- Can absorb sextupole refitting final focus sextupoles, and decapole has been shown to have small effect on IP spot size and final focus bandwidth

Next magnets to be designed

- QF1, SF1 & BB1,2 “standard” magnets ⟷ beam-pipe ⟷ optics iteration (improved pocket fields)

  LAL, Saclay and Cockcroft

- “Panofsky” – style large aperture quads

  L. Hand & W. Panofsky, Review of Scientific Instruments, Vol. 30, No. 10, 927-930, 1959

  LAL & Cockcroft in collaboration with other groups (being explored at present time)

- Design uses NbTi SC QD0 & large bore SF1 for 500 GeV CM

  R&D ➔ Nb_3Sn SC QD0 for 1 TeV upgrade

  LBL & FNAL ? ⟷ Cockcroft & LAL to iterate optics

- Not considered in detail so far : dump and collimators ➔ need to connect to baseline work on these

Vertex detector backscattered photon hits from extraction line losses

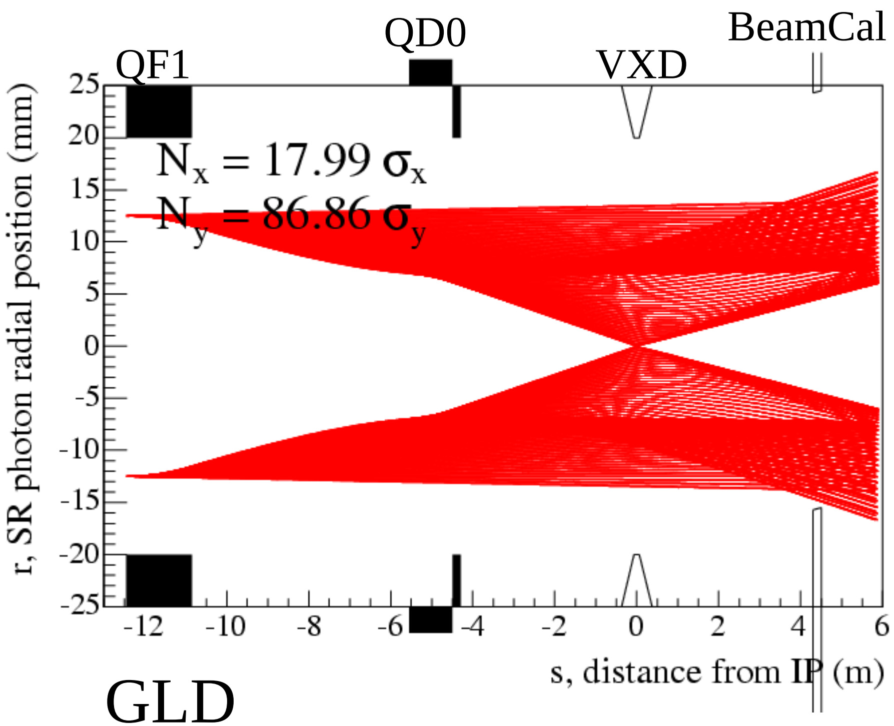
BDSIM model of extraction line constructed to assess photon hits in VXD from charged beam losses on the main extraction line collimators (with a Mokka model of the LDC detector, hit probability in detector ~2.2%)

	D [m]	X [cm]	P [kW]	#γ's/bx	VXD hits
QEX1COLL	45	20	0.2	1.3	0.02
QE2COLL	53	-	0	0	0
BHEX1COLL	76	41	0.1	0.2	0.004
COLL1	131	85	52.3	40	0.8
COLL2	183	115	207.5	82	1.8
COLL3	286	-	0	0	0

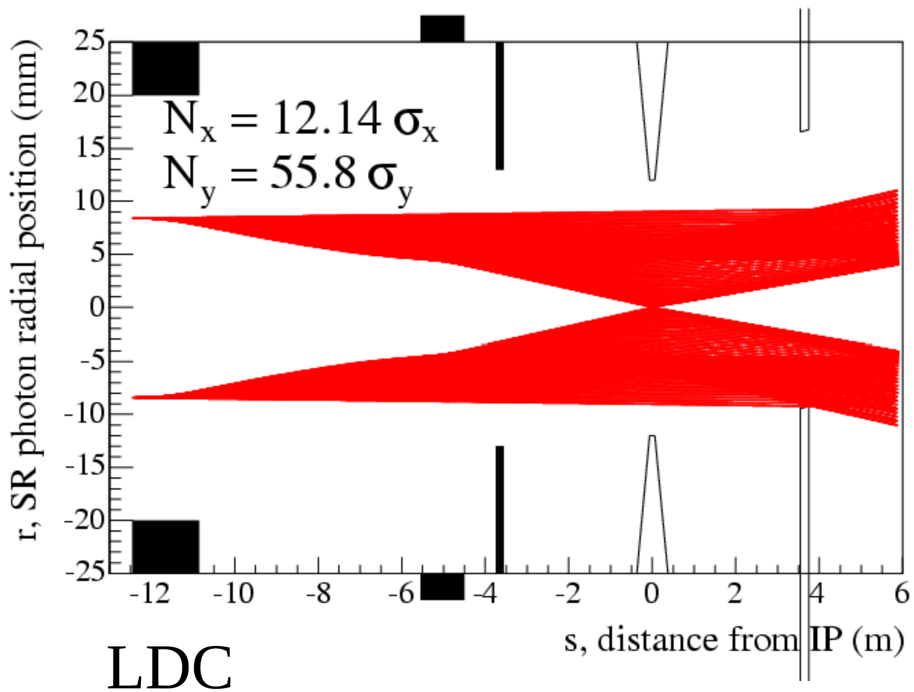
Conclusion: rate is negligible from this contribution compared to other sources e.g. beam-beam induced hits

(Notes: γ's reach through LoS through BeamCal, radius 1.2 mm, Collimator as Cu)
(Photons reach VXD through line-of-sight from collimator i.e. no reflections)

Collimation depths



GLD



LDC

Best case GLD, worst case LDC,
but the collimation depths are acceptable

EDR plans

Aim of proposed EDR-phase 2 mrad tasks are to bring the design to the level of a credible alternative to the 14mrad baseline design

- Optics and beam transport
  - variable l* IR and extraction line layout (CI)
  - study of extraction line aberrations on final focus beam(CI, LAL)
  - Iteration of design and losses as magnet designs progress (LAL, CI)
  - integration of FD for 2 mrad in final focus optics design for the incoming beam (CI)
- Magnet design studies
  - design of large aperture final horizontal bends BB1 and BB2 (LAL, CI)
  - design of standard warm FD magnets QF1 and SF1 (LAL)
  - design of a modified Panofsky quadruple magnets (exploring possibilities) [Feasibility,Cost]
  - Engineering design of QD0 and SD0 (?) [Feasibility for compact size]
- Engineering, integration and cost-related work
  - Integration of final doublet into detector, including
    - cryostat design and FD support/services
    - anti-solenoid or skew-quadrupoles for coupling correction, with appropriate integration
  - design of beam pipe in shared area (LAL) [detailed drawings critical]
  - design of beampipe in extraction line (LAL) [detailed drawings critical]

There is real flexibility in this scheme, with margins and adjustable parameters

Summary

- We should do the best we can with small crossing angle schemes
  - We should, if possible, have alternatives (backups)

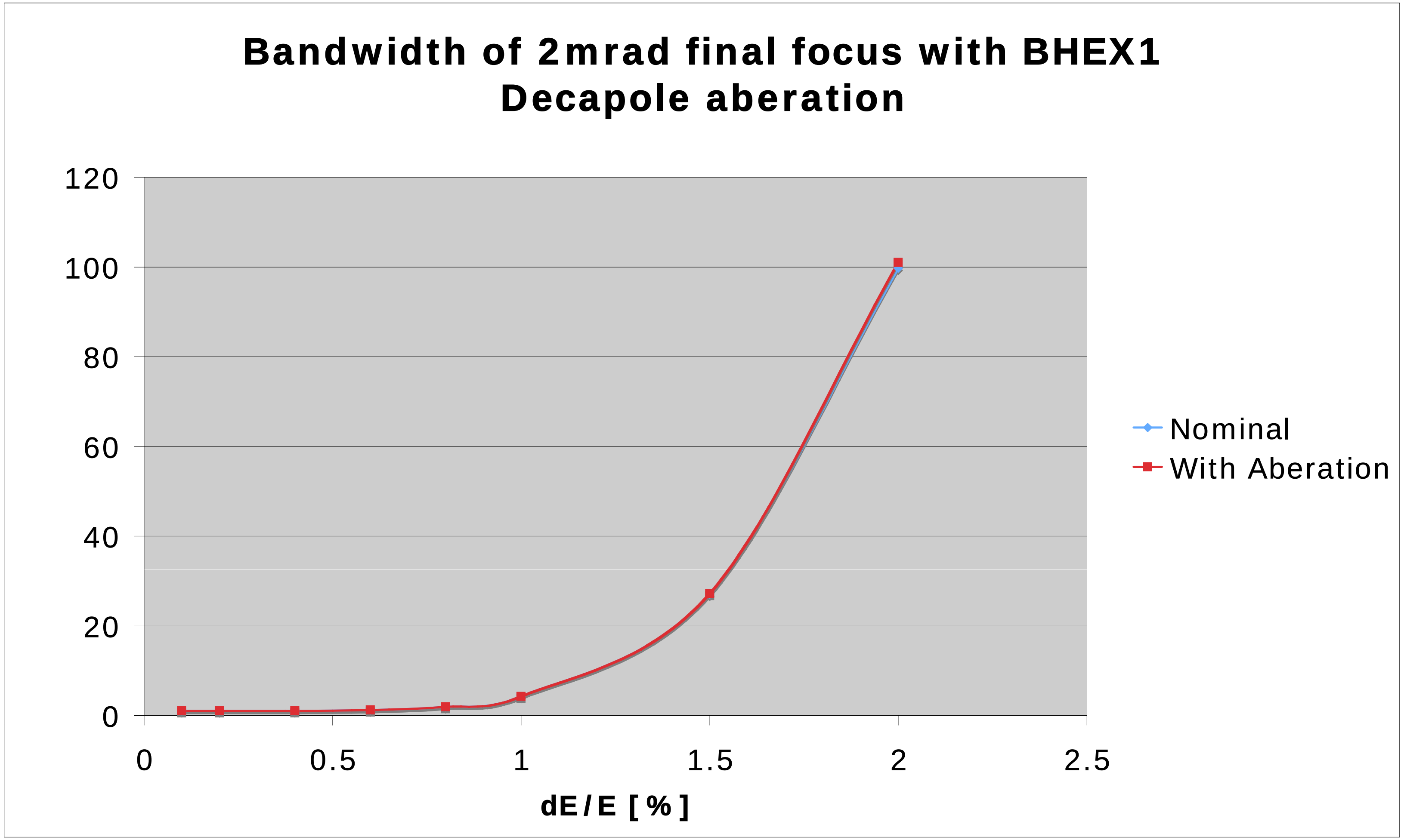
- A viable alternative to the 14mrad baseline solution now seems both technically possible and cost-effective, this is the 2mrad scheme

- Plenty of progress has been made on beam transport, magnets, IR layout, backgrounds, collimation and so on

- Some design and engineering issues exist, and an EDR plan exists to confront these topics and allow a fair evaluation of alternative merits

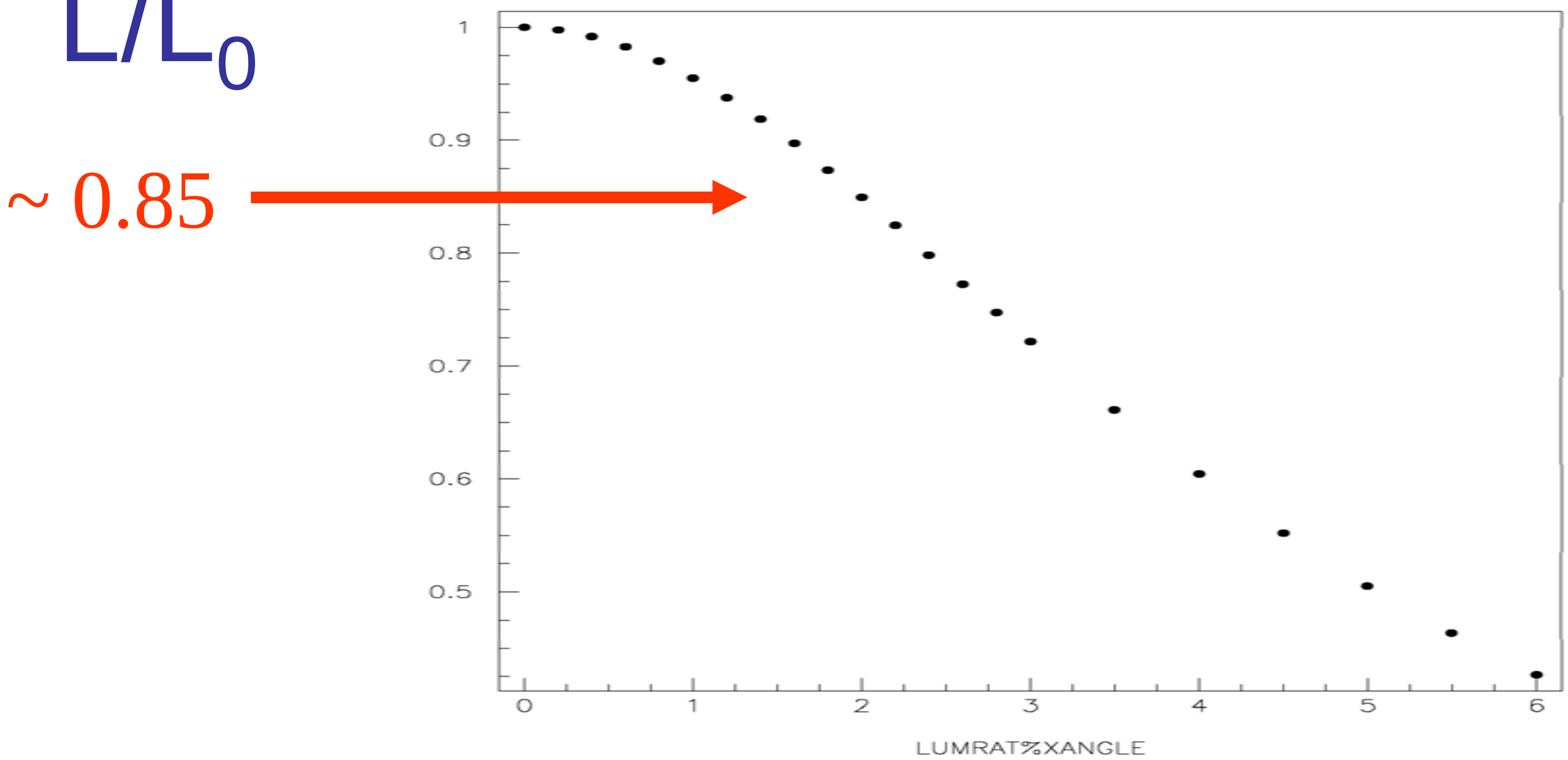
Backup slides

Bandwidth from BEX1 decapole component



Luminosity loss without beam crab

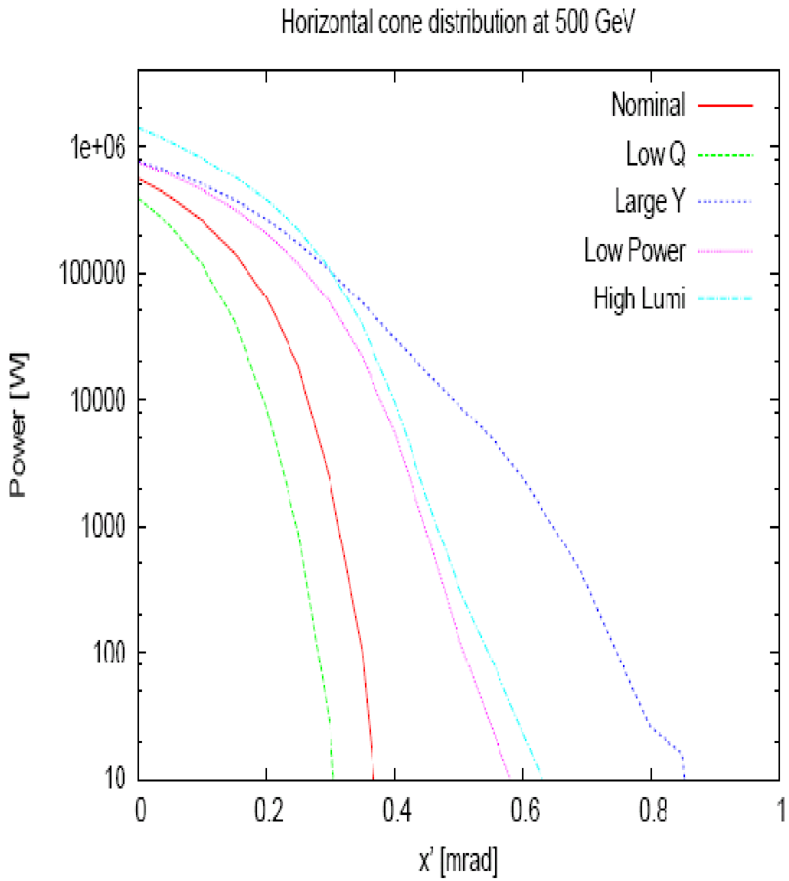
L/L_0

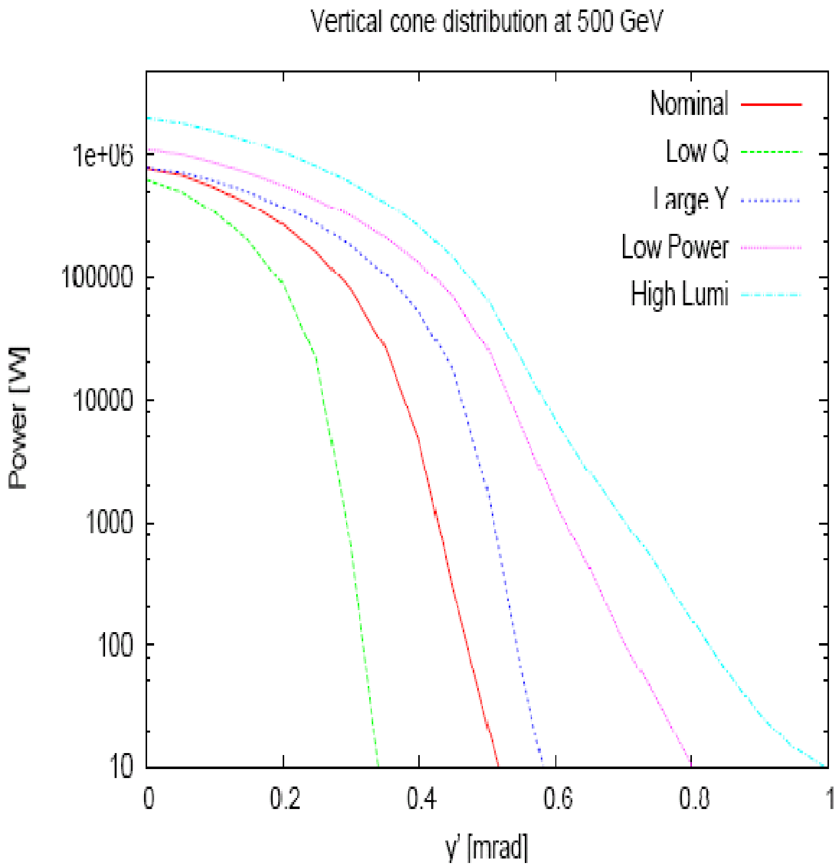


2θ[mrad]

20 mrad $\rightarrow L/L_0 \sim 0.2$

Beamstrahlung cones





Integrated power beyond half- opening angle