Compact design for the RTML Extraction Beamlines

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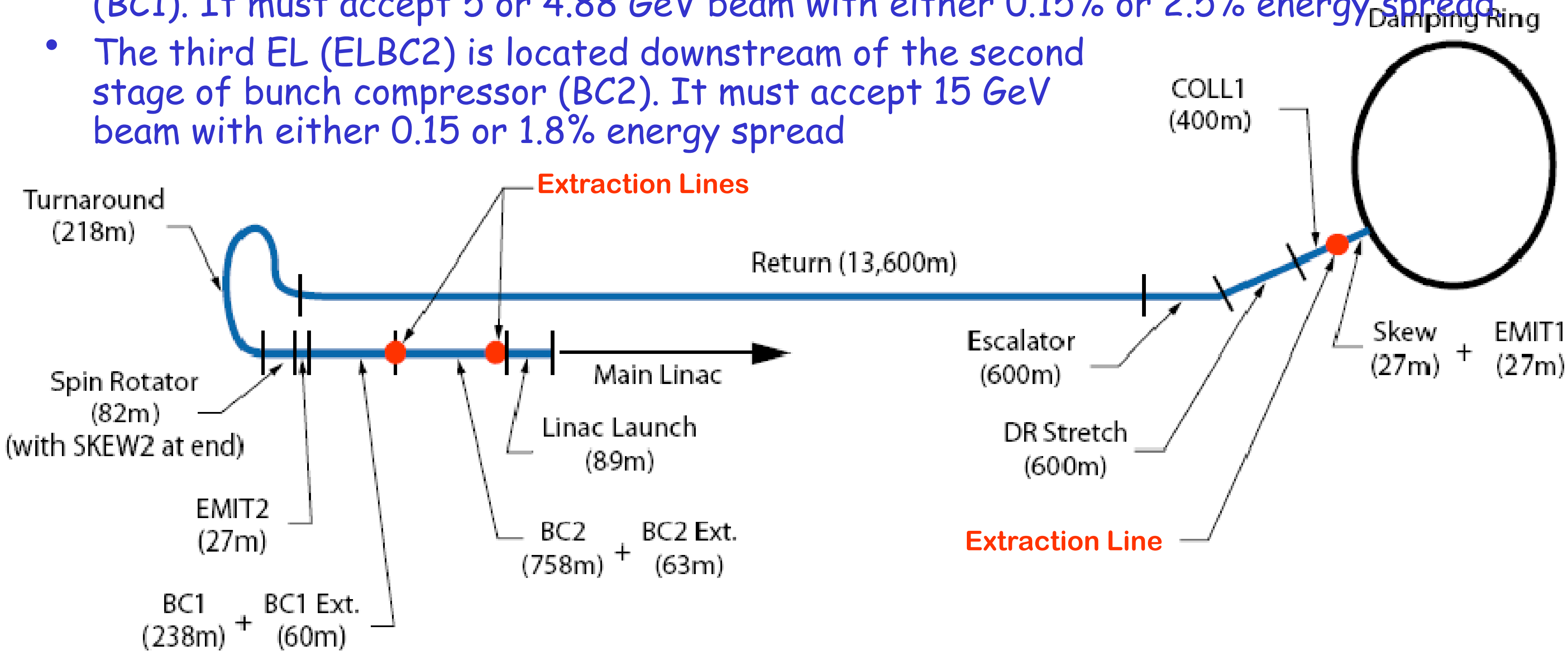
Introduction

- The RTML incorporates three extraction lines that can be used for either an emergency abort of the beam or for a train-by-train extraction.
  - First EL (EL1) is located downstream of the Damping Ring extraction arc. It must accepts 5 GeV beam with 0.15 % of energy spread.
  - The second EL (ELBC1) is located downstream of the first stage of bunch compressor (BC1). It must accept 5 or 4.88 GeV beam with either 0.15% or 2.5% energy spread.
  - The third EL (ELBC2) is located downstream of the second stage of bunch compressor (BC2). It must accept 15 GeV beam with either 0.15 or 1.8% energy spread



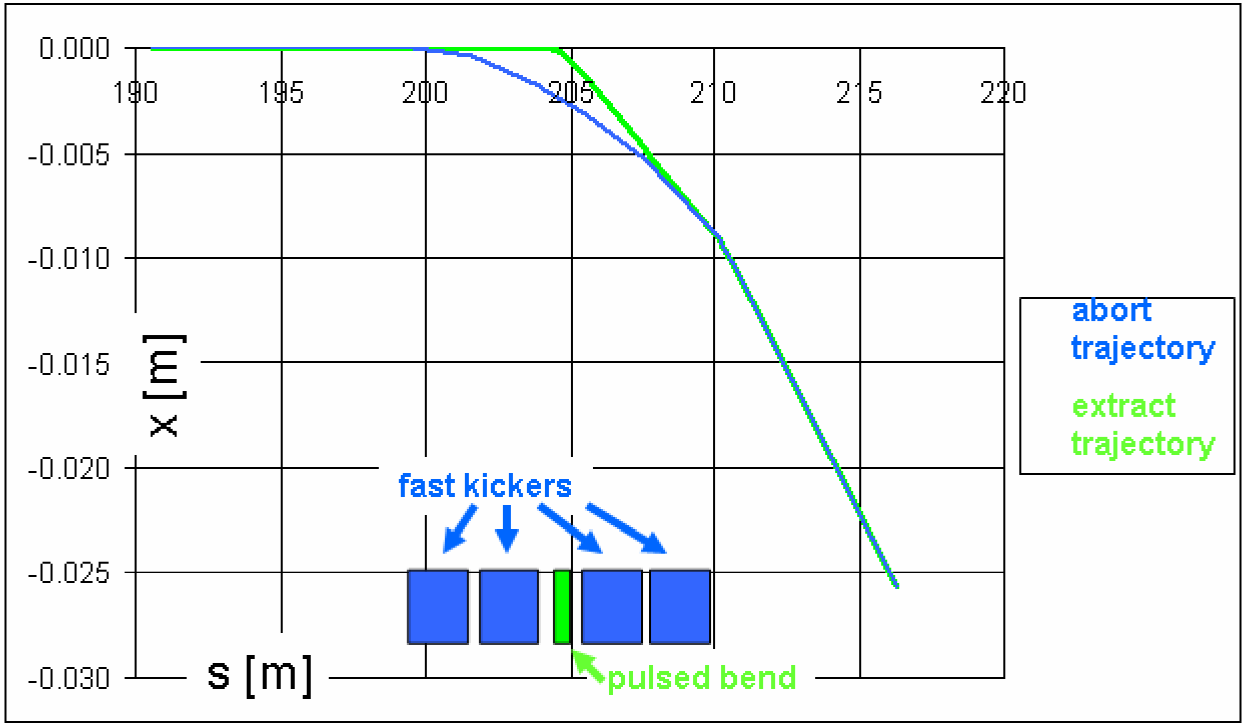
- *All 3 beam dumps are capable of absorbing 220 kW of beam power.*

Requirements to the EL

- Horizontal offset of the dump from the main beamline is 5 m center-to-center.
- The beam size on the dump window is at least 12 mm^2.
- The EL has to accommodate both the beam with RMS energy spread of 2.5% and the uncompressed beam, i.e. the beam with the energy spread of 0.15% (for the EL located after the first stage of the BC).
- The elements of the straight-ahead beamline and the extraction beamline must have enough transverse clearance so that they do not occupy the same physical space.
- One has to arrange for both the train-by-train extraction and emergency abort of the beam.
- The magnets must be physical. Here we limit ourselves to 1 T pole-tip fields for the quads, 1.8 T fields for the bends, and 0.1 T fields in septum magnets.
- The extraction line must be made as short as possible.

Extraction System

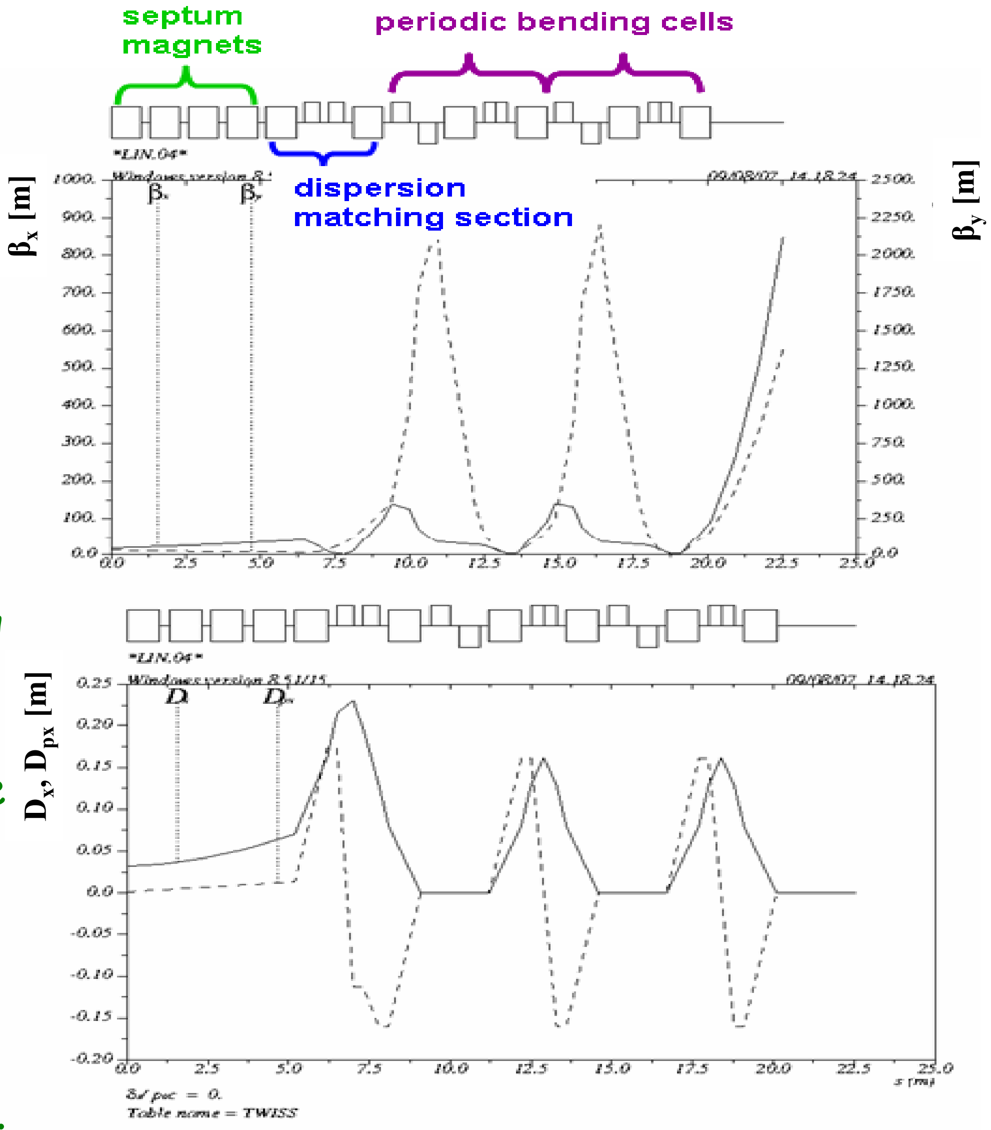
- In EL1 and ELBC1 the train-by-train extraction of the beam is realized by the 1m long pulsed bend with 280G field. Four 2 m long fast kickers that are powered up to 35G in 100 ns are used for the abort extraction of the beam.



- The ELBC2 extraction system consists of ten 1m long fast abort kickers, and a single 1m long tune-up extraction bend placed in between two central kickers. The abort kickers can be charged to 90G each in 100ns. The tune-up bend is excited to 900G.

EL Design (Concept)

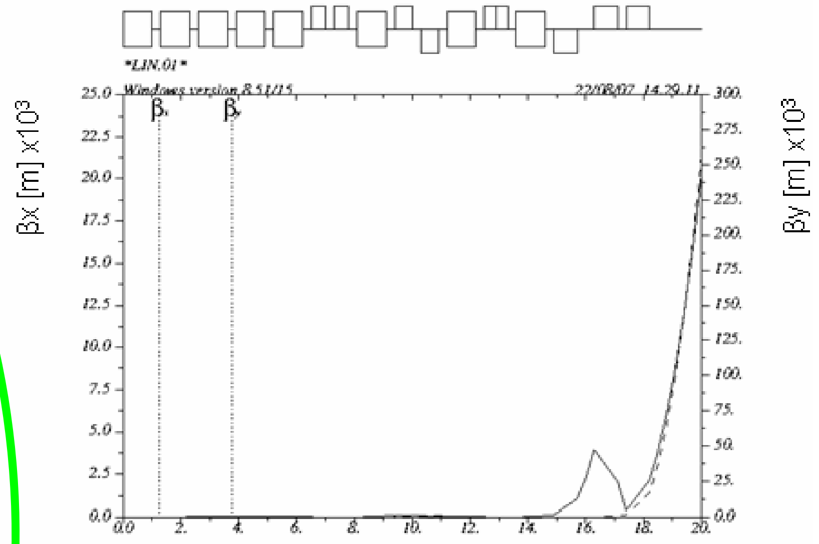
- We would like to make EL as short as possible and we need to have enough transverse separation to clear the cryomodule located 2m downstream of the extraction point. So we need as much bending as possible, as early as possible.
- On the other hand, horizontal dispersion and requirements to the strength of bends set their limits.
- Therefore, we suggest to use double bend achromats (DBA) as our bending blocks.
- Since we are confining the beam within 4 cm aperture we can not make bends too long. We must balance a wish for stronger bending at the beginning of the EL with allocating enough space for focusing quads.
- We build the EL of periodic cells consisting of DBA and focusing quads.

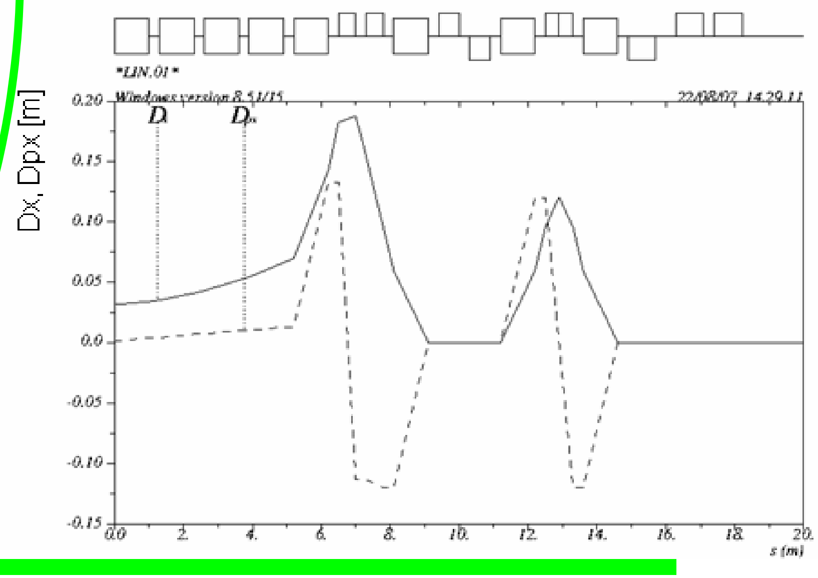


EL Design (Solution)

- We start with choosing maximum strength of the bends (less than 1.8 T) for which the dispersion inside achromats is still reasonable.
- Then we minimize the DBA quad's length keeping its strength within set limits.
- Next, we adjust two fitting quads to make cell periodic.
- Finally we stack as many obtained cells as we need to achieve 5 m separation of the dump center from the main line.

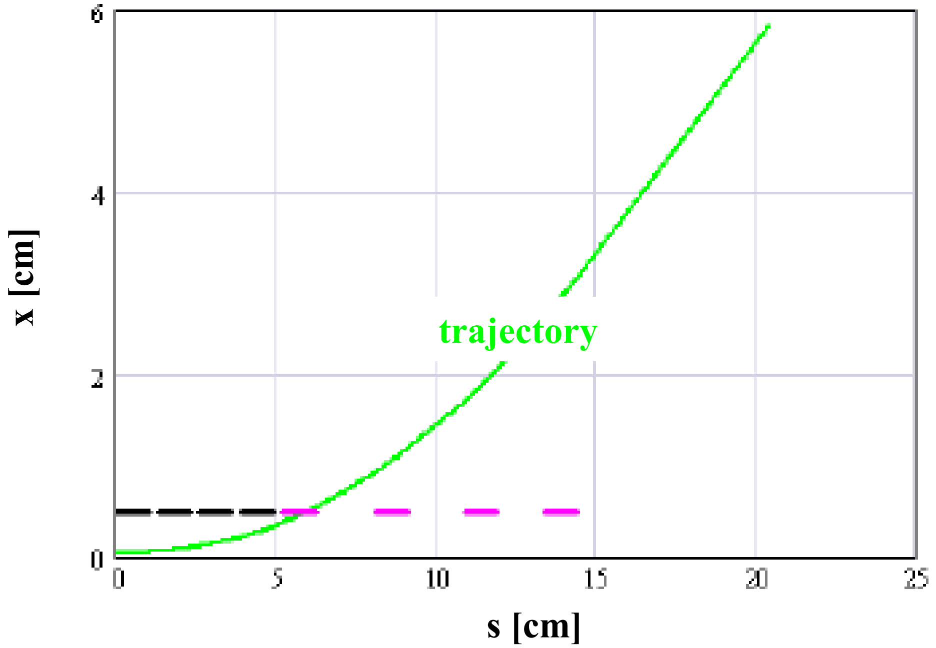
We repeat these steps trying to minimize element-to-element drifts.

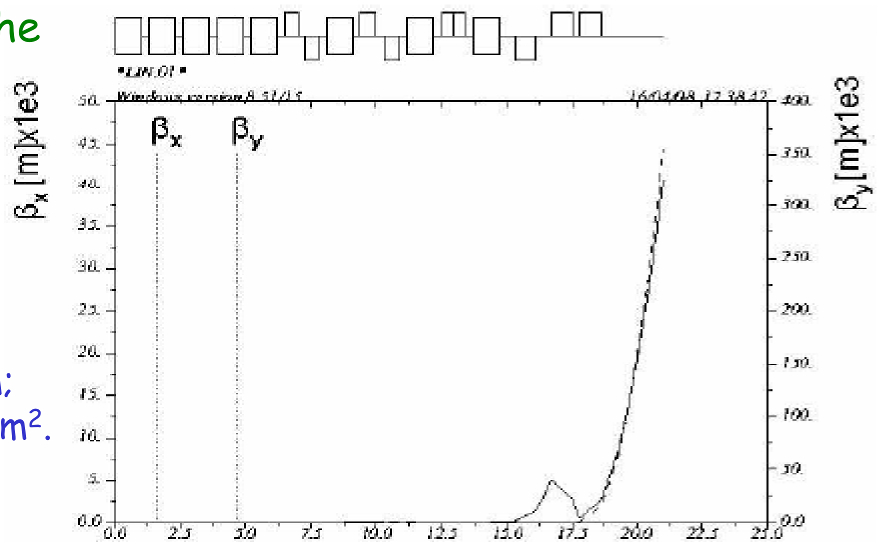


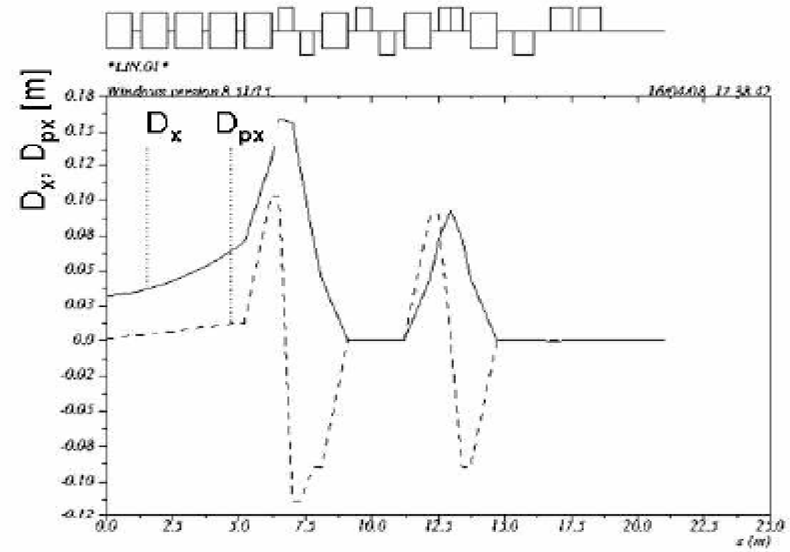


EL Design (Solution)

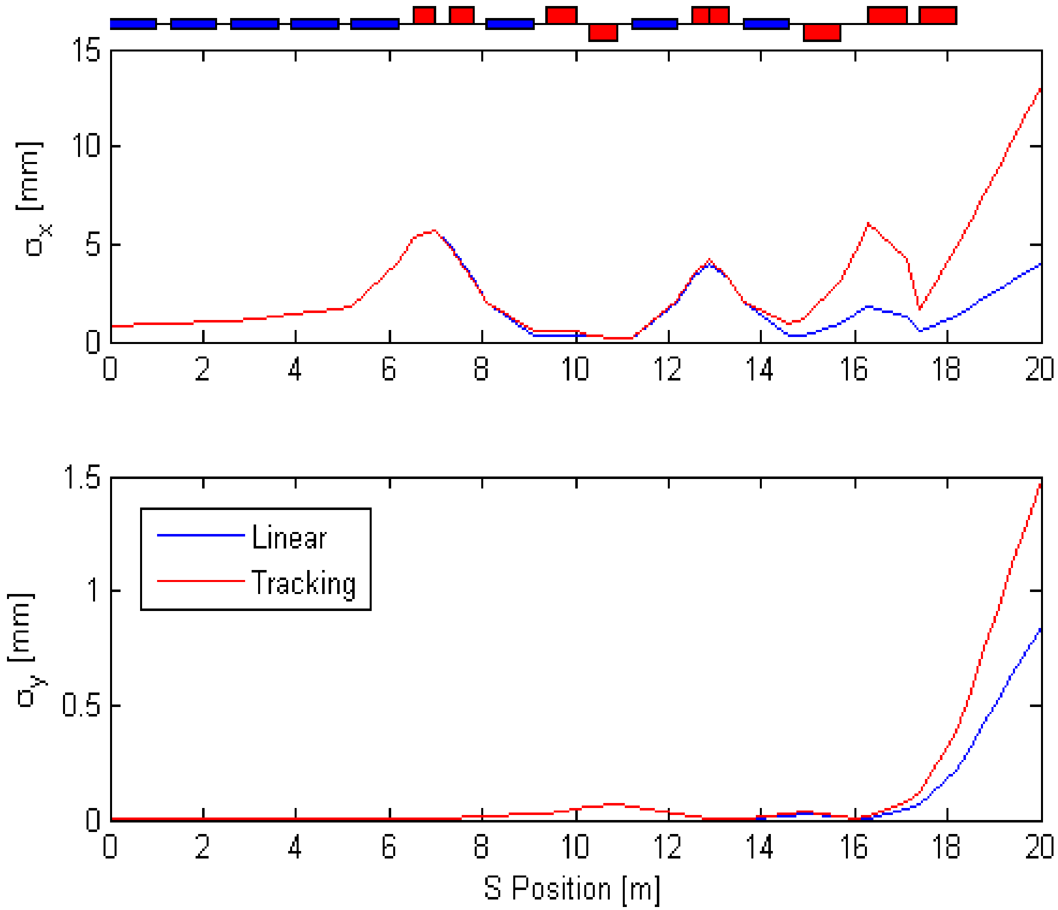
- Only one periodic cell is needed in addition to the dispersion matching cell to separate the dump from the main line by required distance.
- The three additional quads at the end of the dump line are used to blow up the beam size.
- Finally:
  - The separation of the two lines at cryomodule location is 2m;
  - Separation of the dump and the main line is 5.8 m;
  - The size of the beam on the dump window is 15 mm².





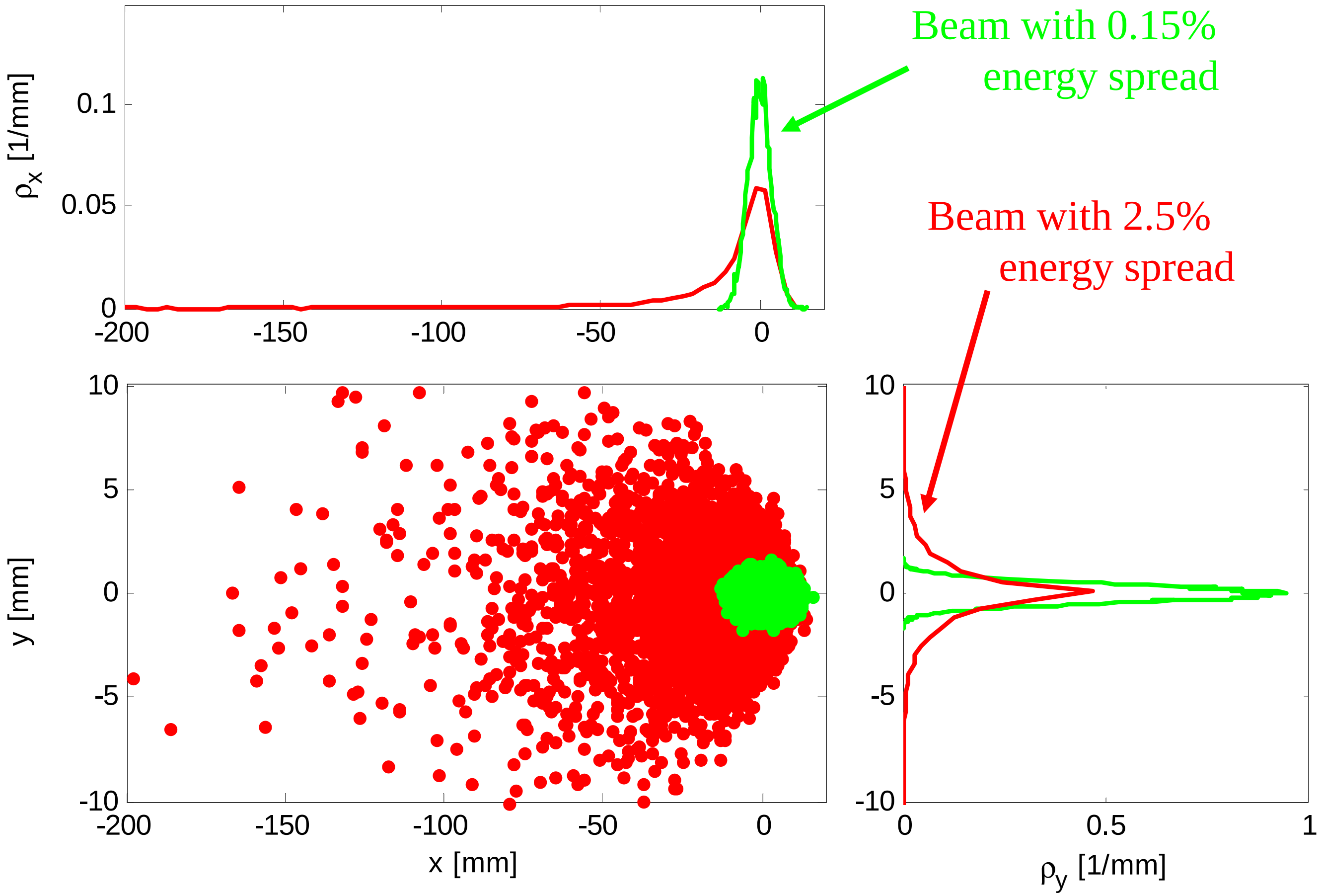


- For the beam with high energy spread, there is a substantial blowup in the beam size from chromaticity and nonlinear dispersion at the end of the beamline.

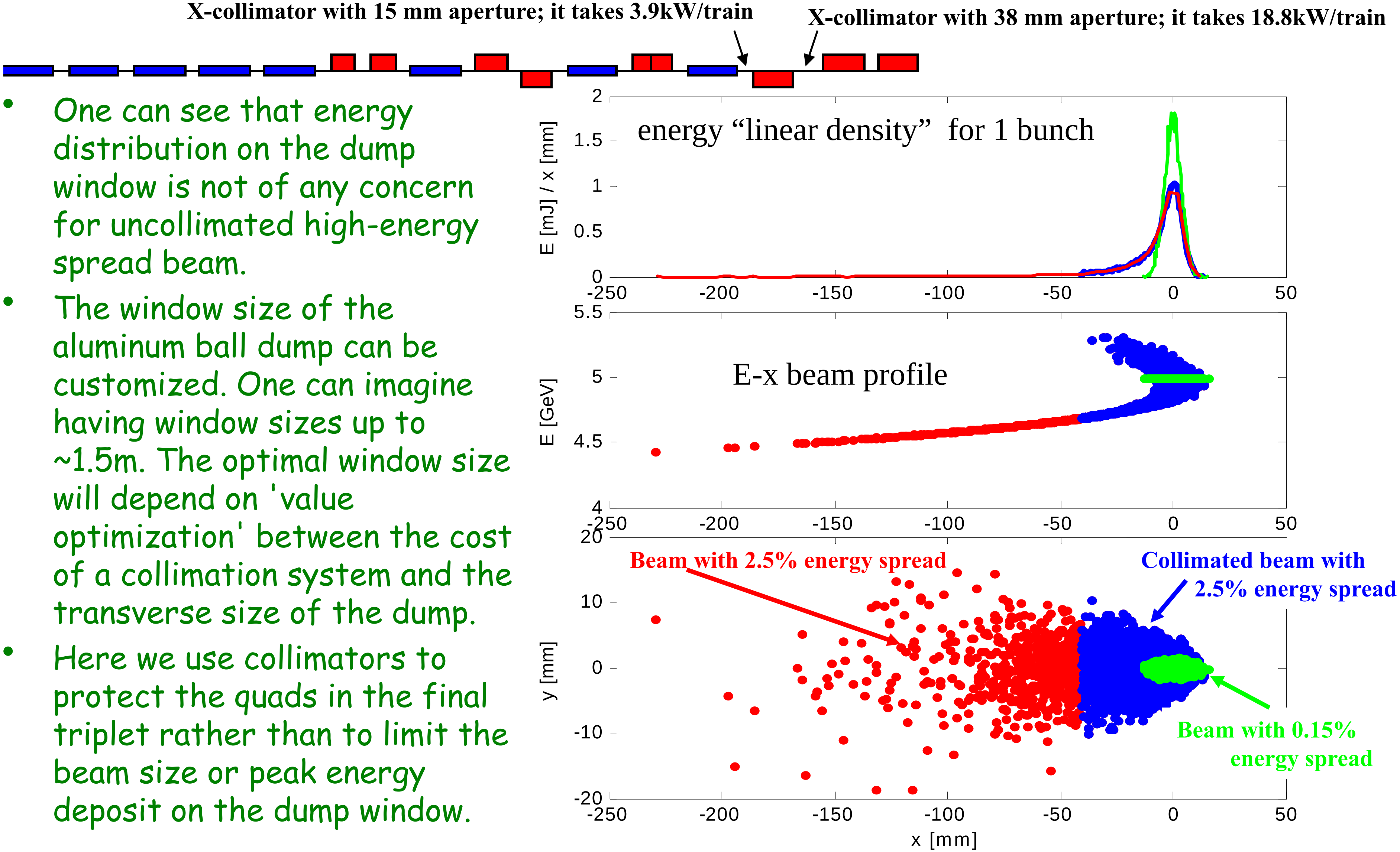


Beam's Nonlinear Halo

- While the beam with low energy spread has the designed size at the end of the dump line and on the dump window, the beam with 2.5 % energy spread is much larger.
- The main portion of the particles from the off-energy tails is deposited on the final quad triplet.

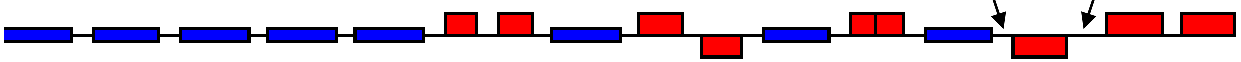


Beam Collimation

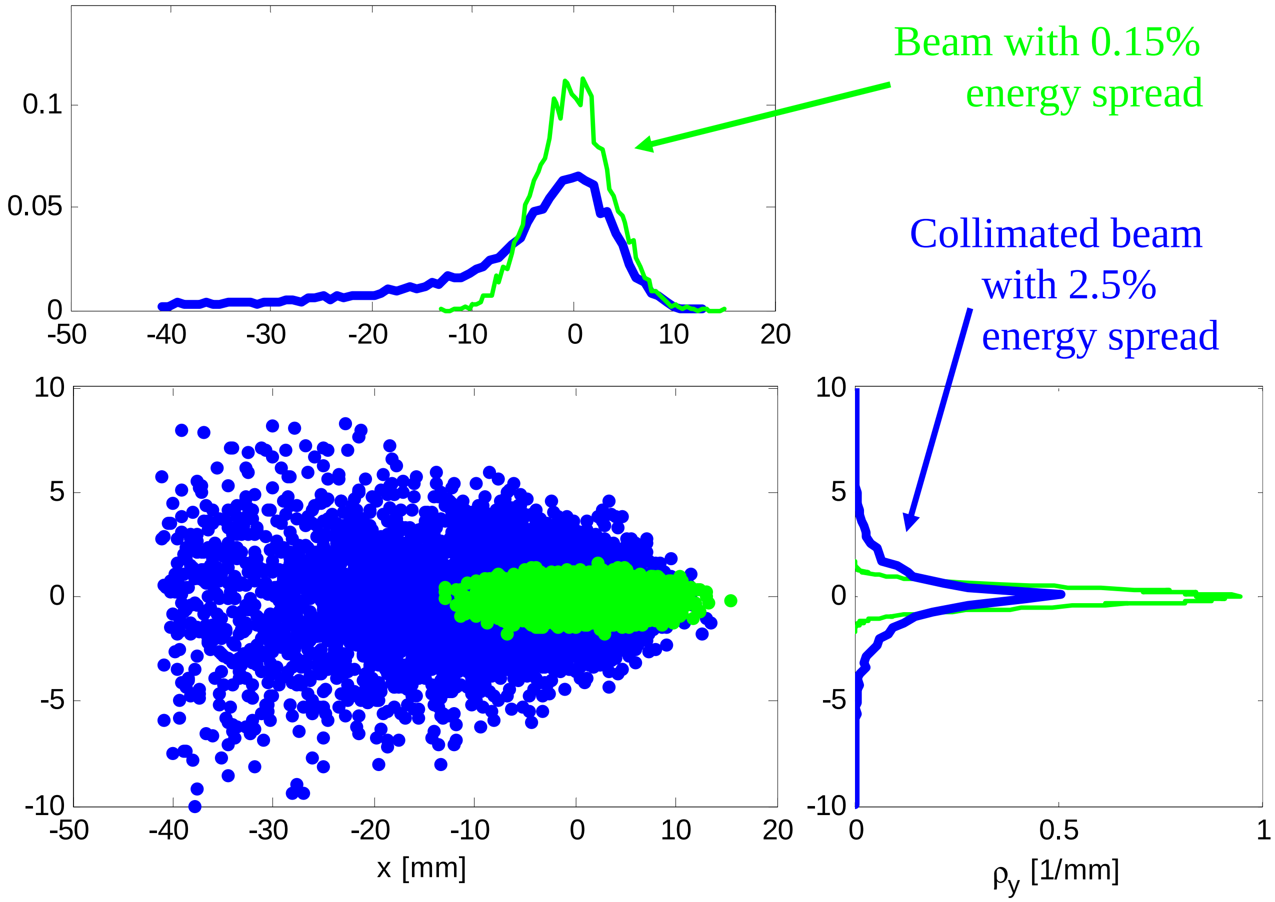


- One can see that energy distribution on the dump window is not of any concern for uncollimated high-energy spread beam.
- The window size of the aluminum ball dump can be customized. One can imagine having window sizes up to ~1.5m. The optimal window size will depend on 'value optimization' between the cost of a collimation system and the transverse size of the dump.
- Here we use collimators to protect the quads in the final triplet rather than to limit the beam size or peak energy deposit on the dump window.

Beam Collimation

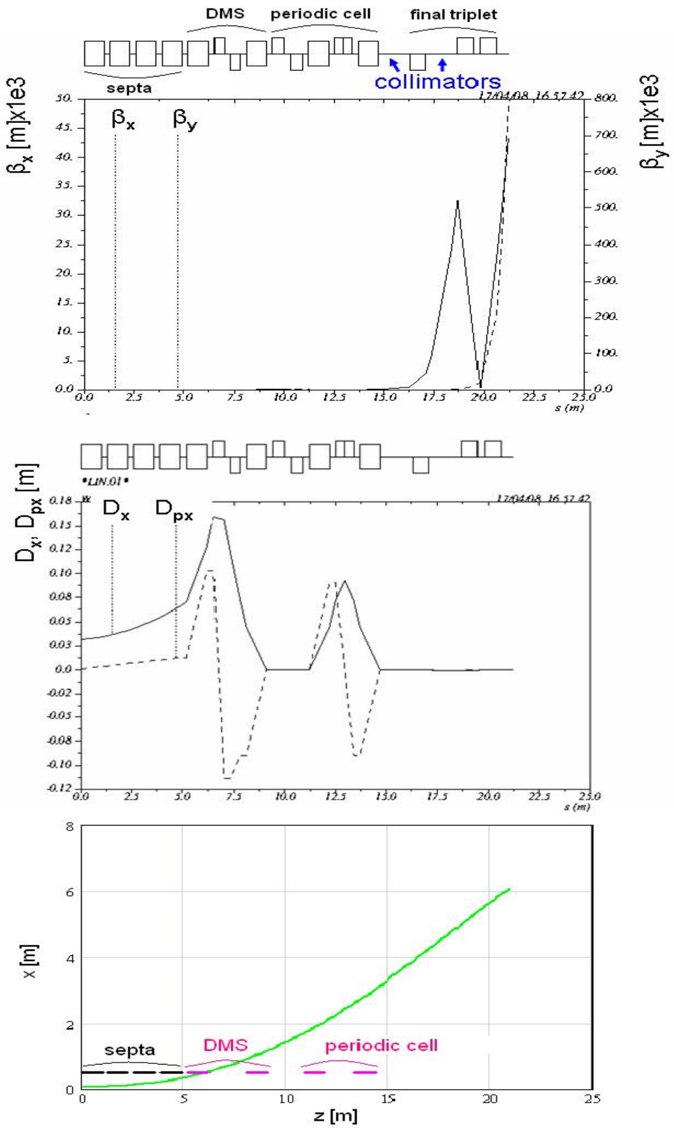


- We suggest to use a system of two collimators with 15mm and 38 mm fixed apertures, which take 3.9kW/train and 18.8kW/train of beam power respectively.



EL Design (Final)

- In final design the ELBC1 is 20.7m long
- The dump is separated from the main beamline by 6m, center to center
- The beam size on the dump window is 24mm2 for the low energy spread beam; the high energy spread beam does not require the dump window radius to be larger than 5cm



ELBC2 and EL1 Design

- The ELBC2 was designed in accordance to the principles outlined above.
  - Separation of the beam dump and the main beamline by 5m, center to center.
  - The beam size on the dump window is 45mm^2 for 0.15% energy spread; the high energy spread beam does not require the dump window radius to be larger than 5cm.
  - Length of the ELBC2 is 45m.
- The EL1 was designed in straightforward manner. It has FBDB lattice optimized to provide a suitable beam spot on the dump window.
  - Separation of the dump window from the main beamline is 6m center to center.
  - The beam size on the dump window is 13mm^2.
  - The extraction line is 19m long.

Beam Dumps

- For each of the three 220kW dumps both low and large momentum spread beam is contained within a 5cm radius circle.
- To allow for equipment positioning tolerances a dump window diameter of 12.5cm was chosen.
- An aluminum window using a 1mm thick hemispherical design is feasible for a suggested aluminum sphere dump.
- It has the promise of long term safe operation, even for the 0.15% $\Delta p/p$ optics with beam spot area on the dump window larger than $12mm^2$.
- There are no steady state heat transfer issues to reject the energy deposited by the beam to the cooling water.

Specifications

Magnets					
type	quantity	length, m	ID, cm	B_{max}, G	comments
quad 1	6	0.3	4.5	1e4	One may need to substitute one of these quads with figure 8 quad
quad 2	2	0.5	4.5	1e4	
quad 3	2	0.6	4.5	1e4	
quad 4 quad 5	7 1	0.8 0.9	4.5 4.5	1e4 1e4	
quad 6	6	1.1	4.5	1e4	
quad 7	2	1.8	4.5	1e4	
regular bend	15	1	4.5	1.5e4	One may need to substitute two of these bends with C-shape bends
C-shape bend	1	1	4.5	1.5e4	At this bend's location beamlines are separated by 7.7cm center to center
septum bend	14	1		500	
pulsed bend	3	1		900	EL1 and ELBC1 pulsed bends are run at 280 G at maximum
fast kickers 1	8	2		35	EL1 and ELBC1 kickers; ramped up to designed field in 100ns
fast kickers 2	10	1		90	ELBC2 kickers; ramped up to designed field in 100ns

Specifications

Collimators				
location	quantity	length, m	x-aperture, mm	power/train, kW
ELBC1	1	1	15	3.9
ELBC1	1	1	38	18.8
ELBC2	1	1	4	5.2
ELBC2	1	1	40	14.1

Dumps
3 aluminum sphere dumps capable of absorbing 220kW of beam power. Dumps have 1mm thick, hemispherical aluminum windows of 12.5cm diameter.

Diagnostics
Button-style BPMs, which are part of the quad vacuum chamber, and located on one side of the quad.

Design Options (Exotic Magnets)

- Magnets of exotic shape may have to be deployed in all three extraction lines. This is dictated by marginally insufficient separation of extraction beamline and main beamline at the location of these particular magnets. Alternative for C-magnets and figure 8 quads is to use more septum bends, and/or to increase the drift from the last septum to the first conventional magnet.
- As an example let us consider EL1.

	baseline scenario	alternative scenario
Separation of the extraction and main beamlines at the location of first quad, m	0.35	1
Separation of the extraction and main beamlines at the location of first bend, m	0.43	1.1
Numer of septum bends	4	7
Number of regular bends	5	5
Number of C-shape bends	1	0
Number of regular quads	5	5
Number of figure 8 quads	1	0
Length of the extraction line, m	19	21.1

- The main purpose to use collimators in ELBC1 is to protect the final quad triplet from direct hits by off-energy beam particles. Obvious possibility to avoid collimation is to increase the apertures of three final quads.

	2 collimators	no collimation
Final quad triplet	Regular quads with 1T pole tip field, and 4.5cm aperture	SC quads with 11T pole tip field, and 50cm aperture
Collimators	3.9kW/train and 18.8kW/train collimators	no collimators required
Dump window diameter, cm	12.5	60
Length of the extraction line, m	20.4	20.7

Design Options (Beam Collimation)

- The first of two collimators used in ELBC2 protects the final quads from the direct hits of off-energy beam particles. The second collimator is used to collimate the beam spot size on the dump window.
- One of the possible options is to use the first collimator only, and to have the dump window of bigger diameter.
- Another possibility is to do without collimators at all.

	2 collimators	1 collimator	no collimation
Final quads	Regular quads with 1T pole tip field, and 4.5cm aperture	Regular quads with 1T pole tip field, and 4.5cm aperture	Quads with 2T pole tip field, and 8cm aperture
Collimators	5.2kW/train and 14.1kW/train collimators	5.2kW/train collimator	no collimators required
Dump window diameter, cm	12.5	30	100

Summary

- ILC RTML extraction lines are designed.
- Each extraction line is designed to be used for both fast intra-train extraction, and for continual extraction.
- All three extraction lines are capable to accept 220kW of beam power. This implies that the first 2 dumps, which are at 5GeV, can absorb the full beam power, while the third dump, at 15GeV, can absorb only 1/3 of the beam power, and the beam trains must be run to this dump at reduced repetition rate.
- The second and the third extraction lines are capable of accepting both low energy spread and high energy spread beams, which is required for different scenarios of machine tune-up.
- The list of hardware specifications employed in all three extraction lines is given.
- There is possibility for variations of the baseline design.
- Detailed report of the done work will be published soon.