Final design of extraction line for single stage BC

Sergei Seletskiy

October 1, 2009

Linear Collider Workshop of Americas

Outline

- Requirements to the Extraction Line (EL) and some obvious design challenges.
- Baseline design of the EL.
- Adverse nonlinear effects and how to defeat them.
- Final design of the extraction line.

Requirements to the EL

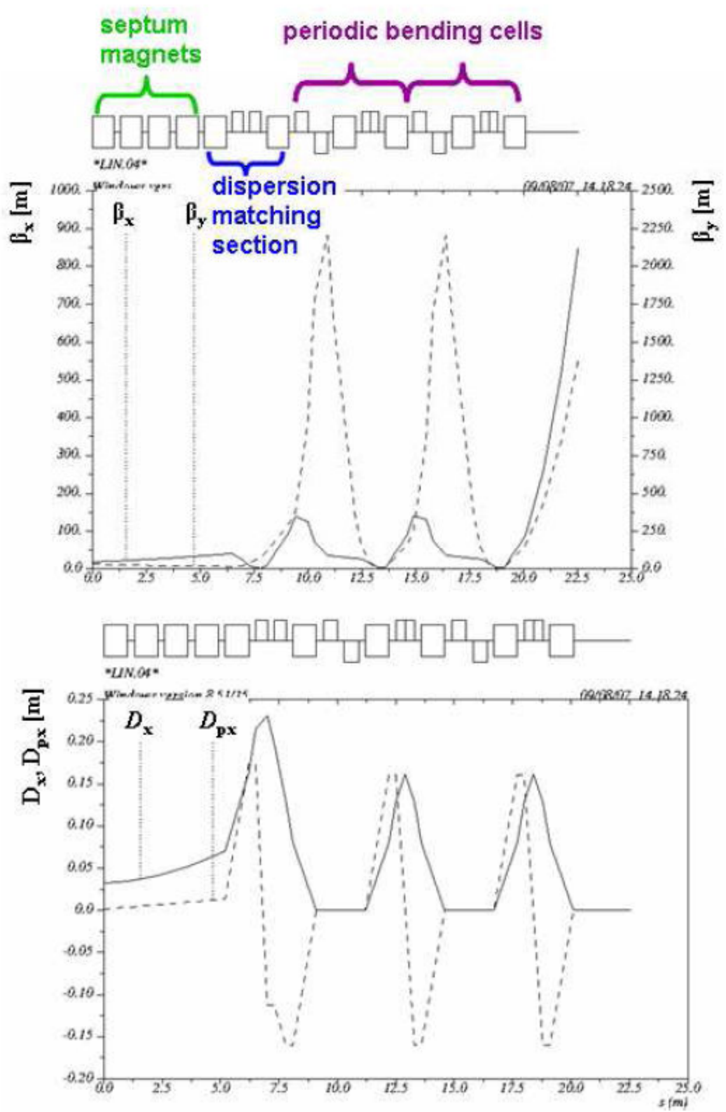
- Horizontal offset of the dump from the main beamline is 5 m center-to-center.
- The beam size on the dump window is at least 12 mm^2.
- The EL has to accommodate both the beam with RMS energy spread of 3.54% and the uncompressed beam, i.e. the beam with the energy spread of 0.15%.
- Beam energy is 4.38GeV.
- 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, 1.5 T fields for the bends, and 0.05 T fields in septum magnets.
- The extraction line must be made as short as possible.

Design Challenges

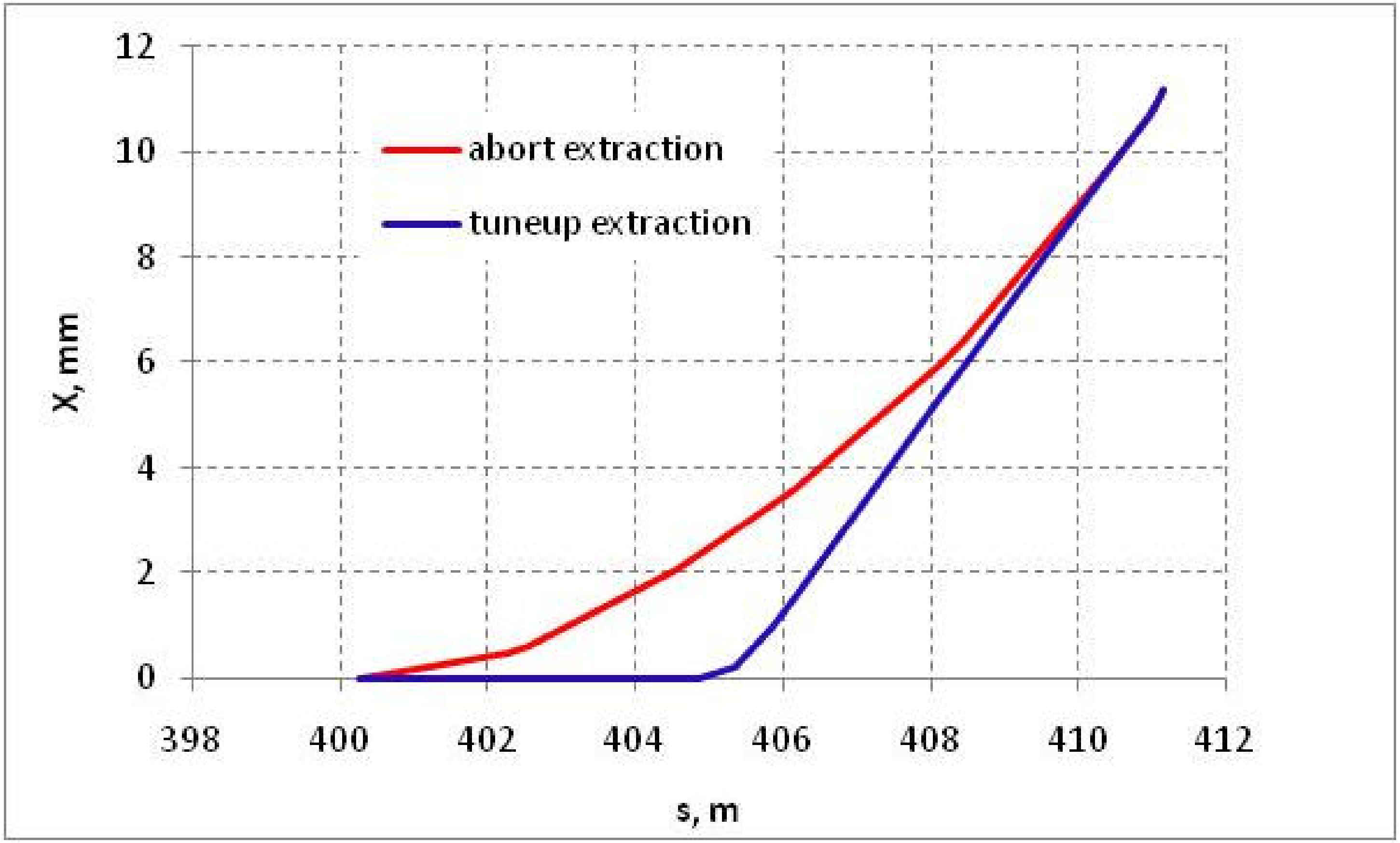
- On one hand, the strong wish to make the beamline as compact as possible drives the design into "as much bending as possible, as early as possible" scenario.
- On the other hand, horizontal dispersion limits bends' strength, and we are keeping the bending field below 1.5T.
- In addition to it, we need to keep reasonable beam size throughout the extraction line for both high energy spread and low energy spread beams. Still, we need the large beam size on the dump window for both beams, therefore dispersion is useless for maintaining beam spot of appropriate size on the dump, and is harmful for keeping reasonable beam size through the extraction line.
- Also, since we are confining the beam within 4.7 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.

EL Design Solution

- To reconcile conflicting requirements oto the EL discussed above we suggest using Double Bend Achromats (DBA) as our bending blocks.
- Indeed, by utilizing the DBAs for our bending needs we completely uncouple the dispersion and beam size issues.
- We suggest starting with the cell, which has periodic solution for Twiss parameters, and consists of DBA and focusing quads. Then we would build the extraction line stacking as many such cells as one needs to provide enough separation between the beam dump and the main line.
- In the shown example, after septums we have Dispersion Matching Section (DMS), which consists of two bends separated by quad doublet tuned to zero the dispersion at the exit of the DMS. We follow DMS with periodic bending cells consisting of DBA and quad doublet focusing the beam.



Extraction System Design

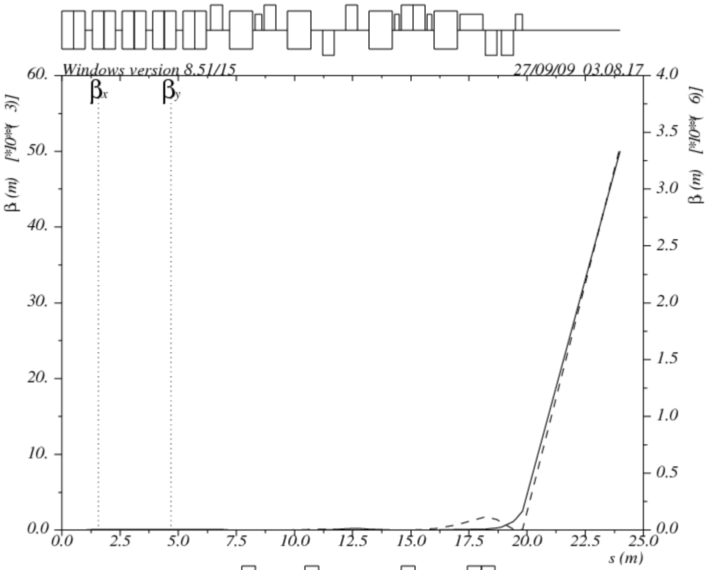


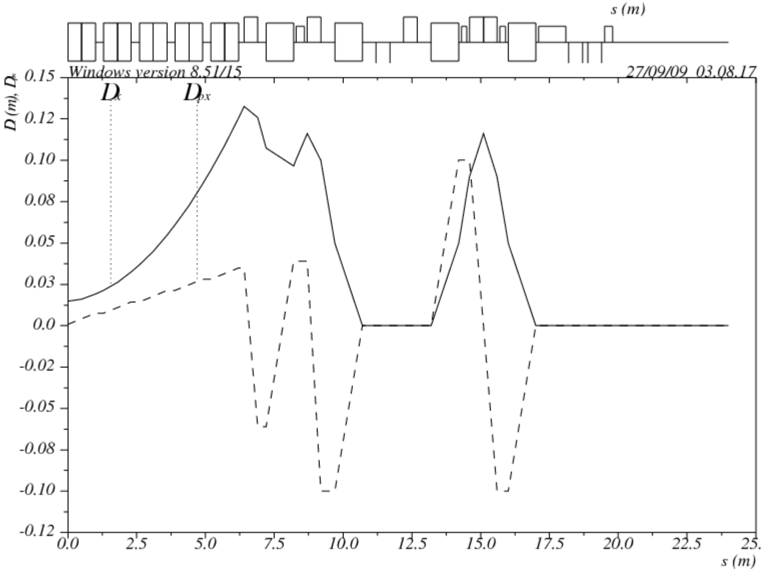
- Extraction system consists of four 2m long fast abort kickers, and a single 1m long tune-up extraction bend placed in between two central kickers.
- The abort kickers can be charged to 35G each in 100ns. The tune-up bend is powered to 280G.

Beam Dump

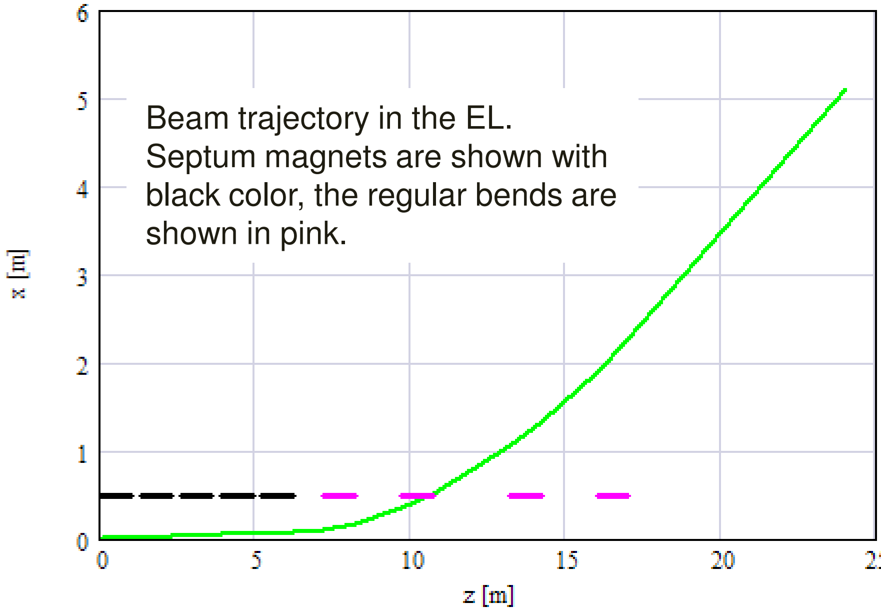
- We are utilizing 220kW aluminum ball dump. For 4.37GeV beam energy the total power/train is just 184kW.
- A dump window diameter of 12.5cm is considered to be a basic choice.
- An aluminum window using a 1mm thick hemispherical design is feasible for a suggested aluminum sphere dump.
- It has the promise of long term safe operation, even for the 0.15% $\Delta p/p$ optics with beam spot area on the dump window equal to or larger than $12mm^2$.
- There are no steady state heat transfer issues to reject the energy deposited by the beam to the cooling water.
- Larger diameter (up to 1m) dump window can be made.

EL Baseline Design



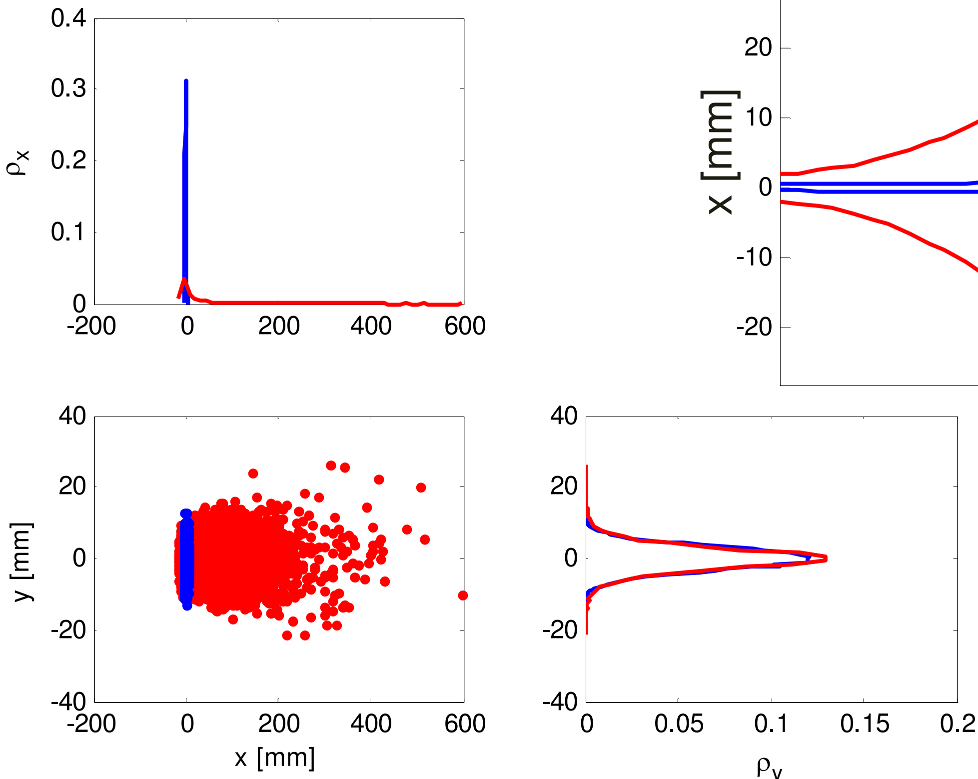


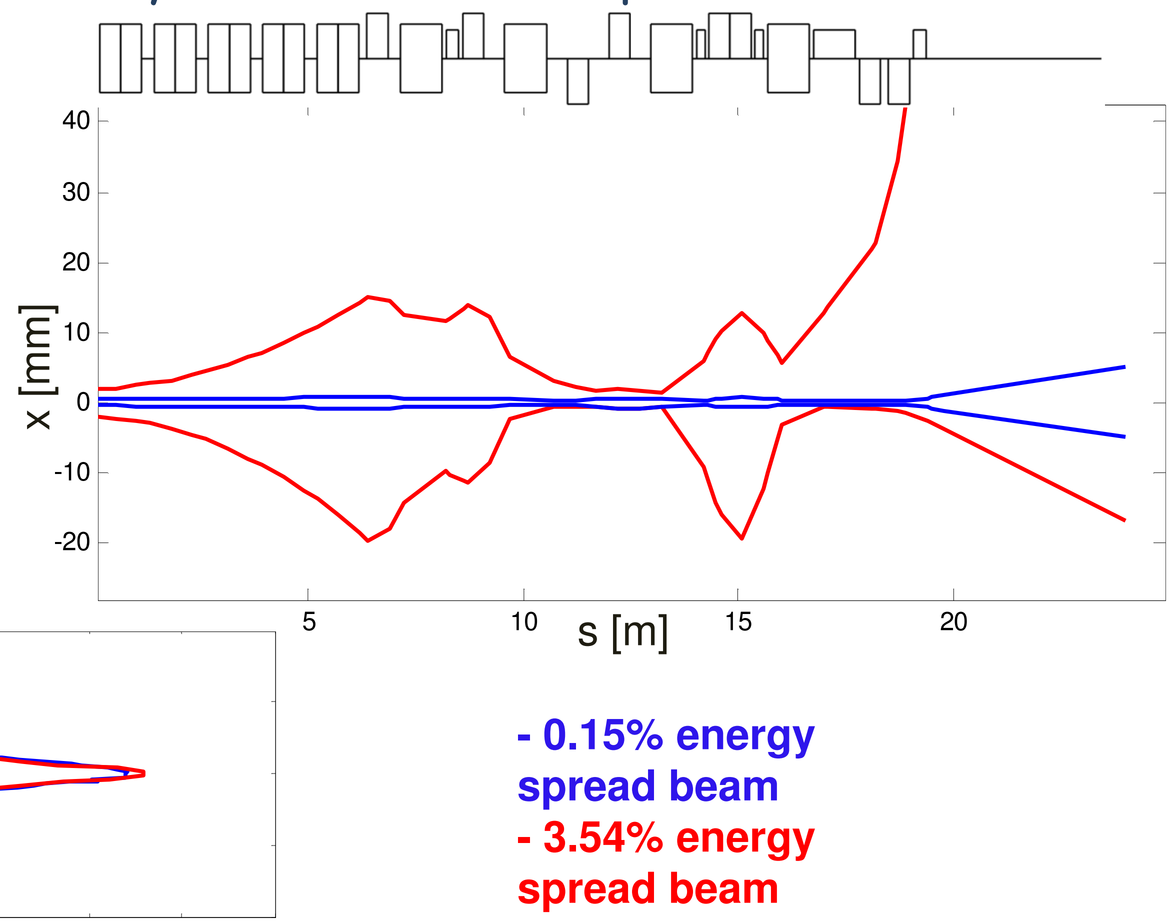
- Taking the described approach to EL design, we obtain (in "linear"/"low energy spread" approximation): 24m long beamline with 17mm² beam size on the dump window. Dump is separated from the main beamline by 5.1m.



Nonlinear effects

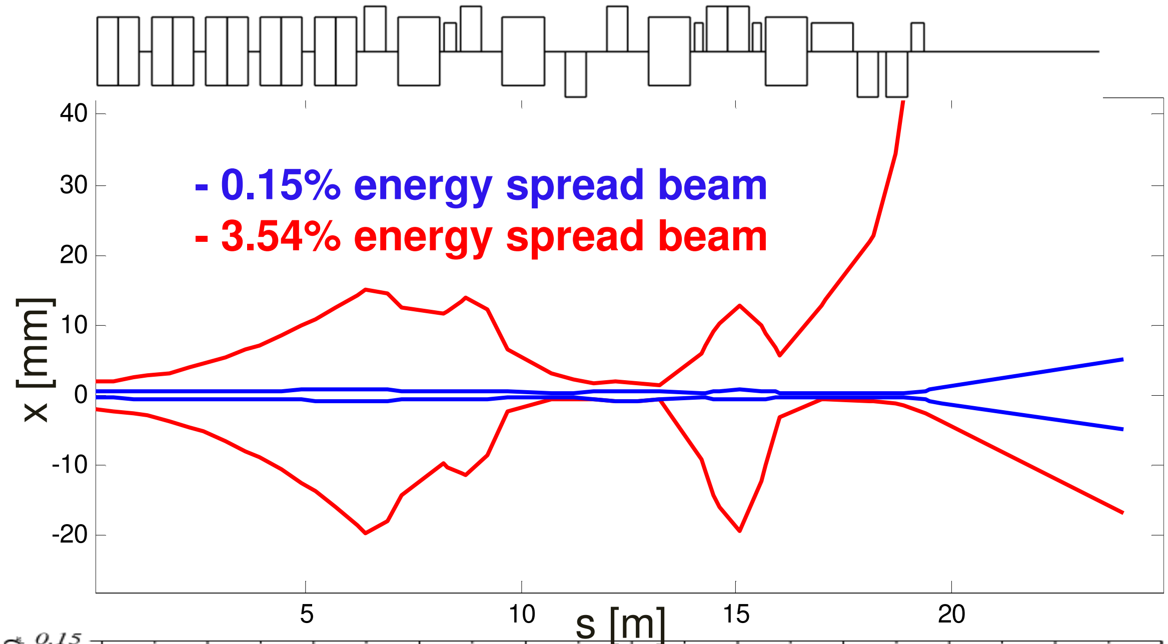
- For the beam with high energy spread, there is a substantial blowup in the beam size from chromaticity and nonlinear dispersion at the end of the beamline.

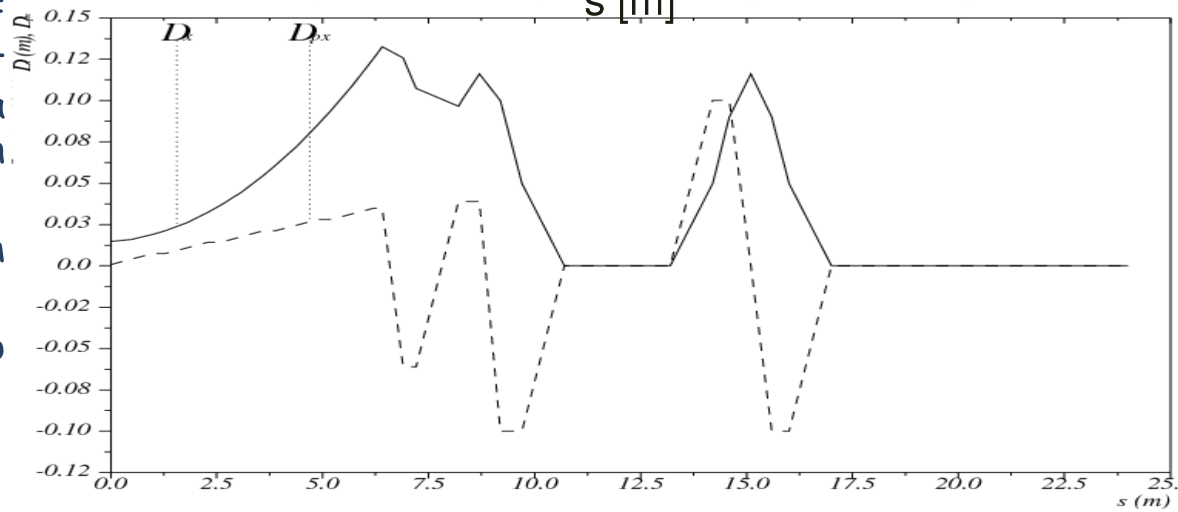




Nonlinear effects

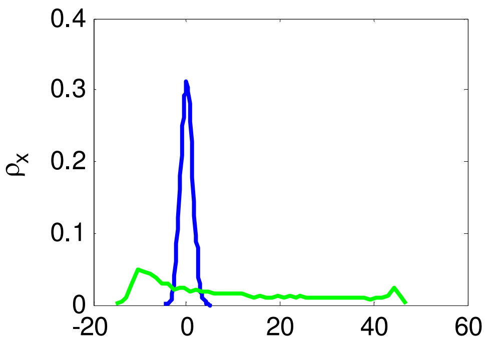
- To mitigate the nonlinear halo one can utilize collimators, sextupoles or some combination of those with superconducting quads of large aperture together with large diameter dump window.
- Collimators present simple but inelegant solution complicating the overall EL design.
- Since the main source of high-energy halo is nonlinear dispersion, it is logical to place a sextupole at the very beginning of the EL. Such solution requires just a couple of sextupoles, but the one located at the exit of last septum shall be a very compact magnet, probably of an exotic shape (figure-8 sextupole?).
- We also want to stay away from using SC magnets in the dump line.
- In addition, the larger is dump window the pricier is the EL.

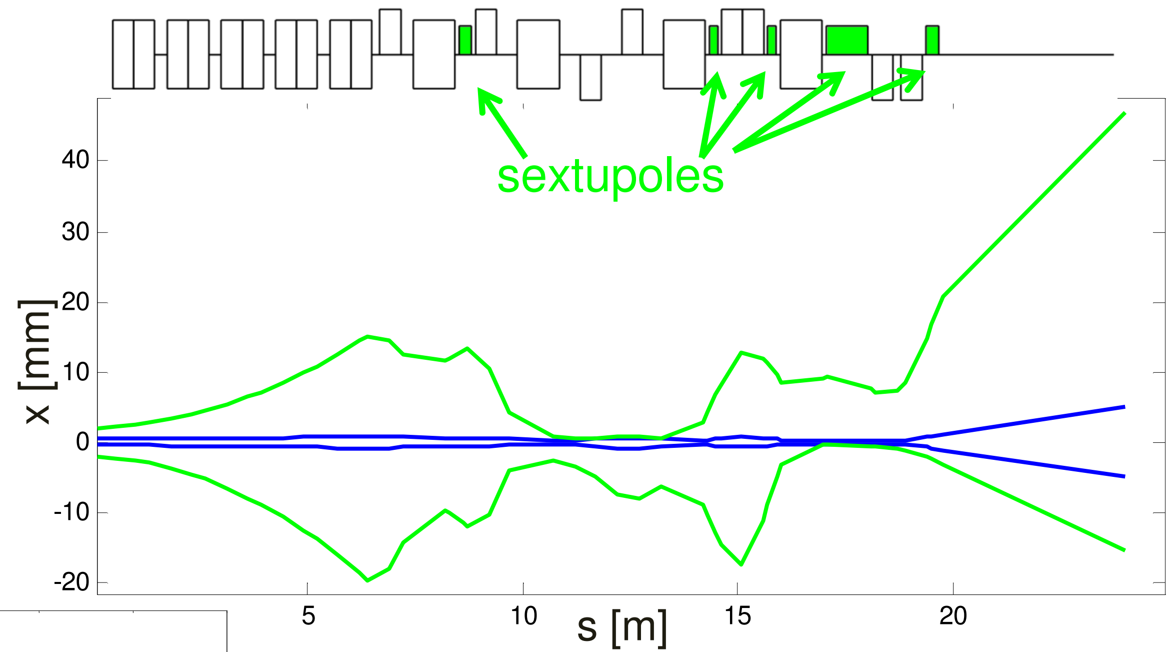


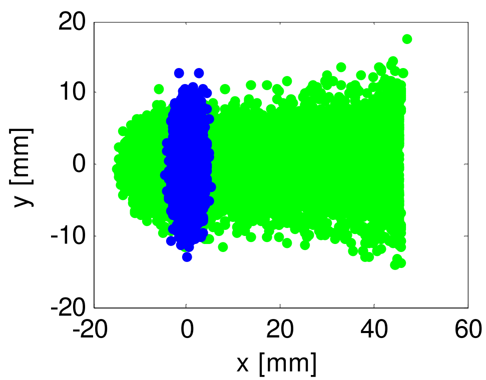


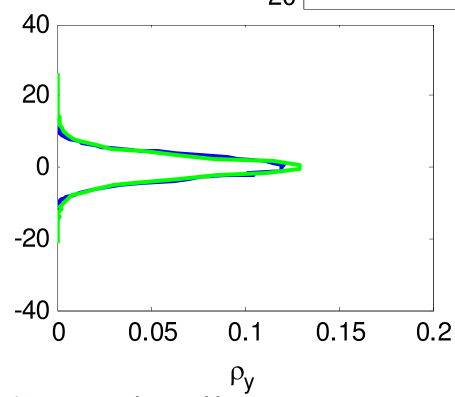
Solution of the Nonlinear Halo Problem

- 0.15% energy spread beam
- 3.54% energy spread beam (sextupoles)









- We found the solution with sextupoles distributed through the extraction line.
- The high energy spread beam in this scenario can be accommodated by the dump window of nominal 12.5cm diameter.

- There is no need in additional collimation, SC magnets or exotic sextupoles.

Final EL Design

Class	*# of magnets*	*Length [m]*	*Maximum pole tip field [kG]*	*Aperutre [cm]*	*Comments*
Abort kickers	4	2	0.035		charged to 35G each in 100nS
Tune-up bend	1	1	0.28		
Septum bends	5	1	0.5	5	
Bends	4	1	15	5	
Quadrupoles	1	0.5	10	5	figure-8
	8	0.5			
	1	1			
Sextupoles	1	0.3	5	5	
	2	0.2	10		
	1	1	10		
	1	0.3	10		
Aluminum Ball Beam Dump: maximum acceptable power is 220MeV/train; beam dump window diameter is 12.5cm					

- The Extraction Line is 24m long.
- Beam size on the dump window is $17mm^2$ in low energy spread case and less then 70mmx40mm in high energy spread case.
- Dump is separated from the main beamline by 5.1m.

Summary

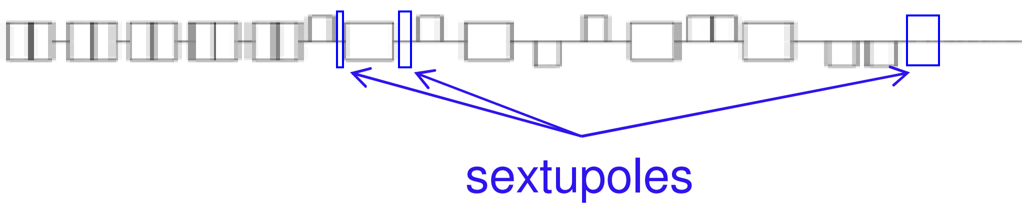
- We finalized the design of the ILC RTML extraction line located downstream a single-stage bunch compressor. The extraction line is capable of accepting and transmitting up to 220kW of beam power. The EL can be used for both fast intra-train and continual extraction, and is capable of accepting both 0.15% and 3.54% energy spread beams at 5MeV and 4.37MeV respectively.
- This design can be easily tweaked. For instance one can reduce strength of the sextupoles sacrificing size of the beam dump window.
- Just in case, there are other design options, which have been studied in detail. They can be quickly revitalized if we find some need in them.

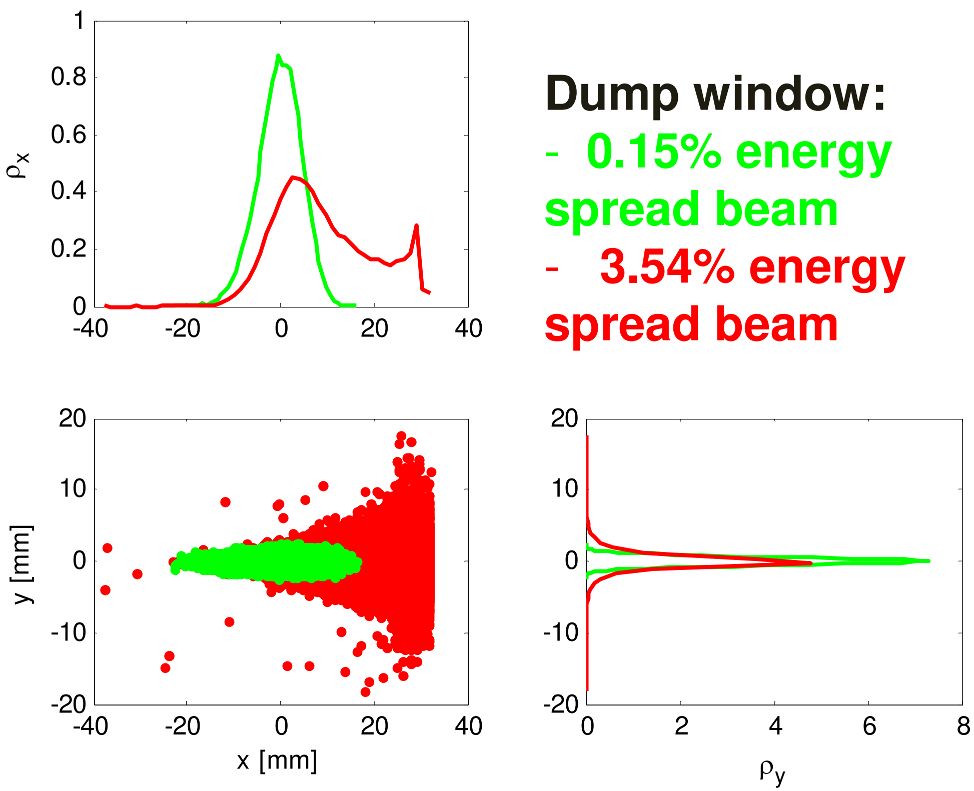
Bonus Material

Collimation summary

	No collimation	No collimation SC magnets	1 collimator (weak collimation)	2 collimators (strong collimation)
Collimators			1.9kW/train; 7.4mm horizontal aperture;	2.2kW/train; 7.2mm horizontal aperture;
				11.7kW/train; 5cm horizontal aperture;
Sextupoles	1T pole tip field; exotic shape	Two sextupoles with 12cm aperture and pole tip filed <6T	1T pole tip field	
	Two <1T pole tip field			
Dump window	12.5cm diameter	60cm diameter	60cm diameter	20cm diameter
Final doublet	5cm aperture; 1T pole tip field;	12cm aperture; Pole tip field<2.4T	5cm aperture; 1T pole tip field	5cm aperture; 1T pole tip field

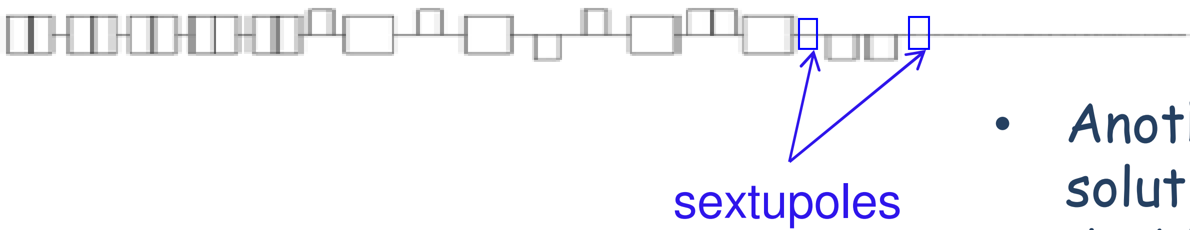
Not Collimated I

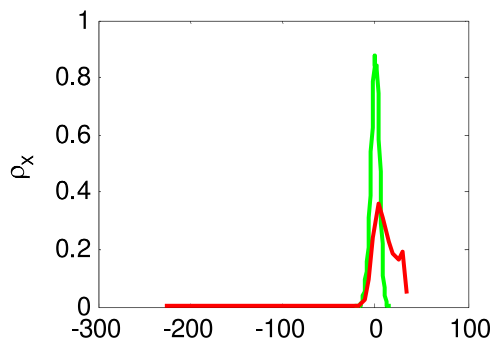




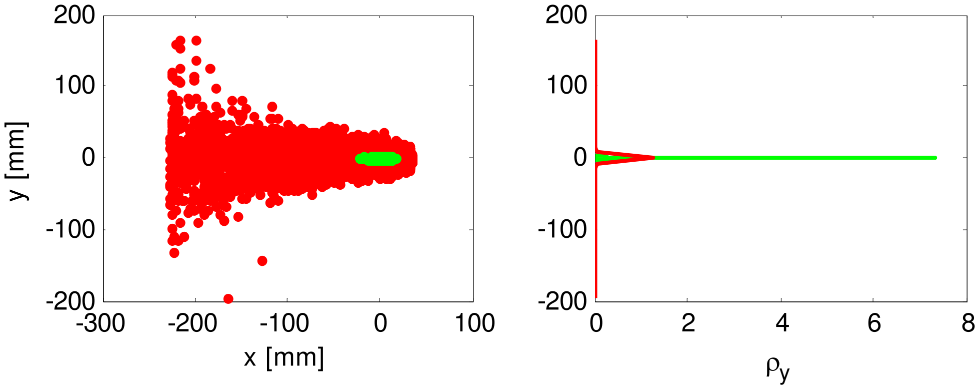
- We found solution, which doesn't require any collimation for high δ beam.
- Three strong (1T pole tip) sextupoles must be used to counteract the nonlinear dispersion and to fold beam tails.
- A "standard" dump window of 5inch diameter can accommodate the beam.
- The drawback of this solution is that the first sextupole is located in the region where separation between main and extraction beamlines is small, so we may need to build a sextupole of exotic shape.

Not Collimated II



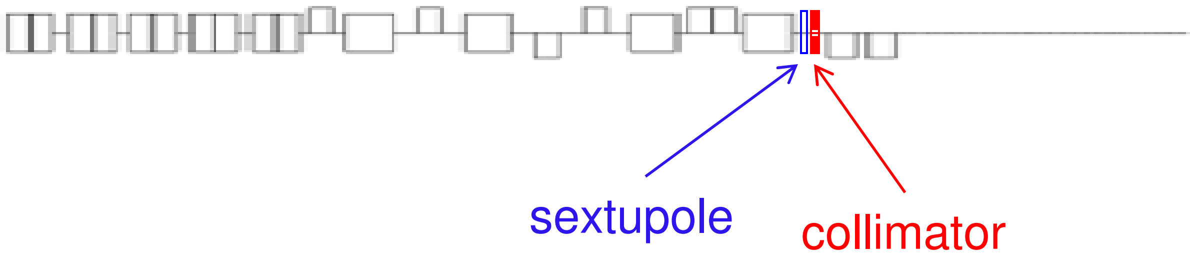


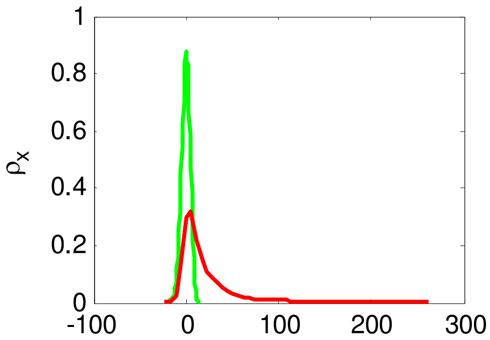
Dump window:
- **0.15% energy spread beam**
- **3.54% energy spread beam**



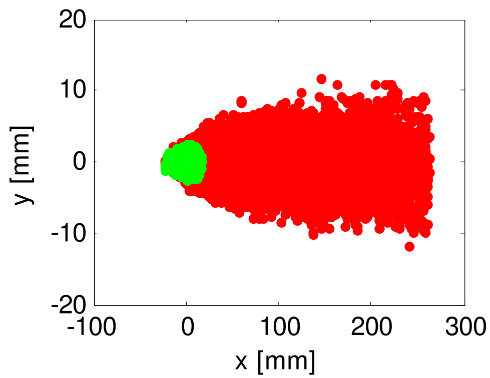
- Another non-collimated solution requires the final doublet quads and two tail-folding sextupoles of 12cm aperture and pole tip field up to 6T.
- The dump window must be 60cm in diameter.
- An obvious disadvantage of this scheme in addition to large dump window is SC magnets in the extraction line.

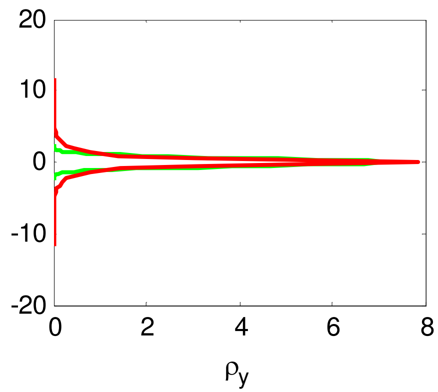
Weak Collimation





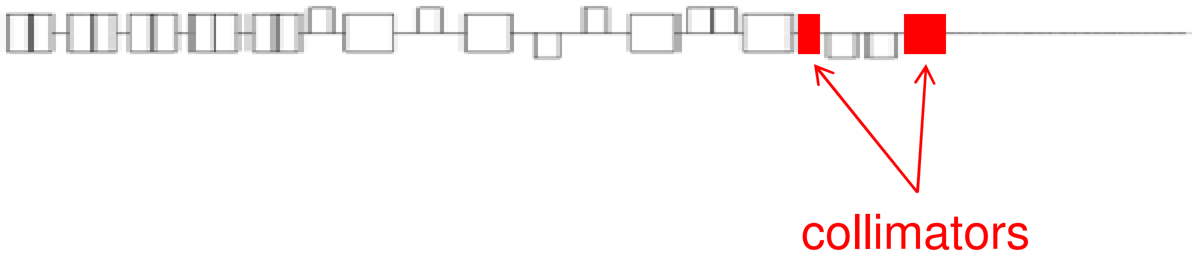
Dump window:
- **0.15% energy spread beam**
- **3.54% energy spread beam**

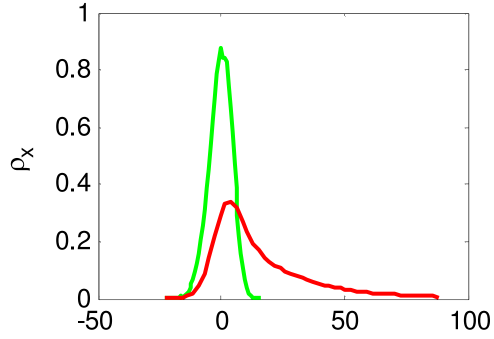




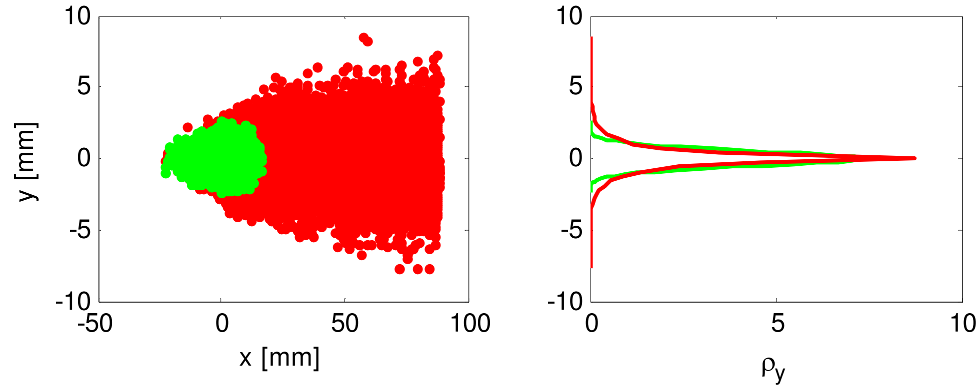
- Weak collimator (1.9kW/train) will be able to protect final doublet. Collimator's horizontal aperture is 7.4mm.
- The dump window must be 60cm in diameter.

Strong Collimation





Dump window:
- 0.15% energy spread beam
- 3.54% energy spread beam



- Using two collimators to protect the doublet (2.2kW/train, 7.2mm horizontal aperture) and to collimate the beam on the dump window (11.7kW/train, 5cm horizontal aperture) one can accommodate beam with 20cm diameter dump window.