RTML: Single-Stage Bunch Compressor

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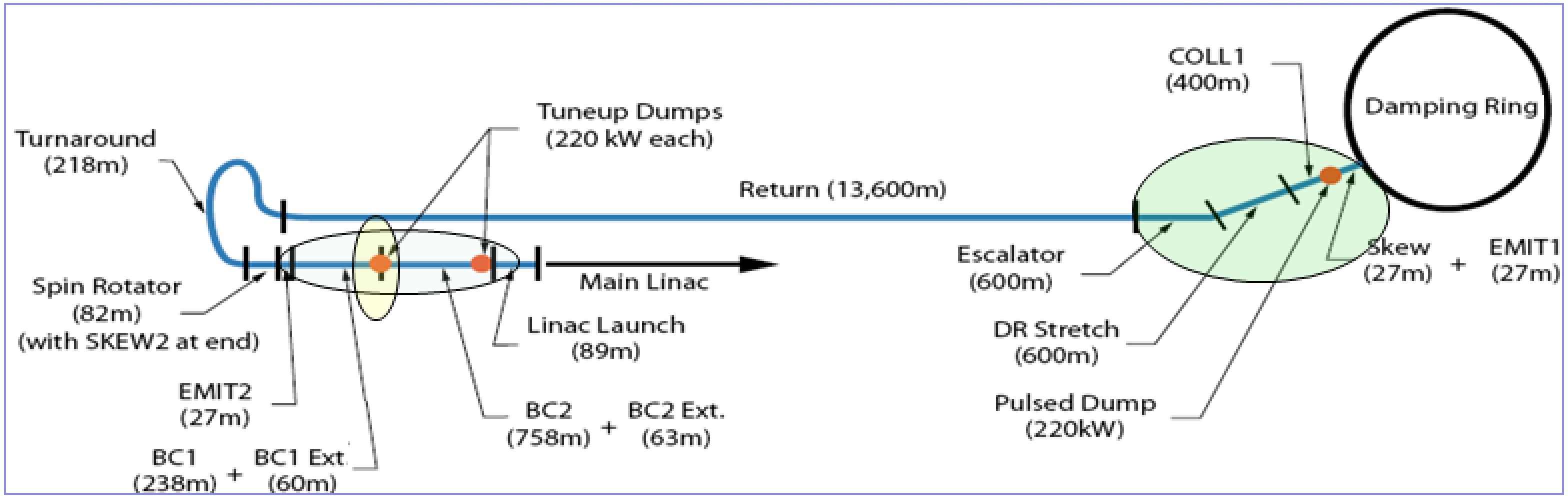
Outline

- **RTML in SB2009 proposal**
- **Single-stage BC (BC1S)**
  - *Lattice Design*
  - *Performance of the single-stage compressor*
  - *RDR design vs. single-stage SB2009 design*
- **Additional changes in RTML lattice in SB2009 design**
  - *Re-design of the BC1S Extraction Line*
  - *Central region modifications*
- **RTML R&D plans**
- **Summary**

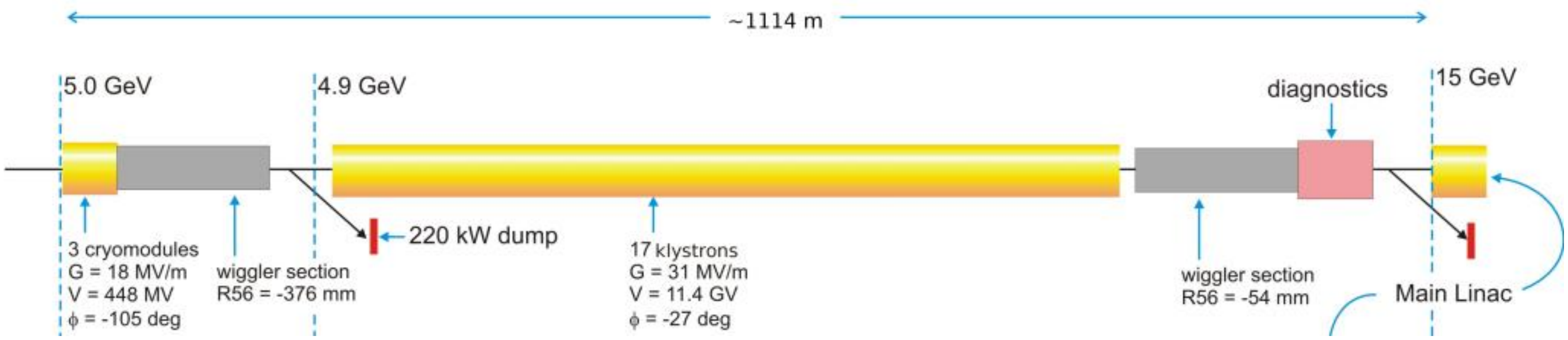
RTML changes in SB2009



Major modifications to the RTML lattice are:

- Single-stage bunch compressor
- Re-design of the second extraction line, after bunch compressor, to accommodate larger energy spread (3.5% vs. 2.5%)
- Re-design of the RTML lattice in central integration area, associated with new layouts of the DR, electron and positron sources and BDS
  - *S-shape curved DR-to-Linac transition (in horizontal plane)*
    - *- Vertical dogleg, Extraction line*
  - *Correction, Diagnostics and Collimation sections in BDS tunnel*

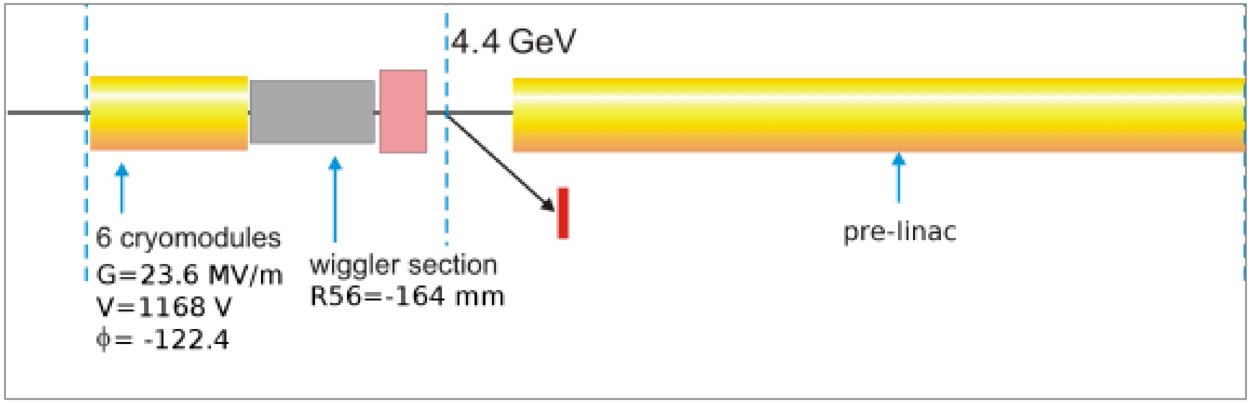
RDR Baseline: Two-Stage Compressor



Compression from 6/9 mm at DR exit to 0.2/0.3 mm at ML entrance

- Stage 1: at 5 GeV, bunch length down to about 1 mm
- Stage 2: from 5 to 15 GeV, bunch length down to 0.2/0.3 mm
  - Compression ratio: up to ~ 45 (flexibility in range 20-60)
  - Two diagnostics stations (after BC1 and BC2)
  - Two extraction lines (after BC1 and BC2)

SB2009: Single-Stage BC

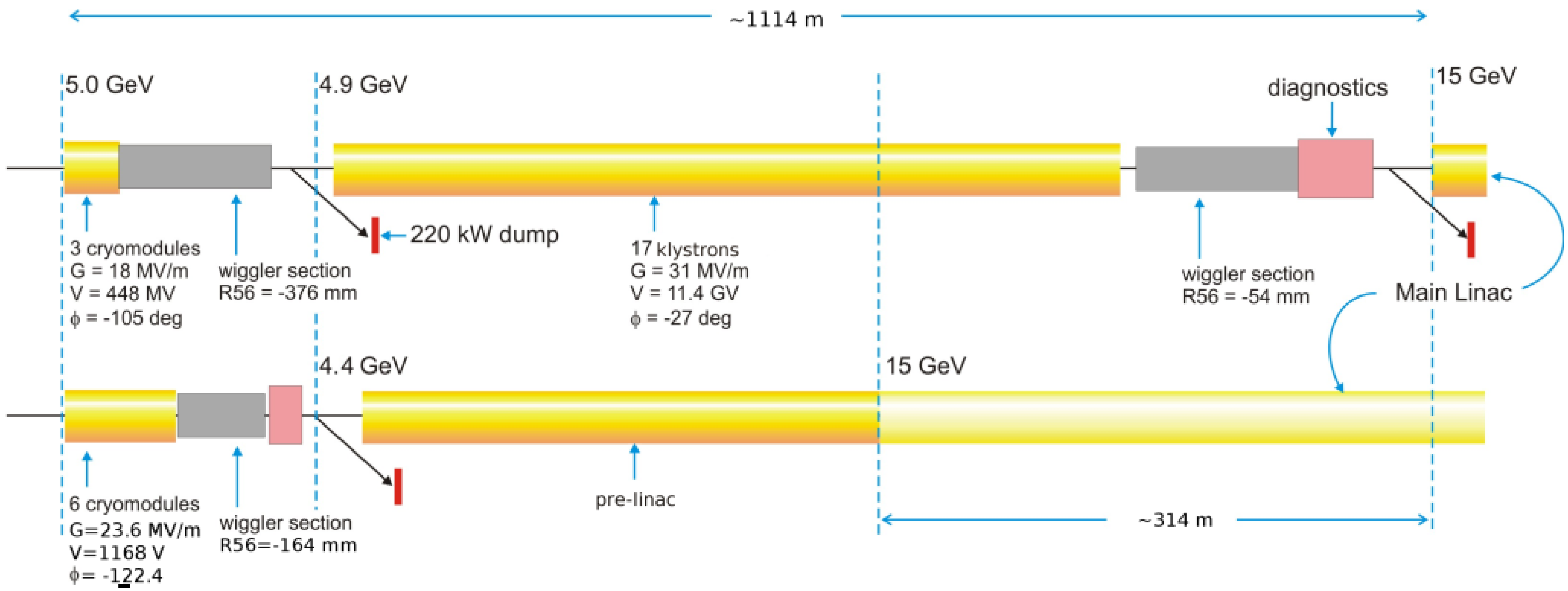


- New design of the Damping Rings allows **6 mm** bunch length
- Final bunch length fixed to **0.3 mm**
- Compression factor can be reduced to **~ 20**

<u>BC1S: Design features:</u>

- 6 crymodules from 5 to 4.37 GeV;
- Wiggler; Diagnostics; Extraction line for tune-up beam dump
- Pre-linac: from 4.37 to 15 GeV, configuration and parameters are identical to those of main linac - now it is considered as an extension of the ML

BC1S: what we gain / loose



Pros:

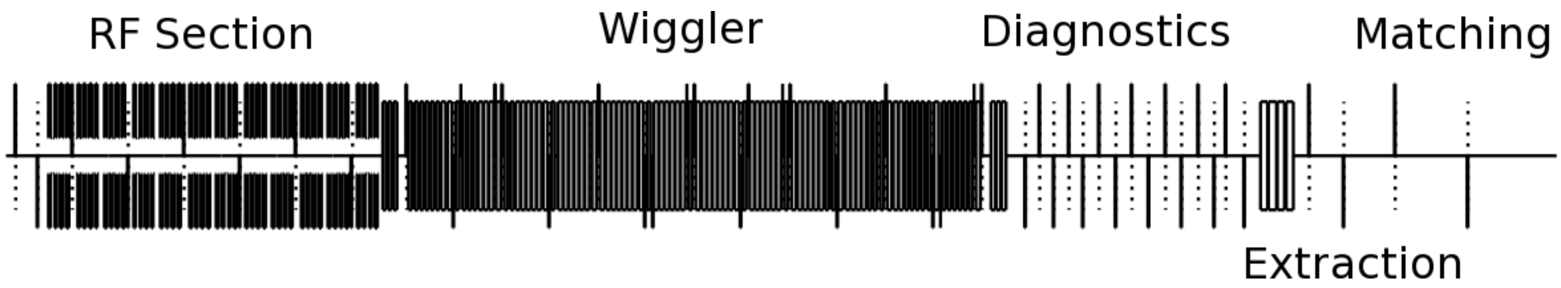
- Reduction in beamline and associated tunnel length (~314 m)
- Removal of the second 220 kW/15 GeV beam dump and extraction line components
- Removal of one section of the beam diagnostics

Cons:

- Less flexibility (not support for 200 um bunch length)
- Larger energy spread at BC exit: 3.5% @ 4.4 GeV
- Emittance preservation and additional tuning issues (e.g. DFS in ML)

BC1S Lattice

- Starting point - optimized PT lattice (2005). Some beam dynamics studies done for this lattice.
- Latest lattice uses compact wiggler design proposed by PT/Seletskyi (RDR).



Single-Stage BC is structured as follows:

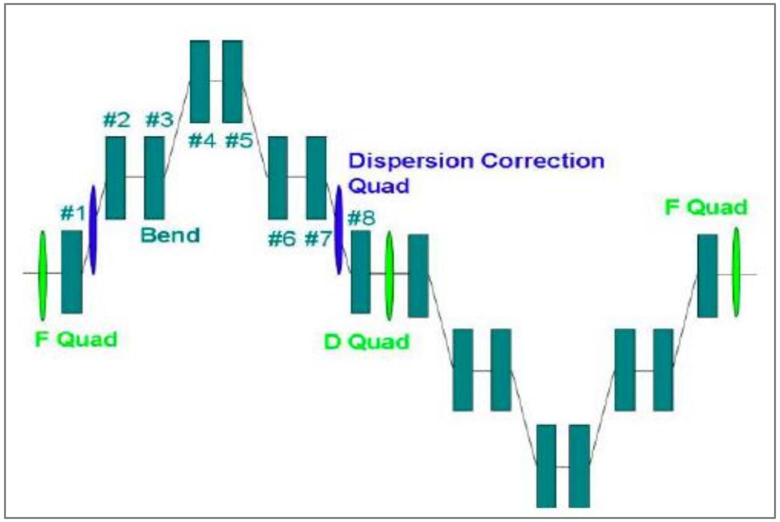
- **Matching**: from spin rotator (2 quads)
- **RF Section**: 6 cryomodules; 48 accelerating structures; Gradient = 23.8 MV/m; RF phase=-122.38 deg; energy loss = 627.9 MeV
- **Wiggler:** PT/Seletskyi's type (PAC07): 6 FODO cells with 90^o phase advance; R56 = -164.8 mm; 2 dispersion matching sections
- **Diagnostics:** adapted from BC2: 4 LW, LOLA cavity for bunch length monitoring, phase monitor
- **Extraction line:** must accommodate beams with *dE/E = 0.15% − 4%*
- **Matching:** to the main linac, with injection at 4.4 GeV (2 quads)

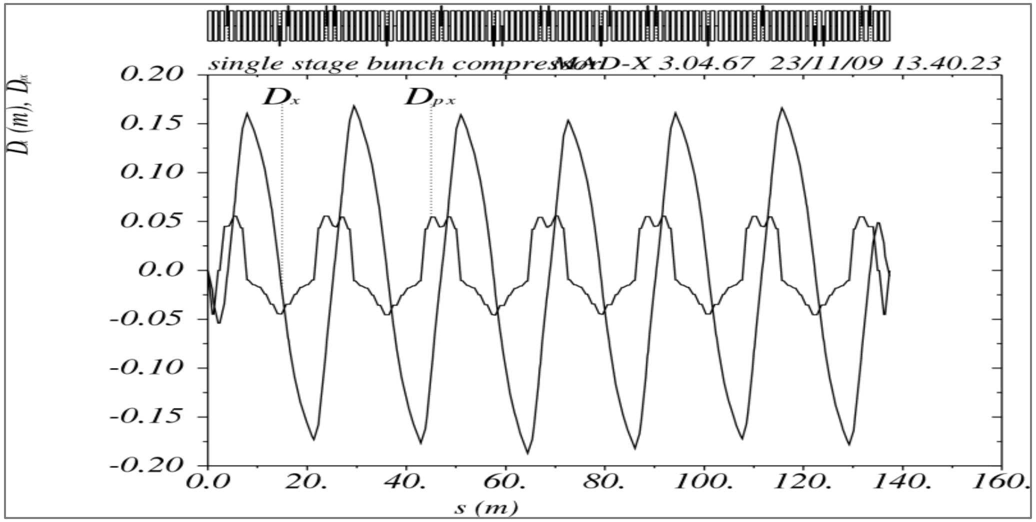
Total Length is 342 meters

BC1S Wiggler and Optimization

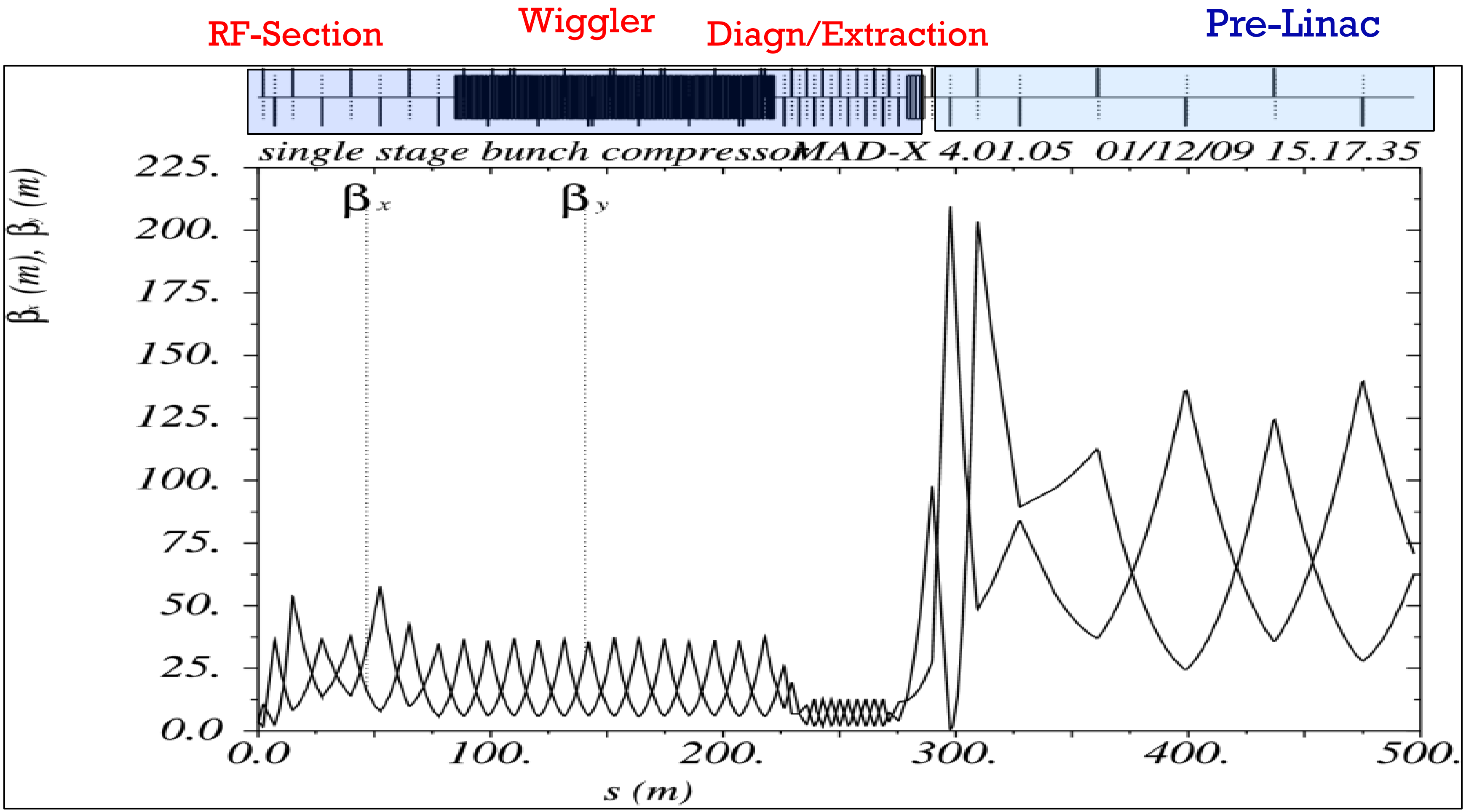
Wiggler consists of 6 identical cells

- Cells are contained in FODO structure with 90 deg phase advance per cell
- Focusing and defocusing quads are placed in the zero dispersion regions
- There are 4 additional normal quads and 4 skew quads (in cells 1,3,4 and 6) that are used for possible dispersion correction without introducing betatron coupling or mismatches
- Sixteen bends allow tuning R56 while preserving beam's trajectory in quads





BC1S Optics



Entrance:
- Energy = 5 GeV
- dE/E = 0.15%
- Bunch length = 6 mm

Exit:
- Energy = 4.37 GeV
- dE/E = 3.5%
- Bunch length = 0.3 mm

Beam Parameters (RDR vs. SB2009)

RDR

- **BC1**

- Bunch length: 6/9 mm → 1 mm
- Energy: 5 → 4.88 GeV
- Energy spread: 0.15% → 2.5%

- **BC2**

- Bunch length: 1 mm → 0.3/0.15 mm
- Energy: 4.88 → 15 GeV
- Energy spread: 2.5% → 1.07%

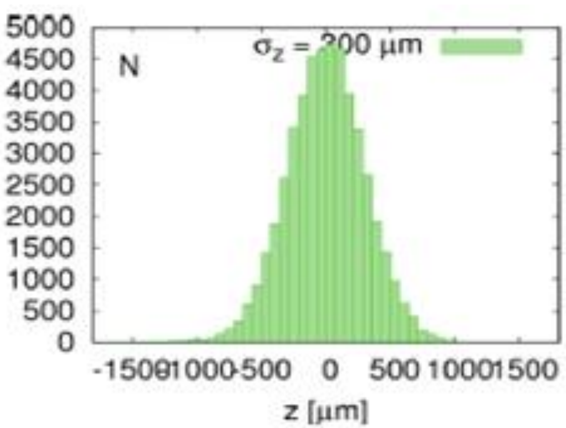
SB2009

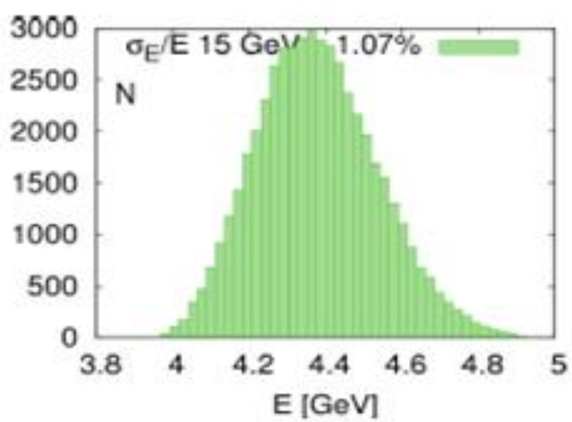
- **BC1S**

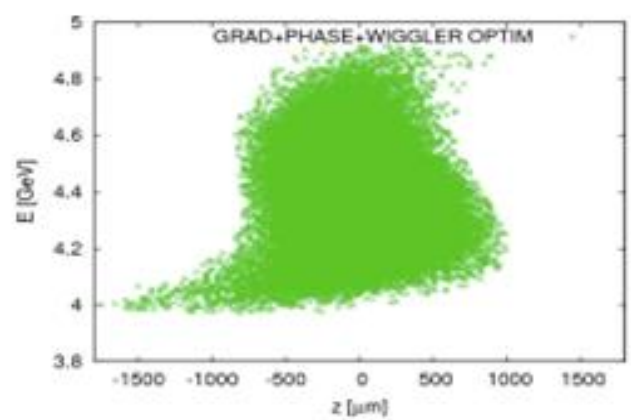
- Bunch length: 6 mm → 0.3 mm
- Energy : 5 → 4.37 GeV
- Energy spread: 0.15% → 3.5%

- **Pre-Linac**

- Bunch length: 0.3 mm
- Energy: 4.37 → 15 GeV
- Energy spread: 3.5% → 1.07%







Saving beamline components

	BC1+BC2	BC1S + preLinac*
Length [m]	1114	800
RF units / klystrons	16	14
Cryomodules	48	42
Cavities	414	360
Bends	148	76
Quads (warm)	71	42
BPMs	71	42
LOLA profile monitor	2	1
Bunch length monitor	2	1
Phase monitor	2	1
Laser Wires	4	4

* pre-Linac is now part of ML, but components are count for comparison only

Savings from removed BC2_Extraction Line

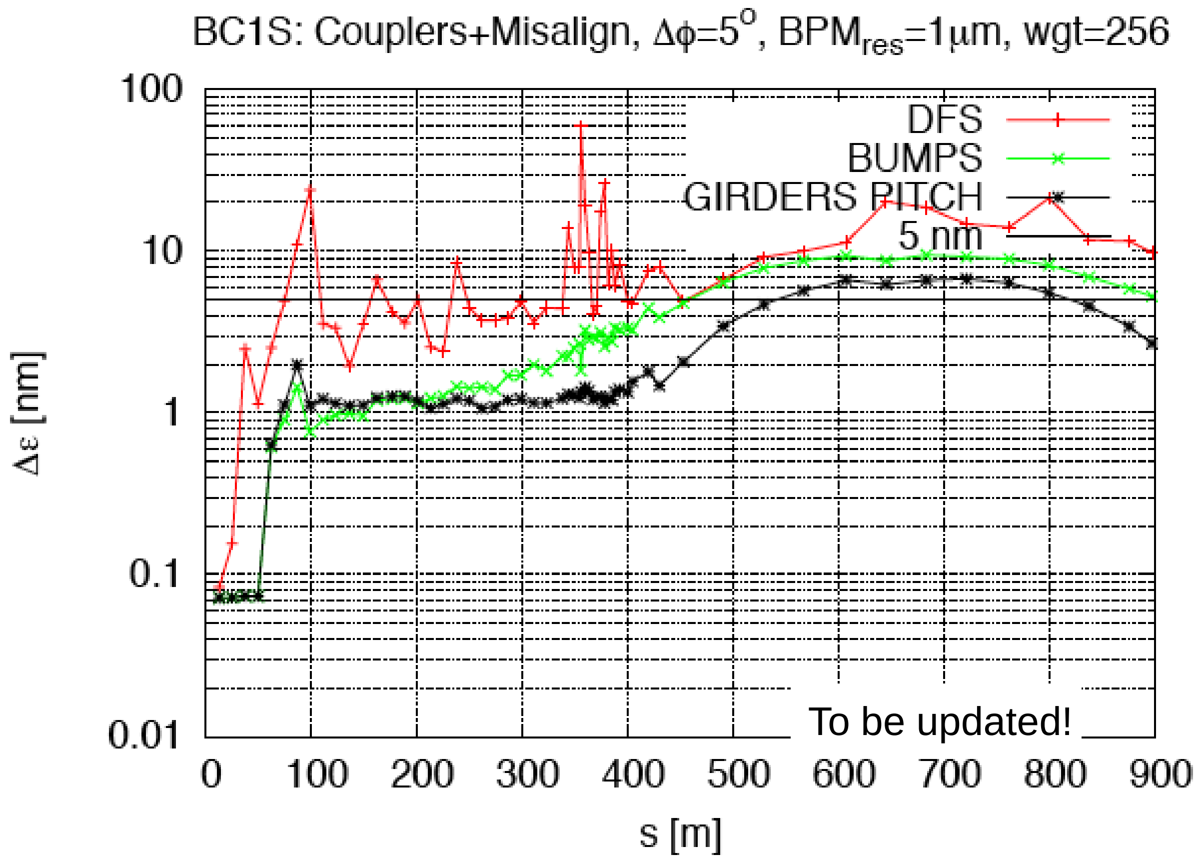
- 10 fast kickers, 6 Septum magnets, 6 bends, 12 Quads, 220 kW beam Dump
- Length ~25 m (tunnel)

BC1S Beam Dynamics Studies

Emittance preservation studies are done for BC1S, incl. pre-Linac:

- Alignment Studies, includes coupler kicks = RF + Wakefield
- Dynamic Effects (next)
- Failure modes (next)

Simulations should include the Main Linac



$\Rightarrow$ Final vertical emittance growth is $\boxed{\Delta\epsilon = 2.6 \text{ nm}}$

No misalignments: emittance growth in RTML+ML < 0.5 nm

BC1S Beam Dynamics Studies (2)

Studies showed similar performances between
(BC1+BC2) and (BC1S+preLinac)

- Two-stage bunch compressor

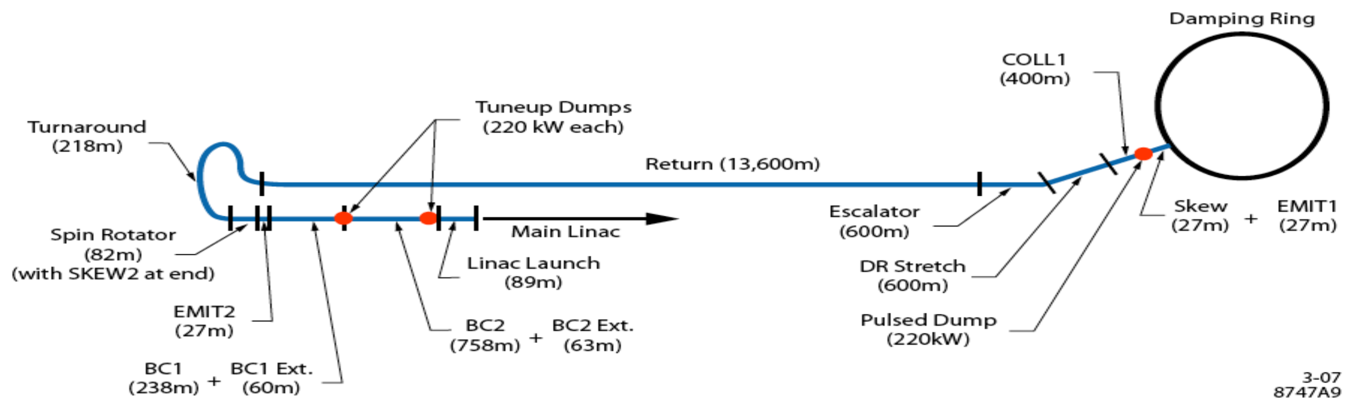
Technique	Misalignments	Couplers$^{(1)}$	Misalign+Couplers
DFS	91.2 nm	7.7 nm	371.0 nm
BUMPS	2.1 nm	4.3 nm	6.9 nm
GIRDER	-	0.5 nm	2.0 nm

- Single-stage bunch compressor

Technique	Misalignments	Couplers$^{(1)}$	Misalign+Couplers
DFS	14.8 nm	4.8 nm	27.0 nm
BUMPS	1.47 nm	3.4 nm	4.6 nm
GIRDER	0.8 $^{(*)}$ nm	2.5 nm	2.6$^{(*)}$ nm

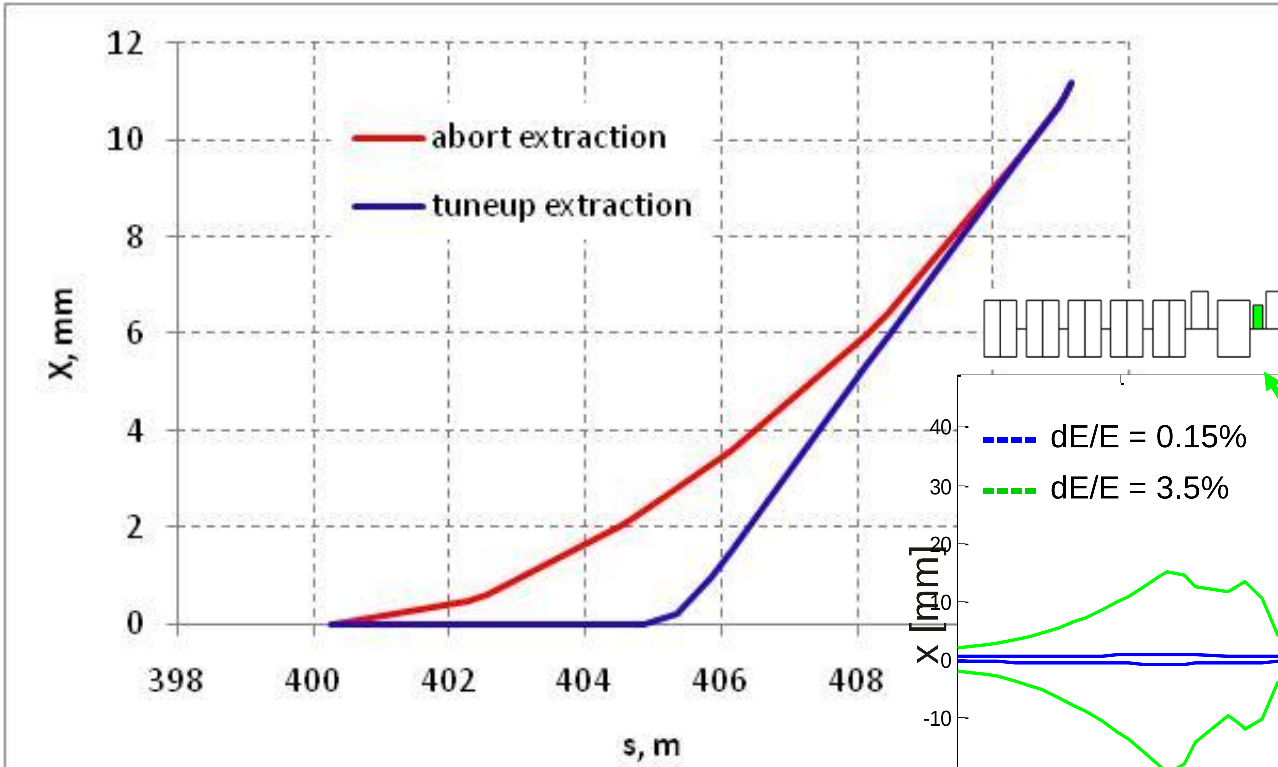
(1) 1 machine
(*) 40 machines

Extraction Lines

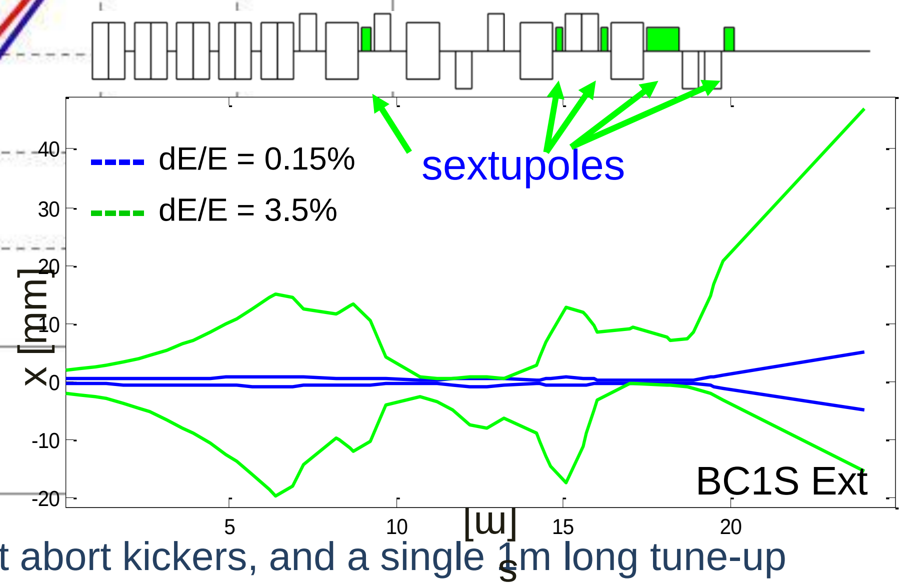


- RDR baseline's RTML contains three 220 kW extraction lines per linac for beam tune-up and emergency abort:
  - ELDR: after DR (5GeV, dE/E=0.15%);
  - ELBC1: after BC1 (5GeV, dE/E=0.15% and 2.5%)
  - ~~ELBC2: after BC2 (15GeV, dE/E=1.5%).~~
- In case of single-stage compressor there are no needs for 15 GeV extraction line
- But second extraction line has to be redesigned to accommodate larger energy spread in the beam coming from BC1S (4.4 GeV, dE/E=3.54 %)
- Few possible designs were proposed and studied in FY2009
- The best of them was accepted as base for further studies and cost estimations

Extraction System Design



S. Seletskiy



- 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.
- When energy spread is high 3.5%, there is a significant beam size blowup due to chromaticity and non-linear dispersion. Sextupoles need to be used.

Extraction line for BC1S

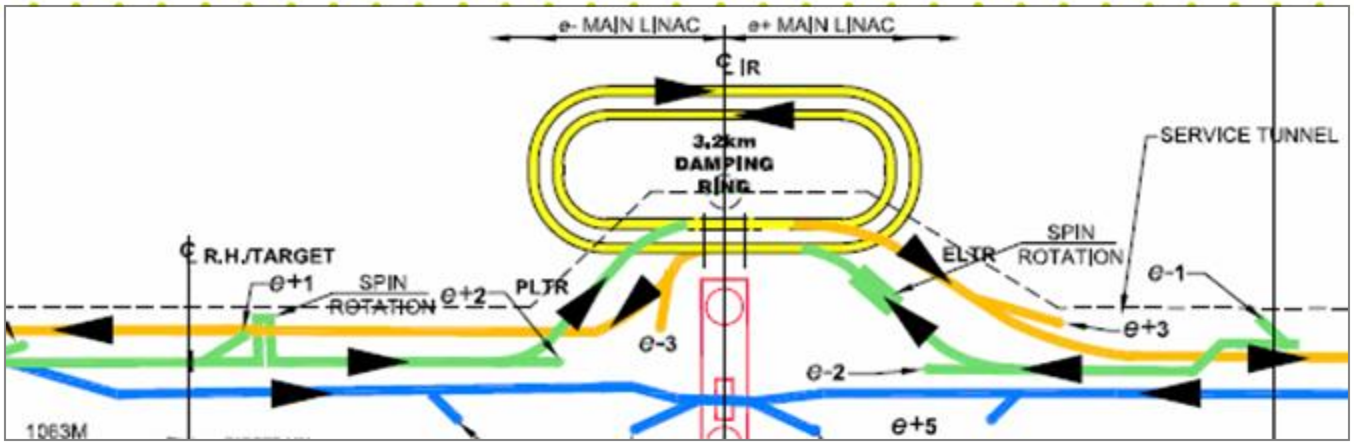
Class	*# of magnets*	*Length [m]*	*Maximum pole tip field [kG]*	*Aperutre [cm]*	*Comments*
Abort kickers	4	2	0.035		charged to 35G each in 100nS
Tune-up bend	1	1	0.28		
Septum bends	5	1	0.5	5	
Bends	4	1	15	5	
Quadrupoles	1	0.5	10	5	figure-8
	8	0.5			
	1	1			
Sextupoles	1	0.3	5	5	
	2	0.2	10		
	1	1	10		
	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.

BC1S Extraction Line Summary

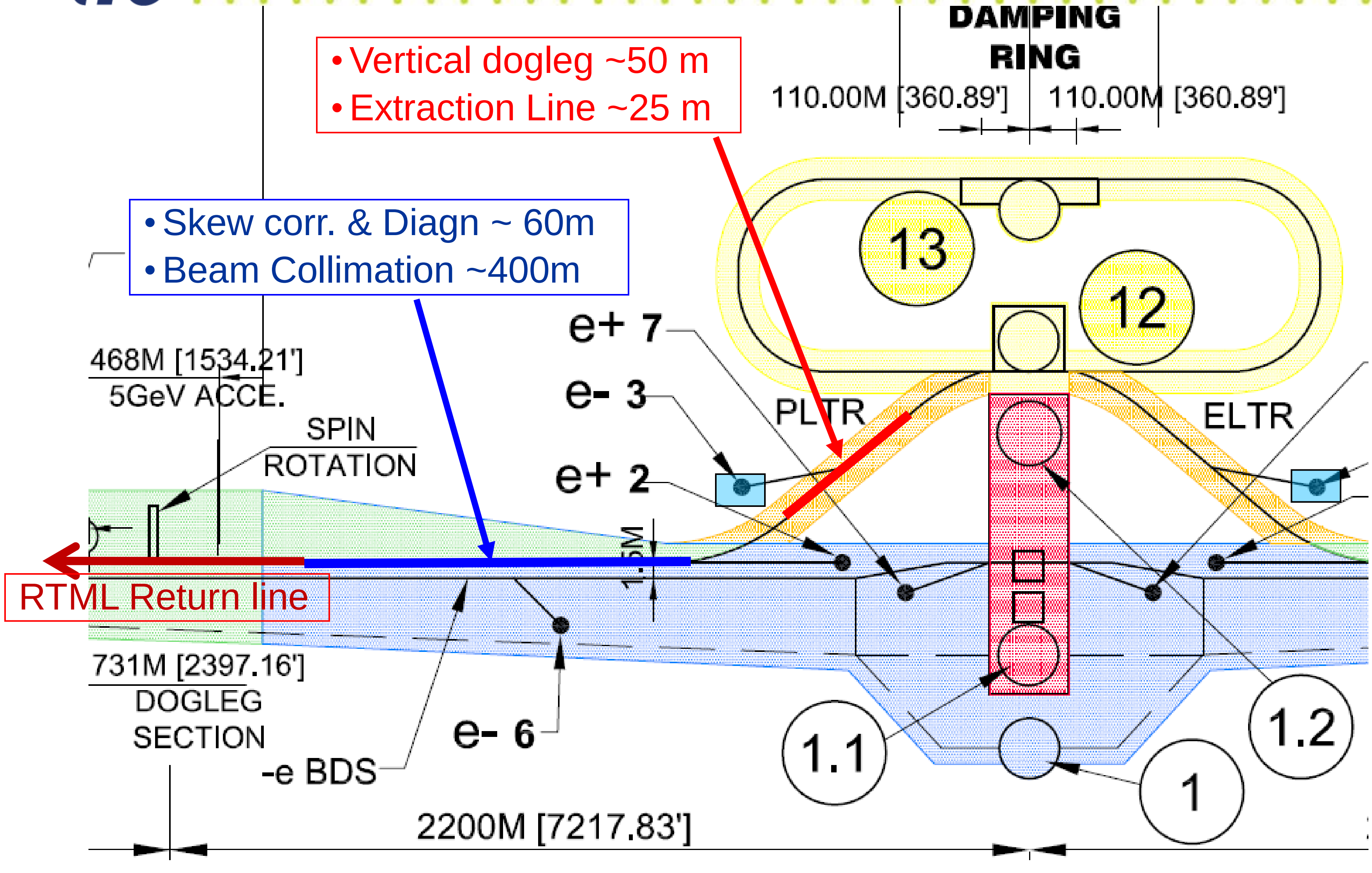
- RTML extraction line located downstream a single-stage bunch compressor was finalized.
- The extraction line is capable of accepting and transmitting up to 220kW of beam power.
- The EL can be used for both fast intra-train and continual extraction, and is capable of accepting both 0.15% and 3.54% energy spread beams at 5 MeV and 4.37 MeV respectively.
- This design can be tweaked. For instance one can reduce strength of the sextupoles sacrificing size of the beam dump window.

Central Area Layout

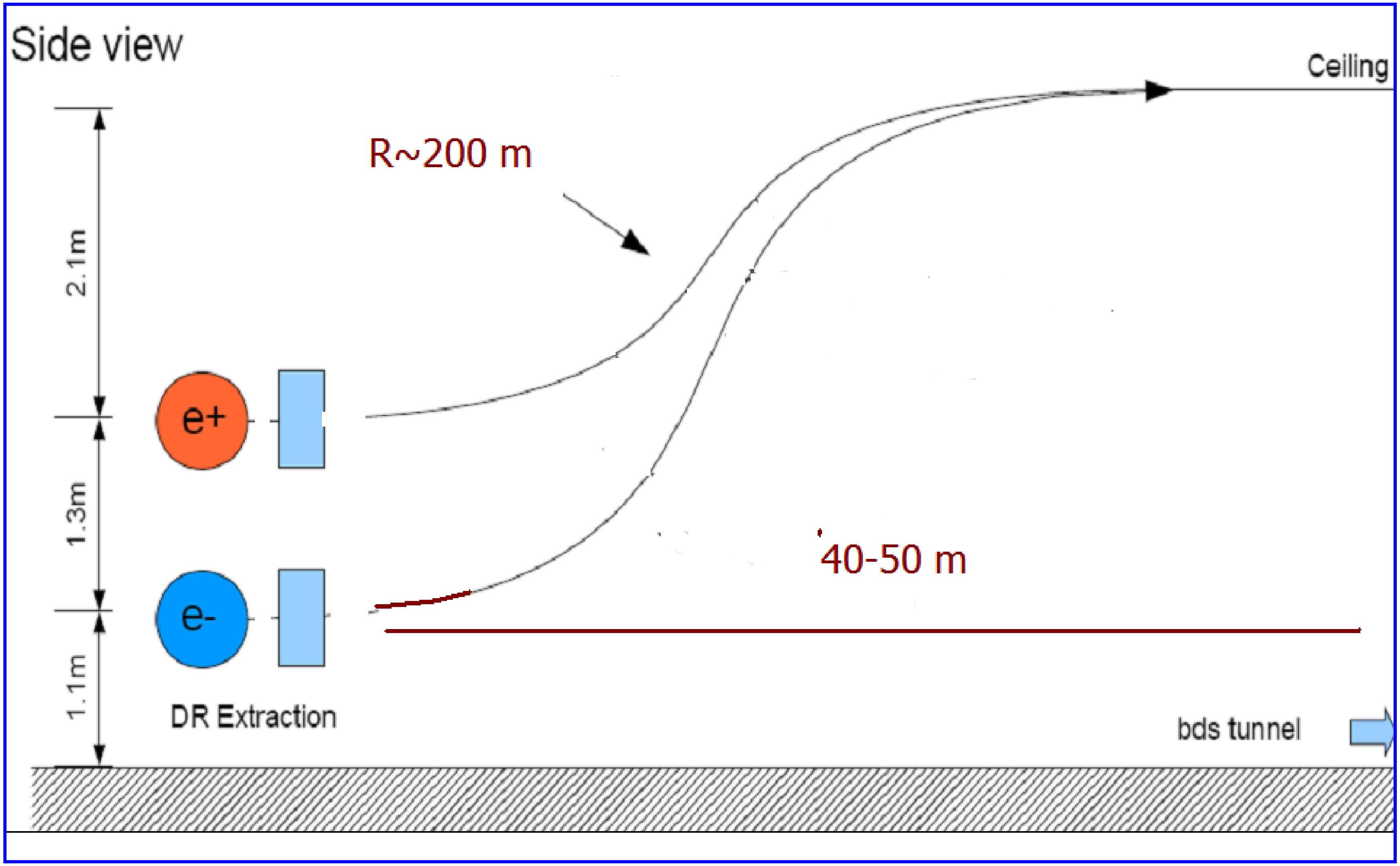


- In SB2009, damping rings circumference has been reduced to 3.2 km
- RDR DR extraction was ~1 km from the central plane, in the direction of the turnaround, now the DR ext is located at about 100 meters from the central plane. DR vertical elevation was ~10m above ML tunnel.
- This change required a re-design of the beamlines without reduction in performance and functionality of the RTML.
- Main advantage of this change is the simplification in the overall layout (in terms of number of horizontal and vertical doglegs)
- Possible risks might arise from the performances of the new system from the point of view of the low emittance transport

RTML configuration in Central Area

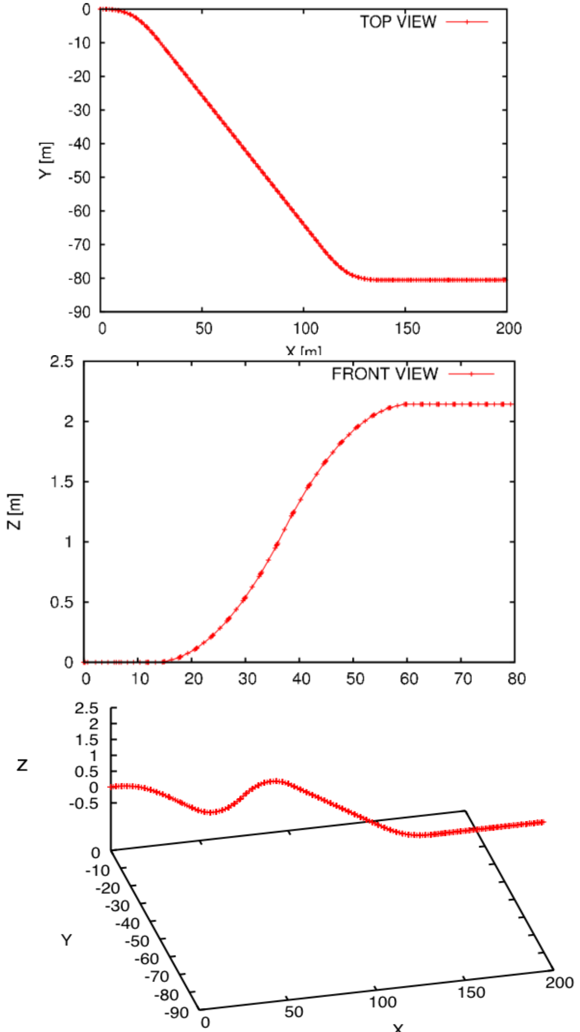


Vertical doglegs in straight section



RTML Central Area Lattice design

e+ DR extraction line



Geometrical configuration (PLACET)

Preliminary lattice files for extraction line in central area exist (needs some adjustment)

- Geometry depends on the geometry of DR injection line layouts e+ / e- Sources transport lines (PLTR and ELTR) and CFS constrains
- Most systems were adopted from RDR lattice
- Simpler than RDR: less doglegs, straightforward layout
- Instrumentation, collimation and extraction line are included in lattice

Beam Dynamics simulations and technical issues are under consideration

Proposed Relevant Studies

- Complete and document lattice design of a single-stage bunch compressor, diagnostics and matching sections
- Beam physics simulation to study effect of coupler RF kick, alignment and phase/amplitude stability of the RF system and provide requirements. The goal to demonstrate that RTML emittance budget can be achieved and beam parameters at the exit of RTML system provide acceptable emittance budget in Main Linac
- Developing CAD models for single-stage BC components, including cryogenic lines for CMs and SC solenoids, alcoves, electronics
- Experimental studies of amplitude and phase stability, required for single-stage bunch compressor at FLASH/DESY facility (9 mA studies). This study is required to both RDR and SB2009 configurations
- Complete design of the RTML section from DR tunnel to ML tunnel. It requires close coordination with other AS involved: DR and electron / positron sources.

Summary

- Single-stage Bunch Compressor lattice designed is done. Design looks feasible:
  - Emittance growth in 1-stage compressor can be effectively controlled (DFS, bumps and possible CM angle adjustment).
  - BC1S performance (beam parameters, emittance growth, etc.) is comparable with RDR 2-stage design for the same compression ratio: 20
  - BC1S not supports short bunches option
- Extraction line is re-designed to accommodate bunch with a larger energy spread after single-stage compressor.
- Preliminary lattice design for RTML in central area is done. Matching and beam dynamics studies are in progress.
- Remaining issues are subject for R&D program