Update of RTML,
Status of FNAL L-band and CLIC X-band BPM,
Split SC Quadrupole

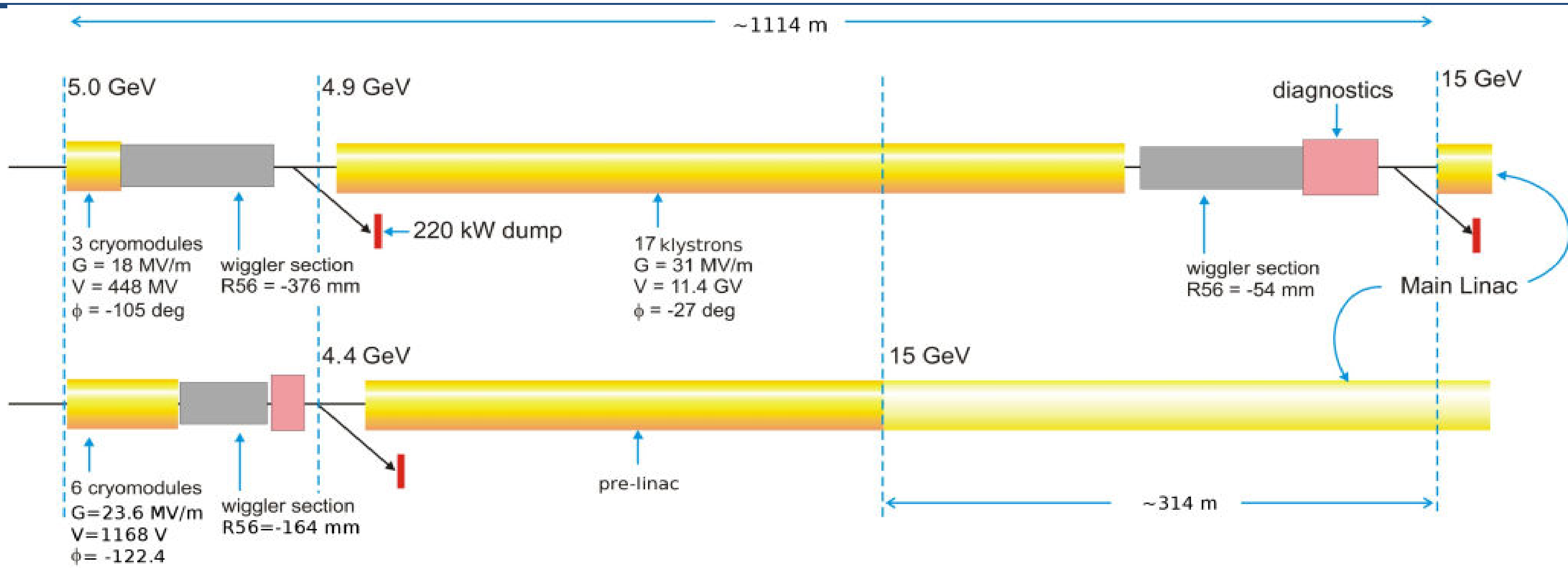
Nikolay Solyak
Fermilab

(On behalf of RTML team)

OUTLINE

- Single stage BC design upgrade
- Emittance preservation study
- RF kick simulation upgrade
- Proposal for BC RF phase/amplitude stability study at FLASH
- ILC/CLIC RTML collaboration
  - Spin-rotator
  - Main Linac X-band BPM design
- Summary

Single-stage BC in SB2009



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

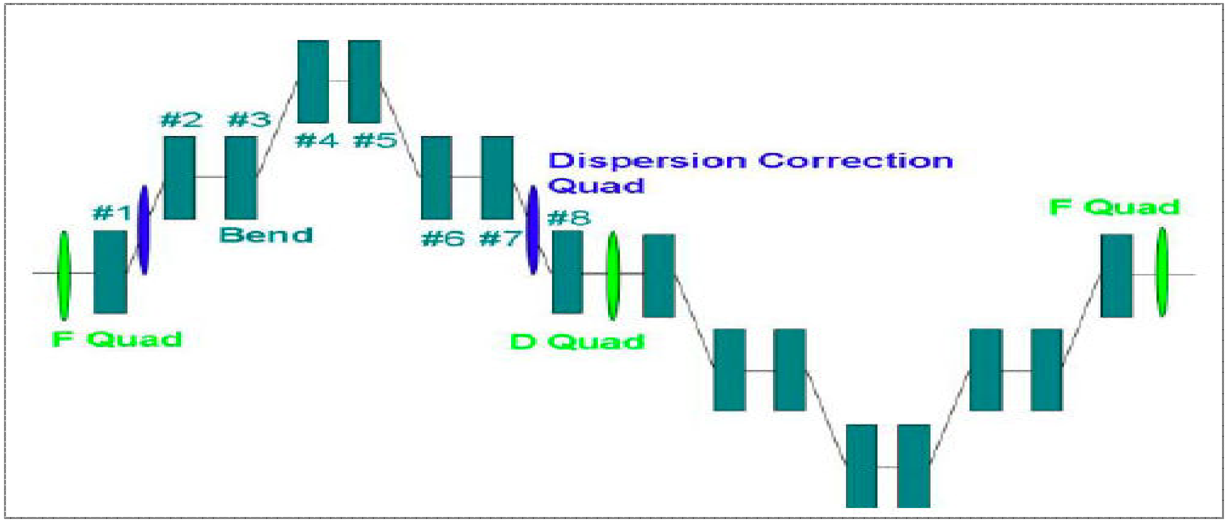
Cons:

- 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)

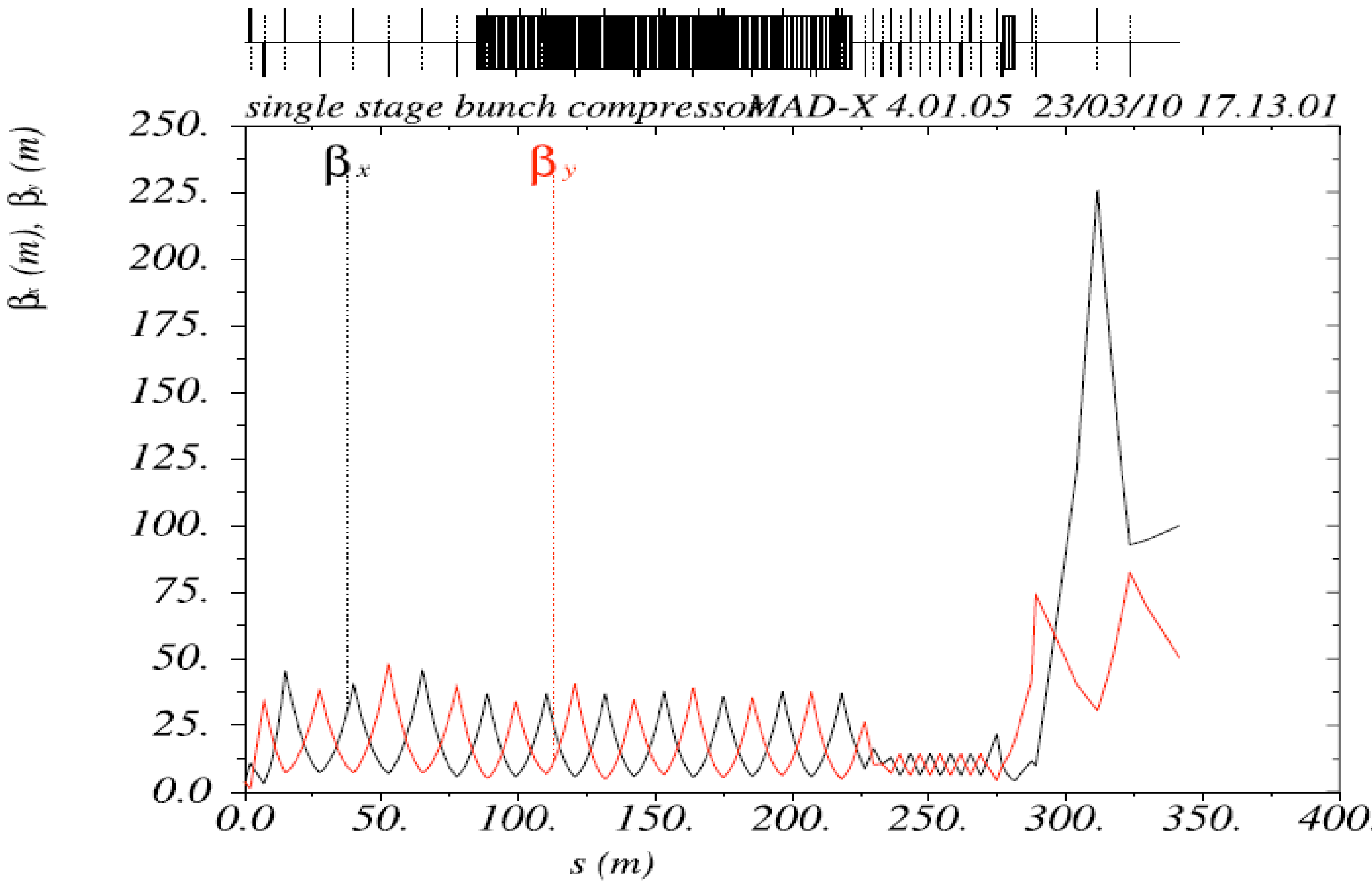
BC1S Wiggler Optimization

Wiggler description (modified BC1 design):

- 6 cells (see fig.) in a FODO lattice with 90° phase advance per cell
- Focusing and defocusing quads are placed in the zero dispersion regions
- 4 additional normal quads and 4 skew quads (in cells 1,3,4 and 6) for dispersion correction without introducing betatron coupling or mismaand coupling cancellation
- Sixteen bends allow tuning R56 while preserving beam's trajectory in quads



BC1S Optics and matching



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

Beam Parameters (RDR vs. SB2009)

RDR

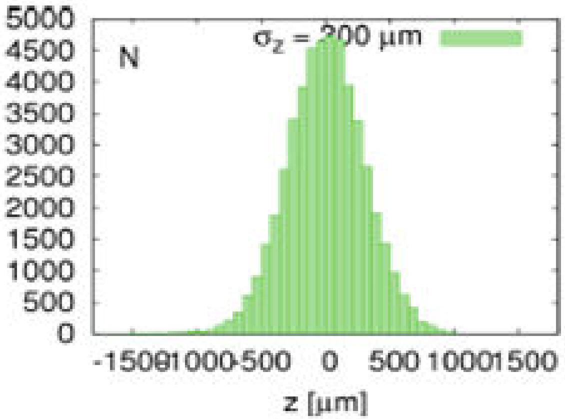
- **BC1**
- Bunch length: 6/9 mm → 1 mm
- Energy: 5 → 4.88 GeV
- Energy spread: 0.15% → 2.5%

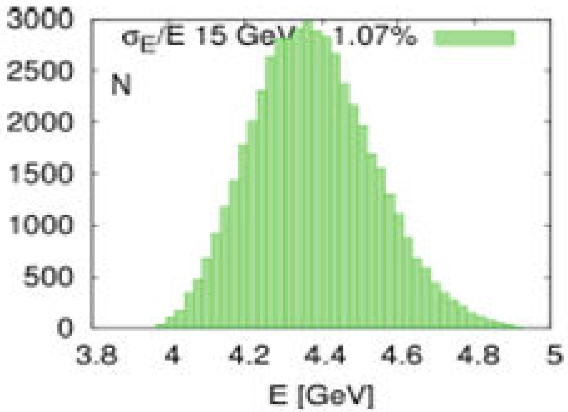
- **BC2**
- Bunch length: 1 mm → 0.3/0.15 mm
- Energy: 4.88 → 15 GeV
- Energy spread: 2.5% → 1.07%

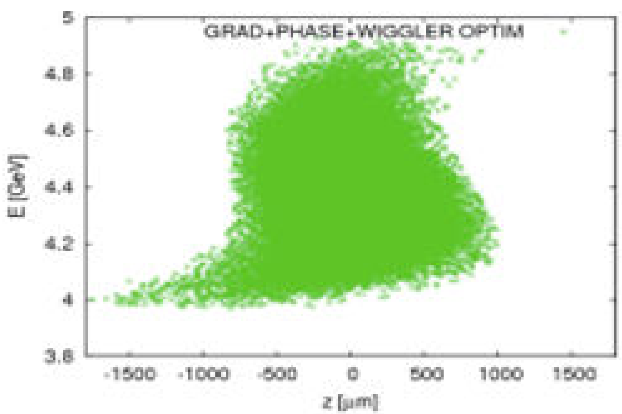
SB2009

- **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%







What minimum bunch length in BC1S?

•Achieved bunch length = 300 μm by retuning RF system and wiggler

- In order to obtain bunches shorter than 250 μm we have to reduce T_{566}
- This can be achieved:
  - by introducing sextupoles in the lattice for instance
- Sextupoles have been added to the lattice where the skew quadrupoles are (this can probably be optimized)
- Full 6d tracking results

R56	STD	STD+3rd	STD+Sextupoles	STD+3rd + Sextupoles
-0.120	249	226	234	220
-0.100	241	223	237	236

(STD = standard BC1S)

More detailes in A.Latina talk

RTML emittance dilution overview

Region	BBA method	Dispersive or Chromatic mean Emittance Growth	Coupling mean emittance Growth
Return Line	Kick Minimization and feed-forward to remove beam jitter	0.15 nm	2 nm (without correction)
Turnaround and spin rotator	Kick Minimization and Skew Coupling Correction	1.52 nm (mostly chromatic)	0.4 nm (after correction)
Bunch Compressor	KM or DFS and Dispersion bumps	greater than 4.9 nm (KM + bumps) 2.68 nm (DFS and bumps)	0.6 nm (without correction)
Total		~5 nm almost all from BC	3 nm (without complete correction)

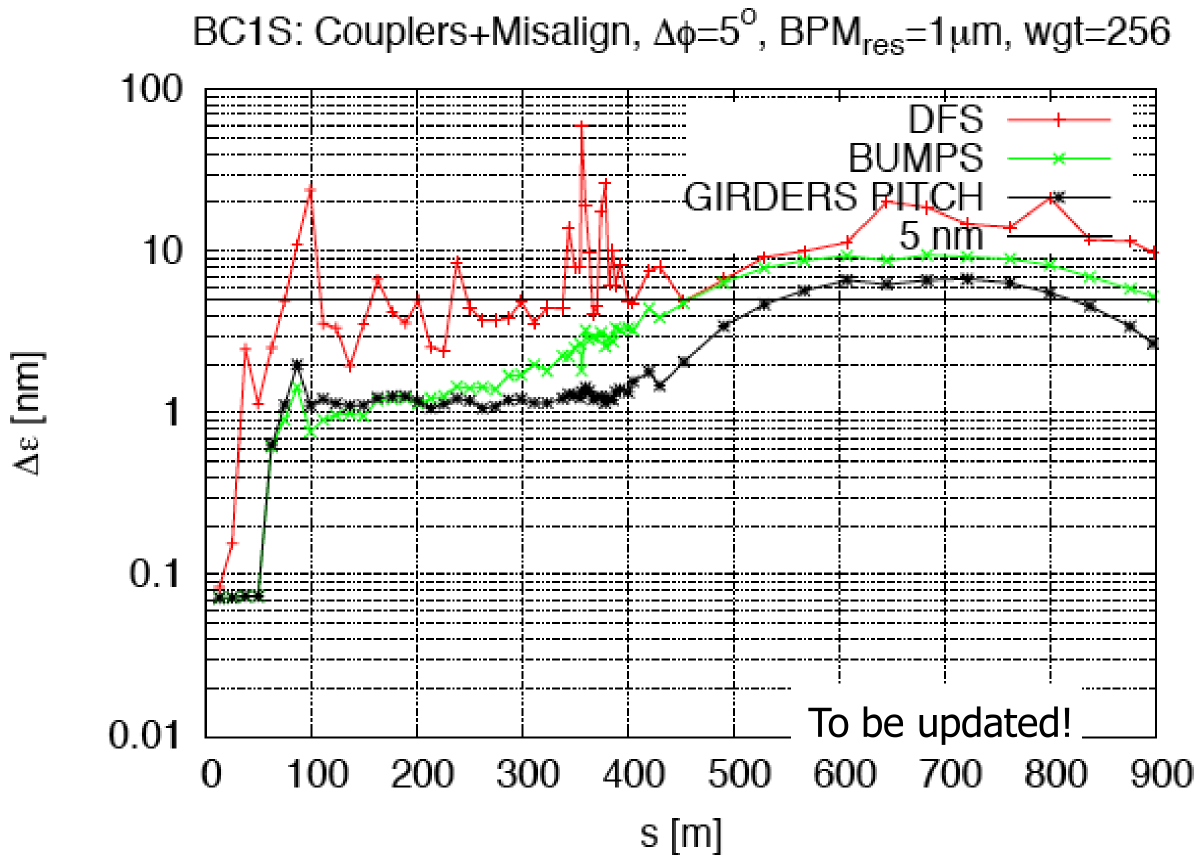
BC gives the biggest contribution in RTML emittance dilution budget (RDR, SLAC, Dec 2007)

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 also done for BC1S and 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

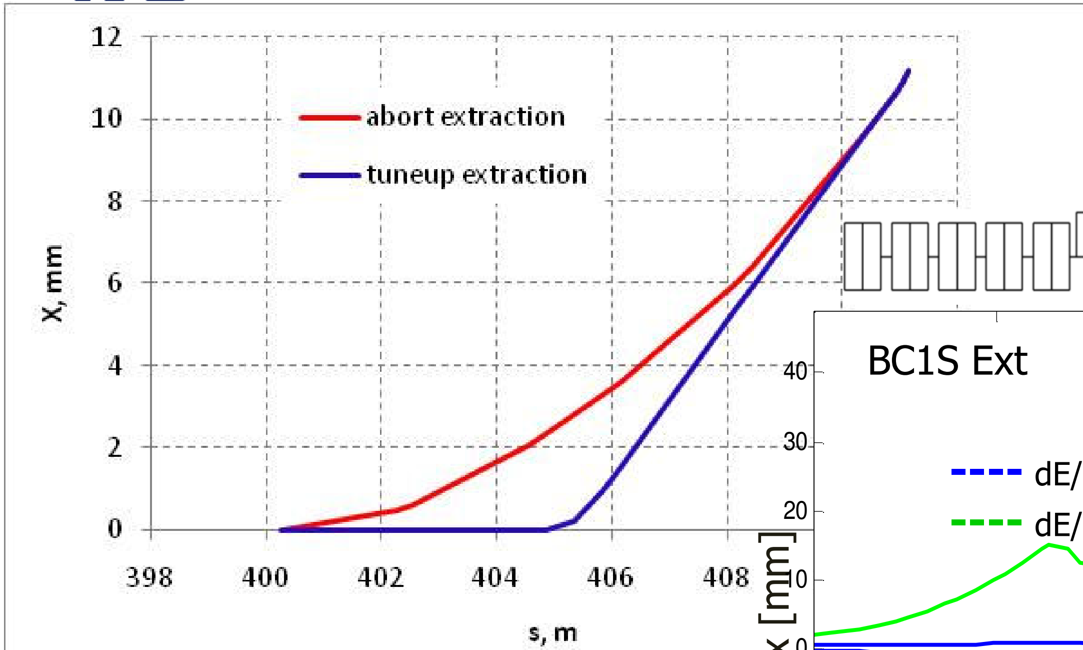
- Single-stage bunch compressor

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 → **2.3 nm Av. 100 seeds**

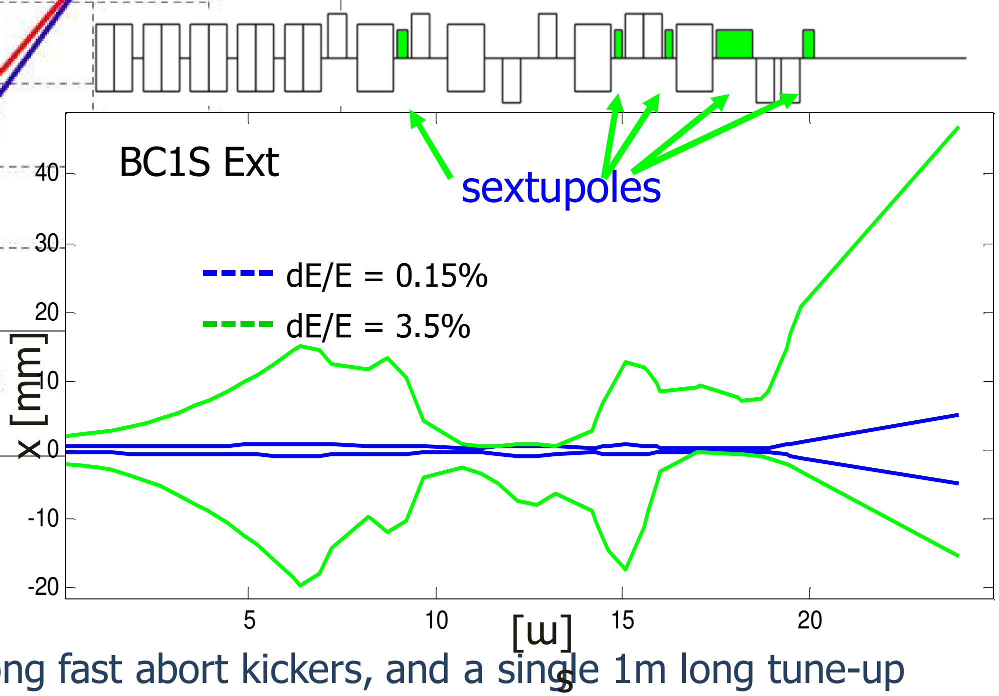
(1) 1 machine
(*) 40 machines

Bunch length = 300 μm

Extraction System Design (EBC1)



S. Seletskiy



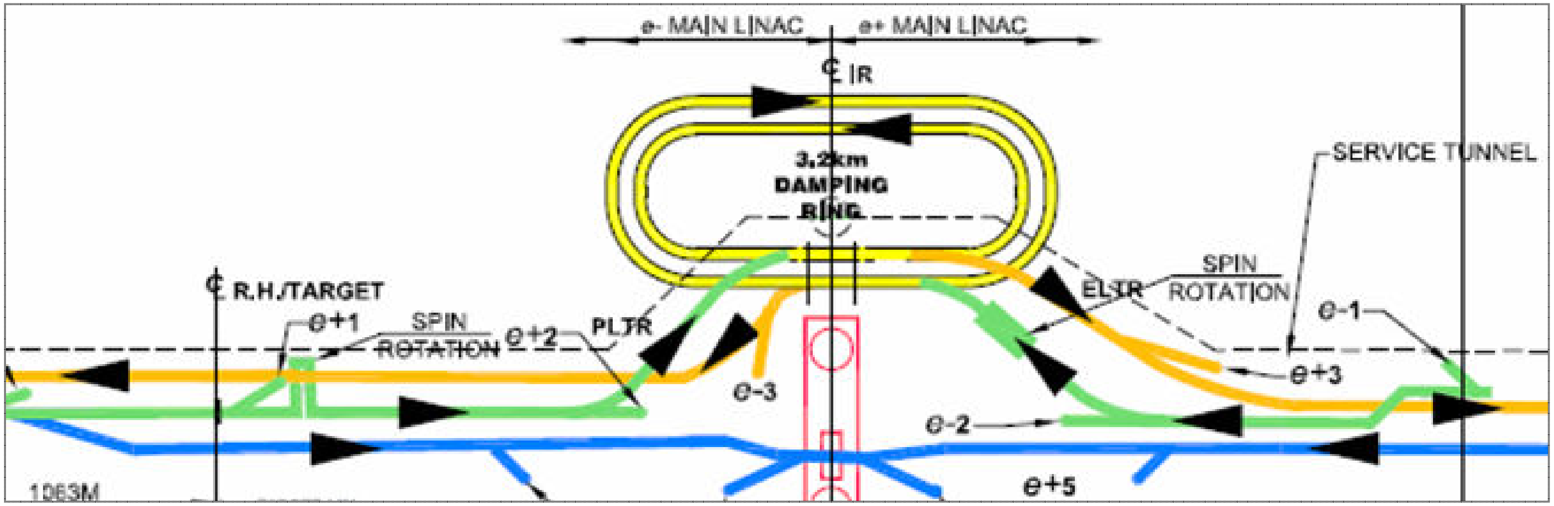
- Extraction system consists of four 2m long fast abort kickers, and a single 1m long tune-up extraction bend placed in between two central kickers.
- The abort kickers can be charged to 35G each in 100ns. The tune-up bend is powered to 280G.
- When energy spread is high 3.5%, there is a significant 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					

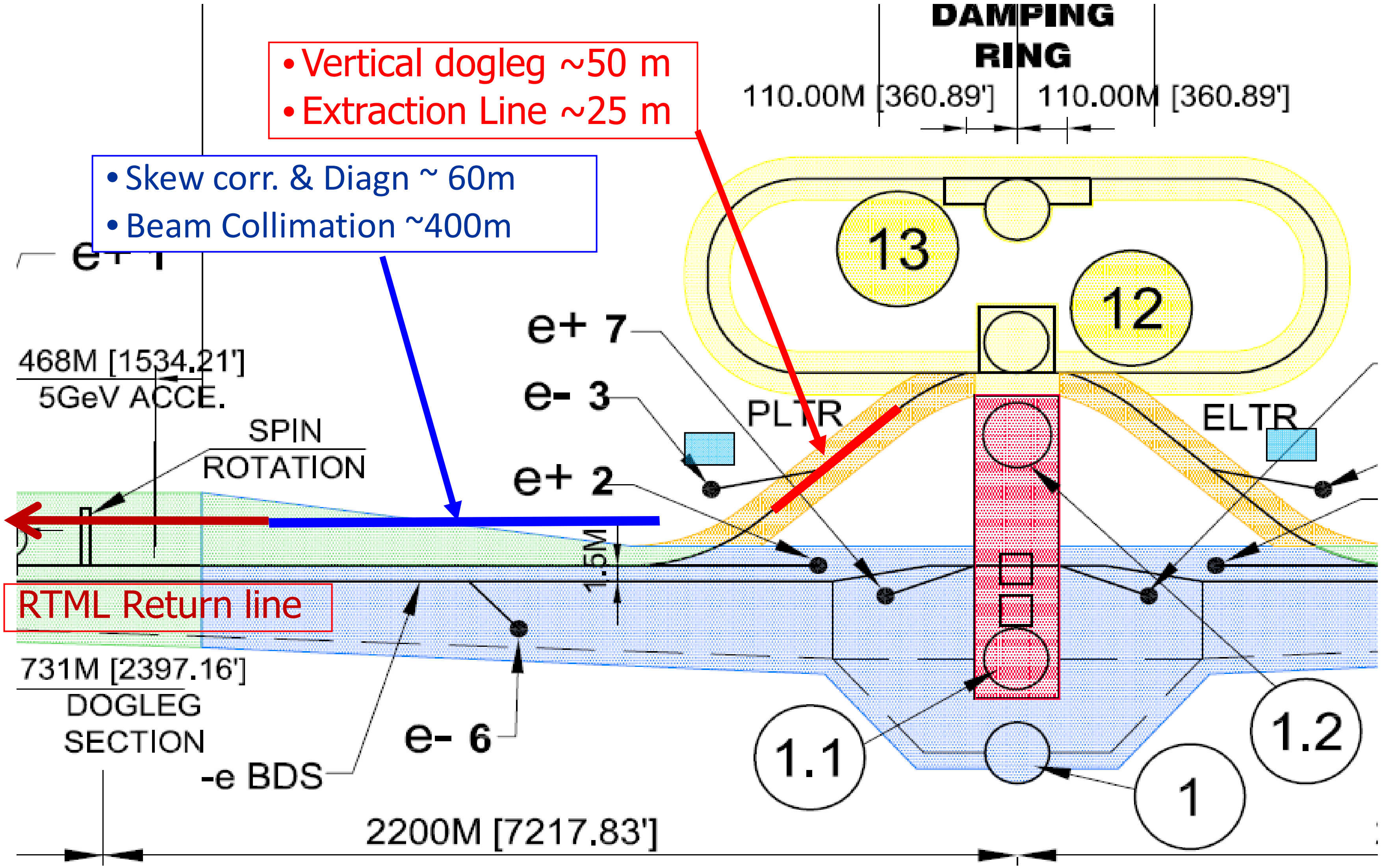
- The Extraction Line is 24m long.
- Beam size on the dump window is 17mm^2 in low energy spread case and less then 70mmx40mm in high energy spread case.
- Dump is separated from the main beamline by 5.1m.

Central Area Layout

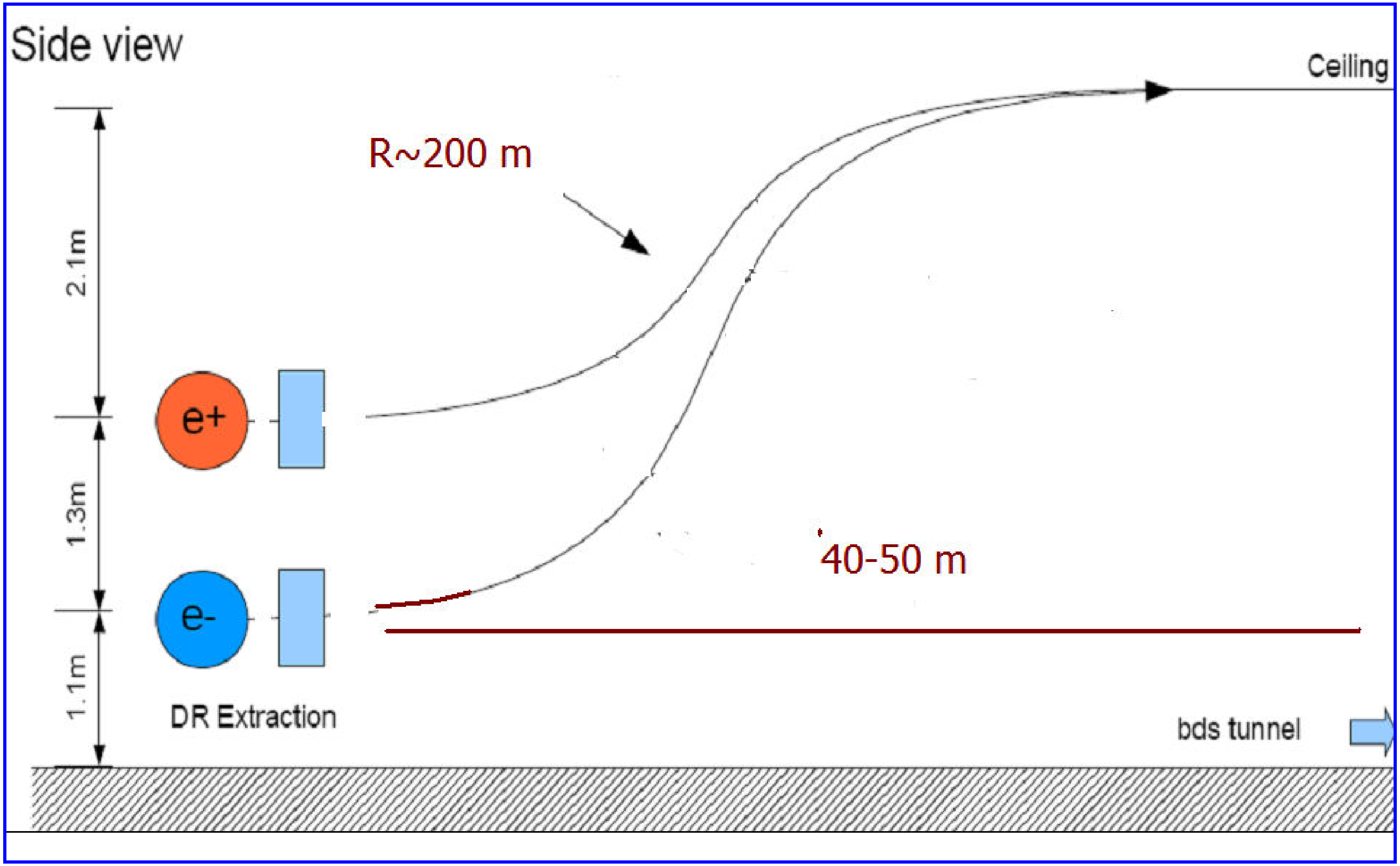


- In SB2009, DR's circumference has been reduced to 3.2 km
- Longer RTML extraction line from DR to ML tunnel. DR vertical elevation was ~10m above ML tunnel in RDR
- This change required a re-design of the beamlines without reduction in performance and functionality of the RTML.
- Main advantage of 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 new configuration in Central Area

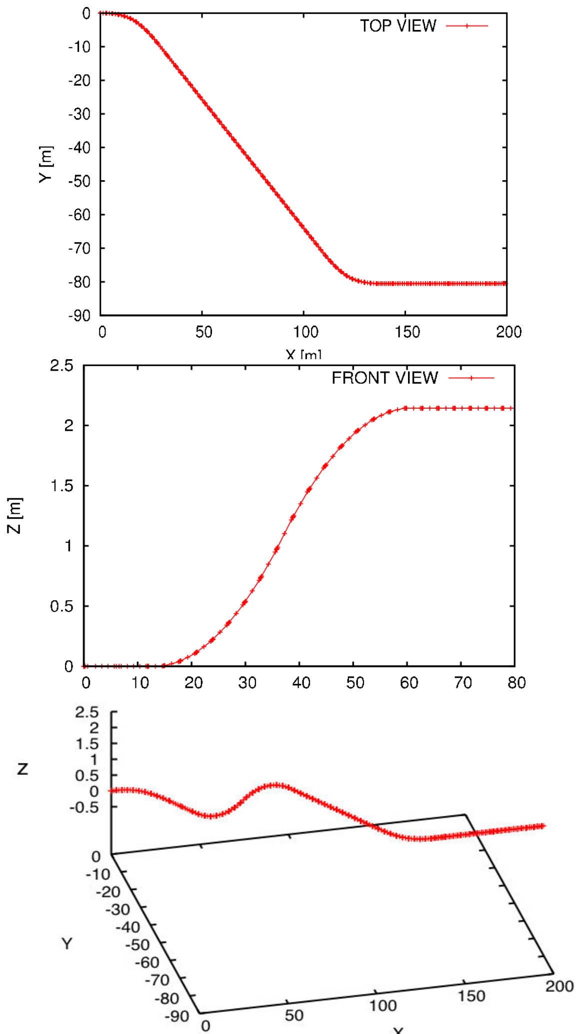


Vertical doglegs in straight sections



RTML Central Area Lattice design

e+ DR extraction line



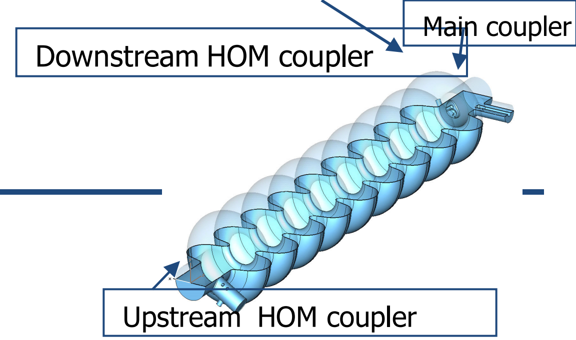
Geometrical configuration (PLACET)

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

Total RF-kick



	NEW FNAL* (HFSS & CST MWS & COMSOL)		OLD FNAL (HFSS)	SLAC (Omega3P)	DESY (Mafia)
	Direct	Direct	Direct	Direct	Direct
KickX	Up & Down Ends	Full Structure			
$\frac{10^6 \cdot V_x}{V_z}$	-98.5+85.2i (HFSS) -96.8+83.2i (CST) -99.6+82.8i (COMSOL)	- - - 104.3+80.0i**	-105.3+69.8i	-86.0+60.7i	-82.1+58.1i
KickY	Up & Down Ends	Full Structure			
$\frac{10^6 \cdot V_y}{V_z}$	-7.9+19.5i (HFSS) -8.3+20.4i (CST) -7.8+19.5i (COMSOL)	- 0.1+21.2i** -8.3+17.1i**	-7.3+11.1i	-4.6+5.6i	-9.2+1.8i

** The End-group effect is taken into account during V_z calculation*
*** A phase-lock mistake was found in a post processing.*
**** For reference only, results were not checked for convergence*

RF kick simulation results

- Calculation convergence checked and achieved;
- RF kick calculation results made by three codes coincide very well;
- Results for separate coupler calculations and for the full structure are the same;
- Normalization factor is checked and improved;
- Phase lock mistake in upstream coupler calculation was found and fixed;
- The RF kick results may be trusted.

The result for $Q_{ext}=3\times10^6$ (averaged over results of different codes)

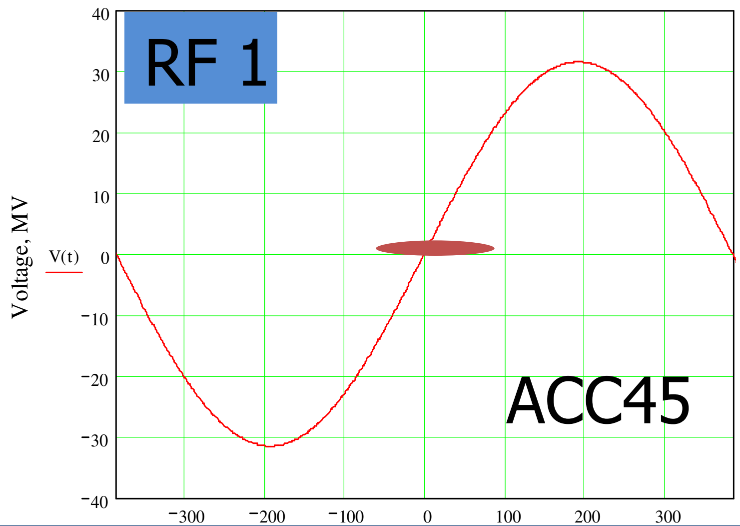
$V_y/V_z = (-8.0+19.8i)\times10^{-6}$;
$V_x/V_z \approx (-98.3+83.7i)\times10^{-6}$.

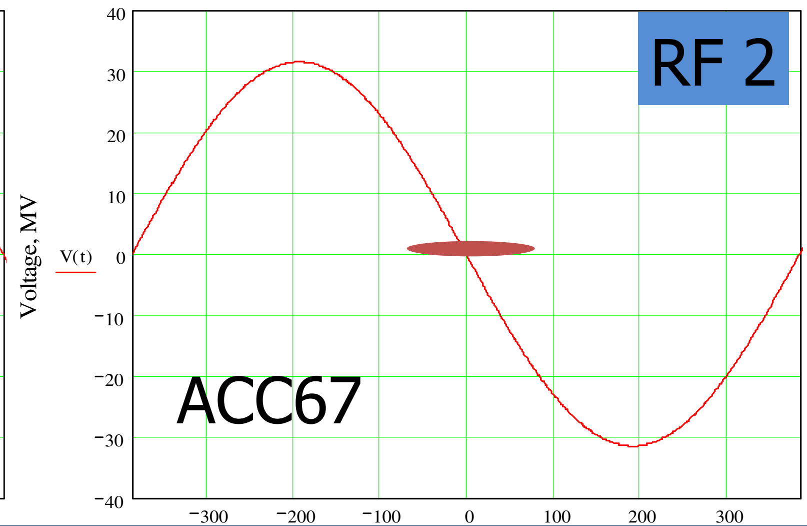
RF phase stability study @ FLASH for BC

- Idea- run two RF system 180°apart. Allows to evaluate two systems with respect to each other
- Relaxes the bunch arrival requirements (cancel arrival jitter)

- Input Energy ~ 540 MeV
- ACC Voltage ~ 370 MeV
- Bunch length = 1 mm ←

For phase jitter 0.25°
→ Jitter: ΔE~3*MeV* → *E/E ~0.6%* (x20)
→ Spread : ΔE~3*MeV* → *ΔE/E ~0.3 % (:6)*

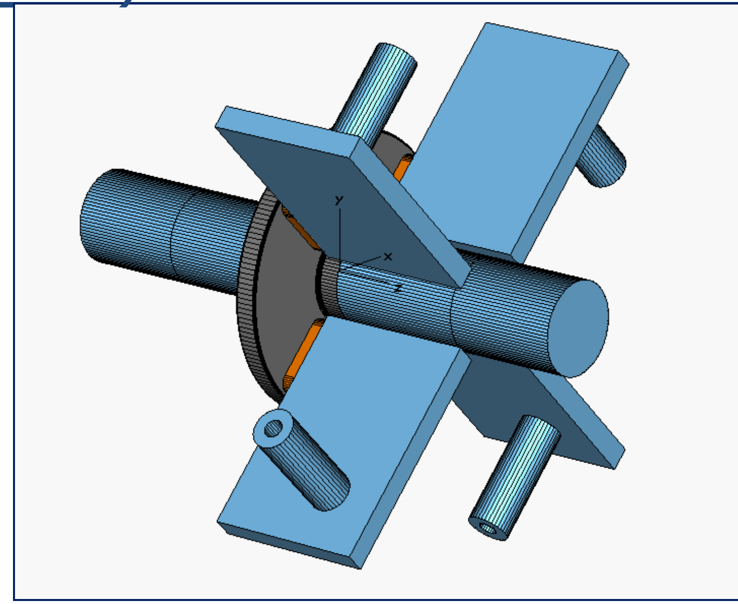


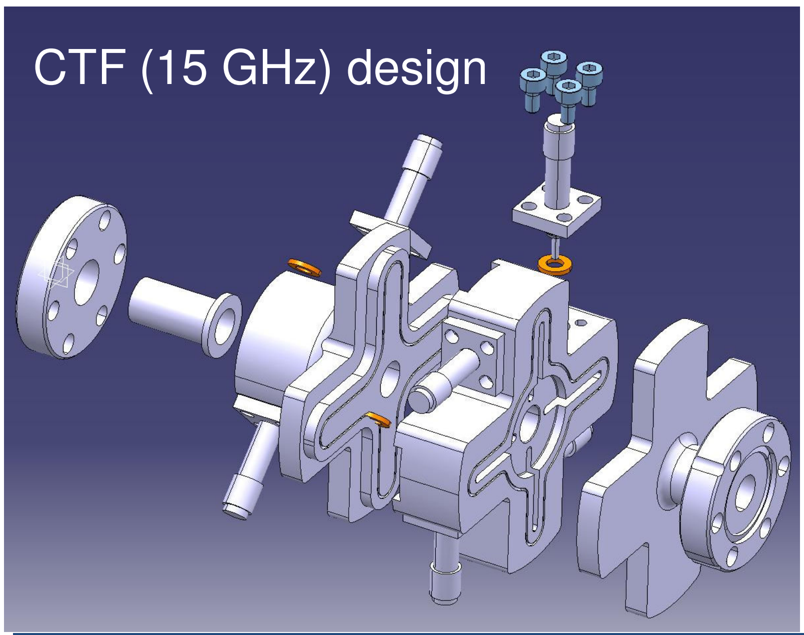


Schematic of the bunch jitter compensation. The two RF modules RF1 and RF2 are operating in counter-phase near the zero crossing.

Concept of the sub-micron resolution BPM for CLIC (14 GHz)

	CLIC	CTF
Nominal bunch charge [nC]	**0.6**	**?**
Bunch length (RMS) [µm]	**44**	**?**
Batch length, bunch spacing [nsec]	**156, 0.5**	**?, 0.33**
Beam pipe radius [mm]	**4**	**4**
BPM time resolution [nsec]	**<50**	**<50**
BPM spatial resolution	**<0.1**	**<0.1**
BPM dynamic range [µm]	**±100**	**±100**
BPM dipole mode freq. f_{110} [GHz]	**14.00**	**14.989**
REF monopol. mode freq. f_{010} [GHz]	**10.00**	**8.9934**

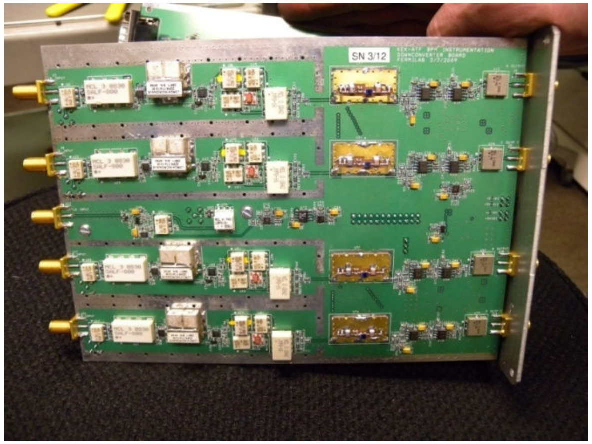
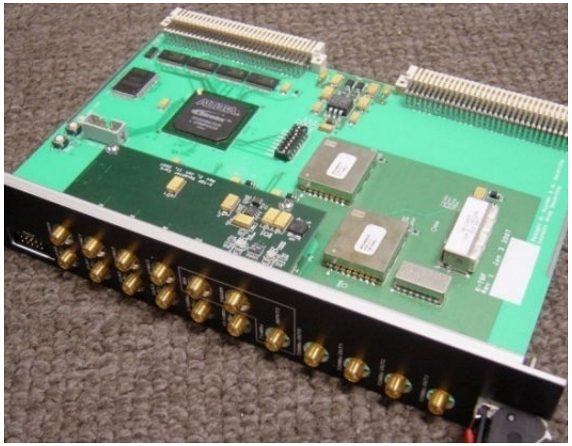



CTF (15 GHz) design

- RF design is completed
  - Resolution
  - Spectum analysis
  - Tolerances,
- Mechanical design in progress
- BPM readout system in progress
- Collaboration FNAL/CERN/KEK

BPM Read-out System

- Based on in-house developed analog & digital signal processing hard- and firmware
  - Implemented this June at the ATF damping ring (to a total of 96 BPMs)
  - Demonstrated <200 nm resolution (narrowband), <10 µm TBT resolution (broadband, ~400 nsec)
  - Integrated calibration system
- Modified versions to be applied for
  - Linac / transport-line button-style BPMs (electrons / hadrons)
  - Cavity BPMs, HOM signal processing, etc.

CLIC RTML spin rotator

- Design a Spin rotator for CLIC
  - (Andrea Latina presentation in this meeting)

Summary

- Single-stage Bunch Compressor designed is done.
  - 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 compr. ratio: 20
  - BC1S is able to compress bunch from 6mm to ~220 μm
- 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.
- Simulations of RF kick from the coupler was updated
- ILC-CLIC collaboration: BPM and spin rotator design
- Remaining issues are subject for R&D program

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.