RTML progress in FY08

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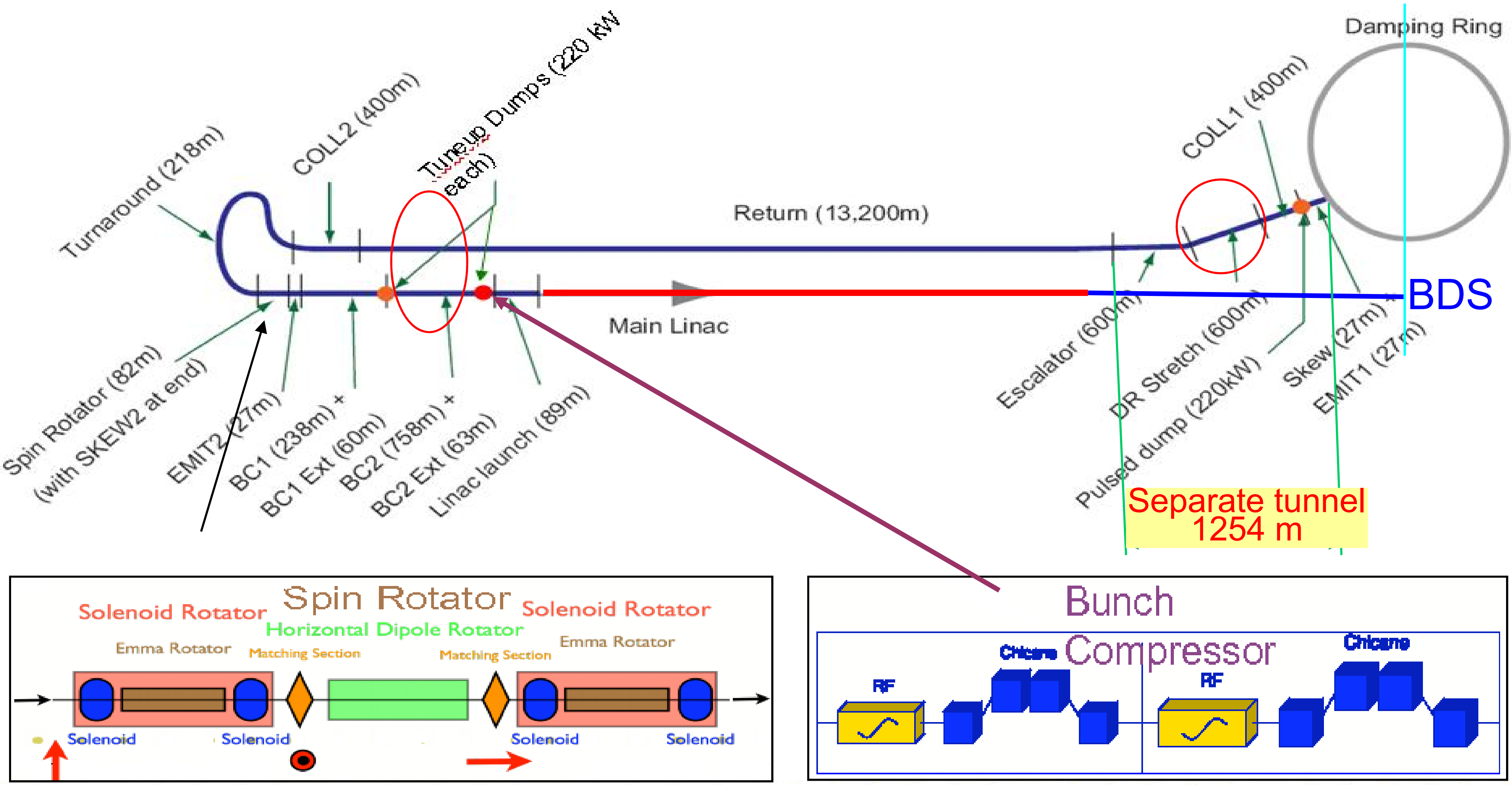
RTML status

- Very limited resources were available in FY08 due to funding cut
- R&D plans and milestones, discussed at SLAC LET meeting, Dec.2007 were delayed.
- Nevertheless few important studies were accomplished.
- New task: Support Minimum Machine configuration –
  - **Design of the Single-stage Bunch Compressor**
  - **Emittance preservation studies in baseline and 1-stage BC**
  - **Redesign Extraction line**

RTML Schematic

Note: e- and e+ RTMLs have minor differences in Return line (undulator in e- linac side) and Escalator (DR's at different elevations); they are otherwise identical.



RTML Progress in FY2008

- Simulations of coupler RF kick and wakes and studies of emittance growth in RTML BC
  - **Different beam parameters and requirements**
  - **Documentation:** WakeFest07, EPAC08 (DESY/FNAL/SLAC)
- Design of the Single-stage BC *(A.Latina, E-S.Kim-alternative)*
  - **Including re-design of diagnostics, matching section and post-acceleration linac 5→15 GeV**
- Studies of Emittance growth and control in Bunch Compressor
  - **Single stage BC** *(A.Latina/FNAL, E-S.Kim/Korea)*
  - **Two stage BC** *(K.Kubo/KEK, A.Latina/FNAL)*
- ILC-CLIC RTML collaboration:
  - **Dark current**
  - **BPM design**

RTML Progress in FY2008 (2)

- Design and preliminary studies of all three Pulsed Extraction Lines for emergency beam abort (MPS) and tune-up *(S. Seletskiy)*
  - **Different beam parameters and requirements**
  - **Specifications for all elements (magnets, kickers, septum magnets, collimators, etc.)**
  - **Documentation: Report, SLAC preprint, EPAC08**

- Code development
  - **Support and develop codes, incorporation of a new physics (coupler kick and wake) and BBA algorithms in codes:**
    - Merlin, Placet, Sad, Lucretia (FNAL&Dehli Univ)and CHEF
    - GdFidL on computer farm to support wake field and dark current simulations.
  - **cross-checking results** *(Kruecker/Latina/Kubo/Ostiguy):*
    - Lucretia/SAD/Merlin/ Placet (RF kick/wake- Dehli Univ/FNAL)
    - CHEF vs. Lucretia – DFS algorithm in ML

RTML Progress in FY2008 (3)

Technical Systems:

- Re-evaluation of the Vacuum system for RTML return line *(Xiao Qiong, IHEP/China)*
  - **Conceptual design of vacuum system and specs for SS passivated and non-passivated tubes.**
  - **Component counts and Cost estimation.**
- Magnetic Stray field studies (requirements for return line <2nT) – *(D.Sergatskov)*
  - **ILC: H < 2 nT (f>1Hz); CLIC: H< 0.2 nT (f>10Hz)**
  - **Measurements in A0/FNAL area, demonstrated ~3nT**
- Design and prototyping of the SC quadrupole for RTML cryomodule and Low energy part of the ML *(V.Kashikhin)*
  - **First prototype was built, studies of center stability underway.**
- Ground Motion studies at Fermilab site *(J.Volk)*
  - **Effect of natural sources of motion (tides, rain fall, earth quakes) and cultural sources (sump pumps, cryoplant, etc.)**
  - **Lot's of multi-year measurements in Aurora mine, MiINOS hall available for analysis and models for emittance studies**

Emittance Growth in RTML

Summary of Studies (LET meeting, Dec.2007 SLAC)

Region	BBA method	Dispersive or chromatic mean emittance growth	Coupling mean emittance growth
Return Line	KM and FF to remove beam jitter	0.15 nm	2 nm (with correction)
Turn around Spin rotator	KM and Skew coupling correction	1.52 nm (mostly chromatic)	0.4 nm (after correction)
Bunch Compressor	KM or DFS and Dispersion bumps	>5 nm (KM+bumps) 2.7 nm (DFS+bumps)	0.6 nm (w/o correction)
Total		~5 nm almost all from BC	3nm (w/o complete correction)

- Effect of coupler RF kick & wakes are not included
- Dynamic effects are not included
- Emittance growth is large (pre-RDR budget 4nm, might be ≤10nm)
- Need further studies to reach goal for emittance growth
- Cross-checking with different codes (important)

Effect of coupler on emittance growth

- Couplers introduce transverse RF kick and wakes (DESY 2007)
- Effect of coupler is significant for long bunch in RTML BC.
- Can be compensated by adjusting CM tilt or using crab cavities

Summary Tables of the vertical emittance growth, induced by the Coupler RF-Kick and Wakes in perfectly aligned BC.

Single-stage BC +post-acceleration 5-15 GeV

Correction algorithm	$\Delta\varepsilon_y$ - RF kick	$\Delta\varepsilon_y$ -Wakes	$\Delta\varepsilon_y$ Total
1-to-1 correction + bumps	1.9 nm	1.4 nm	3.4 nm
crab cavity corr. + bumps*			0.47 nm*
Girder pitch optimization+ bumps**			0.4 nm**

* Each CM have CC at the end, replacing one of the ILC cavity

** Range of CM tilt ~30urad (~300 um displacement with step resolution ~10um)

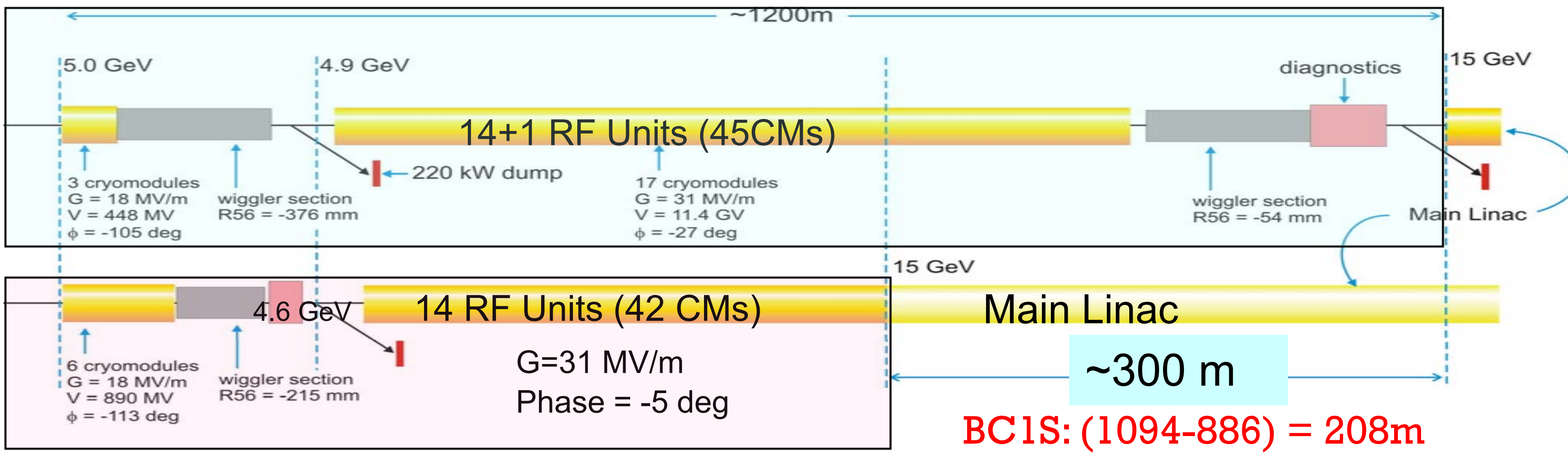
Baseline design: BC1+BC2

Correction algorithm	$\Delta\varepsilon_y$ -RF kick	$\Delta\varepsilon_y$-Wakes	$\Delta\varepsilon_y$-Total
1-to-1 corr. + bumps	1.59 nm	2.8 nm	5.5 nm
1-to-1corr.+Skew corr			2.5 nm
Girder pitch optimization+bumps			0.58 nm

Girder (CM) pitch optimization is very effective for emittance control

RTML in Minimum Machine Configuration

The RTML two-stage Bunch Compressor (top) and a possible short single-stage compressor (bottom). Lengths compared for 15 GeV.



Single-stage BC is possible, if not support flexibility of parameter set

- Changes: 9/6 mm→0.3/0.2mm (RDR) to 6mm →0.3mm (x20 compression)
  - Reduction in beamline and associated tunnel length by ~200÷300 m (including some in SCRF linac)
  - Removal of the second 220 kW dump and dump line components
  - Shortening of the diagnostics sections (lower energy)

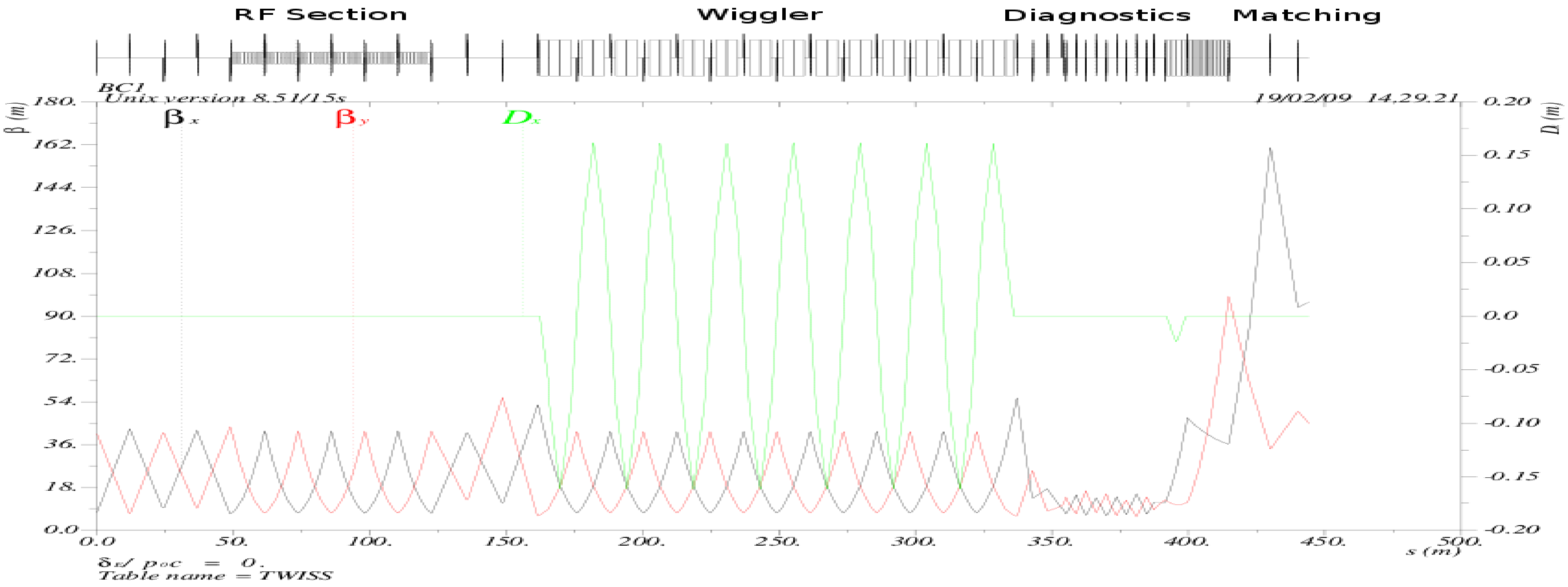
Single-stage bunch compressor for the Minimum Machine

Simplification of overall design

- Two Single-stage designs are under studies now:
  - **PT modified design with wiggler** ***(A.Latina talk):***
  - **Alternative short design with chicane (*Eun-San Kim*)**
- Re-design of the diagnostic section, matching section to launch beam to ML and post-acceleration (5-15 GeV) linac
- Re-design of Extraction Line to accommodate larger energy spread after single-stage BC *(S.Seletskiy talk)*
- Beam Dynamic and Emittance control studies for single-stage BC
  - **Effect of coupler RF kick and wakes included**
  - **BBA technique to tune nominally misaligned BC**
  - **New Methods and special hardware to better control emittance growth in BC**
    - Adjustable Tilt of Cryomodules
- Crab cavity in each CM

Single-Stage Bunch Compressor

Based on the original design, proposed by PT et al. in April 2005:
http://www-project.slac.stanford.edu/ilc/acceldev/LET/BC/OneStageBC.html



- six cryomodules for RF acceleration (Eacc=26MV/m, phase=-119)
- 6-cells wiggler: a single bend magnet between quads in a 6-cells FODO lattice

+ NEW sections added:

(1) beam diagnostics adapted from BC2, re-design extraction after BC→shorter
(2) Post-acceleration linac from 5 to 15 GeV – part of ML (Eacc=31.5 MV/m)

Single-stage Bunch Compressor (2)

Design Characteristics

- The beam properties at injection are:

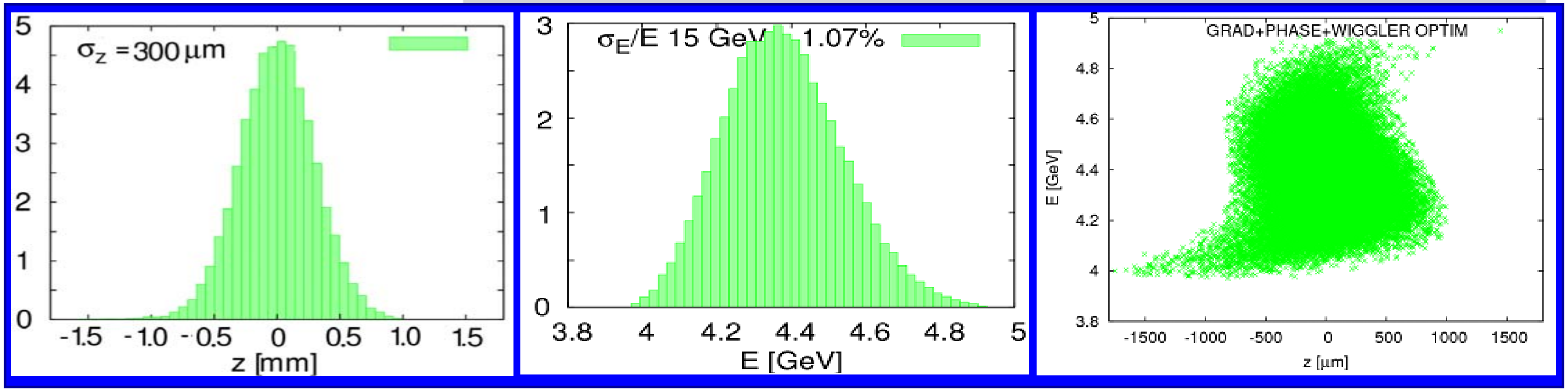
Charge	2e10 (3.2 nC)
Energy	5 GeV
Energy spread	0.15% (0.13% from DR)
Bunch Length	6 mm

- Properties of the bunch compressor:

Integrated voltage	1275 MV @ 1.3 GHz
Cavity gradient	≈25.6 MV/m
Accelerating Str	48 (6 CM ; old-type)
Phase	-119.5 degrees
Energy Loss	627.9 MeV
R_{56}	-147.5 mm
Total length	∼433 m

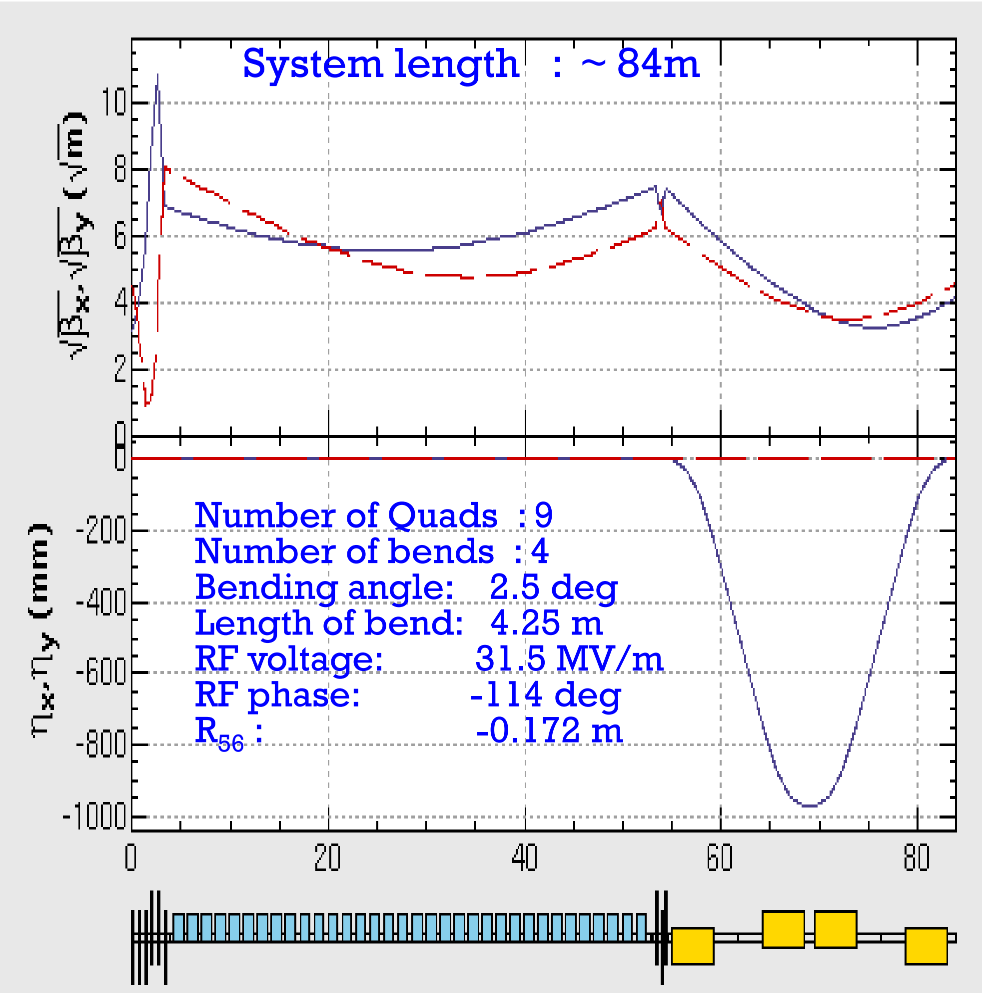
After optimization:

- Bunch length = 300 um
- energy spread = 3.54 %
- energy spread @ 15 GeV = 1.07 % (as 2-stage)



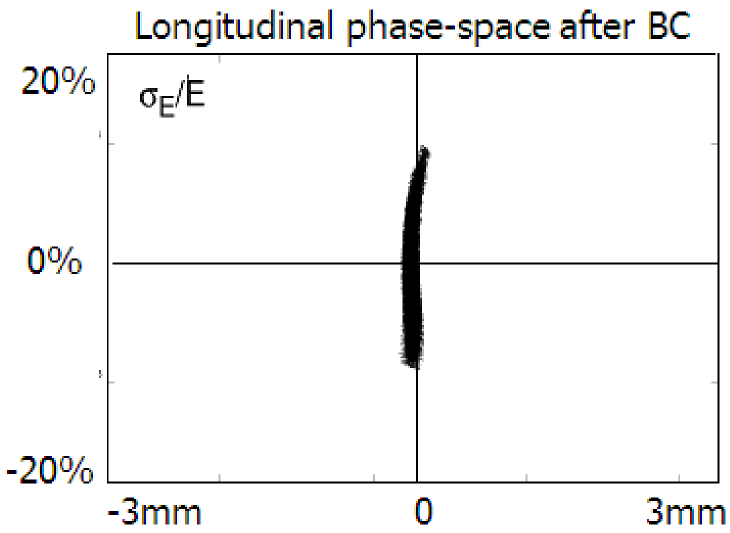
Need modifications: CM type4, modified wiggler design, shorter EL on beamline (shorter system with better performances)

Alternative Short Single-stage BC



	Initial	Final
Beam energy, GeV	5	4.57
Bunch length, mm	6	0.3
energy spread, %	0.15	3.46
X-Emittance, um	8.00	8.28
Y-Emittance, um	0.02	0.02*

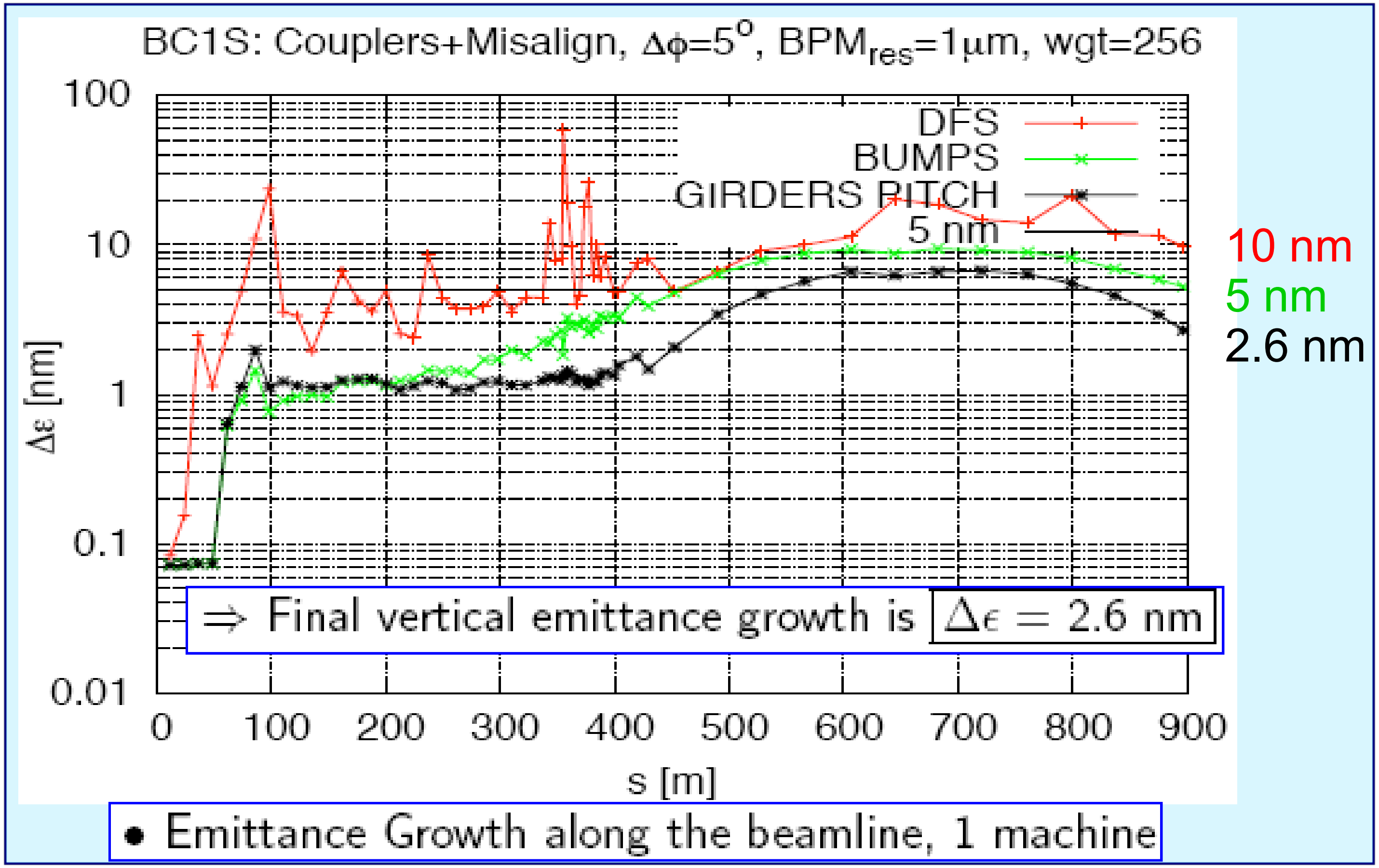
* Kick from cavity tilts and coupler not included



(E-S Kim, LCWS09,Chicago)

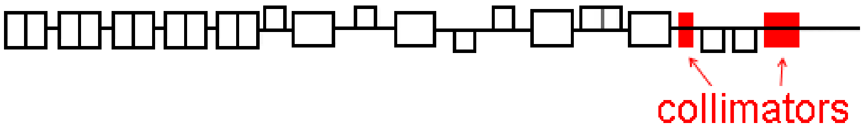
Requires emittance preservation studies!!!

Coupler and Misalignments in BC1S

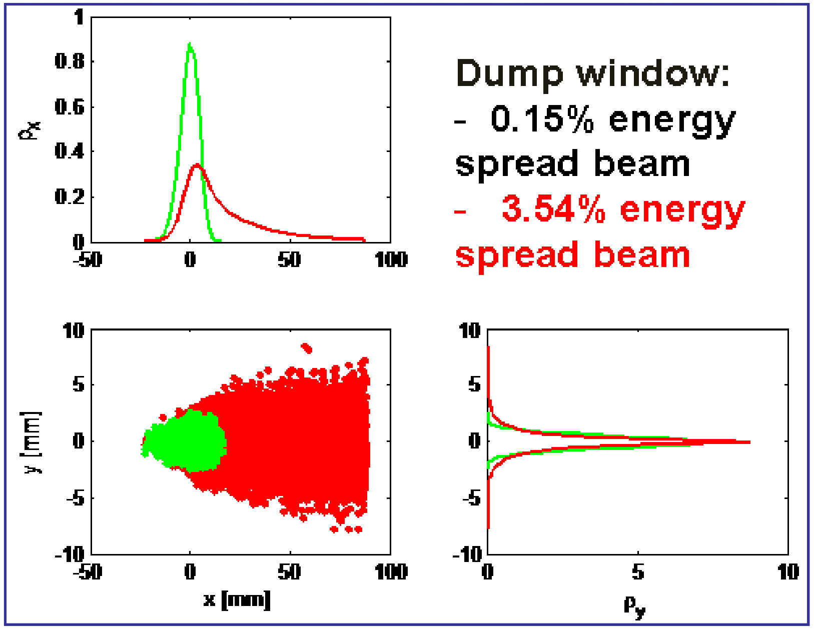


- BC1S (incl. diagnistics+matching+acceletration linac 5➔15 GeV).
- Standard misalignments (300 um/300urad); ISR +coupler RF kick/wake
- 1-to-1, DFS and bumps, girder optimization

Extraction Line after BC1S: Collimation summary

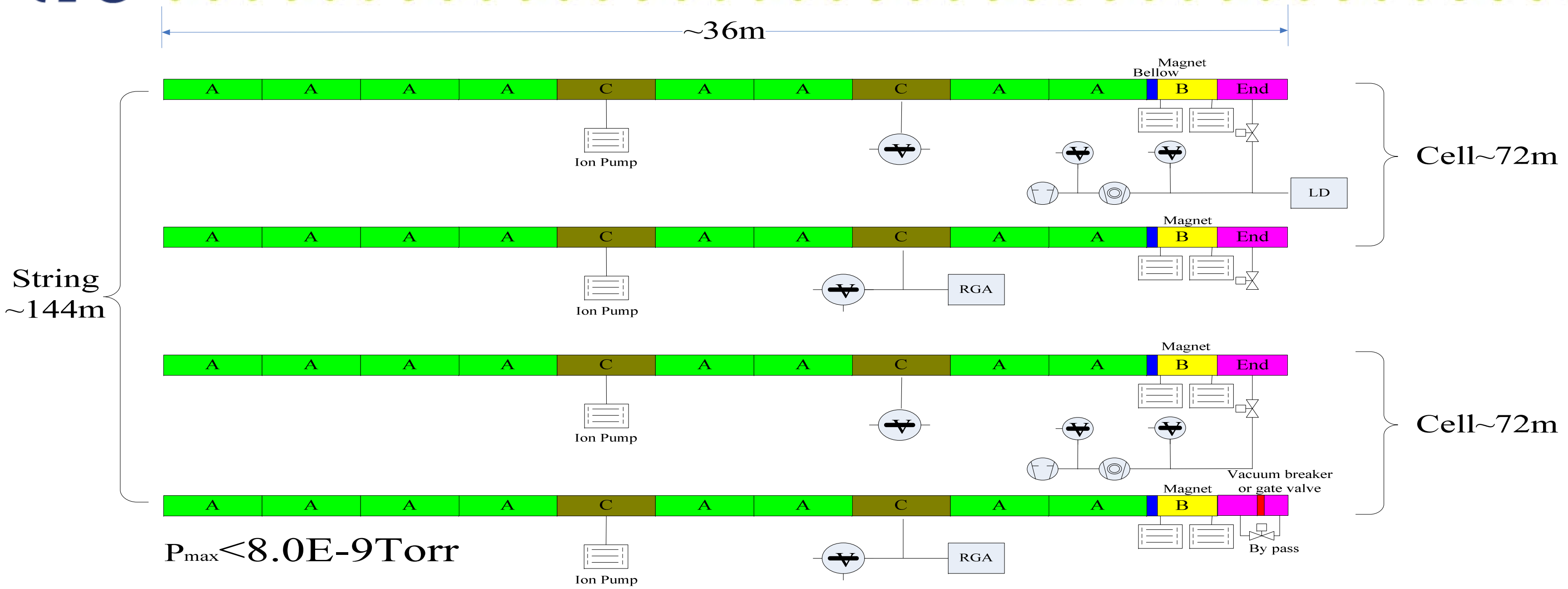


- Designs for 3 Extraction Lines done.
- Re-design EL after BC1S → first look
- Example: Option with Strong collimation
  - Two collimators to protect the doublet and use dump with small window *(details: S.Seletskyi talk)*

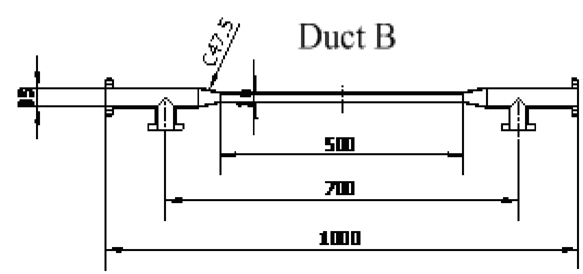


	No collimation	No collimation SC magnets	1 collimator (weak collimation)	2 collimators (strong collimation)
Collimators			1.9kW/train; 7.4mm horiz. aperture	2.2kW &11.7 kW per train 7.2mm & 50mm H-aperture
Sextupoles	1T pole tip field; exotic shape	Two sextupoles 12cm aperture and pole tip filed <6T	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

Return line Vacuum system (Xiao Qiong, IHEP/China)



- Tight vacuum req. in Return Line (<10nTorr)
- Design features:
  - Passivated SS, ID=35mm, in magnet ID=16mm
  - 86 curved strings followed by 8 straight strings;
  - 1 bellow/1 quad magnet
  - If one string uses vacuum breaker, the next string uses gate valve.
- Final Report with Cost estimation



Magnetic Stray Fields Studies

- RTML requirement for stray fields in Return Line < 2nT (freq>1Hz)
- SLAC measurements (at Station A) are promising (~2nT)
- Need more studies for different sites. Stability of 60Hz is an issue

<u>Hardware:</u>

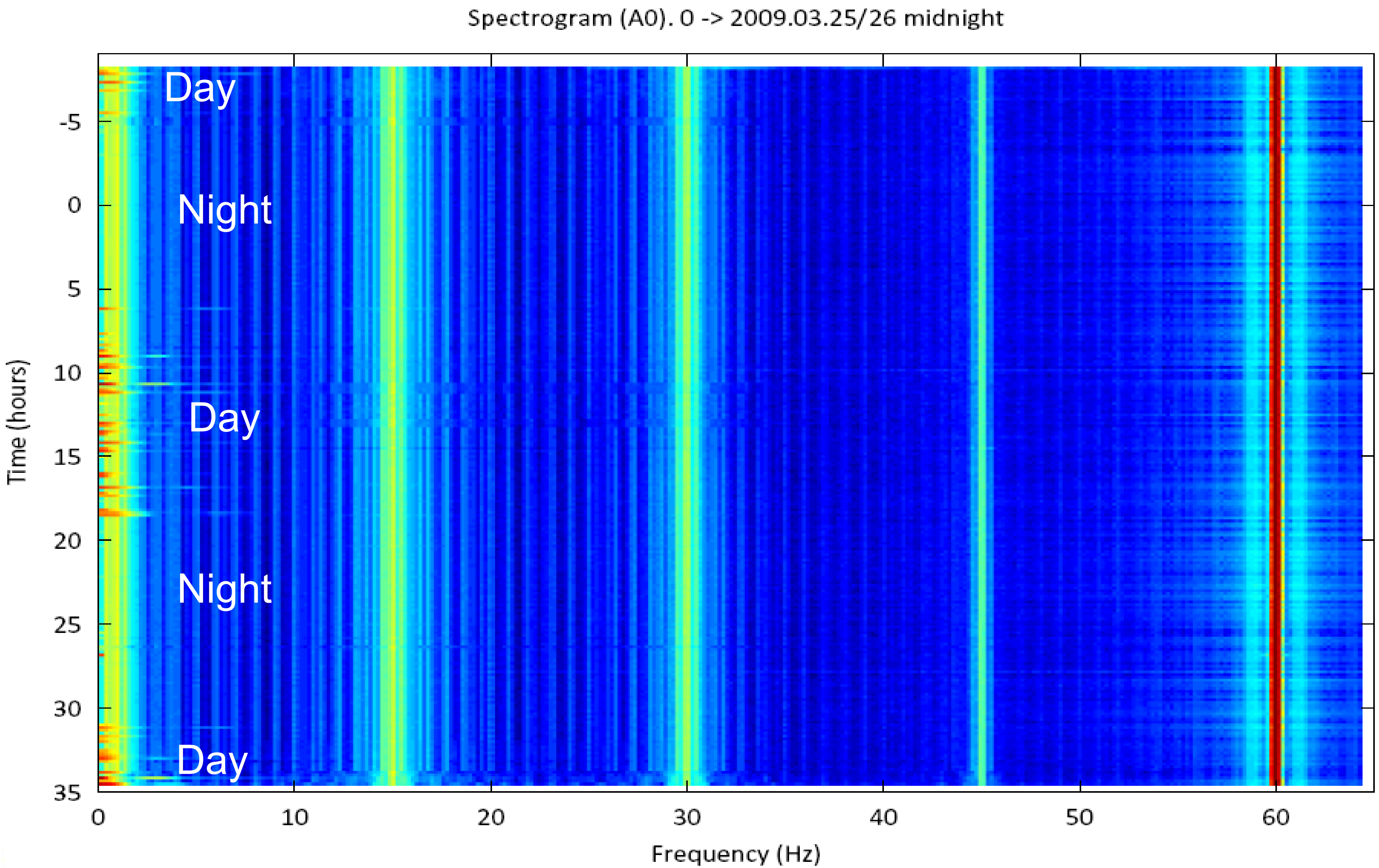
- 3-axis fluxgate magnetometer
- 0.1mT full scale
- DC to 3 kHz
- 20 pT/sqrt(Hz)

<u>Measurement:</u>

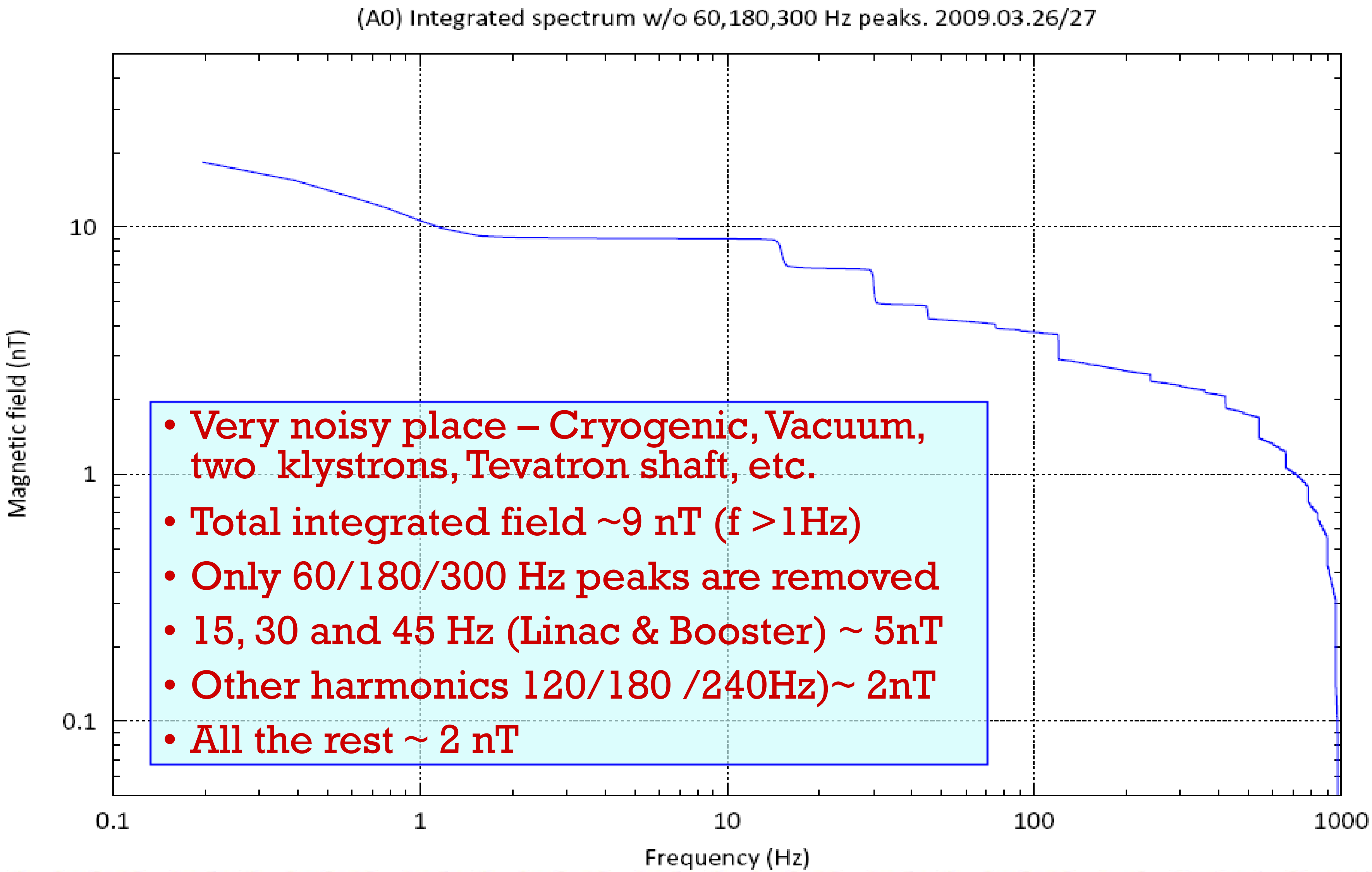
- Near klystron
- In shielded cave (20m from kly)
- Klystron On/Off

Fermilab A0 experimental area with cryogenic and 5 MW klystron/modulator

Stray magnetic fields: Spectrogram



Integrated spectrum



- Very noisy place – Cryogenic, Vacuum, two klystrons, Tevatron shaft, etc.
- Total integrated field ~9 nT (f >1Hz)
- Only 60/180/300 Hz peaks are removed
- 15, 30 and 45 Hz (Linac & Booster) ~ 5nT
- Other harmonics 120/180 /240Hz)~ 2nT
- All the rest ~ 2 nT

Future work on critical R&D

- Continue Accelerator Physics Studies (with K.Kubo AP group):
  - **Complete Static emittance preservation studies**
    - Implement new alignment models and stray-field models
  - **Start Dynamic simulation in RTML**
    - Design of FB/FF system
  - **Code development**
- Continue Study of magnetic stray-field
- Amplitude-phase stability Studies at FLASH (9-mA studies - Sept.09 ?)
- Support MM studies:
  - **Complete design, optimization and single-stage BC. Emittance preservation studies in both lattices (BC1S and short design):**
  - **RE-design DRX, transport Lines in Central Area (new configuration of sources)**
- Technical systems:
  - **Complete evaluation of RTML vacuum system**
  - **Prototyping SC quad for low energy ML and RTML**
  - **Re-evaluate alignment requirements for RTML Cryomodules**

Resources !!!

Conclusion

Progress in RTML design was achieved in a few areas (FY08):

- Studies were focused on most critical work packages
  - **Emittance preservation in Bunch compressor**
    - Effect of coupler kick and wake on emittance growth
    - CM tilt optimization to compensate cavity and coupler tilt → very effective for emittance control but requires a special movers with step < 10um)
  - **Design of Single-stage BC, incl. diagnostics and matching**
  - **Design of all extraction lines for baseline lattice and preliminary design of EL for single-stage BC.**
  - **Magnetic stray field measurement (requirements <2nT)**
  - **Re-evaluation of vacuum system for return line to provide required vacuum P<10 nTorr.**
- We supported important studies started in previous years
  - **Ground motion and vibration studies in deep tunnel (FNAL)**
  - **Design, prototyping SC magnet for RTML and low energy**
- Progress was limited by available resources in FY08

Appendix Slides

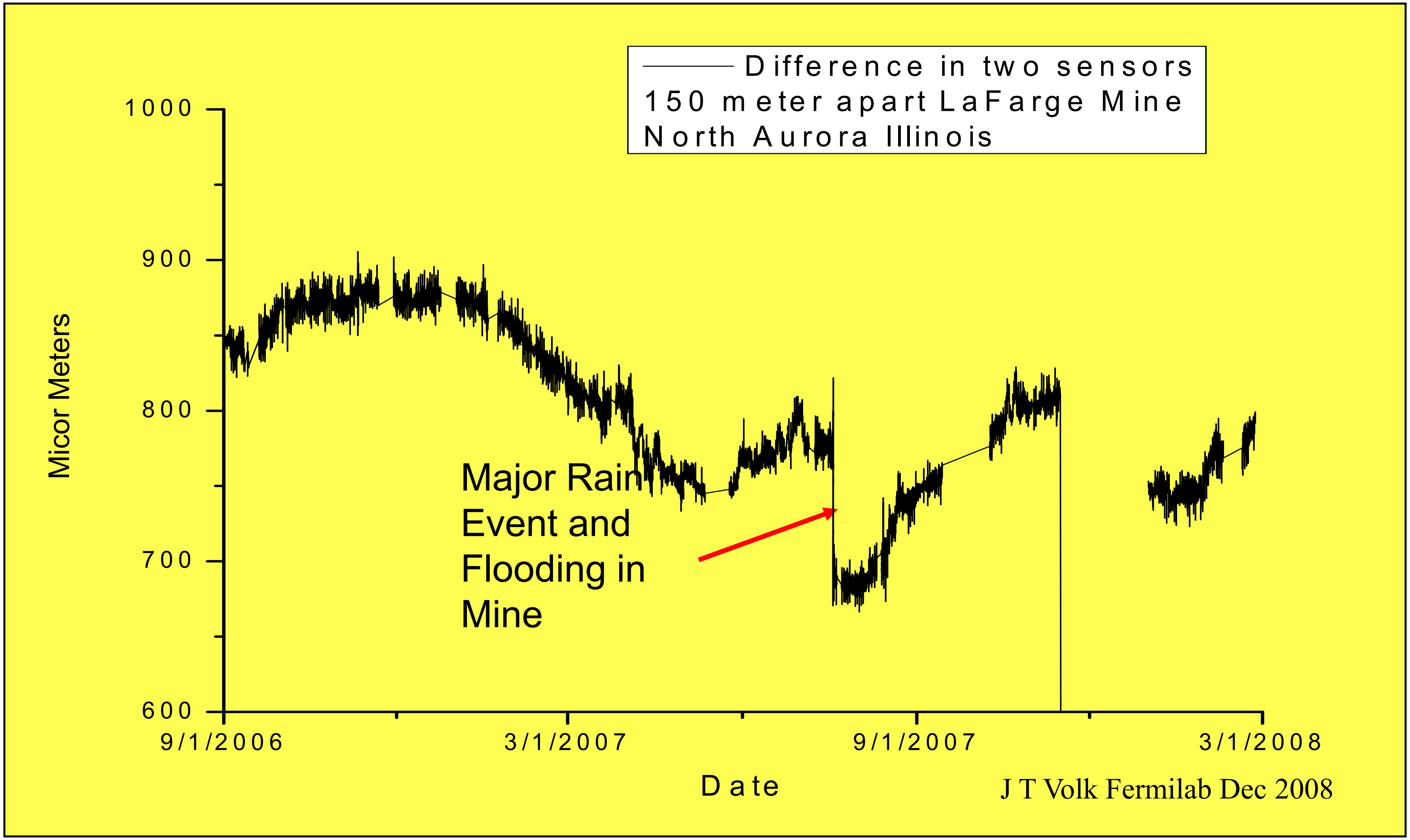
Ground Motion Summary

- There are several HLS system taking data at Fermilab
  - **Aurora mine; MINOS hall; NML hall.**
- They are accurate and reliable can run for several years.
- They are useful for determining ground motion and tilt.
- The data are available at; http://dbweb1.fnal.gov:8100/ilc/ILCGroundApp.py/index
- There are natural sources of motion: tides, rain fall, earth quakes both large and small.
- There are cultural sources such as sump pumps.
- Plans for new systems in the works.

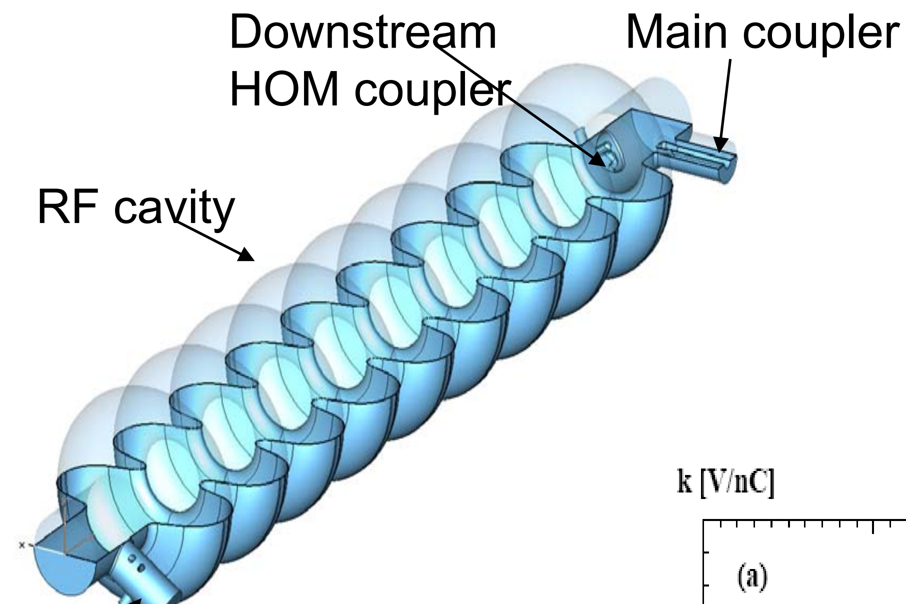
J T Volk Fermilab

Difference in two sensors150 meters apart

18 months of data



Simulations of Coupler Kick and Wakes

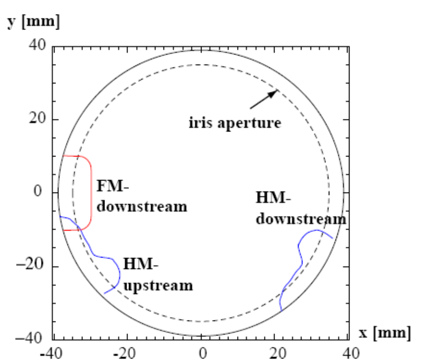


The couplers break the RF field symmetry and cause transverse RF kick and Wakes DESY,2007. Simulations: DESY/FNAL/SLAC

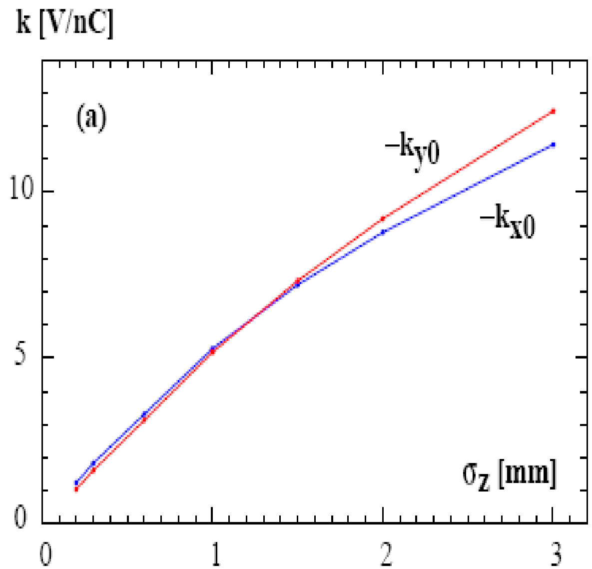
Total RF KICK:

$$\frac{\overrightarrow{V_\perp}}{V_a} \times 10^6 = \begin{pmatrix} -105.3 + 69.8i \\ -7.3 + 11.1i \end{pmatrix}$$

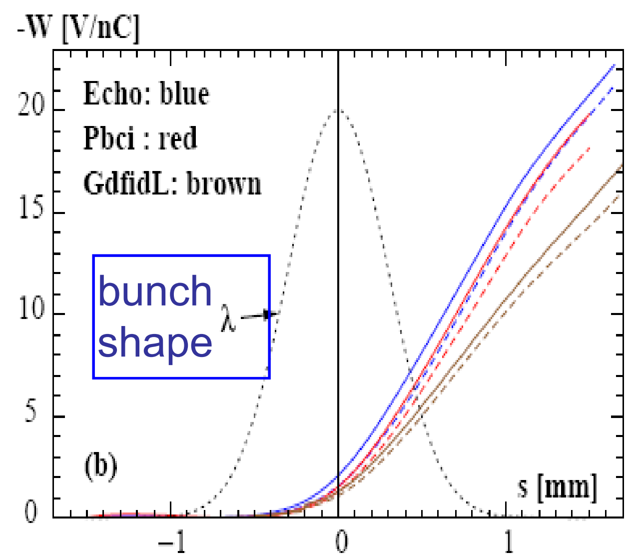
Coupler Transverse Wakefield



The profiles of the 3 couplers, as seen from the downstream end.



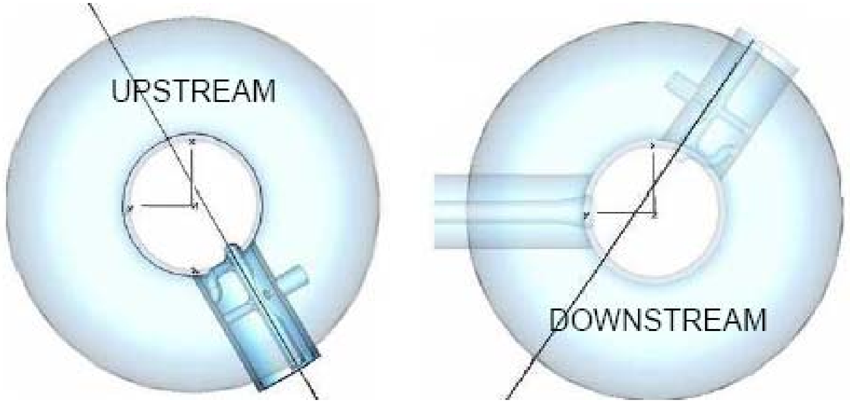
On-axis kick factor vs. σ_z



$W_x(s)$-solid,, $W_y(s)$-dashed for σ_z = 300 μm.

Reduction of the coupler RF kick & Wake

1. Symmetrical coupler geometry (upstream coupler rotated 104°)



Does not work

- Wakes – OK
- But RF kick increases

2. Compact detachable coupler unit that provides axial symmetry of the RF field and the cavity geometry in the beam channel: