Beam dynamics issues in RTML

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Wrap-Up from RTML KOM (PT)

- RTML is a large system by any standard
  - **Total length > ILC footprint**
  - **Total number of components enormous**
  - **Combined e+,e- RF systems**
- Impressive amount of design work done for RDR, nonetheless…
- …Technical maturity of RTML design is lagging
  - ***Missing or incomplete beamlines***
  - ***Performance studies out of date and inadequate***
  - **Area, Technical, Global, Cost information are not consistent with each other**
  - **Many hardware performance specifications unknown**
  - **Required functions of various subsystems not reviewed**

More work was done after RTML KOM. Latest results are presented at this LET face-to-face meeting

EDR RTML work packages

- Goal of EDR RTML work packages
  - **Address to solve Valuable Risk, Design and Cost issues**

- Working assumptions for RTML WP's
  - **Not cover work already covered by ML or other technical groups, unless RTML requirements are different from their needs**
    - Cavities, Cryomodules, HLRF, LLRF, Cryogenic
    - Most diagnostics: Laserwire, OTR, L-band BPM
  - **Leading/coordination each WP by one person/one institution**
  - **Result oriented WP with goals/deliverables/milestones**
  - **Resources are limited**
    - need priorities
    - wider geographic, new countries, institutions, groups

EDR RTML Work Packages (2)

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Structure of EDR Work packages in RTML

There are ten WP in RTML, among which there are nine technical WP while the first one is primarily managing and integration:

1. RTML group managing and Specs development
2. ✓ Engineering Lattice design
3. ✓ Accelerator physics
4. ✓ R&D on amplitude and phase stability in BC
5. ✓ Alternative Ultra-short Bunch Compressor
6. Magnets and power supplies
7. Collimation system
8. Beam dump system
9. RTML Vacuum system
10. RTML Instrumentation

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RTML Work Packages (cont.)

1. **RTML managing and Specifications development**
   - **Specs for all technical systems, CFS**
2. **Engineering Lattice design for EDR geometry**
3. **Accelerator Physics**
   - **Static Tuning study**
     - Errors sensitivity study
     - Failure mode analysis
   - **Magnetic stray fields studies**
   - **Space-charge effects studies**
   - **Study of beam halo in the RTML**
   - **Dynamic tuning. Specify and develop FB/FF system**
   - **Beam Loss and radiation load simulations (?)**
   - **Design, Specify MPS**
4. **R&D on phase stability in BC1/BC2 (beam timing)**
   - **Study at TTF2/DESY and ILCTA/FNAL**

RTML WP's (cont.)

5. Alternative Ultra-short Bunch Compressor

- Lattice design
- Control of emittance growths
- Sensitivity studies on machine errors
- Cost estimation

6. Magnets and Power Supplies

- Design, specify & optimize DC conventional magnets
- Optimize number of types and apertures
- Design warm quads, bends and correctors
- Design and prototype BC wiggler wide aperture magnet
- Design, prototype quad/corrector for return line
- Design tune-up Septa and PS
- Design and Specify pulsed magnets
- Design tune-up extraction kickers and pulsers
- Design feed-back, feed-forward correctors and PS
- Design/prototype SC quad/corrector for BC1/BC2
- Design, specify SC solenoid
- Optimize PS and cabling
- Design, specify DC PS
- Design stable supports for magnets

RTML WP's (cont.)

7. Collimation system

- Optics design
- Theoretical and computer simulations of wakefields
- Engineering design of the collimator

8. Beam Dump system (six in RTML, 5-15 GeV; 220kW)

- Energy deposition and radiation shielding simulations
- Engineering design of the dump
- Design / costing handling system

9. RTML Vacuum system

- Engineering design of the vacuum system in RT transport line
- Impedance design of vacuum system
- Cost estimation

10. RTML Instrumentation

- Specify Instrumentation requirements, interfaces, locations
- Specify warm BPMs
- Alignment system design
- Design of FB/FF system

RTML Work Packages (EOI)

Confirmed or requested Effort													
WP	**WP Title**	ANL	Cornell	FNAL	SLAC	UBC Canada	STFC UK	DESY	Russia	KEK Japan	IHEP China	KNU Korea	India
1	RTML managing and Spec. development		x										
2	Engineering Lattice design		x										
3	Accelerator Physics			?	x								
4	R&D on amplitude and phase stability in BC			x								?	
5	Alternative Ultra-short Bunch Compressor									?		x	
6	Magnets and PS			x									
7	Collimation system						x						
8	Beam Dump system				x								?
9	Vacuum system	x							?				
10	Instrumentation			x									

* Preliminary Table, Not confirmed by all institutions/groups yet

RTML WP vs. Acc. Simulation Group WP (Kubo)

How to organize/coordinate Work on Accelerator Physics Simulations in RTML area system? This is a subject for discussion on this meeting.

- **Work items related to (almost) one single area are under Area Groups (RTML, ML or BDS)**
- **Basically, inter area work items are under Simulations Group.**
- **All LET beam dynamics simulation workers should be in Simulations Group and closely communicate each other.**
- **Important simulation results should be cross checked by more than one group.**

Accelerator Physics Issues

- RTML Lattice Design/Revision (is not RTML WP only)
  - Baseline RTML Lattice - SLAC (PT), Cornell, ...
  - Alternative BC – KNU (Korea), Cornell, SLAC, KEK,...
- Static Tuning - SLAC*, Cornell, KEK, CRN, DESY, FNAL(?)
  - Demonstrate required emittance budget
    - Concentrate on most critical systems (BC)
  - Develop and document BBA strategy
  - Error sensitivity studies (similar to ML)
  - Failure mode analysis (BPM, Correctors, ...)

  Cross-checking all results by other groups is essentially important
- Stray Magnetic fields - FNAL, SLAC(?), KNU,...
  - Study correlated and uncorrelated sources of magnetic field
  - Develop models for beam simulation
- Space-charge effects studies – FNAL, Dubna, Cornell (?), ...
- Beam halo in the RTML – Cornell, ...
- Dynamic tuning. Specify and develop FB/FF system – SLAC, Cornell, KEK, CERN, DESY
- Beam Loss and radiation load simulations - FNAL, SLAC(?), ...
  - **Beam Dumps, Collimators, stoppers**
- Design, Specify MPS

ILC Lattice Files Punch List (PT, Dec.2007)

1. **Definite Changes for Conformity with RDR**

   ERTML/PRTML -- VDOG from e- DR elevation to EGETAWAY/PGETAWAY(ceiling) elevation missing
   ERTML/PRTML -- x separation EGETAWAY/PGETAWAY vs PSOURCE/ESOURCE incorrect
   ERTML/PRTML -- escalator position and angle not consistent with PSOURCE/ESOURCE (see above)
   ERTML/PRTML -- horizontal dogleg into linac tunnel needed (see item above)
   ERTML -- 5 GeV beamline should be further from linac axis than PSOURCE, opp of CFS drawings
   ERTML/PRTML -- 3 dumplines not yet in production

2. **Items Which Must be Checked for Conformity with RDR**

   ERTML/PRTML – straight, curved sections of RETURN line match straight, curved sections of ML/BC
   ERTML/PRTML -- vertical dispersion match in ERETURN/PRETURN
   ERTML/PRTML -- offset of ETURN/PRETURN HDOG and VDOG
   All areas: -- are pulsed extraction lines present?
   -- are aisleways maintained?
   -- do coexisting beamlines fit in same tunnel given expected tunnel diameter?
   -- directions of bending of various arcs

3. **Changes Required for Conformity With Deckmastering Standards**

   All areas -- use common, CALL'ed definitions file to load CM and other common element definitions

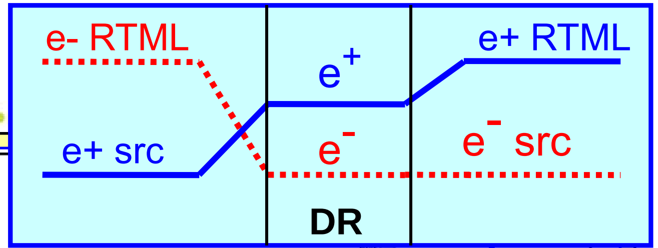
4. **Cost-Neutral, Performance-Enhancing Changes**

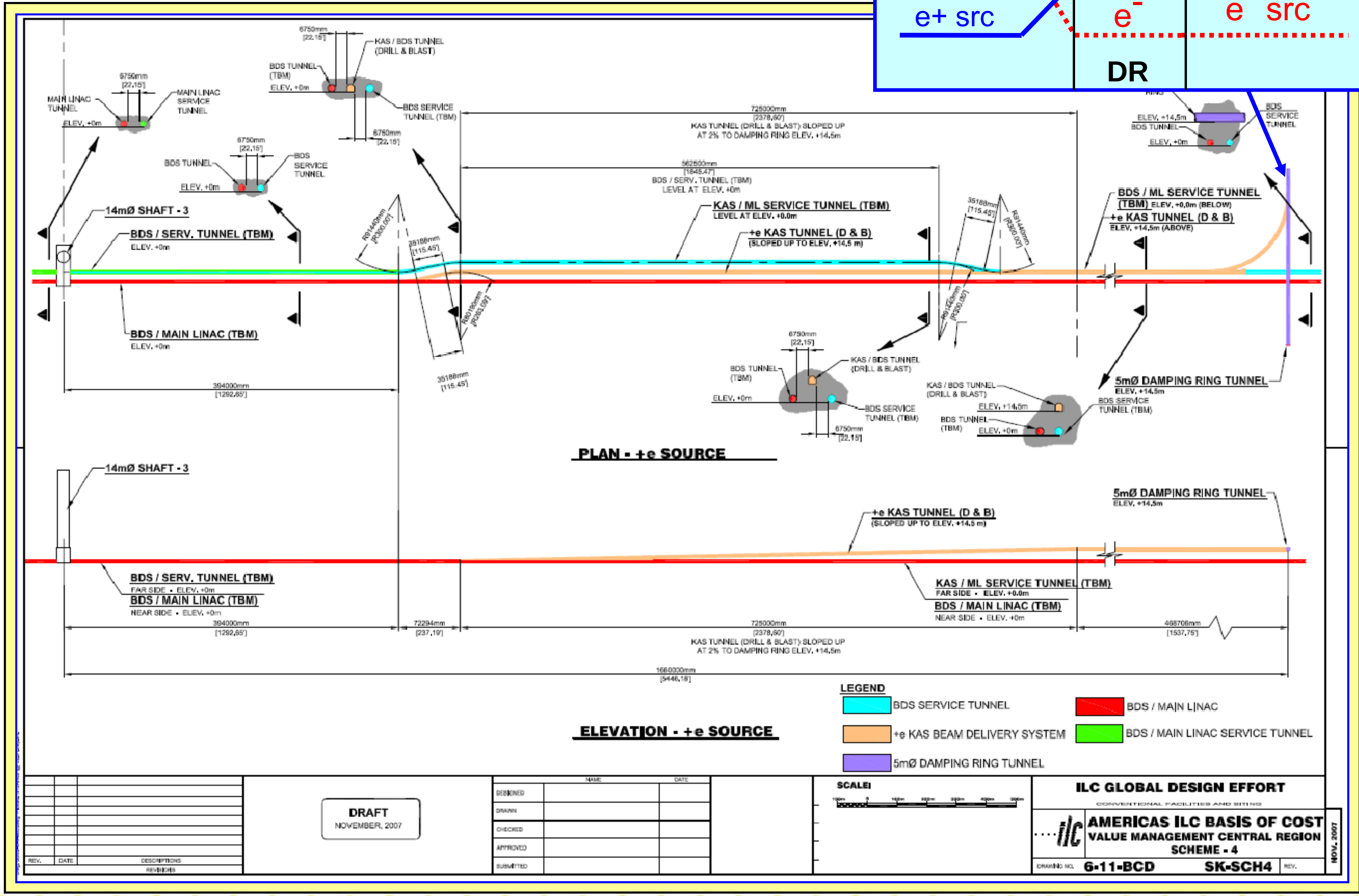
   ERTML / PRTML -- improve beta / eta matching in all areas

5. **Changes which Impact Cost and Performance**

   ERTML/ PRTML -- reduce packing fraction in dense areas to something achievable

RTML Lattice Design





Emittance Preservation (PT, RTML KOM)

Sources of luminosity degradation we've thought about

- **Synchrotron radiation**
  - From DRX arc, turnaround, BC wigglers
- **Beam-ion instabilities**
- **Beam jitter**
  - From DR
  - From stray fields
- **Dispersion**
  - DR extraction
  - Misaligned quads
  - Rolled bends
- **Coupling**
  - DR extraction septum
  - Rolled quads
  - Misaligned bends
  - Quad strength errors in spin rotator
- **Pitched RF cavities (BC)**
  - Produce time-varying vertical kick
- **RF phase jitter (BC)**
  - Varies IP arrival time of beams
- **Beam halo formation**
- **Collimator Wakefields**

Sources we haven't thought enough about

- **Space charge (recent FNAL results)**
- **Resistive wall wakes in vacuum chamber**

Summary of studies done at RDR stage was presented by PT at RTML Kick-Off Meeting, Sept 27-29, 2007.

http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1851

Short Summary

- Synchrotron Radiation
  - Mainly managed by optics design, 0.9 µm emittance growth in x, Vertical bends negligible, Analytic estimates indicate no CSR issues
- Beam-ion instabilities
  - Sets 20 nTorr pressure limit in Return line (Limits jitter growth to 9%)
- Beam Jitter
  - Handled by FF in turnaround and living clean
  - Sets limits on tolerable AC fields in Return line ~ 2 nTesla limit
- Halo formation
  - Sets 100 nTorr vacuum spec downstream of Return line (10^{-6} halo formation)
- Collimator Wakefields
  - Y wakes seem marginal for "razor blade" collimators.
  - Probably OK for tapered collimators
  - Need to revisit this issue! (incl. Resistive wakes of absorbers, etc)
- Dispersion
  - Local correction via steering / orbit control (BBA: BPM,Ycorr in each quad**)**
  - Global correction via normal / skew quads in locations with dispersion
    - DRX arc; Escalator; Turnaround, BC1 / BC2 wigglers

Short summary (2)

- Coupling
  - Global correction via orthonormal skew quads
    - Two decoupling systems: After DRX arc, After spin rotator
- Pitched RF cavity
  - Global correction via BC dispersion knobs
    - YZ coupling (pitch) + ZE coupling (off-crest running) = YE coupling (dispersion)
- How well can we correct dispersion, coupling, cavity pitch?
  - Studies with 2006 optics + Return line OK except for BC1 cavity pitch
    - Can get in the realm of RTML emittance budget (4 nm vertical growth, 90% CL)
  - BC1 cavity pitches blew budget by ~ factor of 2
    - Preliminary result – no attempt to improve upon this was made!
  - Need to revisit in a more complete manner with up-to-date optics
    - Likely to get worse

Will see updates of Emittance simulations on this meeting

WP 3.2: Stray Magnetic Field studies

RTML needs to transport low-emittance 5 GeV beam over ~15 km from DR to ML. Requirement on stray magnetic fields in the RTML is less than 2 nT.

Proposal summary (2years):

- Evaluate possible sources of the stray fields, correlated and uncorrelated with the beam.
- Survey the existing sites to verify assumptions in that analysis (FNAL, DESY, SLAC, CERN)
- If the result of this study would require, propose shielding approach for the beam pipe.
- Develop a stray field model suitable for linac simulation frameworks.

Deliverables:

- A comprehensive analysis of the effects of stray magnetic fields on RTML.
- Design, build and test a low-magnetic field, broadband survey system.
- Survey sites: Fermilab, CERN, SLAC, and other sites representative of ILC environment. The data will be available via WWW.
- Parametrical model of stray magnetic fields for Acc. Physics simulations
- A design recommendation for RTML line, RF system
- Results published in ILC report and presentation at the appropriate conferences

Personnel: Total effort is 0.5 FTE of R&D personnel and 0.25 FTE of support (electronics, mechanics)

Equipment (Magnetometers, PS, amplifiers, cables, GPIB and DAC): ~17k$

Stray Magnetic Fields Studies (cont.)

Previous work

- "Sensitivity to Nano-Tesla Scale Stray Magnetic Fields", published by J. Frisch, T. Raubenheimer, P. Tenenbaum, SLAC, LCC Note-0140 (June 7, 2004)
  - Analysis for NLC
  - Data from SLC (End station B)
  - Conclusion: *we are mostly OK*

- Rough estimation of effects of fast changing stray field in long transport of RTML – "Emittance dilution in Turnaround", K. Kubo, KEK, ILC-Asia-2006-05 October 12, 2006
  - Requirement for high frequency stray magnetic fields (estimation): rms B < 2 nano-Tesla (ILC RDR)

Stray Magnetic Fields (2)

Magnetic field examples

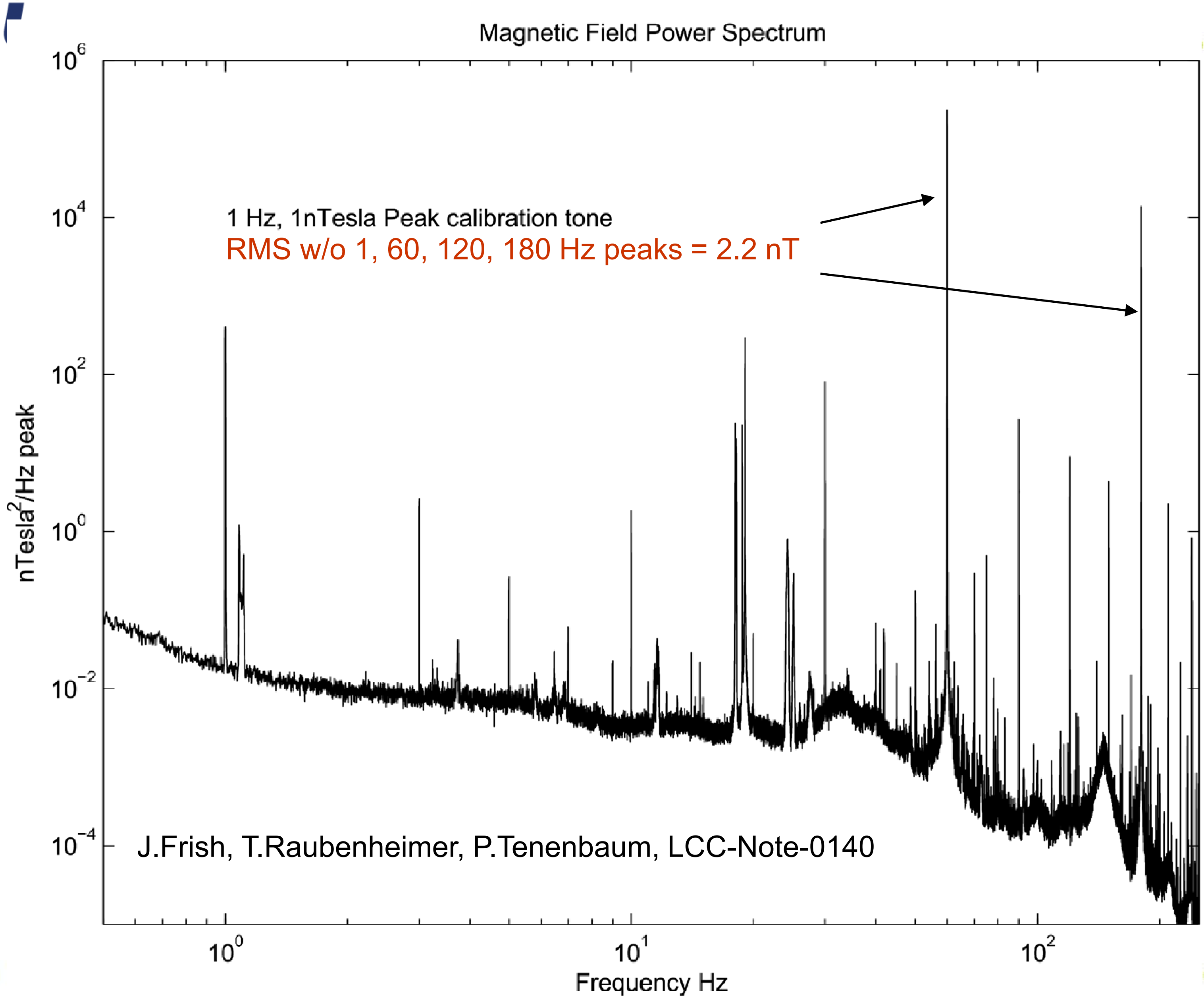
- Commercial SC solenoid – **10 Tesla (1 e+1)**
- Earth magnetic field – **50 micro-Tesla (5 e-5)**
- Cell phone – **100 nano-Tesla (1 e-7)**
- ILC-RDR requirement – **2 nano-Tesla (2 e-9)**
- Beating human heart – **~ 10 pico-Tesla (1 e-11)**

Frequency dependence

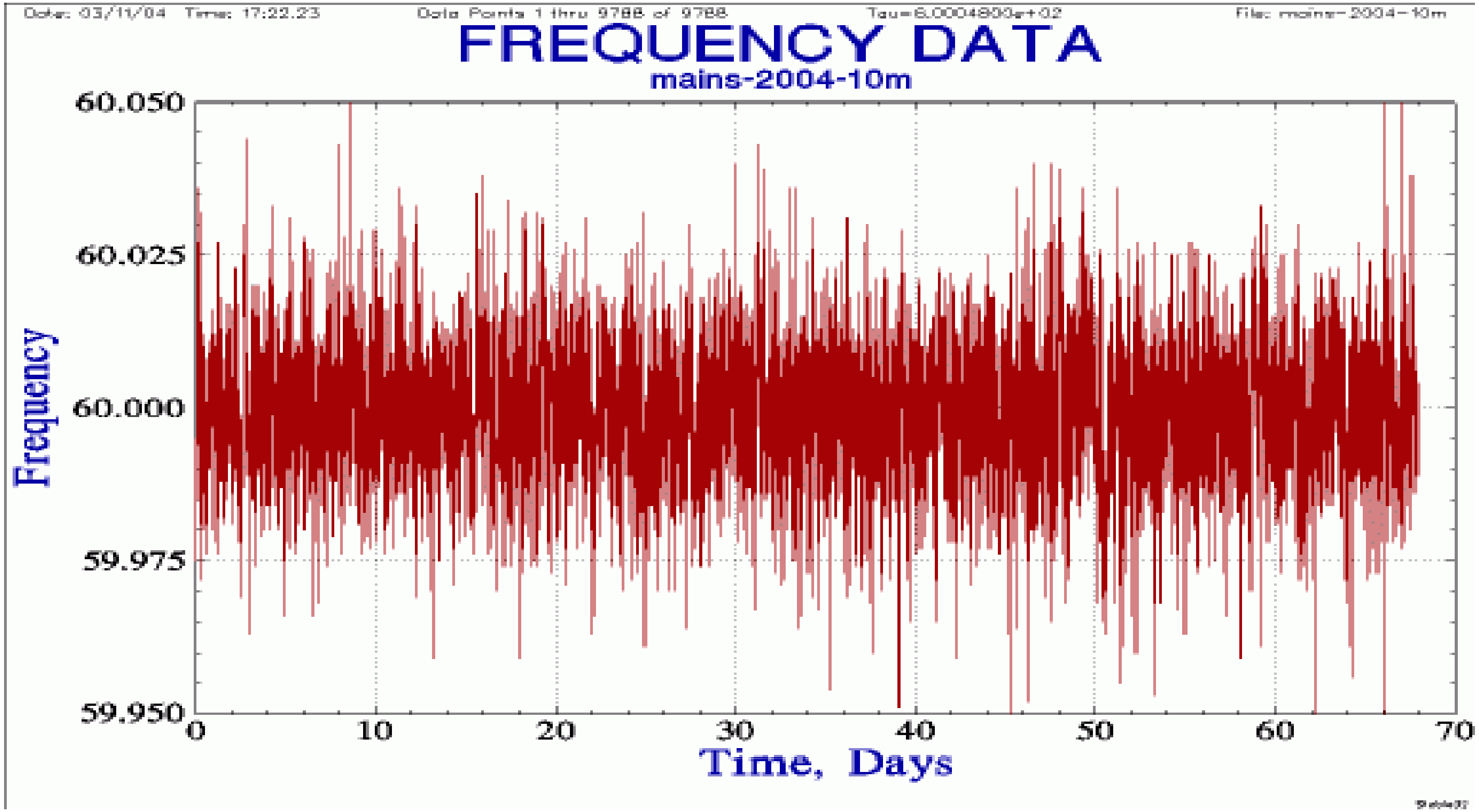
- < 0.1 Hz (can be compensated by control system)
- > 100 kHz (attenuated in the structure)

Classification (following F.R.T.)

- 60 Hz and its harmonics (near-coherent with 5-Hz pulsing)
- Fields from RF systems (coherent with 5-Hz pulsing)
- Others (non-RF technical sources) (uncorrelated with pulses)

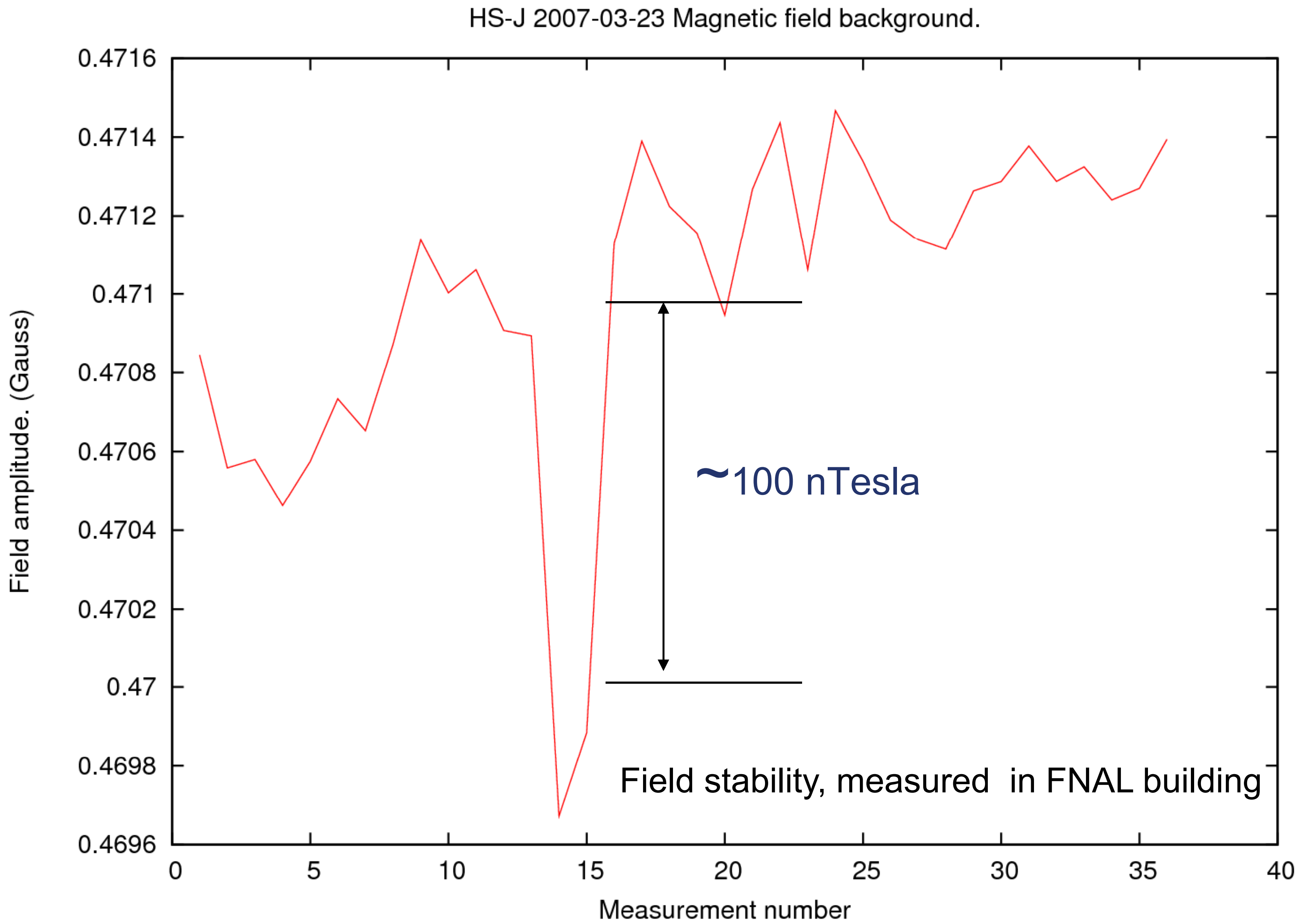

Magnetic Field Power Spectrum
1 Hz, 1nTesla Peak calibration tone
RMS w/o 1, 60, 120, 180 Hz peaks = 2.2 nT
J.Frish, T.Raubenheimer, P.Tenenbaum, LCC-Note-0140
nTesla²/Hz peak
Frequency Hz
10^6
10^4
10^2
10^0
10^-2
10^-4
10^0
10^1
10^2

Frequency 60 Hz



A 1-second frequency sample was taken every 10 minutes.

Tom Van Baak: http://www.leapsecond.com

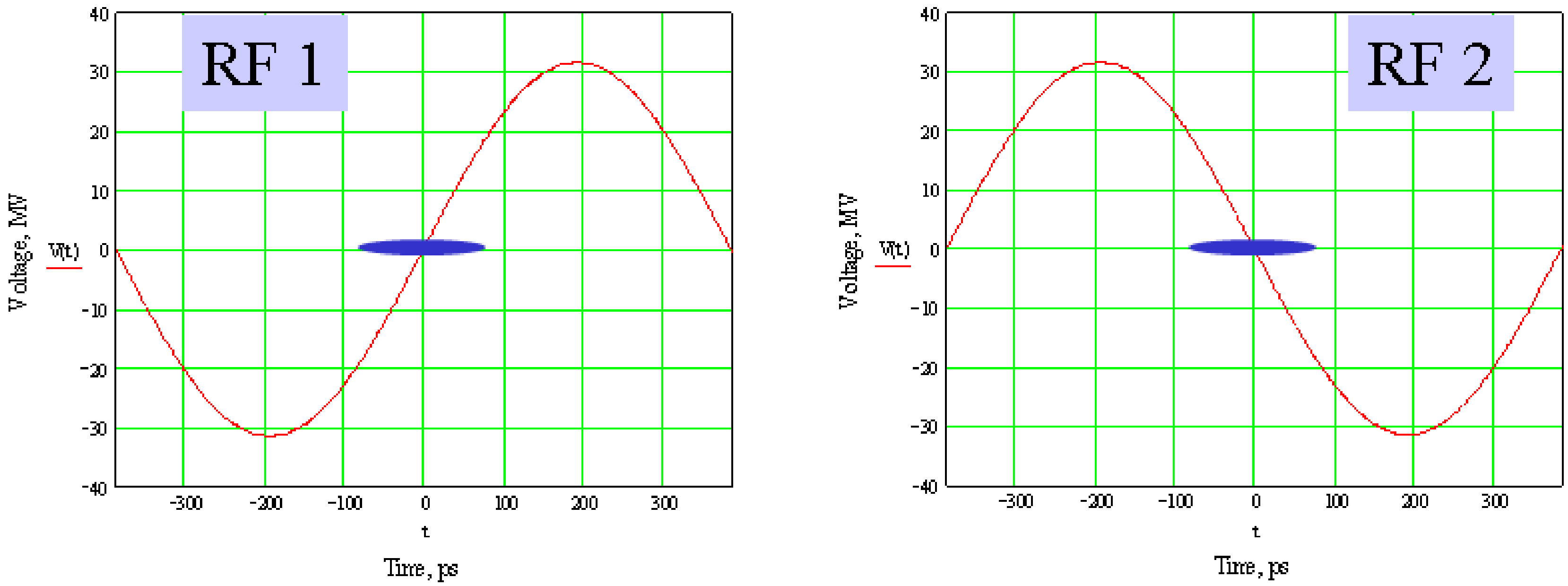

HS-J 2007-03-23 Magnetic field background.
Field amplitude. (Gauss)
0.4716
0.4714
0.4712
0.471
0.4708
0.4706
0.4704
0.4702
0.47
0.4698
0.4696
0
5
10
15
20
25
30
35
40
Measurement number
~100 nTesla
Field stability, measured in FNAL building

WP4: R&D on Phase and amplitude stability

- It is proposed to make direct measurements of the phase and amplitude stability of the RF system of the TTF-2 operating close to zero crossing.
- The required tolerances for amplitude and phase stability in BC are very tough:
  - Phase stability tolerance: 0.25°/0.16° rms @1.3 GHz –long/short bunch
  - Amplitude stability tolerance: 0.5%/0.35% rms – long/short bunch
- Bunch compressor RF cavities operate close to zero-crossing:
  - Phase 105° off-crest (first stage), beam decelerates
  - Phase 27.6° off-crest (second stage)
- The gradient in the RF system ~30 MeV/m. The beam loading in the RF system operating close to zero crossing is primary reactive. In this case the LLRF feed-forward system may operate in quite different regime than for acceleration.
- TTF2 measurements will allow to check whether existing LLRF system meets the RF phase/amplitude stability requirements for the beam near zero-crossing
- The beam energy after pre-accelerator is 40 MeV

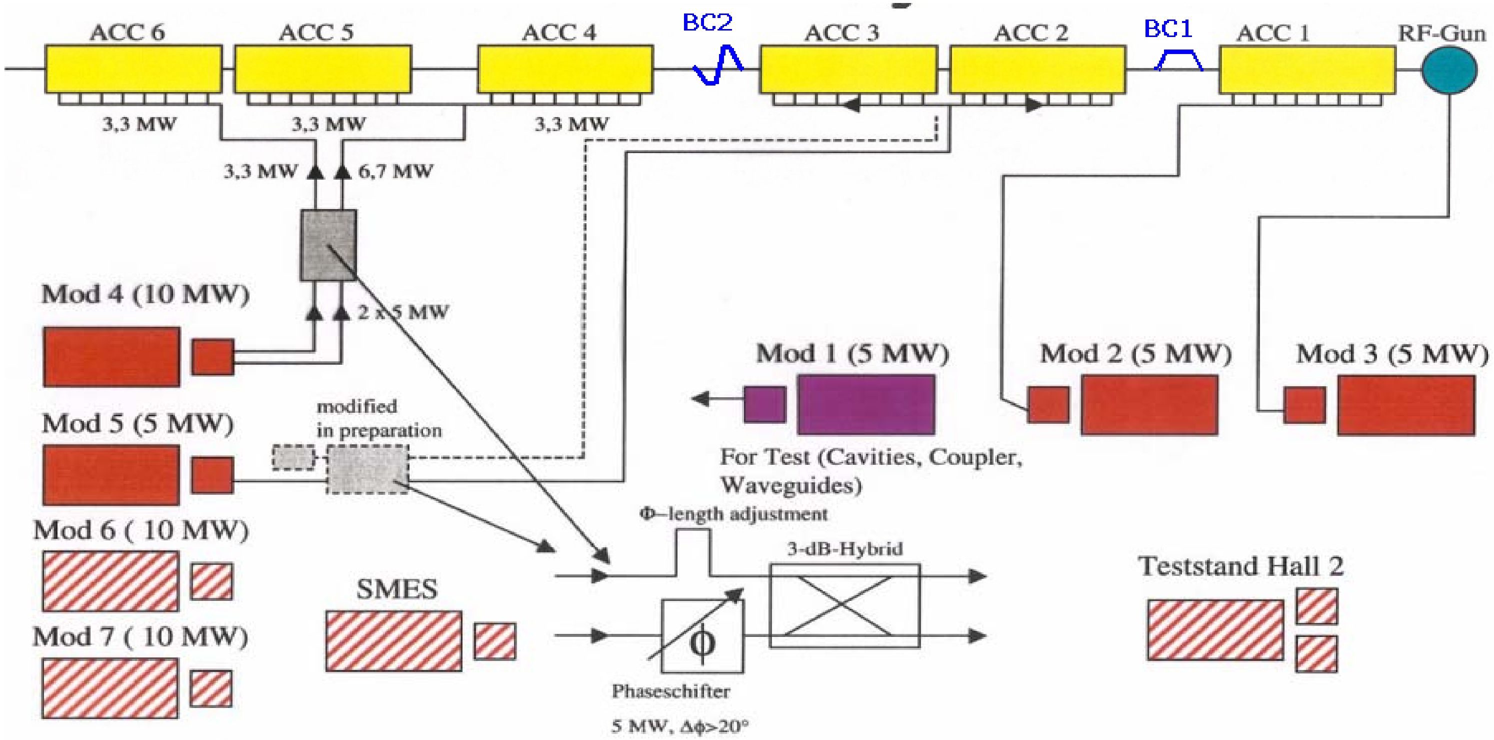
Experiment schematic at DESY

- Use the two cryo-modules, fed by separate klystrons in counter-phase to exclude bunch arrival jitter, caused by the laser, RF gun and pre-accelerator (T.Himel, PT)



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

TTF-2 RF System



- Use ACC3 and ACC4 (AAC2, ACC5, and ACC6 are detuned), excited with the same amplitude, but in counter-phase, adjusted for a beam near zero crossing;
- Other regime: (ACC2+ACC3) and (ACC4+ACC5). Better resolution
- Dipole magnets of the BC2 are to be switched off (re-adjust beam optics)
- The beam energy fluctuations caused by RF amplitude/phase instability will be determined by measuring of the beam transverse position by stripline BPMs after ACC6, where dispersion is high enough.

Location of the beam position monitors

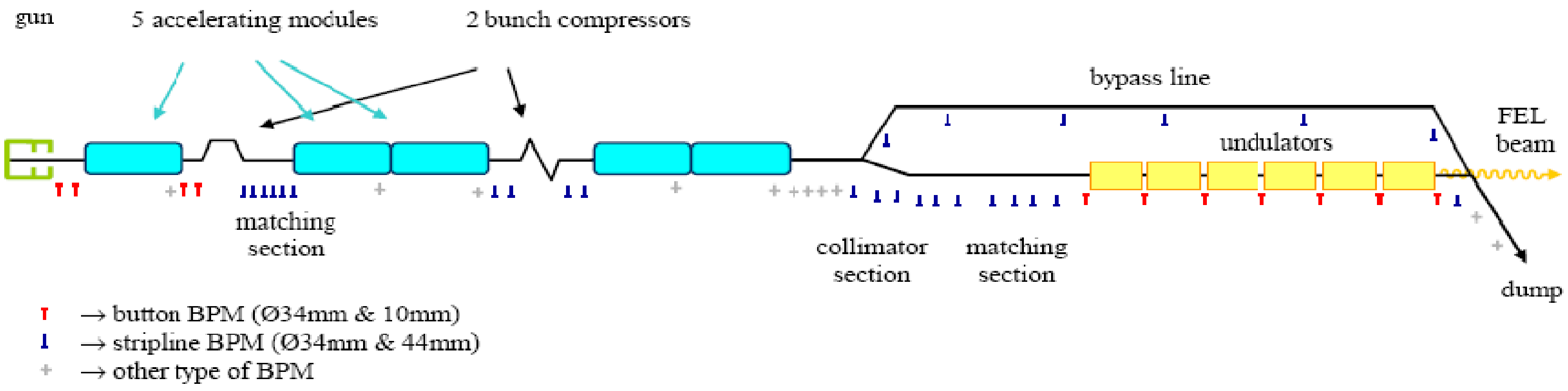
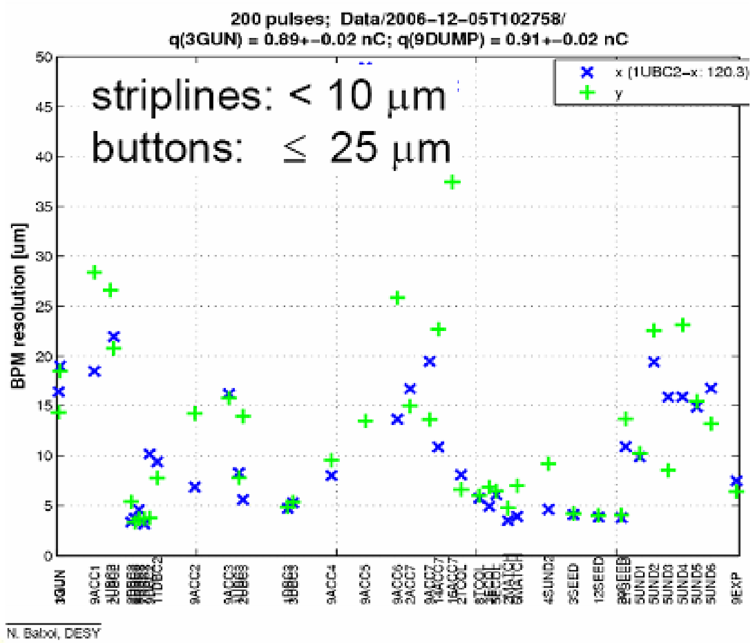


Figure 1: Schematic of the FLASH facility and of the BPM types built in

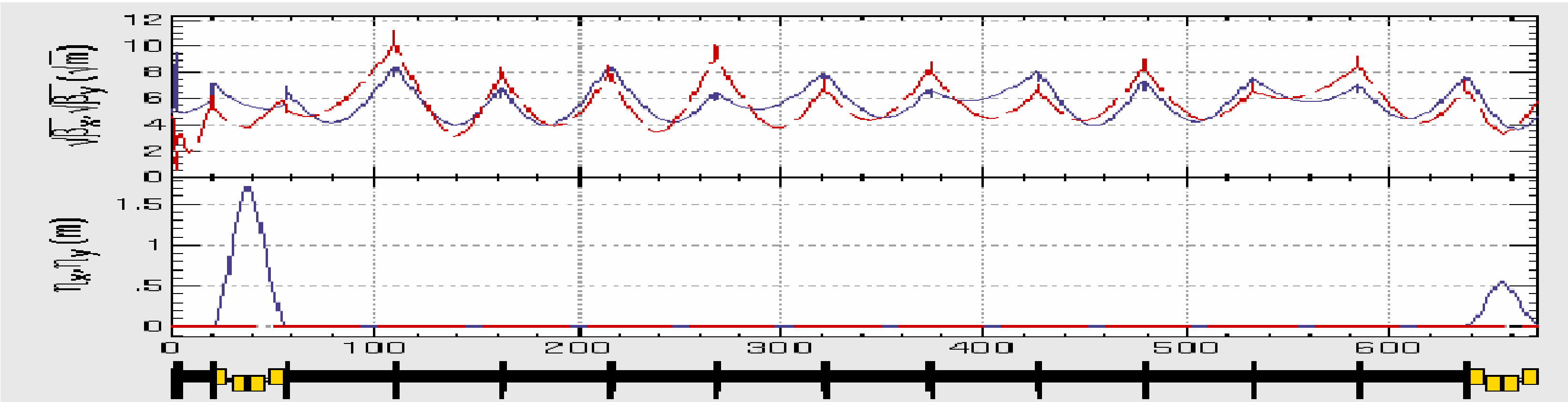
For Eacc= 23 MeV/m

- Phase error 0.25º ➔ ~0.6 % in beam energy
- Ampl. error 0.5 % ➔ ~0.7 % in beam energy
- If dispersion near the BPM ~2mm ➔ 12-15 μm beam transverse position change
- Stripline BPM resolution better than 10 μm:



WP5: Alternative Bunch Compressor

- **An alternate bunch compressor design exists**
  - **6-cell wigglers (~150 m each, 102 bend magnets) replaced by chicanes (~40 m each, 4 bend magnets) – (En-san Kim)**
  - **Advantages – Shorter, Simpler, Cheaper (?)**
  - **Disadvantages:**
    - Big x offset from straight line (~1.8 m)
    - Doesn't have natural locations for dispersion tuning quads
- **Need carefully evaluate the two existing BC schemes**
  - **Maybe neither one is optimal?**



Summary

- Emittance preservation in RTML is one of the major risks for delivering luminosity in IL

- EDR Working packages are aiming to solve most critical issues to reduce risk, improve performances and reduce cost by better design, simulations, value engineering, needed R&D program.

- WP's related to RTML Lattice design, Accelerator Physics simulations and R&D programs are in a few groups: RTML, Lattice integration, Acc. Physics Simulation Groups. We need good collaboration and communication between to achieve EDR goals.