“Workshop on Linac Operation with Long Bunch Trains” Summary

Feb.22,2010-Feb.24,2010

Shin MICHIZONO (KEK)

Working Groups

- Working Group #1:
  FLASH setup, tuning, and operation
  - **Leaders: B. Faatz, J. Carwardine**
- Working Group #2:
  FLASH feedback and control
  - **Leaders: H. Schlarb, V. Ayvazyan**
- Working Group #3:
  ILC studies at FLASH
  - **Leaders: N. Solyak, S. Michizono**
- Working Group #4:
  DAQ and data analysis
  - **Leaders: T. Wilksen, N. Arnold)**

ILC Goals for FLASH

Marc Ross
Nick Walker
Akira Yamamoto
ILC GDE Project Managers

Highest priority goal:

- ***<u>to demonstrate beam phase and energy stability at nominal current</u>***

- (including a test of beam based feedbacks),
- This can only be done at the DESY-based main linac beam test facility TTF / FLASH
  - Until late 2012
  - ~2013 → Fermilab 'NML' test facility and KEK 'STF' begin beam operation

Secondary goals,

- which have impact on the cost of the ILC:

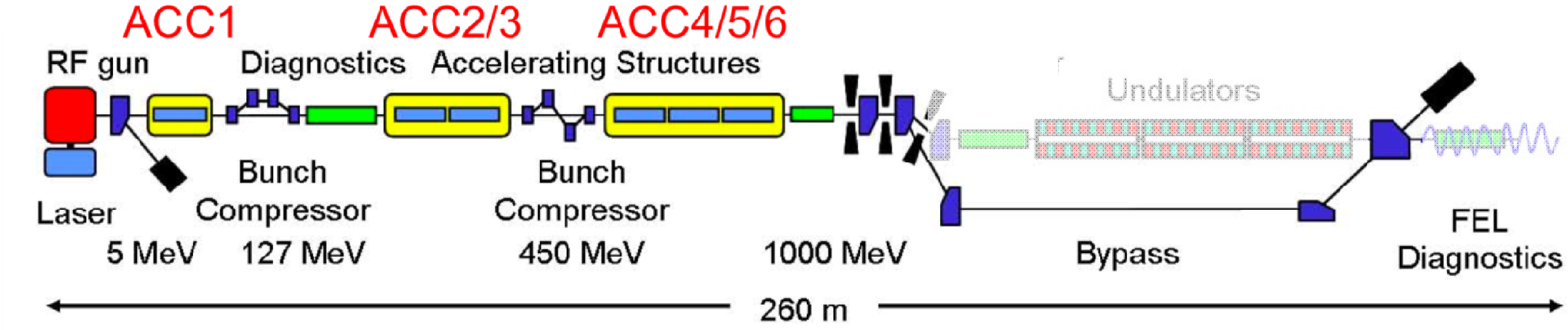
1. demonstrate ***operation of a nominal section*** or RF-unit,
2. determine the ***required power overhead*** under practical operating conditions,
3. to measure ***dark current*** and x-ray emission
   – (to be used to establish precise radiation dose-rate limit vertical test acceptance criteria),
4. and to check for heating from ***higher-order modes*** in order to determine the ***dynamic cryogenic heat load*** with full beam current operation.

Status of Long Bunch Trains in FLASH
(goals for the workshop)

Nicholas Walker

Workshop on Linac Operation with Long Bunch Trains
February 22nd, 2010

TTF/FLASH 9mA Experiment



		XFEL X-Ray Free-Electron Laser	ilc	FLASH design	FLASH experiment
Bunch charge	nC	1	3.2	1	3
# bunches		3250*	2625	7200*	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9

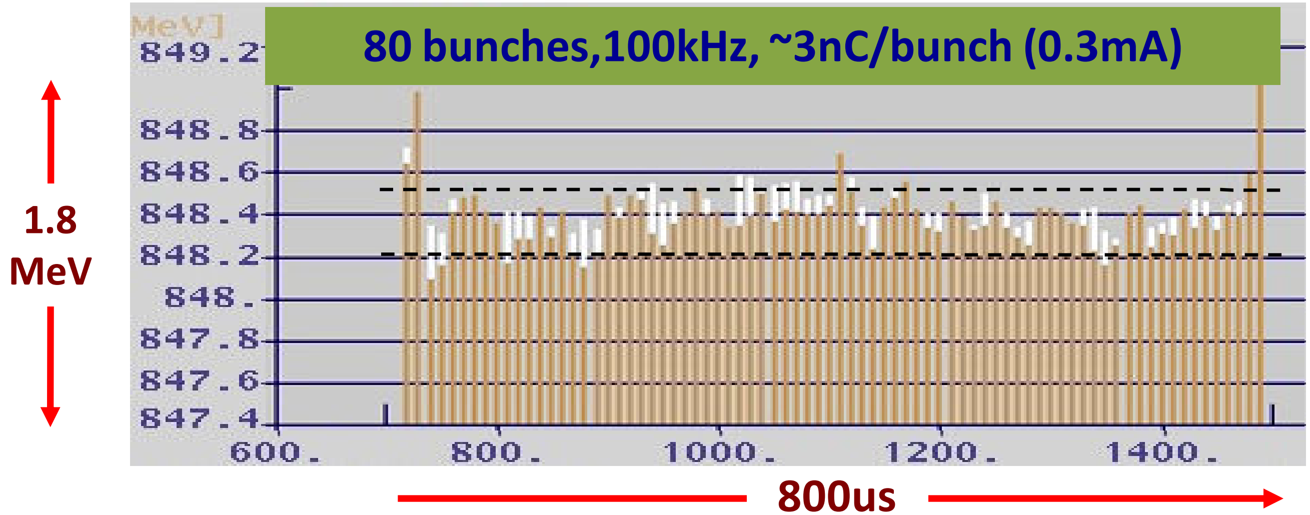
Major achievements

Metric	Goal	Achieved
Bunches per pulse	800 x 3nC (1MHz)	800 x 3nC
	2400 x 3nC (3MHz)	1800 x 3nC 2100 x 2.5nC ~2400 x 2nC
Charge per pulse	7200nC @ 3MHz	5400nC @ 3MHz
Beam power	36kW (7200nC, 5Hz, 1GeV)	22kW (5400nC, 5Hz, 800MeV)
Gradients close to quench	Up to 32Mv/m	Several cavities above 30Mv/m at end of long pulse

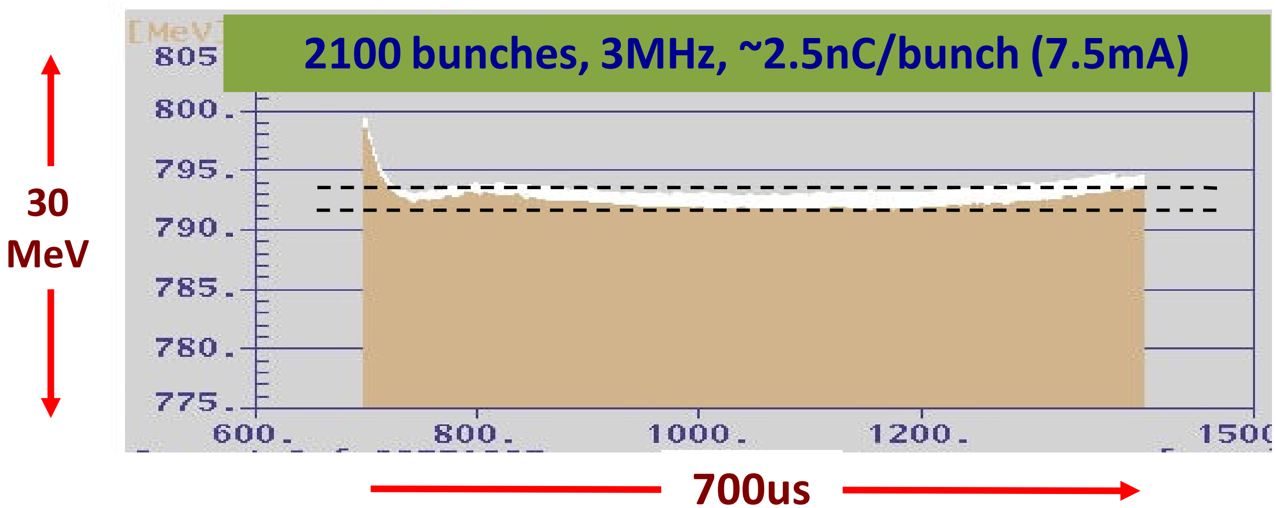
- 15 contiguous hours running with 3mA and 800us bunch trains
- Running at ~9mA with bunch trains of 500-600us for several hours
- Full pulse length (800us, ~2400 bunches) at ~6mA for shorter periods

- Energy deviations within long bunch trains: <0.5% p-p (7mA beam)
- Energy jittter pulse-pulse with long bunch trains: ~0.13% rms (7mA)

Energy deviation along bunch train (examples)



Along pulse: 0.035% p-p



Along pulse: 0.5% p-p
Pulse-pulse: 0.13% RMS

(Rev)

FLASH Long-train Workshop

WG3 Summary

Nikolay Solyak, Shinichiro Michizono

ILC 9mA test: Where we are with accomplishments on this list?

- Long-pulse high beam-loading (9mA) demonstration
  - 800μs pulse with 2400 bunches (3MHz) close to √
  - 3nC per bunch √
  - Beam energy 700 MeV ≤ E_{beam} ≤ 1 GeV √
- Primary goals
  - Demonstration of beam energy stability (ΔE/E < 0.1%). X
    - Over extended period X
  - Characterisation of energy stability limitations Partially done
    - Operations close to gradient limits X
  - Quantification of control overhead X
    - Minimum required klystron overhead for LLRF control X
  - HOM absorber studies (cryoload) Partially done
  - …

- It has been a major challenge for FLASH
  - Pushes many current operational limits

WG3 Agenda, Feb.23,2010

Session 1: HOM absorbers

- HOM absorber studies - J. Sekutowicz (*DESY*)
- Study of absorber effectiveness in ILC cavities – C.Adolphsen,K.Bane

Session 2: Cavity and klystron overhead

- Results on beam loaded experiments @ FLASH - (C.Adolphsen , S.Pei)
- Results of high-gradient study S.Michizono (*KEK*)
- High gradients with 9mA beam – J.Branlard (*FNAL*)
- Consideration on ILC SCRF Cavity Gradient and the Operational Margin A. Yamamoto (KEK/GDE)

Session 3: WG2+3: LLRF experience from 9mA studies (WG2)

Session 4: WG2+3 (WG3 agenda)

- Study of stability requirements for ILC BC(beam off-crest) N. Solyak ,FNAL
- Comparison between ILC spec. and FLASH 9mA study - B.Chase (*FNAL*)
- Future works for long-pulse high beam loading demonstration –G. Cancelo (*FNAL*)

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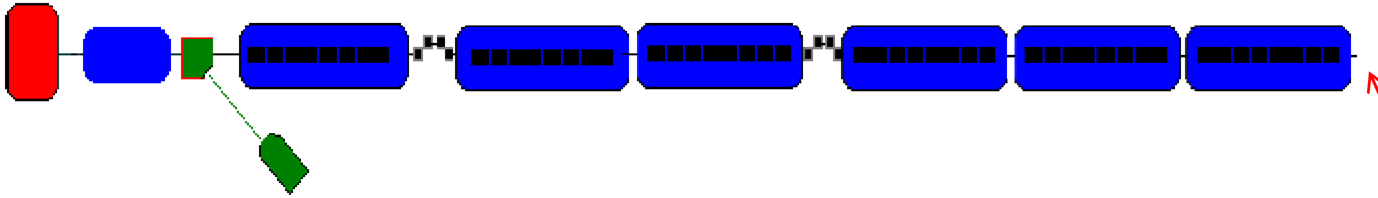
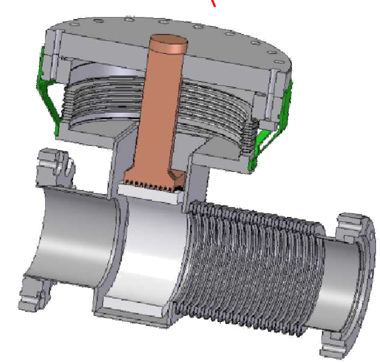
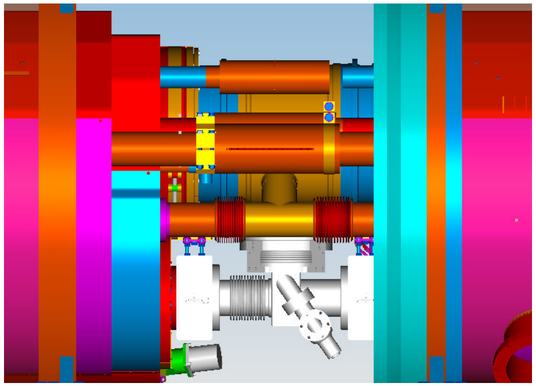


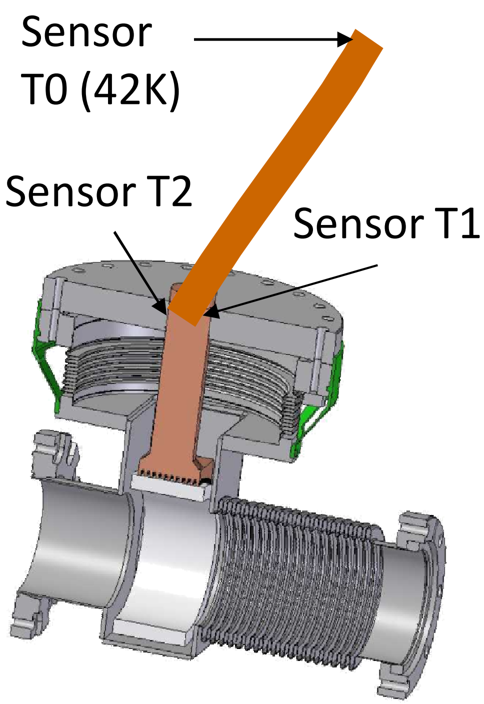
Beam Line Absorber tests at FLASH

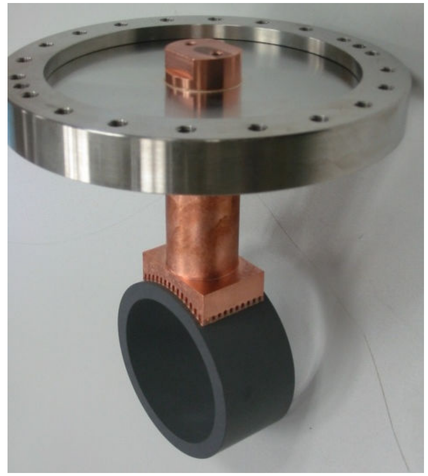


J. Sekutowicz
DESY

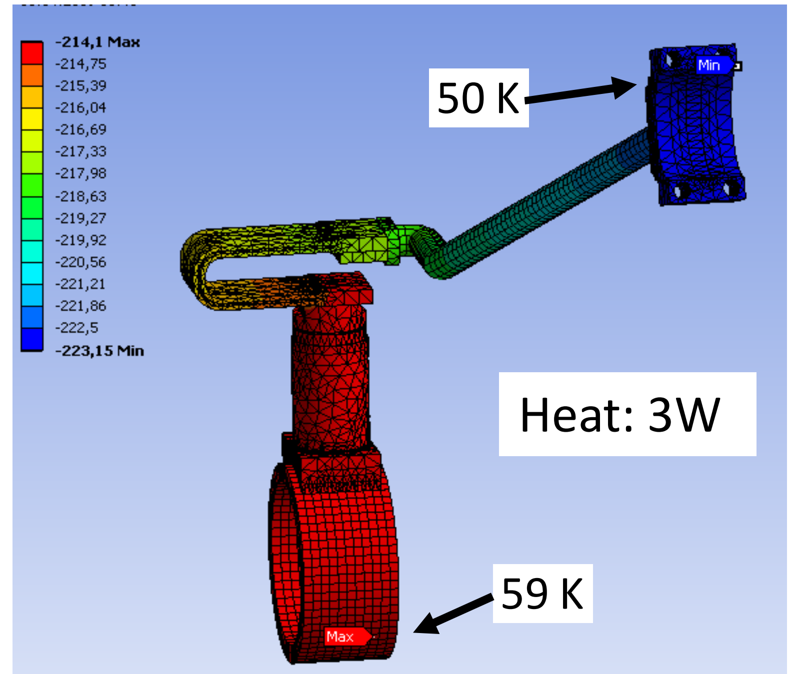


Beamline Absorber

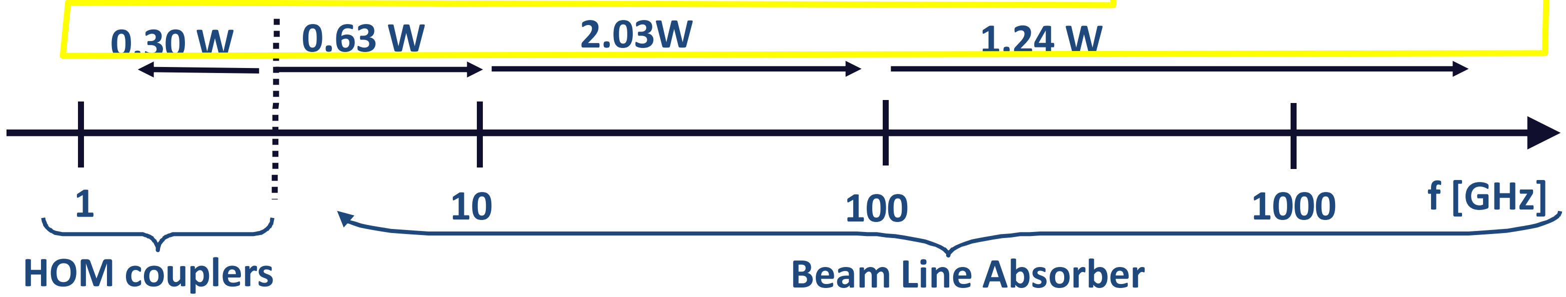




Lossy ceramic
CA137 (Ceradyne):
ε´ =15 and ε´´ =4

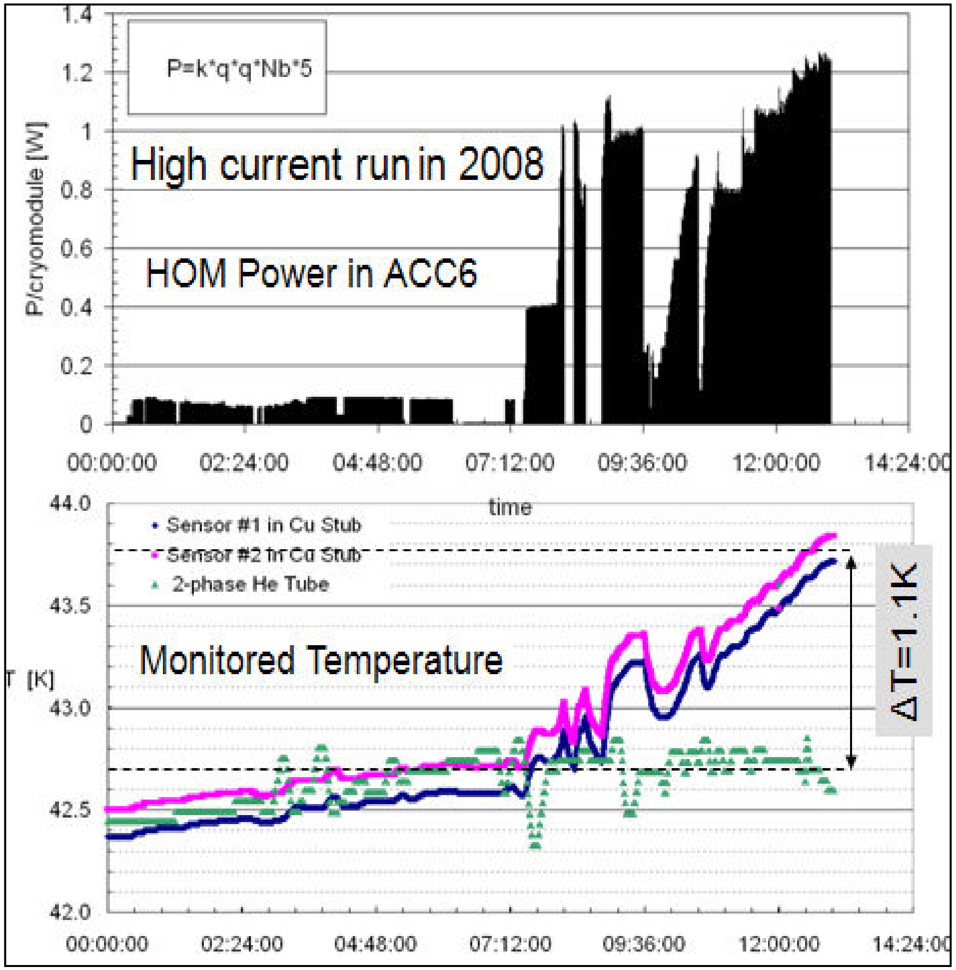


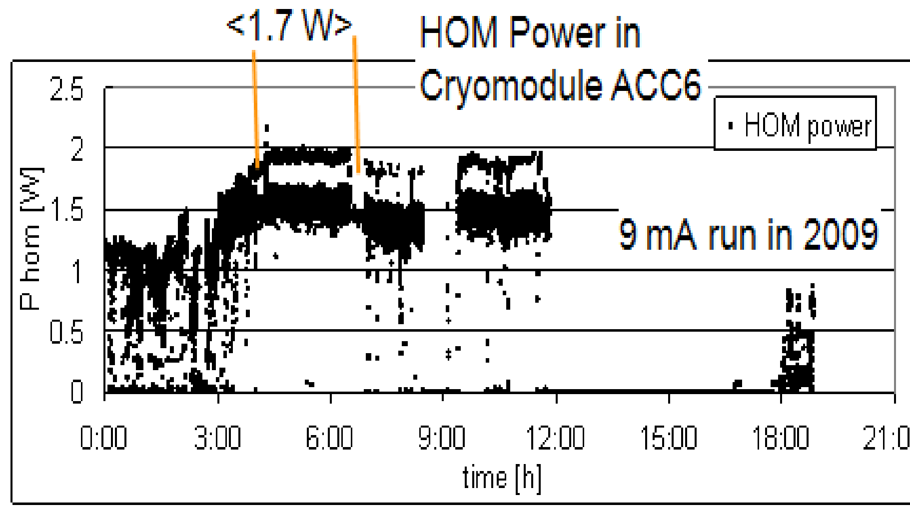
ILC beam (3.2nC & 3MHz & σ_z = 300 μm & 0.4% DF): 16.7 W/cryomodule
XFEL beam (1nC & 4.5 MHz & σ_z = 25 μm & 0.6% DF): 4.2 W/cryomodule

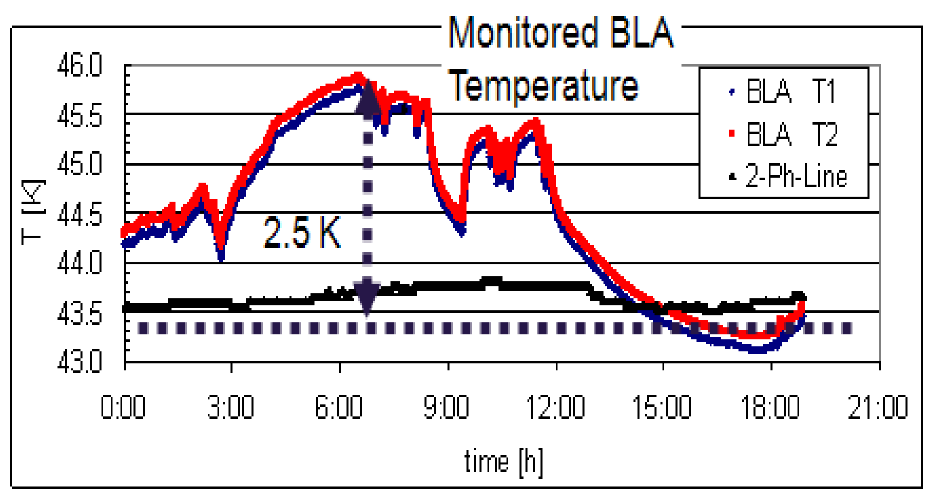


European XFEL

Tests in September 2008 and 2009







Tests in Sept. 2008 and 2009 & Plans.

Results of two tests at FLASH (at ~2 mm bunch length)

	September 08	September 09
Computed Absorbed Power [W]	0.180	0.255
Measured Absorbed Power [W]	0.143	0.325

- In two tests we observed absorption of the high frequency HOMs
- The amount of HOM power was close to the calculated power
- Fabrication of new prototypes is in progress
- Thermal connection to 70 K (40K) has been designed for XFEL
- Mechanical support needs to be designed soon.

Proposals for further studies

- Measure at shorter bunches (1mm, 0.6mm)
  - need ~few hours stable bunch to reach steady-state
- 2.2 MHz, 800 bunches, 1.5nC, short bunches for lasing is good regime for HOM studies.
- More BLA is desired

Study of Absorber Effectiveness in the ILC Main Linacs

Goal:

Compute the HOM monopole losses in the 2K NC beam pipe relative to the losses in the 70 K beamline absorbers.

Procedure:

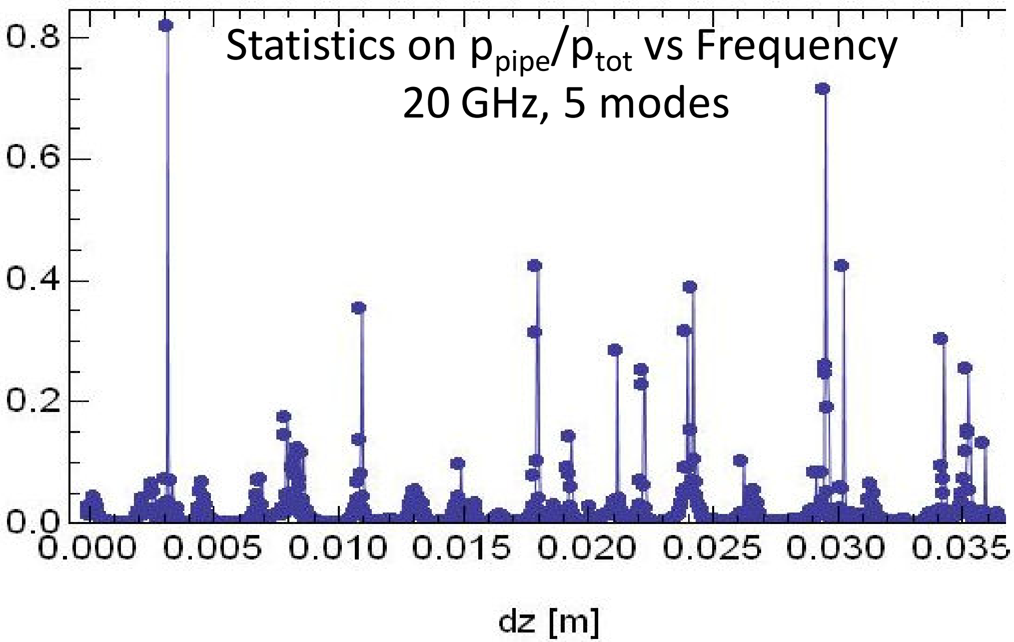
For select frequencies, TM0n modes and cavity spacings, compute relative power losses in a periodic system of cryomodules to assess probability that the beam pipe cryoload is significant due to 'trapped' modes. At worse, such losses would double 2K dynamic load as the HOM power above cutoff is of the order of the 1.3 GHz wall losses.

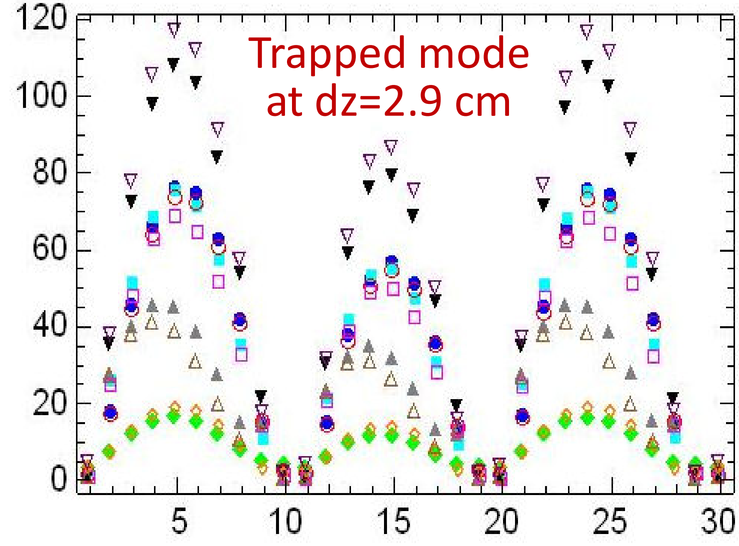
K. Bane, C. Nantista and C. Adolphsen

SLAC, Feb 23, 2010

Statistics on p_{pipe}/p_{tot} vs Frequency

Model for losses: 1 BLA per CM, nc copper plated bellows between cavities





Field vs. number of object number

f [GHz]	average	rms	.90 quantile
4	.041	.037	.070
8	.006	.005	.011
12	.014	.030	.025
16	.024	.056	.047
20	.025	.053	.053

Summary

Method provides a quick, worst-case estimate of relative losses with different absorber configurations - cavity losses (walls, HOM ports and power couplers) are not included.

Find low probability for trapped modes that produce significant (> 10%) losses in 2K beam pipe versus absorbers. Is the average loss over dz the relevant quantity ?

Should redo with a more realistic beamline model, more frequencies and non-uniform cavity spacings.

WG3 Agenda, Feb.23,2010

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Consideration on

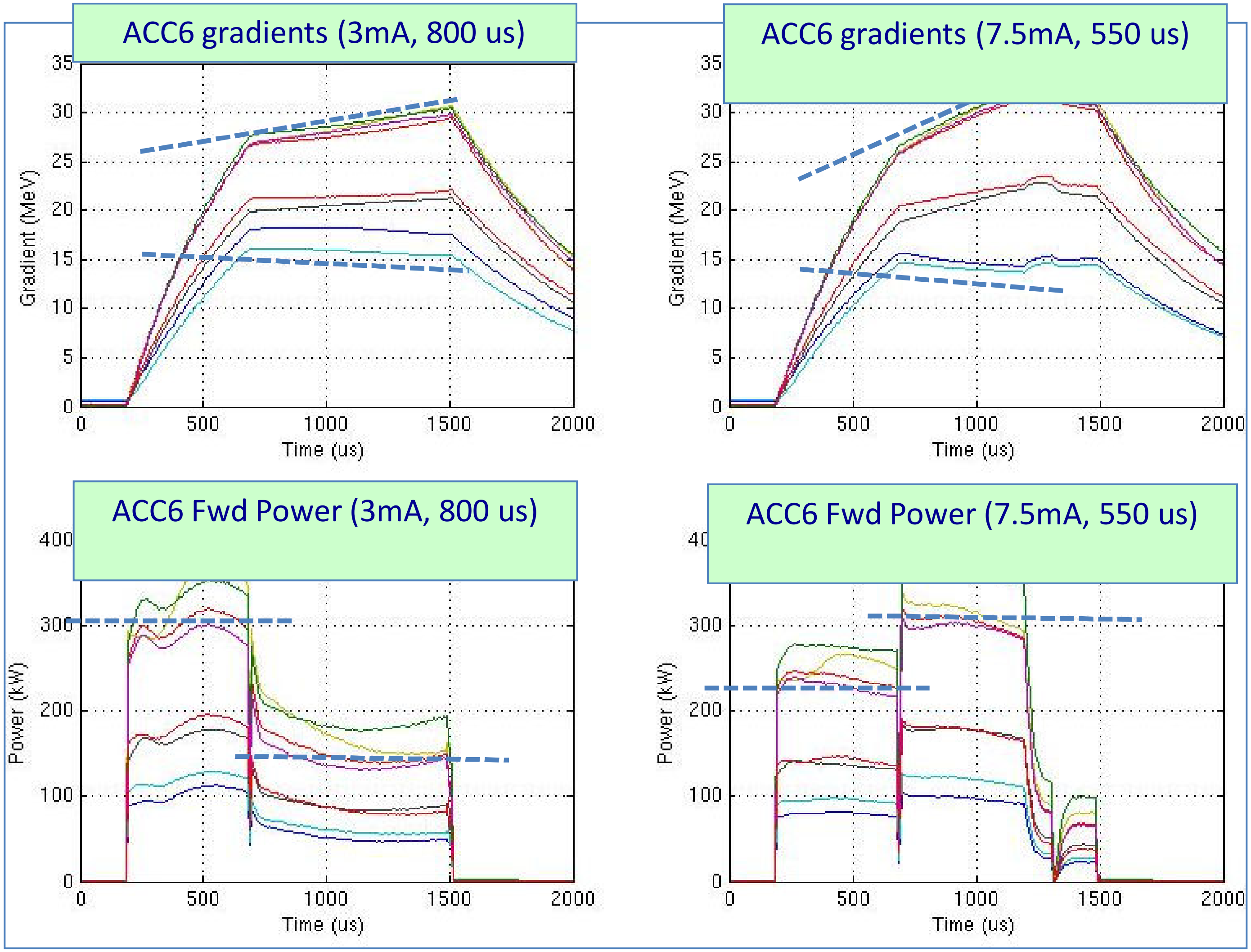
ILC SCRF Cavity Gradient
and the
Operational Margin

Akira Yamamoto
(KEK/ILC-GDE)

Presented at FLASH-9mA Workshop
Held at DESY, Feb. 22-24, 2010

From Nick’s talk on Feb. 22:

Cavity tilts with long bunch trains and heavy beam loading (3mA and 7.5mA, long bunch trains)



Gradient tilts are a consequence of using a single RF source to power cavities running at different gradients

At 7.5mA, ACC6 cavities #1 and #2 approached their quench limits at the end of the pulse

The RF power during flat-top is higher than the fill power for the 7.5mA case

Re-evaluation of Field Gradient

Important, optimum balance for 'Gradients'

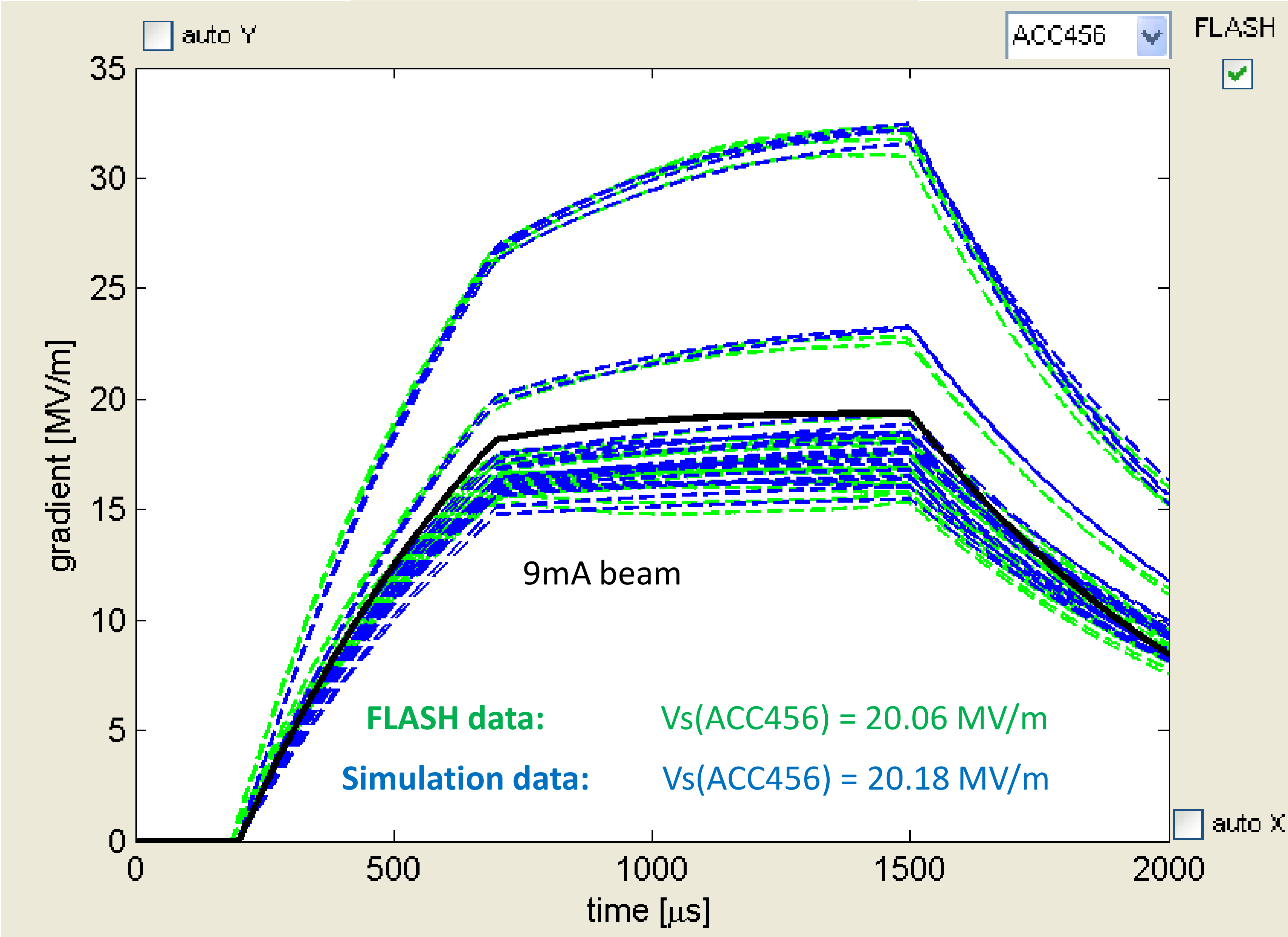
- In Construction(in acceptance) and Accelerator Operation
  - Cavity > Cryomodule > ILC Cromodule string
    - For example: 1 > 0.95~xx > 0.9~xx
  - Spread of Gradient
    - To be optimized in balance of RF distribution efficiency
  - Operational Margin
    - Cavity (itself) operational margin in terms of field/field-emission/cryogenics-load
    - LLRF tune-ability/operational margin or overhead
      - Expect S2 R&D: critical with FLASH (only by 2012)
- Much effort for re-evaluation required

High Gradient Operations with 9mA Beam Loading

analyzing FLASH data from Sept. 09 test

Julien Branlard, Gustavo Cancelo, Brian Chase

Workshop on Linac Operation with Long Bunch Trains – DESY – Feb. 22-24 2010



FLASH data from **Sept. 21st 2009**, 2:50 am

High Gradients with 9mA Beam : Summary

- Simulation tool was validated with Sept. 09 DAQ data
- Using simulations, a machine tuning optimization scheme (Q_L's P_K's) was proposed to achieve higher operating gradient while preventing cavity quench
- Reiterate analysis with new power distribution at FLASH (ACC6 & 7)
- Come up with a similar proposal for next high-beam test
- Benefits:
  - **Flat gradients**, especially for high gradient cavities
  - **Higher vector sum** gradient, even for high beam current
  - Better understanding of **power overhead**
  - Better understanding of **cavity tuning** and **LFD**

Analysis of the Sept 09 Beam On Cavity Gradient Stability Data

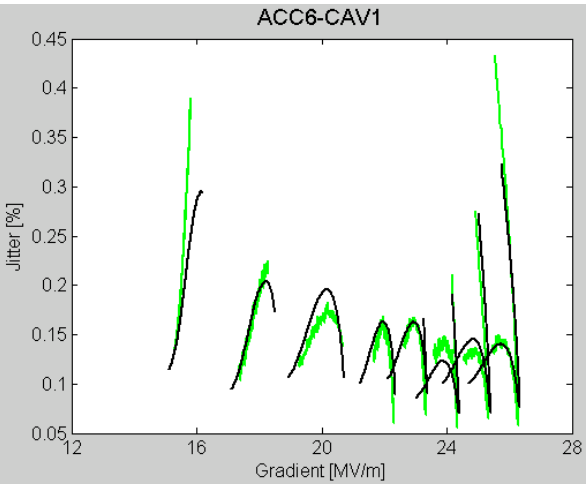
Shilun Pei, Chris Adolphsen

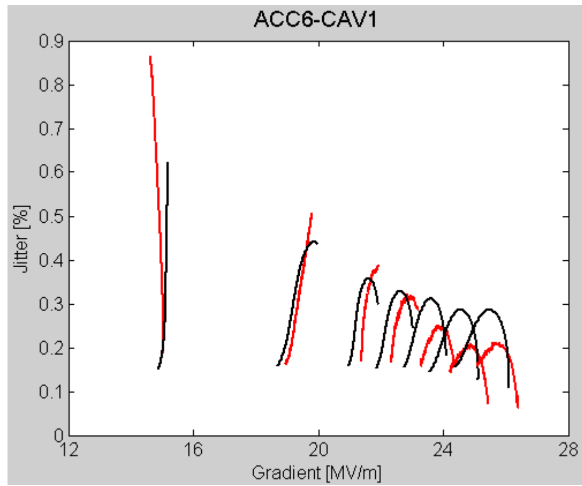
Feb 22, 2010

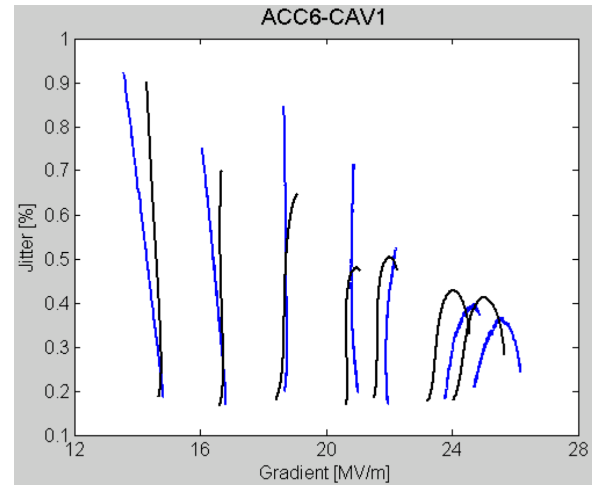
Cavity Gradient Stability

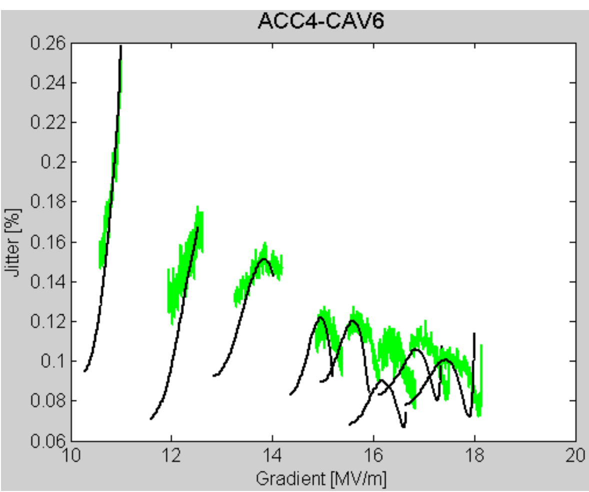
January 2009 Measurement

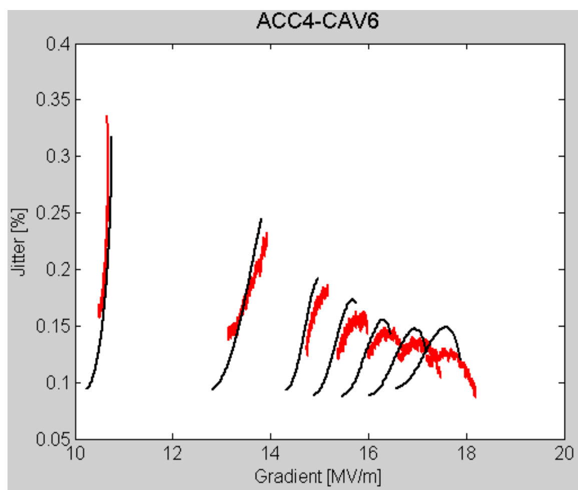
Comparison of beam-off measurements of pulse-to-pulse cavity gradient jitter during the flattop period for different gradients and initial cavity detuning (green, red and blue lines) to a cavity fill model including Lorentz force detuning (black lines) with two degrees of freedom (initial and initial rms detuning)

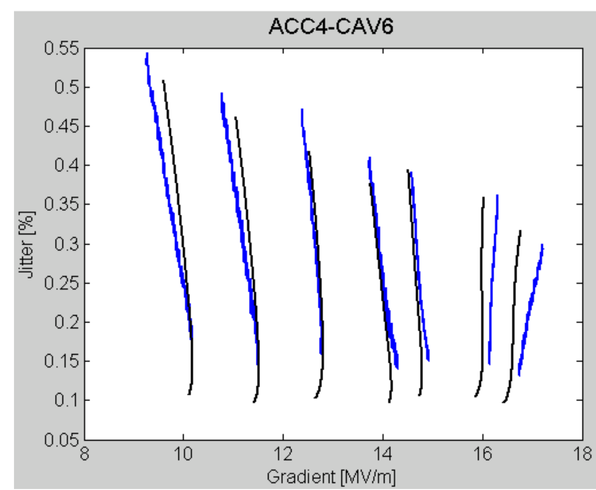








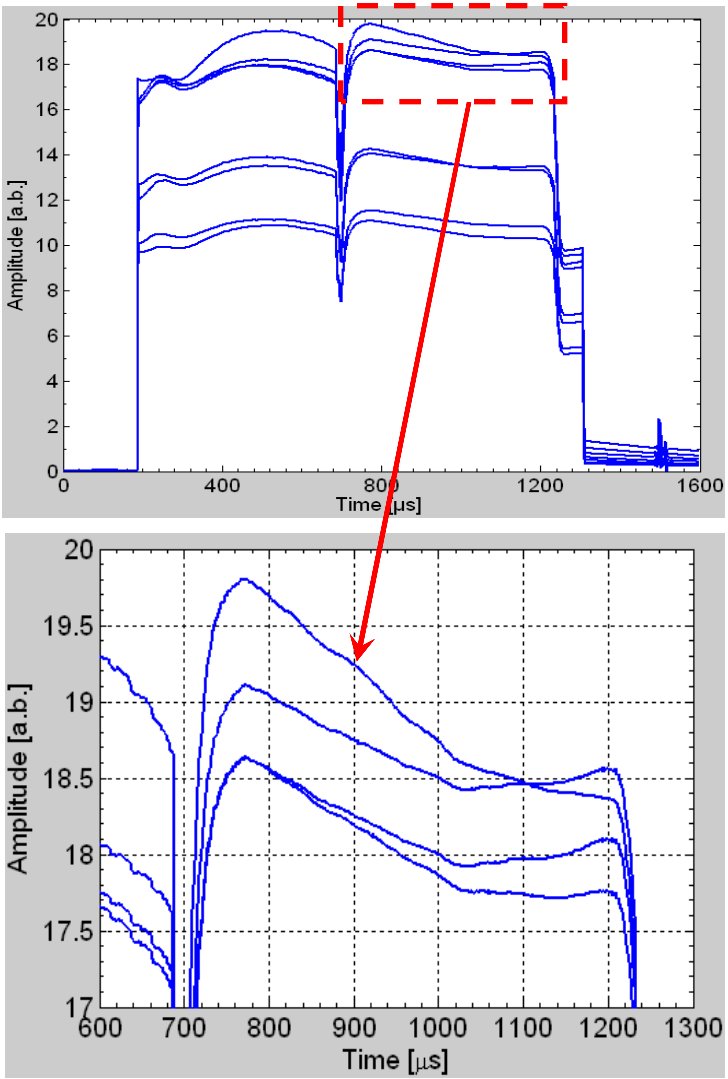




RF Power Overhead Issue

September 2009 Measurement

Cavities in ACC6 with piezo off
3MHz/3nC beam with 1600 bunches



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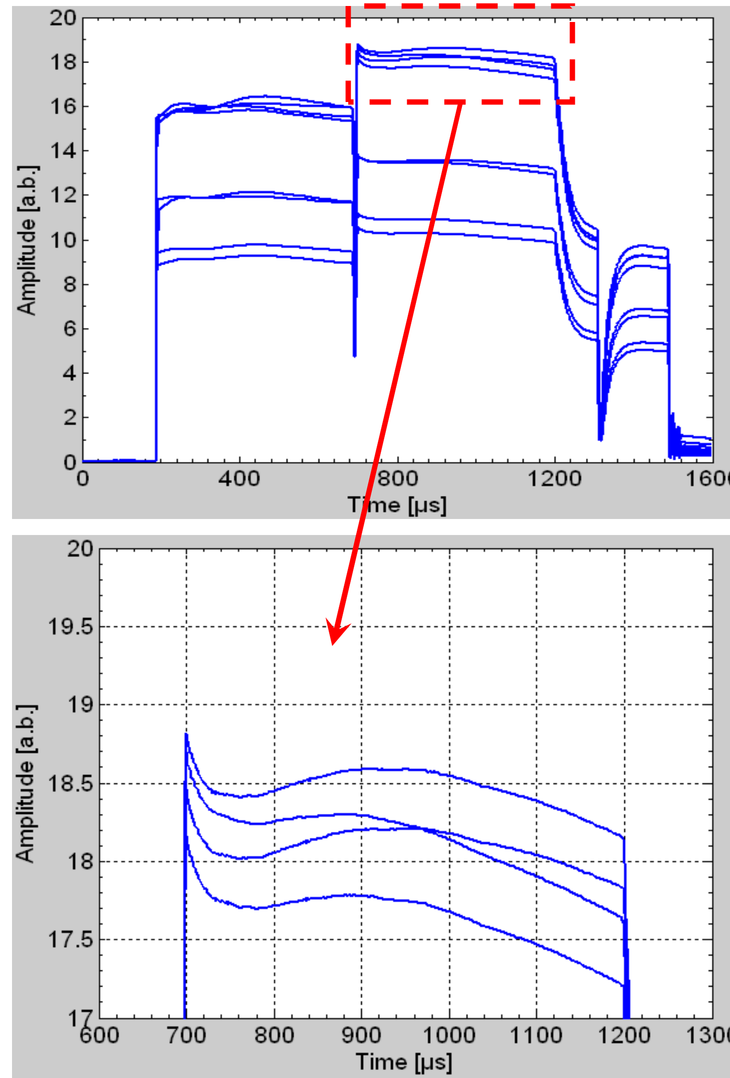


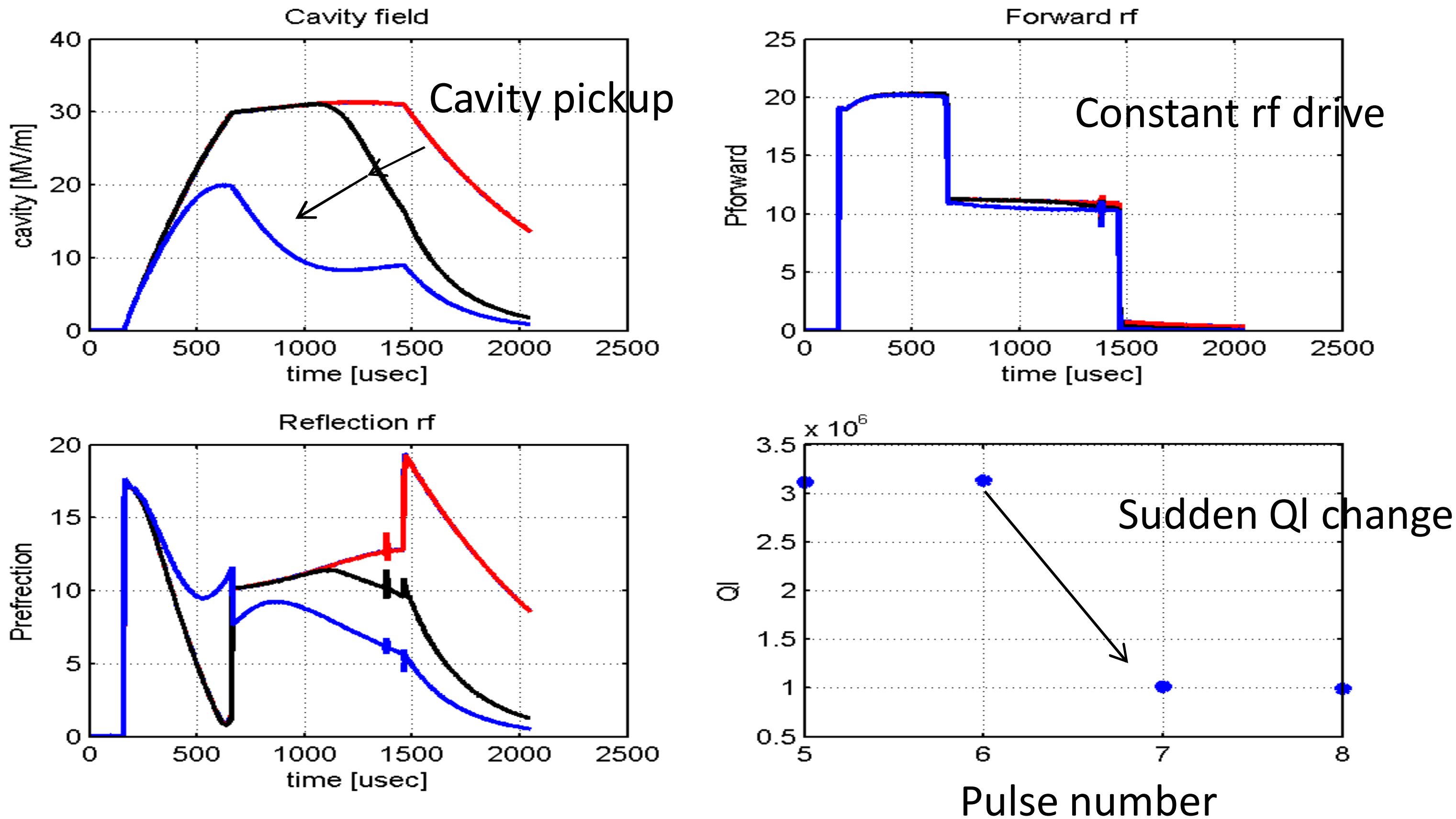
Results of high-gradient study

Shin MICHIZONO (KEK) .

- Waveguide system and the performance
- Focus of the study
- Typical waveform at quench
- Quasi-quench phenomena
- Pulse-width dependence
- Quench limit observed at KEK
- Summary

Typical waveform at quench

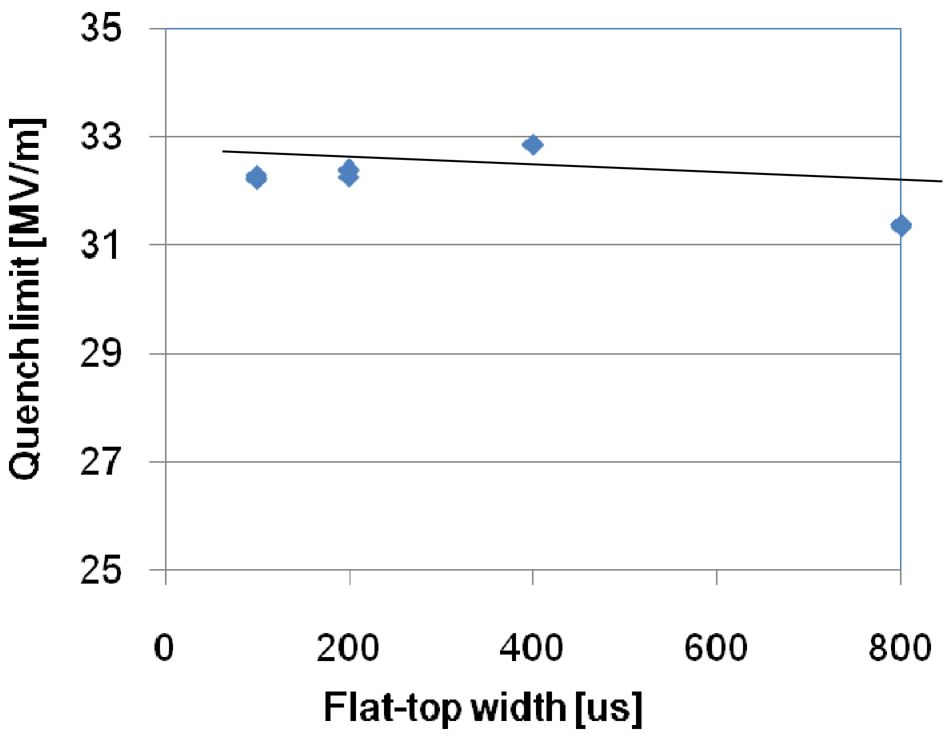
- Quench limit of No.2 cavity @ACC6 was studied.
- Study was carried out with FF mode. (without feedback) in order to avoid excessive rf input.
- Sudden Ql change was observed when quench happened.



Quench limit v.s. flattop width

- Quench limit is not sensitive to rf flattop.

- It is confirmed that the cavities should be operated under the quench limit including the tilt effects under the beam loading.



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Study of stability requirements for ILC bunch compressor

Nikolay Solyak
Fermilab

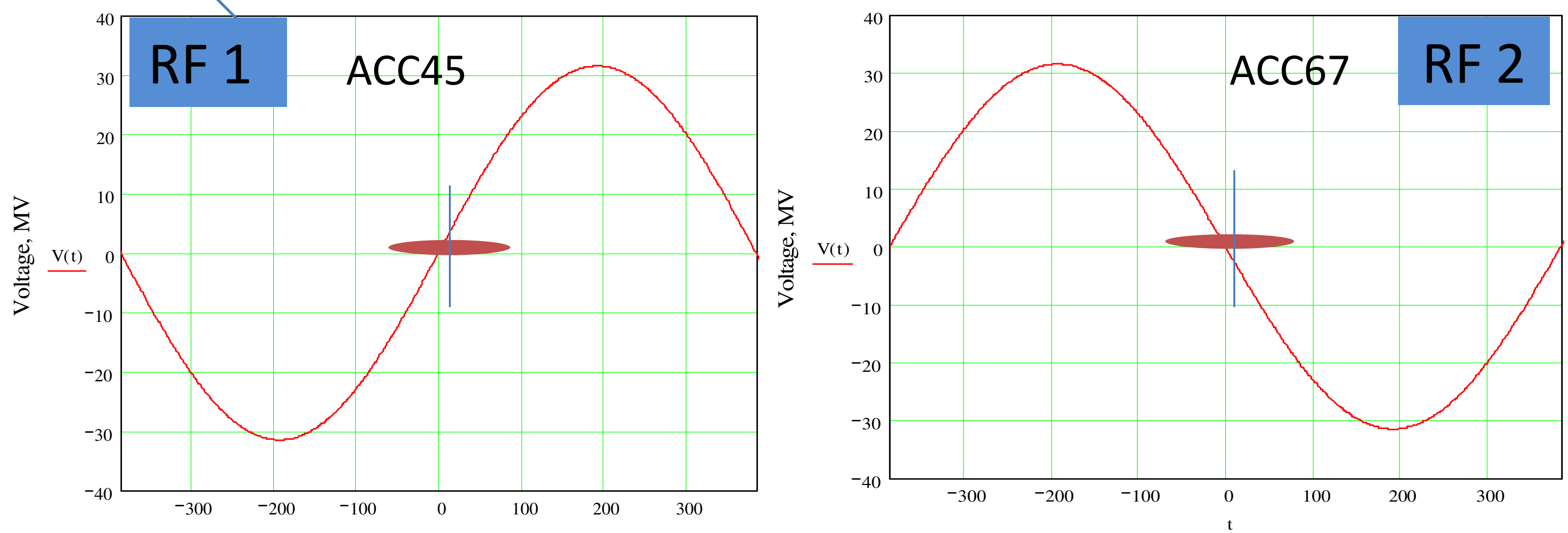
FLASH DESY, February 23, 2010

ILC bunch compressor (RDR):

- Bunch compressor RF phase and amplitude stability tolerances. For 6mm→0.3 mm compression
  - 0.25° and 0.5% rms @ 1.3 GHz
- Bunch compressor rf cavities operate close to zero-crossing:
  - -105-degrees off-crest (first stage), beam decelerates
  - -20 to -40-degrees off-crest (second stage)
  - Gradient: typ. 25-30 MeV/m
- Tolerance even tighter for high compression regime 6mm→0.2mm or for single-stage compressor.

Two RF systems

- Two configuration is possible: One (ACC67)or Two (ACC45 and ACC67) RF stations



Schematic of the bunch jitter compensation.

Single ACC67 RF unit:

Energy resolution is OK for 0.25 deg

Large energy spread (~1%) if σ > 1mm

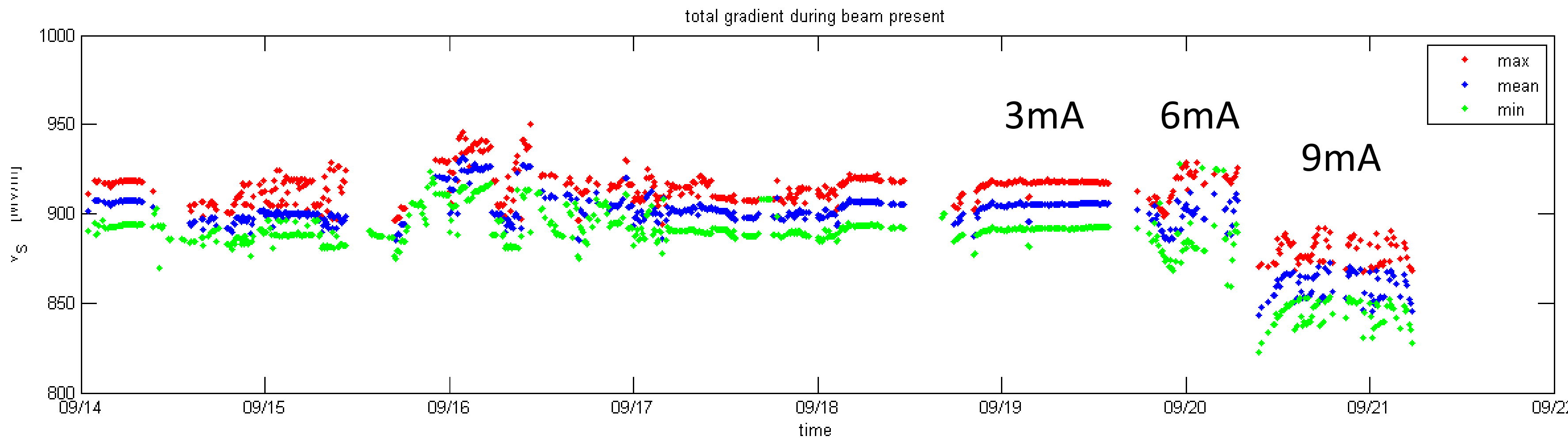
Two RF systems ACC45 and ACC67

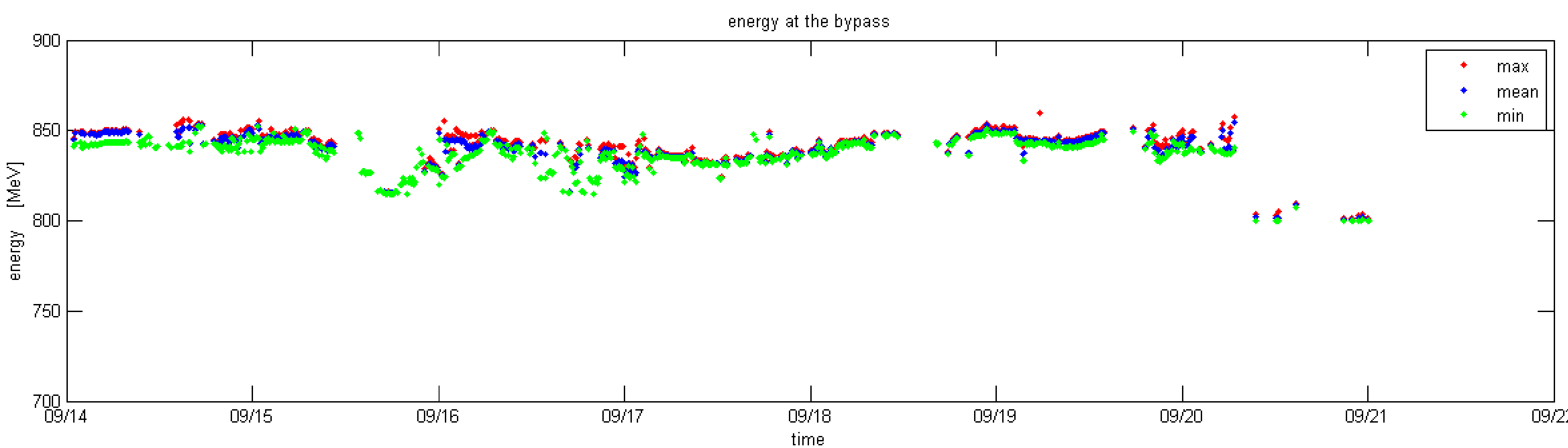
- Low Energy ~ 500 MeV
- *Resolution is OK*
- *Bucnch length independent*

Comparison between ILC specification and FLASH 9mA study

Brian Chase (Fermilab)
Julien Branlard, Gustavo Cancelo

Vector Sum and Beam Energy





Vector Sum Phase

LLRF: Moving forward

Gustavo Cancelo, FNAL

- Goal stabilize LLRF to reach long term energy stability within 0.1%.
  - Start with a good simulation of FLASH current parameters including:
    - Power limitations.
    - Detunings.
    - Major disturbances.
    - Loop delays, bandwidth limitations, measurement noise.
    - Calibration error.
  - Use the simulation to verify current data and to plan improvements towards energy stability goal.
    - Improve Kp and include Ki gain in the control.
    - Improve VS calibration procedure.
    - Include beam current information in the control.
    - Try to define a phase reference for the VS.

Proposed studies from WG3

- LLRF
  - Long-term energy stability
  - Performance regulations at high gradient and high current
- Gradient overhead studies (ACC67)
  - Optimization of Qext, prove concept for at least 3mA
  - Microphonics and LFD, can be done w/o beam
- Klystron Overhead
  - Need high current, at 3mA need retune Qext
- ILC Bunch compressor stability studies
  - 2 RF units ACC45 & ACC67 to demonstrate 0.25 deg phase stability
- HOM studies

<u>Beam requirements:</u>

- Most studies are require high current regime > 3mA
  - 1.5 nC, 3 MHz, 800 bunches: (XFEL goal 4.5 mA)