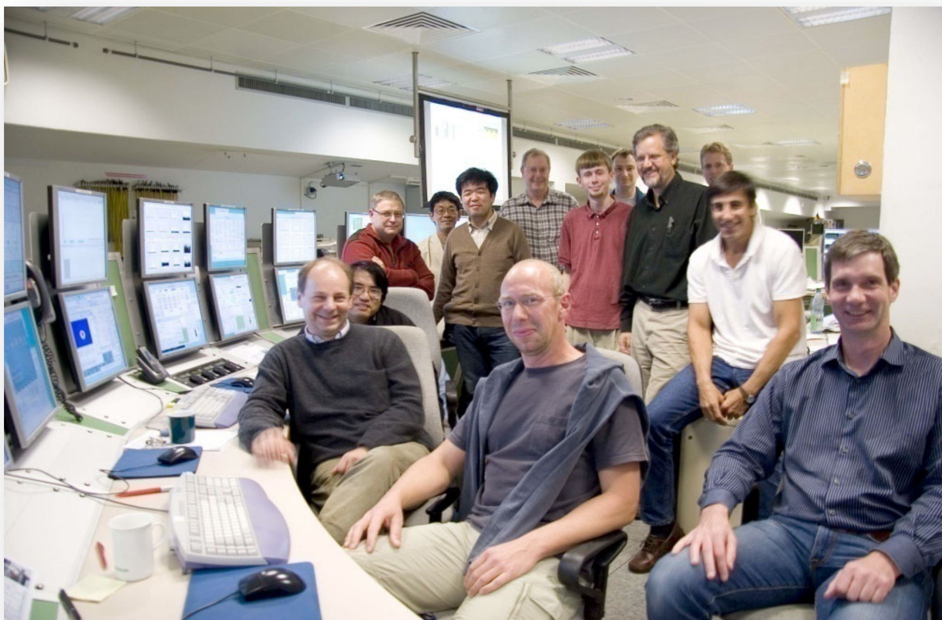
Cryomodule String Test: TTF/ FLASH 9mA Experiment



Nick Walker (DESY)
John Carwardine (ANL)

GDE AAP Review April 2009

Outline

- Cryomodule String Test goals
- TTF/FLASH facility overview
- Overview of the 9mA program
- Preparations for August/September 09 studies
- Estimated gradient limits
- Extrapolation to ILC gradients
- Wrap-up

String Test: goals from R&D Plan

Integration Tests

- *The highest priority goal is to demonstrate beam phase and energy stability at nominal current*

- *Important because of their potential cost impact:*
  - ***demonstrate operation of a nominal section or RF-unit***
  - ***determine the required power overhead***
  - ***to measure dark current and x-ray emission***
  - ***and to check for heating from higher order modes***

- *Needed to understand linac subsystem performance:*
  - ***develop RF fault recognition and recovery procedures***
  - ***evaluate cavity quench rates and coupler breakdowns***
  - ***test component reliability***
  - ***tunnel mock up to explore installation, maintenance, and repair***

Primary objectives of 9mA program

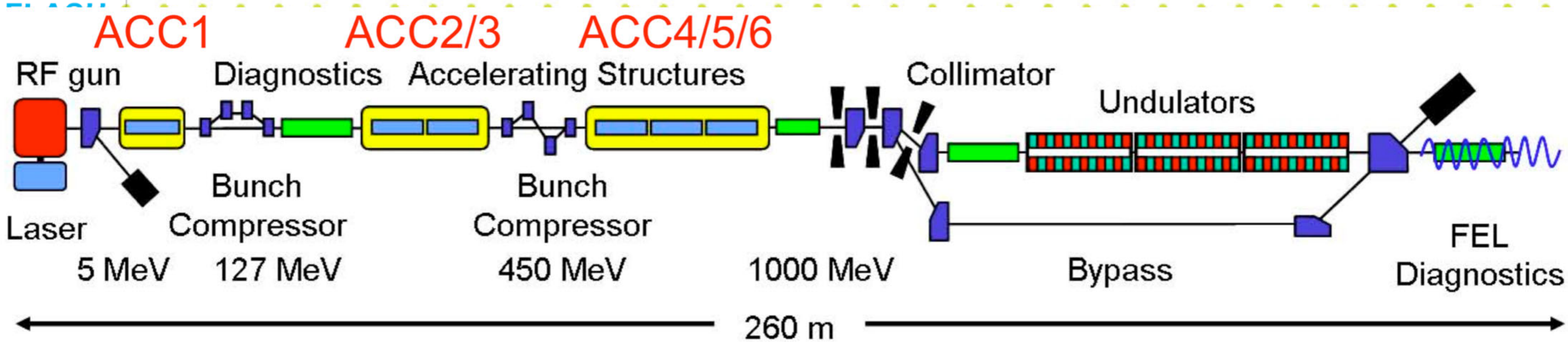
- Long-pulse high beam-loading (9mA) demonstration
  - **800μs pulse with 2400 bunches (3MHz)**
  - **3nC per bunch**
  - **Beam energy 700 MeV ≤ E_{beam} ≤ 1 GeV**
- Primary goals
  - **Demonstration of beam energy stability**
    - Over extended period
  - **Characterisation of energy stability limitations**
    - Operations close to gradient limits
  - **Quantification of control overhead**
    - Minimum required klystron overhead for LLRF control
  - **HOM absorber studies (cryo-load)**
  - **…**

Primarily a LLRF experiment

- Major operational challenge for FLASH !
  - **Pushes many current operational limits**

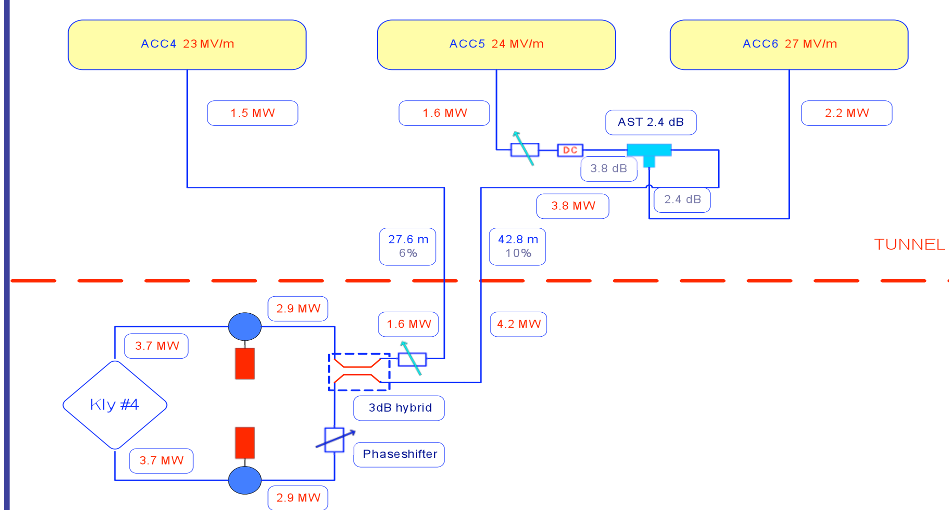
TTF/FLASH facility overview

FLASH accelerator layout



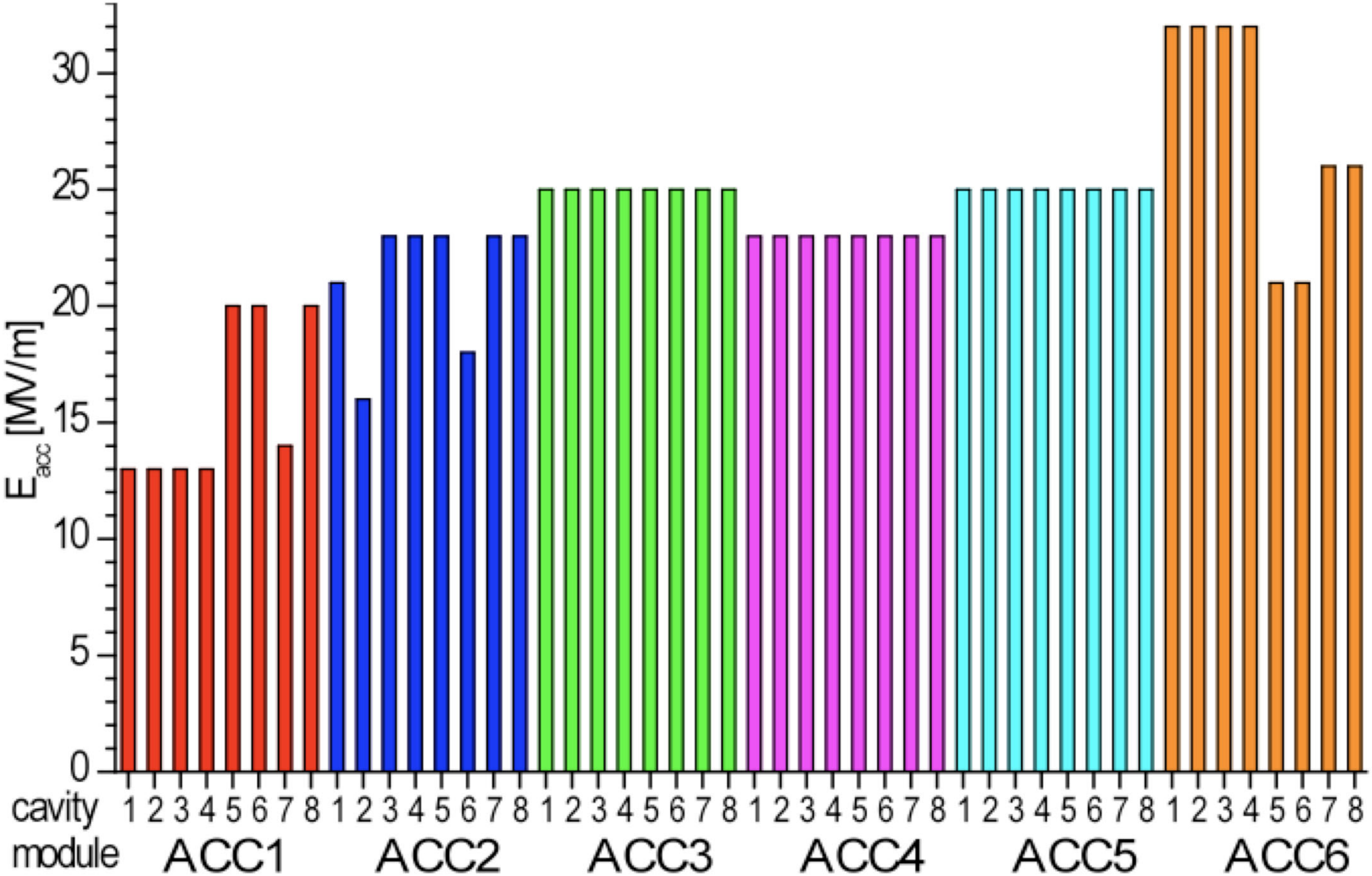
Comparison of machine parameters

		XFEL	ILC	FLASH design	9mA studies
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



ACC456 is main focus of 9mA RF studies

FLASH Gradient limits



Denis Kostin, MHF-sl, DESY

FLASH milestone: lasing with 800 bunches

The Milestone

HELMHOLTZ | ASSOCIATION

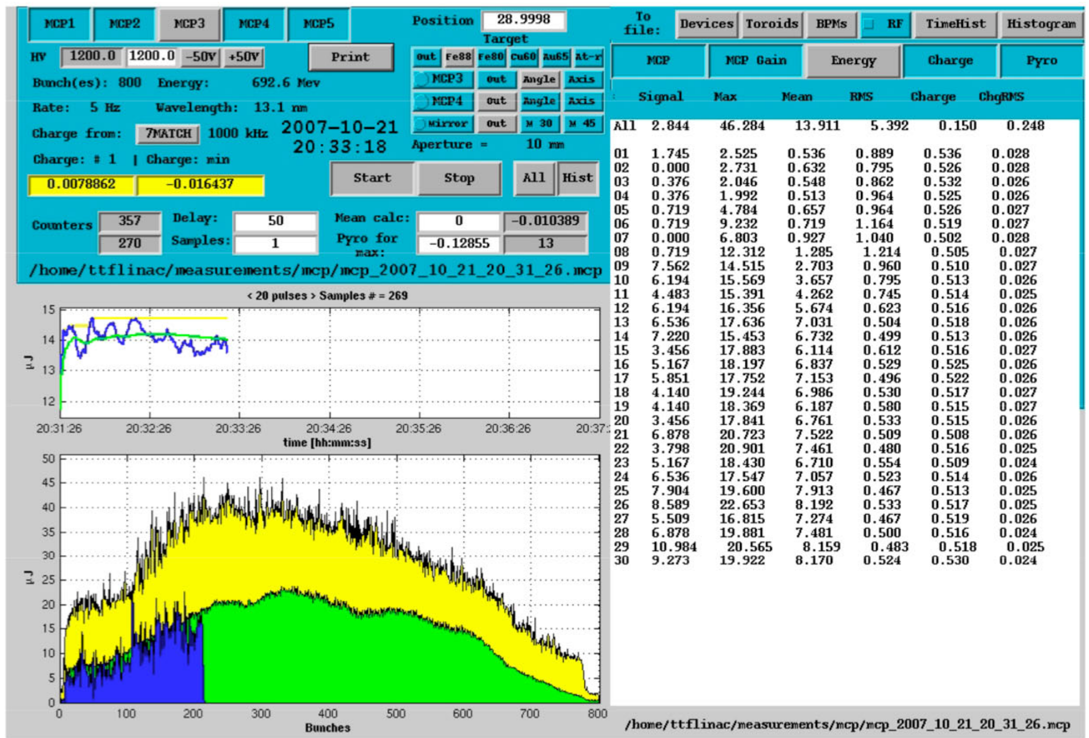
- Milestone: Lasing with 800 bunches, >10 µJ/pulse **achieved**

...without destroying the machine

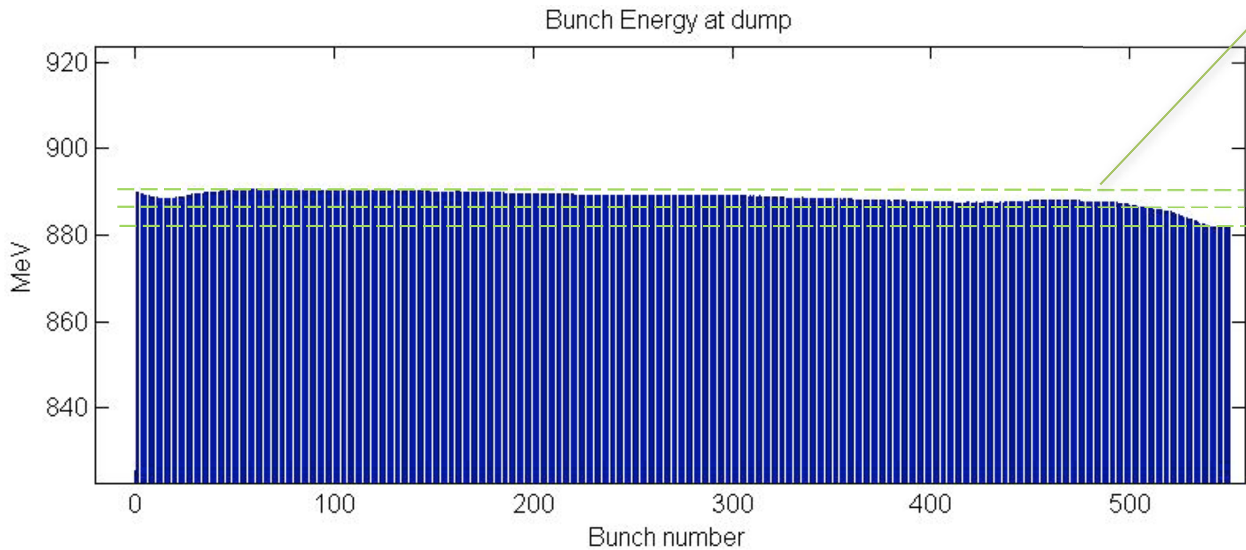
800 bunches at 685 MeV

electron beam: 2.7 kW

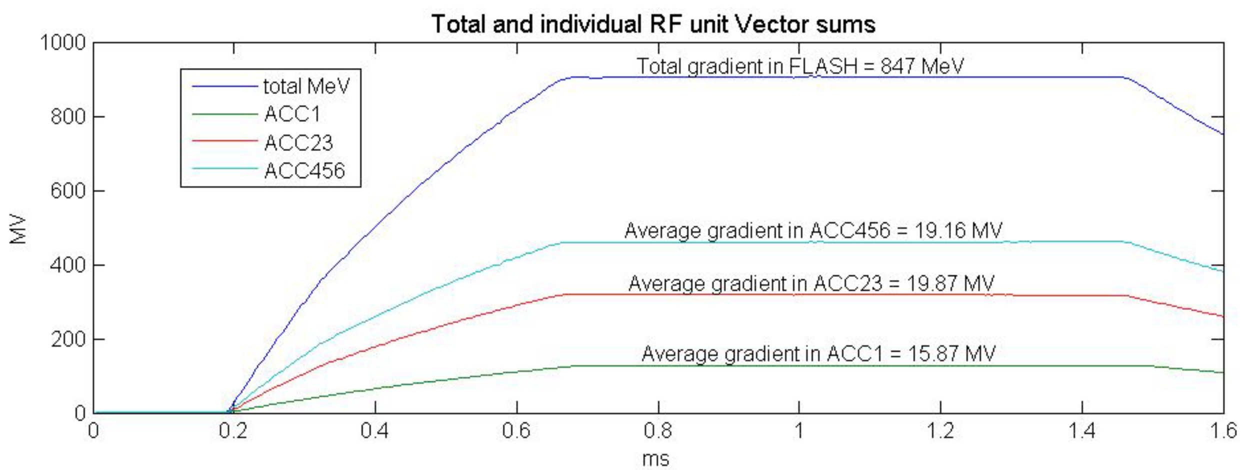
photon beam: 56 mW



High Beam-Loading Long Pulse Operation



10 MeV over 550 bunches (~1%)
(~4 MeV over 1st 500)



- 450 bunches achieved with stable operation
  - **Few hours of archived data**
  - **Currently under analysis**
  - **(vacuum OK)**
- Long bunch trains with ~2.5 nC per bunch:
  - **550 bunches at 1MHz**
  - **300 bunches at 500KHz**
  - **890 MeV linac energy**
- All modules (RF) running with 800us flat-top and 1GeV total gradient
- Increase from 450 to 550 bunches eventually caused vacuum incident
  - **The "straw that broke the camels back!"**

FLASH operations

- TTF/FLASH is used for different purposes
  - **VUV and soft X-ray FEL photon source**
  - **Test bench for accelerator R&D**
- Typical accelerator parameters for photon users:
  - **2-30 bunches (up to 200), ≤ 1nC per bunch, 1MHz bunch rate**
  - **400MeV-1GeV**

- 2008 machine time allocations
  - **FEL user operation: 161 days**
  - **FEL studies: 119 days**
  - **Accelerator studies: 49 days**

- 9mA program has received 16 8hr shifts during the last three accelerator studies periods

The 9mA Experiment

The (International) Team

- **FLASH Experts (DESY)**
  - Siggi Schreiber - laser/gun injector set-up
  - Bart Faartz - general set-up
  - Lars Froehlich - TPS installation / commissioning, BLM calibration
  - Florian Loehl - optics matching & emittance
  - Holger Schlarb - optics & steering
  - Nina Golubeva - optics calculations
  - Vladimir Balandin - optics calculations
  - Valeri Ayvazyan - - LLRF set-up and tuning
  - Mariusz Grecki - LLRF set-up and tuning
  - Waldemar Koprek - LLRF set-up and tuning (mostly gun)
  - Jacek Sekutowicz - HOM absorber measurements
  - Stefan Simrock - LLRF (general)
  - Kay Rehlich - controls (DAQ)
  - Kay Wittenburg - diagnostics
  - Dirk Noelle - diagnostics (BPM)
  - Nick Walker - overall coordination
  - Katya Honkavaara - planning
  - Mikhail Krasilnikov - RF gun modelling
- **ANL**
  - John Carwardine - LLRF / overall coordination
  - Xiaowei Dong - data analysis, optics modeling
- **FNAL**
  - Brian Chase - LLRF (experiment & data analysis)
  - Gustavo Cancelo - LLRF (experiment & data analysis)
  - Michael Davidsaver - DAQ applications programming
  - Jinhao Ruan - laser setup
- **KEK**
  - Shinichiro Michizono - LLRF (experiment & data analysis)
  - Toshihiro Matsumoto - LLRF (experiment & data analysis)
- **SLAC**
  - Chris Adolphsen - LLRF (experiment & data analysis)
  - Tom Himel - Planning & scope
  - Shilun Pei - LLRF (experiment & data analysis)
- **SACLAY**
  - Abdallah Hamdi - TPS installation / commissioning

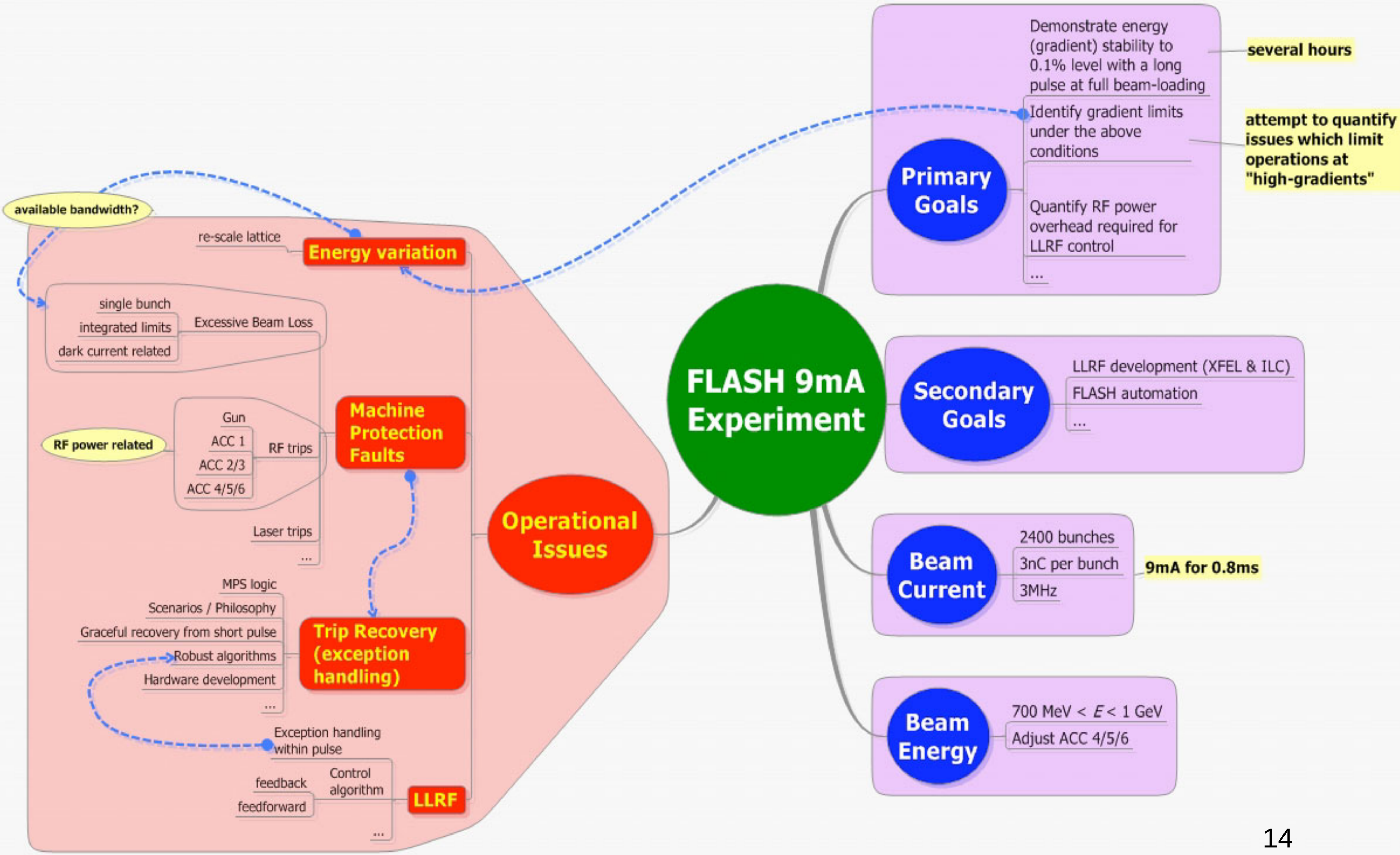
~40 subscribers to ttf9mA mailing list (not all shown here)

RF/LLRF collaborators:
DESY, KEK, FNAL, SLAC

The 9mA experiment in context

- Experiment addresses needs of ILC, XFEL and FLASH
  - **ILC: International GDE stated milestone**
    - Driver: important and visible deliverable for international effort
  - **XFEL: Close collaboration with world-wide LLRF groups**
    - Focus (potentially accelerate) development and planning for XFEL
    - “Operation at limits” experience provides important input for future XFEL development
    - Important demonstration also for XFEL
  - **FLASH: Addresses many operational issues**
    - Automated exception handling and recovery
    - Better characterisation of machine
    - Towards routine high-power long-pulse operation for users.
- Growing International Collaboration (ILC-driven)
  - **SLAC, FNAL, KEK, SACLAY, ANL,DESY…**
- TTF2/FLASH remains a unique facility world-wide

Achieving the goals…



9mA experiment chronology

- First run (May 08)
  - Hardware failures (power-out) effectively made shifts unusable
  - Resulting poor set-up of injector / accelerator made by-pass optics/steering virtually impossible.

- **Second run (September 08)**
  - Significant progress on all fronts
  - Careful set-up of injector (3nC, 1MHz) resulted in 'loss-free' transmission to dump (via by-pass)
  - Vacuum incident resulted in aborted programme

- Third run (January 09)
  - Beam loss studies
  - LLRF regulation, beam loading compensation algorithms
  - Run cavities at higher gradients

Results to date compared with the 9mA goals

	Achieved in Sept 08	Goal for Sept 09
Bunch charge to dump	2.5nC @ 1MHz	3nC @ 3MHz
Bunches/pulse	550 @ 1MHz	2400 @ 3MHz
Beam pulse length	550uS	800uS
Beam power	6kW (550x3nC/200mS @ 890MeV)	36kW (2400x3nC/200mS @ 1GeV)
Gradient in ACC4-6	Ensemble avg: ~19MV/m	Ensemble avg: to ~27MV/m Single cavities: to ~32MV/m

Plus…

- All RF systems operating routinely with 800us flat tops.
- Improved characterization of the bypass and dump line optics
- Characterization of LLRF feed-forward and feedback performance.
- Collected and analyzed cavity data for RF power overhead study

Schedule: April – October 2009

- Now to Aug 17:
  - **Deliver beam to users + fel studies**
  - **No machine studies scheduled**

- Aug 17-Sep 21: 5 weeks of dedicated machine time
  - **Tunnel access to repair dump vacuum line (3 weeks)**
  - **Two weeks of 24/7 dedicated 9mA beam studies**

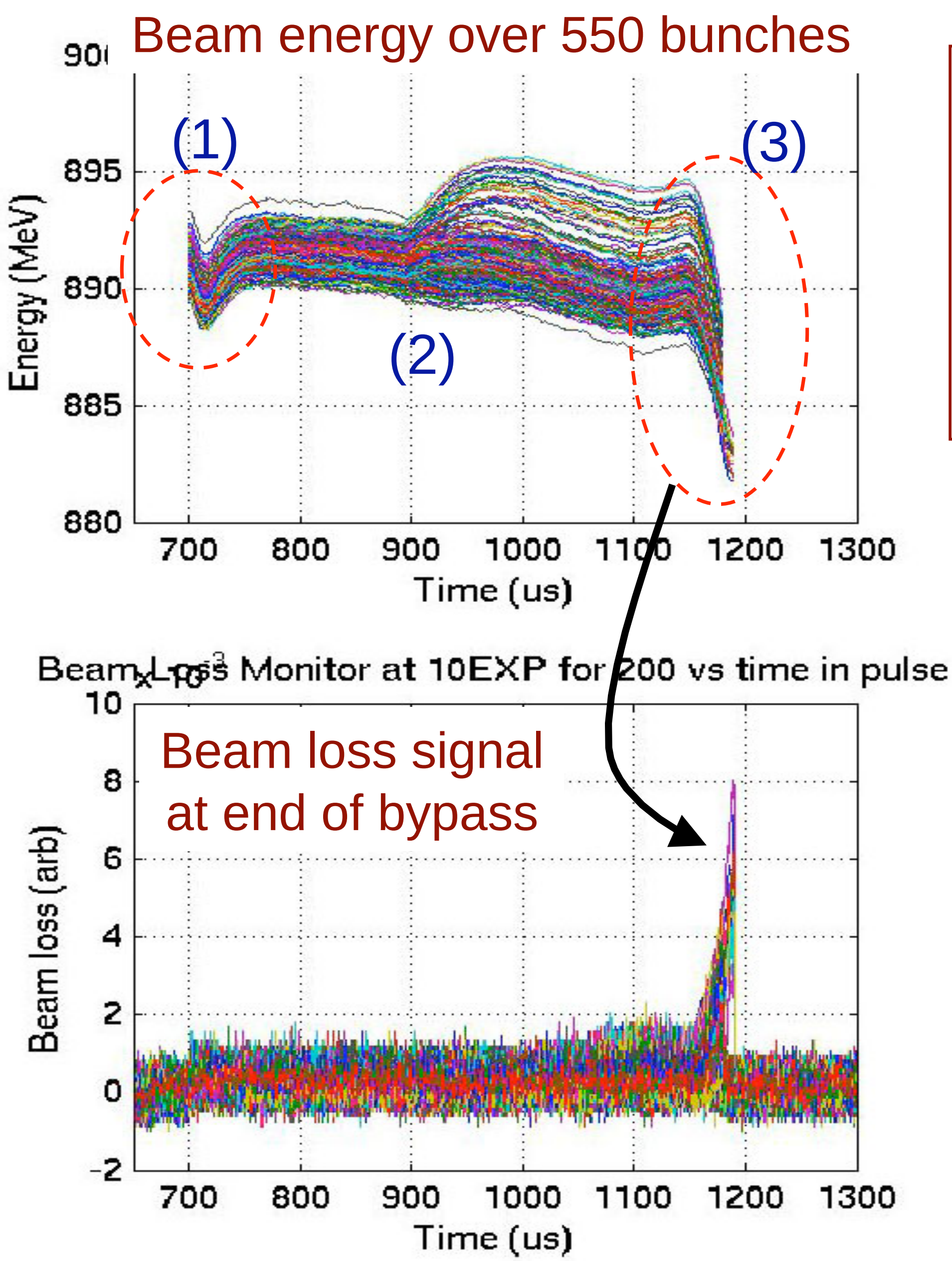
- Sept 21: FLASH shutdown begins

Preparing for August/September 9mA studies

Operations lessons learnt

- Main operational issue: controlling peak + integrated beam loss
- We don't have an adequate understanding of the bypass optics
- A well-tuned and well-matched gun & injector is almost essential
- LLRF systems require expert attention when increasing beam current or pulse length
  - **Tuning beam loading compensation**
  - **Reduce energy spread over long bunch trains: transients at start and end of pulse; slope over flat-top**
- Be methodical: ramp up carefully, tune and monitor at each step

Energy profile over long bunch trains



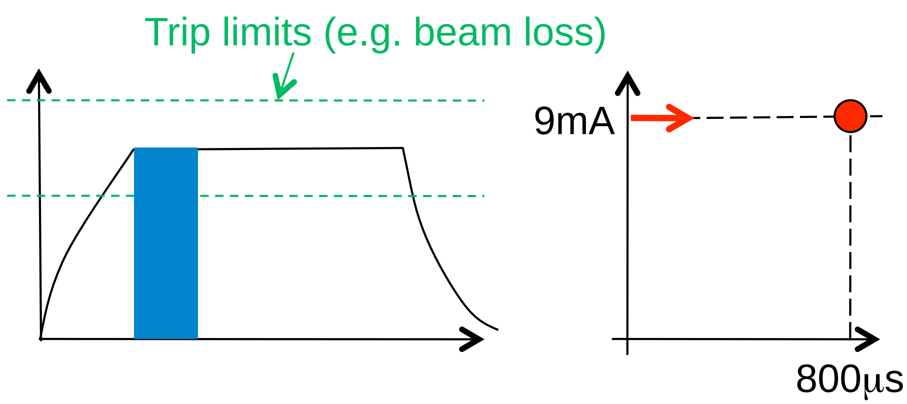
Systematic effects

1. Beam turn-on transient (regulator)
2. Slope over flat top (bunch charge?)
3. Droop at end of the flat top (imprecise beam loading compensation)

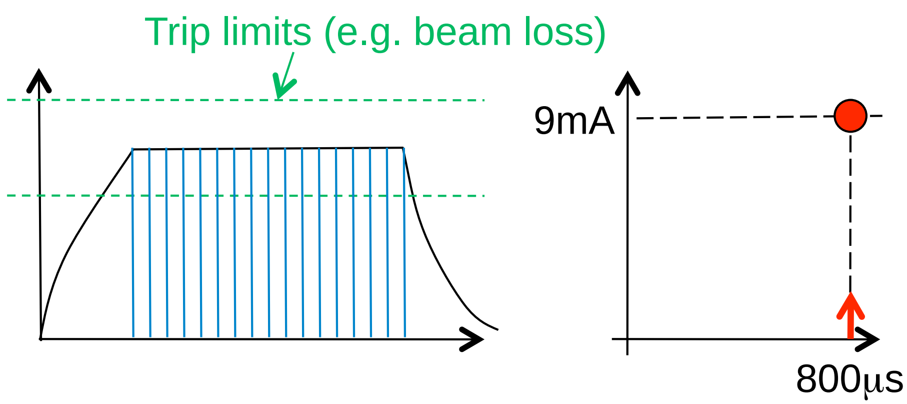
Improve LLRF regulation through…

- Increase feedback gain!
- Upgrade to latest generation LLRF
- Better beam loading compensation
- Better feed-forward tables

Strategies for ramping up to high current…?



- Start with a short pulse and 9mA beam (3nC @ 3MHz)
- Increase beam pulse width
- (Used in Sept 08)



- Start with a full-length pulse but at low bunch rep rate
- Reduce the bunch spacing to increase average current

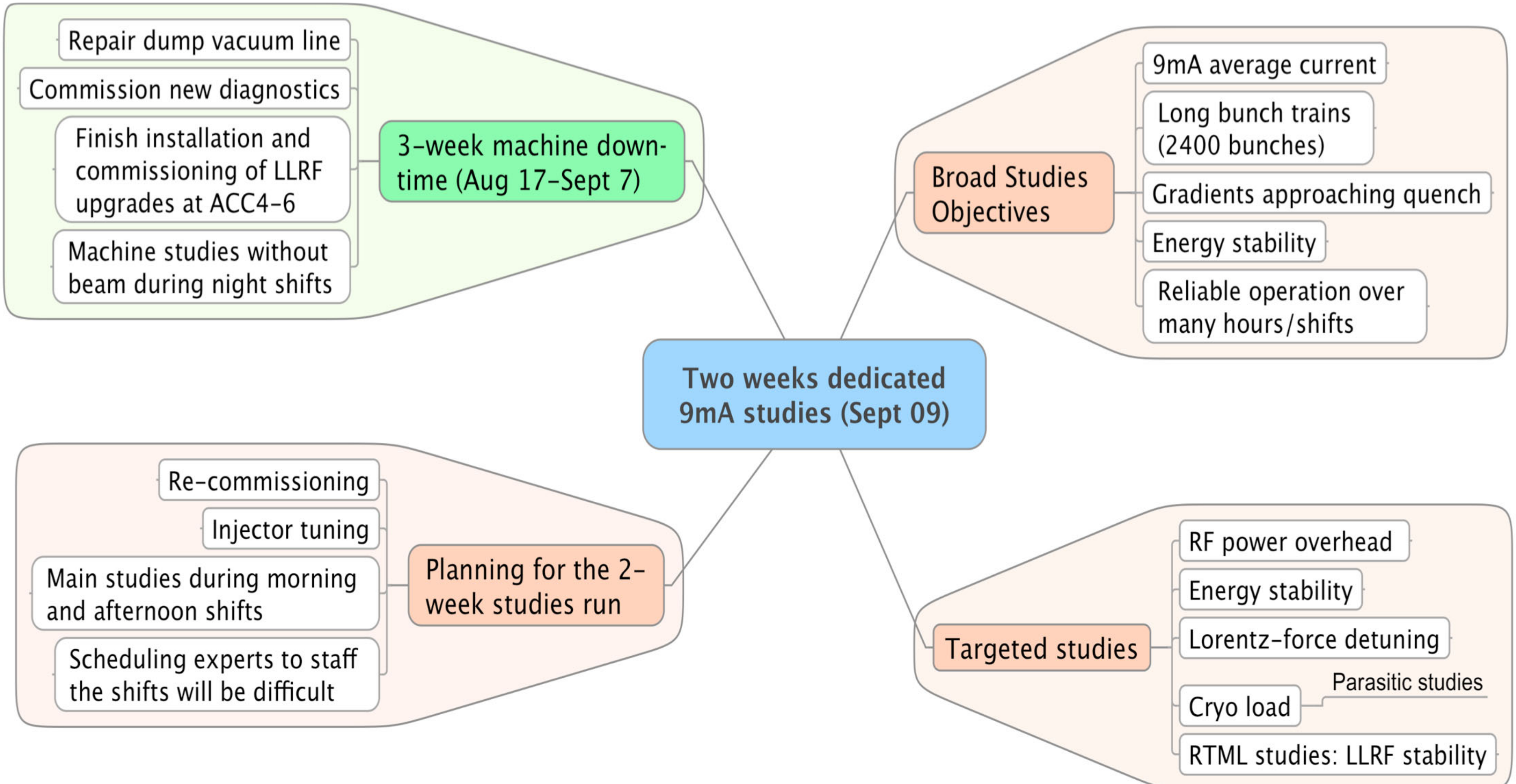
Preparatory work prior to August

- LLRF system upgrades at ACC456 (ACC23)
  - **Upgrade hardware to latest generation (SimconDSP)**
  - **Upgrade rf signal down-converters for higher IF**
  - **Algorithm improvements: beam loading compensation, feed-forward waveform generation, …**
  - **LLRF system modeling, study planning**

- Optics work
  - **Improve alignment between model and measured lattice**
  - **Improve understanding of loss points and apertures**
  - **Refine the bypass lattice**
  - **Develop a methodical tuning process, online physics model**

- Prepare gun laser and timing system for operation with a 3MHz bunch rate: install pockel cells, timing system

Aug/Sept 2009 studies planning



Detailed studies planning is just beginning

Energy Stability study

- Goal: measure performance, and characterize limitations under full beam loading conditions
  - **Stability within bunch train vs pulse to pulse**
  - **Systematic vs random effects**
  - **Impact of running close to saturation on klystron**
  - **Impact of running close to gradient limits**
  - **LLRF hardware/firmware performance limitations**

- RDR rf stability tolerances (RDR Table 3.9-1):

Location	Phase (degree)		Amplitude (%)		limitation
	correlated	uncorr.	correlated	uncorr.	
Bunch Compressor	0.24	0.48	0.5	1.6	timing stability at IP (luminosity)
Main Linac	0.35	5.6	0.07	1.05	energy stability $\leq$0.1%

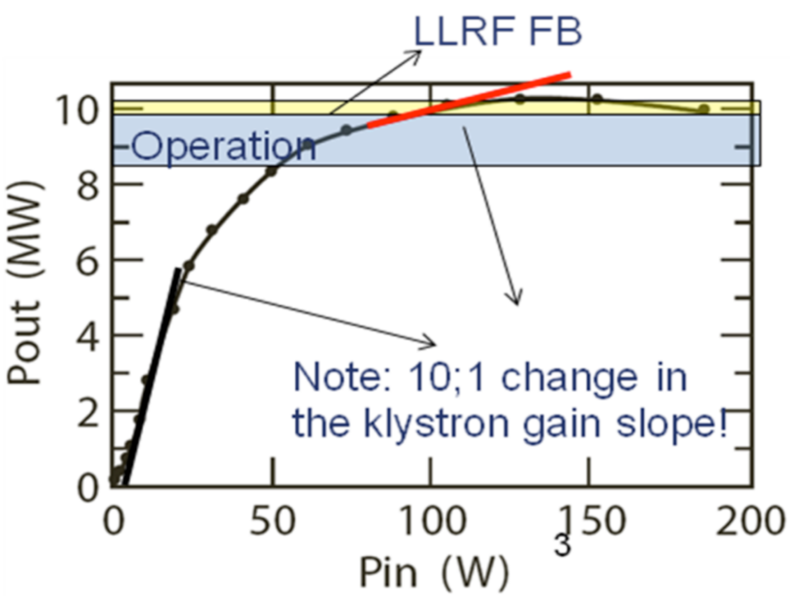
RF power overhead studies

- RF power is a cost driver for the ILC
- To study…
  - **What power overhead is needed meet spec over extended operations periods? (RDR design uses 14%)**
  - **How effectively we can minimize static detuning errors**
  - **How well we can compensate Lorentz-force detuning**
  - **How close to saturation before klystron linearization is dominated by errors and regulation becomes unstable**

- More than can be done in Sept: should be able to start bounding the problem

Operating near klystron saturation

- ***goal: to operate near the klystron saturation.***
- ***The present operation point of the klystron is -5% from its saturation (the worst case*).***
- ***The llrf performance should be evaluated under the circumstance and compare with the case of -10% or more.***



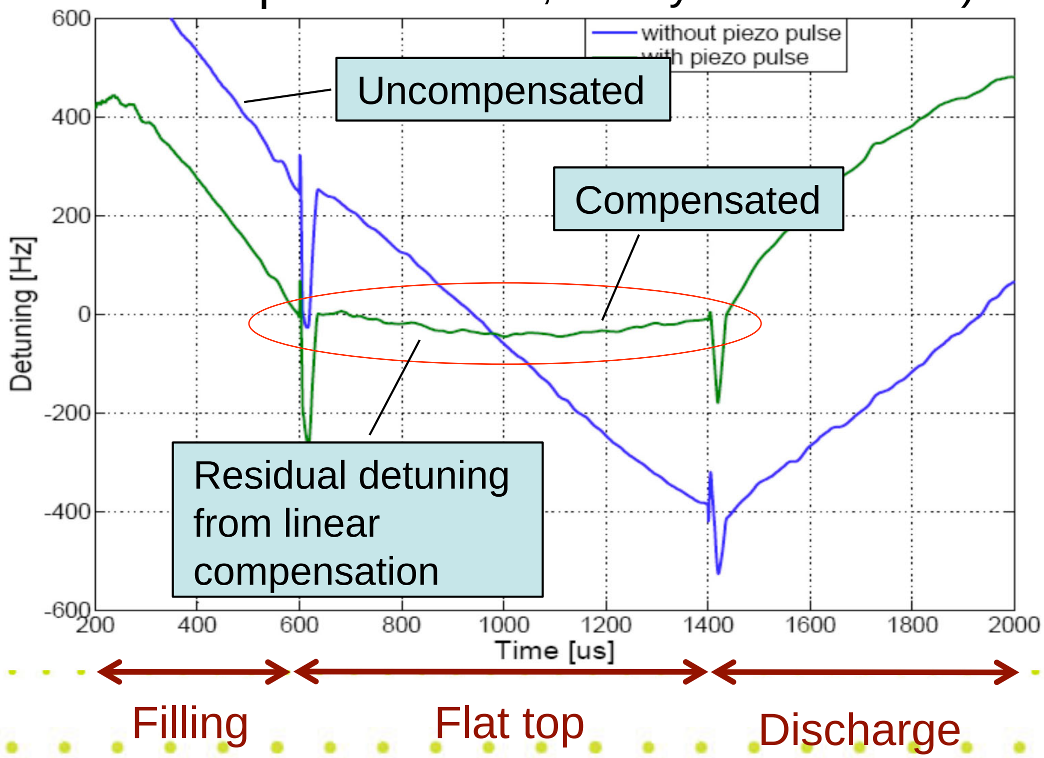
* RF power budget cavity input 8.02 MW (33 MV/m * 1.038 m * 26 cav. * 9 mA)
a) reflection from waveguide system 1% (VSWR~1.2)
b) non-optimal coupling 2% (if over-coupling x1.3)
(We should also consider the rf-output reduction due to the rf reflection to klystron)
c) rf loss 8.54% (should be minimized!)
d) beam fluctuation 1% (should be compensated by fast feedforward)
e) modulator ripple 2.5% (pulse-to-pulse +/- 0.5%HV ripple)
f) cavity detuning 2% (*40 Hz peak* of Lorentz force and microphonics)
Remained rf power:
10 MW – 8.02 MW*(1.01 * 1.02 * 1.01* 1.025 * 1.02)/(1-0.0854)=0.47MW
LLRF feedback overhead
8.02* (1.01 * 1.02 * 1.01 * 1.025 * 1.02* X)/(1-0.0854)=10
X=1.049 (5%) *(2.5% in amplitude)*

- ***proposed measurements:***
Field regulation under the rf operation near saturation (-5%, -10%, -20%)

Detuning compensation study using piezos

- Piezo tuners are installed and operational at ACC56
- Detuning compensation will be needed for 9mA test to reach high gradients with full beam loading

Example: Module 6, Cavity 3 at 35MV/m)



- Feed-forward compensation has been demonstrated on FLASH at up to 35MV/m but with low beam loading
- We plan to study operation and evaluate performance with full beam loading

K. Przygoda

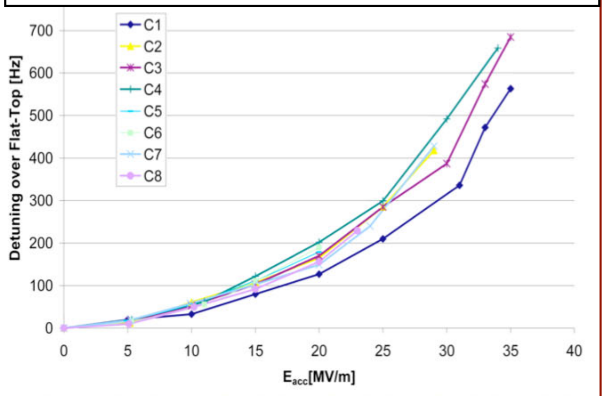
Misc. study topics

- Gain experience running a high power SC linac
- Explore rf operational parameter space
  - **Best way to set up loaded-Qs…?**
  - **Dealing with LFD with long pulse**
  - **Tuning methodologies for high beam loading**
- How to efficiently tune, perform calibrations,…
- **Is it practical to operate with a vector sum that is only 1.5MV/m below cavity quench limits (31.5MV/m vector sum)**
- Meeting stability specs and maintaining beam current
- Process-based vs expert-based machine operation
- Measures of reliable operation include being able to run hands-off for reasonably long periods

Estimates of maximum operating gradients for Sept studies

FLASH cavity gradient limits:
Assessing maximum achievable gradients

Lorenz-force detuning vs gradient (1mS flat-top)

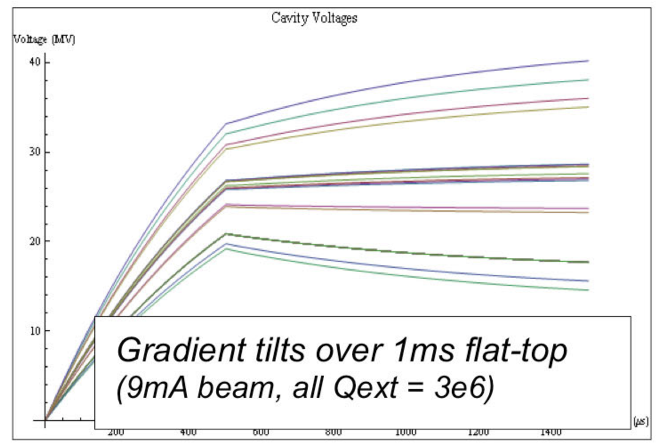


Maximum usable gradient

Quench limits

Gradient overheads
- RF Distribution System setup
- Margin for reliable operation (~2MV/m?)
- **Gradient tilts**

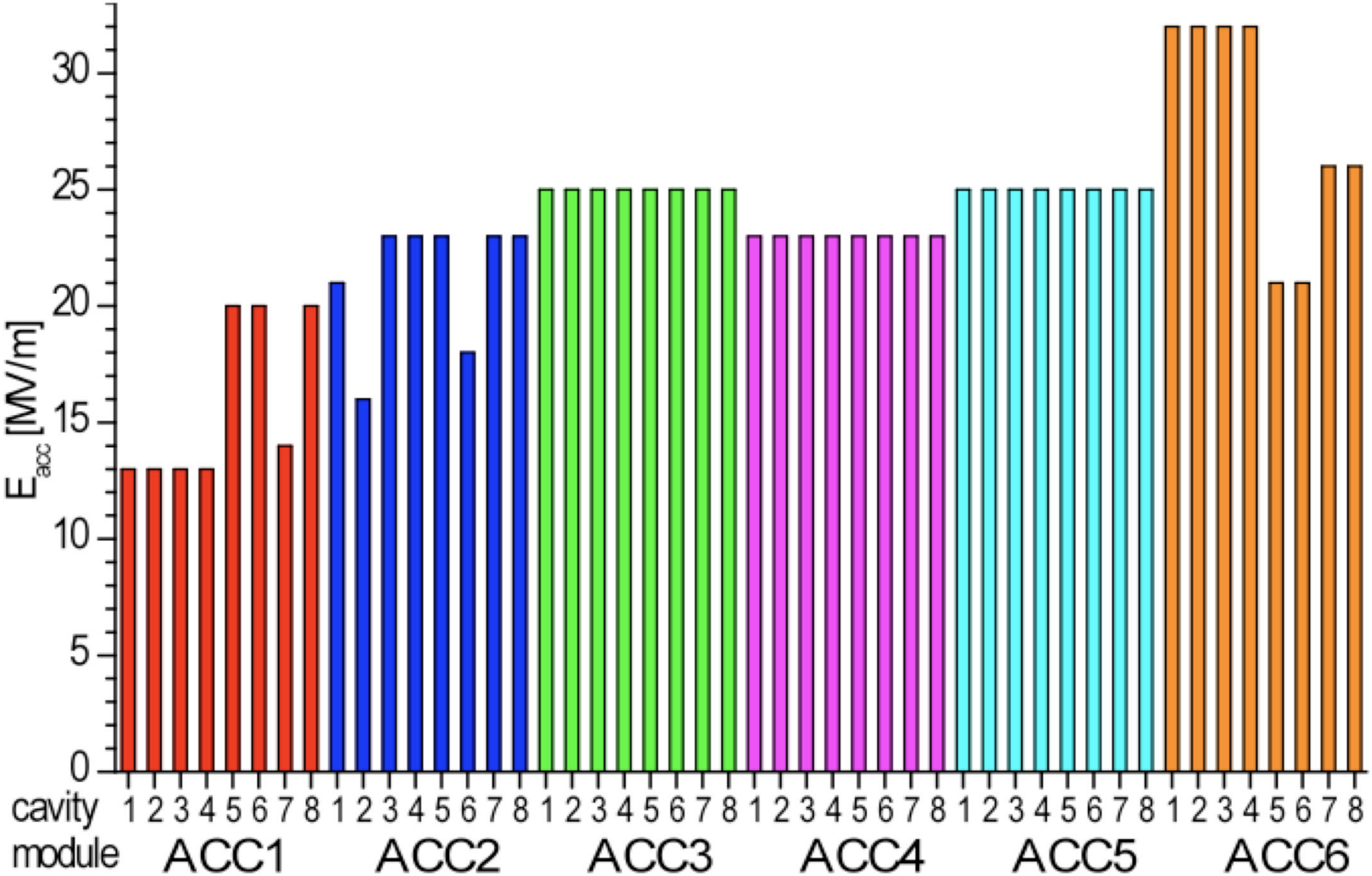
RF power
- Overcome cavity detuning
  - **Lorentz-force detuning**
  - Microphonics
  - Static tuning errors
- Margin from klystron saturation to maintain minimum gain
- Cavity circulator power limit: 390kW
  Klystron power limit: 5–7MW



Gradient tilts over 1ms flat-top (9mA beam, all Qext = 3e6)

Qext tuning options

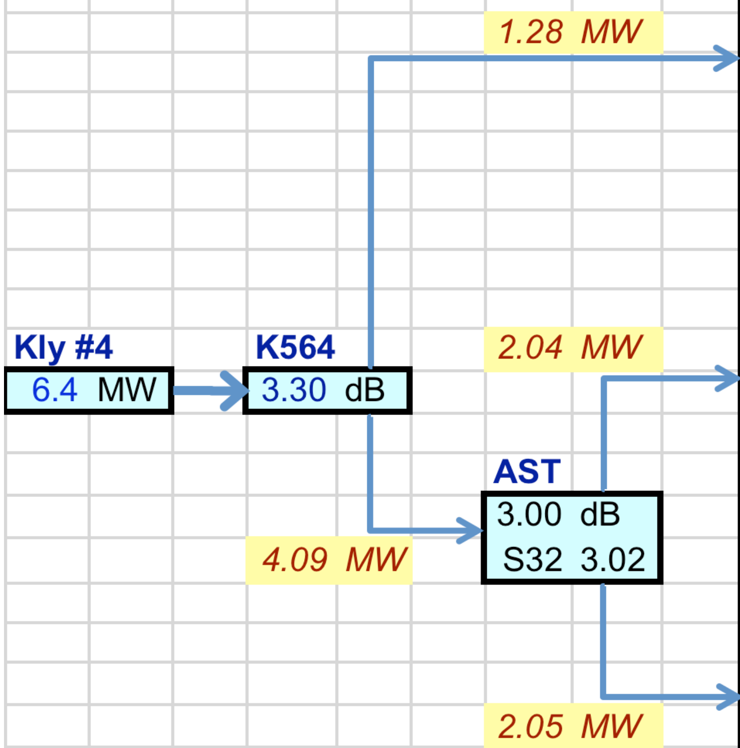
FLASH Gradient limits



Denis Kostin, MHF-sl, DESY

ACC456 RF Power Distribution spreadsheet (nominal settings)

FLASH



Module	Cav	Atten. (dB)	Qext	Gradient (max)	Pfor (KW)	Gradient	I match (mA)
ACC4	1	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	2	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	3	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	4	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	5	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	6	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	7	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
	8	9.5	3.00E+06	23 MV/m	144.0 kW	20.1 MV/m	6.7
ACC5	1	9.67	3.00E+06	29 MV/m	220.3 kW	24.9 MV/m	8.3
	2	9.64	3.00E+06	27 MV/m	221.8 kW	25.0 MV/m	8.3
	3	9.61	3.00E+06	28 MV/m	223.3 kW	25.1 MV/m	8.4
	4	9.53	3.00E+06	28 MV/m	227.5 kW	25.3 MV/m	8.4
	5	9.34	3.00E+06	29 MV/m	237.7 kW	25.9 MV/m	8.6
	6	9.35	3.00E+06	28 MV/m	237.1 kW	25.8 MV/m	8.6
	7	9.38	3.00E+06	28 MV/m	235.5 kW	25.7 MV/m	8.6
	8	9.39	3.00E+06	26 MV/m	235.0 kW	25.7 MV/m	8.6
ACC6	1	7.85	2.95E+06	34 MV/m	336.5 kW	30.9 MV/m	10.5
	2	7.54	2.97E+06	32 MV/m	361.4 kW	32.0 MV/m	10.8
	3	8.16	3.00E+06	34 MV/m	313.4 kW	29.7 MV/m	9.9
	4	8.31	2.98E+06	32 MV/m	302.7 kW	29.2 MV/m	9.8
	5	12.27	3.00E+06	21 MV/m	121.6 kW	18.5 MV/m	6.2
	6	12.03	2.98E+06	21 MV/m	128.5 kW	19.0 MV/m	6.4
	7	10.28	2.99E+06	29 MV/m	192.3 kW	23.3 MV/m	7.8
	8	10.37	2.98E+06	26 MV/m	188.4 kW	23.1 MV/m	7.8

Fill time 500 us

Adjustments available remotely

- Klystron K564 hybrid: power ratio ACC4/ACC56
- ACC45 cavities: 3-stub tuners
- ACC6 cavities: coupling + phase shifters (XFEL design)

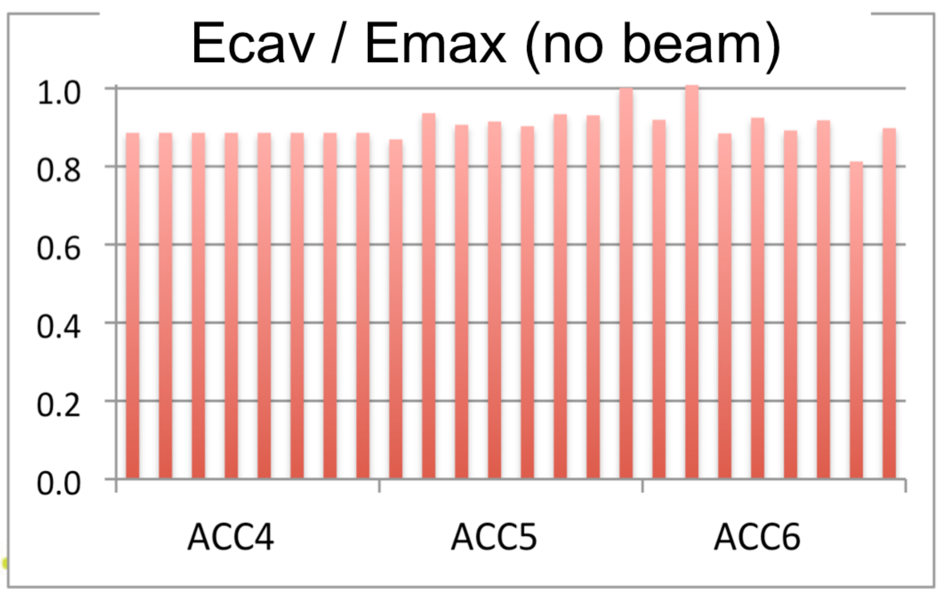
V. Katalev

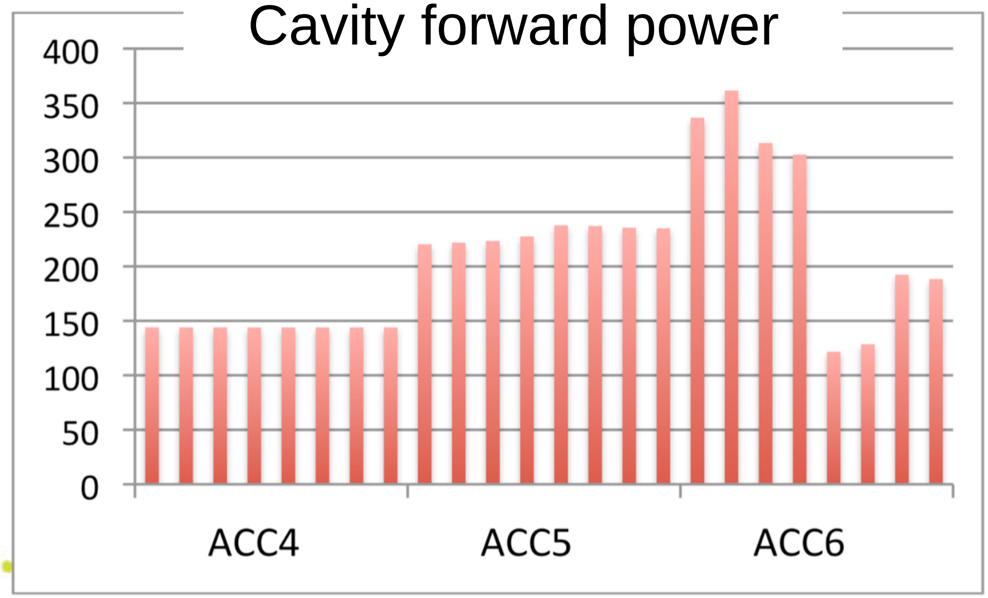
Ecav / Emax

(All Qexts set equal, nominal power ratios)

- If cavities are filled to point where first cavity quenches,
  - **Average gradient ACC4/5/6 ~24MV/m**
  - **Average gradient ACC6 C1-C4 ~30.8MV/m**
  - **Klystron power 6.4MW**
  - **ACC6 C2 forward power 360kW**

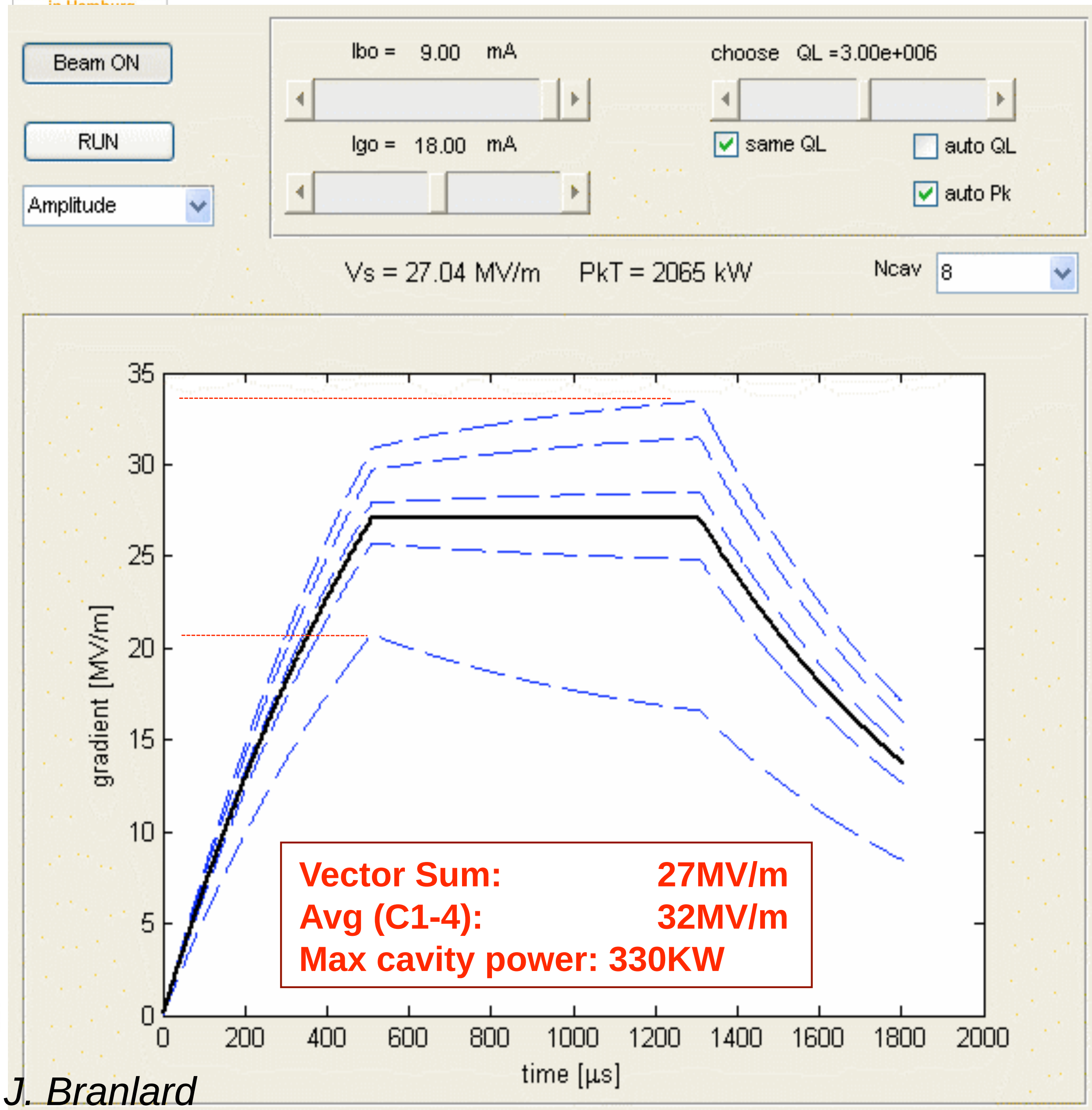
Limit: 5-7MW
Limit: 390kW

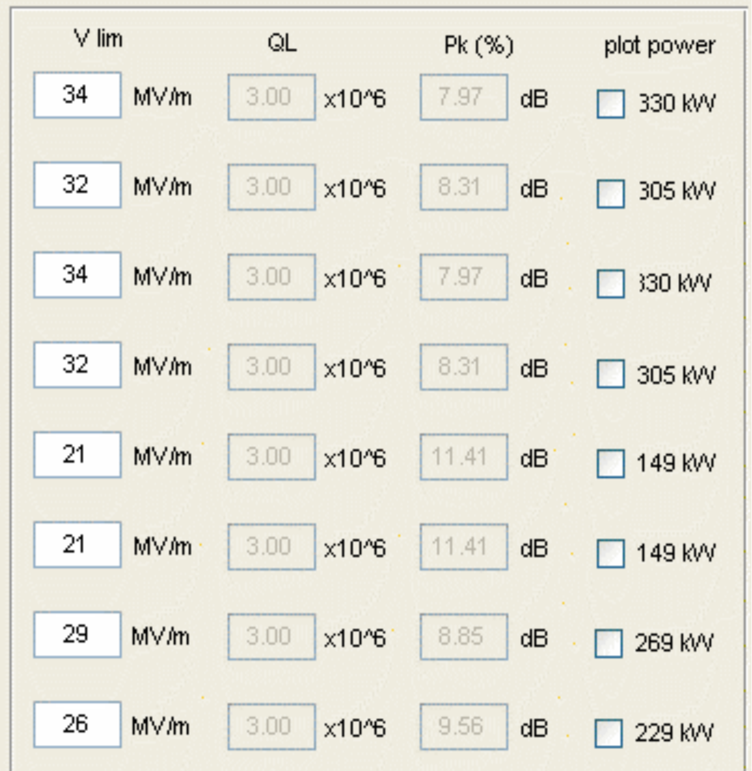




ACC6 maximum gradients

(9mA, 800us, all Qexts=3e6, optimized coupling, no LFD)





Qexts are set equal: gradients are flat with no beam

Alternative: set Qexts to give flat gradients at 9mA
(tilts occur at lower currents)

J. Branlard

Estimated maximum gradients

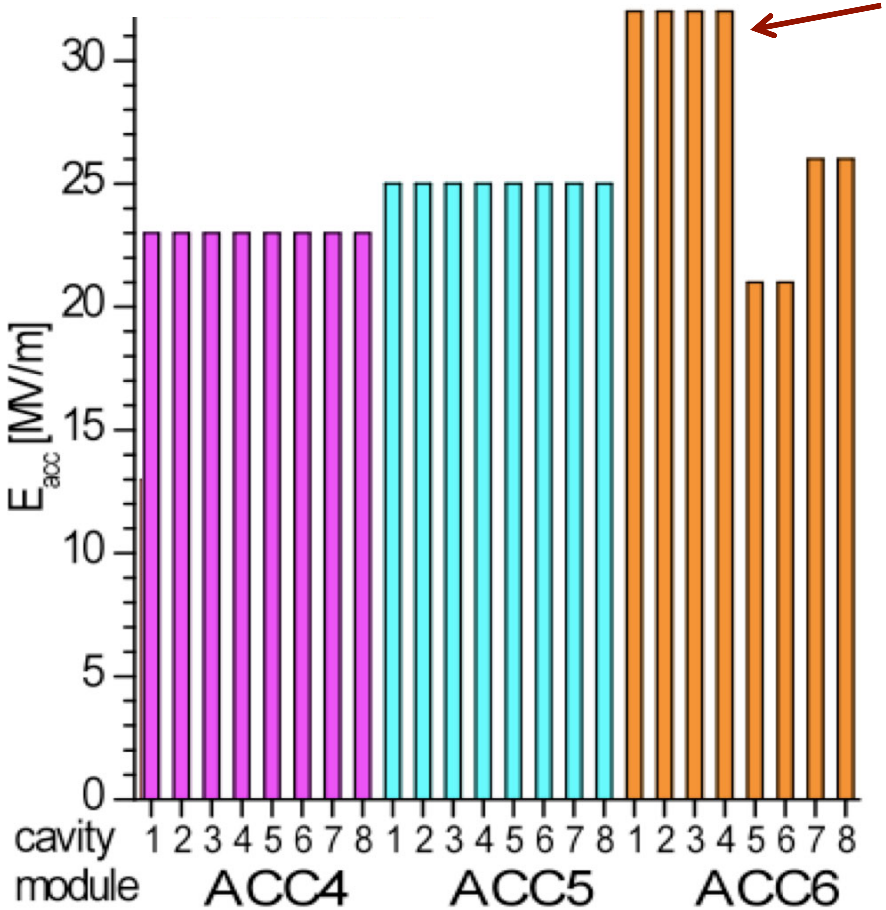
- 9mA, 800us: Qexts set for flat gradient without beam (before subtracting 2MV/m for operating margin)
  - **Nominal maximum vector sum: ~24MV/m**
  - **Average for ACC6 Cav 1-4: ~27MV/m**
  - **Maximum vector sum with optimized coupling: 27MV/m**
  - **Average for ACC6 Cav 1-4: ~32MV/m**

- Tuning Qexts for zero tilt at 9mA should gain some gradient, but cavities will quench unless there is full beam loading

- At maximum gradients, rf power levels are at the thresholds of causing arcs on cavity circulators and klystron waveguide
  - **Piezo compensation of LFD will be critical**

Extrapolating to ILC gradients

Extrapolating to ILC gradients



- 1/2 cryomodule could be running close to ILC gradients with ILC beam
- Opportunity to study:
  - **Lorentz-force detuning + piezo compensation near ILC gradients**
  - **rf overhead near ILC gradients**
  - **rf distribution system near ILC cavity powers**

- Broadly, we get information on operating cavities with full beam loading, eg
  - **Piezo compensation of LFD**
  - **Running high gradient cavities close to quench**
  - **Vector Sum field regulation**

Comparison of gradient-related operational issues

	RDR	ACC4-6	
Nominal maximum operating gradient over all cavities in RF unit	31.5MV/m	~27MV/m	
Spread in nominal maximum operating gradients	31.5MV/m +/-0	21-32MV/m (4 cavities at 32MV/m)	
Number of cavities operating at 31.5MV/m or above	26 of 26	4 of 24	
Cavity quench limits	All: >33MV/m	Range: 21-35MV/m	
LFD compensation with piezos	All cavities	ACC5,6 (16 cavities)	
Operate cavities close to quench?	Yes	Yes	

Last few slides…

FLASH long-range schedule

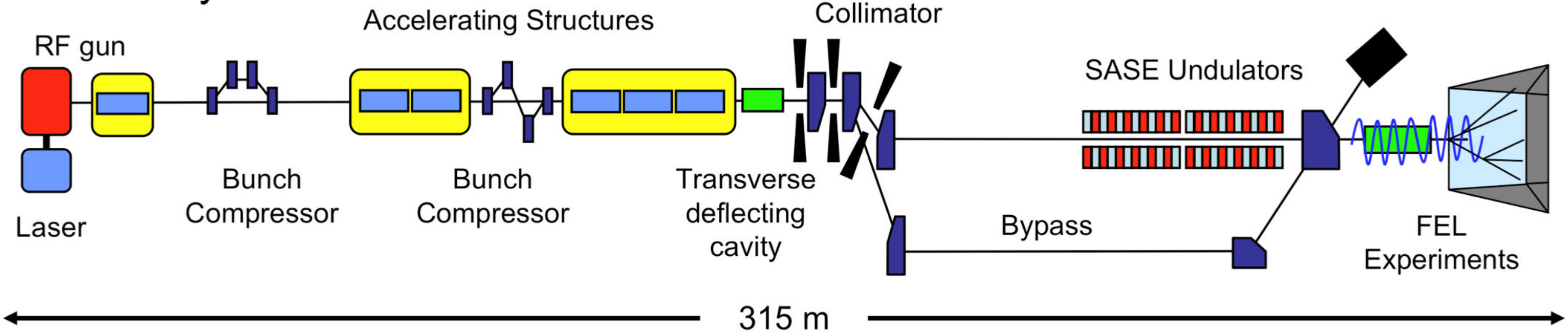
- Shutdown for FLASH upgrade: Sept 21 – March 09

- Re-commission + machine & FEL studies: ~ 3months
- Restart operation for photon users: Summer 09
- User operation continues until end 2011
- Shutdown for FLASH-II upgrade: early 2012

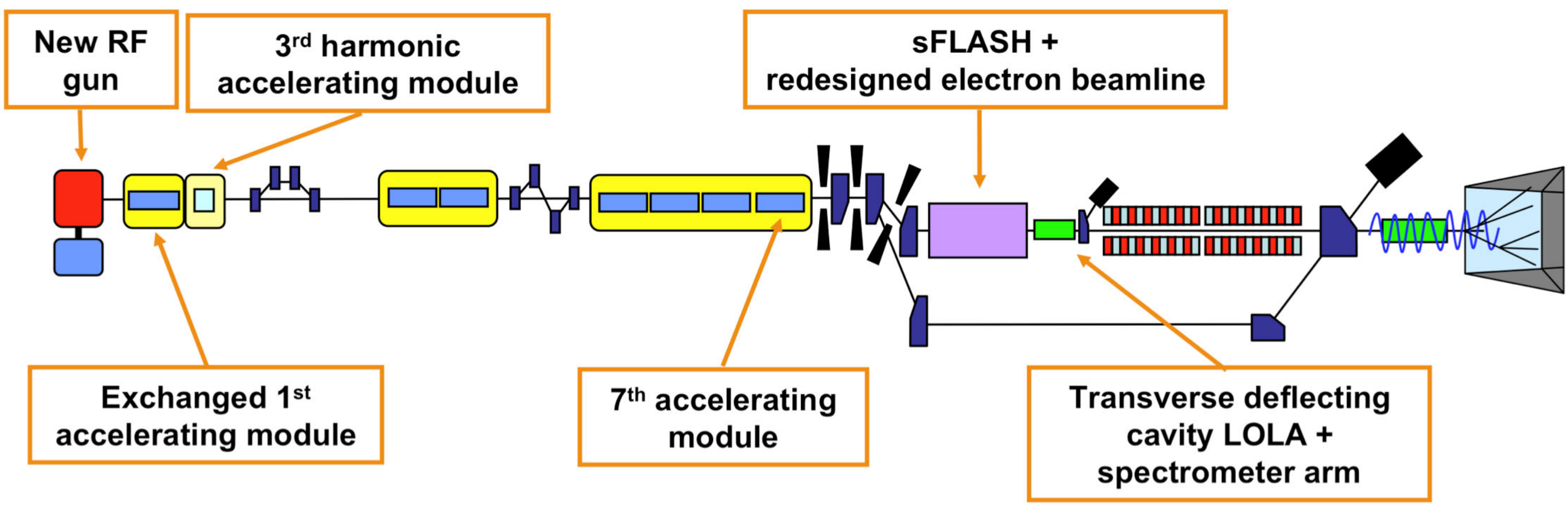
FLASH Upgrade 2009/10

FLASH
Free-Electron Laser in Hamburg

Present layout



New layout

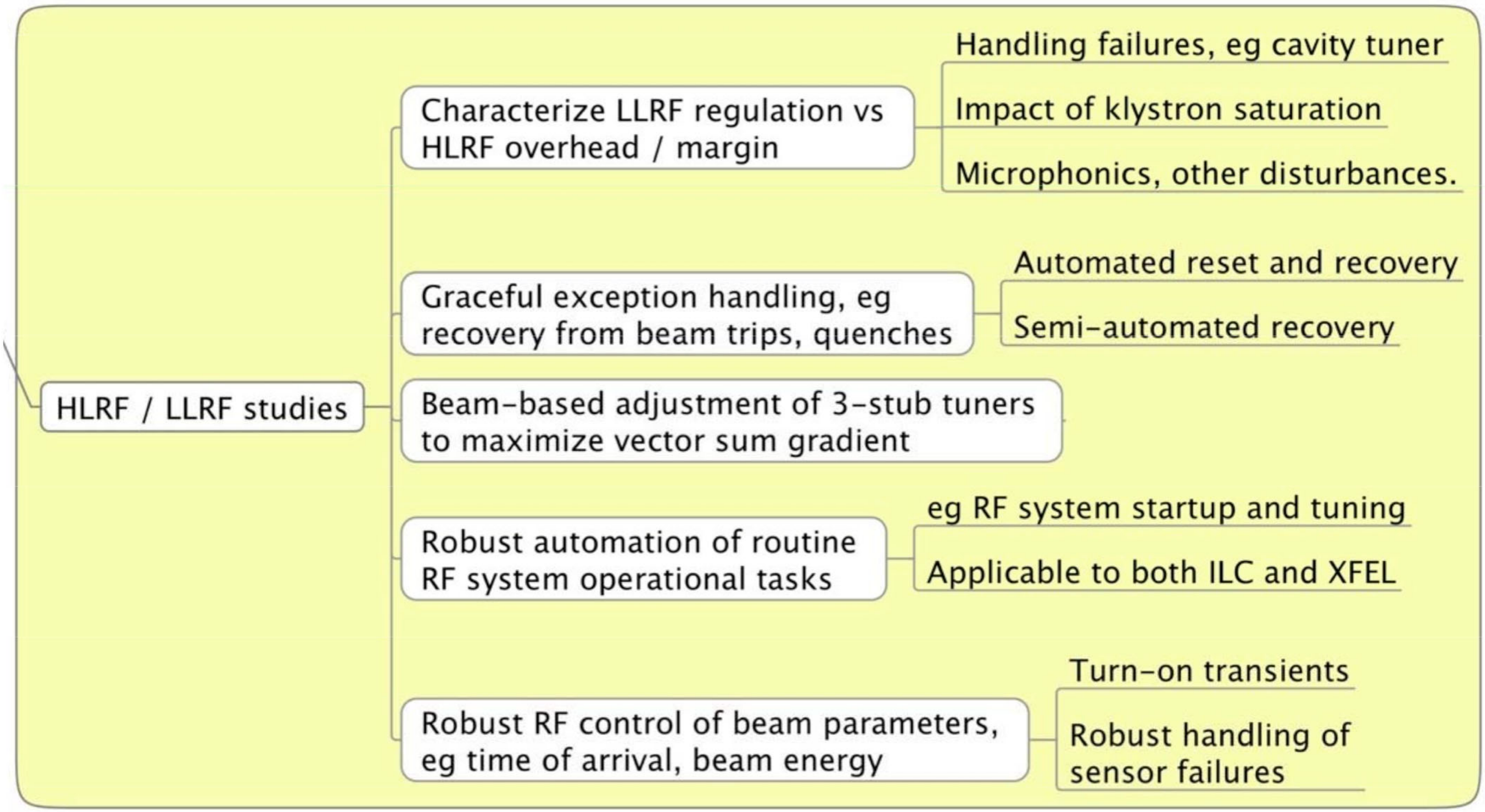


Possible future ILC studies at FLASH

- The new RF distribution system means we no longer have an ILC-like RF unit (now 16 cavities / klystron)
  - **Not a “show stopper” for String Test demo**

- If the machine can be operated reliably with high beam power, then the 9mA program could continue.
  - **Continue with the major 9mA program topic areas**
  - **Add: priority 2 an 3 items not covered earlier**
  - **Add: new ILC-related studies, eg RTML (Nikolai)**
  - **Add: studies of mutual interest to ILC and XFEL**

HLRF/LLRF Integration studies



Wrap-up

- FLASH is the only facility where possible to run ILC-like beams until after 2012
- Average gradients are lower than the ILC reference unit, but the same gradient-related issues will be encountered and studied
- Two weeks of 24/7 studies in Sept give an opportunity to achieve ILC-like beam current, pulse length, and energy stability
- We should not under-estimate the operational challenges – much is already being learnt about running high power beams
- The program has strong support from DESY and there is strong international participation.

Backups

Accelerating Modules

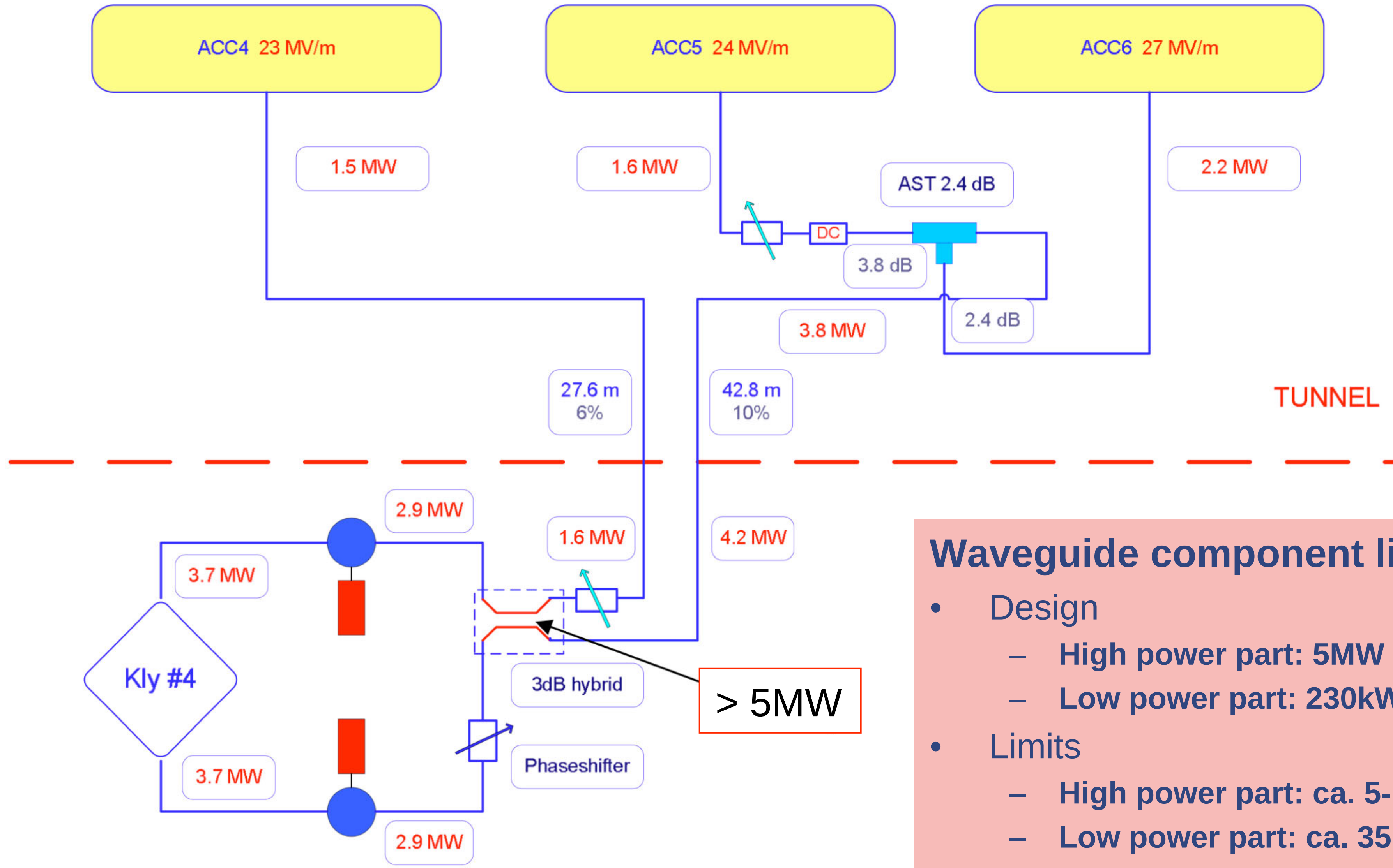
Six accelerating modules were installed into the TTF tunnel as a part of the FLASH Linac
Each module has 8 superconducting cavities and RF power input couplers

position	module	type	assembled	coupler type	cold window	warm window
ACC1	2*	II	Jan. 2004	FNAL/TTF III	Conical/Cyl.	Planar/Cyl
ACC2	1*		Mar. 2000	FNAL/TTF II	Conical/Cyl.	Planar
ACC3	7		Dec. 2006	TTF III	Cylindrical	Cylindrical
ACC4	4	III	Jul. 2001	TTF II	Cylindrical	Plane, WG
ACC5	5		Jun. 2007	TTF III	Cylindrical	Cylindrical
ACC6	6		May. 2006	TTF III	Cylindrical	Cylindrical
ACC7	8		upgrade	TTF III	Cylindrical	Cylindrical

After upgrade ACC1 will be module 3** (Typ II, TTF III couplers), ACC7 will be added.

ACC4-6 RF Power Distribution

Waveguide distribution for klystron #4 *(status 06.08.07)*



Waveguide component limits

- Design
  - **High power part: 5MW max**
  - **Low power part: 230kW max**
- Limits
  - **High power part: ca. 5-7MW**
  - **Low power part: ca. 350kW**

S. Choroba

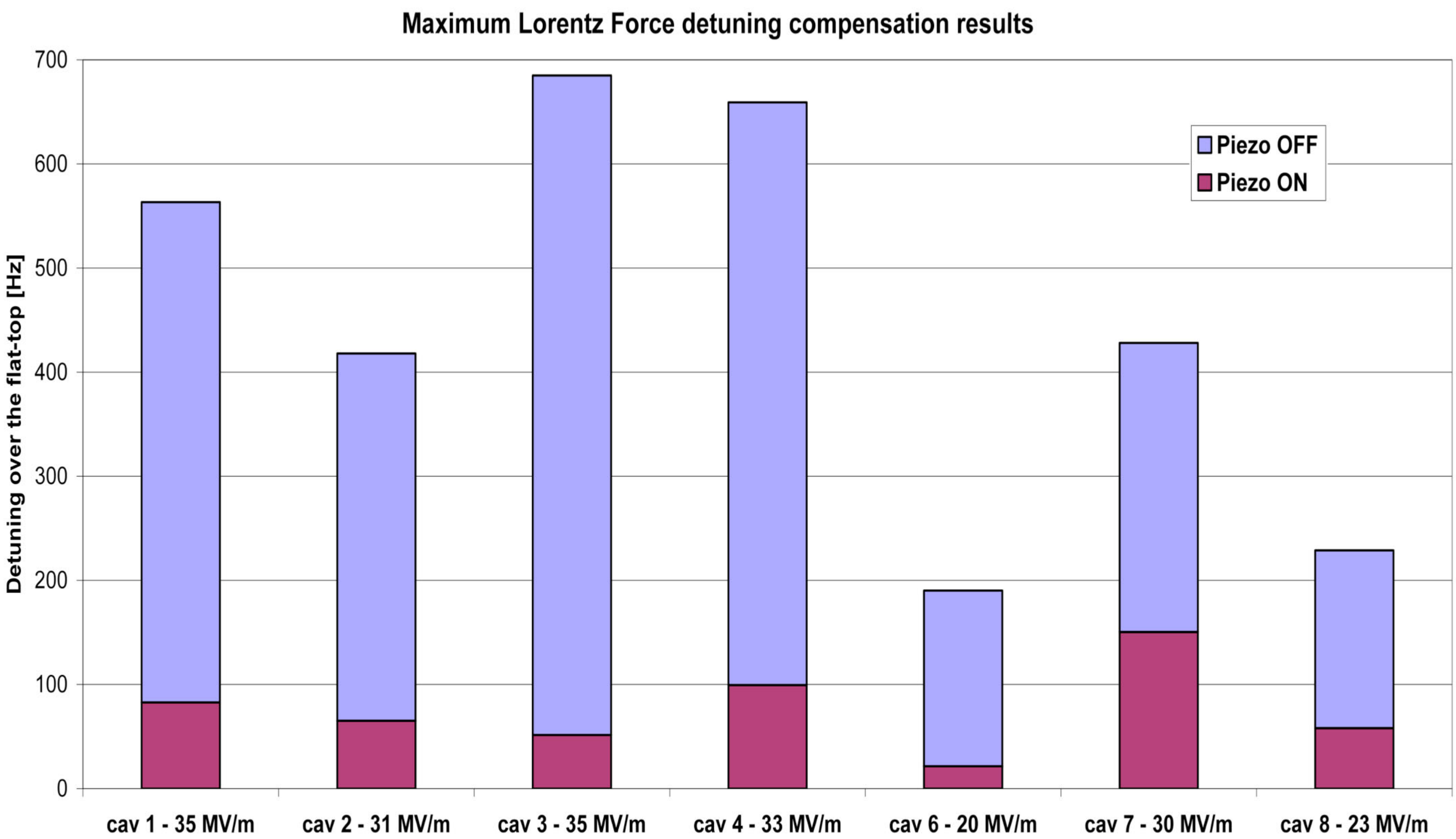
Sept 08 studies shifts summary

Goal			
Calibrate by-pass BLM	1.5 shifts	➽	
Install/commission by-pass TPS	1.5 shifts	➽	software mask problem prevented long-pulse operation until Friday AM
Injector set-up for 3nC bunches (laser/gun set-up) Loss-free transmission to dump via bypass (optics & steering)	3 shifts	➽	Achieved complete loss-free transmission up to our max of 550 bunches (after LLRF tuning)
Gradually increase bunch number @ 1MHz (3mA) as far as possible; identify problems and constraints. HOM absorber measurements	3 shifts planned ¾ shift achieved	➽ ➻	• Actually achieved* ~2.5 mA with (max) 550 bunches (μs) at ~880 MeV to dump after about four-hours tuning (LLRF). • An average beam power of ~6 kW (final goal 36 kW). • ΔT reported on HOM absorber consistent with current.
Not planned!!		➻	Dump vacuum failure at ~13:00 on Friday 26.09

*) 3nC at gun – but ~20% was estimated to be lost at gun collimator to reduce downstream losses

Maximum Compensation per Cavity

(Module Test Stand)



TTF high current long bunch train result:
1800 bunches @ 2.25MHz, 3.5nC/bunch

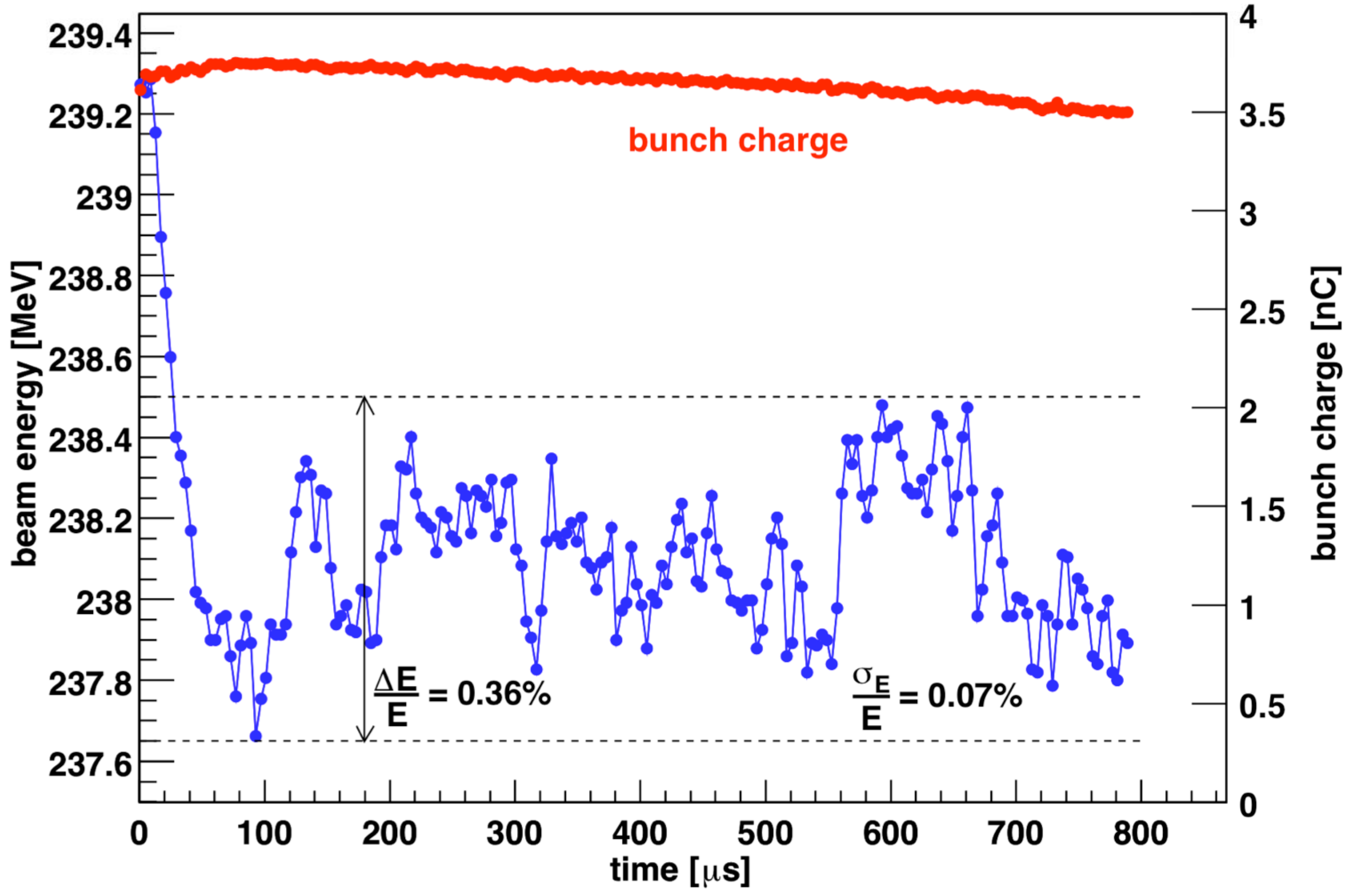


Figure 3.11: Acceleration of long macro pulses. The beam energy and the bunch charge within one single macro pulse are shown. The RF control system was operated with beam loading compensation. The bunch spacing was 444 ns.

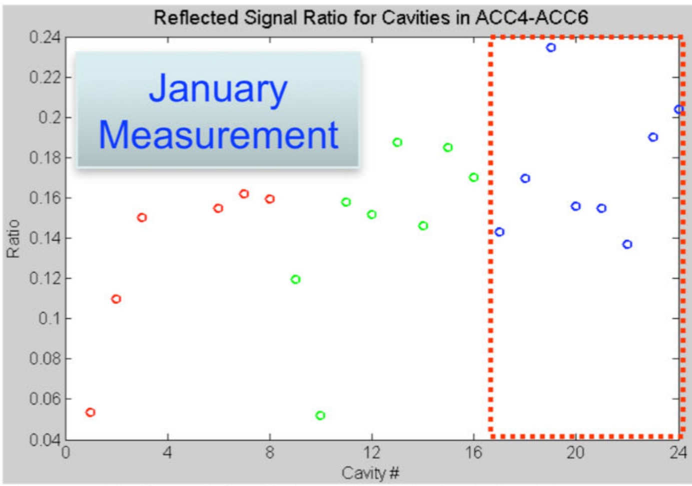
LLRF regulators presently installed

Unit	Systems installed		Systems under development	
	C67 System (2004 design)	Simcon-3.1 (2006 design)	Simcon-DSP (2008 design)	ATCA System (late 2008)
RF Gun		✔		
ACC-1		✔	*(being tested)*	
Devt. System		✔		
ACC-2/3	✔			
ACC-4/5/6	✔		*(being tested)*	

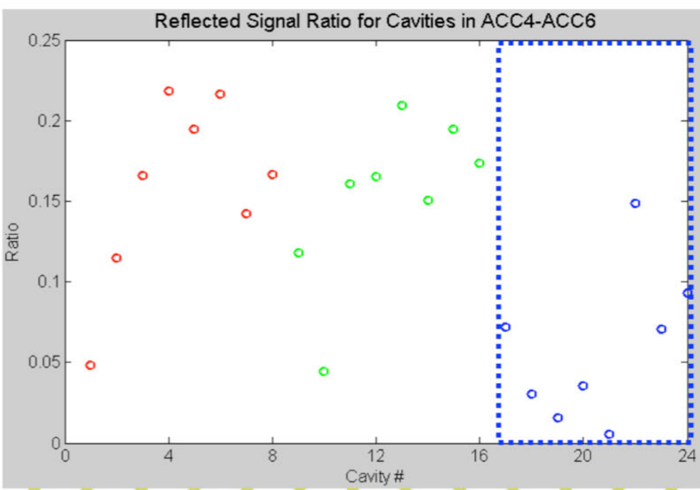
- Planning to upgrade C67 systems to 'Simcon' systems
  - **Simcon-DSP is already undergoing testing at FLASH**
  - **Simcon-ATCA is still being developed (XFEL prototype system)**

See Stefan Simrock's talk

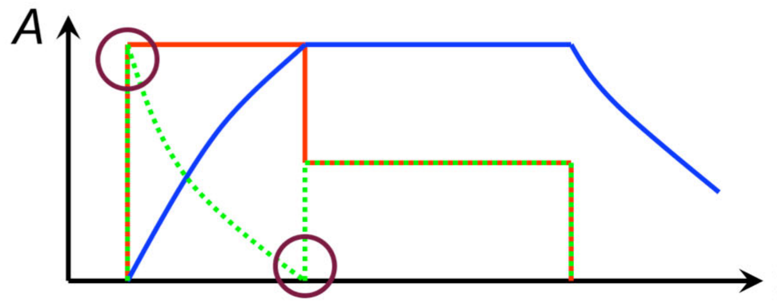
Reflected Ratio for Piezo On/Off

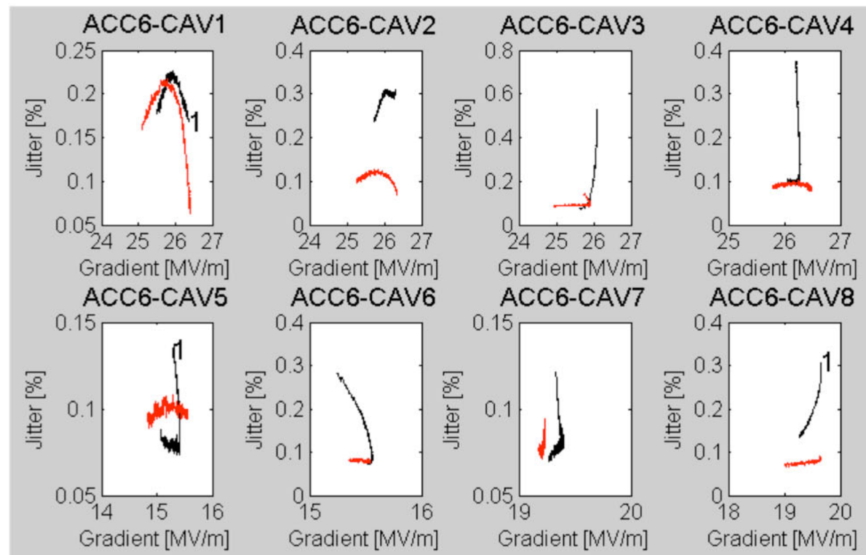


Piezo Off with Nominal Initial Detuning



Piezo On with Nominal Initial Detuning



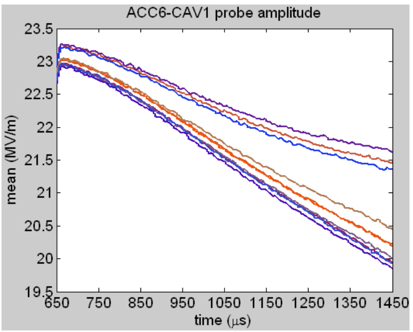


Red → Nominal Initial Detuning with Piezo Off.
Black → Nominal Initial Detuning with Piezo On.

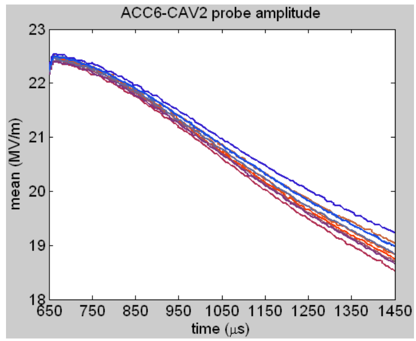
Piezo works well to reduce the reflection ratio (hopefully will minimize the rf power overhead) but adds some jitter as expected.

Measurement of ACC6 cavity probe amplitudes: flat-top jitter

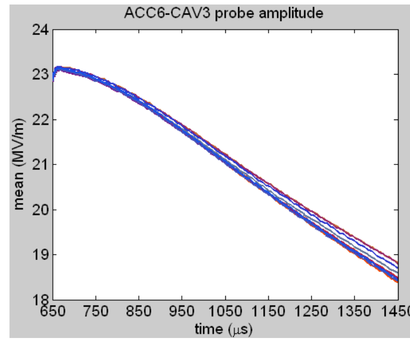
ACC6 with FB Off, AFF off, 100 pulses, 800us flat-top



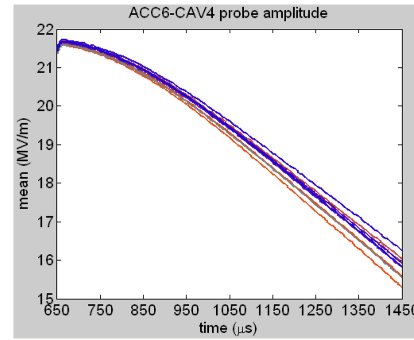
CAV1



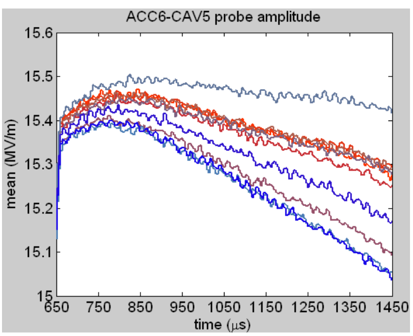
CAV2



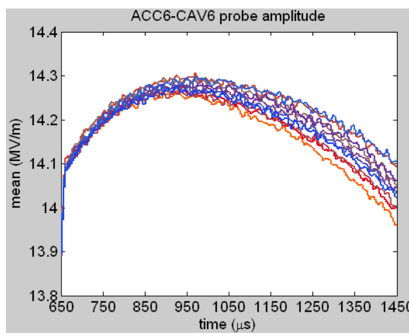
CAV3



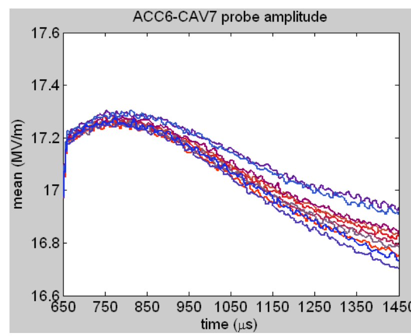
CAV4



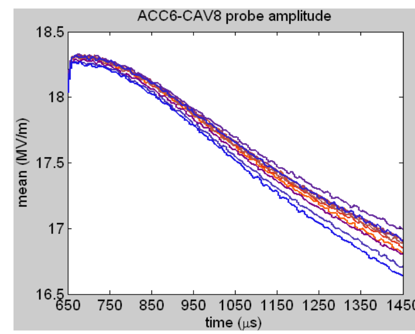
CAV5



CAV6



CAV7



CAV8

- Gradient slope is different for different cavities
- Jitter increases along the flat top
- Some cavities have worse jitter than others (worst is cavity 1)