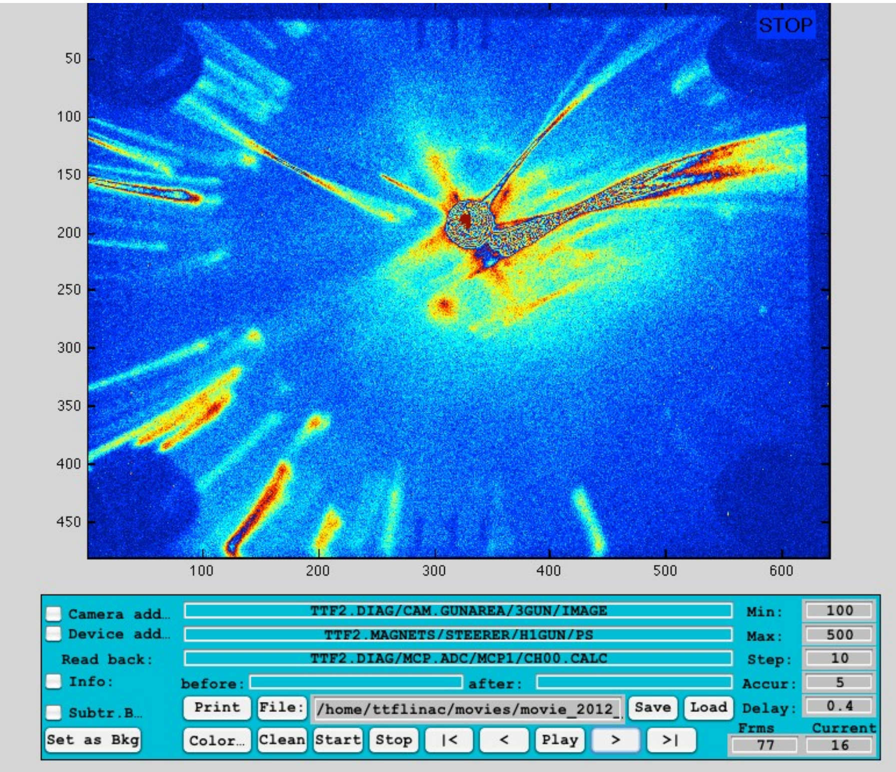
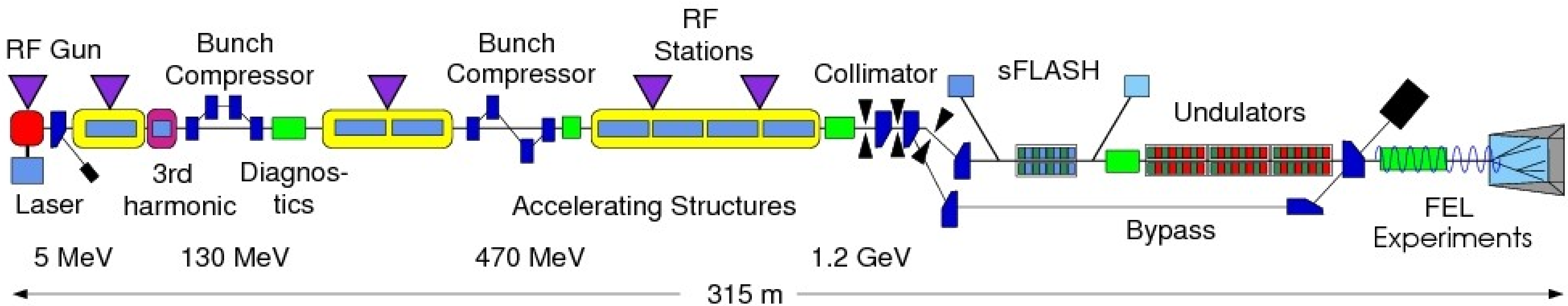
Examples of Beam Loss Mechanisms at FLASH

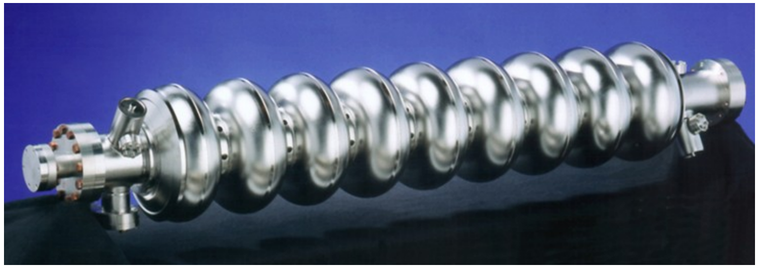


Gun Dark Current
Beam Losses in Collimator
Beam Losses due to Change of Beam Loading

Free Electron **Las**er in **H**amburg – FLASH



- Linac with superconducting RF cavities, 1.3 GHz
- Short bunches, flexible bunch pattern, low emittance ...



Field emission(RF gun gradient ~45 MV/m) → Dark Current → Protection of Undulators

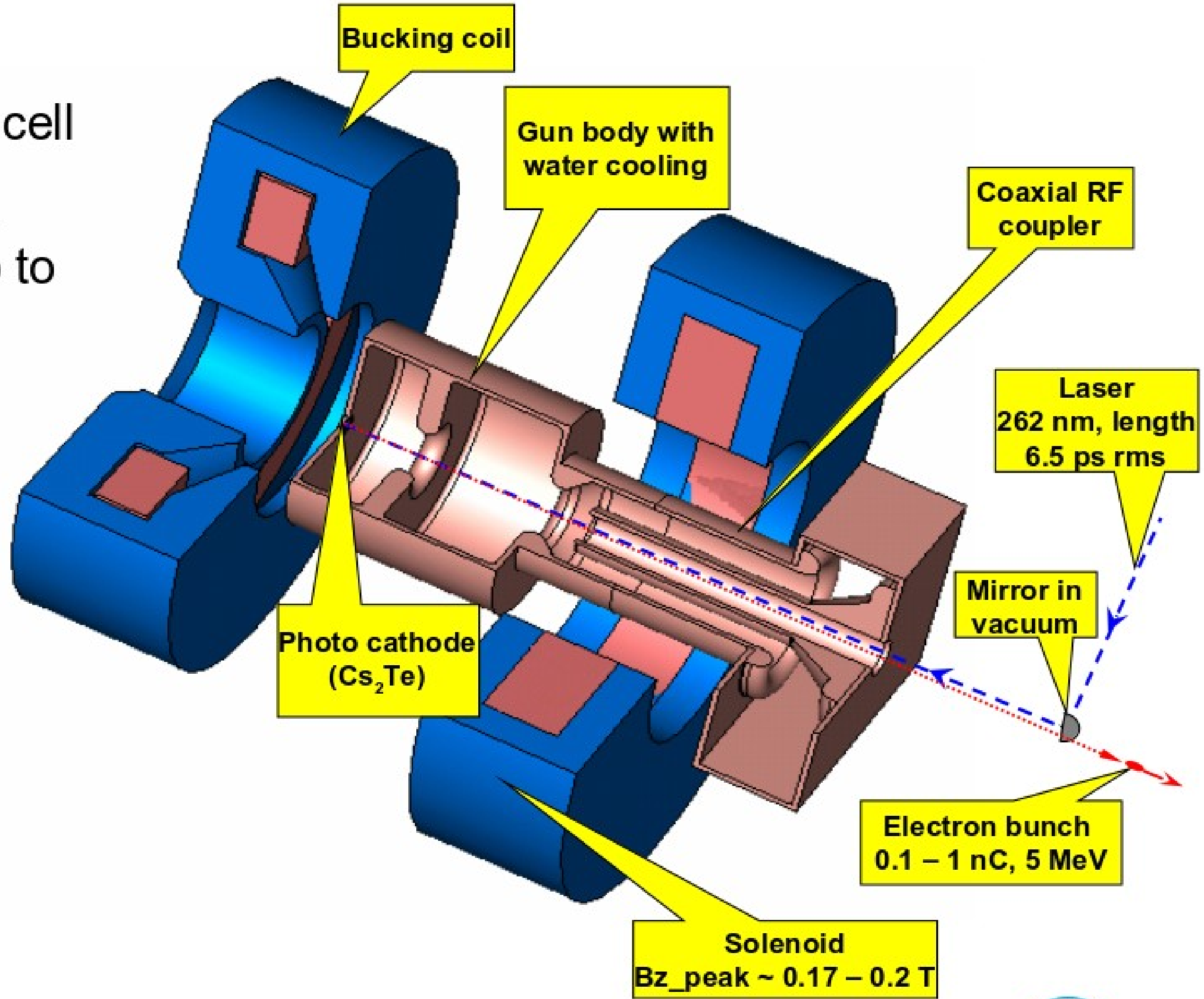
'Predictable sources' of beam losses : screens, wire scanners, LOLA Kicker
Beam losses in collimator are 'pre-programmed'

Toroids & Beam Losses Monitors are there to protect the machine from damage

Gun Dark Current

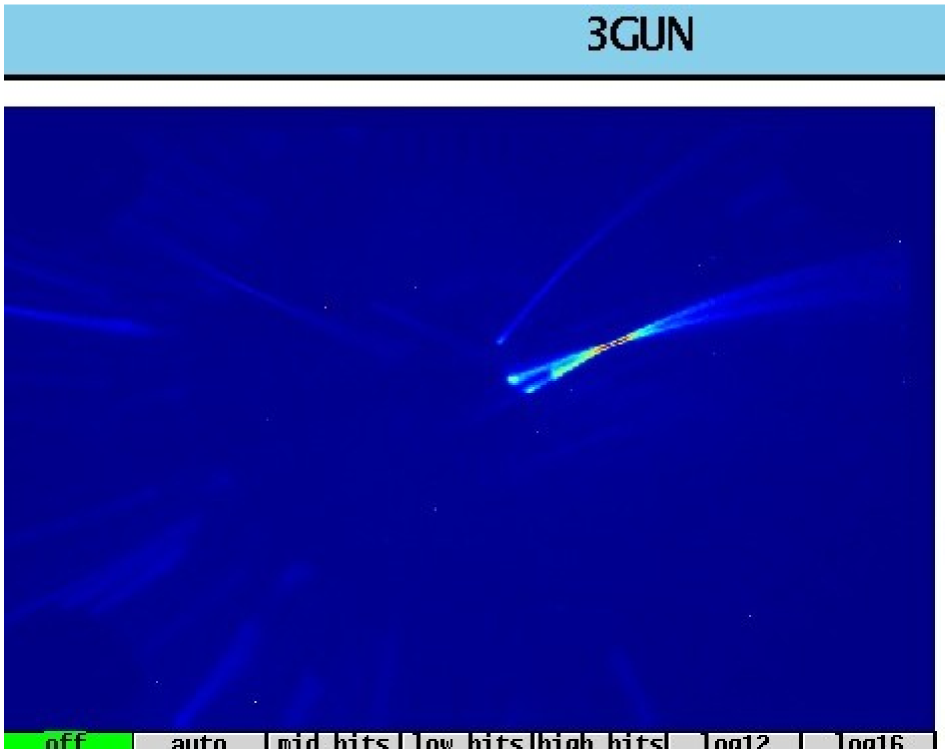
RF Gun

- RF gun: 1.3 GHz copper cavity, 1 ½ cell
- RF power 3.8 MW, RF pulse length up to 850 µs, 10 Hz
- New gun tested and commissioned at PITZ (DESY-Zeuthen)



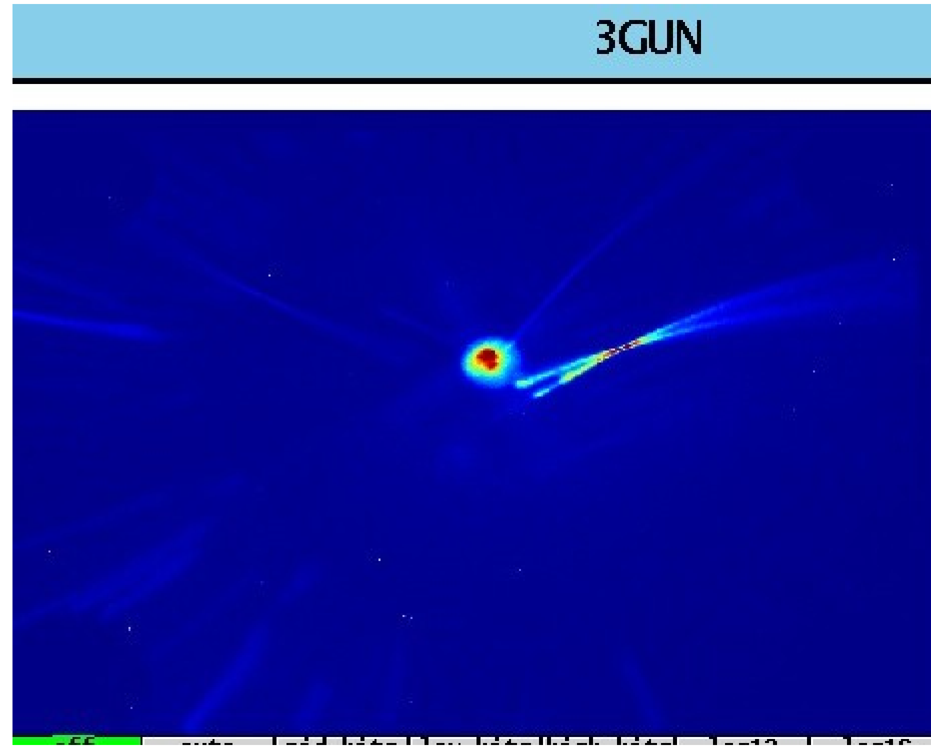
An Example of Gun Dark Current

as seen on 3GUN Ce:YAG Screen



2012-05-29T16:07:25-00

No beam (laser off)



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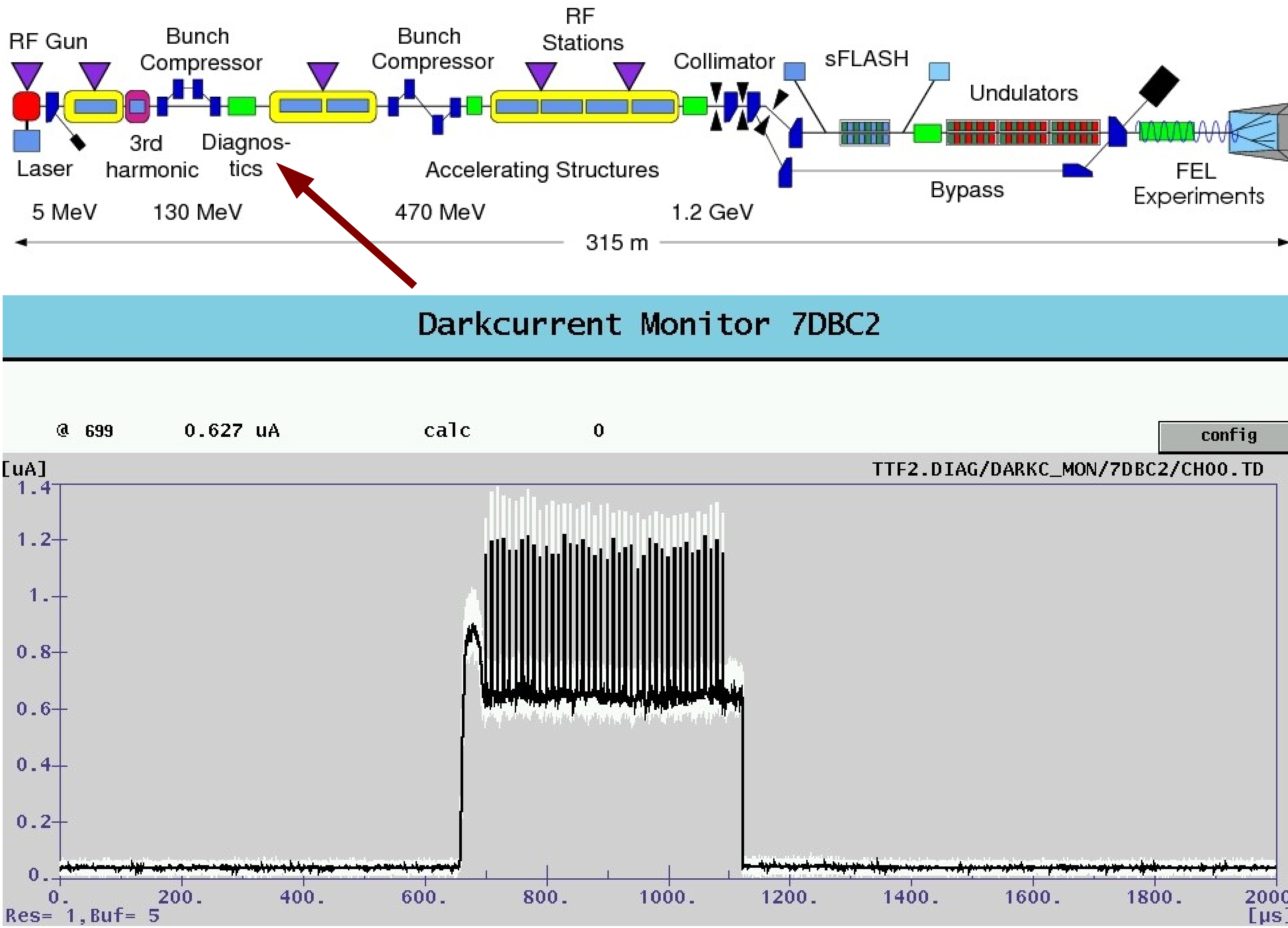
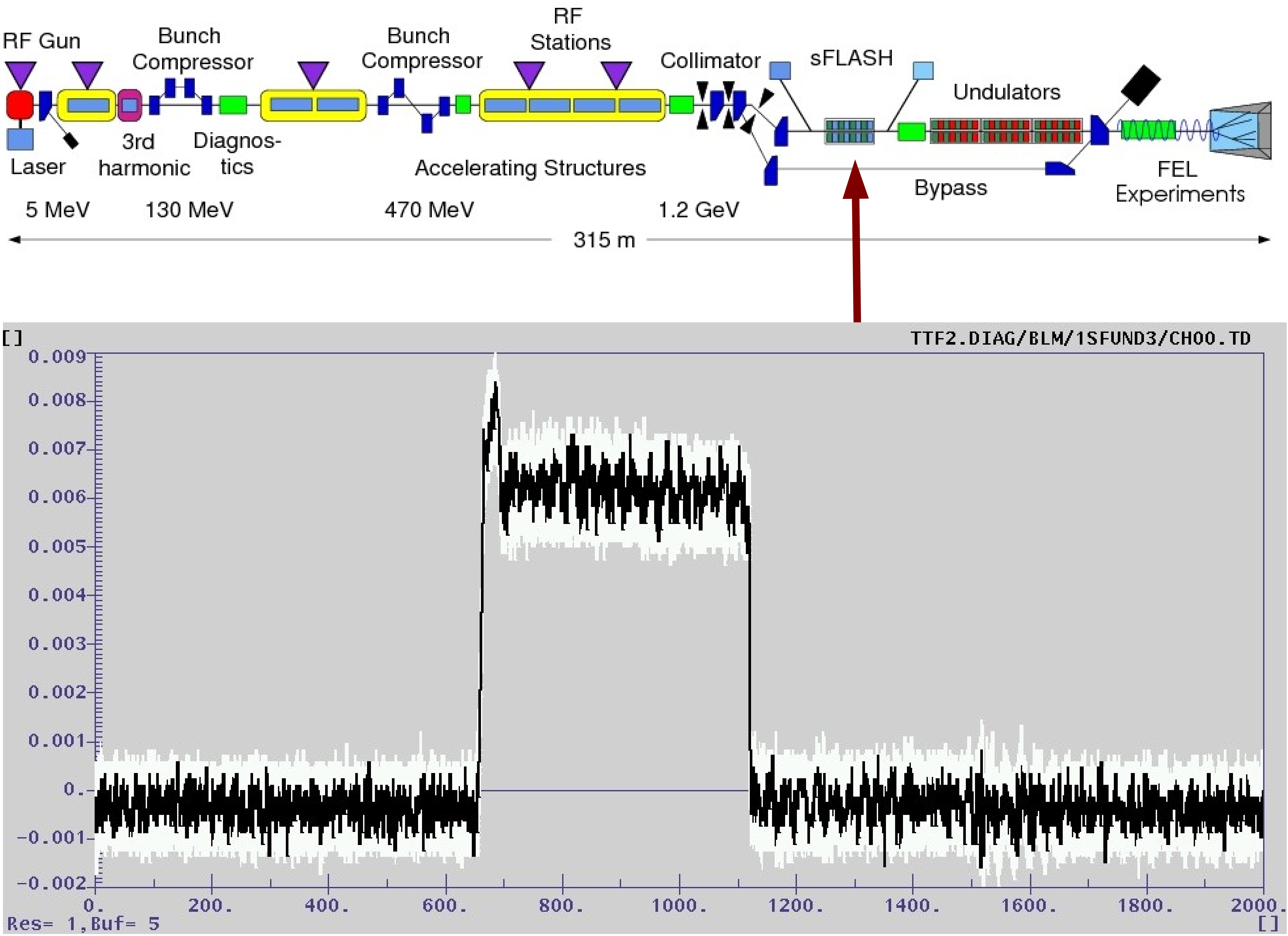
With beam (laser on)

Dark Current Monitor

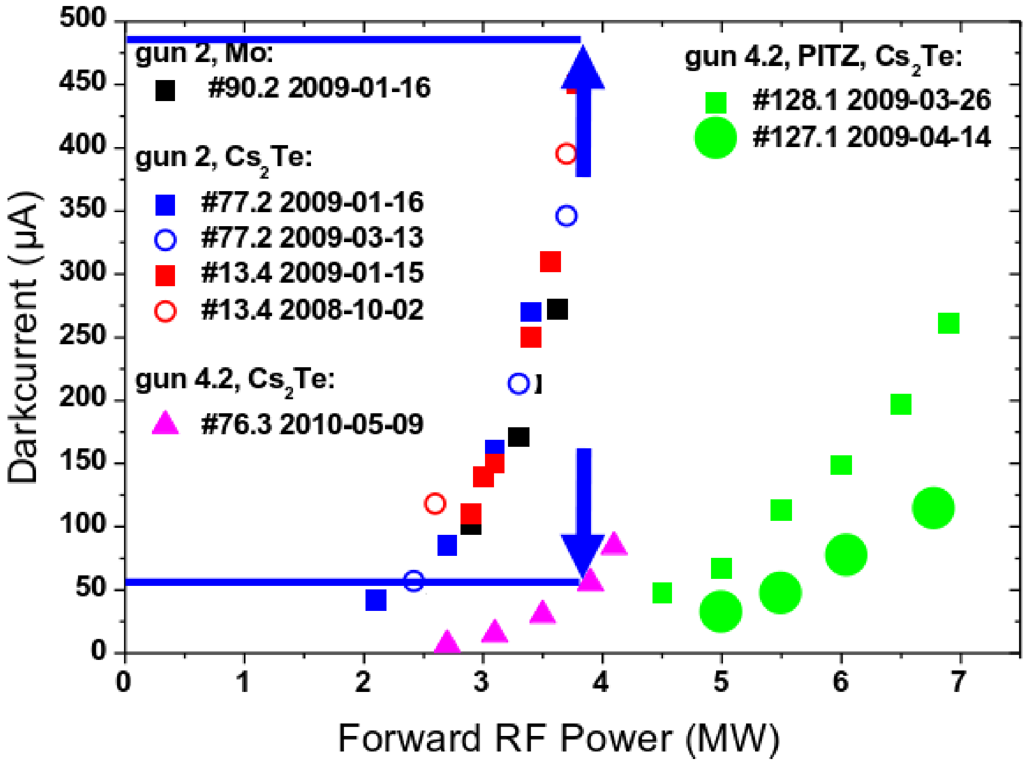


Transport of the Dark Current

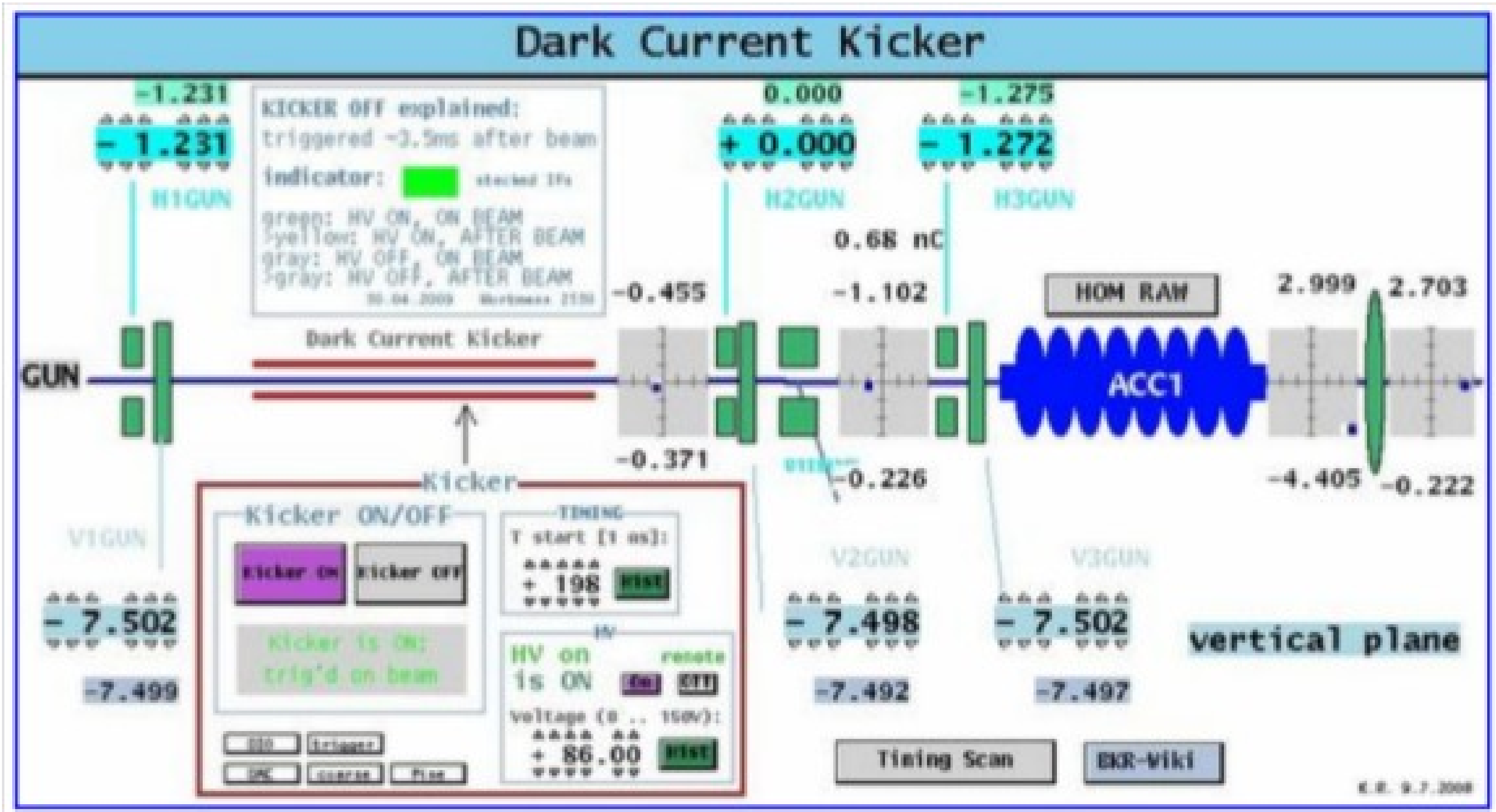


RF gun darkcurrent

- Dry ice cleaned gun body
- Darkcurrent is reduced by a factor of 10 compared to previous guns
- This allows operation with 10 Hz and in the future with higher gradients



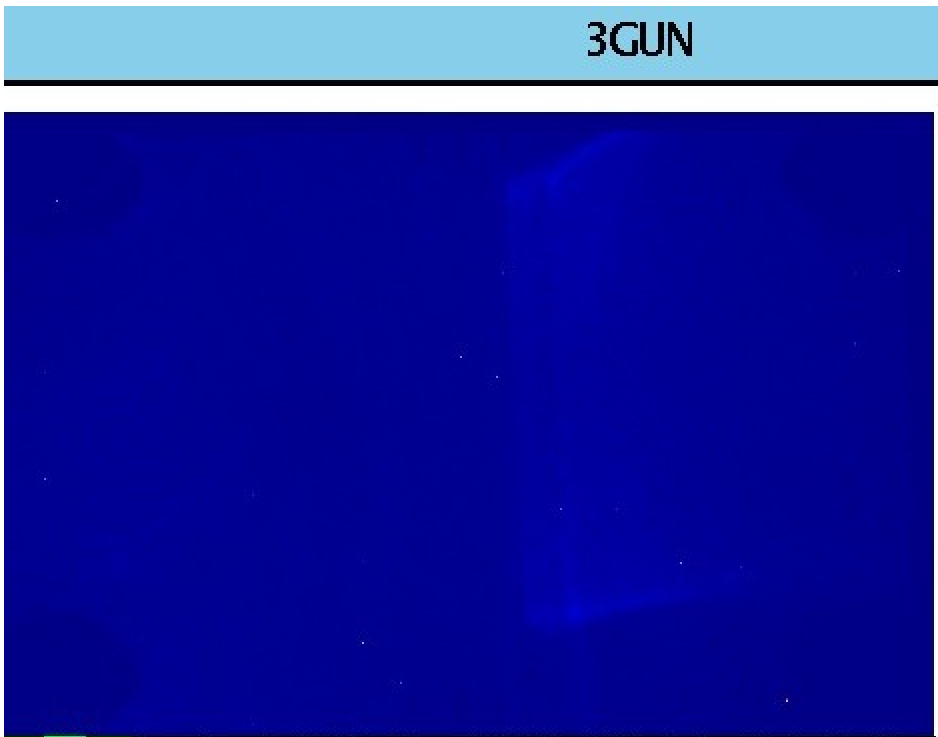
Dark Current Kicker

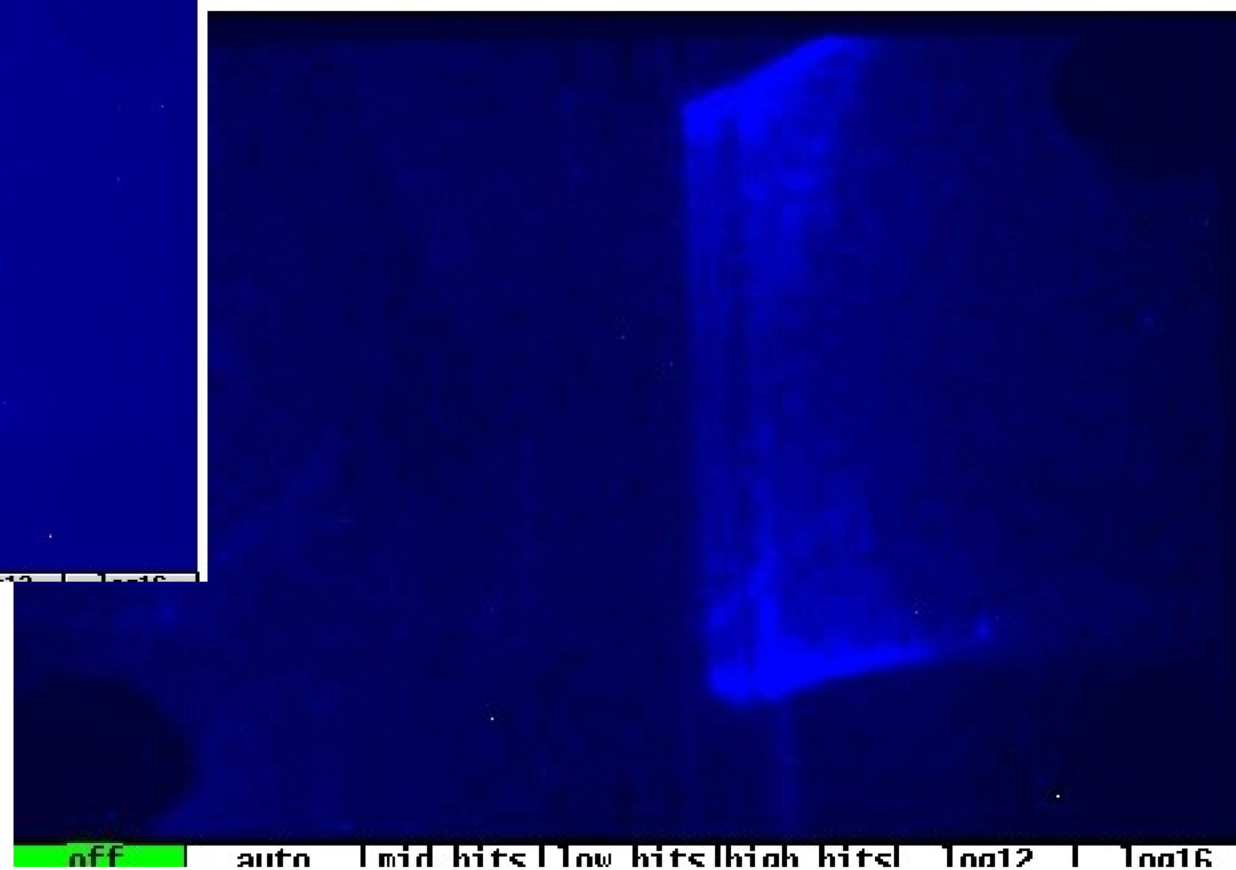


Gun Dark Current: Kicked !

29.05.2012 16:58 S. Schreiber, S. Lederer **screen 3GUN**

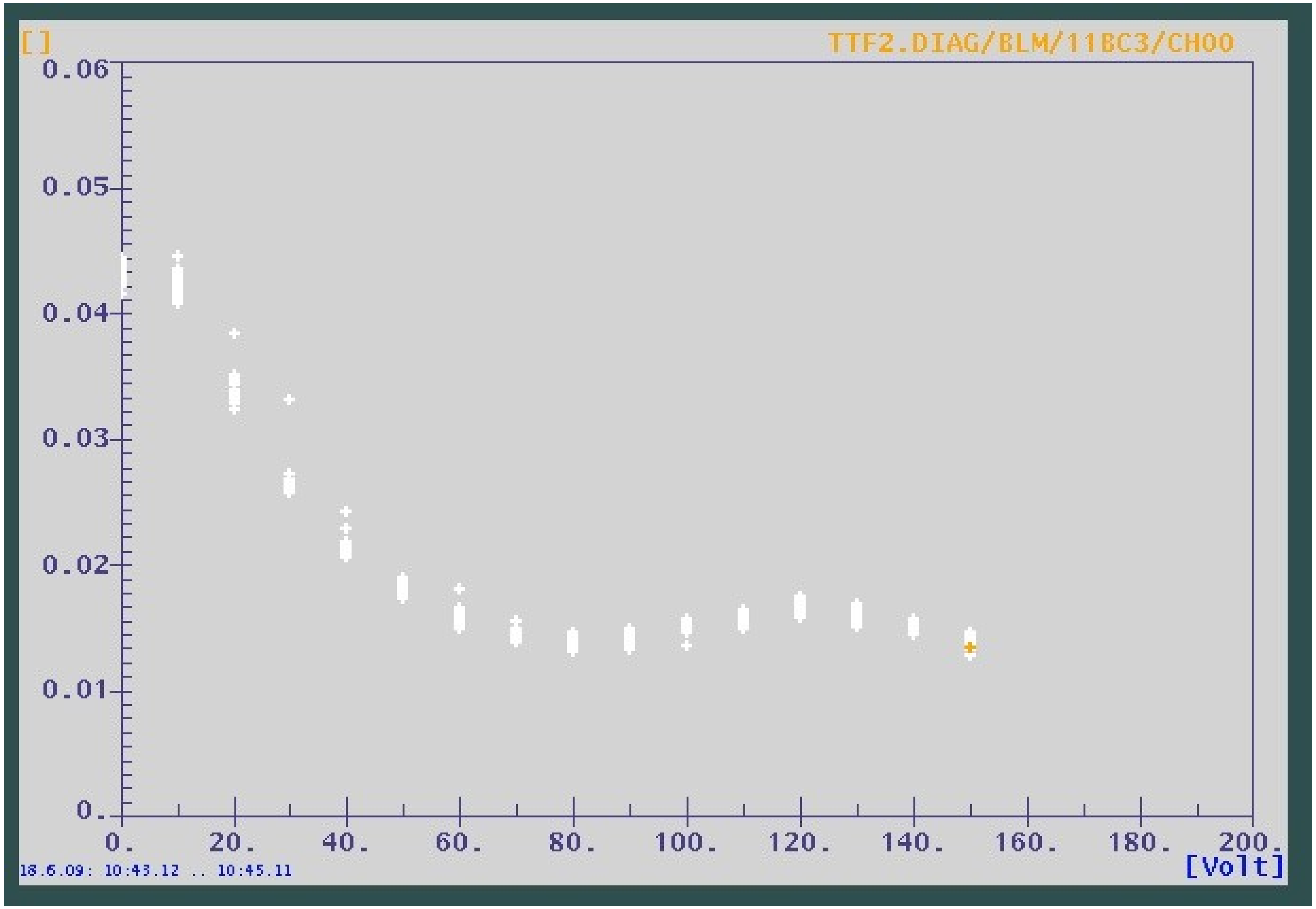
- darkcurrent kicker back on
- screen moved out
- collimator moved in
- valve ACC1 opened





Contrast enhanced

BLM Signal vs Dark Current Kicker Voltage



Please note: old data !

Beam Losses in Collimator

Layout and Functionality of Collimator System

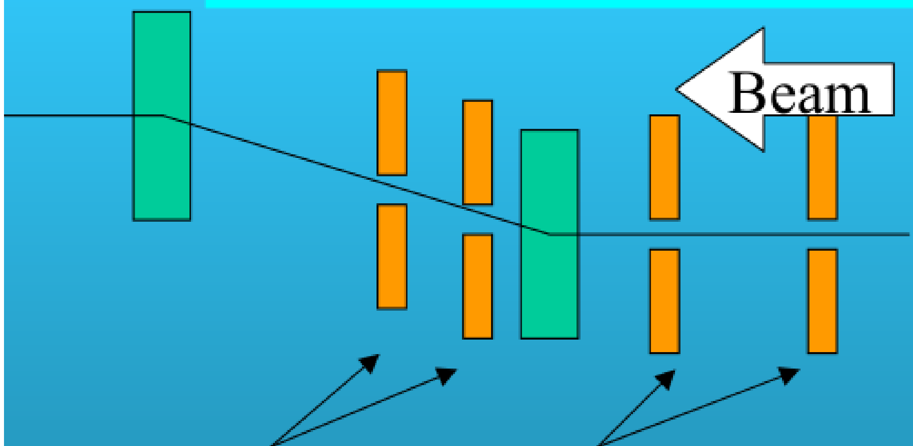
Purpose: Protection of Permanent Magnet Undulator

transversal collimation ⇒ beam halo separation
energy collimation ⇒ dark current separation

TTF2 Design for high average beam power

- 72 kW average beam power

  1 nC, 800 µs, 9 MHz, 10 Hz, 1 GeV

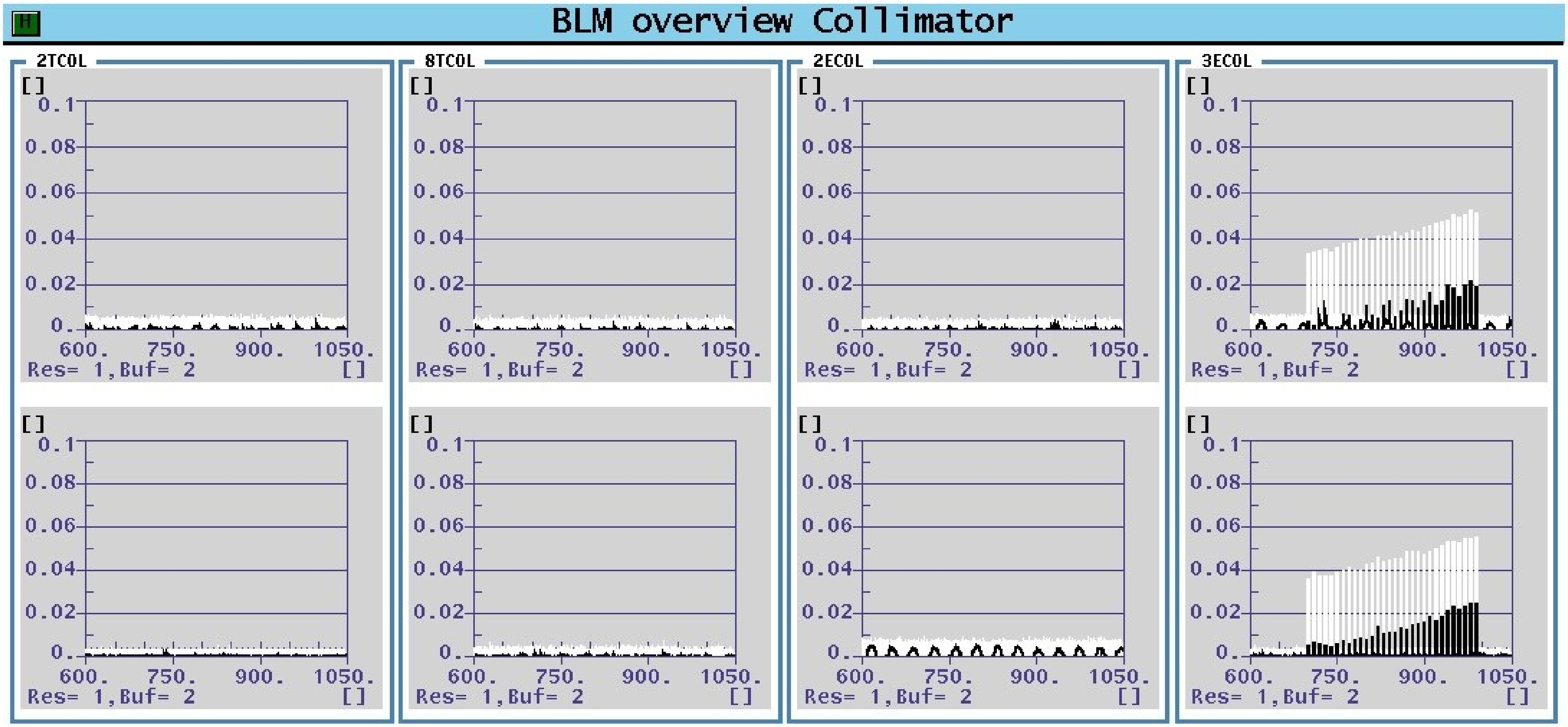


Energy & Transversal Collimation

Collimator Scheme

Design take into account:
beam dynamics
material science
interaction of e- and collimator

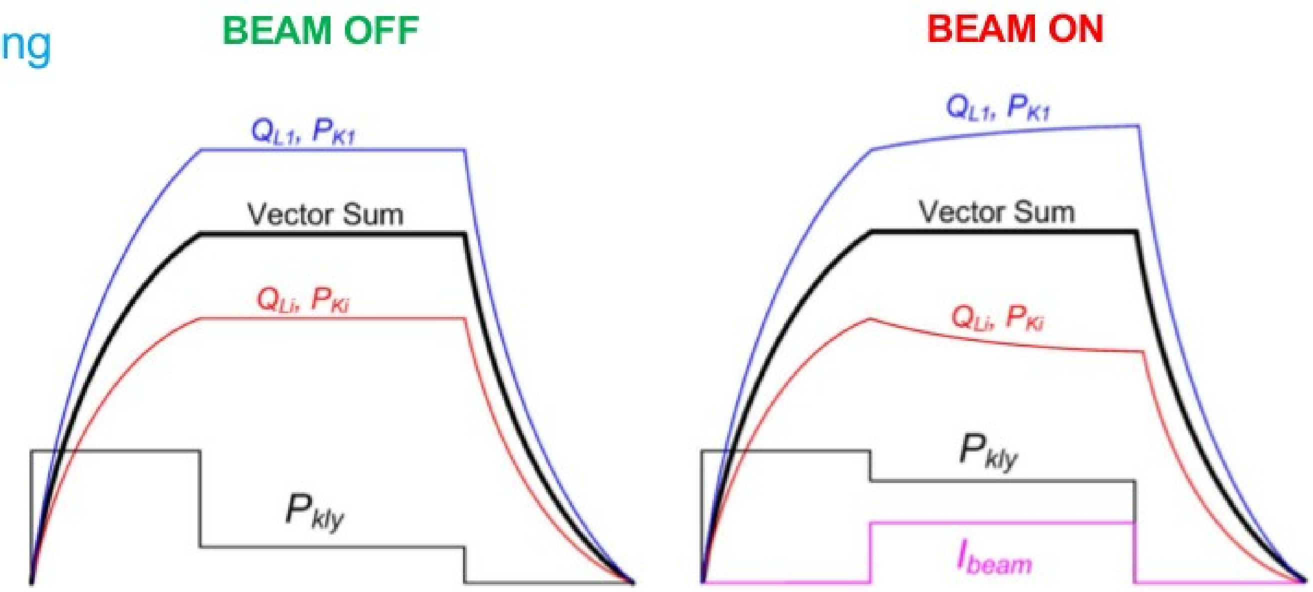
An Example of Beam Loss in Collimator



Beam Losses due to Change of Beam Loading

II. Some key concepts to understand the ILC study

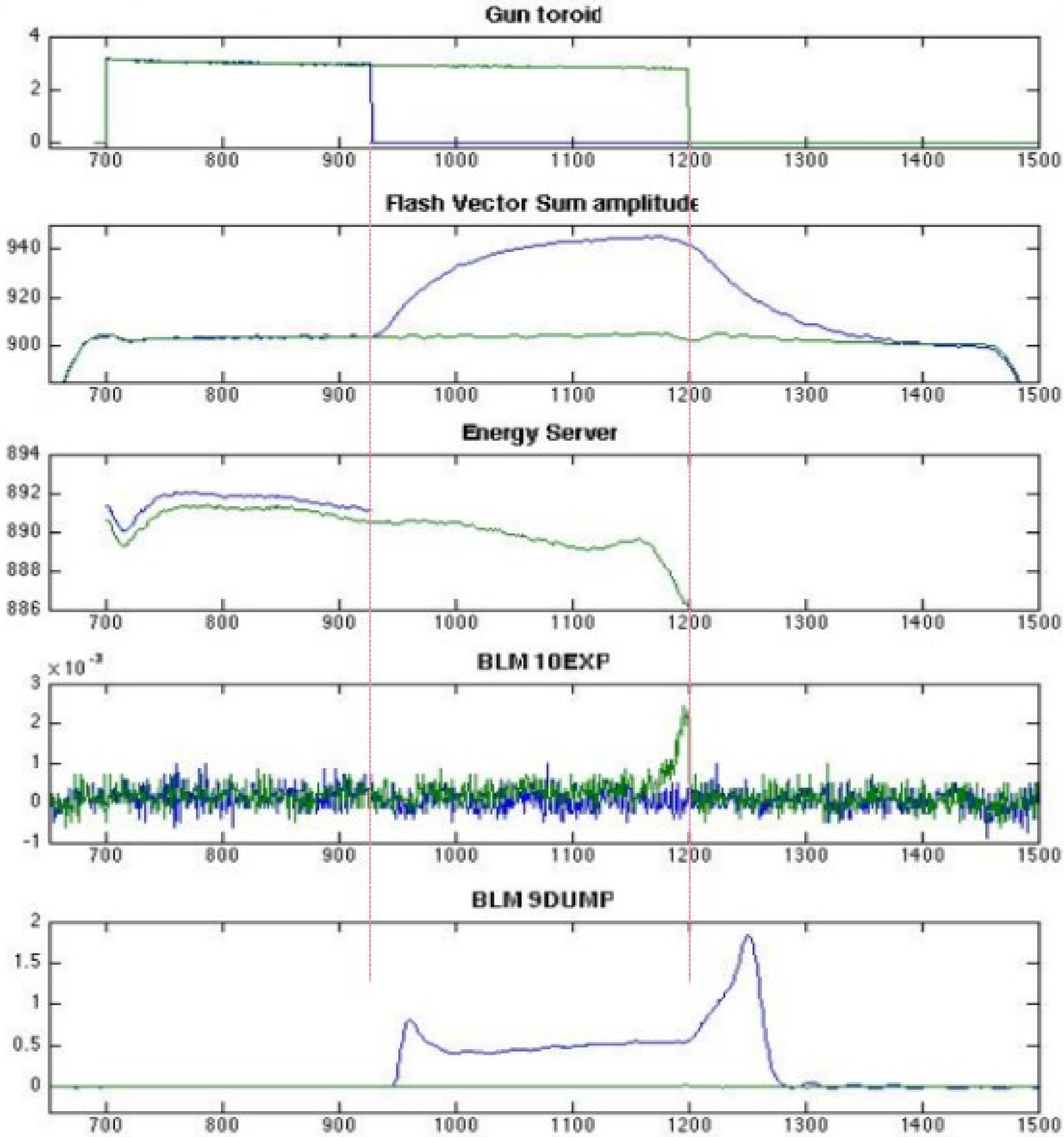
> Beam loading



> Why do we care about individual flat gradients?

- "Effect of Cavity Tilt and RF Fluctuations to Transverse Beam Orbit Change in ILC Main Linac" K. Kubo, Jan. 2010

Correlation with BLMs for two consecutive pulses
(First: full 500 bunches; second: MPS inhibit after ~230 bunches)



Green traces: full 500 bunches
Blue traces: terminated early

VΣ rises when beam loading lost. Falls at end-point of adjustment to FF table for BL compensation

Energy droops at end of bunch train because BL compensation ends before bunch train

BLM signal rises as energy droops. (Energy aperture?)

Large signal on terminated case, that starts after the bunch train terminates (dark current)

Courtesy J. Carwardine

Instabilities after a trip

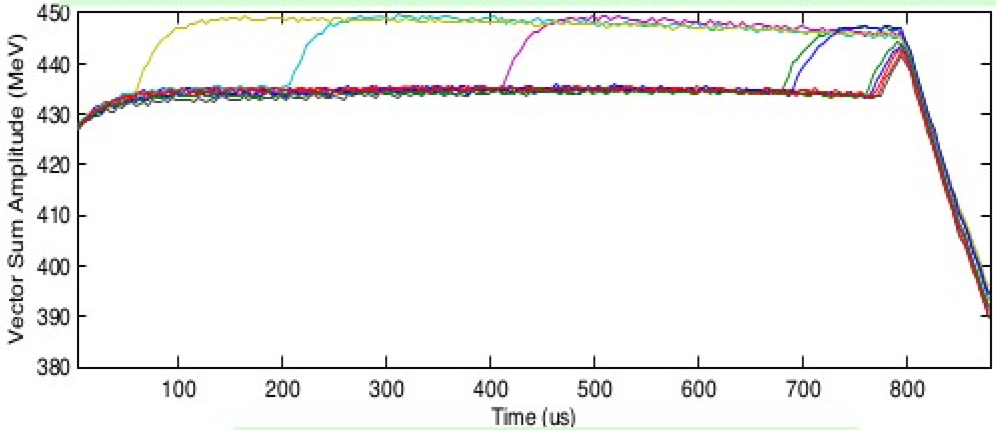
FLASH. Free-Electron Laser in Hamburg

Instabilities induced by a simple trip somewhere in the train

- A cut in the bunch train causes changes of temperature load on
  - RF to modules (transition in beam loading)
  - Laser: since we cut before last amplifier, load change effects the laser stability as well, most important conversion into UV
  - Transition to stable state may take a few 100 seconds
- A change or fluctuation in beam loading causes LFF algorithms to react and to adapt to the new situation → this may take a few shots as well
- These effects together may lead to a catastrophic failure (burst of trips which can only be cured by operator action),
  since wrong beamloading and badly adaption
  (cause eg by temperature effects)
  cause losses which themselves induce more instabilities and so on

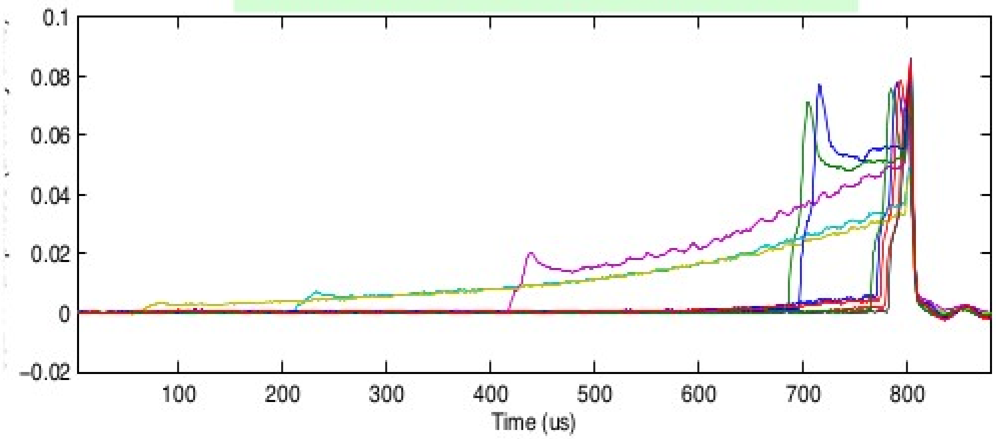
'Phantom' trips due to dark current

ACC1 Vector Sum Amplitude over bunch train



Cavity voltage jumps due to loss of beam loading

BLM 36BYP over bunch train



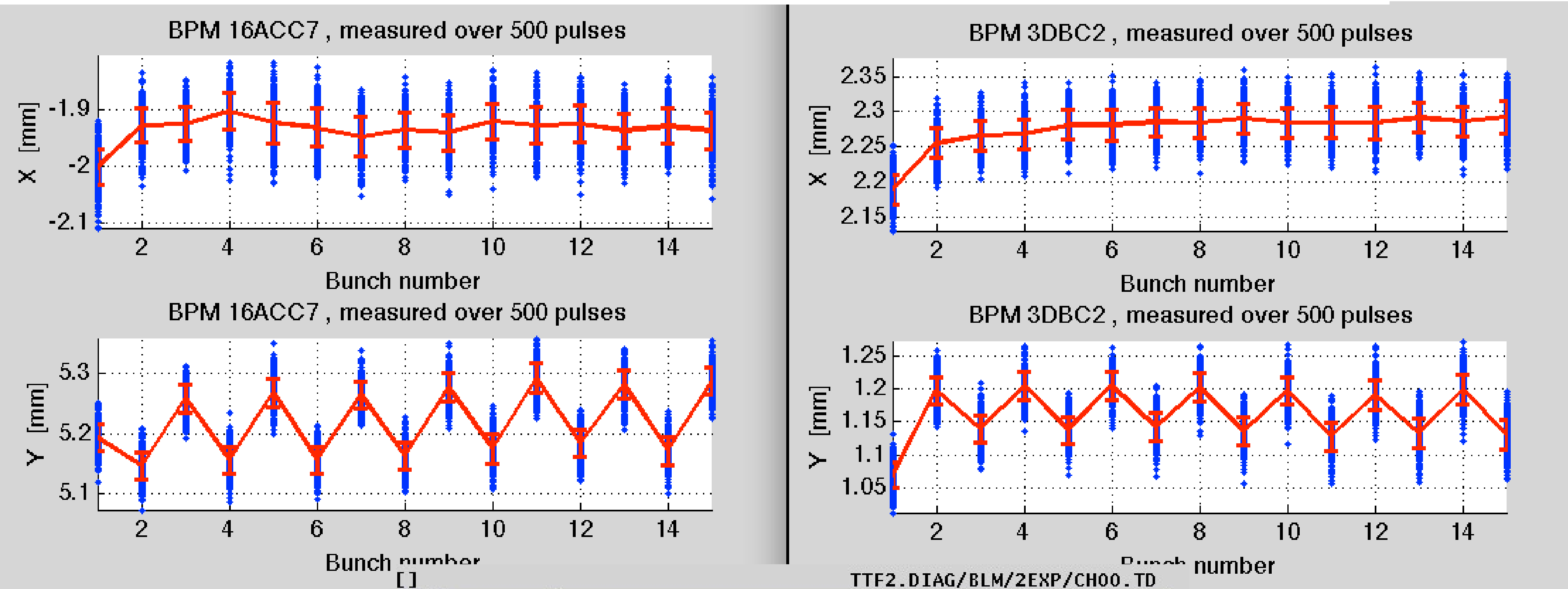
Total gradient vector sum increases, dark current hits wall, BLM signal rises

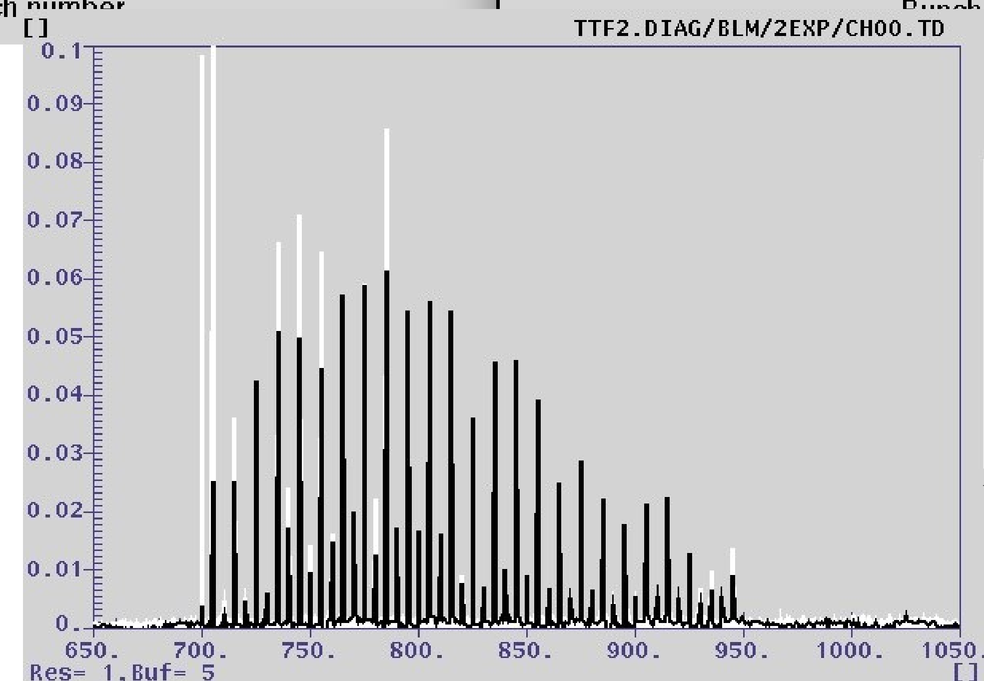
Courtesy J. Carwardine

Beam Loss of Even/Odd Numbered Bunches ?

05.04.2012 16:12 MKBock, CSchmidt **nice orbit pattern**

reason is unclear, but most likely this is independent of the feedback (bandwidth to low)





Summary

The Dark Current of the FLASH gun is the largest source of lost particles
Experience gained with: new gun cathodes, methods of cleaning, ideas on dark current kicker

Beam losses in collimator is not an issue, can be minimized.

Beam Losses due to change of Beam Loading : adaptive thresholds of BLMs ?

Acknowledgment

Many thanks to J. Branlard, J. Carwardine, N. Golubeva, M. Koerfer, D. Lipka, S. Schreiber for their slides and information.

Charge Measurement: Principle

$$U = U_0 \sin(\omega t) \exp\left(-\frac{t}{\tau}\right)$$

$$\omega = 2\pi f$$

$$\tau = \frac{Q_L}{\pi f}$$

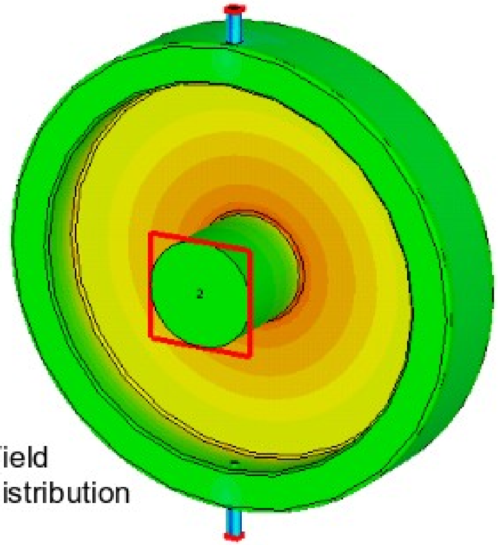
Induced voltage in a resonator from a beam oscillates with resonance frequency *f* and decays with decay time τ. Q_L is the loaded quality factor.

Amplitude $U_0 \sim q$ of the beam (here monopole mode is assumed).

By measuring U_0 the charge of the beam is determined.

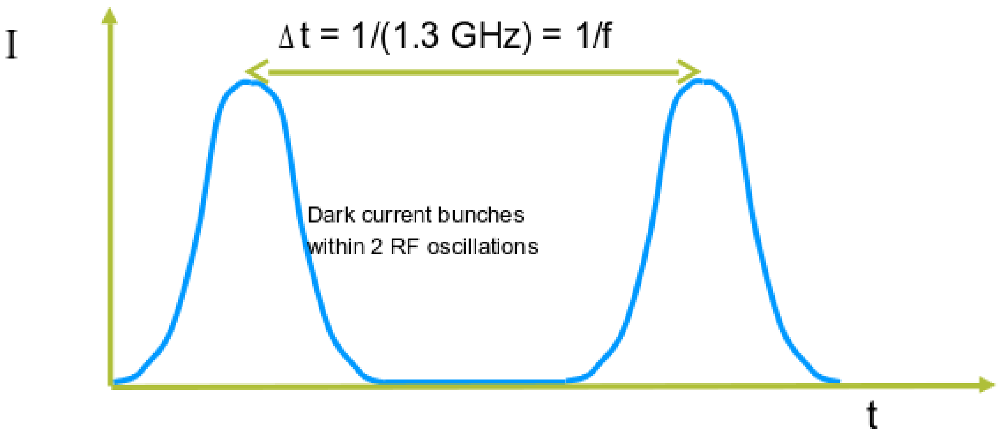
$$\frac{U_0}{q} = \pi f \sqrt{\frac{Z}{Q_{ext}}\left(\frac{R}{Q}\right)} = S$$

Sensitivity *S* can be determined by line impedance *Z*, external quality factor Q_{ext} and normalized shunt impedance *(R/Q)*.



Field distribution

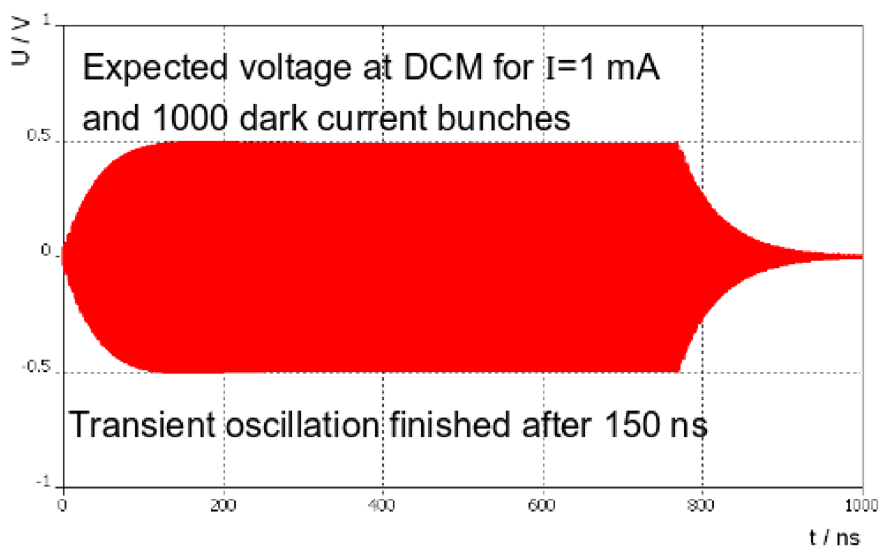
Dark Current analysis



$I=Q/\Delta t=Q*f$ is mean current

$Q=U_0/S$

S=11.83 V/nC (proven with bunch charge measurement)



U_{DaMon} is envelope voltage after transient oscillation

$U_{DaMon}=U_0*(1-e^{-\pi/QL})^{-1}$

This results in

$I=U_{DaMon}\, f\, (1-e^{-\pi/QL}) / S$

Breakdown burst

laser on