Instrumentation R&D at FLASH

a personal and incomplete overview

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HELMHOLTZ ASSOCIATION

DESY

goals and needs

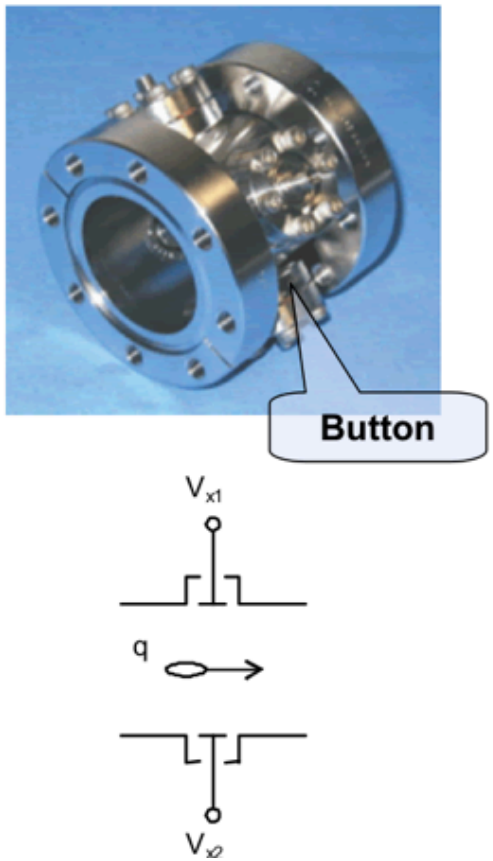
- instrumentation R&D at FLASH driven by needs and boundary conditions of FLASH and E-XFEL
- SC linac, 1 MHz bunch spacing, up to 800 bunches, 10 Hz train repetition rate
- special FEL demands: σ_{bunch} << 1ps, timing stability ≤ 10 fs
- continuous strive for shorter bunches & lower charge (1 nC ➛ 100 pC and less)

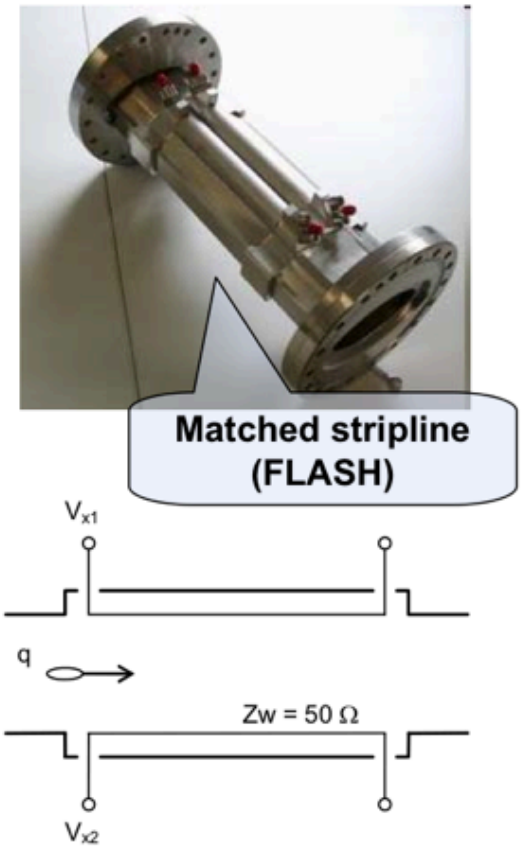
- few examples from standard diagnostics (BPM, DCM ...)
- special diagnostics, longitudinal profiling and phase space
- timing and synchronization developments

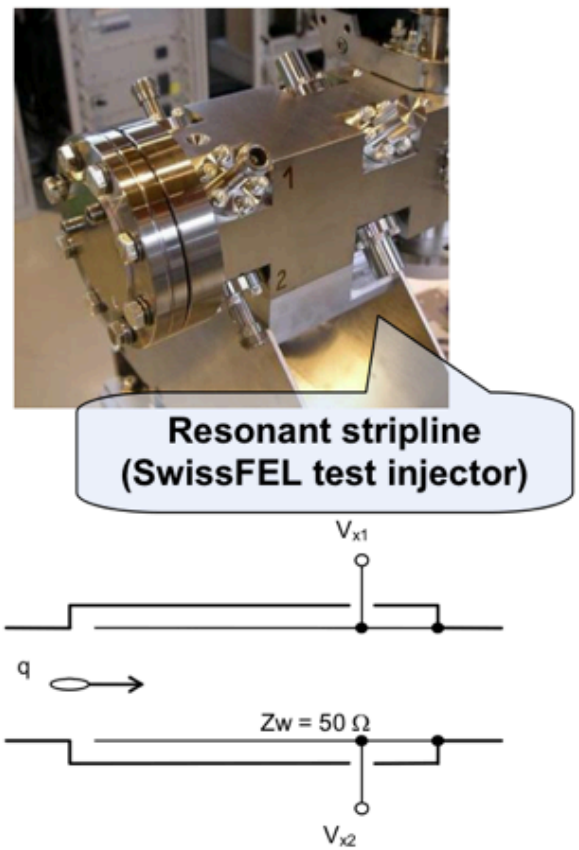
E-XFEL BPM development in collaboration with PSI and CEA

RF BPMs: Common Types

courtesy Boris Keil, PSI





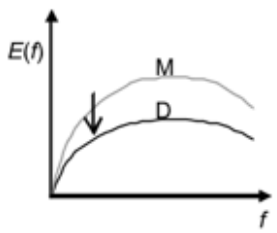
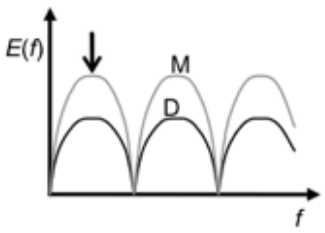
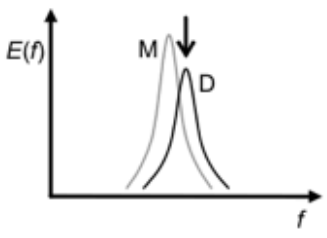
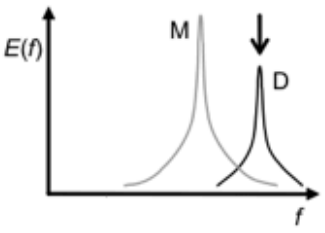


BPM: various types required

RF BPMs: Common Types (Cont'd)

Low cost: Standard BPM

Best resolution, lowest drift: Undulator BPM

Pickup	Button	Matched Stripline	Resonant Stripline	Cavity
Spectrum				
Monopole Mode Suppression	Modal (hybrid) / electronics	Modal (hybrid) / electronics	Modal (hybrid) / electronics	Modal (coupler), frequency, phase (sync. det.)
Typical RMS Noise, 20pC, *40mm pipe*	~100µm	<60µm	<4µm	~1µm
Typical Electronics Frequency	300…800MHz	300…800MHz	500-1500MHz	3-6GHz

"Typical" noise: Examples & estimates (scaling, …) based on existing systems, not theoretical limit …

courtesy Boris Keil, PSI

BPMs : collaboration and XFEL needs

Preliminary (3/2011)

BPM Type	Count	Pickup / Mechanics	RF Front-End Electronics	ADC, Digital Back-End Electronics	FPGA Firmware/ Software
Cold Button	56	DESY	PSI	PSI	PSI
Re-Entrant Cavity	26	CEA/Saclay	CEA/Saclay	PSI	PSI
Warm Button *	237	DESY	PSI	PSI	PSI
Transfer Line Cavity	24	DESY	PSI	PSI	PSI
Undulator Cavity	98	DESY	PSI	PSI	PSI

-- cold -- ---- warm ---

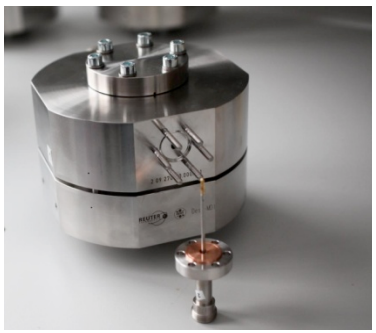
* Different types / pipe apertures needed (beam dump: 100mm, transfer lines: 40.5mm, …)

- Modular electronics, common “generic” digital back-end.
- Pickup-specific RF front-ends.
- Common hardware & firmware: Less work & costs.

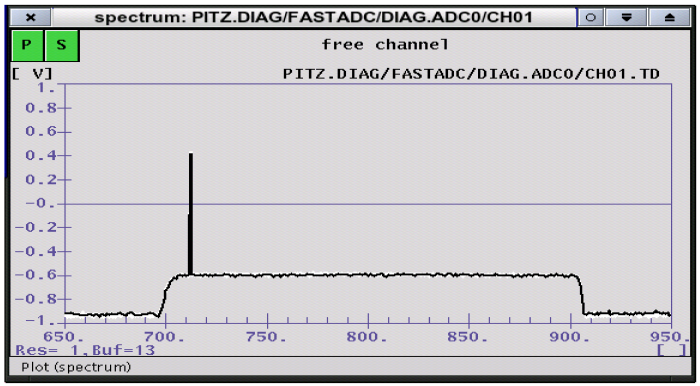
contact person @ DESY : Dirk Noelle (MDI)

prototype tests ongoing at FLASH

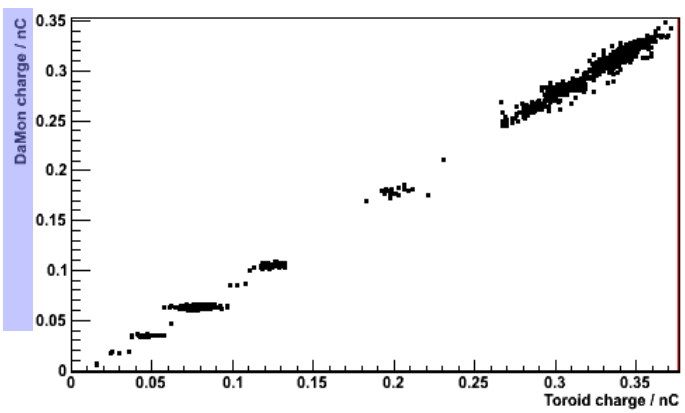
Resonant Dark Current Monitor



- Initial intention: Detect dark current to optimize collimation efficiency
- Idea: Use the pile up in (low Q) cavity resonant to 1.3 GHz
- Detection limit at Flash: 40 nA
- large dynamic range



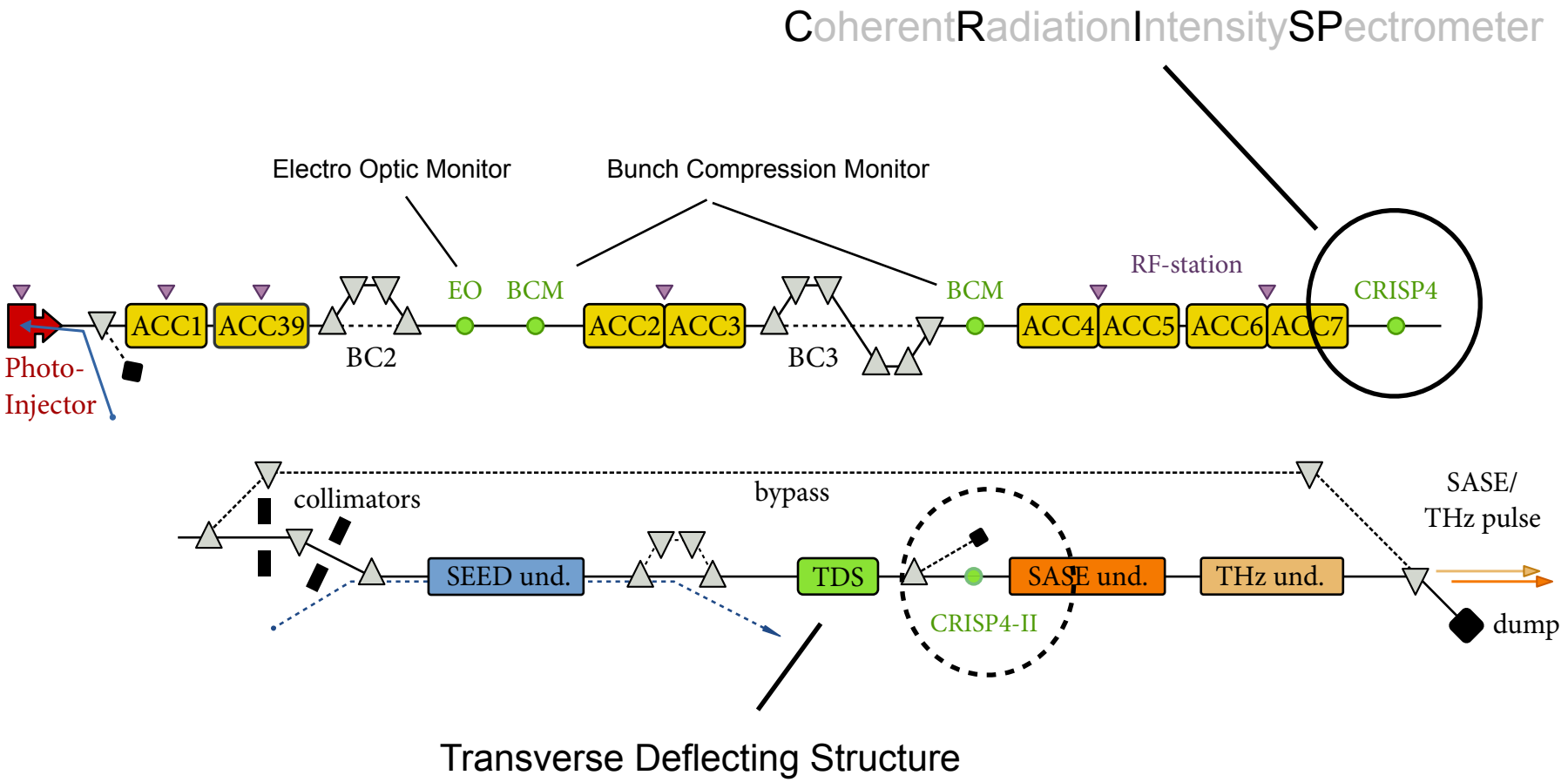
- The 2 Ports of the monitor are connected:
  - To a dark current processing path
    - ➔ Sensitive but slow, measure before or after the bunch train
  - To a beam charge processing path
    - ➔ Fast enough to measure single bunch
    - ➔ Large dynamic range, and excellent resolution.



- Both monitors show excellent performance over a wide charge range.
- Linear response to at least 3 nC.
- Sensitivity sufficient for a few pC operation.
- Noise levels well below 1 pC can be achieved.
- Noise environment of the machine will be the limiting factor.

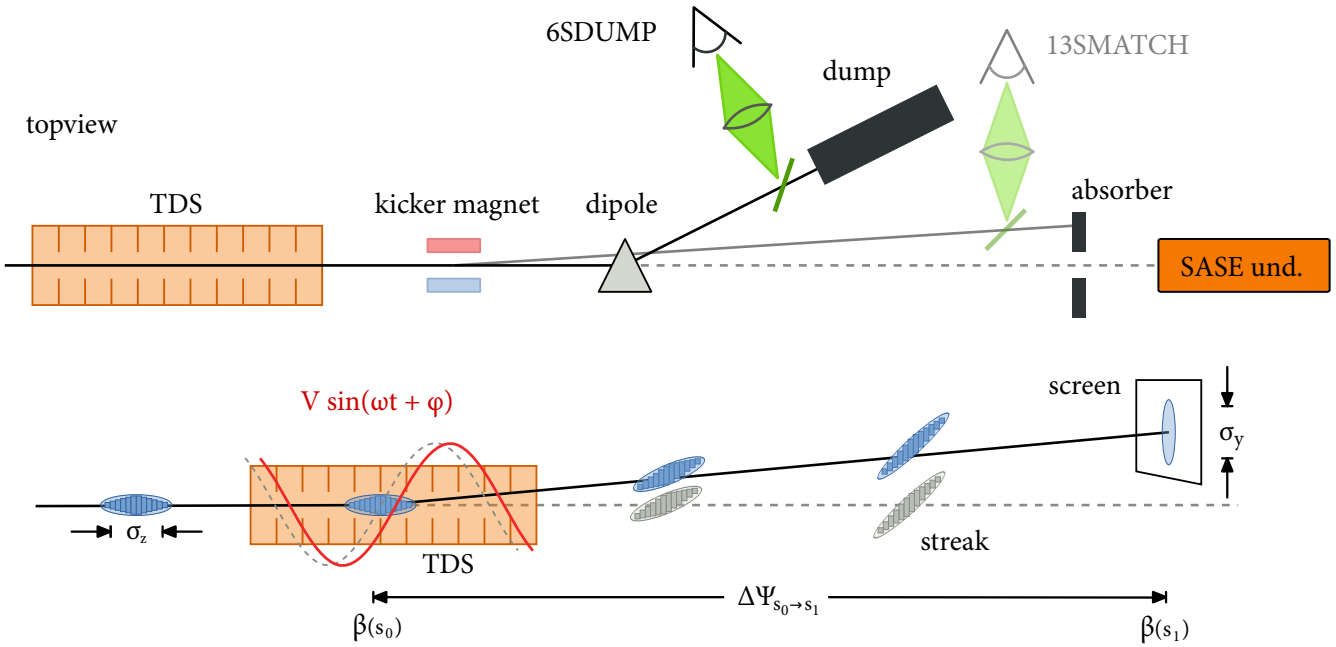
contact person @ DESY : Dirk Lipka (MDI)

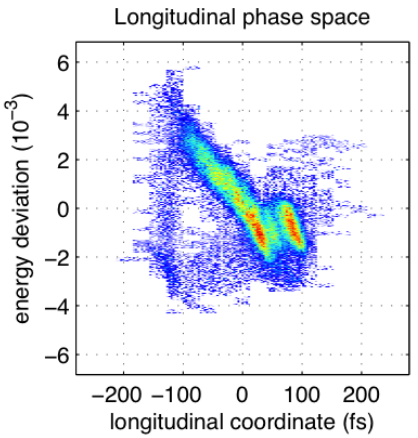
Longitudinal Diagnostics at FLASH

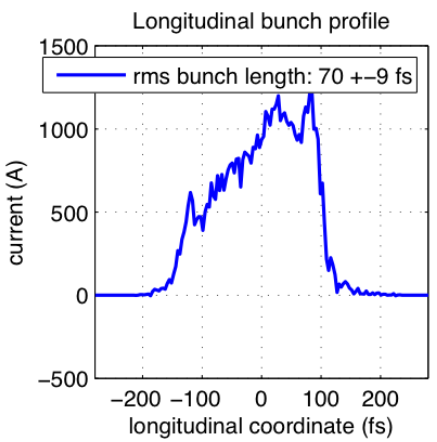


Longitudinal benchmark with Transverse Deflecting Structure

> direct time domain technique, transverse streaking of longitudinal profile





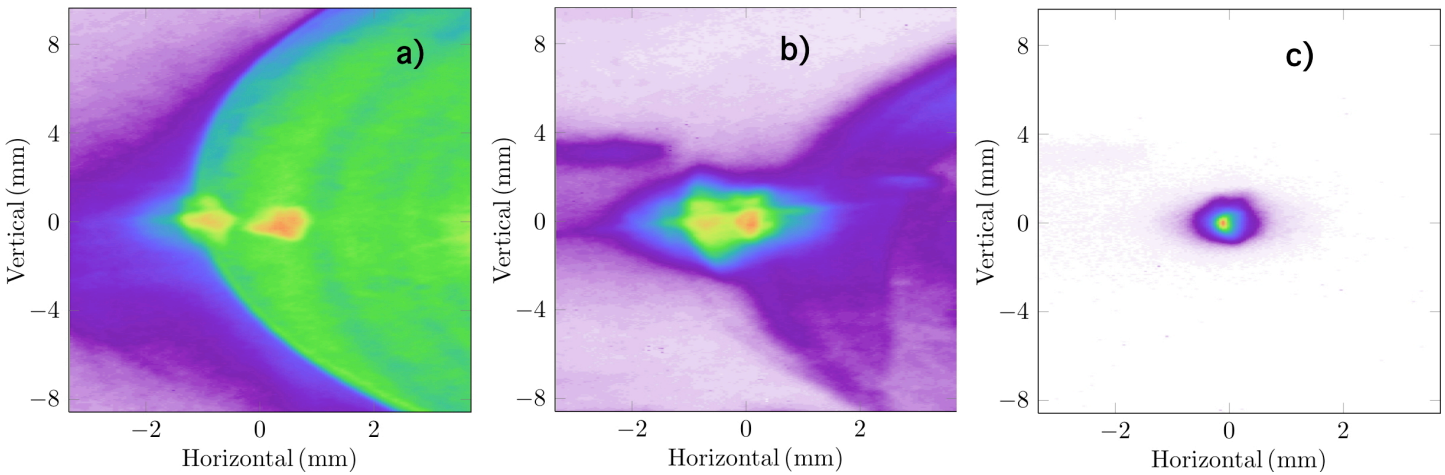


- uses always dispersive arm due to **strong COTR in „direct“ path**
- not applicable during FEL operation
- resolution depends on streak power and machine optics

contact persons @ DESY :
C. Behrens & C. Gerth (MPY)

COTR : suppression by delayed imaging technique

scintillator + fast gated camera :
only scintillation afterglow, COTR light completely blocked



OTR - prompt | scintillator - prompt | scintillator + 100 ns

courtesy : Minjie Yan (DESY)

CRISP4 : a multi-stage grating spectrometer for coherent radiation

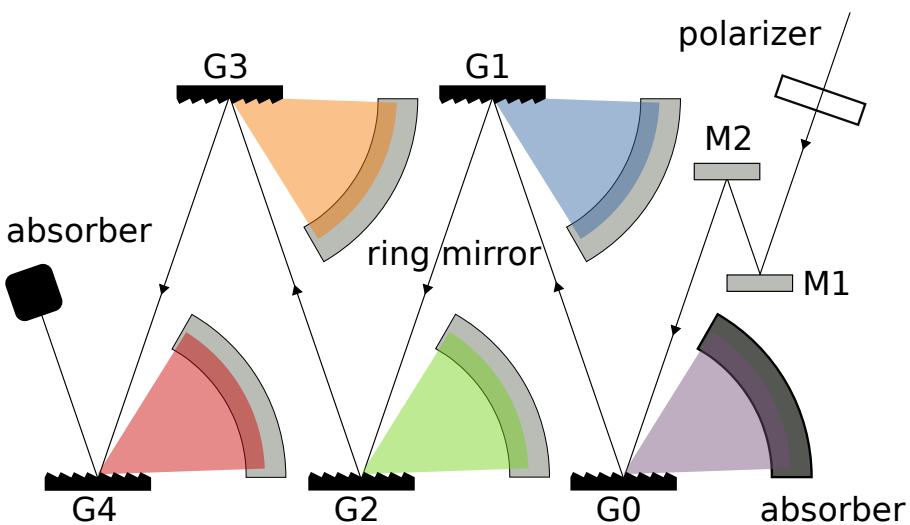
frequency domain longitudinal diagnostics

coherent radiation intensity

$$\frac{dU}{d\lambda d\Omega} \approx \left(\frac{dU}{d\lambda d\Omega}\right)_1 N^2 \left|F(\lambda)\right|^2$$

bunch form factor

$$F(\lambda) = \int_{-\infty}^{\infty} S(z) e^{-2\pi i z/\lambda} dz$$



NIM-A, Volume 665, 11 February 2011, Pages 40–47

requires broad wavelength range spectroscopy

gratings as pre-filter and dispersive device
from short to long wavelengths

4 stages : 1 decade in λ (parallel)

2 x 4 stages : 2 decades in λ (sequentially)

monitoring : relative intensities ok

form factor :
absolute intensity as function of λ required ! Needs detailed understanding of all components

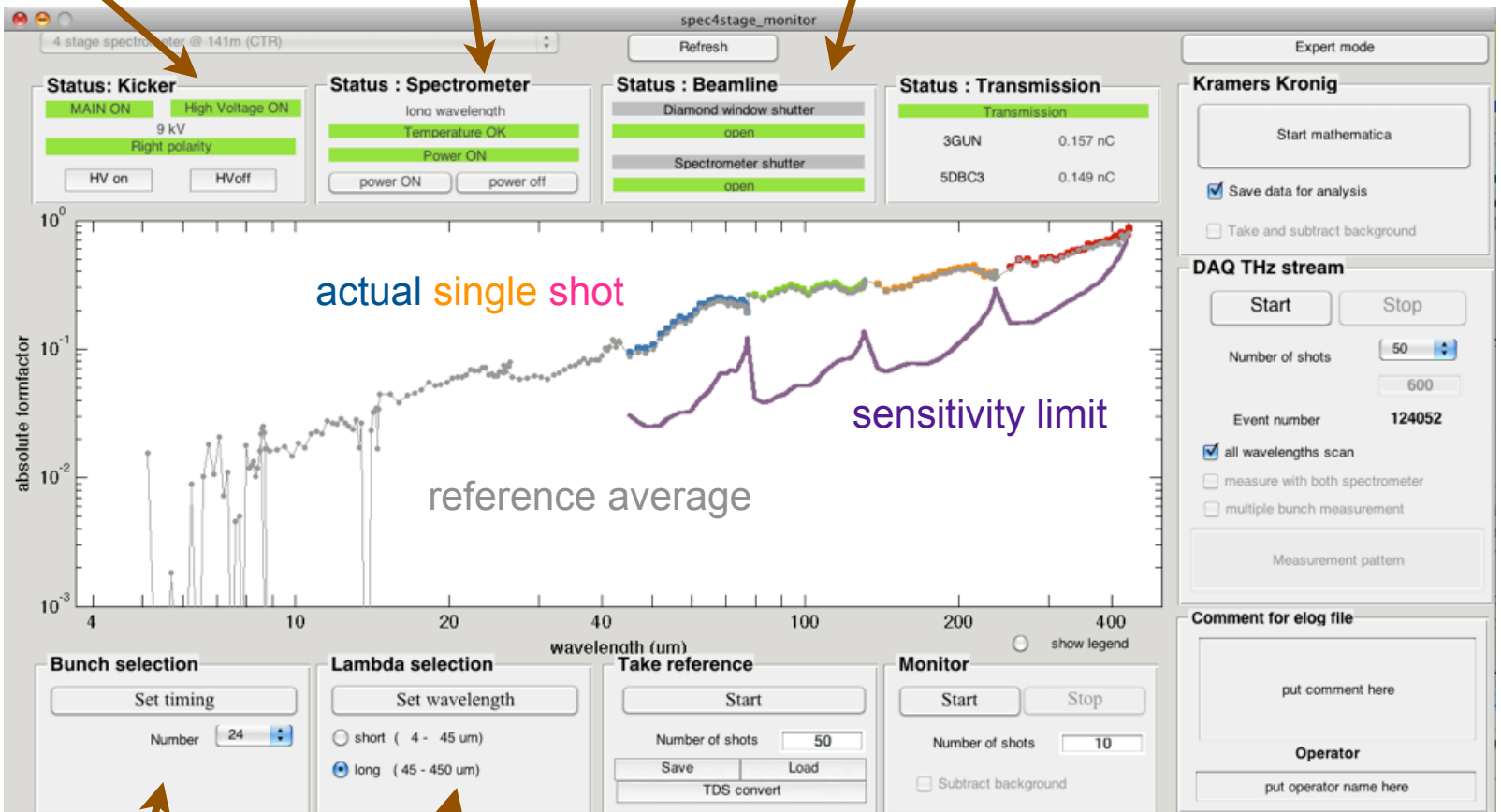
CRISP4 as an online-tool, after 6 years development

kicker

spectrometer

beamline

courtesy S. Wesch (FLA)



DAQ

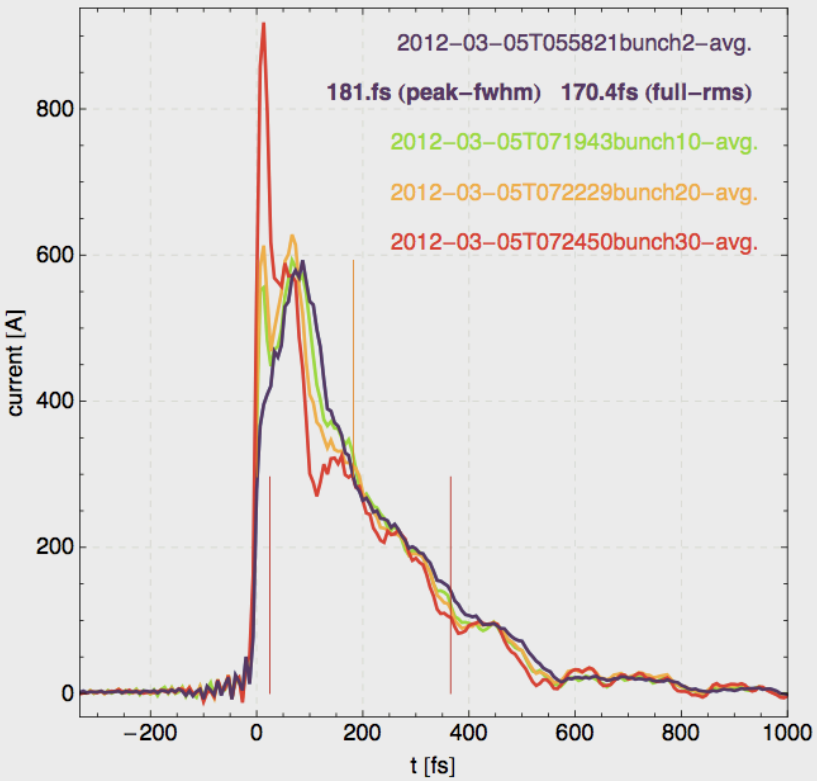
bunch number

grating set

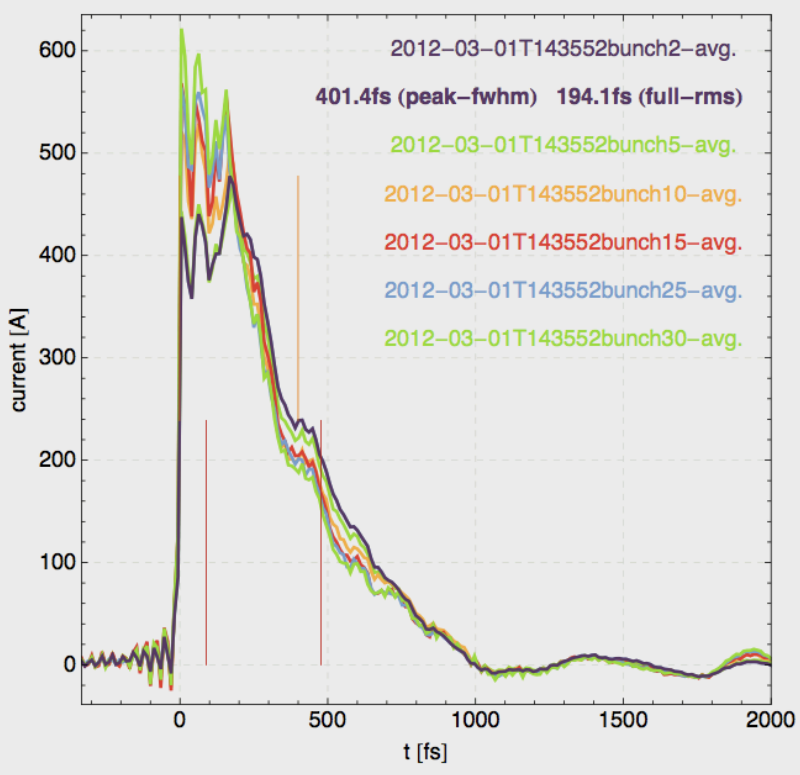
data taking

bunch profile reconstruction using phase-retrieval

Q = 0.137 nC
E = 500 MeV



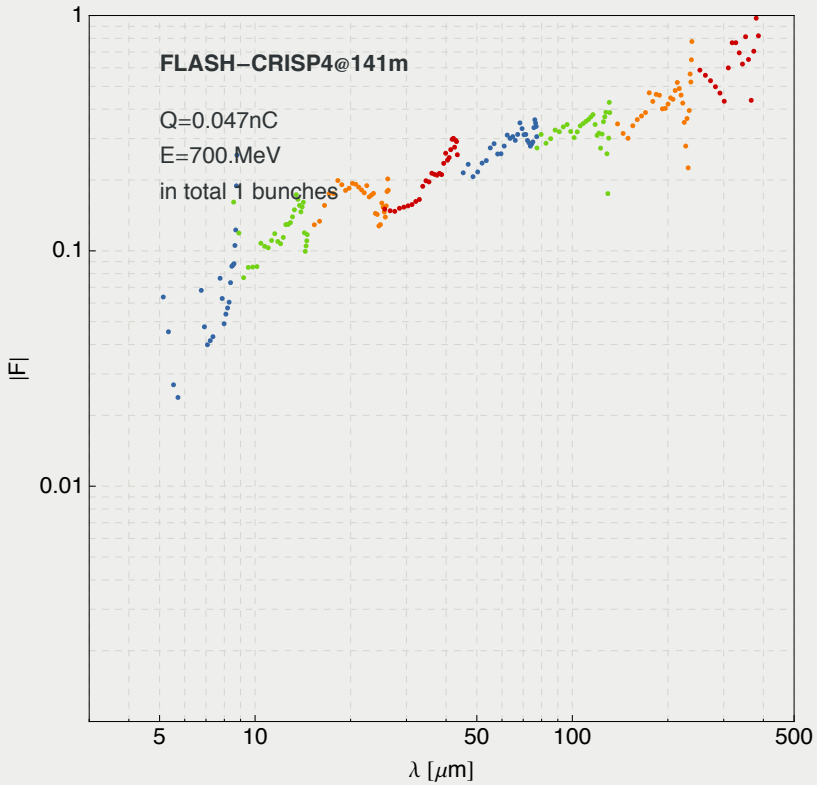
Q = 0.200 nC
E = 700 MeV

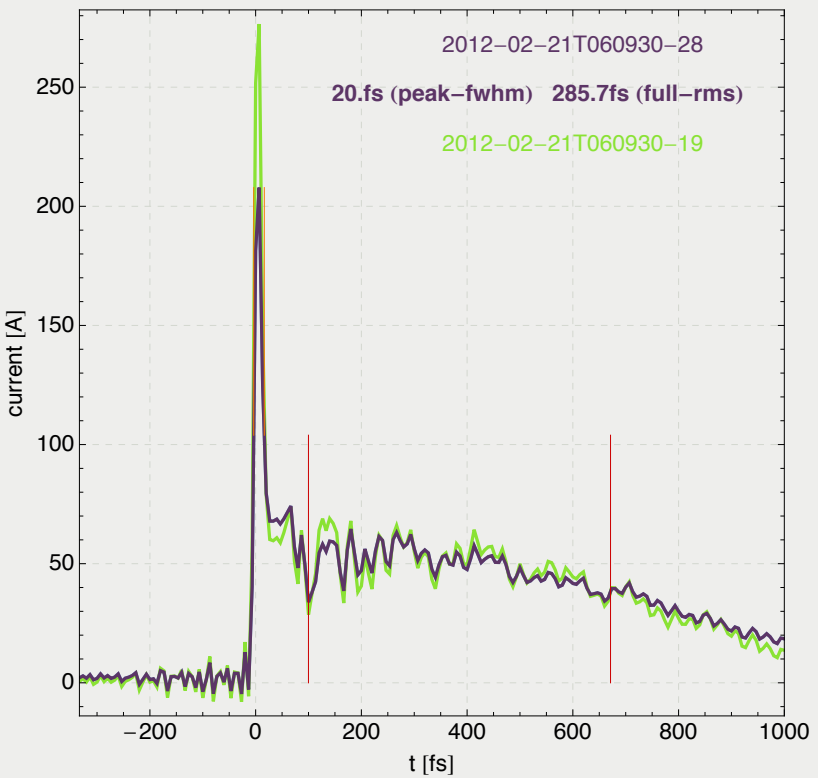


profiles along the bunch train

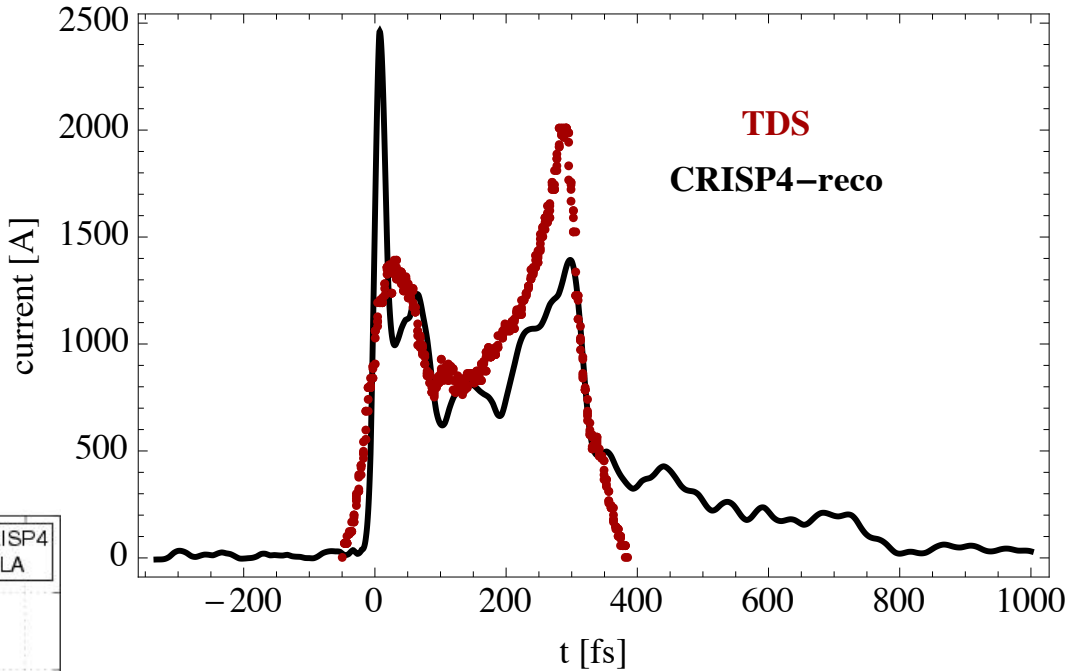
CRISP4 works with 50 pC

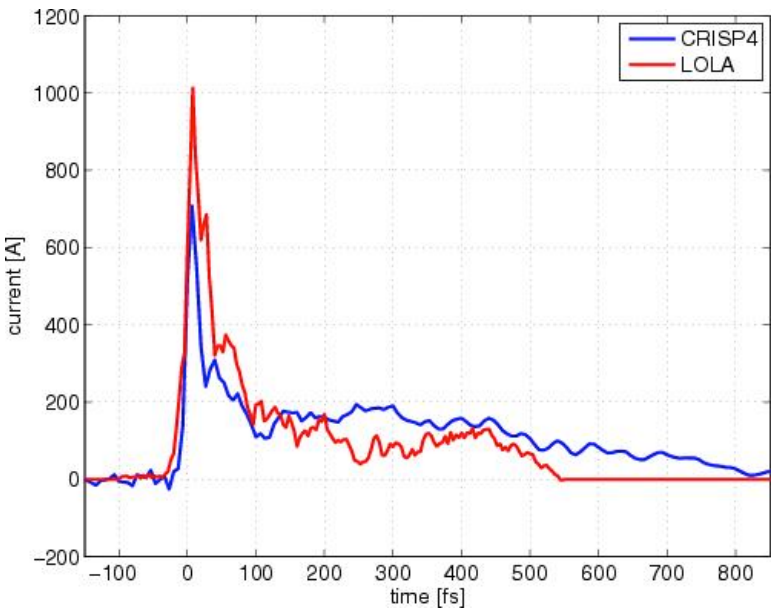
- even with a single bunch
- very sharp leading spike (**8.5 fs rms**) on long tail





comparison with TDS measurement

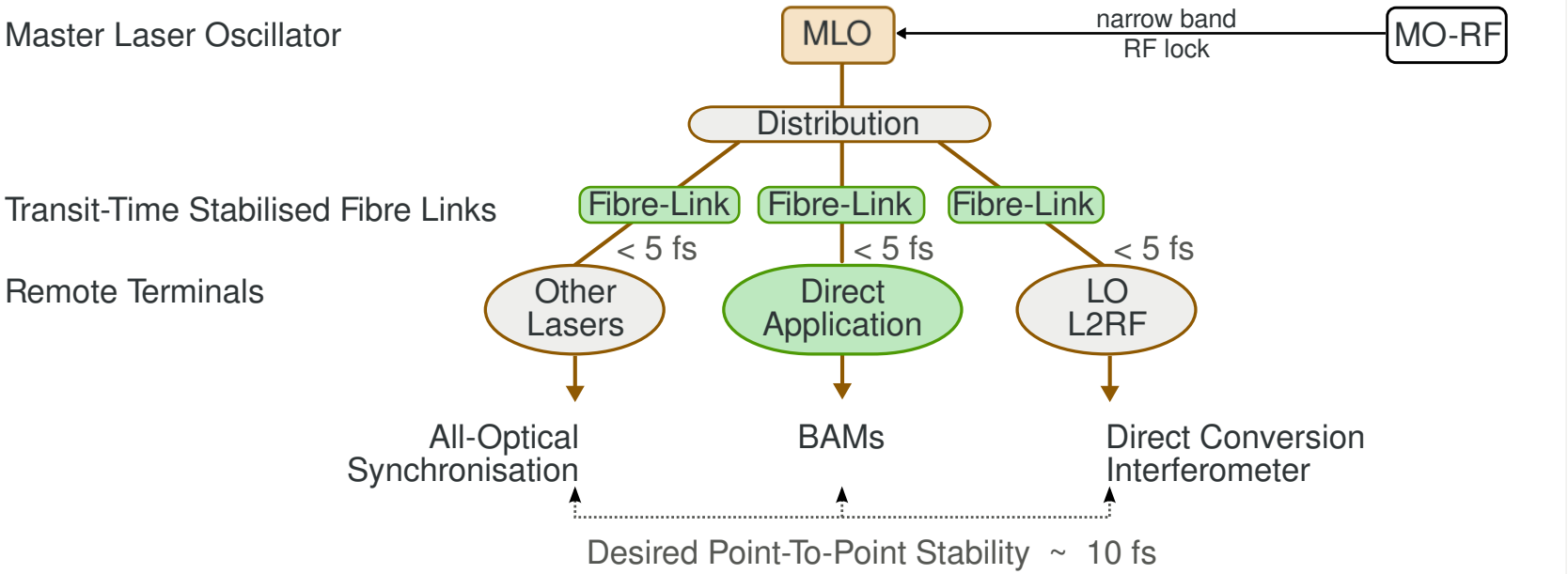




courtesy S. Wesch & E. Hass (FLA)

Pulsed optical timing and synchronisation

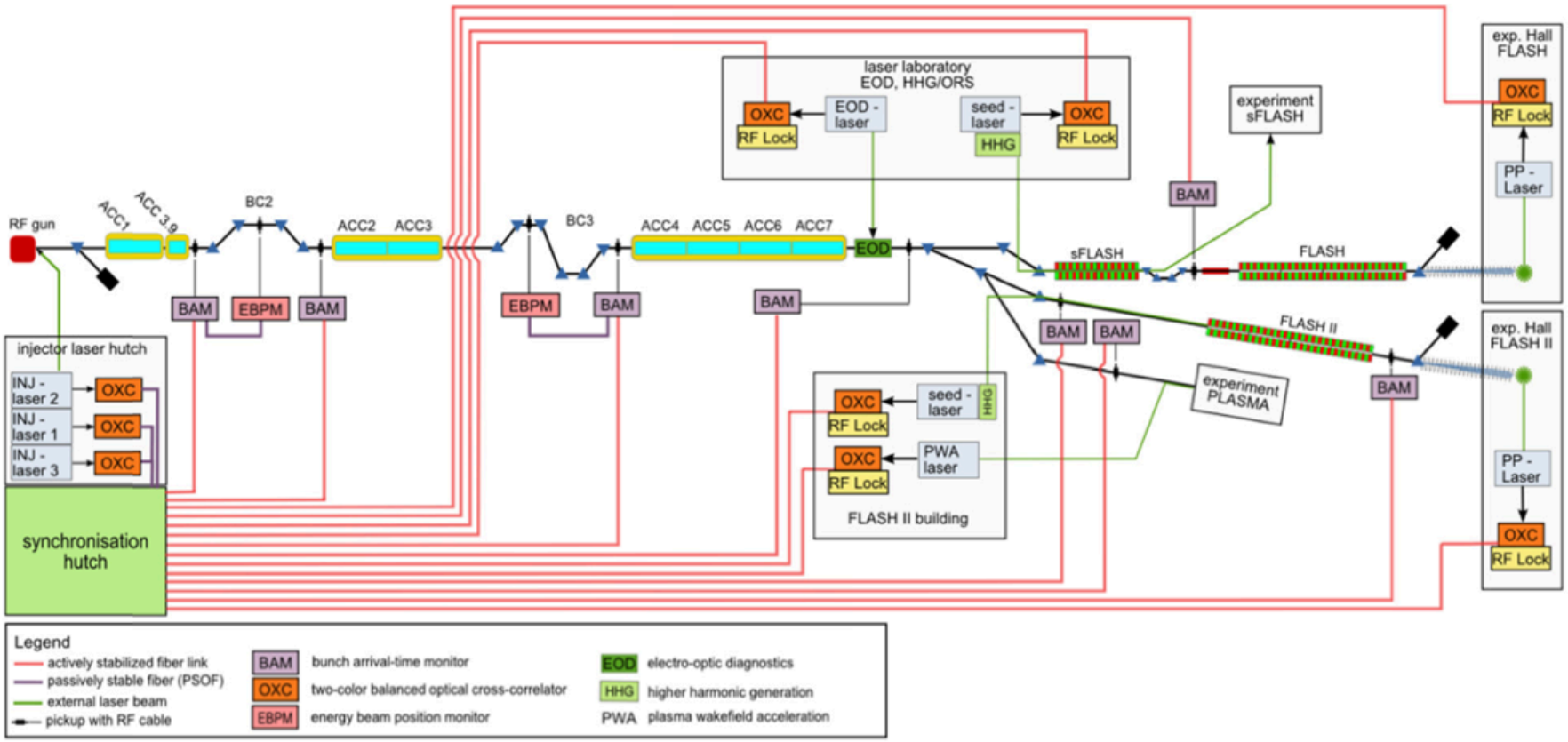
proposed by MIT, 2004



contact person @ DESY : H. Schlarb (MSK)

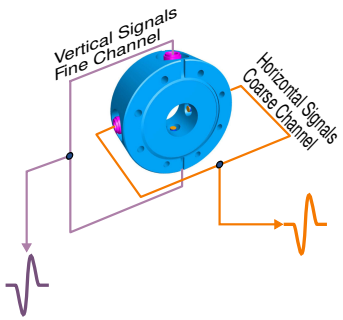
implementation at FLASH ongoing

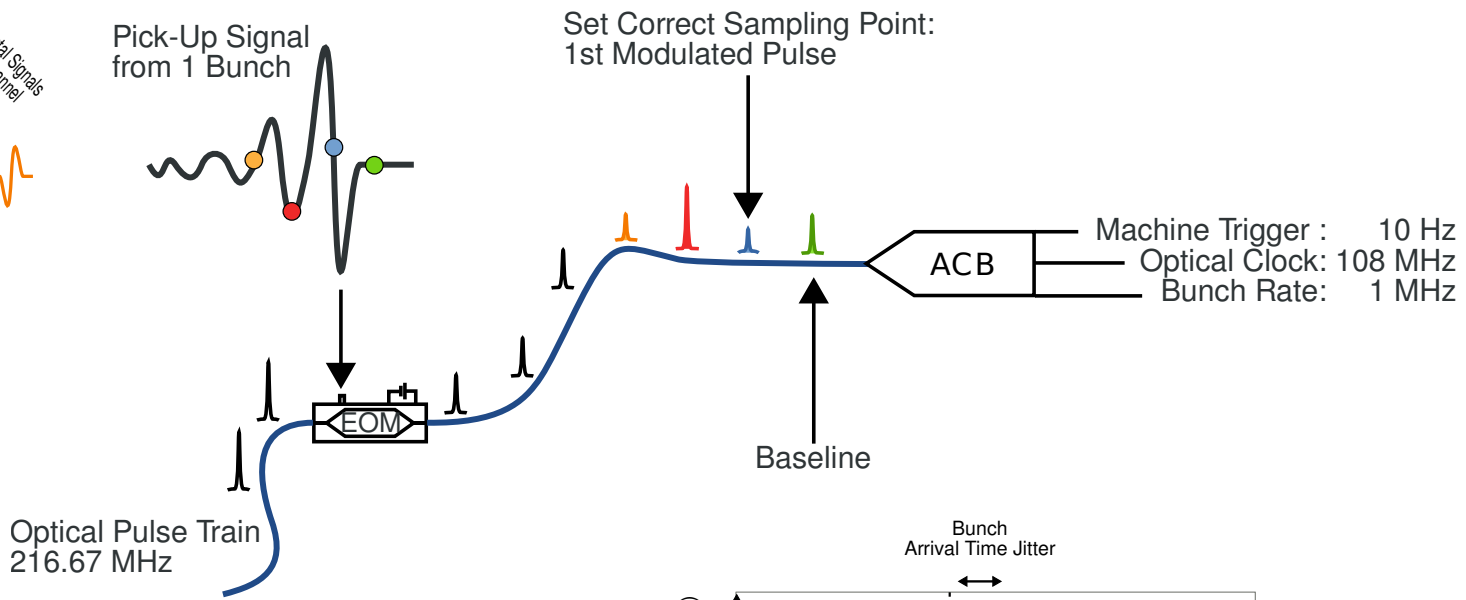
the complete system as foreseen...



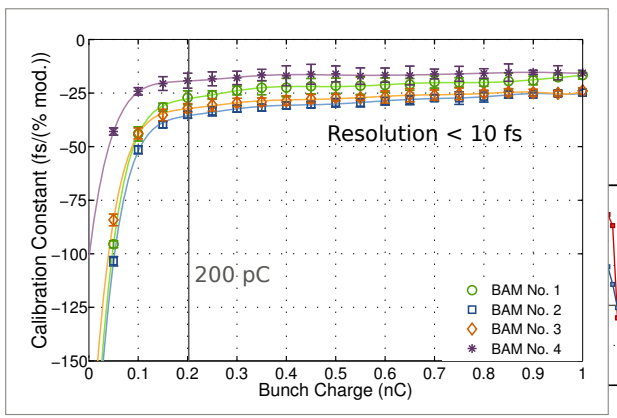
at present : 7 links operational

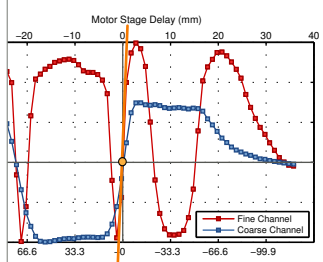
Beam Arrival Time Monitors (BAM)

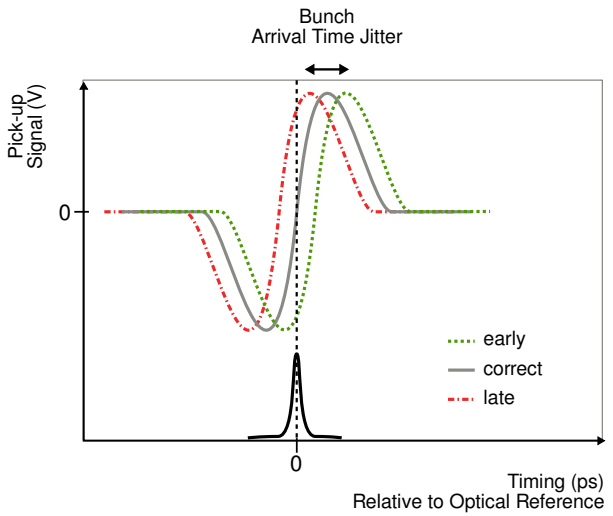




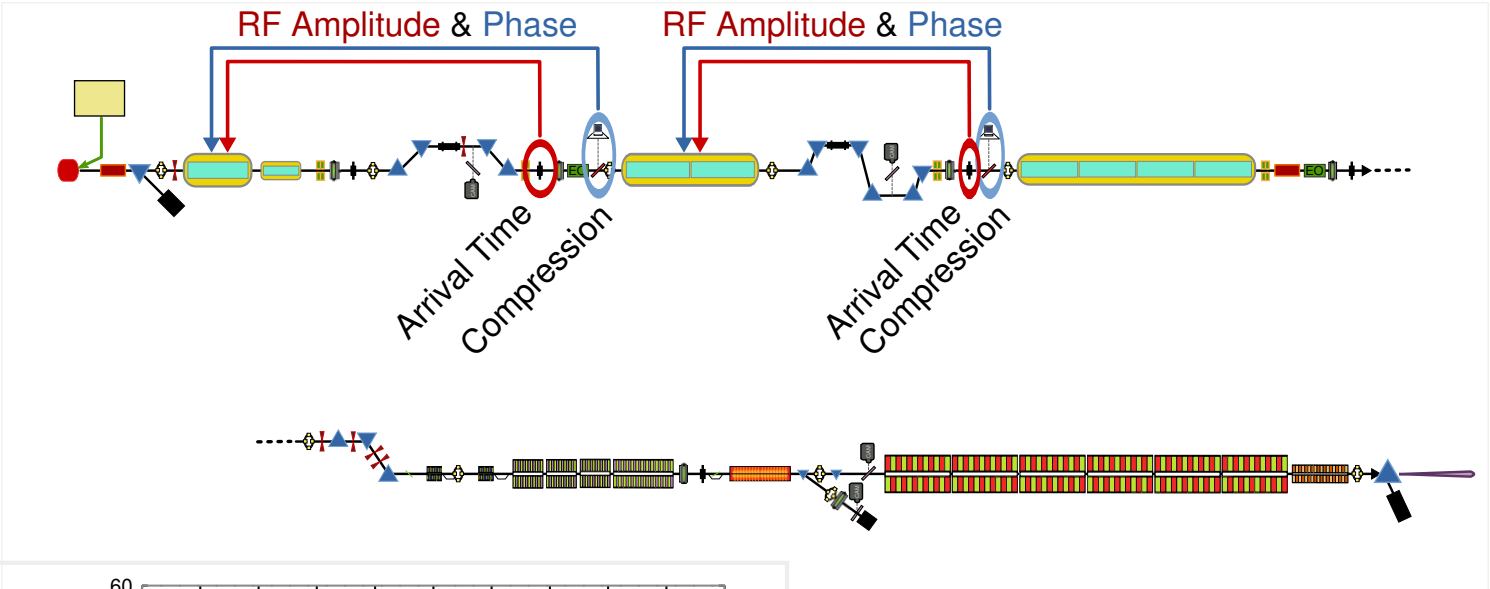
courtesy M.K. Bock (FLA)

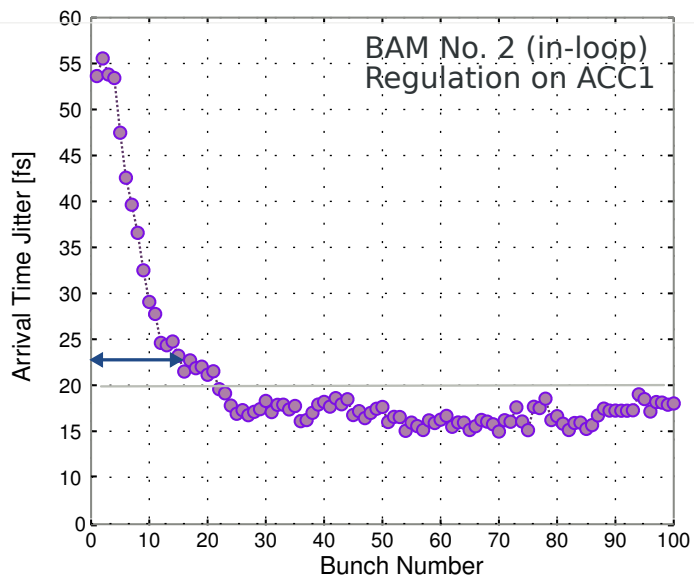






intra-bunch train feedback





courtesy S. Pfeiffer (MSK)

end of the overview

thank you for your attention