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Trieste

IBIC 2013
International Beam Instrumentation Conference

Longitudinal Phase Space Characterization at FERMI@Elettra

E. Ferrari on behalf of FERMI Timing,
Diagnostics, Laser and Commissioning Teams

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Outline

- ★ Seeded FEL vs. SASE FEL
- ★ FERMI project
- ★ Longitudinal diagnostics, measurements and performance at FERMI
- ★ Conclusions and prospective

Motivation

The goal of the timing system is to generate and distribute the phase reference signal and to synchronize all time-critical accelerator components, down to the beamlines (with fs accuracy).

This requires diagnostics with comparable accuracy!

Seeded high gain FELs

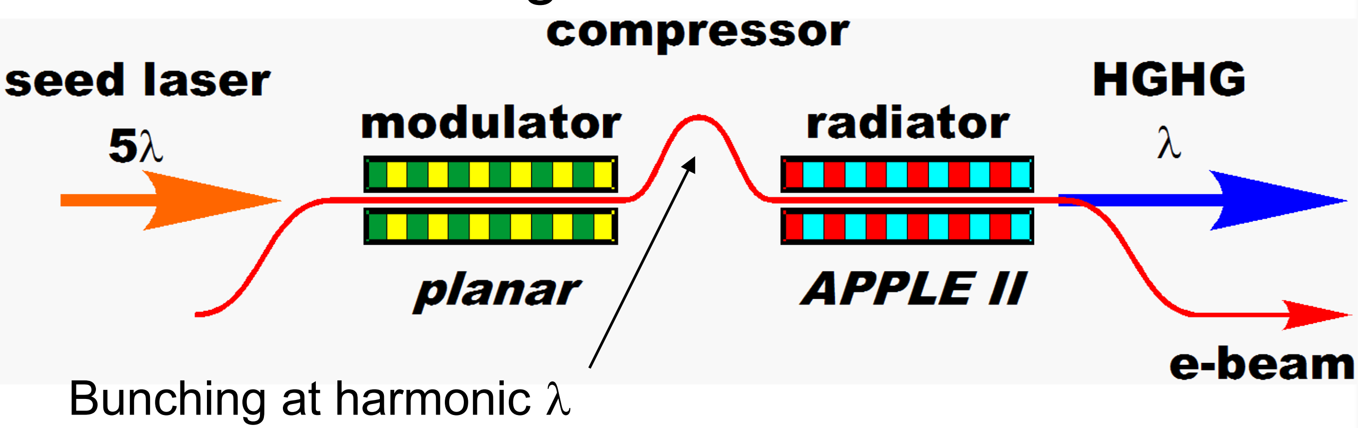
Seeding controls the start-up of the FEL pulse within the electron bunch and helping to produce:

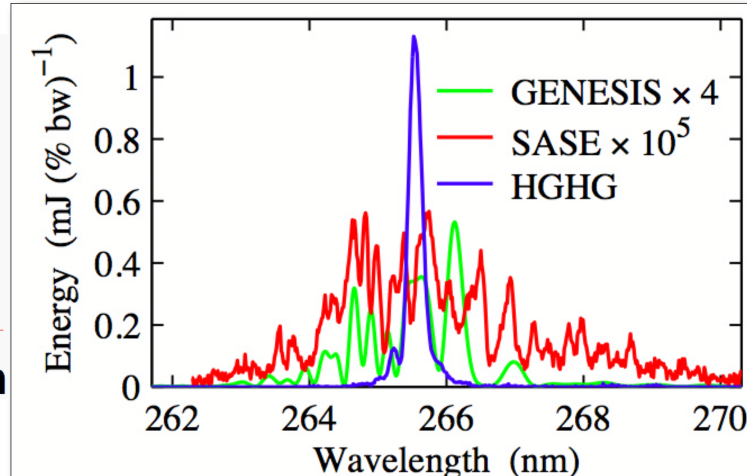
- Temporal coherence of the FEL pulse.
- Control of the time duration, wavelength and bandwidth of the coherent FEL pulse.
- Close to transform-limit pulses that provide excellent resolving power without monochromators.
- Natural synchronization of the FEL pulse to the seed laser.
- Reduction in undulator length needed to achieve saturation.
- High peak flux and brightness

Benefits of seeding strongly depend on the electron beam quality. Seeded FELs are more sensitive to electron beam energy and phase space distortion than SASE.

High Gain Harmonic Generation

The HGHG scheme of L.H. Yu was proposed after preliminary works(*) on FEL harmonic generation.





L.H. Yu et al. PRL 91, 074801 (2003)

FIG. 4: Single shot HGHG spectrum for 30 MW seed (blue), single shot SASE spectrum measured by blocking the seed laser (red) and simulation the SASE spectrum after 20 m of NISUS structure (green). The average spacing between spikes in the SASE spectrum is used to estimate the pulse length.

Compared to SASE devices, the HGHG approach is more compact (but also more complex) and produces nearly fully temporally coherence output. Spectral parameters are in principle easily controlled.

HGHG requires an high brightness and high energy electron beam, two kinds of undulators (modulator and radiator) a dispersive section and an external laser.

(*) I. Boscolo et al. Il Nuovo Cimento 58, 271 (1980).
B. Girard et al. Phys. Rev. Lett. 53, 2405 (1984), …

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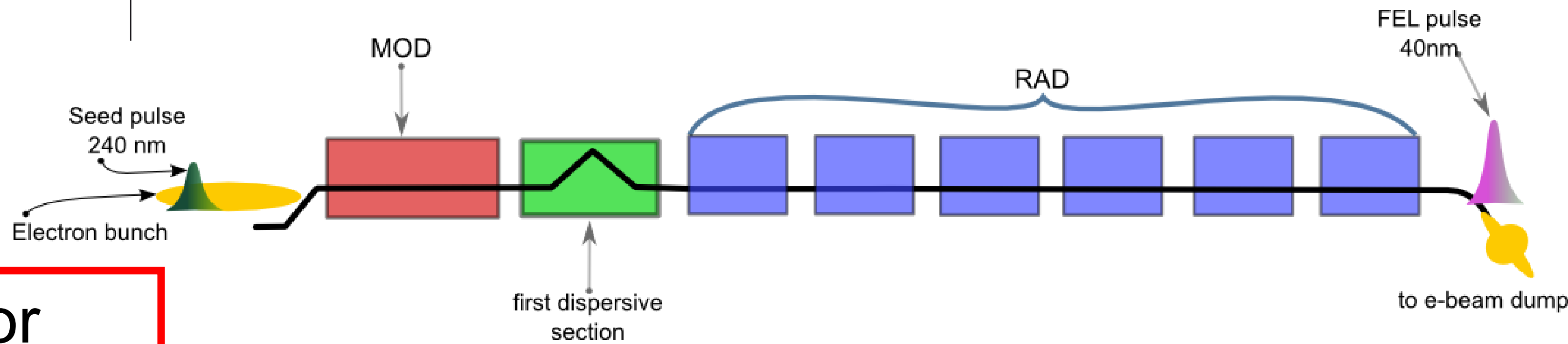
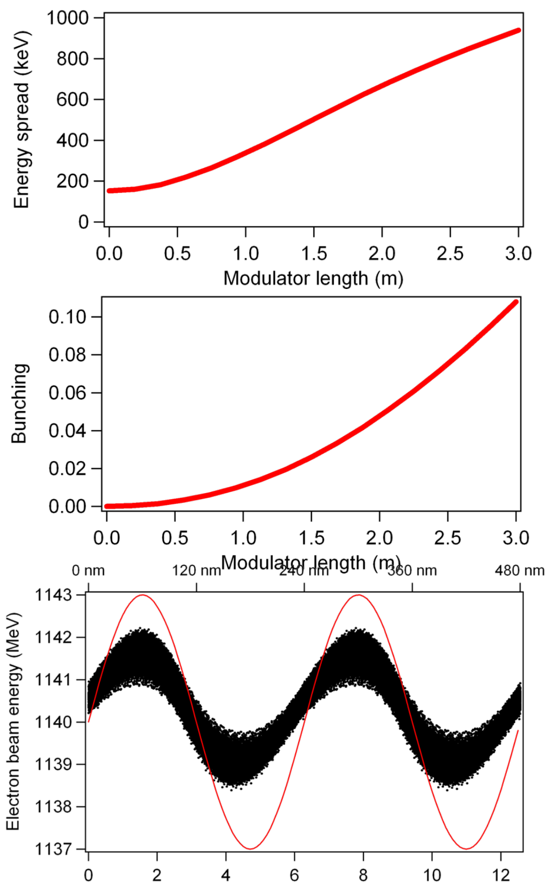
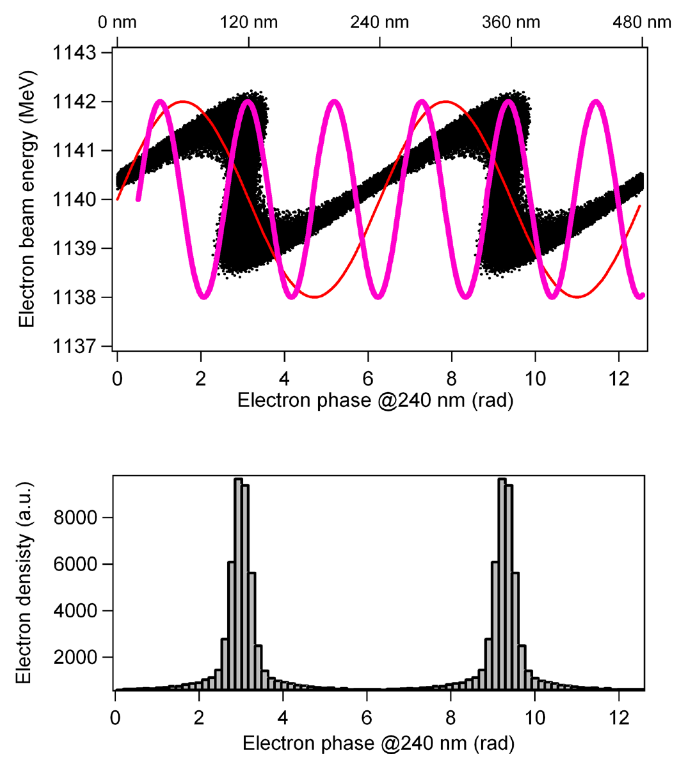
HGHG mechanism



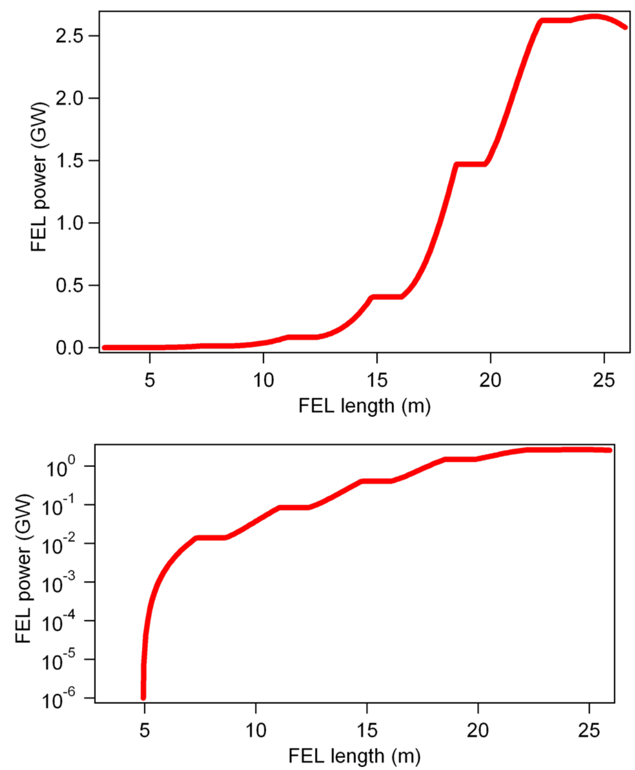
Modulator



Dispersive section

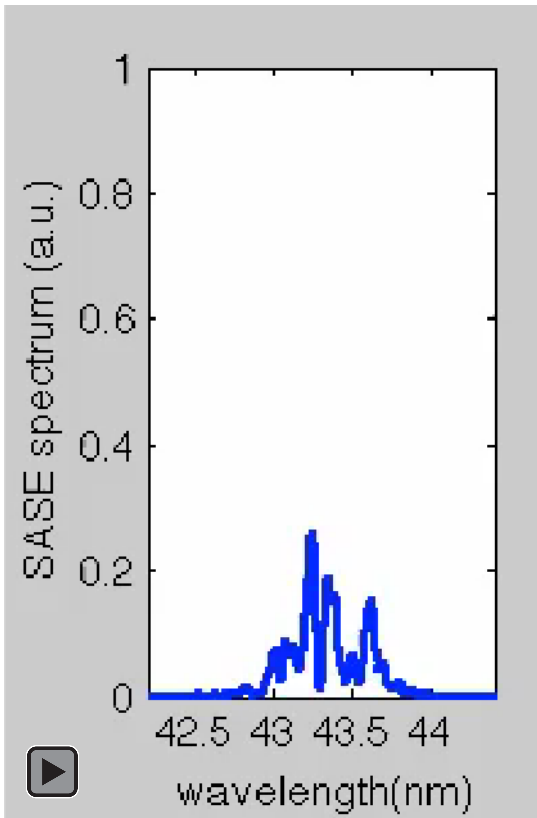


Radiator

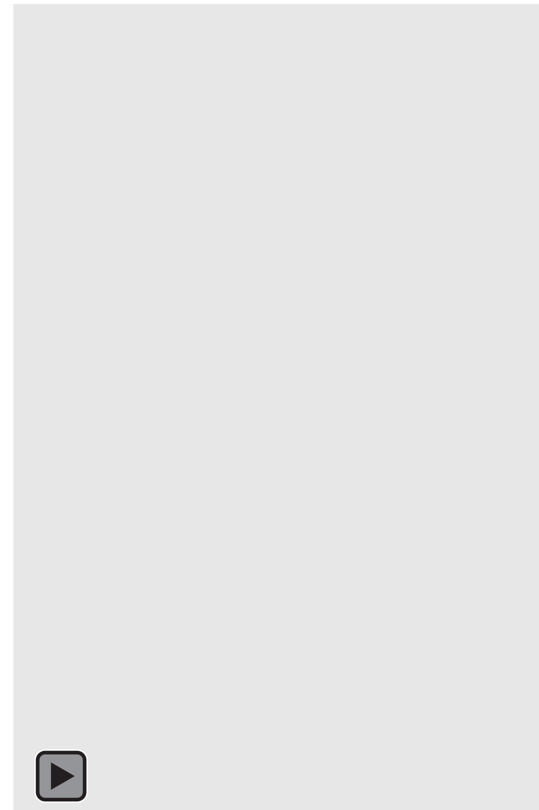


Seeding vs. Sase

FERMI in SASE mode



FERMI in HGHG mode



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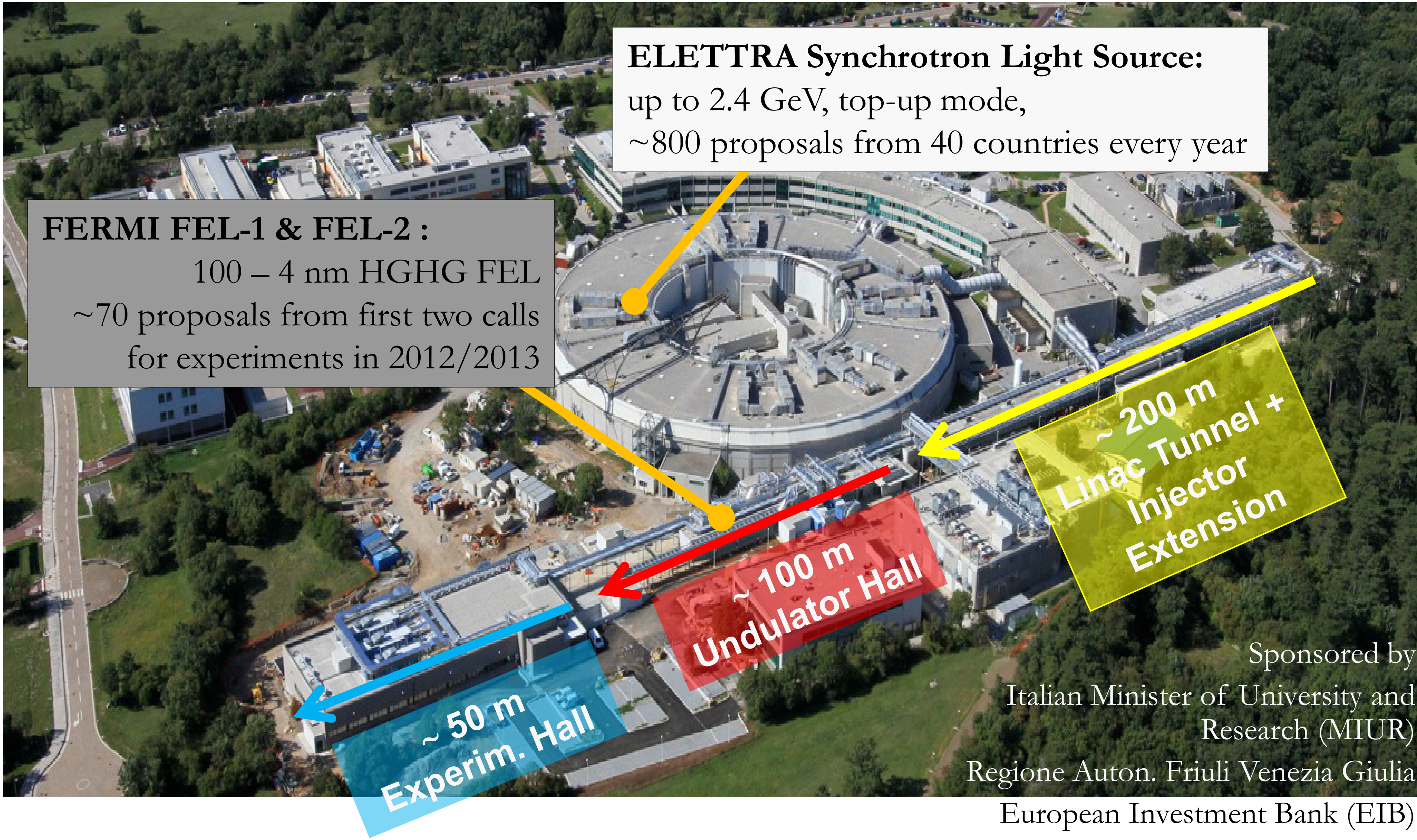
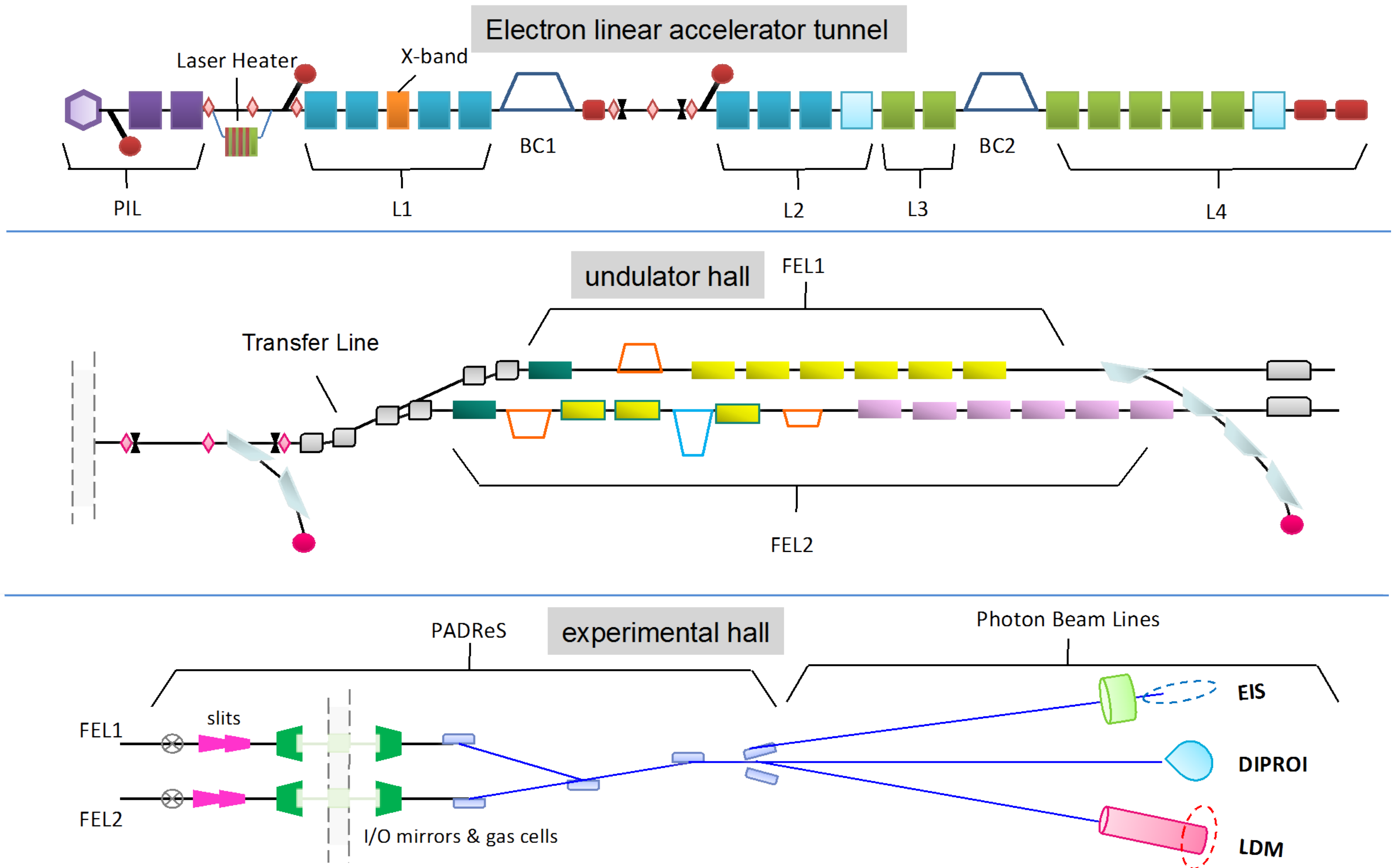
Facility: Fermi and Elettra



Sponsored by
Italian Minister of University and Research (MIUR)
Regione Auton. Friuli Venezia Giulia
European Investment Bank (EIB)
European Research Council (ERC)
European Commission (EC)

FERMI layout



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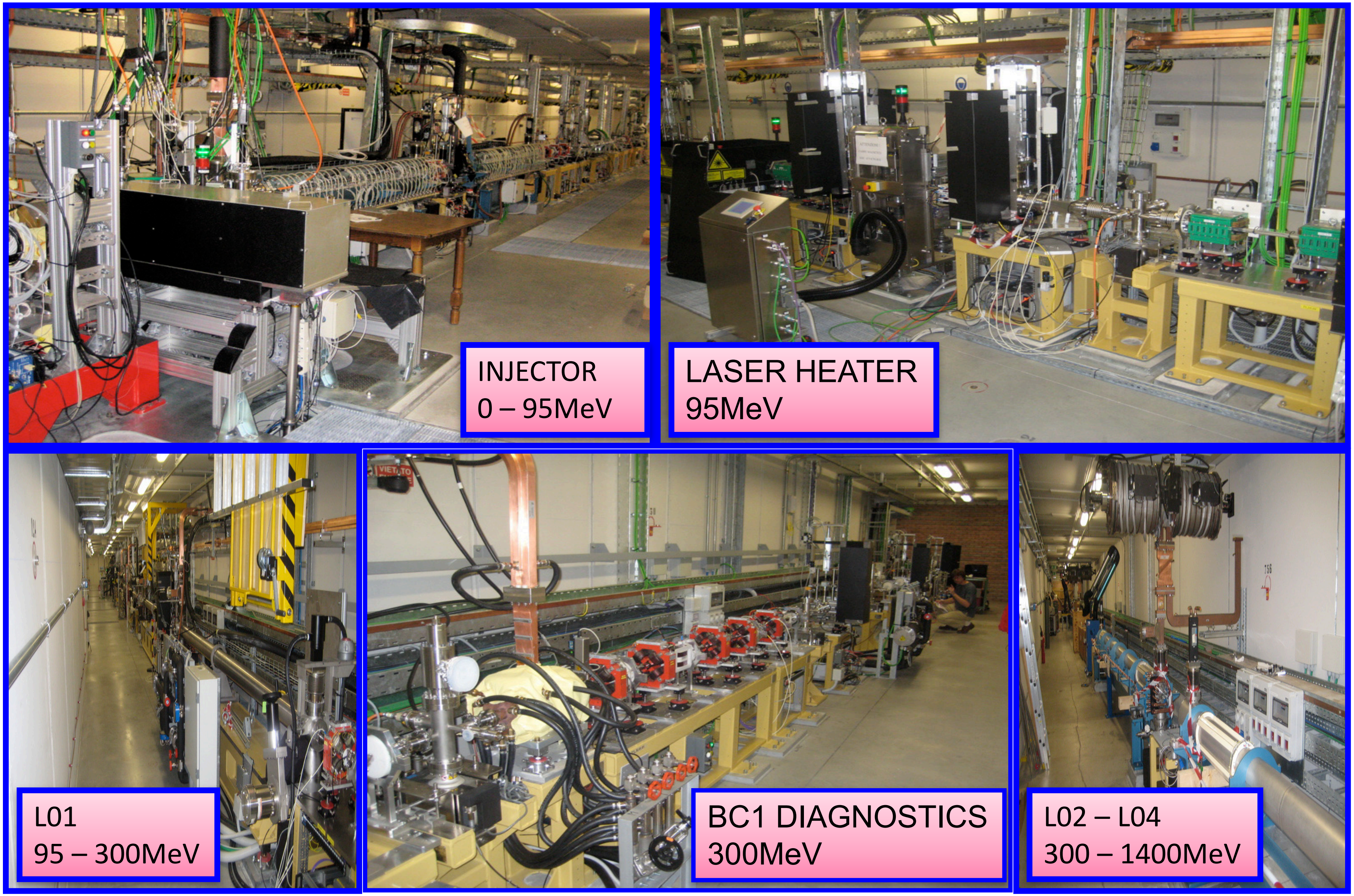
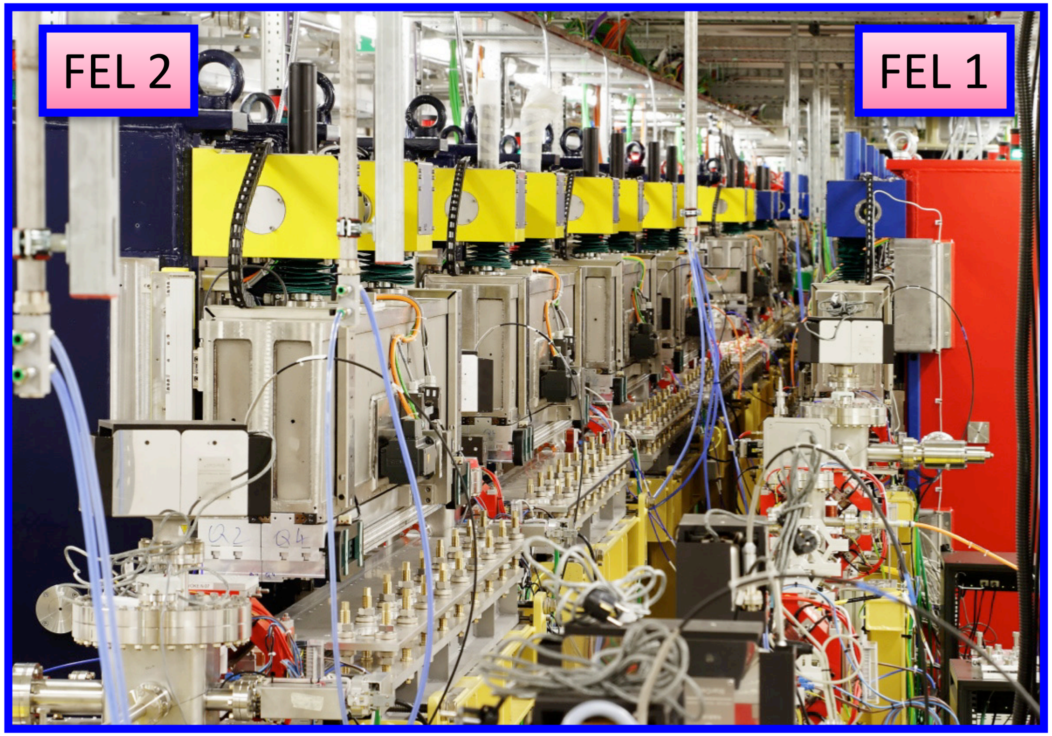
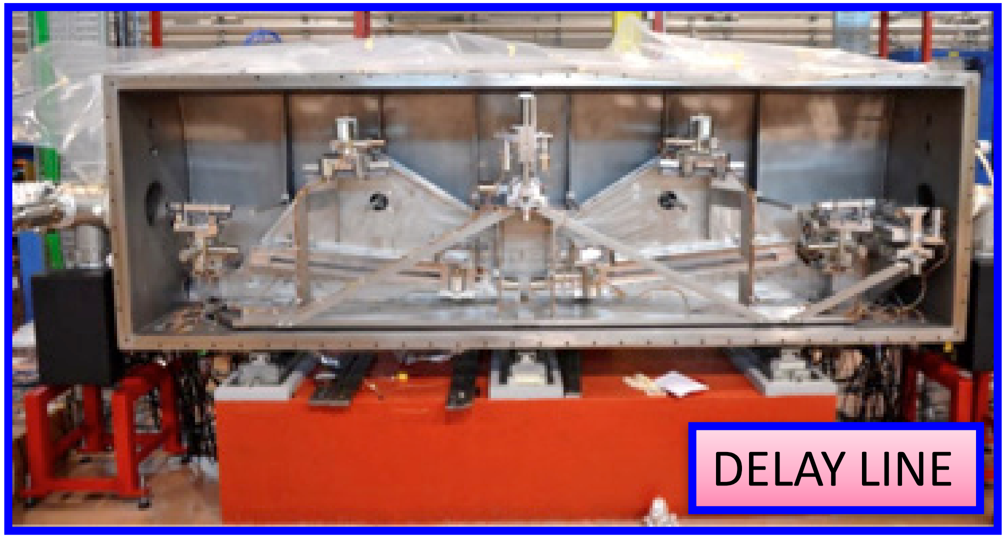
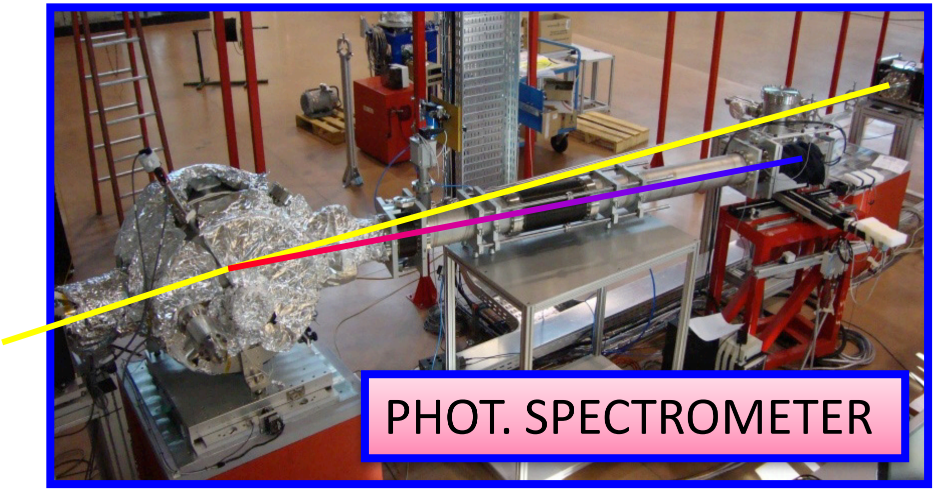
Fermi linac

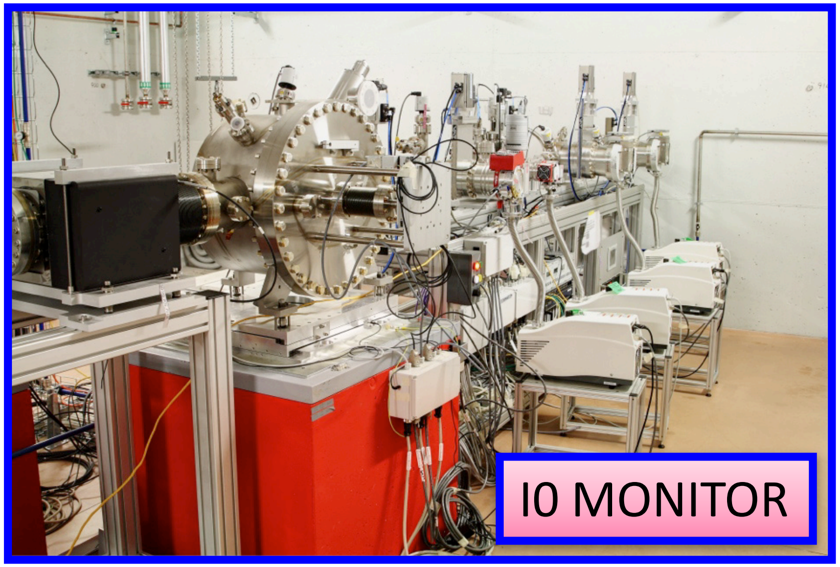


Fermi Undulator Hall and Photon Diagnostics

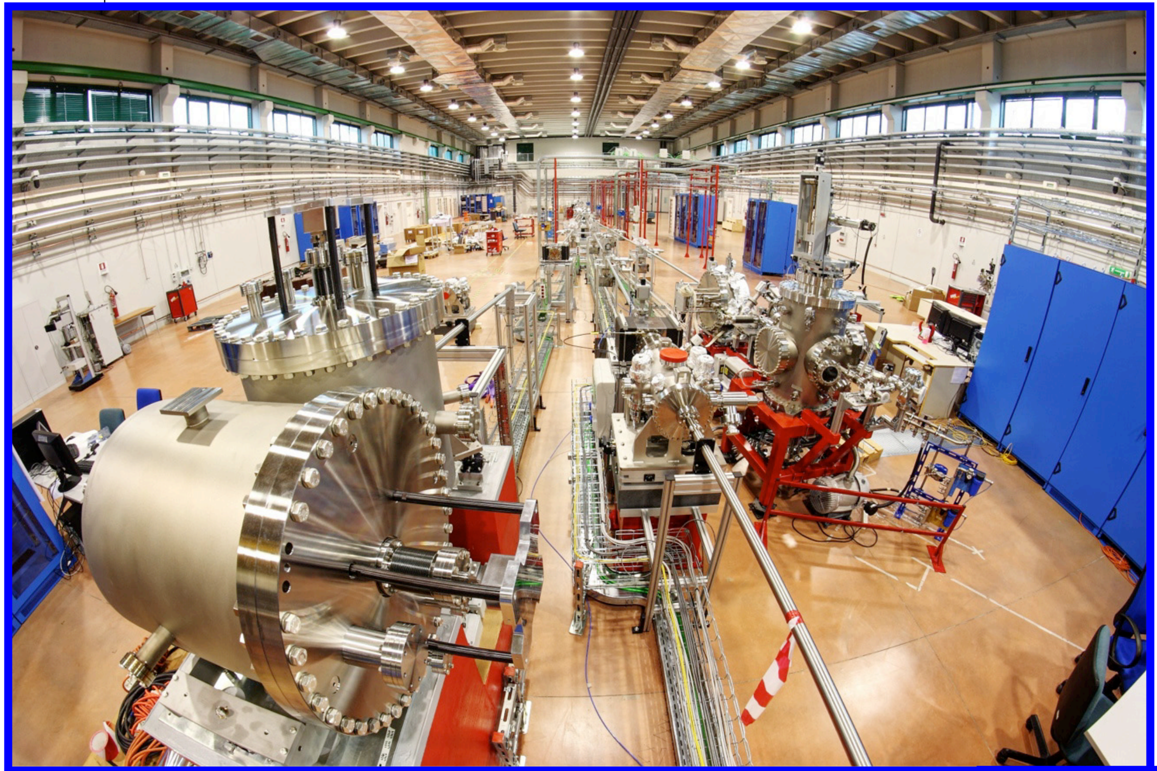


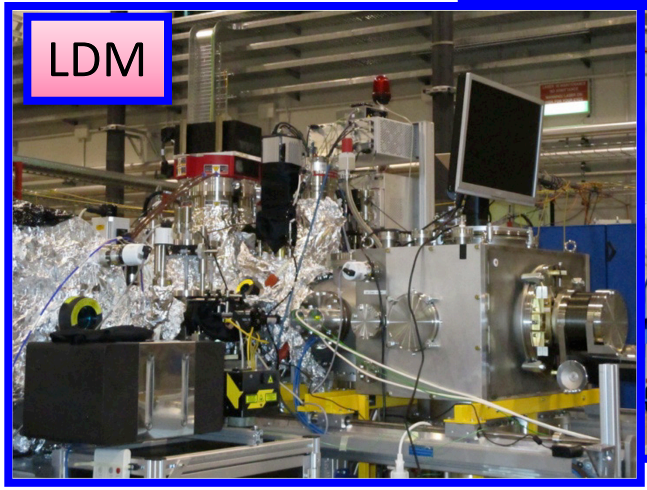


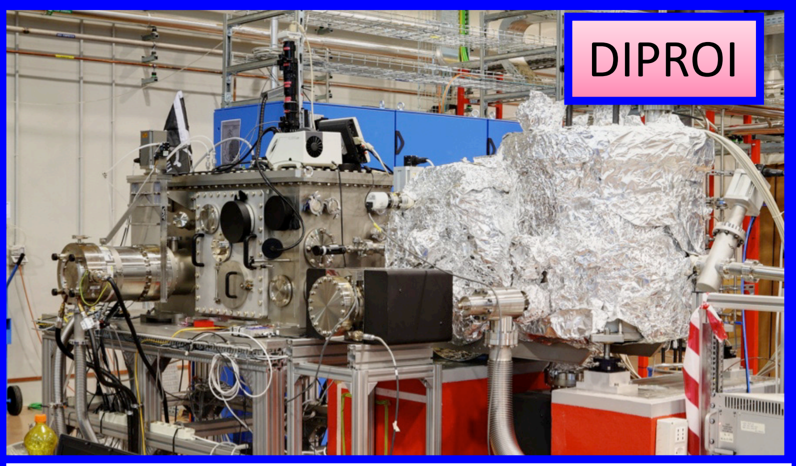




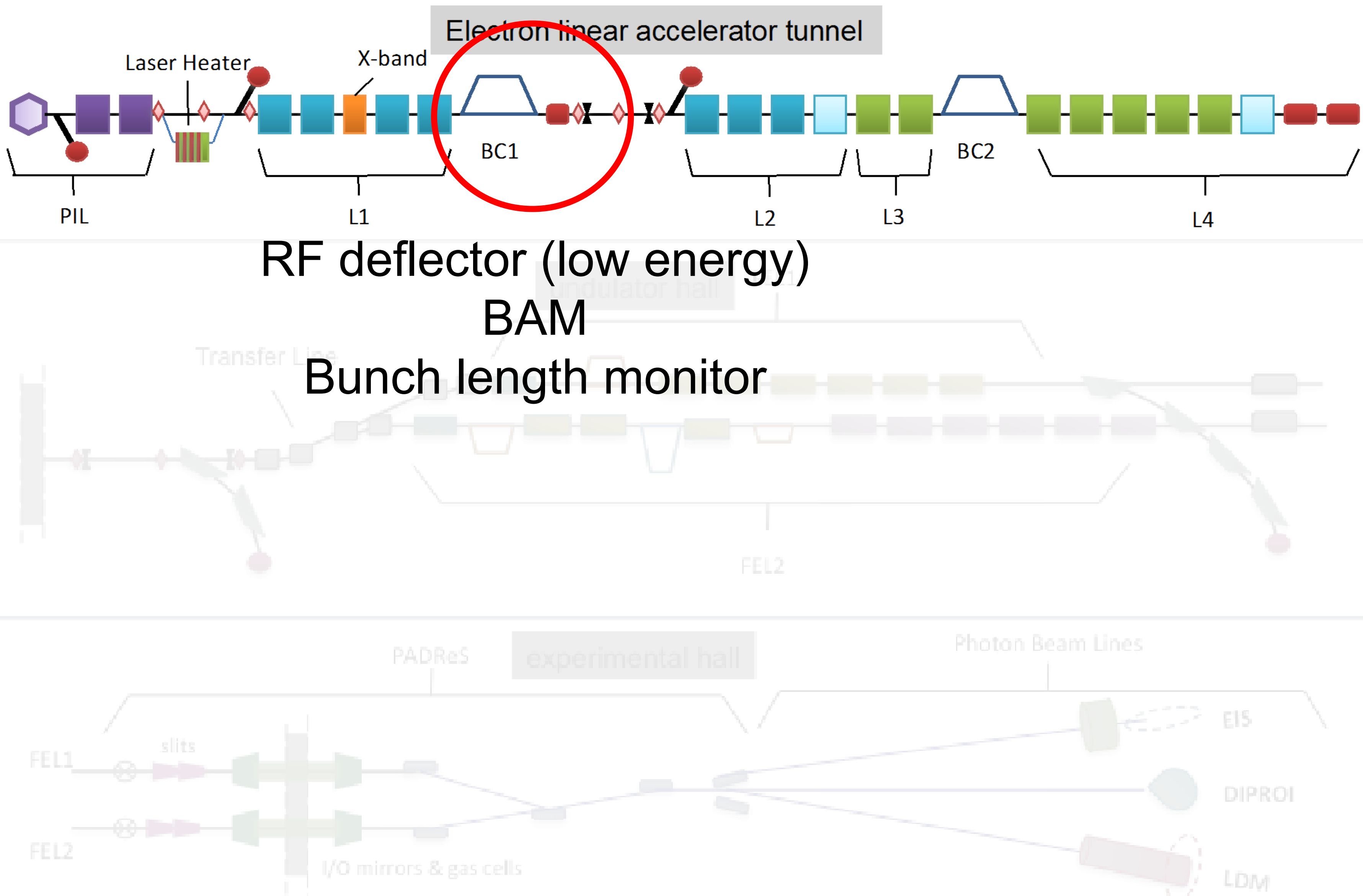
Experimental Hall







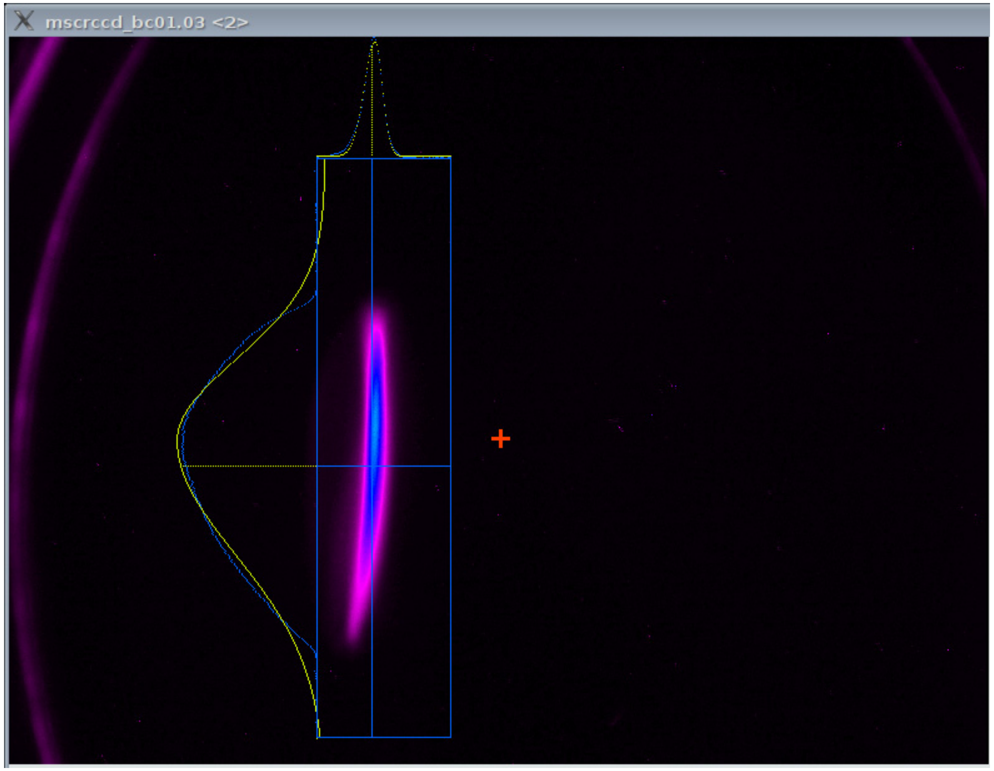
FERMI layout



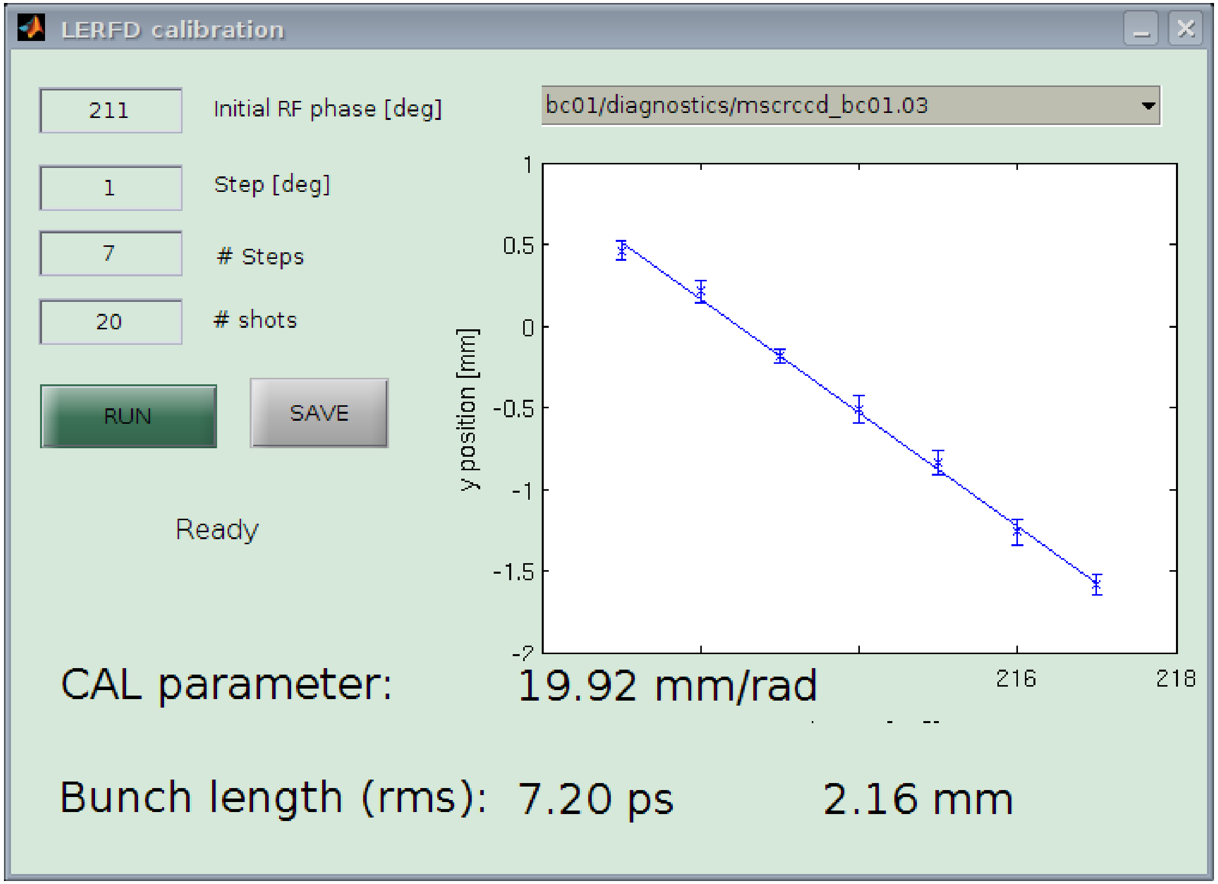
RF deflector (low energy)
BAM
Bunch length monitor

Low Energy RF Deflector

1. Deflected beam



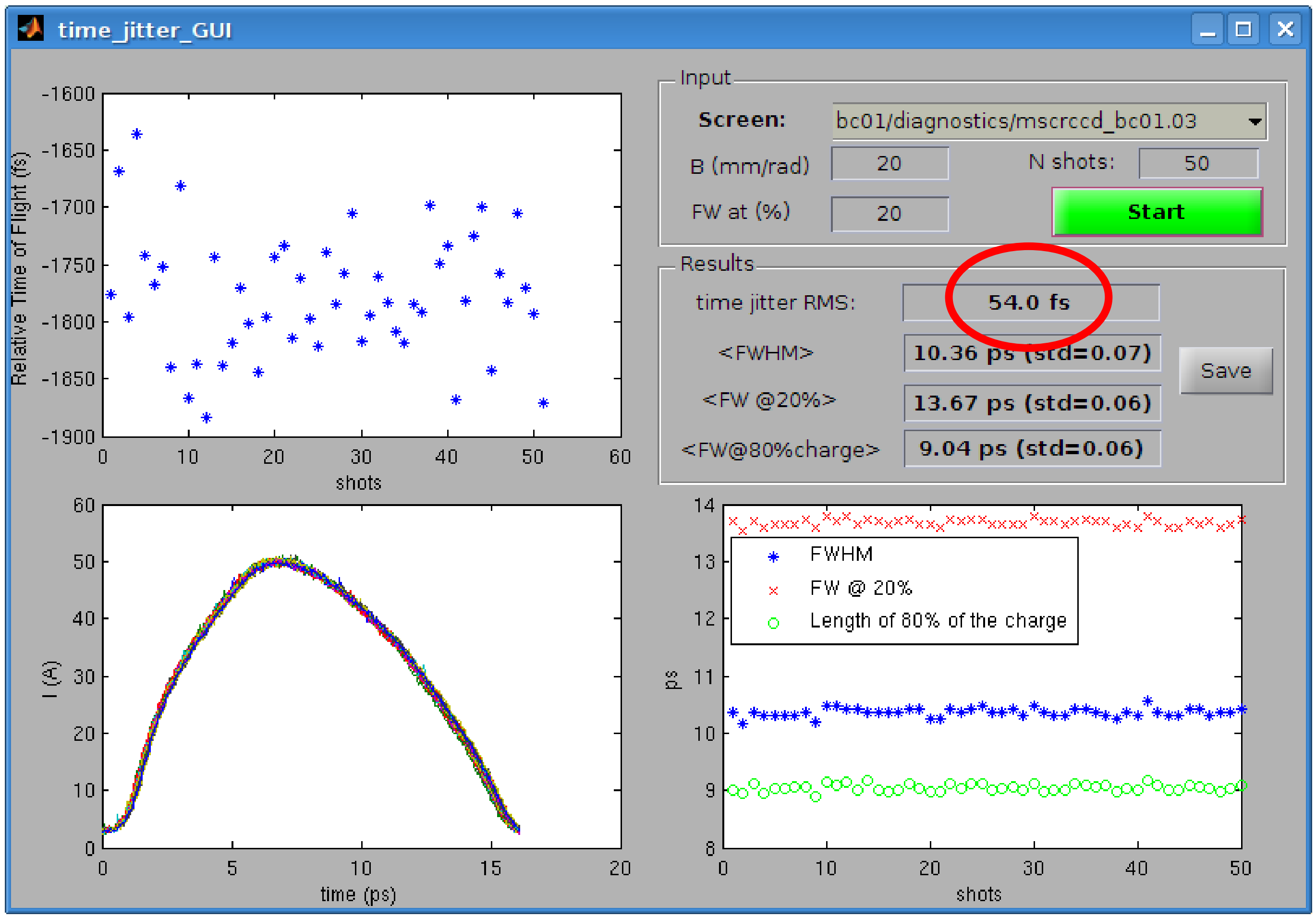
Low Energy RF Deflector



2. Screen calibration

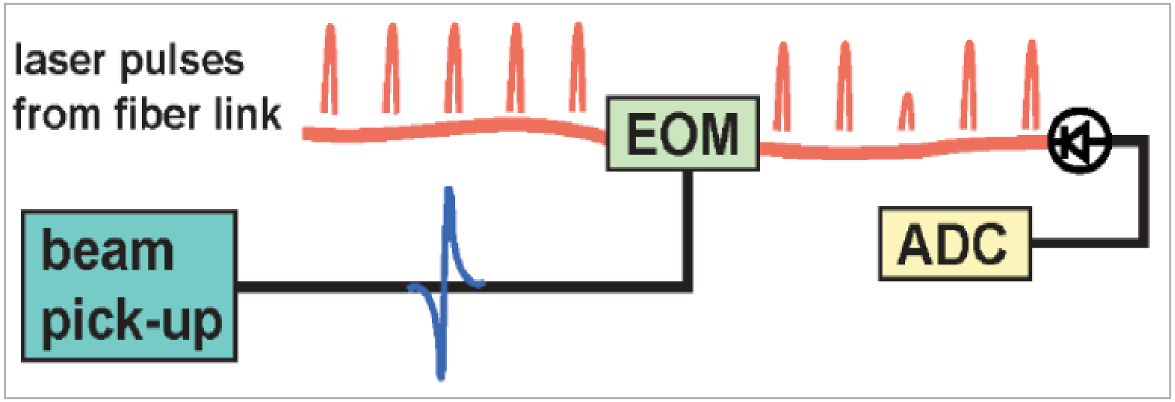
Low Energy RF Deflector

3. Time jitter measurement

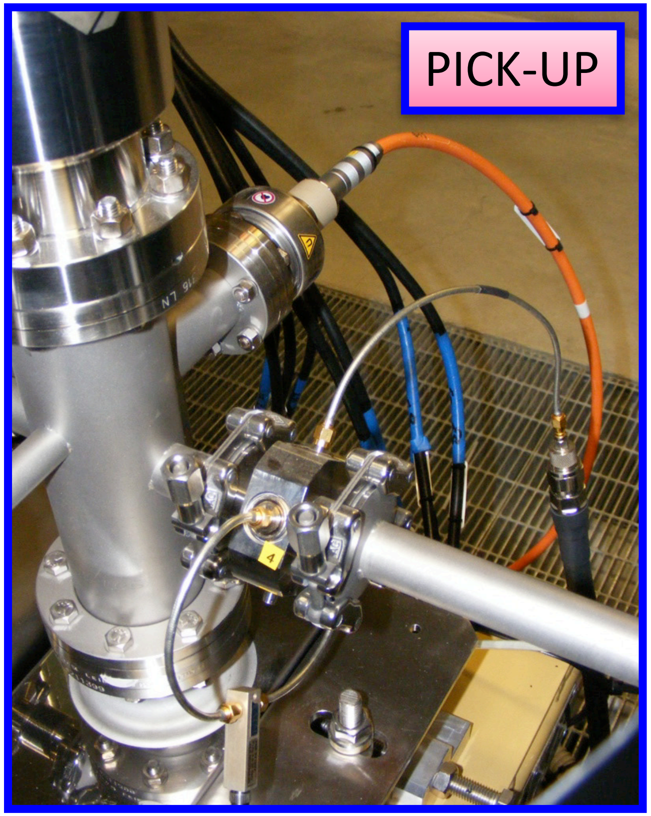


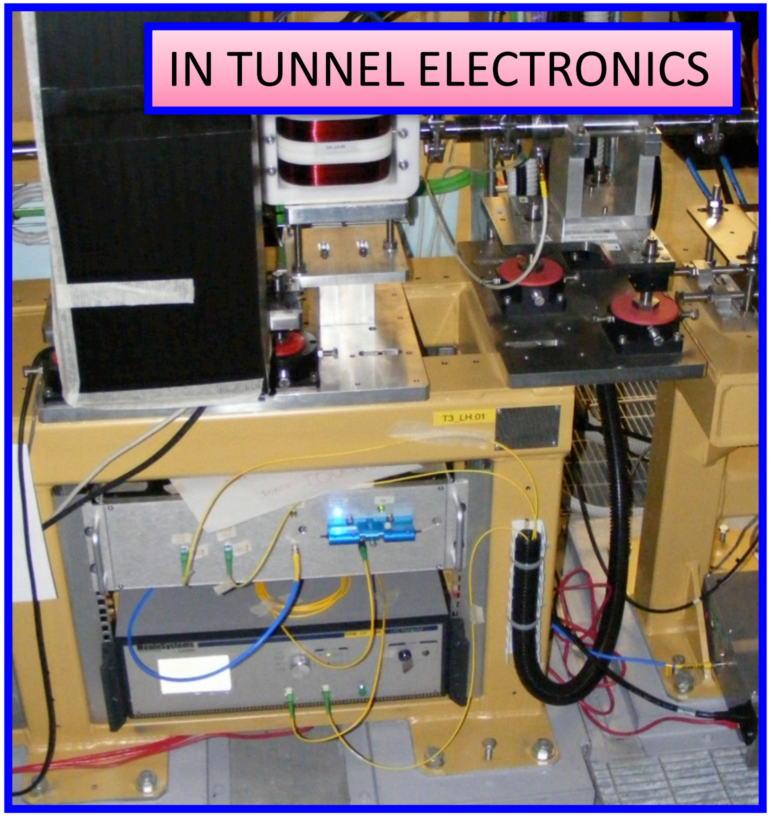
Routinely used for measuring:
Bunch length, charge distribution, bunch shape, slice emittance…

Bunch Arrival Monitor (BAM)

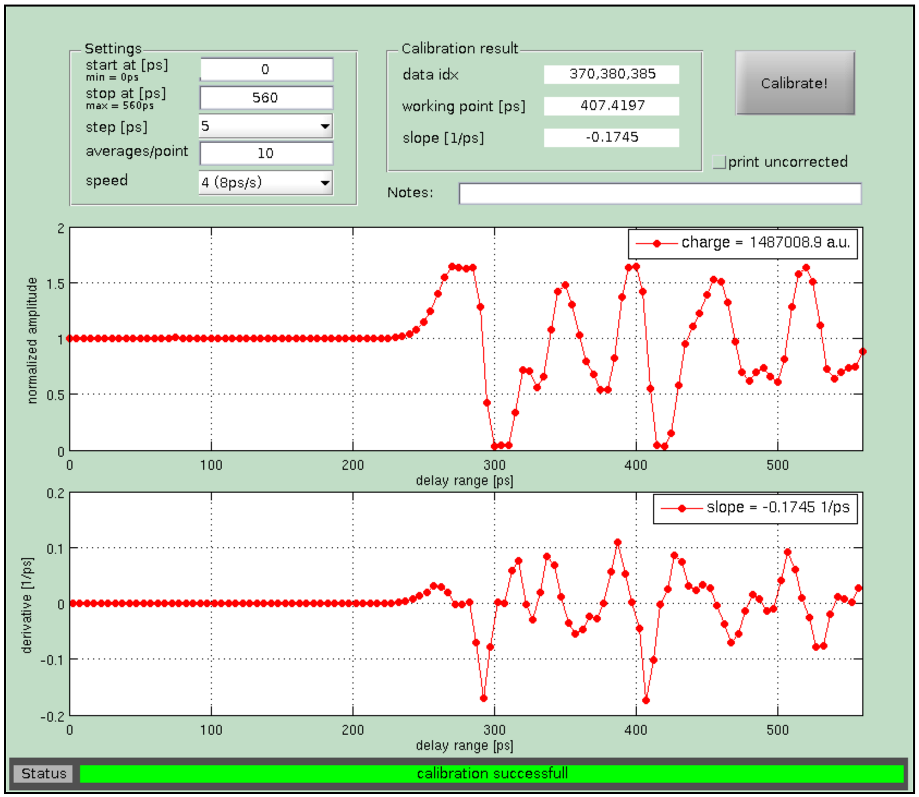


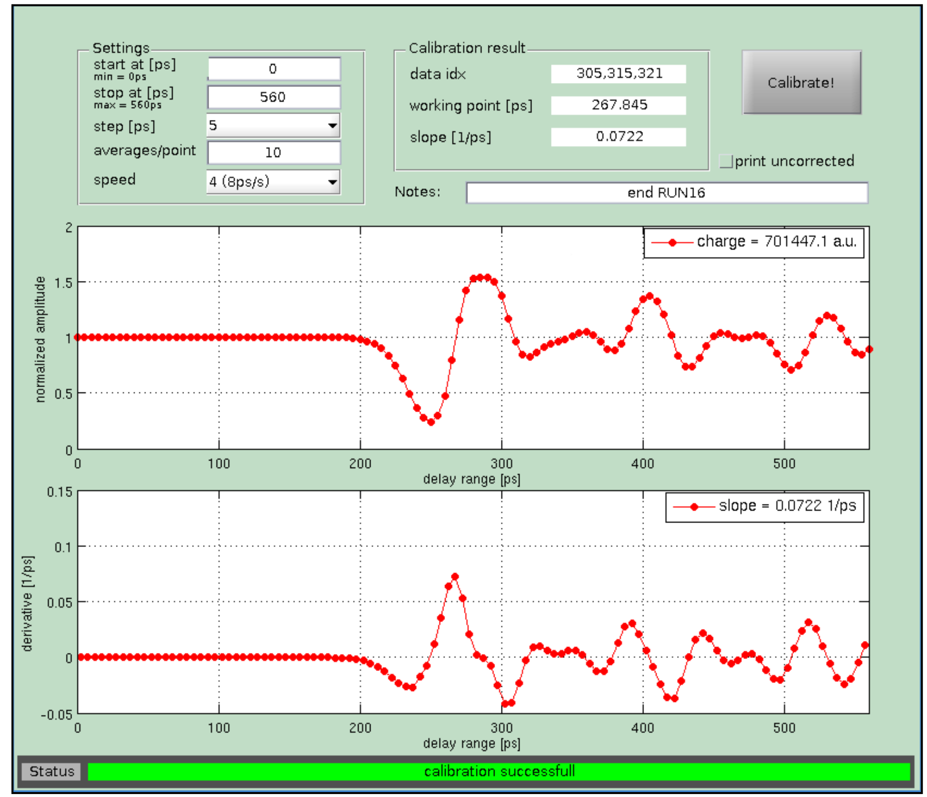
H. Schlarb, DESY;
F. Loehl, PhD Thesis,
Uni. Hamburg 2009





Bunch Arrival Monitor (BAM)





BAM calibration via optical delay line scan of the reference laser pulse over the BAM pick-up signal.

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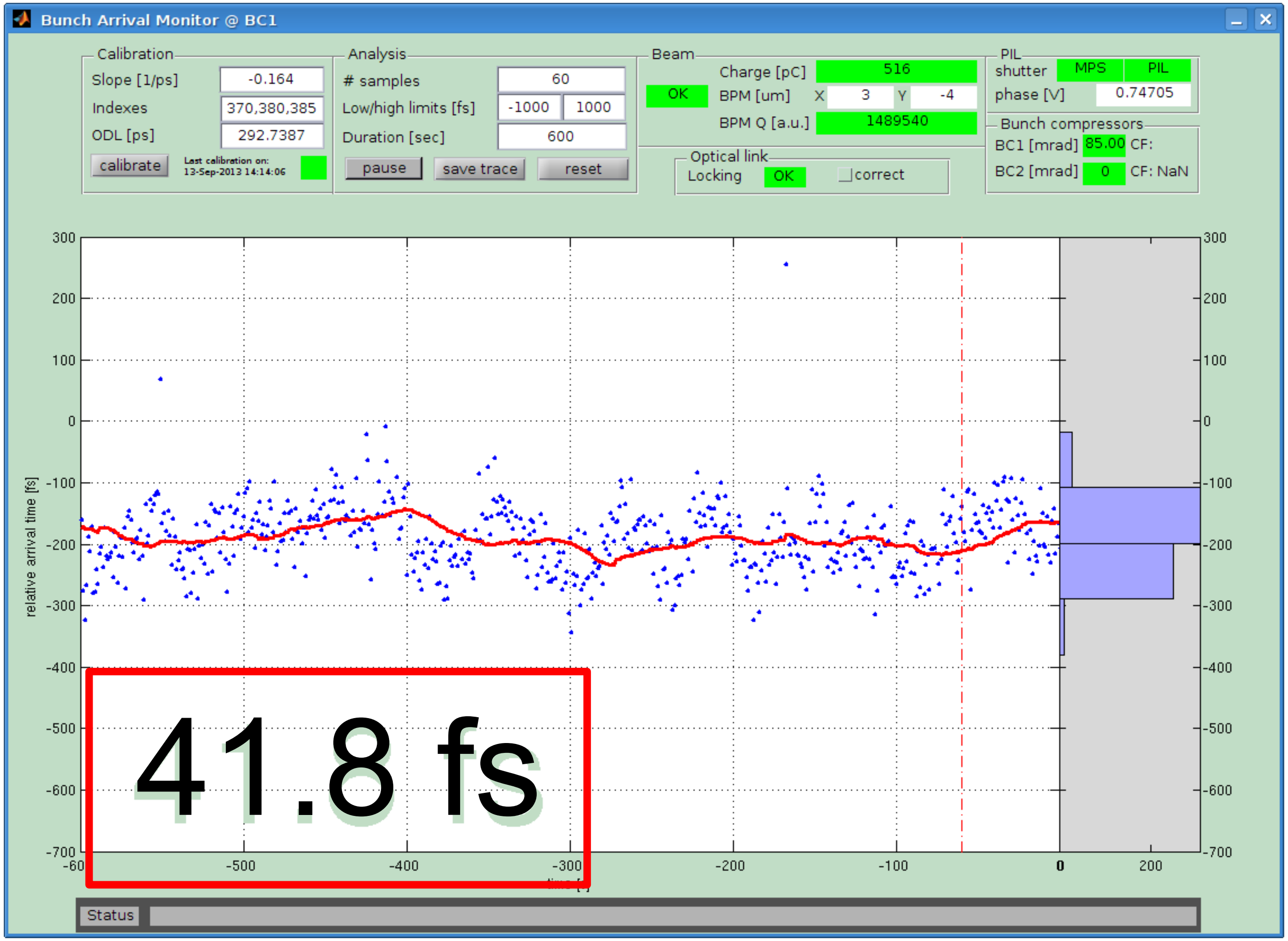
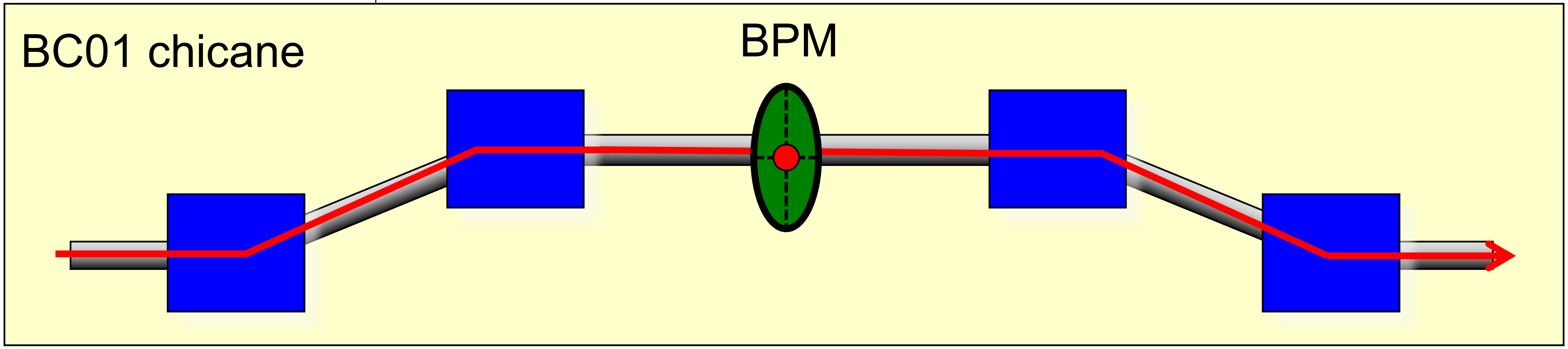
Bunch Arrival Monitor (BAM)

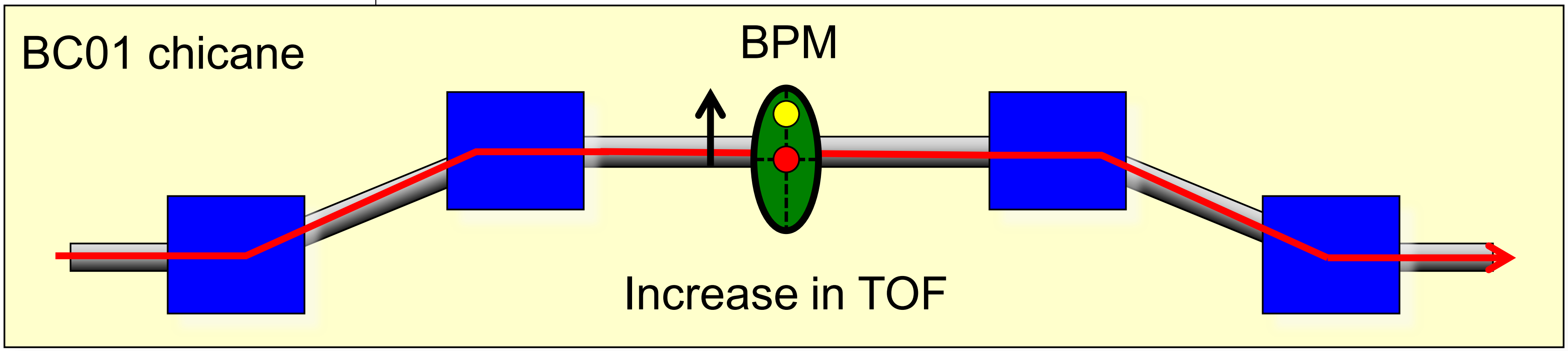


Acquisition over 10 minutes

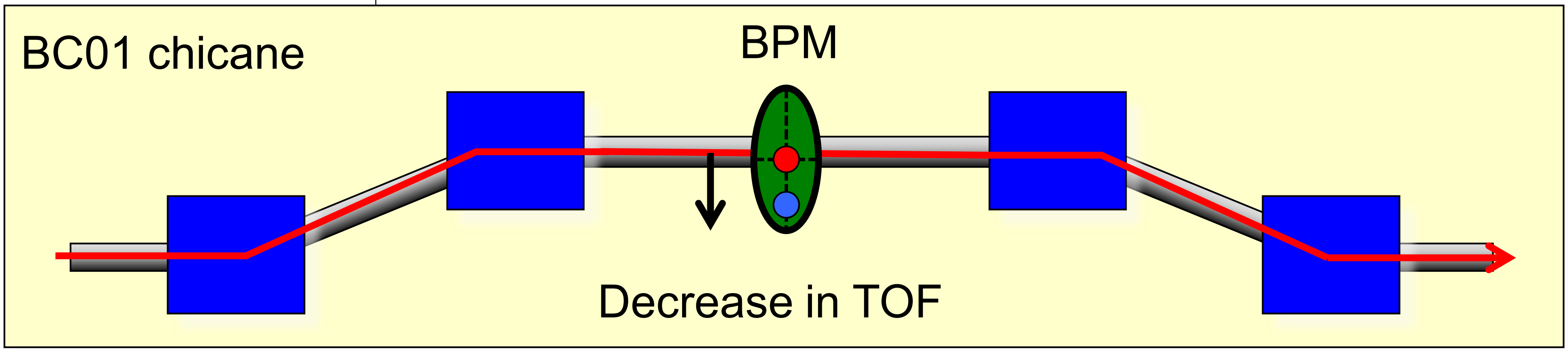
BAM Cross Calibration



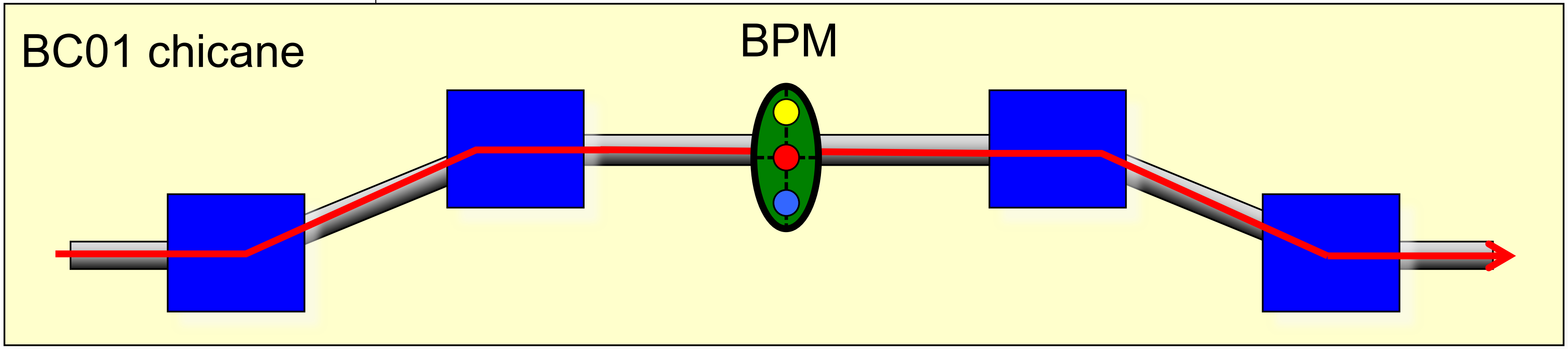
BAM Cross Calibration

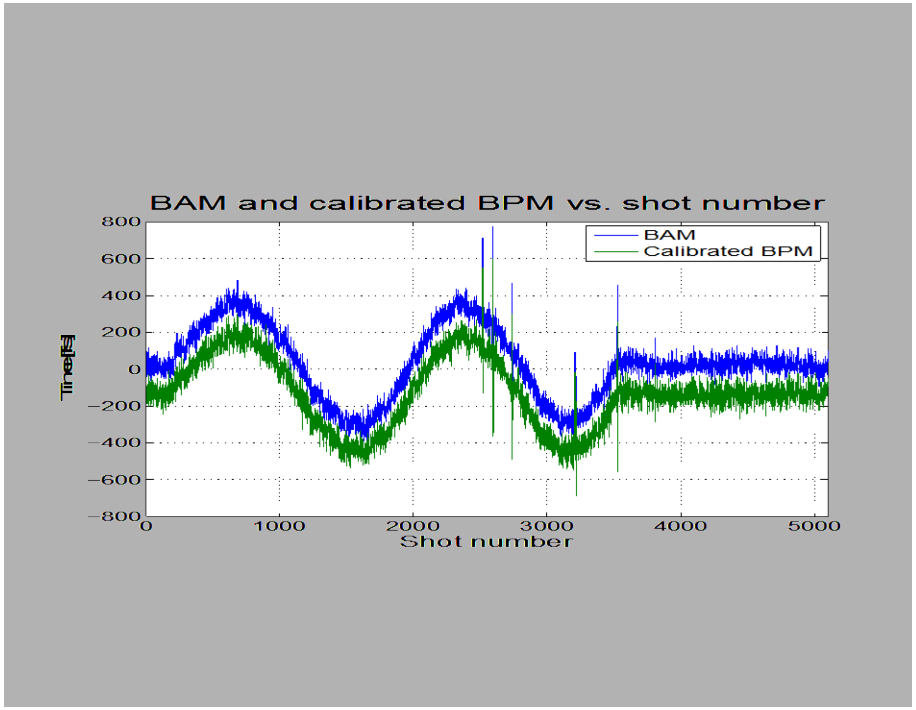


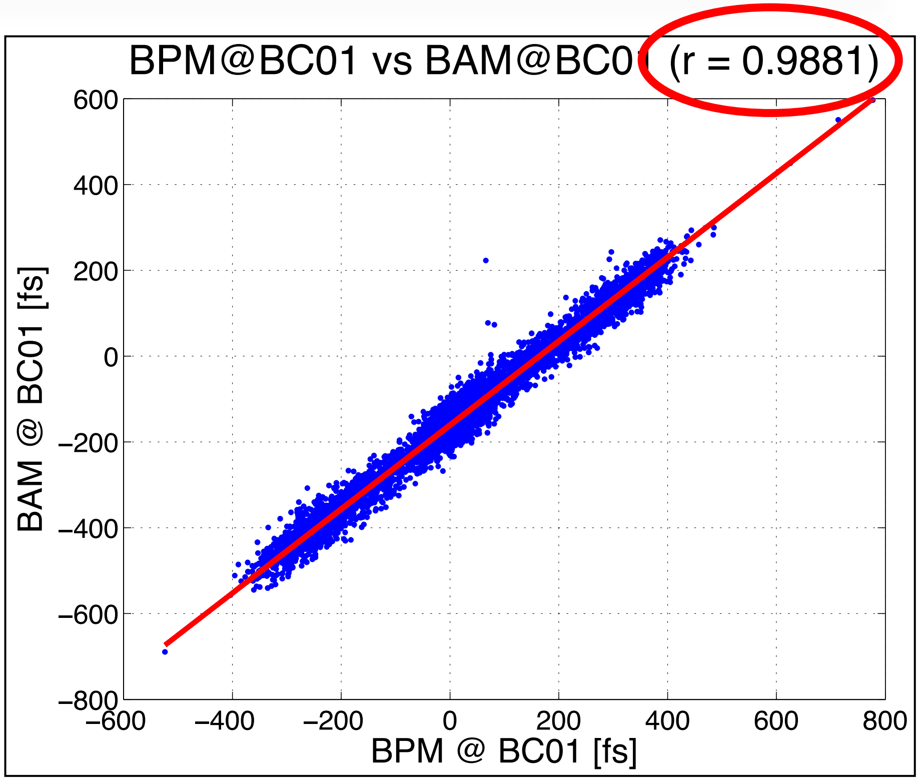
BAM Cross Calibration



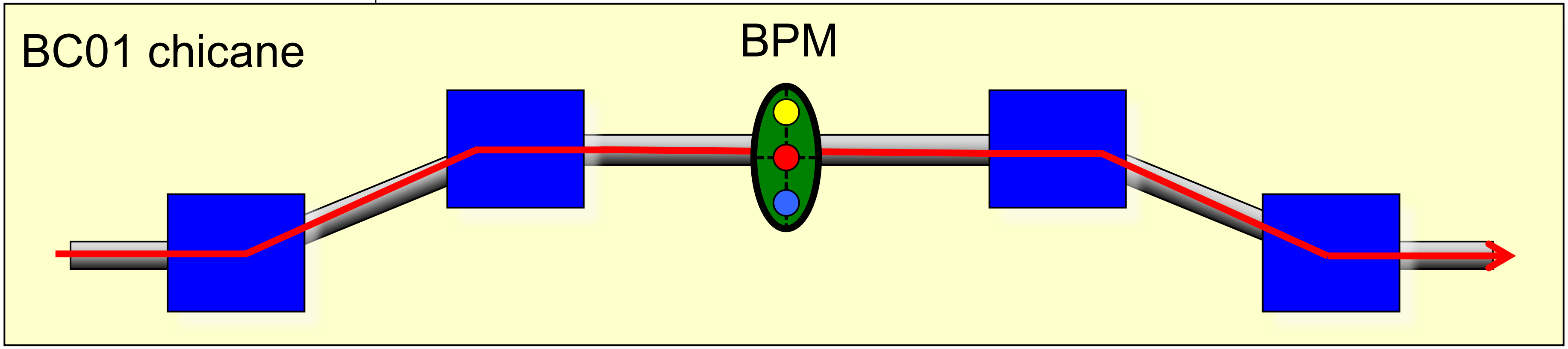
BAM Cross Calibration

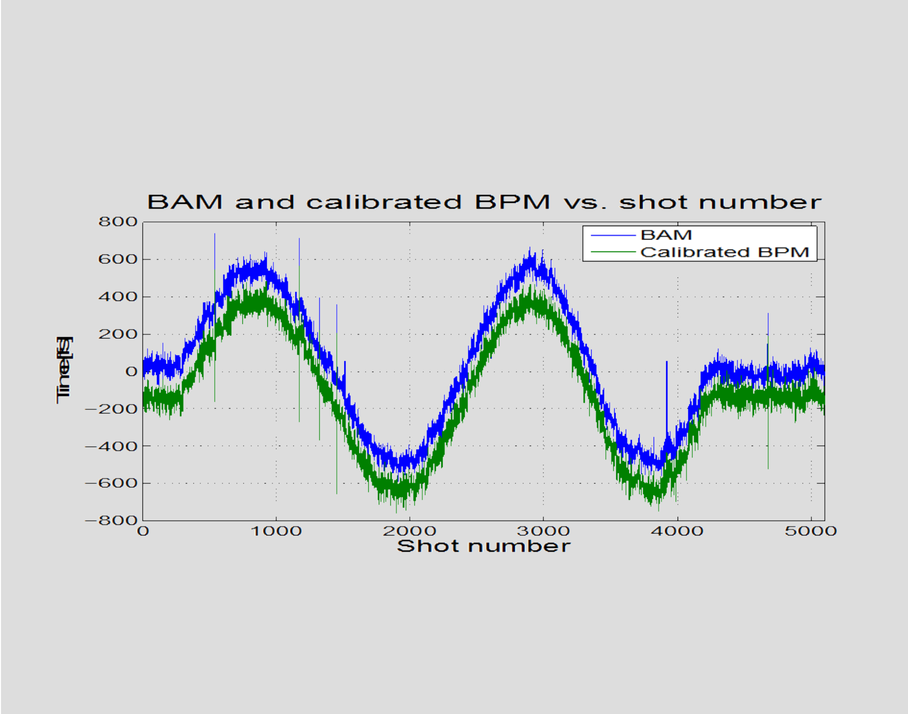


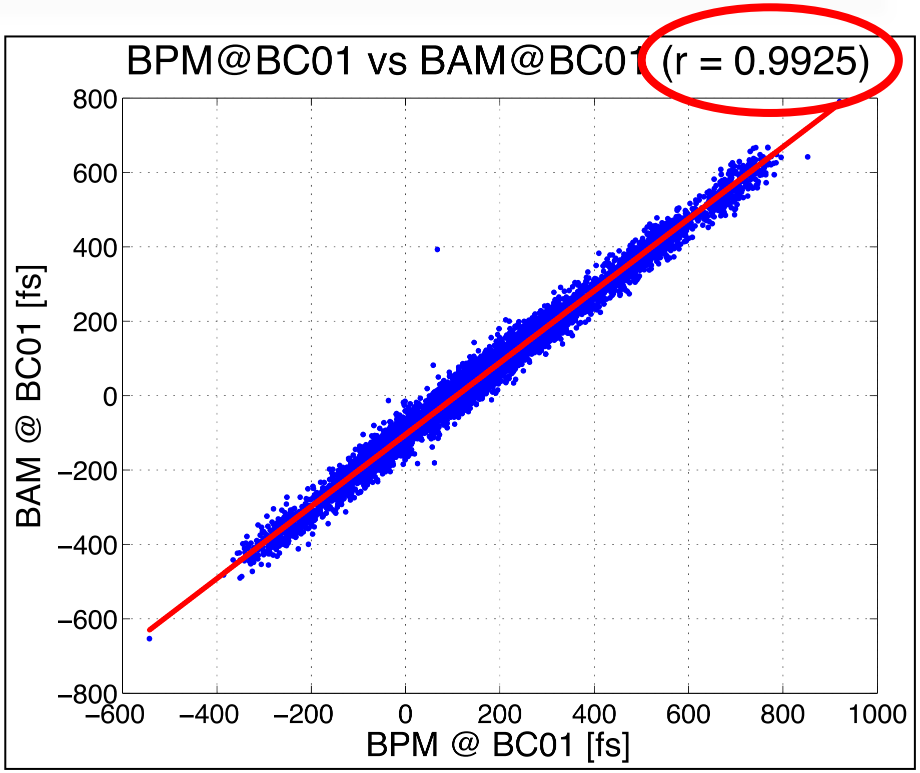




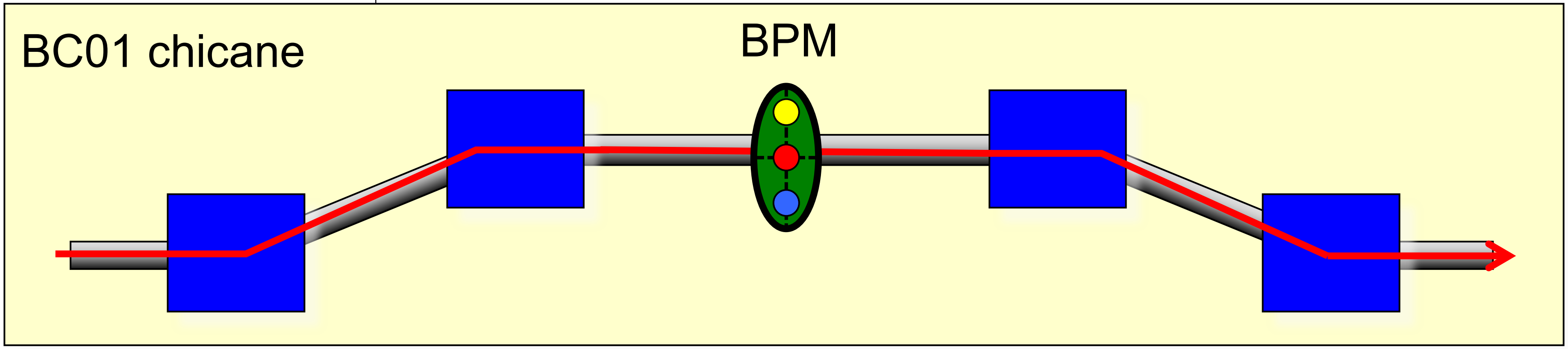
BAM Cross Calibration

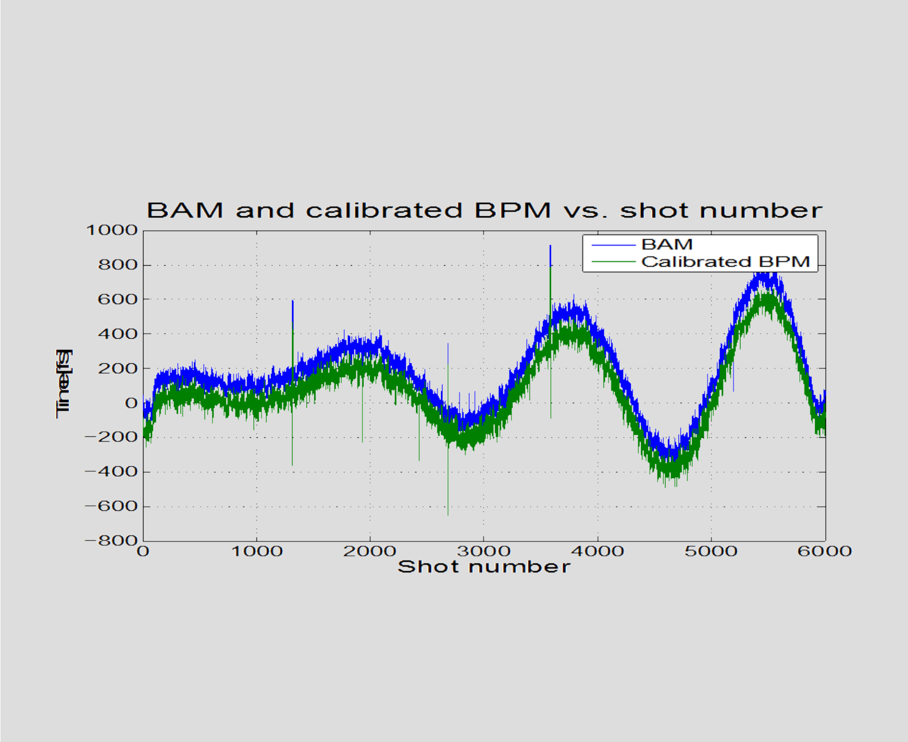


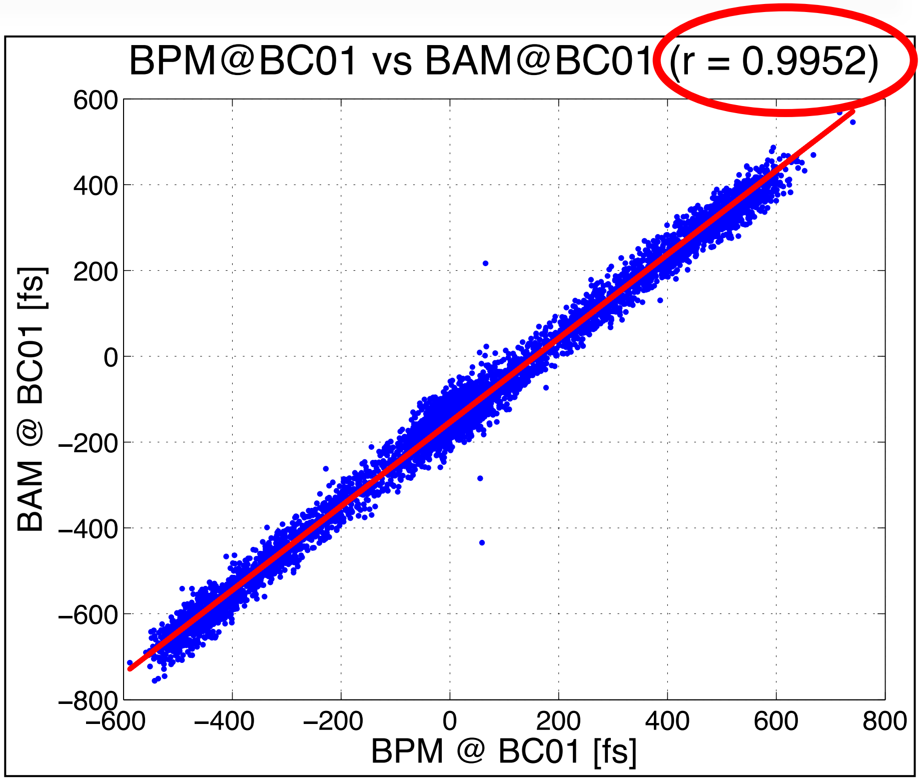




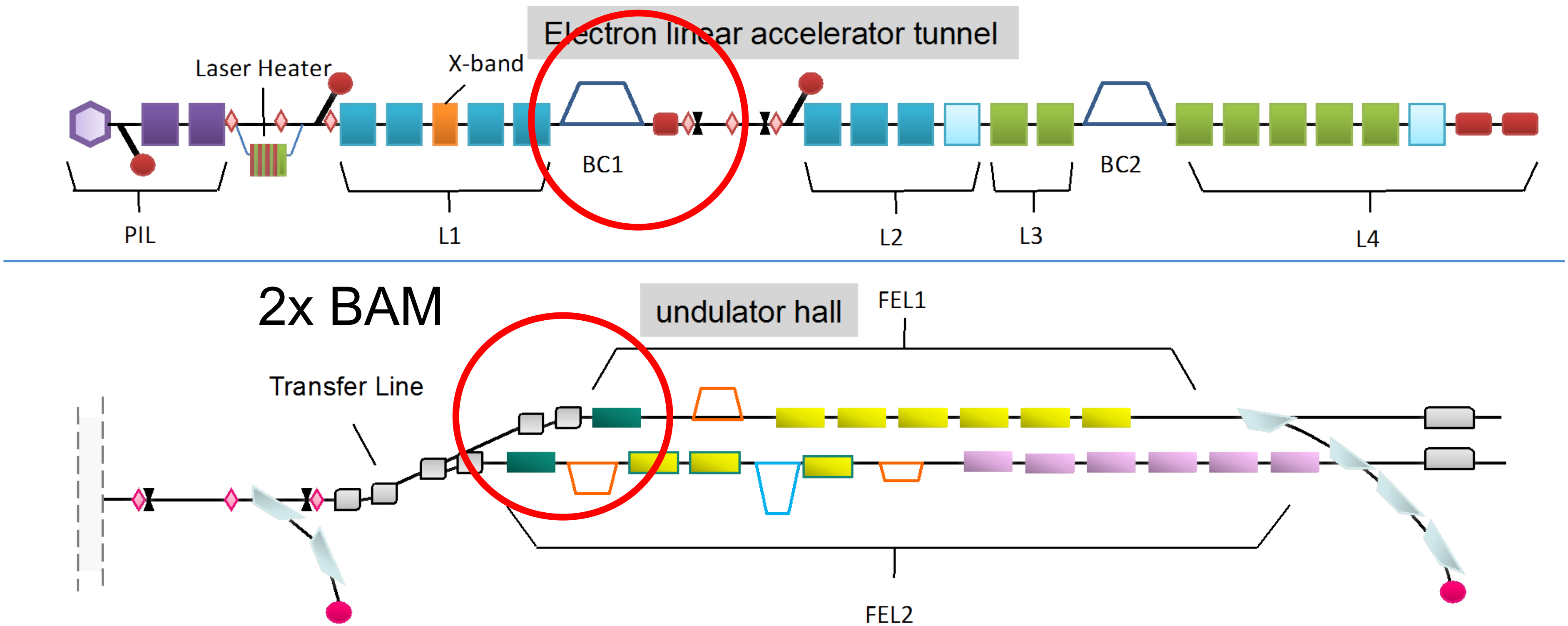
BAM Cross Calibration







FERMI layout



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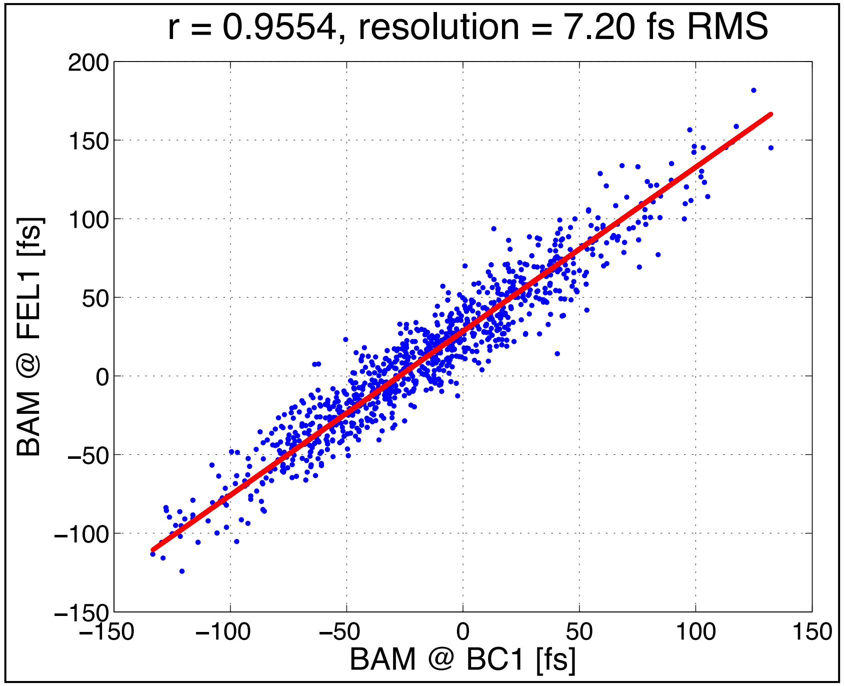
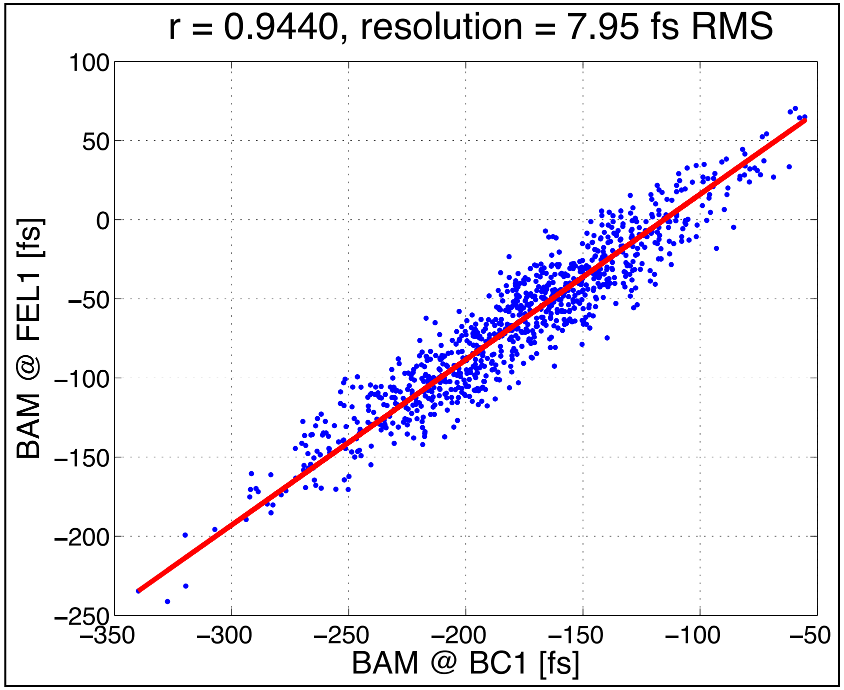
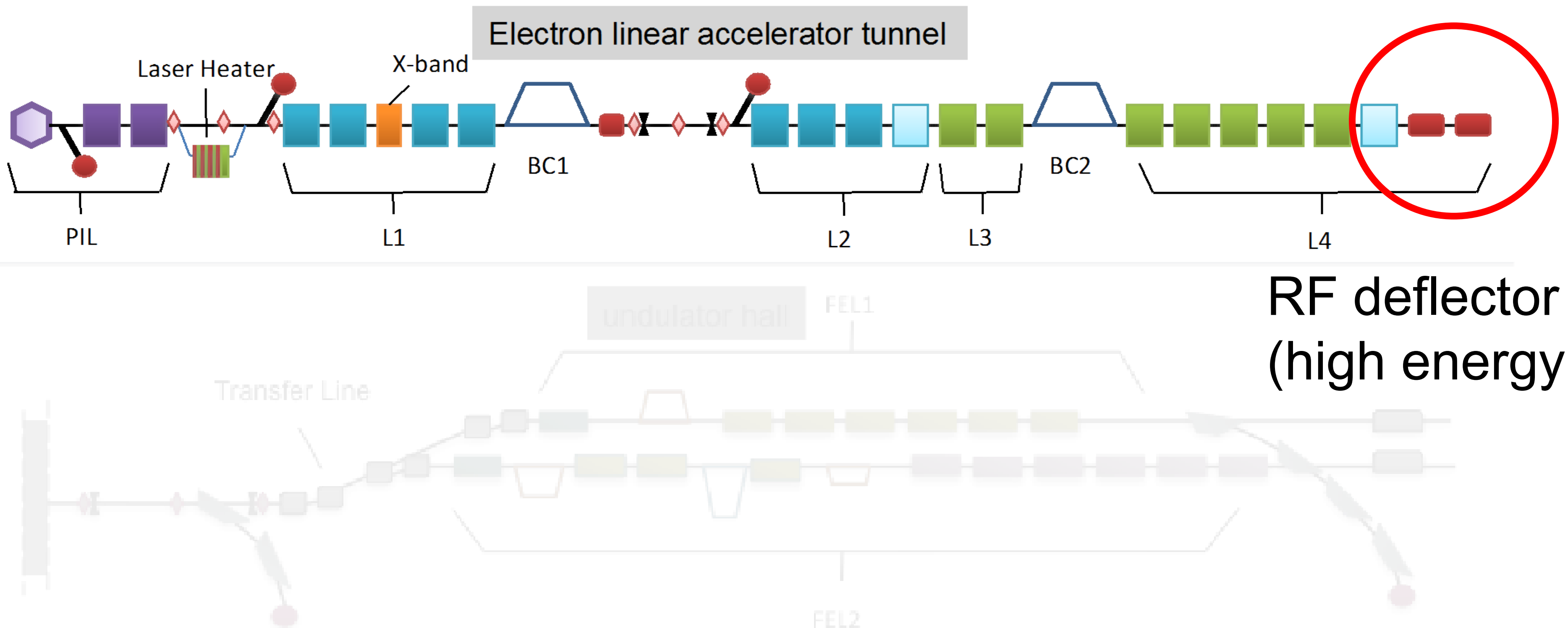
BAM Performance





The correlations between the two BAMs is constant.
The experimental resolution of each device is below 8 fs.
BAMs represent the reference arrival time diagnostic for FERMI.
Usefull to investigate time jitter sources.

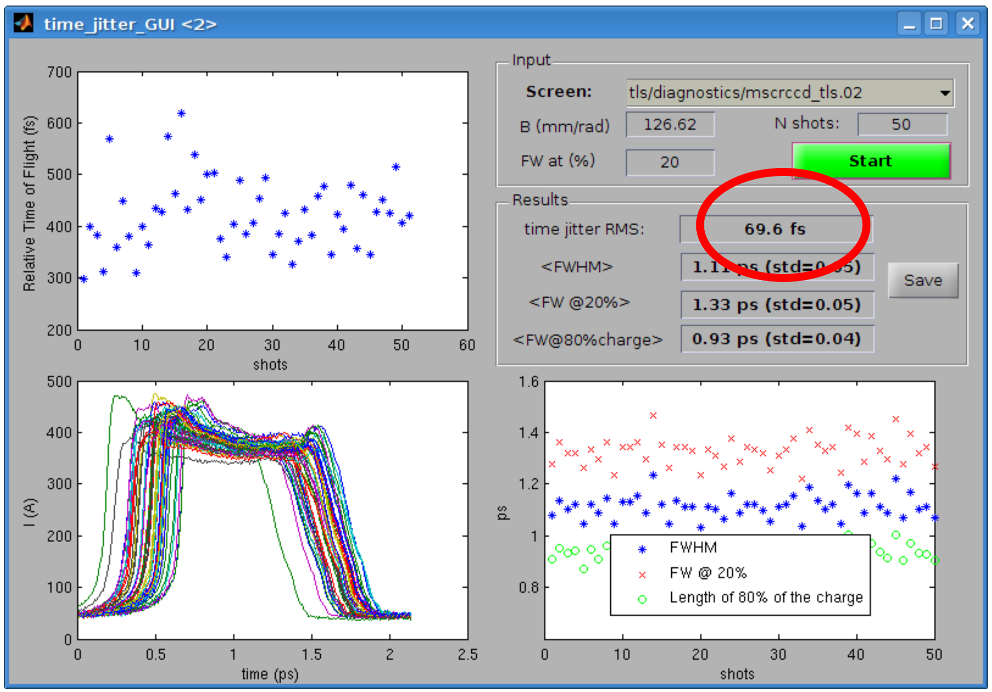
FERMI layout



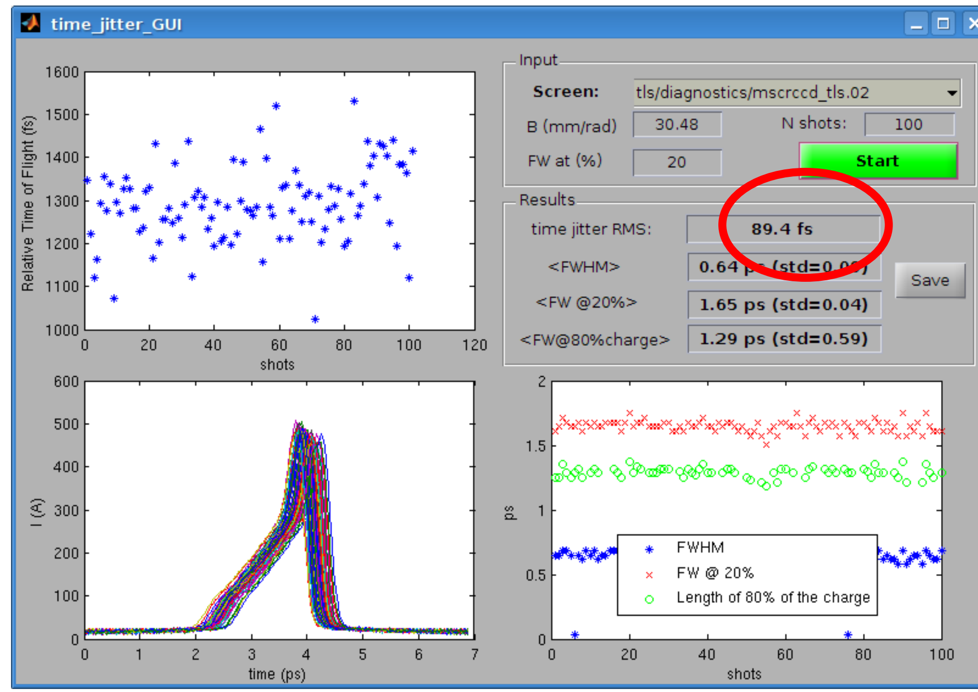
RF deflector (high energy)

High Energy RF Deflector (HERFD)

Time jitter, charge distribution and bunch shape measurements for different beam tuning.

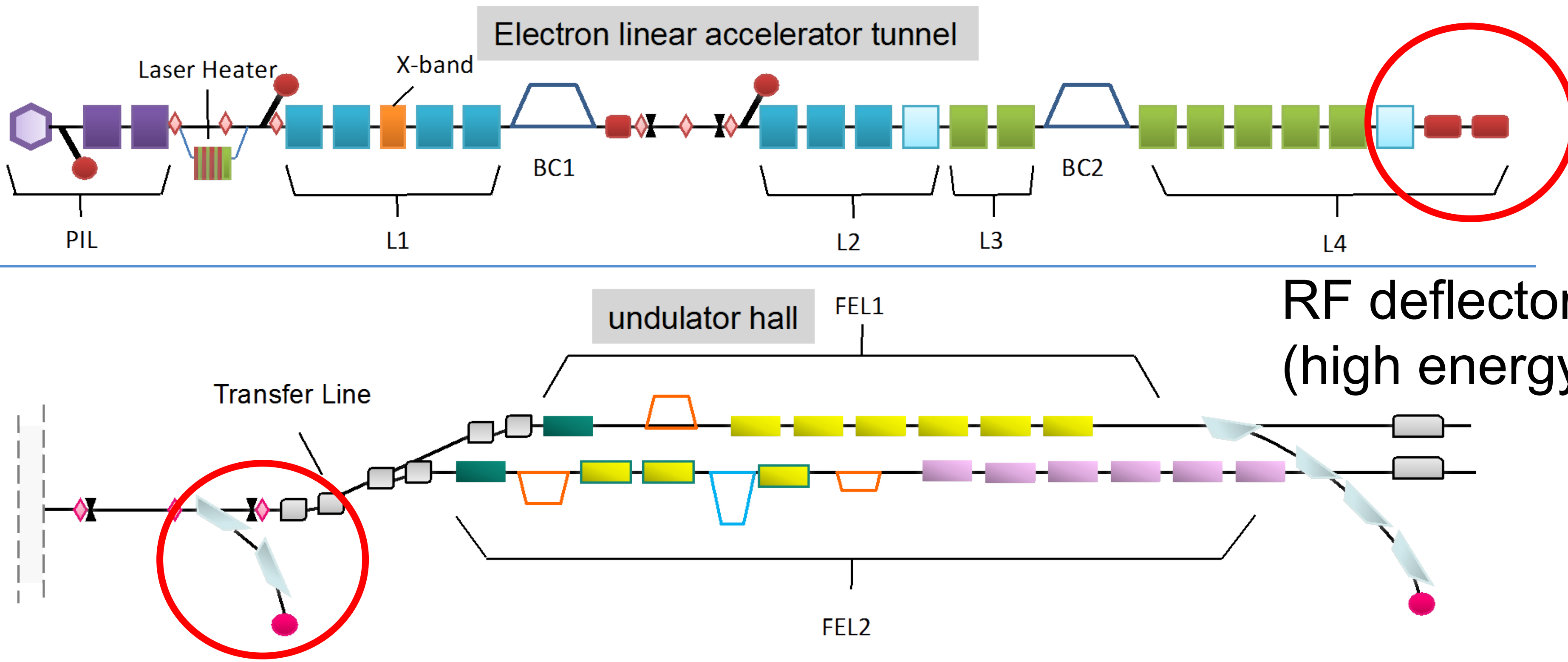


Linearized beam



Ramped current profile
(no X-band cavity)

FERMI layout

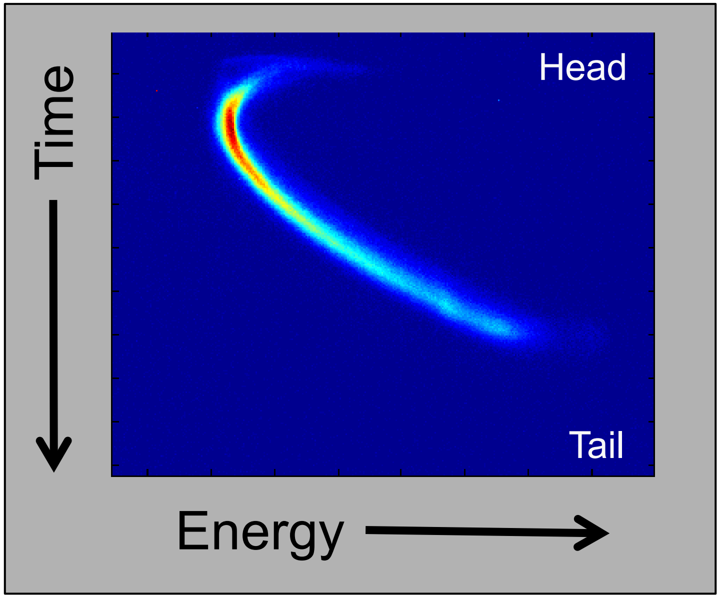


RF deflector (high energy)

DBD Spectrometer

DBD Spectrometer + HERFD

Measurement of the longitudinal phase space



Coupled RF deflector (vertical) and dipole spectrometer (horizontal)

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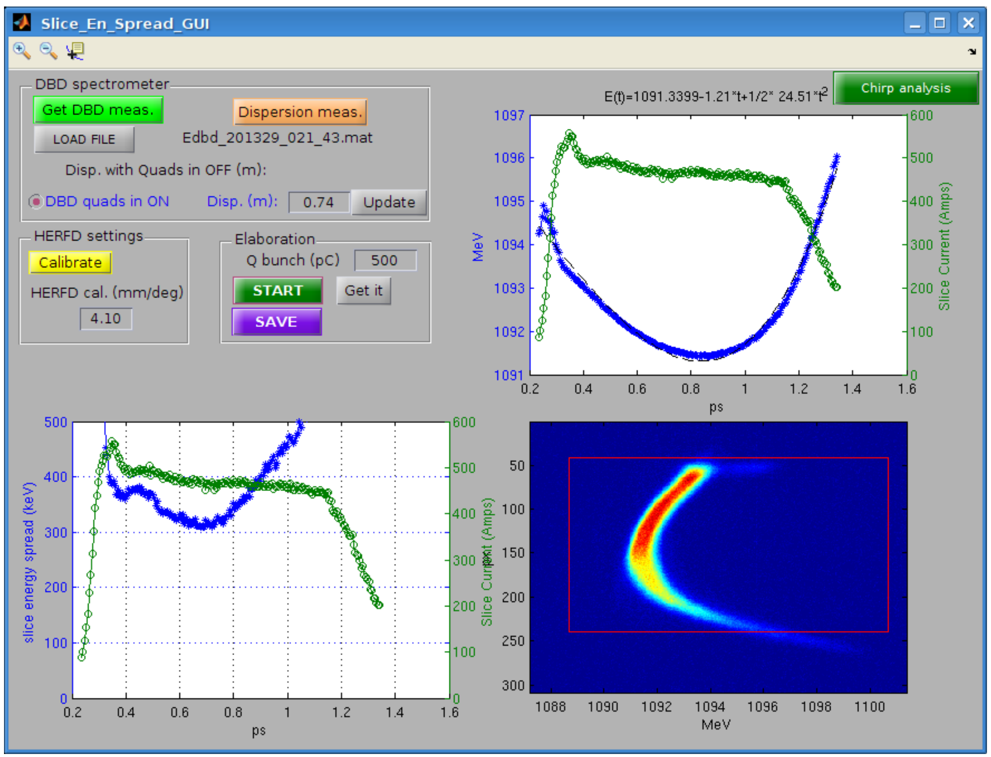
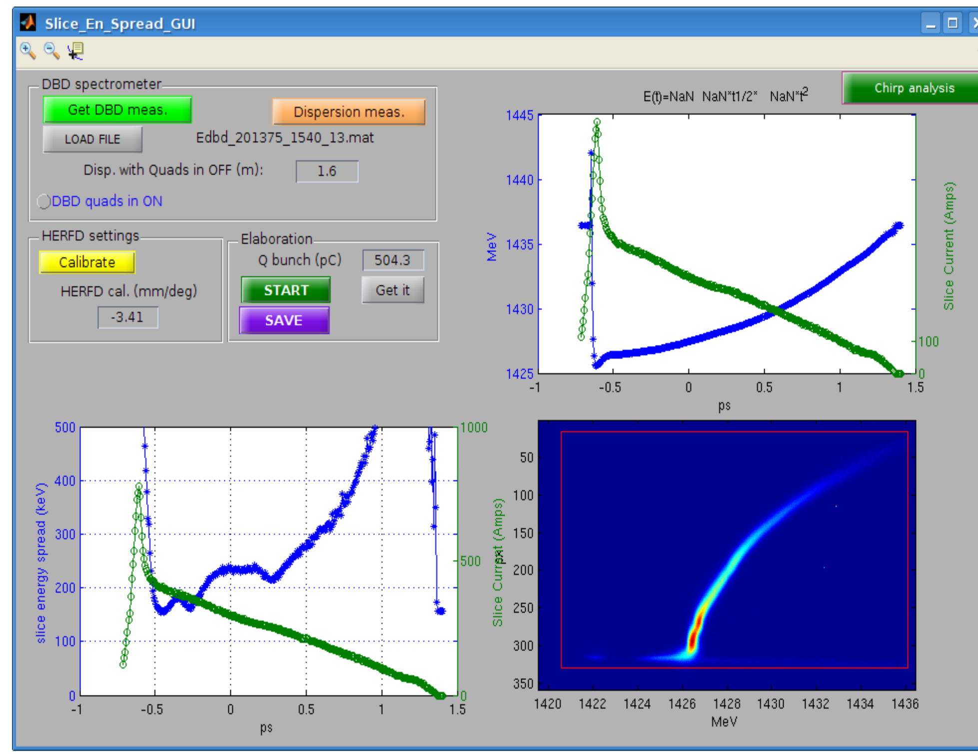
DBD Spectrometer + HERFD

Measurement of the longitudinal phase space



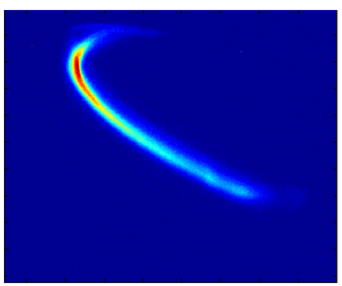
Linearized beam



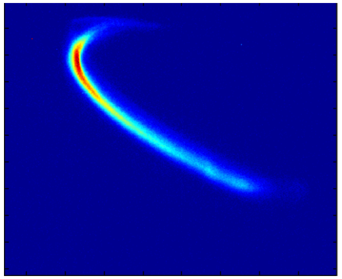
Ramped current profile
(no X-band cavity)

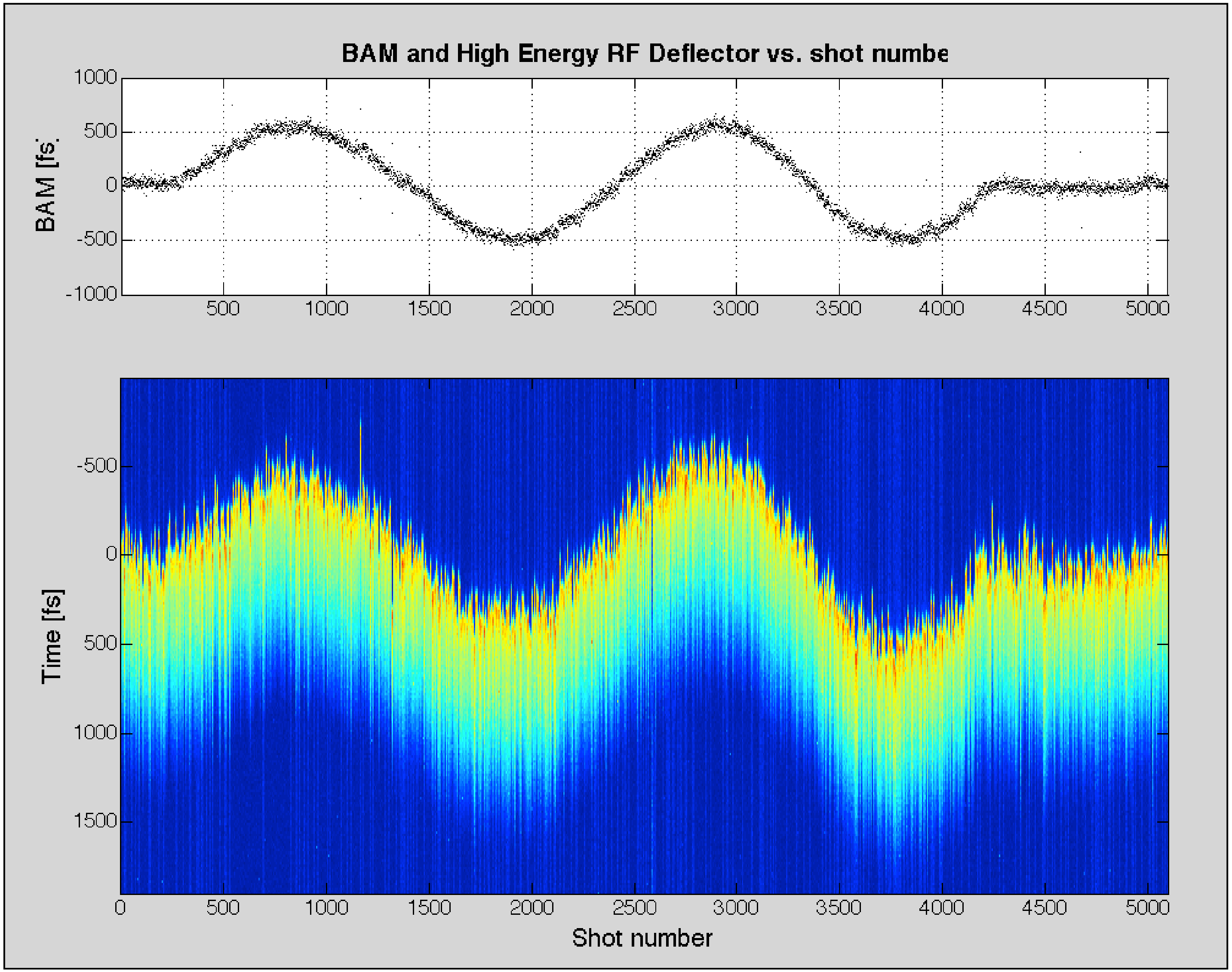
Also, slice energy spread, current profile, energy chirp, etc.

HERFD and BAM



HERFD and BAM





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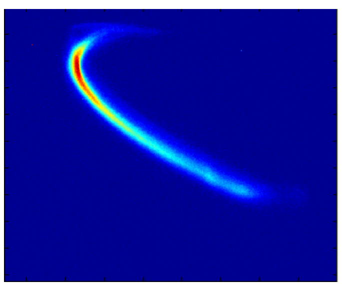
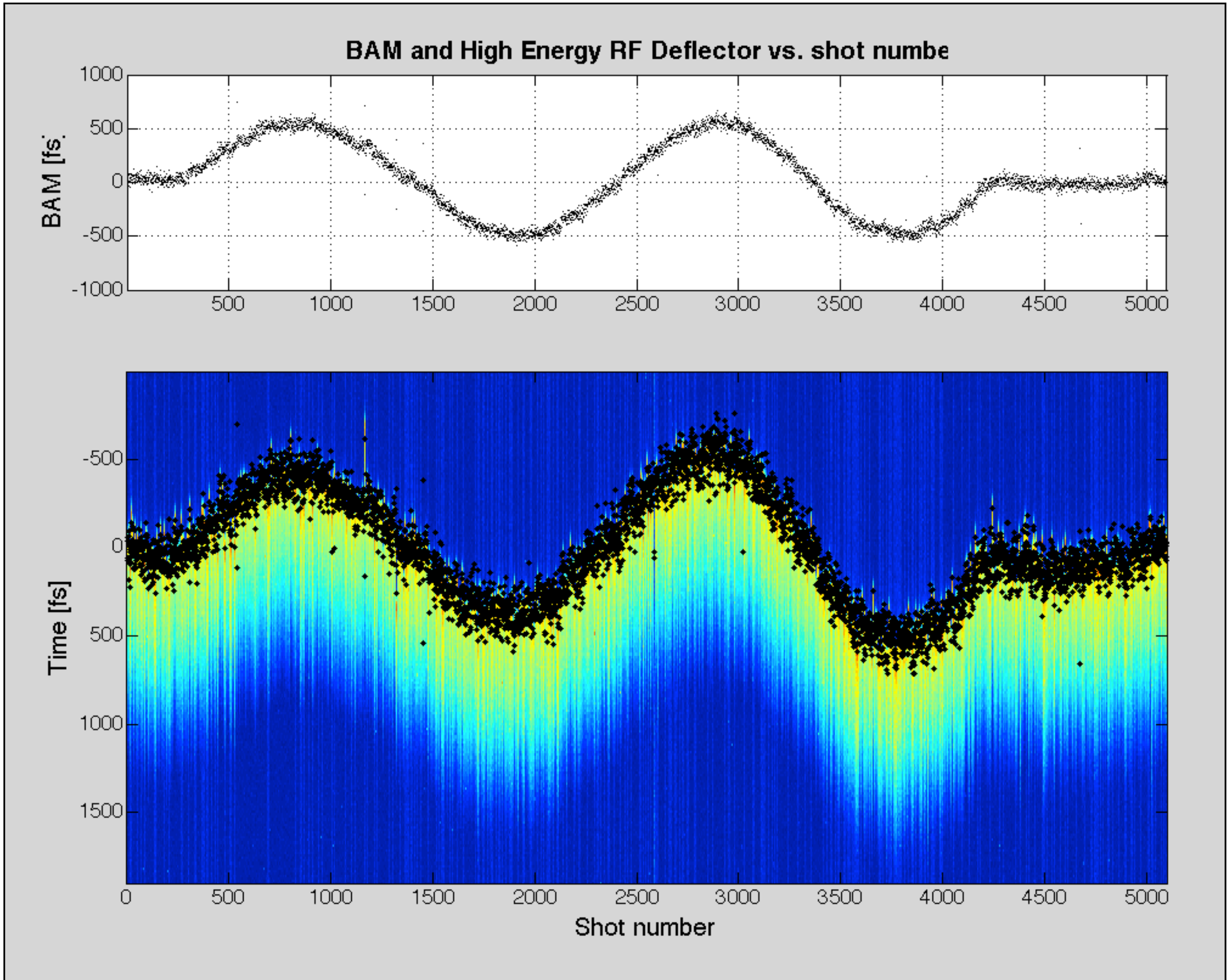
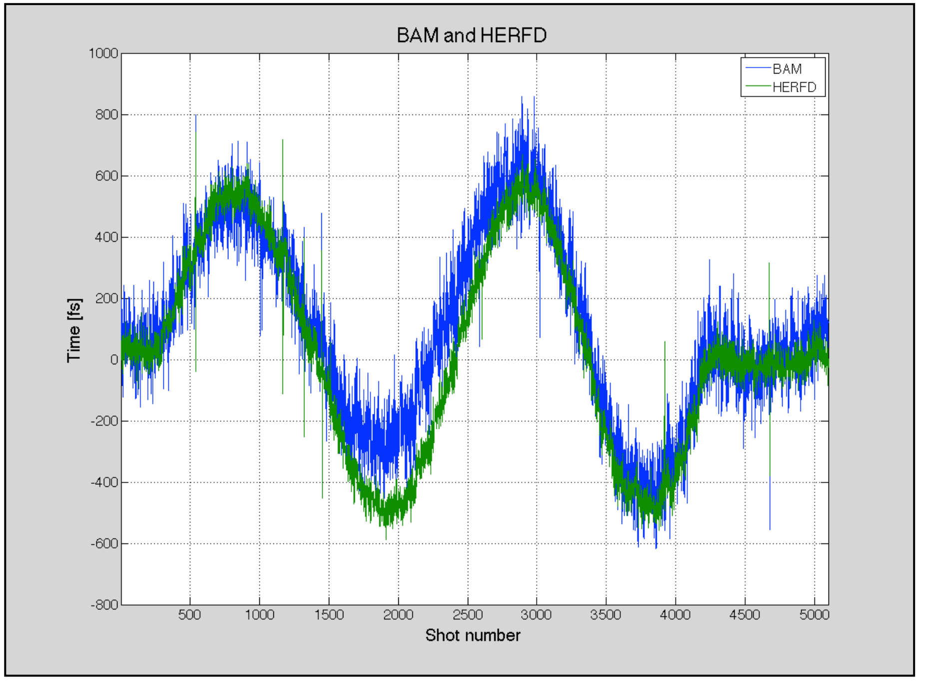
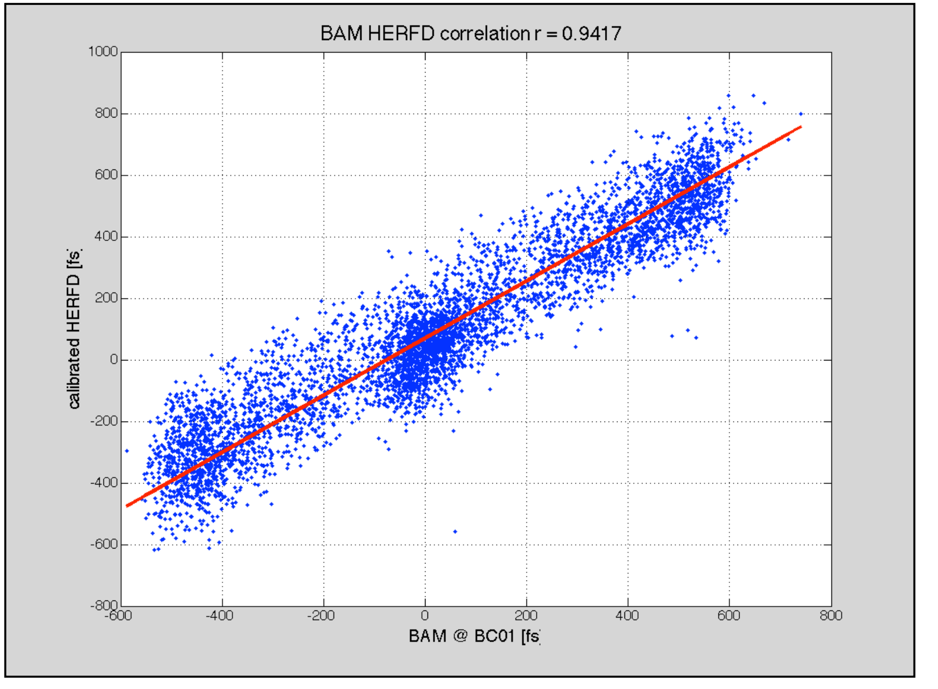
HERFD and BAM





HERFD and BAM

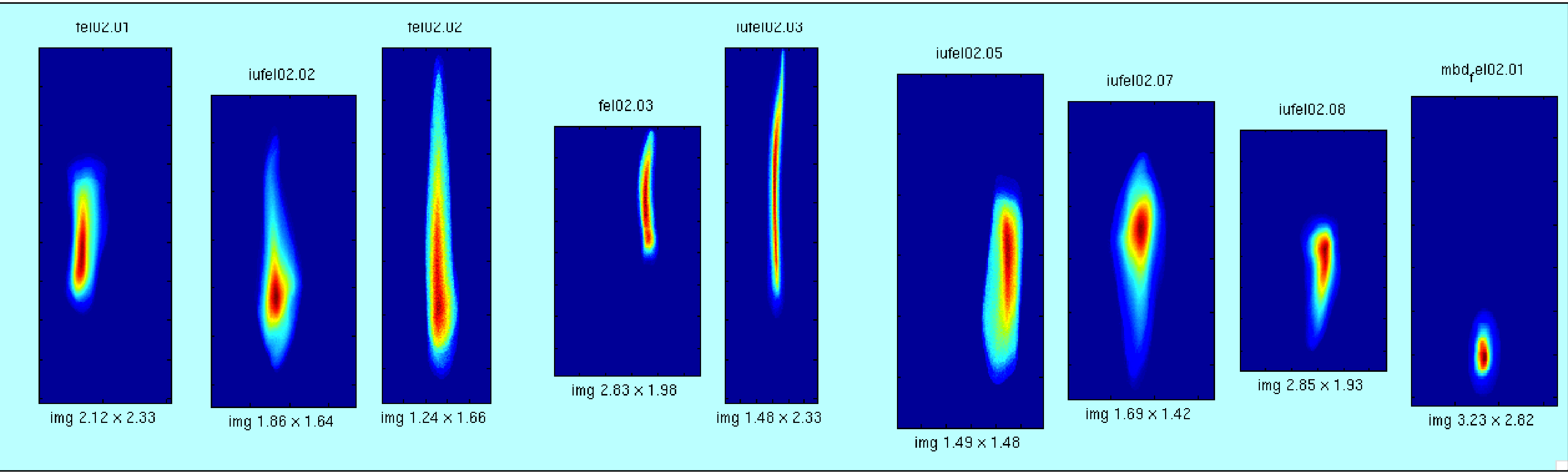




High correlation (94%) between BAM and HERFD

Resolution of HERFD ~50 fs

HERFD in Undulator Chain

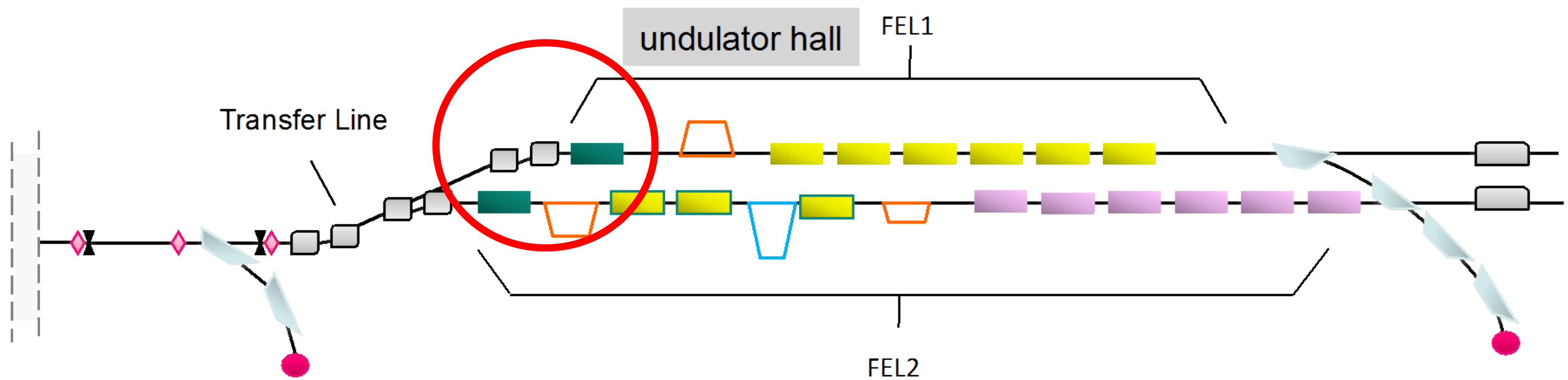


Envelope reconstruction along the undulator chain with deflected beam (e.g.: transverse wakefield compensation check).

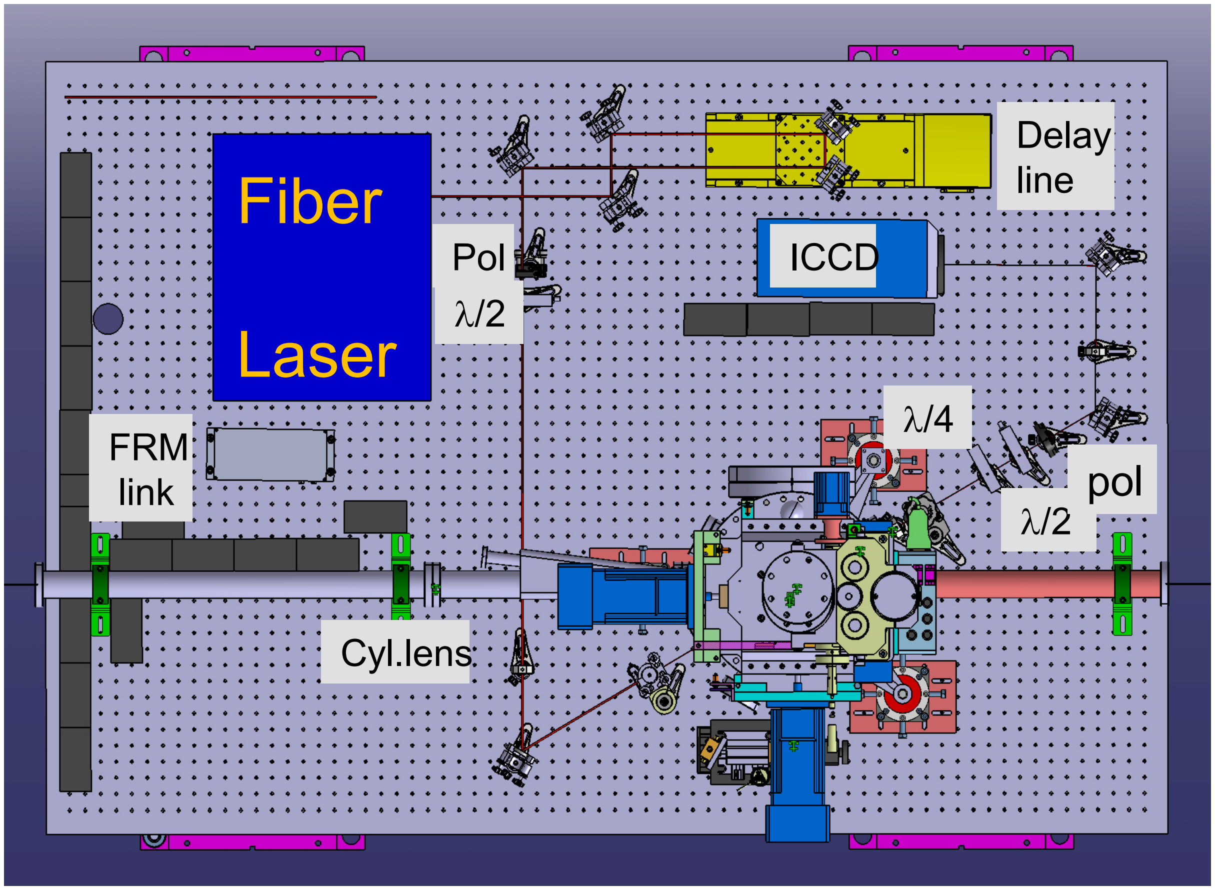
Limitations:
low deflecting power for reducing radiation losses, beam optics.

FERMI layout

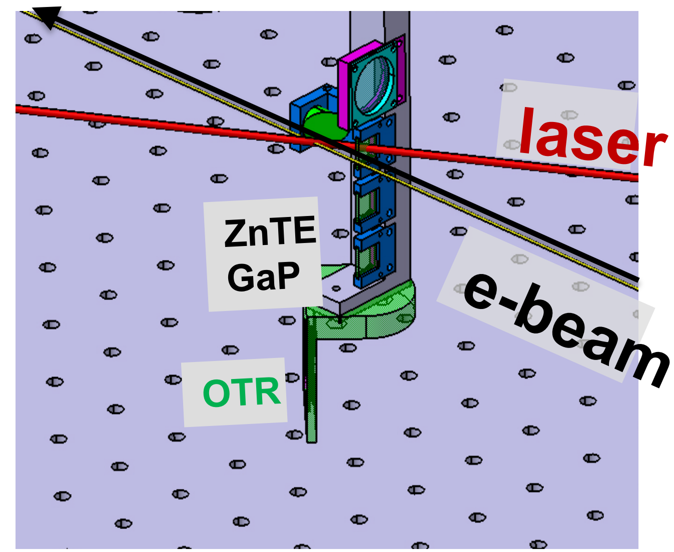
EOS
BAM



Electro-Optical Sampling (EOS)

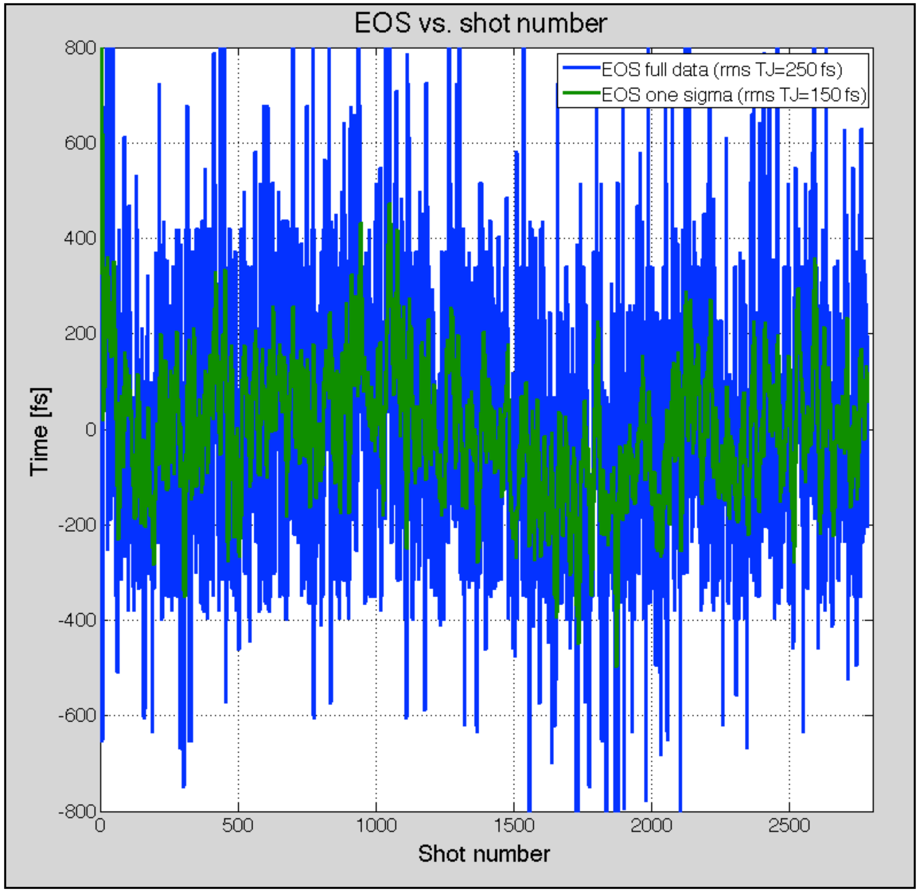


EOS measurements
Spatial encoding scheme
With fiber laser



Courtesy M. Veronese

EOS and BAM



Arrival time at EOS station.
Shot to shot time jitter estimation:

- peak to peak 250 fs
- if one considers one sigma 150 fs.

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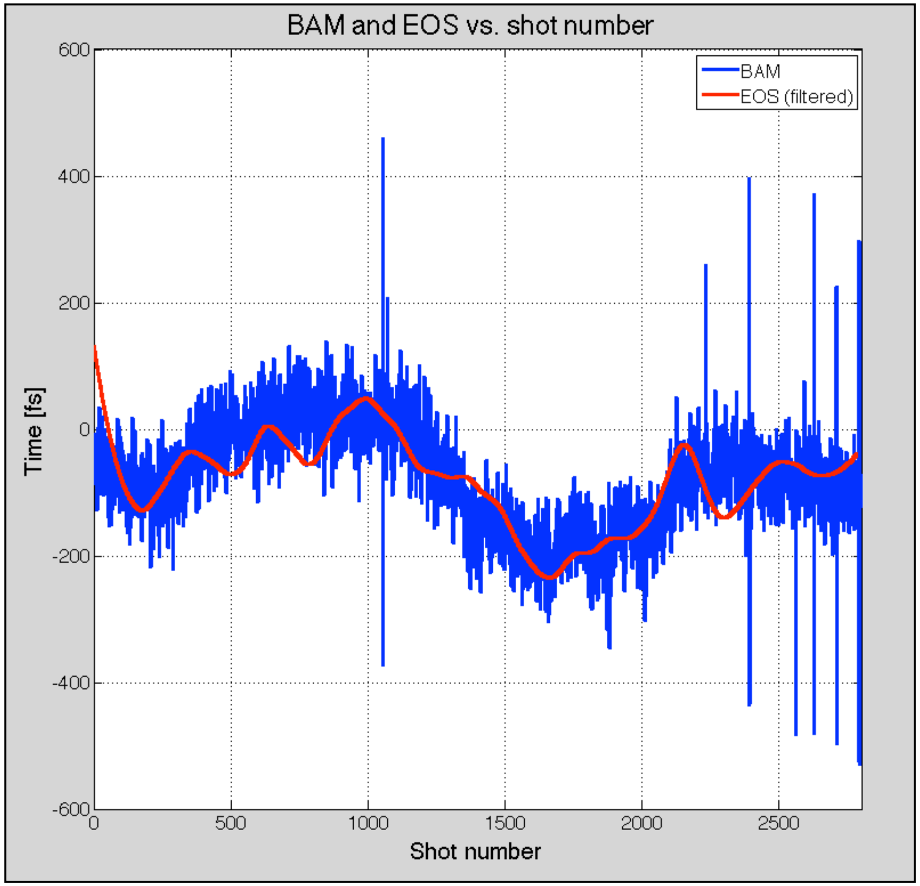
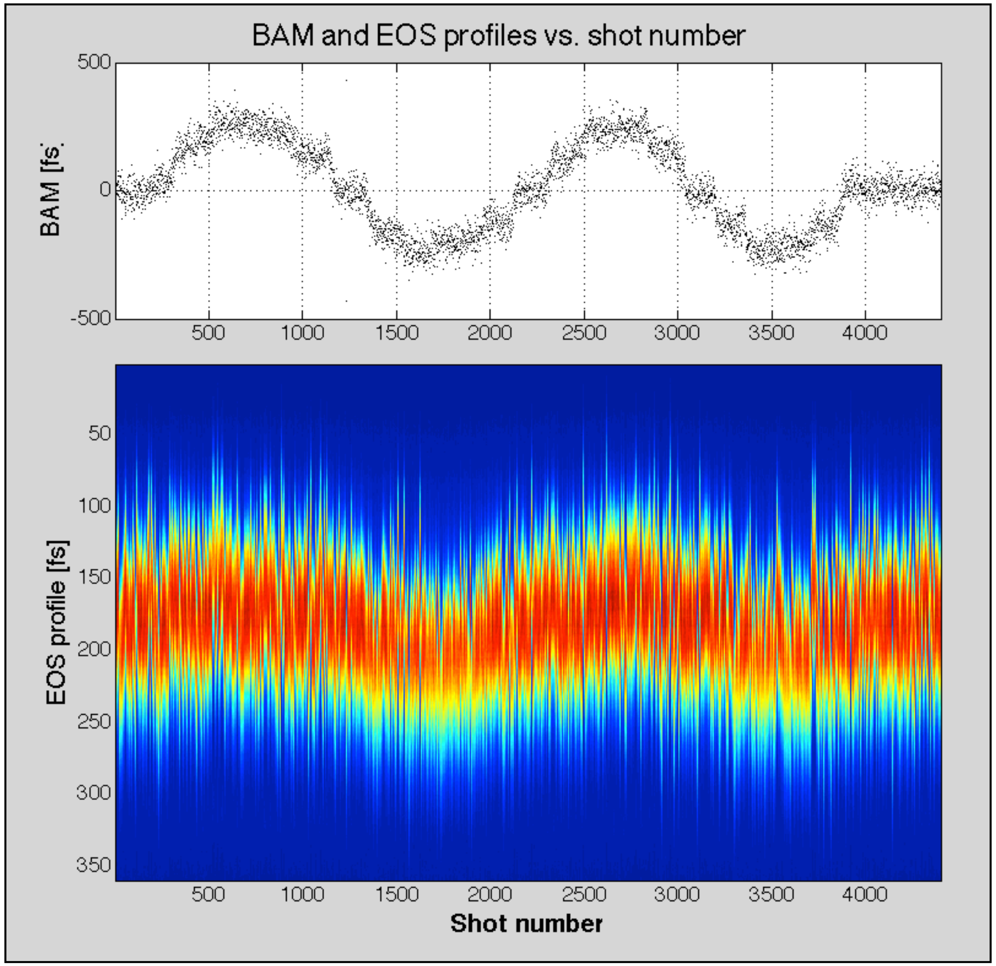
EOS and BAM

Instead if one considers the mean arrival time, the trend is compatible with the BAM one (time jitter of ~80 fs).



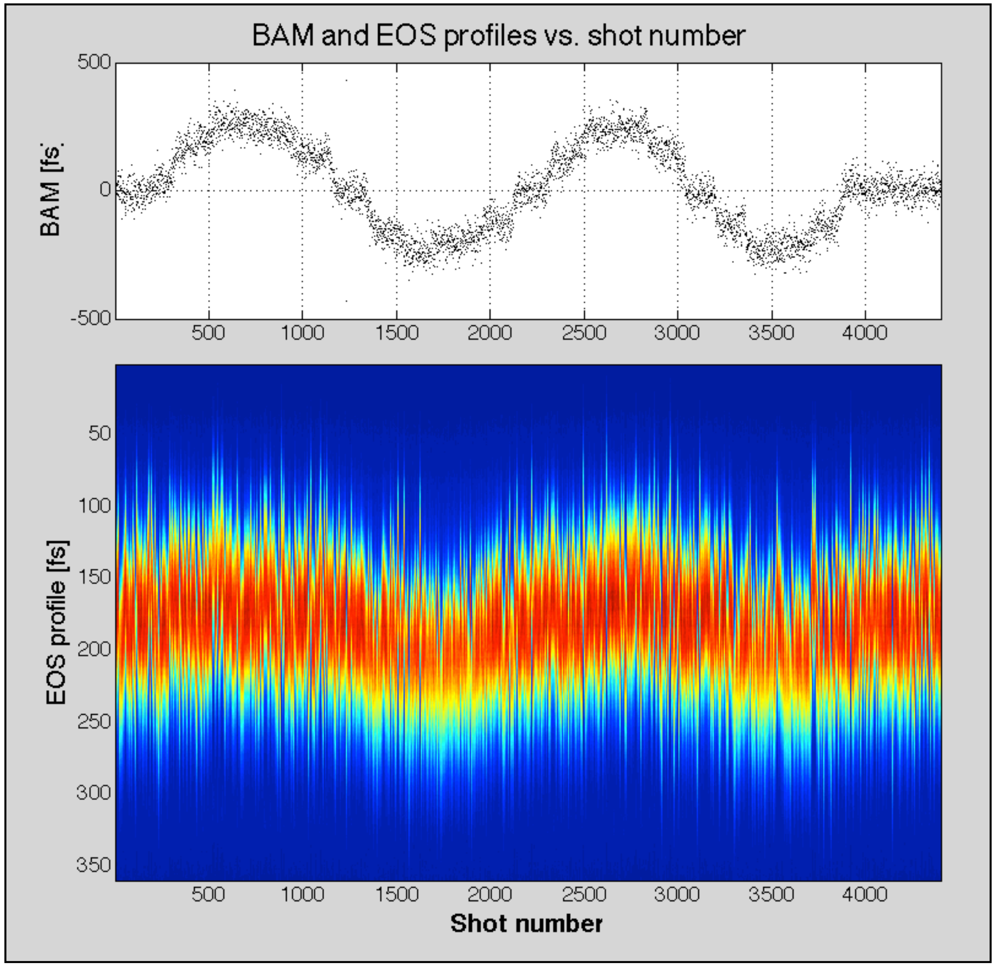
EOS and BAM



The agreement of BAM and EOS can be also tested by changing the time of flight in the compressor chicane

Elettra Sincrotrone Trieste

EOS and BAM

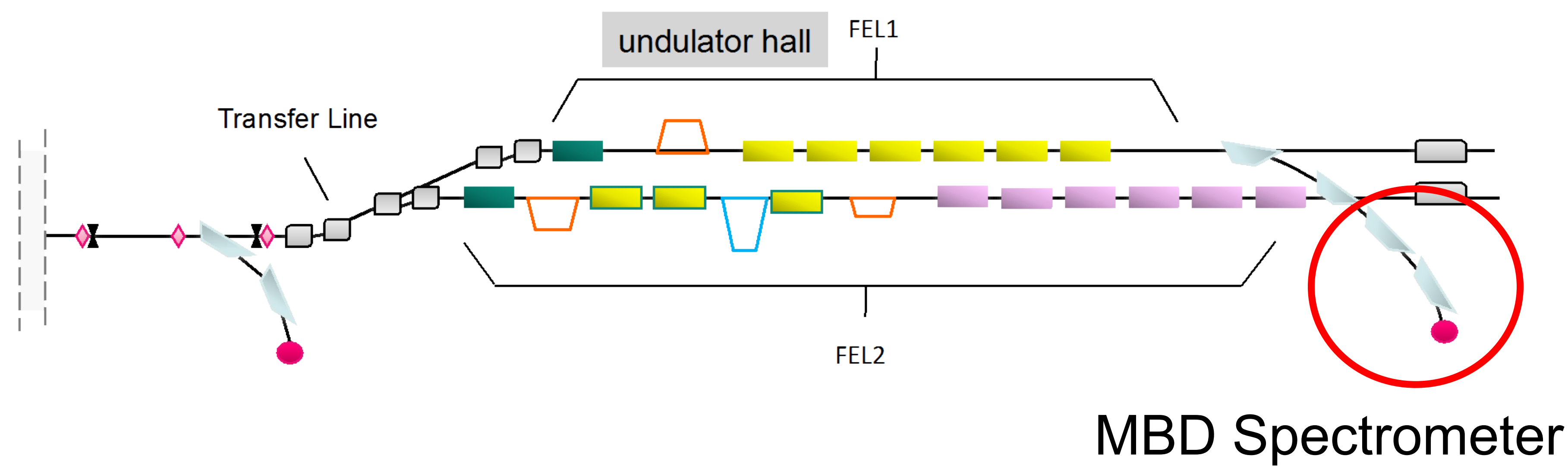


Limitations:

Noisy measurement.

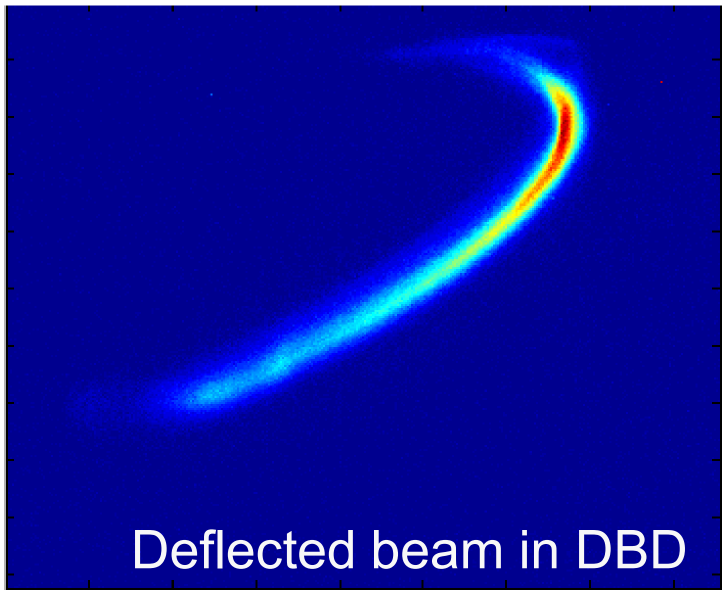
Jitter of fiber laser timing. Under investigation, locking needs to be improved

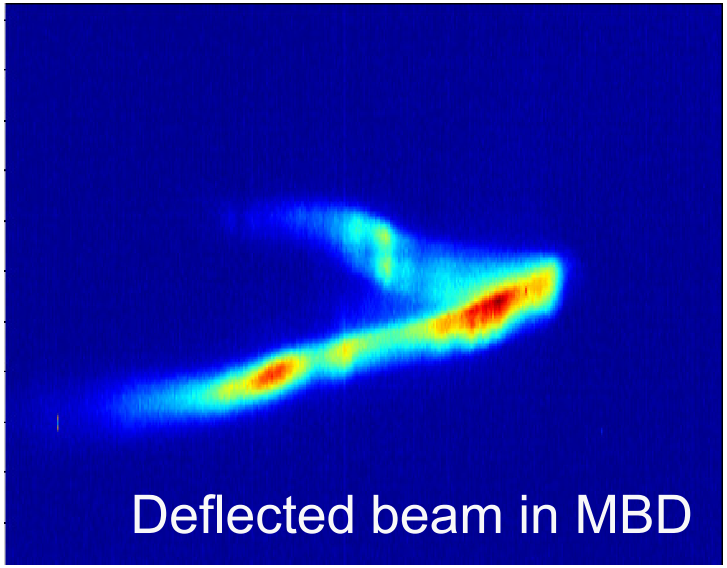
FERMI layout



MBD Spectrometer + HERFD

Deflected beam transported for ~100 m.
Still able to produce FEL radiation!

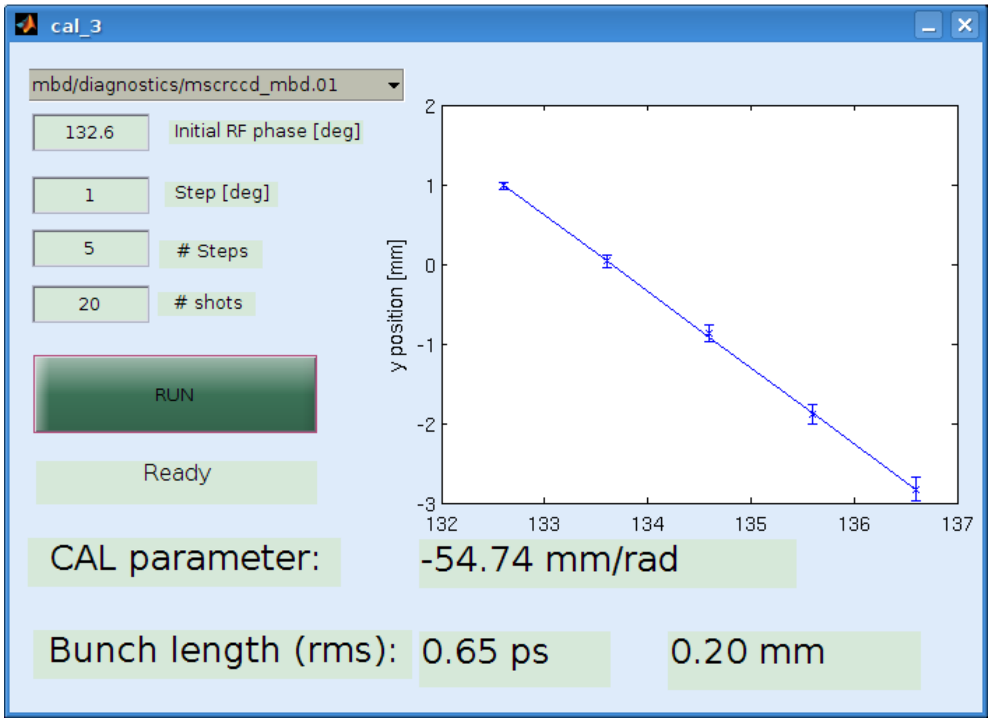


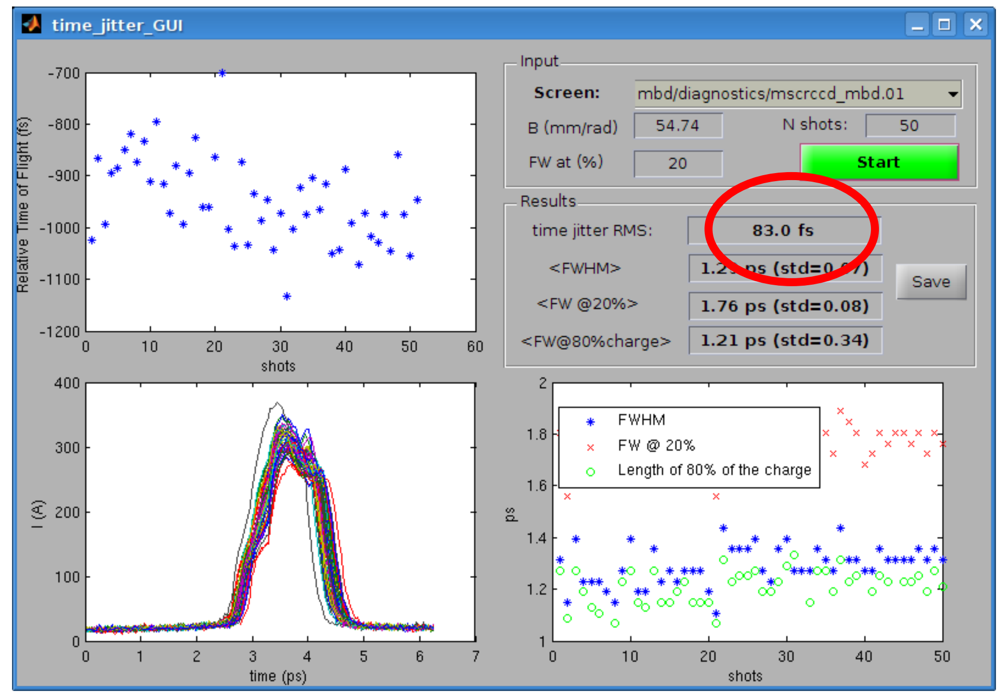


Usefull during user shifts as fast check of beam properties.

MBD Spectrometer + HERFD

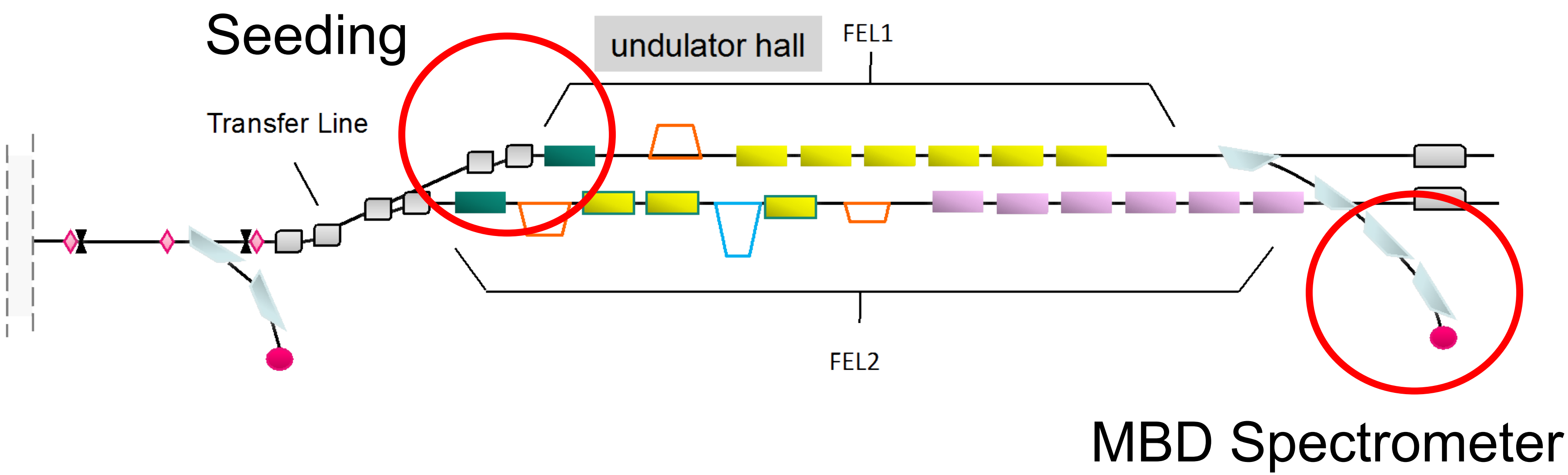
Screen calibration and time jitter measurement after the undulator



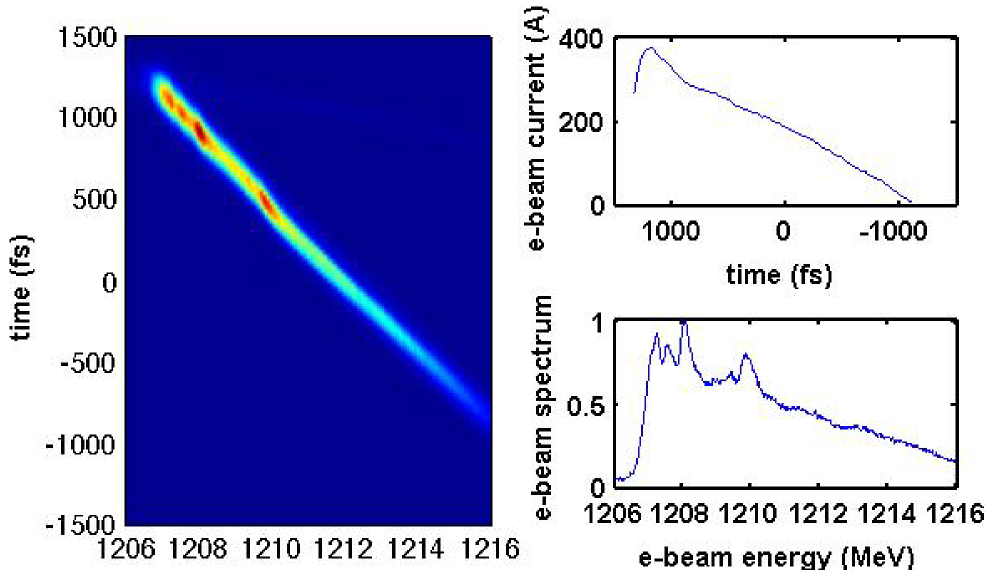


Limitations:
low deflecting power for reducing radiation losses, beam optics.

FERMI layout

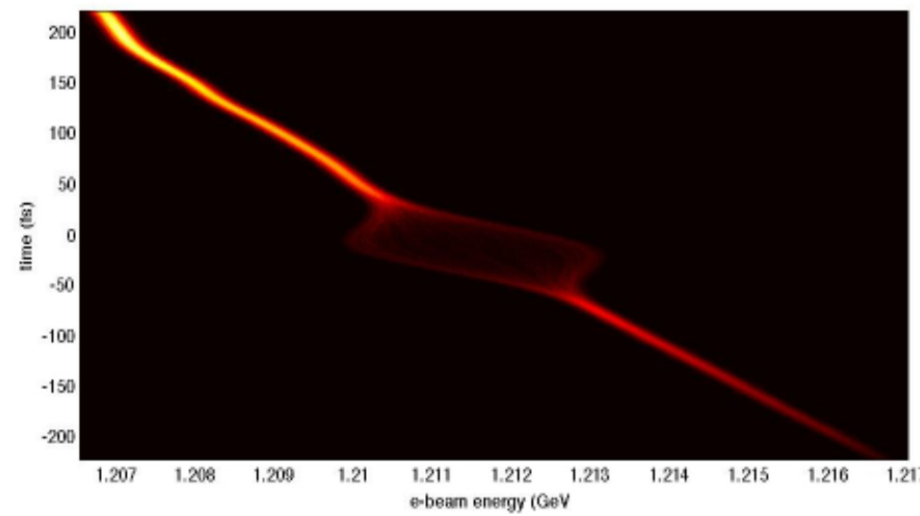


MBD Spectrometer + Seeding

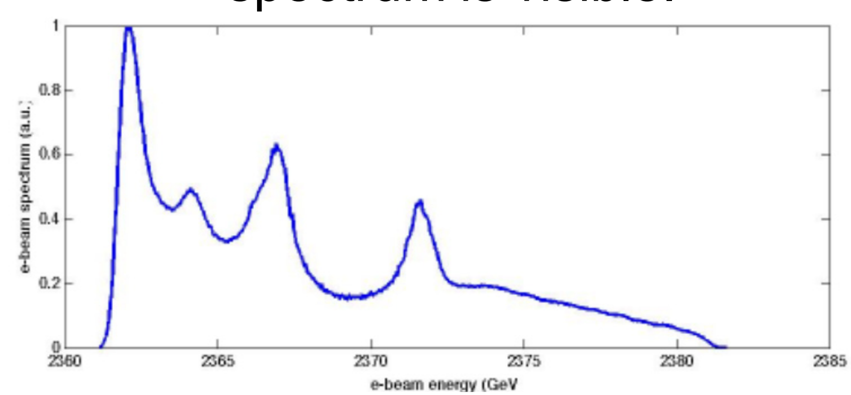


In specific configurations of the linac the electron beam measured at the end of the accelerator shows strong linear correlation.

Due to the linear time-energy correlation the hole in the spectrum can be used to follow timing drifts between the seed laser and the electron beam.



<u>FEL numerical simulations:</u>
a clear evidence of the modification of the local energy spectrum is visible.



Courtesy E. Allaria

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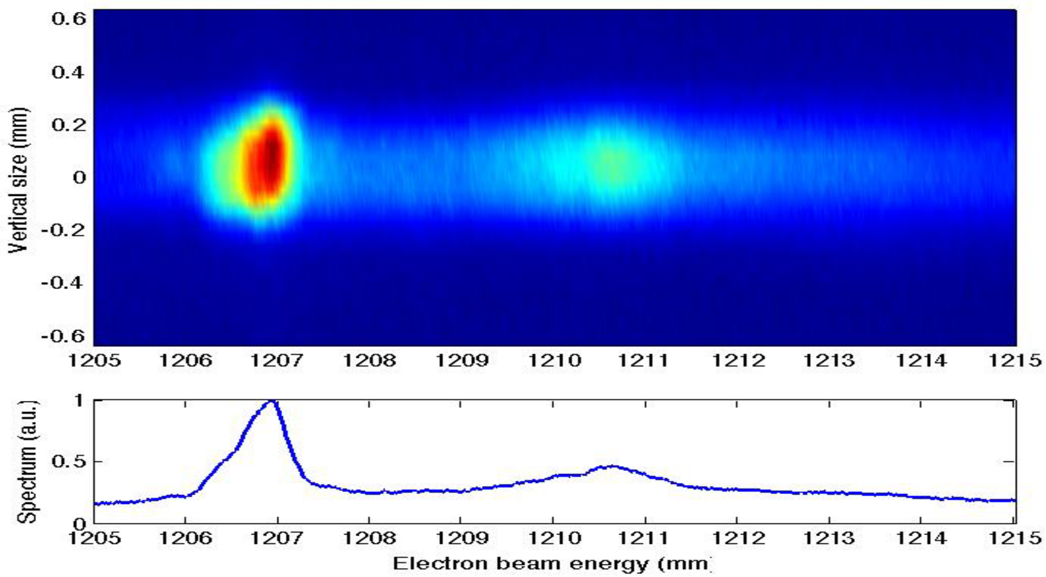
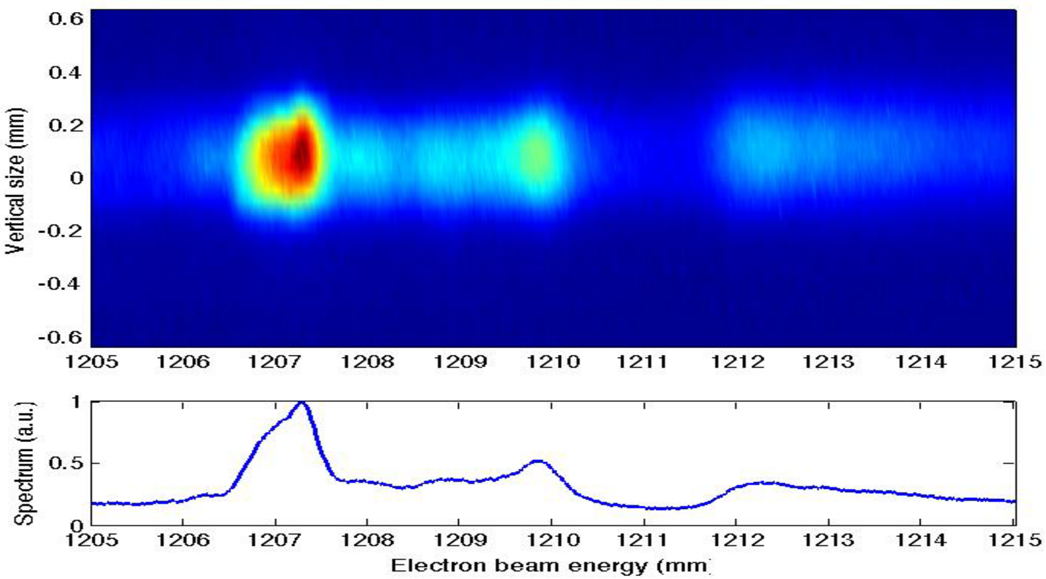
The hole



Measured electron beam spectrum at MBD for the beam not seeded.

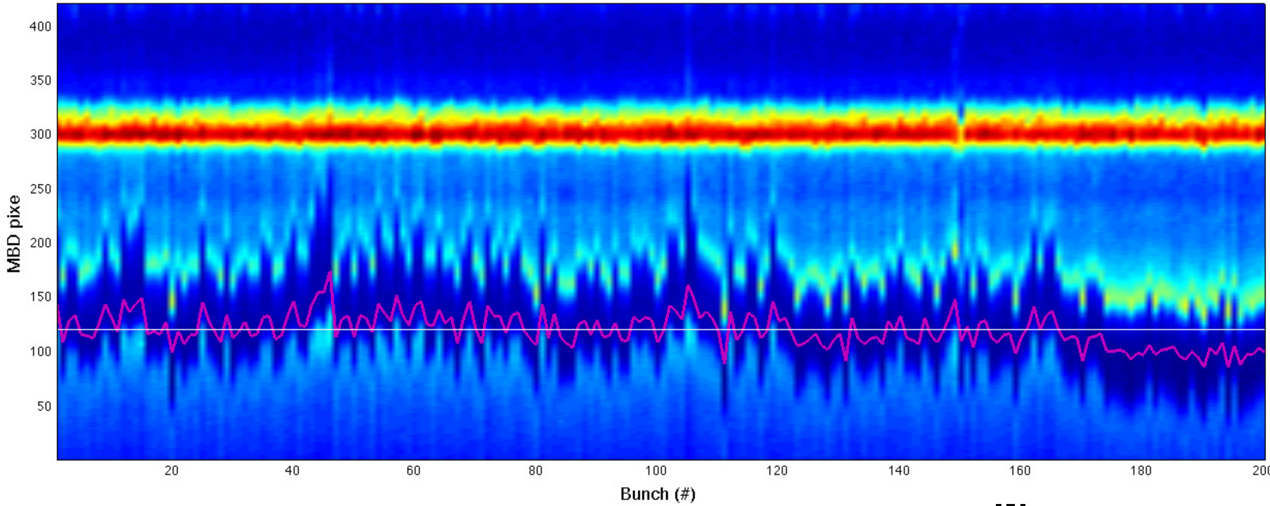


Measured electron beam spectrum at MBD for the beam seeded.

Experimental results clearly show an hole on the electron beam spectrum as a result of the seeding.

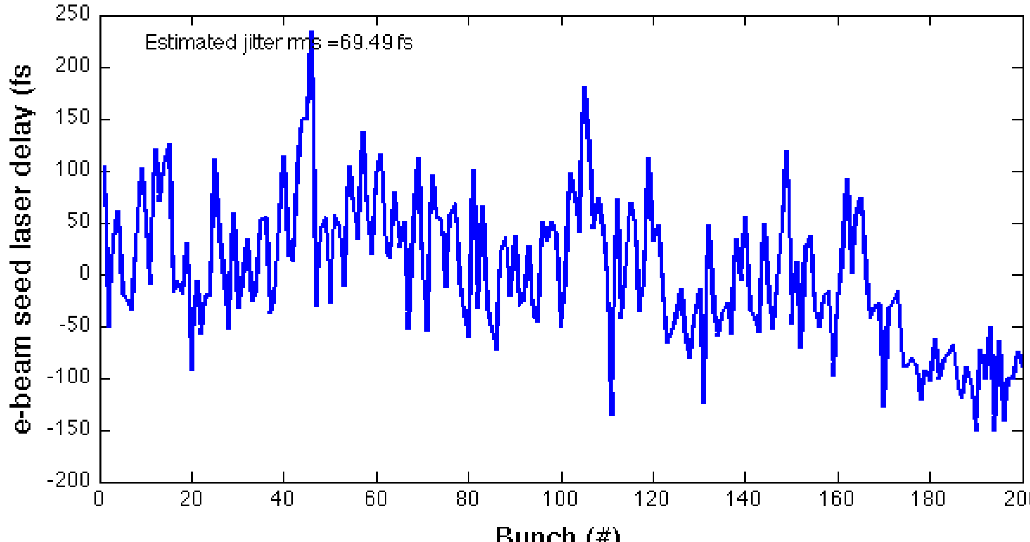
Courtesy E. Allaria

Time jitter with the hole



Sequence of 200 seeded electron beam spectra measured in MBD. While the peak is fixed in energy, the position of the seed induced "hole" is moving.

After a proper calibration, it is possible to retrieve the relative position between the e-beam and the seed in fs and measure the jitter between the two.

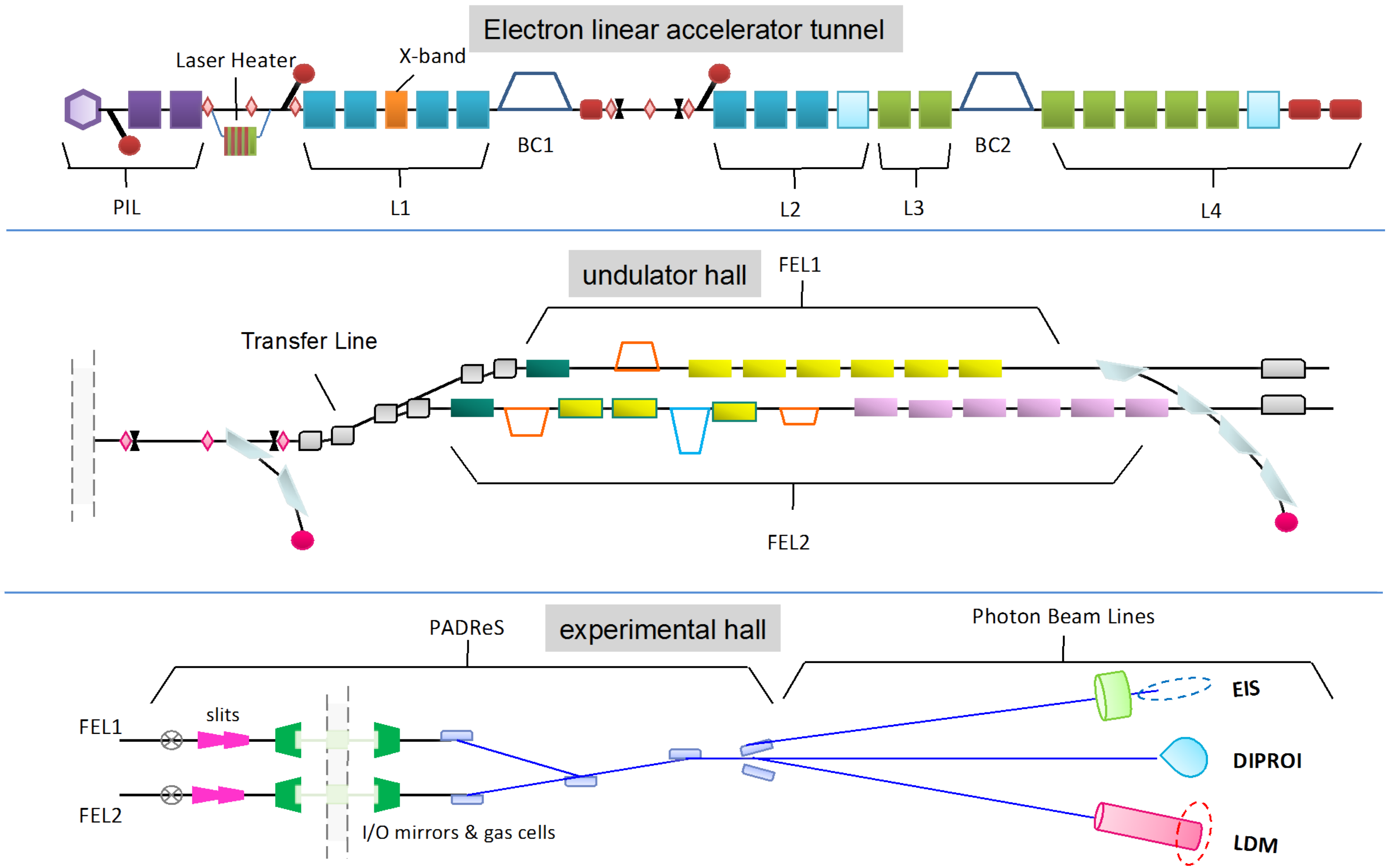


With this method we are able to measure a jitter of about 70 fs rms

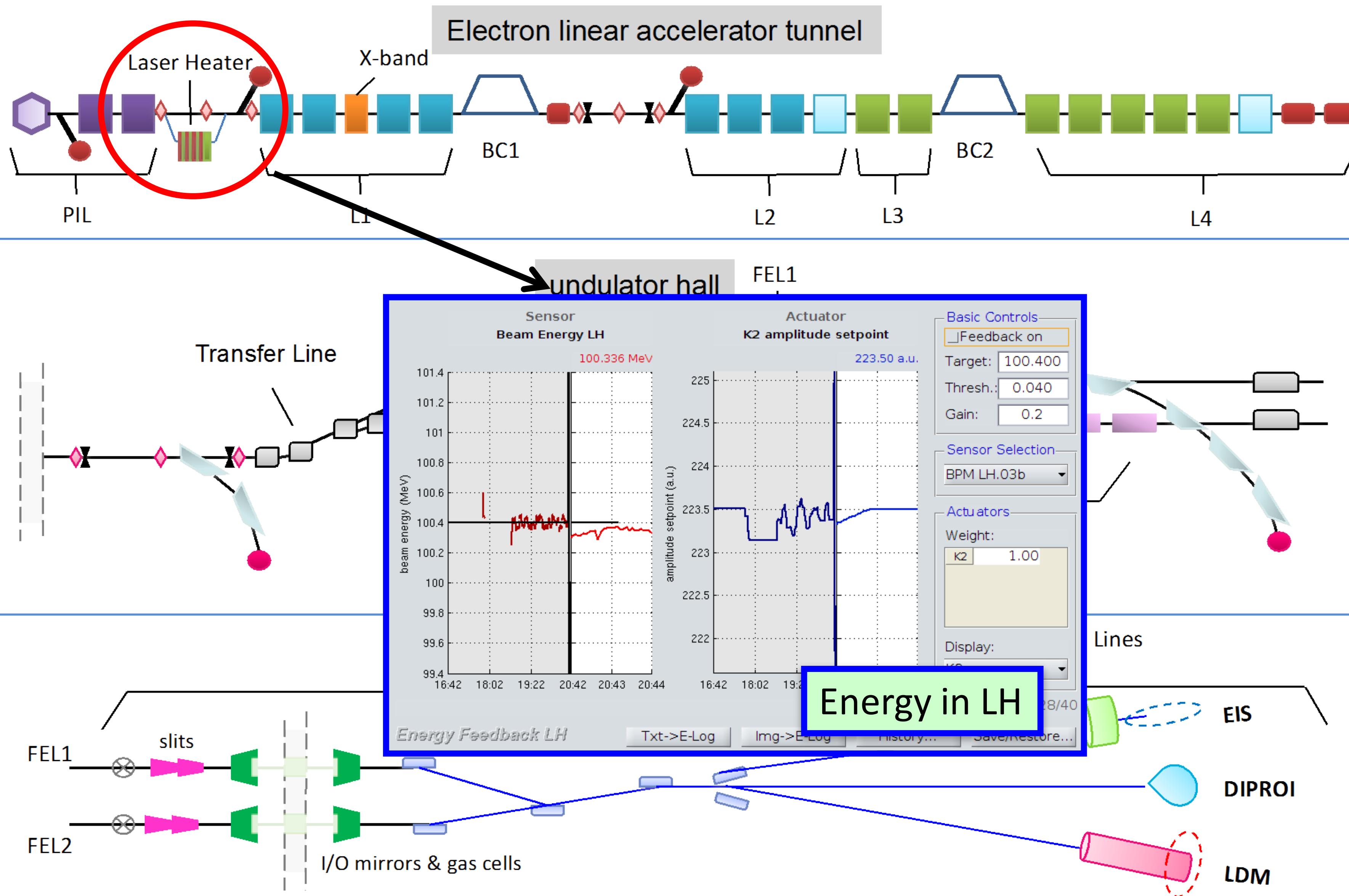
By measuring the evolution of the "hole" we can measure the changes in the relative timing between the electron and seed laser for each shot.

Courtesy E. Allaria

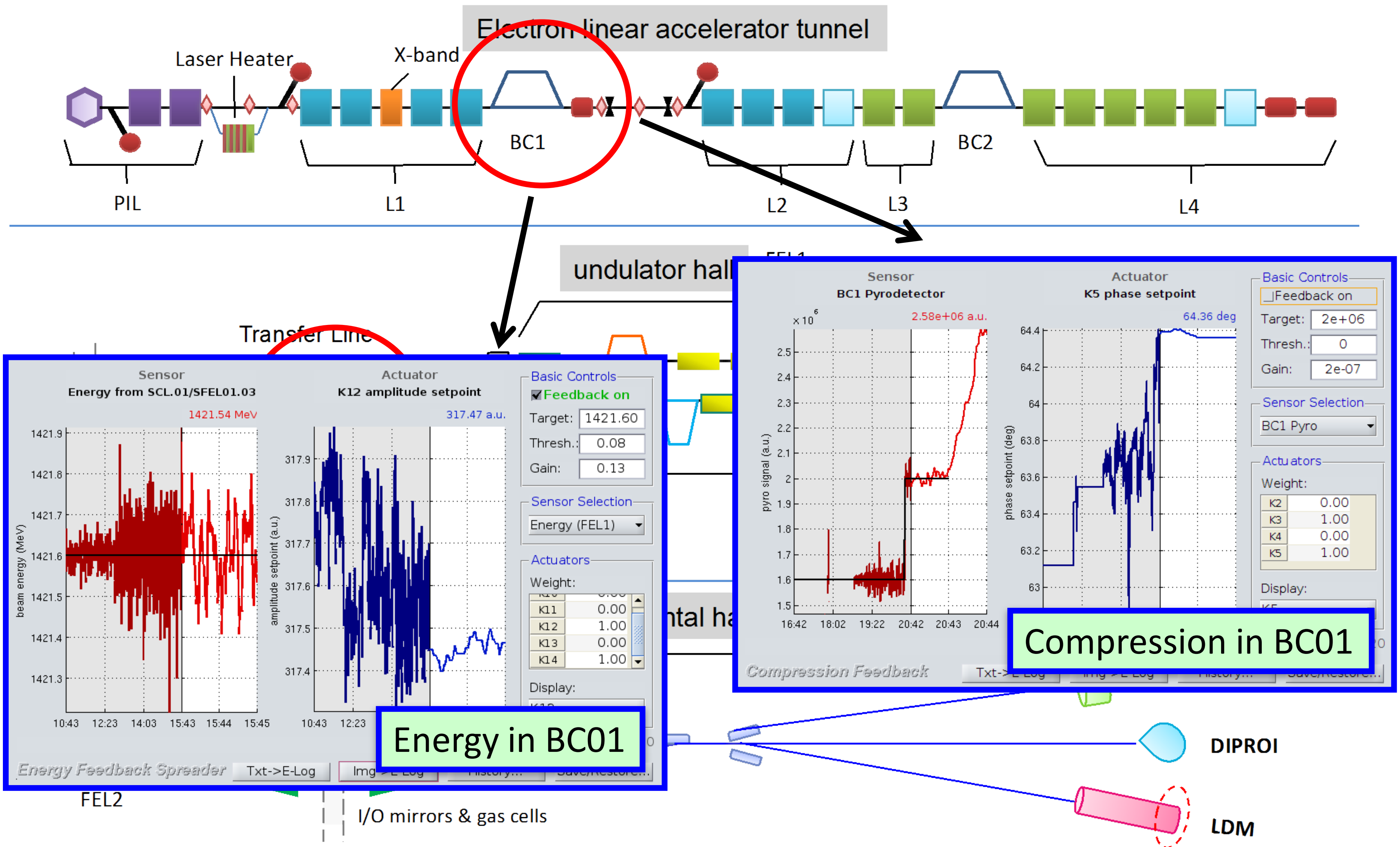
Longitudinal Feedbacks



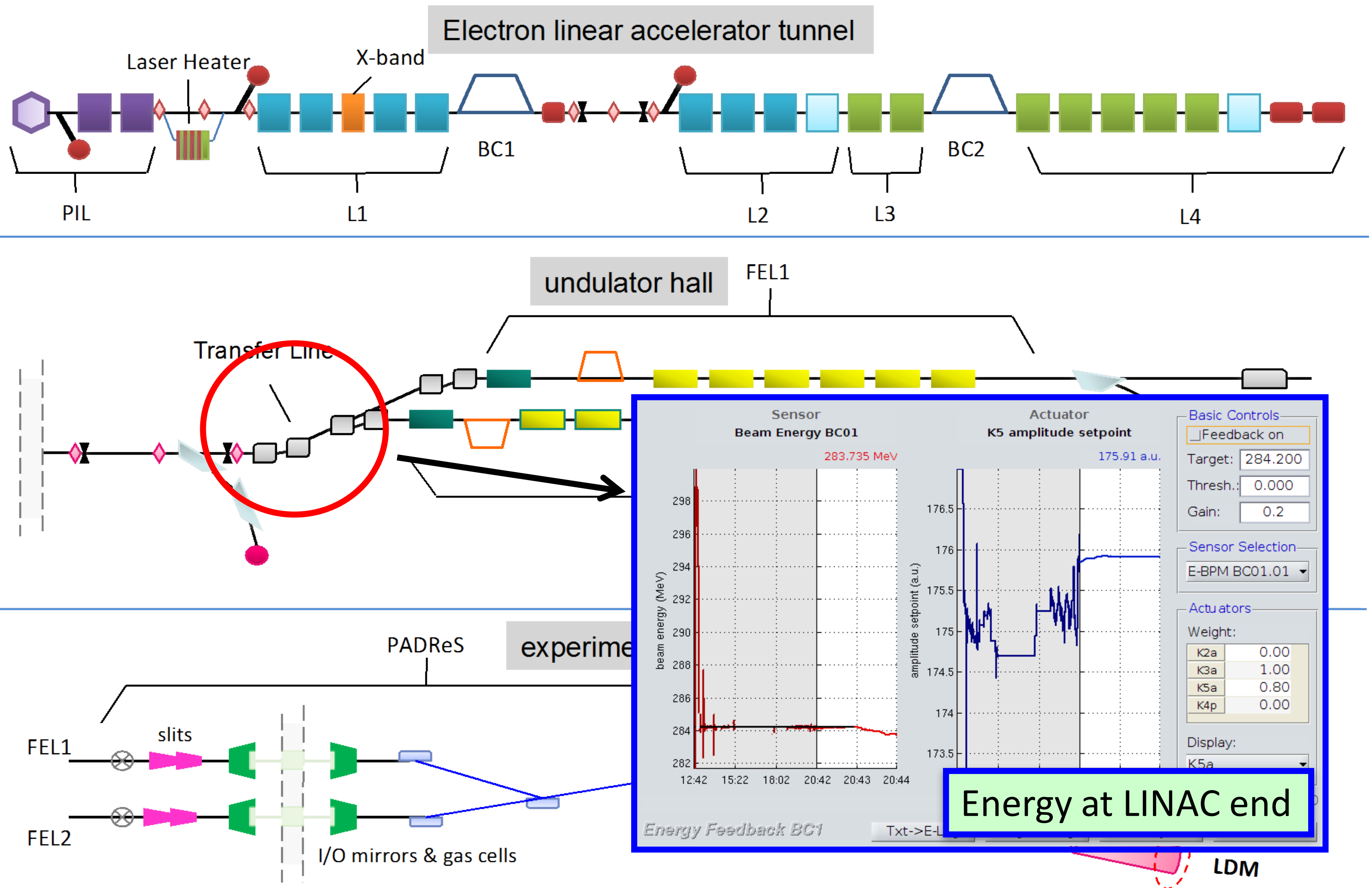
Longitudinal Feedbacks



Longitudinal Feedbacks



Longitudinal Feedbacks



Conclusions and Prospectives

FERMI FEL1 (single cascade HGHG), has been commissioned and is now open for user experiments.
FEL2 (double cascade HGHG) is in commissioning phase.

The diagnostics system is undergoing continuous improvements (improved reliability, issue solving, etc.)

A major update will be the inclusion of the different feedbacks into a single tool.

Other possible upgrades:

- Move one high energy RF deflector from the linac end to the end of the undulator chain;
- Include BAMs output in timing feedback loops;
- Improve EOS laser for on-line longitudinal beam profiles;
- FEL emission measurement using “the hole”.

More on FERMI at IBIC13

R. Appio, this session (in some minutes)

S. Di Mitri, Monday poster session (MOPC04)

L. Fröehlich, Tuesday poster session (TUPC45)

M. Veronese, Wednesday poster session (WEPF27)

Elettra
Sincrotrone
Trieste

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Thanks in particular to:
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Thank you for your attention!