Elettra Sincrotrone Trieste

X-band Experience at FERMI@Elettra FEL

Gerardo D'Auria

Elettra - Sincrotrone Trieste

Outline

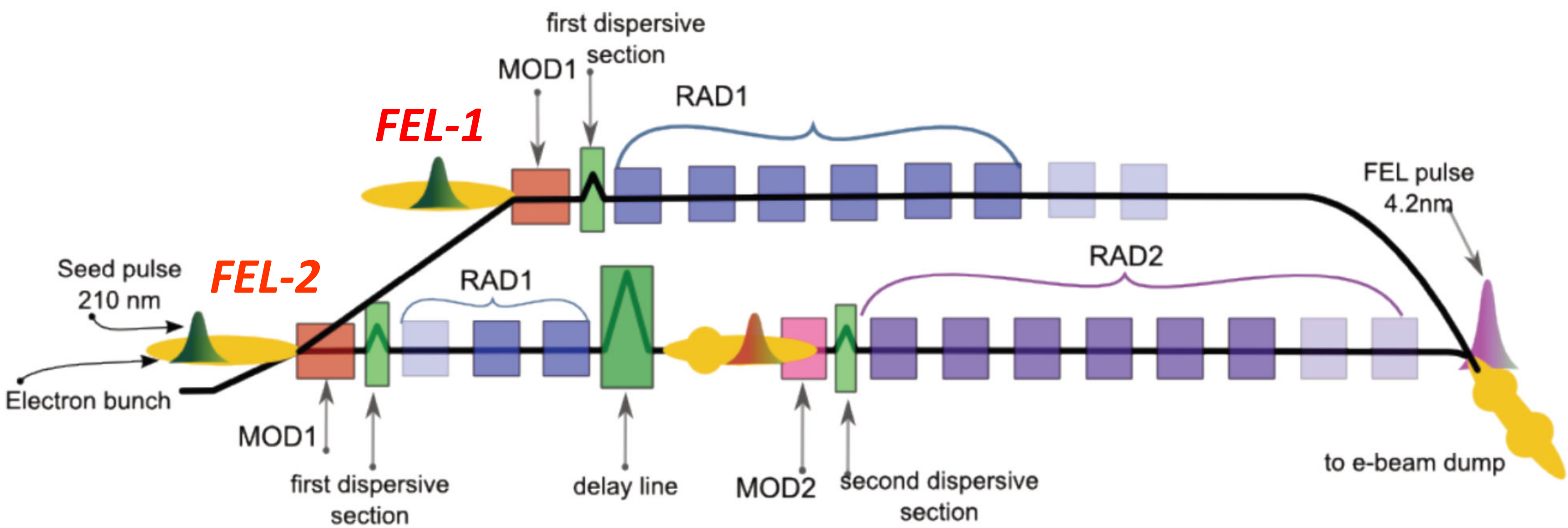
- ***The FERMI@Elettra FEL project***
- ***Machine layout and longitudinal phase space linearization***
- ***X-band system layout and operational data***
- ***Interests on high gradients at FERMI@Elettra FEL***
- ***Outlook and conclusions***

FERMI@ELETTRA FEL

In the current configuration, FERMI@Elettra is a seeded Free Electron Laser with two different FEL lines:

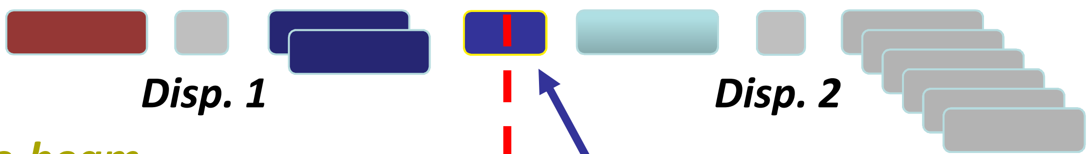
a. ***FEL-1, based on a single stage High Gain Harmonic Generation (HGHG), with a UV Seeding Laser, that covers the spectral range 80-10 nm.***

b. ***FEL-2 based on a two stages HGHG scheme, with the "fresh bunch technique", that covers the wavelength range 10-4 nm.***



The "fresh bunch" technique

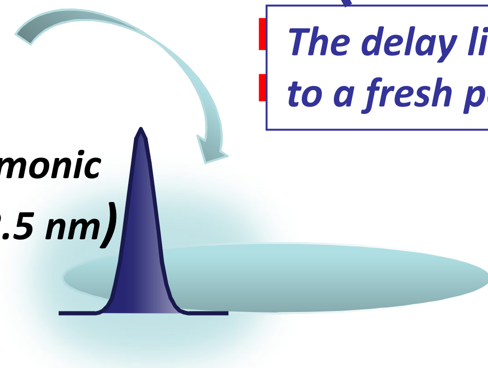
First stage | **Second stage**

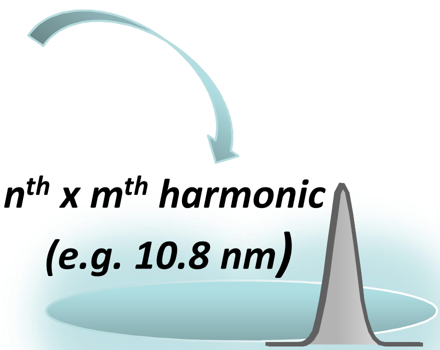


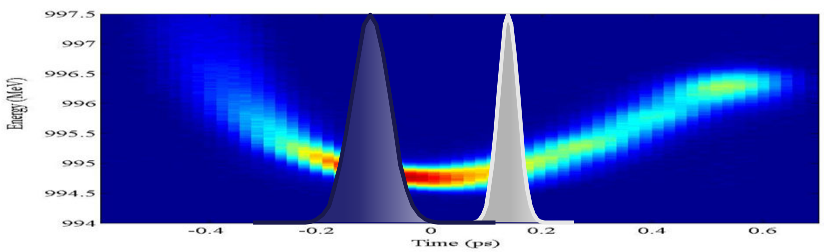
The seed @260nm
is on the tail of the e-beam

The delay line shifts the first stage output to a fresh portion of the e-beam

The first stage converts the seed to the n^{th} harmonic (8^{th} harmonic @32.5nm)







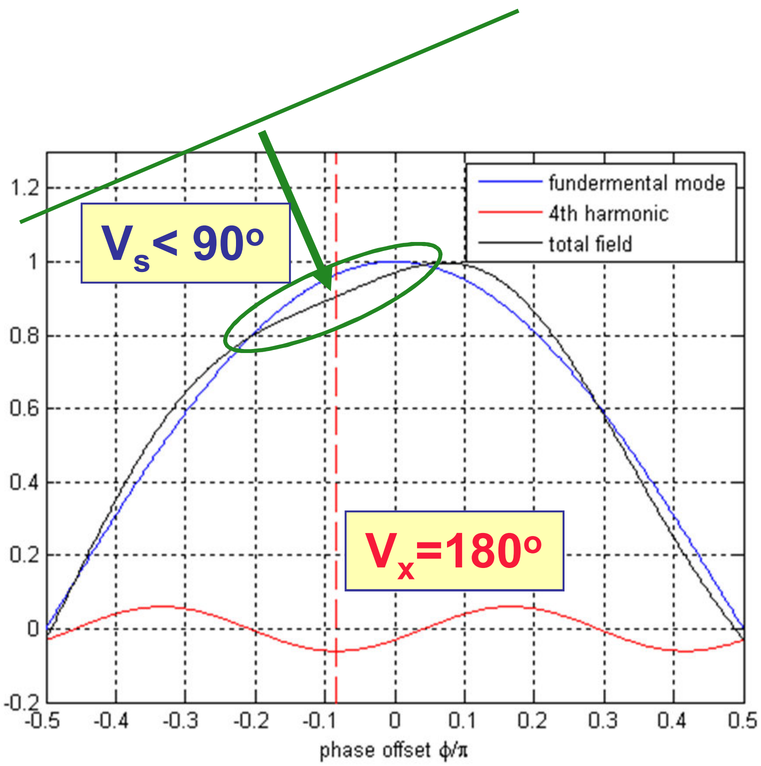
The second stage converts the first stage to the n^{th} x m^{th} harmonic of the seed (24^{th} harmonic at 10.8nm)

We need a "long" electron bunch to ensure room to accommodate the seed in the first and second stage

Courtesy of L. Giannessi

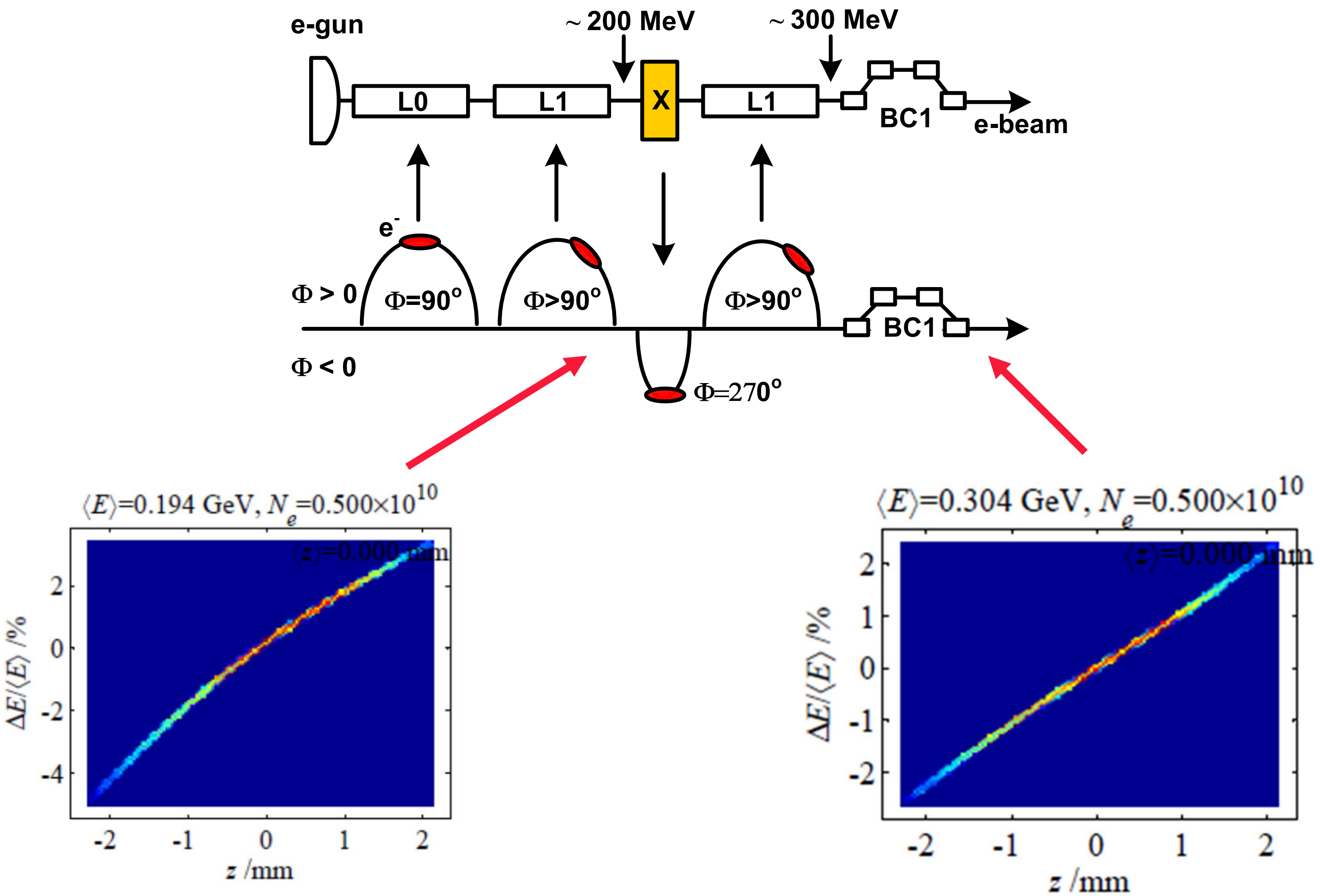
Longitudinal Phase-Space Linearization

- ***Single pass X-ray FELs require very high peak currents (~kAs) at the undulator entrance.***
- ***This is generally achieved by using one or more magnetic chicanes on a chirped e-bunch, that compress the beam at the requested value.***
- ***An harmonic structure is employed to linearize the compression process, compensating for the RF time-curvature and the second-order momentum compaction term, T_{566}.***



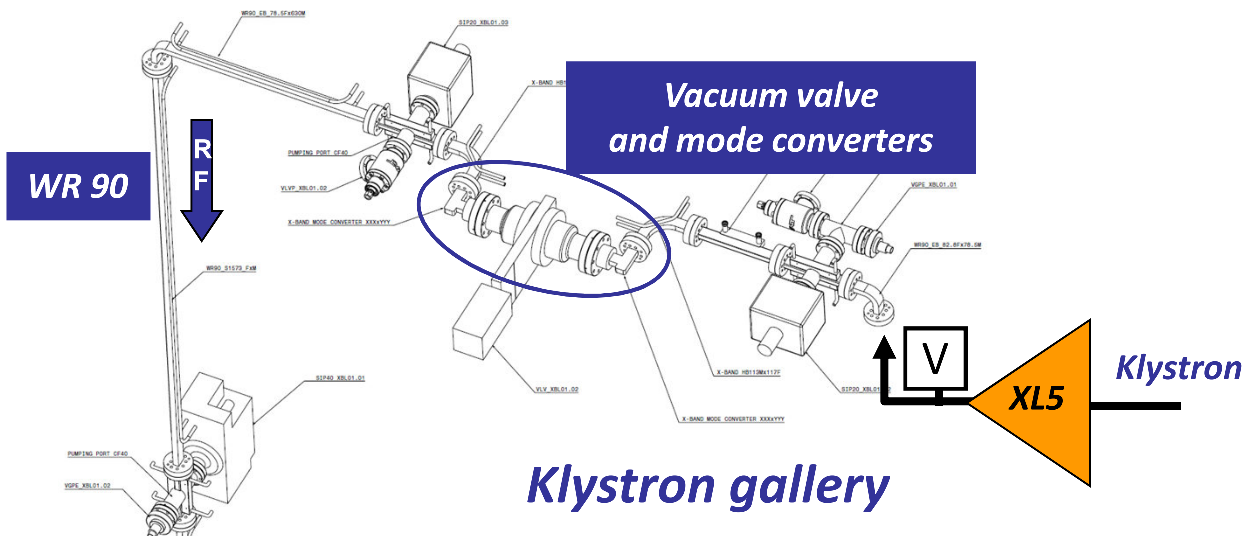
$$1/N^2 = V_x/V_s$$

FERMI@Elettra X-band linearizer

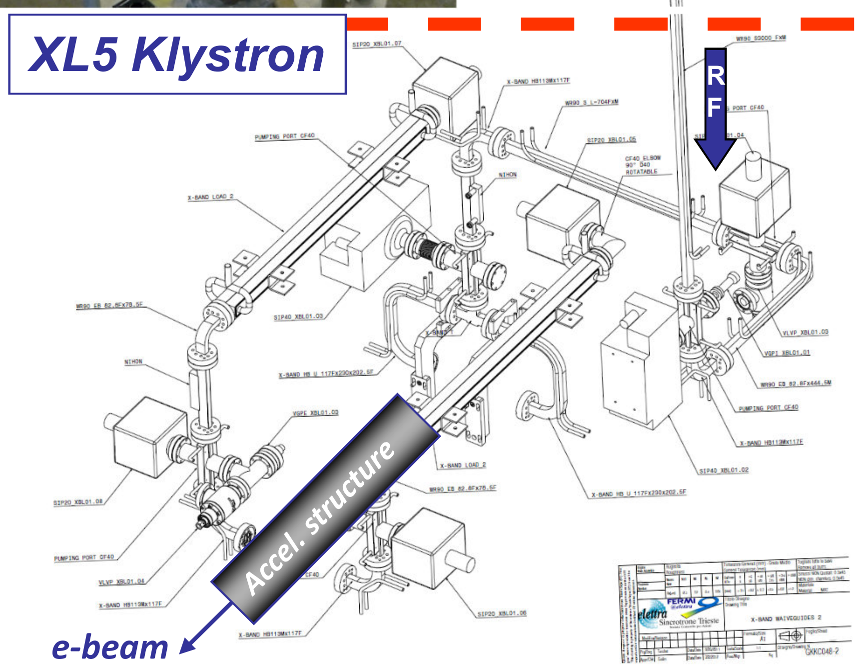


X-band RF power plant

XL5 Klystron and WG circuit



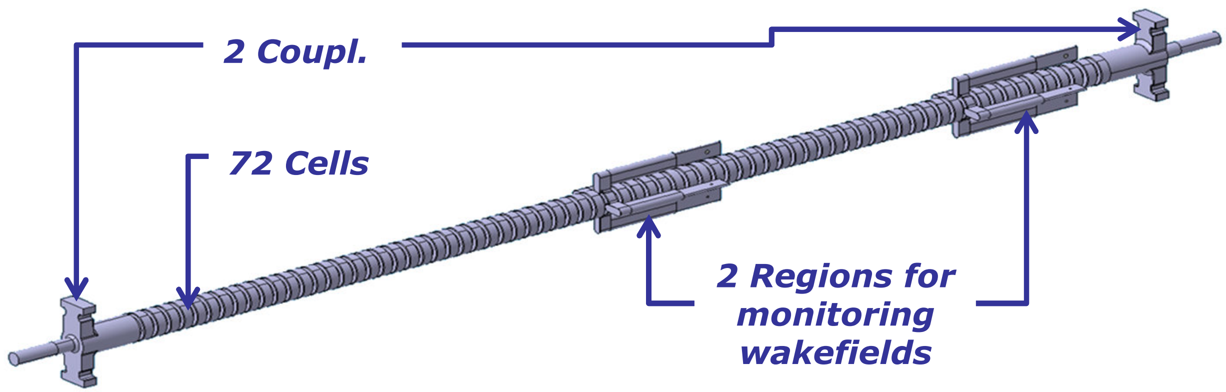
Klystron gallery

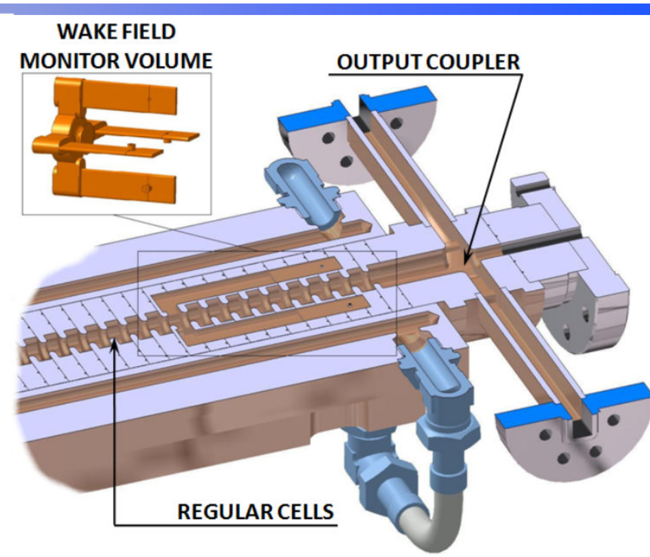


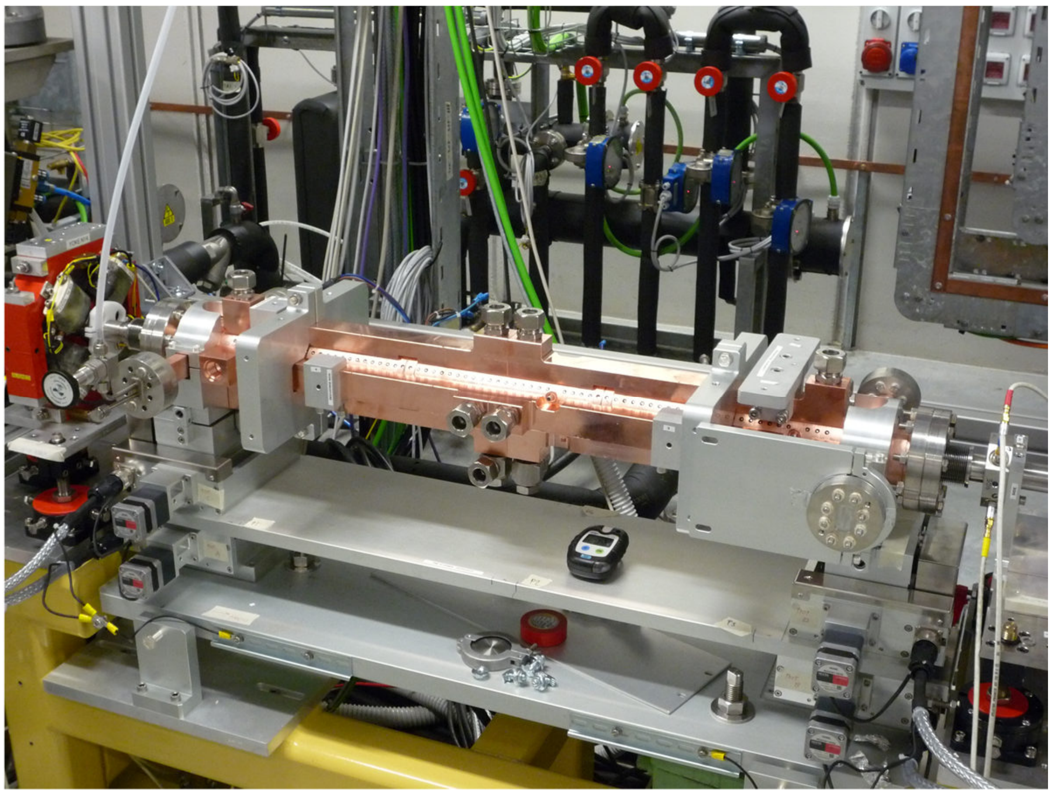
Linac tunnel

Total length of the WG circuit
~ 10 m   RF losses ~ 20%

Accelerating Structure







Parameter	*Value*	*Units*
Structure type	72 cells, CG, 5/6 π, no HOM damping	
Working frequency	11.992	GHz
Overall length	0.965	m
Active length	0.75	m
Iris diameter (average)	9.1	mm
Group velocity variation	1.6 - 3.7	%
Average grad. with 29 MW RF	40	MV/m
Filling time	100	ns
Pulse repetition rate	50	Hz

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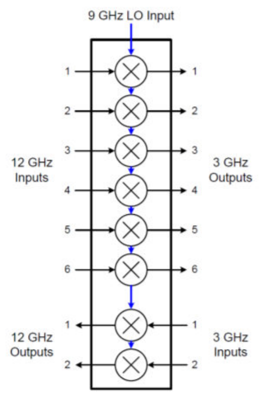
LLRF system

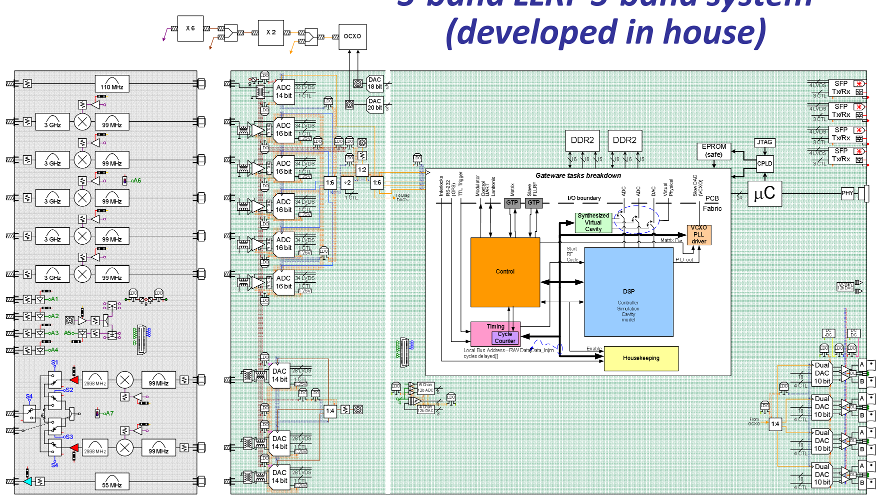
Cav. Ampl. stab. ~0.05% rms

X-band front-end (supplied by industry)



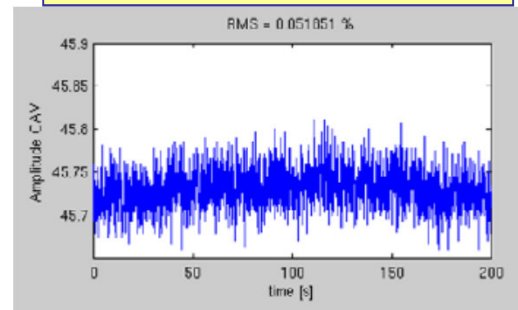
3-12 GHz up/down conversion chassis

S-band LLRF S-band system (developed in house)

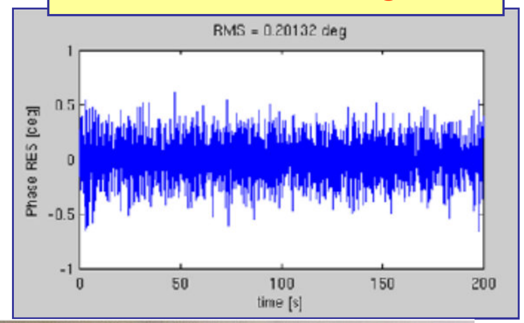


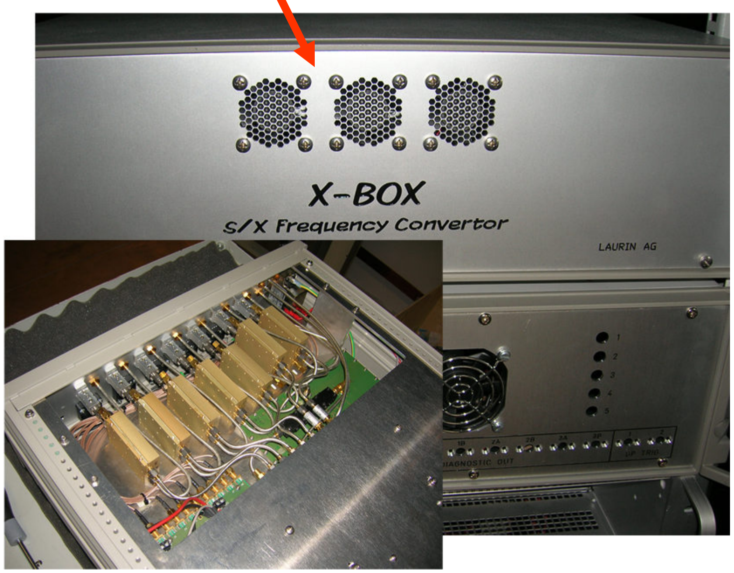
S-band front-end

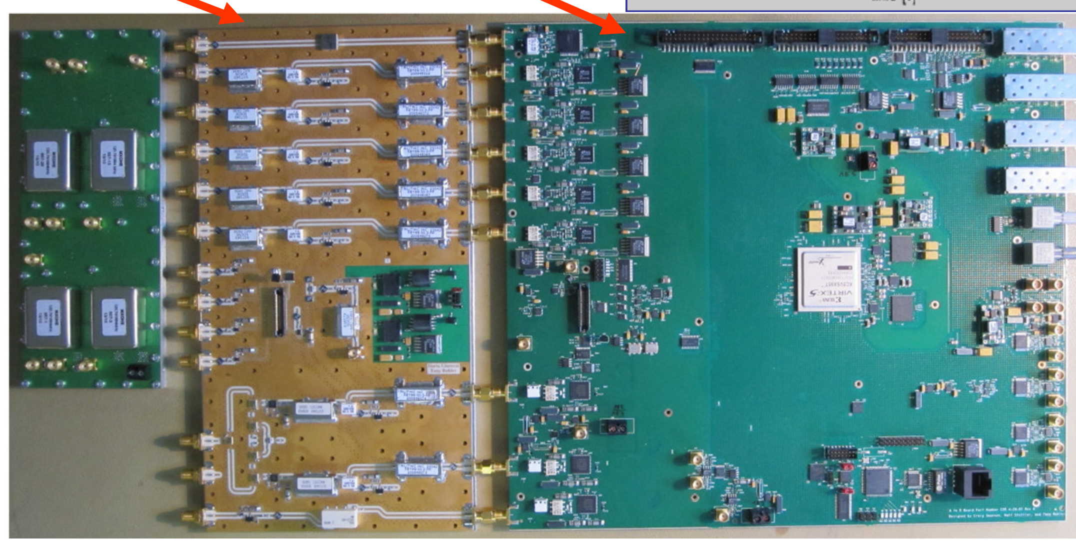
Digital board



Cav. Phase stab. ~0.2 deg-X rms







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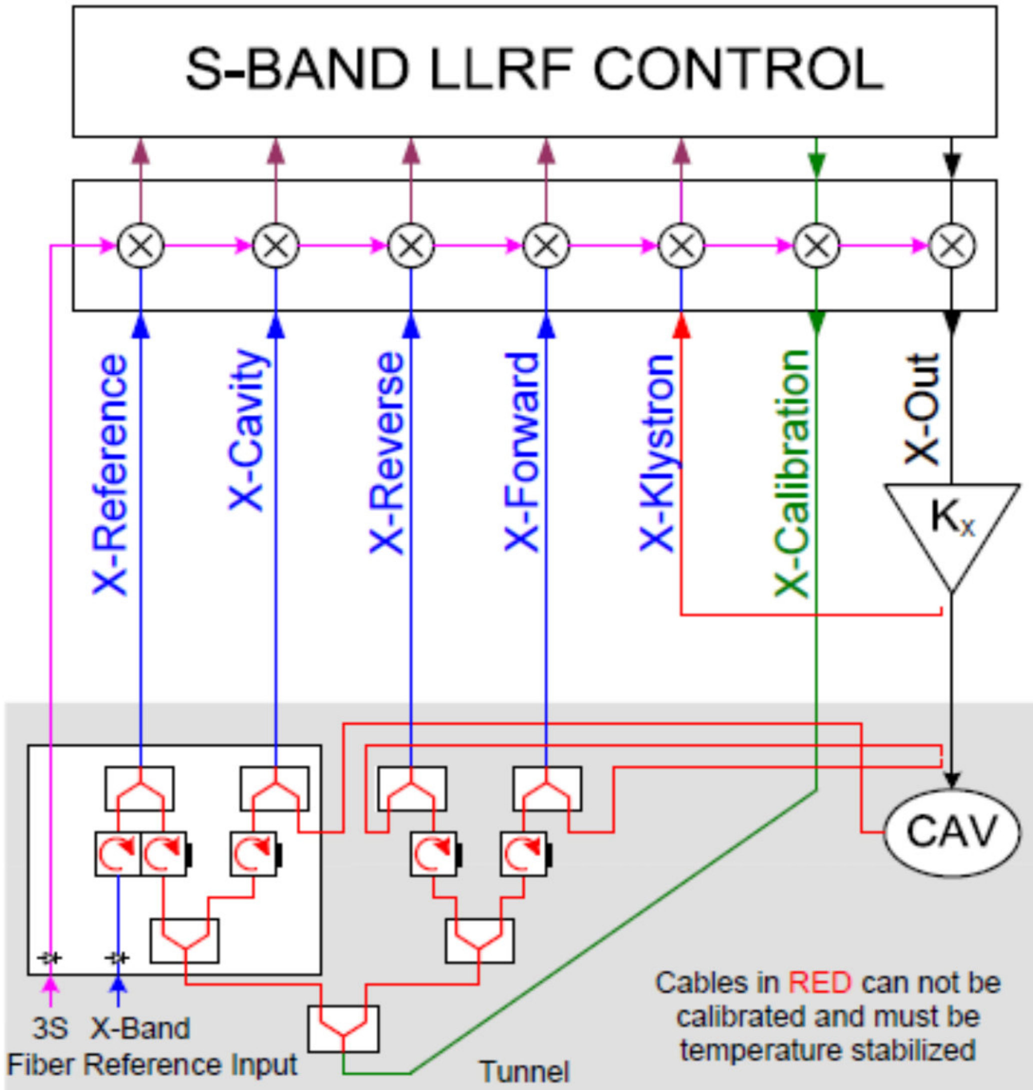
Active cable calibration



Coutesy of T. Rohlev

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Operation and statistics

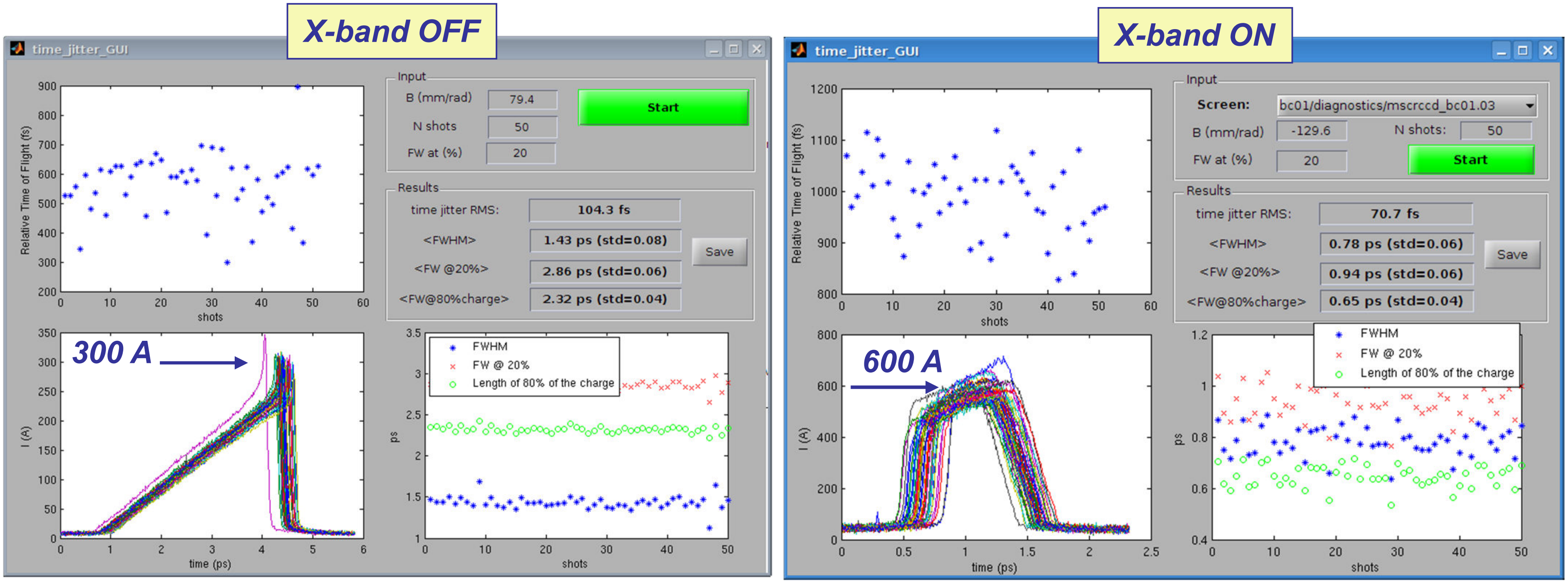
XL5-1B Operating data						
Voltage	Current	Micro-perv	Transm. eff.	Input RF PW	Output RF PW	RF pulse length
V_k(KV)	I_k(A)	(µP)	η(%)	RF_{in}(W)	RF_{out}(MW)	τ (nsec)
350	245	1.18	99.02	571	9.1	Up to 550
360	259	1.20	99.12	571	12.1	
370	267	1.19	99.05	571	15.7	
380	278	1.19	99.04	571	19.5	
390	289	1.19	99.18	571	24.3	
400	300	1.19	99.20	571	29.2	Up to 350
410	311	1.18	99.19	571	34.5	

X-band operational statistics

Filament hours (total)	Run	From	Op. hours	Uptime
8434	13	24-09/28-10 2012	824	~98%
HV hours	14	05-11/18-12 2012	1035	> 99%
6567	15	14-01/28-03 2013	1197	> 99%

Present XL5 operating power ~ 25 MW

Beam Compression

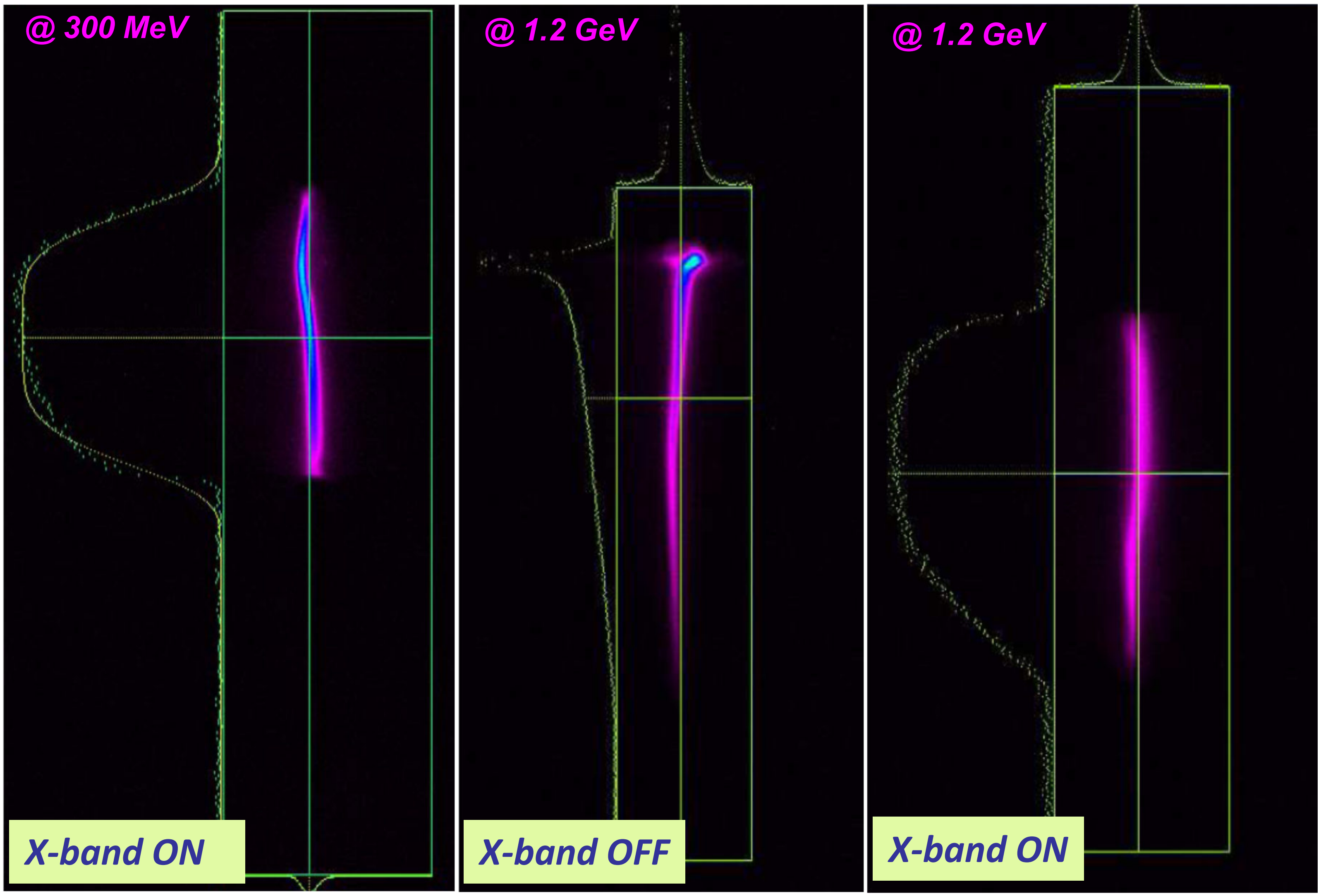


Bunch temporal profiles with and without X-band downstream BC1, using a TDC@300 MeV.
Analysis on 50 shots

Courtesy of S. Di Mitri

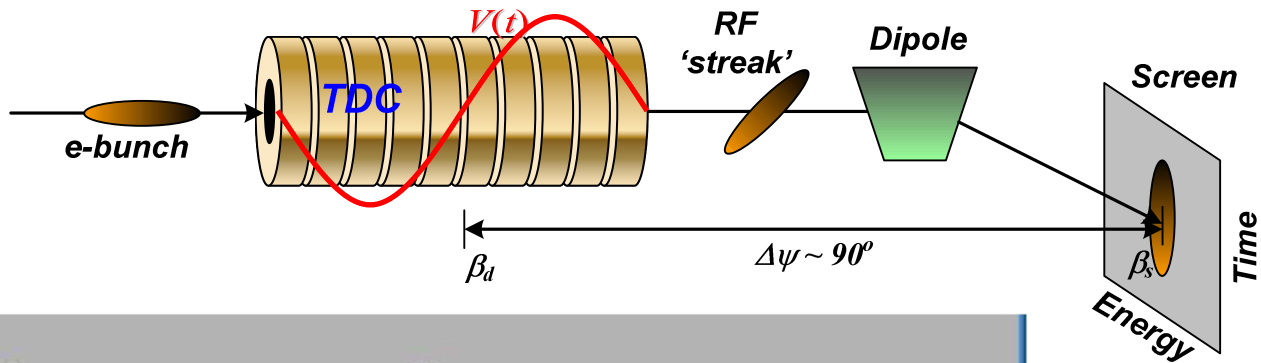
Bunch charge distribution

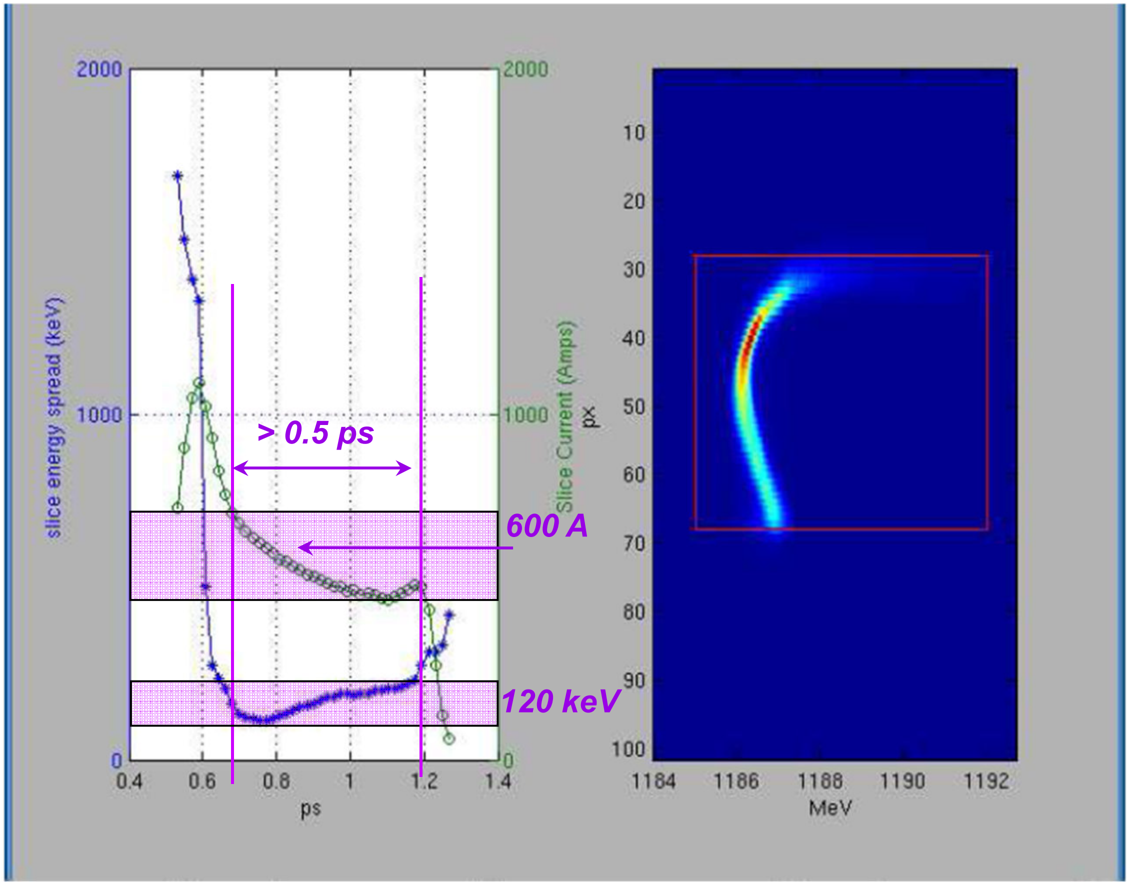
Analysis performed using transverse deflecting cavities @ 300 MeV and 1.2 GeV (note: the vertical coordinate is the z-axis)



Slice measurements

Slice beam analysis made @1.2 GeV using a high energy TDC





Courtesy of
G. Penco

Future interests on high gradients at FERMI@Elettra FEL

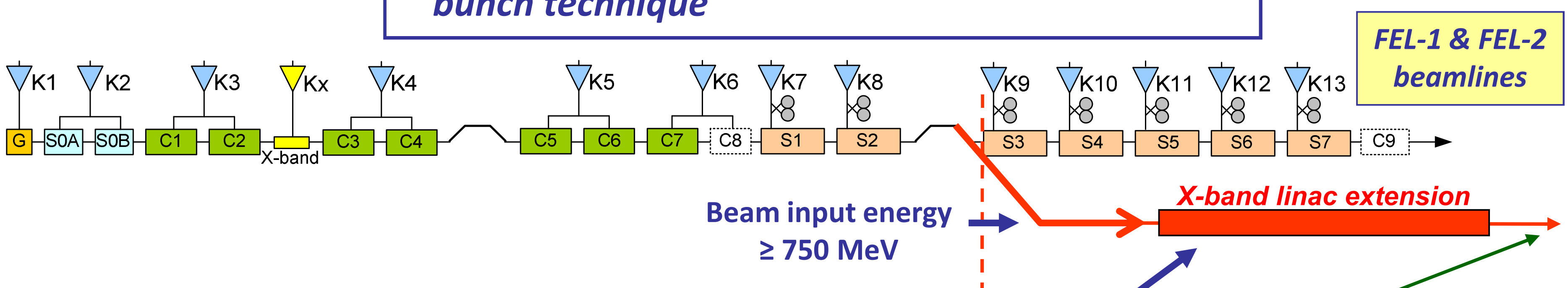
Considerations and ideas for future developments

- With the present layout at 1.5 GeV, FERMI is expected to reach a wavelength of 4 nm.
- The machine, based on a NC linac, was originally designed to operate at a 10 Hz repetition rate and an extension at 50 Hz has already been implemented. A further increase of its operating frequency (i.e. 100 Hz) and average power, has to be carefully evaluated (maybe the costs and benefits do not balance!)
- On the other hand, an extension of its capabilities in terms of wavelength (i.e. down to 1 nm or lower), seems to be very attractive for the Users community.
- However, to reach the above mentioned wavelength region, it is necessary to bring the electron beam energy up to 3 GeV or more.
- To pursue this goal, considering the limited space available in the present machine tunnel, the use of very high gradient structures is mandatory.

Present layout and energy upgrade

FERMI current layout and performance

- ***E_{beam} up to 1.5 GeV***
- ***FEL-1 at 80-10 nm and FEL-2 at 10-4 nm***
- ***Seeded schemes***
- ***Long e-beam pulse (up to 700 fs), with "fresh bunch technique"***



X-band energy upgrade

- ***Space available for acceleration*** — ***40 m***
- ***Accelerating gradient @12 GHz*** — ***60 MV/m***
- ***X-band linac energy gain*** — ***2.4 GeV***
- ***Injection energy*** — ***.75 GeV***
- ***Linac output energy*** — ***3.15 GeV***

Beam for a new FEL beamline
λ≤ 1 nm
Operation with
short bunch (< 100 fs)
and low charge (< 100pC)

~50 m available

40 m (80%)
available for acceleration

Issues and requirements

- Define the new FEL layout, wavelength range, operating parameters, and expected performance (choices and assessments that are Users driven).
- Starting from the FEL performance, define the linac working point, maximizing the brightness while keeping the collective effects under control.
- Design an accelerating structure unit that, taking into account the beam requirements, minimizes the project costs in terms of number of RF plants to reach the final energy (in collaboration with CERN - CLIC group).
- Confirm with prototype tests that the design parameters are feasible and provide reliable operation.

⇩

X-band test station

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X-Band test station

- The test station can use the XL5 spare klystron already at Elettra since August 2012. Note that a periodical check and operation of the tube is also suggested by SLAC.
- Equipped with a proper RF compressor, with ≤ 35 MW from the klystron, the station would deliver more than 80-90 MW at the load input.
- At these power levels, it would be possible to extensively test X-band structures and modules, obtaining the optimal choice for the FERMI energy upgrade.
- The station could also be used for the CLIC high gradient structures test program, giving the opportunity to continue to acquire experience and know-how at 12 GHz.

Summary

- The FERMI X-band linearizer is now operational with a very beneficial effect for the FEL performance.
- The whole system was commissioned at the beginning of 2012 and up to now has been operational for more than 6000 hours HV.
- Tipically the XL5 klystron is operated at 25 MW – 550 ns and the system uptime is close to 100%.
- The operating RF stabilities are in the specs reaching ~0.05% in amplitude and ~0.2° X in phase.
- To extend the FERMI wavelengths capabilities (down to 1 nm or lower), an increase of the linac beam energy up to 3.0 GeV using X-band technology has being studied.
- To further explore this possibility, to validate the machine layout and the component design, the assembly of a X band testing station would be mandatory and is under evaluation.

Thanks for your attention