A Multi Purpose X-band structure

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- Motivation and Design
- Fabrication
- Tuning
- First experience with beam
- Outlook

General overview

Goal: a multi purpose accelerating structure in (European) X band

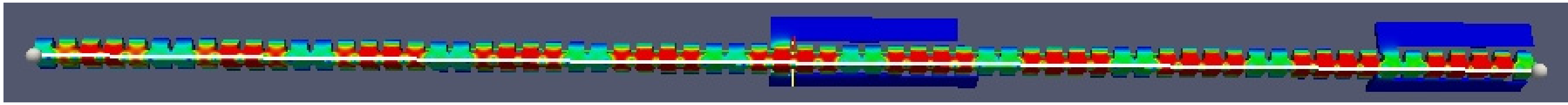
Motivations:

- A different type of structure to be used in the high gradient test program
- Validation of design and fabrication procedures at CERN
- Get X band technology into the main stream
- Practical application: FEL projects SwissFEL and FERMI need higher harmonic X band structure to compensate long. phase space nonlinearities
- High gradient/power requirements of CLIC = expect safe operation at the more relaxed parameters of the PSI X-FEL

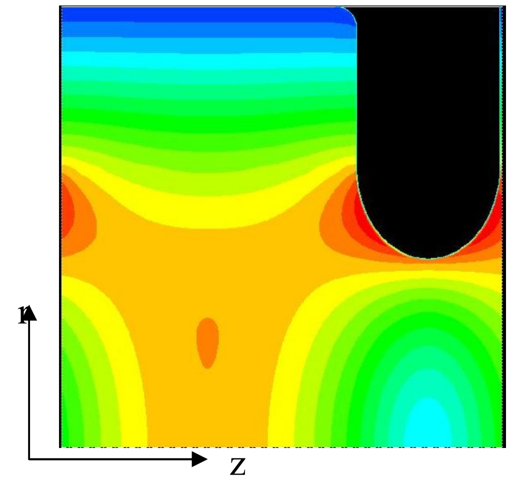
Special considerations for FEL applications:

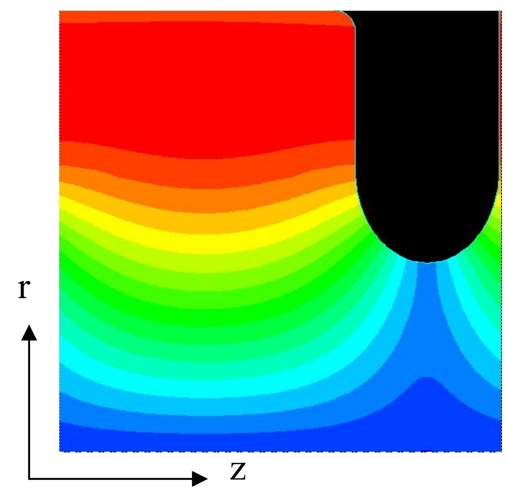
- Operating structure at relatively low beam energies of few hundred MeV, so have rather high sensitivity to transverse wakefields!
- Strategy:
- Passive: Try to have open structure while maintaining good efficiency and breakdown resilience
- Active: Wake field monitors
- See offsets before they show up as emittance dilution
- Possibly measure higher order/internal misalignments (tilts, bends ….)

Electrical layout



- Long constant gradient design: 72 cells, active length 750 mm
- No HOM damping
- Cooling design for 1 usec/100 Hz RF pulse
- Use 5π/6 phase advance:
  - Long cells with large mean aperture of 9.1 mm: small transverse wake
  - Intrinsically lower group velocity: Good gradient even for open design with large iris
- Wake field monitors to ensure optimum structure alignment
- Model: NLC type H75 omitting the damping manifolds
- Average gradient 40 MV/m (30 MeV voltage) with 29 MW input power
- Group velocity variation: 1.6-3.7%
- Fill time: 100 nsec
- Average Q: 7150





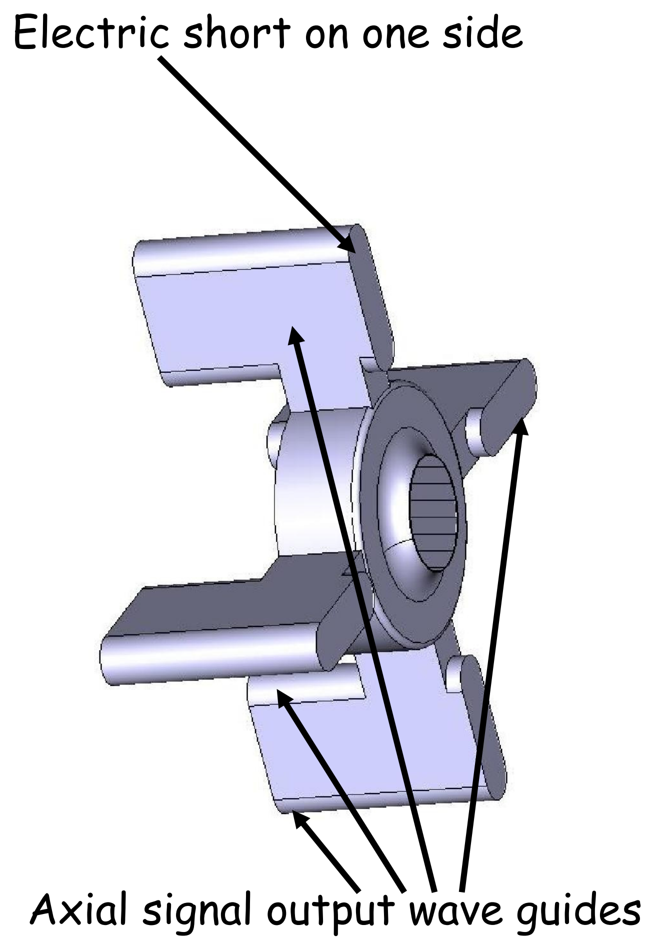
Up- and downstream HOM coupler a la NLC DDS

TE type coupling minimizes spurious signals from fundamental mode and longitudinal wakes

Need only small coupling (Qext<1000) for sufficient signal

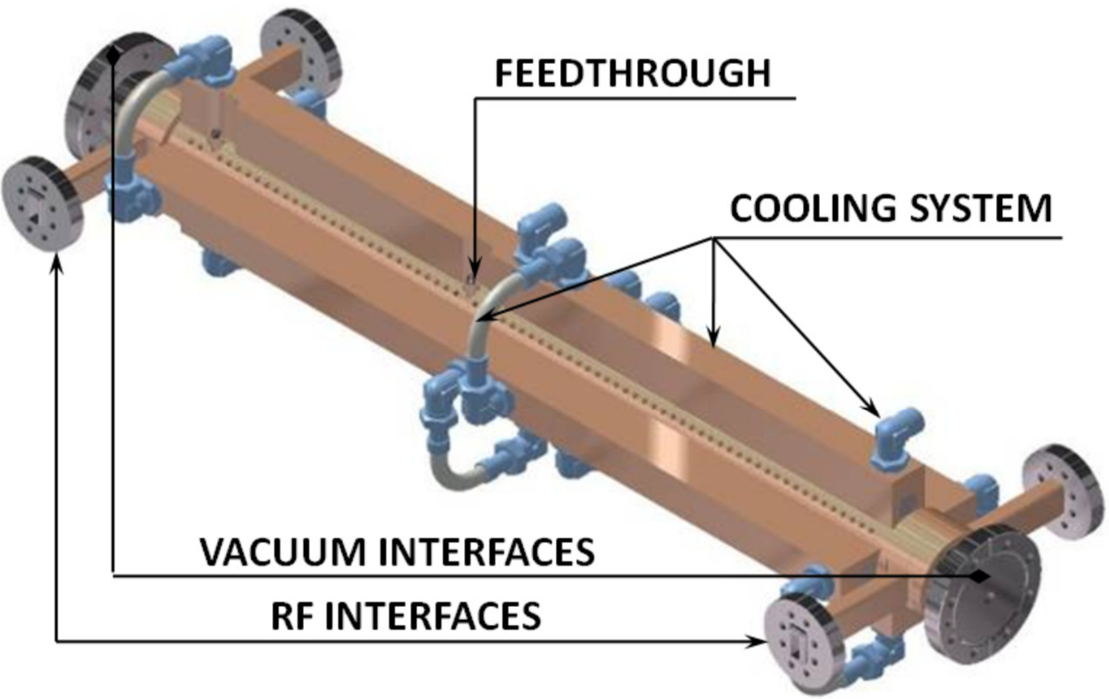
Minor loss in fundamental per-formance: 10% in Q, <2% in R/Q

Output wave guides with coaxial transition connecting to measurement electronics

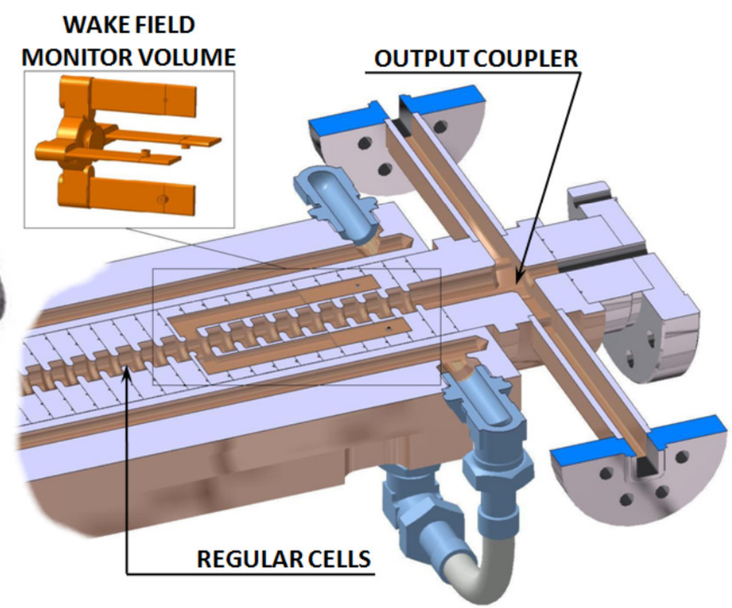


Mechanical model

Each two structures for PSI (SwissFEL) and ST (FERMI @ ELETTRA) with wakefield monitors fabricated

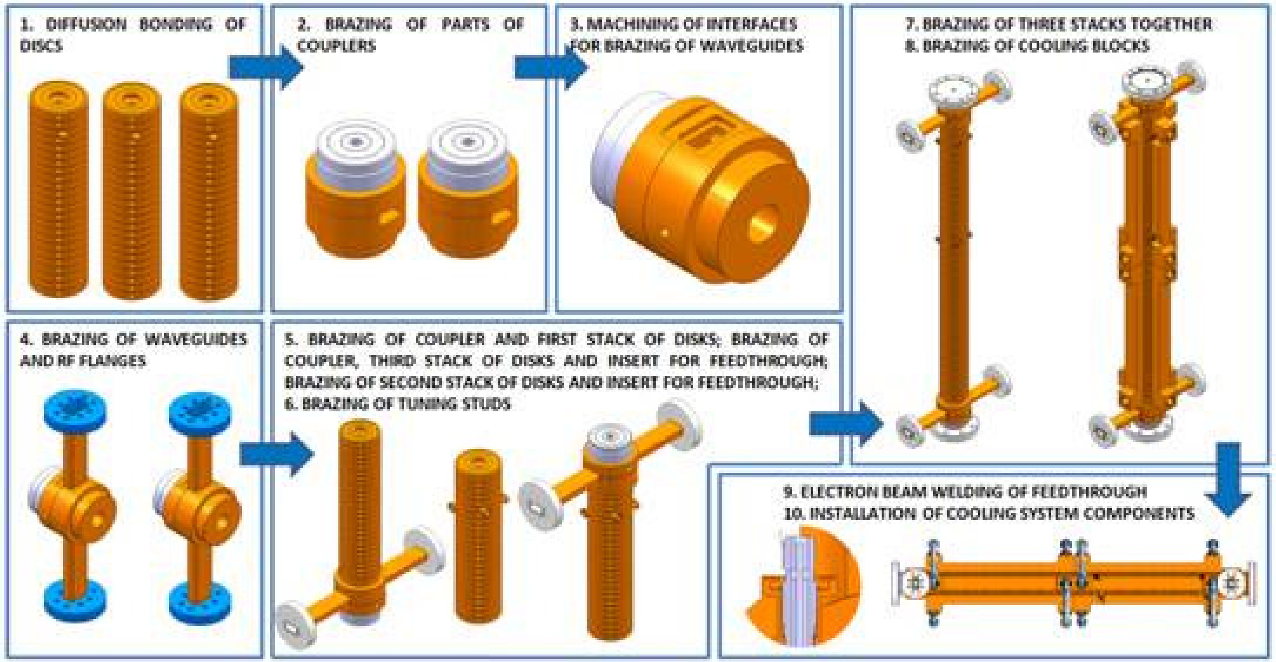


Wakefield monitor details



Fabrication

- Prefabricated parts
  - High precision machined disks (VDL/NL)
  - Custom made vacuum feedthroughs (OMW, Japan)
- Diffusion bonding following procedure developed by SLAC

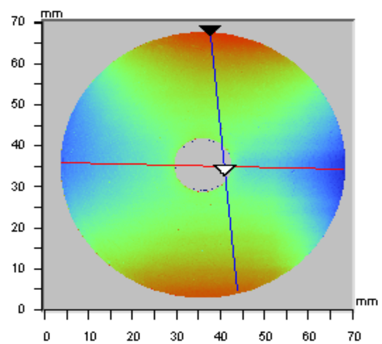


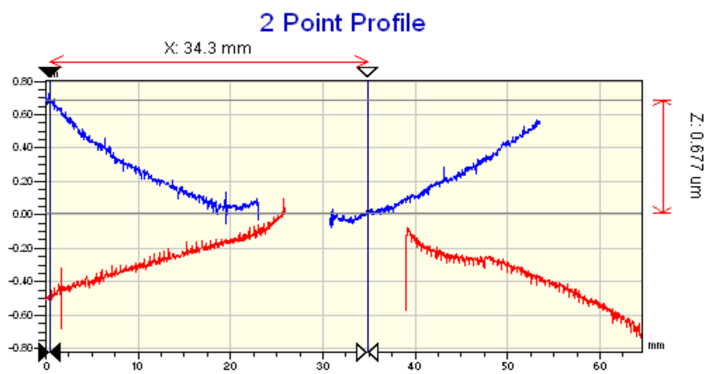
- Hydrogen bake out

Prototype disks

Typical flatness profile

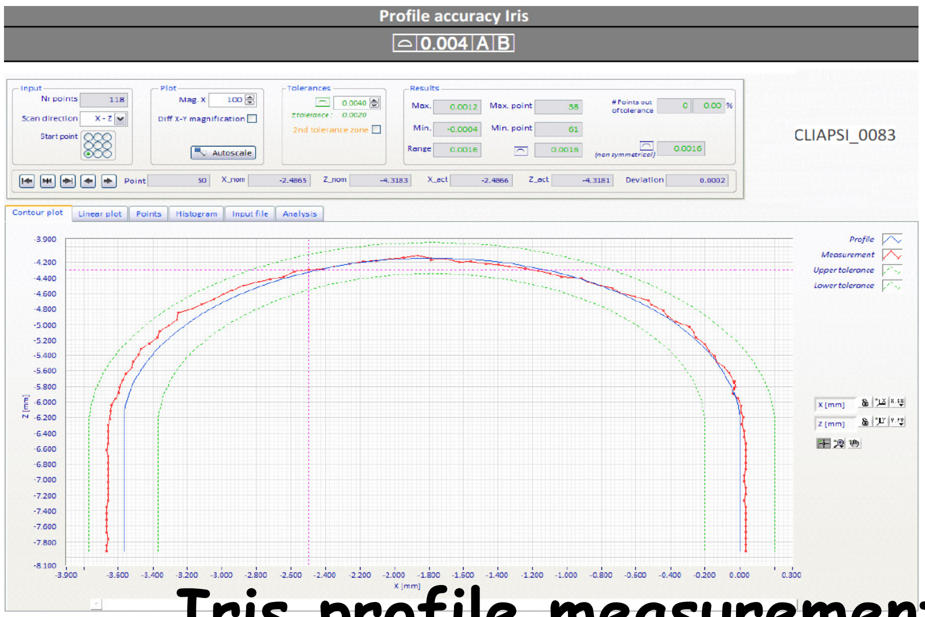
Veeco





Title: CLIAPSI-0001

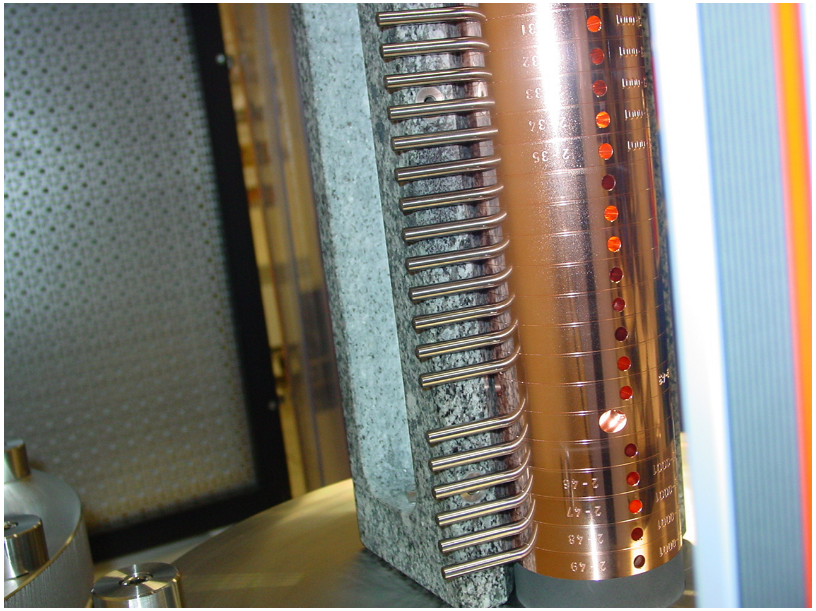
Note: Disk 2-46

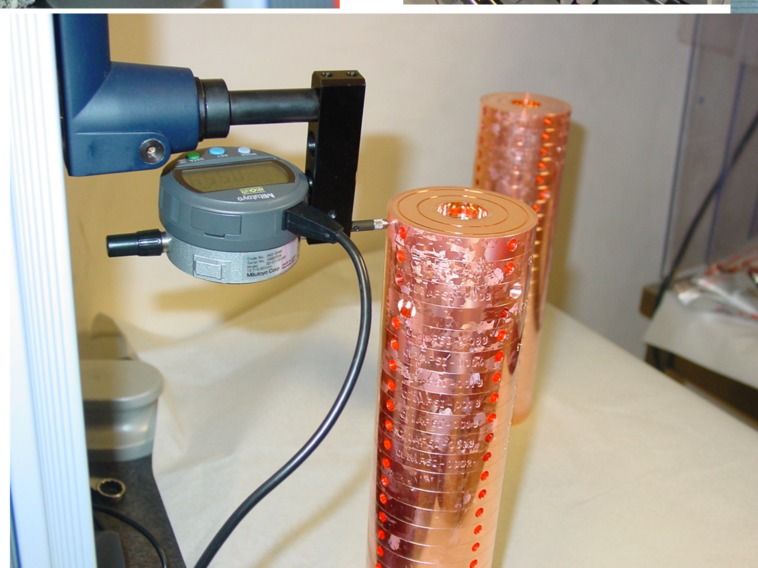


CLIAPSI_0083

Iris profile measurement

Assembly and bonding



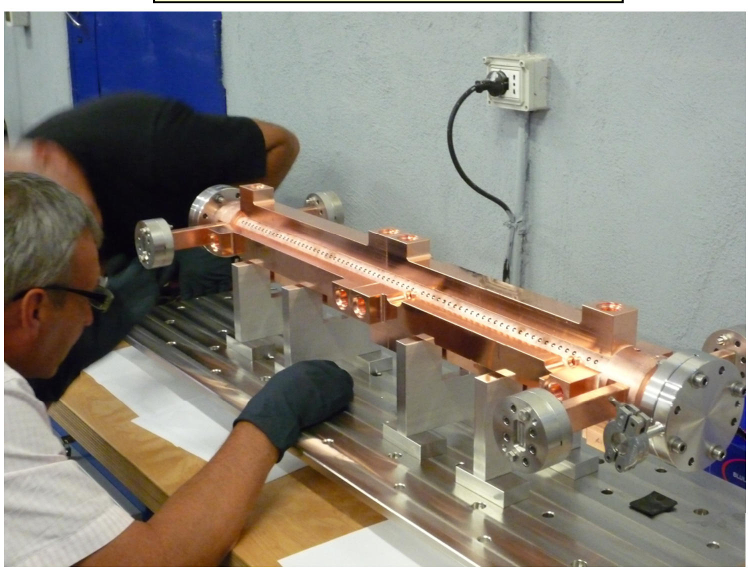


Structure vacuum baking

Structure vacuum bake-out at CO.ME.B. (Rome):

- *~ 350 hours*
- *oven pressure ≤ 10^{-8} torr*
- *T = 650 ^{o}C*

Structure preparation



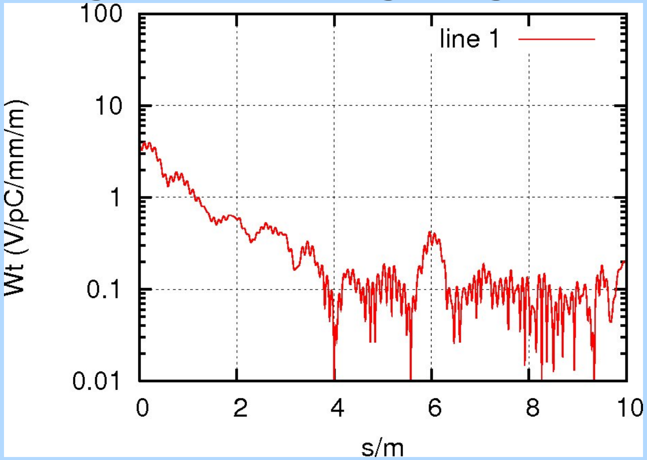
Finished structure

First structure developed lateral offsets during brazing of substacks of 350 um, subsequently corrected by introduction of copper sleeves.

What about effects of these offsets on performance?

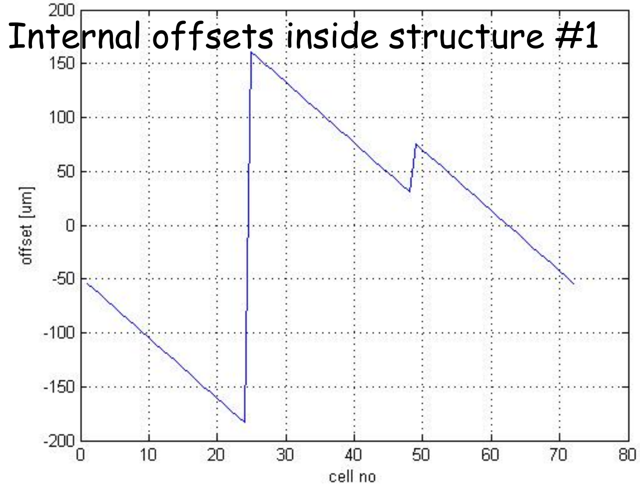
By aligning the structure in average, can find a position with satisfactory single bunch wake.

But getting non zero long range wake

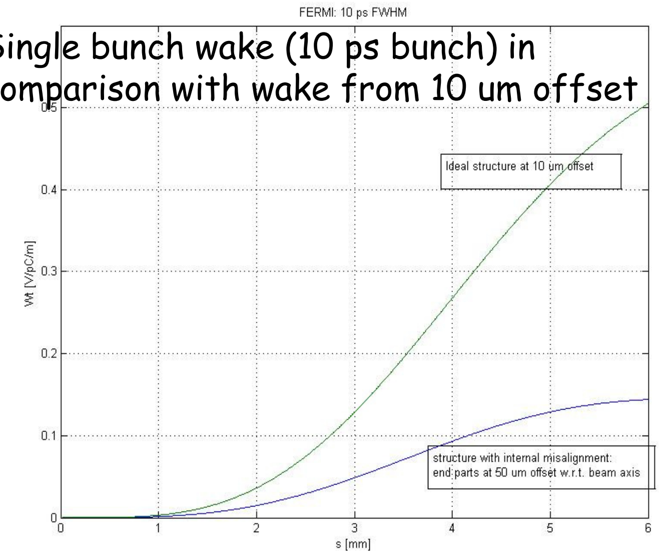


How about operation of wake field monitors?

Internal offsets inside structure #1



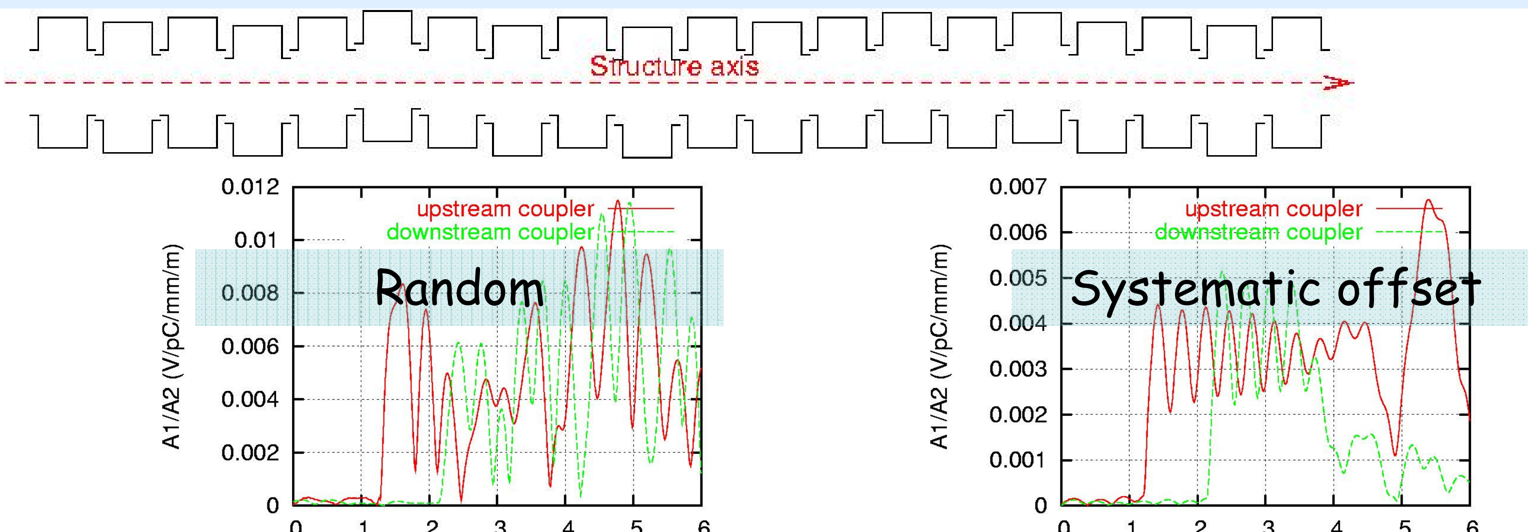
Single bunch wake (10 ps bunch) in comparison with wake from 10 um offset



Wake field monitor resolution

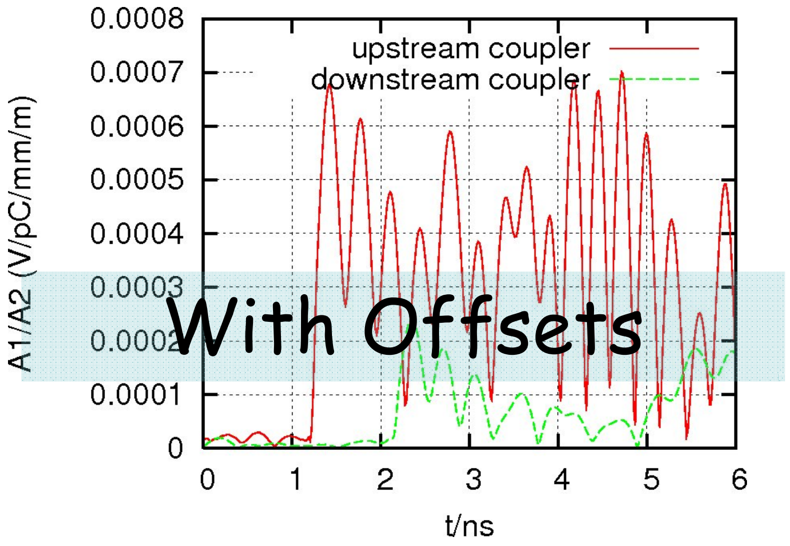
Dilution by

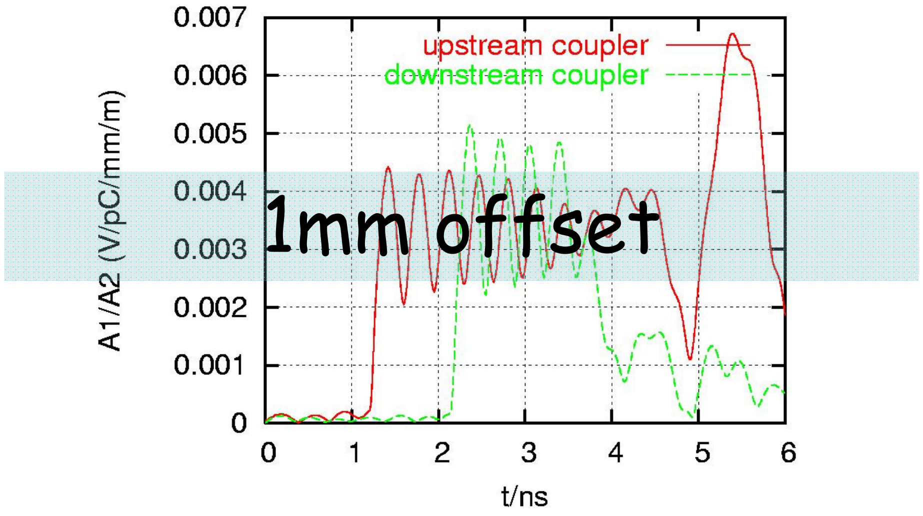
- Noise in RF front – only an issue for low bunch charges
- Spurious signal from fundamental, longitudinal wakes - negligible due to TE coupling, waveguide length plus (if still necessary) additional filtering
- **Main effect: random misalignment of individual cells!**



Comparing random and systematic offsets

WFM signals assuming true lateral offsets





Effective WFM resolution reduced to 100 um (Mech. Alignment precision ~ 50 um)!!

- This structure still OK for high gradient tests – no effects on field balance etc.
- As mentioned, subsequently corrected by introduction of copper sleeves reducing alignment error to lesser 18 um.

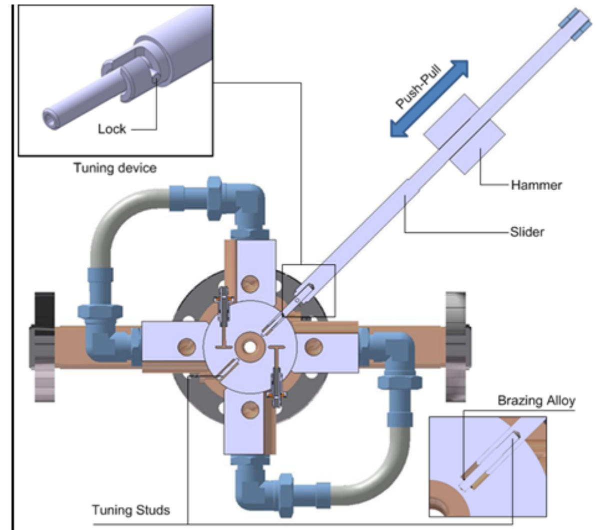
Tuning procedure

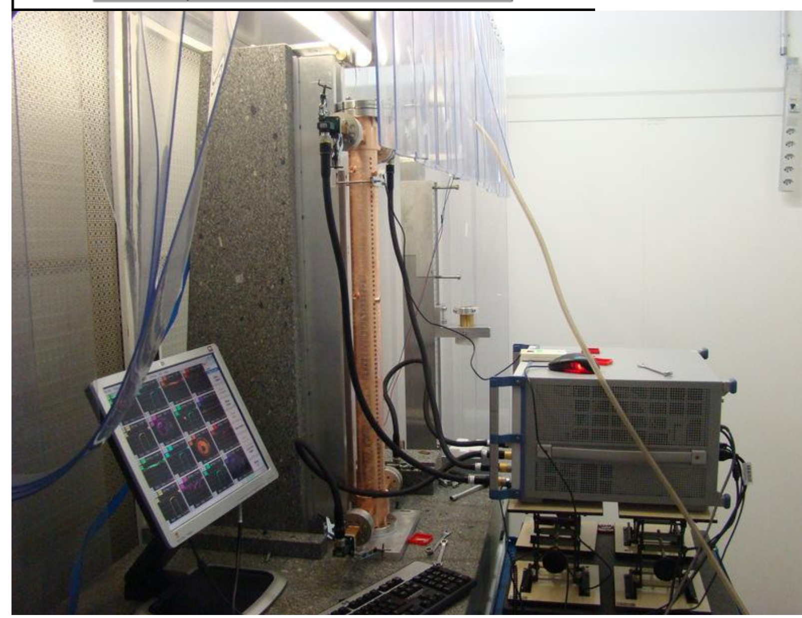
- Bead-Pull to measure field distribution
- Compute local reflection in individual cells
- Compute required tuning changes
- Tune cells using push-pull system

But, what precision should be expected from untuned structure?

- Precision of mechanical parts corresponds to frequency deviations < 1 Mhz

- Other contribution comes from precision of electrical design - validation with ACE3P





Validation with ACE3P

Start:

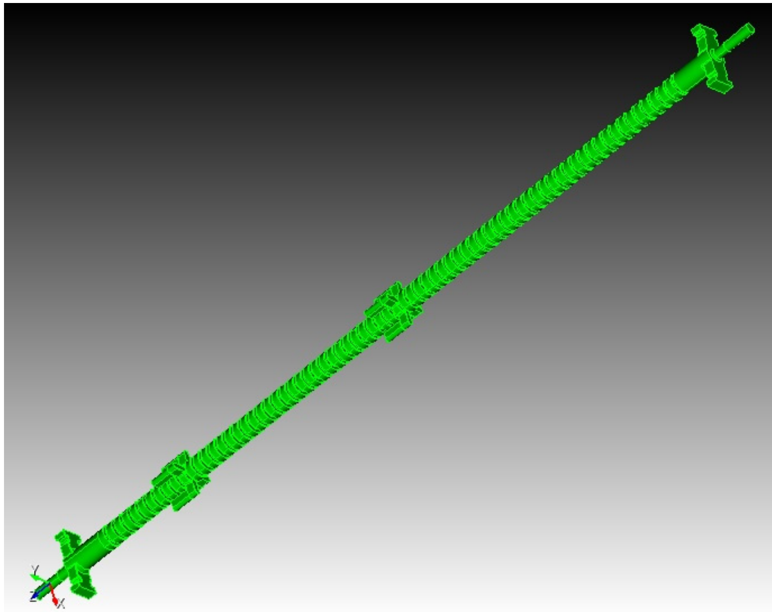
Eigenvalues with Omega3P using 66 cell substructure (No couplers, matching cells)

Computed resonance frequency:

F = 11.99235 GHz (w/o losses)

F=11.9912 GHz (including losses)

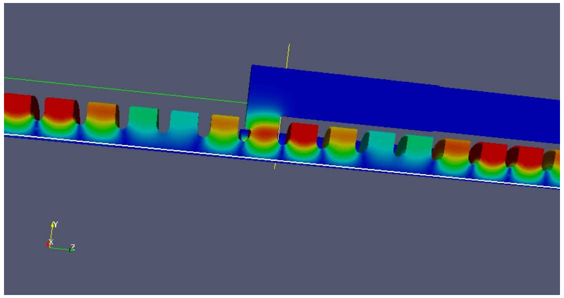
Design: F=11.991648 GHz



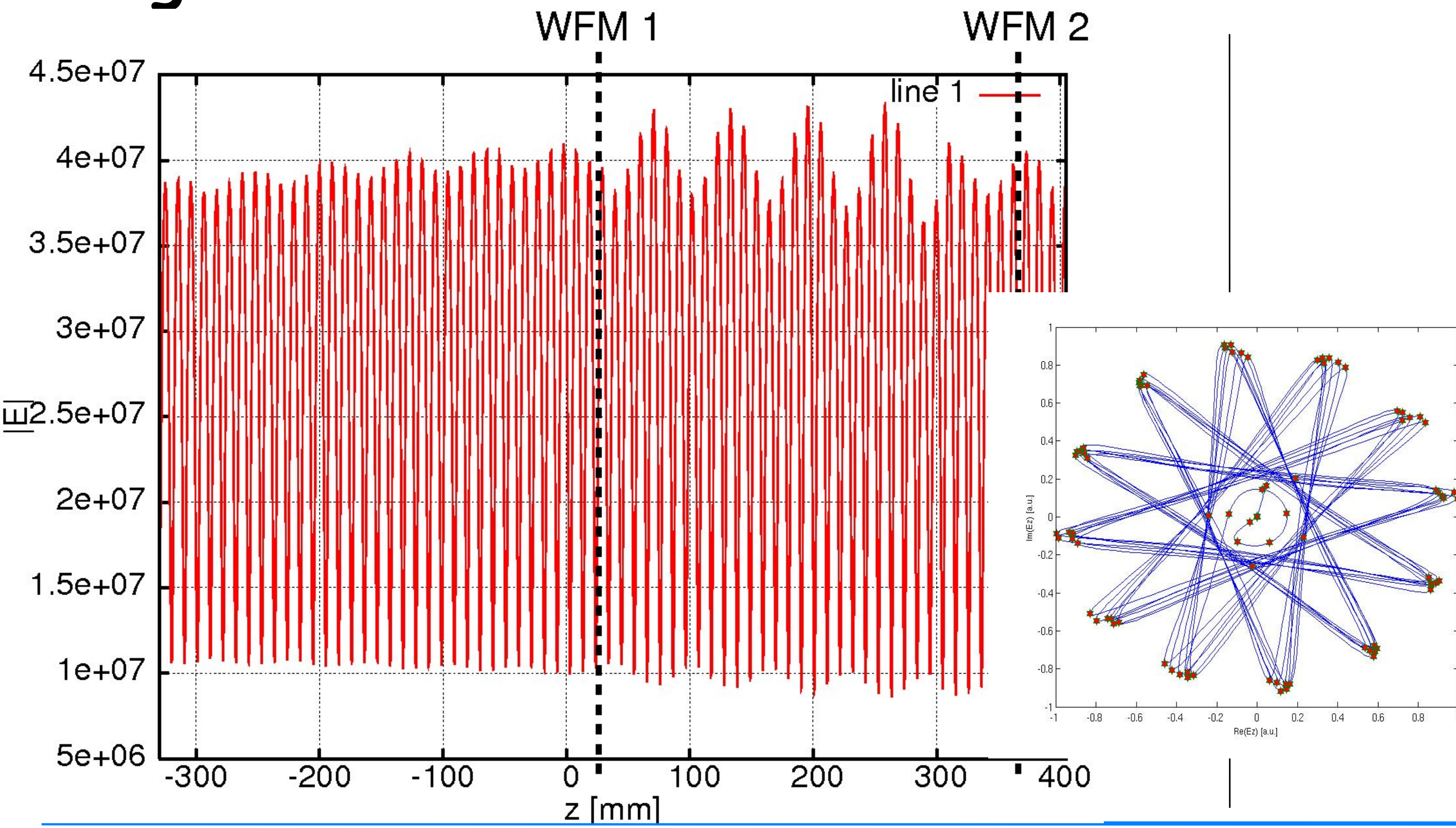
Then:

Simulate full structure as driven problem using s3p at calculated resonance frequency (including couplers, matching cells, effect of metallic losses):

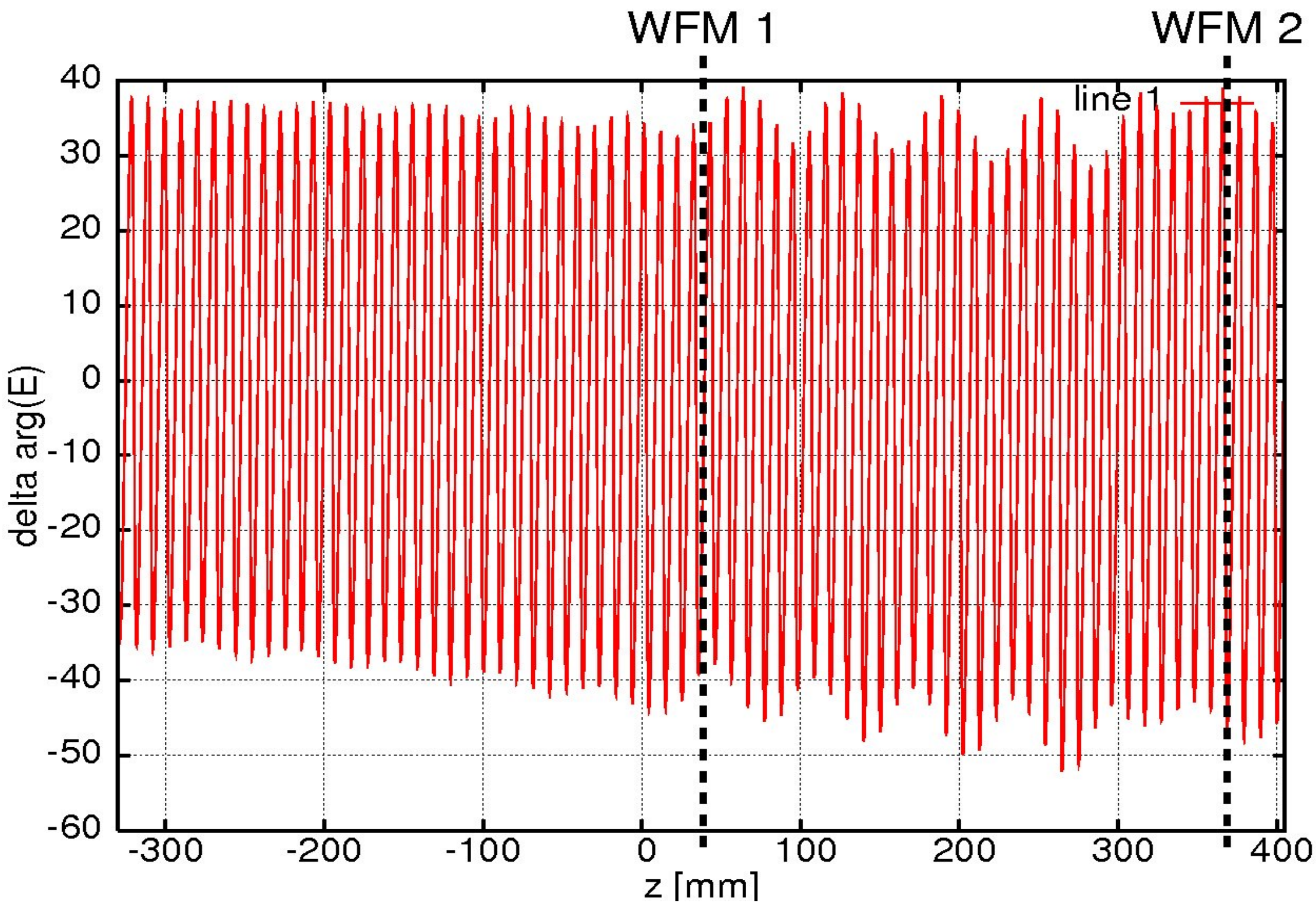
Electric field at middle WFM



Longitudinal electric field on axis



Phase error



WFM 1
WFM 2
line 1
40
30
20
10
0
-10
-20
-30
-40
-50
-60
delta arg(E)
-300
-200
-100
0
100
200
300
400
z [mm]

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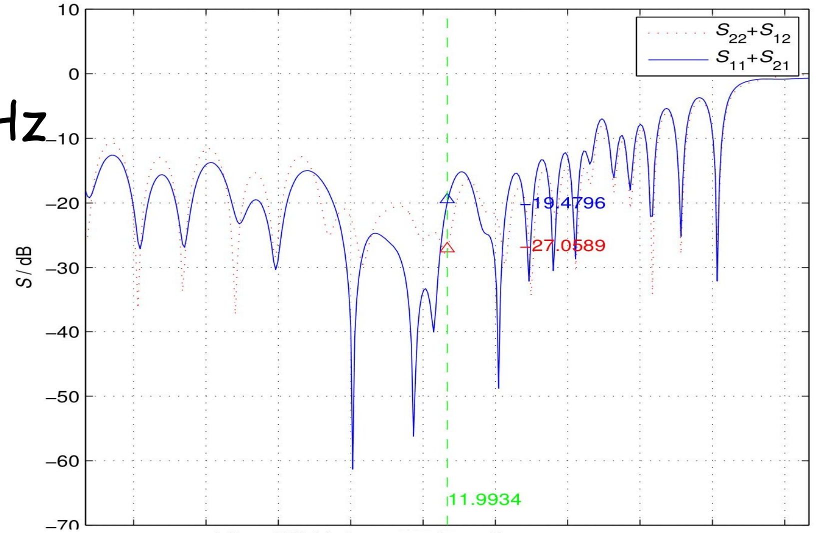
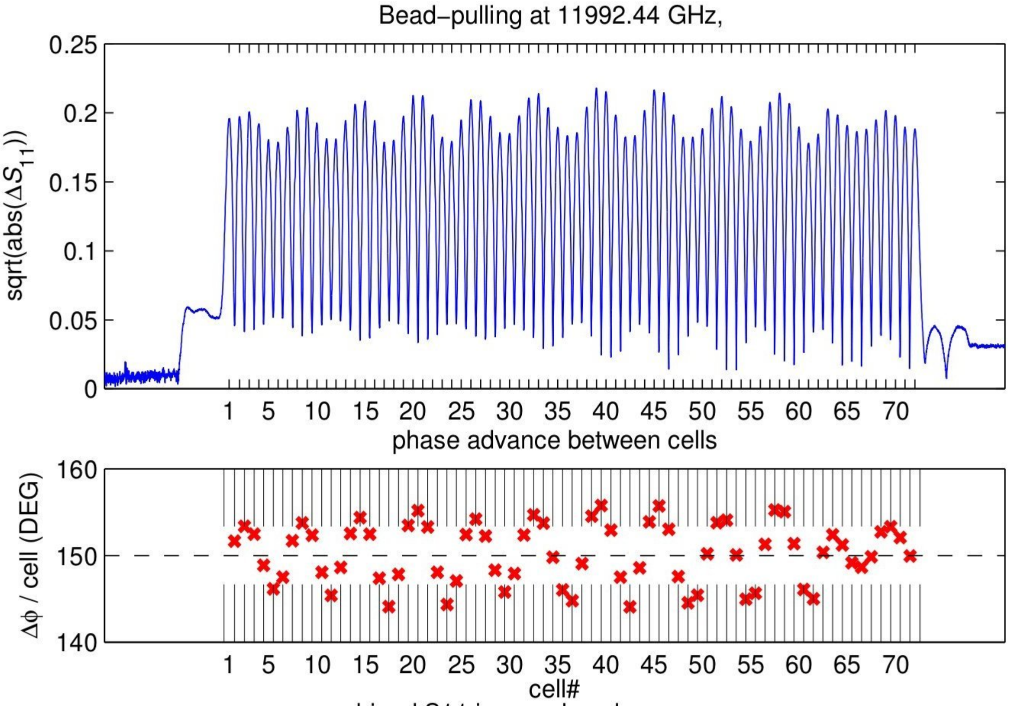
Untuned structure (#1)

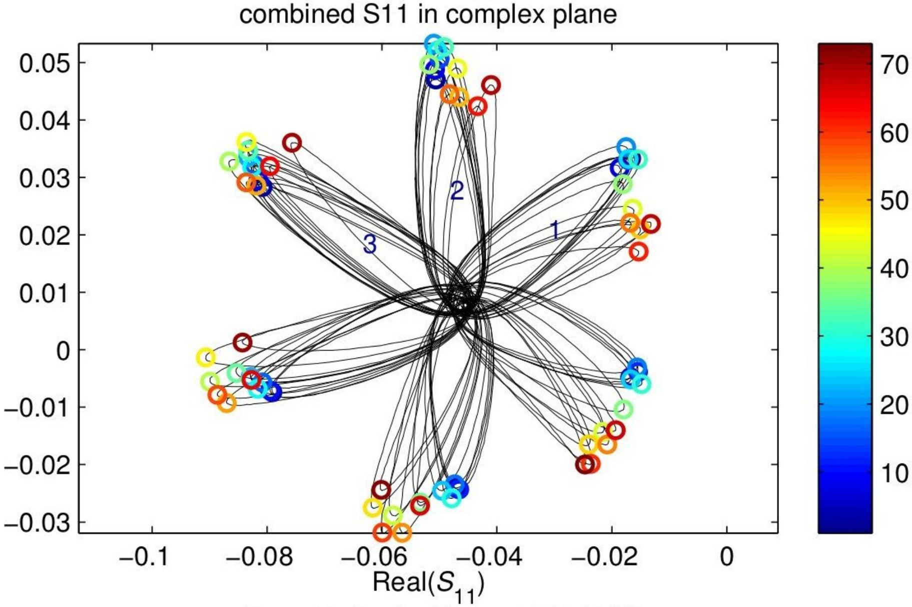
FERMI @elettra

Frequency systematically too low by 1 MHz

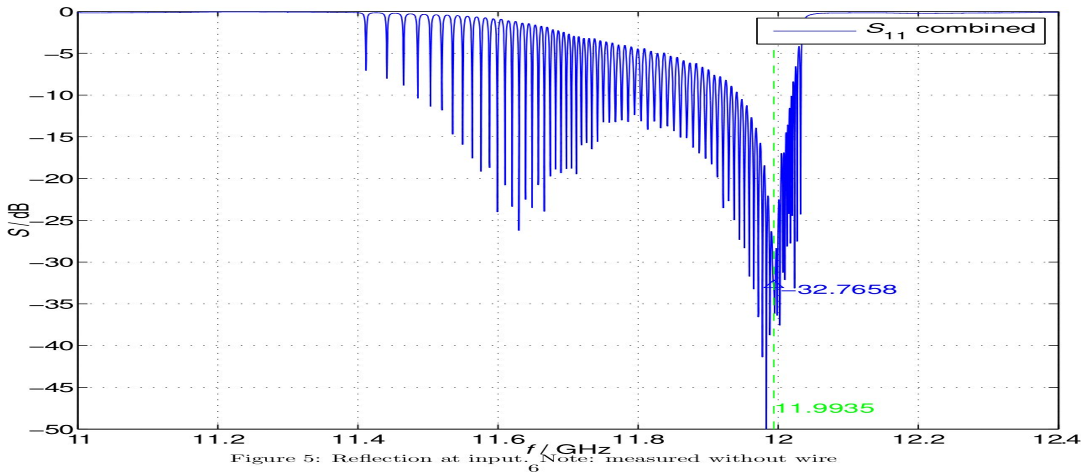
Very consistent in amplitude and phase advance

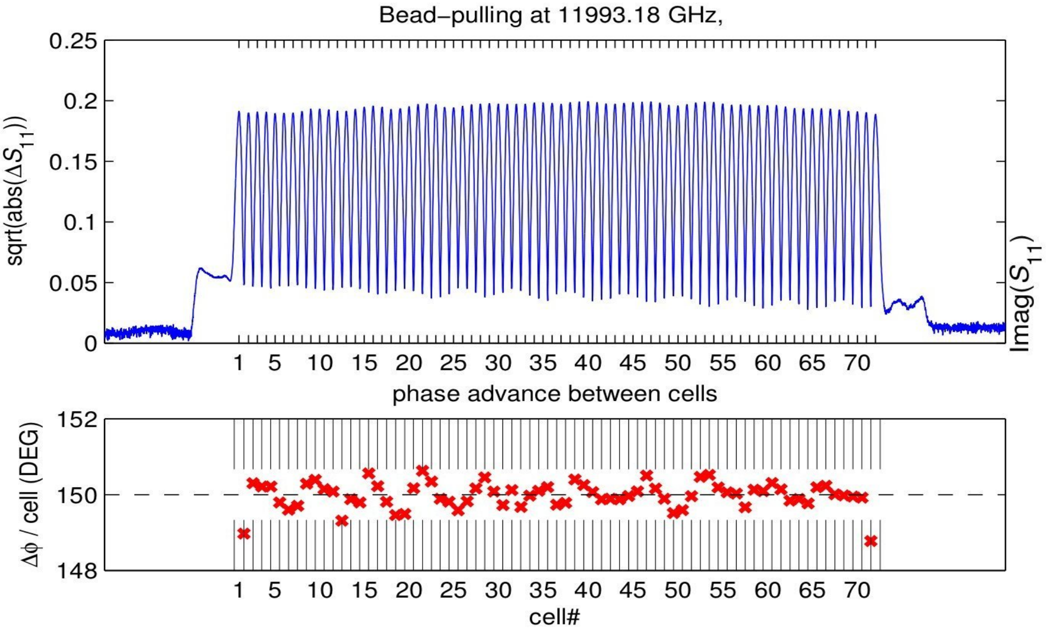


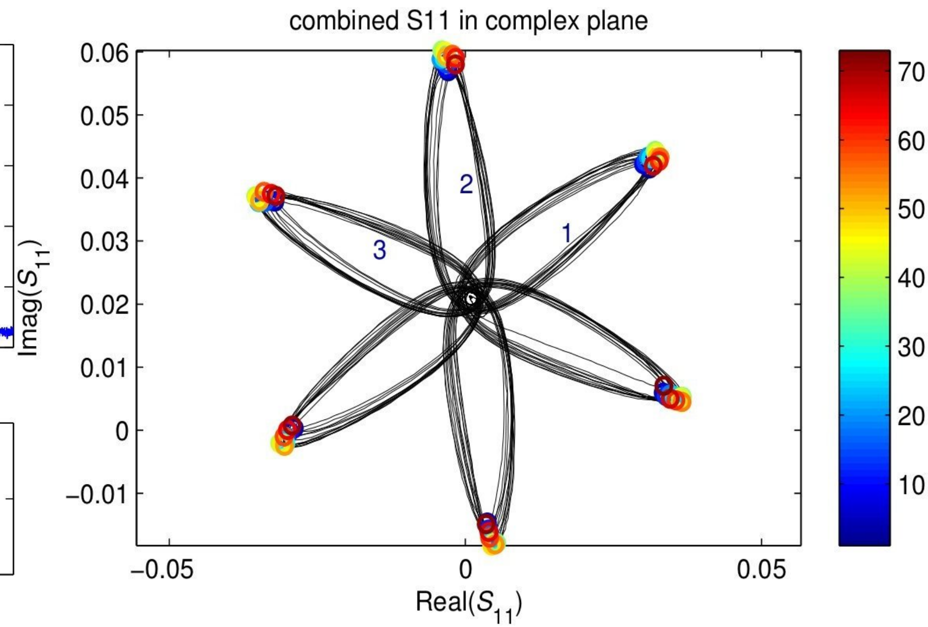




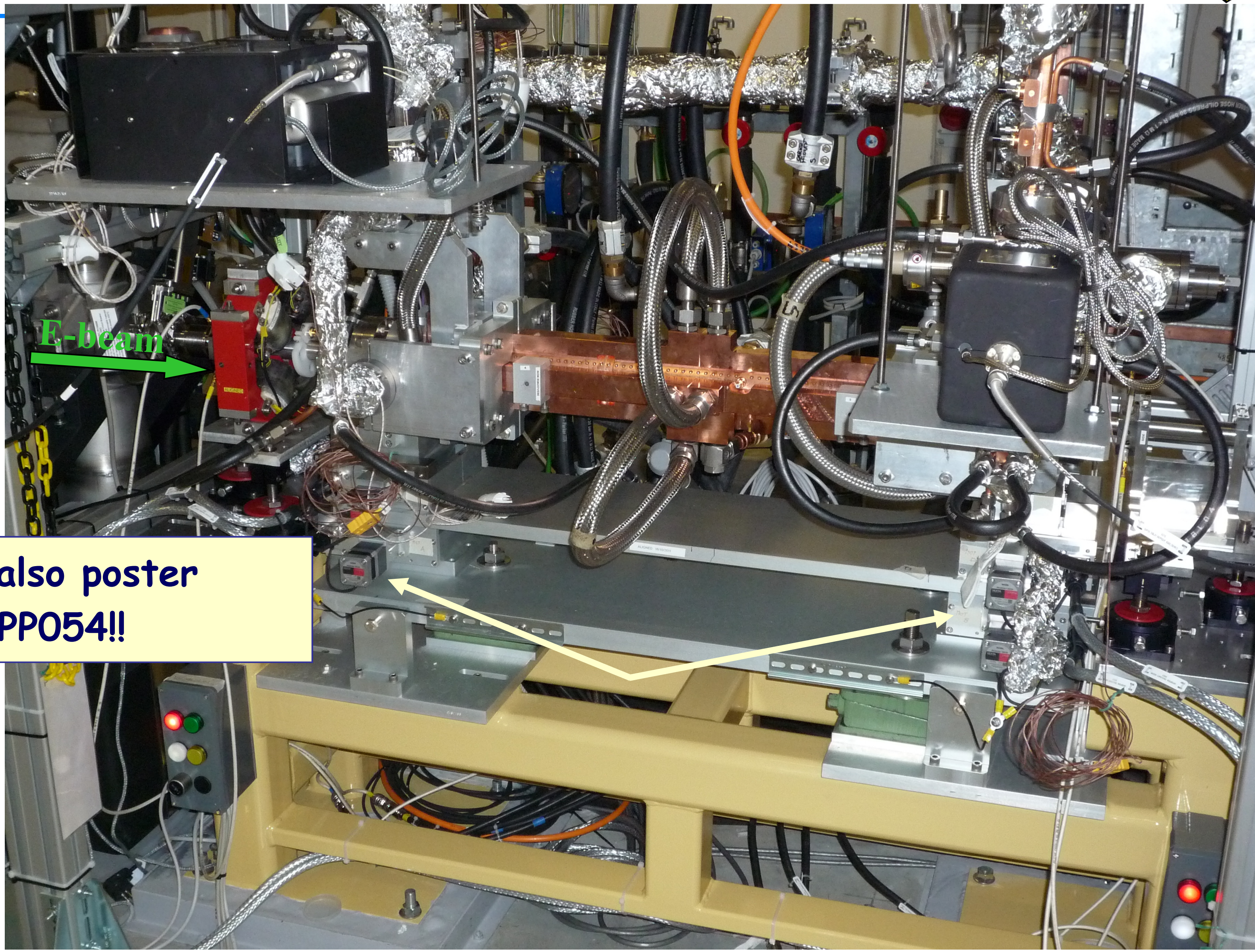
Wire measurement after tuning (structure N1)





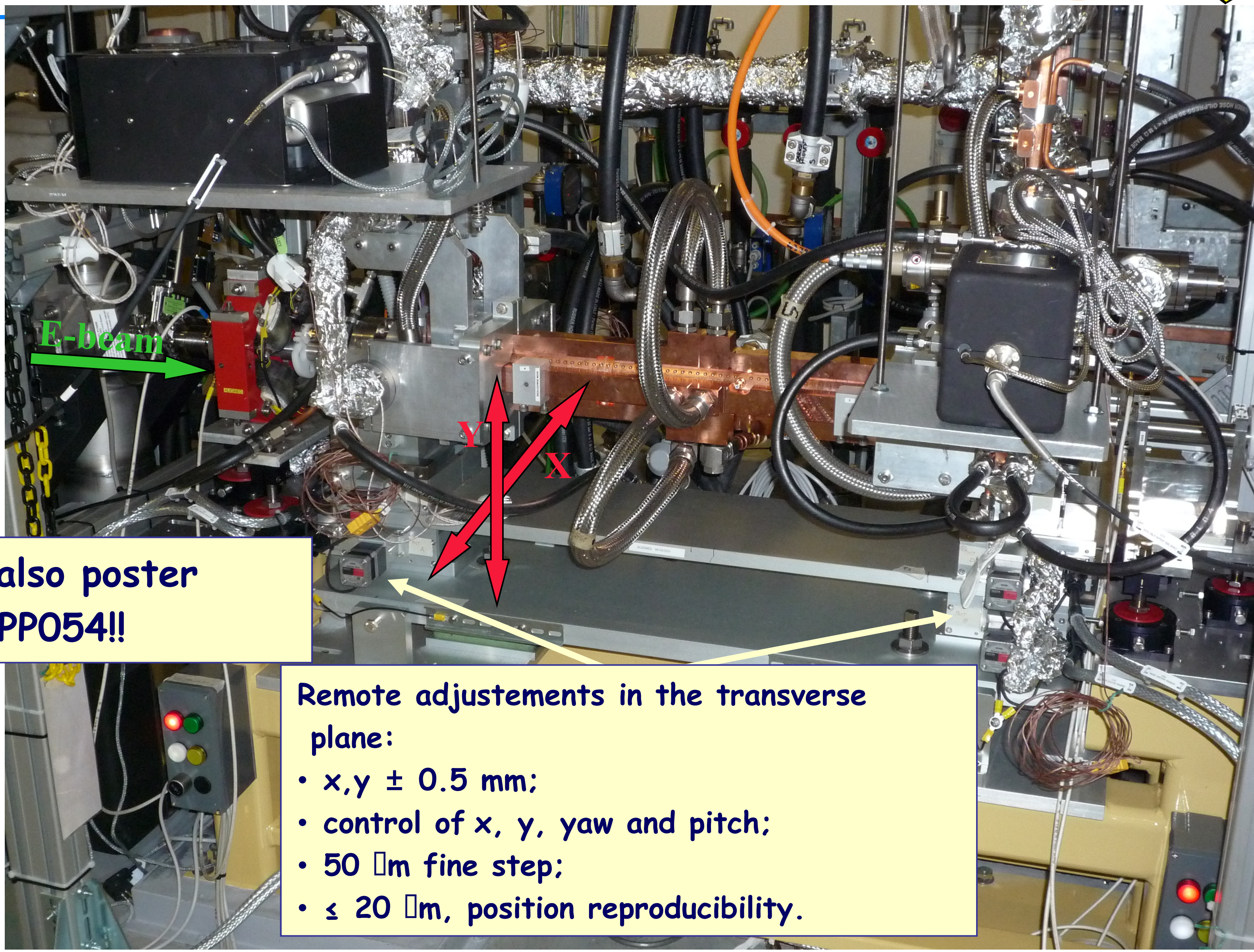


First structure installed at FERMI FEL



See also poster TUPPP054!!

First structure installed at FERMI FEL



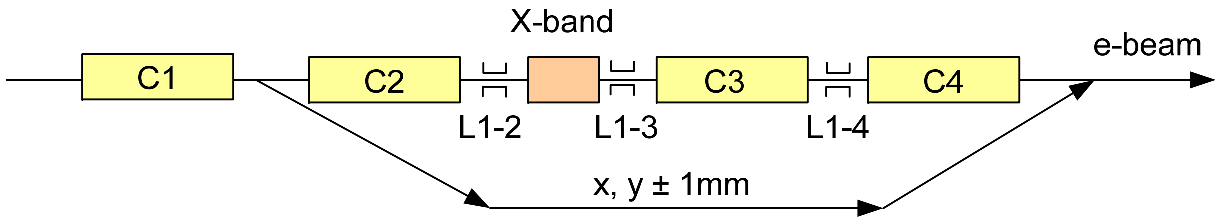
See also poster TUPPP054!!

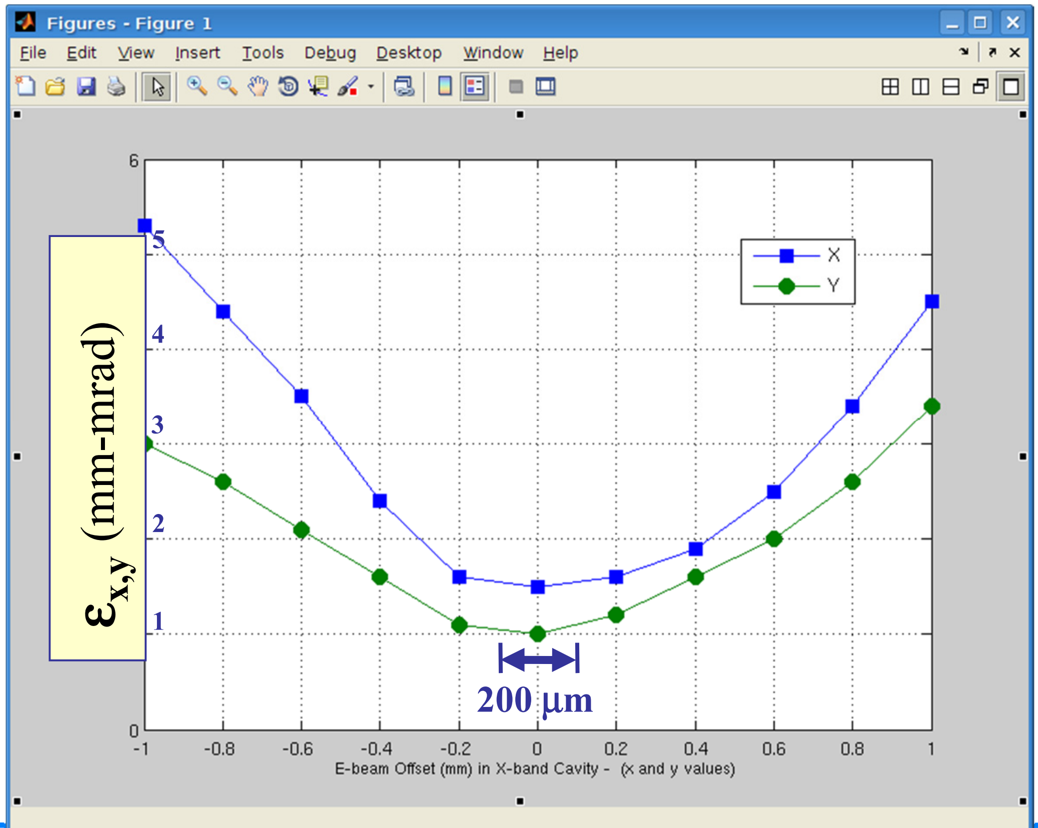
Remote adjustements in the transverse plane:

- x,y ± 0.5 mm;
- control of x, y, yaw and pitch;
- 50 μm fine step;
- ≤ 20 μm, position reproducibility.

Emittance dilution

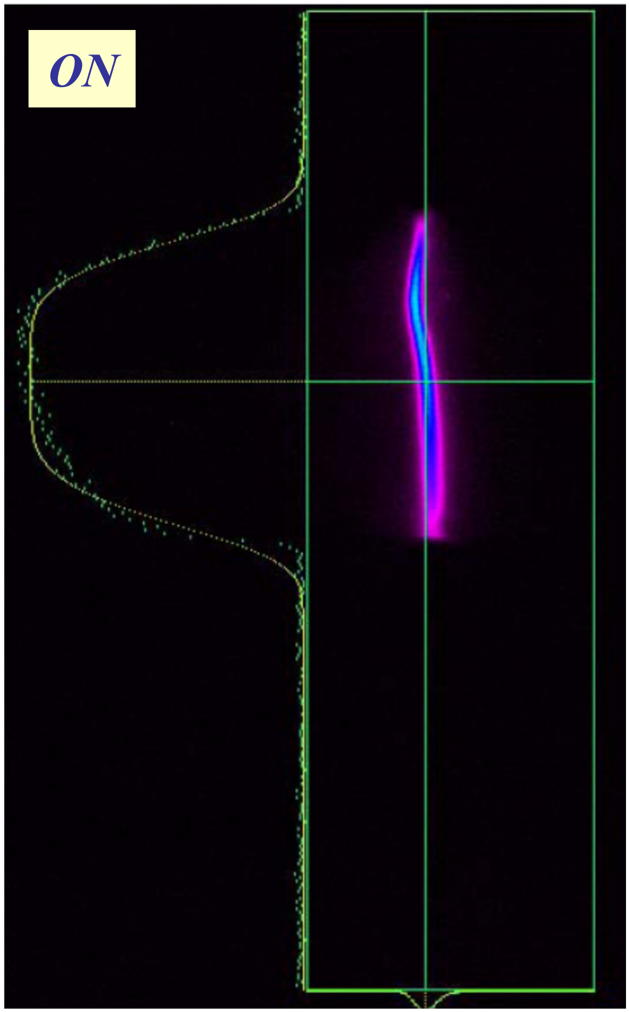
Measured ε_x and ε_y as we move the beam (6.5 ps_fwhm, 350 pC) along a line from ±1 mm in x-y, through the X-band structure (passive, no RF)



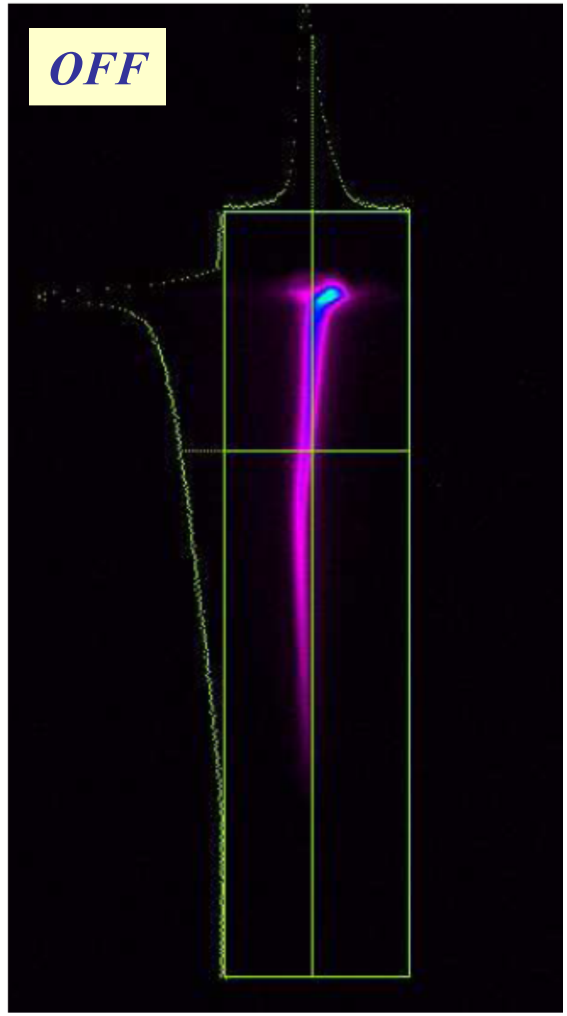


Charge density with deflecting cavities

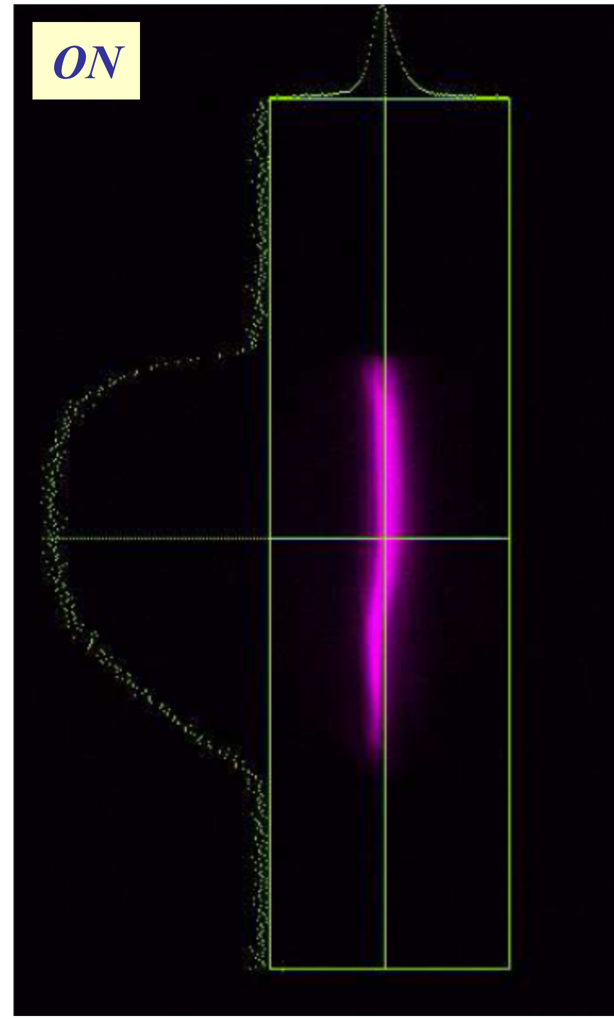
X-band @-19 MeV



mscrccd_bc01.03 @ 300 MeV



mscrccd_tls.03 @ 1.2 GeV



mscrccd_tls.03 @ 1.2 GeV

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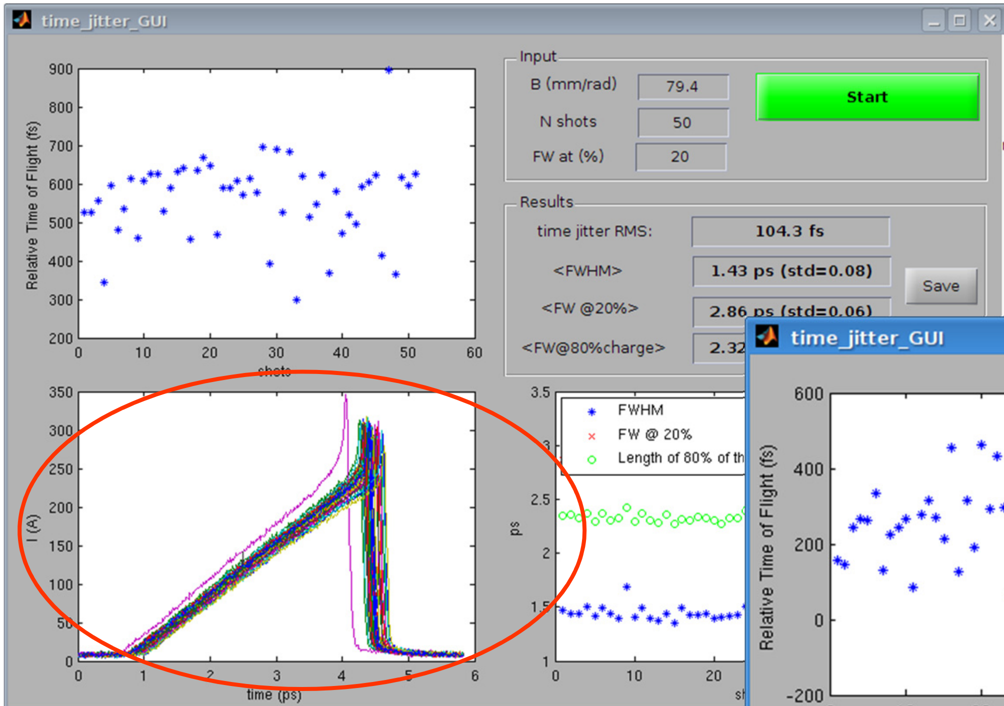
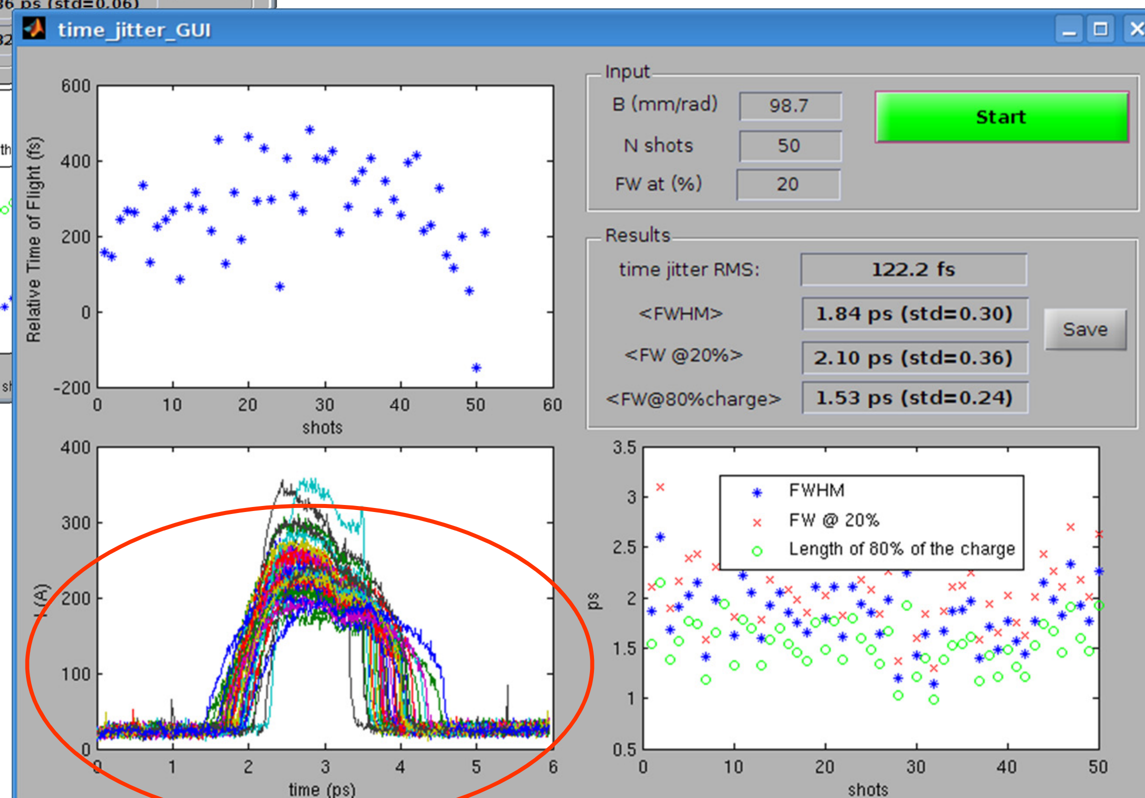
Beam compression

FERMI @elettra



Without X-band



With X-band at -17.5 MeV

Summary

- Completed four structures by now
- Structure #1 developed internal kinks (lateral shifts between substacks) of few hundred microns, so preparing to launch fabrication of another 1-2 structures
- Looking forward to
  - Commissioning of structures at PSI injector in summer
  - First results using the wake field monitors
  - Breakdown results at CERN

Thanks a lot!