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Multi Purpose X-band structure fabrication and testing first practical experiences

M. Dehler, A. Citterio, R. Zennaro

Paul Scherrer Institut

A. Grudiev, G. Riddone, J. Shi, D. Gudkov, A. Samoshkin, W. Wuensch

CERN

G. D'Auria, C. Serpico

Sincrotrone Trieste

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General overview

Goal: a multi purpose accelerating structure in X band

Motivations:

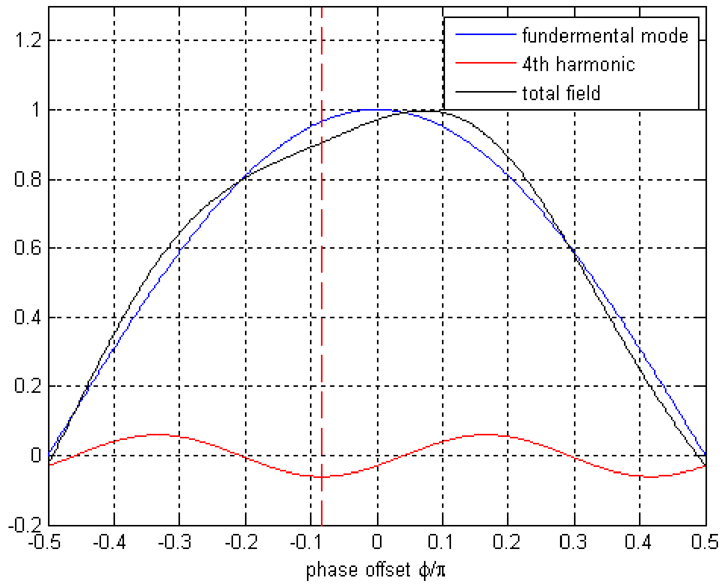
- A different type of structure to be used in the high gradient test program
- Validation of design and fabrication procedures at CERN
- Get X band technology into the main stream
- Practical application: FEL projects SwissFEL and FERMI need higher harmonic X band structure to compensate long. phase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

On linearization of long. phase space

Removal of quadratic component from RF curvature:

$$V_X = -V_S \left(\frac{3\ \mathrm{GHz}}{12\ \mathrm{GHz}}\right)^2 \cos(\varphi_S)$$

with x-band on-crest – this can be changed for fine tuning of compression.



2. Compensation of the quadratic contribution to the path length through the chicane

$$\Delta s = R_{56} \cdot \delta + T_{566} \cdot \delta^2 + \ldots$$

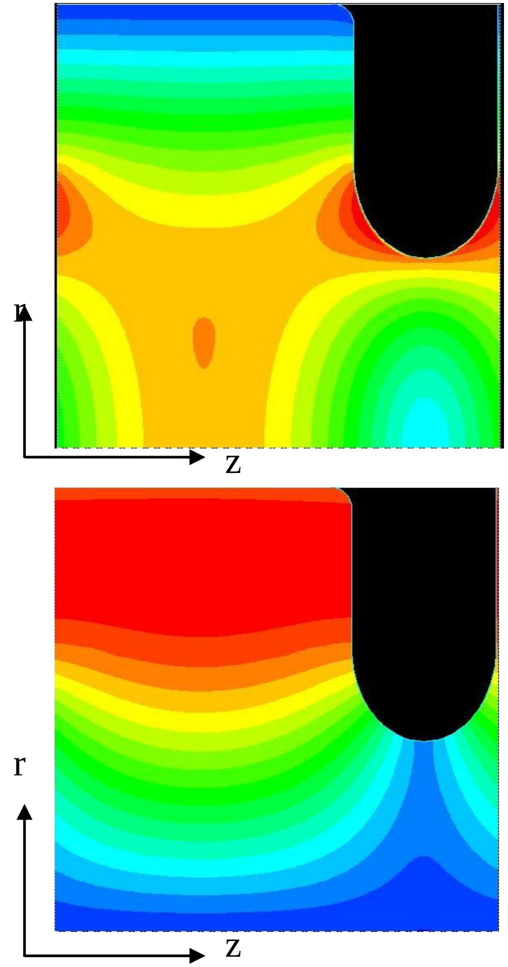
Court.: B. Beutner

Special considerations for FEL application

- 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



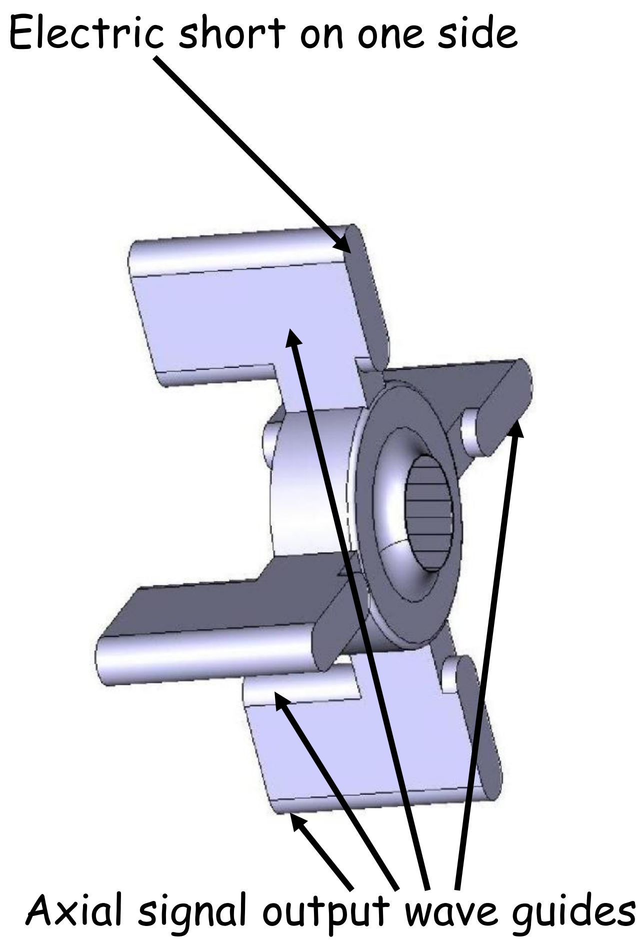
Up- and downstream HOM coupler a la NLC DDS

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

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

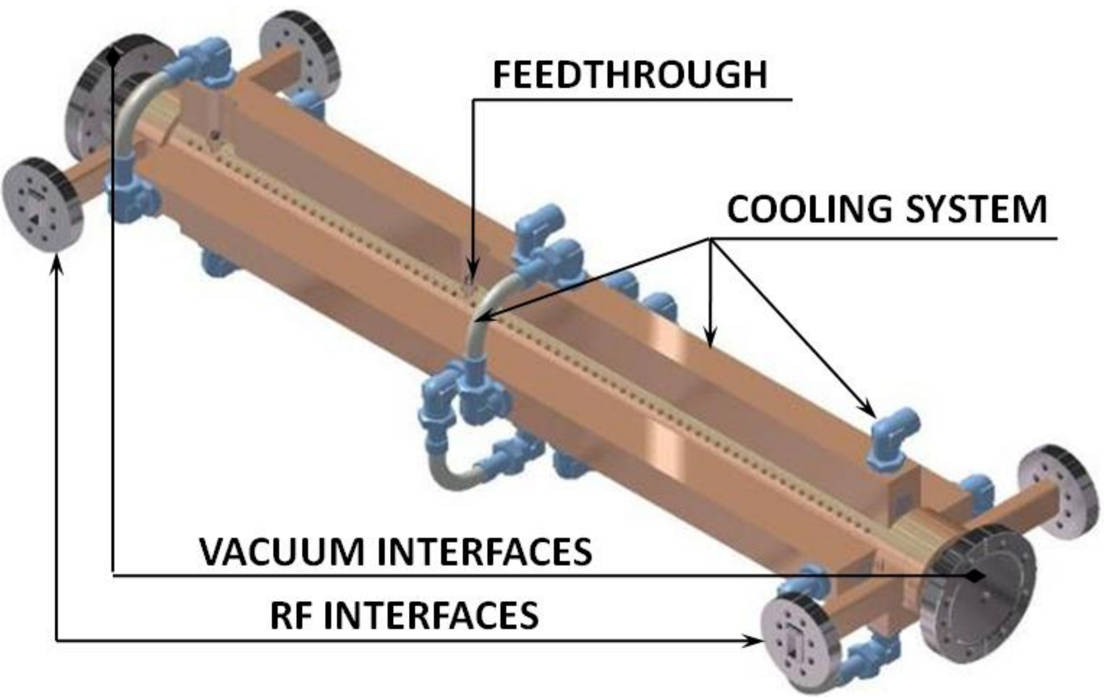
Minor loss in fundamental per-formance: 10% in Q, <2% in R/Q

Output wave guides with coaxial transition connecting to measurement electronics

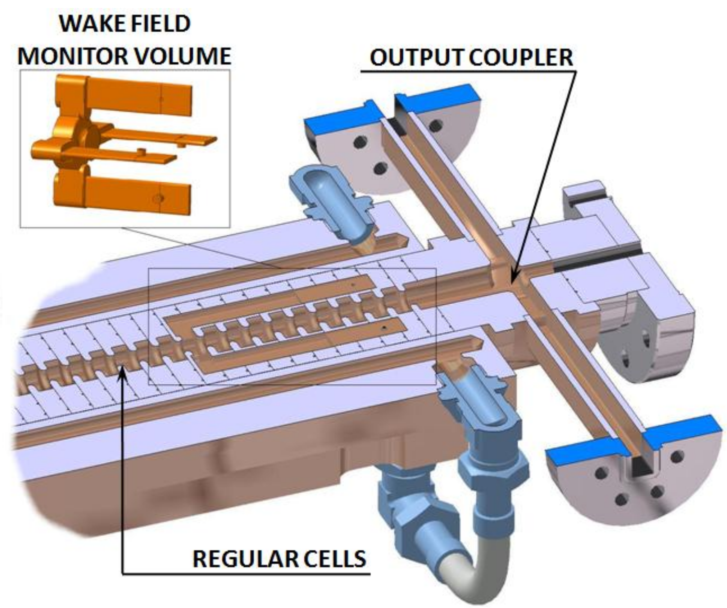


Mechanical model

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



Wakefield monitor details



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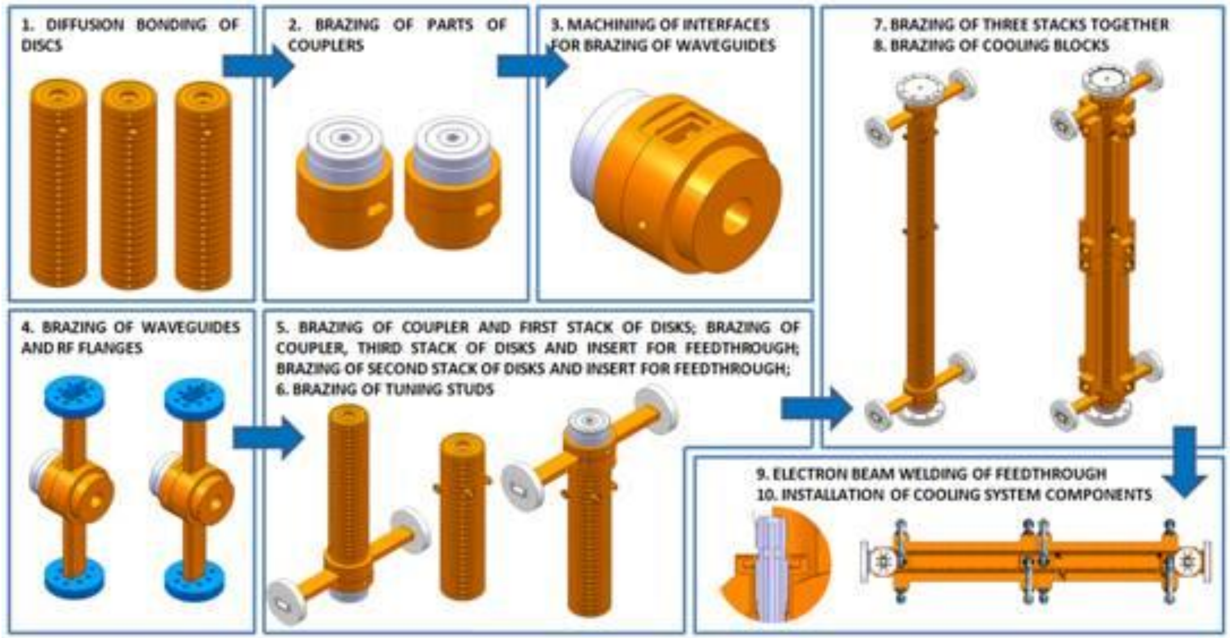
Fabrication

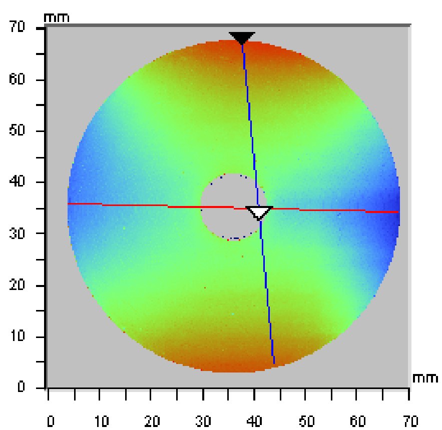
- Prefabricated parts
  - High precision machined disks (VDL/NL)
  - Vacuum feedthroughs with special mounts (OMW, Japan)
- Assembly
- Bonding (SLAC recipe)
- Brazing

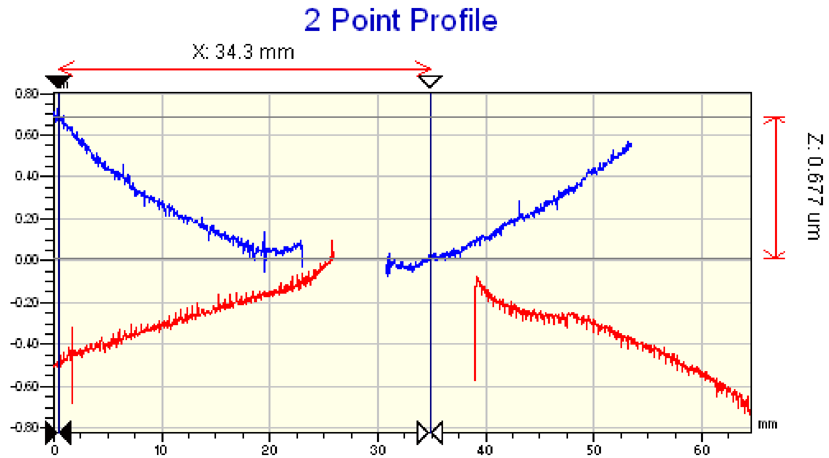


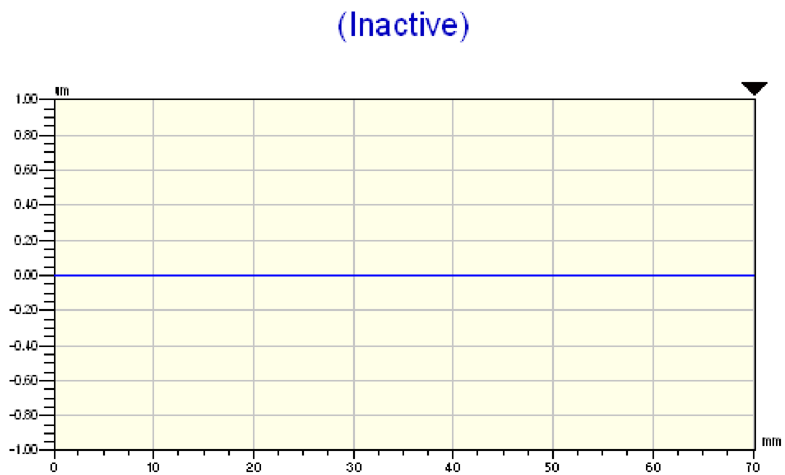
- Hydrogen bake out

Prototype disks

Flatness profile







Title: CLIAPSI-0001

Note: Disk 2-46

Court.: Didier GLAUDE

Testing bonding procedure for short stack done with prototype disks

Bonding at 1040°C for 90 minutes under H_2

Metallurgical polishing + etching 75 s in Ammonium peroxodisulfate $(NH_4)_2S_2O_8$

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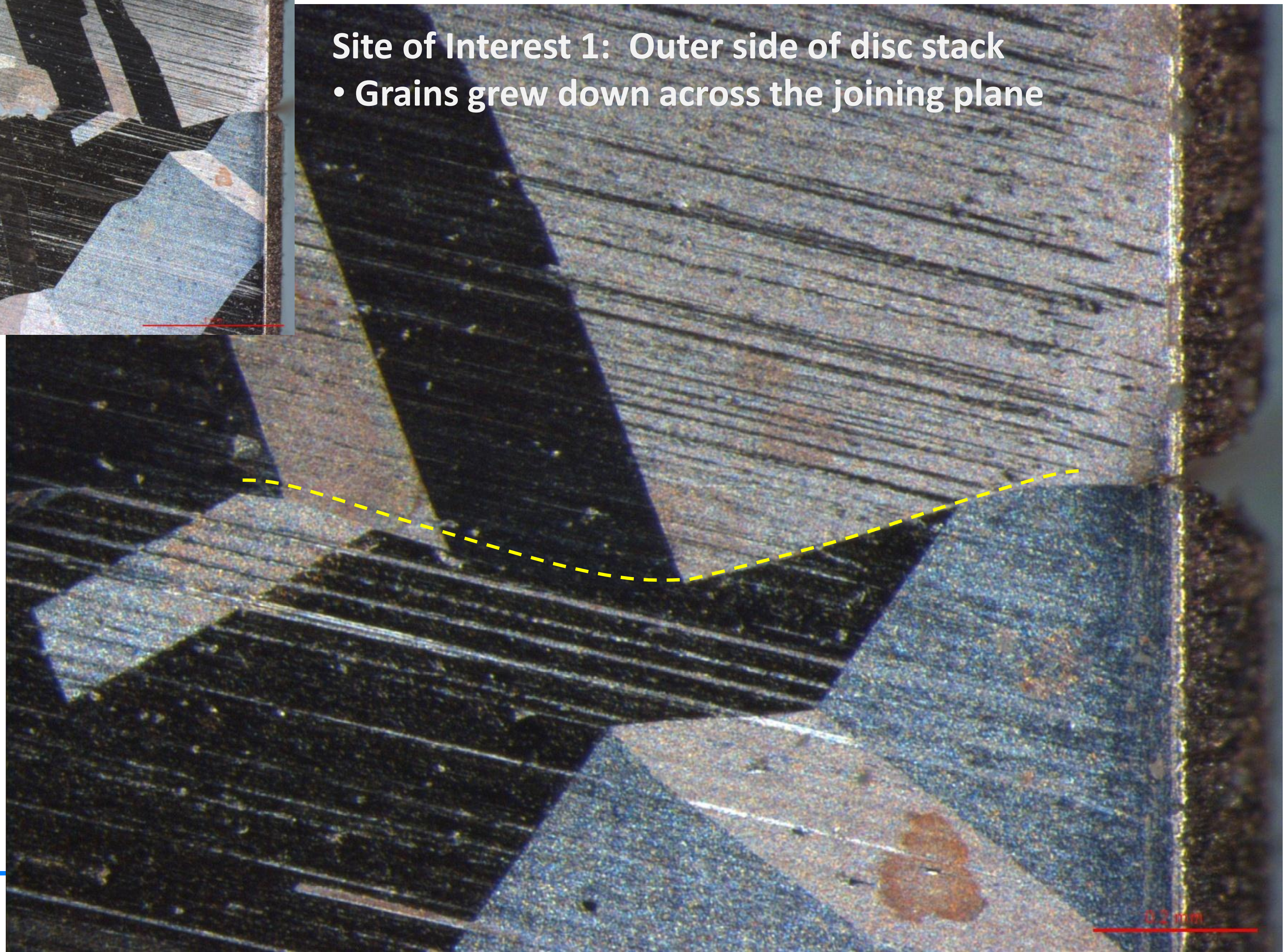
(Court.: Markus AICHLER)

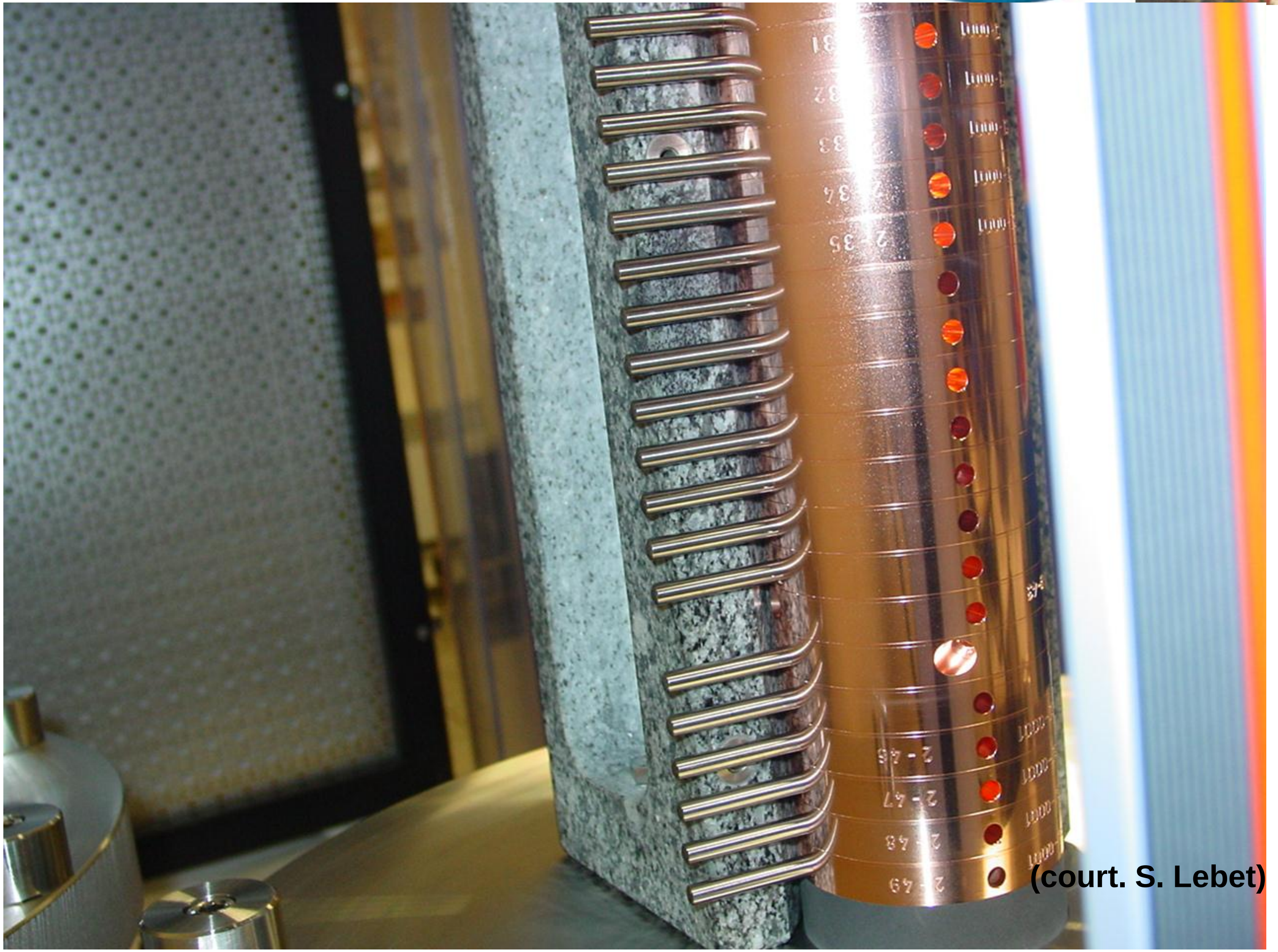
Site of Interest 1: Outer side of disc stack

- Grains grew down across the joining plane



Joining plane

Assembly structure for bonding

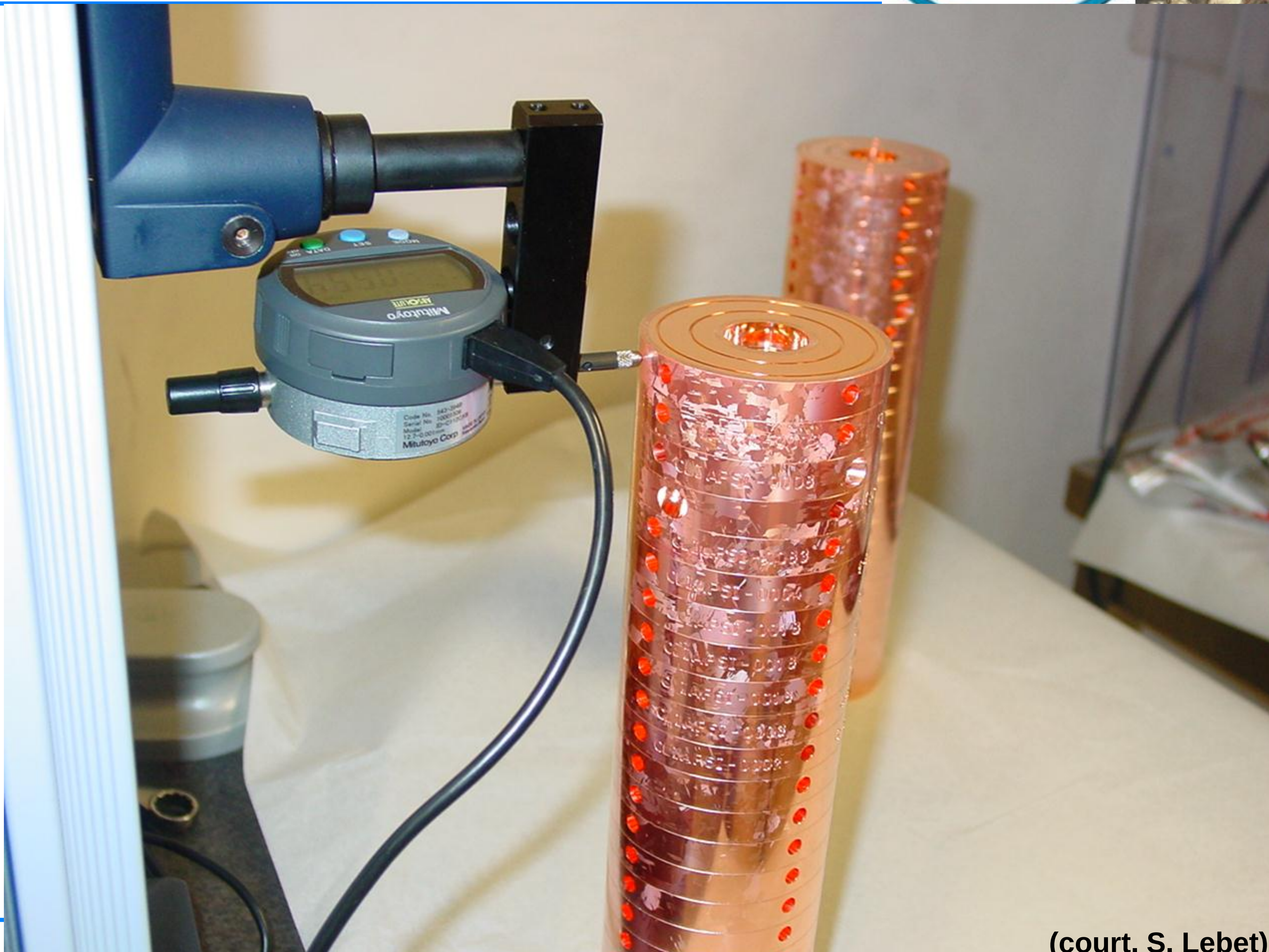


(court. S. Lebet)

3 substacks ready for bonding

(court. S. Lebet)

Straightness check after bonding



(court. S. Lebet)

Hydrogen bake out (COMEB, Italy)

Low Level RF tests

- Measurement of assembled, unbonded stack showed no critical deviations
- Before discussing tuning results after bonding and brazing, what should we expect?

RF match of assembled, unbonded structure

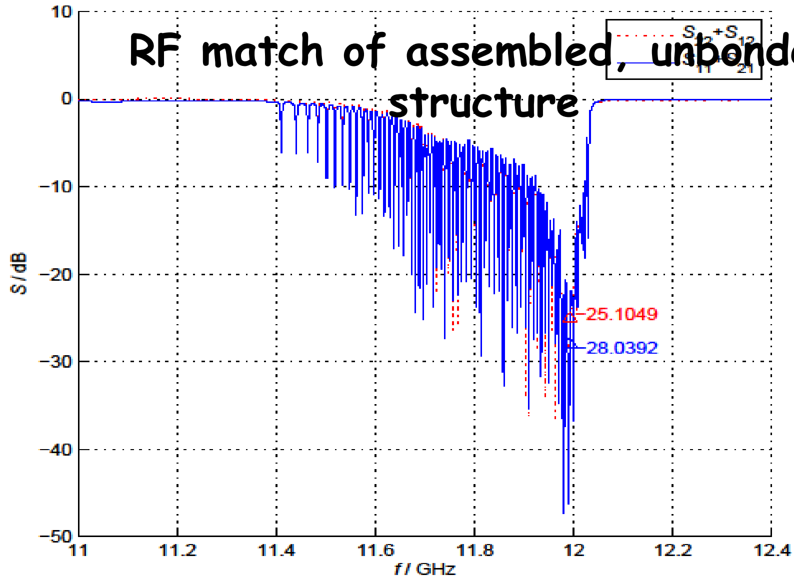


Figure 1: Reflection at input

(court. J. Shi)

2

The accelerating mode

66 cell substructure:

Omit power couplers, matching cells

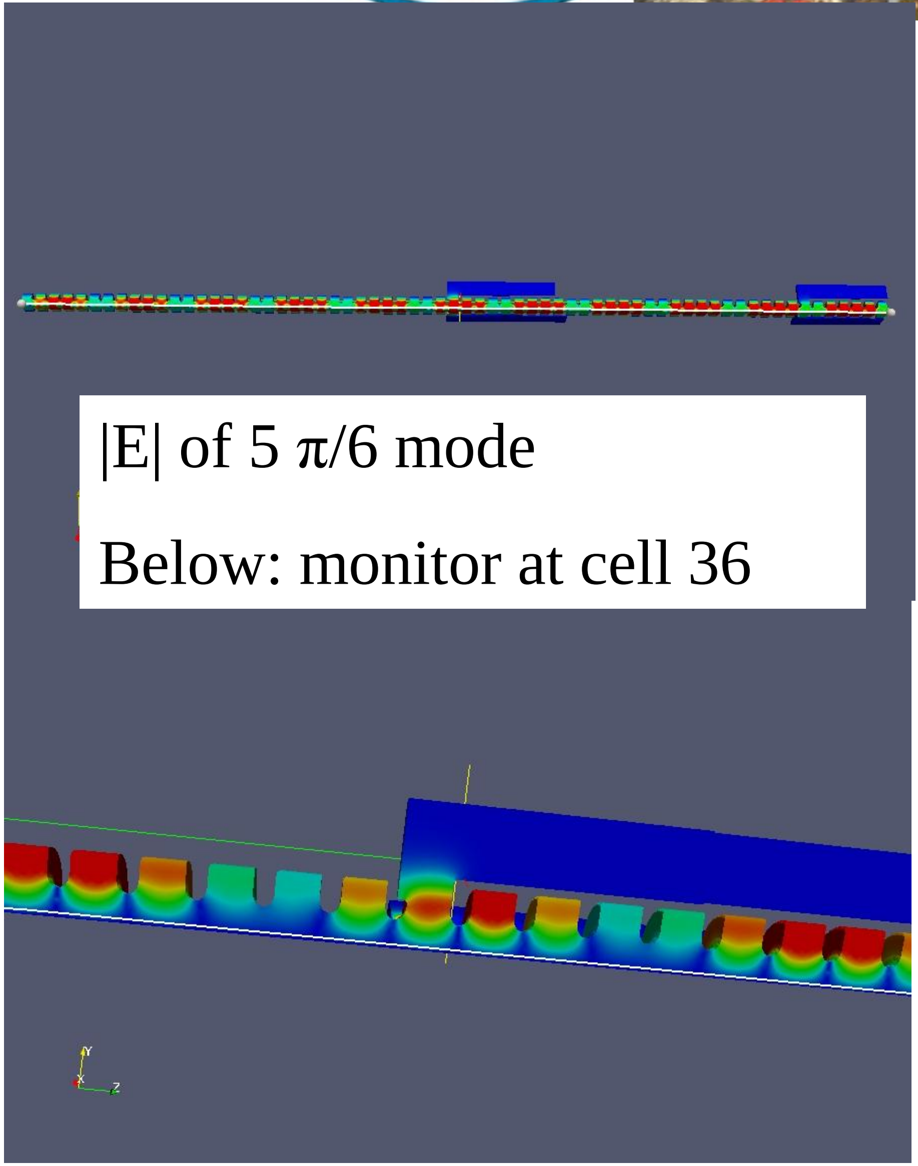
500'000 elements, 10'000'000 unknowns (3rd order approach required)

Computed resonance frequency:

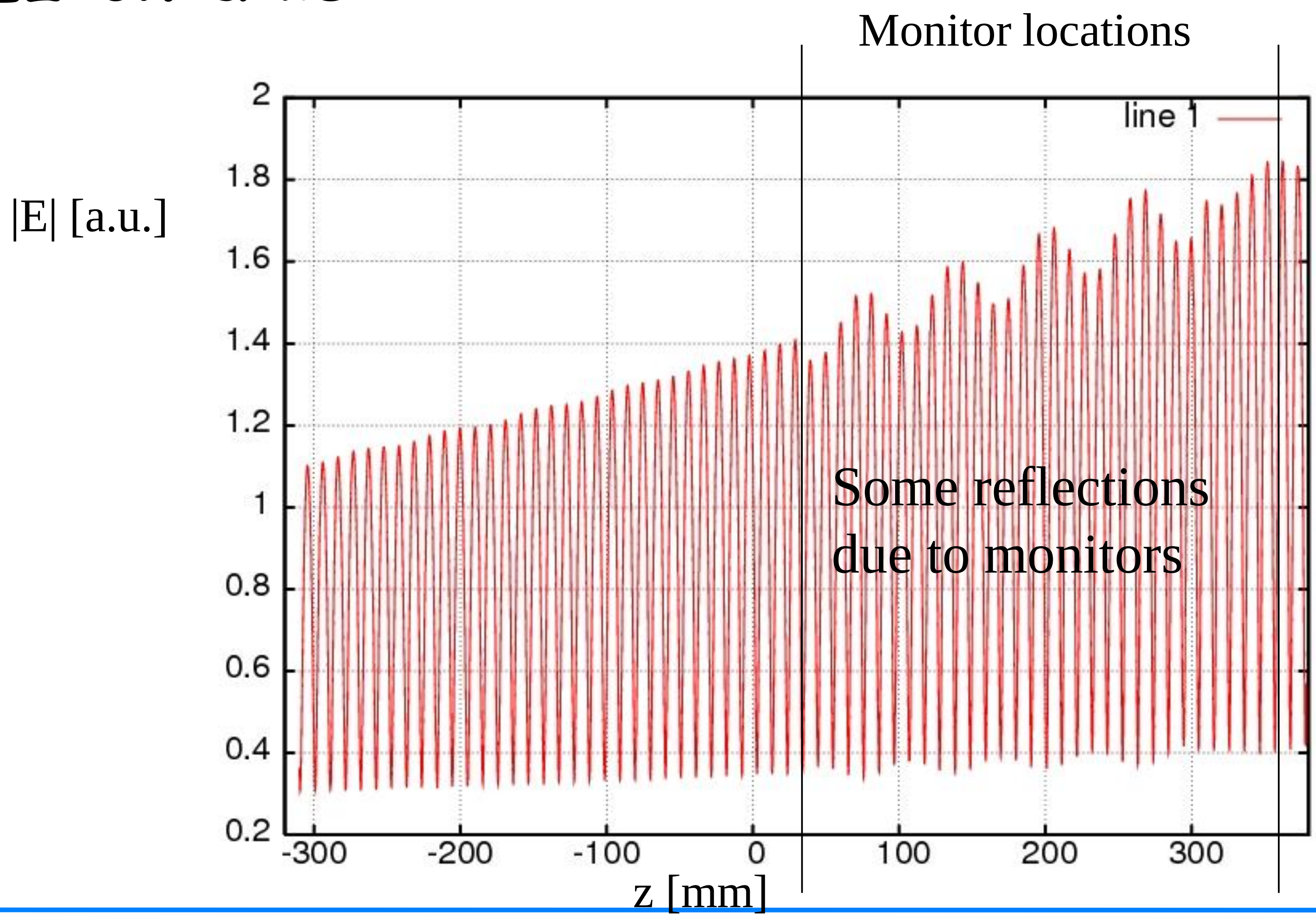
F = 11.99235 GHz (w/o losses)

~ F=11.9912 GHz (including losses)

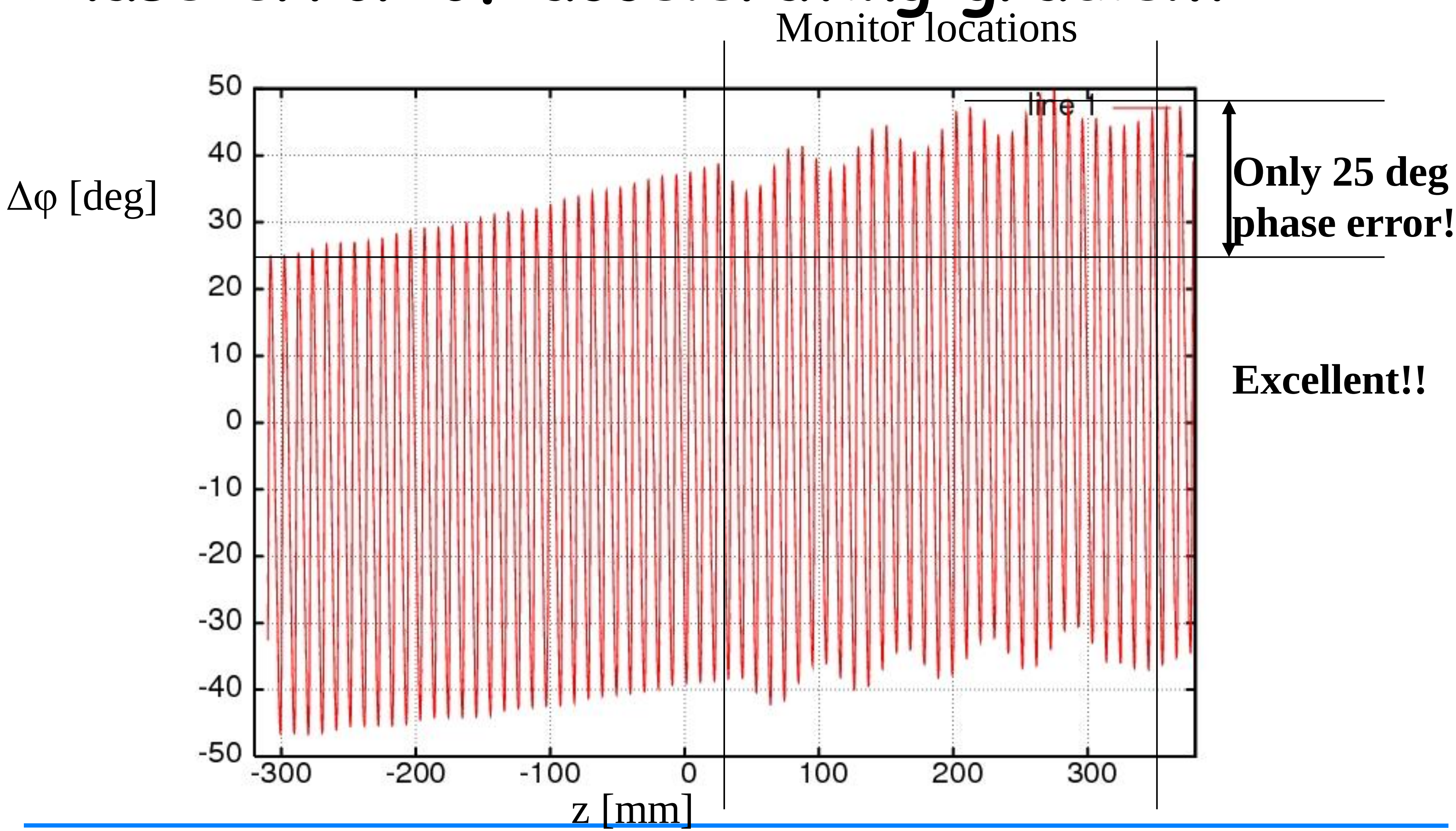
Design: F=11.991648 GHz



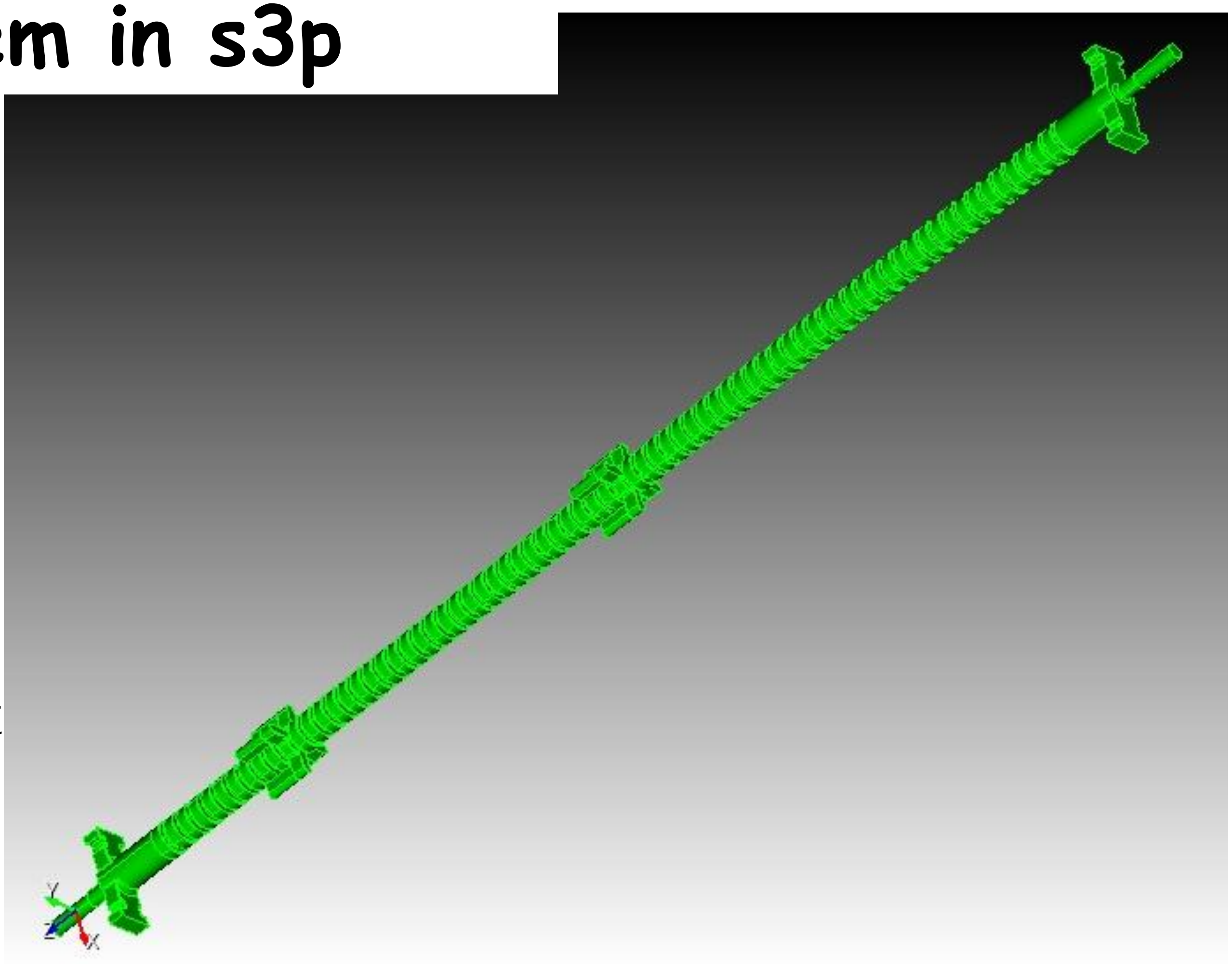
Ez on axis


Monitor locations
|E| [a.u.]
line 1
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
-300
-200
-100
0
100
200
300
z [mm]
Some reflections
due to monitors

Phase error of accelerating gradient

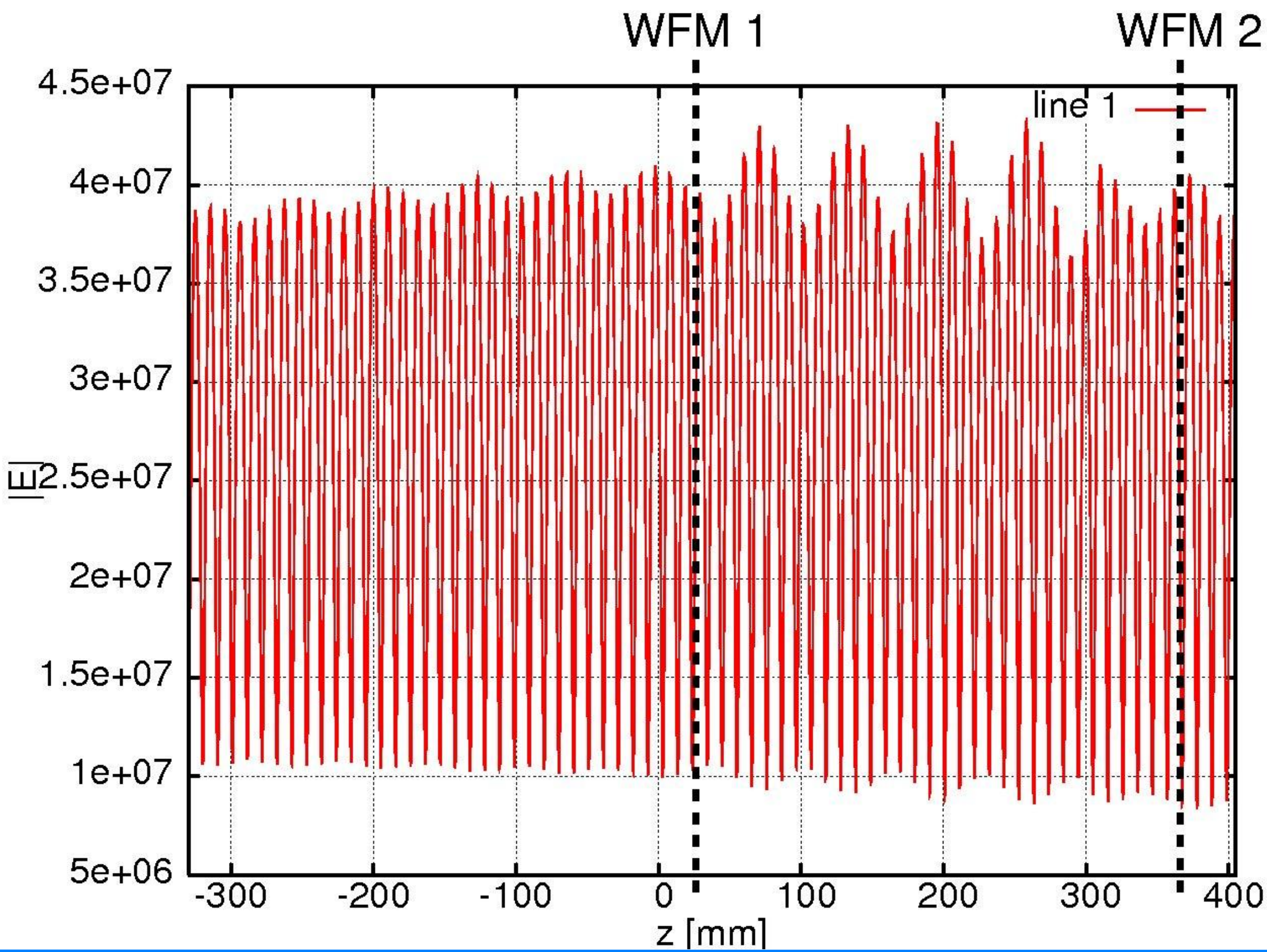


Driven problem in s3p



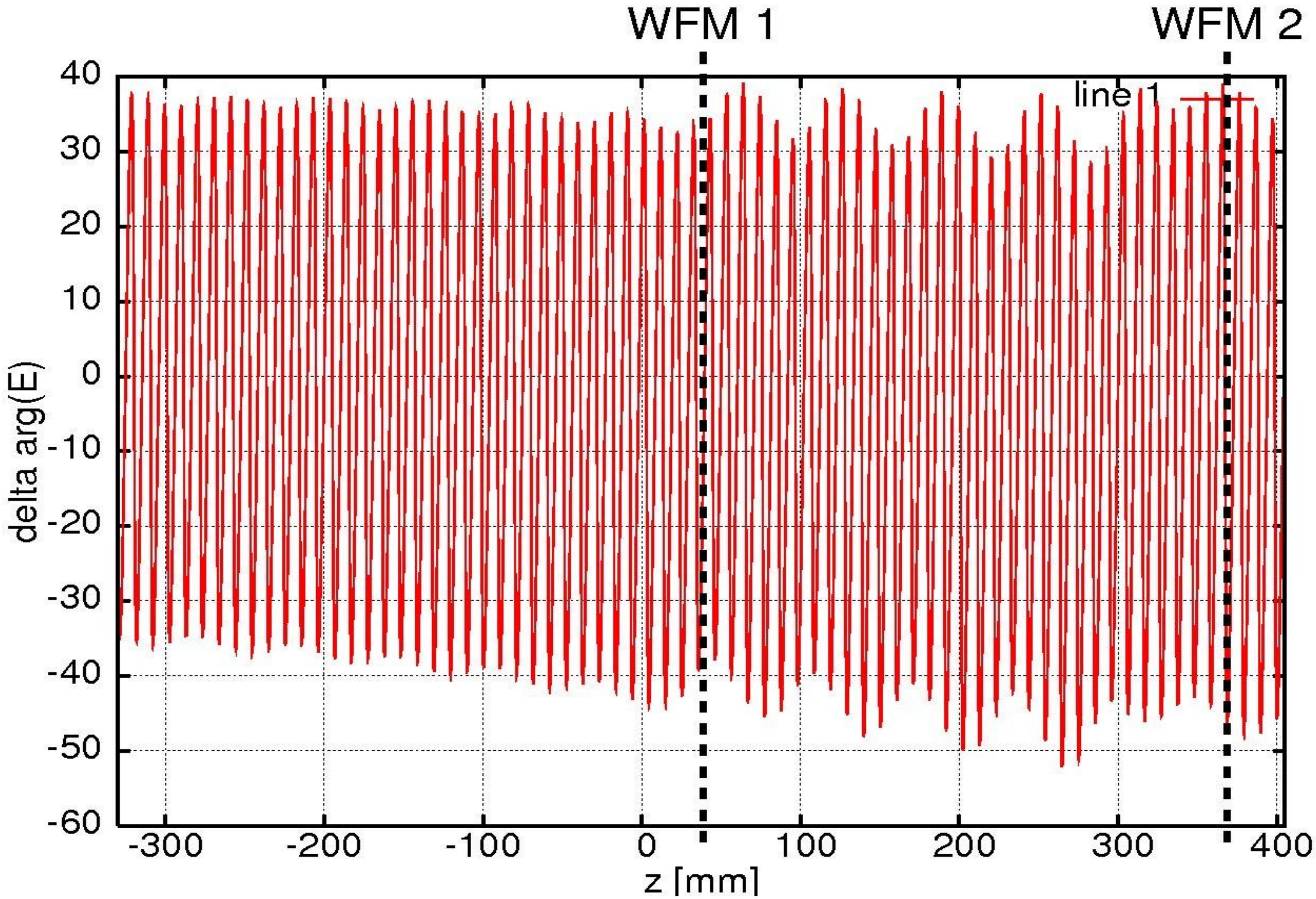
- Include matching cells and power couplers
- Include conduction losses
- Using 2nd order elements (somewhat higher numerical error)

Ez on axis



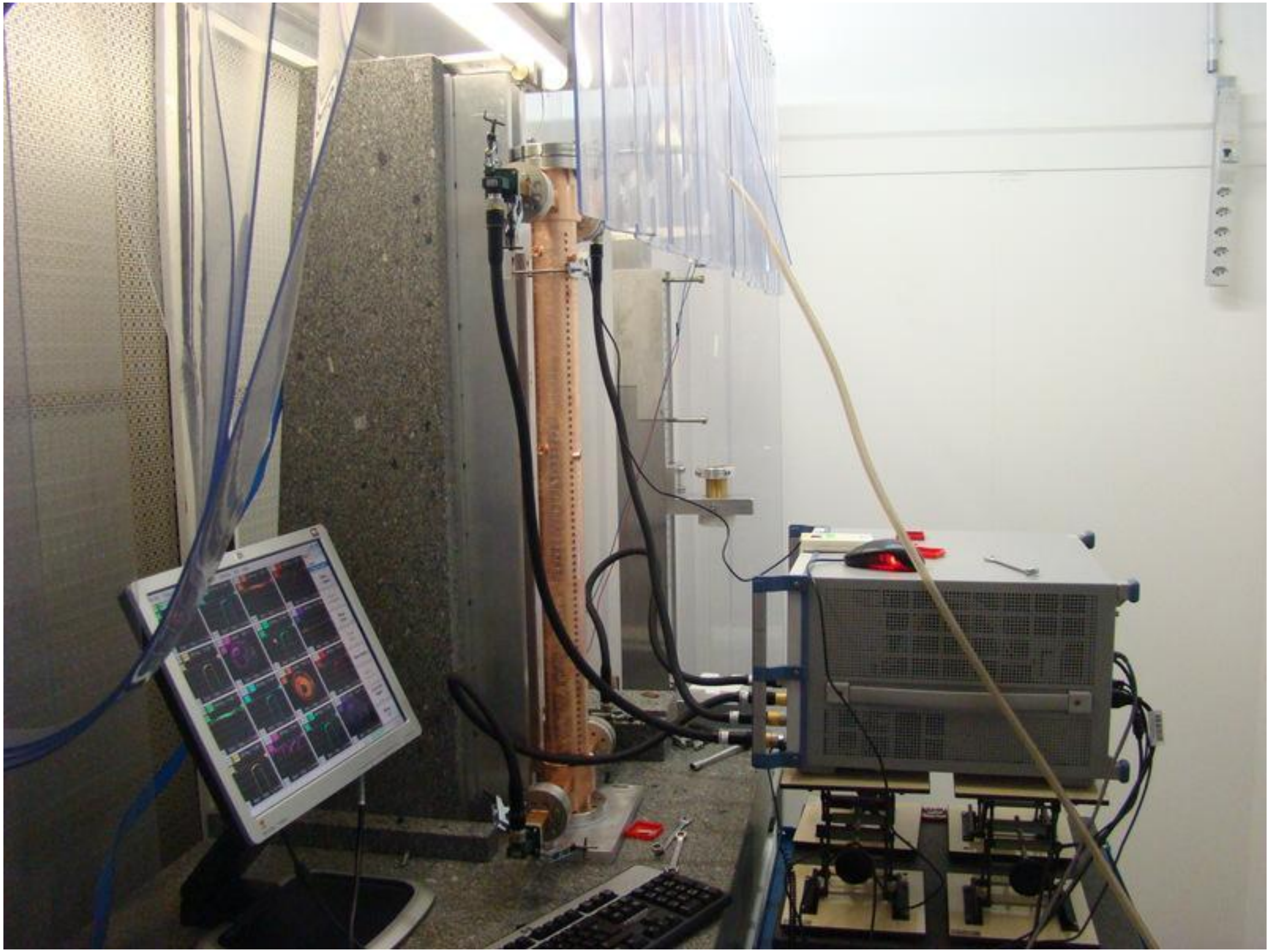
WFM 1
WFM 2
4.5e+07
4e+07
3.5e+07
3e+07
2.5e+07
2e+07
1.5e+07
1e+07
5e+06
|E|
line 1
-300
-200
-100
0
100
200
300
400
z [mm]

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]

Tuning setup



Input reflection before tuning

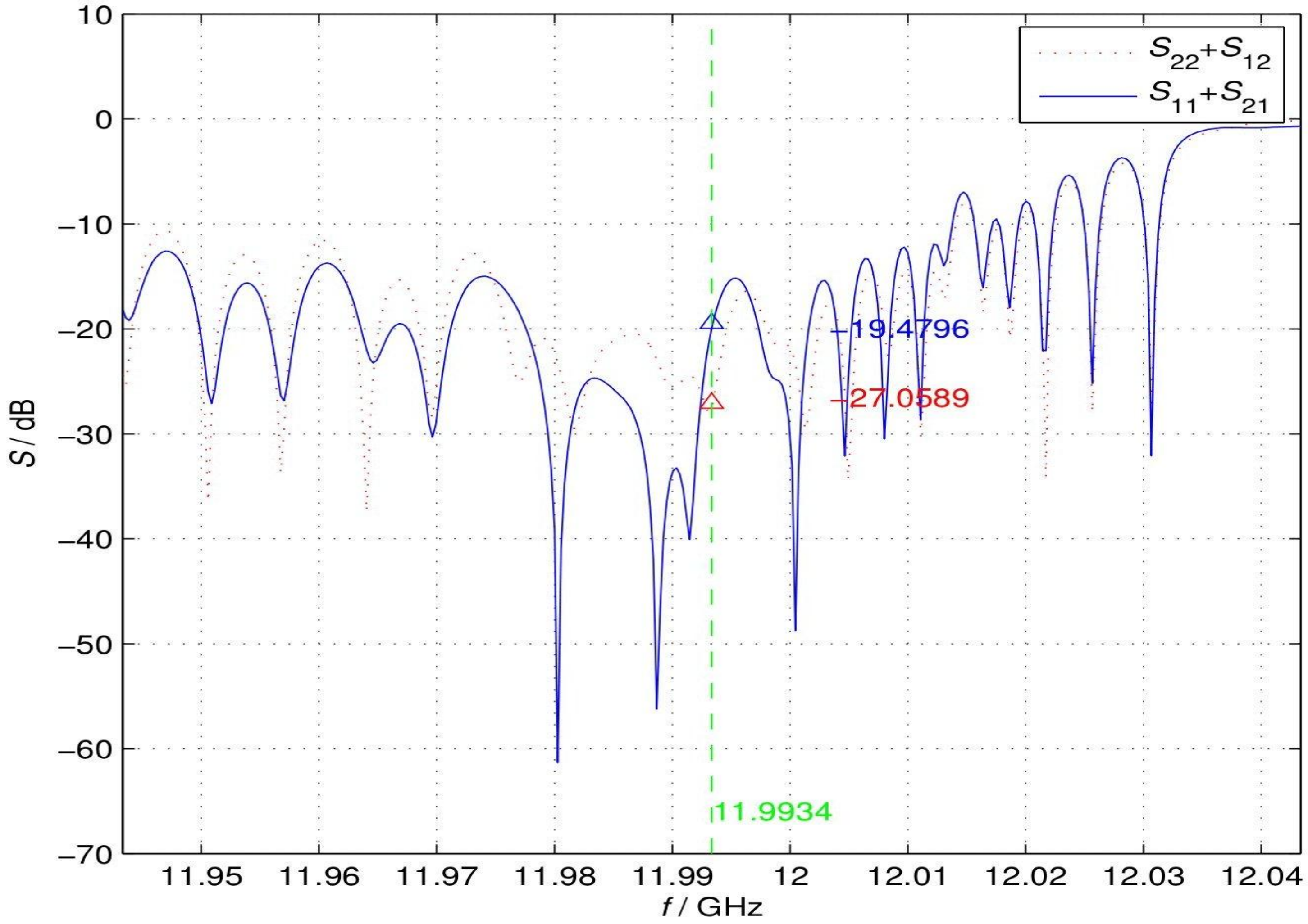
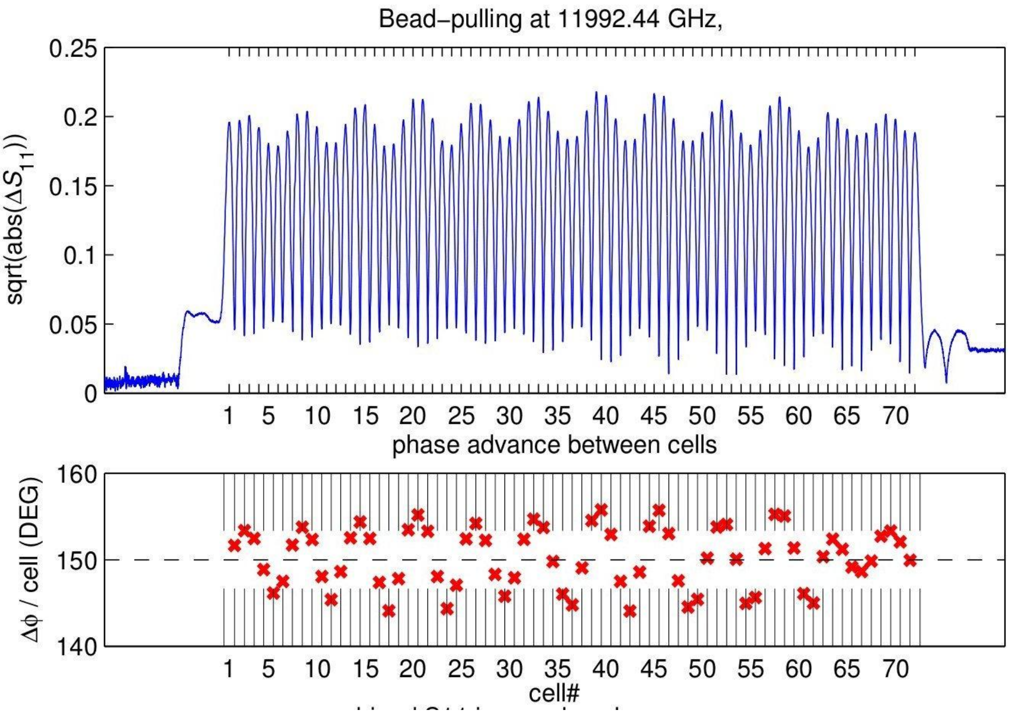


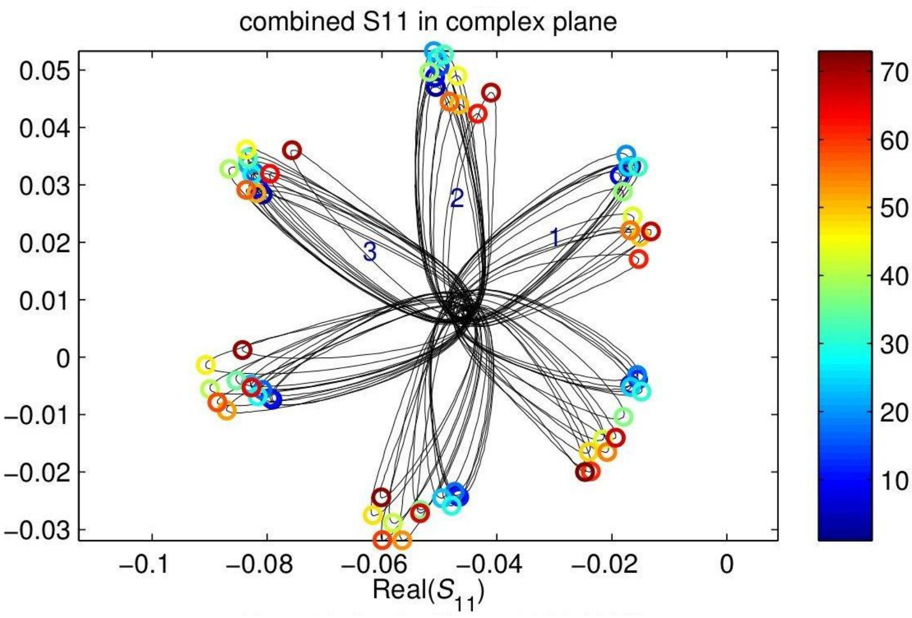
Figure 6: Reflection at input

Wire measurement before tuning (structure N1)

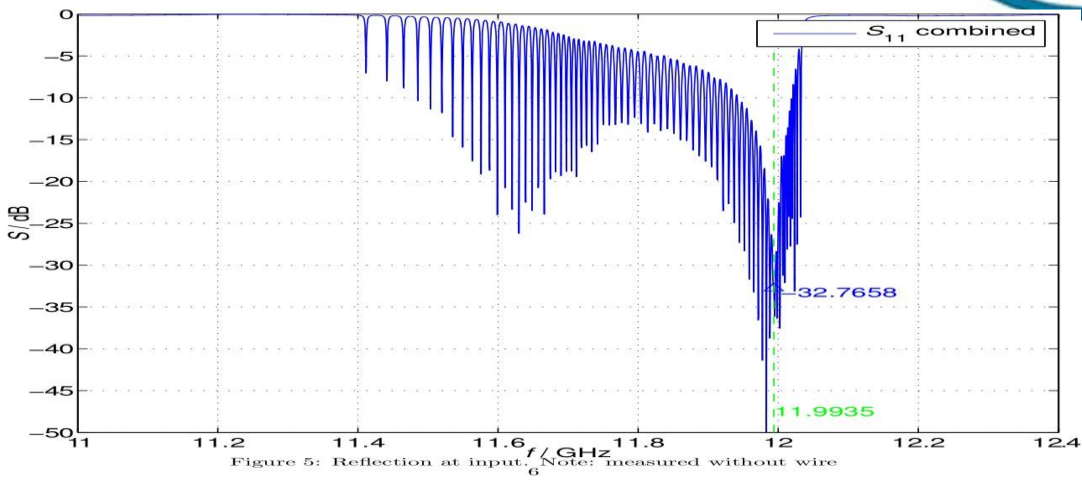
Frequency systematically too low by 1 MHz

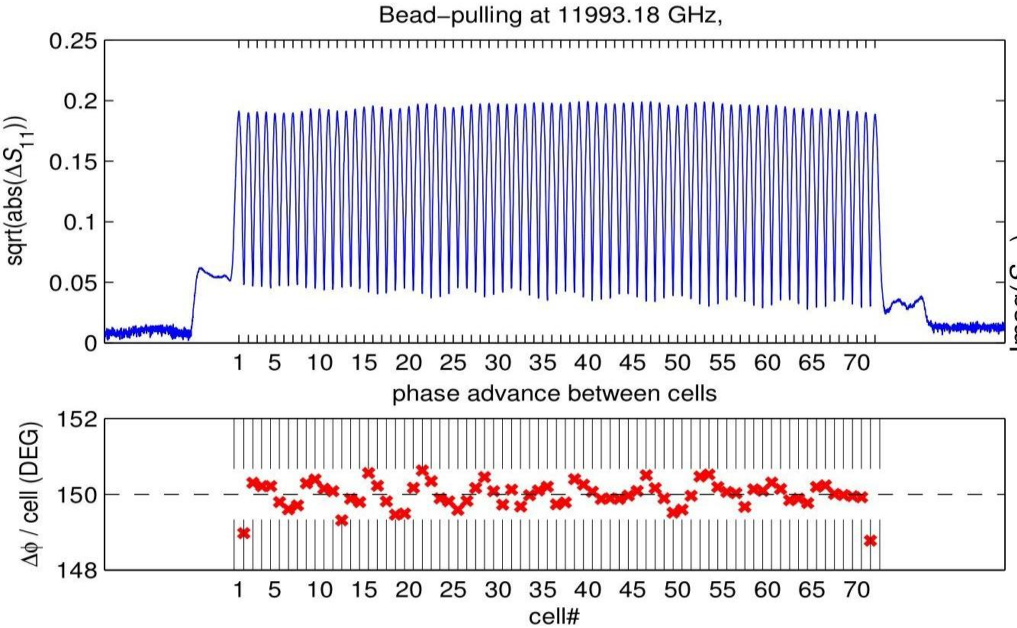
Very consistent in amplitude and phase advance

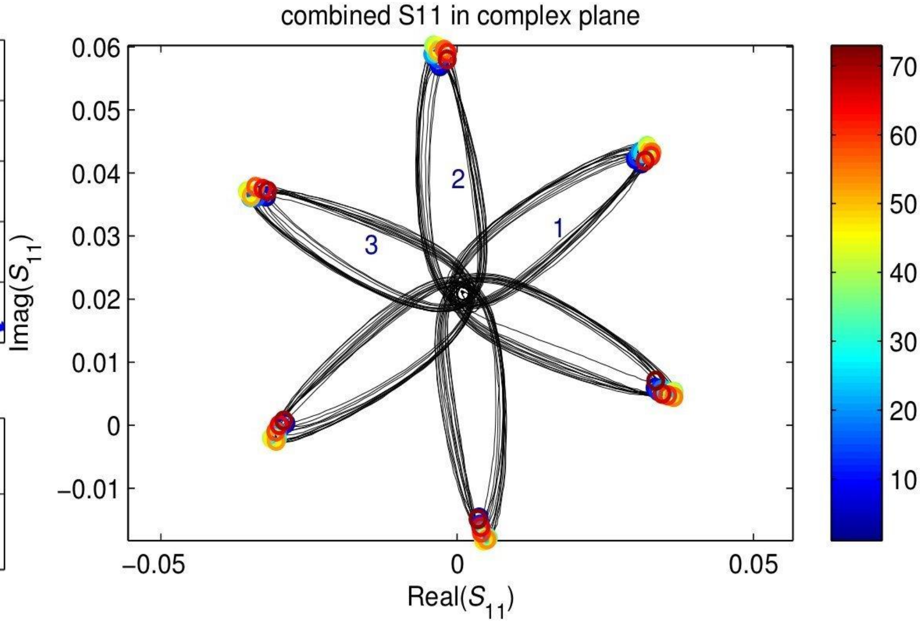




Wire measurement after tuning (structure N1)







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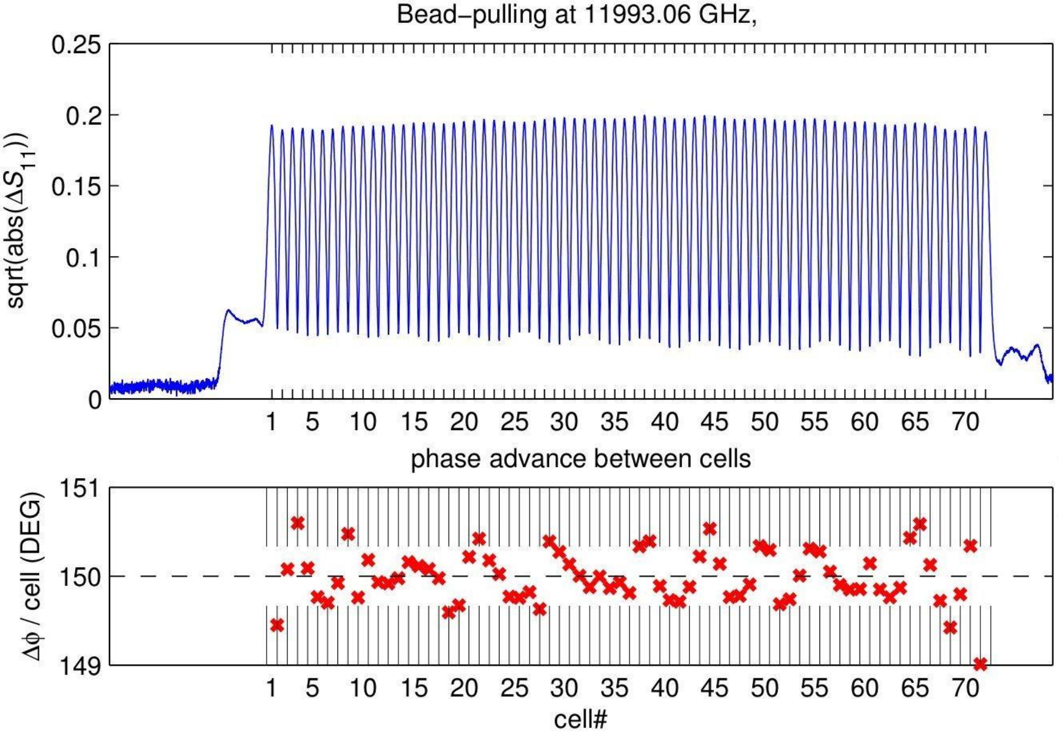
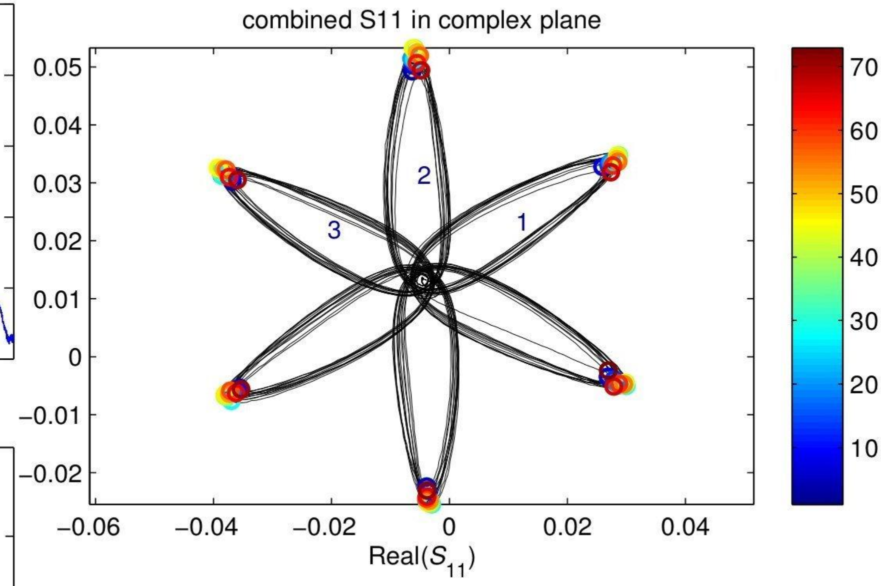
Wire measurement after tuning (structure N2)





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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
- Commissioning of first structure and first experiences with beam at FERMI → Talk of G. d'Auria!
- Looking forward to
  - Commissioning of structures at PSI injector in summer
  - First results using the wake field monitors

Thanks a lot!