5th Annual Workshop: Physics at the Terascale

Bonn, 8 December 2011

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Bunch by Bunch Feedback (FB) in a Fast Ramping Storage Ring

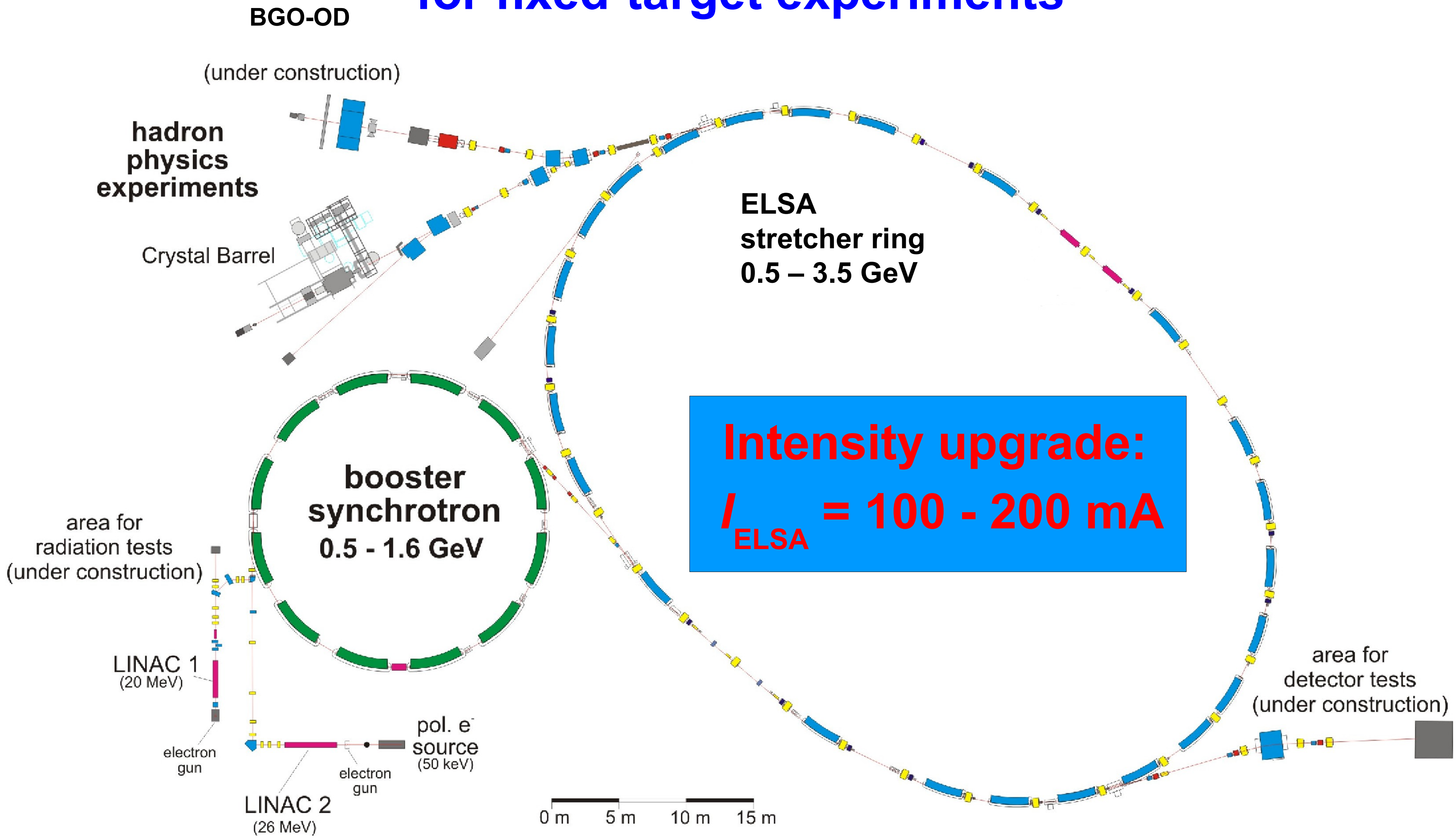
ELSA beam current upgrade

Setup & installation of FB at ELSA

Operation during energy ramp

Conclusion & outlook

1.2 – 3.2 GeV (polarized) electron beam of 15 – 20 mA for fixed-target experiments



Intensity upgrade:

I_{ELSA} = 100 - 200 mA

Coherent bunch oscillations:
longitudinal & transversal multibunch instabilities

➡ Limitation of storable beam current and beam quality

- Harmful HOMs of 2 installed five-cell 500 MHz PETRA cavities: longit. coupled-bunch mode 252 observed above 15 mA

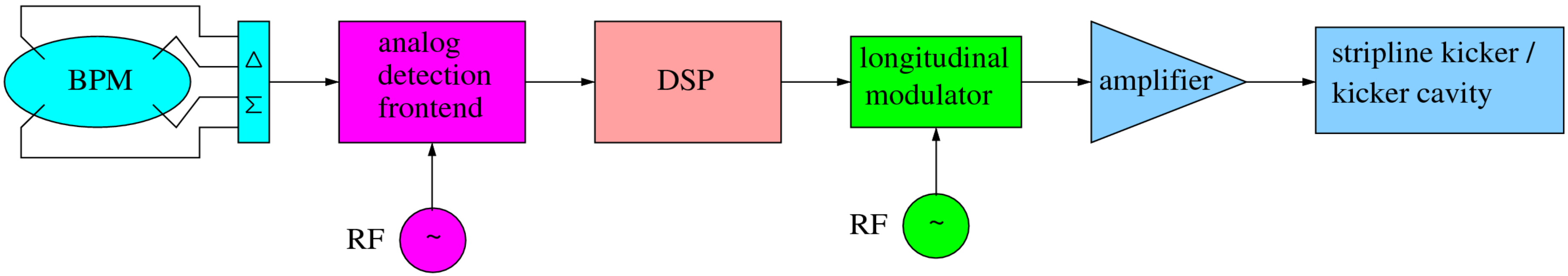
- Instabilities (transversal) driven by:
  - vacuum chamber: resistive wall, discontinuities
  - residual gas: ions

➡ Counteractions:

- Temperature stabilization system for cooling circuit of PETRA cavities

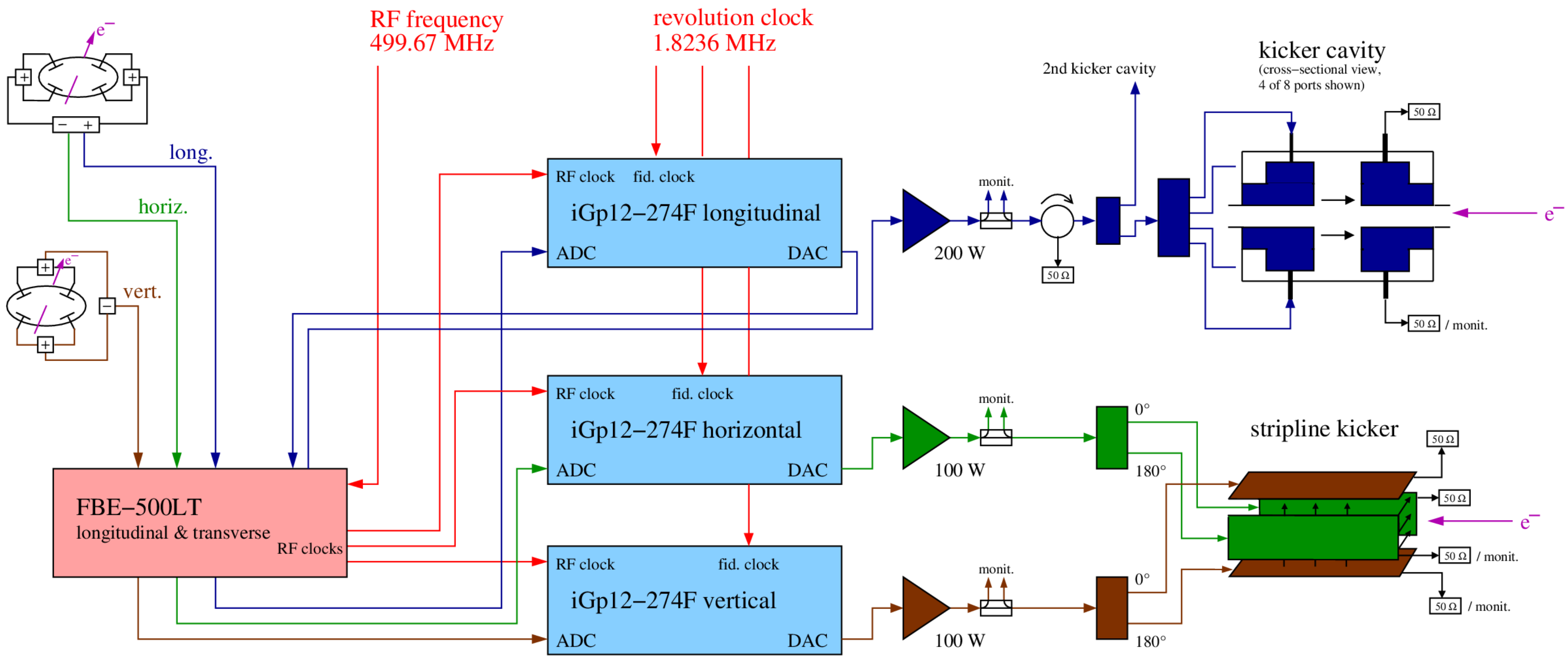
- Active damping of instabilities: bunch by bunch feedback (FB) system

Bunch-by-bunch feedback systems
analog bandwidth: f_{RF} / 2 = 250 MHz



1. **Detection of displacement of each bunch via Σ- & Δ-BPM signals**
2. **Front-end: phase (longitudinal) & amplitude (transversal) demodulation via mixing with 3rd RF harmonic**
3. **Digital signal processing at 500 MHz: Bunch-by-bunch digital bandpass filter at f_{syn}, f_{β}**
4. **Longitudinal back-end: upconversion to 1 GHz**
5. **Powerful damping via broadband amplifiers & kickers, longitudinal: kicker cavity, transversal: stripline kicker**

System layout of 3d FB at ELSA



Electronics is commercially available: DIMTEL

- front-/back-end: 3 wideband RF channels

- 3 DSP units: FPGA platform, 12-bit ADC, FIR filter (≤ 32 taps), 14-bit DAC; timing, phase adjustment, filter generation & data acquisition via EPICS

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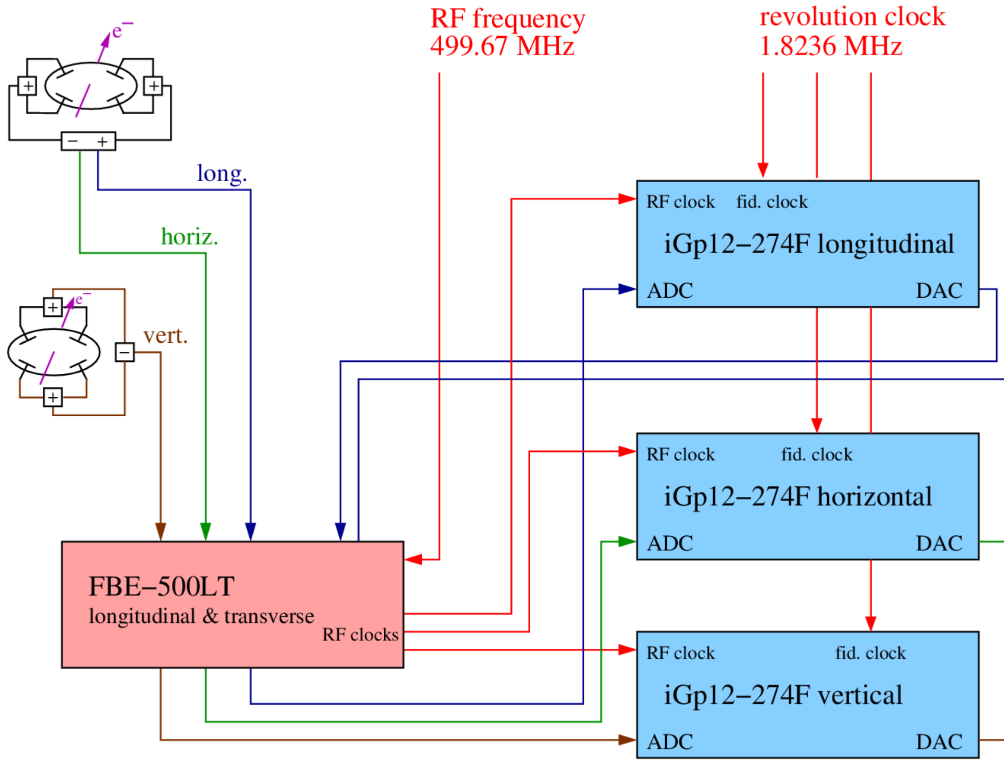

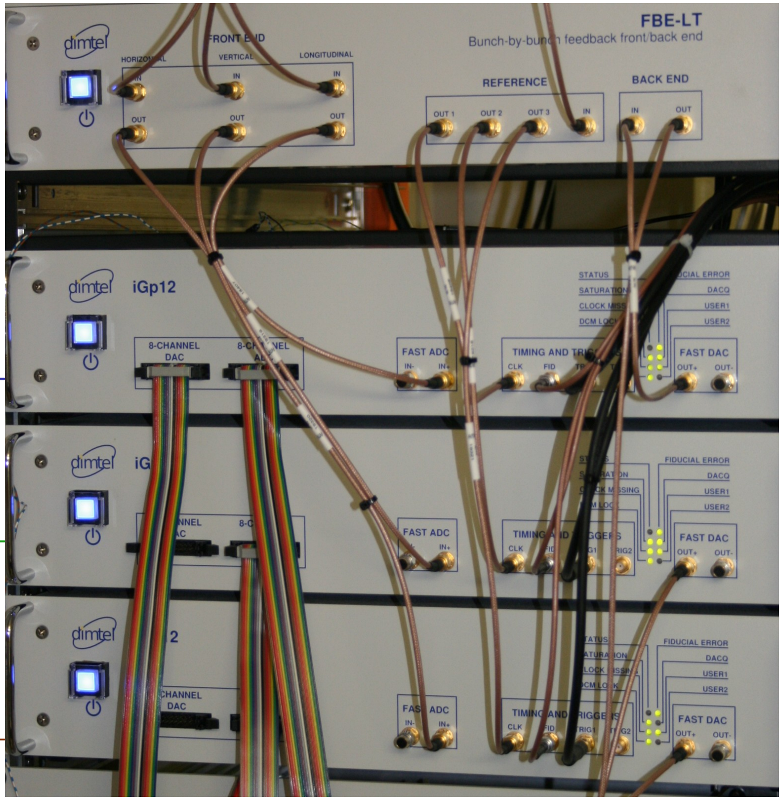

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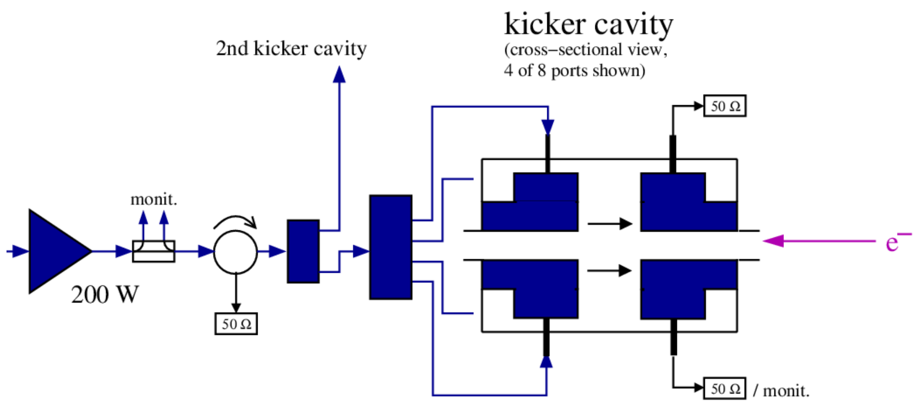
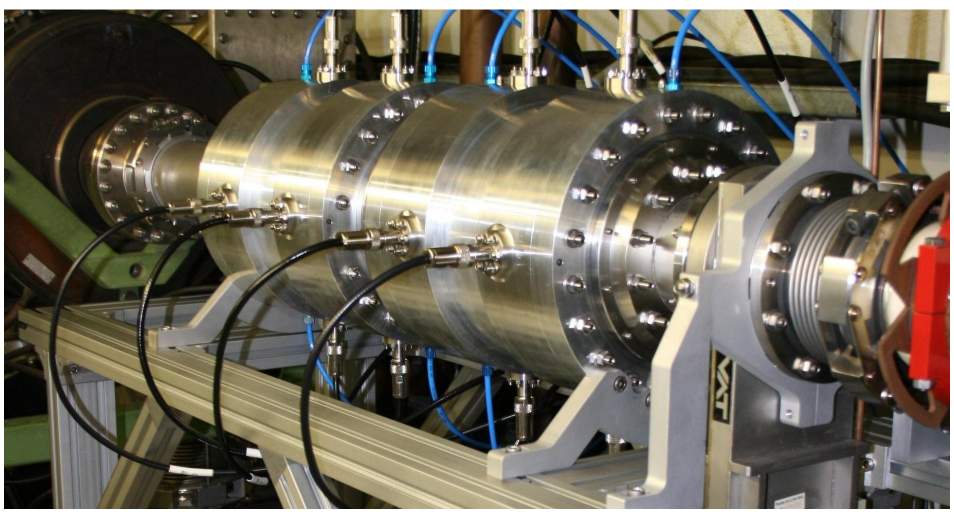
Broadband kickers - longitudinal

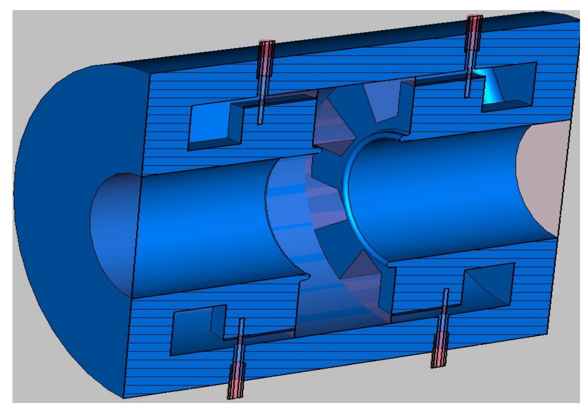


2 kicker cavities:

- 4 input & 4 output ports
- f_{cent} = 1.125 GHz
  bandwidth at least: 250 MHz (Q_L = 4.5)
- one 200 W 1-2 GHz amplifier



Simulation with CST Microwave Studio & In-house fabrication



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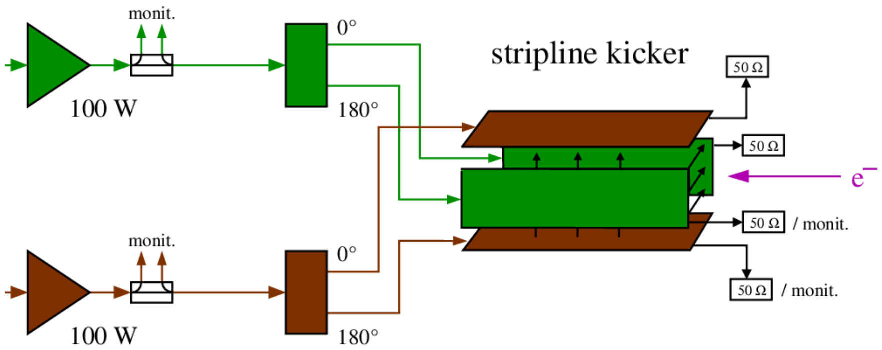
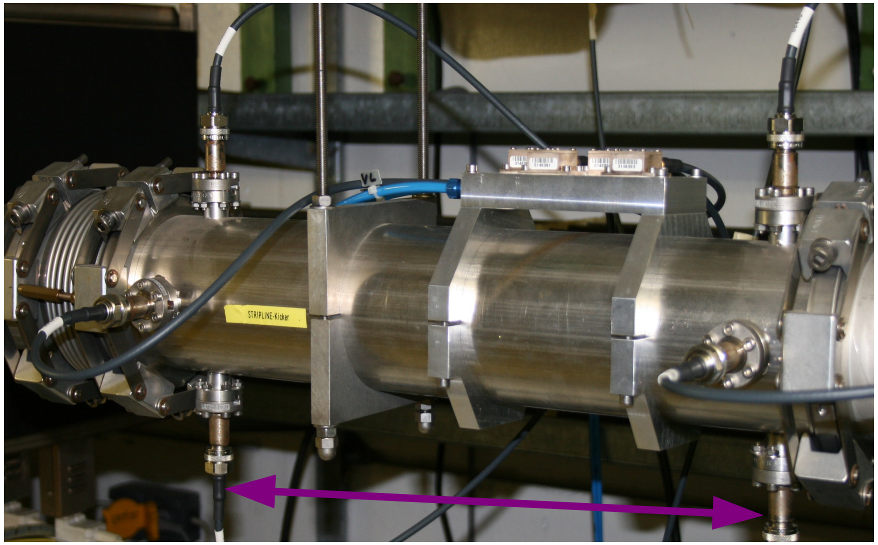
Broadband kickers - transversal

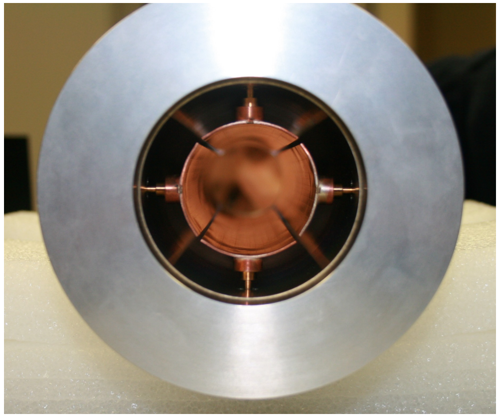




43 cm

Existing kicker with horizontal & vertical striplines, driven using two 0° / 180° splitter & 100 W 10 kHz – 250 MHz amplifiers

2012: Installation of new kicker with larger bandwidth (striplines: 30 cm)



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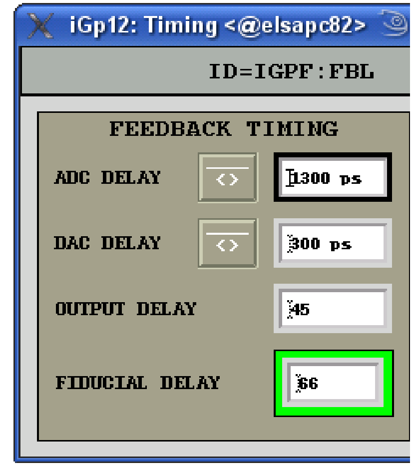
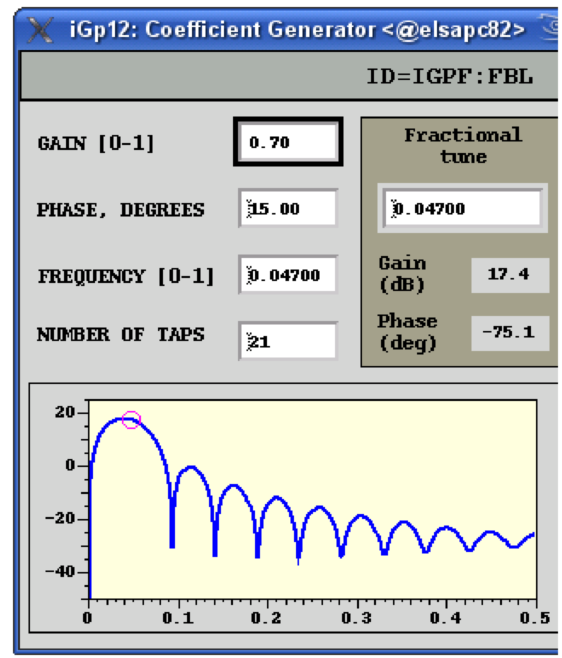
Timing & closing of (longitudinal) FB loop

ELSA storage mode, constant energy:

- **Adjust front-end phase for phase demodulation**
- **ADC delay (1 - 2000 ps) for maximum input signal**
- **Via internal frequency generator (DC - 250 MHz):**
  excitation of one bunch with f_{syn} (86 kHz)
- **Observe response of the same bunch &**
  optimize output delay (1-274 buckets),
  DAC delay (1 - 2000 ps) & back-end phase
  for maximum kick and isolation between bunches
- **FIR-bandpass filter at f_{syn} ,**
  π/2 phase shift required for resistive feedback,
  (phase-energy relation in longit. phase space)





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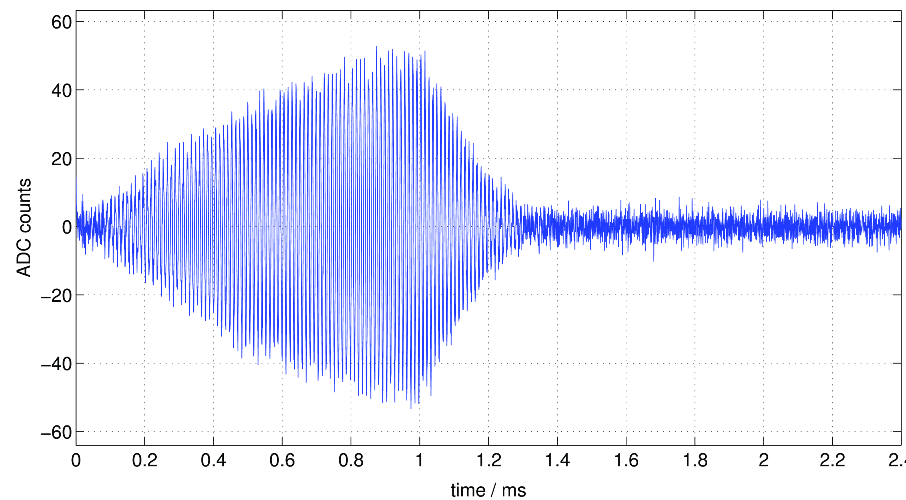
Drive-damp measurement longitudinal FB

Storage ring operation of 10 mA

at 2.35 GeV, beam is stable

longitudinal turn-by-turn ADC-data of

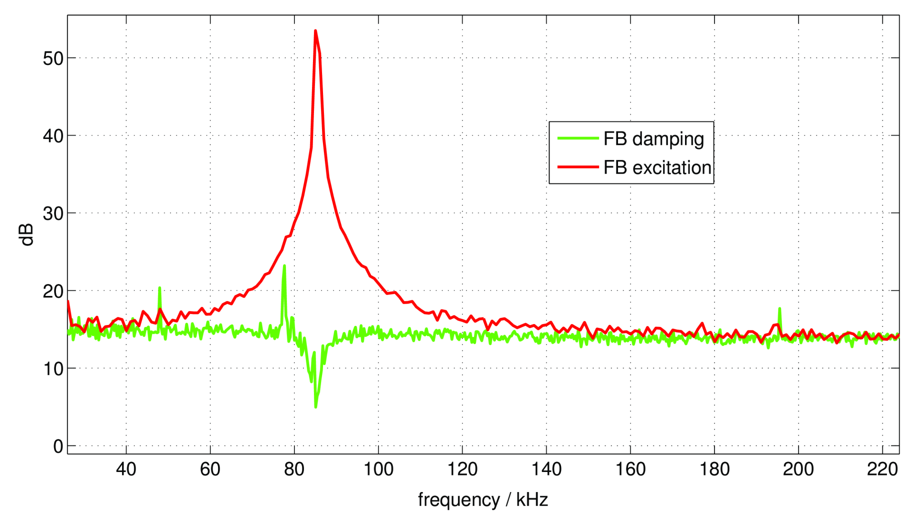
bunch with largest oscillation amplitude



0 – 1 ms: filter phase shifted by 180°

at 1 ms: filter coeff. set back,

FB is clearly working



Fourier spectrum of ADC data averaged

over all filled buckets:

excited & damped: f_{syn} = 86 kHz

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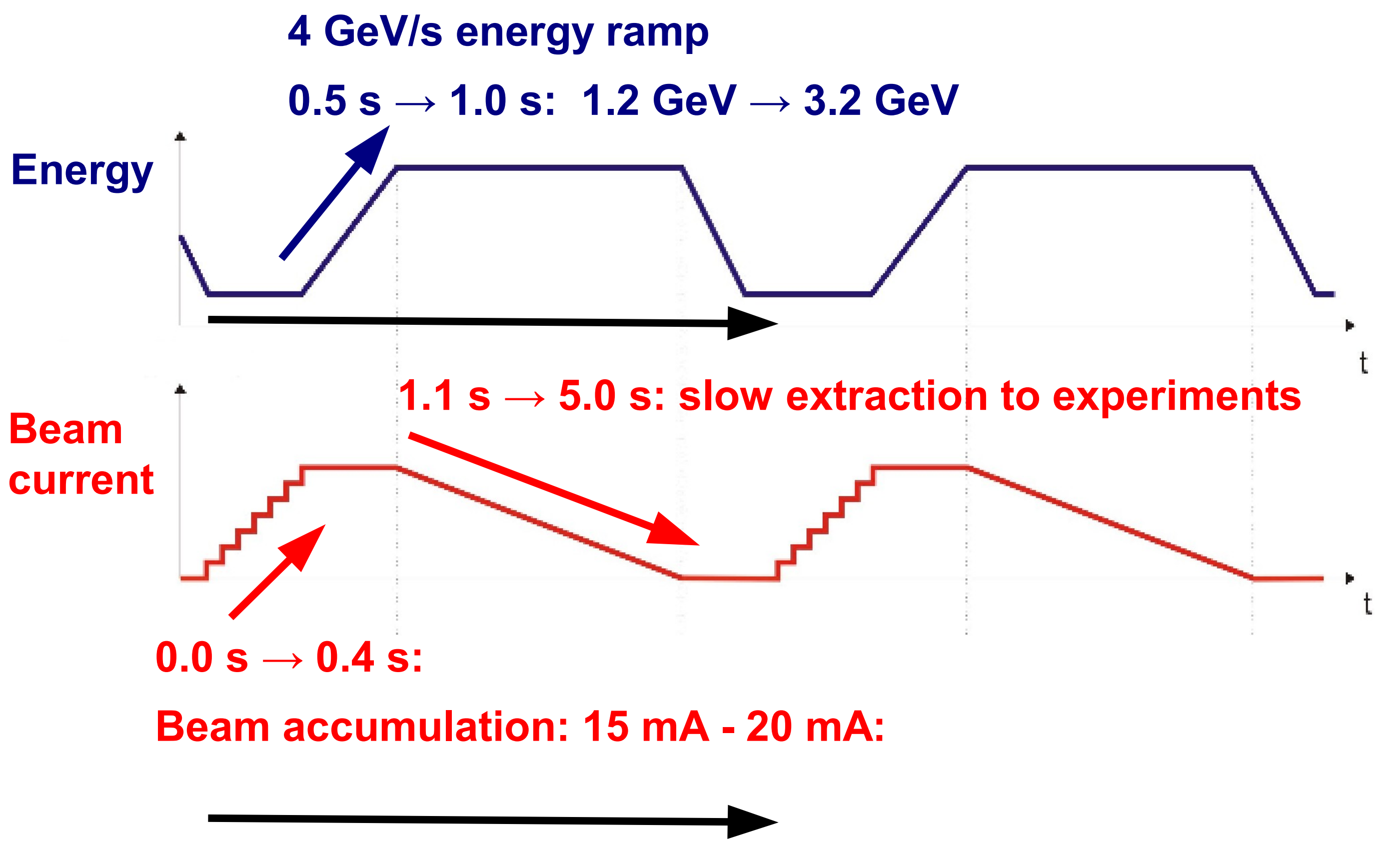
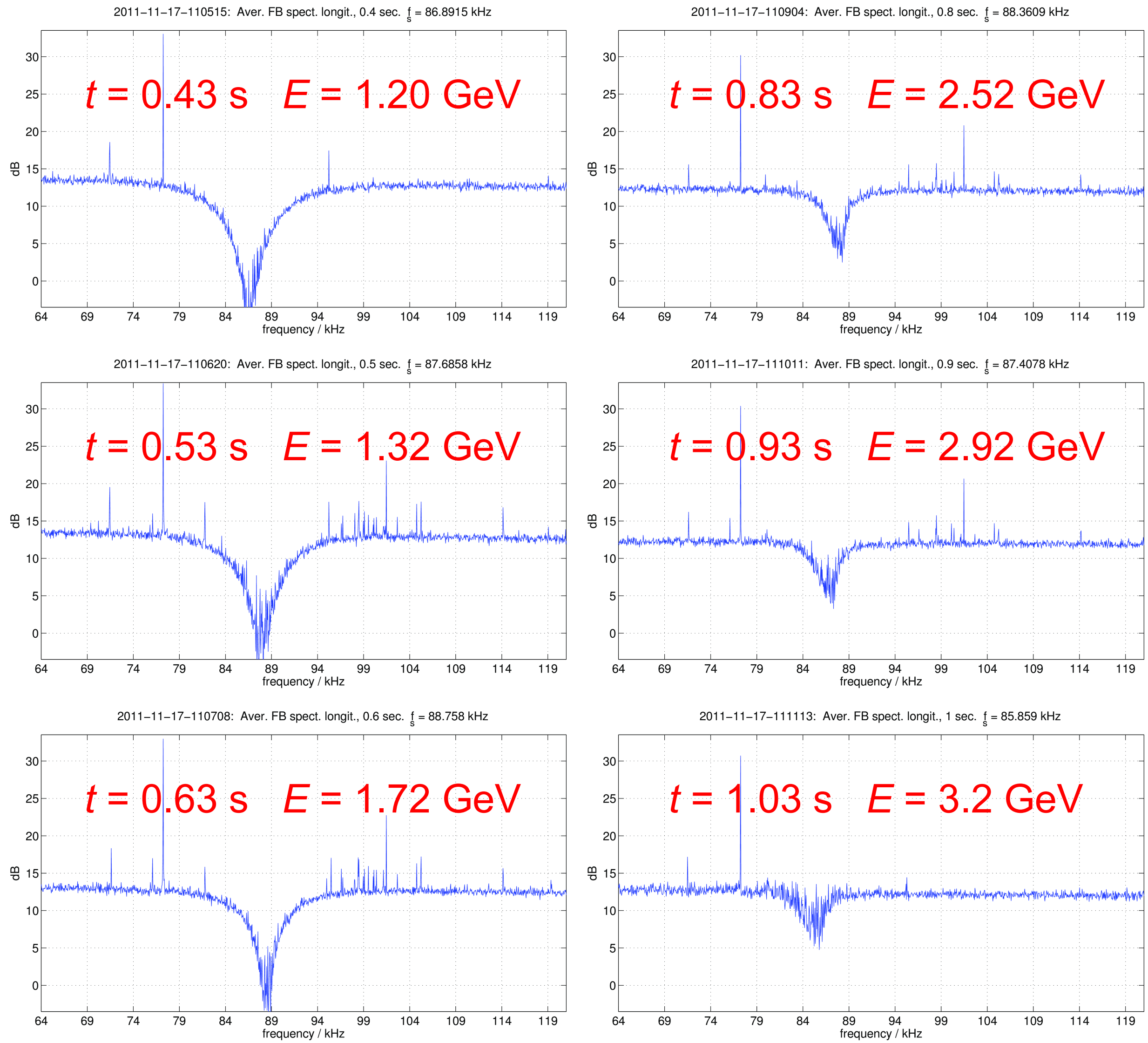
FB operation during ELSA booster mode



ELSA operation cycle: 5.0 s

Fourier spectrum longitudinal FB

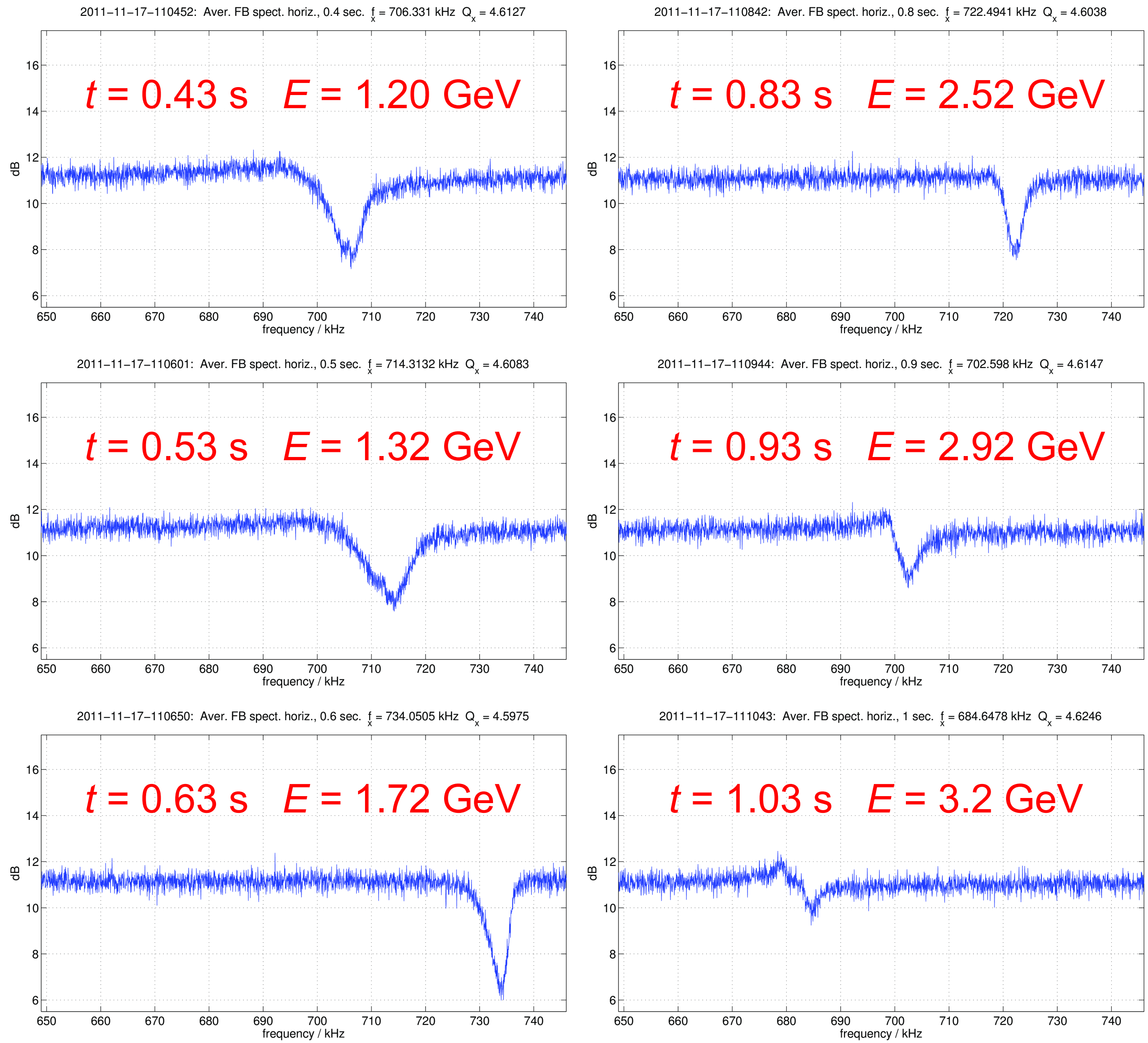
- **linear ramp of cavity voltage:** **1.02 MV → 2.73 MV**
- **stabilizes synchrotron frequency:** **f_s = (87.4 +/- 1.5) kHz,** **essential for bandpass filtering at f_s !**
- **ensures succesful operation of LFB**



Fourier spectrum horizontal FB

- **variation of horizontal tune:** **f_x = (709 +/- 25) kHz,** **due to induced eddy currents during energy ramp**

- **more wideband bandpass filter is used to ensure succesful operation of HFB**



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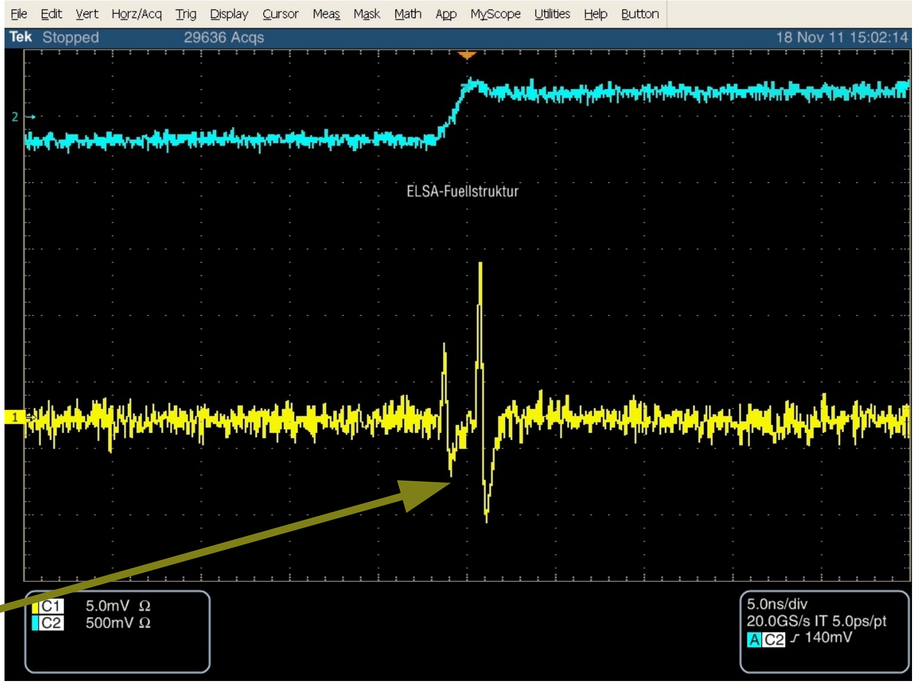
Conclusion & outlook

- Full 3d bunch by bunch FB installed at ELSA:
  LFB & HFB sucessfully working during booster & storage mode,
  VFB loop will be closed in the future
- FB operation for higher currents in booster mode: limits? more gain FB necessary?
- Detailed instabilities studies:
  grow-damp transients,
  coupled-bunch modes,
  sources & thresholds
- Control of filling pattern:
  excite & kick out all 274
  bunches, except 137 & 138



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Thanks to my colleagues:

M. Schedler (stripline kicker),
R. Zimmermann & N. Heurich (kicker cavity)

Thank you

for your attention!

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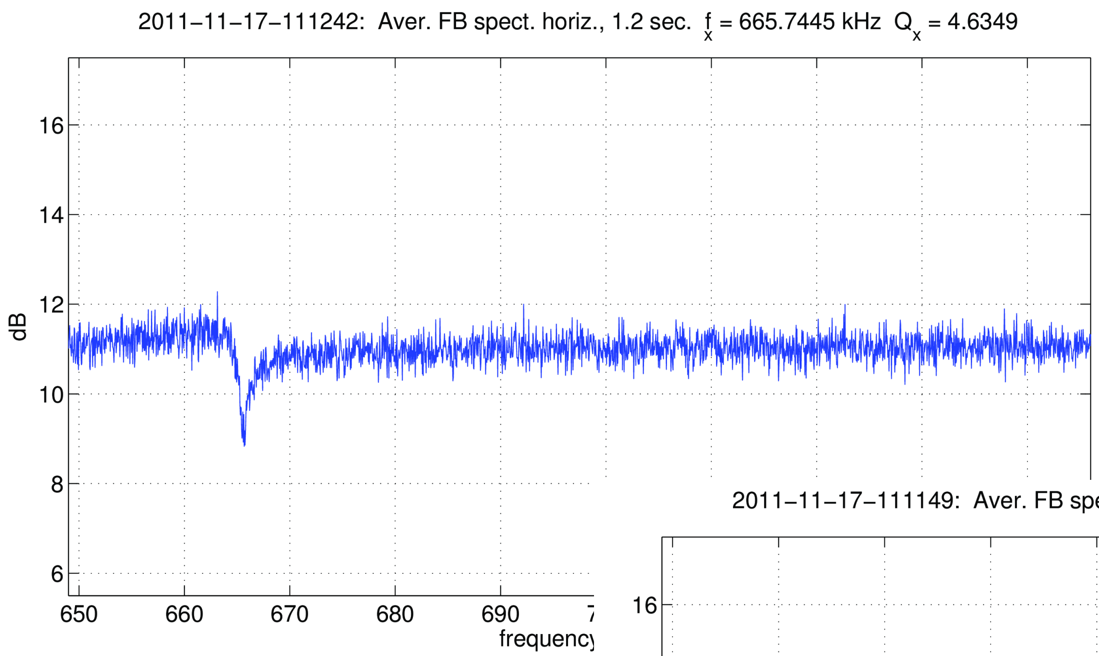
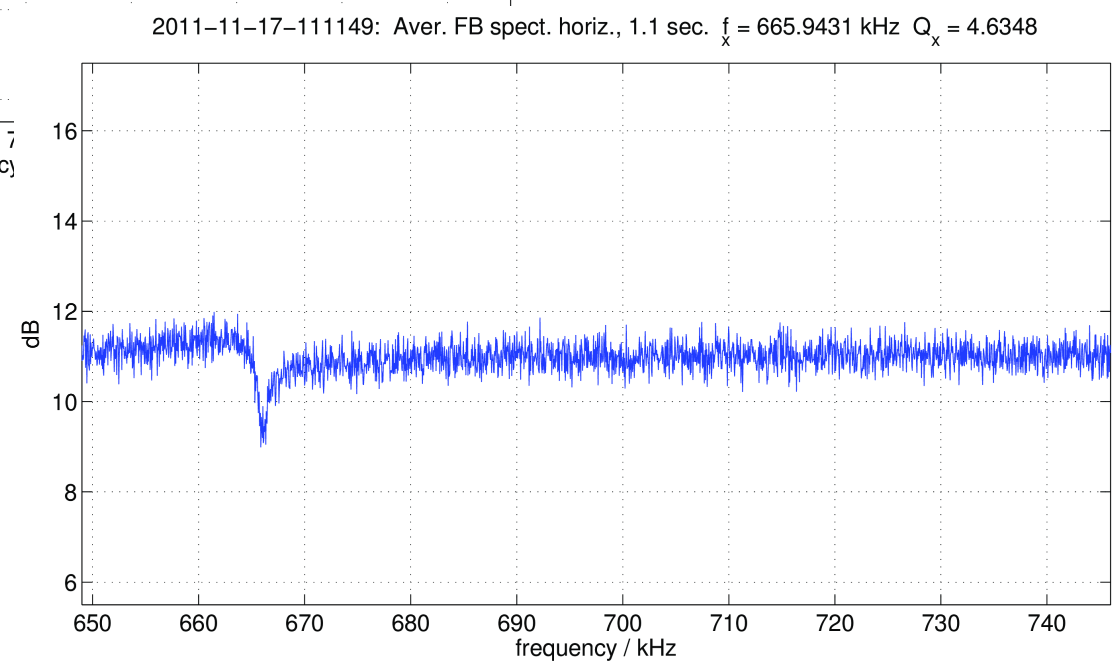
Horizontal FB: beam extraction
At 3.2 GeV (1.1 & 1.2 sec)



f_x = 666 kHz !

Tune for extraction!



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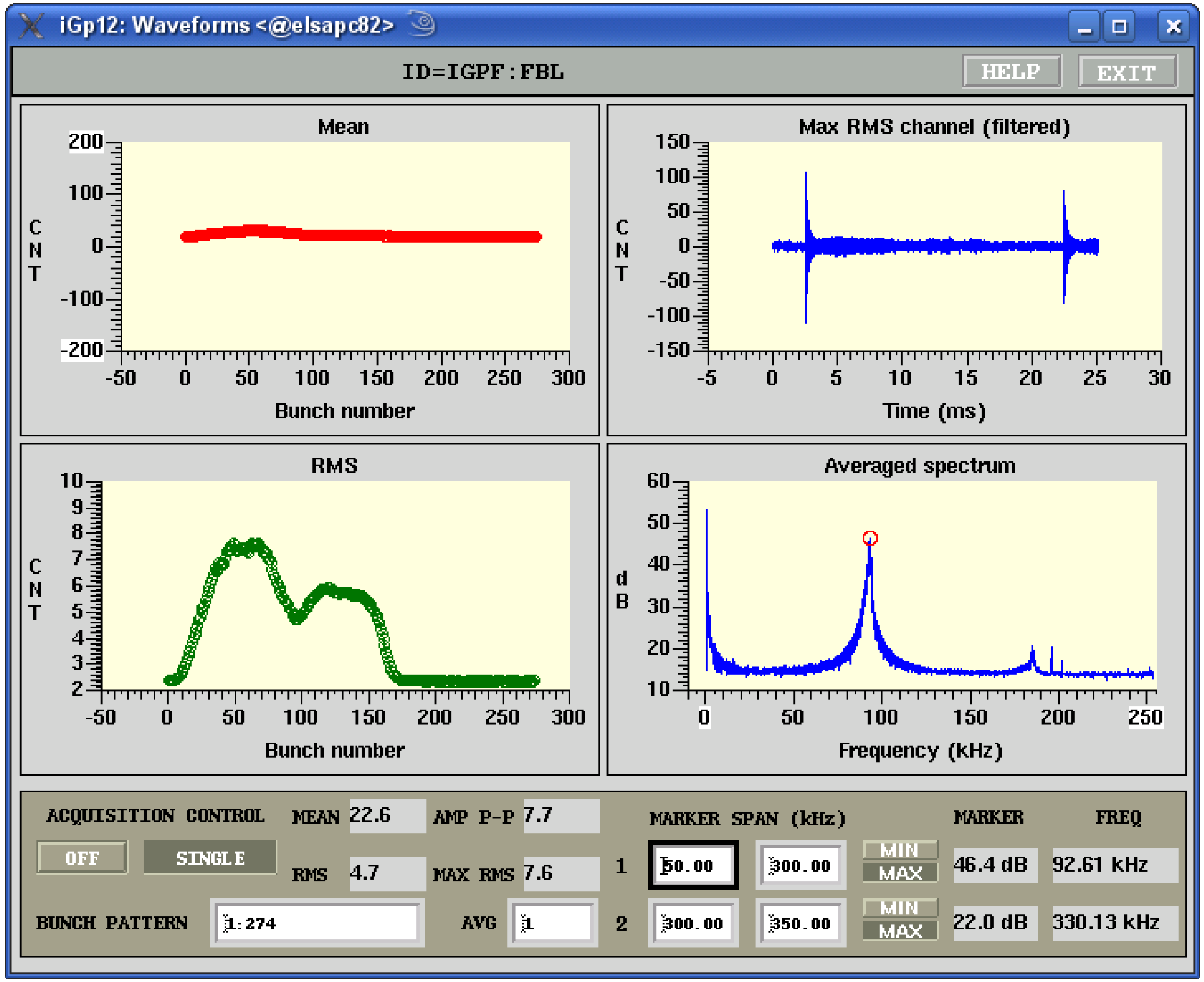
Bunch-by-bunch beam diagnostic & data acquisition

- ≤ 25 ms record length for later ADC data analysis
- Synchrotron oscillations: MEAN=0,
- RMS indicates oscillations
- Spectrum: averaged over bunch pattern
- Example: Oscillations because of injections (each 20 ms) in the stretcher ring



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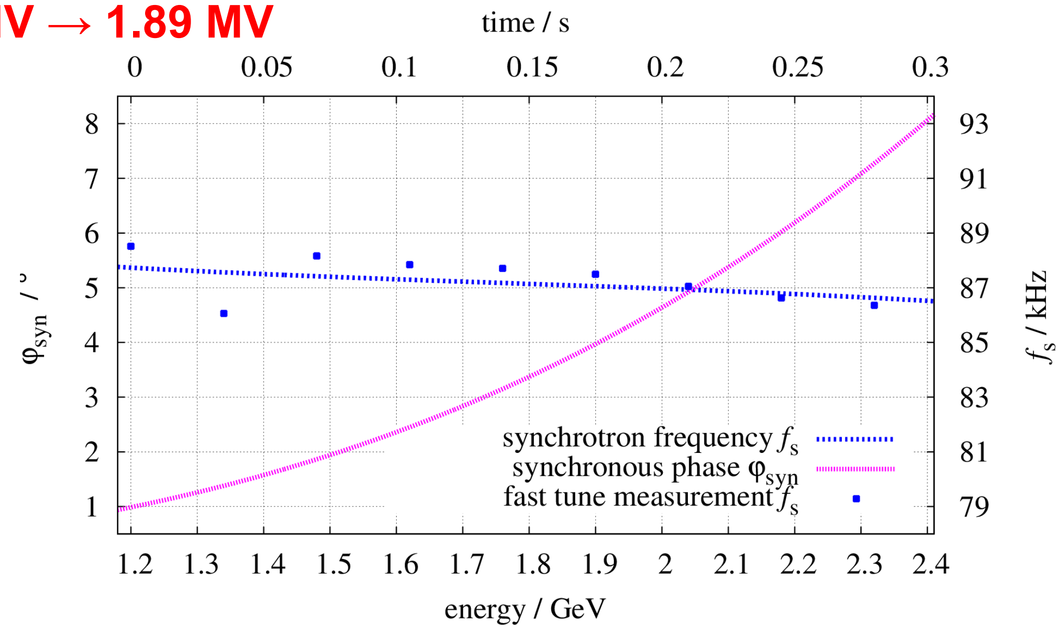
Fast energy ramp of ELSA booster mode

Longitudinal FB operating range:

stretcher ring beam injection energy: 1.2 GeV & typical extraction energy: 2.35 GeV

- **Linear ramp of cavity voltage: 0.98 MV → 1.89 MV**
- **Shift of bunches' synchr. phase φ_{syn} in acceptable range: 6.6°**
- **f_s should be nearly constant for bandpass filtering: (87.0 +/- 1.5) kHz**



- **LFB works sucessfully during ELSA booster mode:**
  - **better injection efficiency at 1.2 GeV**
  - **significant lower beam loss during ramp**
  - **damped long. CBI, until now tested with $I_{beam} \leq 30$ mA**

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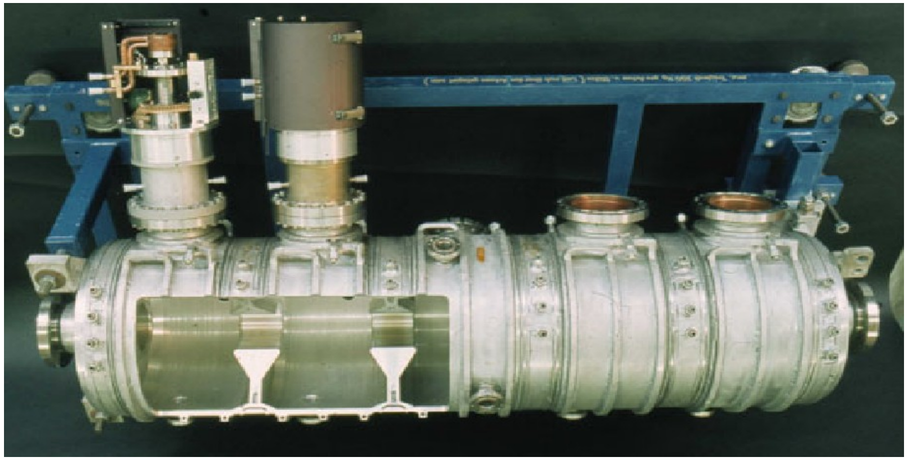
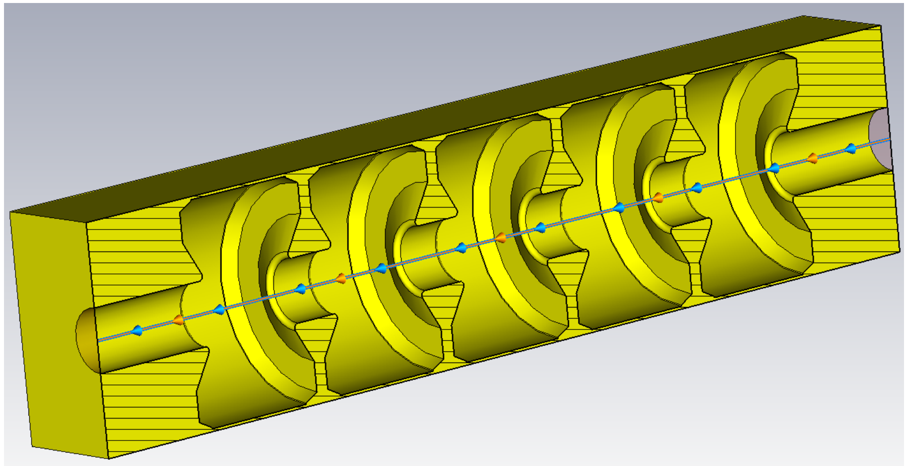
Main source of long range wake fields and multibunch instabilities at ELSA

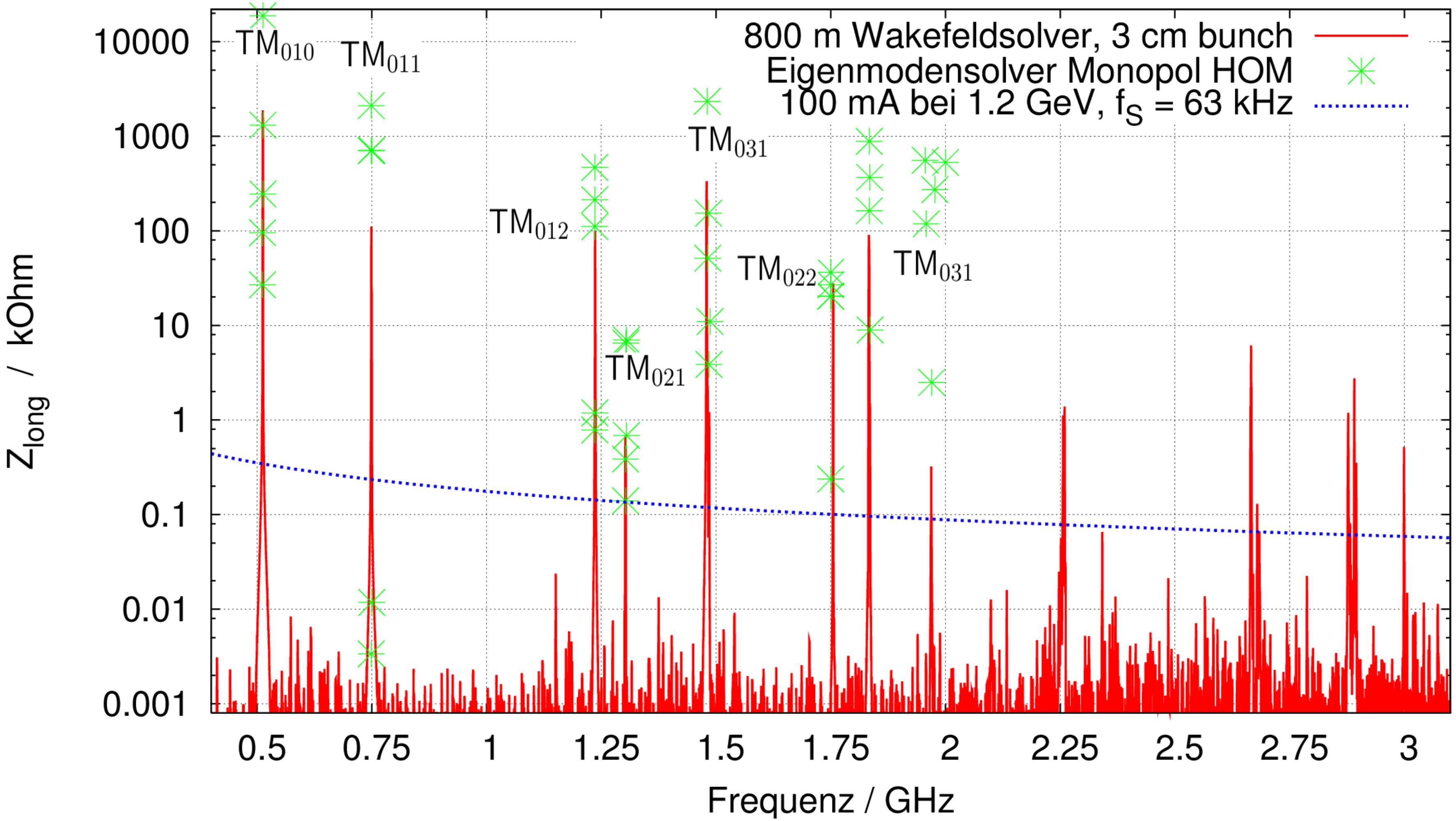
Higher Order Modes of 500 MHz PETRA cavities



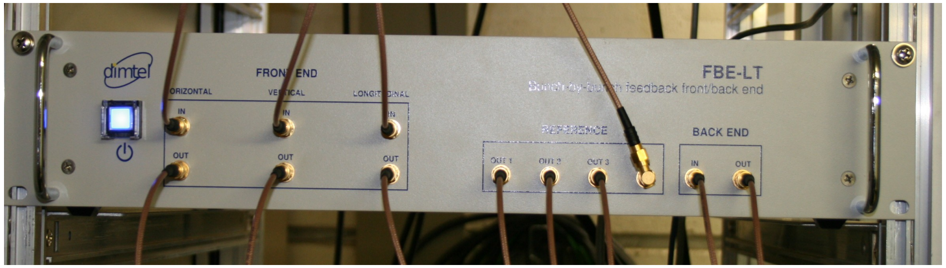
Numerical simulations with CST microwave and particle studio (eigenmode & wakefield solver)

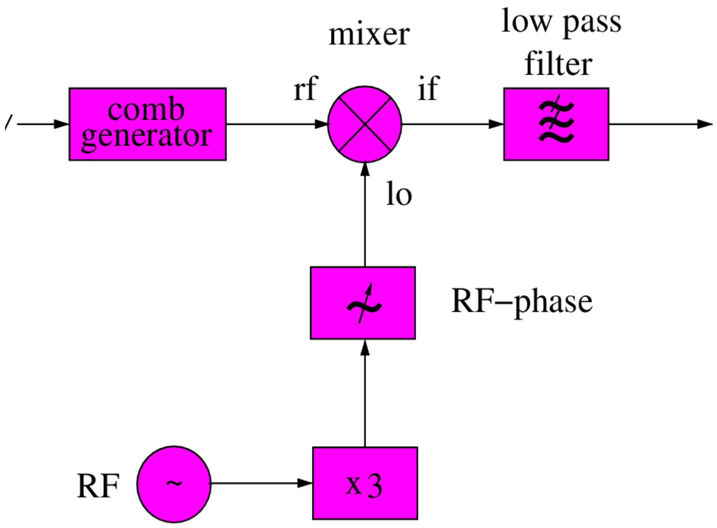


Impedances of HOMs are well above multibunch stability thresholds due to radiation damping!



Frontend signal demodulation





- 3 channel demodulation at 1.5 GHz
- Longitudinal: phase demodulation

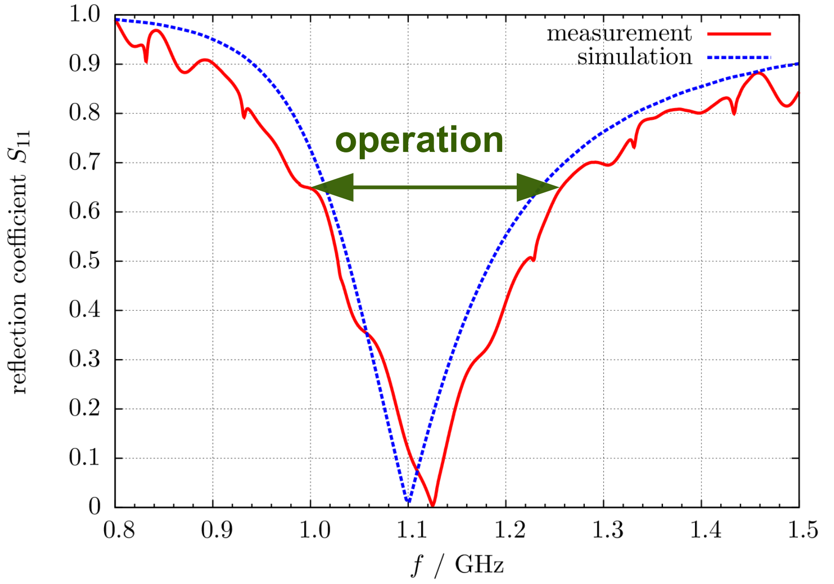
$$\sin\left(3\,\omega_{\mathrm{RF}}\,t\;+\;\varphi(t)\right)\cdot\sin\left(3\,\omega_{\mathrm{RF}}\,t\;+\;\pi/2\right)\;\propto\;\varphi(t)$$

- Transverse: amplitude demodulation

$$A(t)\;\sin\left(3\,\omega_{\mathrm{RF}}\,t\right)\cdot\sin\left(3\,\omega_{\mathrm{RF}}\,t\right)\;\propto\;A(t)$$

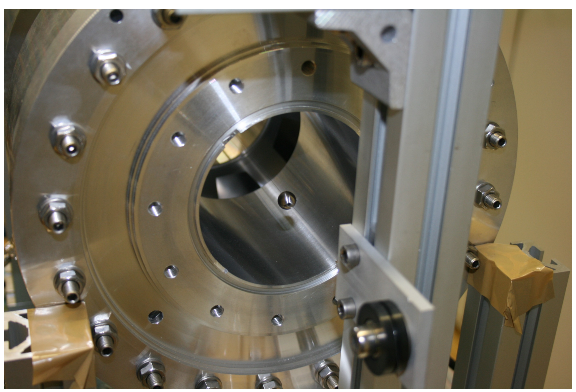
Kicker cavities: measurements

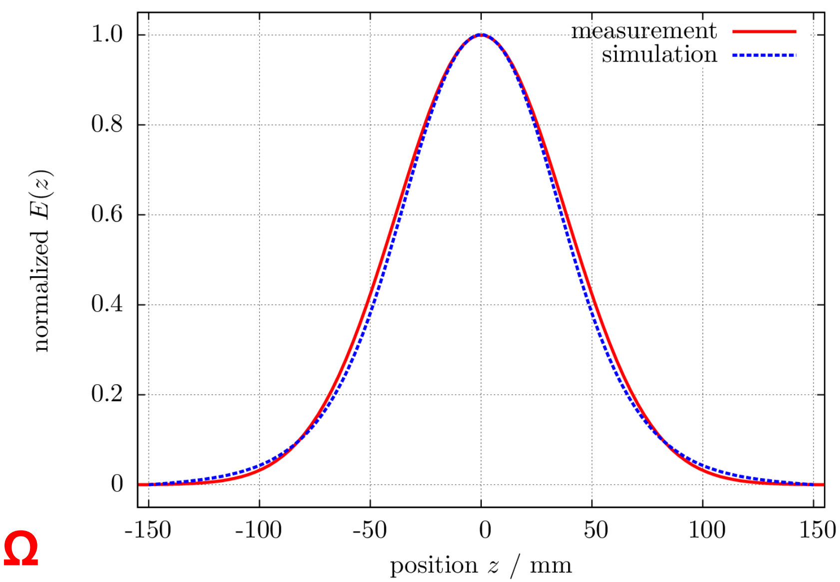
Reflection measurement with network analyzer:



f_{center} = 1.125 GHz,
bandwidth: 297 MHz, Q_L = 3.79

Electric field & shunt impedance via resonant bead pull measurement:





R_S = (338 +/- 16) Ω

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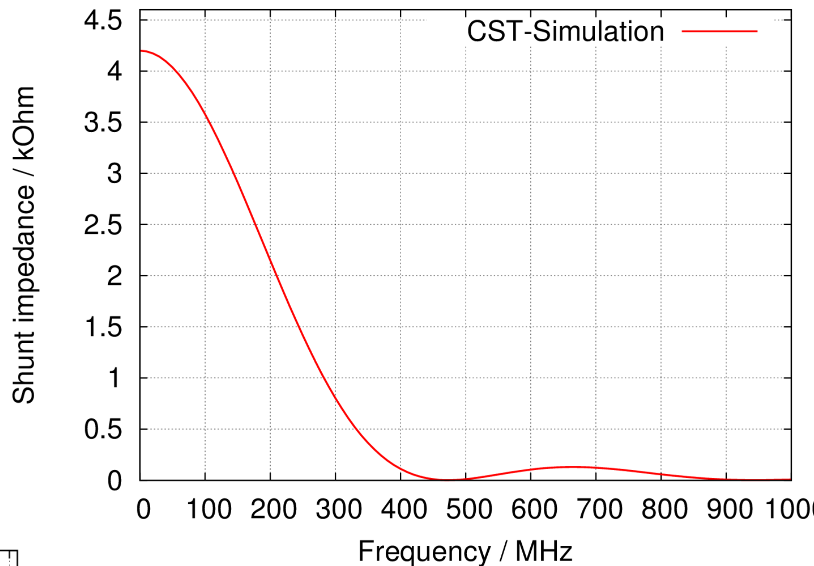
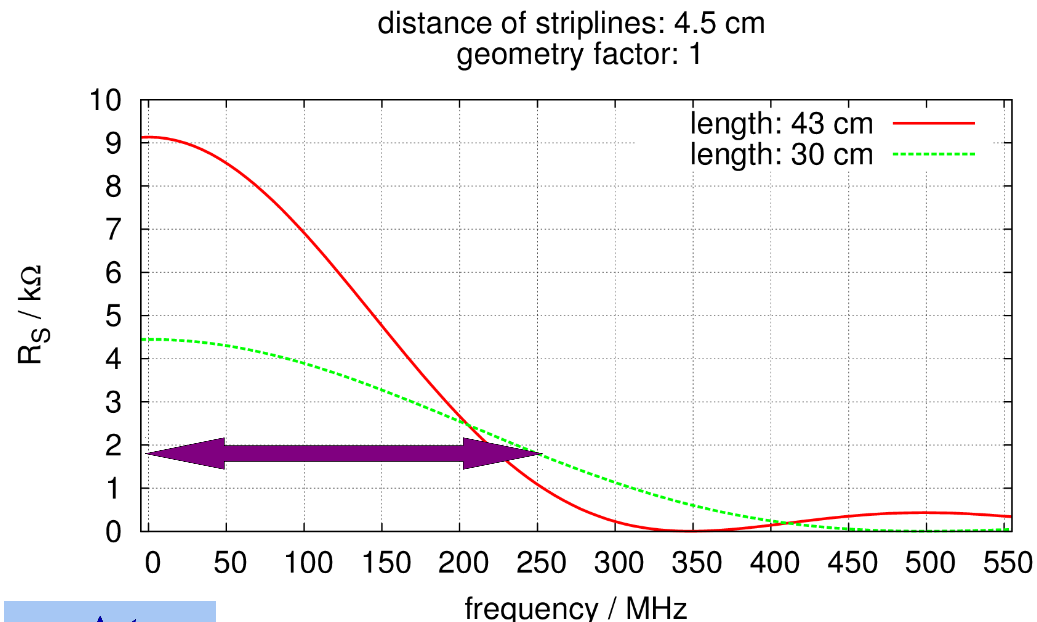
Transverse Stripline Kickers: shuntimpedance vs. frequency

general behaviour: ~ sin(x)/x

Simulation





30 cm:
- zero @ 500 Mhz
- larger BW