ESLS RF Meeting, ESRF Grenoble, 5 October 2011

André Roth, PhD student

Institute of Physics, University of Bonn

Multibunch Feedback Systems at ELSA

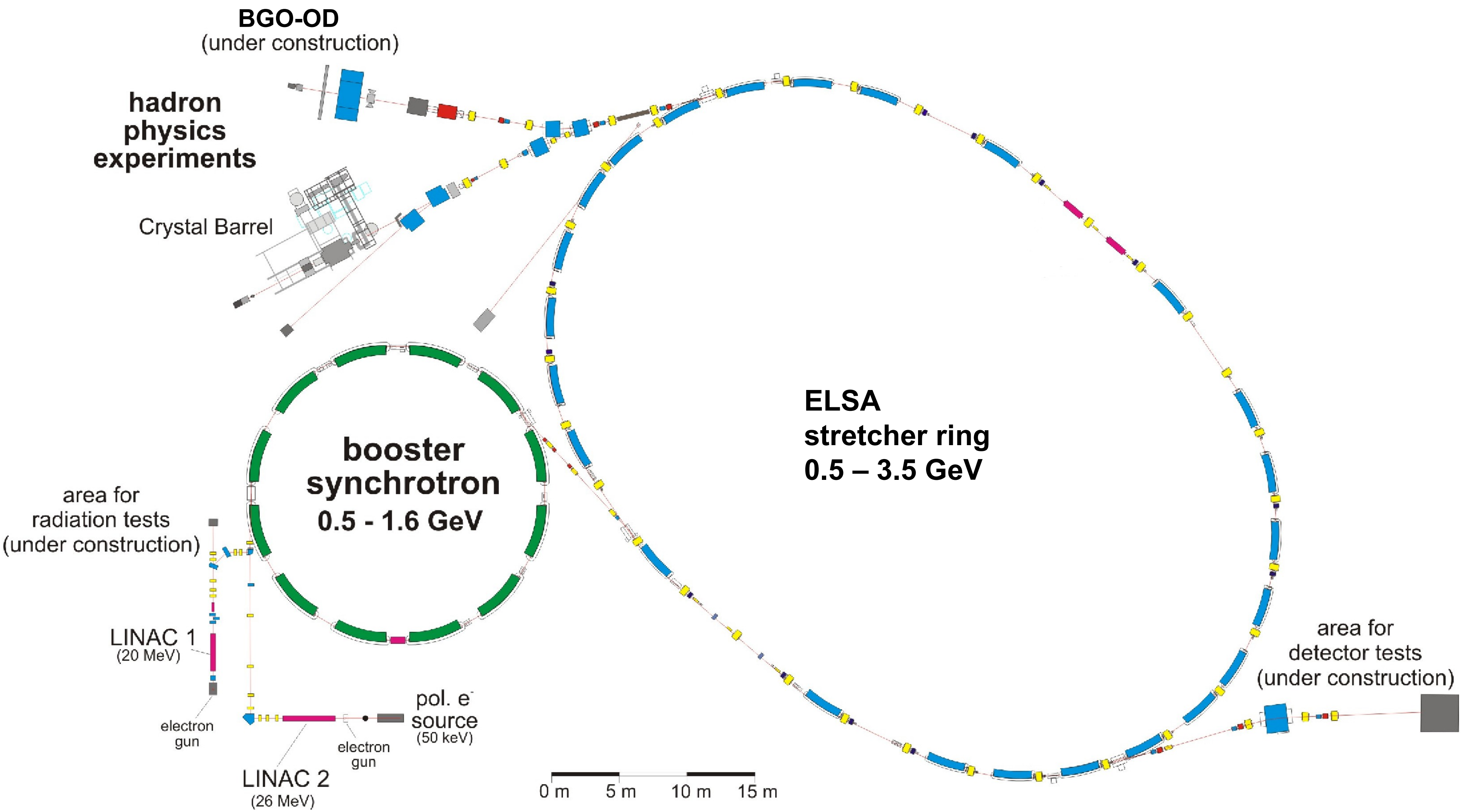
ELSA operating mode & beam current upgrade

Setup of multibunch feedback systems (FB)

Commissioning of longitudinal FB

Status & outlook

(1.2 – 3.2) GeV polarized e$^-$ beam for fixed-target experiments



ELSA booster mode

4 GeV/s fast energy ramp:

0.3 (0.5) s for 1.2 GeV to 2.4 (3.2) GeV

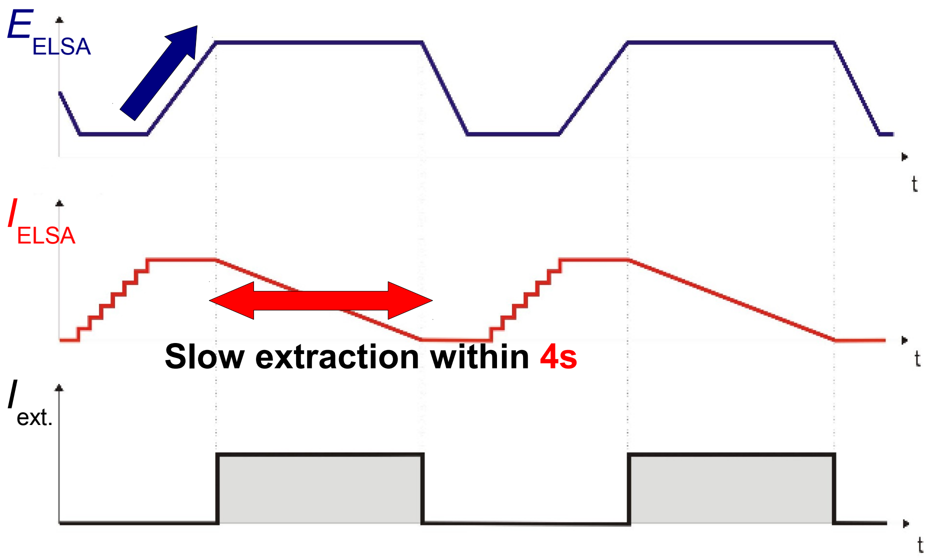
Beam accumulation in stretcher ring:

up to (15 - 20) mA

without filling gap

At experiments:

External duty cycle: ≤ 80 %



Planned intensity upgrade: I_{ELSA} = (100 - 200) mA

Operation different from Synchrotron Light Sources,

but: same problems with beam instabilities!

Multibunch instabilities

➡ Limitation of storable beam current and beam quality

- Many 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 system

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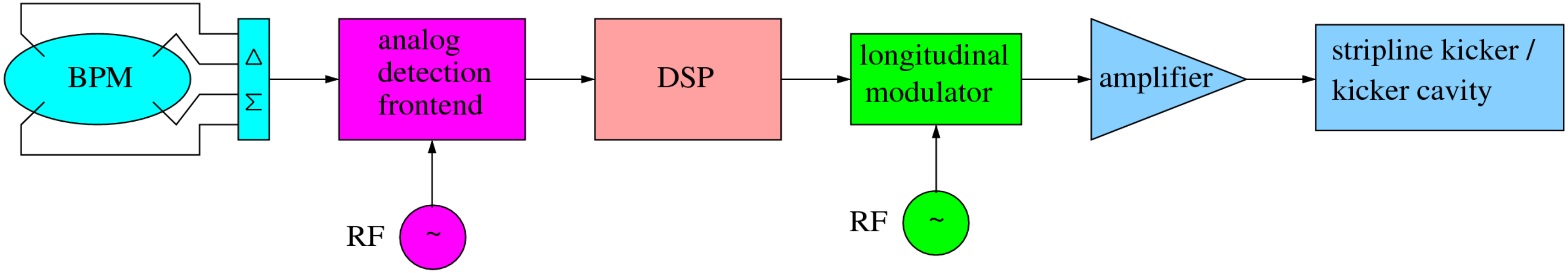
Bunch-by-bunch feedback systems
analog bandwidth: f_{RF} / 2 = 250 MHz



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

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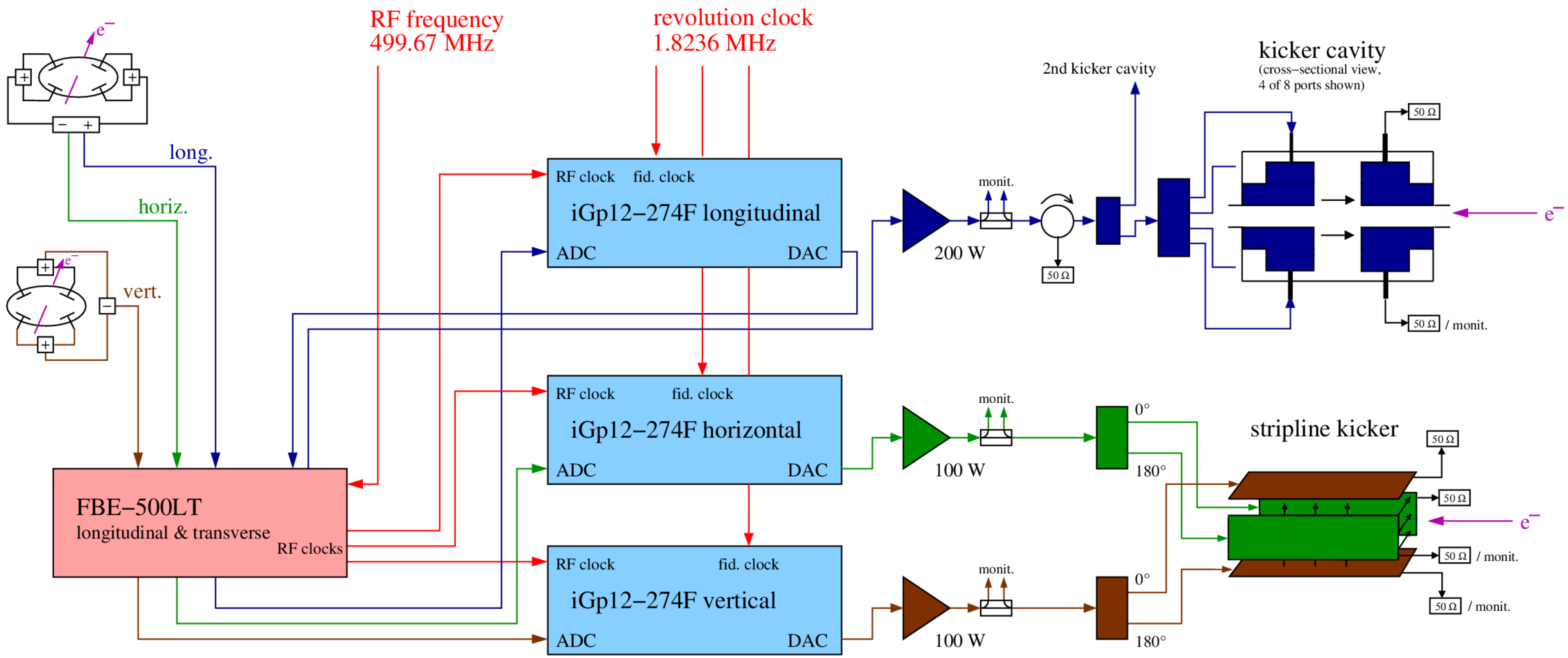
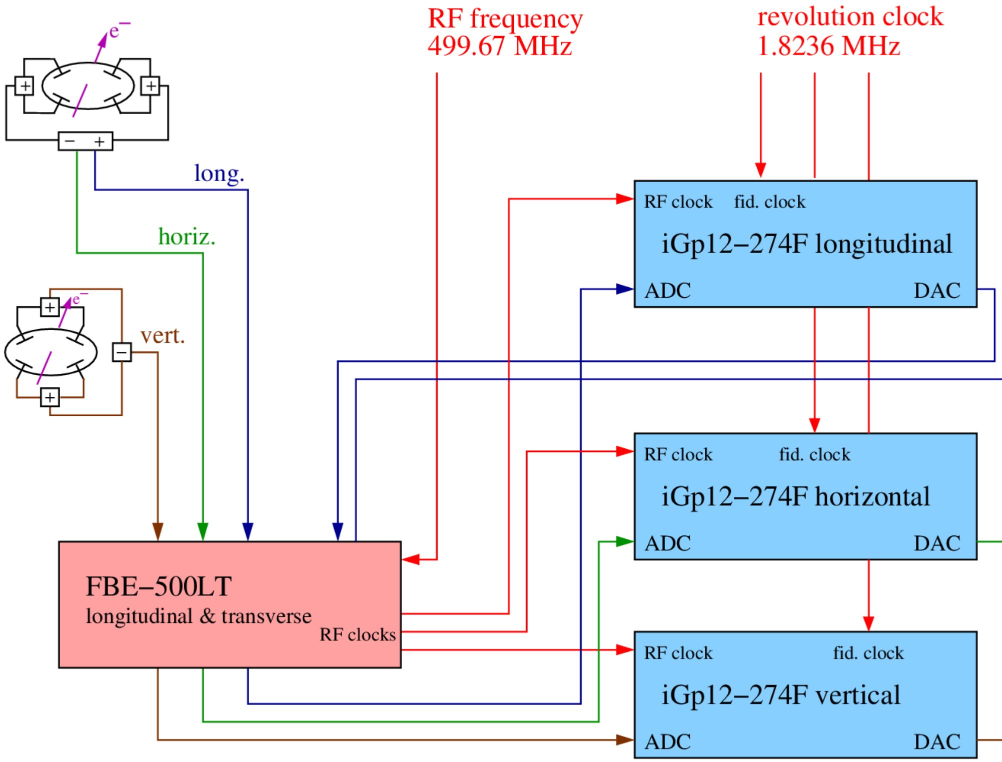
System layout at ELSA

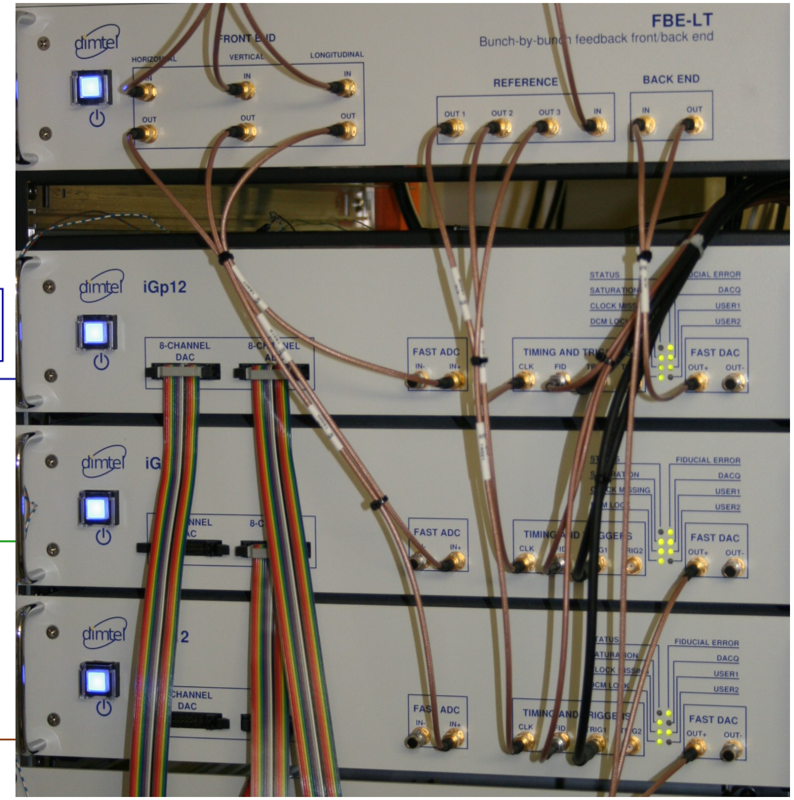


Electronics is commercially available: DIMTEL

- 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

System layout at ELSA





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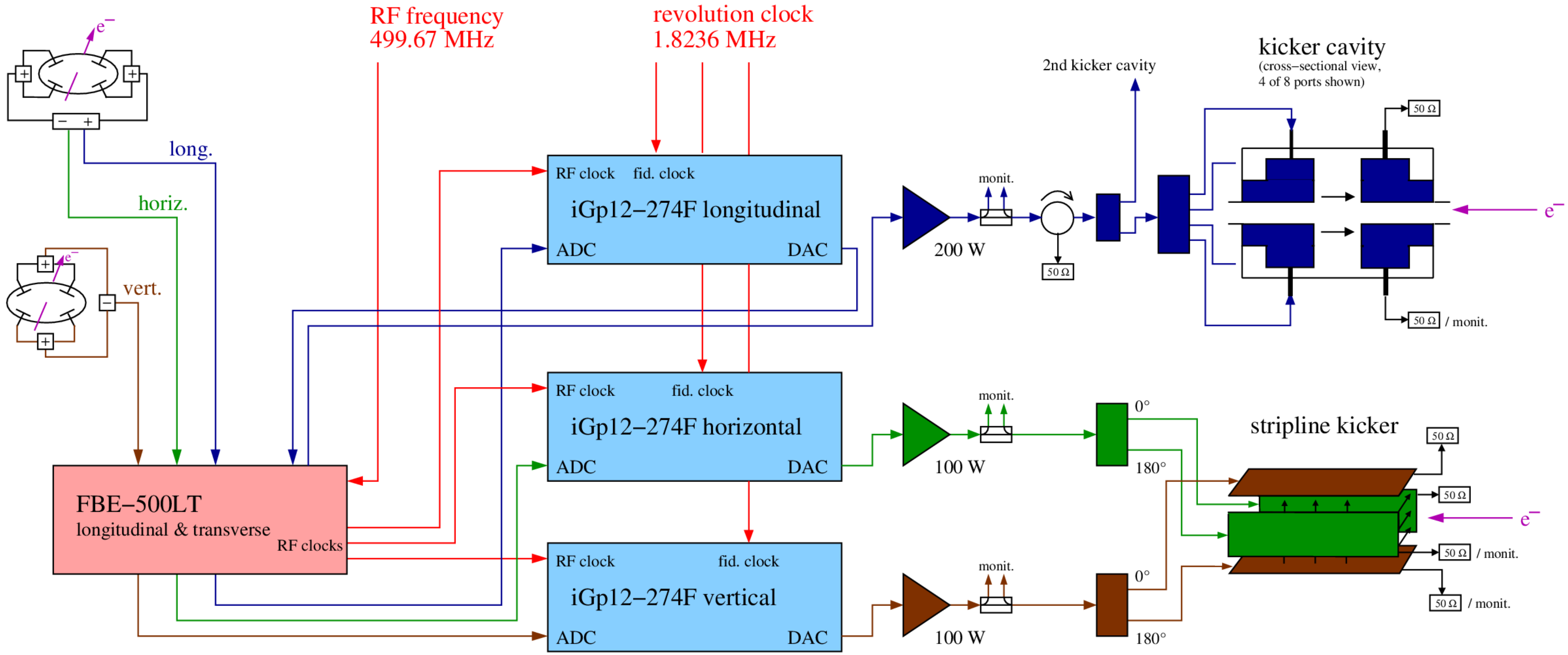
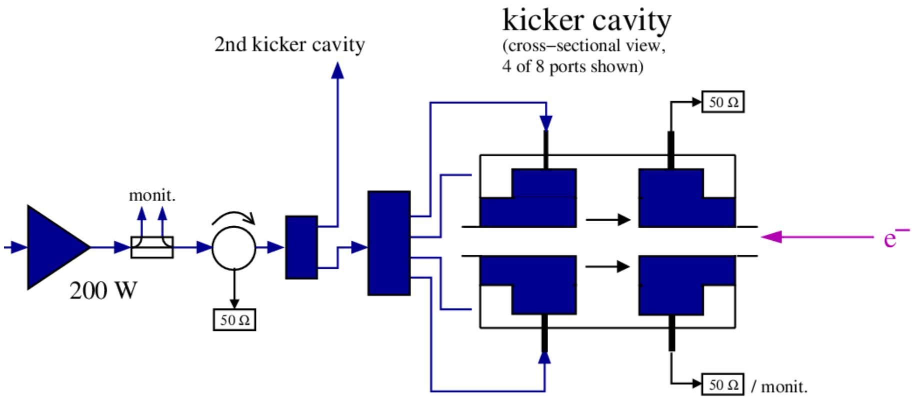


Broadband amplifiers

- longitudinal: (1 – 2) GHz, 200 W, Milmega

- transversal: 10 kHz – 250 MHz, 100 W, Amplifier Research

Broadband Kickers - longitudinal



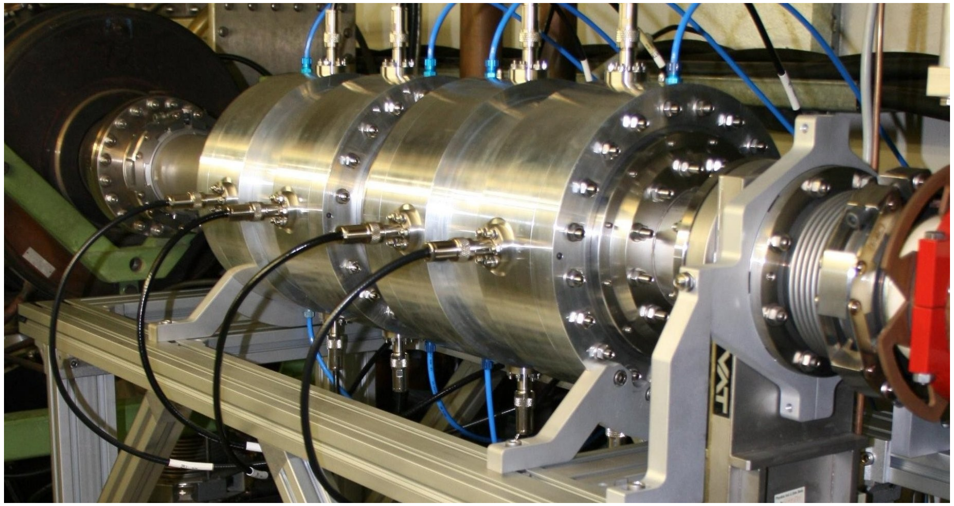
If in the future necessary:
one amplifier for each cavity

2 kicker cavities:

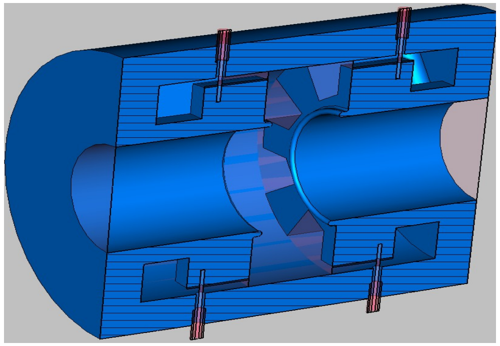
- 4 input & 4 output ports
- choice of f_{cent} = 1.125 GHz
  consider ELSA bunch length: 2 – 6 cm!

$$\frac{\lambda_{cent}}{2} - 6\text{ cm} > \text{accelerating gap of the cavity}$$

- bandwidth at least: 250 MHz: $Q_L = 4.5$



Simulation with CST Microwave Studio & In-house fabrication



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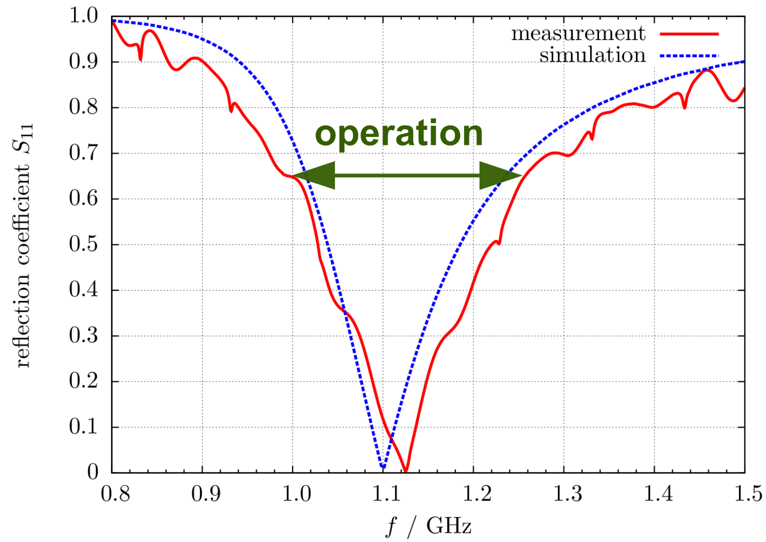
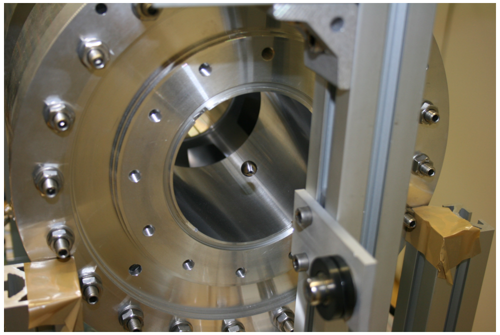
Kicker Cavities: Measurements

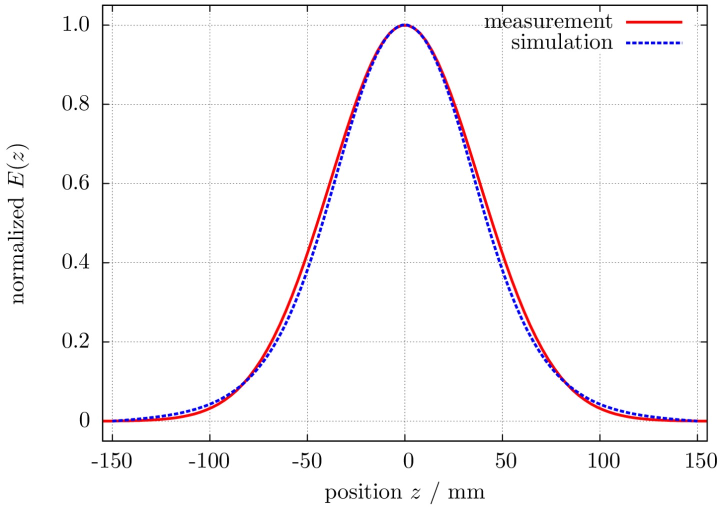
Reflection measurement with network analyzer:

f_{center} = 1.125 GHz, simulated: 1.100 GHz
bandwidth: 302 MHz, Q_L = 3.73



Electric field & shunt impedance via resonant bead pull measurement:





R_S = (374 +/- 16) Ω

Not very large, because:

- beam pipe diameter of 10 cm
- f_{cent} has to be lower than usual

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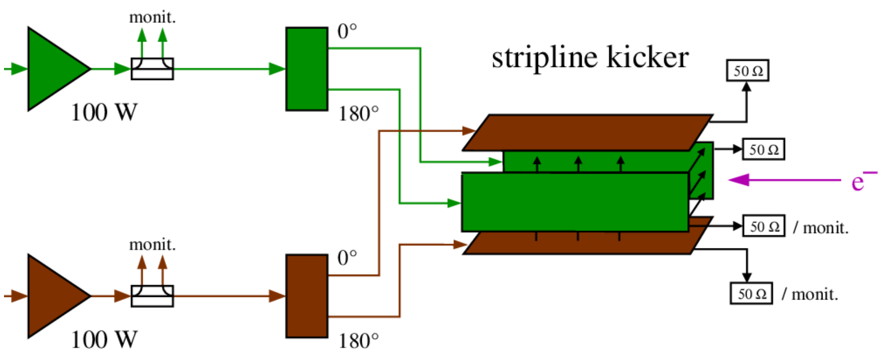
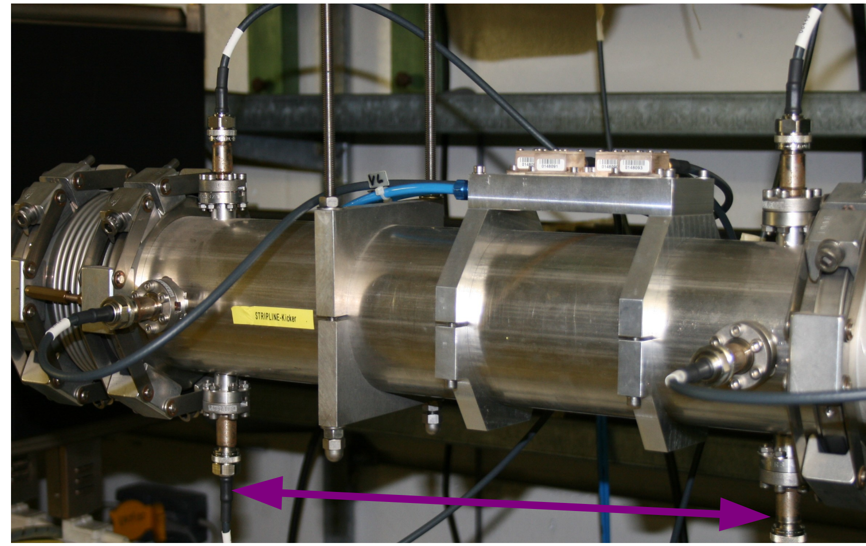
Kicker - transversal

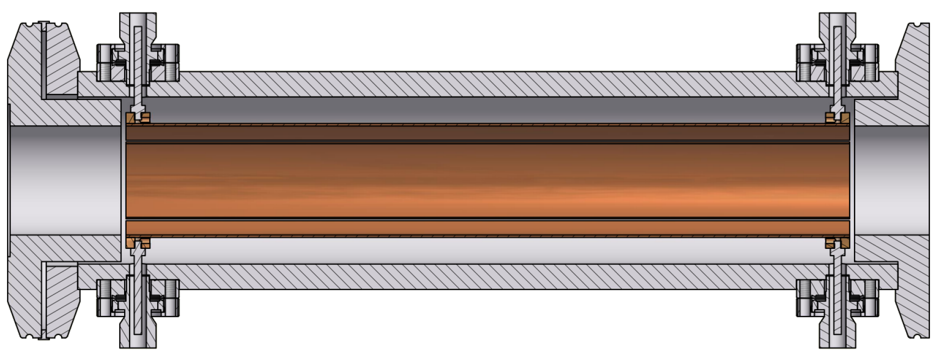




43 cm

Existing kicker with
horizontal & vertical striplines,
driven by a 0° / 180° splitter

Currently fabrication of a new transverse kicker with larger bandwidth:
stripline length of 30 cm



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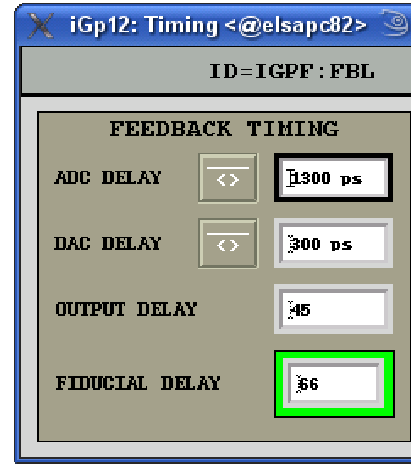
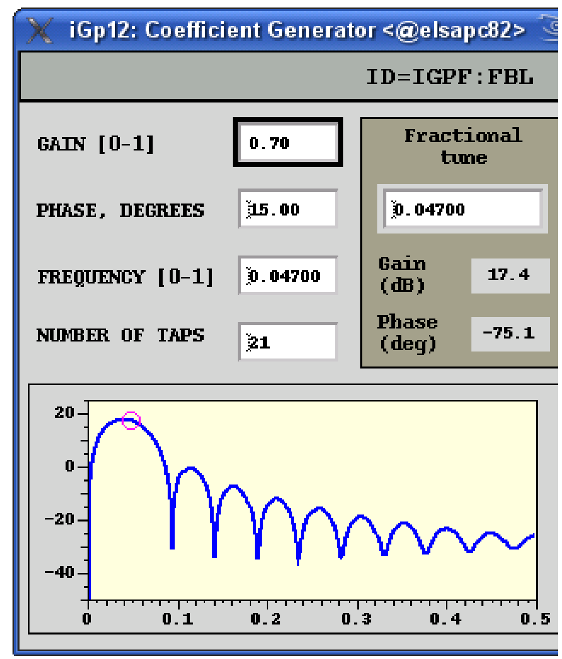
Timing & closing of longitudinal feedback loop

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}
- **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} ,**
  $\pi/2$ phase shift required for resistive feedback,
  (phase energy relation in longit. phase space)





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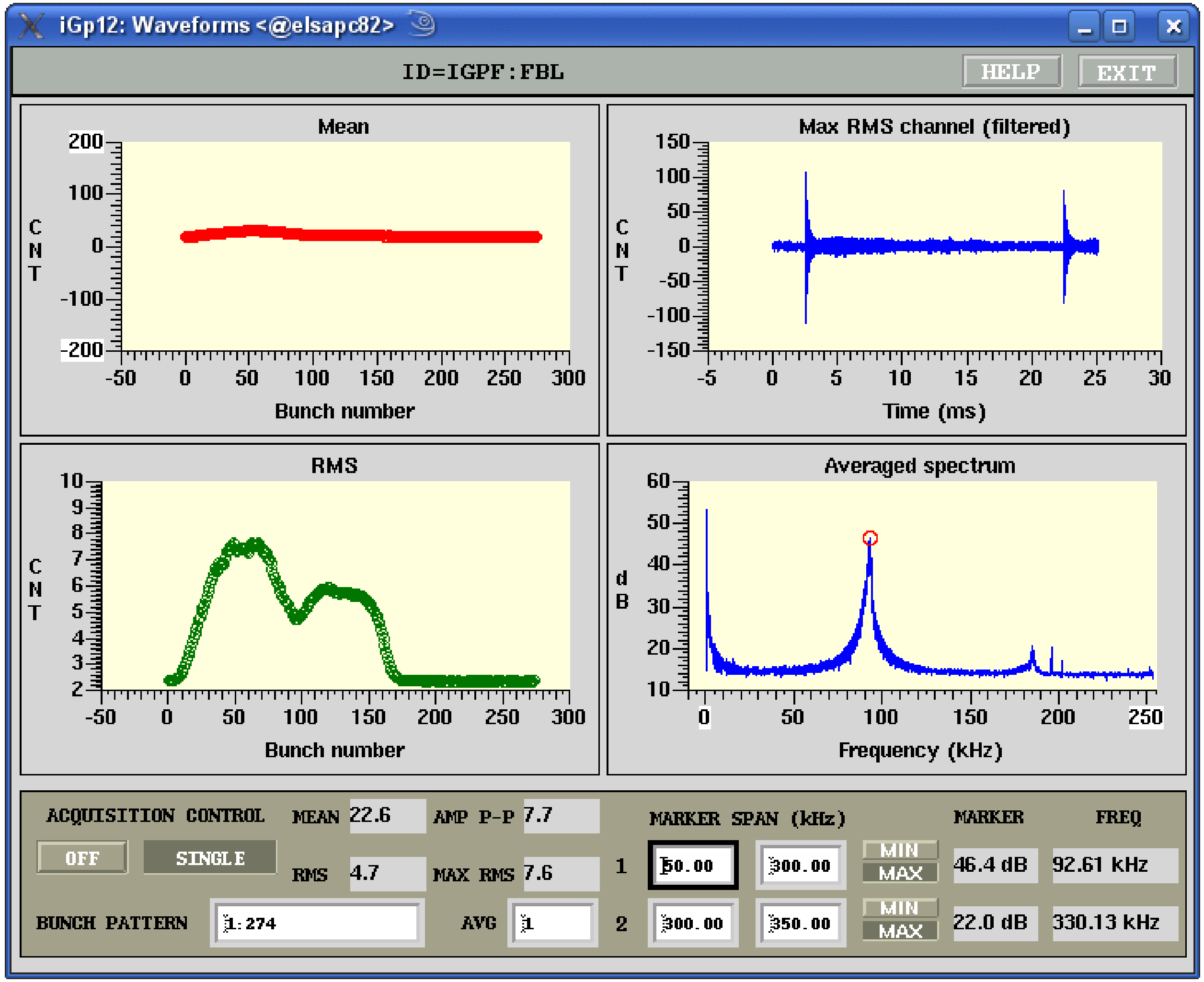
Bunch-by-bunch beam diagnostic & data acquisition

- ≤ 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



Drive-damp measurement at 2.35 GeV

10 mA stored in stretcher ring,

beam is stable,

longitudinal turn-by-turn ADC data of

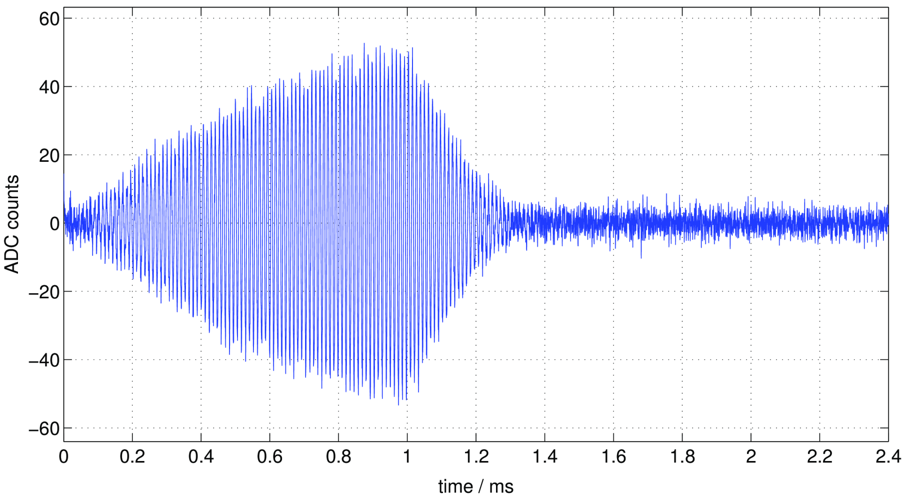
bunch with largest oscillation amplitude

0 – 1 ms: filter phase shifted by 180°,

excitation of syn. oscillations

at 1 ms: filter coeff. set back,

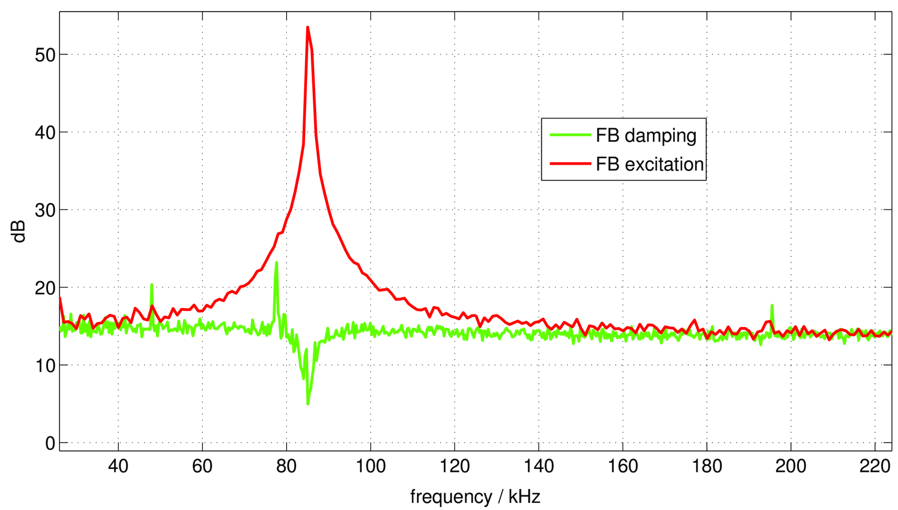
FB is clearly working



Fourier spectrum of ADC data averaged

over all filled buckets:

excited & damped: f_{syn} = 86 kHz



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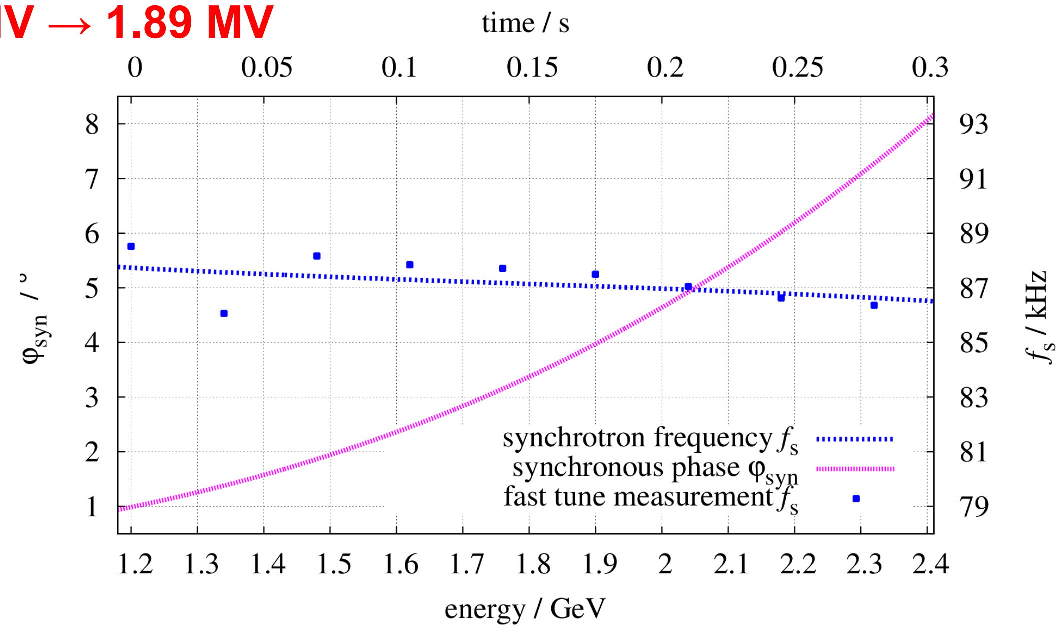
Fast energy ramp & booster mode

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} ≤ 30 mA**

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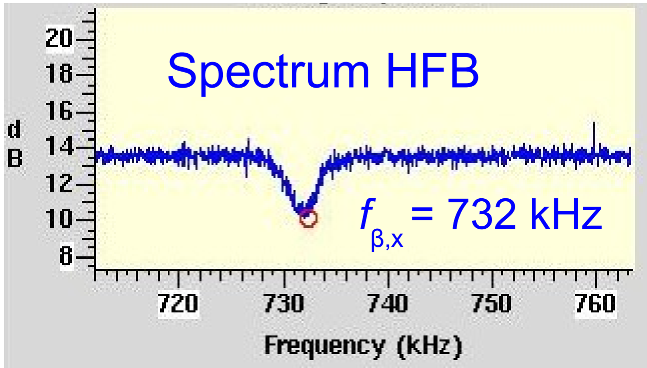
Status of horizontal FB

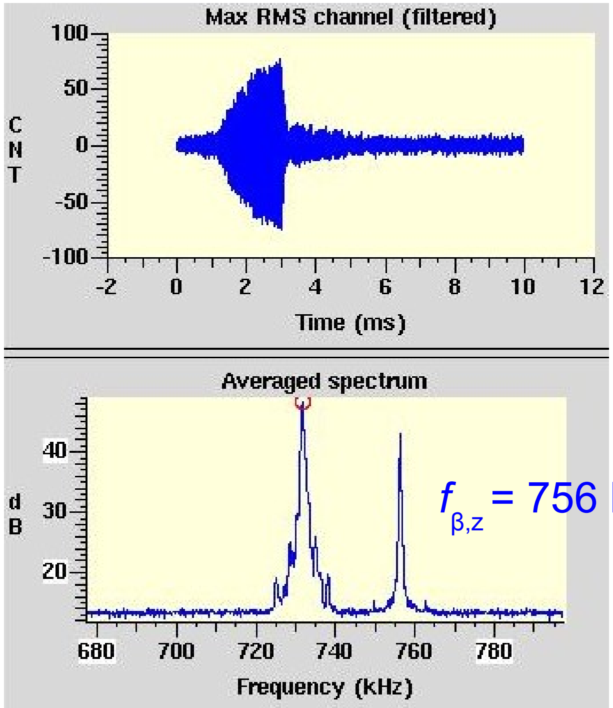
First test in storage ring mode at 2.35 GeV, I_{beam} up to 100 mA



- LFB is active: beam becomes transverse instable
- HFB loop closed: betatron oscillations of bunches damped sucessfully

Horizontal drive-damp measurements at 50 mA

- FB shows good damping performance
- Beam becomes also instable vertical, but at that time, vertical FB was not ready for operation



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Conclusion & outlook

- **Setup of multibunch feedback systems for all 3 planes is completed at ELSA**
- **LFB loop successfully closed & FB is working well during booster mode**
- **HFB & VFB is ready for detailed tests with beam in the future**
- **FB operation for booster mode: limit for beam current / more FB gain necessary?**
- **Detailed studies at the stretcher ring:**
  - **instabilities thresholds, grow-damp transients, coupled-bunch modes, source of instabilities**
  - **bunch cleaning: single bunch possible?**

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Thanks to my colleagues:

R. Zimmermann & N. Heurich (Kicker Cavity),
M. Schedler (Stripline Kicker),
W. Hillert, F. Frommberger

Thank you

for your attention!

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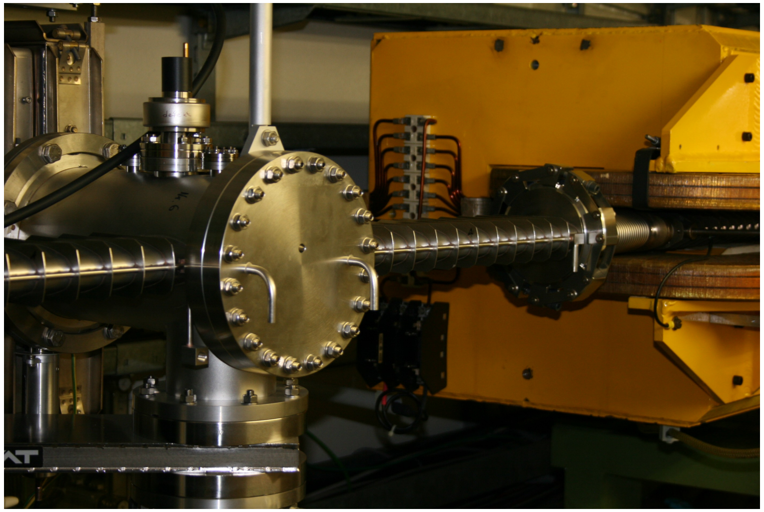
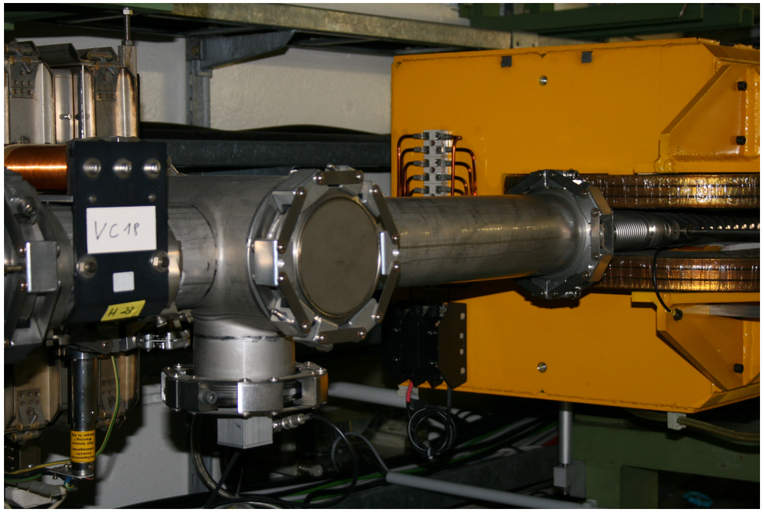
New elliptical cross pieces





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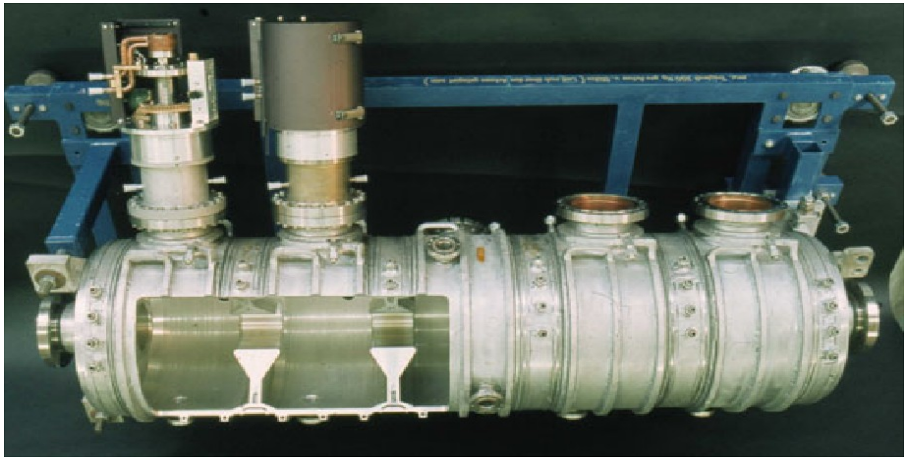
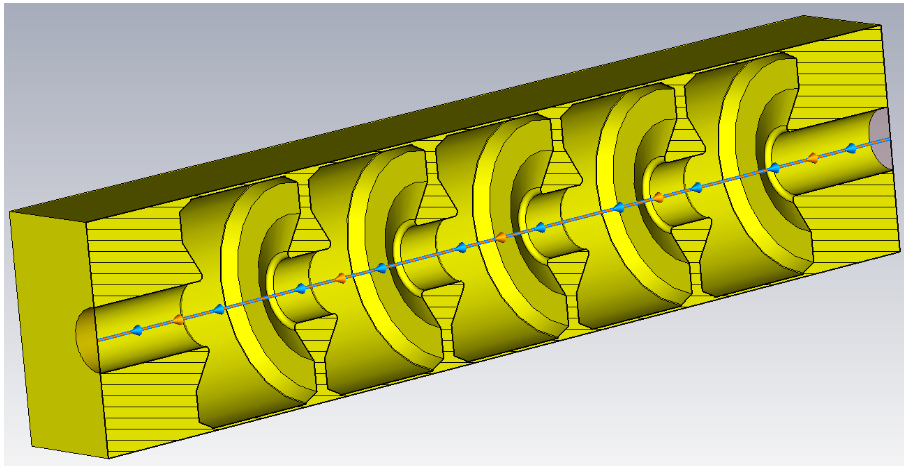
Main source of long range wake fields and multibunch instabilities at ELSA

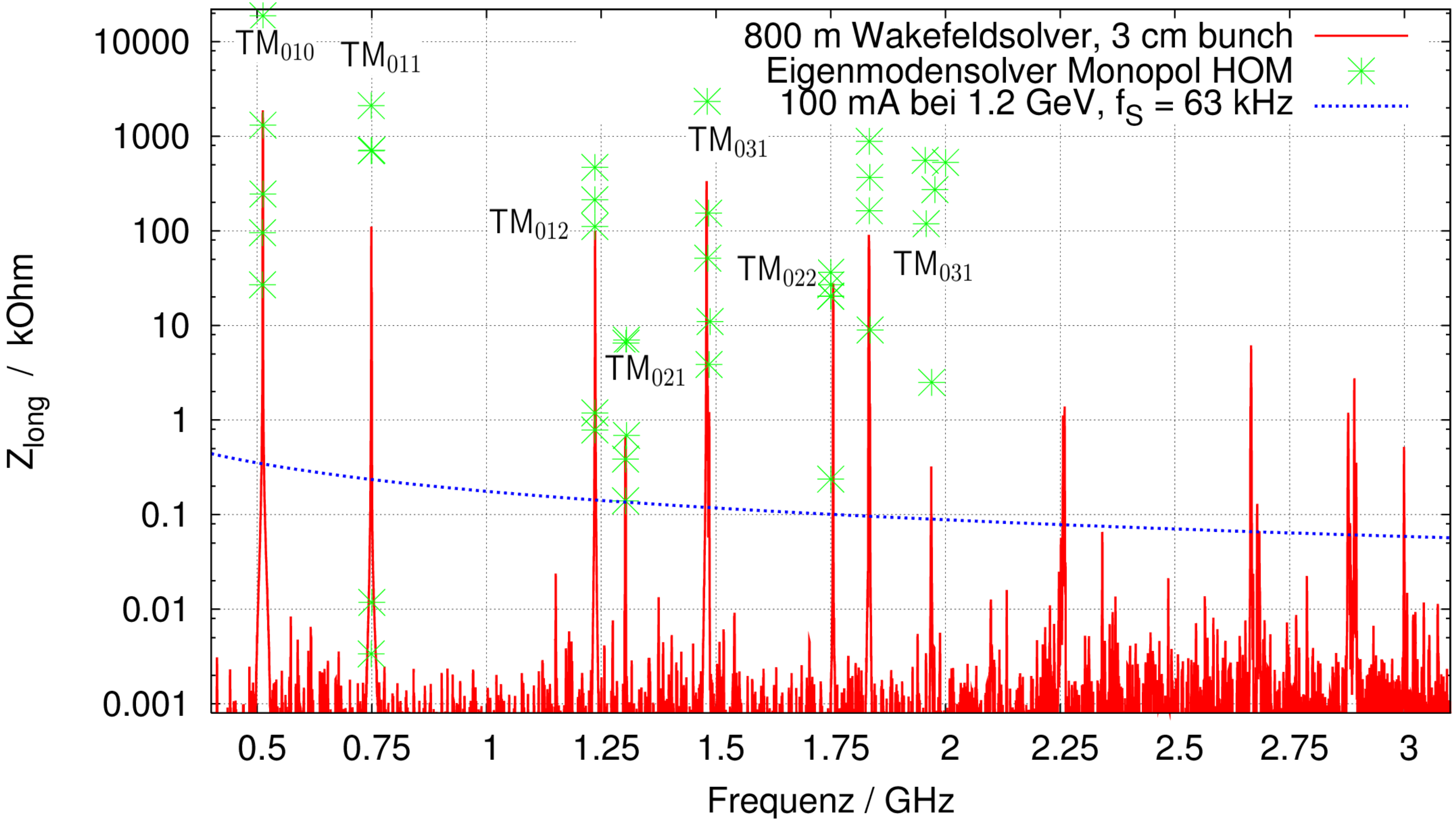
Higher Order Modes of 500 MHz PETRA cavities



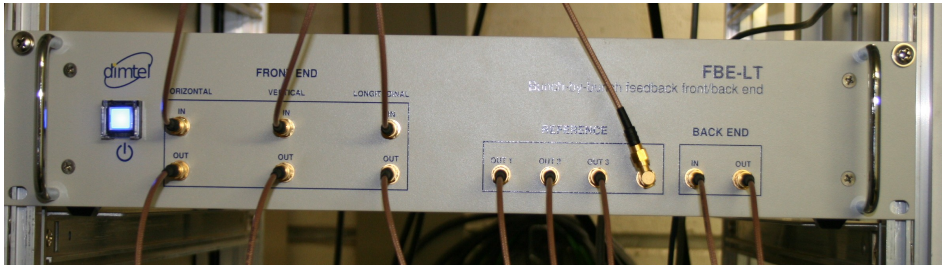
Numerical simulations with CST microwave and particle studio (eigenmode & wakefield solver)

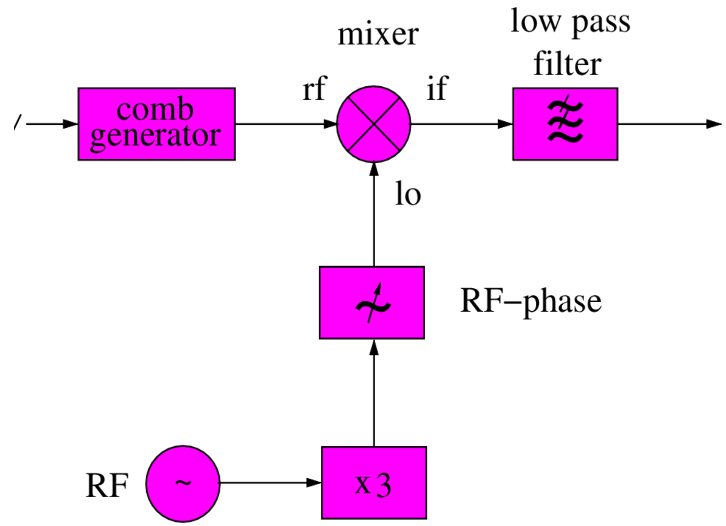


Impedances of HOMs are well above multibunch stability thresholds due to radiation damping!



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**

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

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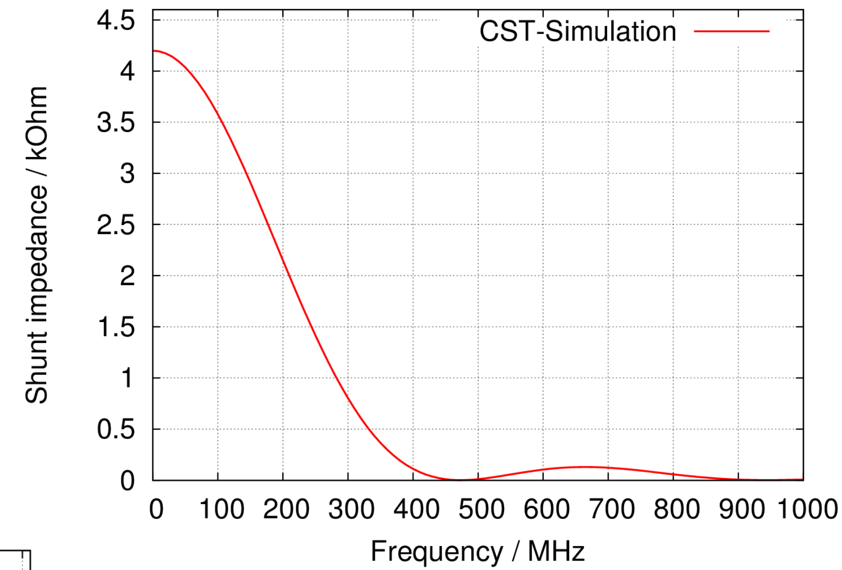
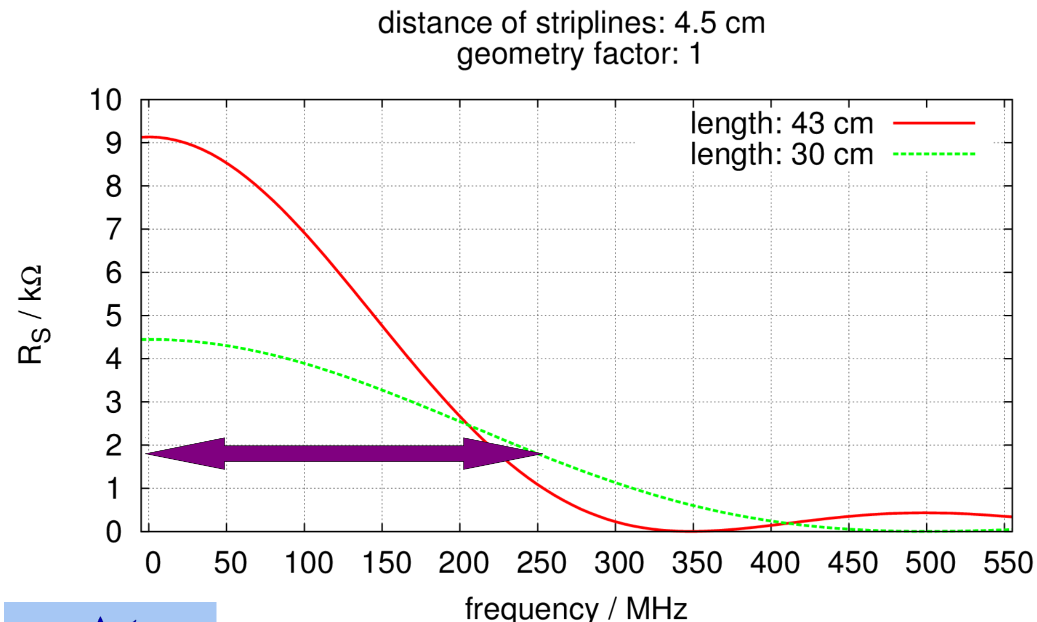
Transverse Stripline Kickers: shuntimpedance vs. frequency

general behaviour: ~ sin(x)/x

Simulation





30 cm:
- zero @ 500 Mhz
- larger BW