Beam Parameter Stabilization at MESA for P2

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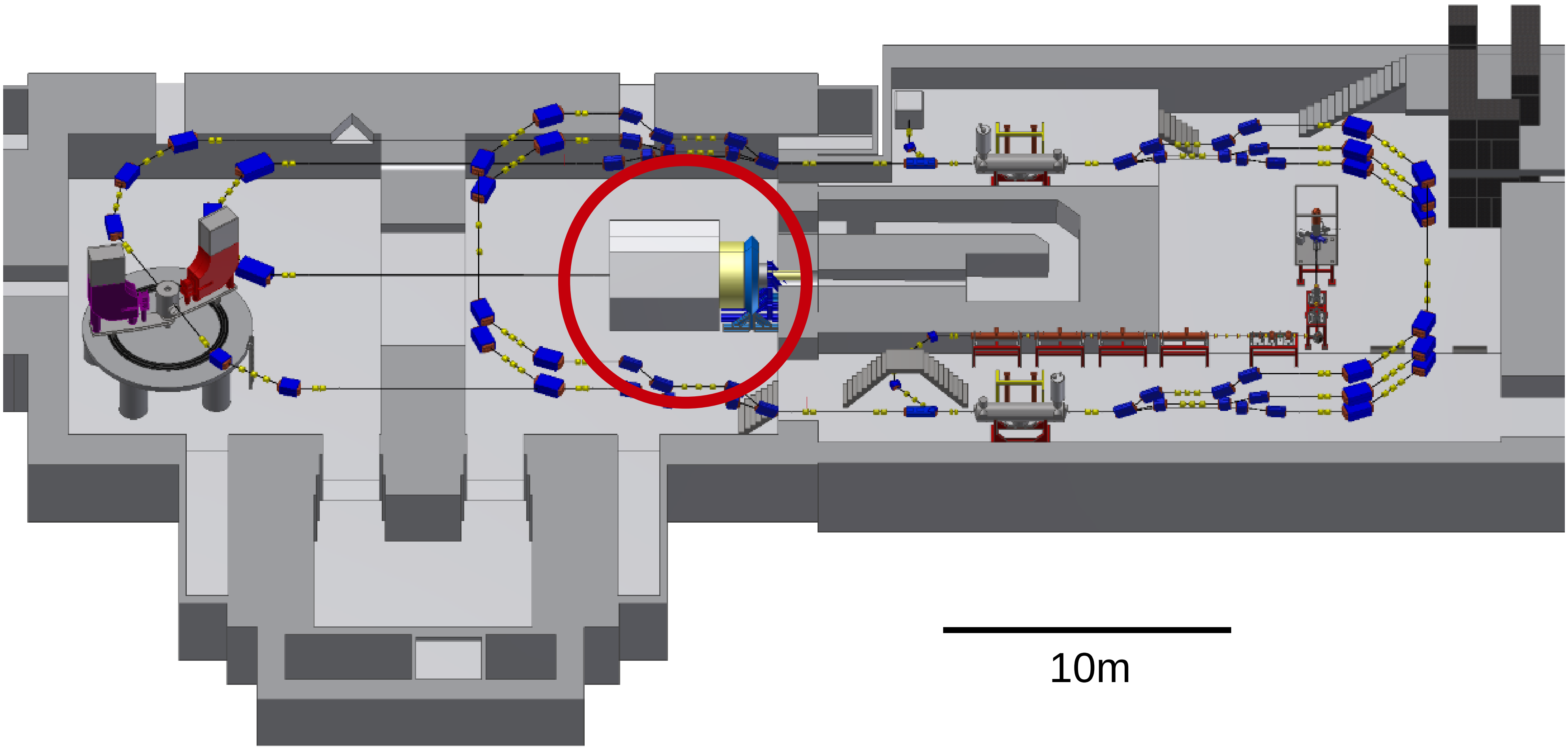
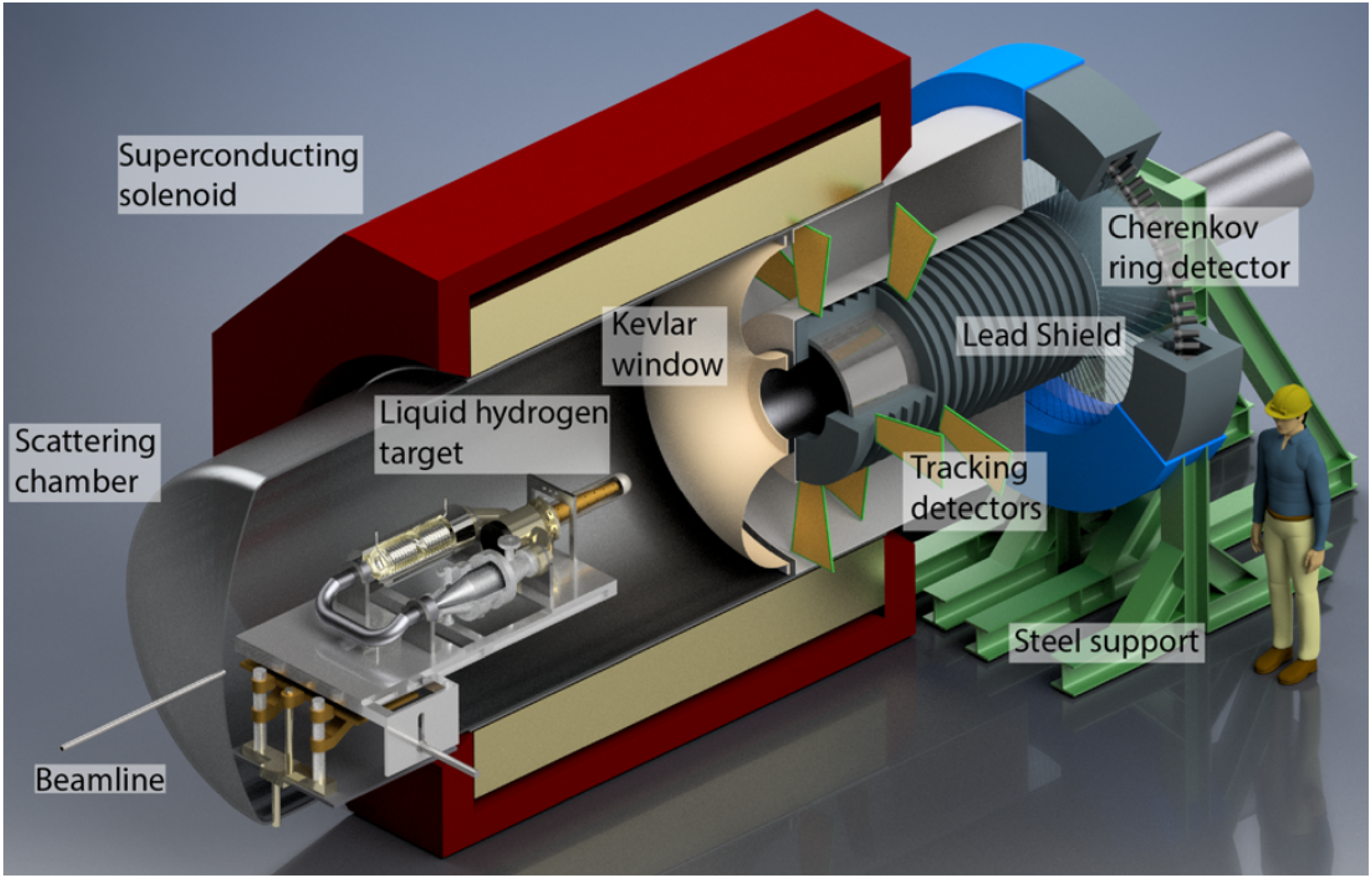
P2 @ MESA



P2 Detector



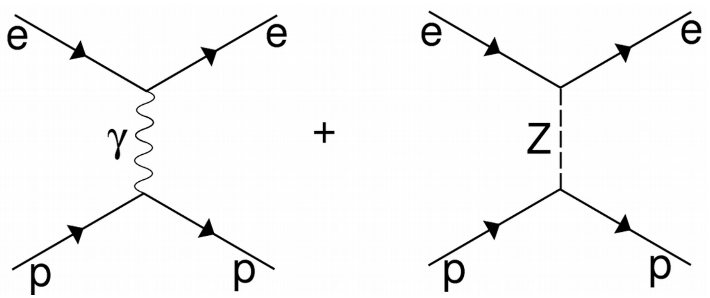
See also:
The P2 Experiment
arXiv:1802.04759

Motivation

- **P2 experiment at MESA**
- Measuring the weak mixing angle
- external beam mode with low energy and high current:
  - **150µA, 155MeV**
- longitudinally polarized beam
  - fast helicity flipping **~kHz**
- parity violation (elastic ep scattering)
  - expected asymmetry **~30ppb**
- **very strong demands on beam quality!**
  - **intensity, energy, position, angle**

Measuring Asymmetry with Electron-Proton-Scattering

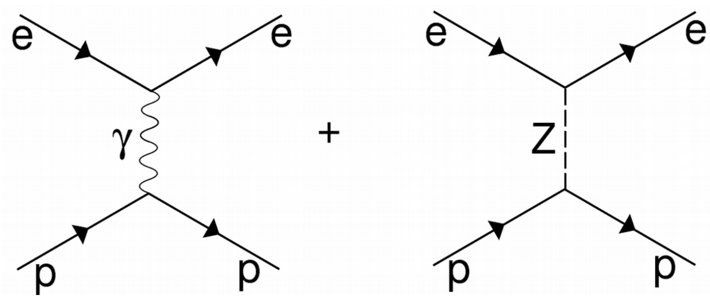
electromagnetic



weak

Measuring Asymmetry with Electron-Proton-Scattering

electromagnetic



weak

- Measured asymmetry determined by the cross section for electron-proton-scattering with polarized electrons:

$$A^{\mathrm{PV}} \equiv \frac{\sigma_{\mathrm{ep}}^{+} - \sigma_{\mathrm{ep}}^{-}}{\sigma_{\mathrm{ep}}^{+} + \sigma_{\mathrm{ep}}^{-}}$$

Measuring Asymmetry with Electron-Proton-Scattering

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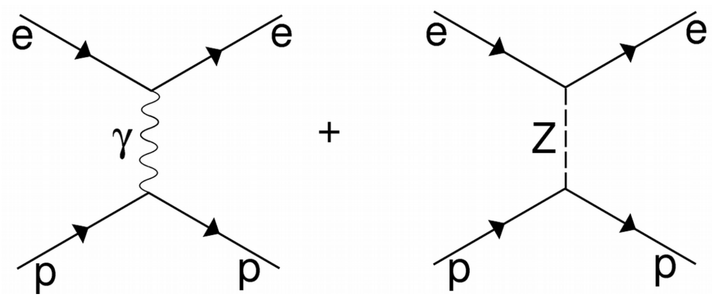
electromagnetic  weak

- Measured asymmetry determined by the cross section for electron-proton-scattering with polarized electrons:

$$A^{\mathrm{PV}} \equiv \frac{\sigma^{+}_{\mathrm{ep}} - \sigma^{-}_{\mathrm{ep}}}{\sigma^{+}_{\mathrm{ep}} + \sigma^{-}_{\mathrm{ep}}}$$

$$\sigma^{+}_{\mathrm{ep}} \propto |M_\gamma + M_{Z,R}|^2$$
$$\sigma^{-}_{\mathrm{ep}} \propto |M_\gamma + M_{Z,L}|^2$$

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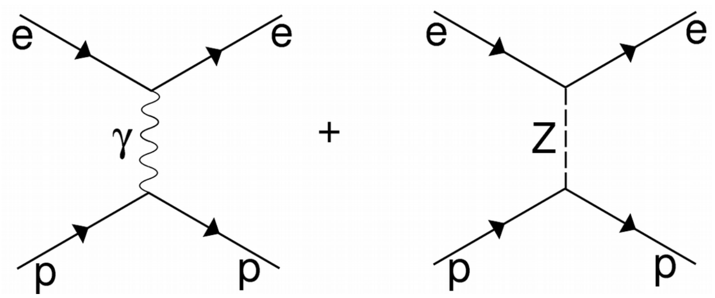
Measuring Asymmetry with Electron-Proton-Scattering

electromagnetic



weak

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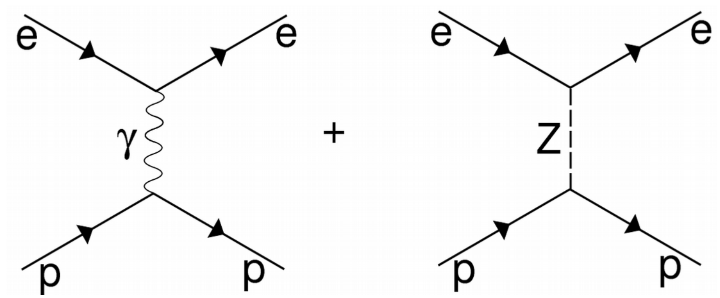
$$\sigma_{\mathrm{ep}}^{+} \propto |M_\gamma + M_{Z,R}|^2$$
$$\sigma_{\mathrm{ep}}^{-} \propto |M_\gamma + M_{Z,L}|^2$$

$$M_\gamma \propto \frac{1}{Q^2}$$
$$M_Z \propto \frac{1}{m_Z^2}$$

Measuring Asymmetry with Electron-Proton-Scattering

electromagnetic



weak

- Measured asymmetry determined by the cross section for electron-proton-scattering with polarized electrons:

$$A^{\mathrm{PV}} \equiv \frac{\sigma^+_{\mathrm{ep}} - \sigma^-_{\mathrm{ep}}}{\sigma^+_{\mathrm{ep}} + \sigma^-_{\mathrm{ep}}}$$

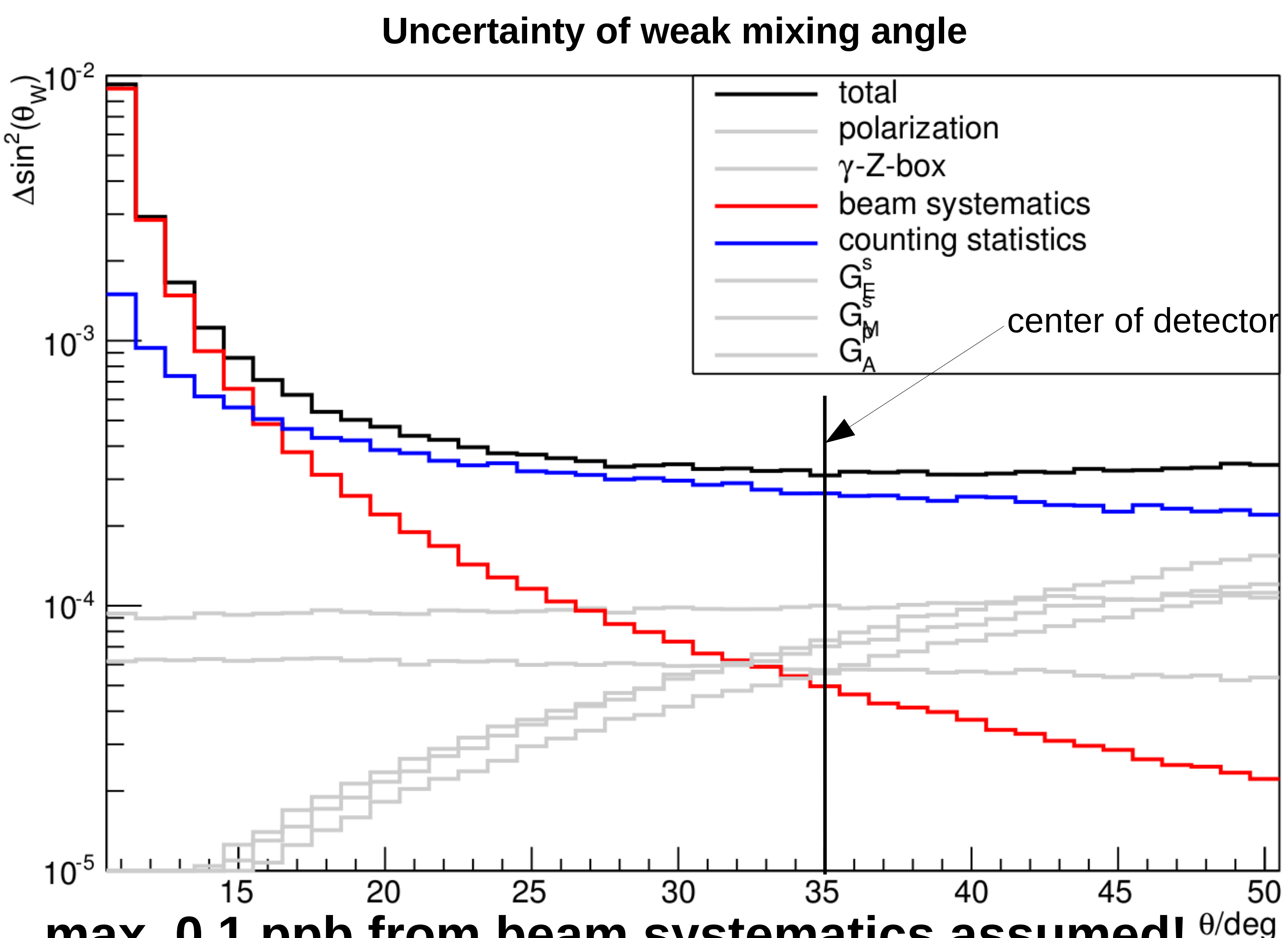
$$\sigma^+_{\mathrm{ep}} \propto |M_\gamma + M_{Z,R}|^2$$
$$\sigma^-_{\mathrm{ep}} \propto |M_\gamma + M_{Z,L}|^2$$

$$M_\gamma \propto \frac{1}{Q^2}$$
$$M_Z \propto \frac{1}{m_Z^2}$$

- Expected asymmetry determined by spin polarization and apparative asymmetry.

$$A^{\mathrm{exp}} = P \cdot \langle A^{\mathrm{PV}} \rangle_{L,\ \delta\theta_{\mathrm{f}}} + A^{\mathrm{app}}$$

P2 Beam Quality Requirements



max. 0.1 ppb from beam systematics assumed!

See also arXiv:1802.04759

Measuring Asymmetry in 4ms

- STA: short term asymmetry
- Measured in a 4ms pattern of spin states of 1ms length: +--+ or -++-
- In 10kh measuring time are 9×10^9 STAs.

$$\Delta A^{\mathrm{app}} = \frac{\sigma}{\sqrt{9 \times 10^9}} \stackrel{!}{=} 0.1\,\mathrm{ppb}$$

$$\Rightarrow \quad \sigma = \Delta A^{\mathrm{app}}(STA) \stackrel{!}{=} 9.5\,\mathrm{ppm}$$

Approach for Stable and Accurate Beam

- Digital Control System (FPGA)
  - Further Pros: highly flexible, quickly replaceable
- IQ-Demodulation
- Differential Signal Transfer
- Feedback and Feedforward Control
  - „Feedforward“: pre-adaption to upcoming beam shift from helicity switch
- High Sensitivity Beam Position Monitors

Stabilization Principle and Setup of Hardware

Arrangement of Steerers and BPMs in Hall B (RTM3)@MAMI

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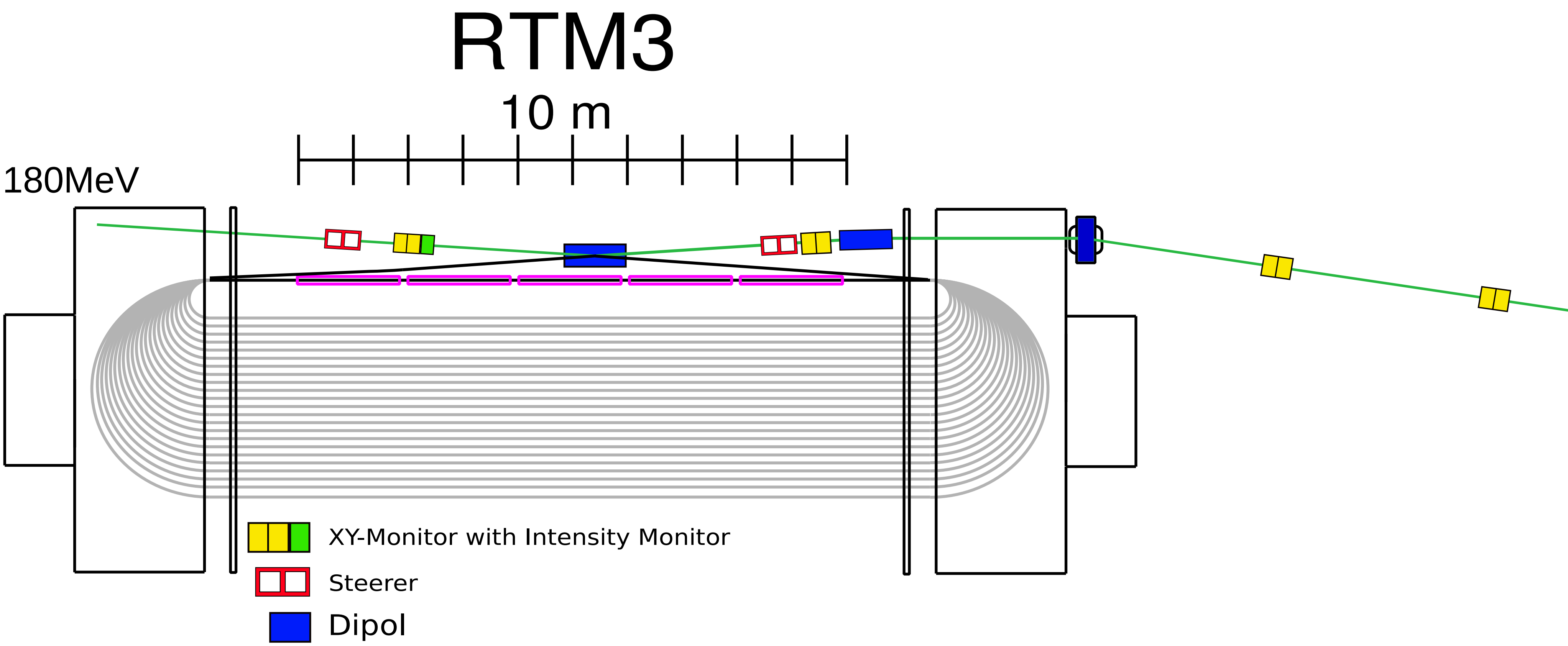
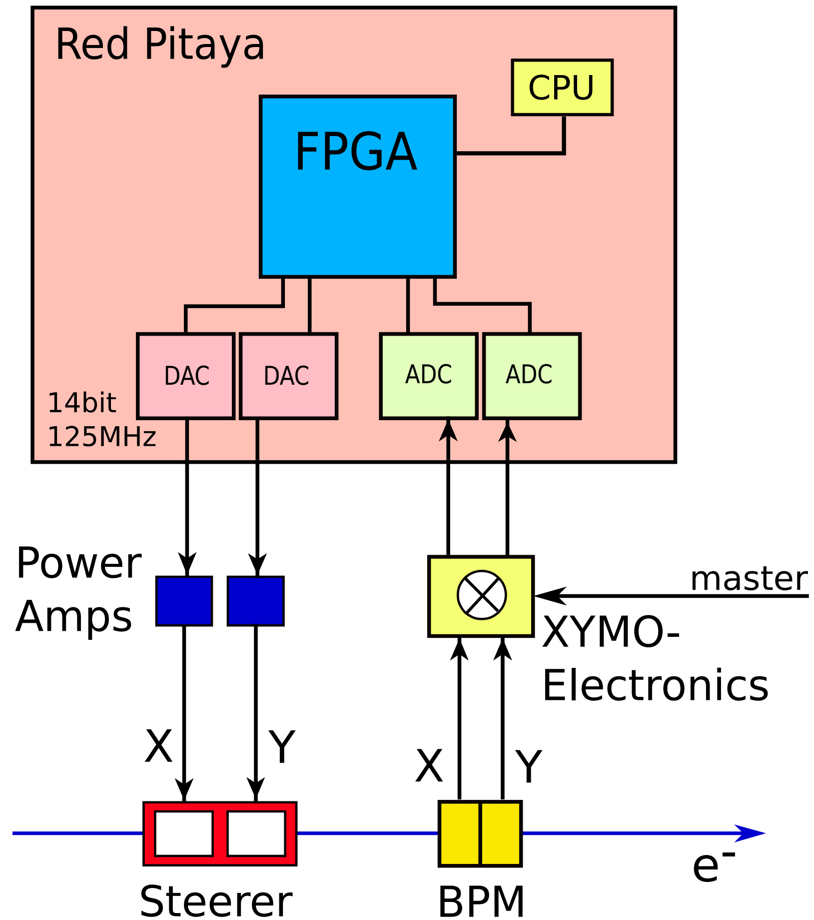
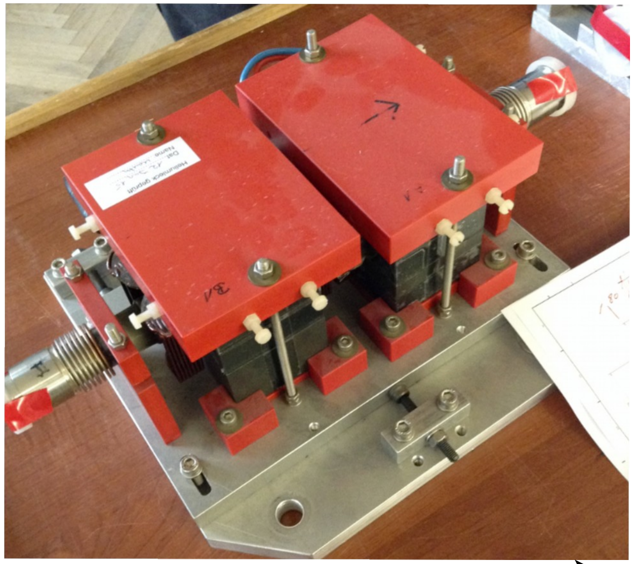


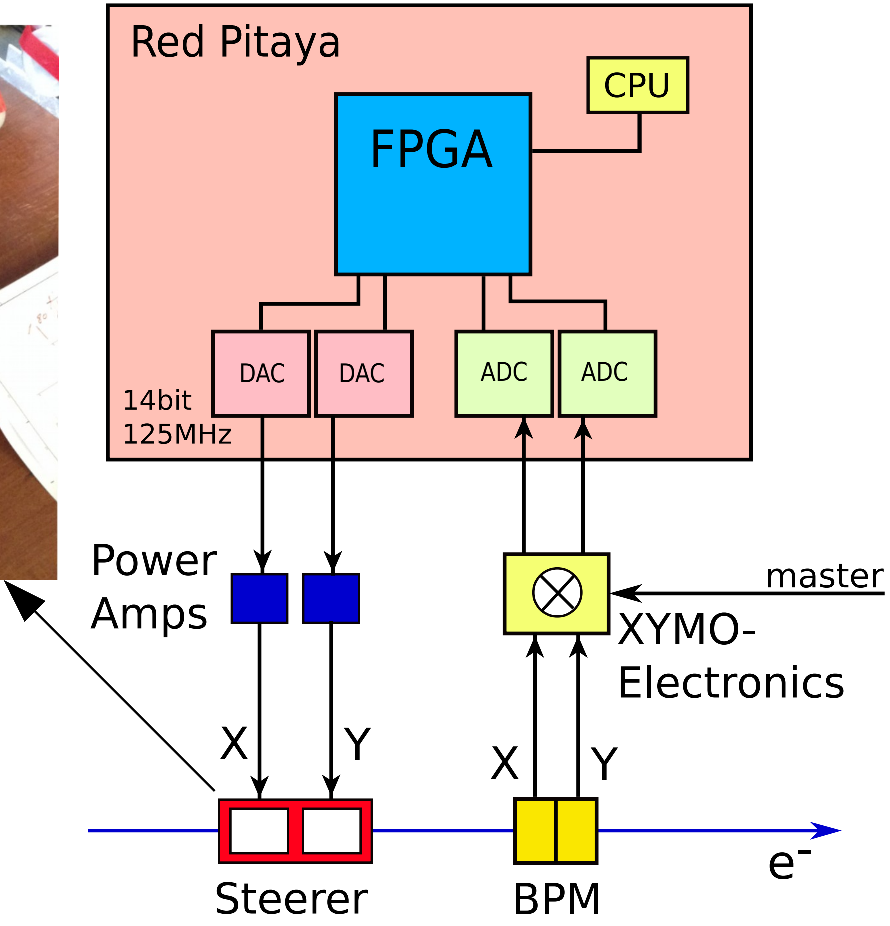
Stabilization Principle and Hardware



Stabilization Principle and Hardware

Fast Steerer





Stabilization Principle and Hardware

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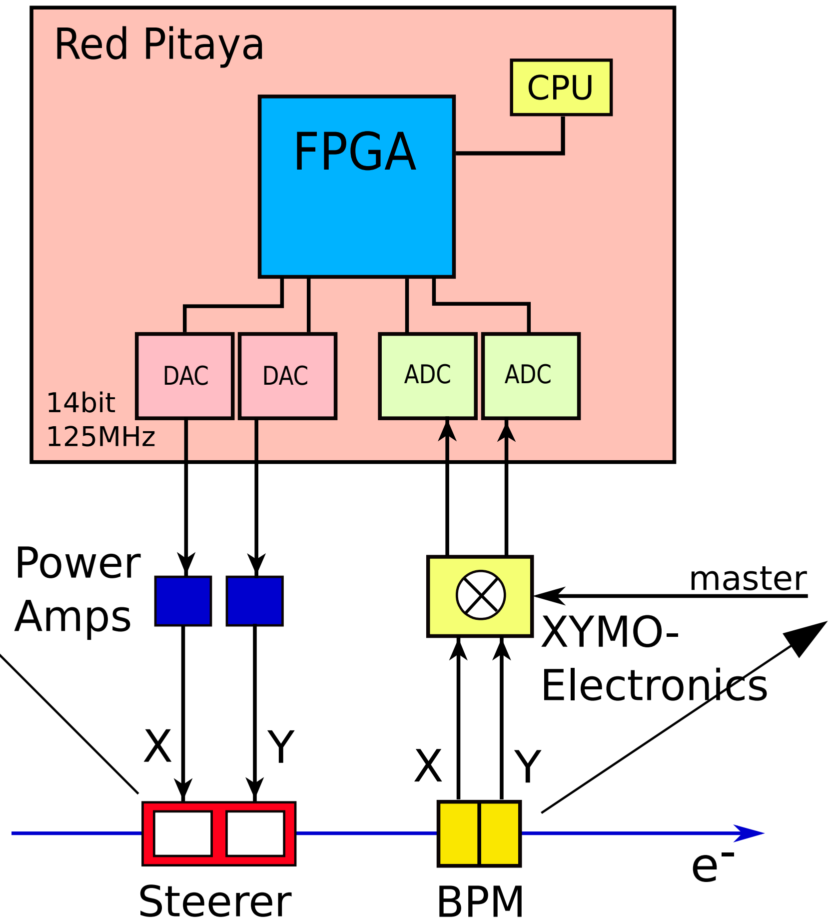
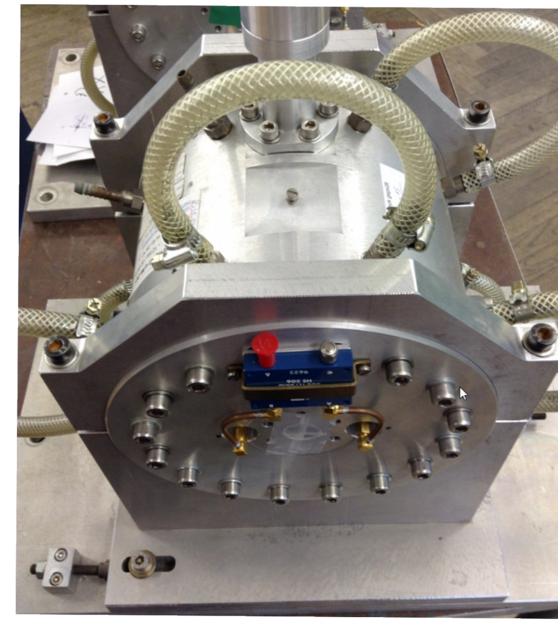


BPM



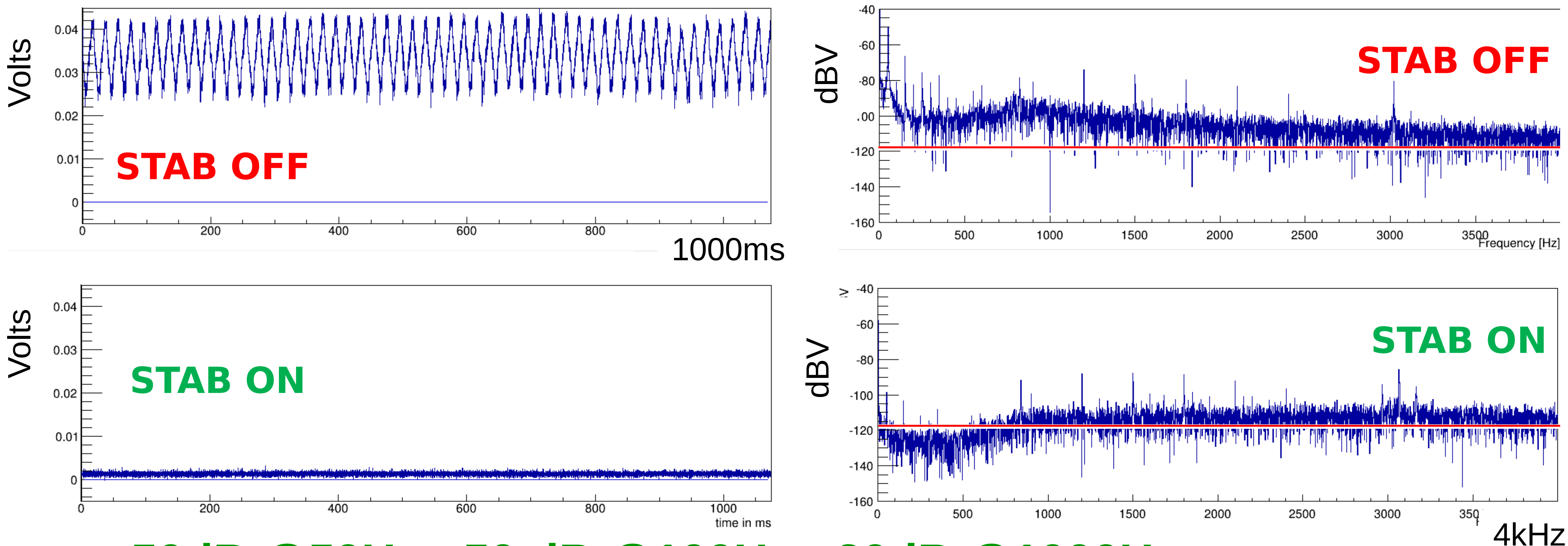
- 2 Resonating Cavities
- 2.45 GHz resonance frequency

Successful Stabilization Tests

- using RedPitaya internal PID blocks (used only PI)!

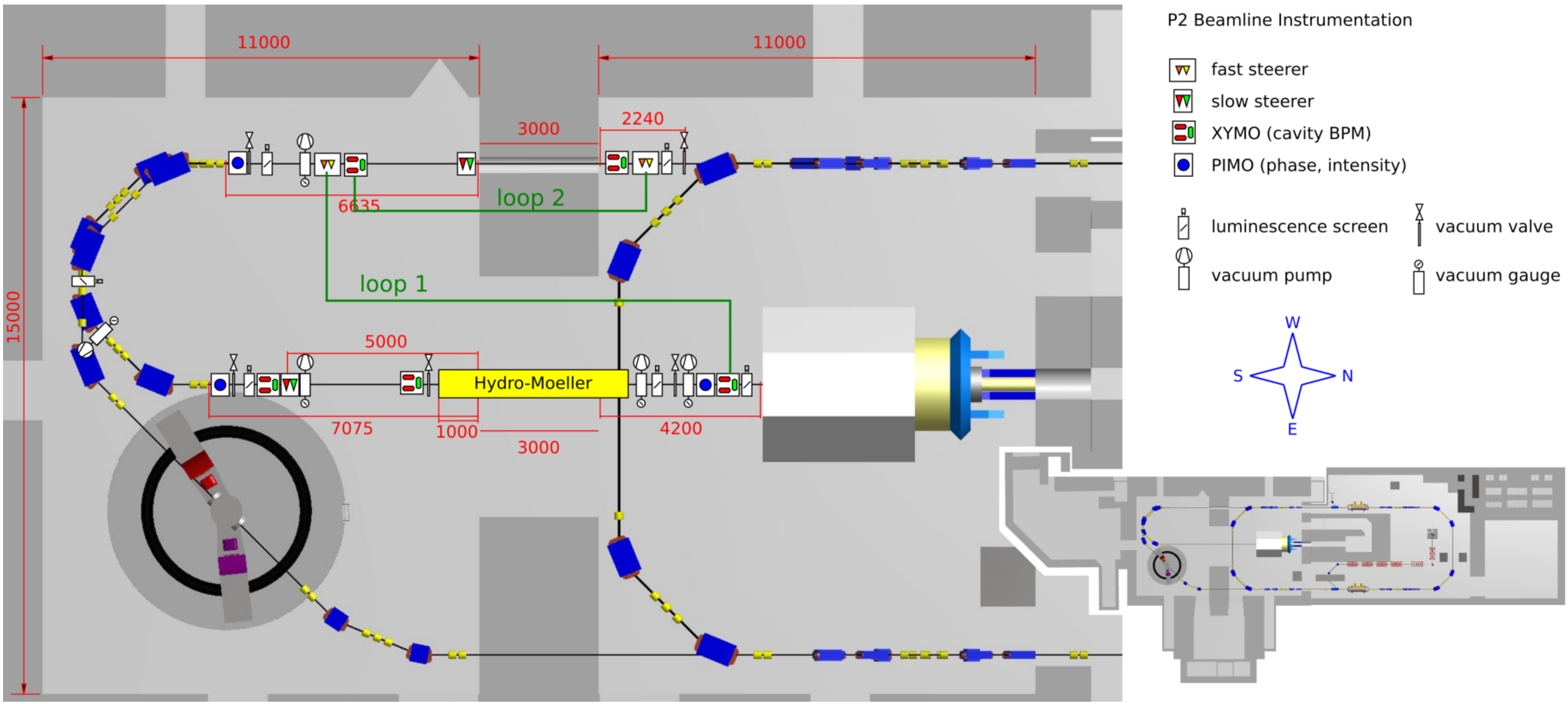
Time plot (1000ms)

Spectrum (0-4kHz)



- **-50dB @50Hz, -50 dB @100Hz, -20dB @1000Hz** (A4/MAMI: -40dB@50Hz)

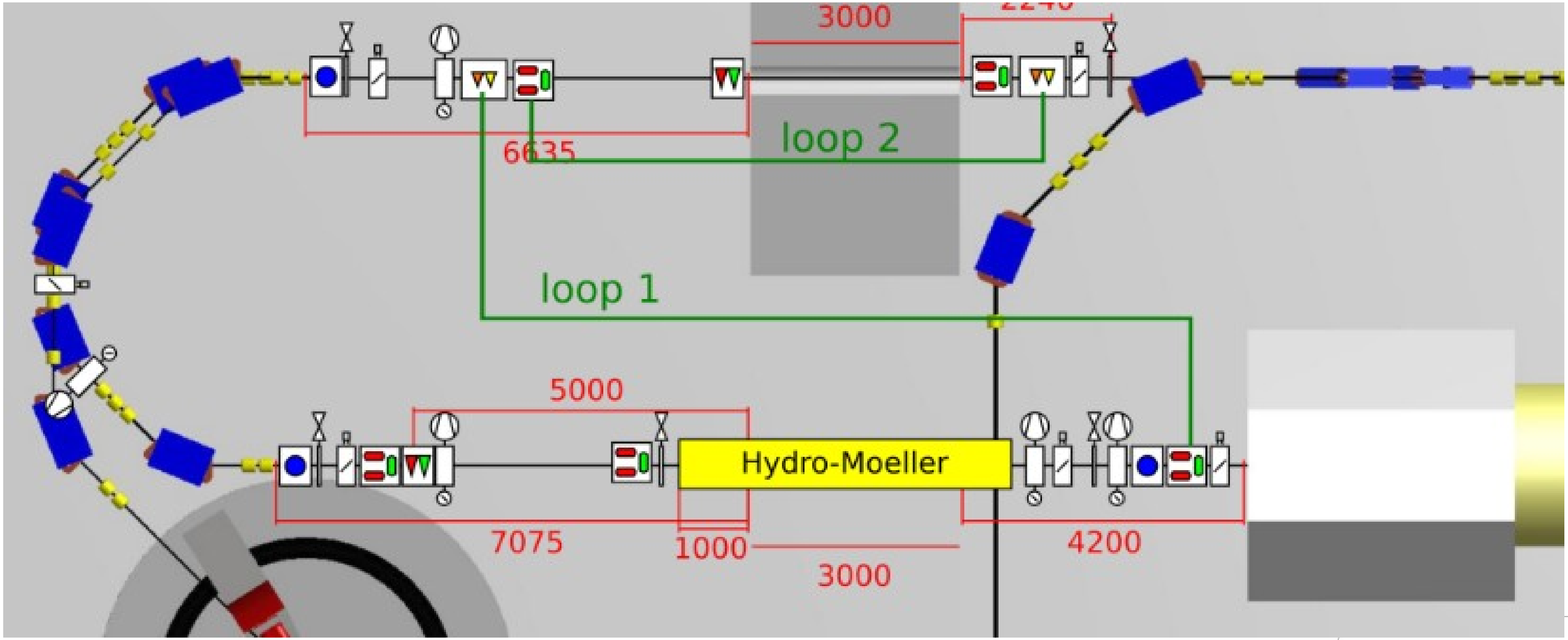
Planned Setup Beam Control in MESA



Planned Setup Beam Control in MESA

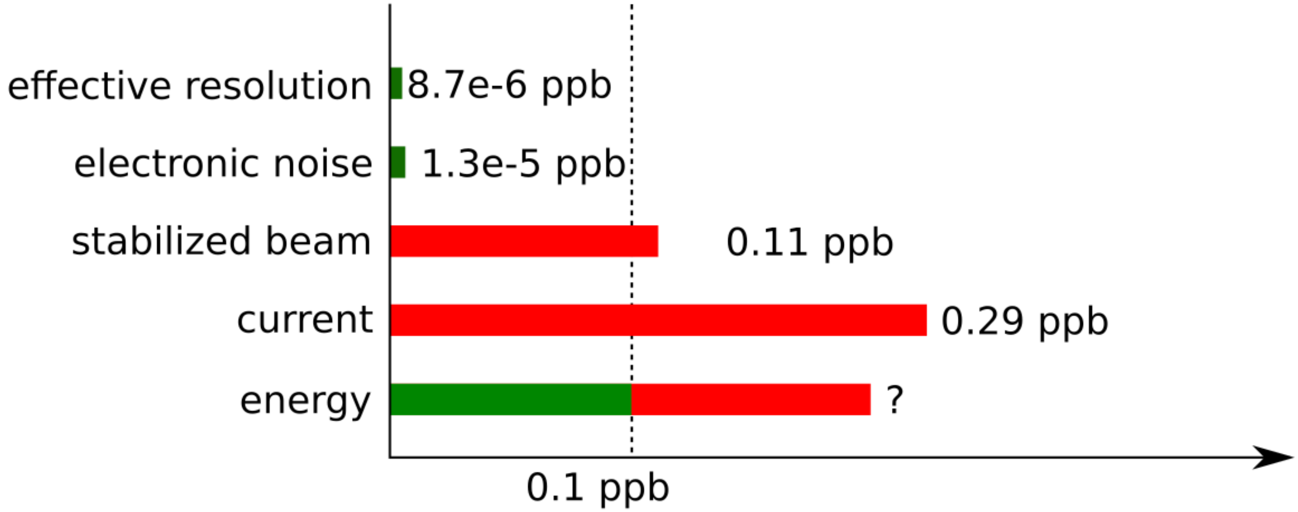
P2 Beamline Instrumentation

- fast steerer
- slow steerer
- XYMO (cavity BPM)
- PIMO (phase, intensity)



Asymmetry Uncertainties Results

Expected Asymmetry Uncertainties after 10kh measuring time at 150µA



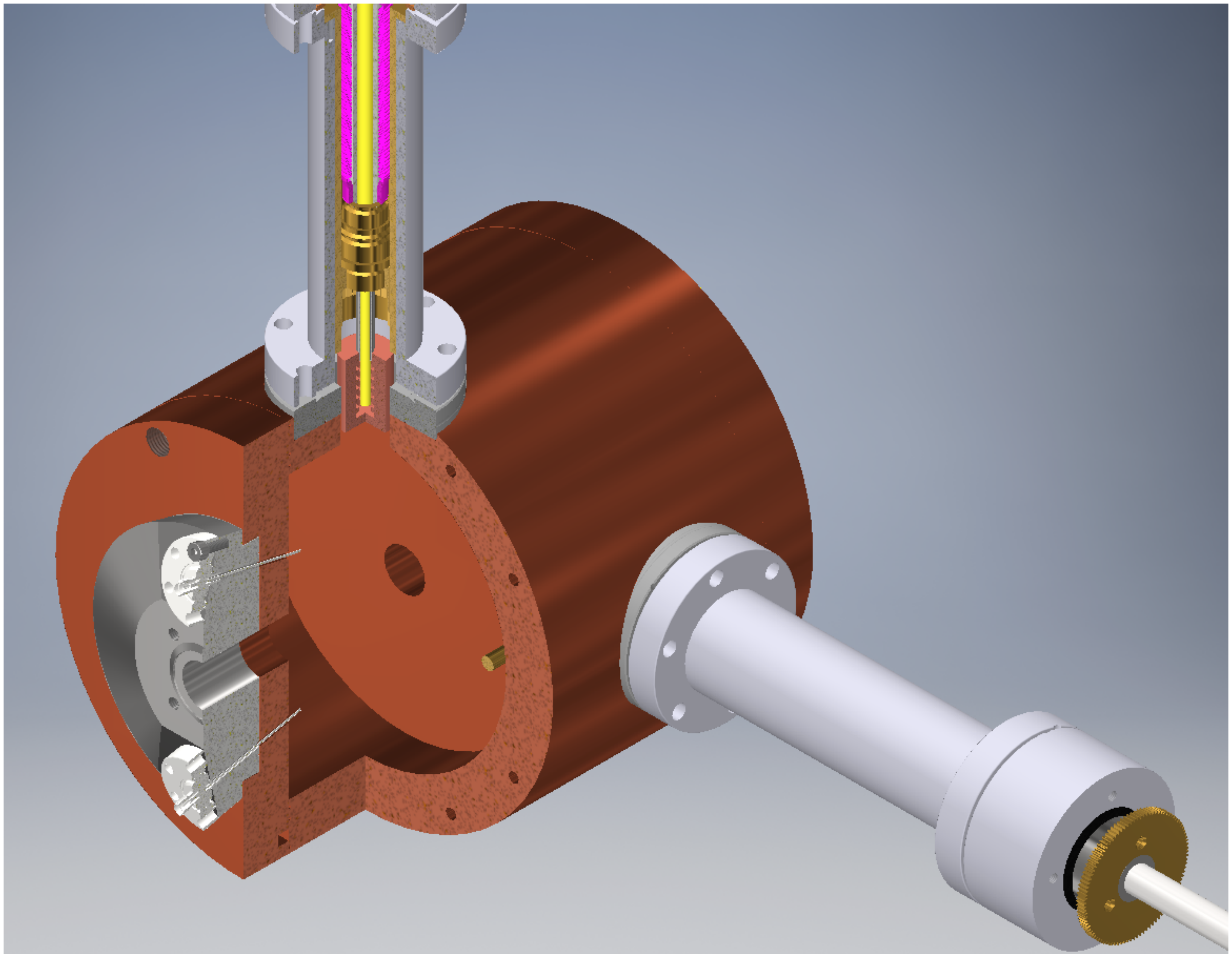
- Position and current based on signal widths measured in Tests at MAMI
- Scaled to 150µA in 10kh and averaged over 8192 samples of 8ns.
- Energy asymmetry is estimated from A4 data. 0.1 ppb feasible but not yet demonstrated. Relative energy width of 10^{-5} needed.

Thank you for your attention

Backup

Cavity Design

Cavity Design



- 2 Pillboxes in one
- TM110-mode
- 2,6GHz resonance frequency
- 250kHz bandwidth
- Electric coupling
- Remote tuning/detuning
- Water cooled

Polarized Beam:
Short Term Asymmetry

Beam Current Measurement:

- Stabilization off

- maximize asymmetry with half wave plate

- Helicity flip :

  +--+ -++-   (8ms)

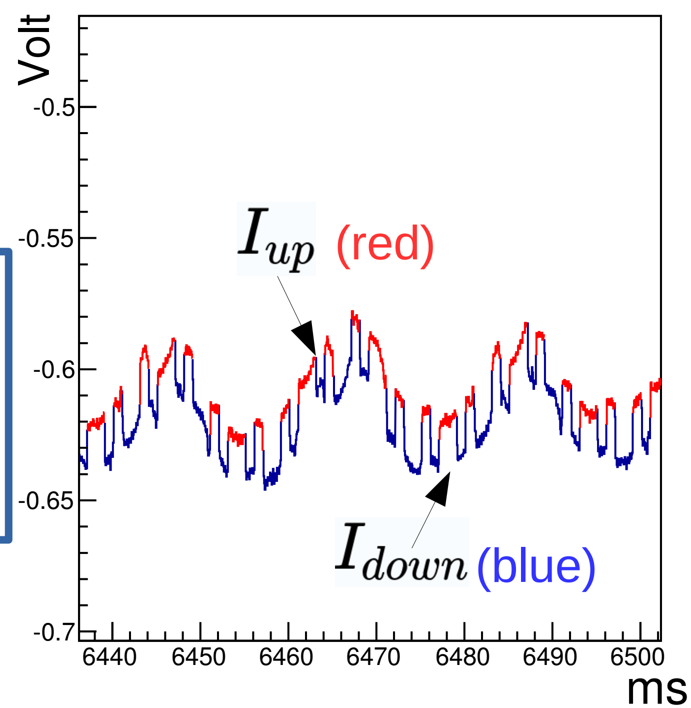
Asymmetry

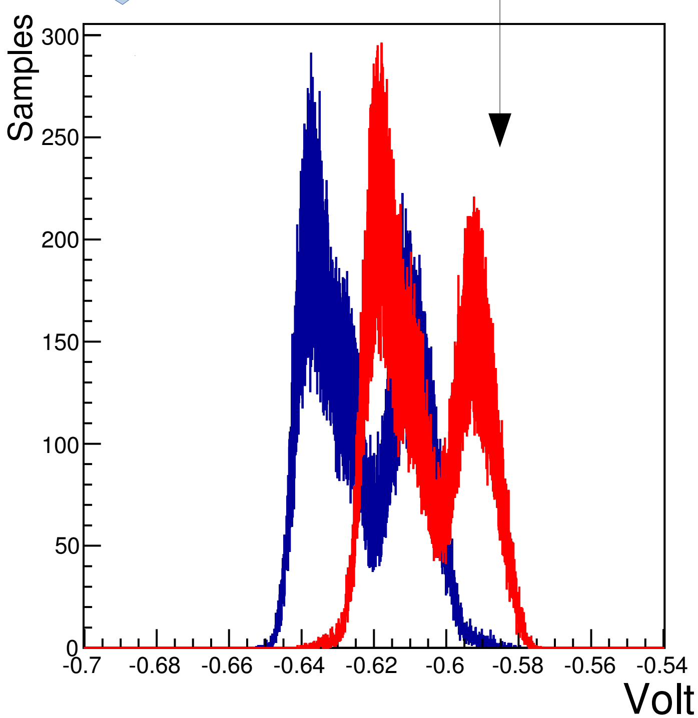
$$A = \frac{I_{up} - I_{down}}{I_{up} + I_{down}}$$

How do you avoid effects from drifts ?!

Beam current shift under helicity switch

Histogrammed





DAQ with "RedPitayas"

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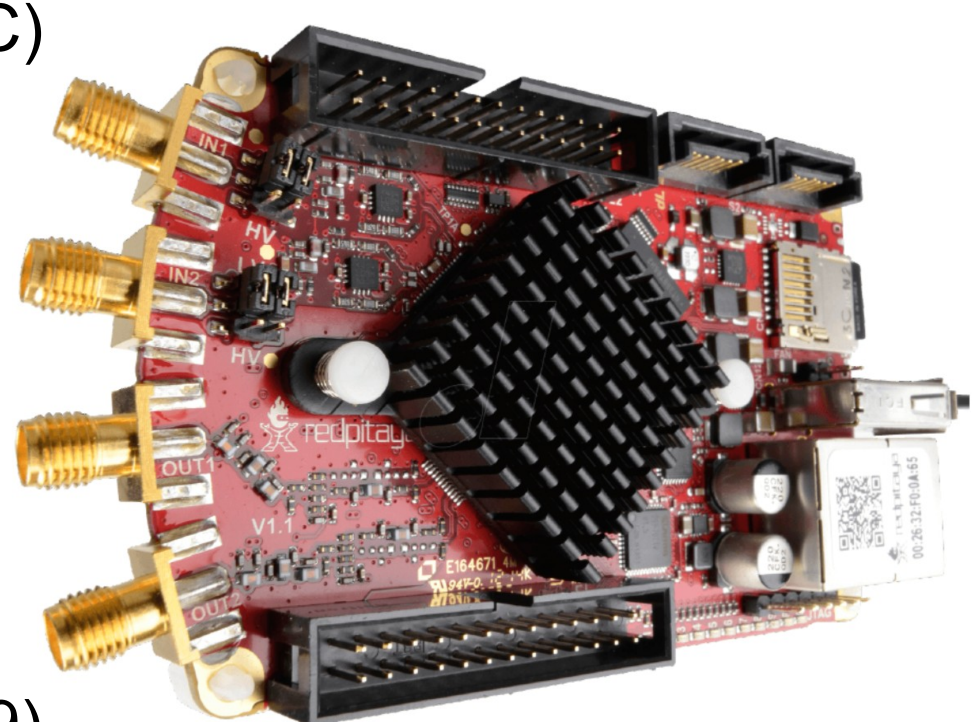
- FPGA+CPU (Xilinx Zynq 7010 SoC)
- 2 fast DACs, 14 Bit / 125MSa/s
- 2 fast ADCs, 14 Bit / 125MSa/s
- GPIO connector w/digital pins (trigger, clock, ...)
- Ethernet, USB
- Linux on dual core ARM (Cortex A9)
- open source (firmware/software)
- ~250 €/pc.



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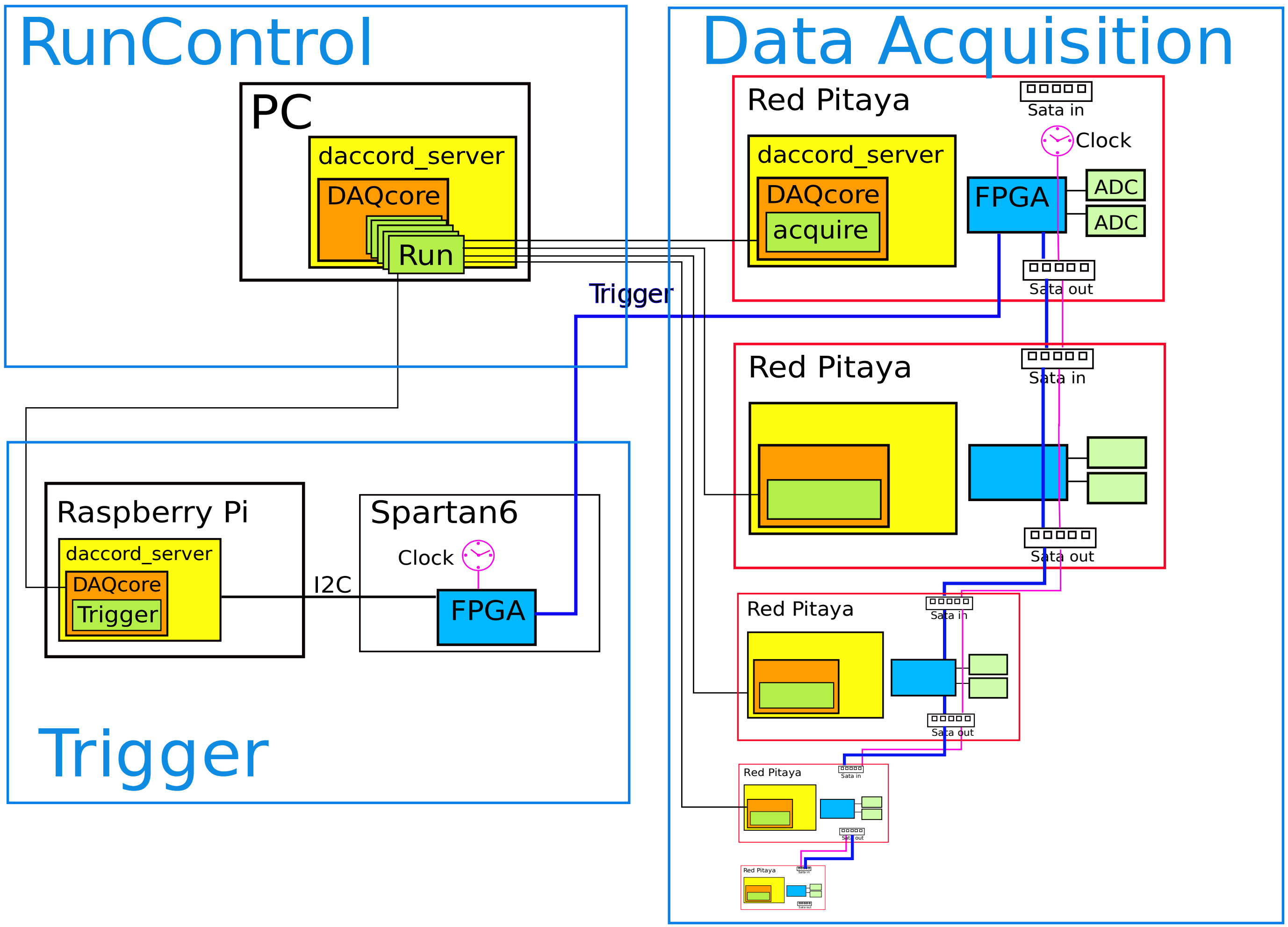
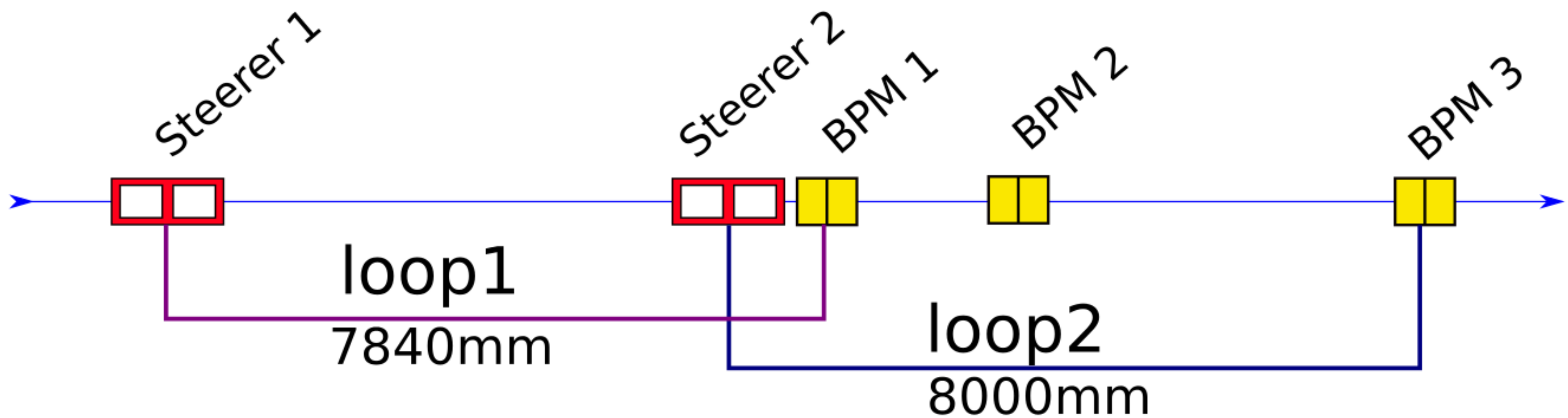
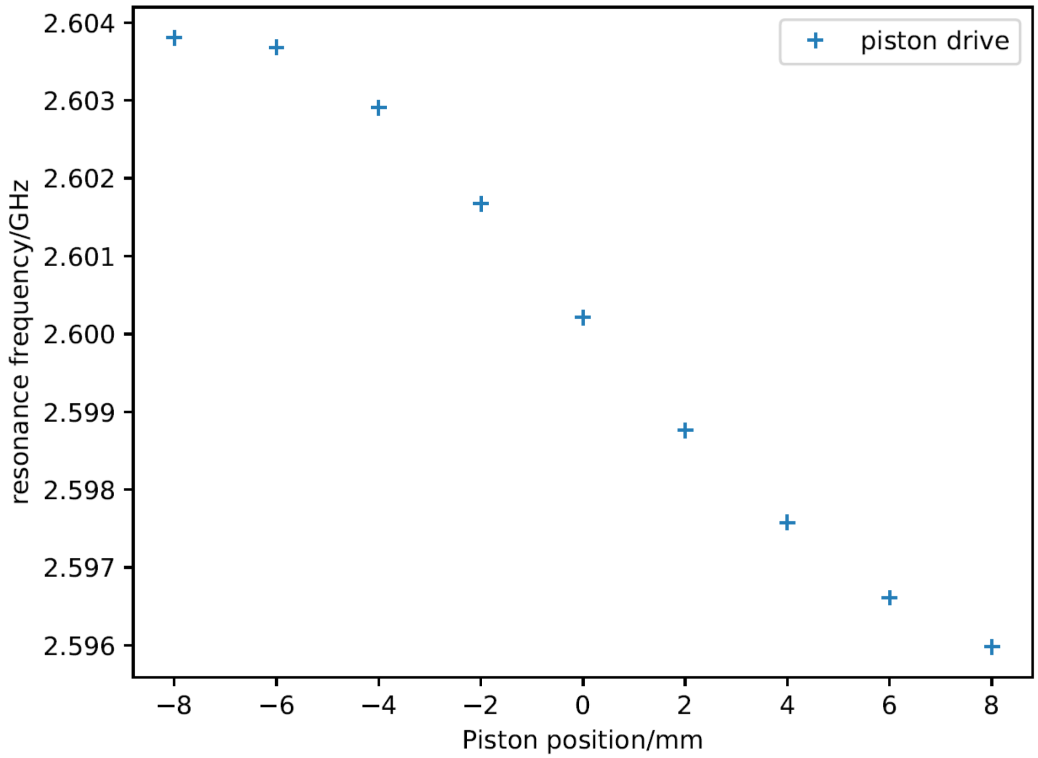
DAQ with “RedPitayas”



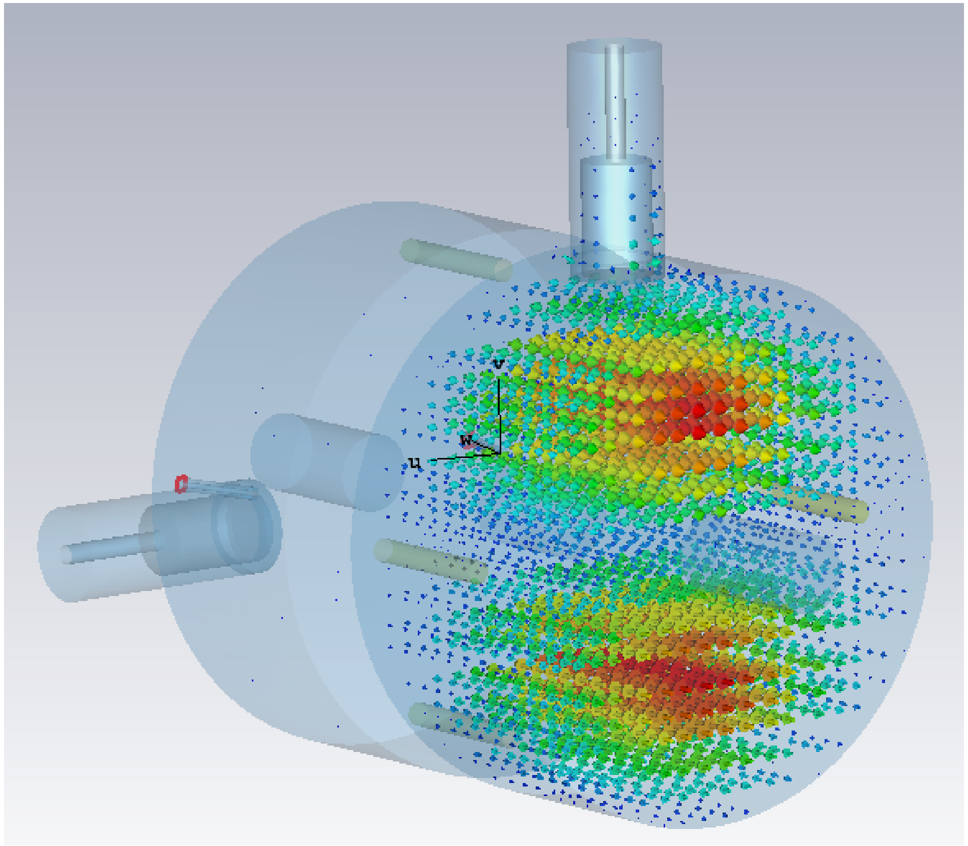

Steerer 1
Steerer 2
BPM 1
BPM 2
BPM 3
loop1
7840mm
loop2
8000mm

Tuning and Detuning



- Moving the Piston changes the resonance frequency
- Piston can drive 12 mm
- Motor makes 7000 steps

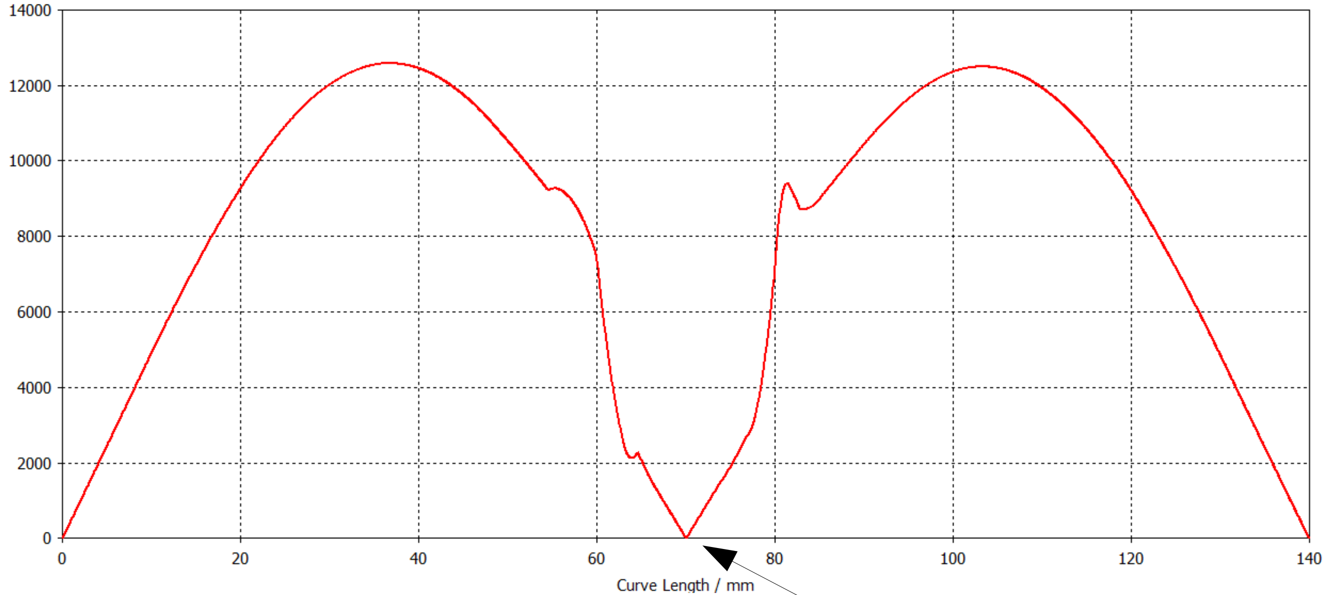
TM110-mode



- Node at the axis of the cavity
- Linear close to the cavity axis
- Perpendicular mode suppressed with mode dividers

TM110-mode

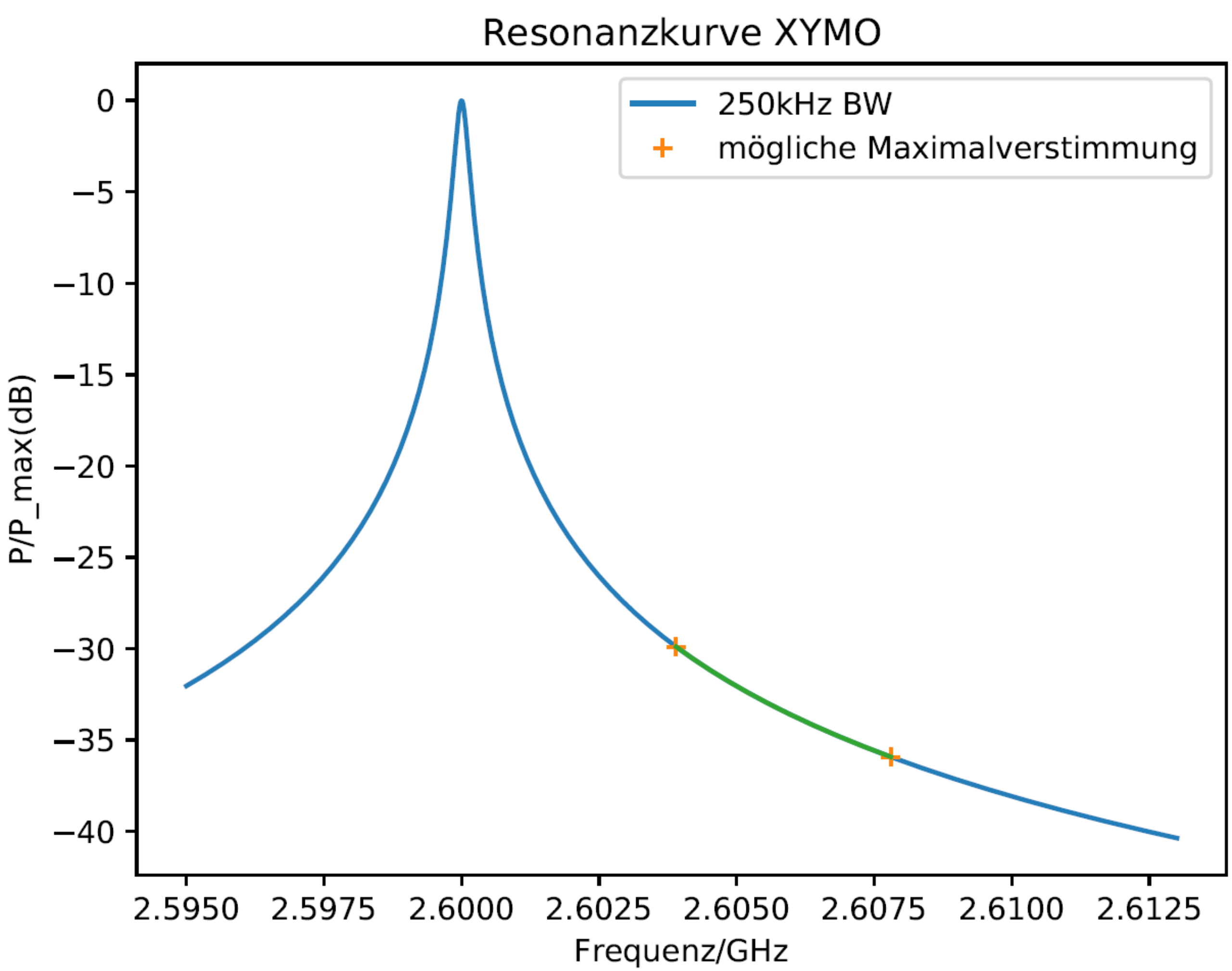
Field Magnitude along antenna axis (without antennas)



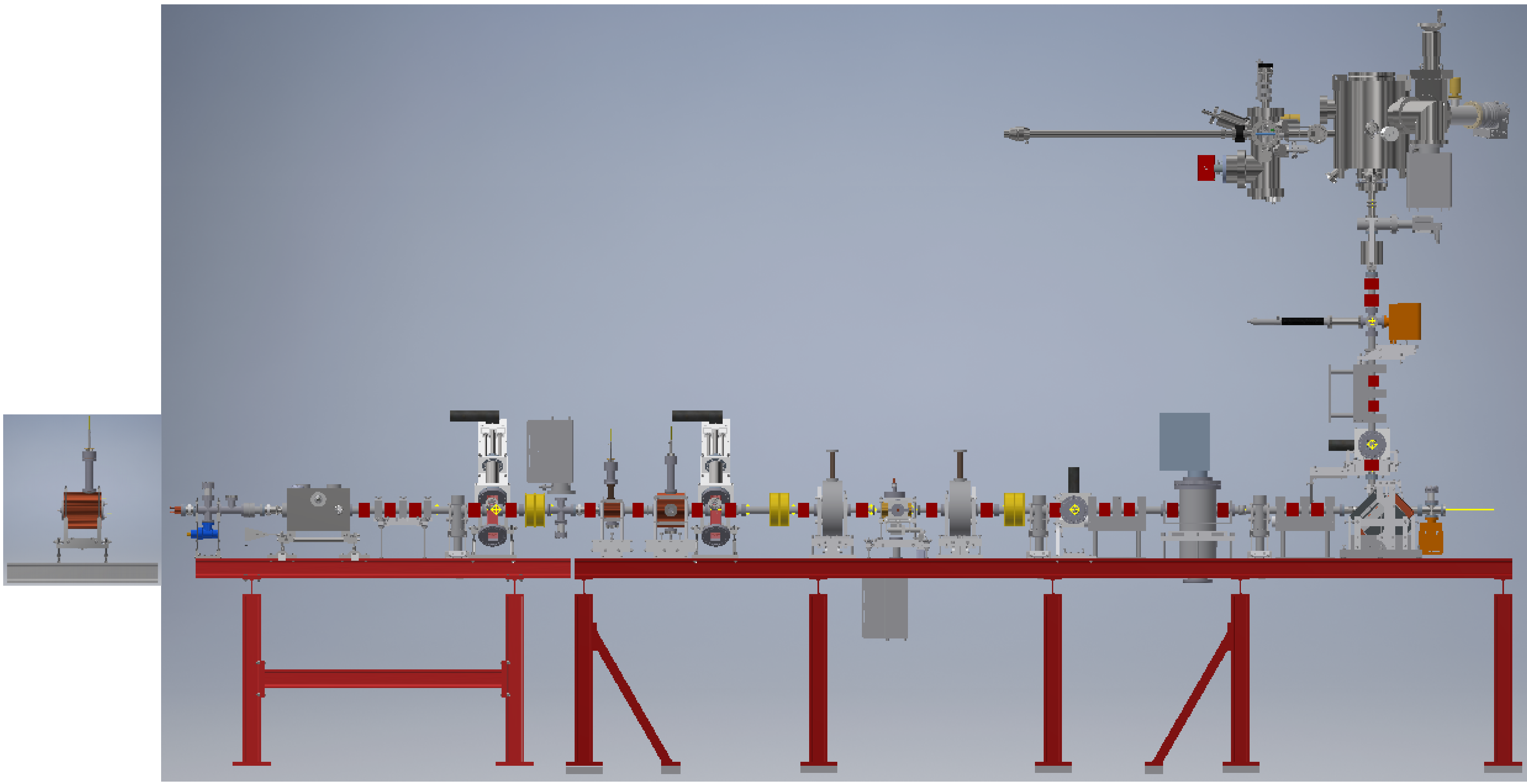
Maxima at +- 33 mm

Linear close to the axis

Remote Tuning und Detuning



- To save sensitive electronics in case of high displacements
- Possible maximal damping: **-30 to -36 dB** depending on piston position at 2.6GHz



Double Differences

- Check for beam loss between two beam current monitors
- Yet no data, example for A4:
- The double difference:

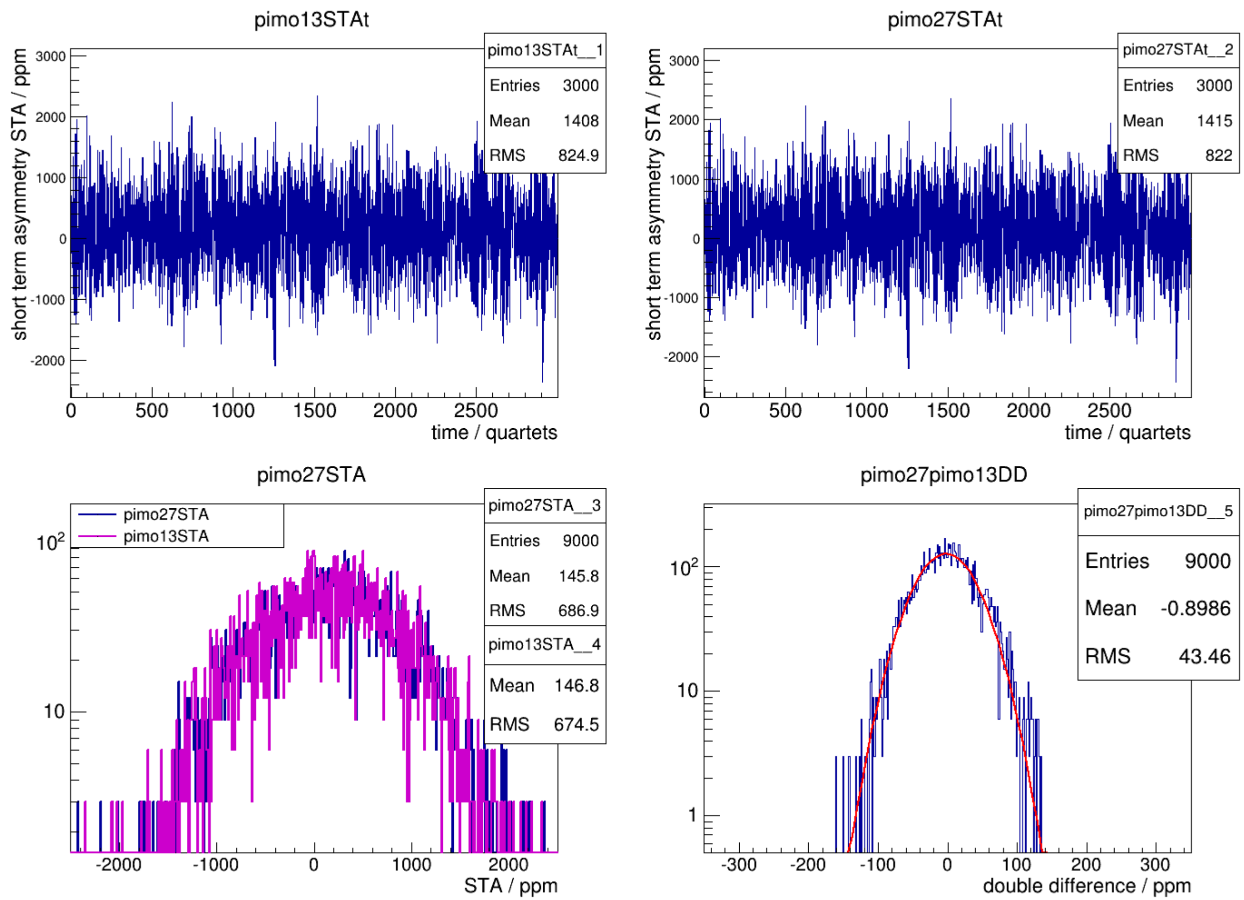
$$dd = sta_1 - sta_2$$

is strictly around zero if no beam was lost.

- The width indicates the resolution of the monitors:

$$\sigma(dd) = \sigma(pimo_{13})^2 + \sigma(pimo_{27})^2$$

- Tests with our setup in December

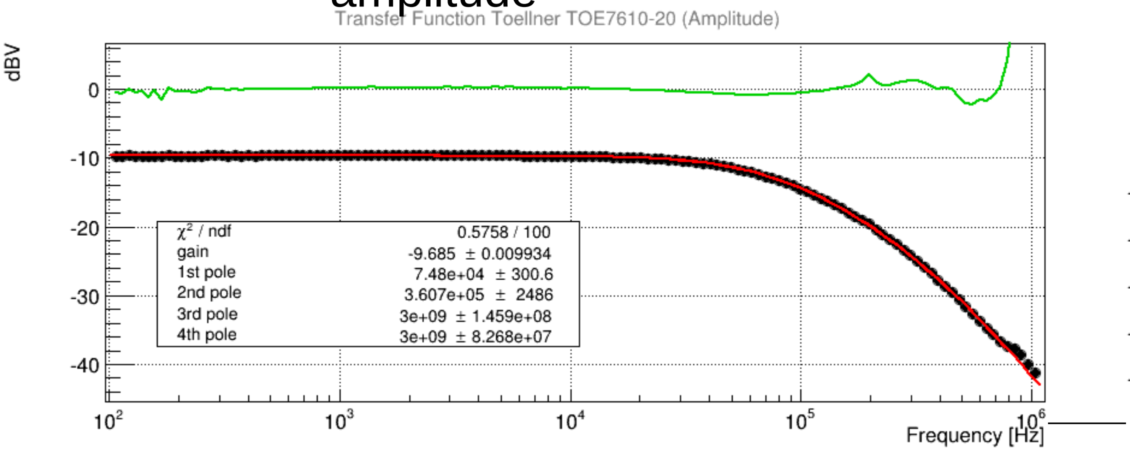


Measurements of Transfer Functions

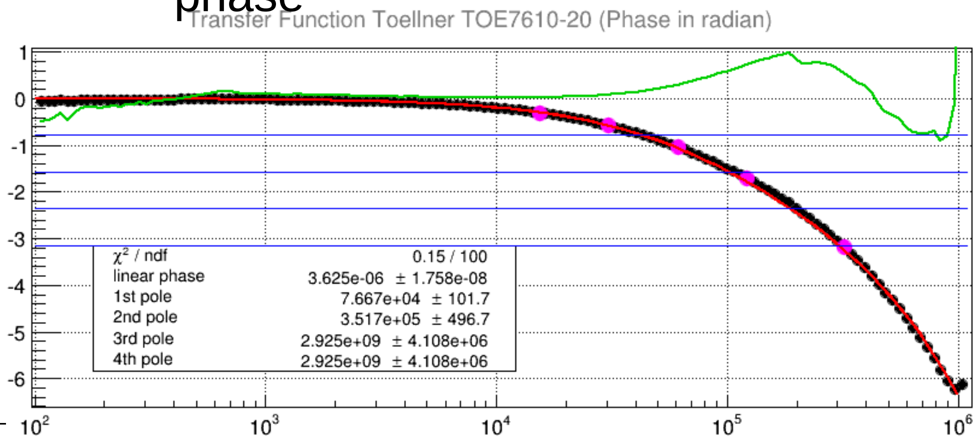
- automatic measurement
  - RedPitaya as signal generator + digitizer
  - With beam at MAMI or without beam at test stand (MESA halls)
- characterization of components of control loop
- open loop → predict closed loop behavior

<u>Transfer function Example</u>

amplitude

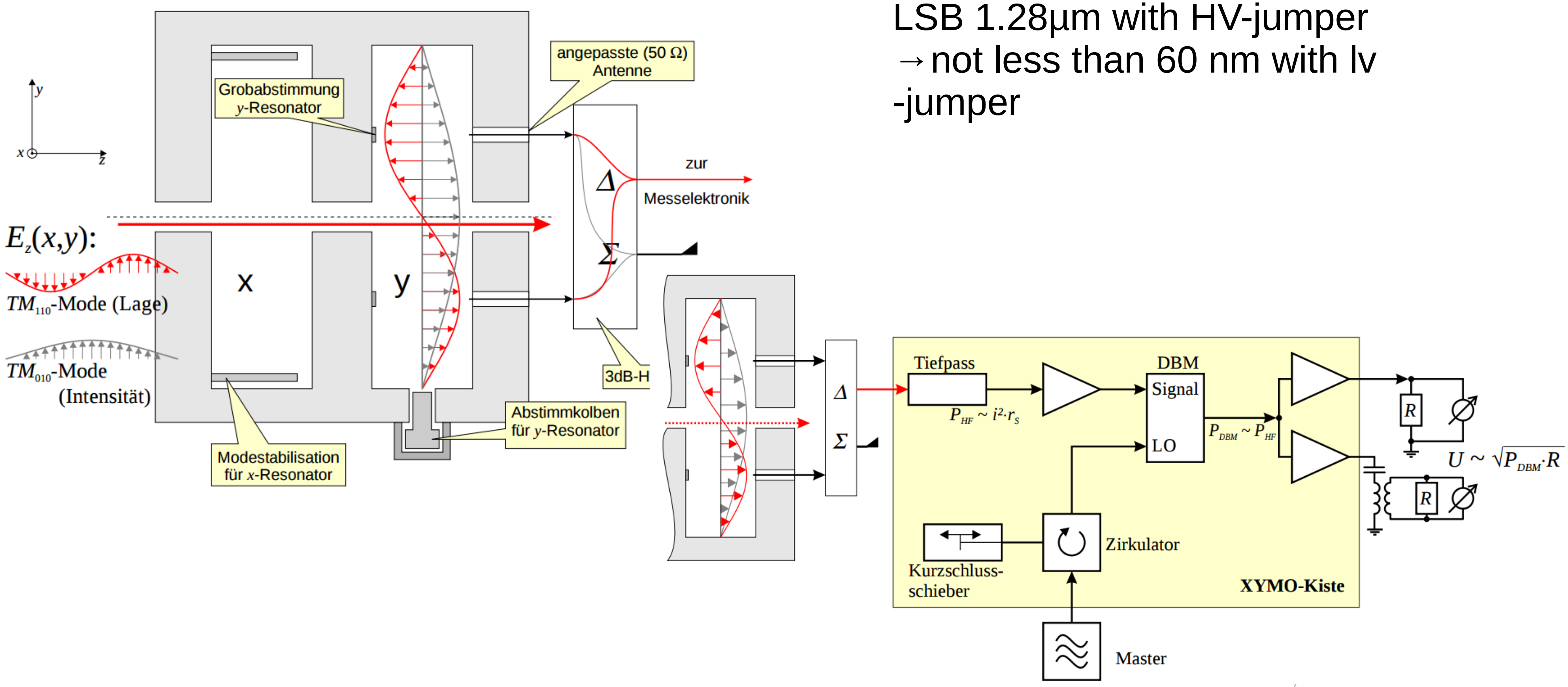


phase

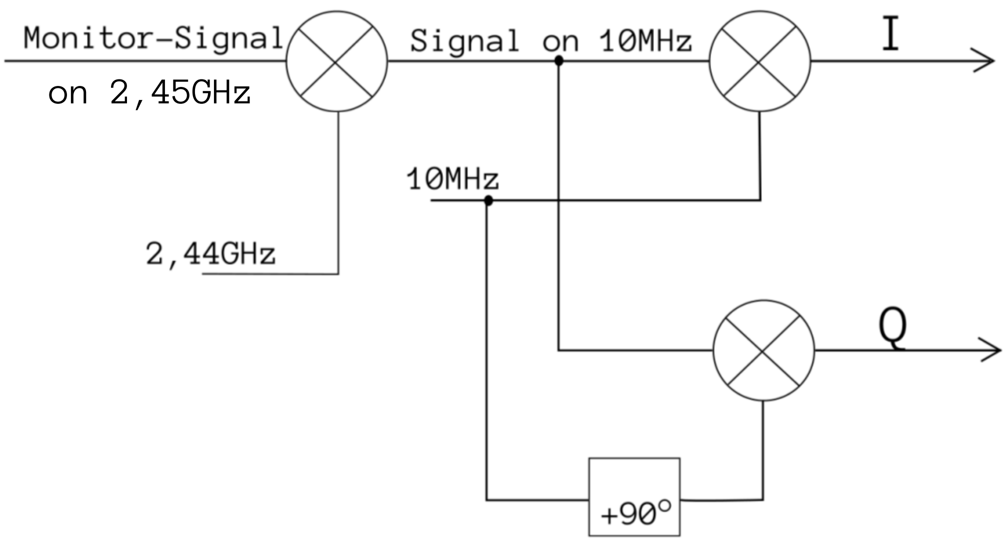


Principle of Beam Monitoring

Resolution of XYMOs:
2.2V/mm
LSB 1.28µm with HV-jumper
→not less than 60 nm with lv
-jumper

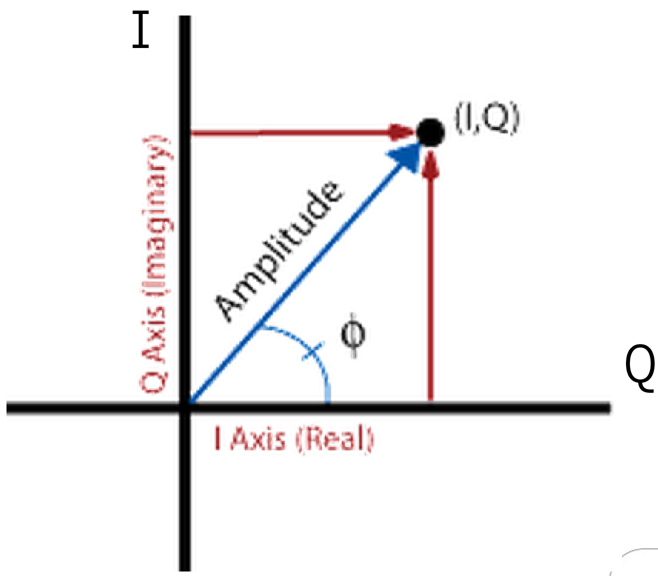


IQ-Demodulation



- XYMO-Signal: MAMI 2,45GHz carrier
- After 2,44 GHz mixing: 10MHz carrier
- Two branches demodulated with 90° shifted 10MHz.

→ signal amplitude = $A = \sqrt{I^2 + Q^2}$

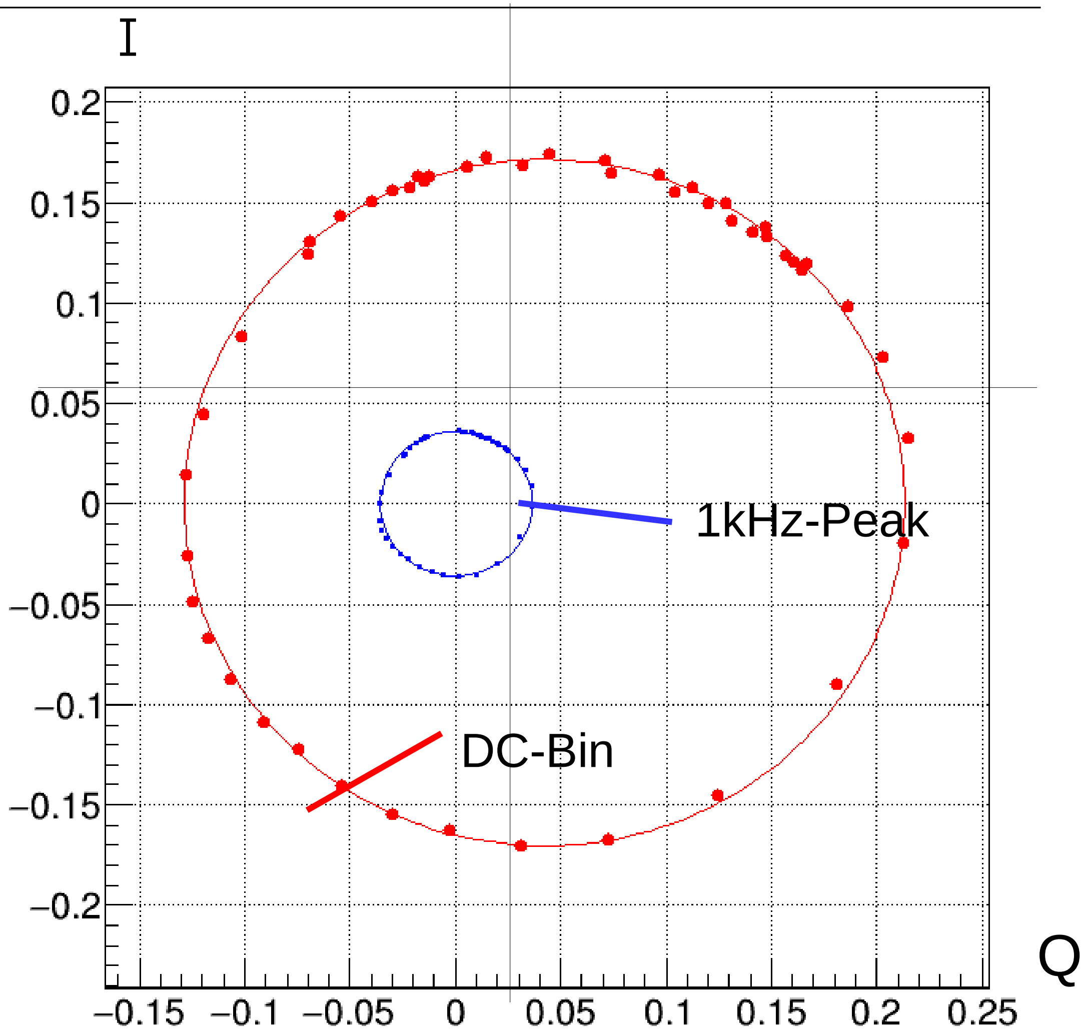


No nasty phase tuning needed any more because signal is always reconstructable with *I* and *Q*.

IQ-Demodulation

- Measurement of *I* and *Q* of the 1000 Hz Peak at different phase tunes result in a circle.
- Circle is not evenly circular.
- Electronics are still susceptible to DC Offsets, errors in gain matching of *I* and *Q*
-

→ Digital IQ-Demodulation maybe better ?! Offline tests after beamtime with Signal on 10MHz



Digital Feedforward – (@Test Stand)

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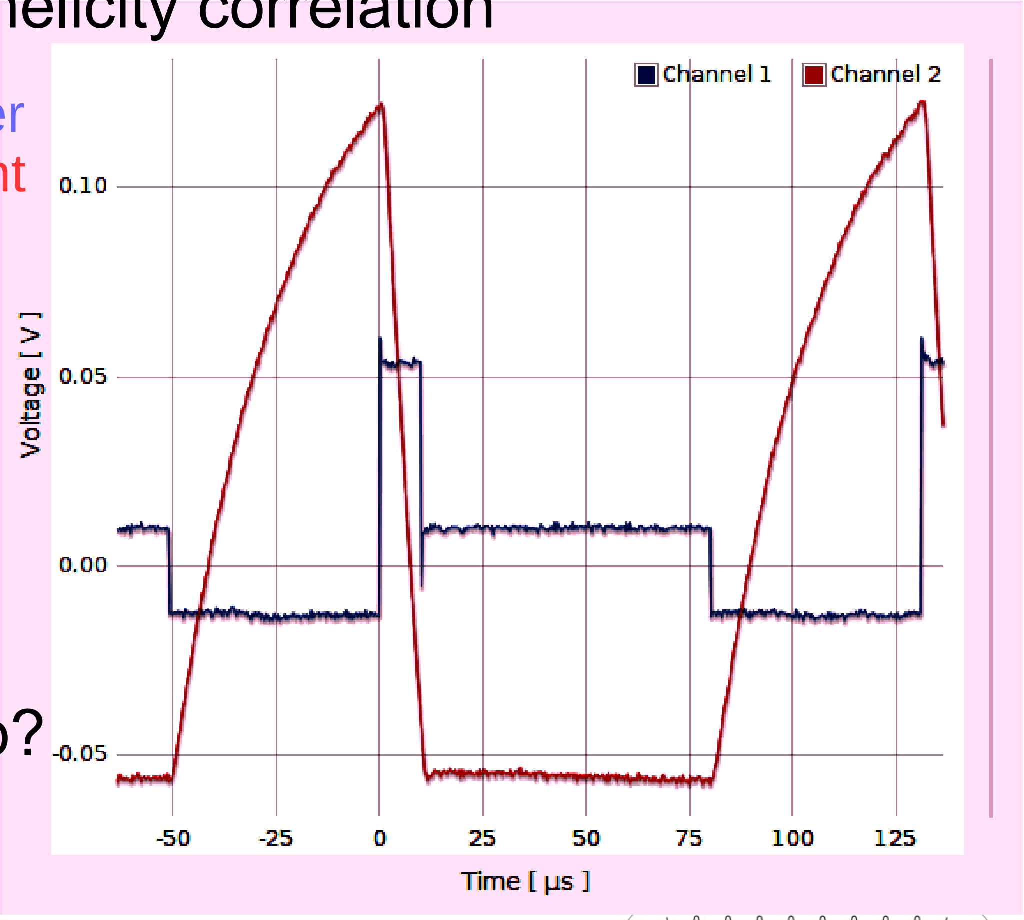
- helicity flip → beam position “jump”
- measure “jump” → push current into coils during flip!
  - feedback takes care of residual helicity correlation

drive signal from FPGA to power amplifier

fast steerer current



- 300 mA/µs possible
  - uses only 50% of amplifier output swing
  - other 50% swing available for feedback
- adjust feedback loop gain during flip?

digital system → no problem!

Polarized Beam:
Short Term Asymmetry

Beam Current Measurement:

- Stabilization off

- maximize asymmetry with half wave plate

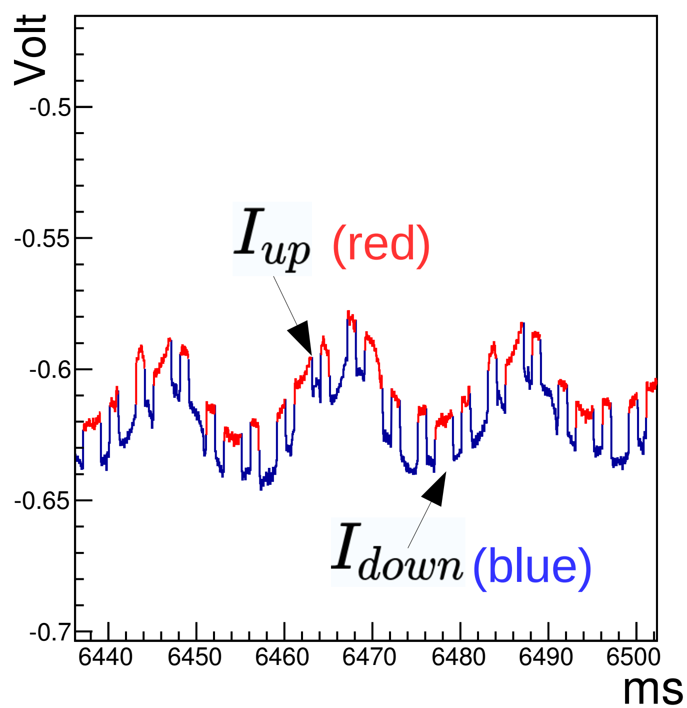
- Helicity flip :

  +--+ -++-   (8ms)

Beam current shift under helicity switch

Histogrammed

pimo Signal



pimo Histogramm