WP 12.3.3
Electrico-optical front end for wake field monitors – current state

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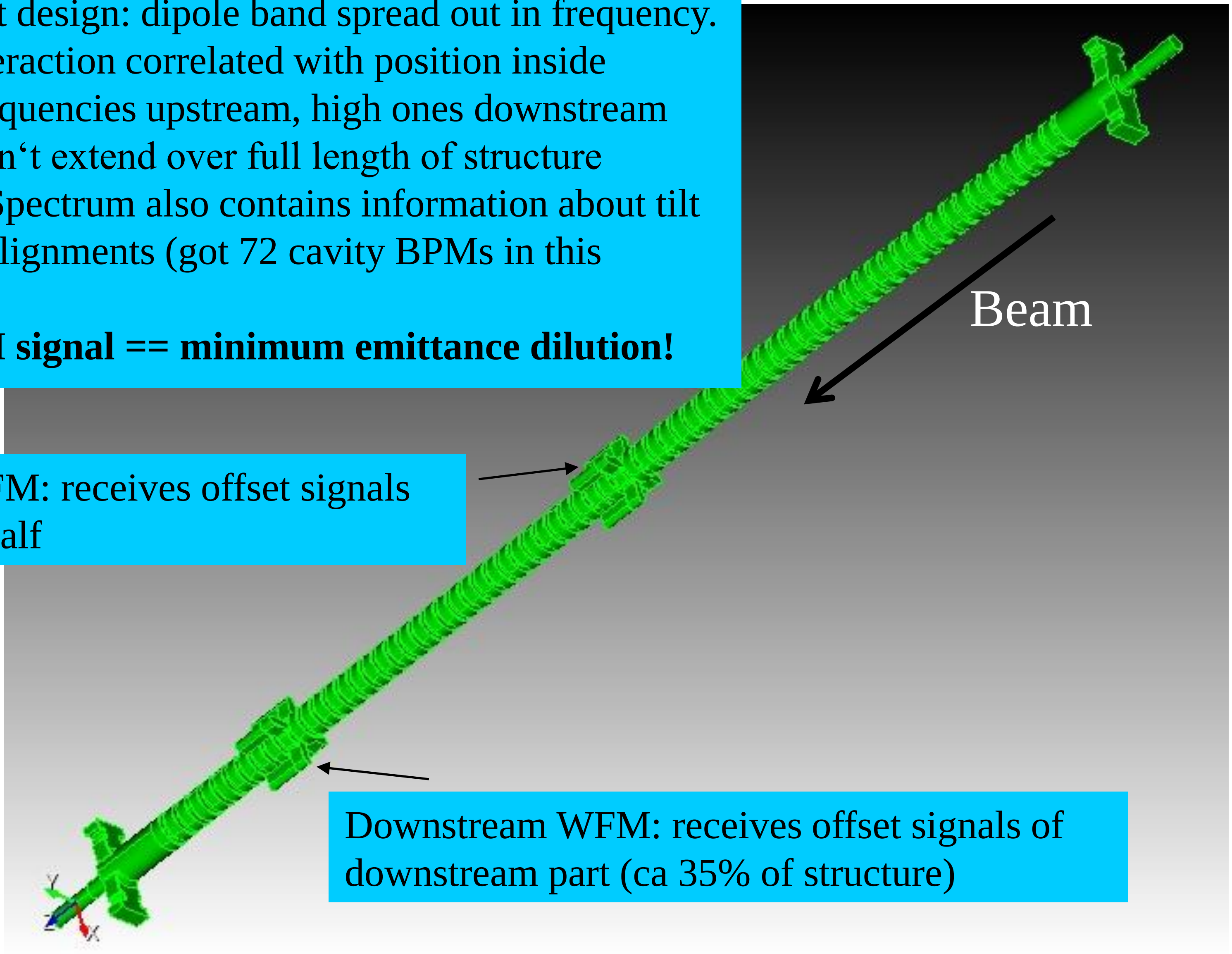
WFMs in the CLIAPSI X band structure

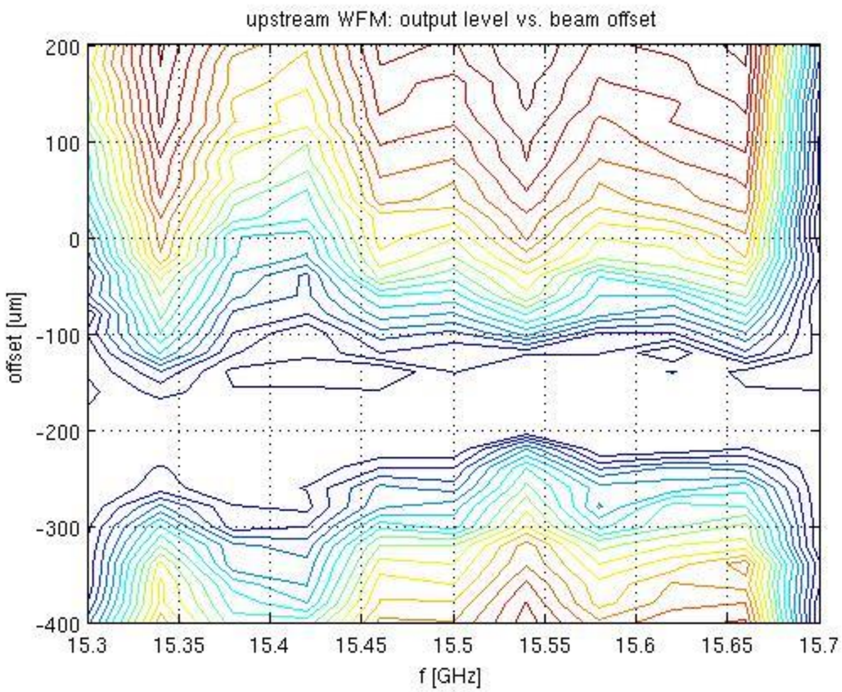
Constant gradient design: dipole band spread out in frequency. Frequency of interaction correlated with position inside structure, low frequencies upstream, high ones downstream
Dipole modes don‘t extend over full length of structure
Big Advantage: Spectrum also contains information about tilt and internal misalignments (got 72 cavity BPMs in this structure!)
Minimum WFM signal == minimum emittance dilution!

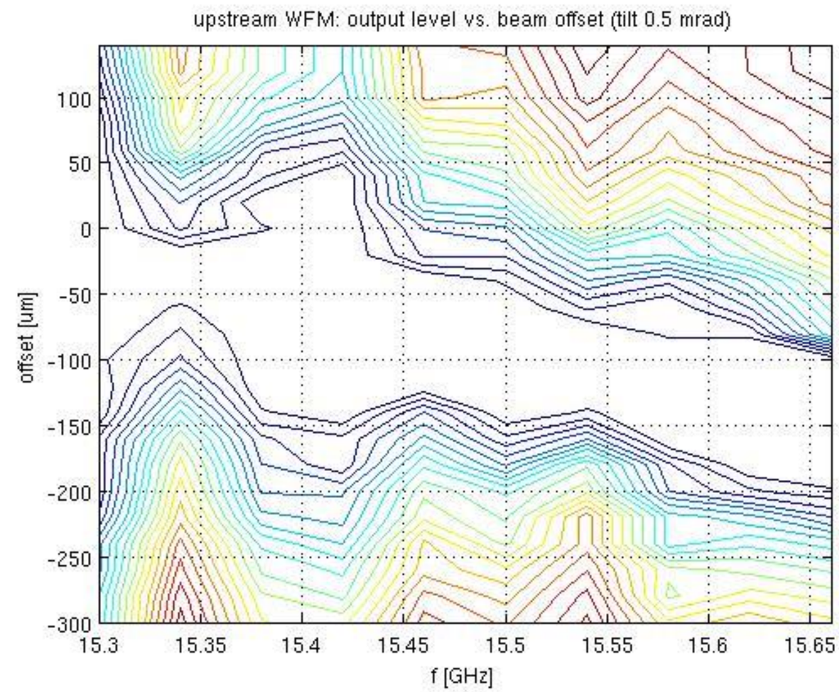


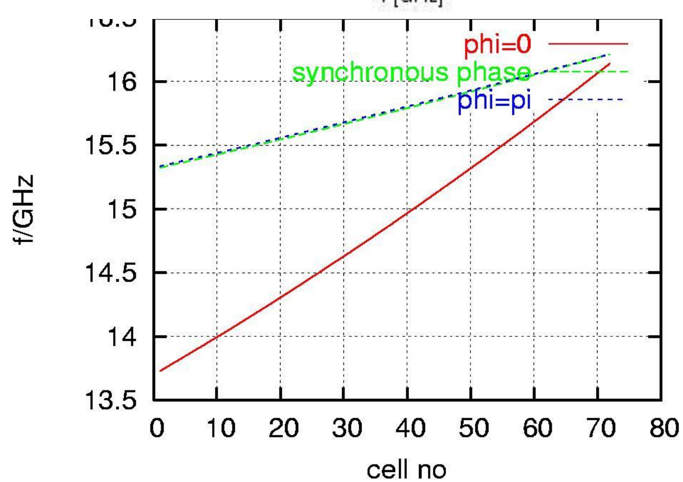
Upstream WFM: receives offset signals of upstream half

Downstream WFM: receives offset signals of downstream part (ca 35% of structure)

Offset vs. tilted structure: Frequency scan



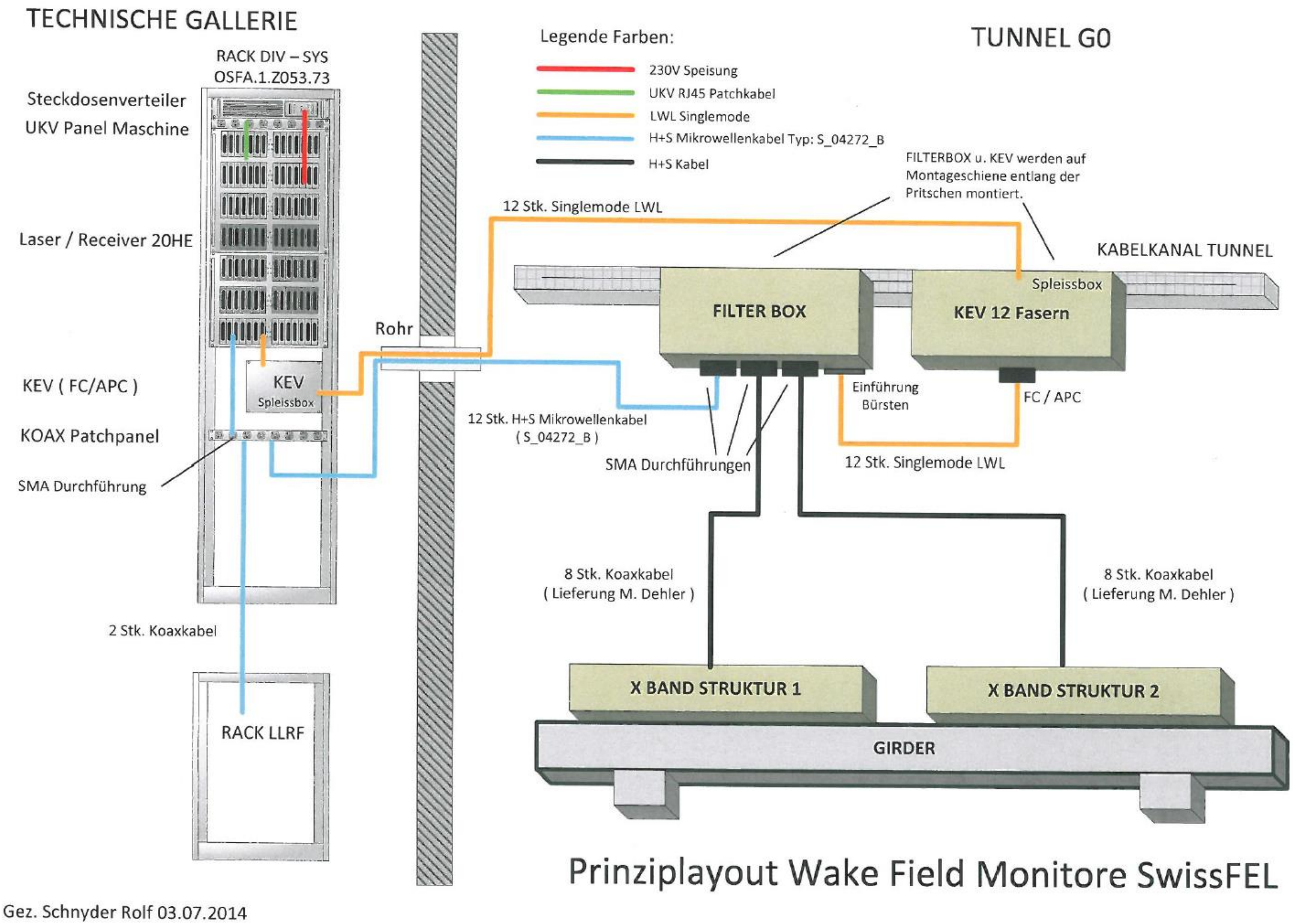




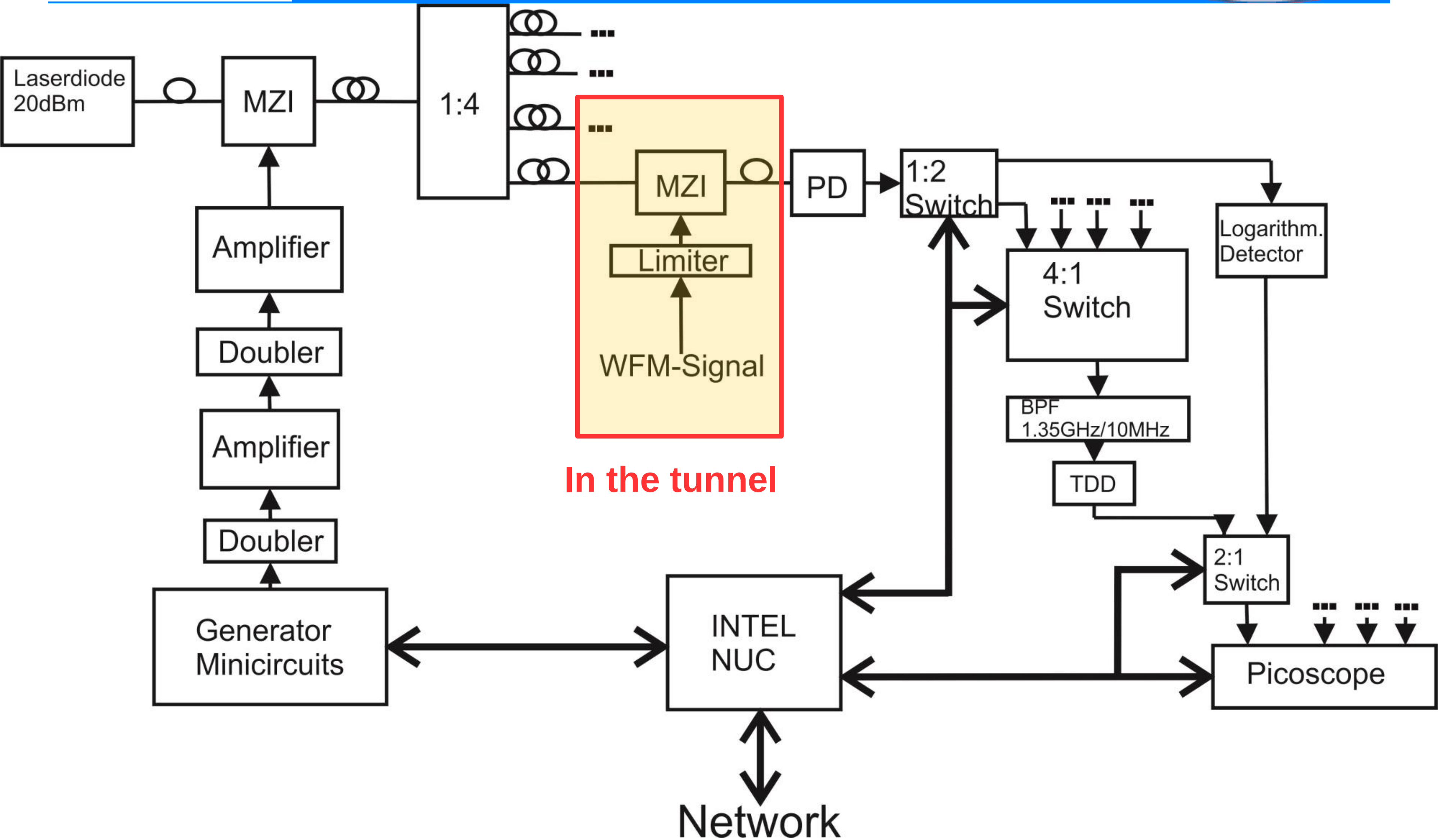
(Rather noisy) frequency scan with narrow band filter (BW 10 MHz):

- Frequencies correspond to locations inside structure given by green sync. phase line shown left
- Location of minimum versus frequency shows tilts (and bends, kinks …)
- Looking forward to strongly improved resolution in final system

Sysem setup at SwissFEL



Block diagram

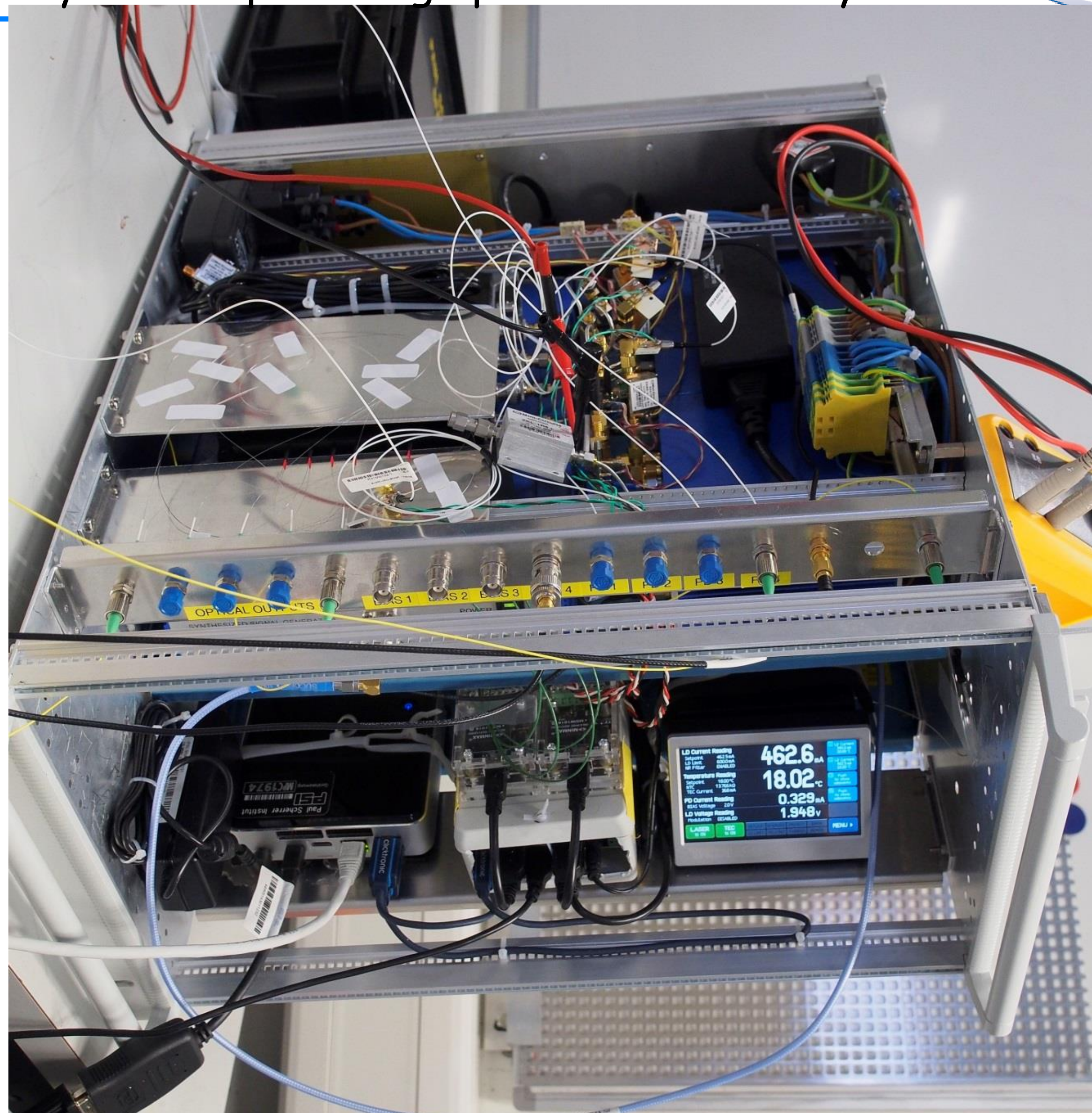


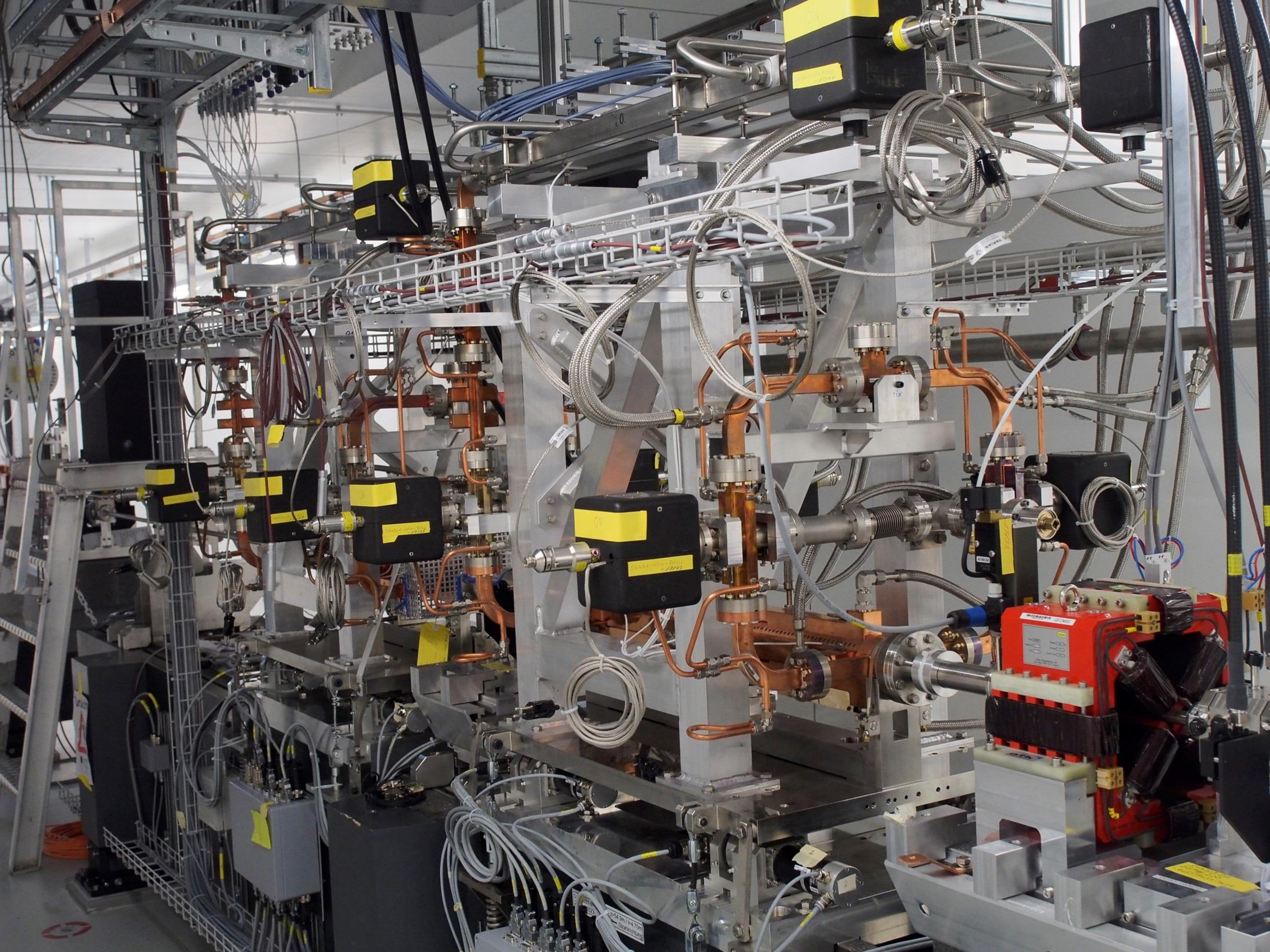
Last spring: partially assembled prototype system

- Upper plane: signal generator, readout electronics, switches etc.
- Lower plane: electro-optical system and analog post processing

- Self contained system using passive cooled PC (Intel NUC)
- Digital control of LO, 14 bit digital scope readout, RF switches etc. via USB
- Planning to use Matlab for control and digital post processing

Now: partially disassembled (but complete) system: Optimizing optical detection system



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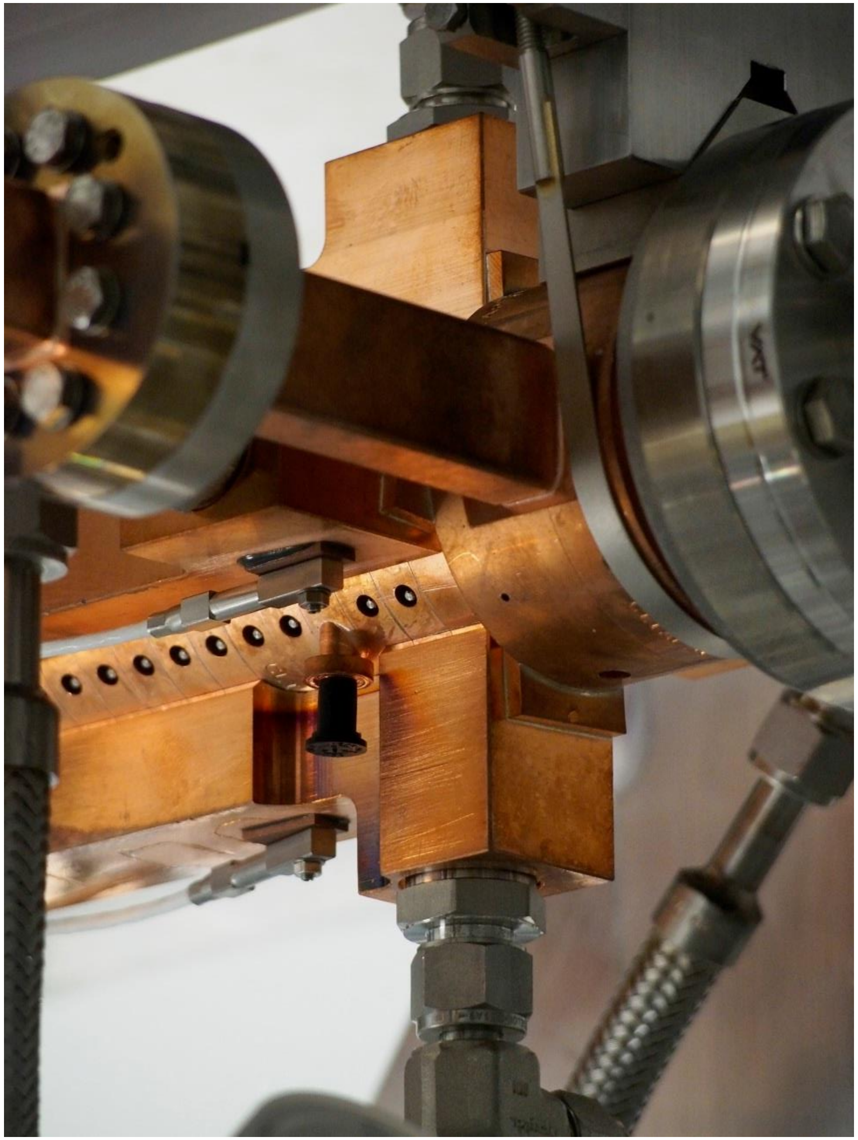
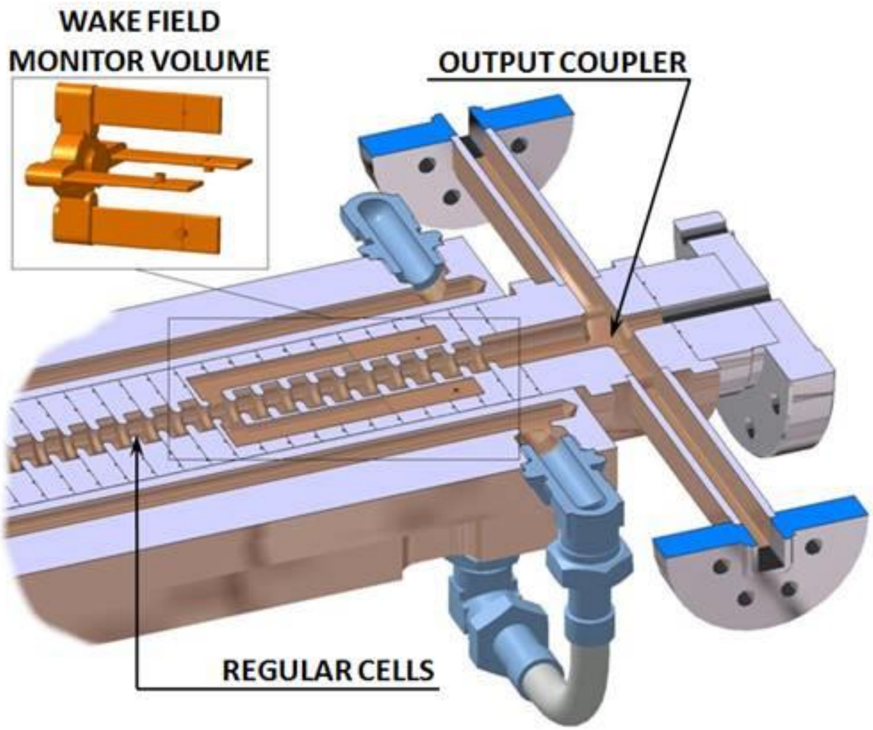
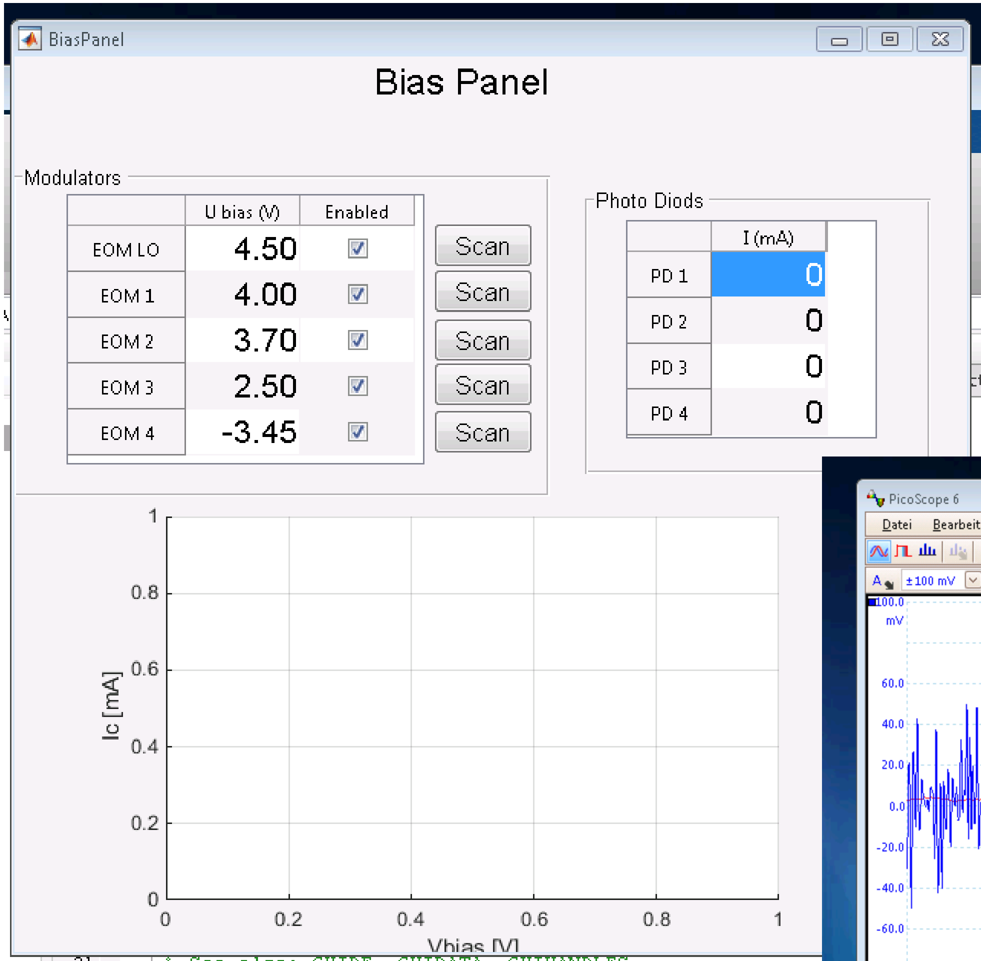
WFM pickup



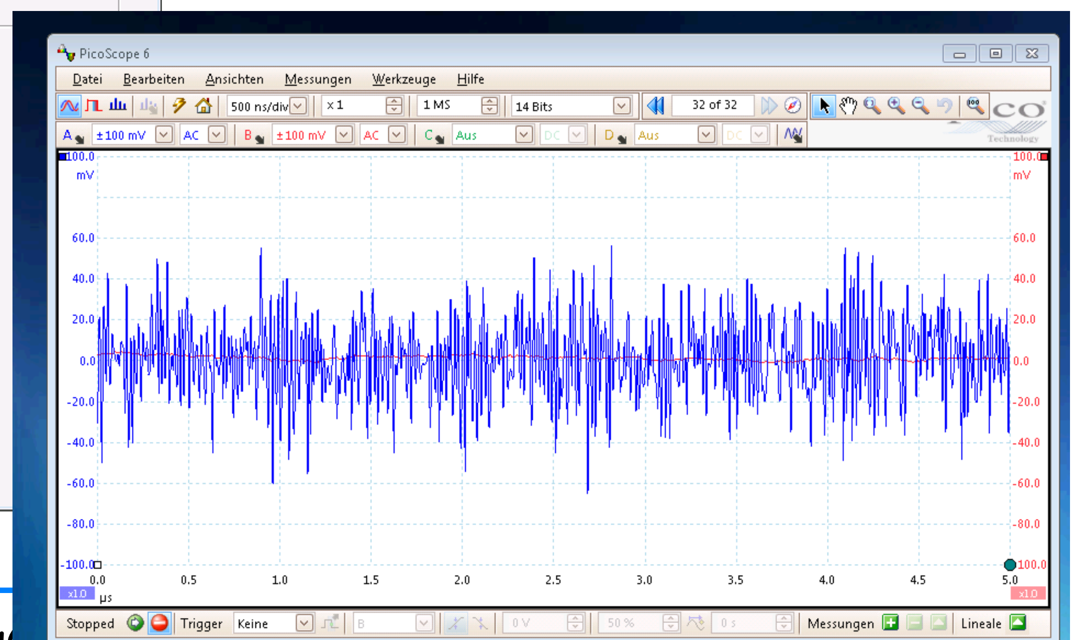


Grunt work:
Interfaces, GUIs, procedures



Standalone system

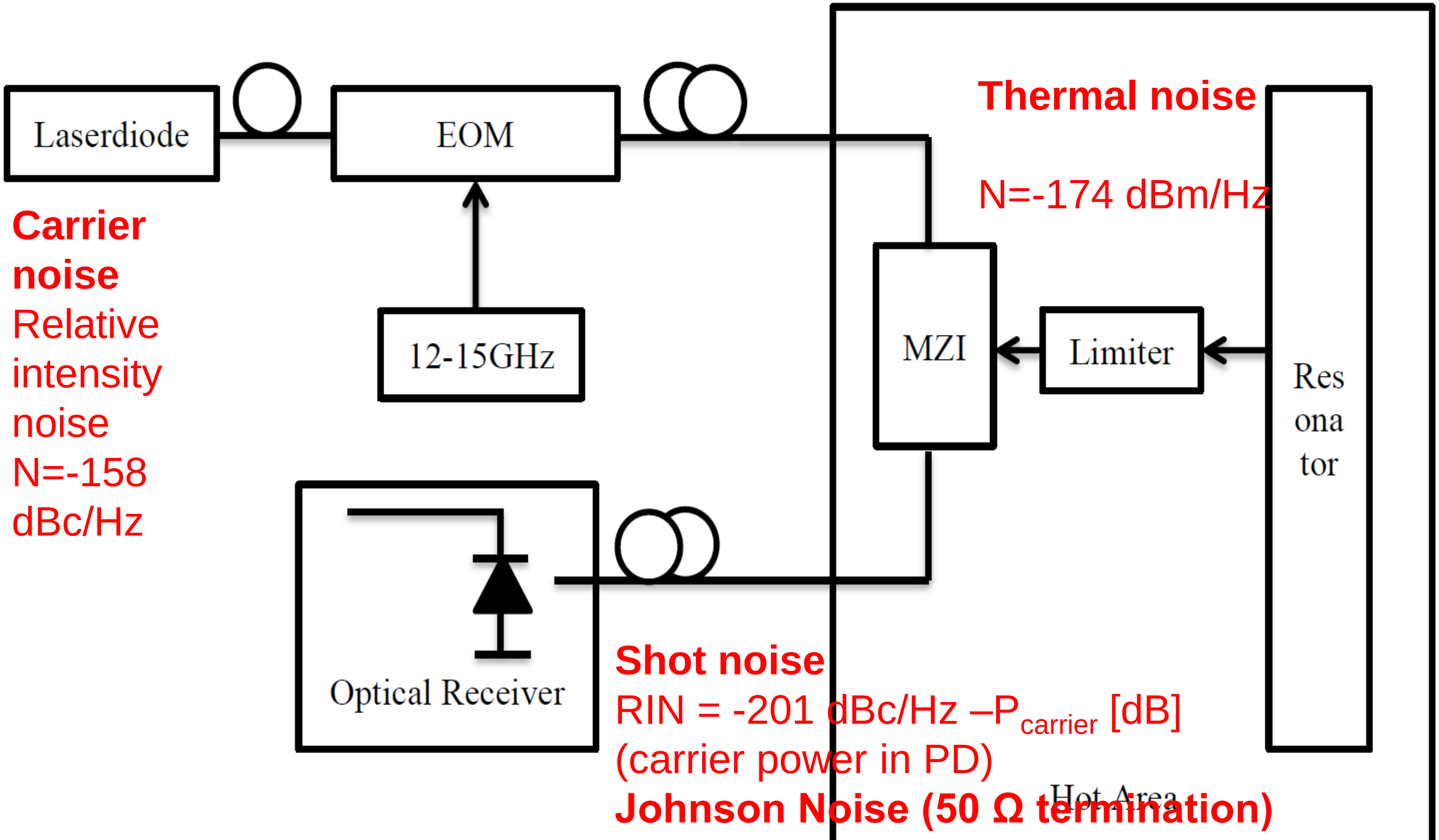
- Intel NUC PC running windows
- Devices interfaced via USB
- Matlab as control software



Signal conversion factors

- **EOM modulated by wakefield signal**
  Modulation factor m = Vsig*π/Vπ or
  m[dBc] = 0.5 Psig [dBm] – 7.5 dB
- **2nd modulation with LO**: reduction by 6 dB
- **Photo diode** with 0.98 A/W
  P_{out} [dBm] = 2 $P_{carrier}$ [dBm] +2*m [dBc] -16 dB
- **Carrier power**
  theoretical: 20 dBm (LD) – 7dB (LO EOM) – 7dB (1:4 splitter)
  – 7 dB (WFM EOM) -2..3 dB (transitions) = -3..4 dBm
  measured -6 dBm
- **Total link insertion loss** including splitter w/o optical amplification:
  IL = -15 (EOM) -6 (LO) -12 (Carrier) -16 (PD) = **-49 dB**
- Detection thresholds electronics:
  Log amp: DT = -64 dBm
  Tunnel diode: DT = -80 dBm
- **Signal thresholds for 4 um resolution:**
  Broad band measurement (BW=0.5 GHz): -33…-38 dBm
  Intra structure misalignment (BW=10 MHz): -63… -68 dBm

Noise



Carrier noise
Relative intensity noise
N=-158 dBc/Hz

Thermal noise

N=-174 dBm/Hz

Shot noise
RIN = -201 dBc/Hz –$P_{carrier}$ [dB]
(carrier power in PD)
Johnson Noise (50 Ω termination)
N = -171 dBm/Hz

Noise paths (std setup)

- RIN: Laser diode has -158 dBc/Hz

  N(output PD) = 2*P_c + RIN -13 dB

  = -12 dB -16 dB (IL PD) -158 dBc/Hz = -186 dBm/Hz = **-96 dBm/GHz**
- Thermal Noise at input modulator: -174 dB/Hz

  N_PD = -174 dB/Hz -49 dB (IL optischer link)

  = -223 dBm/Hz = **-133 dBm/GHz**
- Photo Diode

  Shot Noise:

  N_PD = -201 dBc – 6 dBm (Carrier power) =

  -207 dB/Hz = **-117 dBm/GHz**

  Johnson Noise:

  N = - 171 dBm/Hz = **-81 dBm/GHz**

Thermal noise in photo diode dominates followed by RIN of laser source.

Thermal noise in photo diode independent of carrier power.

Theoretical detection threshold (1 GHz BW): -33 dBm (at the limit)

For internal alignment measurement (10 MHz BW): -53 dBm (~10 um) ☹

Improving noise/detection threshold

Strategy 1: Improve power of optical carrier, reduce insertion loss, increase signal strength

- Expensive/complicated: Use fiber amplifier
  - Amplification limited by power rating of EOMs
  - Amplifier noise figure typically 3-4 dB
  - price
  - Max gain in DT: 12 dB
- Replace on 1:4 optical splitter by optical switch
  - price
  - Gain in DT: 12 dB
  - Tested – works!
  - cannot measure four channels in parallel (important?)

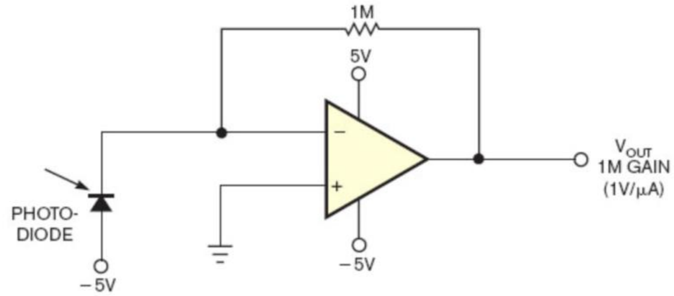
Improving noise/detection threshold

Strategy 2: Reduce thermal noise in photo diode by trans-impedance amplifier

Johnson noise (other than shot noise) determined by shunt resistance of photo diode

(50 Ohms in current std configuration): $$i_j = \sqrt{\frac{4kT\Delta B}{R_{sh}}}$$

Use socalled trans-impedance amplifier to increase R_{sh}

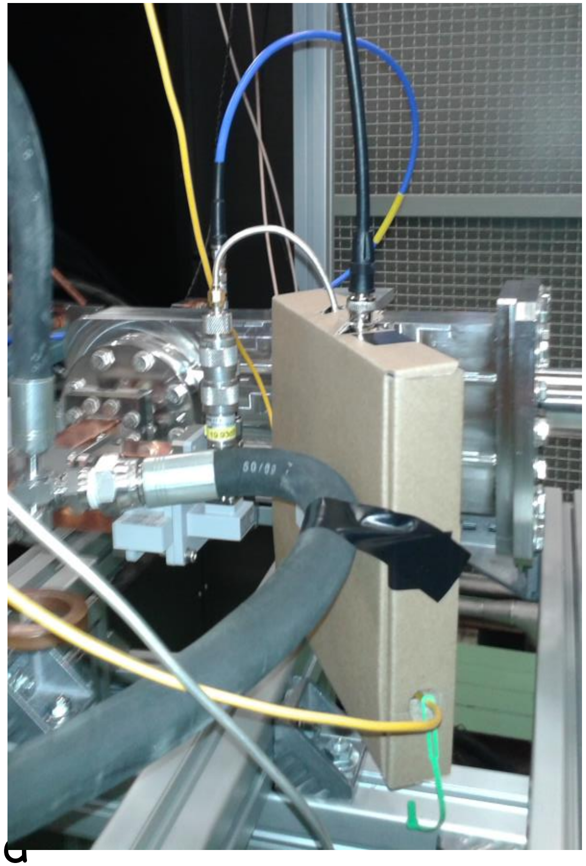


- Can theoretically decrease PD noise to shot noise limit by 30 dB
- Some reduction of bandwidth (if controlled, welcome)
- Practical limit in setup given by RIN of laser diode, giving theoretical improvement of detection limit by 15 dB

Currently evaluating approach, still need to practically prove improvement

Other applications:

Quick and dirty tests at Xbox measuring 12 GHz break down signals



To the right:
How to do a provisorical front end
Within 1 ½ days ...

- works in principle, problems with optical connection (signal level fluctuated, when moving fiber)
- not ideal test case – signal is narrow band width, system is ultra wide band width and so noisy
- no definite conclusions, due to time constraints could do only one test.

Outlook

- Still improving detection threshold
  - Easy way out with strong improvement would be to insert LNAs between pickup and EO modulator, but would contradict philosophy of passive, radiation hard front end ….
- Finish software (partially needs to be done together with beam tests)
- Beam tests:

  SwissFEL injector commissioning expected to start June

  Fall back solution: WFM measurements at CALIFES?

  Signal level, spectra, indirect test of specs.
- Outreach

  submitted abstract for LINAC '16 (MSU/USA)

  PRST paper on SITF (section on WFM stuff), to be submitted