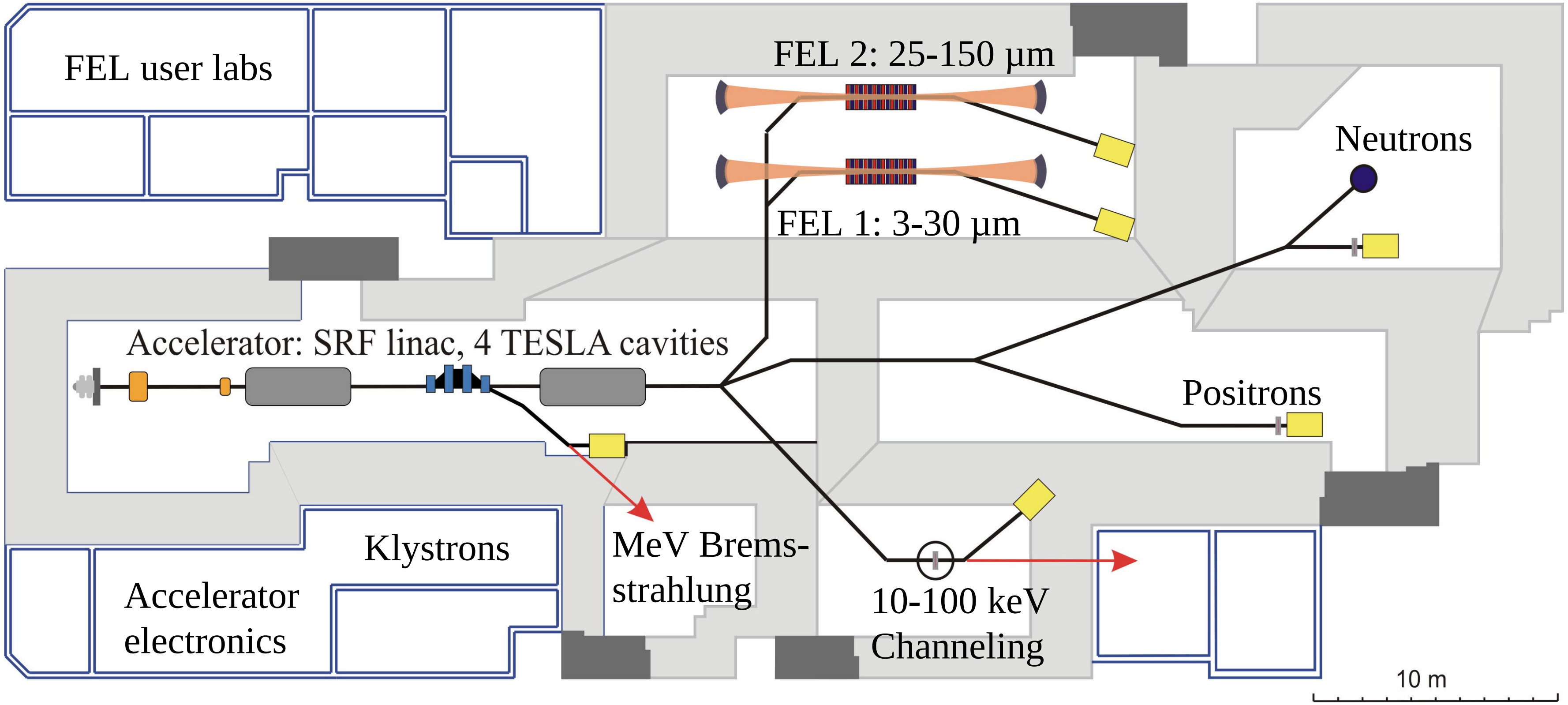
Electron Beam Diagnostics at the radiation source ELBE

- Radiation source ELBE
- Bunch length measurements
- BPM system
- Video acquisition
- Beam loss & machine protection

The radiation source ELBE

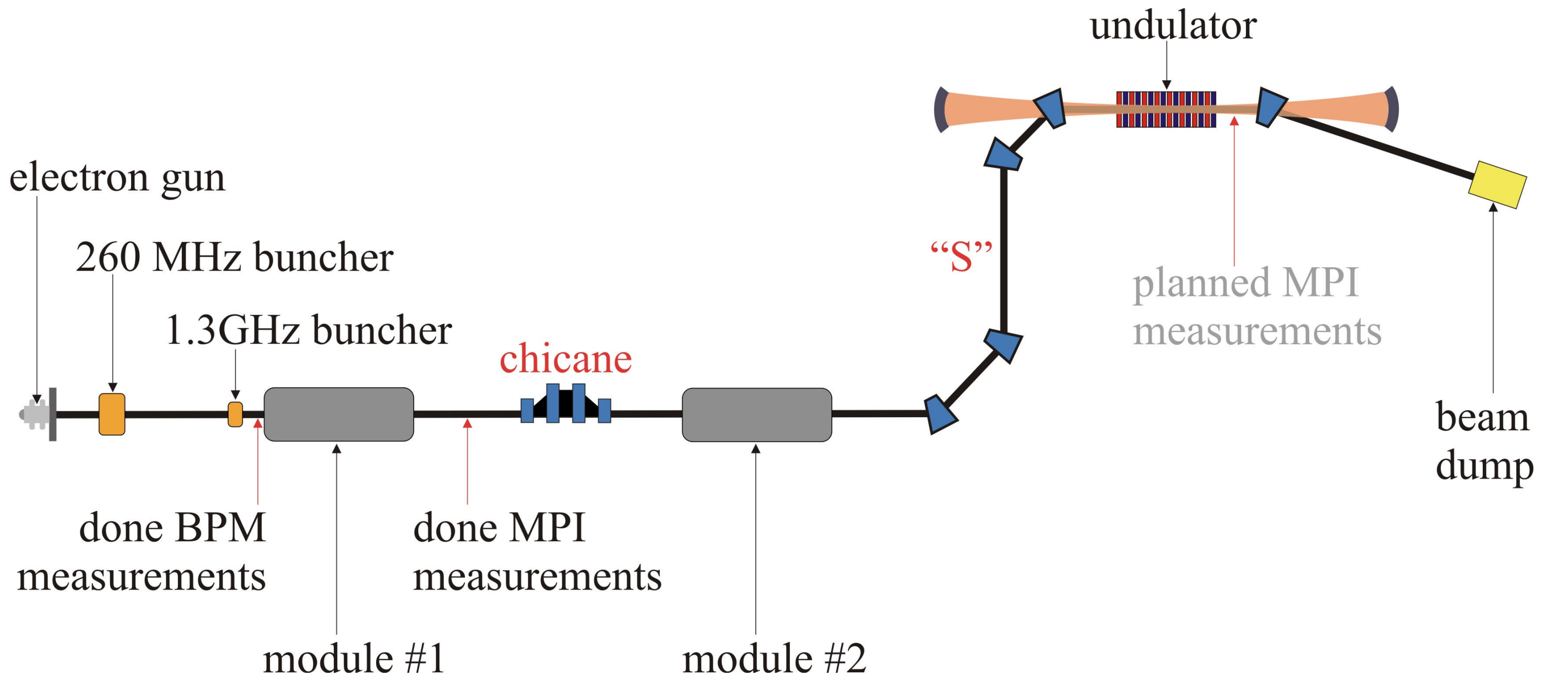


- nuclear physics experiments are running since January 2002
- channeling radiation since September 2003

FEL 1 commissioning now

FEL2 in the design phase

Bunch length evolution (general idea)



- the gun produces 450 ps long bunch
- compressed down to 10 ps in the injector
- at the module #1 exit is about of 1ps
- chicane with adjustable R_{56}
- "S" with constant R_{56}

- <u>The main goal – to minimize the bunch length at the undulator entrance</u>

ps bunch length measurements using CTR

1. Transition radiation is produced when the electron bunch passes a boundary of two media.

2. Respond time is zero. Shape of the radiation pulse is a “copy” of the electron bunch shape.

3. When the wave length of the radiation becomes more than the bunch length the radiation becomes COHERENT. ($\lambda >> L$)

4. Power is proportional to:

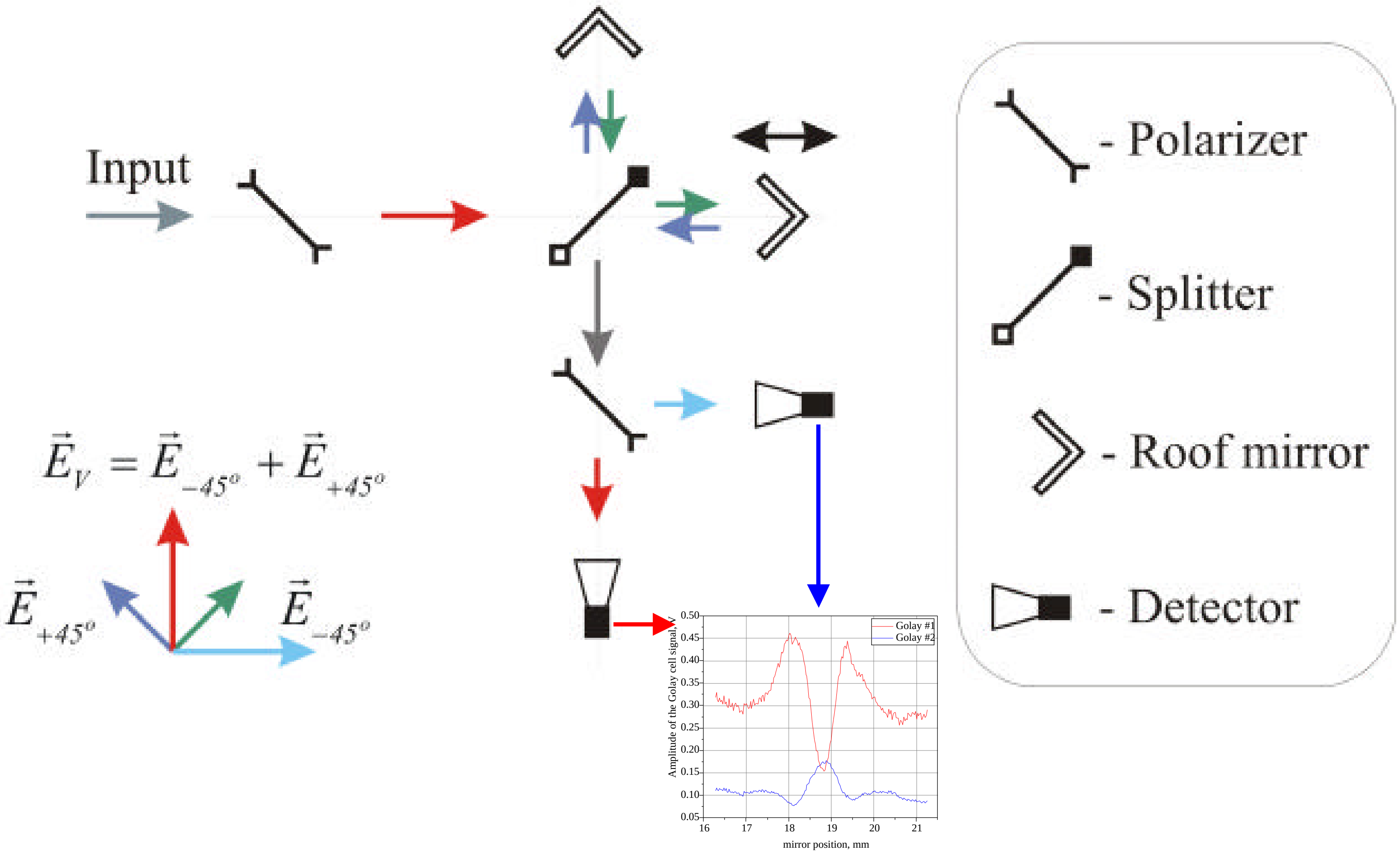
   incoherent radiation N   at 77pC N 5×10^8

   coherent radiation N^2

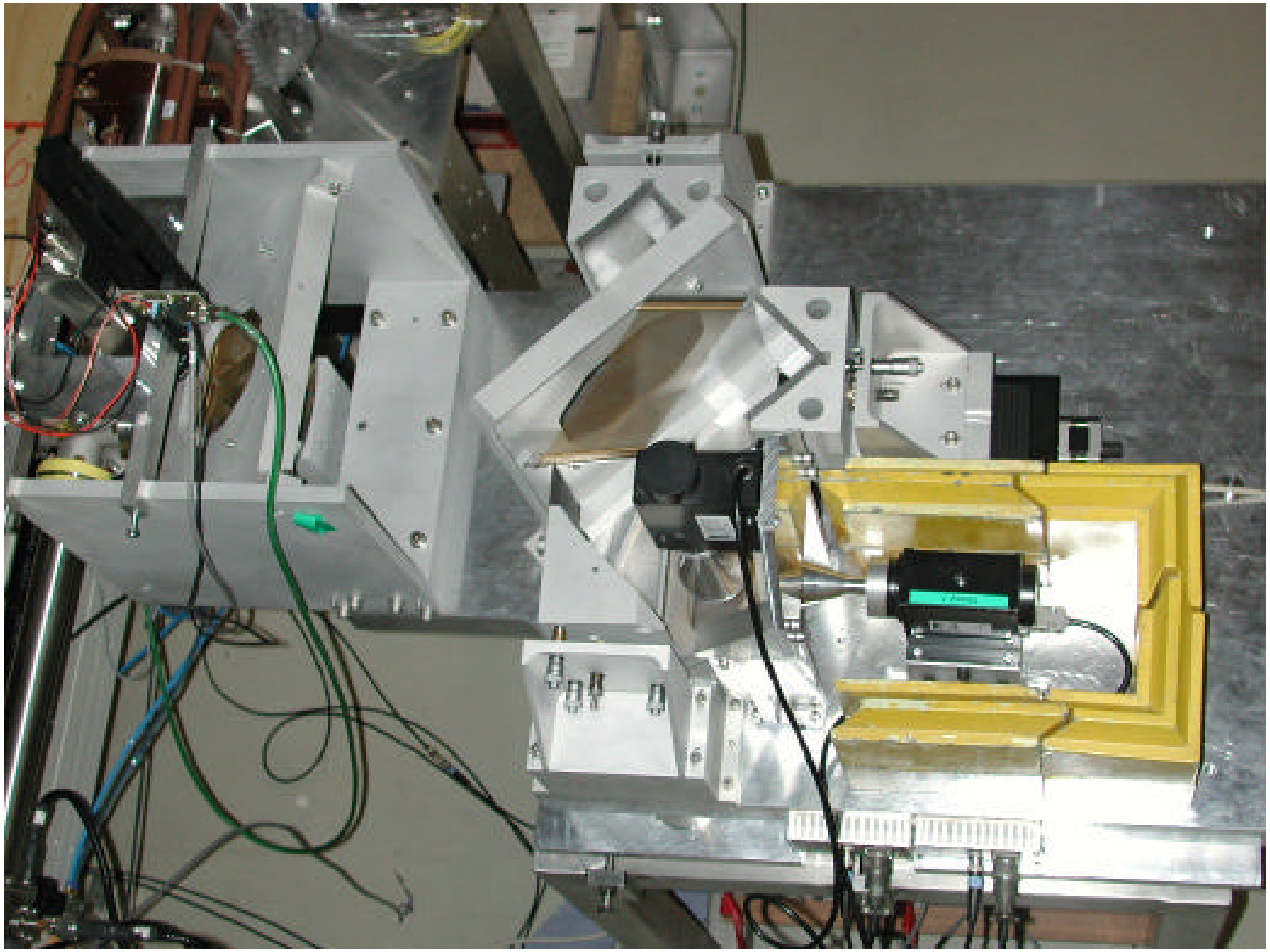
5. Measurements of the radiation spectrum give information about the bunch length.

How to measure the spectrum ? the Martin-Puplett interferometer

The Martin-Puplett interferometer (basics of operation)



The Martin-Puplett interferometer (the same as at TTF, built in Aachen)



The Martin-Puplett interferometer (mathematics)

- longitudinal field profile at the MPI entrance

$$E_{in}(t) = E_0 g(t)$$

- longitudinal field profile at the MPI exit

$$E_{out}(t) = \sqrt{T\ R_{||}/2}\,E_0\big(g(t) + g(t-t)\big)$$

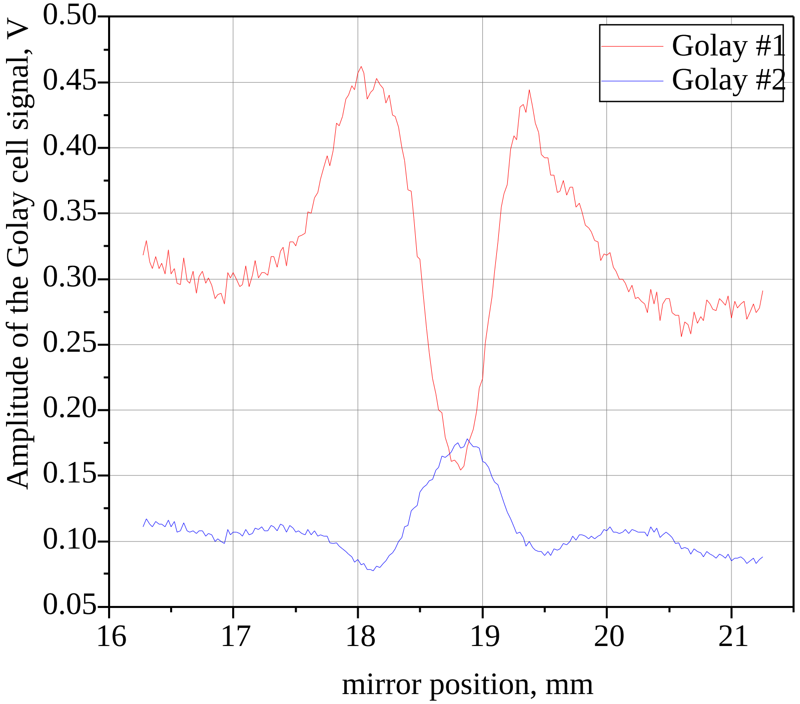
- detectors measure intensity I E^2

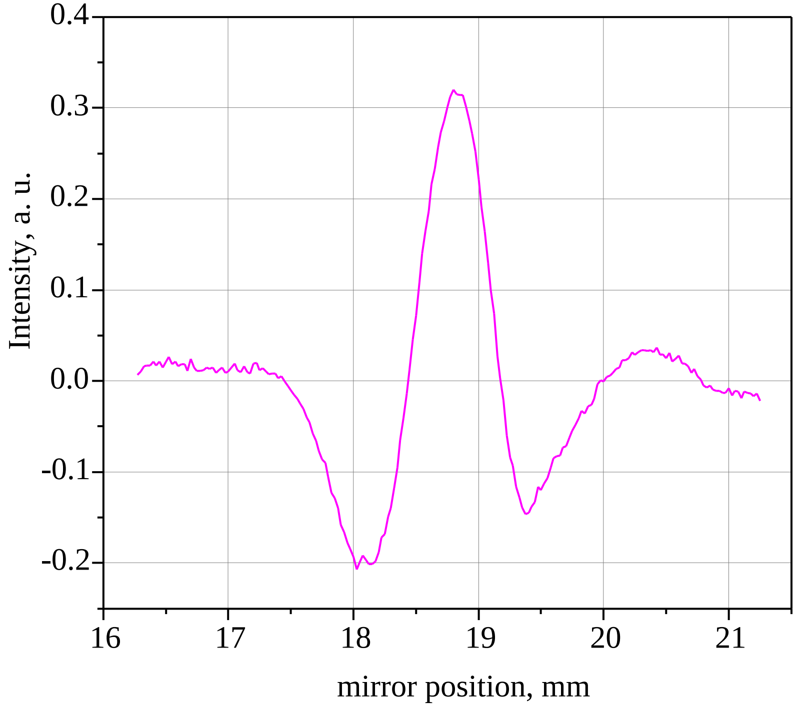
$$U(\tau)\quad E_o^{\,2}T\ R_{||}\int_{-\infty}^{+\infty}\Big(\big(g(t)\big)^2 + g(t)g(t-\tau)\Big)dt$$

the autocorrelation function is measured with the help of the MPI

- The Wiener-Khintchine theorem says: “the Fourier transform of the autocorrelation function is the power spectrum”.

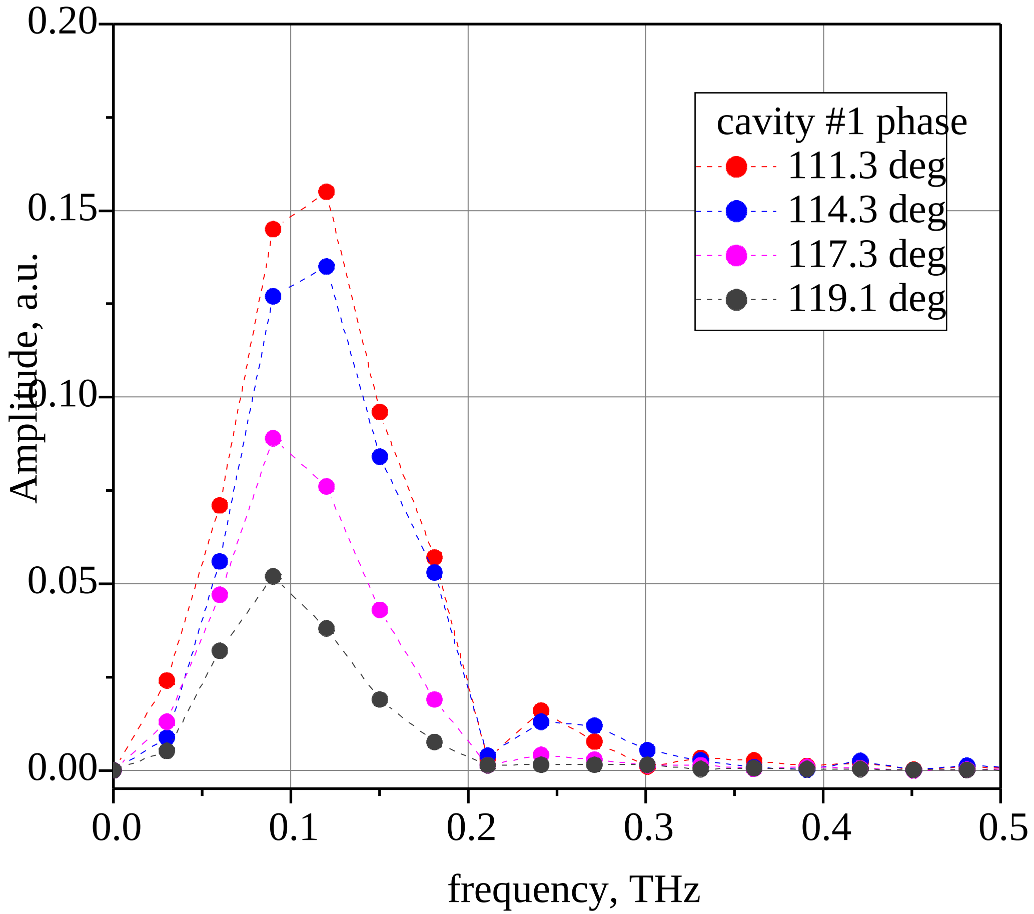
The MPI scan:
raw data vs. normalized difference





- The measurement contains the bunch length related component and noise.
- The normalized difference contains much less of the noise, which is not related to the bunch length.

The power spectrum



- Only real part of the spectrum is used.

Bunch length reconstruction

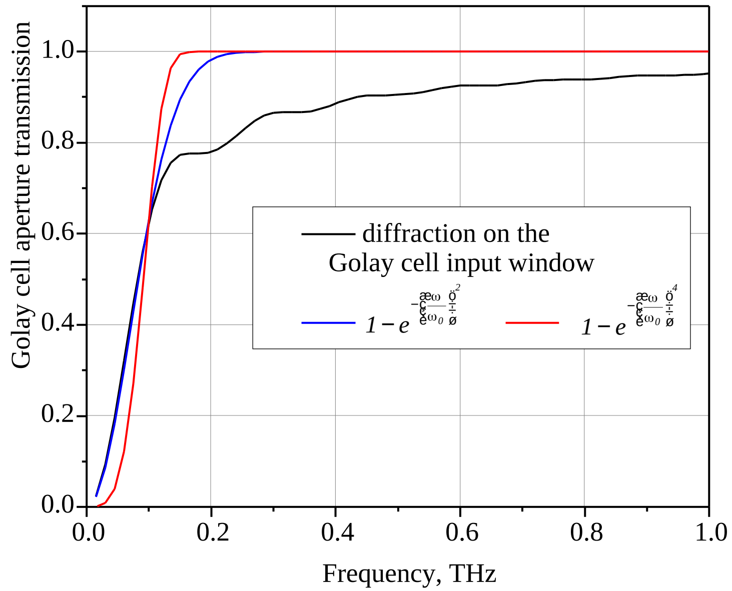
- the Gaussian shape of the bunch is assumed

$$n(t)=\frac{Q}{c\sigma_t\sqrt{2\pi}}\,e^{-\left(\frac{t}{\sigma_t\sqrt{2}}\right)^2}$$

- its power spectrum is also Gaussian

$$\tilde{P}(\omega)=C\,e^{-(\omega\sigma_t)^2}$$

- low frequency cut-off diffraction on the Golay cell input window



two filter functions were considered:

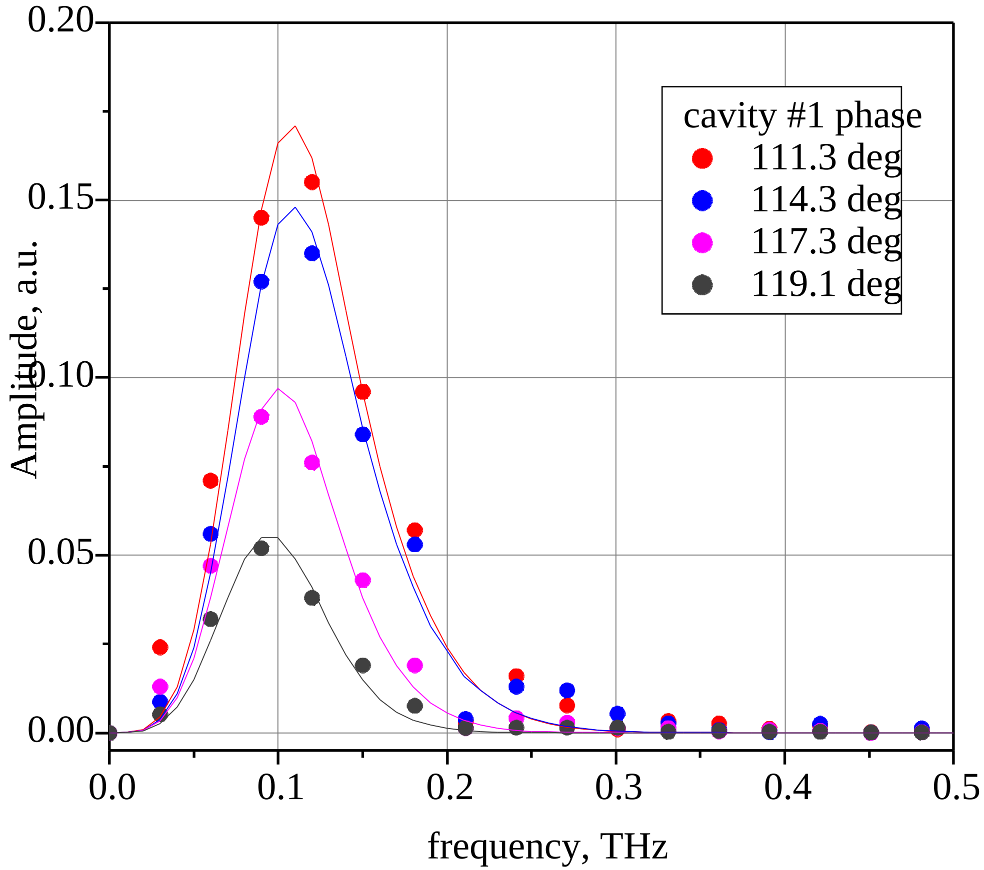
$$F1_{filter}(\omega)=1-e^{-(\omega/\omega_0)^2}$$

$$F2_{filter}(\omega)=1-e^{-(\omega/\omega_0)^4}$$

- The fit function is used

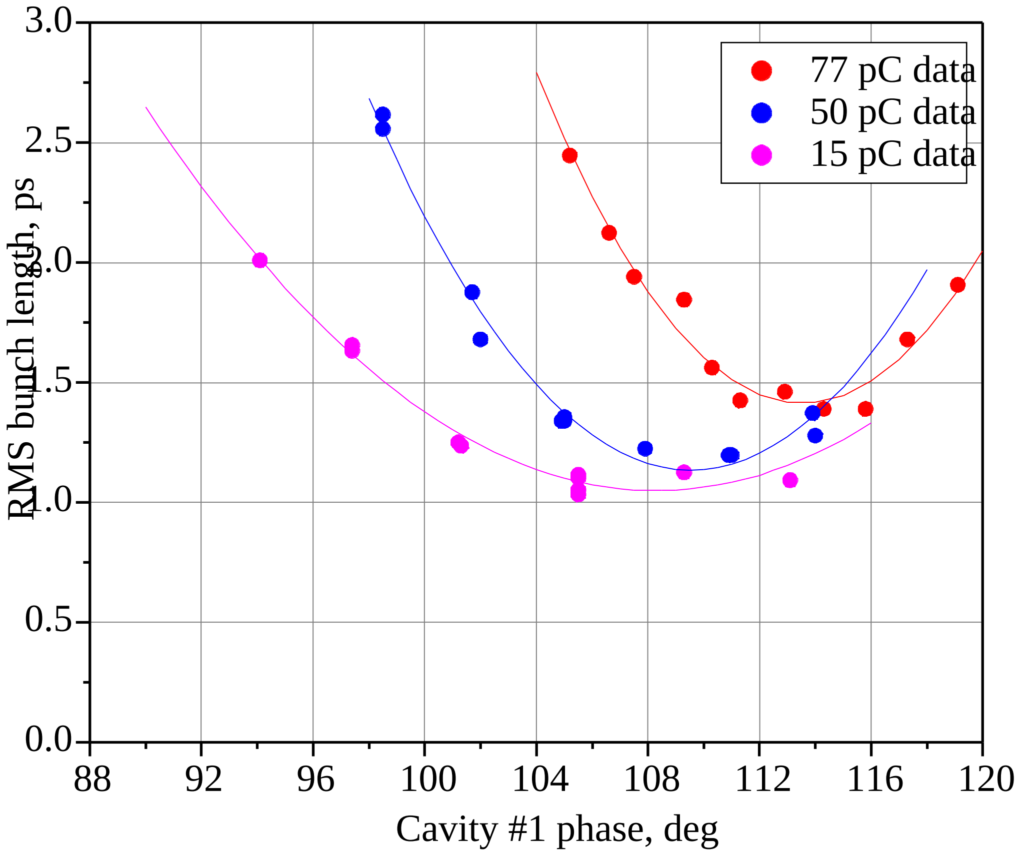
$$f_{fit}(\omega)=\left(1-e^{-(\omega/\omega_0)^4}\right)C\,e^{-(\omega\sigma_t)^2}$$

The power spectrum and the fit functions

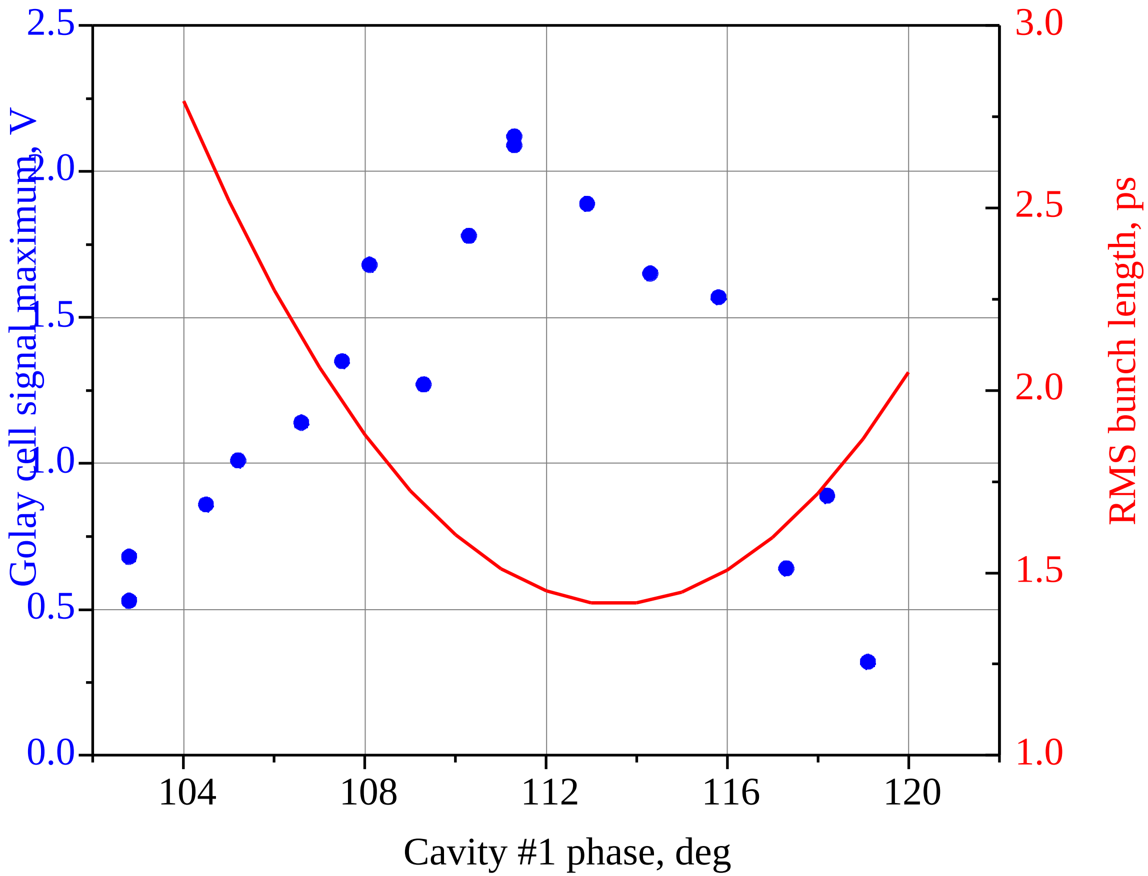


In our case the main parameters are the cavity #1 phase and the bunch charge.

RMS bunch charge vs. cavity #1 phase



Bunch length minimization without MPI scan



- the Golay cell signal is maximized at the bunch length minimum

What is to improve on the diagnostic

- the bunch length reconstruction procedure
  (might be too empirical;
  different bunch shapes)
- understand better the low frequency cut-off
  (the best way – measure
  0 – 200 GHz how?)
- Make a crosscheck measurements with completely different method
  (we are working on the electro-optical sampling)
- The same measurements can be done with
  the CSR and with the diffraction radiation
  to make the diagnostic nondestructive.

Choice of the BPM

The BPM system is based on a stripline BPM since:

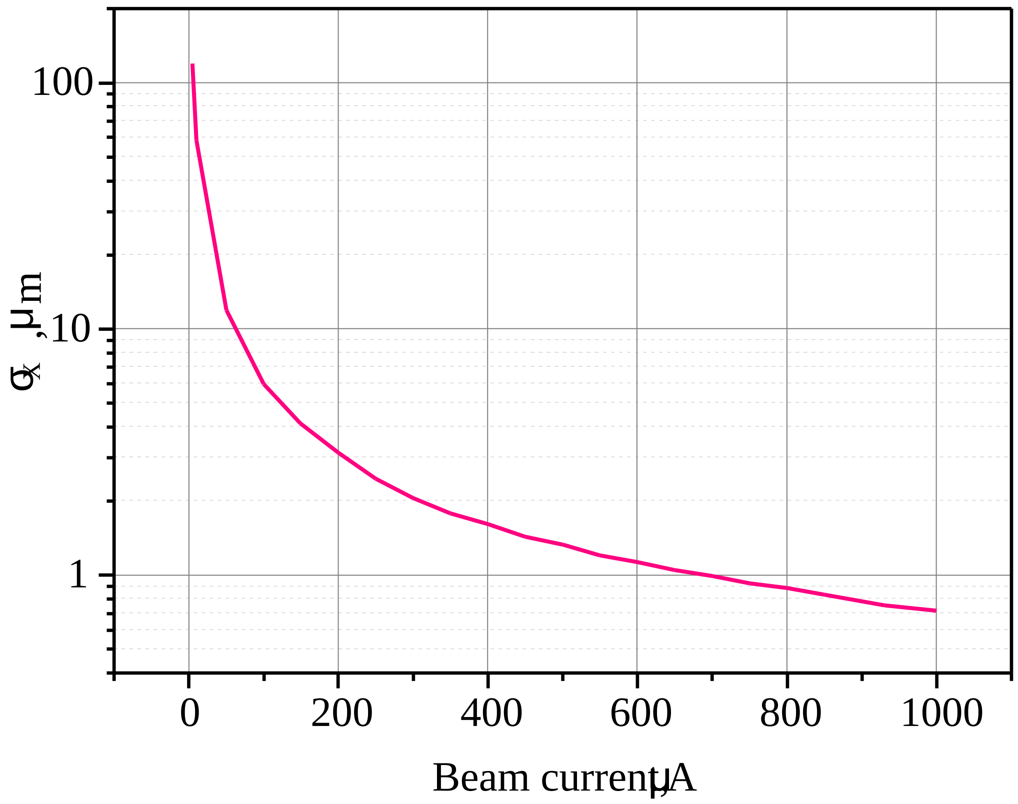
- can easily meet the system requirements
  (resolution of 100 µm)
- mechanical design is more simple (in our experience)
- cheap
- the BPM induces less wakefields

Question: with 10 nC bunch charge and with N (?) BPM cavities
What will be the emittance degradation due to wakefield?

Resolution of the stripline BPM

$$x = \frac{R}{2}\frac{\theta/2}{\sin(\theta/2)}\frac{I_R - I_L}{I_R + I_L} \Rightarrow \sigma_X = \frac{R}{2}\frac{\theta/2}{\sin(\theta/2)}\frac{\sqrt{2}\sigma_I}{2I} = \frac{R}{2\sqrt{2}}\frac{\theta/2}{\sin(\theta/2)}\sqrt{\frac{P_N}{P_S}}$$

- Measured dependence of the BPM signal vs. beam current is enough to estimate the potential BPM resolution.
- Real resolution of the system is always worse, because an electronics always makes some extra noise.



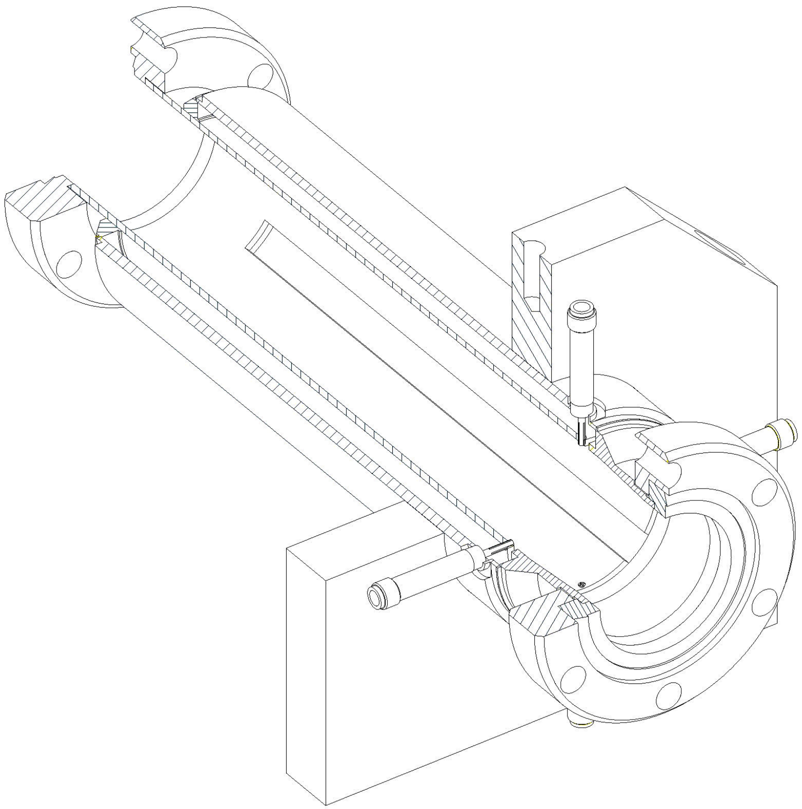
_λ BPM vs. _λ BPM (1)

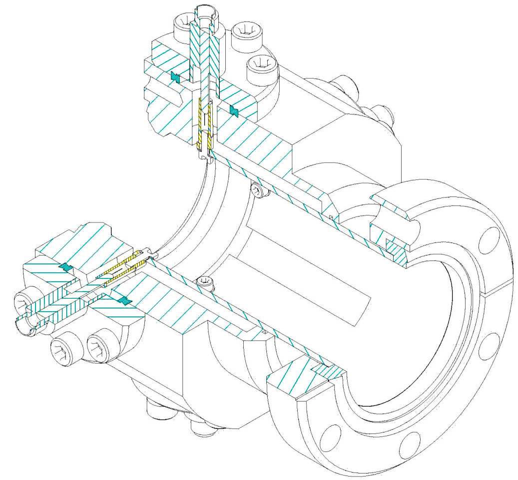
$$V_{BPM}(\omega) = 2V_0\sigma\, e^{-\frac{\omega^2\sigma^2}{2}} \,\mathrm{sinc}\left(\frac{\omega L}{c}\right)$$

L is the BPM electrodes length;

maximum of the BPM sensitivity at L=(2n+1)_λ

λ=23 cm at 1.3 GHz





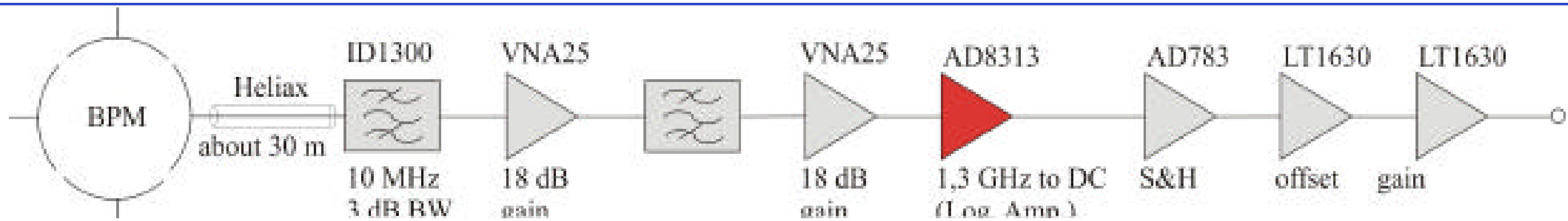
_λ BPM vs. _λ BPM (2)

_λ BPM vs. _λ BPM (3)

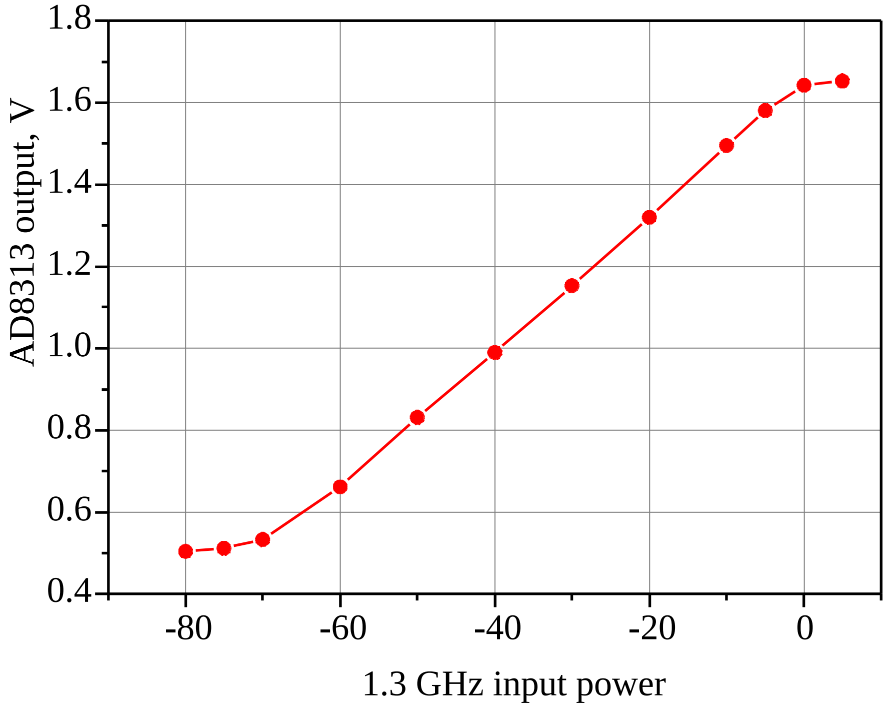
_λ BPM	_λ BPM
40 mm	144 mm
85 mm	235 mm
brazed	e^- beam welded
-24 dBm @ 1 mA	-24 dBm @ 1mA
0.8 dBm/mm	0.8 dBm/mm
1500 Euro	2800 Euro

- More than 20 _λ BPM were manufactured, installed and are operational at ELBE.
- Some of the BPMs are used by a separate system of current Difference measurements – machine protection system.

The BPM electronics



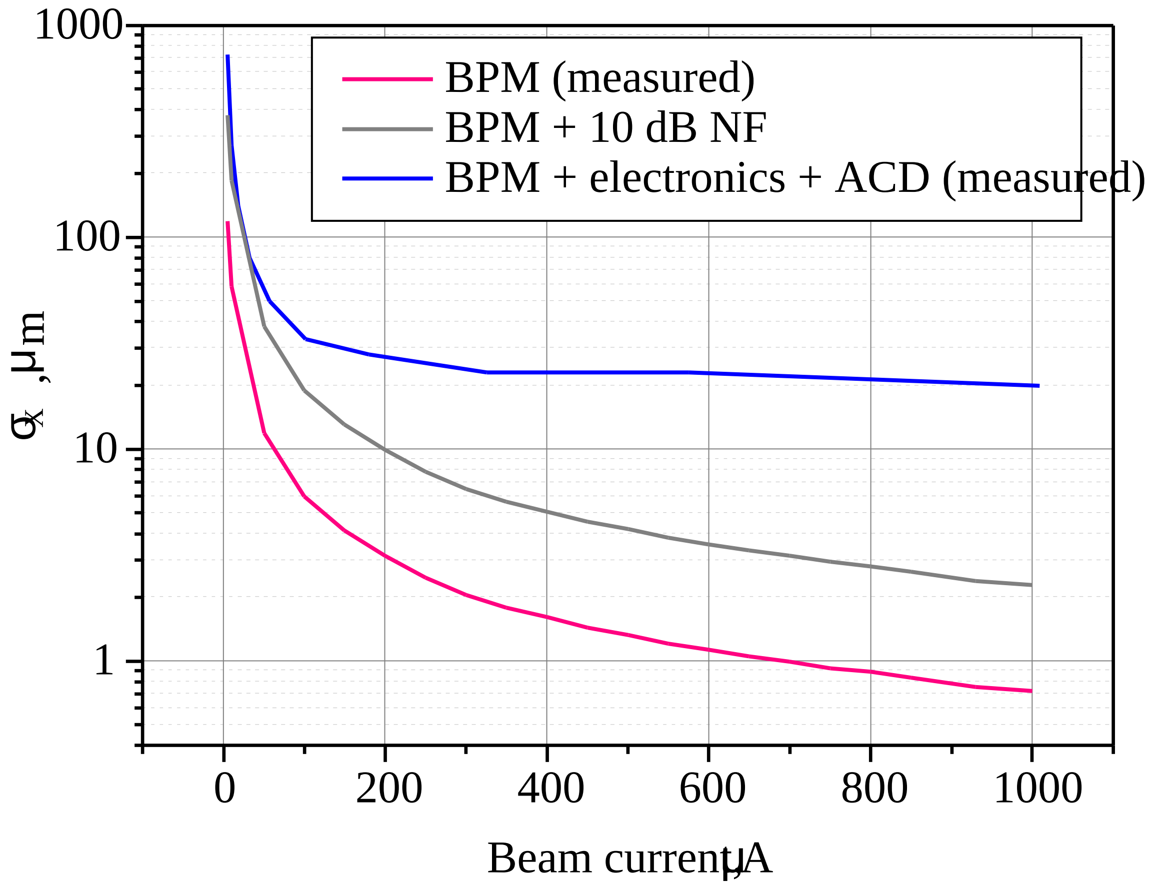
- The core element is the logarithmic detector AD8313 made by Analog Devices Inc.
- The log amp is a direct RF to DC converter rated up to 2.5 GHz.
- The log amp has linear dynamic range going from –65 dBm up to –5 dBm.



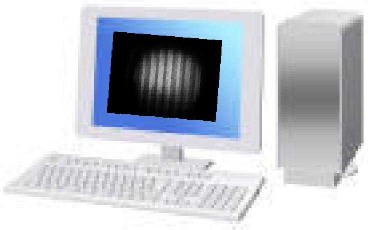
Entire system performance

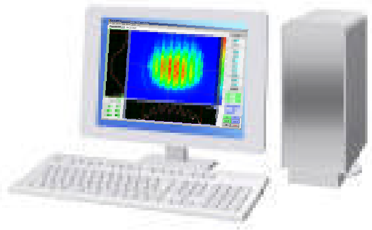
- To measure the system resolution with a beam one needs a beam with stability degree better than the system noise.

- An RF generator
  is used with 1-to-4 splitter
  to measure
  the system resolution.



Video acquisition system

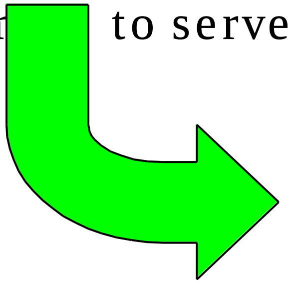




Video DAQ PC:
NI PCI-1407 monochrome 8 bit framegrabber

-
- averaging
- background subtraction

saves im to server

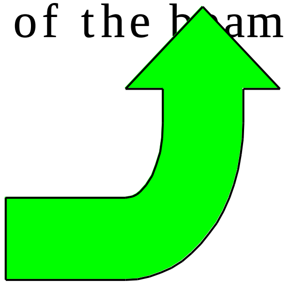


logbook server

Data evaluation PC:
LabVIEW application

- loads an image from server
- calculate emittance
- calculate RMS parameters

of the b am profile



Lessons of video acquisition and beam profile measurements

Lesson 1: A PC based system with PCI framegrabber is probably most cost efficient

Lesson 2: The combination OTR+vidicon works OK only when the beam is well focused on the view screen.

(Note: we have the limitation $I_{av.} \times T_{m.pulse} = 400\mu A \times ms$ in the diagnostics mode)

Lesson 3: The combination Chromox+vidicon works OK for long macro pulses only (small bunch charge).

Next steps:

Image distribution over network;

real-time measurements;

Vidicon → CCD or OTR → YAG;

crosscheck measurements;

Beam loss monitoring and machine protection

- The motivation:
  40 MeV×1 mA=40 kW of CW beam,
  and some bad experience.

- The solution:
  two completely independent systems.

  1. Current difference measurements
  2. Ionization chamber based
     beam loss monitors

- Sensitivity: 100nA of beam loss

Thank you for your attention