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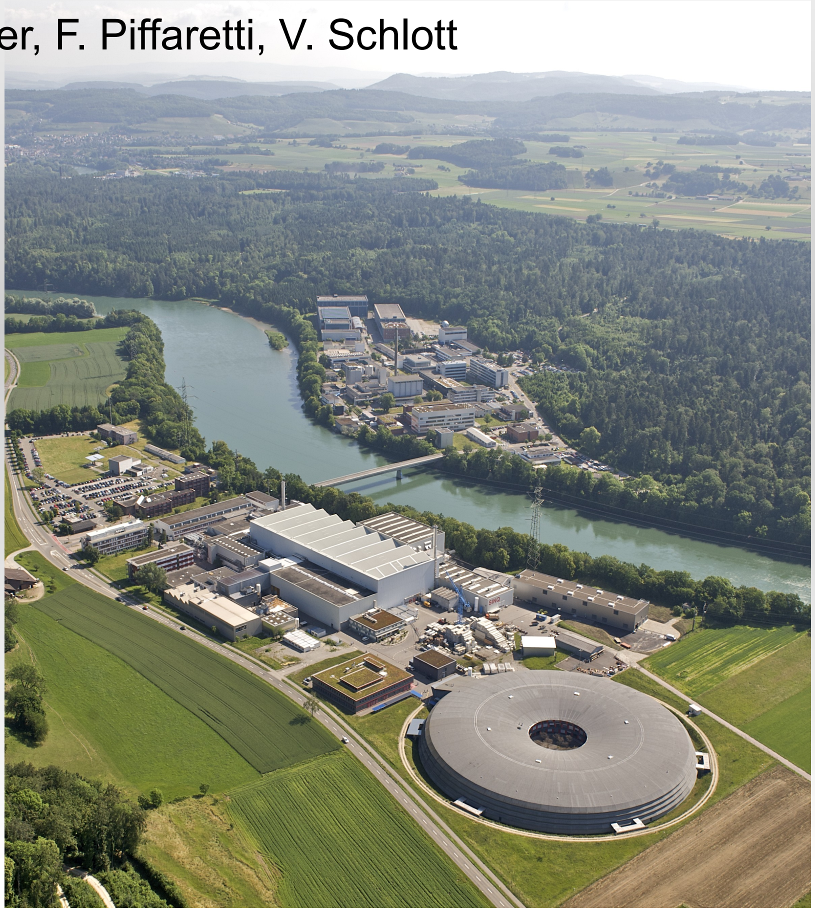
# The Bunch Arrival Time Monitor at the PSI 250 MeV Injector

V. Arsov

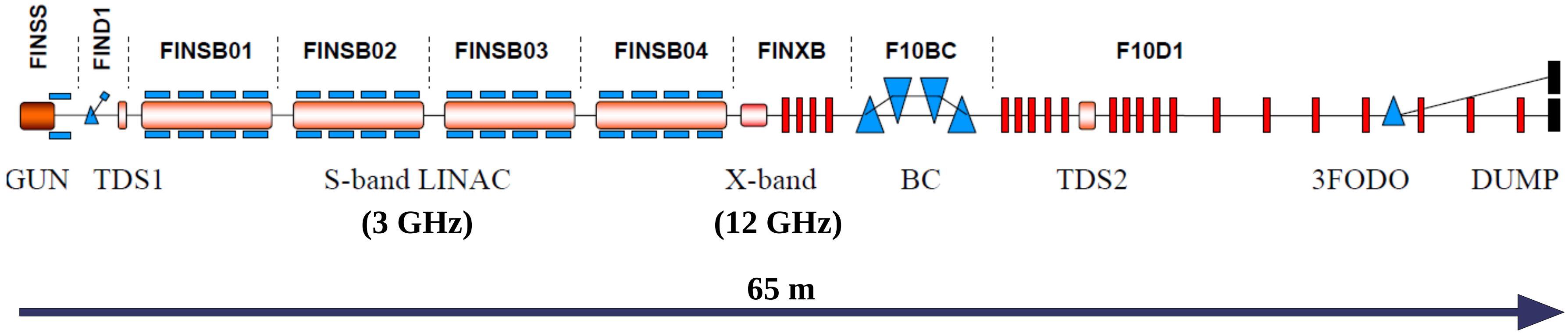
A. Citterio, M. Dehler, S. Hunziker, F. Piffaretti, V. Schlott



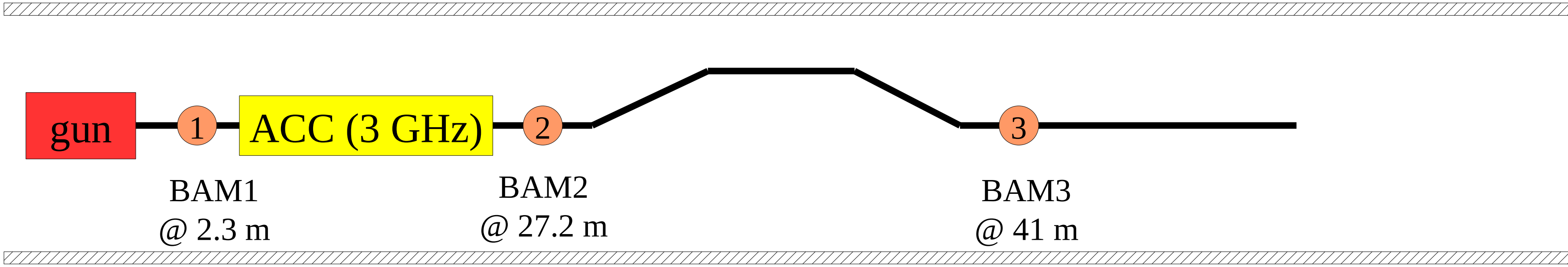
Outline:

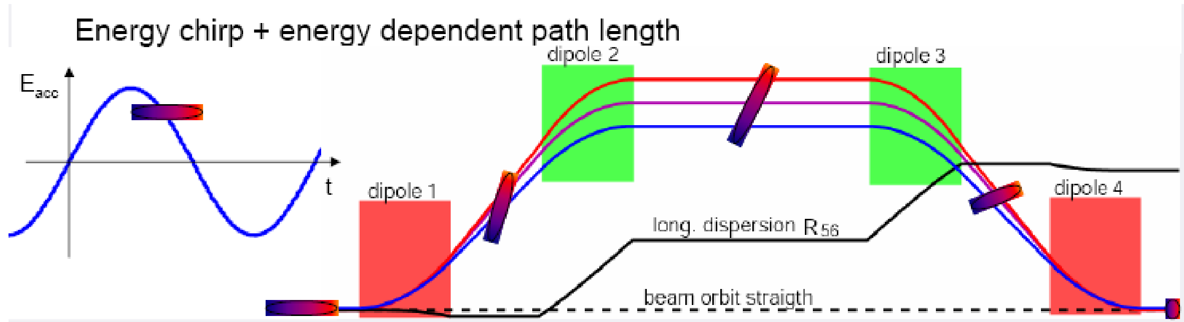
- Overview of the facility
- Sources of timing jitter
- BAM principle and implementation challenges
- BAM pick-up design
- Stability issues, choice of components

# The PSI 250 MeV Injector




# Estimated timing jitter, 250 MeV injector




timing jitter behind the chicane

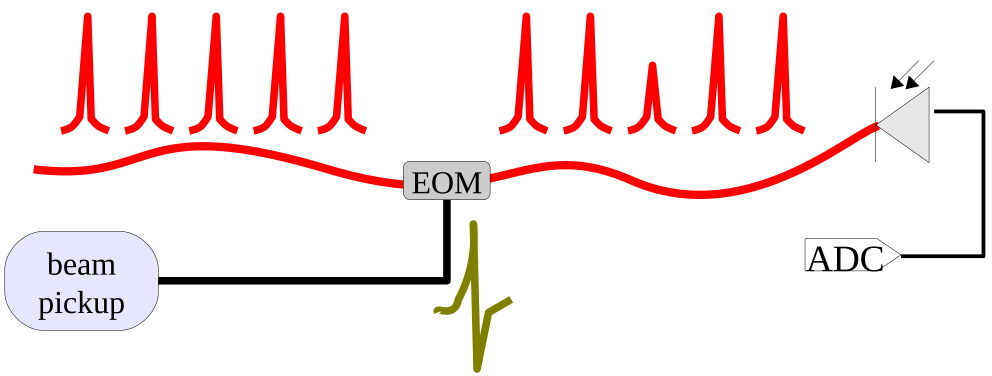
RF amplitude stability

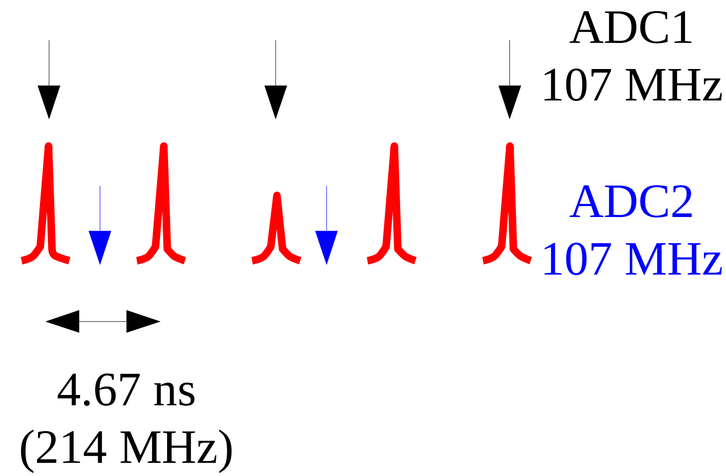
RF phase stability

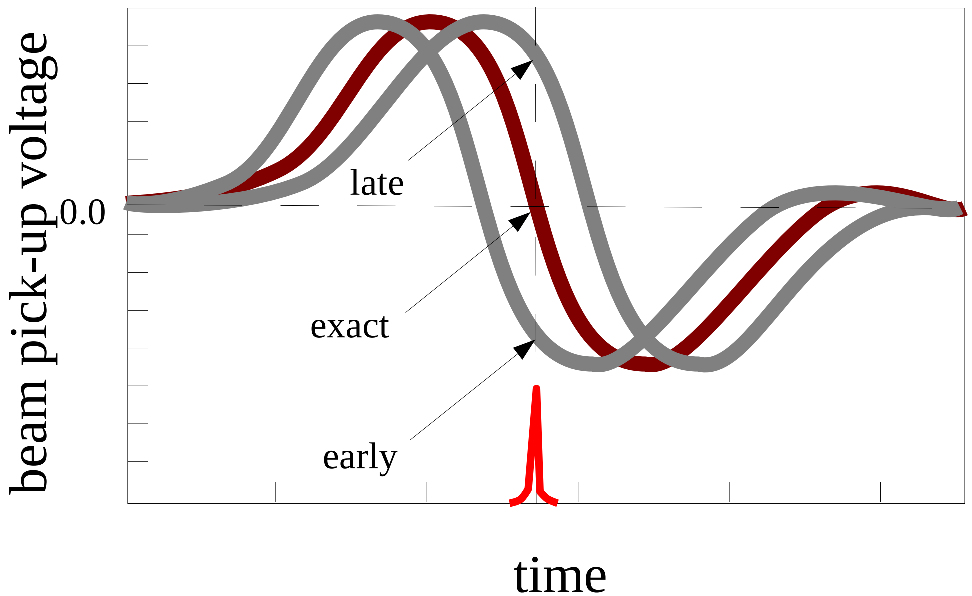
reduction of incoming timing jitter due to compression

$$\sigma_t^2 \approx \left(\frac{R_{56}}{c_0}\frac{\sigma_U}{U}\right)^2 + \left(\frac{C-1}{C}\right)^2\left(\frac{\sigma_\phi}{2\pi f_{RF}}\right)^2 + \left(\frac{1}{C}\right)^2\sigma_{i,t}^2$$

# BAM detection principle




Patented in 2006 by DESY,
Work of F.Löhl &
carried on by the LbSyn Team

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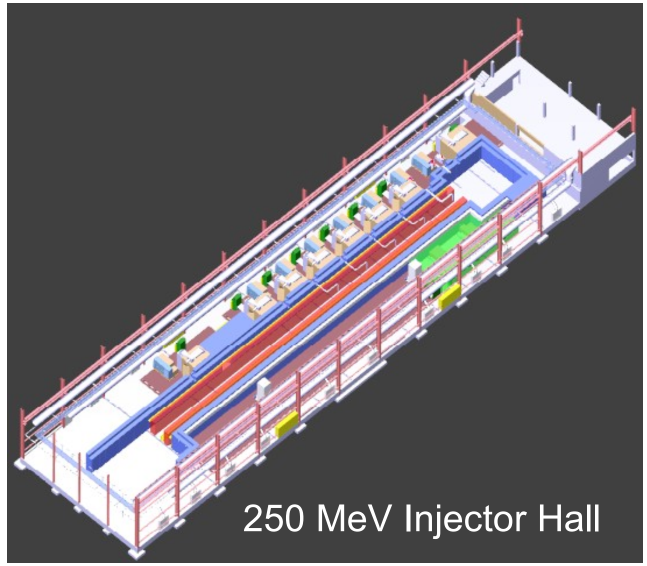
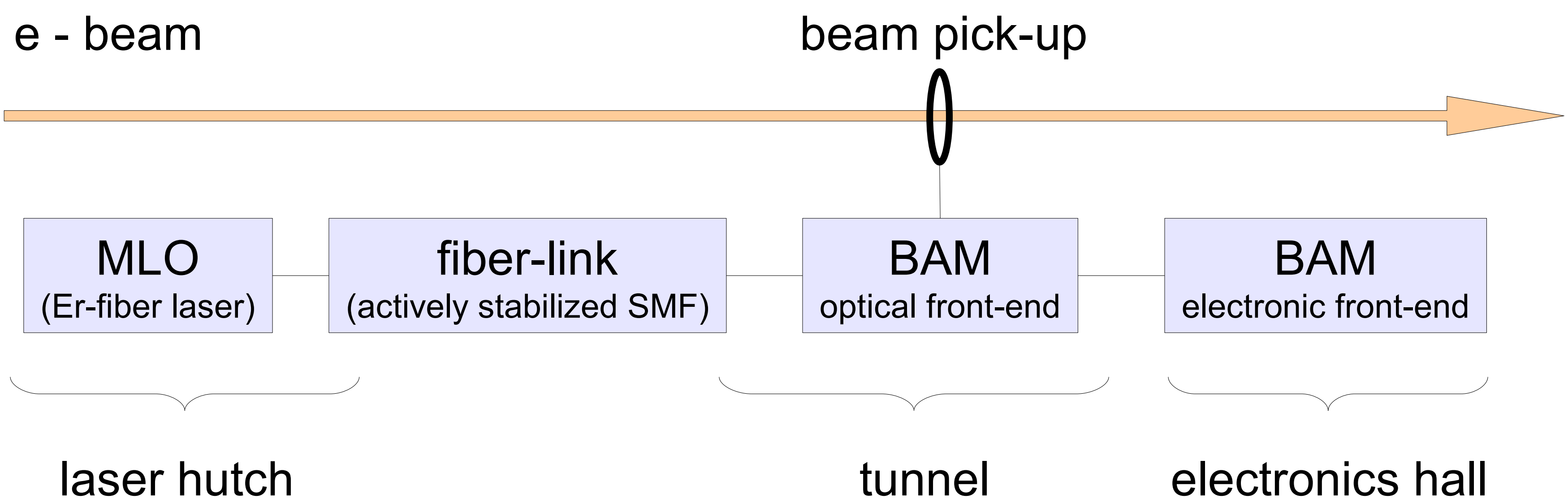
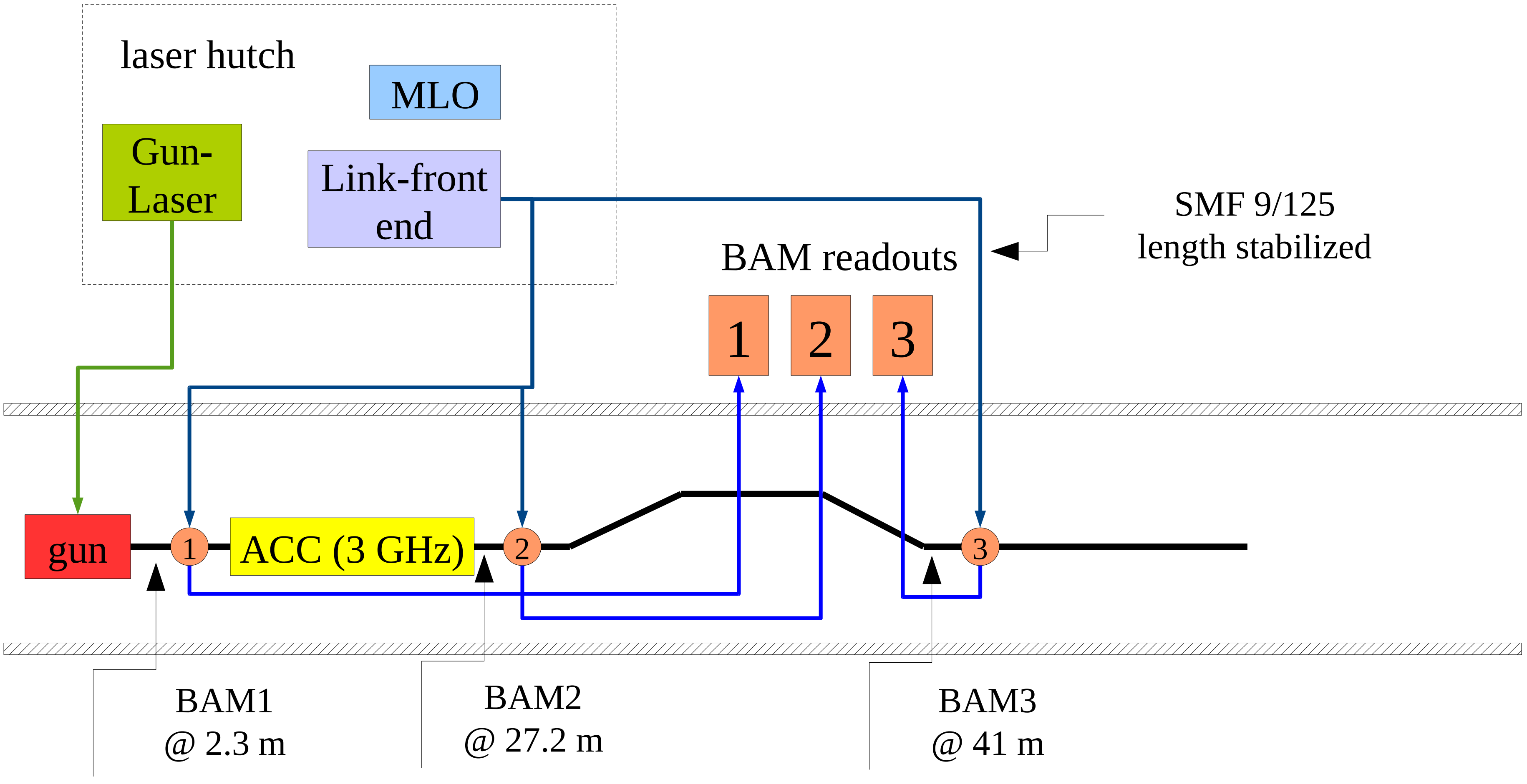
# BAM general layout



# BAM positions in the 250 MeV injector



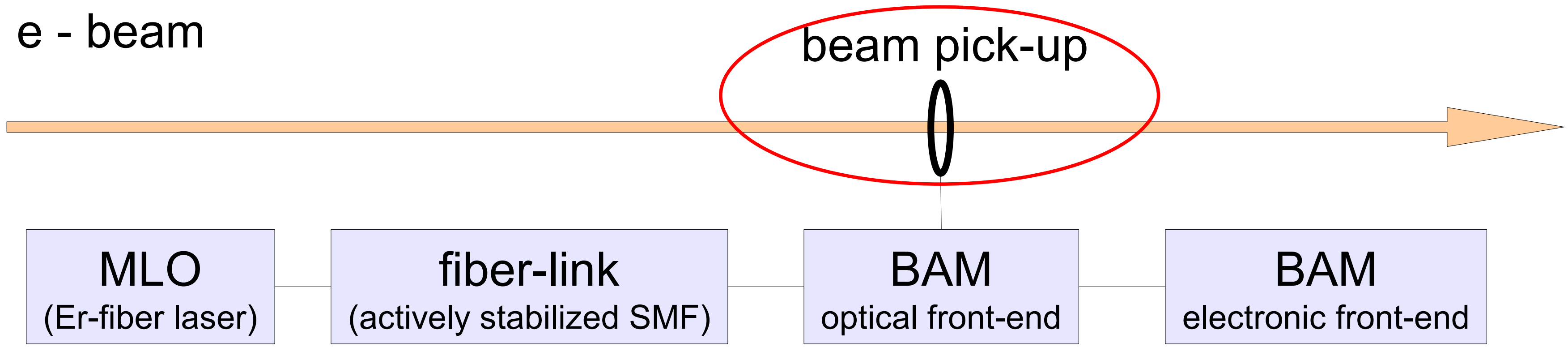

I) 10 pC, 1 ps (rms)

II) 200 pC, 2.8 ps (rms)

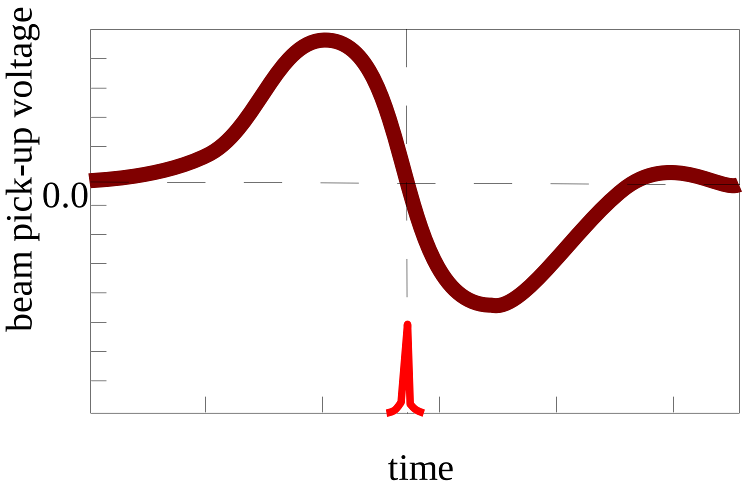
I) 10 pC, 33 fs (rms)

II) 200 pC, 193 fs (rms)

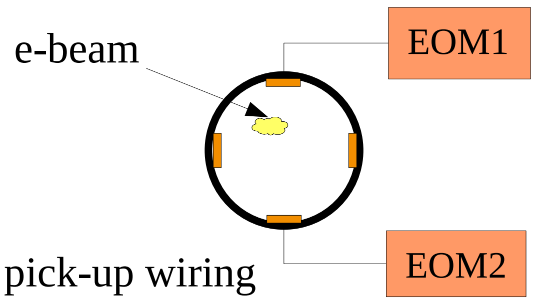
# Beam pick-up requirements




- steep slope at zero-crossing
- low peak-peak voltage
  EOMs stand only ±5 V
- low bandwidth
  reduces the dependence
  of the zero-crossing position
  on the bunch shape



# BAM Orbit Dependence




expected resolution ~30 fs, but...

differential signal EOM1-EOM2 = 1.5 ps ☹

- Strong orbit dependence !
- Precision beam position measurements are possible ☺

$$\left.\begin{aligned} t_{arrival} &= t_{meas,1} + a_{x,1}\, x + a_{y,1}\, y \\ t_{arrival} &= t_{meas,2} + a_{x,2}\, x + a_{y,2}\, y \end{aligned}\right\} \text{ with } \begin{aligned} a_{x,1} &= (6.94 \pm 0.05)\ \text{fs}/\mu\text{m};\ a_{x,2} = (-10.7 \pm 0.02)\ \text{fs}/\mu\text{m} \\ a_{y,1} &= (0.16 \pm 0.07)\ \text{fs}/\mu\text{m};\ a_{y,2} = (-0.29 \pm 0.02)\ \text{fs}/\mu\text{m} \end{aligned}$$

accounting the orbit dependence improved resolution to 3 µm over 1 mm range

- dependent on BPM accuracy
- sensitive to calibration constant errors

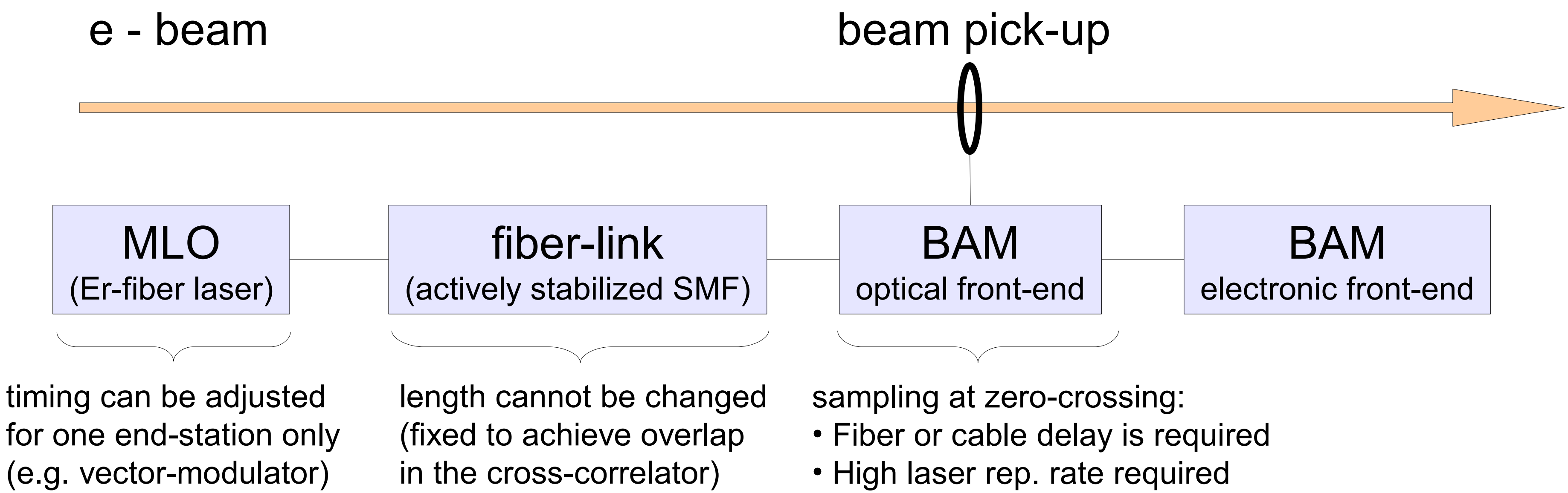
$\Rightarrow$ reduce orbit dependence !

- combine opposite pick-up outputs
- optimize for steep zero-crossing and low peak voltage



F.Loehl, PhD Thesis, DESY-THESIS-09-031, 2009

# BAM Timing Issues

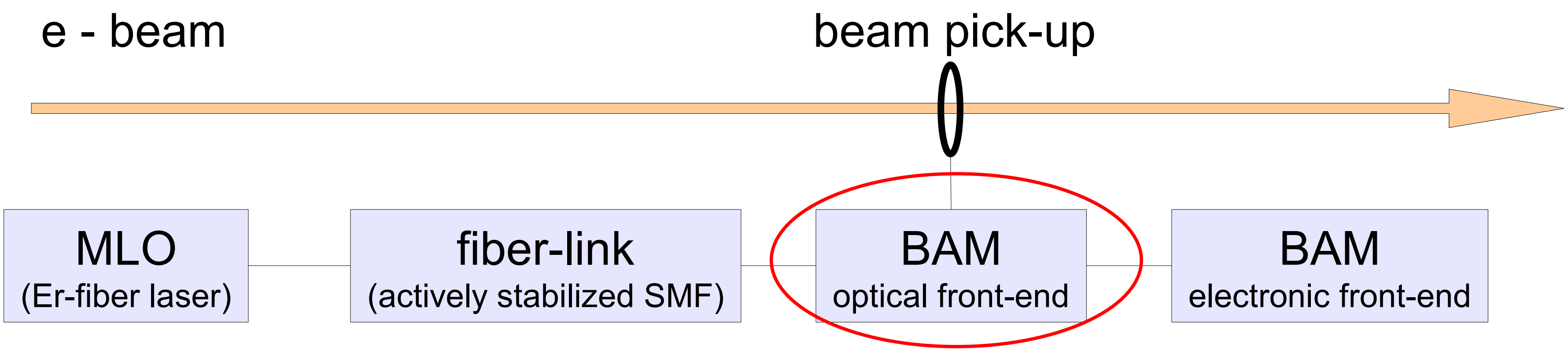



- All timings have to be adjusted for delays outside the fiber link
- Vectror modulator  for the MLO is needed to calibrate the delays
- Motorized delay stages @ the optical front-end is needed to compensate timing changes (phase jumps)

# BAM Optical Front-End Issues

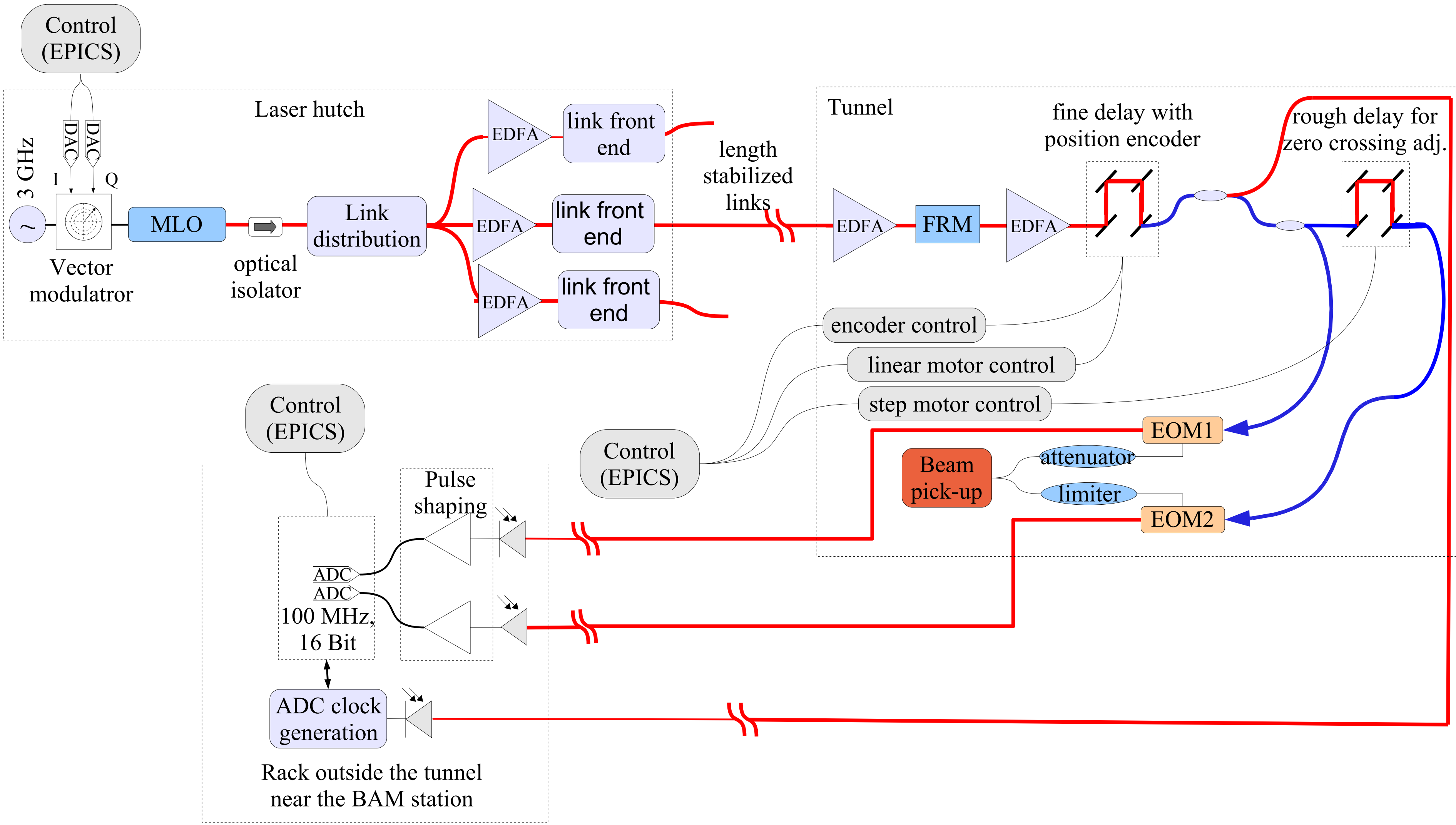
Experience at FLASH (F. Loehl)

Installed in the accelerator tunnel:
• Radiation shielding
• Remote control

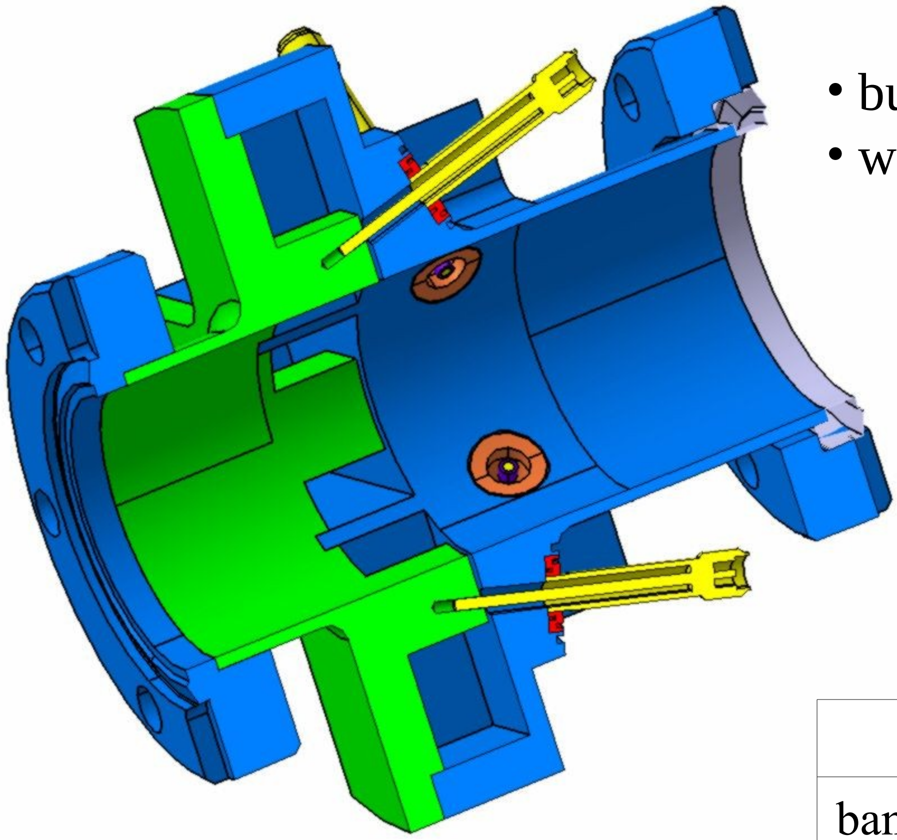



Nevertheless:
• Radiation / EMI / ground currents:
  - position encoders occasionally fail;
  - VME crates for the laser diode drivers occasionally crash;
  - EDFA pump diodes sensitive to ground potential differences between the beam pipe and the VME;
• Some optical delay stages are mechanically not robust enough

# Layout of the bunch arrival time monitor



# BAM-Pickup Design



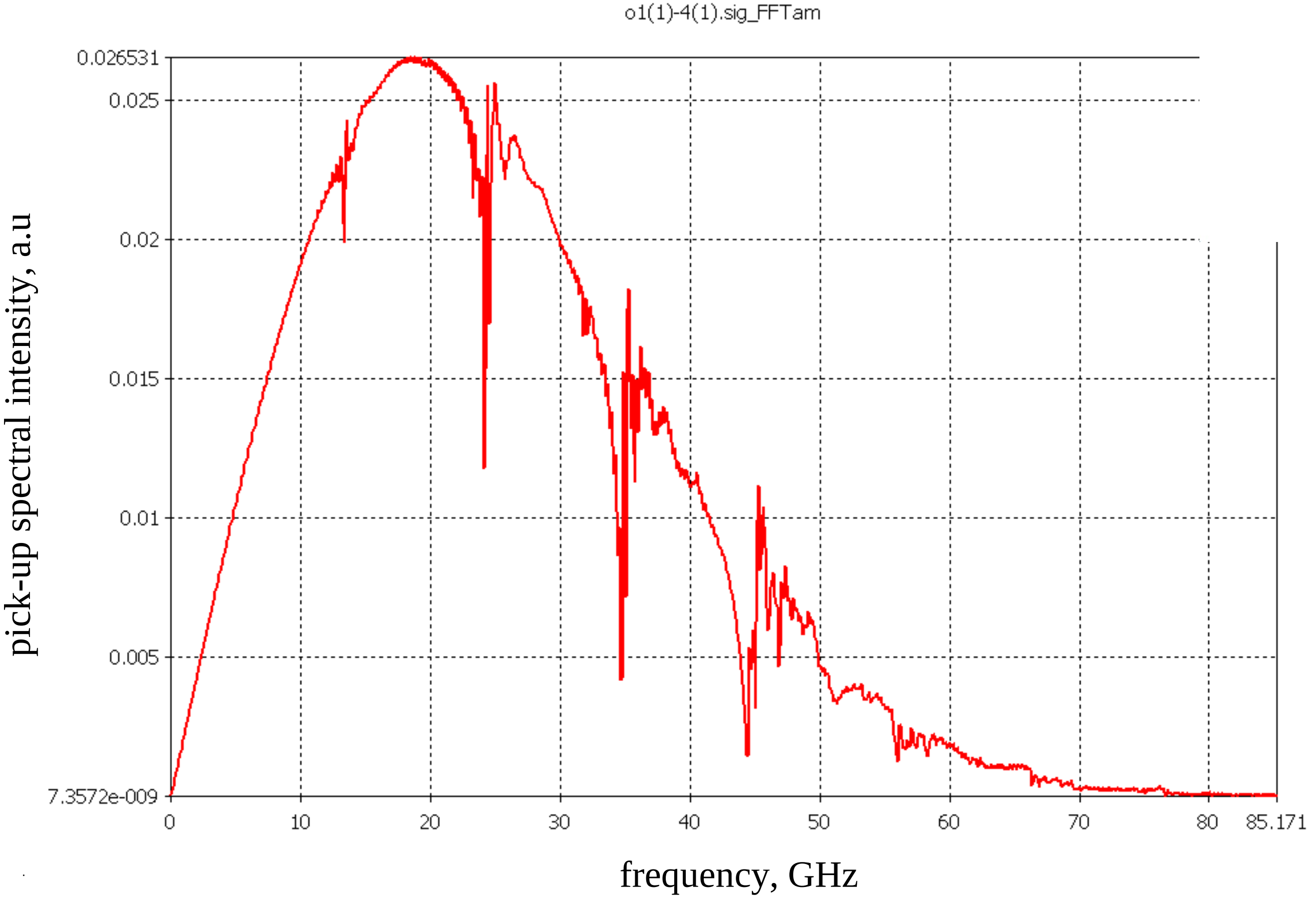
- button: higher bandwidth, lower intesity
- waveguide: lower bandwidth, higher intensity

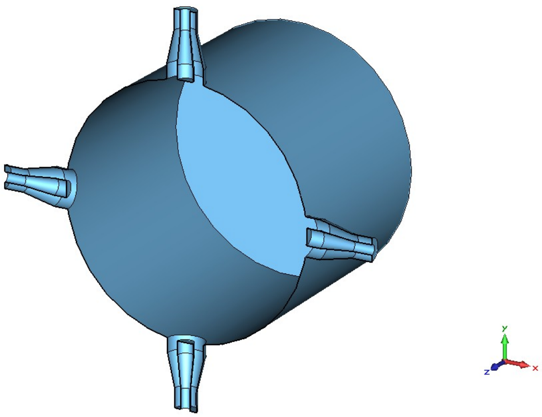
| | button | waveguide |
|---|---|---|
| bandwidth, GHz | 60 | 25 |
| slope, mV/ps.pC | 1 | 4.5 |

Courtesy: A.Citterio, M.Dehler, F.Piffaretti

# BAM-Button Pick-up Spectrum

- bunch charge: 1 nC; bunch length: 6 ps (rms)

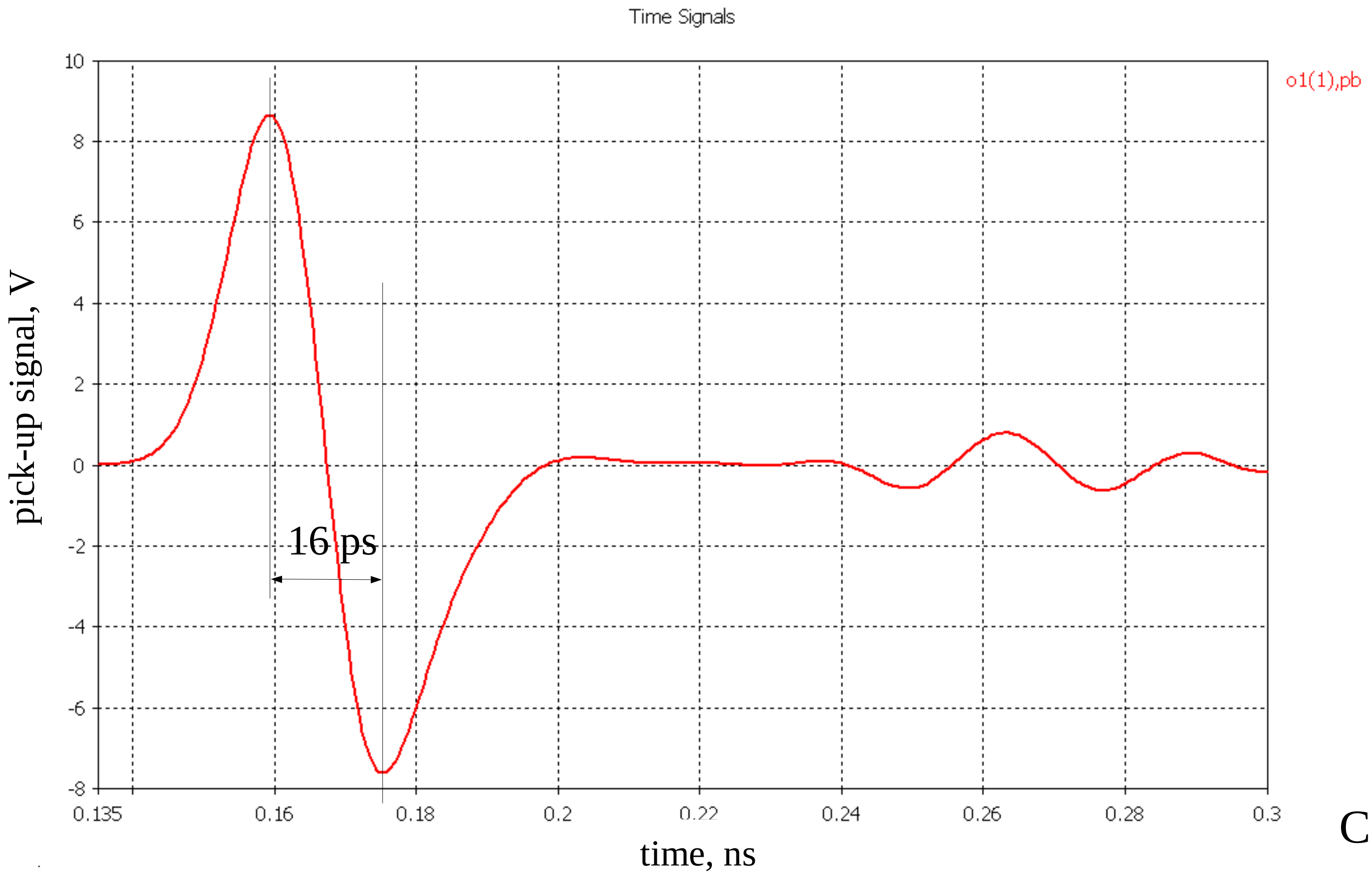


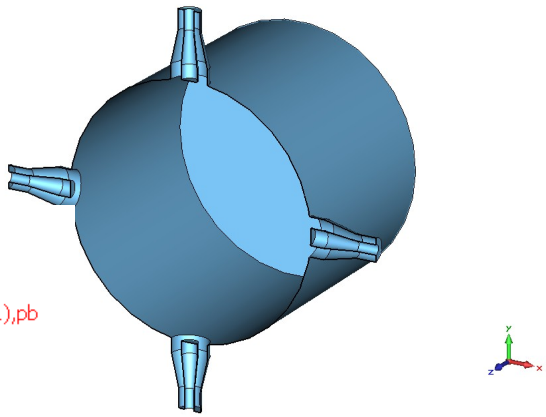



Courtesy: M.Dehler

# BAM-Button Pick-up Simulation

- bunch charge: 1 nC; bunch length: 6 ps (rms)
- signal amplitude: 16 V (p-p), 1 m cable
- signal duration: 16 ps (p-p),
- signal slope: 1 mV / ps.pC

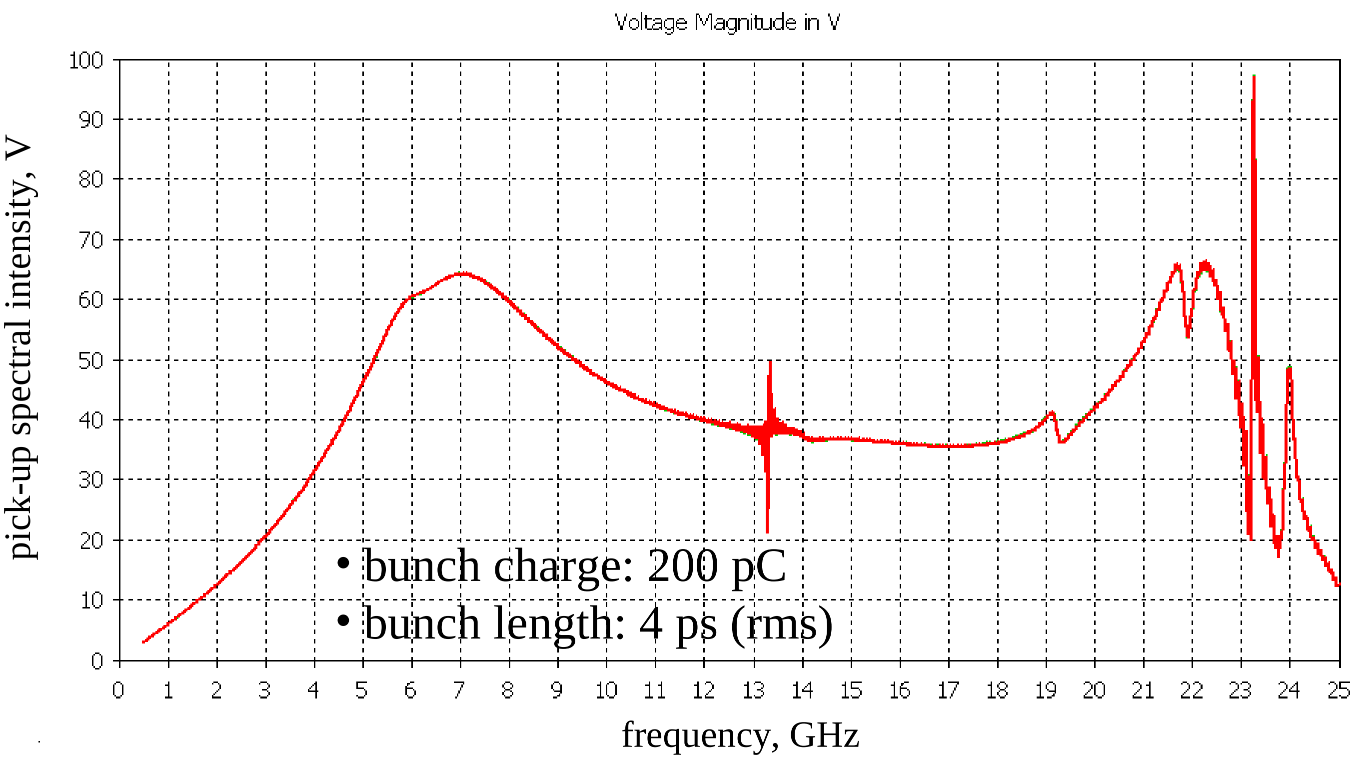


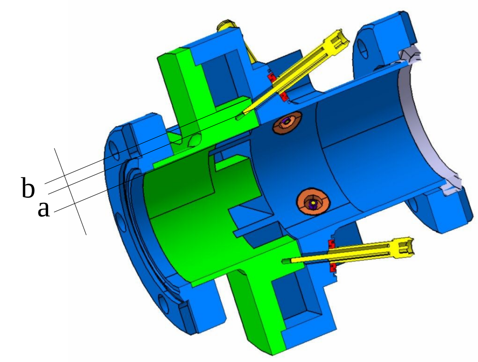



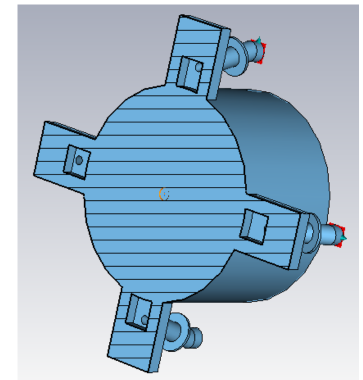
Courtesy: M.Dehler

# BAM-Waveguide Pick-up Simulation

- Beam pipe -pickup distance is critical for the spectral bandwidth
- A short distance helps to dump the higher order modes.
- Mechanical constraints: a = 4 mm distance to beampipe.
- In order to dump the 19 GHz resonance the ridge is very close to the pickups (b = 1.2 mm)
- The resonance in the range 13 - 14 GHz cannot be eliminated.



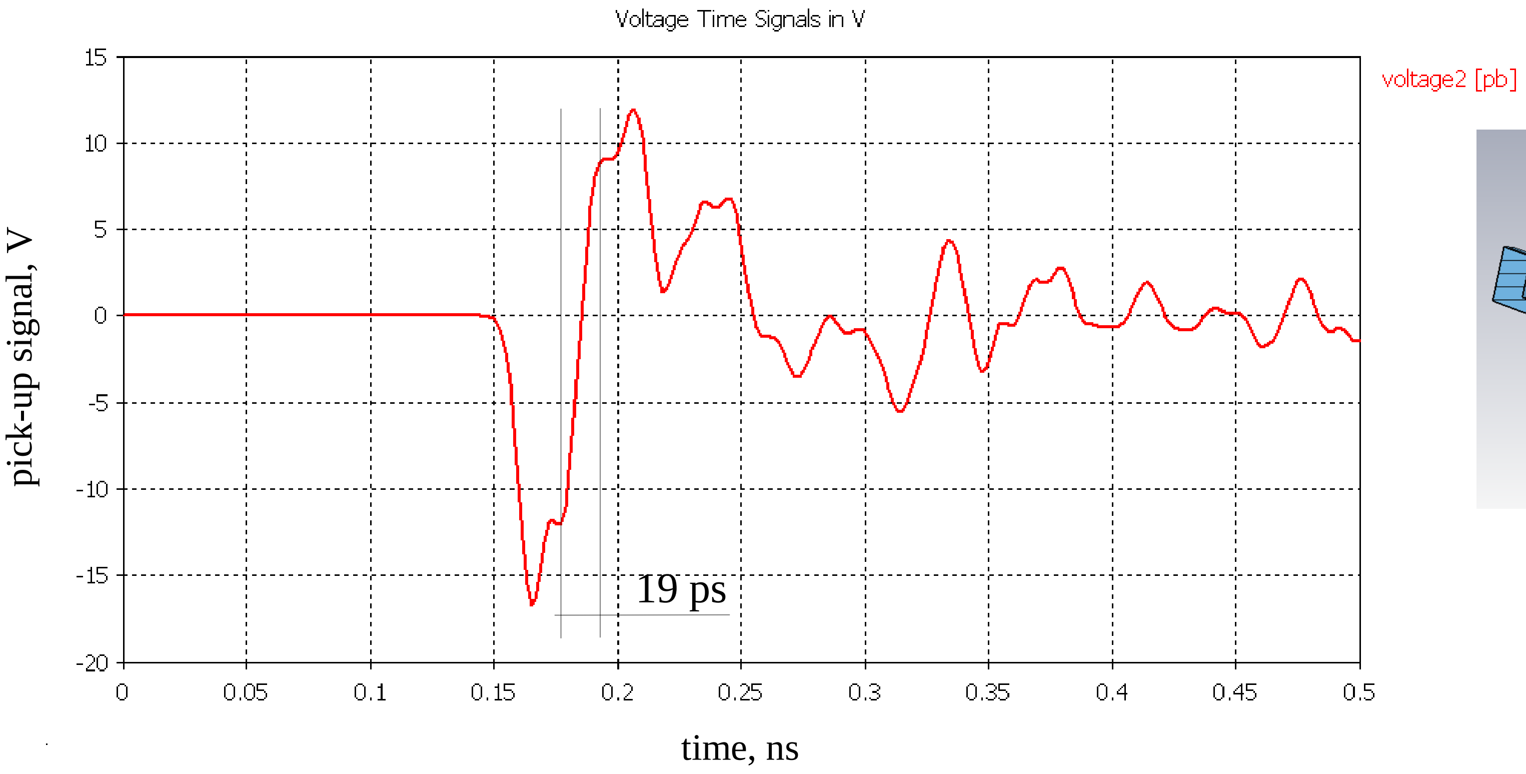



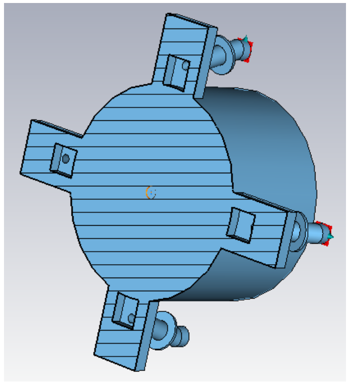



Courtesy: A.Citterio

# BAM-Waveguide Pick-up Simulation

- bunch charge: 200 pC; bunch length: 4 ps (rms)
- signal slope: 4.5 mV / ps.pC

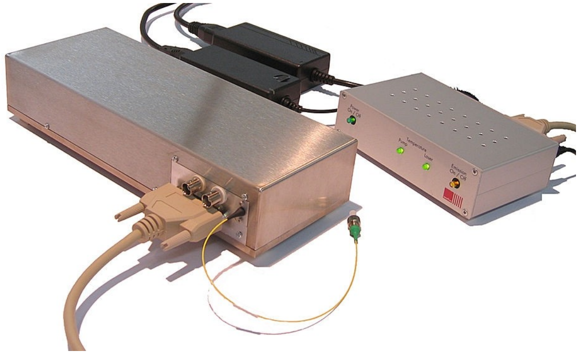


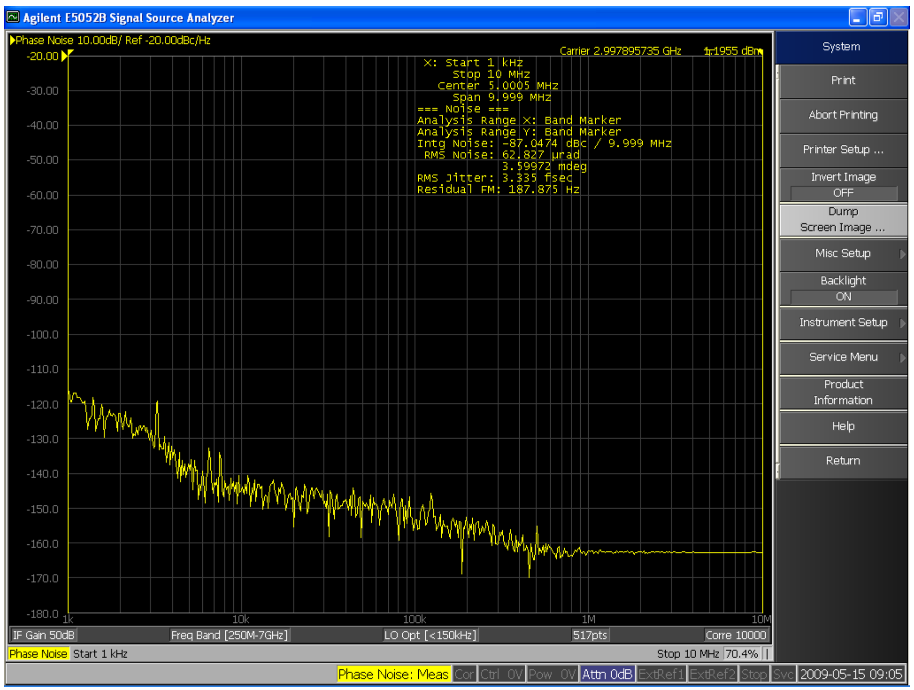
Courtesy: A.Citterio

# Master Laser Oscillator (MLO)

## Origami - 15 soliton laser by OneFive



- $\lambda_0$ = 1562.7nm
- $\Delta\lambda$ = 14.6 nm ($sech^2$, FWHM)
- f = 214.13656 MHz
- $\tau$ = 179 fs (free space)
- P > 120 mW (free space)
- P > 70 mW (fiber coupled)




## Phase noise spectrum

timing jitter = 3.3 fs @
$\Delta f$ = 1kHz..10 MHz
$f_0$ = 2.998 GHz
($14^{th}$ harmonic of 214.14 MHz)



Courtesy: Stephan Hunziker

# Requirements for the BAM fine delay stage

The BAM timing is determined from the motor encoder:

- BAM Resolution < 10 fs ⇒
- Positioning accuracy < 300 nm (< 1 fs)
- Encoder resolution ~10 - 50 nm
- Dynamic range ~300 ps (100 mm travel)

1) High precision step motor stage, Limes-80-115, OWIS with Heidenhain Encoder LC483

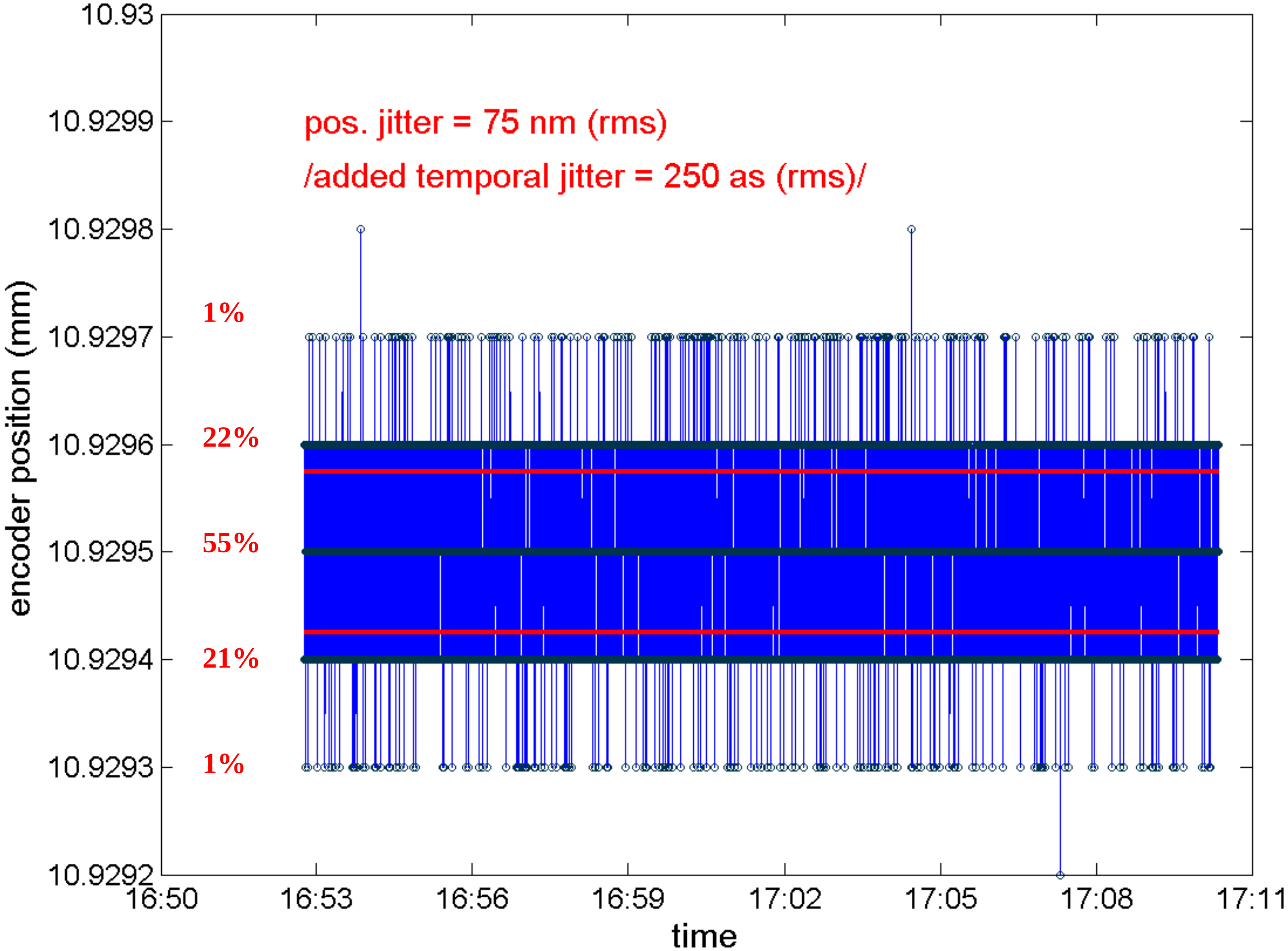
- Travel: 115 mm
- Encoder resolution: 10 nm
- 2 Phase Step Motor, 0.9°/step
- max velocity: 5 mm/s
- Positional accuracy: < 16 μm / 100 mm
- Bi-directional repeatability < 2 μm
- Price: ~6 kCHF

2) Linear Motor MX80L, Parkem

- Travel: 100 mm
- Encoder resolution: 10 nm
- max acceleration: 4G
- max velocity: 30 mm/s
- Peak force: 8 N
- Positional accuracy: 5 μm / 100 mm
- Bi-directional repeatability ± 400 nm
- Price: ~8 kCHF

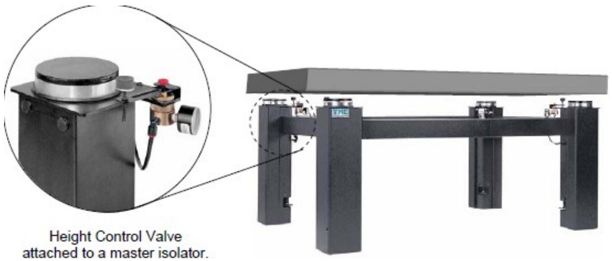
# Test of the Linear Motor MX80L, Parkem

## Encoder readings, MX80L under voltage, but not moved



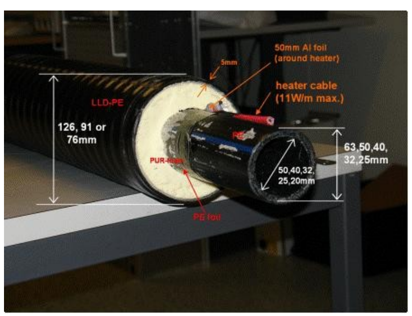

**calibration constant: $10^{-4}$ count/mm (100 nm/count)**
**total # of points: $10^{4}$ (~17 min)**

# Further Stability Precautions...




- Active vibration insulation of the optical tables

- Temperature stabilization (< 0.1°) of the Tunnel and the laser hutch
- Humidity stabilization




- Heated insulated cable pipes
  - T° sensors located at the inner tube
- Low T°-drift RF cables
  - e.g. 7/8“ Cellflex or 3/8“ Heliax (Andrew)
- Low T°-drift optical fibers$
  - e.g. Furukawa SMF28

- radiation & EMI shielding
- avoidance of ground loops
- etc...

# Summary and outlook

- The work is at a very early stage, the machine is still not available
- One can not have BAM without a complete chain of the Optical Reference system
- The design and choice of components is mostly finished
- Construction and test of prototypes has begun in laboratory

# Thank you for your attention!