

# Diagnostics for the PSI-XFEL

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# Diagnostics for the PSI-XFEL

- Measured Quantities
- Instrumentation
  - Working Principle
  - Presently foreseen Performance, Tolerance, Resolution and Precision for 200 pC
  - Performance for 2 pC Bunches
  - Research vs. Development efforts, Items beyond Current State of the Art
- Questions

# Measured Quantities

Quantity	Instrumentation	Notes
Projected emittance @ 7 MeV and 250 MeV	OTR screens, quadrupole scan	Alternatively, phosphor screens may be used
	OTR screens, FODO lattice	
Horizontal slice emittance @ 7 MeV and 250 MeV	Deflecting cavity, OTR screens, quad scan or FODO lattice	Bunch compressor is horizontal
Bunch length	Electro-optical	non-destructive, single-pulse
	Deflecting cavity	Collaboration between RF and Diagnostics
Compression	Pyro detector	CSR from the 4 <sup>th</sup> BC bend
Bunch arrival time	Bunch arrival monitor	
Transverse position	BPMs	non-destructive, single-pulse
Transverse position and profile	OTR screens	
Energy spread	Spectrometer dipole	7 MeV and 250 MeV
Slice energy spread	Deflecting cavity, spectrometer dipole	7 MeV and 250 MeV
Charge	ICMs	non-destructive, single-pulse
	OTR screens (?)	It will have to be seen whether this measurement is affected by COTR
	BPM sum signal	

# Instrumentation

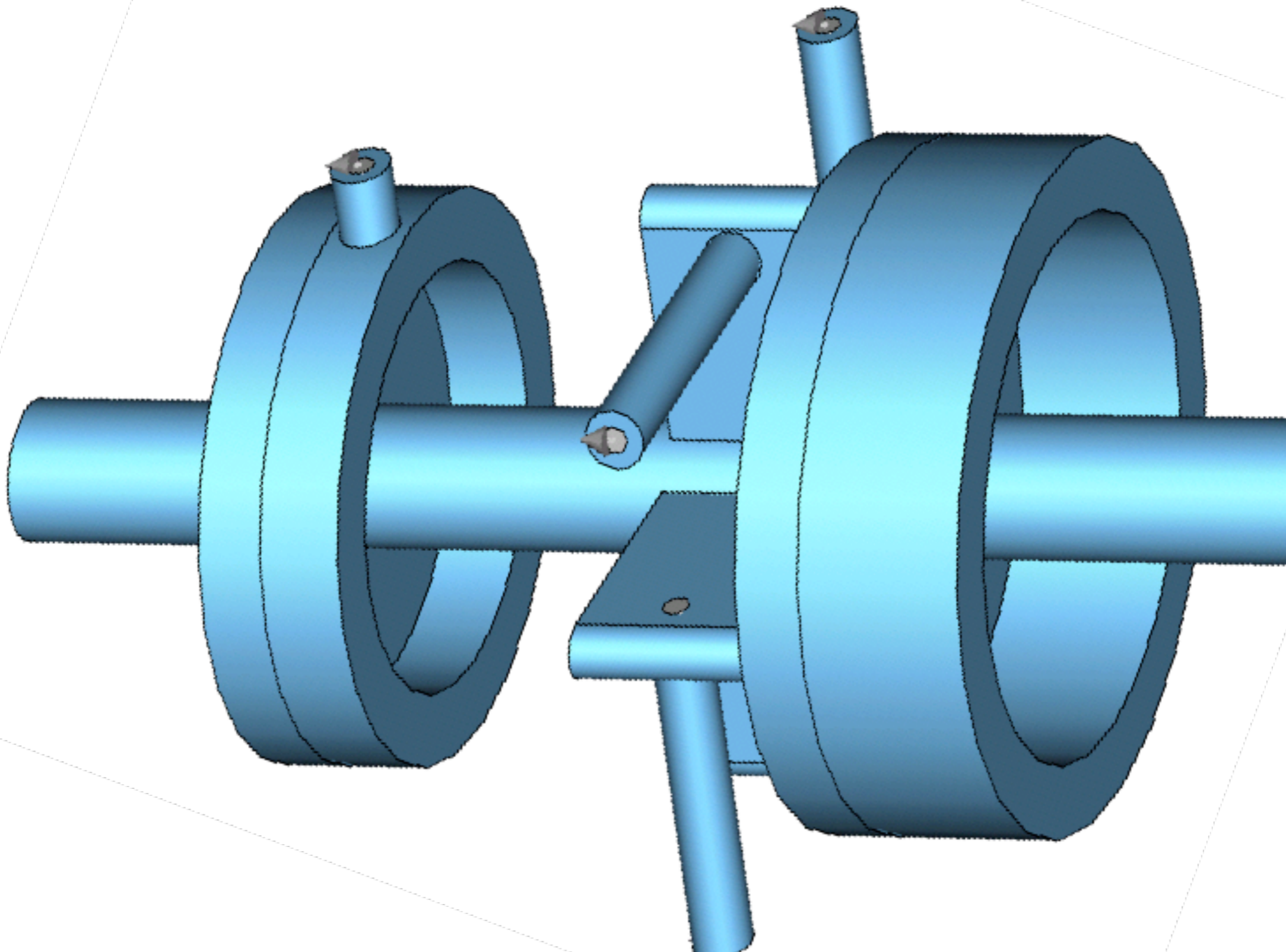
## Planned instruments for the PSI-XFEL:

- Beam position monitors
- Screen monitors
- Electro-optic bunch length monitors
- Current monitors
- Compression monitors
- Bunch arrival monitors
- Transverse deflecting structure
- Timing and synchronization

## More possible instruments (currently not under investigation):

- Loss monitors
- Special BPMs for the bunch compressor
- Laser wire scanners
- Femtosecond streak camera
- Undulators as diagnostics elements

# Beam Position Monitors



# Beam Position Monitors

## Expected Performance

### Expected Performance for 200 pC

- For the 250 MeV Injector:
  - Resonant stripline BPMs
  - 20...200 pC operating range
  - Resolution: 10  $\mu\text{m}$  rms
- For the PSI-XFEL linac: 2 options:
  - Resonant stripline BPMs — 10  $\mu\text{m}$  rms
  - Cavity BPMs (developed by PSI for the European XFEL) — goal: 1  $\mu\text{m}$  rms
- For the PSI-XFEL undulator:
  - Cavity BPMs (developed by PSI for the European XFEL) — goal: 1  $\mu\text{m}$  rms

### 2 pC Options

Stripline BPMs: possible option as standard BPMs

- Existing electronics: 50...100  $\mu\text{m}$
- New electronics: 3...4 times better?

Cavity BPMs

- Use European XFEL pickup (3.3 GHz) with improved electronics: expecting  $\sim 2$   $\mu\text{m}$
- Further improvement possible by designing a pickup with higher frequency (6...11 GHz)
- BPMs are sensitive to dark current!

Items where we do research

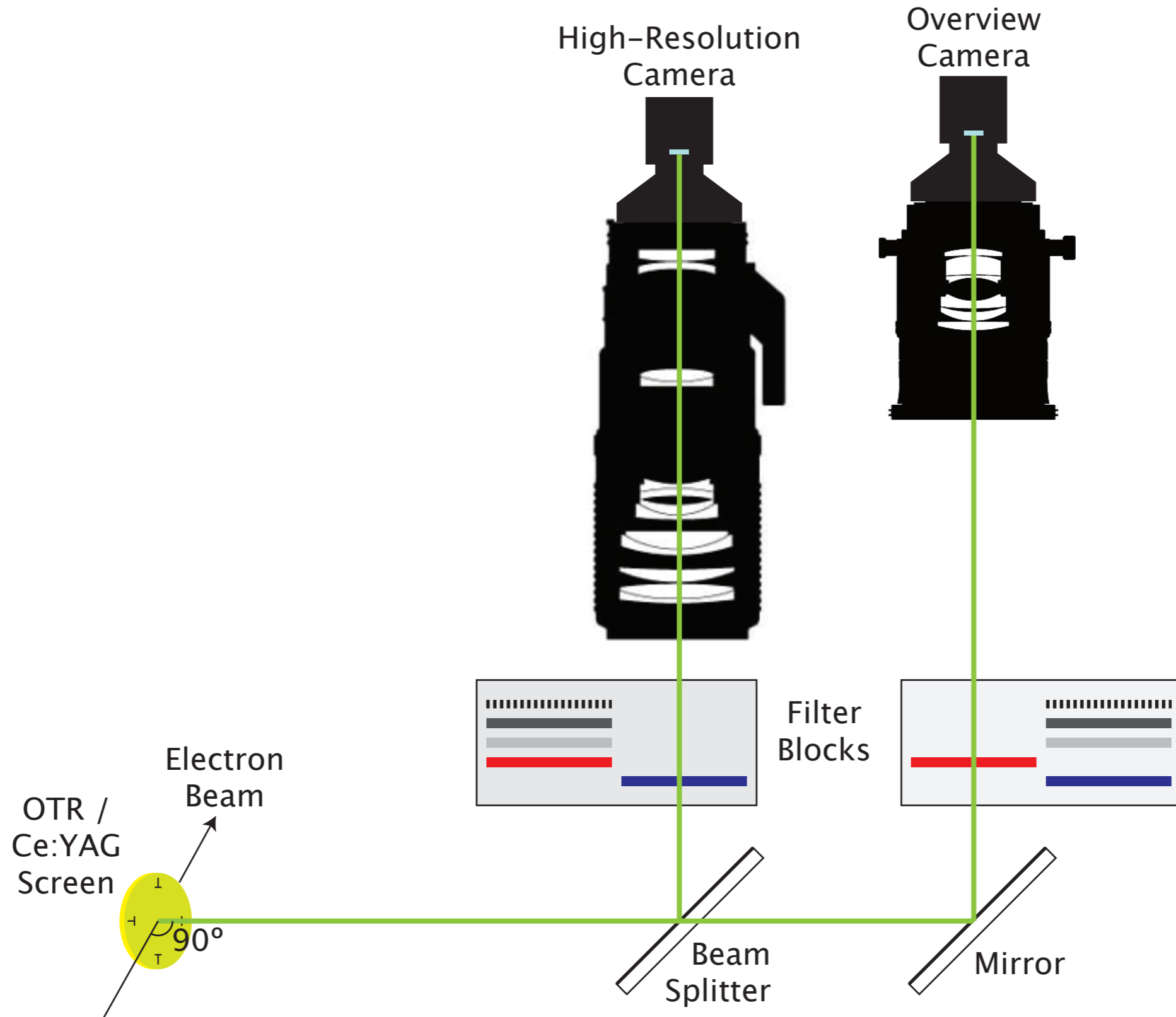
- Higher frequency cavity BPMs: new pickup, adapted / new electronics

Items where we do development

- Cavity and stripline BPM pickups
- Electronics for cavity and stripline BPMs (cavity electronics: developed by PSI for the European XFEL)

Items that we purchase

# Screen Monitors



# Screen Monitors

## Expected Performance

### Expected Performance for 200 pC

- Projected pixel size (overview):  $23\ \mu\text{m} \Rightarrow$  resolution  $\sim 50\ \mu\text{m}$ 
  - Field of view:  $37 \times 28\ \text{mm}^2$
- Projected pixel size (HR):  $4.4\ \mu\text{m} \Rightarrow$  resolution  $\sim 10\ \mu\text{m}$ 
  - Field of view:  $5 \times 1\ \text{mm}^2$
- Expected visible transition radiation ( $\gamma = 1000$ ): 50 fJ per pC
- Ce:YAG crystal:  $\sim 100\ \text{nJ}$  per pC in  $4\pi$  solid angle
- Coherent OTR may spoil the measurement; Backup solutions:
  - Ce:YAG crystals (limited resolution)
  - Wire scanners (no single-shot measurements, no measurement of slice emittance possible)

### 2 pC Options

- Ce:YAG crystals should generate enough light
- However, we expect blooming and saturation of the crystals
- Sensitive cameras can detect 50 fJ OTR light
- When the bunch length is below  $\sim 1\ \text{fs}$ , coherent OTR plays the dominant role
- Can we use the coherent OTR to measure beam properties?
- Dark current may spoil the measurements

#### Items where we do research

- Coherent optical transition radiation (Collaboration with DESY)
- Far field angular distribution of OTR (Collaboration with ENEA)

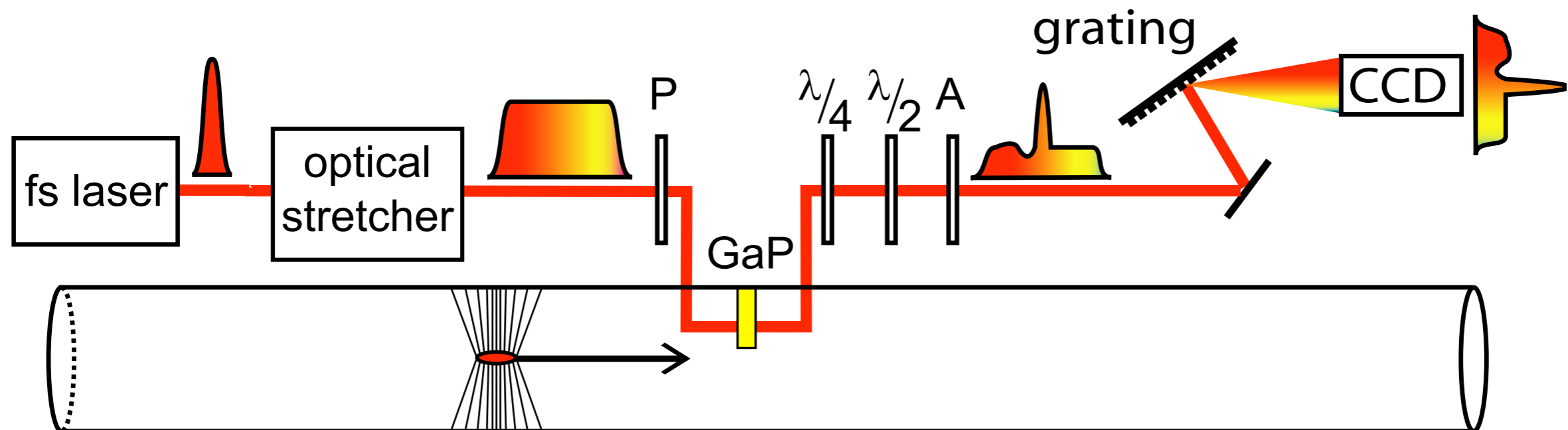
#### Items where we do development

- Imaging of OTR radiation

#### Items that we purchase

- Cameras
- Lenses

# Electro-Optic Bunch Length Monitors

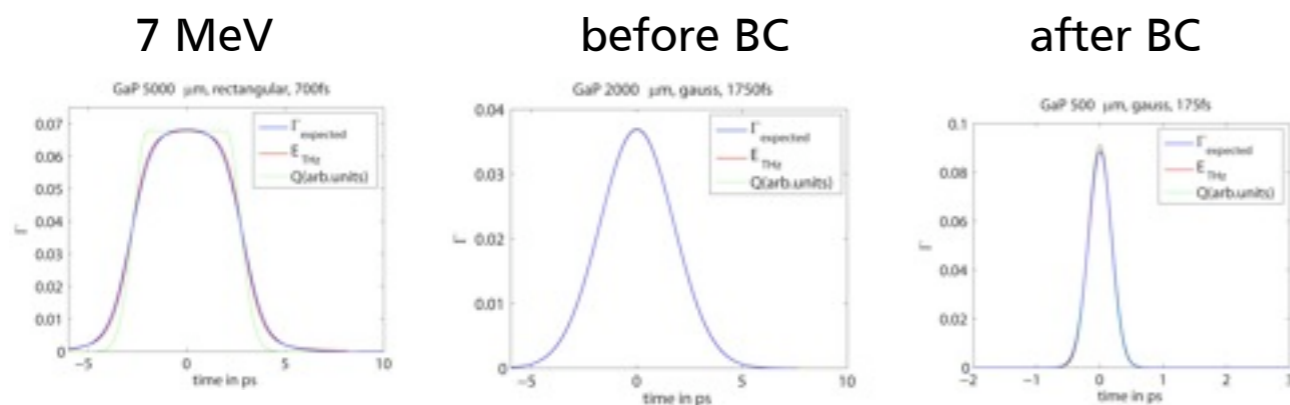


# Electro-Optic Bunch Length Monitors

## Expected Performance

### Expected Performance for 200 pC

- Resolution goal: 150 fs rms
- Fiber laser @ 1030 nm
- Spectral decoding (spectrometer)



### 2 pC Options

- No plans to use electro-optical bunch length monitors for 2pC, 0.45 fs pulses
- ⇒ Measure the visible spectrum of coherent transition radiation (diffraction radiation, synchrotron radiation)

#### Items where we do research

#### Items where we do development

- Laser
- Compact spectral decoding setup
- Synchronization

#### Items that we purchase

- Crystals
- Optical fibers and optical components

# Current Monitors



# Current Monitors

## Expected Performance

### Expected Performance for 200 pC

- Accuracy: 5 pC rms (to be confirmed)

Items where we do research

Items where we do development

### 2 pC Options

- Use the monopole mode of a resonant cavity
- Synergy with BPM / proton accelerator developments at PSI
- Dark current may spoil the measurements

Items that we purchase

- ICTs for > 20 pC

# Compression Monitors



# Compression Monitors

## Expected Performance

### Expected Performance for 200 pC

- Relative measurements only!

Items where we do research

### 2 pC Options

- For femtosecond bunch lengths, we will observe coherent visible radiation
  - Quantum detectors are available below 2.5  $\mu\text{m}$

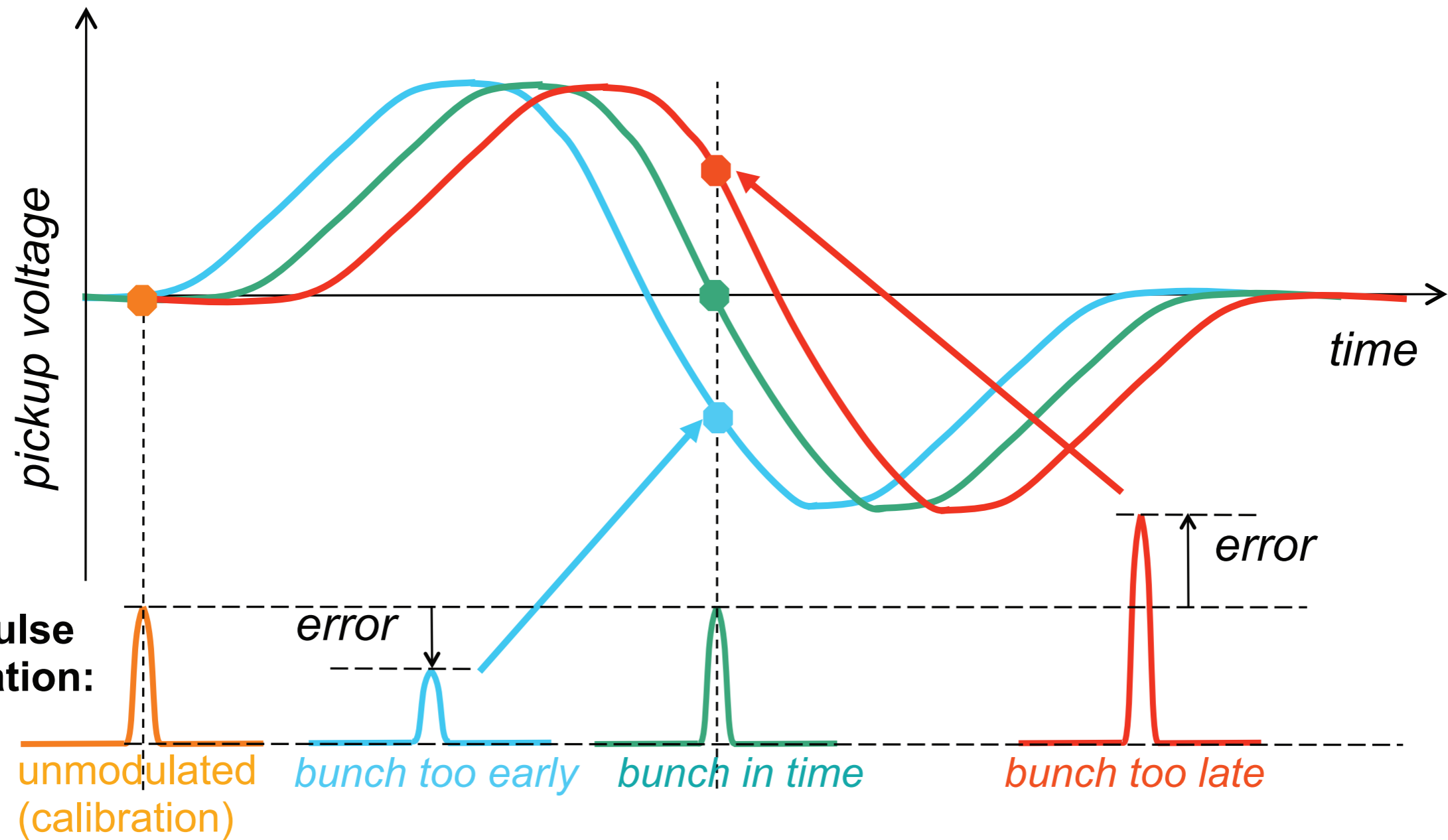
Items where we do development

- Frequency selection (collaboration with DESY)

Items that we purchase

- Detectors

# Bunch Arrival Monitors



# Compression Monitors

## Expected Performance

### Expected Performance for 200 pC

- Goal: 50 fs rms for the 250 MeV injector
- PSI-XFEL goal: 10 fs rms

Items where we do research

### 2 pC Options

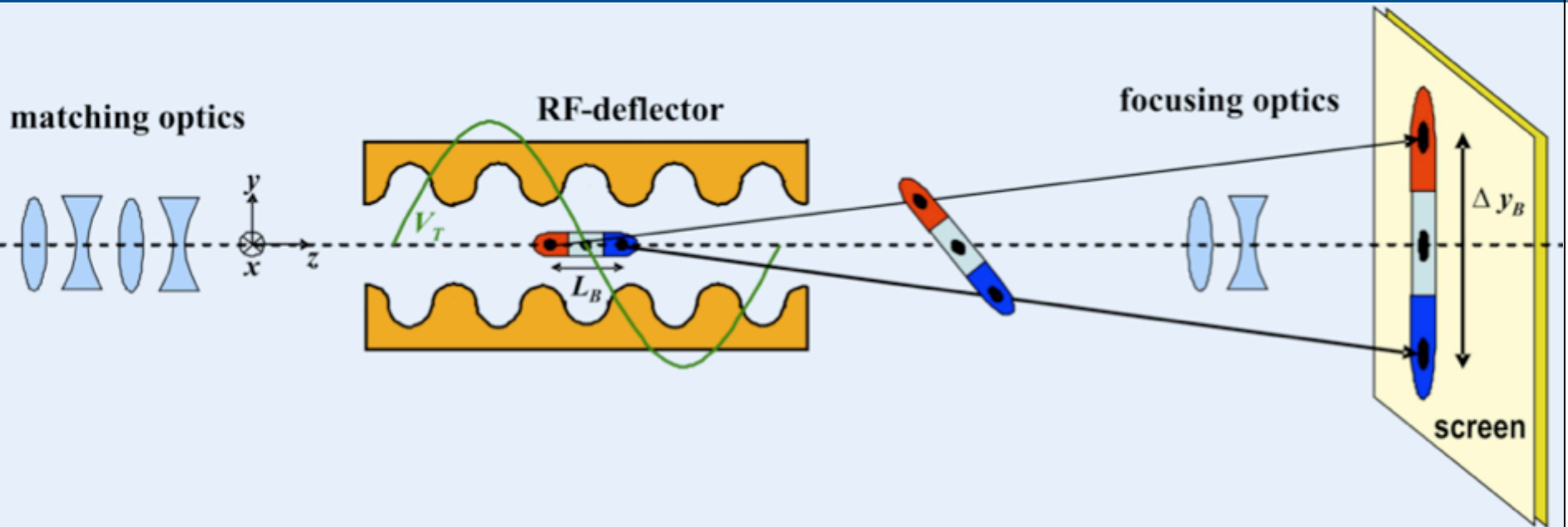
- We would need to design a new pickup for 2 pC

Items where we do development

- Connection to optical master oscillator
- Pickup

Items that we purchase

# Transverse Deflecting Structure



# Transverse Deflecting Structure

## Expected Performance

### Expected Performance for 200 pC

- Expected parameters of the 250 MeV TDS
  - 21 slices of ~20 fs in the 1.2 mm FWHM of the beam

Items where we do research

### 2 pC Options

- For sub-femtosecond pulses, we need a higher deflecting voltage  
⇒ Longer structures, possibly travelling-wave
- Detection of fewer electrons 🖱️ Screen Monitors

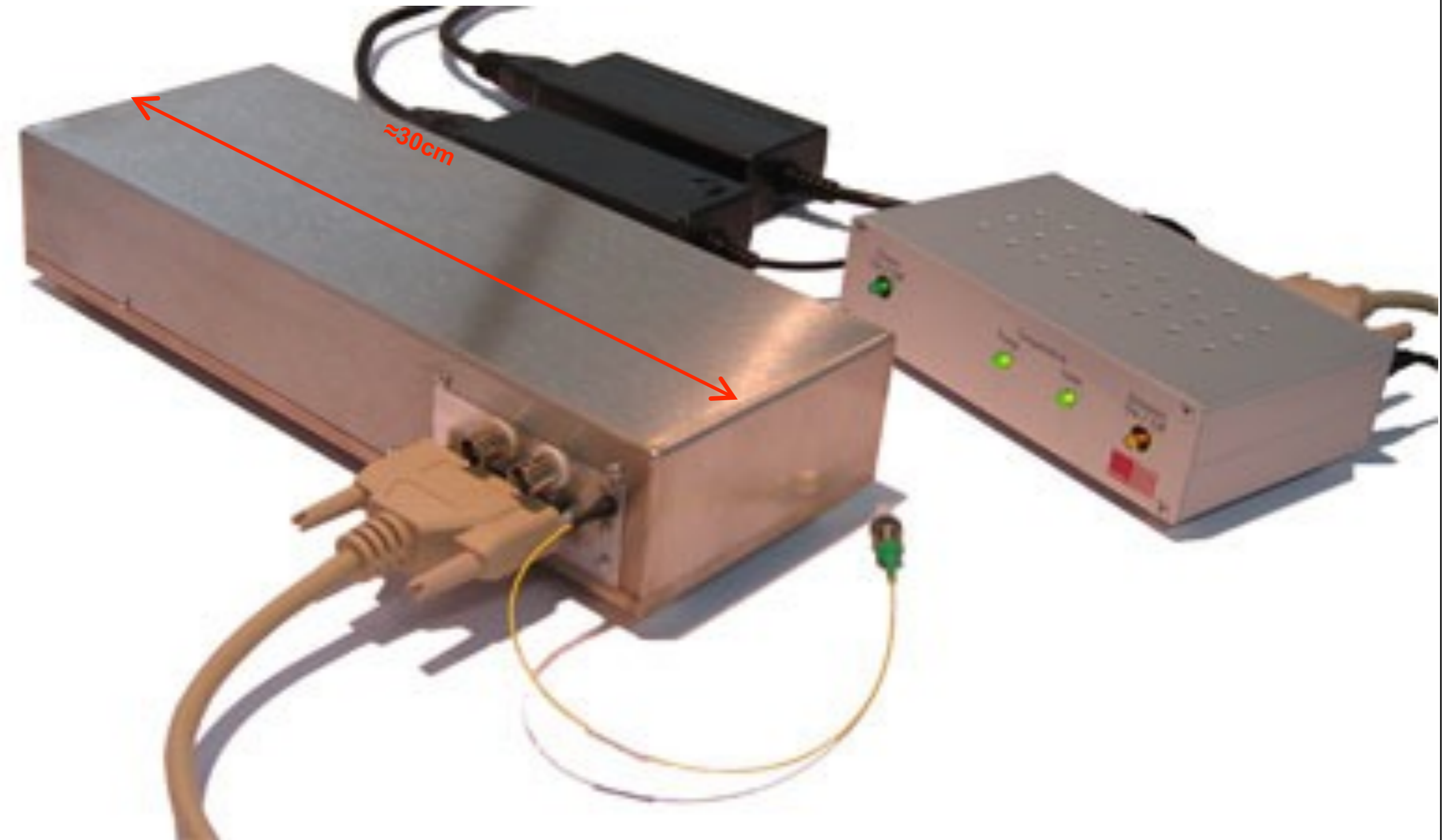
Items where we do development

- Beam optics

Items that we purchase

- Cavity
- RF system

# Timing and Synchronization



# Timing and Synchronization

## Expected Performance

### Expected Performance for 200 pC

- RF system:
  - 40 fs total drift (gun area)
  - 100 fs to the end of the injector
- Optical system final goal: 8 fs (1 kHz – 10 MHz) for the entire system

#### Items where we do research

- Direct laser → RF conversion
- Sagnac loops (in collaboration with DESY, MIT, Menlo Systems)

#### Items where we do development

- Distribution topology
- Stabilization
- Conversion to RF signals of relevant frequencies

#### Items that we purchase

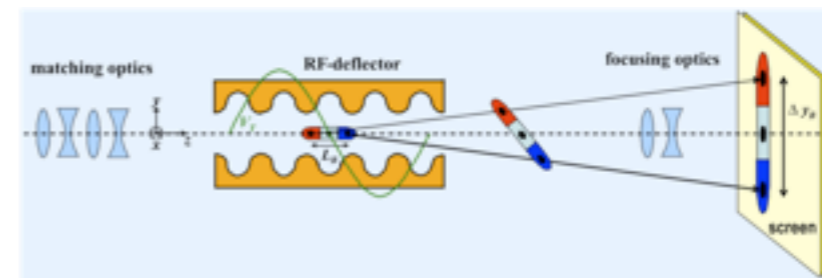
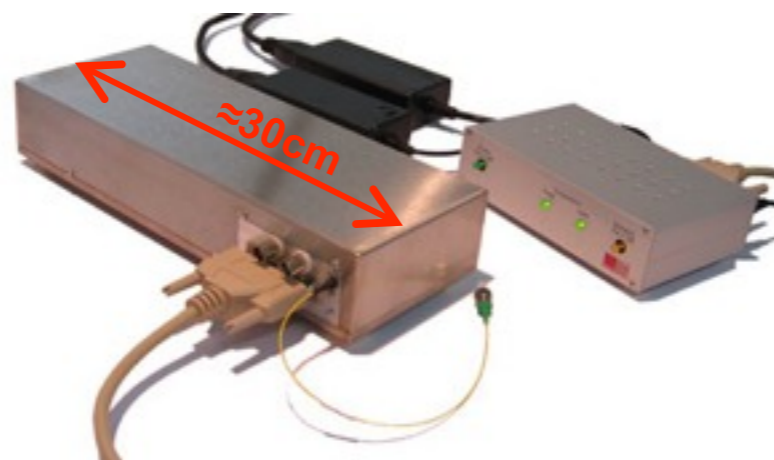
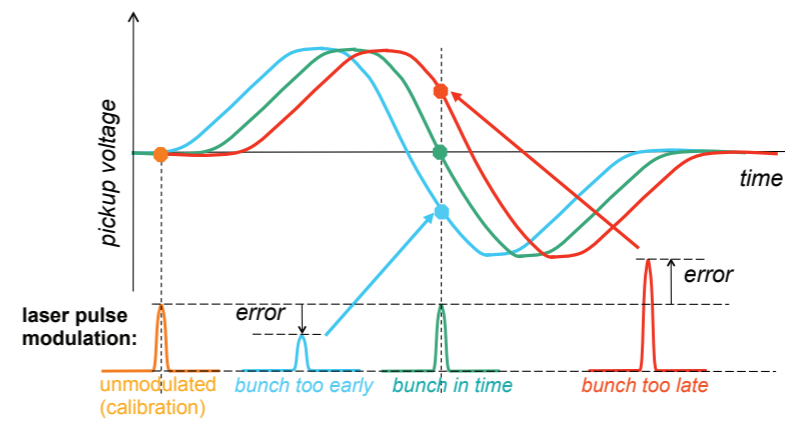
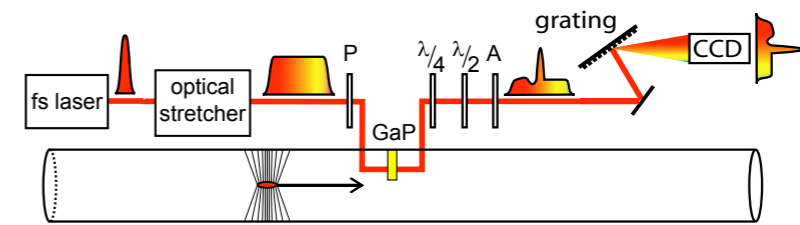
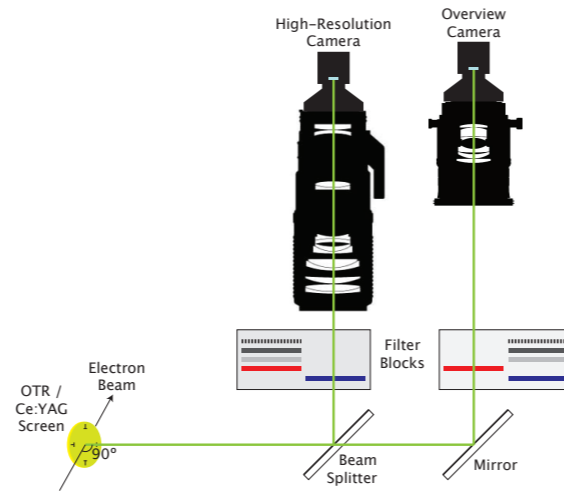
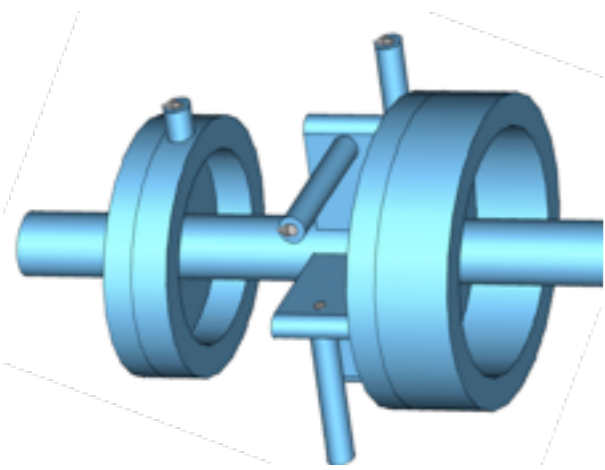
- RF master oscillator
- Optical master oscillator

### 2 pC Options

- No problem here



# Summary



# Summary

## Expected Tolerance, Resolution and Precision (200 pC)

- BPMs: 10  $\mu\text{m}$  to  $\sim 1 \mu\text{m}$
- Screen monitors: 50  $\mu\text{m}$  to  $\sim 10 \mu\text{m}$
- Electro-optical bunch length monitors:  $\sim 150 \text{ fs}$
- Integrating current transformers:  $\sim 5 \text{ pC}$
- Compression monitors: relative measurements only
- Bunch arrival time monitors:  $\sim 10 \text{ fs}$
- Transverse deflecting structure:  $\sim 20$  slices of  $\sim 20 \text{ fs}$  each
- Timing and synchronization:  $\sim 8 \text{ fs}$  (1 kHz – 10 MHz)

More possible instruments (currently not under investigation):

- Loss monitors
- Special BPMs for the bunch compressor
- Laser wire scanners
- Femtosecond streak camera
- Undulators as diagnostics elements

# Summary

## Options for 2 pC Bunches

- Possibilities exist for most diagnostics
- These need some research and development
- A timely decision on expected beam parameters will allow us to plan ahead

# Summary

## Research and Development, Current State of the Art

### Items where we do research

- Coherent OTR
- Diagnostics for low-charge operation
- Optical timing and synchronization

### Items where we do development

- Beam diagnostics for baseline parameters

### Items that we purchase

- Wherever we can

Thank you for your attention

Questions

# Beam Position Monitors

## Our Questions

- What is the required performance in the different parts of the accelerator for the three bunch charges?
  - Single bunch resolution / noise
  - Drift (hour / day / week)
  - Offset of the electrical & mechanical center
  - Operating position range
  - Charge range
  - x/y crosstalk
  - Linearity
- How much dark current do we expect in the 2 pC case?
- What is the expected stability of the current girder concept and lattice in the undulators?
  - What are the eigen-modes of the girders?
  - What is the effect of quadrupole vibrations on the transverse beam stability?
- Do we need a transverse feedback?
- ...?

# Screen Monitors

## Our Questions

- What is the required resolution?
- Do beam dynamics simulations predict coherent OTR for the PSI-XFEL?
- Which screens should be upgraded with more sensitive cameras to detect 2 pC bunches?
- What is the desired slice length for the 2 pC case?
- What is the expected dark current?
- What is the importance of the RF shield?
- ...?

# Electro-Optic Bunch Length Monitors

## Our Questions

- Bunch lengths, desired resolutions?
- At what positions in the linac is the bunch length interesting
  - Measurement?
  - Stability monitoring?
- ...?

# Integrating Current Transformers

## Our Questions

- What is the required precision?
- What is the maximum drift?
- Is an absolute calibration necessary?
- Will the ICTs be used for transmission measurements (interlock)?
- What is the expected dark current?
- ...?

# Compression Monitors

## Our Questions

- Where do we want to monitor the compression?

# Bunch Arrival Monitors

## Our Questions

- What is the required stability
  - 250 MeV Injector
  - PSI-XFEL with 200 pC
  - PSI-XFEL with 2 pC
- ...?

# Transverse Deflecting Structure

## Our Questions

- Is it planned to do time-resolved measurements on the 2 pC bunches?
- ...?

# Timing and Synchronization

## Our Questions

- What is the required accuracy?
- For what time scales are drift and jitter specified?
- ...?