HIGHLIGHTS FROM DIPAC 2009

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Abstract

The 9th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC 2009) was hosted by Paul Scherrer Institute (PSI) and took place at the Hotel Mercure Conference Center in Basel, Switzerland from May 25th – 27th 2009. A record number of 210 registered participants contributed to an exciting scientific program with ten invited talks, fourteen contributed orals and 118 poster contributions. In this talk, I will provide an overview of the various fields of beam instrumentation, which have been discussed during the workshop. A number of highlights from the scientific program have been selected, illustrating some of the outstanding achievements in accelerator diagnostics, which have been presented at DIPAC 2009.

INTRODUCTION

The DIPAC workshop series represents the European pendant to the biannual Beam Instrumentation Workshop in the US. The 9th DIPAC edition [1] was held by Paul Scherrer Institut (PSI) at the Hotel Mercure Conference Center in Basel, Switzerland from May 25th – 27th 2009. As a strong increase in the number of participants could already be observed at DIPAC 2007 in Venice (189 participants), DIPAC 2009 reached a record number of 206 registered participants presenting 142 contributions (10 invited, 14 contributed talks and 118 poster presentations). Since the workshop duration of 2½ days needed to be kept due to organizational reasons, the program committee decided to omit the parallel discussion sessions in favour of an additional (third) poster session, while providing sufficient time for discussions during the 7 plenary oral sessions. An industrial exhibition, a workshop dinner in Schloss Bottmingen and an optional visit of the accelerator-based large research facilities at PSI completed the workshop program. The scientific program of DIPAC 2009 could be divided into the following categories:

- diagnostics overviews and commissioning experience
- BPM systems and position stability / stabilization
- transverse profile and emittance measurements
- beam charge and loss monitors
- longitudinal diagnostics, timing & synchronization

The vast majority of the presentations were of excellent quality and almost all of the presenters submitted their papers by the end of the workshop, so that the proceedings could be made available over JACoW [2] and in a printed hard copy within 4 months after the event.

For this paper, I have selected highlights from each of the above categories, trying to spread the choices over the different accelerator types and particle species at the same time. Still, the list of the quoted contributions is of course not complete and my personal interest and present field of work has certainly influenced the selection.

COMMISSIONING EXPERIENCE

Almost 20 contributions presented an overview of diagnostics systems for specific accelerators and reported about the first commissioning experiences with their beam instrumentation.

First Experiences with LHC Beam Diagnostics

Rhodri Jones reported on the first results from LHC beam diagnostics, which could be obtained during injection tests and the subsequent days of circulating beam in LHC [3]. Thanks to years of planning, testing, hardware commissioning and excellent collaborations with internal and external groups, all LHC diagnostics devices were available and operational from the very beginning. Injection and the first turn in LHC could be observed on a 1 mm thick alumina screen by the LHC beam observation (BTV) system on 10/9/2008.

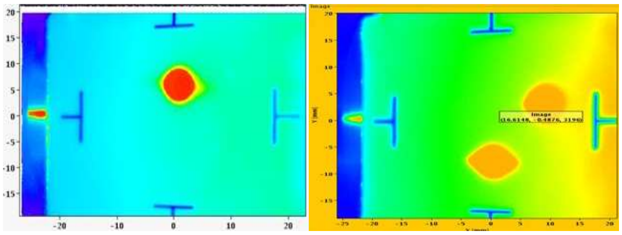

Figure 1: First injection into LHC (left side) and first full turn in LHC (right side) as recorded by the BTV system. Courtesy of Rhodri Jones.

The signal to noise level of the beam loss monitor (BLM) system, consisting of over 4000 N_2 filled ionisation chambers and secondary emission monitors, is 2 orders of magnitude lower than the signal from the pilot bunch ($2x10^9$ protons). This should be sufficient to allow safe and quenchless injection with a total intensity up to $5x10^{11}$. Likewise, the high sensitivity of the beam charge monitors (~ $7x10^8$ protons or 1.3 µA and a dynamic range from $2x10^9$ to $5x10^{14}$) allowed the observation of the first circulating beam in ring 2.

The 1054 BPMs in combination with the powerful on-line optics software provided in the beam threading mode first turn position data to allow for checks of BPM polarity and machine optics errors. The BPM system resolution of ~ 5 µm in orbit mode with a single pilot bunch confirmed the lab sensitivity measurements. Still, electronics drifts induced by air temperature variations could be observed in some locations.

The availability of the tune, chromaticity and coupling measurements at an early stage, being capable of measuring tunes with only a few turns allowed to adjust injection tunes in order to circulate the beam long enough to attempt the first RF beam capture.

LCLS Commissioning and Cavity BPMs

Clearly, one of the highlights at DIPAC 2009 was the report from Steve Smith on the LCLS commissioning presenting the first exciting results, which have been obtained with lasing at 1.5 Å in the nominal "250 pC mode" and the short-pulse "20 pC operation mode" of the LCLS accelerator.

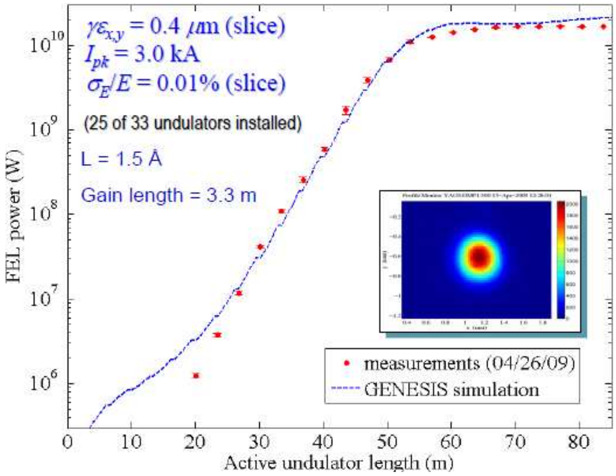

Figure 2: FEL power gain length measurement at 1.5 Å made by kicking the beam after each undulator sequentially (red points), a prediction (blue line) and the laser spot on a YAG screen [4]. Courtesy of Steve Smith.

A short overview of the LCLS diagnostics system was provided, highlighting the important contribution of the X-band cavity beam position monitor system (SLAC and Argonne National Laboratory collaboration) to the successful and very efficient LCLS commissioning. A more detailed description of this system will be given in the following paragraph.

Beam Diagnostics for XFEL / SRing8

Hirokazu Maesaka reported on the experience and results from the XFEL / Spring8 diagnostics systems, which have been achieved at the SCSS test facility [5]. Compact, low Q cavity BPM pick-ups resonating at 4760 MHz and made from stainless steel have been designed as precision BPMs for the undulator sections. Their position resolution including a IQ demodulation electronics and a 12 bit VME ADC has been determined with a dedicated test set-up to ~ 200 nm (rms) at 0.3 nC beam charge. By using the monopole cavity signals from two adjacent BPMs and comparing their phase differences, the arrival time jitter of the SCSS electron beam could be measured to ~ 50 fs (rms) with a resolution of 27 fs.

In addition, the design and test of a high resolution imaging system for beam profile measurements has been presented. The customized lens system is mounted on a motorized translation stage to provide a 1x to 4x magnification. The optical resolution was determined to 2.5 µm (HWHM) using a grid distortion target. Figure 3 shows a comparison of profile measurements with the horizontally focused 250 MeV SCSS beam. The images were taken with a 100 µm thick stainless steel OTR screen and a YAG:Ce screen.

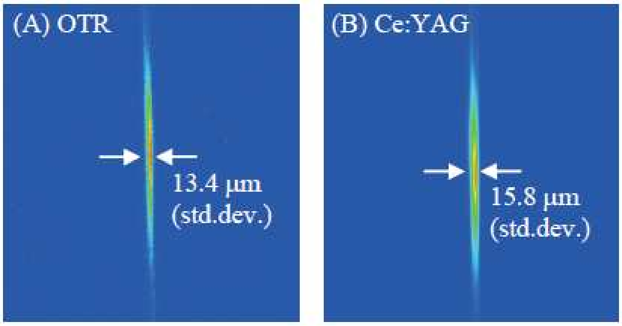

Figure 3: Beam images taken by an OTR screen (A) and a YAG:Ce screen (B). The magnification of the lens system was set to 4. Courtesy of Hirokazu Maesaka.

Finally, the design of a 1.7 m long C-band travelling wave RF deflecting structure, named RAIDEN, was presented. It is a periodically disk-loaded waveguide with race track shaped irises to separate horizontal and vertical modes. Two of these RAIDEN structures will be used in the XFEL / Spring8 allowing bunch length and sliced beam parameter measurements with a few fs time resolution.

Further Commissioning Reports

The new hard x-ray synchrotron radiation source PETRA III has been commissioned at DESY, Hamburg. Klaus Balewski reported on the first beam physics and commissioning results and summarized the performance of the diagnostics systems [6]. He highlighted a fast current monitor for control of top-up operation, a wire system, which monitors mechanical movements of BPM blocks and the X-ray diagnostics beam line using a compound refractive lens and a pinhole camera for measurement of the ultra-low (1 nmrad) emittance beam.

Yongbin Leng gave an overview of the SSRF (Shanghai Synchrotron Radiation Facility) beam instrumentation and reported on the commissioning results of their diagnostics systems [7]. The LIBERA BPM system allowed them to obtain high precision beam position information in the LINAC (33 µm single-shot) as well as turn-by-turn (3 µm @ 694 kHz) and closed orbit data (200 nm @ 10 Hz) in the storage ring. Their diagnostics beam line is equipped with two visible light synchrotron radiation interferometers for determination of beam sizes (< 10 µm spatial resolution), a fast, gated (3 ns gate width) camera for injection studies and a 2-D streak camera (Hamamatsu C5680) for bunch length and multi-bunch instability studies. For damping of these instabilities, a digital transverse multi-bunch feedback system has already been commissioned.

BPM SYSTEMS AND BEAM STABILITY

Almost 40 contributions reported on the design of BPM pick-ups and electronics and dealt with all aspects of beam position stability in different accelerator types. In this respect, BPM systems and beam stability turned out to be an "evergreen" topic during DIPAC 2009.

Beam Position and Orbit Stability

Boris Keil reviewed the beam stability and BPM system requirements for linear and circular accelerators [8]. He compared different pick-up types and electronics circuits for sub-micron beam position measurements in view of their applicability in different accelerator types. For storage ring based light sources with low emittance and low coupling, he stated that the fulfilment of the $\sigma/10$ stability criterion not only demands sub-micron beam position measurements at kHz bandwidth to allow for global and local orbit feedbacks, but that it also requires an overall stability concept, which includes features like top-up operation, filling pattern feedbacks, temperature control and the inclusion of photon monitors. In LINAC-based light sources beam-based alignment (BBA) of the undulator segments represents the driving factor for sub-µm BPM resolution and extremely low drift performance. Thus, BBA methods like dispersion free steering permit the alignment of undulator segments on a micron level.

Nicolas Hubert presented the latest achievements in beam orbit stability at 3rd generation light sources [9]. He presented an overview of orbit feedback implementations in storage rings world-wide (see table 1).

Table 1: overview of orbit feedbacks in SR light sources

SR Facility	FB type (user mode)	# of sets of correctors	Bandwidth
ALBA*	fast	1	DC – 130 Hz
ALS	slow & fast	1 (fast corr. are subset of slow ones)	DC – 60 Hz
APS	slow & fast	1 (fast corr. are subset of slow ones)	DC – 100 Hz
DIAMOND	fast	1	DC – 130 Hz
ELETTRA	fast	1	DC – 150 Hz
ESRF	slow & fast	2	DC – 150 Hz
ESRF-U*	fast	1	DC – 150 Hz
NSLS II*	slow & fast	2	DC – 500 Hz
PETRA III*	slow & fast or only fast	2	dead band or DC – 500 Hz
SLS	fast	1	DC – 100 Hz
SOLEOL	slow & fast	2	DC – 250 Hz
SPEAR3	fast	1	DC – 100 Hz
SSRF*	slow & fast	2	DC – 100 Hz

* feedback systems that are not yet commissioned

He explained the concepts of global and local orbit feedbacks and reviewed the performance requirements of sub-system components to allow for sub-micron stability from DC to a few hundred Hz. As the most efficient orbit correction strategy, he identified the interaction between fast and slow orbit feedback systems. In this scheme, the slow system corrects for the difference between the actual and the "golden" orbit and removes the orbit created by the DC component of the fast correctors, while fast orbit feedback corrects any transient disturbance in the storage ring. Applying this approach, SOLEIL could improve long term stability at the bending magnet source points in the vertical to about 2 µm.

BPM Pick-Up Design and Cavity BPMs

Piotr Kowina presented the successful application of FEM-based (finite element methods) simulations to design characteristic features of BPM pick-ups leading to optimized BPM realizations in hadron accelerators [10]. As examples from the FAIR project [11], he presented the optimization steps in the design of a linear cut BPM for proton and ion synchrotrons and a button-type BPM for low energies ($0.1 \leq \beta \leq 0.37$) in proton LINACs. For the linear cut BPM, the insertion of separating rings between the electrodes increased the position sensitivity by a factor of two. In case of the button-type BPM, the frequency dependent position sensitivity of low β beams was compared for the first three harmonics of the accelerator frequency at 325 MHz, 650 MHz and 925 MHz. The resulting two dimensional position maps are presented in figure 4 for $\beta = 0.1$ and $\beta = 0.3$.

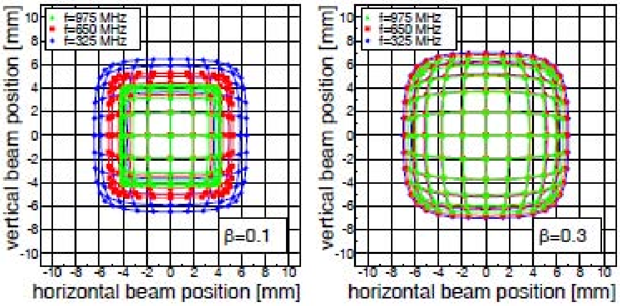

Figure 4: Response of button-type BPM on variation of transv. beam position for $\beta = 0.1$ (left) and $\beta = 0.3$ (right). Courtesy of Piotr Kowina.

The operating principle of high resolution cavity BPMs, which are typically used in high energy electron accelerators, was explained by Dirk Lipka and examples of recent developments and measurement results from LCLS, Spring8 / XFEL, European XFEL and ILC were presented [12]. As an impressive example from a successfully commissioned XFEL facility, Steve Smith presented the design and performance of the LCLS X-band cavity BPMs [13]. The 10 mm diameter TM_{010} monopole mode and the position sensitive TM_{110} dipole mode copper cavities are 36 mm apart, providing 130 dB isolation. The cavities are installed between the undulator segments and connected via rigid waveguides to the 3-channel heterodyne receiver electronics, which is placed below the undulator stands. The x, y and reference signals are down-converted to an intermediate frequency of 25 - 50 MHz, digitized at a sampling rate of 119 MS/s by a 4-channel, 16 bit VME digitizer in the technical gallery. Undulator BPMs are typically calibrated by mechanically moving the cavity pick-ups, while transfer line BPMs, which are not mounted on movers, are calibrated by moving the beam. BPM resolution has been determined with stable beam (< 10 μm jitter) via correlation between BPMs, using least-square fits of the predicted BPM position as a linear combination of the position measured in adjacent BPMs. Typical (median) resolutions of σ_x ~ 440 nm with few above 1 μm and σ_y ~ 230 nm with none above 1 μm have been achieved.

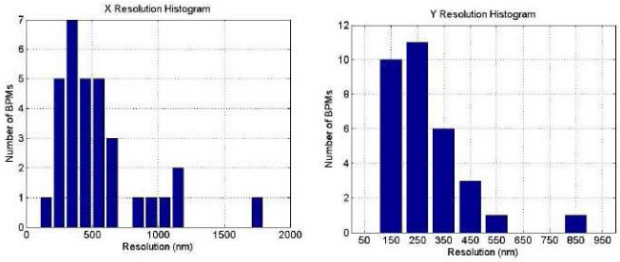

Figure 5: Histogram of measured LCLS X-band cavity BPM resolutions. Courtesy of Steve Smith.

TRANSVERSE PROFILE MONITORS

Almost 40 contributions dealt with the measurement of transverse profiles and emittances in various types of accelerators. A large variety of physical properties and techniques such as transition, diffraction and synchrotron radiation, wire and laser scanners as well as fluorescence and ionization of residual gases have been applied to visualize the particle beams.

SNS Electron Scanner

For the non-invasive measurement of the transverse beam profile in the Spallation Neutron Source (SNS) accumulator ring, an electron scanner has been designed by the Budker Institute of Nuclear Physics and Willem Blokland presented the first experimental results with this device [13].

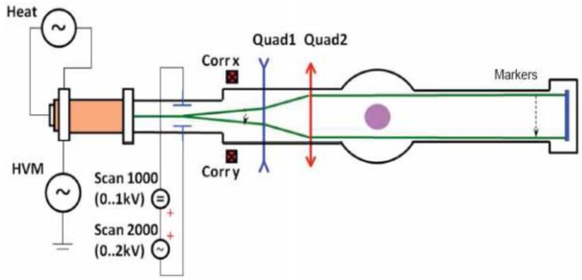

Figure 6: Schematic Diagram of SNS electron scanner. Courtesy of Willem Blokland.

A 75 keV electron beam is projected on a diagonal line by a pair of deflector plates and sent through the proton beam. This titled sheet of electrons is deflected from a straight line when passing through the proton beam and the projection can be visualized on a phosphor screen at the end of the electron scanner. The derivative of the projection results in the transverse proton beam profile. The deflector plate ramp time of 20 ns allows viewing of 3-dimensional bunch profiles or the visualization of profiles from any turn during the accumulation cycle.

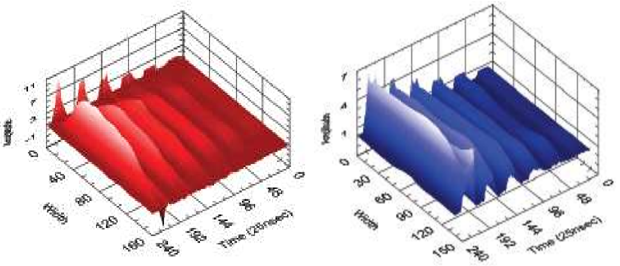

Figure 7: Bunch profiles from multiple accumulation turns. Horizontal (red) and vertical (blue) scales are given in pixels of 0.3 mm, time scale is in 25 ns per count. Courtesy of Willem Blokland.

Studies of Light Yield from Gases and Screens

For online transverse profile measurements of high intensity ion beams, Frank Becker studied the beam induced fluorescence (BIF) of different residual gases (Xe, Kr, Ar, He, N_2) by using an imaging spectrograph in the visible spectral range [14]. After irradiation with 5 ms long beam pulses of $3 \cdot 10^{11}$ S_{6+} ions at 5.16 MeV/u, nitrogen gas could be identified as the most suitable choice for a BIF profile monitor, providing the highest light yield and undistorted profile widths.

Gero Kube investigated the light yield of luminescent screens of different materials, having been illuminated by high energy (855 MeV) and high brilliant electron beams at the X1 beam line of the Mainz Microtron MAMI [15]. He compared YAG:Ce with diamond, Al_2O_3, Al_2O_3:Cr (Cromox), ZrO_2 (Z700-20A) and ZrO_2:Mg (Z507). Although the beam profiles measured with YAG:Ce screens were slightly distorted, it seems to be the most suitable material, providing the highest light yield (one order of magnitude more than Cromox) without showing any material degradation as in case of ZrO_2.

LONGITUDINAL DIAGNOSTICS

More than 20 contributions dealt with the measurement of longitudinal particle beam properties, such as bunch pattern and bunch lengths, beam arrival time and the implementation of highly stable reference systems for synchronization of particle beams with accelerator sub-systems on a femto-second scale.

Sliced Beam Parameter Measurements

The application of standing wave or travelling wave transverse RF deflecting structures (TDS) for time resolved (sliced) beam parameter measurements has been presented by David Alesini as one of the key diagnostics for the full characterization of beam properties in LINAC-based Free Electron Lasers [16]. A TDS induces a linear correlation between the longitudinal and the transverse coordinates of short particle (electron) bunches, when passing at the zero crossing of the RF deflecting voltage. The deflected beam can be imaged on a screen monitor downstream of the TDS, providing a measurement of the longitudinal bunch profile with femto-second time resolution. The characterization of the "sliced" energy distribution (longitudinal phase space) can be achieved by inserting a spectrometer (dipole) magnet in the beam path between TDS and screen monitor. The transverse "sliced" emittances can either be determined by a quadrupole scan performed with a triplet in front of the TDS or by a suitable (FODO) beam lattice downstream of the TDS providing sufficient phase advance in the transverse (non-deflected) plane. Image processing software allows the determination of "sliced" beam parameters by dividing the deflected beam profiles in time slices, which are equal to the width of the un-deflected beam size. Examples of "sliced" emittance measurements and the visualization of the longitudinal trace space using the SPARC TDS are shown in figure 8.

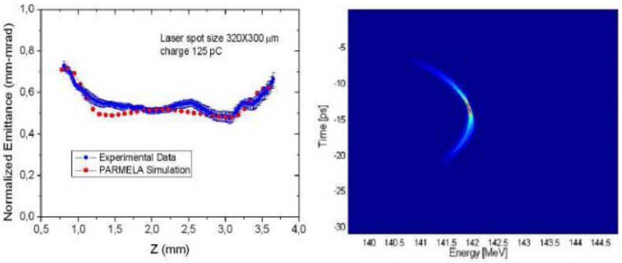

Figure 8 (left): Comparison between "sliced" emittance measurements and PARMELA simulations. Right side: longitudinal trace space of the 140 MeV beam at SPARC. Courtesy of David Alesini.

BLM WITH OPTICAL FIBERS

Friedrich Wulf presented a comprehensive and very instructive overview of beam loss monitoring with optical fibers [17]. He divided optical fiber based loss monitor systems into two categories: the integrating optical power meter as local and global dosimeter systems and the optical time domain reflectometer for time or spatially resolved loss measurements.

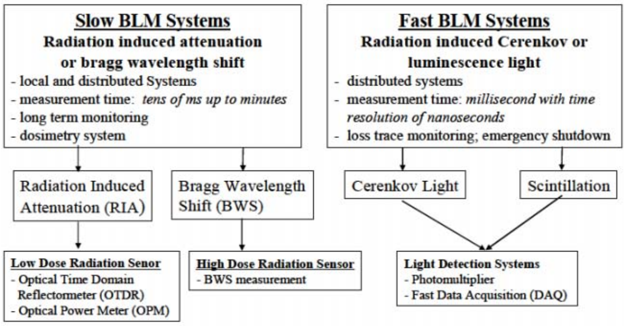

Figure 9: Classification flow chart of beam loss monitor systems using optical fiber sensors. Courtesy of Friedrich Wulf.

For total dose measurements the radiation induced attenuation (RIA) in optical fibers can be used up to a few thousand Gray, while Bragg wavelength shifts are useful for high dose applications. The detection of radiation induced Cerenkov light or luminescence in an optical fiber allows for fast or localized detection of radiation sources. For both applications, the individual characterization of each fiber lot turns out to be indispensible and a key for the actual use of optical fibers as radiation sensors (loss monitors).

As an example for a fiber based monitoring of the total ionization dose (TID) along an accelerator facility, the accumulated dose rate at FLASH has been presented [18].

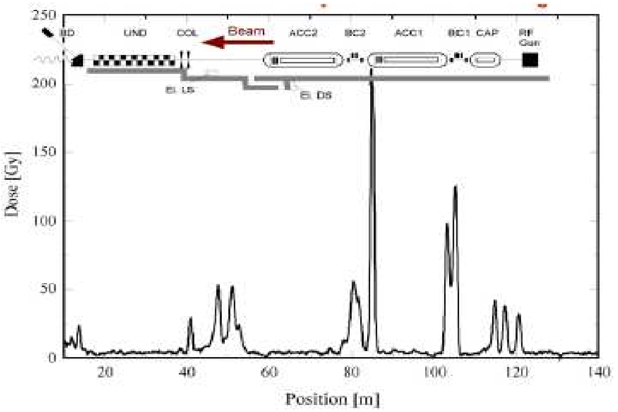

Figure 10: Measured TID at the entire FLASH beam line. Courtesy of Friedrich Wulf.

A fast loss monitor system based on Cerenkov light, which is synchronized to the bunch clock, can provide high position resolution (up to 25 cm) along a beam line, when calibrated with beam line components (e.g.: OTR screens, slits etc.) at known locations. By putting four fibers around the beam pipe (see inlet of figure 11), it is even possible to define the direction of the centroid of the Bremsstrahlung shower.

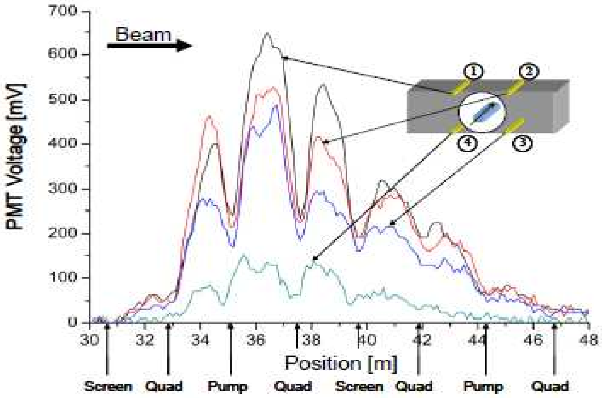

Figure 11: Example of a beam loss position monitor measurement at an interesting part of the accelerator. Courtesy of Friedrich Wulf.

FUTURE REQUIREMENTS

The instrumentation requirements for future accelerator based facilities were reviewed by some contributions, providing perspectives for new trends and tightened performance specifications of diagnostics systems.

The beam diagnostics for the FAIR project at GSI [11, 19] needs to cover for example not only a wide range of intensities for different ion species (10^{11} U_{28+} / pulse to 10^{13} protons / pulse) but should also provide non-invasive turn-by-turn beam profile measurements for monitoring fast profile changes in the SIS 100 heavy ion synchrotron.

Low charge (10 pC) and ultra short pulse (< 10 fs) operation of compact X-ray Free Electron Laser projects such as the SwissFEL at PSI [20, 21] demand not only sub-micron beam trajectory control along the SASE radiation sources (undulators) but also highest RF (< 0.05° S-, C- and X-band phase control) and beam arrival time (< 10 fs) stability on the order of the electron / photon bunch lengths. Optical master oscillators and actively stabilized optical and RF link distributions of the reference signals provide potential solutions for such tight specifications [22]. Electro-optical beam arrival time monitors [23] are newly developed instrumentation to measure the longitudinal stability of the electron bunches on a sub-10 fs scale and to control the amplitude and phase stability of RF systems to the desired level.

The achievement of highest luminosities at future linear colliders (like e.g. the Compact Linear Collider (CLIC) project) require not only beam trajectory measurement and control along the accelerator and in the interaction points to a nanometer scale but may also include the active stabilization of large scale objects like quadrupole magnets on the same level [24]. While first feasibility studies for new measurement systems are already on the way [25], it became clear that only the gradual improvement of diagnostic and feedback systems as well as the high standard of beam instrumentation as presented during DIPAC 2009 will allow a successful realization of these very ambitious future projects.

REFERENCES

[1] For more detailed information about DIPAC 2009 and a full overview of the workshop contributions, please visit the DIPAC 2009 web-page under http://dipac09.web.psi.ch/

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