Highlights from DIPAC 2009

• Some General Information about DIPAC
• Commissioning Results from New Facilities
• The “Evergreen” BPMs
• Transverse Profile Monitors
• Bunch Length & Time Resolved Diagnostics
• Beam Loss Monitoring
• Requirements for Future Accelerators
• Conclusions & Outlook

Volker Schlott
Paul Scherrer Institut, Villigen, CH
 Highlights from DIPAC 2009

DIPAC Participants & Scientific Programs (1997 – 2009)

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Participants</th>
<th>Inv. Talks</th>
<th>Contrib. Talks</th>
<th>Posters</th>
<th>Discussions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>INFN-Frascati, Italy</td>
<td>129</td>
<td>11</td>
<td>12</td>
<td>50</td>
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<tr>
<td>1999</td>
<td>Daresbury Lab., UK</td>
<td>103</td>
<td>8</td>
<td>12</td>
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<td>2001</td>
<td>ESRF, France</td>
<td>150</td>
<td>12</td>
<td>11</td>
<td>42</td>
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<td>2003</td>
<td>GSI, Germany</td>
<td>131</td>
<td>10</td>
<td>11</td>
<td>56</td>
<td>3</td>
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<tr>
<td>2005</td>
<td>CERN, Switzerland</td>
<td>148</td>
<td>12</td>
<td>8</td>
<td>92</td>
<td>6</td>
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<tr>
<td>2007</td>
<td>ELETTRA, Italy</td>
<td>189</td>
<td>10</td>
<td>117</td>
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<tr>
<td>2009</td>
<td>PSI, Switzerland</td>
<td>206</td>
<td>10</td>
<td>14</td>
<td>118</td>
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</table>

DIPAC 2009: 206 Participants from 18 Countries World-Wide
- 153 colleagues from 12 European countries
- 2 colleagues from (South) Africa
- 19 colleagues from the US
- 19 sponsors and industrial exhibitors
- 13 colleagues from Asia and Australia

Growing interest in Diagnostics might be caused by...
- tremendous performance and reliability of existing diagnostics, FBs and instrumentation
- more complex diagnostics & instrumentation for new and advanced accelerator facilities
- new areas of instrumentation like e.g.: lasers, synchronization, micro-positioning, X-rays etc...
DIPAC 2009: Overview of Scientific Program

- Invited Orals 10
- Contributed Orals 14
- Posters 118
- Sum of Contributions 142

Contributions in the Fields of…:
- instrumentation overviews & commissioning reports (20)
- BPM systems & beam position stability (36)
- transverse profiles & emittance measurements (37)
- beam charge and loss measurements (16)
- longitudinal diagnostics, bunch length & timing (21)
- others… (12)

- 7 Plenary Oral Sessions with 110 minutes for questions and discussions in the plenary
- 3 Poster Sessions with 105 minutes for each session
- 2 Days Industrial Exhibition with 2 sponsors and 9 exhibitors

Discussion Sessions at DIPAC 2009 had to be moved to the evenings in the bars of Basel.

To keep the workshop atmosphere of DIPAC, a full 3rd or even 4th day might be needed…
...for the growing number of presentations (posters)
...to re-install the discussion groups.
DIPAC 2009 in Basel – Some Impressions

Reception with Live Music

Drinks and

Relaxation...

Exciting Talks

Interested Participants

Back to Business...!
DIPAC 2009 in Basel – Some More Impressions

Poster Sessions  |  Plenary Discussions  |  Industrial Exhibition

Conference Dinner at Schloss Bottmingen  |  PSI Visit
Performance and First Experiences with the LHC Beam Diagnostics
courtesy of Rhodri Jones / MOOA02

Beam Profile Measurements (LHC TV System)
- 37 BTV Systems with 100% availability !!!
- 1 mm thick alumina (scintillator) screens
- 12 μm thick Tantalum foil OTR screens
- all BTV stations equipped with both screens
- alumina sensitivity: < 10⁹ protons (first injections)
- OTR sensitivity: ~ 2·10⁹ protons (pilot bunch)
- multiple OTR screens in beam (transfer lines)
- multi-turn observations with OTR screens

Beam Position Monitors
- 1054 BPMs with 99% availability !!!
- beam threading around LHC ring
- check of polarity errors
- measure phase advances
- threshold: ≥ 1.5·10⁹ protons (pilot bunch)
- short term resolution & stability: ≤ 10 μm (rms)
- but: temp. drifts of electronics ~ 50 μm/° C
Performance and First Experiences with the LHC Beam Diagnostics  

courtesy of Rhodri Jones / MOOA02

Beam Loss Monitors
- > 4000 BLMs installed at likely loss locations
- 50 cm long N₂ filled (1.5 l) ionisation chambers
- 10 cm long secondary emission monitors
- designed for signal speed (85 $\propto$ s) & reliability
- dynamic range: > $10^9$
- noise level: ~ 1% of pilot bunch
  $\rightarrow$ quenchless injection @ $5 \times 10^{11}$ protons

Beam Charge Monitors
- 2 BCMs installed to measure circulating beam
- 4 ranges are provided simultaneously to cover entire dynamic range from $2 \times 10^9$ to $5 \times 10^{14}$ protons
- sensitivity: ~ $7 \times 10^8$ (1.3 $\propto$ A)
- offset: ~ $2.5 \times 10^9$ (4.5 $\propto$ A) still to be corrected

Conclusion: good start for all instrumentation systems
thanks to years of planning, testing & HW commissioning and good collaborations with other groups
Diagnostics for SPring8 / XFEL – Experience with SCSS Test Facility

courtesy of Hirokazu Maesaka / MOOA03

Cavity Beam Position Monitors
- 56 cavity BPMs operating at 4760 MHz
- compact TM110 & TM010 cavity design
- electronics: IQ demodulation
- position resolution: ~ 200 nm (@ 0.3 nC)
- arrival time resolution: ~ 25 fs

Beam Profile Monitors
- YAG:Ce for low energy beam (< 100 MeV)
- OTR: 0.1 mm thick SS foil
  surface roughness tens of nm, flatness 3 μm
- customized lens system
  variable magnification (x1 and x4)
- spatial resolution: 2.5 μm (HWHM)

OTR Image (250 MeV beam)

Variable Magnification Imaging System
- spatial resolution: 2.5 μm (HWHM)
Other Reports on Accelerator Facility & Diagnostics Commissioning

**LCLS Commissioning @ SLAC**  
(by Steve Smith – TUOC03)
- *lasing 1.5 Å* with nominal „250 pC mode“ and short-pulse, low emittance „20 pC mode“
- 12 GHz cavity BPMs with $\sigma_x \sim 440$ nm, $\int_y \sim 230$ nm resolution (by SLAC & Argonne NL collaboration)  
  (more about SLAC BPMs later…)

**PETRA III Light Source @ DESY**  
(by Klaus Balewski – MOOB02)
- 6 GeV storage ring with 2304 m circumference, 100 mA beam current & extremely low *emittance 1 nm* !
- commercial LIBERA Brilliance BPM electronics
- transverse multi-bunch feedback available from the beginning
- X-ray beam line for emittance diagnostics: pinhole with $20 \, \alpha m$ resolution,  
  31 compound refractive Be lenses with $2 \, \alpha m$ resolution
- Hamamatsu C5680 streak camera for bunch length measurements using visible SR

**SSRF Light Source @ Shanghai**  
(by Yongbin Leng – MOOB03)
- 3.5 GeV storage ring with 432 m circumference, 200 - 300 mA beam current & 3.9 / 11.2 nm emittance
- commercial LIBERA Brilliance BPM electronics
- visible light diagnostics beam line with…: visible light interferometer ($< 10 \, \alpha m$ res.) & streak camera
Sub-Micron Beam Position Measurement & Stabilization
courtesy of Boris Keil / TUOC01

Storage Rings & 3rd Generation Light Sources
- beam stability requirements are driven by user demands and fast orbit feedback...
  → $\sigma/10$ criterion in low $\varepsilon$ and low-coupling machines with vert. beam sizes of 2 - 5 $\propto m$
    results in few 100 nm BPM noise (@ 10 kHz BW) and comparable drift requirements (sec to days)
      examples for straight sections:  SUPER-ACO (1987) $\otimes y/\int y \sim 23 \, \mu m$
                                          NSLS II (2013) $\otimes y/\int y \sim 200\, nm$
- sub-\(\mu\)m beam stability depends not only on BPMs and FOFB but on overall stability concept
  → machine optics, top-up (!), temp. stability, filling pattern, photon monitors...

LINACs & 4th Generation Light Sources
- BPM noise & drift requirements are amongst others driven by BBA of quads in undulator areas...
  → $\sqrt{\tau}/10$ criterion over few gain lengths result in low charge XFELs to sub-\(\mu\)m resolution and drift
- for SC LINAC-based facilities: high bandwidth FBs (tens of kHz) are feasible
- for NC LINAC-based facilities: machine needs to be stable / FB only for random pertubations < 10 Hz
  - BBA by dispersion free steering (DFS) accounts for all residual dipole fields in undulator area
    → can be done to a few micron level (e.g. LCLS undulator)
## BPM Pick-Up Types for Sub-Micron Beam Position Measurements

**courtesy of Boris Keil / TUOC01**

### Common Pickups

Qualitative/subjective pros & cons ...  

<table>
<thead>
<tr>
<th></th>
<th>Button</th>
<th>Matched Stripline</th>
<th>Resonant Stripline, Normal Coupling</th>
<th>Single Cavity Normal Coupling</th>
<th>Two Cavities, Hybrid Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal/Noise</td>
<td>-</td>
<td>- / +</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Monopole Mode Suppression</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>- / +</td>
<td>-</td>
</tr>
<tr>
<td>Single-Bunch Resolution (@ low charge)</td>
<td>-</td>
<td>- / +</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Electronics Drift</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
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<tr>
<td>Weight 10mm pipe</td>
<td>+ +</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Weight 40mm pipe</td>
<td>++</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
</tr>
<tr>
<td>Design Effort</td>
<td>+ +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
</tr>
<tr>
<td>Fabrication Costs</td>
<td>+ +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
</tr>
<tr>
<td>Tuning Effort</td>
<td>+ +</td>
<td>+</td>
<td>- / +</td>
<td>- / +</td>
<td>- / +</td>
</tr>
</tbody>
</table>

- **“Standard” BPM types** for warm linac beam lines (where ~ 5 - 50 µm resolution is needed)
- **Typical choice for SASE undulators, intra-train & IP feedbacks**: sub-µm single-bunch resolution

**resonant stripline**

**“two-cavity” BPM**

**current transformer BPM**

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Volker Schlott

Volker Schlott
Global Orbit FB Systems Down to DC using Fast and Slow Correctors

courtesy of Nicolas Hubert / MOOC01

Sources of Pertubations

- **long term (hours to days):** e.g.: diurnal temp., heat load (decaying beam), tides… \(10 – 100 \ \mu \text{m}\)
- **medium term (sec. to minutes):** e.g.: ID gaps, crane, fast magnets, pumps… \(\text{few } 10 \ \mu \text{m}\)
- **short term (up to a few 100 Hz):** e.g.: booster cycling, ground vibrations, mains… \(< 10 \ \mu \text{m}\)

Orbit Feedback Systems (fast & slow)

- **distributed BPMs:** sub-\(\mu \text{m}\) @ kHz BW, local processing & global data exchange, SVD algorithms
- **correctors & PS:** strong (iron core), laminated correctors for „golden orbit“ (strength \(\pm 1 \ \text{mrad}\))
  - weak (air coil) correctors for fast pertubations (strength \(\sim 10 – 40 \ \text{rad}\))
  - high resolution (19 + bit) PS, setting-rates up to 250 kHz

Correction Schemes to „Golden Orbit“

- **+ single system**
- **+ continuous frequency domain**
- **- limited corrector range (sat.)**
- **- orbit (only) effectively corrected at corrector locations**
- **+ very good long term stability**
- **+ correction over whole frequency spectrum for every source point**
- **- slow FB: \(\Delta \) golden / actual orbit**
- **- fast FB: no correction of DC part**

Orbit Stabilty @ SOLEIL: Bending Magnet BLs & PSD
## Overview of FOFB Implementations in Storage Rings

<table>
<thead>
<tr>
<th>SR Facility</th>
<th>FB type (users operation)</th>
<th>Number of sets of correctors</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALBA*</td>
<td>Fast</td>
<td>1 (fast corr. are a subset of slow ones)</td>
<td>DC-130 Hz</td>
</tr>
<tr>
<td>ALS</td>
<td>Slow + Fast</td>
<td>1</td>
<td>DC-60 Hz</td>
</tr>
<tr>
<td>APS</td>
<td>Slow + Fast</td>
<td>1 (fast corr. are a subset of slow ones)</td>
<td>DC-100 Hz</td>
</tr>
<tr>
<td>DIAMOND</td>
<td>Fast</td>
<td>1</td>
<td>DC-130 Hz</td>
</tr>
<tr>
<td>ELETTRA</td>
<td>Fast</td>
<td>1</td>
<td>DC-150 Hz</td>
</tr>
<tr>
<td>ESRF</td>
<td>Slow + Fast</td>
<td>2</td>
<td>DC-150 Hz</td>
</tr>
<tr>
<td>ESRF-U*</td>
<td>Fast</td>
<td>1</td>
<td>DC-150 Hz</td>
</tr>
<tr>
<td>NSLS II*</td>
<td>Slow + Fast</td>
<td>2</td>
<td>DC-500 Hz</td>
</tr>
<tr>
<td>PETRA III*</td>
<td>Slow + Fast or Fast</td>
<td>2</td>
<td>Dead-band or DC-500 Hz</td>
</tr>
<tr>
<td>SLS</td>
<td>Fast</td>
<td>1</td>
<td>DC-100 Hz</td>
</tr>
<tr>
<td>SOLEIL</td>
<td>Slow + Fast</td>
<td>2</td>
<td>DC-250 Hz</td>
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<tr>
<td>SPEAR3</td>
<td>Fast</td>
<td>1</td>
<td>DC-100 Hz</td>
</tr>
<tr>
<td>SSRF*</td>
<td>Slow + Fast</td>
<td>2</td>
<td>DC-100 Hz</td>
</tr>
</tbody>
</table>

* Feedback systems that are not yet commissioned
Computer Simulations for BPM Design & Optimizations

FEM Simulations (using CST-Suite (MAFIA), Comsol, HFFS & MAGIC)

→ volume typically divided in 3-dim mesh (~ 10^7 cells)
→ beam simulated as travelling wave on wire
→ time domain solver: Gaussian shaped pulse

Output: time dependent signals, field distribution, frequency dependencies, S-parameters etc...

„Shoe-Box“ Type BPM Optimization

• sensitivity increased by factor 2
  (using ceramic rings for cross talk reduction)

• offset reduction (grounded symmetric guard rings)

• x-y plane independence
  (careful treatment of fringe fields)

Button Type BPM Optimization

• 30 mm aperture diameter, f_{RF} = 325 MHz, \tau = 150 ps

• study of low © (0.1 / 0.3) beam effects
  → signal shape & frequency spectrum position dependent
  → position sensitivity depends on frequency and ©
  → readouts are non-linear (typical for button BPMs)
Commissioning Results from LCLS Cavity BPMs

courtesy of Steve Smith / TUOC03

LCLS Cavity BPMs (collaboration between ANL & SLAC)

- monopole & dipole cavity @ $f_{RF} = 11.384$ GHz
- cavities are 36 mm apart $\rightarrow$ 130 dB isolation
- material copper, diameter 10 mm
- 34 cavity BPMs along undulator, 2 in transport line

receiver: chassis underneath undulator stand
3 channels (x,y,ref) – heterodyne receiver waveguide in / coax out
down-conversion from X-band to 40 MHz

digitizer: 4 channel VME ADC outside tunnel
16 bit, up to 130 MS/s
ext. clock (119 MHz) sync. to LINAC RF

DFS Alignment of LCLS Undulator
(En: 4.3 – 13.64 GeV)

Resolution Histograms

$\sigma_x \sim 440$ nm
$\sigma_y \sim 230$ nm
Overview of Recent Cavity BPM Developments Worldwide

**SPring8 / XFEL** (see SPring8 / XFEL overview)

- monopole @ $f_{RF} = 1255$ MHz, dipol @ $f_{RF} = 1724$ MHz
- material SS, $Q_m \sim 24$, $Q_d \sim 59$, diameter 78 mm
- electronics: single downconversion per plane
- design resolution: $< 1 \, \mu m$ from 0.1 - 1 nC

**European XFEL Precision BPMs** (DESY & PSI)

- monopole & dipole cavity @ $f_{RF} = 3300$ MHz
- material copper, $Q_m,d \sim 600$, diameter 78 mm
- anticipated resolution: $< 1 \, \mu m$ within $\pm 1$ mm
- status: EM-simulations & constructions finalized

**European XFEL SC LINAC BPMs** (CEA-Saclay)

- monopole @ $f_{RF} = 1255$ MHz, dipol @ $f_{RF} = 1724$ MHz
- material SS, $Q_m \sim 24$, $Q_d \sim 59$, diameter 78 mm
- electronics: IQ demodulation
- resolution: $5 - 10 \times 10^{-6}$ m @ 1 nC (FLASH beam tests)

**Cold BPM for ILC Cryomodules** (FERMI-lab)

- common monopole-dipol cavity (1125 / 1468 MHz)
- material copper, $Q_m,d \sim 600$, diameter 78 mm
- anticipated resolution: $< 1 \, \mu m$ within $\pm 1$ mm
- status: EM-simulations & constructions finalized
Overview of Recent Cavity BPM Developments Worldwide

courtesy of Dirk Lipka / TUOC02

Cavity BPM for ILC Spectrometer
- collaboration of UK & US institutes / universities
- monopole & dipole cavity @ $f_{RF} = 2859$ MHz
- material copper, loaded $Q \sim 600$, diameter 36 mm
- electronics: IQ demodulation
- resolution: horiz. $0.53 \ \mu m /$ vert. $0.46 \ \mu m$ @ $2.6$ nC

Cavity BPM for ILC IP
- collaboration of US & Japanese & European institutes
- design: minimize X-Y contamination by rect. cavities
  suppress beam angle effect by thin cavity gap
- X-port: $f_{RF} = 5707$ MHz, $QL \sim 2182$
- Y-port: $f_{RF} = 6421$ MHz, $QL \sim 1308$
- pipe shape: 6 and 12 mm apertures, material copper
- electronics: down-conversion & IQ phase detection
- resolution: $\sim 8.72$ nm @ $\sim 1.1$ nC (2 nm desired)
Electron Scanner for SNS Ring Profile Measurements

Electron Scanner Hardware & Principle

- tilted sheet of electrons will be deflected by proton beam → measure at projection

- ingredients:
  - 75 kV electron gun
  - linear deflector (tilt line)
  - phosphor screen & CCD

- full CS integration of electron scanner
- image analysis SW package (LabView)

- time-resolved (25 ns) 3-D profiles with resolution of 0.3 mm / CCD pixel

Multiple Bunches in Accumulator Ring (horizontal = red / vertical = blue)

ELS Images (horiz. & vertical scans)

3-D Profile (4 μC bunch)

Long. Profile (from current monitor)
Light Yield of Luminescent Screens for High Energy & High Brilliant Electron Beams
courtesy of Gero Kube / TUPD39

Motivation: study light yield of scintillator screens for high energy & high brilliant electron beams

Set-Up: using MAMI X1 beam line at 855 MeV screens were mounted in air irradiation with cw beam for ~ 1 min. with few nC Vidicon camera system mounted at 1 m distance

<table>
<thead>
<tr>
<th>material</th>
<th>d / mm</th>
<th>current / nA</th>
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<tbody>
<tr>
<td>YAG:Ce</td>
<td>1</td>
<td>0.5</td>
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<tr>
<td>Diamond</td>
<td>0.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Al₂O₃:Cr (Chromox)</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>ZrO₂ (Z700-20A)</td>
<td>1</td>
<td>32.4</td>
</tr>
<tr>
<td>ZrO₂:Mg (Z507)</td>
<td>1</td>
<td>32.4</td>
</tr>
</tbody>
</table>

Results:  
- YAG:Ce provides highest light yield  
- beam profile slightly distorted  
- Cromox & Al₂O₃ ~ 10 times less light yield  
- ZrO₂ ceramics provide low light yield and show material degradation under bombardment → seems to be not suitable

Data Taking: record profiles \( I \) and integrated normalized intensities

<table>
<thead>
<tr>
<th>material</th>
<th>( \sigma_x ) [mm]</th>
<th>( \sigma_y ) [mm]</th>
<th>( I_{\text{norm}} ) [a.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG:Ce</td>
<td>0.91</td>
<td>0.77</td>
<td>1</td>
</tr>
<tr>
<td>Chromox</td>
<td>0.93</td>
<td>0.73</td>
<td>( 72.6 \times 10^{-3} )</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.04</td>
<td>0.80</td>
<td>( 41.8 \times 10^{-3} )</td>
</tr>
<tr>
<td>Diamond</td>
<td>-</td>
<td>-</td>
<td>( 24.9 \times 10^{-3} )</td>
</tr>
<tr>
<td>ZrO₂:Ce</td>
<td>0.57</td>
<td>0.46</td>
<td>( 1.6 \times 10^{-3} )</td>
</tr>
<tr>
<td>ZrO₂:Mg</td>
<td>0.86</td>
<td>0.62</td>
<td>( 0.6 \times 10^{-3} )</td>
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</table>

<table>
<thead>
<tr>
<th>material</th>
<th>( \Delta E ) [keV]</th>
<th>light yield [photons/keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG:Ce</td>
<td>680</td>
<td>8 (Ref. [5])</td>
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<tr>
<td>Chromox</td>
<td>619</td>
<td>0.639</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>619</td>
<td>0.367</td>
</tr>
<tr>
<td>ZrO₂:Ce</td>
<td>829</td>
<td>0.011</td>
</tr>
<tr>
<td>ZrO₂:Mg</td>
<td>829</td>
<td>0.004</td>
</tr>
<tr>
<td>ZrO₂</td>
<td>829</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Investigation of Different Gases for Beam Induced Fluorescence (BIF) Monitors
courtesy of Frank Becker / TUPB02

Motivation: investigation of gas transitions for low profile distortions at high charge densities for high intensity ion beams

Set-Up: imaging spectrograph with intensified CCD chromatically corrected UV optics residual gas analyzer & quad. mass spectrometer working pressure ~ 10^{-3} \text{ mbar N}_2\text{-equivalent}

Data Taking: spectra averaged over 2000 pulses calibration to known transitions 1 nm accuracy of central wavelength

Results: - N_2 & He lines are well separated
- besides He, all gas species show similar profile widths
- N_2 transitions 1, 5, 6 show profile broadening
- only He transitions 2 & 3 show no broadening
- N_2 shows highest light yield at 390 – 430 nm
- all N_2 lines show similar profile width

N_2 seems to be the optimal choice
Sliced Beam Parameter Measurements

courtesy of David Alesini / TUOA01

RFD Principle of Operation

- RFD introduces correlation between longitudinal bunch coordinate ($\tau_b$) and transverse coordinate at the screen ($y_S$)
- "zero"-crossing operation of RFD provides linear deflection of bunch in transverse plane

RFD Time Resolution...

$$\sigma_{\tau_b,RES} = \frac{\sigma_{y_b}}{V_T} = \frac{e\beta_S}{V_T}$$

...depends on: beam energy $E$, deflecting voltage $V_T$, norm emittance $\Sigma$ and $\sigma$-function

RFD Time Resolution depends on:
- beam energy $E$
- deflecting voltage $V_T$
- norm emittance $\Sigma$
- $\sigma$-function

SPARC Parameters

- $\Sigma = 1$ mm mrad
- $f_{RF} = 2.856$ GHz
- $\beta_S = 1$ m
- $y_B = 58$ m (@ 150 MeV)
- $y_B = 18$ m (@ 1.5 GeV)
- $L = 4$ m

time resolutions < 10 fs

SW vs TW RFD Structures

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency per unit length</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Filling time</td>
<td>slow</td>
<td>fast</td>
</tr>
<tr>
<td>Maximum number of cells</td>
<td>15</td>
<td>3-4 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulator</td>
<td>yes</td>
<td>not</td>
</tr>
<tr>
<td>$E_{PEAK}$</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Beam impact</td>
<td>low</td>
<td>High</td>
</tr>
</tbody>
</table>
Sliced Beam Parameter Measurements
courtesy of David Alesini / TUOA01

RFD Induced Energy Spread

Panowski-Wenzel theorem directly relates deflecting voltage to longitudinal electric field gradient...:

→ induced energy spread if RFD is operated at „zero“-crossing of deflecting voltage
→ energy spread depends linearly on vertical slice size in RFD

\[ \sigma_{E_{\text{RFD}}} \approx \frac{\omega_{RF}}{c} \hat{V}_{\text{DEFL}} \sigma_{y_{\text{RFD}}} \text{[eV]} \]

Measurements at two different deflecting voltages takes out RFD contribution to sliced energy spread

RFD Measurement: LCLS „Sliced“ Energy Spread @ 135 MeV with Laser Heater off & on
Beam Loss Monitoring with Optical Fibers  

**Optical Fibers** as radiation sensors can measure…
- the total ionization dose (mGy – kGy even up to MGy) using the effect of radiation induced attenuation
- position & dynamic of losses by radiation induced Cerenkov and luminescence light (ms to ns)

**Integrating Optical Power Meter – Local and Global Dosimeter Systems**

![Model of Vacuum chamber](image1.png)

![Sensor Holder](image2.png)

![Fiber sensor](image3.png)

![Optical connector](image4.png)

![Beam loss measurements at TESLA Test Facility of DESY Hamburg](image5.png)
Beam Loss Monitoring with Optical Fibers
courtesy of Friedrich Wulf / WEOA01

Fast BLM Systems using Cerenkov Light

- radiation resistant, large, multi-core (300 μm) fibers
- electron with E > 175 keV generate Cerenkov light
- PMTs detect Cerenkov light in sync. with the beam
- locations calibrated with known BL elements (e.g. OTR)
- light velocity in fibers ~ 0.6·c (expanded time scale)
  → beam loss position accuracy ~ 25 cm

Screen Shot of Fast BLM System at FLASH (March 2009)

BL Position Monitor (beam transport line)
Beam Loss Monitoring with Optical Fibers
courtesy of Friedrich Wulf / WEOA01

Overview of and Areas of Applications for Slow and Fast BLM Systems

<table>
<thead>
<tr>
<th>Application</th>
<th>Slow BLM Systems</th>
<th>Fast BLM Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distributed Dosimeter System</td>
<td>Local Dosimeter System</td>
</tr>
<tr>
<td>Measurement principle:</td>
<td>Optical Time Domain Reflectometer</td>
<td>Optical Power Meter</td>
</tr>
<tr>
<td>Bunch resolution</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Measurement time (response)</td>
<td>minutes</td>
<td>ms to minutes</td>
</tr>
<tr>
<td>Range of maximum dose TID [Gy]</td>
<td>3 – 450 limited by OTDR</td>
<td>0.06- 2000 limited by fiber type</td>
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<tr>
<td>Wavelength range</td>
<td>850 - 1330 nm</td>
<td>860 nm</td>
</tr>
<tr>
<td>Position resolution</td>
<td>1.5 m</td>
<td>0.05 m</td>
</tr>
<tr>
<td>Reasonable Fiber length*</td>
<td>≤ 5 km typical ≤100 m sections</td>
<td>-</td>
</tr>
</tbody>
</table>

* Depending on max. Dose and required position resolution
Instrumentation Requirements for Future Accelerators

*a collection of aspects and issues mainly taken from: MOOA01 / WEOA04 / WEOB01 & WEOB03*

- **FAIR – Facility for Antiproton & Ion Research:**
  various accelerators and storage rings, energy up to 30 GeV/u, *high current p and U operation*
  high precision (few %), high dynamic range (10 $\mu$A - 20 A) *current measurement* up to MHz BW
  *ionization profile monitors* with 100 $\mu$m spatial resolution & 100 ns time resolution

- **ILC & CLIC luminosity budget:** beam *position stability* & stabilization of large structures: nm scale

- **Colliders & XFELs:** sub-$\mu$m BPMs and *fast (some 100 kHz BW) position FBs* for SC facilities
  reference signal and *bunch arrival time stability < 10 fs scale* *(target: few fs)*
  *beam-based longitudinal FBs* actively stabilizing accelerator RF
  *bunch length meas. / monitoring of few fs (sub-fs) electron & photon pulses*
  high precision *instrumentation for few pC operation modes*

**What else will / may come...**

... *extreme mechanical stability (sub-nm) and temperature stability / control (0.001° C)*
... photon (X-ray) beam diagnostics, possibly laser beam diagnostics (gun lasers & seeding)
... *new challenges in logistics & reliability as facilities become larger & BI-systems more complex*
...
Final Remarks & Outlook

reflects mainly my personal impressions & opinion...!

DIPAC 2009...

... showed a largely growing interest in beam instrumentation & diagnostics
  → over 200 participants (~ 150 from Europe / ~ 50 world-wide )
  → over 140 contributions ( 24 talks / 118 posters )

... experienced an extremely high quality of oral and poster presentations
  → almost all submitted during the event allowing to publish the proceedings „in time“

... included already some contributions from neighboring areas (lasers, photons, timing& sync...)
  → remember years ago, FPGA developments & some CS-related issues were integrated

... initiated already quite some inspiring discussions in the PC about „the future“
  → will / should be discussed with the BIW PC and Asian colleagues
  → might lead to closer collaboration with broader scope and efficient information exchange

... caused quite some work for the PC and LOC  but  was a lot of fun !!!

Thank you for your patience and attention...!!!