This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

ARIES Network ADA on Beam Diagnostics

WP8: Advanced Diagnostics at Accelerators

1st ARIES Annual Meeting, Riga, May 23th, 2018

Work-package leader: Peter Forck GSI

Task 2: Beam Diagnostics at hadron LINACs → Peter Forck GSI

Task 3: BD at hadron synchrotrons → Rhodri Jones CERN

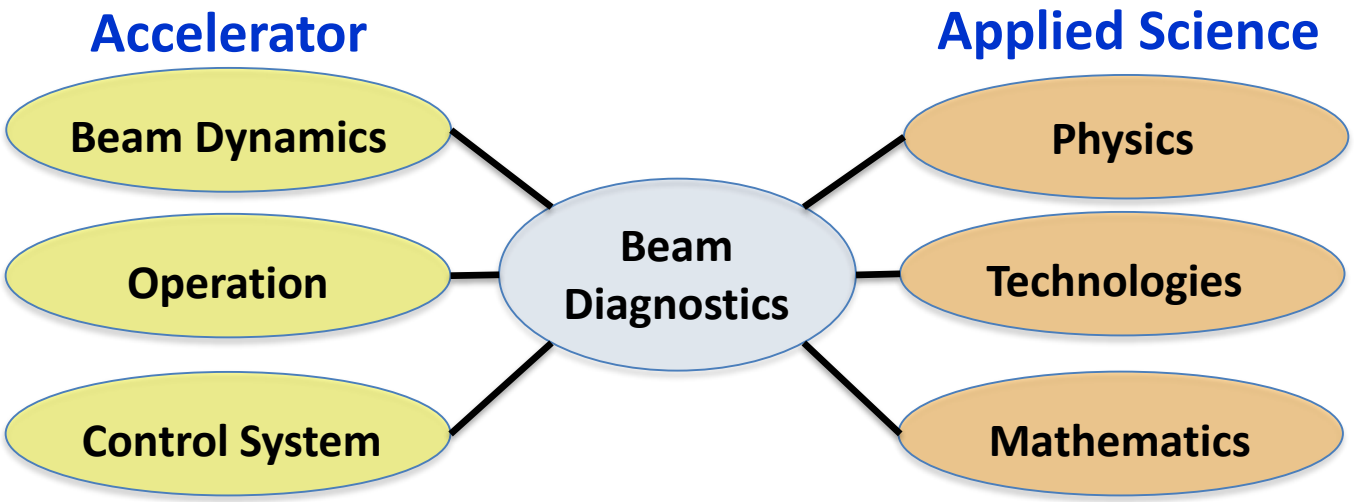
Task 4: BD at circular light sources → Fancis Perez ALBA-CELLS

Task 5: BD at linear light sources → Kay Wittenburg DESY

Network Activity concerning Beam Diagnostics

Requirements for beam diagnostics at novel accelerators:

- Commissioning & enhanced operation of adequate diagnostics
- Instruments are based on quite different physical principles and techniques
- Design of diagnostics for novel accelerators



Goal → Focusing of activities at different labs:

- Discussion of requirements, improvements and novel methods

Goal concerning Beam Diagnostics

Method → Organization of topical workshops and exchange of personnel:

- Meeting of physicists, engineers, technicians from acc. labs, universities & industry (engineers are a major part of a successful technical development)
- Interaction with experts of beam dynamics, operation & industry for technology
- Education: Meeting of experts and newcomers like PhD students

⇒ Documentation of state-of-the-art knowledge

Reason for topical workshops:

Beam diagnostics community is very active e.g. conference with ≈ 300 participants

Topical workshops:

One subject can be discussed in detail in connection with other communities

≈ 30 to 40 participants with various field of expertise

Three topical workshops executed so far as new events!

Exchange of personnel or invitation of expert typically for ≈ 2 weeks:

For common device development of instruments and methods

Three visits covered by ARIES: FNAL → GSI, Uni Milan → ALBA & GSI → DIAMOND

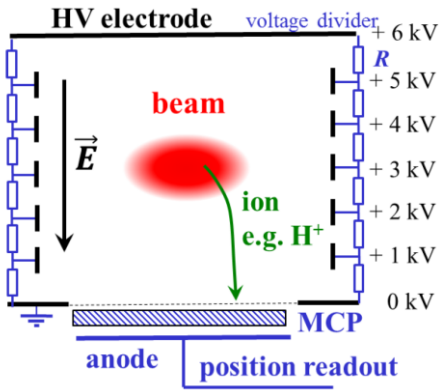
ARIES-Workshop on 'Simulation, Design & Operation of Ionization Profile Monitors'

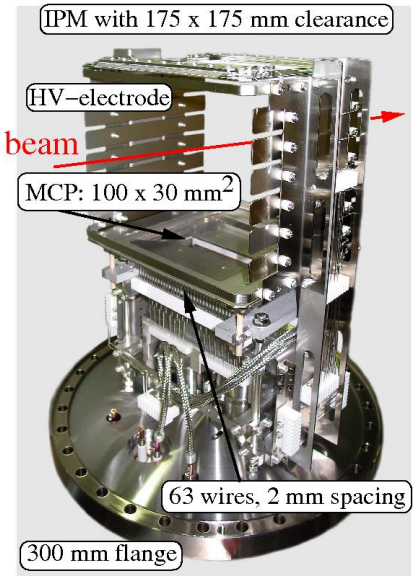
Workshop on 22nd - 24th of May 2017 at GSI
see http://indico.gsi.de/event/5366/

33 participants from Austria, CERN, China, France, Germany, Japan, Russia, UK, USA

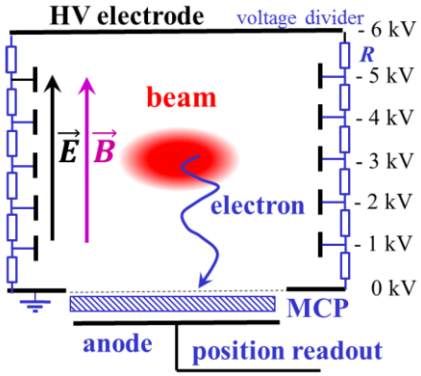
- General compilation on IPM realization at LINACs and synchrotrons
- Exchange of novel ideas
- Common code development for image reconstruction

Ion detection mode:





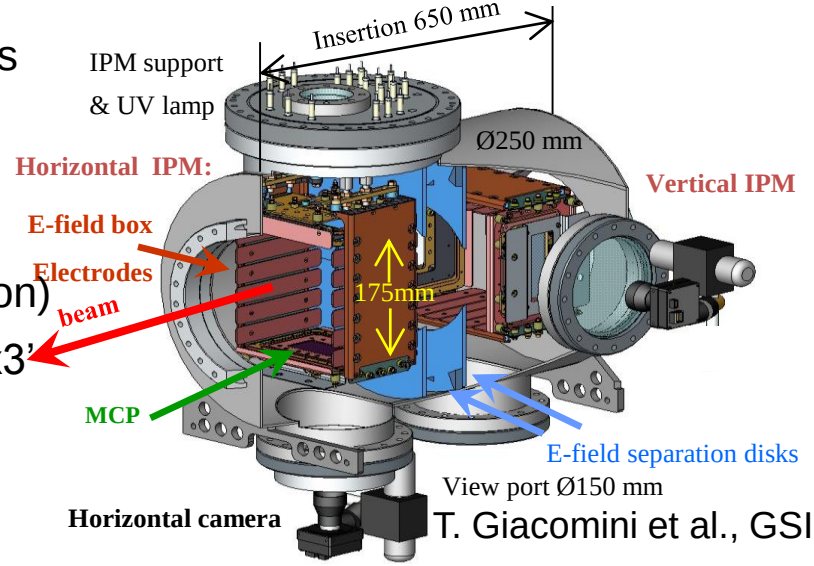
Electron detection mode:



Topic 1: Detector design and technologies

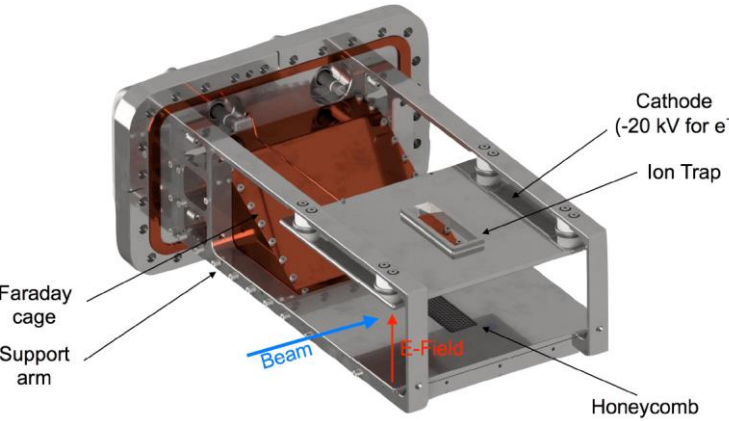
- Simulation & design of eclectic field box and magnets
- Most IPMs have MCPs as single particle detector; discussion concerning aging and calibration
- Readout technology: Wire readout (turn-by-turn capability) versus phosphor + camera (high resolution)
- New design at CERN: Silicon pixel detector 'TimePix3' for high resolution and fast readout
- Comparison to other techniques like electron beam scanner, beam induced fluorescence monitor

IPM with ion detection at GSI



T. Giacomini et al., GSI

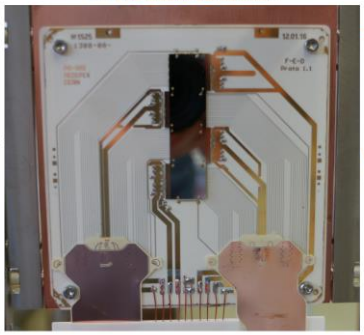
IPM magnet & compensation at CERN PS



Pixel detectors:
- 4 TPX3 assemblies
- Full readout
- Independent power and data-in

Carrier board:
- 2 metal layer, Al_2O_3 substrate, no solder mask
- Manufactured and assembled by Hightec (ch)

TPX3 based Detector



Signals:
- 100 ohm differential Impedance

WireBond:
- Wedge-wedge aluminum
- Bias: Hand placed gold wire, secured with conductive epoxy

J. Storey et al. CERN

Topic 2: Operational issues

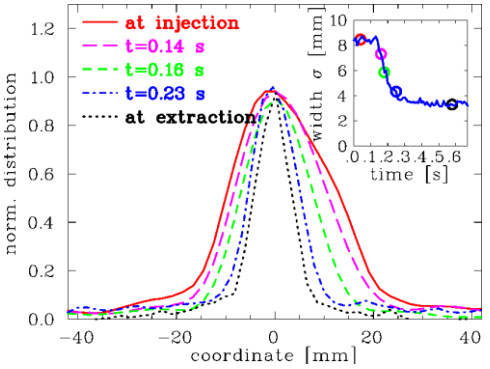
- Requirements for **daily operation** of IPMs
- How to reach the resolution & timing limit
- Noise reduction, 'de-convolution' and data handling
- Using as online monitor at high power LINACs like ESS

Topic 3: Advanced methods:

- **Machine learning** for image reconstruction
- Workshop triggered common experiment

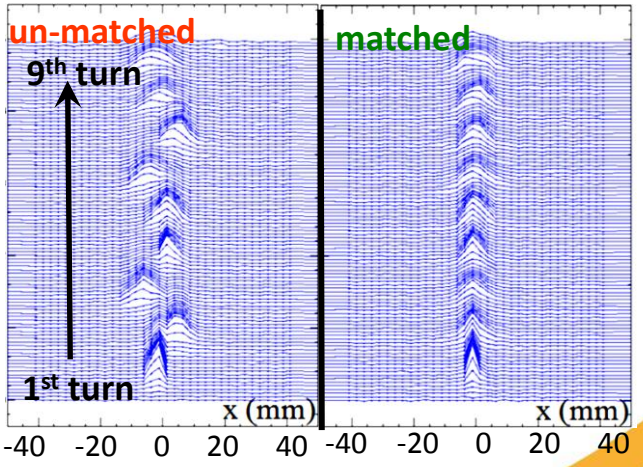
by CERN and GSI

Profiles during acceleration at GSI



Turn-by-turn readout at J-PARC MR

K. Satou et al., J-PARC



Topic 4: Code for space charge broadening by beam's space charge

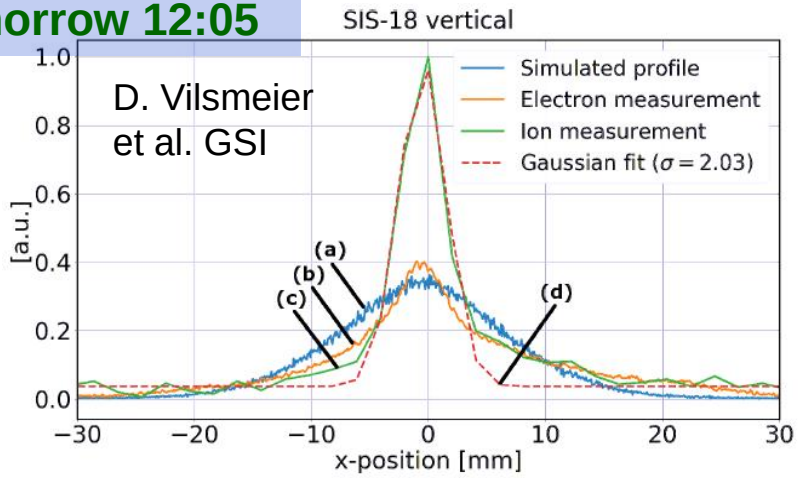
Each laboratory has its own code with special application & restriction

⇒ Discussion underlying physics & software, validation as initialized by m. Sapinski GSI

Talk by D. Vilsmeier tomorrow 12:05

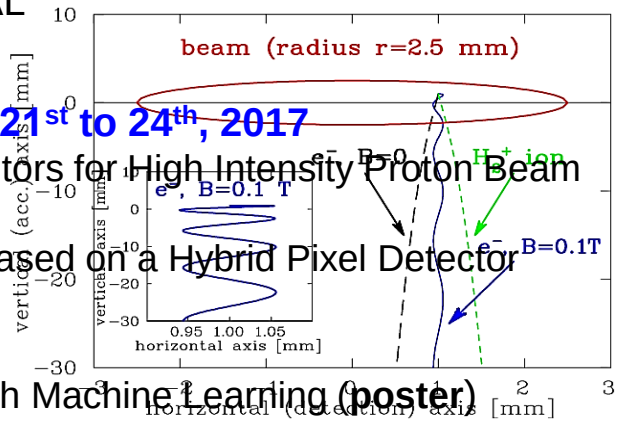
Code includes:

- Application for **LINACs**
  i.e. short bunches, non-relativistic
- Application for **synchrotrons**
  i.e. long bunches, relativistic ⇒ 2d calc.
- Homogeneous $\vec{E}$ & $\vec{B}$ fields ***or*** input CST maps
- Realistic e⁻ generation: $\frac{d^2\sigma}{dE \cdot d\theta}$ and tracking
- Meaningful GUI
- twiki.cern.ch/twiki/bin/view/IPMSim/



Present participants: CEA, CERN, ESS, FNAL, GSI, J-PARC, RAL

Further interest by: BNL, CAS (China), FZ-Jülich, SNS



Related contributions at IBIC'17 in Grand Rapids USA August 21st to 24th, 2017

- K. Satou J-PARC, Simulation and Progress in Ionization Profile Monitors for High Intensity Proton Beam (**invited talk**)
- J.W. Storey et al., CERN, First results from the Operation of a IPM based on a Hybrid Pixel Detector (**contributed talk**)
- D. Vilsmeier et al. GSI, A modular for IPM Simulations (**poster**)
- R. Singh et al. GSI., Simulation Supported Profile Reconstruction with Machine Learning (**poster**)

ARIES-Workshop ‘Extracting Information from electro-magnetic Monitors’

Workshop on 14th - 16th of May 2018 at CERN

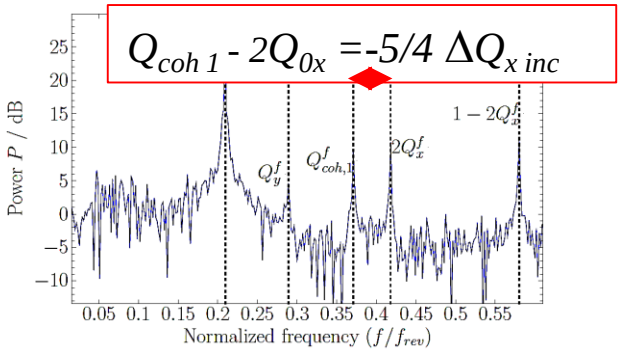
see https://indico.cern.ch/event/705430

32 participants from CERN, France, Germany, Japan, Switzerland, Russia, USA

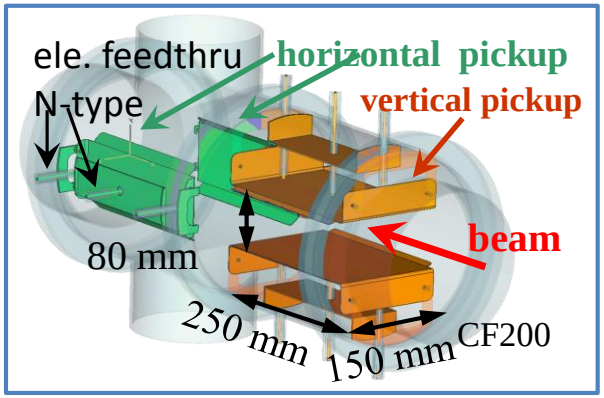
- Measurements of machine optics
  e.g. tune and beta-beating
- Beam parameter measurements
  e.g. quadrupolar oscillation → tune spread
- Schottky signal analysis

→ **‘beam dynamics meets diagnostics’**

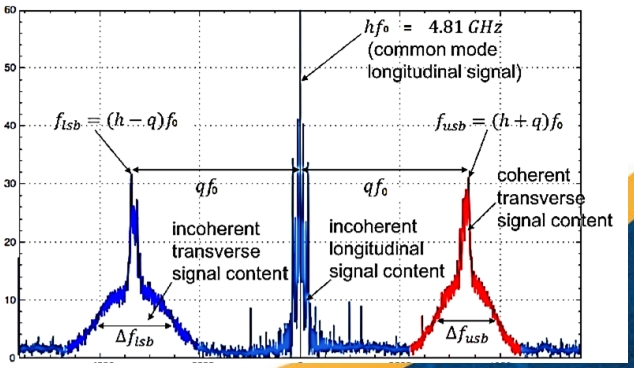
Tune & quadrupole oscil.



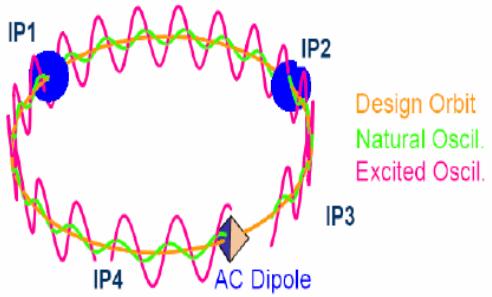
BPM



Schottky spectrum

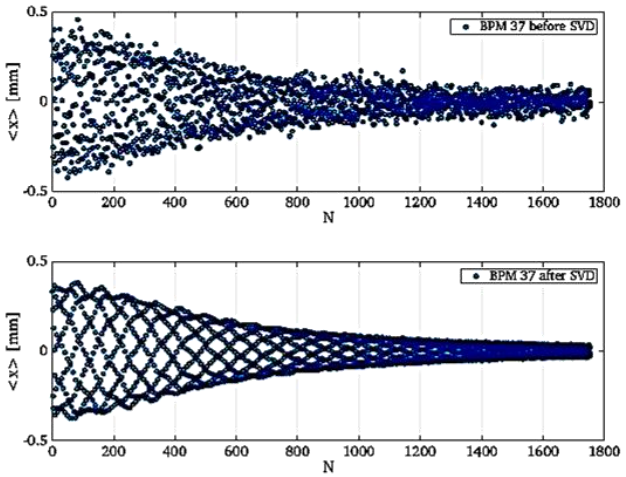


Topic 1: Tune and chromaticity measurements



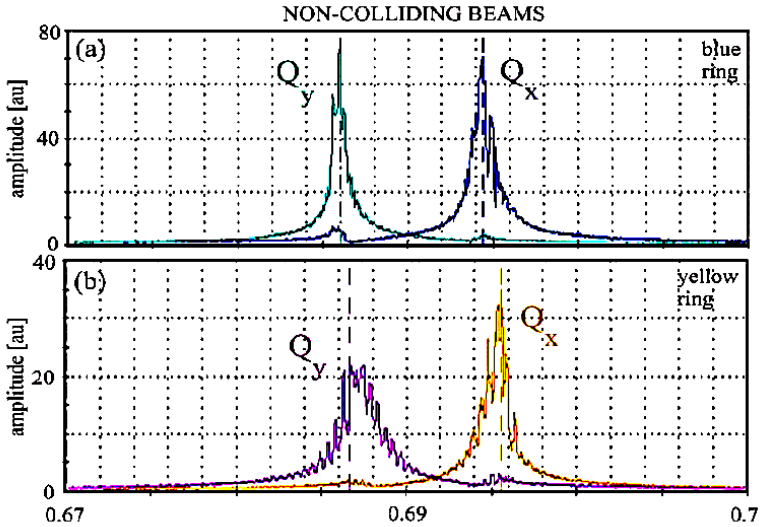
- Measurement of tune, tune shift by space charge or beam-beam, chromaticity etc.
- Improved sensitivity & accuracy BPM readout
  $\Rightarrow$ lower beam excitation
- BPM data treatment by filtering e.g. SVD and improved FFT algorithms
- short dipole kick versus ac-dipole excitation

Example LHC: position data SVD-filter



P. Zisoloulos et al., CERN

Example RHIC tune by BTF



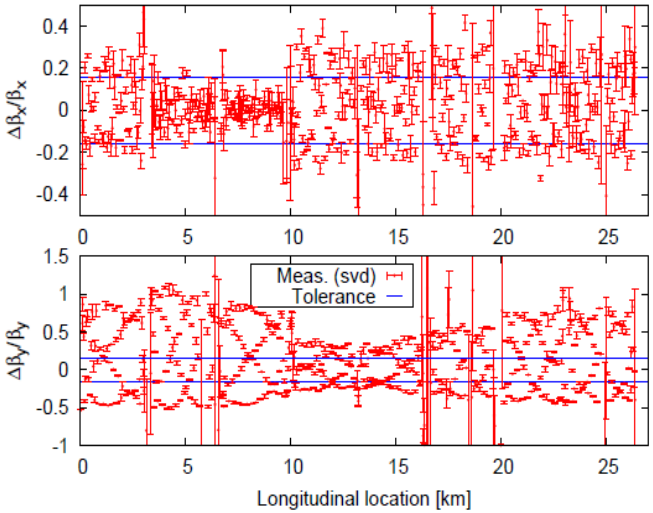
M. Minty, BNL & T. Pielone CERN et al.,

Topic 2: Beta-beating measurements $(\beta_{meas} - \beta_{theo}) / \beta_{theo}$

- Overview talk from A. Franchi ESRF, comparison of different methods
- Significant improvements by statistical analysis of BPM data and advanced fitting routines
- Examples at ESRF, LHC and RHIC for significant improvements discussed

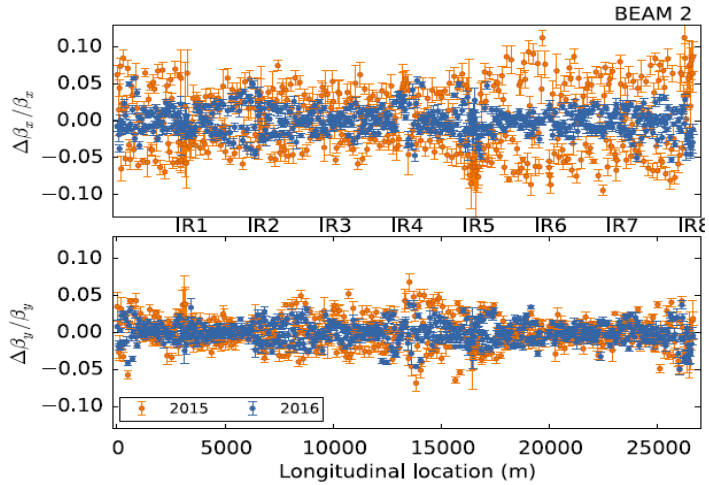
Example LHC at initial commission

- BPM with ≈ 100 µm resolution
- Kick excitation and turn-by-turn readout
- Main quadrupole error identified



Example LHC today

- BPM data cleaned by SVD method
- AC-dipole excitation and turn-by-turn readout
- One ingredient: improved BPM accuracy



R. Tomas et al., CERN

M. Aiba et al. PRAB 12, 081002 (2009) and T. Person et al., PRAB 61002 (2017)

R. Tomas et al., PRAB 20, 054801 (2017) and A. Wegscheider at al., PRAB 20, 111002 (2017)

Topic 3: Quadrupole mode oscillations for tune spread & injection matching

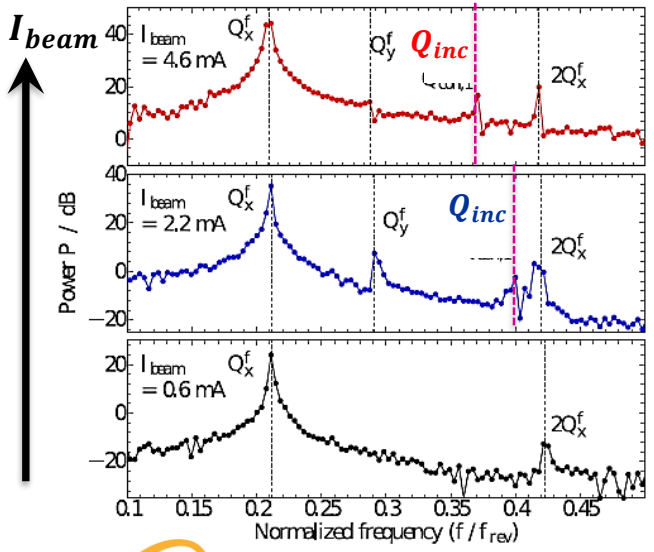
- Envelop oscillation by space charge tune spread modifies tune spectrum leading to as $Q_{inc,x} = 2\,Q_{0,x} - \Delta Q_{KV} \cdot \left(3 - \frac{\sigma_x}{\sigma_x - \sigma_y}\right)/2$ in dependence on beam size σ

⇒ direct determination of tune spread → actual **'hot topic'** for beam dynamics & diagnostics

- Additionally, detailed study for usage of quadrupole signal for beam size determination

Example GSI: Current dependent Q_{inc}

Beam: N^{7+} E_{kin} = 11 MeV/u,
$\varepsilon_{x/y}$= 8 / 12 mm mrad

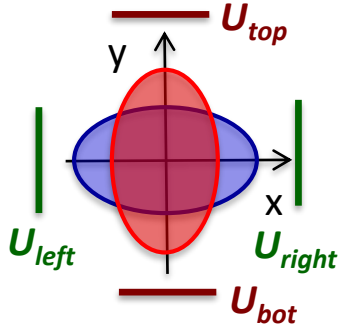


R. Singh et al., GSI

BPM turn-by-turn shape oscillation
⇒ beam size
⇒ tune spread

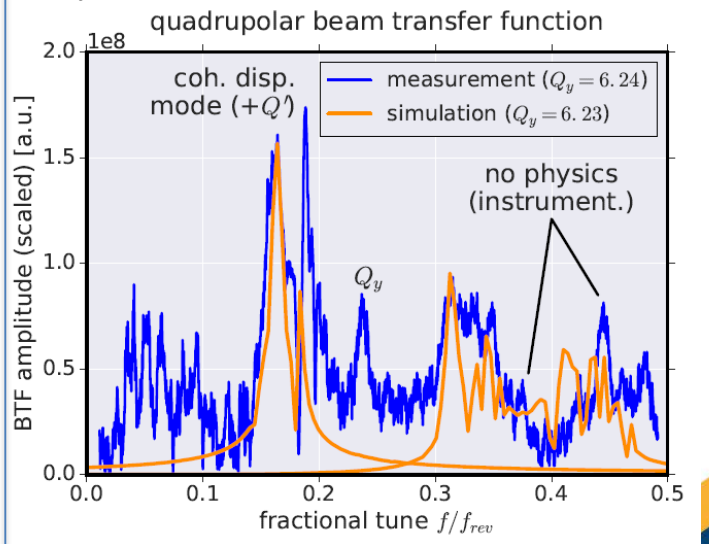
Quad. moment

$U_Q(t) \propto (U_{left}+U_{right}) - (U_{top}+U_{bot})$



Example CERN PS: Simulation ↔ measurement

Beam: p, $4 \cdot 10^{11}$ /bunch, E_{kin} = 11 MeV/u,
$\varepsilon_{x/y}$= 2.3mm mrad, $Q_{KV} \approx 0.02$



A Öftiger et al., CERN

Topic 4: Schottky signal analysis as non-influencing monitoring

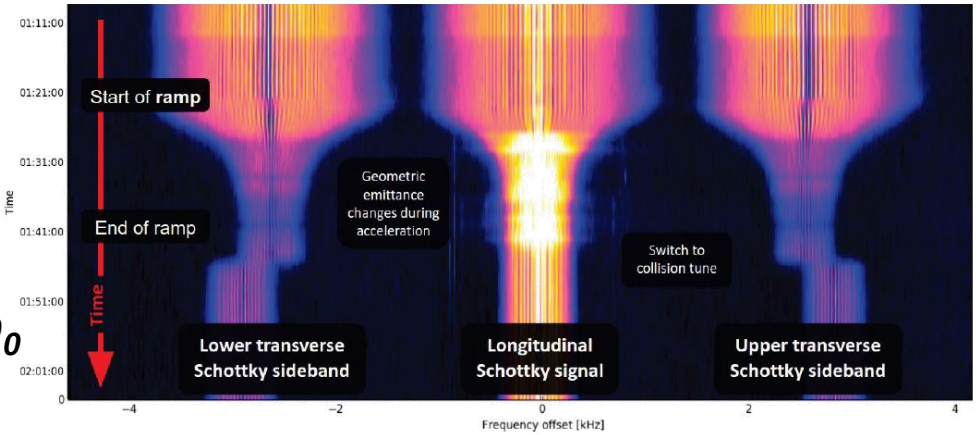
- Discussion on diagnostics possibility for **online** monitoring
- Understanding of signal shape for coasting and bunched beam
- Longitudinal: e.g. momentum $\Delta p/p_0$, revolution f_0, synchr. frequency f_s and spread Δf_s

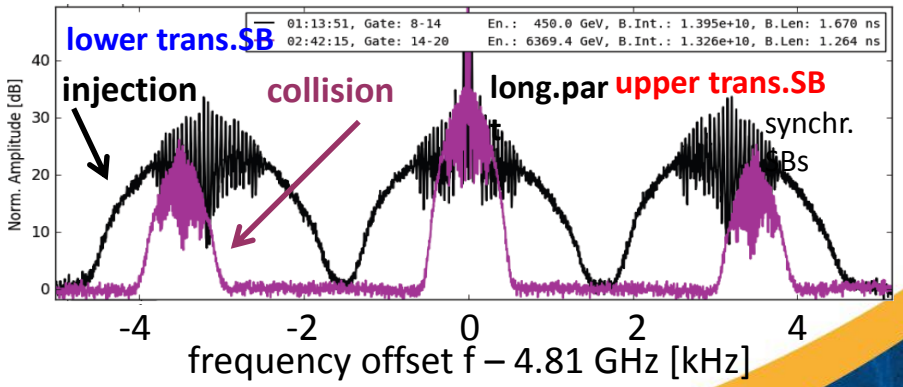
Example LHC: Schottky at ramp & store

Schottky spectrogram during LHC ramp and collision:

Form incoherent part of the spectrum

- **Longitudinal part**
  - ***Width:*** → momentum spread $\Delta p/p_0$
- **Transverse part**
  - **Center:** → tune q
  - **Width**: → chromaticity $Q' = \xi Q_0$ difference of lower & upper SB
  - **Integral** : → trans. emittance $\varepsilon_{x/y}$





M. Betz et al., NIM A 874, p. 113 (2017)

BPMs for coasting beam:

Schottky signals from individual electrodes

⇒ 1 mm resolution @ 10 ms time scale

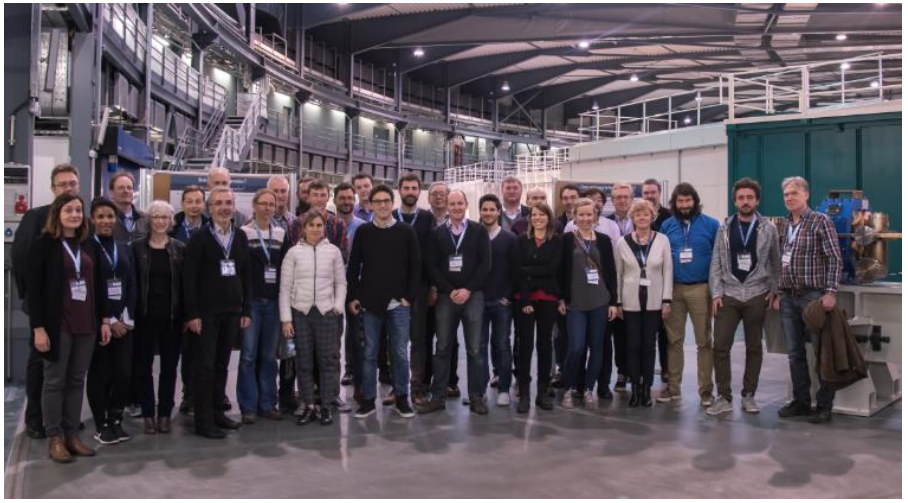
R. Singh, P. Forck et al. GSI

ARIES-Workshop on 'Emittance Measurements for Light Sources and FELs'

Workshop on 29th - 30th of Jan. 2018 at ALBA

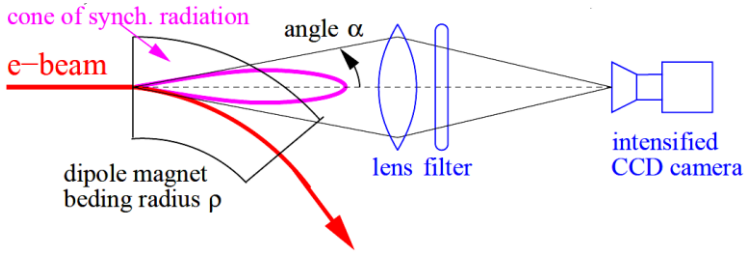
see https://indico.cells.es/indico/event/128/

37 participants from CERN, France, Germany, India, Italy, Japan, Poland, Sweden, Spain, Switzerland, Russia, UK, USA

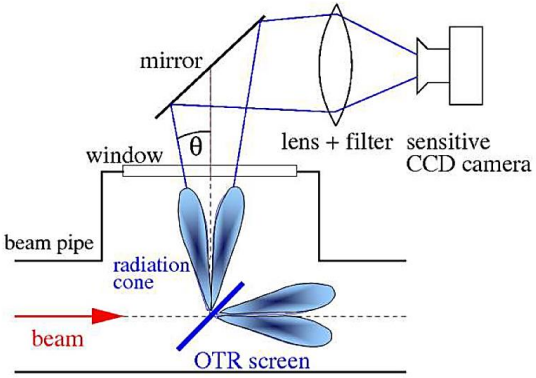


- Resolution challenges at light sources
- Direct images technique
- Measurements from light coherence analysis
- FEL challenges and OTR & ODR techniques
- Wire and laser scanner techniques

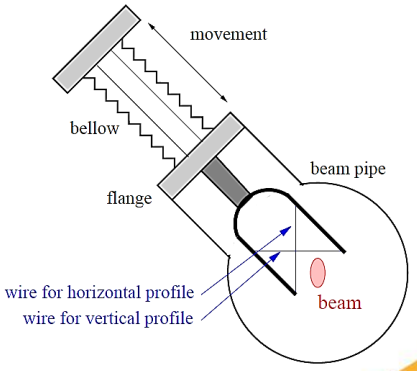
Synch. light monitor visible x-ray



OTR screen & ODR



Wire & laser scenner



Summary by U. Iriso (ALBA) on Workshop DULER at DIAMOND 19th to 20th April, 2018 & Invited Talk at IBIC 2018, Shanghai September 2018

Comparison of different methods of synchrotron light monitors (visible or x-ray)

⇒ **Different techniques for circular SLS compared, technical realization discussed, dedicated beam line required**

Method for circular accelerator	smallest σ [µm] (measured)	Workshop Talk
Scintillator (reference)	**1.5**	G. Kube (DESY)
X-ray Pinhole	7	L. Bobb (DLS)/ F. Ewald (ESRF)
Comp. Refractive Lenses	10	F. Ewald (ESRF)/ A. Snigirev (Kalin.)
Vis. Light Interf.	3.9	T. Mitsuhashi (KEK)
Vis. Light Inter. (mask)	2 (sim)	L. Torino (ESRF)
p-polarization (vis)	3.7	A. Andersson (MAXLab)
Coded Aperture	5	J. Flanagan (KEK)
In-air X-ray Det.	9	F. Ewald (ESRF)
X-ray Diffraction	4.8	A. Snigirev (Kaliningrad)
X-ray (multi/lens) Inter.	4.8	A. Snigirev (Kaliningrad)
HNFS	130	M. Siano (Milan)

Comparison of different methods (invasive optical methods, wire & laser scanner)
⇒ Different techniques for linear FELs compared, technical realization discussed

Method for linear accelerator	smallest σ [µm] (measured)	Workshop Talk
Scintillator (reference)	**1.5**	G. Kube (DESY)
OTR Techniques	1.5	L. Sukhikh (Tomsk)
ODRI Techniques	??	E. Chiadroni (INFN)
COTR Techniques	3.8	A. Potylitsyn (Tomsk)
Wire Scanner Technique	0.490	K. Wittenburg (DESY) / S. Borrelli (PSI)
Laser Wire Technique	0.070	P. Karataev (RHUL)
Multi-Slit Mask Technique	200	M. Kraskilnikov (DESY)

Recent improvements for Au-wires (strips from membrane) down to ∅ 1 µm

Further events of ARIES-ADA

Further planned events:

- **Workshop on 'Longitudinal diagnostics for FELs', 25th to 27th of June 2018 at DESY**
  see **https://indico.cern.ch/event/702602/**, presently 30 registrants (co-sponsor)
- **International workshop 'Non-invasive Beam profile Monitors for Hadron Machines '**
  18th to 20th Sept. 2018 at J-PARC (Japan), no ARIES event but follow-up
- **ARIES workshop 'BPM Signal Treatment and Orbit Feedback at Hadron Synchrotrons ',**
  Begin of December 2018 at GSI (Collaboration from SLS and hadron synchrotrons)
- **ARIES workshop 'Beam Diagnostics for Hadron LINAC Commissioning',**
  Feb. or March 2019 at CERN
- **ARIES workshop 'Feedback Systems for Synchrotron Light Sources', at ALBA**
  co-organization with WP7 (Rings for ultra-low Emittance)
- **WP7 workshop 'Beam Stability Requirements for Low Emittance Rings', at ALBA**
  co-organization with WP7

More workshops will be planned soon, proposals are welcome !

Summary: WP8 on Advanced Diagnostics at Accelerators

Workshop on actual topics

Style: Typical number of attendance: 30 to 40 worldwide experts

Documentation: very useful to monitor state-of-the-art knowledge

Open for everybody: published on ARIES web-site & personalized announcement

Networking: Common topics with beam dynamics, operation & industry

Exchange of personnel or invitation of expert typically for 2 to 4 weeks:
Support for design and realization of instruments and methods

Thank you for your attention!