Summary of TWIICE-II second Topical Workshop on Collective Instabilities and Impedance Effects

R. Bartolini

Diamond Light Source
and
John Adams Institute, University of Oxford

LER - SOLEIL
Paris, 27th October 2016

TWIICE-II
Abingdon (UK) 8-10 February 2016

5 sessions plus summaries

59 participants – 46 talks

Topics:

- **Keynote (Vaccaro)**
- **Review on collective effects in DLSR (Bane)**
- **Report on "Beam dynamics meet diagnostics" (Franchetti)**
- **Theory 6**
- **Beam dynamics codes 3**
- **Impedance calculations 2**
- **Comparison measurement – beam dynamics simulations 14**
- **Facility overviews (collective effects related) 6**
- **Instrumentation 7**
- **Summaries 5**

http://www.diamond.ac.uk/Home/Events/2016/TWIICE-2.html

Theory: CSR

CSR – still a major research topic: extension of CSR model: new theoretical framework CSR from an arc + shield plates → curing divergence on ΔE by including edge radiation + shield plates; generalized to generic trajectories (Stupakov see talk on Friday)

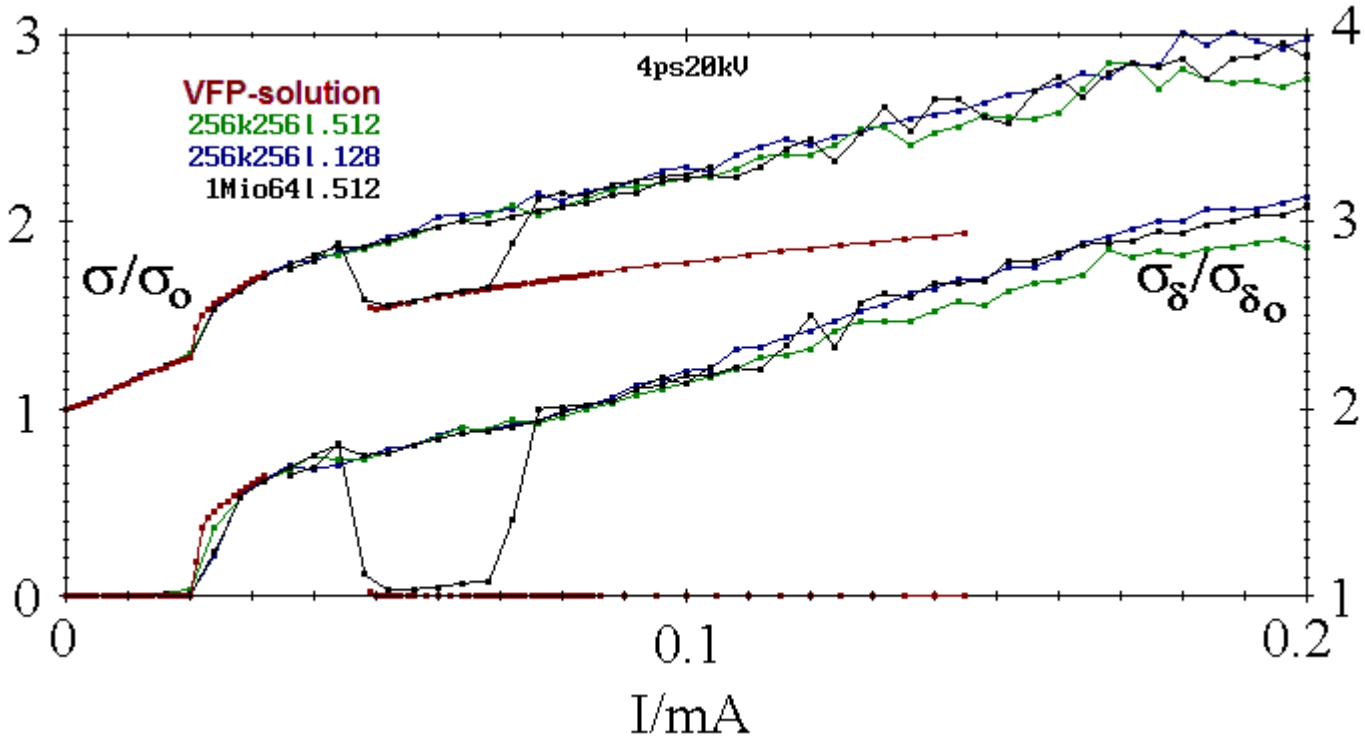
– lots of effort in matching simulations/experimental data Kuske at MLS with $\alpha<0$; extending theory of $\alpha>0$ not obvious; Brosi at ANKA: superb diagnostics (KAPTURE) bbb+tbt

discussion:

behaviour of beam beyond threshold hard to model
matching simulations/experimental data still difficult
devise better operating modes (e.g. negative alpha?)
benefit from more and faster diagnostics
e.g. t-b-t measurement of profile and energy spread

Code comparisons (Kuske)

4ps with 20 kV, F_{syn}=813Hz, β=17.6 10^{-3}



Comparing tracking vs VFP solver

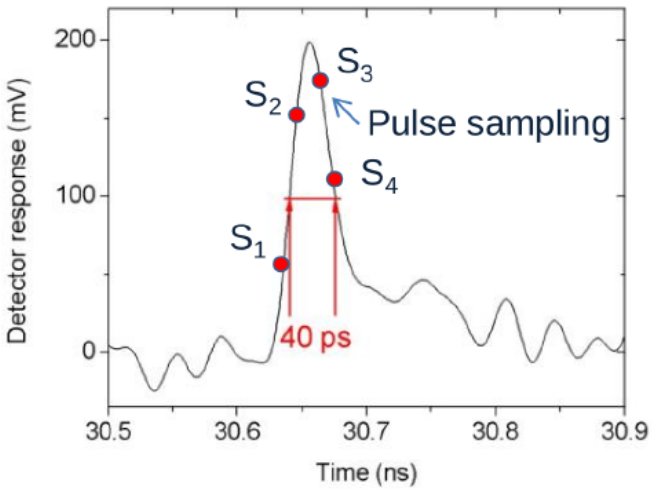
Dependence of results on initial distribution (Haissinski vs double Gaussian)

Disagreement mainly in short bunches for negative alpha

KAPTURE at KIT (Brosi)

DAQ: KAPTURE

KArlsruhe Pulse Taking and Ultrafast Readout Electronics

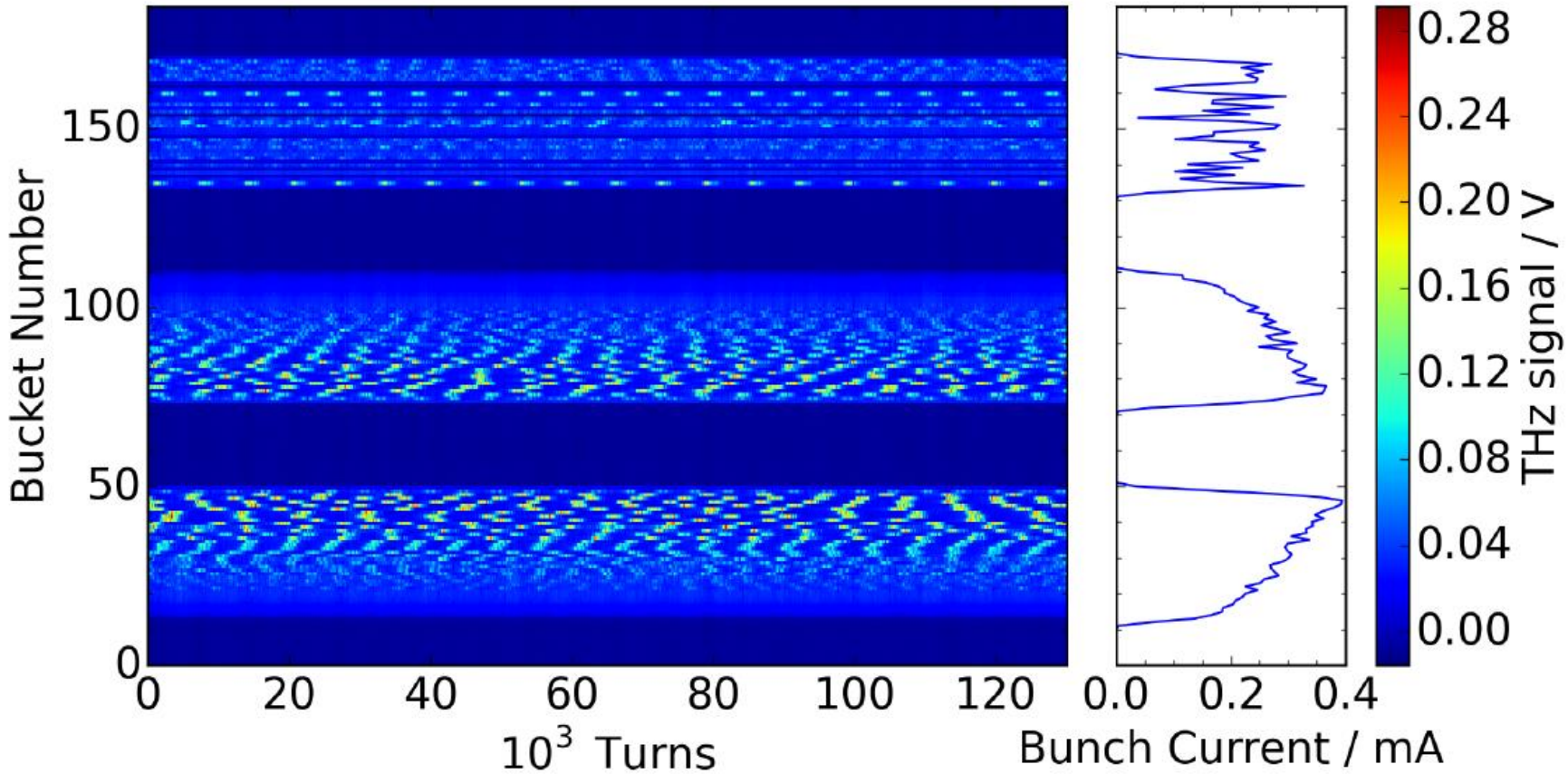


Peak reconstruction
(M. Caselle, IPAC 2013 Shanghai, WEOBB202)

- Simultaneous monitoring of all 184 buckets
- Continuous turn-by-turn read-out of each bucket (500 MHz) $\rightarrow$ 32 Gb/s
- Four sampling channels with a 12 bit ADC each
- Adjustable delay for each channel in 3 ps steps
- Local sampling rate up to 300 GSa/s
- Alternative: read out multiple detectors simultaneously
- New possibilities in diagnostics

Online monitoring of detector peak height for each bucket at every turn!

Bbb tbt data from THz emission (Brosi)



Theory: general

General:

review for DLSR (Bane)
two particles model for fast head-tail instability with space charge (Chin)
interplay chromaticity and TMBF (Burov)
high gain FEL - bypass at ELETTRA (Di Mitri)

discussion:

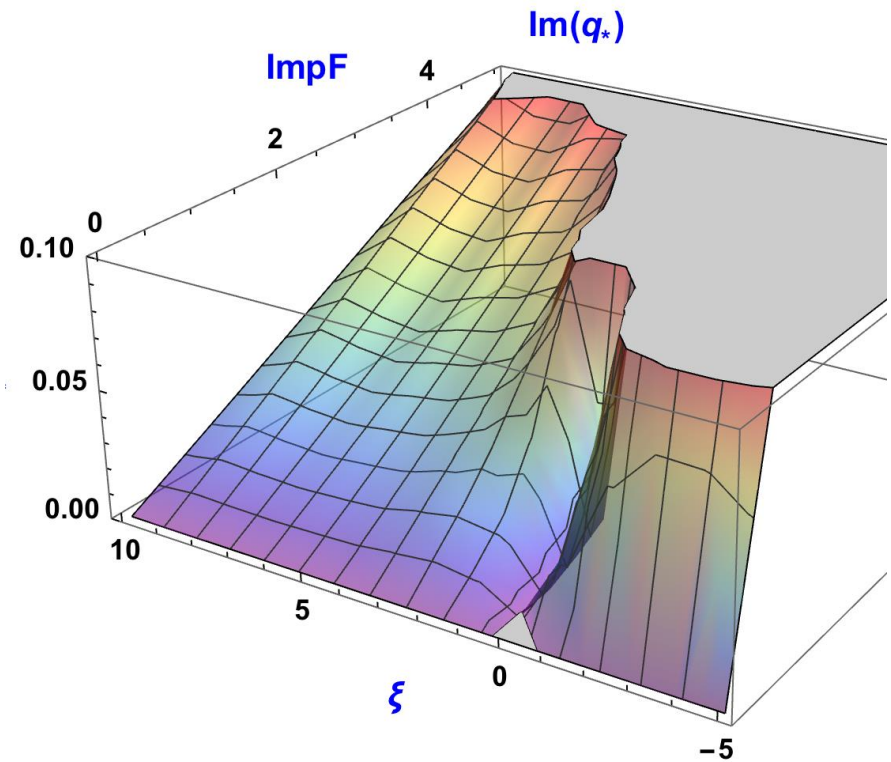
matching simulations/experimental data
understanding/identifying impedance sources

Propose new operating modes (timing, low alpha, FEL, …)

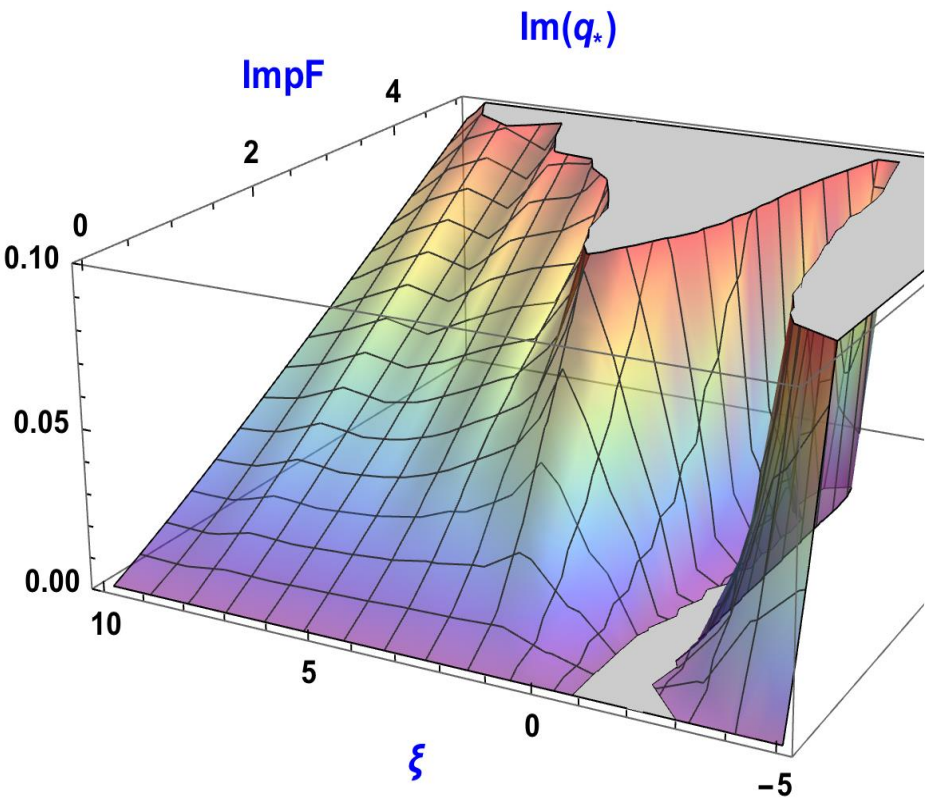
Single bunch threshold (Burov)

ImpF = N_e/4e11 i.e. charge; Im(q) growth rate of most unstable mode grey means unstable

no feedback gain



with feedback gain



See talk by E. Koukovini-Platia this afternoon

Codes and impedance modelling

Impedance modelling:

Modelisation of coating:

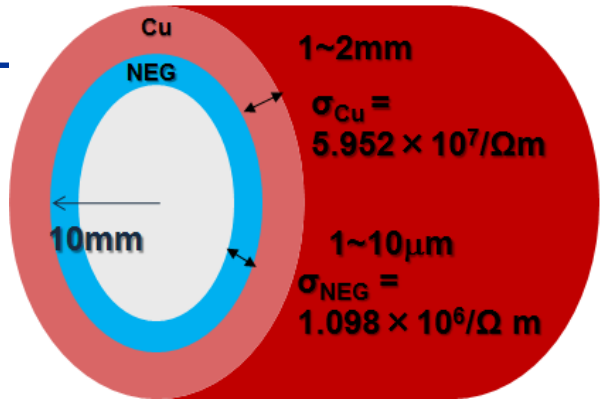
impedancewake2 vs theory (Chin)
needs the modelisation of the AC conductivity of the material up to high frequency (>>100 GHz)

NEG coating at high frequency (750 GHz)

crucial role of non-uniformities in NEG coating (Koukovini-P)

ECHO (Zagorodnov) Major efforts made on: Low dispersive schemes, indirect algorithm, modelling of conducting walls, … Fully 3D geometries in ECHO3D + Particle-In-Cell code (long. only)

NEG impedance (Chin)



Analytical impedance studies based on a two layer coating model

Three frequencies model

$\epsilon_0 \omega \ll \sigma$ (below ~100GHz)

The usual (simplified) formula of the skin depth is valid

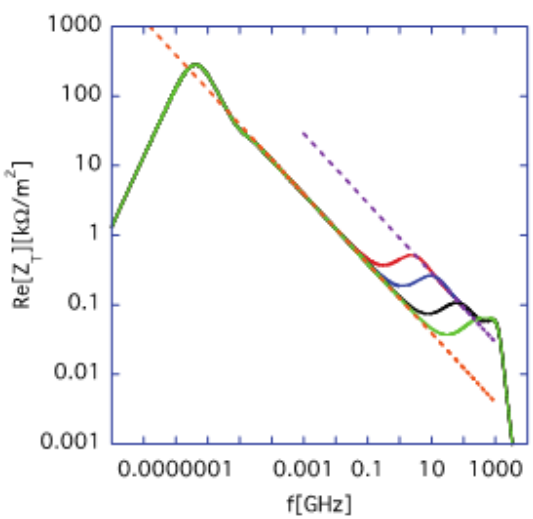
$\epsilon_0 \omega \sim \sigma$ (between ~100GHz and ~1THz)

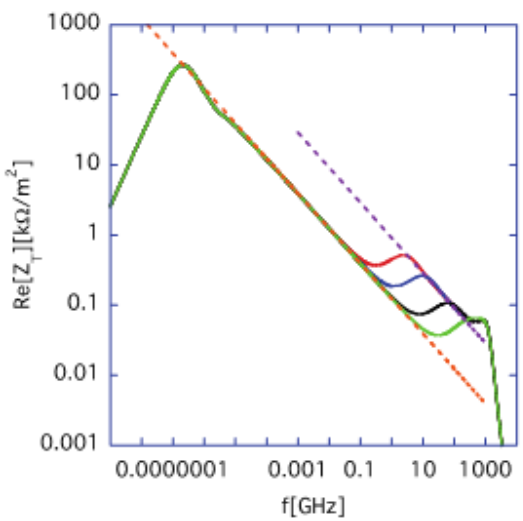
The induction term $\epsilon_0 \partial \vec{E}/\partial t$ becomes comparable to the current density term $\vec{j}$. The skin depth formula is no longer valid.

$\epsilon_0 \omega \gg \sigma$ (above 1THz)

the conductive material behaves almost like vacuum

longitudinal



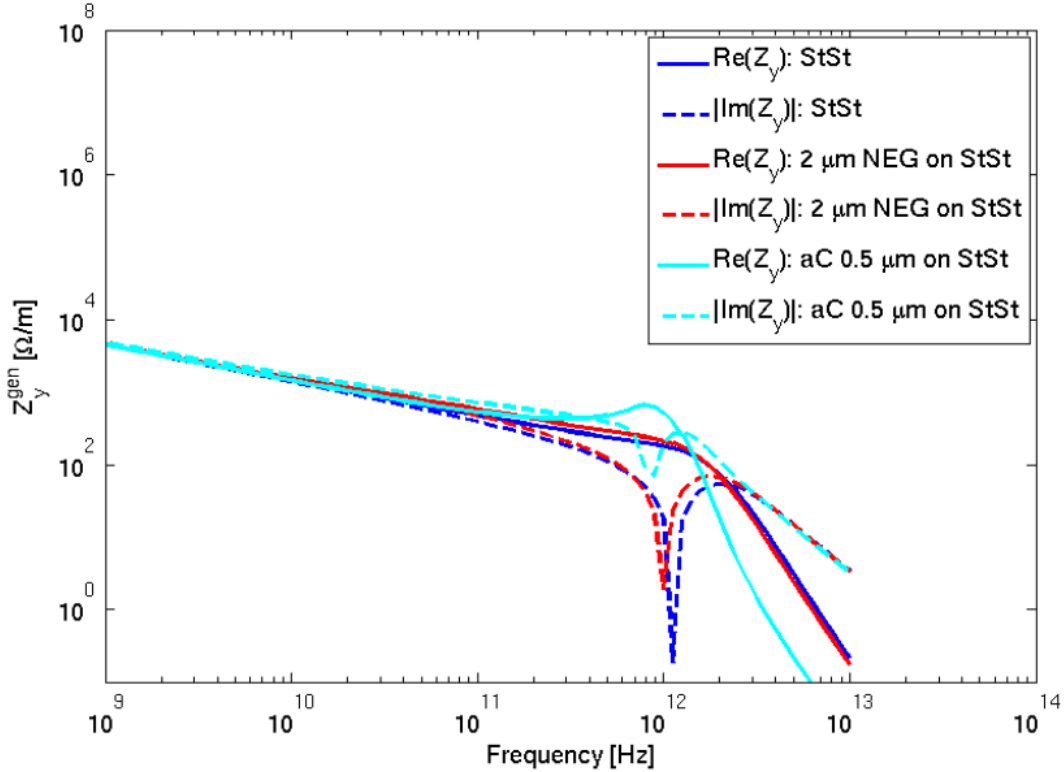


transverse

NEG thickness
Green: 1μm
Black: 2μm
Blue: 5μm
Red: 10 μm

Measurement of NEG impedance (Koukovini-Platia)

Measurements of NEG coating impedance at high frequencies



- Coating is transparent up to 10 GHz
- NEG properties at such high frequencies were still unexplored

At high frequency the contribution of surface roughness and non-uniformity of coating becomes important

Codes: beam dynamics

Multiparticle tracking:

merging single bunch and multi-bunch
parallelisation – high throughput

pyheadtail Fast-ion (Mether see talk Friday) – elegant (APS) – mbtrack (SOLEIL) + local developments (sbtrack at SOLEIL, Diamond, …)

Vlasov (VFP) solvers:

solver developed in different labs (Bessy-II, ANKA, NSLS-II, …)
parallelisation reduced CPU time by factor 150 (Scheonenfield, ANKA)
Multibunch Vlasov solver: SPACE (Bassi)

Discussion on a possible comparison/benchmark of these codes

some work at DLS but not a full benchmark … for discussion!

Activities/Report from facilities

Intense effort in all machines to

- **identify impedance sources and minimise them at the design stage**
- **simulate compute the beam dynamics**
- **benchmark simulation with measurements of beam observables**

Significant improvement in the available observable

- **thanks to progress with beam diagnostics**

Simulations/measurements

Single bunch:

longitudinal: bunch lengthening – phase offsets – energy spread
transverse: TMCI, head tail mode threshold and spactra
with more BBRs, CSR, RW, …

NSLS-II Vlasov solver (Bassi)

at Diamond sbtrack development (Koukovini-Platia: see talk)

CLIC damping ring: damping vs chromaticity (Passarelli)

mostly fitting BBR model to match the measured observable

Simulations/measurements

Multi-bunch:

NSLS-II – code development and analysis of the PETRAIII RF cavities (Bassi)

VSR at BESSY-II
coupled bunch instabilities drivne by HOM in VSR cavities
transient beam loading studies (Ruprecht)

SLS-II operating with negative momentum compaction factor (comparison pyheadtail and mbtrack – Xu see talk)

Simulations/measurements

Single-bunch + Multi-bunch:

multiparticle capabilities presently developed in elegant (Borland) and mbtrack (Nagaoka)

- **Detailed simulations with `elegant` code. Model include:**
  - **Single particle dynamics with higher order chromaticity and momentum compaction factor**
  - **Multi-bunch multi-particle**
  - **Extensive impedance model including resistive chambers, geometrical contributions, resonant cavity modes**
  - **Bunch-by-bunch feedback systems**
  - **Simulating stored beam swap-out fault; filling from zero; …**

Vlasov solver (Bassi)

Vlasov solver for single bunch and multibunch

SPACE: Self-consistent Simulations for Collective Effects

Self-consistent Parallel Tracking Code

SPACE*

(Self-consistent Parallel Algorithm for Collective Effects)

General Features and Capabilities

- Efficient study of short and long-range wakefield effects in 6D phase-space via parallel processing communications.
- Study of slow head-tail effect + coupled-bunch instabilities.
- Passive higher harmonic cavity effects with arbitrary fillings.
- Landau damping from betatron tune spread.
- Microwave instability.
- Efficient methods for density estimation from particles.
- Localized wakefield effects.

* G. Bassi, A. Blednykh and V. Smaluk, "Self-consistent Simulations and Analysis of the Coupled-Bunch Instability for Arbitrary Multi-bunch Configurations", accepted for publication on Phys. Rev ST Acc. Beams.

Report from facilities: DLSR

ESRF (White)

preliminary estimates for future machine. In particular, new vacuum chamber geometry (very small apertures), novel designs of flanges, RF fingers, BPMs, … working toward an complete impedance budget

APS (Lindbergh)

new vacuum components. Constraints dictated by present timing modes at APS that need to be preserved

now 352 MHz (h = 1296) fill pattern has 324 and 48 bunches implications of swap-out on axis injection

effect of high harmonic cavities
effect of longer RF wavelength (e.g. 100 MHz) help with IBS

Report from facilities

Modelling impedance budget

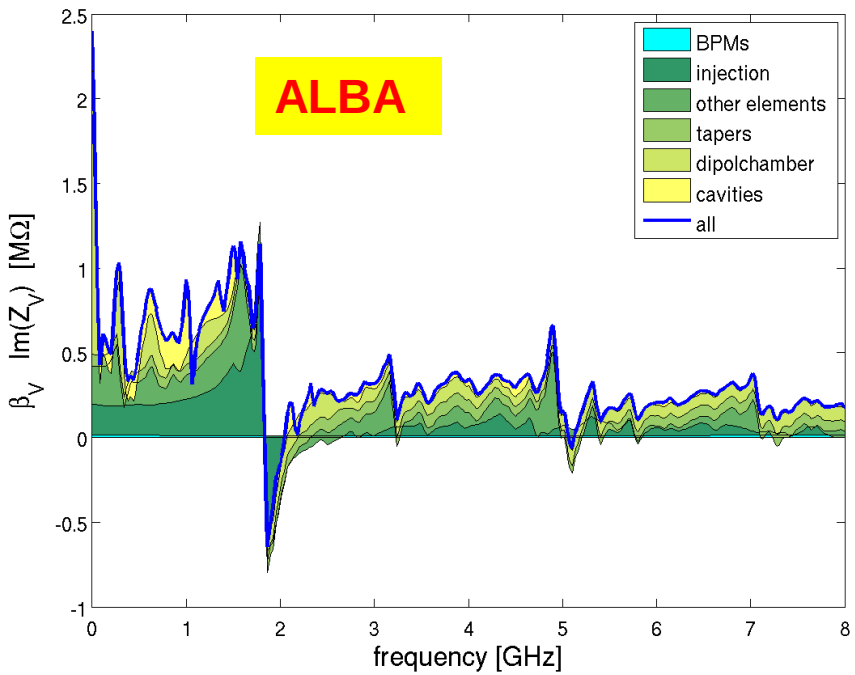
ALBA: (Gunzel) single bunch detuning; revision of the impedance model supported by more refined simulations with gdfidl.

Localisaiton of transverse impedance using t-b-t- data measuring phase advance between BPMs as a function of current (Carla': see talk)

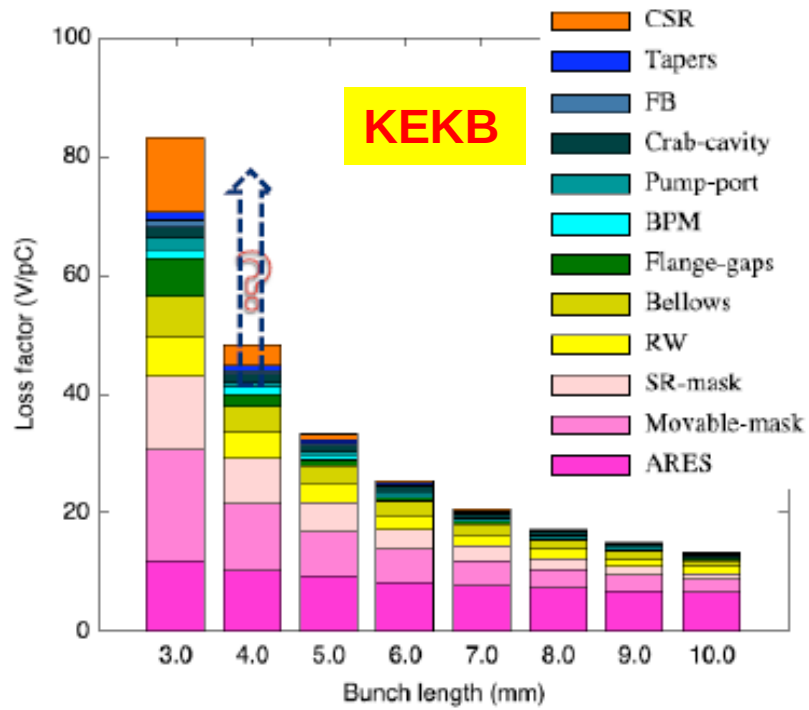
KEKB: (Zhou) impedance model built form single bunch analysis of bunch lengthening and energy spread increase thresholds by fitting BBR parameters;

Impedance model for SuperKEKB: CSR considered a major issue, strong effort in simulations (comparing 5 codes) and analytical approaches

Modelling the impedance budget



Guntzel



Zhou

Facilities report

MAX IV: (Cullinan, Skripka see talk): initial data on bunch lengthening and TMCI thresholds; no single bunch issues;
Multi-bunch instabilitiy at 3 mA: cured by TMBF, chromaticity scans, harmonic cavities

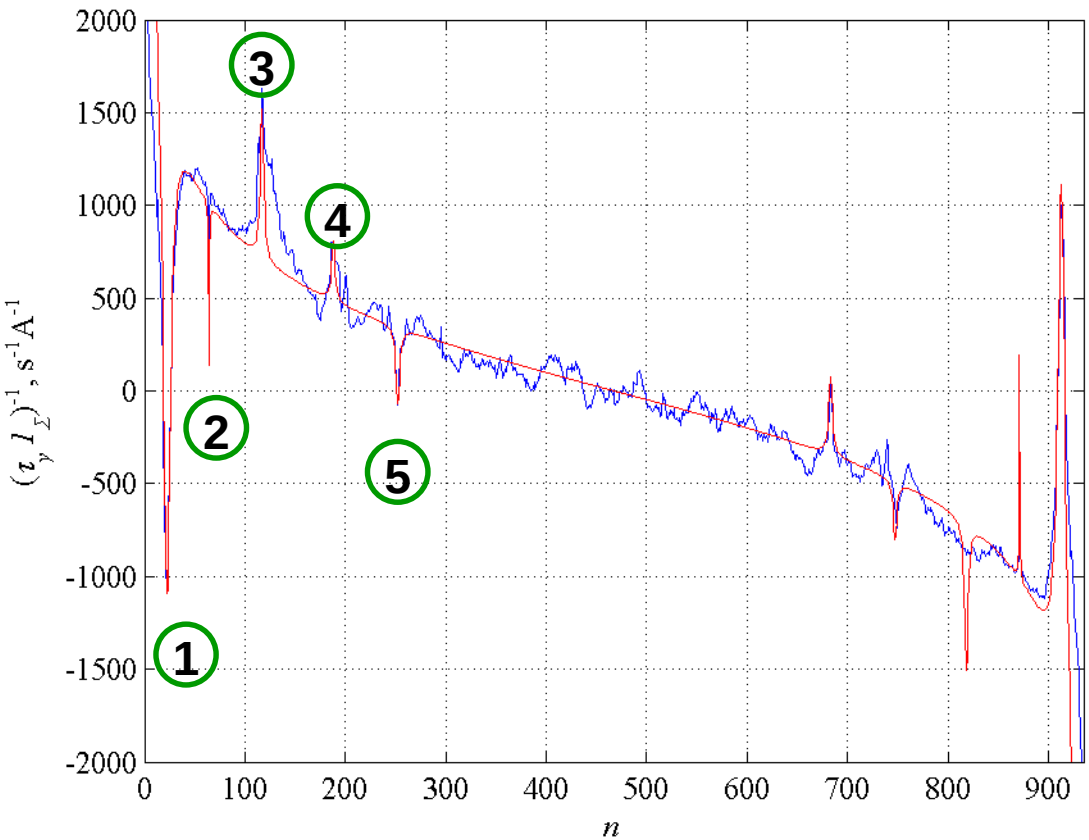
Diamond: (Bartolini) wealth of TMBF data: grow damp experiment and their intepretation

ELETTRA: (Karantzoulis) single bunch tuneshift: significant effects from NEG coating chambers, although difficult to interpret quantitatively. Multibunch cured with temperature control of cavities

SOLEIL: (Nagaoka) 500 mA, half chamber has NEG, TMBF working but also chromaticity and lower voltage are used; beam heating is the most critical issue

Growth rates of vertical coupled bunch modes

Vertical TMBF data (Bartolini)
full fill – zero chromaticity – ID gap open
Radiation damping subtracted
blu measured – red fit



1) V collimators; 3) IDs gap; others not-identified

data suggest resistive wall and few high Q resonators

$$\Delta\Omega_n = -\frac{i}{4\pi}\frac{\omega_0\bar{\beta}}{E/e} I \sum_{p=-\infty}^{\infty} Z_\perp(\omega_{pn}) h(\omega_{pn})$$

$$\omega_{pn} = (pN_b + n + \nu_\beta)\omega_0 \qquad h(\omega) = e^{-\omega^2\sigma^2}$$

$$Z_\perp = Z_\perp^{rw} + \sum Z_\perp^{res}$$

Resistive Wall

β = 12.25 m, b = 13.5 mm,
$\rho = 7.3\cdot10^{-7}\ \Omega\cdot$m

$$\frac{Z_{x,y}^{rw}}{L} = G_{1x,y}\frac{\operatorname{sgn}\omega + i}{\pi b^3}\sqrt{\frac{Z_0 c\rho}{2}}\,|\omega|^{-1/2}$$

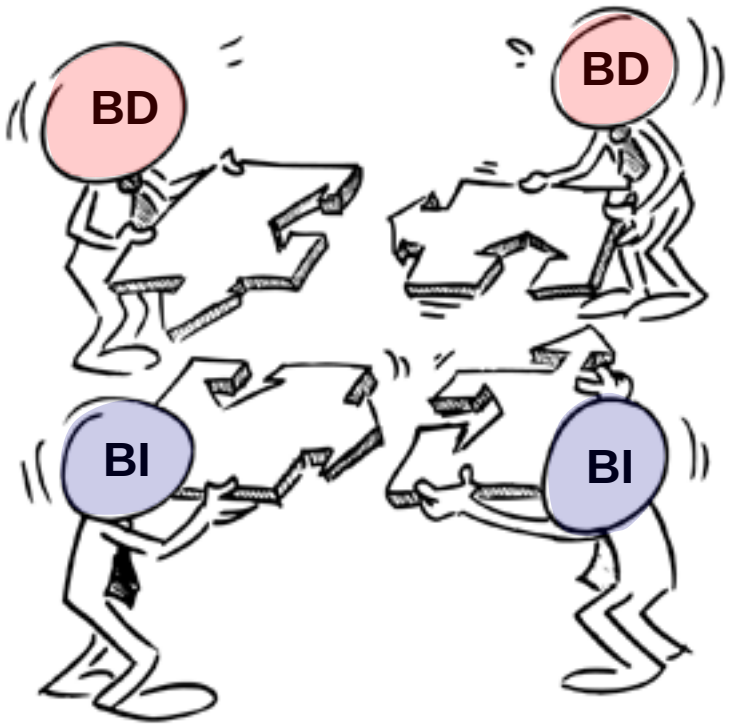
Resonator $$Z_\perp^{res} = \frac{R_s}{\frac{\omega}{\omega_r} + iQ\left(\frac{\omega^2}{\omega_r^2} - 1\right)}$$

Instrumentation

G. Franchetti: summary of "Beam dynamics meets diagnostics" workshop Firenze Nov. 2015

2) Beam instrumentation participants say that it is mandatory clear specification of the feature of the devices required by the beam dynamics colleagues. i.e. what needs measuring

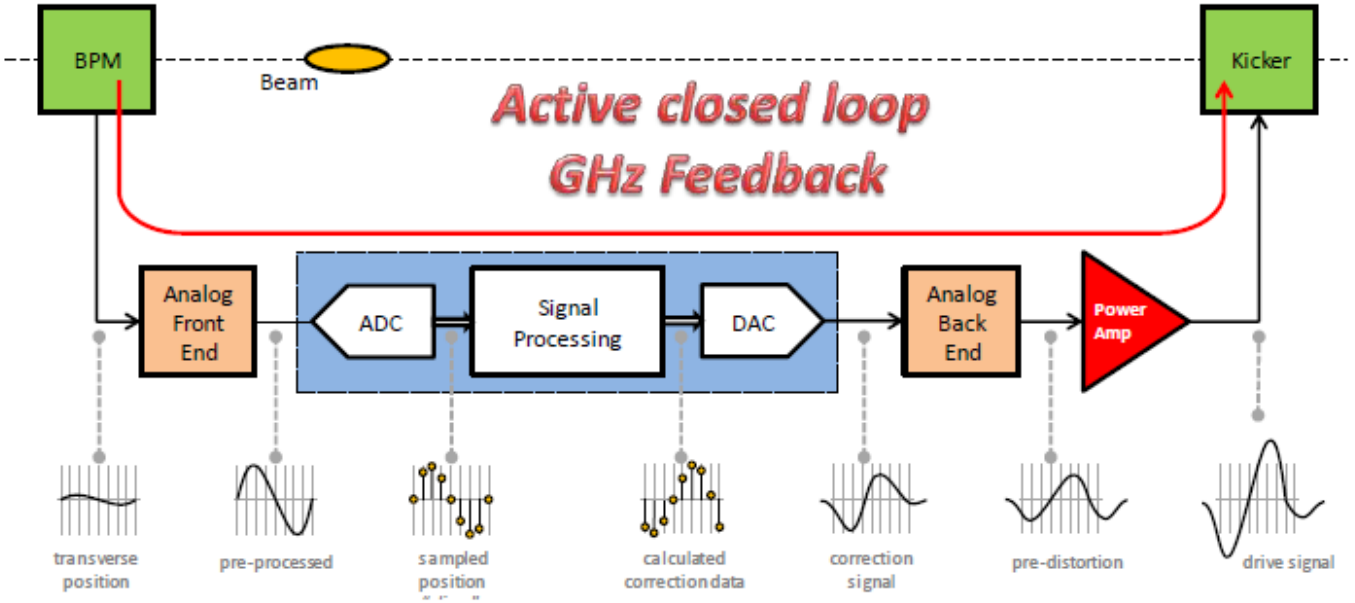
7) It was suggested that the beam dynamics people should be involved with beam diagnostics in the early design of devices to optimize design and be aware of what is possible to measure and what not.



development in instrumentation improves understanding and further improvement of the machine performance

Wide band feedback for intra-bunch motion at SPS (Fox)

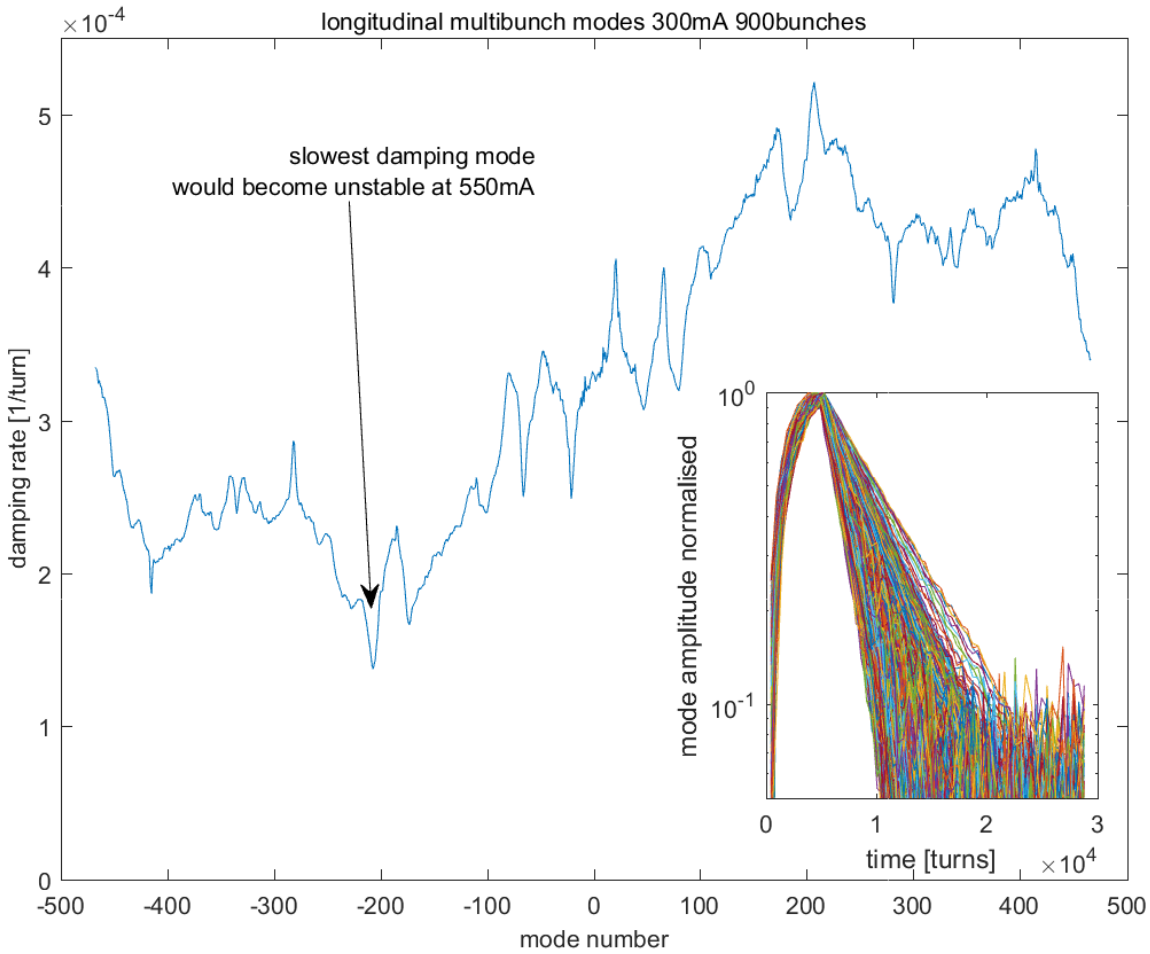
Architecture for a wideband feedback (GHz bandwidth) for intra-bunch control



- Control of Non-linear Dynamics (Intra-bunch)
- GHz Bandwidth Digital Signal Processing - 4 GS/s ADC and DAC
- Optimal Control Formalism - allows formal methods to quantify stability and dynamics, margins
- Research Phase uses numerical simulations (HeadTail), Reduced Models, technology development, Demonstrator System, SPS Machine Measurements
- Demonstrator system 1 - 64 bunches, modest kicker power with 1 GHz bandwidth

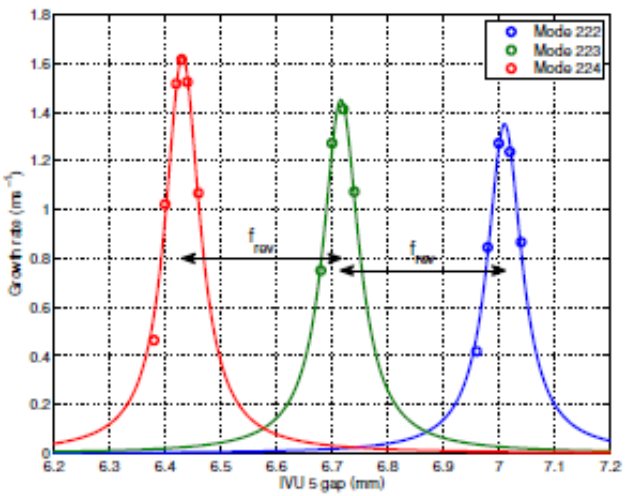
LMBF at Diamond

Longitudinal multibunch feedback: implementation and observation at Diamond (Rehm)



TMBF (IVU gap analysis - Teytelman)

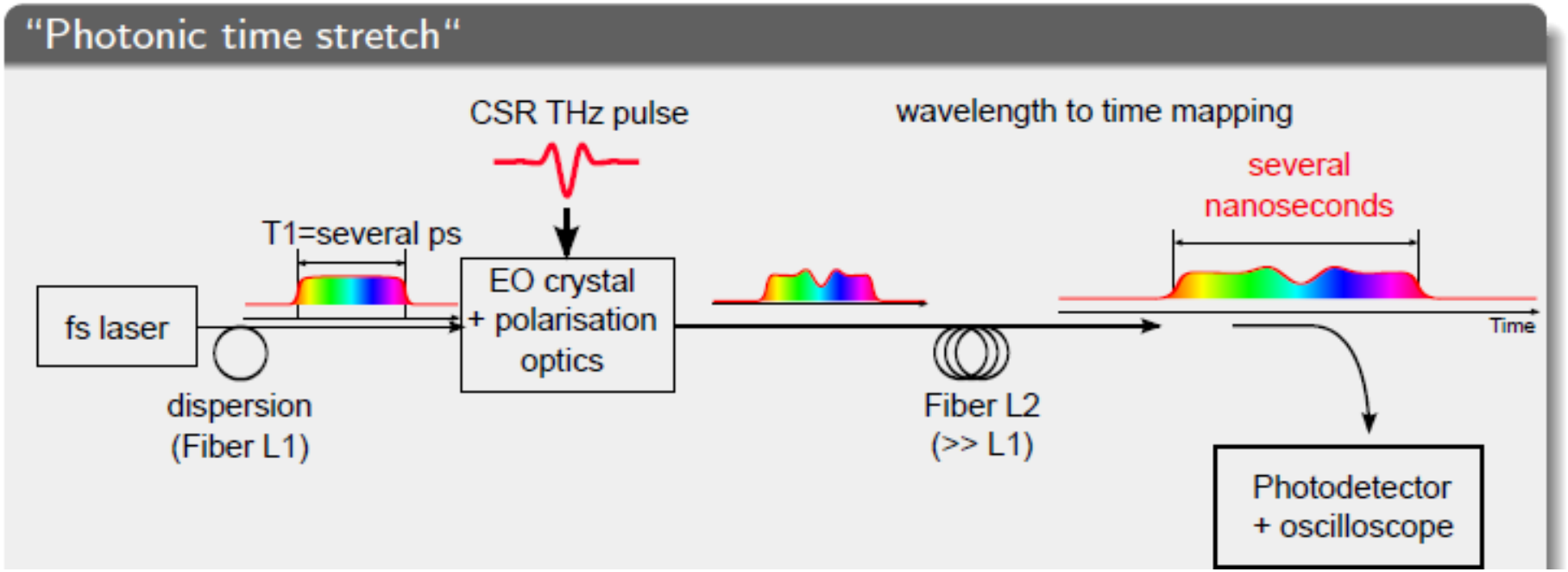
IVU Impedance Conclusions



- HOM frequency seems to change linearly with the gap position:
  - Two revolution harmonic distances are within 3%;
- Tuning sensitivity 4.8 MHz/mm;
- Bandwidth of 76 μm translates to 365 kHz;
- If the HOM is really at 7.3 GHz its Q is 20,000.

Diagnostics for CSR @ SOLEIL and U. Lille

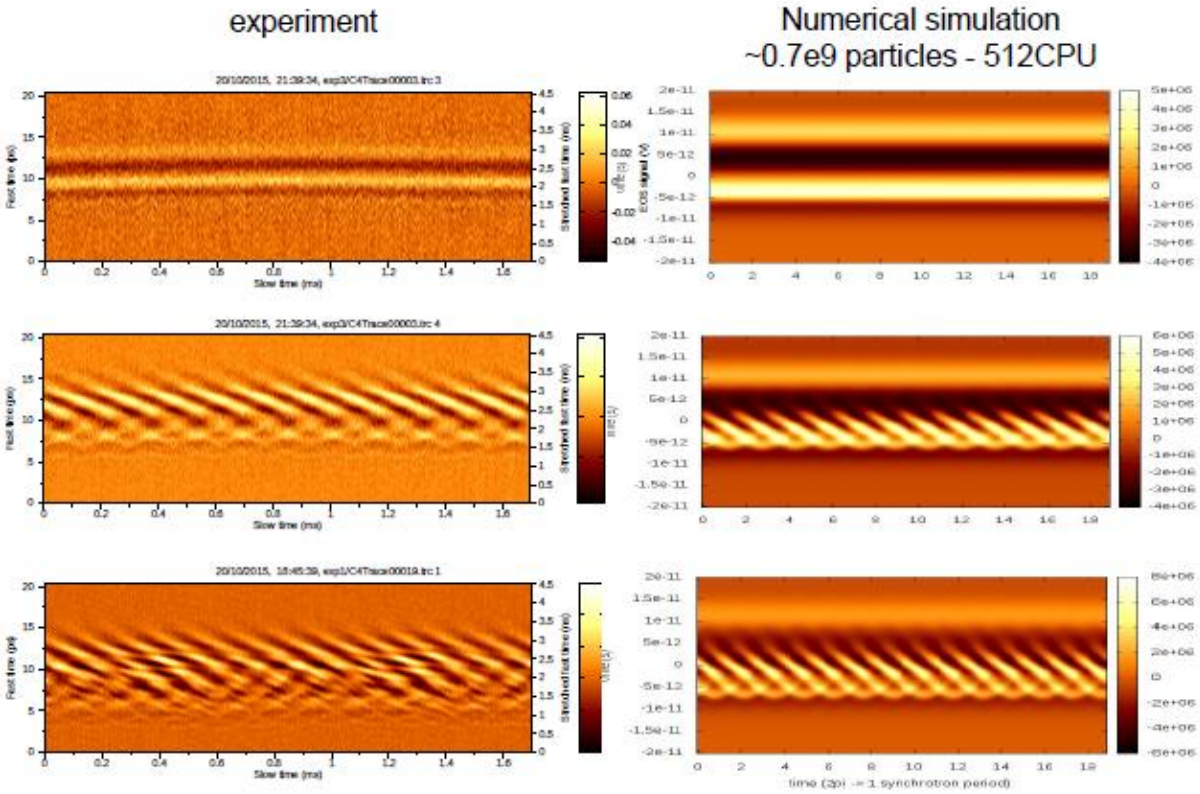
High rep rate pulse profiling with EOS with spectral encoding (aiming at tbt)



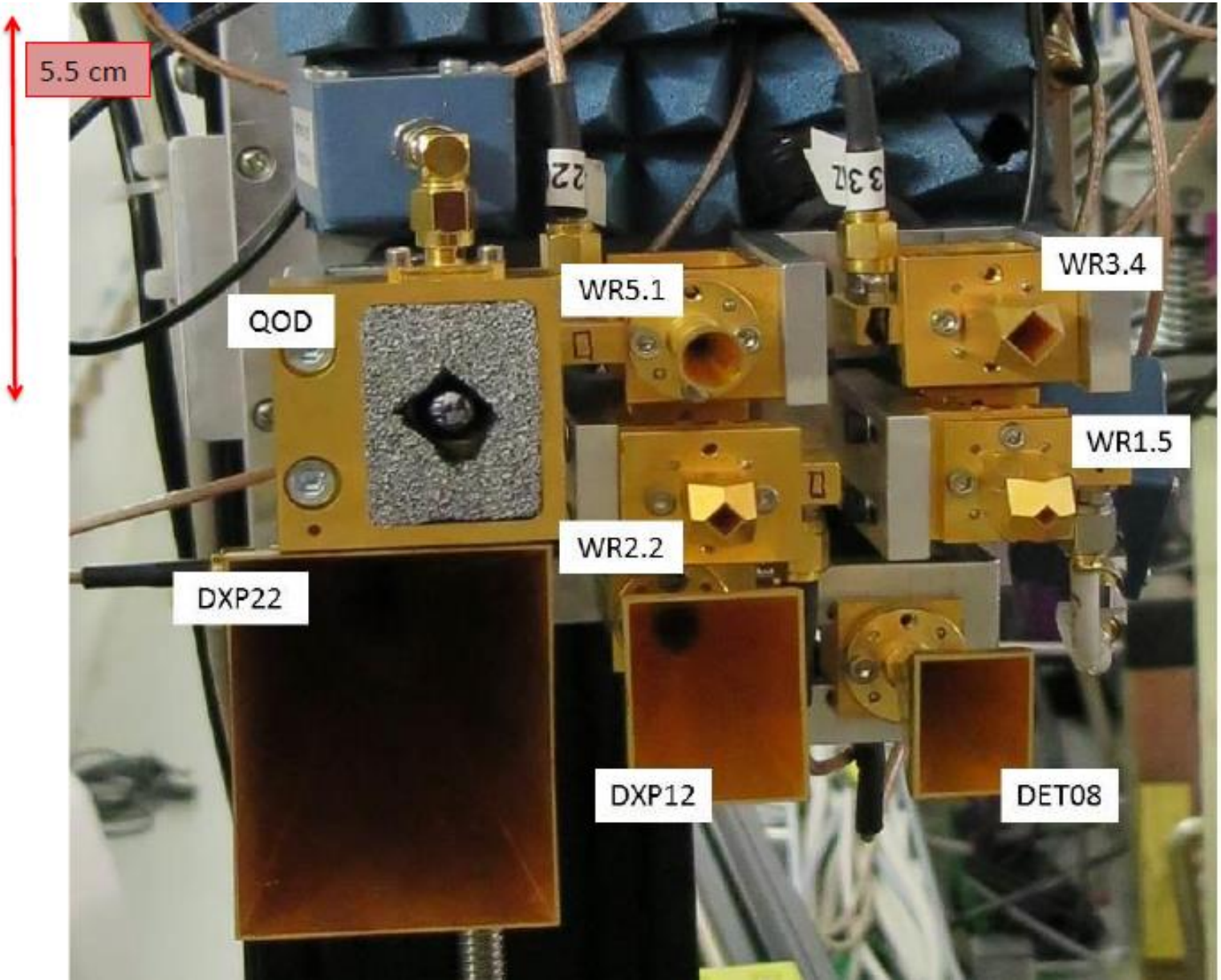
Single shot sub-ps resolution at MHz cycles

Diagnostics for CSR @ SOLEIL and U. Lille

- Wakefield: parallel plates + CSR only [Murphy et al., Part Acc 57, 9 (1997)]
- Parallel Vlasov, and Macroparticle (real number of particles).



Diagnostics for CSR @ Diamond and RHUL



Conclusions

John Adams Institute for Accelerator Science

LER - SOLEIL
Paris, 25th October 2016

diamond

Keynote speaker

Shortly she will be fifty, but she does not look it
Sophie Marceau

ISR-RF/66-35
November 18, 1966

EAM ABOVE TRANSITION, DUE TO
SCONTINUITIES.

ro

on on an ion beam, of a dis-
ance. We still consider the
ficiently small compared with
e considered as concentrated.

John Adams Institute for Accelerator Science

Paris, 25th October 2016

diamond

Conclusions

Open questions (non exhaustive list…)

Challenges for DLSR

low apertures – computation of impedances at high frequency

are IBS and CSR an issue (e.g. in VSR rings)?

CSR beyond threshold

is this relevant for DLSR?

Thank you for your attention !

Mode

characterisation of impedance

Agreement codes + Agreement simulations/measurements

Feedbacks are mandatory

Better diagnostics for measuring tbt-bbb dynamics are key for the understanding of the beam dynamics and the improvrment of the performance of the ring