Impedance Computation and Measurements in Modern Storage Rings

11th EPAC, 23-27 June 2008, Magazzini del Cotone, Genoa

R. Nagaoka, Synchrotron SOLEIL, Gif-sur-Yvette, France

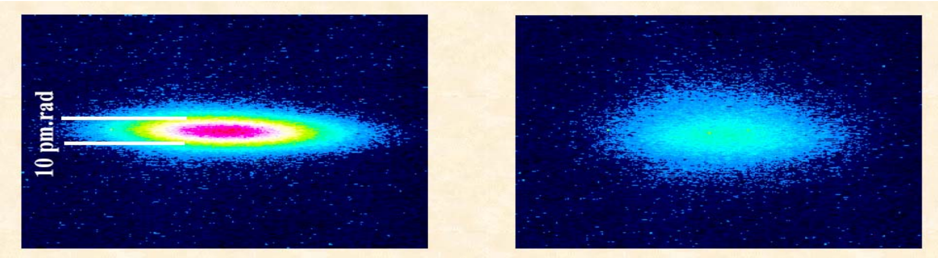
1. Introduction and Outline

Modern accelerators are always pushed for higher beam intensities:

- Light source storage rings…Higher brightness (average/bunch current)
- High energy physics rings (colliders)…Higher luminosity (average/bunch current)
- Linac-based FEL machines…Higher peak brightness (bunch current)

⇨ Stronger beam interactions with self-induced EM fields, i.e. wake fields.

Likely result in beam quality degradation, instability and vacuum components heating.

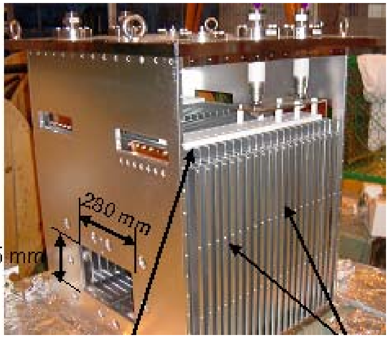


Images taken at the ESRF

Melted RF finger at SOLEIL
Courtesy N. Béchu

10 mm gap chamber at SOLEIL

RCS kicker at J-PARC
Courtesy YH. Chin



Specifically, wake effects (sources) may differ according to the type of machines:

Light source rings: Distributed impedance, tapers, resistive-wall, mm 3D structure, trapped modes, short and long range effects, ….

High energy physics rings: Collimators, kickers, metallic coated ceramic chambers, short and long-range effects, very low frequency wakes, ….

Linac-based FELs: Sub-mm bunches, collimators, long accelerating cavities, resistive-wall, surface roughness, high frequency wakes, CSR, ….

LHC graphite collimator

TESLA 9-cell cavity

Confronted impedance issues become the driving force to advance studies and developments in the related areas:

1) Time domain numerical wake field computations
2) Analytical wake field studies (geometric and resistive-wall)
3) Simulation of collective beam dynamics
4) Measurement of impedance (beam-based, bench)

whose outcomes are often appreciated in other types of machines.

In the following, we shall overview the progress in the areas above, and also see

5) Comparison made between measurement and expectation in some of the modern storage rings including those recently commissioned.

2. Time domain numerical geometric wake field computations

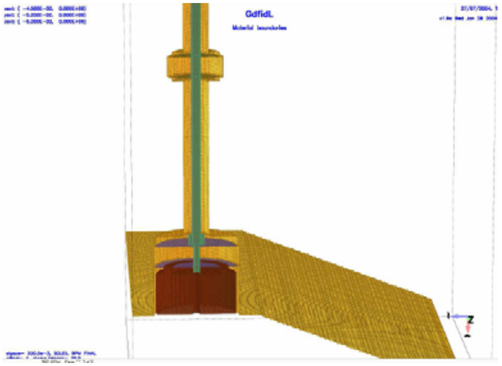
Wake fields in a general structure may be most accurately obtained via numerical solution of Maxwell's equations.

⇨ Since '80s, the first 2D and 3D codes were developed.

TBCI, *MAFIA*, *ABCI*, *NOVO*, *XWAKE*, ….

Newer rings since '90s, having flat chambers and shorter bunches, demand more powerful computation.

Smaller mesh & longer integration time
→ Larger memory and cpu time



A quarter of a BPM chamber (SOLEIL)

Linac-based FEL machines require wakes of even shorter bunches (< mm) over longer structures.

⇨ Major breakthroughs are being made, which are beneficial for storage rings.

- Parallelisation

Using a cluster of cpu's, wake computations are parallelised in several codes.

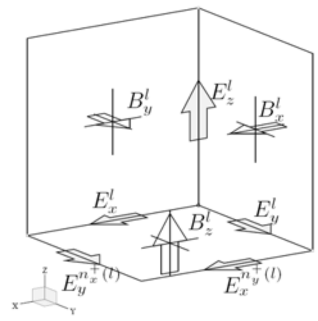
GdfidL: W. Bruns, Linac02.

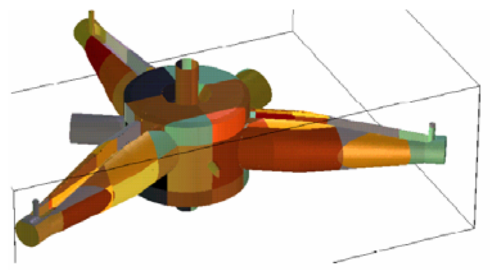
3D TDBEM: K. Fujita, H. Kawaguchi, I. Zagorodnov, T. Weiland, EPAC04.

PBCI: E. Gjonaj, X. Dong, H. Hampel, M. Karkkainen, T. Lau, WFO. Muller, T. Weiland, ICAP06.

<u>Scheme developed in GdfidL:</u>

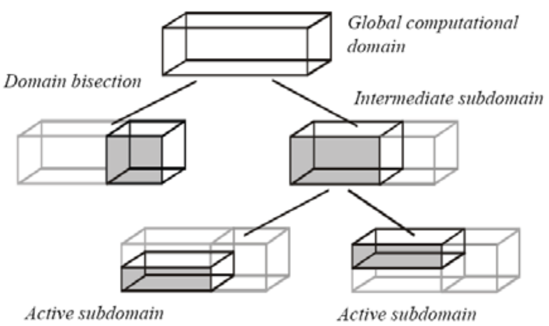
- *Linked lists* allows reducing the computational volume to non-conducting materials.
- Division into many sub-volumes leaves only a small non-conducting volume, which is distributed to different cpu's.





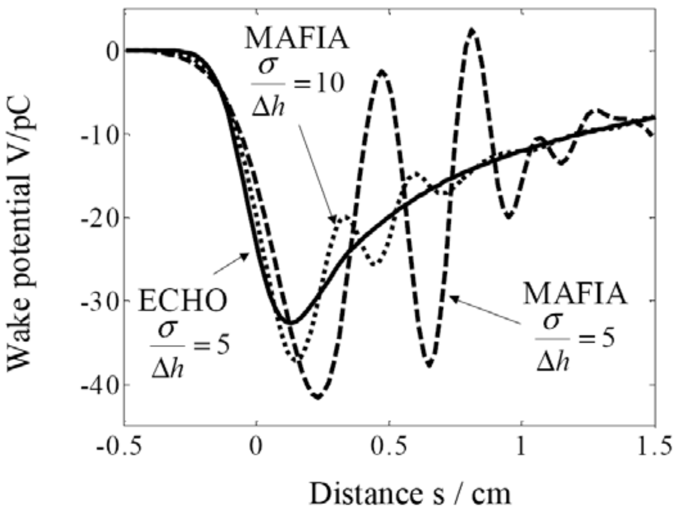
<u>Scheme developed in PBCI:</u>

- Geometric decomposition (recursive orthogonal bisection) of the computational volume with a load balancing scheme.



- Dispersion-free transformation/Moving-mesh

Solution of EM fields via FDTD creates numerical grid dispersion errors.



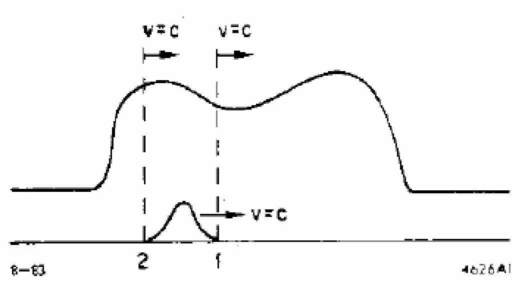
Several dispersion-free schemes, compatible with parallelisation (i.e. *explicit* integration), are developed.

Mesh rotation: R. Hampel, I. Zagorodnov, T. Weiland, EPAC04.

Split-Operator: E. Gjonaj, X. Dong, H. Hampel, M. Karkkainen, T. Lau, WFO. Muller, T. Weiland, ICAP06

TDBEM: K. Fujita, R. Hampel, WFO. Muller, T. Weiland, H. Kawaguchi, S. Tomioka, T. Enoto, PAC07

Dispersion-free condition allows employing "moving mesh" that greatly reduces the memory and cpu time.



K. Bane, T. Weiland, SLAC-PUB-3173

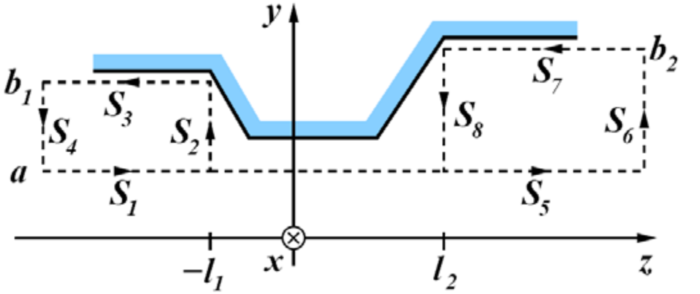
- Generalisation of Napoly integration to 3D structures

It requires wake fields to catch up relativistic bunches long after discontinuity.

⇨ Ways to evaluate the infinite integration along the beam pipe in 3D structures have recently been developed:

Time domain approach: H. Henke, W. Bruns, EPAC06.

Integration of TM and TEM fields along the contours

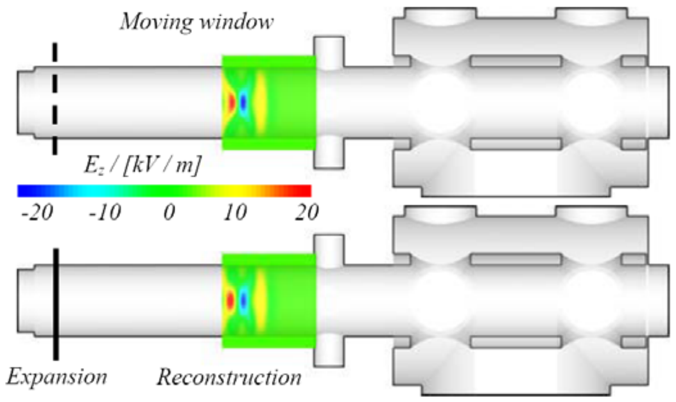


Frequency domain approach:

I. Zagorodnov, PRSTA 9, 102002 (2006).

E. Gjonaj, X. Dong, H. Hampel, M. Karkkainen, T. Lau, WFO. Muller, T. Weiland, ICAP06

2D eigenmode decomposition at a given longitudial position



3. Analytical Wake Field Studies

• Improved taper impedance models in the inductive regime

B. Podobedov, S. Krinsky, EPAC06; B. Podobedov, I. Zagorodnov, PAC07; B. Podobedov, S. Krinsky, PRSTA **9**, 054401

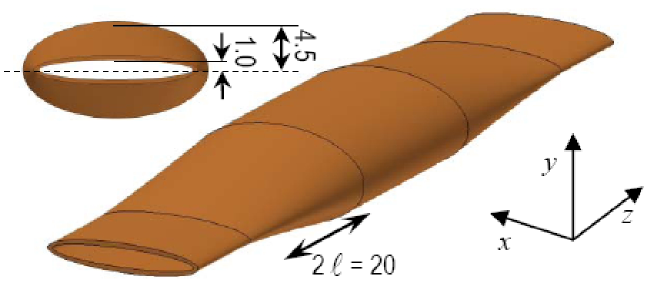
- Higher-order expansion w.r.t. previous works (Yokoya and Stupakov).

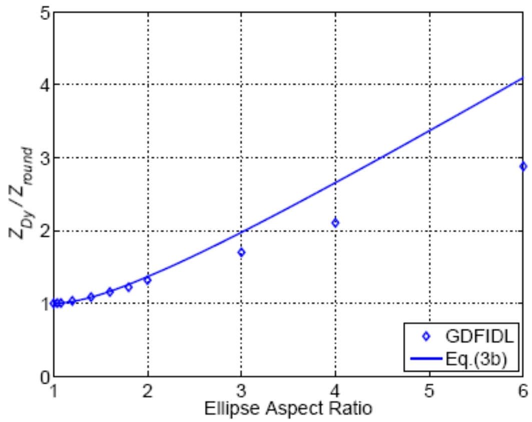
- Application to elliptic cross section.

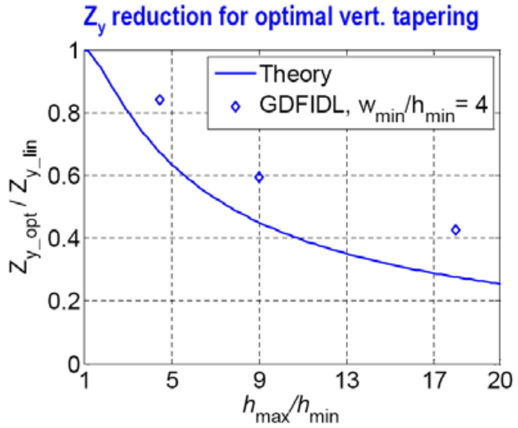
- Distinction of dipolar and quadrupolar contributions.

- Comparison with numerical methods (*ABCI*, *GdfidL*, *ECHO*)
  → Good agreement

- Substantial reduction (more than a factor of 2) achieved by nonlinear tapering.





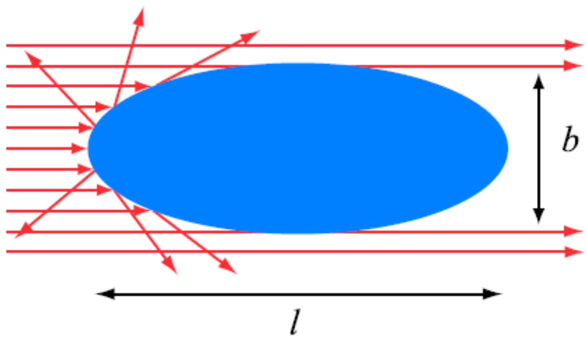


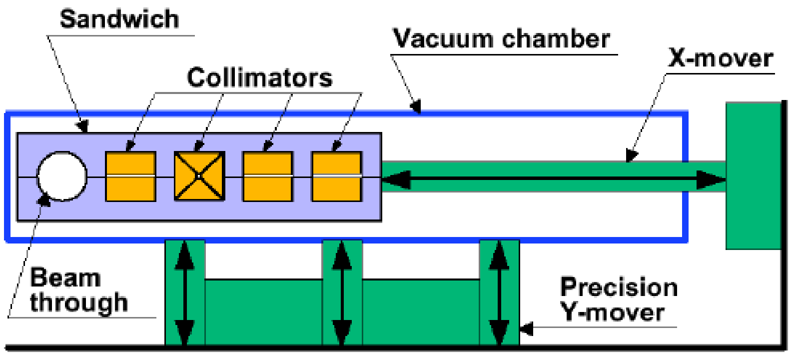
• Optical approximation and its application to collimators

G. Stupakov, KLF. Bane, I. Zagorodnov, PRSTA **10**, 054401; KLF. Bane, G. Stupakov, I. Zagorodnov, PRSTA **10**, 074401

- For sub-mm bunches, numerical methods would not be practical.

- When $\sigma_z << b$ and $l << b^2/\sigma_z$, diffraction becomes small.





- Experimental studies of geometric wake dominated collimators at SLAC.

P. Tenenbaum, KLF. Bane, L. Eriksson, J. Irwin, RK. Jobe, D. McCormick, CK. Ng, TO. Raubenheimer, MC. Ross, G. Stupakov, D. Walz, PRSTA **10**, 034401

- Precise deflection measurement and comparison with theoretical & numerical kick factors (*MAFIA, ECHO*) → Fairly good agreement

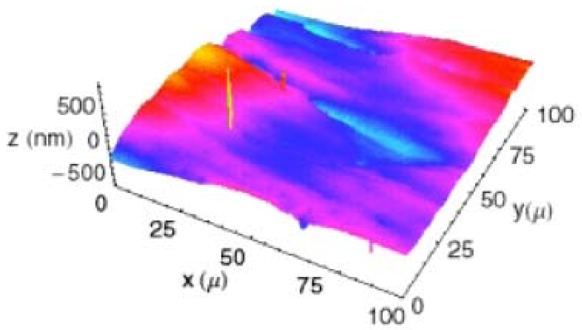
• Surface roughness impedance

- Collection of uncorrelated bumps on the smooth surface.
  KLF. Bane, CK. Ng, AW. Chao, PAC97

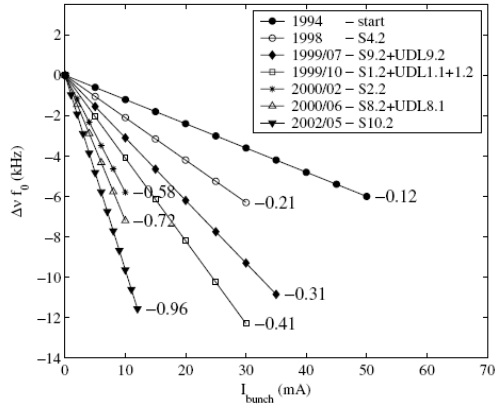
- Correlated bumps in the small angle approximation + measurement.
  G. Stupakov, RE. Thomson, D. Walz, R. Carr, PRSTA **2**, 060701

- Excitation of resonant modes in periodically corrugated pipes.
  A. Novokhatski, A. Mosnier, PAC97

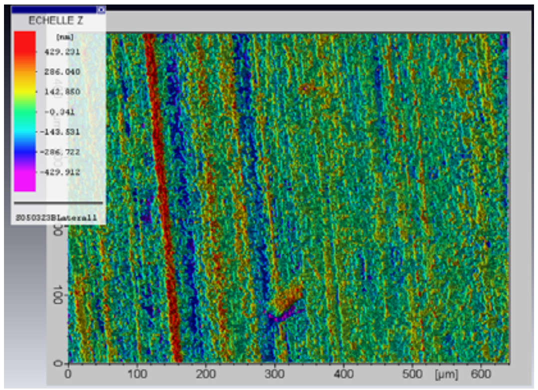
cf) A talk by KLF. Bane at EPAC04



*G. Stupakov et al. PRSTA **2**, 060701*



*E. Karantzoulis, V. Smaluk, L. Tosi, PRSTA **6**, 030703*



Measured surface roughness of a NEG coated Al chamber at SOLEIL..
Courtesy M. Thomasset Optics group

cf. At SOLEIL, NEG coating (~50% of the ring) thickness was reduced (1 → 0.5 μm).

• Studies of resistive-wall (RW) wakes beyond the classical regime.

Classical formulae

$$Z_\perp(\omega) = (1-i)\frac{R}{b^3}\sqrt{\frac{2cZ_0\rho}{\omega}}$$

$$W_\perp(t) = \frac{2R}{b^3}\sqrt{\frac{cZ_0\rho}{\pi}}\frac{1}{t^{1/2}}$$

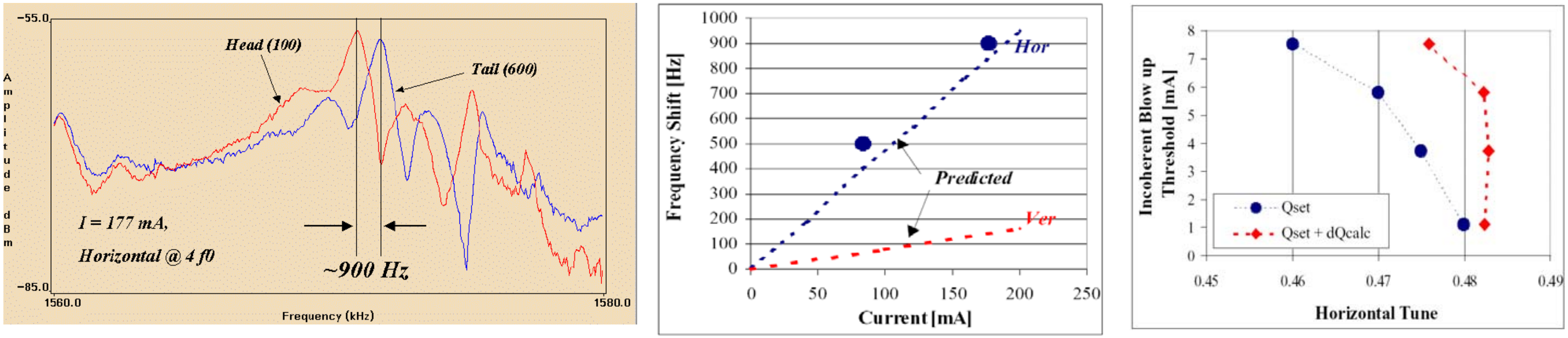
- General multi-layered impedance formulae for circular and flat beam pipes.

  A. Burov, V. Lebedev, EPAC02

- Incoherent tune shifts due to non-circular RW beam pipes.

  A. Chao, S. Heifets, B. Zotter, PRSTA **5**, 111001

Measured incoherent tune shifts in multibunch & single bunch at the ESRF:



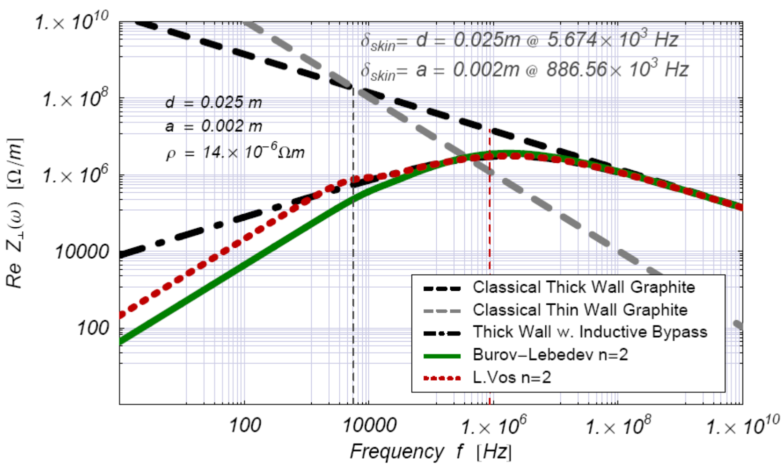
R. Nagaoka, JL. Revol, P. Kuske, EPAC02

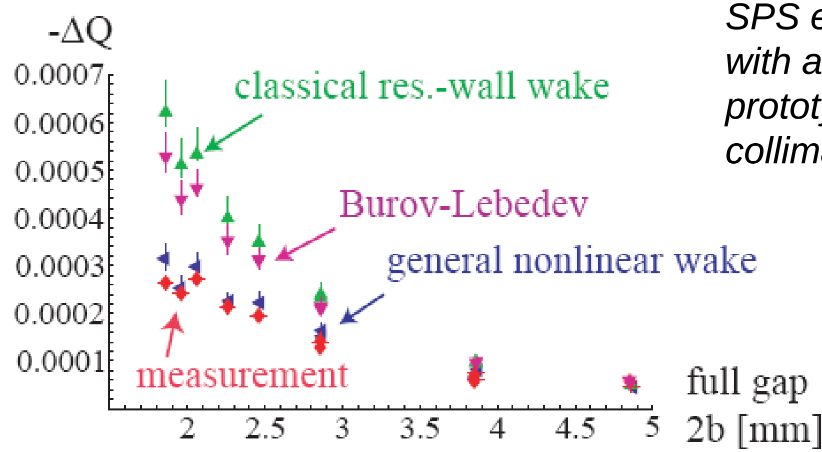
- RW impedance of collimators: … “*Revealing a new physical regime*”

A. Koschik, F. Caspers, E. Métral, L. Vos, B. Zotter, EPAC04**;** **E. Métral**, B. Zotter, B. Salvant, PAC07**;** **E. Métral**, G. Arduini, R. Assmann, A. Boccardi, T. Bohl, F. Caspers, M. Gasior, OR. Jones, KK. Kasinski, T. Kroyer, S. Redaelli, G. Robert-Demolaize, G. Rumolo, R. Steinhagen, T. Weiler, F. Zimmermann, C. Bracco, B. Salvant, F. Roncarolo, PAC07

- Skin depth δ < wall thickness, but the classical model does not apply.
- When δ >> *a* (pipe radius), the effective aperture a_{eff} >> *a*.

→ Re$Z_\perp$ becomes ~2 orders of magnitude smaller at the 1st betatron line.





SPS experiment with a LHC prototype collimator

- Coherent and incoherent tune shifts induced by nonlinear wakes.

F. Zimmermann, G. Arduini, R. Assmann, H. Burkhard, F. Caspers, M. Gasior, R. Jones, T. Kroyer, E. Métral, S. Redaelli, G. Robert-Demolaize, F. Roncarolo, G. Rumolo, R. Steinhagen, J. Wenninger, PAC07

3. Simulation of collective beam dynamics

• Use of more realistic impedance models

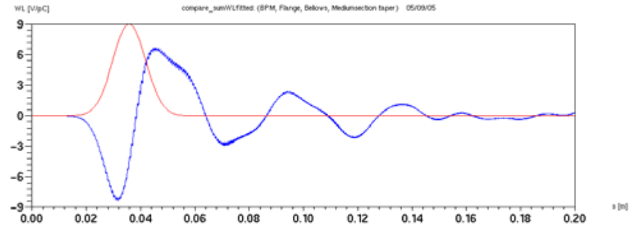
- Direct use of wake potentials numerically obtained (*GdfidL*) for short bunches with (parallelised) *elegant*: YC. Chae (APS), PAC07

- 2D and 3D *MAFIA* results fitted to analytical impedance models (inductive, resistance, cavitylike) in *CISR* and *SISR*: T. Nakamura (SPring-8), EPAC96

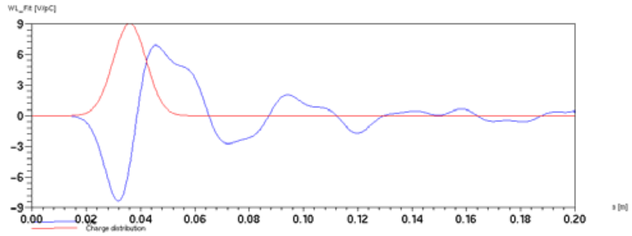
- Use of collimator wake function and outputs of *ECLOUD* in *HEADTAIL*: G. Rumolo, E. Métral (CERN), ICAP06

- Decomposition of *GdfidL* outputs into analytical impedance models, use of short range RW wake function in *rwmbi*, *sbtrack*, *mbtrack*: R. Nagaoka (SOLEIL), EPAC06

Original wake potential



Reconstructed



Name	s1 [m]	s2 [m]	a0 [mm]	b0 [mm]	d0 [mm]	rho [ohm*m]	shape	surface	dW/dy	r	keffs [m-2]	<betaH> [m]	<betaV> [m]
IDLD_S1	0.000	5.434	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	11.06	9.23
STND_S1.1	5.434	5.864	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	13.25	11.99
BPM_S1.1	5.864	6.064	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	13.55	12.38
STND_S1.2	6.064	7.234	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	20.18	9.38
BPM_S1.2	7.234	7.434	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	23.10	7.33
STND_S1.3	7.434	8.948	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	9.79	11.85
SOUF_S1.1	8.948	9.089	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	2.58	14.30
BEND_S1.1	9.089	10.677	35.000	12.500	2.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	0.94	15.90
STND_S1.4	10.677	11.147	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	3.17	16.55
BPM_S1.3	11.147	11.347	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	6.22	13.35
STND_S1.5	11.347	12.413	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	13.91	7.91
BPM_S1.4	12.413	12.613	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	16.71	6.44
STND_S1.6	12.613	13.679	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	14.48	7.55
BPM_S1.5	13.679	13.879	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	7.05	12.49
STND_S1.7	13.879	14.453	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	3.35	16.29
SOUF_S1.2	14.453	14.594	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	1.45	17.03
BEND_S1.2	14.594	16.182	35.000	12.500	2.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	1.08	15.60
STND_S1.8	16.182	17.042	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	7.26	11.29
BPM_S1.6	17.042	17.242	42.000	12.500	17.000	1.00e-06	elli	NoCo	2.17e-01	1.00	1.00e-06	15.00	6.61
STND_S1.9	17.242	18.412	35.000	12.500	2.000	2.80e-08	elli	Coat	3.63e-02	1.00	4.18e-07	13.67	6.70

RW machine file

• Inclusion of different sources of instability, short & long range forces

- BBR, RW, space charge, electron cloud, dipole & quadrupole wake fields in *HEADTAIL*:
  G. Rumolo, E. Métral, ICAP06

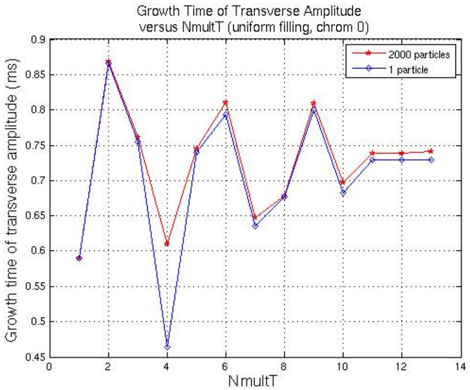
- Wake fields, space charge, CSR, IBS in elegant:
  M. Borland, APS Light Source Note LS-287, 2000

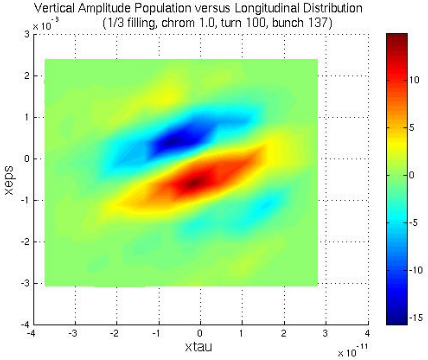
- Space charge, wake fields in ORBIT, *TRANFT* and *SIMPSONS*:
  V. Danilov, J. Galambos, J. Holmes, PAC01
  M. Blaskiewicz, BNL-77074-2006-IR (2006)
  Y. Shobuda, F. Noda, S. Machida, YH. Chin, K. Takata, T. Toyama, EPAC06

- Multibunch tracking code *MULTI-TRISIM* to simulate RW-induced coupled-bunch instability in high energy proton rings: A. Koschik (CERN), EPAC04

- Simultaneous treatment of single and multibunch effects in *mbtrack*:
  R. Nagaoka (SOLEIL), EPAC06

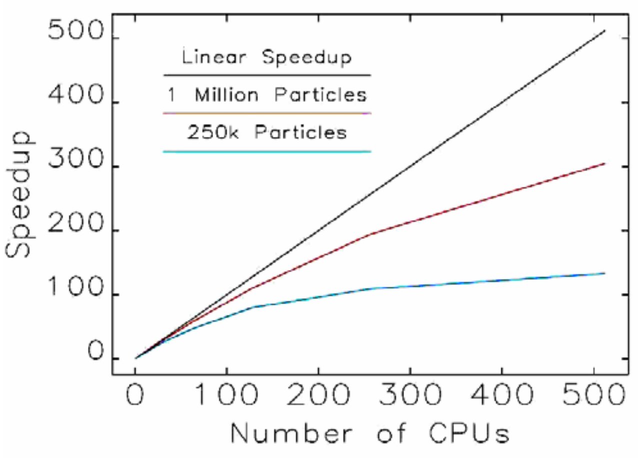
Growth time versus multi-turn field (mbtrack)





Bunch internal motion (mbtrack)

• Parallelisation, FFT convolution



- *Pelegant* (parallel version of *elegant*) processes single particles in parallel. For collective effects, higher efficiency as $N_{particle}$ increases.

  Y. Wang, M. Borland, PAC07

- In *mbtrack*, each bunch (comprising many macroparticles) is processed by a processor. The *master* distributes information on other bunches to compute inter-bunch forces.

  R. Nagaoka (SOLEIL), EPAC06

- Inverse FFT to reduce the $O(N_{particle}^2)$ dependence of wake (space charge) potential convolutions.

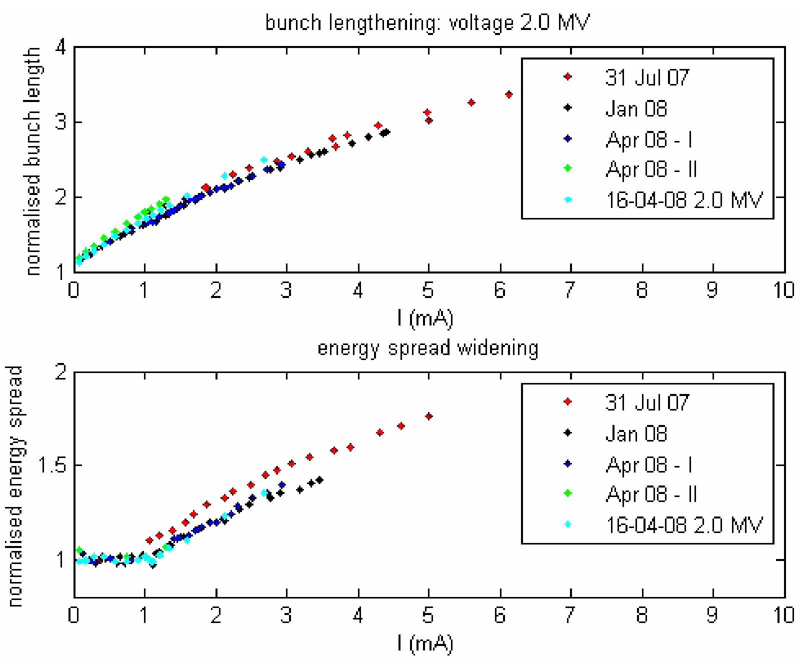
• Efforts of benchmarking different instability codes

cf) Summary found in "Accelerator code WEB repository", F. Zimmermann et al., EPAC06

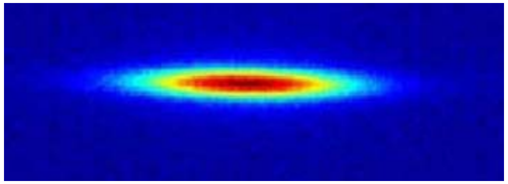
5. Measurement of Impedance and Instability in Storage Rings

• Global impedance measurement

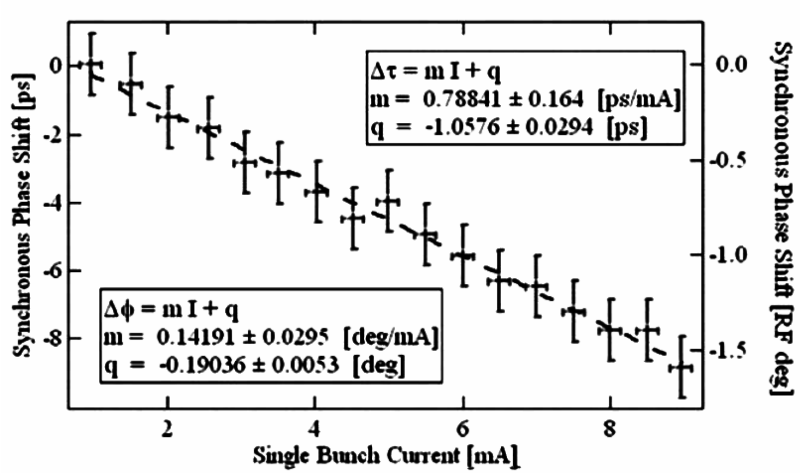
- Instability threshold current
- Coherent tune shift (detuning)
- Bunch length, energy spread, loss factor (synchronous phase shift)



Courtesy R. Bartolini, DIAMOND



X-ray pinhole image (SOLEIL)



Synchronous phase shift measured with a streak camera in the Australian Synchrotron.

R. Dowd, M. Boland, G. LeBlanc, M. Spencer, Y. Tan, PAC07

• Local impedance measurement

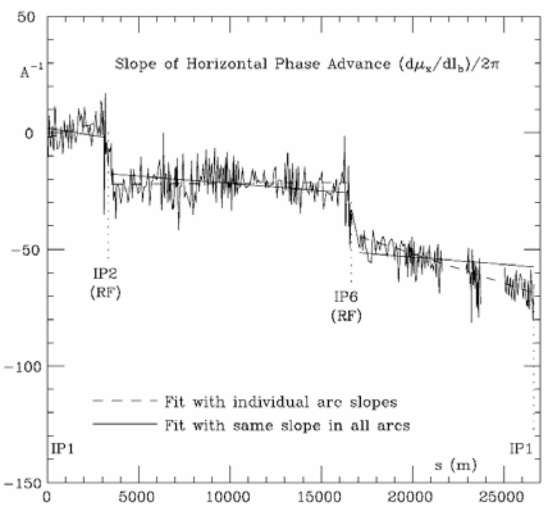
- Transverse (inductive) impedance behaves like a *pseudo defocusing quadrupole*, allowing it to be measured locally.

$$K \cdot l = -\frac{IT_0}{2\sqrt{\pi}\sigma_\tau E/e}\,\mathrm{Im}(Z_\perp)_{eff} \quad [\mathrm{m}^{-1}]$$

$$\theta = (K \cdot l) \cdot y_0 \quad (y_0\text{: offset})$$

NB: - Information on the effective imaginary part.
- For flat chambers, complications due to incoherent (de)focusing.

• Use of turn by turn BPMs



- Early measurement in LEP (CERN):

D. Brandt, P. Castro, K. Cornelis, A. Hofmann, G. Morpurgo, GL. Sabbi, J. Wenninger, B. Zotter, PAC95

At each BPM;
- Deduce betatron phase $\mu(I)$ using turn/turn data.
- Then fit the slope $d\mu/dI$.

→ Large contribution of RF cavities were confirmed.

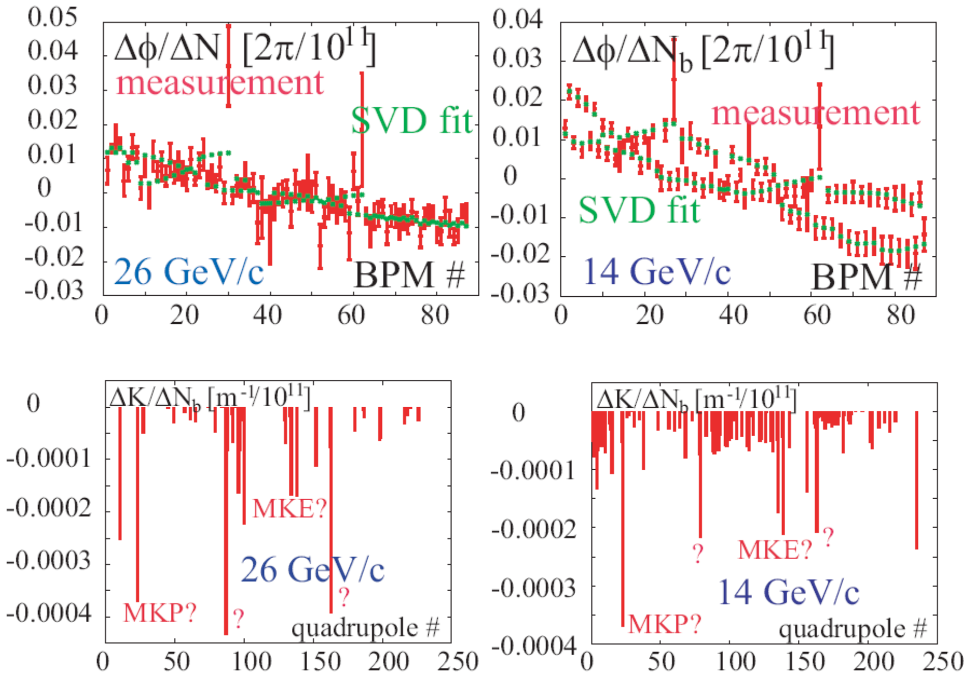
- Recent measurements in SPS (CERN):

G. Arduini, C. Carli, F. Zimmermann, EPAC04

To increase precision, focusing strengths fitted to reproduce the measured phase distortion (beating) $\Delta\phi$ w.r.t. model optics.

$$\Delta\vec{\phi} = M \cdot \Delta\vec{K}$$

Solution via e.g. SVD



→ Obtained solutions;

- Well reproduced measured phase slopes.

- Exhibited several large peaks including those that appear to represent kickers.

• Measurement of deflection using local orbit bumps

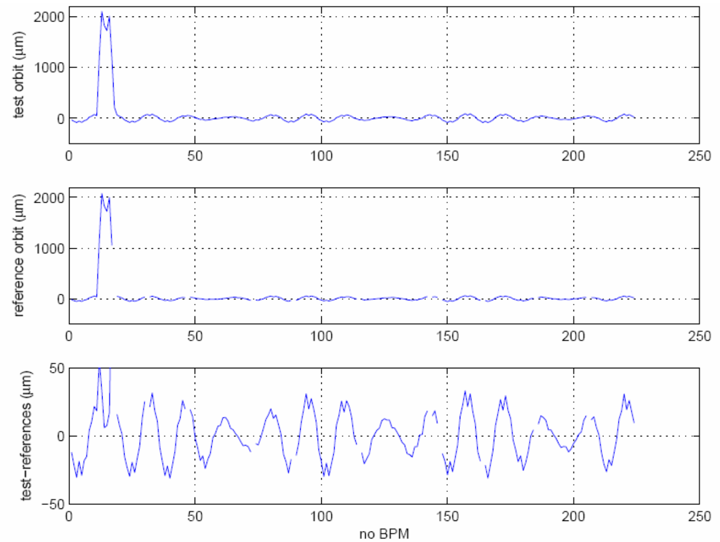
- Originally applied at APS and BINP around the same time

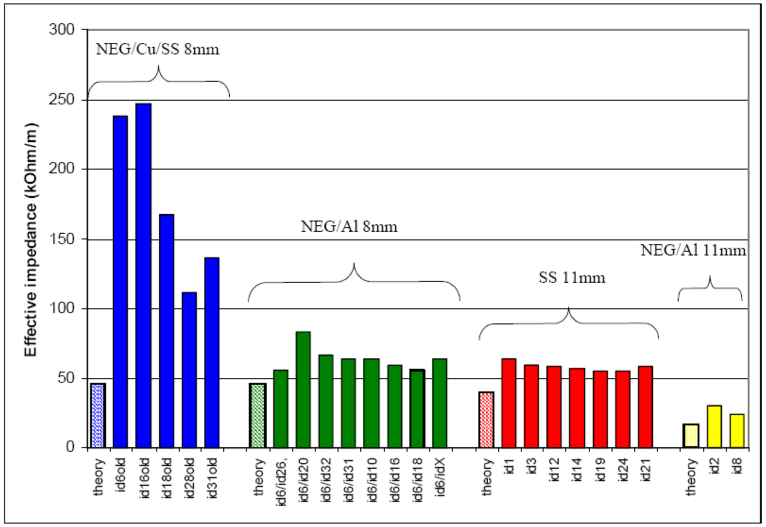
  L. Emery, G. Decker, J. Galayda, PAC01

  VA. Kiselev, V. Smaluk, V. Zorin, PAC01

- Extensive measurement performed at the ESRF

  T. Perron, L. Farvacque, E. Plouviez, EPAC04; T. Perron, dissertation, ESRF, 2005





- Measurement error (fluctuation) ~10 kΩ/m.
- Extension made to global measurements with non-localised bumps.
- Accelerated replacement of abnormally high impedance chambers (NEG coated S.S.).

• Measurement of focusing strengths via orbit response matrix

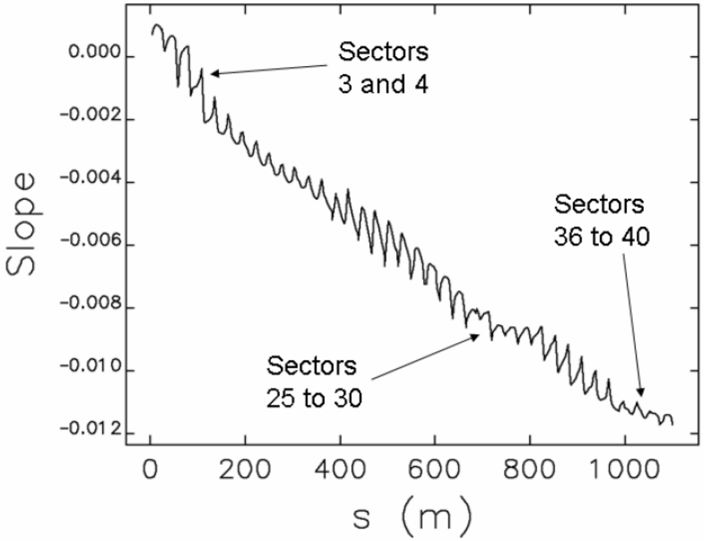
- Successful application at APS

V. Sajaev, ICFA Beam Dynamics News Letter, Dec07; V. Sajaev, PAC03

- Phase distortion fit using normal quads.

- Derivation of $d\mu/dI(s)$.

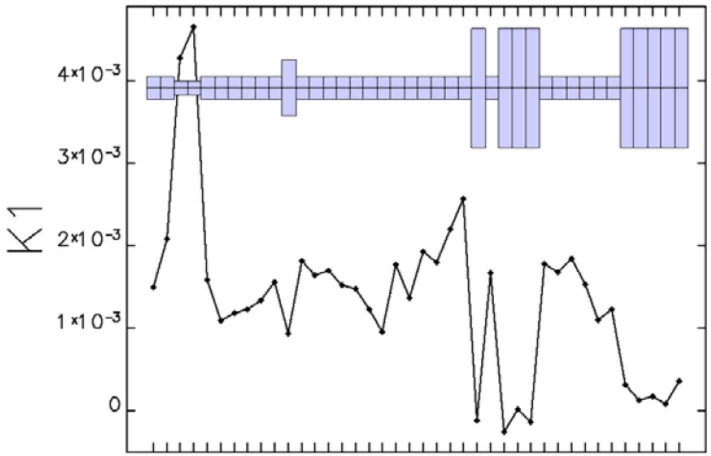
- Fit of $d\mu/dI(s)$ with additional quads (straight section quads + arc quads, 80 in total).



- Obtained results:

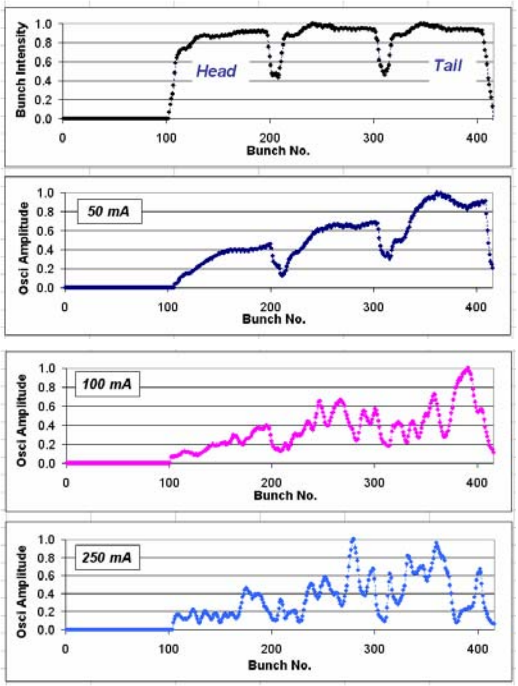
	Measured	Expected
$(Z_{8mm})^{eff}$ [kΩ/m]	31	28
$(Z_{5mm})^{eff}$ [kΩ/m]	86	110
$(Z_{total})^{eff}$ [MΩ/m]	1.3	1.2

(*~28% fluctuation among 28 8mm-gap-chambers*)

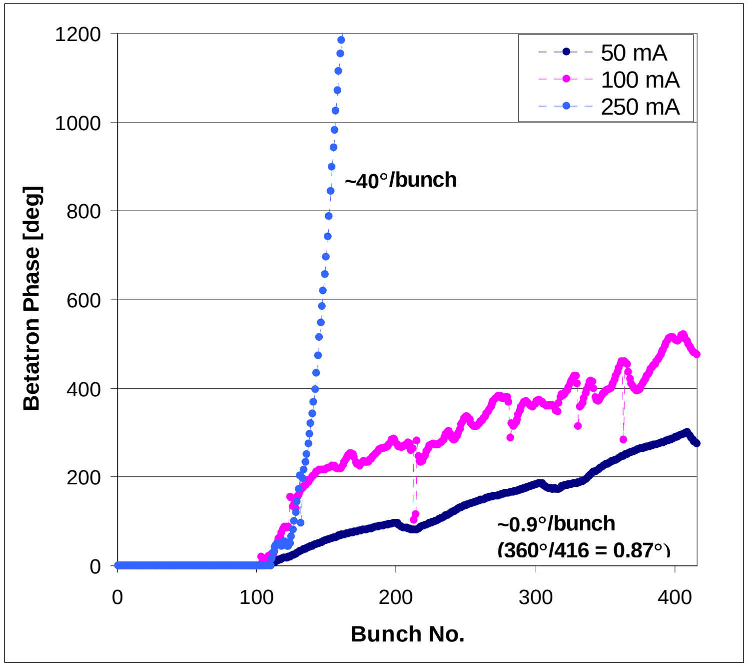


- <u>Turn by turn and bunch by bunch measurement:</u>

  - With a wide band pickup and a bunch by bunch digital processor, it opens new possibilities to coupled-bunch instability and impedance analysis.



Oscillation amplitude along a bunch train for different beam intensities.



Transition of betatron phase between adjacent bunches observed at SOLEIL

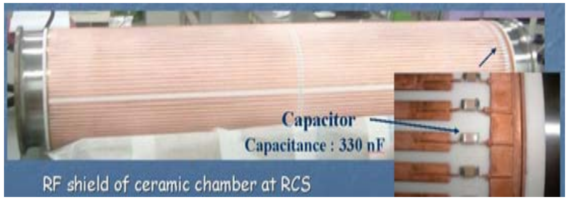
R. Nagaoka, M.P. Level, L. Cassinari, M.E. Couprie, M. Labat, C. Mariette, A. Rodriguez, R. Sreedharan, PAC07

- **Bench measurement:**

- Another independent and powerful means to estimate and validate vacuum chamber elements that make critical contributions to the total impedance budget.

- Simulation of beam with a wire (longitudinal) or with a twin-wire (transverse), and measurement of scattering coefficients (S_{21} and S_{11}).

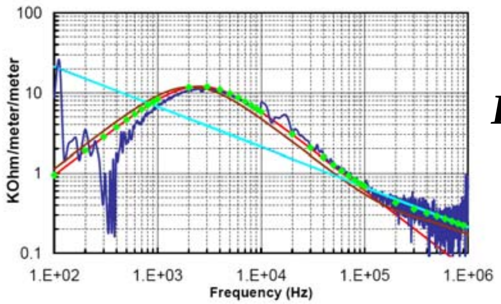
- Efforts made to improve measurement methods and accuracy at low frequencies, which is particularly important for high intensity proton rings (LHC, SNS, J-PARC, …).



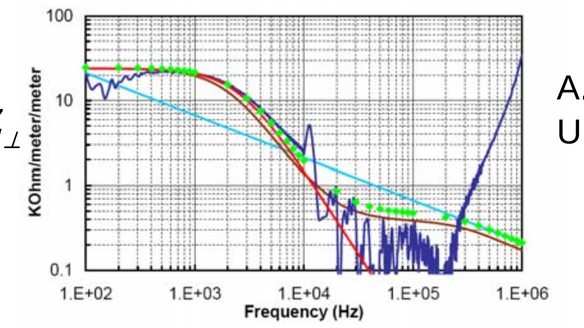
RF shielded ceramic pipe for RCS
Courtesy YH. Chin, J-PARC

- Comparison with theory for a circular steel tube:

$ReZ_\perp$



$ImZ_\perp$



A. Mostacci, F. Caspers, L. Vos, U. Iriso, PAC03

- Estimate of the total kicker impedance budget for SNS: H. Hahn, PRSTA **7**, 103501

6. Comparison between Measurement and Expectation

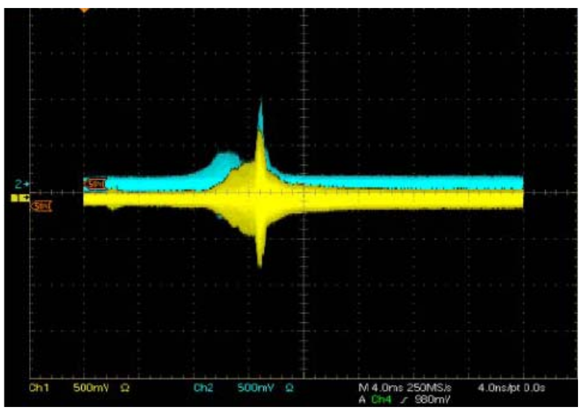
• SNS (Spallation Neutron Source, ORNL)

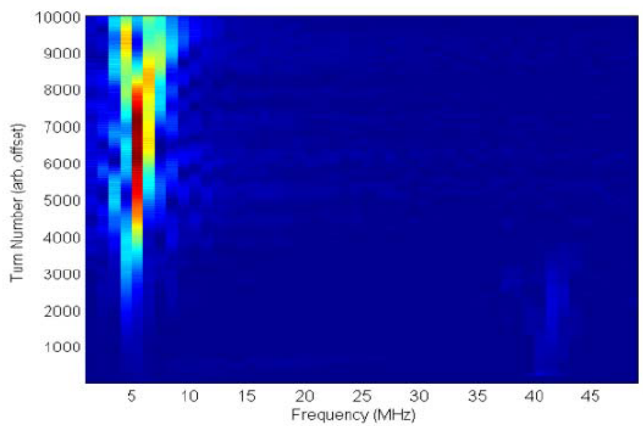
V. Danilov, S. Cousineau, A. Aleksandrov, S. Assadi, W. Blokland, C. Deibele, S. Henderson, J. Holmes, M. Plum, A. Shishlo, HB2006

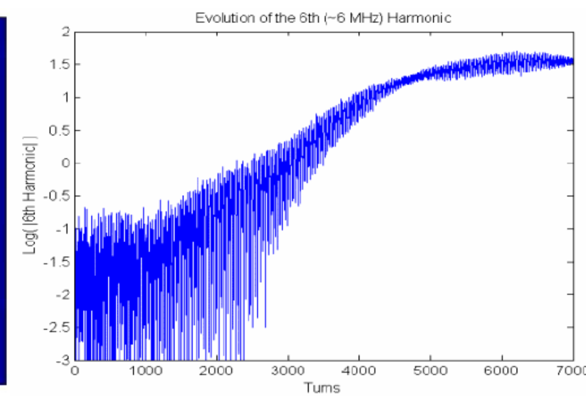
- Designed to accumulate up to 1.5×10^{14} protons/pulse, commissioned in Jan06.

- Great efforts of instability suppression (TiN coating, extraction kickers).

- Impedance (growth time) measurements by rendering the beam unstable.







⇨ $(\mathrm{Re}Z_{\perp})_{meas}$ = **34 kΩ/m** (at ~200 kHz), while estimated: **25 kΩ/m** (kicker)

14 kΩ/m (chamber RW)

• TEVATRON

V. Lebedev, A. Burov, FERMILAB-CONF-04-534-AD

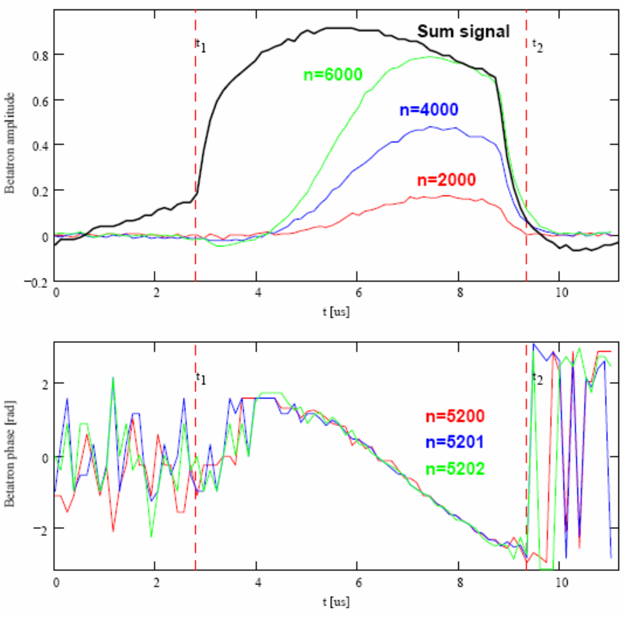
- Impedance reduction in the Tevatron complex helped increase luminosity.

- More than 4 times larger τ^{-1} measured in Tevatron was due to laminated Lambertson magnets → Removal and shielding reduced $Z_\perp$ by a factor of 3-4.

$$Z = (1-i)\frac{gZ_0L}{2\pi a^3}\frac{c}{\sqrt{2\pi\sigma\omega}}\frac{2a\sqrt{\mu}}{d}$$

- τ^{-1} was measured in the $(Z_\perp)_{RW}$ dominated recycler ring.

  → Agreement with expectation to within 10-20% for the most unstable mode.



Measured betatron amplitude and phase along the bunch for given turns.

• SSRF (Shanghai Synchrotron Radiation Facility)

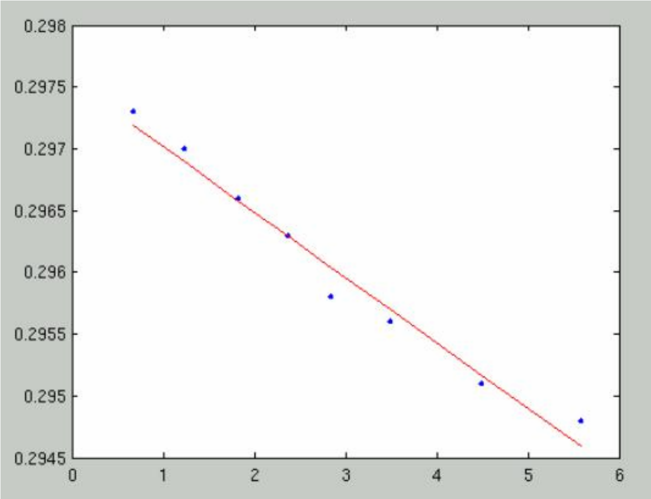
J. Bocheng, C. Guanglin, C. Jianhui, "Collective effects of SRRF storage ring 3 GeV Phase I commissioning", SSRF internal note, April 2008; J. Bocheng, "Impedance budget of SSRF storage ring", SSRF internal note, April 2008.

- Geometric impedance calculation using *ABCI* and *MAFIA*, and resistive-wall (RW) impedance analytical.

- Longitudinal: $(Z_{//})_{eff}$ = **0.22 ~ 0.30** Ω measured, while **0.2** Ω calculated.

- Vertical: $(Z_{\perp})_{eff}$ = **98 ~ 136 kΩ/m** measured from the coherent tune shift, which is nearly a **factor of 2** above expectation.

Qy



[mA]

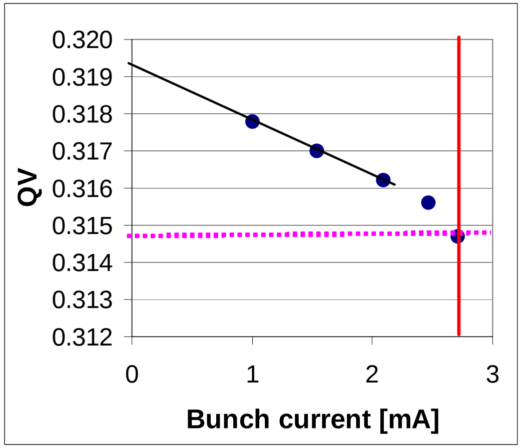
- $(I_{th})_{RW}$ ~64 mA (ξ_y = 0.1) and
  > 100 mA (ξ_y > 0.5).

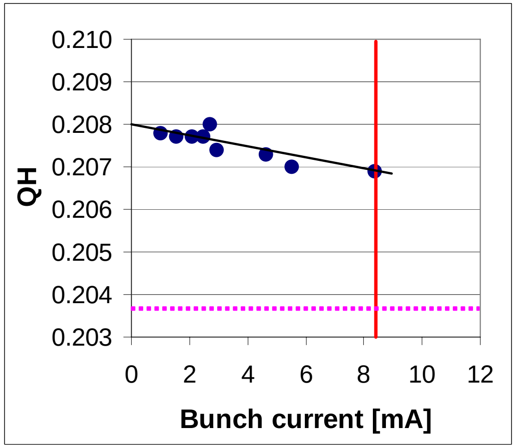
- Ion instabilities disappeared 1 month after the start of commissioning when the vacuum improved to 5×10^{-10} Torr.

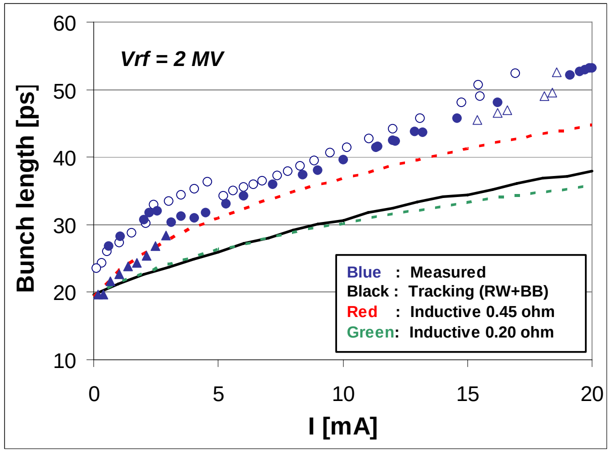
• SOLEIL

R. Nagaoka, MP. Level, L. Cassinari, ME. Couprie, M. Labat, C. Mariette, A. Rodriguez, R. Sreedharan, PAC07.

Measured/expected impedance: ~1.8 (V), ~1.7 (H), ~2.2 (L)



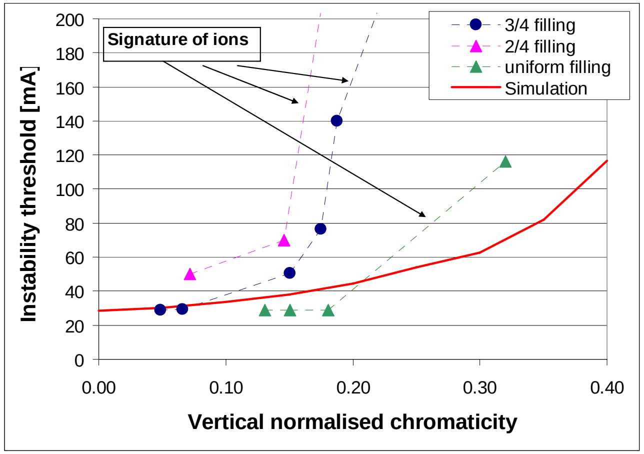




- Measured $(Z)_{eff}$ is larger than expected by a **factor of ~2** in all H, V and L planes.

- Both measured and expected energy spread show no substantial widening up to 20 mA.

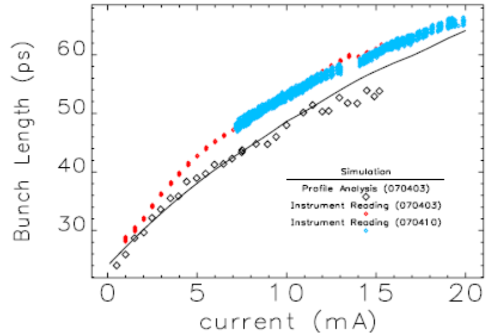
- In multibunch, the RW threshold at zero chromaticity is in good agreement with expected.

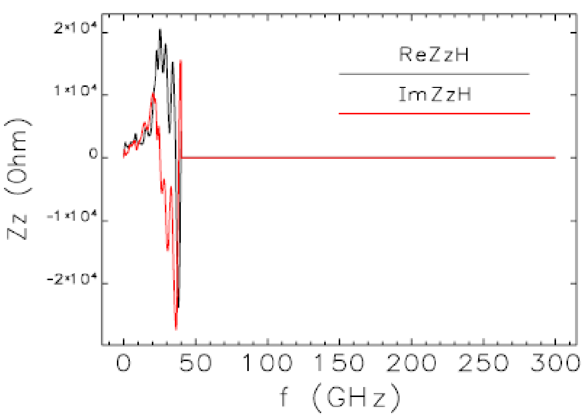


• APS

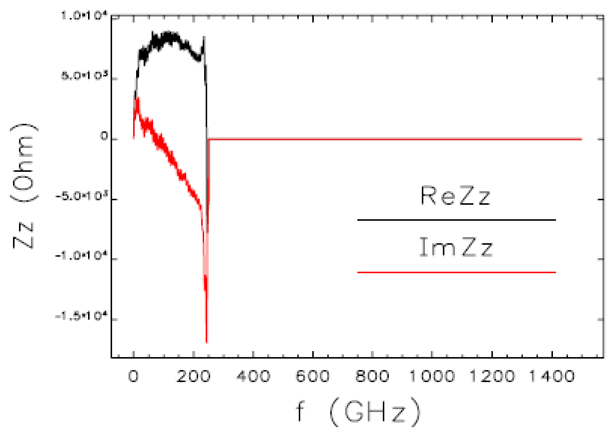
YC. Chae, Y. Wang, PAC07;   YC. Chae, ICFA Beam Dynamics Newsletter, April'08.

- Initial impedance database ***IDB-1***: σ_z = 5 mm, f_{max}=40 GHz, calculated with *MAFIA*.
- To reproduce measured bunch lengthening and energy spread, $Z/n = i0.1\ \Omega$ was added.
- To find the missing 0.1 Ω, impedance was recalculated for σ_z = 1 mm, f_{max}=250 GHz, with *GdfidL* (60 node, 240 GB cluster), to obtain ***IDB-2***.
- *IDB-2* well reproduced the measurement without any modification.
- In the vertical plane, Z_{RW} not included in *IDB-1* was mainly responsible for the remaining discrepancy.

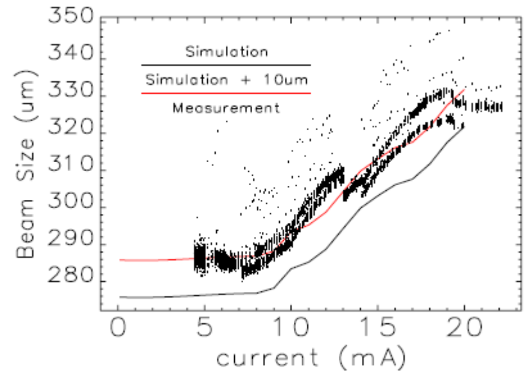




IDB-1



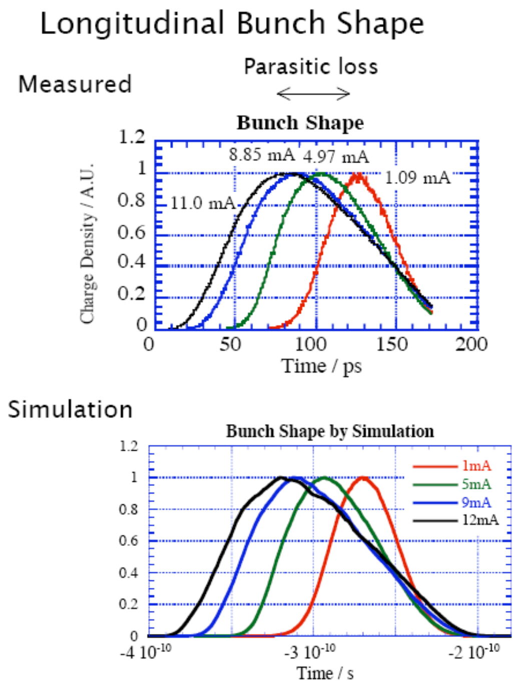
IDB-2

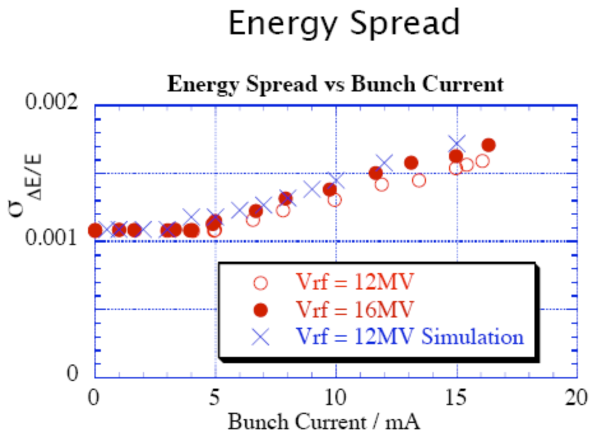


• SPring-8

T. Nakamura, “Simulation of Beam Instabilities in SPring-8”, SAD workshop 2006.

- Geometric impedance calculation using *MAFIA (2 & 3D)*, and resistive-wall (RW) impedance analytical.
- Wake functions defined as wake potentials obtained for a 1 mm bunch (0.1 mm grid).





- Vertical thresholds:

	$\xi = 0$ (TMCI)	$\xi = 4$
Measured	3.5~4 mA	> 16 mA
Calculated	3 mA	10 mA

7. Conclusion

- Remarkable progress in the numerical and analytical evaluation of wake fields, many of them being driven by needs in future accelerators.
- Instability simulations getting steadily closer to reality, both in terms of wake fields and beam dynamics.
- Large progress in measuring the impedance locally in a storage ring.
- Most measurements agree with expectation to within a factor of 2.

Acknowledgement

The author is grateful to the help of F. Zimmermann (CERN), YC. Chae, K. Harkay (ANL), YH. Chin, T. Ieiri, T. Toyama (KEK), V. Danilov (ORNL), A. Burov (Fermilab), T. Nakamura (SPring-8), Z. Zhao (SSRF), W. Bruns (Tech. Univ. Berlin), R. Bartolini (DIAMOND), R. Dowd (ASP), M. Thomasset, N. Béchu (SOLEIL) in preparing this talk.