Low emittance Rings 2010 Workshop summary and collaboration

Yannis PAPAPHILIPPOU, CERN

Special thanks to workshop conveners and co-organizers

March, 30th 2010

LER2010 scope

- **Bring together** experts from the scientific communities working on low emittance lepton rings (including damping rings, test facilities for linear colliders, B-factories and electron storage rings) in order to **discuss** common beam dynamics and technical issues.
- Targets **strengthening the collaboration** within the two damping ring design teams and with the rest of the community.
- **Profit from the experience** of colleagues who have designed, commissioned and operated lepton ring colliders and synchrotron light sources.

LER2010 demographics

- 70 registered participants (+ WebEx)
- 12 countries (4 continents)
  - Australia, France, Germany, Greece, Italy, Japan, Russia, Spain, Switzerland, Sweden, UK, USA
- 24 institutes:
  - Argonne (1), Australian Synchrotron (1), BINP (3), BNL (2), CELLS (1), CERN (17), CERN/NTUA (1), CERN/EPFL (2), Cockroft Institute (2), Cornell Un. (3), DESY (1), Diamond/JAI (1), Elettra (1), Fermilab (2), KEK (2), KIT (2), JASRI/SPring-8 (2), LBNL (1), LNF-INFN (8), MAX-lab (2), PSI (4), PSI/EPFL (1), SLAC (2), SOLEIL (6), Un. of Minnesota (1).

Timing of the Workshop

- CLIC conceptual design report (2010)
- ILC Strawman baseline (2009) and technical design (2012)
- Vigorous experimental program in test facilities (CESR-TA, ATF)
- Upgrade plans in B-factories (SUPERB, SUPERKEKB)
- Important breakthroughs in light sources for reaching ultra-low vertical emittances (SLS, DIAMOND, Australian LS)
- Commissioning of PETRA III (wiggler dominated light source)
- New light source projects and studies targeting ultra-low emittances in regimes where Intra-beam scattering becomes important (NSLSII, MAX4, Spring-8 upgrade, Ultimate Storage Ring, PEP-X)

A *Very* Busy Week…

- 59 scheduled talks (all plenary)
  - 56 were successfully presented
  - 3 were not presented due to the technical difficulties with WebEx connections **(apologies)**
- The talks covered a broad range of topics:
  - Status of linear collider damping ring designs, B factory designs, and test facilities
  - Low emittance lattice design
  - Low emittance tuning
  - Nonlinear dynamics
  - Collective Effects
    - Fast Ion, Electron Cloud (characterization and mitigations), CSR, IBS, Impedance Modeling and Measurement
  - Technical Issues
    - Vacuum design (including EC mitigation, wiggler radiation absorbers,…), Kickers, Magnets and Wigglers, Alignment, Instrumentation, Feedback systems, RF systems
- Discussion sessions
  - Dedicated sessions at the end of each day
  - Special discussion session during the 2nd day of the workshop on methodology for designing rings with extremely small emittance (organized by K. Sutome (Spring-8))
  - A lot of off-line discussions

Lattice design, simulations and measurements

M. Biagini, P. Raimondi

SuperB and 3.2km ILC ARC Lattice

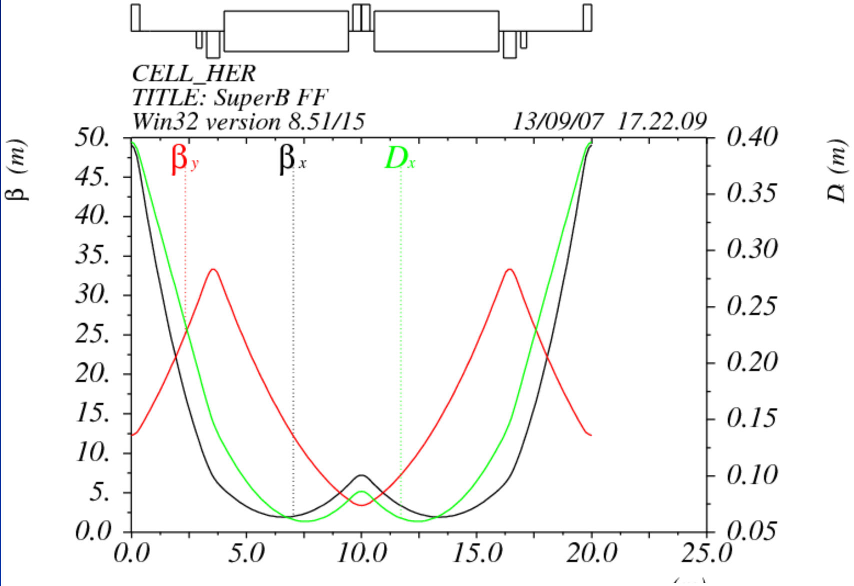
- Equilibrium emittance for this cell decreases fast with mux
- Alternating two cell in the arc:

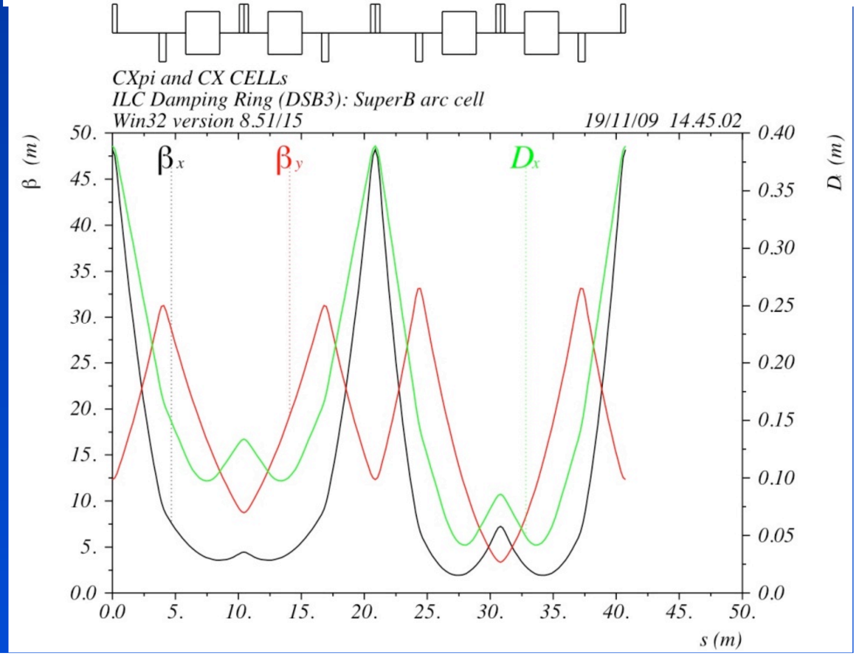
one with mux=0.5 and one with mux=0.75 the

intrinsic emittance decreases and the number of cells can be reduced

Even larger ARC Dynamic aperture because the

-I between the Horizontal Sextupoles and Arc sextupoles correct all chromaticity phases





Emittance of Ring-Based Light Sources

We set "ultimate" target of emittance to
"Fully Diffraction Limited" for 10keV Photon:
$\varepsilon_x \sim \varepsilon_y \sim$ **10pmrad**

2nd Generation

Far from Diffraction Limit

3rd Generation

Diffraction Limited in Vertical Direction

Small Emittance (~nmrad) and Small Coupling (~0.1%)

Next

Toward Diffraction Limited in Both H and V Directions

T. Watanabe, K. Sutome

Toward "Fully Diffraction Limited" (3)

Radiation Excitation and Damping Manipulations:

Combined B (Partition Control)

Robinson Wiggler (Partition Control)

T.Nakamura, unpublished note (sufficient dispersion needed)

Longitudinally Variable B (Optimized Radiation Integral)

R.Nagaoka and A.Wrulich, NIMA575(2007)292;

Y.Papaphilippou and P.Elleaume, PAC05, ...

Damping Wiggler : PETRA-III, PEP-X, NSLS-II, MAX IV ...

... Effects on the energy spread should also be considered.

Phase Space Manipulations:

Round Beam with Solenoid Field (at Special Straights)

A.Burov and V.Danilov, FERMILAB-TM-2043; R.Brinkmann, EPAC02;

H.Tanaka, unpublished note; K.Harada, K.Oide, private com.;

K.-J. Kim, PRST-AB 6(2003)104002

Round Beam

T. Watanabe, K. Sutome

A.Burov and V.Danilov, FERMILAB-TM-2043

Figure 1: General scheme of the insertion.

Transformation between canonical and physical momentum in solenoid is

$$\pi_x = p_x + eA_x = p_x - (eB_z/2)y$$

$$\pi_y = p_y + eA_y = p_y + (eB_z/2)x$$

This is essential for manipulating emittance defined by (x, p_x, y, p_y) .

... K.Oide

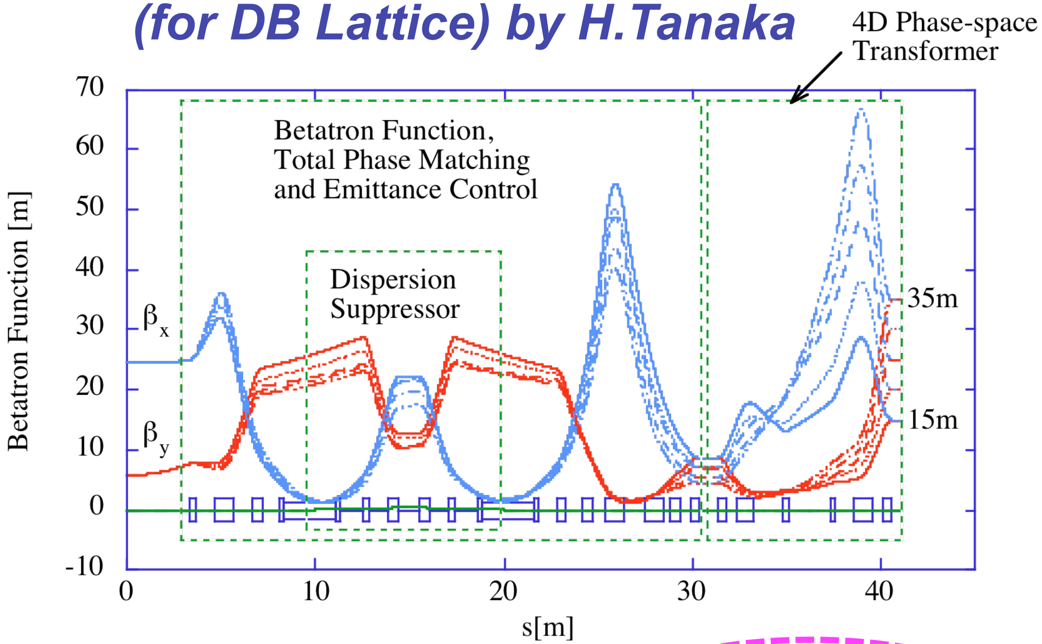
$$\beta = \frac{2[B\rho]}{B_z}$$

$$\sigma_x = \sigma_y = \sqrt{\frac{\beta\varepsilon_x}{2}}$$

$$\sigma_{x'} = \sigma_{y'} = \sqrt{\frac{2\varepsilon_y}{\beta}}$$

$$\sigma_x\sigma_{x'} = \sigma_y\sigma_{y'} = \sqrt{\varepsilon_x\varepsilon_y}$$

Example Design of Matching Section (for DB Lattice) by H.Tanaka



e.g. $B_z = 1.5T, E = 6GeV, \varepsilon_x = 0.2nmrad, \varepsilon_y = \varepsilon_x \times 0.003 \Rightarrow \sqrt{\varepsilon_x\varepsilon_y} = 11pmrad$

T. Watanabe, K. Sutome

Modified Sextupoles (Gaussian Sextupoles)

Sextupole field is damped at large betatron oscillation.

$$B_x = Se^{K(x^2-y^2)}\left[\left(x^2-y^2\right)\sin\left(2Kxy\right)+2xy\cos\left(2Kxy\right)\right]$$

$$B_y = Se^{K(x^2-y^2)}\left[\left(x^2-y^2\right)\cos\left(2Kxy\right)-2xy\sin\left(2Kxy\right)\right]$$

M.Cornacchia and K.Halbach, NIM A290 (1990) 19

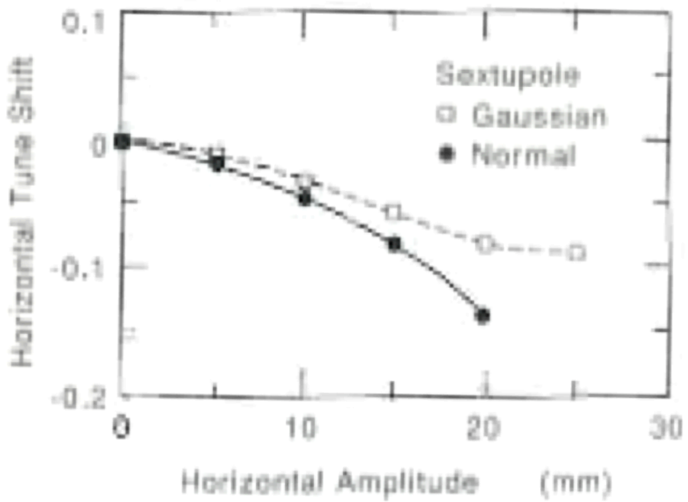


Fig. 4. Horizontal tune shift versus maximum betatron amplitude for normal and Gaussian sextupoles.

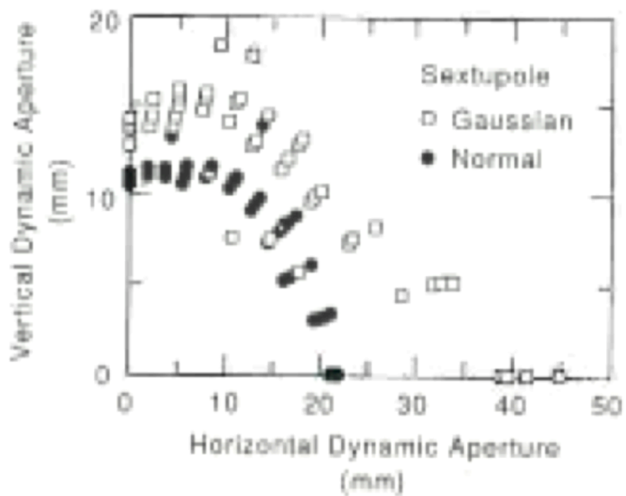


Fig. 6. Dynamic aperture of five different machines having magnetic field gradient errors randomly distributed in the quadrupoles. The rms value of the distribution of the relative gradient errors is 0.001.

J.C.Lee and W.Wiedemann, EPAC98
H.Tanaka, private com.

PEP-X

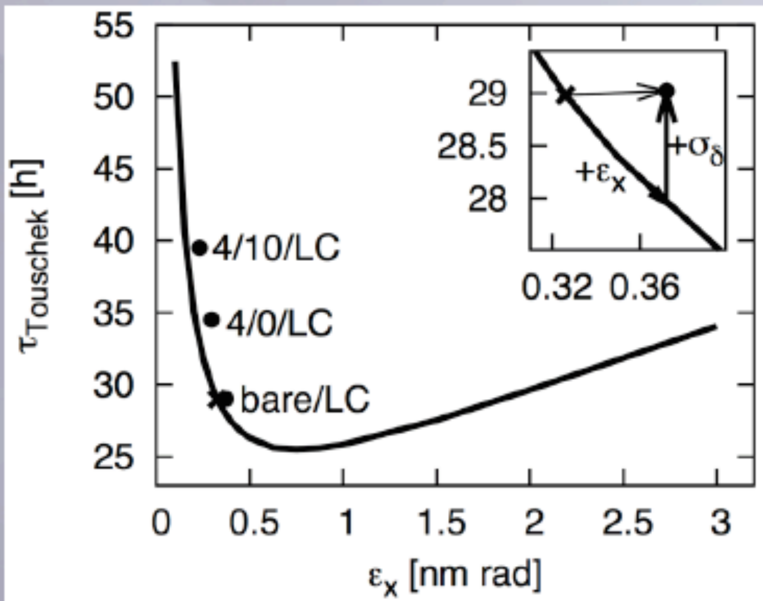
Y. Cai

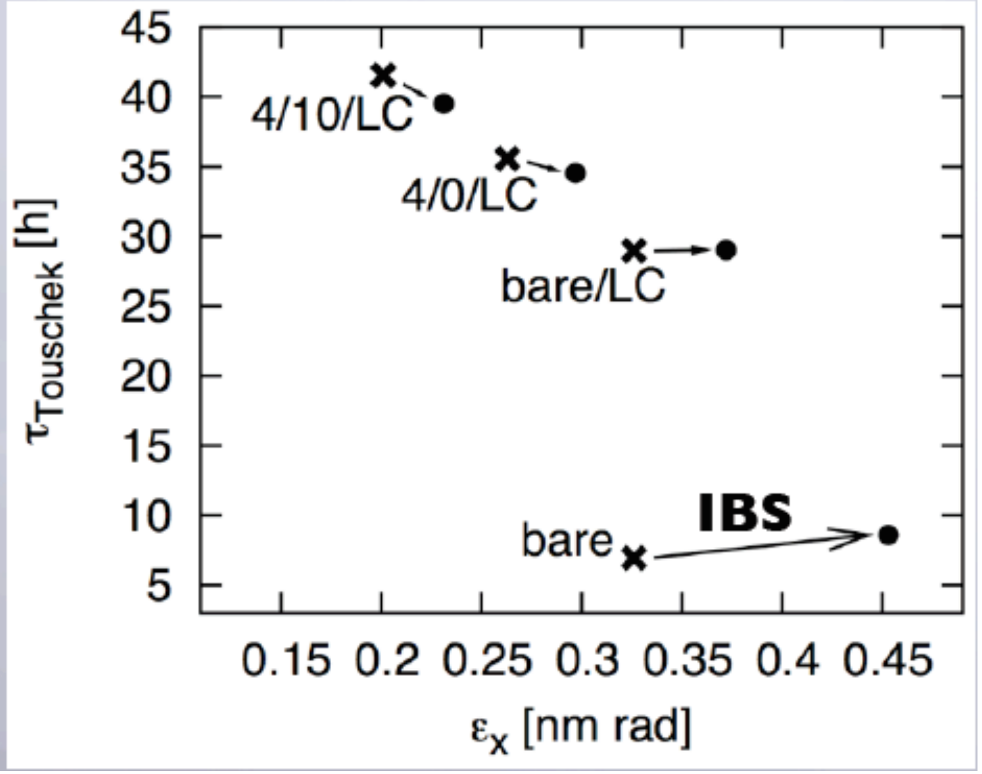
Parameter	Value (wiggler on)	Value (wiggler off)
Energy, E_0 [GeV]	4.5	4.5
Circumference, C [m]	2199.32	2199.32
Emittance, ε_x [pm-rad, 0 current]	85.7	379
Beam current, I [A]	1.5	1.5
Harmonic number, h	3492	3492
Number of bunches, n_b	3154	3154
Bunch length, σ_z [mm]	3	3
Energy spread, σ_δ	1.14×10^{-3}	0.55×10^{-3}
Momentum compaction, α	5.81×10^{-5}	5.81×10^{-5}
Tunes, $\nu_x/\nu_y/\nu_s$	87.23/36.14/0.0077	87.23/36.14/0.0037
Damping times, $\tau_x/\tau_y/\tau_s$ [ms]	20.3/21.2/10.8	101/127/73
Energy loss, U_0 [MeV/turn]	3.12	0.52
RF voltage, V_{RF} [MV]	8.9	2.0
β_x/β_y at ID center, [m] (low)	3.00/6.07	3.00/6.07
β_x/β_y at ID center, [m] (high)	16.04/6.27	16.04/6.27

Emittance and IBS

- MAX IV 3 GeV SR is IBS-limited!
- Damping wigglers reduce emittance (B = 2.22 T, λ = 80 mm, L = 2 m)
- DWs also increase energy spread → reduce IBS contribution
- Landau Cavities → reduce effect of IBS & increase Touschek lifetime

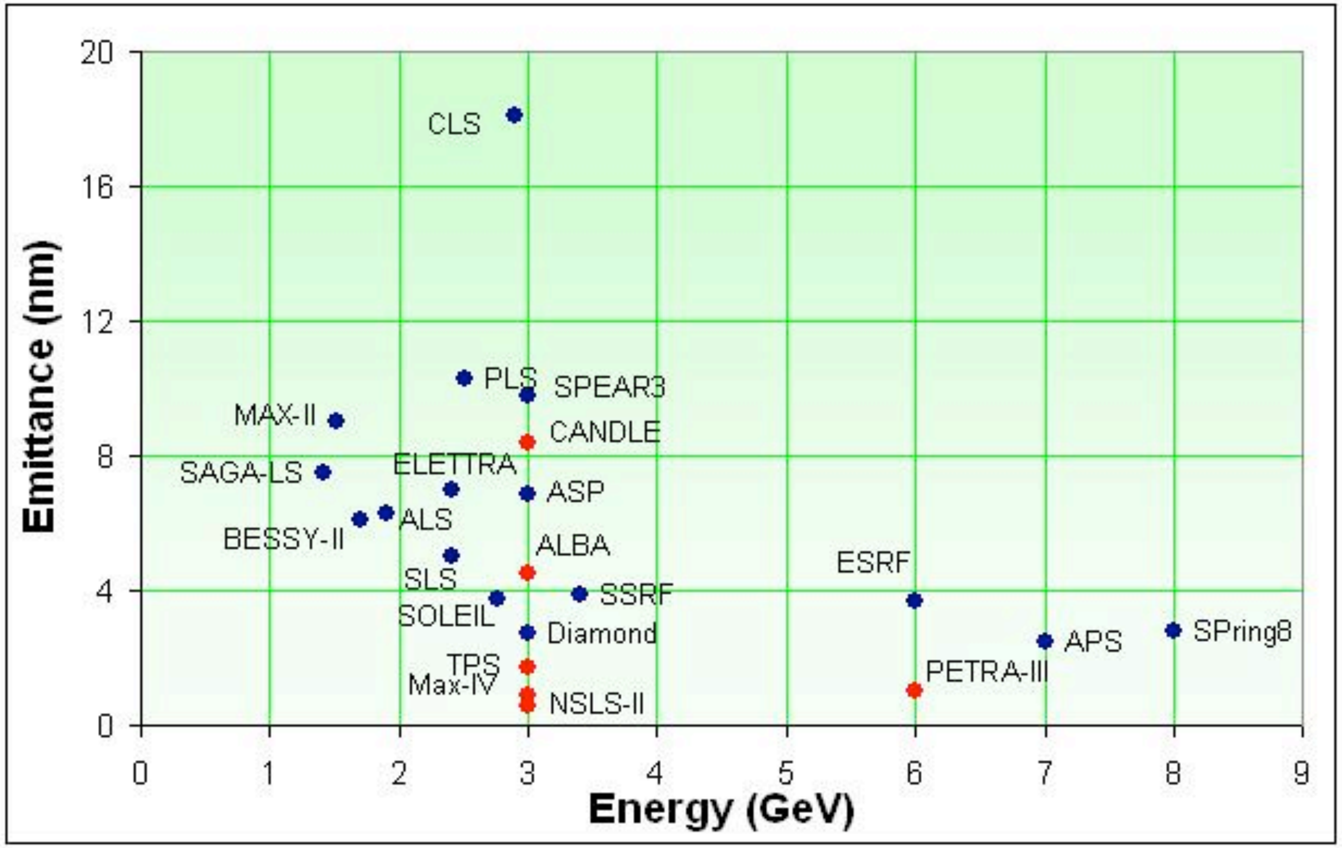
	ε_x [nm rad] Without IBS	With IBS
Bare lattice	0.326	0.453
Bare lattice with LC	0.326	0.372
Lattice with four PMDWs and LC	0.263	0.297
Lattice with four PMDWs, ten IVUs, and LC	0.201	0.231





Brilliance and low emittance

The brilliance of the photon beam is determined (mostly) by the electron beam emittance that defines the source size and divergence



$$\text{brilliance} = \frac{\text{flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}}$$

$$\Sigma_x = \sqrt{\sigma_{x,e}^2 + \sigma_{ph,e}^2} \qquad \sigma_x = \sqrt{\varepsilon_x \beta_x + (D_x \sigma_\varepsilon)^2}$$

$$\Sigma_{x'} = \sqrt{\sigma_{x',e}^2 + \sigma'^2_{ph,e}} \qquad \sigma_{x'} = \sqrt{\varepsilon_x \beta_x + (D'_x \sigma_\varepsilon)^2}$$

SLS vertical emittance

SR - Dispersion/Betatron Coupling Correction - Summary

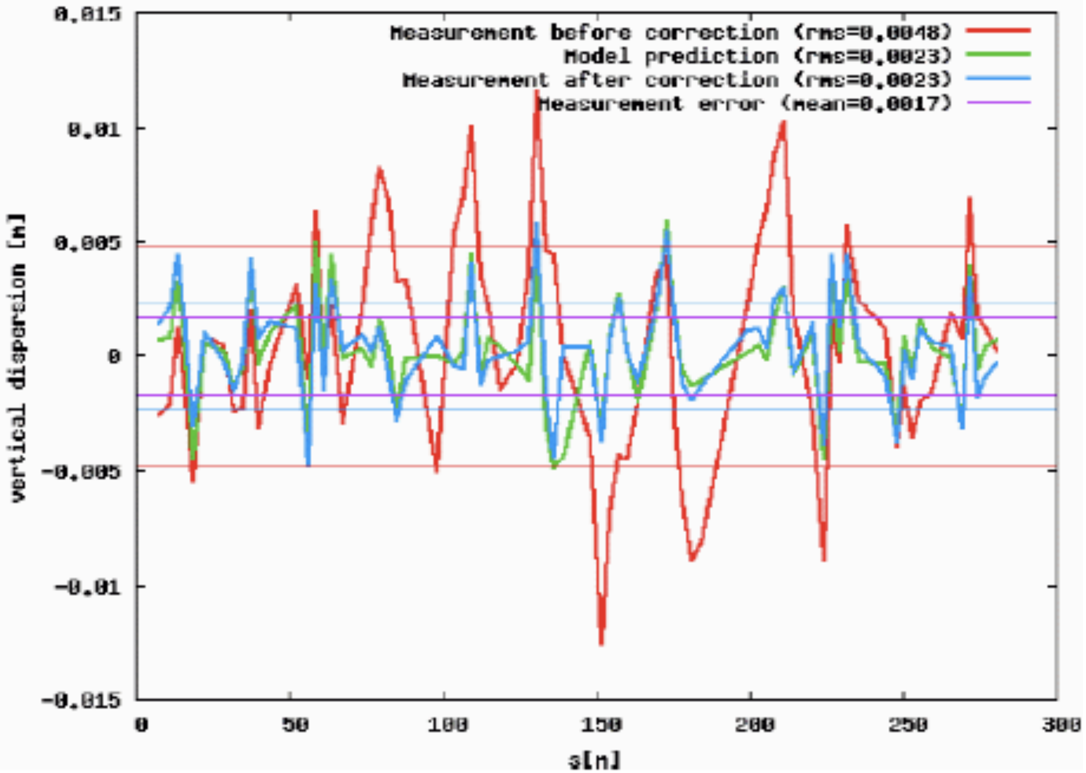
M. Böge

1. Suppression of η_y by 12 $\eta_x > 0$ skew quads:
   η_y from off-momentum orbit measurement and SVD fit
2. Suppression of $Q_x \pm Q_y$ by 24 $\eta_x = 0$ skew quads.
   response matrix measurement and SVD fit using model RM
3. + some empirical tuning of skew-quad Hamiltonian modes
   h_{00101}, h_{10100} and h_{10010}
   for best ratio $T/\sqrt{\varepsilon_y}$

➔ lowest V-emittance:

$\varepsilon_y = 2.8\ (\pm 0.4)$ pm rad
$= 5 \times \varepsilon_{yo}$ from $1/\gamma$
$= 0.05\%$ of ε_x

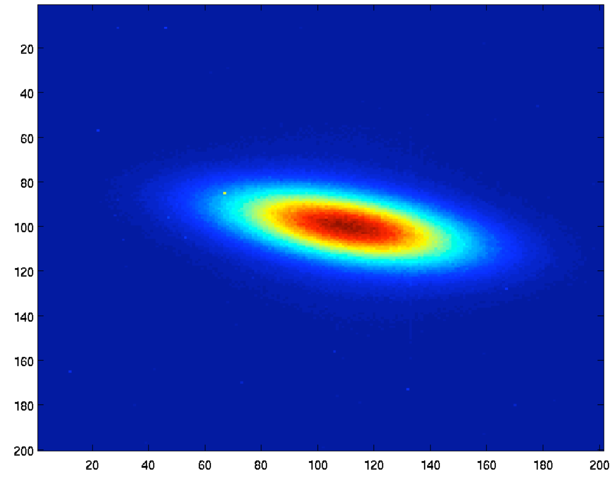
➔ option: η_y-wave to adjust $\varepsilon_y \leftrightarrow T$ on $T \propto \sqrt{\varepsilon_y}$ scaling curve



Measured emittances

Coupling without skew quadrupoles off K = 0.9%

(at the pinhole location; numerical simulation gave an average emittance coupling 1.5% ± 1.0 %)



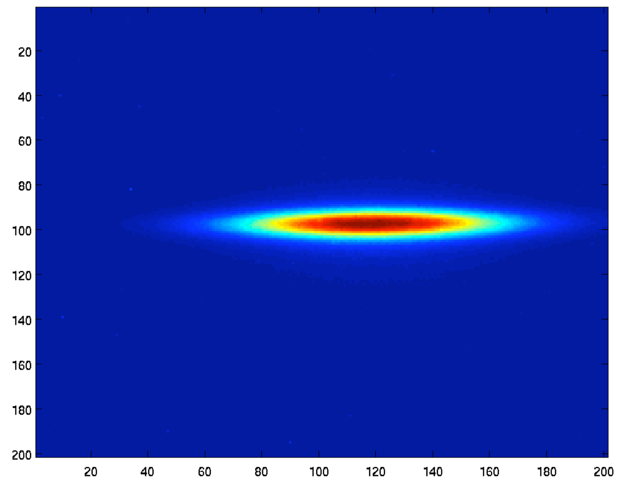
Emittance [2.78 - 2.74] (2.75) nm

Energy spread [1.1e-3 - 1.0-e3] (1.0e-3)

After coupling correction with LOCO (2*3 iterations)

1st correction K = 0.15%

2nd correction K = 0.08%



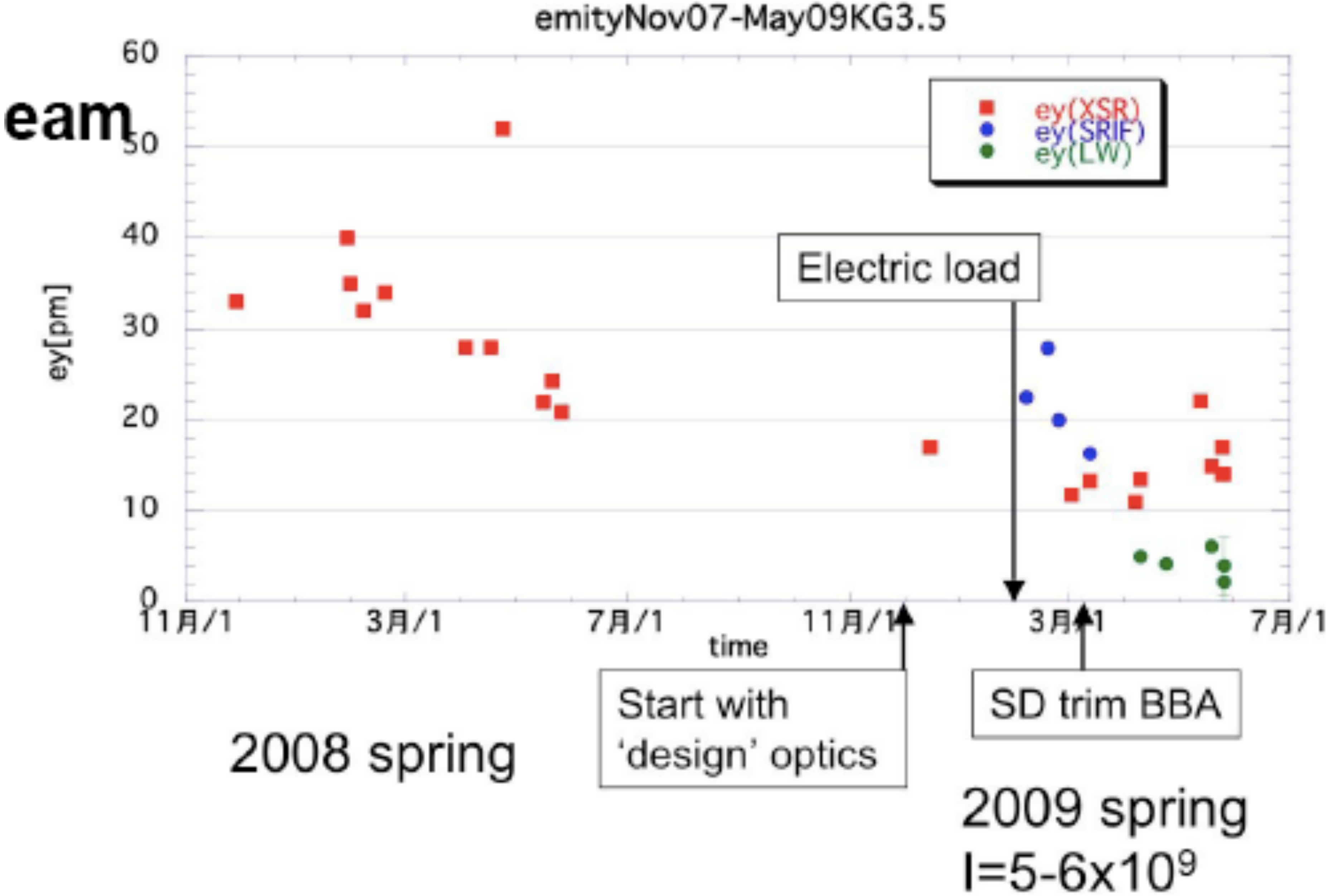
V beam size at source point 6 μm

Emittance coupling 0.08% → **V emittance 2.2 pm**

Variation of less than 20% over different measurements

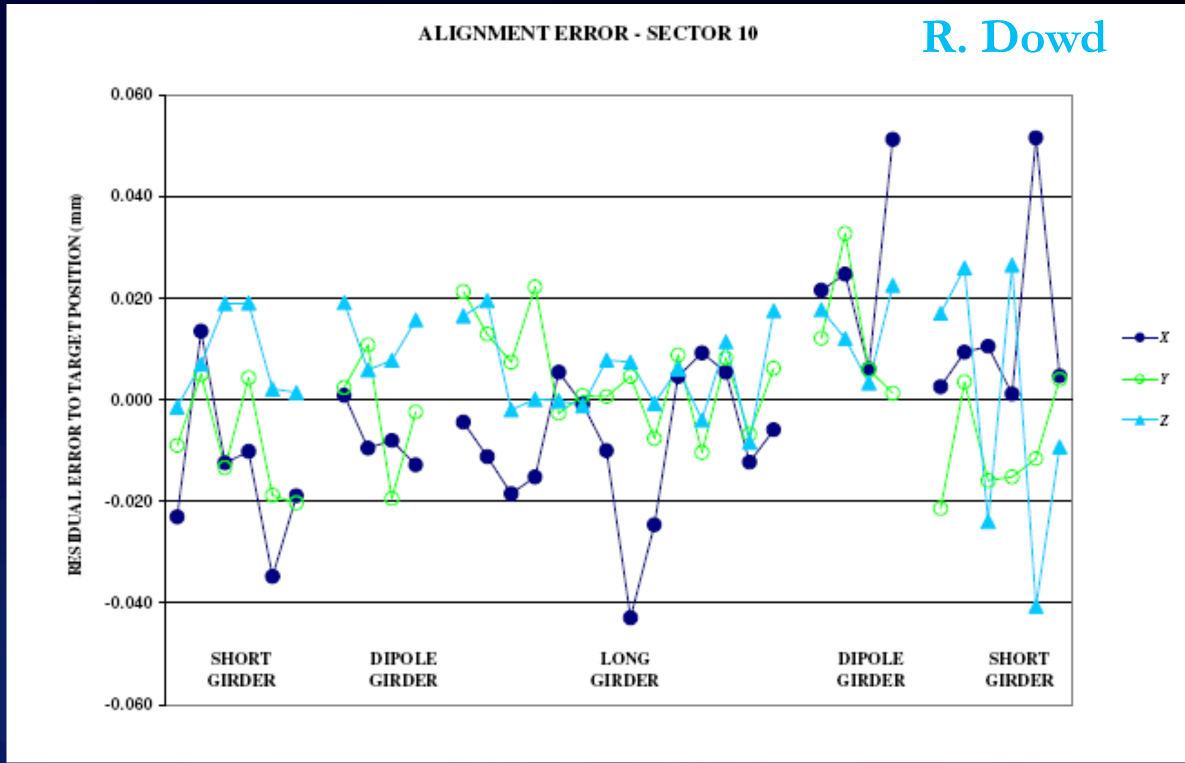
ATF vertical emittance

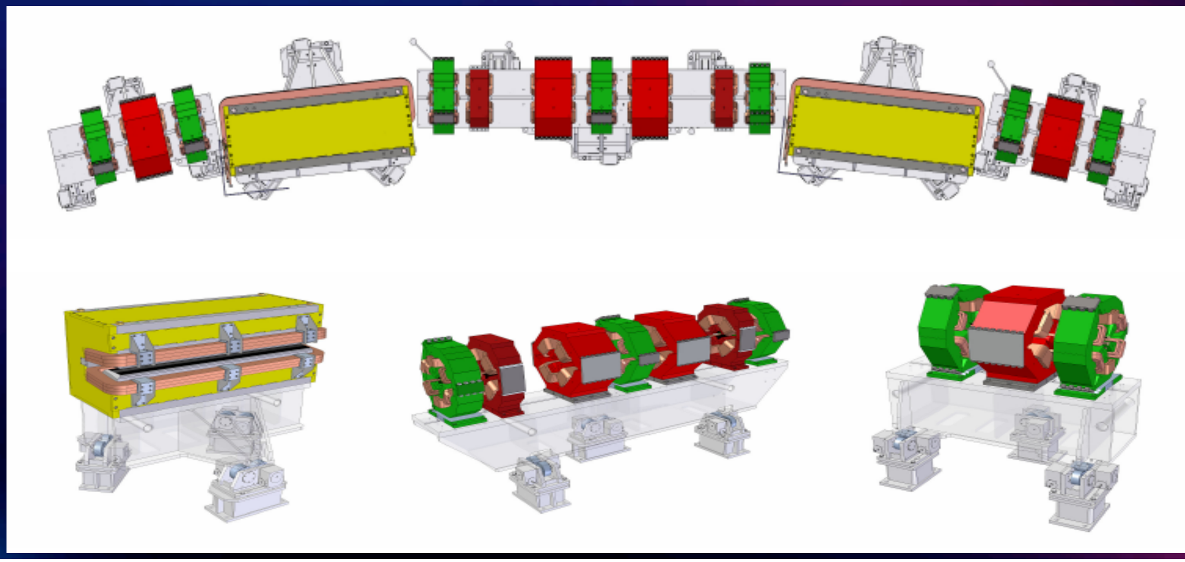
S. Guiducci



Alignment

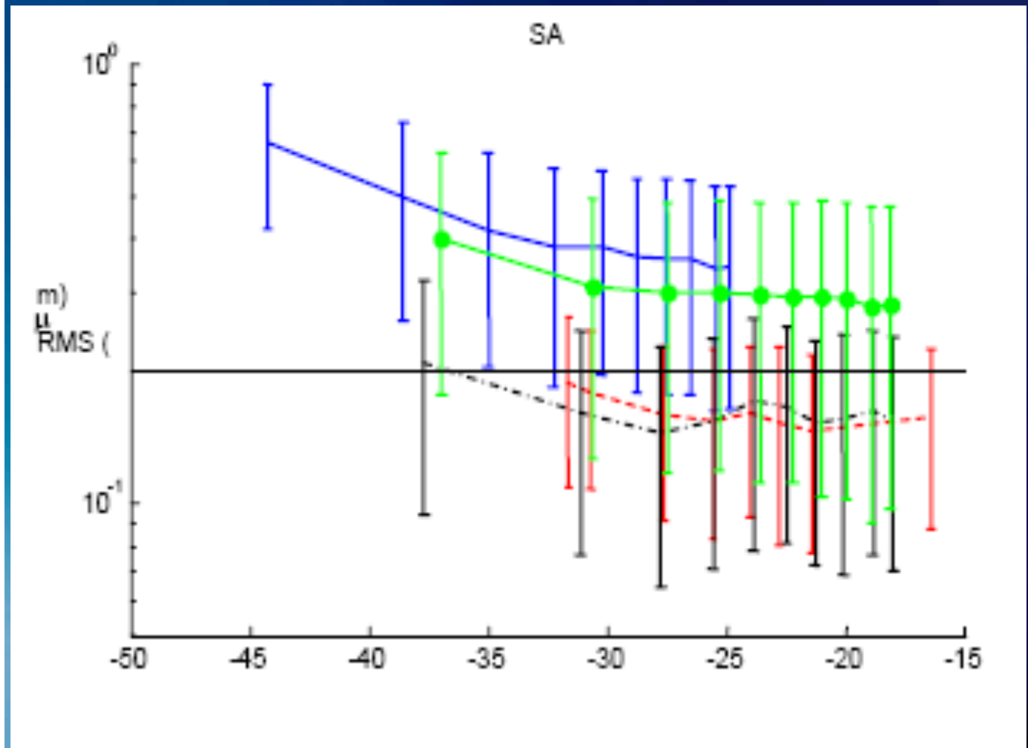
- Alignment error:
  26 µm Quadrupoles,
  18 µm Dipoles
- Intrinsic Fiducial and assembly error:
  16 µm (Quad)
  6 µm (Dipole)
- Full ring realignment conducted every year.
- Current 'natural' emittance coupling = 0.059%

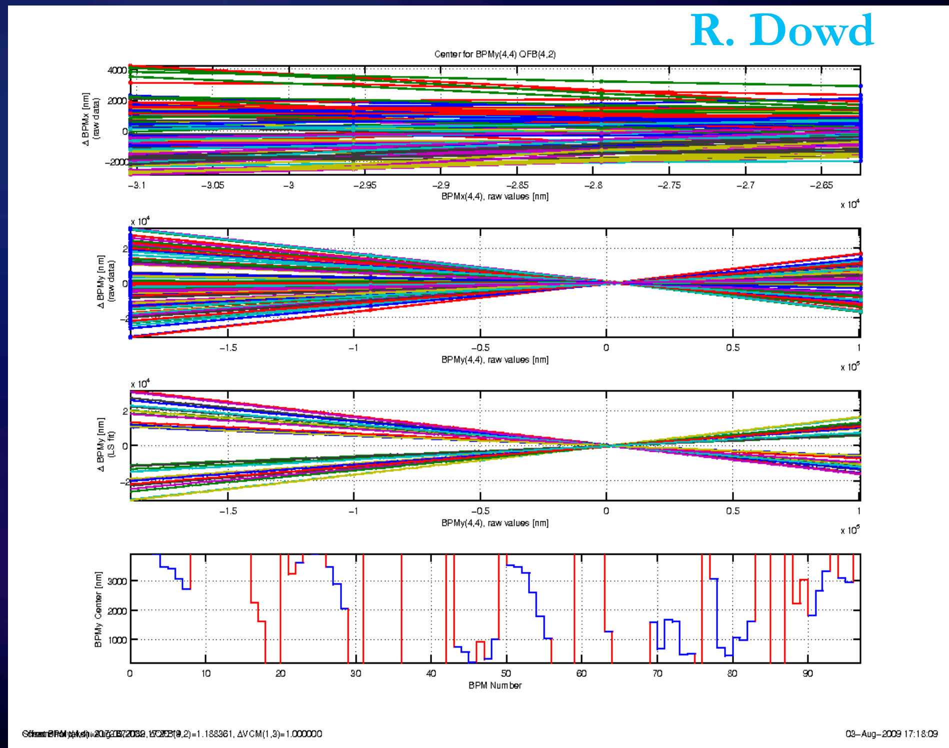




BPM resolution and Beam Based Alignment

- Libera BPM electronics
- BPM resolution ~0.1 um (rms)
- Resolution of BBA is ~10 um.
- BPM mechanical alignment resolution <20 um



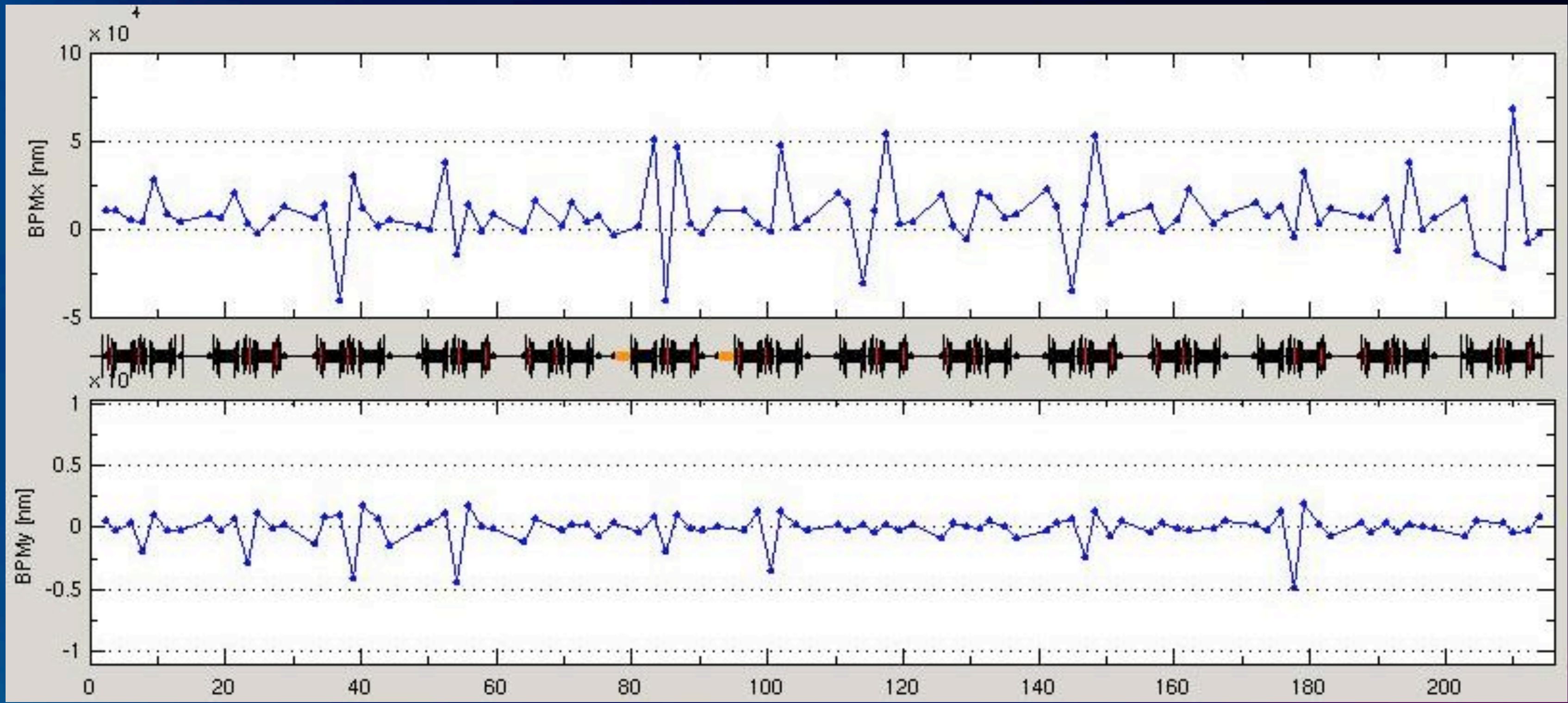


Orbit correction

Australian Synchrotron

RMS orbit deviation typically: <20 μm Horizontal, <10 Vertical

R. Dowd



- Naturally low coupling achieved by good mechanical and beam based alignment.
- LOCO is an effective tool for lattice measurements and manipulations
- Large number of skew quads allows for good control of coupling
- Tousheck Lifetime Analysis indicate ε_y ~ 1-2 pm
- Direct measurements (interferometer) would be nice.

R. Bartolini

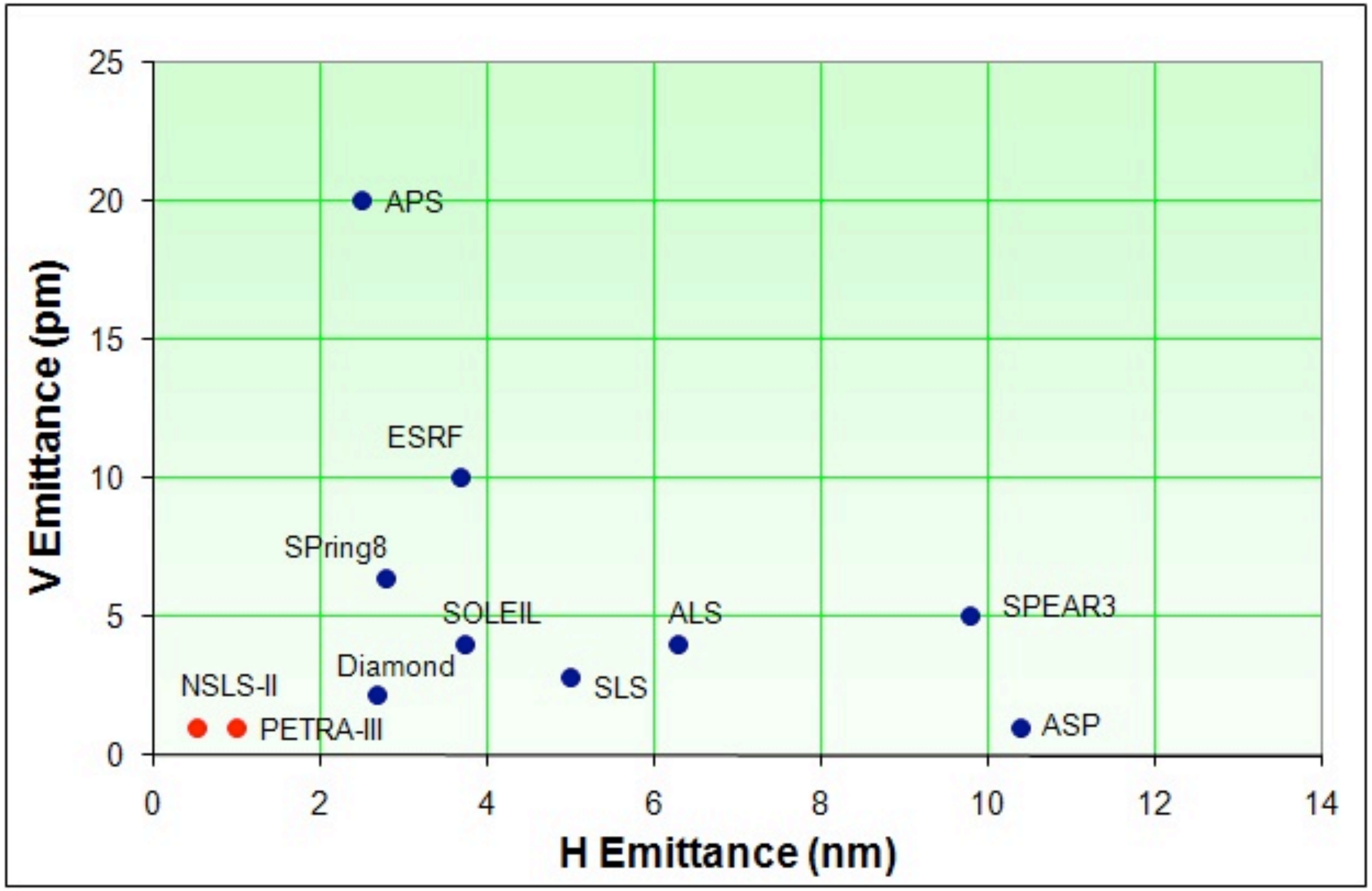
Comparison model/machine for linear optics

	Model emittance	Measured emittance	β-beating (rms)	Coupling* (ε_y/ ε_x)	Vertical emittance
ALS	6.7 nm	6.7 nm	0.5 %	0.1%	4-7 pm
APS	2.5 nm	2.5 nm	1 %	0.8%	20 pm
ASP	10 nm	10 nm	1 %	0.01%	1 pm
CLS	18 nm	17-19 nm	4.2%	0.2%	36 pm
Diamond	2.74 nm	2.7-2.8 nm	0.4 %	0.08%	2.2 pm
ESRF	4 nm	4 nm	1%	0.25%	10 pm
SLS	5.6 nm	5.4-7 nm	4.5% H; 1.3% V	0.05%	2.8 pm
SOLEIL	3.73 nm	3.70-3.75 nm	0.3 %	0.1%	4 pm
SPEAR3	9.8 nm	9.8 nm	< 1%	0.05%	5 pm
SPring8	3.4 nm	3.2-3.6 nm	1.9% H; 1.5% V	0.2%	6.4 pm

* best achieved

R. Bartolini

Vertical Emittance in 3rd generation light sources



Best achieved values – not operational values

Assuming 10^{-3} coupling correction , the V emittance of the new projects can reach the fundamental limit given by the radiation opening angle;

Measurements of such small beam size is challenging !

Overview of fast orbit feedback performance

Summary of integrated rms beam motion (1-100 Hz) with FOFB
and comparison with 10% beam stability target

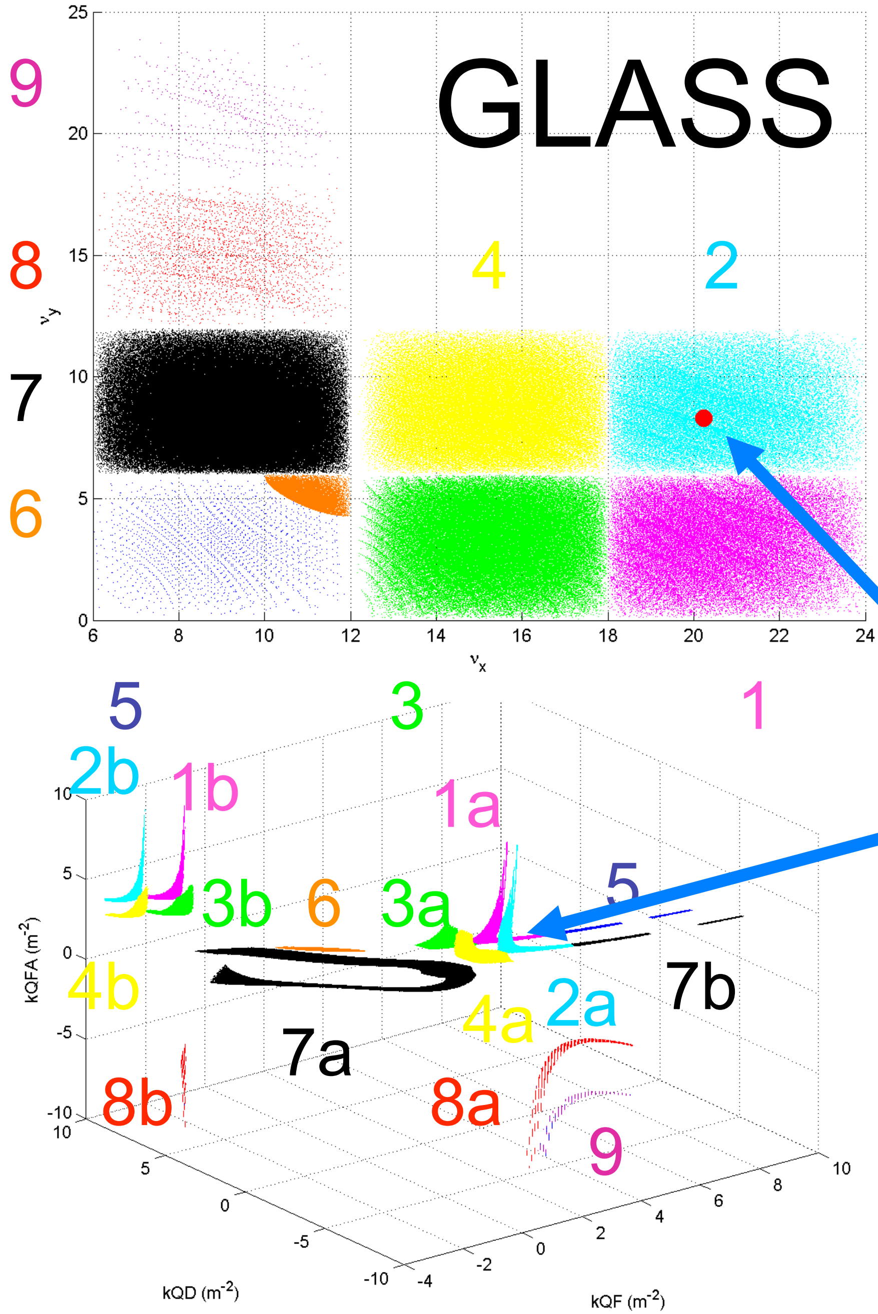
	FOFB BW	**Horizontal**	**Vertical**
ALS	40 Hz	< 2 μm in H (30 μm)*	< 1 μm in V (2.3 μm)*
APS	60 Hz	< 3.2 μm in H (6 μm)**	< 1.8 μm in V (0.8 μm)**
Diamond	100 Hz	< 0.9 μm in H (12 μm)	< 0.1 μm in V (0.6 μm)
ESRF	100 Hz	< 1.5 μm in H (40 μm)	~ 0.7 μm in V (0.8 μm)
ELETTRA	100 Hz	< 1.1 μm in H (24 μm)	< 0.7 μm in V (1.5 μm)
SLS	100 Hz	< 0.5 μm in H (9.7 μm)	< 0.25 μm in V (0.3 μm)
SPEAR3	60Hz	~ 1 μm in H (30 μm)	~ 1 μm in V (0.8 μm)

* up to 500 Hz

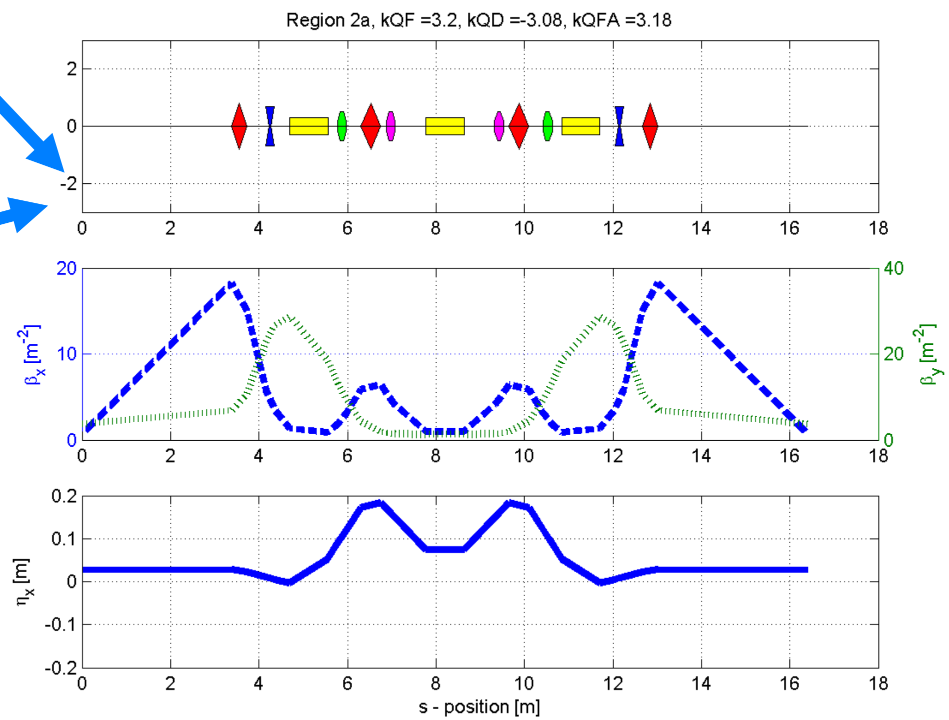
** up to 200 Hz

Trends on Orbit Feedback

- restriction of tolerances w.r.t. to beam size and divergence
- higher frequencies ranges
- integration of XBPMs
- feedback on beamlines components

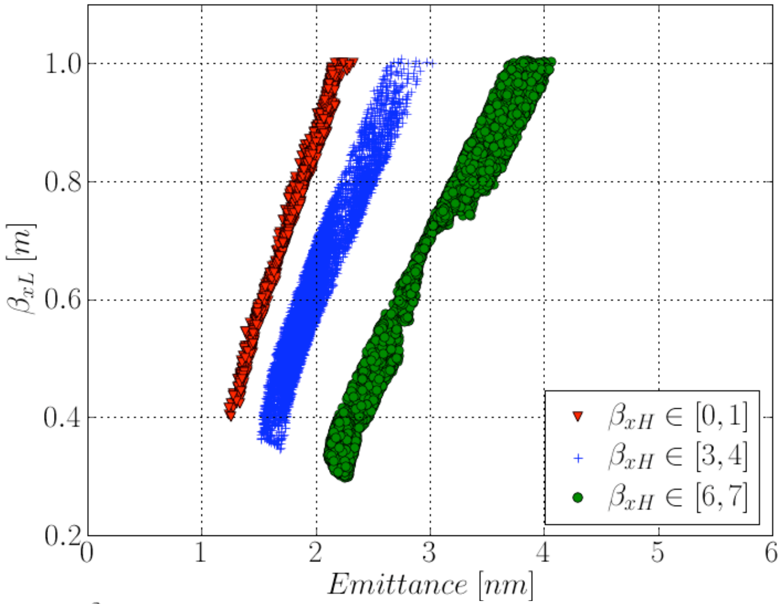


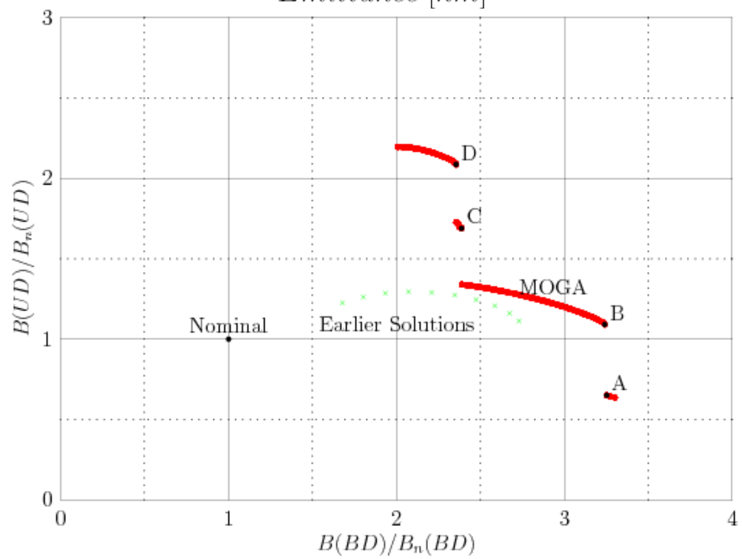
- *Low emittance*
- *Low momentum compaction*
- *Small beta functions in center bend*
- *Small horizontal beta in straights*



Results of MOGA and future Plans

- Studied lattices with more parameters (6-10)
  - low beta functions in both planes in ½ or most of the straights (optimize diffraction match)
  - Withy sufficient beta function in injection straight to allow injection
- Did not find lattice with emittances significantly below 2 nm baseline
- Starting with simultaneous optimization of linear and nonlinear dynamics
  - Lingyun is just getting first results for NSLS-II (like Michael at APS)



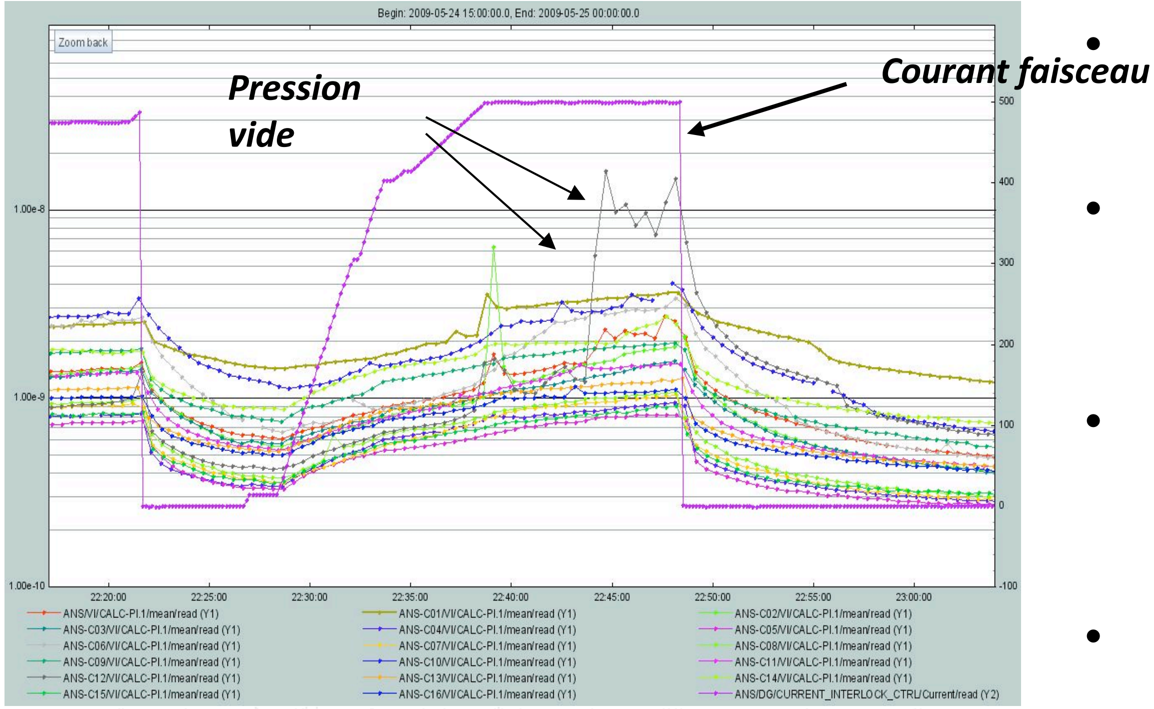


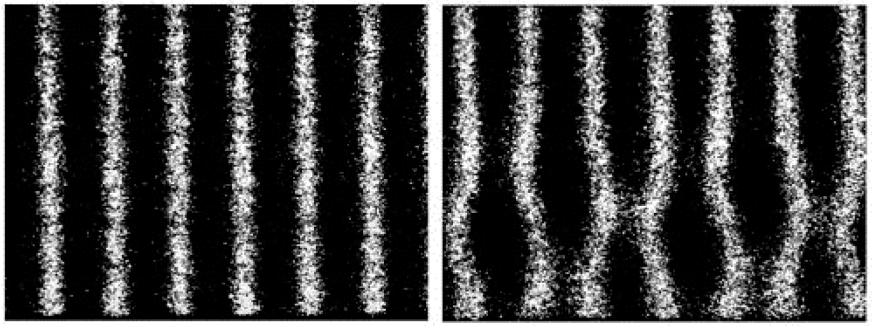
Collective effects

Two-stream phenomena

R. Nagaoka

Ion effects in electron rings





(a) P=0.4nTorr (normal)

(b) P=1nTorr w/o He injection

(M. Kwon et al., Phys. Rev. ***E57*** *(1998) 6016)*

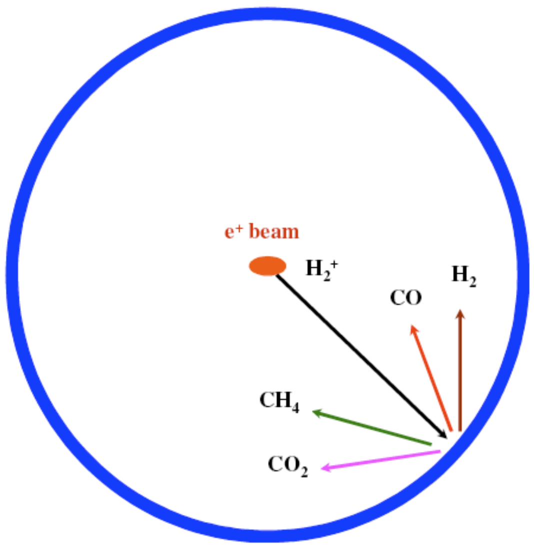
- Due to residual gas ionization ions can be generated and then trapped around a bunch train
- Even if the presence of a gap between trains clears the ions, a **Fast Beam Ion Instability** (ex. SOLEIL below) can be excited over one train
- The threshold for this instability critically depends on the pressure in vacuum chamber (and residual gas composition)
- Usually the **FBII** has been observed in electron rings
  - During commissioning/start up (chamber not yet conditioned, bad vacuum)
  - Because of some localized pressure rise (e.g., directly connected to heating caused by impedance degradation)
  - Artificially induced by injecting gas into the chamber and raising the pressure by more than one order of magnitude
- It seems to be stabilized by other effects (yet to be explained)
- No quantitative comparison between theoretical predictions and measurements

O. Malyshev

Two-stream phenomena

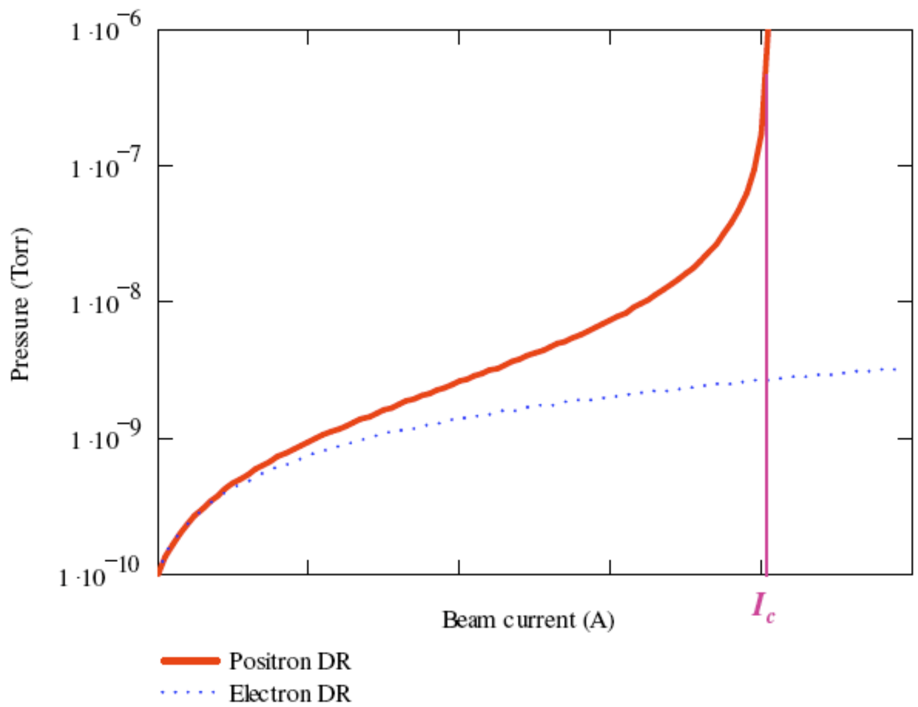
Ion effects in positron rings

- Ions from gas ionization can also cause trouble in the positron DRs
- When lost to the chamber walls, they produce more molecules according to their energy and the wall desorption yield
- Consequently, more ions are produced and the process can lead to an **ion induced pressure instability**



- **Use of NEG coating fully eliminates the probability of the ion induced pressure instability.**

From O. Malyshev



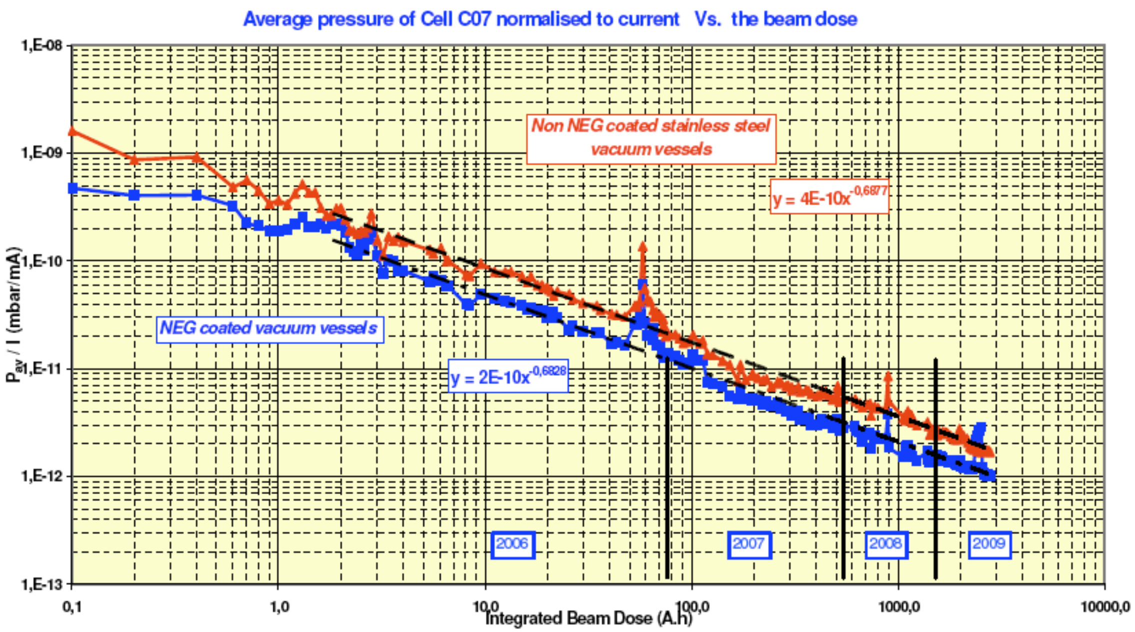
Two-stream phenomena

C. Herbeaux

Suppression of the ion effects

- Very good vacuum required
  - **In the electron DR, to be sure that we are far enough from the FBII threshold**
  - **In the positron DR, to be sure that there is no pressure instability**
- NEG coating seems a good option
- Other types of coatings (provided they are UHV compatible) could be envisioned for the positron DR (against electron cloud, see next slides)
- SOLEIL experience shows the advantages of activated NEG coating
  - Lower photon stimulated desorption
  - No vacuum limitation at the beginning, fast recovery after venting + re-activation

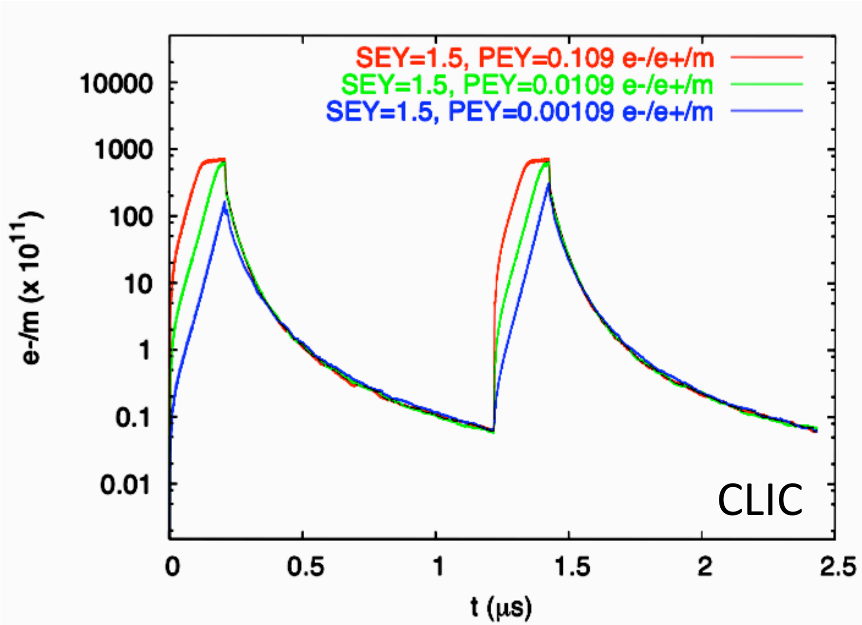
→ But ALS has uncoated Al chambers and seems to have equally good performances…

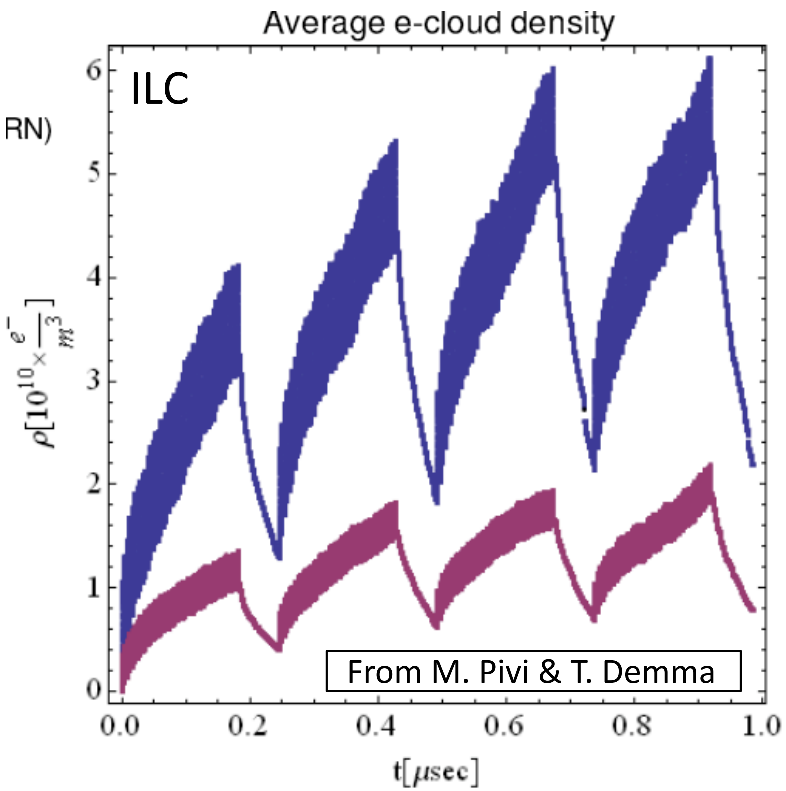


Two-stream phenomena

Electron cloud

- In the positron DR, **electron cloud formation** is an issue
- Primary electrons (seed) come from:
  - Photoemission from synchrotron radiation (can be significant even without multiplication)
  - Gas ionization (negligible)
- Multiplication to be avoided by keeping the Secondary Emission Yield below 1.



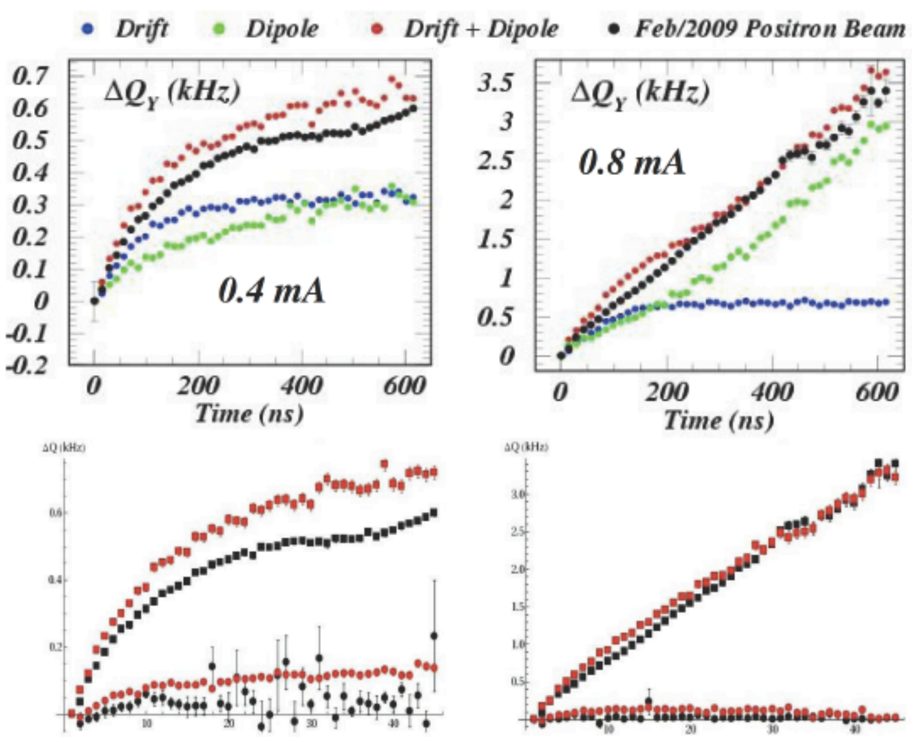


Simulations show that both for the CLIC and ILC DRs SEY<1.2 is necessary, as well 99% absorption of the SR

Two-stream phenomena

Electron cloud simulations

- **Electron cloud simulations** are based on codes for
  - Build up (ECLOUD, POSINST, CLOUDLAND,..)
  - Single bunch instability (HEADTAIL, PEHTS, WARP, CMAD,…)
  - Coupled bunch instability (PEI-M)
- Based on tune shift measurement, code predictions have been benchmarked against experimental data at Cesr-TA (simulation parameters tuned)



With appropriate care taken to be sure that the cloud models are the same, both POSINST and ECLOUD give similar results.

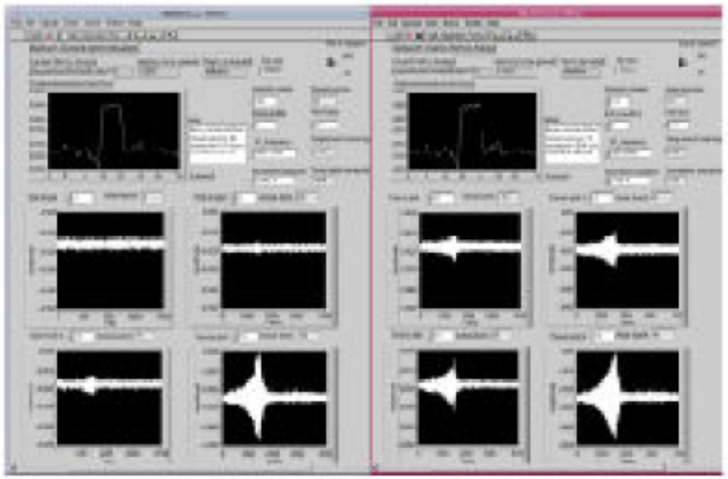
ECLOUD

POSINST

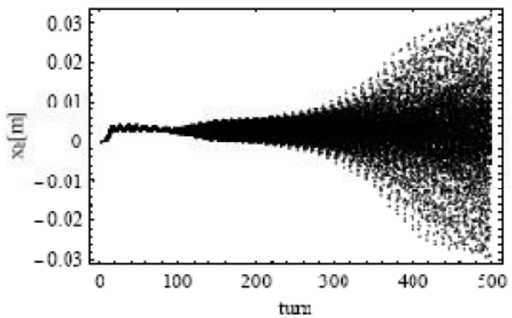
From G. Dugan

Two-stream phenomena
Electron cloud simulations

- **Coupled bunch instability** data from DAFNE (only positron ring) have been compared with the simulations with PEI-M
- Very good agreement found, which confirms that the observed instability is caused by electron cloud



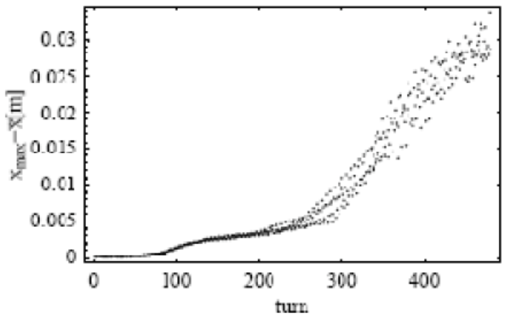
Horizontal instability on mode -1

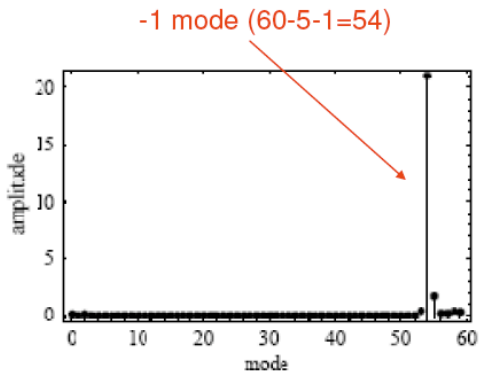


60 equispaced bunches

Beam current 1.2 A

Growth time ~ 100 turn



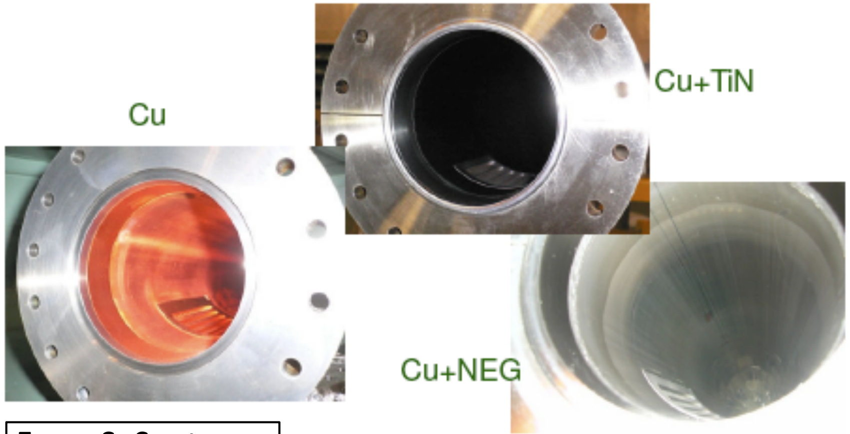


From T. Demma

Two-stream phenomena

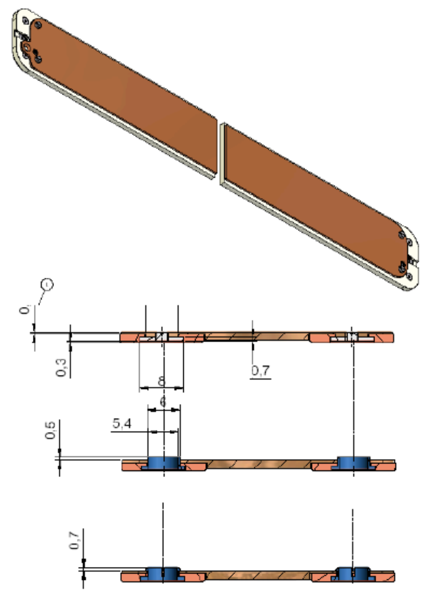
Electron cloud **mitigation/suppression** techniques

- To combat electron cloud:
  - Surface coating with low SEY materials (Cu, NEG, TiN, a-C)
  - Non-smooth surfaces (natural roughness, grooves)
  - Clearing electrodes
  - Solenoids
  - Conditioning, scrubbing

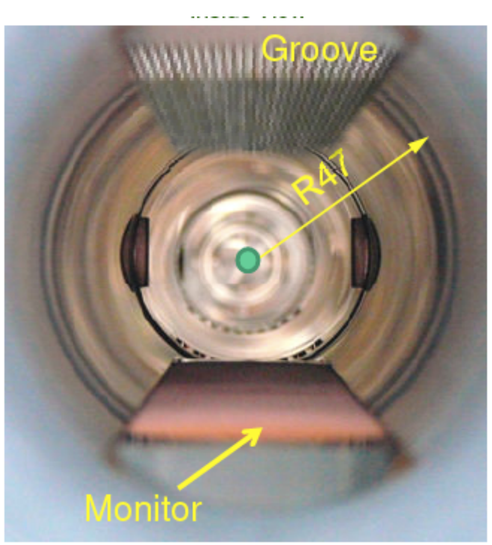


From S. Suetsugu

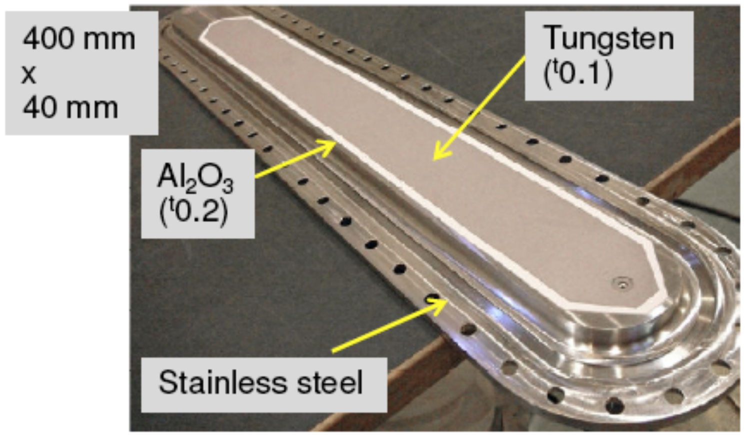
Clearing electrodes for DAFNE



From T. Demma

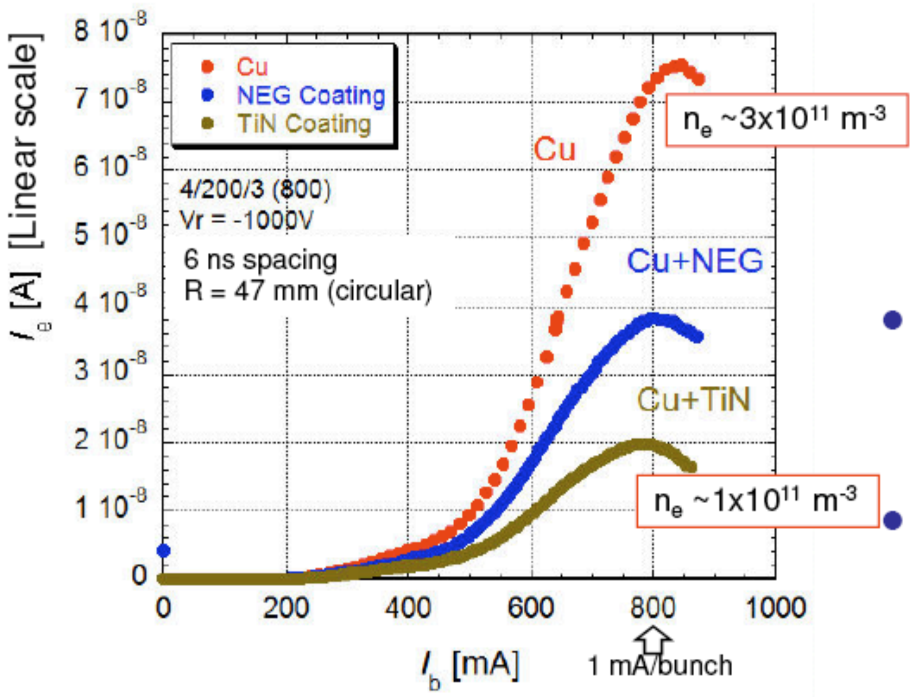


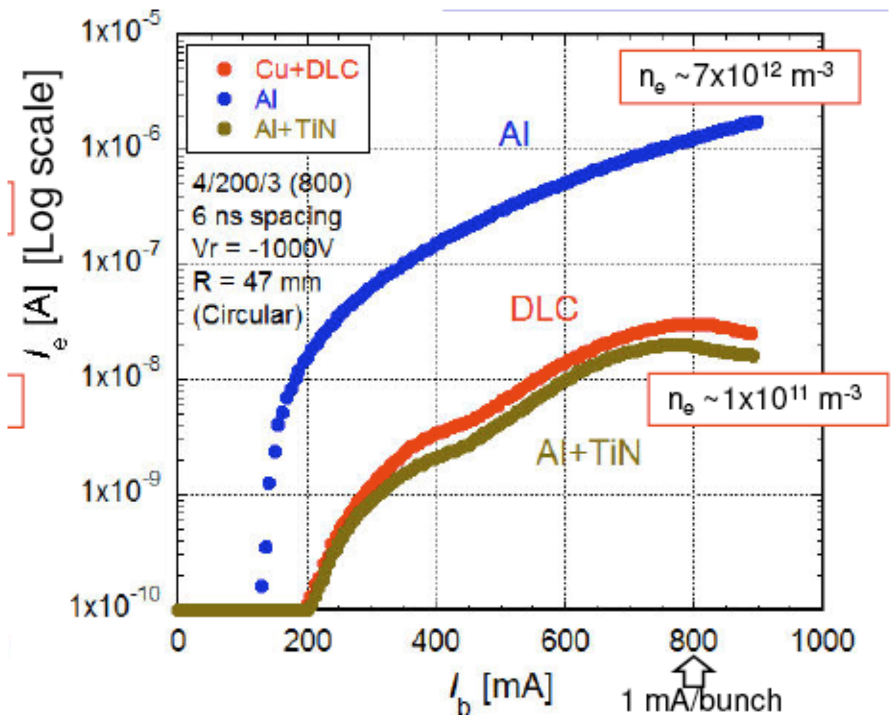
An insertion for test with a thin electrode



Two-stream phenomena
Surface coating (I)

- Experience with **coatings** at KEK shows that:
  - Aluminum needs to be coated!
  - TiN coating is better than NEG coating
  - However, TiN coating shows large desorption at the beginning (improves with scrubbing)



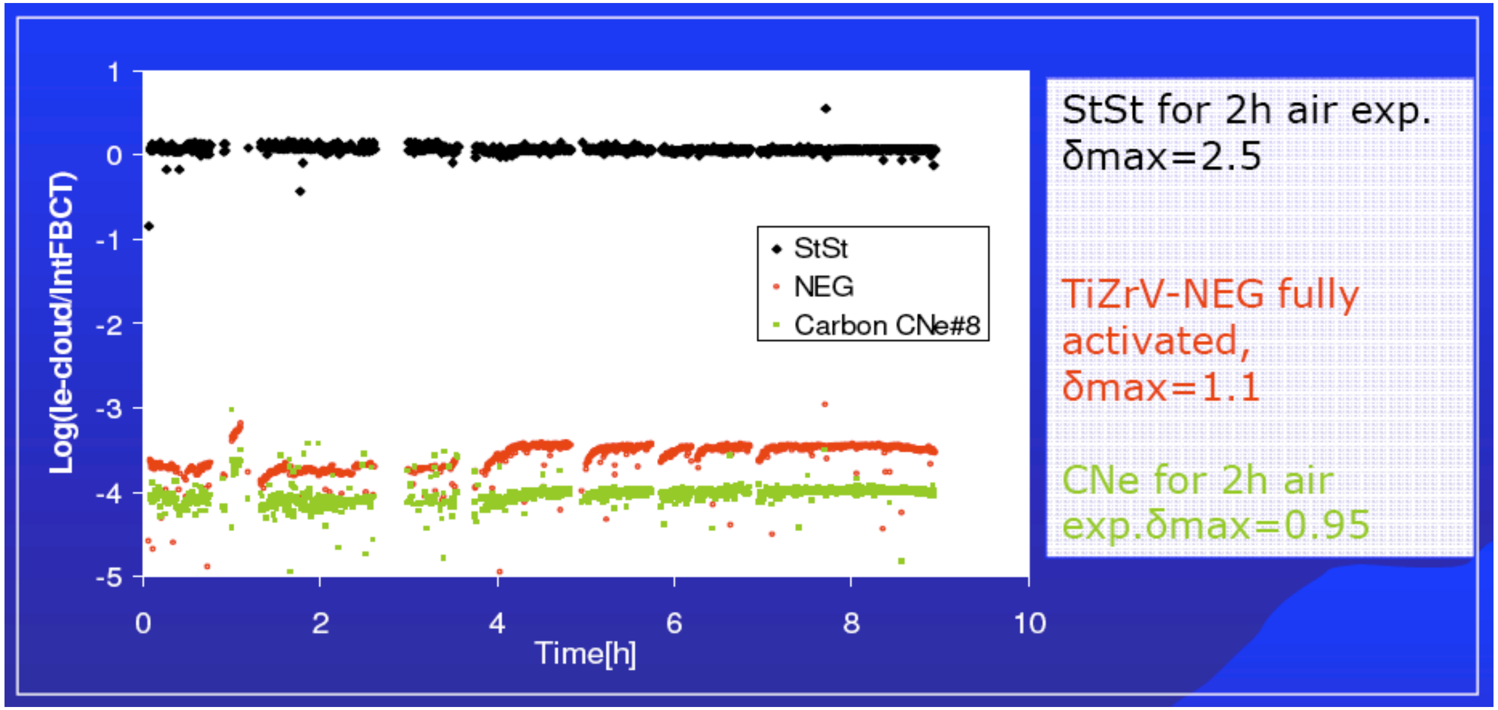


From S. Suetsugu

Two-stream phenomena

Surface coating (II)

- Experience with **coatings** at CERN shows that:
  - Stainless Steel has maximum SEY>2
  - a-C coating is slightly better than NEG coating (from direct electron signals)
  - Pressure data on a-C coated vs. uncoated chambers not fully understood yet
  - In any case, a-C does not need activation/baking and the experience at the SPS over 1.5 years shows that it is stable and very robust against ageing.

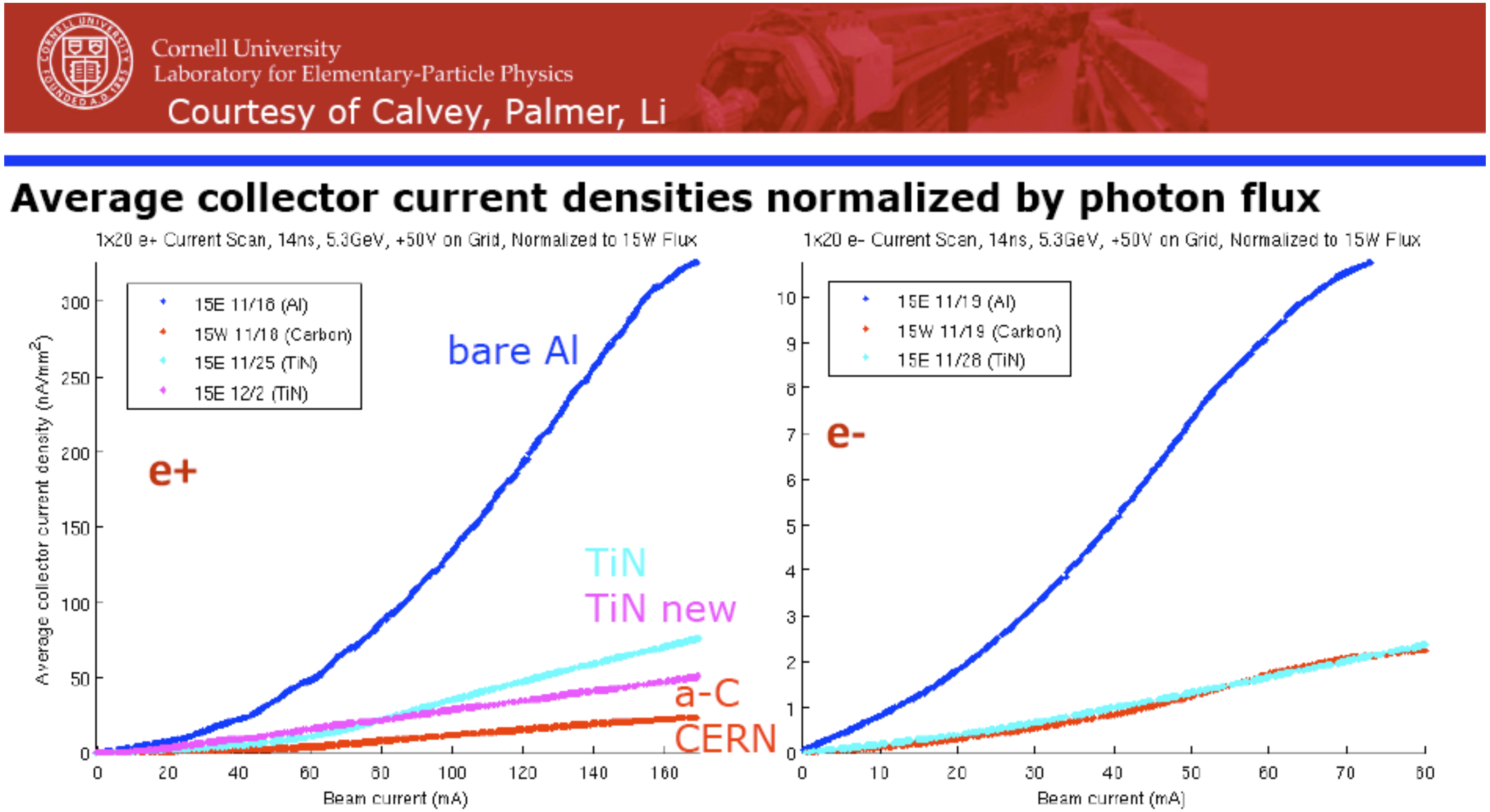


From M. Taborelli

Two-stream phenomena

Surface coating (III)

- Experience with **coatings** at Cesr-TA shows that:
  - a-C is well behaved also with respect to photoemission (at least factor 10)
  - a-C coating is slightly better than TiN coating, at least with positrons
  - RGA shows peaks for CO and CO_2 at the gauge close to the a-C coated chamber

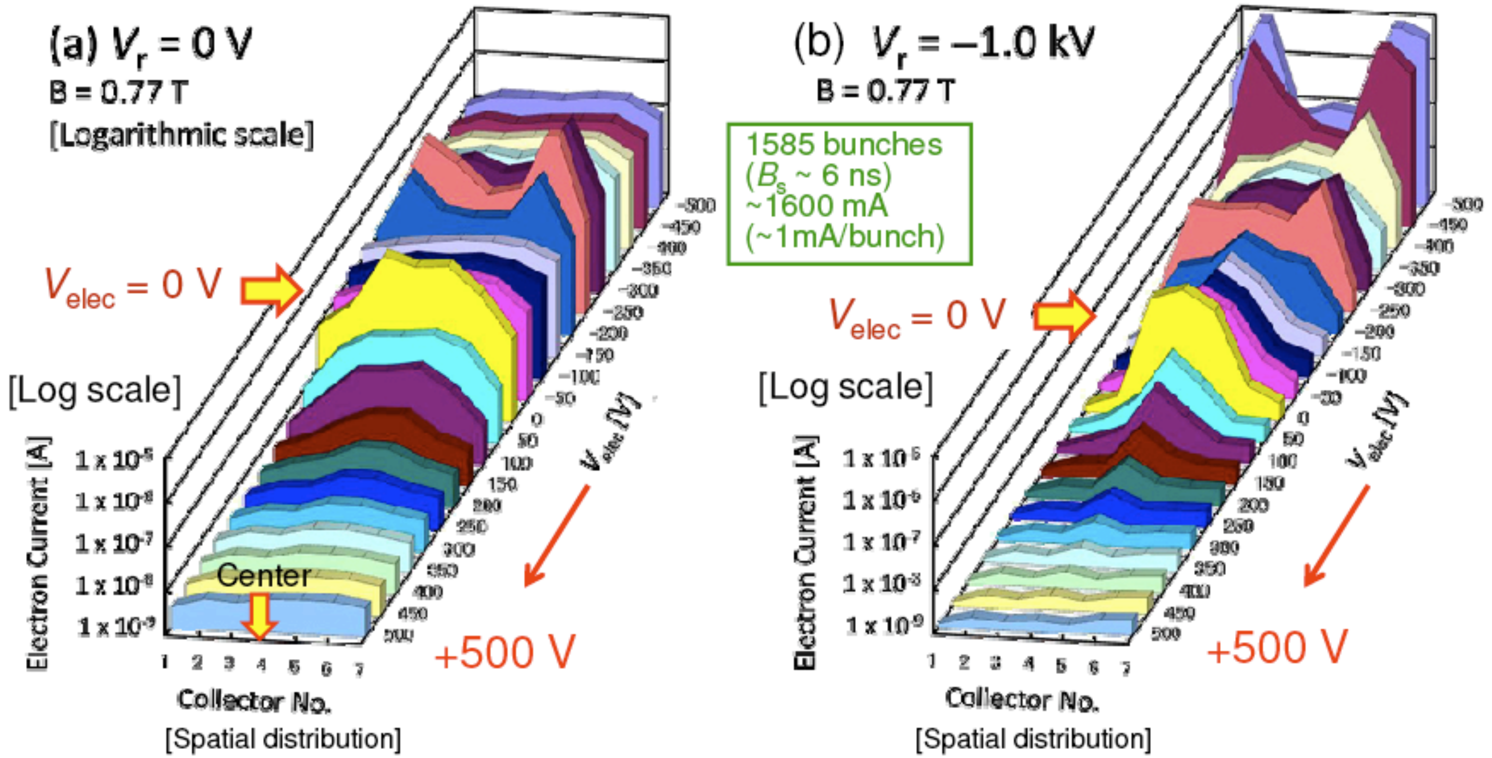


From M. Taborelli

Two-stream phenomena

Clearing electrodes

- Experience with **clearing electrodes** shows that:
  - There is a drastic reduction of the electron cloud when the voltage is applied
  - Beware of the impedance!
  - Low impedance design needed

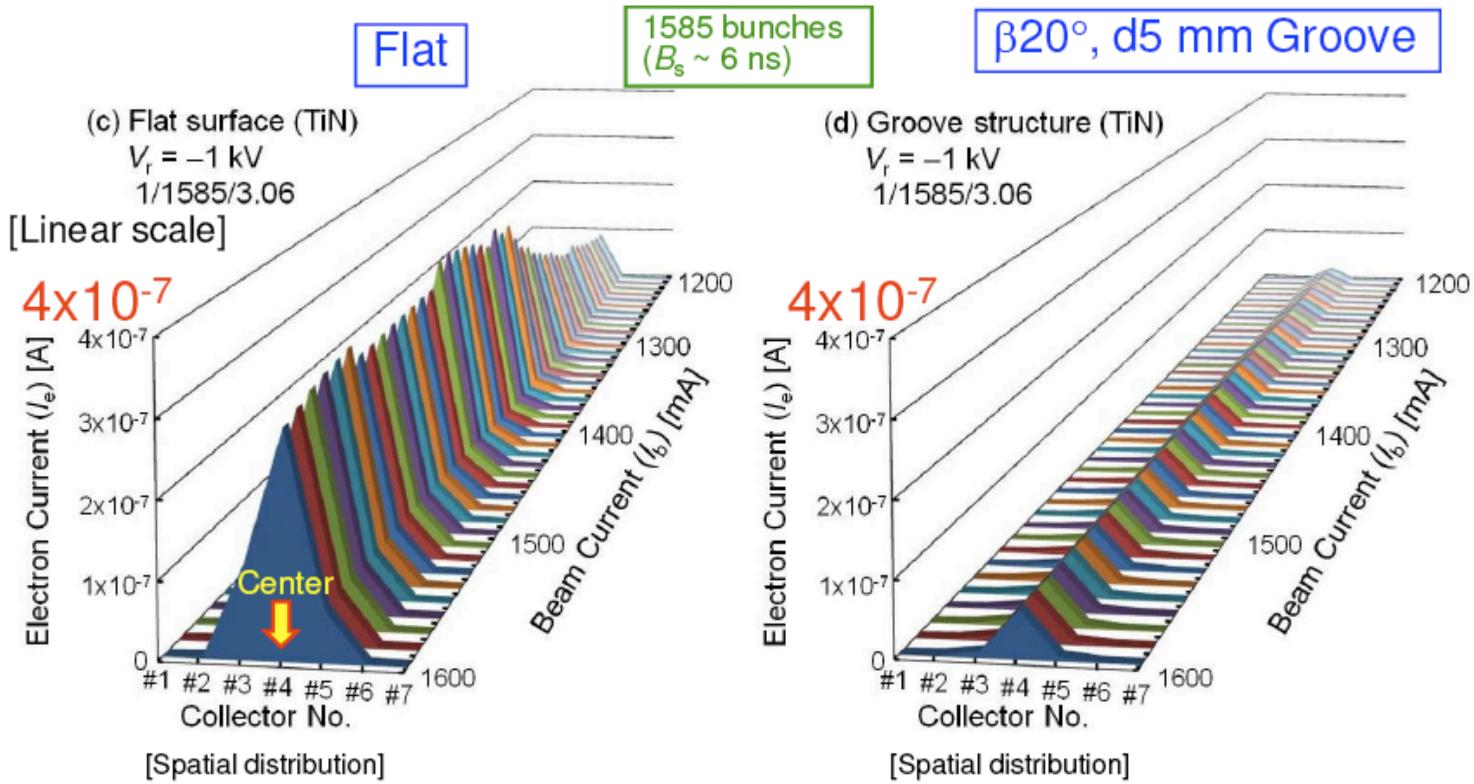


From S. Suetsugu

Two-stream phenomena

Grooved surface

- Experience with a **grooved surface** at KEK shows that:
  - Also grooves are effective against cloud formation
  - No significant change with beam dose, however it produces less electrons than all the other surfaces
  - Impedance does not seem to be an issue (GdfidL simulations)

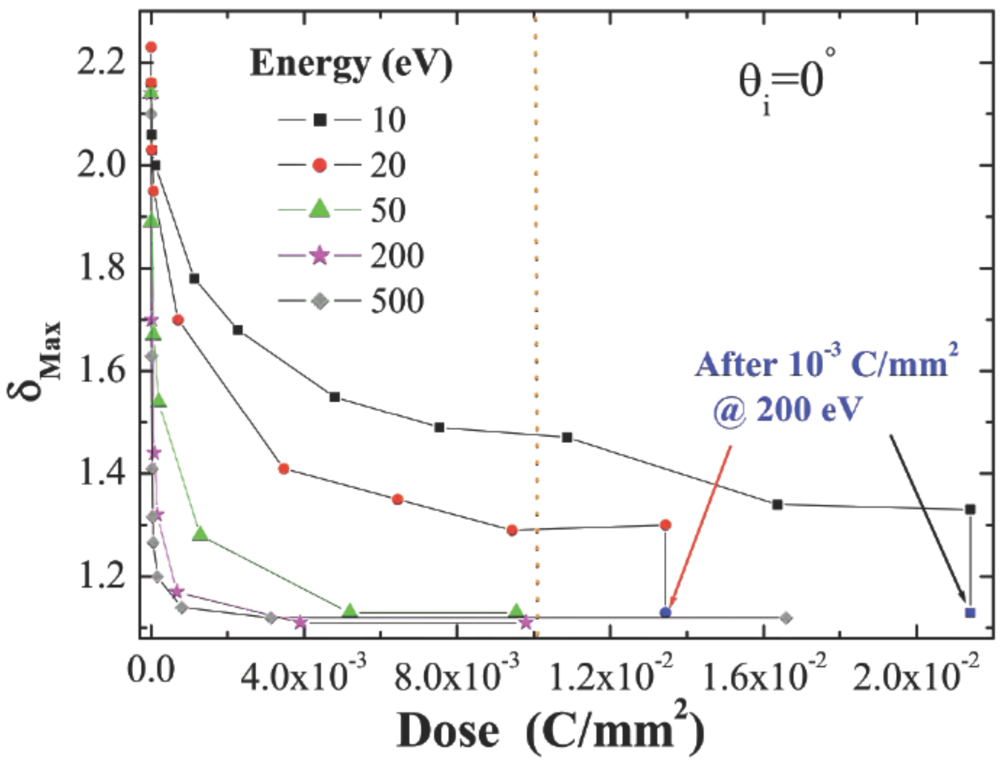


From S. Suetsugu

Two-stream phenomena

Conditioning, scrubbing

- Many machines rely on **scrubbing** to reduce the SEY of the pipe walls and increase the current threshold for electron cloud build up
  - The scrubbing "e-folding dose" depends on the energy of the impinging electrons
  - The final SEY value also depends on the energy of the electrons, low energy electrons (which dominate the energy spectrum in an e-cloud) are not equally efficient

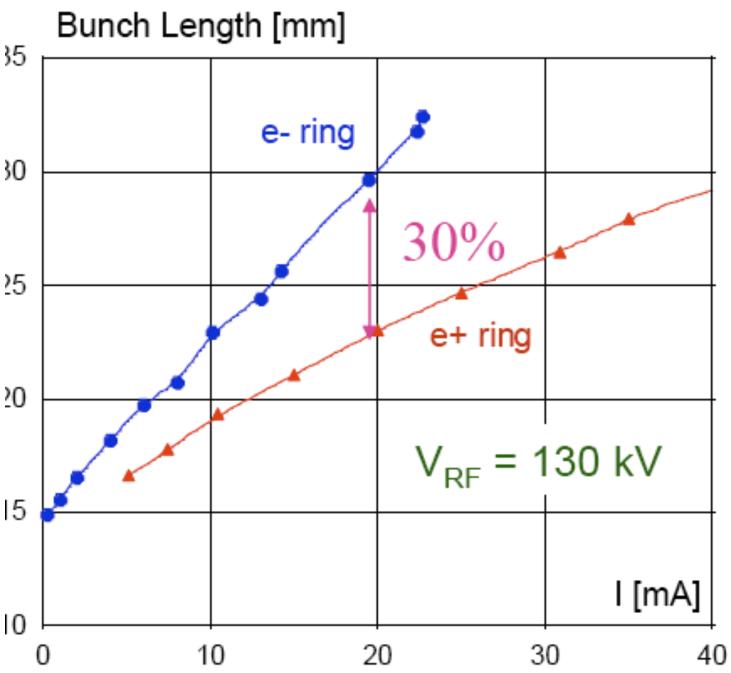


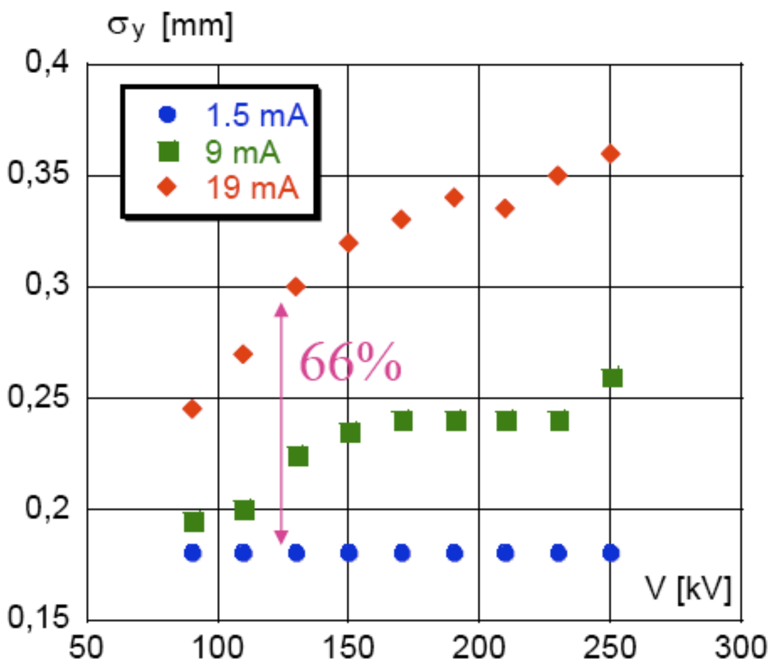
From R. Cimino

Impedances

Clearing electrodes: impedance issue

- Clearing electrodes at DAFNE (originally installed in the electron ring, to clear from ions) shows that:
  - They can significantly contribute to the impedance
  - Bunch lengthening, quadrupole instability, vertical emittance blow up (they all disappeared after removing the electrodes)
  - New low impedance design being implemented for the electron clearing electrodes to be installed in the positron ring



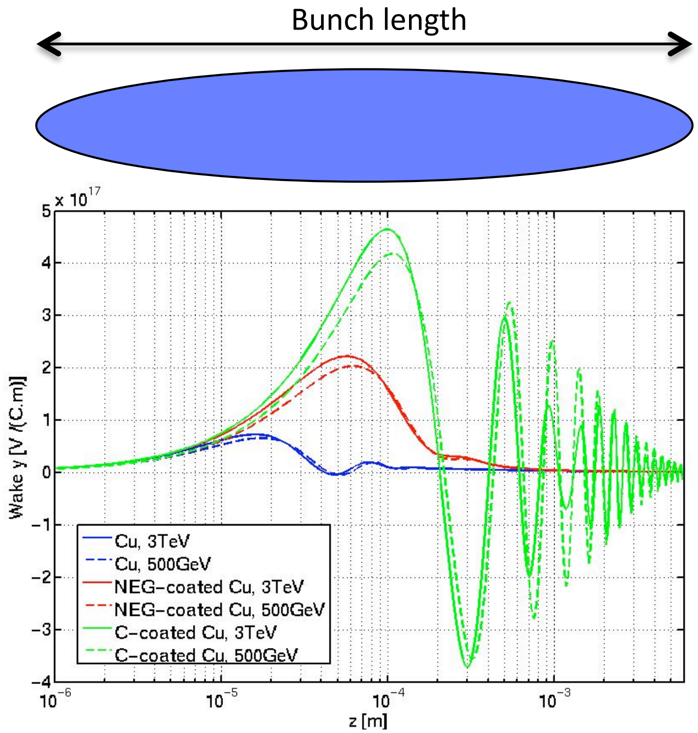


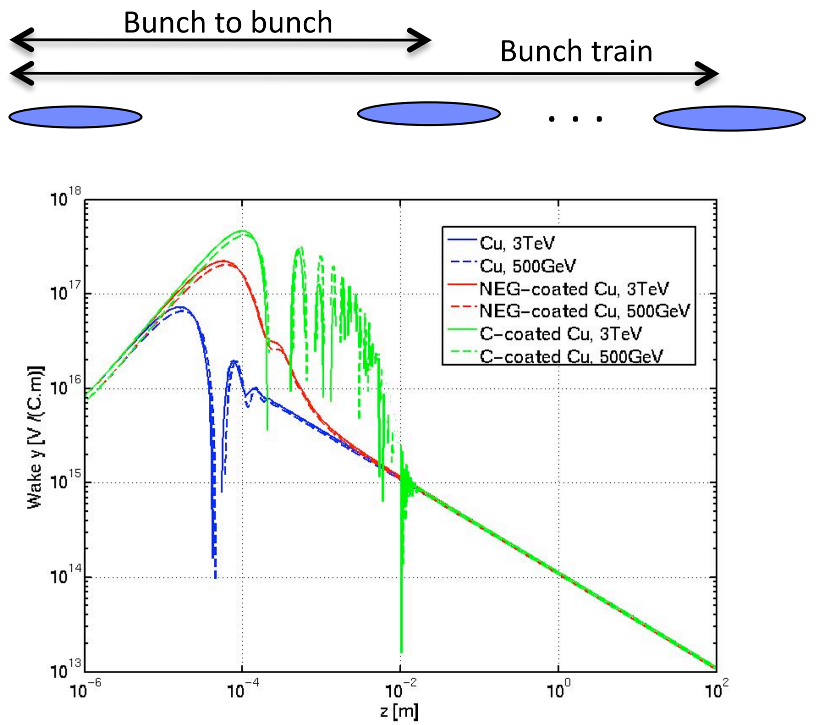
From M. Zobov

Impedances

Resistive wall impedance: high frequency & coating

- The resistive wall phenomena in the DRs need to be studied taking into account that:
  - The frequency regime to be covered is much higher, which also entails a few unknowns (a.c. conductivity, anomalous skin effect…)
  - The influence of coatings for vacuum or electron cloud suppression
- Solution found for axisymmetric structure with multi-layer boundary
  - Impedance and wake field (needed for beam dynamics simulations with HEADTAIL)



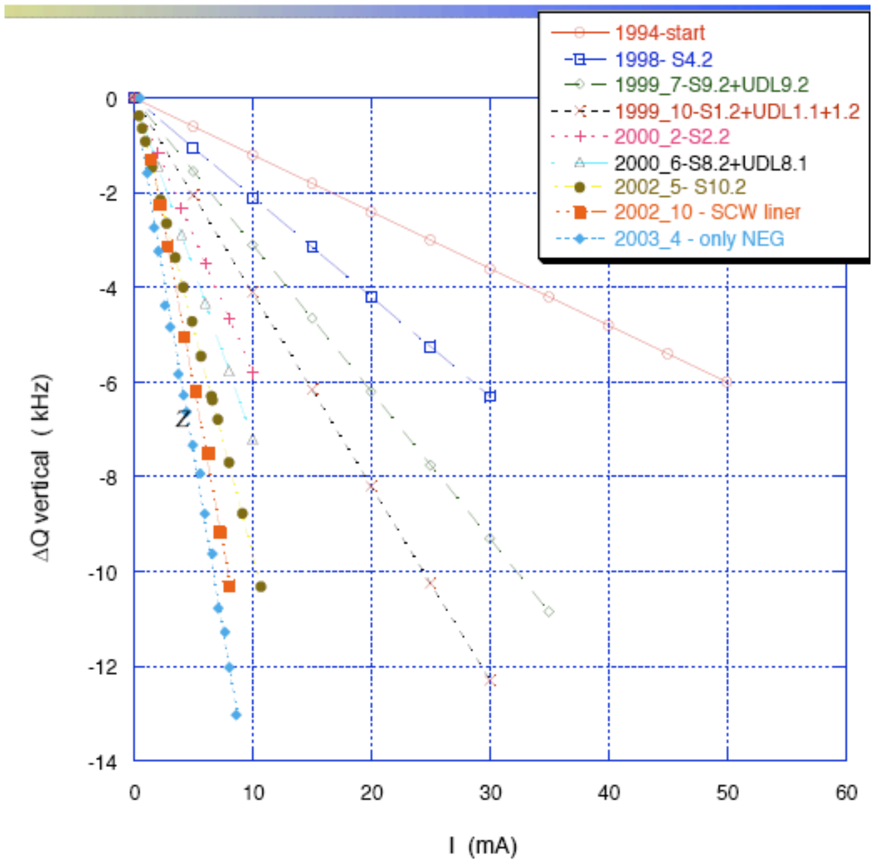


From N. Mounet

Impedances

Influence of coating on the ring impedance

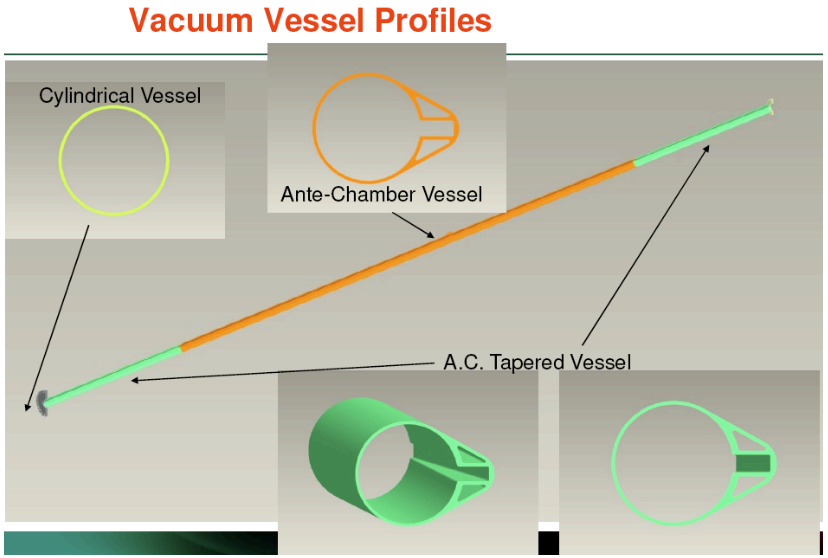
- At ELETTRA an increase of the slope of the tune shift with intensity was observed after the installation of NEG chambers
- More measurements done at ESRF and Soleil showed that NEG coating should have increased the machine impedance by a smaller amount



From E. Karantsoulis

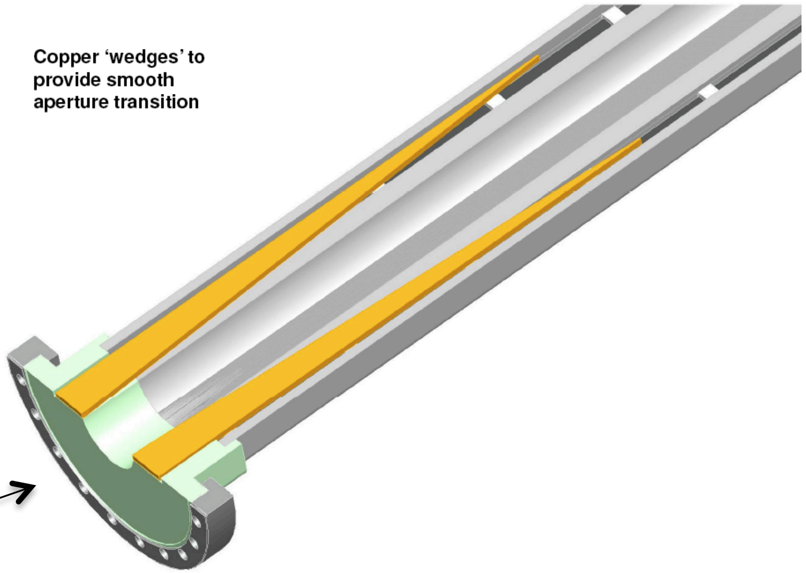
Impedances
General

- The accelerator design must be oriented to impedance minimization
  - Smooth design based on tapering without abrupt transitions (broad-band impedance, especially important for single bunch stability)



Tapering to chamber with antechamber

ILC vacuum vessels design



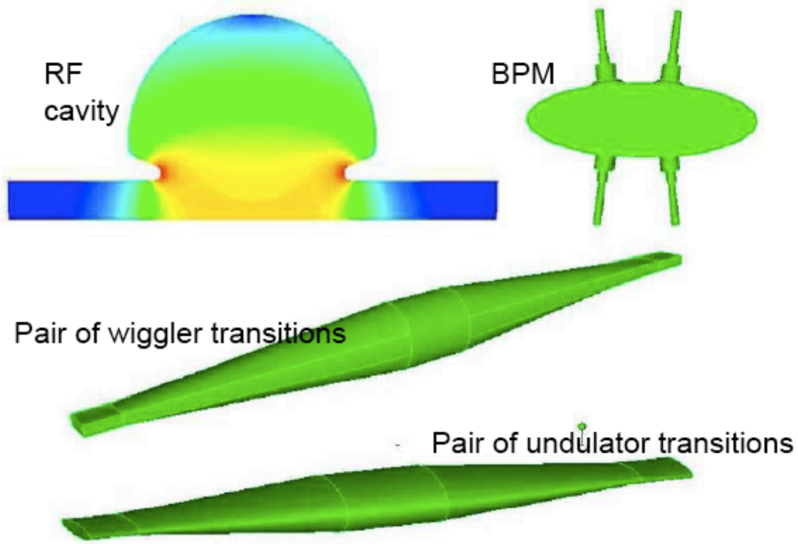
Tapering to the wiggler chamber

From O. Malyshev

Impedances
General

- The accelerator design must be oriented to impedance minimization
  - While designing a future facility, the contributions to the impedance can be evaluated based on existing machines
  - All contributions summed up and compared with the impedance budget

Selected Impedance Sources



Selected impedance objects included in our straw man PEP-X design.
inspired by objects in other machines, such as PEP-II

Impedance Budget

Object	Single Contribution			Total Contribution			
	k_{loss}[V/pC]	R [Ω]	L [nH]	N_{obj}	k_{loss}[V/pC]	R [Ω]	L [nH]
RF cavity	.92	30.4	–	16	14.7	487	–
Undulator taper (pair)	.06	3.2	.32	30	1.9	95	9.6
Wiggler taper (pair)	.43	21.4	.72	16	6.8	340	11.5
BPMs	.013	.6	.005	839	11.3	465	4.1
Bellows slots	.00	.0	4e-4	720	.0	.0	.3
Bellows masks	.005	.2	.004	720	3.7	142	2.7
Resistive wall wake					21.3	880	11.3
Total					59.7	2409	39.5

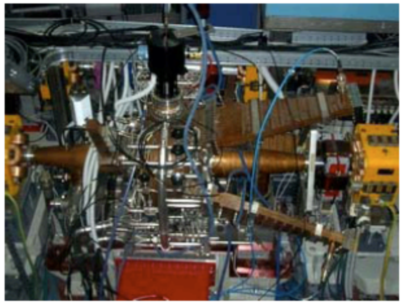
Impedance budget for PEP-X,

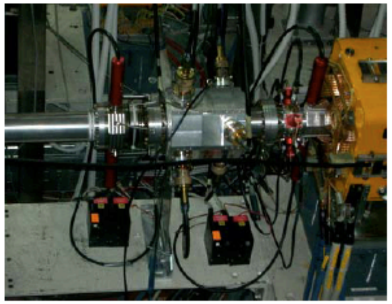
From K. Bane

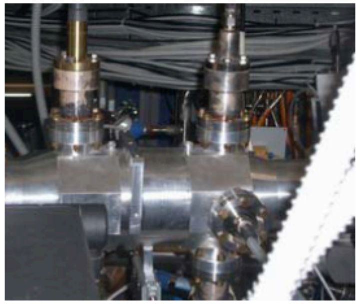
Impedances
General

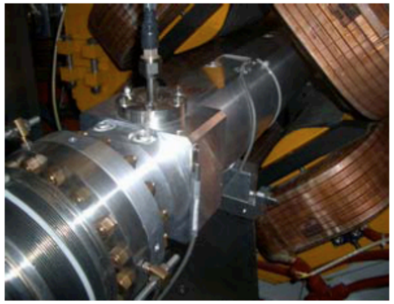
- The accelerator design must be oriented to impedance minimization
  - HOM as well as potentially harmful trapped modes have to be damped (narrow-band resonators, especially important for coupled bunch stability)

HOM Damped Vacuum Chamber Elements

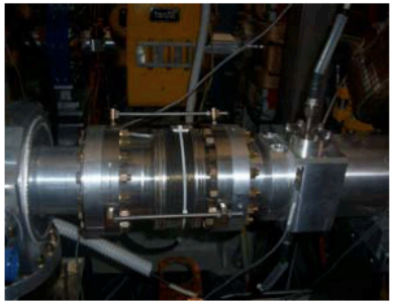

RF CAVITY


LONGITUDINAL KICKER


TRANSVERSE KICKER

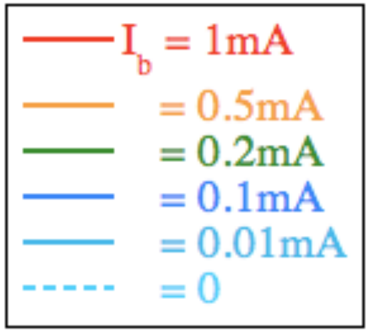

INJECTION KICKER


WALL CURRENT & DCCT MONITOR

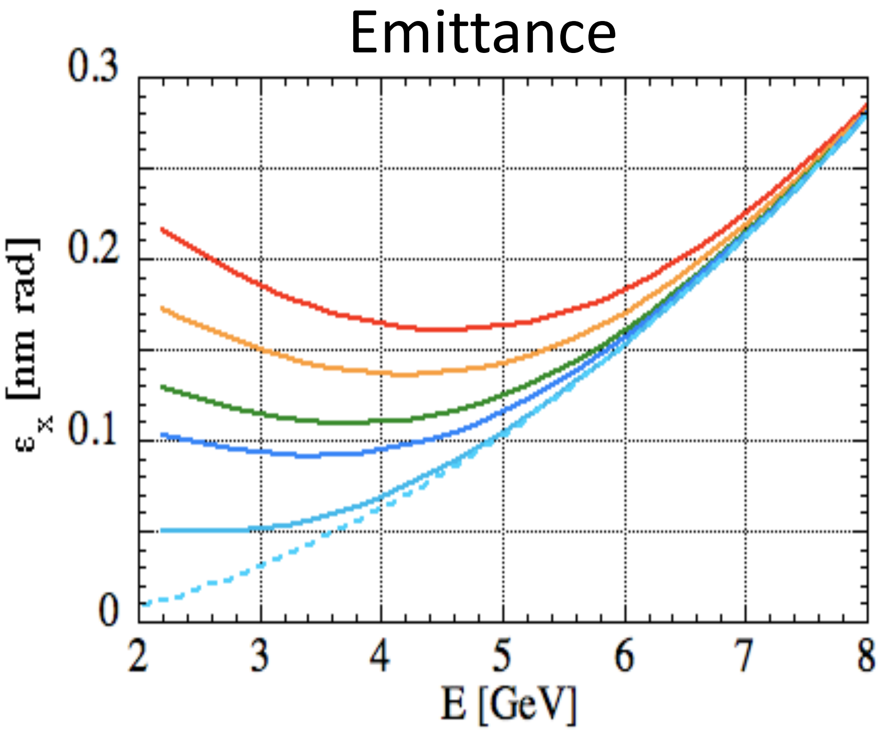

SHIELDED BELLOWS

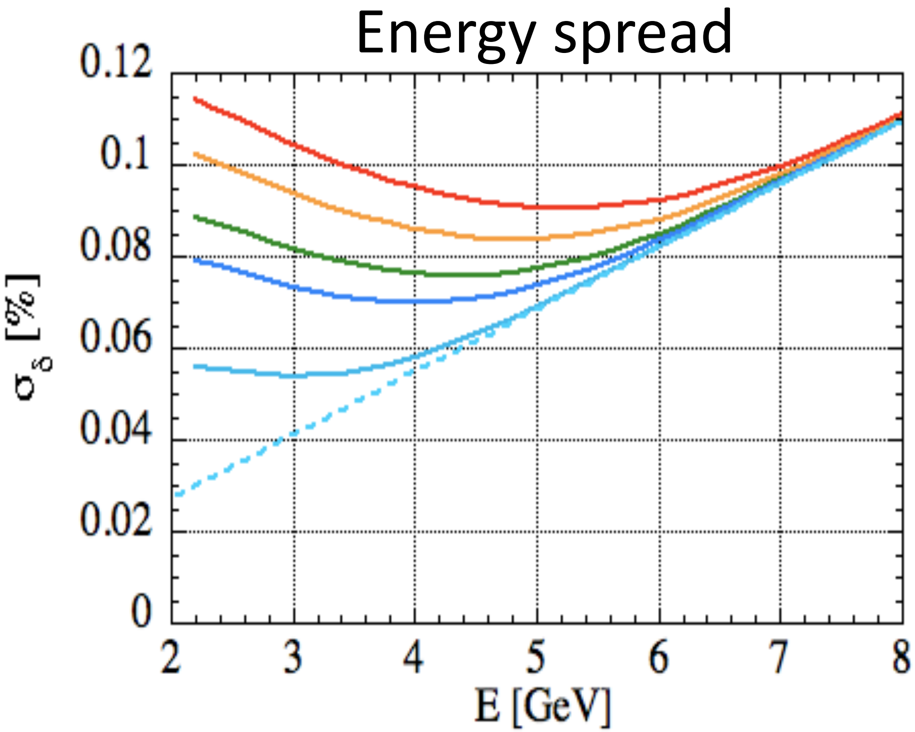
From M. Zobov

Intra-beam scattering (IBS)



Conditions for calculation
QB lattice: ε_y = 10 pm.rad, V_{rf}/U_0 = 2.4 (7MV@6GeV)
w/o potential well distortion





T. Watanabe, K Sutome

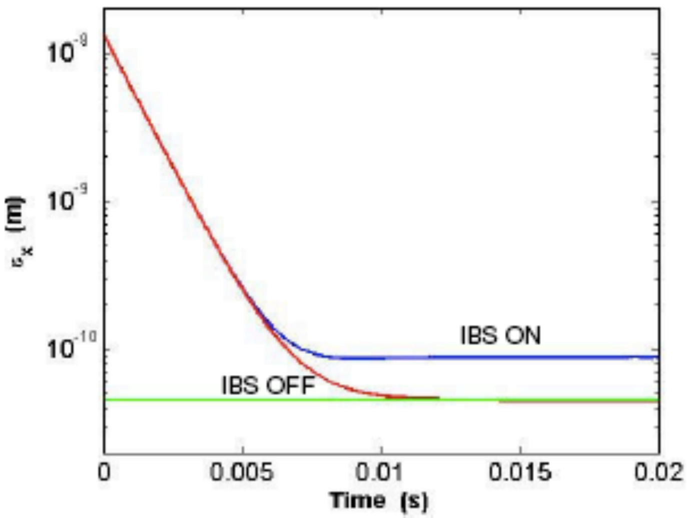
K.Bane, PRST-AB 5(2002)084403

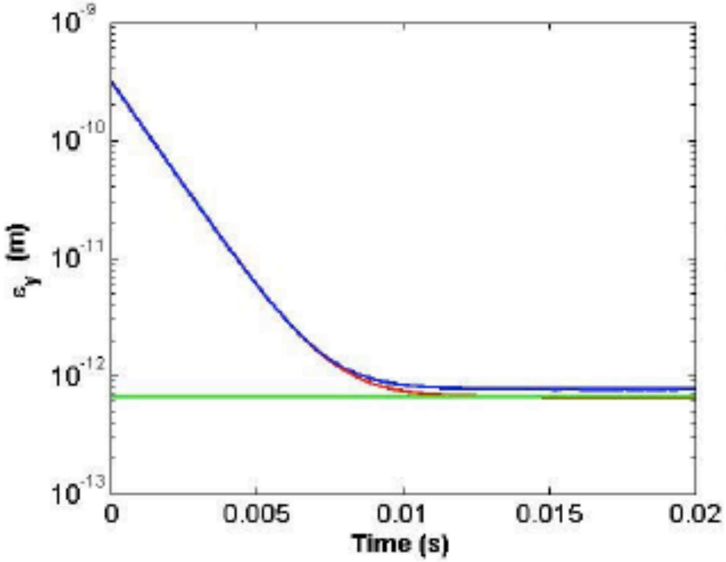
We will determine the electron energy, watching the development of insertion device technologies (Mini-Pole U., Cryo-U., ...).

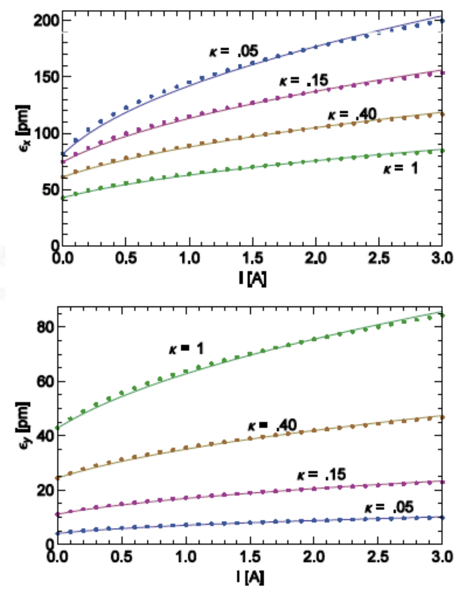
Intra-beam scattering

- High brilliance is also associated to strong **IBS**, which are potentially responsible for beam quality degradation, or could prevent a DR from reaching the design emittance
- Should be considered in the lattice design
  - **IBS** modeled taking into account a self-consistent particle distribution for the CLIC DRs. While the vertical emittance levels off to a value very close to nominal, the horizontal emittance is almost twice the nominal value.
  - Bjorken-Mtingwa (BM) method with a fast algorithm, applied to PEP-X calculations

K. Bane







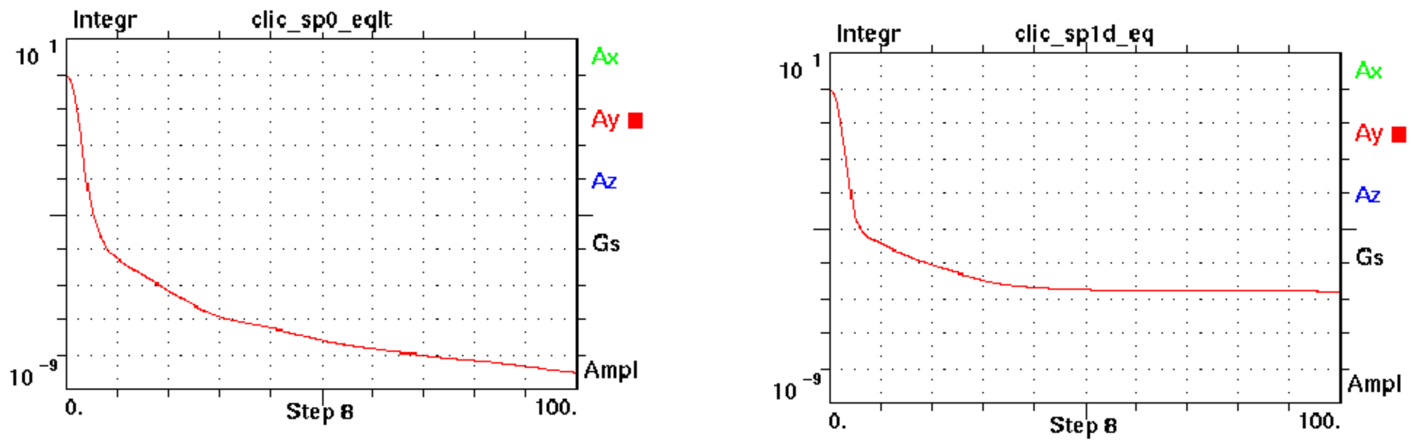
A. Vivoli

Steady-state emittances as function of current in PEP-X for various couplings. Dots give the solution to the fitted 1d equation.

Space charge effect

Here we start from the Gaussian distribution with equilibrium emittances. The resulting equilibrium distribution is shown below.

OFF ON



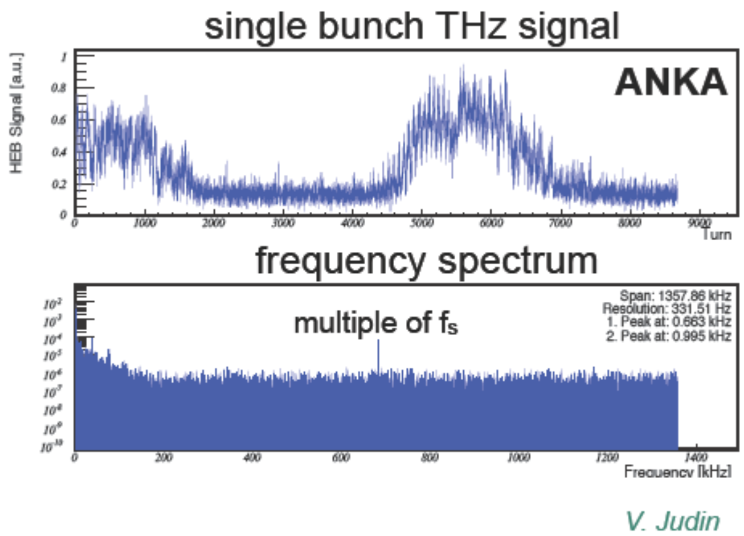
Fraction of particles (vertical axis, Log scale) located behind the vertical amplitude indicated in the horizontal axis. Without (left) and with the space charge effects.

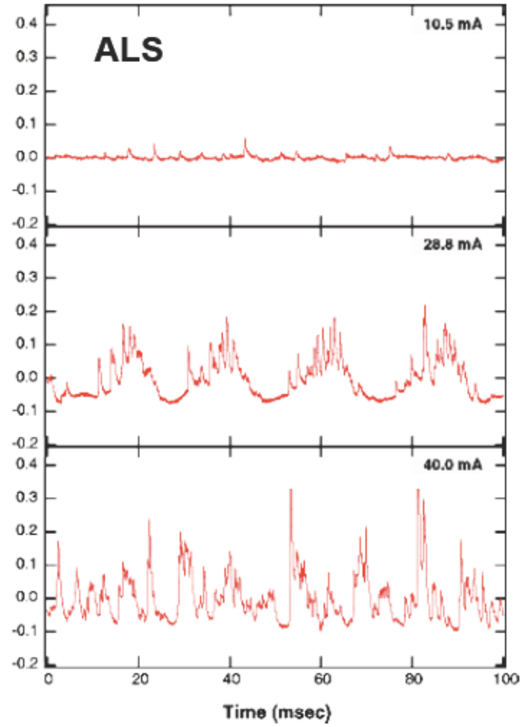
The fraction of particles on large amplitudes is rather small: 10^{-8} without and 10^{-6} with the space charge. **When crossing the resonances due to damping, this fraction becomes 10^{-2}.**

Instabilities & beam quality degradation

Coherent Synchrotron Radiation

- Unshielded **CSR** from main and fringe fields is an important effect for machines operating with short bunches (mainly in the THz regime)
  - CSR can cause a microwave-like instability
  - Saturation of this instability and radiation damping leads to a sawtooth-like patterna as a function of time
  - CSR changes with bunch current and shape





From A. Müller

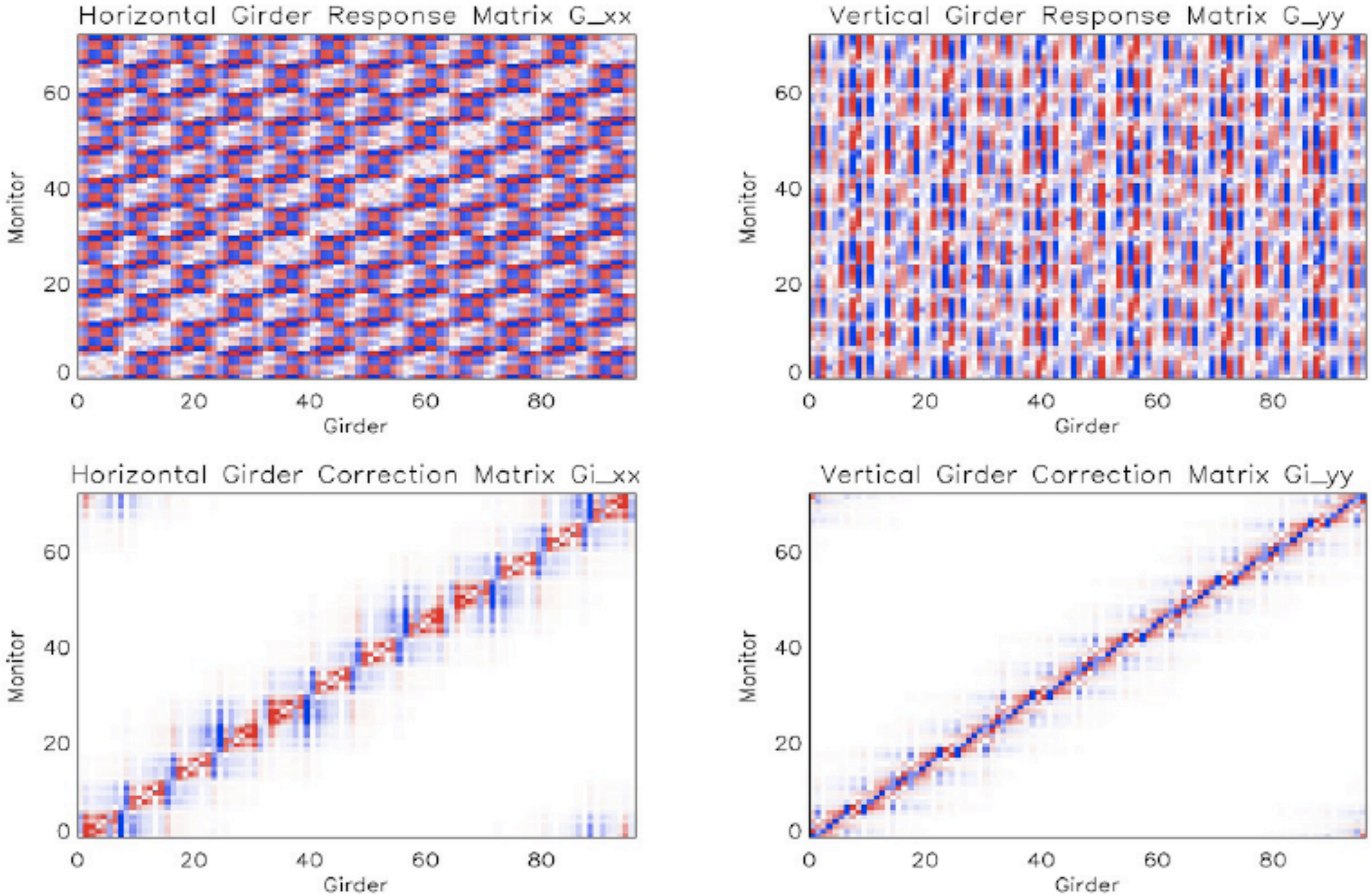
Low Emittance Rings technology

Beam Based Girder Alignment....

A. Streun

48 girders = 96 hor. & 96 vert. "correctors"   ($x_{2n/2n+1} = u_n \pm L\chi_n$)

Response and correction matrices:



PETRAIII wigglers

A. Kling

- Peak Field: 1.58 T
- Magnetic Gap: 24 mm
- Period Length: 20 cm
- Pole Width: 8 cm
- SR critical energy 35.8 keV
- Wiggler SR power 42.1 kW @ 200mA

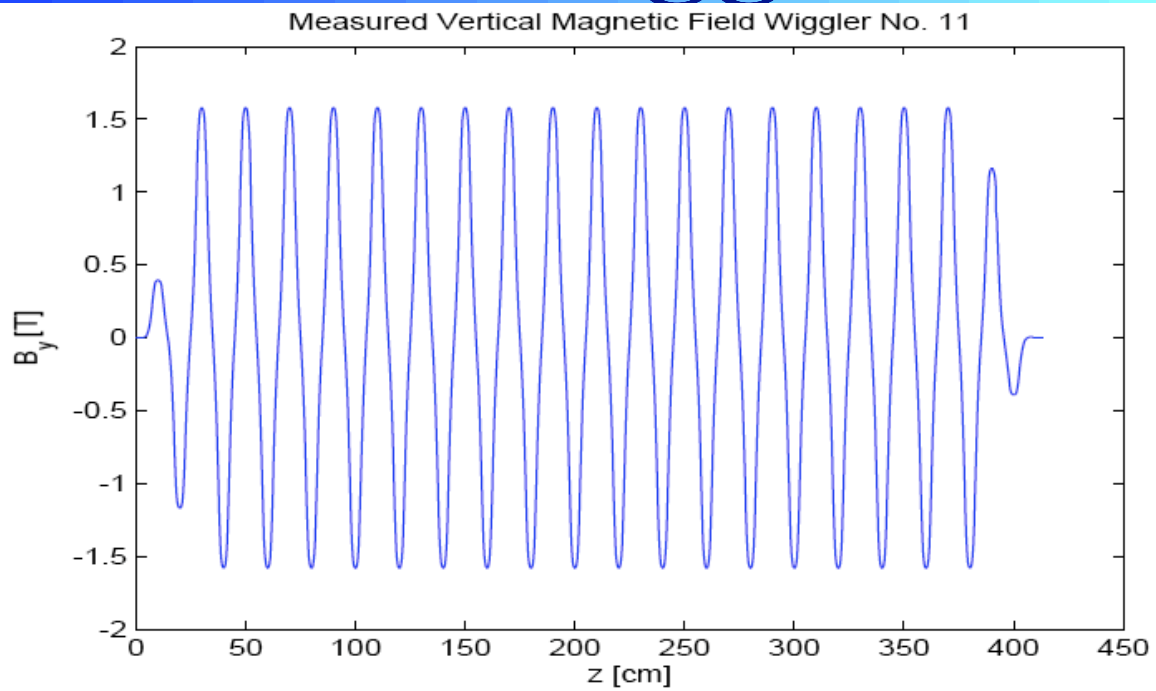


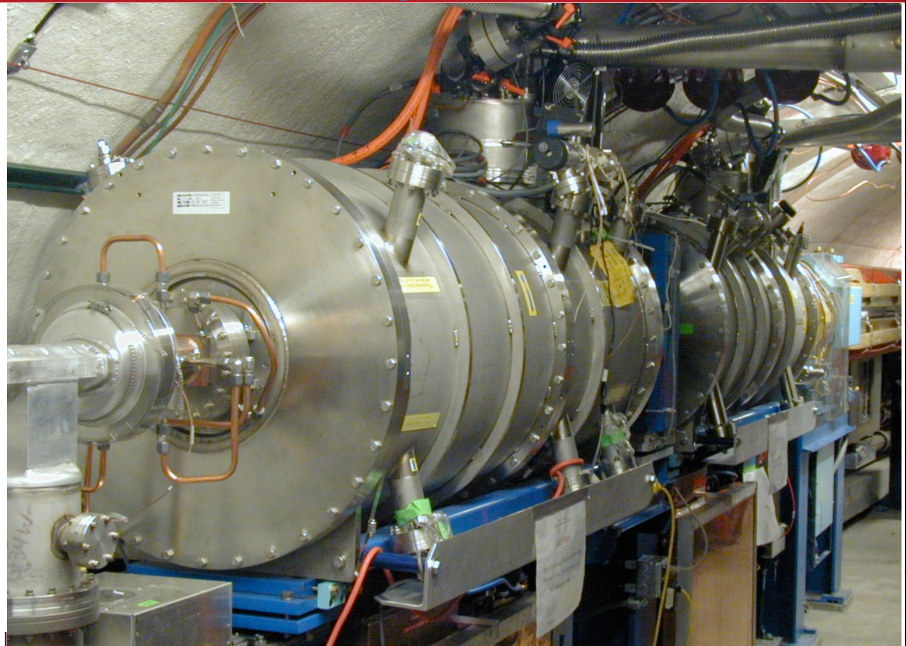
FIGURE: Vertical magnetic field after peak field tuning. $\Delta B/B_{\max} \approx 10^{-4}$

Parameter	Design	Achived
ε_x (nm rad)	1	1
ε_y (pm rad)	10	< 20
Current (mA)	100	89
Orbit Stability	10%	x o.k. / y almost
Single Bunch Current (mA)	2.5	2.5

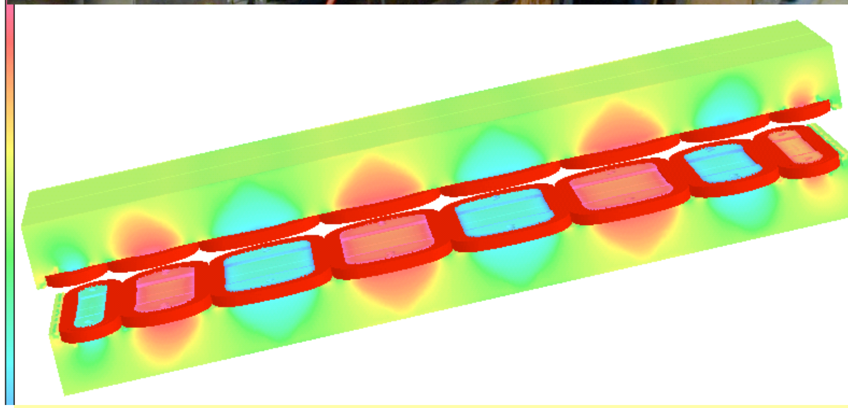
TABLE: Achievements in commissioning of PETRA III since April 2009.

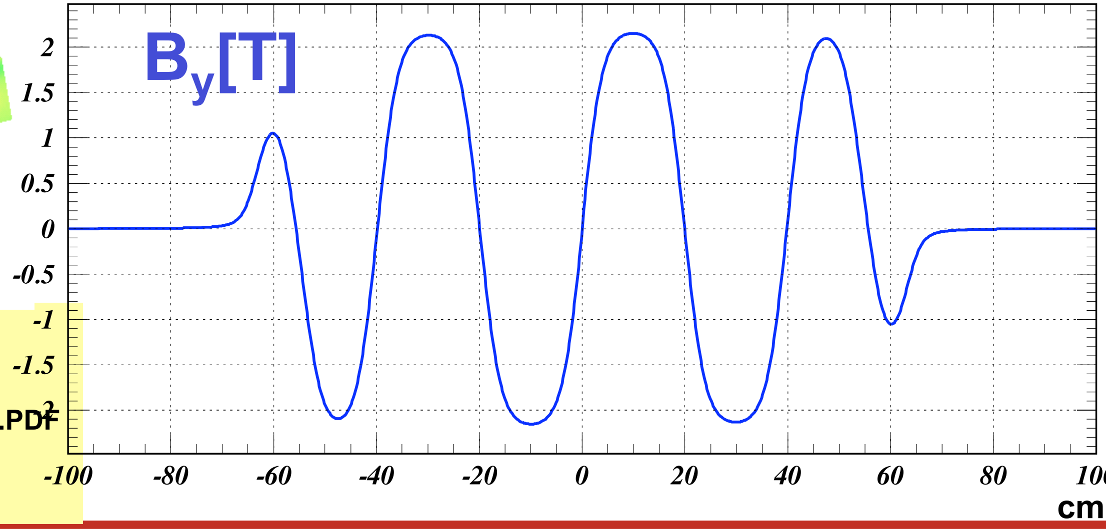
Cornell University
Laboratory for Elementary-Particle Physics
M. Palmer

CESR-c Damping Wigglers



B_{peak} [T]	2.1
Period [cm]	40
Pole gap [cm]	7.65
Beam Stay Clear [cm]	5.0
No. Poles	8
ΔQ_y	~0.1/wiggler
Magnetic Length [m]	1.3
Transverse Field Roll-Off	+0.0, -0.3% @ ±20mm
Static Heat Load @ 4K [W]	~1.3W
Static Heat Load @77K [W]	~40W





Further details:

PAC03 Paper (D. Rice *etal)*

http://accelconf.web.cern.ch/accelconf/p03/PAPERS/TOAB007.PDF

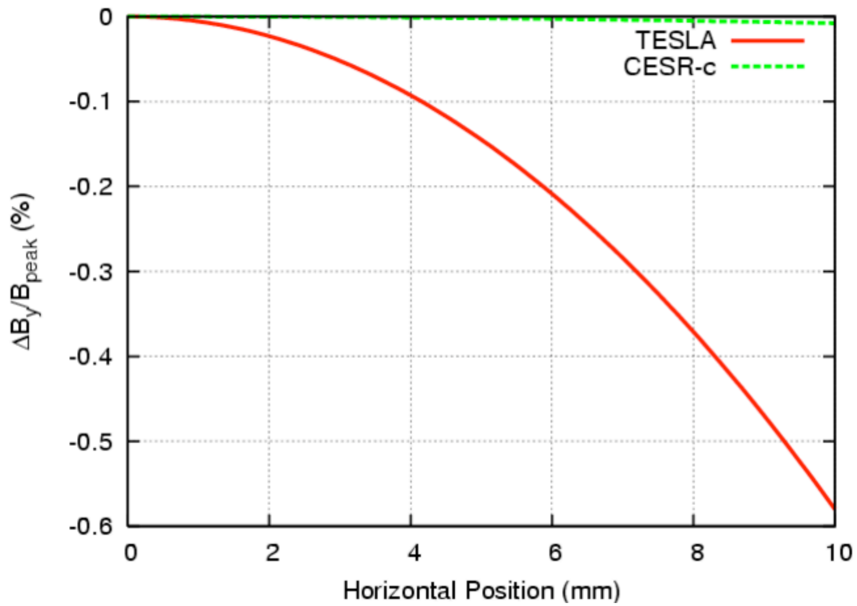
WIGGLE05 talk (A. Temnykh)

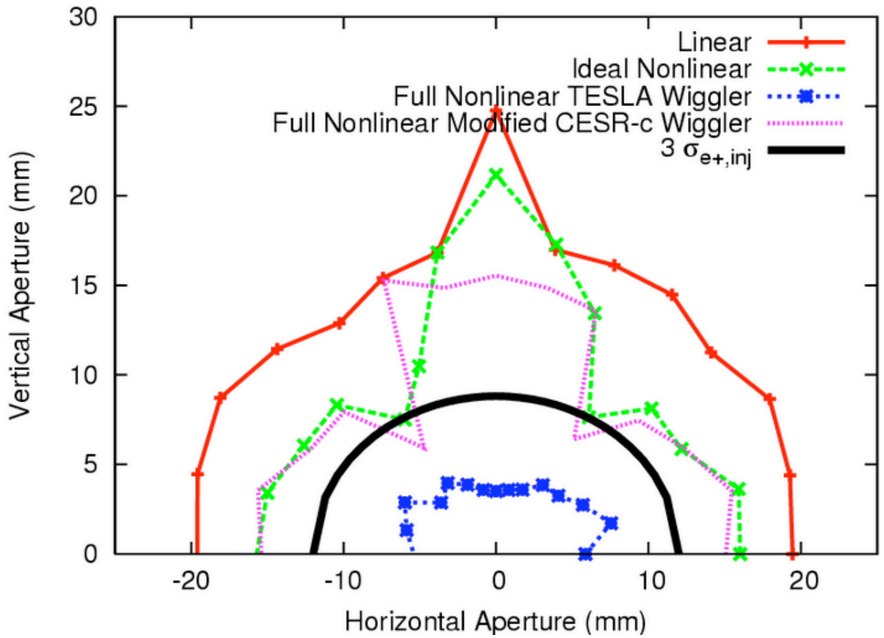
http://www.lnf.infn.it/conference/wiggle2005/talks/Temnyk.pdf

ILC DR Wiggler Choice

M. Palmer

- Basic Requirements
  - Large Physical Aperture
    - Acceptance for injected e+ beam
    - Improved thresholds for collective effects
      - Electron cloud
      - Resistive wall coupled bunch instability
  - Dynamic Aperture
    - Field quality
    - Wiggler nonlinearities





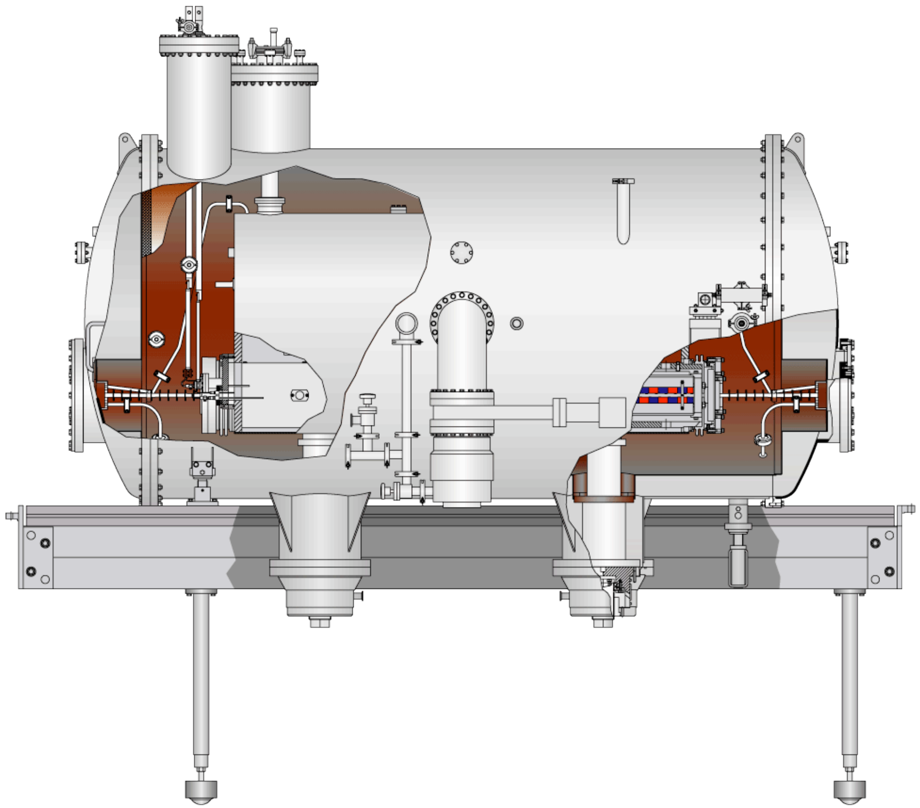
	TESLA	CESR-c	Modified CESR-c
Period	400 mm	400 mm	400 mm
$B_{y,peak}$	1.67 T	2.1 T	1.67 T
Gap	25 mm	76 mm	76 mm
Width	60 mm	238 mm	238 mm
Poles	14	8	14
Periods	7	4	7
Length	2.5 m	1.3 m	2.5 m

The MAX-Wiggler.

Two wigglers have been built for the beamlines I811 and I911 at MAX II.

Parameter list of the MAX-Wiggler.

Wiggler period	61 mm
Vertical Aperture	10.2 mm
Horizontal Aperture	70 mm
Total Length of Magnetic Assemblies	1472 mm
Number of Full Size Poles	47
Total Number of Poles	49
Peak Field	3.54 T
Peak Field for End Poles	2.10 T
K, Deflection Parameter	21.2
Total emitted power, 200 mA beam	5.0 kW
Stored magnetic energy	48 kJ



The MAX-Wiggler, a cold bore superconducting wiggler with 47 3.5T poles, [E. Wallén, G. LeBlanc, and M. Eriksson] Nuclear Instruments and Methods in Physics Research A 467-468 (2001) 118-121.

Quench Analysis of a Superconducting Magnet with 98 Coils Connected in Series [E. Wallén] IEEE Transactions on Applied Superconductivity, Vol. 13, (2003) 3845-3855.

Evaluation of the MAX-Wiggler, [G. LeBlanc and E. Wallén] Nuclear Instruments and Methods in Physics Research A 521 (2004), 530-537.

Cryogenic system of the MAX-Wiggler, [E. Wallén and G. LeBlanc] Cryogenics 44 (2004) 879–893.

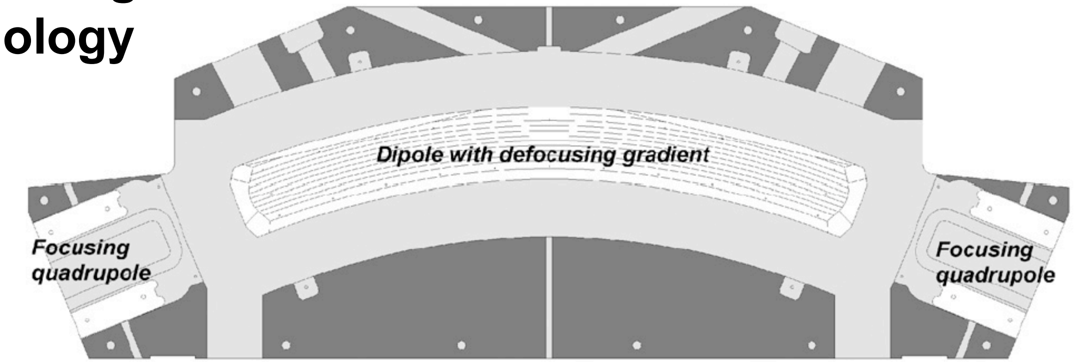
Several wigglers similar to the MAX-Wiggler have been built recently

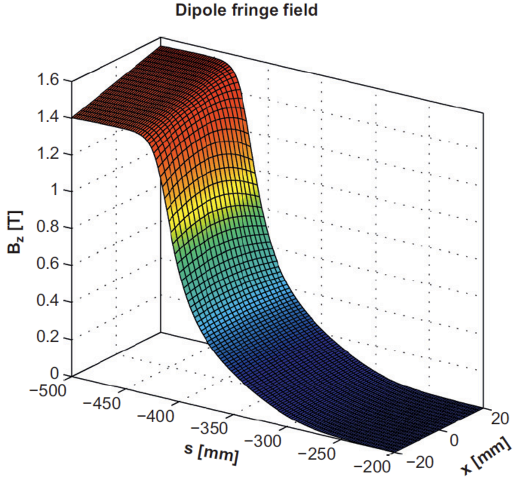
List of superconducting wigglers with period < 70 mm produced by Budker INP, Russia

	Year	Magn.Field [T] (max)	# of full size poles	Period [mm]	Magn. Gap [mm]	Vert. Apert. [mm]	Liq. He Cons. [litre/hr]
Multipole wiggler for ELETTRA (Italy)	2002	3.7	45	64	16.5	11	≈0.5
Multipole wiggler for CLS (Canada)	2005	2.2	61	34	13.5	9.5	<0.05
Multipole wiggler for DIAMOND (England)	2006	3.75	45	60	16.5	11	<0.05
Multipole wiggler -2 for CLS (Canada)	2007	4.34	25	48	14.5	10	<0.05
Multipole wiggler for DIAMOND (England)	2009	4.25	45	48	13.5	10	<0.05
Multipole wiggler for LNLS (Brazil)	2009	4.19	31	60	18.4	14	<0.05
Multipole wiggler for ALBA-CELLSc(Spain)	2009	2.1	117	30.15	12.6	8.5	<0.05

Contact person at Budker INP, Novosibirsk: Nikolai Mezentsev, Email: N.A.Mezentsev@inp.nsk.su

MAX III Magnet Technology



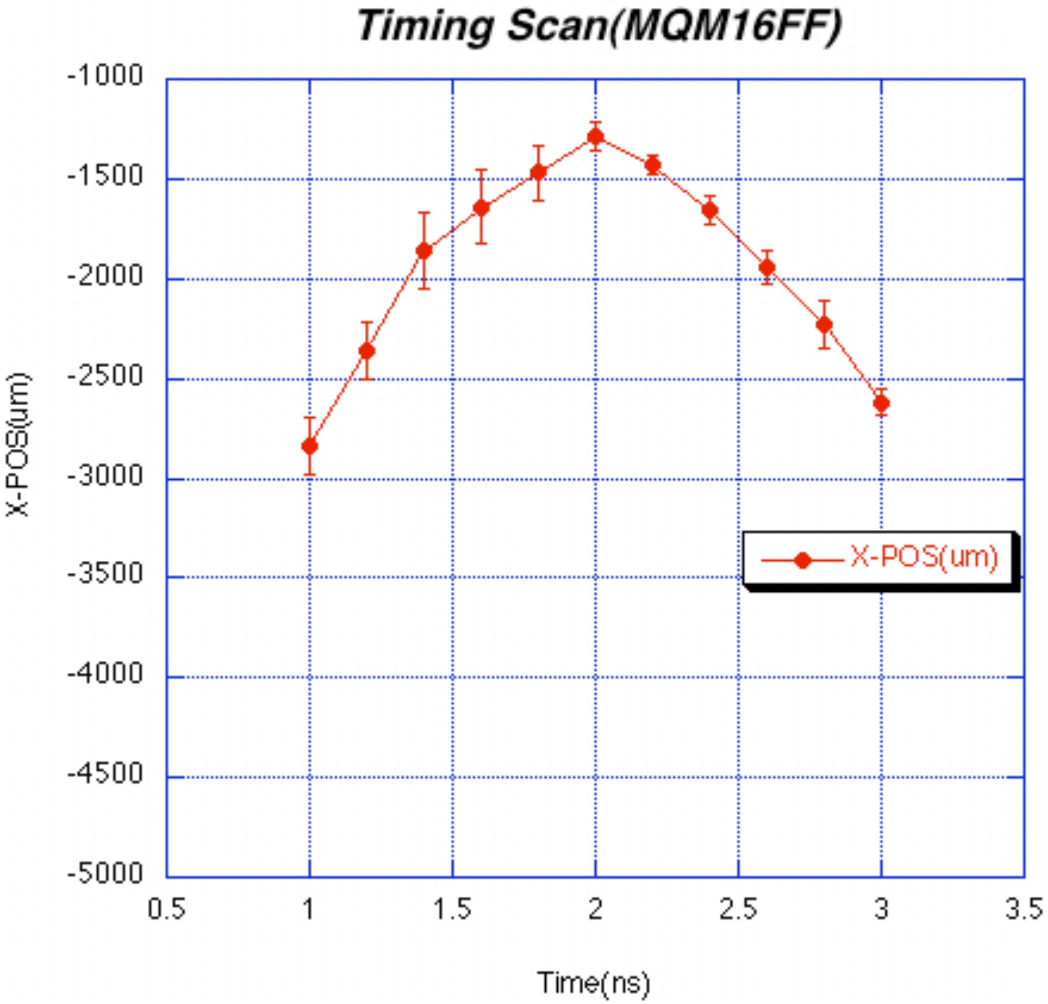


LER2010
E. Wallén

The MAX III storage ring [M.Sjöström, E.Wallén,M.Eriksson, L.-J. Lindgren] Nucl.Insrt.and Meth. A 601 (2009) 229–244.

Kick field profile and Timing jitter

T. Naito



The graph shows the measured horizontal beam position at the extraction line, when the kicker pulse timing was scanned with 200ps interval. The position displacement corresponds to the kick field difference. A cavity BPM(MQM16FF) at the ATF2 beam line was used for the measurement.

There is no flat-top for the kick field of the strip-line kicker. The estimated kick angle jitter is about 2x10^-3, when the designed R12 is used. We suspect the trigger timing jitter was caused by the kick angle jitter. One of four pulses had a large timing jitter(~500ps) compare to the others. We are trying to reduce the timing jitter.

Technology Connections Between Groups

- Potential or existing areas for collaboration between groups:
  - **Pulsed magnets and kickers**
    - Low impedance strip-line kickers
      - Broadband requirements, high voltage reliability
      - Ongoing collaboration: DAΦNE, Damping Rings groups
    - Fast rise- and fall-time high voltage pulsers with good amplitude stability and high reliability
      - Ongoing collaboration: DAΦNE, Damping Rings groups
    - Methods to minimize kicker-induced orbit errors
    - Pulsed magnet design for on-axis injection schemes
  - **Magnet Designs**
    - High Field Wigglers and Undulators
      - Aperture, peak field, field quality and shimming, and non-linear optimization for widely varying applications
      - SC wire choices, properties, and methods for SC designs
      - Connection with vacuum chamber design: photon absorbers, electron cloud build-up, cold-mass heat loads, protection against losses, radiation damage
    - Conventional magnet approaches for low emittance cell design, particularly when “high occupancy” cells are required

Technology Connections Between Groups

- Alignment
  - **Precision alignment and magnet fiducialization**
    - Vibrating wire technique (with detailed study/suppression of systematic effects) provides alignment capability which is well-matched to low emittance ring requirements.
  - **Beam-based alignment techniques**
  - **Real-time alignment technologies**
    - Girder alignment/movers ⇨ magnet movers ⇨ correctors
- Instrumentation
  - **BPM Systems**
    - Turn-by-turn capabilities and correction methods
    - Orbit feedbacks and maximum attainable bandwidths
    - Calibration and stability/repeatability issues
  - **Synchrotron Radiation Monitors for Emittance Characterization and Tuning**

Technology Connections Between Groups

- Feedback Systems
  - **Impact of digitization resolution on low emittance operation**
  - **Specifications for control of instabilities in high intensity, low emittance rings**
- RF Systems
  - **Low Level RF Design**
  - **RF Power – solid state amplifiers vs klystrons**
  - **Cavity design for various bunch structure requirements**

Have Our Hopes Been Met?

- Bringing together experts…
  - **70 registered participants representing a cross section of all the major groups working on low emittance rings**
- Profiting from experience…
  - **56 presentations highlighting critical design issues for low emittance electron and positron rings**
  - **An impressive range of observations from light sources, B factories and test facilities presented**
    - Clear areas of mutual interest identified
    - Many design issues highlighted
  - **There appear to be many synergies between plans being developed for future light source development and the plans for low emittance high energy physics rings**
- All leading to…
  - **a range of animated discussions**
  - **exploration of possibilities for collaboration**

Have Our Hopes Been Met?

- Profiting from Experience – an example:
  - Major concern for damping ring teams has been the attainability of the targeted ultra low emittance parameters
  - F

- Vertical emittance in the range required for the ILC Damping Rings has been demonstrated
- Demonstrated emittances are also very similar to the values proposed for the Super B factories
- Values are rapidly approaching the CLIC damping ring regime!
- Plans for future light sources are in even closer proximity to the damping ring parameters

⇨ Greatly improves our confidence in the proposed designs!

					al ce
ALS					n
APS					n
ASP					m
CLS					n
Dian					n
ESR					n
SLS					n
SOL					
SPEAR3	9.8 nm	9.8 nm	< 1%	0.05%	5 pm
SPring8	3.4 nm	3.2-3.6 nm	1.9% H; 1.5% V	0.2%	6.4 pm

Have Our Hopes Been Met?

- Strengthening collaboration
  - **Many discussions explored the possibility of developing new collaborations or enhancing existing ones**
  - **Summary presentations clearly identified areas where further collaboration across the community can yield benefits for all**
  - **This shows great promise, but how should we proceed?**

A proposal…

Beyond LER2010

- Low emittance rings working groups
  - Any other subjects?
  - Coordinators to be confirmed (others to be added?)
  - Task: Identify collaboration items as discussed in the workshop
  - Collect "expressions of interest" from community (LER2010 participants and beyond)
  - Start collaboration work to be reported to the next workshop!

	Subject	Coordinators
1	**Low emittance cells design**	M. Borland (APS), Y. Cai (SLAC), A. Nadgi (Soleil)
2	**Non-linear optimization**	R. Bartolini (DIAMOND/JAI), C. Steier (LBNL)
3	**Minimization of vertical emittance**	A. Streun (PSI), R. Dowd (Australian Synchrotron)
4	**Integration of collective effects in lattice design**	R. Nagaoka (SOLEIL), Y. Papaphilippou (CERN)
5	**Insertion device, magnet design and alignment**	S. Prestemon (LBNL), E. Wallen (MAXlab)
6	**Instrumentation for low emittance**	M. Palmer (Cornell), G. Decker (APS)
7	**Fast Kicker design**	P. Lebasque (Soleil), C. Burkhardt (SLAC)
8	**Feedback systems (slow and fast)**	A. Drago (INFN/LNF), B. Podobedov (BNL), T. Nakamura (JASRI/SPring8)
9	**Beam instabilities**	G. Rumolo (CERN), R. Nagaoka (SOLEIL)
10	**Impedance and vacuum design**	K. Bane (SLAC), S. Krinsky (BNL), E. Karantzoulis (Elettra), Y. Suetsugu (KEK)

Beyond LER2010

Introducing the QUANTUM

Limit **O**f **V**ertical **E**mmitance

Prize

for the Low Emittance Ring first reaching this limit

More details to follow…

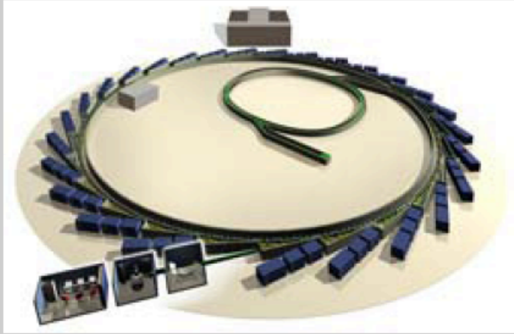
http://www.linearcollider.org/newsline/readmore_20100128_atw.html

Aiming low, shooting high

Experts from different fields get together to tackle a common problem: emittance

Not all people who have the same goals use the same means to achieve them — just think of the two proposed electron-positron colliders ILC and CLIC. And not all people who use the same means also pursue the same goals. A workshop held in January at CERN in Geneva brought the two linear colliders and many of the world's light sources and B-factories together to discuss one common problem: how to make your beam as small and intense as possible to either produce more particle collisions or produce more brilliant light for your light source users, or in short: how to design or operate low-emittance rings.

Organised by the ILC/CLIC working group on damping rings, it was the first meeting that brought light source, B-factory, test facility and damping ring experts together to discuss common issues like machine design, different technologies and beam dynamics challenges. What came out in the end was more than just interesting discussions — participants took home solutions to problems they didn't know they were going to face or designs for parts they didn't know existed already. "There is such an enormous potential in this collaboration to exploit all the similar work efforts," says local organiser and CLIC damping ring expert Yannis Papaphilippou. "It was good to see the community uniting under the common goal of creating low-emittance beams. We are looking forward to the results of ten new task groups."



Light sources like Diamond in the UK currently hold the low-emittance record. Image: ©Diamond Light Source

Because particles within a beam repel each other, and because no magnet arrangement is perfect, particle beams have the annoying tendency to spread out in all directions. Damping rings are there to 'cool' the beams — to force them to give off energy and thus bring them onto the same level both in terms of energy and in terms of size. Depending on the different design parameters of different machines, the spread of the beam, its emittance, has to be low to extremely low (0.8 picometres in the vertical plane for CLIC) — the record emittance at the workshop was shared by the UK light source Diamond and the Swiss light source at PSI with close to 2-3 picometres each, whereas the accelerator physicists of the Australian Light Source think they have already gone lower than that.

Some of the workshop participants gathered for a group picture in the snow.

A common means of achieving low emittance is to put so-called wigglers in the paths of the beams: their array of short magnets with changing polarity forces charged particles on a wiggly course, which in turn forces them to give off energy in the form of photons. Light sources use these photons to create very intense, or very brilliant, beams of light to direct onto samples and experiments. Damping rings hand the wiggled and thus cooled beam over to the main linear accelerator where they get accelerated and directed onto their counterparts. The wigglers can be tricky things because some have to be superconducting to produce the right light wavelength, or desired dampening effect. A superconducting wiggler produced by the Russian Budker institute that has proved itself in the UK light source Diamond is a potential technology for linear collider damping rings. Novel technologies using different types of superconducting wires are presently being tested at CERN. And in Cornell's CESR-TA, superferric wigglers are used for damping the beam to a very low horizontal emittance: "we found out a lot of the technical challenges of these