TWIICE 2 workshop

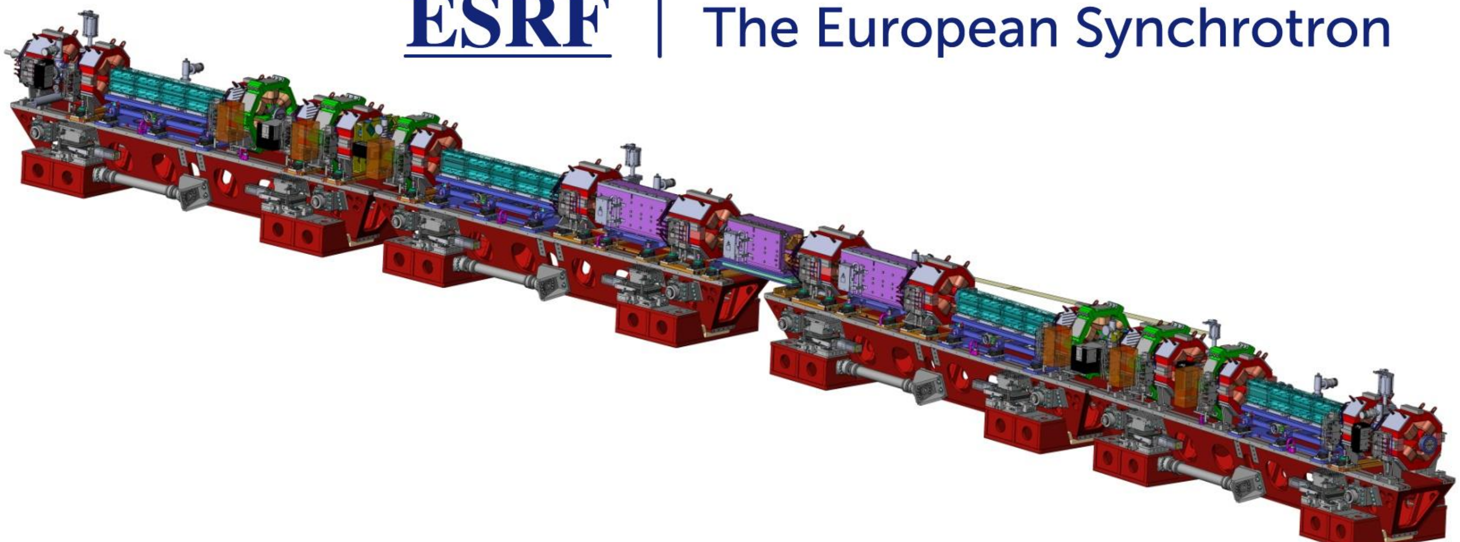
Abingdon, 8 February 2016

Collective effects in the ESRF upgrade machine

S. White

On behalf of the ASD group

ESRF | The European Synchrotron



OUTLINE

Project overview

Performance goals, lattice,

vacuum chambers

comparison with present machine

Resistive wall

tune shift

coupled bunch modes

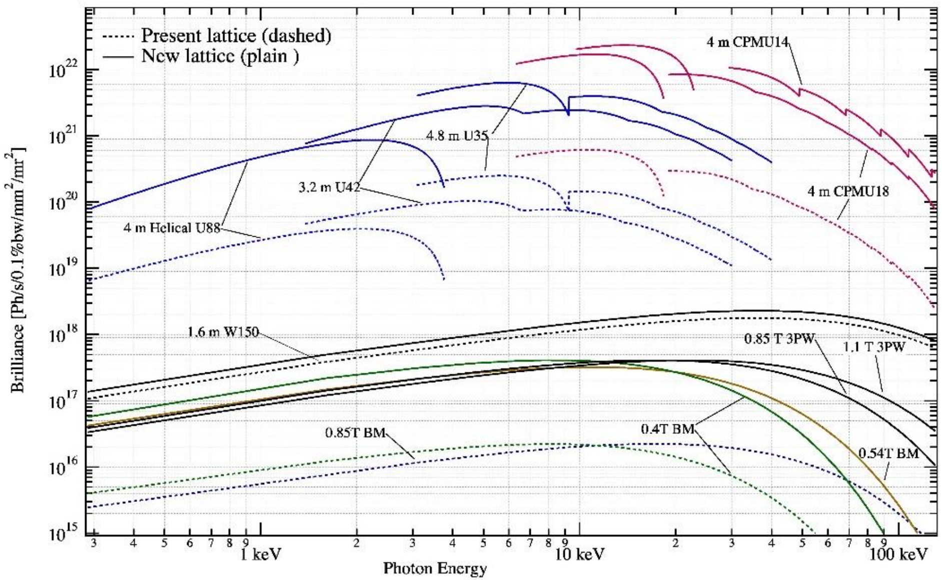
Geometric impedance

RF cavities, RF fingers, flanges,

BPMs, preliminary model

Summary and outlook

DESIGN GOALS



- **The ESRF-EBS program (*E*xtremely *B*rilliant *S*ource) :**
  - Reduction of the horizontal equilibrium emittance
  - Increase of coherence and brilliance

	ESRF	upgrade
Hor. Emittance [pmrad]	4000	134
Vert. Emittance [pmrad]	3	2
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

- **Constraints related to the present machine and users:**
  - Beam lines currently operating in dipoles and straight sections unchanged
  - Same temporal structure of the bunches and a total current of 200mA
  - Re-use as much as possible the current injectors and infrastructures
  - Installation and commissioning should not exceed a duration of 19.5 months

The European Synchrotron | ESRF

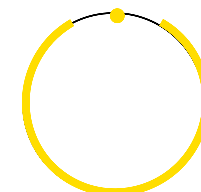
MACHINE PARAMETERS AND FILLING MODES

	Upgrade	ESRF
Energy [GeV]	6.00	6.04
Circumference [m]	843.98	844.39
Max. beam/bunch current [mA]	200/10	200/10
Natural emittance [pm]	135	4000
Tunes	75.21, 26.34	36.44, 13.39
Multi-bunch Chromaticity	6, 4 (10,10)	4, 7 (8,12)
Energy spread [%]	0.095	0.106
Momentum compaction	8.72e-5	17.8e-5
Synchrotron tune	3.52e-3	5.92e-3
Average β (X/Y) [m]	4.0/7.6	16.6/24.8
Lifetime multi-bunch [h]	~20	~80

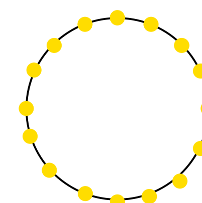
- **Reduced lifetime mitigated by top-up operation**

Uniform:
992 bunches
200mA total

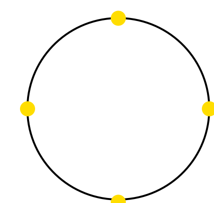
7/8+1:
868+1 bunches
200mA total
8mA single



16 bunches:
90mA total
~6mA per bunch

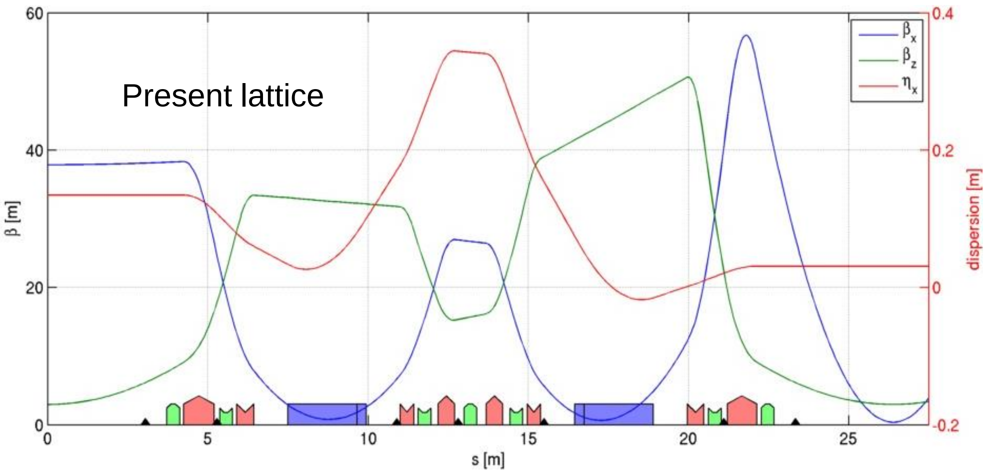


4 bunches:
40mA total
10mA per bunch

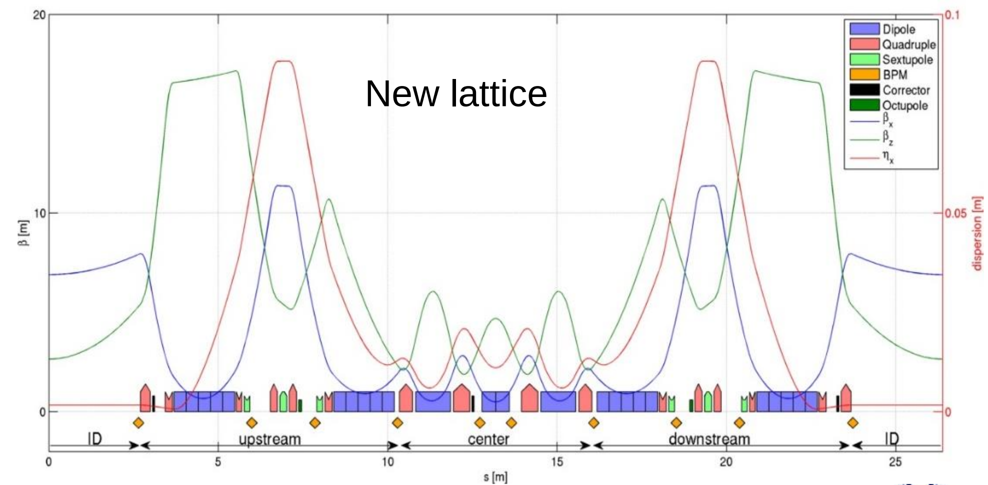


- **Stability conditions required for a large variety of configurations**

LINEAR OPTICS

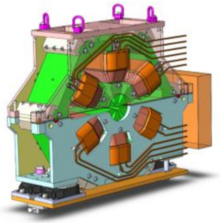


- **Present lattice:**
  - 16 super-periods (32 cells in total)
  - 2 dipoles per cell
  - Emittance ε_x~4nm
- **New lattice:**
  - 32 super-periods
  - 7 dipoles per cell
  - Emittance ε_x~135pm



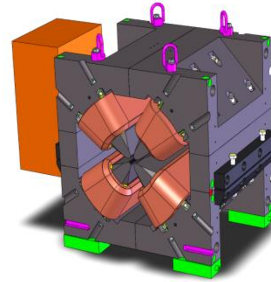
- **Main characteristics:**
  - 2 high dispersion zones to allow for chromatic corrections
  - $\Delta\phi$~π between chromatic sextupoles: partial sextupolar resonances compensation
  - Longitudinal gradient in dipoles: emittance reduction

MAGNETS



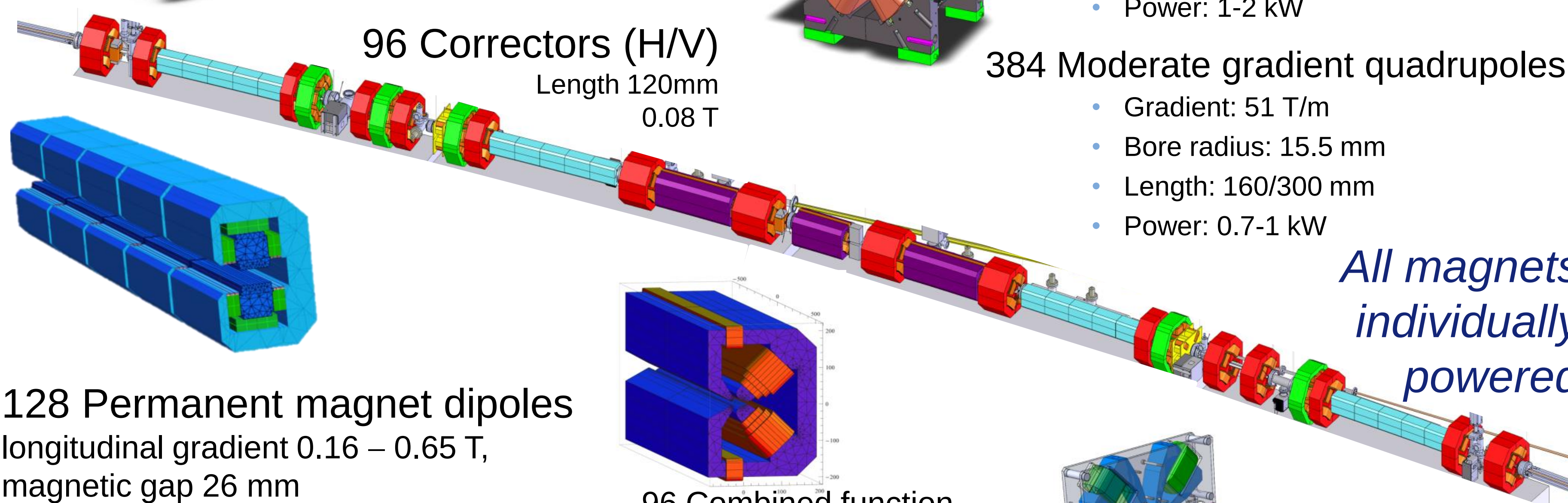
192 Sextupoles

Length 200mm
900-2200 Tm^{-2}
Also used as dipole and skew quad correctors



128 High gradient Quadrupoles

- Gradient: 85 T/m
- Bore radius: 12.5 mm
- Length: 390/490 mm
- Power: 1-2 kW



96 Correctors (H/V)

Length 120mm
0.08 T

384 Moderate gradient quadrupoles

- Gradient: 51 T/m
- Bore radius: 15.5 mm
- Length: 160/300 mm
- Power: 0.7-1 kW

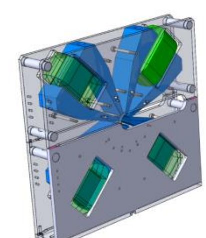
All magnets individually powered

128 Permanent magnet dipoles

longitudinal gradient 0.16 – 0.65 T,
magnetic gap 26 mm
1.8 meters long, 5 modules
Hybrid Sm2Co17 / Strontium Ferrite

96 Combined function Dipole-Quadrupoles

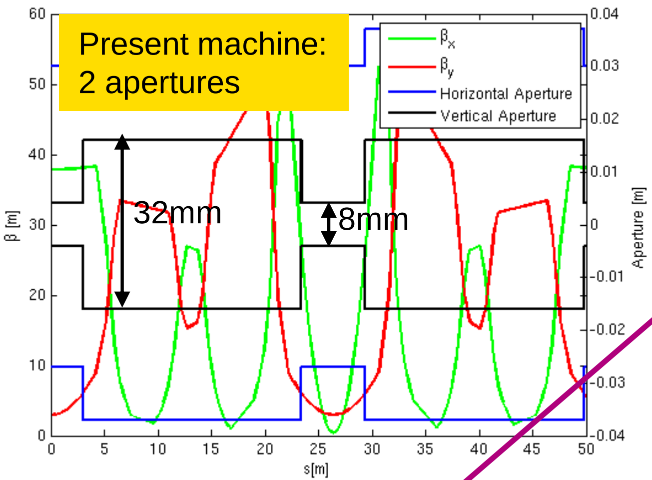
0.54 T / 34 Tm^{-1}
& 0.43 T / 34 Tm^{-1}

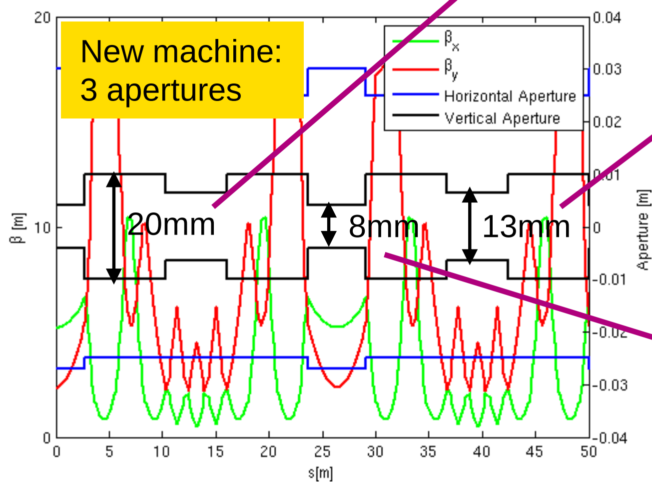


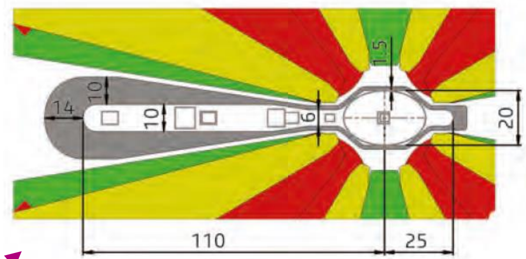
64 Octupoles

51.2 10^3 T/m^{-3}

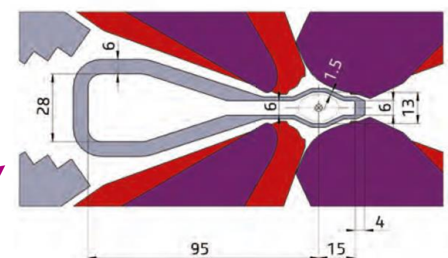
Courtesy of G. Le Bec



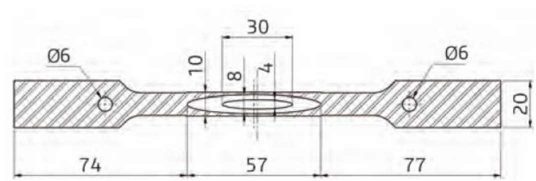




Upstream/downstream chamber
TM cut-off = 9.33 GHz



Central (strong focusing) chamber
TM cut-off = 13.76 GHz



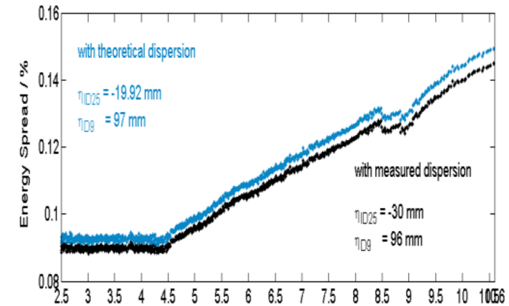
ID chamber

- **Present machine:**
- Arc vertical aperture 32mm stainless steel
- ID vertical aperture 8mm NEG coated aluminum

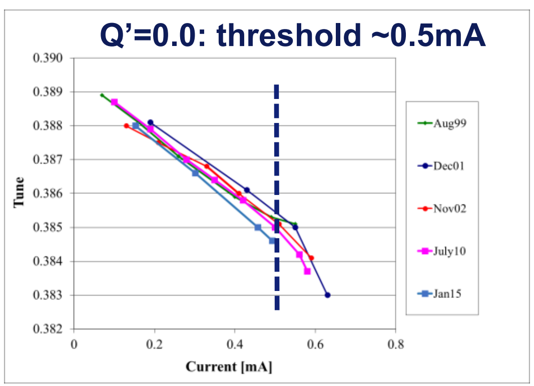
- **New machine:**
- Upstream/downstream vertical aperture 20mm stainless steel
- Central vertical aperture 13mm stainless steel
- ID vertical aperture 8mm NEG coated aluminum
- Aluminum chambers in all dipoles

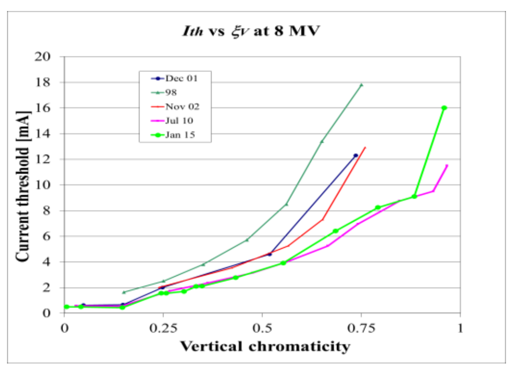
PRESENT SITUATION AND IMPLICATION OF NEW PARAMETERS

- **Reduced beam pipe aperture- increased geometric and resistive wall wake fields:**
  - Stronger single bunch instabilities: TMCI, microwave
  - Stronger resistive wall multi-bunch instabilities
- **Beam / lattice parameters:**
  - Smaller Q_s / α_p: TMCI/microwave at lower currents?
  - Lower β-functions: improved transverse impedance effects
- **Present situation (See E. Plouviez's talk for details):**
  - **Feedbacks not required to stabilize standard operation modes**
  - **Used to stabilize ion instabilities during vacuum conditioning**

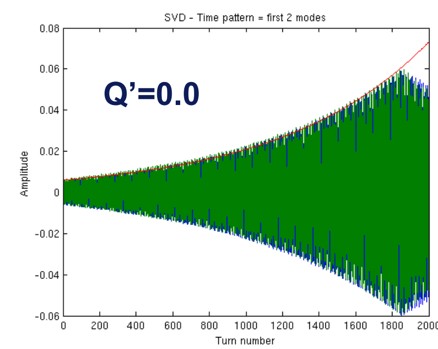


Microwave threshold ~4.5mA





Tune shift and threshold: instability cured by chromaticity up to >10mA



Multi-bunch transverse instability:
cured by chromaticity up to 200mA

RESISTIVE WALL

	L [m]	$<\beta_x>$ [m]	$<\beta_y>$ [m]	Rx [mm]	Ry [mm]	s [S/m]
Present Machine						
Arc	673.2	14.7	29.8	37.0	16.0	1.45e6 (SS)
ID	171.2	23.5	4.1	28.5	4.0	3.5e7 (NEG,Al)
New Machine						
Central	96.9	1.83	2.73	25.0	6.5	1.45e6 (SS)
Up/down	255.7	6.24	9.38	25.0	10.0	1.45e6 (SS)
Dipole	91.4/228.9	1.24/1.16	11.3/3.75	25.0	6.5/10.0	3.5e7 (Al)
ID	171.2	7.4	3.98	28.5	4.0	3.5e7 (NEG,Al)

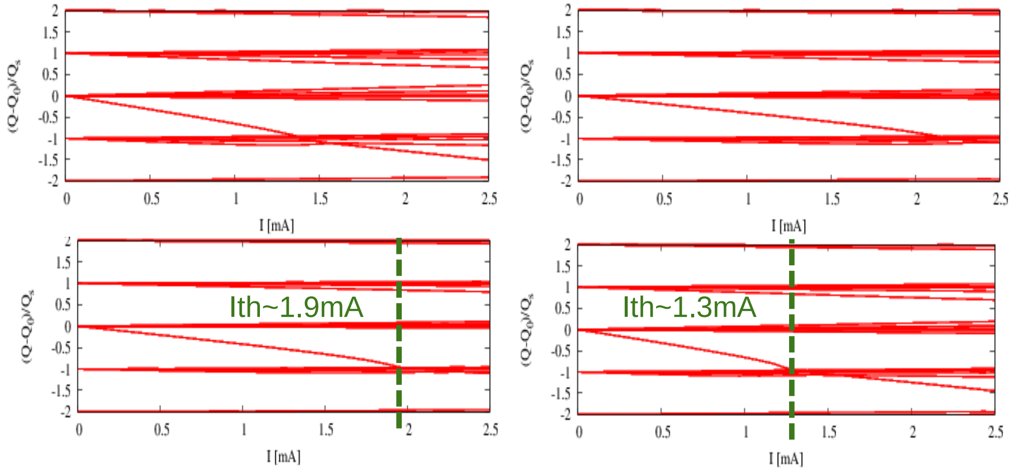
$$W_{x,y}\,(z) = \frac{c\,Z_0 L}{\pi\,R_y^3}\sqrt{\frac{1}{Z_0 \sigma\,\pi\,z}}\,Y_{x,y}$$

Y is the Yokoya factor to account for elliptical shape: for a flat beam chamber: ~0.41/0.82

- The total wake field is the sum of the components weighted by $<\beta>$
- The wake is computed using IMPEDANCEWAKE2D (N. Mounet)
- assumed 8mm NEG coated Aluminium beam pipe in all IDs: in-vacuum undulators are not taken into account

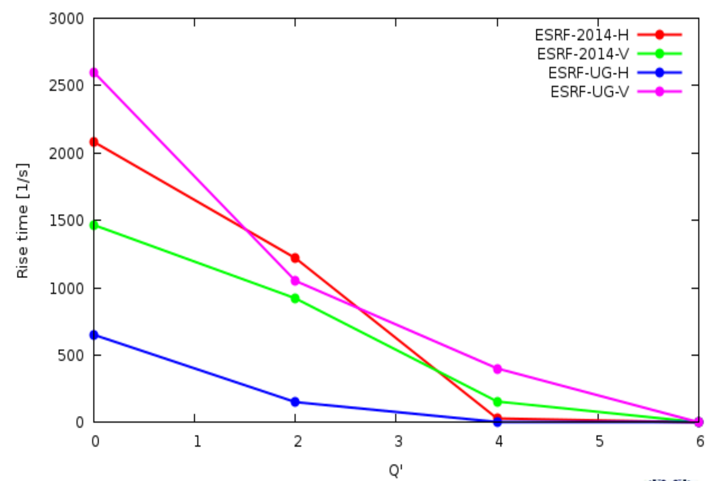
TRANSVERSE TUNE SHIFT AND COUPLED BUNCH MODES

Present machine *New machine*

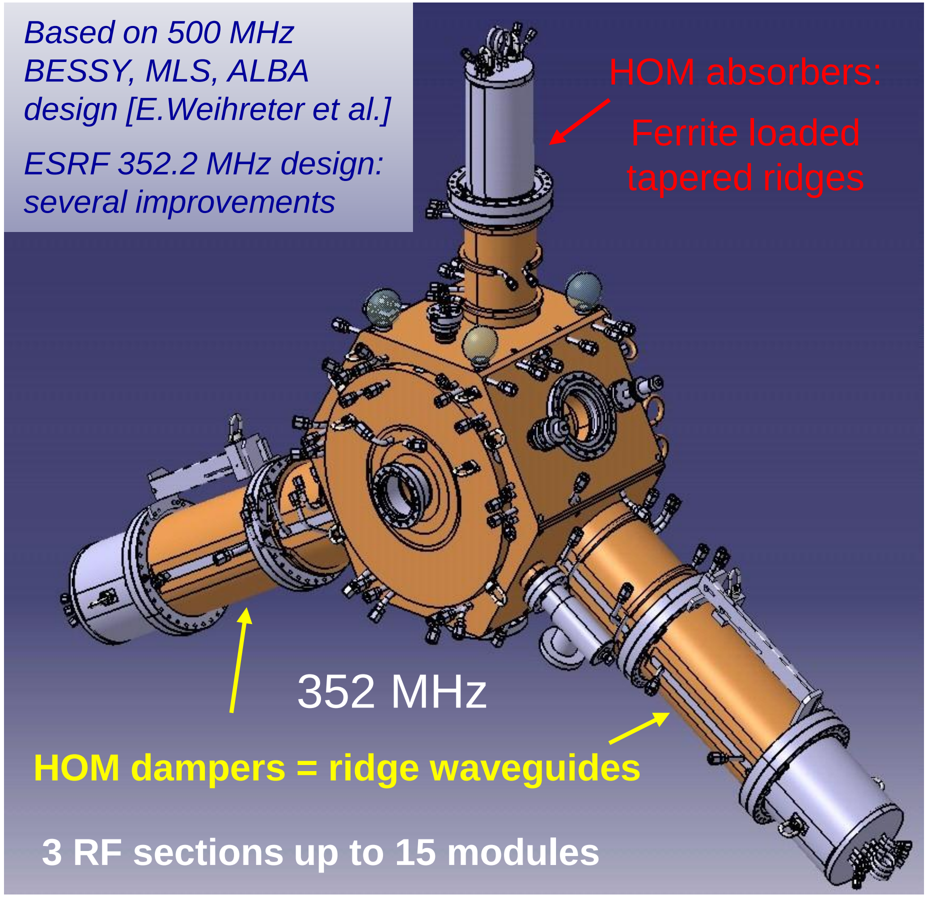


- The vertical threshold is the most important
- **ΔQ/Qs degraded by approximately 50% in the vertical plane, better in the horizontal plane**
- Stability to be evaluated with the complete model
- Feedbacks could become useful again

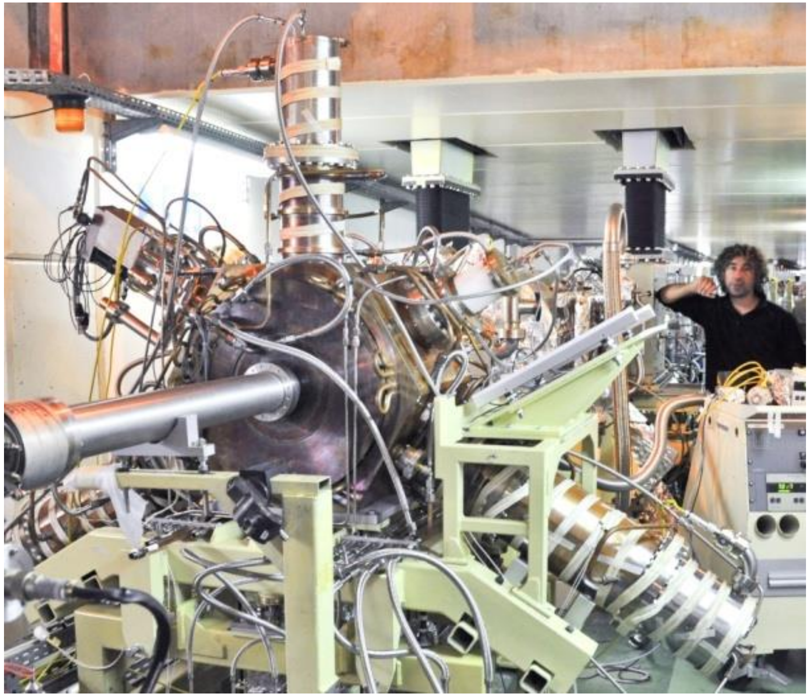
- **Simulations done with HEADTAIL including radiation damping:**
- **7/8 filling pattern, 868 bunches, 200mA total current: well below TMCI threshold**
- **The chromaticity thresholds for the present machine are consistent with operational data Q~4-6**
- **Behaviour should be relatively similar for the upgrade machine + feedbacks available**



RF CAVITIES



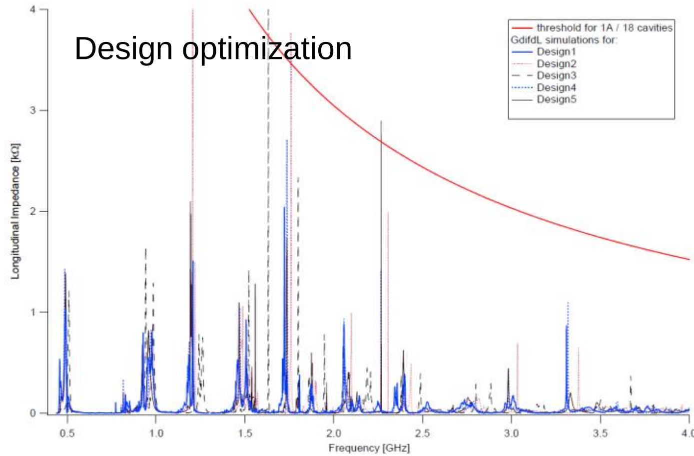
3 cavities installed and tested (passive and active) in the ESRF

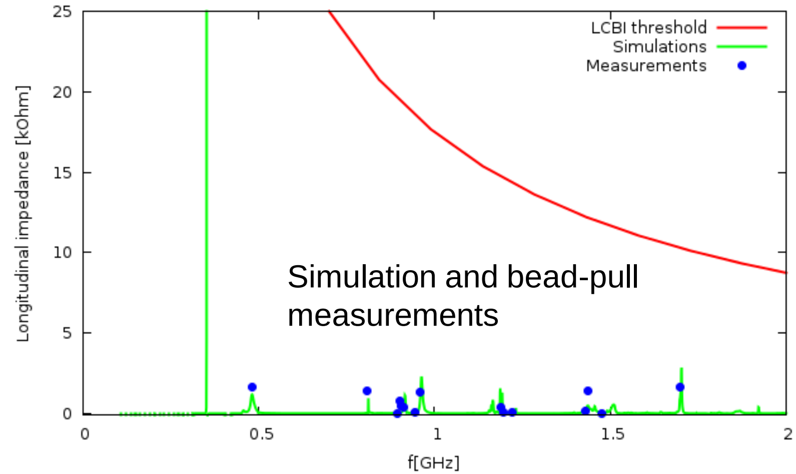


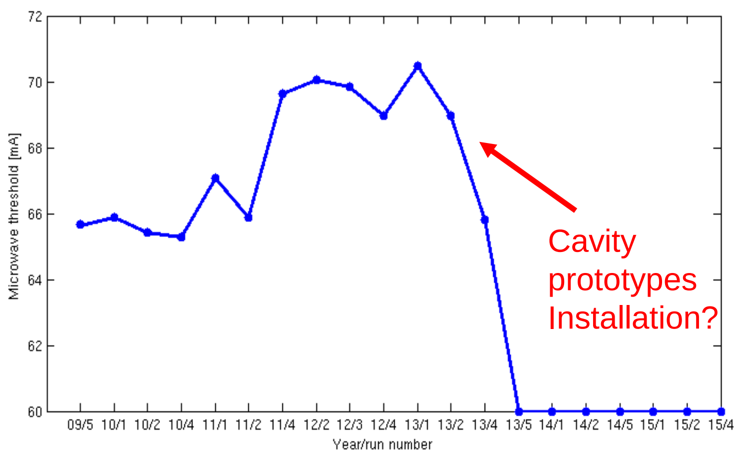
Courtesy of V. Serriere

SIMULATIONS AND MEASUREMENTS

- Very exhaustive design study. See: *‘Cavity design report’* , V. Serriere et al.
- Longitudinal coupled bunch instabilities should not be an issue





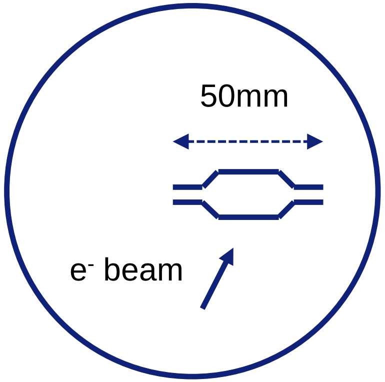


- The microwave threshold can be monitored during USM (**U**ser **S**ervice **M**ode) in 16 bunches operation by looking at the energy spread
- The installation of prototype cavities seems to be correlated to a degradation: **large contribution to the overall impedance budget**
- The same degradation was observed on bunch length measurements

RF FINGERS

Being patented:
Schematic view

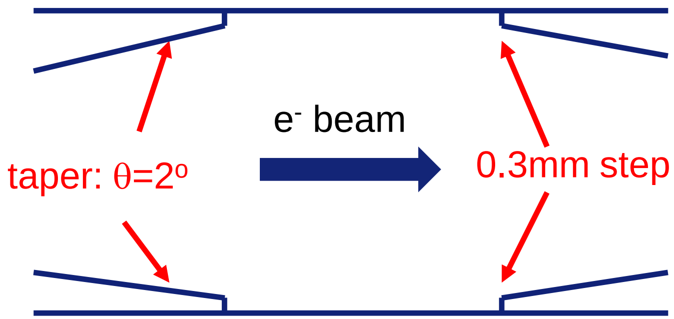
front view



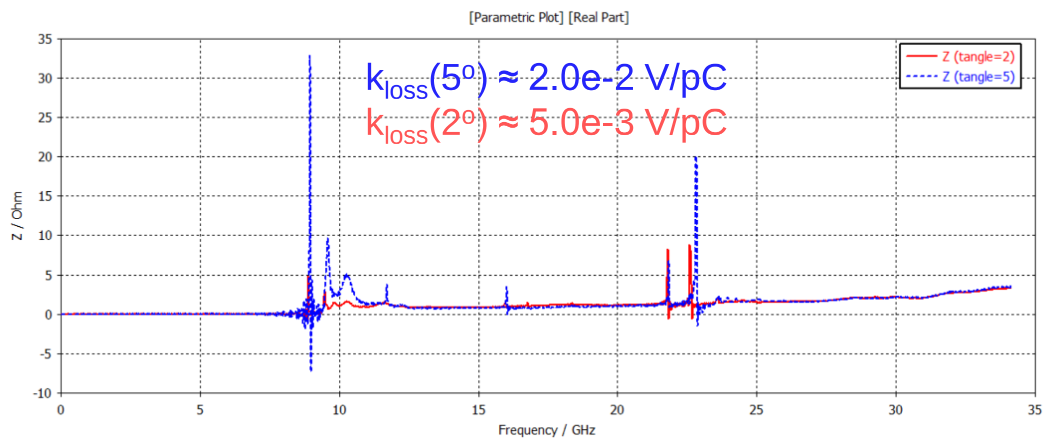
In-house design (T. Brochard):
-Mechanically very robust
-Impossible for a finger to 'fall' in the vacuum chamber

Non axisymmetric geometry:
Enforced constant profile at +/-25mm for all devices

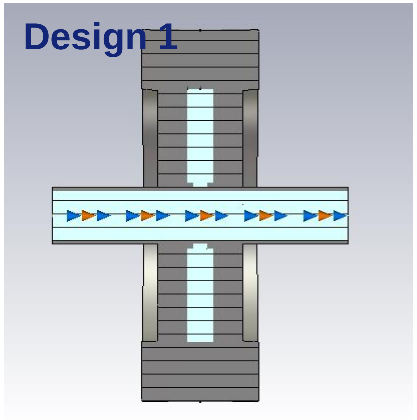
Side view, X=0

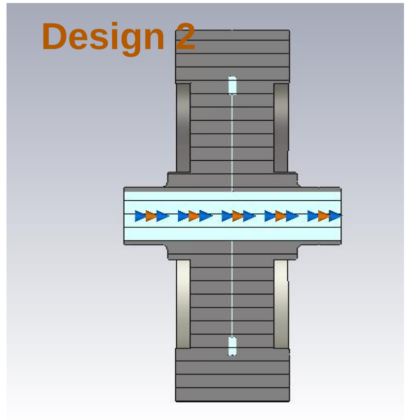


- **Side blades added and distance between blades <1mm:** impedance given by transitions from the chambers to the blades
- **Prototype installed:** some heating observed but the data is polluted by a nearby absorber: further tests required

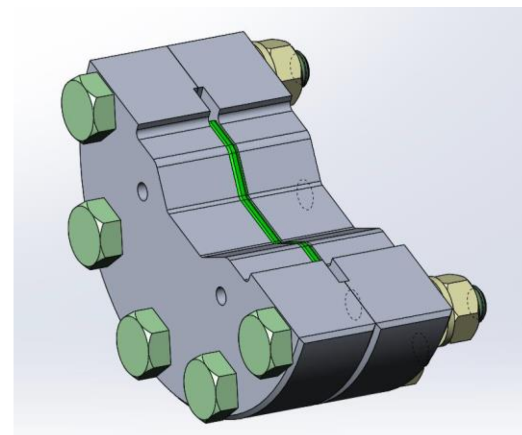


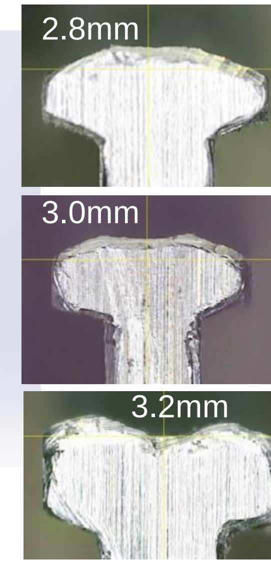
FLANGES

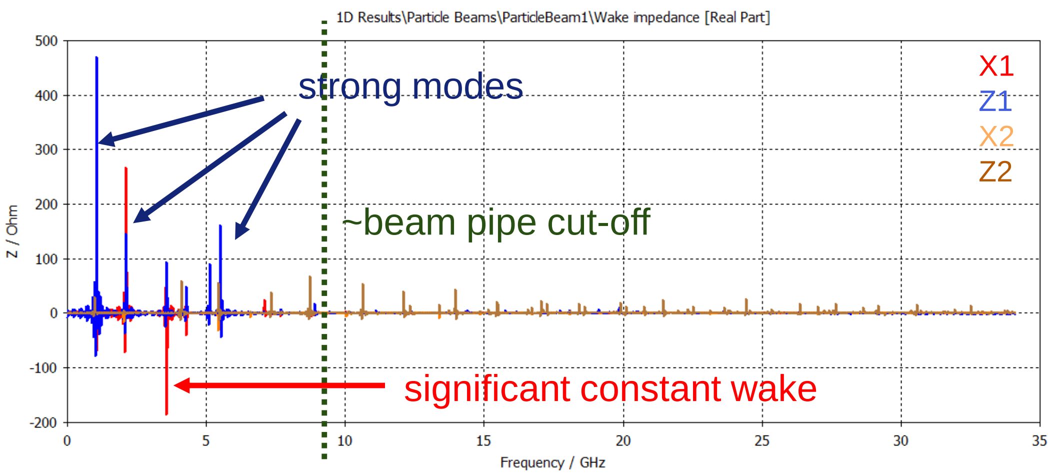




- Two designs initially proposed by the drafting office
- **About 500 flanges in the new machine**

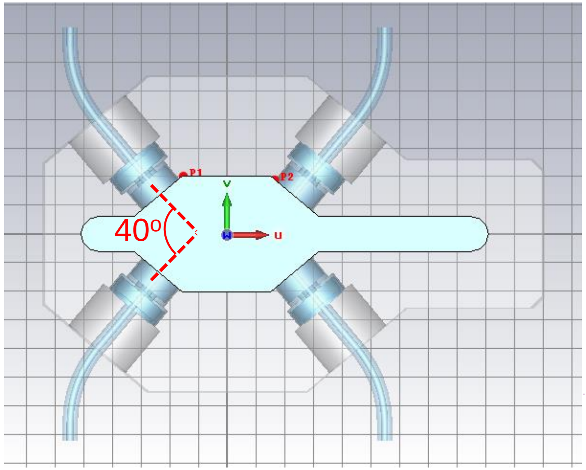


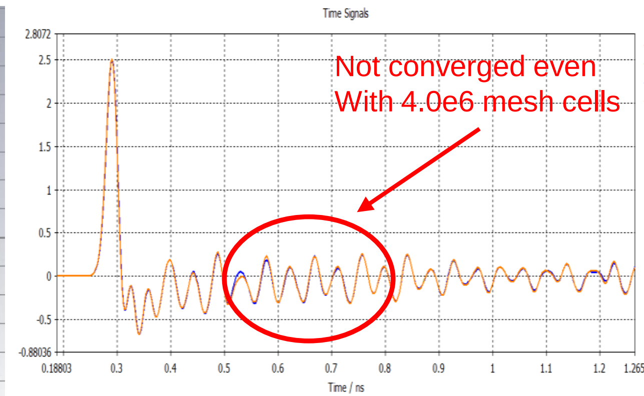


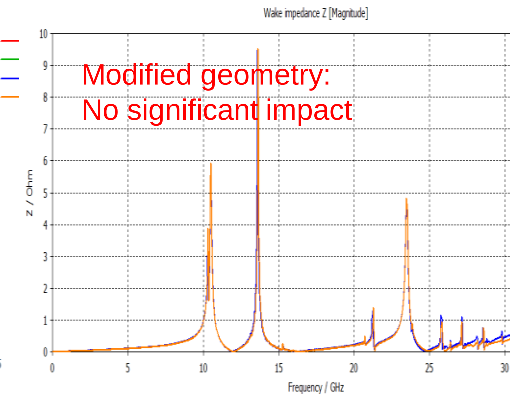


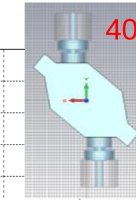
- **Finally decided to add a conductor joint to design #2 to minimize impedance**
- Joint shape optimized to minimize discontinuities in the profile

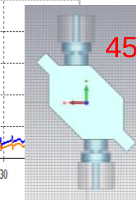
BEAM POSITION MONITORS

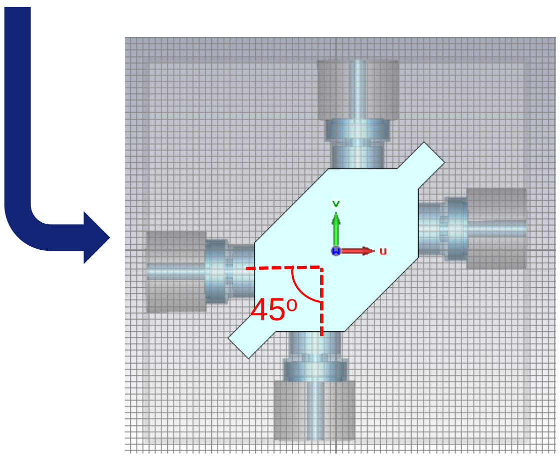




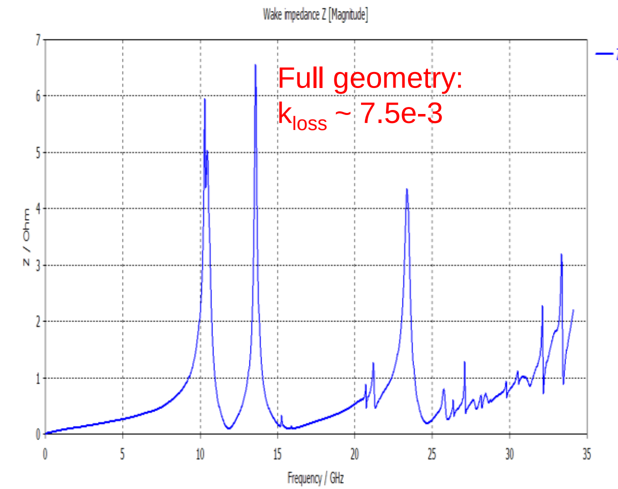




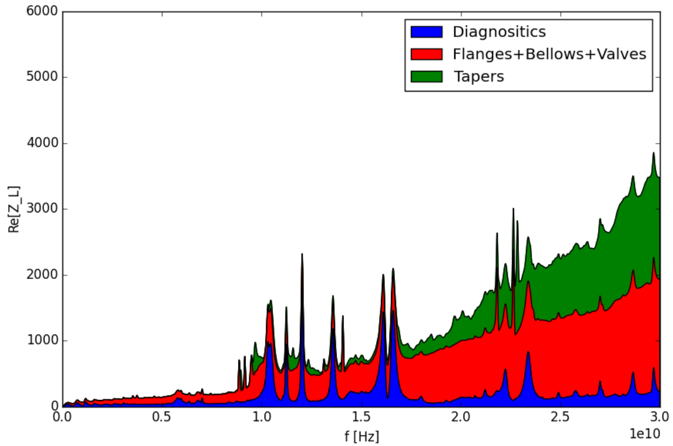


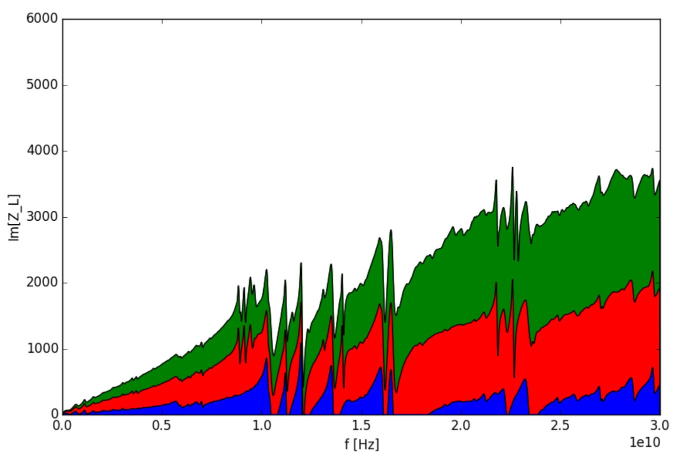


- **Issues meshing the coaxial structure in CST:**
- **Aligned BPMs with the XYZ reference system**
- **Changed the angle between buttons to 45º**



PRELIMINARY LONGITUDINAL IMPEDANCE MODEL





- **The present model includes (all calculated for both chamber profiles and σ_s=3mm):**
  - BPMs, CTs, striplines
  - Flanges, bellows, vacuum valves
  - Tapers to/from ID, small profile, large profile
  - Cavities and cavities tapers
  - Resistive wall with all IDs with 8mm aperture

- **For now we are still below the measured Z/n~0.85 (2015)**

- Still missing: scrapers, absorbers, undulators, ceramic chambers,…

	K_{loss} [V/pC]	Z/n [Ω]
Diagnostics	3.4	8.5 10^{-3}
Flanges+bellows	7.7	25 10^{-3}
Tapers	1.5	21 10^{-3}
Cavities	4.5	0.39
Resistive wall	38.7	0.22
Total	55.8	0.67

BUNCH LENGTHENING

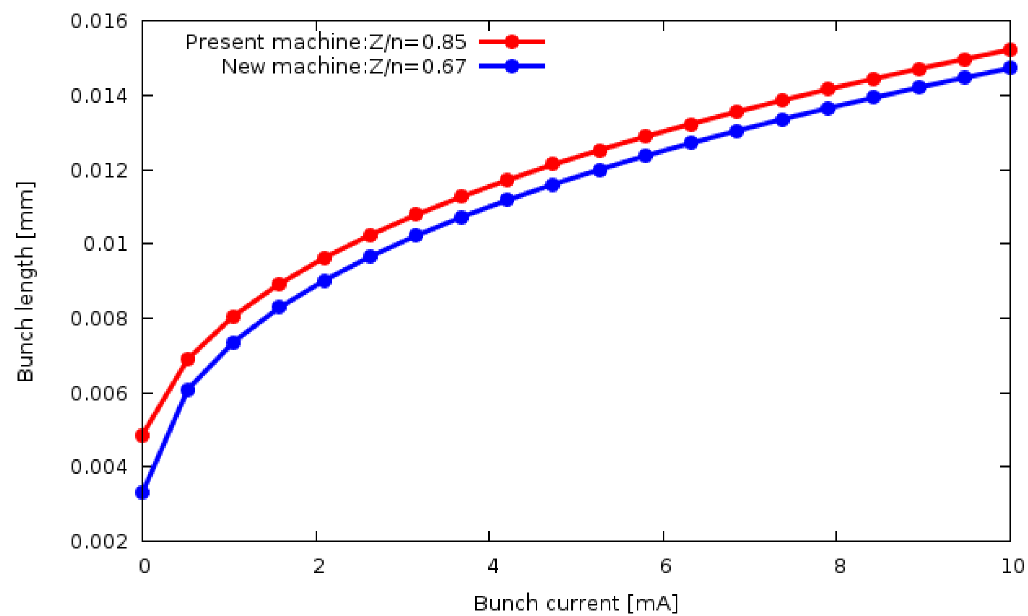
- **Assuming a pure inductance we can estimate the bunch lengthening versus current using:**

$$\left(\frac{\sigma_s}{\sigma_{s0}}\right)^3 - \frac{\sigma_s}{\sigma_{s0}} = \frac{\sqrt{\pi}\, I\, Z_n}{2\, V_{rf} h \cos\varphi_s \left(\frac{\omega_0}{\omega_s}\alpha\, \sigma_{\delta 0}\right)^3}$$

- Although the impedance the impedance of the new machine is smaller (for now) **the bunch length are almost equal in both cases**

- **This also has an impact on lifetime (Touschek losses):**
  - Radiation protection
  - Collimator design

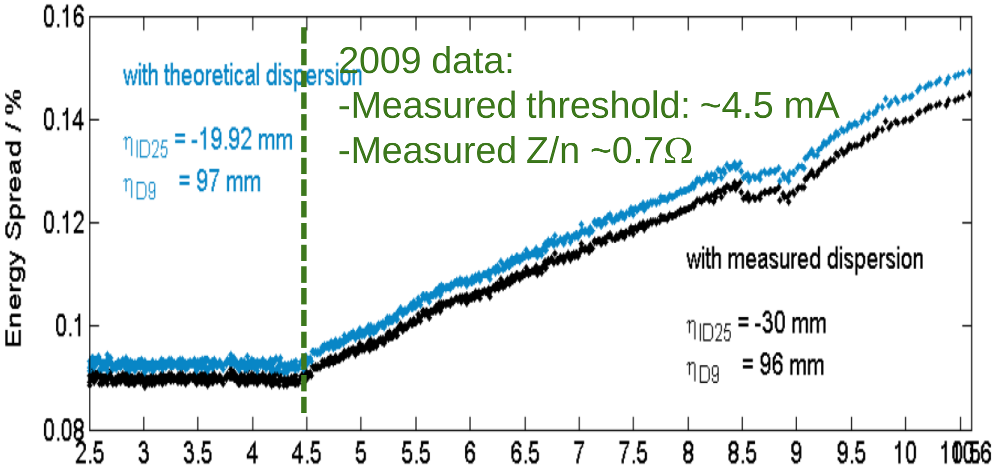
- **Tracking simulations required to validate these results**



MICROWAVE THRESHOLD

- The Keil-Schnell-Boussard criterion for bunched beams gives:

$$\left|\frac{Z}{n}\right| < \sqrt{\frac{\pi}{2}}\frac{Z_0 \alpha \gamma}{N r_0}\sigma_s\left(\frac{\Delta p}{p}\right)^2$$



To be noted: since then a degradation of ~20% was observed without any complains for the beam lines

- **The analytical estimate for 0.7Ω give a threshold at 0.8mA which is well below the measured value:**
  - Poor approximation for ESRF parameters (short bunch length)
  - We can however used this formula to scale the threshold
- **Using the new machine beam parameters and impedance estimates we get 0.25mA:**
  - Scaling the measured threshold we get 1.4mA
  - This is fine for multi-bunch operation <1.0mA/bunch
  - We can expect a strong degradation of single bunch operation
- **This is again to be confirmed with tracking once the full model is available**
- **Studies are ongoing to evaluate de benefits of a 3rd harmonic cavity**

SUMMARY AND OUTLOOK

- **The reduction of beam pipe and modification of machine parameters has some impact on beam instabilities: the new machine will be more sensitive to impedance effects**

- **Resistive wall:**
  - The negative impact of the reduction of aperture and synchrotron tune is partially compensated by changes of material and reduced β-functions
  - Multi-bunch instabilities should not be an issue, **ΔQ/Qs in the vertical plane is 50% larger**

- **Geometric impedance:**
  - Mostly iterations with drafting office to reduce impedance until now, no detailed model
  - **New HOM cavities: longitudinal coupled bunch instabilities mitigated**
  - Tried to reduce as much as possible the impedance of the main contributors: **flanges, bellows and tapers are improved w.r.t the present machine**

- **Longitudinal model:**
  - Very preliminary, more refined model needed: for now lower than present impedance obtained
  - Bunch length should be similar, **microwave threshold strongly degraded**

- **Outlook:**
  - Missing devices to be calculated and optimized
  - Transverse impedance model calculation ongoing
  - Short-range wake field for tracking simulation should become available over the coming year
  - **3rd harmonic cavity studies ongoing**

THANKS FOR YOUR ATTENTION