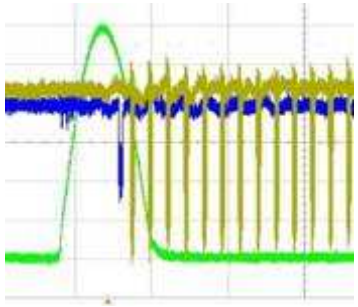
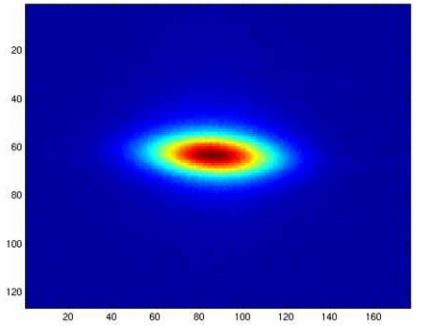
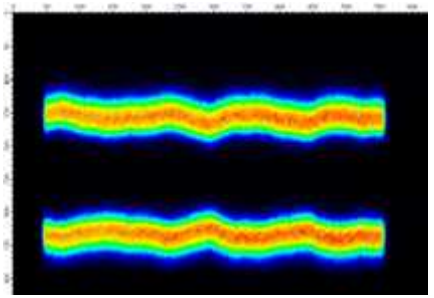
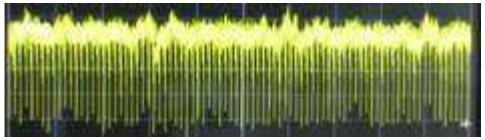
Status of the SOLEIL project
Commissioning from Linac to beamlines

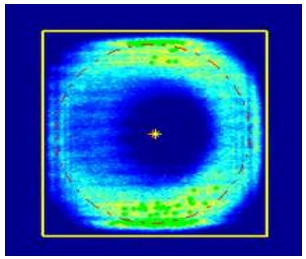
On behalf of the commissioning team

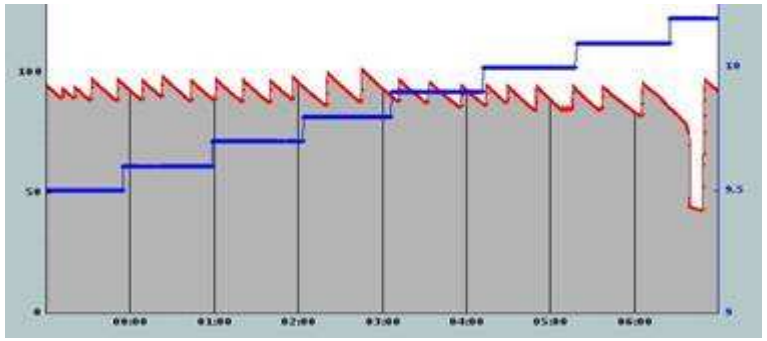


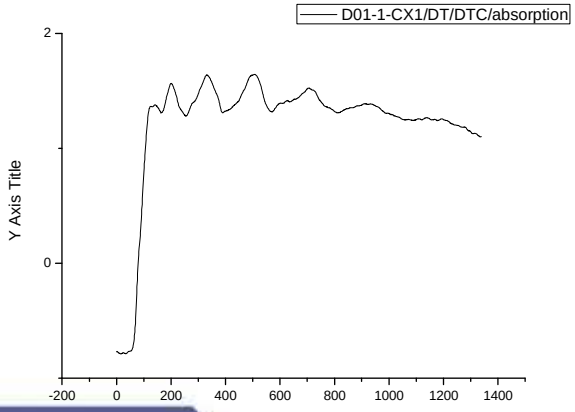












Site and Budget

SOLEIL SYNCHROTRON

at Gif-sur-Yvette
25km south of Paris, France

350 permanent staff

19 Hectares

Total budget

for 2002 - 2009 period

454 M€

Investments	**248 M€**
Functioning	**53 M€**
Salaries	**153 M€**

Functioning budget per year starting in 2010: **~ 45 M€.**

CEA and CNRS own 28% and 72% of the Synchrotron Soleil company respectively.

SOLEIL Characteristics

- Electron energy: 2.75 GeV
- Extended spectral range
  ⇒ From UV (5 eV) up to hard X-Rays (30 keV)
- 3rd generation ⇒ Many Insertion Device beamlines
  ⇒ 21 straight sections available (29% of ring circ.)
- High brilliance (10^{20}) in the soft X-ray range
  ⇒ small emittance and high intensity
- Best achievable beam position stability

24 beamlines

24 Beamlines approved by the Council + 1 beamline to be founded

18 on insertion devices and 7 on bending magnets

Spectral range equally shared :

50% below 1.3 keV and 50% above

Phase 1: 11 beamlines being built =>open to external Users in 2007

6 on insertion devices and 3 on bending magnets + **2 IR**

Phase 2: 7 beamlines open to external Users in 2008

5 on insertion devices and 2 on bending magnets

+ 7 beamlines on ID open to external Users in 2009

3 Straight sections still free + 14 bending magnet beamports!

LINAC and Booster designed for topping-up operation

2.75 GeV BOOSTER

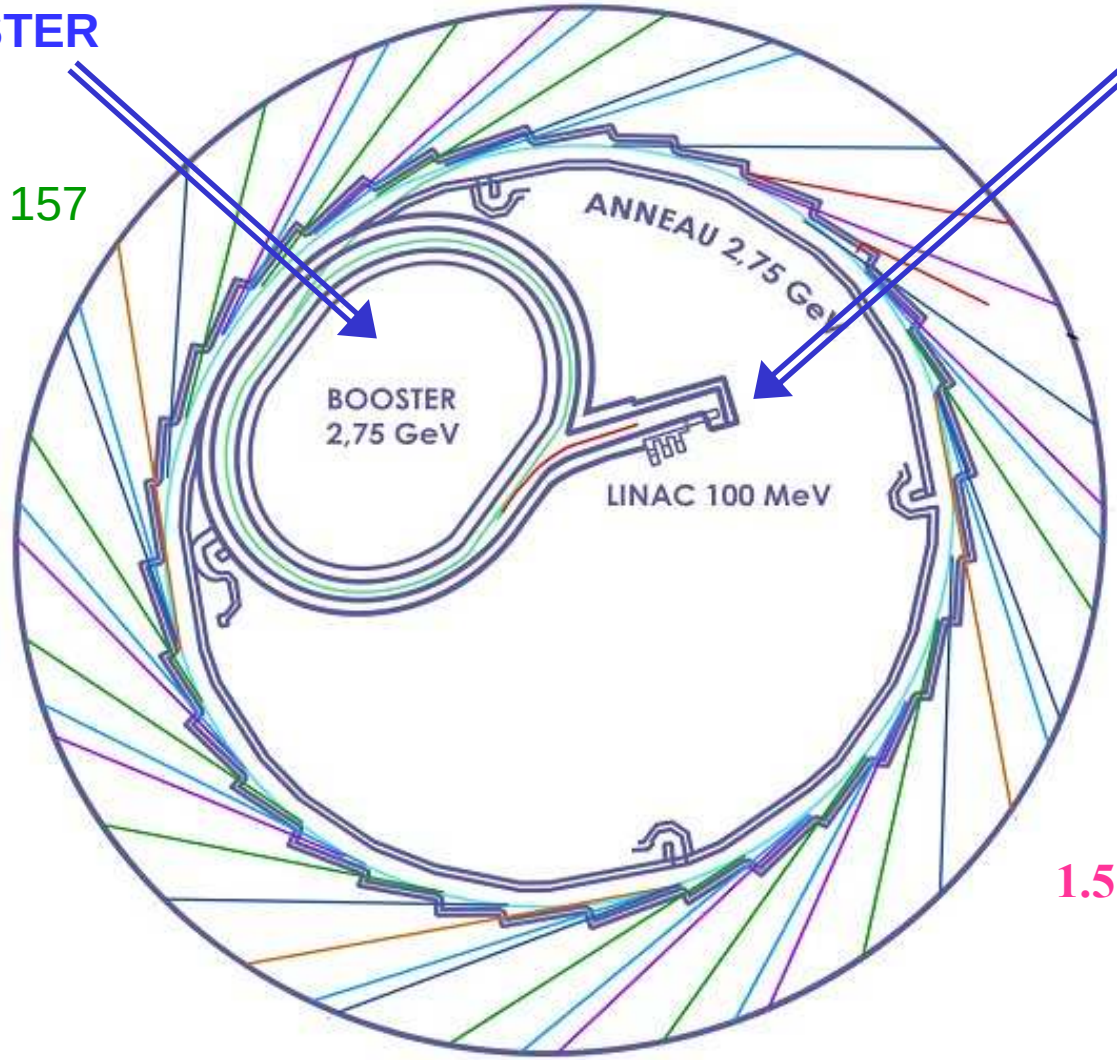
2 super periods
Circumference: 157 m

36 Dipoles :
0.67 T / 2.17 m

44 Qpoles:
10.3 T/m - 0.4 m

Emittance:
110-150 nm.rad

Power supplies cycling at 3 Hz



LINAC

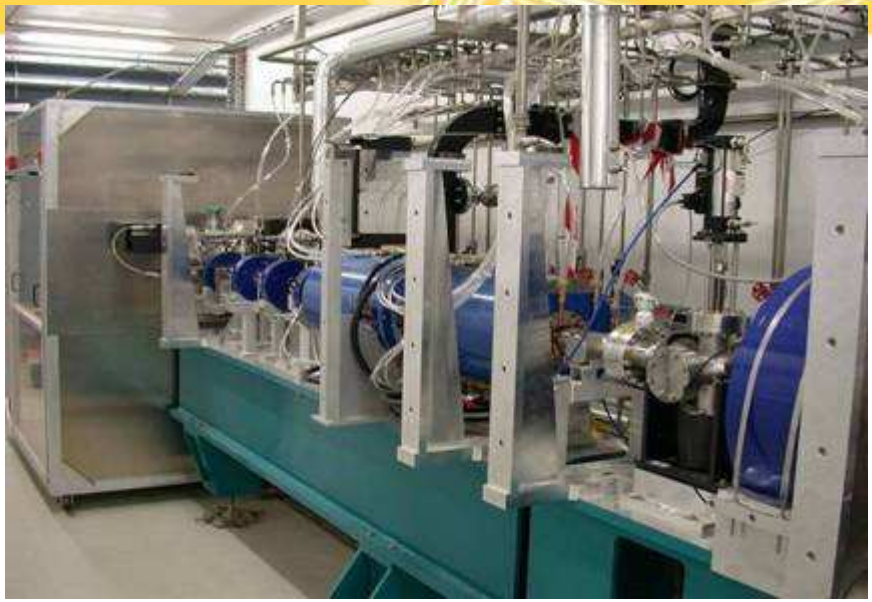
100 MeV
3 Hz rep Rate

Output charge :
8 nC in 300 ns
in multibunch mode
(500 mA in SR)

1.5 nC in 3 pulses (2ns)
in 8 bunch mode
(90 mA in SR)

LINAC "turn key system" provided by THALES:

1st beam on July 2nd 2005



Excellent performances: stability/reproducibility

Spec. :
(γε at 90 %) < 200 π.mm.mrad

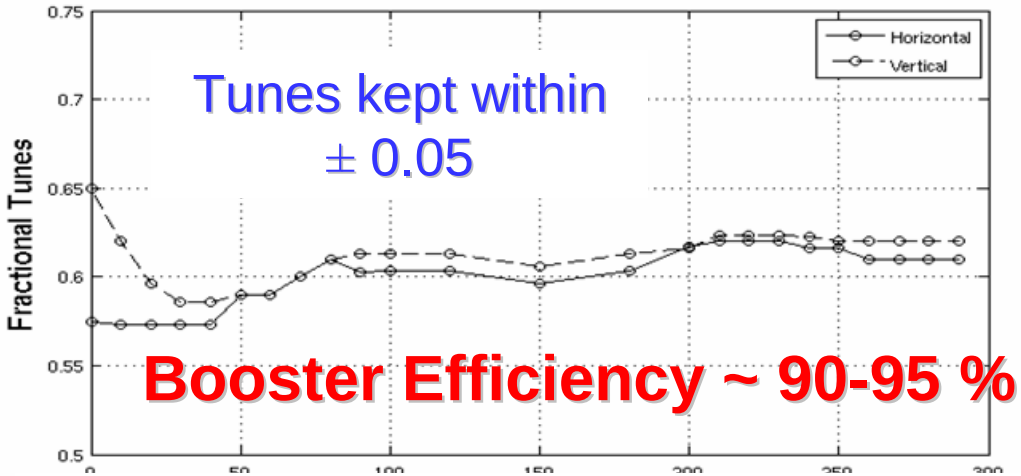
Mode	Beam Charge	Horizontal π mm.mrad	Vertical π mm.mrad
Long Pulse	10.6 nC	47	52
Short Pulse (1)	0.55 nC	64	67
Short Pulse (4)	2.27 nC	67	78

Final Acceptance pronounced on November 15th, 2005

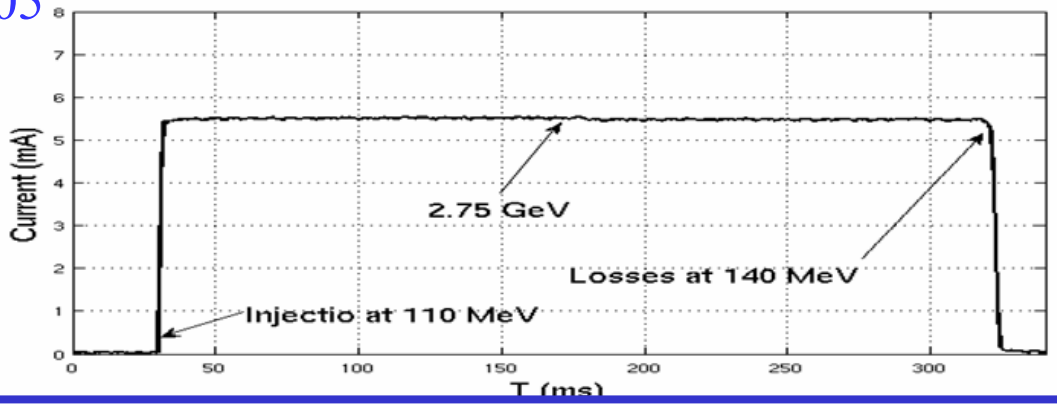
Booster ring commissioning

1st beam in the Booster at 110 MeV

July 23rd, 2005



4 power supplies (Bruker) ramped at 3 Hz:
"Tracking" ± 0.2 %



Beam decelerated down to 140 MeV

Storage Ring main parameters

Energy	2.75	GeV
Circumference	354.097	m
RF frequency	352.202	MHz
Harmonic number	416	
Betatron tunes (H/V)	18.20 /10.30	
Natural chromaticities (H/V)	-53 / -23	
Momentum compaction α_1 / α_2	4.5×10^{-4} /$4.6\ 10^{-3}$	
Radiation loss per turn (with IDs)	1200	keV
Damping times	7, 7, 3.5	ms
Emittance	3.7	nm.rad
Relative energy spread	1.016×10^{-3}	
Natural bunch length (@ 4 MV)	4	mm
Coupling	1	%
Multibunch mode	500	mA
Expected Beam Lifetime	16	h

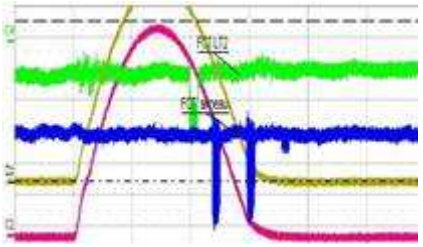
Specificities and innovative aspects

- High ratio (43 %) of ID straight sections over total 354 m circumference
- Extreme requirements for beam stability
- Specific super-conducting cavities (352 MHz)
- RF power generator: solid state amplifier of 4 x 190 kW (never done)
- Innovative insertion devices
- Al chamber vessels with NEG coating (56 % of the circumference)
- New type of BPM digital electronics: LIBERA module

Commissioning Milestones in 2006

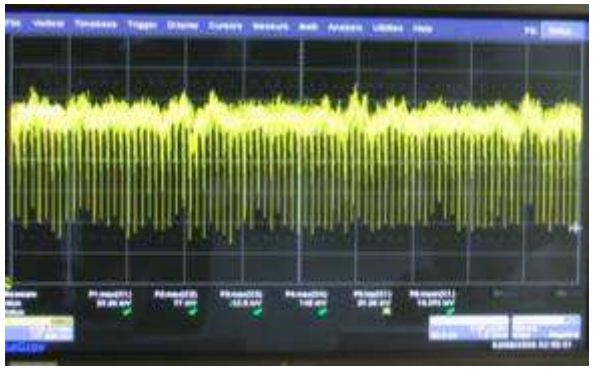
12 effective weeks

5/14 First turn
6/04 First stored beam
6/04 First beam accumulation: 8.35mA



7/04 100mA achieved
7/10 5 A.h beam dose

shutdown 7/11 – 9/4 (water + holidays)



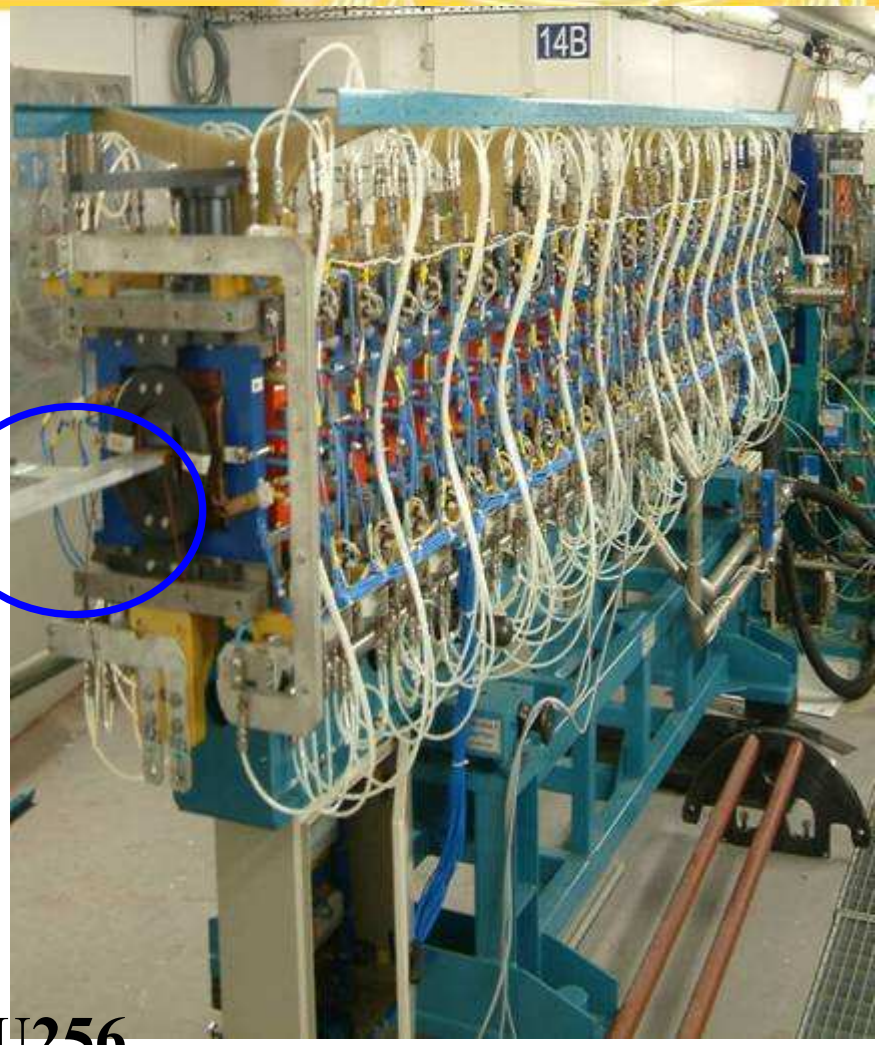
9/13 First photons to a beamline (DIFFABS)
9/16 200mA
9/21 First photons to a beamline (TEMPO)
9/25 300mA achieved ; 30A.h
9/29 U20 at 5.5 mm gap
9/21 First photons to a beamline (ODE)
10/15 beam lifetime = 8h @ 100mA in 312 bunches

shutdown 10/16 – 12/01 (21°water circuit cleaning)

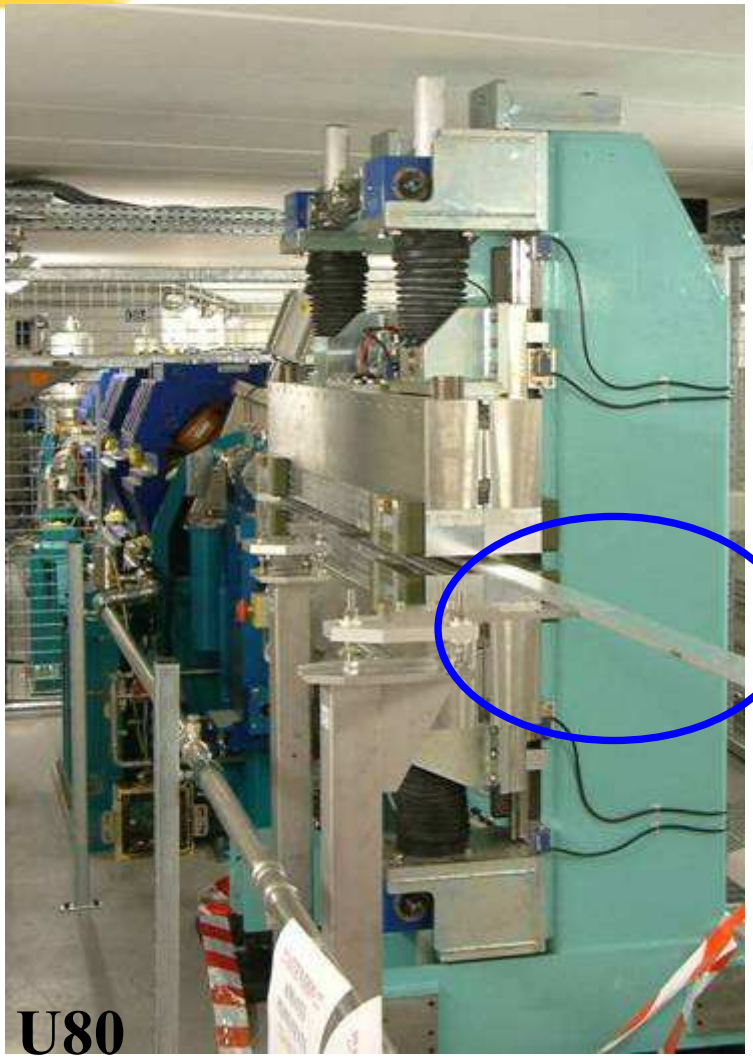
12/12 First photons to a beamline (SAMBA)
12/13 first photons to a beamline (DESIRS)
12/21 75 A.h beam dose
12/21 beam lifetime =10h @ 100mA in 312 bunches

Expected obstacles:

10mm inner height ID vacuum vessels
since the first day on 10 medium straight sections



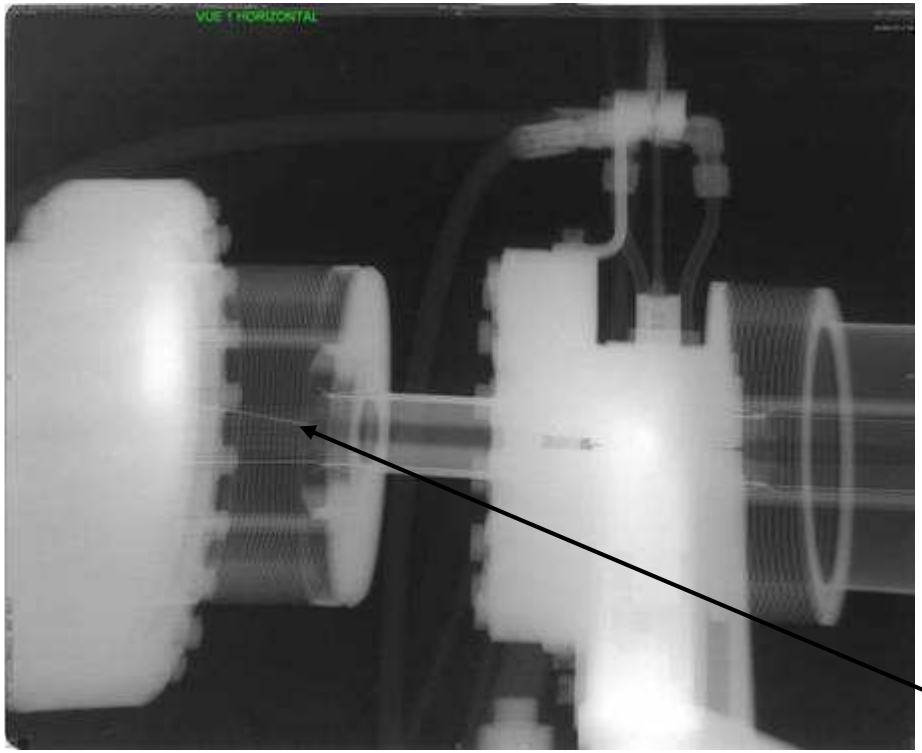
HU256

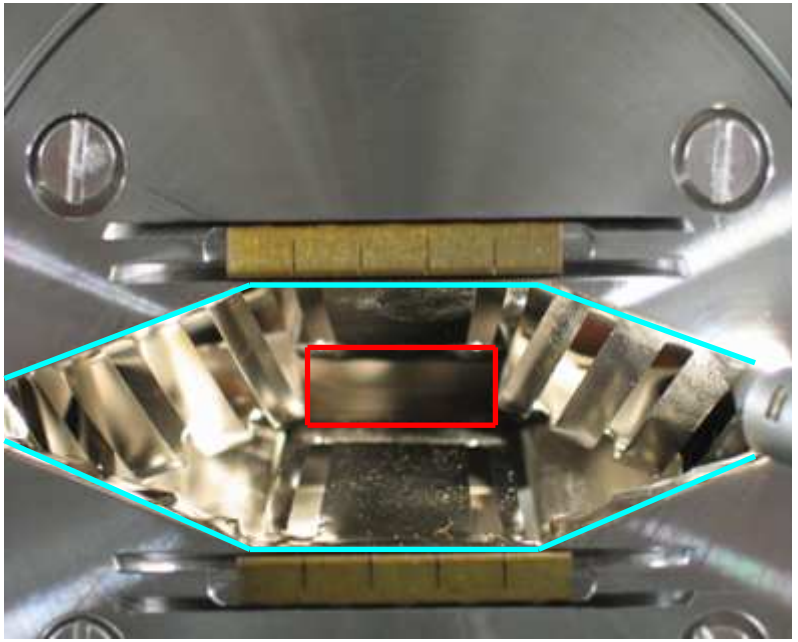


U80

Unexpected obstacles:

Bad mounting of some RF Fingers in short straight sections





RF finger at 1.5 mm from beam axis !

But the beam went nicely through these very small apertures!

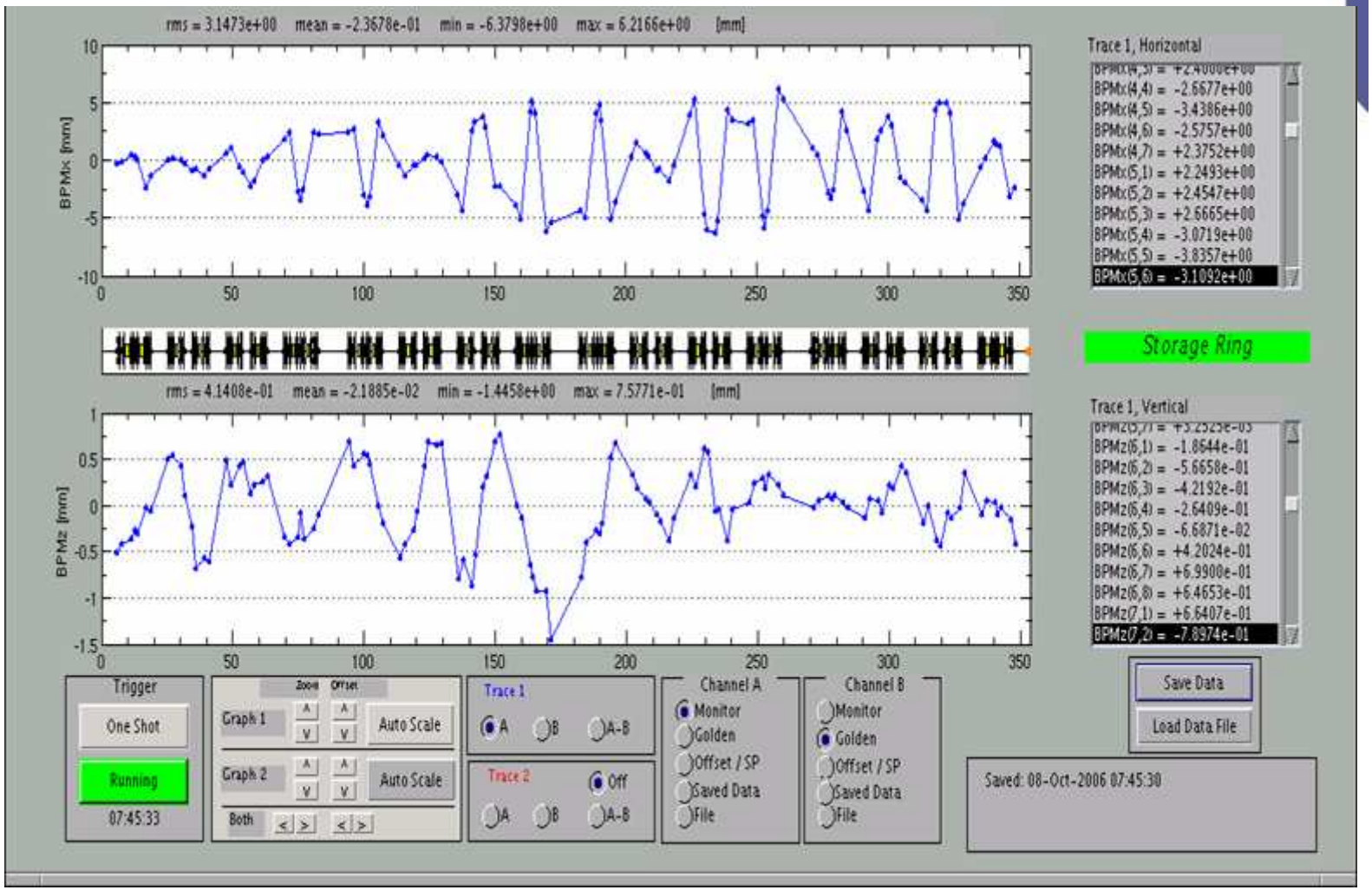
Problem fixed now (they all have been replaced)

Measured Closed Orbit With All Correctors switched OFF.

(BPM offsets included after BBA)

H-plane
Rms = 3.1mm
Max = 6.4mm

V-plane
Rms = 0.4mm
Max = 1.4mm



Closed Orbit Correction after the Application of the Beam Based Alignment

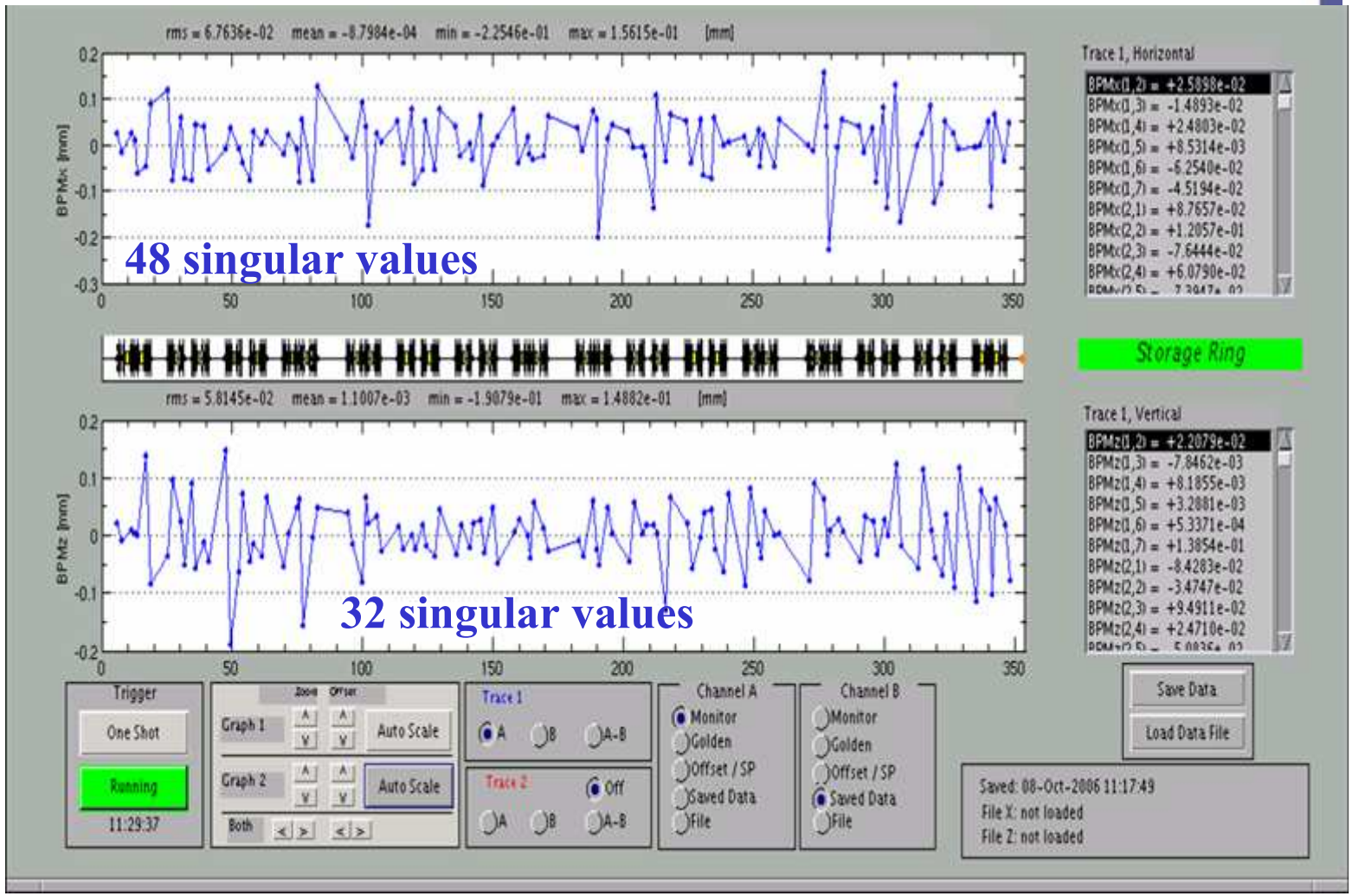
56 correctors in each plane and 120 BPMs.

H-orbit
rms = 68μm
max = 225μm

rms HCOR
1.1 A →1 A

V-orbit
rms = 58μm
max = 190μm

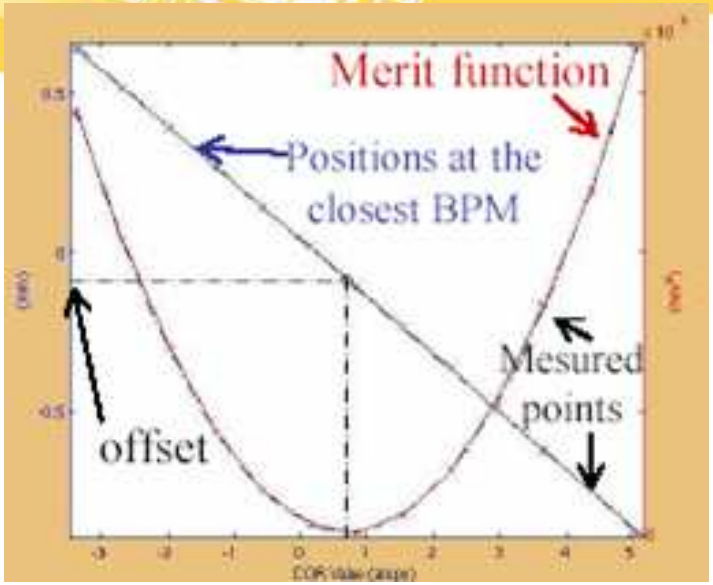
rms VCOR
2.0 A →0.4 A



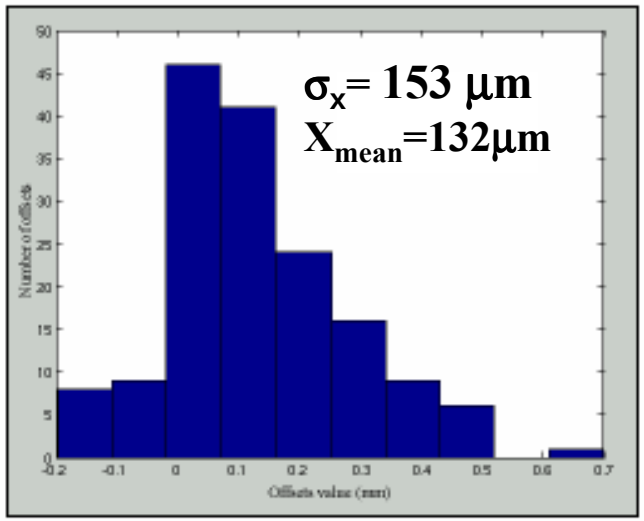
Quadrupole Beam Based Alignment

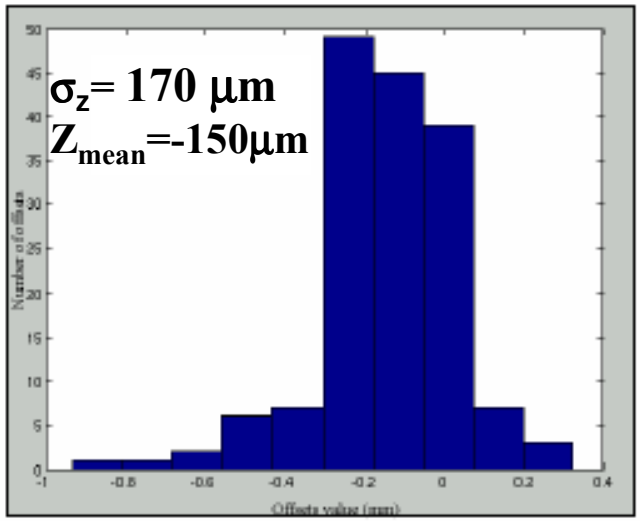
- Minimize the merit function

$$f(I_{cor}) = \left[\sum_{i=1}^{N_{BPM}} (y_i(+\Delta K) - y_i(-\Delta K))^2\right] \propto (I_{cor})^2$$



- Statistics of the offsets (first iteration)





Storage Ring: magnetic measurements

Very careful metrology to reach excellent alignment


alignment of the Magnetic measurement bench

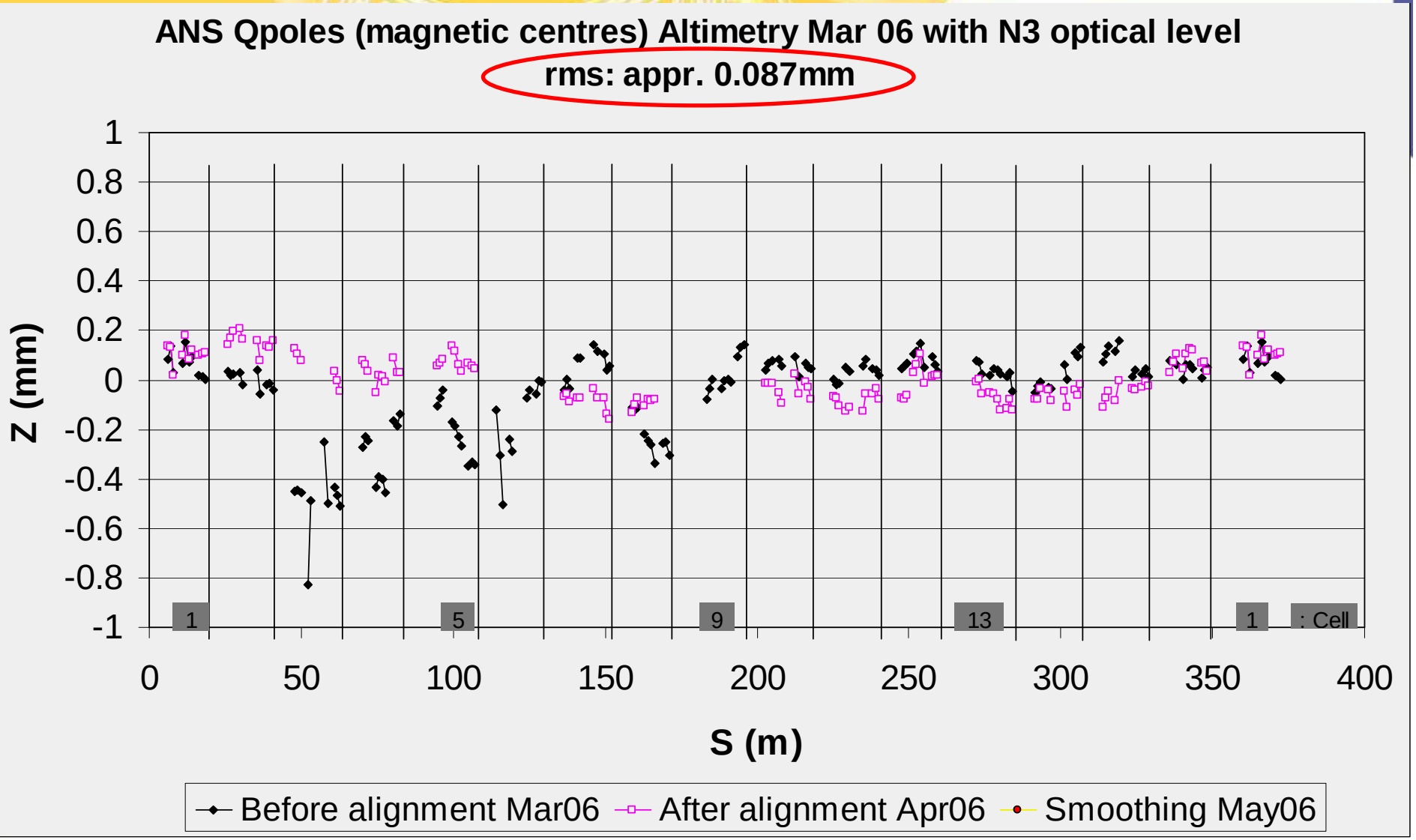
May 2004-Aug. 2005
Magnetic measurements of 326 electro-magnets: magnetic axis centering, field properties

Rotating coil bench built to reach magnetic centering to
± 25 µm and tilt ±0.1mrad

Table 1

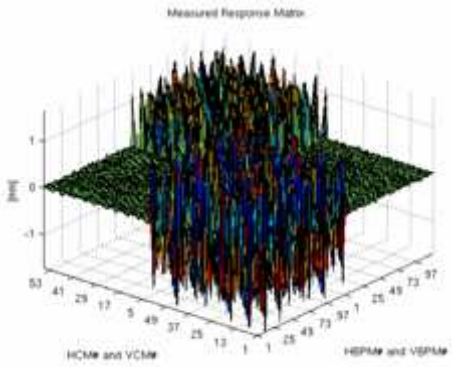
	Statistical analysis of measurements			
	Quadrupoles		Sextupoles	
	Mean Value	RMS value	Mean Value	RMS value
ΔX (microns)	1.5	8.4	-3	15
ΔZ (microns)	2.6	7.5	2	10
Tilt (mrad)	0.008	0.040	0.010	0.100

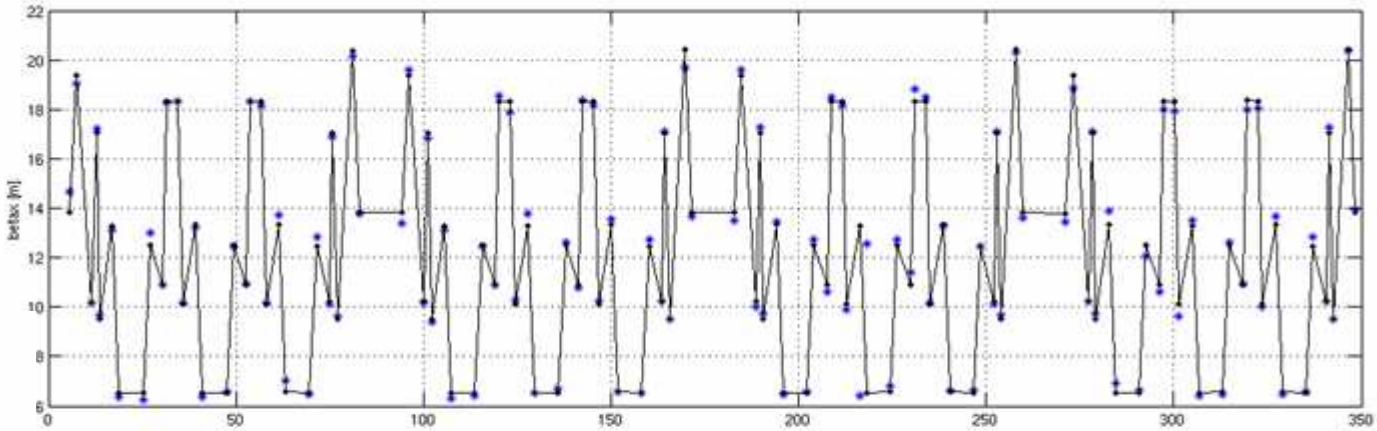
Storage Ring: Q-Magnet alignment



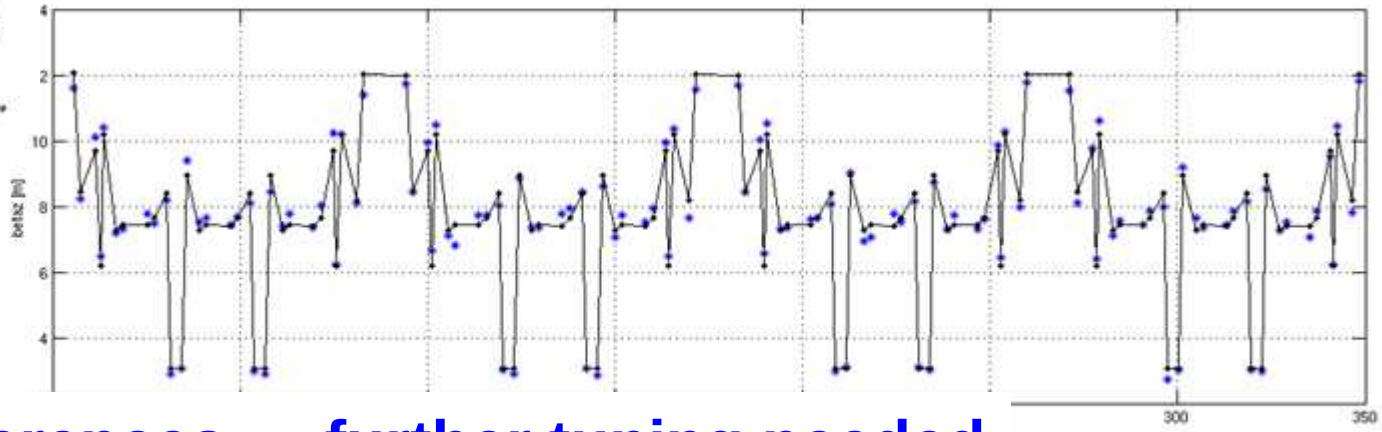
β functions at the BPMs after LOCO application: comparison measured and theoretical values

H Plan



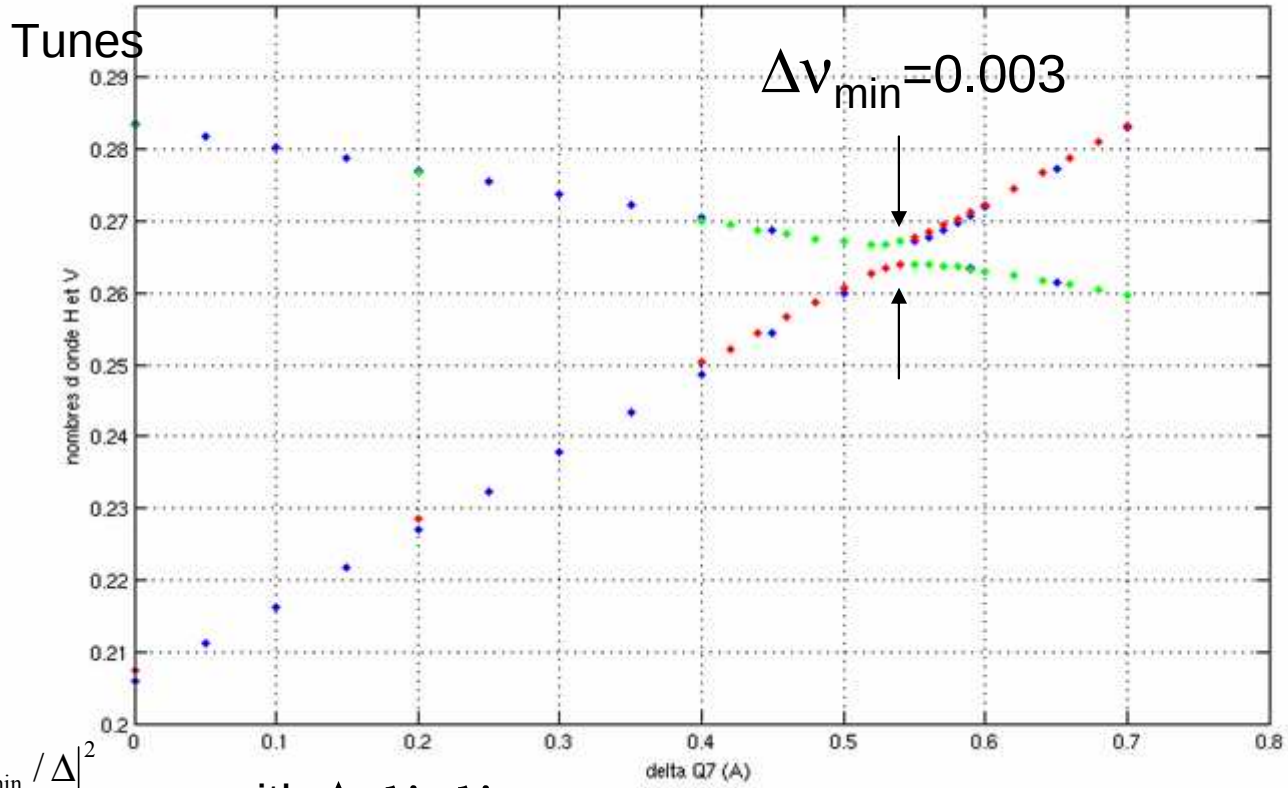


V Plan



~ 5 % differences ⇒ further tuning needed

Betatron Coupling from Closest Tune Approach
without any skew quadrupole correction



Without coupling correction

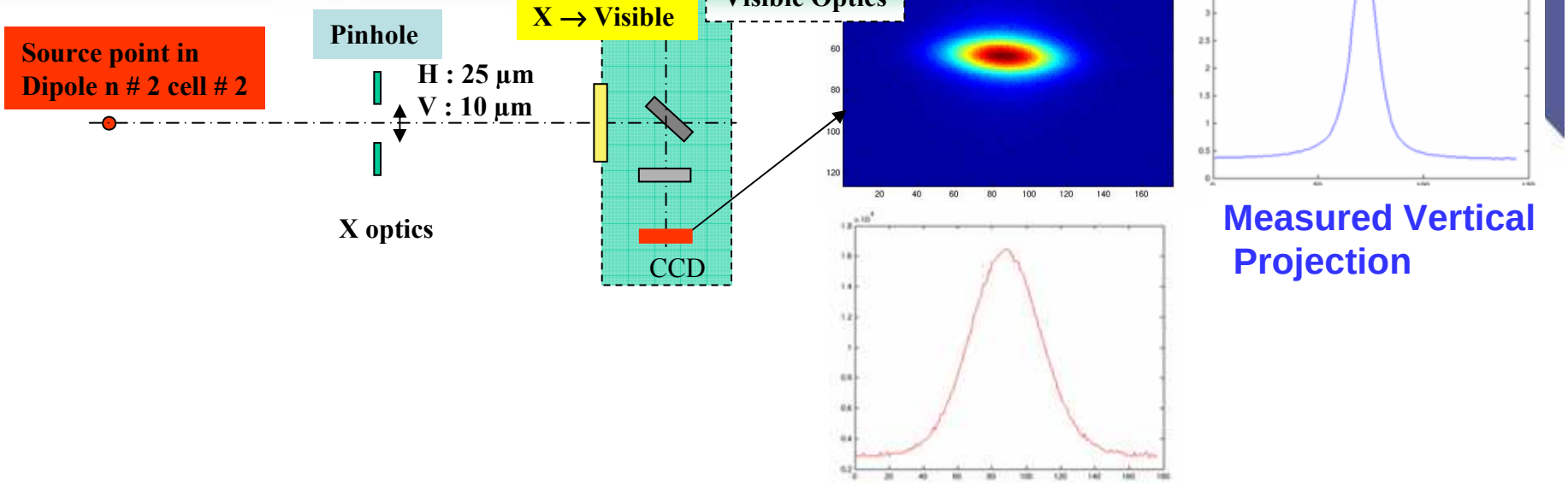
$$\kappa = \frac{|\Delta\upsilon_{min}/\Delta|^2}{(2+|\Delta\upsilon_{min}/\Delta|^2)}$$

Guignard, CERN 95-06

with $\Delta=\nu_x-\nu_z-p$ (no vertical dispersion & single resonance approximation)

ν_x=18.2088 ν_z=10.2840 , p=8 **κ = 0.08 %**

Beam Emittance Measurements



Measured Vertical Projection

Measured Horizontal Projection

- Camera with good linearity
- Image analysis by Gaussian fit and Deconvolutions
- Error bar on emittances :
  - ✓ *β value at source point : +/- 5 % possible beta beat*
  - ✓ *Instrument parameters : a few 10^{-3} on H , a few 10^{-2} on V*
  - ✓ *Vertical profile distortion remains to be understood*

ε_x = 3.9 nm.rad ± 0.25

ε_z = 11 pm.rad ± 2

$\kappa \approx 0.3\%$ (natural coupling)

Design: ε_x = ***3.75 nm.rad*** ***@ 2.75 GeV***

Tune shifts with energy

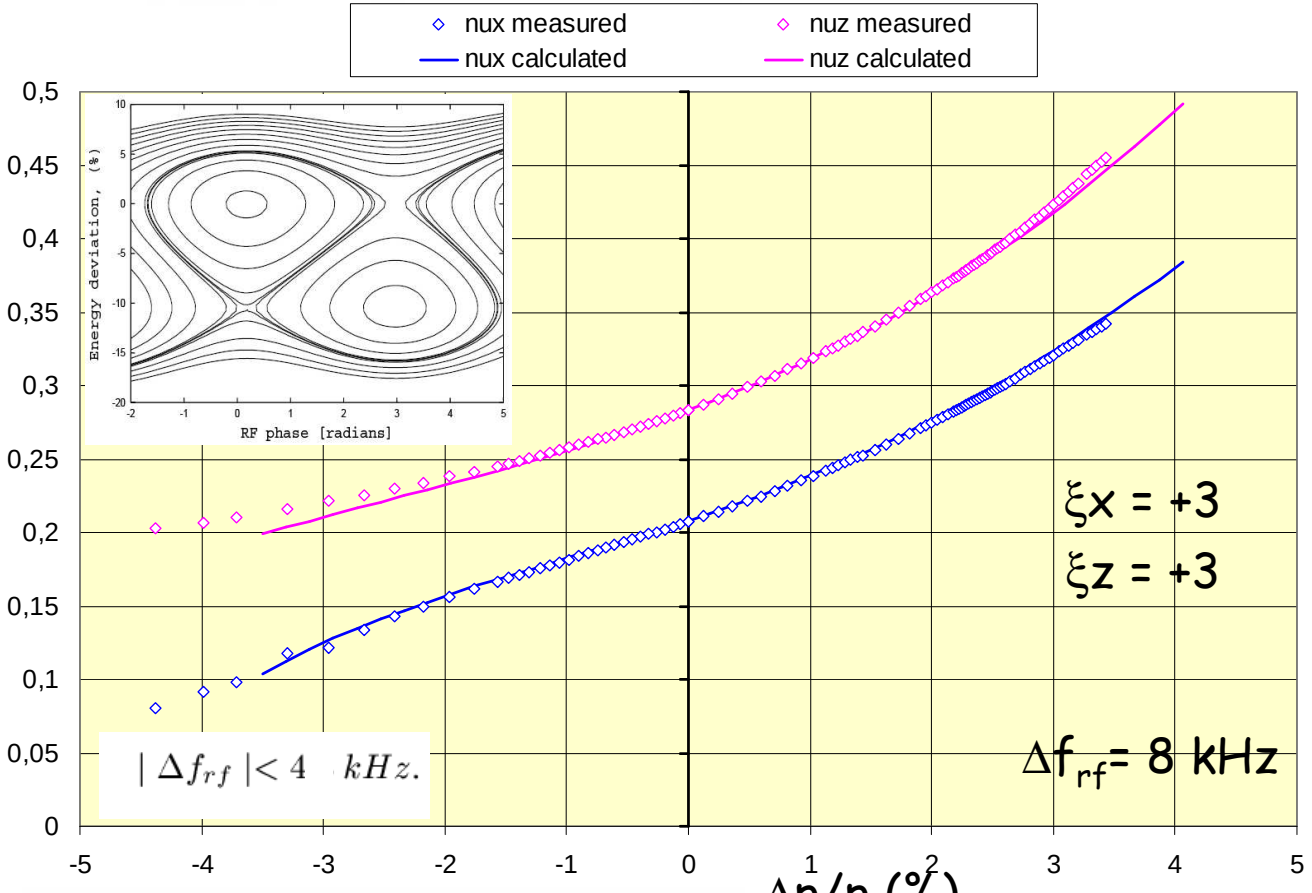
Good Agreement with model

DP/P > 0: loss on half Integer resonance (0.02 wide)

DP/P < 0: loss on longitudinal beam dynamics

$\alpha_1 = 4.5\ 10^{-04}$

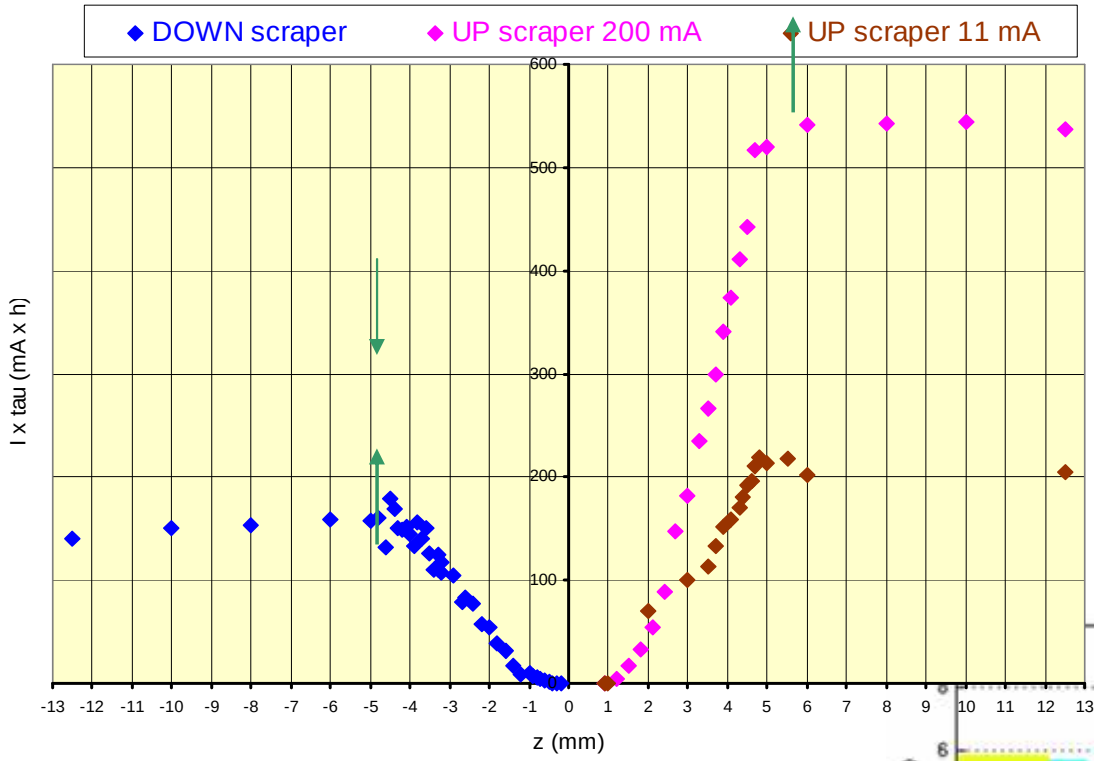
$\alpha_2 = 4.6\ 10^{-03}$



$$\delta_{1,2} = -\frac{\alpha_1}{2\alpha_2}\left(1 \pm \sqrt{1 - \frac{4\alpha_2}{\alpha_1^2}\,\frac{\Delta f_{RF}}{f_{RF}}}\right)$$

Vertical Acceptance

Measured Ixτ vs. vertical position of scrapers (up and down)



Scraper is located in a long Straight section

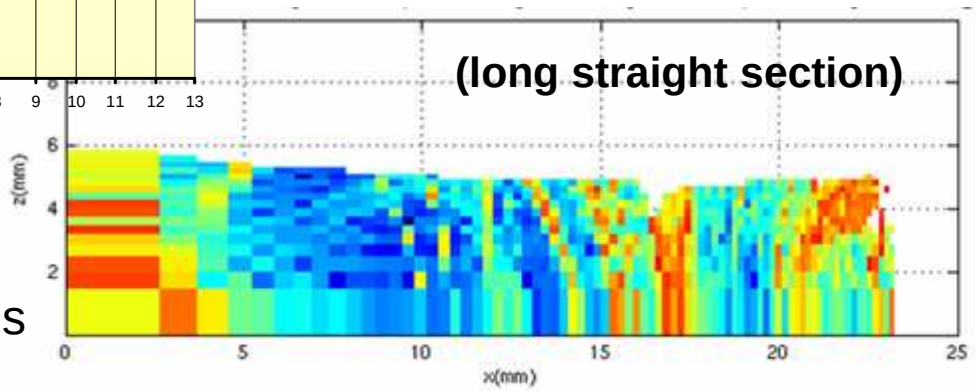
⇨ Measured ~ +/- 5mm.

Simulations parameters:

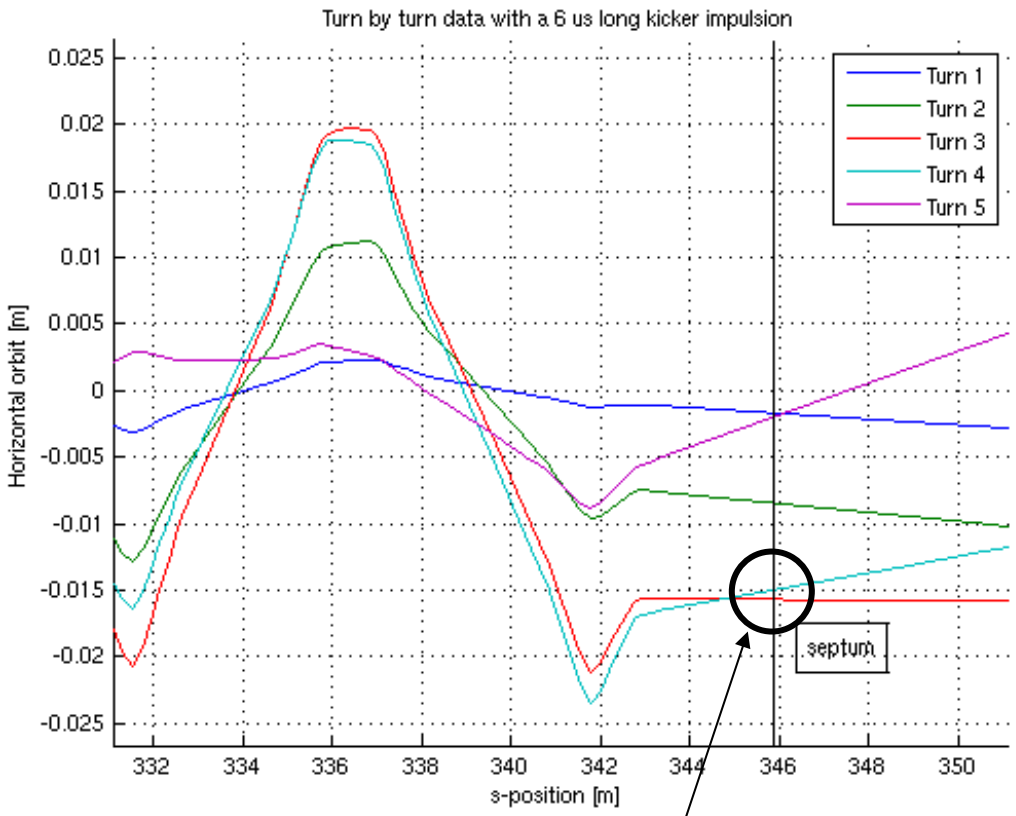
κ = 1%

Zmin = ±5mm in medium straight sections

Simulated Dynamic Aperture



Horizontal Acceptance



Measured: - 15mm

Deduced from turn by turn data kicking the beam with one injection kicker

Confirmed by inserting the scrapers at septum equivalent position and kicking the beam with the same kicker

Beam loss: Septum Position (-15mm)

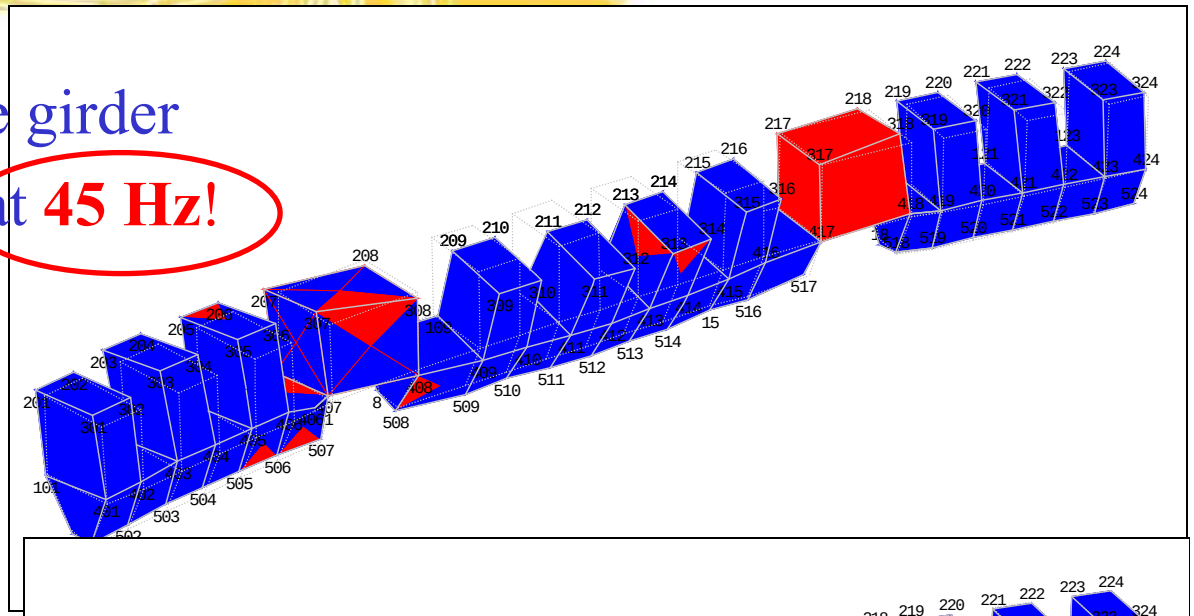
Vibration measurements on SR girders

Experimental Modal Analysis

- 1st mode on quadrupole girder

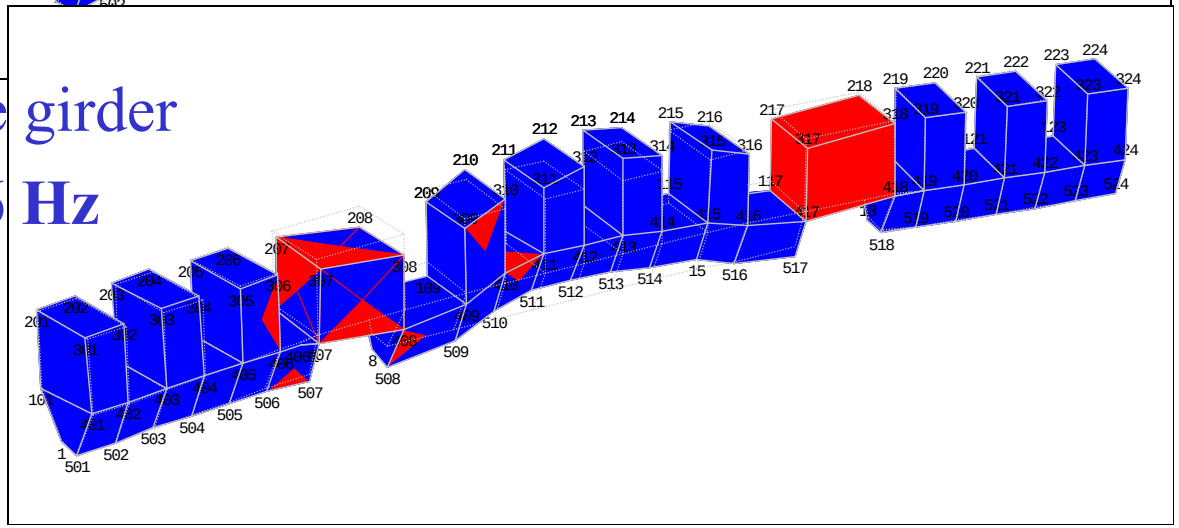
⇒(transversal flexion) at **45 Hz**!

⇒(design value 40 Hz)

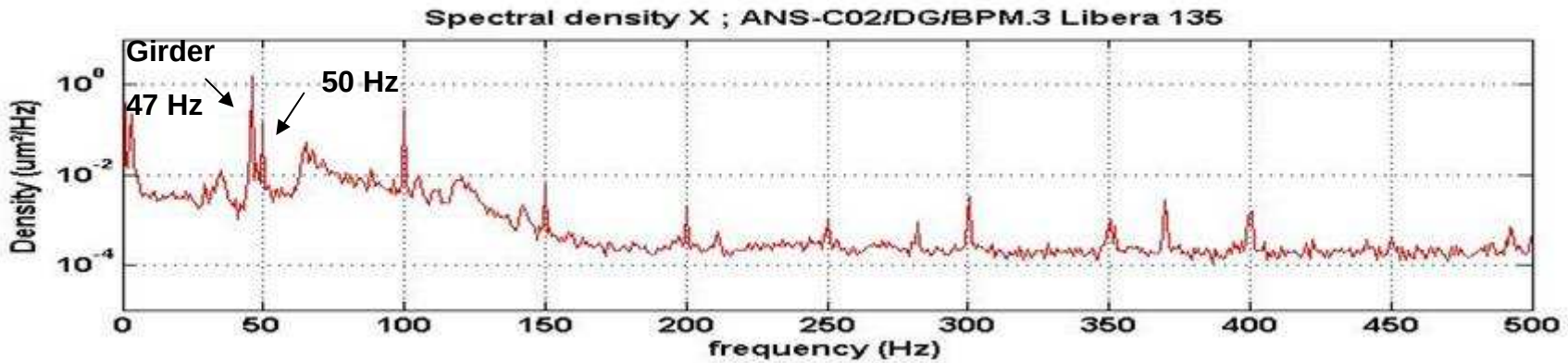


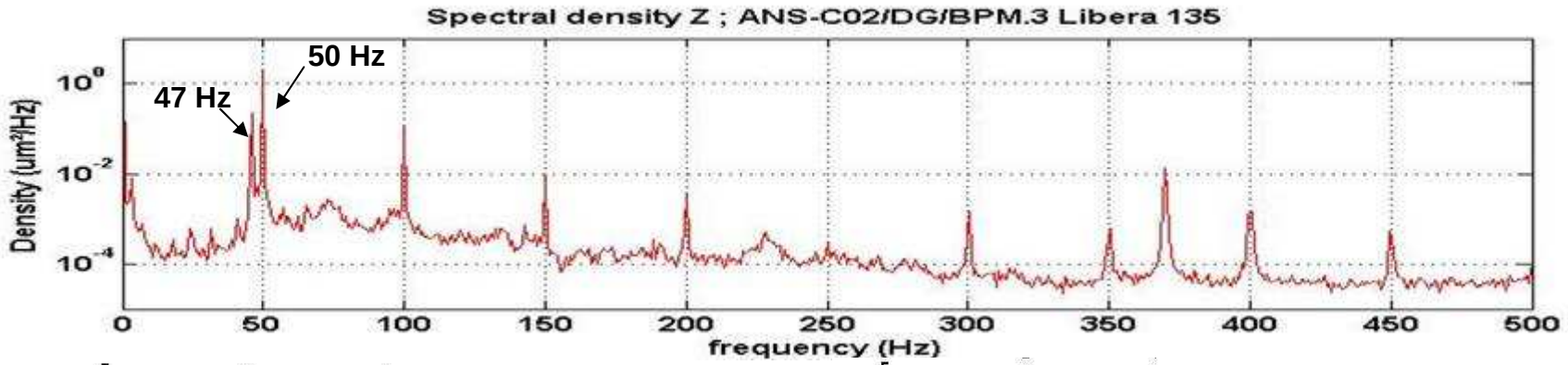
- 2nd mode on quadrupole girder

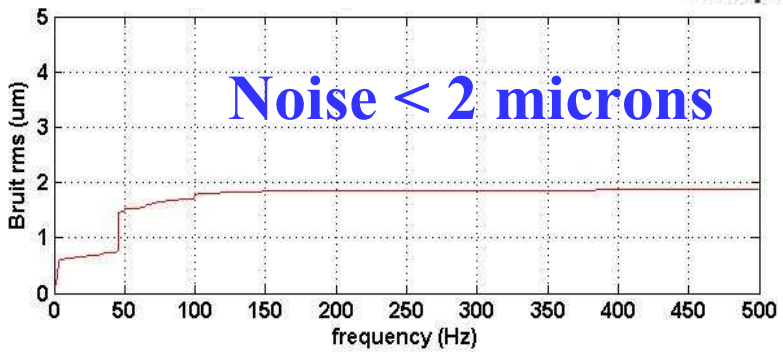
⇒(vertical flexion) at **56 Hz**

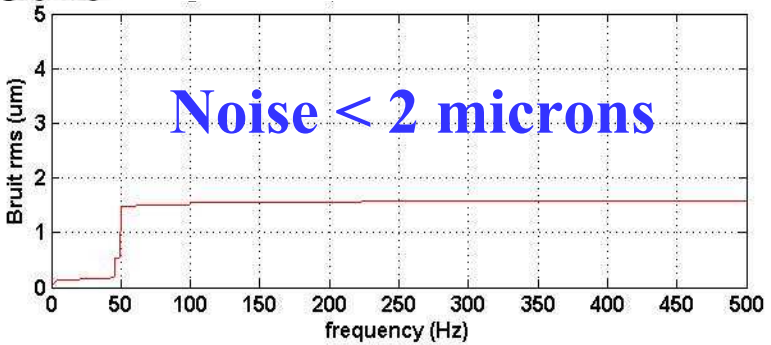


Typical noise spectrum
BPM + Beam: 0 to 500 Hz







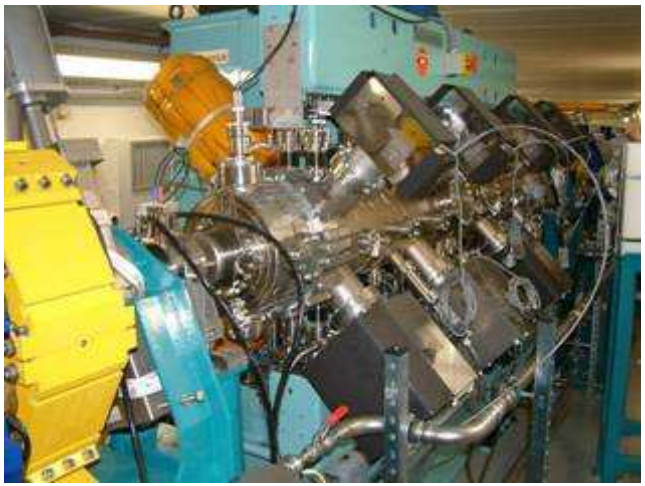


Insertion devices commissioning

HU640
10 m

2x HU80

2x U20

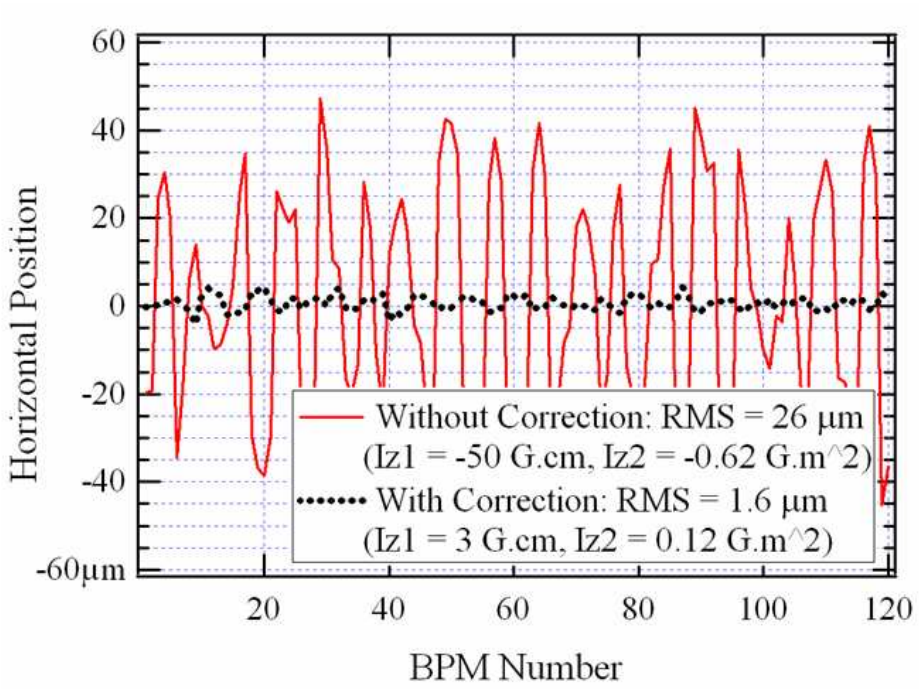


2x HU256

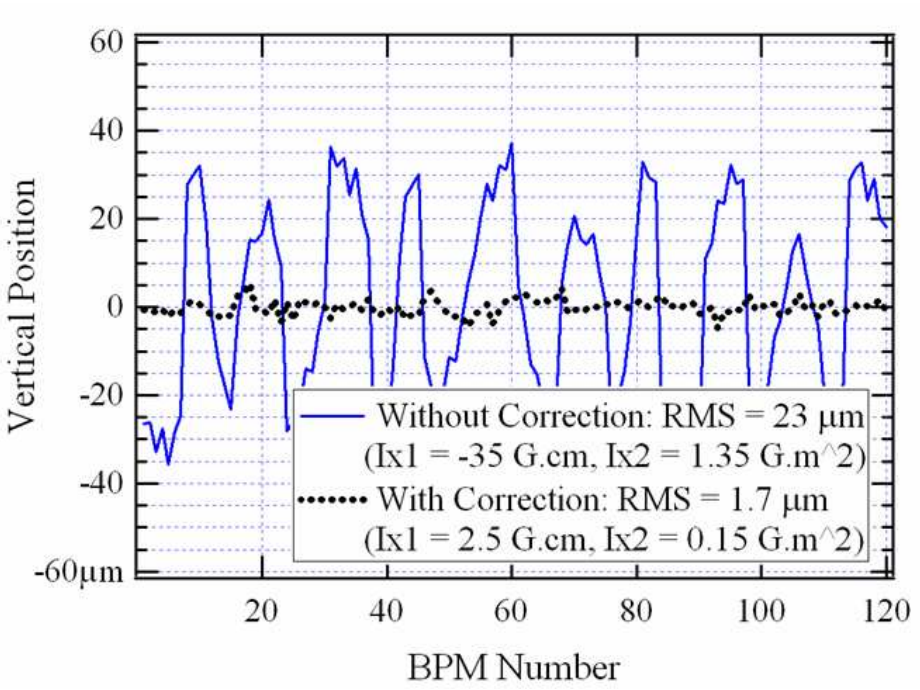
HU80-TEMPO Commissioning: Feed-Forward Correction Test

Minimal Gap (15.5 mm)
Helical Mode (Phase = 20 mm)

Horizontal BPM Data

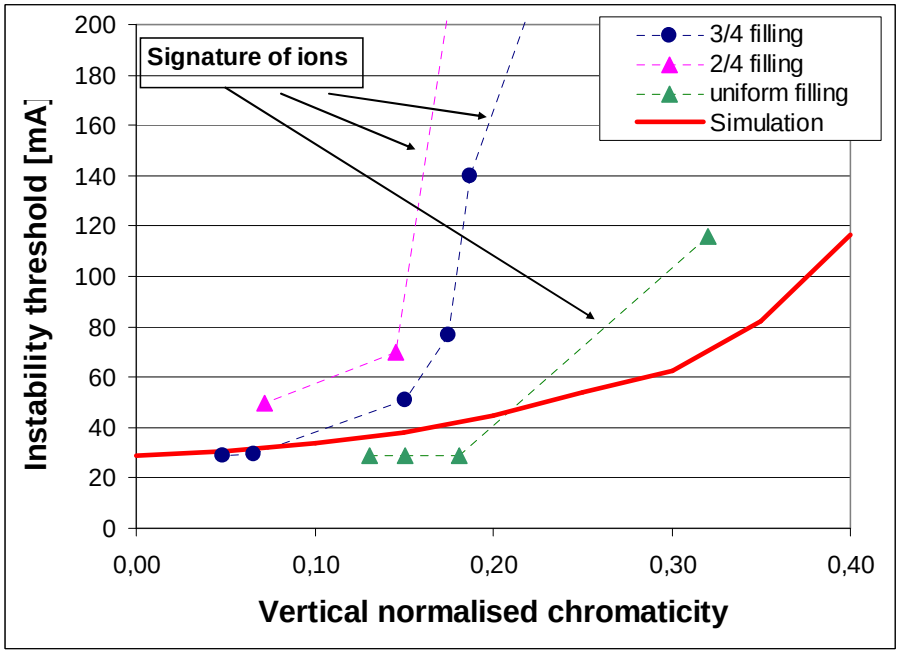


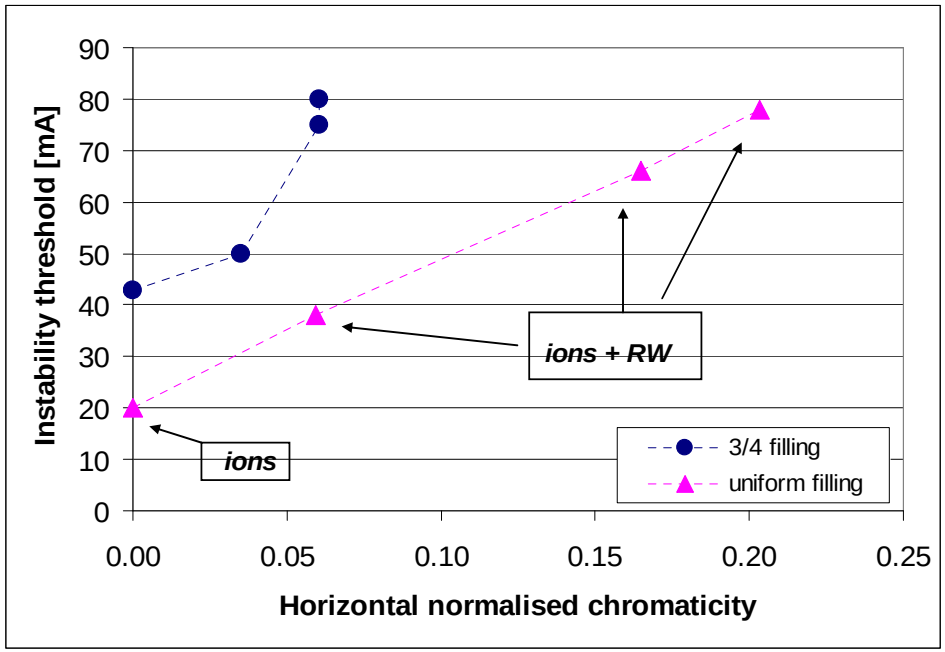
Vertical BPM Data



Multibunch Instabilities

- ✓ **Mixture of resistive-wall (RW) and ion induced** instabilities in both vertical & horizontal planes.
- ✓ No instability observed in the longitudinal plane.

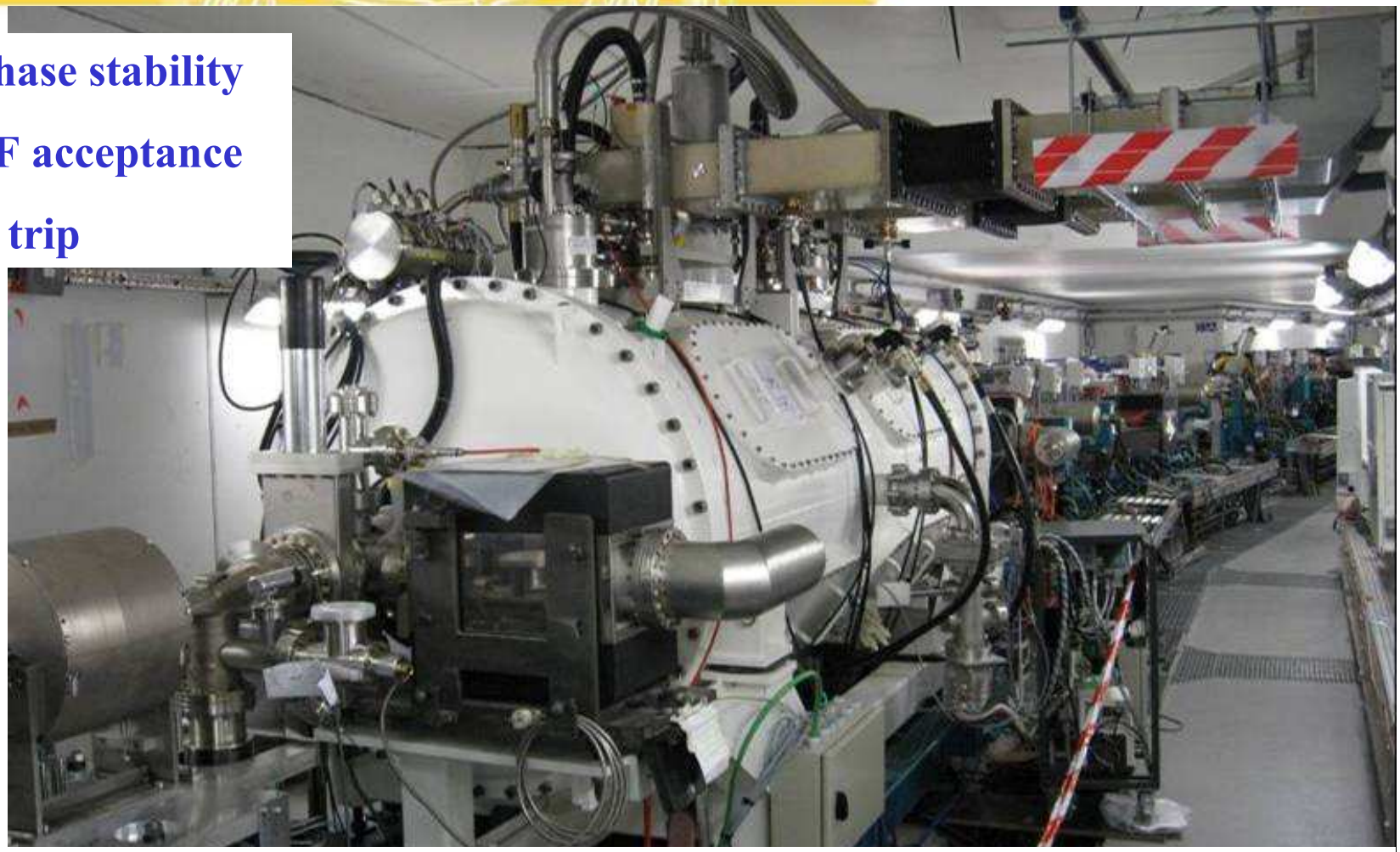




- Behaviour of ion-induced instability depends much on the beam filling pattern.
- Vertical threshold at low chromaticity in rather good agreement with prediction.
- Horizontal threshold much lower than expected.(90 mA)
- Single bunch current thresholds seem to be a factor 2 smaller than simulation

Dedicated superconducting RF cavities

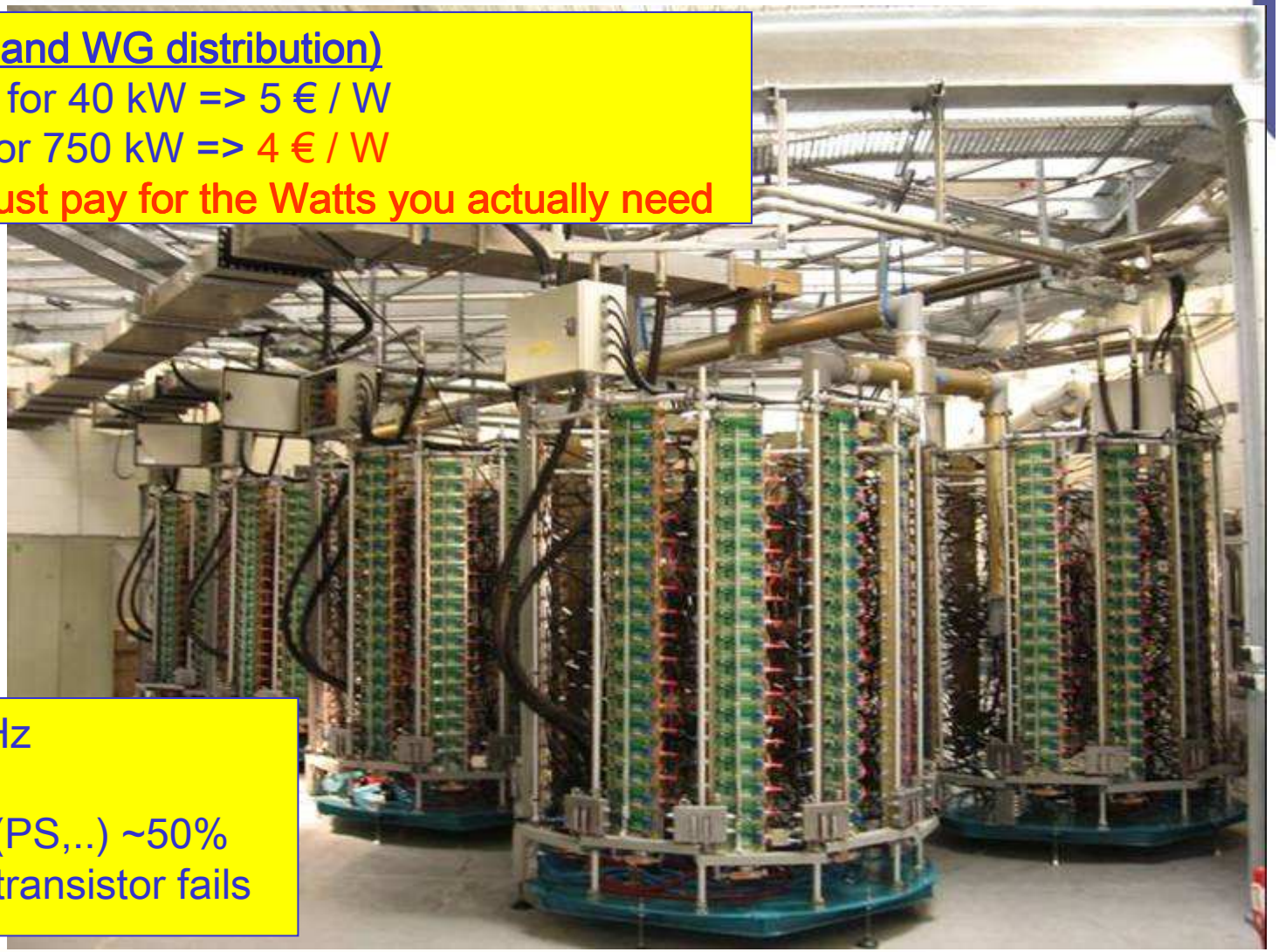
- 0.1 ° phase stability
- 6 % RF acceptance
- No RF trip



1st cryomodule will enable alone operation up to 300 mA.
A 2nd cryomodule is being built by ACCEL for operation at 500 mA (early 2008)

Storage Ring RF plant
4 x 190 kW power amplifiers

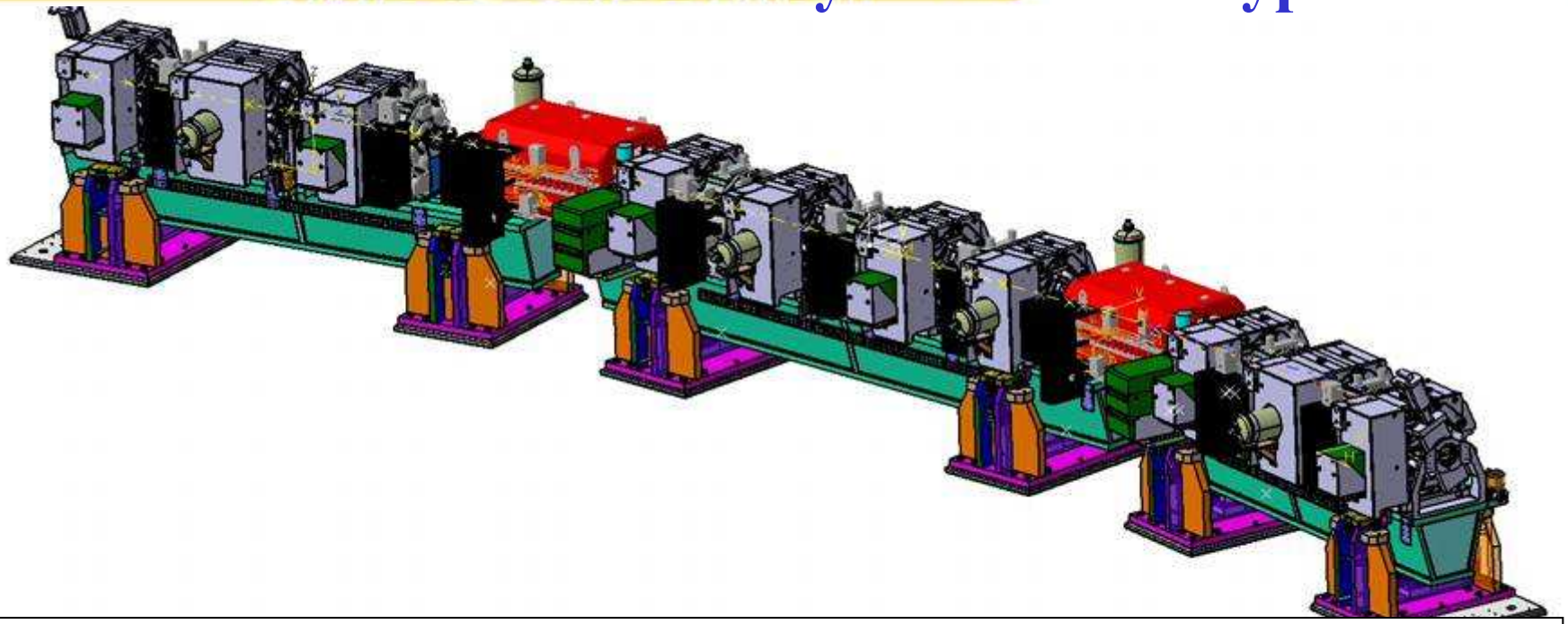
Full Cost (with PS and WG distribution)
Booster : 200 k€ for 40 kW => 5 € / W
Stor. Ring : 3 M€ for 750 kW => 4 € / W
Modularity = You just pay for the Watts you actually need



190 kW @ 352 MHz
Gain = 52 dB
Overall Efficiency (PS,..) ~50%
No RF trip even if transistor fails

Storage Ring Vacuum system

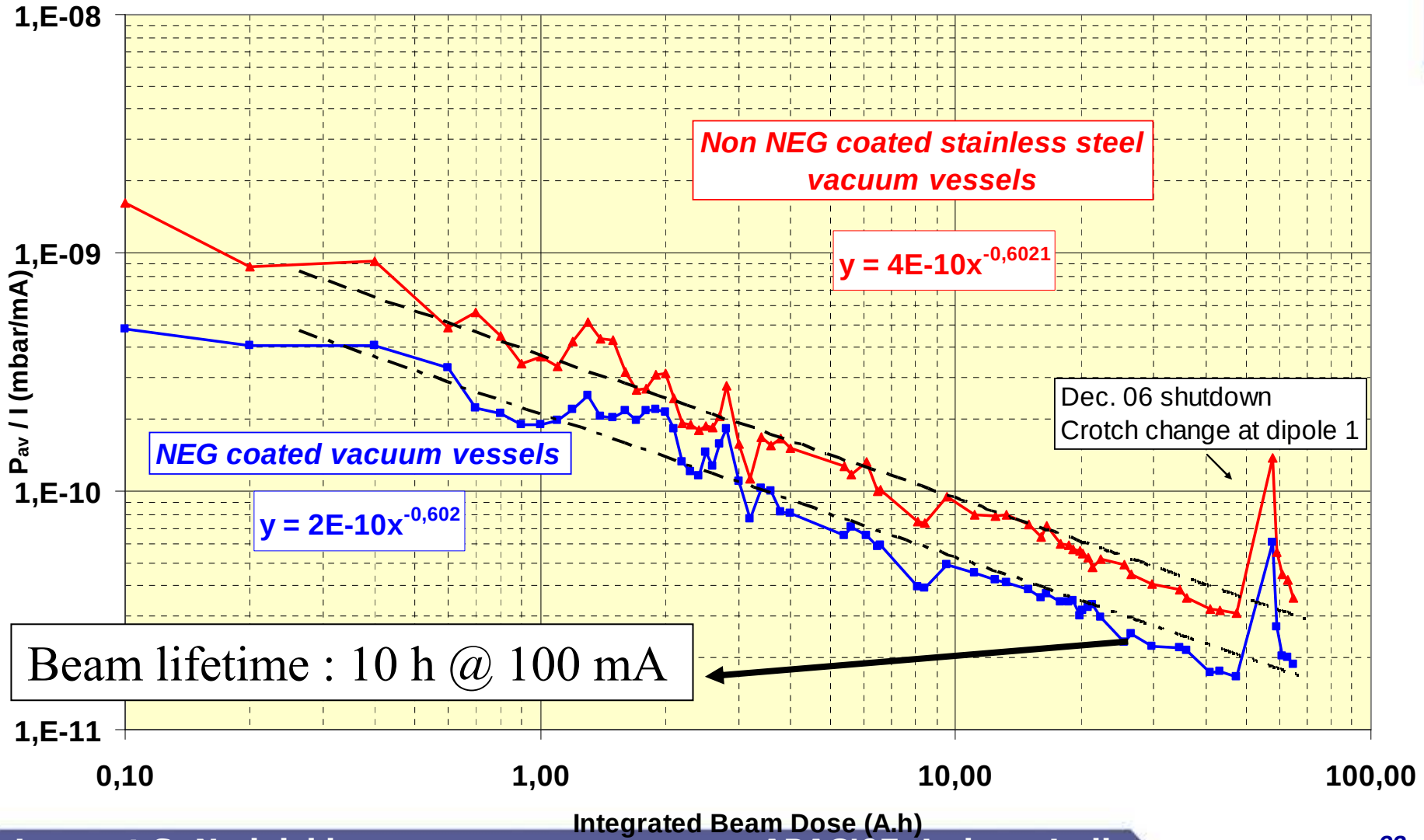
Vacuum system for one typical cell



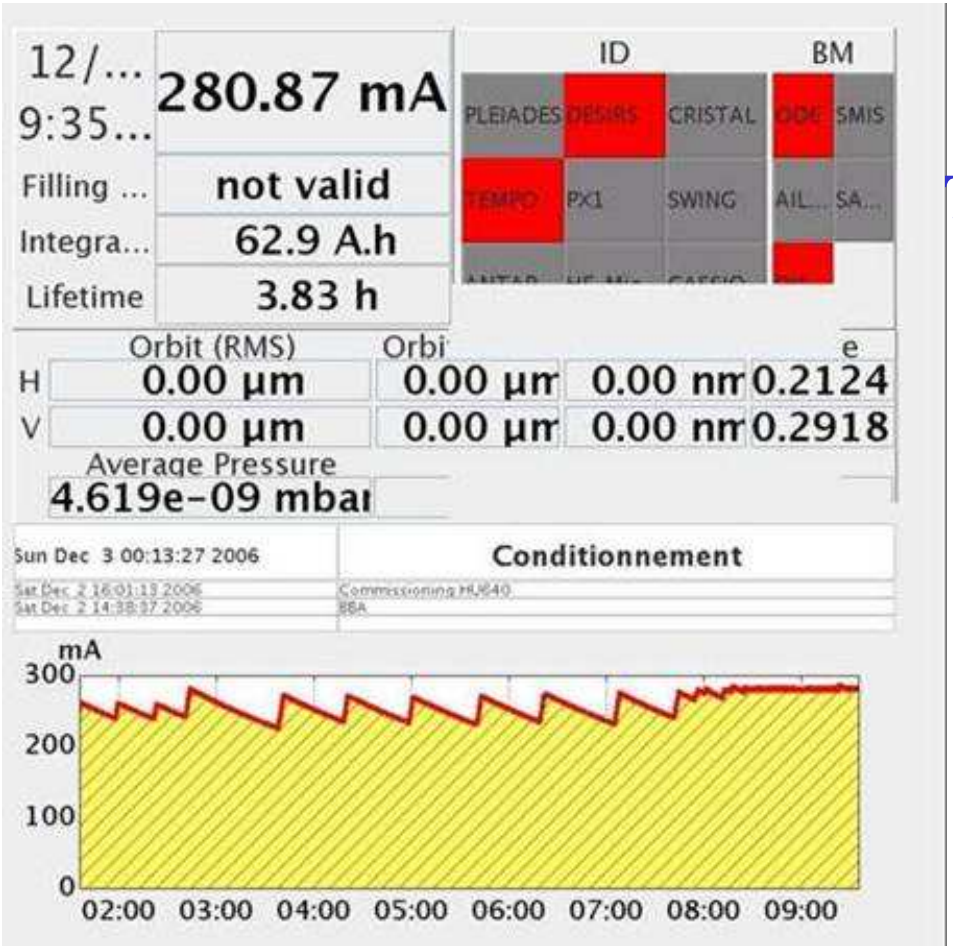
Together with the Straight Section chambers,
~200 m of NEG coated Al chamber (56% of the ring)

SOLEIL = first SR Machine with extensive use of NEG coated AL vessels

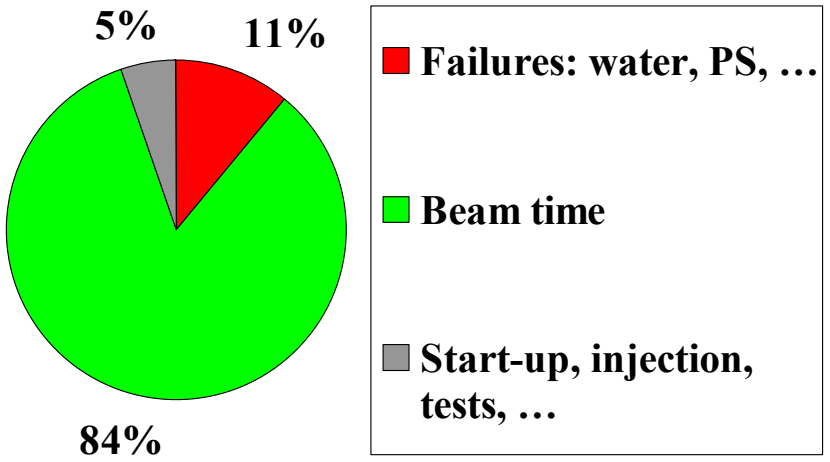
Vacuum Conditioning is well progressing



Beam time by the end of 2006



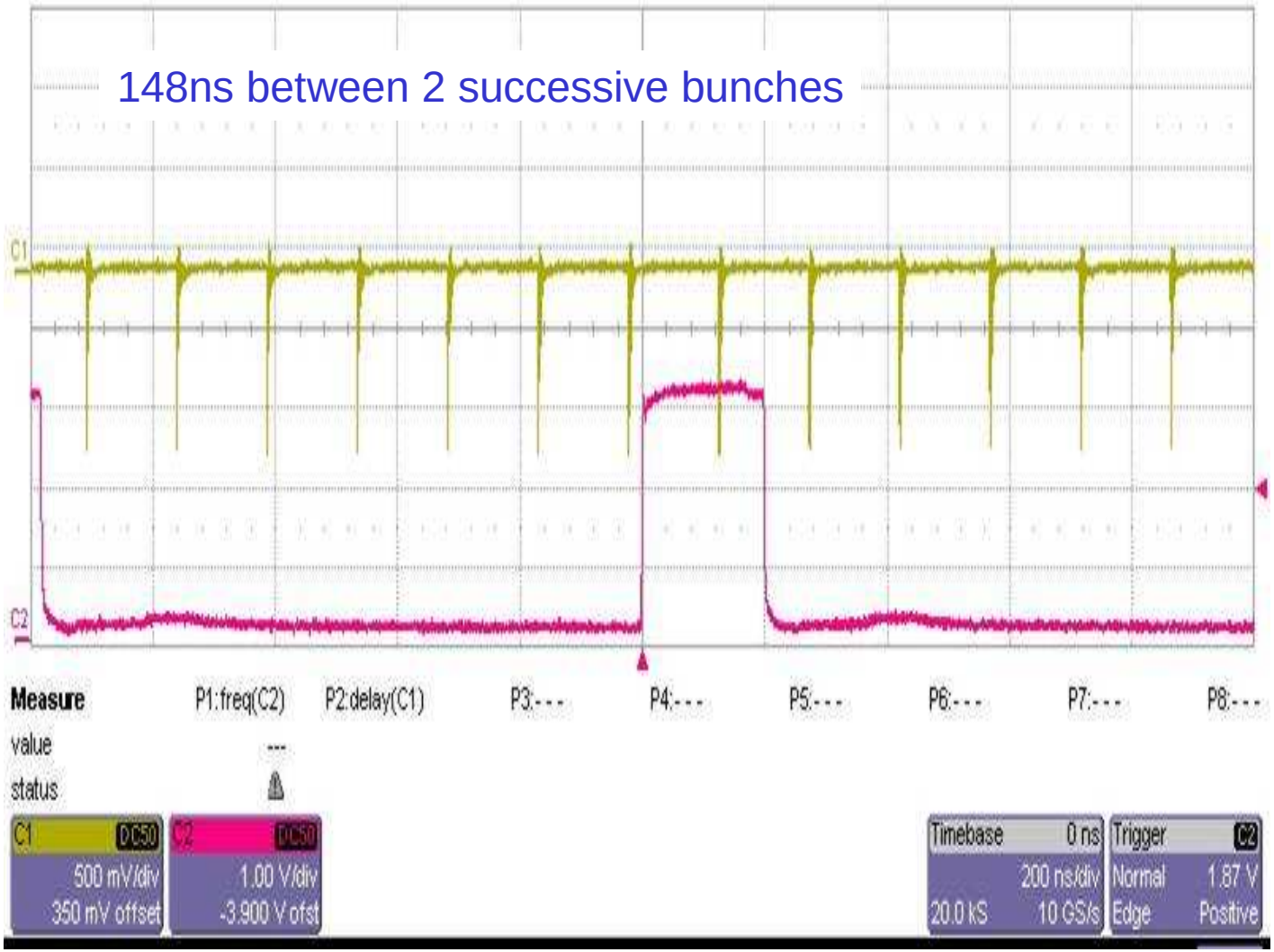
Maximum current: 300 mA
in 312/416 buckets
Total beam integrated dose: 75 A.h



July / December 2006: 1400 hours

Time structure mode

- 20 mA in 1 bunch
- 80 mA in 8 bunches



TANGO control system

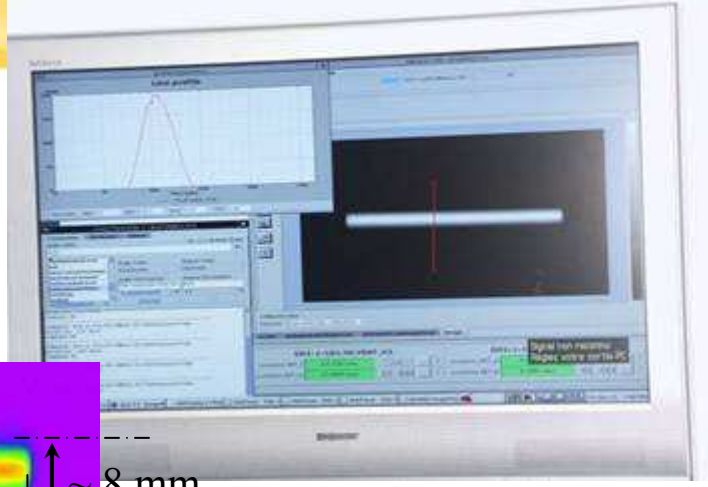
SOLEIL first facility using TANGO at full scale

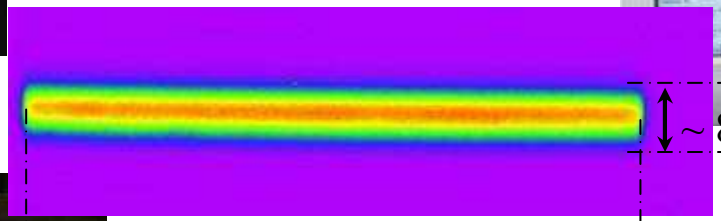
Collaboration ESRF/ELETTRA/SOLEIL/ALBA

- **Easy and efficient tools to control any equipment**
- **Control of all equipments from the control room, data archiving**
- **Supervision done using "GlobalSCREEN" applications All hardware installed (Crate with CPCI and boards, PLC's..)**
- **Machine commissioning: Matlab applications (Matlab Middle Layer Toolkit, Accelerator Toolbox, ...)**

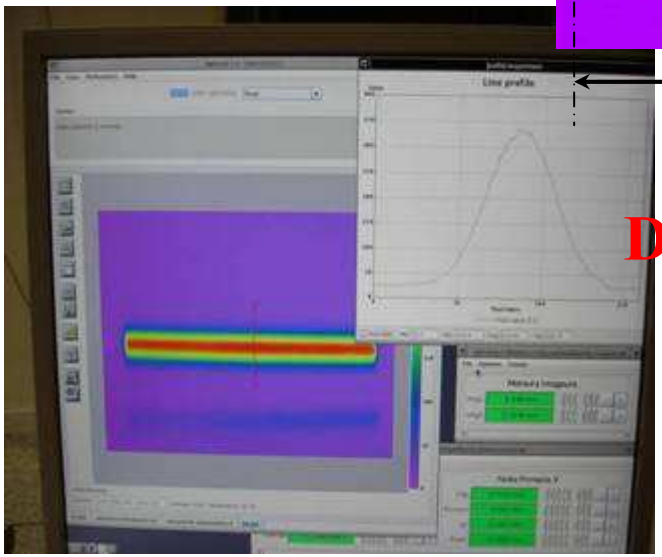
Beamline commissioning

TEMPO 09/20/06



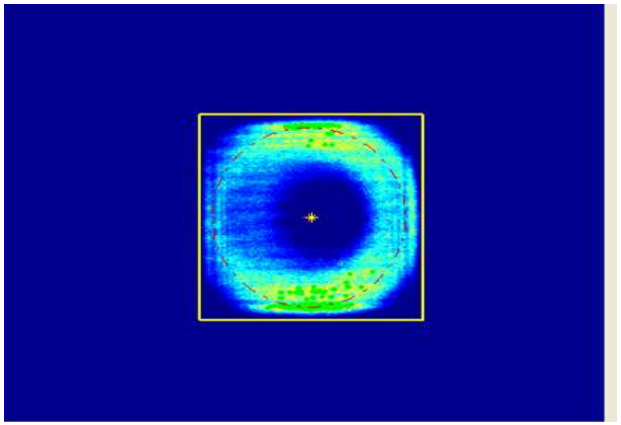


ODE 10/13/06



~ 80 mm

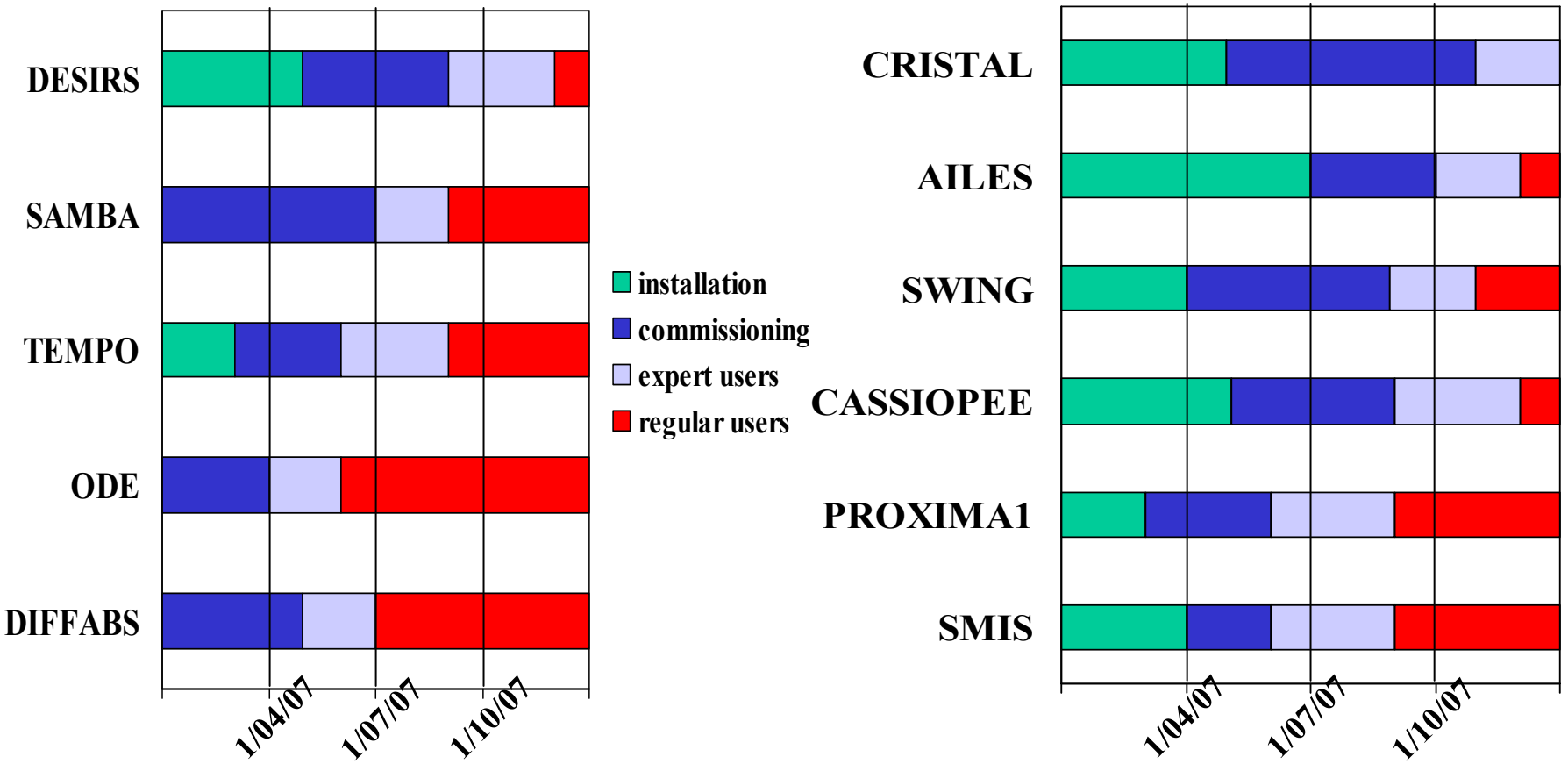
DIFFABS 09/13/06



DESIRS 12/14/06

SAMBA 12/13/06

Schedule for the first beamlines in 2007



Planned Operation in 2007
8 runs of 3 or 4 weeks ⇒ 3264 h for beamlines
+ 1584 h for the machine.

janv 2007		févr 2007		mars 2007		avr 2007		mai 2007		juin 2007		juil 2007		août 2007		sept 2007		oct 2007		nov 2007		déc 2007		janv 2008	
lun 01	. . .	jeu 01	1 1 1	jeu 01	. . .	dim 01	. . .	mar 01	1 1 1	ven 01	1 1 1	dim 01	m m m	mer 01	. . .	sam 01	m m m	lun 01	. . .	jeu 01	1 1 1	sam 01	1 1 1	mar 01	. . .
mar 02	. . .	ven 02	1 1 1	ven 02	m m m	lun 02	. . .	mer 02	1 1 1	sam 02	1 1 1	lun 02	m m m	jeu 02	. . .	dim 02	m m m	mar 02	. . .	ven 02	1 1 1	dim 02	1 1 1	mer 02	. . .
mer 03	. . .	sam 03	1 1 1	sam 03	m m m	mar 03	. . .	jeu 03	1 1 1	dim 03	m m m	mar 03	1 1 1	ven 03	. . .	lun 03	m m m	mer 03	. . .	sam 03	1 1 1	lun 03	1 1 1	jeu 03	. . .
jeu 04	. . .	dim 04	m m m	dim 04	m m m	mer 04	. . .	ven 04	1 1 1	lun 04	m m m	mer 04	1 1 1	sam 04	. . .	mar 04	1 1 1	jeu 04	. . .	dim 04	1 1 1	mar 04	m m m	ven 04	. . .
ven 05	. . .	lun 05	m m m	lun 05	m m m	jeu 05	. . .	sam 05	1 1 1	mar 05	1 1 1	jeu 05	1 1 1	dim 05	. . .	mer 05	1 1 1	ven 05	. . .	lun 05	1 1 1	mer 05	1 1 1	sam 05	. . .
sam 06	. . .	mar 06	m m m	mar 06	1 1 1	ven 06	. . .	dim 06	1 1 1	mer 06	1 1 1	ven 06	1 1 1	lun 06	. . .	jeu 06	1 1 1	sam 06	. . .	mar 06	m m m	jeu 06	1 1 1	dim 06	. . .
dim 07	. . .	mer 07	1 1 1	mer 07	1 1 1	sam 07	. . .	lun 07	m m m	jeu 07	1 1 1	sam 07	1 1 1	mar 07	. . .	ven 07	1 1 1	dim 07	. . .	mer 07	1 1 1	ven 07	1 1 1	lun 07	. . .
lun 08	. . .	jeu 08	1 1 1	jeu 08	1 1 1	dim 08	. . .	mar 08	m m m	ven 08	1 1 1	dim 08	m m m	mer 08	. . .	sam 08	1 1 1	lun 08	. . .	jeu 08	1 1 1	sam 08	1 1 1	mar 08	. . .
mar 09	. . .	ven 09	1 1 1	ven 09	1 1 1	lun 09	. . .	mer 09	1 1 1	sam 09	1 1 1	lun 09	m m m	jeu 09	. . .	dim 09	1 1 1	mar 09	. . .	ven 09	1 1 1	dim 09	1 1 1	mer 09	. . .
mer 10	. . .	sam 10	1 1 1	sam 10	1 1 1	mar 10	. . .	jeu 10	1 1 1	dim 10	m m m	mar 10	1 1 1	ven 10	. . .	lun 10	1 1 1	mer 10	. . .	sam 10	1 1 1	lun 10	1 1 1	jeu 10	. . .
jeu 11	. . .	dim 11	1 1 1	dim 11	m m m	mer 11	. . .	ven 11	1 1 1	lun 11	m m m	mer 11	1 1 1	sam 11	. . .	mar 11	m m m	jeu 11	. . .	dim 11	1 1 1	mar 11	m m m	ven 11	. . .
ven 12	. . .	lun 12	m m m	lun 12	m m m	jeu 12	. . .	sam 12	1 1 1	mar 12	1 1 1	jeu 12	1 1 1	dim 12	. . .	mer 12	1 1 1	ven 12	m m m	lun 12	. . .	mer 12	1 1 1	sam 12	. . .
sam 13	. . .	mar 13	m m m	mar 13	1 1 1	ven 13	. . .	dim 13	1 1 1	mer 13	1 1 1	ven 13	1 1 1	lun 13	. . .	jeu 13	1 1 1	sam 13	m m m	mar 13	. . .	jeu 13	1 1 1	dim 13	. . .
dim 14	. . .	mer 14	. . .	mer 14	1 1 1	sam 14	. . .	lun 14	. . .	jeu 14	1 1 1	sam 14	1 1 1	mar 14	. . .	ven 14	1 1 1	dim 14	m m m	mer 14	. . .	ven 14	1 1 1	lun 14	. . .
lun 15	. . .	jeu 15	. . .	jeu 15	1 1 1	dim 15	. . .	mar 15	. . .	ven 15	1 1 1	dim 15	m m m	mer 15	. . .	sam 15	1 1 1	lun 15	m m m	jeu 15	. . .	sam 15	1 1 1	mar 15	. . .
mar 16	. . .	ven 16	. . .	ven 16	1 1 1	lun 16	. . .	mer 16	. . .	sam 16	1 1 1	lun 16	m m m	jeu 16	. . .	dim 16	1 1 1	mar 16	1 1 1	ven 16	. . .	dim 16	1 1 1	mer 16	. . .
mer 17	. . .	sam 17	. . .	sam 17	1 1 1	mar 17	. . .	jeu 17	. . .	dim 17	1 1 1	mar 17	1 1 1	ven 17	. . .	lun 17	1 1 1	mer 17	1 1 1	sam 17	. . .	lun 17	1 1 1	jeu 17	. . .
jeu 18	. . .	dim 18	. . .	dim 18	m m m	mer 18	. . .	ven 18	. . .	lun 18	. . .	mer 18	1 1 1	sam 18	. . .	mar 18	m m m	jeu 18	1 1 1	dim 18	. . .	mar 18	. . .	ven 18	. . .
ven 19	m m m	lun 19	. . .	lun 19	m m m	jeu 19	. . .	sam 19	. . .	mar 19	. . .	jeu 19	1 1 1	dim 19	. . .	mer 19	1 1 1	ven 19	1 1 1	lun 19	. . .	mer 19	. . .	sam 19	. . .
sam 20	m m m	mar 20	. . .	mar 20	m m m	ven 20	m m m	dim 20	. . .	mer 20	. . .	ven 20	1 1 1	lun 20	. . .	jeu 20	1 1 1	sam 20	1 1 1	mar 20	. . .	jeu 20	. . .	dim 20	. . .
dim 21	m m m	mer 21	. . .	mer 21	1 1 1	sam 21	m m m	lun 21	. . .	jeu 21	. . .	sam 21	. . .	mar 21	. . .	ven 21	1 1 1	dim 21	1 1 1	mer 21	. . .	ven 21	. . .	lun 21	. . .
lun 22	m m m	jeu 22	. . .	jeu 22	1 1 1	dim 22	m m m	mar 22	. . .	ven 22	. . .	dim 22	. . .	mer 22	. . .	sam 22	1 1 1	lun 22	1 1 1	jeu 22	. . .	sam 22	. . .	mar 22	. . .
mar 23	m m m	ven 23	. . .	ven 23	1 1 1	lun 23	m m m	mer 23	. . .	sam 23	. . .	lun 23	. . .	jeu 23	. . .	dim 23	1 1 1	mar 23	m m m	ven 23	m m m	dim 23	. . .	mer 23	. . .
mer 24	1 1 1	sam 24	. . .	sam 24	1 1 1	mar 24	1 1 1	jeu 24	. . .	dim 24	. . .	mar 24	. . .	ven 24	. . .	lun 24	. . .	mer 24	1 1 1	sam 24	m m m	lun 24	. . .	jeu 24	. . .
jeu 25	1 1 1	dim 25	. . .	dim 25	1 1 1	mer 25	1 1 1	ven 25	m m m	lun 25	. . .	mer 25	. . .	sam 25	. . .	mar 25	. . .	jeu 25	1 1 1	dim 25	m m m	mar 25	. . .	ven 25	. . .
ven 26	1 1 1	lun 26	. . .	lun 26	m m m	jeu 26	1 1 1	sam 26	m m m	mar 26	. . .	jeu 26	. . .	dim 26	. . .	mer 26	. . .	ven 26	1 1 1	lun 26	m m m	mer 26	. . .	sam 26	. . .
sam 27	1 1 1	mar 27	. . .	mar 27	m m m	ven 27	1 1 1	dim 27	m m m	mer 27	. . .	ven 27	. . .	lun 27	. . .	jeu 27	. . .	sam 27	1 1 1	mar 27	1 1 1	jeu 27	. . .	dim 27	. . .
dim 28	m m m	mer 28	. . .	mer 28	. . .	sam 28	1 1 1	lun 28	m m m	jeu 28	. . .	sam 28	. . .	mar 28	. . .	ven 28	. . .	dim 28	1 1 1	mer 28	1 1 1	ven 28	. . .	lun 28	. . .
lun 29	m m m			jeu 29	. . .	dim 29	m m m	mar 29	1 1 1	ven 29	m m m	dim 29	. . .	mer 29	. . .	sam 29	. . .	lun 29	1 1 1	jeu 29	1 1 1	sam 29	. . .	mar 29	. . .
mar 30	1 1 1			ven 30	. . .	lun 30	m m m	mer 30	1 1 1	sam 30	m m m	lun 30	. . .	jeu 30	. . .	dim 30	. . .	mar 30	m m m	ven 30	1 1 1	dim 30	. . .	mer 30	. . .
mer 31	1 1 1			sam 31	. . .			jeu 31	1 1 1			mar 31	. . .	ven 31	m m m			mer 31	1 1 1			lun 31	. . .	jeu 31	. . .

Milestones in 2007

- **Beam stability**
  - SOFB/ FOFB/ multibunch transverse feedbacks
  - Feedforward for IDs
  - XBPM commissioning
- **IDs**
  - Construction of 7 IDs (and installation & commissioning)
- Preparation for **top-up operation**
- **Single bunch** and **8 bunches** operation
- **Beam instabilities and high current operation**
  - Instabilities threshold
  - Transverse feedback
- **Nonlinear dynamics characterization**
- **Delivery of 2nd cryomodule for 500mA operation**

The first phase of the Machine commissioning has enabled to demonstrate that the expected high performances are or will be met.

Acknowledgements

Operator team
Magnetism and insertion group
RF, Linac, Diagnostics groups
Vacuum group
Alignment group
Mechanical and Engineering group
Electronics and Computer groups
Infrastructure group
Safety group
Beam Lines