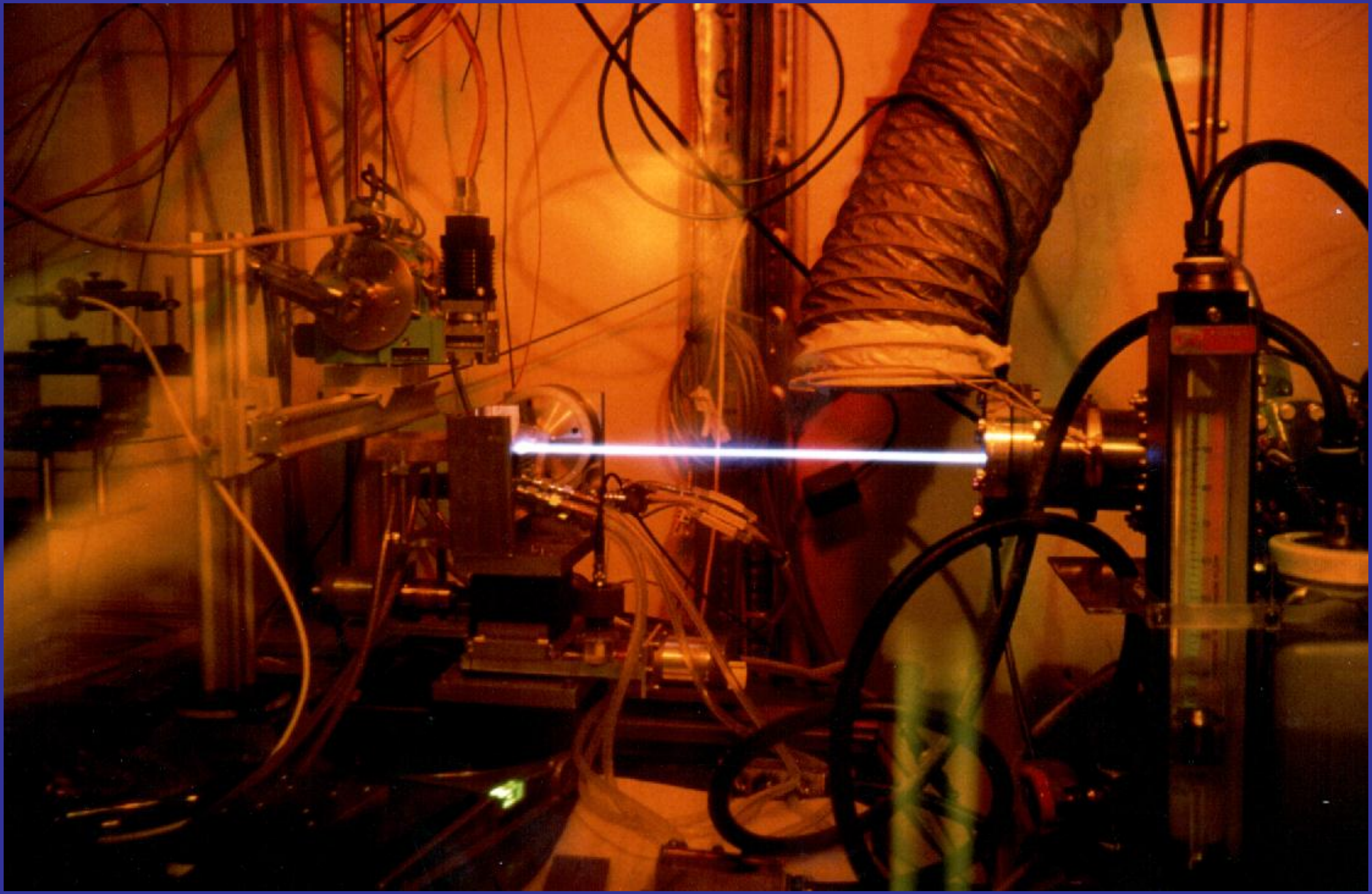


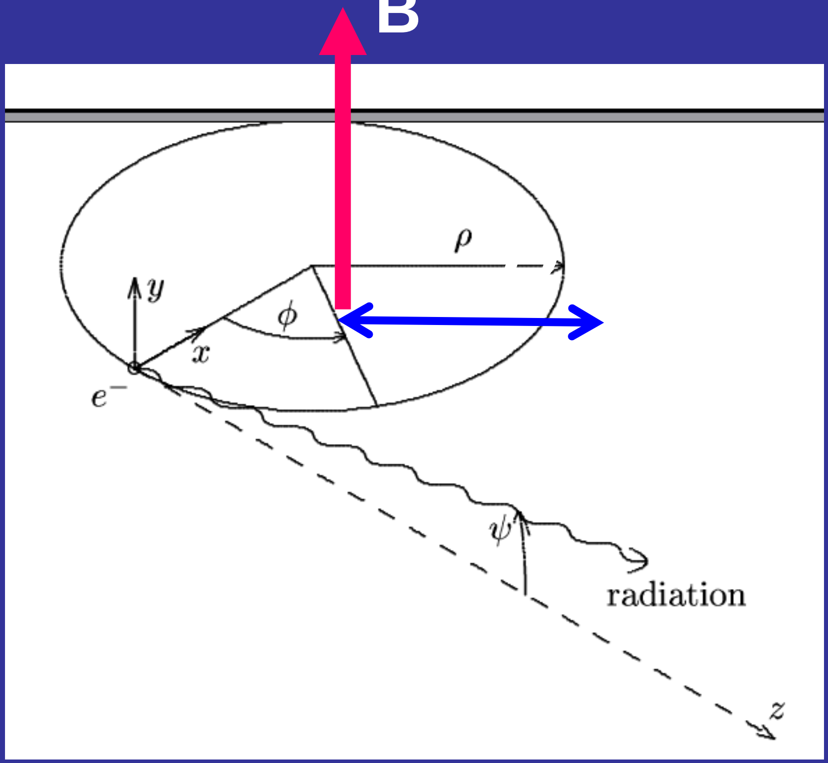
ESRF: Accelerator and Source Overview and Operation

ESRF Accelerator and Source Presentation: JUAS, January 2012, J.L. Revol

- ➢ INTRODUCTION
- ➢ THE ESRF COMPLEX
- ➢ Day to day OPERATION
- ➢ CONCLUSIONS

Principle

- When a charged particle is deviated in a magnetic field,
  it loose energy by emitting electromagnetic radiation (photons),call synchrotron radiation, tangent to the trajectory.

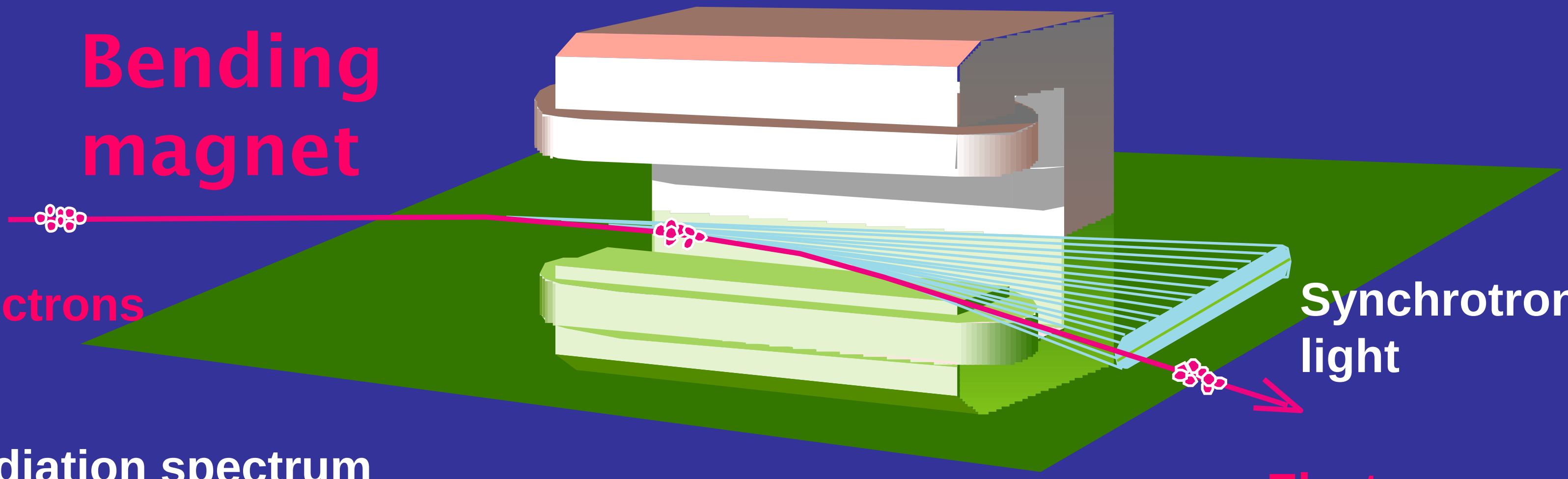


$$P \propto \left(\frac{E}{mc^2}\right)^4 \frac{I}{\rho}$$

Large difference between electrons and protons !

Scale with the square of the energy!

Emission of synchrotron radiation in circular machine



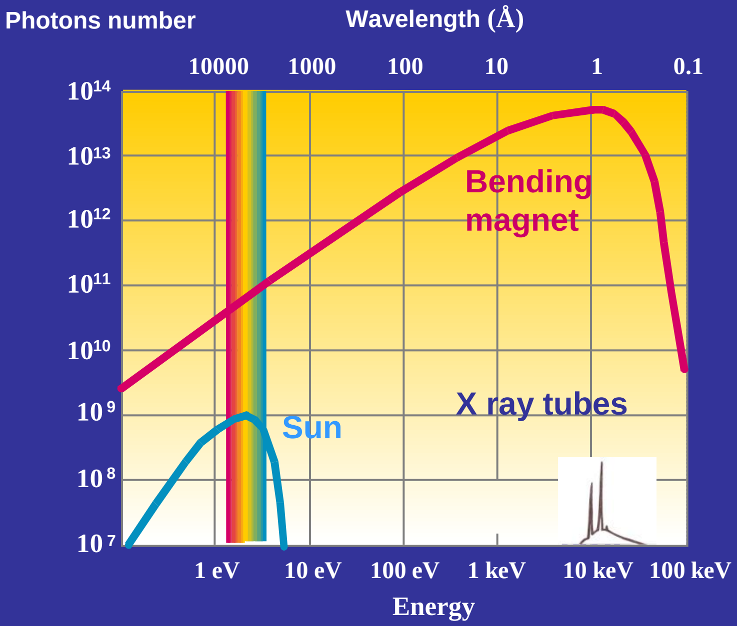
Bending magnet

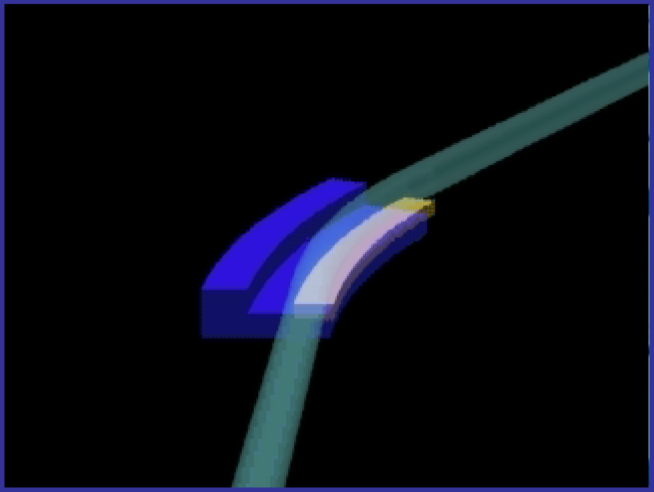
Electrons

Synchrotron light

Electrons

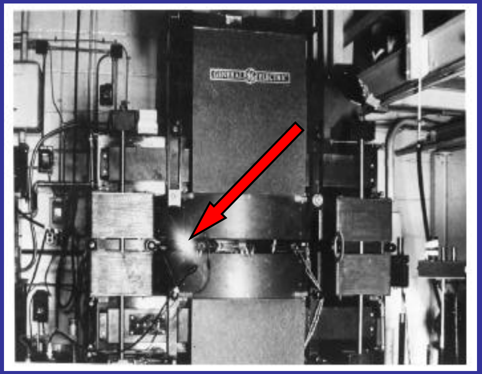
Radiation spectrum



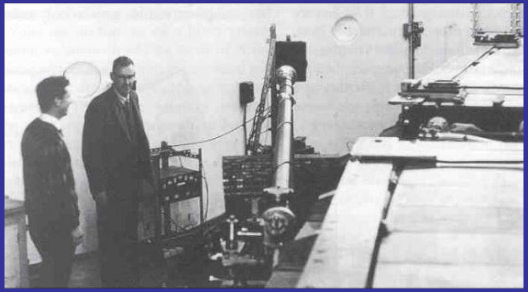


From parasitic use to dedicated user facility

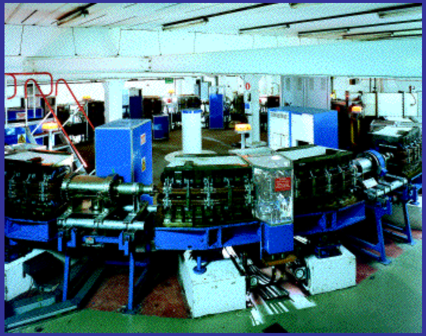
1947: First observation of synchrotron radiation



« Nina », first beamline at Daresburry in1966 (synchrotron 6 GeV électron). 1st generation



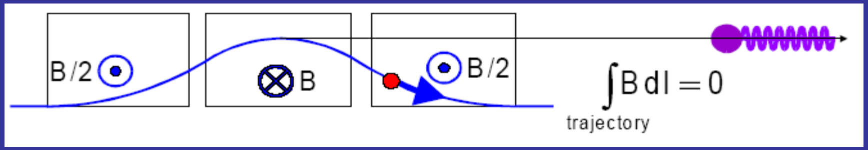
1981: SRS (UK) 1st dedicated X ray light source 2nd generation

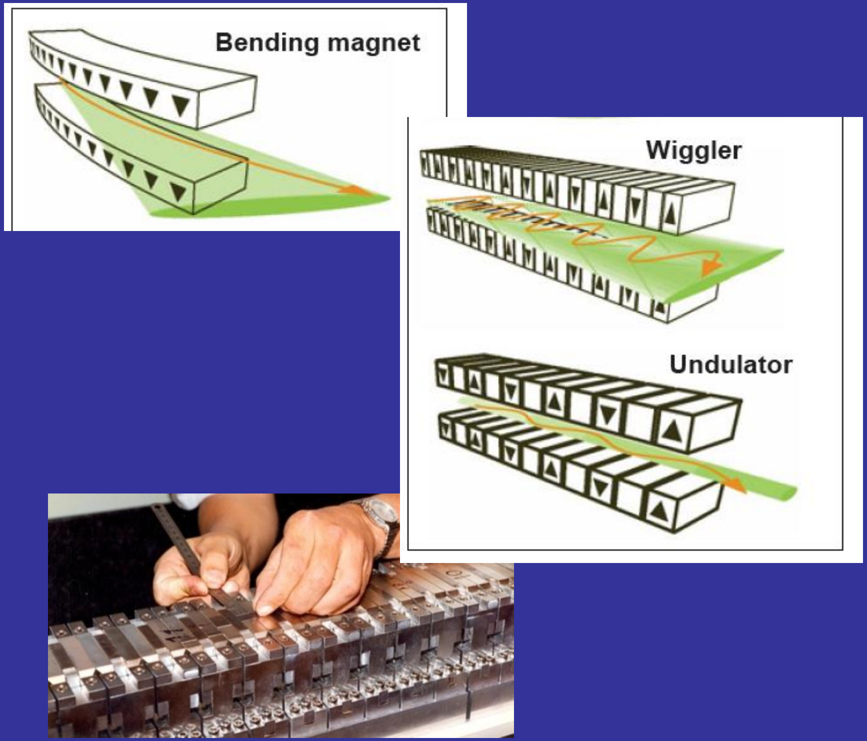


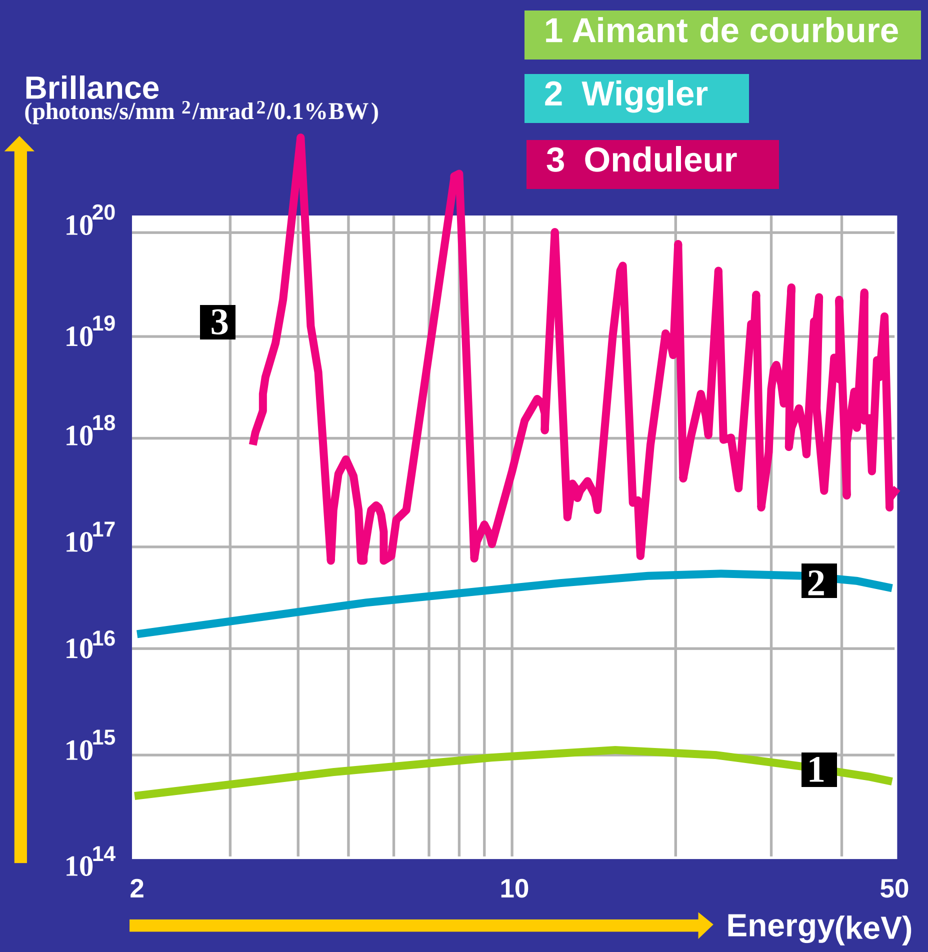
1994: Inauguration of the l'ESRF, The first X ray light source of the 3rd generation

Principle of insertion devices

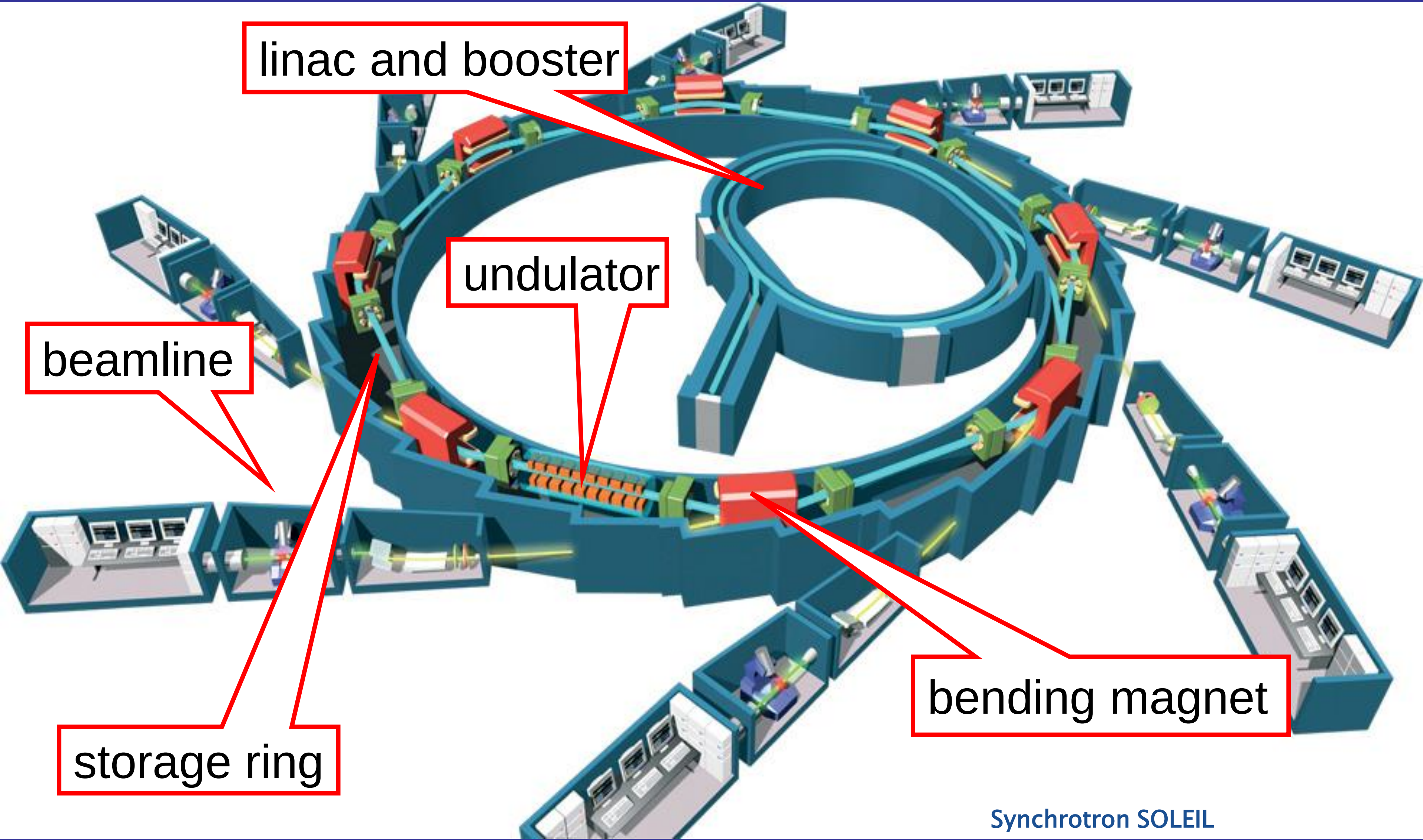
Insert permanent magnets to provide an alternative magnetic field to bend the trajectory.







A typical user facility



Synchrotron SOLEIL

Brilliance of light sources

Progress of X ray light sources are summarized in the evolution of the brilliance

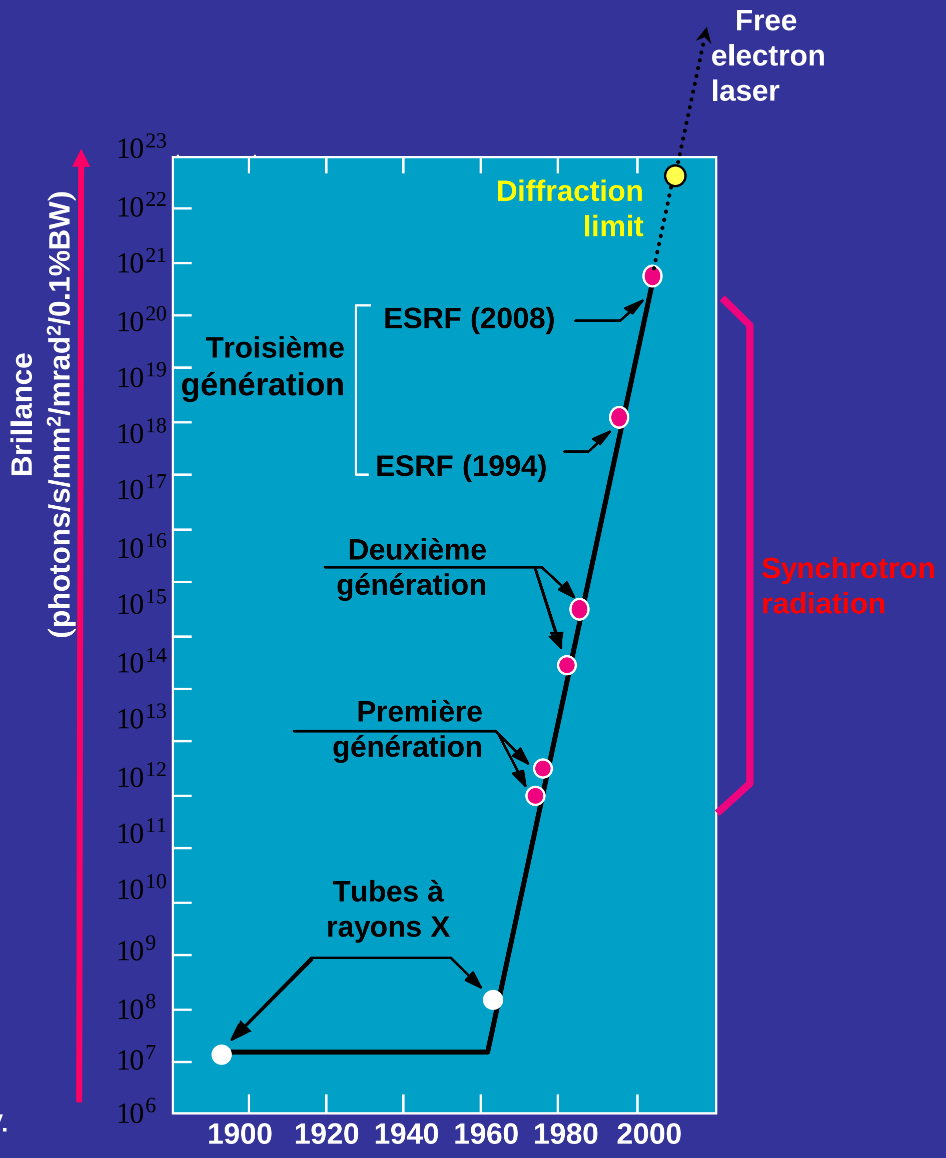
Brilliance =
photons /s / mm^2 /mrad^2 /0.1% bandepassante

Number of
photons per
second

Size
horizontale*vertical

Divergence
horizontal *vertical

In a bandwith of 0.1 %
around the considered energy.



History of the ESRF

- 1975 Project of a synchrotron capable of producing very brilliant hard X-rays
- 1988 Signature between the governments of the member countries.
- 1992 First electron beam in the storage ring. Commissioning phase.
- 1994 Opening to users.
15 beamlines are available.
- 1998 End of construction.
40 beamlines are operational.

- **2008** 20 years after signature.
Start of the upgrade programme.

More than 50 synchrotron light sources around the world

Many Medium energy rings :2.7-3.5 GeV

SOLEIL, DIAMOND, CLS, ALBA, SSRF, TPS ,Australian Synchrotron, NSLS II …

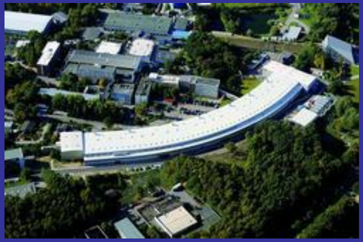
High energy rings (≥ 6.GeV)

SPRING 8

ESRF Upgrade

APS Upgrade

Petra III



X FELs (4th generation light sources)

- LCLS (Stanford)
- SACLA (SPRING8)
- Flash, European XFEL (Hamburg)
- Fermi@ elettra
- …..

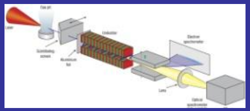
LCLS

SACLA

European XFEL

Fermi

Laser plasma acceleration: 5th generation light sources



The ESRF today

The ESRF is in operation for more than seventeen years

Inauguration: 30 September 1994

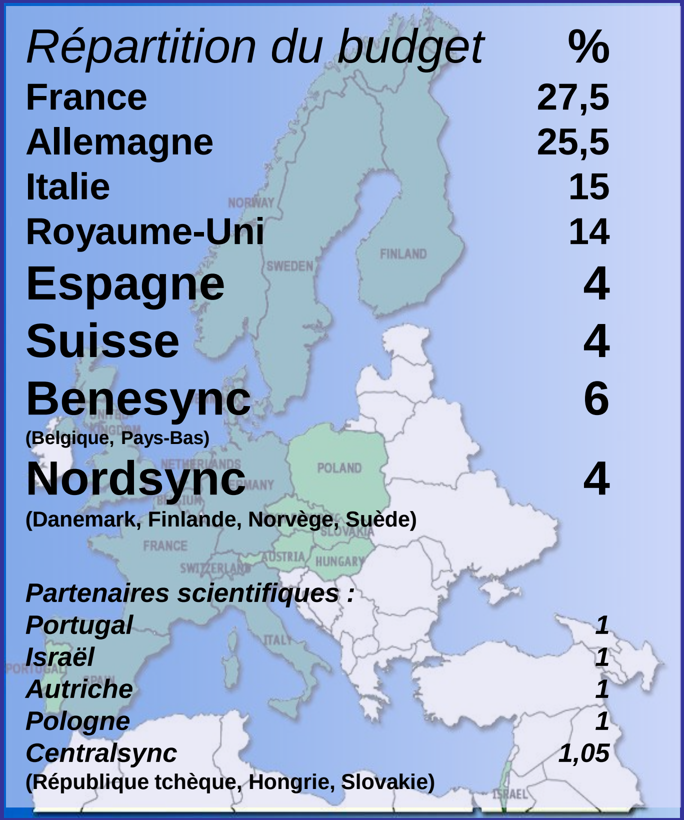
The ESRF is a « société civile » under French law, but it is financed and run by 19 countries.

Xray beam availability in2011: 98.91%

Mean time between failures in 2011: 108 hours

In 2010:
2000 Research porposals
~ 6300 Users, 1500 Experimental Sessions
~ 1800 Scientific Publications scientifiques *with referee*

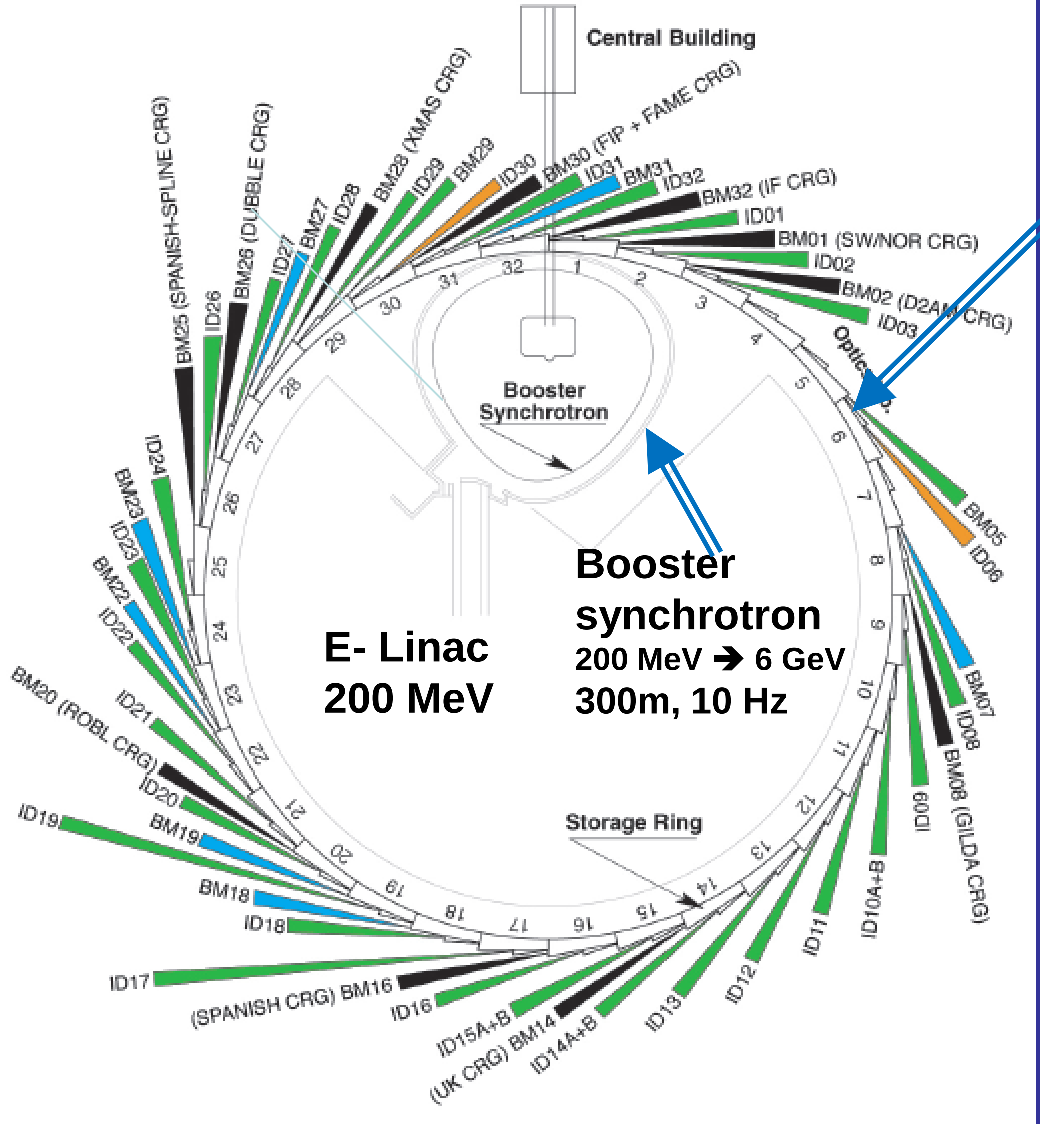
Budget annuel : 90 M Euros.



Répartition du budget	**%**
France	**27,5**
Allemagne	**25,5**
Italie	**15**
Royaume-Uni	**14**
Espagne	**4**
Suisse	**4**
Benesync **(Belgique, Pays-Bas)**	**6**
Nordsync **(Danemark, Finlande, Norvège, Suède)**	**4**
Partenaires scientifiques :	
Portugal	***1***
Israël	***1***
Autriche	***1***
Pologne	***1***
Centralsync **(République tchèque, Hongrie, Slovakie)**	***1,05***

600 Employees originated from 30 countries

The ESRF today



E- Linac
200 MeV

Booster synchrotron
200 MeV → 6 GeV
300m, 10 Hz

Storage ring
6GeV, 844 m

Energy	**GeV**	**6.04**
Multibunch Current	**mA**	**200**
Horizontal emittance	**nm**	**4**
Vertical emittance	**pm**	**3.5**

32 straigth sections

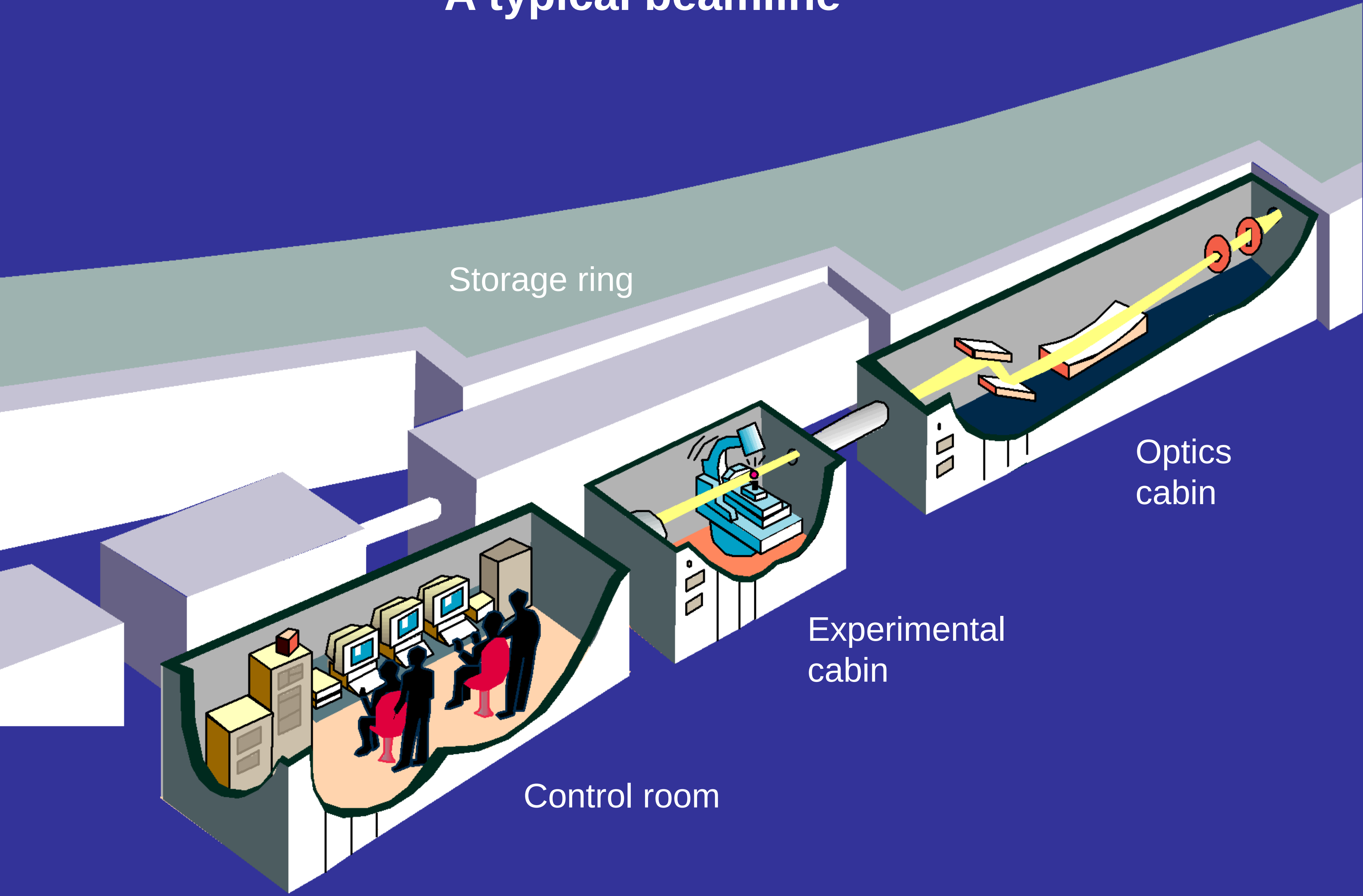
42 Beamlines

12 on dipoles

30 on insertion devices

72 insertion devices:
53 in-air undulators, 6 wigglers,
11 in-vacuum undulators, including
1 cryogenic

A typical beamline



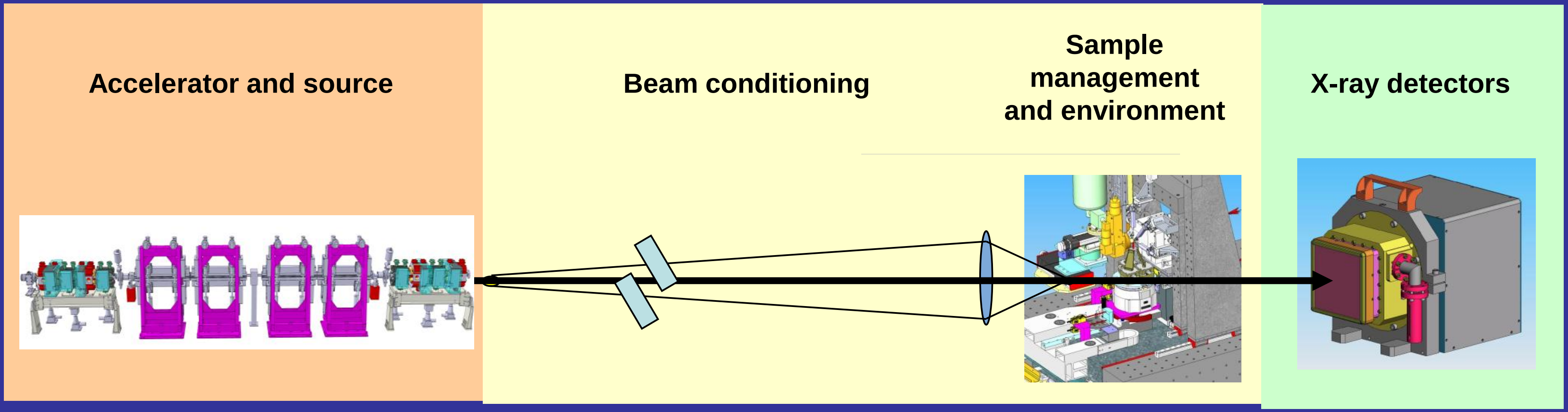
Scientific requirements

Scientific requirements for the beam:

- Tunable wavelength
- Flux
- Low emittance
- Position stability
- Temporal structure
- Reliability and reproductibility

A good experiment also requires a performing experimental environment:

- X ray optics
- Sample preparation
- Dedicated detectors
- Data analysis and computing capacity



Accelerator and source

Beam conditioning

Sample management and environment

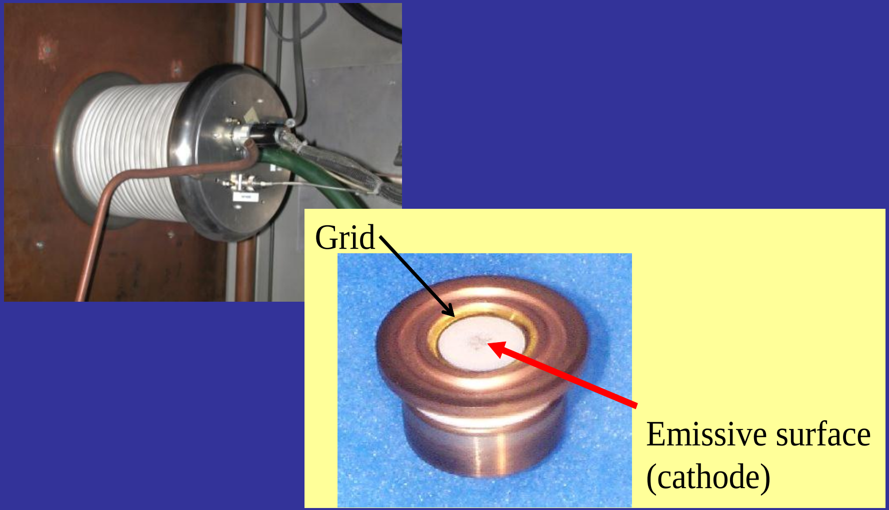
X-ray detectors

The accelerator complex

The linear accelerator

The Linac consists in one **TRIODE** (cathod – anod – grid) powered with 100 KV. Electrons produced have then an energy of 100 keV. The electrons are then accelerated in 2 sections (each section = 6 meters), accelerating the beam by 100 MeV, i.e., a total of 200 MeV.

Operation mode	Long pulses	Short pulses
Peak current	25 mA	250 mA
Pulse length	1µs	2ns
Energy spread	+/- 1%	+/- 0.5%



The transfer line from the Linac to the Booster: TL1

- Length: 16 metres
- Main components: 2 bending magnets, 7 quadrupoles, 2 pairs of steerers
- Diagnostics: insertable screens + synchrotron radiation

  screens

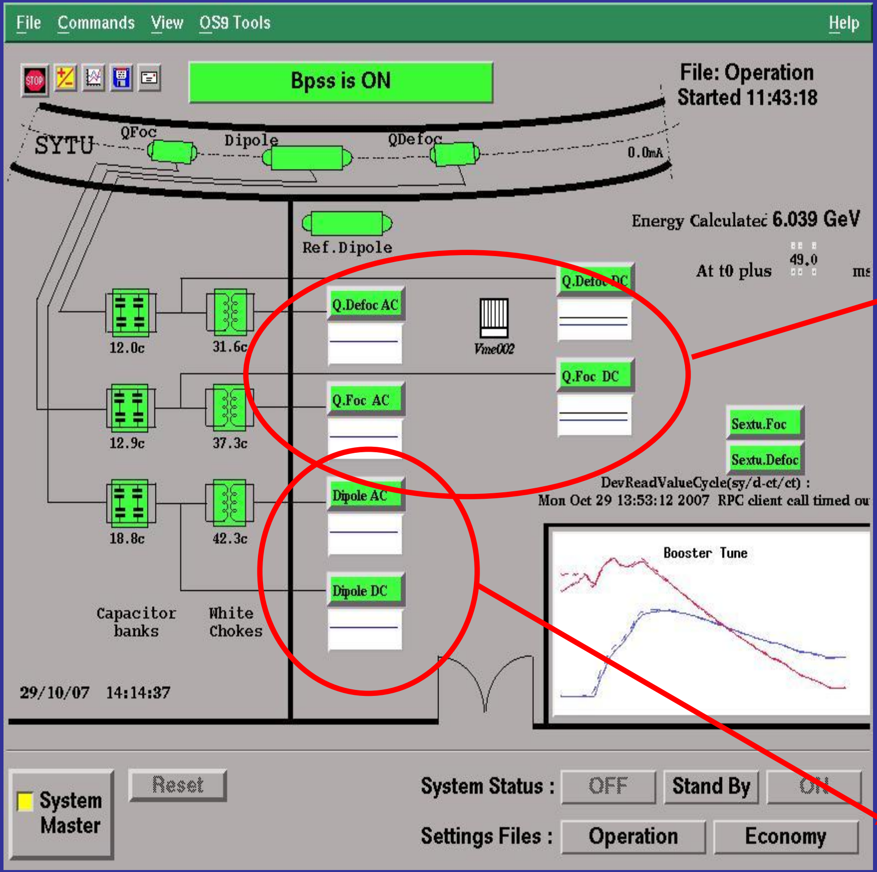
The synchrotron (or Booster)

Goal: Accelerate the electrons from 200 MeV to 6 GeV

Cycle: period of 100 msec (50 msec for the acceleration cycle)

Length: 300 metres

The booster magnets



Bpss is ON

File: Operation
Started 11:43:18

Energy Calculated 6.039 GeV

At t0 plus 49.0 ms

DevReadValueCycle(sy/d-ct/ct) :
Mon Oct 29 13:53:12 2007 RPC client call timed ou

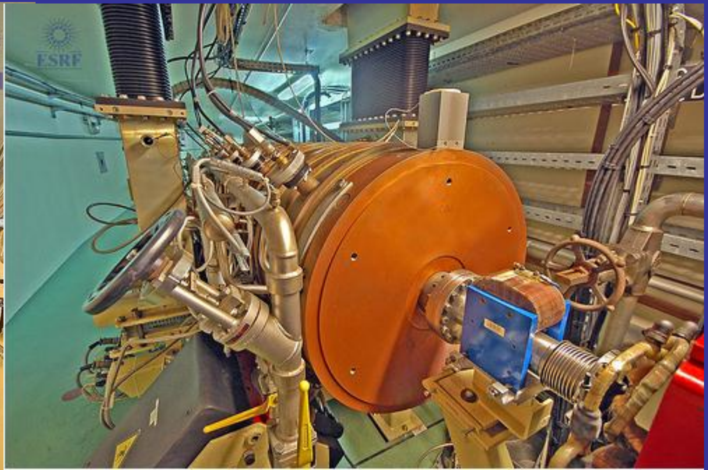
29/10/07 14:14:37

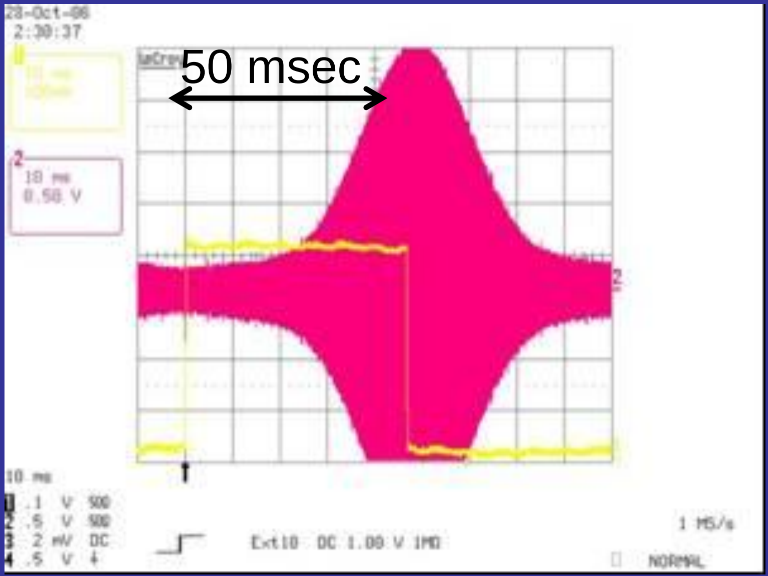
System Status : OFF Stand By ON

Settings Files : Operation Economy

When the field is minimum in the dipoles, it defines the « T0 »: the first trigger of the timing system which manages all the injection/extraction chain.

The booster radiofrequency system



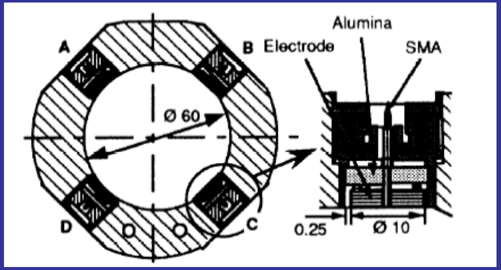


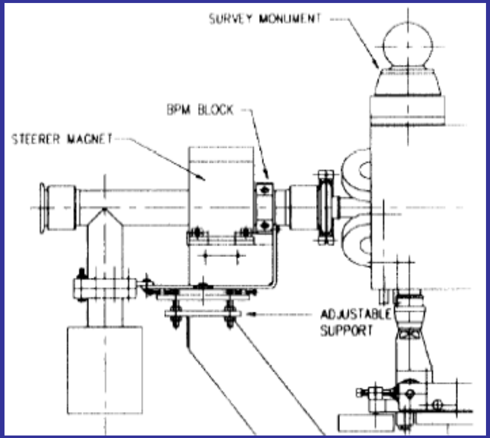
- 2 cavities with 5 cells (LEP-type)
- Klystron: 1 MW – 352.2 MHz
- 2 windows / cavity

The booster diagnostics

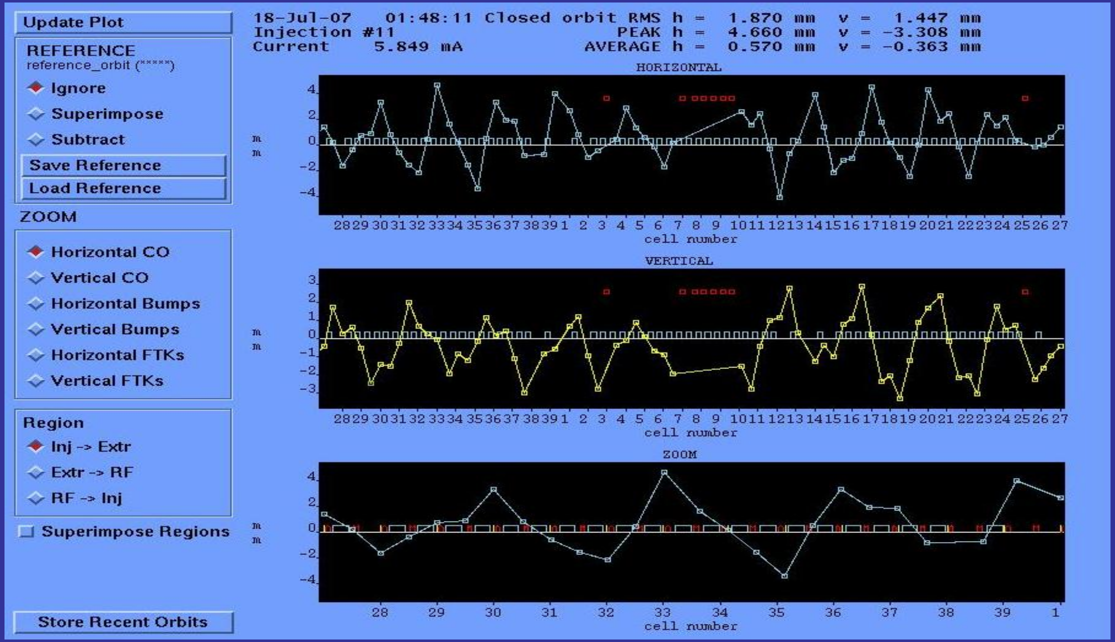
Beam position / orbit

75 (Beam Position Monitor) blocks.





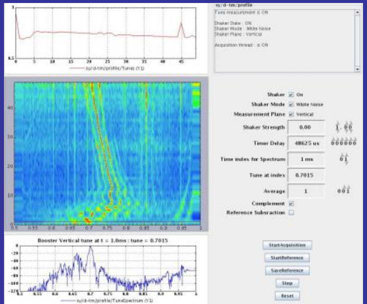
+ 8 insertable screens



```
18-Jul-07   01:48:11 Closed orbit RMS h =  1.870 mm  v =  1.447 mm
Injection #11                     PEAK h =  4.660 mm  v = -3.308 mm
Current    5.849 mA            AVERAGE h =  0.570 mm  v = -0.363 mm
```

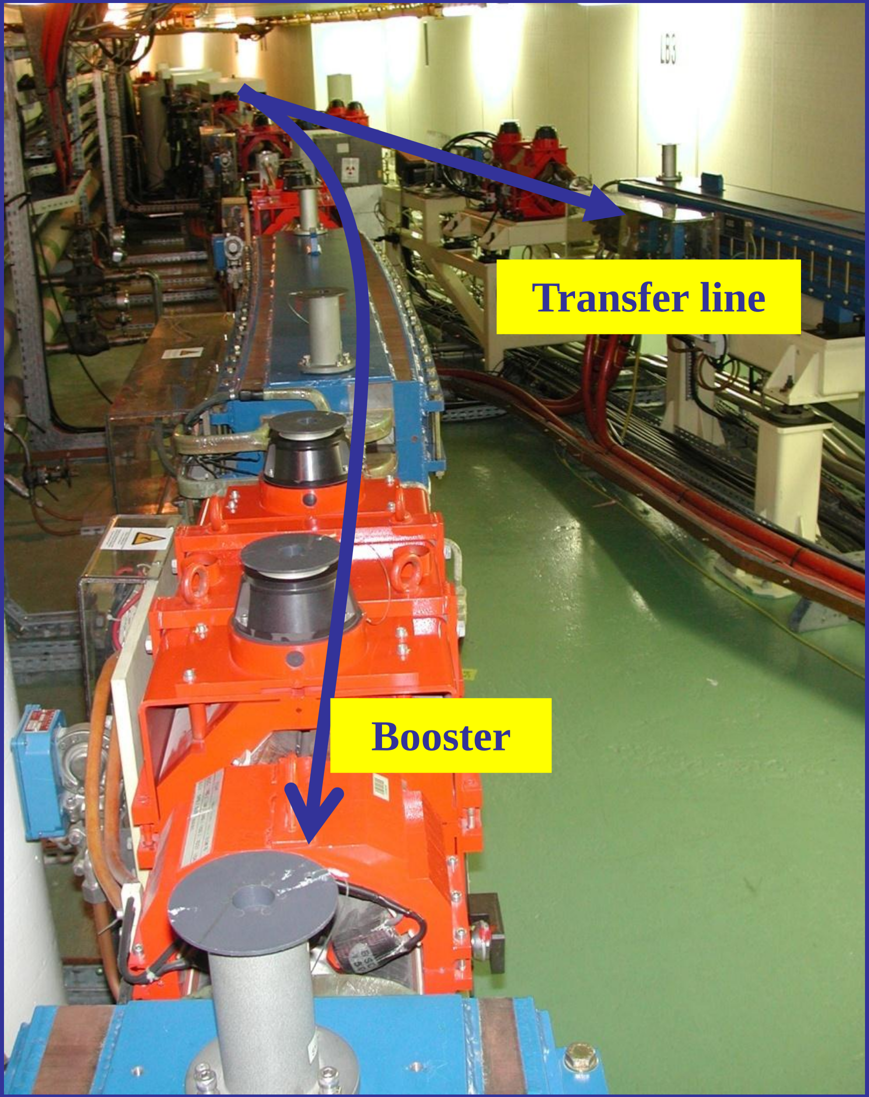
+ Synchrotron light monitors

+ Tune monitor



ESRF Accelerator and Source Presentation: JUAS, January 2012, J.L. Revol

The transfer line from the Booster to the Storage Ring: TL2

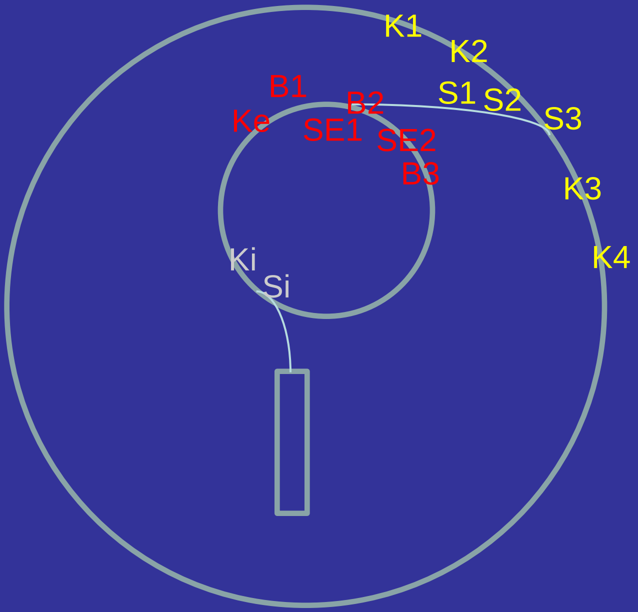


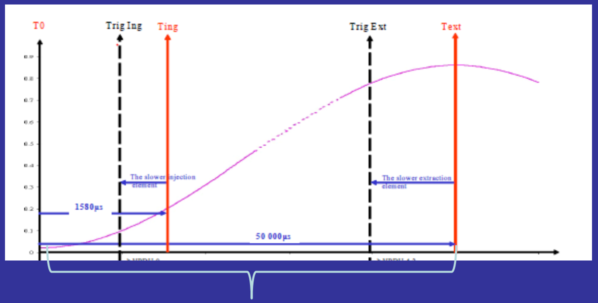
Goal:

Transfer the 6 GeV electrons from the Synchrotron to the storage ring:

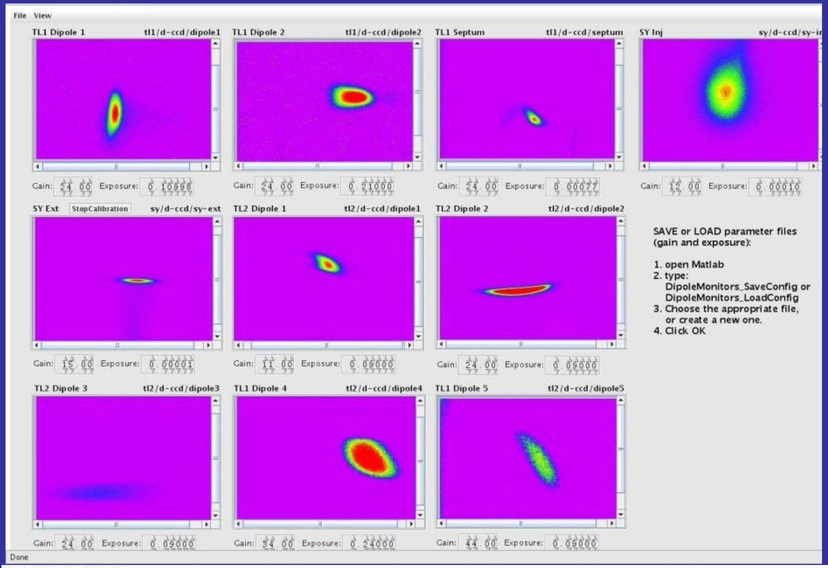
- 5 bending magnets (powered in serie with Booster dipoles)
- 14 quadrupoles
- 9 insertable screens
- Beam Position Monitors
- Synchrotron radiation screens (1 screen / dipole)
- Length: 65 metres

The injection/extraction system





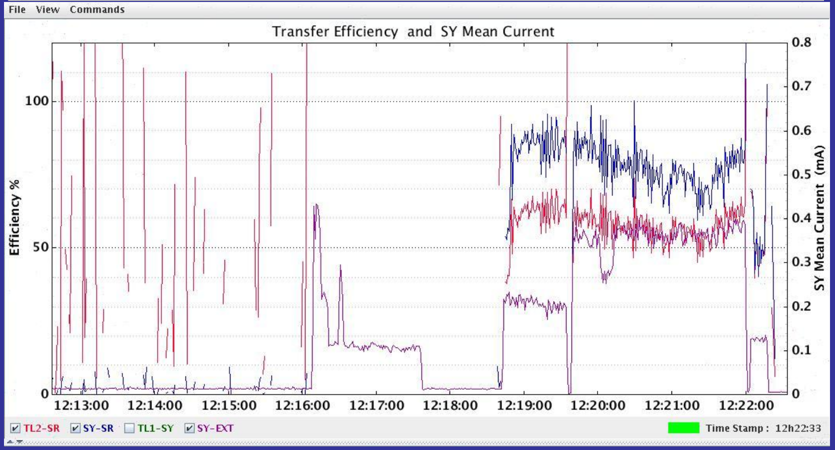
Injection cycle = 50 ms



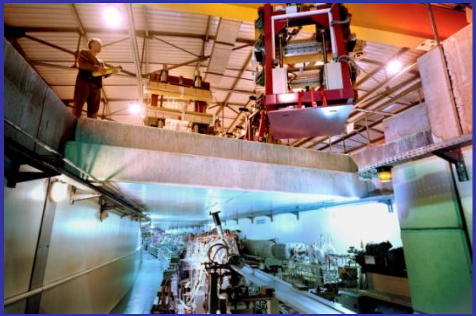
Gain: 24.00 Exposure: 0.10998
Gain: 24.00 Exposure: 0.21000
Gain: 24.00 Exposure: 0.00077
Gain: 12.00 Exposure: 0.00010
Gain: 15.00 Exposure: 0.00001
Gain: 11.00 Exposure: 0.09000
Gain: 24.00 Exposure: 0.09000
Gain: 24.00 Exposure: 0.09000
Gain: 24.00 Exposure: 0.24000
Gain: 44.00 Exposure: 0.09000

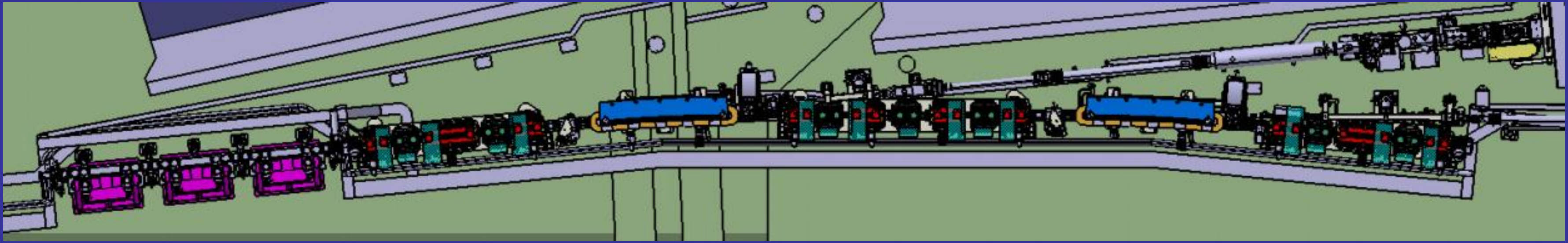
SAVE or LOAD parameter files
(gain and exposure):

1. open Matlab
2. type:
   DipoleMonitors_SaveConfig or
   DipoleMonitors_LoadConfig
3. Choose the appropriate file,
   or create a new one.
4. Click OK



The storage ring

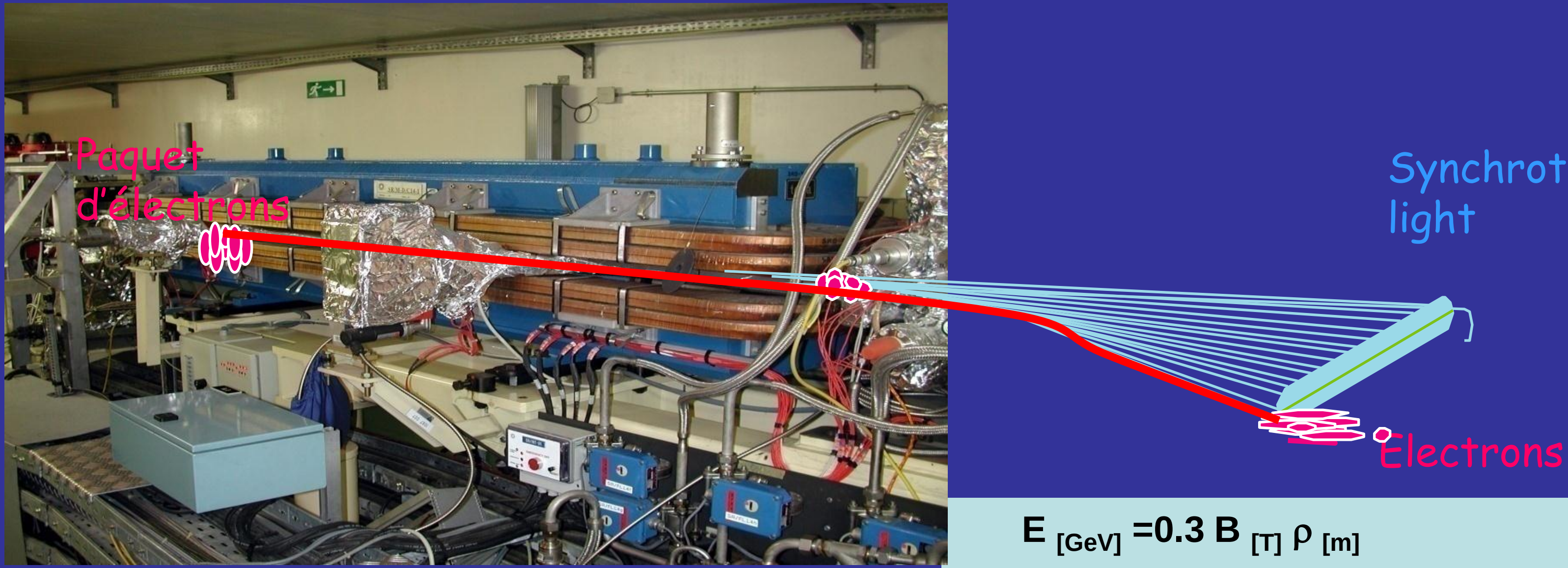




- Circumference: 844 metres
- 16 super-periods of 2 mirror cells→ 32 cells
- Energy: 6 GeV
- Nominal intensity: 200 mA
- Highest intensity: 300 mA
- Emittance: 4nm rad
- Usual coupling : 0.1 %

The storage ring bending magnets

64 bending magnets (dipoles)



Numbers :	64 (2 per cells)
Bending angle :	5.625 °
Magnetic field :	0.8612 Tesla
Number of family :	1
Nominal intensity :	714.993 A

$$E_{[GeV]} = 0.3\, B_{[T]}\, \rho_{[m]}$$

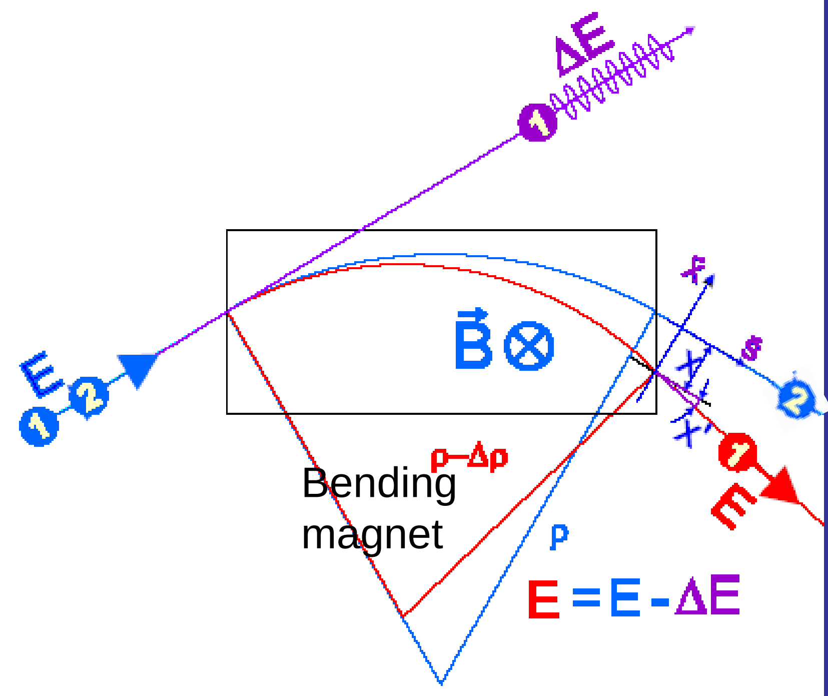
$$B=0.8\ T \quad \rho = 25\ m$$

Energy lost per turn of ring by one electron

$$\Delta E_{[keV]} = 88.5 \frac{E^4_{[GeV]}}{\rho_{[m]}} = 4.6\ \text{MeV}$$

The power radiated around the length of the ring bending magnets by a current of 200 mA = 920 kW

Generation of an horizontal emittance by radiation



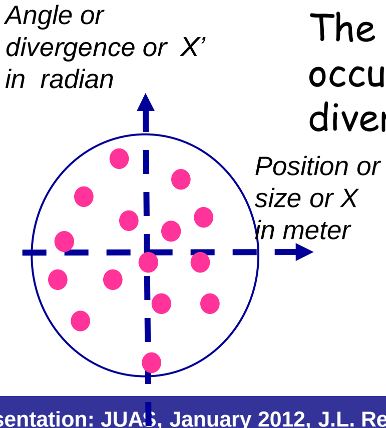
Electron 2 emits Δe at the exit of the bending magnet.

- *➔ same energy when crossing the magnet*
- *➔ stay on the reference trajectory*

Electron 1 emits ΔE at the entrance of the bending magnet.

- *➔ lower energy when crossing the magnet*
- *➔ larger curvature*

A horizontal beam size and divergence (or emittance) and an energy spread is created.



The beam emittance is the **surface** occupied by the beam in size and divergence.

$$\varepsilon_{x[m^{*}rad]} = \frac{1}{\pi}\oiint dx\,dx'$$

The storage ring quadrupole magnets

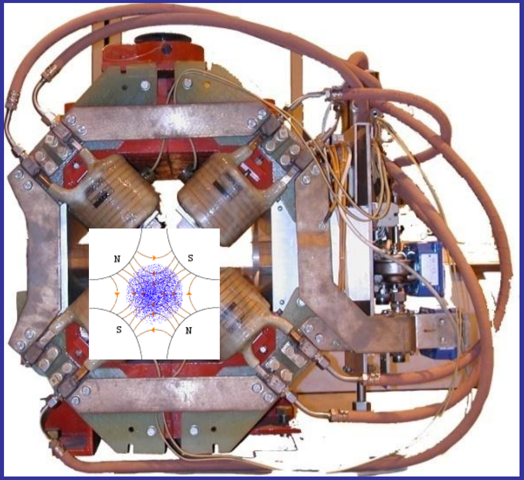
256 quadrupoles shared in 6 families

Name	Number	Intensity
QF2	32	216.730 A
QD3	32	-334.022 A
QD4	64	- 415.454 A
QF5	64	411.798 A
QD6	32	- 491.497 A
QF7	32	375.181 A

The goal of the **quadrupoles** is to focus the electron beam so as to maintain its size as small as possible

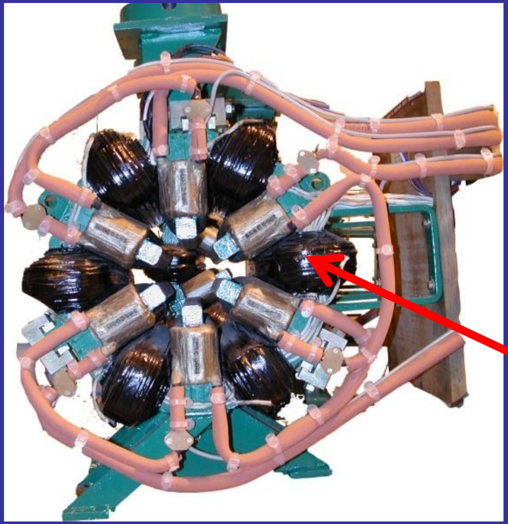
The quadrupole settings are also important for:

- the tune values,
- the beam size,
- the injection speed,
- the betatronic resonances, etc



The storage ring sextupole magnets

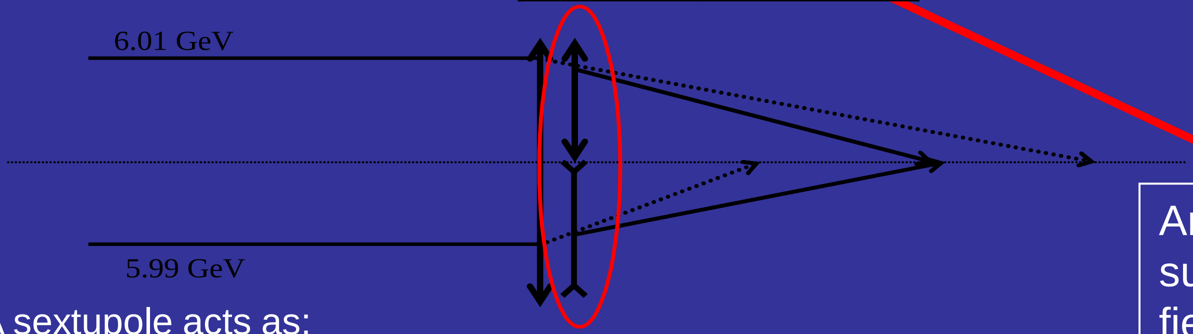
224 sextupoles shared in 7 families



Name	Number
S4	32
S6	32
S13	32
S20	32
S19	32
S22	32
S24	32

Their settings are important for:

- the chromaticities,
- the betatronic resonances
- the dynamic aperture,
- and therefore the beam lifetime



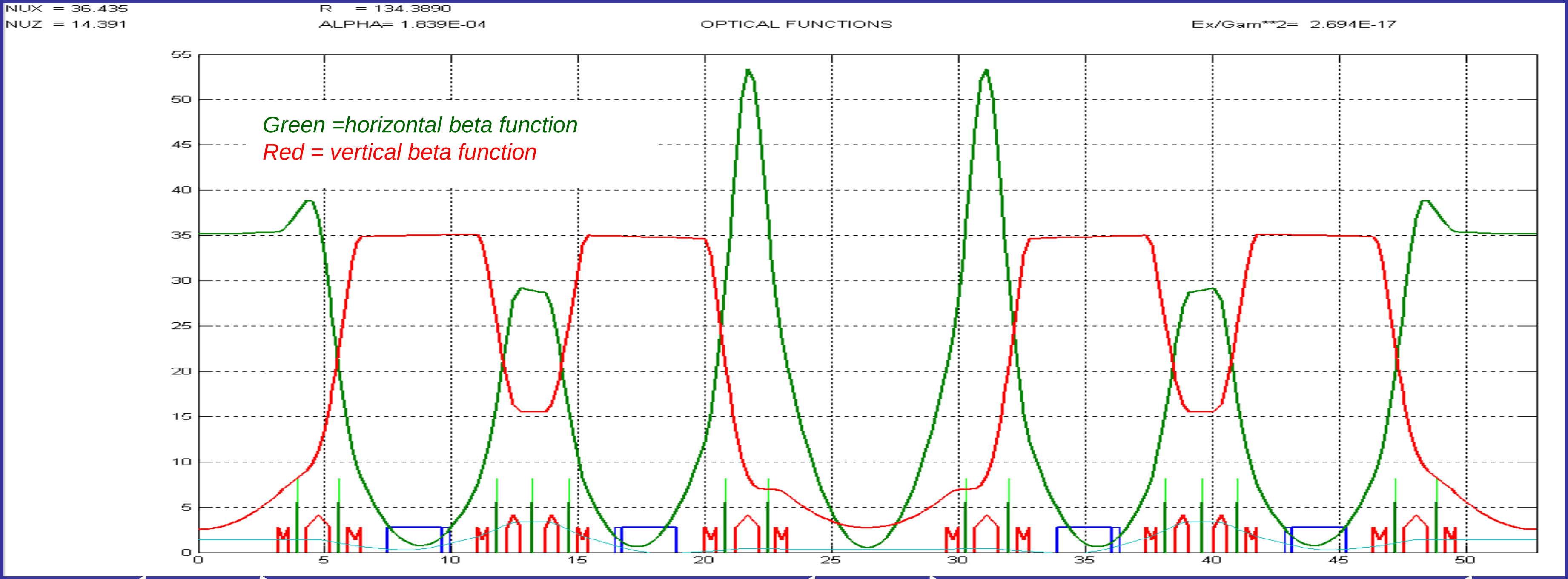
A sextupole acts as:

- A focusing quadrupole for the electrons which have a higher energy

- A defocusing quadrupole for the electrons which have a lower energy

And steerers (3 power supplies to get a H or V field)

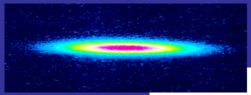
The ESRF Storage Ring lattice



5 m **5 m** **5 m**

Even cells

Odd cells



ESRF Horizontal emittance = 4 nm.rad

ESRF vertical emittance = 5pm

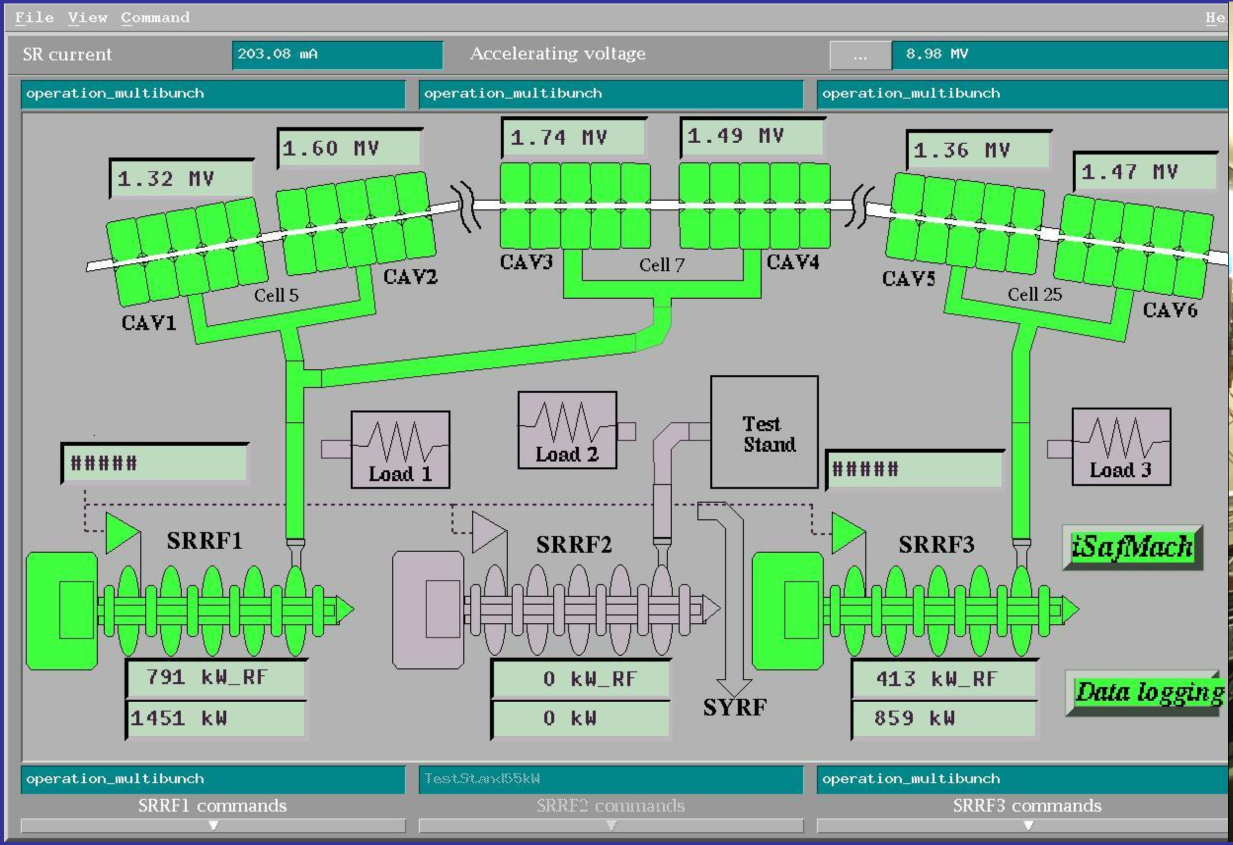
Vertical emittance is determined by the coupling to the horizontal motion due to magnet or alignment imperfections.

$$\sigma_x = \sqrt{\varepsilon_x \beta_x} \qquad \sigma_x' = \sqrt{\varepsilon_x / \beta_x}$$

$$\sigma_y = \sqrt{\varepsilon_y \beta y} \qquad \sigma_y' = \sqrt{\varepsilon_y / \beta_y}$$

Taille *Divergence*

The Storage Radiofrequency System



SR current 203.08 mA

Accelerating voltage 8.98 MV

operation_multibunch

operation_multibunch

operation_multibunch

1.32 MV

1.60 MV

1.74 MV

1.49 MV

1.36 MV

1.47 MV

#####

#####

791 kW_RF

1451 kW

0 kW_RF

0 kW

413 kW_RF

859 kW

operation_multibunch

TestStand55kW

operation_multibunch

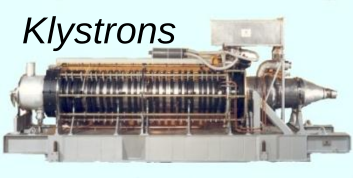
SRRF1 commands

SRRF2 commands

SRRF3 commands

Goal: compensate the energy loss turn / turn by the electrons, following the synchrotron radiation emission, i.e., 6.25 MeV (with all insertion devices)

The Storage Radiofrequency System



For a beam intensity of 200mA :

6 active cavities (1 klystron powers 4 cavities, the second one powers 2 cavities)
Accelerating voltage : 9 MV
Voltage / cavity : 1.5 MV
Klystron total power : 1.3 MW (1MW for beam + 42 kW/cavity+20kW reflected)

- **macroscopic**: the RF frequency imposes the maximum number of bunches on the circumference.

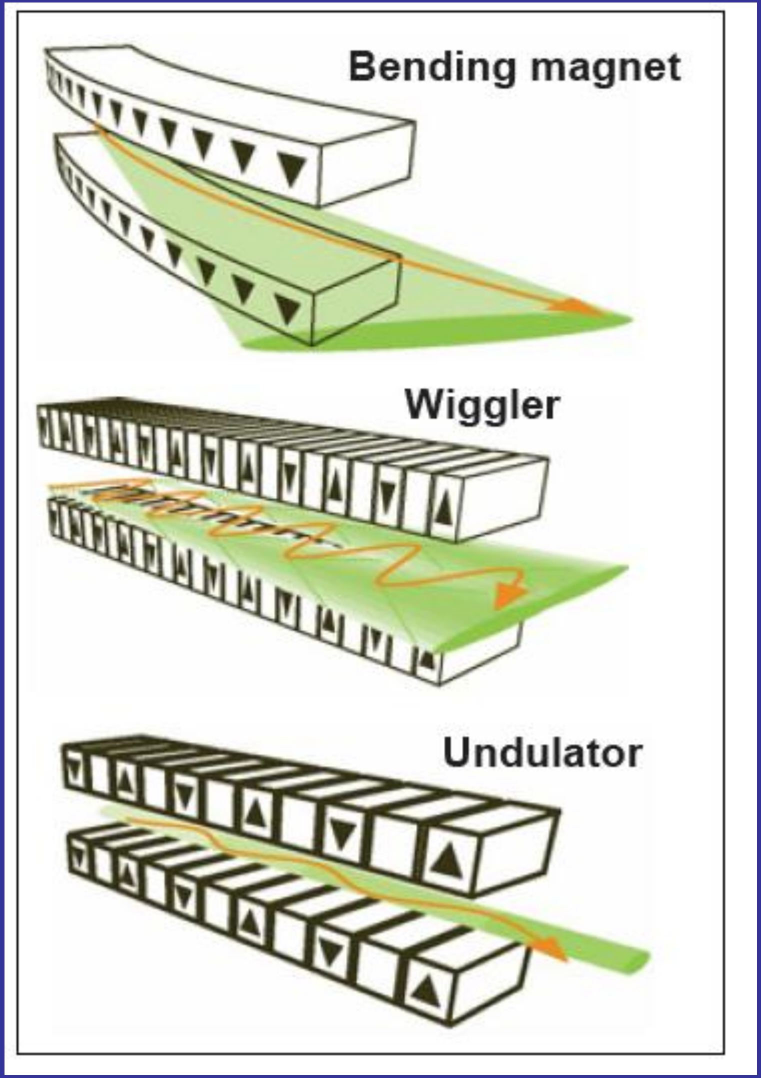
$$h = \Delta \frac{F_{RF}}{F_{rev}} = 352\ \text{MHz} / 355\ \text{kHz} = 992$$

- **microscopic**: the RF frequency imposes the revolution time of the reference particle. For a given field of the bending magnets, it defines the length of the trajectory and therefore the energy of the reference particle.

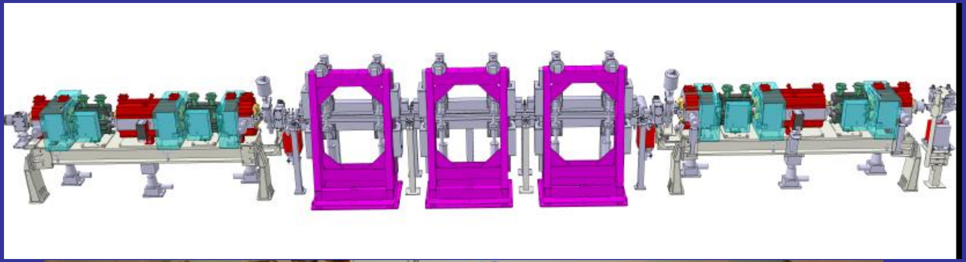
With ESRF data, a difference of 3.5 KHz (10^{-5}) will induce an horizontal displacement of the beam of 18 mm, visible on the screens.

Insertion devices

Insertion devices

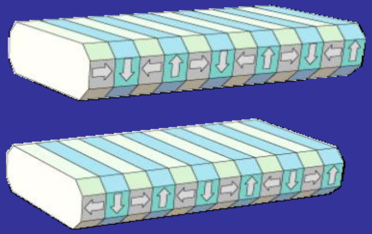


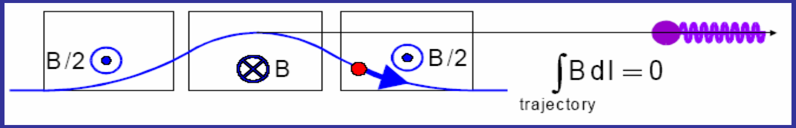
Goal: produce X-rays with specific properties which are different from those emitted by the dipoles, for example, tuneable energy spectrum, polarisation, higher brilliance...



Insertion devices

Generally designed « on request » for a given beamline

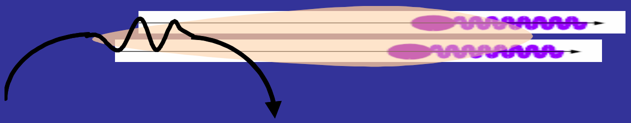




Two main families:

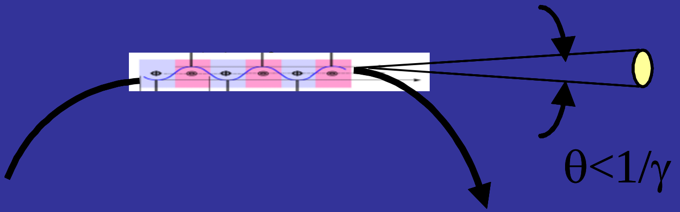
Wigglers : Small number of periods, higher magnetic fields

They produce ‘hard’ X rays (E>10 keV).

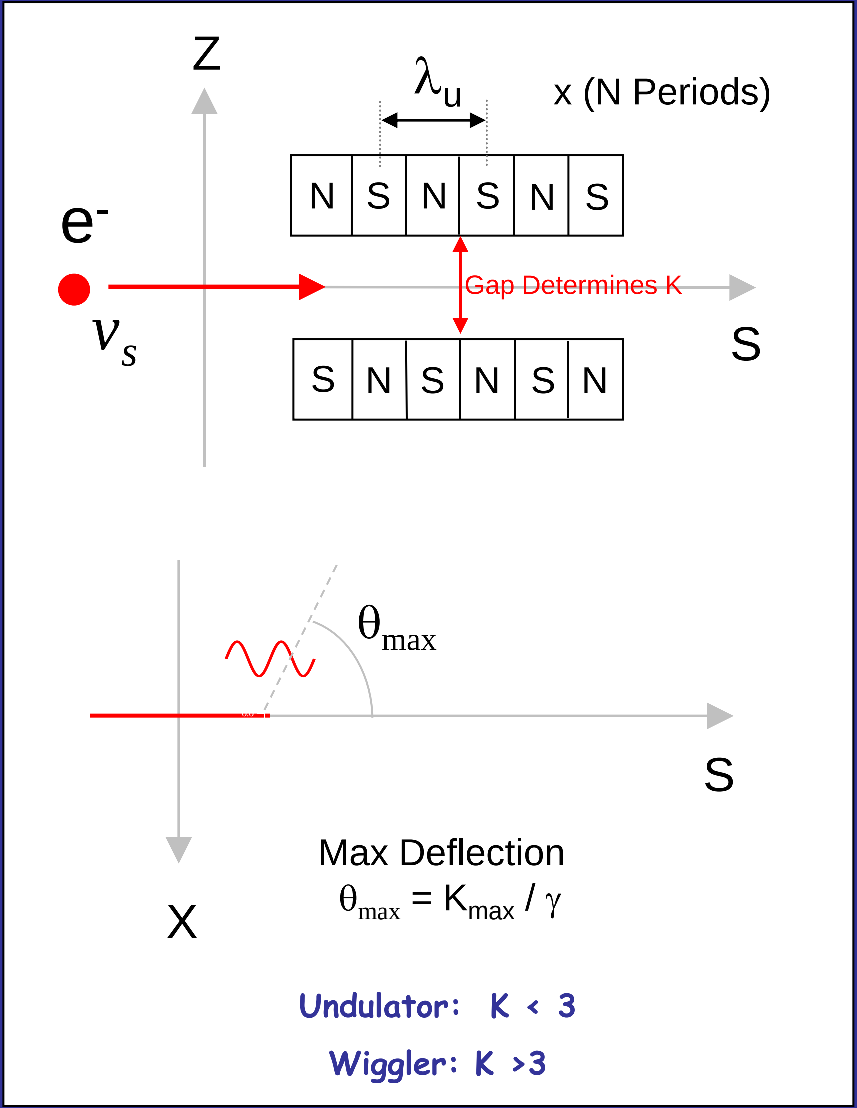


Undulators : Great number of periods .

Larger flux induced by in interference properties..



Insertion devices



Max Deflection
$\theta_{max} = K_{max} / \gamma$

Undulator: K < 3

Wiggler: K >3

The electron takes a sinusoidal path, with a max angular deflection given by K/γ, where K is the deflection parameter given by;

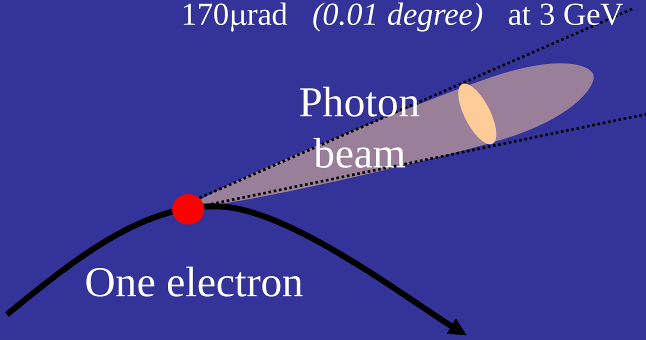
$$K = 0.0934\ \lambda_u\ [\text{mm}]\ B_{peak}\ [\text{T}]$$

In case of undulator ,K ~ 1-2

θ max has to be compared with 1/γ

Narrow cone of natural emission angle 85μrad *(0.005 degree)* at 6 GeV

170μrad *(0.01 degree)* at 3 GeV

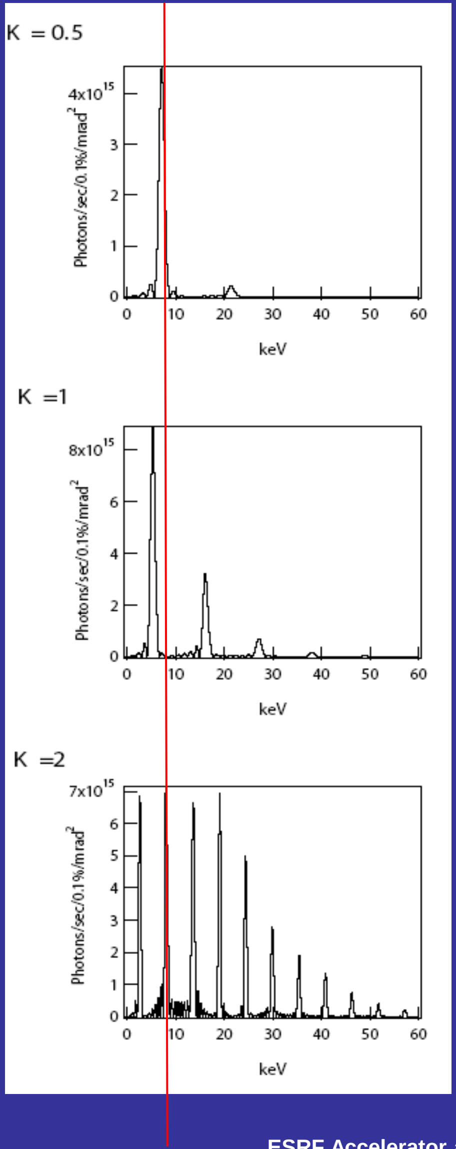


$$\Psi = \frac{1}{\gamma} = \frac{1}{E/E_0}$$

E_0=0.5 MeV

E = 6 GeV

Insertion devices



The deflecting angle is a function of the periodicity and the magnetic field

$$K = 0.0934\ \lambda_u\ [\mathrm{mm}]\ B_{peak}\ [\mathrm{T}]$$

In case of undulator ,K ~ 1-2

The energy of the fundamental on axis is given by

$$\varepsilon_{[keV]} = 0.9.50\ \frac{E^2_{[GeV]}}{\left(1+K^2/2\right)\lambda_{u[cm]}}$$

If K increases the energy fundamental peak of the undulator decreases.

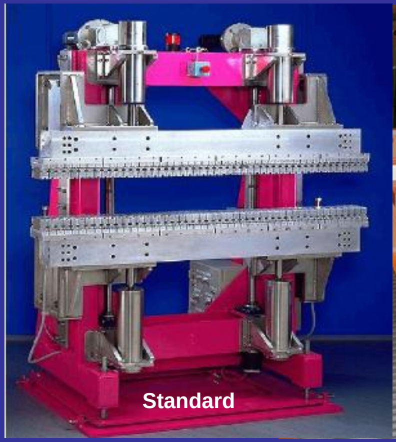
The total emitted power is:

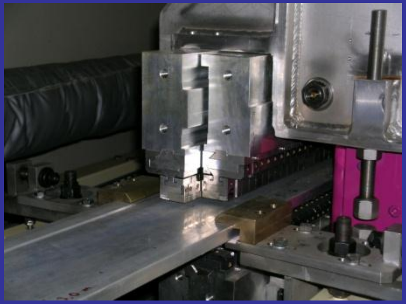
$$P_{[kW]} = 0.633 E_{electron[GeV]} B^2_{peak\,[T]} * L_{[m]} * I_{[A]}$$

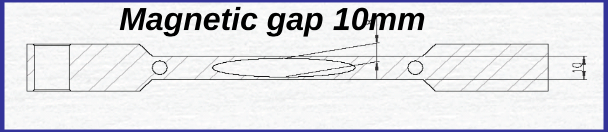
The undulator conception is defined by the beamline requirements

Insertion devices

In-air *length =1.64 m*

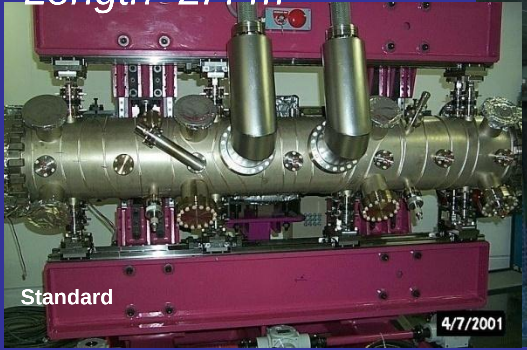


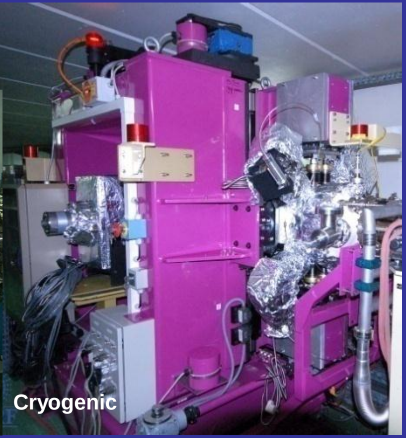




In-vacuum

Length=2.4 m





(2.4 m flenge to flange , 2m magnetic asembly)

Power generated by one undulator (1.6 m) = 3kW

Available power = 250 kW

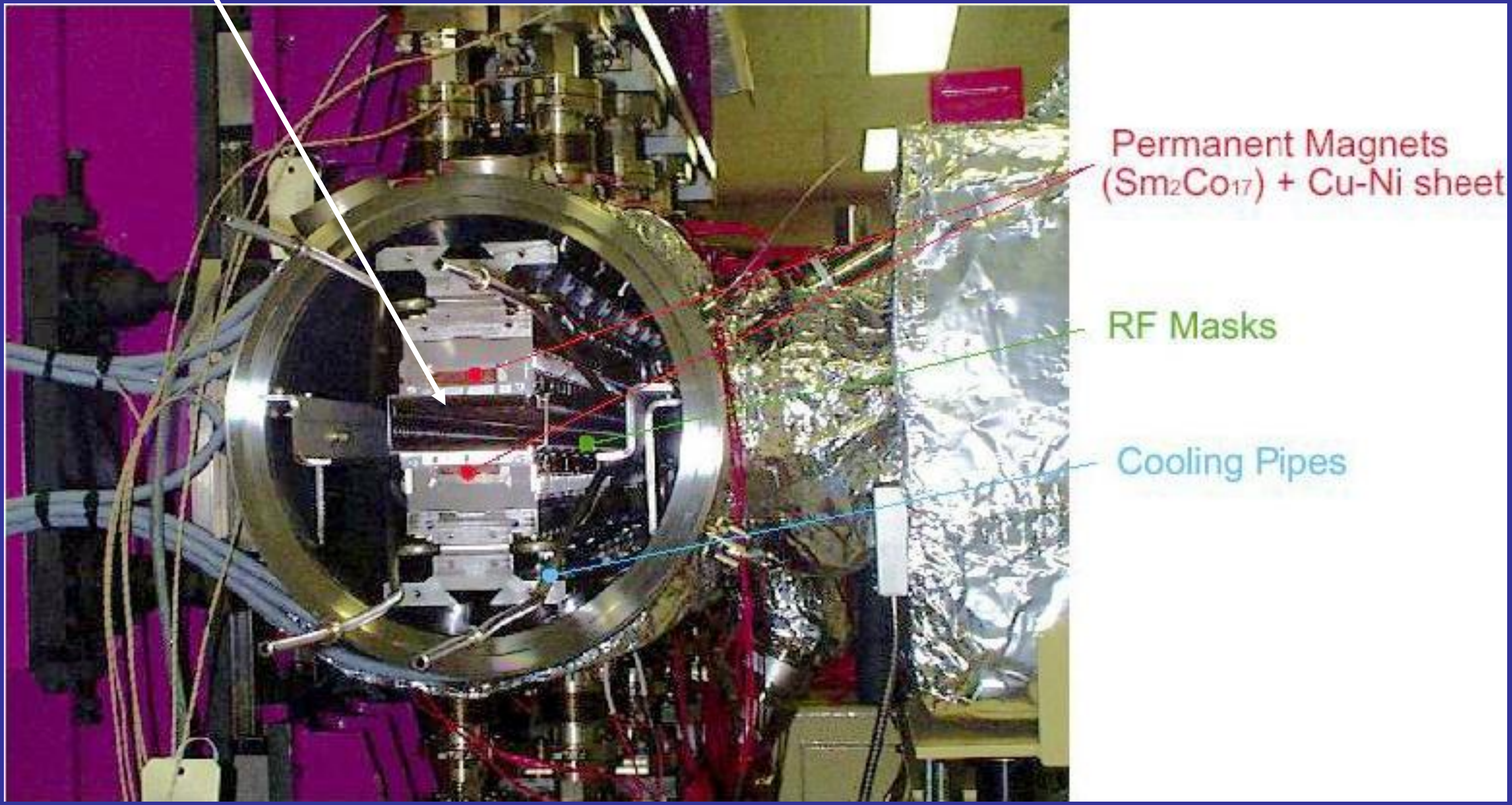
But less than 100 kW is used!!

2kW/mm^2 at 200 mA

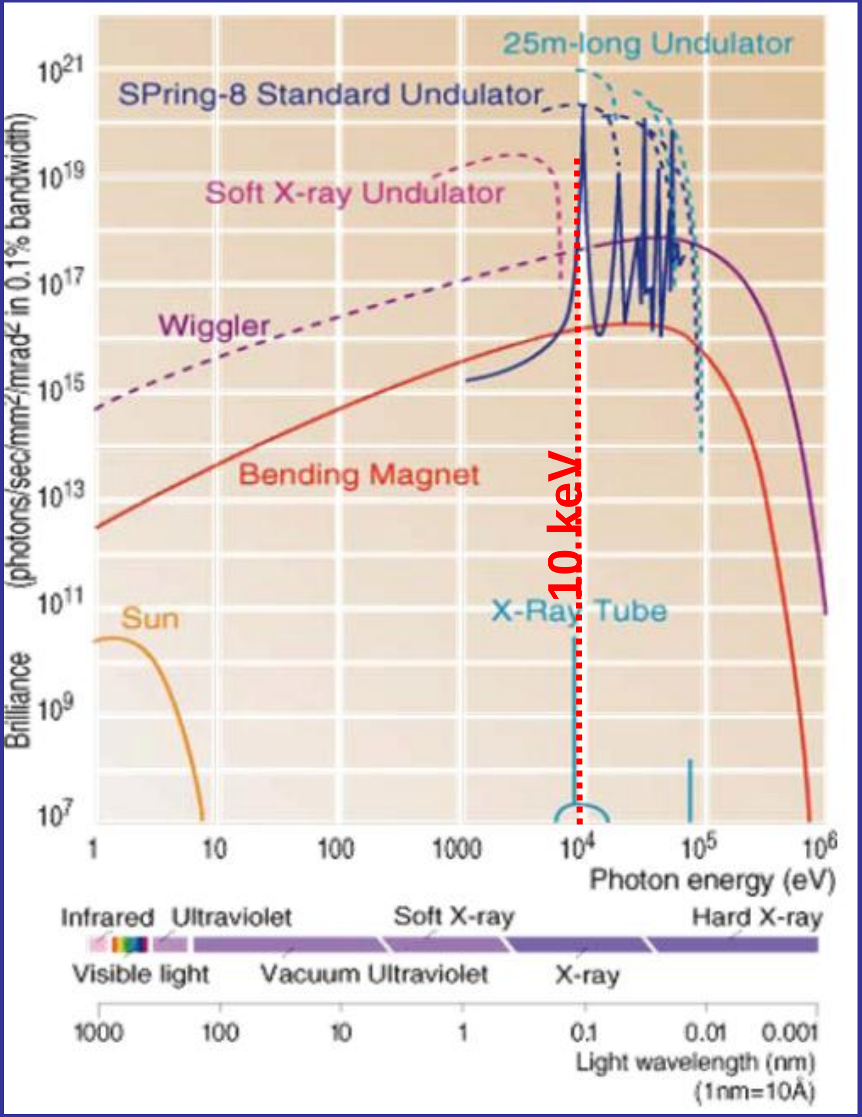
8000 kW of Electrical power is needed to produce it!!
Efficiency: 2% !

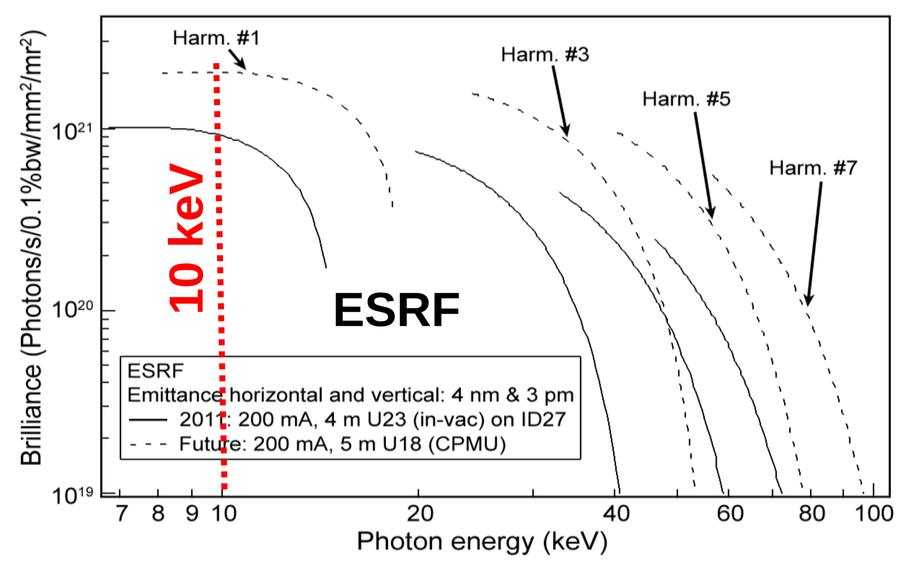
Insertion devices

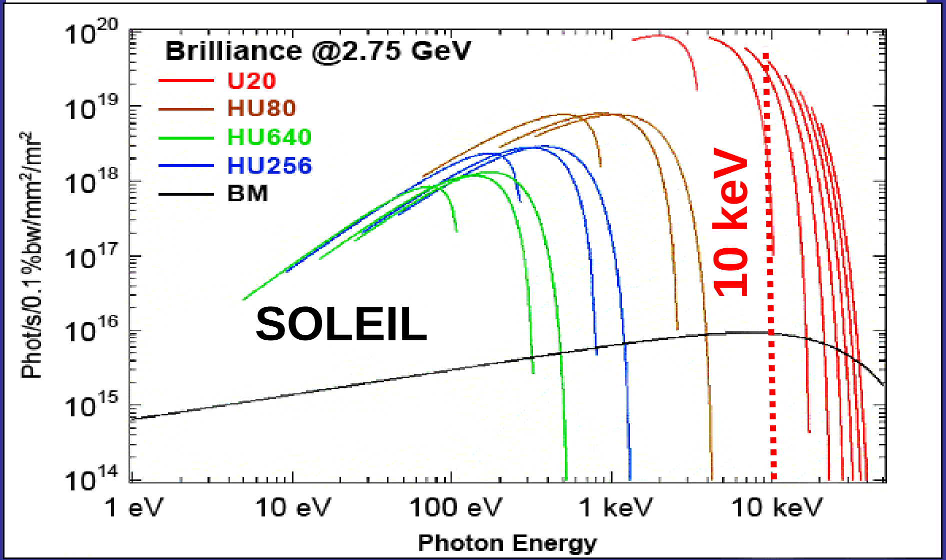
The jaws of the in-vacuum undulators can be closed down to 5 mm



Insertion devices







Beam sizes

Photon Energy	keV	**12**
Wavelength	nm	0.10
Undulator length	m	1.6

Single electron photon beam emittance

Emittance (nm)	*Size(μm)*	*Divergence(μrad)*
0.016	6	3

Electron energy	GeV	6
Coupling		0.2%

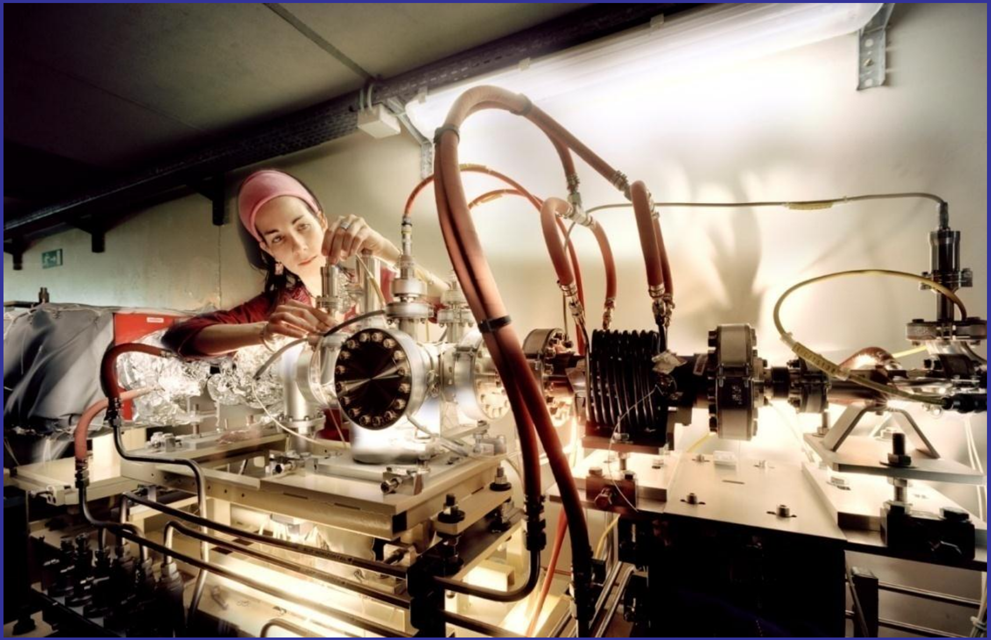
Electron beam emittance

		Beta (m)	*Emittance (nm)*	*Size(μm)*	*Divergence(μrad)*
"high beta section"	Horizontal	*35.6*	***4.0***	**377**	**11**
	Vertical	*2.5*	***0.006***	***4***	***2***

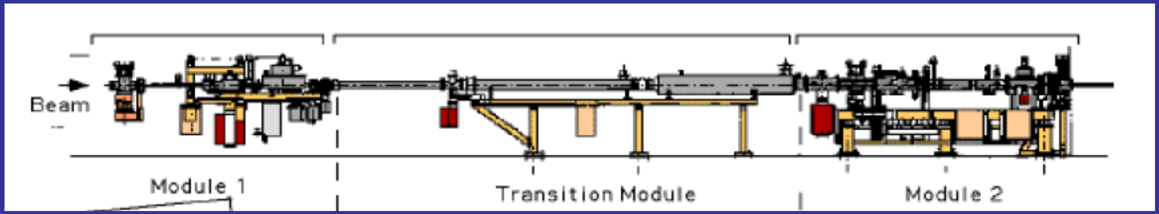
User beam emittance

	Emittance (nm)	*Size(μm)*	*Divergence(μrad)*
Horizontal	**4.1**	**377**	**11**
Vertical	**0.023**	**7**	**3**

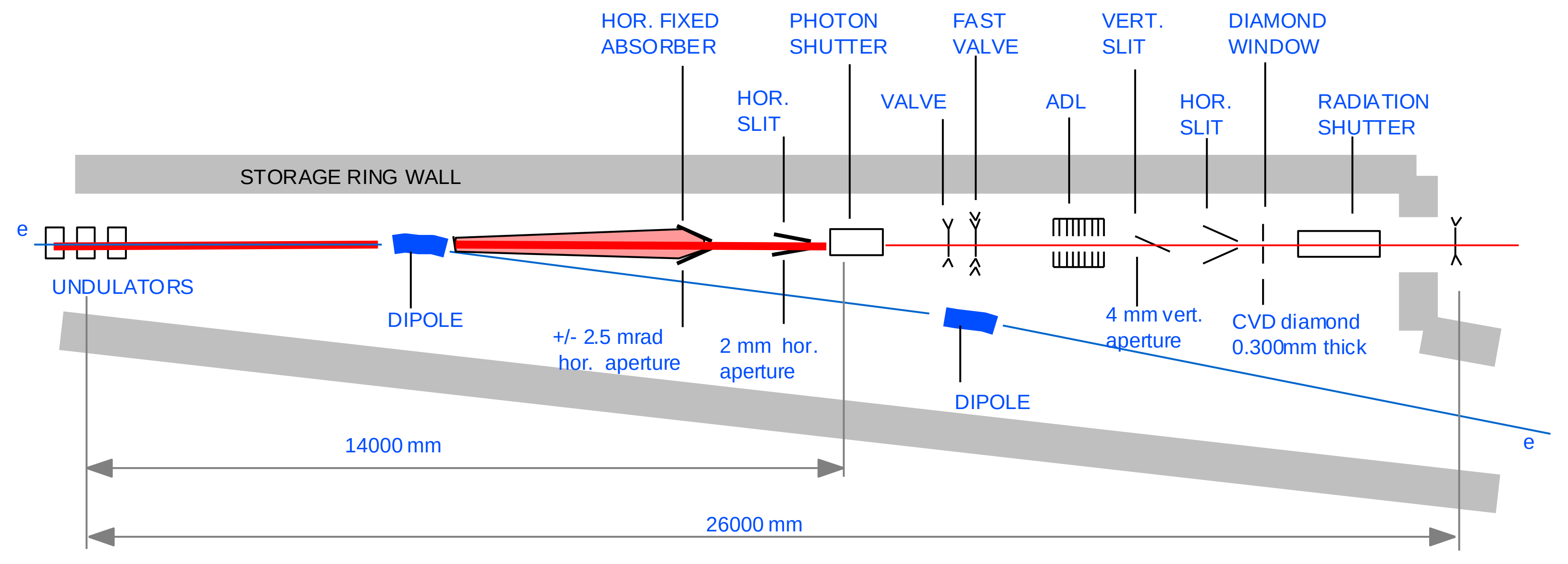
The Storage Ring Front Ends

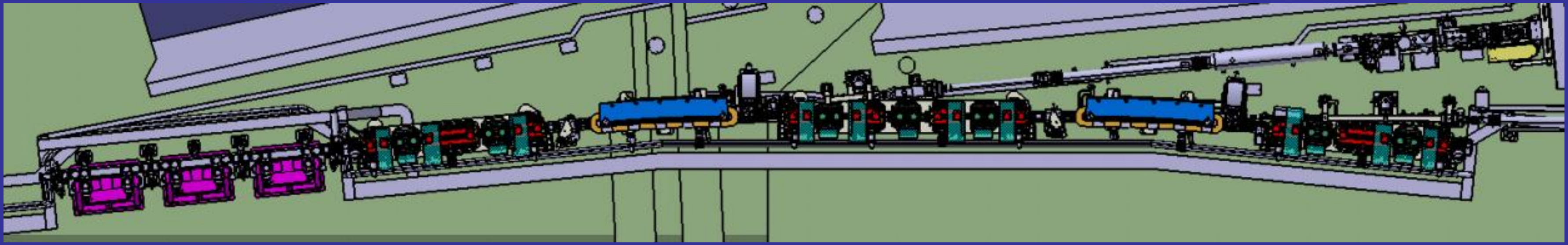


Goal: Drive the X-rays produced either by the dipoles, or by the insertion devices, from the storage ring to the beam line.

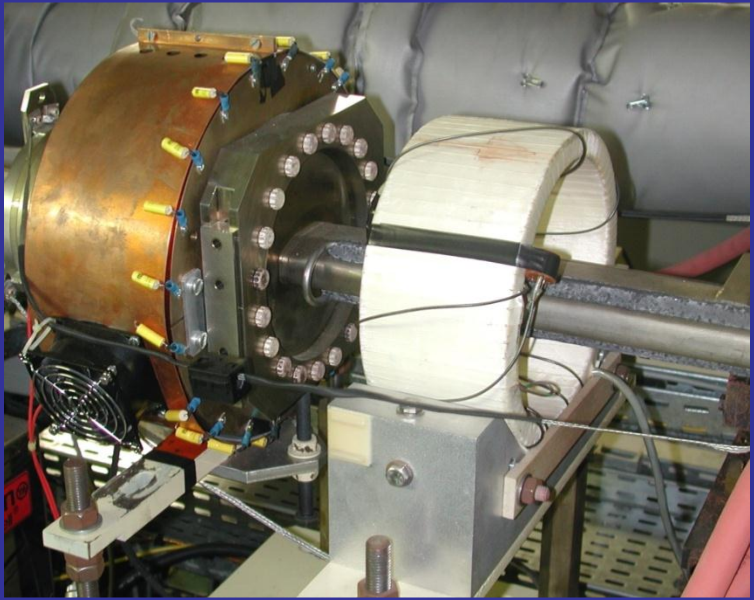


The Storage Ring Front Ends





The Storage Ring Beam diagnostics



Current transformers to measure the beam intensity

- PCTs (for « Parametric Current transformers):

Designed to measure an intensity up to 300 mA with a resolution of 2 µA. They measure the <u>total intensity</u> of the circulating beam (intégration time = 1 second).

- FCTs (for « Fast Current Transformers ») :

Designed to measure the intensity of a <u>single bunch</u> (or several bunches if they are sufficiently close to each other so as to be in a window time of a few nanoseconds).

The 224 Storage Ring Beam Position Monitors

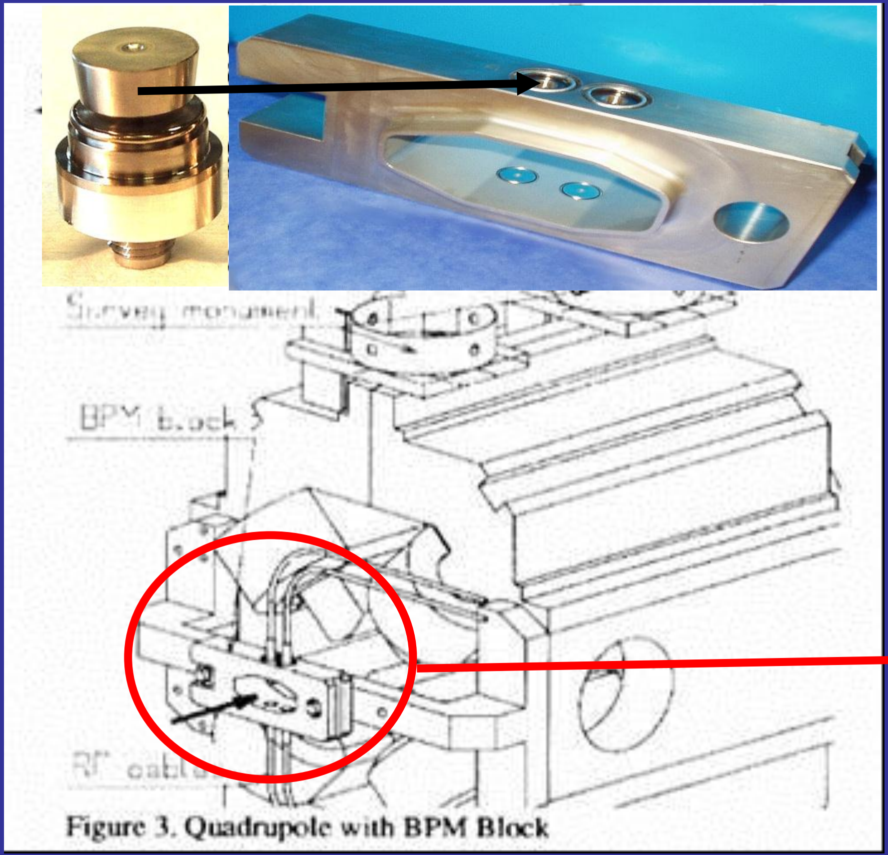
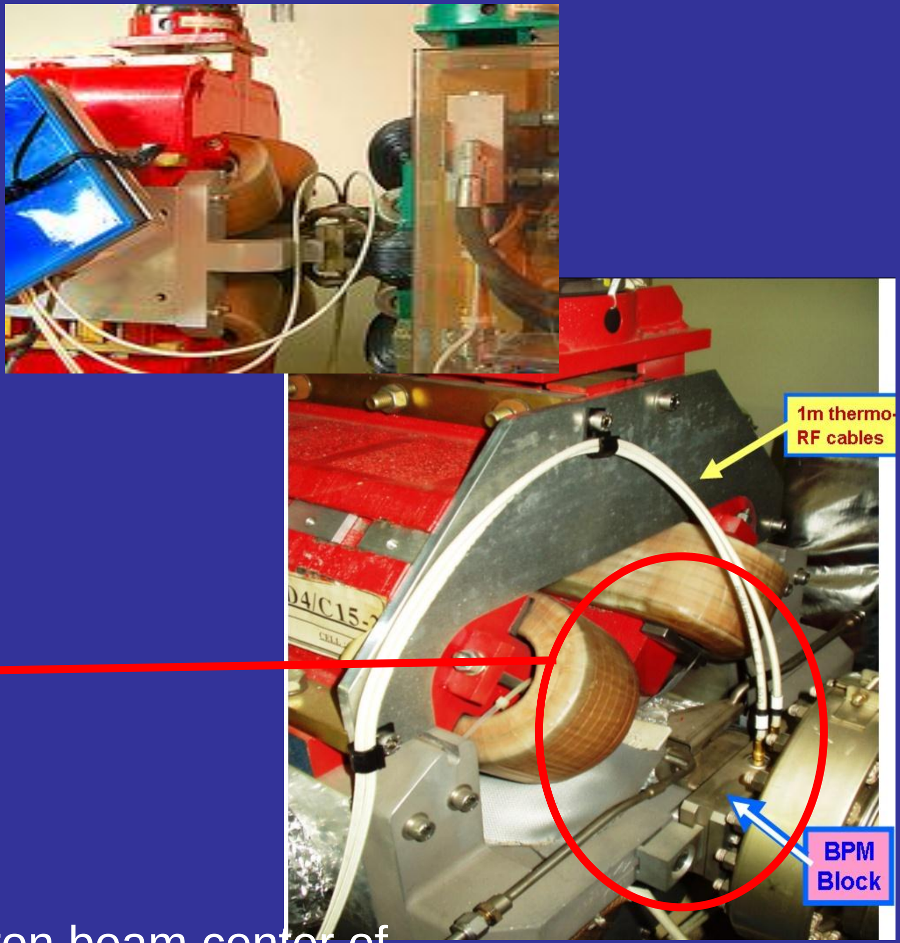


Figure 3. Quadrupole with BPM Block



Goal: measure the positions of the electron beam center of mass in the horizontal et vertical planes

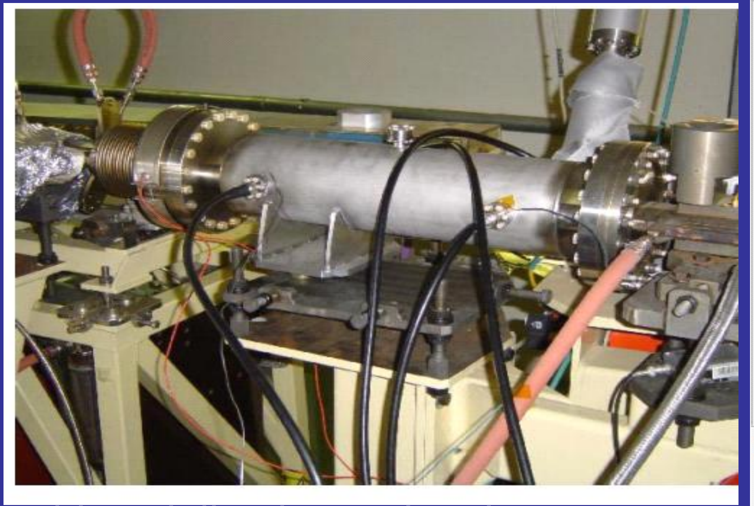
Processing of the low level RF signals of the 224 BPM stations using « Libera Brillance «electronics»

The tune monitor

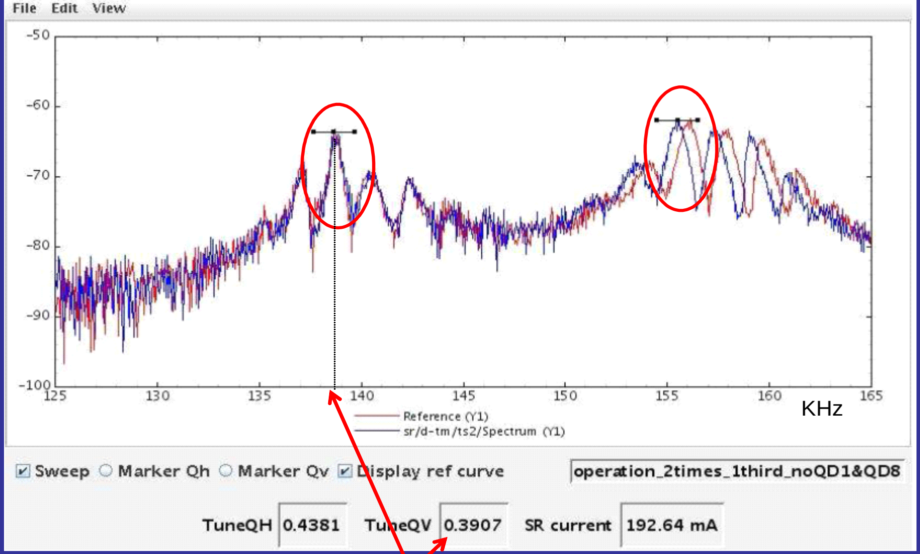
Goal: measure the frequencies of the vertical and horizontal betatronic oscillations of the circulating beam (the « tunes »).

The principle:

- A shaker excites the beam in a frequency range.
- A pick-up gets the signal which will be treated by a apectrum analyser.



This stripline is used at the same time as a shaker and as a pick-up



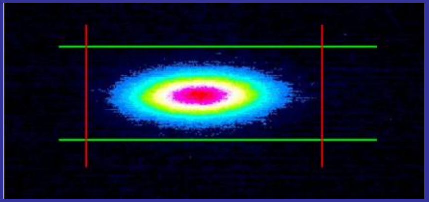
☑ Sweep ○ Marker Qh ○ Marker Qv ☑ Display ref curve

operation_2times_1third_noQD1&QD8

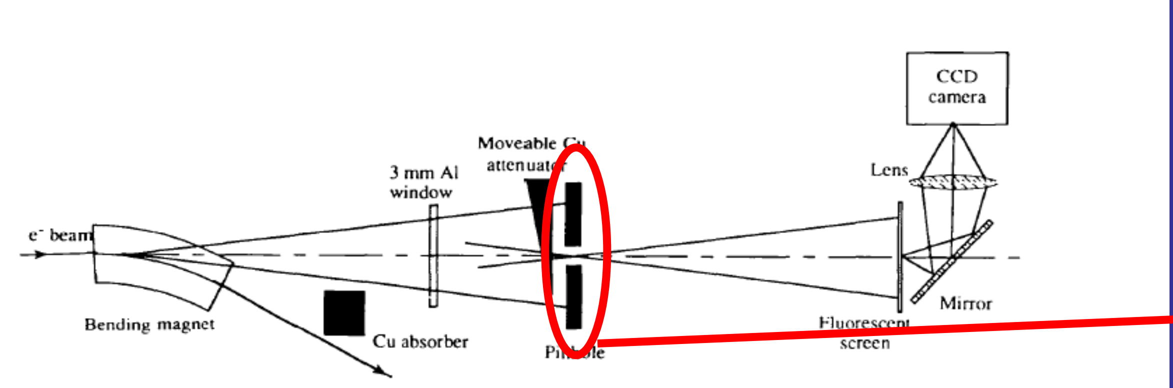
TuneQH 0.4381 TuneQV 0.3907 SR current 192.64 mA

Nombre d'onde vertical

Beam imaging system



Goal: allows to visualize the transverse profile of the electron beam in a bending magnet and compute its emittance.



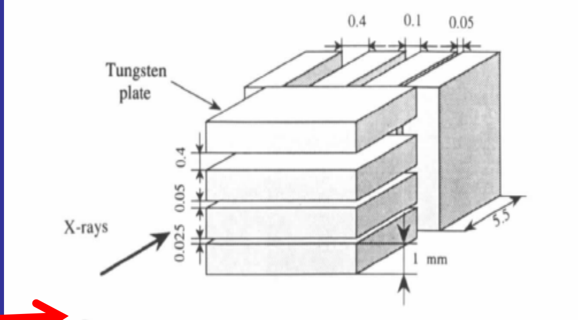


Figure 2
An array of 3 × 3 rectangular pinholes is made with tungsten plates. The wide pinhole is used for alignment purposes using an HeNe laser. The small pinholes are used during the measurement.

Principle:

- An aluminium window separates the high vacuum of the storage ring from the ‘pinhole camera’, which itself is located in the air.
- A ‘pinhole’ assembly is located at 4 meters from the source point and is constituted with small tungsten bars seperated by shims of known thickness (between 25 and 100 µm). The whole is mounted on a motorized table with a possibility of X and Z translation as well as a rotation about X and Z.
- A CCD camera located at 16 metres from the source point takes the picture via a fluorescent screen.

Beam loss detectors

The radiation detectors « Unidos »:

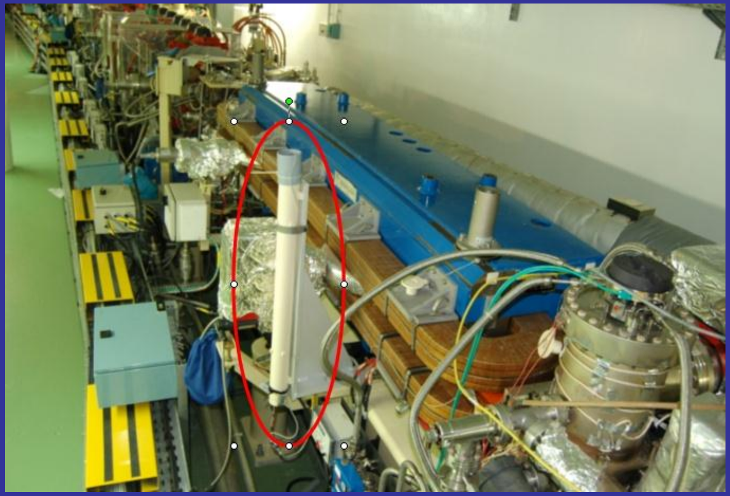
Ionisation chambers located in shielded boxes (10 mm lead) and located on the ground on the external side of the accelerators, at the entrance of every dipole. The detector is a pressurised gas which is ionised by high energy particles passing through this gas (electrons / photons).

Goal of the shielding: eliminate the component ‘synchrotron radiation’. The ionised gas will generate a leak current between 2 plates at high voltage. The advantage of these detectors is their great linearity (no avalanche effect). On the other side, it will be necessary to detect intensities of the order of the … femtoA, which is a slow and costful process !

Beam loss detectors

The ‘slow beam loss’ detectors

- Protected by 1 cm of lead in order to eliminate the ‘synchrotron radiation’ component.
- Located on the internal side of the accelerators at the level of the beam axis at the end of every dipole.
- Constituted of a cylinder of a photoemissive polymer (25 mm diameter / 600 mm long). The emitted light is gathered by a photomultiplier.
- Useful to locate the losses resulting from a scraping effect of the beam on the vacuum vessels and/or due to locally moderate vacuum level.



The vacuum system

Goal: control and maintain an excellent vacuum level in the storage ring:

10^{-10} mbar without beam (static pressure)
10^{-9} mbar with beam (dynamic pressure)

- This vacuum level is ensured by the ionic pumps, NEG coating

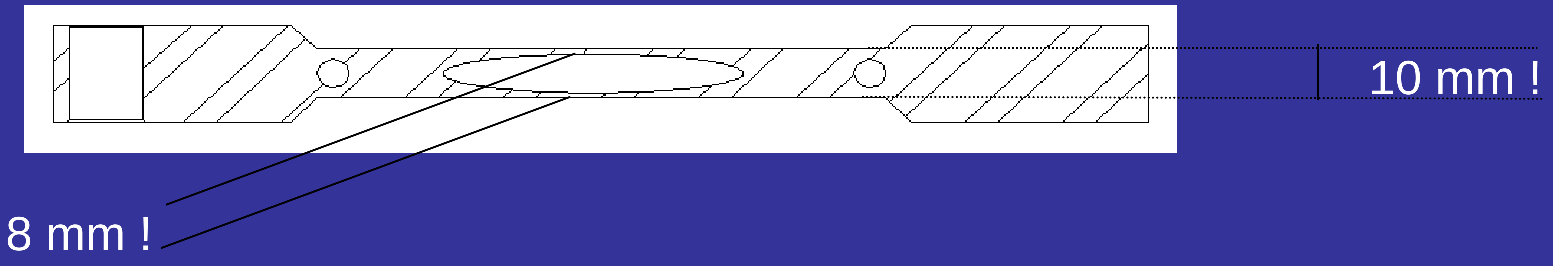
- The pressure control is done with Penning gauges.

- The storage ring is divided in 32 vacuum areas, each of them can be isolated by remotely controlled vacuum valves.

- Thanks to thermocouples, the temperature is controlled at several hundreds of sensitive locations (bellows, crotch absorbers, etc).

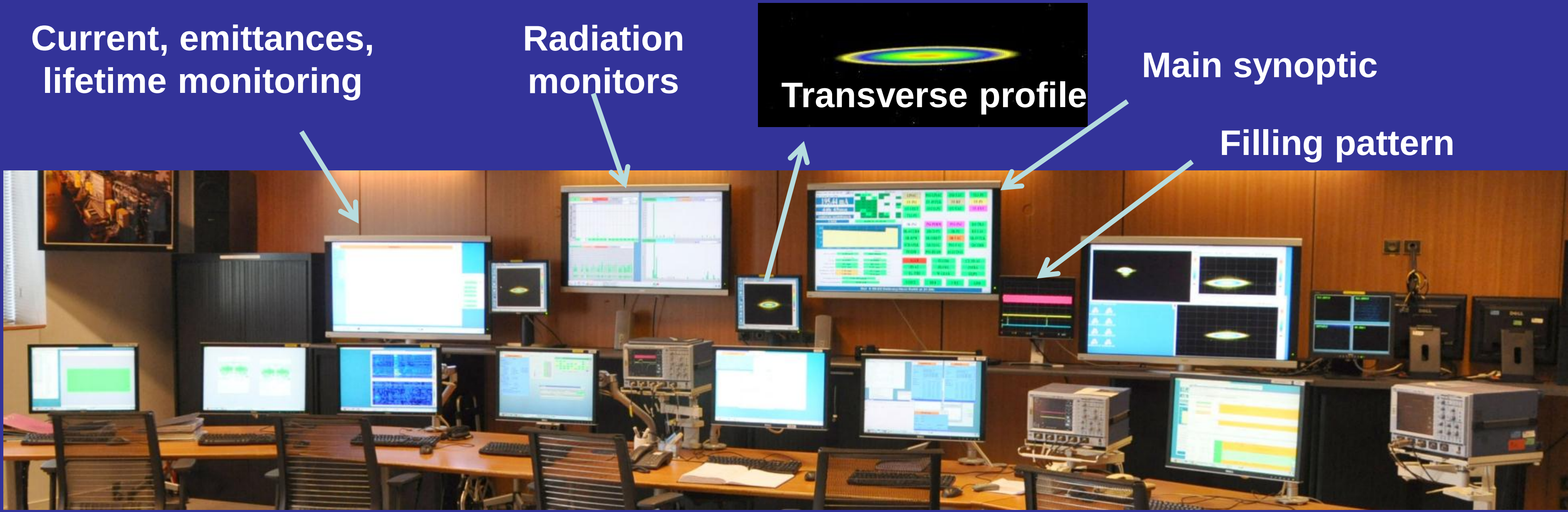
The vacuum system

Length = 5 metres et 6 metres



- Extruded aluminium
- The internal side of these vacuum vessels is covered with a thin coat of NEG material (Non Evaporable Getter) made of an alloy of Titanium, Zirconium, Vanadium. The particularity of this alloy is to trap chemically certain molecules (mainly CO and CO2) and to say it simply, we could say that this material act as vacuum pumps.

The ESRF control room



Current, emittances, lifetime monitoring

Radiation monitors

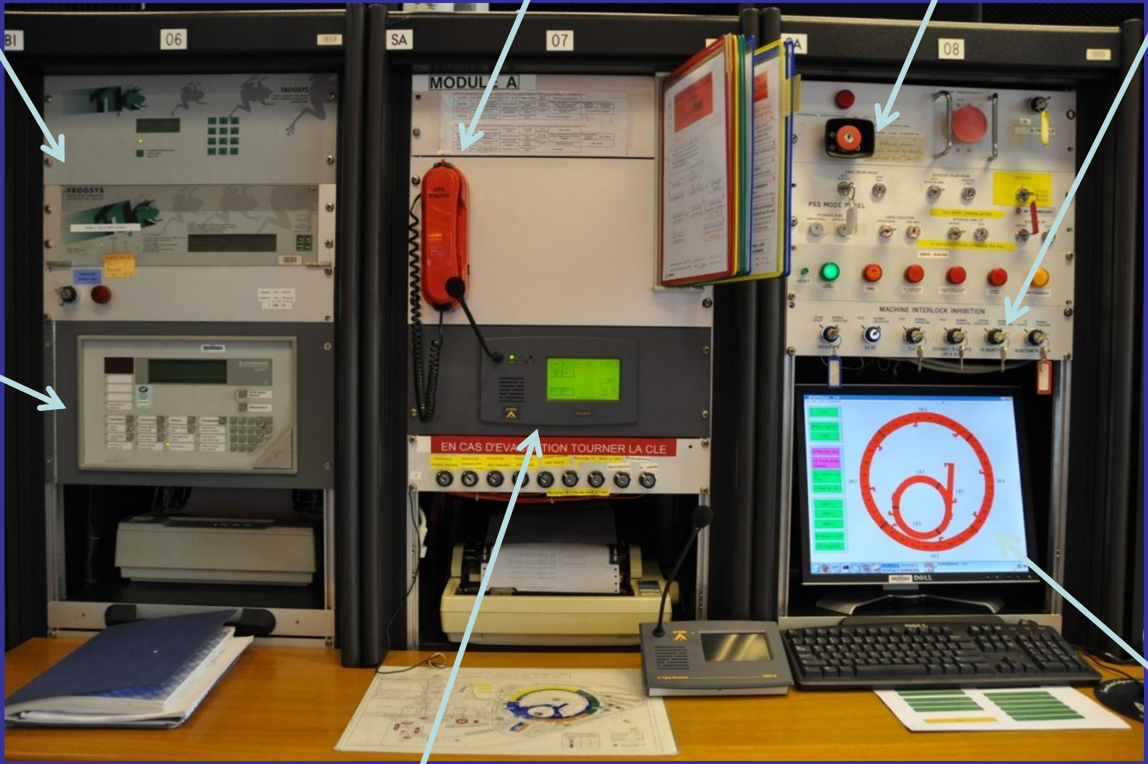
Transverse profile

Main synoptic

Filling pattern

- ➢ Control of the accelerator equipmenrs
- ➢ Réinjections
- ➢ Beam parameters monitoring
- ➢ Fault and failures control and analysis

The ESRF control room



Water leak detection

Red phone

Main urgency stop buttons and operating key configuration

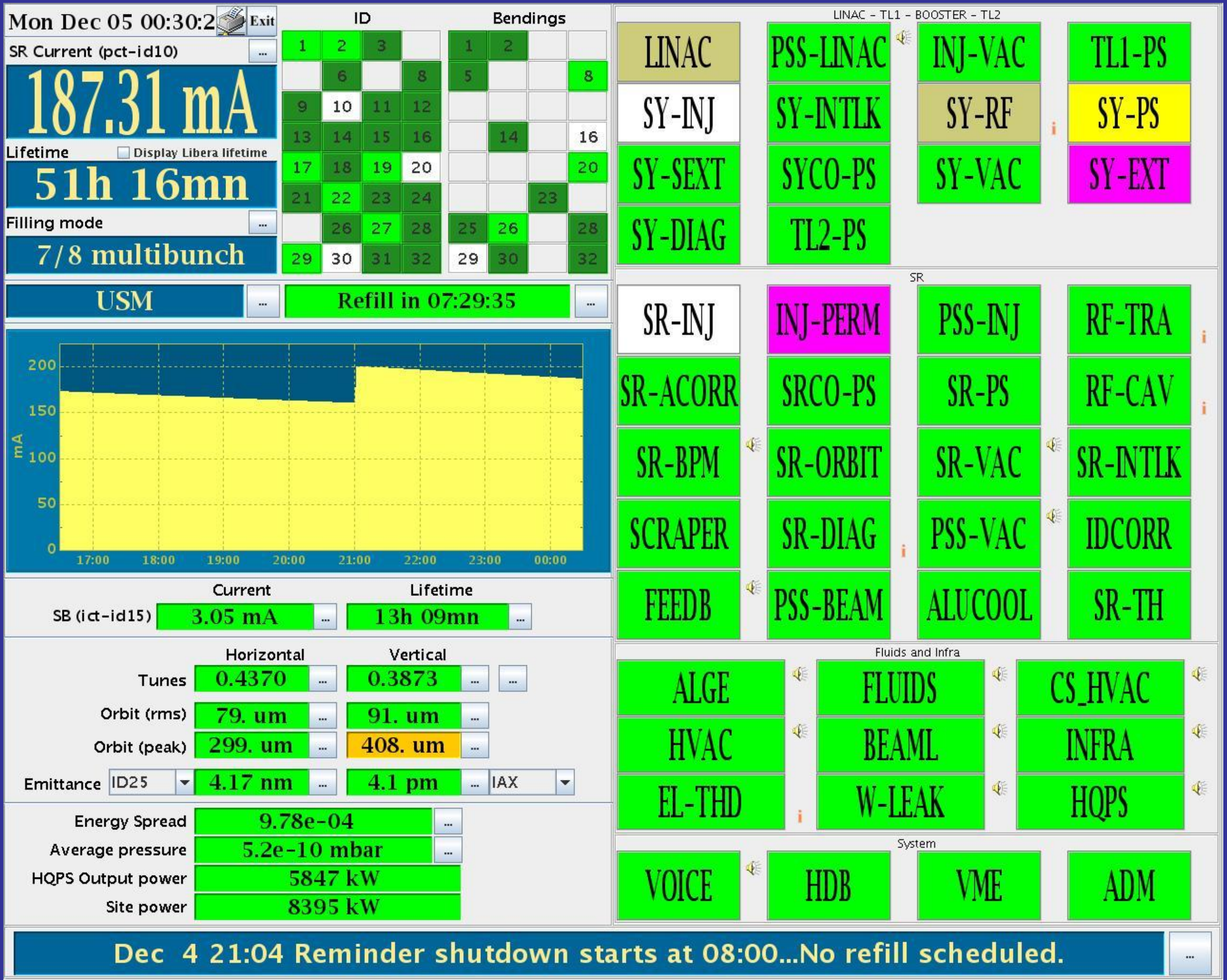
Fire alarm

Human and material safety is part of the accelerator operation

Message diffusion system (évacuations,..)

Personnal safety system for tunnel access

Accelerator operation



Mon Dec 05 00:30:2

SR Current (pct-id10): 187.31 mA

Lifetime ☐ Display Libera lifetime: 51h 16mn

Filling mode: 7/8 multibunch

USM

Refill in 07:29:35

	Current	Lifetime
SB (ict-id15)	3.05 mA	13h 09mn

	Horizontal	Vertical
Tunes	0.4370	0.3873
Orbit (rms)	79. um	91. um
Orbit (peak)	299. um	408. um
Emittance	ID25 4.17 nm	4.1 pm IAX

Energy Spread: 9.78e-04

Average pressure: 5.2e-10 mbar

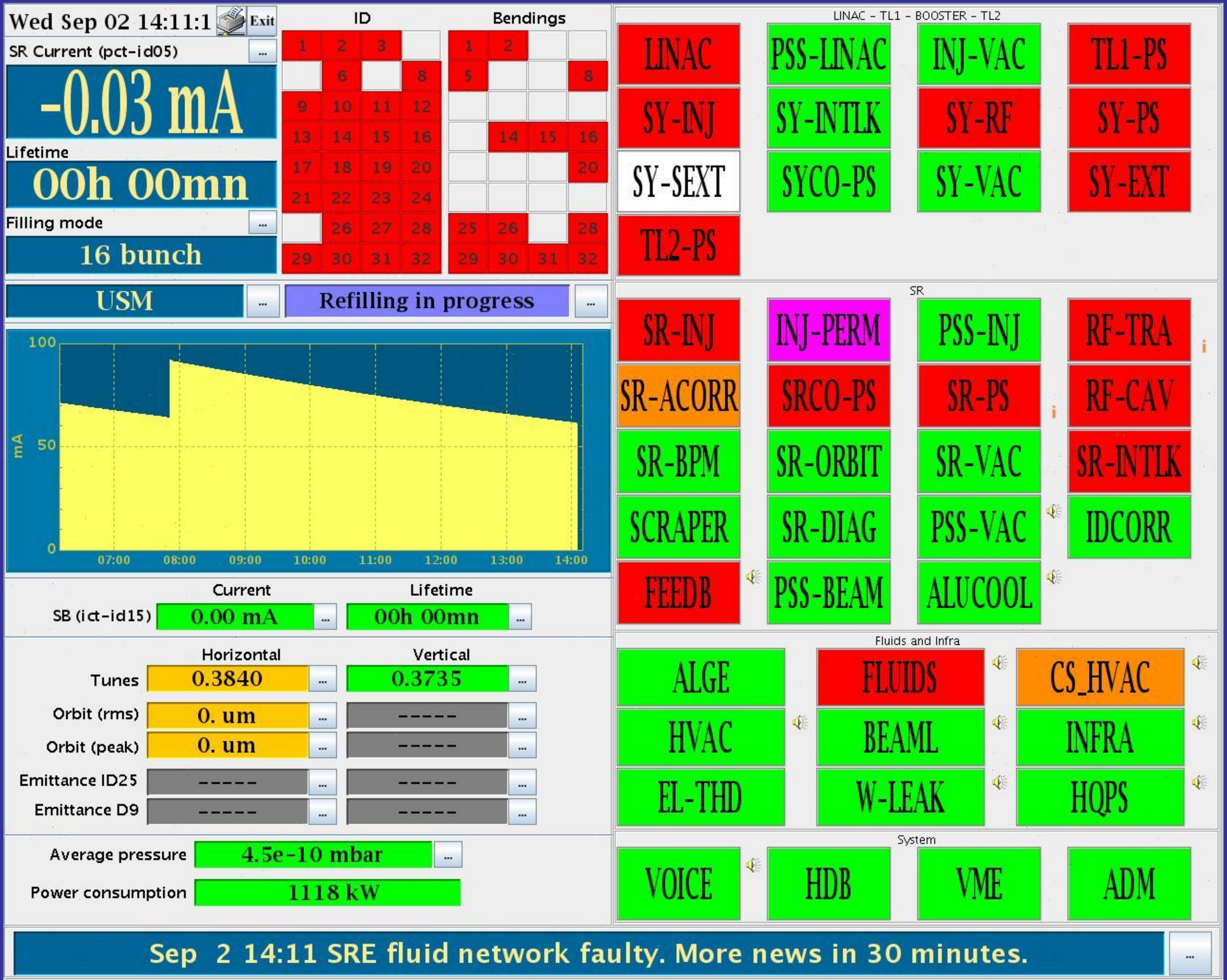
HQPS Output power: 5847 kW

Site power: 8395 kW

Dec 4 21:04 Reminder shutdown starts at 08:00...No refill scheduled.

When everything is fine!

Accelerator operation



Wed Sep 02 14:11:1

SR Current (pct-id05)

-0.03 mA

Lifetime

00h 00mn

Filling mode

16 bunch

USM

Refilling in progress

	Current	Lifetime
SB (ict-id15)	0.00 mA	00h 00mn

	Horizontal	Vertical
Tunes	0.3840	0.3735
Orbit (rms)	0. um	-----
Orbit (peak)	0. um	-----
Emittance ID25	-----	-----
Emittance D9	-----	-----

Average pressure 4.5e-10 mbar

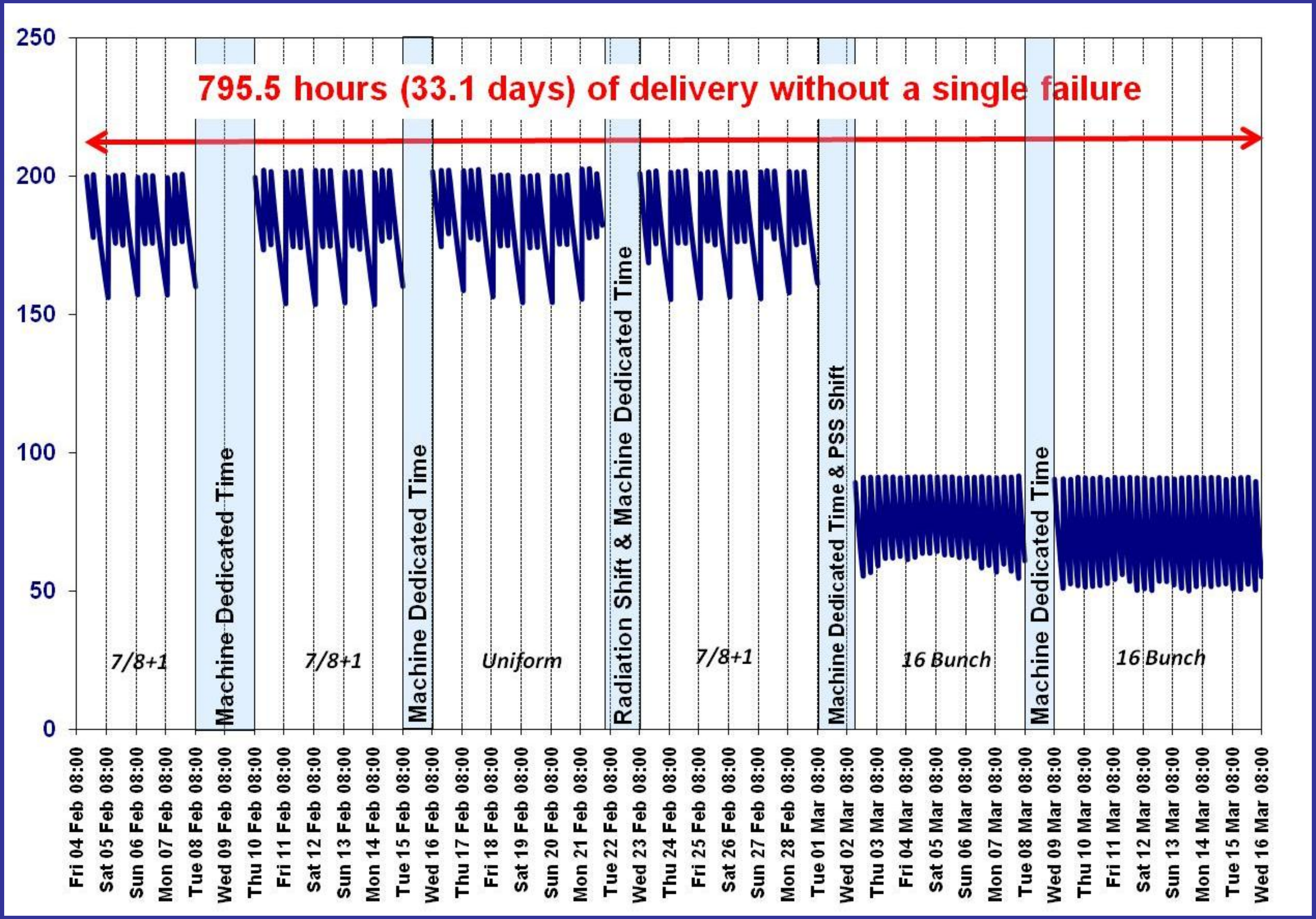
Power consumption 1118 kW

Sep 2 14:11 SRE fluid network faulty. More news in 30 minutes.

In case of fault !!

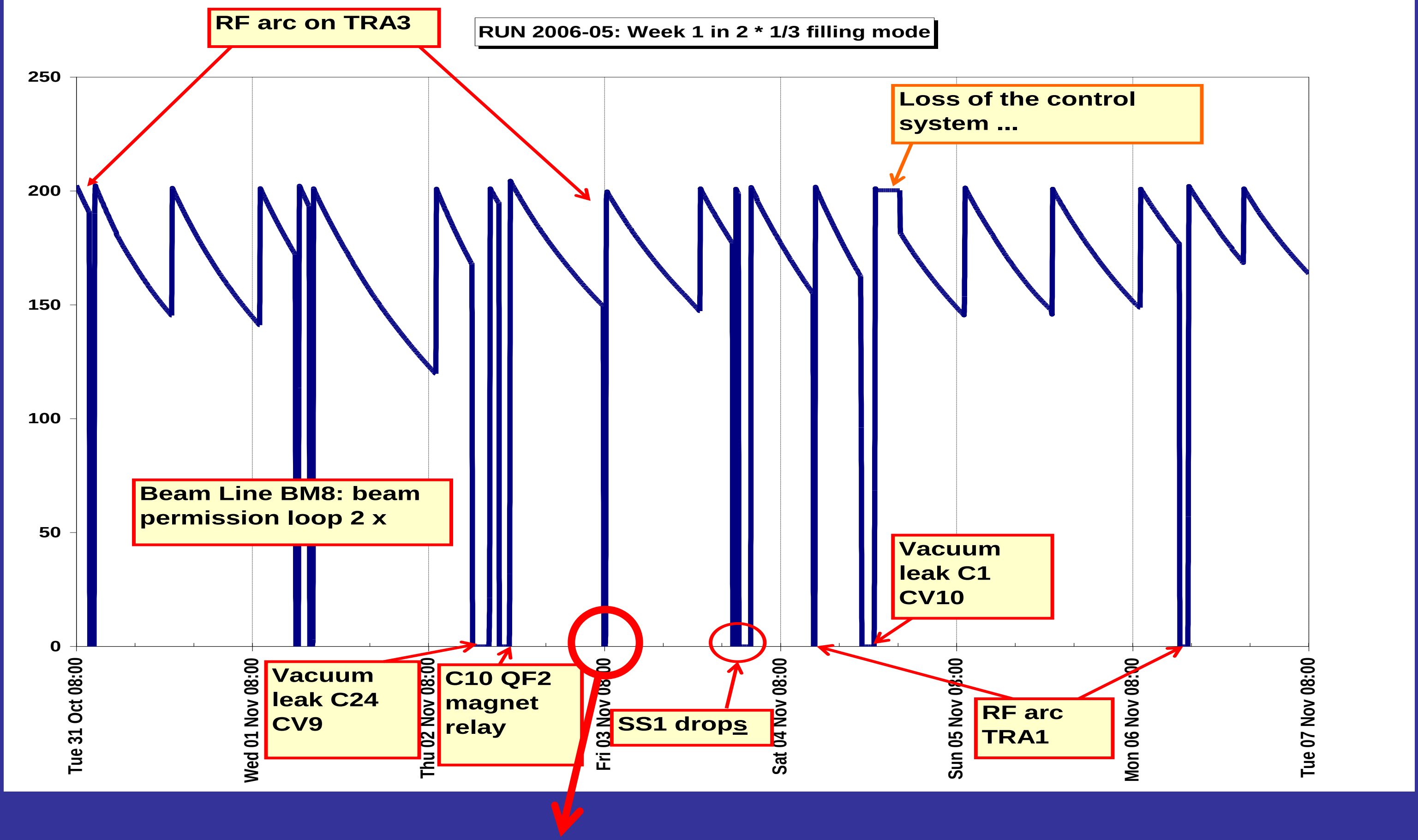
Reliability

ESRF availability record in 2011



Reliability

A n extremely bad week: 11 failures in 7 days. Mean time of a failure: 60 minutes

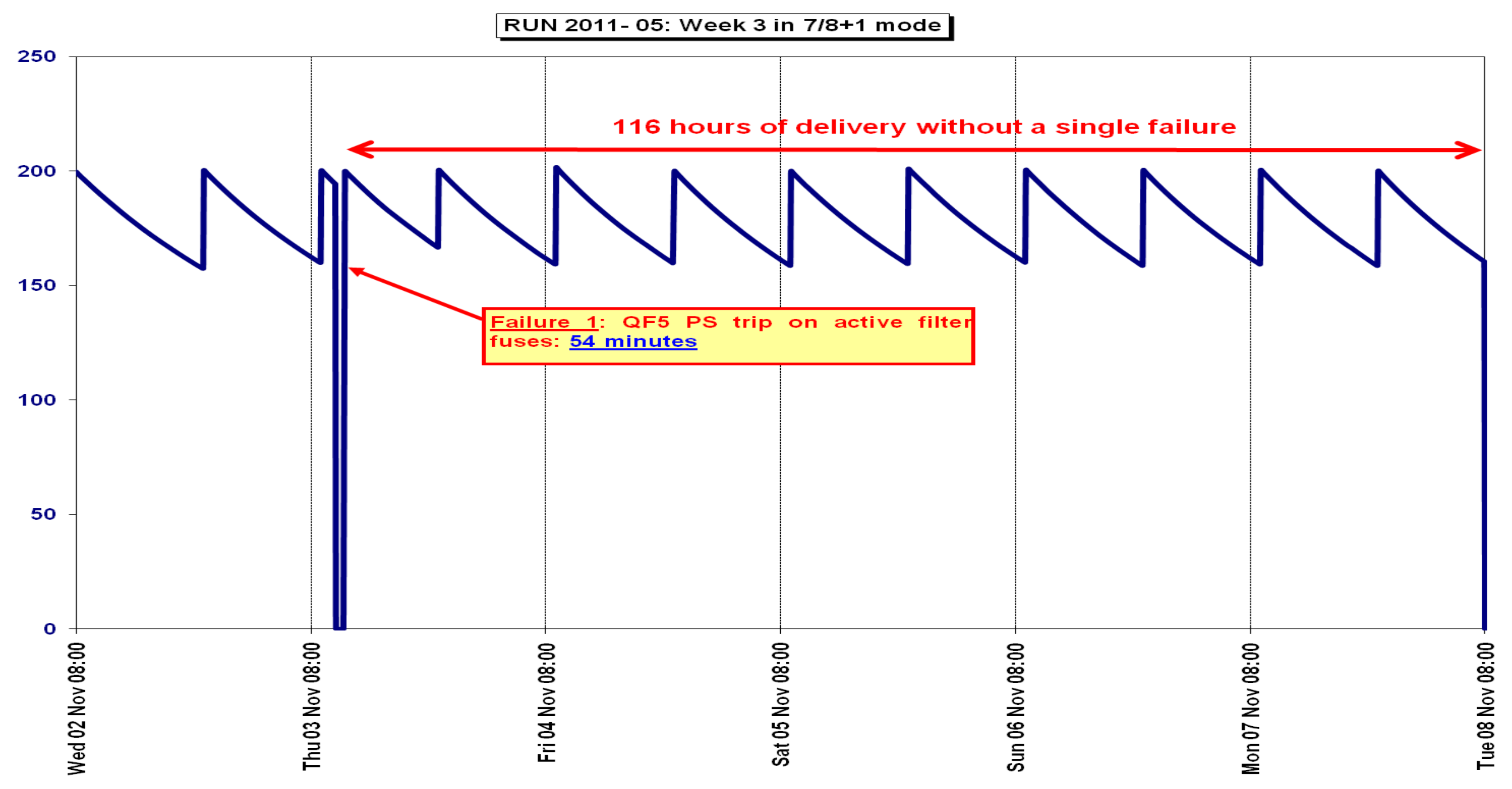


For a lot of users, 15 minutes of beam stop

= 1 hour lost on the beamline (heat load on the optics)

Reliability

A typical week: 1 failure of one hour over 144 hours



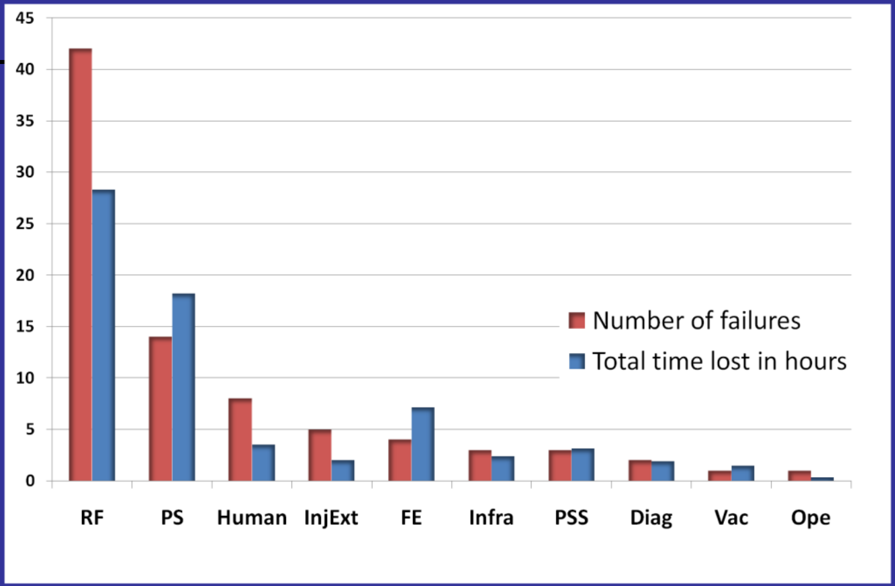
General statistics

Machine statistics	**2009**	**2010**	**2011**
Availability (%)	99.04	98.78	98.91
Mean time between failures (hrs)	75.8	67.50	107.8
Mean duration of a failure (hrs)	0.73	0.82	1.21

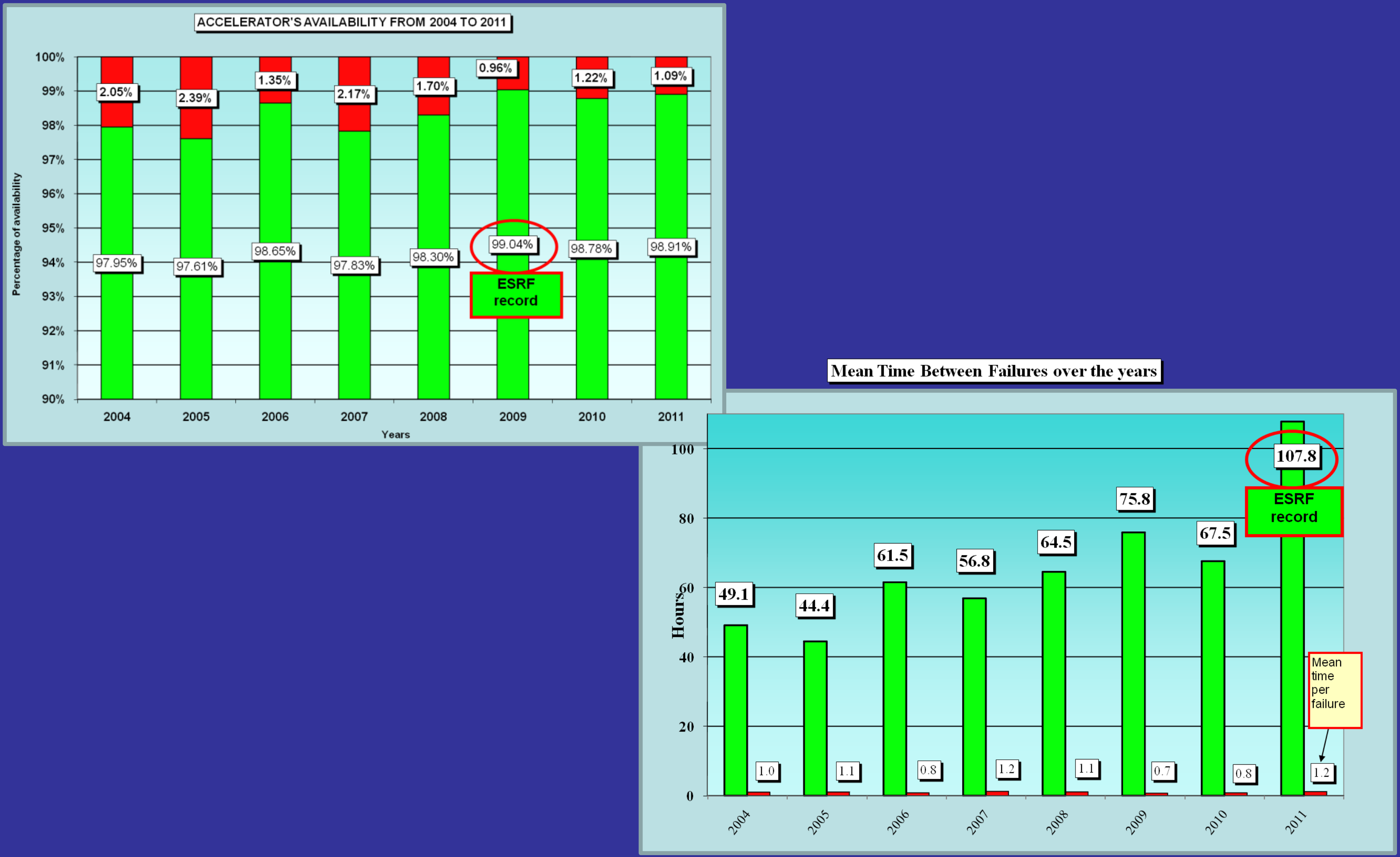
En 2010:
5538 hours effective delivery
including 48.5 hours for 599 refills

68.2 hours lost due to 83 failures

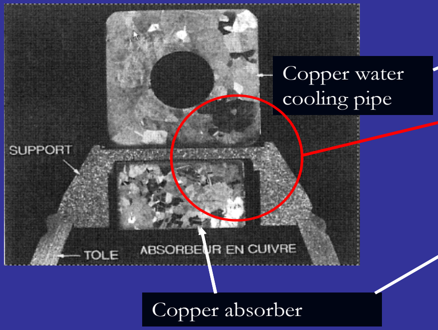
Failure distribution in 2010

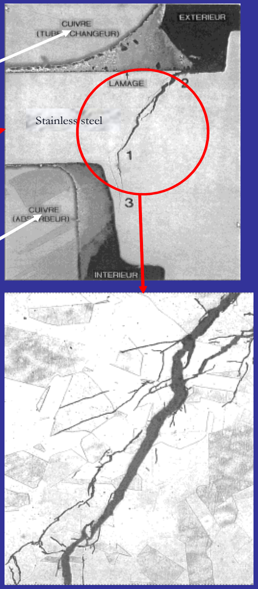


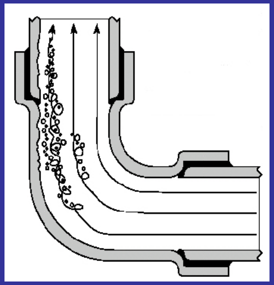
General statistics

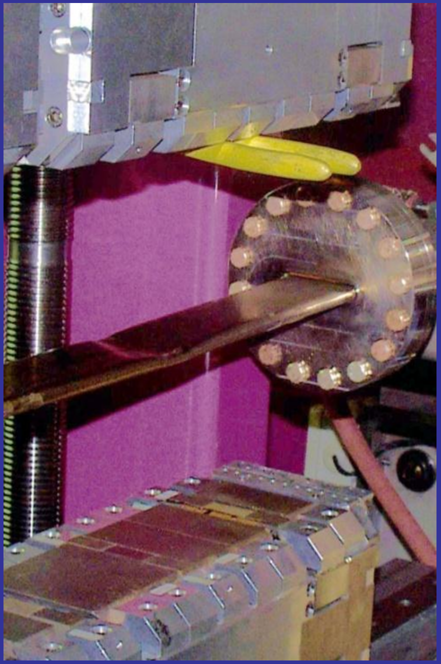


A few examples of failures

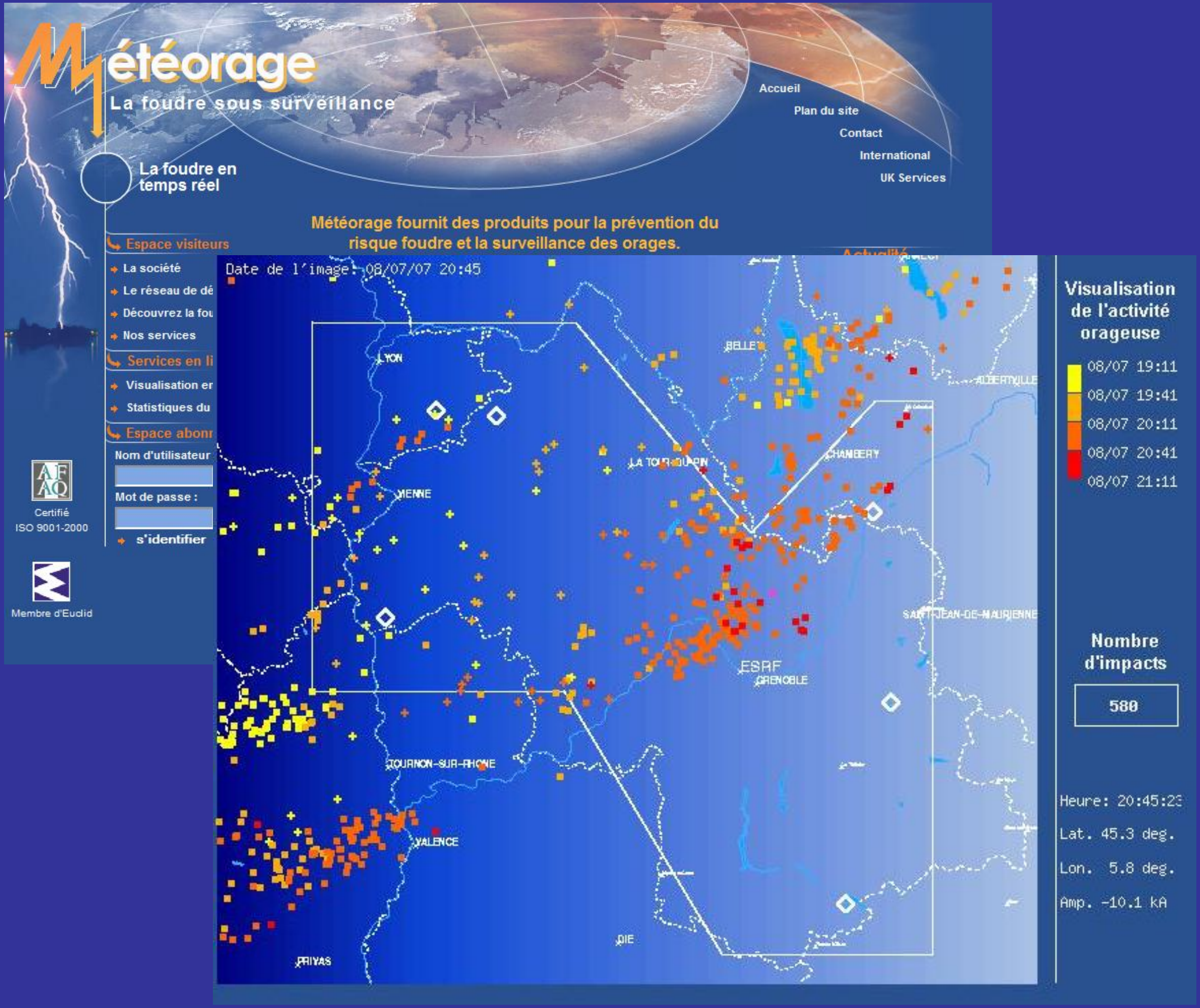








High quality electricity supply



Météorage

La foudre sous surveillance

La foudre en temps réel

- Accueil
- Plan du site
- Contact
- International
- UK Services

Météorage fournit des produits pour la prévention du risque foudre et la surveillance des orages.

Espace visiteurs
- La société
- Le réseau de dé
- Découvrez la fou
- Nos services

Services en li
- Visualisation er
- Statistiques du

Espace abonr

Nom d'utilisateur

Mot de passe :

s'identifier

Certifié ISO 9001-2000

Membre d'Euclid

Date de l'image: 08/07/07 20:45

Visualisation de l'activité orageuse

🟨	08/07 19:11
🟧	08/07 19:41
🟧	08/07 20:11
🟥	08/07 20:41
🟥	08/07 21:11

Nombre d'impacts

580

Heure: 20:45:2

Lat. 45.3 deg.

Lon. 5.8 deg.

Amp. -10.1 kA

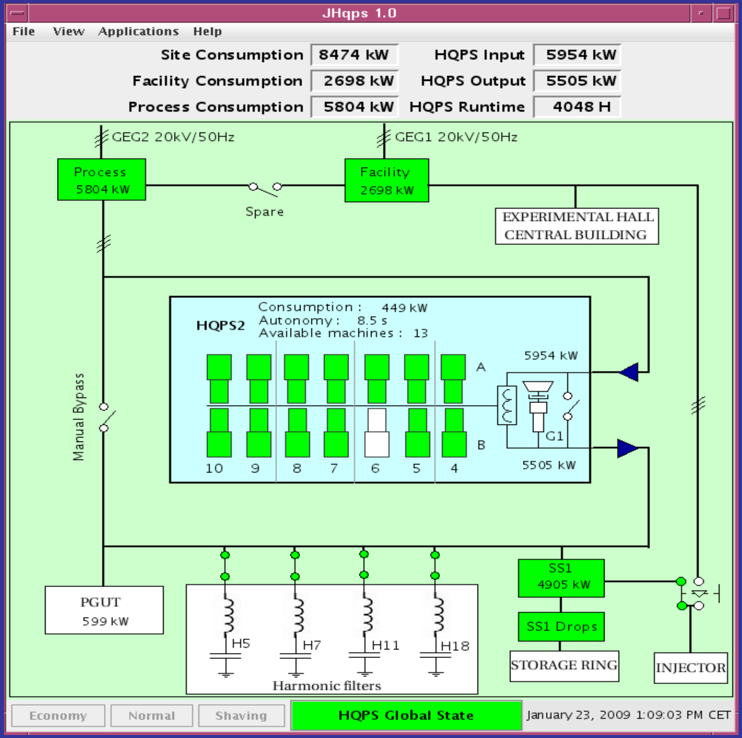
A lot of storms
in the Grenoble
area

Sunday
08/07/2007
500 impacts
In 2 hours

HQPS

:

- 14 accumulators / generators which filter the main 20kV electrical network.
  - 9.3 MW available for a few seconds
  - 1Mw supply from a diesel engine in case of long cut (>3 sec) for control and vacuum system supply



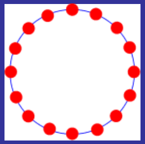
Site Consumption 8474 kW
Facility Consumption 2698 kW
Process Consumption 5804 kW
HQPS Input 5954 kW
HQPS Output 5505 kW
HQPS Runtime 4048 H

HQPS2
Consumption : 449 kW
Autonomy : 8.5 s
Available machines : 13

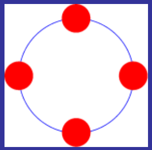
January 23, 2009 1:09:03 PM CET

Increase the MTBF and reduce the stress on equipments

Filling modes

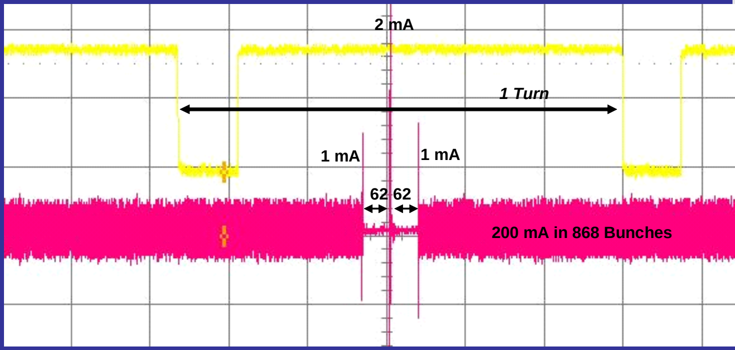


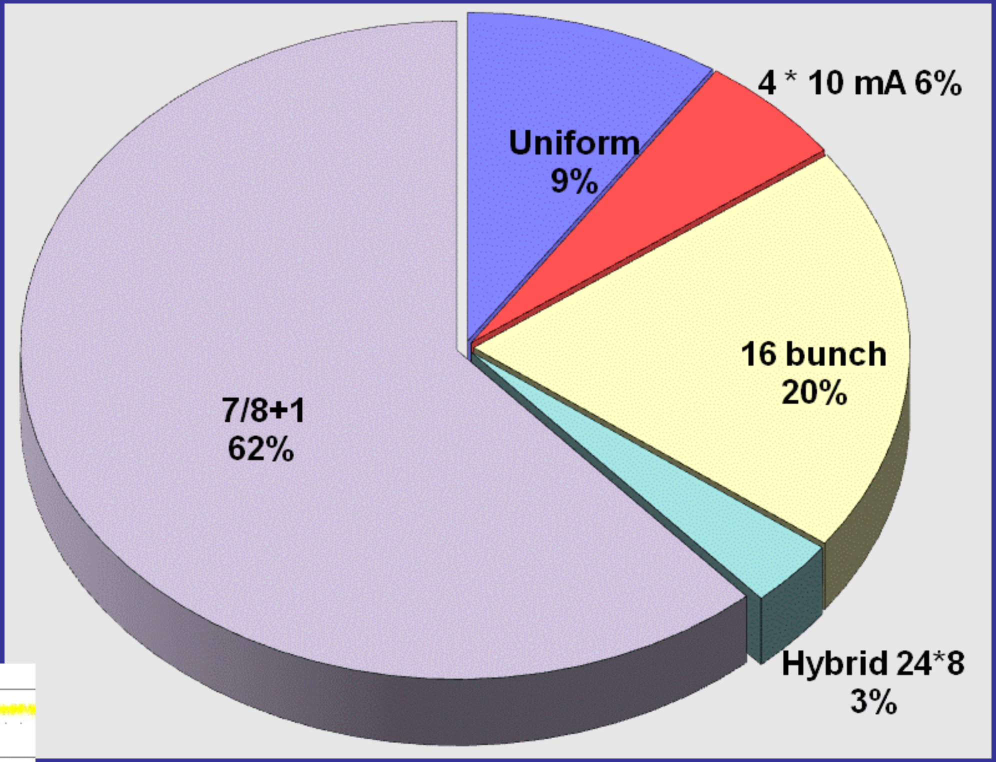
Mode 16 Bunch:
90 mA



Mode 4 Bunch:
40 mA

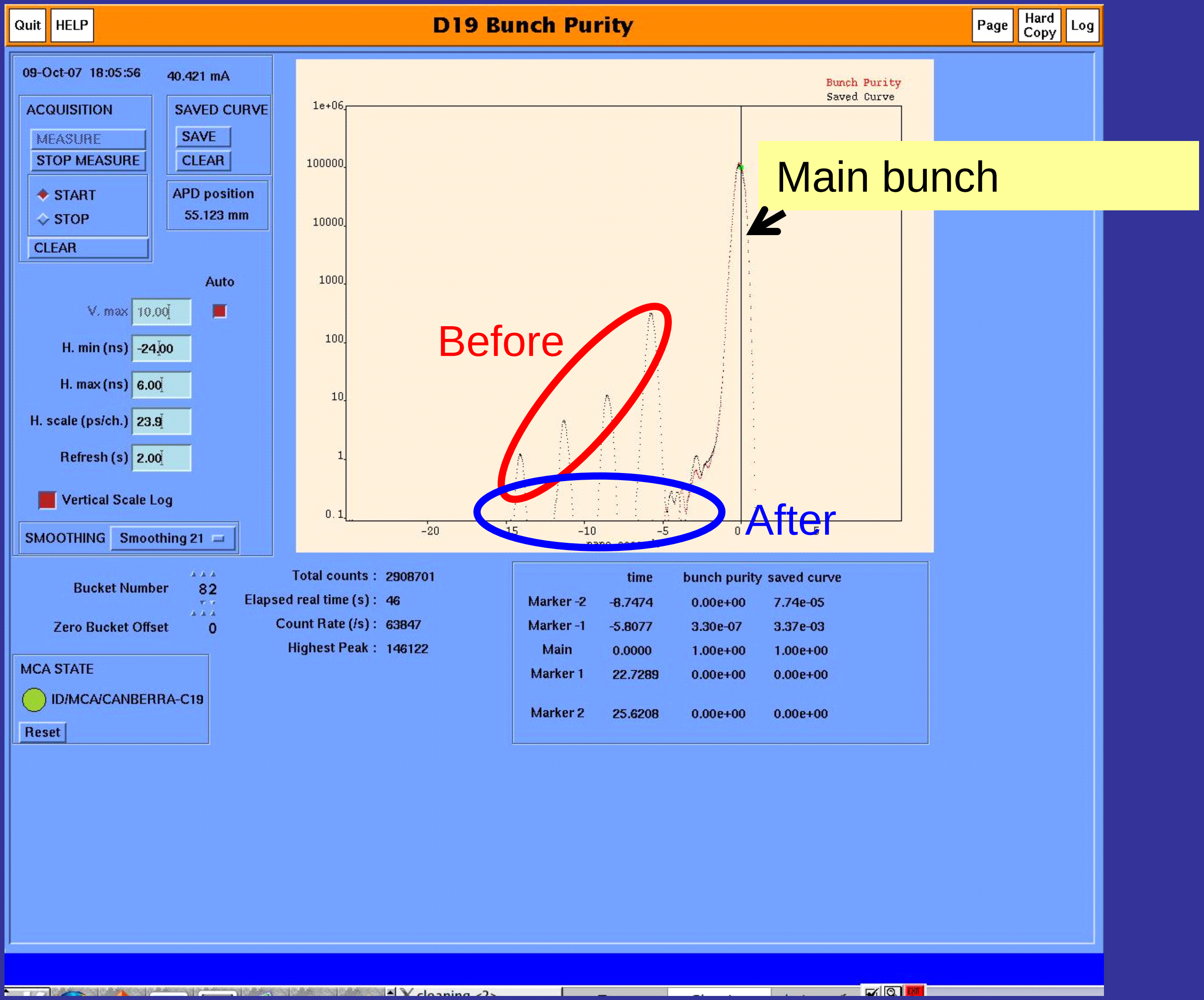
Mode 7/8+1: 200 mA





91 % of Beamtime available for Timing Experiments

Purity in time structure



Main bunch

Before

After

09-Oct-07 18:05:56 40.421 mA

APD position 55.123 mm

V. max 10.00 🟥

H. min (ns) -24.00

H. max (ns) 6.00

H. scale (ps/ch.) 23.9

Refresh (s) 2.00

🟥 Vertical Scale Log

SMOOTHING Smoothing 21

Bucket Number 82

Zero Bucket Offset 0

Total counts : 2908701

Elapsed real time (s) : 46

Count Rate (/s) : 63847

Highest Peak : 146122

MCA STATE

● ID/MCA/CANBERRA-C19

Reset

	time	bunch purity	saved curve
Marker -2	-8.7474	0.00e+00	7.74e-05
Marker -1	-5.8077	3.30e-07	3.37e-03
Main	0.0000	1.00e+00	1.00e+00
Marker 1	22.7289	0.00e+00	0.00e+00
Marker 2	25.6208	0.00e+00	0.00e+00

Beam Lifetime

Decrease of the stored current is a function of:

$$\frac{1}{\tau} = -\frac{1}{I}\frac{dI}{dt}$$

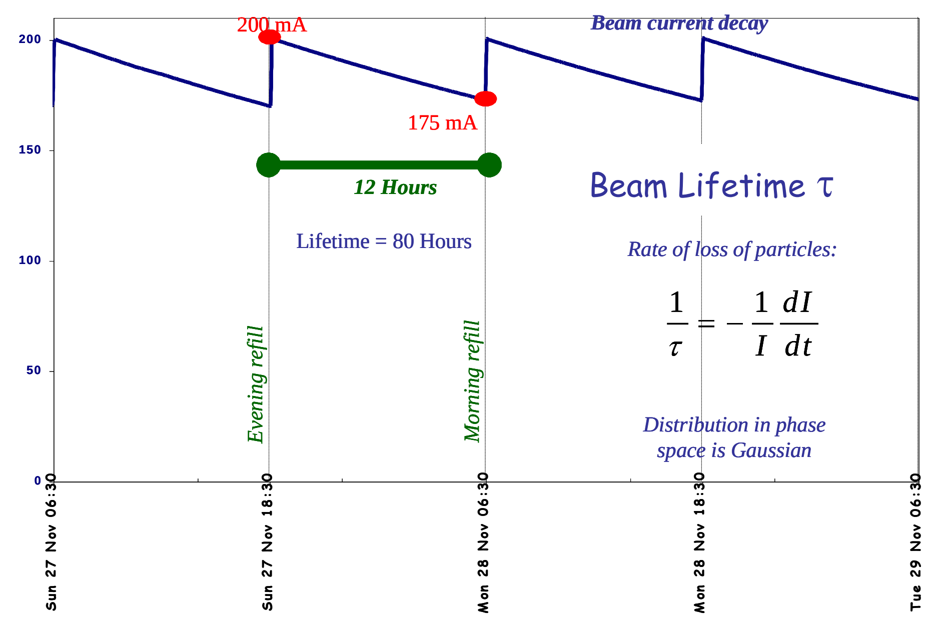
- Vacuum quality
  - ➔ *Probability of collision with residual gas*
- Number of electrons per bunch (i.e. total current)
  - ➔ *Probability of collision within the bunch*
- Lattice
  - ➔ *Transverse and longitudinal dynamic acceptance*
- Size of the vacuum chamber
  - ➔ *Physical transverse acceptance*

$$\frac{1}{\tau} = \sum_i \frac{1}{\tau_i}$$

Large change in current:

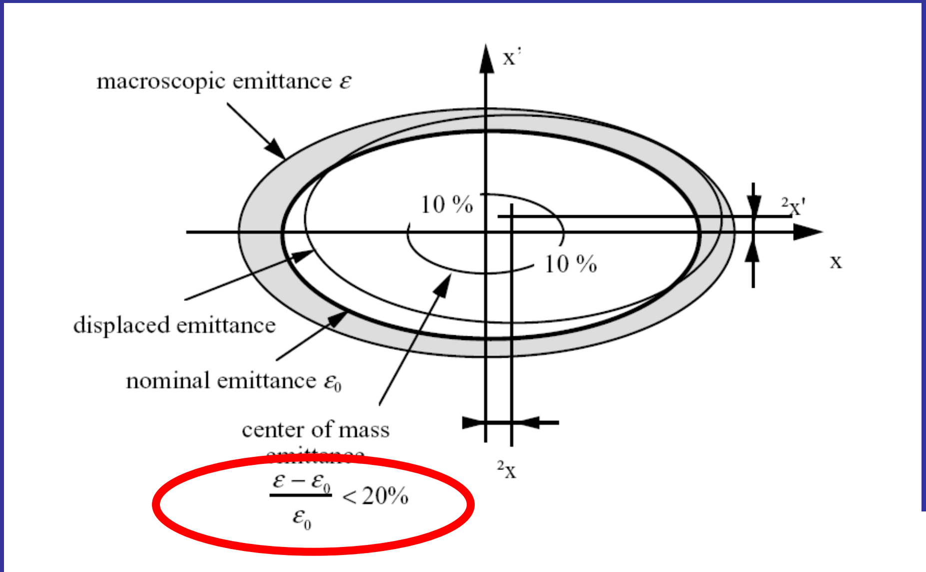
➔ Large variation ofthe heat load on the optics

➔ Detrimental to the position stability on the sample



Beam Stability Requirements

The beam stability is as critical as the beam reliability !



It is agreed that the emittance growth should not exceed 20 %:

10 % variation of the position compared to the beam size and 10 % relatively to its divergence.

Stability requirement at the source point:.

	Horizontal		*Vertical*
Emittances	4 nm		30 pm
β function	2.5	35	2.5
Beam size	45 µm	380 µm	9 µm
Required stability	**4.5 µm**	**38 µm**	**0.9 µm**

Beam Stability Performance

Position stability should be studied on

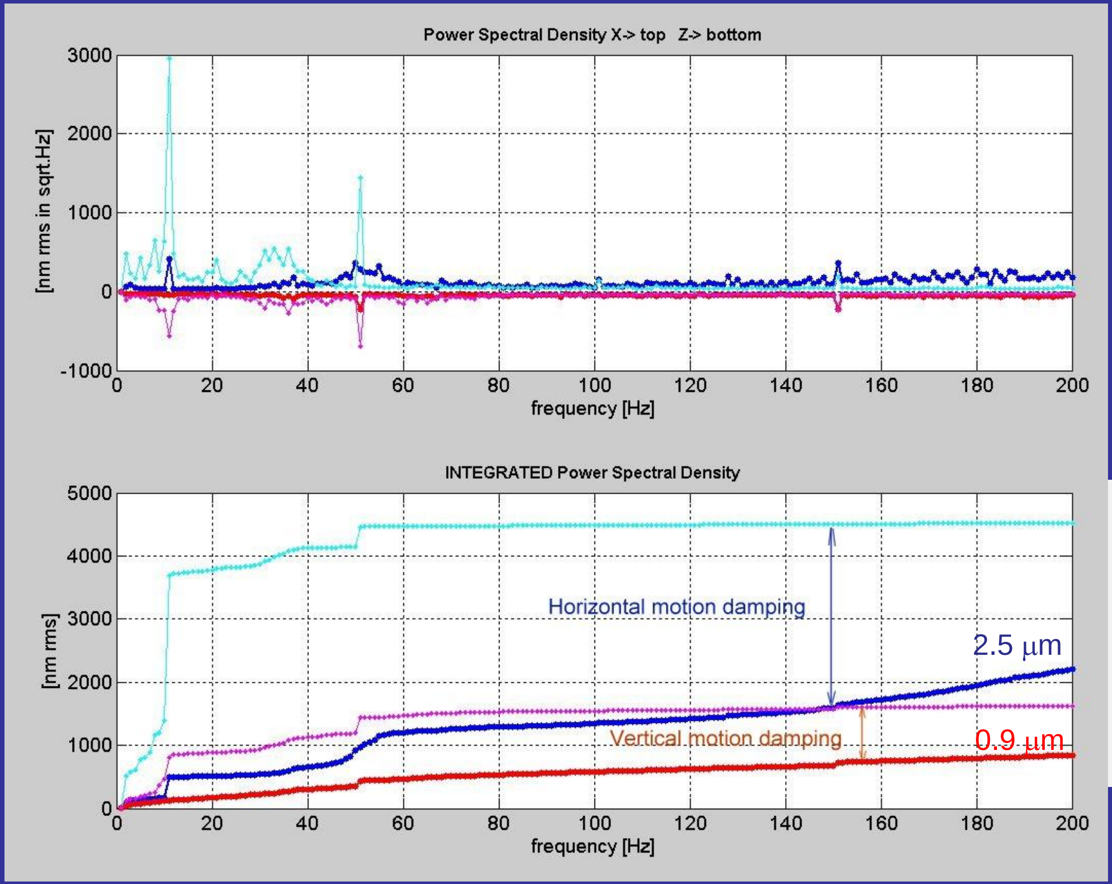
- ➢Short term
  - ➔ Reduction of the perturbations!
  - ➔ Fast Orbit Feedback
- ➢Medium term
  - ➔ Closed orbit correction
- ➢Long term
  - ➔ Magnets realignment

Stability criteria mostly achieved in horizontal but more critical in the vertical plane.

	Horizontal	*Vertical*
10% Beam size	**38 µm**	**0.9 µm**
One week	**11 µm**	**8 µm**
One day	**5 µm**	**2 µm**
One hour	**5 µm**	**2 µm**
One minute	**5 µm**	**2 µm**
One second	**2 µm**	**1 µm**

Beam stability

A new feedback acting du DC à 200 Hz system is under test.

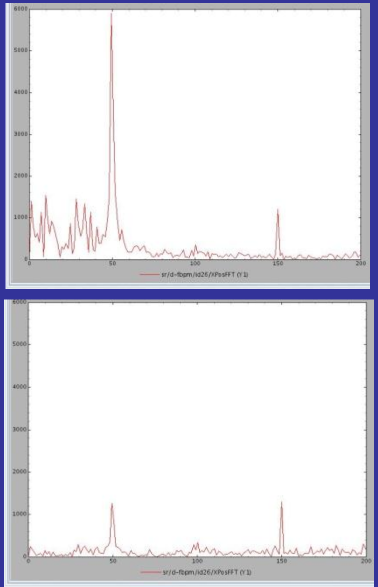


Horizontal OFF

Horizontal ON

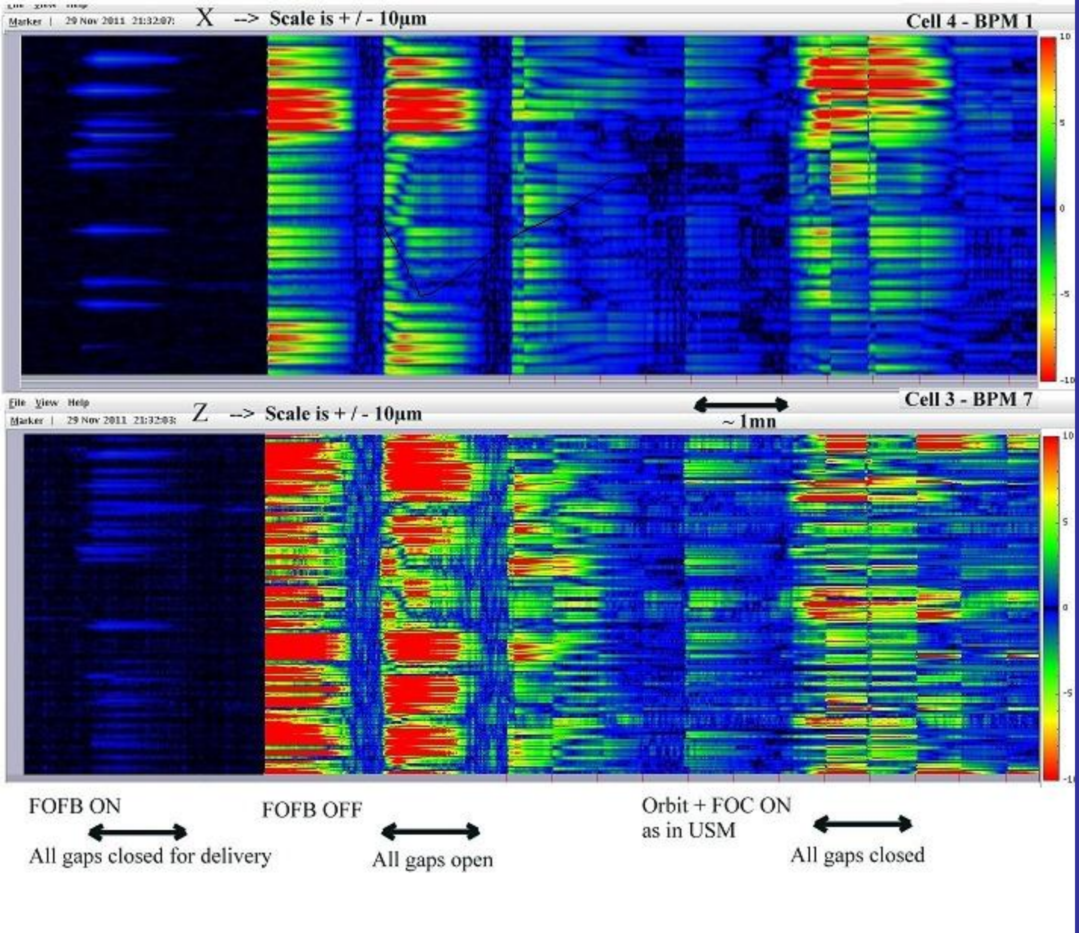
Vertical OFF
Vertical ON

224 BPMs / 96 steerers
Average over 224 BPMs



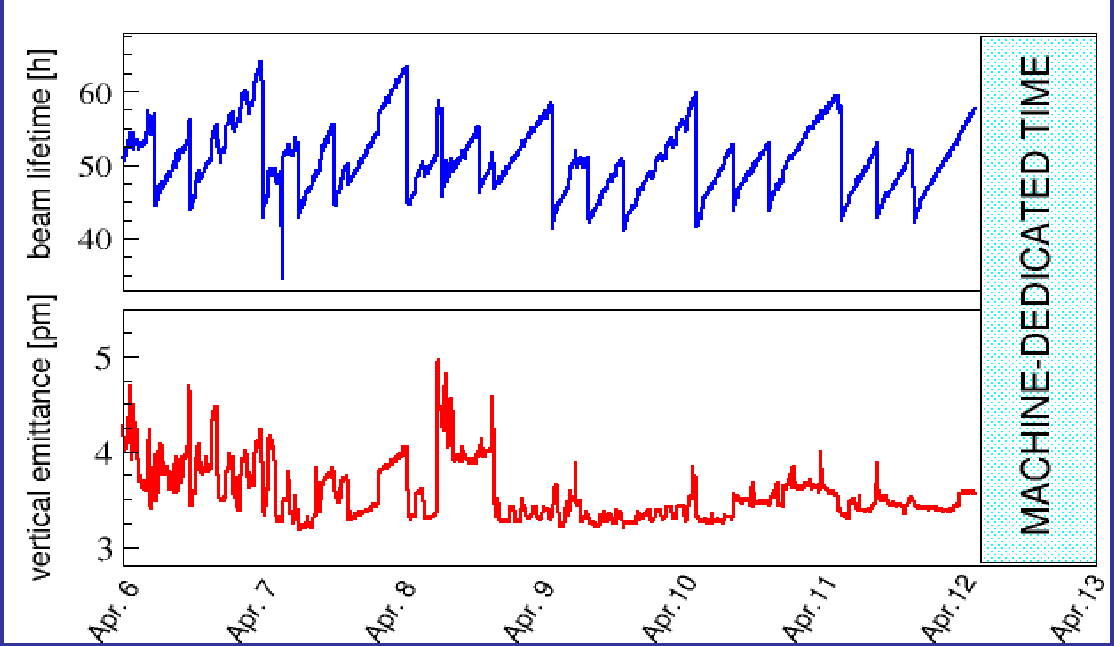
Beam stability

A new feedback acting form DC to 200 Hz is under test.



Improvement of the correction at 0.1 Hz which corresponds to the motion of undulator gaps.

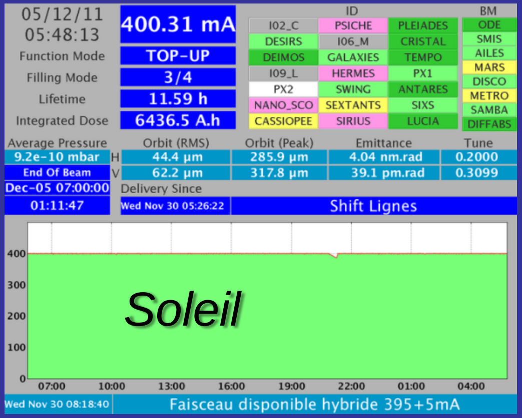
Vertical emittance stability



Coupling correction is evolving with time:
In 2011, the ESRF has put a lot of effort to reduce and maintain the vertical emittance:

- New global correction method
- A few additionnal skew quadrupole to correct undulator motion
- An automatic cooection loop in case of drift

TopUp ?



05/12/11
05:48:13

Function Mode: TOP-UP
Filling Mode: 3/4
Lifetime: 11.59 h
Integrated Dose: 6436.5 A.h

400.31 mA

ID			BM
I02_C	PSICHE	PLEIADES	ODE
DESIRS	I06_M	CRISTAL	SMIS
DEIMOS	GALAXIES	TEMPO	AILES
I09_L	HERMES	PX1	MARS
PX2	SWING	ANTARES	DISCO
NANO_SCO	SEXTANTS	SIXS	METRO
CASSIOPEE	SIRIUS	LUCIA	SAMBA
			DIFFABS

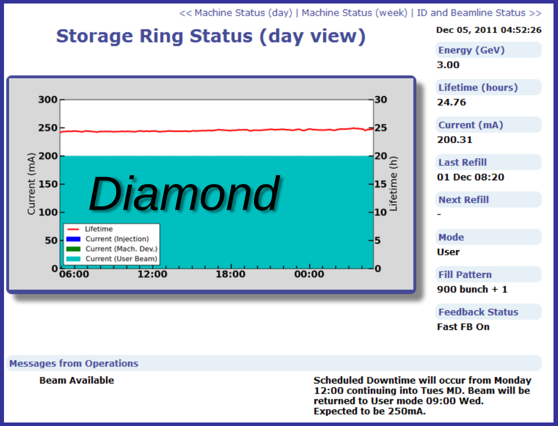
Average Pressure		Orbit (RMS)	Orbit (Peak)	Emittance	Tune
9.2e-10 mbar	H	44.4 µm	285.9 µm	4.04 nm.rad	0.2000
End Of Beam	V	62.2 µm	317.8 µm	39.1 pm.rad	0.3099

Dec-05 07:00:00
01:11:47

Delivery Since
Wed Nov 30 05:26:22

Shift Lignes

Wed Nov 30 08:18:40 Faisceau disponible hybride 395+5mA



<< Machine Status (day) | Machine Status (week) | ID and Beamline Status >>

Storage Ring Status (day view)

Dec 05, 2011 04:52:26

Energy (GeV)
3.00

Lifetime (hours)
24.76

Current (mA)
200.31

Last Refill
01 Dec 08:20

Next Refill
-

Mode
User

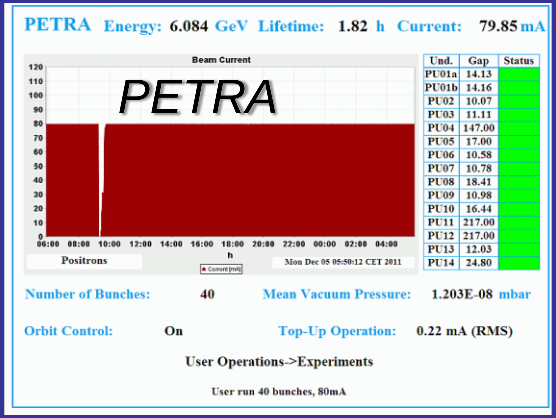
Fill Pattern
900 bunch + 1

Feedback Status
Fast FB On

Messages from Operations

Beam Available

Scheduled Downtime will occur from Monday 12:00 continuing into Tues MD. Beam will be returned to User mode 09:00 Wed. Expected to be 250mA.



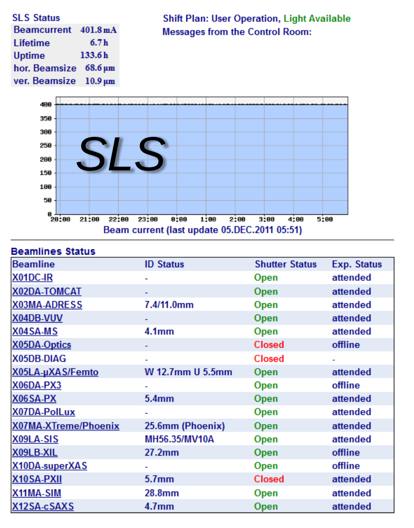
PETRA Energy: 6.084 GeV Lifetime: 1.82 h Current: 79.85 mA

Und.	Gap	Status
PU01a	14.13	🟩
PU01b	14.16	🟩
PU02	10.07	🟩
PU03	11.11	🟩
PU04	147.00	🟩
PU05	17.00	🟩
PU06	10.58	🟩
PU07	10.78	🟩
PU08	18.41	🟩
PU09	10.98	🟩
PU10	16.44	🟩
PU11	217.00	🟩
PU12	217.00	🟩
PU13	12.03	🟩
PU14	24.80	🟩

Number of Bunches: 40
Mean Vacuum Pressure: 1.203E-08 mbar
Orbit Control: On
Top-Up Operation: 0.22 mA (RMS)

User Operations->Experiments

User run 40 bunches, 80mA



SLS Status

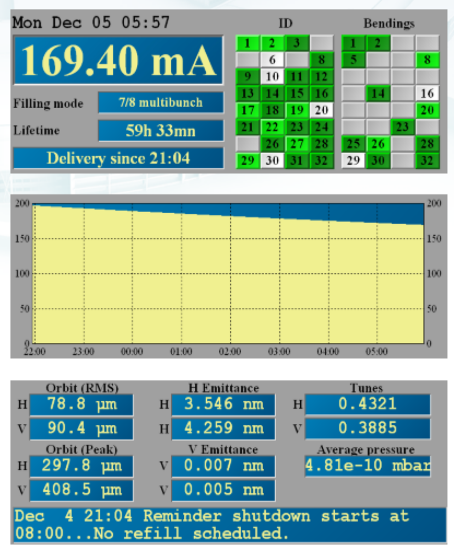
Beamcurrent	401.8 mA
Lifetime	6.7 h
Uptime	133.6 h
hor. Beamsize	68.6 µm
ver. Beamsize	10.9 µm

Shift Plan: User Operation, Light Available
Messages from the Control Room:

Beam current (last update 05.DEC.2011 05:51)

Beamlines Status

Beamline	ID Status	Shutter Status	Exp. Status
X01DC-IR	-	Open	attended
X02DA-TOMCAT	-	Open	attended
X03MA-ADRESS	7.4/11.0mm	Open	attended
X04DB-VUV	-	Open	attended
X04SA-MS	4.1mm	Open	attended
X05DA-Optics	-	Closed	offline
X05DB-DIAG	-	Closed	-
X05LA-µXAS/Femto	W 12.7mm U 5.5mm	Open	attended
X06DA-PX3	-	Open	offline
X06SA-PX	5.4mm	Open	attended
X07DA-PolLux	-	Open	attended
X07MA-XTreme/Phoenix	25.6mm (Phoenix)	Open	attended
X09LA-SIS	MH56.35/MV10A	Open	attended
X09LB-XIL	27.2mm	Open	offline
X10DA-superXAS	-	Open	offline
X10SA-PXII	5.7mm	Closed	attended
X11MA-SIM	28.8mm	Open	attended
X12SA-cSAXS	4.7mm	Open	attended



Mon Dec 05 05:57

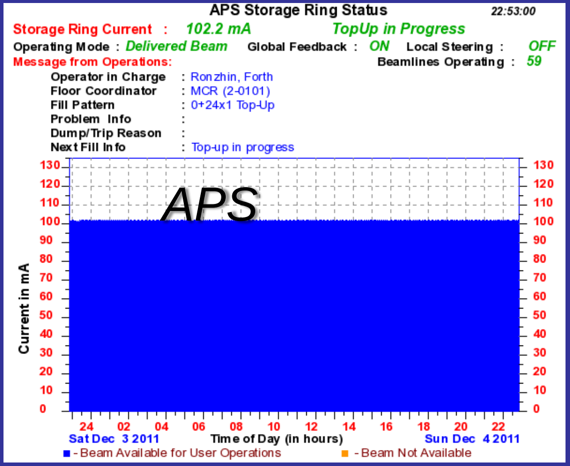
169.40 mA

Filling mode: 7/8 multibunch
Lifetime: 59h 33mn
Delivery since 21:04

ID				Bendings			
1	2	3		1	2		
	6		8	5			8
9	10	11	12				
13	14	15	16		14		16
17	18	19	20				20
21	22	23	24			23	
	26	27	28	25	26		28
29	30	31	32	29	30		32

	Orbit (RMS)		H Emittance		Tunes
H	78.8 µm	H	3.546 nm	H	0.4321
V	90.4 µm	H	4.259 nm	V	0.3885
	Orbit (Peak)		**V Emittance**		**Average pressure**
H	297.8 µm	V	0.007 nm		4.81e-10 mbar
V	408.5 µm	V	0.005 nm		

Dec 4 21:04 Reminder shutdown starts at 08:00...No refill scheduled.

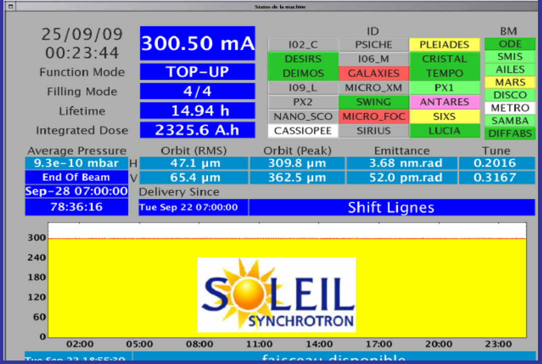


APS Storage Ring Status 22:53:00

Storage Ring Current : 102.2 mA TopUp in Progress
Operating Mode : Delivered Beam Global Feedback : ON Local Steering : OFF
Message from Operations: Beamlines Operating : 59

Operator in Charge : Ronzhin, Forth
Floor Coordinator : MCR (2-0101)
Fill Pattern : 0+24x1 Top-Up
Problem Info :
Dump/Trip Reason :
Next Fill Info : Top-up in progress

TopUp ?



Status de la machine

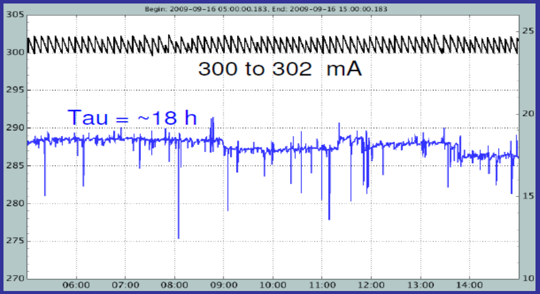
25/09/09
00:23:44

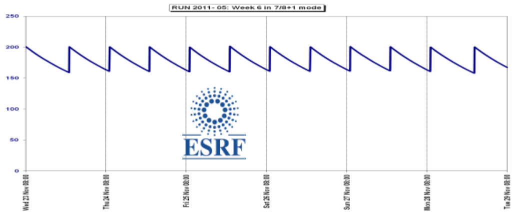
Function Mode: TOP-UP
Filling Mode: 4/4
Lifetime: 14.94 h
Integrated Dose: 2325.6 A.h

300.50 mA

	Average Pressure		Orbit (RMS)	Orbit (Peak)	Emittance	Tune
	9.3e-10 mbar	H	47.1 µm	309.8 µm	3.68 nm.rad	0.2016
	End Of Beam	V	65.4 µm	362.5 µm	52.0 pm.rad	0.3167

Sep-28 07:00:00
78:36:16
Delivery Since: Tue Sep 22 07:00:00
Shift Lignes





Maintain beam current (Δi/I<1%) by frequent reinjection
➔ 1 single injection every 5 to 8 mn
(2mA/injection on ¼ of the ring)

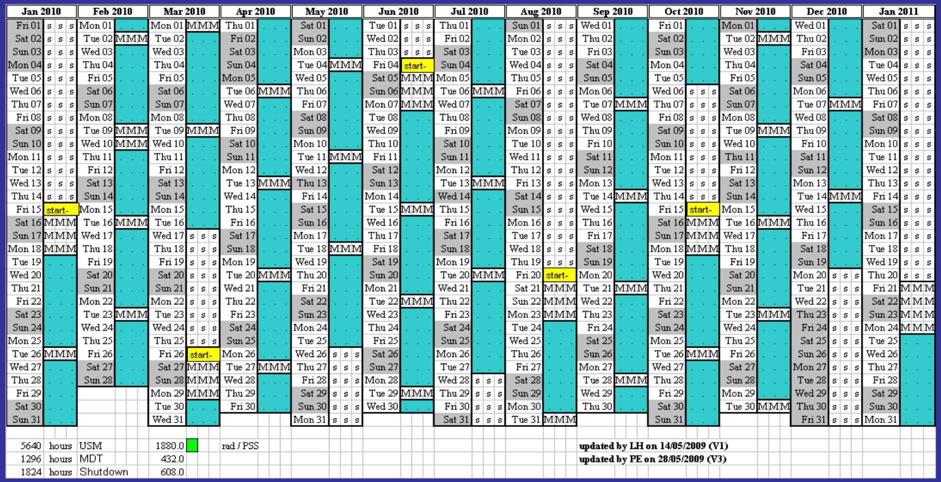
<u>Pro</u>:
Constant courant = constant heat load on the optics
➔ better position stability on the sample

<u>Con</u>:
Position stability deteriorated during
- ➔ for a few milliseconds (injection+damping time)
- ➔ due to injection elements (kickers and septums)
- ➔ sligth increase of the source size 20% in Hor.et 200% in Vert

Provision of a gating signal
- ➔ to blind data acquisition during injection (not often used)

Required in case of small lifetime (SOLEIL = 18h),
low energy ring and/or small emittances
Not mandatory for ESRF:
Lifetime larger than 45 h ➔ Top-up every 12 hours ➔ ΔI = 20%

Day to Day Operation Scheduling



Jan 2010		Feb 2010		Mar 2010		Apr 2010		May 2010		Jun 2010		Jul 2010	
Fri 01	s s s	Mon 01	. . .	Mon 01	MMM	Thu 01	. . .	Sat 01	. . .	Tue 01	s s s	Thu 01	. . .
Sat 02	s s s	Tue 02	MMM	Tue 02	. . .	Fri 02	. . .	Sun 02	. . .	Wed 02	s s s	Fri 02	. . .
Sun 03	s s s	Wed 03	. . .	Wed 03	. . .	Sat 03	. . .	Mon 03	. . .	Thu 03	s s s	Sat 03	. . .
Mon 04	s s s	Thu 04	. . .	Thu 04	. . .	Sun 04	. . .	Tue 04	MMM	Fri 04	start-	Sun 04	. . .
Tue 05	s s s	Fri 05	. . .	Fri 05	. . .	Mon 05	. . .	Wed 05	. . .	Sat 05	MMM	Mon 05	. . .
Wed 06	s s s	Sat 06	. . .	Sat 06	. . .	Tue 06	MMM	Thu 06	. . .	Sun 06	MMM	Tue 06	MMM
Thu 07	s s s	Sun 07	. . .	Sun 07	. . .	Wed 07	. . .	Fri 07	. . .	Mon 07	MMM	Wed 07	. . .
Fri 08	s s s	Mon 08	. . .	Mon 08	. . .	Thu 08	. . .	Sat 08	. . .	Tue 08	. . .	Thu 08	. . .
Sat 09	s s s	Tue 09	MMM	Tue 09	MMM	Fri 09	. . .	Sun 09	. . .	Wed 09	. . .	Fri 09	. . .
Sun 10	s s s	Wed 10	MMM	Wed 10	. . .	Sat 10	. . .	Mon 10	. . .	Thu 10	. . .	Sat 10	. . .
Mon 11	s s s	Thu 11	. . .	Thu 11	. . .	Sun 11	. . .	Tue 11	MMM	Fri 11	. . .	Sun 11	. . .
Tue 12	s s s	Fri 12	. . .	Fri 12	. . .	Mon 12	. . .	Wed 12	. . .	Sat 12	. . .	Mon 12	. . .
Wed 13	s s s	Sat 13	. . .	Sat 13	. . .	Tue 13	MMM	Thu 13	. . .	Sun 13	. . .	Tue 13	MMM
Thu 14	s s s	Sun 14	. . .	Sun 14	. . .	Wed 14	. . .	Fri 14	. . .	Mon 14	. . .	Wed 14	. . .
Fri 15	start-	Mon 15	. . .	Mon 15	. . .	Thu 15	. . .	Sat 15	. . .	Tue 15	MMM	Thu 15	. . .
Sat 16	MMM	Tue 16	MMM	Tue 16	. . .	Fri 16	. . .	Sun 16	. . .	Wed 16	. . .	Fri 16	. . .
Sun 17	MMM	Wed 17	. . .	Wed 17	s s s	Sat 17	. . .	Mon 17	. . .	Thu 17	. . .	Sat 17	. . .
Mon 18	MMM	Thu 18	. . .	Thu 18	s s s	Sun 18	. . .	Tue 18	MMM	Fri 18	. . .	Sun 18	. . .
Tue 19	. . .	Fri 19	. . .	Fri 19	s s s	Mon 19	. . .	Wed 19	. . .	Sat 19	. . .	Mon 19	. . .
Wed 20	. . .	Sat 20	. . .	Sat 20	s s s	Tue 20	MMM	Thu 20	. . .	Sun 20	. . .	Tue 20	MMM
Thu 21	. . .	Sun 21	. . .	Sun 21	s s s	Wed 21	. . .	Fri 21	. . .	Mon 21	. . .	Wed 21	. . .
Fri 22	. . .	Mon 22	. . .	Mon 22	s s s	Thu 22	. . .	Sat 22	. . .	Tue 22	MMM	Thu 22	. . .
Sat 23	. . .	Tue 23	MMM	Tue 23	s s s	Fri 23	. . .	Sun 23	. . .	Wed 23	. . .	Fri 23	. . .
Sun 24	. . .	Wed 24	. . .	Wed 24	s s s	Sat 24	. . .	Mon 24	. . .	Thu 24	. . .	Sat 24	. . .
Mon 25	. . .	Thu 25	. . .	Thu 25	s s s	Sun 25	. . .	Tue 25	. . .	Fri 25	. . .	Sun 25	. . .
Tue 26	MMM	Fri 26	. . .	Fri 26	start-	Mon 26	. . .	Wed 26	s s s	Sat 26	. . .	Mon 26	. . .
Wed 27	. . .	Sat 27	. . .	Sat 27	MMM	Tue 27	MMM	Thu 27	s s s	Sun 27	. . .	Tue 27	. . .
Thu 28	. . .	Sun 28	. . .	Sun 28	MMM	Wed 28	. . .	Fri 28	s s s	Mon 28	. . .	Wed 28	s s s
Fri 29	. . .			Mon 29	MMM	Thu 29	. . .	Sat 29	s s s	Tue 29	MMM	Thu 29	s s s
Sat 30	. . .			Tue 30	. . .	Fri 30	. . .	Sun 30	s s s	Wed 30	. . .	Fri 30	s s s
Sun 31	. . .			Wed 31	. . .			Mon 31	s s s			Sat 31	s s s

Aug 2010		Sep 2010		Oct 2010		Nov 2010		Dec 2010		Jan 2011	
Sun 01	s s s	Wed 01	. . .	Fri 01	. . .	Mon 01	. . .	Wed 01	. . .	Sat 01	s s s
Mon 02	s s s	Thu 02	. . .	Sat 02	. . .	Tue 02	MMM	Thu 02	. . .	Sun 02	s s s
Tue 03	s s s	Fri 03	. . .	Sun 03	. . .	Wed 03	. . .	Fri 03	. . .	Mon 03	s s s
Wed 04	s s s	Sat 04	. . .	Mon 04	. . .	Thu 04	. . .	Sat 04	. . .	Tue 04	s s s
Thu 05	s s s	Sun 05	. . .	Tue 05	. . .	Fri 05	. . .	Sun 05	. . .	Wed 05	s s s
Fri 06	s s s	Mon 06	. . .	Wed 06	s s s	Sat 06	. . .	Mon 06	. . .	Thu 06	s s s
Sat 07	s s s	Tue 07	MMM	Thu 07	s s s	Sun 07	. . .	Tue 07	MMM	Fri 07	s s s
Sun 08	s s s	Wed 08	. . .	Fri 08	s s s	Mon 08	. . .	Wed 08	. . .	Sat 08	s s s
Mon 09	s s s	Thu 09	. . .	Sat 09	s s s	Tue 09	MMM	Thu 09	. . .	Sun 09	s s s
Tue 10	s s s	Fri 10	. . .	Sun 10	s s s	Wed 10	. . .	Fri 10	. . .	Mon 10	s s s
Wed 11	s s s	Sat 11	. . .	Mon 11	s s s	Thu 11	. . .	Sat 11	. . .	Tue 11	s s s
Thu 12	s s s	Sun 12	. . .	Tue 12	s s s	Fri 12	. . .	Sun 12	. . .	Wed 12	s s s
Fri 13	s s s	Mon 13	. . .	Wed 13	s s s	Sat 13	. . .	Mon 13	. . .	Thu 13	s s s
Sat 14	s s s	Tue 14	MMM	Thu 14	s s s	Sun 14	. . .	Tue 14	MMM	Fri 14	s s s
Sun 15	s s s	Wed 15	. . .	Fri 15	start-	Mon 15	. . .	Wed 15	. . .	Sat 15	s s s
Mon 16	s s s	Thu 16	. . .	Sat 16	MMM	Tue 16	MMM	Thu 16	. . .	Sun 16	s s s
Tue 17	s s s	Fri 17	. . .	Sun 17	MMM	Wed 17	. . .	Fri 17	. . .	Mon 17	s s s
Wed 18	s s s	Sat 18	. . .	Mon 18	MMM	Thu 18	. . .	Sat 18	. . .	Tue 18	s s s
Thu 19	s s s	Sun 19	. . .	Tue 19	. . .	Fri 19	. . .	Sun 19	. . .	Wed 19	s s s
Fri 20	start-	Mon 20	. . .	Wed 20	. . .	Sat 20	. . .	Mon 20	s s s	Thu 20	s s s
Sat 21	MMM	Tue 21	MMM	Thu 21	. . .	Sun 21	. . .	Tue 21	s s s	Fri 21	MMM
Sun 22	MMM	Wed 22	. . .	Fri 22	. . .	Mon 22	. . .	Wed 22	s s s	Sat 22	MMM
Mon 23	MMM	Thu 23	. . .	Sat 23	. . .	Tue 23	MMM	Thu 23	s s s	Sun 23	MMM
Tue 24	. . .	Fri 24	. . .	Sun 24	. . .	Wed 24	. . .	Fri 24	s s s	Mon 24	MMM
Wed 25	. . .	Sat 25	. . .	Mon 25	. . .	Thu 25	. . .	Sat 25	s s s	Tue 25	. . .
Thu 26	. . .	Sun 26	. . .	Tue 26	MMM	Fri 26	. . .	Sun 26	s s s	Wed 26	. . .
Fri 27	. . .	Mon 27	. . .	Wed 27	. . .	Sat 27	. . .	Mon 27	s s s	Thu 27	. . .
Sat 28	. . .	Tue 28	MMM	Thu 28	. . .	Sun 28	. . .	Tue 28	s s s	Fri 28	. . .
Sun 29	. . .	Wed 29	. . .	Fri 29	. . .	Mon 29	. . .	Wed 29	s s s	Sat 29	. . .
Mon 30	. . .	Thu 30	. . .	Sat 30	. . .	Tue 30	MMM	Thu 30	s s s	Sun 30	. . .
Tue 31	MMM			Sun 31	. . .			Fri 31	s s s	Mon 31	. . .

5640	hours	USM	1880.0	🟩	rad / PSS
1296	hours	MDT	432.0		
1824	hours	Shutdown	608.0		

updated by LH on 14/05/2009 (V1)
updated by PE on 28/05/2009 (V3)

- User Service:
  - 5640 hours
  - 5 runs per year
  - Operating mode defined 1 year in advance
- Machine development: 1296 heures
  - 4 days at the start of a run, then 1 day per week
- Shutdown: 1824 hours
  - 2 long shutdowns in winter and summer and 3 short shutdowns

Shutdowns

Shutdowns are necessary

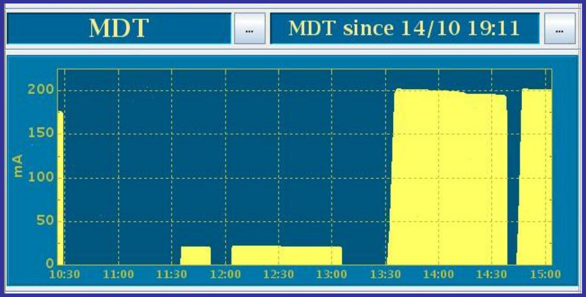
- ➢ Maintenance work
- ➢ Equipment upgrade
- ➢ New installations

A restart of 4 days is necessary for:

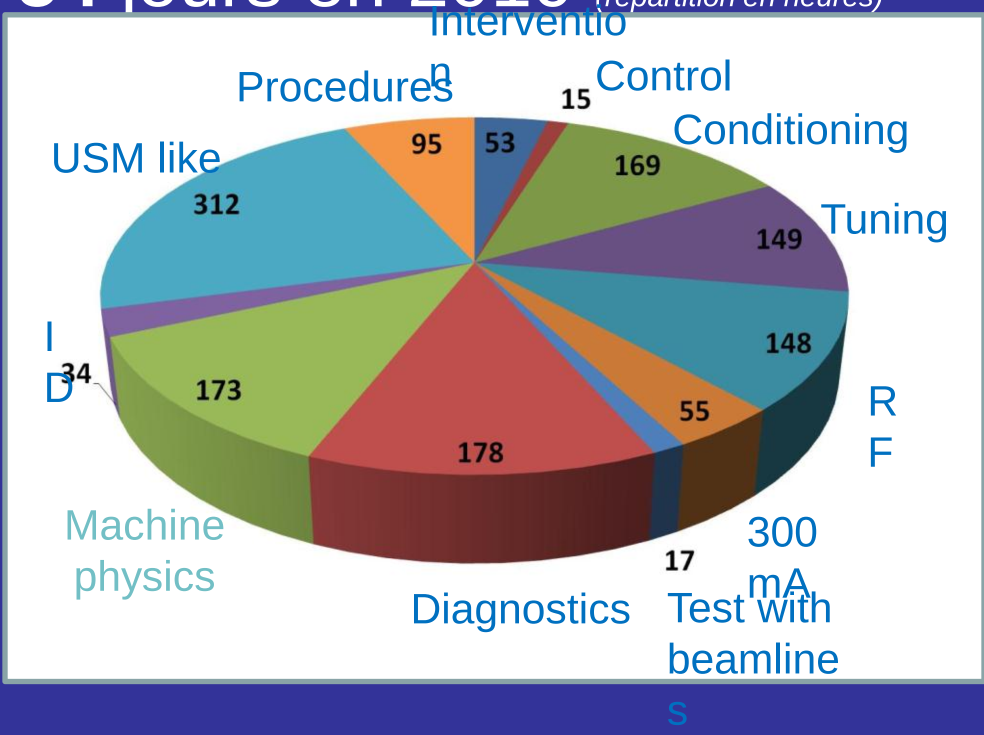
- ➢ Equipment restart
- ➢ Test ofnew equipments
- ➢ Vacuum reconditioning after interventions

Machine Dedicated Time

- Intevention to repai or for maintenance
- Preparation of next user mode
- Machine physics study
- Test of nw equipments
- Test of new operating modes



54 jours en 2010 *(repartition en heures)*



Upgrade Program

ESRF Upgrade 2008-2017

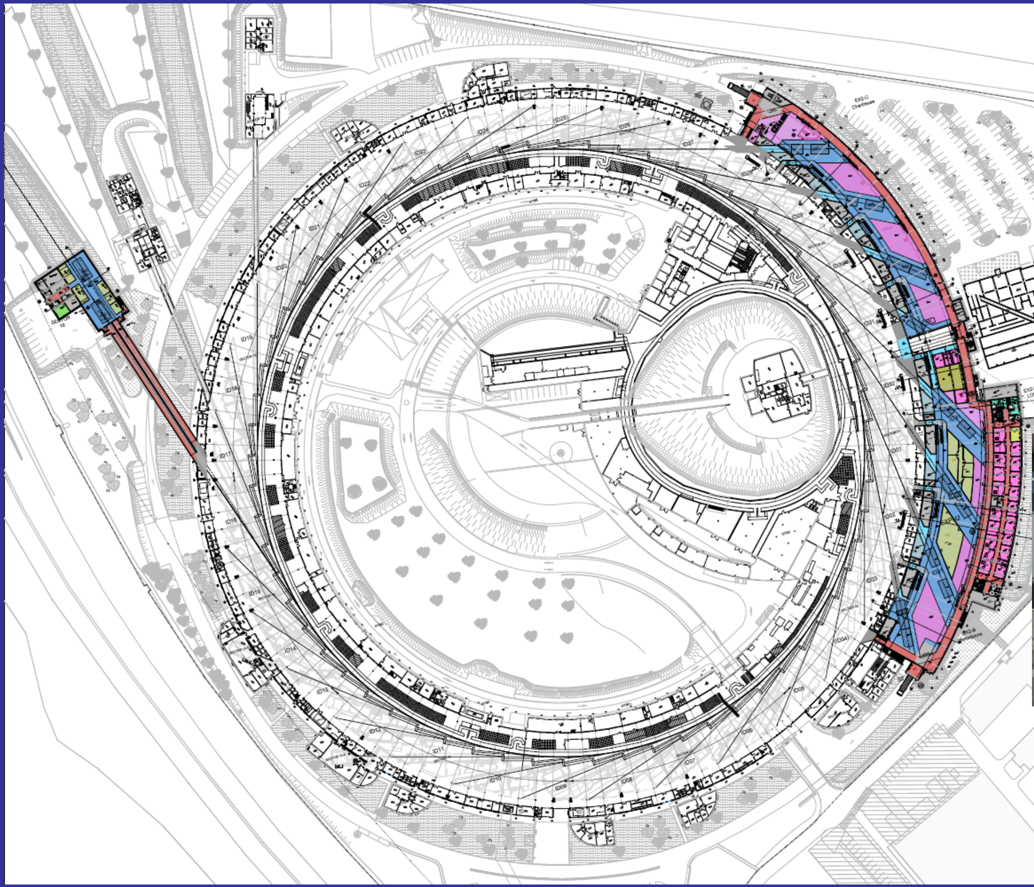
Funding for a first phase (from 2009 to 2015) secured to deliver:

- **Eight new beamlines, with an extension of the experimental hall.**
- **Refurbishment of many existing beamlines**
- **Upgrade of the X ray source for availability, stability and brilliance**
- **Developments in synchrotron radiation instrumentation**

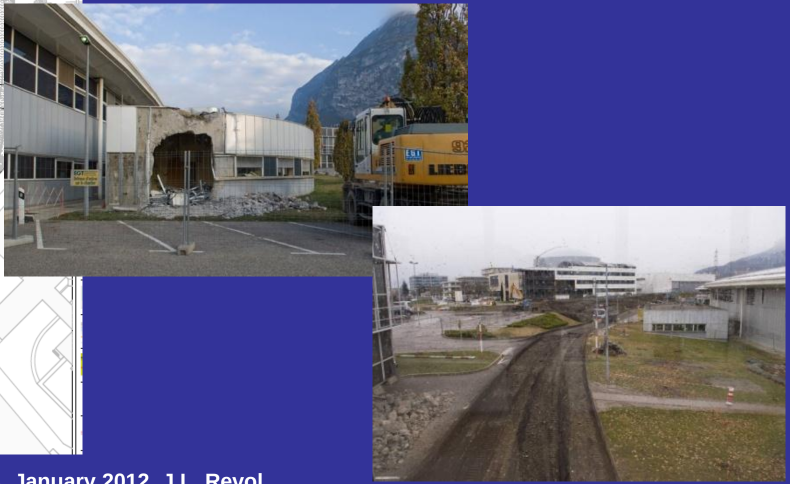
While maintaining an operational facility

Upgrade Program: New Buildings

Longer beamlines
Increased capacity

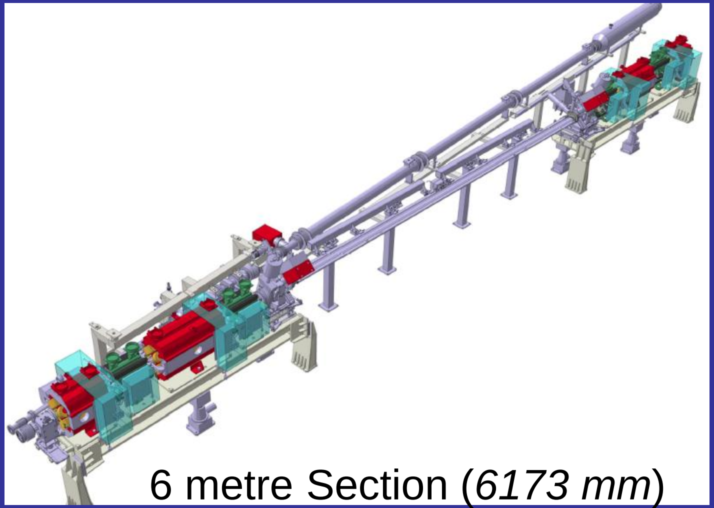


Beginning of works:
October 2011

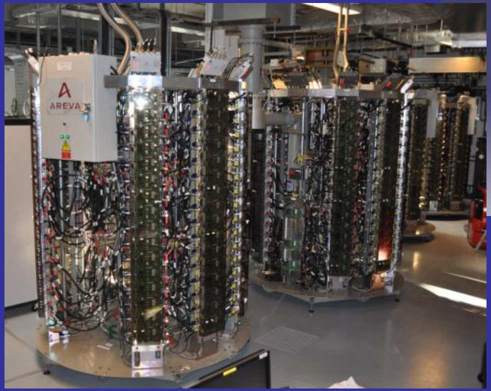


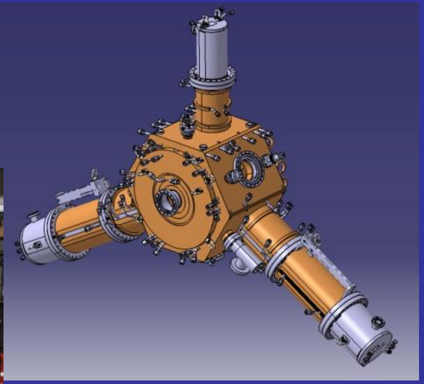
Upgrade Program: Accelerator Upgrade

- Upgrade of BPM electronics
  - Improvement of the beam position stability
  - Coupling reduction
  - New position feedback
- 6 m long straight sections
  - No change in magnet lattice
  - Canted straight sections
- 7 m straight sections
  - Lattice symmetry breaking
  - New magnets necessary
- Cryogenic in-vacuum undulators
- Diagnostics developments
- New RF Transmitters
- New RF Cavities

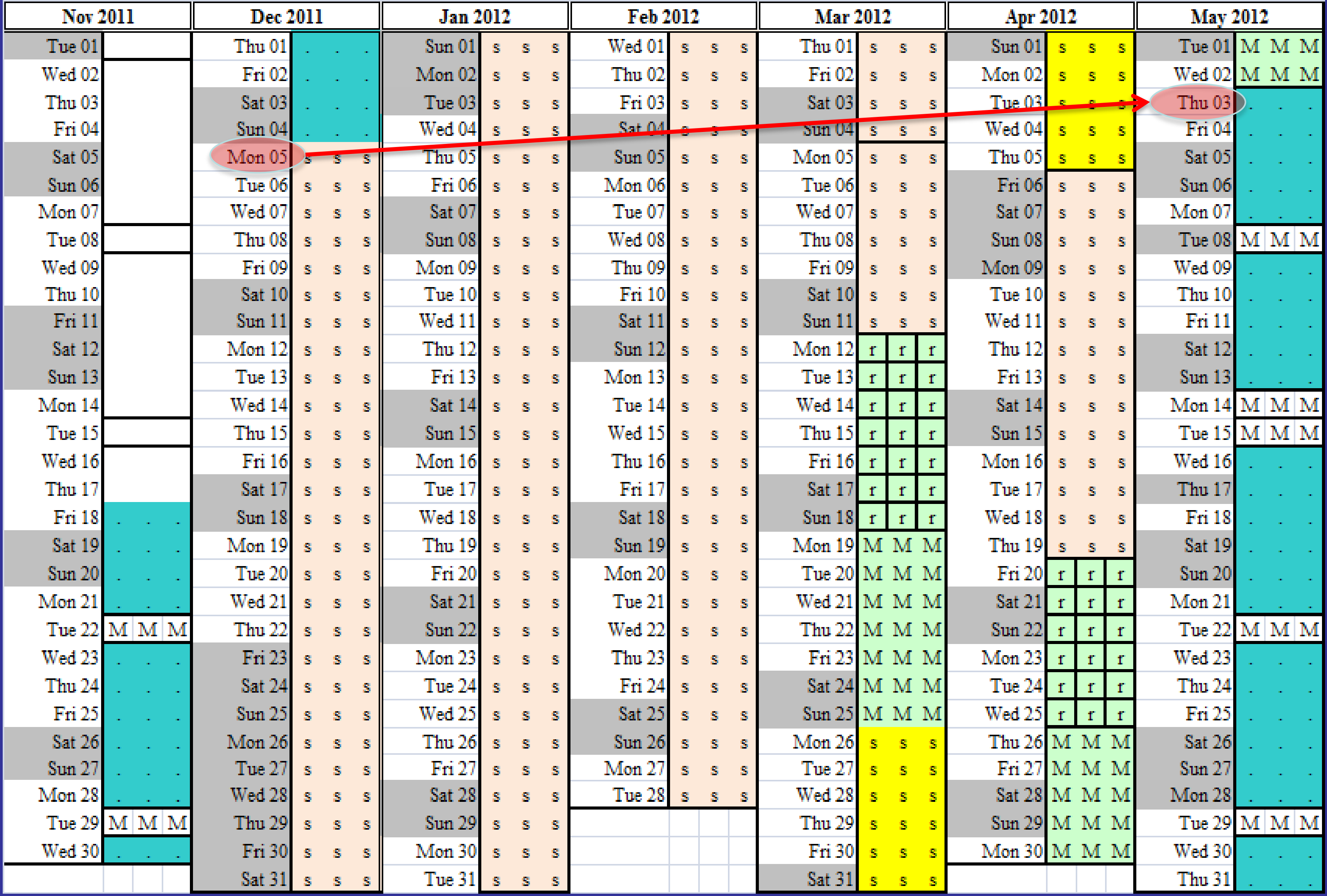


6 metre Section (*6173 mm*)





With a long winter shutdown



Nov 2011				Dec 2011				Jan 2012				Feb 2012				Mar 2012				Apr 2012				May 2012			
Tue 01				Thu 01	.	.	.	Sun 01	s	s	s	Wed 01	s	s	s	Thu 01	s	s	s	Sun 01	s	s	s	Tue 01	M	M	M
Wed 02				Fri 02	.	.	.	Mon 02	s	s	s	Thu 02	s	s	s	Fri 02	s	s	s	Mon 02	s	s	s	Wed 02	M	M	M
Thu 03				Sat 03	.	.	.	Tue 03	s	s	s	Fri 03	s	s	s	Sat 03	s	s	s	Tue 03	s	s	s	Thu 03	.	.	.
Fri 04				Sun 04	.	.	.	Wed 04	s	s	s	Sat 04	s	s	s	Sun 04	s	s	s	Wed 04	s	s	s	Fri 04	.	.	.
Sat 05				Mon 05	s	s	s	Thu 05	s	s	s	Sun 05	s	s	s	Mon 05	s	s	s	Thu 05	s	s	s	Sat 05	.	.	.
Sun 06				Tue 06	s	s	s	Fri 06	s	s	s	Mon 06	s	s	s	Tue 06	s	s	s	Fri 06	s	s	s	Sun 06	.	.	.
Mon 07				Wed 07	s	s	s	Sat 07	s	s	s	Tue 07	s	s	s	Wed 07	s	s	s	Sat 07	s	s	s	Mon 07	.	.	.
Tue 08				Thu 08	s	s	s	Sun 08	s	s	s	Wed 08	s	s	s	Thu 08	s	s	s	Sun 08	s	s	s	Tue 08	M	M	M
Wed 09				Fri 09	s	s	s	Mon 09	s	s	s	Thu 09	s	s	s	Fri 09	s	s	s	Mon 09	s	s	s	Wed 09	.	.	.
Thu 10				Sat 10	s	s	s	Tue 10	s	s	s	Fri 10	s	s	s	Sat 10	s	s	s	Tue 10	s	s	s	Thu 10	.	.	.
Fri 11				Sun 11	s	s	s	Wed 11	s	s	s	Sat 11	s	s	s	Sun 11	s	s	s	Wed 11	s	s	s	Fri 11	.	.	.
Sat 12				Mon 12	s	s	s	Thu 12	s	s	s	Sun 12	s	s	s	Mon 12	r	r	r	Thu 12	s	s	s	Sat 12	.	.	.
Sun 13				Tue 13	s	s	s	Fri 13	s	s	s	Mon 13	s	s	s	Tue 13	r	r	r	Fri 13	s	s	s	Sun 13	.	.	.
Mon 14				Wed 14	s	s	s	Sat 14	s	s	s	Tue 14	s	s	s	Wed 14	r	r	r	Sat 14	s	s	s	Mon 14	M	M	M
Tue 15				Thu 15	s	s	s	Sun 15	s	s	s	Wed 15	s	s	s	Thu 15	r	r	r	Sun 15	s	s	s	Tue 15	M	M	M
Wed 16				Fri 16	s	s	s	Mon 16	s	s	s	Thu 16	s	s	s	Fri 16	r	r	r	Mon 16	s	s	s	Wed 16	.	.	.
Thu 17				Sat 17	s	s	s	Tue 17	s	s	s	Fri 17	s	s	s	Sat 17	r	r	r	Tue 17	s	s	s	Thu 17	.	.	.
Fri 18	.	.	.	Sun 18	s	s	s	Wed 18	s	s	s	Sat 18	s	s	s	Sun 18	r	r	r	Wed 18	s	s	s	Fri 18	.	.	.
Sat 19	.	.	.	Mon 19	s	s	s	Thu 19	s	s	s	Sun 19	s	s	s	Mon 19	M	M	M	Thu 19	s	s	s	Sat 19	.	.	.
Sun 20	.	.	.	Tue 20	s	s	s	Fri 20	s	s	s	Mon 20	s	s	s	Tue 20	M	M	M	Fri 20	r	r	r	Sun 20	.	.	.
Mon 21	.	.	.	Wed 21	s	s	s	Sat 21	s	s	s	Tue 21	s	s	s	Wed 21	M	M	M	Sat 21	r	r	r	Mon 21	.	.	.
Tue 22	M	M	M	Thu 22	s	s	s	Sun 22	s	s	s	Wed 22	s	s	s	Thu 22	M	M	M	Sun 22	r	r	r	Tue 22	M	M	M
Wed 23	.	.	.	Fri 23	s	s	s	Mon 23	s	s	s	Thu 23	s	s	s	Fri 23	M	M	M	Mon 23	r	r	r	Wed 23	.	.	.
Thu 24	.	.	.	Sat 24	s	s	s	Tue 24	s	s	s	Fri 24	s	s	s	Sat 24	M	M	M	Tue 24	r	r	r	Thu 24	.	.	.
Fri 25	.	.	.	Sun 25	s	s	s	Wed 25	s	s	s	Sat 25	s	s	s	Sun 25	M	M	M	Wed 25	r	r	r	Fri 25	.	.	.
Sat 26	.	.	.	Mon 26	s	s	s	Thu 26	s	s	s	Sun 26	s	s	s	Mon 26	s	s	s	Thu 26	M	M	M	Sat 26	.	.	.
Sun 27	.	.	.	Tue 27	s	s	s	Fri 27	s	s	s	Mon 27	s	s	s	Tue 27	s	s	s	Fri 27	M	M	M	Sun 27	.	.	.
Mon 28	.	.	.	Wed 28	s	s	s	Sat 28	s	s	s	Tue 28	s	s	s	Wed 28	s	s	s	Sat 28	M	M	M	Mon 28	.	.	.
Tue 29	M	M	M	Thu 29	s	s	s	Sun 29	s	s	s					Thu 29	s	s	s	Sun 29	M	M	M	Tue 29	M	M	M
Wed 30	.	.	.	Fri 30	s	s	s	Mon 30	s	s	s					Fri 30	s	s	s	Mon 30	M	M	M	Wed 30	.	.	.
				Sat 31	s	s	s	Tue 31	s	s	s					Sat 31	s	s	s					Thu 31	.	.	.

European Synchrotron Radiation Facility

"polygone scientifique" de Grenoble