Alessandro Variola, Fabian Zomer (LAL, Orsay)

Alexandre Loulergue (SOLEIL)

The ThomX Project

Work supported by the EQUIPEX program – Ministère de la recherche, Ile-de-France region, CNRS-IN2P3 and Université Paris Sud XI

The ThomX Project

Compton effect

- **ThomX is a light source based on Compton Back Scattering (CBS)**

- **Why CBS?**

- CBS is by far the most efficient photon energy amplifier : $\omega_{diff}=4\gamma^2\ \omega_{laser}$, ThomX => γ~100 => it is possible to have at one's disposal hard X rays with a relatively low energy electron machine.

  Example : 50 MeV electrons and 1.23 eV laser give up to 50 keV back scattered X-rays

- But for a light source: $\sigma \sim 6.6524\ 10^{-25}\ cm^2$, it is low!!!!!

  - Thomx target is a high AVERAGE flux so we need many electrons and photons colliding in a small volume at high frep => CHOICE:

  - Storage ring + high average power laser amplified in a Fabry Perot resonator (French collaboration among different kinds of expertise)

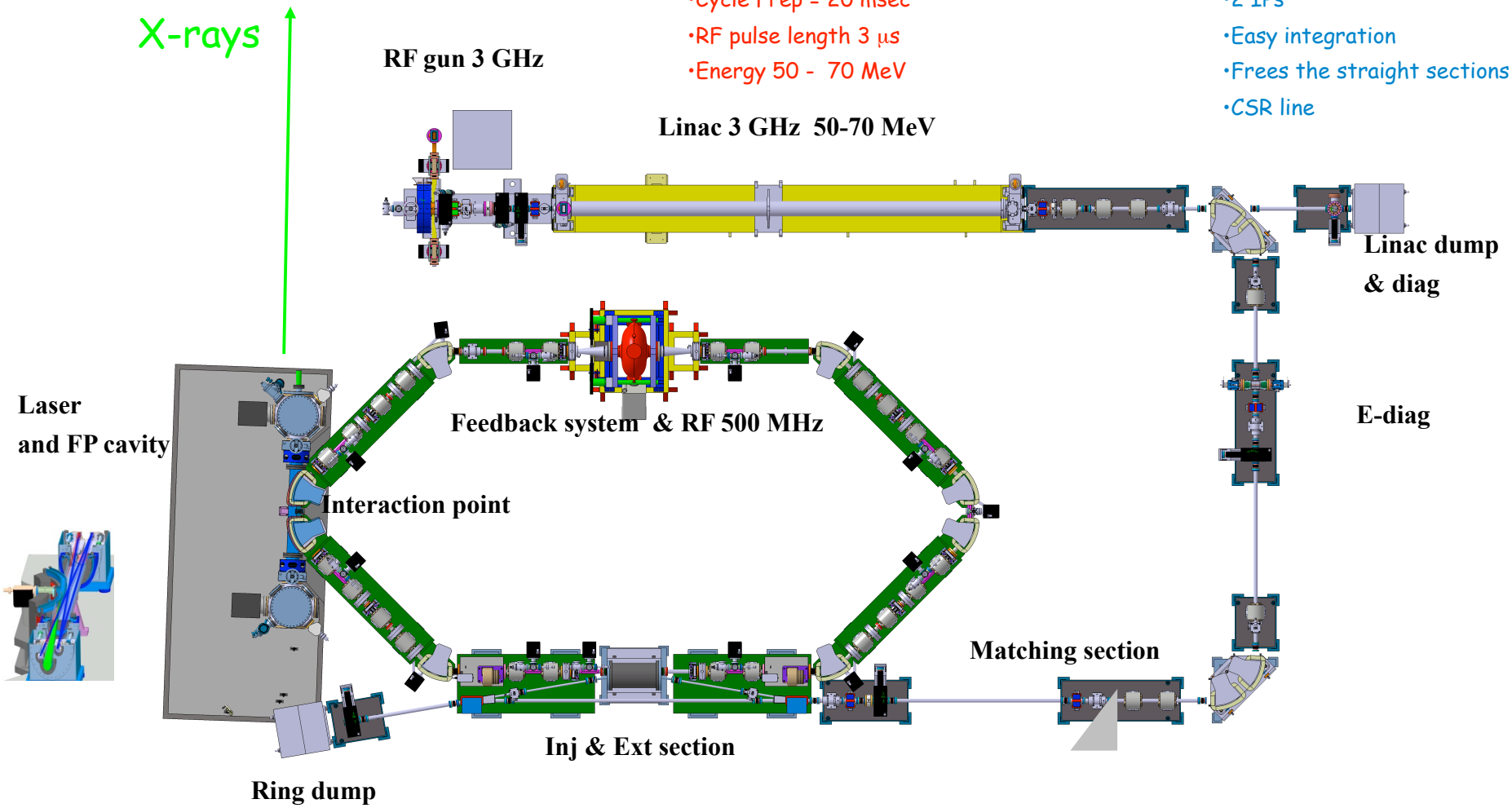
    => 10^{13} Ph/s

- **Target** : Store one electron bunch of 1 nC over 20 ms in the ring
  Store one laser pulse of 25 mJ in the FP cavity

==> Thom-X is a demonstrator

How it works

ThomX scheme and design

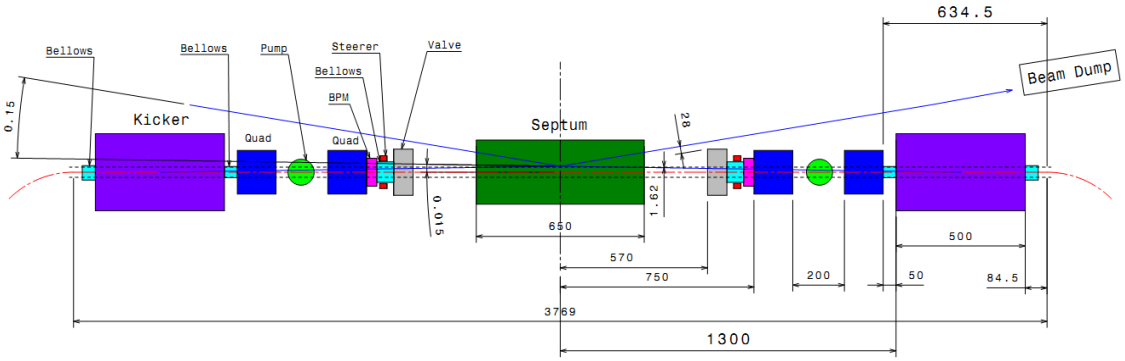


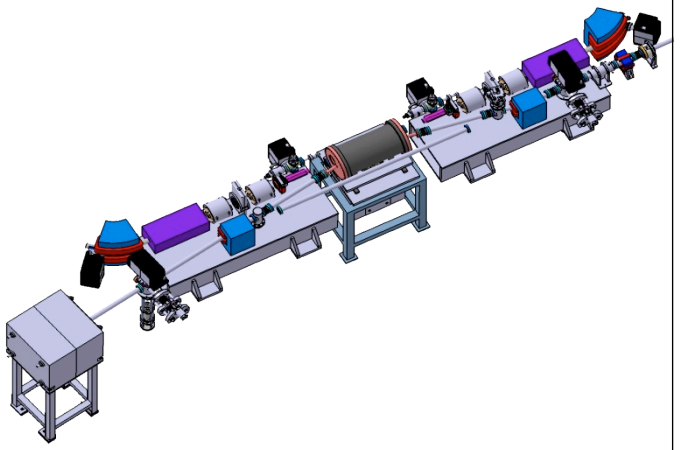
• Acknowledgments to M.Jore, M Lacroix

Injection

One septum, two kickers

Injection section

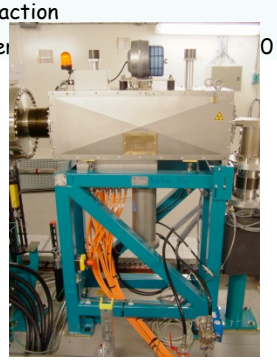


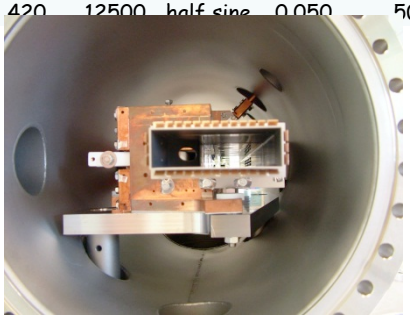


Equipment	Active length (mm)	Overall length (mm)	Transverse Beam stay clear H (mm)	Transverse Beam stay clear V(mm)	Septum thickness (mm)	Ceramic thickness (mm)
Septum magnet	250	650	30	12	3	
Injection kicker	250	450	40	28		6
extraction kicker	250	450	40	28		6

Equipment	Deviation (mrad)	Magnetic field length (mT)	Peak current (A)	Charging voltage (V)	Pulse shape	Pulse duration (μs)	Repetition rate (max) (Hz)
Septum magnet	150	100	960	150	full sine	130	50
Injection kicker	15	10	420	12500	half sine	0.050	50
extraction kicker			420	12500	half sine	0.050	50

R&D => pulsed power supplies for the kicker magnets (ring revolution 56 ns) = > a very high di/dt (~20 kA/μs), fast rise time and fast blocking of the negative current, and a very small time jitter

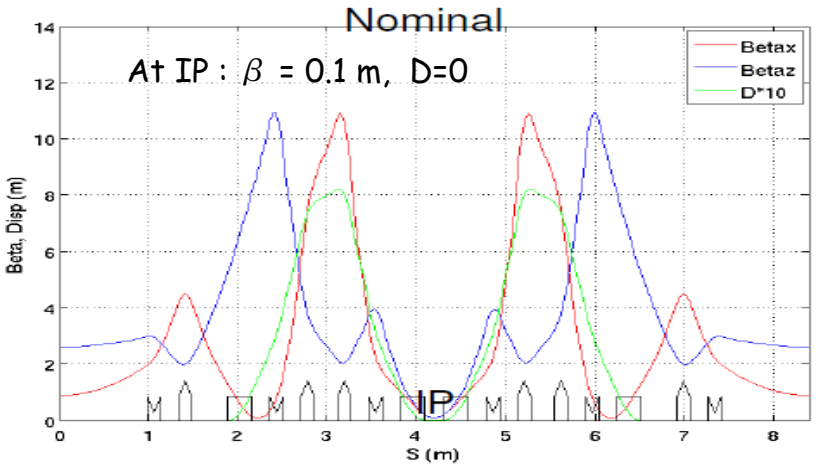


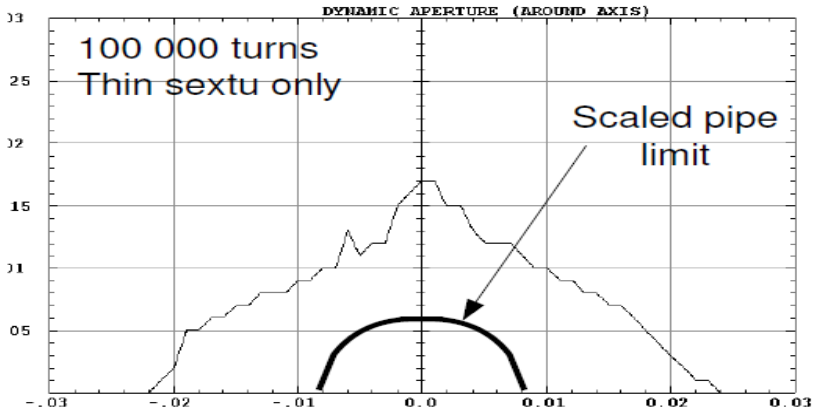


• Acknowledgments to P.Lebasque, T Vandenberghe

Ring

Linear optics and mechanics





$\beta_x = \beta_z = 1.8$

Versatile lattice

Low H function

Circ = 16.8 m / 2 IPs

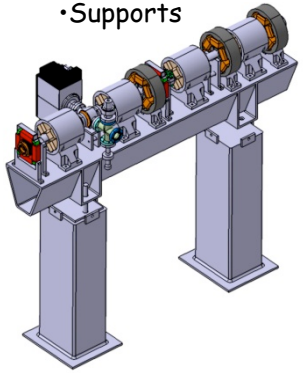
But :

Strong quadrupoles

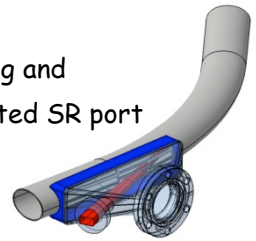
Short bend radius

Large dispersion

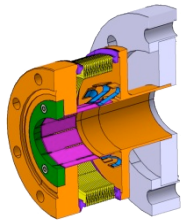
•Supports



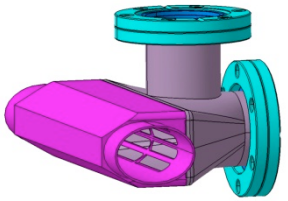
•Pumping and integrated SR port



•Bellows



•Pumping ports

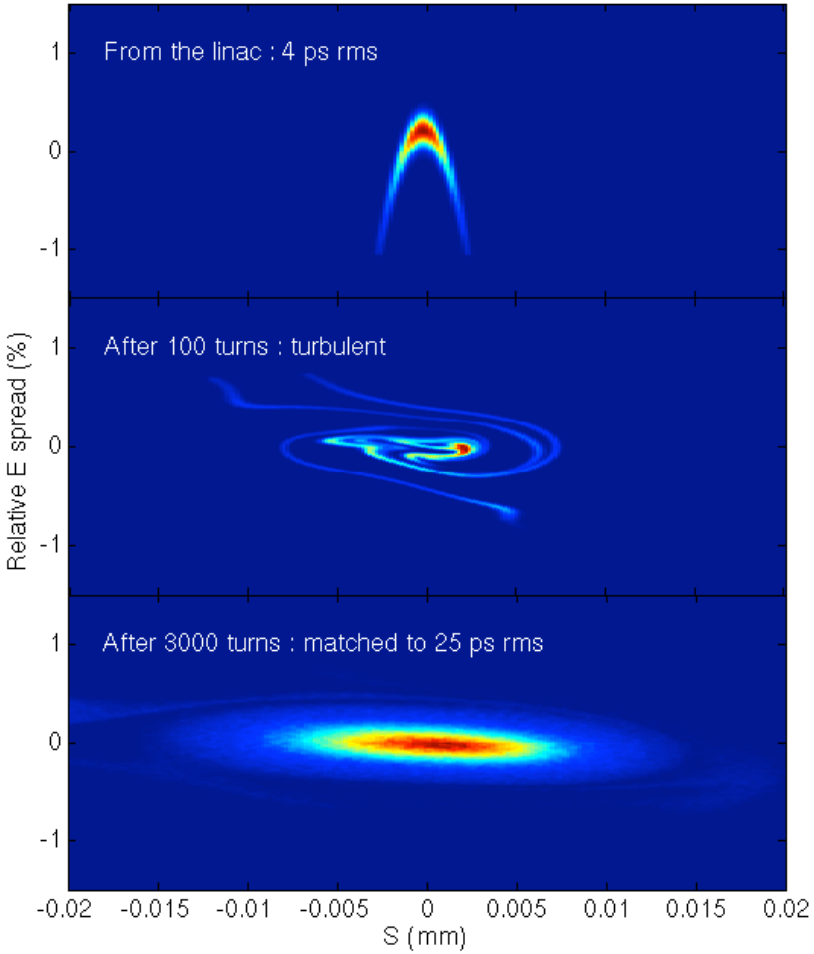


• Acknowledgments to A.Loulergue, T.Vandenberghe, C.Prevost, B Mericer, A. Gonnin, R.Marie

Ring injection dynamics

Longitudinal mismatch

1 nC – 50 MeV



Typical longitudinal shape from the linac

Strongly mismatch in the ring

Undergoes "turbulent" dynamics

Strong collective effects

Strong Needs: Position feedback in the 3 planes

Side effects : Horizontal emittance increase

Main risk : To brake the bunch / losses

Finally reach a ring matched form

Still subject to some head tail effects

Ring injection dynamics

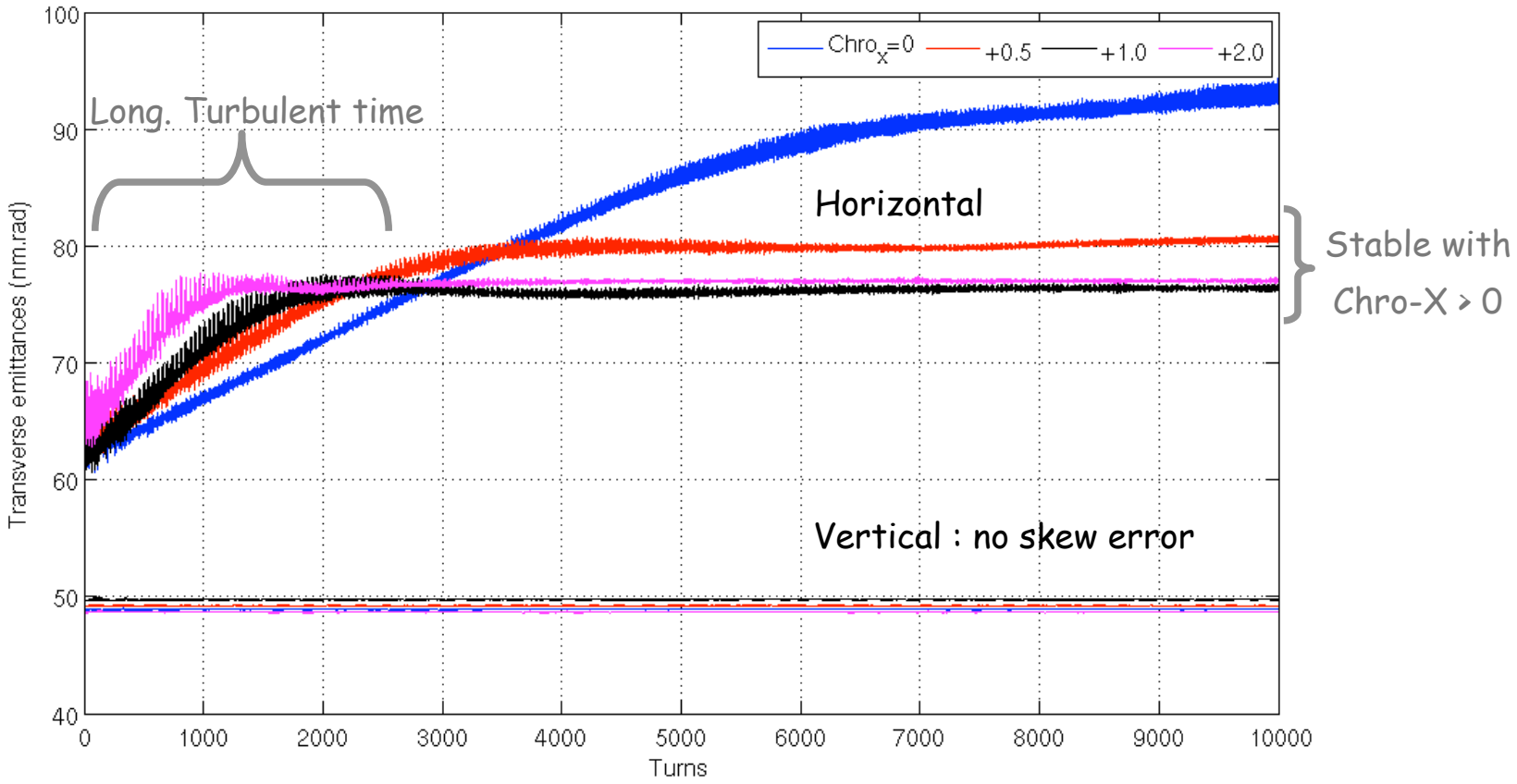
Transverse side effect from longitudinal mismatch

Transverse emittance in the first turns versus chromaticities

6D tracking : symplectic mapping + long. Collective effects at 50 MeV, 1 nC

10.000 turns =0.5 ms

Over 20 ms storage



Ring injection dynamics

Transverse side effect from longitudinal mismatch

Transverse emittance in the first turns versus chromaticities

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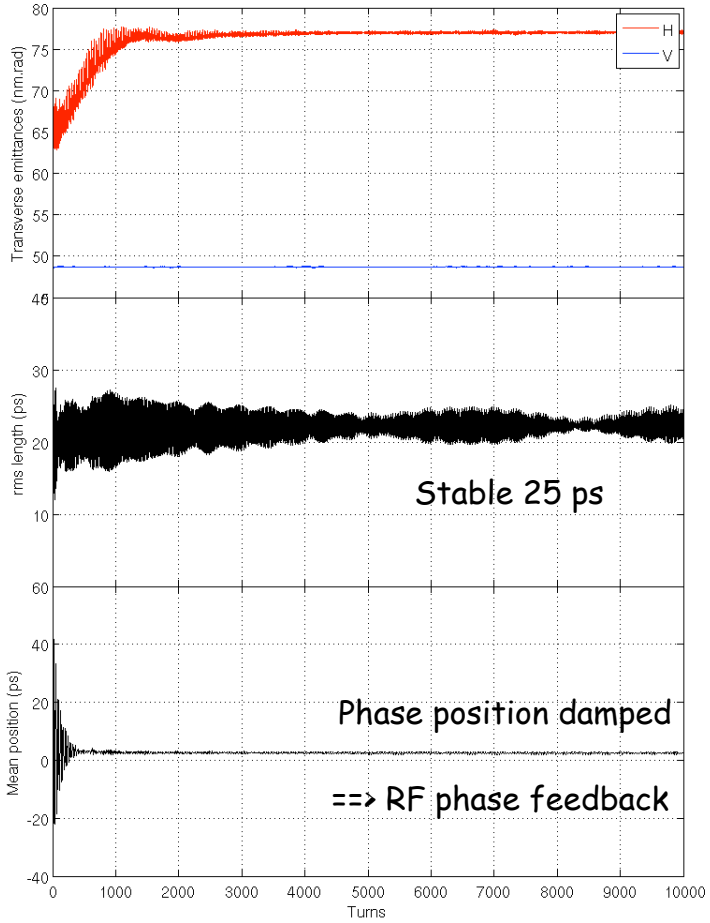
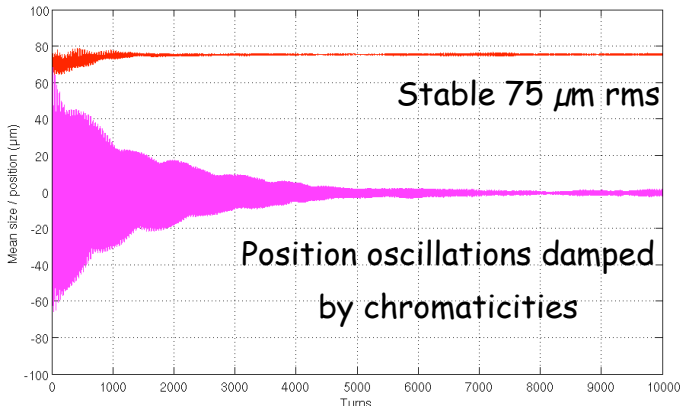
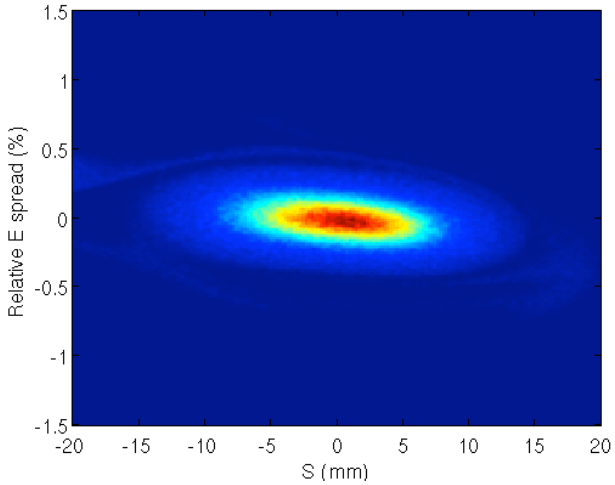


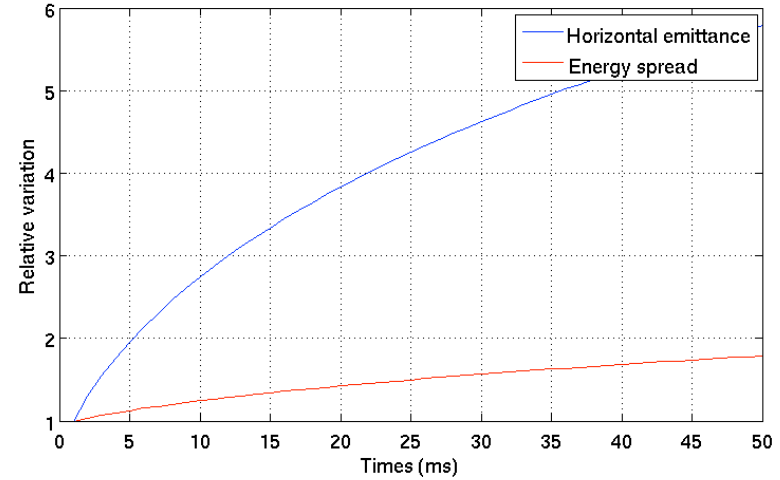




Ring dynamics

Compton recoil and Intra-Beam Scattering effects

50 MeV, 1 nC

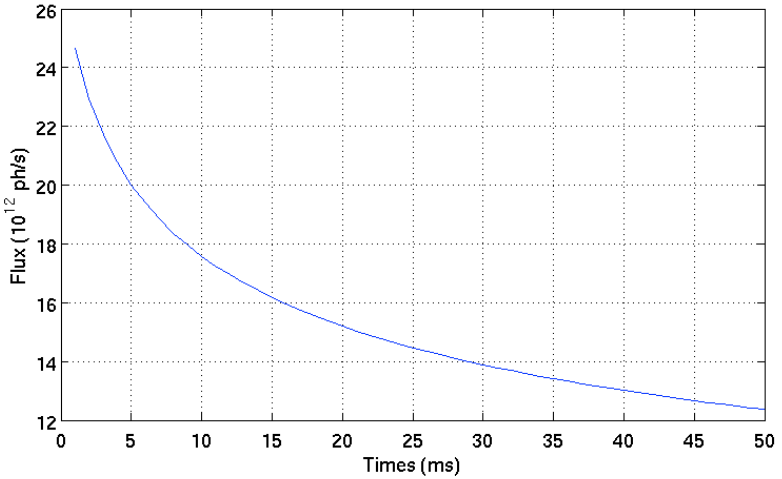


Horizontal emittance x 6 over 50 ms

==> IBS dominated

Relative E-spread x 2 over 50 ms

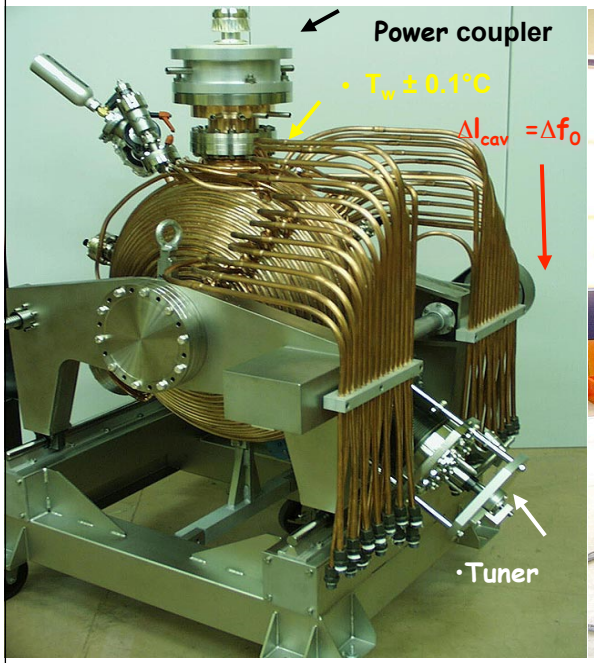
==> CBS dominated

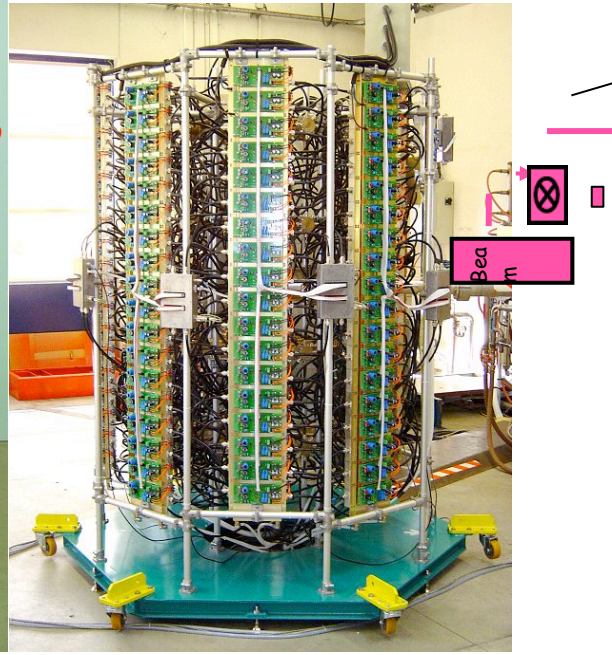


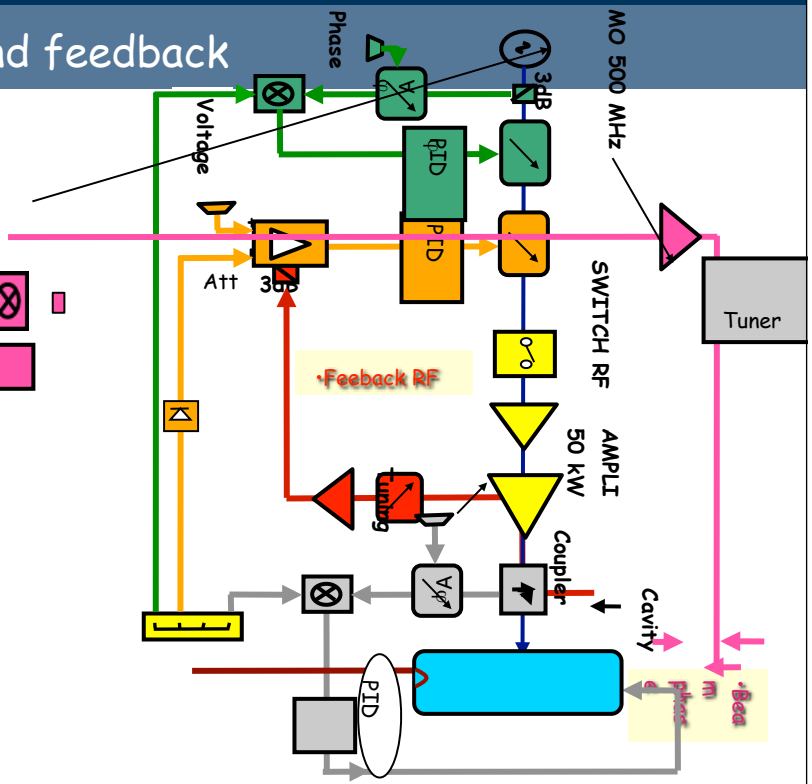
X-Rays flux reduced by ~2 over 50 ms

Ring RF

Cavity, Rf source and feedback







'Elettra' type cavity

3 different tuning knobs

Temperature (30÷60 C°, ±0.05 C°)

Mechanical length adjustment Δl

Tuner on the equator

'SOLEIL' type transistor amplifier

No HT, modularity (easy to maintain)

Tested (5 years, +25,000h of operation)

Operational efficiency 99.995%

1 Module @352 MHz 330W => Can be extended to 500 MHz

'Slow and Fast feedback

Slow Amplitude, phase , frequency loops

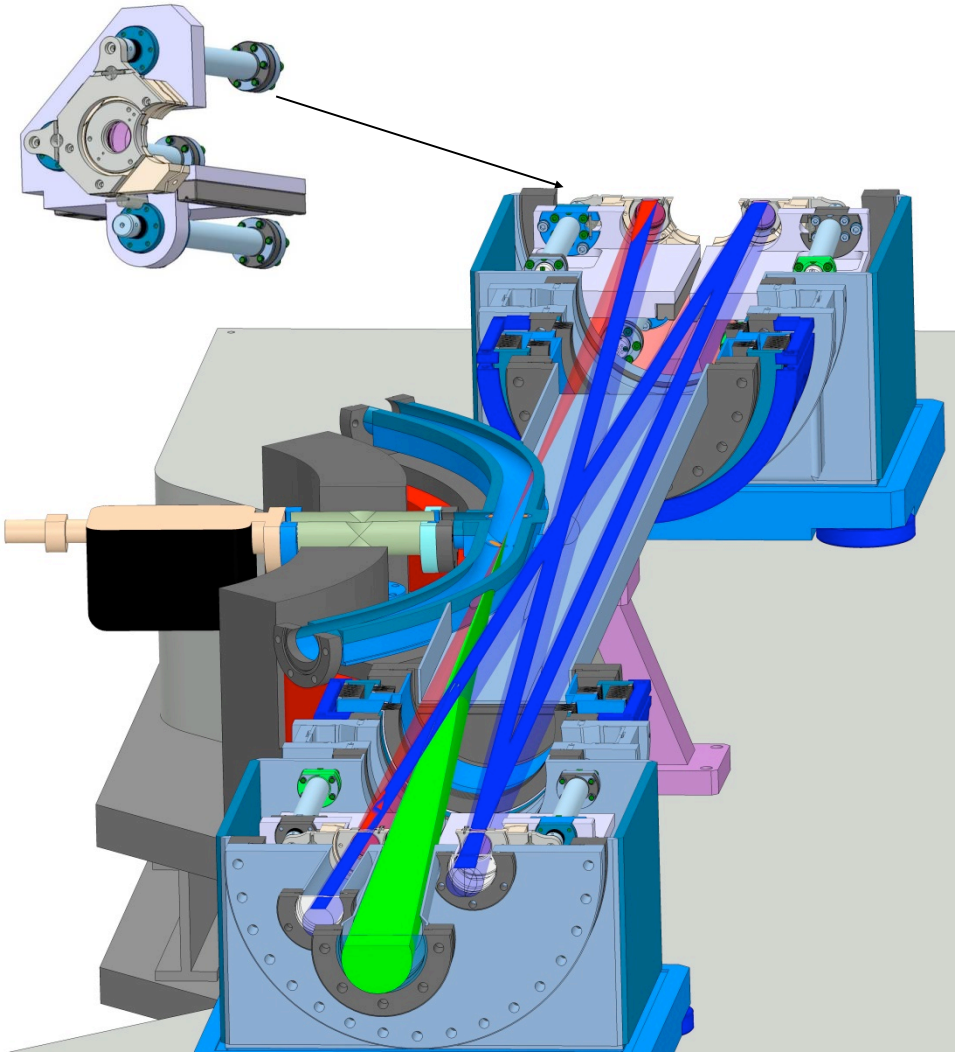
Fast RF FB

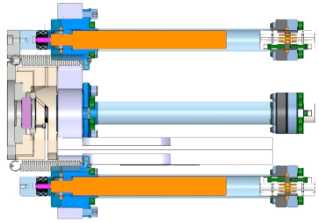
Phase loop => beam oscillations @ 500 kHz, $\Delta\Phi_{inj}$, HOM,...

Acknowledgments to P.Marchand

Fabry-Perot cavity

•Towards ThomX





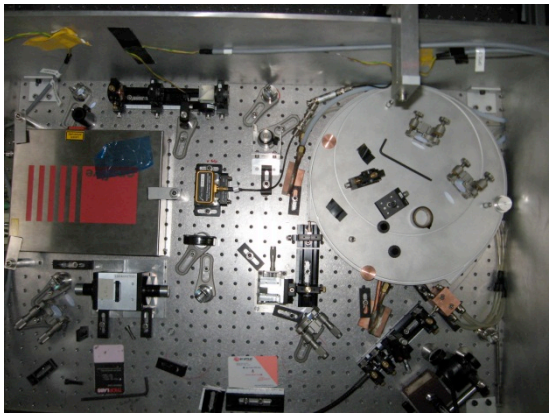
- Dipoles Integration
- Dedicated BPM
- Bakable
- Easy to access, mounting
- 2 degrees collisions
- Laser insertion

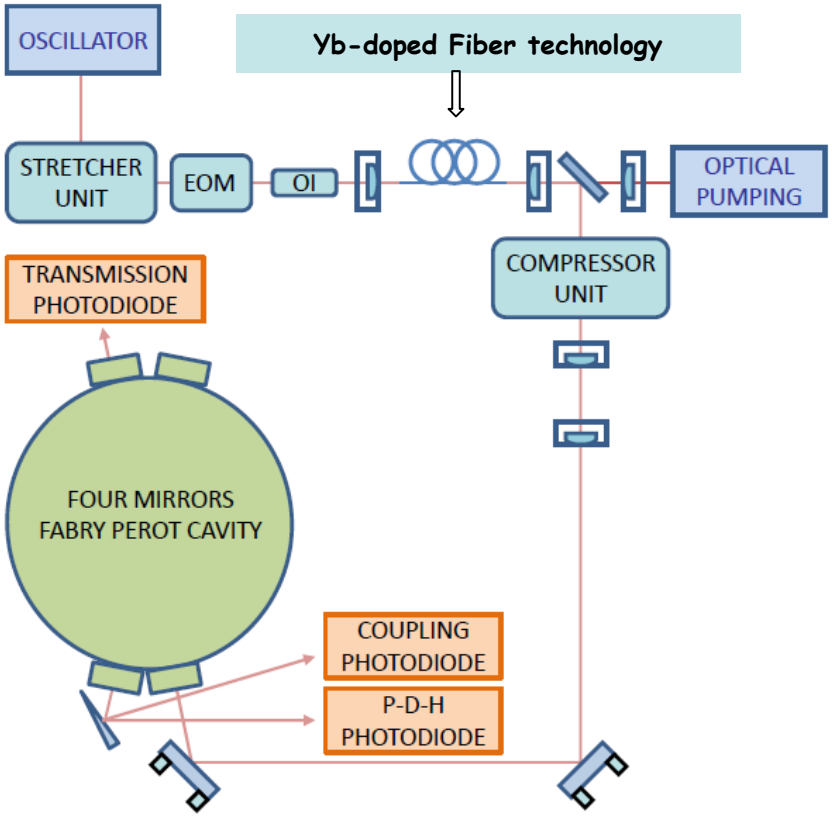
Laser and FP cavity	
Laser wavelength	1030 nm
Laser and FP cavity Frep	36 MHz
Laser Power	50 - 100 W
FP cavity finesse / gain	30000 / 10000
FP waist	70 μm

• Acknowledgments to M.Lacroix, Y.Peinnaud

Laser

•The MightyLaser experience





•CPA for Mighty Laser

- Oscillator
- 178 MHz
- Stretcher
- unit
- Fiber amplifier
- 50 W
- Compressor
- unit
- FP Cavity

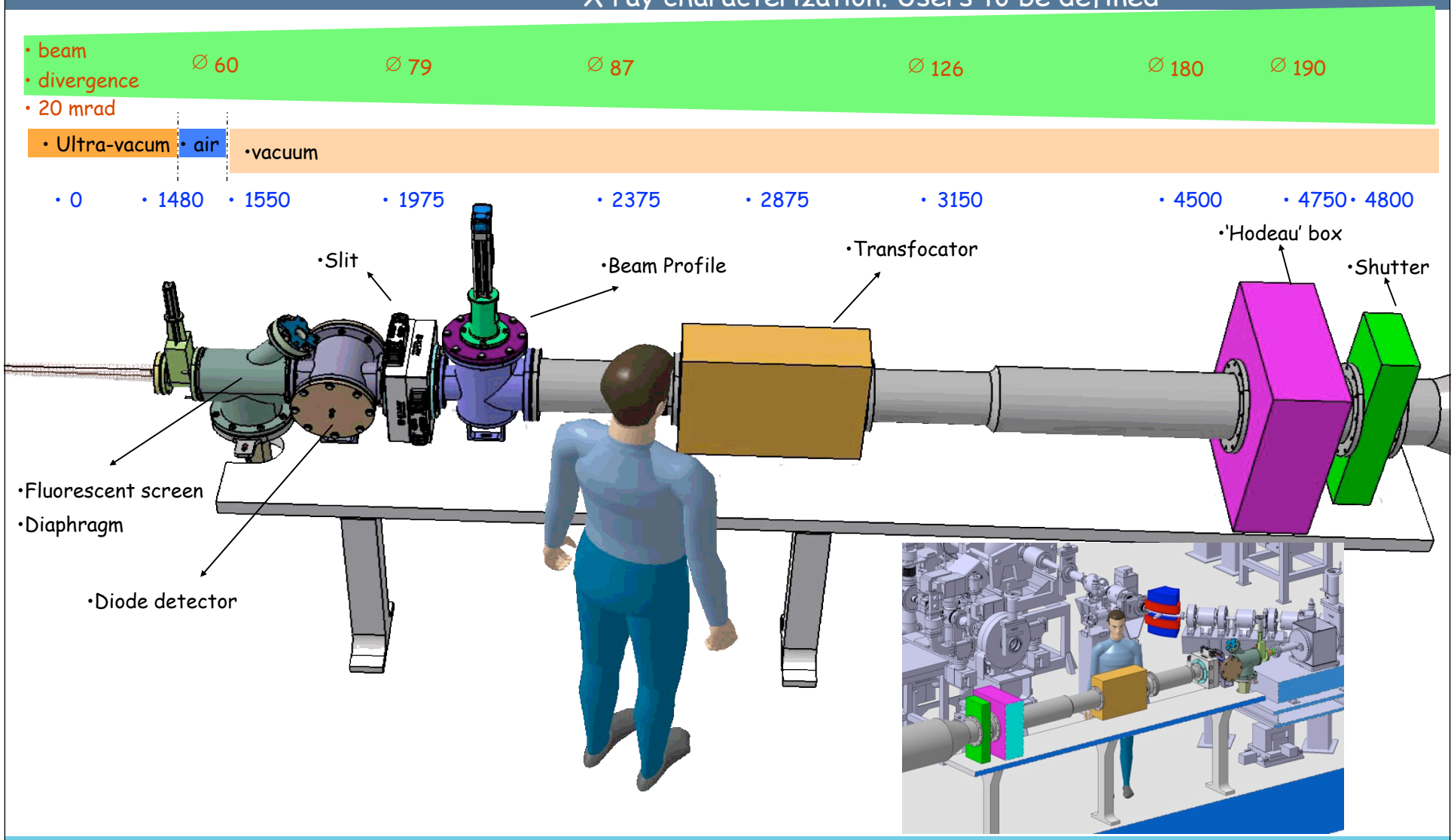
- E = 281 nJ
- T = 100 ps
- P_{peak} = 2,8 kW
- I = 42 kW/cm²
- B = 0.24 rad

Compatible with low noise amplification

Acknowledgments to E.Cormier, V.Soskov, F.Labaye

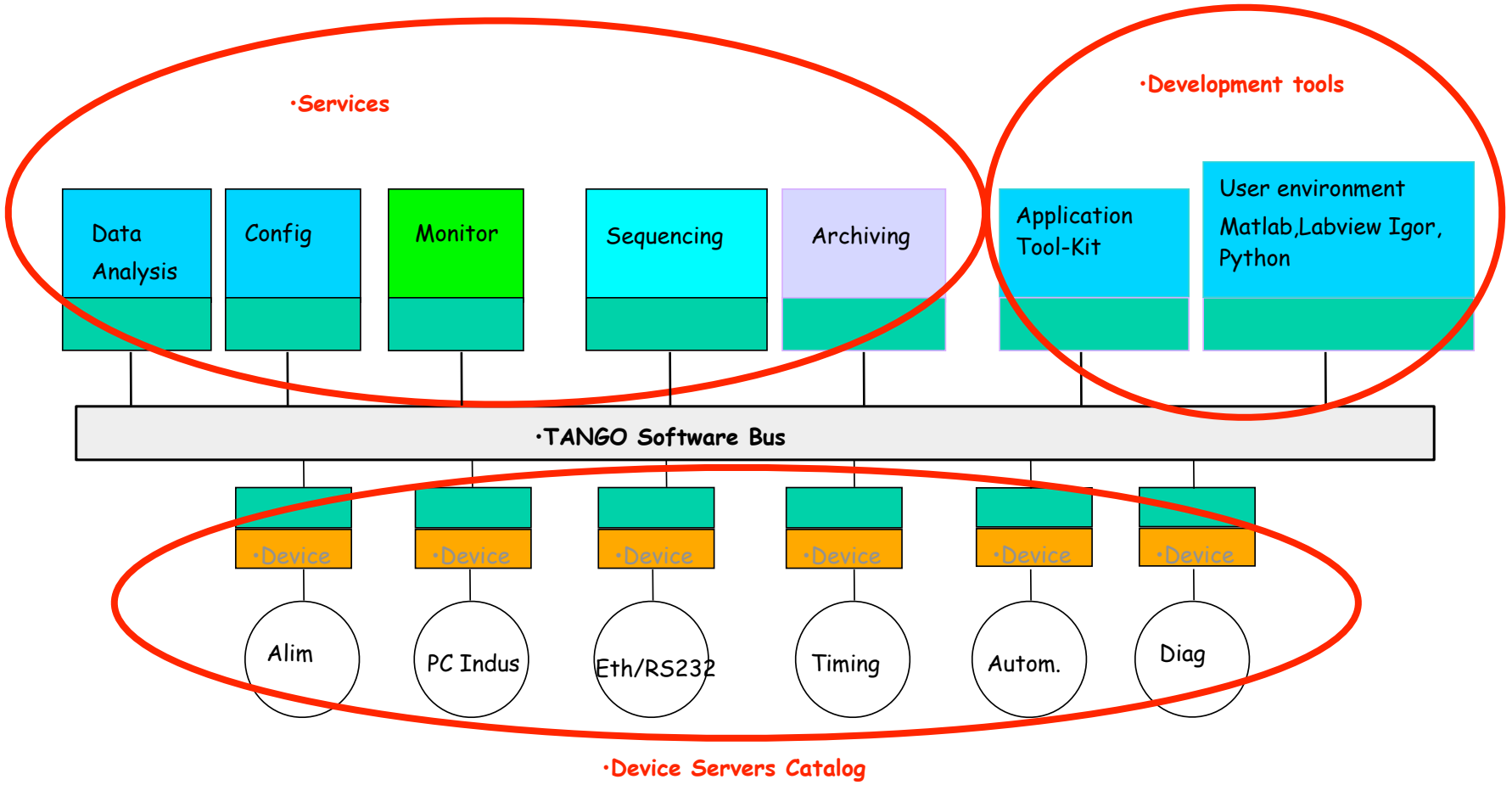
X ray line

•X ray characterization. Users to be defined



• Acknowledgments to M.Jacquet, J.L Hodeau, J.L Hazemann, P.Jeantet

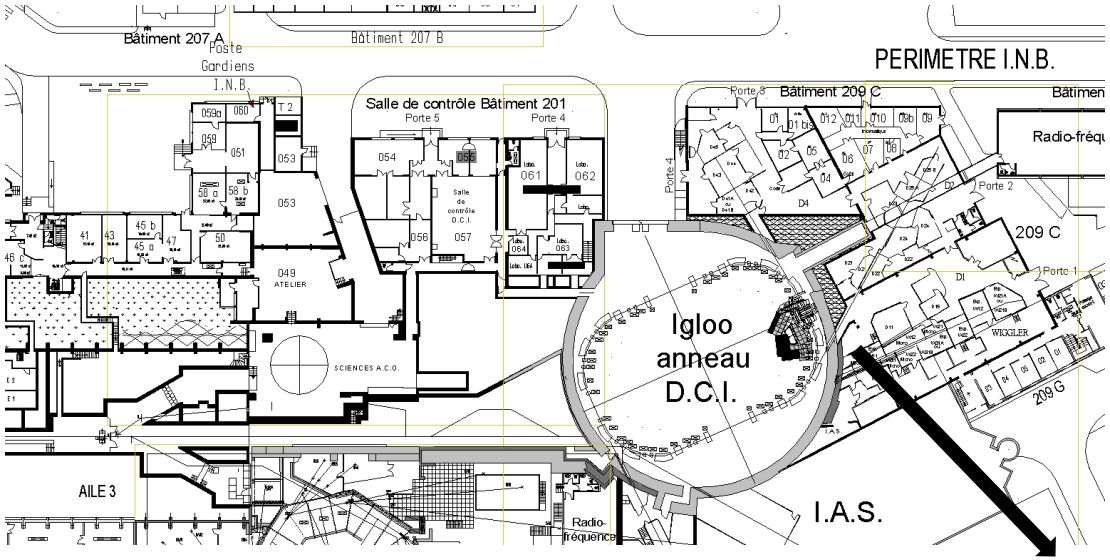
Controls



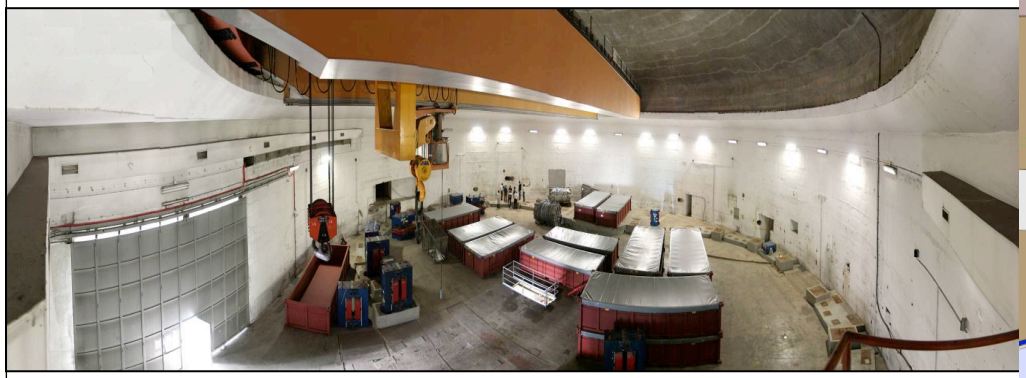
Acknowledgments to X.Renon

Integration and Site

Paris-Sud University Campus



- OLD Orsay IGLOO



- Acknowledgments to A.Pichot, M .Tran

Scientific Case

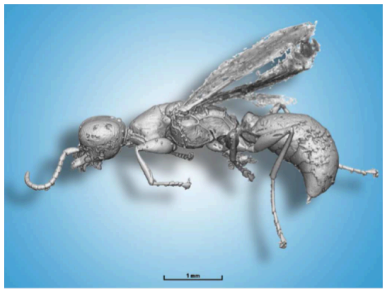
• Cultural heritage and medical science

- Transfer of the SR techniques to these new machines. Many fields can be interested…
- At present two contributors: Medical field (ESRF, INSERM Grenoble)
  Cultural Heritage (C2RMF CNRS – Louvre Museum)

• Painting analysis

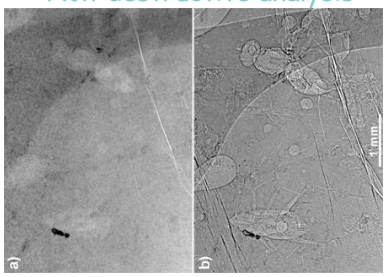
•K-edge imaging (Pb➔white, Hg➔ vermilion…) of a Van-Gogh's painting

•J. Dik et al., Analytical Chemistry, **2008**, 80, 6436



•Paleontology

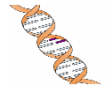
•Non-destructive analysis

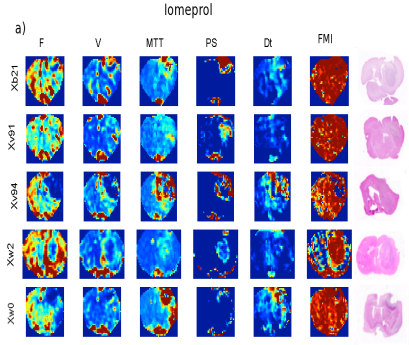


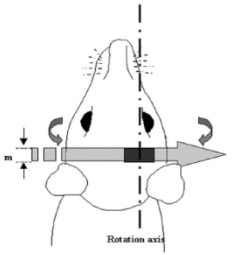
•Physiopathology and Contrast agents,

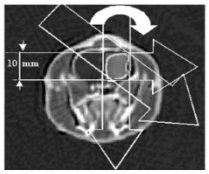
•Dynamic Contrast Enhancement SRCT

•Convection Enhanced Delivery =>Stereotactic Synchrotron RT







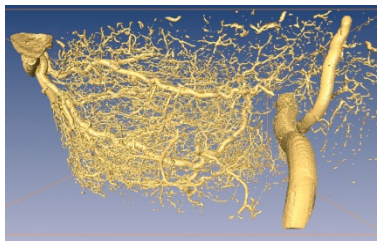


•Imaging,

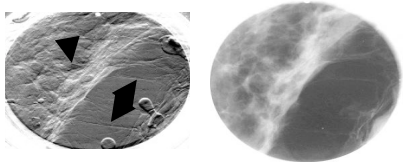
•Mammography

•Microtomography

•Biston et al, Cancer Res 2004, 64, 2317-23



•J Cereb Blood Flow and Metab, 2007. 27 (2):292-303.



•Journal of Radiology 53, 226-237 (2005)

• Thanks to G.Le Duc, P.Walter

Planning

2010 CDR

2011 Founded by EQUIPEX program

2012 TDR

2012-2013 construction phase

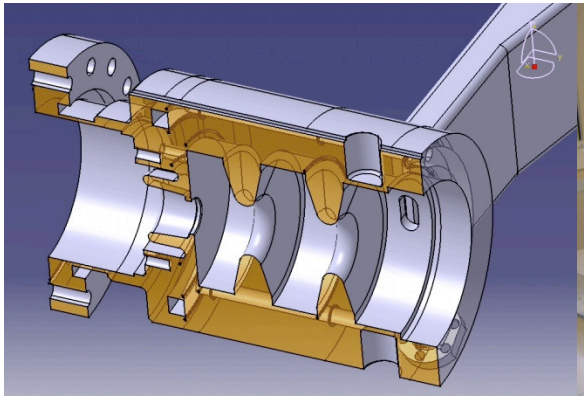
2014 Commissioning

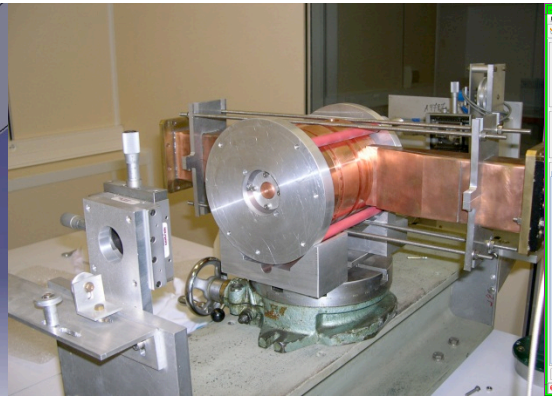
2015 Users !

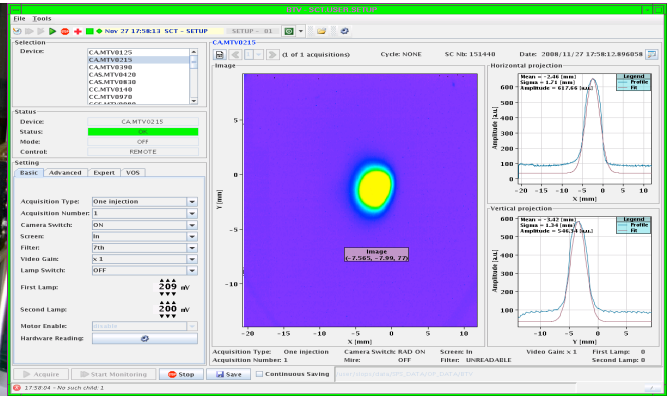
• Acknowledgments to A.Pichot, M .Tran

Injector

• Electron gun and accelerating section







- Probe Gun, LAL Design,
- Already tested in the CTF facility for high current

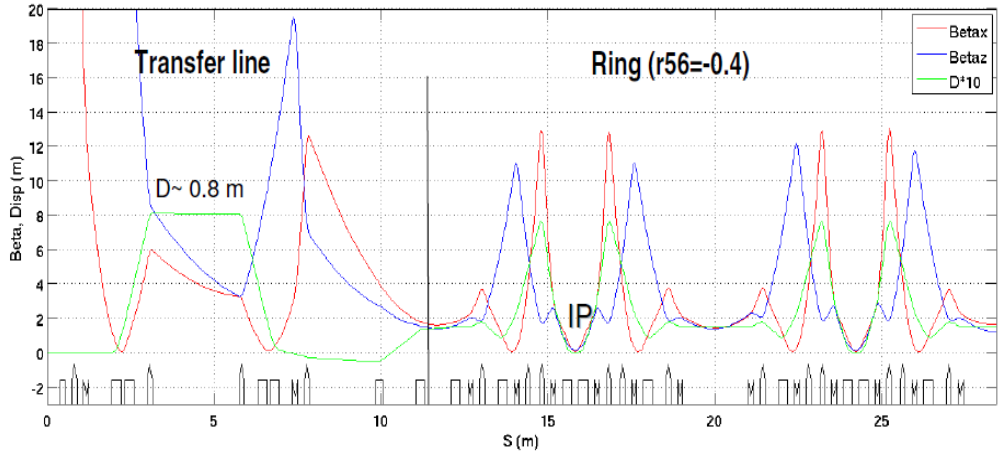
- Accelerating section => LIL type section
- 4.6 m, 135 cells, 2.998.46 MHz @ 31 C°, mode 2π/3.
- Q = 14800, 12.6 MV/m for the 50 MeV case
- Entrance => 160 cm from the cathode
- Phase stability required $\Delta\phi \leq 1°$

• Acknowledgments to R.Roux, P.Marchand, J.P.Pollina

Transfer line

Transport and diagnostics

- 4 correctors
- 4 stripline BPMs
- 3 screens
- 2 valves
- 2 ICT
- 1 scraper



Linac

Dump

- Emittance
- Beam size
- Steering

- Energy Spread
- Beam steering

Injection

- Longitudinal and transverse emittance
- Dispersion matching (2 BPM)
- Orbit steering (2 coorrectors)

- Acknowledgments to A.Loulergue

CDR

- 42 Contributors
- 7 Research partners/ 1 Company
- 136 pages / 7 chapters
- Internal review committee. Eight international experts
- Published as a note:
- **LAL RT 09/28**
- **SOLEIL/SOU-RA-2678**


LAL RT 09/28
SOLEIL/SOU-RA-2678

THOMX
Conceptual Design Report

Editors:
A.Variola
A.Loulergue
F.Zomer

Expected beams characteristics

- Injector, ring, laser, Fabry-Perot resonator and the source

Injector	
Charge	1 nC
Laser wavelength and pulse power	266 nm, 100 μJ
Gun Q and Rs	14400, 49 MW/m
Gun accelerating gradient	100 MV/m @ 9.4 MW
Normalized r.m.s emittance	8 π mm mrad
Energy spread	0.36%
Bunch length	3.7 ps

Laser and FP cavity	
Laser wavelength	1030 nm
Laser and FP cavity Frep	36 MHz
Laser Power	50 – 100 W
FP cavity finesse / gain	30000 / 10000
FP waist	70 μm

Source	
Photon energy cut off	46 keV (@50 MeV), 90 keV (@ 70 MeV)
Total Flux	10^{11}-10^{13} ph/sec
Bandwidth	1 % - 10%
Divergence	1/γ ~ 10 mrad without diaphragm @ 50 MeV

Ring	
Energy	50 MeV (70 MeV possible)
Circumference	16.8 m
Crossing-Angle (full)	2 degrees
$B_{x,y}$ @ IP	0.2 m
Emittance x,y (without IBS and Compton)	3 10^{-8} m
Bunch length (@ 20 ms)	30 ps
Beam current	17.84 mA
RF frequency	500 MHz
Transverse / longitudinal damping time	1 s /0.5 s
RF Voltage	300 kV
Revolution frequency	17.8 MHz
σ_x @ IP (injection)	78 mm
Tune x / y	3.4 / 1.74
Momentum compaction factor α_c	0.013
Final Energy spread	0.6 %