ThomX Machine Advisory Committee

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Ring Beam Dynamics

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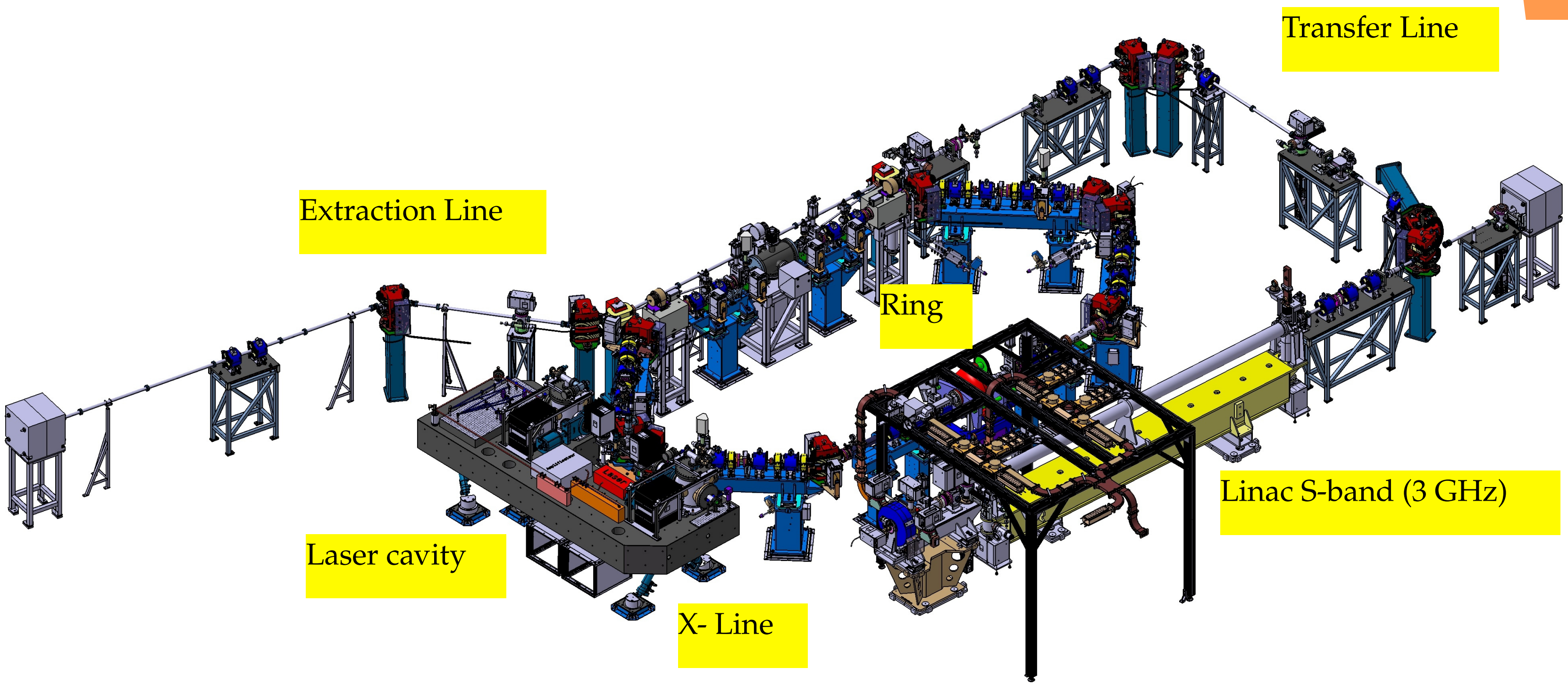
ThomX Accelerator Facility



3 GHz gun and linac delivering 1 bunch of 1 nC every 20 ms (50 Hz)

– Bunch emittance is ~ 50 nm.rad, energy spread is ~ 0.3% rms

– Nominal energy is 50 MeV, Max is 70 MeV

The bunch is stored over 20 ms in a ring (Rev freq ~ 17 MHz Circ= 18 m)

An Fabry-Perot cavity to store the laser pulse (max ~ 20 mJ)

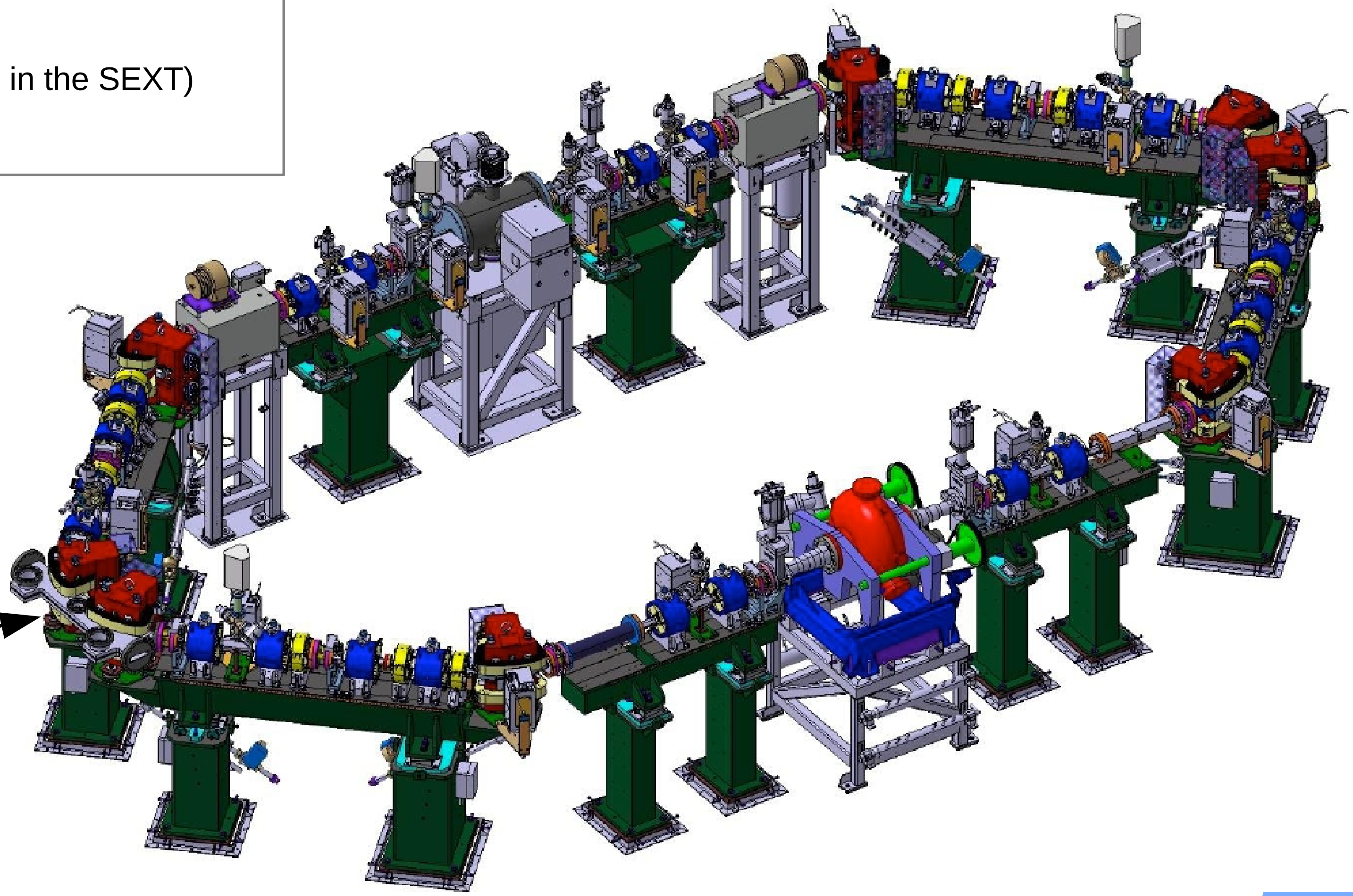
Up to 10^{13} Photons / Second (photon max energy of 90 keV)

Storage Ring Layout

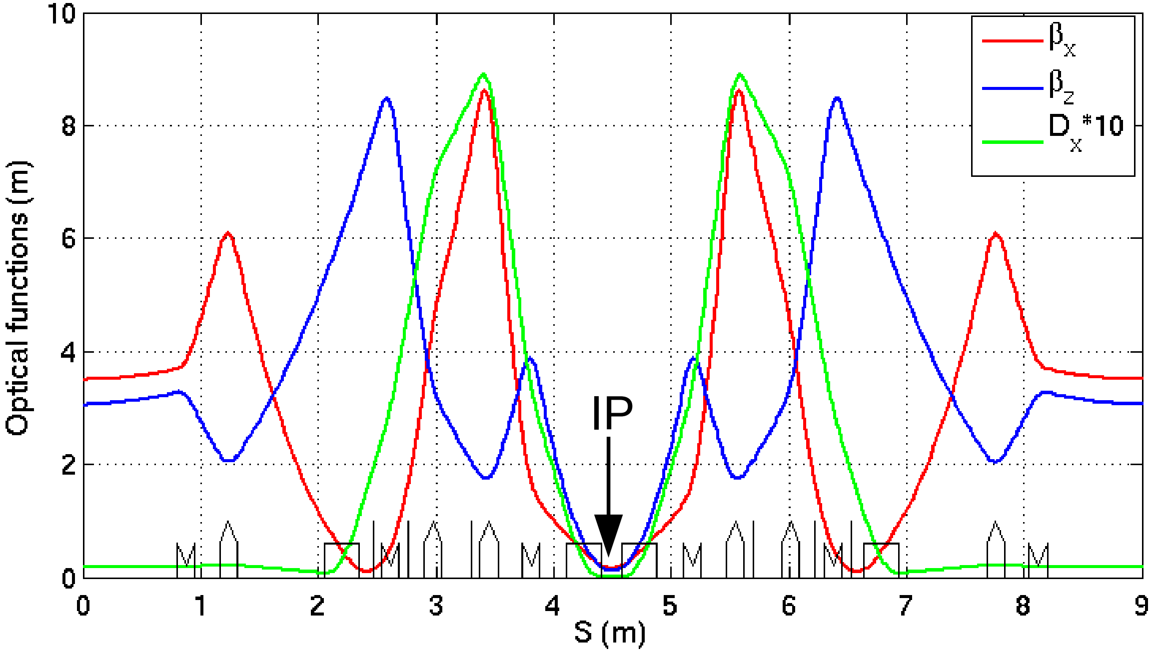
8	Dipoles
24	Quadrupoles
12	Sextupoles
2	Kickers
1	Septum
12	BPM
12	Correctors (integrated in the SEXT)
1	RF cavity (500 MHz)
1	Transverse feedback

Circc = 18 m
T0 = 60 ns
F0 = 16.7 MHz

IP chamber



Storage Ring optics



At IP : β=0.1 m, Disp=0

Double bend achromat
Half lattice ring optics

Circ = 18 m / 2 IPs

Versatile lattice → Optics and momentum compaction

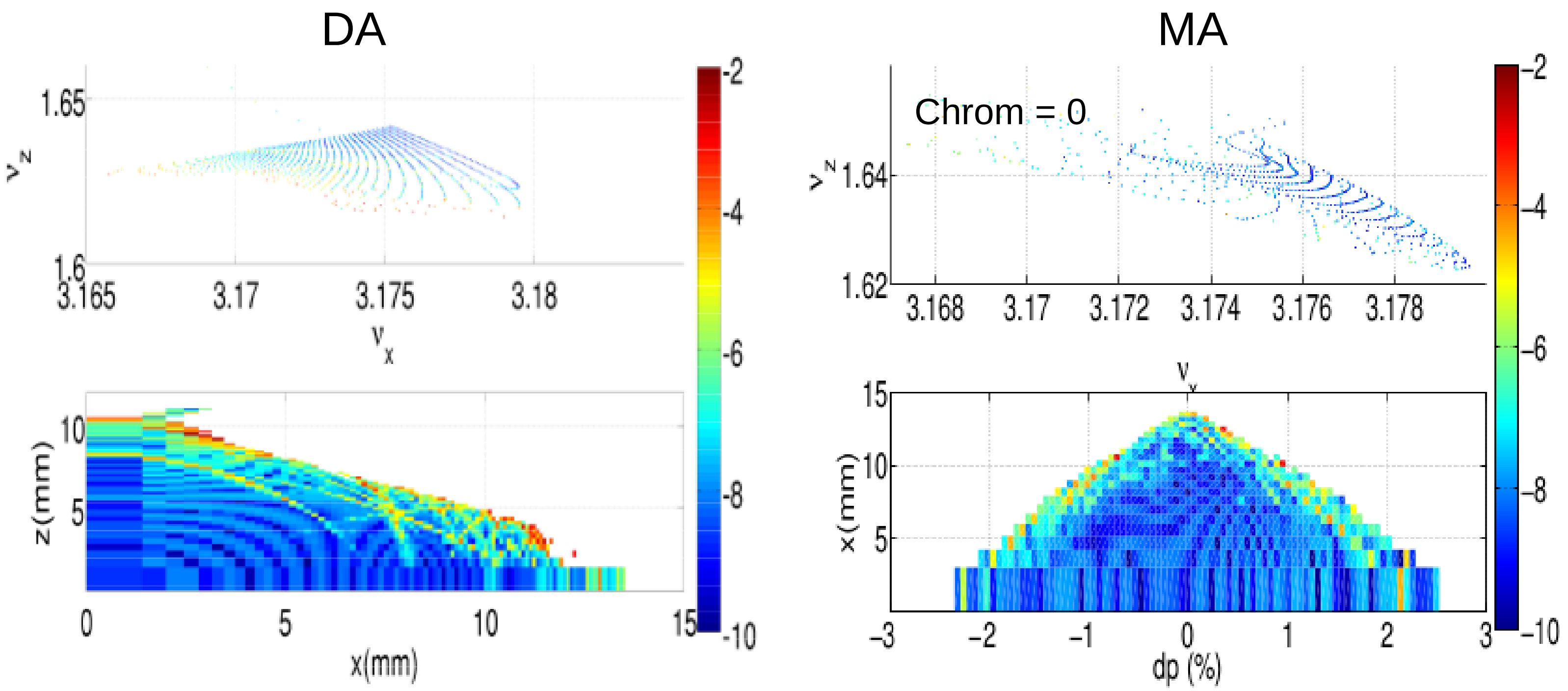
Low H function → Minimize collective impact on emittance

But :

Strong quadrupoles	K ~ 20 m^{-2}
Short bend radius	R = 352 mm
Large dispersion function	Dmax = 0.9 m

Storage Ring frequency map

TRACY3 code



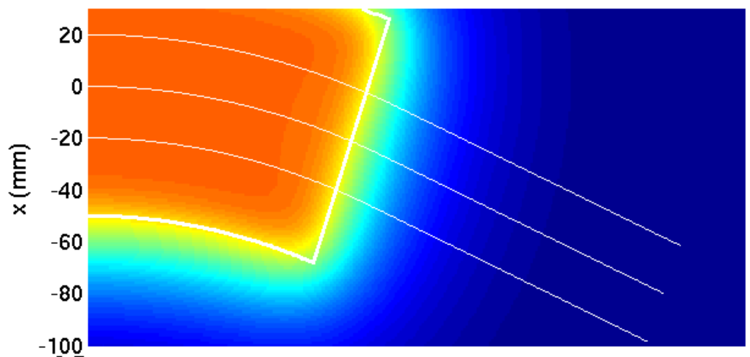
DA and MA frequency map analysis at injection point β=3 m, Disp~0

Stability region including multipoles errors from measurements

Fit the beam pipe aperture

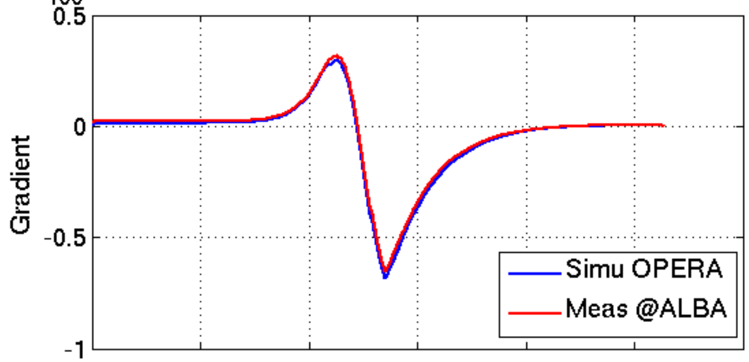
Bunch is injected on axes : 3 rms ~ 0.7 mm

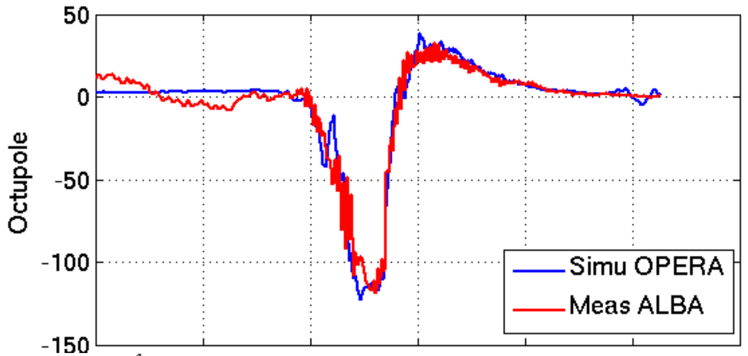
Dipole field analysis

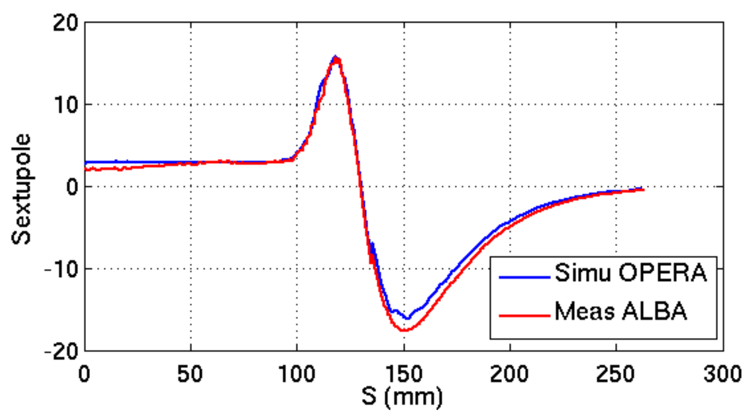


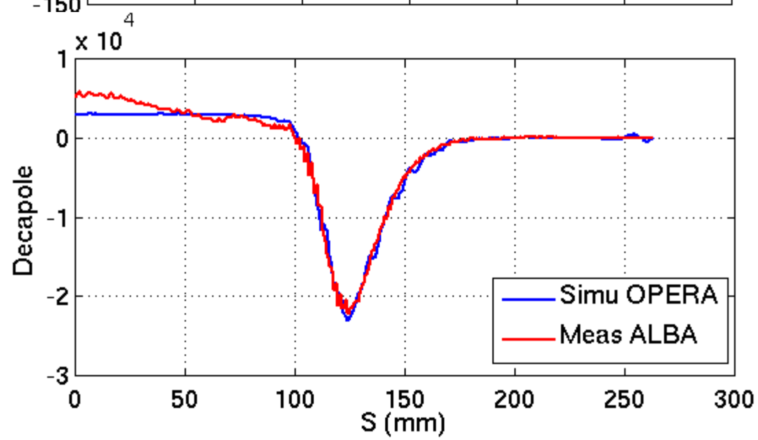
Comparison between simulation and measurements

Multipoles included in FMA as thin lens in core and at edges









Electron beam damping

At low energy (50 MeV) there is no beam damping

From Synchrotron radiation :

Losses per turn : 1.6 eV
Longitudinal damping time : 1.8 second >> 20 ms storage time

Adding the Compton Back-Scattering effect : *(20 mJ in the FB cavity)*

Losses per turn : 2.4 eV
Longitudinal damping time : 1.2 second >> 20 ms storage time

Rising the electron energy to 70 MeV doesn't change the deal ...

Collective effects

Without any beam damping :

Once perturbed, it will never recover

The injected beam is very short for a ring : 1.2 mm or 4 ps rms

The beam is very sensitive to every wakefields

We investigate some collective effects with a 6D tracking code tracking element by elements including :

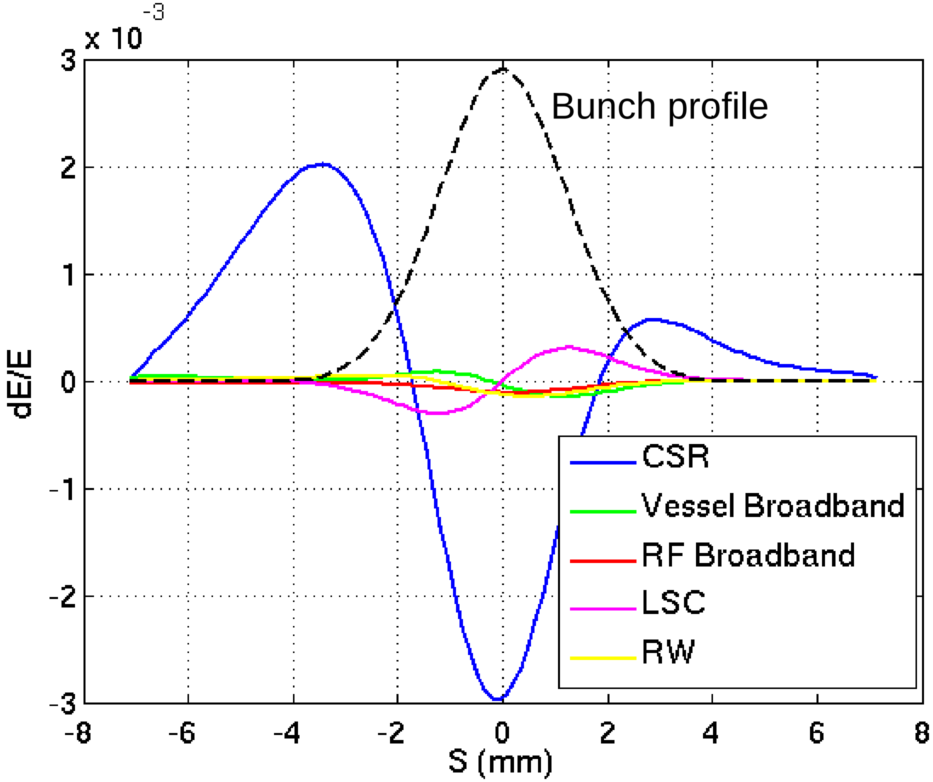
– Non-linear single electron dynamics
– Longitudinal wakes from
  – Pipe *(SOLEIL model from R. Nagaoka data)*
  – Space Charge
  – Resistive Wall
  – Coherent Synchrotron Radiation

At present times a complete ThomX pipe element
Is investigated by A. Gamelin in a frame of a PhD

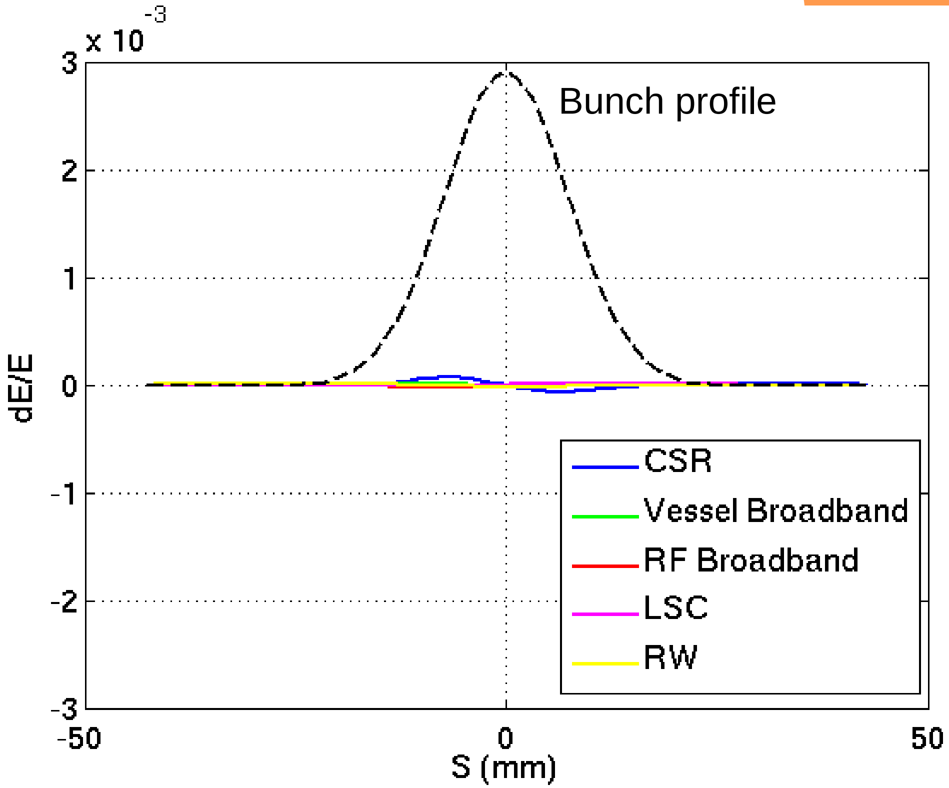
Collective effects

Longitudinal wakefield over 1 turn, 1 nC 50 MeV

Bunch length at injection : 4 ps rms



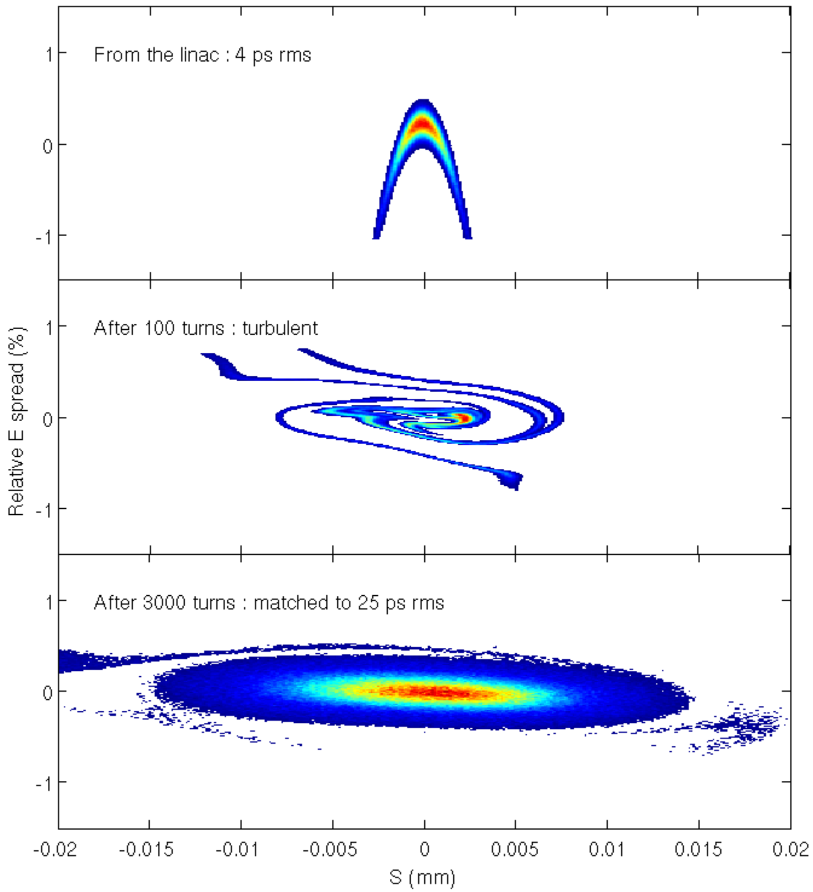
Bunch length 25 ps rms



Dominant effect : Coherent Synchrotron Radiation

Storage Ring beam dynamics
First turns ...

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

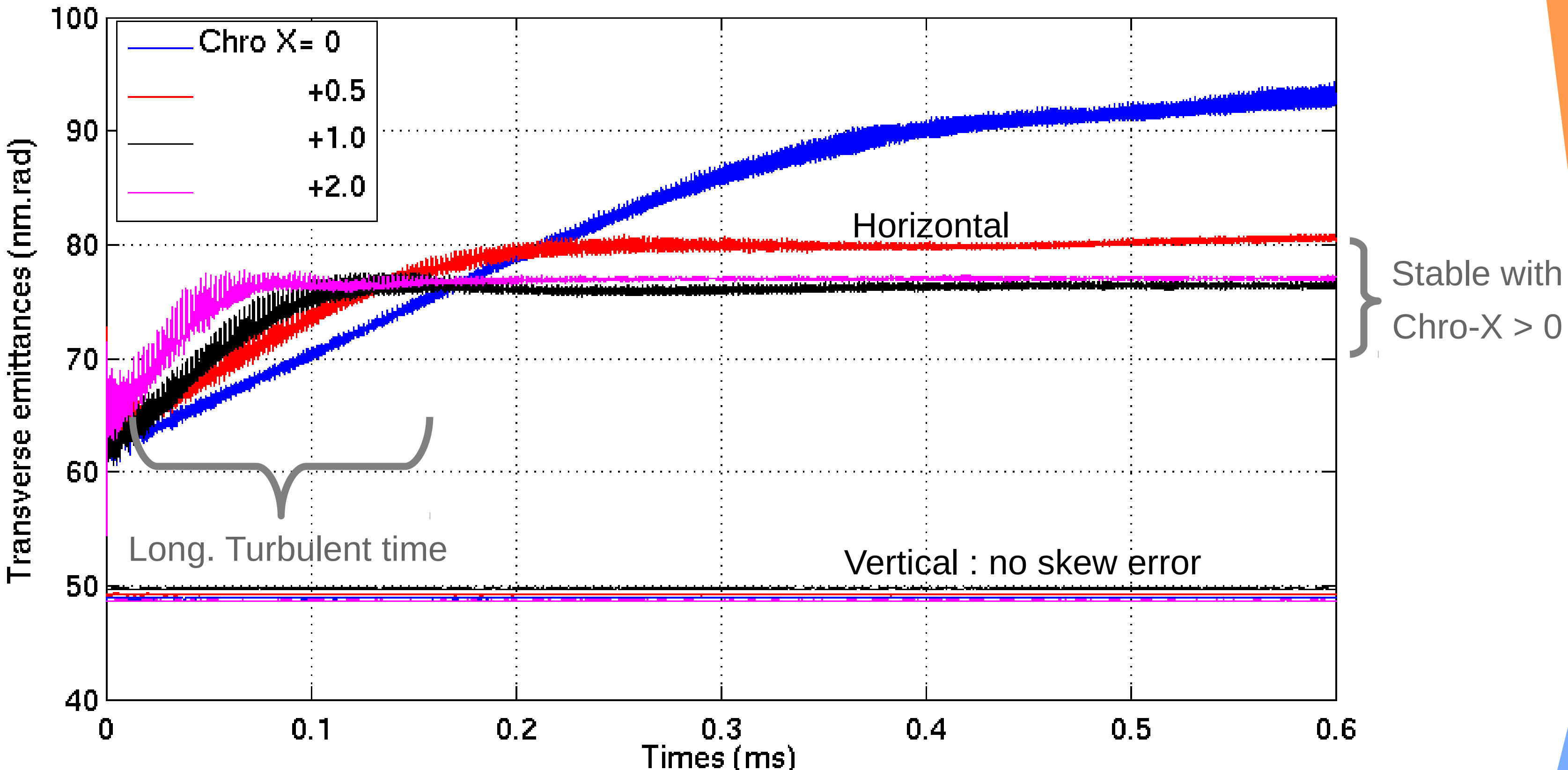
Finally reach a ring matched form

Still subject to some head tail effects

Storage Ring beam dynamics
First turns ...

Transverse emittance in the first turns versus chromaticities

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

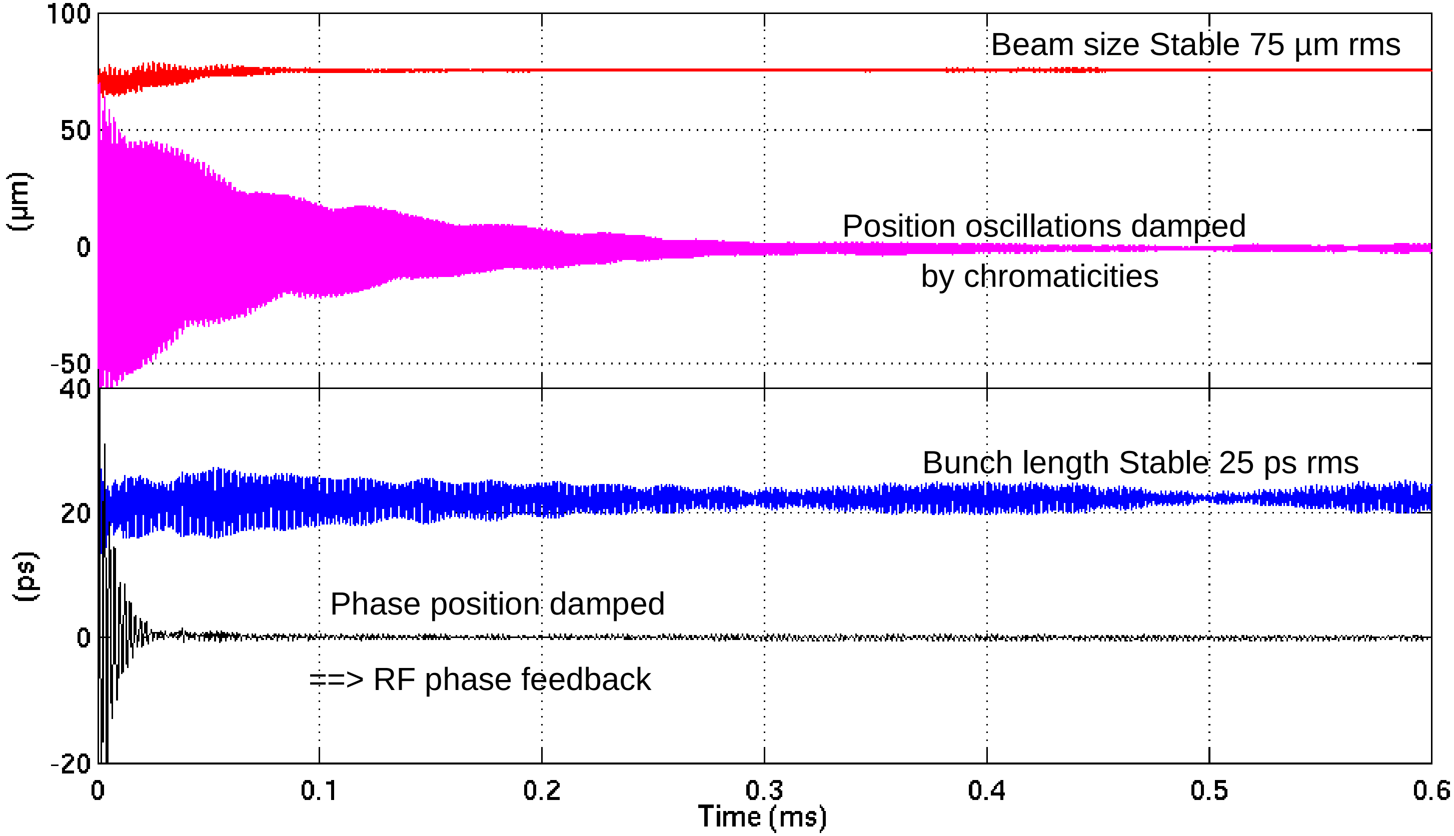


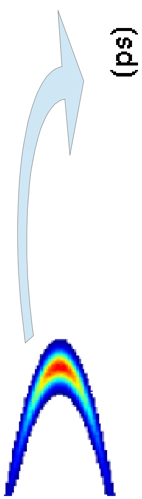
10 000 turns

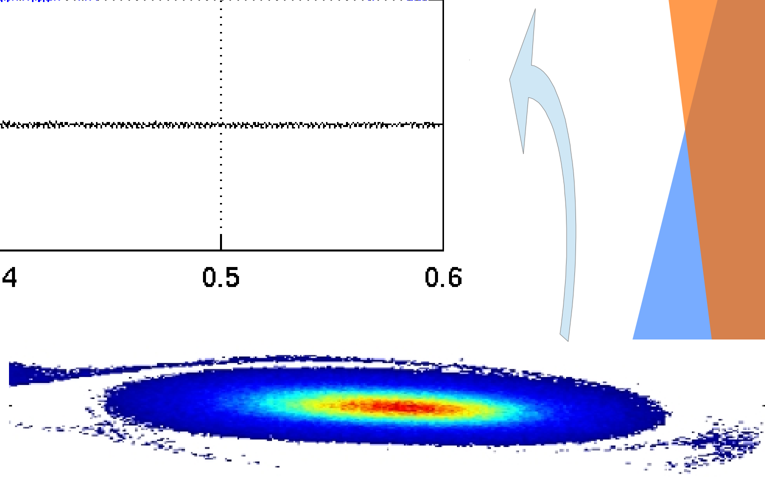
Storage Ring beam dynamics
First turns ...

Bunch size and length at IP in the first turns

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

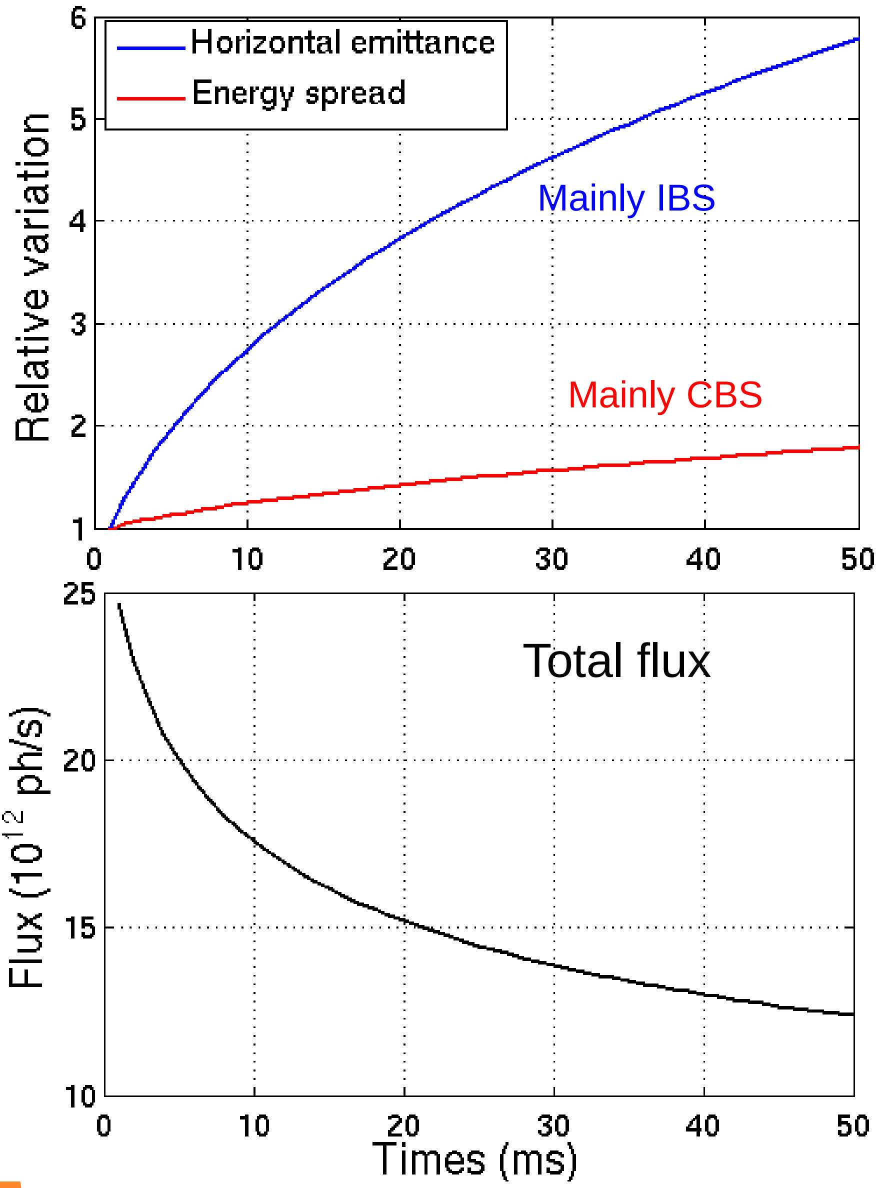






Intra-Beam Scattering and Compton Back Scattering

50 MeV, 1 nC, 20 mJ



Horizontal emittance x 6 over 50 ms

From 50 to ~300 nm.rad rms

==> IBS dominated

Relative E-spread x 2 over 50 ms

From 0.3 to ~0.6 % rms

==> CBS dominated

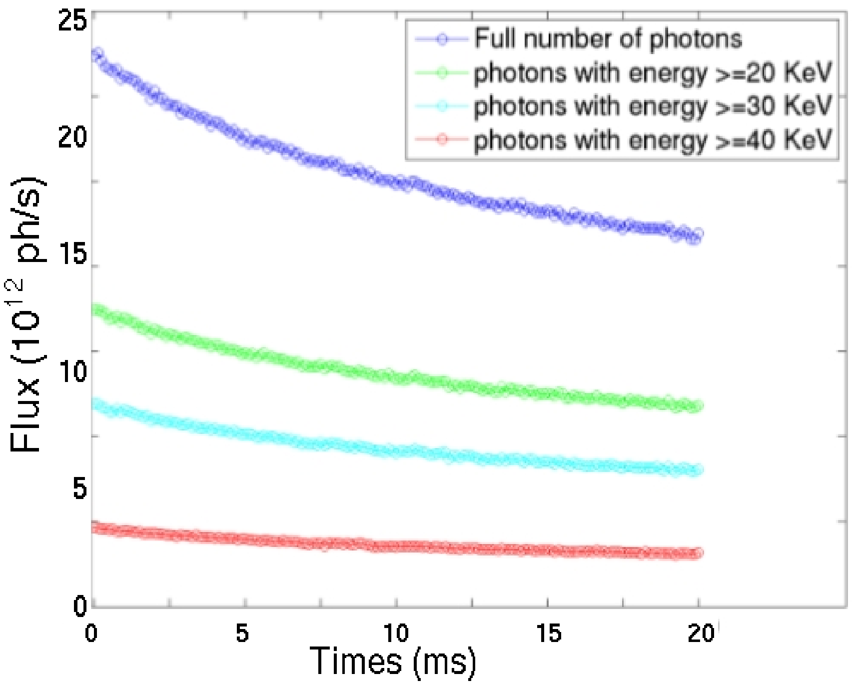
X-Rays flux reduced by ~2 over 50 ms

Flux from geometric formula :

$$L = N_e N_\gamma \, f \frac{\cos\phi}{2\pi} \frac{1}{\sqrt{\sigma_{ye}^2 + \sigma_{y\gamma}^2}\sqrt{\left(\sigma_{x\gamma}^2 + \sigma_{xe}^2\right)\cos^2\phi + \left(\sigma_{ze}^2 + \sigma_{z\gamma}^2\right)\sin^2\phi}}$$

Intra-Beam Scattering and Compton Back Scattering

50 MeV, 1 nC, 30 mJ



PhD thesis of Illya Debrot

6D non linear tracking including
Collective effect and IBS
CBS flux with CAIN code

=> Flux drop by ~20% from previous simplified model

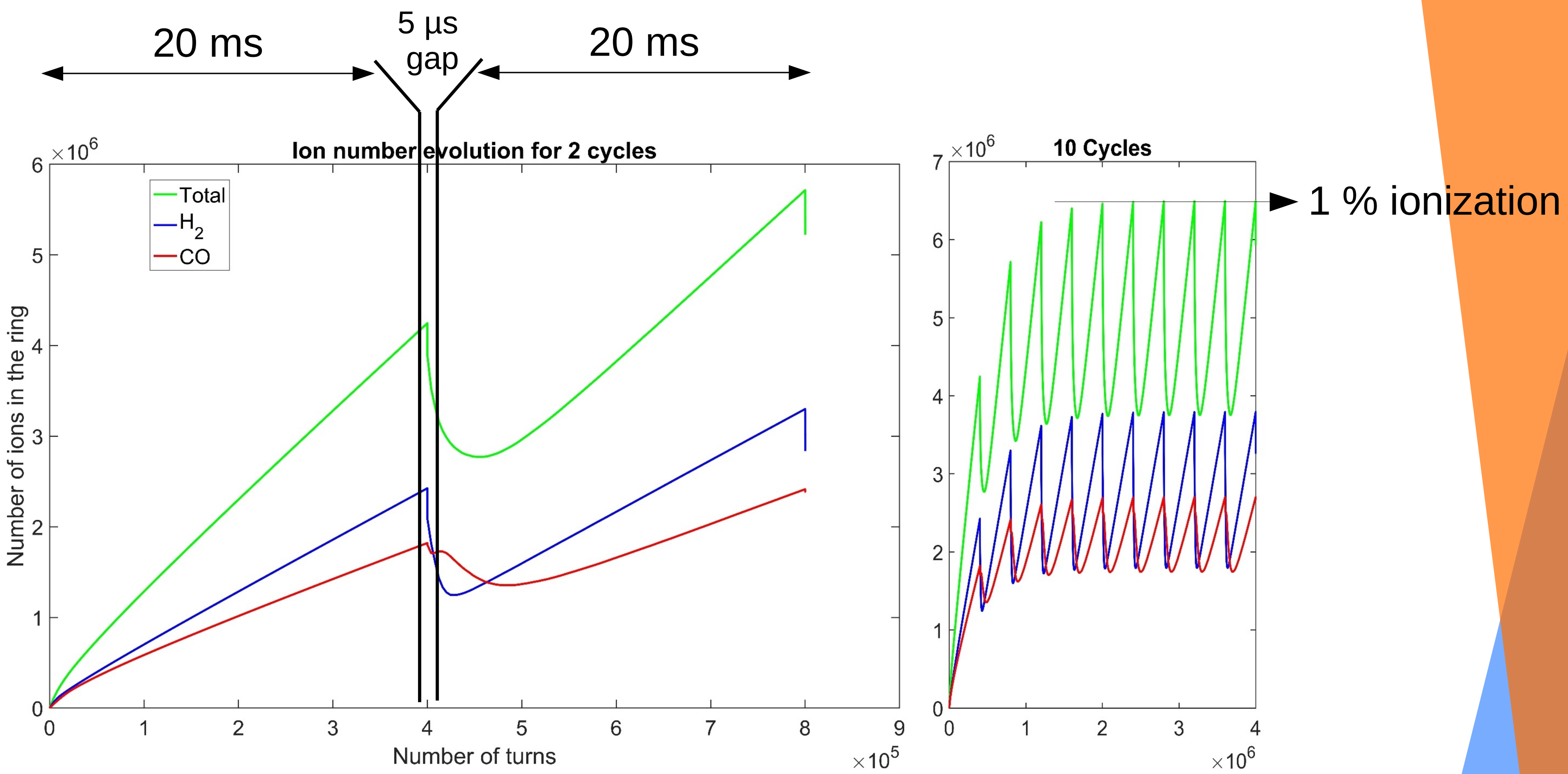
=> Intensive simulations exhibits a risk of bunch breaking due the strong CSR effect

Cure : larger momentum compaction

Tune spread from residual gaz Ionization

Vacuum ionization simulation at 50 MeV, 1 nC with a start pressure of 3 10^{-10} mbar

6D tracking including cleaning electrodes



The tune shift is kept below 0.03
The tune spread is kept below 0.003

Conclusion

Low energy and compact ring :

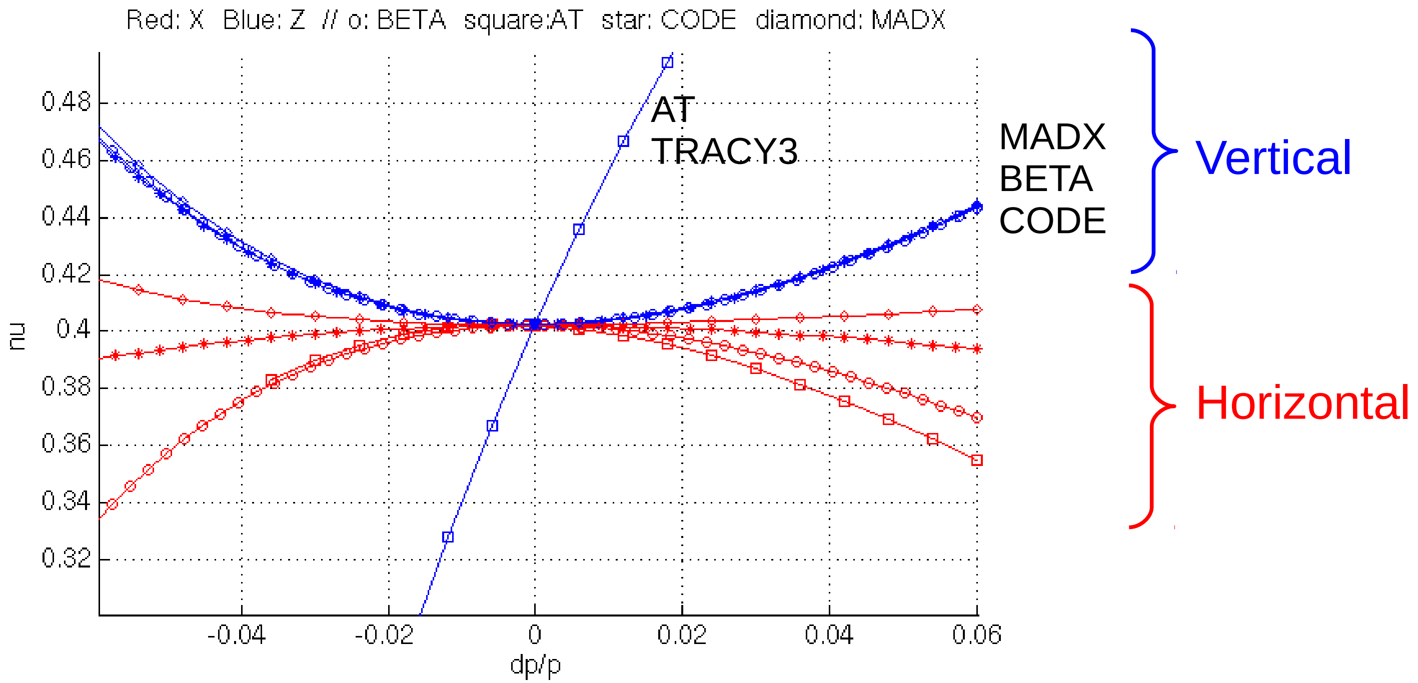
- No damping
- Strong magnetic field vs energy
- Short injected bunch & wakefields

==> Storing 1 nC (20 mA) while preserving the beam characteristics in order to reach the level of X-ray flux will be a bit challenging

Additionnal slides

Dipole modeling

ThomX Tunes vs energy

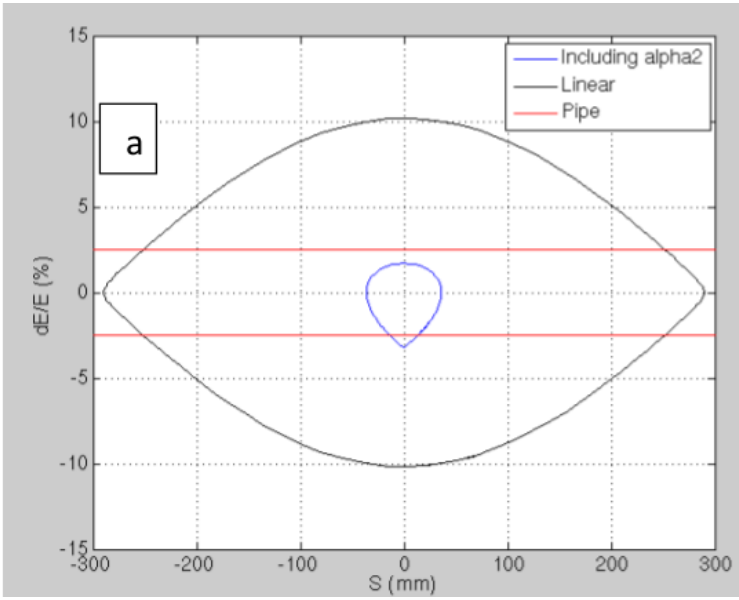


All codes in good agreement on SOLEIL storage ring with much larger dipole radius

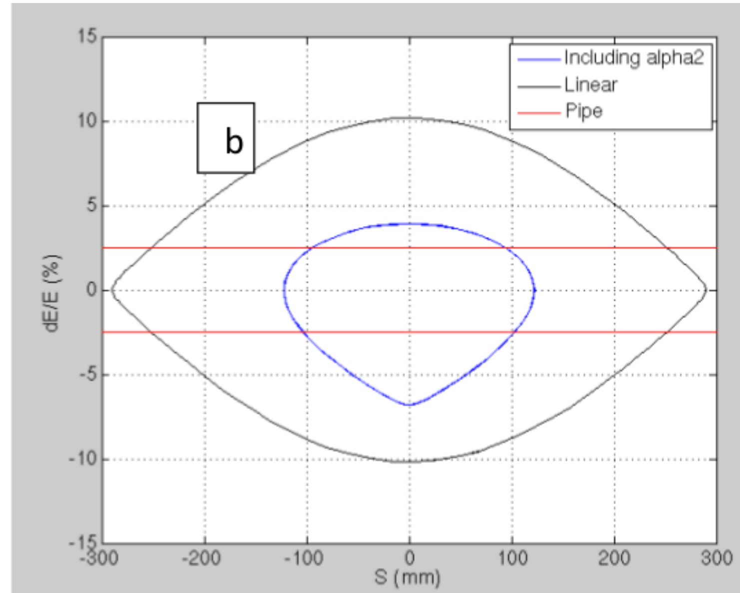
Vertical chromaticity of AT and TRACY3 has been corrected : edge effect

RF acceptance

MCF = 0.013

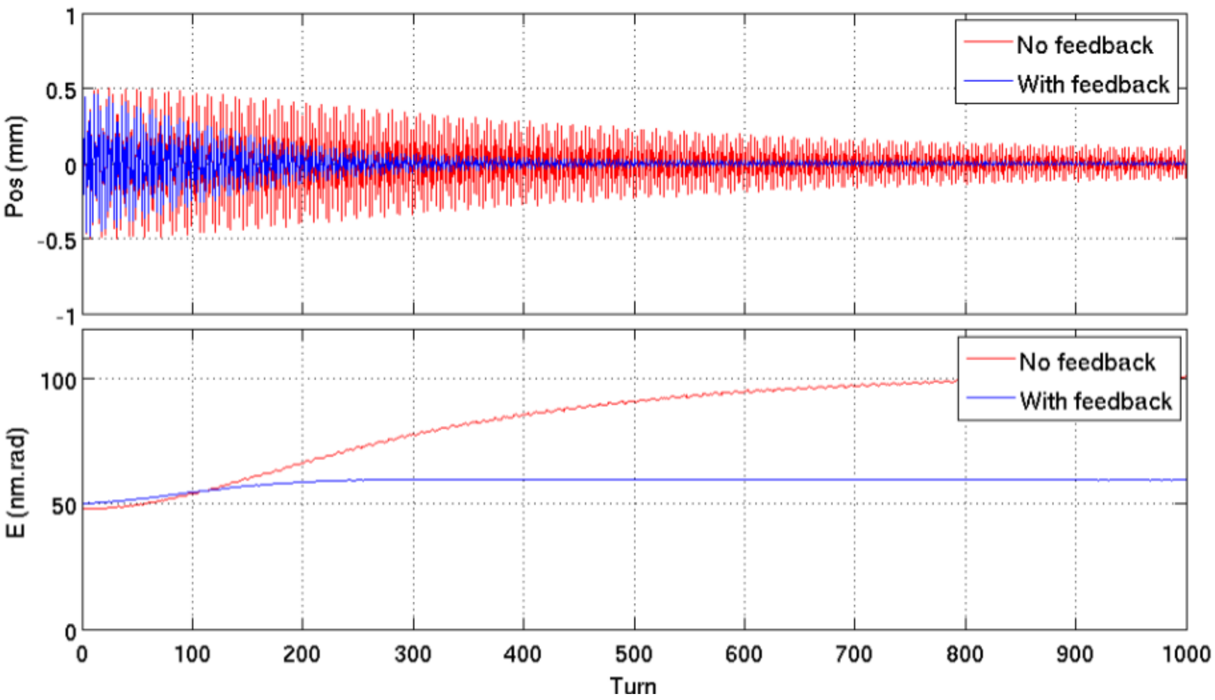


MCF = 0.026



RF acceptance	**nominal r56 = - 0.2 m**	**r56 = - 0.4 m**
Linear (RF bucket)	10%	10%
Non linear	-3.2 % +1.8 %	- 6.8 % +4 %
Pipe limit	2.5 %	2.5 %

Transverse feedback



0.5 mm injection offset
from possible linac jitter

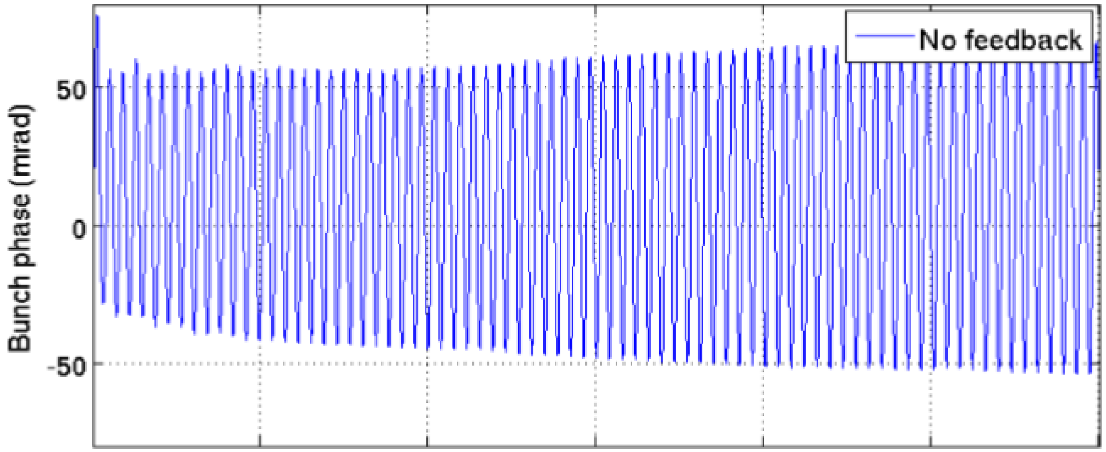
Need to be damped with fast transverse feedback
To prevent from emittance growth

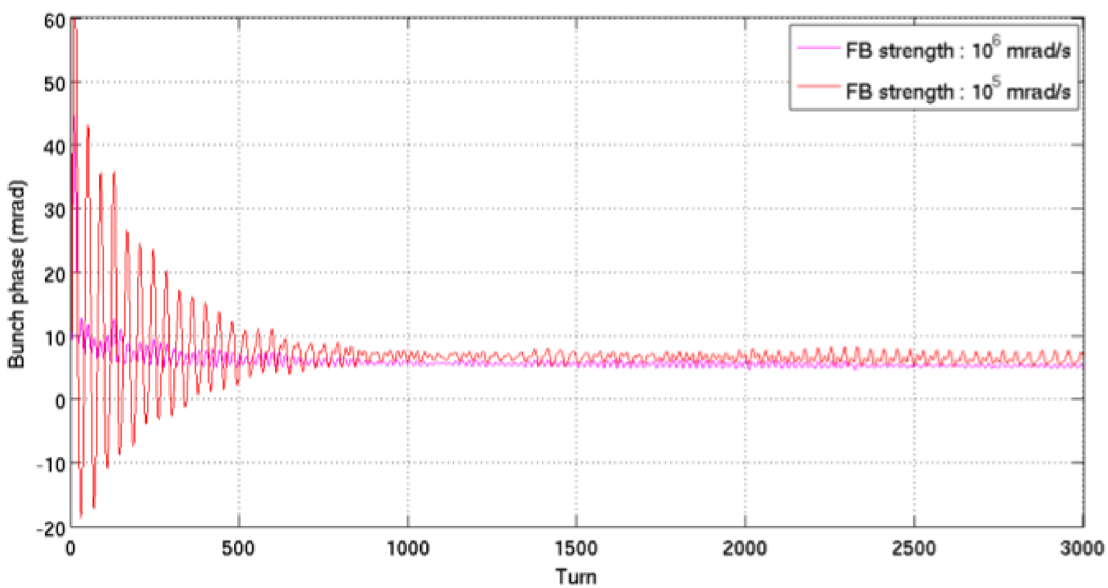
Dedicated stripline

Source	Type	Growth time	Revolution-by-revolution kicker strength
Beam pipe geometry	TMCI Head-Tail	- 160 µs	>10 nrad
Resistive Wall		600 µs	> 2 nrad
Ions		< 100 µs	>20 nrad

Longitudinal feedback

50 MeV, 1 nC,





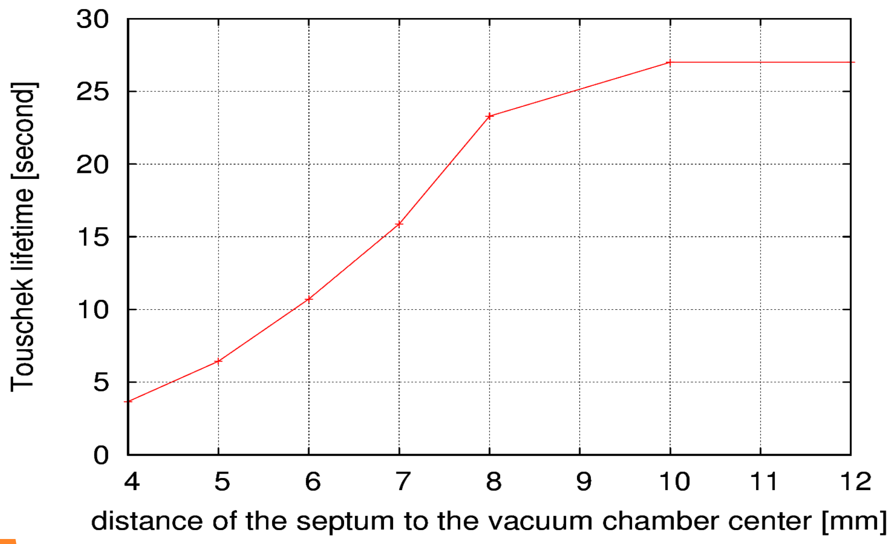
At injection :

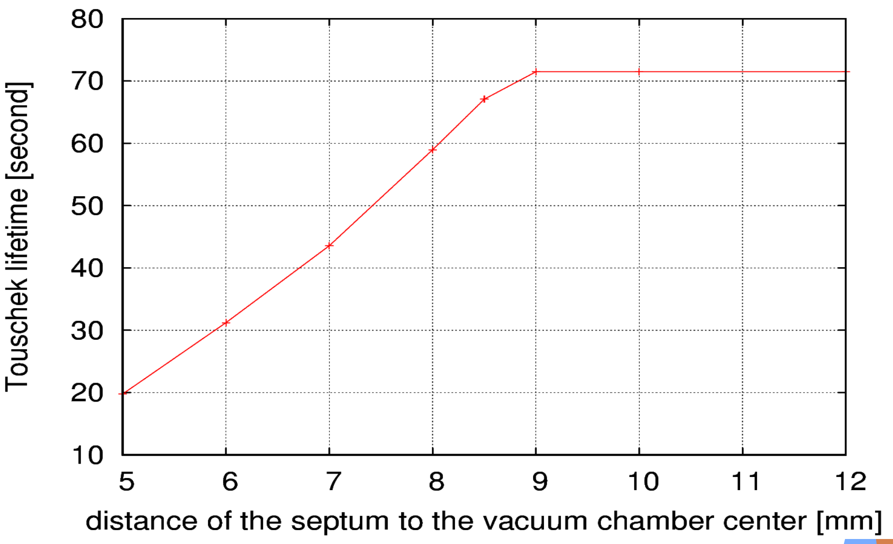
Collective effect energy losses will induce synchrotron oscillation

Need to be damped with fast phase feedback

In the main RF loop

Touschek beam life time

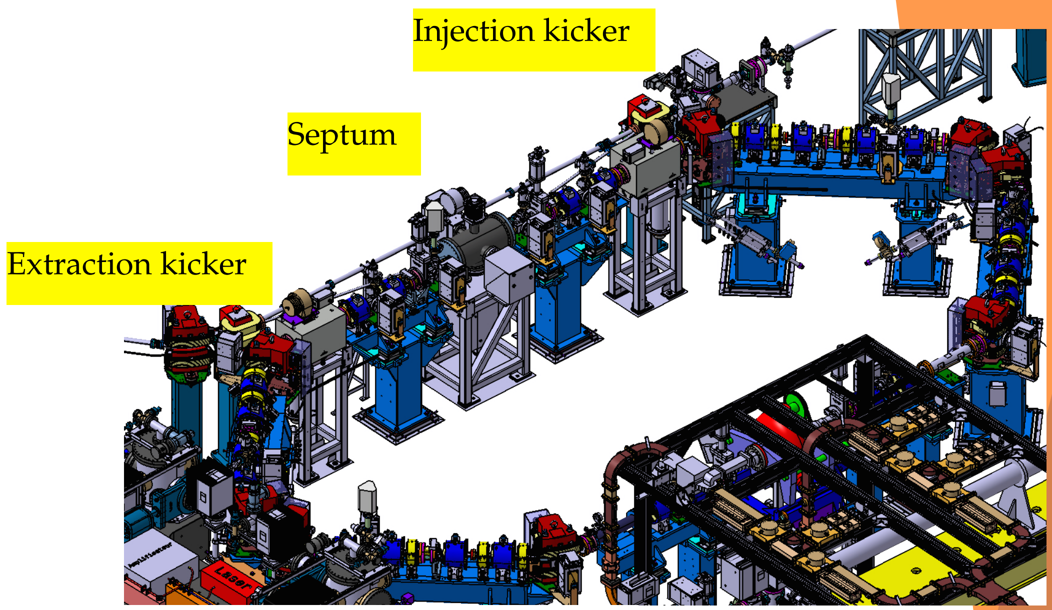


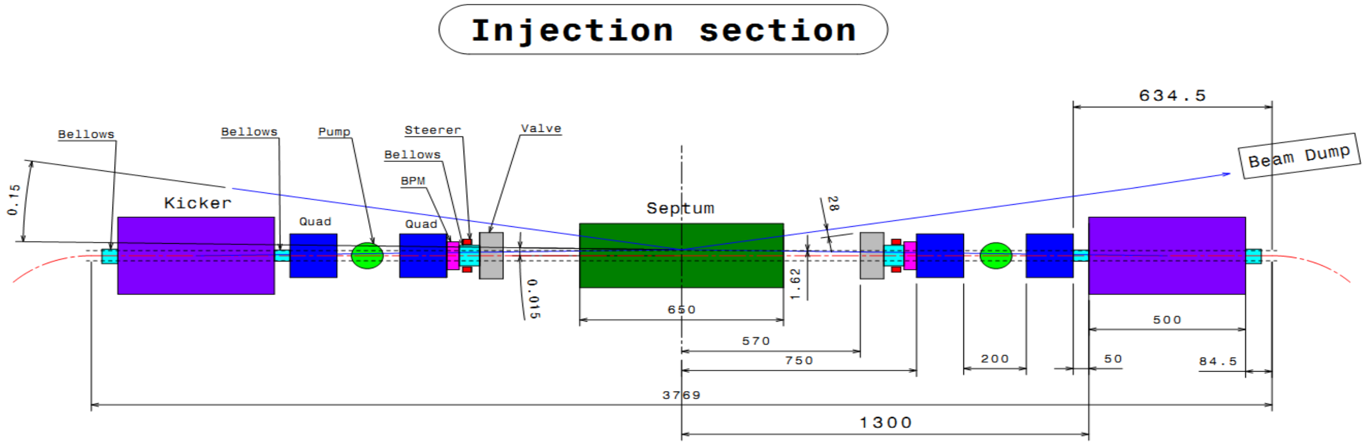


TRACY3 simulation with injected beam characteristics

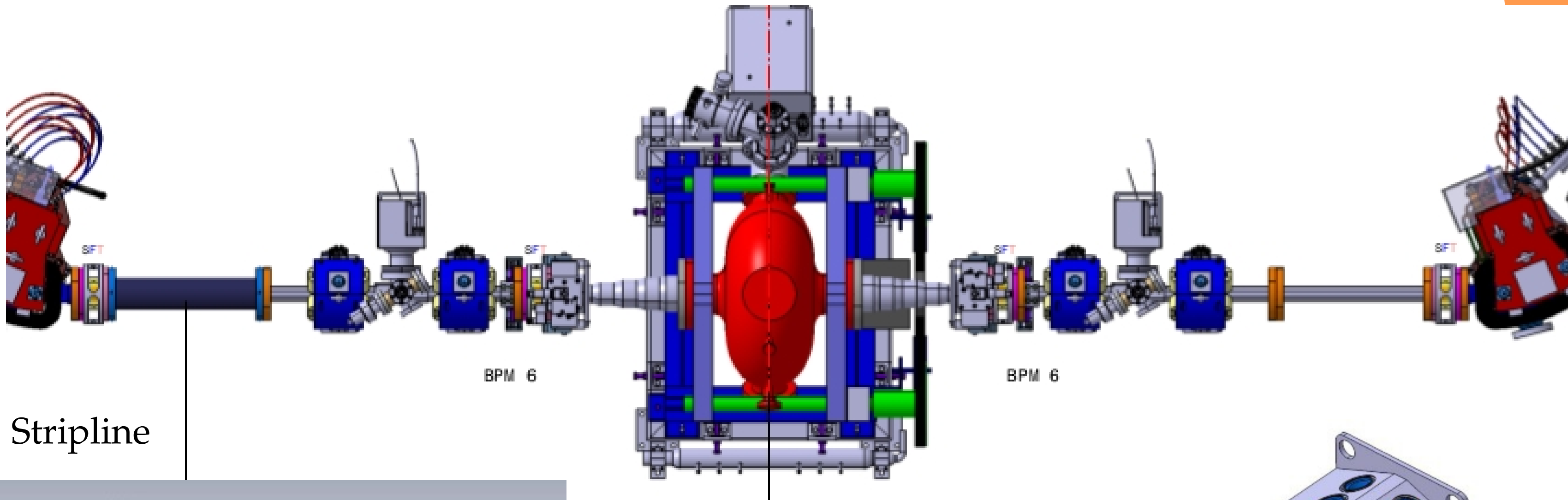
Transfer Line - Storage Ring

Pulsed field magnets: 2 fast kickers + Septum

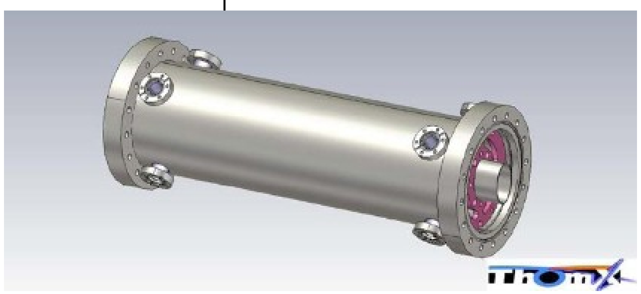


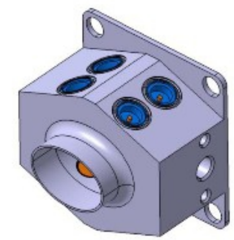


Storage Ring feedback system



Stripline





Double BPM (x4)

- Transverse feedback:
  - Detector: one set of additional buttons.
  - Actuator: stripline (4 electrods of 300 mm for acting in H and V planes, rise time < 1 ns)

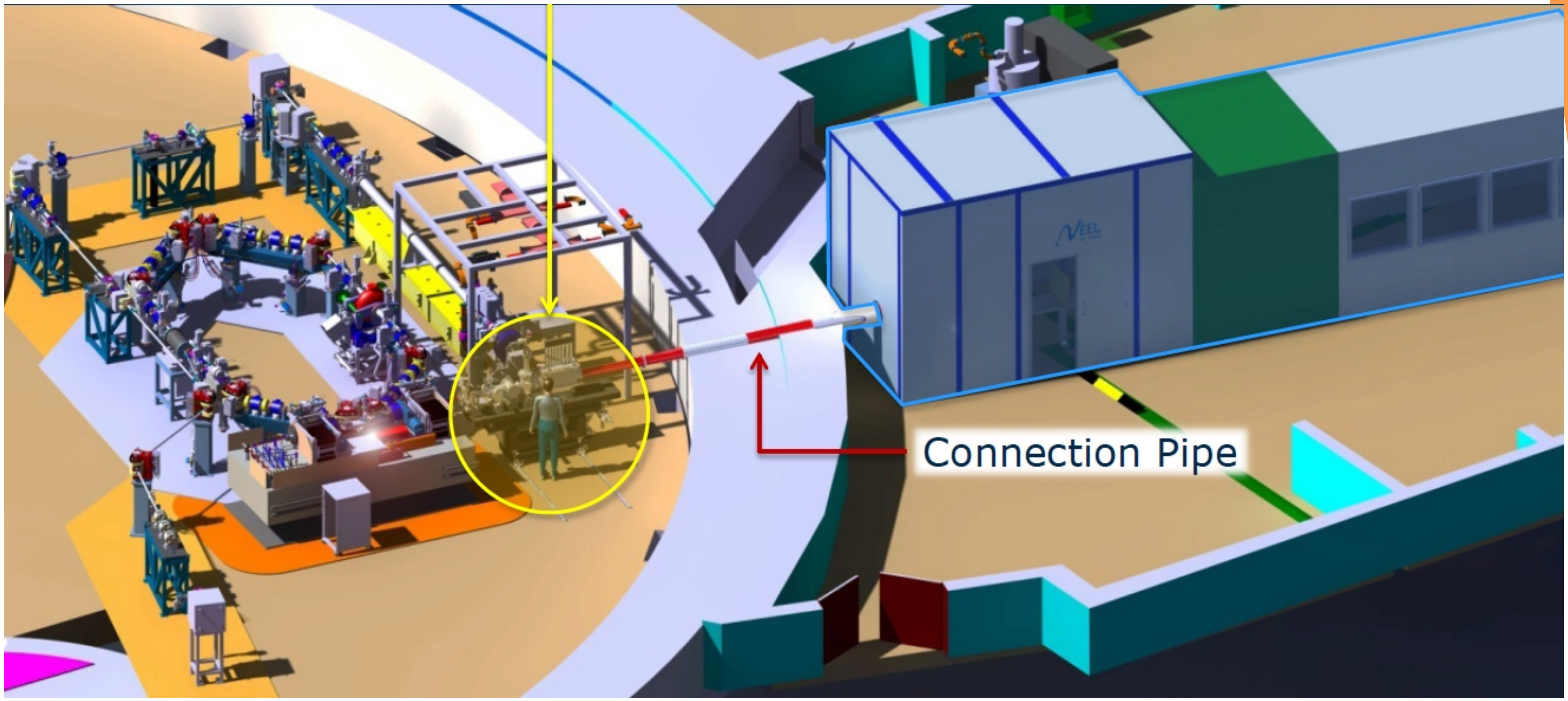
- Longitudinal feedback (synch tune ~ 400 kHz):
  - Detector: one set of additional buttons.
  - Actuator: main cavity as longitudinal kicker ("damping time" < 20 µs)

X line

Phase of manufacturing and tests at SERAS and ESRF

Table 1 - Continuous monitoring

Working zone
X-hutch (exp & control)



- X-ray obturator
- Slits system (alignment/beam shape)
- Fluorescent screens (beam detection)
- Diode detector (intensity)
- Beam profiler (abs. position)
- Transfocator (beam focus)