Diagnostics for ThomX

Diagnostics Experts of European Light Sources Workshop
SOLEIL Synchrotron
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N. HUBERT, M. LABAT, M. EL-AJJOURI, D. PEDEAU, *Synchrotron SOLEIL*

I. CHAIKOVSKA, N. DELERUE, N. EL-KAMCHI *LAL*

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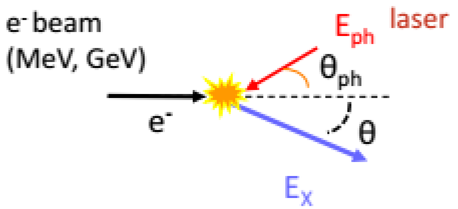
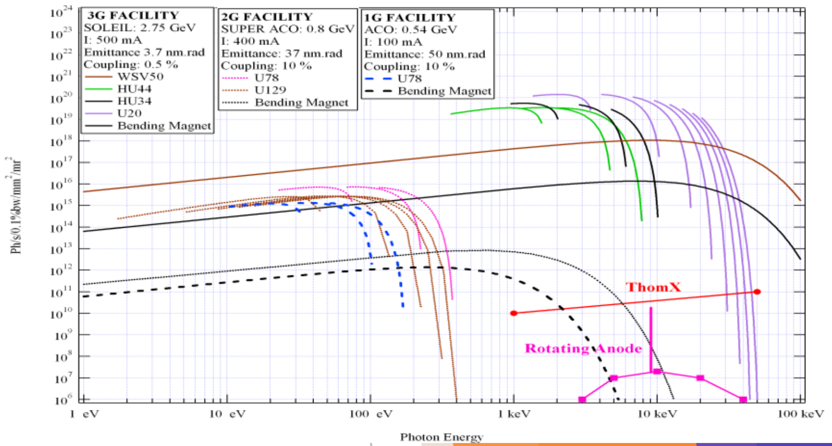
The ThomX Project

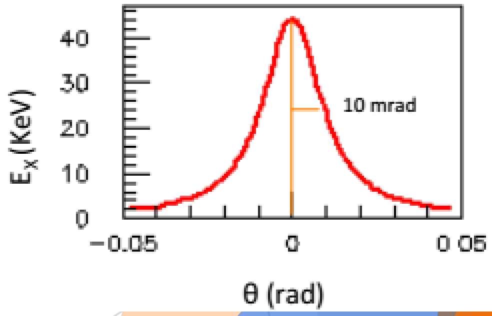




- What is ThomX?
  - Light source based on Compton Back Scattering effect (CBS)
    - Efficient energy amplifier
    - Production of hard X-rays with relatively low energy machine
    - Example : 50 MeV electrons and 1.23 eV laser give up to 50 keV back scattered X-rays
  - High average flux
    - Storage ring to have a high repetition rate
    - high average power laser amplified in a Fabry Perot resonator

Eph : initial photon energy
Ex : scattered photon energy

$$E_X \sim \frac{2\gamma^2 E_{ph} [1 - \cos(\theta_{ph})]}{1 + (\gamma\theta)^2}$$



$$Flux \sim \frac{\sigma_{compt} N_e N_{ph} f_{rep}}{2\pi (\sigma_e + \sigma_\gamma)}$$

• **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
=> 10^{13} Ph/s
==> Thom-X is a demonstrator

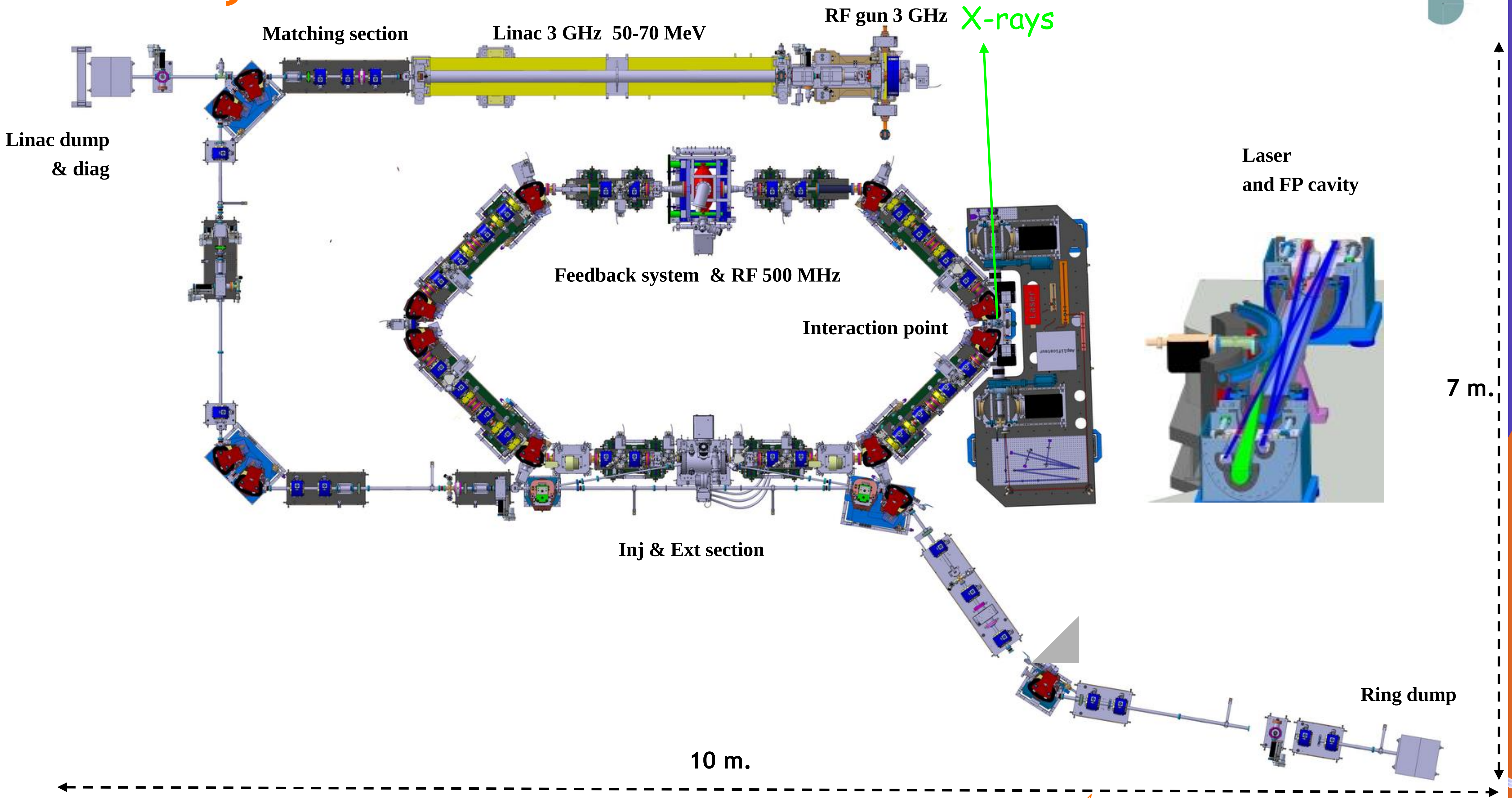
The ThomX Project

- What is ThomX?
  - Collaboration!

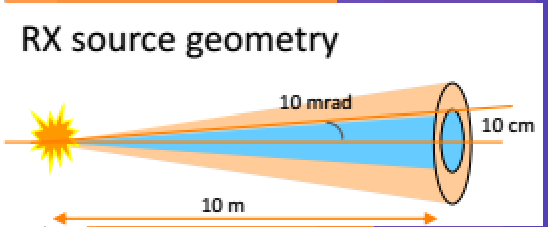
- Leading institute is the LAL (project leader Hugues Monard)
- Supported by
  - the EQUIPEX program – French Research Ministry,
  - Ile-de-France region,
  - CNRS-IN2P3
  - Université Paris Sud XI

- SOLEIL has in charge the design of the accelerator and will be part of the installation tests and commissioning

ThomX Layout

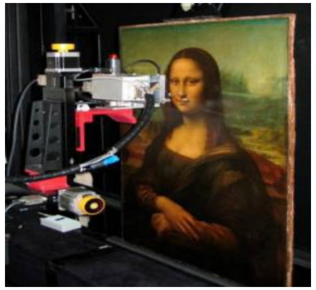


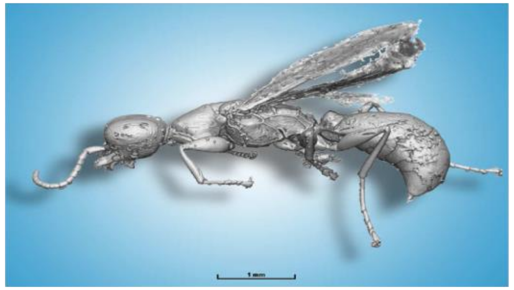
ThomX: what for?



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

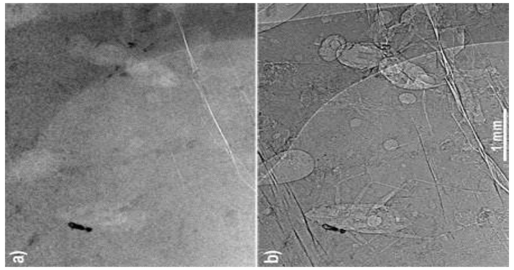
•Painting analysis





•Paleontology

•Non-destructive analysis



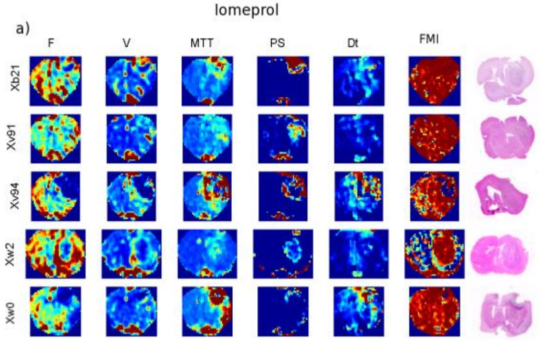
•*K-edge imaging* (Pb→white, Hg→ vermilion…) of a Van-Gogh's painting

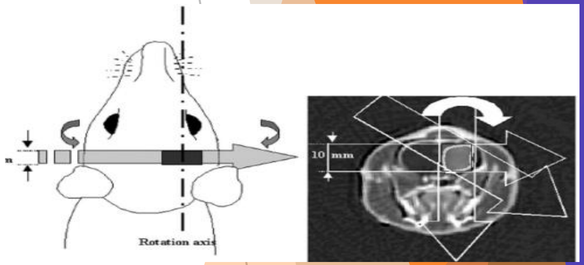
•J. Dik et al., *Analytical Chemistry*, **2008**, *80*, 6436

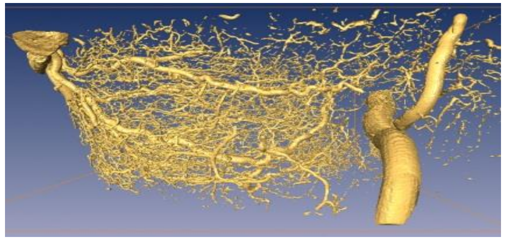
•Physiopathology and Contrast agents,

•Dynamic Contrast Enhancement SRCT

•Convection Enhanced Delivery =>Stereotactic Synchrotron RT







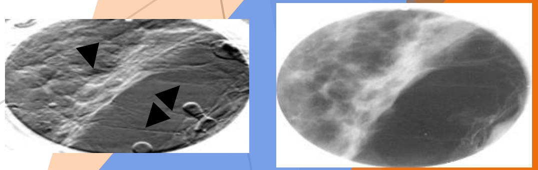
•J Cereb Blood Flow and Metab, 2007. 27 (2):292-303.

•Imaging,

•Mammography

•Microtomography

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



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

• Thanks to G.Le Duc, P.Walter

Expected beams characteristics

Injector	
Charge	1 nC in 1 bunch
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

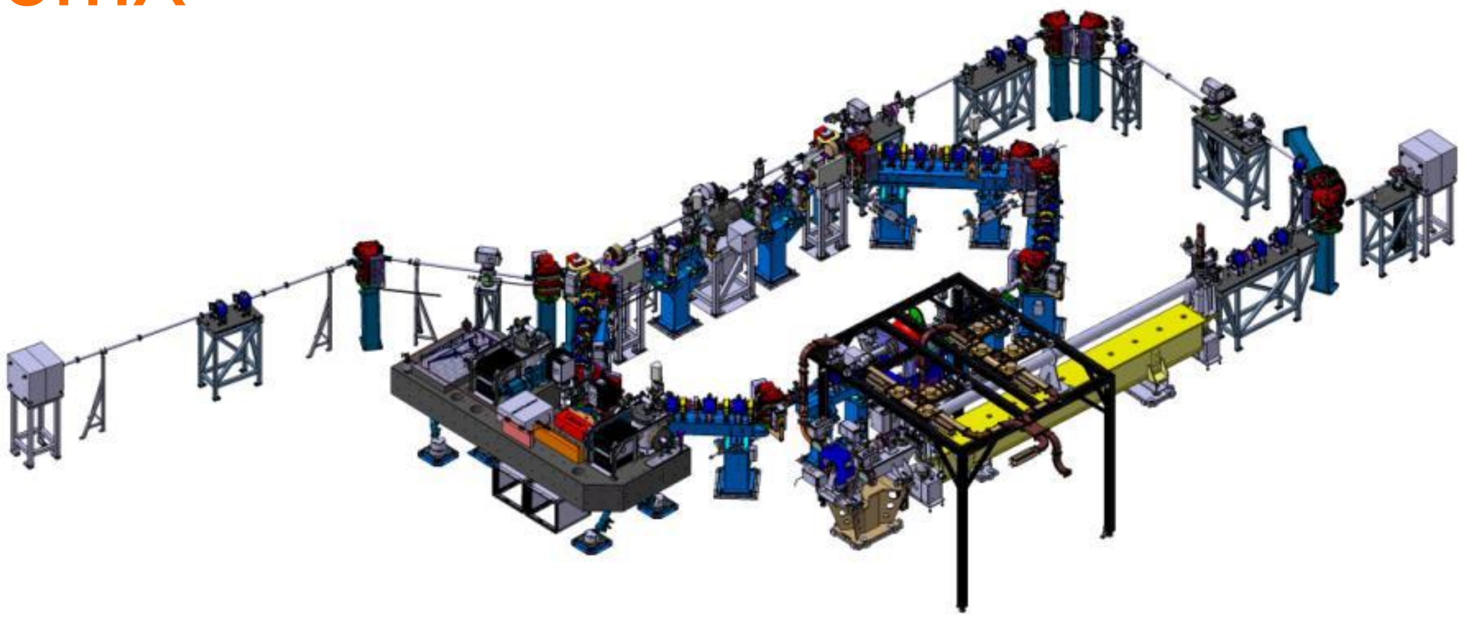
Laser and FP cavity	
Laser wavelength	1030 nm
Laser and FP cavity Frep	36 MHz
Laser Power	50 - 100 W
FP cavity finesse / gain	30000 / 10000
FP waist	70 µm

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	$1/\gamma$ ~ 10 mrad without diaphragm @ 50 MeV

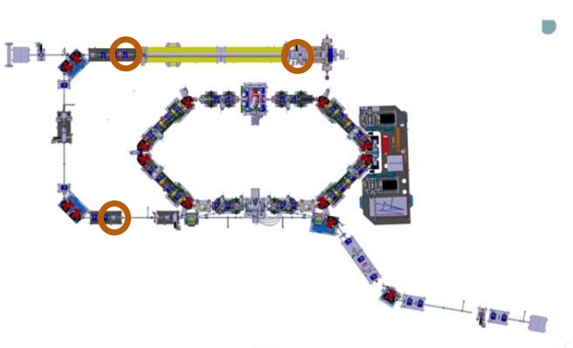
Ring	
Energy	50 MeV (70 MeV possible)
Circumference	18 m
Crossing-Angle (full)	2 degrees
$B_{x,y}$ @ IP	0.2 m
Emittance x,y (without IBS and Compton)	3 10^{-8} m
Bunch length (@ 20 ms)	30 ps
Beam current	17.84 mA
RF frequency	500 MHz
Transverse / longitudinal damping time	1 s /0.5 s
RF Voltage	300 kV
Revolution frequency	16,7 MHz
Harmonic Number	30
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 %

Diagnostics for ThomX

- Charge
- Position
- Diagnostic stations
- Length
- Stripline for transverse feedback
- Losses



Charge measurement (Typ. 1 nC @ 50 Hz)



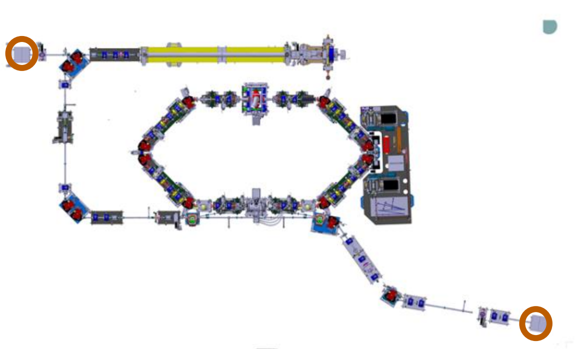
- 3 integrated current transformer (ICT)
  - Location:
    - @ LINAC entrance
    - @ Linac exit (before first TL bending magnet)
    - @ Transfer Line (after the 2 bending magnets)

Bergoz in-flange ICT & Electronics

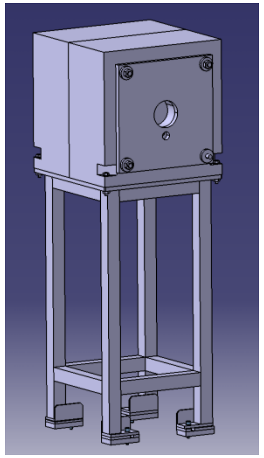
  - Type:
    - In-flange integrating current transformer from Bergoz
    - Dedicated electronics BCM-IHR provides analog voltage proportional to the beam charge
    - Acquisition to be integrated in the control system (Red Pitaya, 14 bits).
  - Expected resolution <1 pC

14 bits Red Pitaya acquisition board

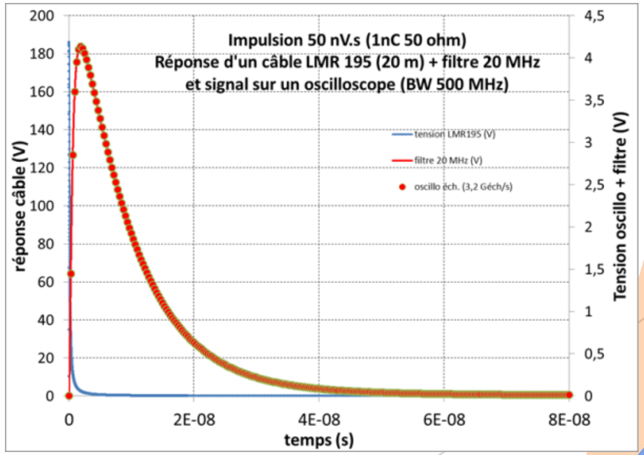
Charge measurement (Typ. 1 nC @ 50 Hz)



- 2 Faraday cups (FC)
  - Location: in the beam dumps
    - @ the end of Linac (behind first TL bending magnet)
    - @ the end of extraction line
  - Acquisition:
    - Few tens of ns pulse to be acquired synchronously to injection or extraction trigger
    - Use of Low Pass filtering and acquisition with the Wavecatcher board (BW 500 MHz; 3.2 GS/s, 12 bits)
    - Tango device ready



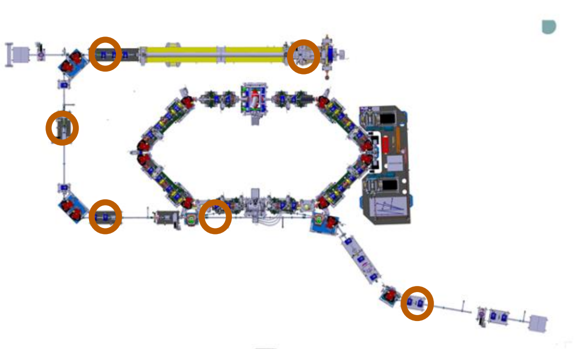
Beam dump



Low-pass filtered signal

Wavecatcher

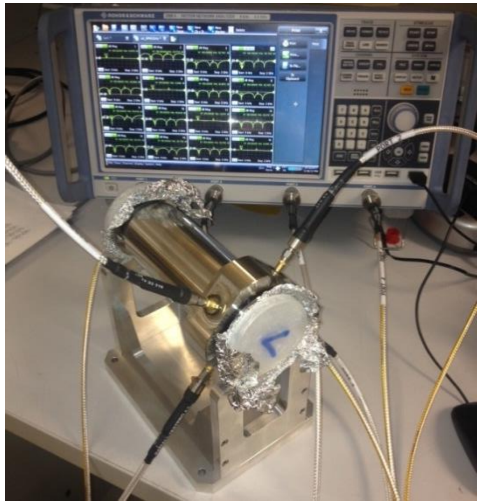
Position measurement (BPM)
Mechanics

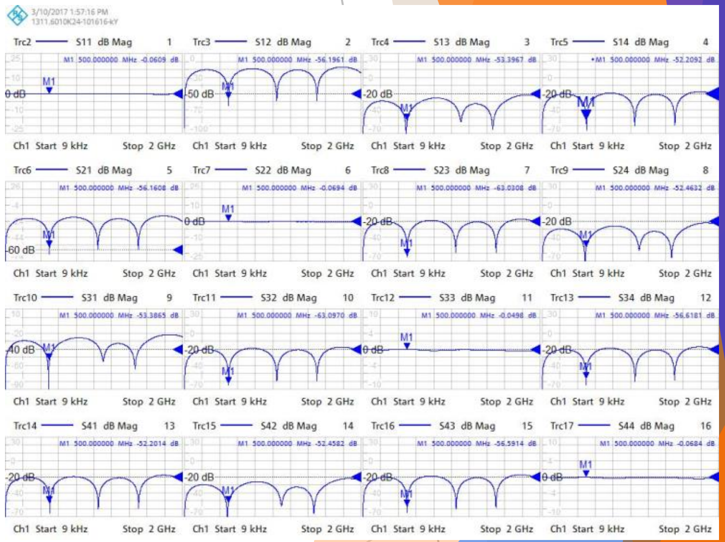


- 6 Striplines
  - 1 stripline on the LINAC
  - 4 striplines on the transfer line
  - 1 stripline on the extraction line

  - λ/4 @ 500 MHz -> Electrode length = 150 mm
  - Resolution requirements: < 100 µm for 1 nC
  - 4 electrodes @ 45° covering ~2/3 of circumference

  - Linac stripline has different design due to larger vacuum chamber diameter
  - Mechanics and soldering (feedthroughs) are done at LAL
  - Electrical tests and calibration done at SOLEIL

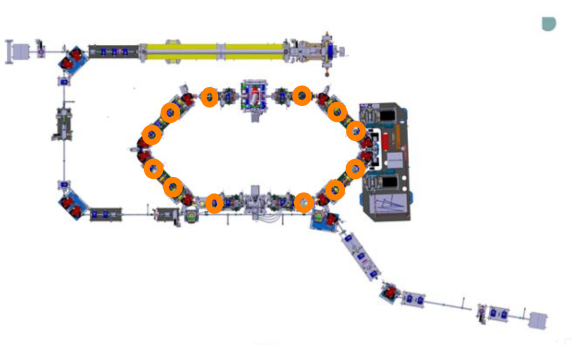




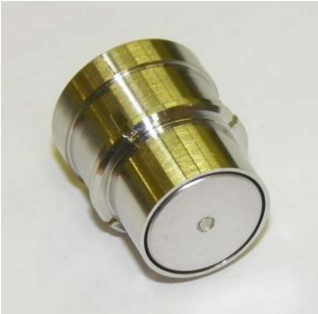
Calibration based on "Lambertson" method using a logic network analyzer

Position measurement (BPM)

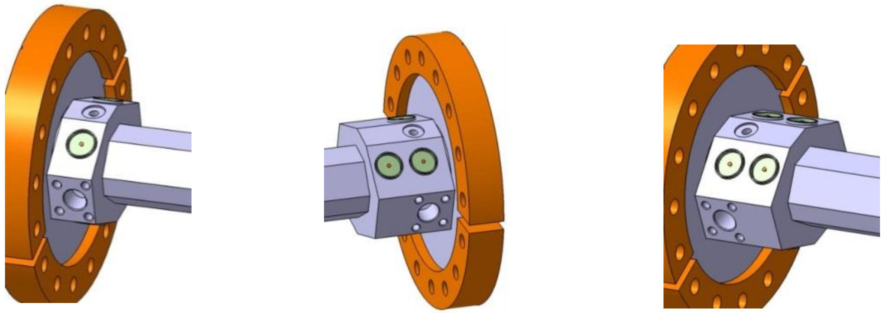
Mechanics



- 12 button BPMs for the storage ring
  - Resolution ~1 μm @ 10 Hz
  - Prototype done at LAL
  - Mechanics and soldering are done by RIAL Vacuum, to be delivered this summer
  - Additional electrodes on double BPM for:
    - Transverse and longitudinal bunch by bunch feedbacks
    - Polarization for ion cleaning



ESRF (old) type
10 mm button



4, 6 and 8 buttons BPMS

BPM prototype

- ✓ Design
- ✓ Prototyping
- ➢ Manufacturing
- ➢ Feedthrough welding
- ➢ Electrical test

Position measurement (BPM)
Electronics

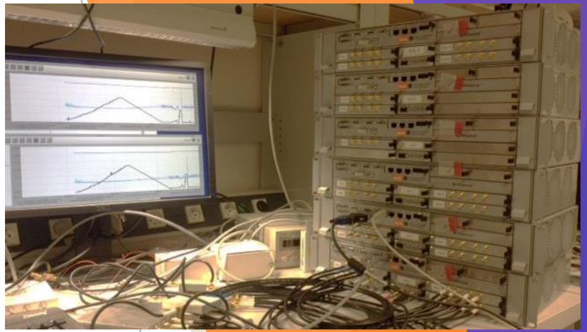
- Libera Brilliance+ (Instrumentation Technologies)
  - 4 BPM boards per crate
  - Data Flow:
    - Single Pass for Linac and Transfer Line
    - @ 8,33 MHz (half rev. freq.) ~turn by turn data for storage ring
    - @10 Hz slow acquisition data for storage ring
  - Automatic gain control
  - Post-mortem and interlock possibilities
  - Tango device available and fully configurable embedded on the ARM processor

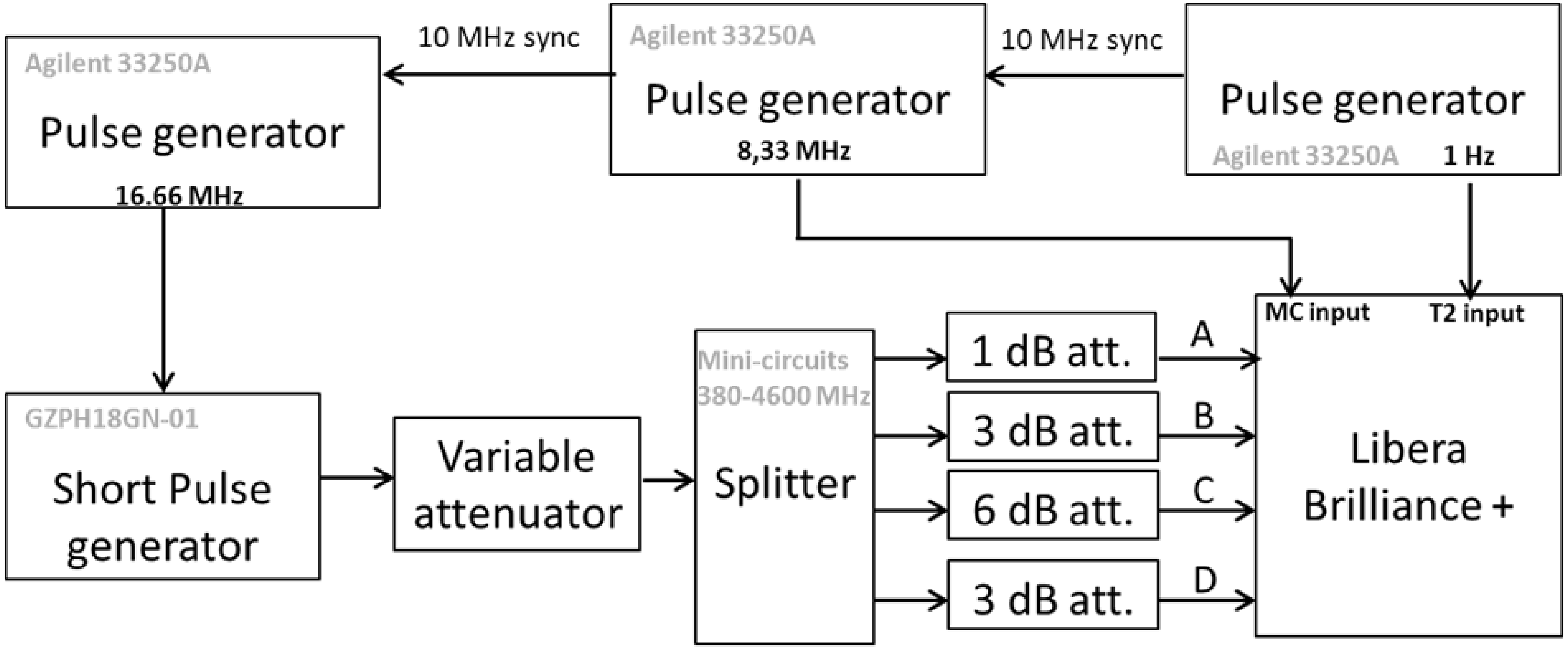
Libera Brilliance +

- ✓ Design (adaptation)
- ✓ Manufacturing
- ✓ Reception tests (more than one year…)

Position measurement (BPM)
Electronics acceptance tests

- Acceptance tests: Turn by Turn (8.33 MHz) and Slow Acquisition data (10 Hz)

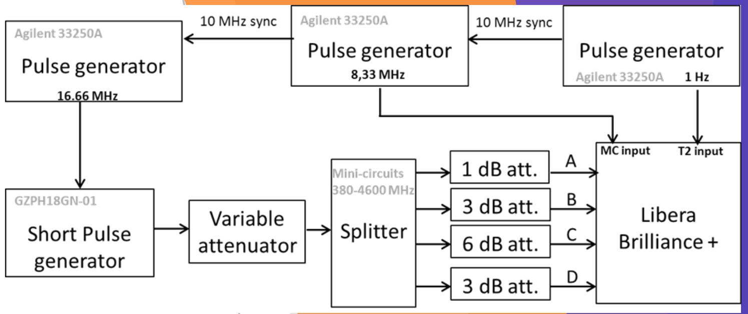




Test bench for acceptance test

Position measurement (BPM)

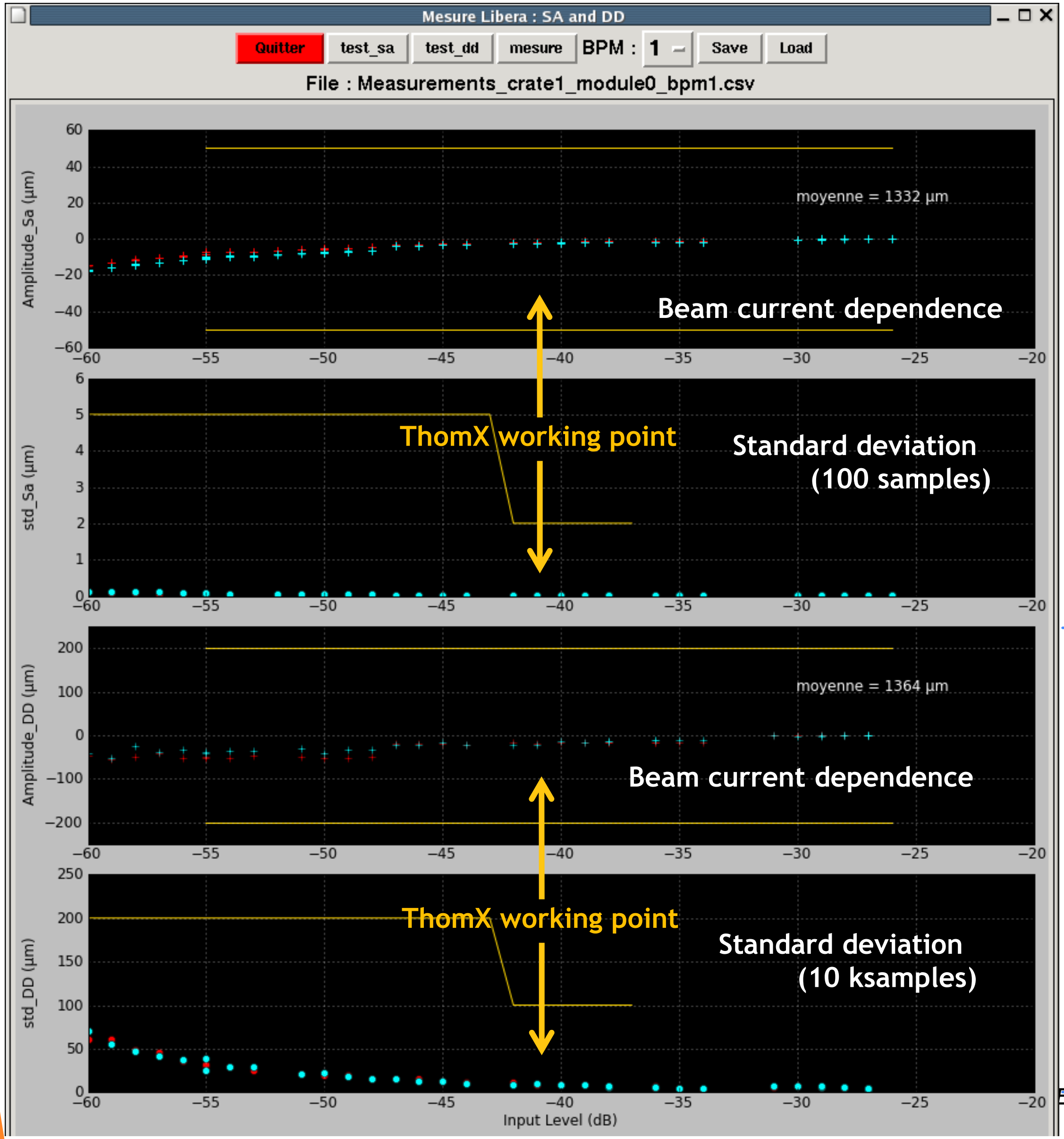
Electronics acceptance tests



Test bench for acceptance test

Slow Acquisition Data (10 Hz)

Turn by Turn Data (8,33 MHz)



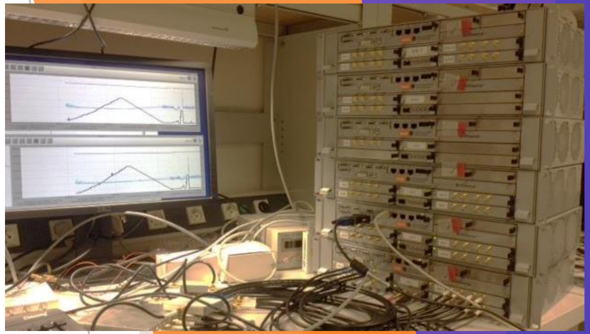
For Slow Acquisition (SA) data
100 samples are acquired at each power level to calculate rms and average values
Switching=1 (enable)
DSCCoeffAdjust=1 (calculation of adjusted coefficient is activated)

For both:
OffsetTune=1
CompensateOffset=1 (enabled)
Automatic Gain Control: ON
Digital Signal Conditioning:
DSCFrequency=10 (1seconde)
DSCType=1 (last calculated adjusted coefficients are used))
DSCCoeffAttDependent=0 (disabled)
DSCToleranceThr=8 (%)

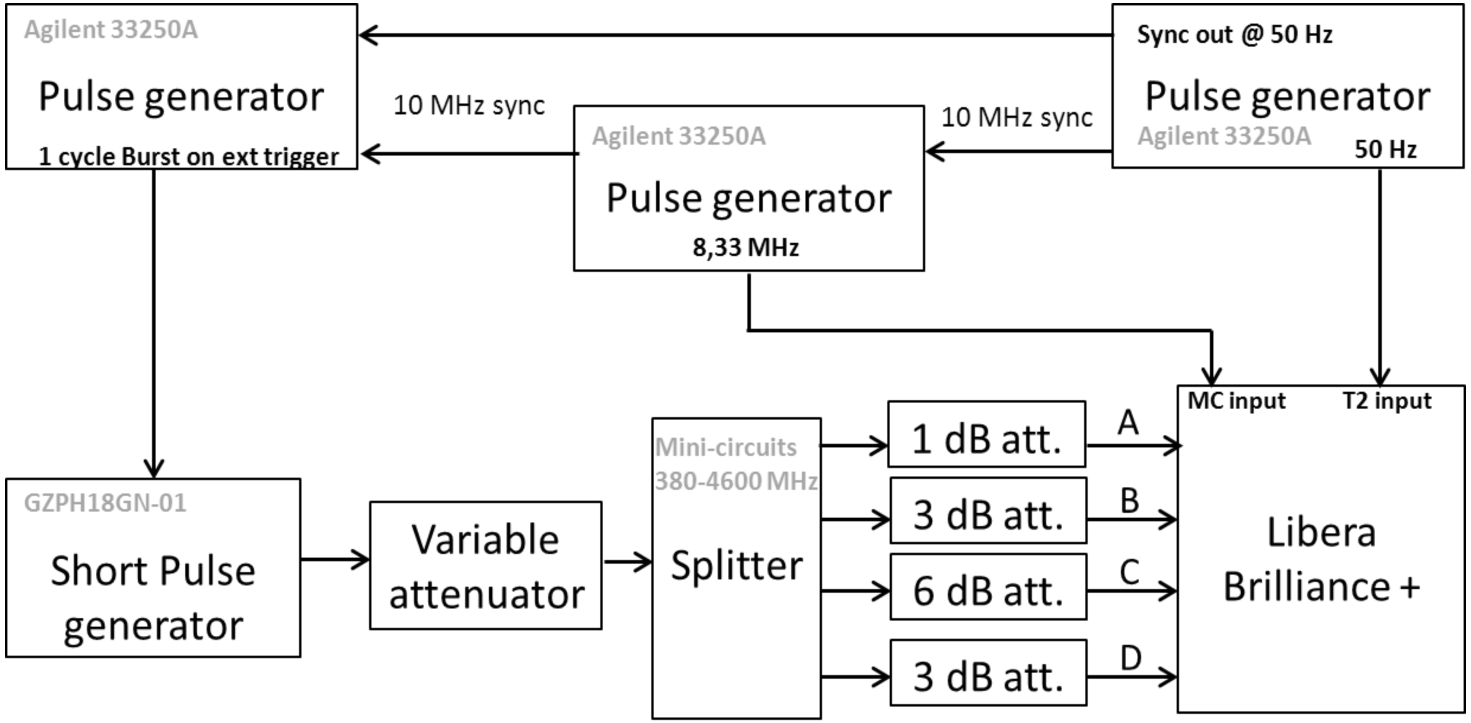
For Turn by Turn data:
DDC data flow is used
Switching=0 (disabled)
DSCCoeffAdjust=0 (calculation of adjusted coefficient is disabled)
Buffer length= 10 000 samples

Position measurement (BPM)

Electronics acceptance tests



- Acceptance tests: Single Pass Data

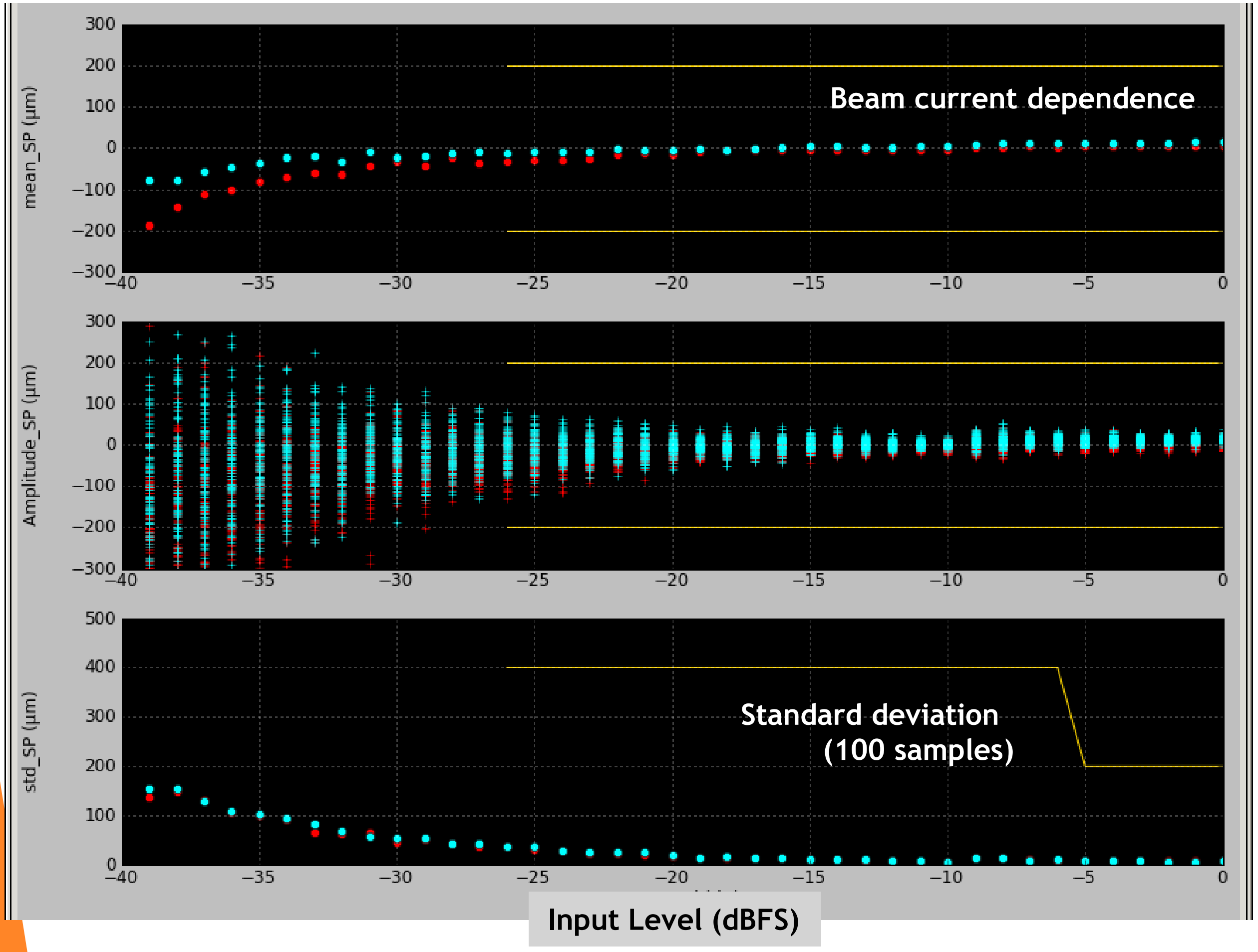


Test bench for acceptance test

Position measurement (BPM)

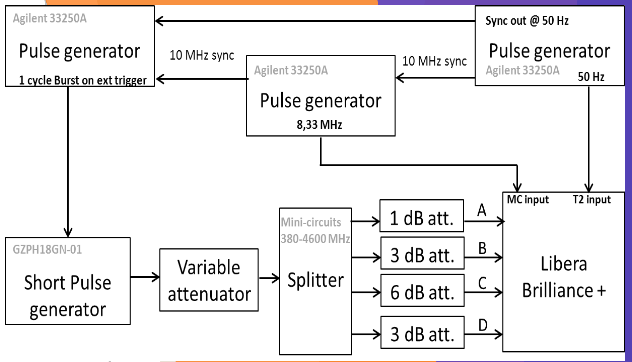
Electronics acceptance tests

- Acceptance tests: Single Pass Data

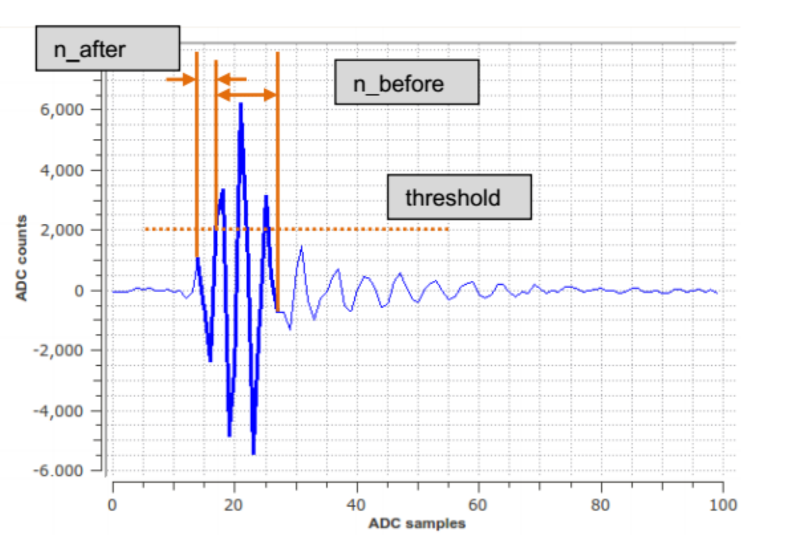


Libera configuration for Single Pass:
OffsetTune=0
Switching=0 (disabled)
CompensateOffset=0 (disabled)
Automatic Gain Control: ON
Digital Signal Conditioning:
DSCType=0 (unity coefficients are used)

SpNBefore=1
SpNAfter= 40
SpThreshold= 256



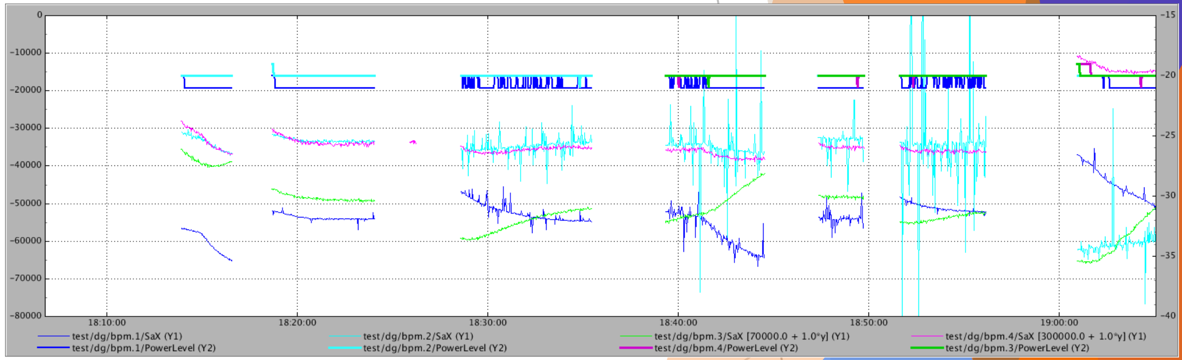
Test bench for acceptance test



Position measurement (BPM)
Electronics

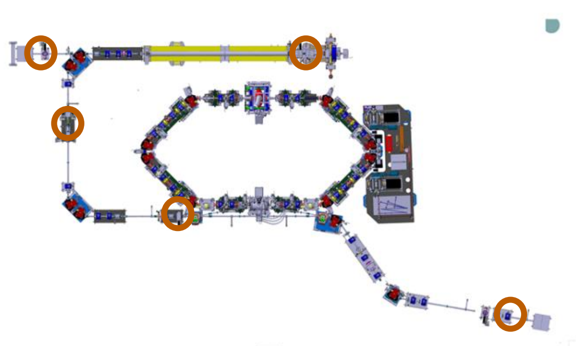
- Reliability issues during Libera Brilliance+ acceptance tests
  - First unit delivered in January 2015
    - Acceptance test validated in march 2015
      - Performances (beam current dependence, resolution…) are ok
      - Reliability issues pointed out (boot, data availability, Tango device server)
  - 5 other modules delivered in september 2015
    - Acceptance test not yet validated
      - Performances (beam current dependence, resolution…) are ok.
      - Still reliability issues
        - Software upgrade: november 2015
        - 1 module back to I-Tech during 6 month
        - Software upgrade: november 2016
        - Hardware patch: november 2016
        - FPGA upgrade: January 2017
          - Added reset on NCO to solve spikes issue
        - OS upgrade: March 2017
          - From Ubuntu 10.04 to 14.04
          - For software and Tango device compatibility

Libera Brilliance +



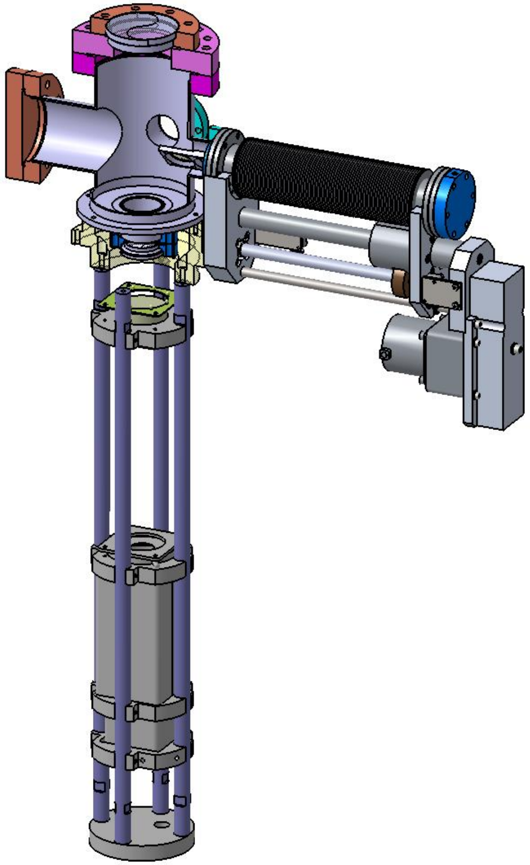
Spikes issues with boot dependance

Diagnostic stations



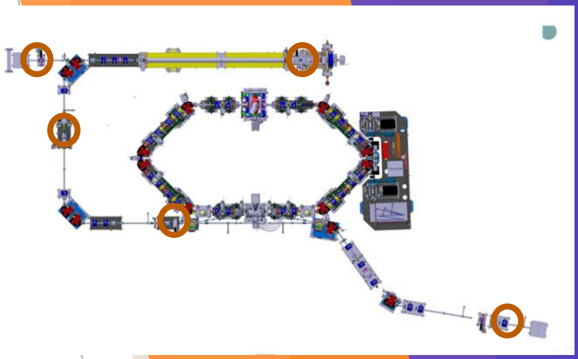
- Location
  - 5 Stations on Linac and transfer lines
- Purpose:
  - Beam size, emittance and energy measurement
- Principle:
  - Screen translation stage
    - Calibration plate
    - YAG (Ce): 25 mm diameter, 100 µm thick
    - OTR : 25 mm diameter, 100 µm aluminised silicon wafer
    - Sapphire screen (station 2 @ end of Linac)
  - View port: Fused Silica DN 60 CF
  - Imaging system
  - Gigabit Ethernet trigged CCD

> ✓ Design
>
> ✓ Screens are delivered
>
> ✓ 1 translation stage is ready, the others to be ordered

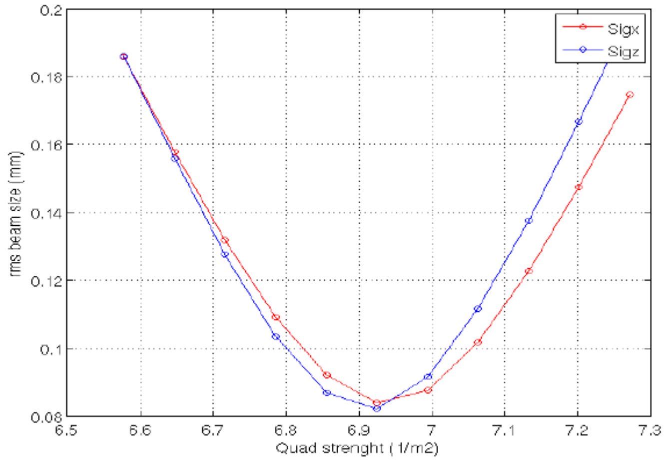


Screen translation stage

Diagnostic stations

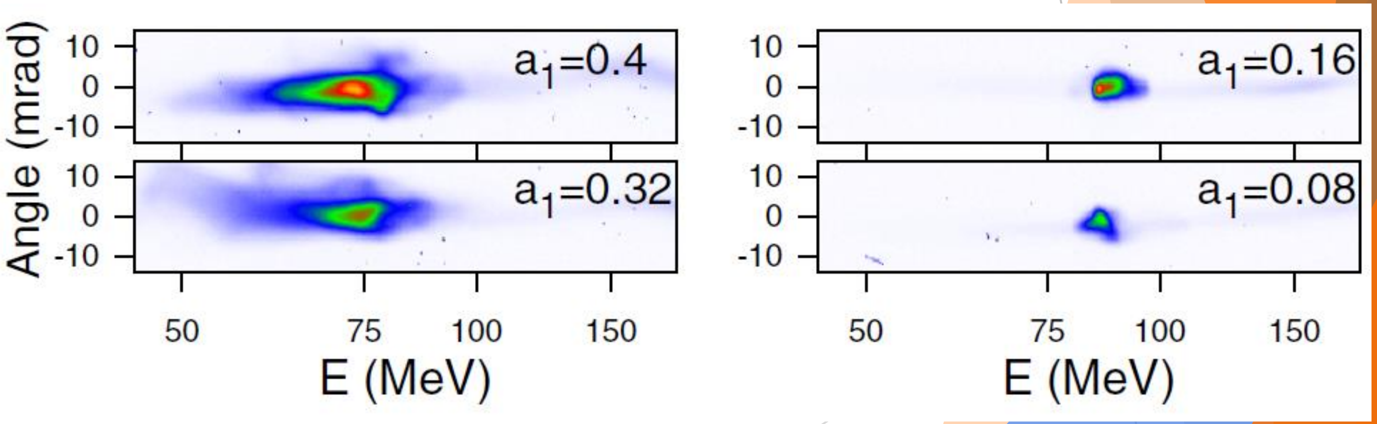


- **Transverse size measurement (1 to 2.5 mm)**

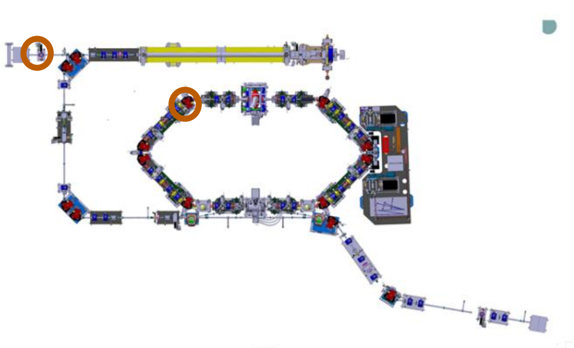


- **Emittance measurement**
  - Using Quadrupole scan method
    - Measure beam size vs Qpole strength
    - Required resolution: 10 pixels/sigma
    - Devices: 1 quadrupole + screen + CCD
    - Location:
      - @ Diag stations 2 and 3

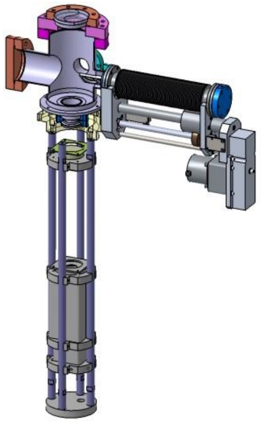
- **Energy measurement:**
  - Passing through dipole magnet → dispersion
    - <x> → E = energy
    - dx → dE = energy spread
  - Device:
    - Dipole + screen + CCD
  - Location:
    - @ middle of transfer line (Diag Station 3)
    - @ dump 2 (Diag station 5)



Bunch length measurement



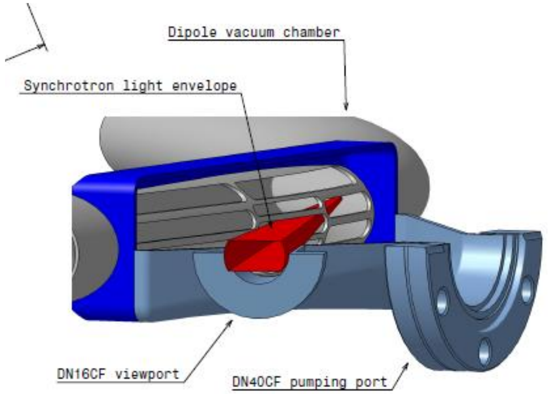
- End of Linac (4.3 ps expected):
  - Cherenkov radiation produced when the electron beam passes through the sapphire screen
  - Sapphire window to extract light
  - Transport the radiation to a streak camera to measure the photon pulse length.



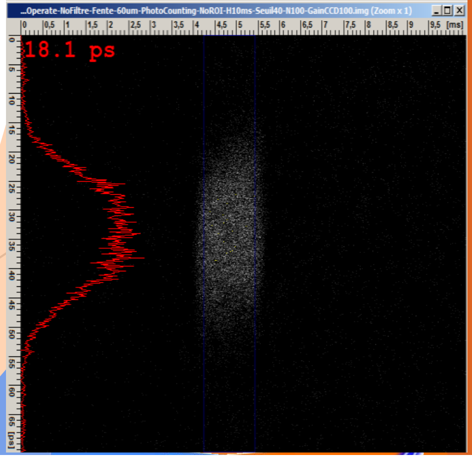
Cerenkov radiation in sapphire screen

- Hammamatsu streak camera
  - Double sweep and UV tube

- Storage Ring (5 to 20 ps expected):
  - Synchrotron radiation produced when the electron beam changes its trajectory in the bending magnet
  - Sapphire window to extract light
  - Transport the radiation to a streak camera to measure the photon pulse length.



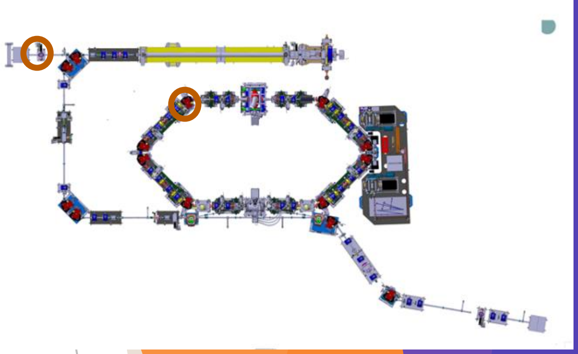
SR extraction port

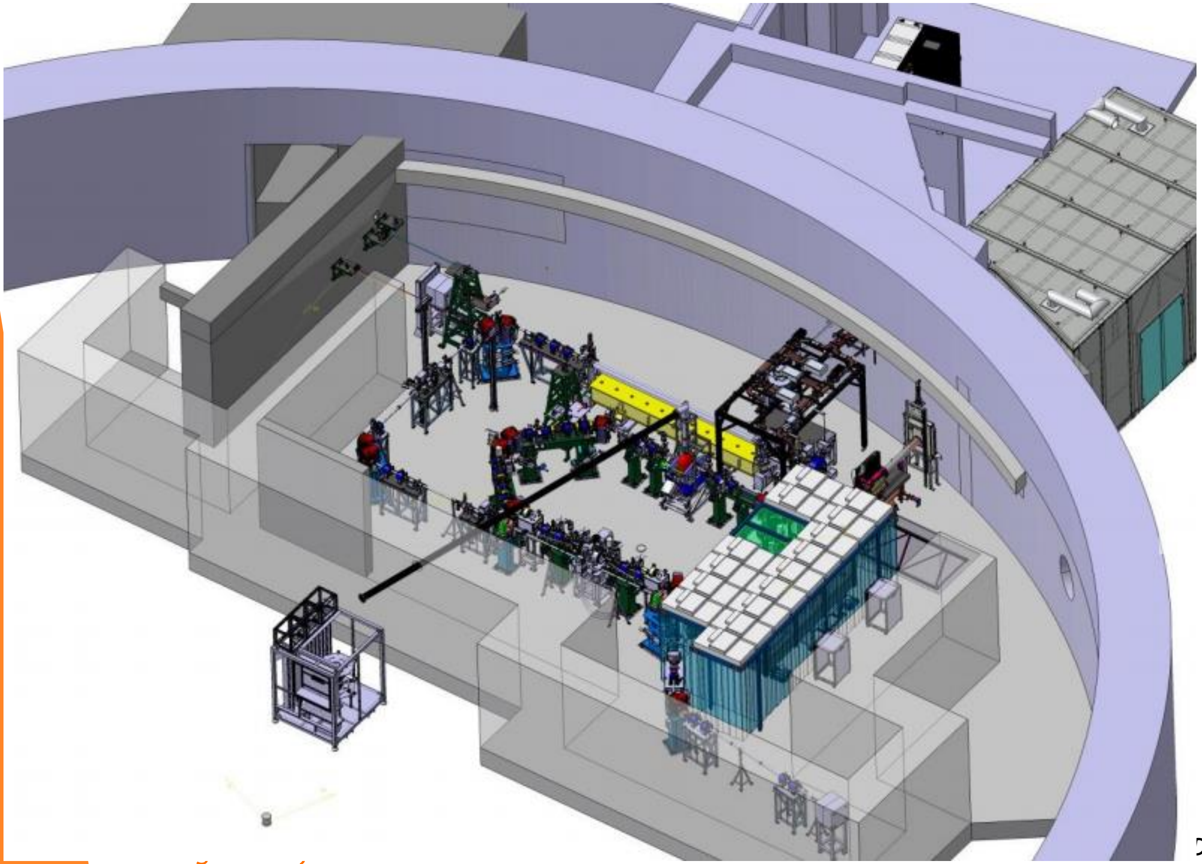


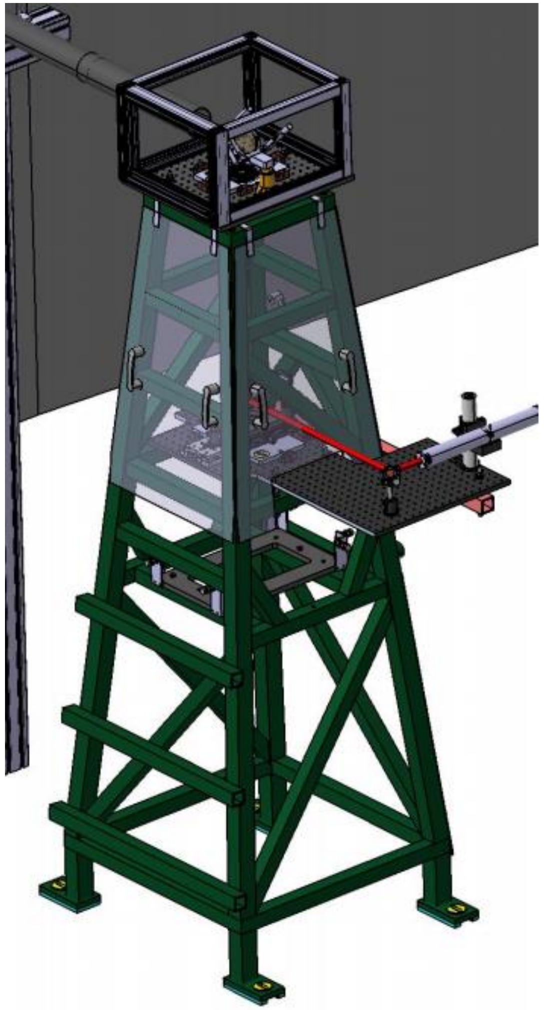
Cerenkov radiation longitudinal measurement on PHIL with ThomX streak camera (photon counting mode)

Bunch length measurement

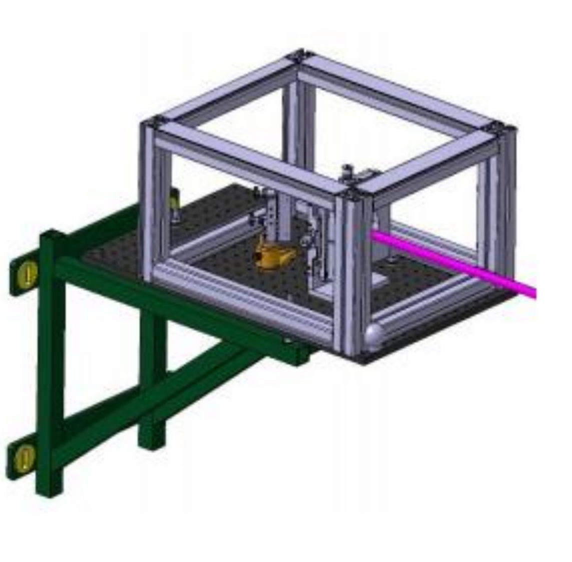
- Complex transport path to the streak camera
  - Streak camera installed inside laser hutch
  - Mirror support at 2.3 meter high

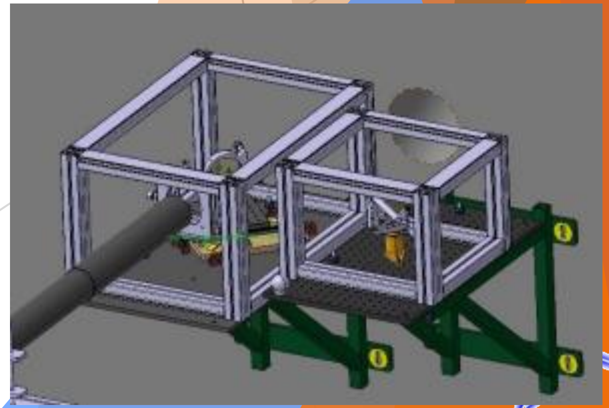




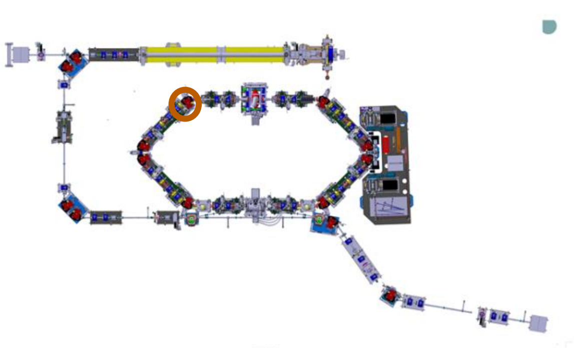


Cerenkov Eiffel Tower

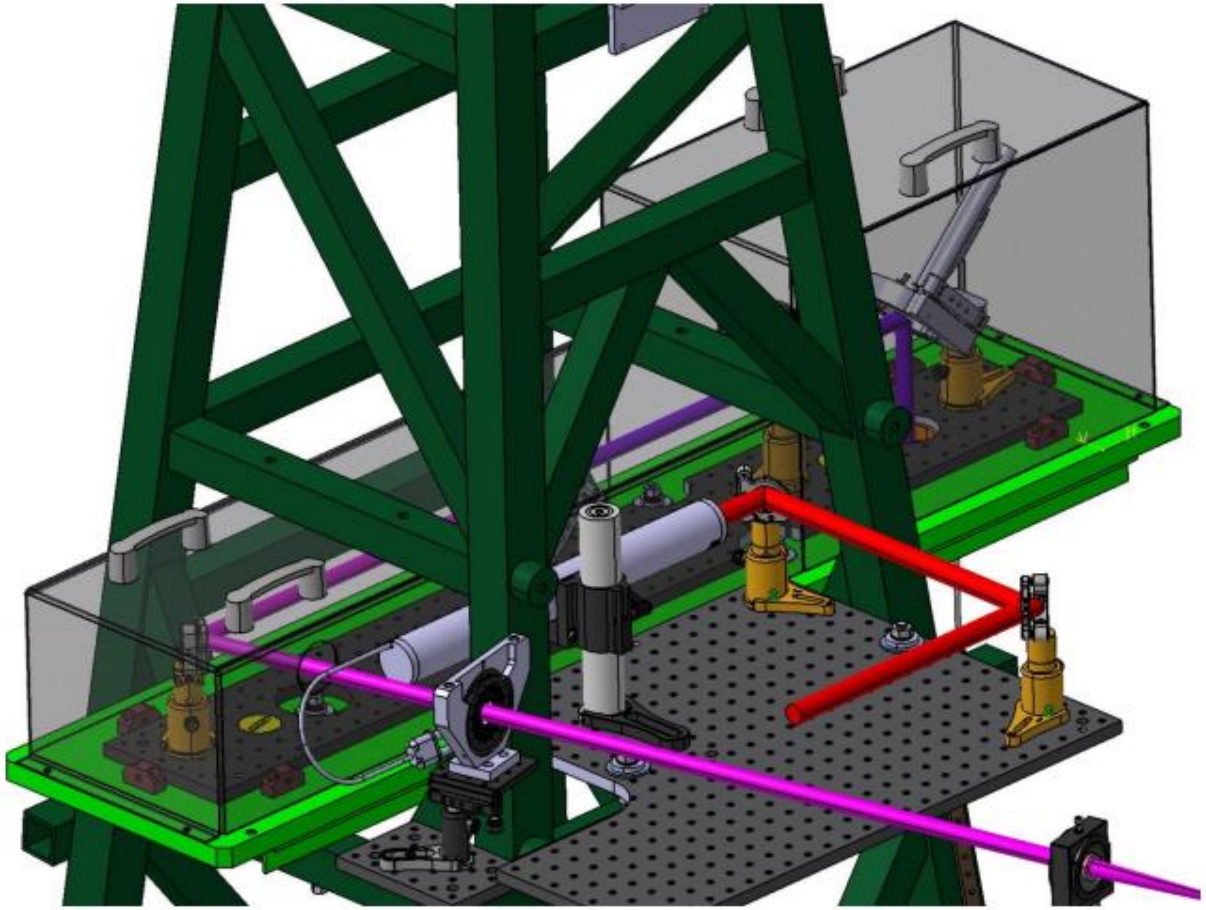




Synchrotron Light Monitor



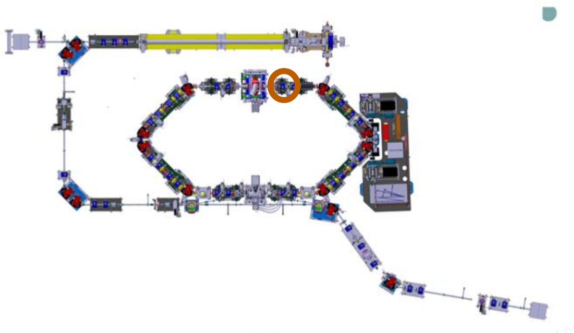
- Visualization of the beam in the storage ring in transverse plane

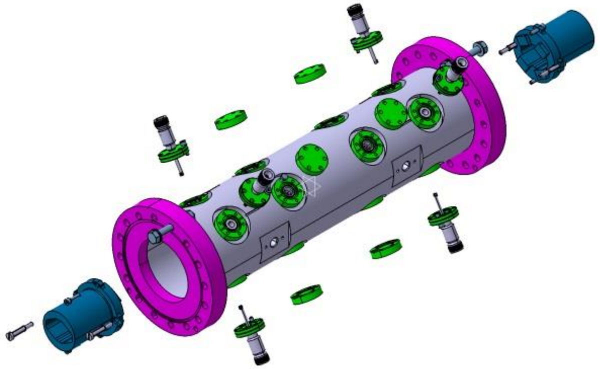


SR Eiffel Tower

Transverse feedback

- Design of a stripline
  - See Moussa presentation tomorrow

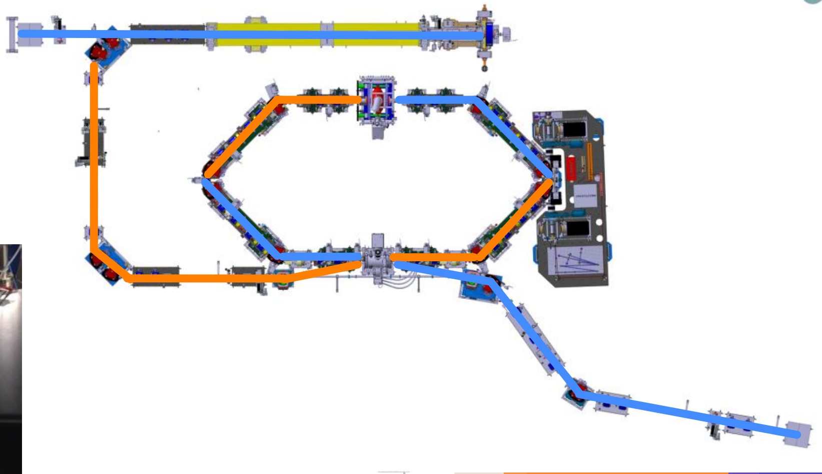


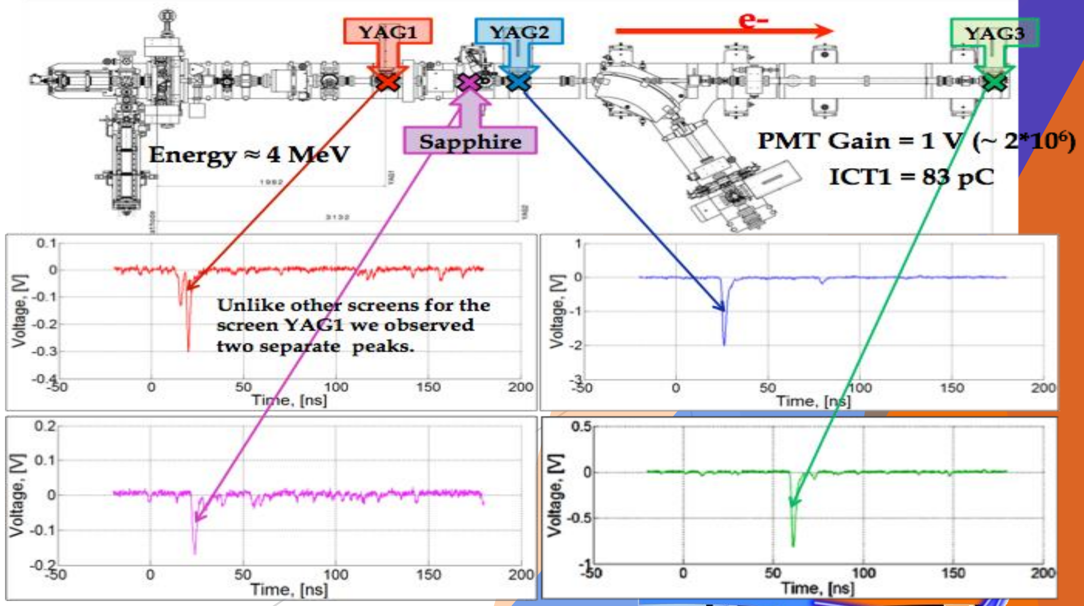


Transverse feedback stripline

Beam Loss Monitors

- Fiber Beam Loss Monitor (FBLM)
  - Principle:
    - Particle loss → passes through the fiber → generates Cherenkov light pulse in the fiber.
    - Pulse propagates to photomultiplier
    - Time at witch the loss pulse arrives with respect to the trigger (reference) gives the location of the loss
  - 1 fiber for the LINAC, 1 for the TL, 4 for the SR and 1 for the EL.
  - The choice of the fibers and PMTs are made, the order to be passed at beginning of 2017. The controller for the DAC to control remotely the PMT gain: the order to be passed at the beginning of 2017.
  - DAQ: Wavecatcher + Scope for the SR
  - Beam test @ PHIL: Wavecatcher and its Tango DS have been successfully tested with the FBLM.





Fiber BLM tests on PHIL

Beam Loss Monitors

- Scintillators coupled to the PMT to monitor the local losses (e.g. @injection)
  - Scintillator: Thalium activated Cesium Iodide CsI(Tl)
  - More sensitive than fibers
  - Positioned at specific locations and to be used during the commissioning and operation.
  - Scintillator is available, PMT and controller for the DAC will be ordered at the same time as for the FBLM.
  - DAQ: RedPitaya card (Tango DS is ready) is under the test => inside crate Diag 5 and 6.
  - The assembly has been tested using the scope with the radioactive sources and with the beam @ PHIL.

CsI(Tl) + PMT

Red Pitaya

Conclusion

- A small machine but many different diagnostics
  - Time spent on:
    - Optical transport for bunch length measurement
    - Transverse feedback stripline design
    - Libera acceptance tests (not expected!)
- ThomX schedule: