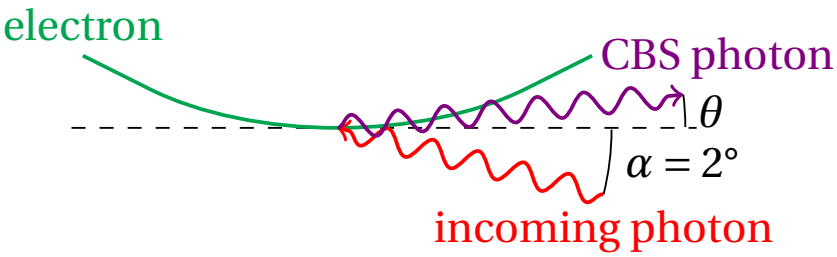
IPAC'22 : First electron beam

Alexandre Moutardier
on behalf of the ThomX collaboration

IJCLab, Orsay, France

June 15th , 2022

ThomX : x-ray source from Compton back-scattering

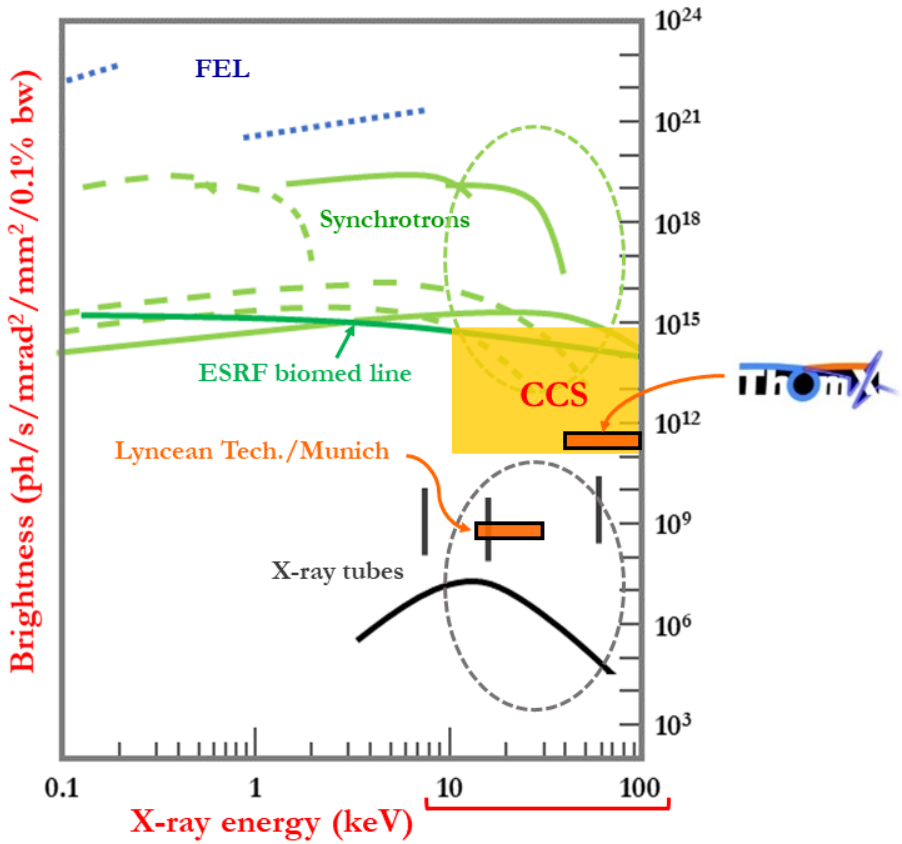


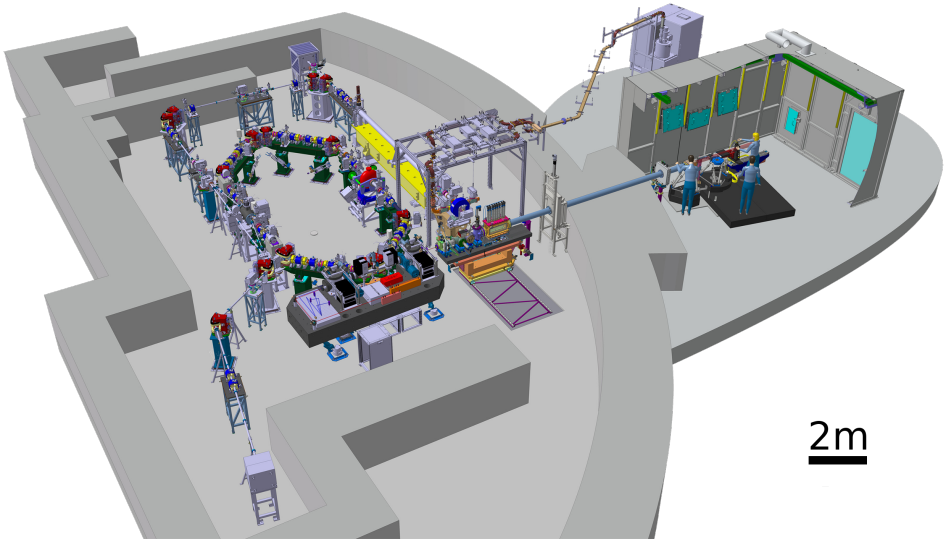
Schematic of Compton back-scattering collision

- CBS : momentum transfer from e^- to γ
- Maximal energy gain ($\theta = 0°$):

$$E_{CBS,max} = 4\left(\frac{E_e}{m_e c^2}\right)^2 \times E_\gamma = 4\gamma^2 \times E_\gamma = 45\,\text{keV}$$

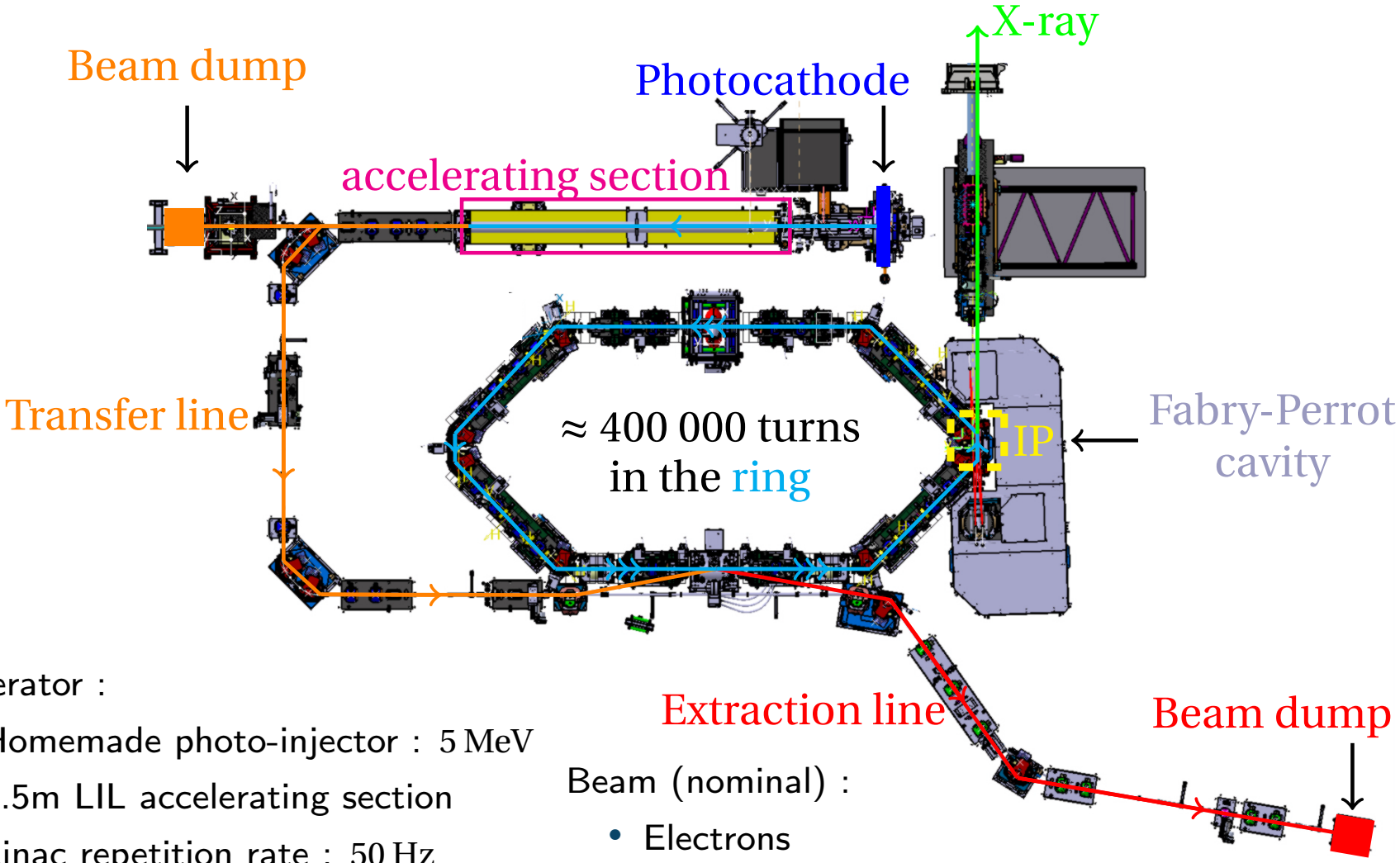
with : $\gamma \approx 100$ the Lorentz factor





ThomX overview

The ThomX accelerator



Accelerator :

- Homemade photo-injector : 5 MeV
- 4.5m LIL accelerating section
- Linac repetition rate : 50 Hz
- Fast injection kicker : 50 ns
- X-ray repetition rate : 16.6 MHz
- Surface : 70 m^2

Beam (nominal) :

- Electrons
- Beam energy : 50 MeV (70 MeV)
- Beam charge : 1 nC
- Transverse emittance : 5πmmmrad

ThomX main dates

2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

- 2007 : First discussion at LAL (Now IJCLab)

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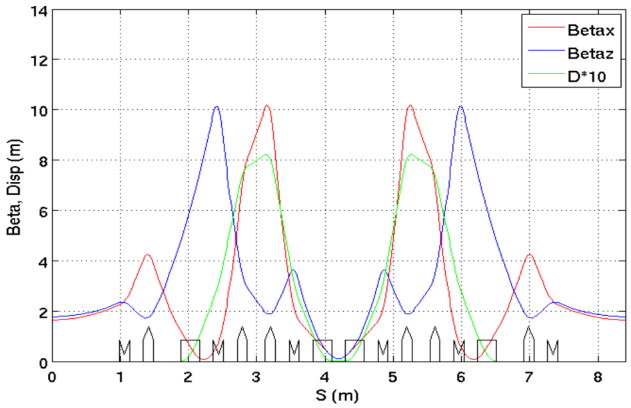


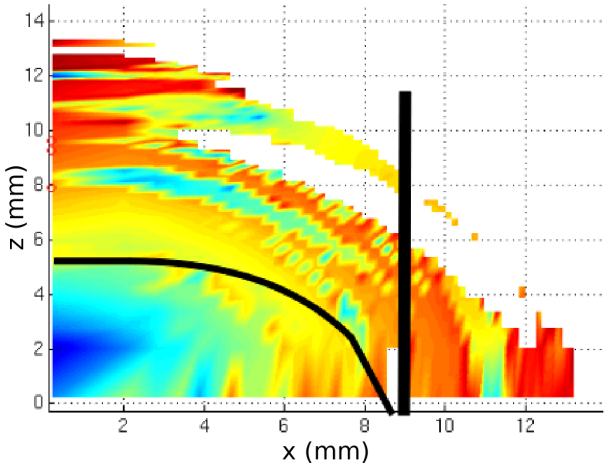
← Half ring lattice :

- Interaction point : $\sigma = 70\,\mu m$

→ Ring acceptance study :

- Blue : particles stored
- Red : particles not captured
- Black ellipse : beam pipe

- https://accelconf.web.cern.ch/IPAC10/papers/thpe060.pdf



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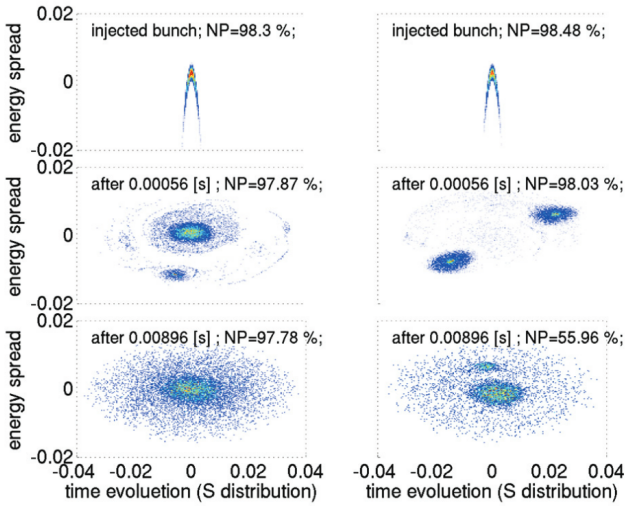

Beam evolution in the ring :

- At injection
- After 0.56 ms
- After 0.896 ms

- Left : CSR without spliting or loss
- Right : CSR with split bunch and ≈50 % losses

- https://accelconf.web.cern.ch/IPAC2013/papers/mopwo004.pdf

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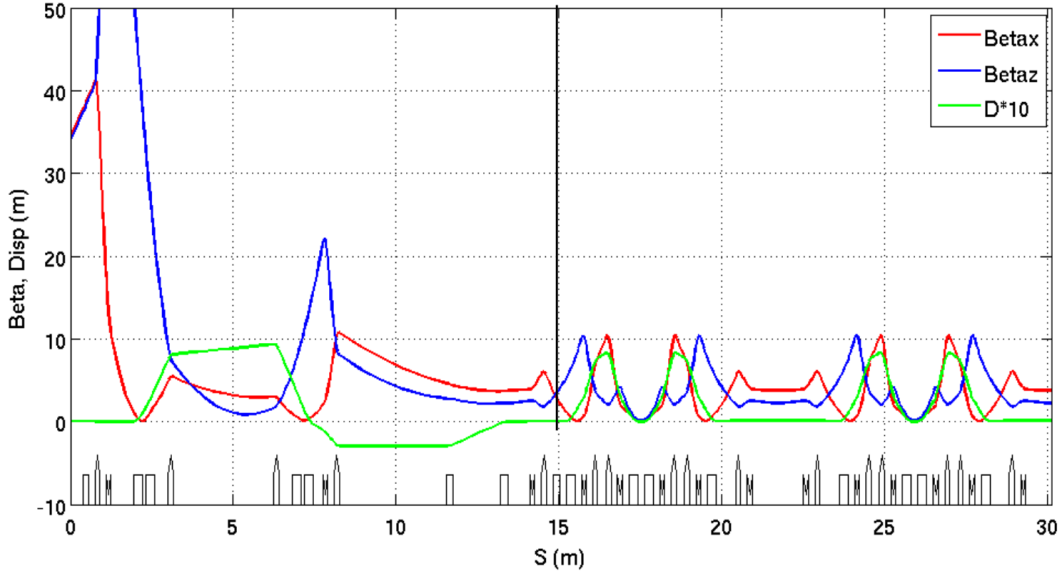

- Transfer line matching with the ring
- https://hal.archives-ouvertes.fr/in2p3-00971281

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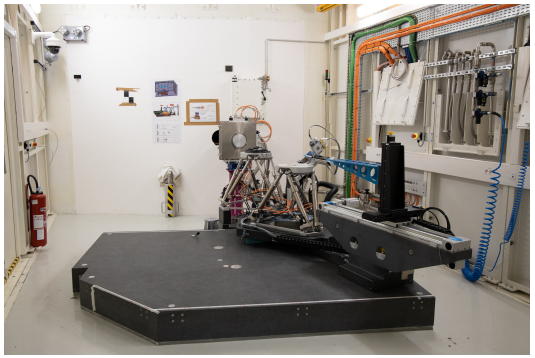
April 2016

May 2016

May 2018



January 2021

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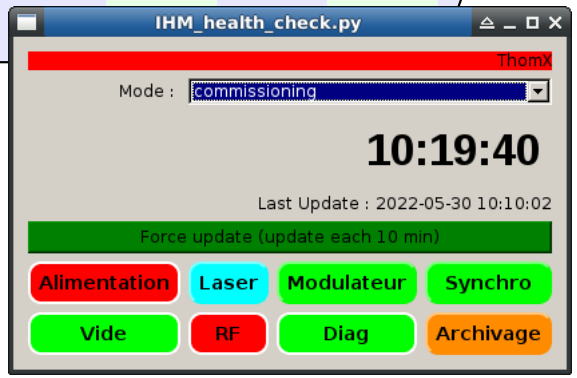
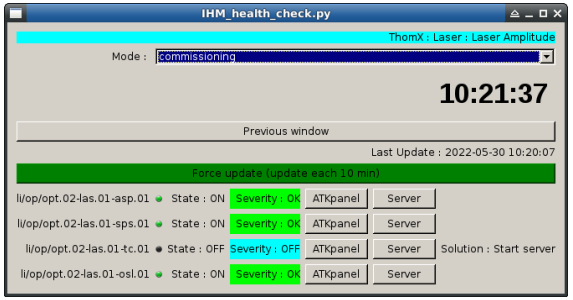
- 2016 : Building rehabilitation
- 2019 : Dry run without RF power

- Dry run without RF
- First dry run : 1 day
- Second dry run : 1/2 day
- Some issue have been pointing out
  - Lots of Device Server to manage
  - ⇒ GUI developed : Health check
- moutardier@ijclab.in2p3.fr





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- 19 May. 2021 : Phase I authorization from French Nuclear Safety Authority

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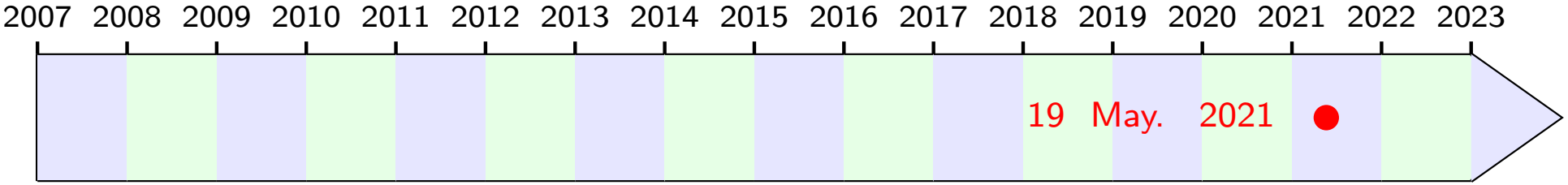
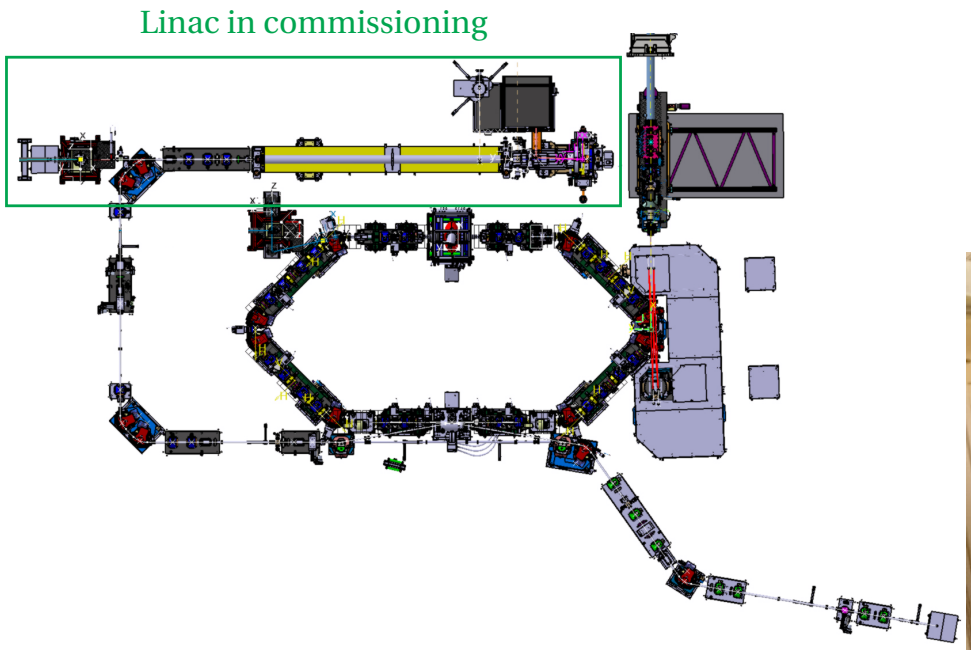
✓ Linac commissioning authorization

- https://fr.wikipedia.org/wiki/Fichier:Logo_ASN.svg

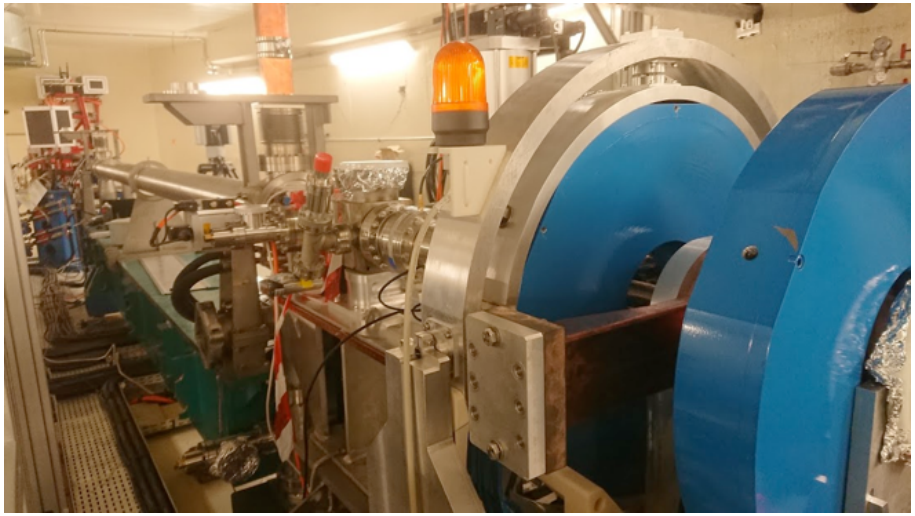
ASN authorization : phase I



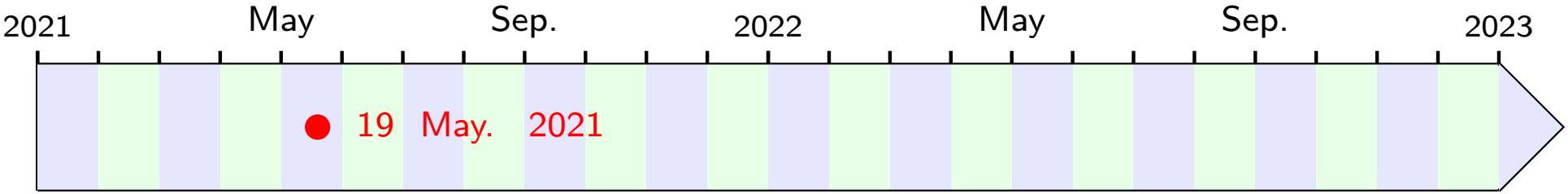


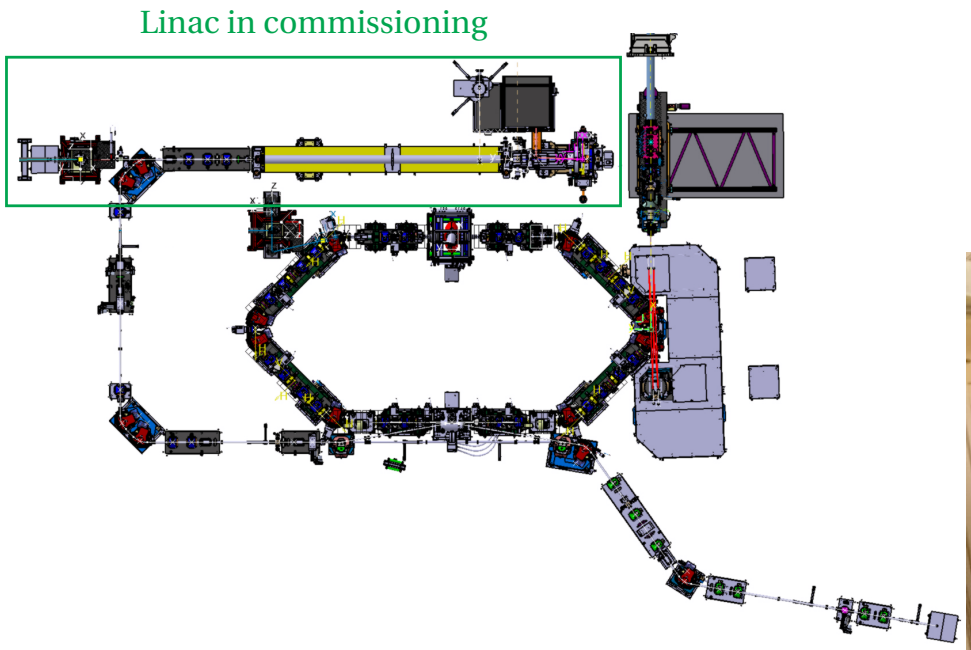
Nominal parameters of phase I :

- Repetition rate : $10\,\mathrm{Hz}$
- Beam energy : $50\,\mathrm{MeV}$
- Beam charge : $100\,\mathrm{pC}$
- Transverse emittance : 2πmmmrad



ASN authorization : phase I





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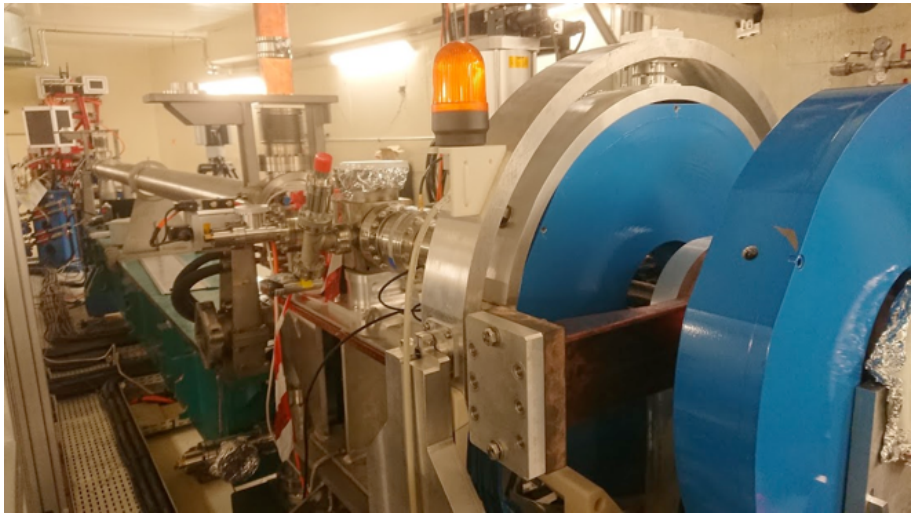
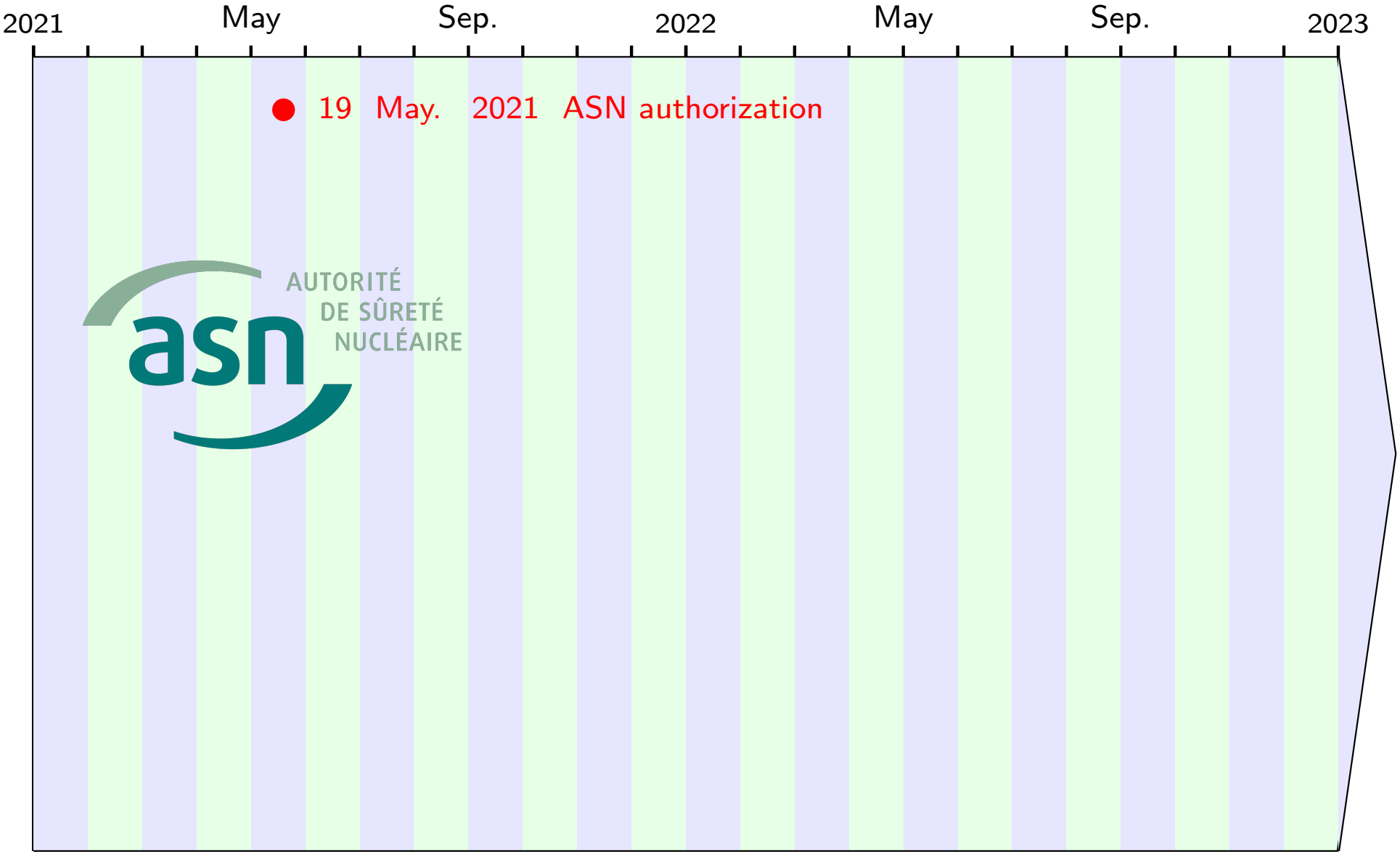


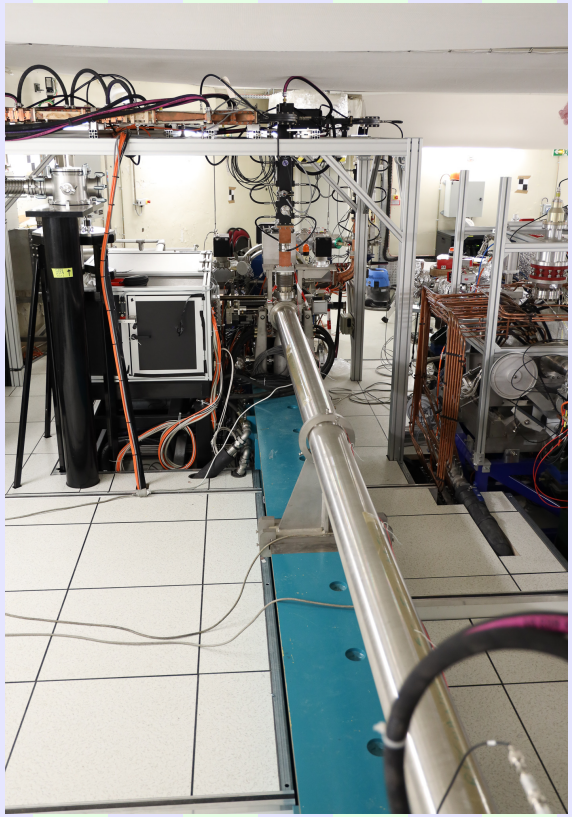
Commissioning main dates



Commissioning main dates

2021 May Sep. 2022 May Sep. 2023

- 19 May. 2021 ASN authorization
- Jun. 2021 Commissioning RF section



← Accelerating section (upstream)

- Lep Injector Linac lend by SOLEIL
- 10 Hz
- 9 MW
- 1 day for RF test, 1 day for section commissioning

Commissioning main dates

2021 May Sep. 2022 May Sep. 2023

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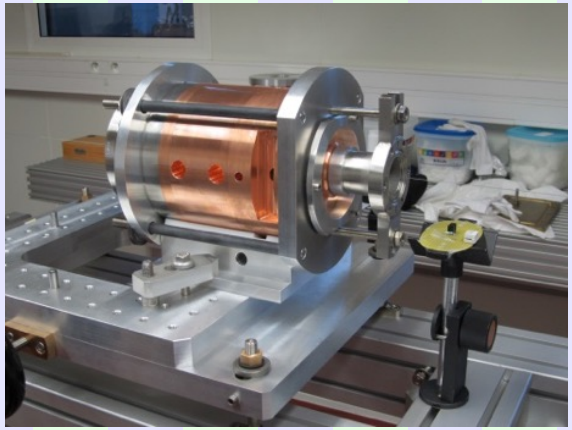
- Jun. 2021 Commissioning RF section
- Sep. 2021 Commissioning RF gun (1 Hz)



- 15 Oct. 2021 Commissioning RF gun (10 Hz)

- Homemade RF gun
- 2.5 cells
- 1 Hz
- $5\,\mathrm{MW} \Rightarrow 60\,\mathrm{MV\,m^{-1}}$
- 3 weeks + 1 week

Commissioning main dates

2021 May Sep. 2022 May Sep. 2023

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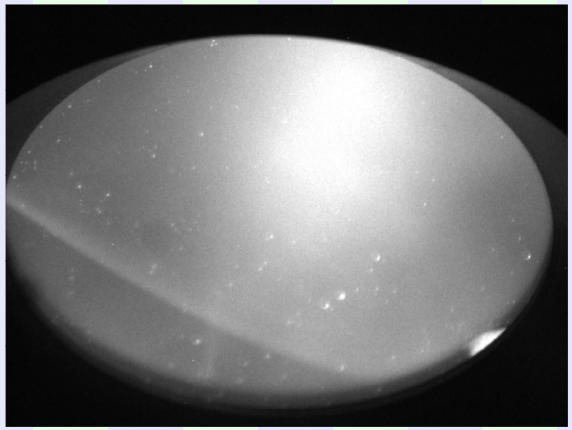
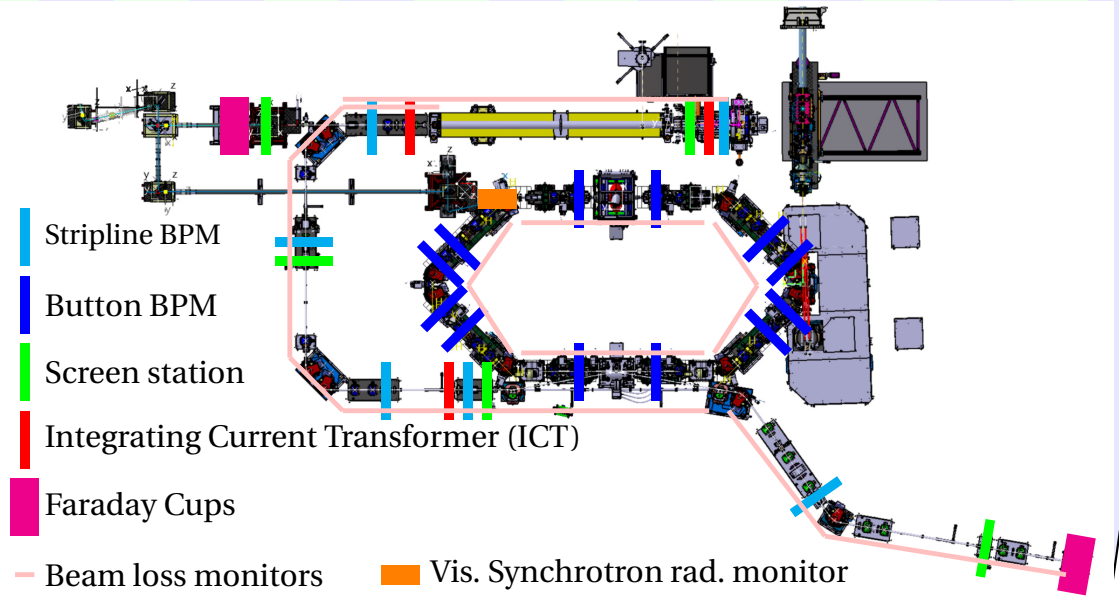
- Jun. 2021 Commissioning RF section
- Sep. 2021 Commissioning RF gun (1 Hz)
- 30 Sep. 2021 First dark current



- Dark current
- YAG:Ce screen
- After the gun



Diagnostics positioning

Commissioning main dates

2021 May Sep. 2022 May Sep. 2023

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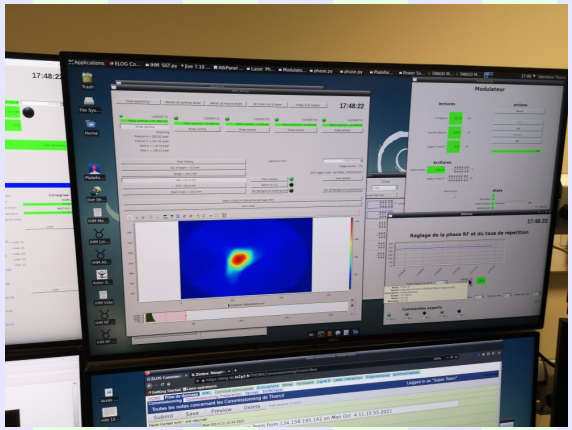
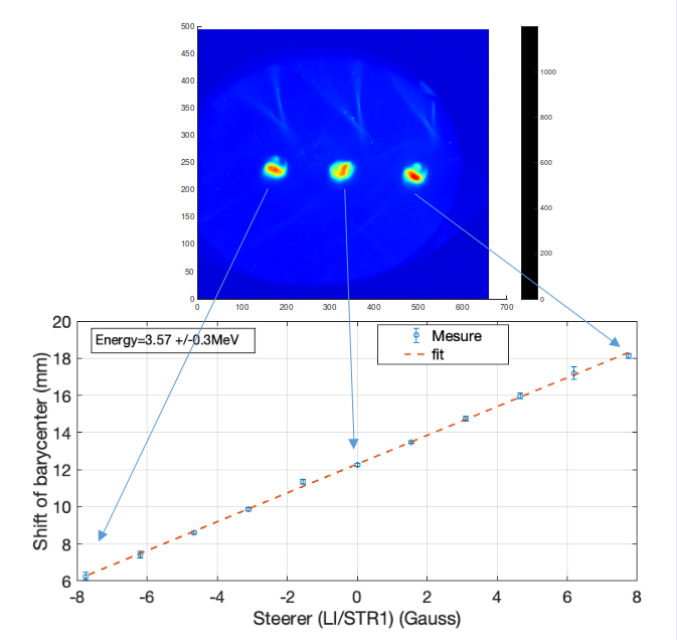
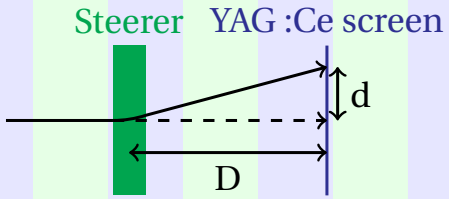
- Sep. 2021 Commissioning RF gun (1 Hz)
- 30 Sep. 2021 First dark current
- 4 Oct. 2021 First e^- beam after the gun (4 MeV)



- Photo-emitted electrons
- YAG:Ce screen
- After the gun





$$E = L_{mag} \times D \times \frac{\Delta B}{\Delta d}$$

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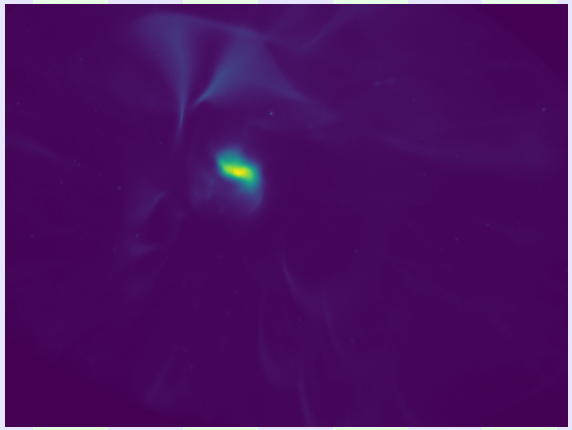

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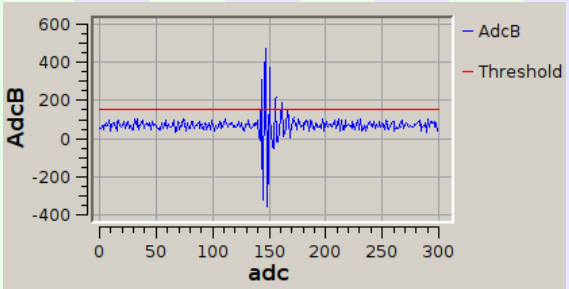

- Blue : Beam Position Monitor signal on top electrode
- Red : triggering threshold
- Electronics : Libera brilliance +

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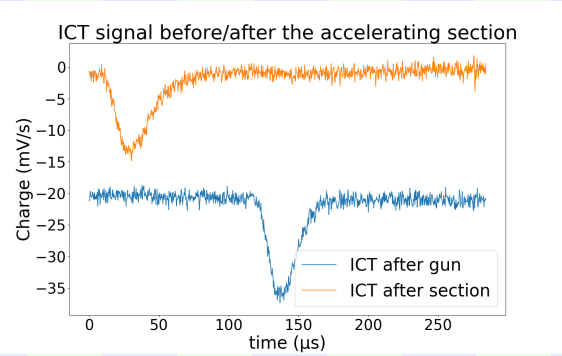
- 7 Oct. 2021 Max allowed charge transmitted (100 pC)



- Integrating Current Transformer (ICT) signal :
  - Blue : after the gun
  - Orange : after the section
- Electronics : homemade WaveCatcher

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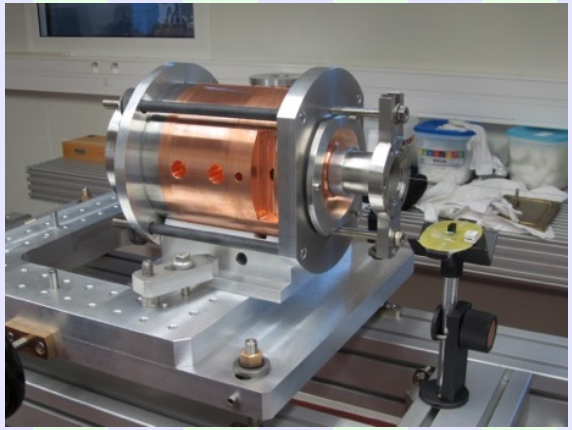

- Homemade RF gun
- 2.5 cells
- 1 Hz
- $5\,\mathrm{MW} \Rightarrow 60\,\mathrm{MV\,m^{-1}}$
- 3 weeks + 1 week

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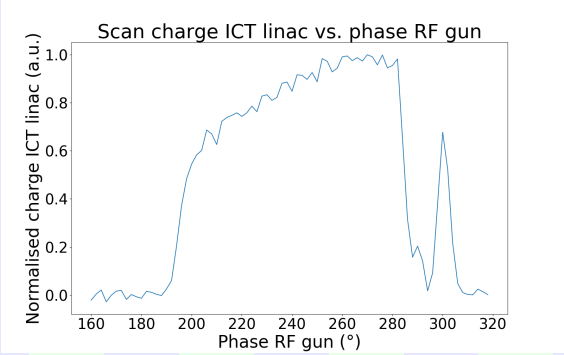
- 20 Oct. 2021 First e^- beam at 10 Hz



Beam charge after the gun vs. gun phase

- 10 Hz ⇒ faster measurement

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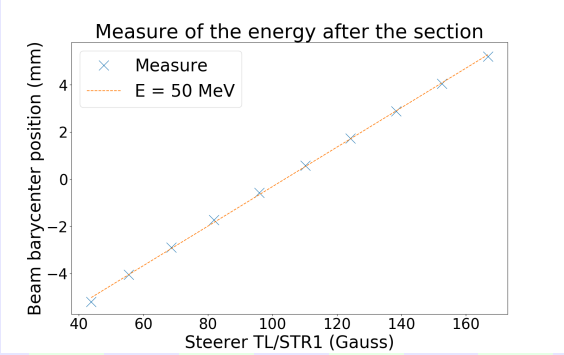
- 7 Oct. 2021 Max allowed charge transmitted (100 pC)
- 15 Oct. 2021 Commissioning RF gun (10 Hz)
- 20 Oct. 2021 First e^- beam at 10 Hz
- 26 Oct. 2021 Nominal energy (50 MeV)



- Steerer after the section
- Screen before the dump

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- 25 Nov. 2021 Safety check for phase II process

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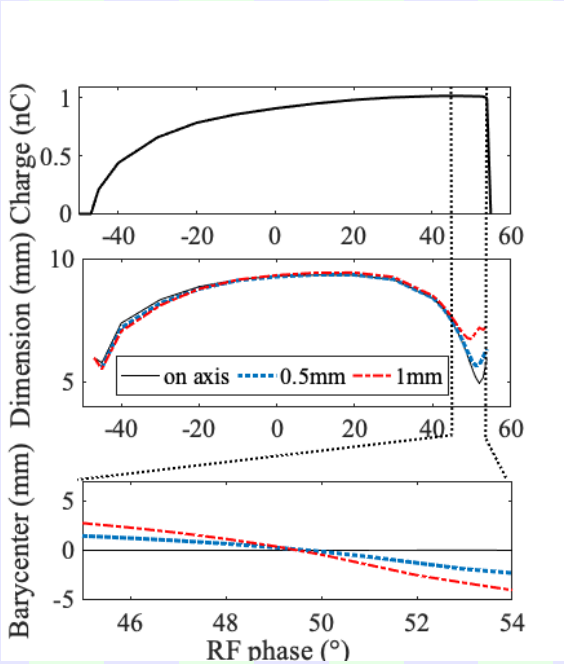
- 25 Nov. 2021 Safety check for phase II process
- Dec. 2021 Alignment study (still ongoing)



Impact of miss-alignment on beam propagation around phase of maximum charge.

See : H.Purwar *et al.*, "Random error propagation on electron beam dynamics for a 50 MeV S-band linac", unpublished.

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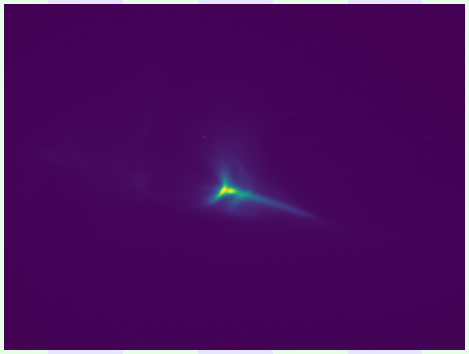
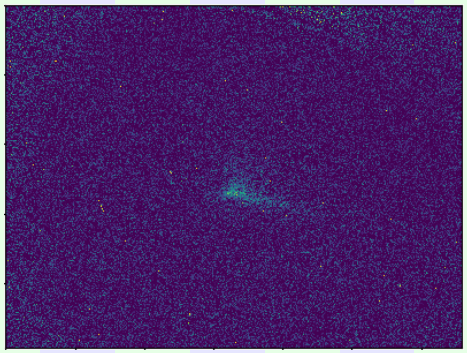
- 25 Nov. 2021 Safety check for phase II process
- Dec. 2021 Alignment study (still ongoing)
- 14 Jan. 2022 First OTR light



↑ YAG screen (one exposure)

↓ OTR screen (100 exposure)



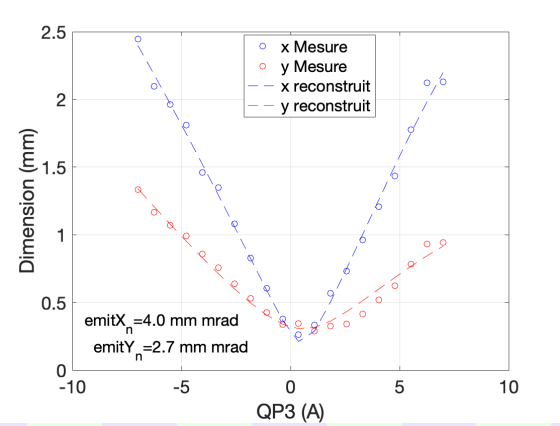
See : A. Moutardier *et al.*, "Characterization of the Electron Beam Visualization Stations of the ThomX Accelerator", presented at the IPAC'22, Bangkok, Thailand, Jun. 2022, paper MOPOPT006, unpublished.

Commissioning main dates

2021 May Sep. 2022 May Sep. 2023

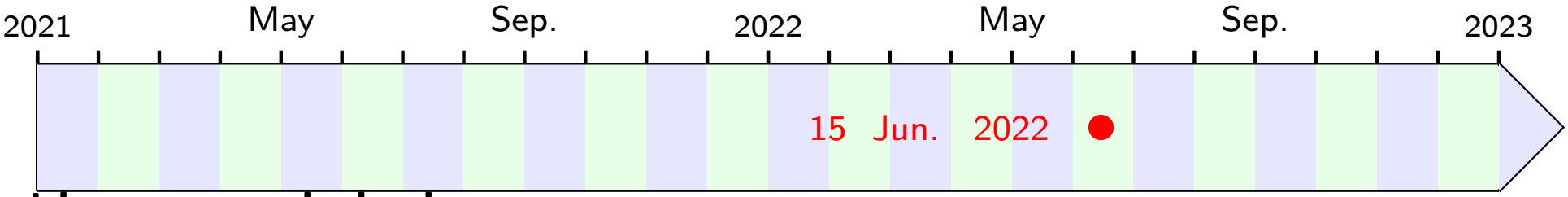
- 19 May. 2021 ASN authorization
- Jun. 2021 Commissioning RF section
- Sep. 2021 Commissioning RF gun (1 Hz)
- 30 Sep. 2021 First dark current
- 4 Oct. 2021 First e$^-$ beam after the gun (4 MeV)
- 6 Oct. 2021 First e$^-$ beam after the section (37 MeV)
- 7 Oct. 2021 Max allowed charge transmitted (100 pC)
- 15 Oct. 2021 Commissioning RF gun (10 Hz)
- 20 Oct. 2021 First e$^-$ beam at 10 Hz
- 26 Oct. 2021 Nominal energy (50 MeV)
- 25 Nov. 2021 Safety check for phase II process
- Dec. 2021 Alignment study (still ongoing)
- 14 Jan. 2022 First OTR light
- 15 Apr. 2022 Emittance measurement

Quad-scan after the section



- $\epsilon_x \approx 40\,\mathrm{nm\,rad}$
- $\epsilon_y \approx 30\,\mathrm{nm\,rad}$
- $\epsilon_{xn} \approx 4\pi\,\mathrm{mmmrad}$
- $\epsilon_{yn} \approx 3\pi\,\mathrm{mmmrad}$

Conclusion

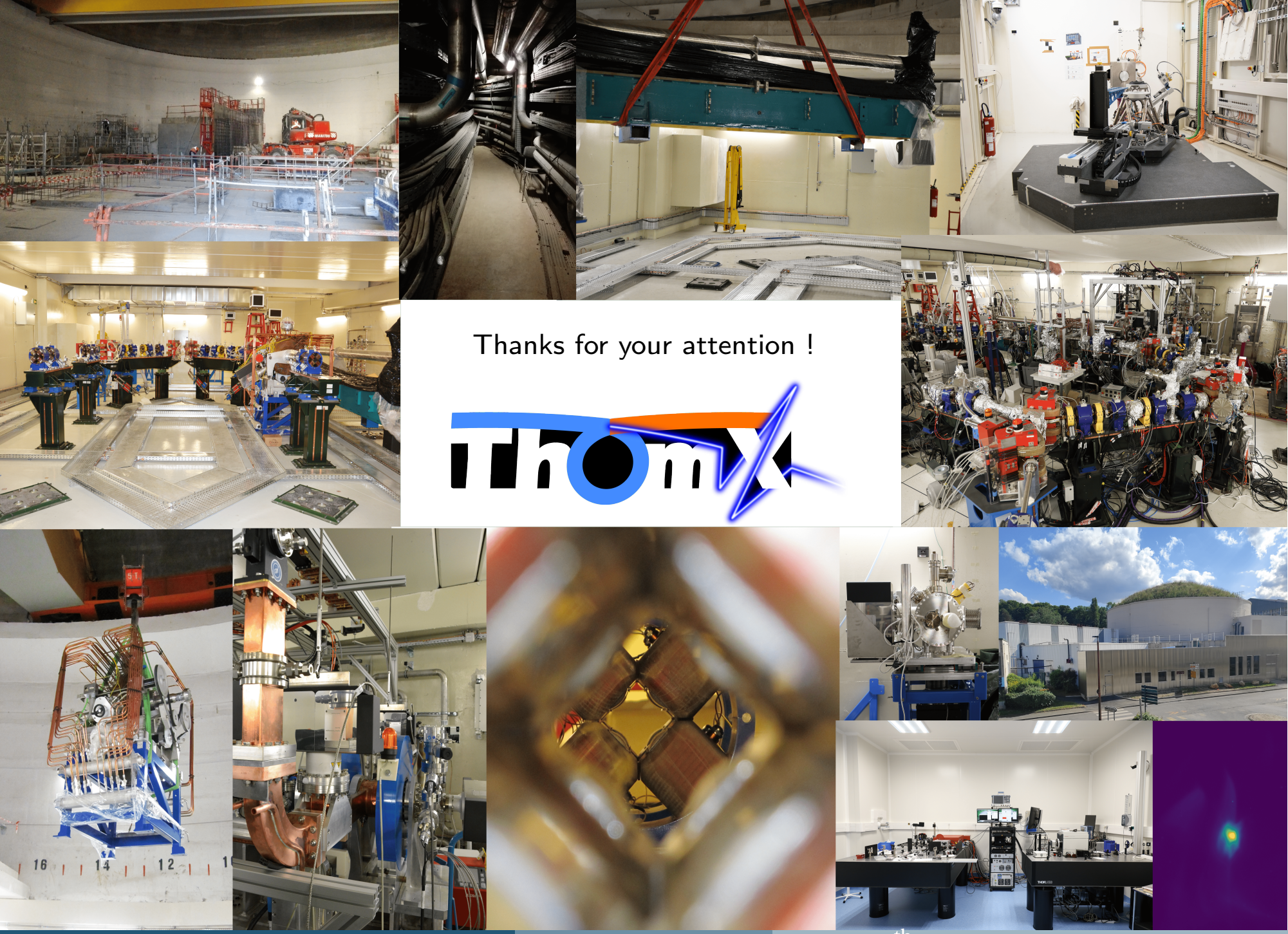


Linac commissioning :

- ✓ Repetition rate : $10\,\mathrm{Hz}$
- ✓ Beam energy : $50\,\mathrm{MeV}$
- ✓ Beam charge : $100\,\mathrm{pC}$
- ≈ Transverse emittance :
  - Theory : $2\pi\mathrm{mmmrad}$
  - Measure $\approx 4\pi\mathrm{mmmrad}$
  - → Optimization under progress (laser optimization, alignment studies)
- Fabry-Perrot cavity optimization under progress

Next steps :

- Waiting for ASN phase II authorization
- TL commissioning (Energy spread optimization, Matching, Orbit corrections, Characterization and optimization for ring injection ...)
- Ring commissioning (Injection, Closed orbit, Tune matching, ...)
- First x-rays : During 2023 according on authorization


Thanks for your attention !
ThomX