

28th LINEAR ACCELERATOR CONFERENCE (LINAC 16)

East Lansing, MI USA, 25-30 September

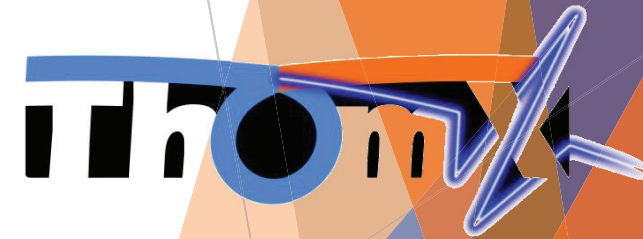
5' Oral Poster Presentation

ELECTRON LINAC UPGRADE FOR THOMX PROJECT

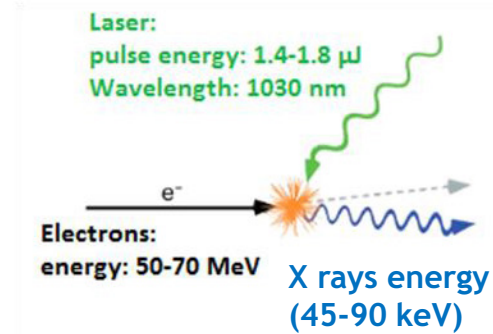
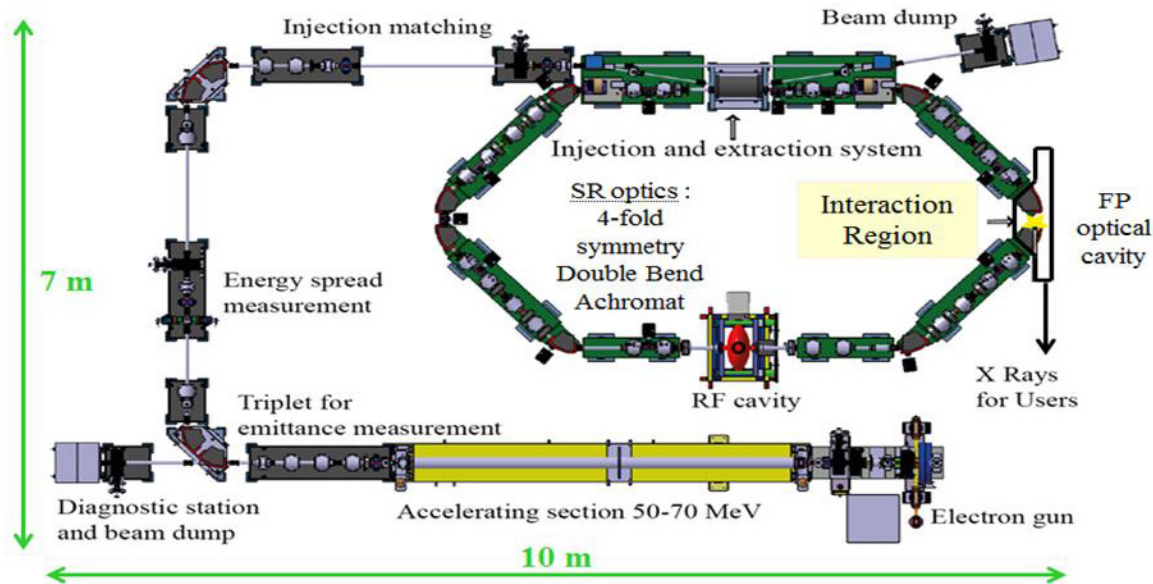
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ThomX project



Compton backscattering principle

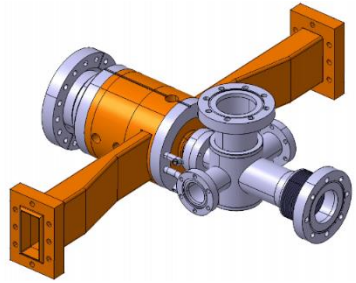
- ▶ French project led by LAL (budget: 12 M€, 10 M€ TTC facility & 2 M€ TTC operation).
- ▶ Compton backscattering compact hard X-rays (45-90 keV) source with high flux (10^{11} - 10^{13} ph/s).
- ▶ Relatively low energy machine (50-70 MeV) which allows installation in hospitals or museums.
- ▶ A demonstrator was recently funded and it is under construction in the Orsay University campus.
- ▶ Application domains:
 - Cultural heritage: imaging, structural & chemical studies of artefacts,
 - Medical science: imaging, radiotherapy,

Industrialisation phase (Thales): ThomX demonstrator can be commercialised as an integrated product.

LINAC main specifications

- To fulfil the accelerator specifications, the LINAC has to be carefully designed, especially the photo-injector.

RF Gun designed & made at LAL

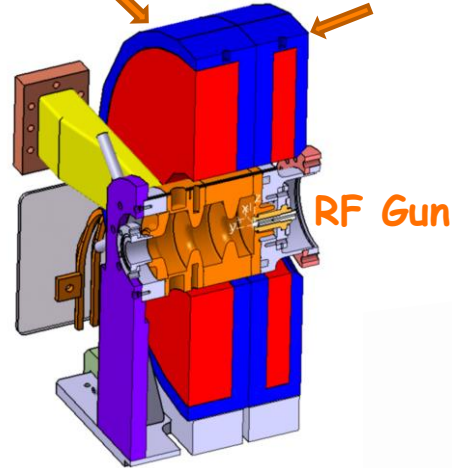


3D-RF Gun
Catia drawing

THOMX
brazed RF Gun



2.5 cells RF Gun
focusing coil bucking coil



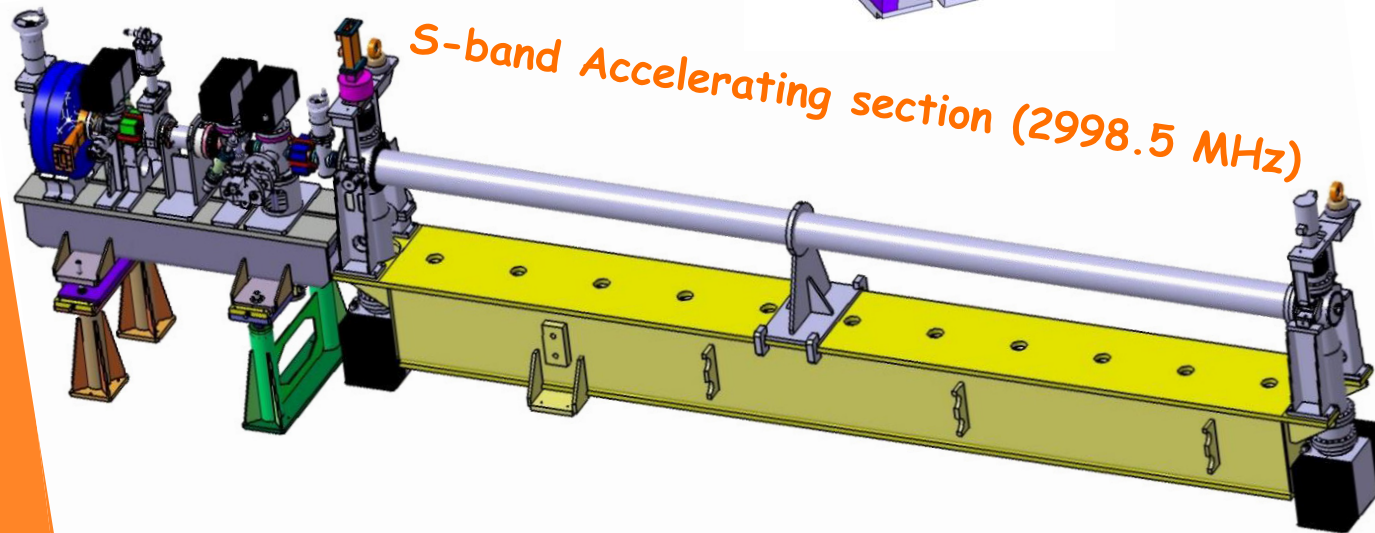
RF Gun

RF Gun specifications

Laser wavelength	266 nm
Laser pulse duration & energy	100 μ J
Q - factor	15000
Shunt Impedance	50 M Ω /m

$E_z = 80 \text{ MV/m}$ ($P_{in} = 6 \text{ MW}$, $3 \mu\text{s}$)
for Energy gain = 5 MeV

S-band RF Gun



S-band Accelerating section (2998.5 MHz)

Nominal LINAC parameters:

- Energy: 50 MeV,
- Bunch charge: 1 nC,
- Repetition rate: 50 Hz,
- rms norm. emittance: $\epsilon_N \sim 4 \pi \text{ mm mrad}$
- rms energy spread: $< 1\%$
- rms bunch length: $< 5 \text{ ps}$

LAL-PMB collaboration on high gradient S-band structure research

- ▶ The collaboration agreement between PMB and LAL has been established from October, 1st, 2014 to September, 30th, 2018.

▶ Commissioning phase: LIL structure LEP Injector Linear structure (LIL)

- Total length: 4.5 m (135 cells),
- Travelling wave section (TW),
- Quasi-constant gradient structure,
- Phase advance per cell: $2\pi/3$ -mode,
- Average acc. field: 14 MV/m @ 12 MW,
- Filling time $\sim 1.35 \mu\text{s}$,

Upgrade



▶ Upgrade phase: PMB-LAL High gradient & compact structure (HGAS)

- Total length: 3.2 m (96 cells),
- Travelling wave section (TW),
- Quasi-constant gradient structure,
- Phase advance per cell: $2\pi/3$ -mode,
- Average acc. field: 20.5 MV/m @ 22 MW,
- Filling time $\leq 1 \mu\text{s}$,

Direct impact on X-rays energy:

50 MeV $\Rightarrow \gamma \sim 45 \text{ keV}$

70 MeV $\Rightarrow \gamma \sim 90 \text{ keV}$

ELECTRON LINAC UPGRADE FOR THOMX PROJECT

► Beam dynamics simulations have been performed using ASTRA code:

- A method to determine the best magnetic field strength which compensates the transverse emittance has been considered.
- A scan over different parameters, such as transverse laser spot size, pulse duration, RF dephasing of the RF gun and accelerating section with respect to $\Phi_{RF} = 0$ Maximum Mean Momentum Gain (MMMGM) has been carried out for energy spread minimisation.
- A preliminary set of parameters able to achieve an energy spread of $\Delta E/E = 0.2\%$, with a reasonable rms transverse emittance has been proposed.

Poster ID: THPLR072

Thank you for your attention

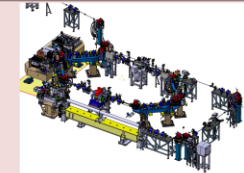
ELECTRON LINAC UPGRADE FOR THOMX PROJECT




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THOMX: A COMPACT HIGH FLUX X-RAYS SOURCE



- Compton back-scattering compact light source machine.
- Collisions between laser pulses and relativistic electron bunches in a optical cavity (Fabry-Perot resonator).
- Intense flux of monochromatic X-rays ($10^{12} - 10^{13}$ ph/s, 45 - 90 keV energy) for a 50 / 70 MeV Linac.
- Low energy electron machine which allows the integration in hospitals or museums.
- THOMX accelerator is under construction in the Orsay university campus.

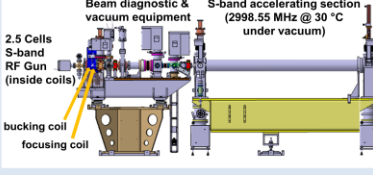
MOTIVATIONS

- To accomplish technical specifications at the interaction point, the LINAC has to be carefully designed, especially the photo-injector.

LINAC REQUIREMENTS	
Nominal Energy	50 MeV
Bunch charge	1 nC
rms norm. emittance	< 5 π mm mrad
rms energy spread	< 0.3 %
rms bunch length	< 5 ps
Average current	50 nA
Repetition frequency	50 Hz

THE THOMX S-BAND LINAC SCHEME

- The RF Gun design $\Rightarrow$ almost the same as for the Probe Beam Photo-Injector (PBPI) at CLIC Test Facility 3.
- To avoid vacuum constraints with high efficiency $\Rightarrow$ metallic magnesium photocathode has been chosen.
- RF Gun properties: Q-factor = 15000, shunt impedance = 50 M Ω /m, pulse = 5 MW, 3 μ s, E_{peak} = 80 MV/m, energy gain = 5 MeV.



Commissioning phase:
LIL structure
Standard section

Length: 4.5 m (135 cells)
Travelling wave section (TW)
Quasi-constant gradient field
 $\Delta\Phi$ per cell: 2 π /3-mode
 $\langle E_{acc} \rangle = 14$ MV/m @ 12 MW
Filling time ~ 1.35 μ s
Final Energy: 50 MeV
45 MeV section + 5 MeV RF gun

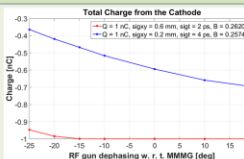
Upgrade phase:
PMB ALCEN - LAL
HG structure (HGAS)

Length: 3.2 m (96 cells)
Travelling wave section (TW)
Quasi-constant gradient field
 $\Delta\Phi$ per cell: 2 π /3-mode
 $\langle E_{acc} \rangle = 20.5$ MV/m @ 22 MW
Filling time < 1 μ s
Final Energy: 70 MeV
65 MeV section + 5 MeV RF gun

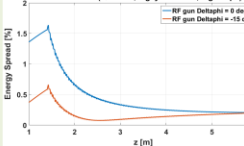
under development

X-rays energy:
50 MeV $\Rightarrow$ $\gamma = 45$ keV
70 MeV $\Rightarrow$ $\gamma = 90$ keV

LINAC BEAM DYNAMICS

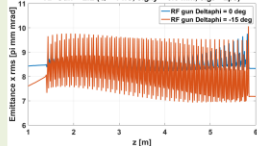


RF Gun + LIL (Q = 1 nC, sig_y = 0.6 mm, sig_t = 2 ps, B = 0.2620 T)



- $\Phi_{RF\ gun} = 0^\circ$, $\Phi_{LIL} = 0^\circ$ Maximum Mean Momentum Gain (MMMGM).
- $\sigma_{x,y} = 0.2$ mm, $\sigma_z = 4$ ps, $B_{peak\ coils} = 0.2574$ T $\Rightarrow \epsilon_{x,y,100} = 4$ π mm mrad.
- High transverse density e^- emission $\Rightarrow$ strong image charge @ 1 nC.
- $\Phi_{RF\ gun} = 0^\circ$, $\sigma_{x,y} = 0.2$ mm, $\sigma_z = 4$ ps loses more than 40% of total charge.
- $\epsilon_{x,y,100}$ & σ_z approximately constant, dephasing has no effect.
- $\Delta E/E$ vs $\Phi_{RF\ gun}$ significant variation, dephasing has strong impact.
- $\Delta E/E = 0.2\%$ for both cases ($\Phi_{RF\ gun} = 0^\circ$, $\Phi_{RF\ gun} = -15^\circ$).
- $\epsilon_{x,y,100} > 8$ π mm mrad, $\Phi_{RF\ gun} = 0^\circ$;
- $\epsilon_{x,y,100} = 7$ π mm mrad, $\Phi_{RF\ gun} = -15^\circ$;
- $\sigma_z = 3.4$ ps, $\Phi_{RF\ gun} = 0^\circ$; $\sigma_z = 3.2$ ps, $\Phi_{RF\ gun} = -15^\circ$;
- $\sigma_z = 3.5$ mm in both cases ($\Phi_{RF\ gun} = 0^\circ$; $\Phi_{RF\ gun} = -15^\circ$).

Parameters	Dephasing [deg]			
	-15	-10	0	+10
$\epsilon_{x,y}$ [π mm mrad]	7.6	8	8.4	8.5
$\Delta E/E$ [%]	0.37	0.6	1.3	2.2
σ_z [ps]	3.1	3	3.1	3.4



CONCLUSIONS & PROSPECTS

- Preliminary beam dynamics investigation on the ThomX Linac $\Rightarrow$ ASTRA tracking code.
- Transverse laser spot $\sigma_{xy} = 0.2$ mm, pulse duration $\sigma_t = 4$ ps $\Rightarrow$ Nominal $\epsilon_{x,y,100} = 4$ π mm mrad out of the RF gun; at the expense of $\Delta E/E$ & σ_z (*)
- A first set of parameters: $\sigma_{xy} = 0.2$ mm, $\sigma_t = 4$ ps, $E_{peak\ coils} = 0.2574$ T, $B_{peak\ coils} = 0.2574$ T, $\Phi_{RF\ gun} = -15^\circ$, $\Phi_{LIL} = 0^\circ$ respect with $\Phi_{RF\ gun} = 0^\circ$, $\Phi_{LIL} = 0^\circ$ Maximum Mean Momentum Gain (MMMGM) allows to obtain $\Delta E/E = 0.2\%$ with $\epsilon_{x,y,100} = 7$ π mm mrad, $\sigma_z = 3$ ps, $\sigma_x = 3.5$ mm.
- To improve $\Delta E/E$ with $\epsilon_{x,y,100}$, σ_z trade off $\Rightarrow$ better position of solenoids & accelerating cavity, several $H_{peak\ coils}$ strength, high gradient accelerating section electric field profile (PMB ALCEN - LAL section).

* L. Garolfi et al., "BEAM DYNAMICS SIMULATIONS OF THE THOMX LINAC", Proceedings of IPAC2016, Busan, Korea.

