Optical Cavity

for high flux X-ray Compton machines

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High flux X-rays machines: application & motivation

Applications

- Example in **Heritage studies**:
  X-ray spectroscopy in arts, paintings, archaeology, ...
- Example in **Material science**:
  X-ray crystallography of ceramics, powders, agglomerates, quasi-crystals, complex compounds analysis, ...
- Example in **X-ray scanning:**
  customs, security, transport...
- Example in **Medical science**
  Imagery, therapy...

Motivations

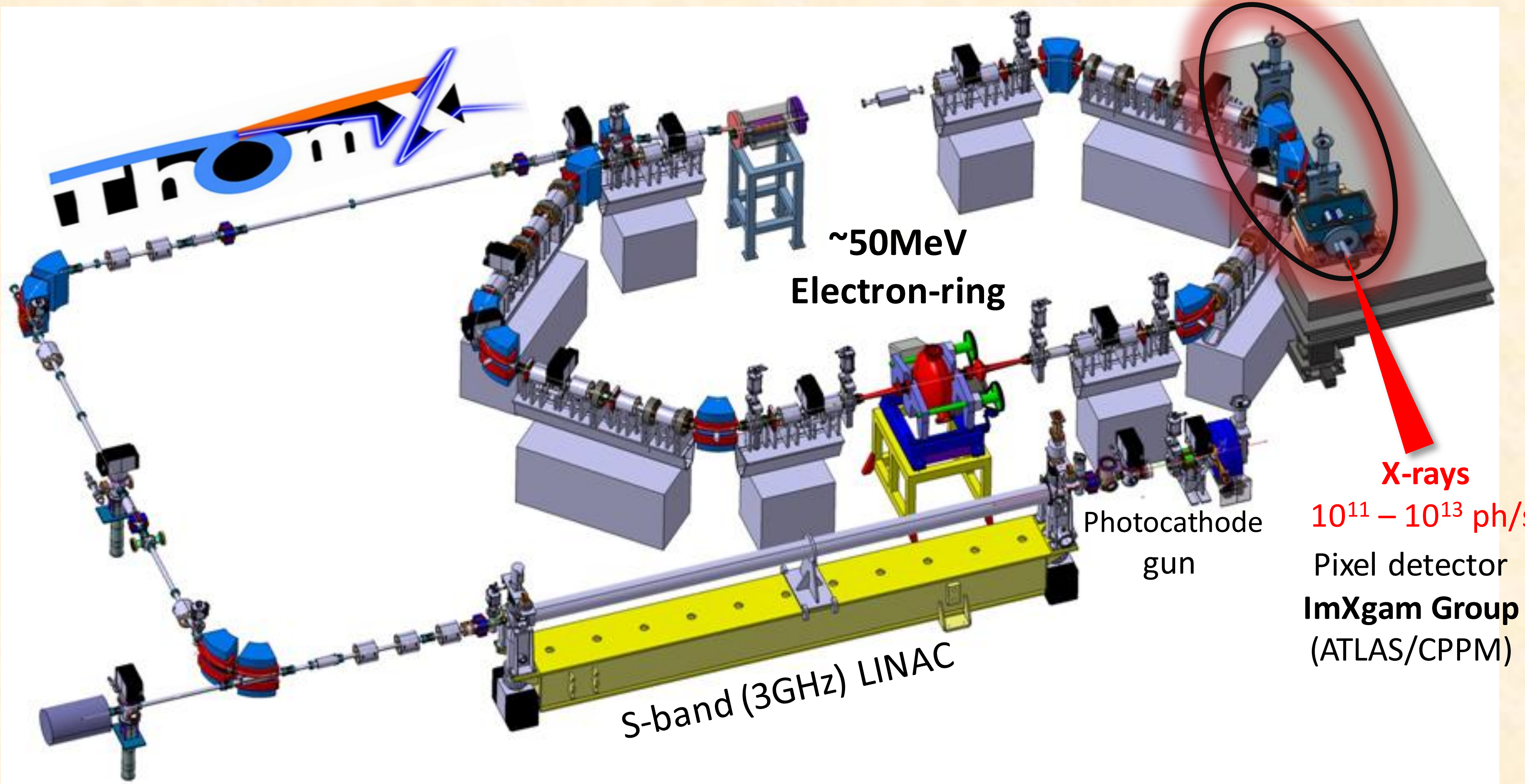
- For **some applications,** lower flux X-rays as $10^6 - 10^{13}$ ph/s is acceptable, if the machine has an easy **access** then the large Synchrotron machine

Synchroton radiation/ Compton scattering comparison

X-ray source	Flux ph/s	Size	Cost	Examples
Synchrotron radiation	$>10^{18}$	C=354m, R ~56m (SOLEIL)	454 million euros (SOLEIL)	France: SOLEIL China : BSRF and SSRF
Compton scattering	$10^{11} - 10^{13}$	10x7m (ThomX)	12 million euros, only machine (ThomX)	ThomX, TTX

Compact Light Source in France : **ThomX**

- **Location** : Orsay - **Size** : 10mx7m
- **Funding** approved 12M€ (Equipex 2012-2015)
- **Optical cavity** : Gain 10k, <P>=500kW



Compact Light Source in China : **TTX**

- **T**singhua **T**homson Scattering **X**-ray Source (TTX)
- Experiment Layout in Tsinghua University
- **Existing** setup:

CPA Amplification, <P>=6W, P_{peak}=20TW, 10Hz, 600mJ/pulse, 60 fs $\rightarrow 10^7$ph/s

Main features:

- ✓ High peak power
- ✓ Low average power
- ✓ Short pulse duration
- ✓ Huge pulse energy

Courtesy of Ch. X. Tang

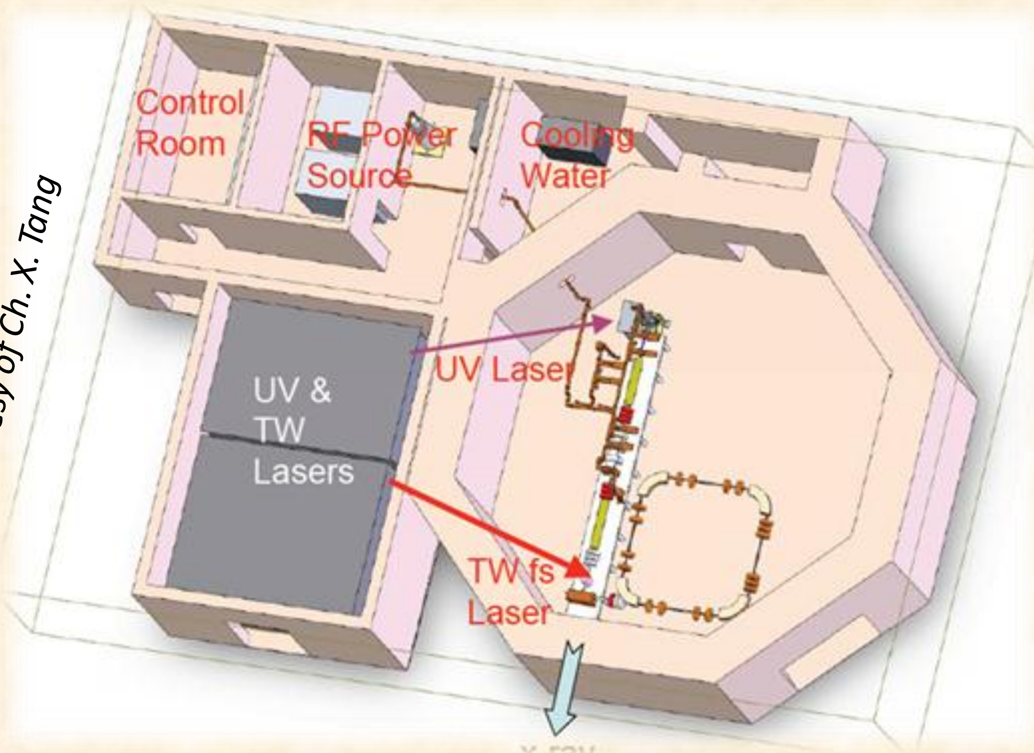


Fig. 1. Existing TTX setup based on CPA.

Compact Light Source in China : **TTX**

- **New setup** in Tsinghua University:

resonant cavity, <P>=10-50kW, 42MHz, 0.24mJ/pulse, 10ps $\rightarrow$ >10^{10} ph/s

Main features:

- ✓ High average power
- ✓ High repetition rate
- ✓ High X-rays flux

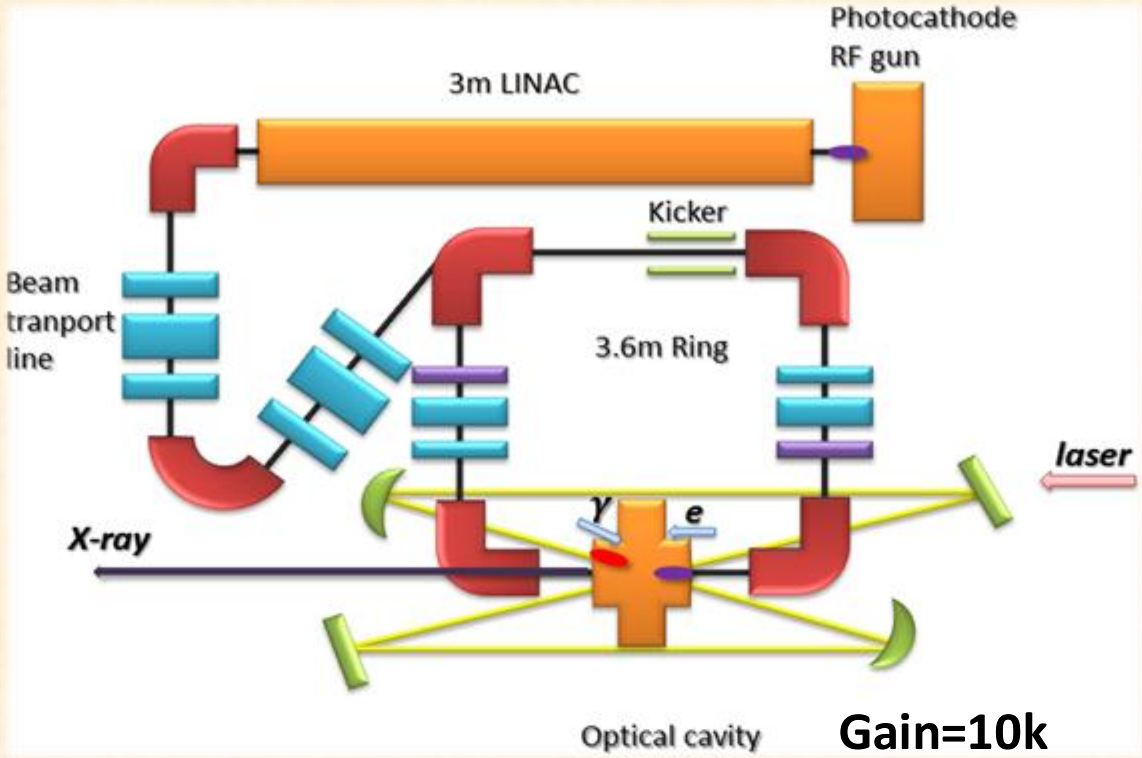
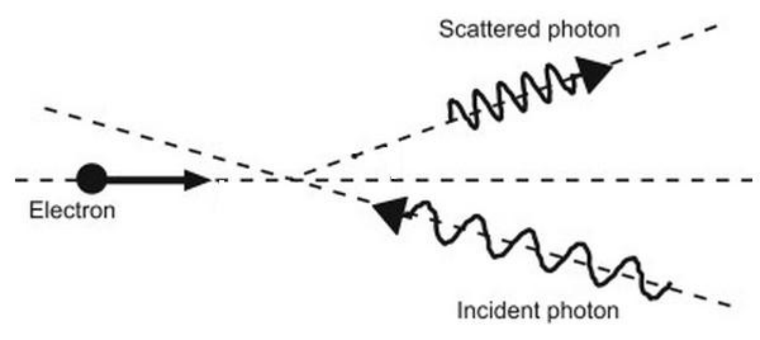


Fig. 1. New TTX setup based on resonant cavity.

Compton Scattering principle



$$\mathrm{FLUX}_{CW} \propto \frac{\lambda P_L I_e \sigma_T F_{rep}}{\sqrt{\sigma_{electron}^2 + \sigma_{laser}^2}}$$

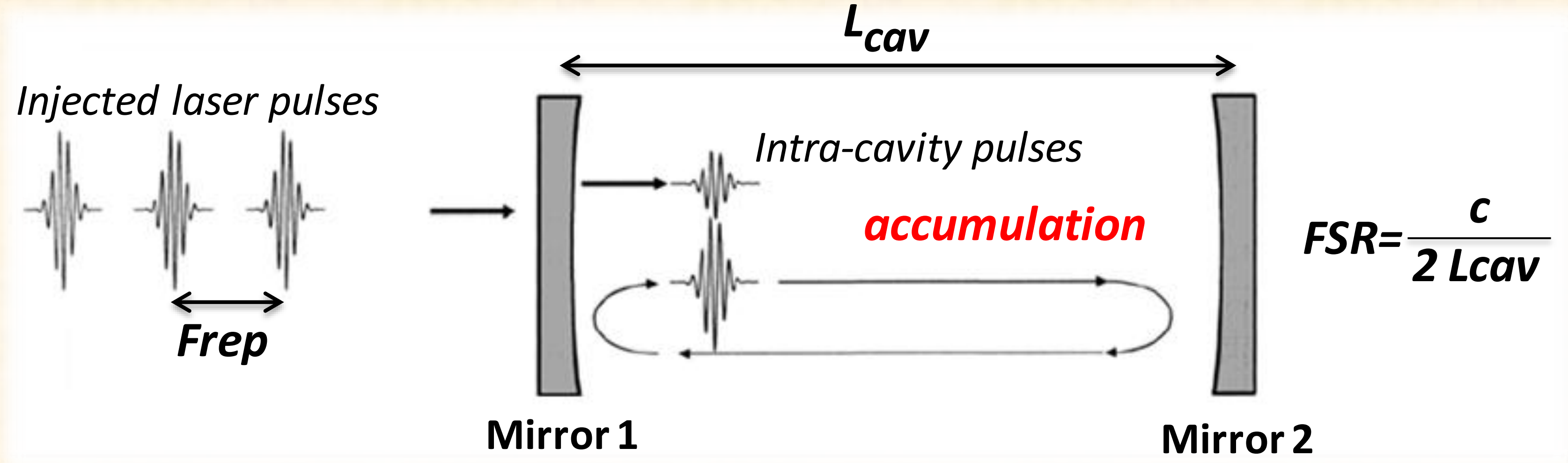
λ : laser beam wavelength
P_L : laser power
I_e : electron beam intensity
σ_T : Compton scattering cross-section
F_{rep} : colliding repetition rate

$\sigma_{electron}$: electron beam size r.m.s
σ_{laser} : laser beam size r.m.s

- Compton (Thomson) scattering is the **exchange of energy** that occurs when a photon collides with an electron.
- It can be used to **boost** low energy (IR, ~eV) photons to X-rays energy (tens of keV) by colliding them with **high energy electrons**.
- The source of photons is typically a **laser** at ~1um(~eV).
- The **cross-section** for this process is **very low** :

$$\sigma_T = 6.65 \times 10^{-29}\ m^2$$

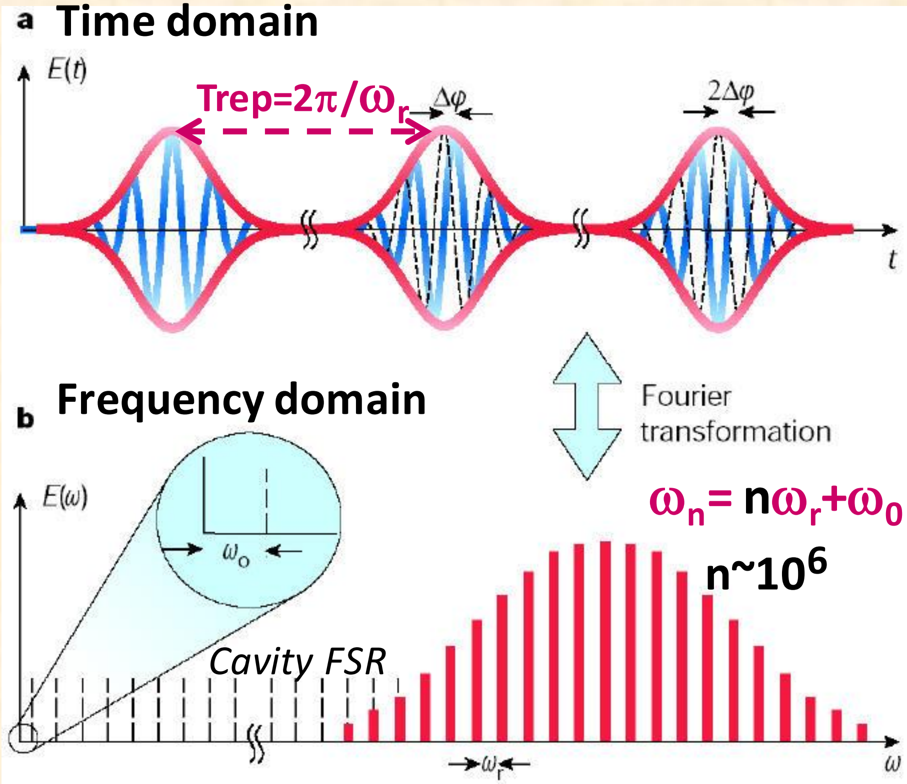
Laser pulses stacking



- **Small Compton cross-section**
  → important to **recycle** laser and electrons
  → Use of a **Fabry-Perot cavity** to accumulate and recycle the laser power
- Allows significant **enhancement factors** on the laser power (10^3~10^4)
- This is **difficult** to achieve
  → Laser and cavity frequency combs need to **match perfectly**
  → Relative precision is **$\delta r \sim 10^{-11}$**

example : for L_{cav} = **1m**, absolute precision = **10pm**

Pulsed laser - feedback requirements



Source : T. Udem et al. Nature 416 (2002) 233

- The laser beam pulses are injected with a **pulse-to-pulse phase** $\Delta\varphi_{ce}$ (laser-design dependent)

- The intra-cavity beam pulses acquire a **phase** $\Delta\varphi_0$ in one cavity round-trip (*mirror effect*)

→ all the **laser comb** must be locked to the cavity, therefore we must **achieve** :

Comb <u>spacing</u> matching $FSR = Frep$

Comb <u>position</u> matching $\Delta\varphi_{ce} = \Delta\varphi_0$

Recent results in optical cavity by Garching MPI **(O.L.35(2010)2052)** :

~70kW, 2ps pulses @78MHz, stored in a cavity

~20kW, 200fs pulses @78MHz

Limitation : power damage threshold of mirrors !

R&D at LAL on Fabry-Perot cavity

- LAL has been working on optical cavity for **about 15 years**.

→ **PLIC** (2004, LAL) : demonstrates high finesse optical cavity, 30k

→ **Mightylaser** (2010, KEK) : demonstrates high instantaneous luminosity and high integrated luminosity. X-ray generated in Oct, **2011**

Paper "Production of gamma rays by pulsed laser beam Compton scattering off GeV-electrons using a non-planar four-mirror optical cavity", 2012

→ **ThomX** (started 2011, Orsay) : **500kW** in cavity, high X-ray flux expected

- Feedback error signal is obtained by the widely used **PDH (Pound-Drever-Hall)** technique. For my thesis, I am currently working on another technique called **Tilt-Locking.**
- LAL has developed a **digital feedback system** to lock the laser to the cavity.

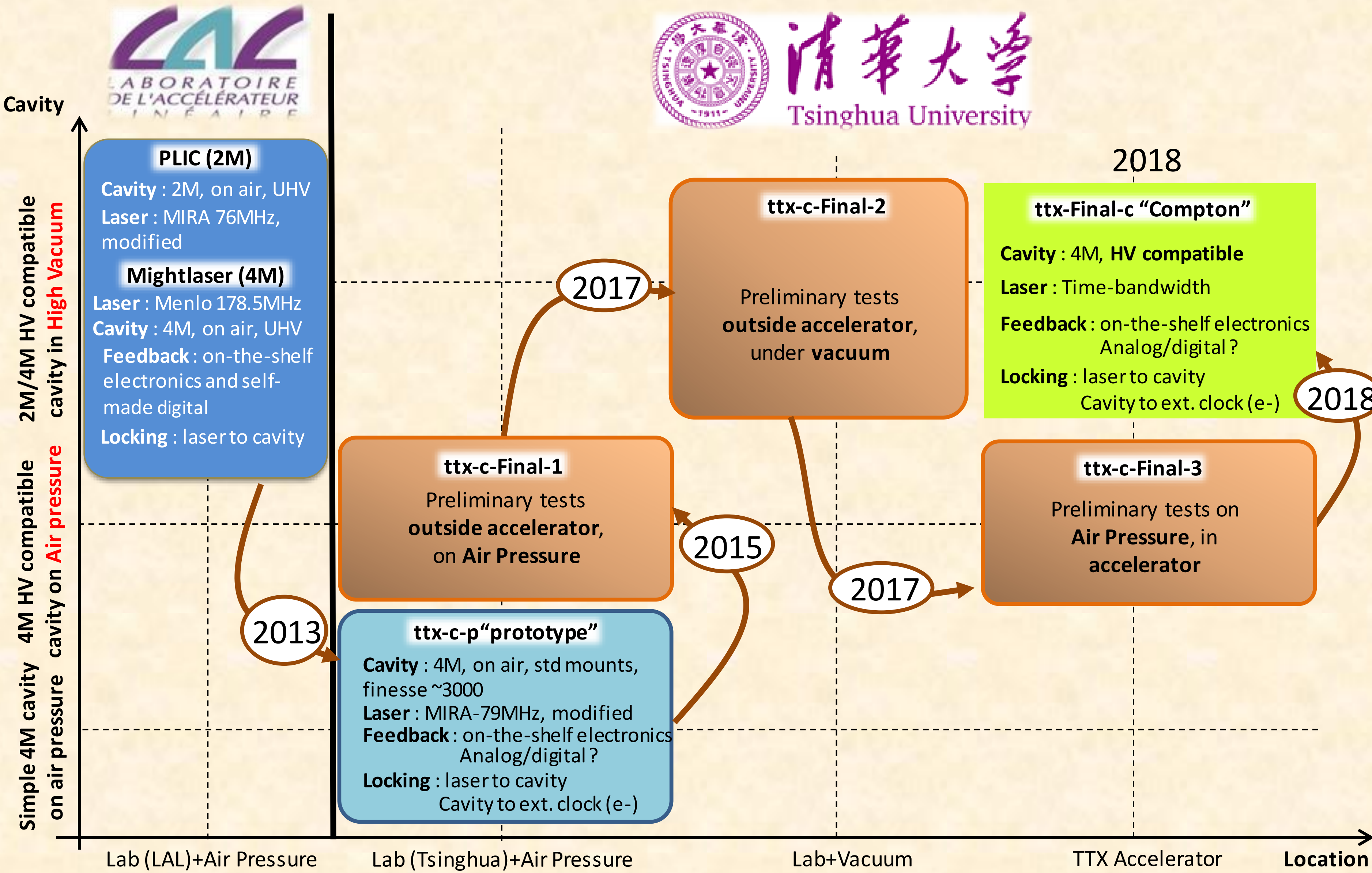
Collaboration between LAL & Tsinghua

- LAL and Tsinghua University are working on **similar project** to build a compact Compton X-ray source: **ThomX / TTX**

- There are **several areas** on which we already cooperate:
  - Optical cavity design
  - Feedback design
  - Laser study
- And **other domains** on which we expect to cooperate:
  - Beam dynamics studies,…

- For my PhD project, I will design and install **ttx-c-prototype** setup, based on **LAL PLIC** and **Mightlaser** setups. Then, this prototype will be **upgraded** to achieve final specifications.

TTX Compton machine schedule



Thank you for listening my presentation