# Optical cavity for high flux Compton machines

Nicolas Delerue

LAL (CNRS) and Université de Paris-Sud

# High flux X-rays machines

Third generation light sources (such as SOLEIL in France or BSRF and SSRF in China) have confirmed that X-rays have many applications.

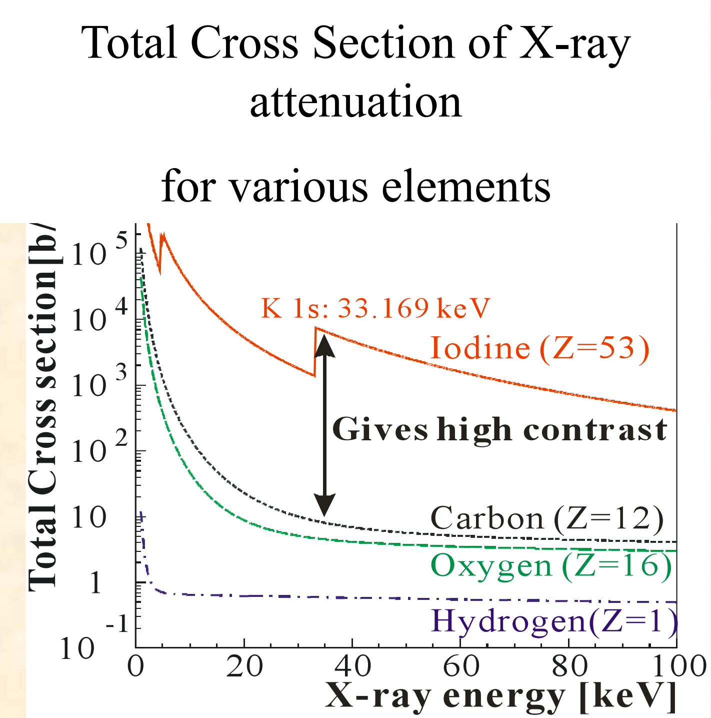
However large light sources are very expensive (1.2 billion yuan for SSRF) and very large
=> Access is difficult

For some applications X-rays of lower quality but easier to get access to would be preferable.
=> Compact light sources
(~10 Millions Euros/ >100 millions yuan)
+ A compact machine can fit in unusual places (museum, hospital,…)

# Motivation for high X-rays flux: Example in heritage studies

**'K edge imaging'**

- Heavy chemical elements are contained in painting pigments
  - Characterised by K absorption edges




*K-edge imaging*
(Pb→blanc, Hg→ vermillion…)
of a Van-Gogh's painting


J. Dik et al., *Analytical Chemistry*, **2008**, *80*, 6436
http://www.vangogh.ua.ac.be/

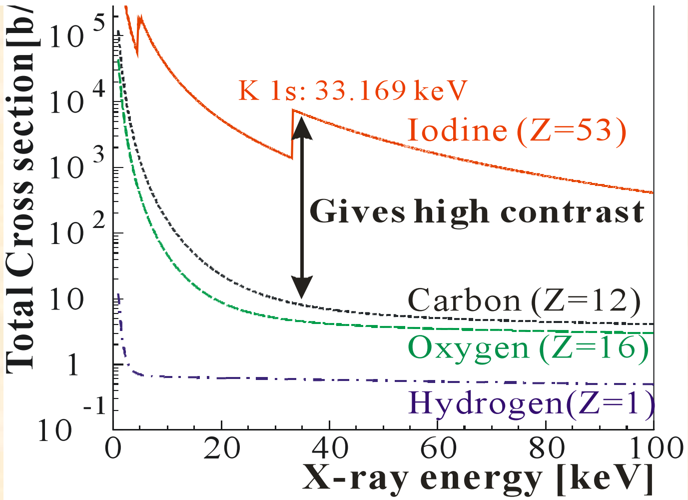
# Motivation for high X-rays flux: Example in heritage studies

**'K edge imaging'**

- Heavy chemical elements are contained in painting pigments
  - Characterised by K absorption edges

Total Cross Section of X-ray attenuation

for various elements

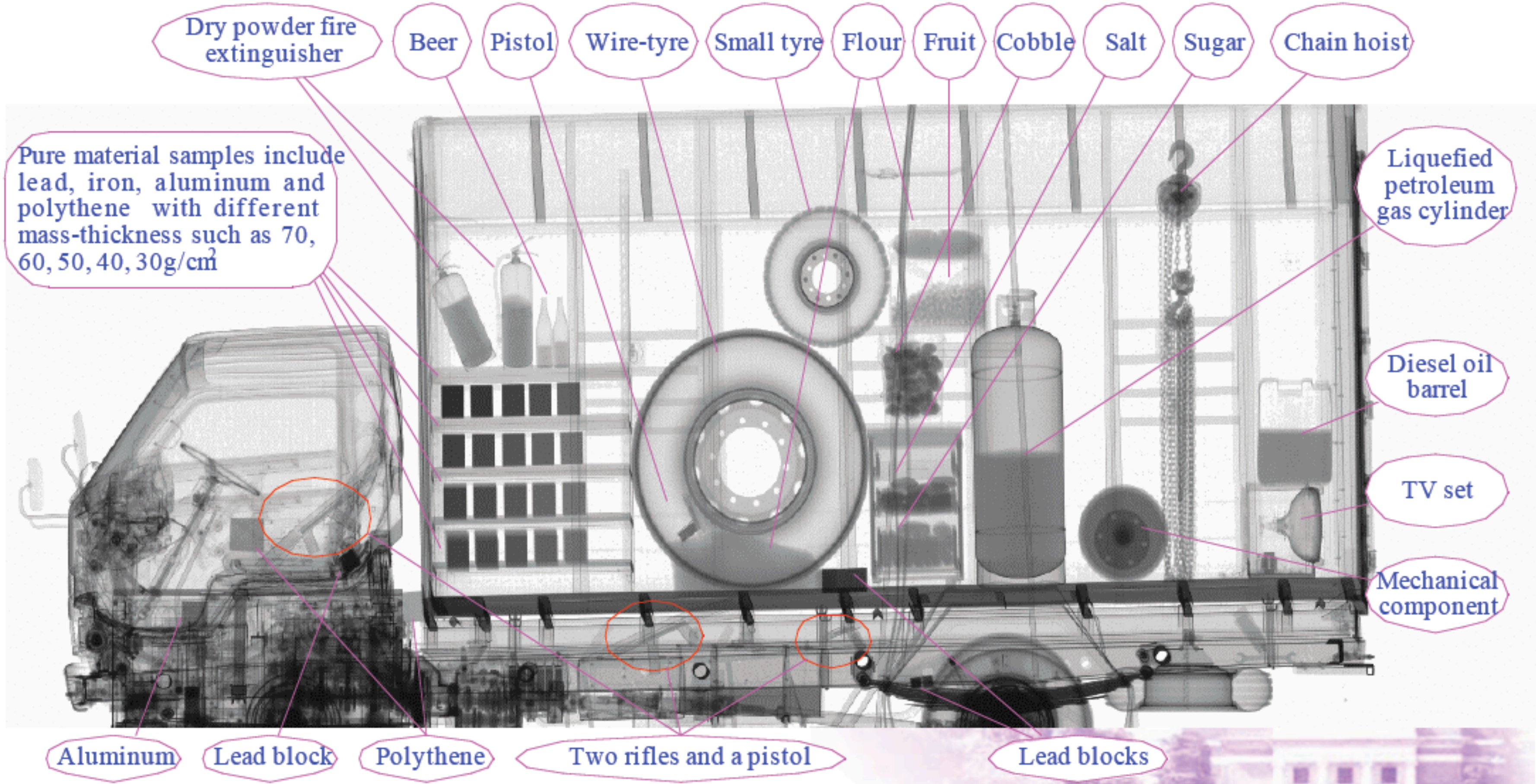



*K-edge imaging*
(Pb➔blanc, Hg➔ vermillion…)
of a Van-Gogh's painting


**But ~30k€ insurance for 2 days**
**➔Compact machine inside Le Louvre museum (was !) decided …**
**➔This was the *original motivation* of ThomX**

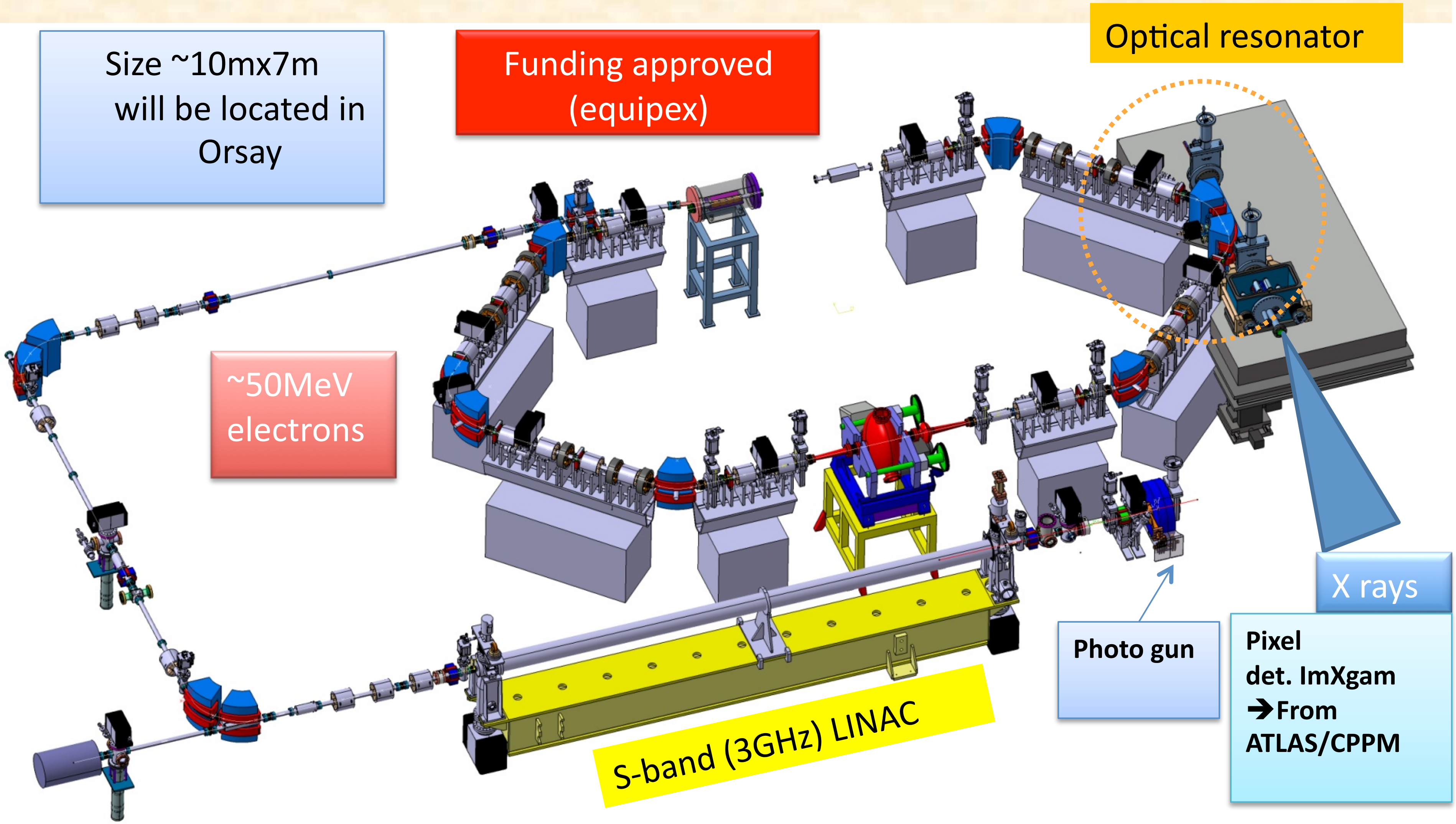
J. Dik et al., *Analytical Chemistry*, **2008**, *80*, 6436
http://www.vangogh.ua.ac.be/

# Image Example and Photo Grey Image of a Van with Different Tested Samples



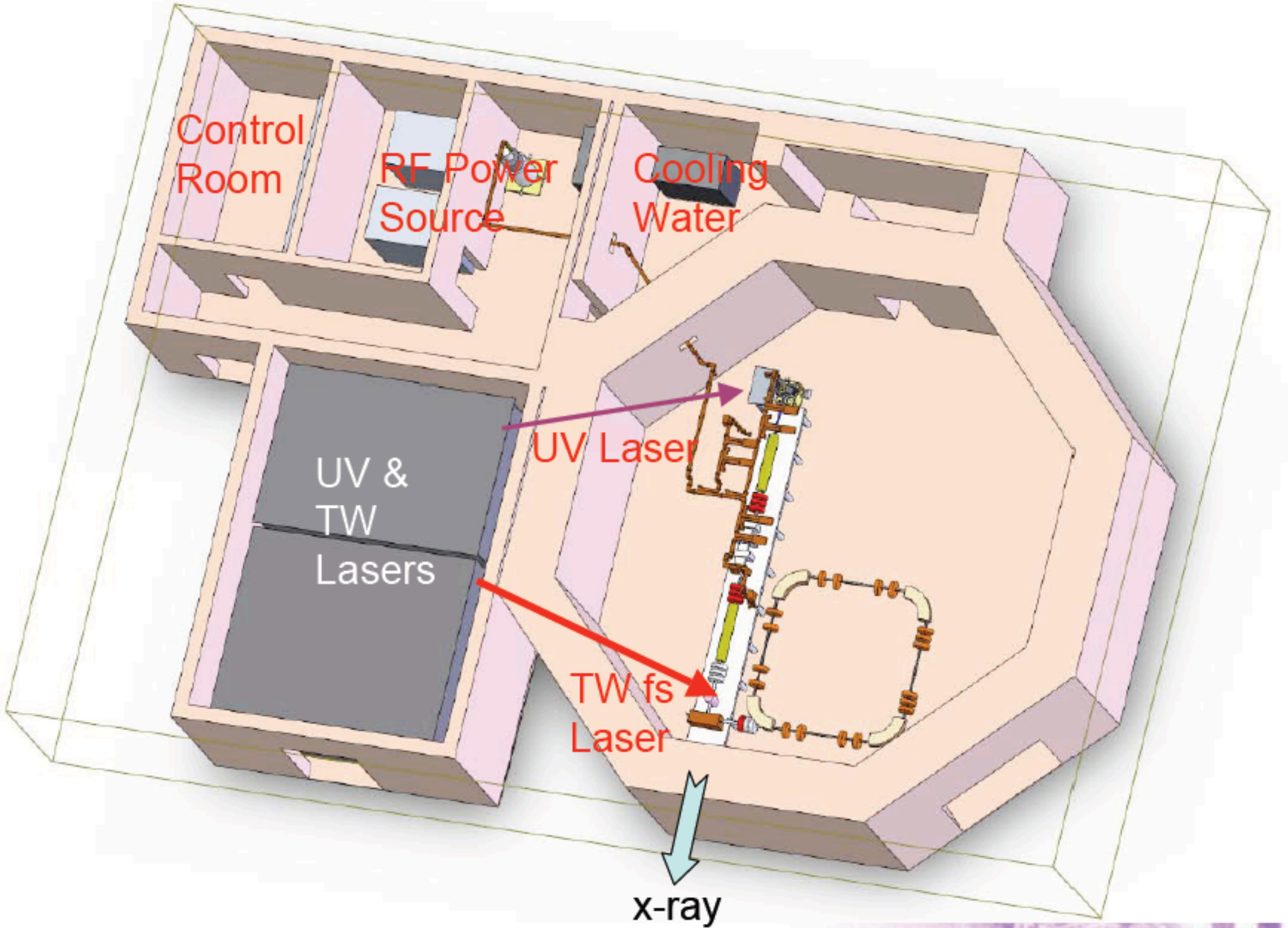

*Slide by Ch. X. Tang*

# Compact light source in France: ThomX



# Compact light source in China:

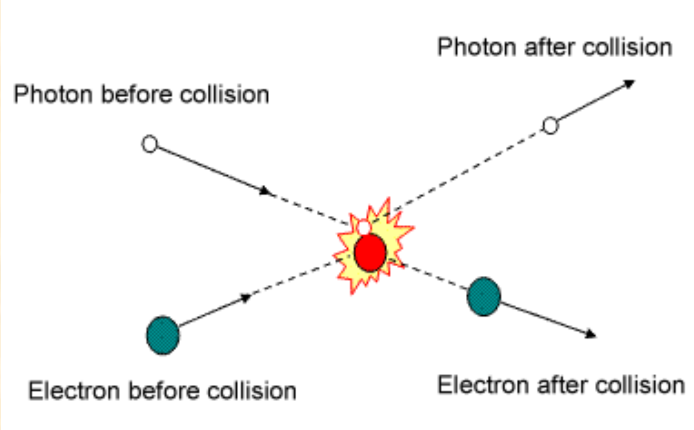
## 3 Tsinghua Thomson Scattering X-ray Source (TTX)




***Project 10735050 supported by NSFC; National Basic Research Program of China (973 Program) (Grant No. 2007CB815102)**

*Slide by Ch. X. Tang*

# Compton scattering



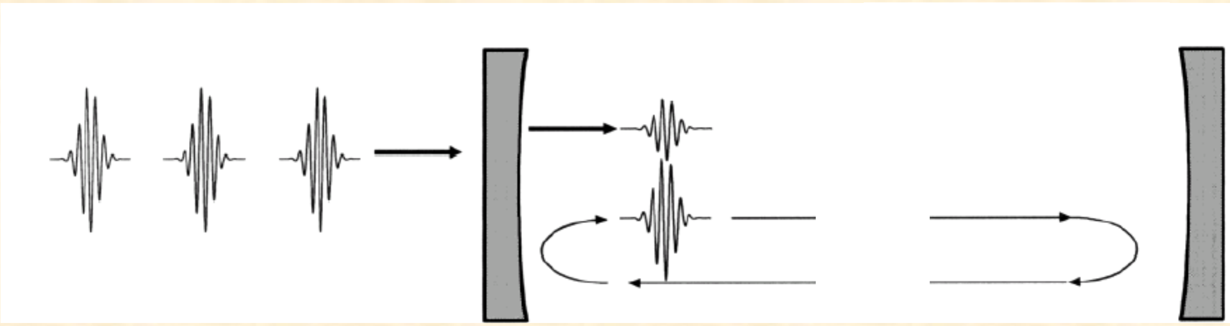

$$Flux_{cw} \propto \frac{\lambda P_L I_e \sigma_T}{\sqrt{\sigma^2_{electron} + \sigma^2_{laser}}}$$

$I_e$: electron beam intensity
$P_L$: laser power
$\lambda$: laser beam wavelength
$\sigma_{electron}$=electron beam size r.m.s
$\sigma_{laser}$=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) photons to X-rays energy by colliding them with high energy electrons.
- The source of photons is typically a laser (IR => eV).
- The cross-section for this process is very low.

# Laser pulses stacking

- Small Compton cross-section
  => important to recycle laser and electrons
  => Use of a Fabry-Pérot cavity to accumulate and recycle the laser power.
- Allows significant enhancement factors on the laser power (1000-10000).
- This is very difficult
  => frequency combs
  => demonstrated in an accelerator with a CW laser by LAL at HERA
  => current prototype with pulsed laser tested by LAL at KEK in Japan.



# Pulsed_laser/cavity feedback technique

Specificity ➔ properties of passive mode locked laser beams

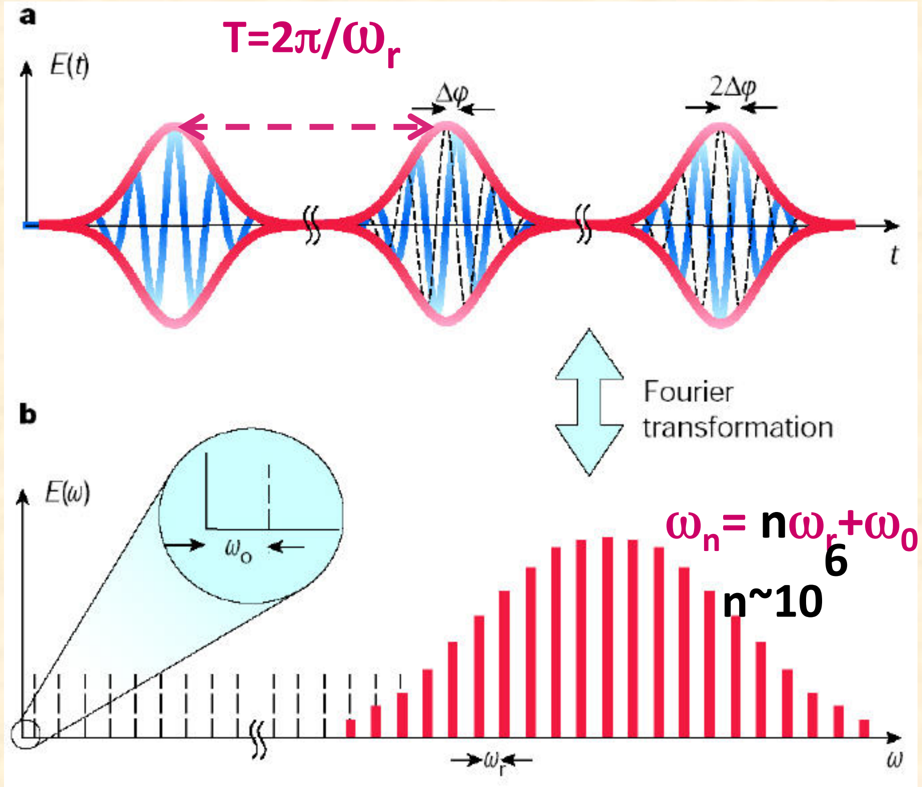
Frequency comb ➔ all the comb must be locked to the cavity

➔ Feedback with

2 degrees of freedom :

**control of the**

**Dilatation & translation (PZT)**




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

State of the art (Garching MPI) : **~70kW,** 2ps pulses @78MHz, stored in a cavity
**(O.L.35(2010)2052)** **~20kW,** 200fs pulses @78MHz

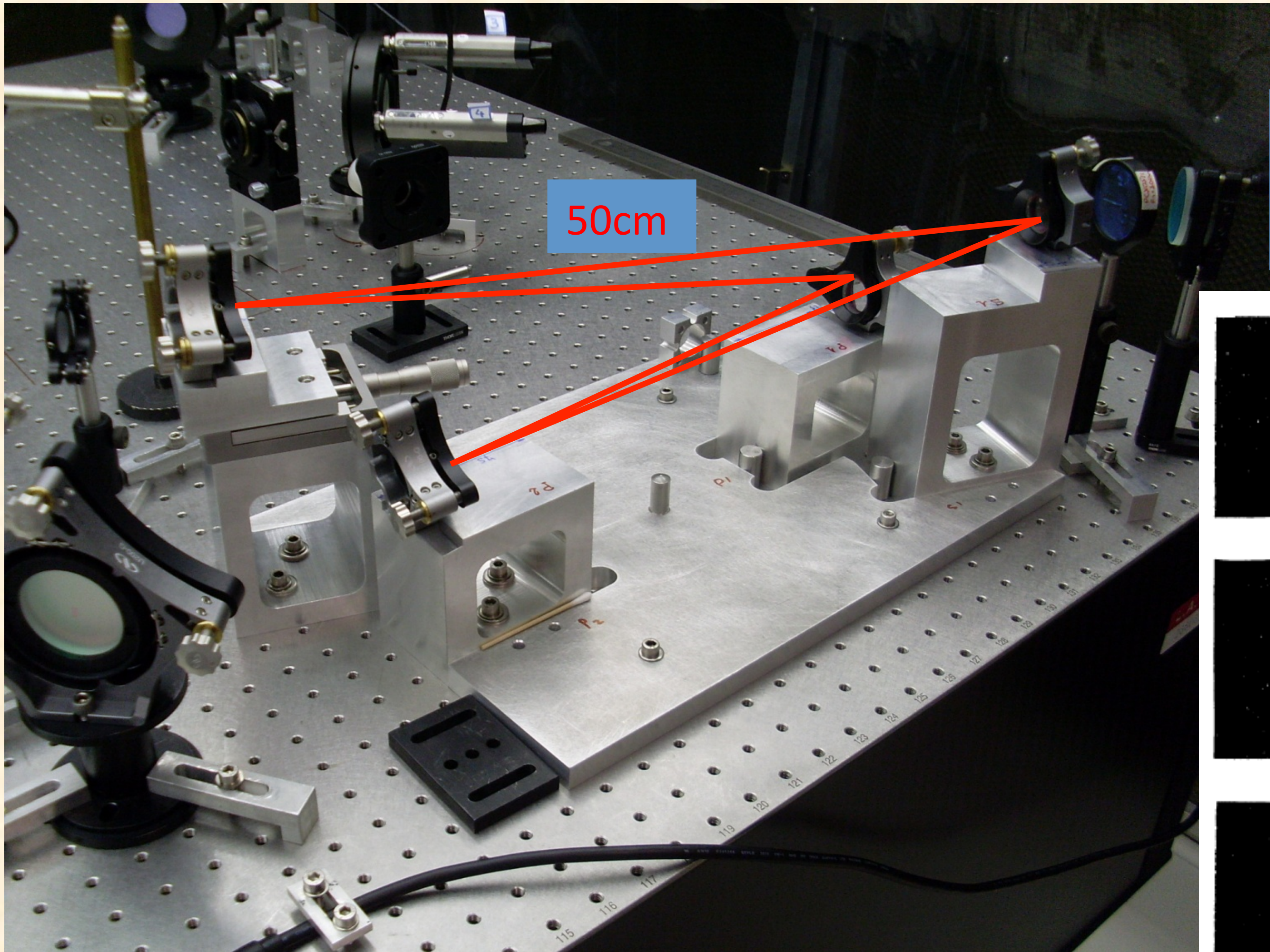
# R&D at LAL on Fabry-Pérot cavities

- LAL has been working on Fabry-Pérot cavities for about 10 years.
  => Polarimetry measurement at HERA
  => High flux positrons source for the ILC
  => Mighty laser / ThomX
- We have 2 Fabry-Pérot cavities installed in our lab for R&D and training (eg: feedback studies, alignment training…)
- We have developed a digital feedback system to control the length of the cavities.

# Fabry-Pérot cavities

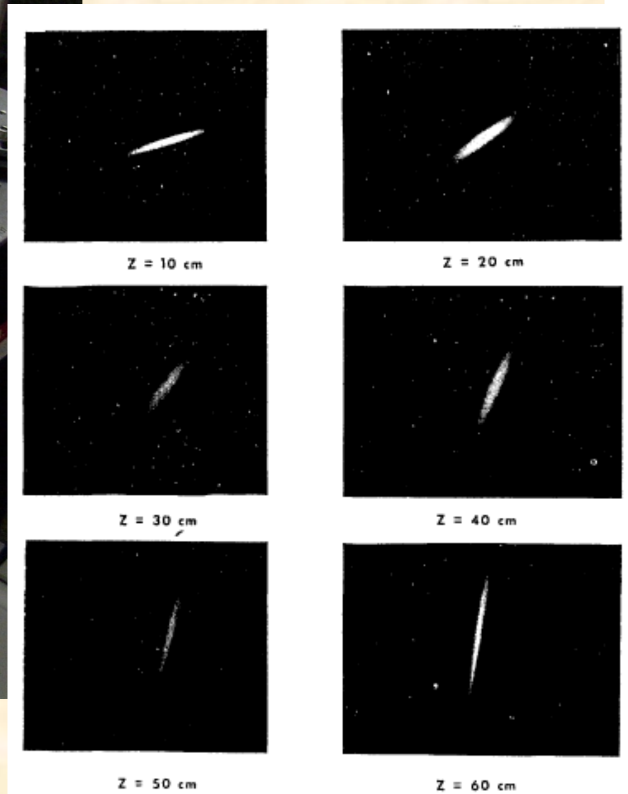
Prototype of non planar 4 mirrors resonator (low finesse)
- Check the general astigmatism mode shape/propagation (*Arnaud, Bell Syst. Tech. ( 1970)2311*)

➔ ok

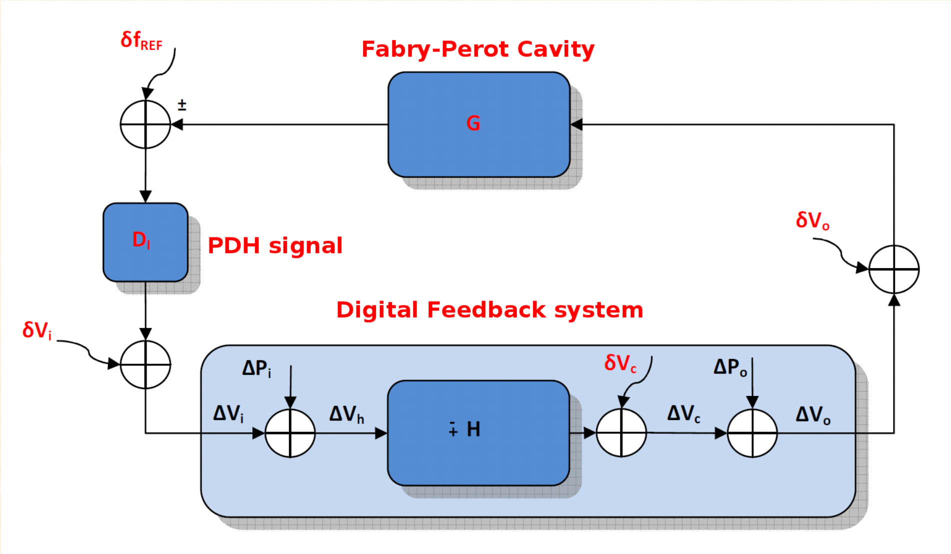


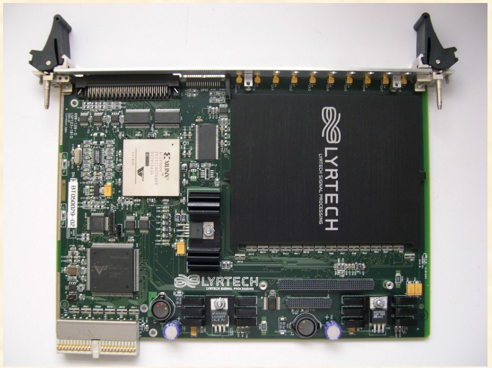

Ellipse intensity profile 'turning'

*Kogelnik, Apl. Opt. 8(1969)1687*



# Digital feedback system

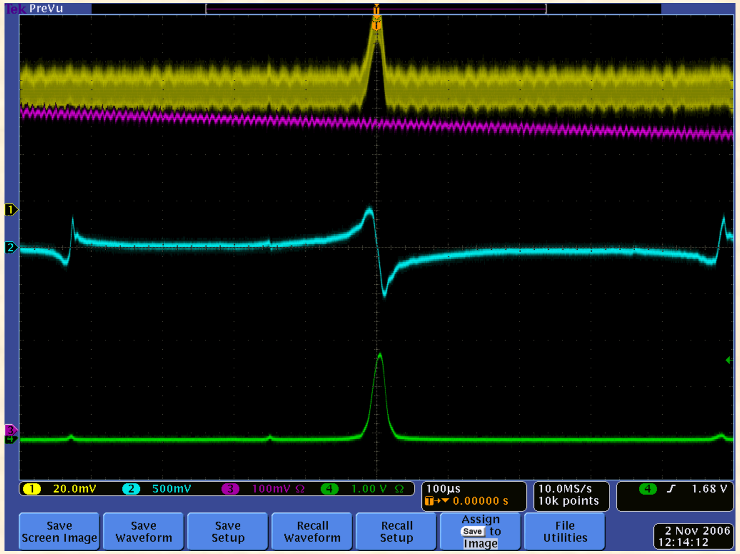




- The length of our cavities is controlled by a digital feedback system.
- Such system gives us more flexibility than an analogue one.
- Based on a FPGA Virtex II board.
- The laser is locked on the cavity using the Pound Drever Hall technique.
- The cavity is locked on the Accelerator clock using a phase lock loop.
- Developed over several years to suit the needs of various cavities.

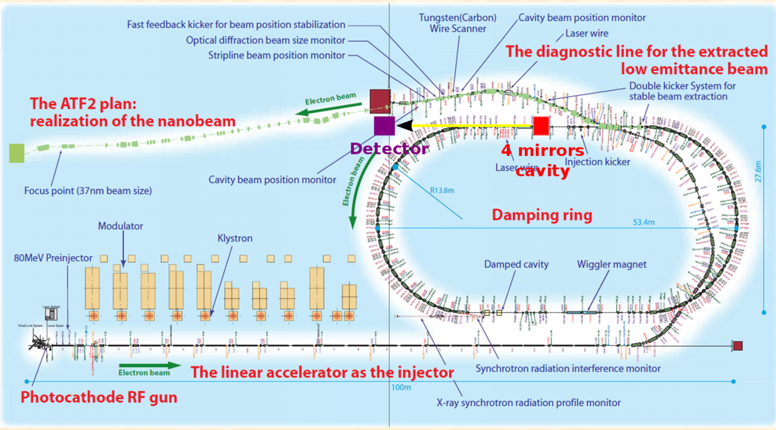
# Cavity stabilisation: Pound Drever Hall technique

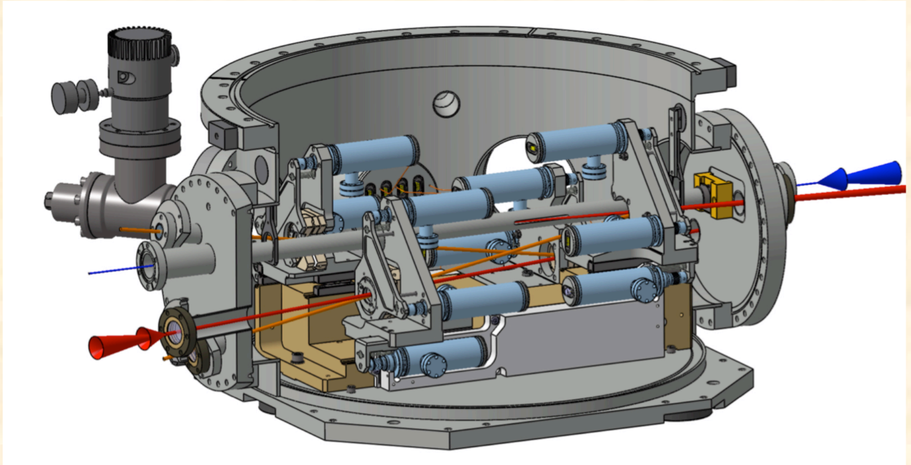



- We use the Pound Drever Hall technique to stabilise the cavity.
- The laser signal is modulated before being injected in the cavity.
- When close from the correct cavity length the signal “reflected” on the coupling port of the cavity is proportional to the correction to be applied on the piezo stack to adjust the laser cavity length.

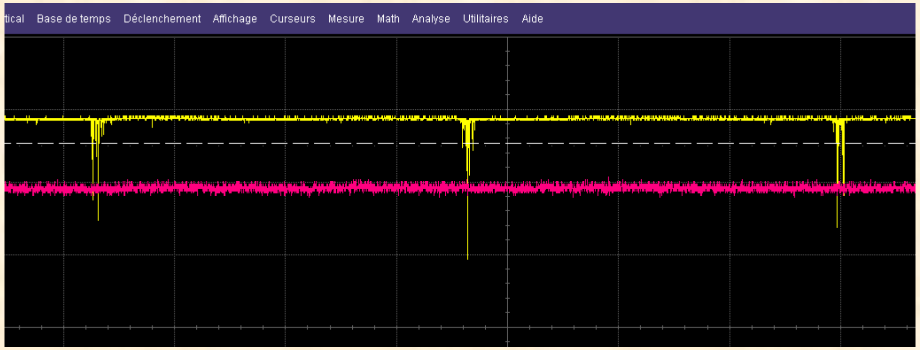
# Mighty laser at KEK

- To demonstrate our Compton production scheme we have installed a Fabry-Pérot cavity at the ATF at KEK.
- Our goal is to show that we can deliver a high instantaneous luminosity and a high integrated luminosity.

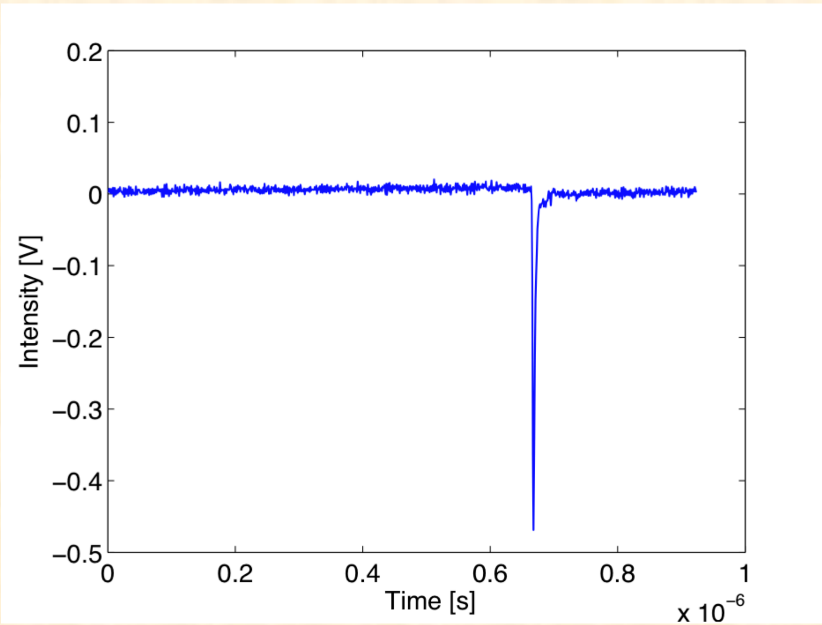


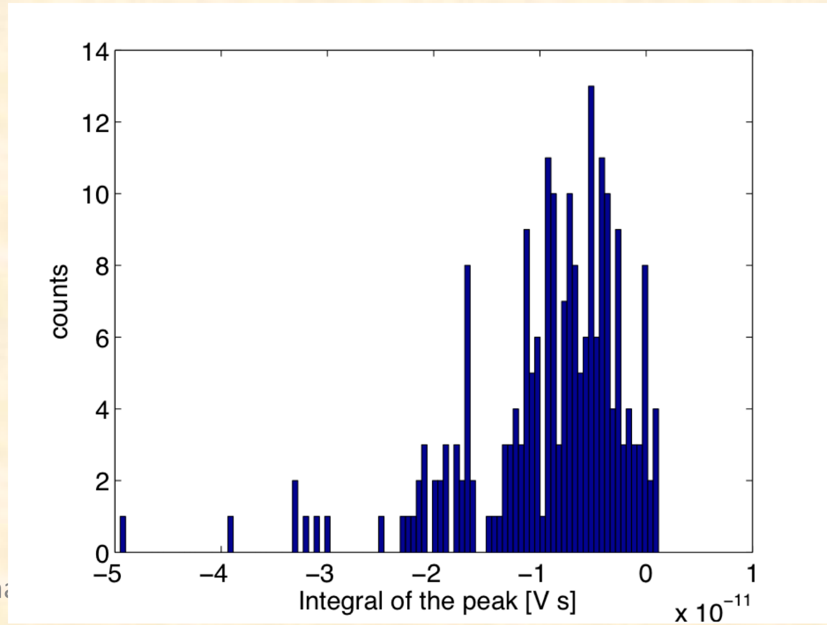
# First data taking




- We achieved electron-laser collision during our first data taking shift and during each data taking run after.

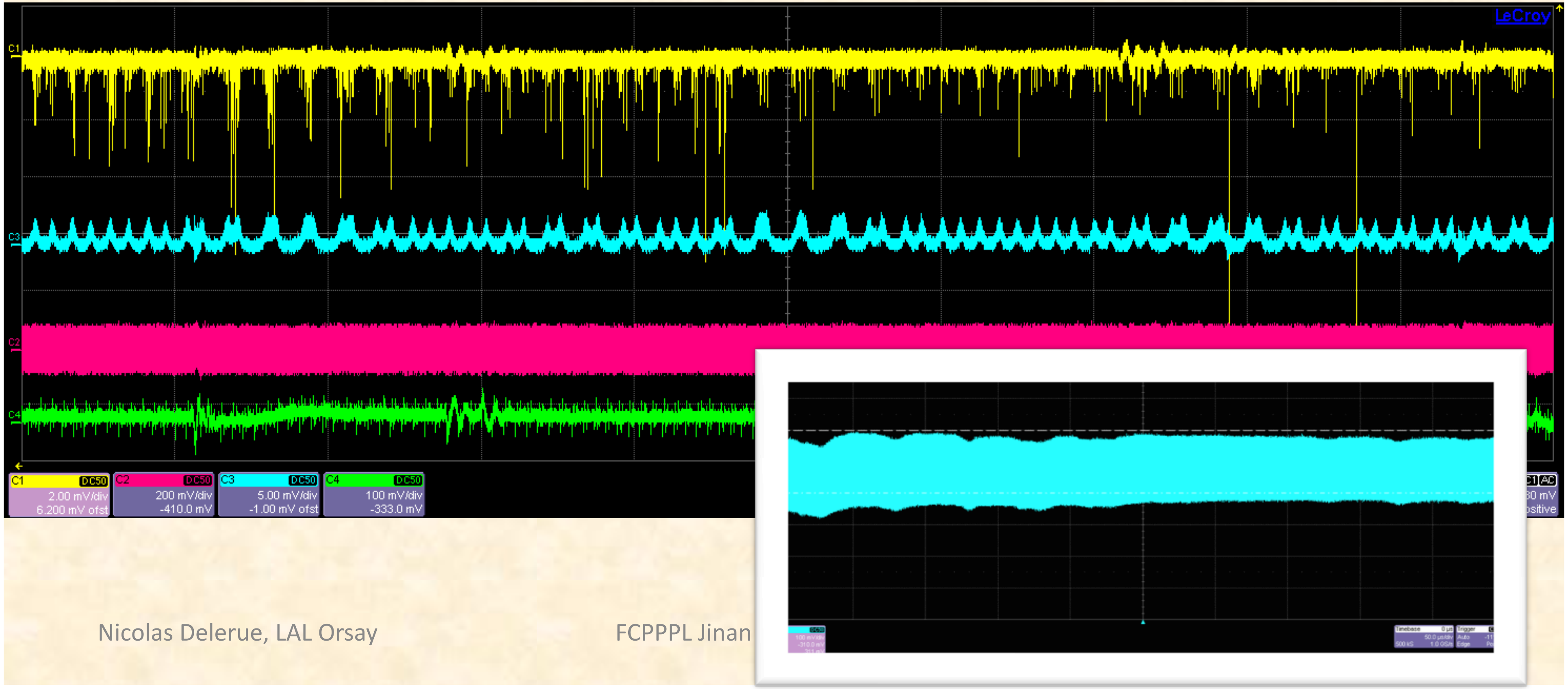



(Chin

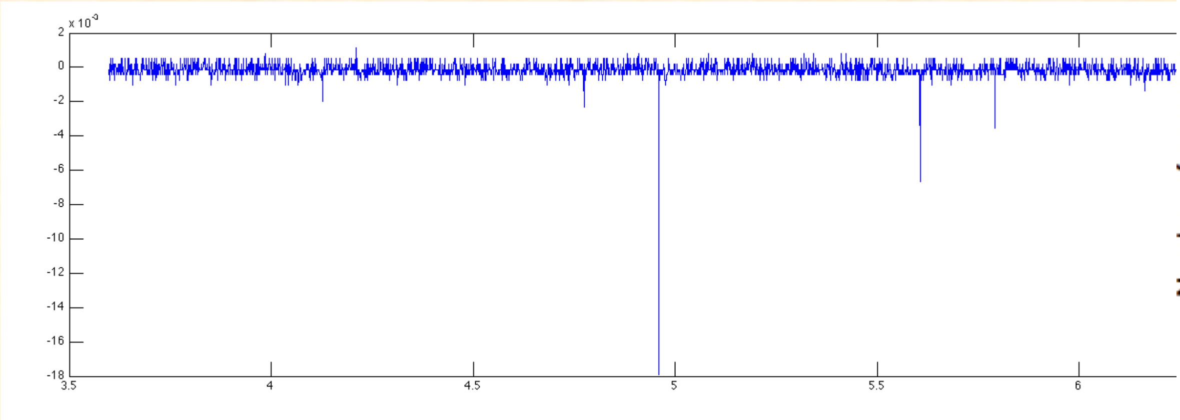


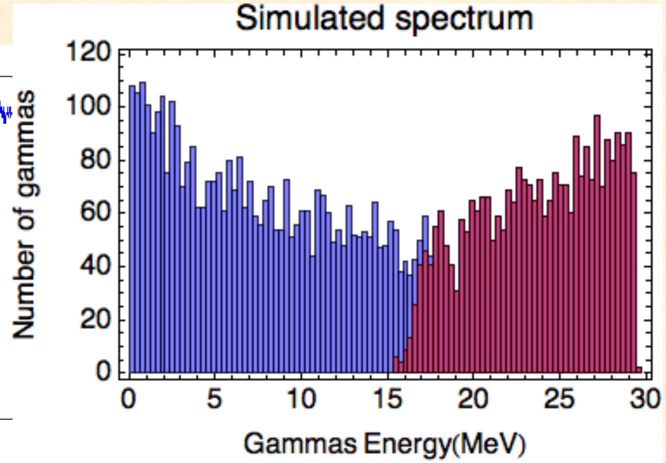
# Cavity stability & Power fluctuations

- During our data taking shifts at the end of 2010 we noticed significant fluctuations of the power stored in the cavity (blue trace) and consequently of the gamma ray yield (yellow trace).
- This issue was resolved in February by changing the filters in the digital feedback (but no Compton data have been taken with these filters yet).



# High luminosity data

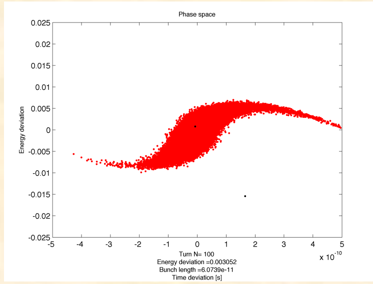


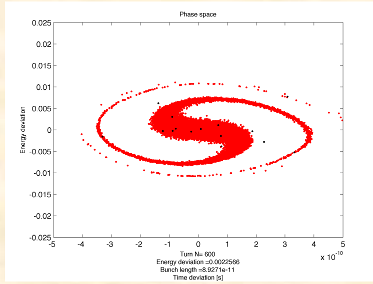


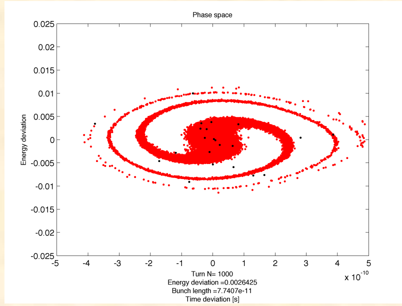

- On several occasions in December and January we observed peaks in our data around 18-20mV.
- We are still analysing these data but for some of them we have confirmed that the timing and the shape was compatible with a Compton signal.
- According to our calibration this would correspond to about 600MeV deposited in our calorimeter.
- Given the expected gamma spectrum this would correspond to about 25 photons/turn in the calorimeter.
  => Good results but more work to be done to demonstrate what is needed for ThomX

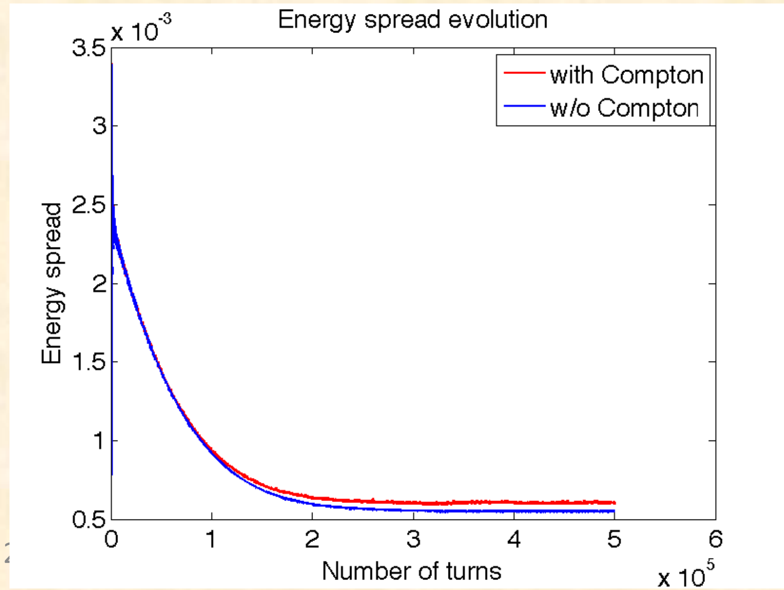
# Beam dynamics

- Beam dynamics play an important role in Compton machines.
- The particles that have been hit by the laser have a much lower energy and therefore they move in the phase space.
- Our results show that our prototype should not affect significantly the beam at the ATF.
- However this is unlikely to be the case in a dedicated machine and extensive beam dynamics simulations will be necessary for both ThomX and TTX.



# Collaboration opportunities LAL/Tsinghua

- LAL and Tsinghua University are working on similar project to build a new type of particle accelerators.
- We have identified several areas on which we could cooperate:
  - Fabry Pérot cavity design
  - Beam dynamics studies
- In a first step we foresee this collaboration to take place mostly through the exchange of students and short visits of academics.