Renewing heterodyne ?

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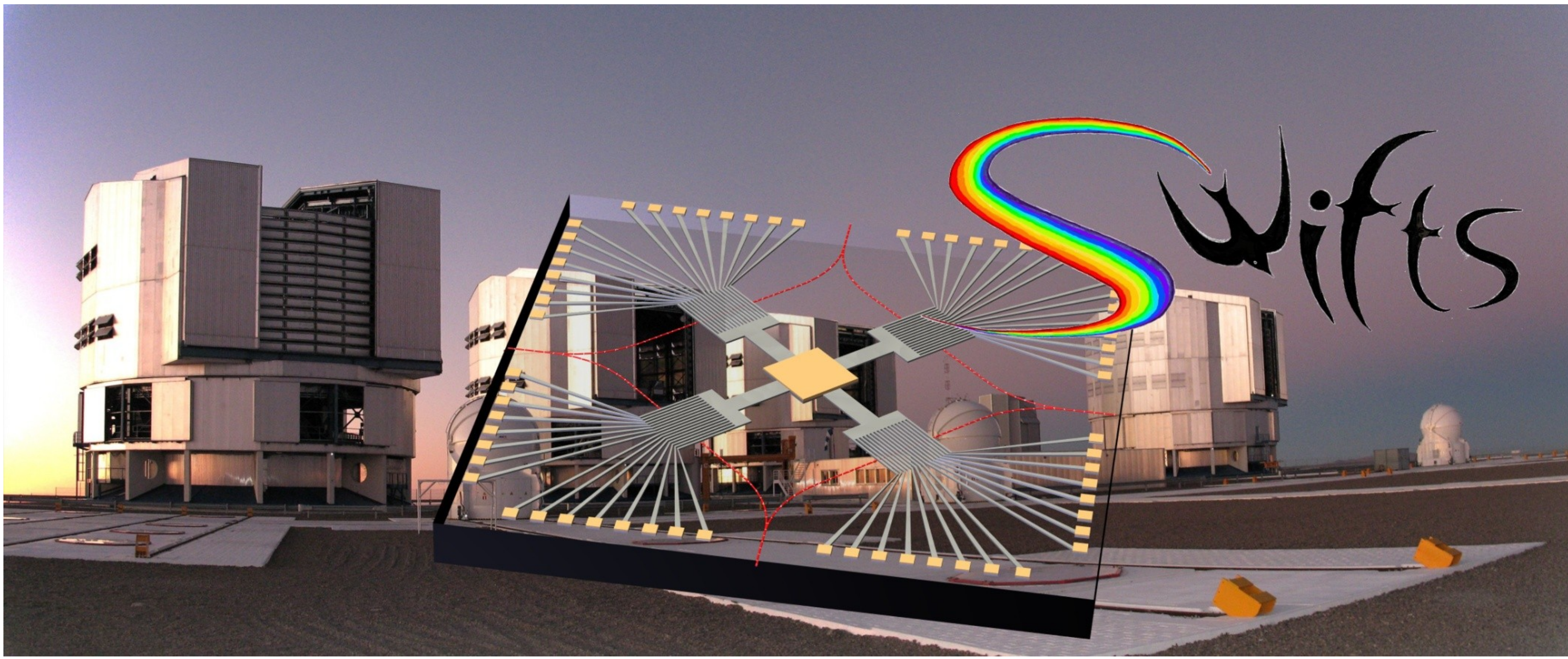

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Introduction

Regard to heisenberg limit , we are not so good …

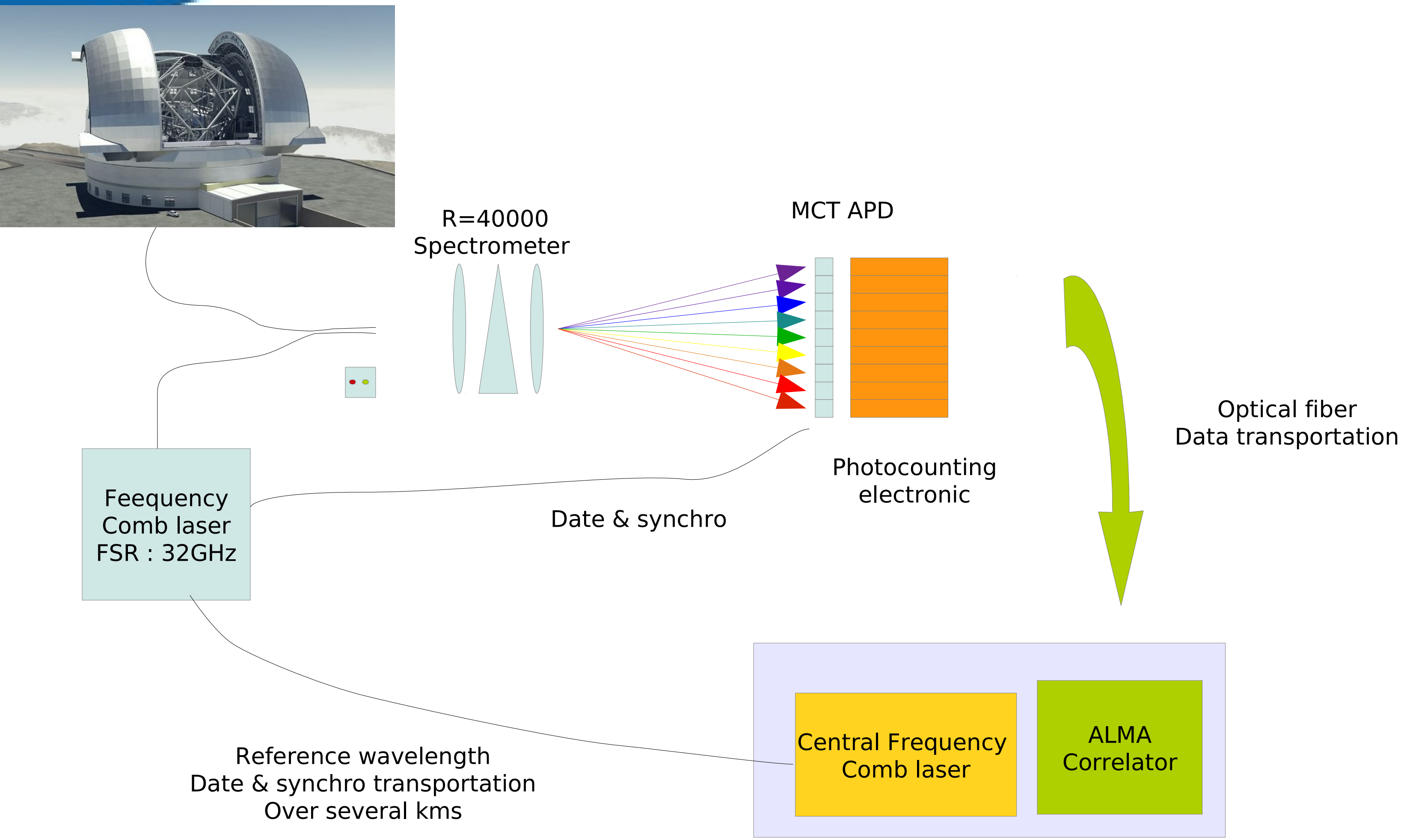
$$\Delta E . \Delta t > \hbar$$

A ideal photon detector should be able to give arriving time with 100ps error and give the measurement of its energy with 40000 resolution …

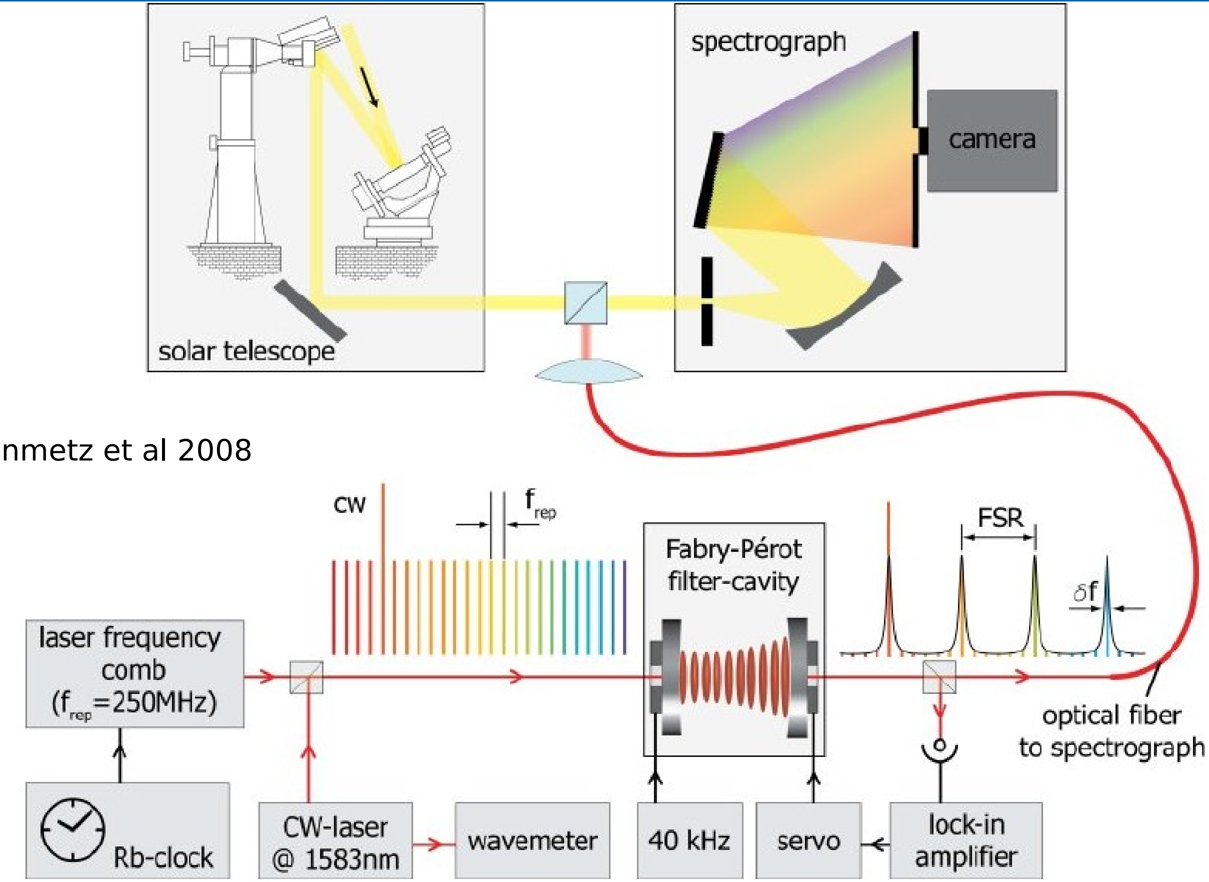
This is the same problem than QuantEye to decide if photon is bunched or not …

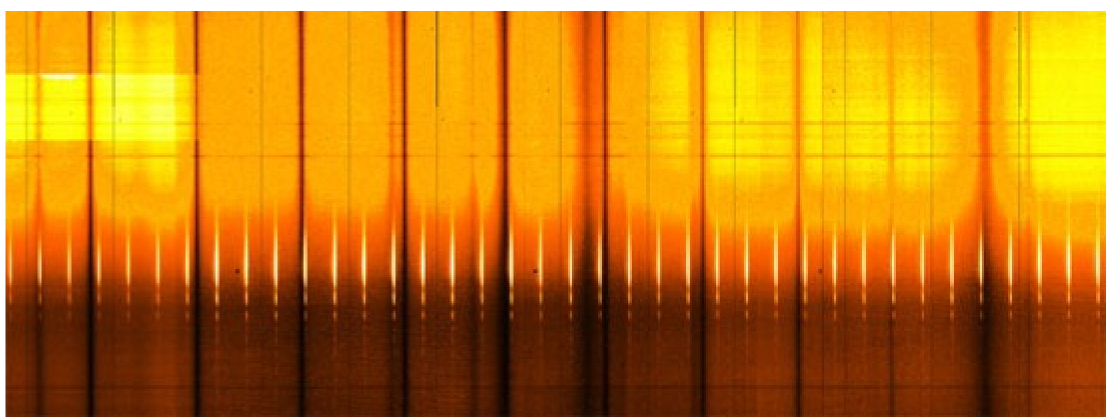
Can heterodyne help us ?

What could be an heterodyne system today ?



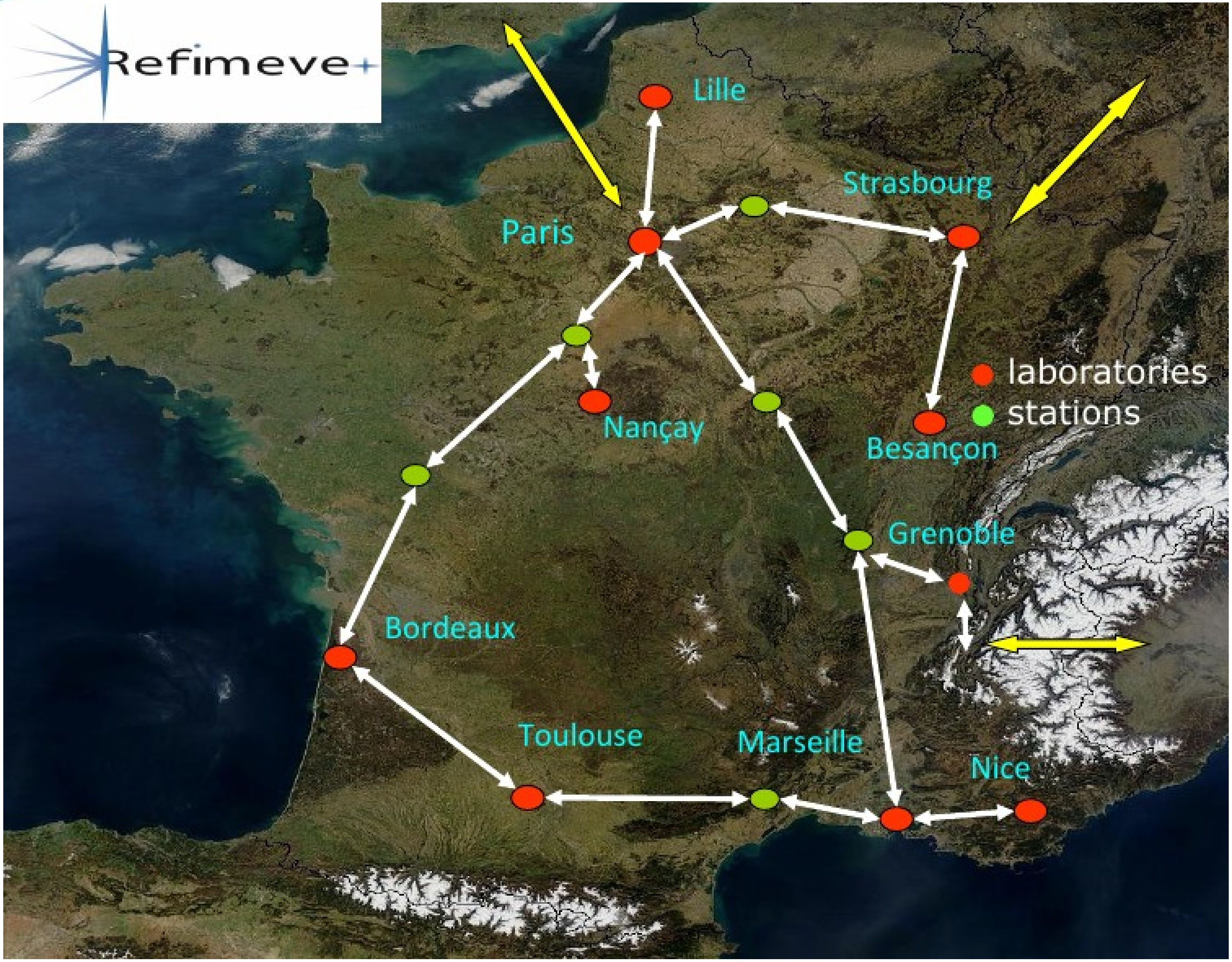
Steinmetz et al 2008

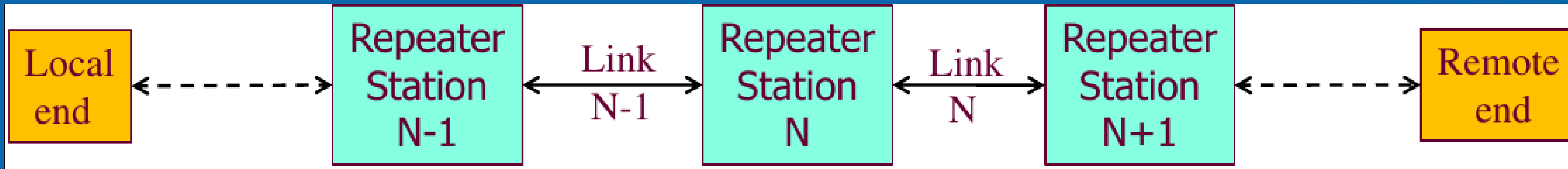




each tooth of the comb have the same phase !

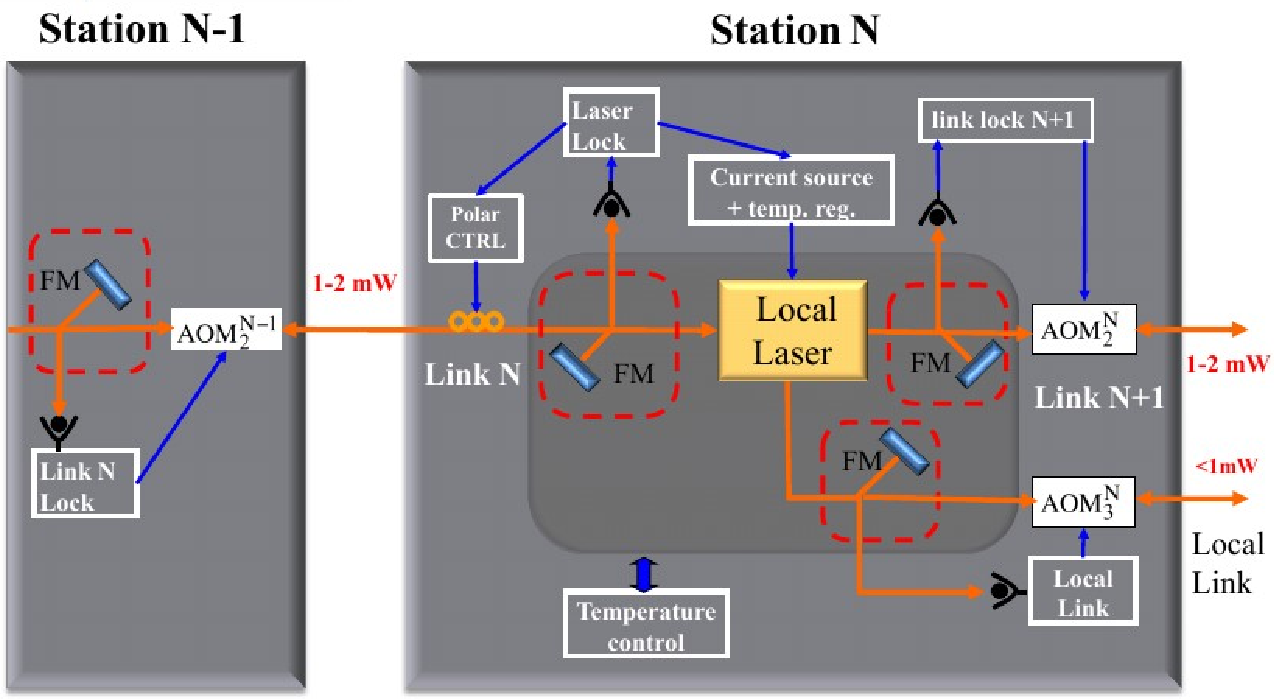
Refimeve+ : long distance frequency and time distribution french facility





Refimeve+

Optical regeneration station



Here the signal is perfect
Receive from station N 2 times distorted signal, compensates it in order
To be perfect at N

Here the signal is distorded : the signal is send back to N-1 station to be compensated then receive close loop
Signal corrected → perfect

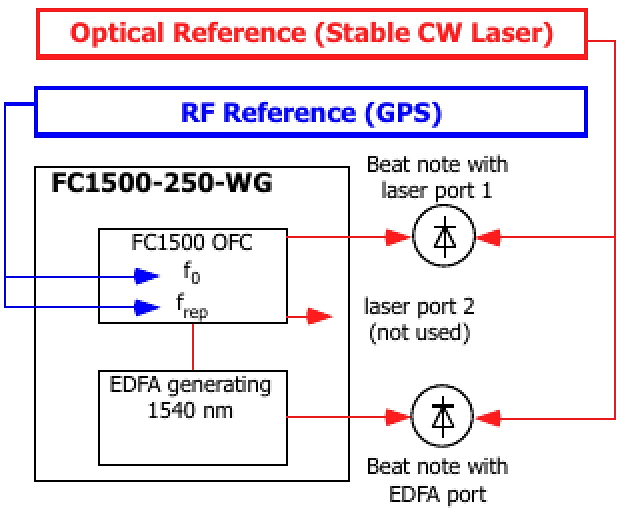
Frequency accuracy 10^{-17}
Frequency stability : 10^{-15} @ 1s
time accuracy 10^{-12}

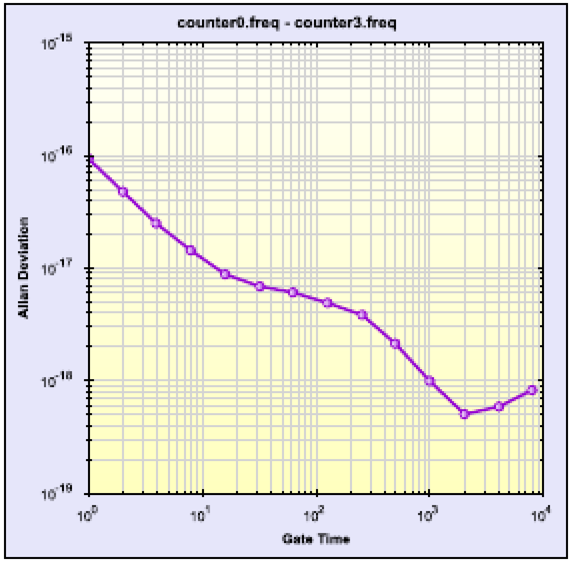
Multi Branch Comb System

MenloSystems

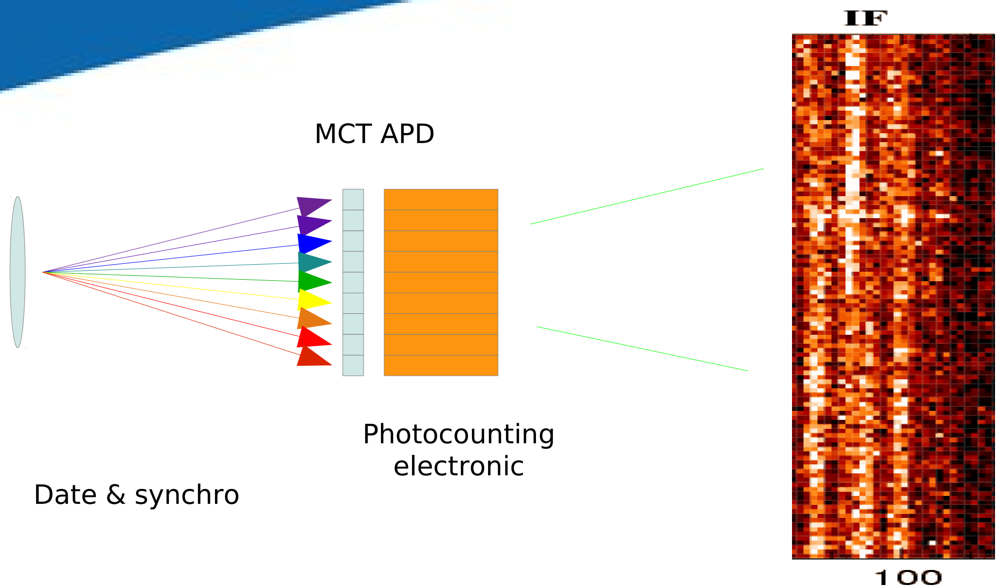
Stability of different comb branches:
- lock frequency comb laser in the RF domain
- beat laser output and EDFA output against a stable cw laser
- Compare the two resulting beat notes

Result: stability <1E-18 (measurement time: >1000 s),
Excellent short-term stability: relative ADEV < 1E-16 @ 1 s.





For each telescope



← inter comparison of detection give an absolute phase if laser are sufficiently stable

Synchronyzed frequency comb laser at 10^{-17}

time

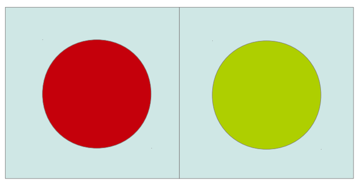
Time distribution better than 10^{-15}

← 10^{-12} in refimeve+ but at 400km what is possible at 10km using dark fiber ?

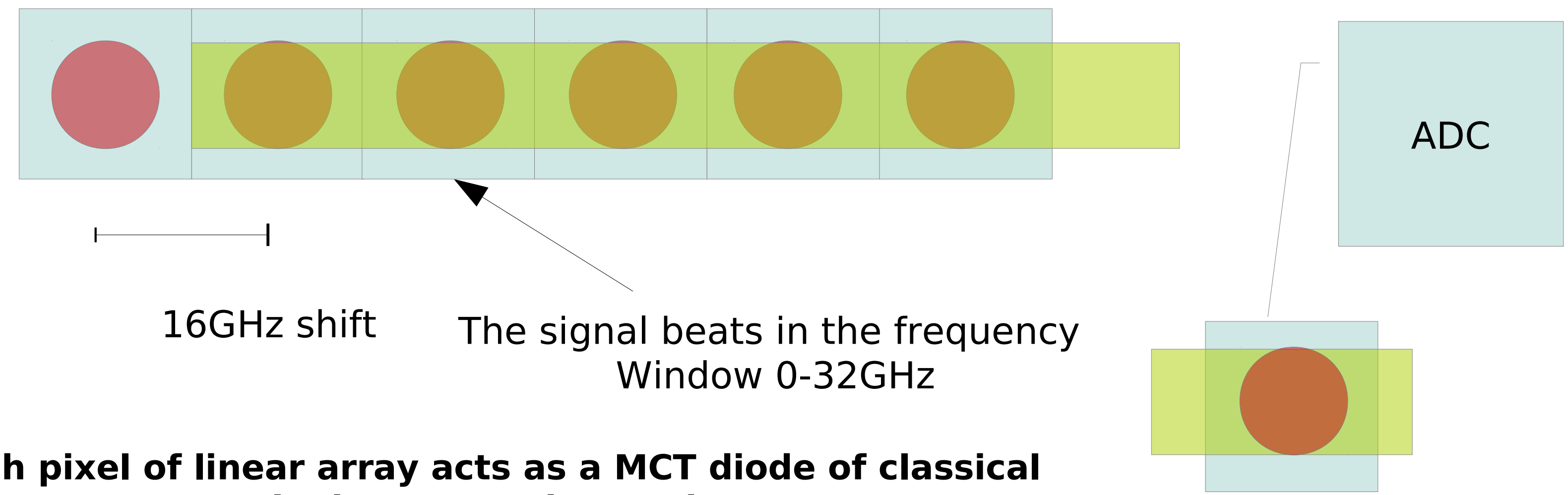
Stability of frequency comb laser better than 10^{-17}

How to mix FCL and light coming from sky ?

Undispersed Slit environment projection on detector pixel



Disspersed Slit environment projection on detector pixel



Each pixel of linear array acts as a MCT diode of classical Analogic 10.6 µm heterodyne

But to mix FCL and light coming from sky must be done at 1.5µm or 750µm

A major concern will be the number of photon !.

- For example if we want 1610^{9} photons/s in a 16GHz bandwidth for Mv=0 at 1µm we need a 1km diameter telescope !
- What happened when we have less photons ?
  - Noise of laser when no photon ...

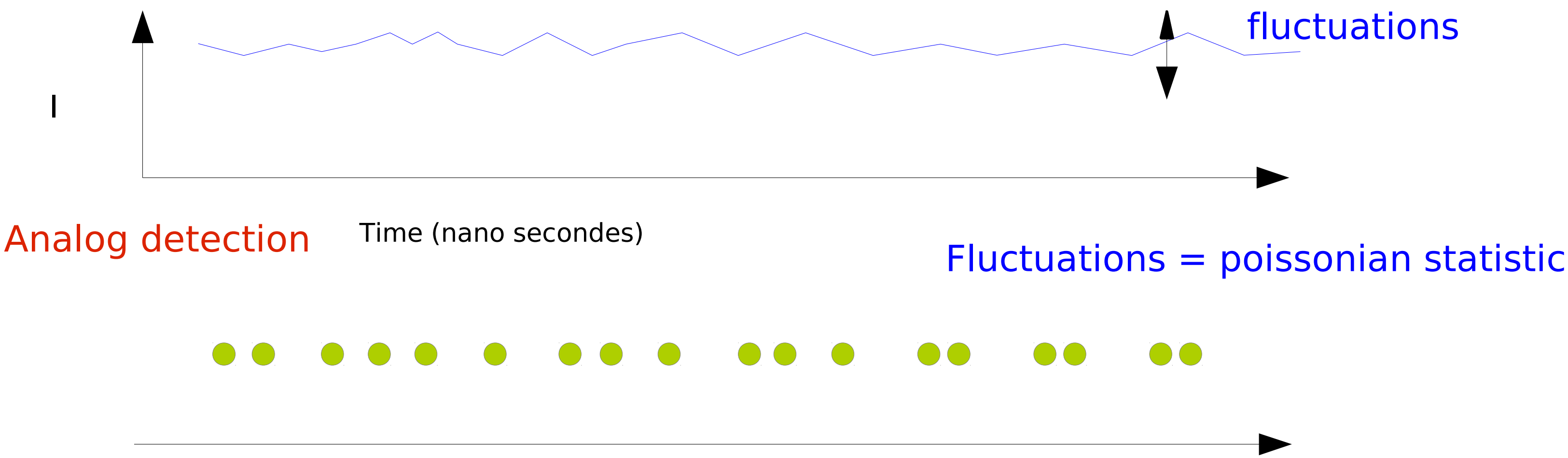
Is it a good idea to use optical amplification ?

- Before mixing :
  - Sudhakar Prasad Vol. 11, No. 11/November 1994/J. Opt. Soc. Am. A
    - Lot of noise is generated between rare photon
- After mixing
  - The noise of laser is amplified

==> It seems that the only possible way is the coherent amplification of signal by laser itself

The photocounting way

Is extremely precise photon counting device useful ?



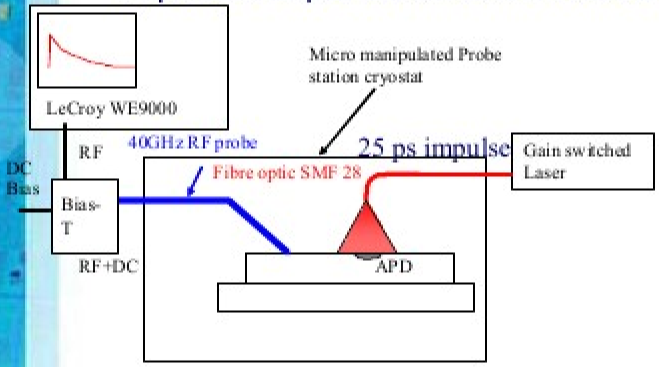
Digital detection = time measuments of photon

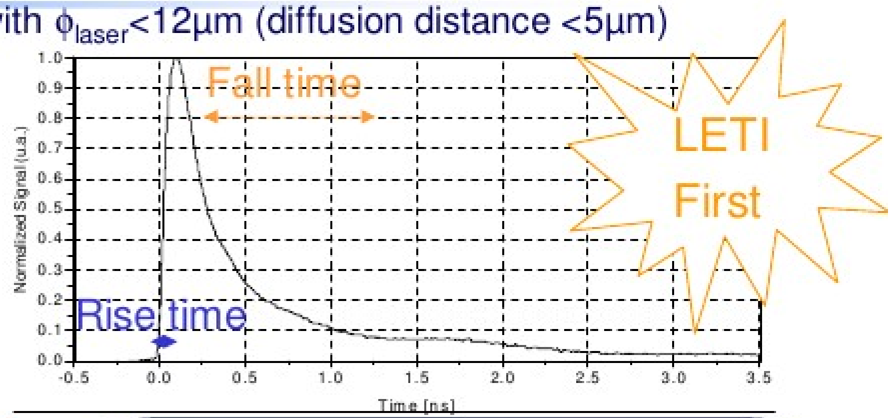
We can consider detector analog signal as a flow of photo-events

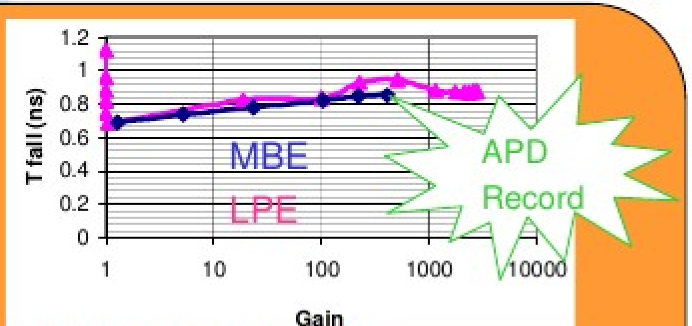
But what is the state of art photon counting permitting such GHz detection ?

Response time measurements in MW e-APDs

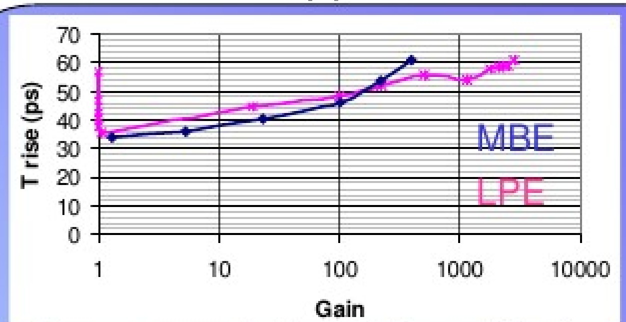
Impulse response time measured with ϕ_{laser}<12µm (diffusion distance <5µm)







- Diffusion limited fall time
- Small increase 600ps(M=1) to 800ps (M=2800)
- BW_{FT}(M=2800)=400MHz (GBW=1.1THz)



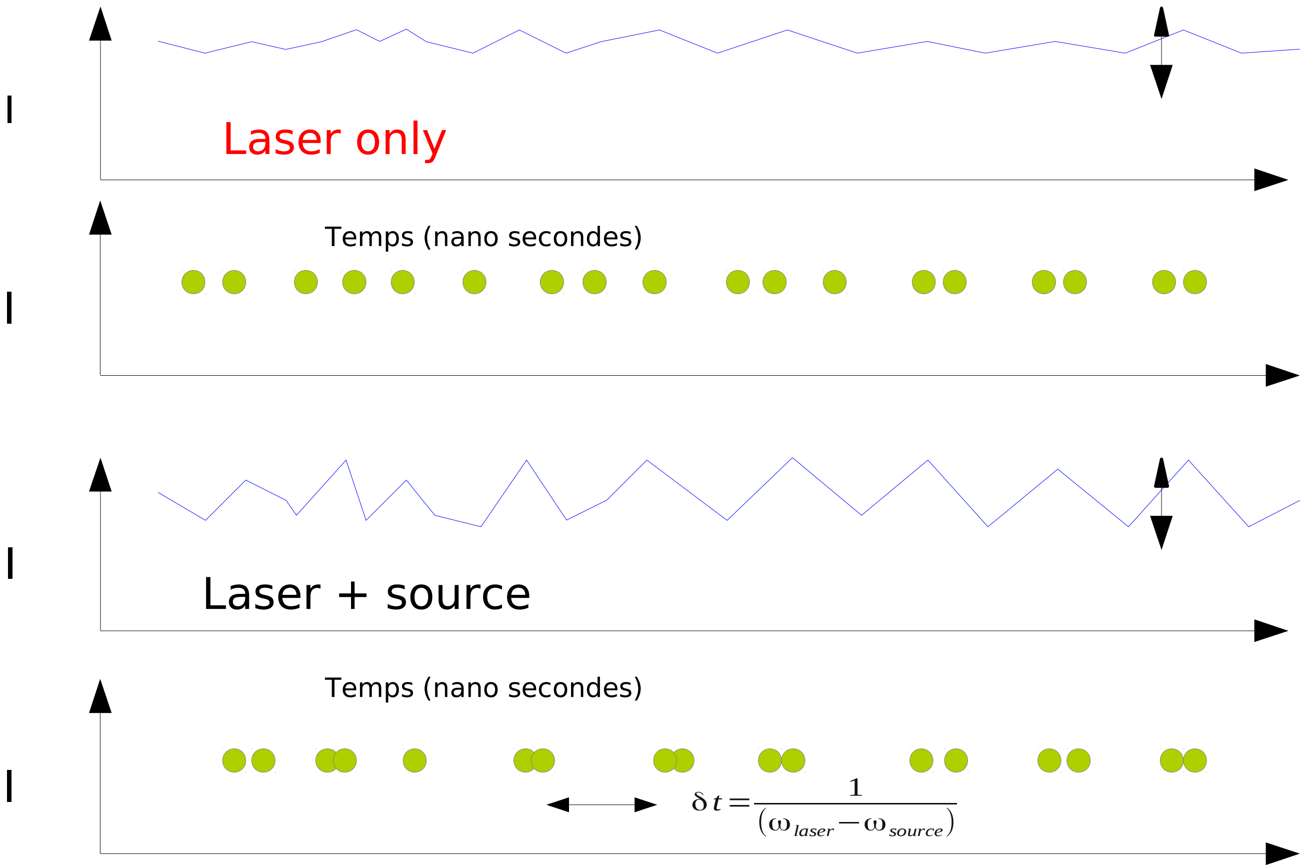
- Measurement -transit time-diffusion-onset limited rise time
- Small increase 40ps(M=1) to 60ps (M=2800)
- GBW limit =18THz

BW close to independent on gain➔

record high GBW=2.1THz (GBW_{limit}=18THz) LETI 2008

Heterodyne seen as a photon-flow ?

$$I = I_{source} + I_{laser} + 2\sqrt{I_{source} I_{laser}} \cos(\omega_{laser} - \omega_{source})t$$



One can see heterodyne as a “bunching” of photon around beating time

New question : is their a limit to see interaction of very low flux interaction with a laser ?

$$I = I_{source} + I_{laser} + 2\sqrt{I_{source} I_{laser}} \cos(\omega_{laser} - \omega_{source}) t$$

When I_{source} =1

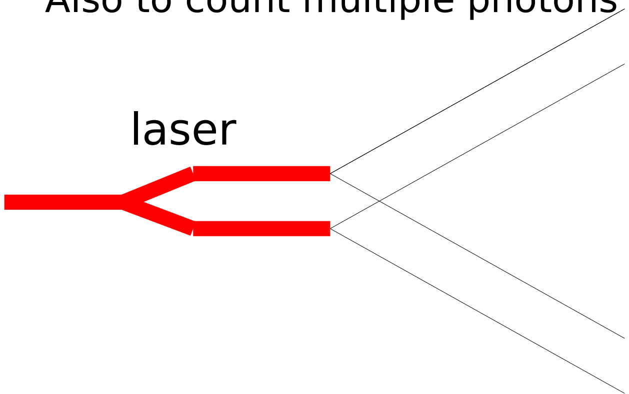
$$I = 1 + I_{laser} + 2\sqrt{I_{laser}} \cos(\omega_{laser} - \omega_{source}) t$$

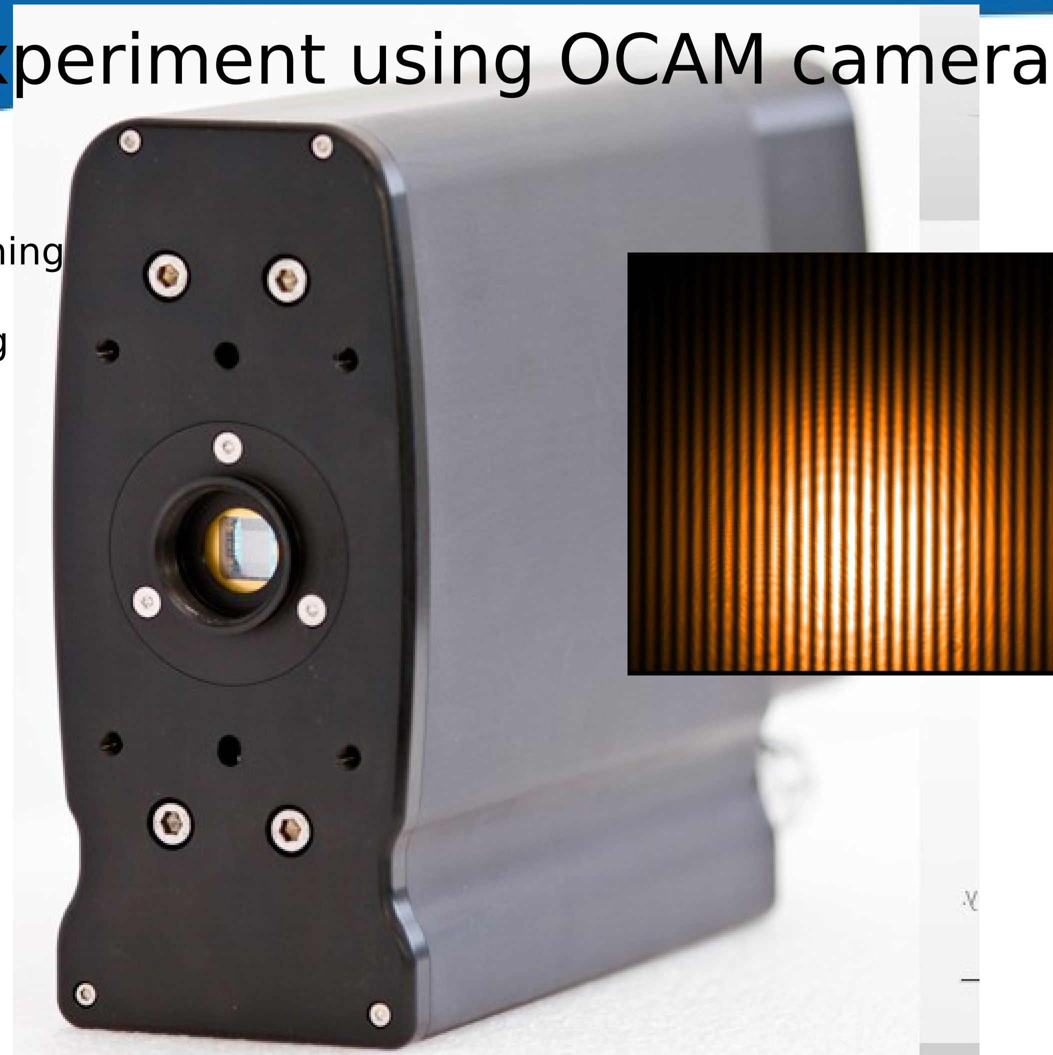
The noise is $=(I_{laser})^{1/2}$ and the beating terme : $2(I_{laser})^{1/2}$

Q?) can we detect only one photon in heterodyne system ?

Young hole experiment using OCAM camera

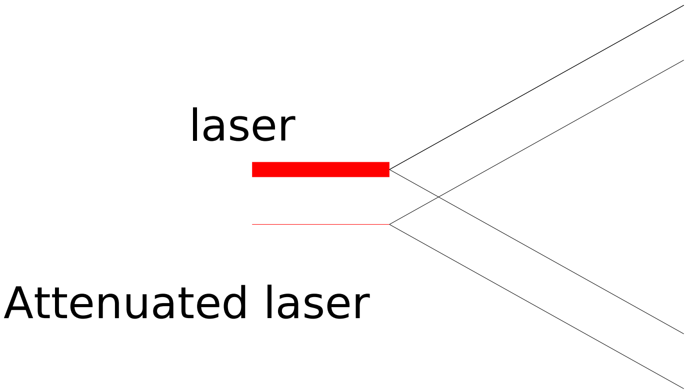
FLIR-OCAM is a fast EMCCD camera running
At 1600 frames/sec
Permitting photon counting permitting
Also to count multiple photons

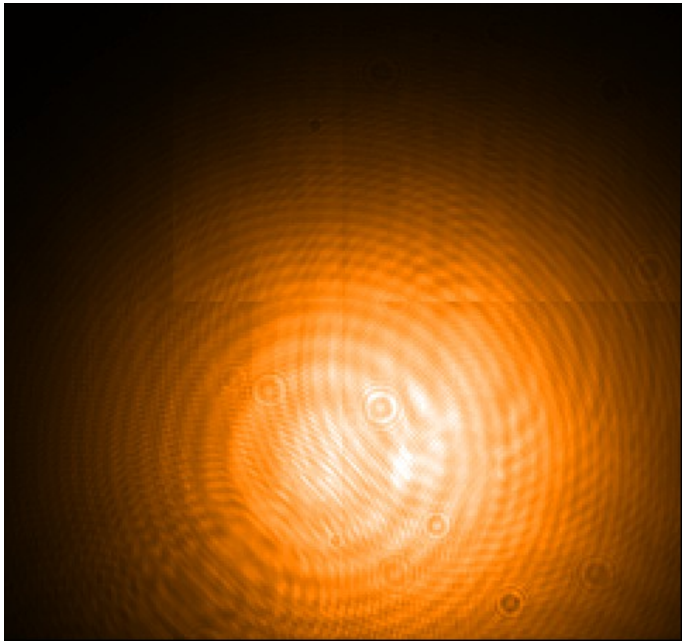




Two optical fibers are mounted on 127µm Vgroove directly placed in front of CCD camera some fringes are due to glass window

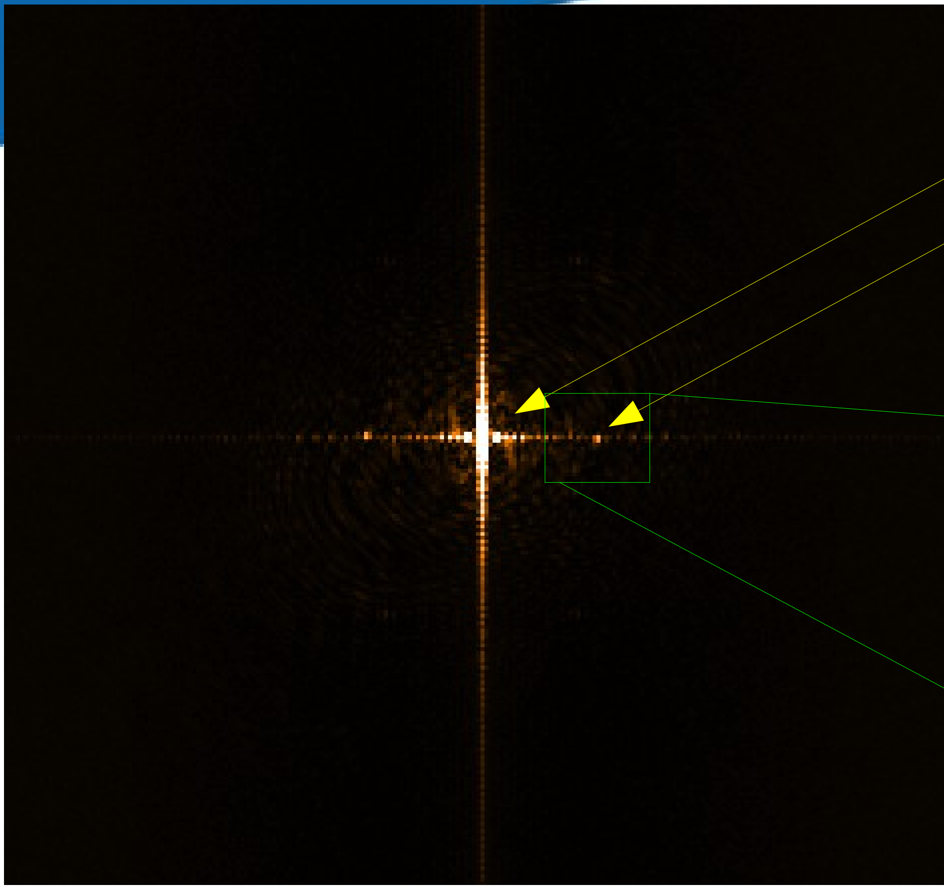
Young hole experiment using OCAM camera





With the knowledge of interference pattern, we decrease the flux in the second arm of Y junction up to have very few number of photons
And perhaps no photon at all ...

FFT of Average of 10000 frames

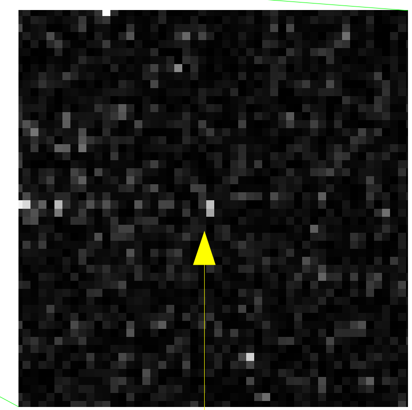


223800 detection/fr

1300 detection/fr

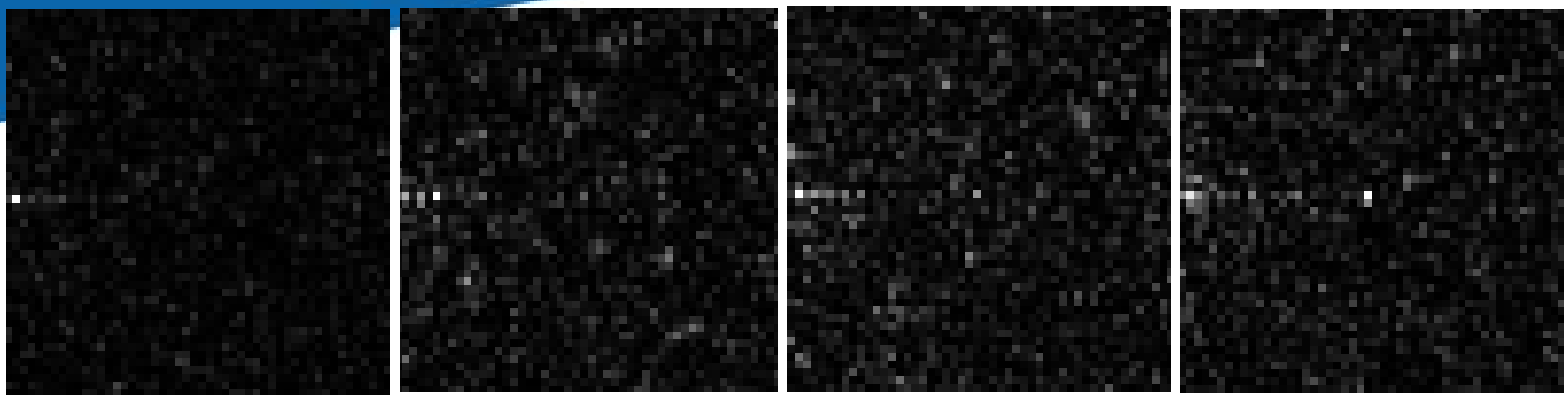
1300 / 2/sqrt(223800)= 2.7 ph /fr
in the attenuated arm

Visibility : 2 10-3



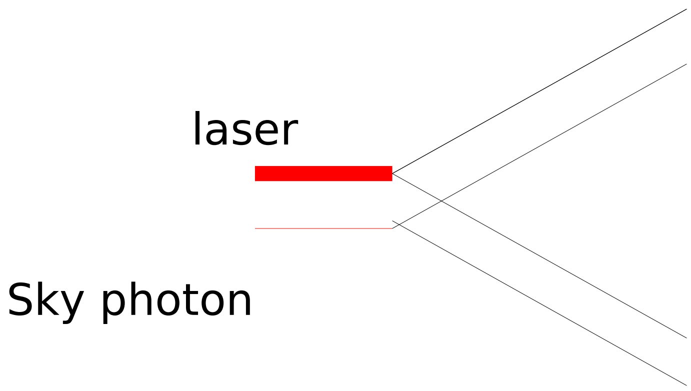
1300 detection in
one frame

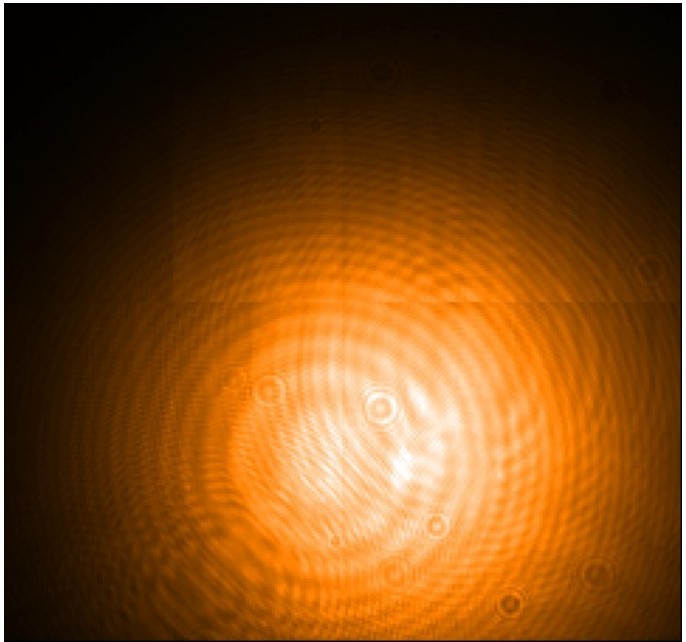
Evolution of peak sorted by number of photon



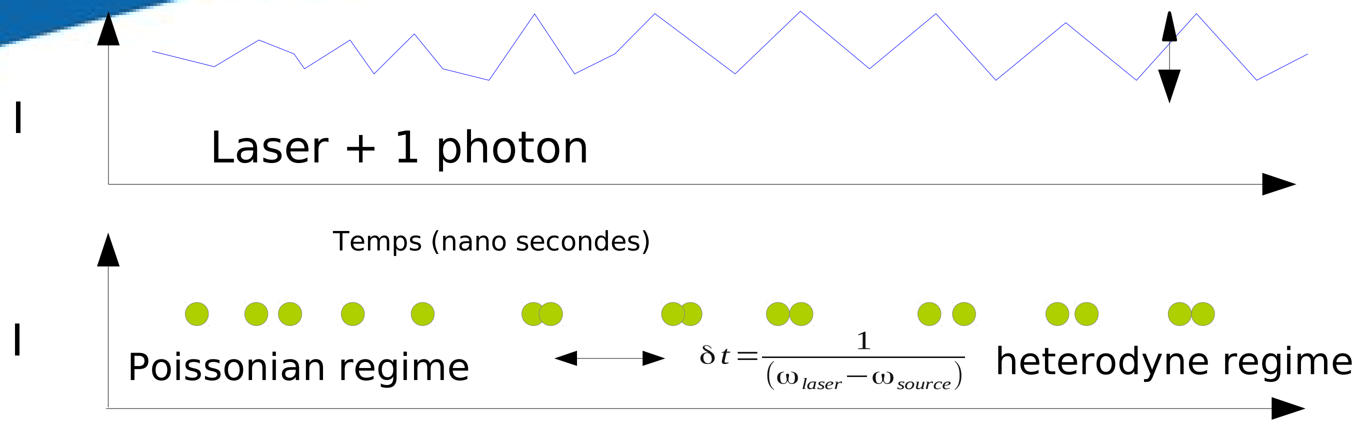
0ph 1ph 2ph 3ph

==> Is it possible to see in real time the impact of one photon
Discovering its frequency at same time ?





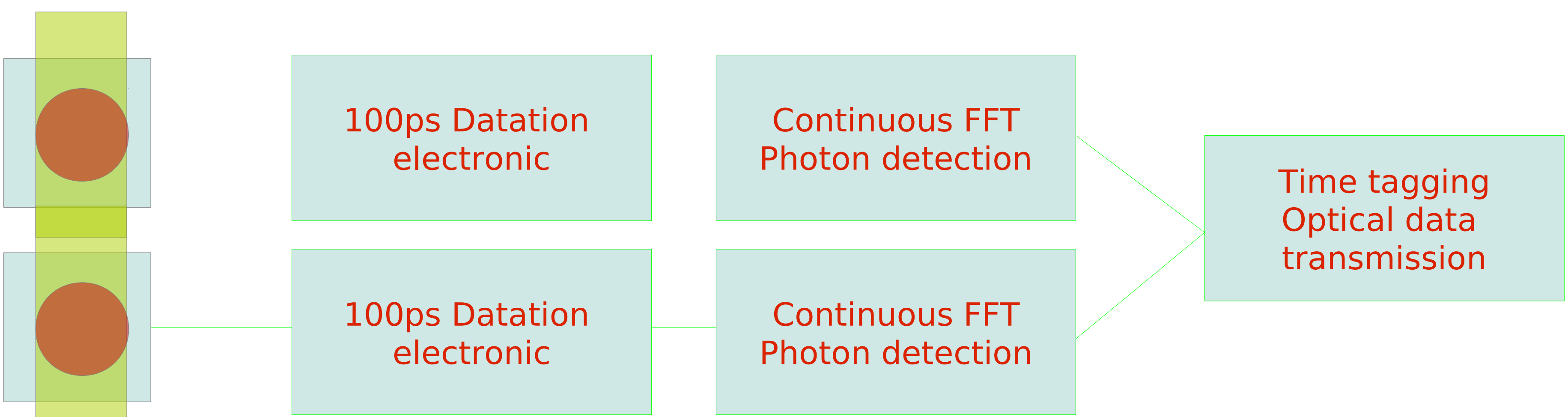
Translating this experiment in time domain



What mean have a photon or wave packet at 16 GHz

HgCdTe-APD are able to detect one photon, giving arriving datation better than 100ps, multiple photon detection with reduced Fano noise
Phd thesis start soon

With new generation of LETI-LIR HgCdTe-APD we should be able to sense heterodyned Photon one by one giving us its energy and phase from UV to 3 micron



Conclusions

Do we violating heisenberg limit heterodyned detection of photon ?

How is understood the heterodyne SNR in this context ?

The detection of heterodyned unique photon is not yet prooved !

But FCL permits us to multiplex lot of heterodyne channels

→ good for SNR , is it sufficient to rebirth heterodyne ?

I have not speak about correllator but we are collaborating with misroelectronic industry and very promising micro-systems coupling optics and electronic are developed (pic32g STMicro) : 32gigabyte optical link between computer cores

Such electronic could be develop to be merged to MCT APD at 77°K