High Speed Imaging
At ICube

Pr Wilfried Uhring

University of Strasbourg and CNRS

Icube laboratory, UMR 7357

Outline

- High speed video Camera
- Ultrafast Imaging
  - Time gated camera
  - Streak imaging
- Time correlated photon counting
- The available light sources
- Applications to environment
  - The time resolved optical turbidity project
  - The WPS project

Wilfried Uhring
Icube, University of Strasbourg and CNRS

High speed video camera

- Camrecord 600x2
    - Resolution 1.280 x 1.024
    - Frame rate @ max. sensor res. 500 fps
    - Exposure time 1 µs - 1/Framerate
    - Pixel size 14 µm x 14 µm
    - A/D conversion 10 bit or 8 bit
    - Dynamic 60 dB (90 dB optical)
    - Sensitivity 25 V/lux*s
    - Shutter Global electronic shutter, >1 µs exposure time
    - Trigger signal TTL, switch, open collector, rising or falling edge, on image content variation
    - Interface Gigabit Ethernet
    - Lens MountNikon F-Mount (optional C-Mount)

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Exemple de vidéo

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Applications video rapide

- Mécanique
  - Barre de Hopkins
  - Découpe bois
  - Dynamique diverse (tournette, microfluidique, TPE …)

- Grand public
  - Démonstration (fête de la science)

- 1280x1024 @500 fps ➜ 655Mpixel/s
  - Reduction image pour augmentation taux d'image

Wilfried Uhring
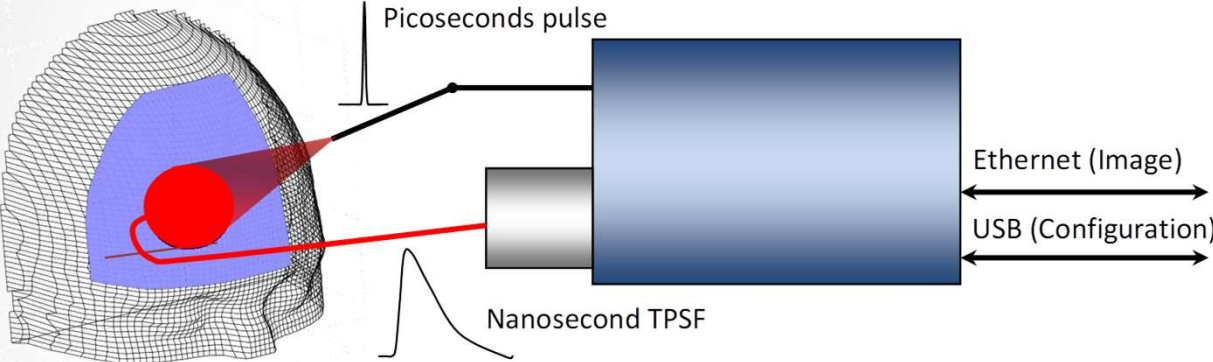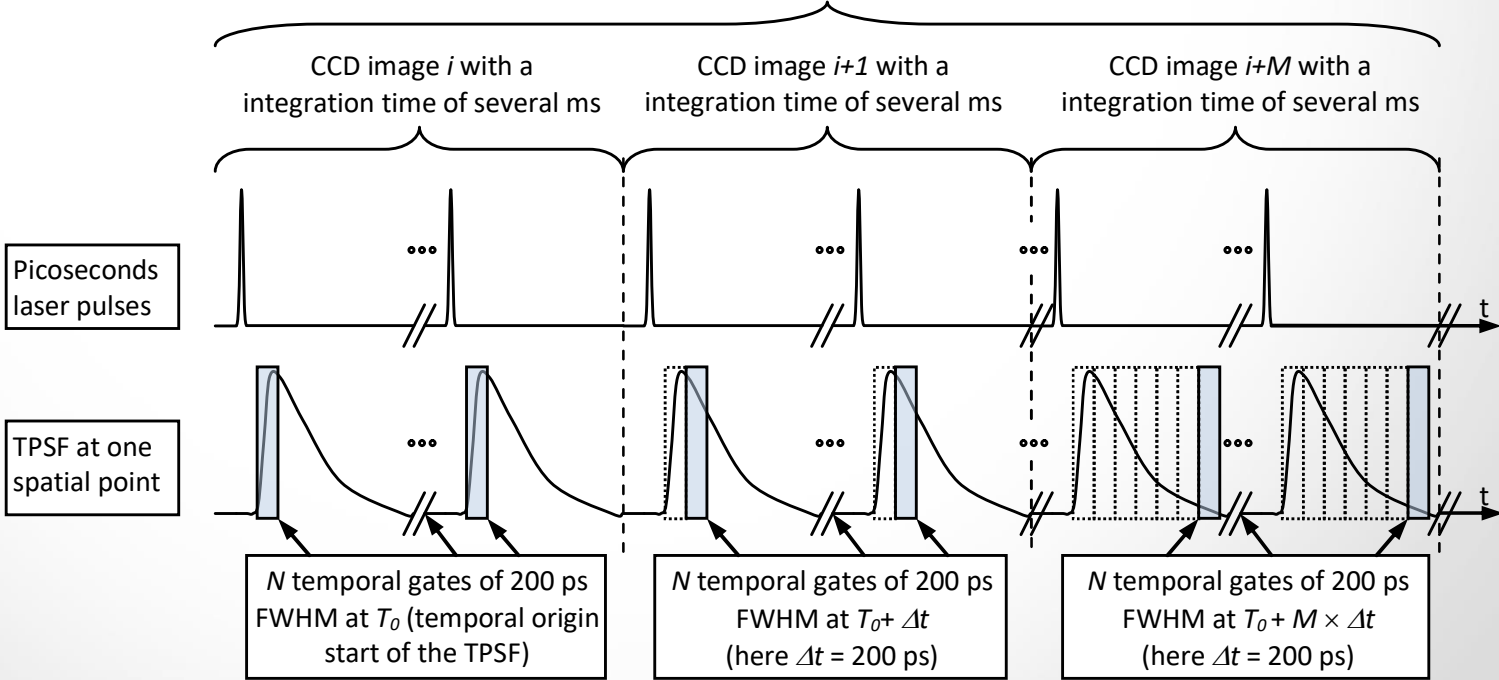*Icube, University of Strasbourg and CNRS*

Caméra intensifiée

- Obturation rapide

Imagerie rapide

- Obturation rapide 200 ps
  - 1.10^6 fois plus rapide qu'un appareil classique
  - ➔Peu de lumière
  - ➔**Intensification nécessaire**
- Résolution spatiale 1 mega pixel obturation 1 ns
- ➔Taux d'échantillonnage

 **1 peta pixels par seconde** $(1.10^{15}$ pixels/s)!

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Principe d'acquisition

Picoseconds pulse

Ethernet (Image)

USB (Configuration)

Nanosecond TPSF

M images for a full TPSF measurement at one wavelength

CCD image i with a integration time of several ms

CCD image $i+1$ with a integration time of several ms

CCD image $i+M$ with a integration time of several ms

Picoseconds laser pulses

TPSF at one spatial point

N temporal gates of 200 ps FWHM at T_0 (temporal origin start of the TPSF)

N temporal gates of 200 ps FWHM at $T_0 + \Delta t$ (here Δt = 200 ps)

N temporal gates of 200 ps FWHM at $T_0 + M \times \Delta t$ (here Δt = 200 ps)

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Intensificateur d'image

- Intensificateur de lumière en 2D spatial
  - Amplification MCP (1973)
- Détection photon unique
- Résolution spatiale
  - 10 à 50 pl/mm
- Résolution temporelle
  - Obturation ultrarapide
  - Impulsion tension sur photocathode
  - Jusqu'à 100 ps
- Electronique de pilotage
- Impulsion ultrarapide et haute tension (-20 à -200 V)

Wilfried Uhring
Icube, University of Strasbourg and CNRS
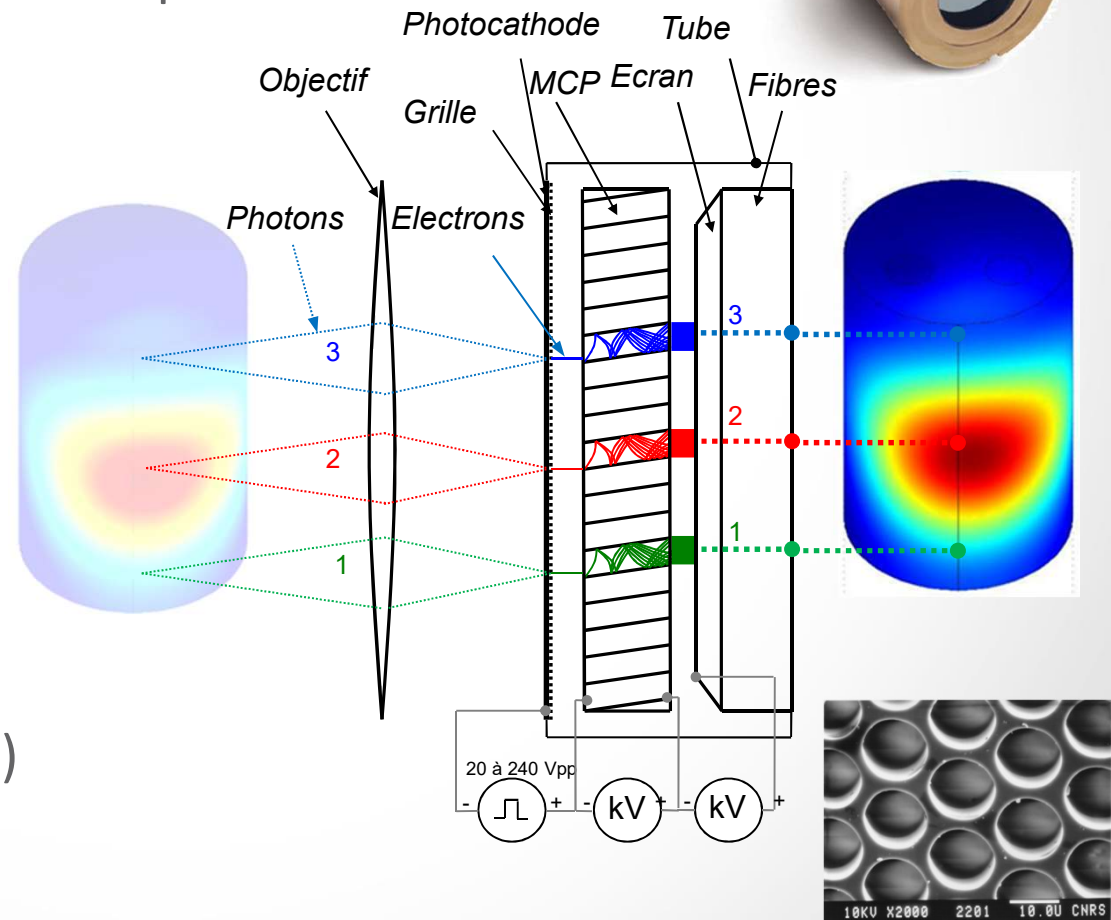
OptoPIC : Picoseconde intensified camera

- ## Optronis/ICube

  - Image intensifier Photocathode gating

  - Temporal gate width : 200 ps

  - Temporal gate position : 10 ps

  - Repetition rate ~ 100 MHz

  → 100 billion fps

Example: propagation of a 200 picosecond light pulse of light in an optical fiber : lassic photography (left), ultrafast movie (right)
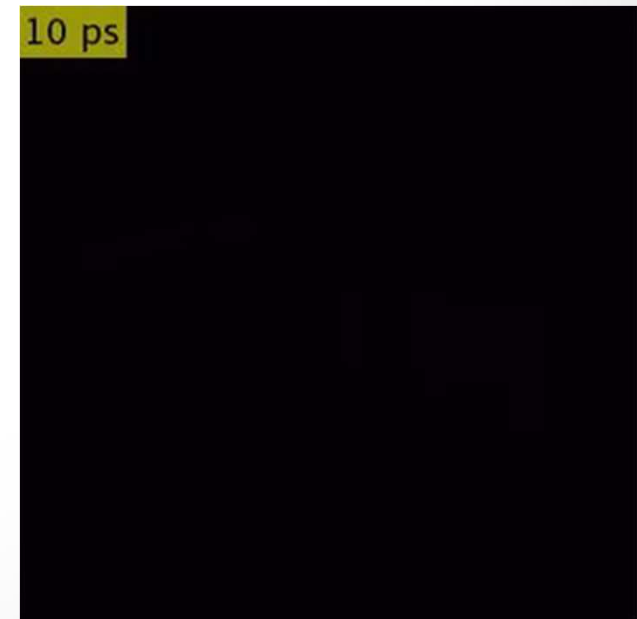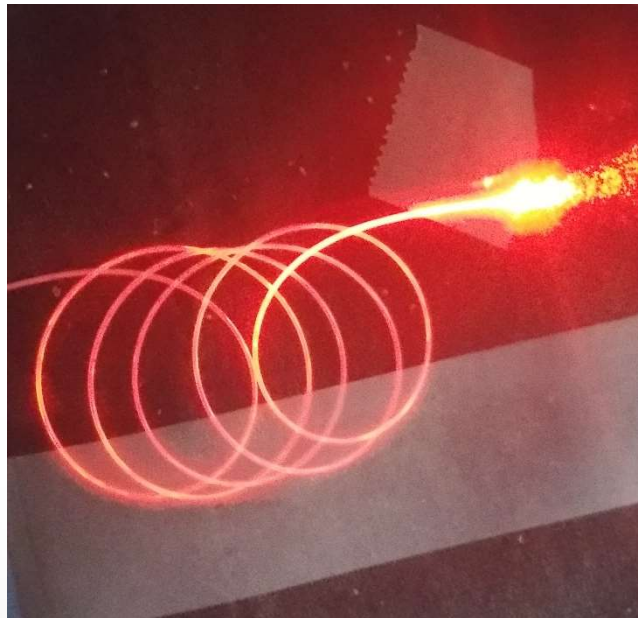
ICube in Light !

- Propagation of a 200 ps FWHM light pulse in a optical fiber
  - Optical fiber shaped to "ICube" name
  - Total movie duration : 3 ns
  - 33 billions frames per second (30ps)
  - Acquisition time : 10 seconds

Image :0 ps
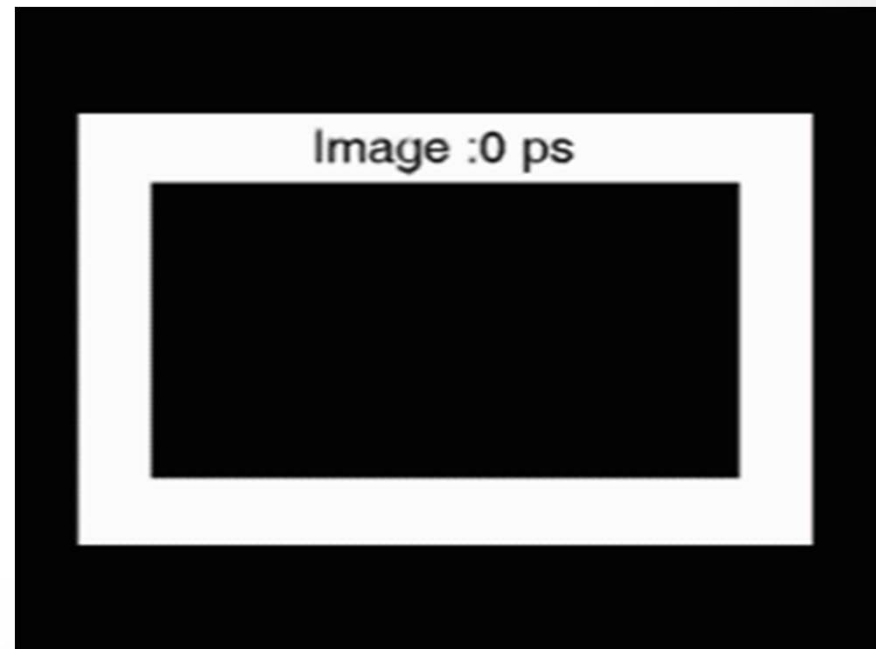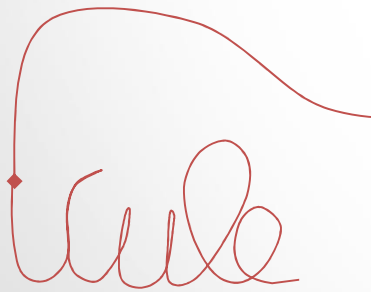
  - Credits : Patrick Poulet, Wilfried Uhring

OptoPIC : Picoseconde intensified camera

- ## Optronis/ICube
  - Propagation of a light pulse through a lego character
  - Total movie duration : 1 ns
  - 100 billions frames per second (10ps)

10 ps
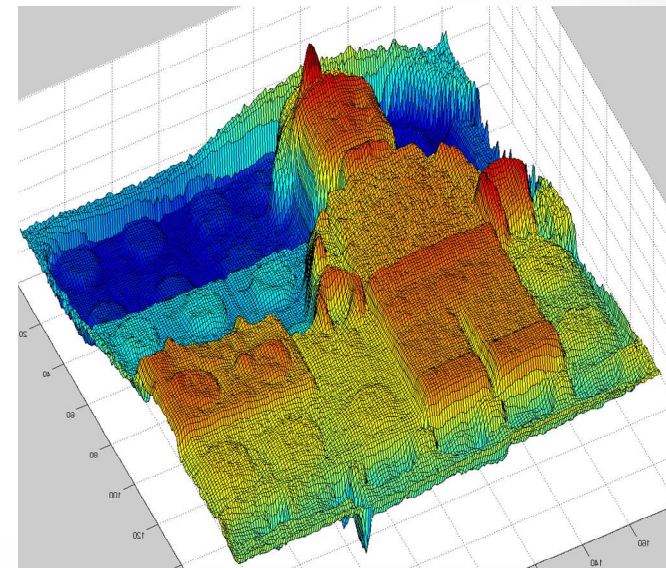
Reconstructed 3D scene by time of flight

iCUBE

Application de FLIM

- Interaction biomoléculaire
  - Pixel intensity is related to the fluorescence lifetime

Wilfried Uhring
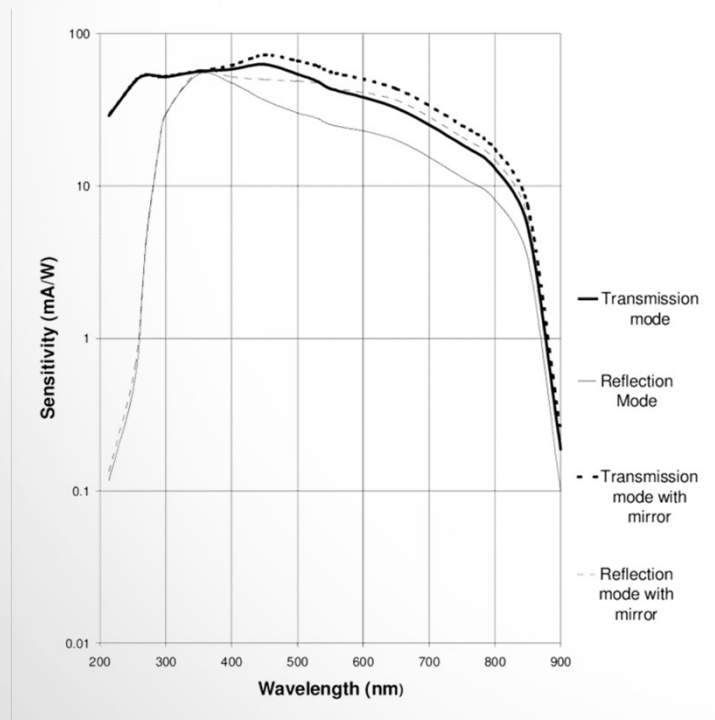*Icube, University of Strasbourg and CNRS*
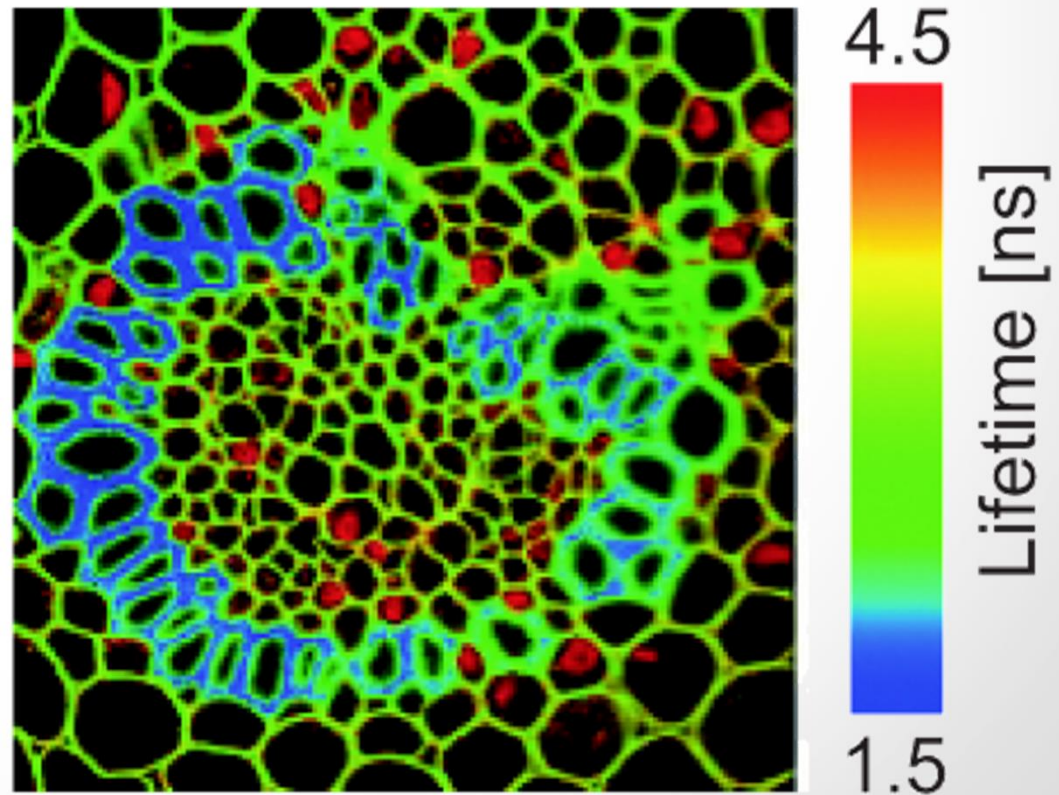
Streak Imaging

- Reducing the spatial resolution increase the frame rate
- Optimal speed obtain for one single column

➔ Streak imaging

- About 100 times faster with whatever the technology
  - Rotating mirror 40 ns Frame ➔ 600 ps Streak
  - Vacuum tube 200 ps Frame ➔ 2 ps Streak
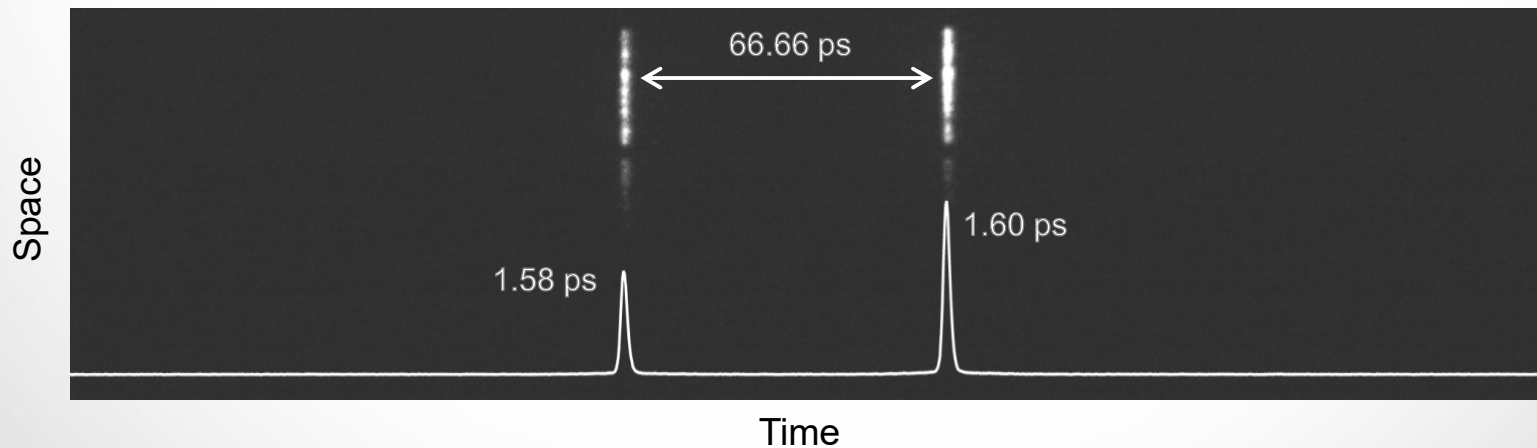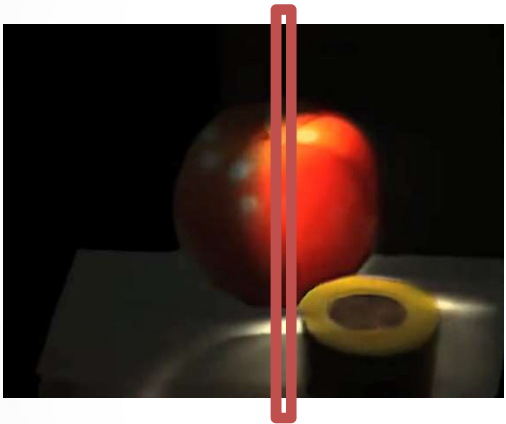 - Solid state 100 ns Frame ➔ 1 ns Streak

X space

Time

Wilfried Uhring
Icube, University of Strasbourg and CNRS
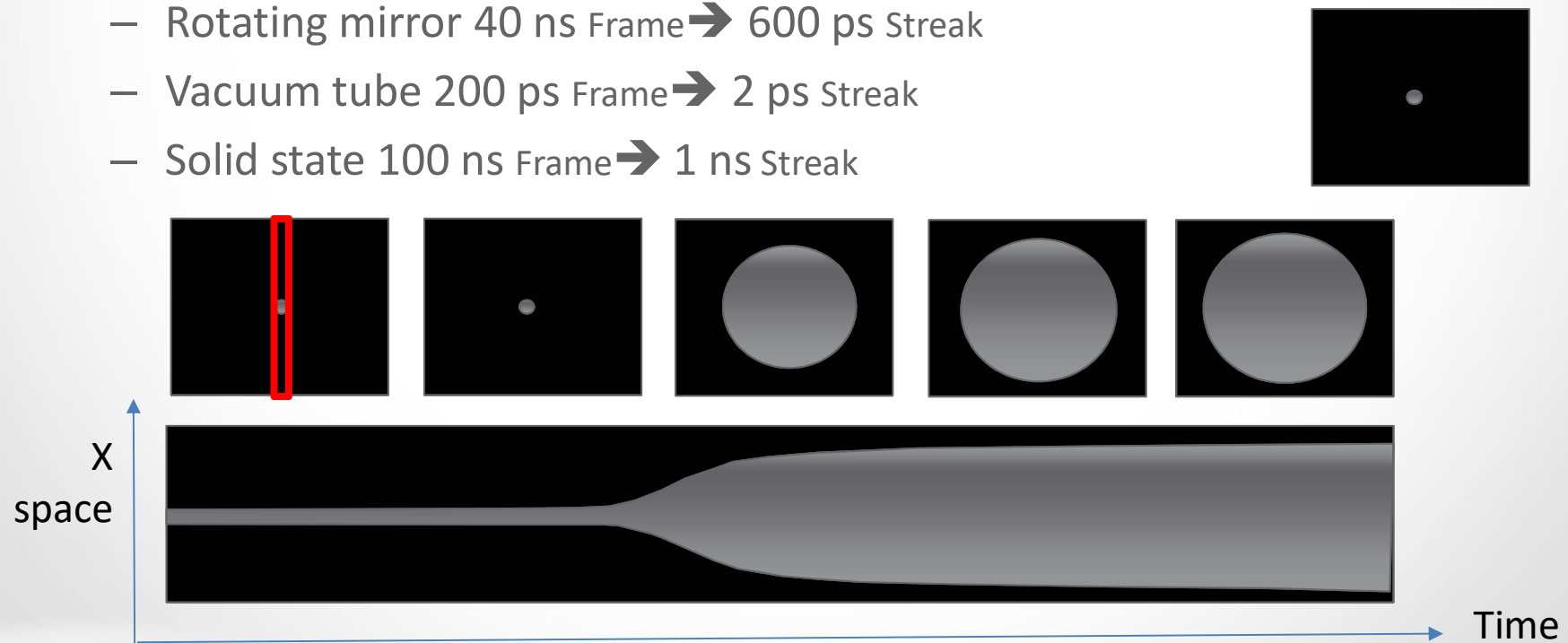
Icube's Streak Camera

- 3,2 ps FWHM

- Synchroscan 81MHz

- S20 photocathode

Wilfried Uhring
Icube, University of Strasbourg and CNRS

1 ps - Streak imaging

- Reduce spatial resolution increase frame rate Camera

66.66 ps

Space

1.60 ps

1.58 ps
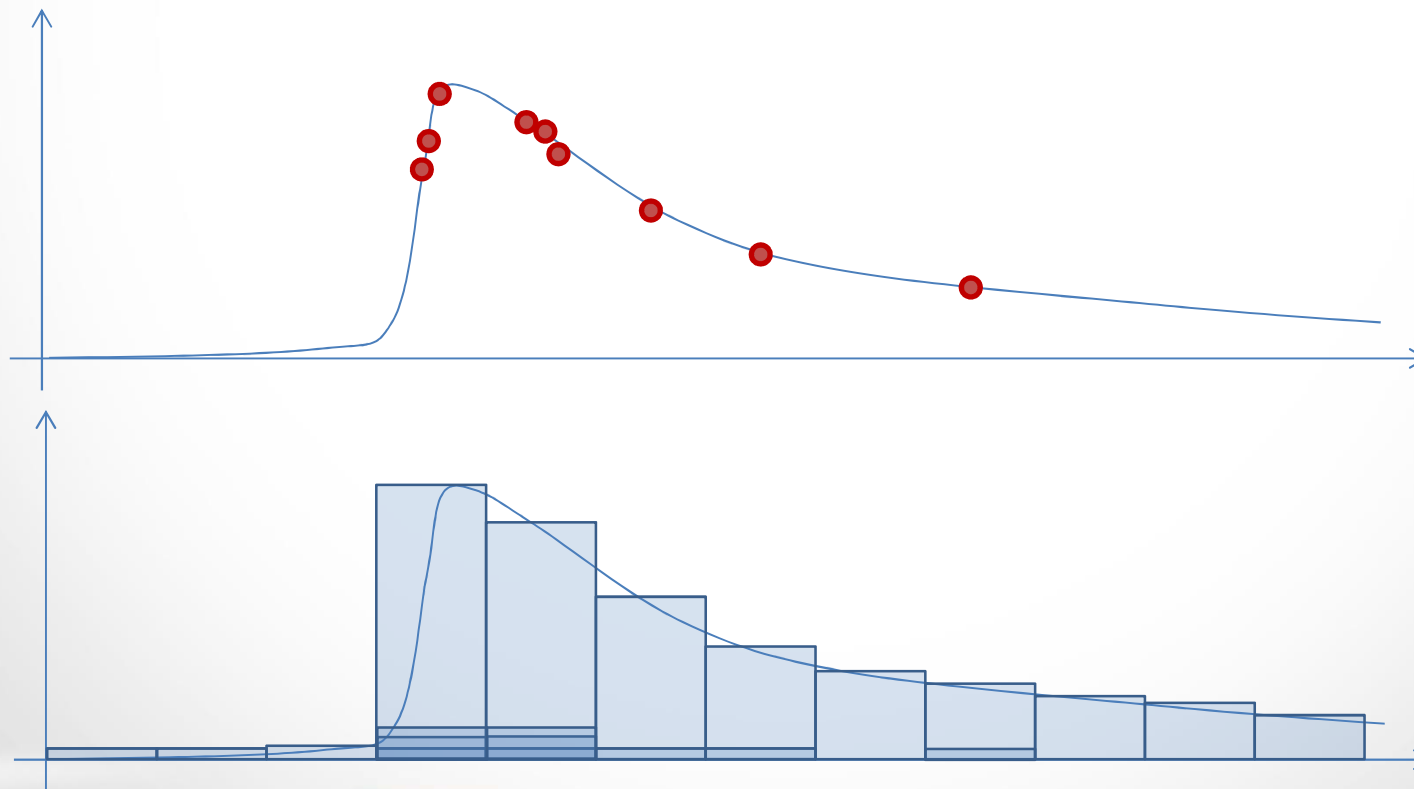
Time

Two Femtoseconde laser pulses delayed by 66,66 ps

Applications

- Time resolved fluorescence

- Photoluminescence

- Laser dynamic

  – Pulsed laser diode response

- Time resolved stray-light

Wilfried Uhring
Icube, University of Strasbourg and CNRS
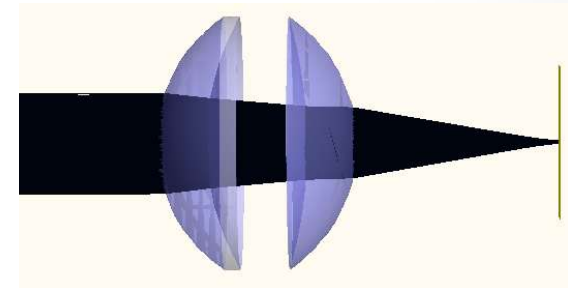
Photon counting

- ## Time resolved photon counting approach

  – **For very weak signal**

  – **Principle : measure when a photon is detected relatively to a start signal, increment the corresponding bin, restart …**

Photon counting

- The time resolved photon counting require a relatively complex electronic
  - Time to digital converter unit with 10th of picosecond resolution

Wilfried Uhring
*Icube, University of Strasbourg and CNRS*
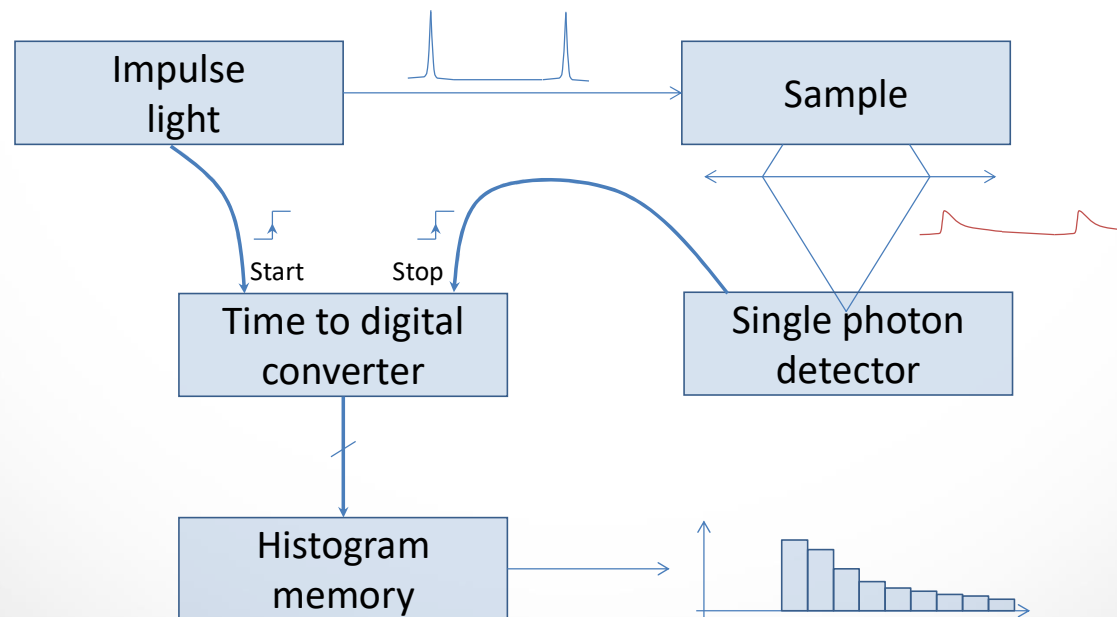
Photon couting

- Characteristics
    - Temporal resolution 50ps FWHM
    - Repetition rate up to 100 MHz
    - Up to 6 Mega photon/s
    - Real time processing
    - Embedded ps laser diode driver
    - ➜ Standalone system

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Time resolved integrated photon counting systems

- ## Streak imaging to push the limits once again
  - ### Example: (ICube) SPAD based streak camera
    - Temporal resolution 10 ps
   - Fill factor > 30%
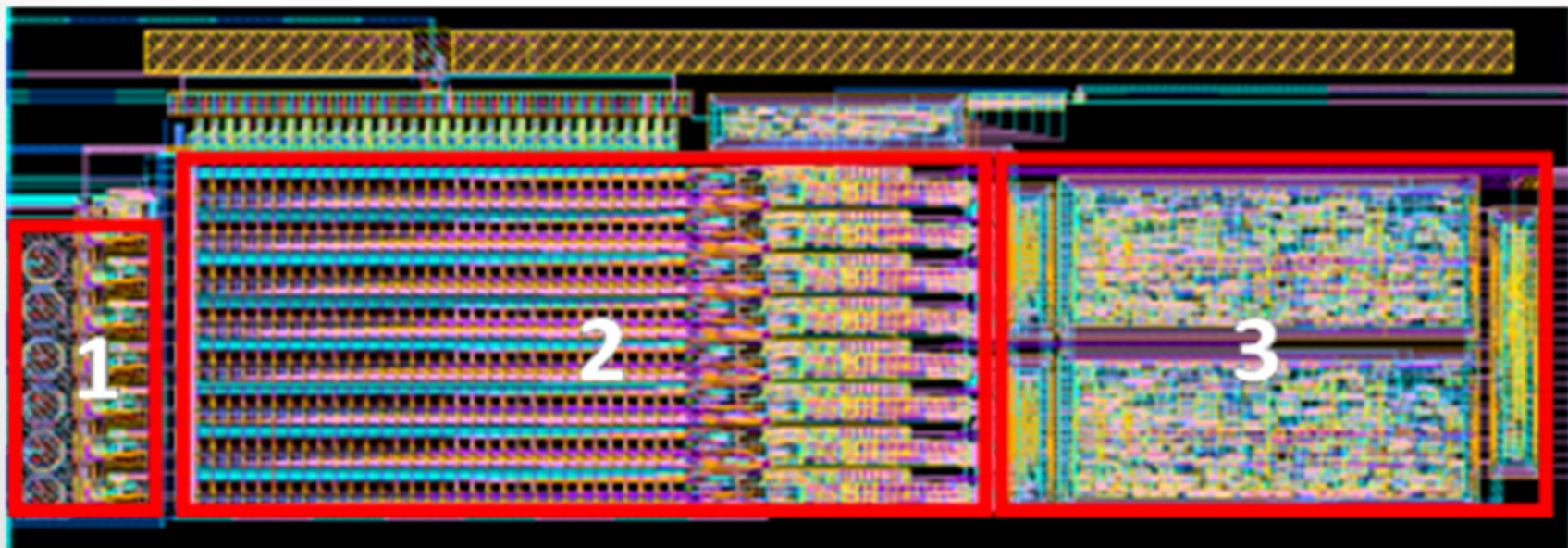
1: Spad & Quench

2: High resolution Time to digital Unit 10 ps quantum

3: FIFO for high data rate acquisition (BW 4 Gbps for 8 SPAD)

Les sources laser

- ## Femtosecond laser source
  - 780 nm, 81MHz, 100fs FWHM
    - Up to 1 W

- ## Picoseconde Supercontinuum
  - 600 to 1000 nm, 79MHz (IPB)
  - 400 to 850nm, 81 MHz, <35 ps FWHM

- ## Laser diode
  - 405 to 1080 nm, up to 100 MHz, 50 to 200 ps FWHM
    - A few 100µW to a few mW
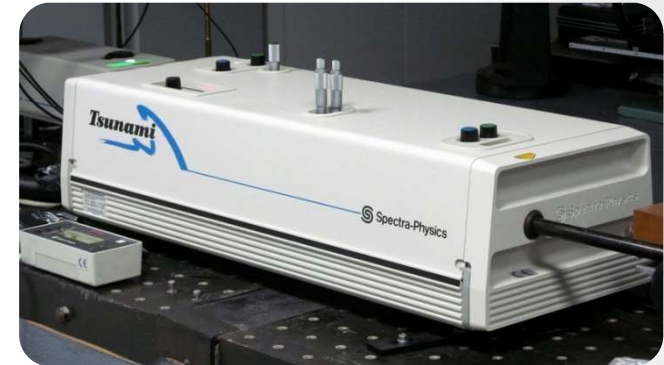
application environnement

- Time resolved optical turbidity

Wilfried Uhring
Icube, University of Strasbourg and CNRS
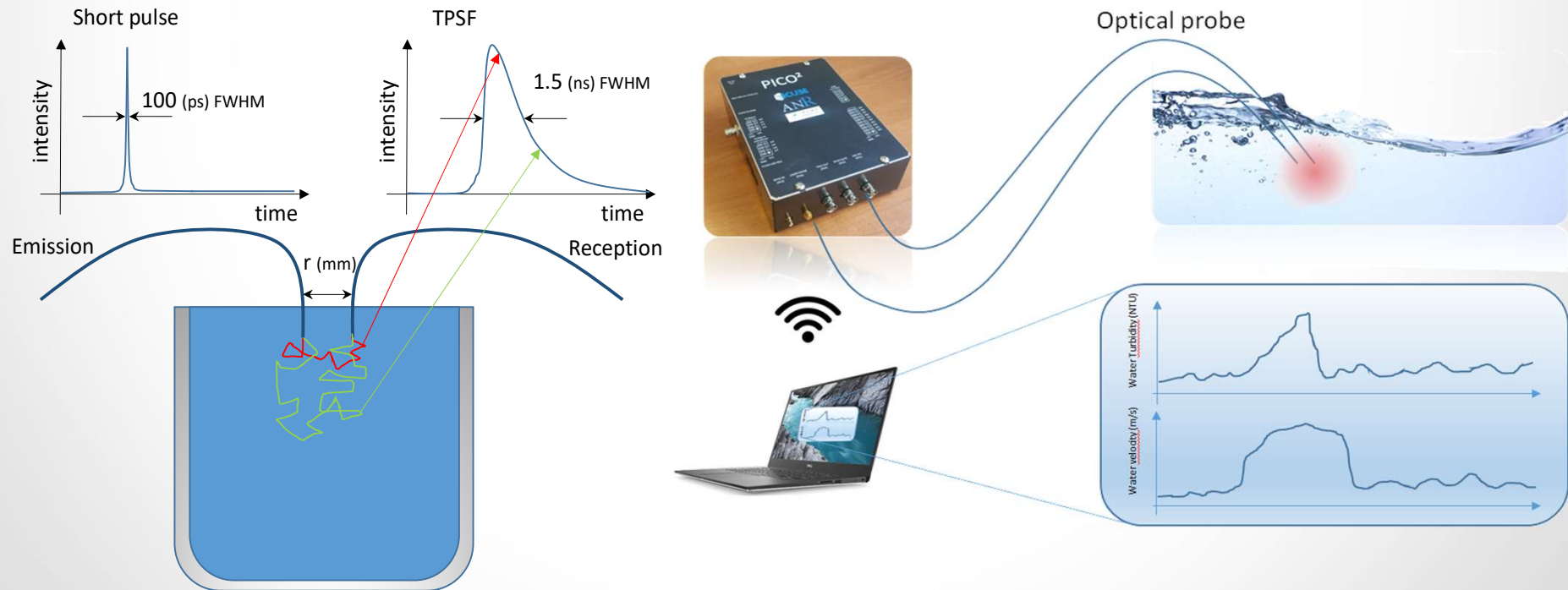
Water pollution sensor

## Projet INTEREG : Water Pollution Sensor

Déploiement d'un réseau de capteurs pour la surveillance en continue des pesticides dans l'eau potable

- Fachhochschule Nordwestschweiz (FHNW) (Suisse)
- Hochschule Furtwangen (HFU)
- Albert-Ludwigs-Universität Freiburg
- Techniche Universität de Kaiserslautern
- IMTEK
- LBSC (ESBS)
- Partenaires associés :
  Bürkert
  Metrolab SA

1/09/2019 – 31/08/2022
~ 1,350 M€ , (400k€ Icube)

Water pollution sensor

Wilfried Uhring
Icube, University of Strasbourg and CNRS
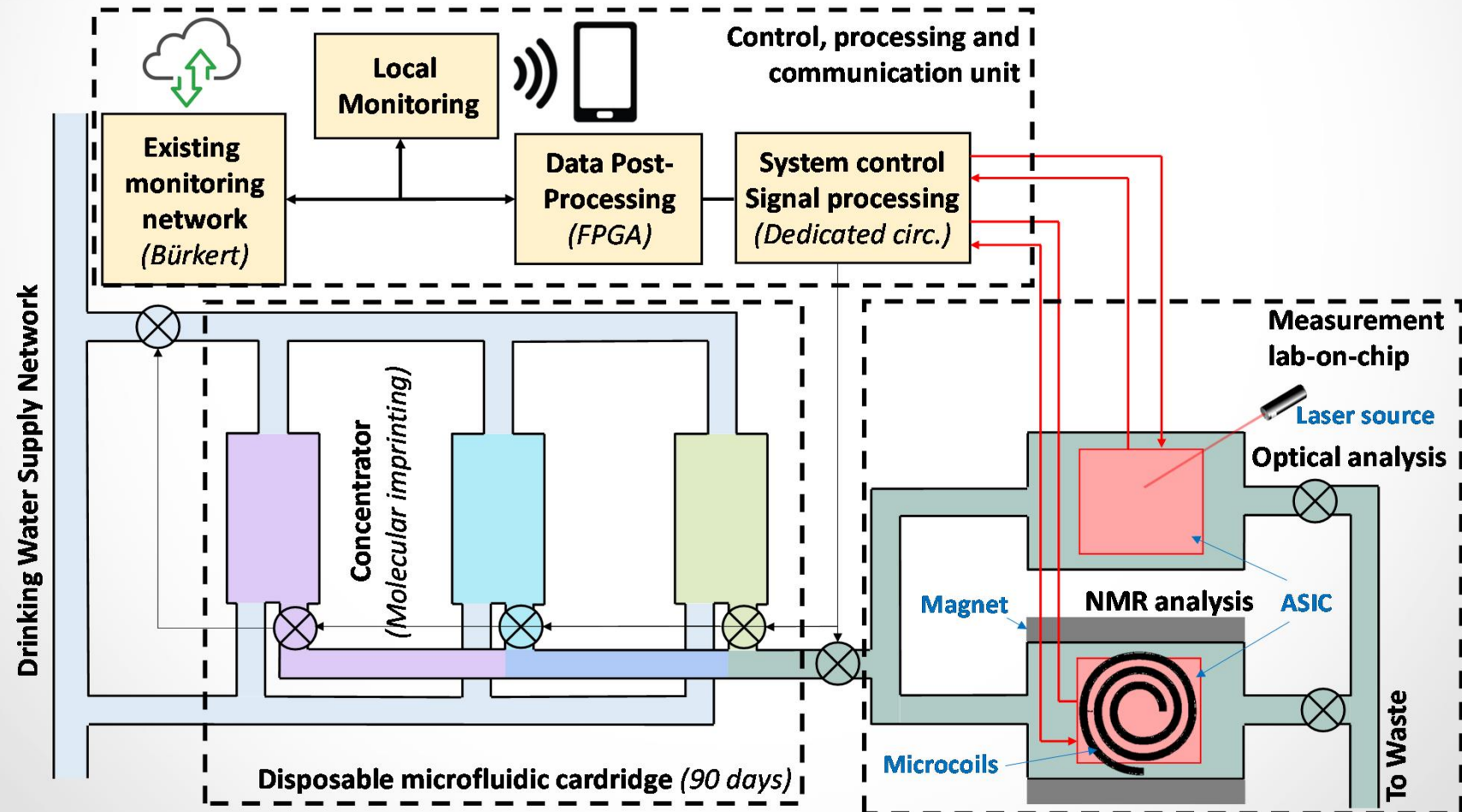
Conclusion

- High speed imaging at Icube
  - From a few ps up to ms
  - Available devices
    - High speed video camera (2D - 500fps)
    - Gated high speed camera (2D - 200 ps FWHM – 10 Gfps) 81 MHz
    - Streak camera (1D, 3 ps FWHM, 1 Tfps, 81 MHz)
  - Available sources
    - Femtoseconde 780 nm, 100 fs
    - Supercontinuum 400 to 850 nm, 30 ps FWHM
    - Pulsed laser diode
- To be continued …
  - New CMOS Streak sensor (to be commercialized)
    - 1D, 4 Gfps down to 1 Mfps, <1ns FWHM
  - CPER
    - Parametric amplifier, fs
    - Single shot
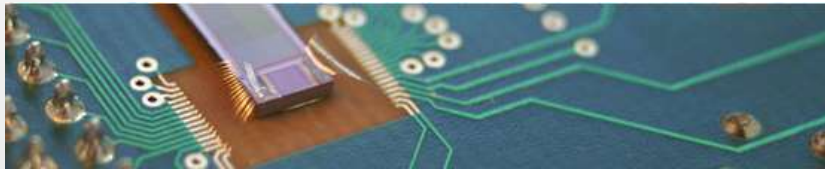   - Time gated camera
      - Streak camera

Contact

Pr. Wilfried Uhring

ICube, University of Strasbourg and CNRS

Strasbourg IHU SMIM (Systems and Microsystems for Medical Instrumentation) Team Leader

ICube SMH (Heterogeneous Systems and Microsystem) team Leader.

Address: 23 rue du Loess
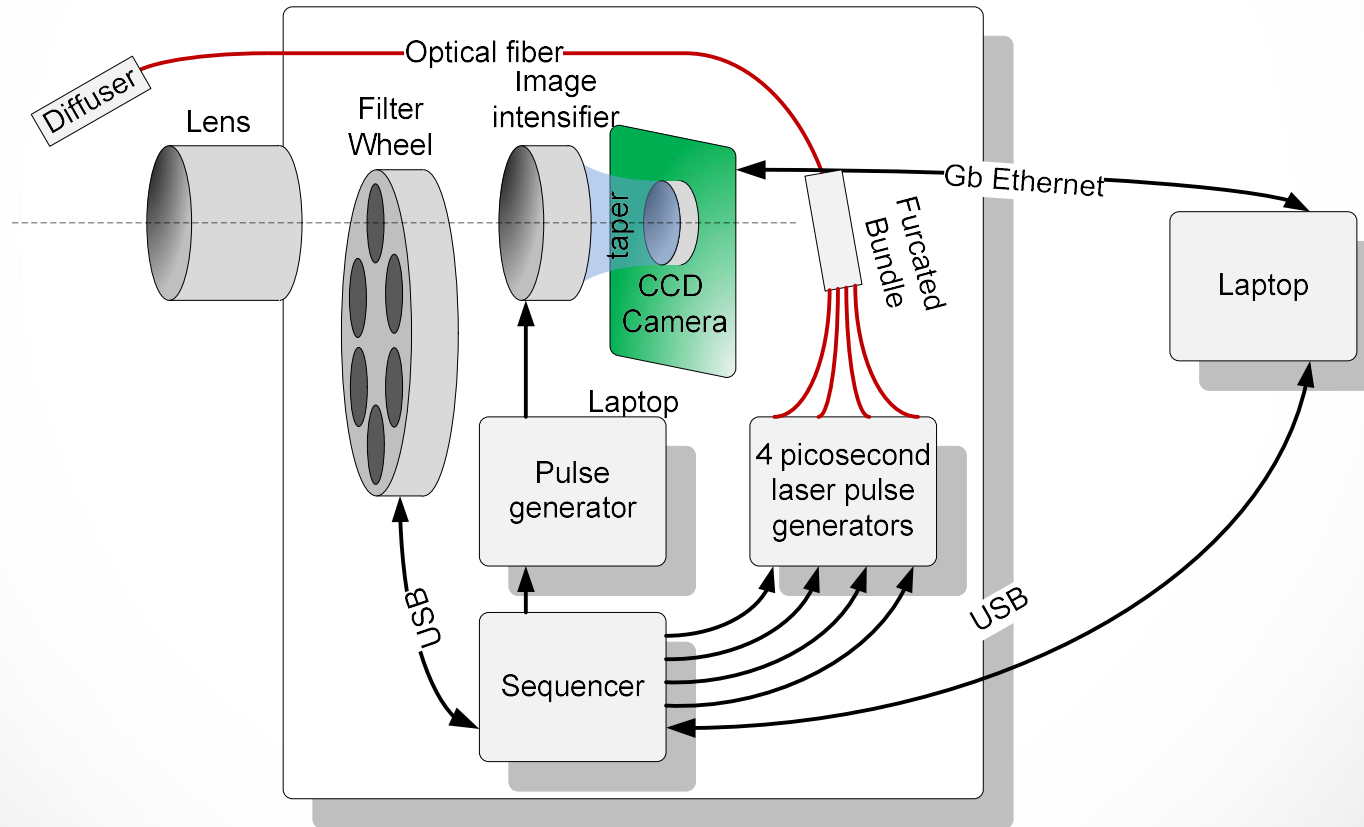67037, Strasbourg Cedex
France

Phone: +33 3 88 10 68 27

Email: Wilfried.uhring@unistra.fr

Synoptique

Wilfried Uhring
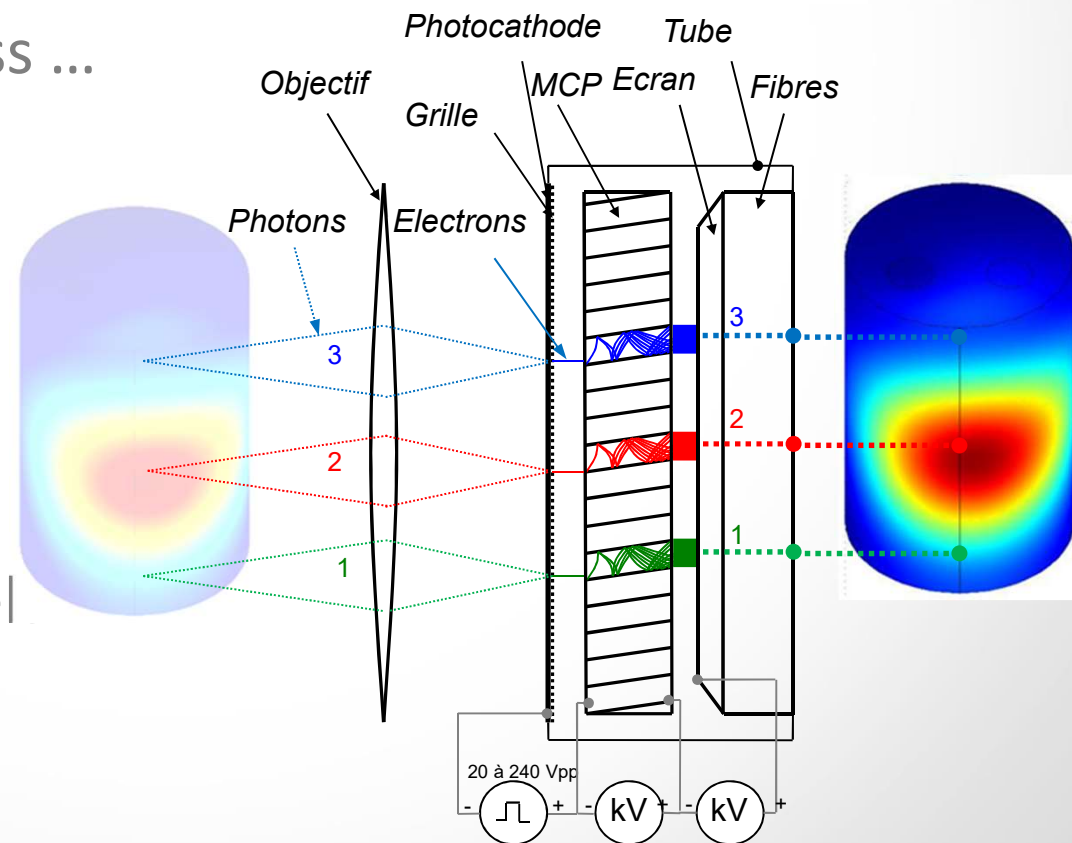*Icube, University of Strasbourg and CNRS*

20th – framing with image intensifier tube

- 1960 first Micro Channel Plate (MCP) electron multiplier

- Still in use and in progress …

- Allows fast gating by driving photocathode with electrical pulses

- 1 frames with exposure time below 10 ns

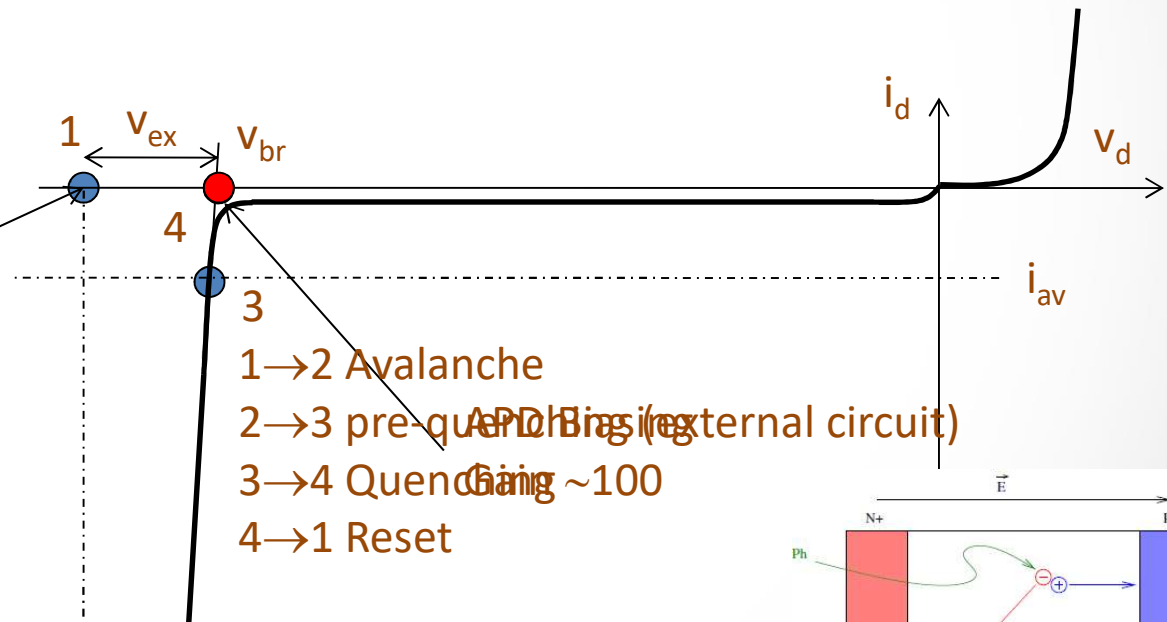- 1 frames 1000x1000 pixel 1 ns ➜ **1 Peta Pixel/s**

Objectif

Photons

Electrons

Grille

Photocathode

MCP   Ecran

Tube

Fibres

3

2

1

3

2

1

20 à 240 Vpp

- ⊓ +   - kV +   - kV +

Wilfried Uhring
Icube, University of Strasbourg and CNRS

20th – The streak imaging tube
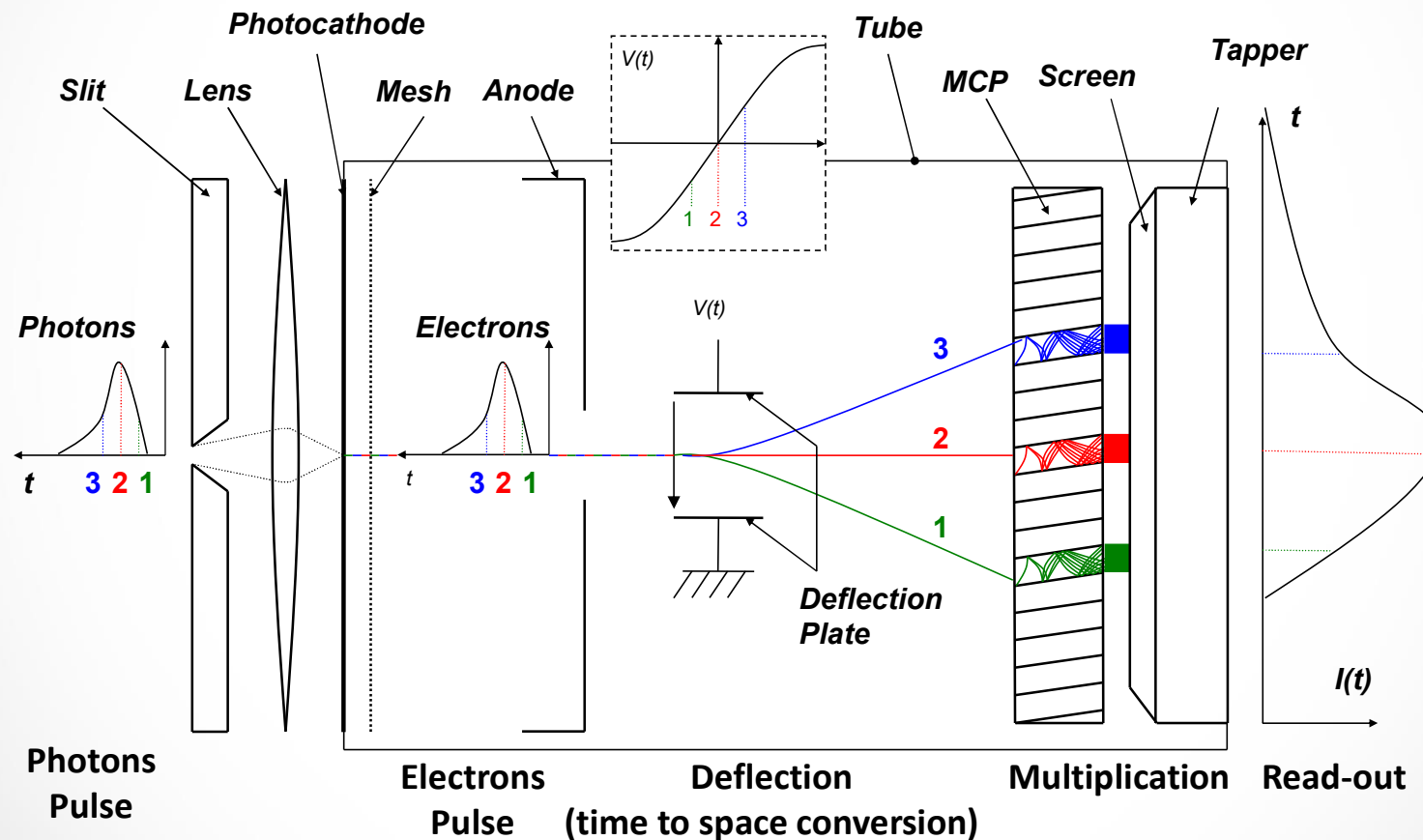
- Temporal resolution down to 1 ps ➔ Tfps
- 1000 spatial pixels ➔ **1 Peta Samples per second !**

Wilfried Uhring
Icube, University of Strasbourg and CNRS

Photodétecteur – les SPAD

- Single Photon Avalanche Diode
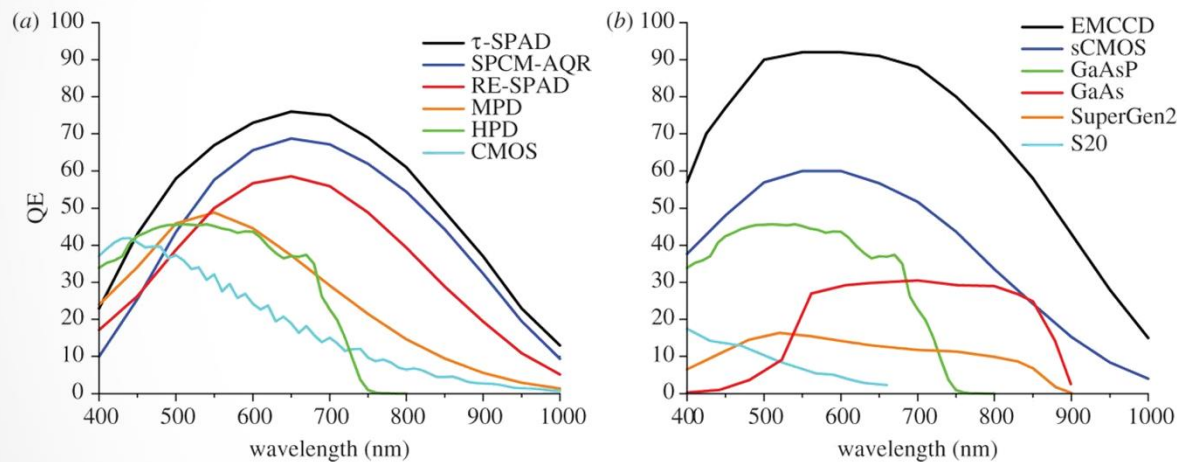 - PN junction based Photodector able to detect a single photon

$1 \rightarrow 2$ Avalanche
$2 \rightarrow 3$ pre-quenching APD Biasing (external circuit)
$3 \rightarrow 4$ Quenching Gain ~100
$4 \rightarrow 1$ Reset

- SPAD Biasing (Geiger)
- $3E^5$ V/cm

Single charge carrier
➔ self-sustaining avalanche (mA)
➔ Infinity gain

Wilfried Uhring
Icube, University of Strasbourg and CNRS

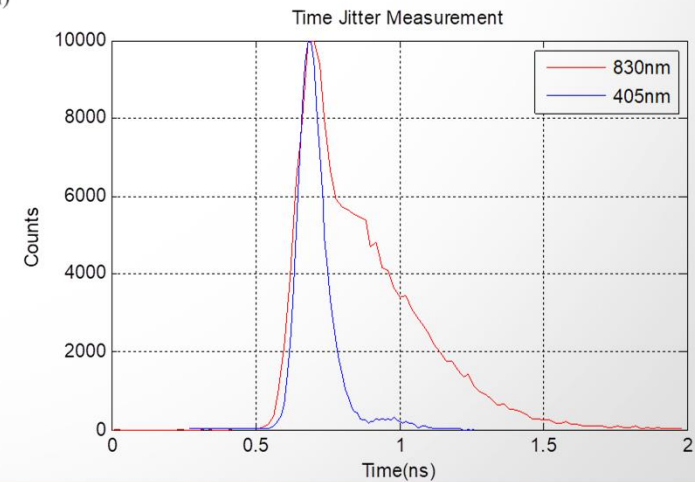Optoélectronique - Pr Wilfried Uhring Icube,   31
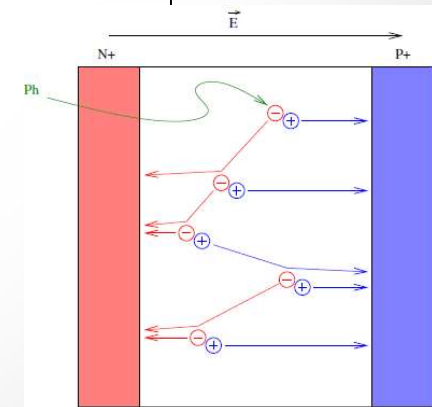
Les photodiodes à avalanche SPAD

- **Excellente sensibilité**
  - probabilité de détection

- **Bonne résolution temporelle**
  - Dépend de la longueur d'onde
  - Jusqu'à 40 ps FWHM

Time gated integrated sensor

- Smart CMOS sensor
  - Time gated SPAD for single photon counting
  - 3D real time video sensor
  - Temporal gate 200 ps
  - Repetition rate up to 100 MHz
  - 36x36µm² pixel size
  - 13.5% fill factor

Wilfried Uhring
Icube, University of Strasbourg and CNRS

iCUBE