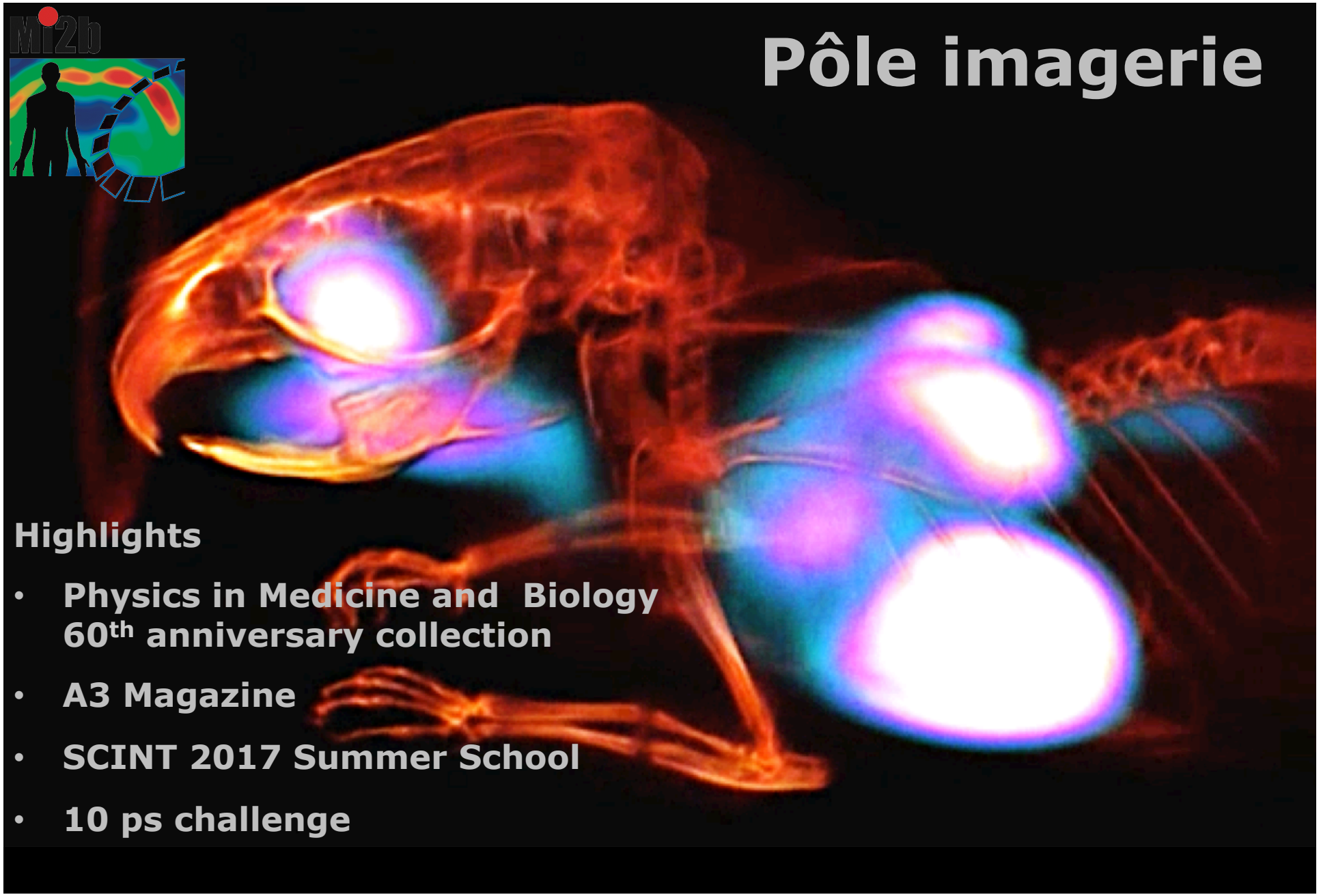
Pôle imagerie



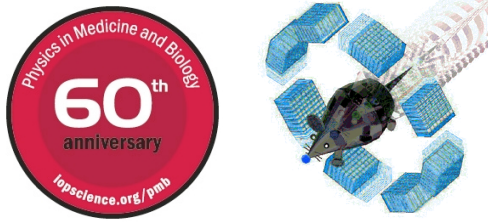
Highlights

- **Physics in Medicine and Biology 60th anniversary collection**
- **A3 Magazine**
- **SCINT 2017 Summer School**
- **10 ps challenge**

Phys. Med. Biol. 60th anniversary collection

1. J E O'Connor **1957** PMB 1 352
2. Christine M E Matthews **1957** PMB 2 36
3. J R Mallard and M J Myers **1963** PMB 8 165
4. N Veall and B L Mallett **1965** PMB 10 375
5. A M Cormack **1973** PMB 18 195
6. R E Alvarez and A Macovski **1976** PMB 21 733
7. R Birch and M Marshall **1979** PMB 24 505
8. J G Colsher **1980** PMB 25 103
9. W A Edelstein et al **1980** PMB 25 751
10. J Sarvas **1987** PMB 32 11
11. P C Johns and M J Yaffe **1987** PMB 32 675
12. D J Convery and M E Rosenbloom **1992** PMB 37 1359
13. S Webb and A E Nahum **1993** PMB 38 653
14. C X Yu **1995** PMB 40 1435
15. Hideo D Kubo and Bruce C Hill **1996** PMB 41 83
16. Di Yan et al **1997** PMB 42 123
17. Yiping Shao et al **1997** PMB 42 1965
18. A Lomax **1999** PMB 44 185
19. Wilfried Schneider et al **2000** PMB 45 459
20. M Krämer et al **2000** PMB 45 3299
21. P J Keall et al **2001** PMB 46 1
22. S Jan et al **2004** PMB 49 4543
23. B W Raaymakers et al **2009** PMB 54 N229
24. Junguo Bian et al **2010** PMB 55 6575
25. Michel Defrise et al **2012** PMB 57 885

Sensitive Phantom

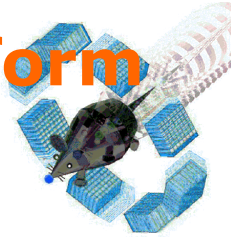


GATE: a simulation toolkit for PET and SPECT

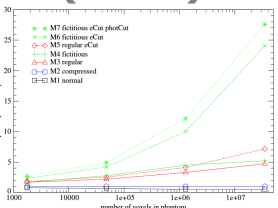
S Jan, G Santin, D Strul, S Staelens, K Assié, D Autret, S Avner, R Barbier, M Bardiès, P M Bloomfield, D Brasse, V Breton, P Bruyndonckx, I Buvat, A F Chatziioannou, Y Choi, Y H Chung, C Comtat, D Donnarieix, L Ferrer, S J Glick, C J Groiselle, D Guez, P-F Honore, S Kerhoas-Cavata, A S Kirov, V Kohli, M Koole, M Krieguer, D J van der Laan, F Lamare, G Largeron, C Lartizien, D Lazaro, M C Maas, L Maigne, F Mayet, F Melot, C Merheb, E Pennacchio, J Perez, U Pietrzyk, F R Rannou, M Rey, D R Schaart, C R Schmidtlein, L Simon, T Y Song, J-M Vieira, D Visvikis, R Van de Walle, E Wieërs and C Morel

2004 *Phys. Med. Biol.* **49** 4543

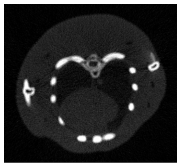
GATE 2004-2014: a constantly-upgraded platform



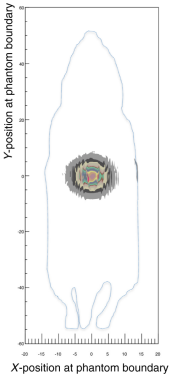
Acceleration (2009)



CT (2011)

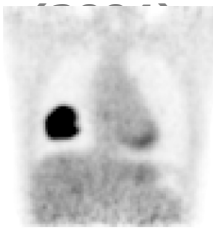


Optical imaging (2011)

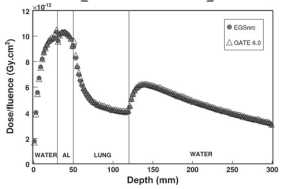


GPU (2014)

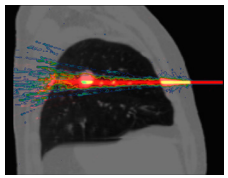
Planar SPECT PET



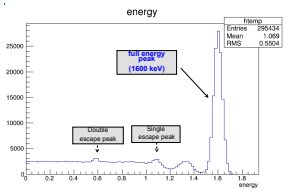
Dosimetry (2011)



Radiation therapy (2011)



EduGATE (2011)



G4 DNA processes (2014)

19 releases

2004
1st GATE public release

2011
GATE V6

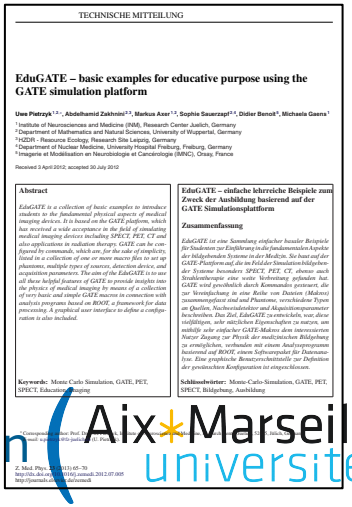
2014
GATE V7

2017
GATE V8


GATE: a simulation toolkit for PET and SPECT


GATE V6: a major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy


Extension of the GATE Monte-Carlo simulation package to model bioluminescence and fluorescence imaging


EduGATE – basic examples for educative purpose using the GATE simulation platform


A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications

2009 PMB Publication prize

2015 PMB Publication prize

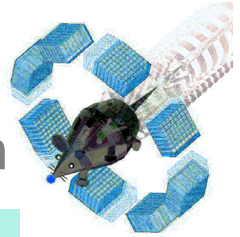
Journées du GDR M2B 5/7 dec 2017 Caen

Aix*Marseille université

CNRS IN2P3

CPPM

Who is developing GATE ?



The OpenGATE collaboration: an evolving collaboration

IMNC/IN2P3 (Orsay) **Albertine Dubois (GATE engineer)**

CEA-SHFJ (Orsay) Claude Comtat, **Sébastien Jan (technical coordinator)**

LaTIM U1101 INSERM (Brest) Dimitris Visvikis

U892 INSERM (Nantes) Ludovic Ferrer

UMR 1037 INSERM (Toulouse) Manuel Bardiès

LPC/IN2P3 (Clermont-Ferrand) Lydia Maigne

CREATIS (Lyon) David Sarrut

CPPM/IN2P3 (Marseille) Christian Morel

IPHC/INSERM (Strasbourg) Ziad El Bitar

Subatech/IN2P3 (Nantes) Jean-Pierre Cussonneau

BIOSIM (Athens) George Loudos

FZJ (Juelich) **Uwe Pietrzyk (spokesman)**

DUT (Delft) Dennis Schaart

MOCAMMED (Vienna) Dietmar Georg

MedAustron (Wiener Neustadt) Loïc Grévillot

MSKCC (New York) Assen Kirov

UC (Davis) Emilie Roncali

Sogang Univ (Seoul) Yong Choi

Association des anciens et amis du CNRS

https://www.a3cnrs.org/

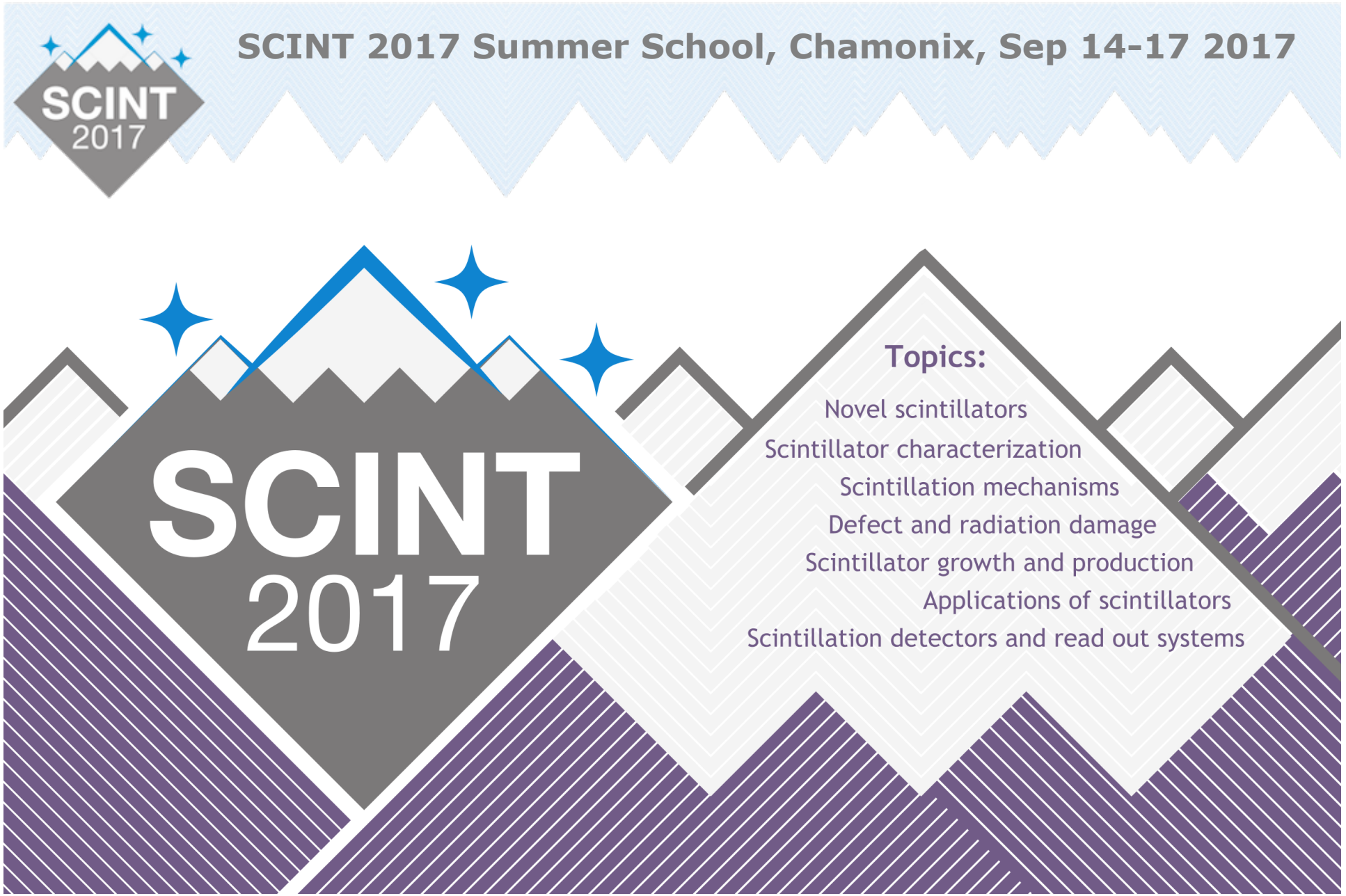
Dossier : l'imagerie médicale

Imagerie moléculaire : *l'érosion des frontières* / David Brasse
Rayons X : des premiers clichés radiographiques au scanner spectral / Christian Morel
Tomographie par émission de positons (TEP) / David W. Townsend
Simulation Monte Carlo en imagerie médicale / Sébastien Jan
Imagerie vibrationnelle des systèmes vivants / Hervé Rigneault
Multimodalité et imagerie médicale / Luc Bidaut
Systèmes hybrides TEP/IRM / Claude Comtat
Enjeux Européens de la R&D en imagerie médicale / Paul Lecoq
NeuroSpin, *voir le cerveau penser* / Fabrice Bonardi

cnrs Magazine des Anciens et Amis du CNRS
N° 69- HIVER 2016/2017

Mi2b Journées du GDR MI2B, 6-7 déc 2017, Caen

Aix*Marseille université — cnrs IN2P3 Les deux infinis — CPPM Centre de Physique des Particules de Marseille



Journées du GDR MI2B, 6-7 déc 2017, Caen

SCINT 2017 Summer School, Chamonix, Sep 14-17 2017

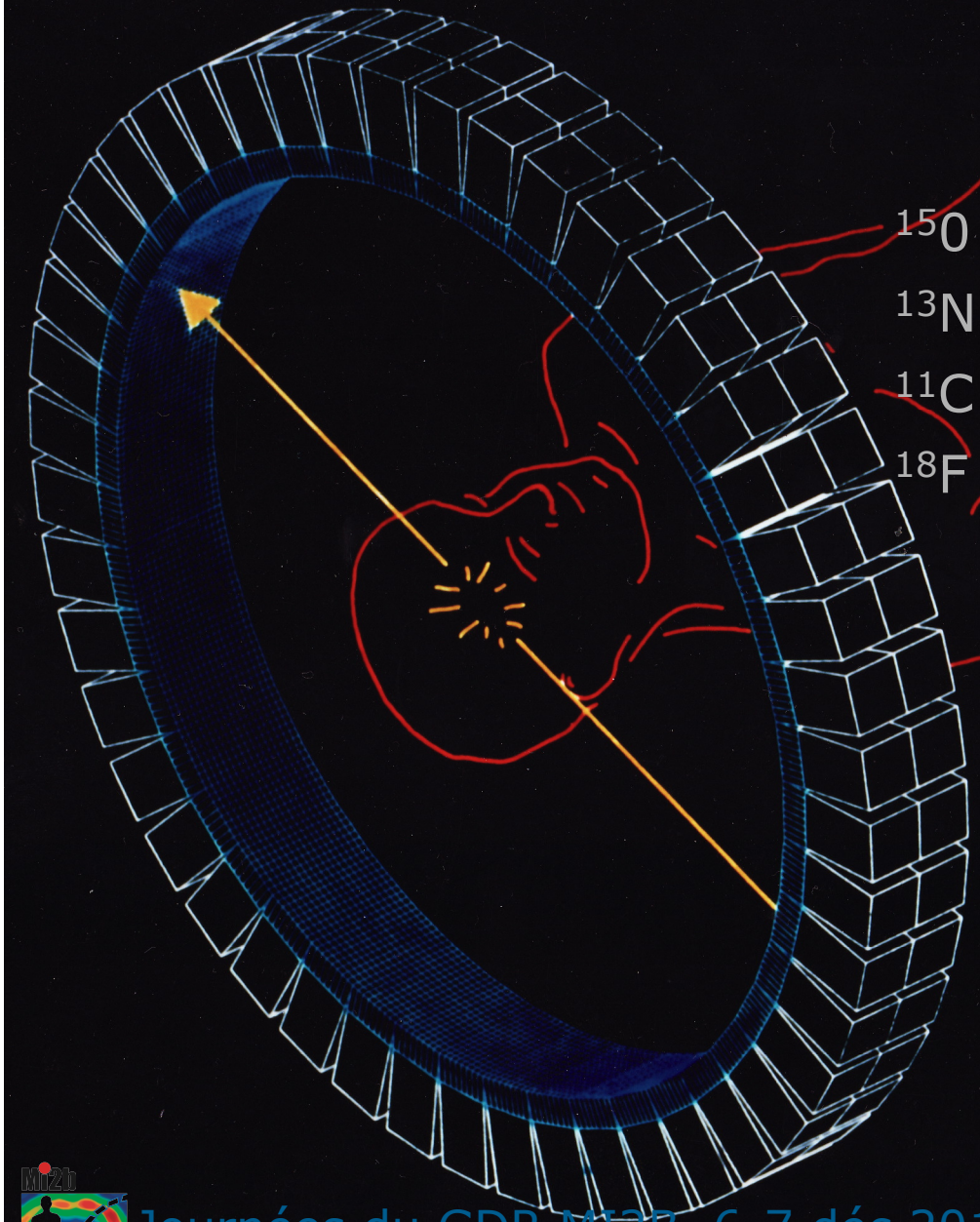
The GDR MI2B has allocated two tuition grants to:

- **Carlotta Trigila (IMNC)**
- **Mattia Fontana (IPNL)**

One full day on Monte Carlo simulation for scintillation detectors mastered by:

- **Mathieu Dupont (CPPM)**
- **Albertine Dubois (IMNC)**

Tomographie par émission de positons (TEP)



^{15}O (2 min) 511 keV

^{13}N (10 min) 511 keV

^{11}C (20 min) 511 keV

^{18}F (110 min) 511 keV

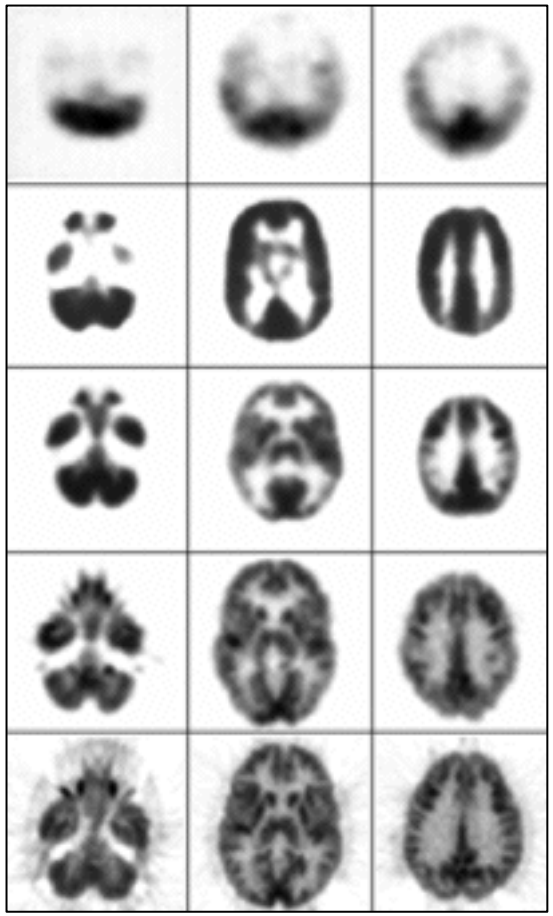
Sensibilité absolue ~ 10^{-2}

Résolution spatiale 3-5 mm

Dose absorbée 5-10 mSv

M.R.C. Cyclotron Unit.
Hammersmith Hospital.
London.

Progrès continus en instrumentation



PET III 1975

ECAT II 1977

NeuroECAT 1978

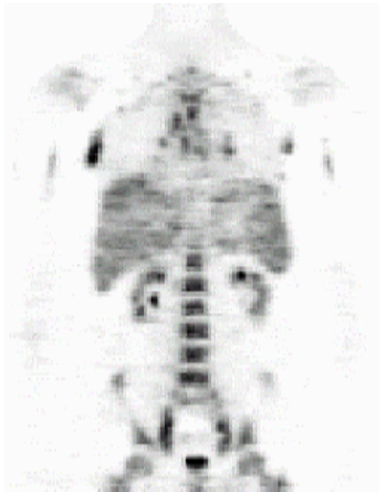
ECAT 931 1985

ECAT EXACT HR+ 1995

Progrès techniques en TEP

	BGO	LSO	GSO
Densité [g/cm^3]	7.13	7.4	6.7
Z effectif	74	66	61
Decay [ns]	300	35-45	30-60
ph/MeV	8200	28000	10000
% NaI(Tl)	15	75	25

3DRP

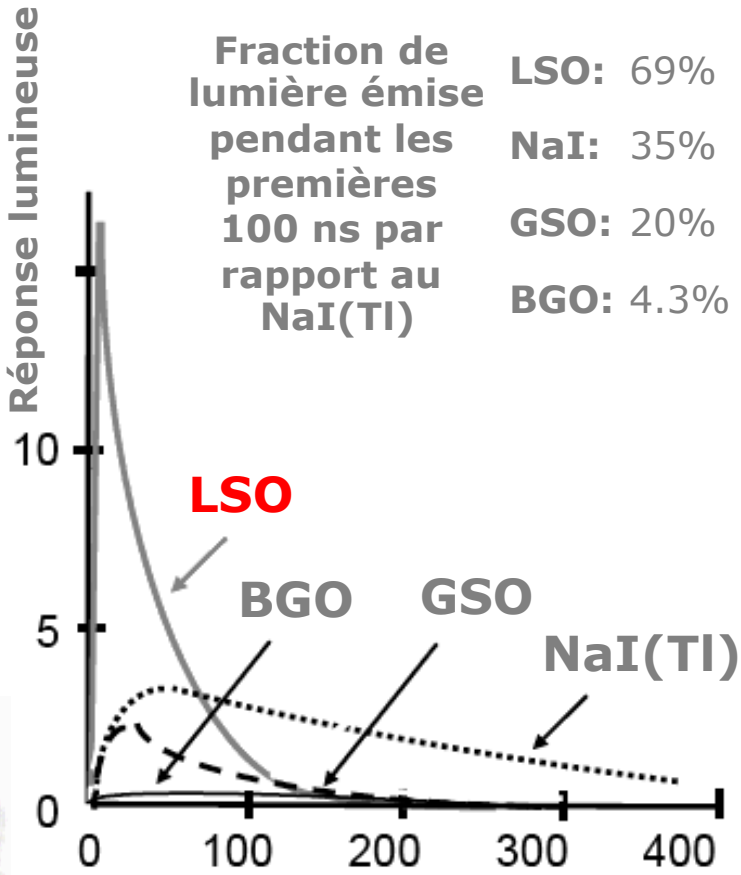


FORE+OSEM

FORE+AWOSEM

Fraction de lumière émise pendant les premières 100 ns par rapport au NaI(Tl)

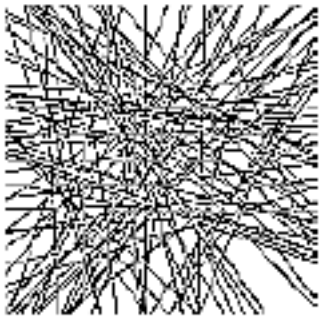
LSO: 69%
NaI: 35%
GSO: 20%
BGO: 4.3%



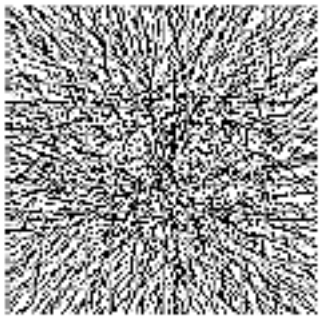
- ✓**Détecteurs**
- ✓**Corrections de données**
- ✓**Reconstruction d'images**

Courtesy: DW Townsend, UPMC

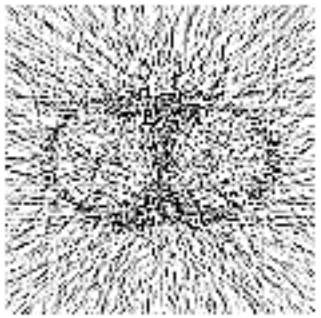
Reconstruction tomographique et statistique de comptage



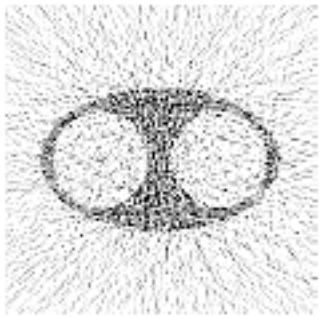
10^2



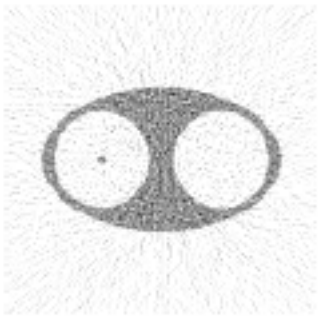
10^3



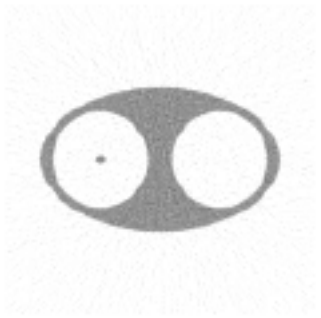
10^4



10^5



10^6



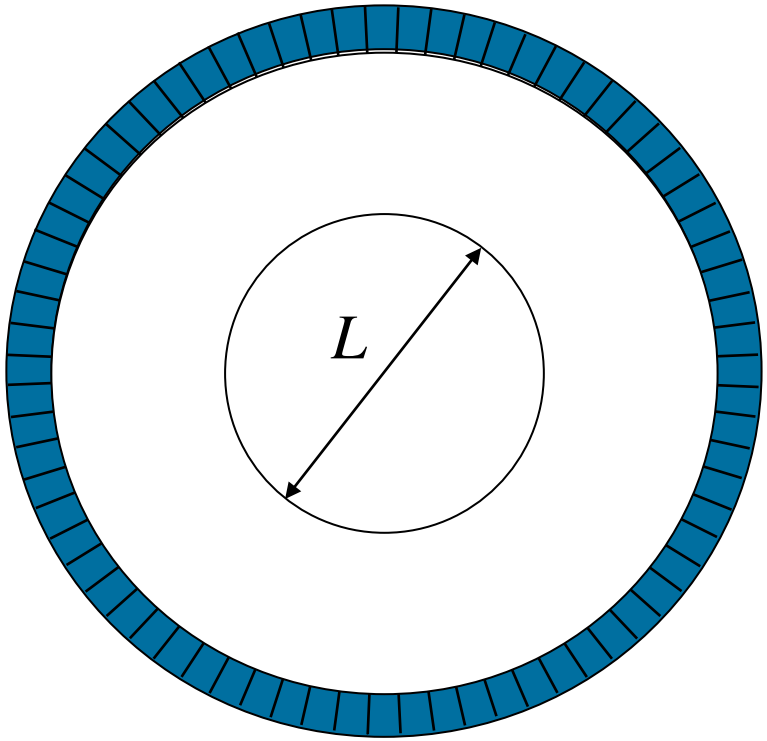
10^7

Courtesy: C. Comtat, CEA-SHFJ

Rapport signal/bruit et statistique de comptage

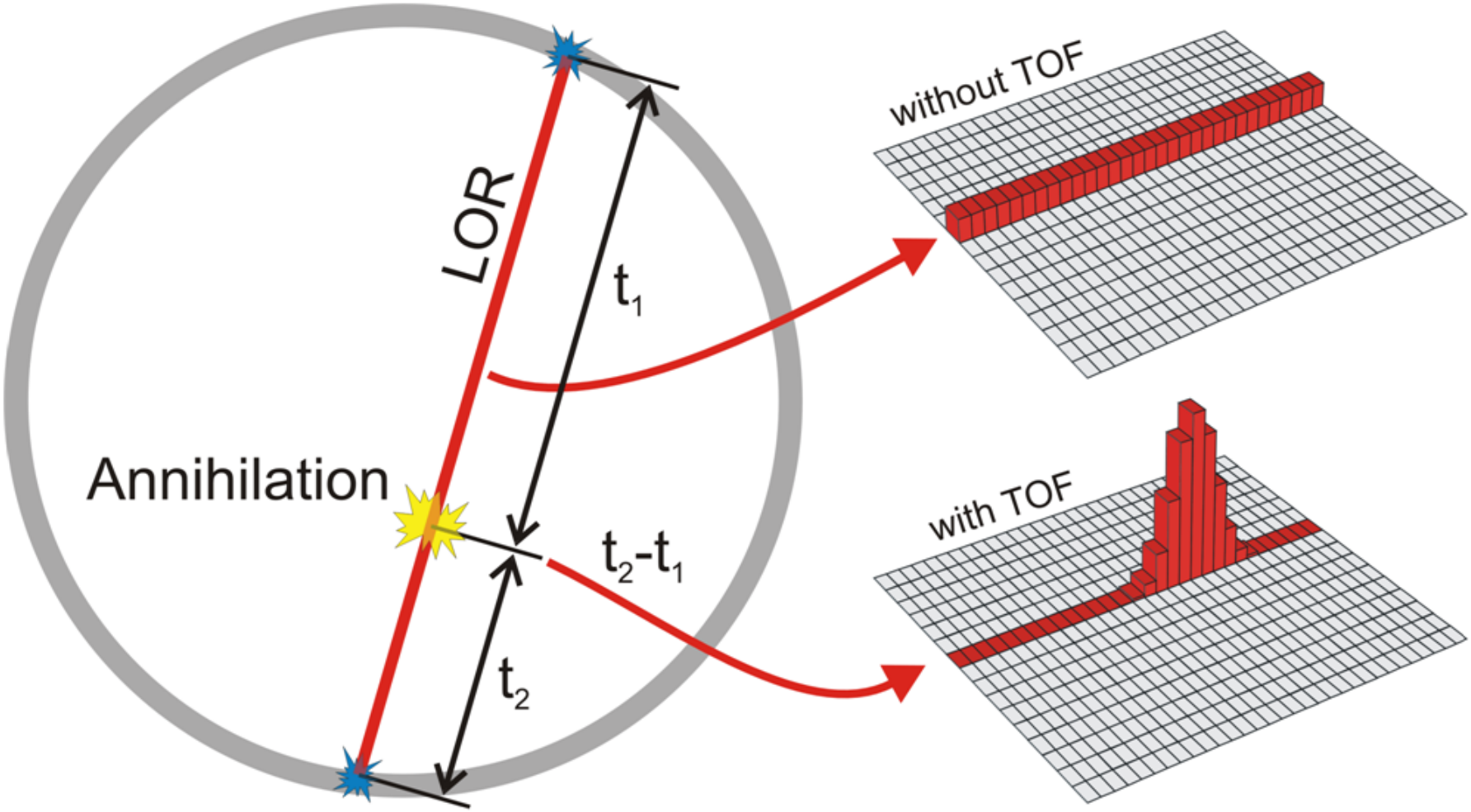
$$\frac{A}{\Delta A} = \sqrt{N_{\beta^+}} \Rightarrow N_{\beta^+} = \left(\frac{A}{\Delta A}\right)^2$$

$$N_{Tot} = \left(\frac{L}{d}\right)^3 \times \left(\frac{A}{\Delta A}\right)^2 \times \left(\frac{L}{d}\right)$$



L'amélioration de la résolution spatiale par un facteur 2 implique d'augmenter la statistique de comptage par un facteur 16 pour obtenir le même rapport signal/bruit dans les voxels de l'image reconstruite.

Rapport signal/bruit et statistique de comptage



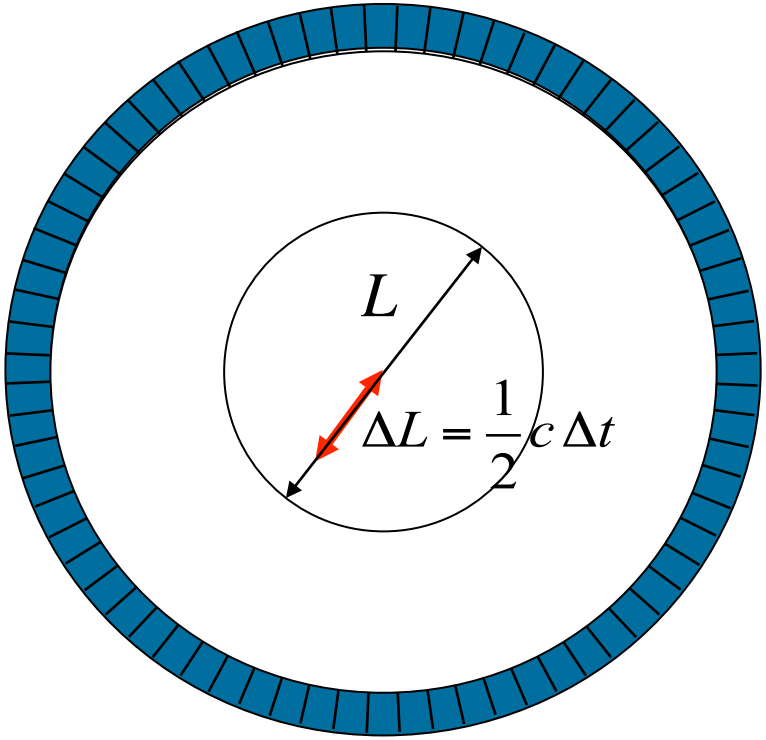
TEP à temps-de-vol et amélioration du rapport signal/bruit

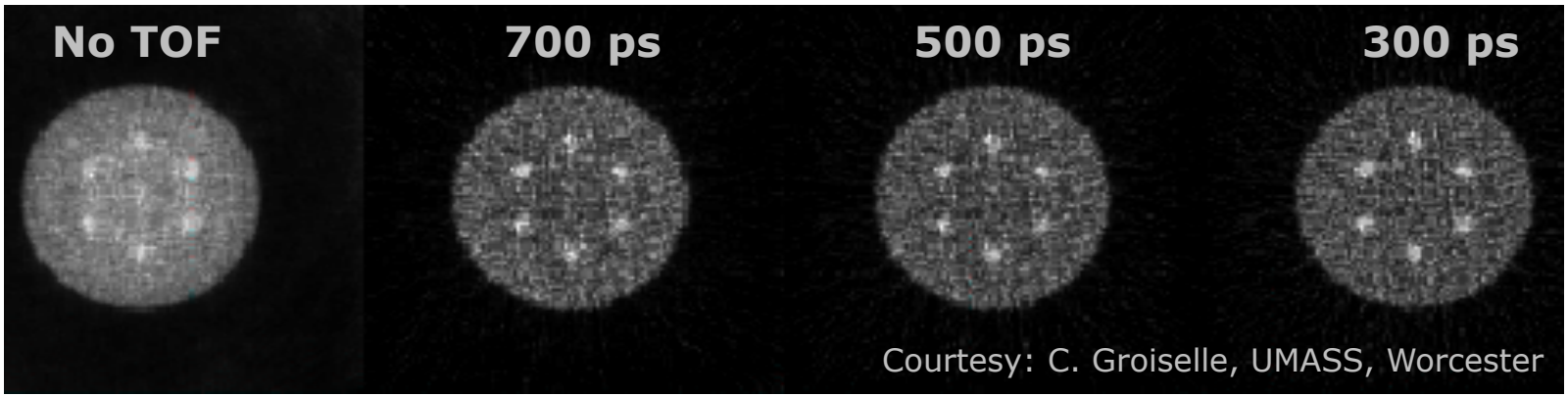
$$N_{Tot} = \left(\frac{L}{d}\right)^3 \times \left(\frac{A}{\Delta A}\right)^2 \times \left(\frac{L}{d}\right)$$

$$N_{ToF} = \left(\frac{L}{d}\right)^3 \times \left(\frac{A}{\Delta A}\right)^2 \times \left(\frac{\Delta L}{d}\right)$$

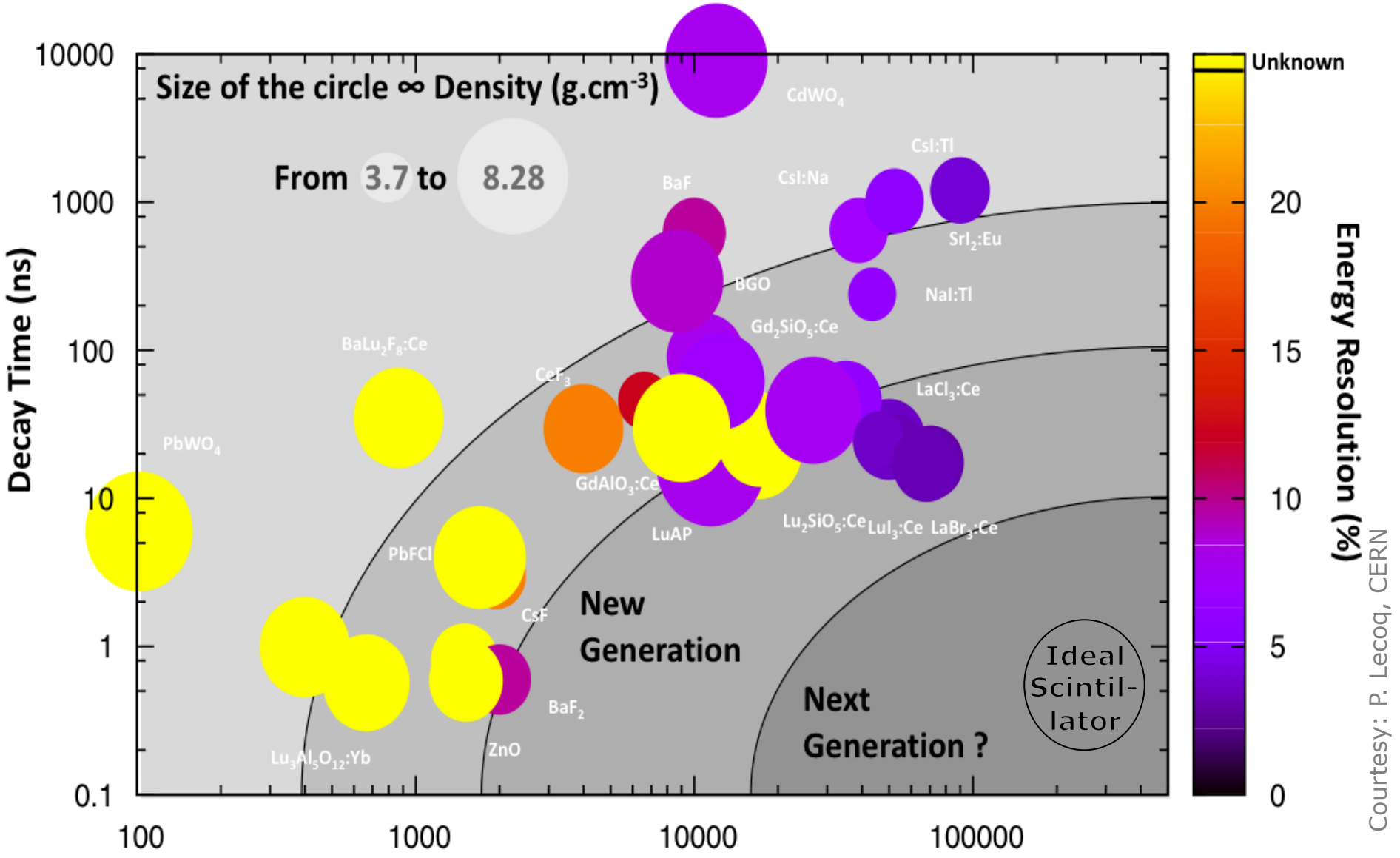
Facteur de réduction de variance

$$f = \frac{L}{\Delta L} = \frac{2L}{c\Delta t}$$



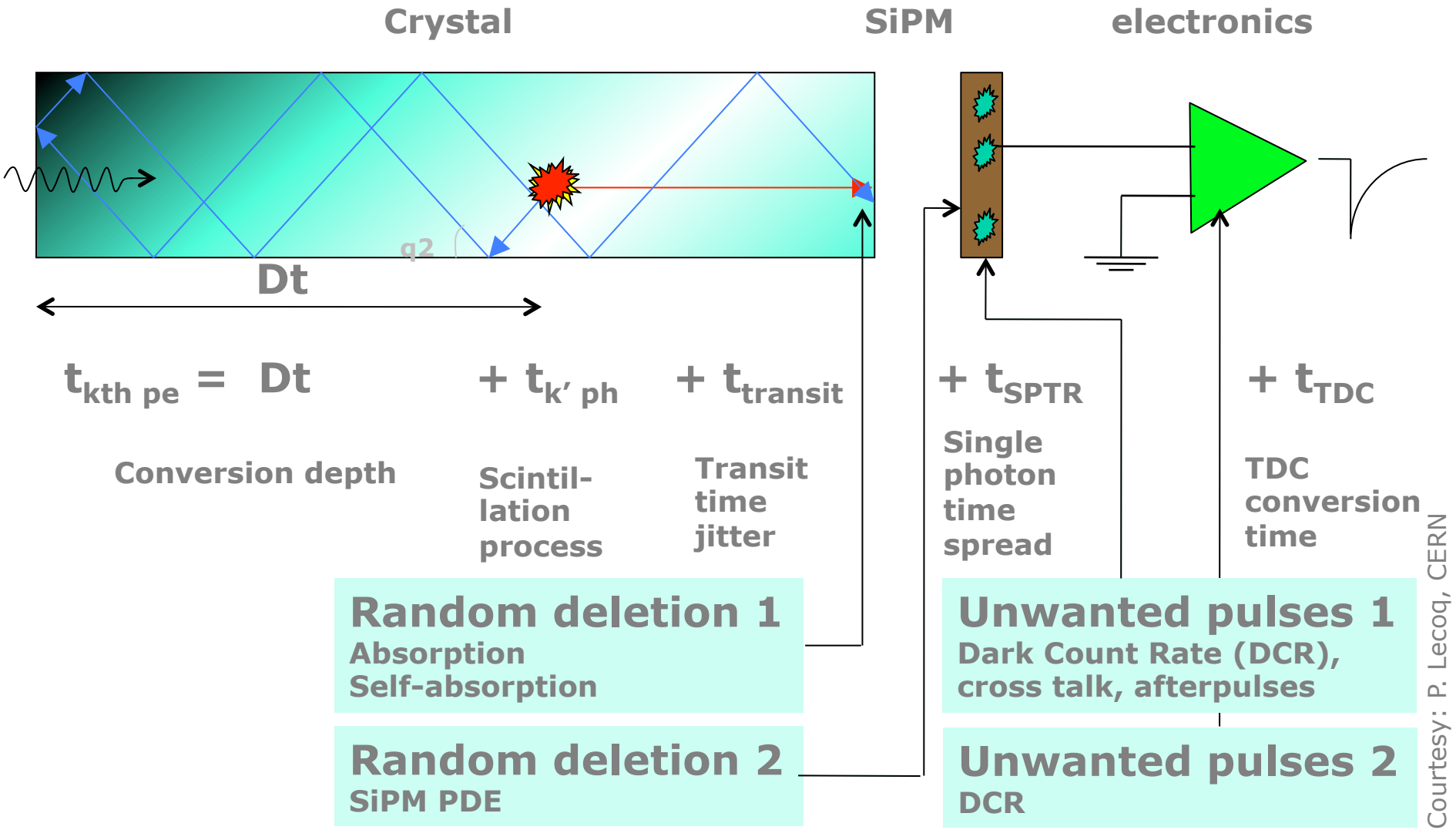


Classification of scintillators



Courtesy: P. Lecoq, CERN

The detection chain



The detection chain

From the time of detection $t_{d,i}$ of n optical photons

$$T_d = \{t_{d,1}, t_{d,2}, \ldots, t_{d,n}\}$$

- provides the Fisher information $I_{Td}(\Theta)$ of the gamma ray interaction time Θ
- defines the Cramér-Rao lower bound by minimizing the variance of the time estimator Ξ

$$\mathrm{Var}(\Xi) \geq 1 / I_{Td}(\Theta)$$

Random deletion 2
SiPM PDE

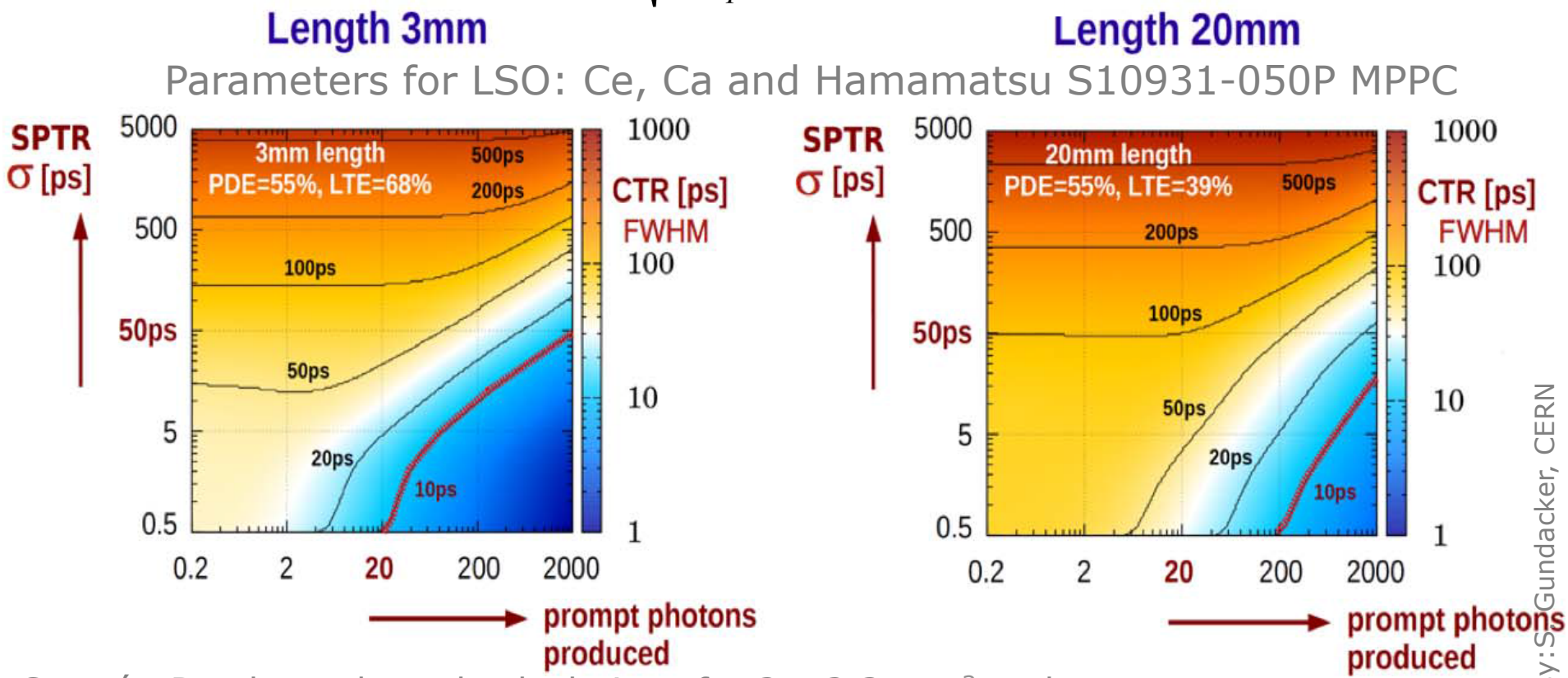
Unwanted pulses 2
DCR

Courtesy:

Prompt photons to boost the timing resolution

$$CRT \propto \sqrt{\frac{\tau_r \tau_d}{N_{pe}}} \xrightarrow[\tau_r \div 10]{} \sqrt{\tau_r}$$

Parameters for LSO: Ce, Ca and Hamamatsu S10931-050P MPPC

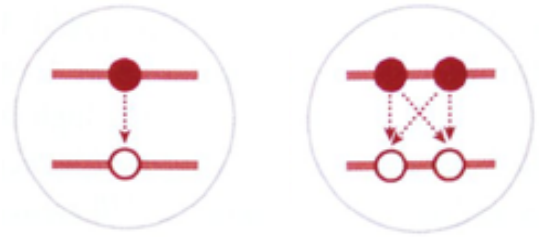


Courtesy: S. Gundacker, CERN

Cramér–Rao lower bound calculations for 2 x 2 3 mm^3 and
2 2 x 2 x 20 mm3 LSO:Ce,Ca scintillator with a SiPM having a PDE
of 55%, as a function of the number of additional prompt photons generated

Possible sources of prompt photons (< 1 ns)

Excitons/bi-exciton
stable at 300 K
(e.g. CdSe CQwells)



Ce^{3+} Activator: 5d-4f
Ca^{2+} & Mg^{2+} co-doping
τ_r ~ 20 ps τ_d < 16 ns

Hot intraband
luminescence
0.1 - 10 ps
(e.g. $PbWO_4$,
$CaWO_4$)

$$\frac{1}{\tau} = \frac{4e^2}{3\hbar c^3}\omega_{21}^3 \left|\vec{r}_{21}\right|^2$$

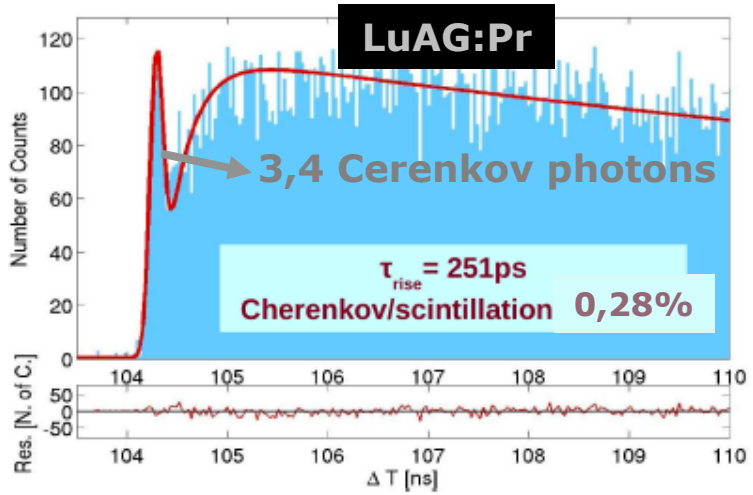
Cross luminescence
<1 ns (e.g. BaF_2)
< 300 nm
low light yield

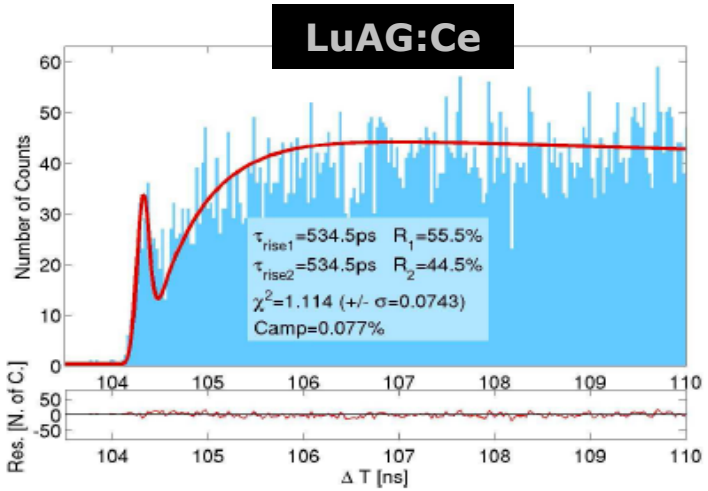
High donor band
semiconductors
< 1 ns (e.g. ZnO)
quenched at room temperature

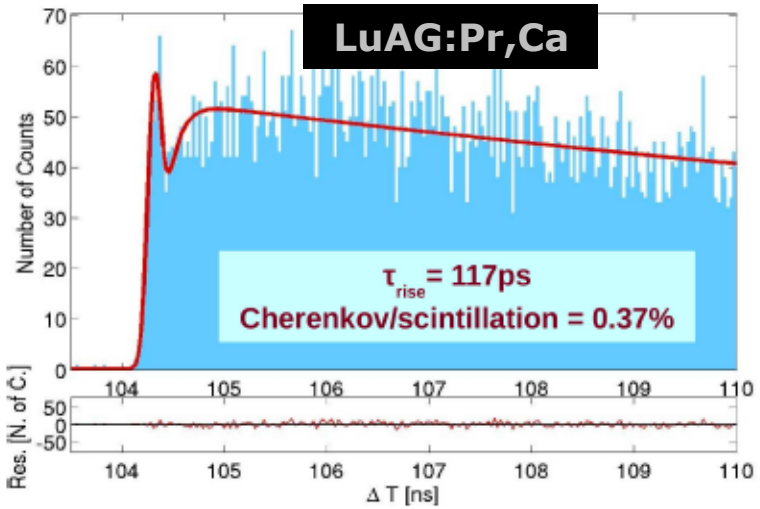
Cerenkov emission
τ ~ 5-10 ps

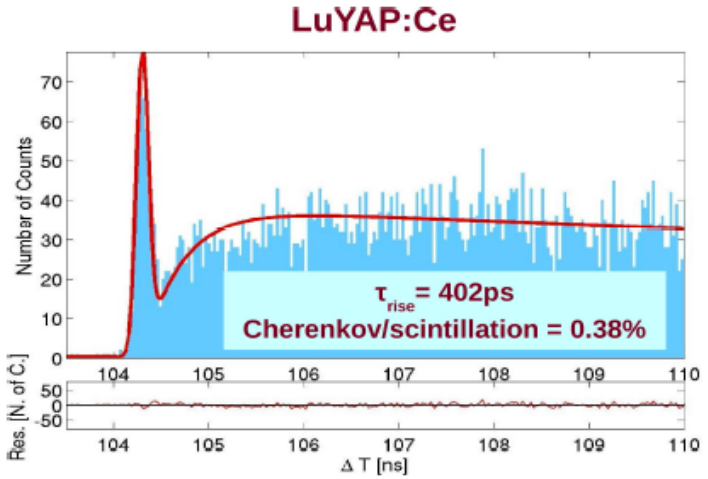
Courtesy: P. Lecoq, CERN

Cerenkov contribution







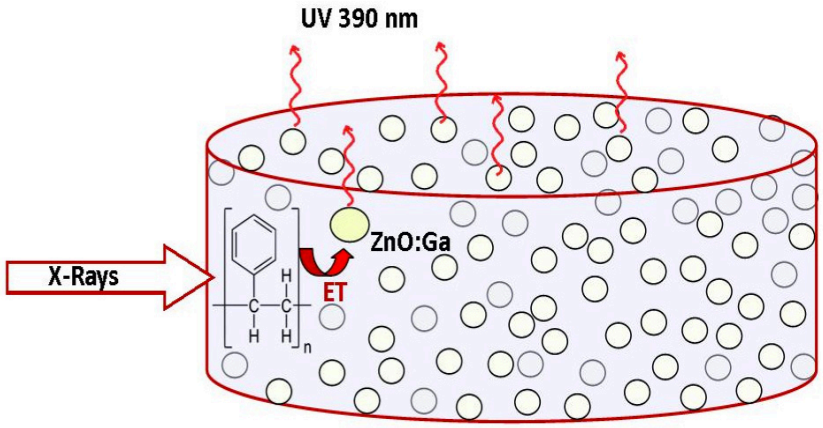


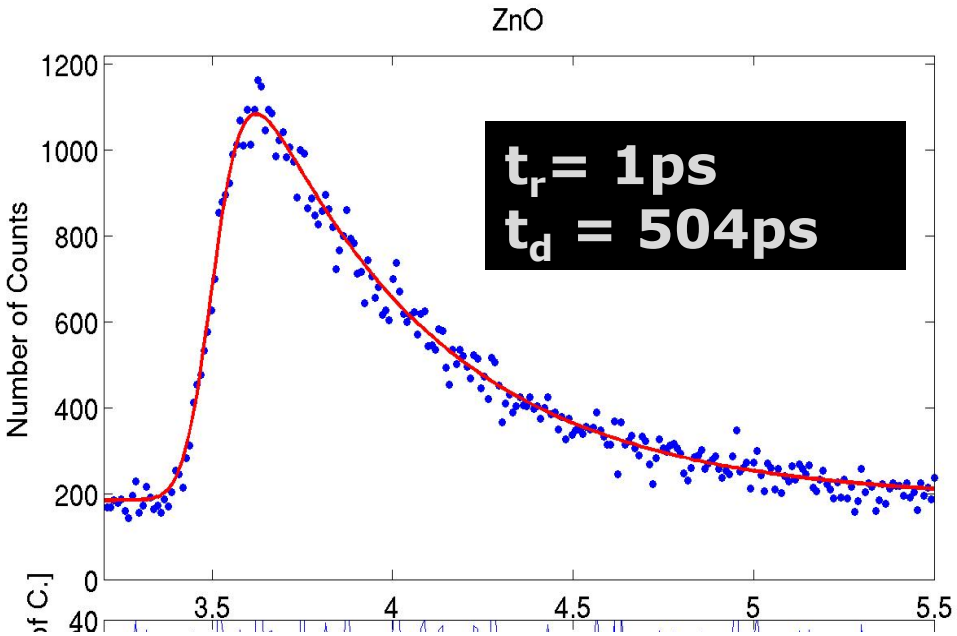
Courtesy: P. Lecoq, CERN

ZnO:Ga polystyrene composite scintillator

Highly luminescent ZnO:Ga nanocrystals 80-100 nm

- Prepared by a photochemical method
- 4000 pe/511 keV in powder (same as LSO)
- Embedded in a polystyrene sheet 10% weigth



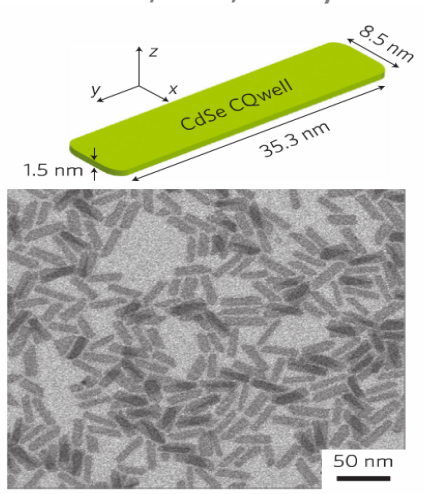


Courtesy: R. Martinez Turtos, CERN

Quantum confined systems

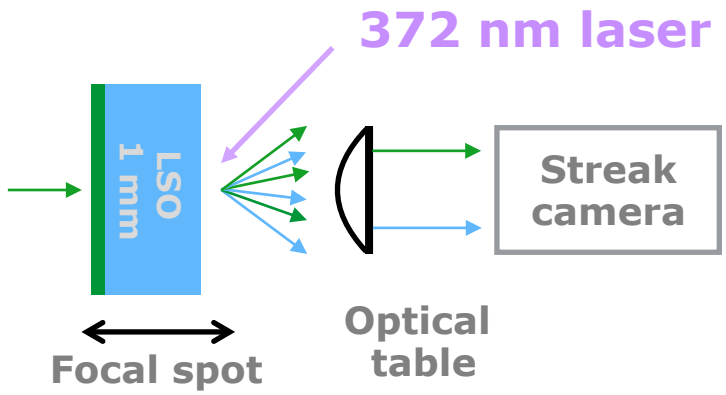
Colloidal CdSe nano-sheets (CQwells)

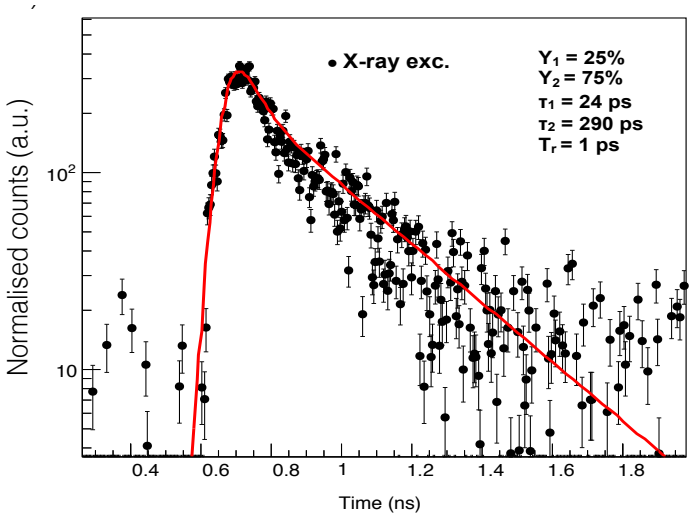
J. Grim, ITT, Italy

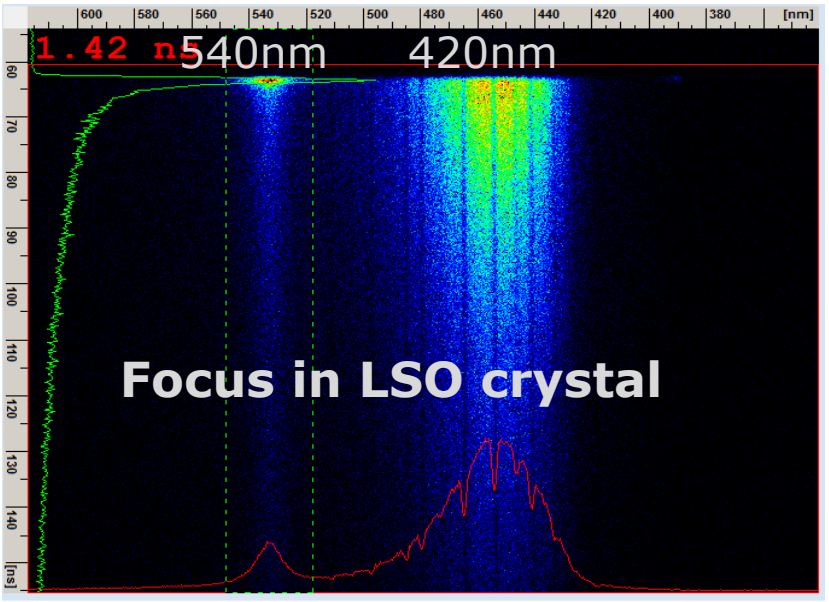


LSO plate 1 mm thick
+ CdSe nanoplate film
100 mm thick

100 mm CdSe film deposition

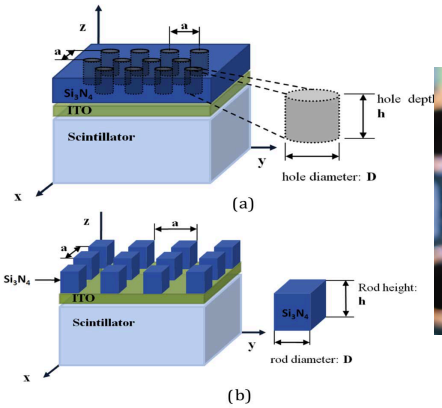


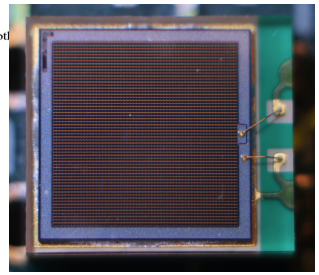


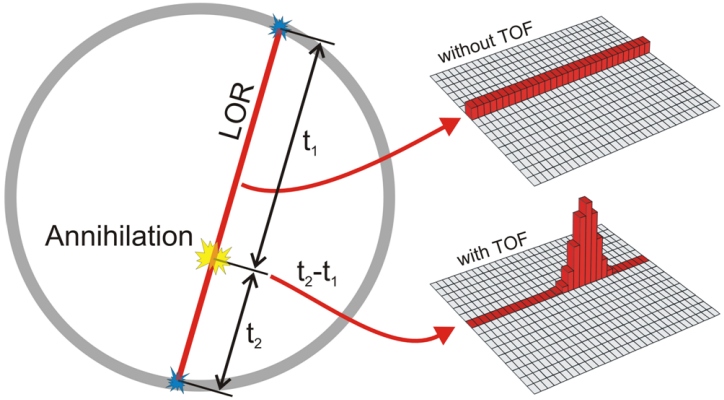


Courtesy: R. Martinez Turtos, CERN

Timing rapide à scintillation : la route vers le TEP temps-de-vol sans reconstruction







P Lecoq et al. Nucl. Instrum. Meth. A 718 (2013) 569

TICAL

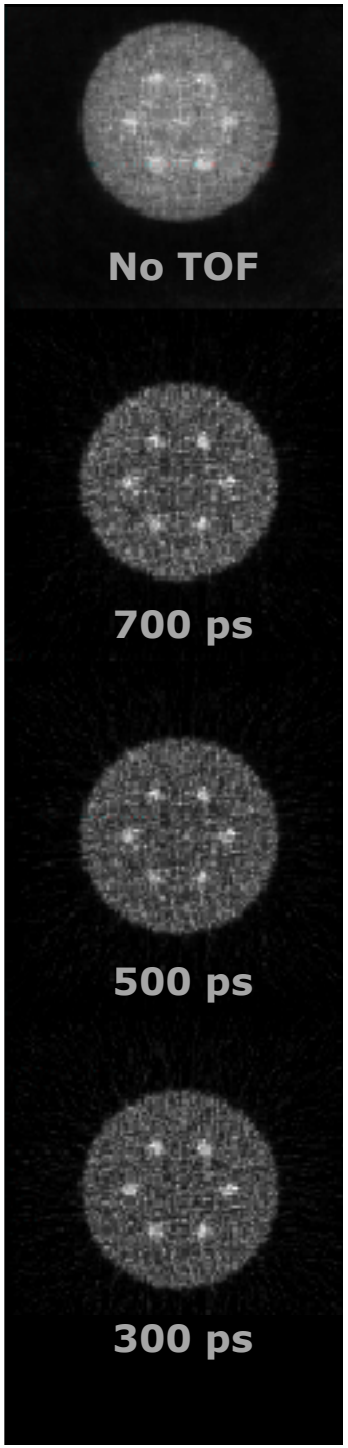
4D total absorption Time Imaging CALorimeter

erc

FAST ADVANCED SCINTILLATION TIMING (2014-2018): http://www.cern.ch/FAST-COST

cost TD1401 EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

FAST



1992: La FAI lance un défi pour le premier tour en ballon de la Terre

This is a clear-cut case to shed light on TOF-PET with CRT < 10 ps FWHM and raise a challenge on reconstructionless positron tomography

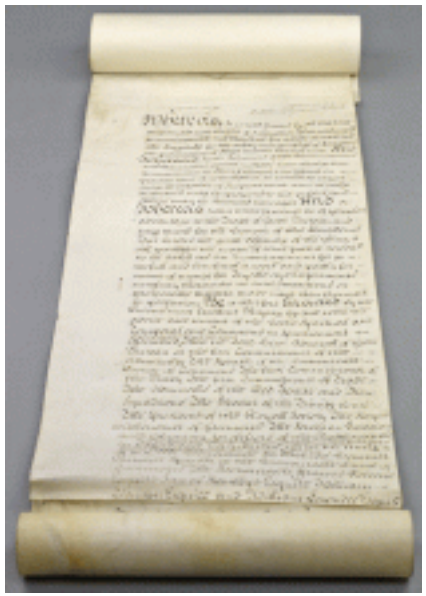
10 ps TOF-PET challenge: the conditions to be met

- Identify the critical parameters
  - ✓ Light production
  - ✓ Light transport
  - ✓ Photodetection
  - ✓ Readout electronics
- For each of the critical parameters
  - ✓ Make sure that no physics barrier will compromise the goal
  - ✓ Identify enabling technologies to reach the objective
  - ✓ Organize a vigorous, ambitious and coordinated effort to push the limits and transform the myth into a reality

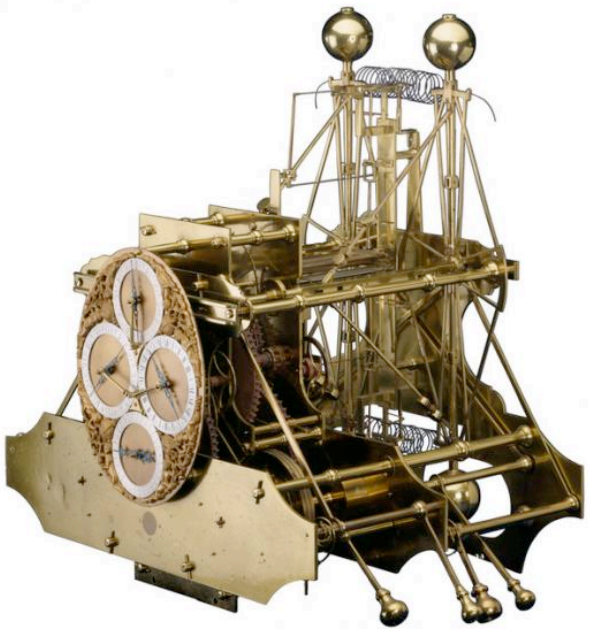
Courtesy: P. Lecoq, CERN

Longitude Act

Le Longitude Act a été édicté par le parlement du Royaume Uni en juillet 1714 suite au naufrage du HMS Association, qui revenait du siège de Toulon, sur les récifs de Gilstone Ledges la nuit du 22 octobre 1707, causant la mort de mille quatre cents à plus de deux mille hommes.



Le Longitude Act fonde le Bureau des longitudes et offre un prix pour quiconque trouvera une méthode simple et pratique pour déterminer précisément la longitude d'un bateau.



John Harrison's H1 Marine Chronometer

Longitude rewards:

- ✓ **£10,000 < 1°**
  (= 110 km à l'équateur)
- ✓ **£15,000 < 40'**
- ✓ **£20,000 < 0,5°**

John Harrison a reçu £10,000 (~1.33 million £ en 2016) en 1765 pour le développement du chronomètre de marine

successfully place a spacecraft on the moon's surface

travel 500 meters

transmit high-definition video and images back to Earth

XPRIZE is an innovation engine
A facilitator of exponential change
A catalyst for the benefit of humanity

We believe in the power of competition. That it's part of our DNA. Of humanity itself. That tapping into that indomitable spirit of competition brings about breakthroughs and solutions that once seemed unimaginable. Impossible.

We believe that you get what you incentivize. And that without a target, you will miss it every time. Rather than throw money at a problem, we incentivize the solution and challenge the world to solve it.

We believe that challenges must be audacious, but achievable, tied to objective, measurable goals. And understandable by all.

We believe that solutions can come from anyone, anywhere and that some of the greatest minds of our time remain untapped, ready to be engaged by a world that is in desperate need of help. Solutions. Change. And radical breakthroughs for the benefit of humanity. Call us crazy, but we believe.

https://www.xprize.org/