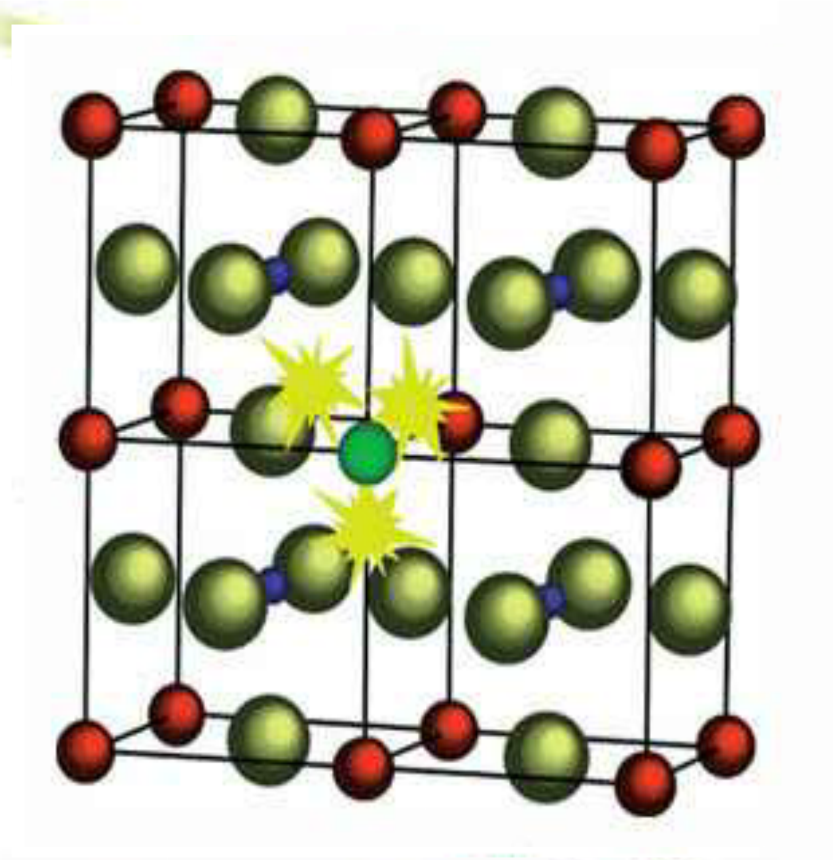
Scintillating Crystals From High Energy Physics to Medical Imaging

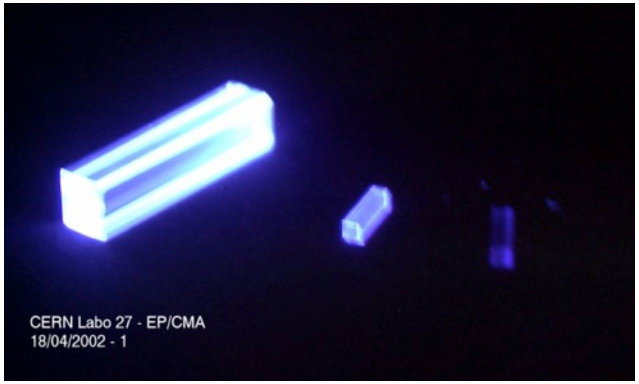
ASCIMAT School

E. Auffray,
CERN, EP-CMX

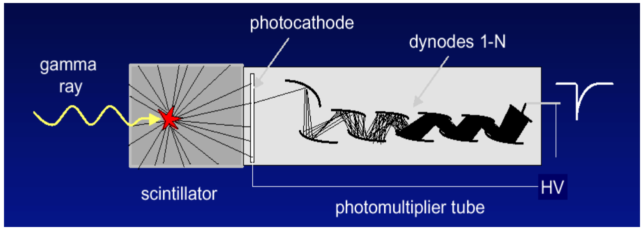
A scintillating crystal

- It emits light when it absorbs energy from incident photons or charged particles
- Light output is directly proportional to energy deposited





The light is readout with photodetector

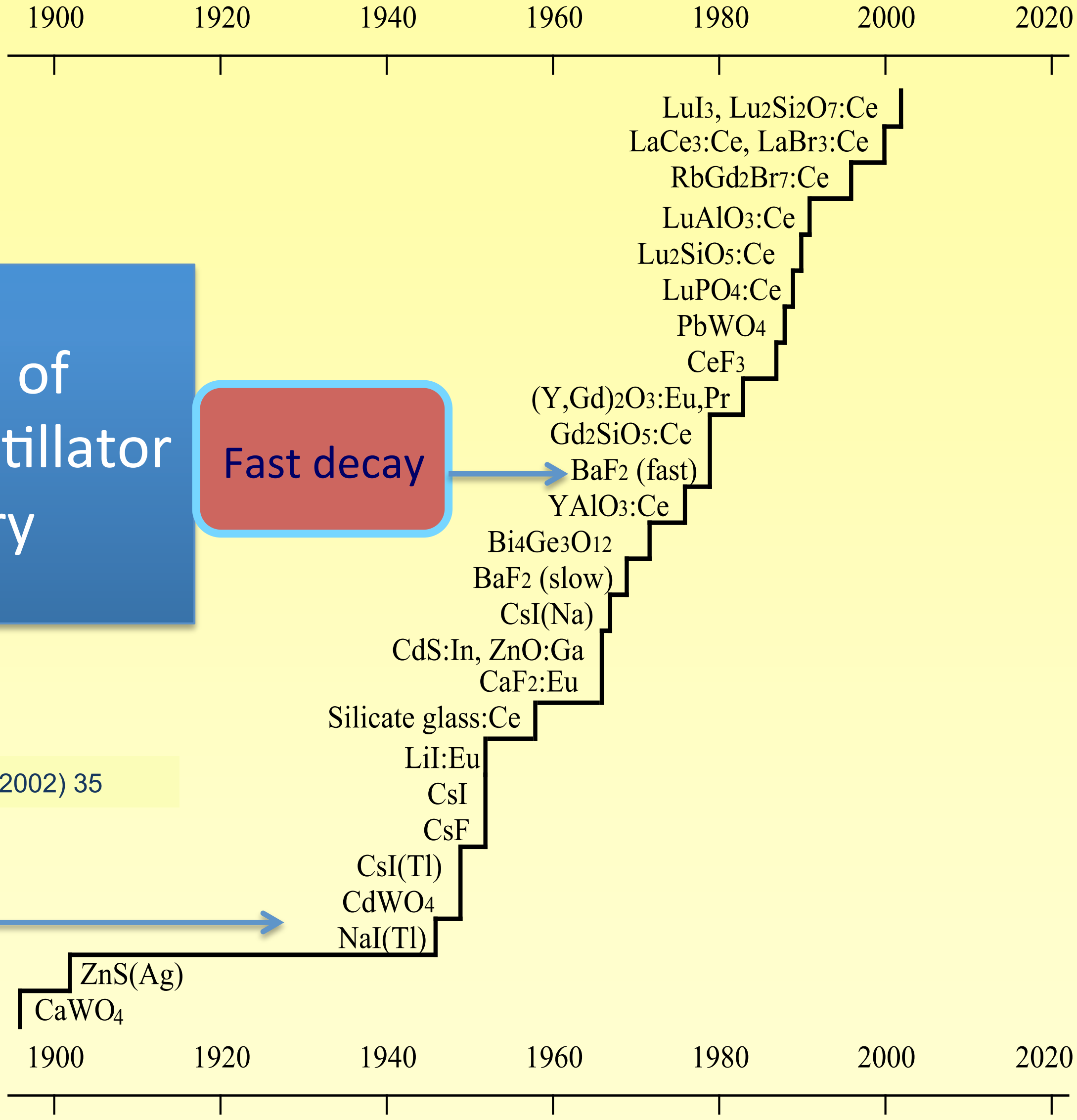


- To convert ALL the energy of the incident particle in to light => dense materials

History of scintillator discovery

120 Years of inorganic scintillator Discovery

Fast decay

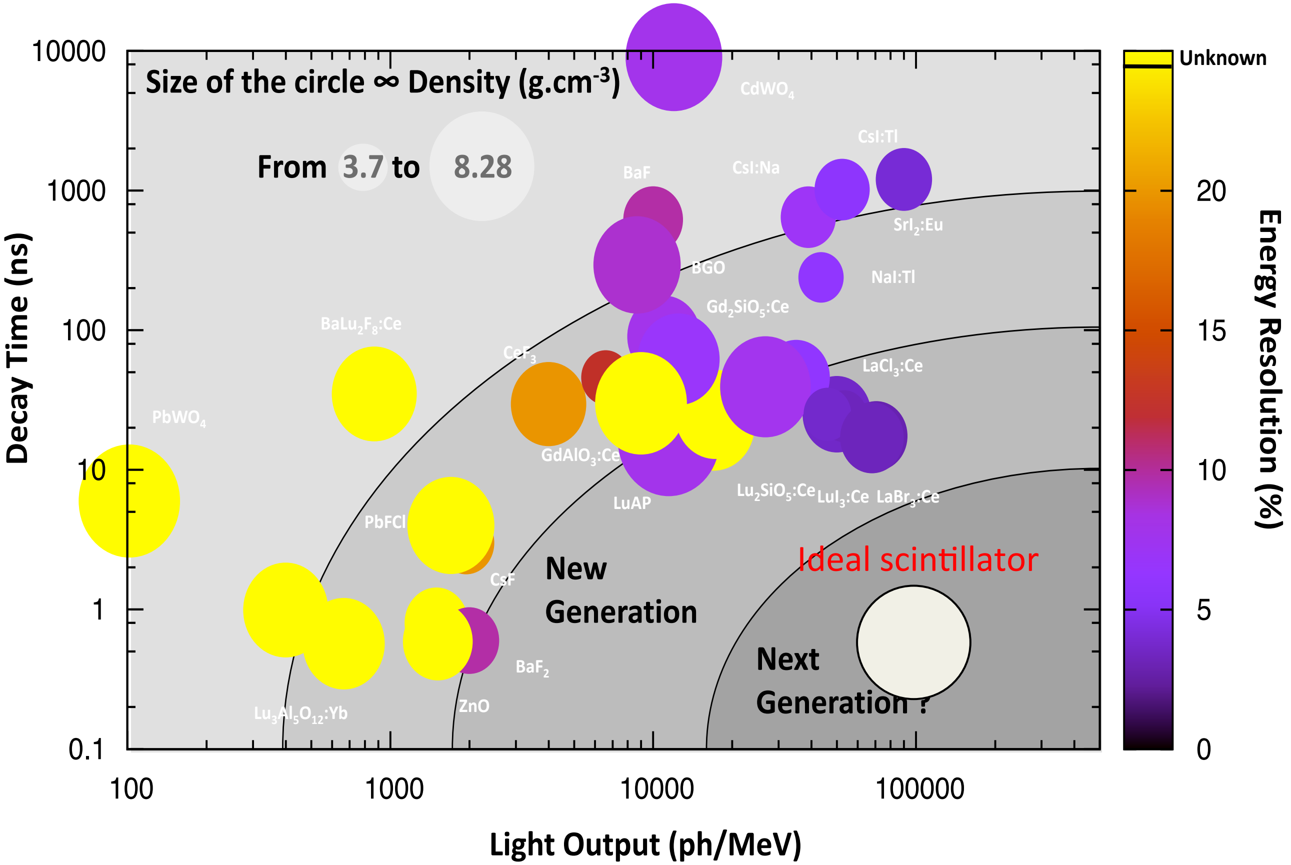


M. J. Weber J. Lumin. 100 (2002) 35

Invention of the photomultiplier tube

Classification of scintillators

- Density
- Light Yield
- Energy Resolution
- Decay Time



Courtesy P. Lecoq

Requirements

- High density
- High light yield
- Short decay time
- Inexpensive, “easy” to manufacture, reproducible
- Large size, easy handling and “machinable
- Radiation hardness (for some applications HEP, Astronomy)

Many Applications

- High Energy Physics
- Astronomy and dark matter searches
- X ray and gamma spectroscopy
  - Safety inspection
- Imaging:
  - Medical imaging: PET/SPECT
  - Gamma imaging
- Monitoring in nuclear plants
- Oil wellsoil drilling

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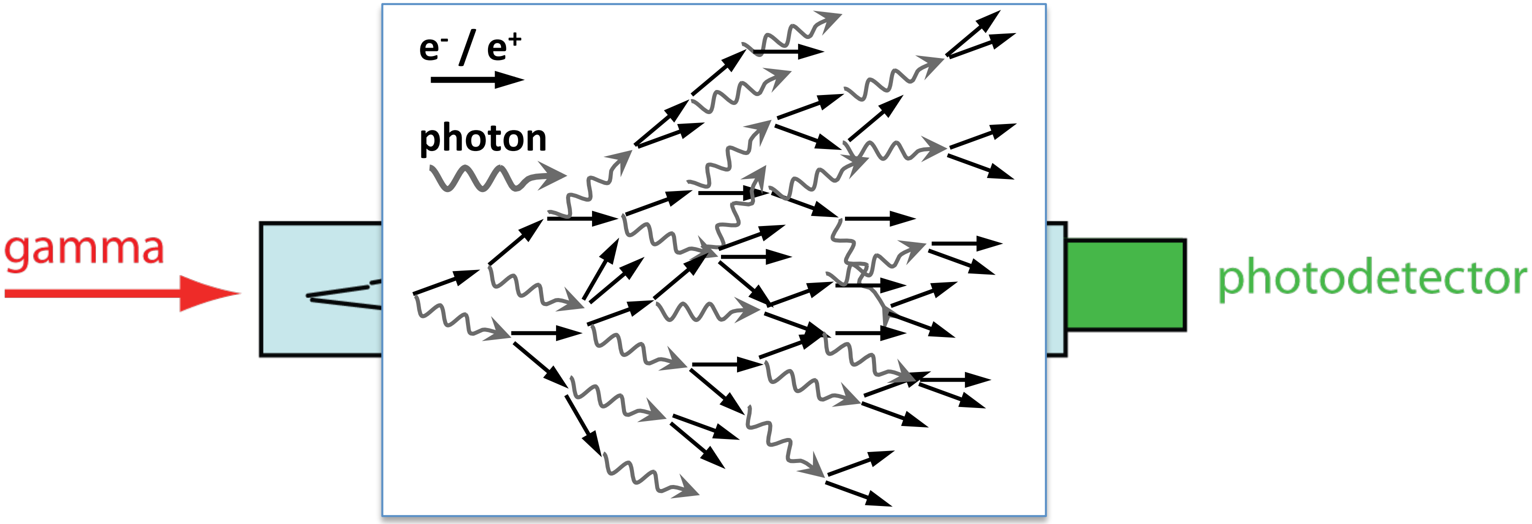
Application in High Energy Physic
Electromagnetic calorimeter

Interaction of a high energy gamma ray in a scintillator

Development of an electromagnetic shower



Characterized by:

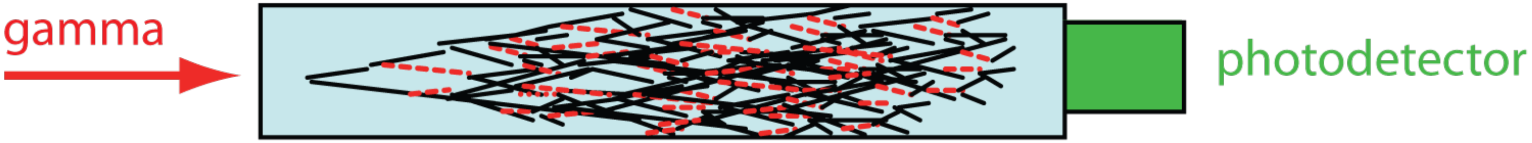
- Radiation length X_o (g/cm^2)

$$X_0 = \frac{716.4A}{Z(1+Z)\ln\left(\frac{287}{\sqrt{Z}}\right)}$$

- Molière radius R_m(g/cm^2)

$$R_m = 0.035 * X_o * (Z + 1.4)$$

Energy resolution of a electromagnetic calorimeter



Energy resolution of electromagnetic calorimeter

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

a: statistical term: depends mainly on light yield

b: noise term negligeable

c: Constant term: depends of light uniformity, calibration

Scintillators requirements for high energy physics

- High density
    - Stopping power, short radiation length X_0 & Molière radius
- Decay time
- Radiation hardness
- light yield less important for high energy gamma rays detection

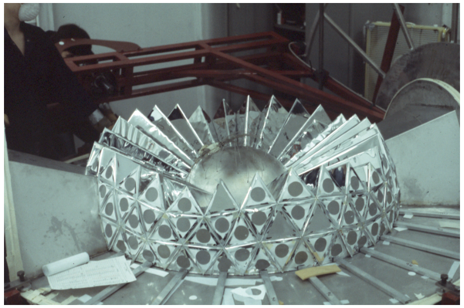
Some popular crystals in HEP

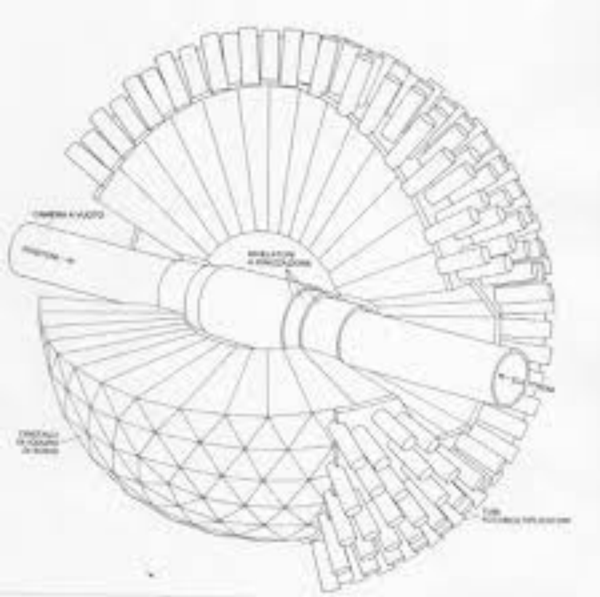
	NaI(Tl)	BaF_2	CsI(Tl)	CeF_3	BGO $Bi_4Ge_3O_{12}$	PWO $PbWO_4$
Xo [cm]	2.59 ☹	2.03 ☹	1.86 😐	1.66 😐	1.12 🙂	0.92 🙂
ρ [g/cm^3]	3.67 ☹	4.89 ☹	4.53 ☹	6.16 🙂	7.13 🙂	8.2 🙂
τ [ns]	230 ☹	0.6 🙂 620 ☹	1050 ☹	30 🙂	340 😐	15 🙂
λ [nm]	415 🙂	230 🙂 310 😐	550 🙂	310 😐 340 😐	480 🙂	420 😐
$n@\lambda_{max}$	1.85 😐	1.56 🙂	1.80 😐	1.68 🙂	2.15 ☹	2.3 ☹
LY [%NaI]	100 🙂	5 ☹ 16 ☹	85 🙂	5 😐	10 🙂	0.5 ☹

Crystal ball calorimeter

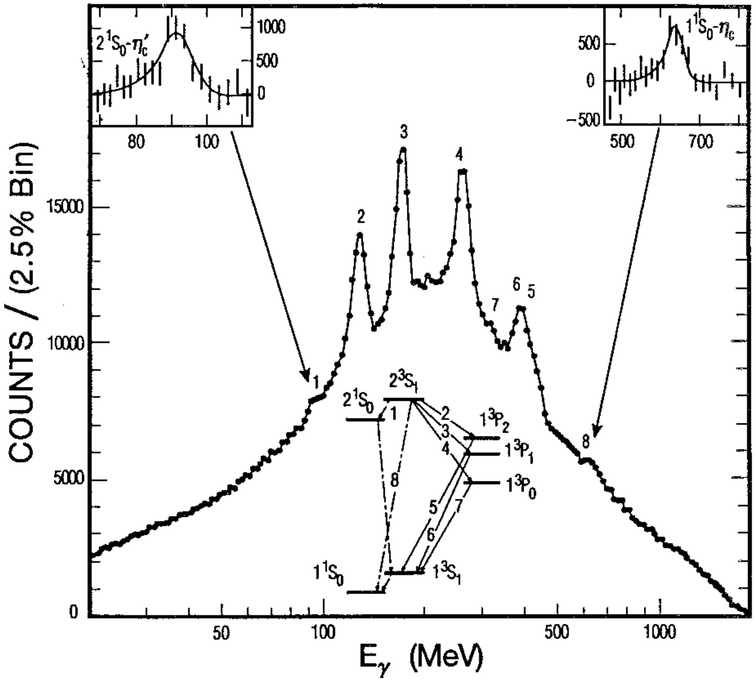
Crystal Ball @SLAC, 1979 for Charmonium spectroscopy

- 50cm diameter spherical ball of NaI(Tl) crystals
- 672 crystals 42cm long, PMT readout
- Very good resolution allowed precise spectroscopic study of charmonium states





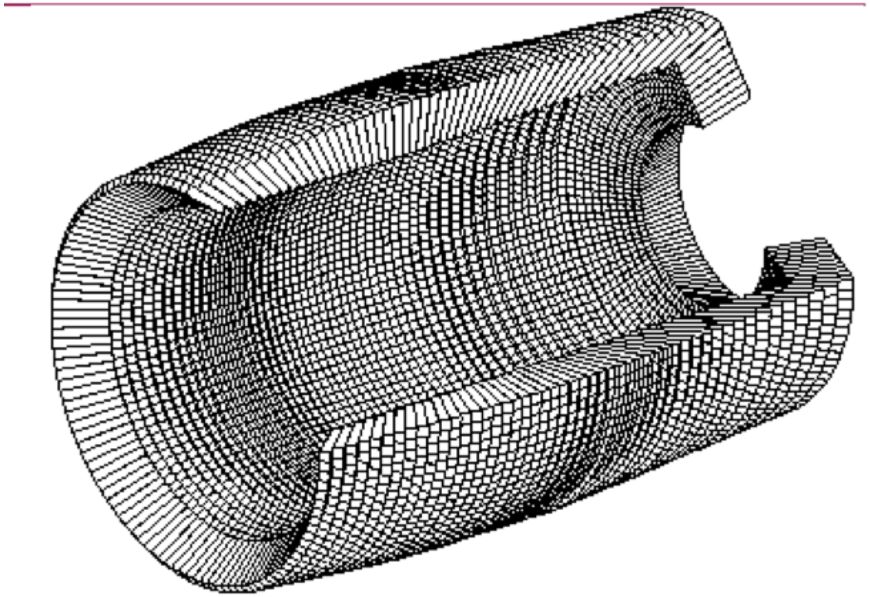
Charmonium decay

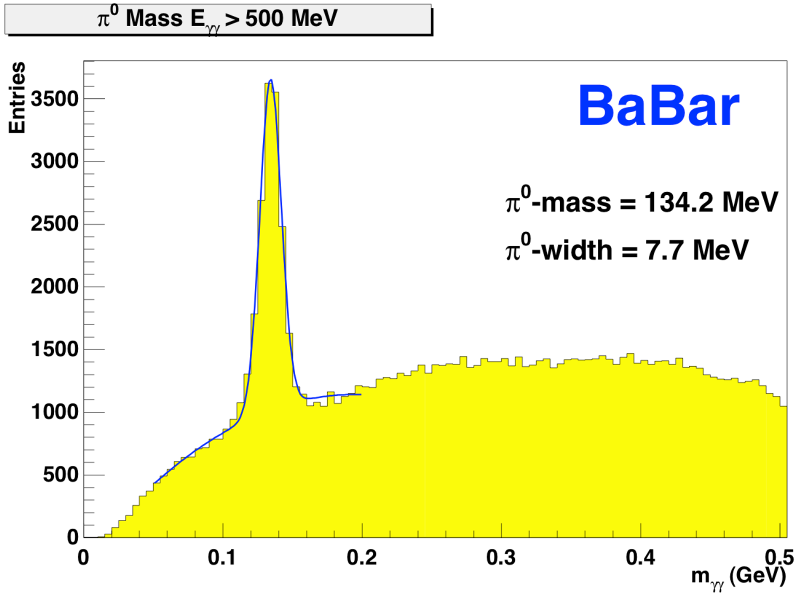


Babar detector at SLAC (PEP-2)

Detailed study of b-quarks, b-quark containing hadrons, and CP violation

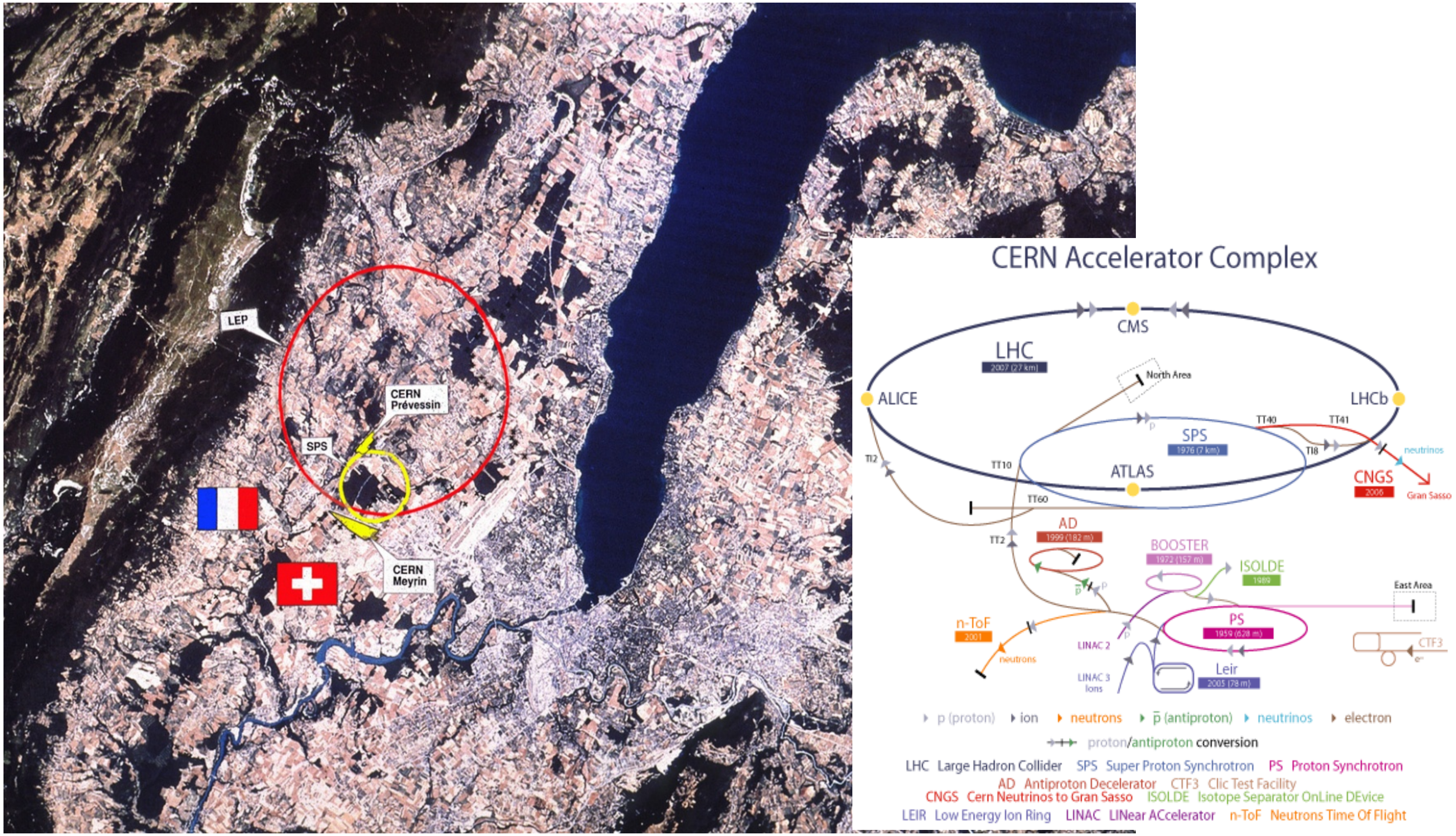
- Cylindrical geometry
- 6580 CsI:Tl crystals, ≈34 cm long,
- Excellent energy, position resolution to reconstruct π0s.





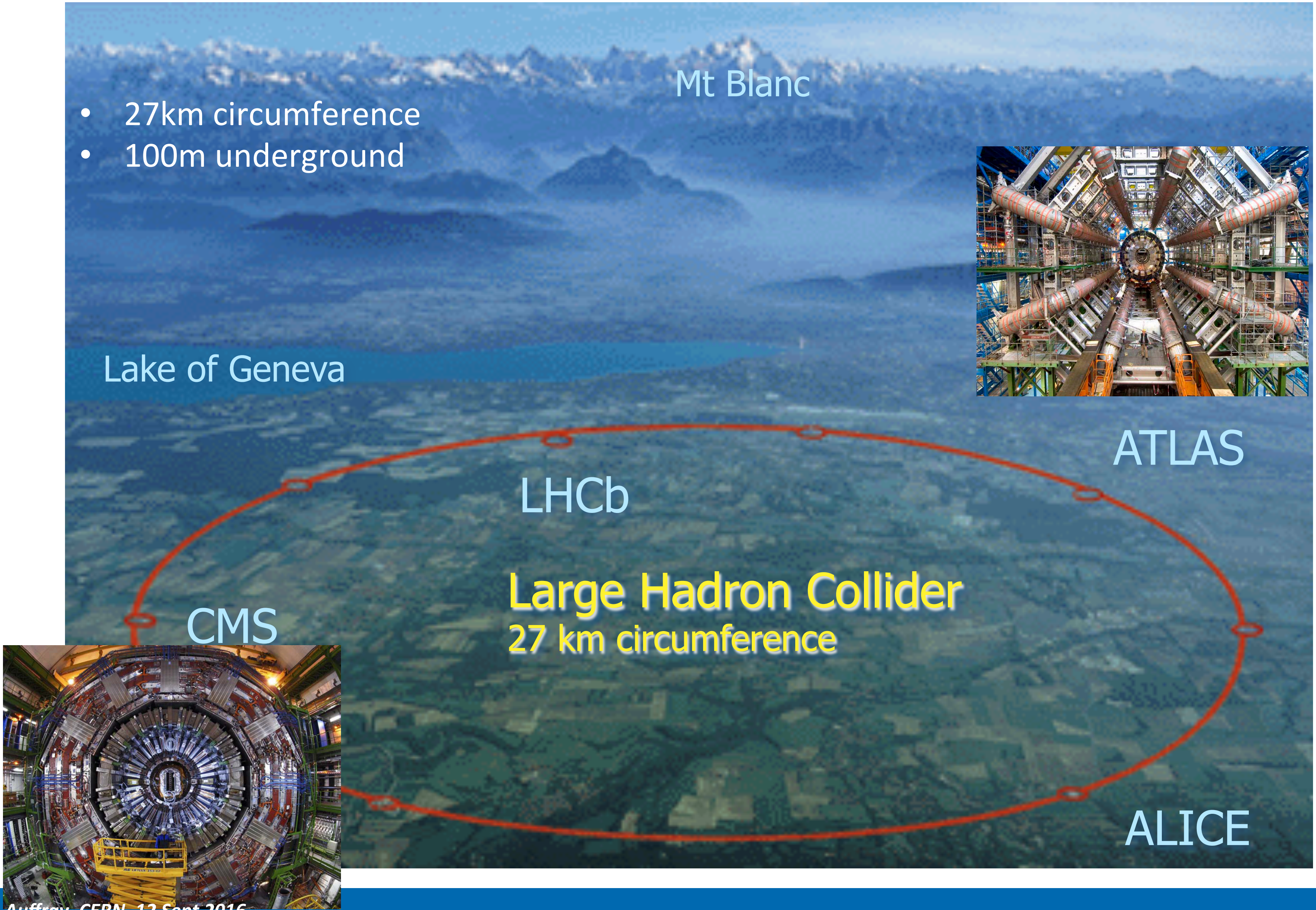
@ CERN

CERN (the European Organization for Nuclear Research) is the world's largest particle physics laboratory, where physicists and engineers probe the fundamental structure of the universe.



The Large Hadron Collider LHC

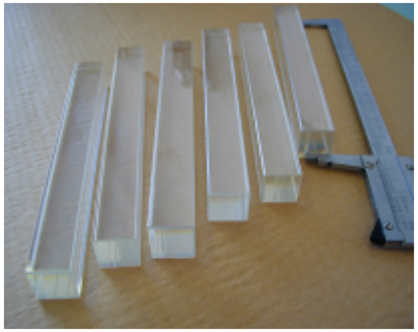
- 27km circumference
- 100m underground



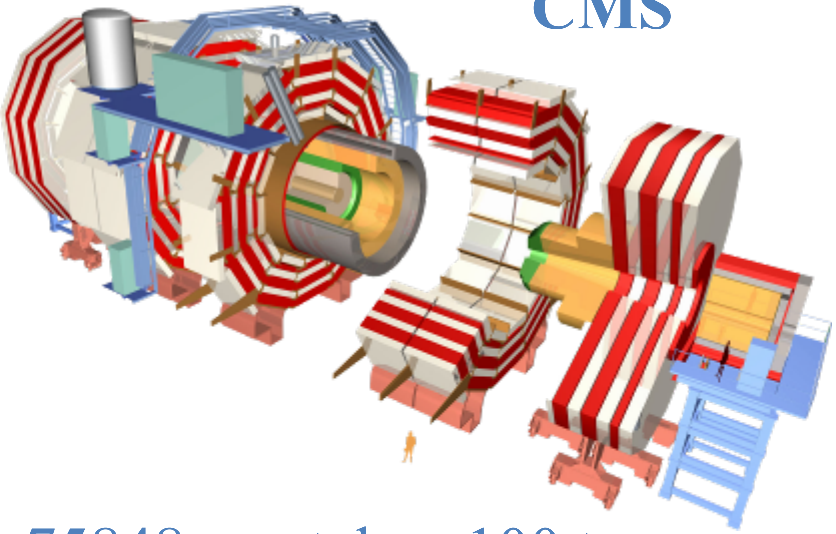
@CERN in LHC

2 experiments use scintillating crystals : Lead tungstate crystals : $PbWO_4$

ALICE :17920 crystals

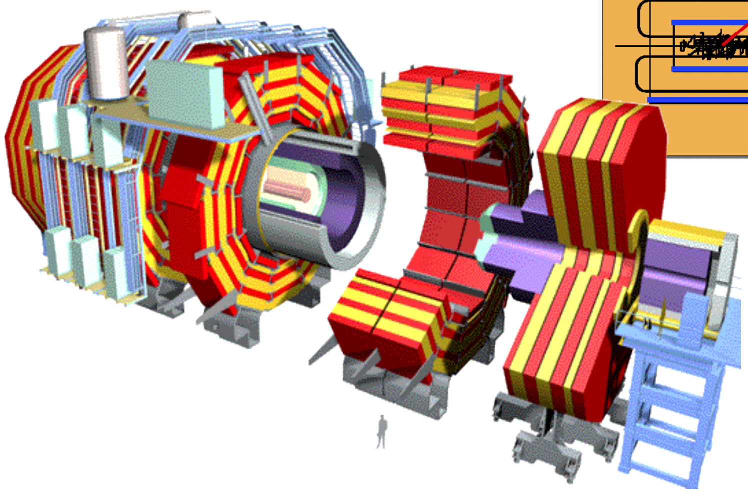


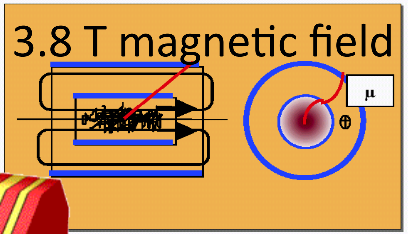
CMS



75848 crystals = 100 tons

CMS : Compact Muon Solenoid @LHC





3.8 T magnetic field

Main CMS goal: search for Higgs and new physics

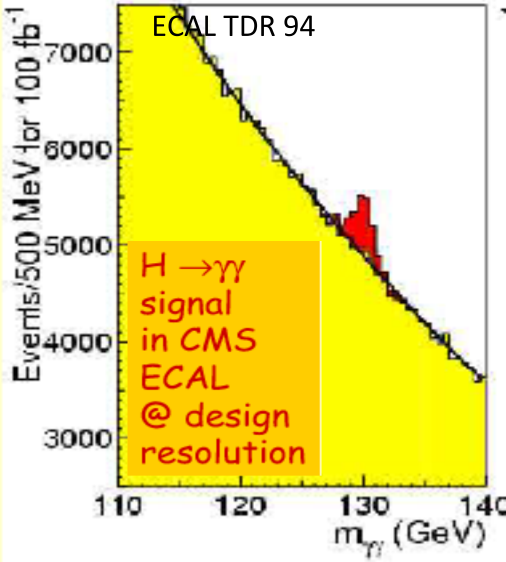
Length ~ 22 m
Diameter ~ 15 m
Weight ~ 14000 t

For a light Higgs

H→γγ best channel. Narrow width, but irreducible background:

Electromagnetic calorimeter (ECAL) resolution crucial !

=>Choice of homogeneous crystal calorimeter



ECAL TDR 94

H →γγ signal in CMS ECAL @ design resolution

Challenges & Choices for ECAL

Challenges:

Fast response (25ns between bunch crossings at LHC)

- High radiation doses and neutron fluences

  500fb^{-1} : 0.3 Gy/h & 4.10^{11} p/cm^2 at $|\eta| < 1.48$;

  6.5 Gy/h & 3.10^{13} p/cm^2 at $|\eta| = 2.6$

Strong magnetic field (3.8 teslas)

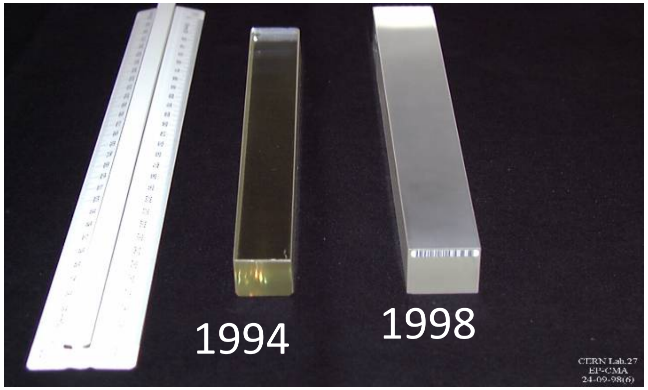
Long term stability monitoring capability

Choices:

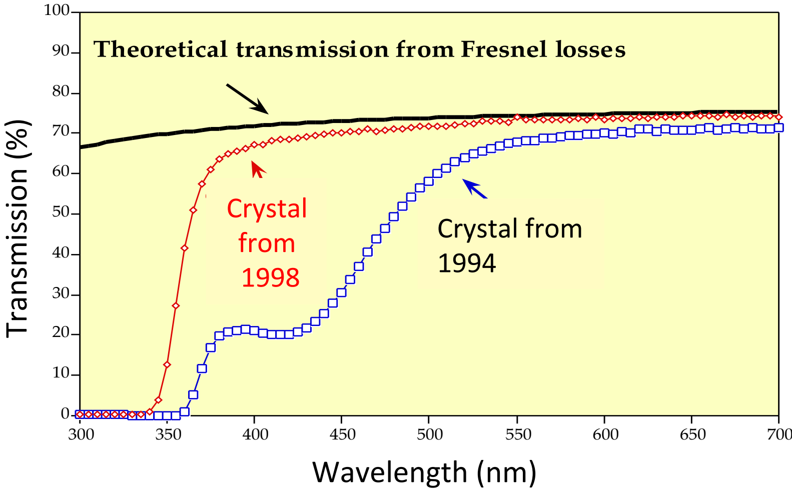
- **Lead tungstate crystals ($PbWO_4$, PWO)**
- Photo detectors :
  - Avalanche photodiodes (APD) in Barrel
  - Vacuum phototriodes (VPT) in Endcaps
- Laser light monitoring system for following the evolution of crystal transparency and photo-detector response

From R&D to Production

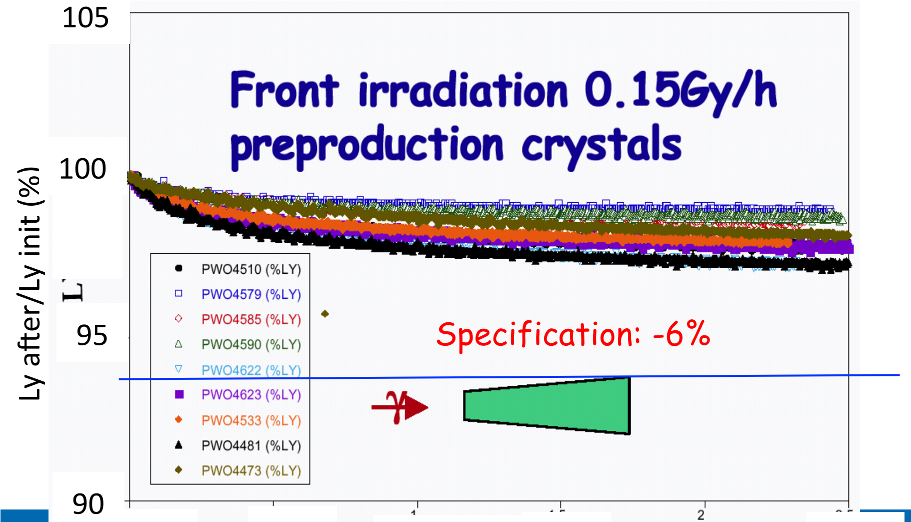
Optical properties improvement



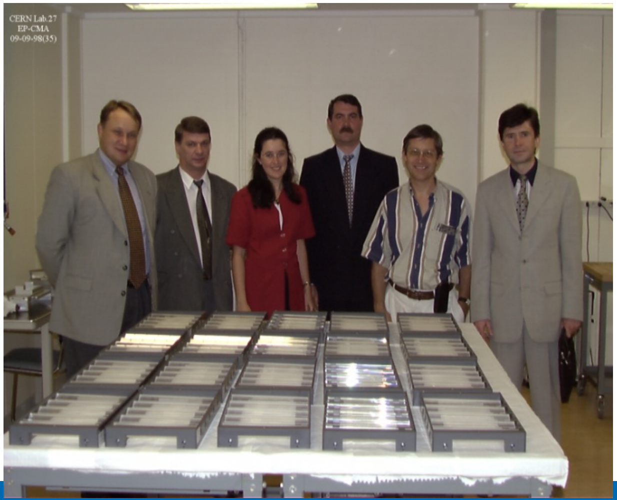
Transmission improvement



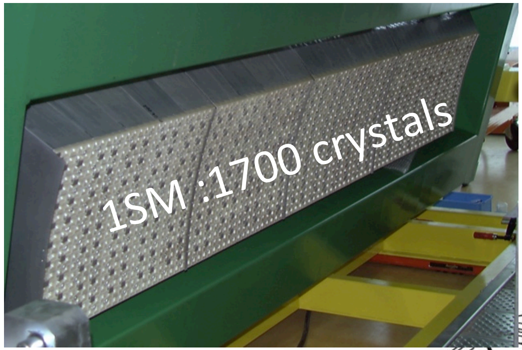
Radiation hardness improvement



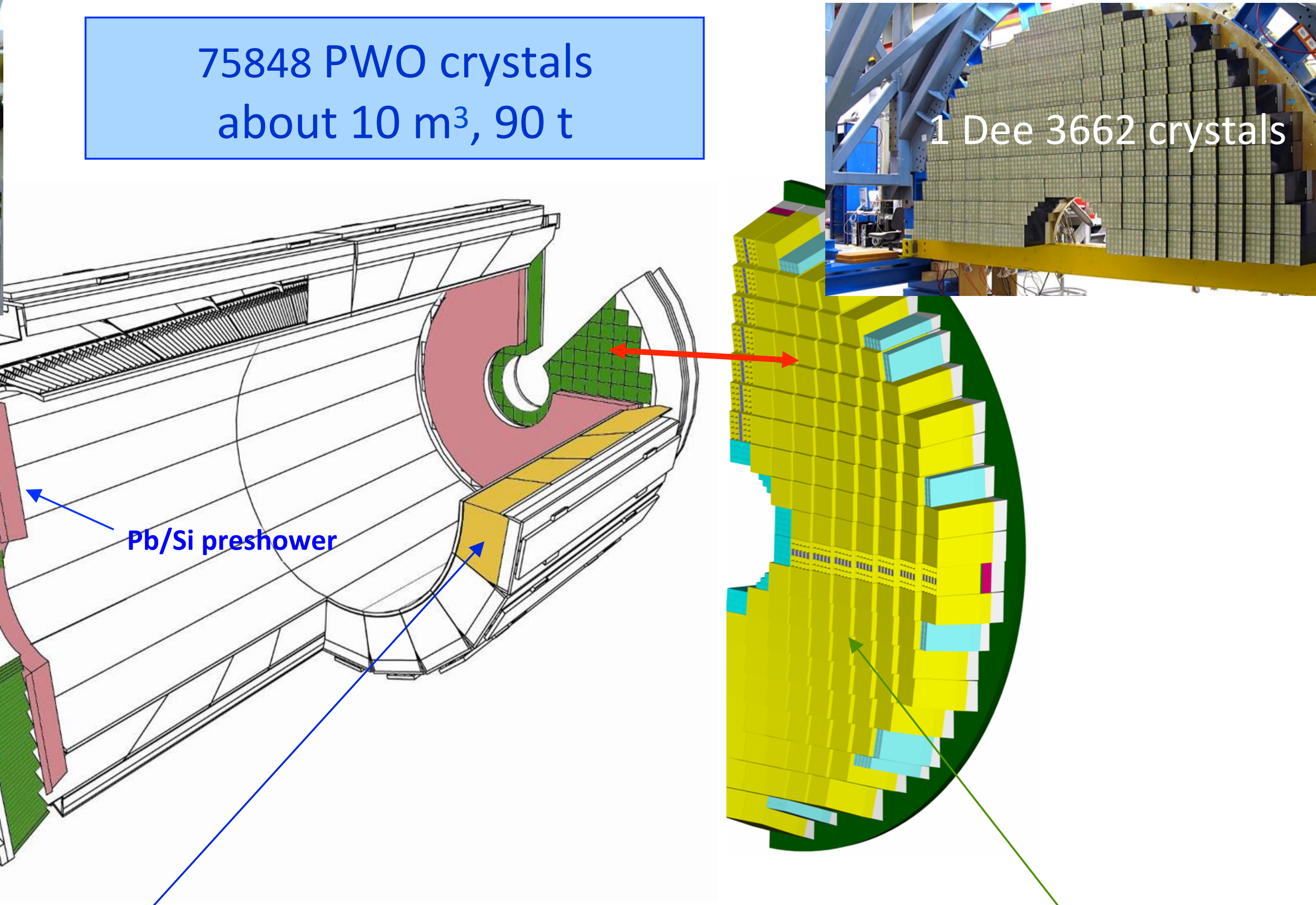
Delivery of the first 100 PWO Crystals Sept 98



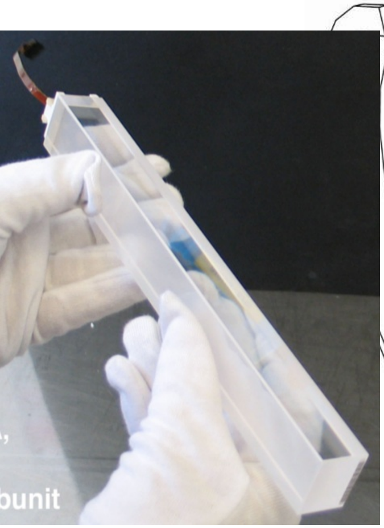
CMS ECAL Design


1SM :1700 crystals

75848 PWO crystals
about 10 m^3, 90 t


1 Dee 3662 crystals

Pb/Si preshower

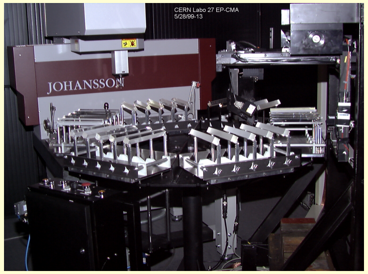


Barrel: $|\eta| < 1.48$
36 Super Modules (SM)
61200 crystals ($2.2 \times 2.2 \times 23$ cm^3)

EndCaps: $1.48 < |\eta| < 3.0$
4 Dees
14648 crystals ($3 \times 3 \times 22$ cm^3)

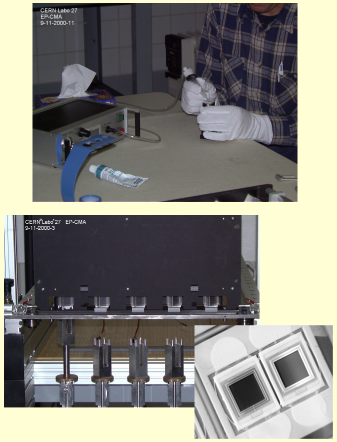
CMS ECAL assembly: 1998-2007

61200 crystals



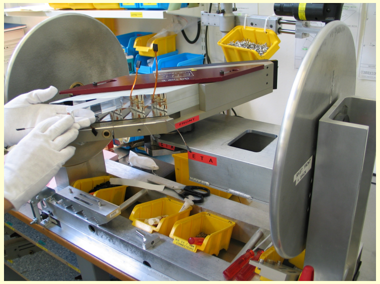
Caracterisation des cristaux/

61200 sub-units



Collage des photodétecteurs sur les cristaux

6120 sub-modules

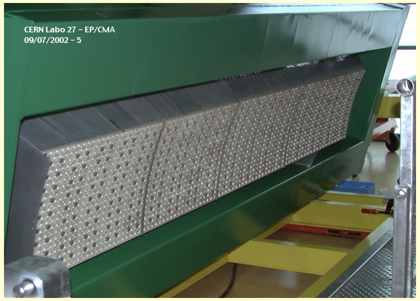


Montage des sous-modules

144 modules

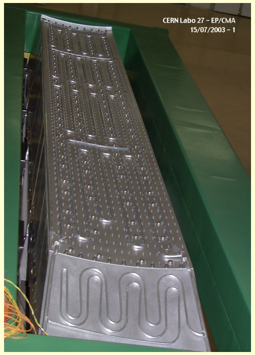
Montage des modules

36 Super- modules



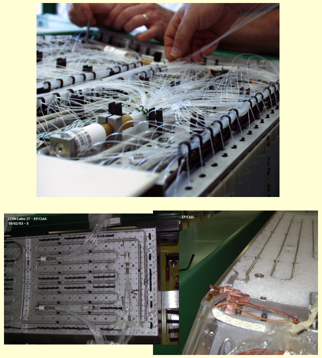
Montage des Supermodules

36 Super- modules



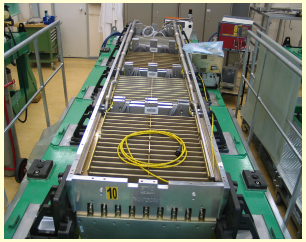
Installation d'écran thermique

36 Super- modules



Installation du système de monitoring

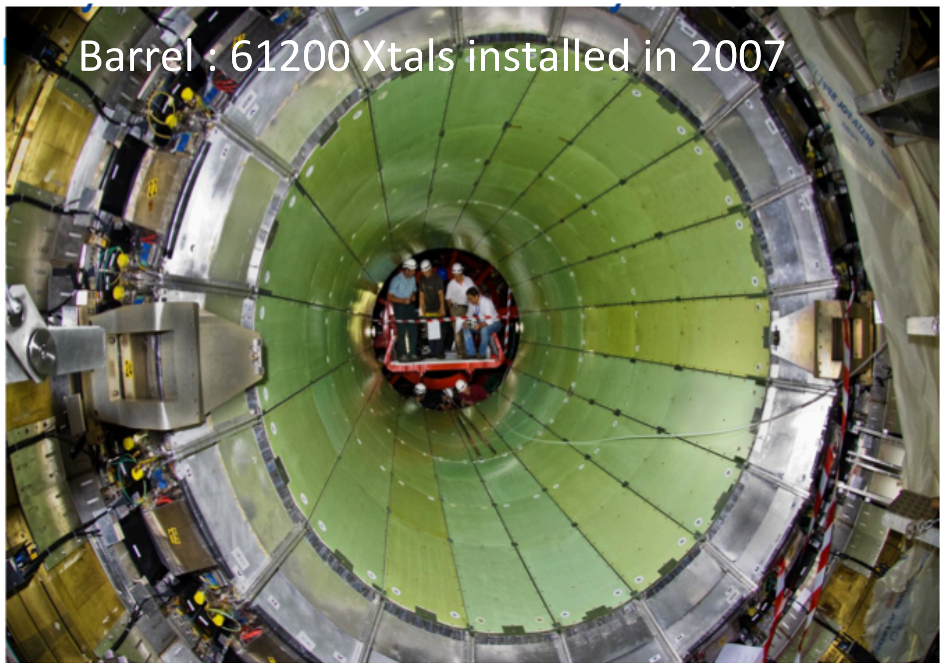
36 Super- modules



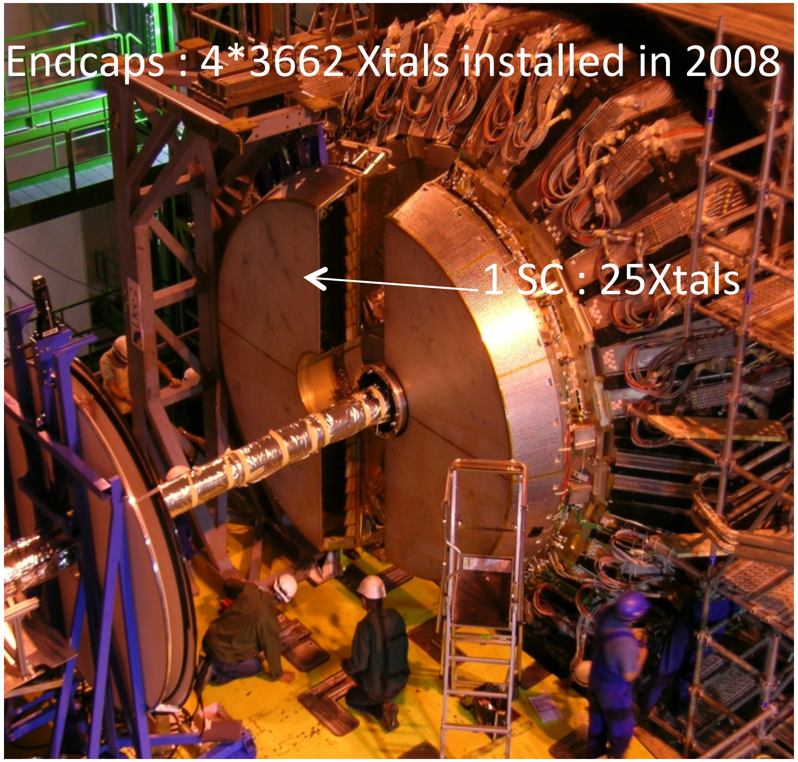
Installation du système de refroidissement

36 Super- modules

ECAL in CMS at P5 Cessy, France



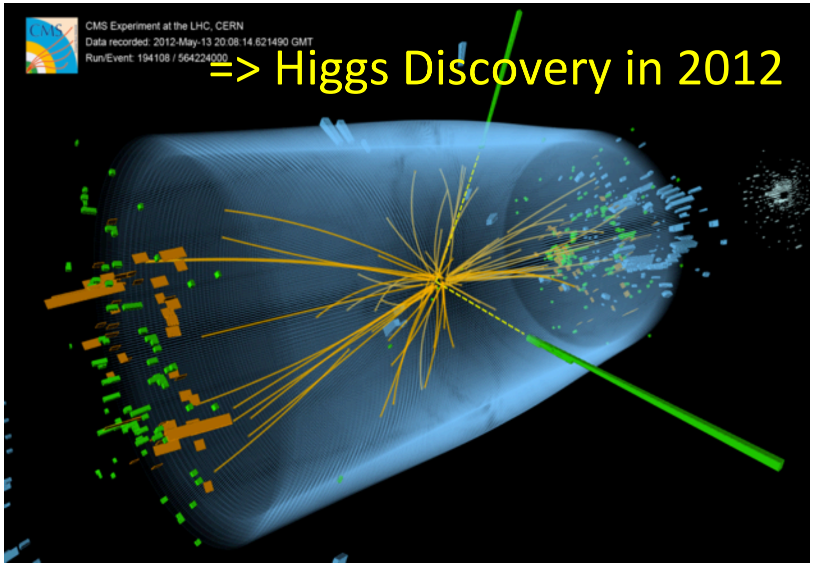
Barrel : 61200 Xtals installed in 2007



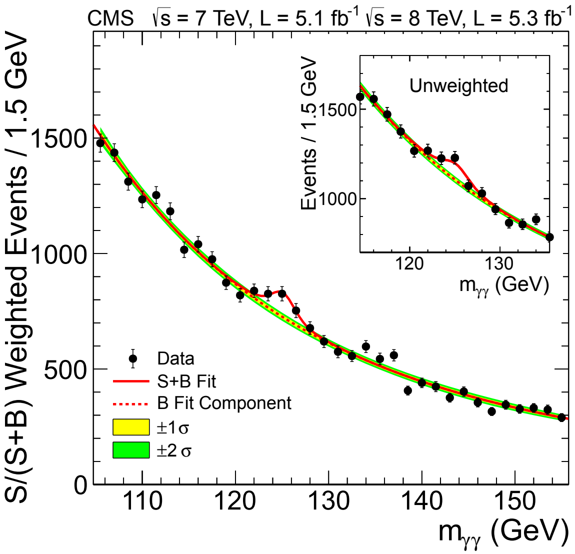
Endcaps : 4*3662 Xtals installed in 2008

1 SC : 25Xtals

CMS ECAL: Higgs bosons



=> Higgs Discovery in 2012



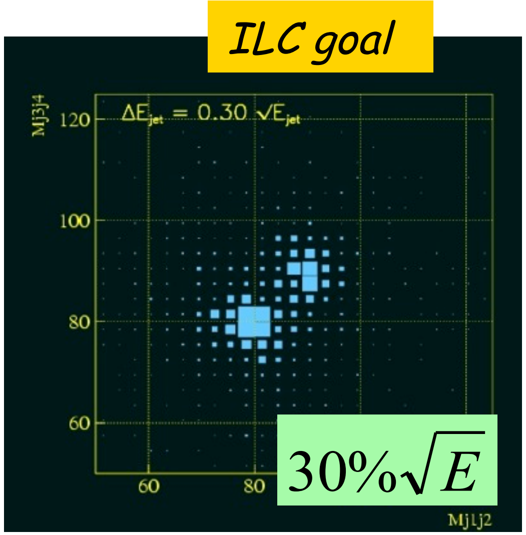
François Englert et Peter Higgs, Physic Nobel Price in 2013

The calorimetry challenge in future High Energy colliders

- Precision Physics at future colliders is characterised by multi-jet final states with small cross section in the order of some fb

=> Precise measurements of multi jet events (separation of W,Z) require :

  - High luminosity (high radiation level)
  - High detector performance 30%/ √E
  - High granularity and identification of shower components



ILC goal

$30\%\sqrt{E}$

The calorimetry challenge in future High Energy colliders New approaches

Particle flow

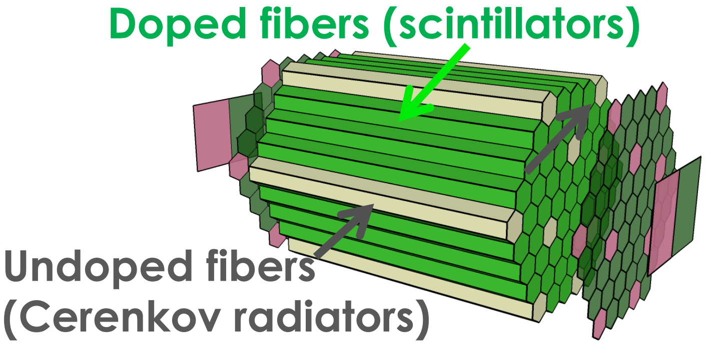
- Each particle in a jet is measured individually

Dual readout method

- Measure event by event the electromagnetic fraction of the hadronic shower by separating Cerenkov and scintillation light

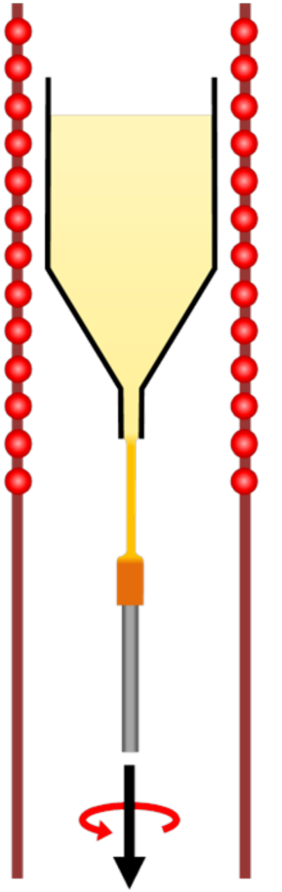
New concept based on metamaterials:

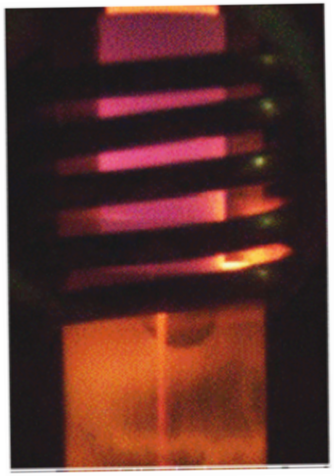
- Scintillating cables made of heavy scintillating fibers
- of different composition ⇨ quasi-homogeneous calorimeter

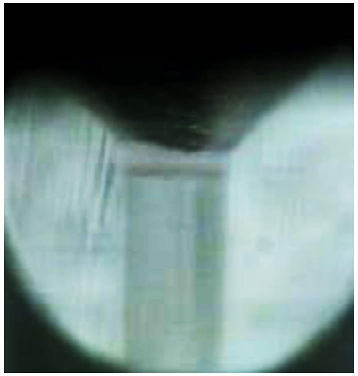


P. Lecoq, CALOR 2008
G. Mavromanolakis et al. CALOR 2010 + JINST 6 p10012 (2011)

Micro-Pulling down technology for crystal fiber growth







Courtesy Fibercryst

Micro-pulling down (*μ*PD) : multiple advantages

- Wide range of diameters 300 *μ*m – 3 mm
- Lengths up to 2 m
- Multiple geometries for capillary die ○ □ ⬡
- Fast pulling rates
- Multi-fibers pulling possibilities (in parallel)

LuAG from Fibercryst

See next talk K Pauwels

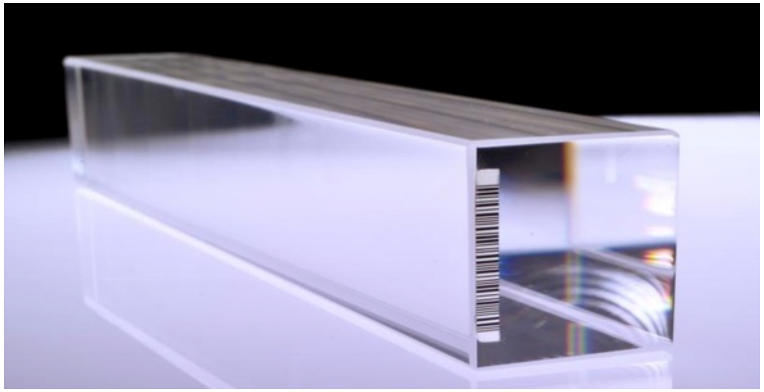
Intelum

CRYSTAL CLEAR

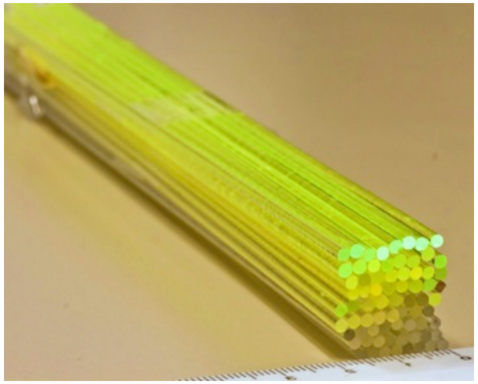
Scintillating crystal fibers: Flexibility for the calorimeter design

Homogeneous calorimeter

From bulk crystal



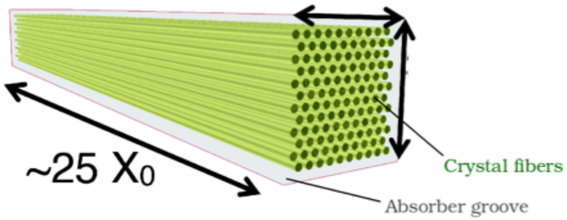
To bloc of fibers



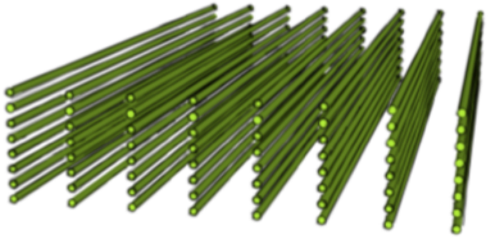
=> Need large volume of fibers with high density

Sampling calorimeter

Pointing Fibers
in a Spaghetti Calorimeter



Layers of Crystal Fibers
in a sampling calorimeter

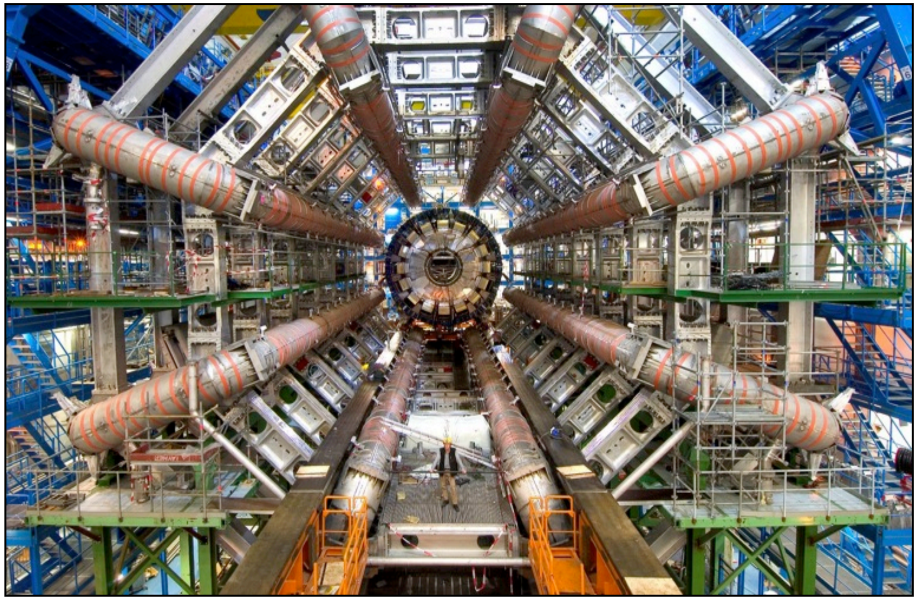


=> Need less fibers, possibility to use materials with lower density

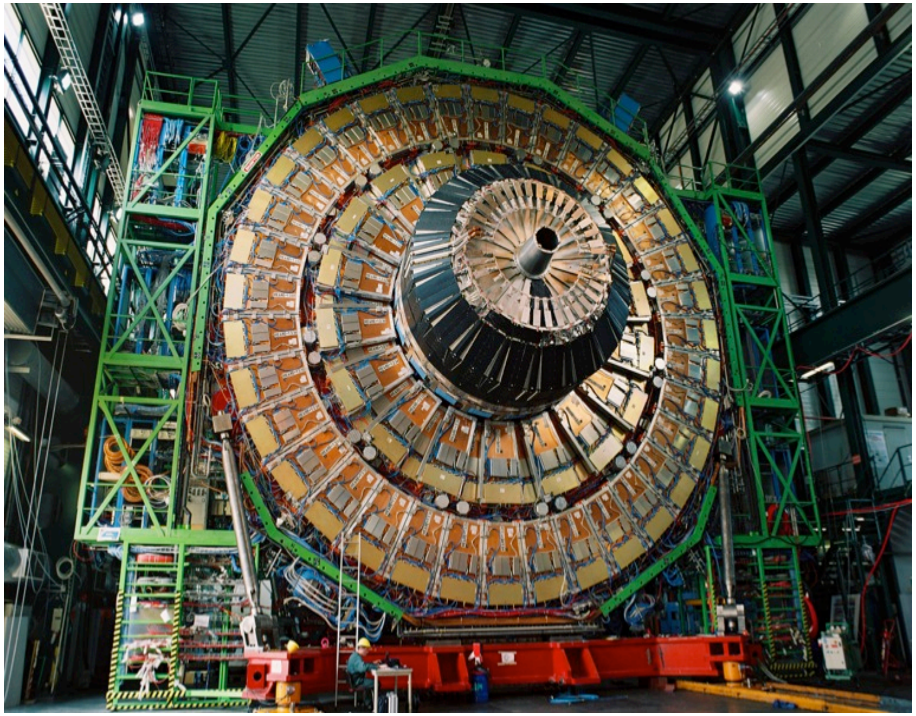
@ CERN development of leading edge technology

To build particles detectors like

ATLAS

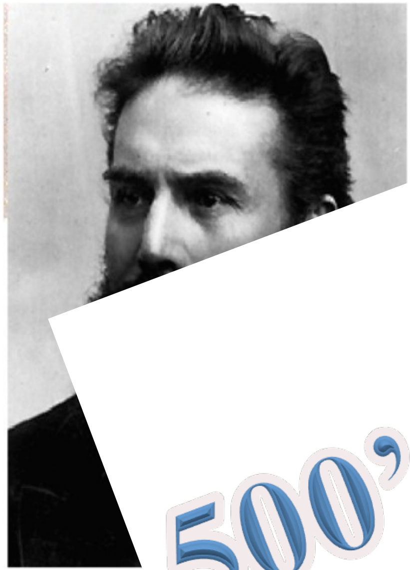


CMS

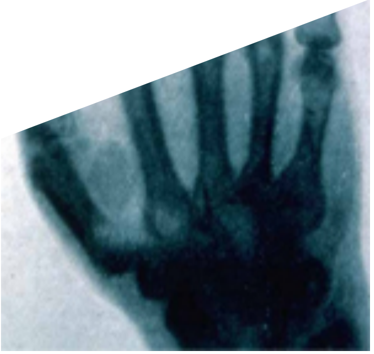


⇒ Application for medical imaging

X rays discovery: 1895



Today
500’000’000 Xray exams/y
In the world



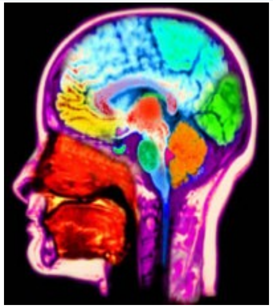
1895 Röntgen discovered Xrays

- vember 1895: First image of spouse’s hand

1st **Nobel prize in Physics** in 1901

Several imaging modalities

Anatomical / structural imaging	Fonctional Imaging
Information on the organs **STRUCTURE**, their shape, their limits, in some cases their contain (bone structures, calculs vesicaux)	Informations on the organs **FUNCTION** des organes, tissus or cells => **METABOLISM.**
Typical exams - **Radiology, CT scan,** - Échography, MRI, optical imaging	**Typical exams** - Scintigraphy - **Positrons emission Tomograph (PET)** - In some applications MRI, imagerie optique

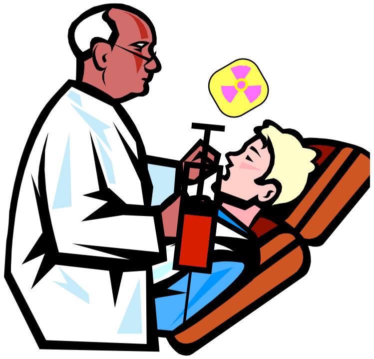


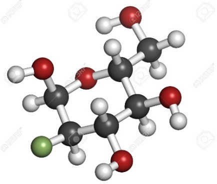
Scintillators in medical imaging

- X-ray detection, radiology, CT-scanner
- Single gamma detection: scintigraphy, SPECT
- **Positron emission tomography (PET)**

PET Principle

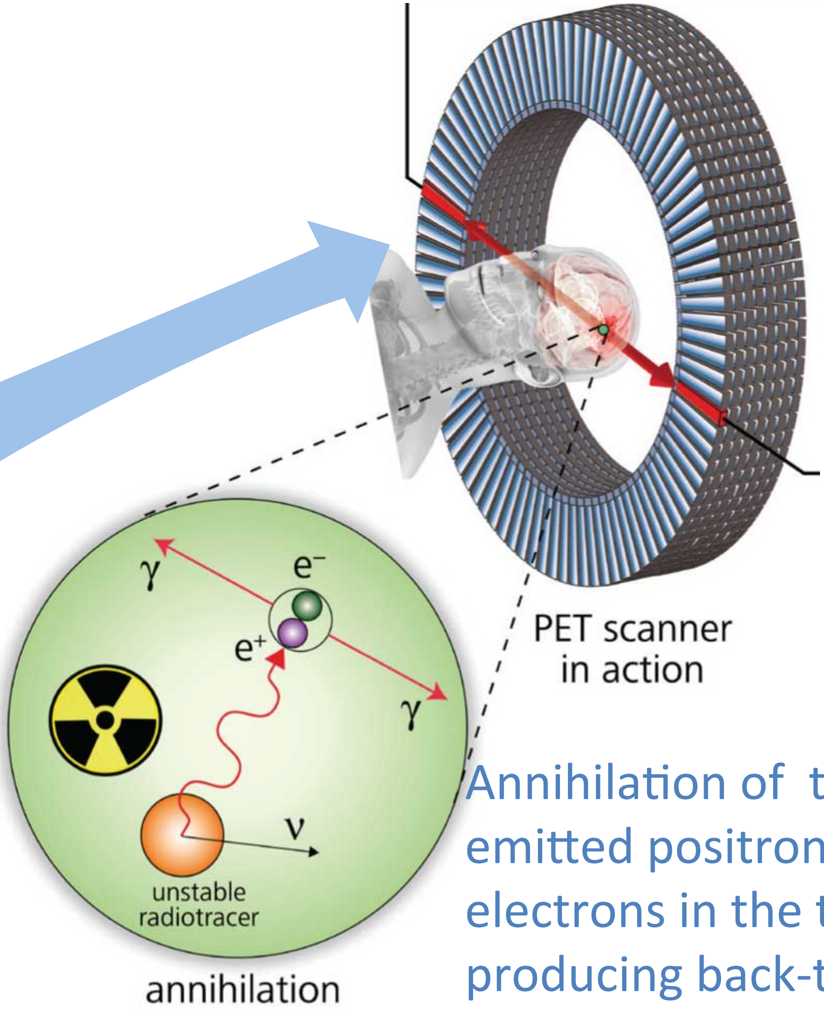
A positron emitting radiopharmaceutical is injected into the patient: the distribution





Fludeoxyglucose (18F-FDG)

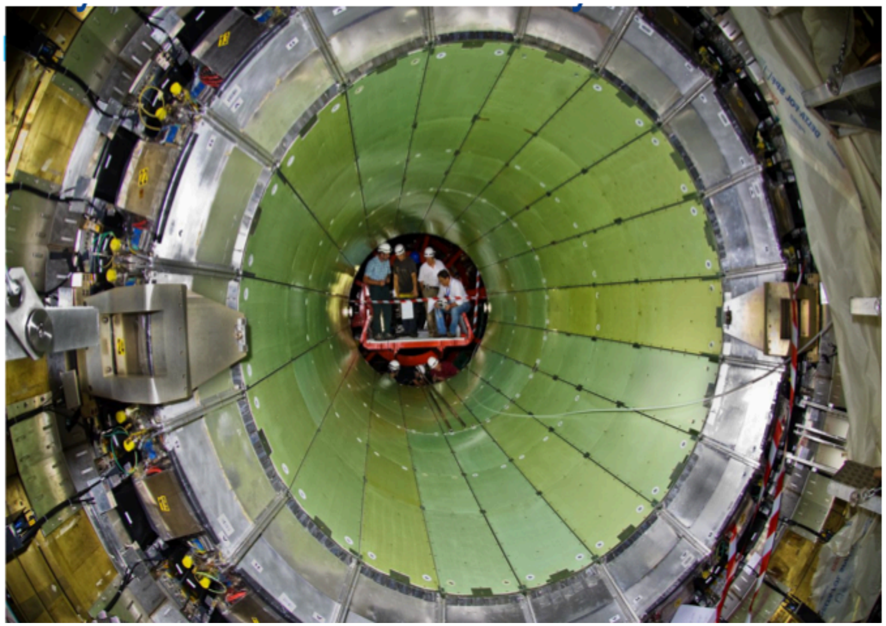
The patient is placed in the imaging scanner



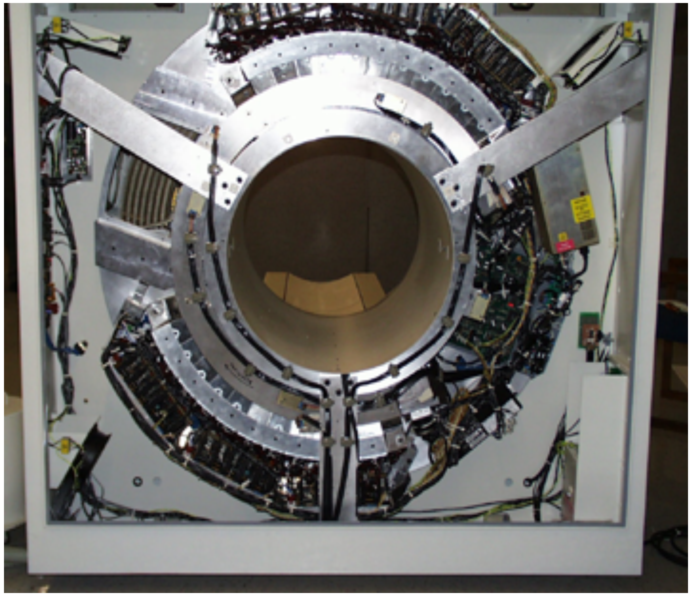
Annihilation of the emitted positrons with electrons in the tissue producing back-to- bac photons detected by scintillating crystals

Similar Challenges in HEP and medical imaging

CMS Electromagnetic calorimeter



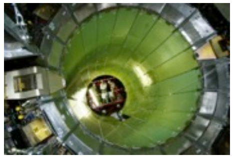
Positron Emission Tomograph (PET)

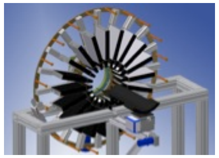


At LHC : Energy of particles < TeV

For PET: 0.000000511 TeV (511keV)Photons

From High Energy Physics to medical Imaging





Requirements for HEP EM calorimetry

Crystals
- High density (> 6 g/cm^3)
- Fast emission (< 100 ns), visible spectrum
- Moderate to high light yield
- High radiation resistance

Technology transfer

Photodetectors
- Compact
- High quantum efficiency and high gain
- High stability

Technology transfer

Readout electronics
- Fast shaping, low noise
- Highly integrated

Technology transfer

Intelligent and parallel DAQ
- Reduce dead time

Technology transfer

Software
- Accurate Monte Carlo simulation

Technology transfer

General design
- Compact integration of a large number of channels (> 10’ 000)

Technology transfer

Requirements for Medical Imaging

Crystals
- High density (> 7 g/cm^3)
- Fast emission (< 100 ns), visible spectrum
- High light yield
- Moderate radiation resistance

Photodetectors
- Compact
- High quantum efficiency and high gain
- High stability

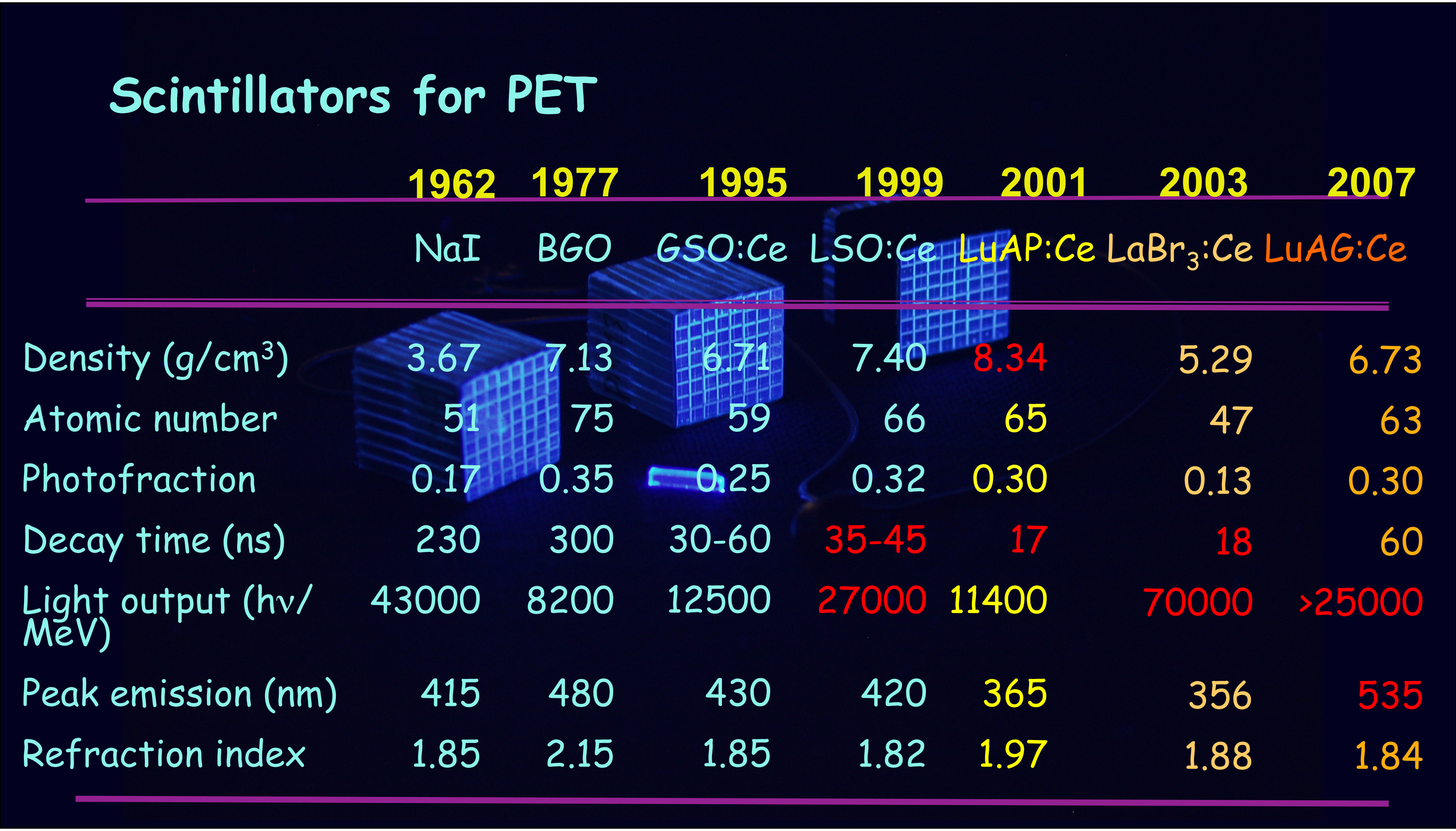
Readout electronics
- Fast shaping, low noise
- Highly integrated

Intelligent and parallel DAQ
- Reduce dead time

Software
- Accurate Monte Carlo simulation

General design
- Compact integration of a large number of channels (> 10’ 000)

Scintillators for PET



Scintillators for PET

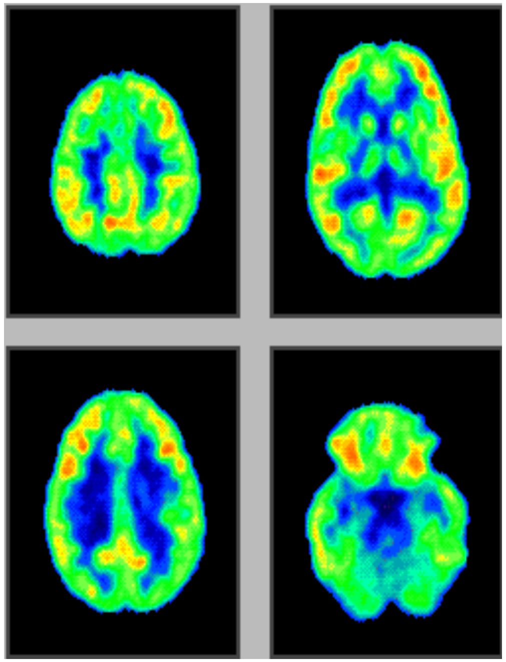
	1962	1977	1995	1999	2001	2003	2007
	NaI	BGO	GSO:Ce	LSO:Ce	LuAP:Ce	$LaBr_3$:Ce	LuAG:Ce
Density (g/cm^3)	3.67	7.13	6.71	7.40	8.34	5.29	6.73
Atomic number	51	75	59	66	65	47	63
Photofraction	0.17	0.35	0.25	0.32	0.30	0.13	0.30
Decay time (ns)	230	300	30-60	35-45	17	18	60
Light output (hν/ MeV)	43000	8200	12500	27000	11400	70000	>25000
Peak emission (nm)	415	480	430	420	365	356	535
Refraction index	1.85	2.15	1.85	1.82	1.97	1.88	1.84

PET application

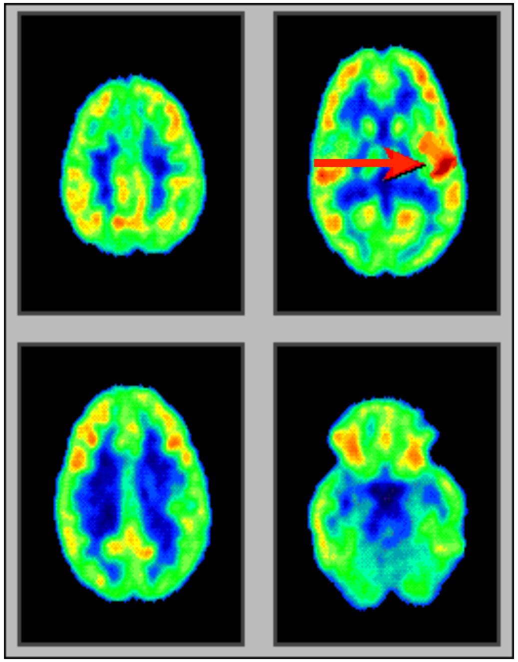
- Brain study
- Brain Disorder
- Heart problem
- Cancer
- Development of medecine

Brain Study

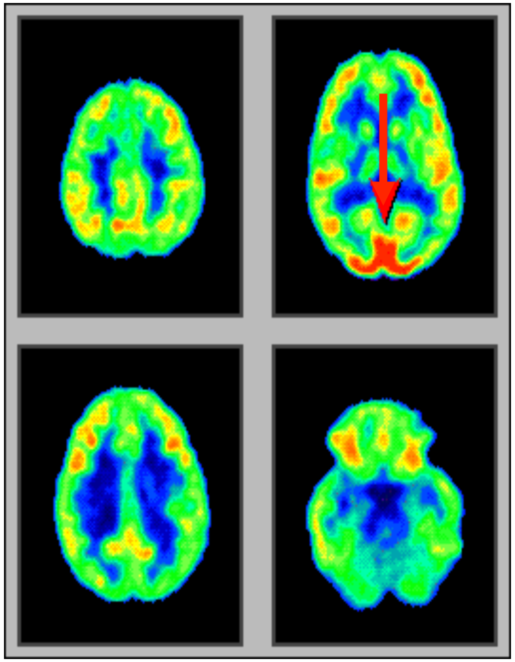
Rested person



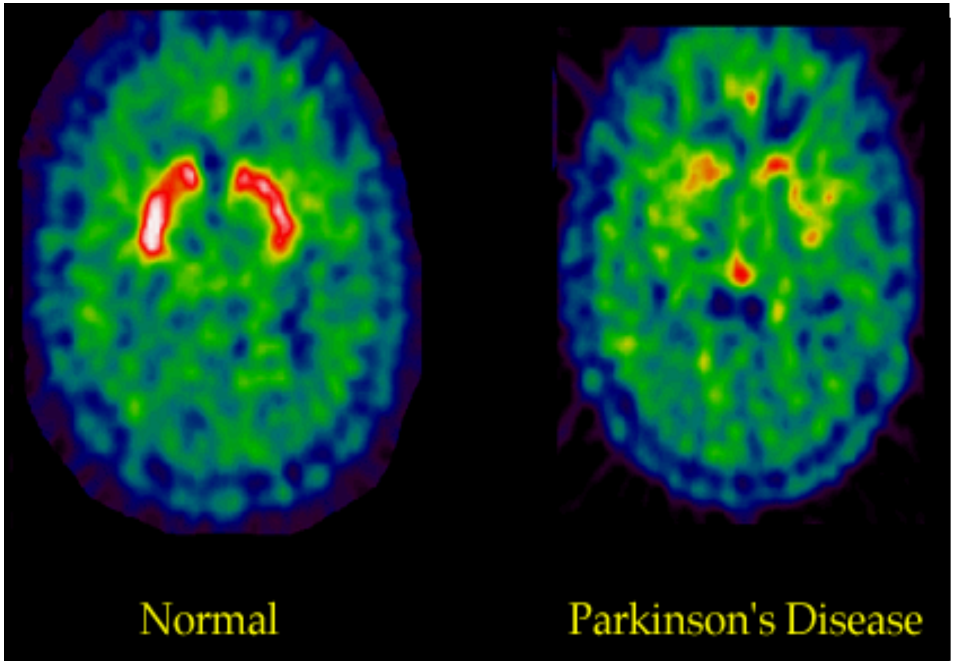
Hearing test



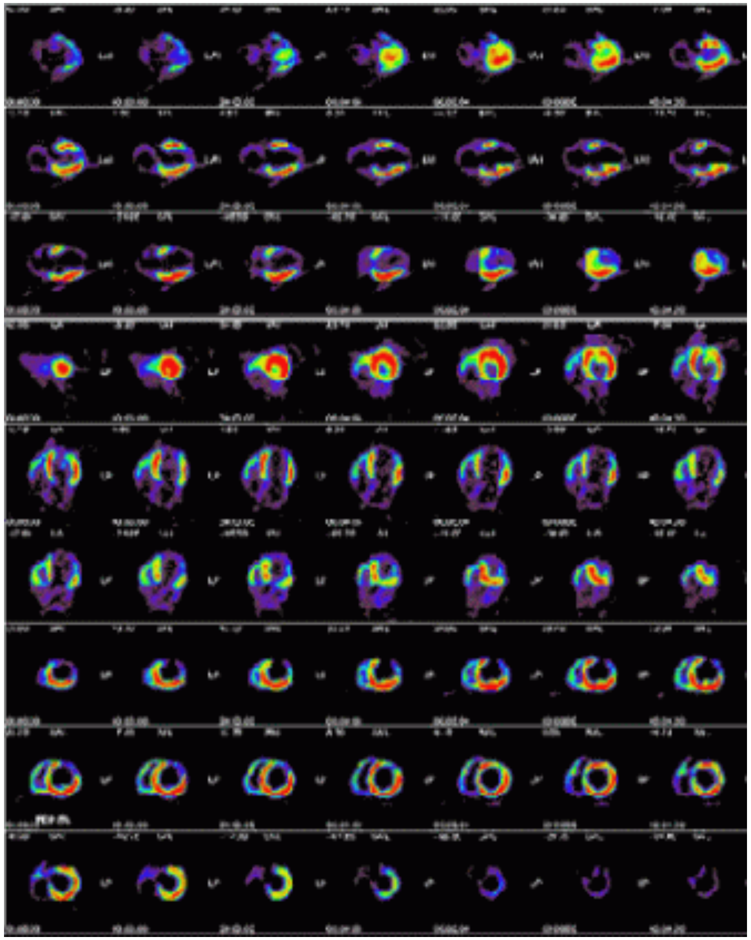
Looking test



Disorder Study

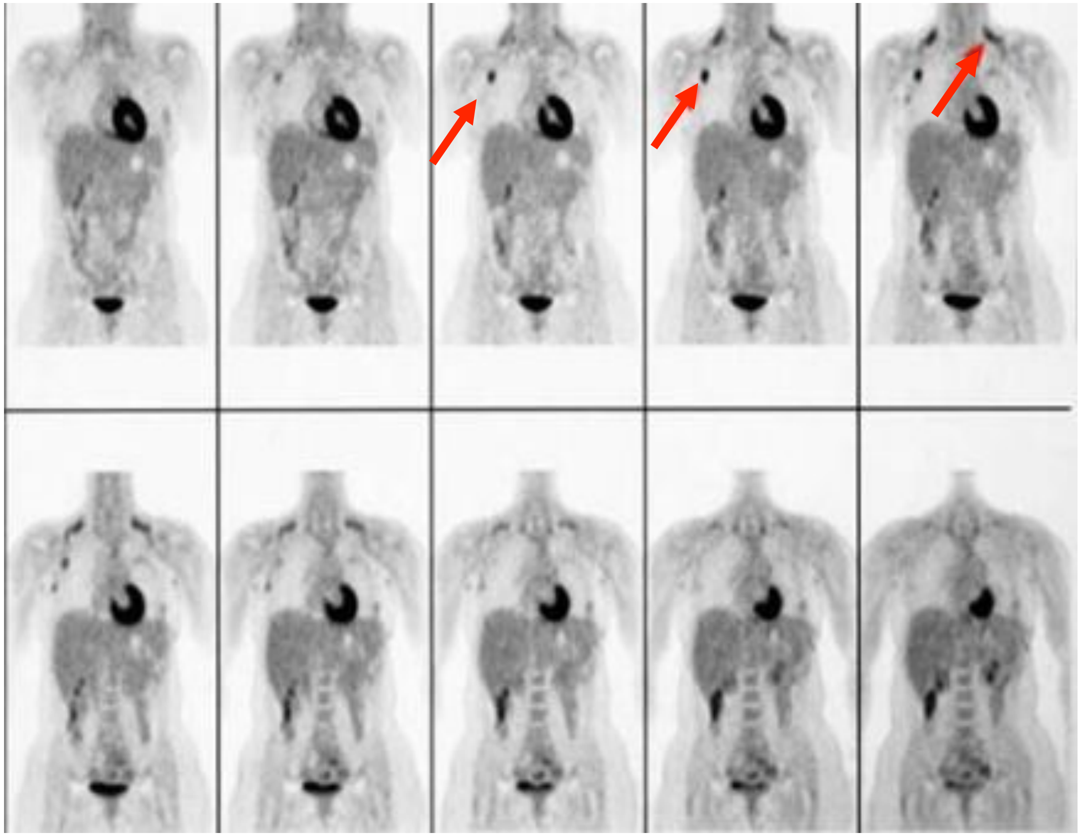


Heart problem



Oncology

Example of the lung tumor

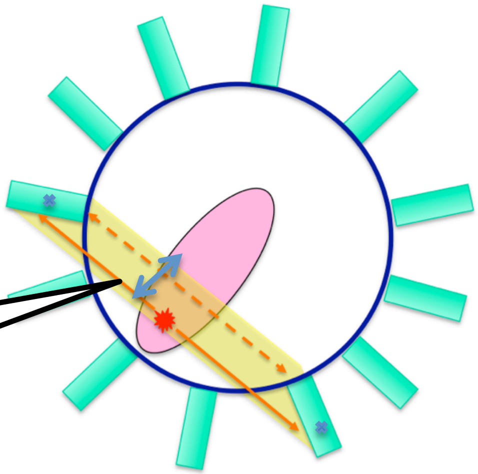


PET Requirements

- Minimize the dose and injection time
  - ⇒ Need sensitivity
    - ⇒ Need stopping power
    - ⇒ Reduce dead time
- Maximize lesion detectability
  - ⇒ Spatial resolution
    - ⇒ Segmentation
  - ⇒ Reduce signal to noise ratio
    - ⇒ Energy resolution
    - ⇒ Timing resolution

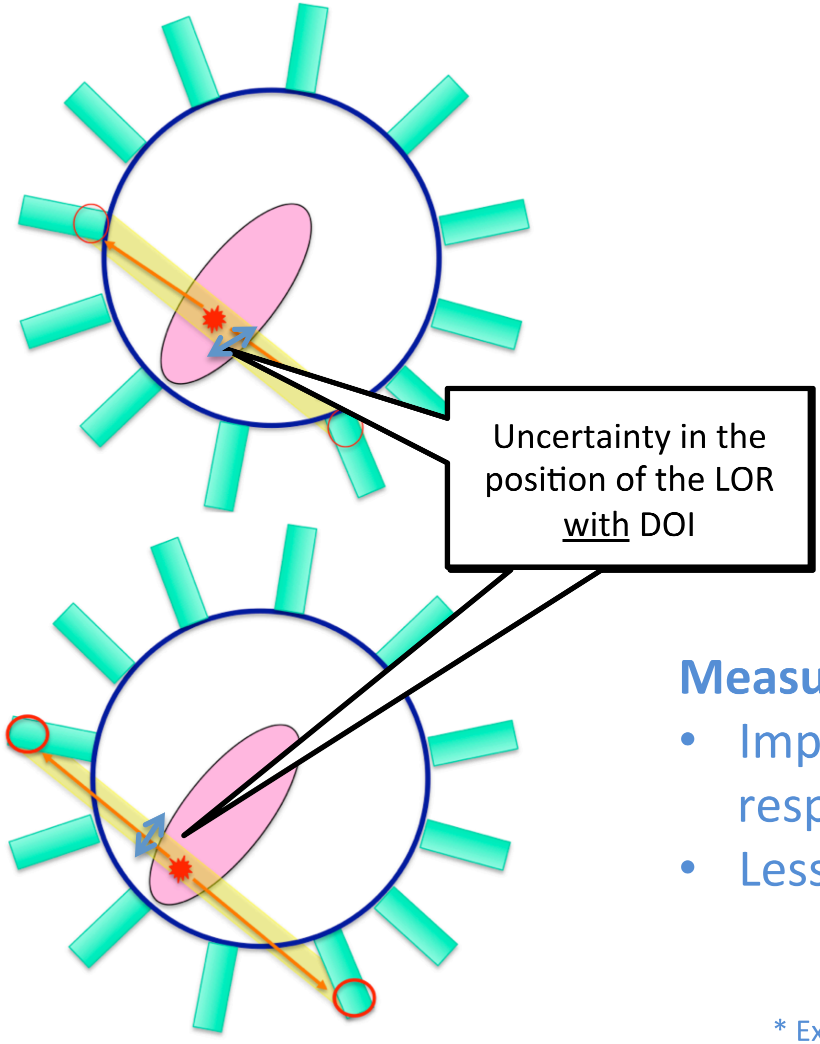
Depth of Interaction (DOI)

No DOI

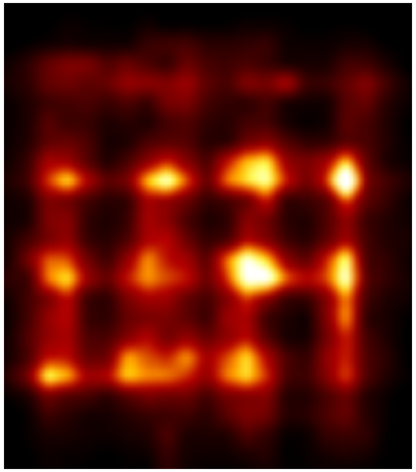


Uncertainty in the position of the LOR <u>without</u> DOI

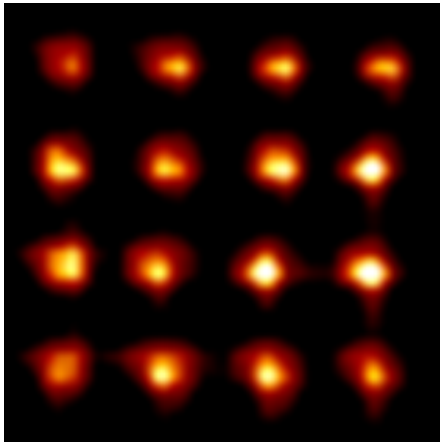
Benefit of Depth of Interaction (DOI) information



Uncertainty in the position of the LOR with DOI



*Without DOI: increased parallax effect



*With DOI

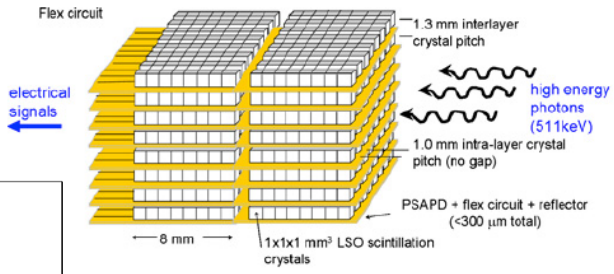
Measurement of DOI improves the spatial resolution:

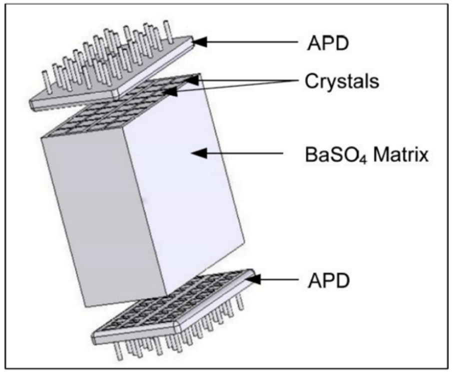
- Improved precision of the position of the line-of-response (LOR) and thus the localisation of events
- Less blurring

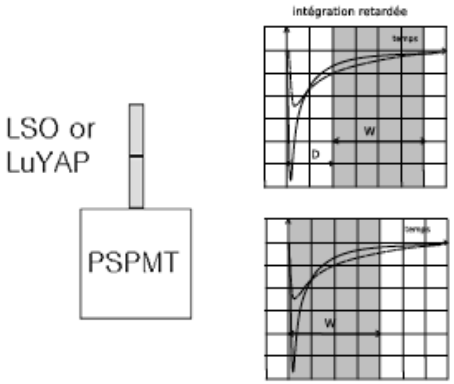
* Example ClearPEM (1mm Na-22 source moved along a grid with 5mm pitch)

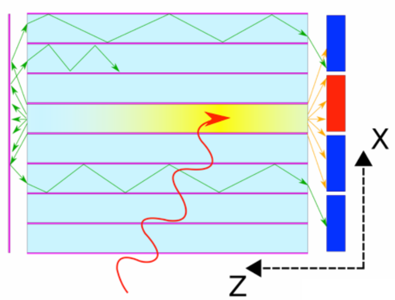
Methods for DOI determination

- Independent readout of multiple crystal layers
    - Excellent DOI resolution
    - System complexity/cost
- Double side readout
    - Very good DOI resolution
    - System complexity
- Pulse shape discrimination
    - DOI with single side readout
    - Degraded energy resolution
- Light sharing
    - DOI with single side readout
    - Degraded timing resolution
- Monolithic scintillators
    - Doi with single side readout
    - Excellent resolution
    - Complicated calibration/algorithm
    - Degraded performance near edges

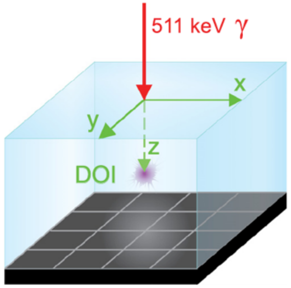








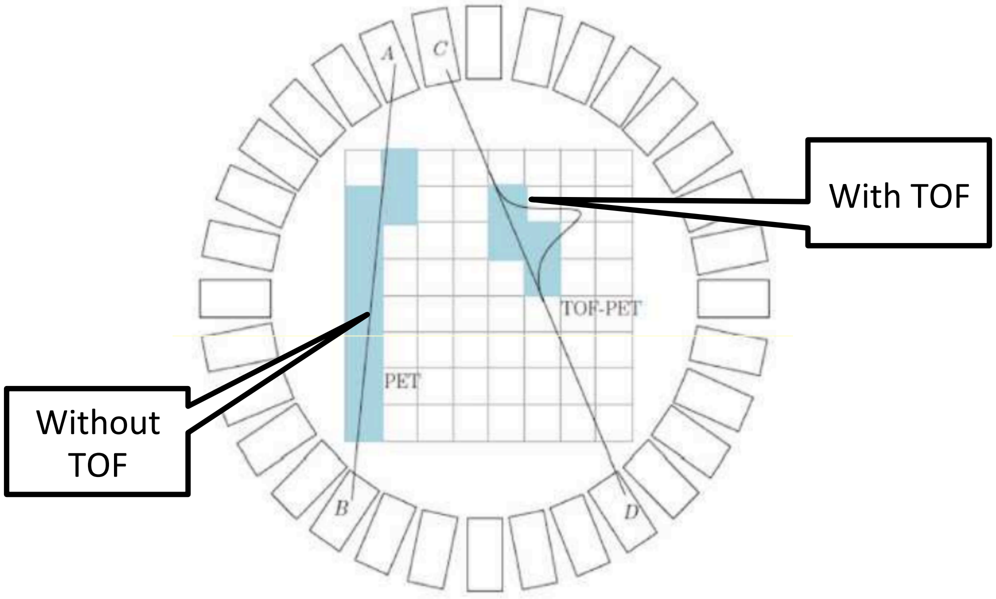
M. Pizzichemi et al., IEEE N



B. J. Peet et al., J. Nucl. Med. 2015, 56(5) 602

Courtesy M. Pizzechemi

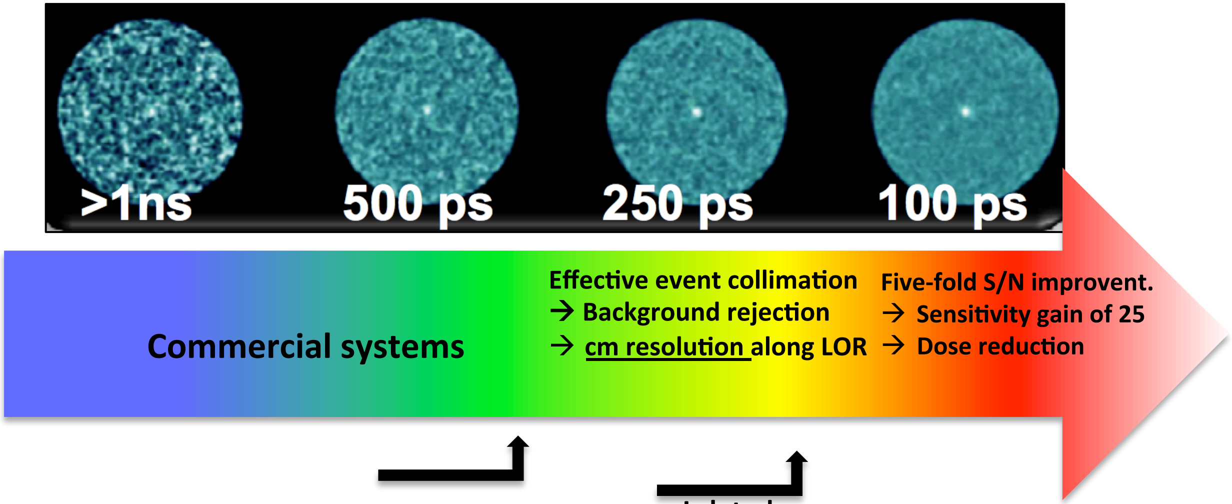
Time Of Flight (TOF)



Compute the difference in **time of arrival** of gamma rays on detectors:

- Improved event localization along the LORs $$\Delta x = c\frac{\boxed{\Delta t}}{2}$$
- Decreased noise correlation in overlapping LORs $$SNR_{TOF} \sim \sqrt{\frac{D}{\Delta x}} \cdot SNR_{CONV}$$

The Merits of Time of Flight in PET (TOF-PET):



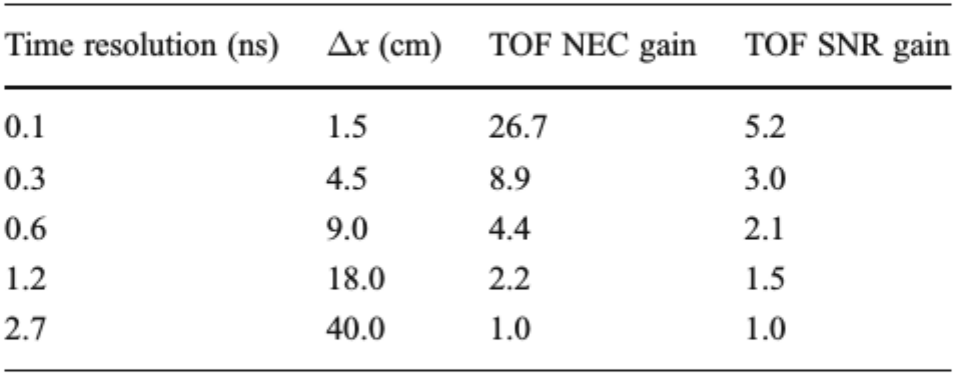
Commercial systems

Effective event collimation
→ Background rejection
→ <u>cm resolution </u>along LOR

Five-fold S/N improvent.
→ Sensitivity gain of 25
→ Dose reduction

Commercial TOFPET today
550ps (380ps)

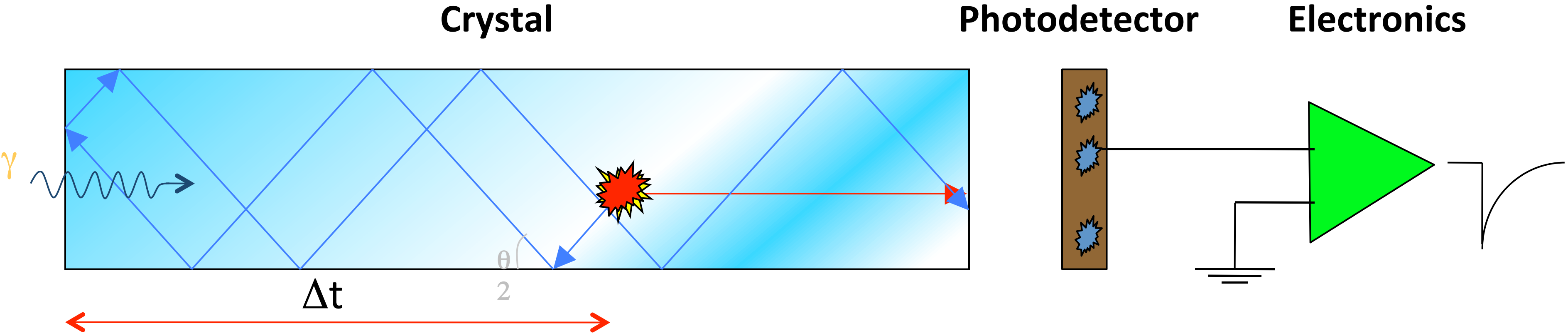
Lab today
150-200ps



Time resolution (ns)	Δx (cm)	TOF NEC gain	TOF SNR gain
0.1	1.5	26.7	5.2
0.3	4.5	8.9	3.0
0.6	9.0	4.4	2.1
1.2	18.0	2.2	1.5
2.7	40.0	1.0	1.0

M. Conti - Eur J Nucl Med Mol Imaging (2011) 38:1147–1157

Need to understand the photodetection Chain



$t_{kth\ pe} = \Delta t + t_{k'\ ph} + t_{transit} + t_{SPTR} + t_{TDC}$

Conversion depth	Scintillation process	Transit time jitter	Single photon time spread	TDC conversion time

Scintillator R & D

- Particule Interaction
- Light generation
- Light transport
- Light transfer
- Light collection

Photodetector R & D

- Reduce SPTR and DCR
- Increase fill factor (PDE)
- Digital SiPM
- MCP for PET & HEP

Electronics R & D

- TDC < 10ps bins
- Monolithic architecture
- High bandwidth
- Low noise
- Massive parallel data
- High number of channels

⇒ **Challenge: Understanding key factors of timing resolution**

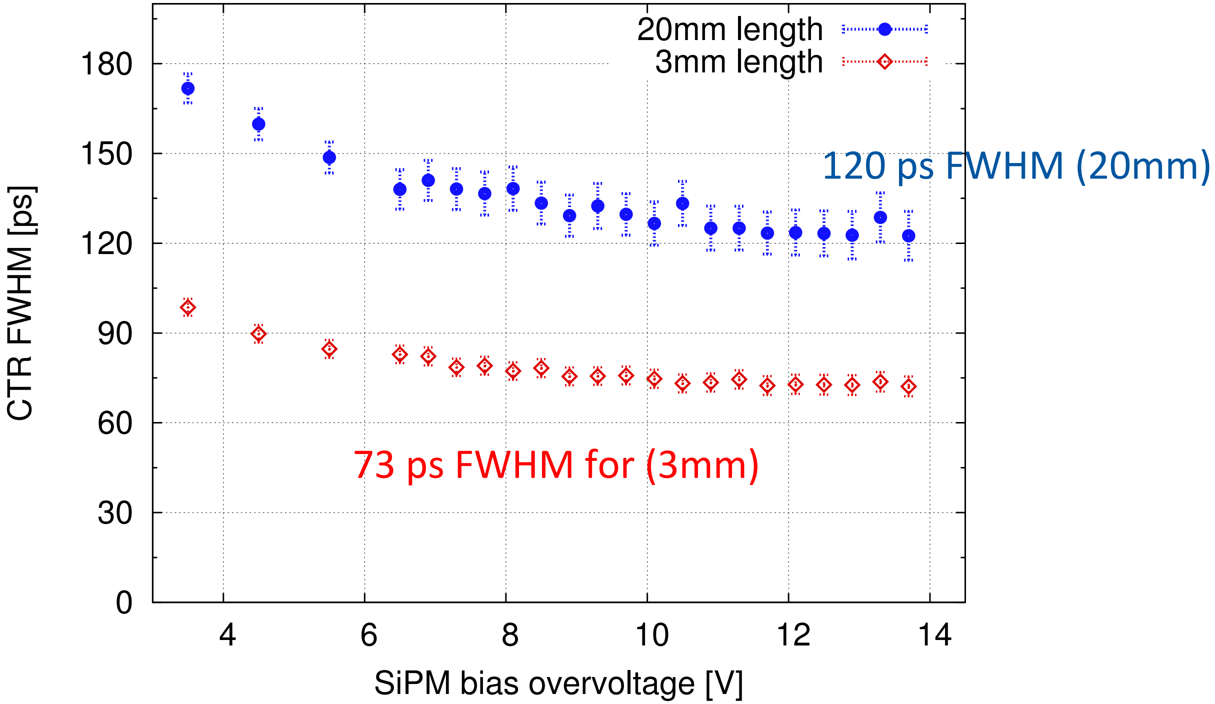
Proposing routes toward 10ps

FAST Action TD1401

Coincidence time resolution best recent results in lab

LSO:Ce:Ca crystal - FBK NUV-HD SiPMs

CTR results @511keV:



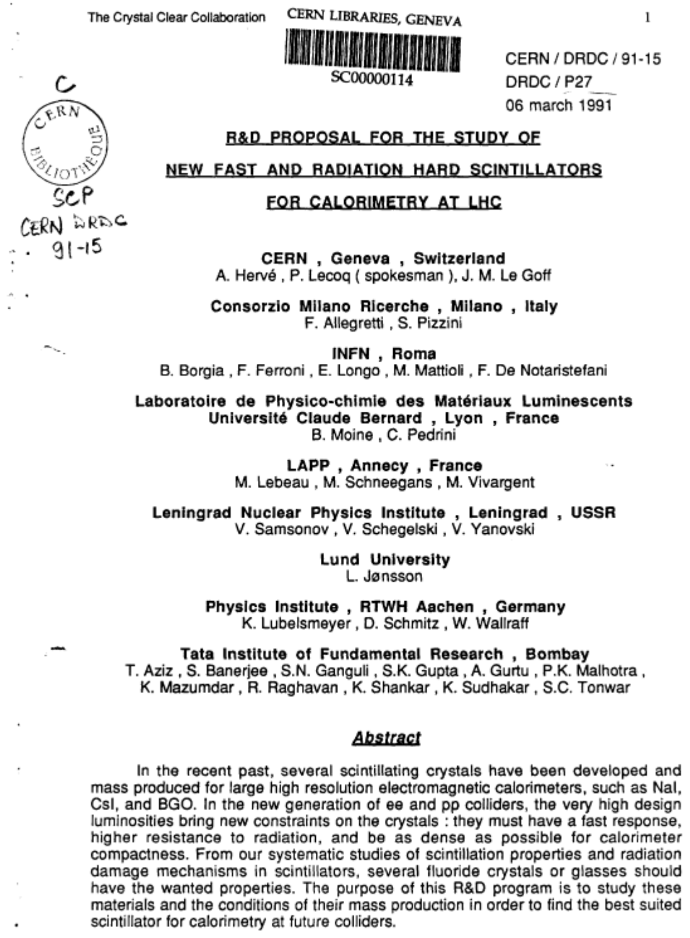
120 ps FWHM (20mm)

73 ps FWHM for (3mm)

S. Gundacker et al, JINST 11P08008

@ CERN

The Crystal Clear Collaboration was created in 1991
initially as part of an R&D (RD18) program for the LHC to study new scintillators for electromagnetic calorimeters.



CERN / DRDC / 91-15
DRDC / P27
06 march 1991

R&D PROPOSAL FOR THE STUDY OF NEW FAST AND RADIATION HARD SCINTILLATORS FOR CALORIMETRY AT LHC

CERN , Geneva , Switzerland
A. Hervé , P. Lecoq (spokesman), J. M. Le Goff

Consorzio Milano Ricerche , Milano , Italy
F. Allegretti , S. Pizzini

INFN , Roma
B. Borgia , F. Ferroni , E. Longo , M. Mattioli , F. De Notaristefani

Laboratoire de Physico-chimie des Matériaux Luminescents
Université Claude Bernard , Lyon , France
B. Moine , C. Pedrini

LAPP , Annecy , France
M. Lebeau , M. Schneegans , M. Vivargent

Leningrad Nuclear Physics Institute , Leningrad , USSR
V. Samsonov , V. Schegelski , V. Yanovski

Lund University
L. Jønsson

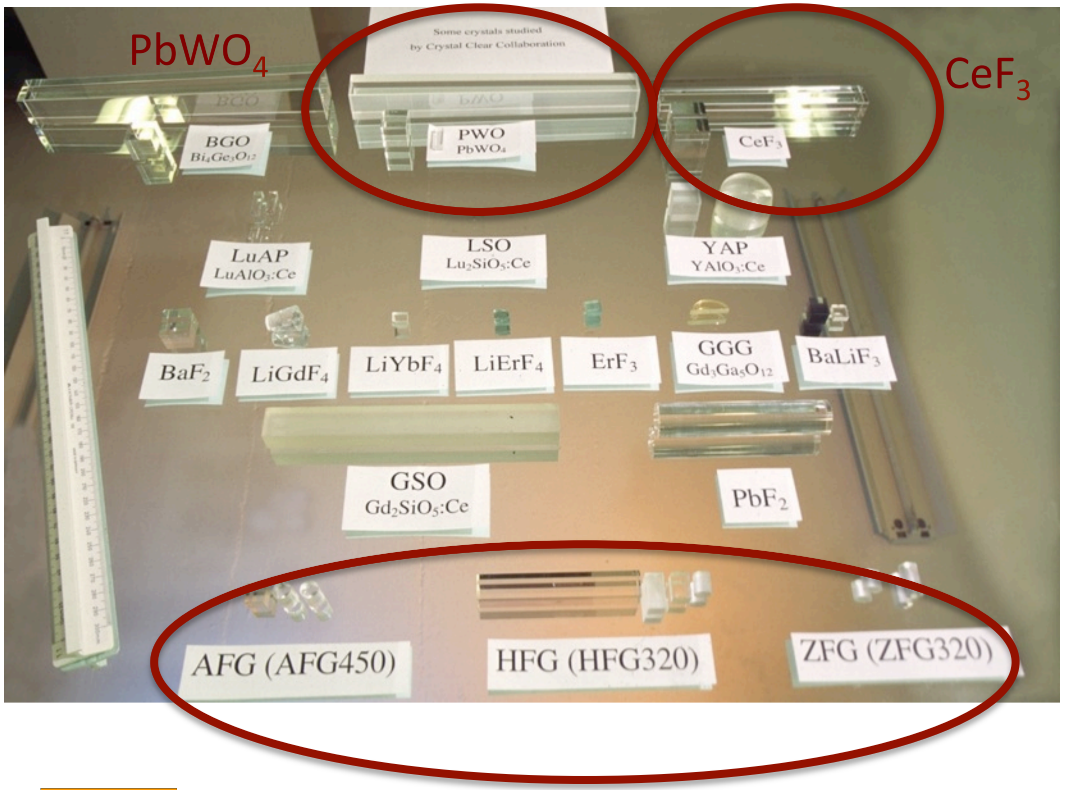
Physics Institute , RTWH Aachen , Germany
K. Lubelsmeyer , D. Schmitz , W. Wallraff

Tata Institute of Fundamental Research , Bombay
T. Aziz , S. Banerjee , S.N. Ganguli , S.K. Gupta , A. Gurtu , P.K. Malhotra ,
K. Mazumdar , R. Raghavan , K. Shankar , K. Sudhakar , S.C. Tonwar

Abstract

In the recent past, several scintillating crystals have been developed and mass produced for large high resolution electromagnetic calorimeters, such as NaI, CsI, and BGO. In the new generation of ee and pp colliders, the very high design luminosities bring new constraints on the crystals : they must have a fast response, higher resistance to radiation, and be as dense as possible for calorimeter compactness. From our systematic studies of scintillation properties and radiation damage mechanisms in scintillators, several fluoride crystals or glasses should have the wanted properties. The purpose of this R&D program is to study these materials and the conditions of their mass production in order to find the best suited scintillator for calorimetry at future colliders.

http://crystalclear.web.cern.ch/crystalclear/

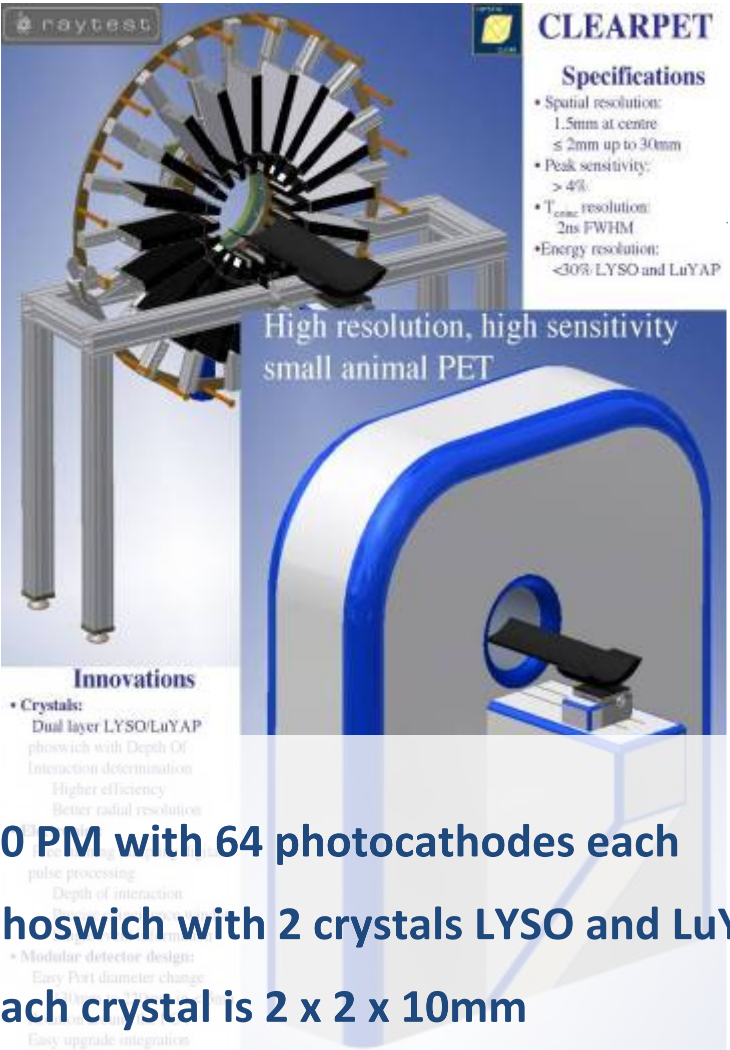


Heavy fluoride glasses

Developed PET systems in Crystal Clear Since 1995

- **Since 1995: ClearPET: PET from small animal**
  - 4 Prototypes inside the CCC collaboration
  - Licence to a company Raytest (Germany)
  - Development ongoing in CPPM in Marseille & in Aachen
- **Since 2001: ClearPEM: PET dedicated to breast imaging**
  - 2 Prototypes installed in hospital for clinical tests
    - 1 in Coimbra
    - 1 in Marseille Hopital Nord -> San Gerardo hospital Milano
    - 1 start-up Petsys has been created in Portugal
  - New development on going to improve modules (KT Fund)
- **Since 2010: EndoTOFPET-US: endoscopic PET for pancreas and prostatic cancer**
  - European FP7 projects with 3 Hospitals as partners out of 11partners
- **2009-2013: Brain PET**
- **Since 2013: PhenoPET**

Clear PET : small animal PET



CLEARPET

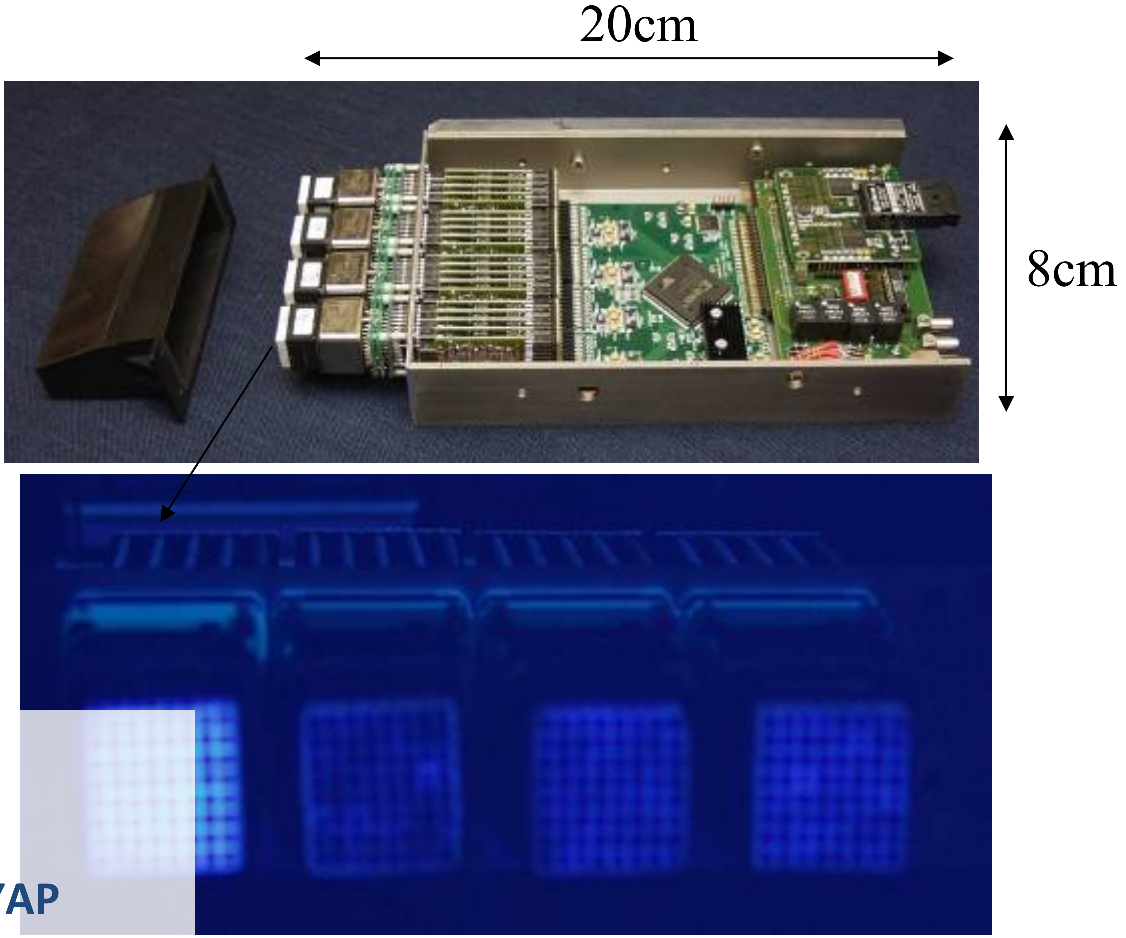
Specifications

- Spatial resolution:
  1.5mm at centre
  ≤ 2mm up to 30mm
- Peak sensitivity:
  > 4%
- T_{coinc} resolution:
  2ns FWHM
- Energy resolution:
  <30% LYSO and LuYAP

High resolution, high sensitivity small animal PET

Innovations

- **Crystals:**
  Dual layer LYSO/LuYAP
  phoswich with Depth Of
  Interaction determination
  Higher efficiency
  Better radial resolution
- pulse processing
  Depth of interaction
- Modular detector design:
  Easy Port diameter change
  Easy upgrade integration



80 PM with 64 photocathodes each

phoswich with 2 crystals LYSO and LuYAP

each crystal is 2 x 2 x 10mm

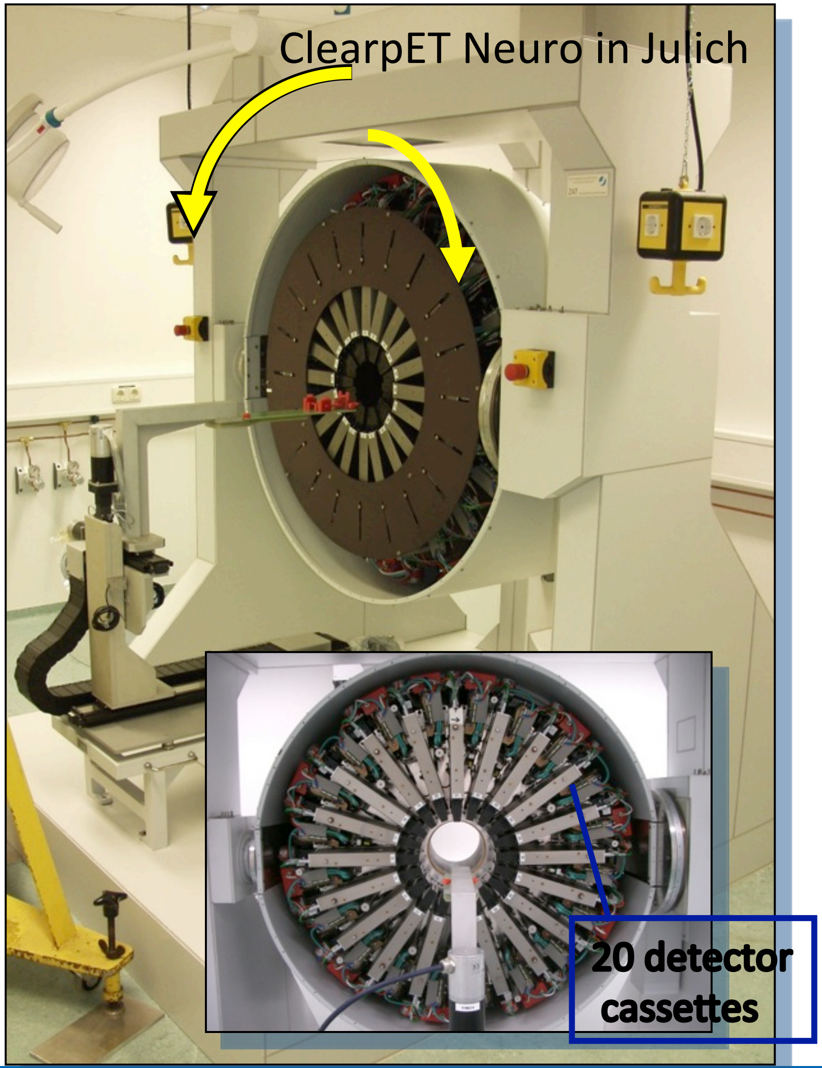
Spatial resolution 1.5 mm at centre

K. Ziemons et al., IEEE NSS/MIC conference record 2003
E. Auffray et al, (NIMA) (2004) 171
K. Ziemons et al, NIMA 537 (2005) 307

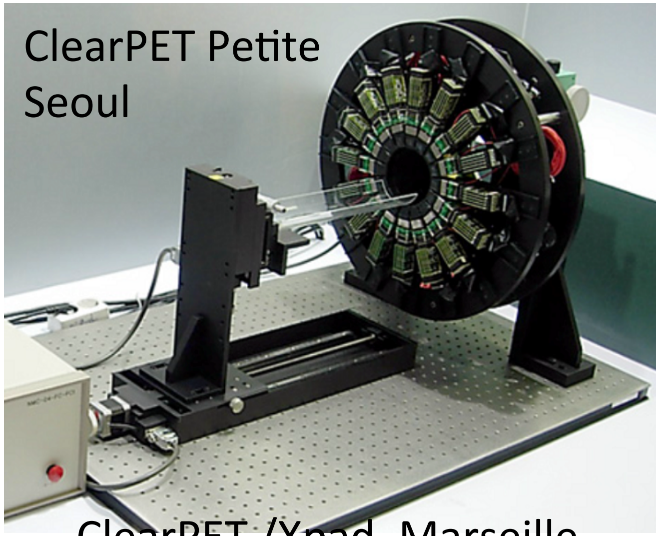
Clear PET : Several prototypes built in CCC

Brussels, Lyon, Julich: ClearPET Neuro, PlantTIs, Ciemat, Lausanne=> CPPM ClearPET/Xpad

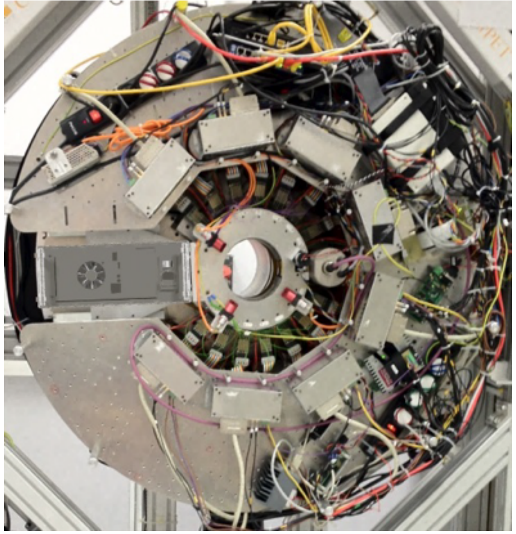
Seoul: ClearPET Petite


ClearpET Neuro in Julich

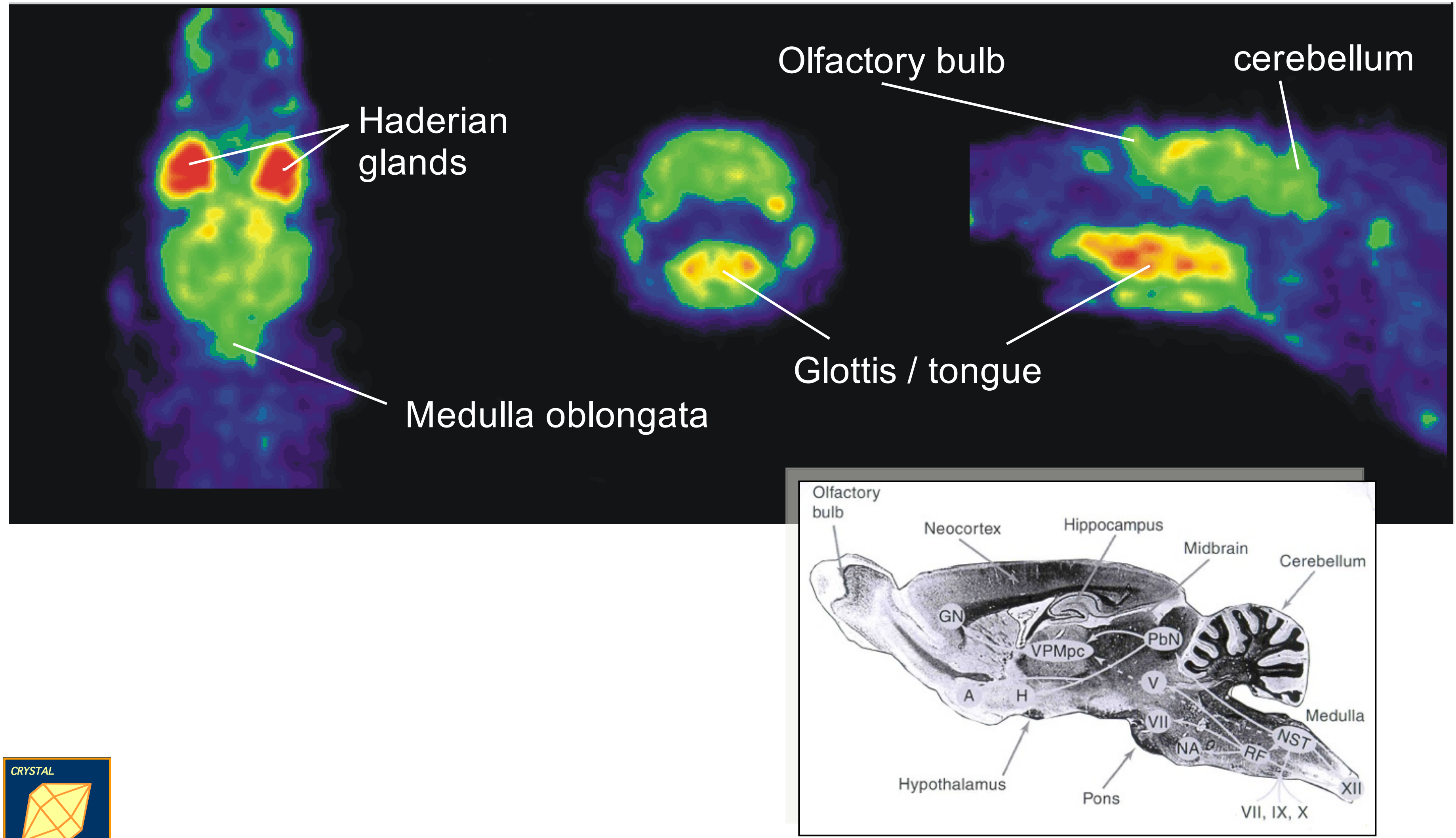
20 detector cassettes


ClearPET Petite Seoul

ClearPET /Xpad, Marseille

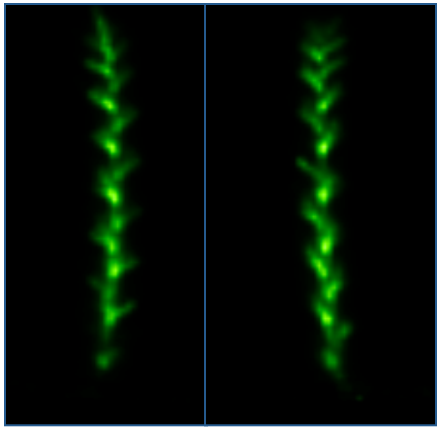


Rat Image with ClearPET Neuro



ClearPET Scanner PlanTIS in Julich, a PET scanner for Plants

Transfer of PET development from health into environmental research.
Investigation of carbon transport within plants using $^{11}CO_2$ as tracer

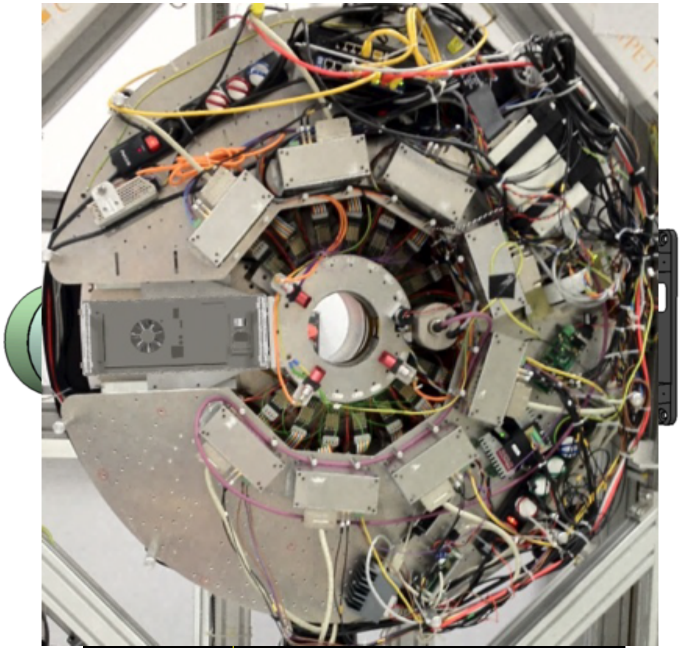


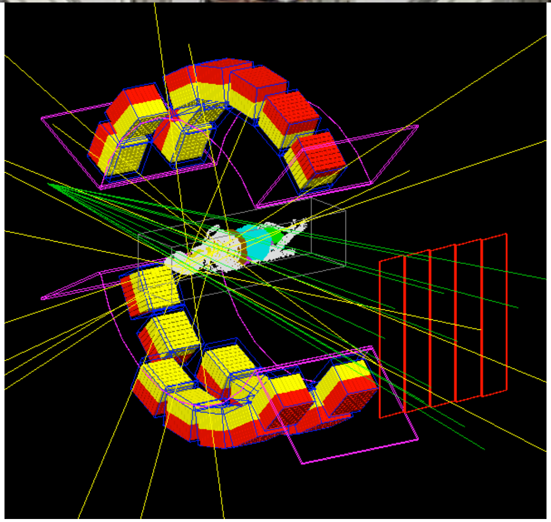
Solute transport in plants (spica)

^{11}C-distribution in a sugar beet

M. Streun et al, IEEE NSS/MIC Conference record 2007

ClearPET/Xpad: A Simultaneous PET/CT developped in Marseilles





First simultaneous PET/CT scans of mice have been presented by M. Hamonet et al. at the 2015 IEEE NSS/MIC conference

M. Khoverdi et al, IEEE NSS/MIC Conference record 2007

Clear PEM : PET for Mammography

1/8 woman will develop breast cancer during her life
2nd cancer related cause of death for women

Conventional detection techniques (X-ray mammography) are very inefficient, especially in dense breasts (common in women aged under 50 years).
With PEM (Positron Emission Mammography), possibility to detect small tumors (<2mm) and to be able to detect tumors in dense breasts.

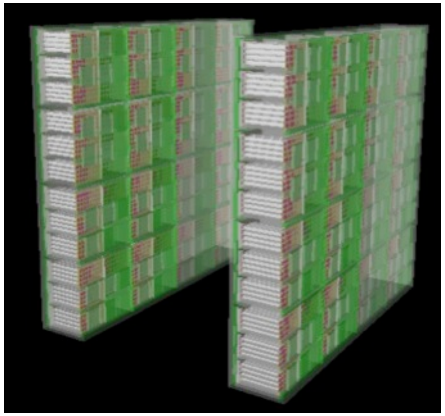
X-ray Mammogramm

Positron Emission Mammogramm

The X-Ray mammography picture reveals nothing special, whereas the tumor is clearly visible in the PEM case.

In 2001: CCC launched the ClearPEM project: A dedicated PET for breast imaging
2 prototypes built: 1 in Coimbra (Pt), 1 in Monza (It) for clinical trials

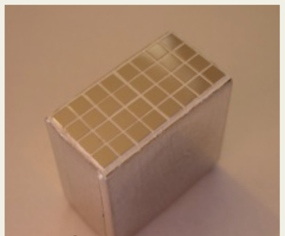
ClearPEM & ClearpEM sonic



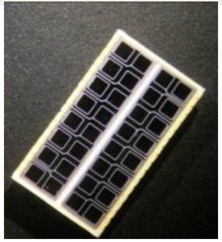
1 Plate 17,3x15,5x3cm =
16 SuperModules =
3072 crystals

Technology :

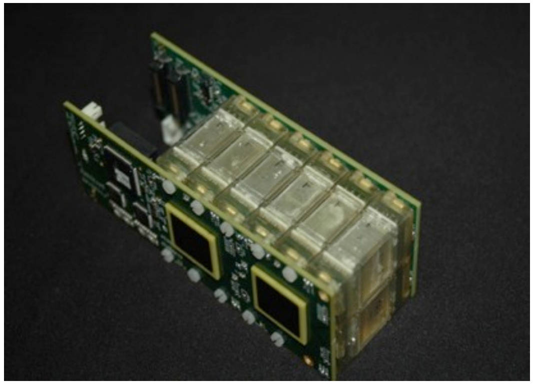
- 2 plates
- 6144 LYSO:Ce crystals in 192 matrices
- Readout in both end with APD arrays
- Dedicated ASICs for fast readout



LYSO/$BaSO_4$ Matrice



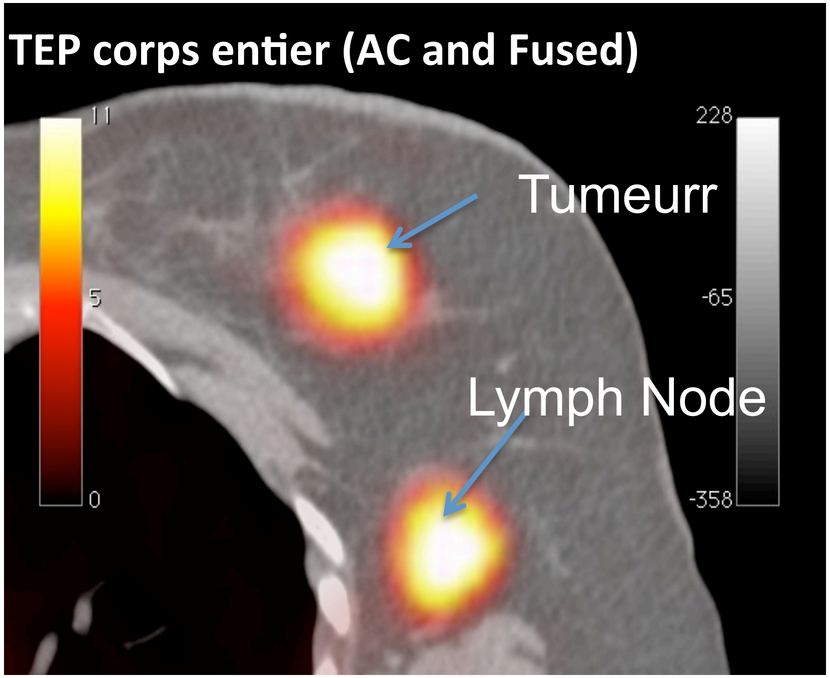
APD array

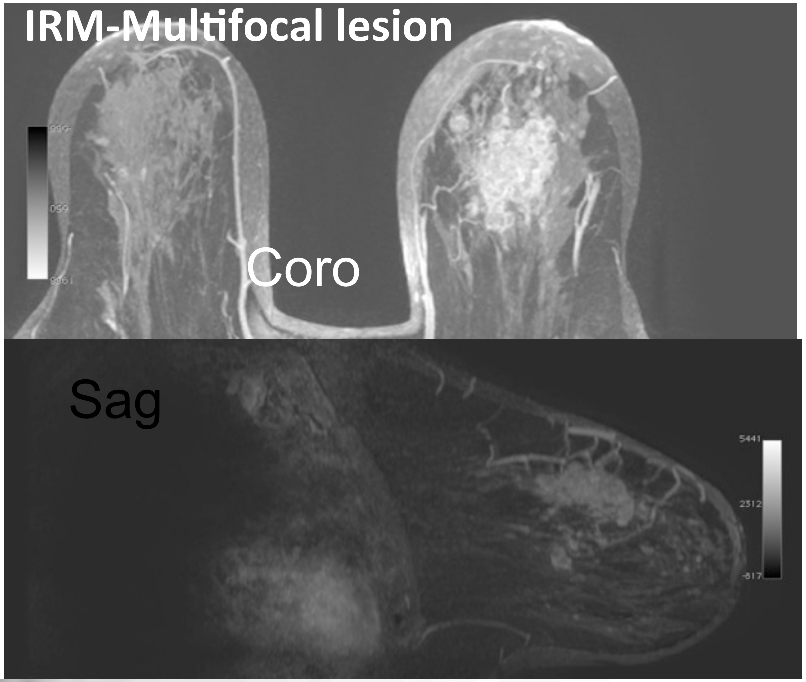


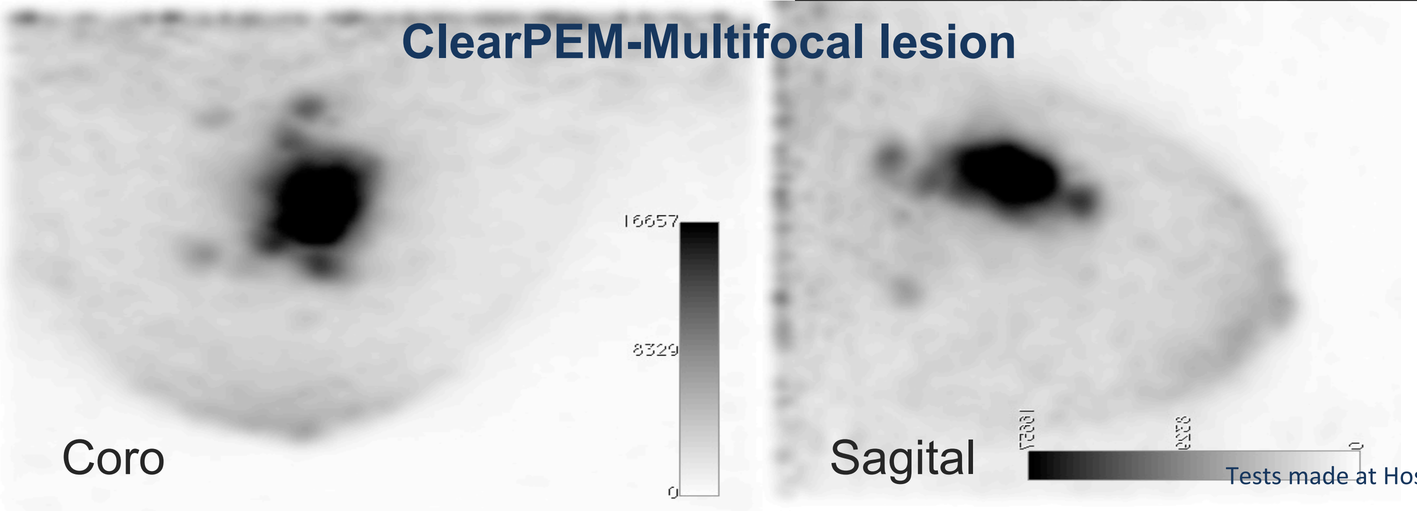
P. Lecoq, J. Varela. NIM. A 486 (2002) 1–6.
J Varela *et al.* NIMA. *A* **571** (2007) 81.
B. Frisch, CERN courrier Article, July.August2013

ClearPEM was the first PET using APDs !
Transfert from CMS detector

First images with ClearPEM


TEP corps entier (AC and Fused)


IRM-Multifocal lesion


ClearPEM-Multifocal lesion

Tests made at Hospital Nord, Marseilles

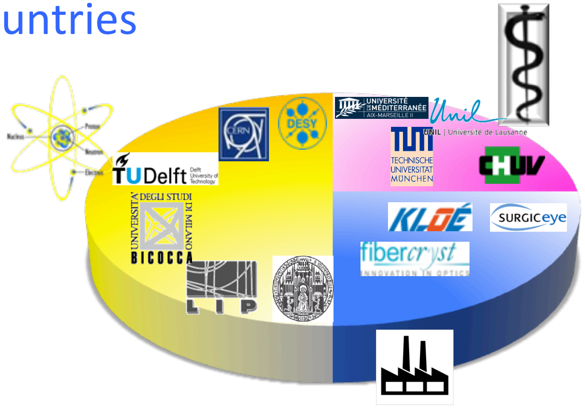
FP7 projet : EndoTOFPET-US 2011-2015

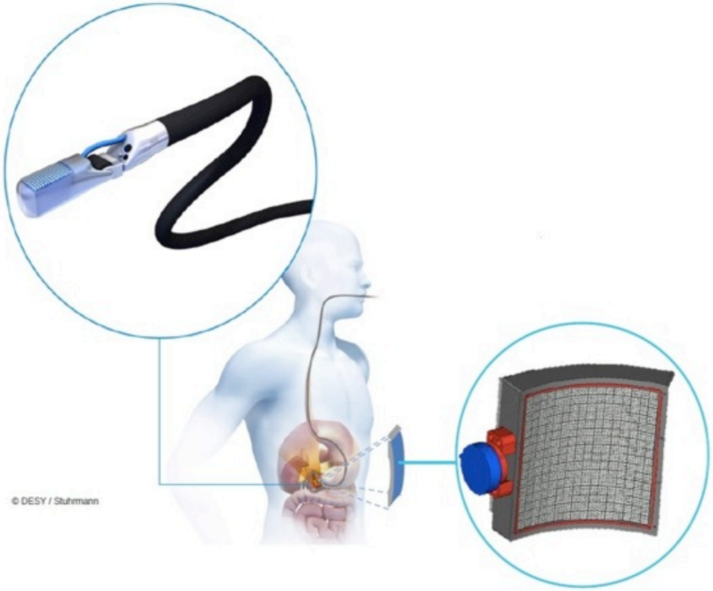
12 partners:

3 Hopitals, 3 compagnies, 6 researches institutes in 6 european countries

To develop:

- **Ultrasound PET for diagnostic of pancreas & prostate cancer**
- **specific biomarkers**





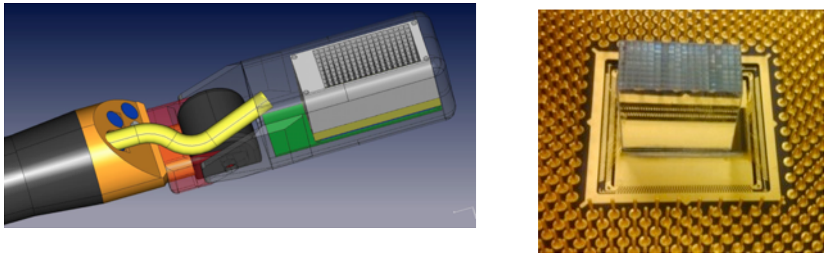
Aim
Spatial Resolution <1mm
Time resolution <200ps
for early detection

(see for instance:
talks P. Lecoq ICTR2012, E. Auffray ICTR2014, SCINT2015)

ENDO TOFPET US
Endoscopic TOFPET & Ultrasound

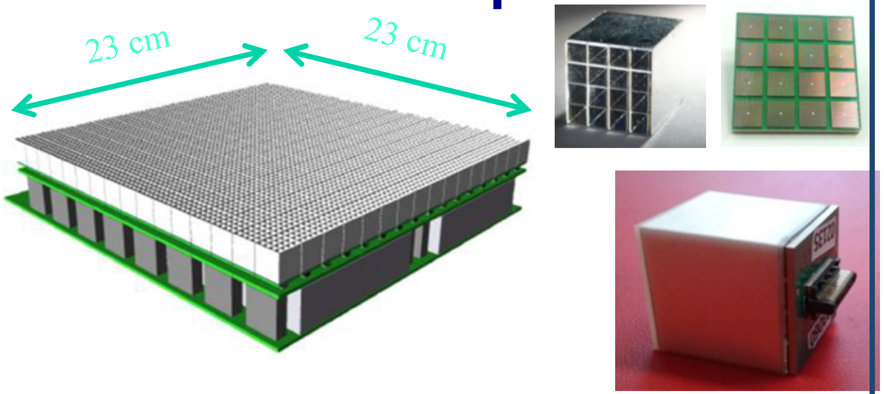
Detector design

Internal probe



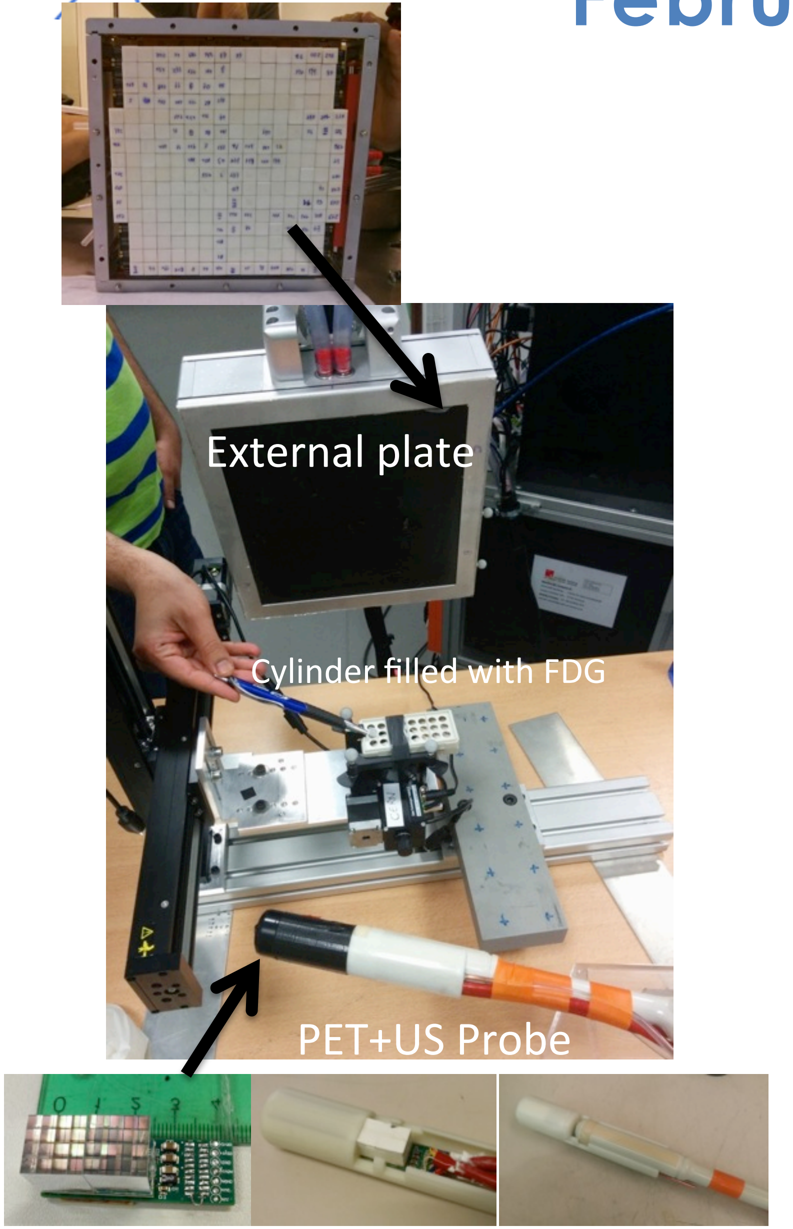
- **Two different versions:**
  - Pancreatic probe diameter **15 mm**
  - Prostatic probe diameter **23 mm**
- Clamped on commercial **US endoscope**
- 1 or 2 matrices of 9x18 **LYSO:Ce** scintillators (Proteus)
  - Crystal size 0.71 x 0.71 x 15 mm^3
  - Crystal pitch 800 µm
  - Coating: ESR reflector by 3M
- **162** or **324** detector channels
- Custom d**SiPM** developed by our consortium (Delft)
- EM **tracking** sensor and **water cooling** to control temperature

External plate

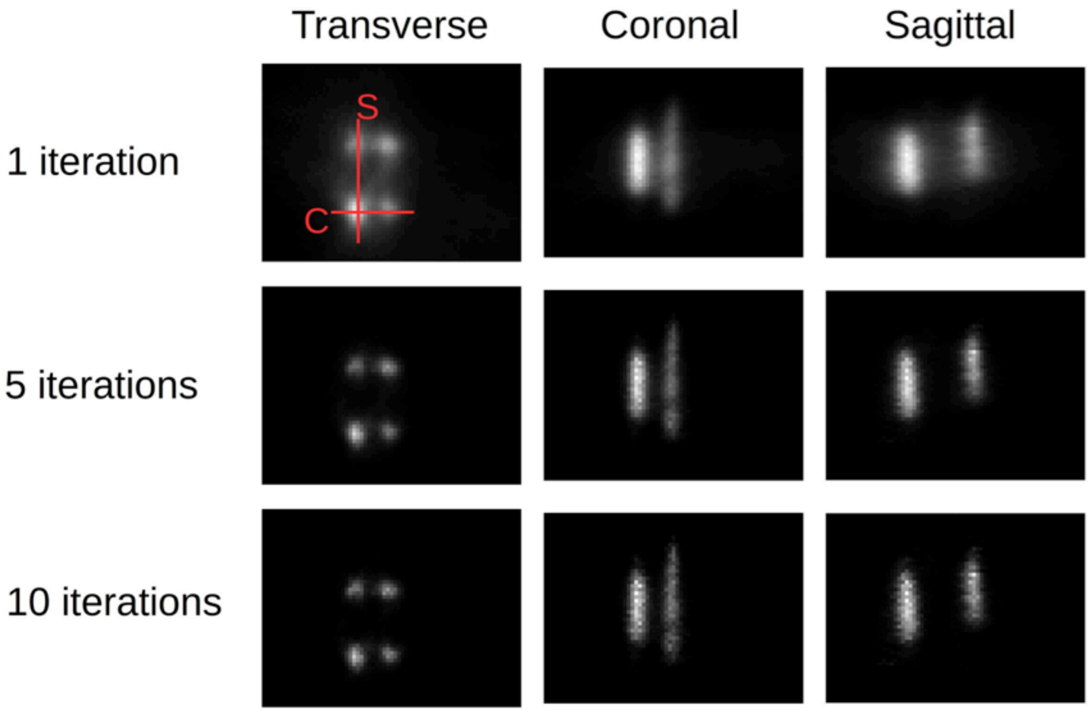


- **256 matrices of 4x4 LYSO:Ce scintillators (CPI) coupled to discrete silicon-through-via (TSV) MPPCs from Hamamatsu**
- For prostate
  - Crystal size 3.5 x 3.5 x 15 mm^3
  - Crystal pitch 3.6 mm
  - Coating: ESR reflector by 3M
  - MPPCs S12643-050CN pitch 3.6mm
- For pancreas
  - Crystal size 3.1 x 3.1 x 15 mm^3
  - Crystal pitch 3.2 mm
  - Coating: ESR reflector by 3M
  - MPPCs S12642-0404PB-50 pitch 3.2mm

1st tests in CERIMED Marseille February- April2015

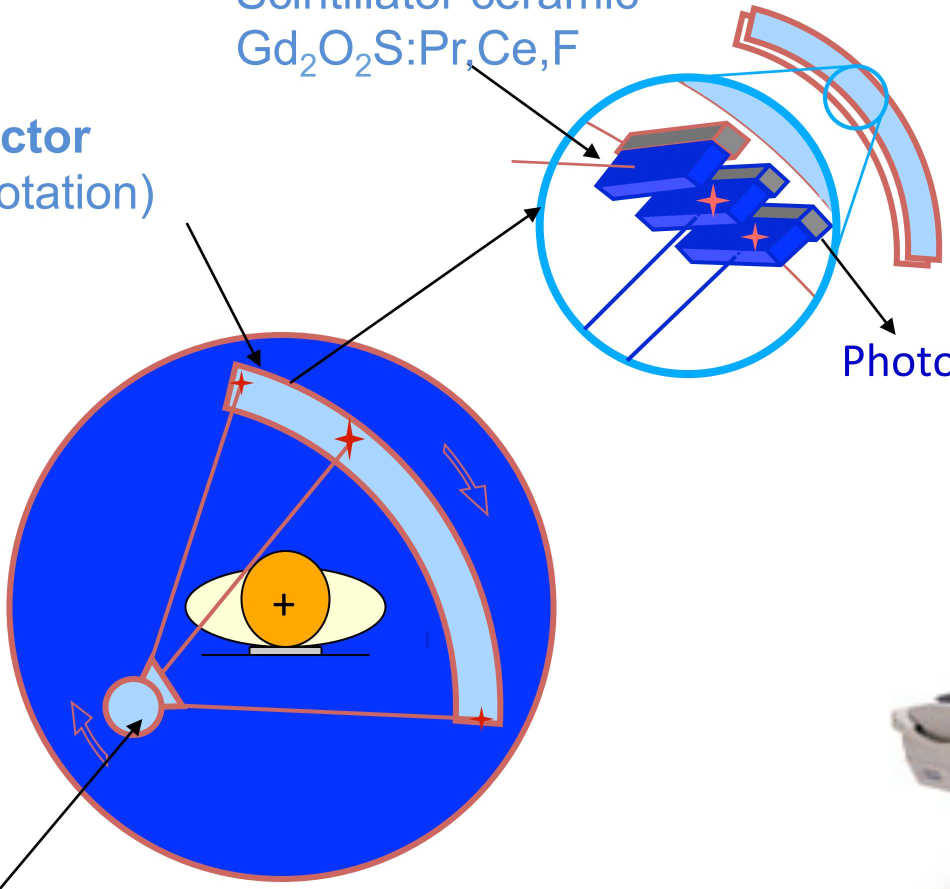


Preliminary images



Others medical imaging applications

Xrays CT



Scintillator ceramic
Gd_2O_2S:Pr,Ce,F

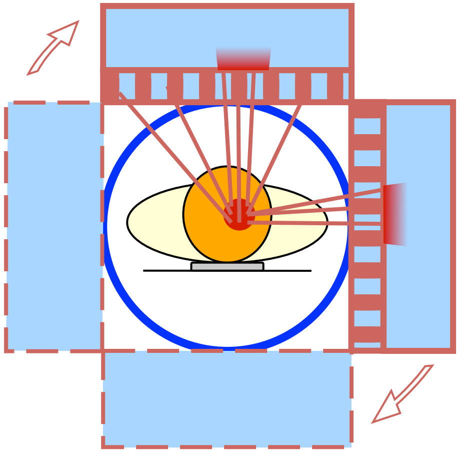
Detector
(en rotation)

Photodiode

Source RX
(en rotation)

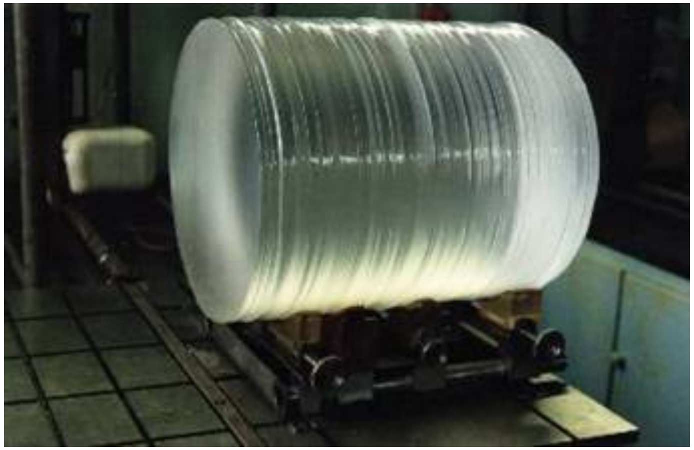
X-ray
Computed
Tomography

Single Photon Emission: SPECT



- SPECT requires large size crystals
- Most commonly used scintillator: NaI:Tl
  - inexpensive, large size
  - gamma m. f. p. ≈ 4 mm. @ 140 keV
  - large light yield
  - moderately good timing; τ= 230 nm

Marconi/Picker IRIX system for SPECT and PET



NaI:Tl single crystal

∅520 mm, mass > 550 kg

Institute of Single Crystals Kharkhov, Ukraine

Conclusion

- Scintillators are used in a large number of scientific and industrial domains
- But no ideal scintillator

  => Need for new idea & developement

- Fascinating field of research !!

Announcement

School on scintillators on their applications, Sept 14-17, 2017

&

14th International Conference on Scintillating materials and their applications

Chamonix, France, Sept 18-22, 2017