Crystal Clear Collaboration
25 years of R&D on scintillating materials and their applications

E. Auffray, CCC Spokesperson
CERN, EP-CMX
An international collaboration active on research and development on inorganic scintillating materials for novel ionizing radiation detectors, for high-energy physics, medical imaging and industrial applications.
History

• Initiated @CERN in 1990 by P. Lecoq
• Approved in April 1991 by DRDC @ CERN for R&D for future LHC detectors
• Initial Aim: develop scintillating materials suitable for use at the future LHC collider.
Today

CCC: 29 institutes all over the world, mainly in Europe

With broad expertise in:
scintillator, crystal growth, photo-detection, electronics,
detector design & realization for many applications
Crystal Clear Collaboration
RD18 experiment

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

Main Activities:

• Generic activities on inorganic scintillators
  • Scintillation mechanisms, timing properties, radiation hardness, crystal production
• Generic activities on photodetectors, electronic readout chain
• Detector Development for several applications,
  • in particular HEP and medical imaging
CCC Community

Community of experts

Solid state physics
Luminescence
Crystallography
Instrumentation

29 Institutes
CCC
>100 Physicists

Scintillator conferences
Crystal2000 (Chamonix 1992)
San Francisco 1994
Scint95 (Delft)
Scint97 (Shanghai)
Scint99 (Moscow)
Scint2001 (Chamonix)
Scint2003 (Valencia)
Scint2005 (Krimé)
Scint2007 (Wake forest)
Scint2009 (Jeju,)
Scint2011 (Giesen)
Scint2013 (Shanghai)
Scint2015 (Berkeley)
Scint2017 (Chamonix)

Industry partners

Crystal growth
Companies

Photodetector
Companies

Medical devices
Integration, Production

Communities of users

High Energy Physics
LCMS, Alice, Belle, BaBar
L3, Panda, FCC etc..

Medical Imaging

Industrial applications

Security systems
The Crystal Clear Collaboration

Initial Objective:
Develop scintillating materials suitable for use at the future LHC collider
From 1991 to 1994: R&D on several types of scintillator

Heavy fluoride glasses

- \( \text{PbWO}_4 \)
- \( \text{CeF}_3 \)
R&D on new scintillators for LHC from 1991 to 1994

<table>
<thead>
<tr>
<th></th>
<th>Before 1990</th>
<th>Developed for LHC Crystal Clear/CMS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>NaI(Tl)</td>
<td>CsI(Tl)</td>
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<tr>
<td>BGO Bi&lt;sub&gt;4&lt;/sub&gt;Ge&lt;sub&gt;3&lt;/sub&gt;O&lt;sub&gt;12&lt;/sub&gt;</td>
<td></td>
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<tr>
<td>Xo [cm]</td>
<td>2.59</td>
<td>1.86</td>
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<tr>
<td>[g/cm&lt;sup&gt;3&lt;/sup&gt;]</td>
<td>3.67</td>
<td>4.53</td>
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<tr>
<td>[ns]</td>
<td>230</td>
<td>1050</td>
</tr>
<tr>
<td>[nm]</td>
<td>415</td>
<td>550</td>
</tr>
<tr>
<td>Ref index</td>
<td>1.85</td>
<td>1.80</td>
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<tr>
<td>n@&lt;sub&gt;max&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LY [%NaI]</td>
<td>100</td>
<td>85</td>
</tr>
</tbody>
</table>
R&D on CeF$_3$

- Understanding of Ce$^{3+}$ scintillation mechanisms
  \(\Rightarrow\) The existence of regular (Ce$_{\text{reg}}$) and perturbed (Ce$_{\text{pert}}$)

Photoluminescence
(exc = 250 nm)

\(\Rightarrow\) Quenching per Ce concentration
  \(\Rightarrow\) very short decay time

Scintillation decay of CeF$_3$
(exc. 22Na, 511 keV)

Many CCC papers
E. Auffray, PhD thesis 1995
M. Nikl (review paper), phys.stat.sol. (a) 178, 595-620 (2000).
Achievements on CeF$_3$

In 1989: 1 crystal of 1 cm$^3$ => in 1993 large crystals (length > 20cm) produced by several companies

Improvement of LY of a factor 2

Excellent radiation hardness
R&D on heavy scintillating glasses

Study of several types of heavy glasses

pure and 5%Ce doped glasses

Extensive work with Le verre fluoré, Rennes, France

AFG became coloured at Ce doping (AFG413, d=1mm)

ZFG did not scintillate

HFG selected to study possible improvements

Main results on HFG glasses

Transmission

Photoluminescence spectra

Decay time

Radiation hardness

Understanding of the scintillation process chain

Case of Ce\textsuperscript{3+} doping

- Inelastic electron-electron scattering
- Thermalization of electrons
- Capture of electrons and holes by traps, selftrapping, etc.
  \[ e + c^+ \rightarrow c^0 + \text{ph} \]
- Interaction of excitations
  \[ c^* + c^* \rightarrow c^* + \text{ph} \]
  \[ c^* \rightarrow c + h\nu \]

- Threshold of e-e scattering
- Auger threshold
- Thermalization of holes
- Emission
  \[ c^* + c^* \rightarrow c^* + \text{ph} \]
  \[ c^* \rightarrow c + h\nu \]

A. Vasiliev, Proceedings of The SCINT99 conference, Moscow, Faculty of Physics, Moscow State University, 2000, p. 43-52
4 first papers on PWO for High Energy Physics applications at first conference on inorganic scintillators (SCINT conf)
Main results on PWO radiation hardness improvement

Radiation damage mainly due to host structure defects:

Primary defects:
- Lead vacancy $V_k$(Pb)
- Oxygen vacancy $V(O)$

Secondary defects created for charge compensation for $V_k$(Pb): $O^- + h, Pb^{2+} + h$
for $V(O)$: $F$ and $F^+$ centres

Optimisation of growth conditions, stoichiometry

A. Annenkov et al., Rad. Measurements Vol29, p27
E. Auffray et al, proceedings of SCINT2007

Compensation by doping: Y, La, Lu, Nb, Sb
optimum codoping Y-Nb

M. Kobayashi et al., NIM A404 (1998) 149 / X. Qu et al., NIM 486 (2002) 102
P. Lecoq et al., NIM A402 (1998) p75

Induced absorption spectra for PWO crystals with different doping
From 1991 to 1994:

- Birth of the “scintillator community”
- Many progress in the understanding of the properties of 3 materials:
  - CeF$_3$ had very good scintillation and radiation hardness properties but no capability for large production
  - Heavy Glasses had good scintillation properties, low cost but were not enough radiation hard for LHC

=> In 1994: Choice of PWO by CMS for the electromagnetic calorimeter
Success of PWO

2 detectors based on PWO crystals installed in LHC (CMS electromagnetic calorimeter, ALICE PHOS)

1 detector based on PWO for Panda experiment at FAIR accelerator at GSI, Germany
From R&D to Production
1994 to 1998

Optical properties improvement

Radiation hardness improvement

Transmission improvement

Delivery of the first 100 PWO Crystals
Sept 98

Front irradiation 0.15Gy/h preproduction crystals

Specification: -6%
CMS ECAL: Higgs bosons

75848 PWO Crystals: 10 years of construction

=> Higgs Discovery in 2012

Installation in CMS in 2007 & 2008

CMS | $\sqrt{s} = 7$ TeV, $L = 5.1$ fb$^{-1}$ | $\sqrt{s} = 8$ TeV, $L = 5.3$ fb$^{-1}$

Unweighted

$S/(S+B)$ Weighted Events / 1.5 GeV

Events / 1.5 GeV

0

110 120 130 140 150

$m_{\gamma\gamma}$ (GeV)

$\pm 1 \sigma$

$\pm 2 \sigma$

Data

S+B Fit

B Fit Component
Study of other scintillating crystals
1995-2016

Perovskites:  LuAP:Ce, LuYAP:Ce, YAP:Ce, LuAP:Pr, LaLuO3:Ce

Garnets:  LuAG:Ce, LuYAG:Ce, LuAG:Pr, YAG:Ce, LuAG:Ce,Ca, LuAG:Pr,Ca, LuAG: Ce, Mg, YAG:Ce,Mg
Recently GGAG:Ce, GGAG:Ce,Ca , GGAG:Ce, Mg

Orthosilicate:  LSO:Ce, LYSO:Ce

Other:  Yb-doped oxides for solar neutrino spectroscopy

Perovskite substrates for thin scintillating films

See for instance
C. Dujardin et al, Proceedings of SCINT'95, Aug 28 -Sept 1, 1995, Delft,
J. Chval et al., NIM A 443 (2000): 331-34
C. Kuntner et al., NIM A 493 (2002) 13-18
M. Lucchini,et al., IEEE TNS 63 (2) 586-590 ,
M. Lucchini et al, NIM A Volume 816, pp 176–183,
M. Nikl et al., Adv. Optical Mater. 2015, 3, 463–481
E. Auffray et al., IEEE Trans. Nucl. Sci., vol. 60, pp. 3163(3171
Crystal properties of some studied scintillating crystals

<table>
<thead>
<tr>
<th></th>
<th>LuAlO$_3$·Ce (LuYAP)</th>
<th>Lu$<em>{0.7}$Y$</em>{0.3}$AlO$_3$·Ce (LuYAP)</th>
<th>Lu$_3$Al$<em>5$O$</em>{12}$·Ce / Pr (LuAG)</th>
<th>Y$_3$Al$<em>5$O$</em>{12}$·Ce / Pr (YAG)</th>
<th>Gd$<em>3$Ga$</em>{5-x}$Al$<em>x$O$</em>{12}$·Ce (GGAG)</th>
<th>Lu$_2$SiO$_5$·Ce (LSO)</th>
</tr>
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<tbody>
<tr>
<td>density (g/cm$^3$)</td>
<td>8.3</td>
<td>7.4</td>
<td>6.73</td>
<td>4.57</td>
<td>6.63</td>
<td>7.4</td>
</tr>
<tr>
<td>$X_0$ (cm)</td>
<td>1.1</td>
<td>1.1</td>
<td>1.3</td>
<td>3.5 cm</td>
<td>1.59</td>
<td>1.1</td>
</tr>
<tr>
<td>Refraction index</td>
<td>1.94</td>
<td>1.94</td>
<td>1.84</td>
<td>1.83</td>
<td>1.85</td>
<td>1.82</td>
</tr>
<tr>
<td>$\Lambda_{\text{max}}$ (nm)</td>
<td>365</td>
<td>365</td>
<td>530/320,370</td>
<td>550/320,370</td>
<td>450</td>
<td>420</td>
</tr>
<tr>
<td>LY @ RT (ph/MeV)</td>
<td>10000</td>
<td>10000</td>
<td>24000/13000</td>
<td>35000/13000</td>
<td>48500</td>
<td>30000</td>
</tr>
<tr>
<td>decay time (ns)</td>
<td>18</td>
<td>25/200</td>
<td>60/20</td>
<td>70/20</td>
<td>58/300</td>
<td>40</td>
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</table>
LuAP/LuYAP development 1995-2005

Very good energy resolution Energy resolution 8.6 (± 0.4) % FWHM

LuYAP

Cs$^{137}$

Small non proportionality

>10000 pixels of 2x2x10mm$^2$ produced by BTCP for ClearPET (PET for small animal) prototypes

C. Kuntner et al., NIM A 493 (2002) 13-18
LuAG:Ce/YAG:Ce development 1995-2016

LY improvement

CCC groups : ILM, CERN, IPR, Prague 2009-2011

Many papers from CCC for instance
Radiation hardness of YAG/LuAG/GGAG material

From Crytur 1cm$^3$

Very Good radiation tolerance under gamma & proton

LuAG From Astharak (1x1x4cm$^3$)

GGAG from Prague (1cm$^3$)

M. Lucchini, et al., IEEE TNS 63 (2) 586-590, M. Lucchini et al, NIM A Volume 816, pp 176–183,
Study of Codoping Ce, X^{2+} in Garnet crystal

LuAG: Ce, Ca

LuAG: Ce, Mg

YAG: Ce, Mg

GGAG: Ce, Mg

Shorter decay time with codoping
=> Role of Ce^{4+}
=> Improvement of timing resolution from 540ps to 233ps in case of GAGG
=> Good radiation damage

Kamada et al, O-14-3 at SCINT2015
M. Lucchini et al, NIM A Volume 816, pp 176–183,
A. Petrosyan et al., Journal of Crystal Growth (2015), pp. 46-51
Study of fast timing detection

Why fast timing?

In HEP: Search for rare events implies high luminosity accelerators

→ Rate problems;
→ Pileup of >140 collision events per bunch crossing at High Luminosity-LHC;
→ Pileup mitigation via TOF requires TOF resolution < 50ps.

In PET imaging:

→ for rejecting background events (event collimation)
  (200ps TOF resolution: for a few cm along LOR)
→ for improving image S/N
  (100ps TOF resolution for x5 S/N improvement, a potential sensitivity gain of 25)
→ for direct 3D information
  10ps TOF resolution for 1.5mm resolution along LOR)
→ for restoring image quality for limited angle tomography

>1ns 500 ps 250 ps 100 ps
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**
- Particle 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

⇒ COST Action TD1401: FAST since Dec 2014 (http://fast-cost.web.cern.ch/fast-cost/)
⇒ Challenge: Understanding key factors of timing resolution
⇒ Proposing routes toward 10ps

See talk Martin Nikl
Understanding of the Scintillator limits for time resolution

1) The scintillation mechanism
   - Light yield;
   - Rise time;
   - Decay time.

2) The light transport in the crystal
   - Time spread related to different light propagation modes

3) The light extraction efficiency
   - Light Yield $\rightarrow$ Light Output;
   - Impact on photostatistics;
   - Weights the distribution of light propagation modes.

$\Delta t_{\text{max}} = 71 \text{ ps for } x = L$
$\Delta t_{\text{max}} = 384 \text{ ps for } x = 0$
$L = 20 \text{ mm}$

Study of fast phenomena is scintillators

- Cerenkov
- Hot intraband luminescence
- Quantum confinement driven luminescence

See talks: M. Nikl, G. Tamulaitis Monday
Study of fast phenomena is scintillators

- Cerenkov
- Hot intraband luminescence
- Quantum confinement driven luminescence

The transient absorption kinetics of a CeF3 single crystal obtained at different wavelength of the probe pulse:

E. Auffray et al., JINST 9 (2014) P07017
Study of fast phenomena is scintillators

- Cerenkov
- Hot intraband luminescence
- Quantum confinement driven luminescence

Colloidal quantum wells

CdSe CQwell

ZnO based quantum dot

Photoluminescence ZnO:Ga

\[ I(t) = 67597 \exp(-t/210 \text{ ps}) + 0.934 \]

J. Grim et al. Nature nanotech. 9, 891–895 (2014),
R. M. Turtos et al. Submitted to JINST

L. Prochazkova et al. Opt Material
R. M. Turtos et al. Submitted to Physica Status Solidi (RRL)
Time coincidence resolution measurements

Time coincidence resolution set-up at CERN

With new SiPM devices from FBK improved CTR results:
LSO:Ce:Ca crystal - FBK NUV-HD SiPMs

Data acquisition:
LeCroy Oscilloscope DDA 735Zi with
3.5GHz Bandwidth and 40Gs/s

S. Gundacker, PhD thesis
S. Gundacker et al, JINST 8 P07014 2013

S. Gundacker et al, JINST 11P08008
time resolution with MIP

Same crystals and SiPM (LSO:Ce:Ca crystal - FBK NUV-HD) test with MIP (muon 150GeV) in H2

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

New approaches have been proposed:

- Particule 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

ILC goal

Undoped fibers (Cerenkov radiators)

Doped fibers (scintillators)

P. Lecoq, CALOR 2008
G. Mavromanolakis et al. CALOR 2010 + JINST 6 p10012 (2011)
Micro-Pulling down technology for crystal fiber growth

Micro-pulling down (µPD) : multiple advantages

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

See talks K. Pauwels, O. Sidletskiy

LuAG from Fibercryst

Courtesy Fibercryst
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

=> Need less fibers, possibility to use materials with lower density
Next step: feasibility study of large production crystal fibers with consistent quality and cheap production cost:

=> Aim of Intelum project (European Rise project grant 644260)

16 Partners (many from CCC) from 12 different countries: 11 academia and 5 companies
## From High Energy Physics to medical Imaging

### Requirements for HEP EM calorimetry

**Crystals**
- High density (> 6 g/cm³)
- Fast emission (< 100 ns), visible spectrum
- Moderate to high light yield
- High 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)

### Requirements for Medical Imaging

**Crystals**
- High density (> 7 g/cm³)
- 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)
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**
- **PET/MRI Activities in many groups**
Clear PET: small animal PET

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
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

20 detector cassettes
Rat Image with ClearPET Neuro

- Haderian glands
- Medulla oblongata
- Olfactory bulb
- Glottis / tongue
- Cerebellum

# ClearPET® Performances

<table>
<thead>
<tr>
<th>Scanner</th>
<th>ClearPET®</th>
<th>MicroPET® Focus 120</th>
<th>eXplore VISTA DR</th>
<th>Mosaïc</th>
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<tr>
<td>Constructor</td>
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<td>Siemens</td>
<td>GE</td>
<td>Philips</td>
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<td>Crystal</td>
<td>LYSO/LuYAP</td>
<td>LSO</td>
<td>GSO/LYSO</td>
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<td>DOI</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<td>Photodetector</td>
<td>MaPMT</td>
<td>PSPMT</td>
<td>PSPMT</td>
<td>PMT</td>
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<td>Axial FOV (mm)</td>
<td>120</td>
<td>76</td>
<td>46</td>
<td>119</td>
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<tr>
<td>Sensitivity</td>
<td>5.5%</td>
<td>5.4%</td>
<td>4%</td>
<td>1.4%</td>
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<tr>
<td>Spatial resolution on axis (mm)</td>
<td>1.3</td>
<td>1.2</td>
<td>1.6</td>
<td>2.2</td>
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<tr>
<td>Spatial resolution 1cm off axis</td>
<td>1.9</td>
<td>1.8</td>
<td>1.9</td>
<td>2.7</td>
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<tr>
<td>Spatial resolution 2cm off axis</td>
<td>2.0</td>
<td>2.2</td>
<td>2.2</td>
<td>2.6</td>
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<tr>
<td>Spatial resolution 4cm off axis</td>
<td>2.6</td>
<td>3.3</td>
<td></td>
<td>3.1</td>
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</tbody>
</table>
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 $^{11}\text{CO}_2$ as tracer.

Solute transport in plants (spica)

$^{11}\text{C}$-distribution in a sugar beet

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

ClearPET/Xpad: A Simultaneous PET/CT developed 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
ClearPEM & ClearpEM sonic

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

ClearPEM was the first PET using APDs!

B. Frisch, CERN courrier Article, July.August2013
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. Lecq ICTR2012, E. Auffray ICTR2014, SCINT2015)
T. Meyer,
Crystal modules CTR

CTR bench with Nino ASIC@CERN
Temperature 19°C
Overbias voltage: 2.5V

Plate for prostate prototype

Plate for pancreatic prototype

CTR (FWHM)(ps)

4*4 LYSO crystals
3.5*3.5*15mm³

Entries 4096
Mean 239.5
RMS 9.715

<CTR>: 239.4ps

4*4 LYSO crystals
3.1*3.1*15mm³

Entries 2512
Mean 223.5
RMS 12.6

<CTR>: 223.5ps

1\textsuperscript{st} tests in CERIMED Marseille
February - April 2015

Preliminary images

<table>
<thead>
<tr>
<th>Transverse</th>
<th>Coronal</th>
<th>Sagittal</th>
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<tbody>
<tr>
<td>1 iteration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 iterations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 iterations</td>
<td></td>
<td></td>
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</tbody>
</table>

External plate
Cylinder filled with FDG
PET+US Probe
Conclusion

The CRYSTAL CLEAR COLLABORATION

- **25 years** old international academic consortium,
- worldwide recognition of collaboration activities
- strong link with industrial and end users
- well structured collaboration, with a collaboration contract (CERN K800), a management structure (steering committee, collaboration board committee)
- Each partner in the CCC collaboration can freely use the results and technologies developed by others for academic purposes
- License based on clearly defined IP rules for commercial use possible
Conclusion

The CRYSTAL CLEAR COLLABORATION
Main current and future activities

• Investigation of new materials & new production method
• Scintillation mechanisms
• Other light production mechanisms (Cerenkov, Hot intraband luminescence, semiconductors)
• Hybrid systems (metamaterials: Nanocrystals, quantum dots, photonic crystals
• Radiation damage
• Fast photodetection
• Applications
Acknowledgement

I thank all CCC colleagues since 25 years

We will celebrate this anniversary on Nov. 24 @CERN: https://indico.cern.ch/event/542268/.
Welcome to

14th International Conference on Scintillating materials and their applications

25 years after Crystal 2000
Back to Chamonix
Sept 18-22, 2017
Today CCC partners: 29 Institutes (2)

Austria
- Stefan Meyer Institute Austrian Academy of Sciences (Contact: J. Marton)

Armenia 🇦🇲- The Institute for Physical Research, Ashtarak, Republic of Armenia (contact: A. Petrosyan)

Belgium 🇧🇪- The Vrije Universiteit Brussel (VUB), Brussels (Contact: S. Tavernier) 🇧🇪- The Universiteit Gent (UGent), Gent (Contact: Y. D’ Asseler)

Belarus
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Estonia
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Switzerland - CERN, Geneva (Contact: E. Auffray (spokeperson))

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- Faculty of Nuclear Sciences and Physical Engineering, Czetch Technical university, Prague (Contact V. Cuba)

Ukraine
- Institute for scintillation materials NAS of Ukraine, Kharkov (Contact: S. Galkin)

United Kingdom - University College London (Dep. of Electronic and Electrical Engineering) (Contact: I. Papakonstantinou)
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