New Approaches in Scintillation Detectors in the Context of HEP Calorimetry and Medical Imaging

Paul Lecoq
CERN, Geneva

X-γ detection

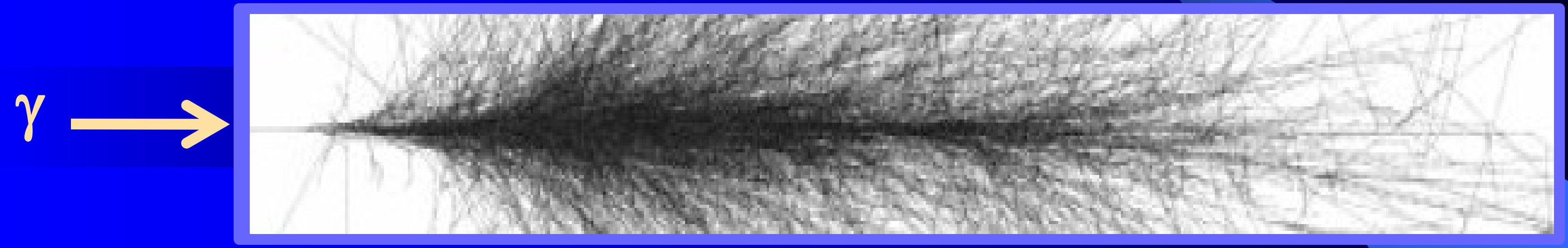
- Whatever the energy range (GeV for HEP, 100s KeV for medical imaging) X-γ detectors record only a global information on the events:
  - time stamp (limited by the timing resolution of the whole acquisition chain)
  - Total energy deposit in a crystal (100cc for HEP, 0.05 to 0.1 cc in PET)
  - Crystal ID for localization (limited by crystal size)
    - Some improvements with COG or DOI capability (several crystal layers or double readout)
      - 1.5mm depth resolution on 20mm long LYSO crystals for the ClearPEM with APD readout

Present limitations

- As a result there is a trade-off between
  - Energy resolution, which requires the full containment of the conversion chain and therefore « large » detector blocks
  - Position resolution, for which the detection volume should be restricted to the first interaction point
- This leads to a trade-off between
  - Reconstructed spatial resolution
  - Sensitivity (less events in photopeak for smaller pixels)

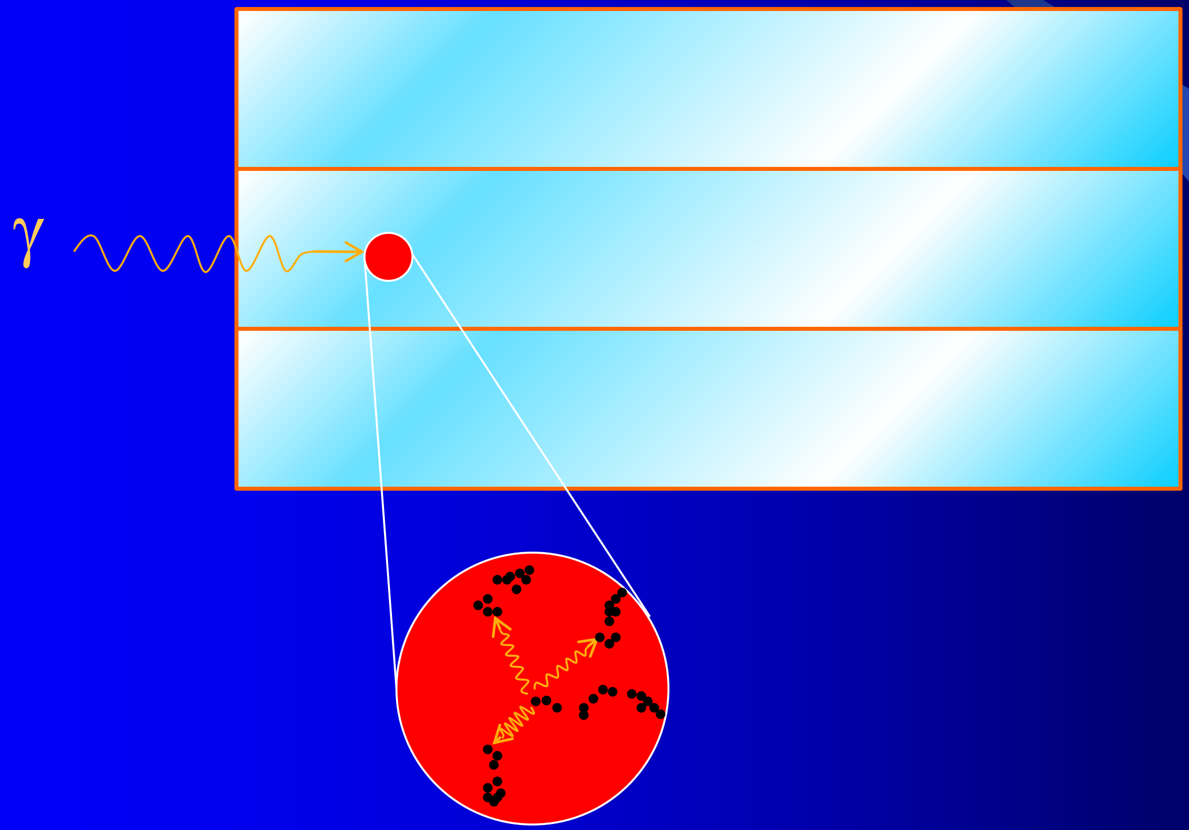
A zoom on the conversion process (HEP)

- The energy conversion from incoming X or γ Rays is a complex process resulting from a cascade of events.

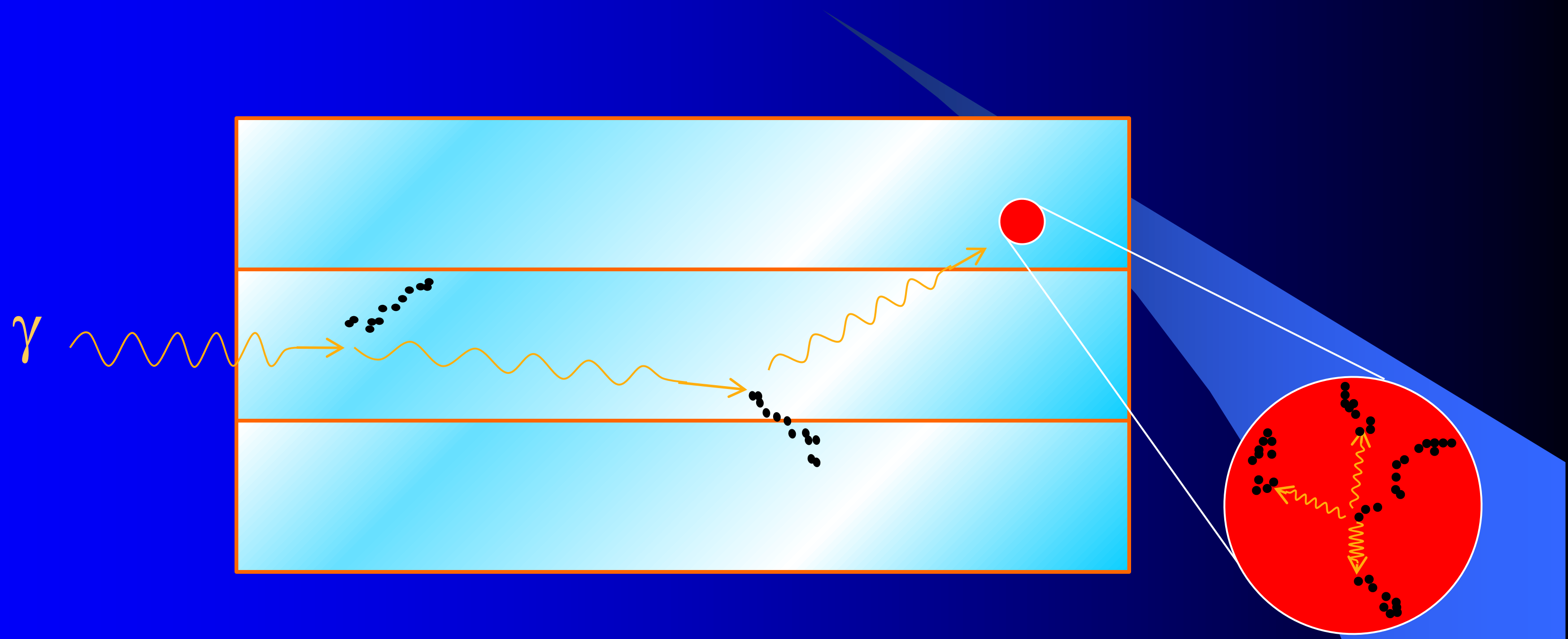


- Hadronic events are even more complex
  - Details of the full cascade for HEP with contributions from different conversion mechanisms: scintillation and Cerenkov, would lead to particle identification within the shower

A zoom on the conversion process (low energy)



A zoom on the conversion process (low energy)



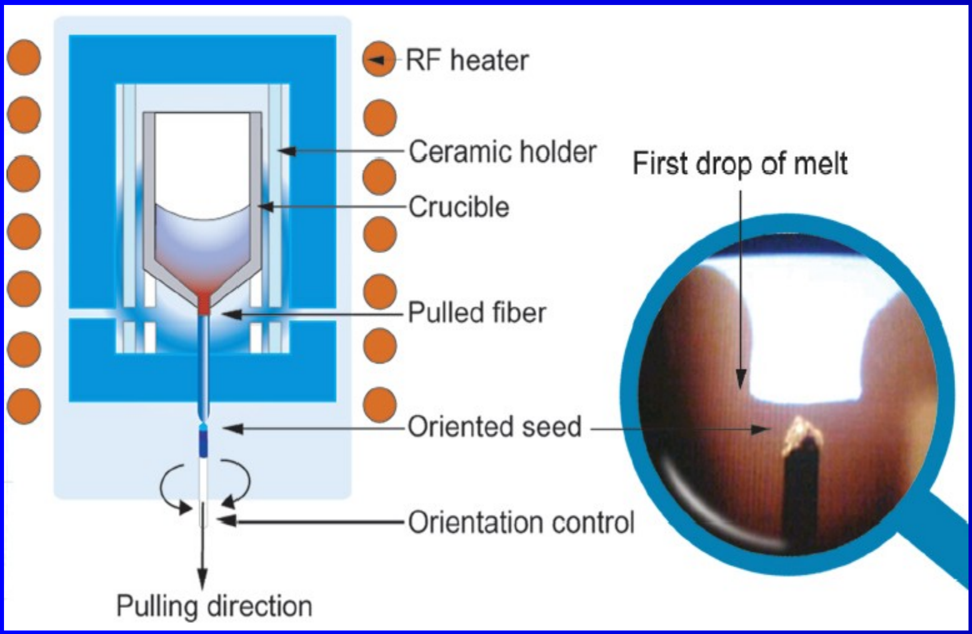
Can we do better?

Can we build an imaging calorimeter ?

Towards intelligent, multifunctional metamaterials

- Progress towards « intelligent » materials,
- metamaterials based on
  - crystalline fibers,
  - quantum dots,
  - photonic crystals
- Progress on photodetectors. Fully integrated and digital mutipixel imaging photodetector
- Towards a fully digital detector head with photon counting and high accuracy timing measurement capability

Micro-pulling-down crystal fiber growth



Crucible and fiber

BGO  Φ=400μ

YAG:Ce 

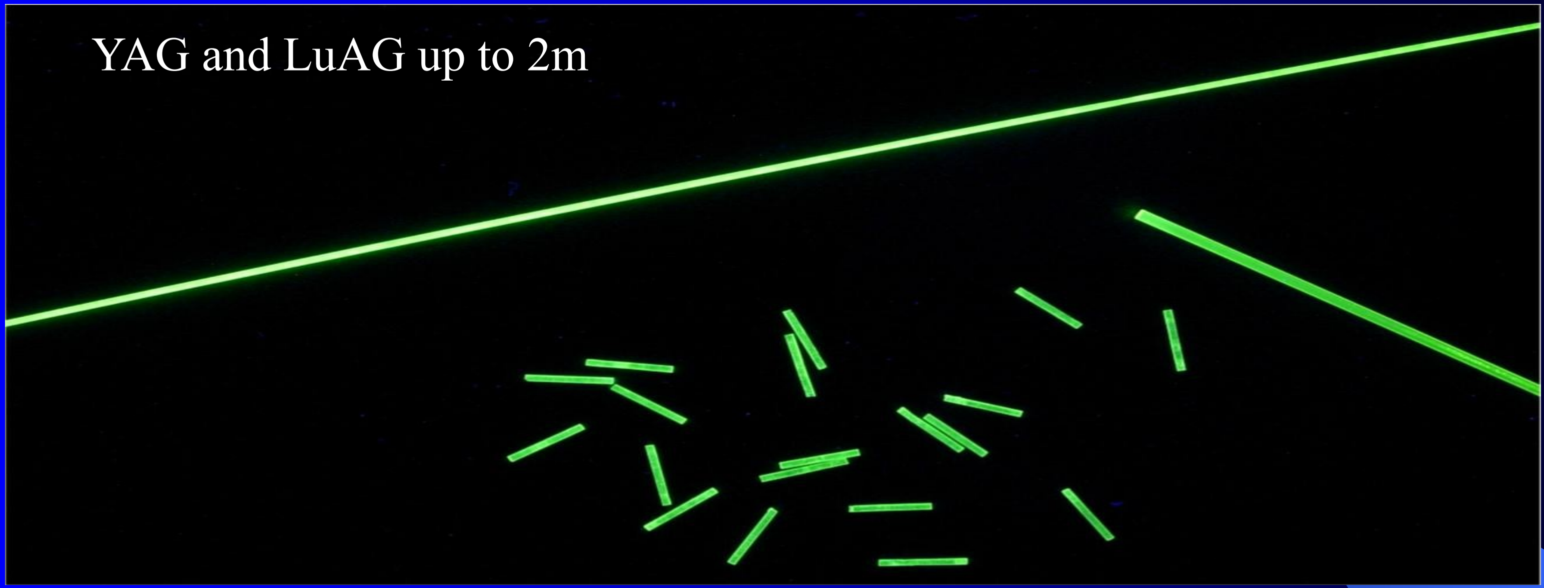
Φ=1mm

LYSO:C  Φ=2mm

YAP:Ce  Φ=2mm

Courtesy Fibercryst, Lyon

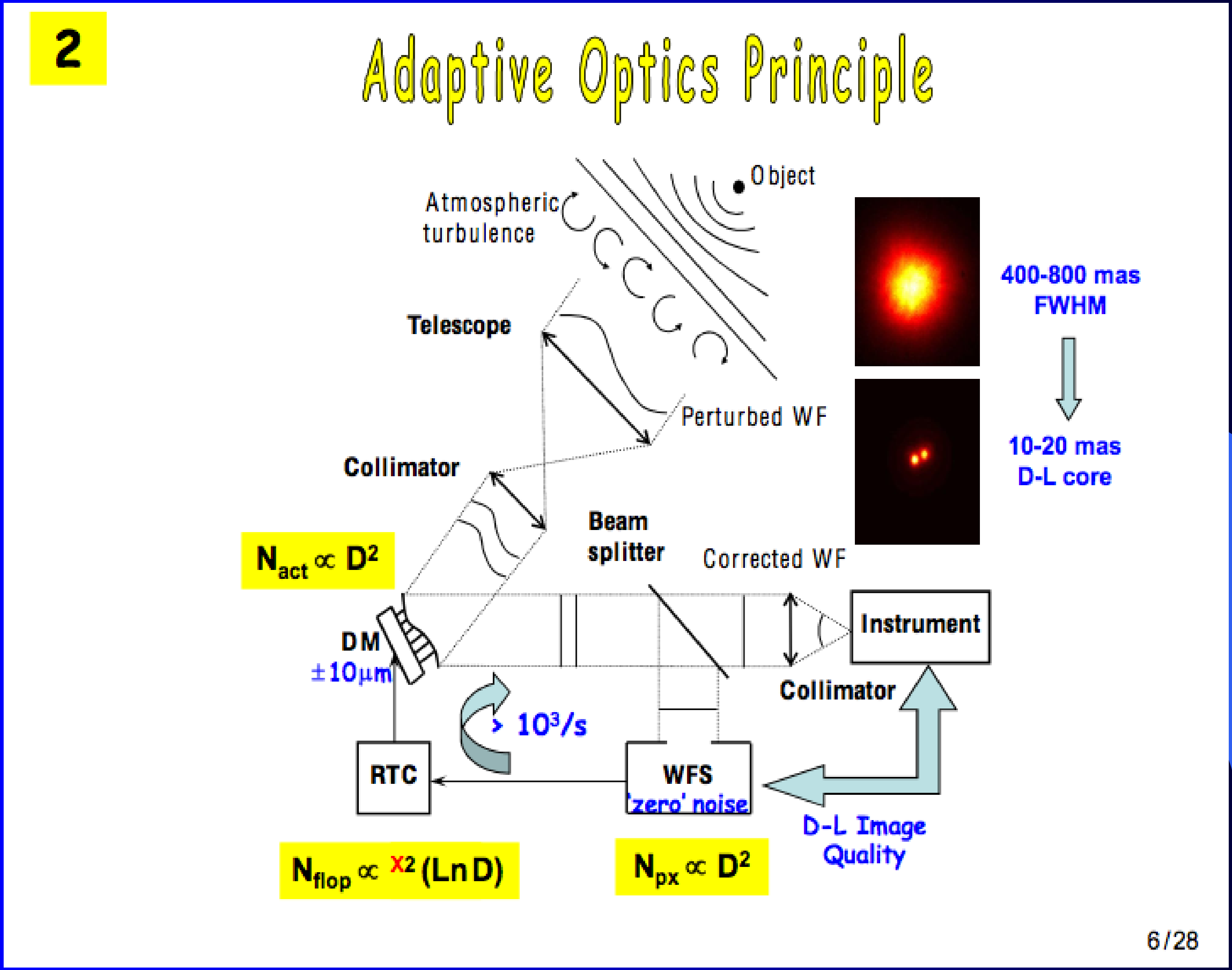
Some crystal fibers



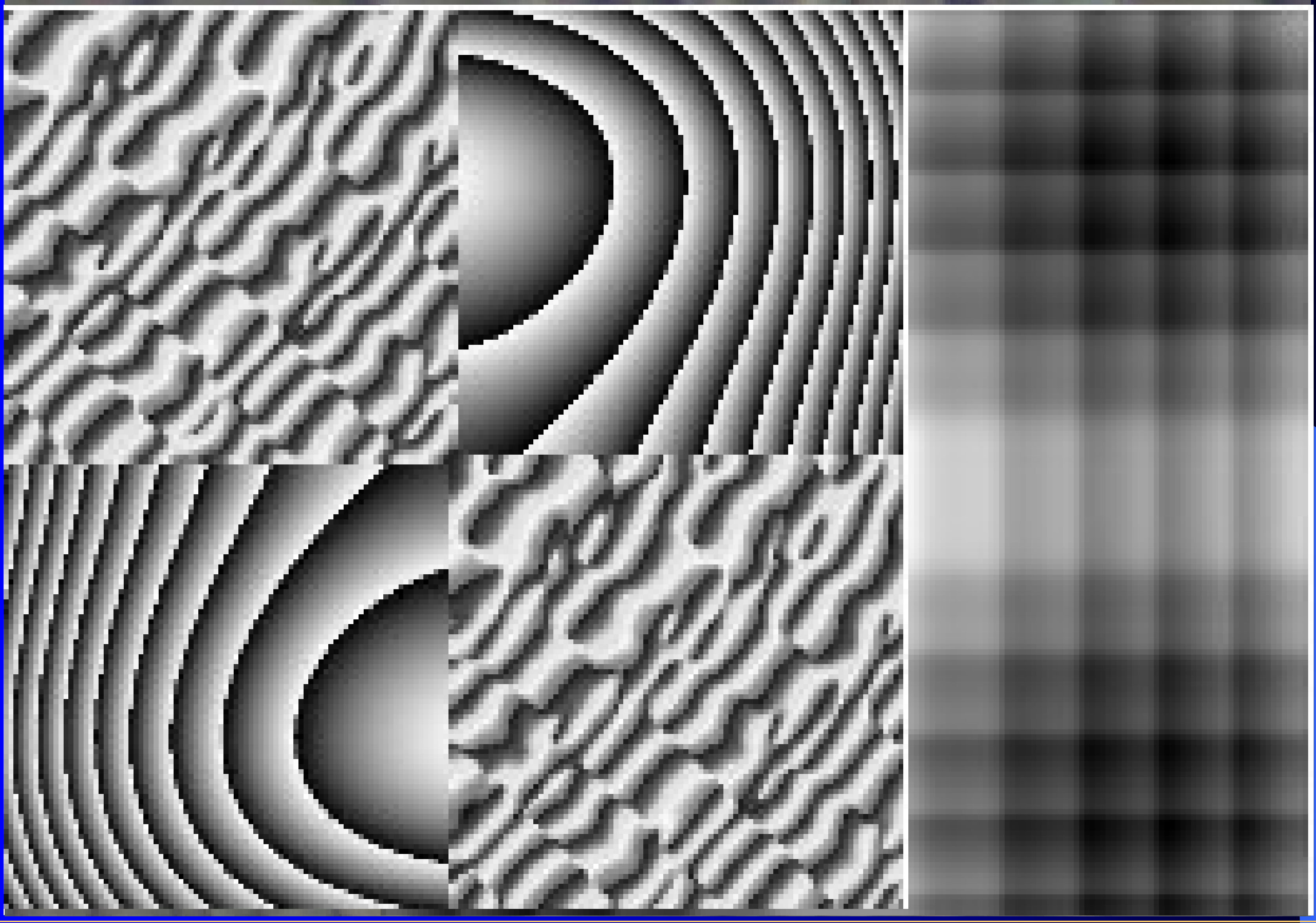
BGO (ϕ : from 0.6 mm to 3 mm ; Length up to 30 cm)

LYSO:Ce (ϕ : from 0.6 mm to 3 mm ; Length up to 20 cm)

Diffractive Optics



Diffractive Optics Technologies



The calorimetry challenge

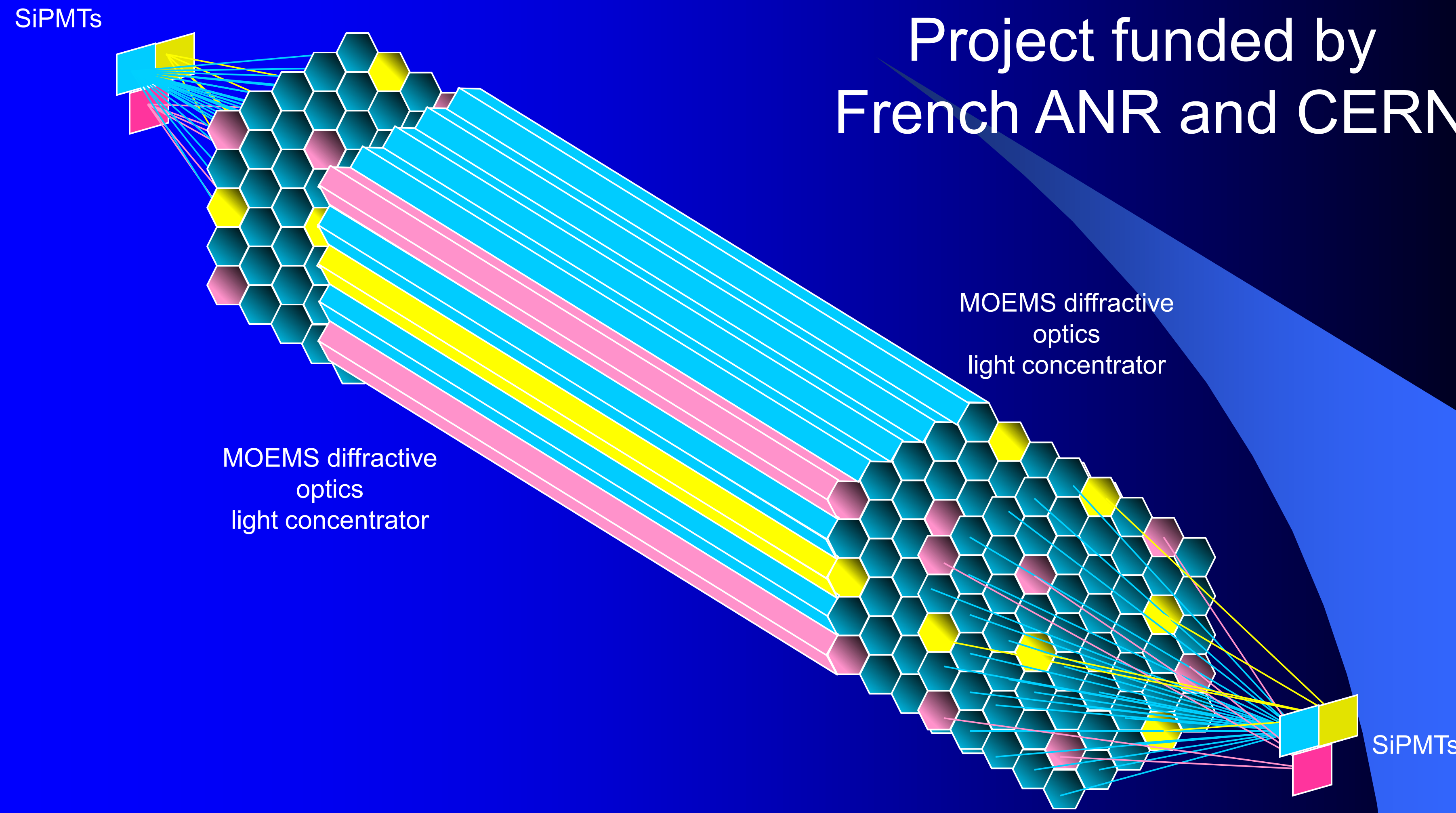
Design goal ILC/CLIC: separate $W,Z \rightarrow q\bar{q}$

Strong EW symmetry breaking
distinguish W and Z in their hadronic decays
w/o kinematic constraints

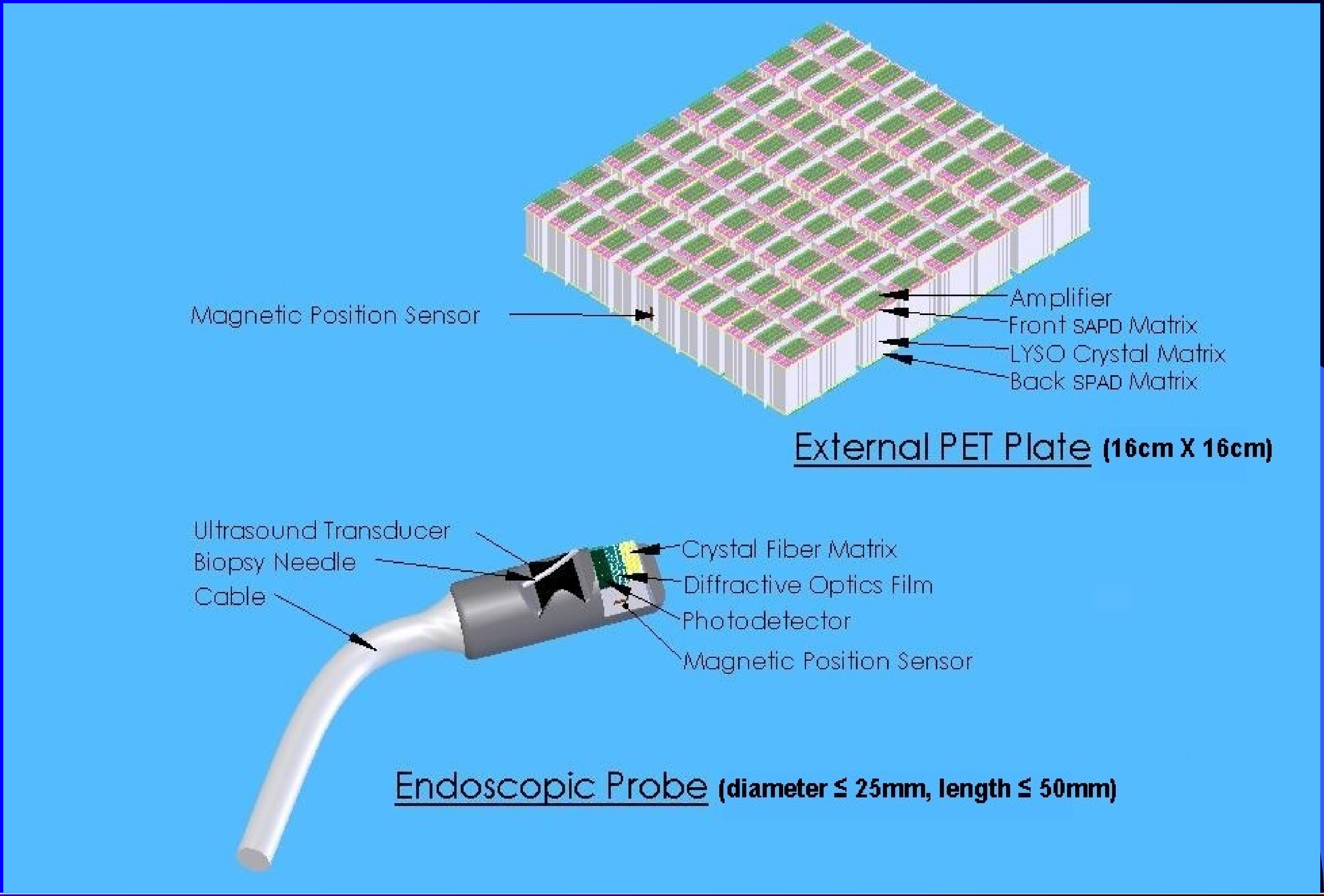
Possible solution: Dual Readout scintillators
Measure on an event to event basis
The electromagnetic fraction in a hadronic shower
By unfolding the Cerenkov contribution
to the total light output

Concept of a Meta-cable for HEP calorimetry

Project funded by French ANR and CERN

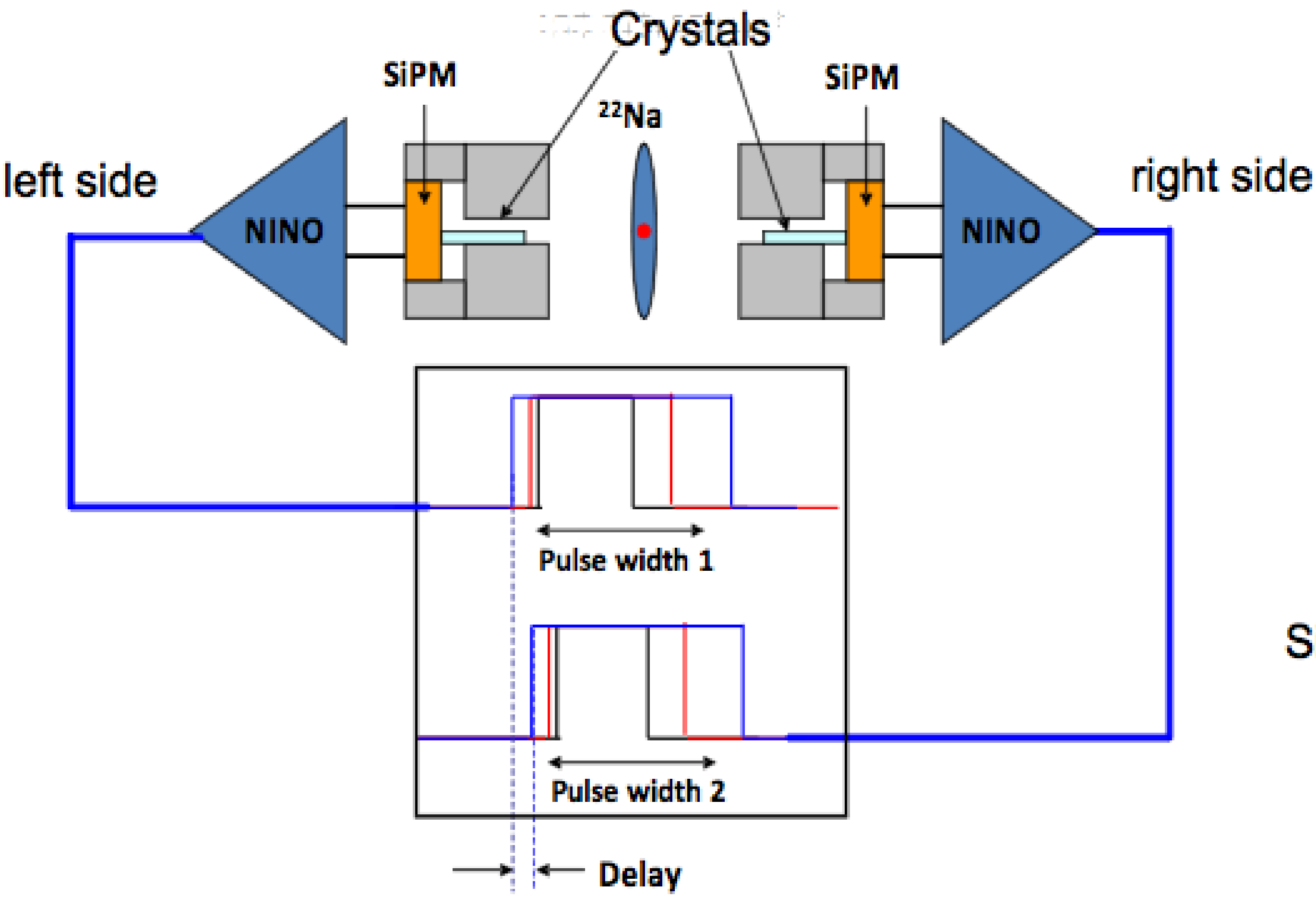


EndoTOFPET-US FP7-project



Coincidence SiPM-SiPM

Coincidence measurement for the 511keV photon pair:



Crystals:
-) LSO 2x2x10mm^3
-) LFS 3x3x15mm^3
-) LYSO 2x2x8mm^3
-) LuAG:Pr 2x2x8mm^3
-) LuAG:Ce 2x2x8mm^3

SiPMs:
-) Hamamatsu 25μ
-) Hamamatsu 50μ
-) Hamamatsu 100μ

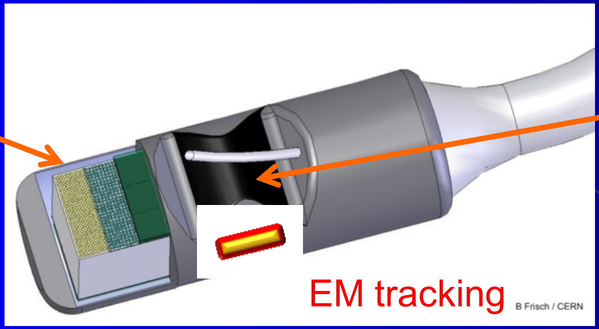
Whole setup with SiPM and Electronics (NINO Chip) assembled at one Board.

Summary of results

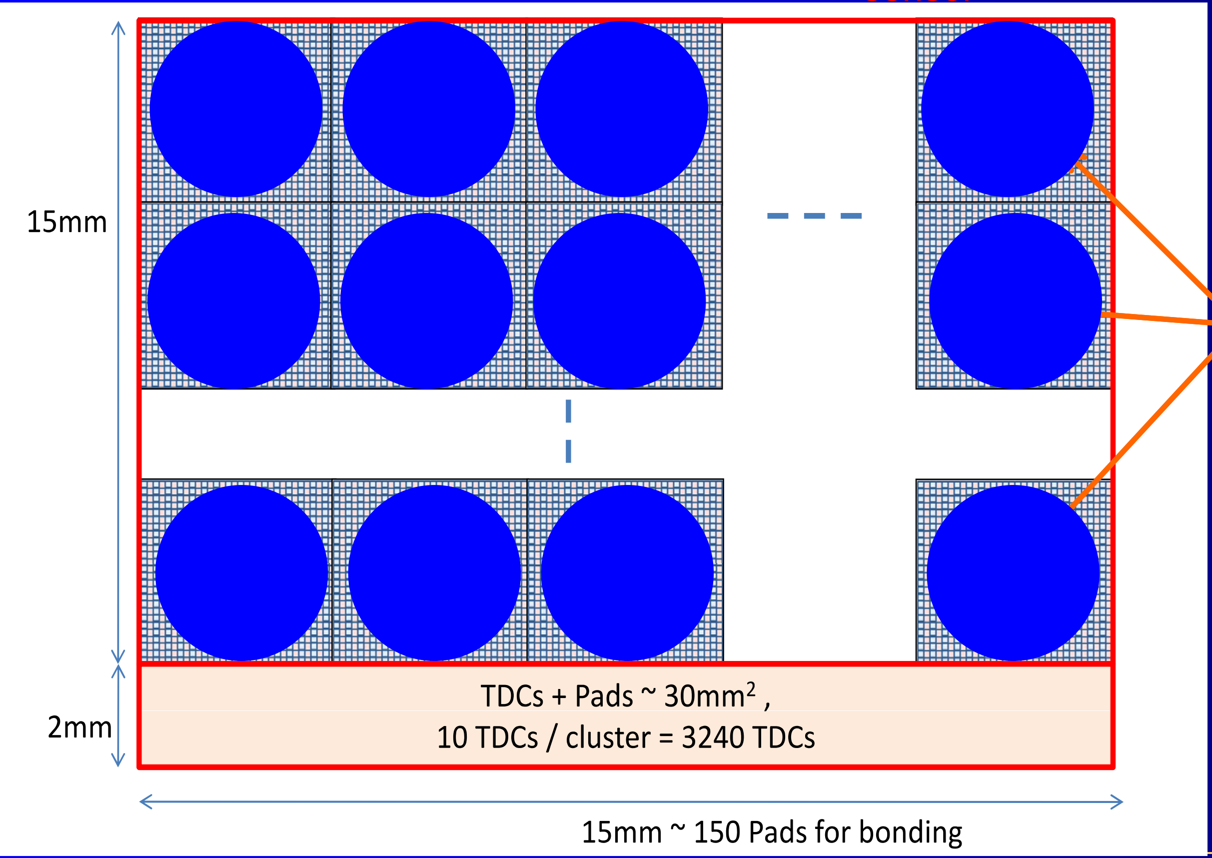
	FWHM in coincidence **Hama. 25µ**	FWHM in coincidence **Hama. 50µ**	FWHM in coincidence **Hama. 100µ**
Fill Factor:	30.8%	61.5%	78.5%
Number of Pixels:	14400	3600	900
Best Settings:	73V Bias 150mV Th.	72.4V Bias 100mV Th.	70.3V Bias 300mV Th.
LSO with LSO 2x2x10mm^3:	340±9ps	220±4ps	280±9ps
LFS 3x3x15mm^3:	429±10ps	285±8ps	340±3.2ps
LuAG:Pr with LuAG:Pr 2x2x8mm^3:	1061±40 ps	672±30 ps	826±40 ps
LuAG:Ce with LuAG:Ce 2x2x8mm^3 :	1534±50 ps	872±50 ps	1176±50ps
LYSO with LYSO 2x2x8mm^3:			282±9ps

Internal probe

PET head
active volume
$15x15x10mm^3$

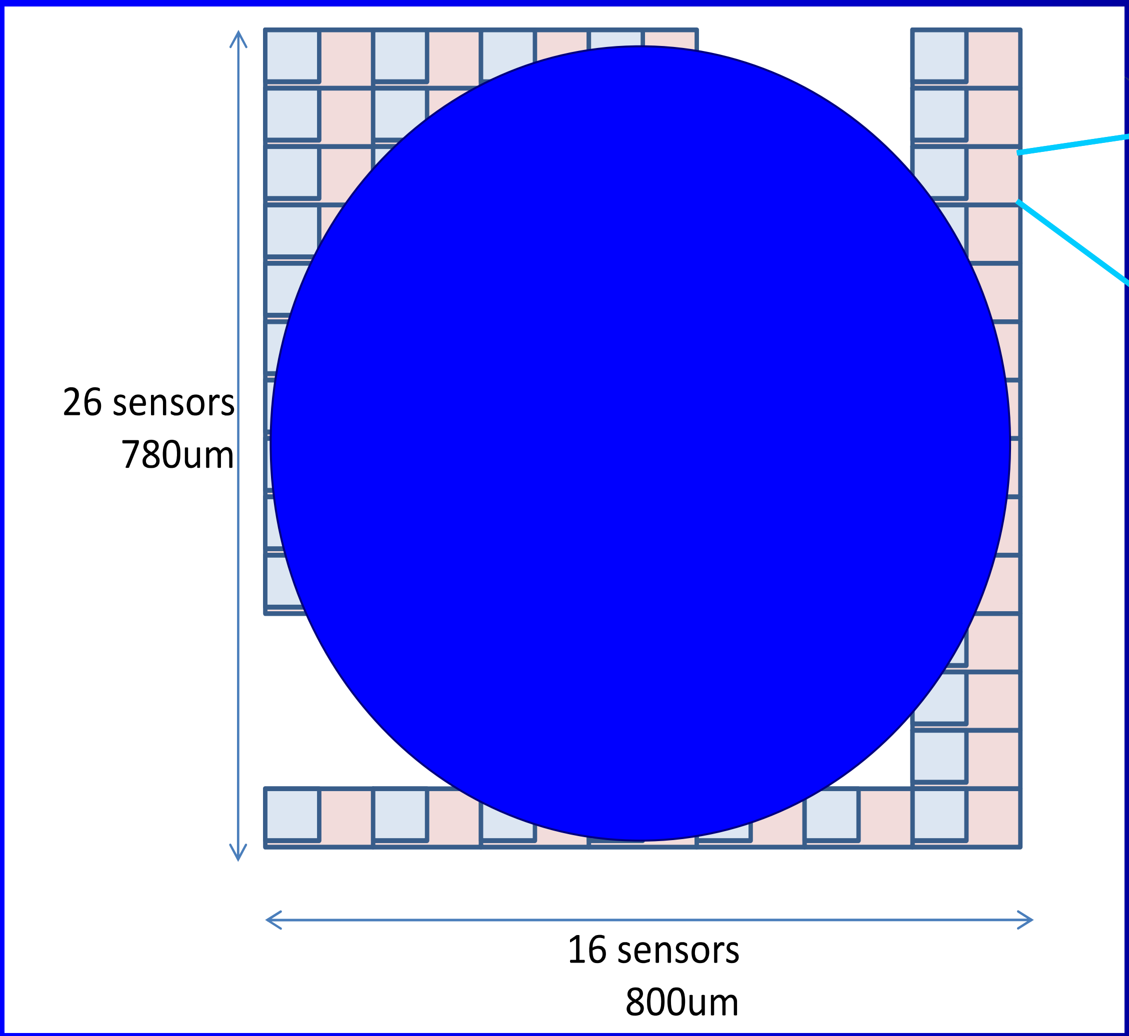


US Probe
with biopsy needle

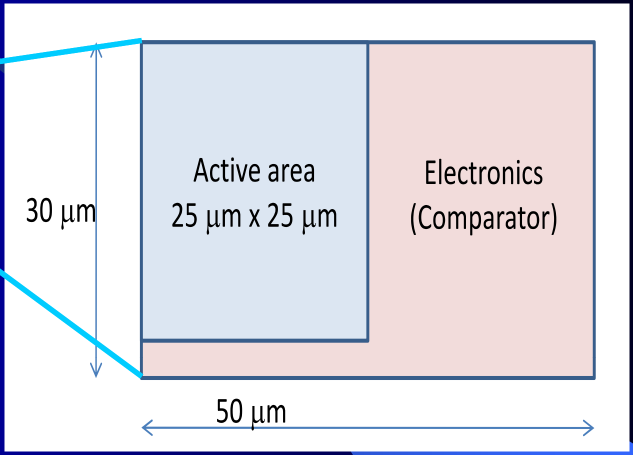


Matrix of 18x18=324 fibers
$\Phi \leq 780\mu m$ L=10mm
Section.cylindrical or square
LYSO:Ce, LuAG:Pr,…

1 chanel of the internal probe



Individual SPAD



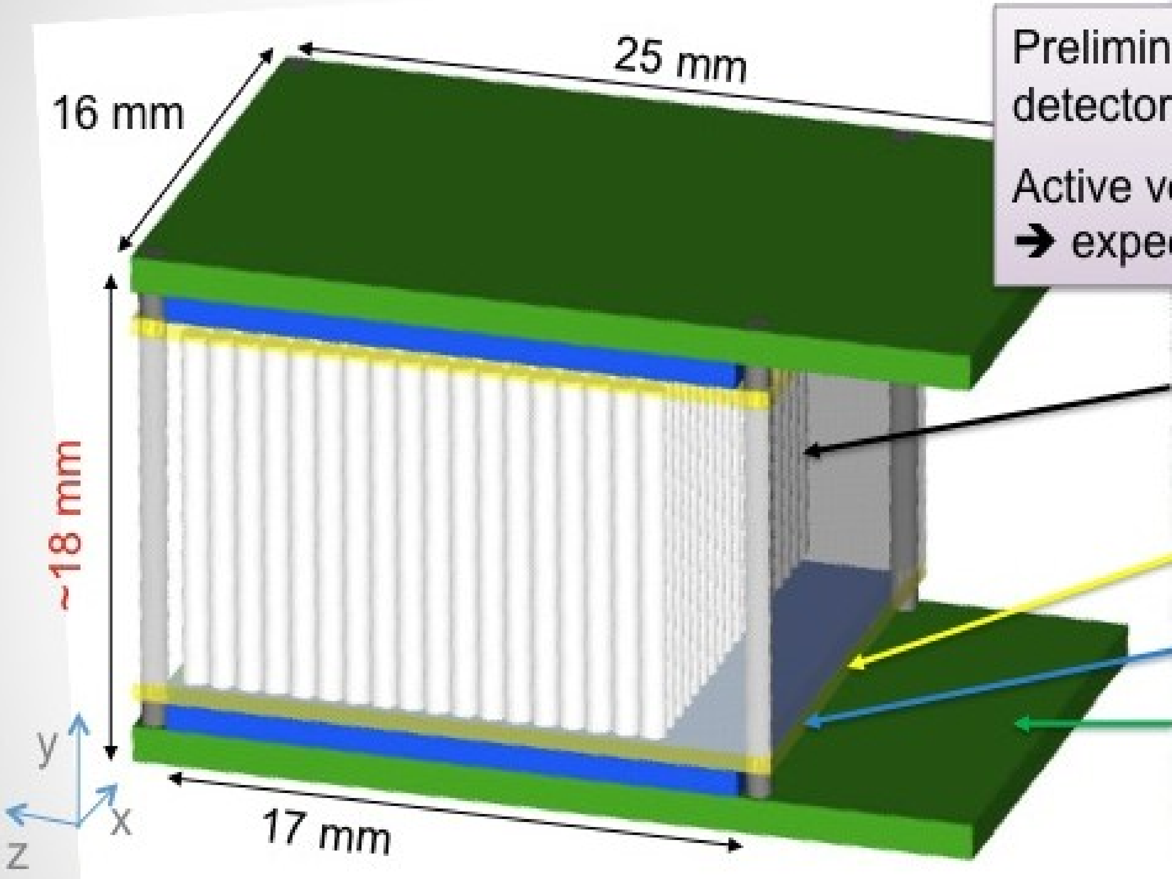
A cluster of
26x16 = 416 SPAD/fiber

10 TDC per cluster

Diffractive light concentrator between fibers and SPADs

Mechanical integration (PET head)

EndoTOFPET_US



Preliminary sizes of naked detector: 16 x 18 x 25 mm^3

Active volume = 15 x 15 x 10 mm^3
➔ expected event rate?

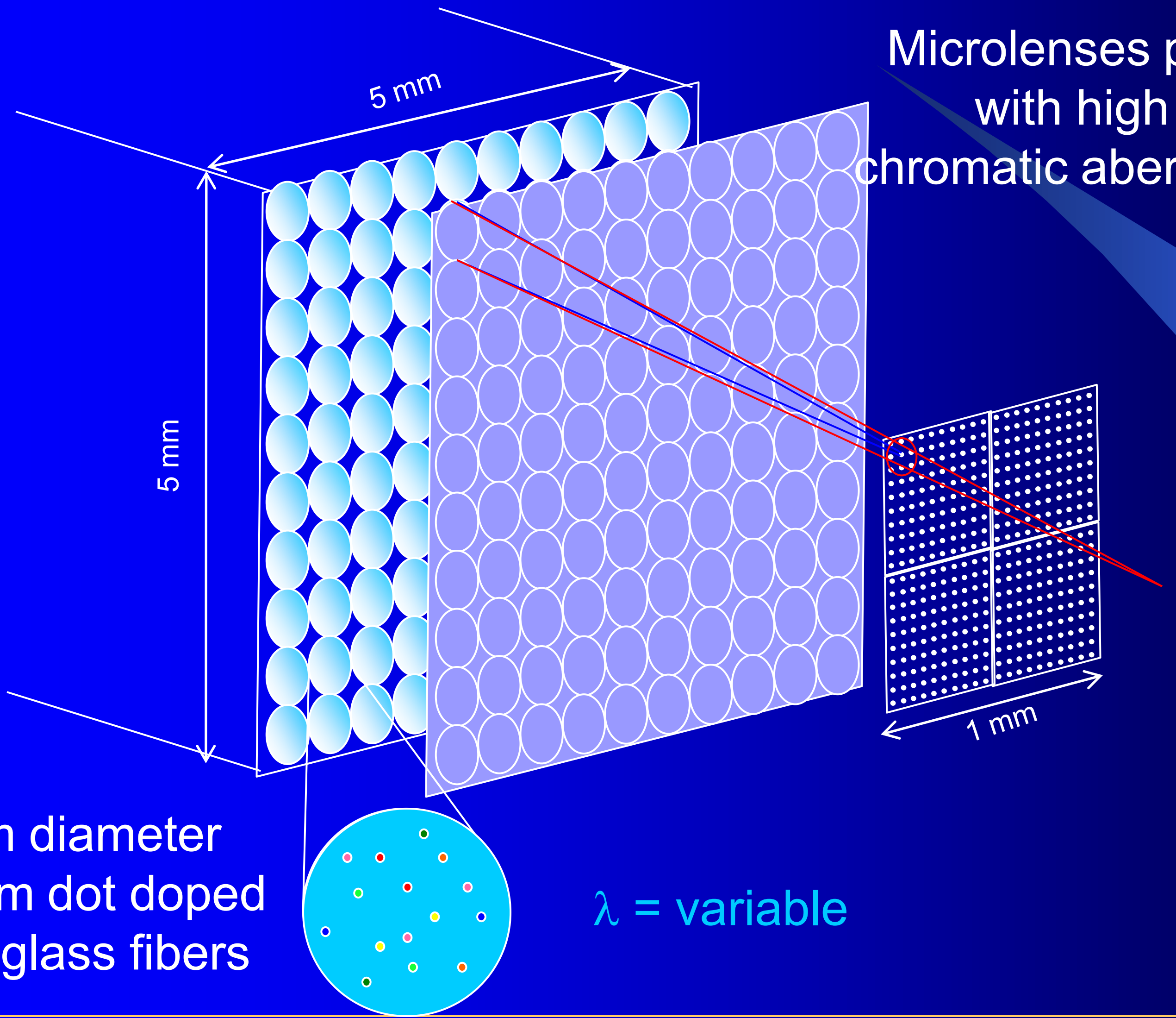
y-dimension = 13.5 mm + diffractive foils + air gaps
= 13.5 mm + 4 mm ~ 18 mm

Karsten Gadow (DESY)

Erika Garutti - WP5

12/01/2011 10

PET matrix - 1 to 9 coupling



Microlenses plate
with high
chromatic aberration

8 μm diameter
sensitive spots
50 μm apart

500μm diameter
Quantum dot doped
Heavy glass fibers

λ = variable

Conclusion

- Metamaterials provide large design flexibility
- Combination of
  - scintillating/Cerenkov heavy crystal fibers
  - quantum dots in heavy host materials: fluorohafnate glasses
  - Fully digital SiPM with photon counting capability
  - Diffractive optics to improve optical coupling between scintillator and photodetector

offer fascinating perspectives for the design of complex and highly performant metamaterials