New crystal technologies for novel calorimeter concepts

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The calorimetry challenge

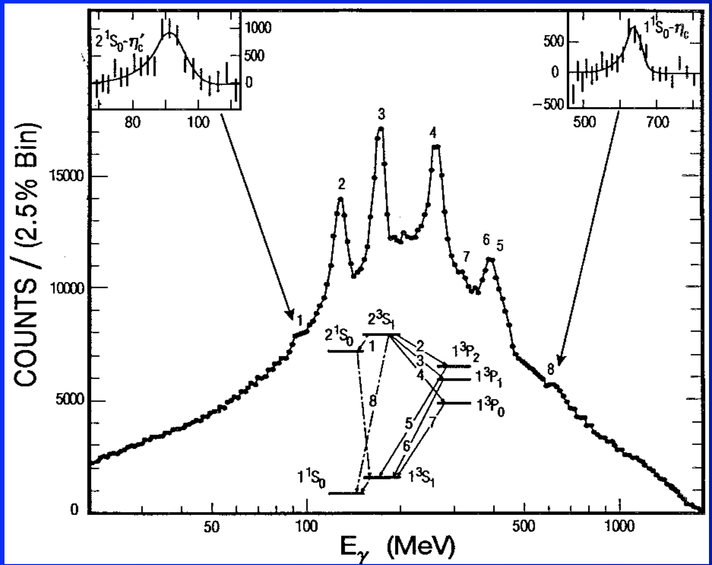
- A Global (integral) approach for jet calorimetry cannot do better than 60-70%/√ E

- Whatever the technical approach, high resolution for jets (30%/√ E) requires high granularity analysis of jet showers and/or a precise determination of the different components (electromagnetic, charged hadronic, neutral)

How can heavy scintillating crystals contribute?

Scintillating crystals for homogeneous calorimeters

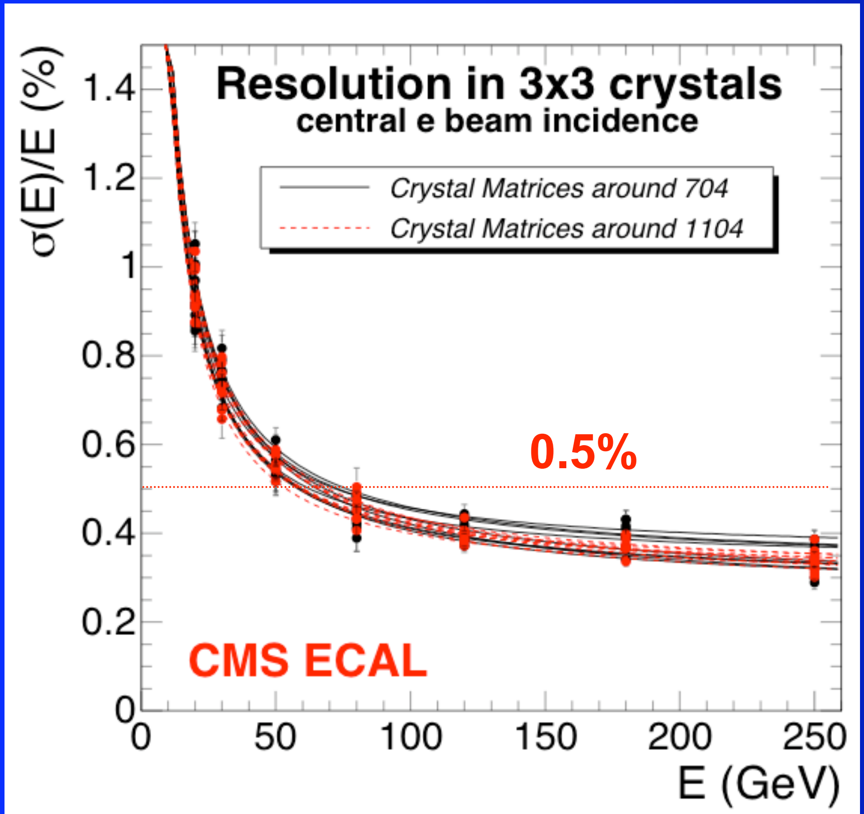
- Since Crystal Ball (NaI:Tl) at SPEAR known to give excellent electromagnetic energy resolution at low energy



Precise spectroscopy of charmonium states

Scintillating crystals for homogeneous calorimeters

- Since L3, Babar, CMS (testbeam),… systematics can be controlled to give excellent energy resolution at high energy (0.5%)



$$\frac{\sigma}{E} = \frac{2.8\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{125}{E(\mathrm{MeV})} \oplus 0.3\%$$

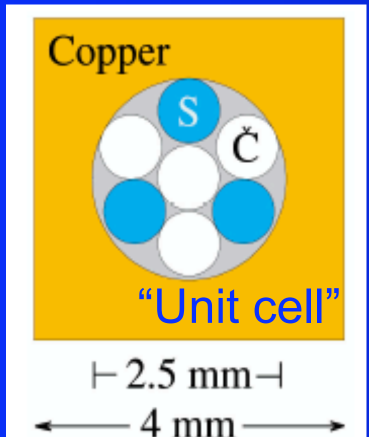
Scintillating crystals for homogeneous calorimeters

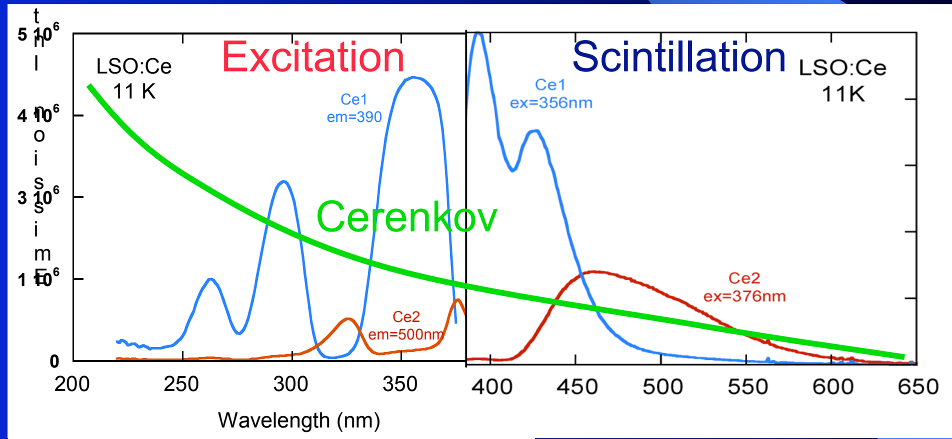
- Considered however to have poor performance for hadronic calorimetry
  - Homogeneous calorimeters are intrinsically non compensating
  - In addition quenching effects limit scintillation efficiency in high ionization density regions
  - $e/h >> 1$
  - e/π decreases with energy (as f_{em} increases) inducing non linearities

$$e/\pi = \frac{e/h}{1 - f_{em}(1 - e/h)}$$

A different detector concept

- PFA provides an attractive approach for a 3D imaging calorimeter
  - Integration issues with huge number of channels
- Dual readout is appealing for f_{em} determination
  - DREAM approach: sampling fluctuations
  - Bulk scintillator approach: coupling between scintillation and Cerenkov light





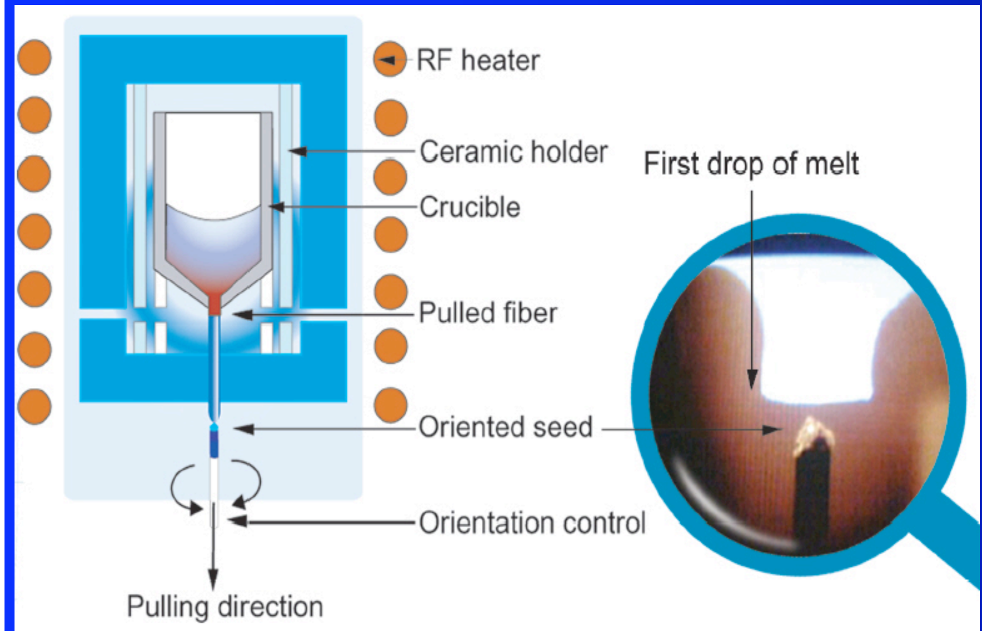
- Can scintillators provide a solution
  - Combining the merits of PFA and Dual Readout
  - Minimizing their relative drawbacks

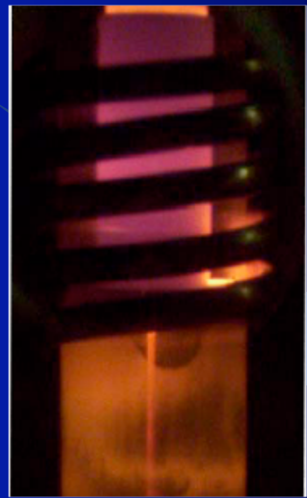
Proposal

- New technologies in the production of heavy scintillators open interesting perspectives in:
  - Design flexibility: detector granularity
  - Functionality: extract more information than simple energy deposit

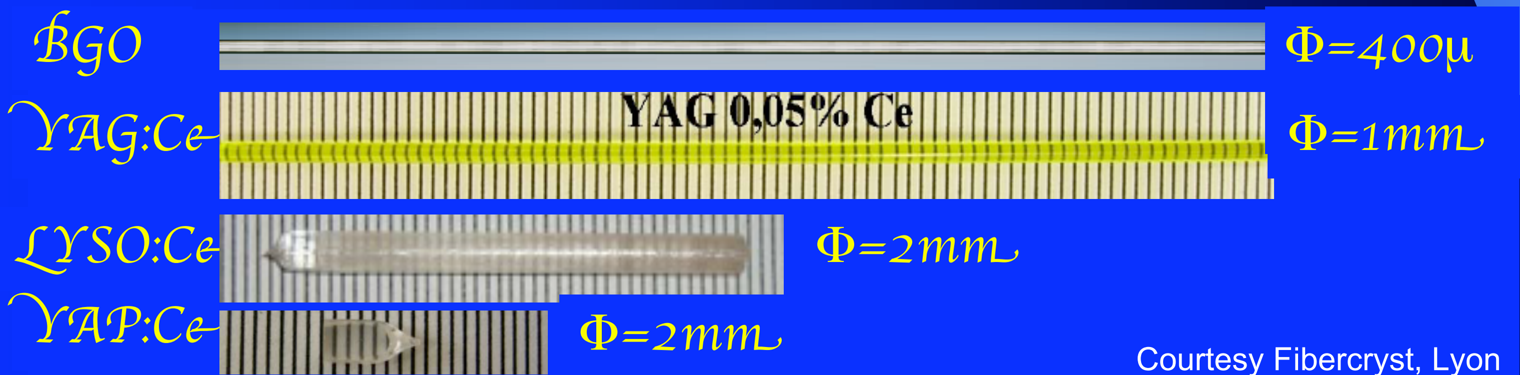
- The underlying concept of this proposal is based on metamaterials
  - Scintillating cables made of heavy scintillating fibers of different composition ⇨ quasi-homogeneous calorimeter
  - Fiber arrangement in such a way as to obtain 3D imaging capability
  - Fiber composition to access the different components of the shower

Micro-pulling-down crystal fiber growth





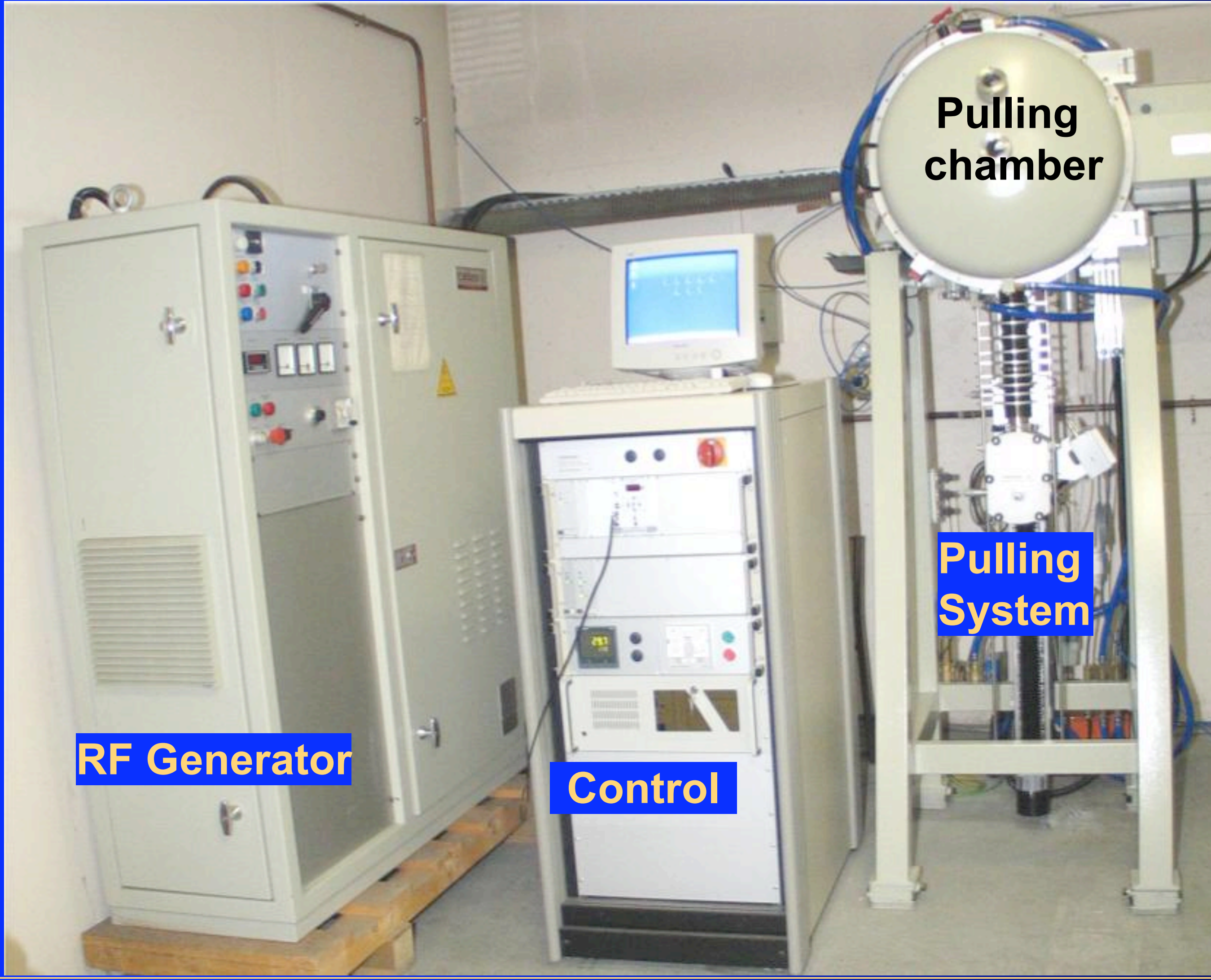
Crucible and fiber

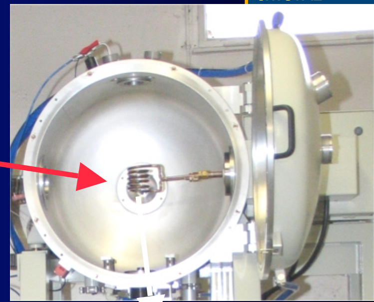


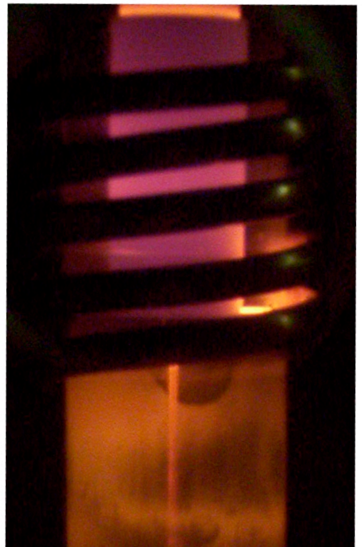
Courtesy Fibercryst, Lyon

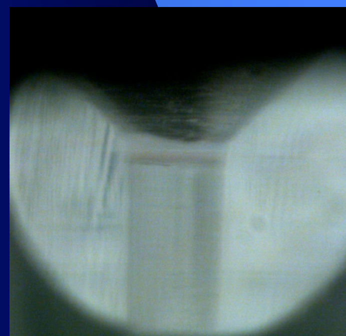
Industrial oven

Courtesy Fibercryst, Lyon and Cyberstar, Grenoble



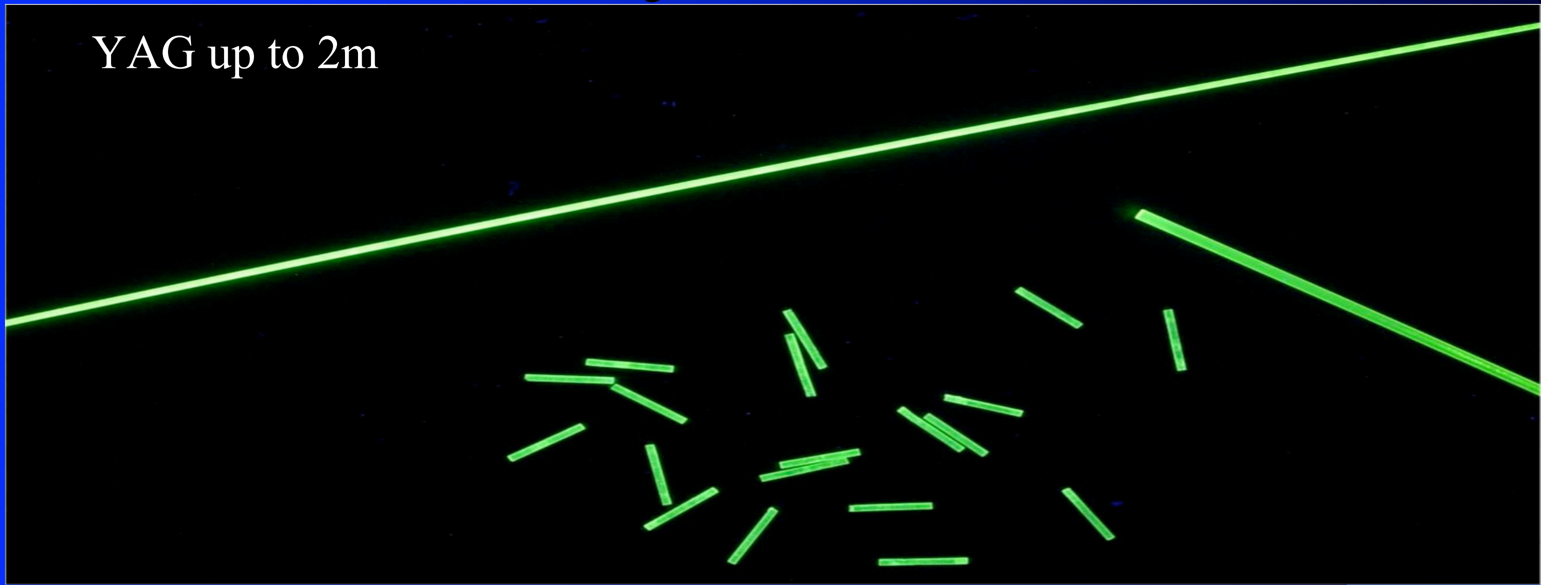






Crucible and fiber

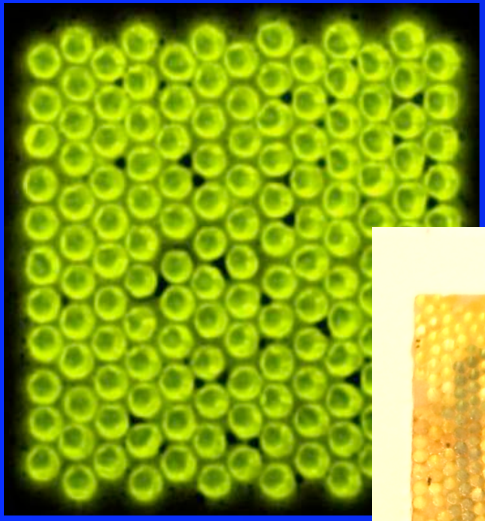
Some crystal fibers



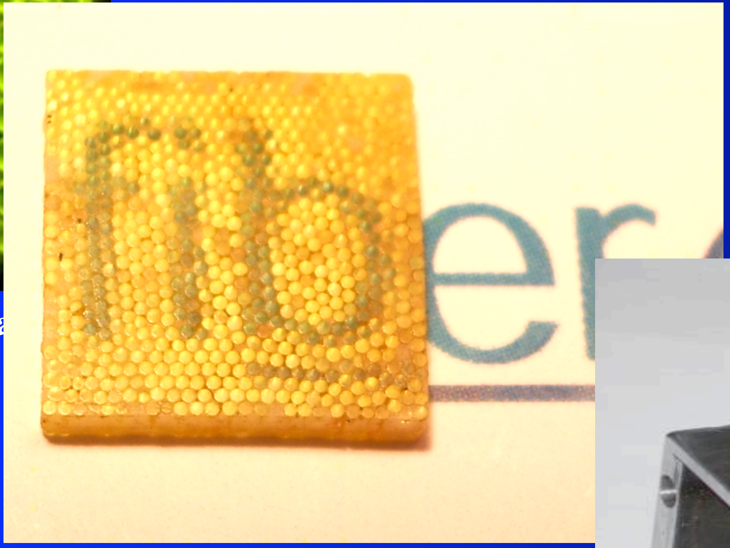
BGO (ϕ : from 0.6 mm to 3 mm ; Length up to 30 cm)

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

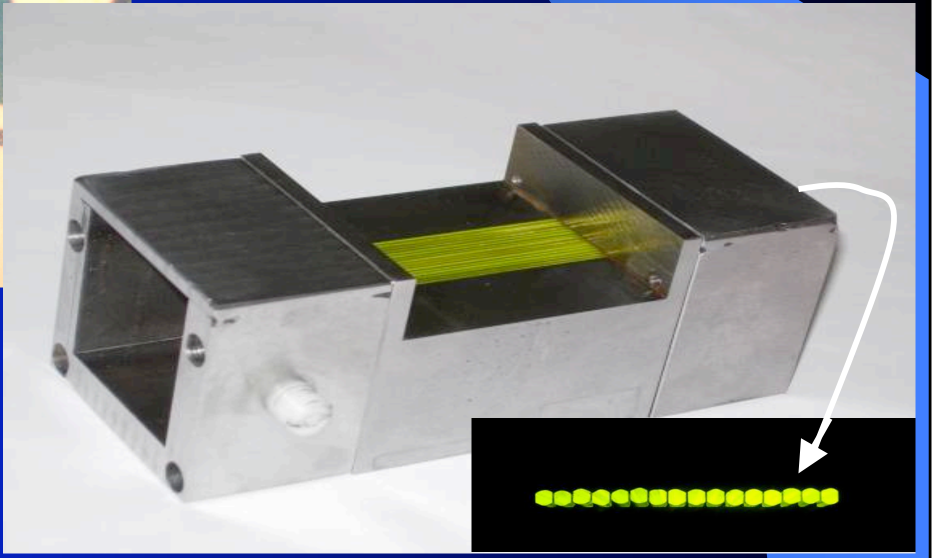
Some applications: LuAG:Ce



Thin pixels, compact a



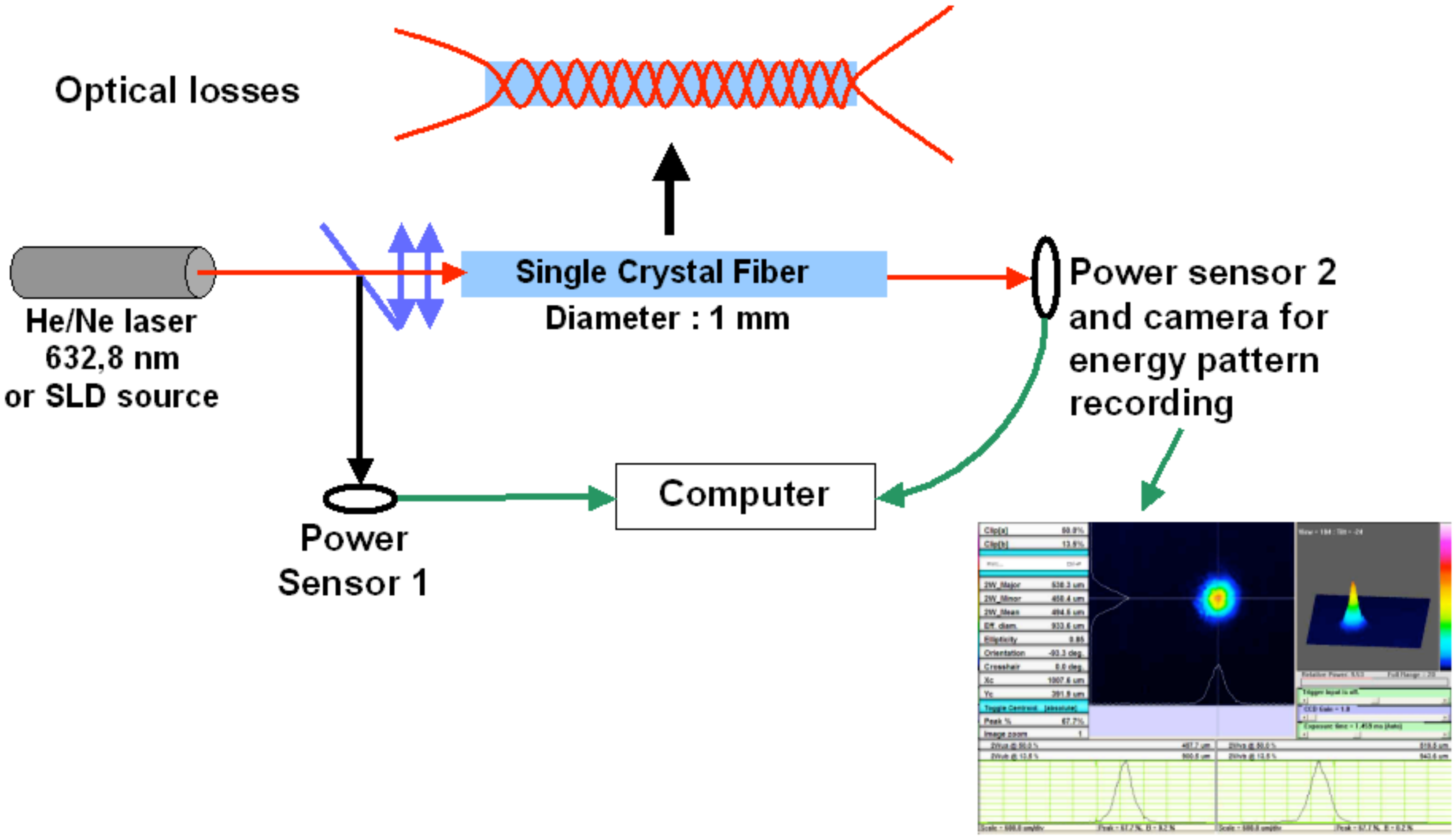
Pixels diameter 350 µm
Array surface 10 mm x10 mm



Alpha particles detector (both ends detection)

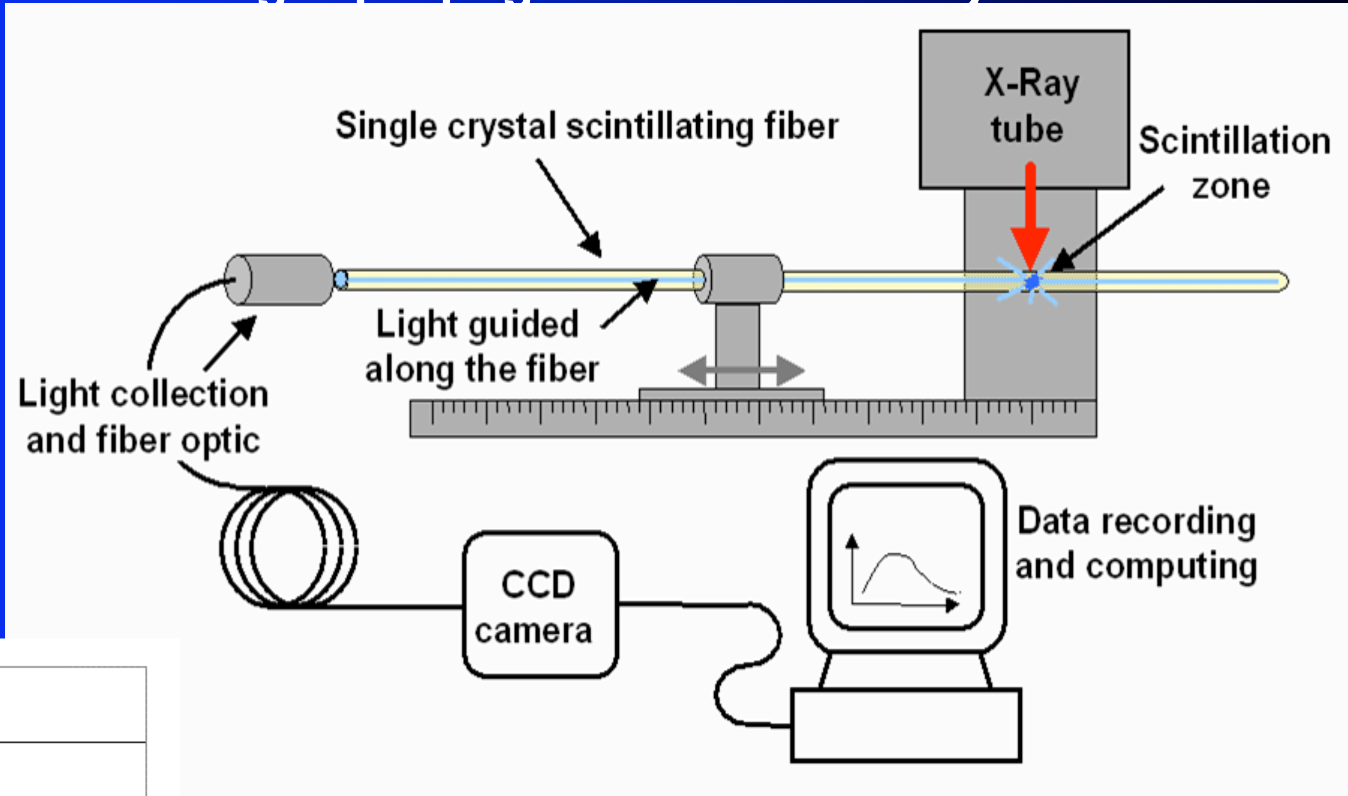
Fiber characterization

Power distribution

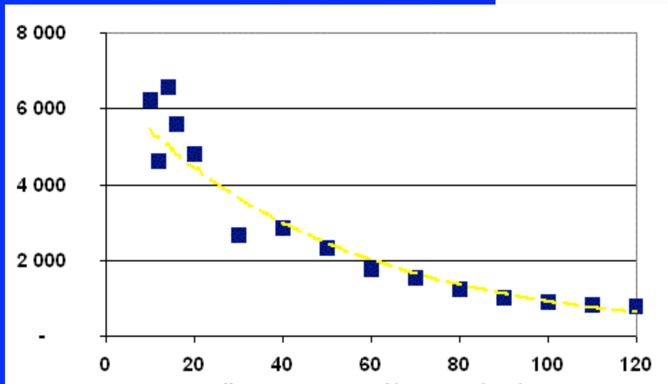


Fiber characterization

Light propagation under X-Rays excitation



Collected light

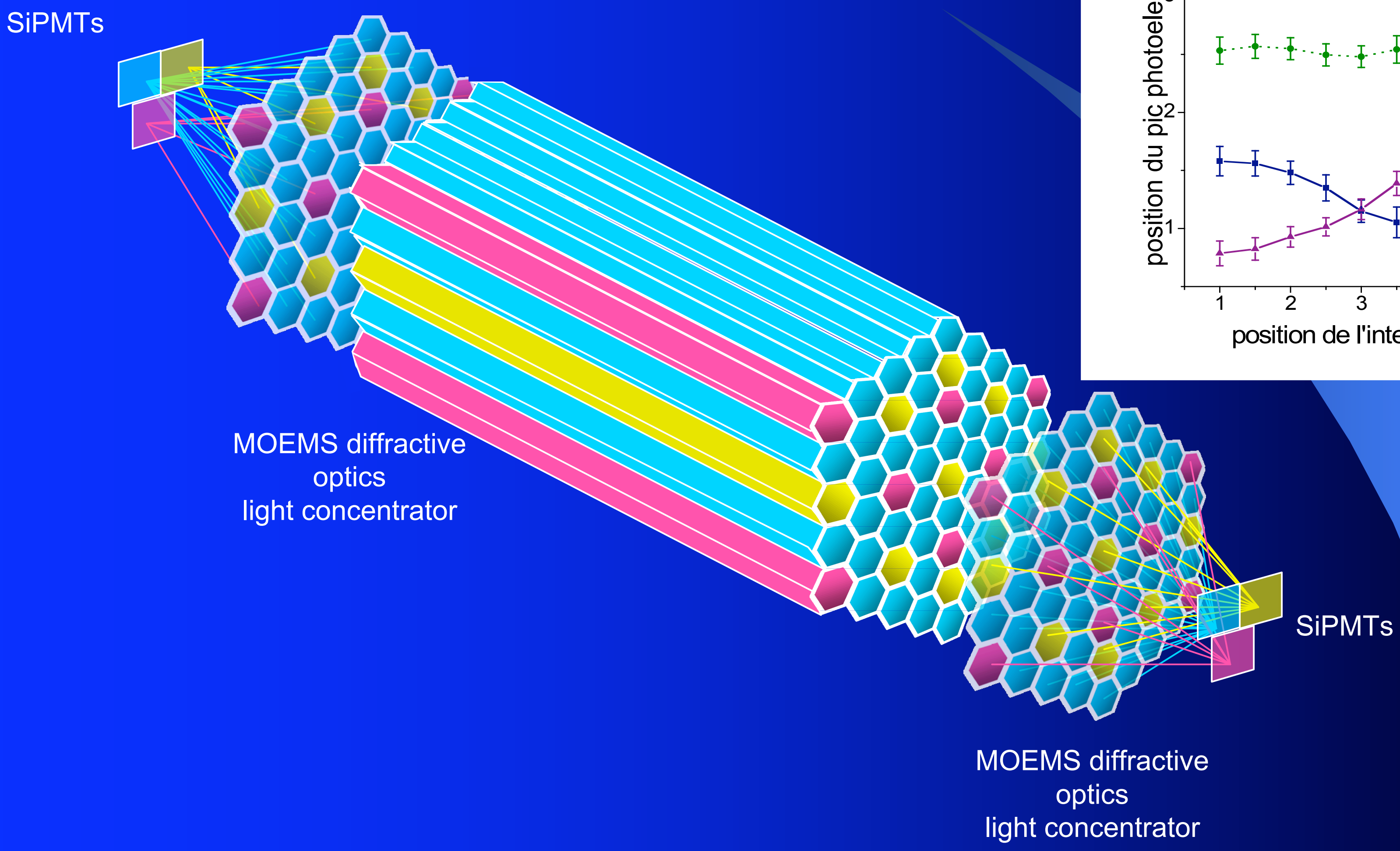


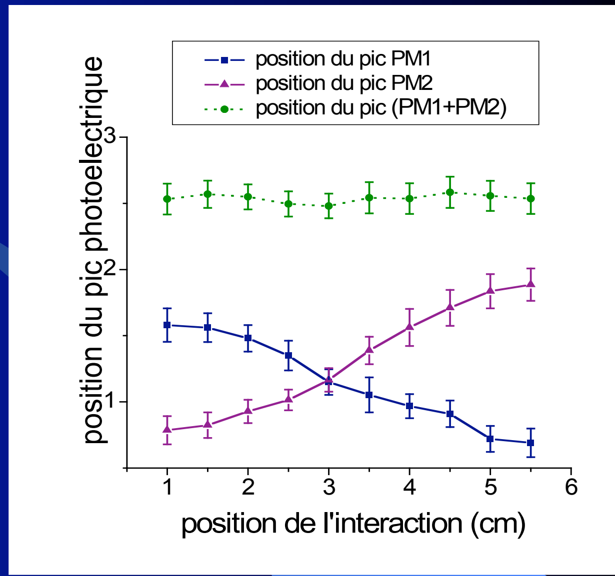
Distance from X-Ray interaction point

Concept of meta-cable

- Select a non-intrinsic scintillating material (unlike BGO or PWO) with high bandgap for low UV absorption
- The undoped host will behave as an efficient Cerenkov: heavy material, high refraction index n, high UV transmission
- Cerium or Praesodinum doped host will act as an efficient and fast scintillator
  - ≈ 40ns decay for Ce
  - ≈ 20ns decay for Pr
- If needed fibers from neutron sensitive materials can be added:
  - Li Tetraborate: $Li_2B_4O_6$
  - LiCaF: $LiCaAlF_6$
  - elpasolite family (Li or B halide of Rb, Sc and rare earth)
- All fibers can be twisted in a cable behaving as a pseudo-homogeneous active absorber with good position and energy resolution and particle identification capability
- Readout on both sides by SiPMT's

Concept of meta-cable





Lutetium Aluminum Garnet LuAG ($Lu_3Al_5O_{12}$)

Physico-chemical properties

Structure / Space group	Cubic / Ia3d
Density (g/cm^3)	6.73
Zeff	62.9
Radiation length X_0 (cm)	1.41
Interaction length (cm)	23.3 *LuAP: 19.8* *Fe: 17*
Hardness (Mohs)	7.5 *PWO: 3* *BGO, glass: 5*
Fracture toughness ($Mpa.m^{1/2}$)	1.1
Cleavage plane / H_2O solubility	No / No
Melting point (°C)	2260
Thermal expansion @ RT ($°K^{-1}$)	$8.8\ 10^{-6}$
Thermal conductivity @ RT (W/m°K)	31

Optical properties

Light yield: Ce or Pr doped (ph/MeV)	20'000 *1/2 NaI(Tl)*
d(LY)/dT	?
Emission wavelength (nm): Ce doped Pr doped	535 290, 350
Decay time (ns): Ce doped Pr doped	70 20
Refractive index @ 633nm (isotropic) $n^2 = 3.3275151 - 0.0149248\ \lambda^2$	1.842 *Quartz: 1.55*
Fundamental absorption undoped (nm)	250
Max. Cerenkov 1/2 angle	57°
Total reflexion 1/2 angle	33°
Cerenkov threshold e energy (KeV)	97

Different Cerenkov materials

Material	Density (g/cm^3)	Radiation length X_0 (cm)	Refractio n index n	Critical angle	Fondamental absorption (nm)	Cerenkov threshold e energy (KeV)	Relative photon yield*
SF6	5.2	1.69	1.81	56°	360	102	100
Quartz	2.2	12.7	1.46	47°	190	190	250
PbF_2	7.66	0.95	1.82	57°	250	101	210
$PbWO_4$	8.28	0.89	2.2	63°	370	63	104
LSO	7.4	1.14	1.82	57°	190	101	329
LuAG	6.73	1.41	1.84	57°	177	97	369
LuAP	8.34	1.1	1.95	59°	146	84	501

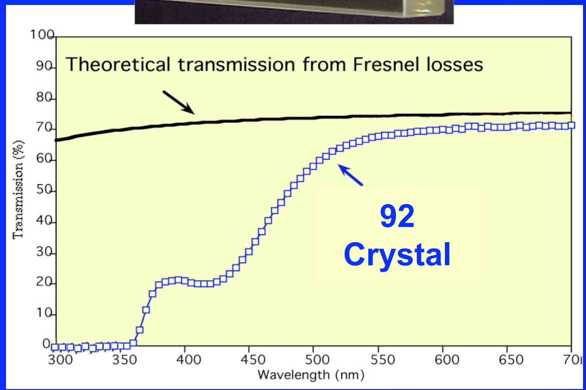
* For β =1 particles. But lower β Cerenkov threshold for high n materials should further improve the photon yield in showers

Conclusions

- This approach is based on the DREAM concept
- Added value: quasi-homogeneous calorimeter
  - scintillating and Cerenkov fibres of the same heavy material allowing to suppress sampling fluctuations
- Additional neutron sensitive fibers can be incorporated
- Very flexible fiber arrangement for any lateral or longitudinal segmentation: for instance twisted fibers in “mono-crystalline cables”
- em part only coupled to a “standard” DREAM HCAL or full calorimeter with this technology? Simulations needed

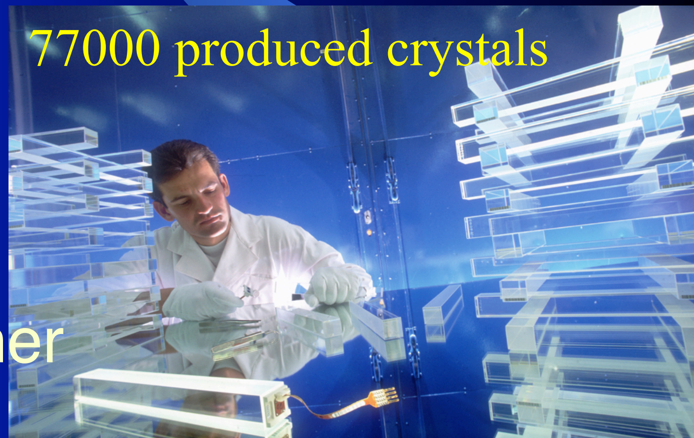
Last comment

10 cm



8 years
R&D

8 years
production



"One of the key lessons learned from other programmes,
including Hubble, is to start your technology early
and mature it before you get into the development stage"