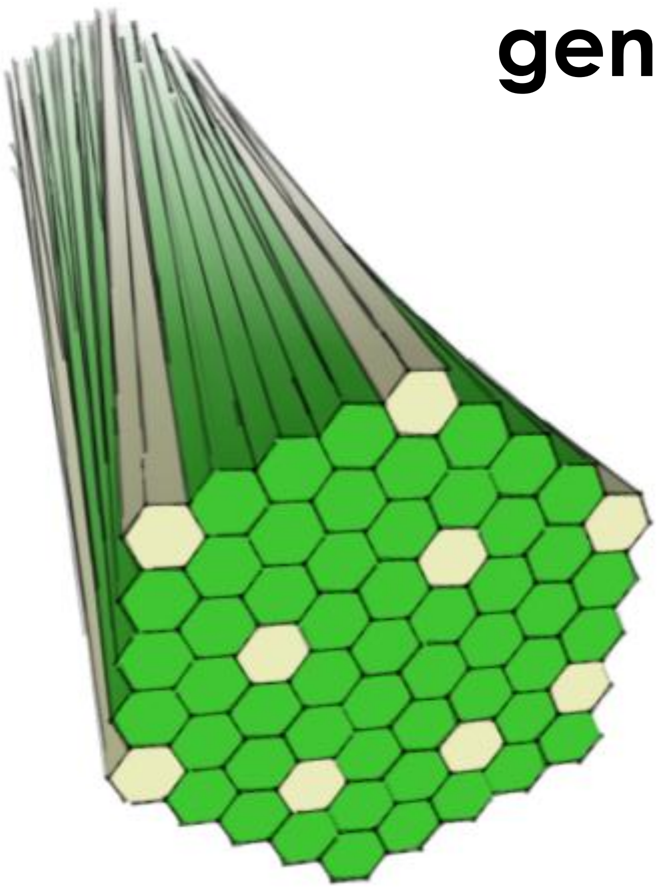
Single crystalline LuAG fibers for next generation calorimeters



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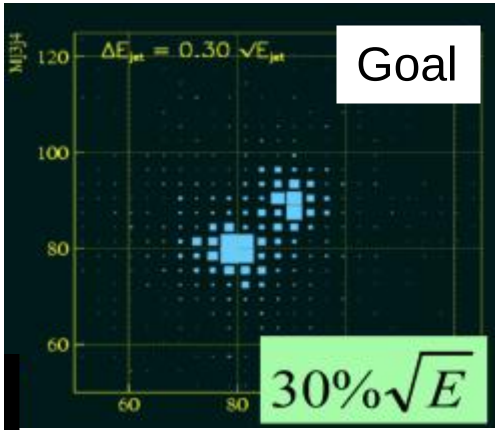
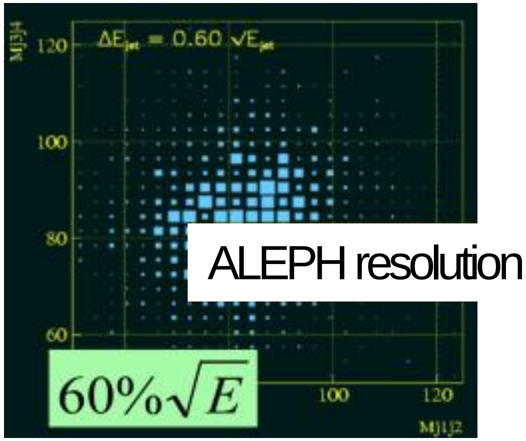
Calorimetry challenges in future high energy colliders

Precision Physics at future colliders characterized by multi-jet final states with a small cross section

Precise measurements of these multi jet events (e.g. separation of W,Z) will require:

- high luminosity
- high detector performance (30%/ √E)





Need for high granularity and particle identification (PID)

Usual hadronic calorimeters (with sampling) are limited to about 60% / √E

To meet the requirements, there are mainly 3 lines of approach

Particle flow paradigm (CALICE)

highly granular EM and HADR calorimeters to allow very efficient pattern recognition for excellent shower separation and PID within jets

Dual readout calorimetry (DREAM)

measurement of both the ionisation/scintillation and Cherenkov signals generated by a hadronic shower in order to determine on an event by event basis the EM fraction of the shower and so to correct for this source of fluctuation that degrades the energy resolution of the calorimeter

Crystal/glass calorimetry (HHCAL Workshops)

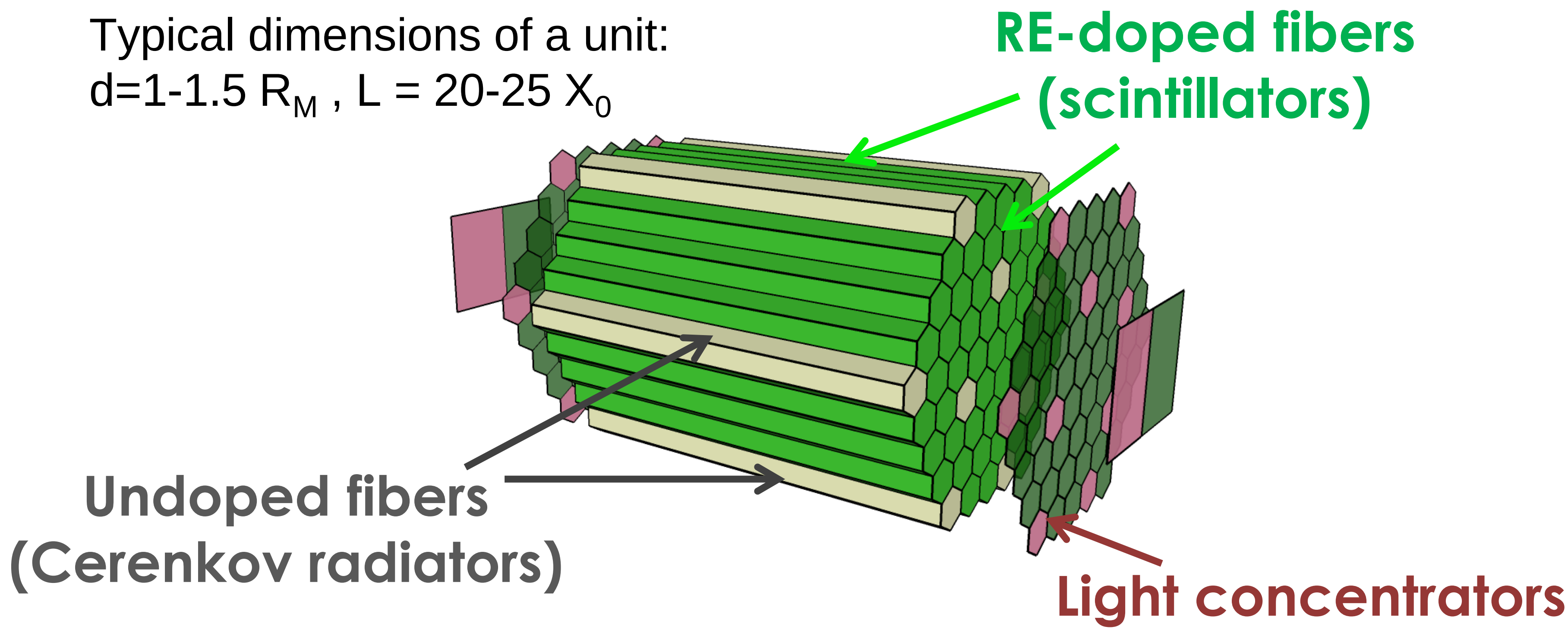
an approach that could combine the excellent energy resolution of crystals (homogeneous detector) with dual readout, if scintillation and Cherenkov signals can be separated and recorded, and with particle flow capabilities if the detector is segmented with high granularity

Dual Readout with metamaterials

Select a non-intrinsic scintillating material (unlike BGO or PWO) with high bandgap for low UV absorption

Homogeneous calorimeters with high granularity and dual readout abilities

Typical dimensions of a unit:
d=1-1.5 R_M , L = 20-25 X_0



P. Lecoq, Journal of Physics 160(1) (2008) *P. Lecoq, IEEE NSS* (2008)

Predictions for detector performances

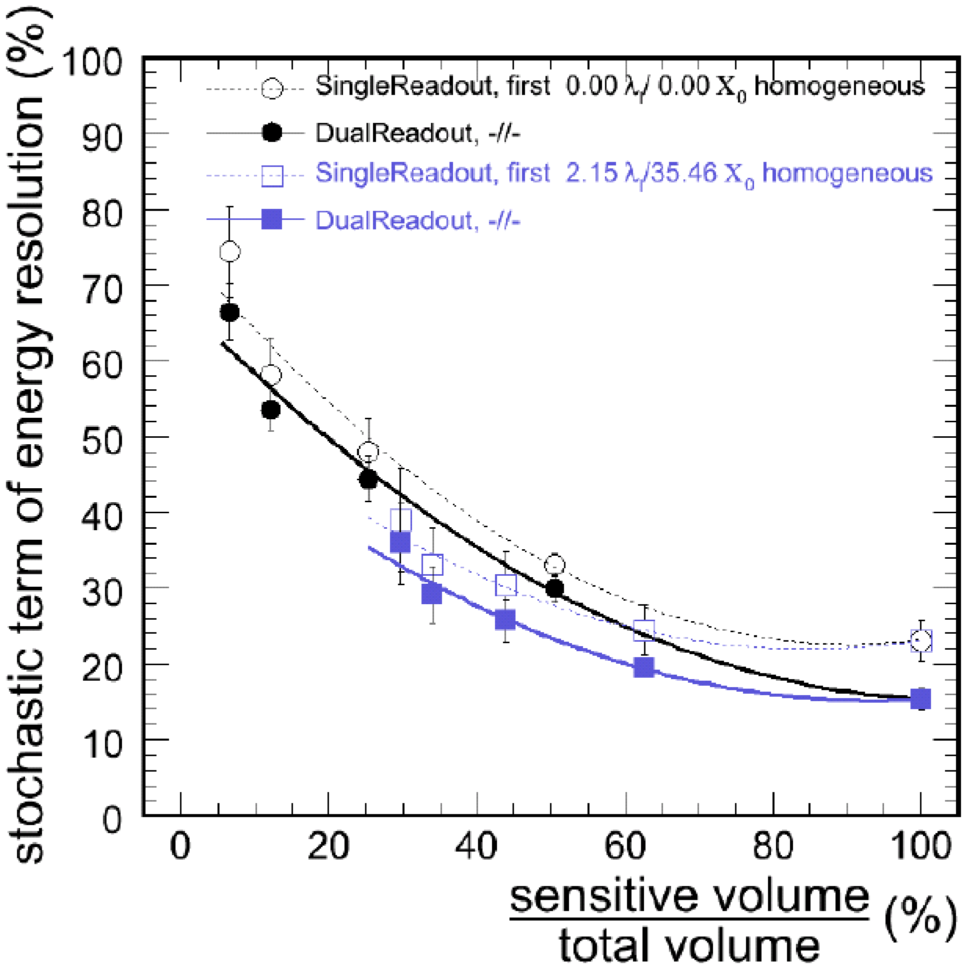
Systematic scanning of the parametric space with respect to:

- Granularity
- Sampling fraction
- Readout fraction
- Total length
- Mixture of conventional and dual readout components
- Mixture of homogeneous and sampling components

Case of an ideal calorimeter without leakage volume of 1x1x2 m^3 (4.3×4.3×8.6 λ_{Int})

G. Mavromanolakis et al., Journal of Instrumentation, 6 p10012 **(2011)**

Predictions for detector performances



Full homogenous
single readout

22 % / √E

Full homogenous
Dual readout

15 % / √E

G. Mavromanolakis et al., Journal of Instrumentation, 6 p10012 (2011)

Lutetium Aluminium garnet (LuAG)

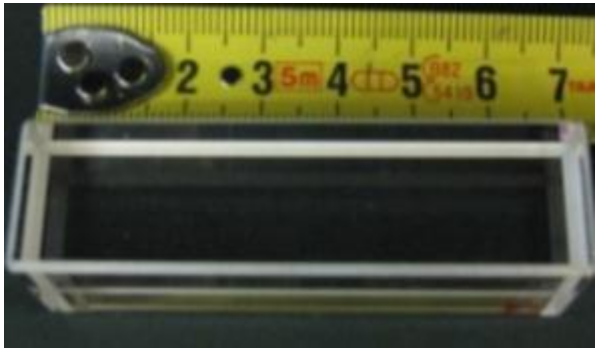
Formula	$Lu_3Al_5O_{12}$		
Zeff	62,9	X_0	1,41 cm
Density	6,73 g/cm^3	λ_{Int}	23,3 cm

Cherenkov radiator

Transmission cutoff	250 nm
Refractive index (250-650 nm)	2.14 – 1.84
Cherenkov threshold	97 keV
Expected yield	1400 ph/cm
Maximum Cherenkov angle	57°

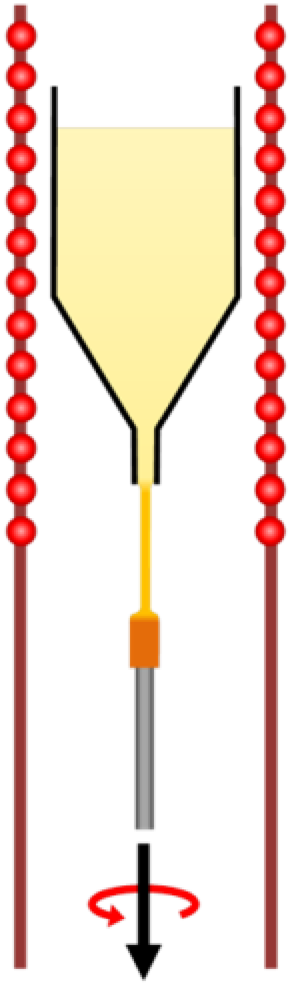
Ce^{3+} activated scintillation

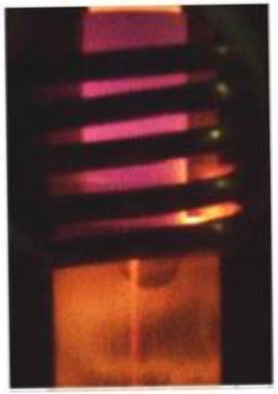
Light yield	30 000 ph/MeV
Emission	520 nm
Decay	60 ns



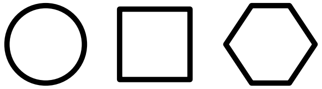
E. Auffray et al., NSS 2009 p2245. E. Auffray et al., TNS 2010 57 (3) p1454

LuAG grown by micro-pulling down





Ø = 300 µm – 3 mm
Lengths up to 2 m

- Multiple geometries for capillary die 

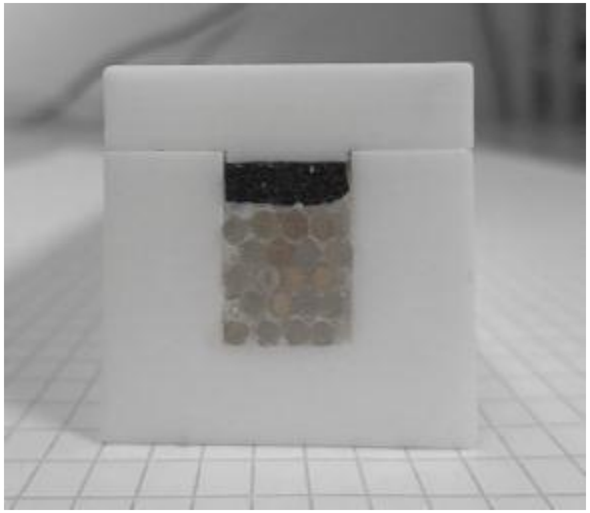
- Fast pulling rates

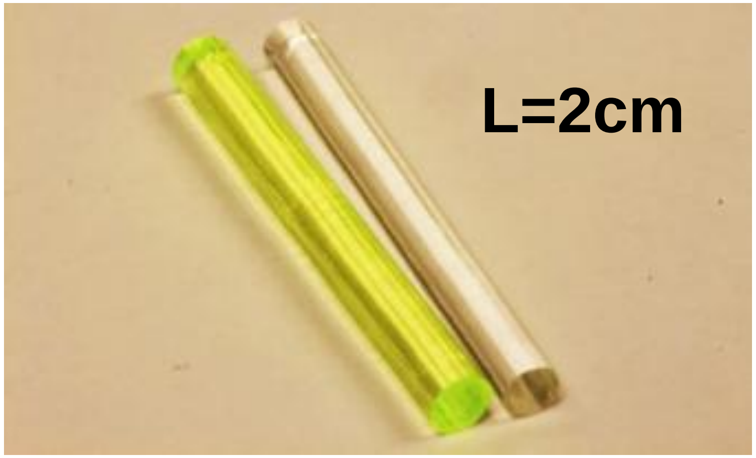
- Multi-fibers pulling possibilities (in parallel)

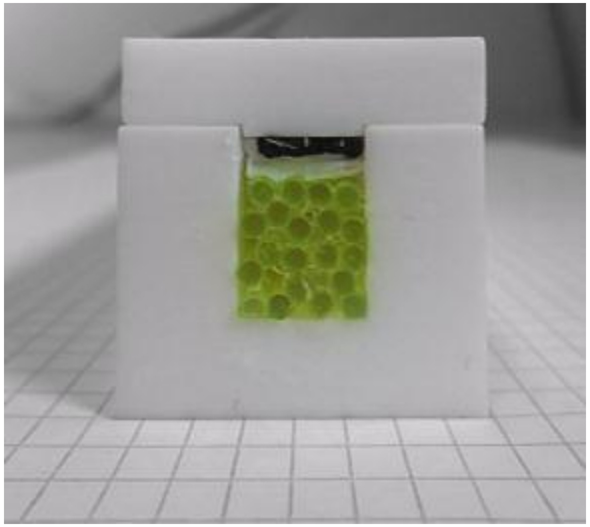
- Overall cost per unit volume of production expected to be comparable to standard crystal growth methods

C. Dujardin et al. Journal of Applied Physics 108 p013510 (2010)

Examples of LuAG crystal fibers







Current state of R&D

Main effort of the R&D on the improvement of the fibers quality

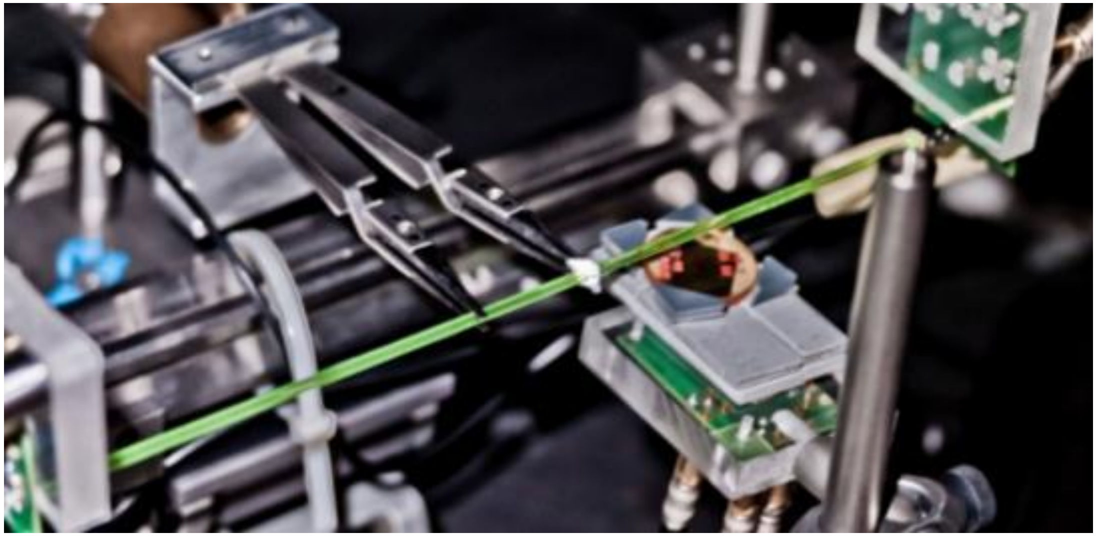
Significant light losses were observed with early batches
Segregation of doping ions led to a non-homogenous light response

We received support from the French National Agency for Research (ANR) with the project INFINHI ANR-10-BLAN-0947

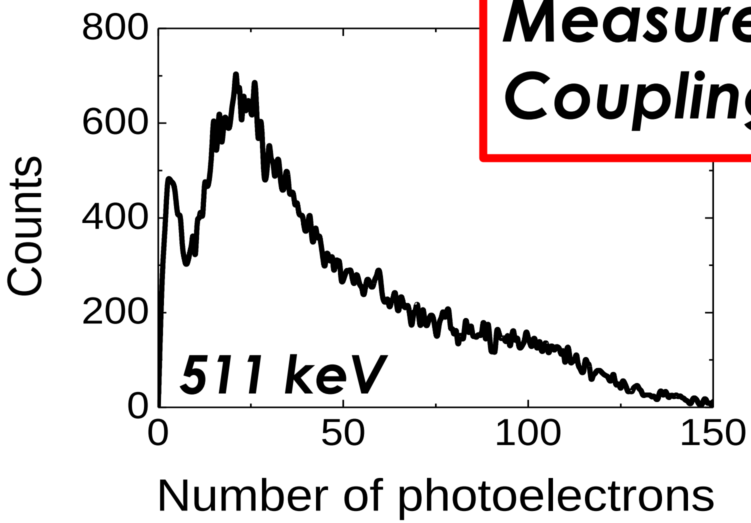
R&D oriented along the following lines:

- Effect of the fiber geometry
- Improvement of the light attenuation
- Homogenousity of the light output
- Selection of a readout scheme
- Validation with test beam

Light output of LuAG fibers



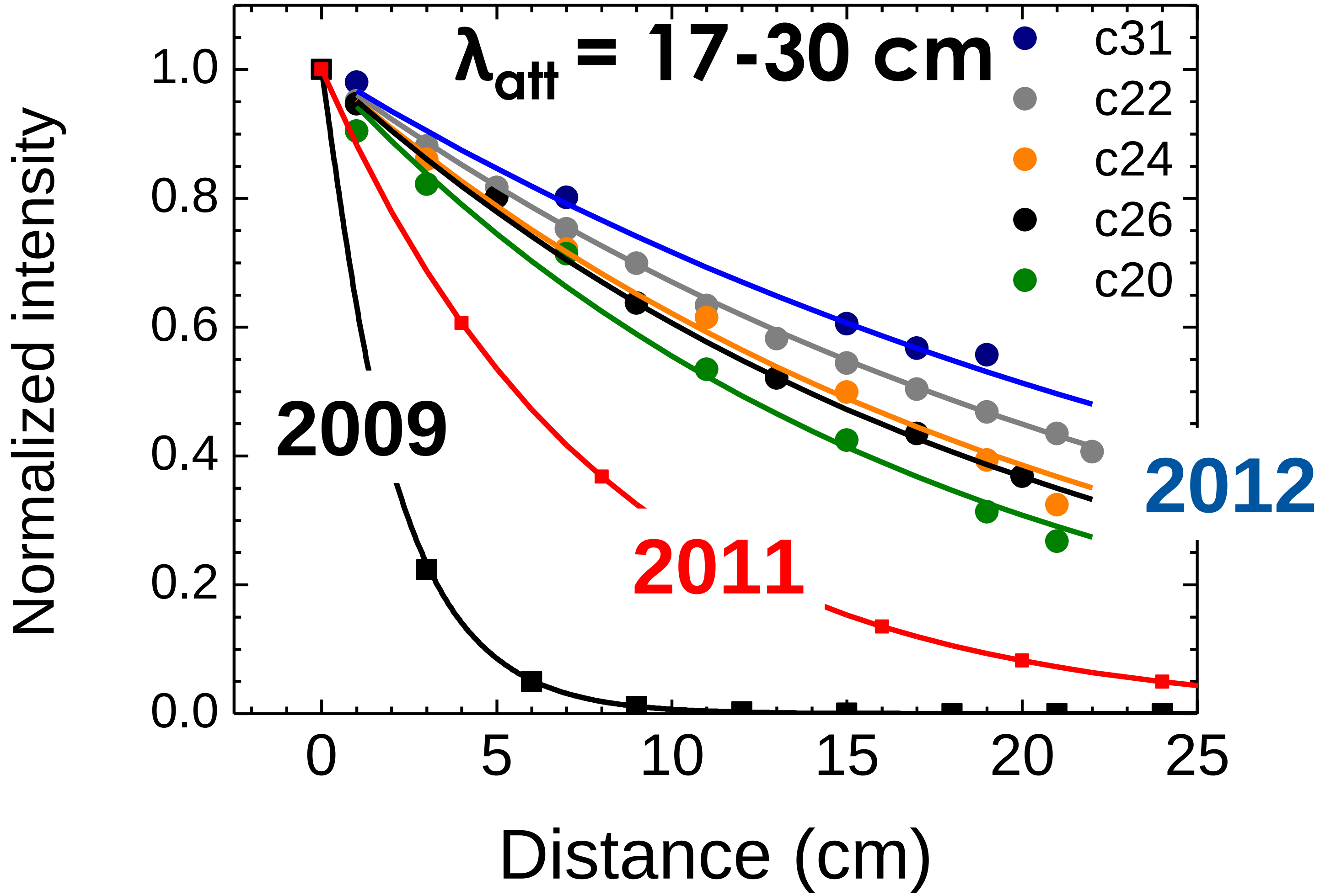
Hamamatsu 3x3mm MPPC 50x50µm



Measured in air (no cladding/coating)
Coupling media: silicon grease (n=1.4)

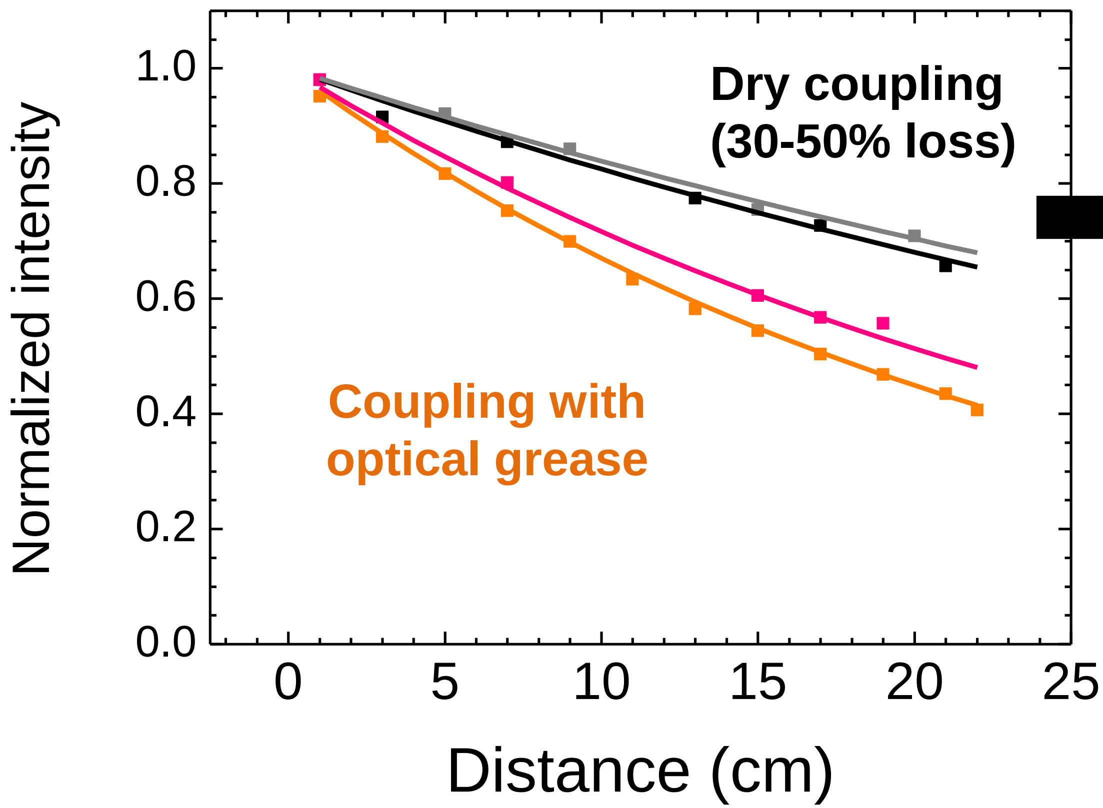
≈ 1000 ph/MeV

Light attenuation in LuAG fibers

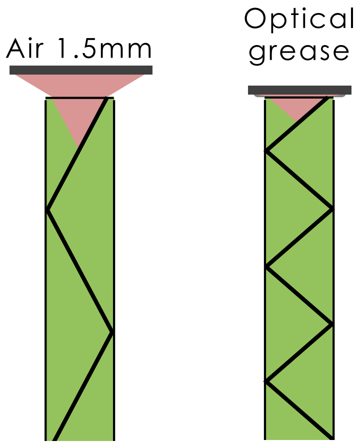


(with optical grease / no wrapping)

Can be further improved …



Lower light output (loss of 30%) but λ_{att} > 50 cm !



If photostatistics allow it, the selection of a narrower collection angle would improve light attenuation (within this cone).

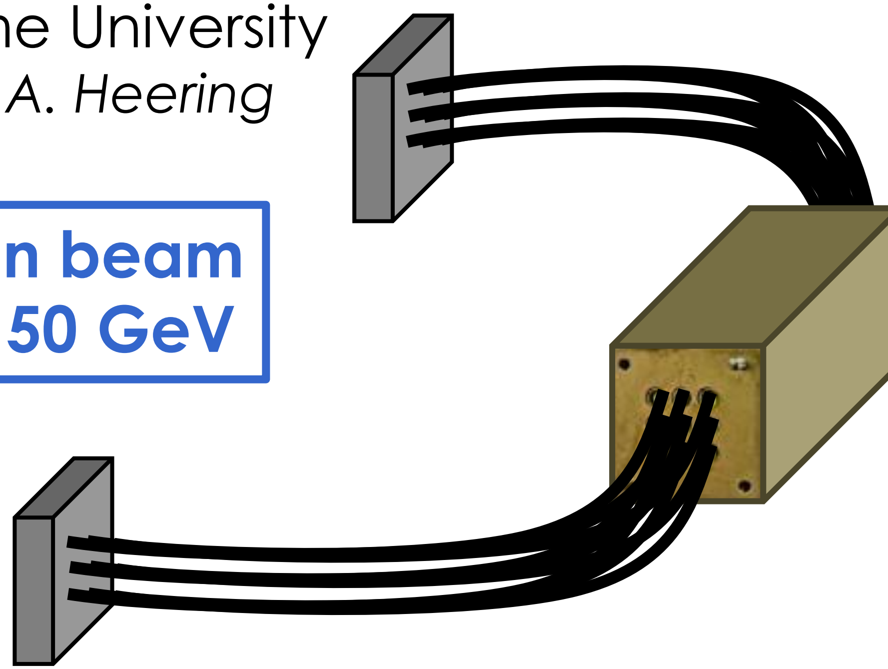
Narrow collection cones are also more interesting for timing aspects …

Test beam with 9 LuAG fibers

In collaboration with
Princeton University
C. Tully, T. Medvedeva
Notre Dame University
R. Ruchti, A. Heering

H2 beamline
SPS North Area
at CERN

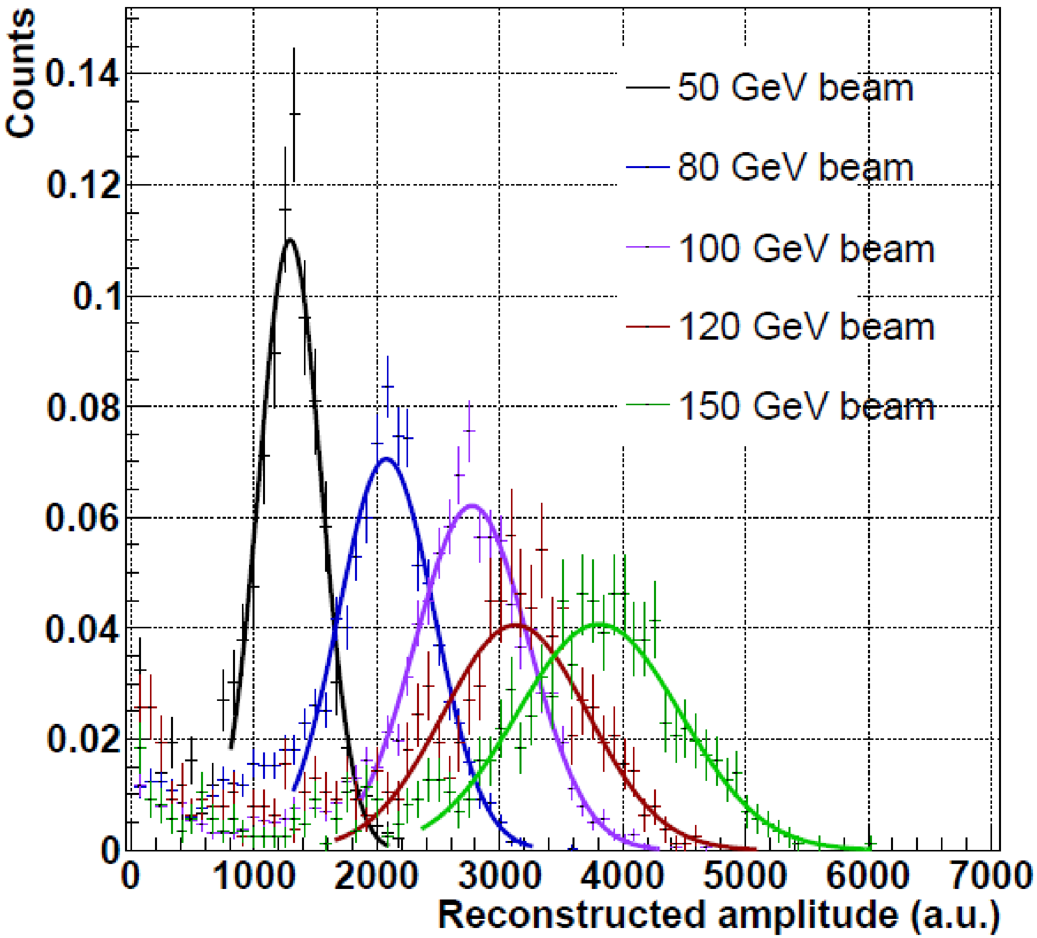
Electron beam
E=50-150 GeV

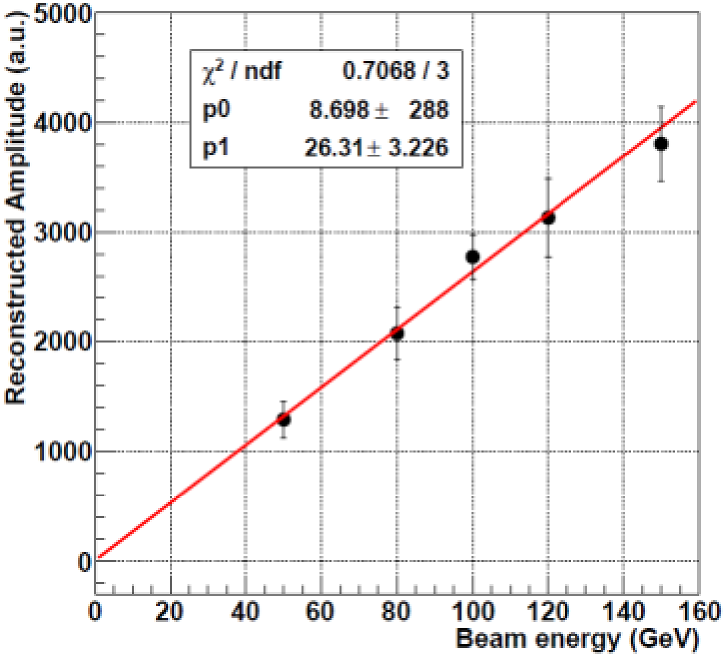


Fibers selected

5 LuAG fibers with highest concentration of Cerium
3 with lower Ce concentration
1 undoped for Cherenkov signature

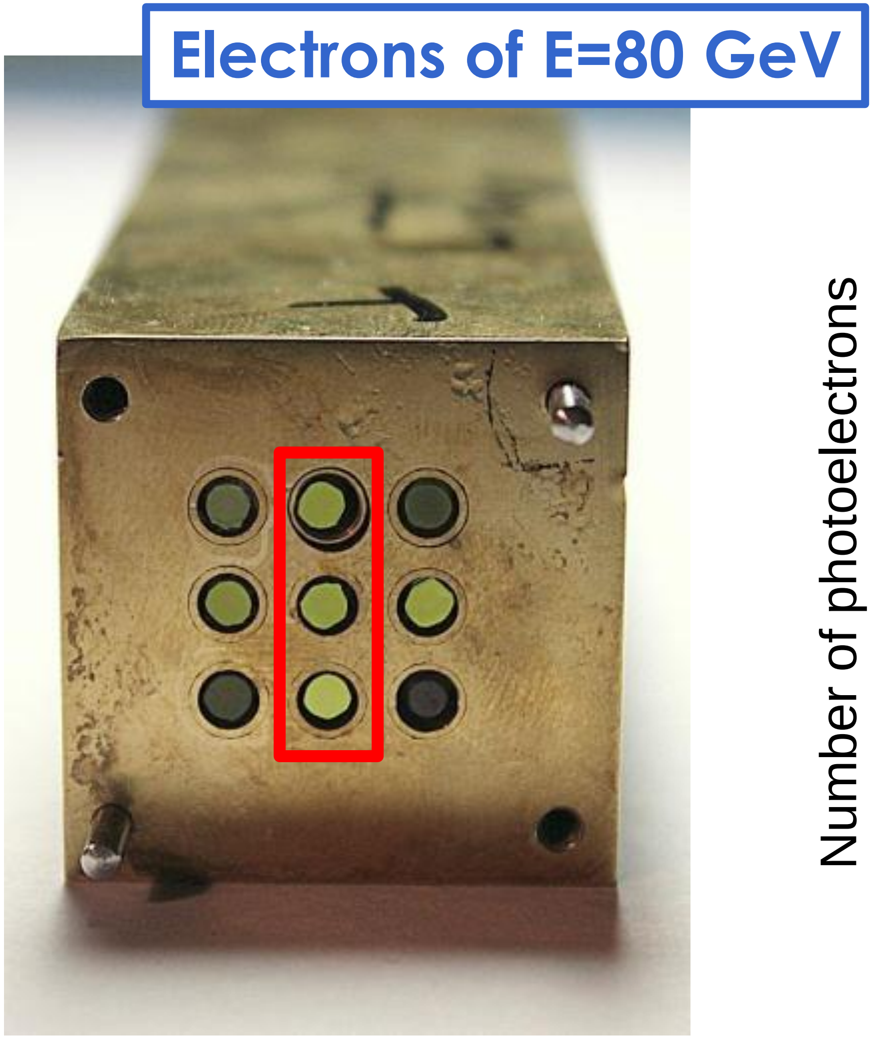
Energy deposits in the 9 fibers for different beam energies

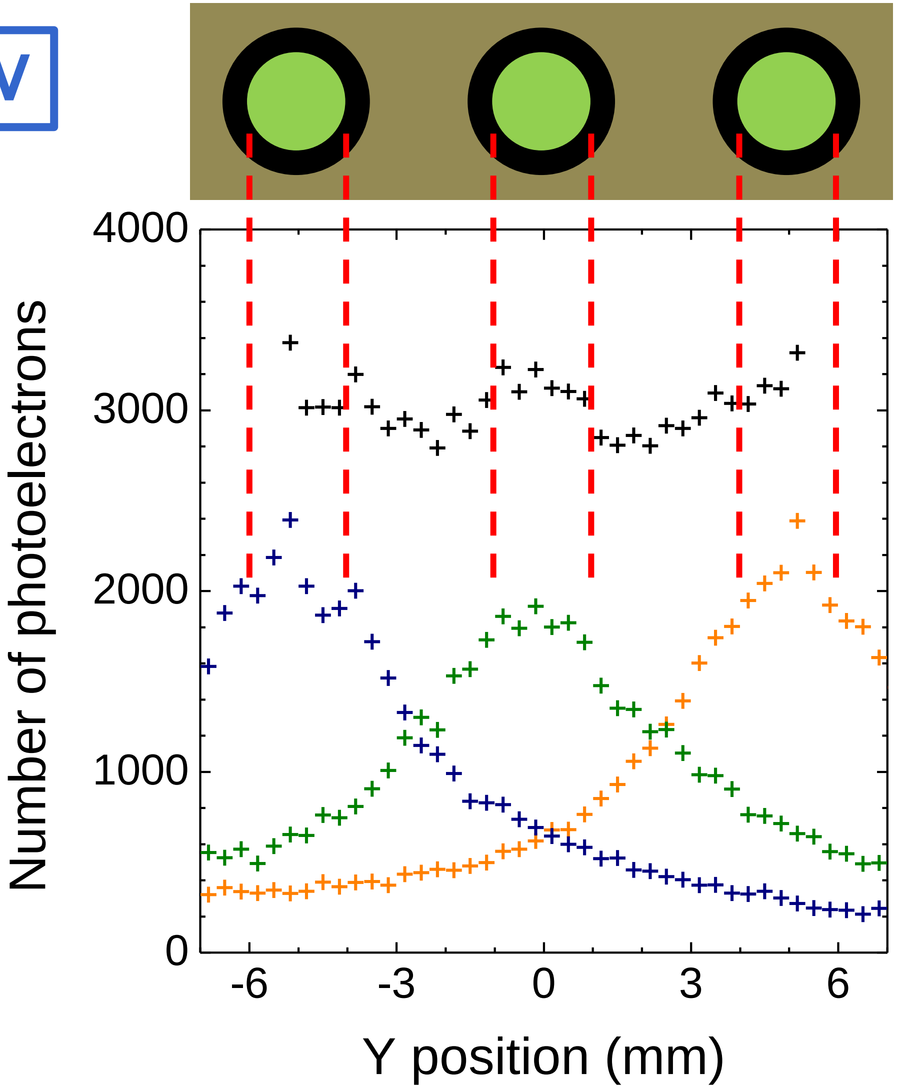




Obtained after intercalibration of the 9 fibers

Readout of a fiber row





Summary and outlook

*Metacables based on fibers open promising perspectives for **fully homogeneous hadronic calorimeter** (usually considered unfeasible due to large detector volumes and cost)*

R&D on materiel and fiber production yielded:

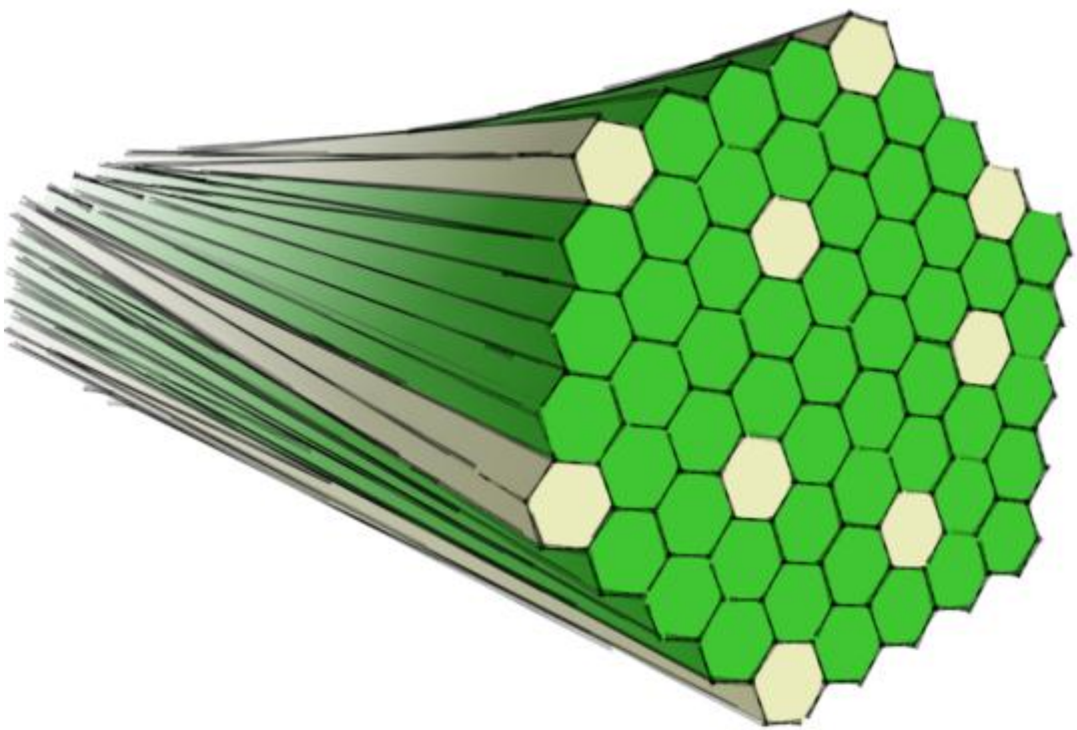
- a light output of **800-900 ph/MeV**
- A behavior as light guide significantly improved

  λ_{att} **= 25-50 cm** *depending on light output required*

Upcoming work

- Development of a larger bundle prototype
- Study of optimized geometry/packing (simulations)
- Dedicated radiation hardness studies (on µPD samples)

Thanks for your attention !



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