

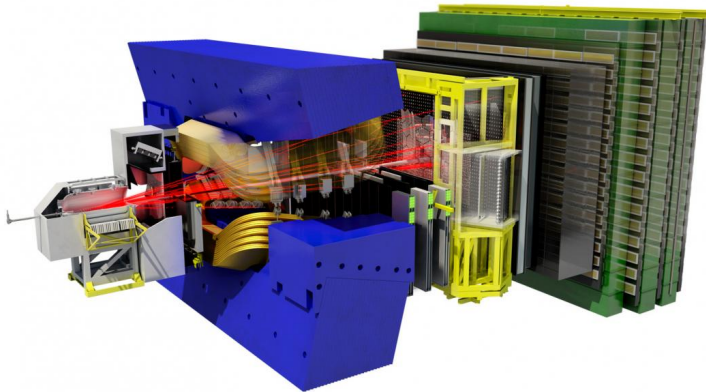
Crystal Fibres for LHCb Calorimeter Upgrade

Loris Martinazzoli

CERN EP-LBO & Crystal Clear Collaboration
on behalf of the LHCb SpaCal R&D Group

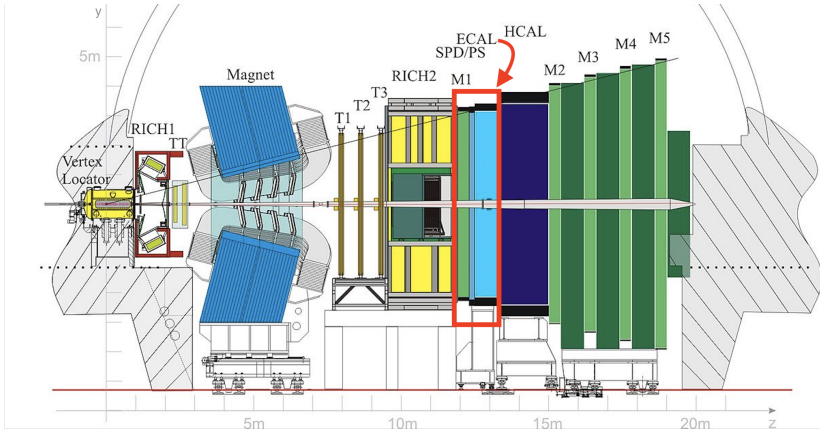


SCINT 2019
30th September

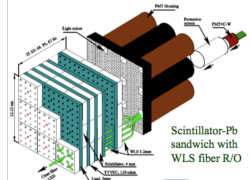
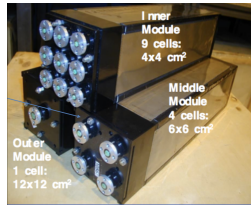
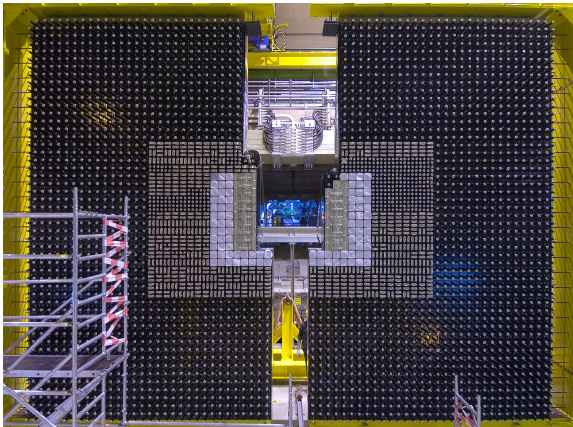


Single-arm forward particle spectrometer at CERN LHC investigating:

- Parameters of CP symmetry violation.
- Physics of the b-quark and the B-mesons (produced along lines close to the beam pipe).



- Design: forward spectrometer with planar detectors
- Size: 21m long, 10m high and 13m wide
- Weight: 5600 tonnes



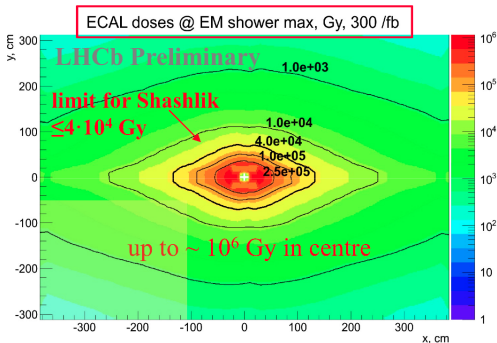
LHCb Electromagnetic Calorimeter (ECal)

- Dimension: $7.76 \times 6.30 \text{ m}^2$
- Horizontal acceptance: $1.4^\circ - 17^\circ$
- Vertical acceptance: $1.4^\circ - 14^\circ$

Shashlik ("skewer") technology:

- 4mm thick scintillating plastic tiles.
- 2mm thick Pb tiles.
- WLS fibres running through the tiles.

With future LHC upgrade (High-Luminosity LHC), the expected radiation dose will increase vastly and vary inside Ecal.



- Simulations suggest that the centremost area will receive a dose up to 1 MGy.
 - Required a radiation hard and dense material.
 - Crystals
- Scintillating crystal garnets are possible candidate materials.

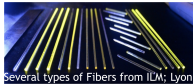
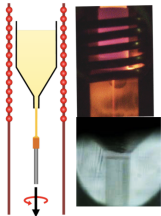
Detector requirements:

- High radiation hardness
- Small cell size and Moliere radius
- Good energy resolution
- Good time resolution

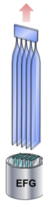
⇒ **Crystal Spaghetti Calorimeter**

Crystal Fibres Production

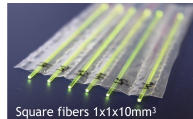
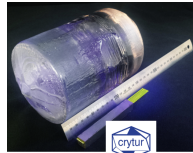
μ -PullingDown Technique



EFG



Czochralski and machining



The feasibility study was the main goal of the Intelum project (European Rise project grant 644260) with 16 Partners (many from CCC) from 12 different countries.

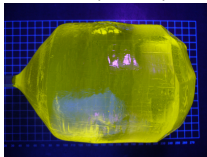
See talk O1-5-5, E. Auffray.



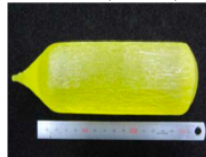
Crystal Fibres for SpaCal

Due to the best achievable quality at present, Czochralski-technique fibres were selected for the onset of the SpaCal project.

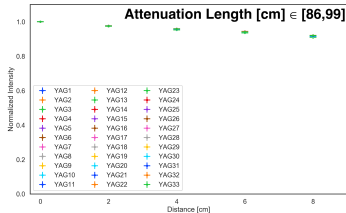
YAG (Crytur)



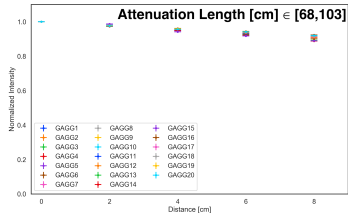
GAGG (Fomos)



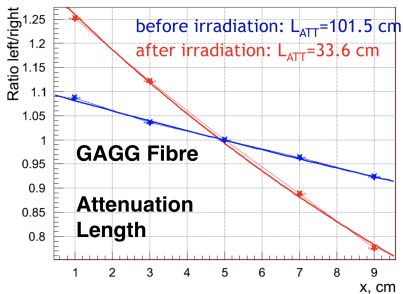
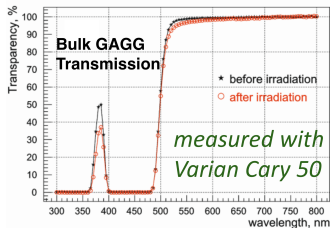
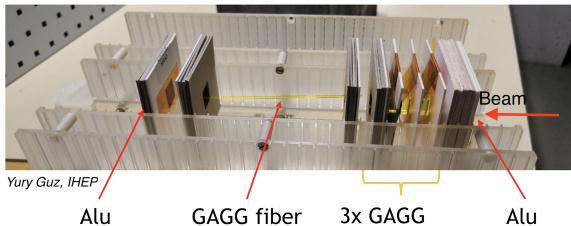
- YAG $1 \times 1 \times 100 \text{ mm}^3$



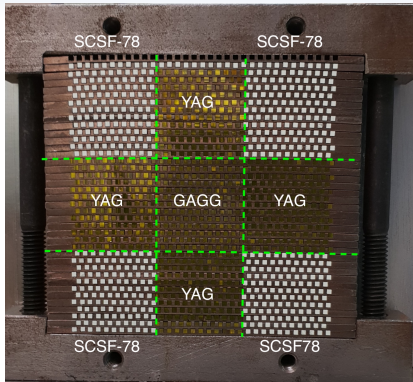
- GAGG $1 \times 1 \times 100 \text{ mm}^3$



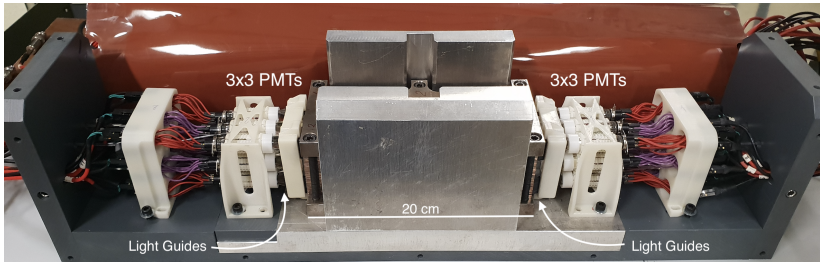
GAGG samples were irradiated with a proton flux of $3.5 \cdot 10^{15}$ p/cm², 24 GeV (1.03 MGy) at CERN PS.

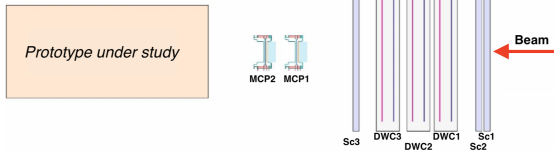


2.5% energy resolution's constant term
if radiation length $X_0 = 0.8$ cm



- Absorber of W/Cu (75/25) alloy.
- Density: 14.9 g/cm^3
- Plates dimension: $1.5 \times 60 \times 200 \text{ mm}^3$
- Grooves dimension: $1 \times 1 \times 200 \text{ mm}^3$
- Cell size: $20 \times 20 \text{ mm}^2$
- 549 Plastic fibres \rightarrow 200 mm long
- 1374 Crystal fibres \rightarrow 100 mm long
 - 278 GAGG fibres
 - 1096 YAG fibres
- Front and back sections are isolated by a thin layer of reflective material.





CERN SPS - H8 beamline:

- Muons - 180 GeV
- Electrons - 20 GeV

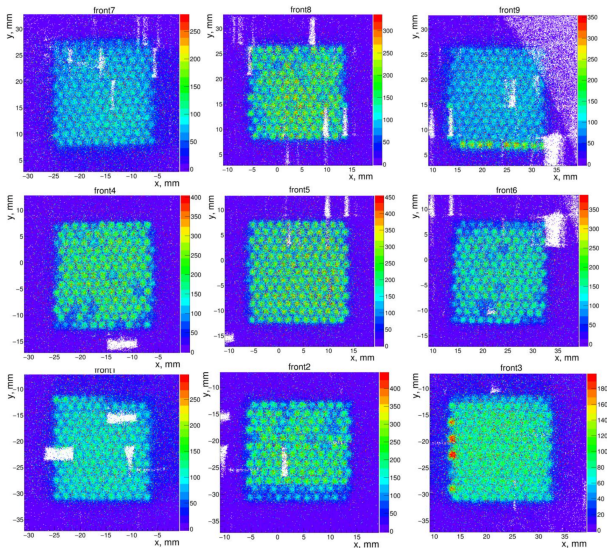
Setup:

- 3 DWCs for beam tracking.
- 3 Scintillating counters as triggers.
- 2 Cerenkov counters for timing.
- CAEN TDC V1290N - DWCs readout
- LeCroy ADC 1182 - Amplitude measurements
- CAEN DT5742 digitizer - Waveform recording

Tilt Angle ($\pm 0.5^\circ$):

- 3° - horizontal plane (azimuthal angle)
- $3^\circ \oplus 3^\circ$ - horizontal and vertical plane (azimuthal \oplus polar angle)
- 90° - horizontal plane (perpendicular to the beam) - Muons only
- 0° - horizontal plane (parallel to the beam) - Muons and electrons timing

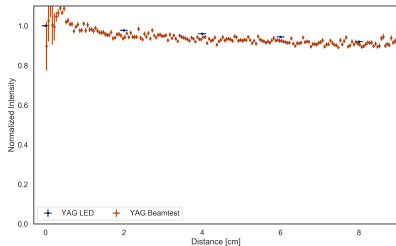
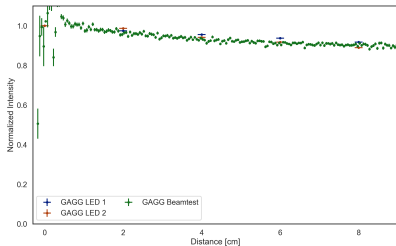
Combining the space information given by the wire chambers and the energy deposition in the prototype it is possible to reconstruct the granularity intrinsically provided by the fibres.



Clearly visible:

- Difference in light yield
- Light guides misplacements
- DWCs inefficient areas
- Individual fibres resolved.

- Placing the prototype orthogonally to the beam, the light attenuation can be checked.

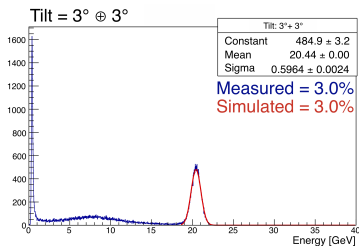
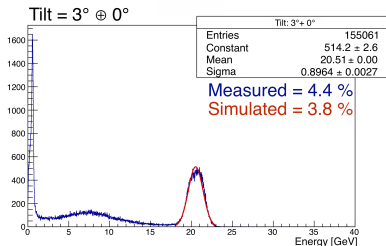


- Attenuation lengths λ compatible with those measured in laboratory.

$$\lambda \in [89, 99] \text{ cm}$$

Energy Resolution at 20 GeV:

To avoid border effects and leakages, only the events hitting in a $10 \times 10 \text{ mm}^2$ square in the center of the prototype were selected.

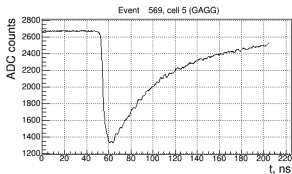
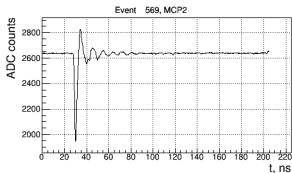
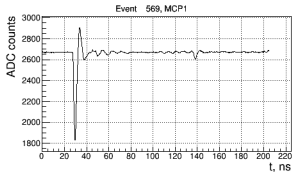


Photoelectrons Yield:

Each PMT is struck by a pulsed LED light.

- GAGG / YAG ratio compatible with the one measured in lab.
- Photoelectrons yield greatly spoilt by the light guides. Raytracing simulations show a loss of a factor ~ 4

Material	Photoelectrons/MeV	\pm
GAGG	9.71	0.22
YAG	6.76	0.16
Plastics	1.15	0.14



The current readout configuration is not optimal for time resolution:

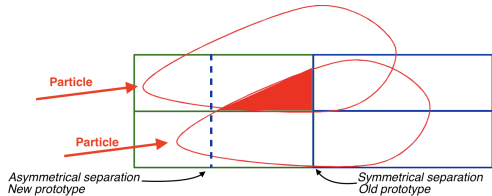
- Light yield hampered by the light guides.
- Readout from the side of the beam entrance worsens timings.

However some measurements were performed on the GAGG front cell (20 GeV electrons):

- Offline CFD technique employed.
- PMT Hamamatsu R12421.
- Corrected for the reference photodetector (MCPs) resolution ($\sigma = 21.8$ ps).

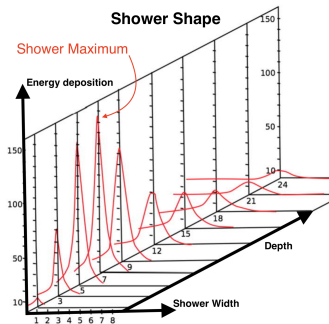
PMT Bias [V]	Time Resolution [ps]
630	85
730	78

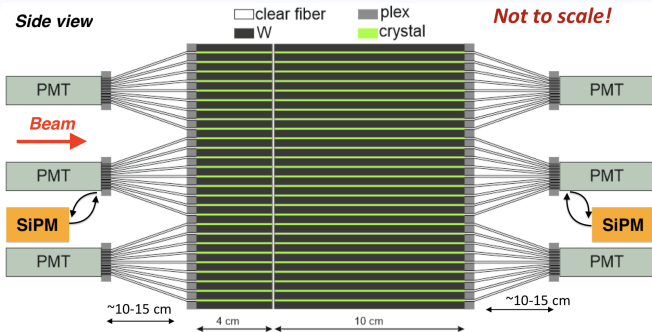
A new prototype is currently being designed and built.



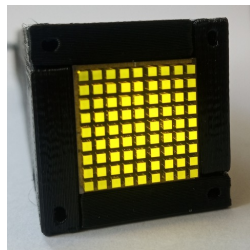
- Shorter front section to enhance shower separation...

- ... but long enough to contain the shower maximum.





- Absorber of pure Tungsten 14 cm long.
Density: 19 g/cm^3 .
 - 6 YAG cells.
 - 3 GAGG cells.
- Cell size: $1.5 \times 1.5 \text{ cm}^2$.
- Each scintillating fibre coupled to an optical fibre.
⇒ **Greater geometrical flexibility!**
- Test with both PMTs and SiPMs.



Proof of concept (CRYTUR)

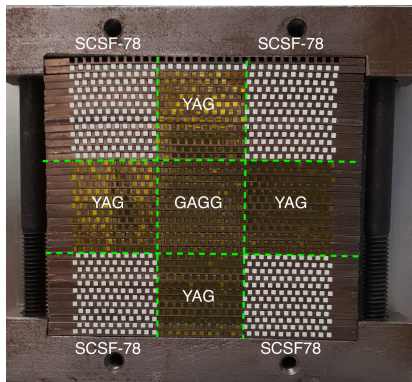
The Crystal Garnet Spaghetti Calorimeter was proven to be a viable option for the inner area of the LHCb Electromagnetic Calorimeter:

- Radiation hardness ✓
- High granularity ✓
Limited by the cell size: $20 \times 20 \text{ mm}^2$.
- Energy resolution (20 GeV electrons):

Prototype Tilt	Resolution $\frac{\sigma}{\langle E \rangle}$ [%]
$3^\circ \oplus 0^\circ$	4.4
$3^\circ \oplus 3^\circ$	3.0

- Time Resolution

PMTs Bias [V]	Resolution σ [ps]
630	85
730	78



Investigation of the crystal properties to improve timing ongoing. See poster on GAGG, N. Kratochwill, SCINT2019 P1-26

Future beam test planned at DESY in November 2019.

BACKUP

In order to find the calibration factors C_i to convert from ADC Channels to Energy, the following procedure was performed:

1. First a set of crude calibration factors μ_i was found making use of the muons as in:

$$\mu_i = \frac{k}{\langle A_i^\mu \rangle} \quad (1)$$

$\langle A_i^\mu \rangle$ is the mean signal in ADC channels generated by the passage of a muon in the channel i , and k is a fitting constant.

2. Secondly, a new set C_i was found minimizing the deviations from the known mean energy E_0 (20 GeV) value:

$$\begin{cases} \nabla_c \sum_{ev} [E^{ev} - E_0]^2 = 0 \\ E^{ev} = \sum_i C_i A_i^{ev} \end{cases} \quad (2)$$

- Leakages must be avoided $\implies 40 \times 40 \text{ mm}^2$ and 18-22 GeV selection window
- Due to impure beam the procedure is iterate until convergence is reached.
- To help convergence the ratio between front and back calibration factors should be fixed to the muons' ones (see *NIMA 485 (2002) 385*):

$$c_i = \frac{\mu_i}{\mu_{i-9}} c_{i-9} \quad i = 10, \dots, 18$$



Configuration	PMT Bias [V]	Time Resolution [ps]
Standard	1000	66
Rotated	1000	177

- A shower longitudinal shift Δz produces a time shift $\Delta t = \frac{\Delta z}{c} (n - 1)$ in the standard configuration, whereas produces a fluctuation $\Delta t = \frac{\Delta z}{c} (n + 1)$ if the particle is entering from the PMT side \implies Worse timing.
- The same argument applies also for the SpaCal prototype!