Testbeam activities for ECAL Upgrade Ib/II

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on behalf of the LHCb CALO & SPACAL-RD group.

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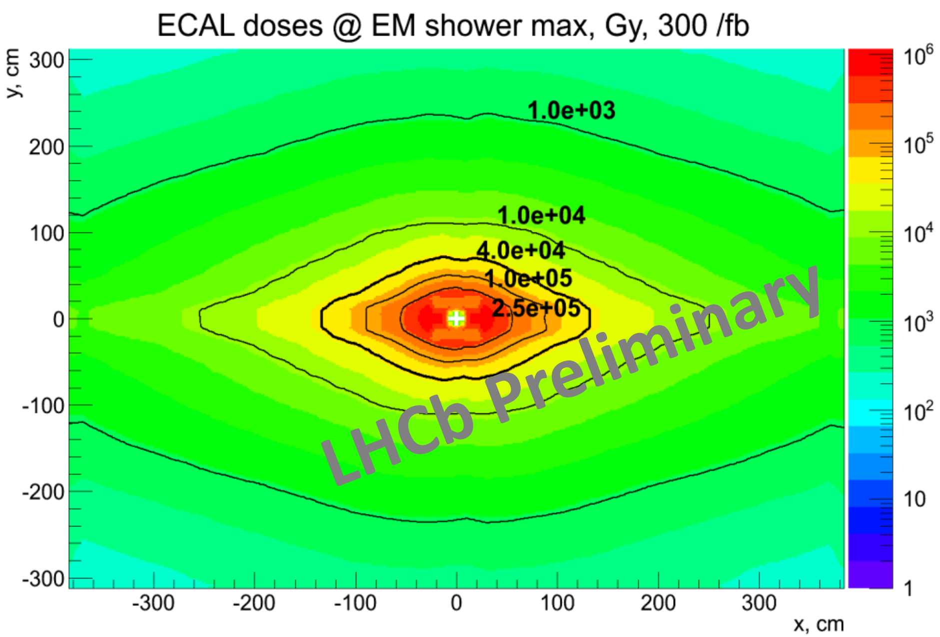
Motivation



up to ~1 MGy in the centre

One can suppose that the U-2 is subdivided into *at least* three zones (not necessarily rectangular)

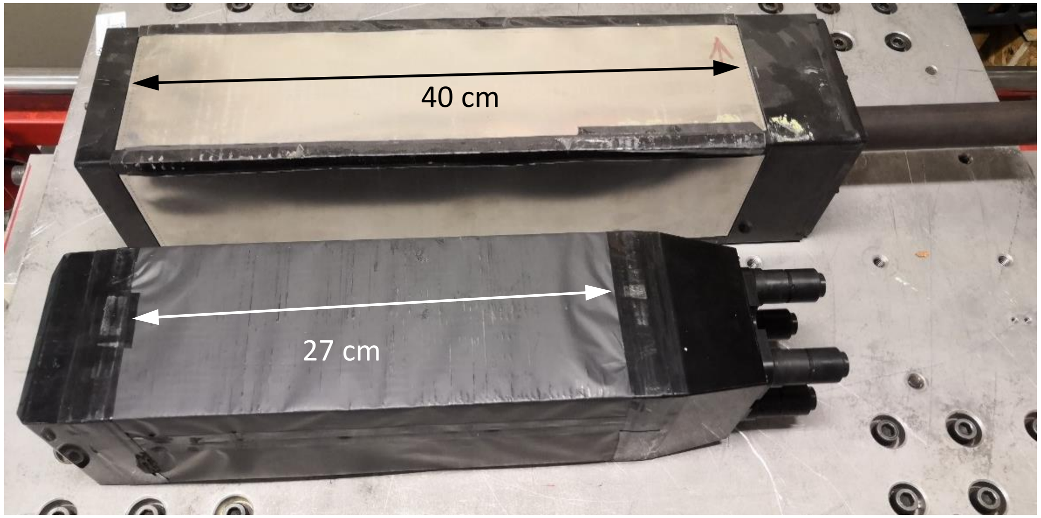
Inner – rad hard and dense, like W/crystal

Middle – Shashlik (smaller cells)

Outer – Shashlik (larger cells)

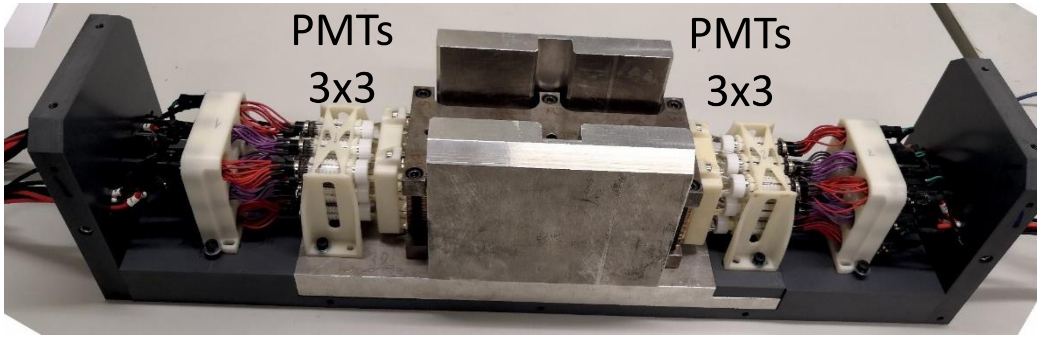
Time measurements are important over the whole ECAL

Prototypes – I



present ECAL module
shashlik, Pb:Sc = 1:2 (vol)
$25X_0$ = 40cm; R_M=36mm

"short" shashlik module
Pb:Sc = 1:1 (vol)
$25X_0$ = 27cm; R_M=27mm
(made in Protvino, 2017)



crystal/W
SPACAL, *W:Sc = 1:0.6,*
~$28X_0$ = 20cm; R_M=16mm

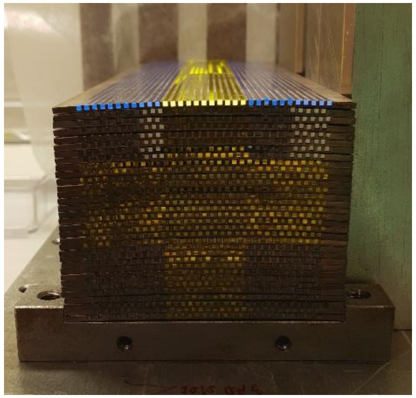
The help from Thomas Schneider in the SPACAL prototype preparation was invaluable!

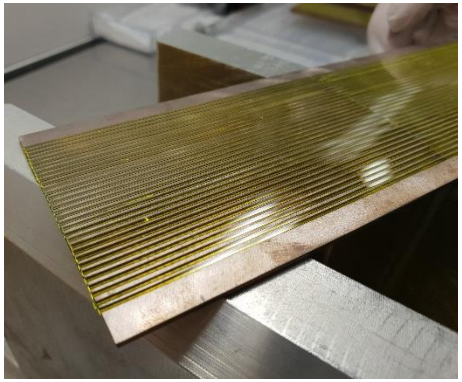
Prototypes – II

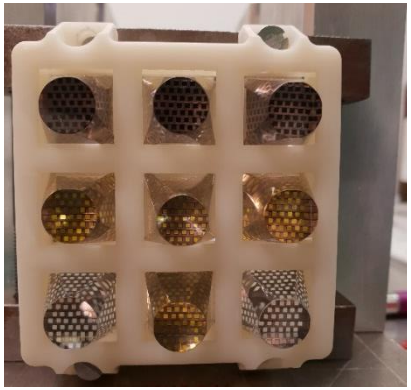
The SPACAL prototype:

- 20 cm long
- split into two sections longitudinally
- 3x3=9 cells in each section
- Three different scintillators used:
    - centre: GAGG:Ce (FOMOS)
    - sides: YAG:Ce (CRYTUR)
    - corners: plastic (KURARAY SCSF-78)
- the crystal “fibers” are 10 cm long
    - one end is aluminized
- the plastic fibers are 20 cm long

- light readout:
    - subdivided into 3x3 cells, 20x20 mm^2 each
    - connected via PMMA light guides
        - light collection efficiency: next talk by Loris
    - PMT HAMAMATSU R12421







Measurements – I

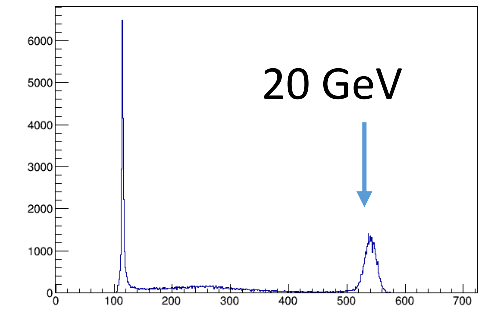
The initial plan:

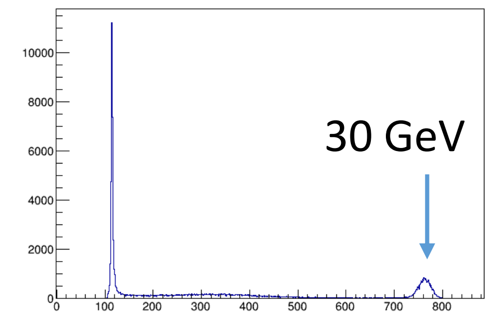
- measure SPACAL $\sigma_E(E)$ for 20-120 GeV electrons, at various beam incident angles, compare to simulations
  - light yield measurements as a byproduct (LED system was present)
- take muon data to study uniformities, obtain initial calibrations *etc*
- do time measurements for all the prototypes – to understand where we are. Try Shashlik with PMT and APD readout.
  - No info in the literature, in particular, on Shashlik time resolution at E>1 GeV (believed to be poor).

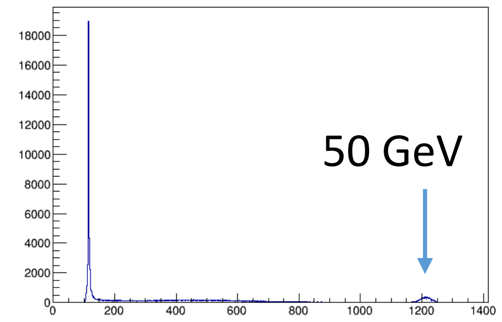
Measurements – II

<u>In reality</u>:

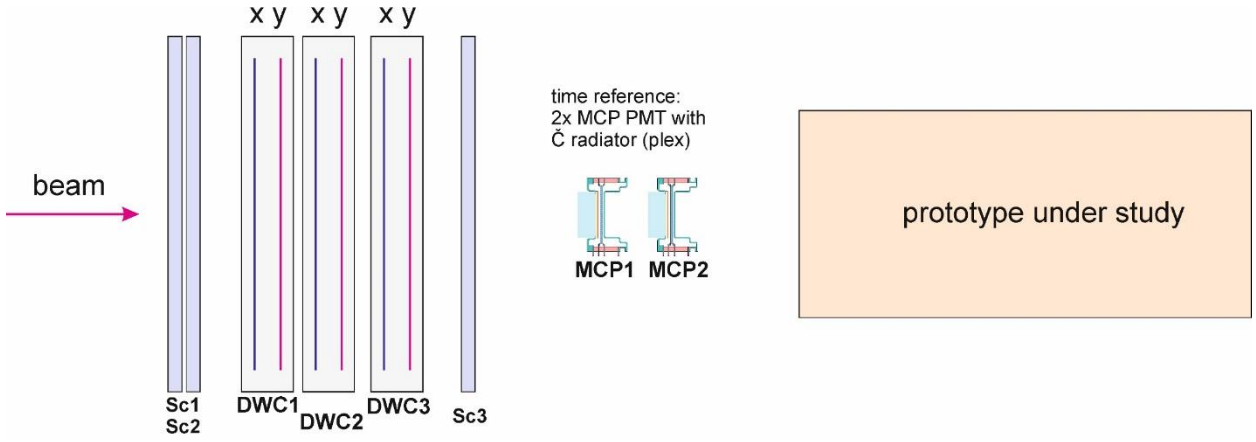
- in 2018 there were problems with electron beam purity at H8
  - not solved; will be addressed during LS2
- as a result, 20 GeV (35% purity), 30 GeV (15%) and 50 GeV (8%) were available
  - a good purity 20 and 30 GeV e- beam during Oct 8-12 at 80 GeV wobbling
  - many thanks to the beam physicists for their efforts to mitigate the problem!
- hence only one point in energy, 20 GeV (in particular for SPACAL)
- the time measurements were done without big problems, with 20 and 30 GeV







Setup

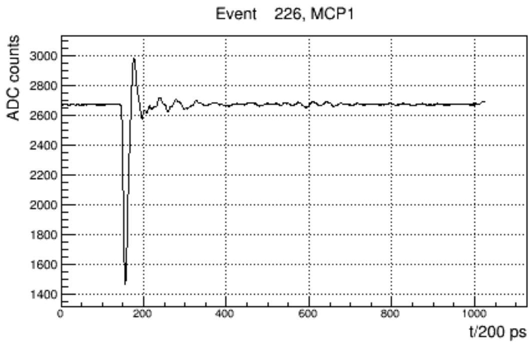


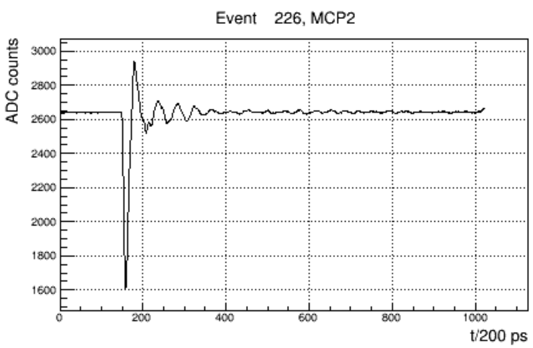
- 3 scintillating counters for a beam trigger
- 3 DWCs for track measurements
- 2 Cerenkov counters (plex) read out by MCP PMTs for time reference(*)

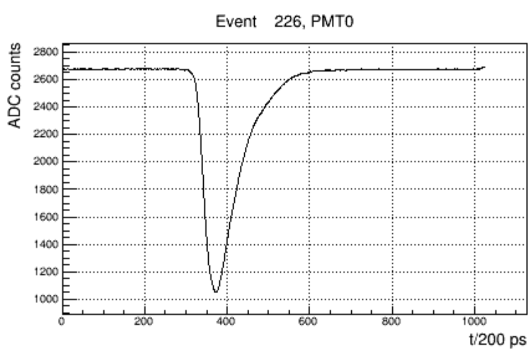
- CAEN TDC V1290N - DWC readout
- LeCroy ADC 1182 – amplitude measurements
- CAEN DT5742 digitizer – 5 GHz waveform recording

(*) The MCP PMTs were kindly provided by A. Barnyakov, BINP, Novosibirsk

Time measurements – I



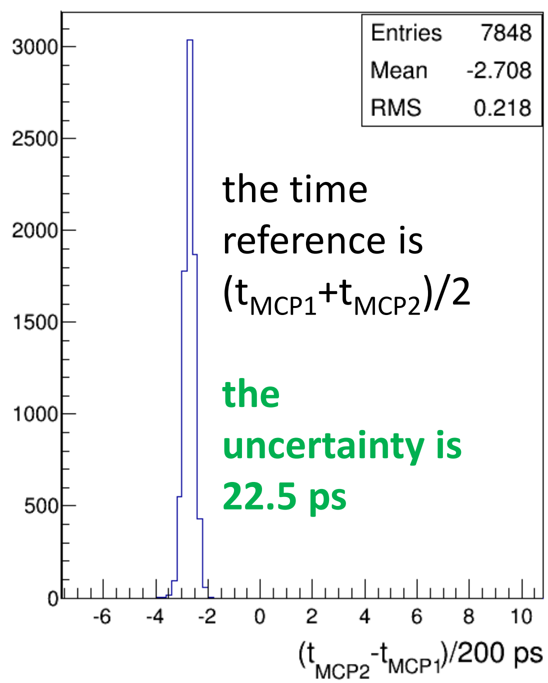


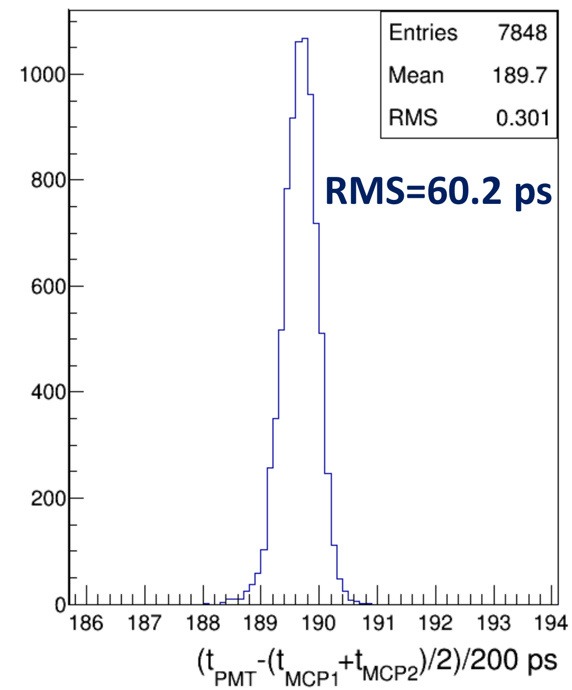


Here: standard shashlik, 30 GeV electrons, PMT readout
The time measurement: moment of time, corresponding to crossing of 50% of amplitude ("offline CFD").

The ECAL module time resolution for 30 GeV:

$$\sqrt{60.2^2 - 21.8^2} \approx 56.1 \text{ ps}$$





Time measurements – II

Present ECAL module with present PMT readout (R7899-20)

E, GeV		<t>, **n**s	σ(t), ps	
20	APD @385V	17.4	77	worse than PMT?
20	PMT @ 800V	37.9	69	
30	PMT @ 800V	37.9	56	
30	PMT @ 750V	38.6	57	
30	PMT @ 700V	40.0	77	noise contribution?

Time measurements – II

Short Shashlik module with present PMT readout (R7899-20)
Here, a test was done with beam entering from front and from back (PMT side)

beam
normal

beam
from the PMT side

E, GeV		beam dir	<t>, **n**s	σ(t), ps
20	PMT @ 1000V	normal	34.3	66
20	PMT @ 1000V	back	34.9	177

Such a big difference suggests that the time resolution is mainly determined by longitudinal shower fluctuations. For two identical showers started at z and z+Δz, the time difference is $\frac{\Delta z}{c}(n-1)$ for normal beam direction and $\frac{\Delta z}{c}(n+1)$ otherwise (n is the refractive index of the WLS fibres of Shashlik, n≈1.59).

The time resolution is not much better than with present ECAL
- noisy PMT was accidentally installed

Time measurements – III

SPACAL module with PMT readout (R12421), GAGG section

E, GeV		<t>, **n**s	σ(t), ps
20	PMT @ 630V	27.5	85
20	PMT @ 730V	26.1	78

The time resolution is modest. However the beam enters from the back side (see previous slide). For a different configuration, with a beam entering from “front”, one can expect 2-3 times better (30-40 ps), if the speculations at the previous slide are valid.

Time measurements – IV

Observations, intermediate conclusions.

- The time resolution "out of box" is just close to the required values (30-40 ps). It is worth continuing the studies: with a good time resolution of the ECAL itself, we will not need a separate timing detector in front of it.
- Simulation with timing information is needed.
- These measurements were done with a DT5742 digitizer @ 5 GHz with memory depth of 1024. It will be expensive to have such a digitizer in every ECAL cell (maybe even in 10 years from now). Need algorithms and corresponding electronics optimization (CMS has experience).

SPACAL energy measurements

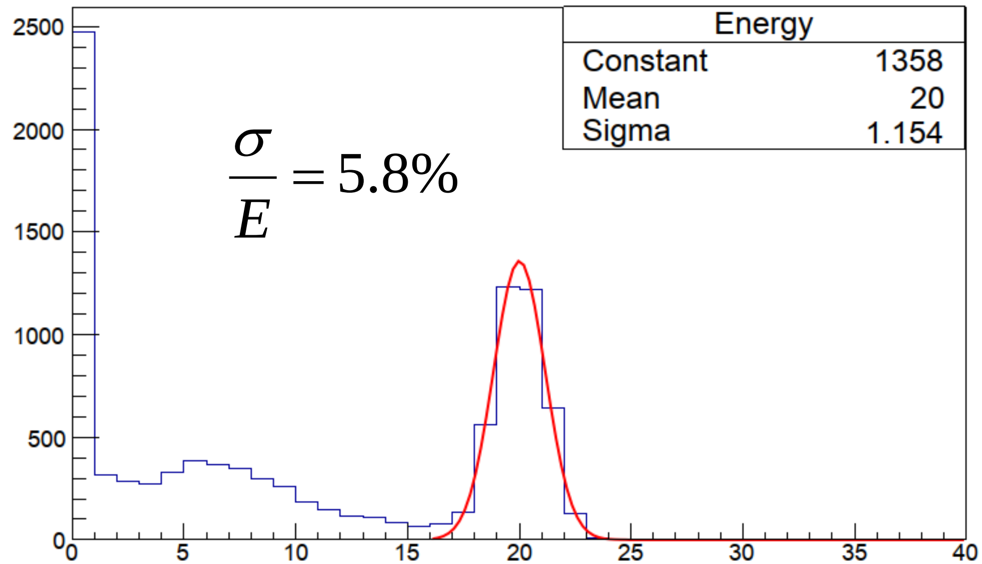
Loris, Evgeni

Condition: tilt 3° in the horizontal plane, no tilt in vertical.

Data with 20 GeV electrons and 180 GeV muons were taken. (Only 20 GeV beam was available with reasonable purity).

A preliminary calibration was obtained from the muon run:

$$E^{ev} = \kappa \sum_{ch} \frac{A_{ch}^{ev}}{< A_{ch}^{\mu} >}$$



Geant4 prediction for this configuration @ 20 GeV: 4.9%, which is not far from the measured value.
A better calibration is expected to solve the discrepancy.
Work is ongoing.

The photoelectron yield was measured for different types of sections using LED data.

A better calibration will improve also this

Scintillator	Light yield
GAGG:Ce	8.2±0.2
YAG:Ce	5.8±0.9
SCSF-78	1.5±0.5

Conclusions

- We had an intense and fruitful beam test period
    - *Many thanks to all the people participating in the prototype construction, setup and data taking!*
- Not all planned studies were done, to be continued

- The data analysis is still ongoing

- The measured SPACAL energy resolution and light yields agree with simulation
- The present light collection scheme is not perfect (cf Loris), to be optimized

- The time resolution of the prototypes (even of Shashlik, even with PMT readout) turned out to be unexpectedly good, and not far from the requirements from the physics side
    - The studies will be continued