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Time resolution improvement of an electromagnetic calorimeter based on lead tungstate crystals

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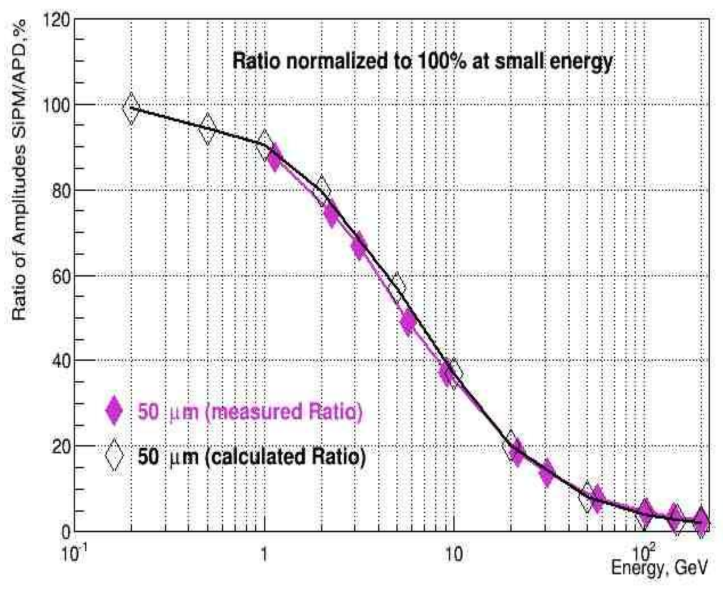
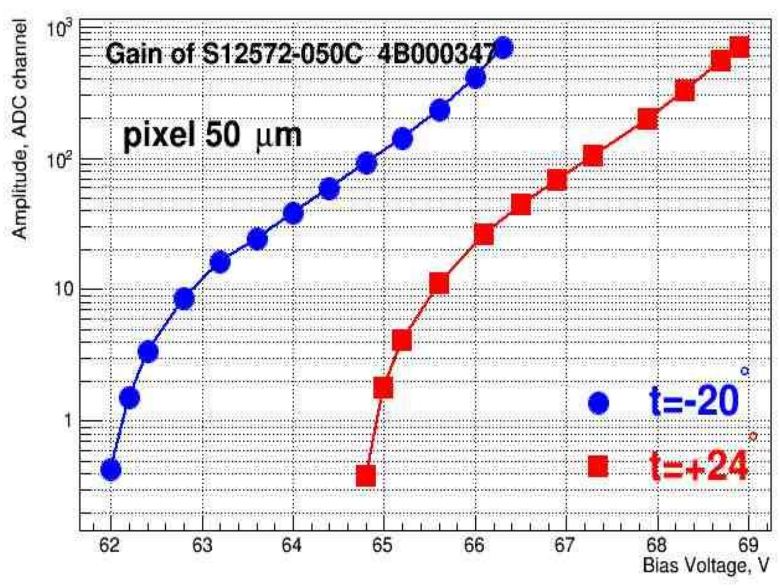
The PHOS is a high resolution electromagnetic calorimeter in the ALICE experiment at the LHC. The PHOS is dedicated for measurements of gammas and neutral mesons. The PHOS is subdivided into 4 independent rectangular modules. The module is segmented into 3584 detection channels (64x56 matrix). Each channel consists of a 22x22x180 mm^3 lead-tungstate crystal, coupled with 5x5 mm^2 Hamamatsu S-8148(S-8664-55) APD. APD is mounted in low noise charge sensitive preamplifiers (CSP) with ENC < 500 e^-. CSP connected with 1 µs peaking time dual gain shaper. For signal sampling 10 MHz ADC is used. To increase the light yield and decrease noise, crystals with APD and CSP operated at a -25ºC. Such system has energy range 5 MeV – 80 GeV, energy resolution $\frac{\sigma_E}{E} = \frac{0.018}{E} \oplus \frac{0.033}{\sqrt{E}} \oplus 0.011$ and time resolution 4 ns@1 GeV.

Upgrade of the PHOS is foreseen during LHC LS2 period. Goals of upgrade of the PHOS 1) Improvement of time resolution < 0.5 ns@1 GeV (now 4 ns) 2)enlarge energy range up to 200 GeV(now 80 GeV)

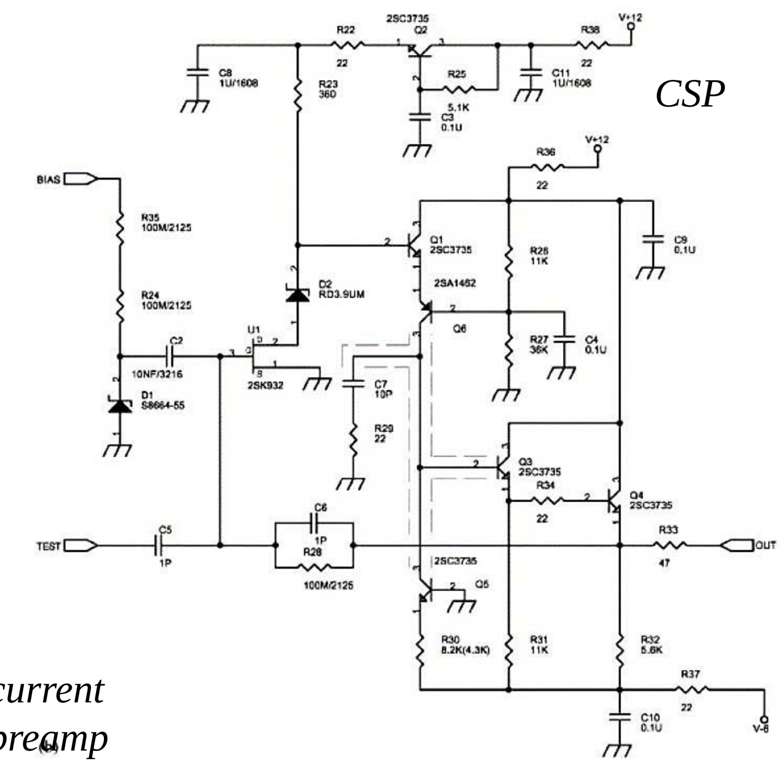
To improve time resolution : dual photoreadout - introduce an additional fast photodetector – SiPM of family of Hamamatsu MPPC S12572 coupled with either fast simple current preamplifier or electronic schema with comparator. For energy measurements we propose to keep existing APD channel.



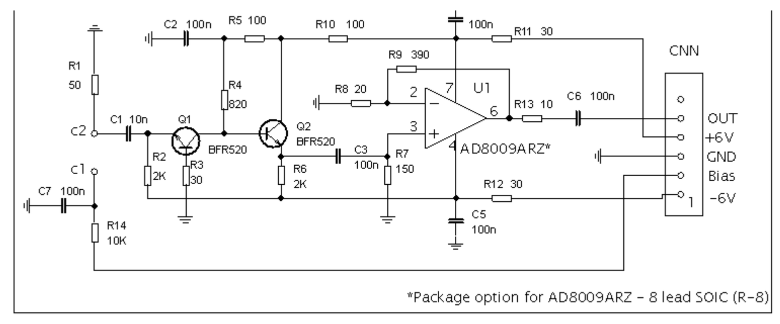
SiPM with 50 µm pitch to APD signals ratio vs energy equivalent of LED light.

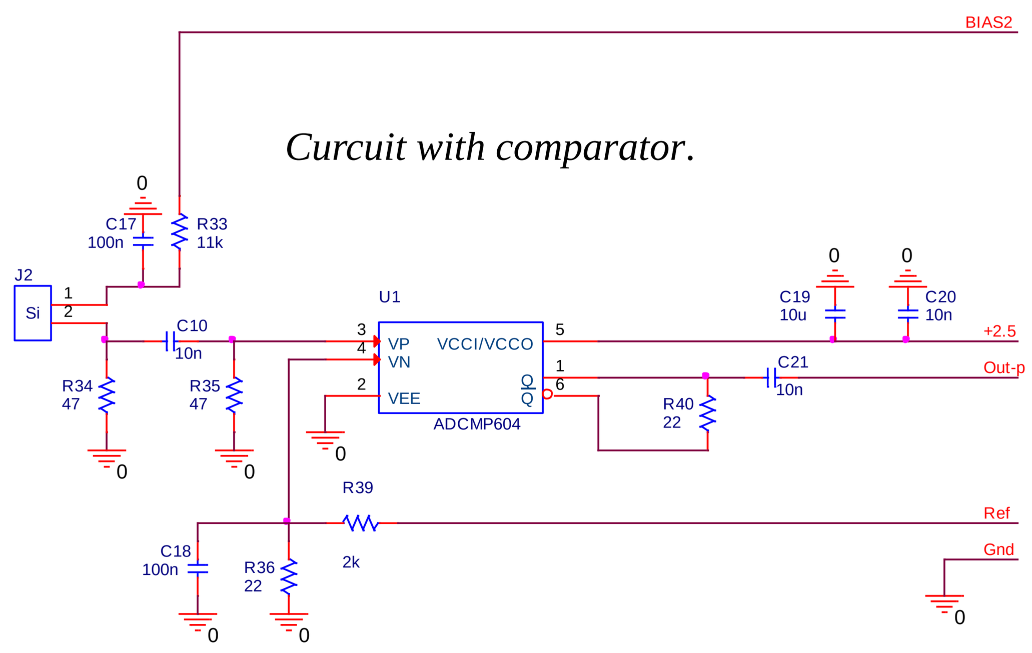


Gain of MPPC vs voltage at room and at -25°C.

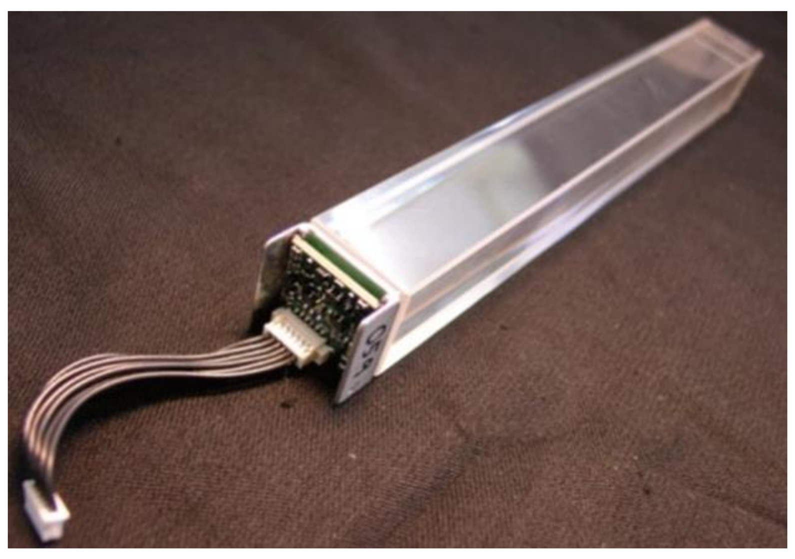


current preamp

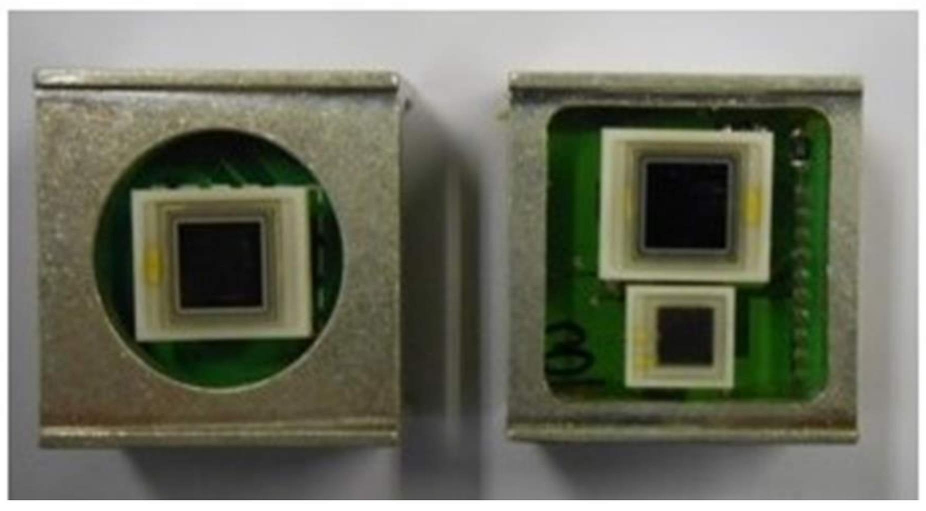




Circuit diagrams of preamplifiers. Additional independent timing channel with Hamamatsu MPPC S12572 family SiPMs presented. For energy measurement APD Hamamatsu S8664-55 (S8148) with PHOS Charge Sensitive Preamplifier was used.

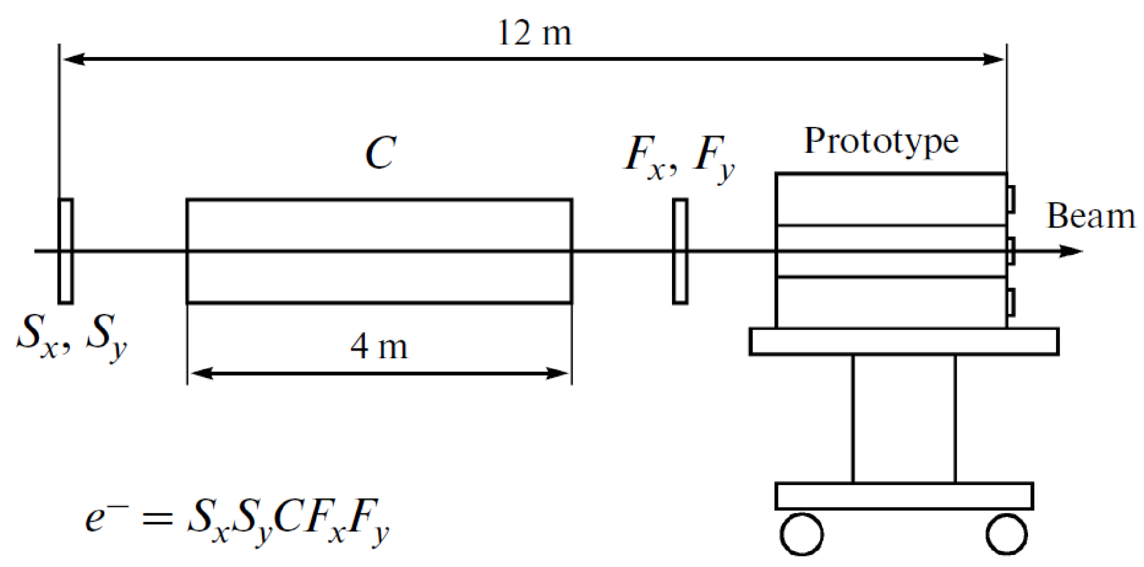


Detection channel. PWO crystal glued with photodetectors.
APD and SiPM mounted on the preamplifier's substrate.
The CSP and the current preamp on a printed circuit board of area 19 mm x 19 mm are mounted to the back side of the photodetectors.

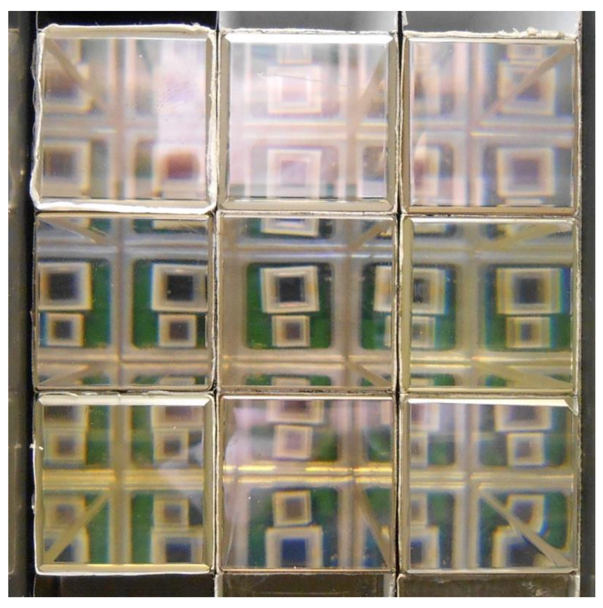


From the left - used PHOS APD single photoreadout.
From the right – APD +SiPM Hamamatsu MPPC S12572-100C dual photoreadout.
In both cases signal of HAMAMATSU S8664-55 (S8148) APD coupled with charge preamp used for energy measurements

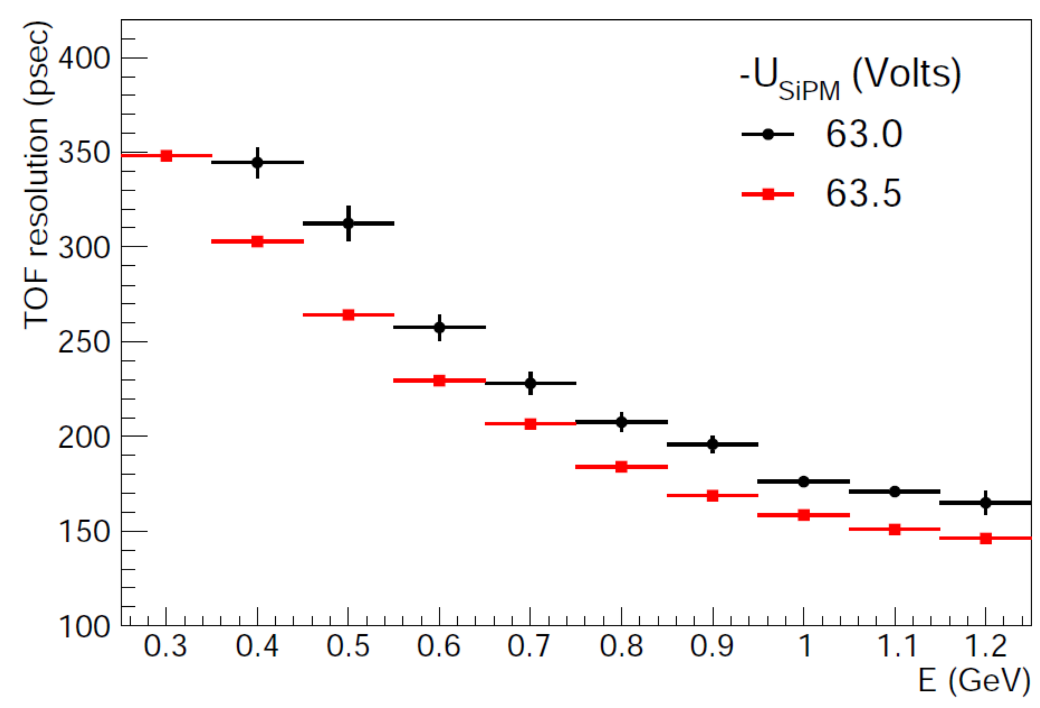
Beam test CERN PS T10 beam-line. Five 3x3 arrays were tested with beam at working temperature -25 °C.
A - reference array (single photoreadout) with current PHOS detection channels.
B, C, D – dual photoreadout arrays with current preamps with 25, 50 and 100 µm SiPMs respectively for timing and APDs for energy mesurements.
E- dual photoreadout 3x3 array with 100 µm SiPM with comparators



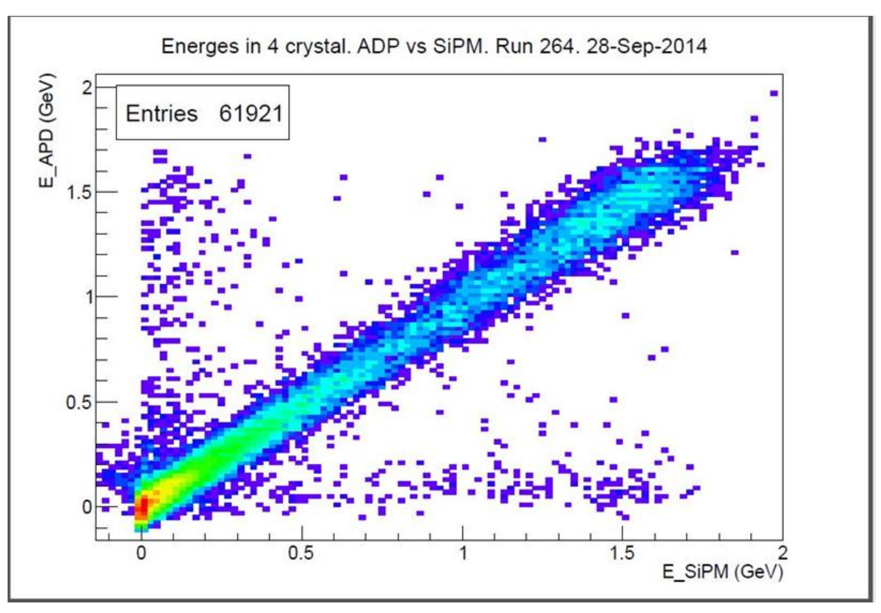
Arrangement of the trigger detectors of the beam-test.
On the bottom left, there is the logic equation for the trigger: coincidences associated with an electron in the beam. Not in scale.



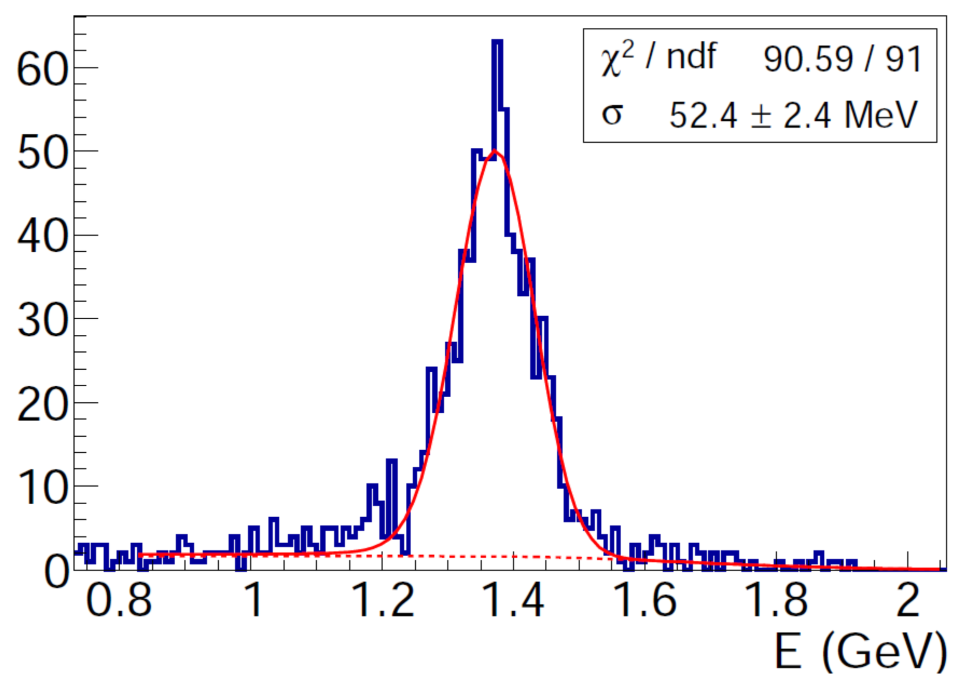
Front view of one of the tested 3x 3 arrays.



PHOS detection channel time resolution with dual photoreadout. Additional timing channel with Hamamatsu MPPC S12572 – 100C SiPM (100 µm pitch size) and simple schema with the AD CMP604 comparator. For energy measurement APD Hamamatsu S8664-55 (S8148) with PHOS CSP was used.



Energy measured by APD vs energy measured by SiPM with currentpreamplifier.



Sum 3x3 distribution measured with APDs.

Beam test results. CERN East Hall PS T10 beam line. Electron beam with P=1, 1.5 and 2 GeV/c

$-U_{SiPM}$ (V)	σ_t (ps)@1 GeV
25 µm with current preamp	
63.0	552 ± 4
63.5	332 ± 10
64.2	240 ± 5
65.0	218 ± 4
67.0	182 ± 3
68.0	150 ± 3
50 µm with current preamp	
62.5	396 ± 24
63.0	267 ± 10
64.0	175 ± 12
65.0	140 ± 2
66.0	113 ± 3

$-U_{SiPM}$ (V)	σ_t (ps)@1 GeV
100 µm with current preamp	
62.0	651 ± 18
62.4	423 ± 5
63.5	183 ± 2
100 µm with comparator	
63.0	167 ± 3
63.5	149 ± 1
σ(E)/E @ 1.5 GeV/c	
APD only array	APD+100 µm+ comparator
0.035 ±0.002	0.037 ±0.001

Conclusions.

The additional SiPM of HAMAMATSU MPPC S12572-100C allows to get time resolution better than 0.2 nano seconds at deposit energy of 1 GeV in the PHOS detection channel. Furthermore the scheme with the AD CMP604 comparator allows not to worsen energy resolution.

We are grateful to the team of the accelerator complex at CERN for the excellent performance of the accelerator, as well as to our colleagues from the PHOS collaboration for their help.