Application of SiPM arrays for the readout of a scintillator based time-of-flight detector

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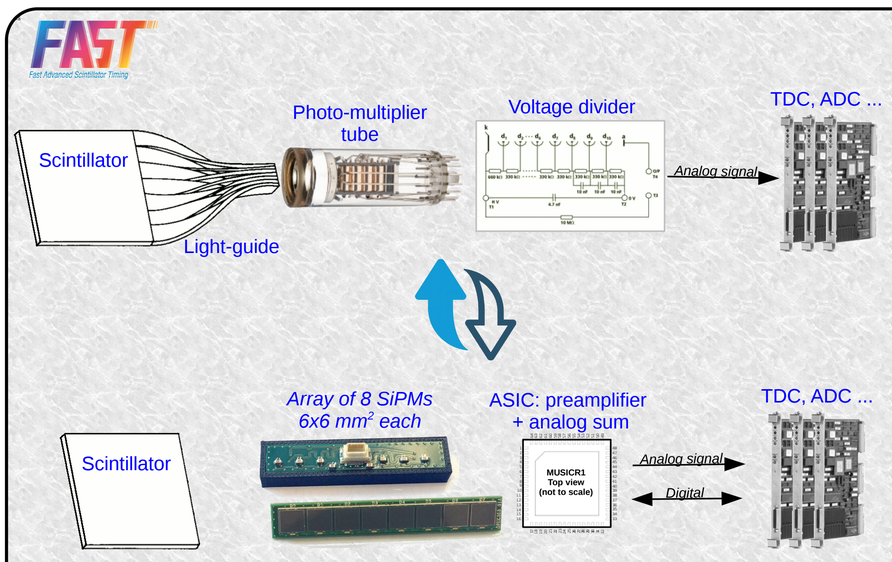
A study of feasibility of replacing a conventional phototube with an array of SiPMs is presented. High gain, low voltage operation and insensitivity to the magnetic field make SiPMs practically useful for the light collection in a physics experiment. In addition, sensors can be assembled in a compact system which is easily scalable. In this study an array of large area SiPMs was coupled to the end of a long plastic scintillator counter. The principal restriction for applications requiring accurate evaluation of the photons arrival time is the large capacitance of SiPM which results in broadening of the signal shape. A natural solution of the problem is to amplify and readout a large SiPM surface in parts. In this study an 8 channel SiPM anode readout ASIC (MUSIC R1) based on a novel low input impedance current conveyor is used. The evaluation board provides individual single ended outputs and the sum of signals. Both analog and digital outputs are supported by the board. Prospects for applications in large-scale particle physics detectors with timing resolution below 100 ps are provided in light of the results.



Advantage of SiPM-array vs PMT

- Compactness
- Low bias voltage ~50 V
- High photon detection efficiency ~40%
- Easily scalable system
- In general any SiPM shape can be ordered from a producer company
- Can be directly attached to a scintillator surface
  - no need in a complex shape light-guide which provides an adiabatic connection
- Can be used in magnetic environment
  - PMT requires ferromagnetic housing which make the construction bulky

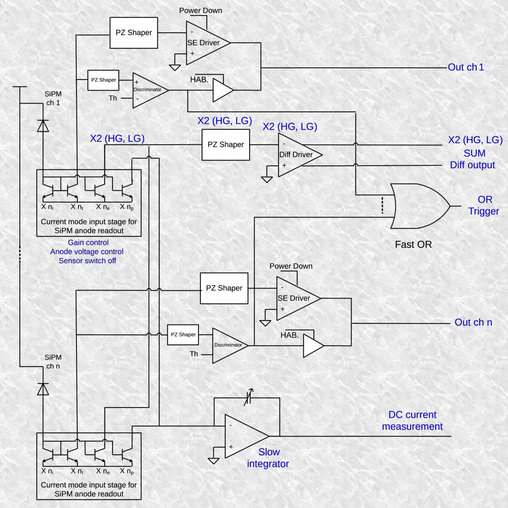
Weak points of SiPM vs PMT

- Typical noise is 50 kHz/mm^2
  - Threshold is not a problem for plastic scintillators where one has 20 kγ emitted per cm
- Large capacitance => large rise time of signal
  - SiPM surface can be split for readout in parts

MUSIC: Multiple Use SiPM IC

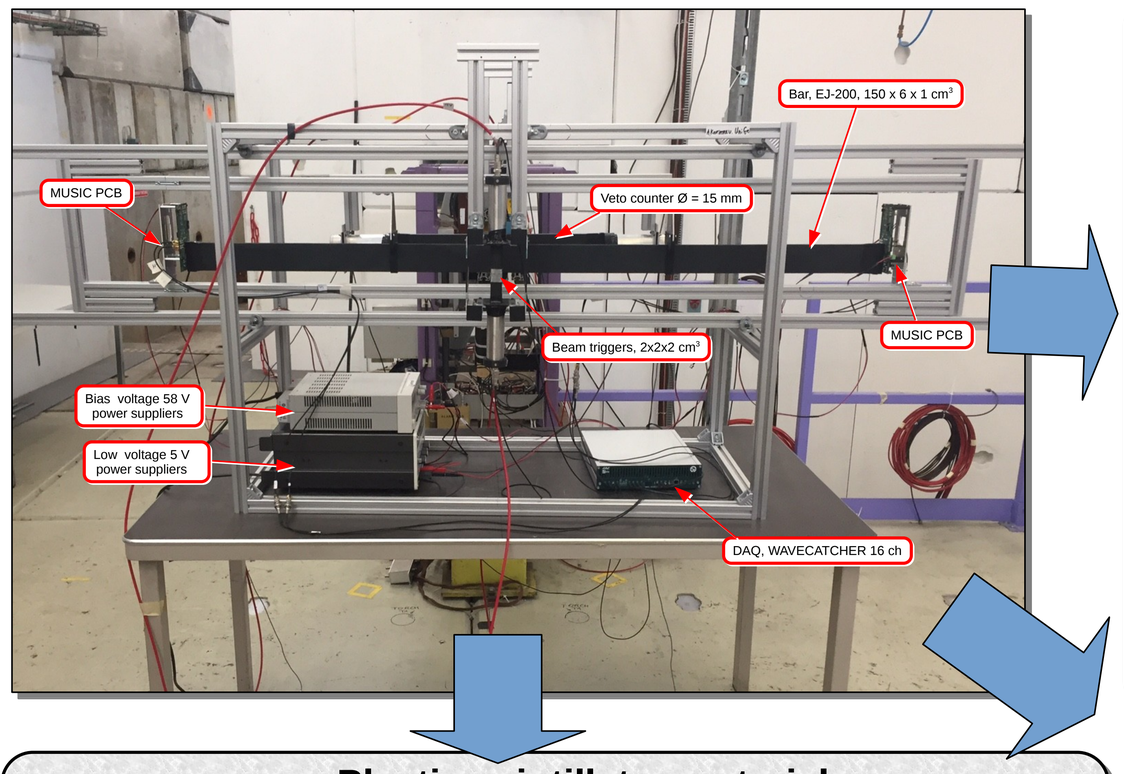
ICCUB Institute of Cosmos Sciences

A summing ASIC and more…

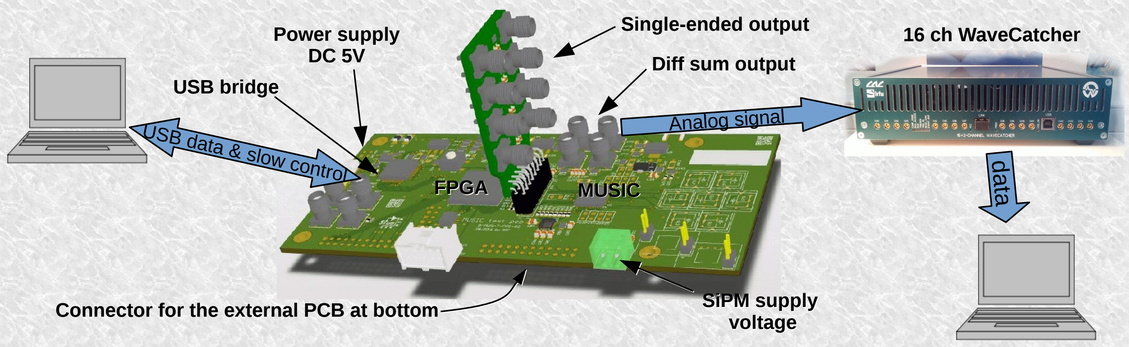


- Input
  - Up to 8 SiPMs of any size
- Outputs:
  - High Gain SUM
    - Diff, 100 Ω, 500 MHz
  - Low Gain SUM
    - Diff, 100 Ω, 500 MHz
  - OR trigger
  - Per channel, choose between:
    - Analog (S.E, 50 Ω, 100 MHz)
    - Digital
  - "DC current"
    - Sum output
    - Per channel mux output
    - Integrator: 1 ms time constant
- Control
  - Any channel can be disabled
  - SPI control

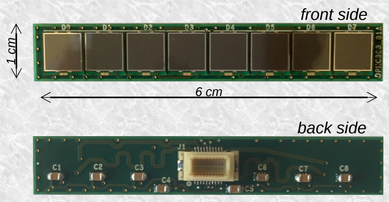
Test-beam at T9 / Est Area CERN PS, June 2017



Sensors and read-out electronics

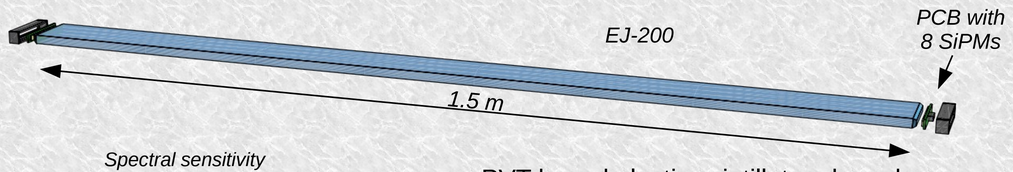


External PCB with sensors

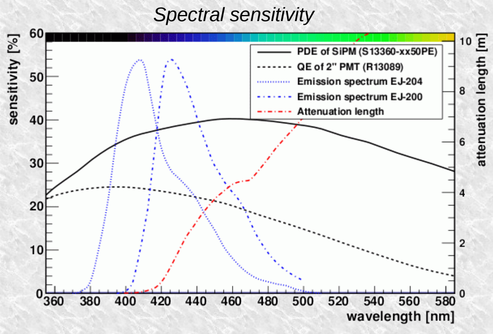


- Customized external PCB with sensors
  - 8 sensors connected either in parallel or in series
  - Hamamatsu S13360-6050PE, size 6x6 mm^2 : pixel pitch 50 µm, gain 1.7x10^6, dark count 2MHz
- Readout from both ends of the bar
- Bias voltage of all SiPMs was calibrated to make amplitudes equal
  - Picosecond light pulser PLP10-040C / 405 nm has been used

Plastic scintillator material



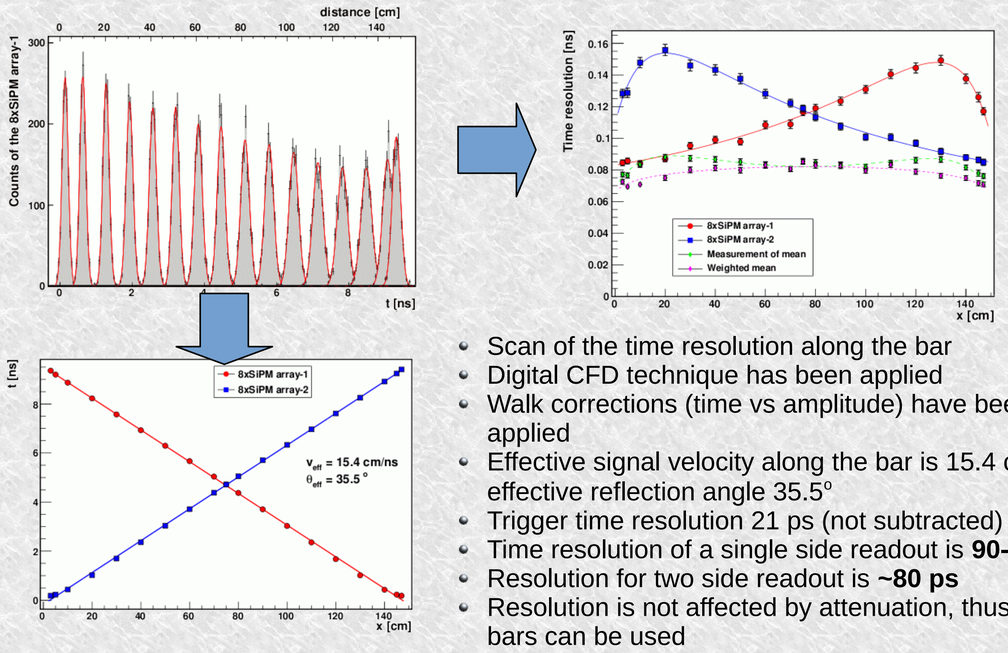
Spectral sensitivity



- PVT based plastic scintillators have been considered: EJ-200 and EJ-204 (commonly used for ToF systems)
- Bar dimensions **150 cm x 6 cm x 1 cm**, cast surface, edges diamond milled
- Readout from both ends
- Trade-off between two effects
  - Fast scintillator (shorter rise and decay constants) emits light in the NUV region
  - Shorter wavelength photons are stronger affected by absorption in the material

ELJEN	SAINT-GOBAIN CRYSTALS	γ / 1MeV e-	Wavelength	Rise time	Decay const	Att. length
EJ-204	BC-404	10.4k	408 nm	0.7 ns	1.8 ns	1.6 m
EJ-200	BC-408	10k	425 nm	0.9 ns	2.1 ns	~3.8 m

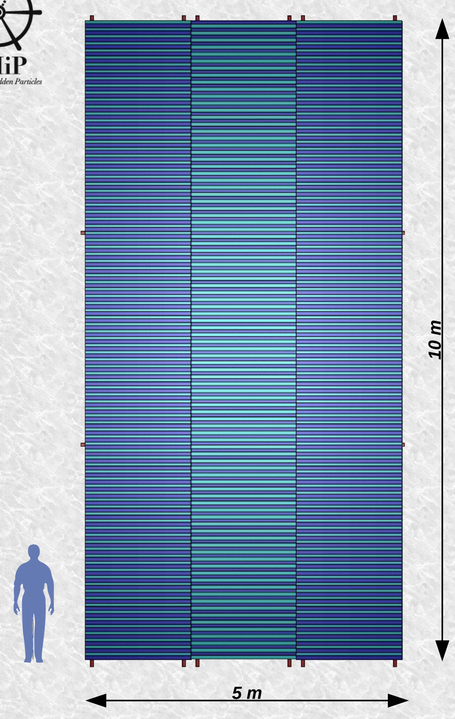
Results of the test-beam



- Scan of the time resolution along the bar
- Digital CFD technique has been applied
- Walk corrections (time vs amplitude) have been applied
- Effective signal velocity along the bar is 15.4 cm/ns, effective reflection angle 35.5°
- Trigger time resolution 21 ps (not subtracted)
- Time resolution of a single side readout is **90-150 ps**
- Resolution for two side readout is **~80 ps**
- Resolution is not affected by attenuation, thus longer bars can be used

Technique is proposed for detectors of following experiments

SHiP Search for Hidden Particles



- The SHiP Experiment is a new general-purpose fixed target facility at the CERN SPS to search for hidden particles as predicted by a very large number of recently elaborated models of Hidden Sectors which are capable of accommodating dark matter, neutrino oscillations, and the origin of the full baryon asymmetry in the Universe
- Purpose of the Timing detector
  - Reduction of combinatorial background by tagging particle belonging to a single event
  - Can be used for PID of few GeV particles
  - Requirement for **time resolution < 100 ps**
  - Positioned downstream of the decay vessel
- For the present design of the detector
  - Transversal dimensions 5 m x 10 m
  - bar size ***167 cm x 6 cm x 1 cm***
  - 3 col x 182 row = 546 bars
  - 546 bars x 2 = 1092 channels
  - 1092 x 8 = 8736 SiPMs
- Time calibration system is a challenge

ND280

- For the present version of the design
  - Transversal size 2.3 m x 2.3 m
  - bar size ***230 cm x 6 cm x 1 cm***
  - In total 288 bars
  - 288 bars x 2 = 576 channels
  - 576 ch x 8 = 4608 SiPMs

- The ND280 is a near detector of the T2K experiment in J-PARC. It is designed to measure the energy spectrum, flavor content and neutral and charged current interaction rates of the non-oscillated neutrino beam; this information is used to predict the non-oscillated interaction rates at Super-Kamiokande
- Purpose of the ToF detector
  - Determination of the direction of particles (inside or outside the target) which are products of beam-neutrino interactions
  - Can be used for PID of sub-GeV particles
  - The **time resolution 100-200 ps**
  - Planes of the detector to be placed in between TPCs and surround the target volume