Monte Carlo processor for calibration of air shower experiments

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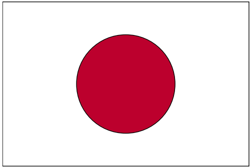
ALPACA collaboration

More than 50 collaborators.
24 academic institutions.

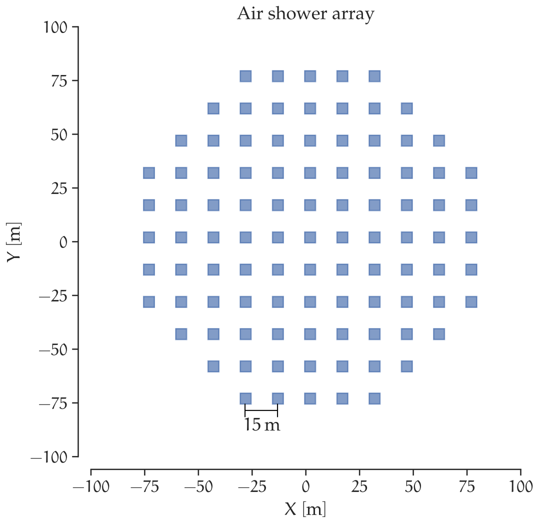
Andes Large Area PArticle detector for Cosmic ray physics and Astronomy

Site coordinates: 4740 m, $16^\circ 23'$**S**, $68^\circ 8'$**W**.

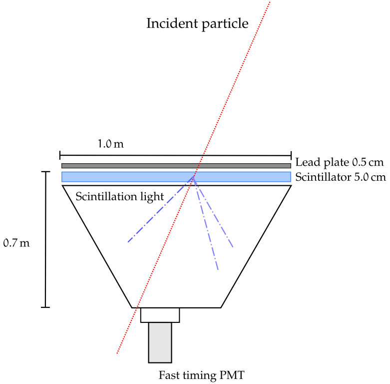
Current status: ALPAQUITA air shower array w/ 97 $1\,\mathrm{m}^2$ detectors.

ALPACA experimental site, June 2023

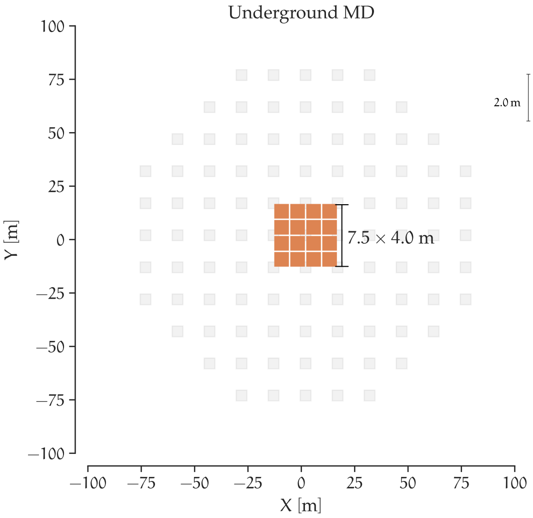
Experimental technique: Surface array detector

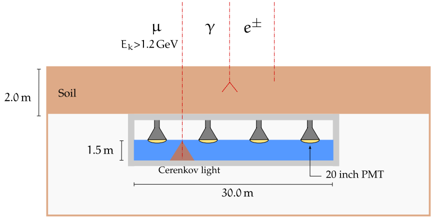


- Area coverage: 18 450 m^2
- Number of elements: 97
- Single-particle peak: 9.4 MeV



Experimental technique: Underground muon detector



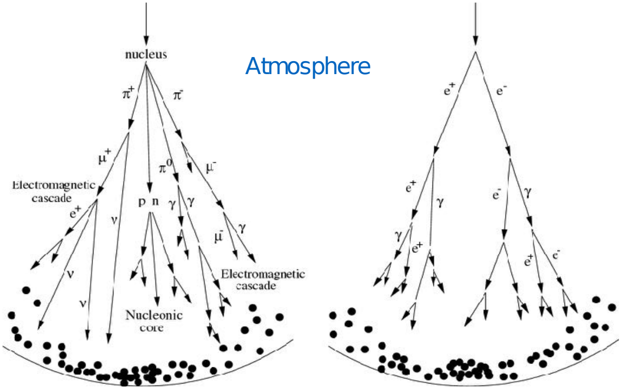


- Area coverage: 900 m^2
- Number of elements: 16 cells.
- Single-muon peak: 24 pe*

* S.Kato et al., Experimental Astronomy (2021) 52:85-107

Experimental technique: γ-ray/hadron discrimination

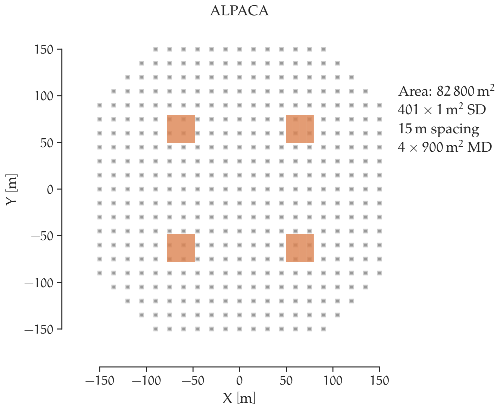
TeV-PeV proton, helium TeV-PeV γ-ray



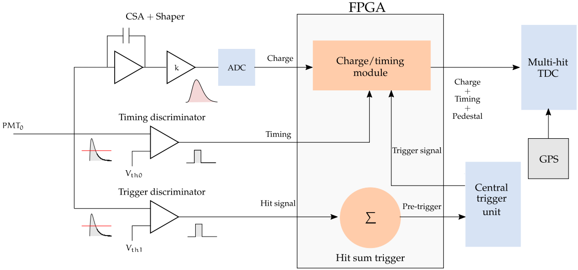
Number of μ's within < 100 m from the core

$\sim 50\mu$ for 100 TeV proton $\sim 1\mu$ for 100 TeV γ-ray

ALPACA's DAQ system



Full ALPACA array



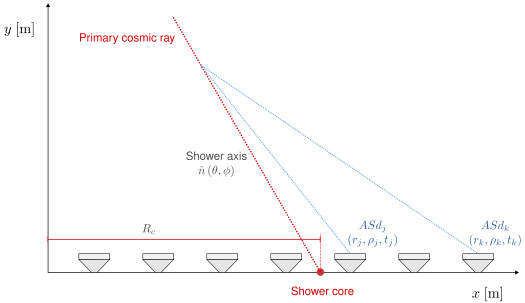
ALPACA DAQ system

Purpose of MC pulse generator

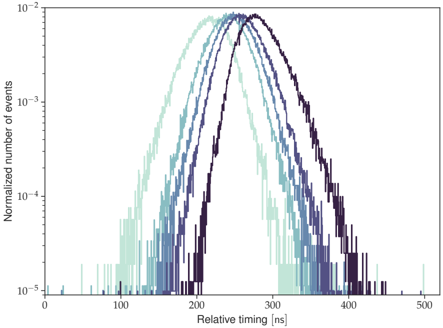
- Future ALPACA array: 1500 surface detectors.
- Array covering 1 km^2 — need new distributed DAQ electronics.
- Large rate by accidental coincidences ($\sim$100 kHz) — need to develop intelligent trigger technique.
- Special purpose generator could help the testing and development of new electronics.
- For now only consider timing characteristics.

Requirements of the generator

- Primary particles interact with atmosphere an develop *laterally*.
- Secondaries arrive in a time window ranging from 0.1 μs to ∼5.0 μs.

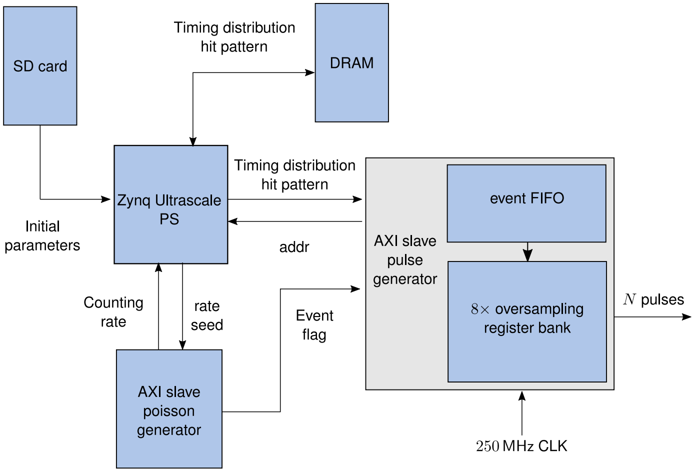


Air shower geometry



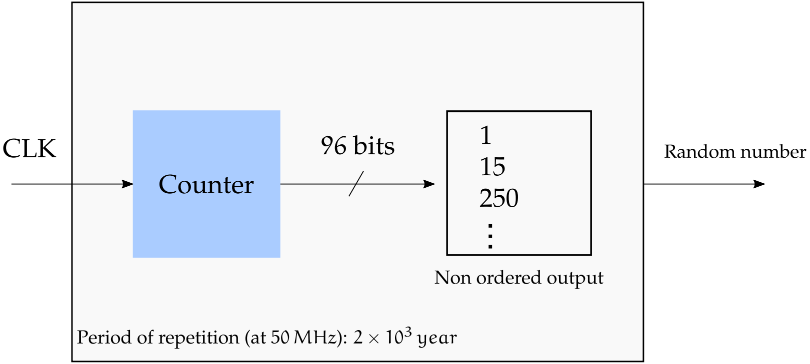
Relative timing distribution

MC pulse generator



How to produce random number generator with logic?

Principle of work: very large counter — Linear Feedback Shift register



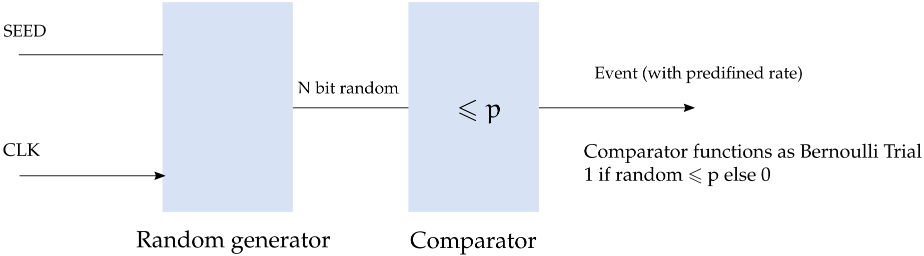
Uniform random number generator

LFSR with 32 bits output

```
process(gclk)
begin
 if rising_edge(gclk) then
  if rst='1' then
   SR<=seed(j);
  else
   SR(95 downto 32)<=SR(63 downto 0);
   for k in 0 to 31 loop
    SR(31-k)<=SR(95-k)xor SR(93-k)xor SR(48-k)xor SR(46-k);
   end loop;
  end if;
 end if;
end process;
```

How to produce Poisson signal with predefined rate?

Bernoulli trial aprox: urnd + comparator $\longrightarrow$ Poisson generator

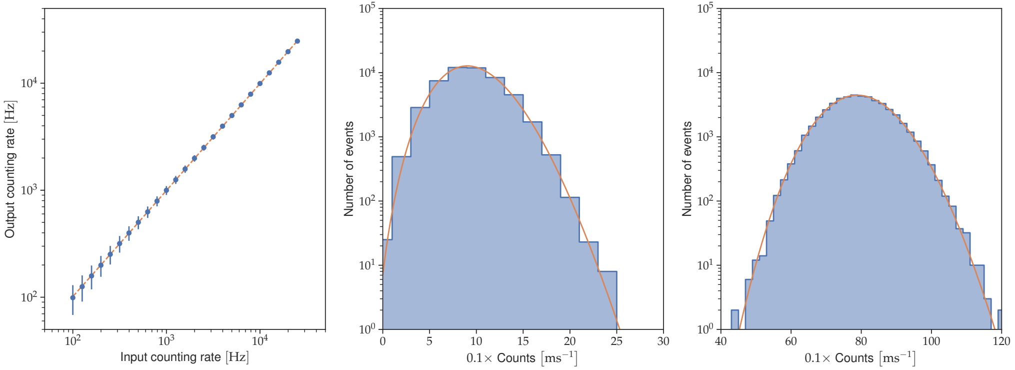


How to produce Poisson signal with predefined rate?

Bernoulli trial aprox: urnd + comparator $\longrightarrow$ Poisson generator

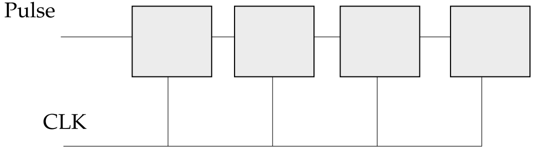
- Rate is defined as $\lambda = N * p$
- N is the number of trials per second (clock frequency).
- Output of urnd gen and p are integers.
- p should be very small.

Evaluation of the pulse generator



Evaluation of Poisson generator.
before connecting Zynq PS.

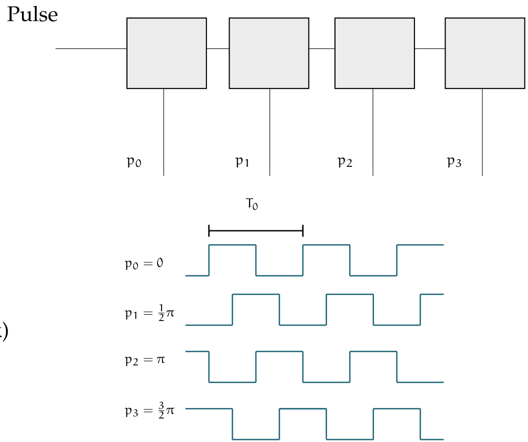
Generating delay for independent channels



Register bank

Pulse is delayed with T_0 units (total delay depends on size of bank)

Delays with 1 ns required 1 GHz CLK

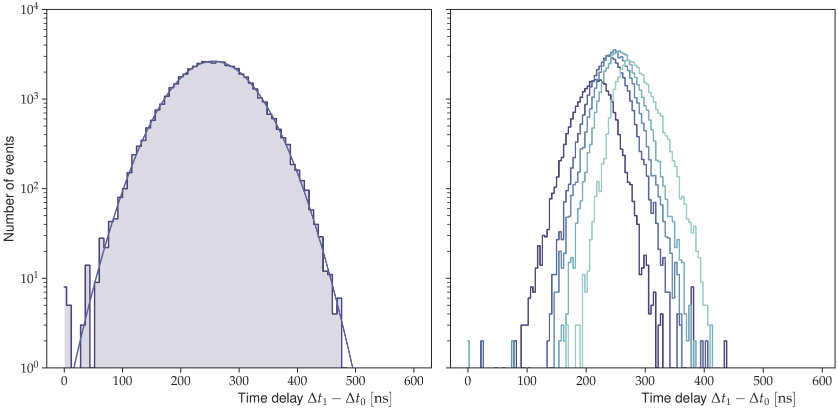


10 bit design with 250 MHz — resolution 0.5 ns, range 500 ns.

Circuit operating with both edges of the clocks

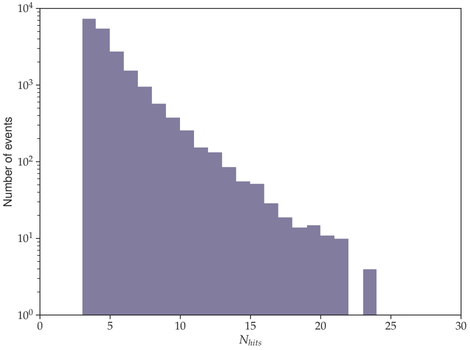
Evaluation of the pulse generator

- Time delay distributions measured with external TDC.
- Events with zero delay are *false events*.

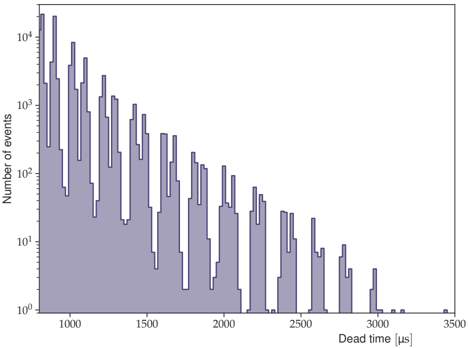


Evaluation of the pulse generator

- Distribution of number of hits reproduces MC simulation.
- Zynq PS (python) limits maximum rate.



Distribution of number of hits



Dead time distribution

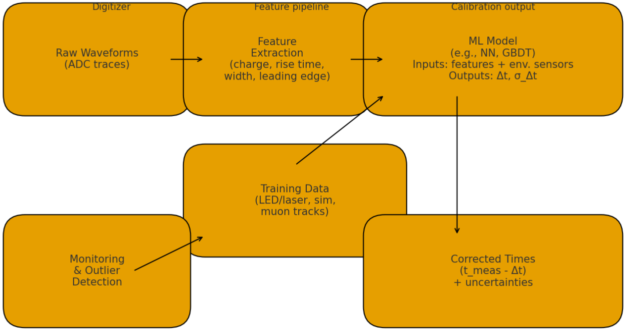
Limitations of current design

- Total number of events is limited by output of MC simulation.
  - Inverse sample number of hits?
- Maximum rate is limited by Zynq PS running python.
  - Translate code to C or change architecture.
- Still need to include charge distributions.

Implement Generative-adversarial Network could solve points one and three

How about real time calibration?

- Air shower detectors are affected by environmental effects.
- Absolute calibration of arrival direction is challenging.



Conclusion and future works

- We successfully develop a pulse generator capable of reproducing air shower timing characteristics.
- Time resolution is about 0.5 ns, with a maximum rate of 1 kHz.
- Can we train a GAN to reproduce all characteristics of the air shower?
- Is it possible to use this pulse generator for improved calibration?
- Important task is to develop analog interface — get budget from KAKENHI.