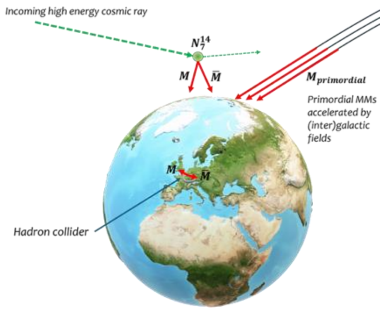


Next Frontiers in Magnetic Monopole Searches

V.Saveliev

Silicon Photomultiplier
an Optical Sensor for High Energy Physics and Astrophysics

September 14, 2026, Beijing

Modern Imaging Cameras

Modern Imaging Cameras:

CMOS Sensor Cameras: Pixel Sensors with Color Sensitivity

Low Photon Flux – Our Expertise

Photos taken throughout the day, from noon to midnight, with the best camera

Critical Problem: Low Sensitivity of Optic Sensors

Low Photon Flux ?

There is probably no upper limit (bosons).

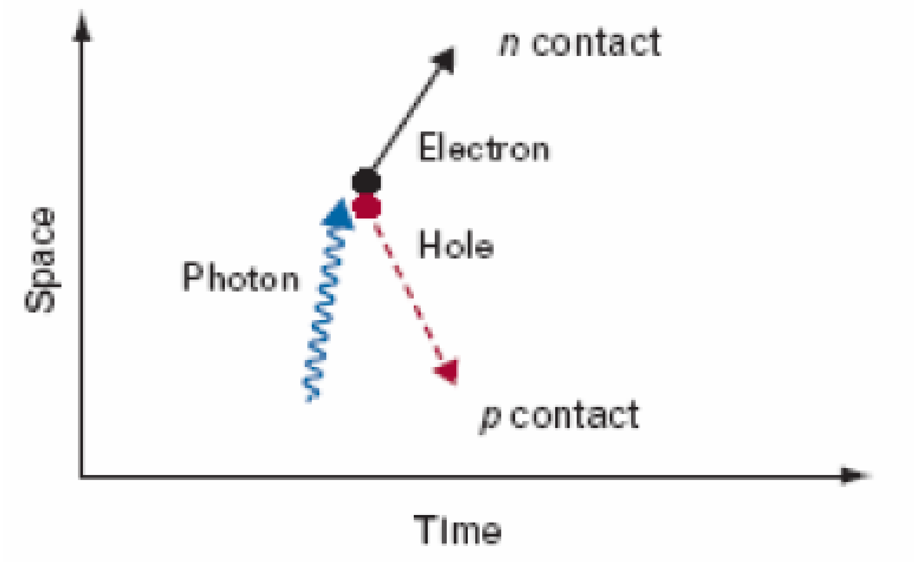
The absolute minimum limit for photon flux is a single photon –
a quantum (photon energy is defined as a function of wavelength, $E = h\nu$).

In Experimental Physics (and other critical fields)
the photon flux is $1 – 10^3$.

Some Physics of the Detection Process

The Basic Principle of photon detection is to “convert” a photon into “another form” (electric charge) that can be used for storage, processing, analysis, etc.

The Photoelectric Effect is the release of electrons from the atoms of a medium (semiconductor) under the influence of photon energy.



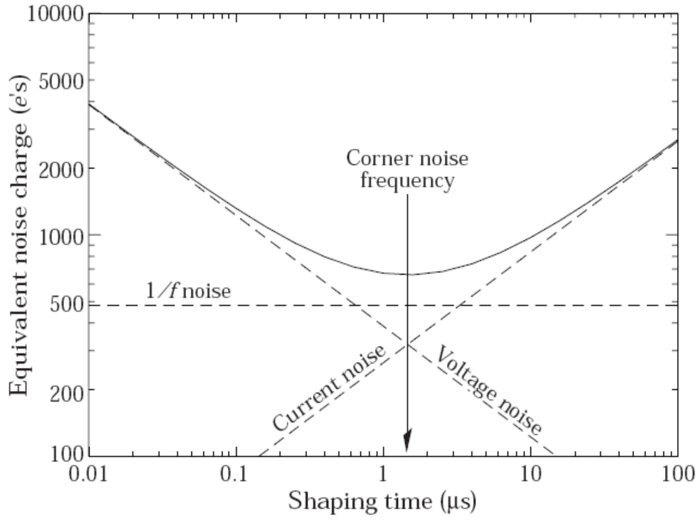
Unfortunately, photoelectric effect has one-to-one ratio:

ONE photon -> liberate ONE electron (hole)

Some Physics of the Detection Process

And, unfortunately, secondly: any electronic measurements are subject to noise (including the noise of the detector itself) – the thermal noise

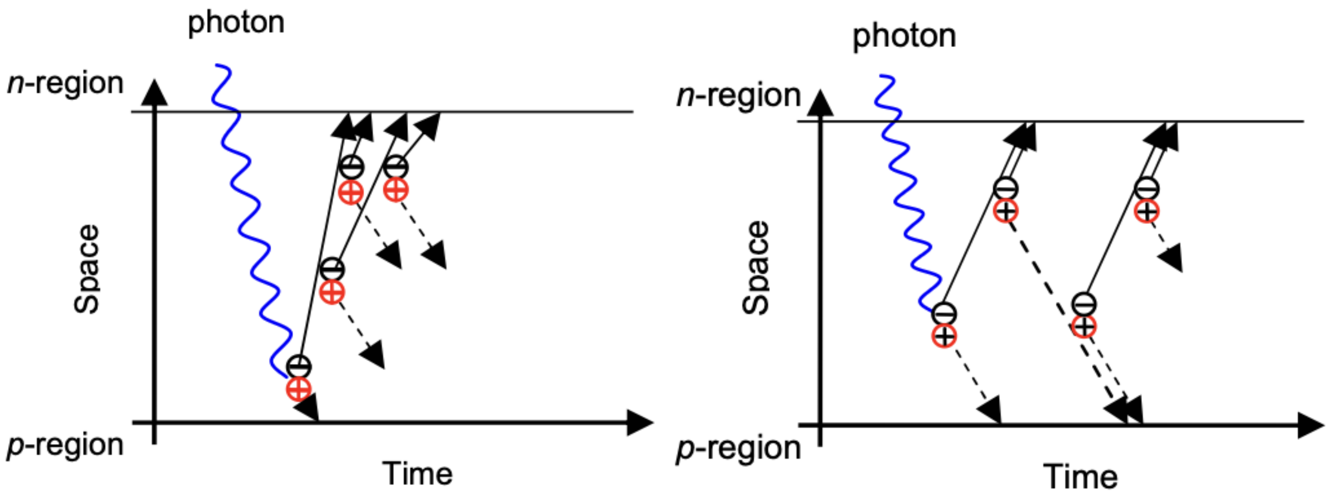
Equivalent Noise Charge
as a function of Time Shaping of Measurement System at Room Temperature



The trade-off between photons as a signal and noise (as an important characteristic of the measuring system) determines the quality of detection.

- it’s necessary to have an internal gain (physical) of at least 10^4;
- or cooling of the entire detection system to reduce thermal electronic noise;

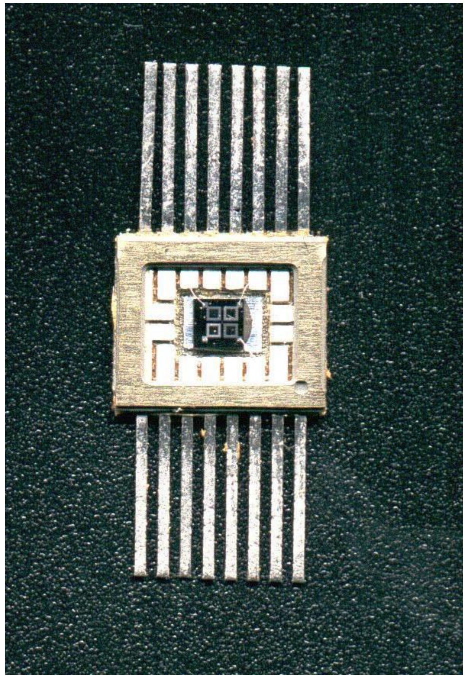
Then we add another process: in a strong electric field, free charge carriers in semiconductors accelerate and can accumulate energy exceeding the ionization energy of valence electrons.

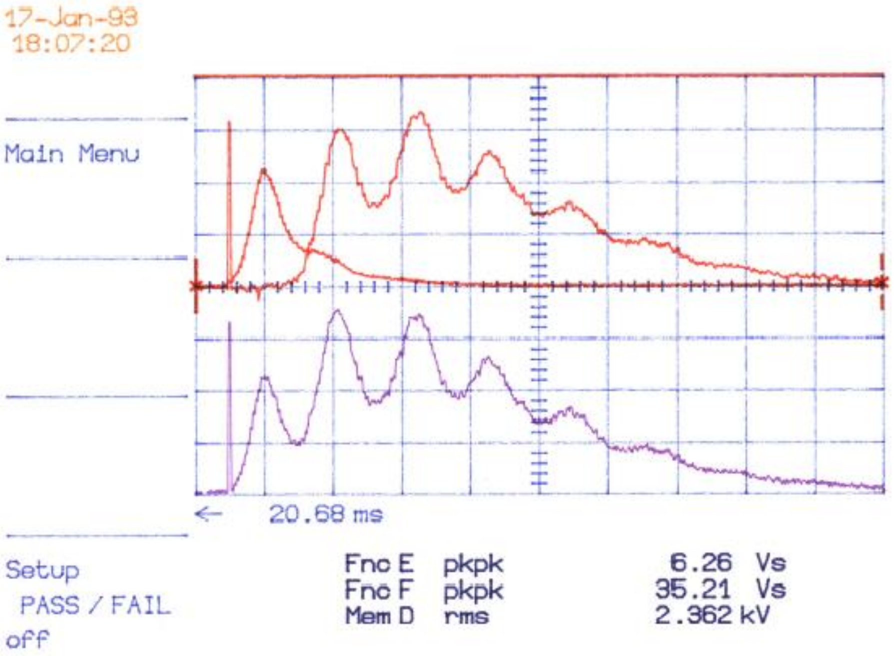


To stop the avalanche breakdown process, quenching elements are used; this function can be provided by a series-connected resistor (as in a Geiger chamber).

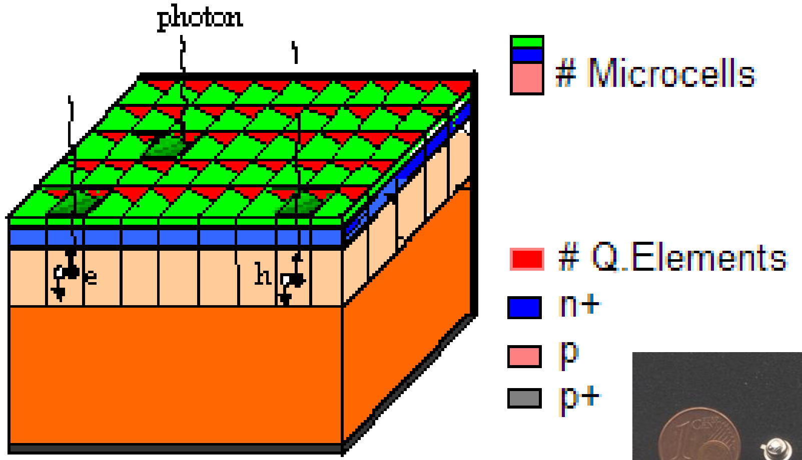
Low Photon Flux and Silicon Photomultiplier

In the late 1980s, we conducted special studies of semiconductor structures to detect extremely low photon fluxes.





First evidence of single photon detection: CERN 1993

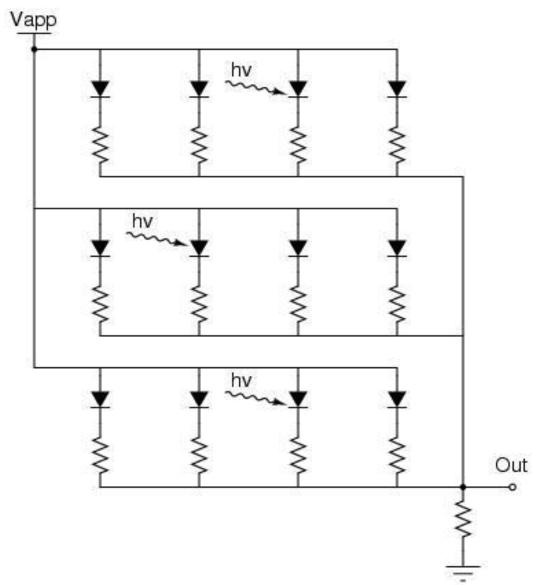


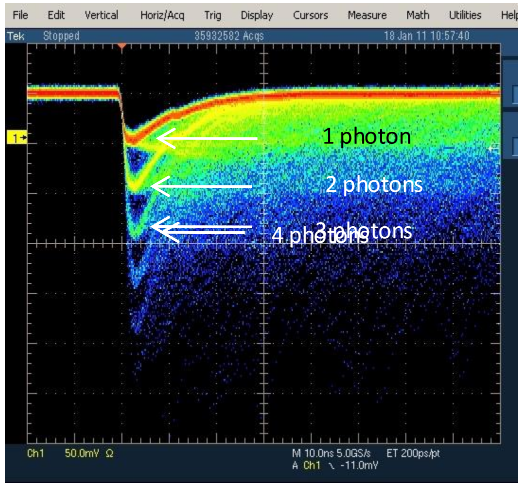
- Semiconductor Fine Micro Sensors Structure ~10^3 / mm^2 distributed over space on the common substrate,
- Breakdown mode operation of the micro sensors, with integrated quenching elements,
- Optic Cross Talk suppression elements,
- Common Output.

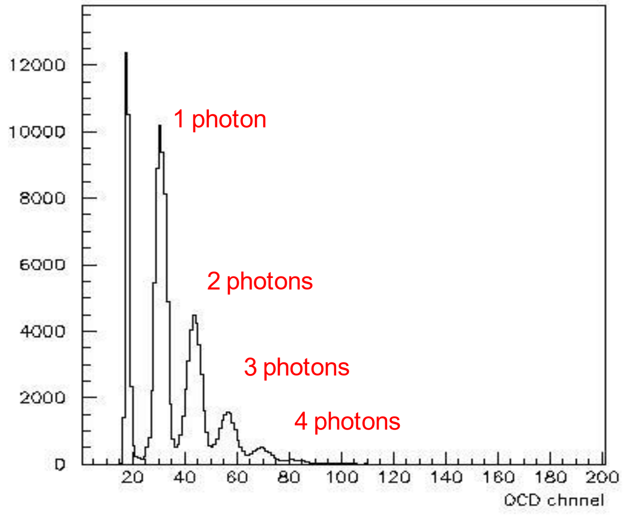
All microsensors are independent and identical, providing a standard single photon signal with a resolution sufficient to recognize the single photon signal.

Traditional SiPM

Signals from micro sensors are summing by analog net on the single analog output:







This allows for a proportional output signal to be obtained as a function of the number of photons.

Main Characteristics:

- Detection Efficiency (>65 % for visible range of photons),
- Internal gain 10^6, sensitivity to single photon,
- Time resolution is range tens of ps (measured now 48 ps),
- Dark Rate ~10^5 Hz/mm^2, ampl. is equal 1 photon,
- optical Crosstalk ~1 %,
- Proportional output signal for photon flux, large dynamic range
- Common Output

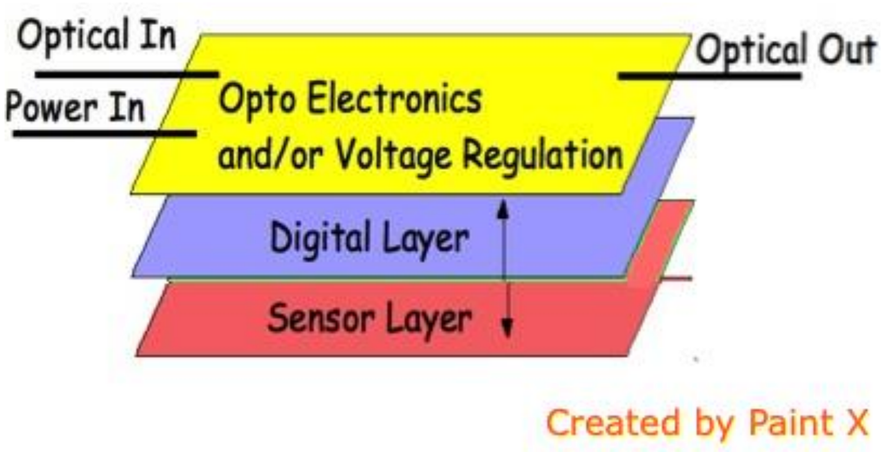
Operational Conditions:

- Low Operational Voltage ~ 10-30 V,
- Room Temperature (with single photon resolution),
- Not Sensitive to Strong Electromagnetic Fields

Advanced Technology of Silicon Photomultiplier

- Material and Technology of micro sensors are compatible with Modern Microelectronics Technology (CMOS),
- The Signals are binary (digital),
- Allowed to implement the Processing Electronics on the same substrate as Sensors

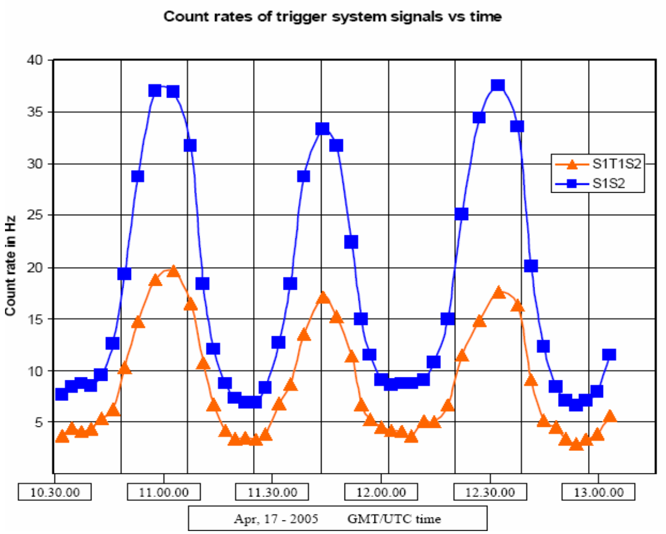
This opens up the potential for creating a fully Digital Optical Sensor on a chip with unique characteristics (SoC).



Silicon Photomultiplier in Astro Physics

The final component for build detector and scaling
is the use of a scintillator to convert the energy losses into photons.

And we are ready to create a large-scale particle detector.

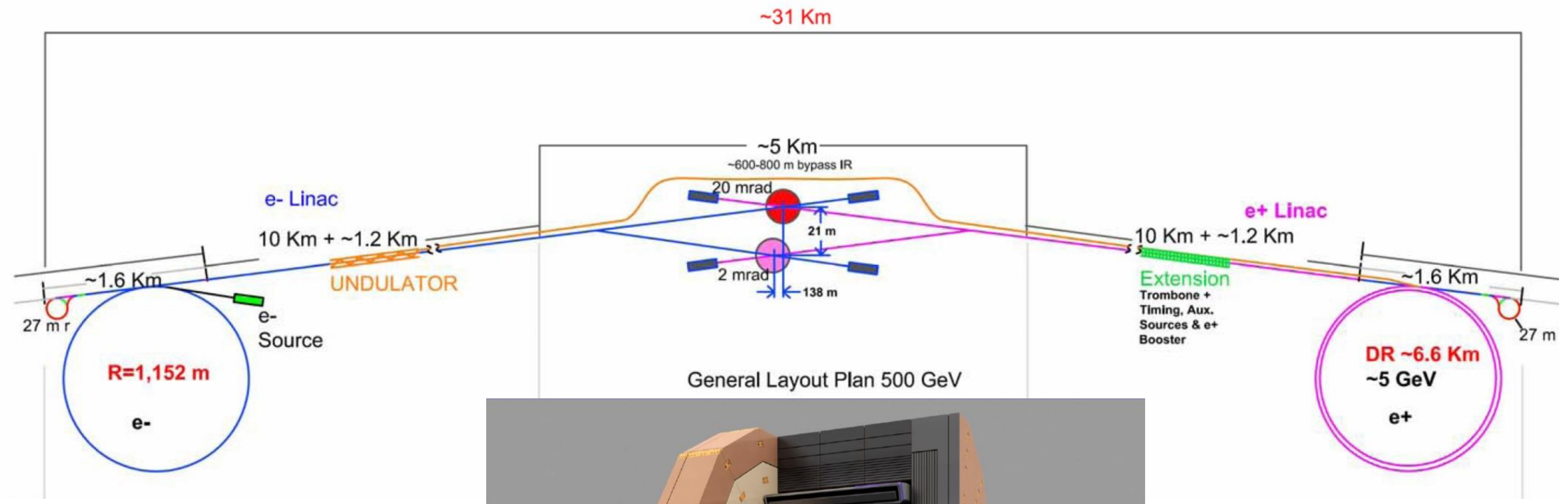


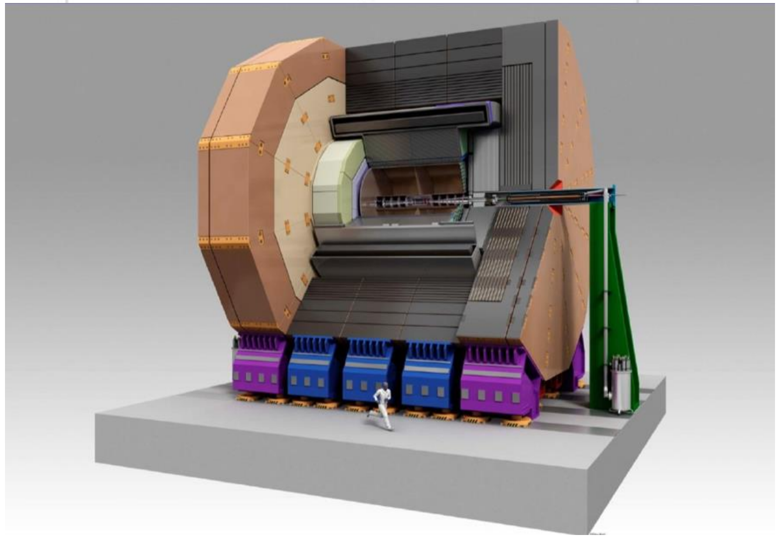
Space Station “Mir” 2000 and ISS 2005: SiPM based Charged Particle Flux System Measurement

(multilayer strip calorimeter on base scintillator and SiPM)

Now let's move on to the current discussion.

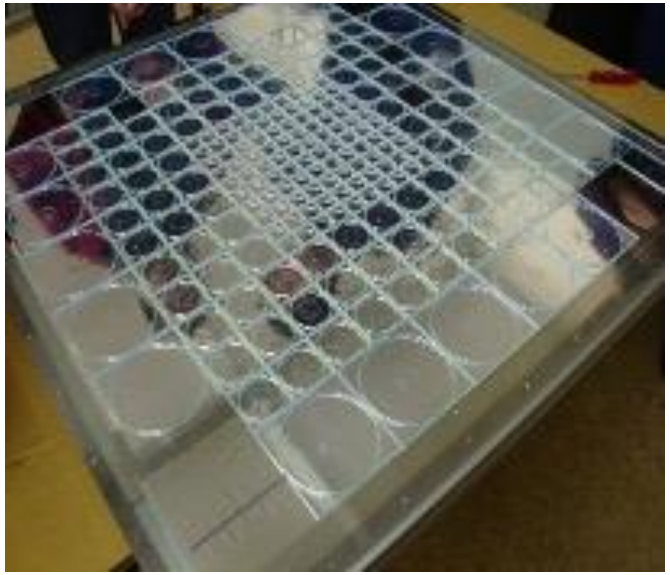
Silicon Photomultiplier in High Energy Physics (ILC)



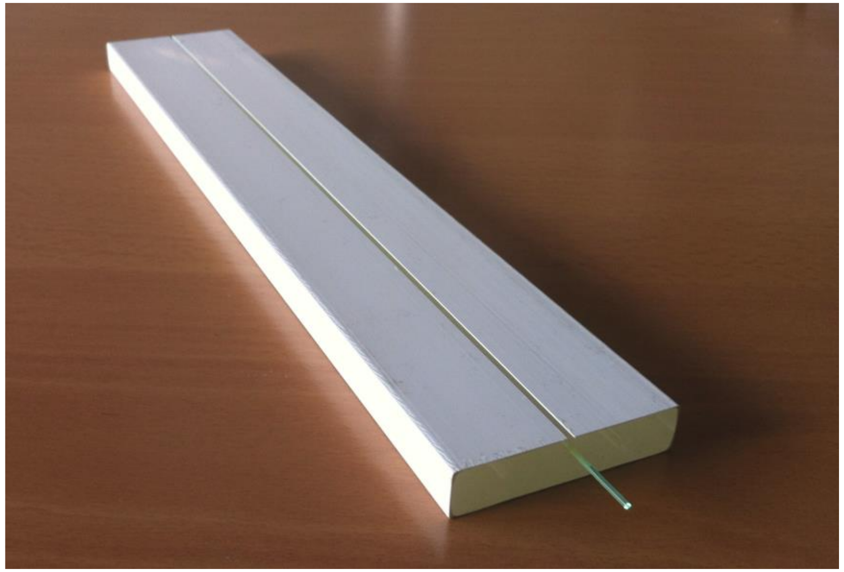


International Linear Collider: 20 M precise measurement channel based on Scintillator and SiPMs

AHCAL and Muon Detection System of ILC (ILD detector) developed two type of Scintillator, Wavelength Shifter, SiPM detection elements



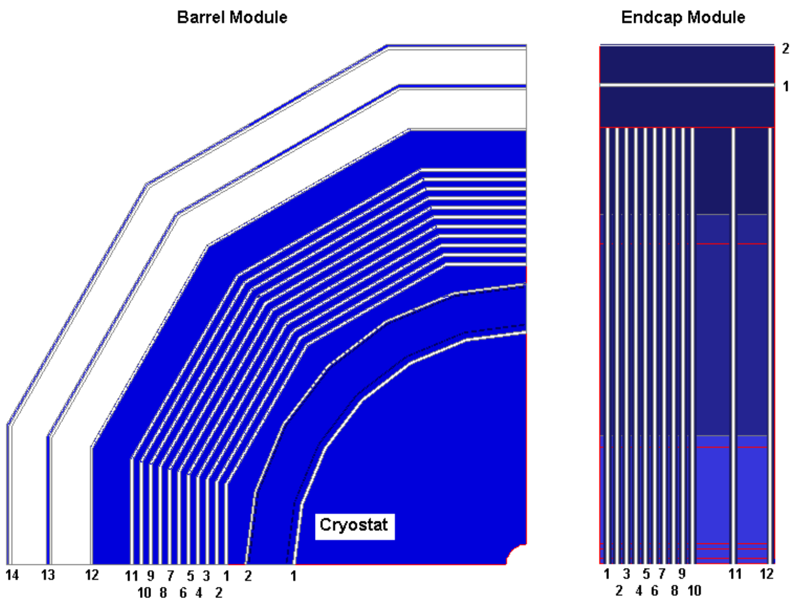
AHCAL



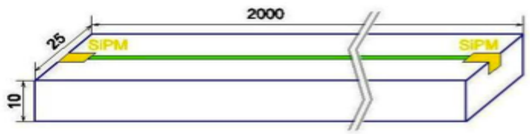
Muon System

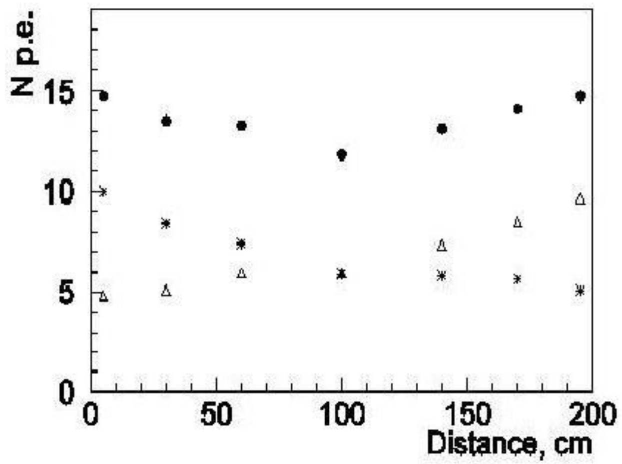
International Linear Collider: 10,000 m² of space is planned for the muon system alone

Muon Detection System of ILC (ILD detector):
Scintillator, Wavelength Shifter, SiPM detection elements



Muon





A 100 m² test prototype was tested at CERN.

Muon Detection System of ILC: Scintillator, Wavelength Shifter, SiPM

The Scintillation Strips are coextruded with the Reflection Cover (TiO_2);
The 1mm wide extruded groove running along the centre of the strips;
Commercially available WLS Fiber (1 mm diameter) is positioned in the groove;

One final note:

If the digital silicon photomultiplier option is used,

the Front End and Processing Electronics are NOT required.

thanks