# Silicon Avalanche Structures for:
# - Photons (Silicon Photomultipliers)
# - Ionising Particles (Avalanche Pixels)

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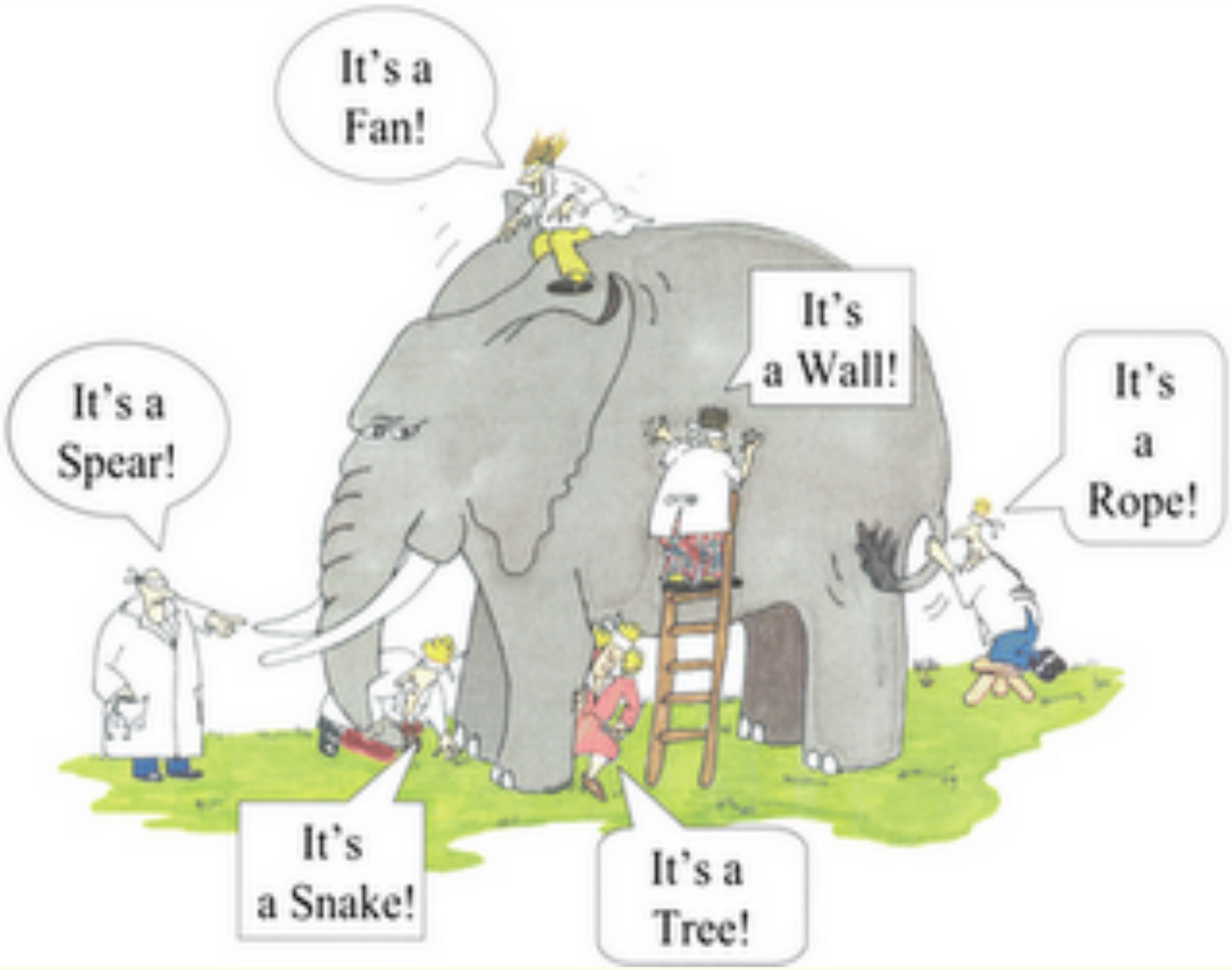
# Photons Detection
# Silicon Photomultipliers (SiPM)

# Visual Information

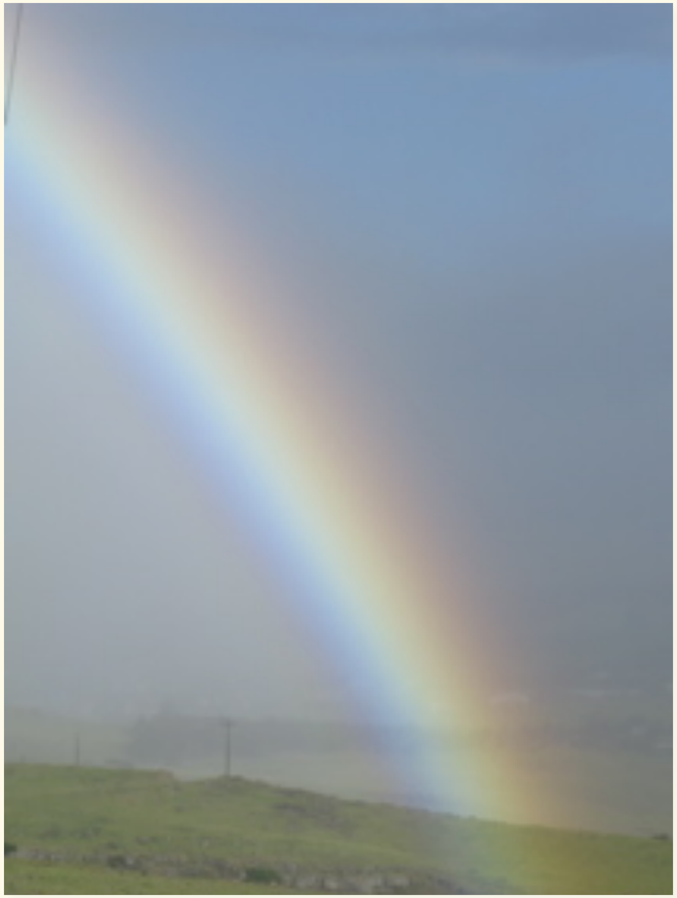
## Why it is so Important

Indian Proverb:
Six wise men went to see an elephant (though all of them were blind)..



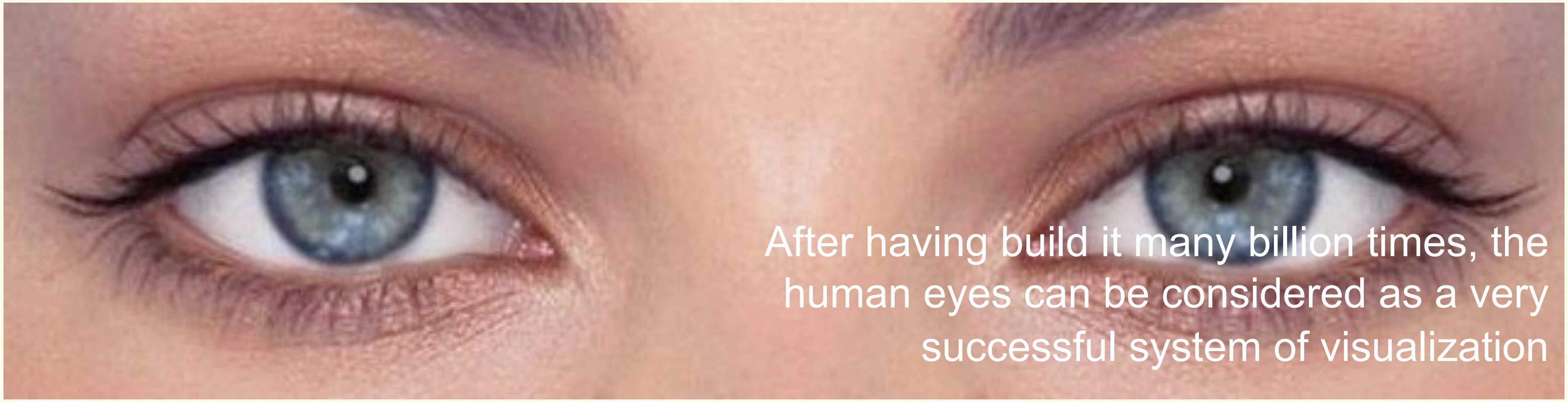
# Visual Information

Most of Information we are getting in Visual Form:



as reflection of the Sun Light (could be other visible light sources…)

# Detection of Visual Information




Challenges:

- Visible Light: Color (wavelength) Recognition;
- Good spatial Resolution <1 mm, (with some accessories <0.01 mm);
- Very large Dynamic Range of Brightness 1:106;
- High Linearity;
- Automatic Adaptation;
- Long Lifetime

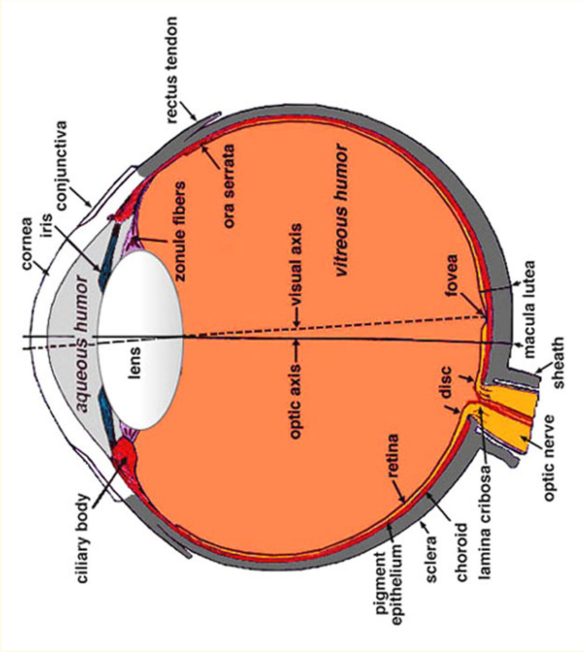
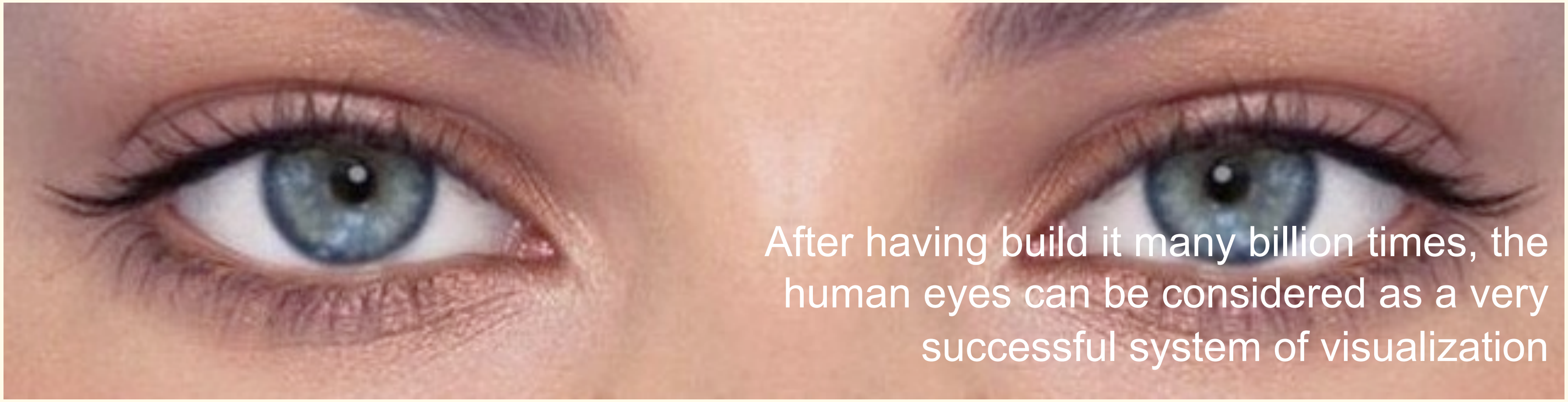



*Fig. 2. Sagittal horizontal section of the adult human eye.*

# Detection of Visual Information



After having build it many billion times, the human eyes can be considered as a very successful system of visualization

Weak points:

- Only visible light;
- Modest Sensitivity: brightness level is quite high for our brain to register a conscious signal;
- Modest Speed, range 10 Hz with understanding (processing);
- Reaction Capability is very poor “Look Now” ~1 second;

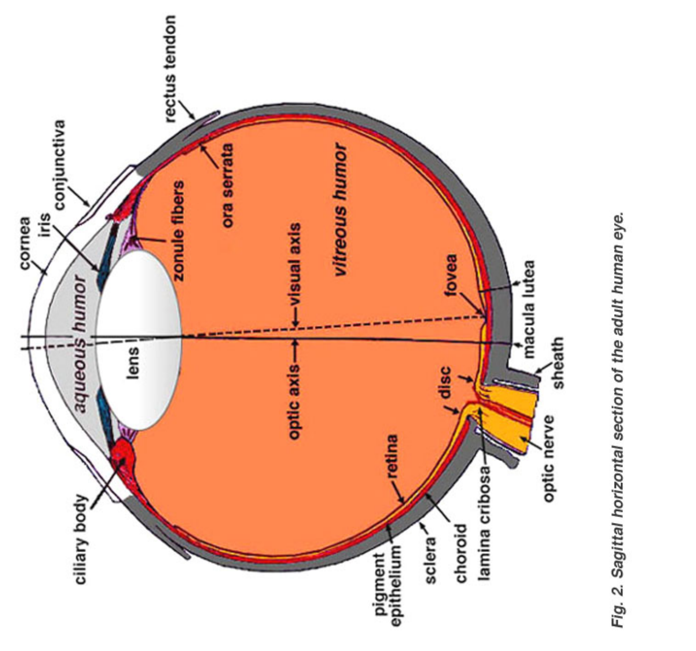
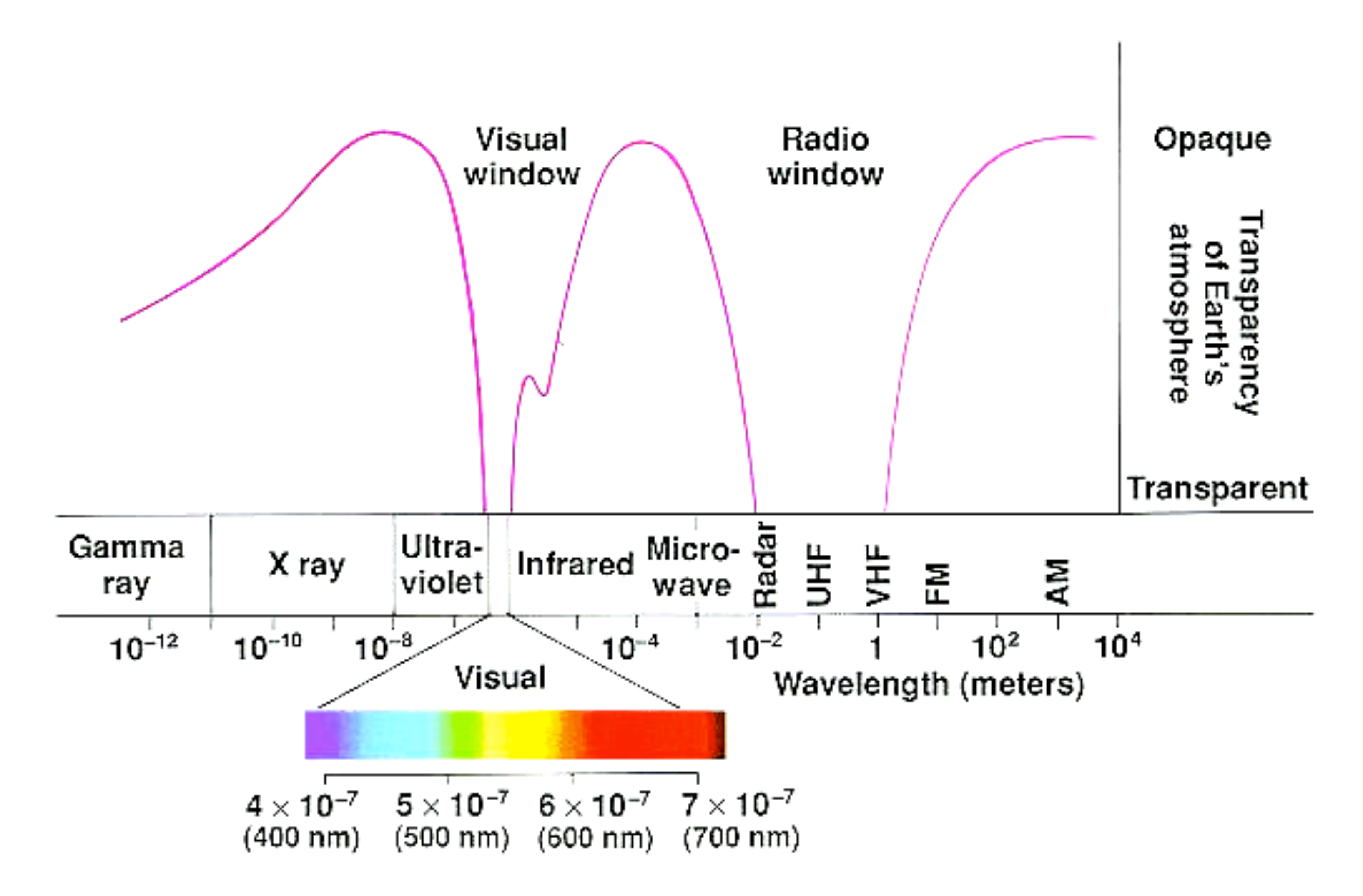



Fig. 2. Sagittal horizontal section of the adult human eye.

# Why Visible Light ?

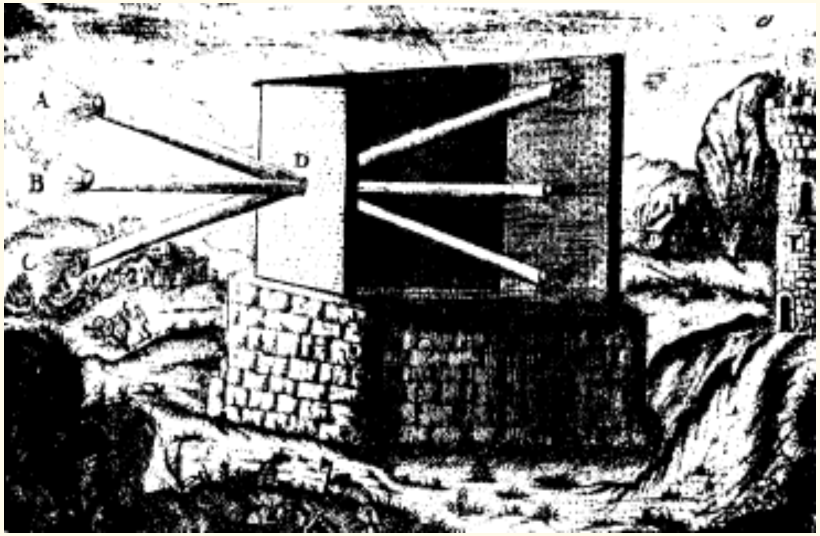


# Modern View of Visualization

# Earlier Day of Visualization

Visualisation:

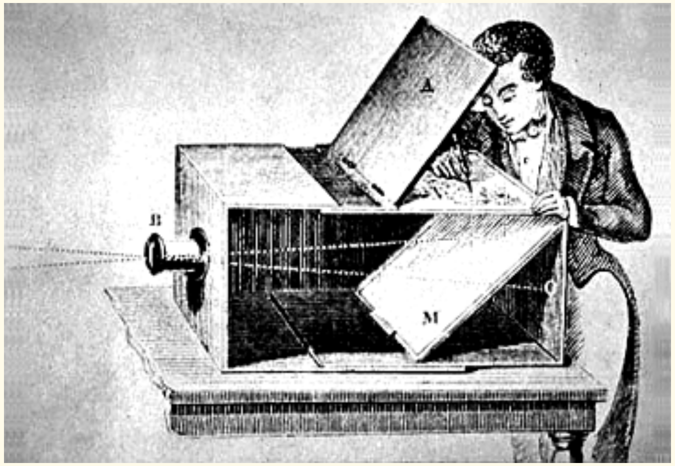
The Chinese were the first people that we know of to write about the basic idea of the pinhole camera or *"camera obscura"* (Latin words meaning "dark room"). About 2,500 years ago (5th Century B.C.) they wrote about how an image was formed upside down on a wall from a pinhole on the opposite wall.



# Earlier Day of Visualization

## Human Pictures:

The camera obscura is believed to have been used in this painting by Jan Vermeer. He painted this in 1665. He was a great master who made paintings that to this day still amaze people with how much they look like a photograph.



# Earlier Day of Visualization

Photography: The world photography came from two Greek words that mean "writing with light".

In 1800 a young English chemist, Thomas Wedgewood, was making "sun pictures" by placing leaves on leather that he had treated with silver salts, but he couldn't find a way to stop the darkening action of light and his leaf images faded into blackness.

For the birth of photography to happen two key discoveries were still needed: a way to combine light-sensitive material with the camera obscura device and a way to make an image permanent.

# Earlier Day of Visualization

"View from the Window at Le Gras, France"

The birth of photography happened in 1826 when a French scientist, Joseph Nicephore Niepce, put a plate coated with bitumen (an asphalt used in ancient times as a cement or mortar) in a camera obscura. He put the camera obscura facing his house for eight hours and made a photograph. It is the earliest camera photograph that we still have today. Here is that first photograph.

# Earlier Day of Visualization

Photography:

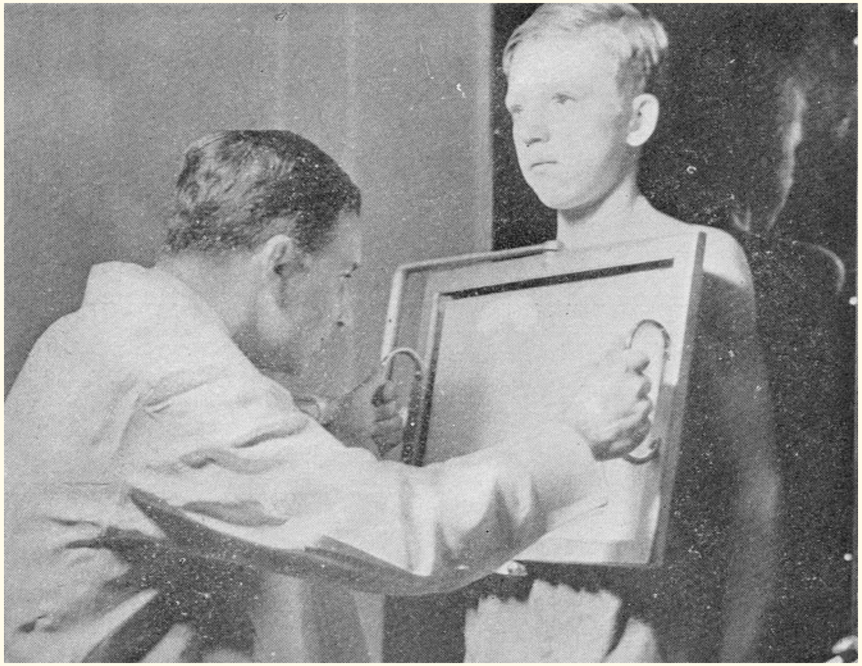
The first time the world "photography" was used in 1839, the year the invention of the photographic process was made public by Sir John Herschel

It was long successful history of PHOTOGRAPHY

Including Particle Physics

# Medical Systems

## X-Ray Scanning



# New Era of Visualization

# Modern Attempt to Visualization

Computing Revolution:

Practically all information NOW are represented in Digital Form (Electric Form) and then could be restore in Visual Form for Analysis

HOW TO SOLVE the problem conversion of Visual Information to Digital Form (Electric Form) ?

# Visible Light – First Understanding

First Attempt of Physicists: describe the light as a complex of Light Waves:


- Brightness represent by Amplitude of Waves,
- Color represent by wavelength

# Electromagnetic Radiation

Many successful attempts of WAVE THEORY of light, (Interference and Diffraction). Huge success of Radio Waves transmission and convert to the Electric Form

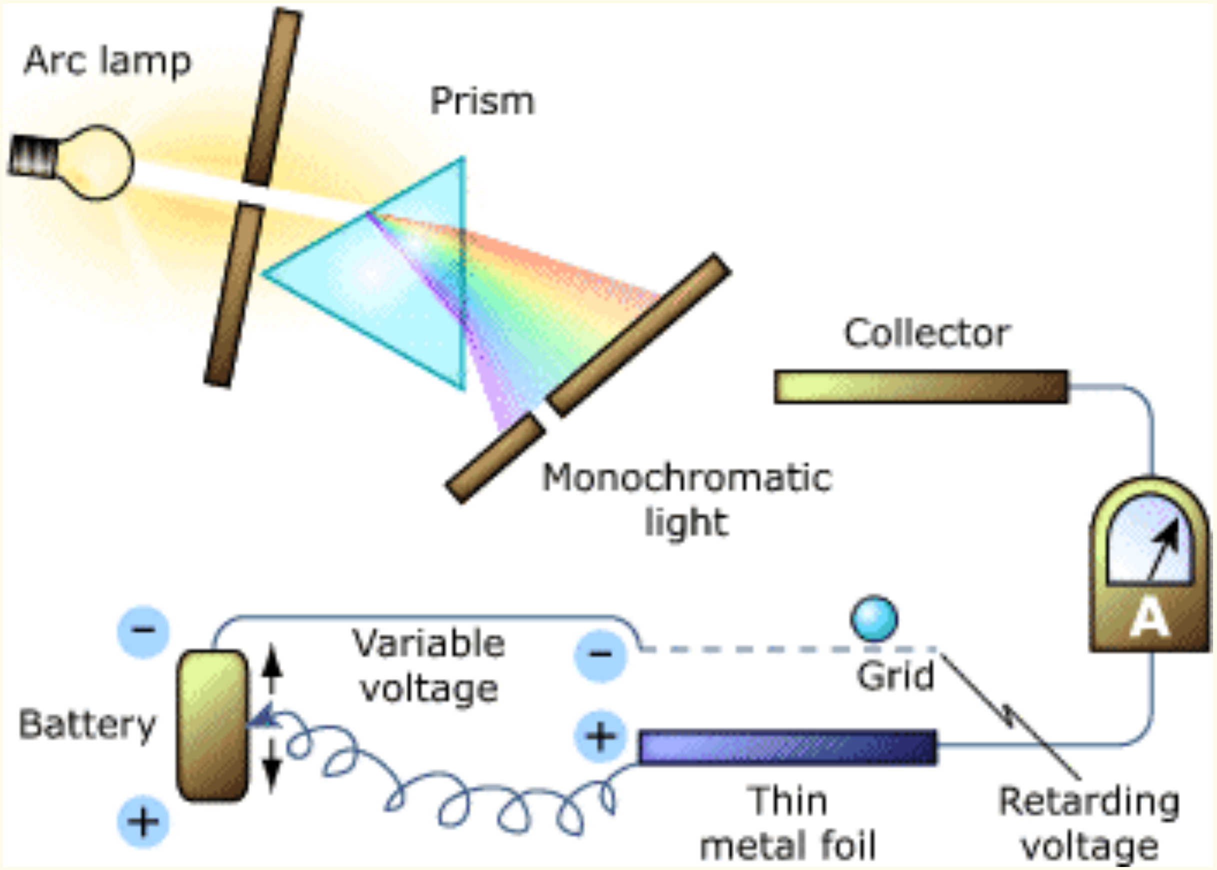
BUT unfortunately WAVE THEORY did not give the answer -

How to convert Light to Electric Form

# Photoelectric Effect

Accidentally experimentally was discovered the Photoelectric Effect: the Metals emit Electrons when Light shined on them,

Lenard' s Photoelectric Apparatus (1887)



# Photoelectric Effect

By varying the voltage on a negatively charged grid between the ejecting surface and the collector plate, Lenard was able to:

- Determine that the particles had a negative charge;
- Determine the kinetic energy of the ejected particles;

Perplexing Observations:

- The Intensity of light had no effect on energy of electrons;
- There was a threshold frequency for ejection;

Classical Physics failed to explain

# Photoelectric Effect

WAVE THEORY is not explain

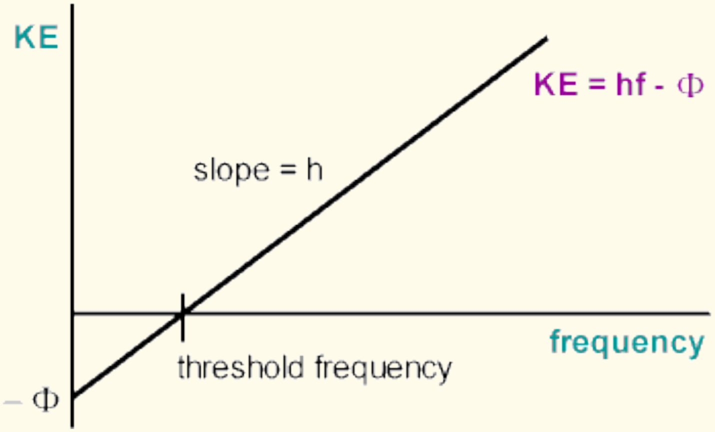
The PHOTOELECTRIC EFFECT (where metals emit electrons when light shines on them)

and SPECTRAL LINES (where only specific wavelengths of light emitted from particular elements)

# Photoelectric Effect is Quantum Effect (Photons)

Einshtein 1905 Interpretation (Quantum Effect, introduction of Light Particles):

- Electromagnetic radiation carry discrete energy packets (Photons);
- The energy per packet depends on wavelength (explaining Lenard's threshold frequency
  Φ is workfunction);
- More Intense Light correspond to more Photons, not higher Energy photons;




This work won Einstein his Nobel Prize in 1922.

# Modern Nature of Light (Photons)

Electromagnetic Energy is carried by PHOTONS;
A PHOTON is a single QUANTUM OF LIGHT.
The Energy of one Photon of a particular frequency is:

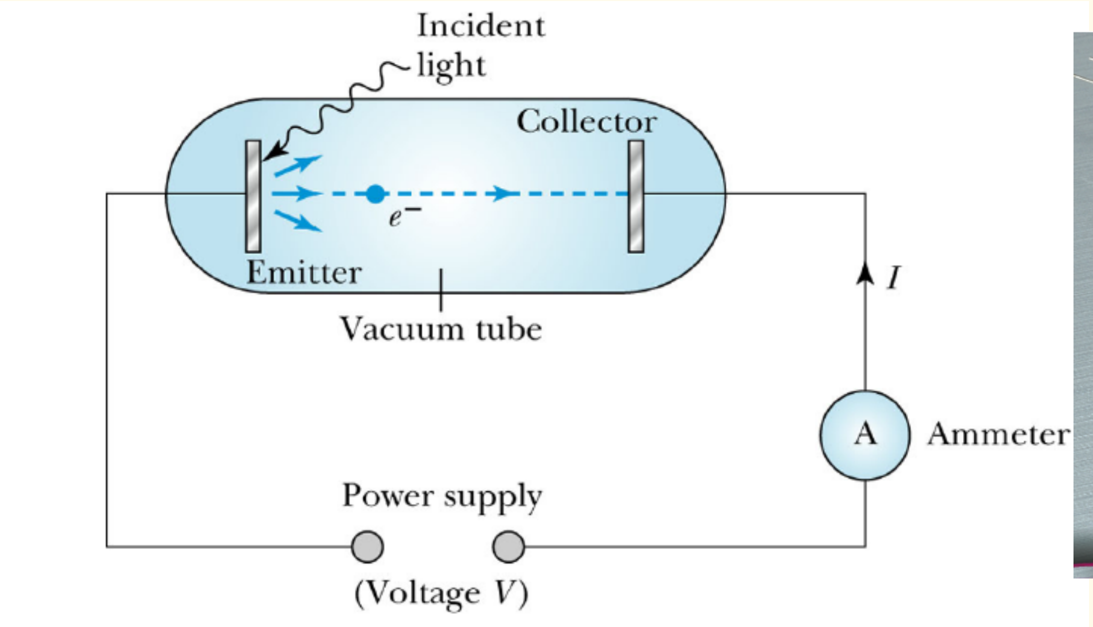
$$E = hf = h\,c\,/\,\lambda$$

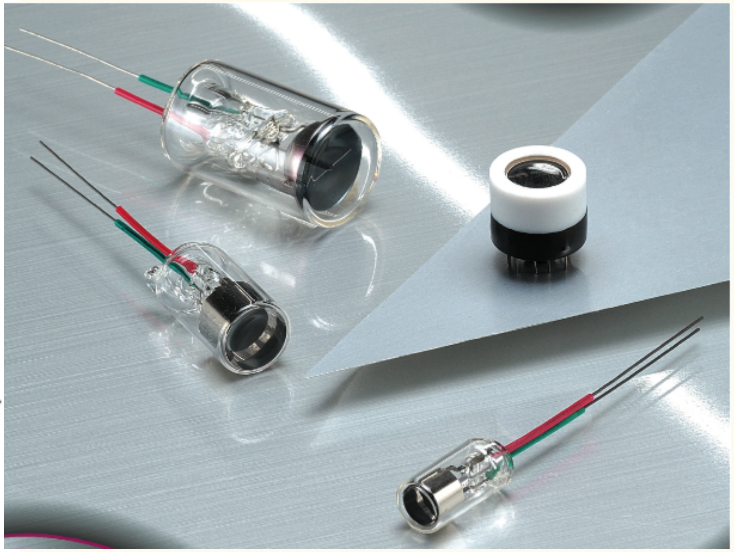
$h = 6.63 \times 10^{-34}$ Joule sec $= 6.63 \times 10^{-27}$ erg sec

is PLANCK's CONSTANT.

# Could be build the Detector of Light ?

Yes, Phototubes or Vacuum Diode



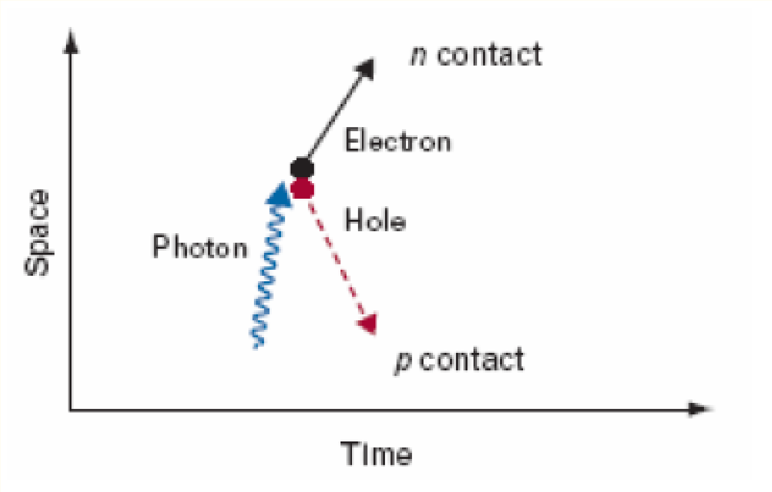
Photon -> Electron (Electric Field) -> Current

Unfortunately the technology is quite complicated… but we will come back to…

# Is Photoelectric Effect is General ?

Internal Photoelectric Effect (in semiconductors)

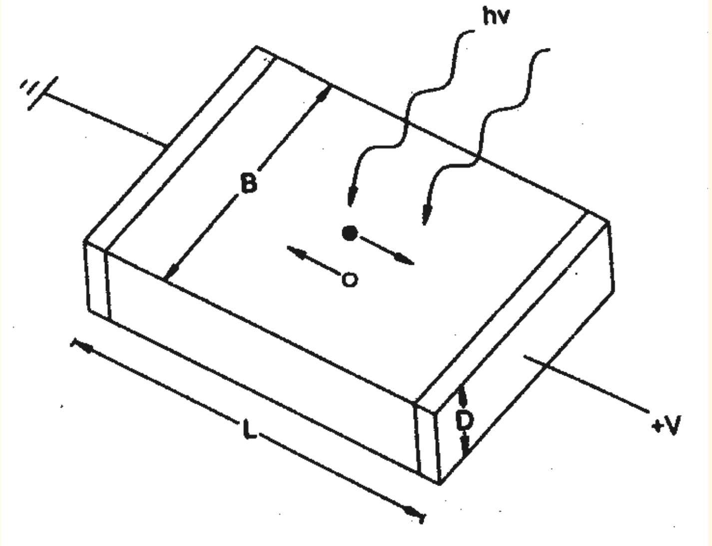
- When an photon impinges on a semiconductor, then an electron from the valance band can be lifted to the conduction band. Semiconductors have a very small workfunction Φ. When the electron cannot recombine with the hole, due to the electric field of a silicon photodiode, it can be collected and the signal amplified.




This process is far more efficient in light detection both in terms of detection efficiency and wavelength sensitivity, because it needs less energy O(1 eV) than the photoelectric effect one O(10 eV).

# Could be build the Detector of Light ?

Yes,




The photoconductor is the simplest type of the detectors and consists of a simple slab of semiconductor across which a bias is applied.

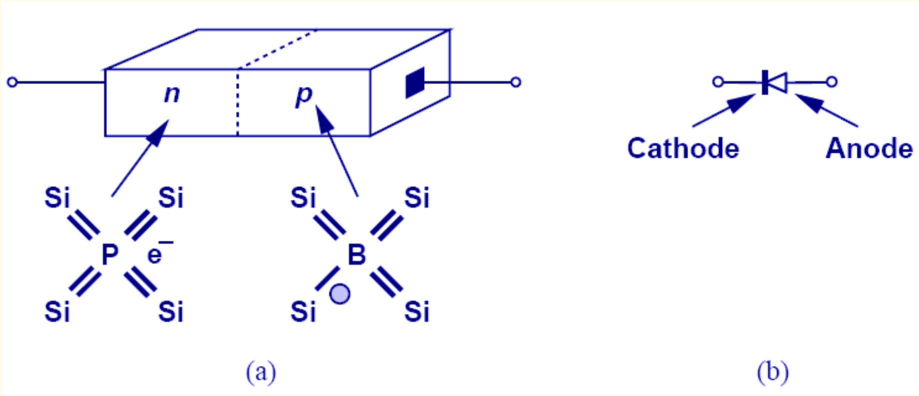
Unfortunately the photoconductors suffers from the presence of a large dark current noise in the detector.

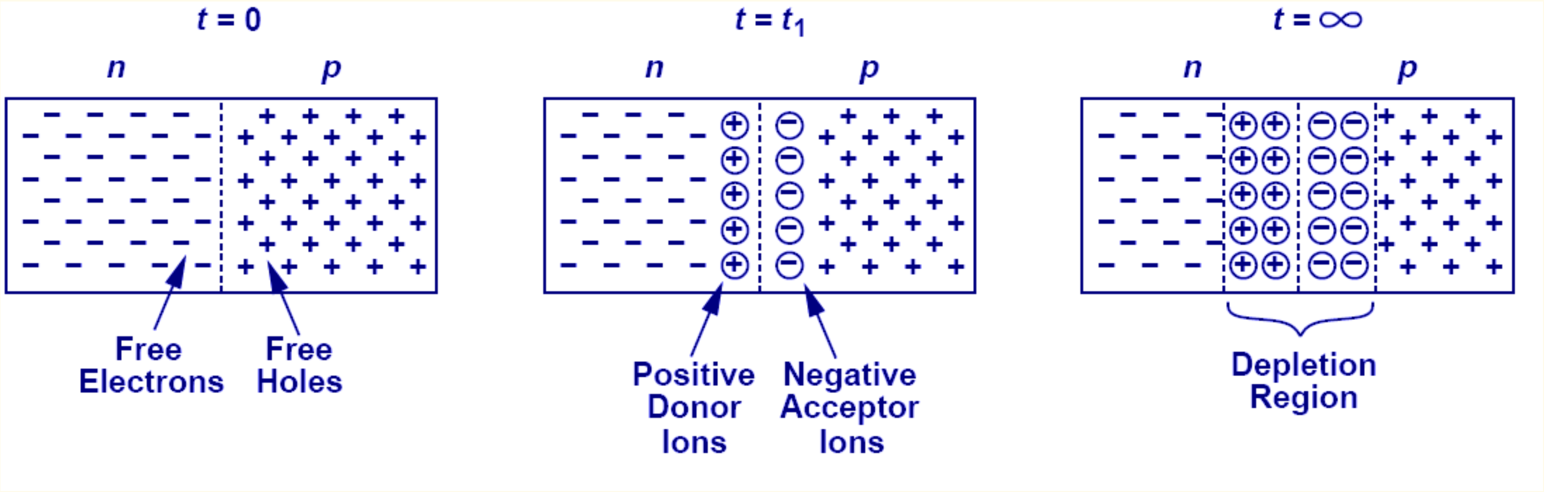
# Resistance Effects of Doping

- If you use lots of Phosphorus atoms (a dopant, or element like P, has 5 valence electrons), there will be lots of extra electrons so the resistance of the material will be low and current will flow freely.
- If you use only a few Boron atoms (a dopant, element B that has only 3 valence electrons), there will be fewer free electrons so the resistance will be high and less current will flow.
- By controlling the doping amount, virtually any resistance can be achieved.

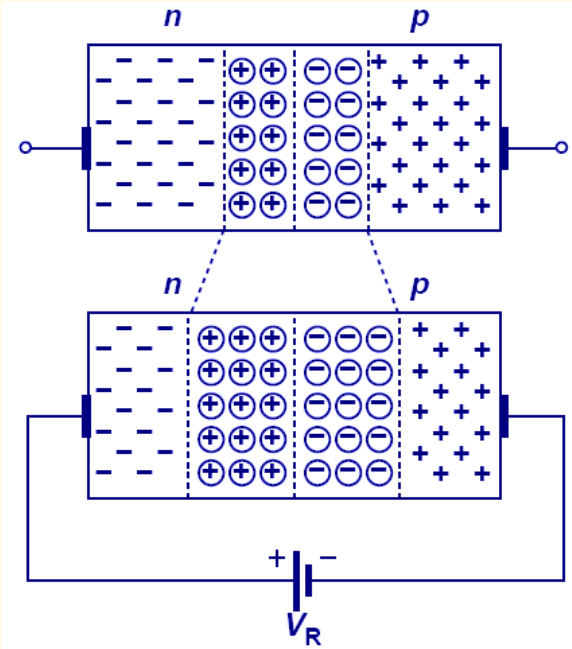
# Could be build the Detector of Light ?

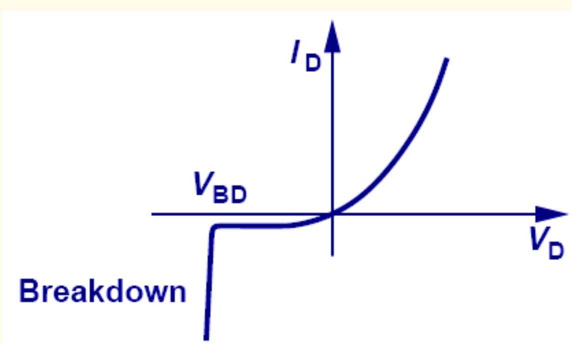
It is well known how to reduce the dark current in semiconductor, needed just create the semiconductor structure - *pn* junction (semiconductor diode)



# Could be build the Detector of Light ?




The pn-Junction is physical contact of two different Type of Semiconductors (n and p type)

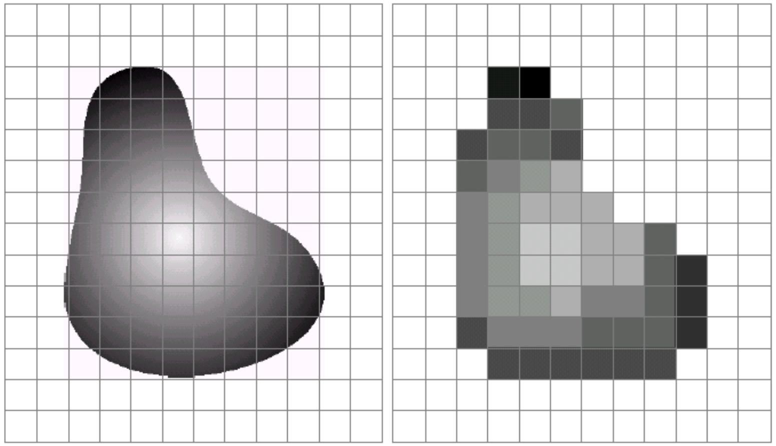
- Electrons and Holes diffuse to area of lower concentration. Electric field is built up and appear the Depletion Layer
- To apply the External Potential bias (direct) the carrier could be move cross the contact between two type of semiconductors.
- To Apply the External Potential (reverse), the Depletion Area is increasing

Depletion Region is Used for the Detection of Photons

# Example CCD and CMOS

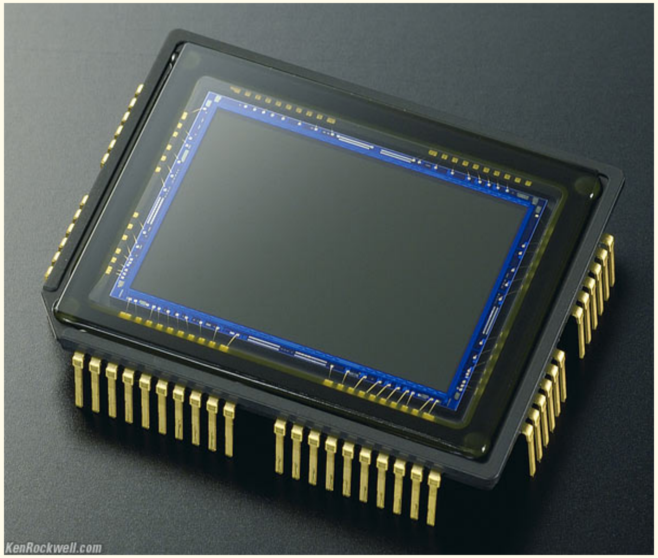
and Semiconductor Technology is so flexible that you could develop compact Imaging Detection System consisting from many elementary cells (pn junctions) and organizing of readout to get the picture in the digital form

As Example two Semiconductor Imager CCD and CMOS



a b

**FIGURE 2.17** (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



# Are We Happy ?


# Visualization is more Complicated Process (Photon Flux)

# Photon Flux Detection Requirements

Quantum Efficiency
- The efficiency in single photon detection;

Sensitivity and Color Sensitivity
- Minimum N of Photons which could be detected with particular Energy;

Dynamic Range and Linearity
- Ratio of Max to Min N of Detected Photons and Functional Dependence;

Gain
- Possibility of Multiplication of the Initial Signal during Detection Process;

Noise
- Minimum N of Equivalent Photons output without input Photon Flux;

Timing and Positioning
- Capability of providing Time and Position Information of the incoming photons;

Experimental Conditions
- B-field, Temperature, Radiation Levels, e.t.c.

Complexity and Scalability
- Physical Shapes of Detectors, Possibility of Changing;

# Low Photon Flux

# Low Photon Flux

The Visualizations is Measurement of Photon Flux:

Photon Flux = (N of Photons)/(Area x Time)

Main Limitations:

- Upper Limit probably does not Exist (photons are bosons);
- Absolute Lower Limit of Photon Flux is Single Photon;

Crucial Understanding is What Is Low Photon Flux

# Low Photon Detection: Where Do we Stand

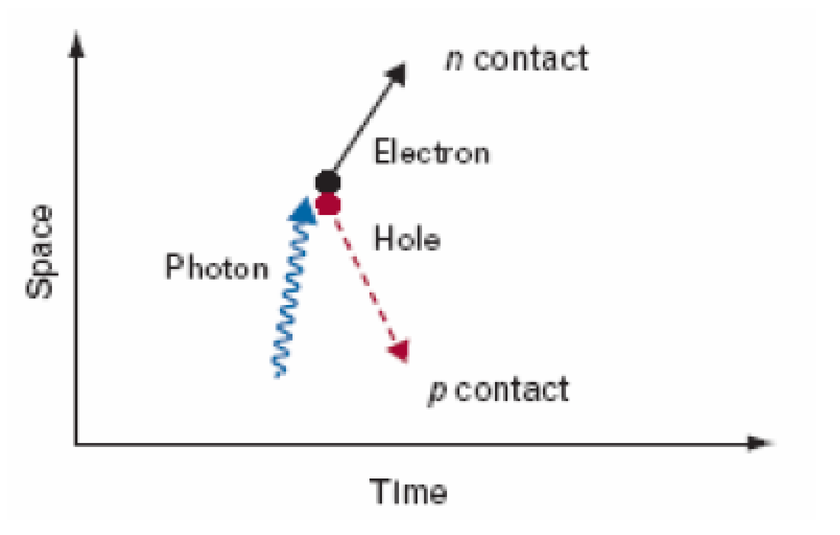
Principle of Detection:

- Main principle of detecting of photons is Photoelectric Effect, liberating electrons from detecting media by the energy of photons

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

  ONE photon ->

  liberate just ONE electron

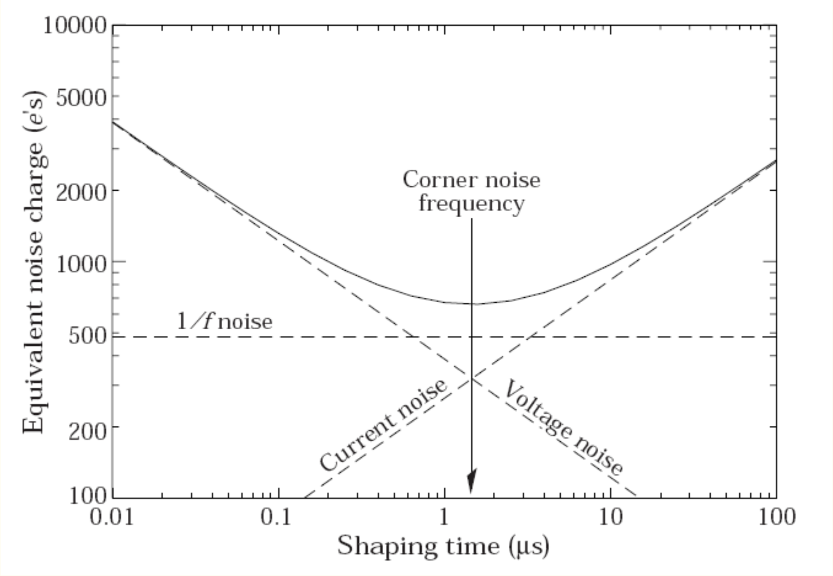



Finally we measure the CHARGE (Electronic Measurement)

# Low Photon Flux Measurement

Any electronic measurements are affected by noise (including detector itself) – mainly Thermal Electron Noise

Equivalent Noise Charge as a feature of the Measurement System at Room Temperature (external front-end electronics)




Trade-off between Photons (correspond to Charge as N of Electrons) as signal and noise (as significant feature of Measurement System) gives the results in quality of detection.

# Low Photon Flux Measurement

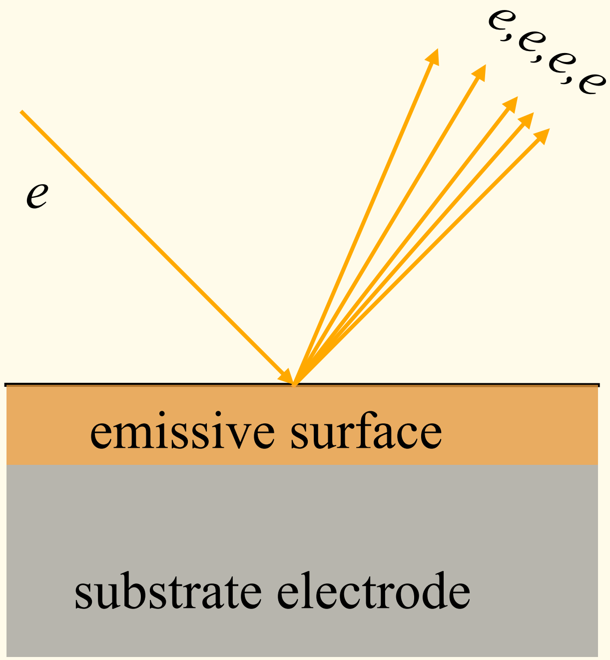
With modern technology Sensors in Some Cases it is possible Embedded the Front-end Electronics, the Sensitivity Level is still ~ 100 of electron, (~ 100 photons)

Alternatives (improving of the signal/noise ratio):

- Cooling down the Detector and Readout Electronics;
- Have to provide the Internal Amplification in the photodetector (before the Readout Electronics) on the level at least $10^4$, more general $10^6$;

# Photomultiplier Tubes

# Secondary Emission of Electrons




In 1902, Austin and Starke reported that the metal surfaces impacted by electron beams emitted a larger number of electrons than were incident. The application of the newly discovered secondary emission to the amplification of signals was only proposed after World War
I by Westinghouse scientist Joseph Slepian

# Secondary Emission of Electrons

The general features of secondary electron emission are well understood. Primary electrons impact the surface and either reflect elastically or suffer energy loss through a variety of channels:

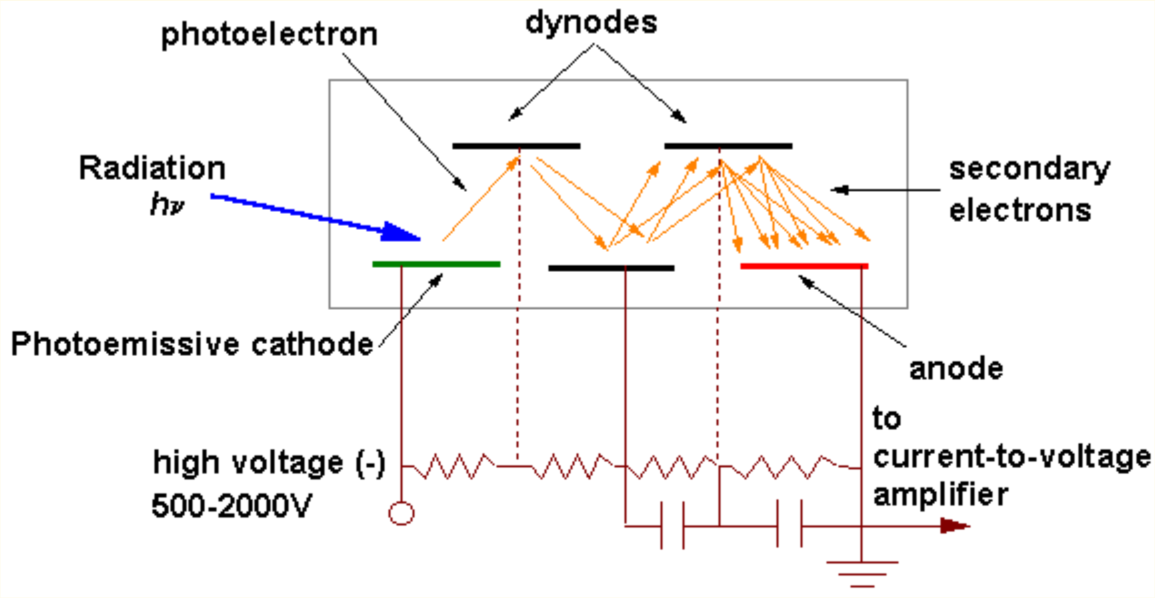
- phonon and plasmon-generating loss,
- ionization of atoms,
- free-electron scattering,
- surface state capture,
- interband transition, etc.

The electrons generated by these inelastic processes are referred to as "true secondary" while re-emitted primary electrons that suffer loss are classed as "re-diffused" primaries.

Most secondaries electrons are of very low energy (2-5 eV), a result of multiple collisions, and must be within a free path of the surface (1-3 nm in metals) in order to escape into vacuum.

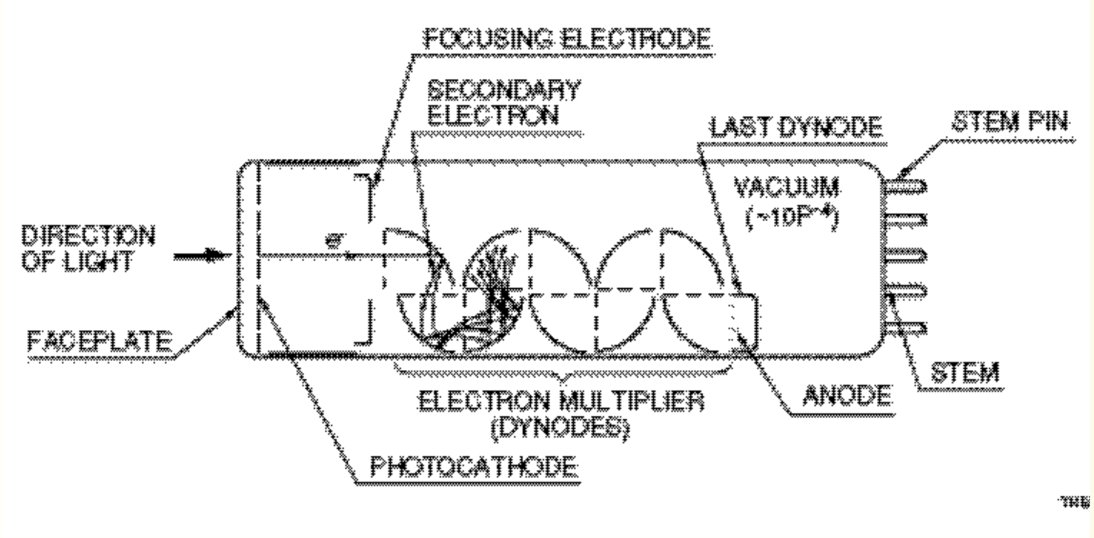
# Principle of Photomultiplier Tube

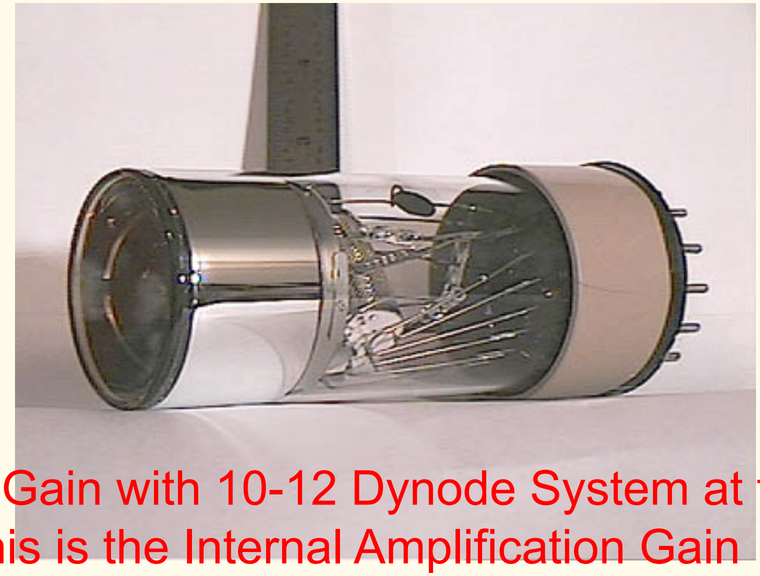
- Photocathode
  - convert photon to electron
- Dynodes
  - secondary electron emission
- One anode
  - collect the electrons




- Photons hit on the photocathode - the result is emission of one electron for approximately every five light photons
- The electron produced is accelerated toward a dynode chain
- The accelerated electron has sufficient kinetic energy to liberate approximately five additional electrons when it strikes each dynode

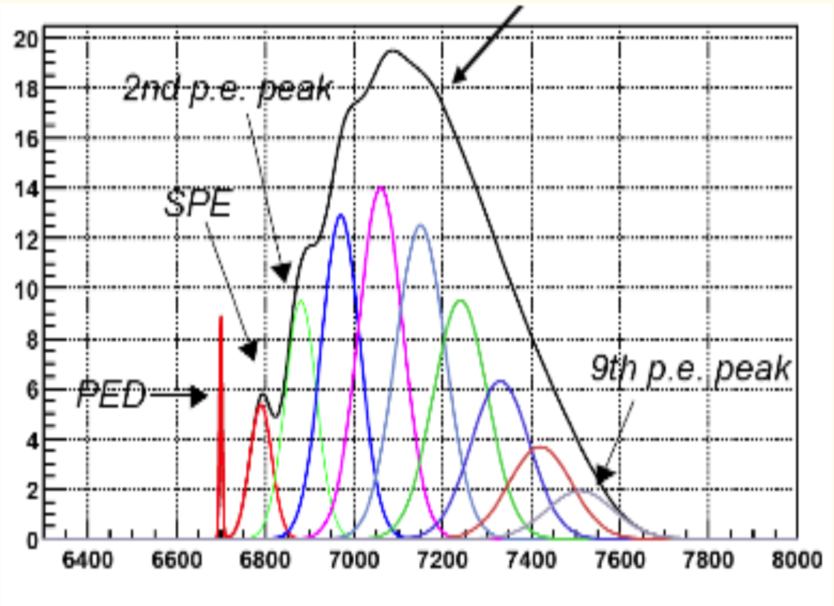
# Construction of Photomultiplier Tube

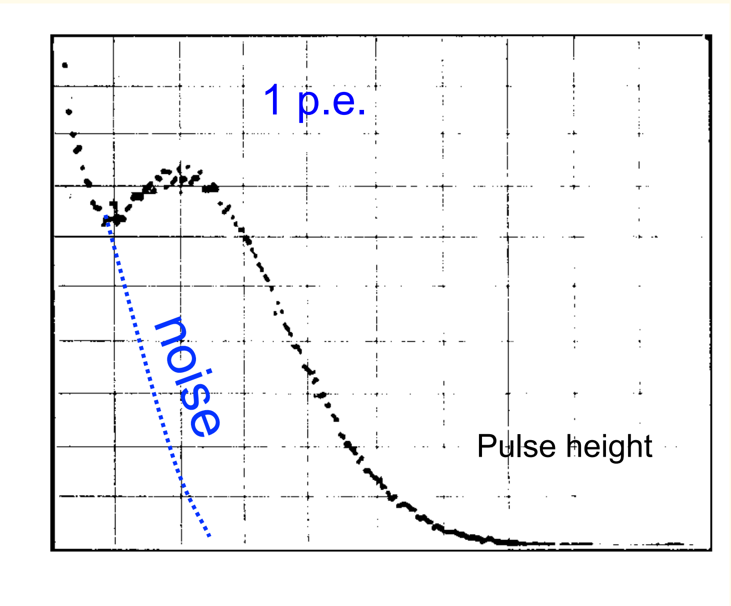


The Amplification Gain with 10-12 Dynode System at the collecting Anode is 10**6 to 10**8 - this is the Internal Amplification Gain

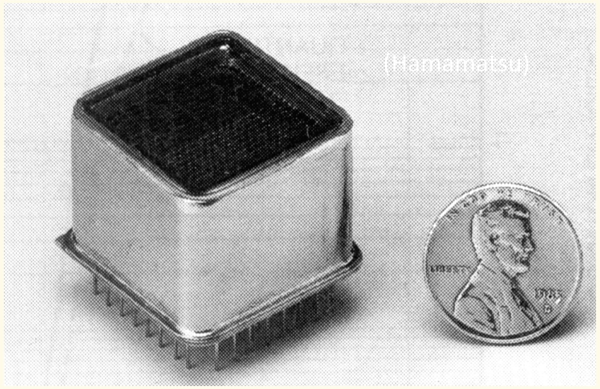
# Performance of Photomultiplier Tube

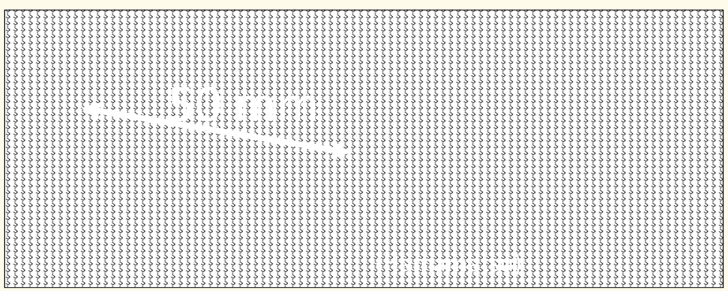



PMT's gives high resolution – up to few photons,
Some type of PMT could reach single photon response

# Modern Photomultiplier Tube



Multi-anode (Hamamatsu H7546)
Up to 8 × 8 channels (2 × 2 $mm^2$ each);
Size: 28 × 28 $mm^2$;
Active area 18.1 × 18.1 $mm^2$ (41%);
Bialkali PC: QE: ≈ 25 - 45%, $I_{max}$ = 400 nm;
Gain: ≈ 3 $10^5$;
Gain uniformity: 1 : 2.5;
Cross-talk: 2%

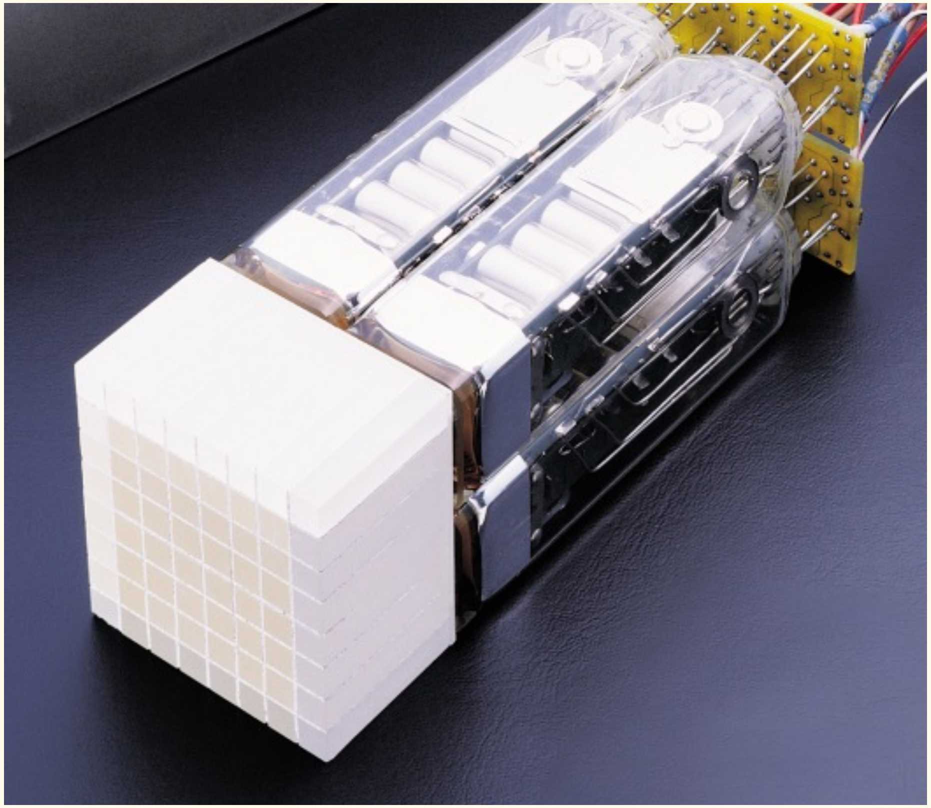
Flat-panel (Hamamatsu H8500):
8 x 8 channels: 5.8 x 5.8 $mm^2$ each
Excellent surface coverage: 89%

# Photomultiplier Tubes

Photomultipliers Tubes
practically only Photonic Device with
high the Single Photon Sensitivity
70 Years old Electro Vacuum
Technology is still could not replaced
by Modern Technology

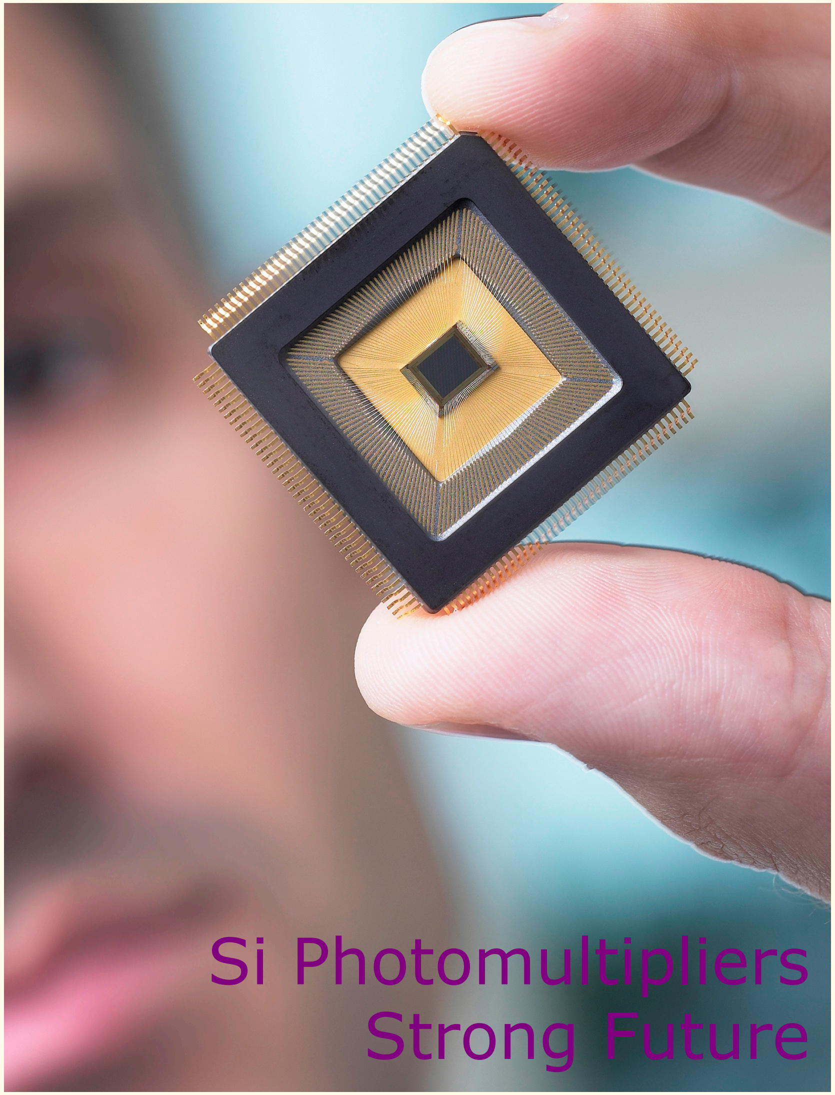
HAMAMATSU produces 417 TYPES of Photomultiplier Tubes

# PET Head with PMT



Preface

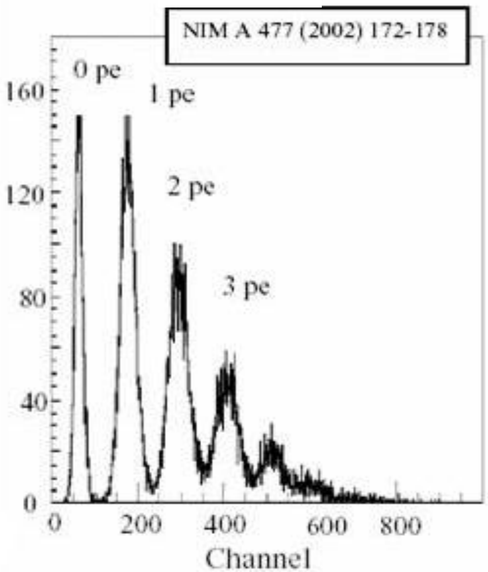

Photomultiplier Tubes
Strong History


Si Photomultipliers
Strong Future

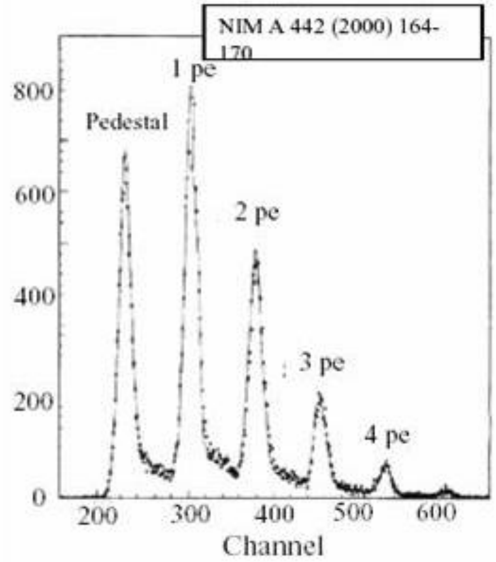
# Attack on Single Photon Response

# Single Photon Detection

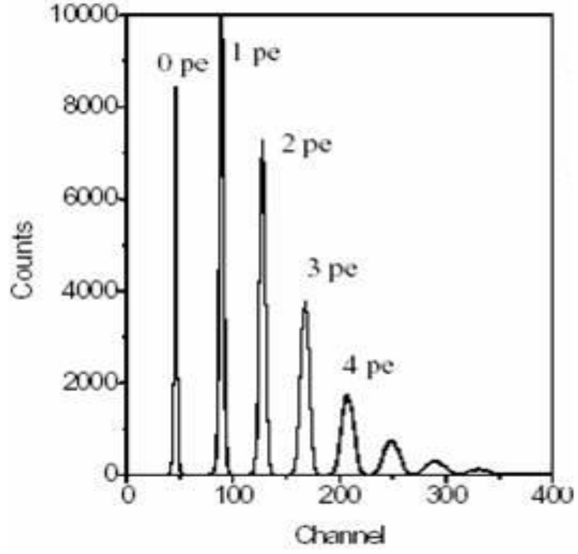
VLPC




HPD




SiPM



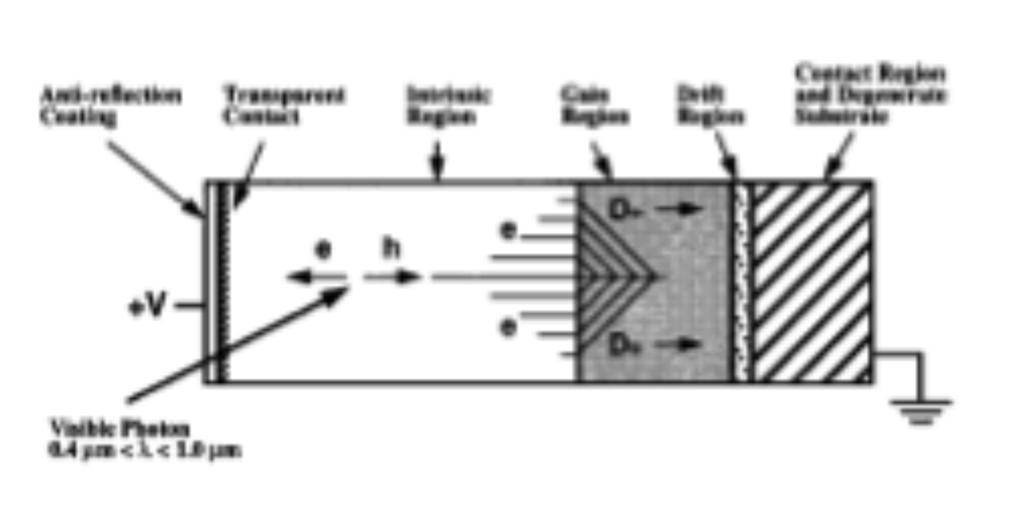

4 degree Kelvin

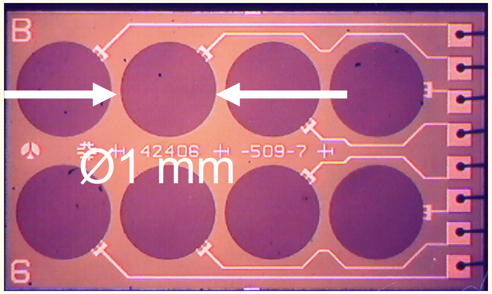
20 KV

Relax Conditions

One of the Smallest Values of Energy in Nature

# Visible Light Photon Counter

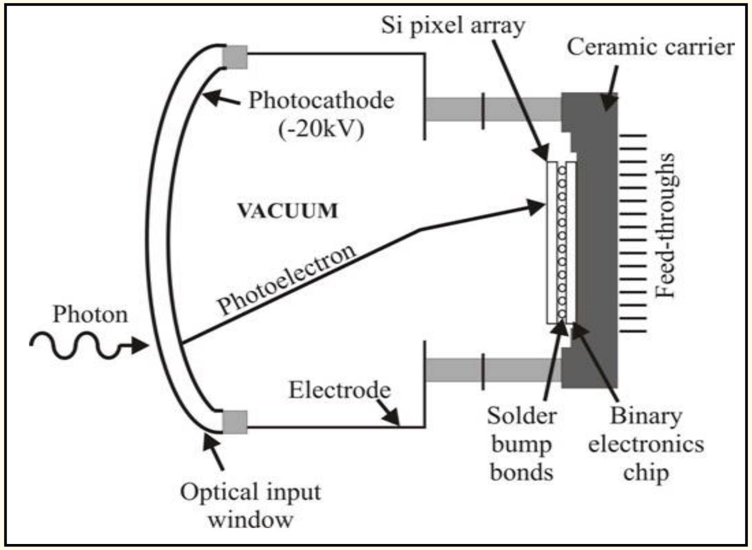



To Suppress the Noise the Device must cooled
up to 4 DEGREE KELVIN

# Hybrid Photon Detector (HPD)

- Combination of vacuum photon detector and solid-state technologies;
- Input: optical window, photo-cathode;
- Gain: achieved *in one step* by energy dissipation of keV pe's in solid-state detector anode
- Output: direct electronic signal;





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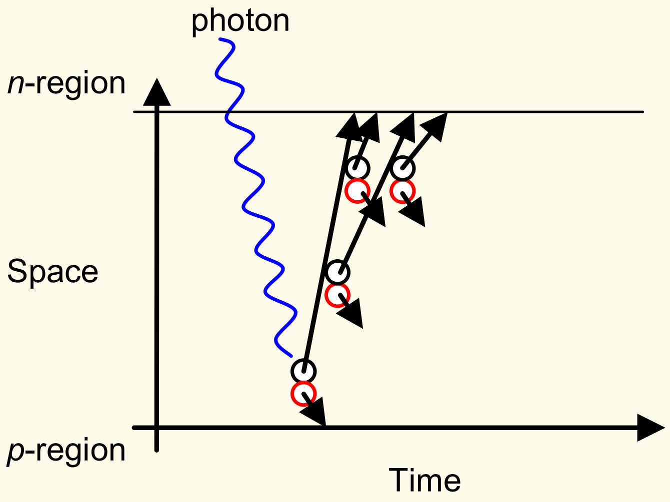
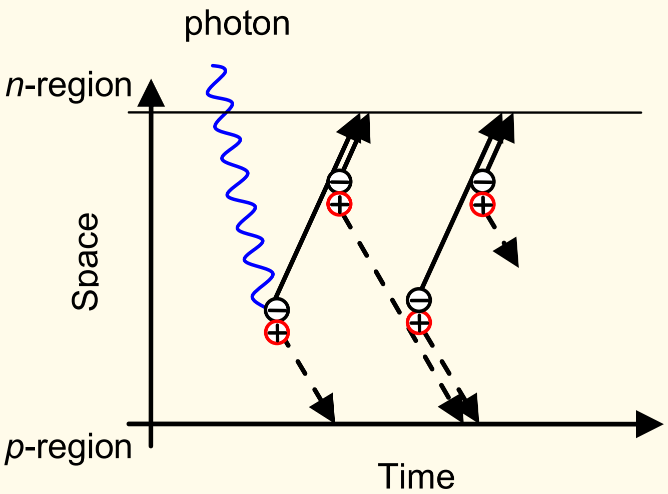
# Silicon Photomultiplier
# New Era of Photon Detection

# Si Avalanche Mode




- High Reverse-Bias Voltage, but below the breakdown voltage
- The primary electron accelerated in High Electric Field and starts a chain of impact ionization events (secondary ionization)
- The process of secondary ionization is one directional, when the primary electron reach the top electrode, the process stops;
- The Gain is order of 100. Output is proportional to photon flux

# Si Breakdown Mode Operation

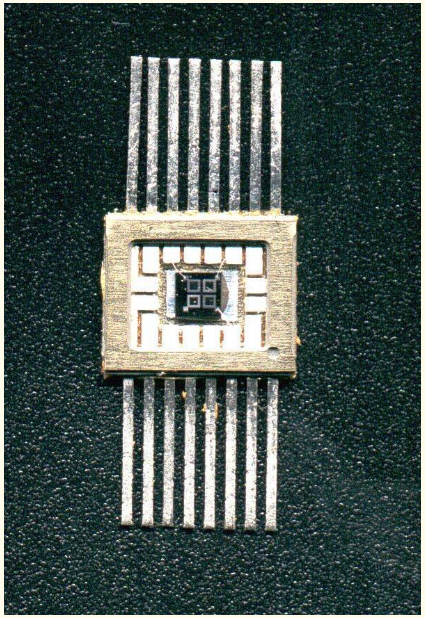


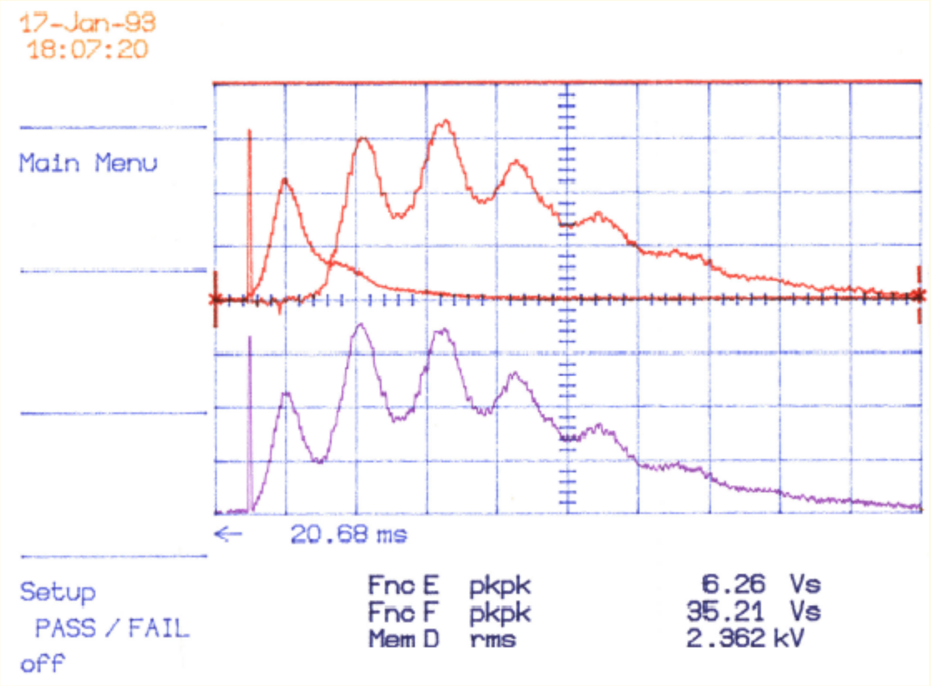

- In the Breakdown (Geiger) mode, the pn junction is biased above its breakdown voltage for operation;
- Electrons and holes are accelerated in the extremely High Electric Field and multiply by secondary impact ionization, resulting in an exponential growth in the current;
- The Gain is infinity, required quenching mechanism
- Output is nonlinear and defined by the breakdown process

The Goal was to find the quenching mechanism to stop breakdown process, and find the possibility to get the proportional output to the incident photon flux

# Earlier Day of Silicon Photomultiplier

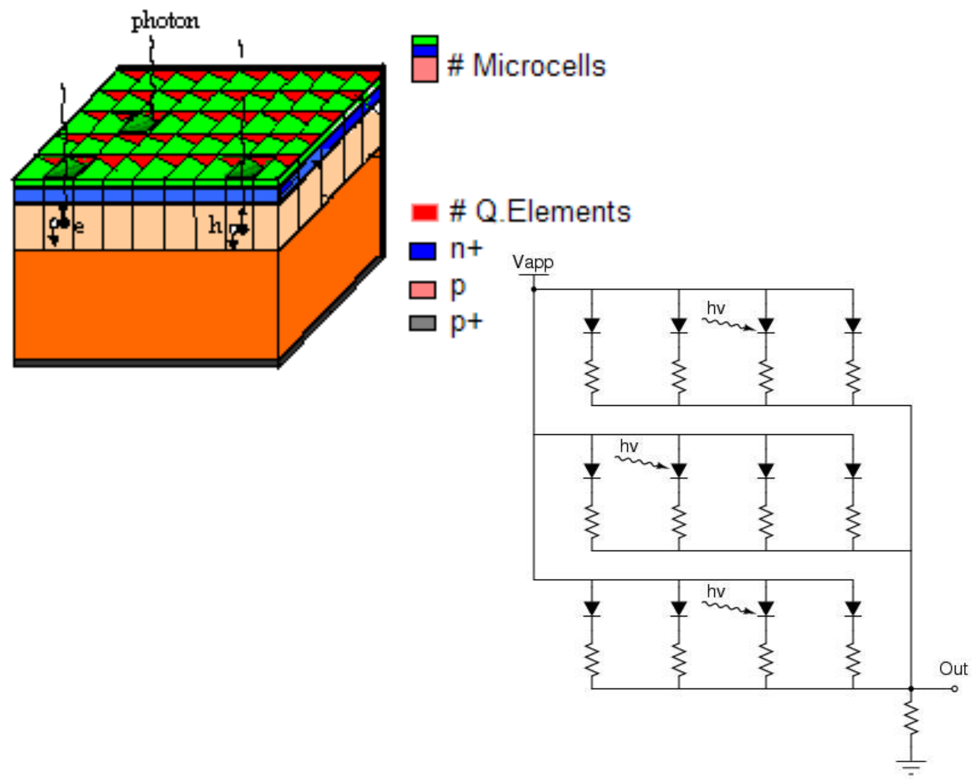
1980 I'm one of the inventors of the idea of SiPM (MRS Structures)
1992 come back to this idea and got first prove of single photon response






1995 first presentation on the international conference (Elma 95)
1999 world accepted the SiPM (Beaune 99)
Citation: > 250 for first published paper,
> 3000 downloads for open access published paper

# Modern Silicon Photomultiplier Structure




- Silicon Fine Micro Cells Structure (*p/n* junctions) on Common Substrate (few thousands)
- Breakdown Mode Operation of Micro Cells
- Integrated Quenching Elements for every Micro Cell
- Common Output
- Trenches for optic crosstalk suppression

- All microcells are independent and identical (give binary signals)
- Output is sum of the standard binary signals of microcells fired by photons

# SiPM Performance and Operation Condition

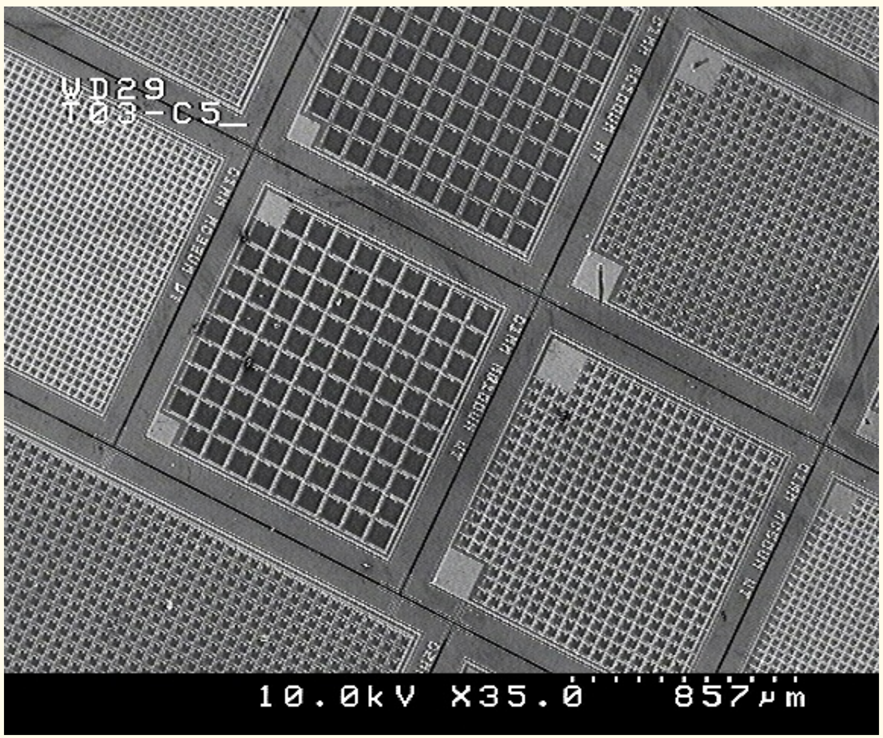
- Detection efficiency (> 45% for visible range of light)
- Single photon performance (Intrinsic Gain ~$10^6$)
- Proportional mode for the photon flux
- Large dynamic range

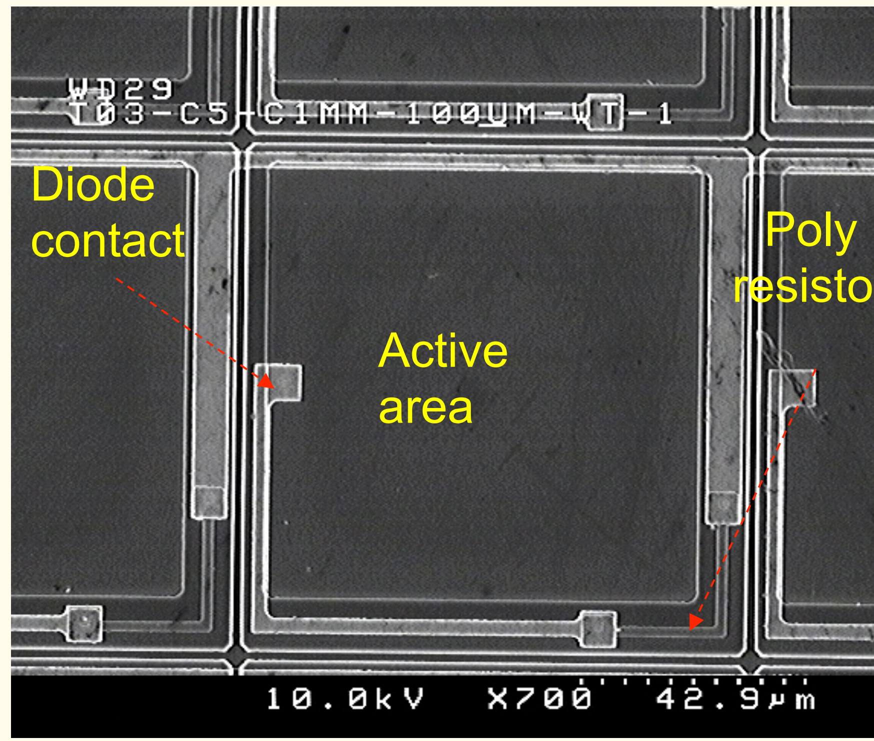
- Operation conditions:
  - Low Operational Voltage ~18-80 V
  - Room Temperature
  - Non Sensitive to Strong Magnetic Field
  - Minimum Required Electronics

- Miniature size and possibility to combine in different shape
- Low cost ( in mass production )

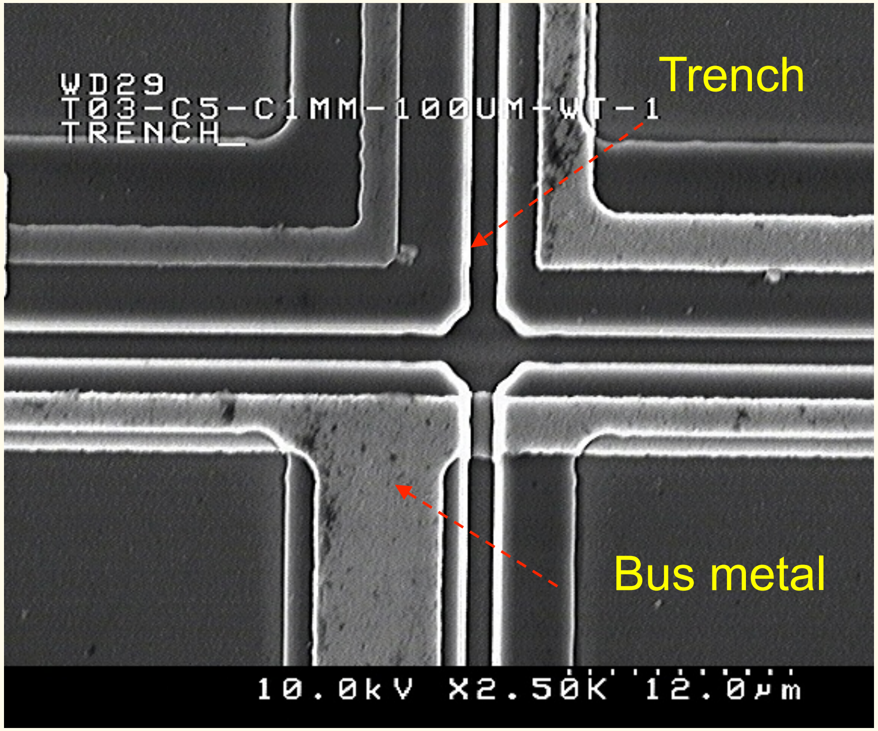
# Advance Technology of SiPM Structures

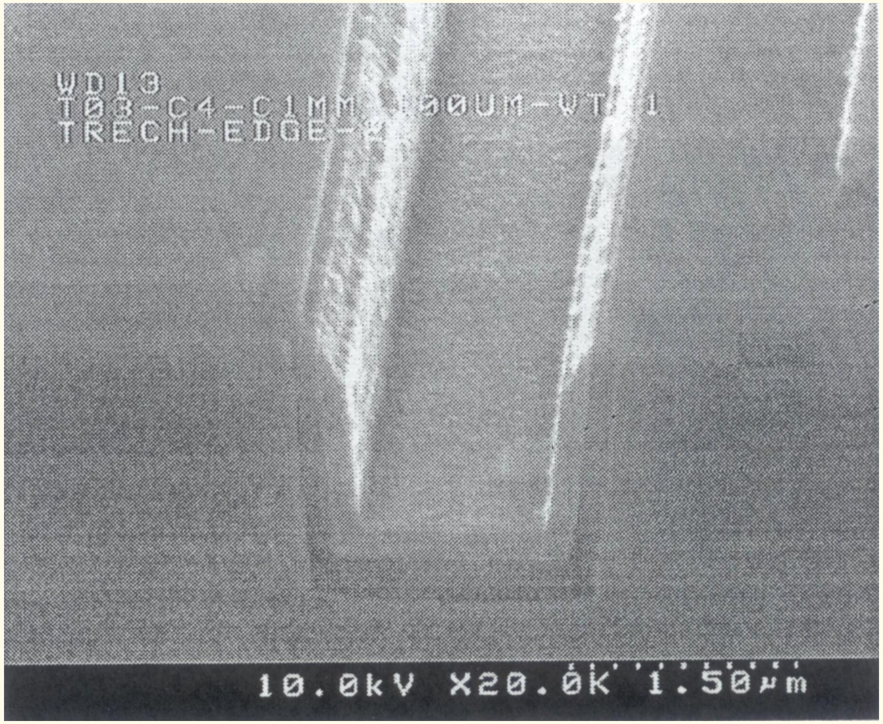
- General view of Silicon Photomultiplier
- Common Electrode Layout
- Microcells with Quenching Elements and Trenches



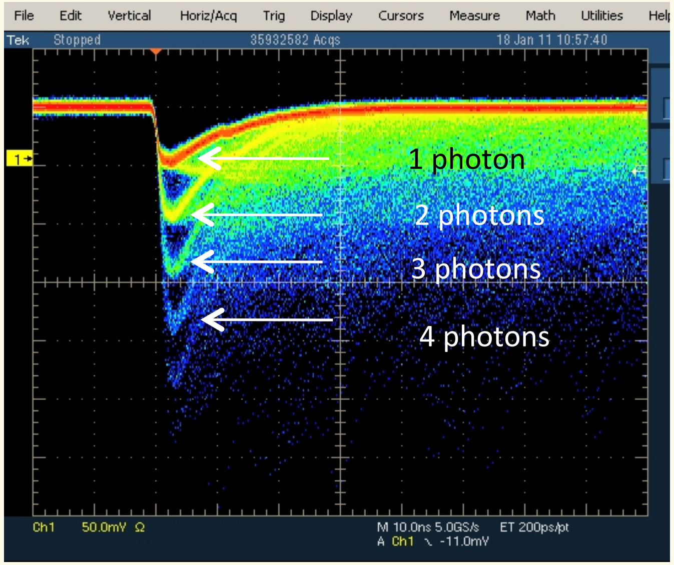
# Advance Technology of SiPM Structures

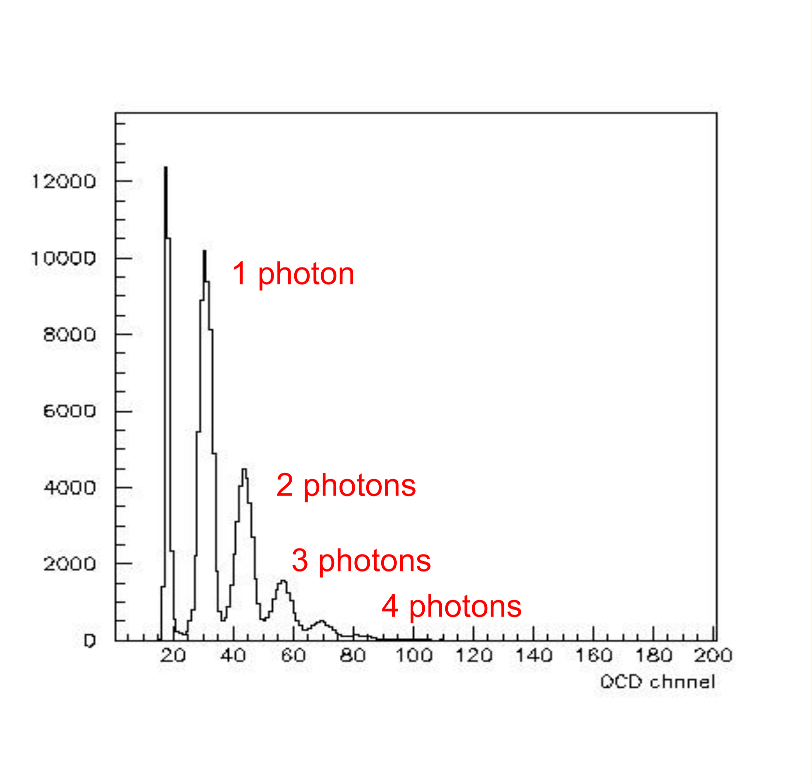



Trench Technology for preventing Optic Crosstalk

# Single Photon Response

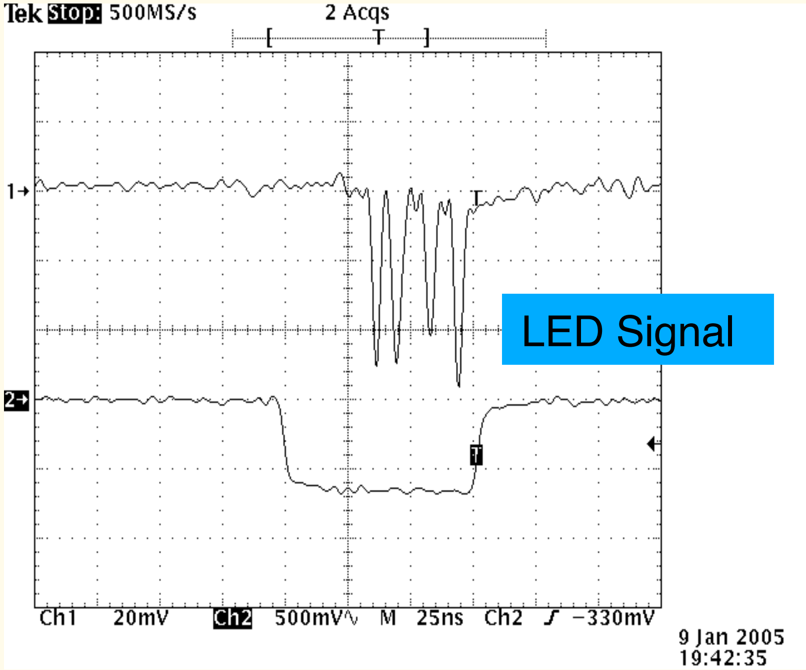


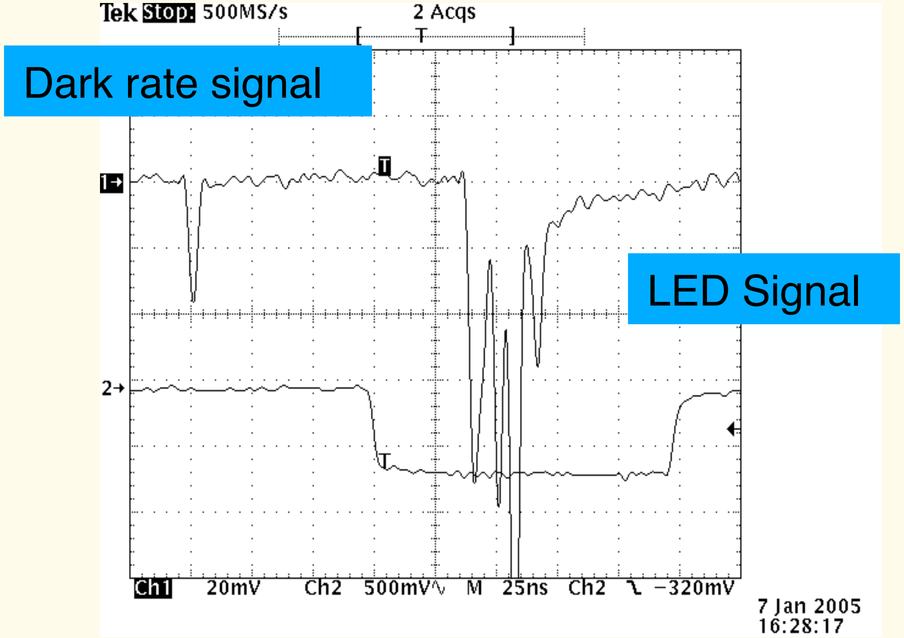




Excellent Single Photon Resolution of SiPM at Room Temperature

# Silicon Photomultiplier Performance

## Signal of Silicon Photomultiplier




Signal of Silicon Photomultiplier can be readout without Front-end Electronics

# Photon Detection Efficiency

The photon detection efficiency (PDE) is the product of:

- quantum efficiency of the active area (QE),
- a geometric factor ($\varepsilon$, ratio of sensitive area to total area)
- the probability that an incoming photon triggers a breakdown ($P_{breakdown}$)

$$PDE = QE \cdot \varepsilon \cdot P_{breakdown}$$

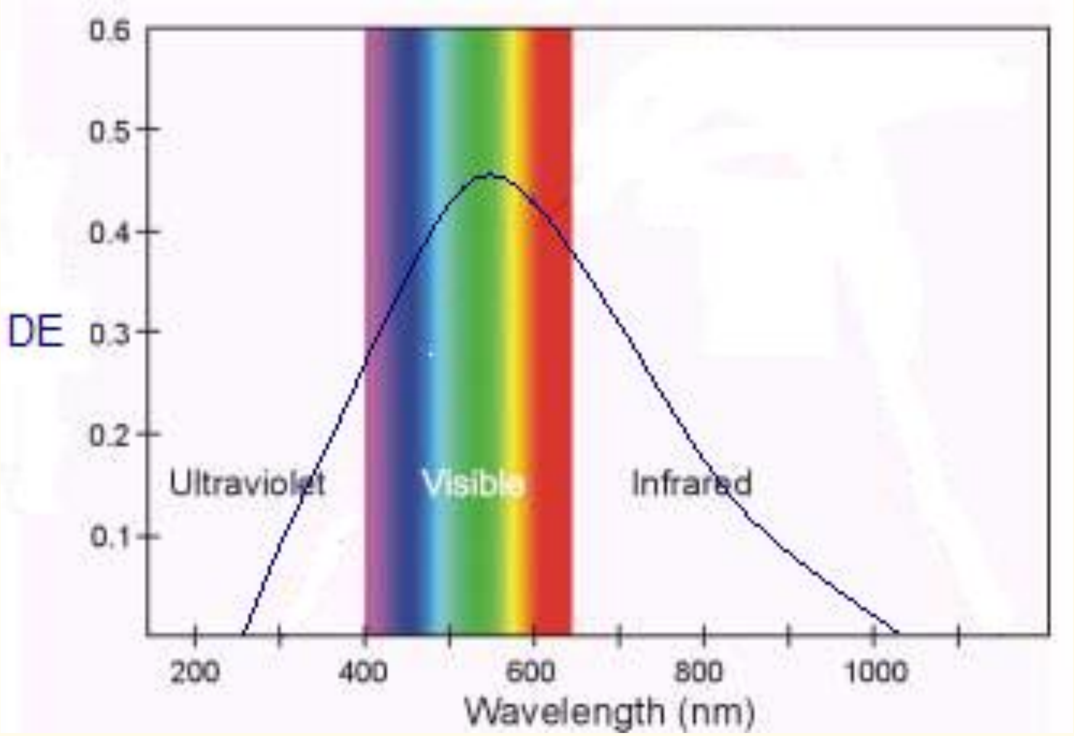
QE is maximal 80 to 90% depending on the wavelength (Silicon).

The QE peaks in a relative narrow range of wavelengths because the sensitive layer of silicon is very thin~few microns

In visible range of light the Photon detection efficiency ~ 30 - 60 %

# Photon Detection Efficiency vs Wavelength

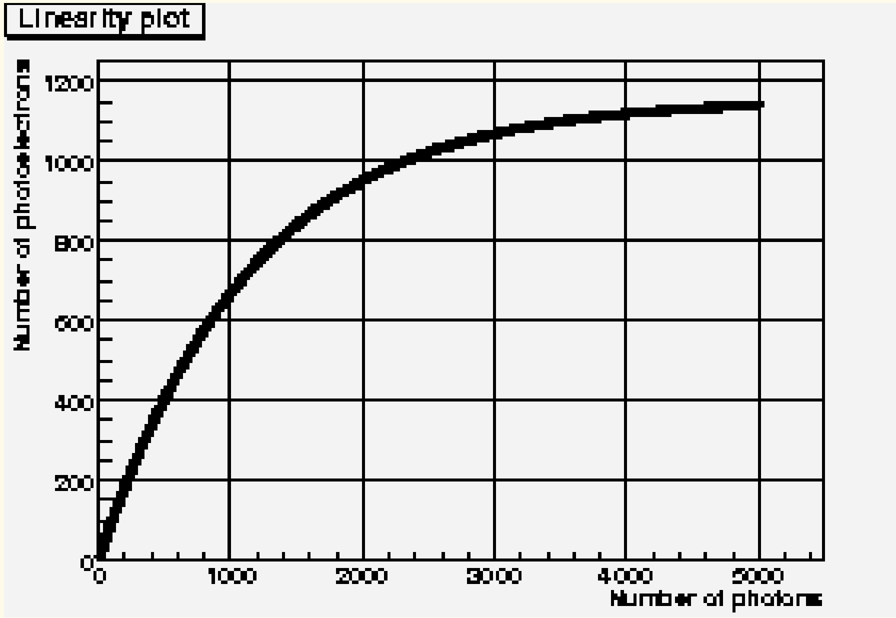
- UV region of Light
  - Is limited by technology layers (dead layer on the top),
- IR region of Light
  - Is limited by thickness of sensitive layer,
- Absolute Value Scaling
  - Is Geometry filling factor




Detection Efficiency as function of wavelength
~ 45% in green area of visible light (example of n on p structures)

# Silicon Photomultiplier Performance

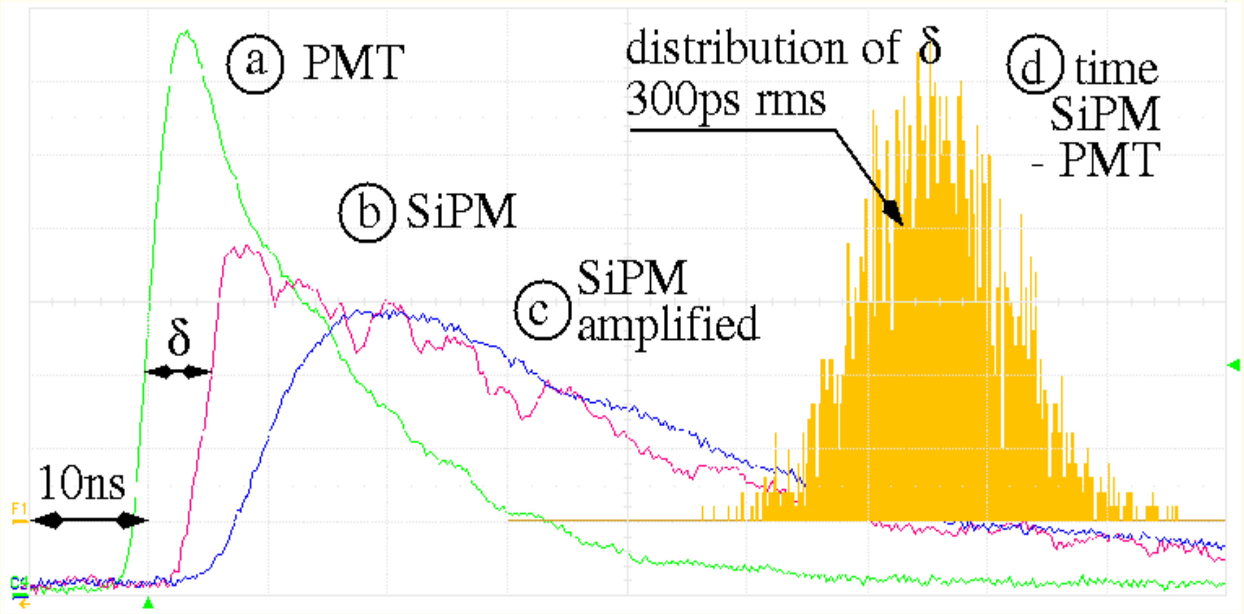
- Linearity
  - Intrinsic linearity of Silicon photomultiplier is very high, differential nonlinearity on the level 20% of single photon response
- Dynamic Range
  - Defined by fine structure of Silicon Photomultiplier – number of microcells (~1180) and statistical response




Statistical character of the photons detections on limited number of cells gives the nonlinearity, which can be correct by statistical function

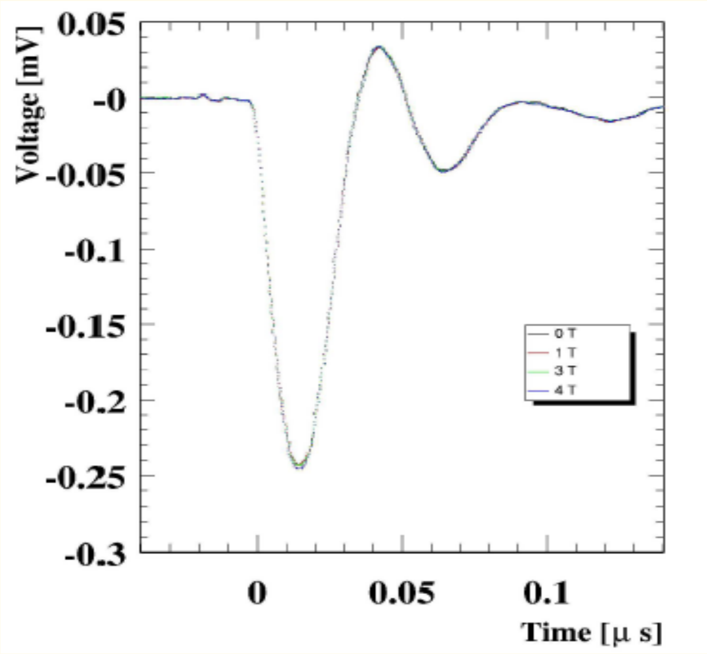
# Time Performance

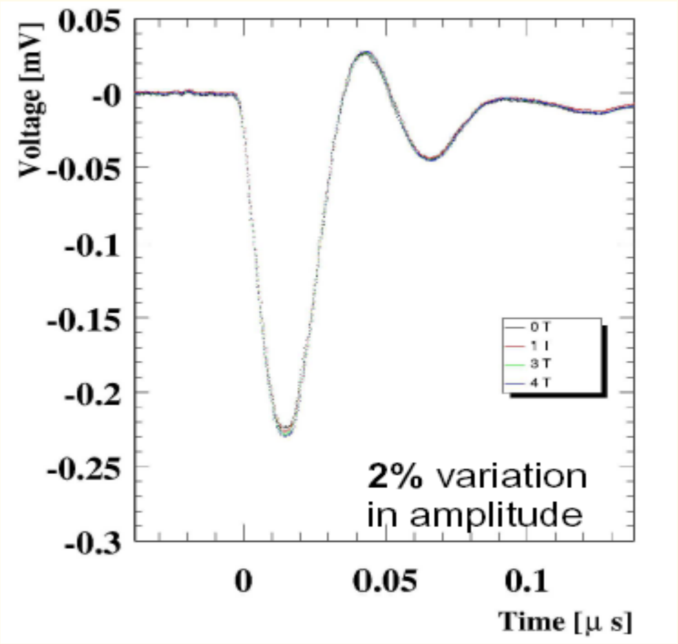
## SiPM Time Response




Time response of SiPM is measured with coincidence with PMT ~ 150 ps

# Silicon Photomultiplier Performance




Test of SiPM in Strong Magnetic Field up to 4 Tesla
(Amplitude of SiPM signal in magnetic field with different orientations of SiPM)
Very important for medical imaging systems, combine PET/MRI

# Silicon Photomultiplier Performance (Noise)

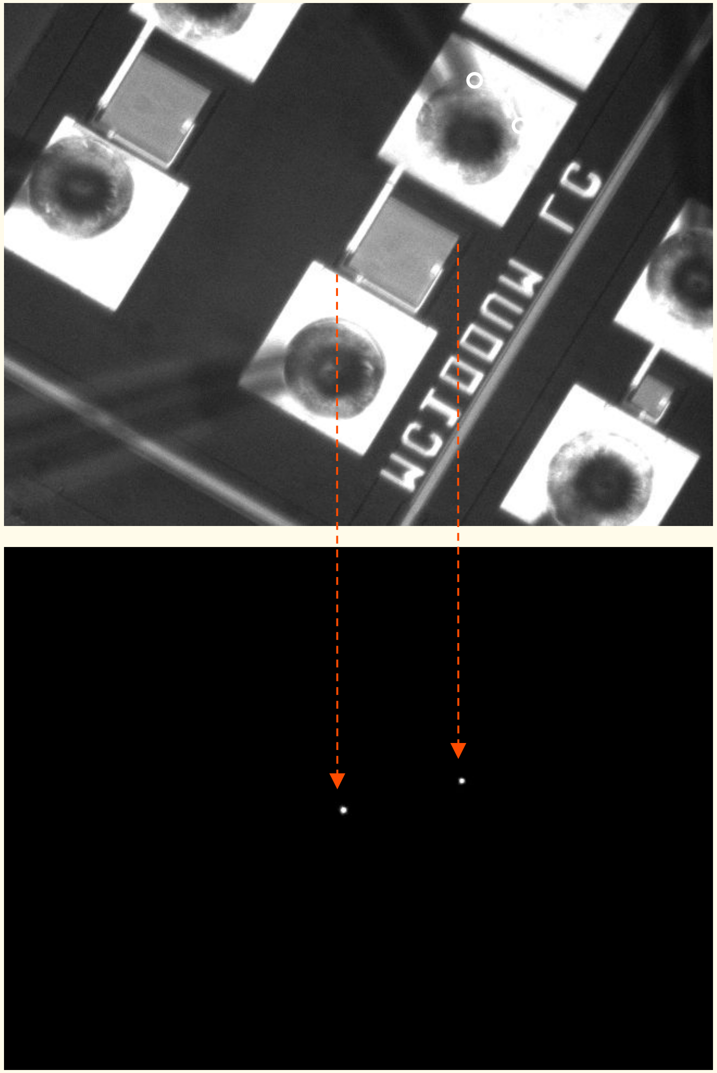
- Dark Count Rate
  - Probability that a bulk thermal electrons will trigger an avalanche process (Voltage Dependent) - characterized by frequency,
- Dark Count Rate Signal Amplitude
  - is amplitude of single photoelectron (cells signal)

Typical value of Dark Rate is 0.6 MHz for 1 mm2 of Si-PM (~1500 cells), depleted layer 5 microns

- Optic Crosstalk
  - During avalanche breakdown a cell emits a photons. These photons could reach the other cells of the SiPM and would result in the initiation of breakdown in those cell

Special Technology (Trench Technology) is necessary for preventing Optical Crosstalk

# Silicon Photomultiplier  Performance



## Optic Crosstalk

- During avalanche breakdown a cell emits a photons. These photons should not reach the other cells of the SiPM because this would result in the initiation of breakdown in those cells

Special Technology (Trench Technology) is necessary for preventing Optical Crosstalk   (only one type of SiPM has such technology now)

# Future Challenges

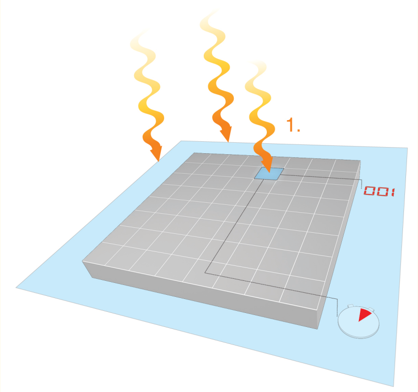
Materials and Technology of SiPM is compatible with Standard Microelectronics Technology

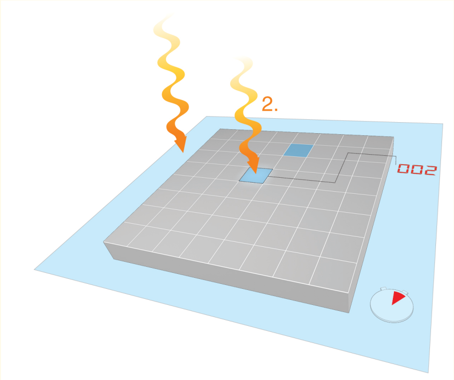
This open the way to getting the Structures (Sensor and Electronics) on the same substrate (Chip)

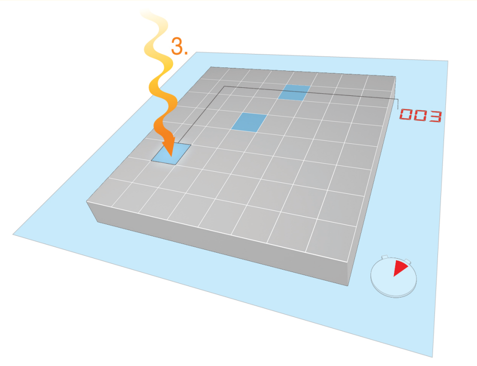
The Feature of SiPM as the practically Digital Signal Sources give the possibility to organize the Readout on the base of  Digital Processing (exclude most complicated and power consuming part as Precise Low Noise Analog Electronics)

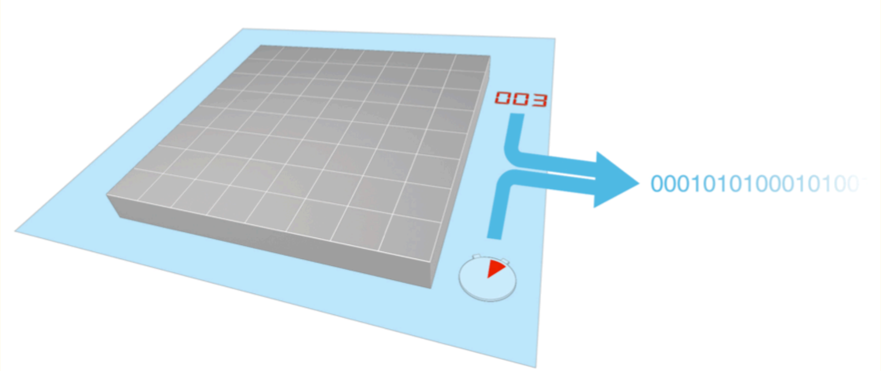
PHILIPS

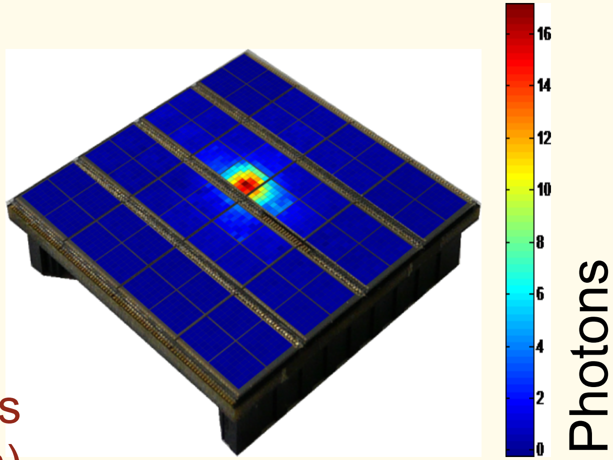
# Philips Digital Photon Counting SiPM



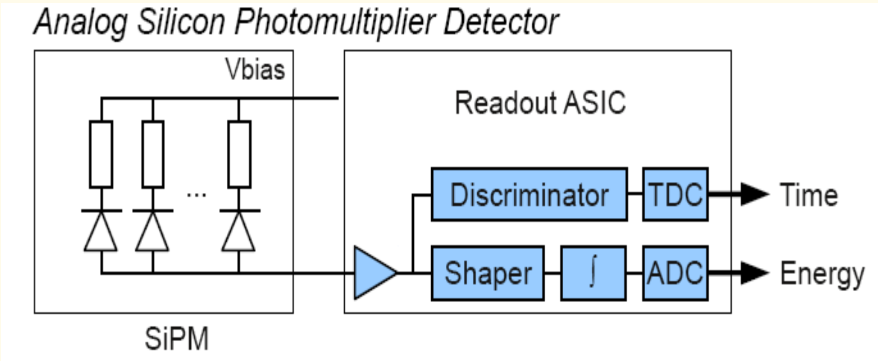



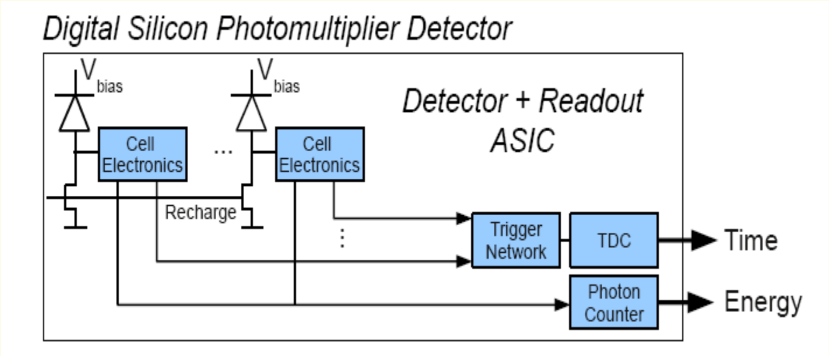




Output: > no. of photons
> time stamp(s)

No analog post-processing necessary!
Photons are counting directly on the same substrate

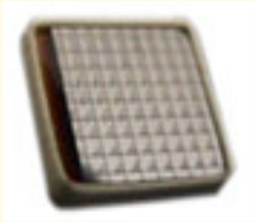
# Digital vs Analog Silicon Photomultiplier

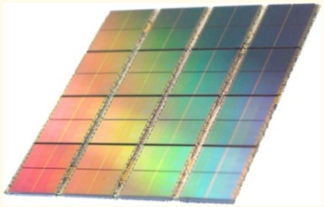



- discrete, limited integration
- analog signals to be digitized
- dedicated ASIC needed
- not scalable

- fully integrated
- fully digital signals
- no ASIC needed
- fully scalable





# Next Generation

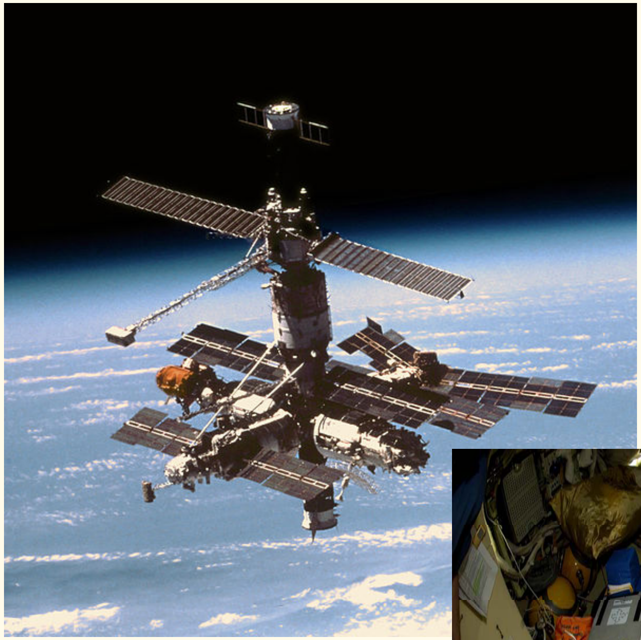
Philips Digital Photon Counting SiPM was developed for Medical Applications in Particular PET

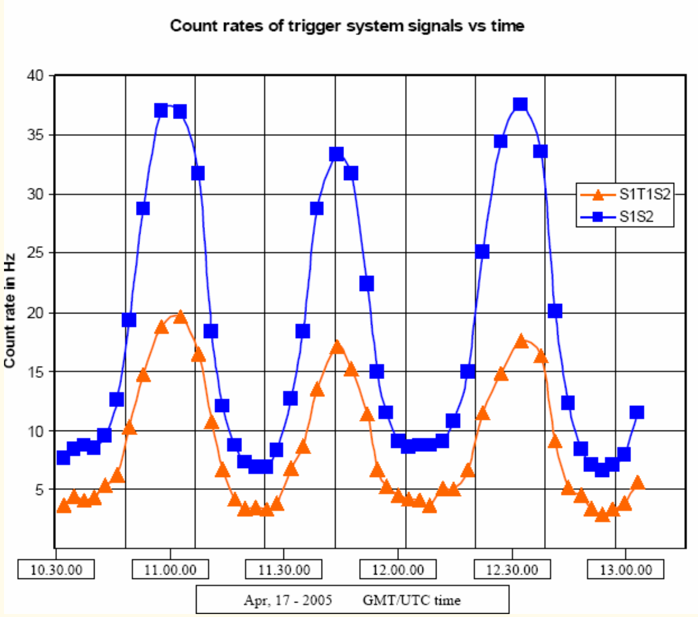
Did Not Provide Pixel by Pixel Readout

Next Generation of SiPM will be fully Digital: with Pixel by Pixel Readout, implemented on the same substrarte

# Silicon Photomultiplier Applications

# Space Research

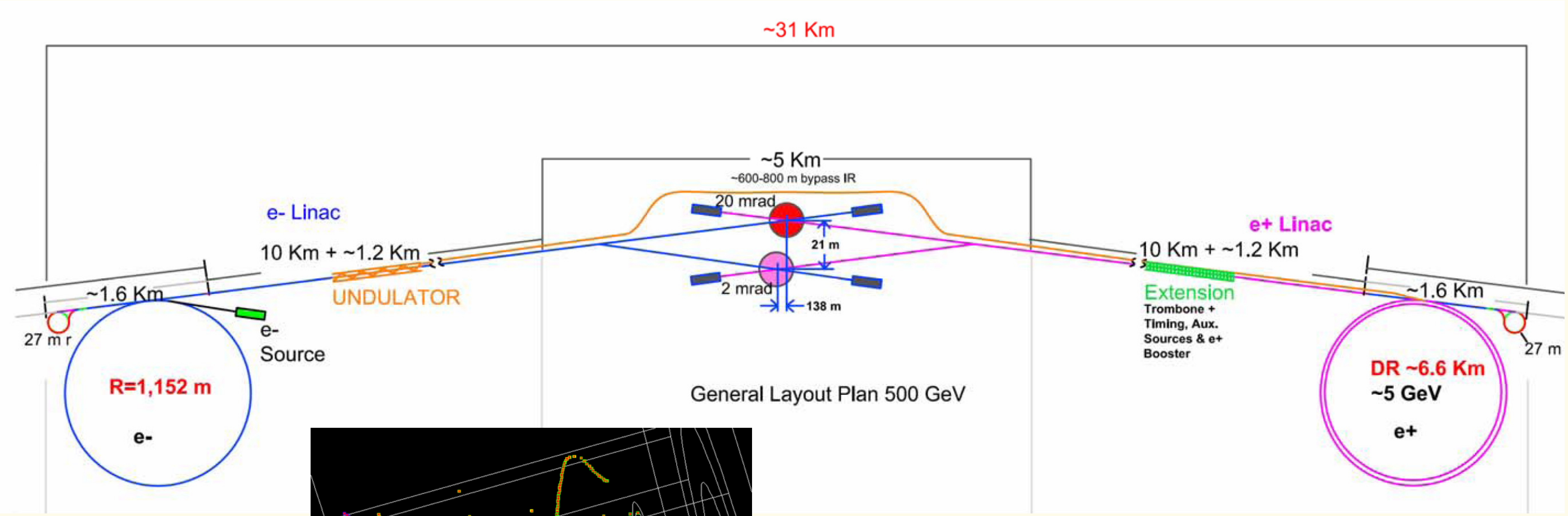


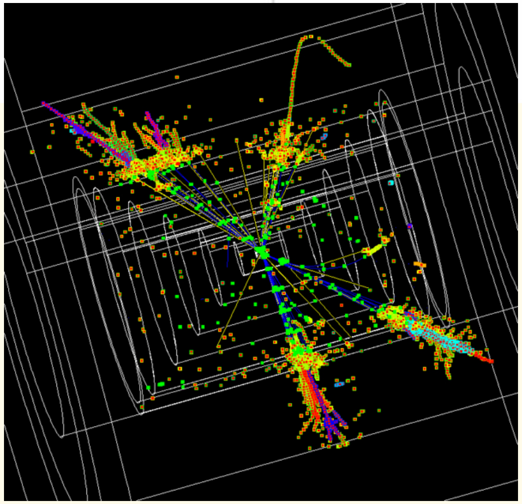




Charge Particles Flux on the orbit

Scintillator/fiber/SiPM few Layers Telescope at Soviet Mir Space Station 2000 and International Space Station 2005

# Fundamental Physics: International Linear Collider

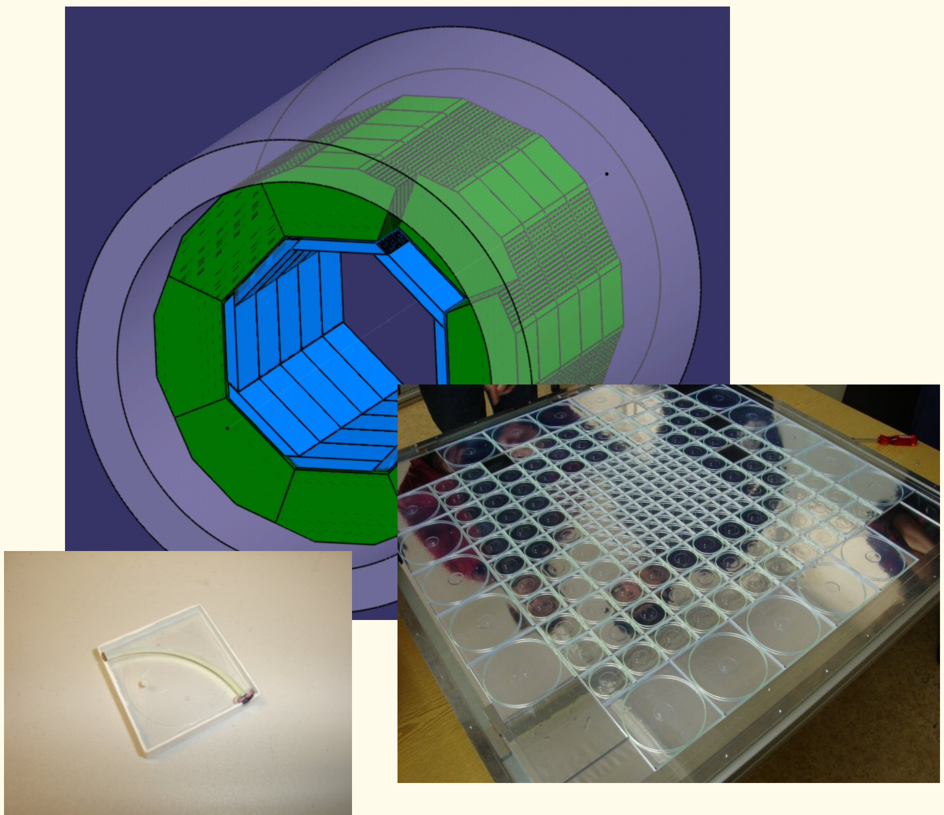


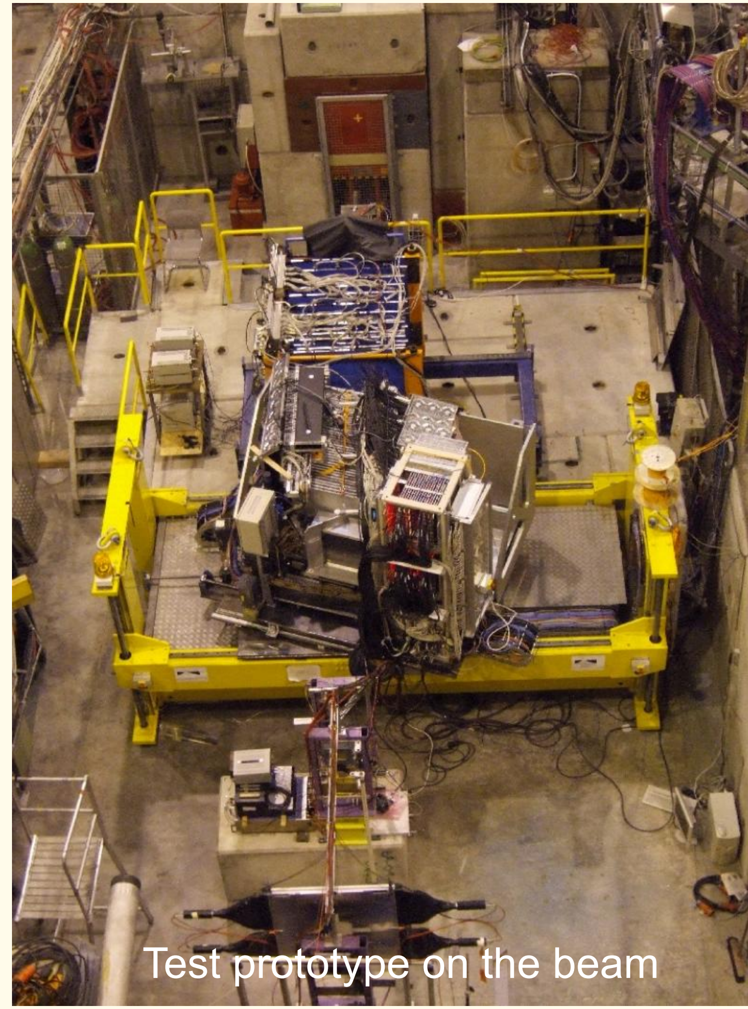



Future project for fundamental physics
ILC: Tens of Millions of SiPMs

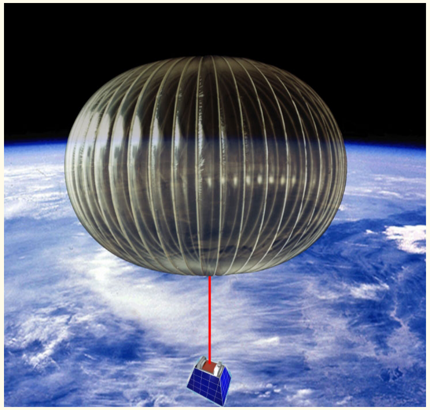
# ILC Hadron Calorimeter

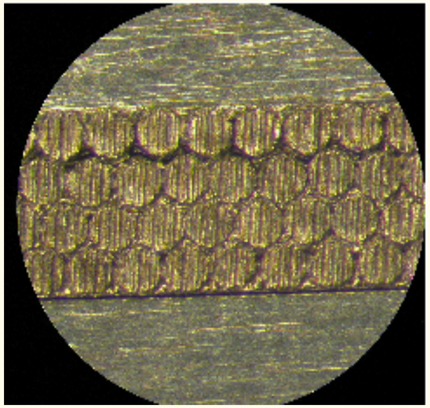
Silicon Photomultiplier (SiPM) is one of the key elements of New Technologies for International Linear Collider, particularly Hadron Calorimetry System

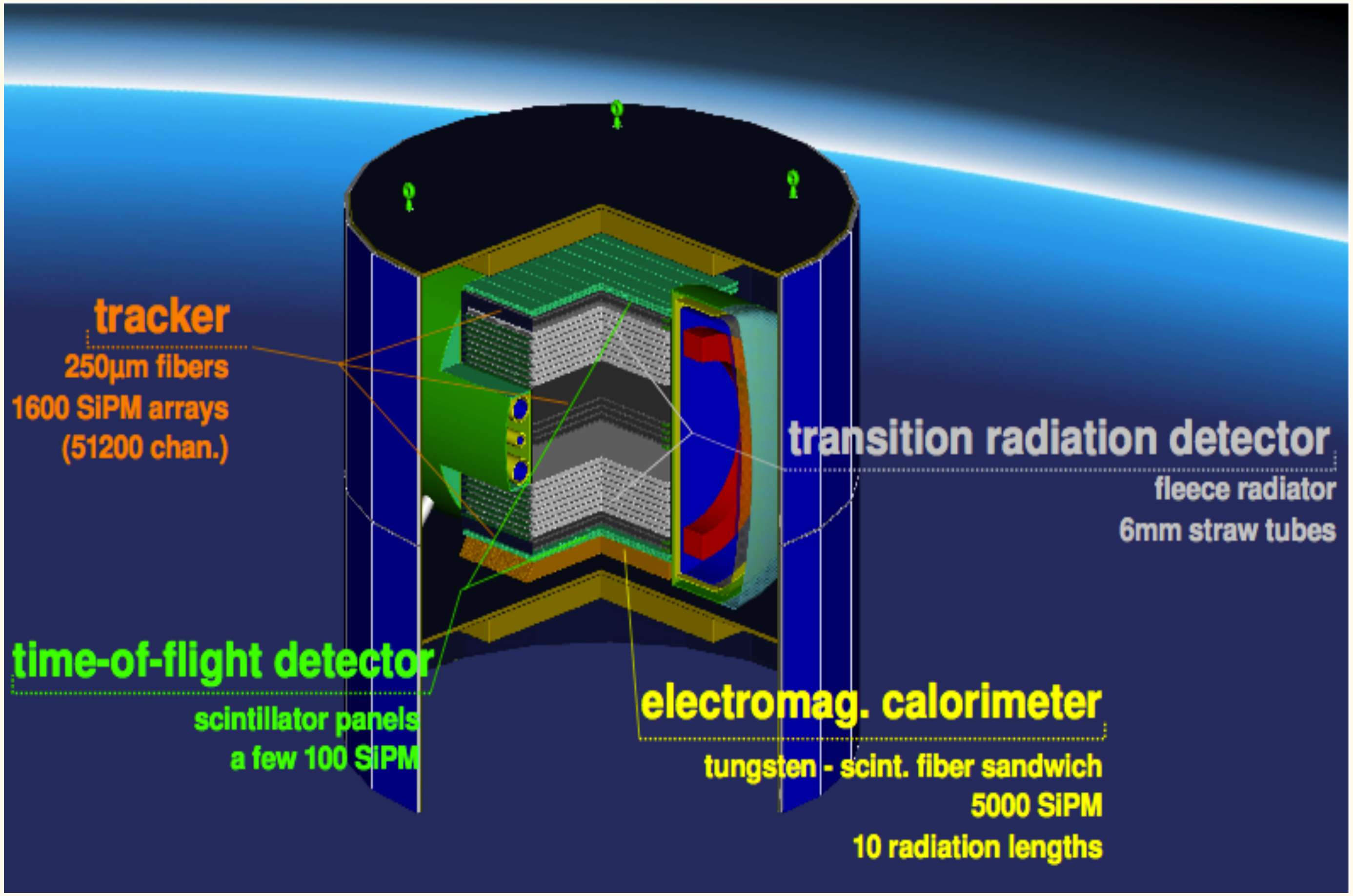




# Ballon Experiment PEBS

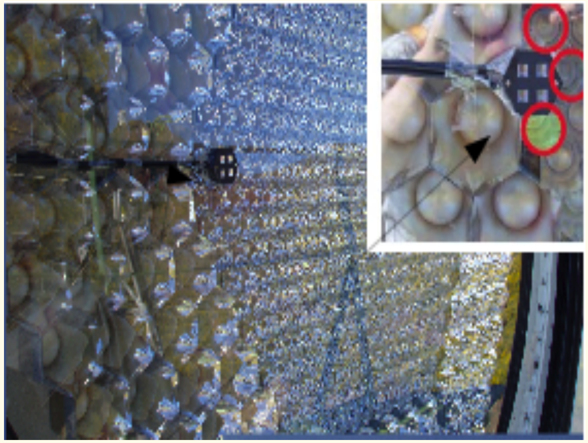






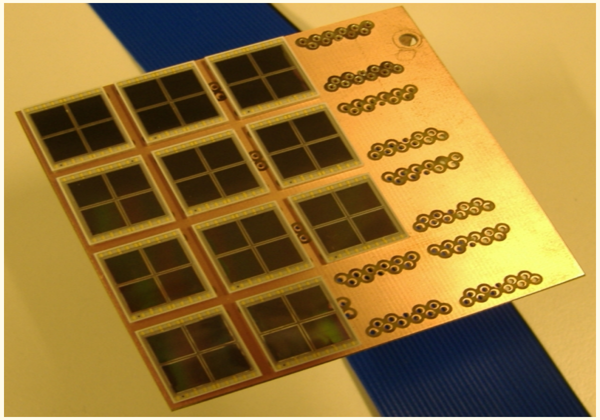

90% of Sensors are SiPMs - more then 56000 SiPMs

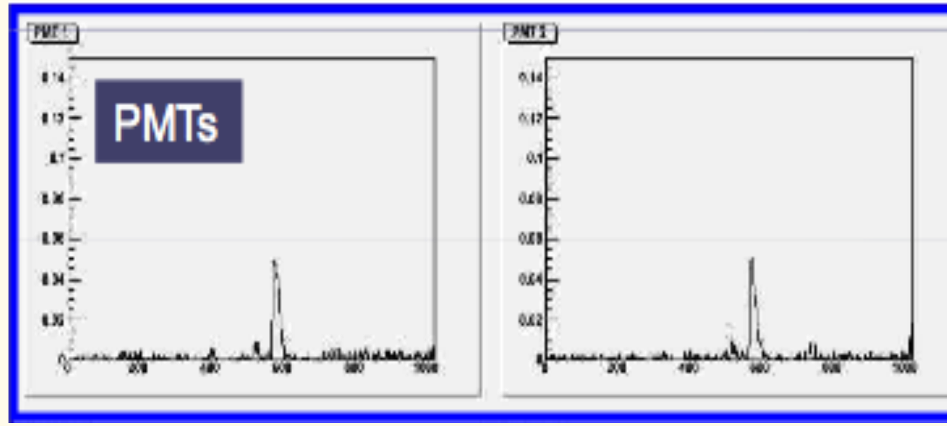
# Astroparticle Physics: Cherenkov Telescopes

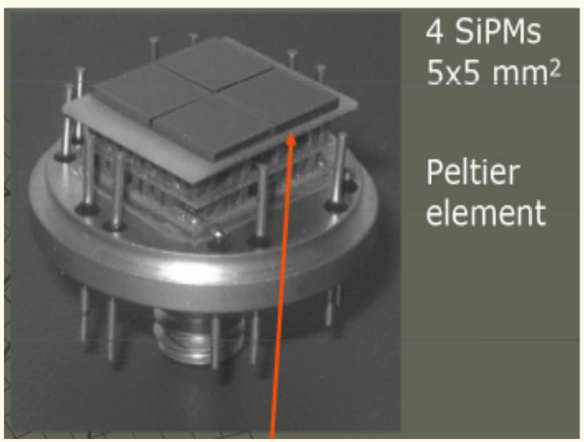


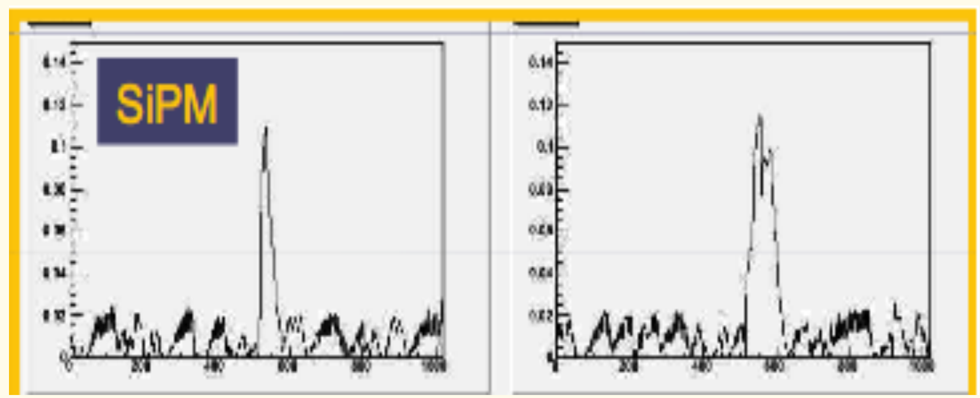
VERITAS, MAGIC, HESS

# MAGIC Photodetector Module with SiPM





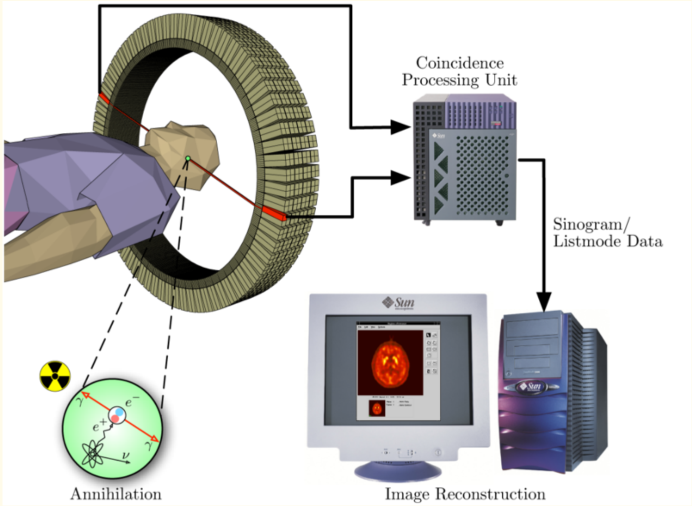



# Medical Application (Positron Emission Tomography)

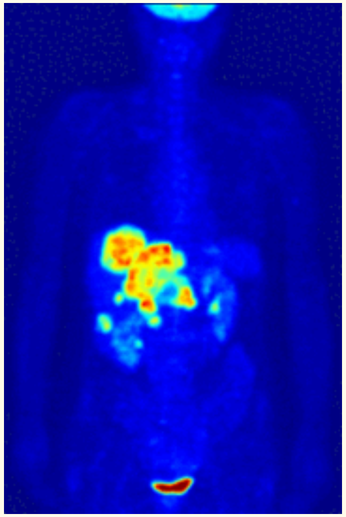
## Functional Diagnostic

PET Principle




PET System Room

Reconstruction



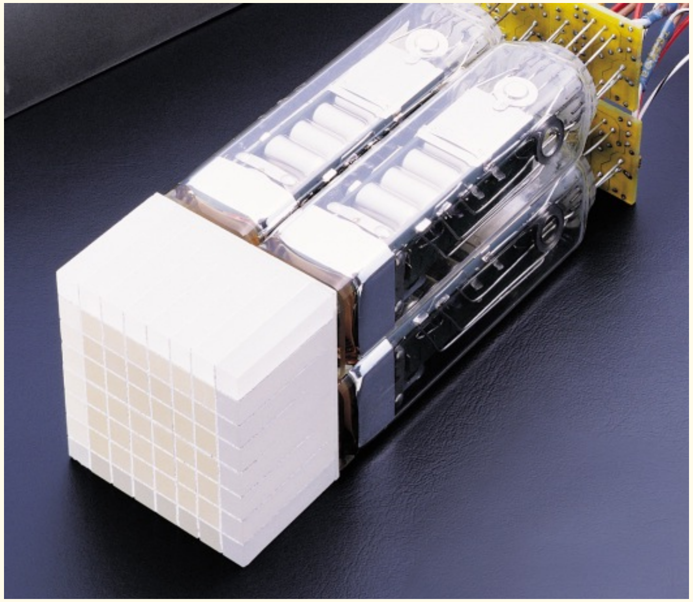
Present situation: Based on the Photomultiplier Tubes:

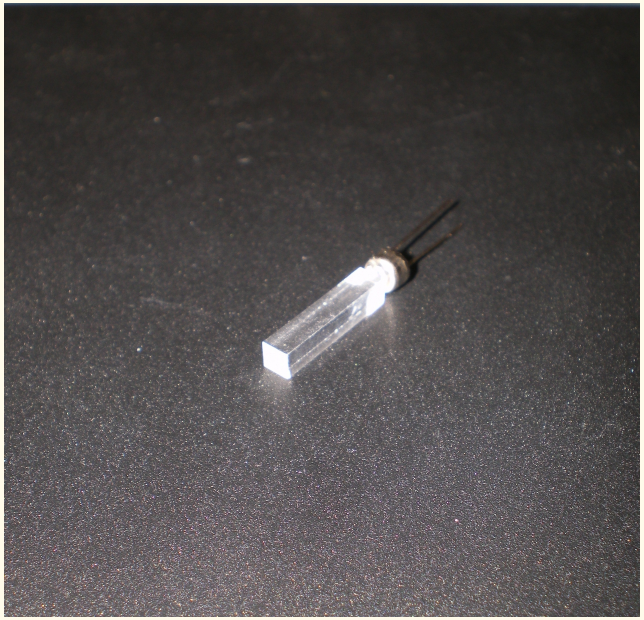
up to few thousands Photomultiplier Tubes per PET,

SiPM is most promising detector for the new generation og PET and Combine PET/MR

# Single Cristal Readout

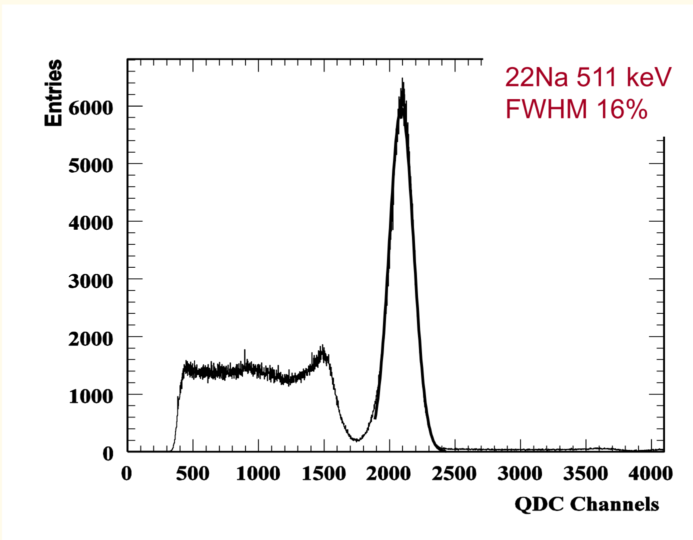
SiPM is most promising photo detector for new generation of PET

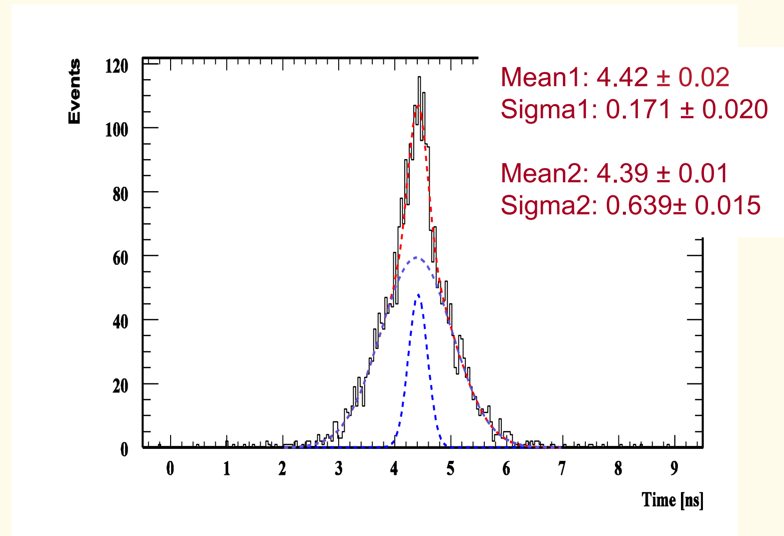




# Energy Resolution and Time Response

Coincidence signal for a 22Na positron source using two 3x3 mm SiPMs coupled with 3x3x15 LYSO crystals.



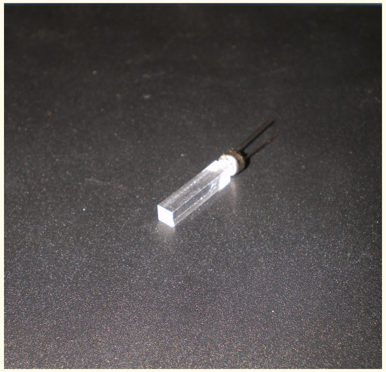

Most important results:

Energy Resolution — 16% FWHM on the photo peak

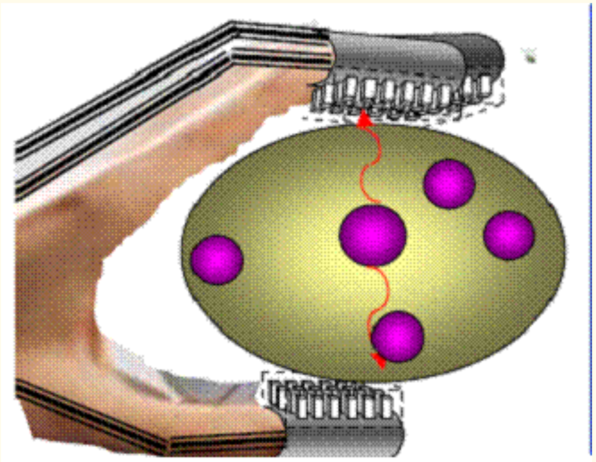
Time response — 170 ps on the photoelectric peak

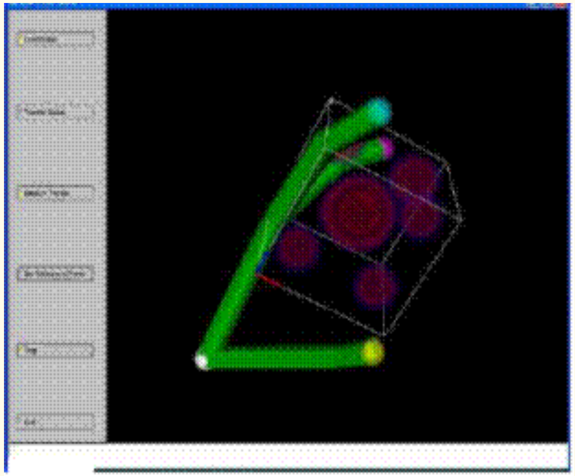
# Strong Future for PET and Multimodality

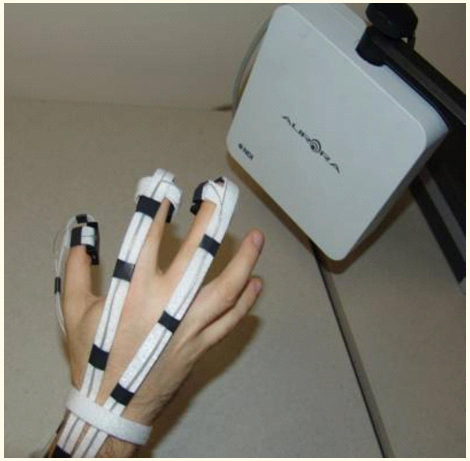
- Higher Sensitivity and Resolution, single crystal readout;
- Time of Flight Implementation;
- Point of Interaction Determination, cristal readout from both side;
- Combining with MR, not sensitive to Strong Magnetic Field;
- Fully Digital Information inside chip;
- Relaxing operation Conditions;
- Reducing the radiation dose on patients,
- Mobile solution of using in any environment;
- Low Cost with using standard CMOS technology;



# Strong Future: SiPM for Medical Applications







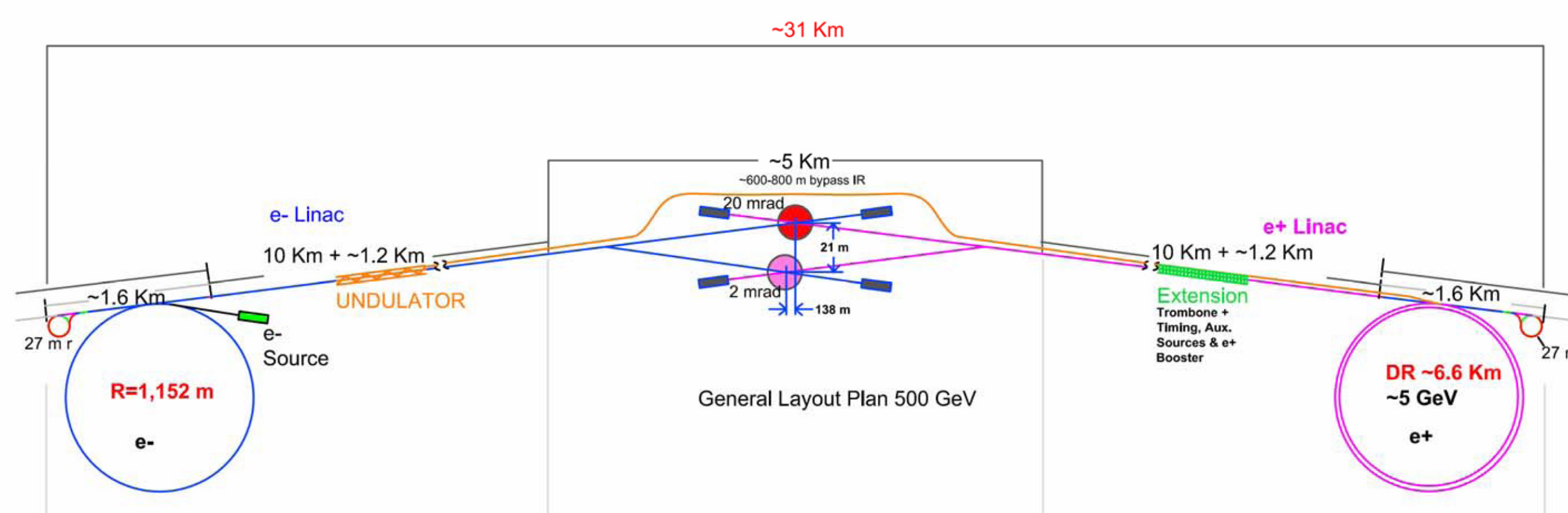
Development of the Medical Imaging System on Base Silicon Photomultiplier: PET - enabled glove for molecular image-guided surgery

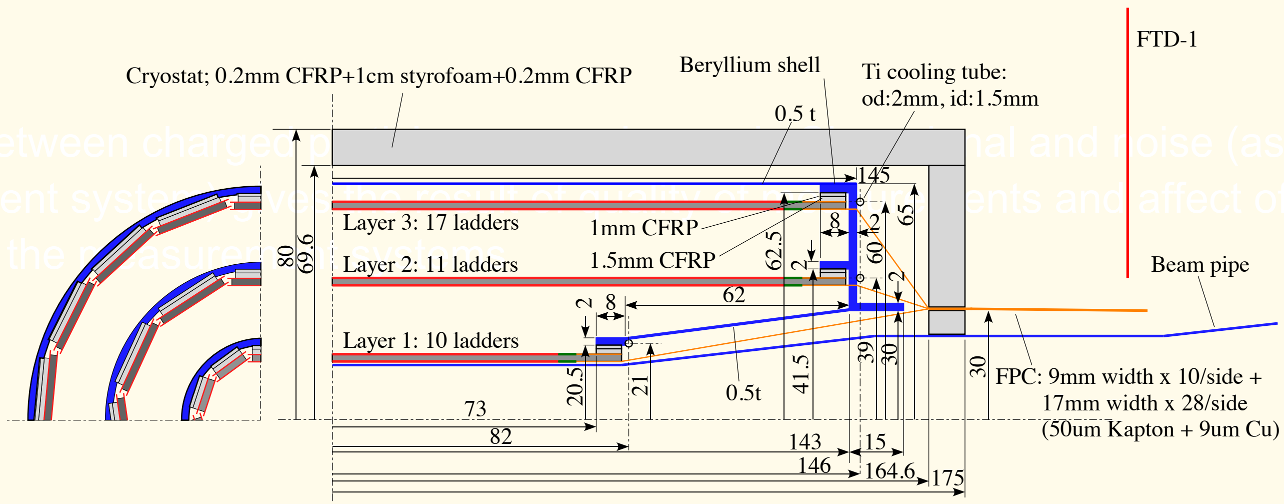
# Strong Feature: SiPM for Homeland Security

Progress in development of Silicon Photomultipliers will completely change the Area of Night Vision System

# Avalanche Pixel (APiX) for Ionizing Particles

# Vertex Detector for ILC



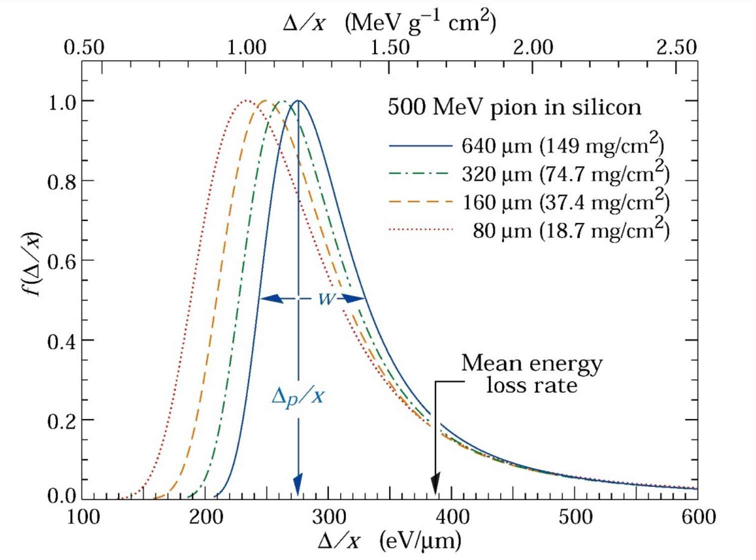
# Coordinate Measurement of Ionizing Particles

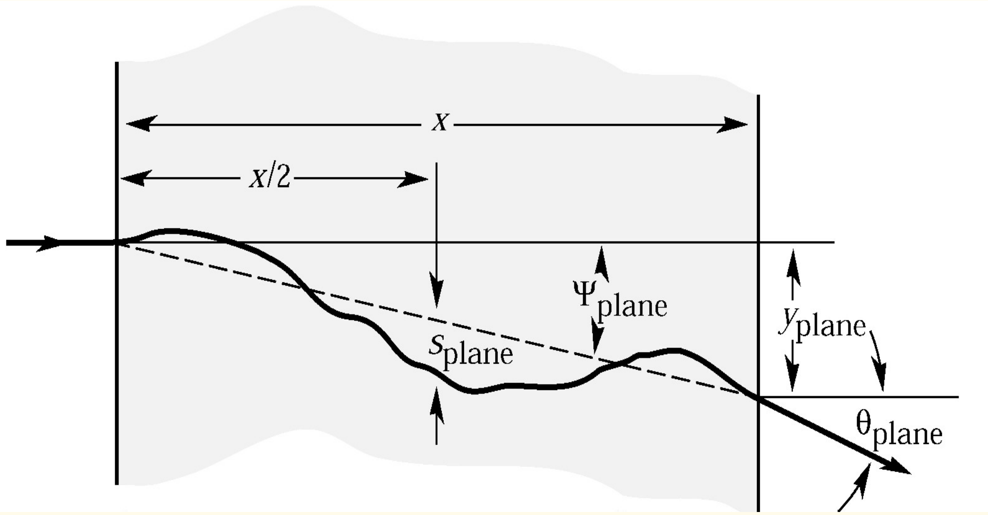
Main Features:

- The interaction physics of the ionizing particles is different from interaction physics of photons with materials : ionization losses.
- The detection of ionizing particles imposes a certain material budget due to necessity of sensitive material, - signal proportional to the path length in sensitive material (ionization energy loses);
- The coordinate measurements of ionizing particles are affected by material budget (Multiple Scattering),
- The signal quality is affected by the electronic noise (including detector itself);

# Main Constrains for Coordinate Measurements

At room temperature the thickness of the sensitive volume is defined by signal/noise ratio. As example for Si strip the necessary thickness is on the range few hundreds microns…




Alternative: minimize the material budget and get Si sensor structure with high intrinsic gain of amplification.

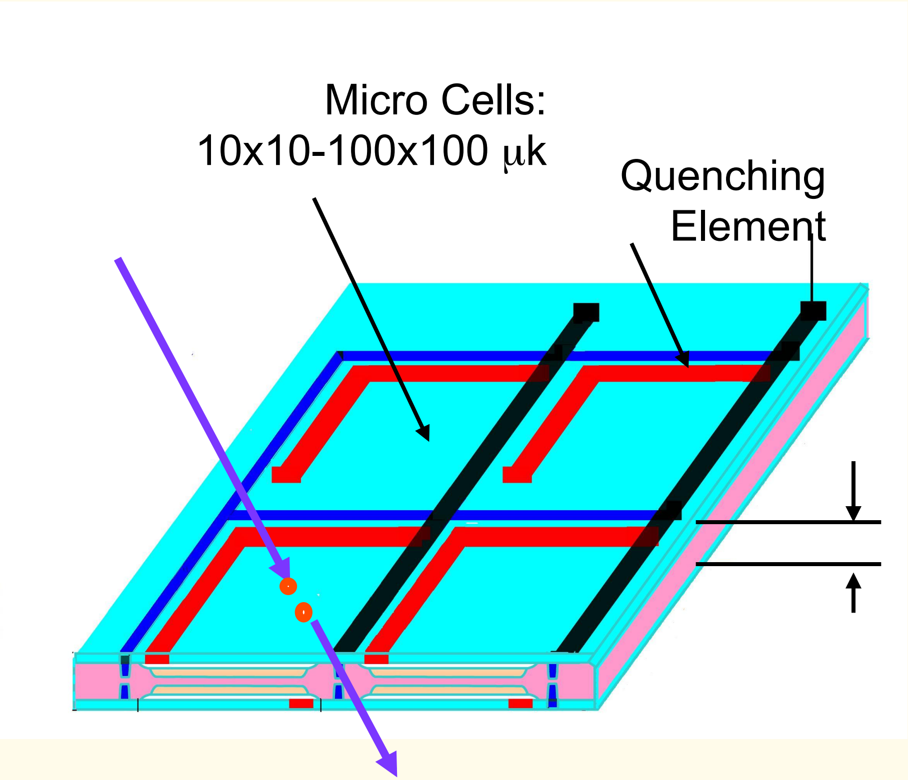
# Avalanche Pixel Sensor for Tracking (APiX)

The structure consist of aligned microcells in two layers, thickness of depletion regions is 4 microns;

Microcells operated in breakdown mode with quenching mechanism;

Two alignment microcells is connected to one logic element "&" and give the coincidence logic signal at the output line.

Signal Readout on base Pixel by Pixel



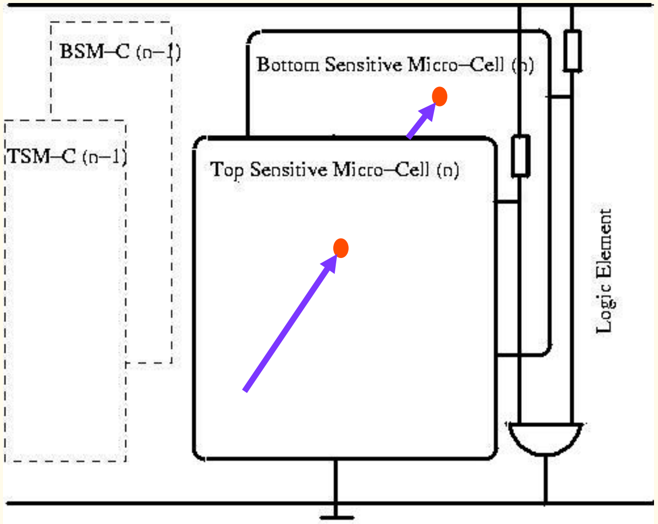
# Avalanche Pixel Sensor for Tracking (APiX)

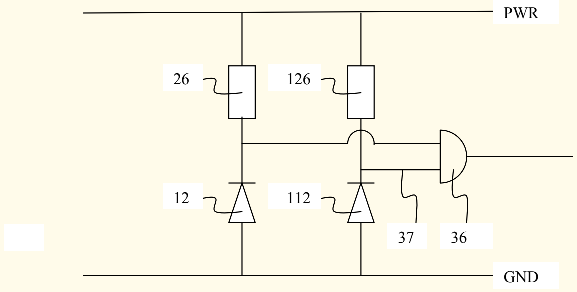
Significant Reduction of Material Budget;

Completely Digital Devices: Logic Signal from Avalanche Pixels and Logic signal from Coinsidense Element;

Significant Reduction of Background signals from dark rate of Avalanche Pixel (tens Hz for 1 $cm^2$);

No sensitivity to background photons (signal from photons will appear only in single pixel;



# Avalanche Pixel Sensor for Tracking (APiX)

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(54) **AVALANCHE PIXEL SENSORS AND RELATED METHODS**

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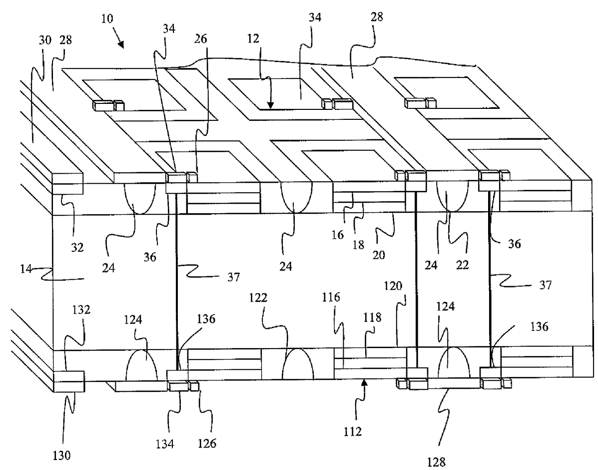
***H01J 40/14*** (2006.01)

(52) **U.S. Cl.** ................................................... **250/214 R**

(57) **ABSTRACT**

According to an embodiment, an avalanche pixel sensor includes a substrate having opposite first and second surfaces, first sensor elements operating in breakdown mode situated on the first surface of the substrate for detecting ionizing radiation from a radiation-emission source, second sensor elements operating in breakdown mode situated on the second surface of the substrate, the second sensor elements each paired with a corresponding first sensor element to experience substantially coincident breakdown in response to ionizing radiation. Logic elements are each electrically interconnected to a respective pair of first and second sensor elements for receiving a signal or signal representing the substantially coincident breakdown of the respective pair to be distinguished from a dark signal even in either of the pair of the first and second sensor elements. Additionally, a detector array, a sensing apparatus, and a method of detecting ionization radiation using first and second sensor elements disposed on opposite sides of a substrate are also provided.



# 3D Advanced Technology

3D Technology will be composed of Avalanche Pixel, FEE and Readout Electronics, overall related DAQ system management plus a new kind of Opto Electronic Connection for Signal Transmission

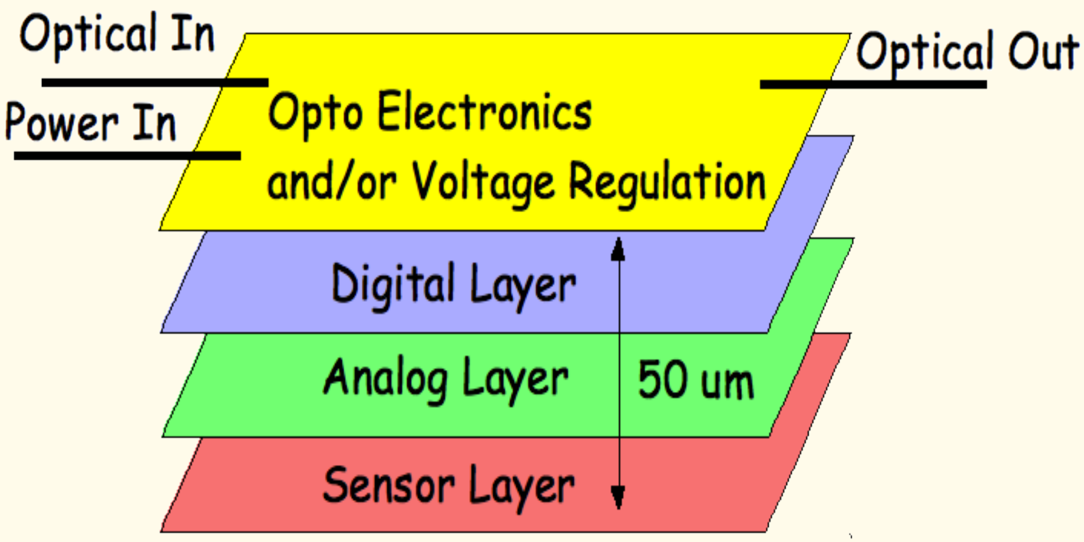
- Pixel:
  - Aligned Double Avalanche pn junction structure with Guard Ring and Quenching Elements,
- Readout to be better specified:
  - Very front end (coinsidence of alignment pixels)
  - Digital Memory,
  - Usual Data Processing of Pixelated Matrix Structures,
- Signal Transmission:
  - Direct Optic Link communication (optoelectronic elements)

All 3 aspects will be embeded on the Chip Level

# 3D Advanced Technology

3D Hybrid Technology:

Sensors, Readout Electronics, Opto Electronic Components




It is just an illustration of 3D hybrid technology, that we want to developed for our Avalanche Pixel Sensors

# Summary

- Silicon Photomultipliers and Avalanche Pixel Sensors is just in the beginning of their Life and History. It is a lot of potentials in development as sensors itself, implementation electronics, data processing, data transmission and other aspect of integrations of such devices in the detecting macrosystems…
- Welcome to Interesting Area