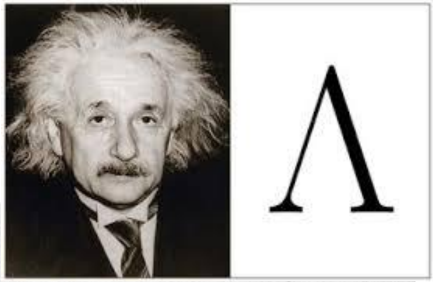
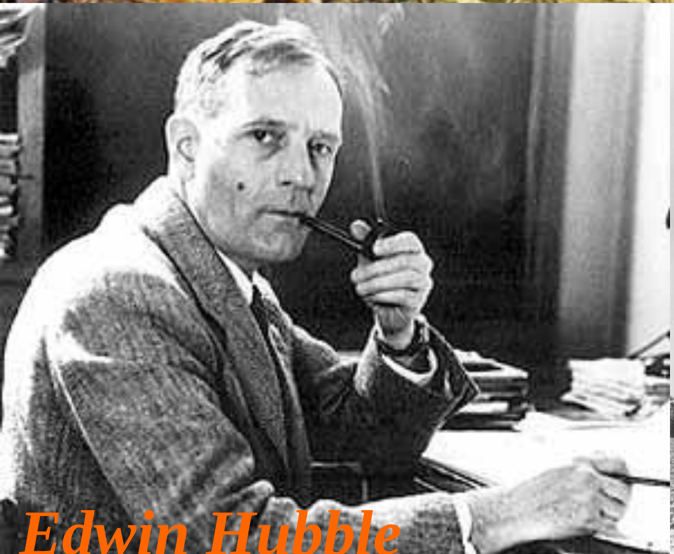
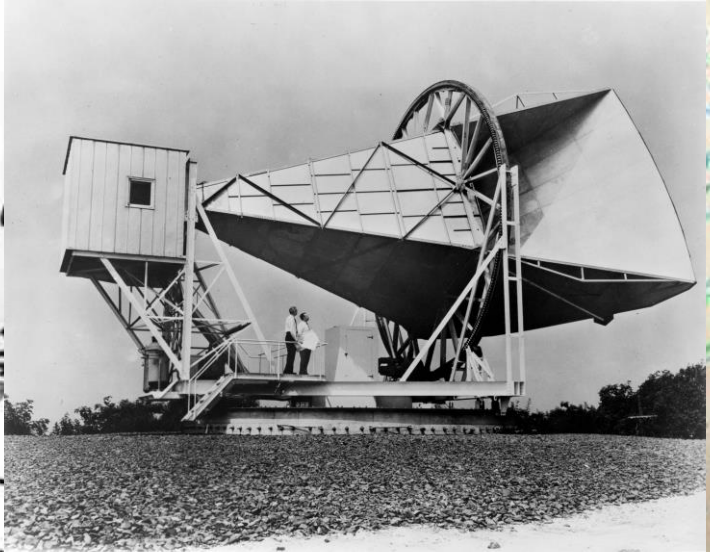
How to make discovery







Գիտական Մեթոդ (Խնչպես արարել գիտելիք)
Գիտելիքի արարման նպատակներն ու գործընթացը

- Հայտնաբերել և ձևակերպել խնդիրը
- Մշակել և կատարել գիտափորձ, հավաքագրել տվյալները.
- Տվյալների մշակման համար ընտրել մաթեմատիկական մեթոդների վերլուծություն, ընտրել այն մոդելը, որը լավագույնս կբացատրի ձեր և աշխարհի տվյալները
- Ձևակերպել և փորձարկել հիպոթեզերը.
- Համեմատել այլ գիտափորձերի հետ.
- Ձևակերպել տվյալները այնպես, որ մարդիկ կարողանան այն ստուգել և համեմատել իրենց տվյալների հետ
- Պատրաստել և ամսագրին ուղարկել հոդված
- Պատասխանել մեկնաբանություններին (քննադատություններին) , կրկին ստուգել բոլոր տվյալները և ուղարկել վերջնական վերանայման

Տիեզերական Ճառագայթների բացահայտում

- Երկրի վրա են ընկնում իոնիզացնող հոսքեր
- Խնչ է դա (բաղադրություն, էներգիան)?
- Աղբյուրները (Արեգակ, Գալակտիկա, SNR, Սև Խոռոչներ, նեյտրոնային աստղեր)?
- Դետեկտորներ (տիեզերական ծագման, մակերևույթային); դետեկտորի պատասխանը.
- Խնչպես լուծել հակադարձ խնդիրը?
- Մոդելավորում; տարածման և փոխազդեցության մոդելներ; մարդու կողմից ստեղծված արագացուցիչներից ստացված տվյալների օգտագործում; մոդելի ստուգում և վավերացում;
- Չափման մոդել: հաճախություն; մասնիկների դասակարգում.

Scientific Method (How to create knowledge)

Principles and procedures for creating knowledge

- Recognize and formulate problem
- Prepare experiment, calculate response, collect data.
- Formulate and test hypotheses.
- Compare with other experiments.
- Choose mathematical methods for data analysis; estimate quantities, choose the theory best explaining your and world data.
- Formulate results in a way people can check it and compare with their results.
- Prepare and send the paper to journal.
- Answer comments of referees, check again all results and send for final revision.

Discovery of Cosmic Rays

- There is a flux of radiation fallen on the earth;
- What it is (composition, energies)?
- Sources (Sun, Galaxy, SNR, Black holes, neutron stars)?
- Detectors (Space born, surface); detector response.
- How to solve inverse problem?
- Simulations; models of propagation and interaction; available data from man-made accelerators; model validation and verification;
- Model of measurement: from counts to intensities; particle classification.

Как Создавать Знание (Принципы и Процедуры)?

- Понять и сформулировать проблему;
- Подготовить и провести эксперимент, собрать данные:
- Формулирование и тестирование гипотез;
- Сравнение с другими экспериментами;
- Выбор математических методов для анализа данных; оценка, выбор модели наилучшим образом объясняющую эксперимент, оценка параметров модели;
- Сформулировать результаты в виде допускающем проверку и сравнение с другими экспериментами;
- Подготовить и отправить статью в журнал;
- Ответить на комментарии рецензентов, проверить результаты и отправить для окончательного рецензирования.

Открытие космических лучей

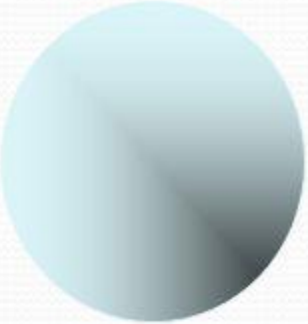
- Измерен поток ионизирующего излучения падающего на землю излучения упали на земле;
- Из чего он состоит (состав, энергии)?
- Возможные источники (солнце, Галактика, SNR, черные дыры, нейтронные звезды?
- Детекторы (Космические, на поверхности);
- Как решить обратную задачу?
- Моделирование; модели распространения и взаимодействия космических лучей, данные с коллайдеров; проверка модели: верификация и валидасия;
- Модель измерения: от электронных сигналов с детекторов к интенсивностям; классификация частиц.

Greek Model

"To understand the very large,
we must understand the very small."

Democritus

- Greek philosopher
- Idea of 'democracy'
- Idea of 'atomos'
  - Atomos = 'indivisible'
  - 'Atom' is derived
- No experiments to support idea, his ideas were forgotten for thousands of years.

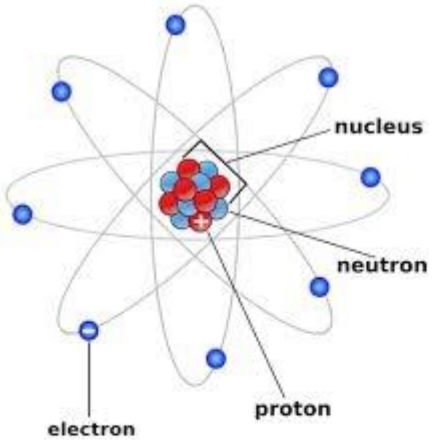


Democritus's model of atom

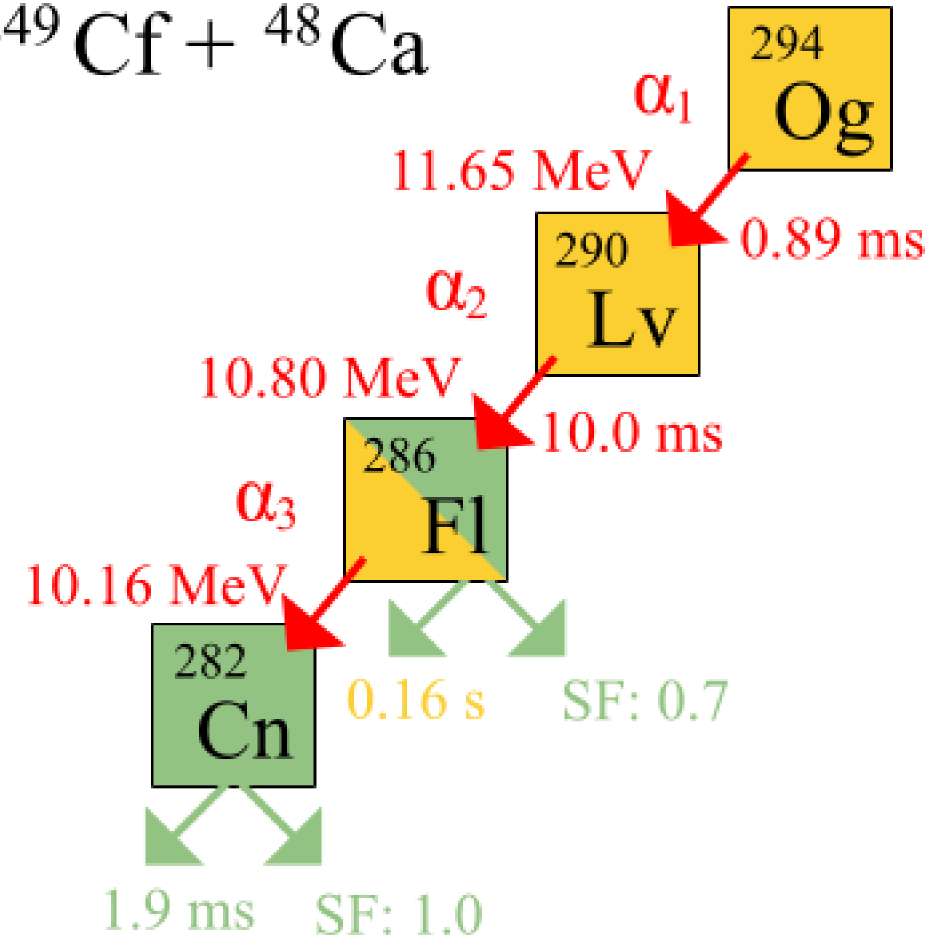
No protons, electrons, or neutrons

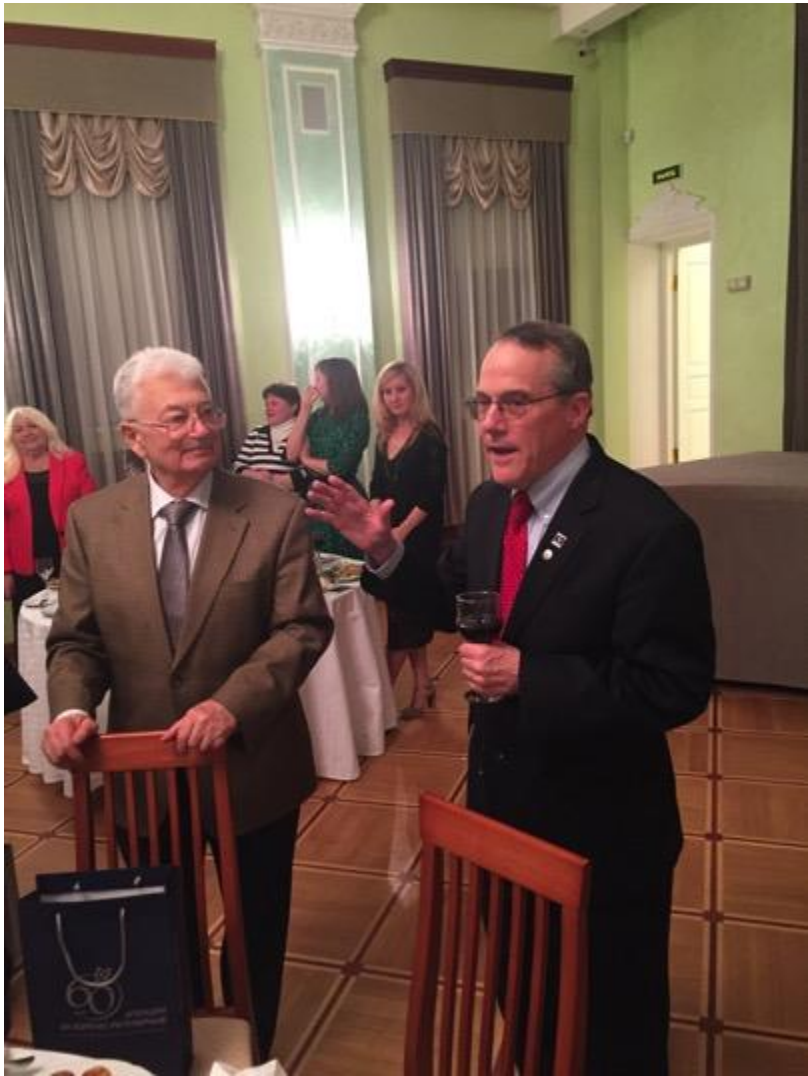
Solid and INDESTRUCTABLE

Oganesson is a transactinide chemical element with symbol Og and atomic number 118.

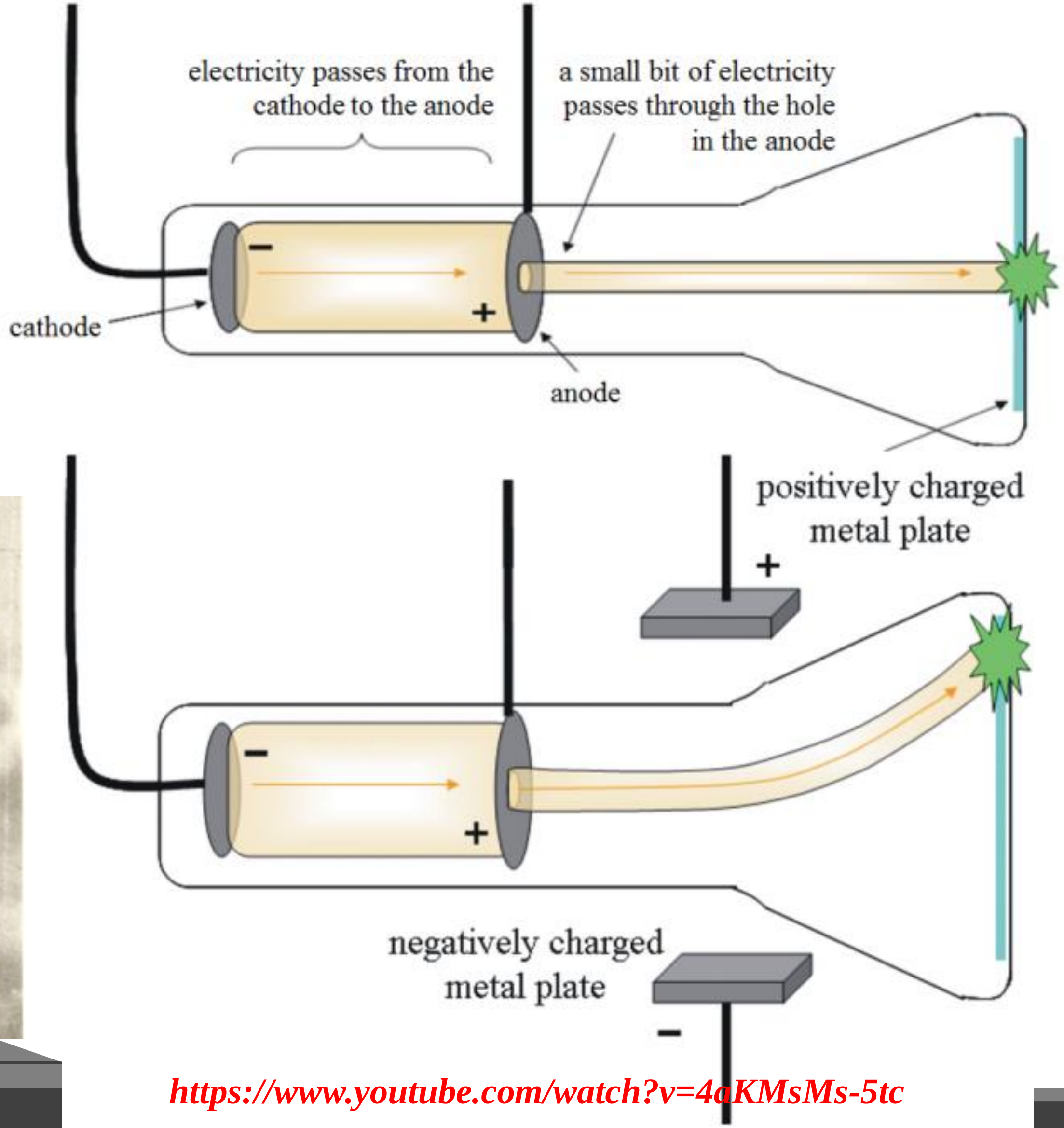


$^{249}Cf + ^{48}Ca$



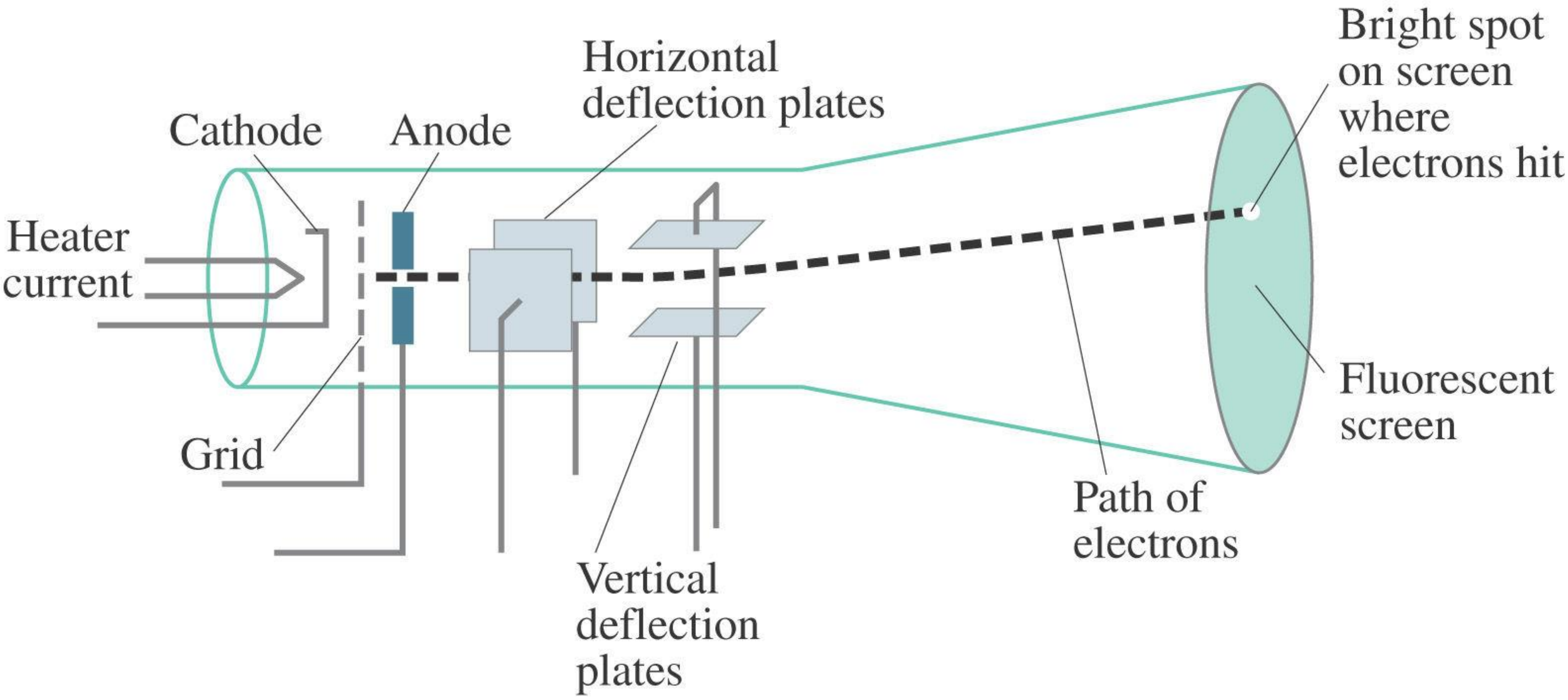


J.J. Thomson's discovery of electron (Cambridge University's Cavendish Laboratory in 1897)



https://www.youtube.com/watch?v=4aKMsMs-5tc

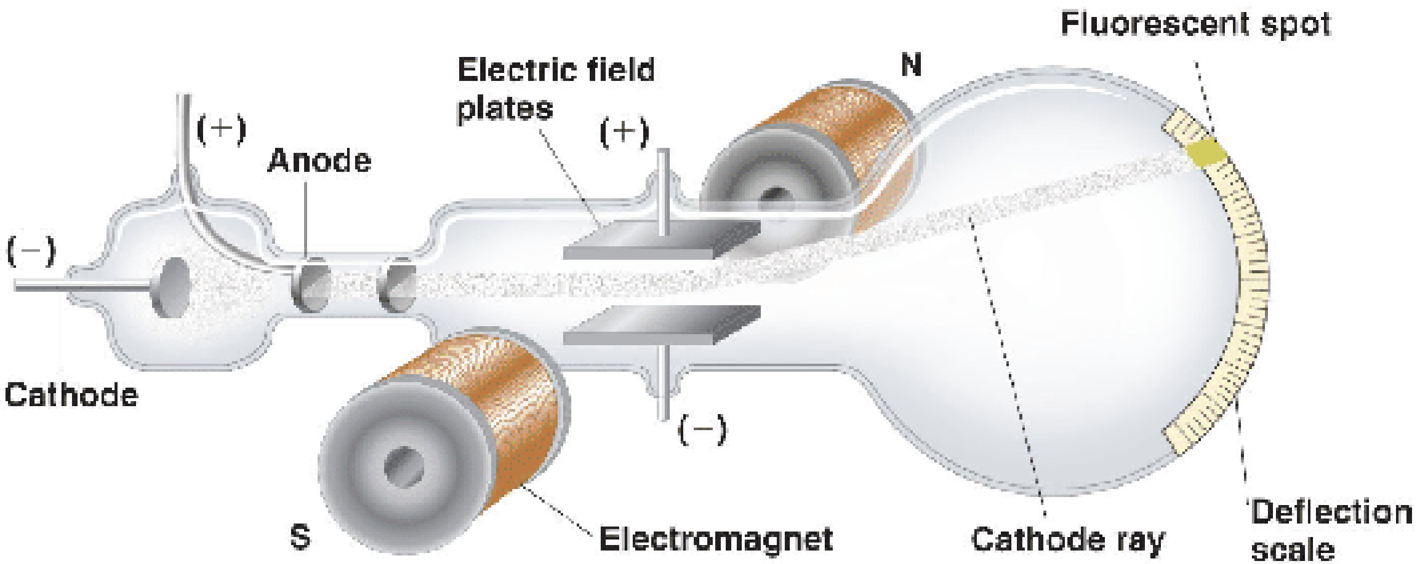
The cathode ray tube (CRT, EGA, VGA) is a vacuum tube that contains one or more electron guns and a phosphorescent screen, and is used to display images. It modulates, accelerates, and deflects electron beam(s) onto the screen to create the images. Now: liquid crystal display (LCD), light-emitting diode (LED), gas plasma or AMOLED is an 'active-matrix organic light-emitting diode' .



Kathodenstrahlen, or cathode rays. Two views were prevalent: one, which was chiefly supported by English physicists, was that the rays are negatively electrified bodies shot off from the cathode with great velocity; the other view, which was held by the great majority of German physicists, was that the rays are some kind of ethereal vibration or waves.

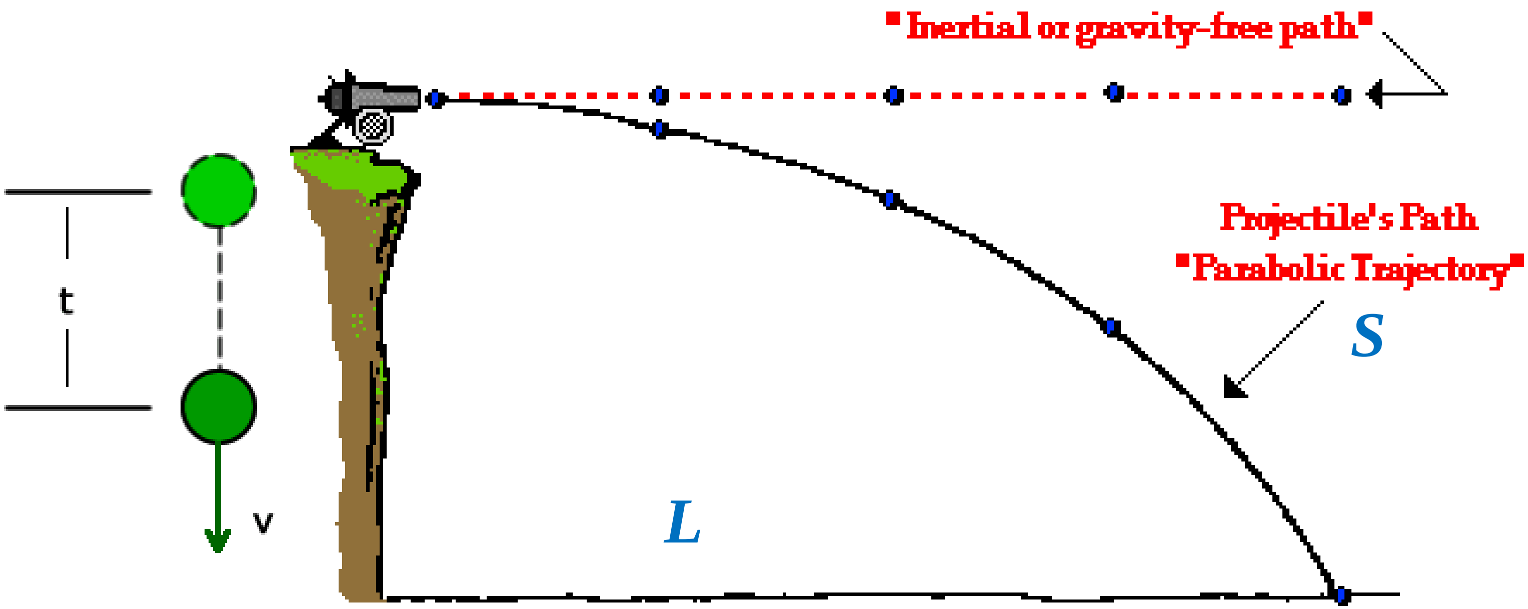
Experimental setup that proves negative charge of cathode rays

The speed of a charged particle can be measured indirectly by perfectly balancing the electric force against the magnetic force so that the charged particle goes in a straight line.



Electric field – E; magnetic field B; force F = eE = evB; v = E/B if the spot is not shifted from the center

Projectile Motion and Inertia



With gravity, a "projectile" will fall below its inertial path. Gravity acts downward to cause a downward acceleration. There are no horizontal forces needed to maintain the horizontal motion – consistent with the concept of inertia.

$V = V_0 + gt$; $V_0 = 0$; $ds/dt = gt$; $ds = gtdt$; $\int tdt = t^2/2$; $s = g\,t^2/2$;
$t = l/v = 1m/10^8\ m/s = 10^{-8}\ s$; $s = (10\ m/s^2 * 10^{-16}\ s^2)/2 – 5*10^{-14}\ m$
The size of atom is ~ 10^{-10} m
So we can neglect the gravitational displacement of electron.
G can be neglected, but E – not!
So $s = at^2/2$; $a = F/m = eEt^2/2m$

First estimations of electron parameters

$$F_q = qE = F_m = qvB \Rightarrow v = \frac{E}{B}, magnetc = electric$$

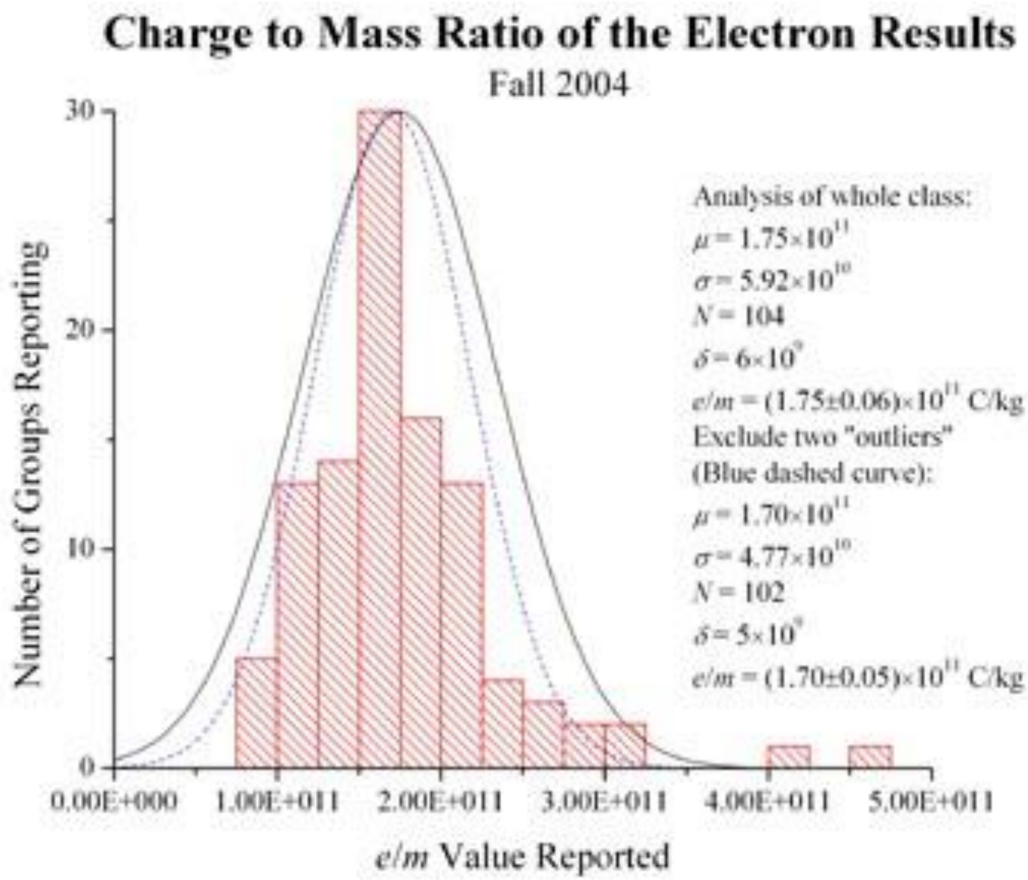
$$s = v_{mean} * t; v_{mean} = \frac{v_0 + v_t}{2}; v_0 = 0; s = \frac{v_t * t}{2} = \frac{at^2}{2}$$

$$a = \frac{F}{m} = \frac{qE}{m}; t = \frac{l}{v}; electric\ only$$

$$s = \frac{qE\, l^2}{2m\, v^2} = \frac{qEl^2B^2}{2mE^2} = \frac{ql^2B^2}{2mE} \Rightarrow \frac{q}{m} = \frac{2sE}{l^2B^2} = 1.7588196 * 10^{-11} CKg^{-1}$$

$S = eEt^2/2m$; $t = l/v = lB/E$; $S = el^2B^2/2Em$; $e/m = 2sE/l^2B^2$

No measurement is valid without error bars!



Случайные события

- Отображение множества событий на множество чисел – Орел/решка – 1/0
- Оценки – {2;3;4;5} или (12 – 20)
- Время ожидания маршрутки (1-10 минут) непрерывная случайная величина
- Восход Солнца – цунами 2003 г.

Duality of Random – Deterministic Variables

- The statistics of a random variable (all you can say about a random variable) are completely defined by its probability density function (pdf), mean and standard deviation.
- The mean is sometimes called the expected value of *X*, *E(X)*. The standard deviation is the square root of the variance.
- Tehran Times from March 1, 2005 – Prayer Time: Sunrise 6:34' :23,45678912345
- The Tsunami of 2004 caused a 3 microsecond change in earths rotation (our day got faster!)
- Earthquake in Chili in February 27,2010 again shortened the day by another few microseconds.

Измерение длины двери

- 201,202,198,199,200
- 180,220,190,210,200
- 201,202,198,199,300
- 200;200;250
- 198;199;200;202;300
- 200
- 4;40;102
- 3.3;10;330

- Почему разные значения?
- Чем отличаются ряды?
- Gross error
- Среднее
- Ранжированный ряд
- Медиана
- Размах
- RMSE

Модель измерения – Распределение случайных ошибок

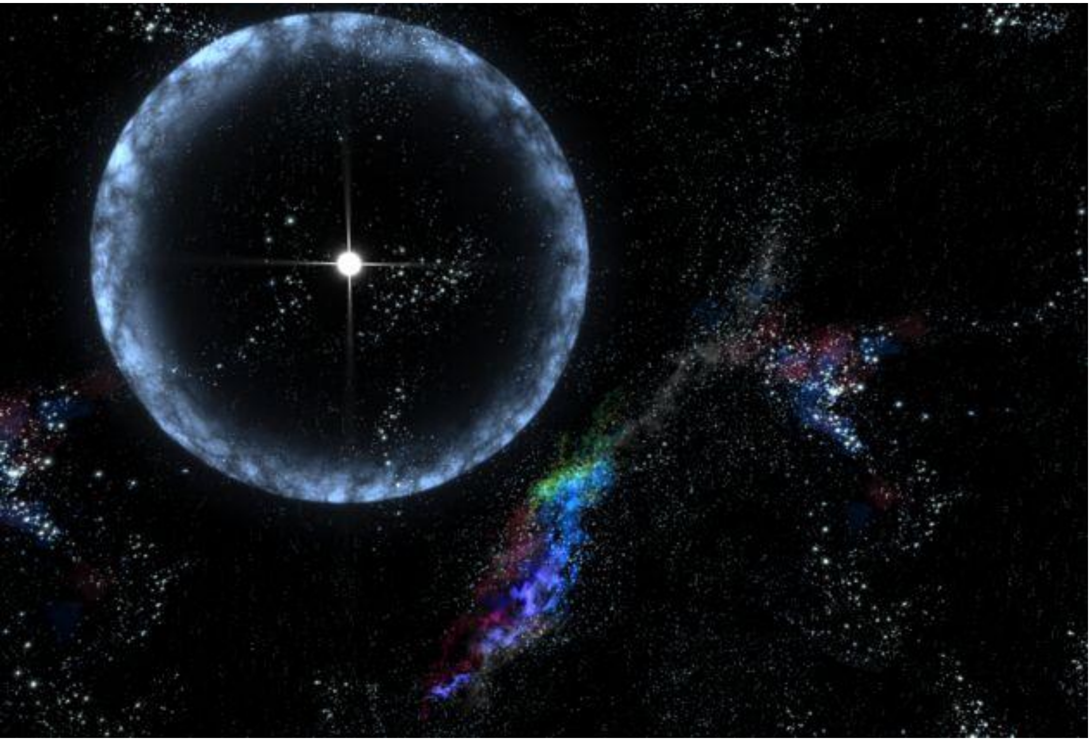
В Японии 20 марта зацвела сакура

Метеорологическая служба Японии в субботу, 22 марта, официально объявила о начале сезона цветения сакуры, сообщает Reuters.

По информации агентства, цветы японской вишни уже распустились в Токио и префектурах Сидзуока (Shizuoka) и Кумамото (Kumamoto). Причем в Токио и Сидзуоке сакура зацвела на шесть дней, а в Кумамото на два дня раньше обычного срока. По информации метеорологической службы, это связано с установившейся на территории Японии теплой погодой.

Ежегодный период цветения сакуры длится менее недели, однако в южных районах Японии он наступает немного раньше, чем в северных. Всего с момента расцветания первых деревьев на юге страны до отцветания последних деревьев на севере проходит около месяца. В это время жители Японии любят выбираться в парки, дворы и даже на кладбища для того, чтобы провести время под цветущей сакурой.

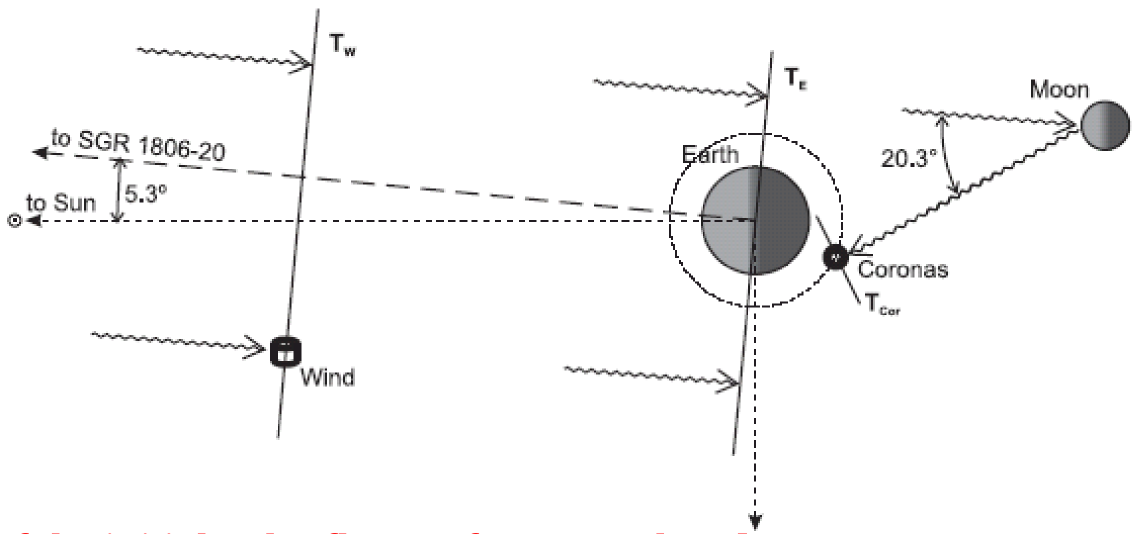
Brightest Galactic Flash Ever Detected Hits Earth



Coronas-F detection of the giant outburst from SGR1806-20 which was scattered back from the Moon.

SGR-1806 is an ultra-magnetic neutron star, called a magnetar, located about 50,000 light years away from Earth in the constellation Sagittarius. The star, named SGR 1806-20, spins once on its axis every 7.5 seconds, and it is surrounded by a magnetic field more powerful than any other object in the universe 10^15 Gauss, the Earths magnetic field is only 0.5 Gauss. A huge explosion halfway across the galaxy packed so much power it briefly altered Earth's upper atmosphere in December 27. The gamma rays hit the ionosphere and created more ionization, briefly expanding the ionosphere. An object only 20 kilometers across, on the other side of our galaxy, releasing more energy in a tenth of a second than the Sun emits in 100,000 years – 10^28 Watt.

The enormous intensity of the initial pulse proved
to be far above the saturation level of the gamma-ray detectors,
with the resultthat the most valuable data on the time structure
and energy spectrum of thepulse is lost.



Estimation of the initial pulse fluence from complete detector
saturation during ≈0.5 s can yield only its lower limit > 10−2 erg cm−2. Thus, direct
observation of an outburst does not permit one to obtain data on the intensity, time history,
and energy spectrum of the initial pulse.
The flare wavefront came from the SGR 1806-20 direction, crossed
Wind at TW, passed Earth at TE = TW+5.086 s, reached and was reflected by the Moon,
and,
finally, back-scattered radiation was detected by Helicon-Coronas-F at TCor = TW +7.69 s.

Probability

- Probability is a numerical measure of the likelihood that an event will occur.
- Probability values are always assigned on a scale from 0 to 1.
- A probability near 0 indicates an event is very unlikely to occur.
- A probability near 1 indicates an event is almost certain to occur.
- A probability of 0.5 indicates the occurrence of the event is just as likely as it is unlikely.

An Experiment and Its Sample Space

- An experiment is any process that generates well-defined outcomes.

- The sample space for an experiment is the set of all experimental outcomes.

- A sample point is an element of the sample space, any one particular experimental outcome.

Constructing Sample Spaces

A good way to construct the sample space is to write down examples of typical outcomes and try to identify the complete set.

Example:

Toss a coin four times.

One typical outcome is four consecutive heads (H,H,H,H), another is a head, tail, head and head (H,T,H,H).

A little thought results in identifying the sample space as the set of all such 4-tuples.

S={ (H,H,H,H), (H,H,H,T), (H,H,T,H), (H,T,H,H),
(T,H,H,H), (H,H,T,T), (H,T,H,T), (H,T,T,H),
(T,H,T,H), (T,T,H,H), (T,H,H,T), (H,T,T,T),
(T,H,T,T), (T,T,H,T), (T,T,T,H), (T,T,T,T) }

Assigning Probabilities

- Classical Method

  Assigning probabilities based on the assumption of <u>equally likely outcomes</u>.

- Relative Frequency Method

  Assigning probabilities based on <u>experimentation or historical data</u>.

- Subjective Method

  Assigning probabilities based on the <u>assignor's judgment</u>.

В Норвегии при раскопках исторической части города Берген археологи нашли игральный кубик XV века, на котором вместо единицы и двойки были вырезаны четверка и пятерка.

Calculate probability to get 5 and 6 in dice experiments

Classical Method

If an experiment has *n* possible outcomes, this method would assign a probability of 1/*n* to each outcome.

- Example

  Experiment: Rolling a die

  Sample Space: $S = \{1, 2, 3, 4, 5, 6\}$

  Probabilities: Each sample point has a 1/6 chance of occurring.

2 dices > 10

Correct dice (1,2,3,4,5,6): Combinations: 6-6; 6-5;5-6.

Fake dice (1,2,3,5a,5b,6): 6-6; 6-5a; 5a-6; 6-5b; 5b-6

Relative Frequency of an Outcome

- Suppose that, in a large number of repetitions, N, of the experiment, the outcome O, occurs K times.

  The relative frequency of O is,

  $$f = K/N$$

  We can think of the probability of O as the value to which the relative frequency settles down as N gets larger and larger.

Subjective Method

- When economic conditions and a company's circumstances change rapidly it might be inappropriate to assign probabilities based solely on historical data.
- We can use any data available as well as our experience and intuition, but ultimately a probability value should express our <u>degree of belief</u> that the experimental outcome will occur.
- The best probability estimates often are obtained by combining the estimates from the classical or relative frequency approach with the subjective estimates.

Probability Density Function (pdf)

- The probability density function (pdf) of a random variable *X* is referred to as $p_X(x)$. This is nearly always shortened to simply $p(x)$. Note lowercase *p*.
- Why pdf rather than PDF is just a historical artifact.
- A capital letter (usually *X*) refers to the random variable – Sun rise in nanoseconds; arrival of microbus; day temperature….
- Small letters refer to specific realizations of *X*, for example $11°$, $12°$, $10.5°$, $17°$ ...

Cumulative Distribution Function

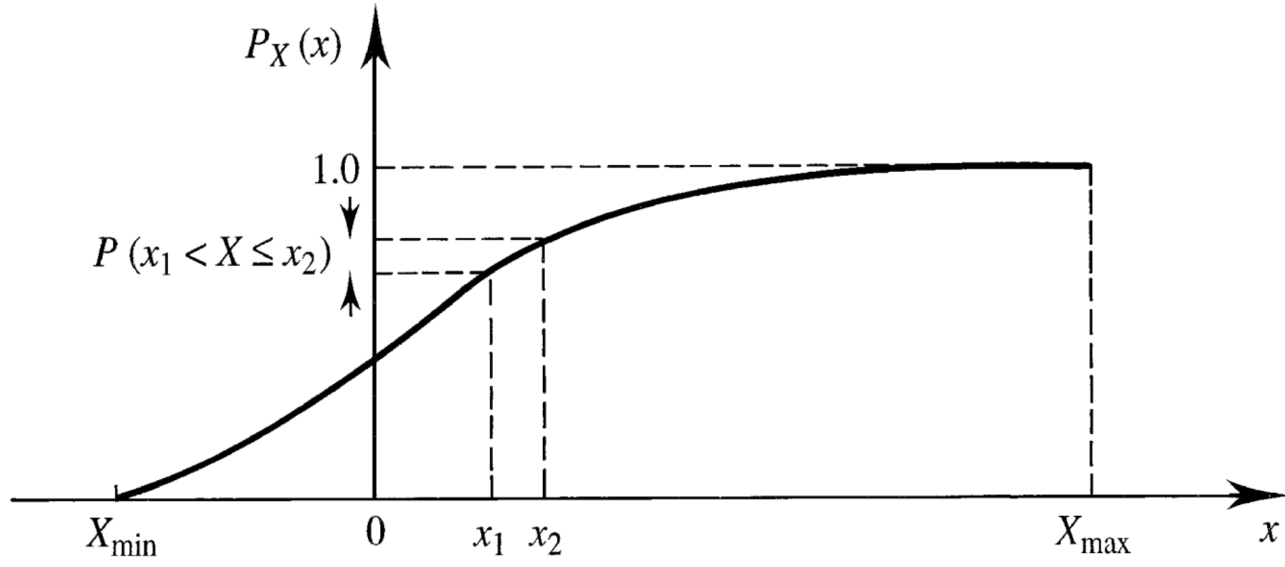
- The same information that is in the pdf can be represented by the cumulative distribution (CD). The CD of a random variable X is denoted $P_X(x)$, nearly always shortened to $P(x)$. Note the capital P.
- In other places CD is described as the cumulative distribution function (cdf).
- In the Digital Signal Analysis course, the CD is called the probability distribution function.

pdf and CD

The CD and pdf are related by the equation:-

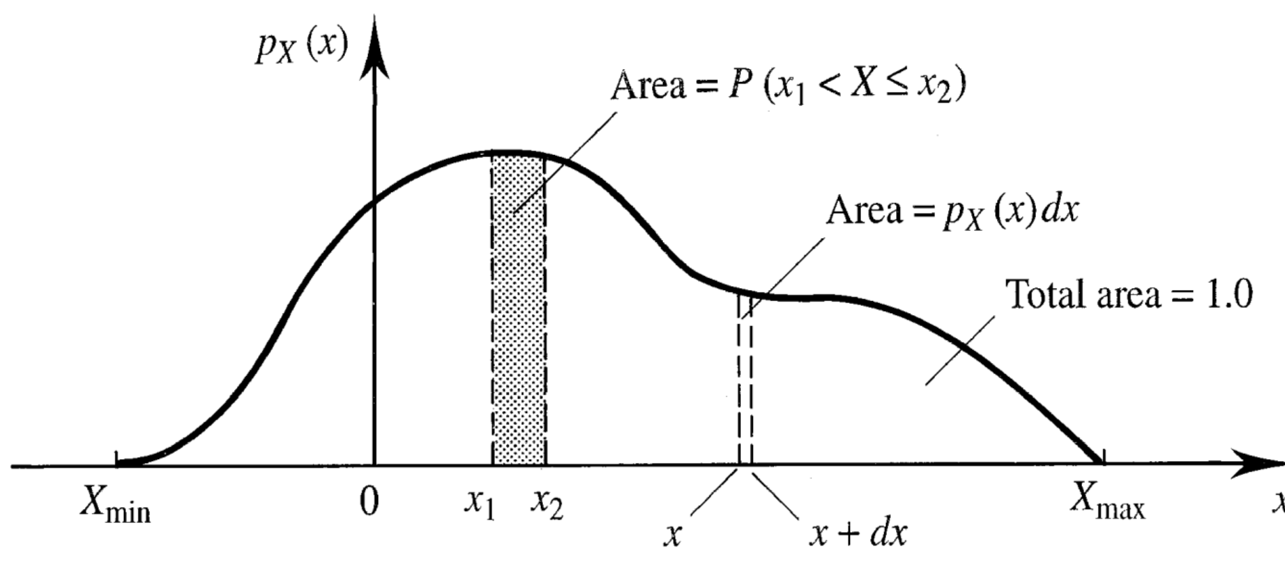
$$P(x) = \int_{-\infty}^{x} p(x)dx$$

CD



(a) Cumulative distribution of X

pdf



(b) Probability density function of X

Probability of X lying between x_1 and x_2:-

$$P(x_1 \le X \le x_2) = \int_{x_1}^{x_2} p(x)dx = P(x_2) - P(x_1)$$

Probability of X being greater than x_1:-

$$P(X > x_1) = \int_{x_1}^{\infty} p(x)dx = 1 - P(x_1)$$

$$\int_{-\infty}^{\infty} p(x)dx = 1$$

$$P(-\infty) = 0 \qquad P(+\infty) = 1$$

Common noise distributions - Uniform

When a random variable X is equally likely to take any value in the range x_1 to x_2, we say that X is uniformly distributed between x_1 and x_2. This is some times written as $U(x_1,x_2)$. The pdf and CD of a uniform distribution are:-

pdf

$$p(x) = \frac{1}{x_1 - x_2}, \ (x_1 < x < x_2)$$

$$= 0 \ (x < x_1, \ \ x > x_2)$$

CD

$$P(x) = \frac{x - x_1}{x_2 - x_1} \ \ (x_1 < x < x_2)$$

$$= 0, \ (x < x_1)$$

$$= 1, \ (x > x_2)$$

- Quantization noise from analogue to digital (ADC) converters is usually uniformly distributed.
- Computer generated random numbers are uniformly distributed (actually, strictly speaking a computer cannot generate random numbers and the random numbers generated can be predicted if you know the deterministic algorithm used, but this is rarely important, they seem random and are uniformly distributed!).

Moments of a Distribution

As stated earlier, there are only two moments of interest for most communication systems, the first moment (the mean, expected value or time average) and the second central moment (the variance).

The first moment can be calculated from the pdf using:-

$$m = E(X) = \overline{X} = \int_{-\infty}^{\infty} x\, p(x) dx$$

For example, if we have a uniform distribution between -0.5 and 0.5, U(-0.5,0.5), the mean is:-

$$m = \int_{-0.5}^{0.5} x \times 1 \;\; dx = \left[\frac{x^2}{2} \right]_{-0.5}^{0.5} = 0$$

For U(0,a):-

$$m = \int_{0}^{a} x \times \frac{1}{a} \;\; dx = \left[\frac{x^2}{2a} \right]_{0}^{a} = \frac{a}{2}$$

The second moment is the mean square of the distribution.

$$\overline{X^2} = \int_{-\infty}^{\infty} x^2 p(x)dx$$

The second central moment (usually called the variance σ^2) is given by:-

$$\sigma^2 = \overline{(x - \overline{X})^2} = \int_{-\infty}^{\infty} (x - \overline{X})^2 p(x)dx$$

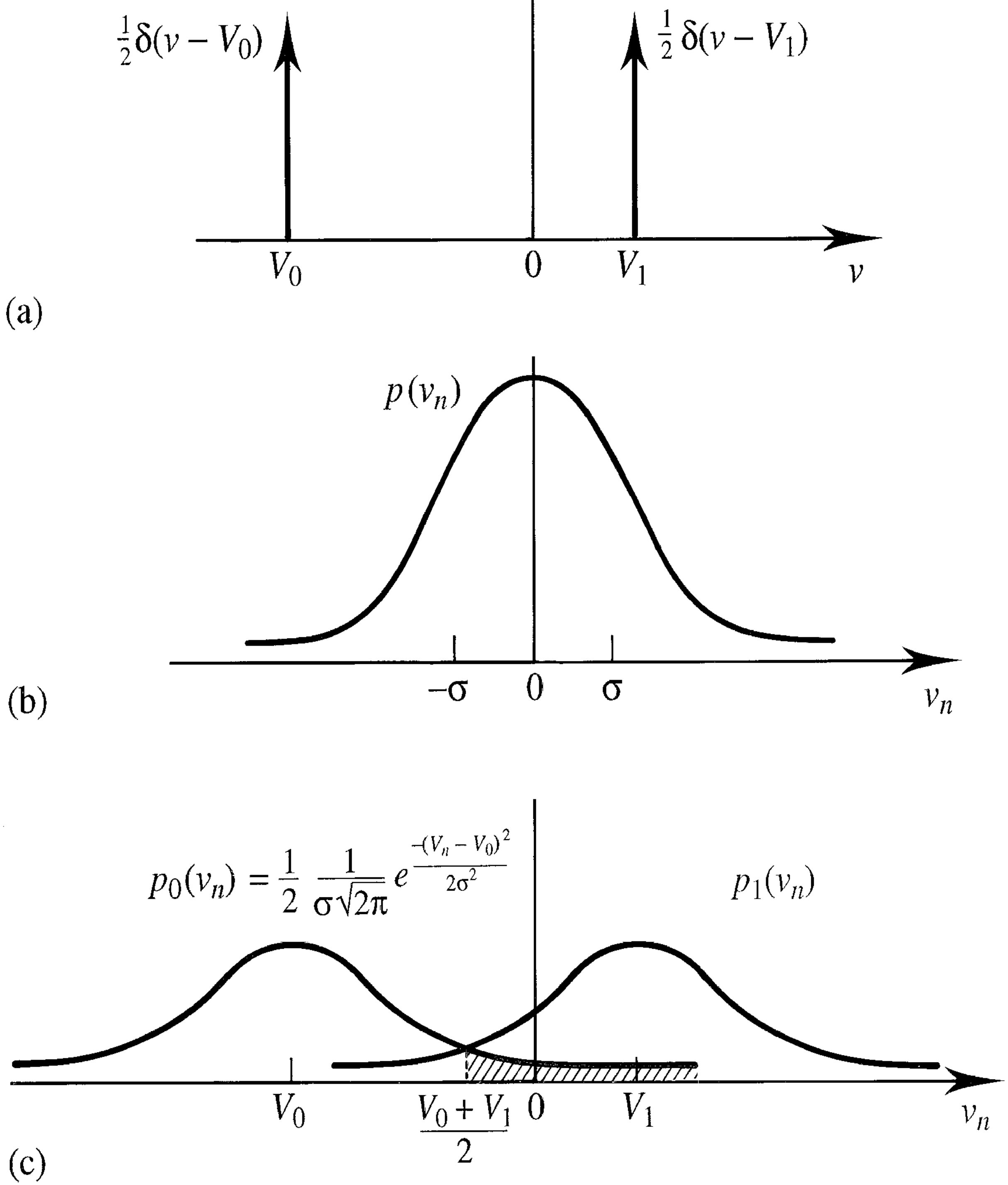
The square root of the variance (σ) is the standard deviation and represents the root mean square (RMS) of the random variable.

For example the variance of the distribution

U(-a/2, a/2) is:-

$$\sigma^2 = \int_{-a/2}^{a/2} x^2 \frac{1}{a} dx = \left[\frac{x^3}{3a} \right]_{-a/2}^{a/2} = \frac{a^2}{12}$$

This is an important result for quantization noise where a is the step size between quantization levels – the ADC at Aragats scintillators.



Probability density function of

a) Binary signal

b) Noise

c) Signal and noise (split into its two components)

Johann Carl Friedrich Gauss

German mathematician, physicist, and astronomer

1777-1855

(en.wikipedia.org)

$$P(X) = \frac{1}{\sigma\sqrt{2\pi}} \exp - \frac{(X - \overline{X})^2}{2\sigma^2}$$

Henri Pointcaré on the uniquity of the normal distribution:

« Everyone believes in it: experimentalist believing that it is a mathematical theorem, mathematicians believing it is an empirical fact »

Carl Friedrich Gauß, immortalized

Central Limit Theorem

Many random variables follow approximately a normal distribution.

The thermal noise is the sum of many different electrons moving about randomly excited by heat. Therefore it tends to have a Gaussian distribution.

Normal Distribution

We use the notation

$$X \sim N(\mu, \sigma^2)$$

to mean

"X has a normal distribution with mean μ and variance σ^2."

Standard Normal Distribution

Normal distribution with:

$$\mu = 0 \quad \text{and} \quad \sigma = 1$$

So, if X follows a standard normal distribution, then $X \sim N(0, 1)$.

Probability Density Function

The pdf for the normal distribution is:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

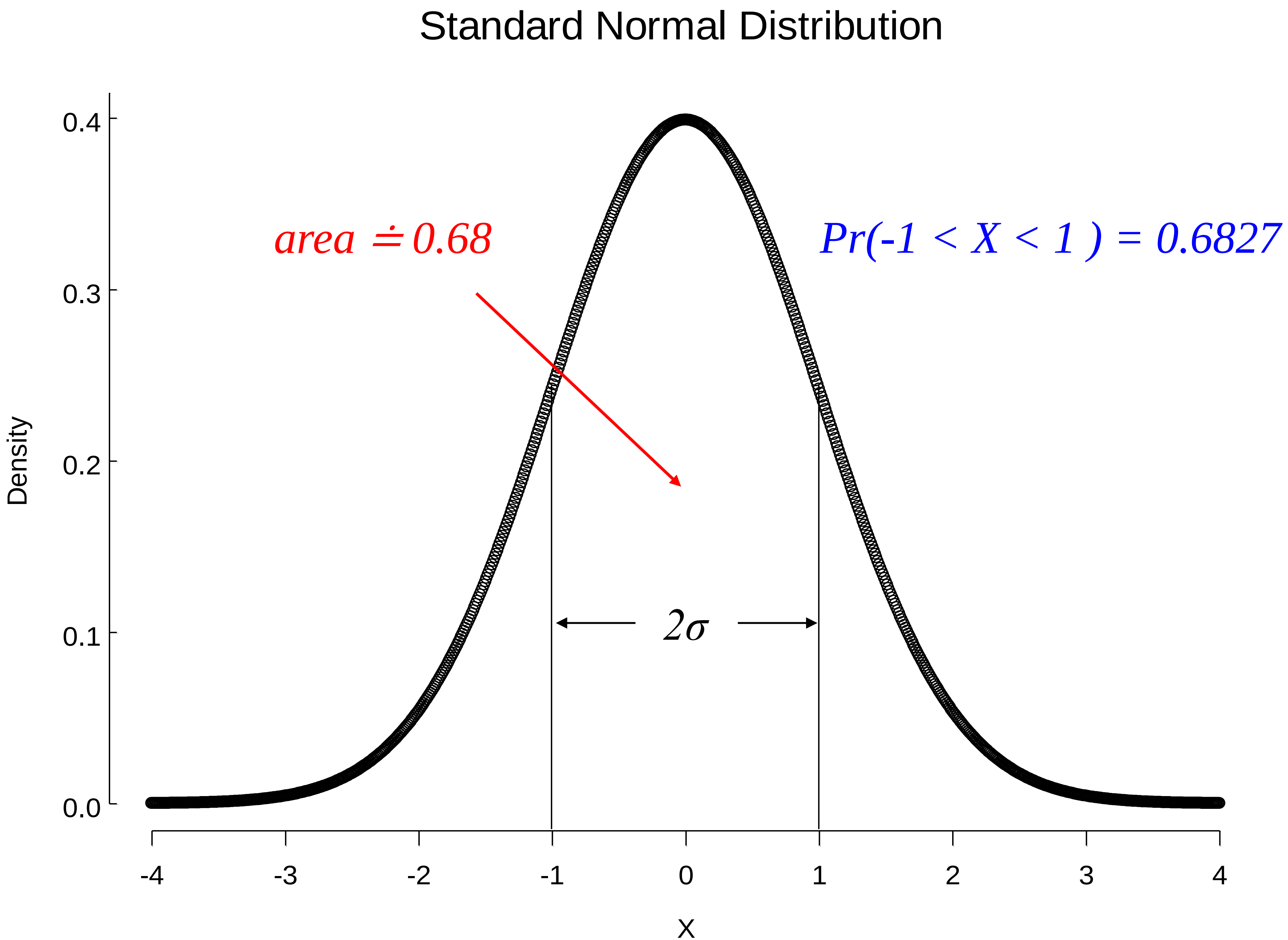
$-\infty < x < +\infty$

Probability Density Function

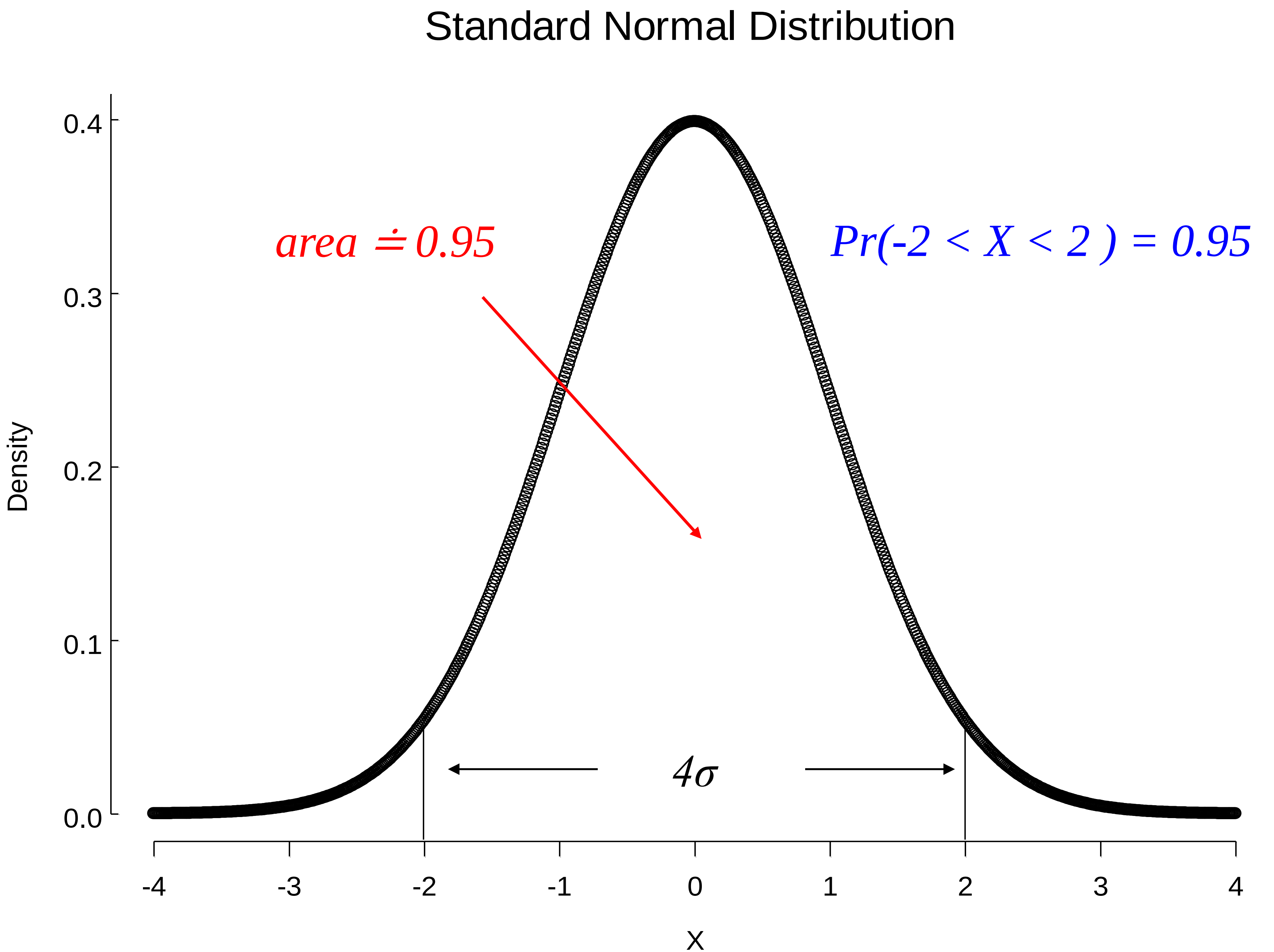
The pdf for the standard normal distribution is:

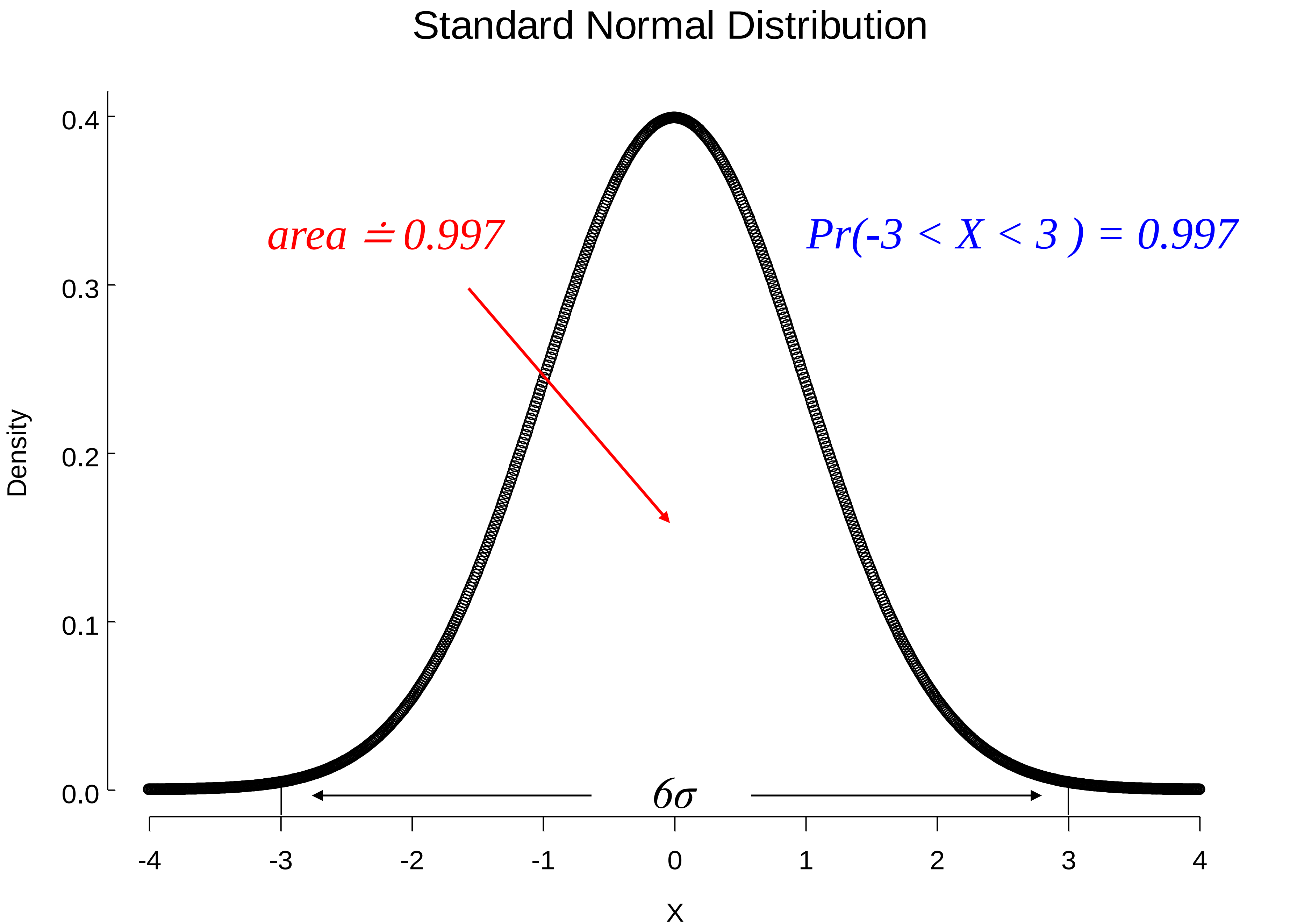
$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\left(\frac{1}{2}\right)x^2}$$

$-\infty < x < +\infty$

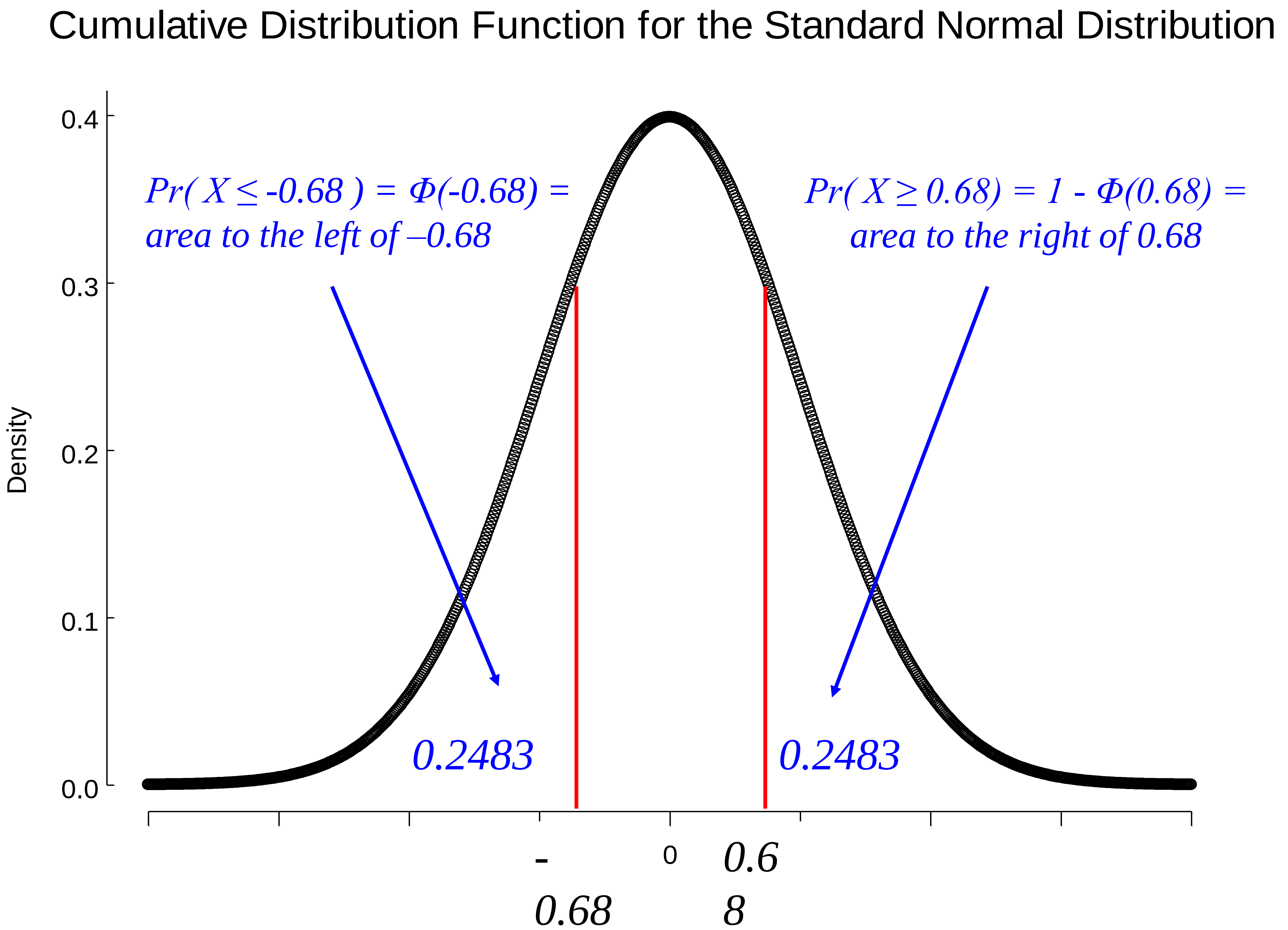


Standard Normal Distribution
area ≐ 0.68
Pr(-1 < X < 1) = 0.6827
2σ
Density
0.0
0.1
0.2
0.3
0.4
-4
-3
-2
-1
0
1
2
3
4
X


Standard Normal Distribution
area ≐ 0.95
Pr(-2 < X < 2) = 0.95
4σ
Density
0.0
0.1
0.2
0.3
0.4
-4
-3
-2
-1
0
1
2
3
4
X



Standard Normal Distribution
area ≐ 0.997
Pr(-3 < X < 3) = 0.997
6σ
Density
0.0
0.1
0.2
0.3
0.4
-4
-3
-2
-1
0
1
2
3
4
X



Cumulative Distribution Function for the Standard Normal Distribution
Density
0.4
0.3
0.2
0.1
0.0
Pr(X ≤ -0.68) = Φ(-0.68) =
area to the left of –0.68
Pr(X ≥ 0.68) = 1 - Φ(0.68) =
area to the right of 0.68
0.2483
0.2483
-
0.68
0
0.6
8

Conversion from $N(\mu, \sigma^2)$ to $N(0, 1)$

If $X \sim N(\mu, \sigma^2)$

and

$$Z = (X - \mu)/\sigma$$

then $Z \sim N(0, 1)$.

Natural Radioactivity

1898 Marie Curie discovers

thorium ($_{90}^{Th}$)

Together Pierre and

Marie Curie discover

polonium ($_{84}Po$) and

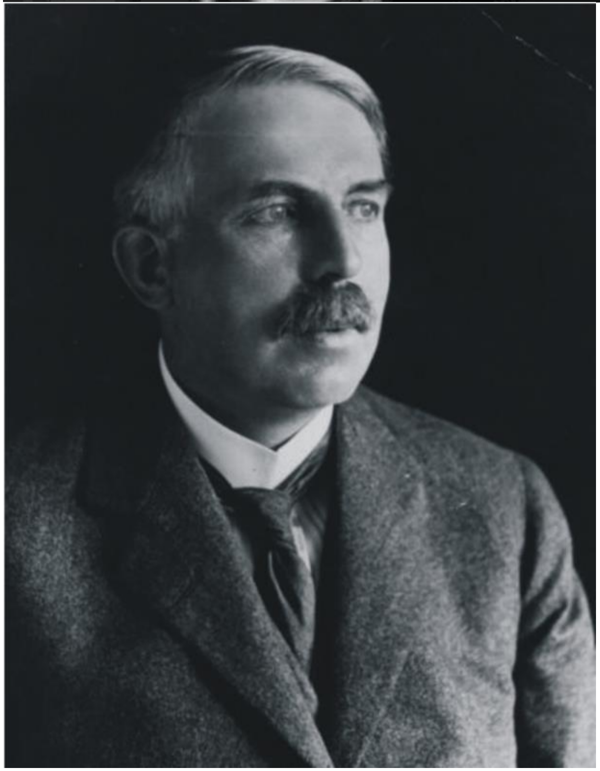
radium ($_{88}Ra$)

1899 Ernest Rutherford identifies 2 distinct kinds of rays

emitted by uranium:

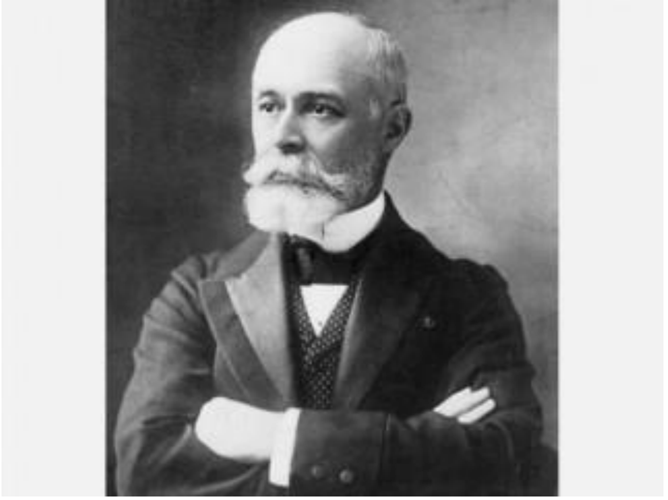
α - *highly ionizing, but completely absorbed by 0.006 cm aluminum foil or a few cm of air*

β - *less ionizing, but penetrate many meters of air or up to a cm of aluminum.*



1900 P. Villard finds in addition to α *rays, radium emits*

γ - *the least ionizing, but capable of penetrating many cm of lead, several feet of concrete*

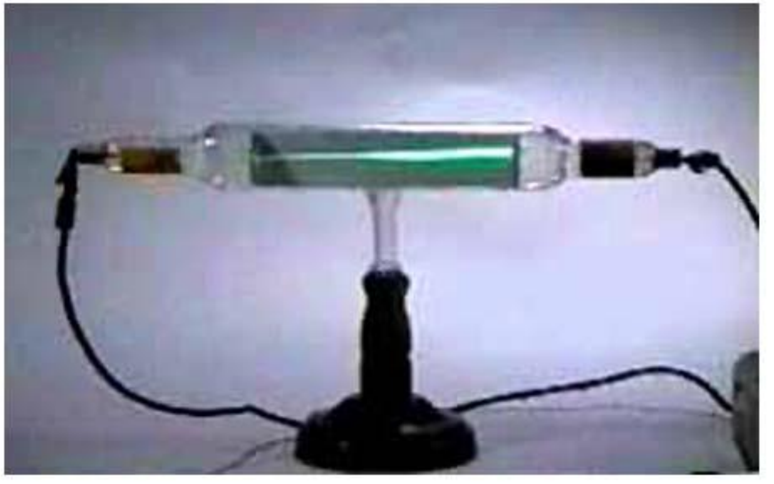


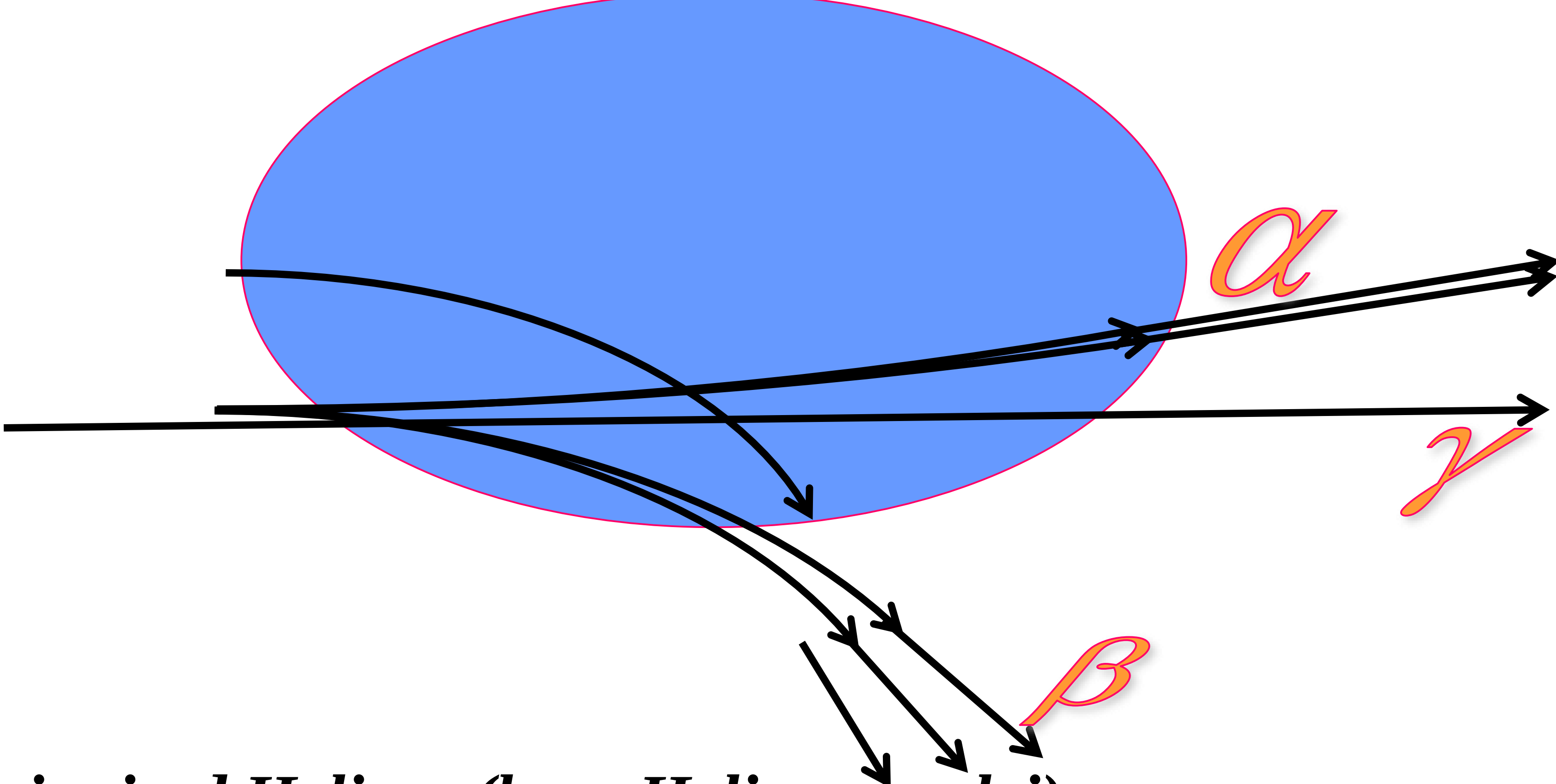
1900-For the discovery of natural radioactivity, which for a number of years was called Becquerel rays, he won the Nobel Prize in physics in 1903. *Studying the deflection of these rays in magnetic fields, Becquerel and the Curies establish* ***α, β*** *rays to be* ***charged particles***

Using the procedure developed by J.J. Thomson in 1887 Becquerel determined the ratio of charge ***q*** *to mass* ***m*** *for*

β: $q/m = 1.76 \times 10^{11}$ *coulombs/kilogram*
identical to the electron!

α: $q/m = 4.8 \times 10^{7}$ *coulombs/kilogram*
4000 times smaller!





αs are ionized Helium (bare Helium nuclei)

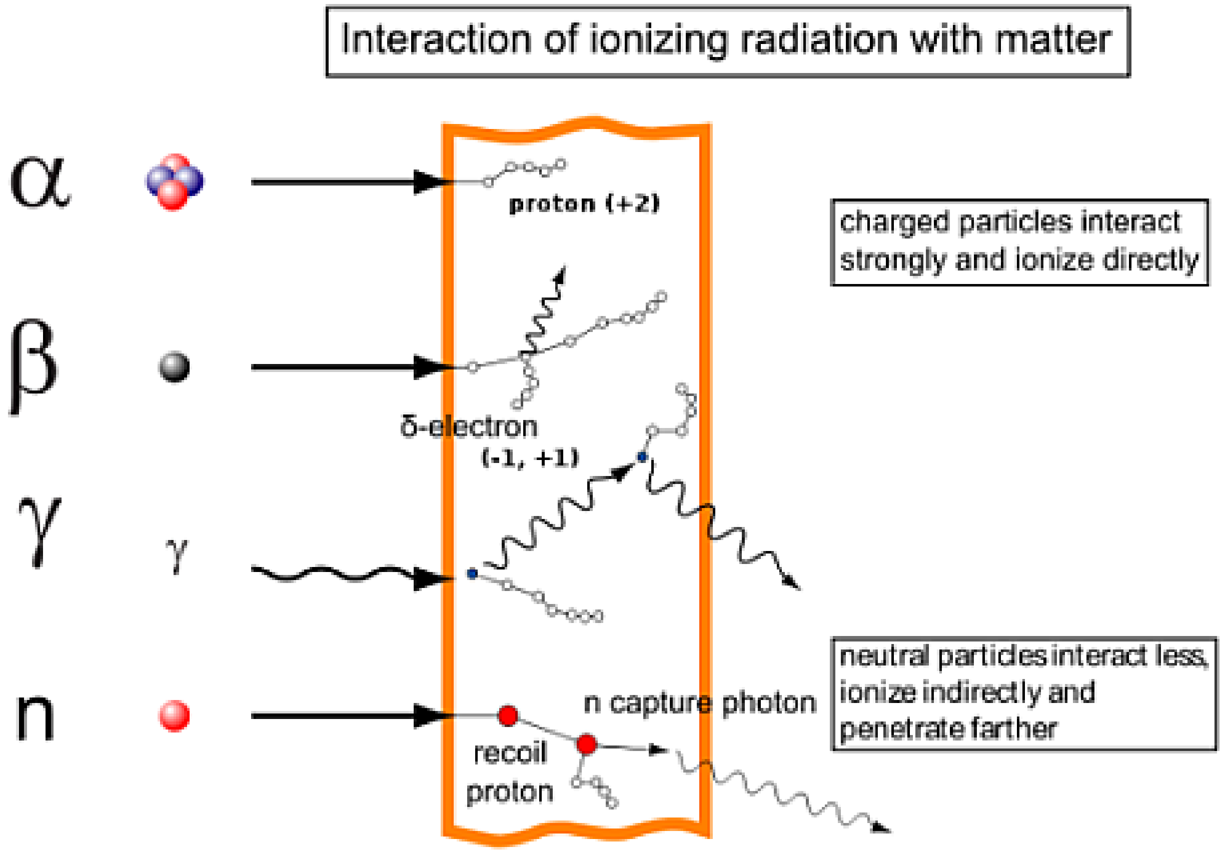
2-protons, 2-neutrons (positively charged)

βs are simply electrons(negatively charged)

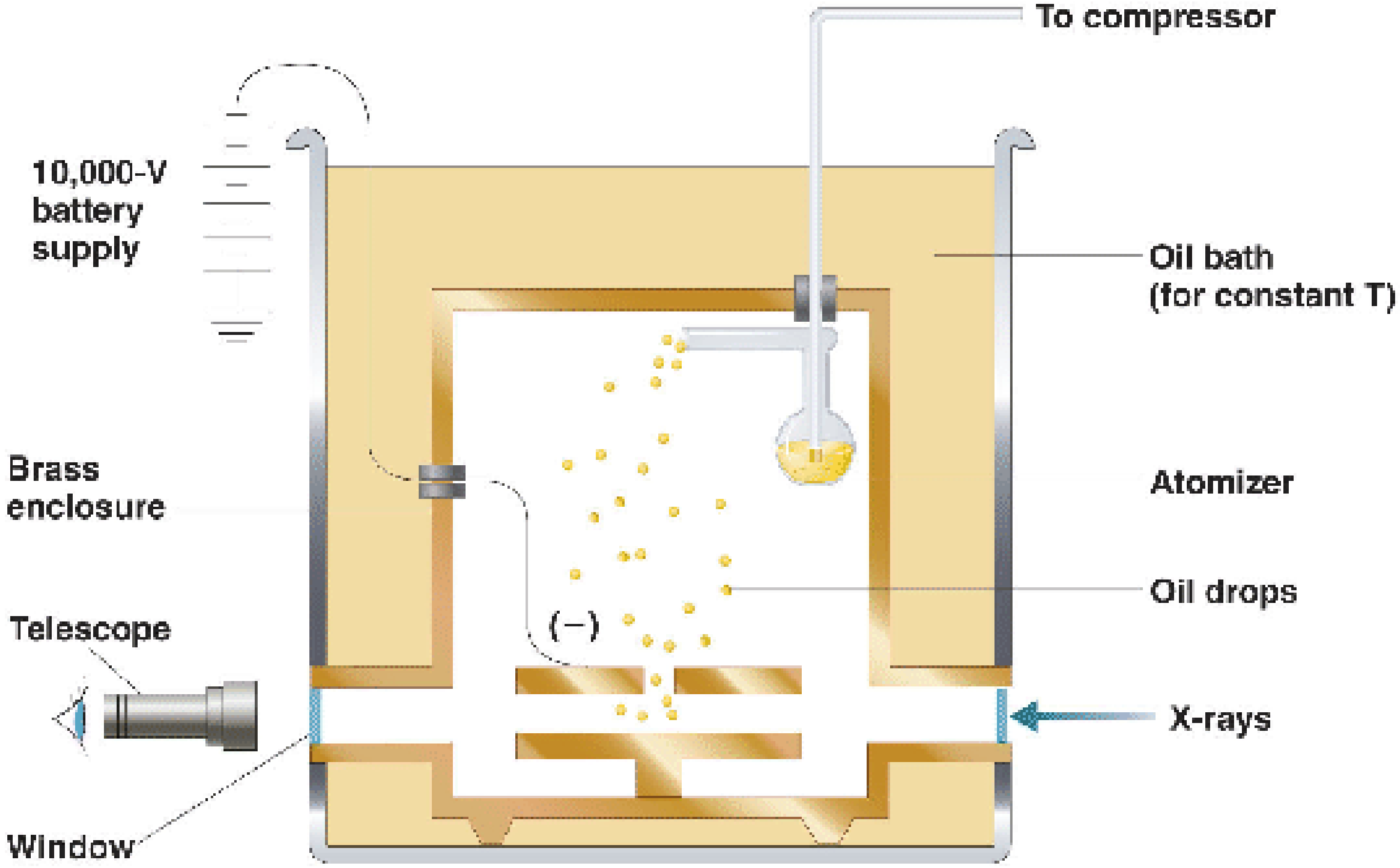
$$\mathbf{q}_{\alpha} = -2\mathbf{q}_{\beta}$$

$$m_{\alpha}=7296m_{\beta}$$

Natural Radioactivity



In 1906, Robert Millikan was able to determine the value of the charge on the electron in his ``oil drop" experiment.



Measurement of the elementary electronic charge

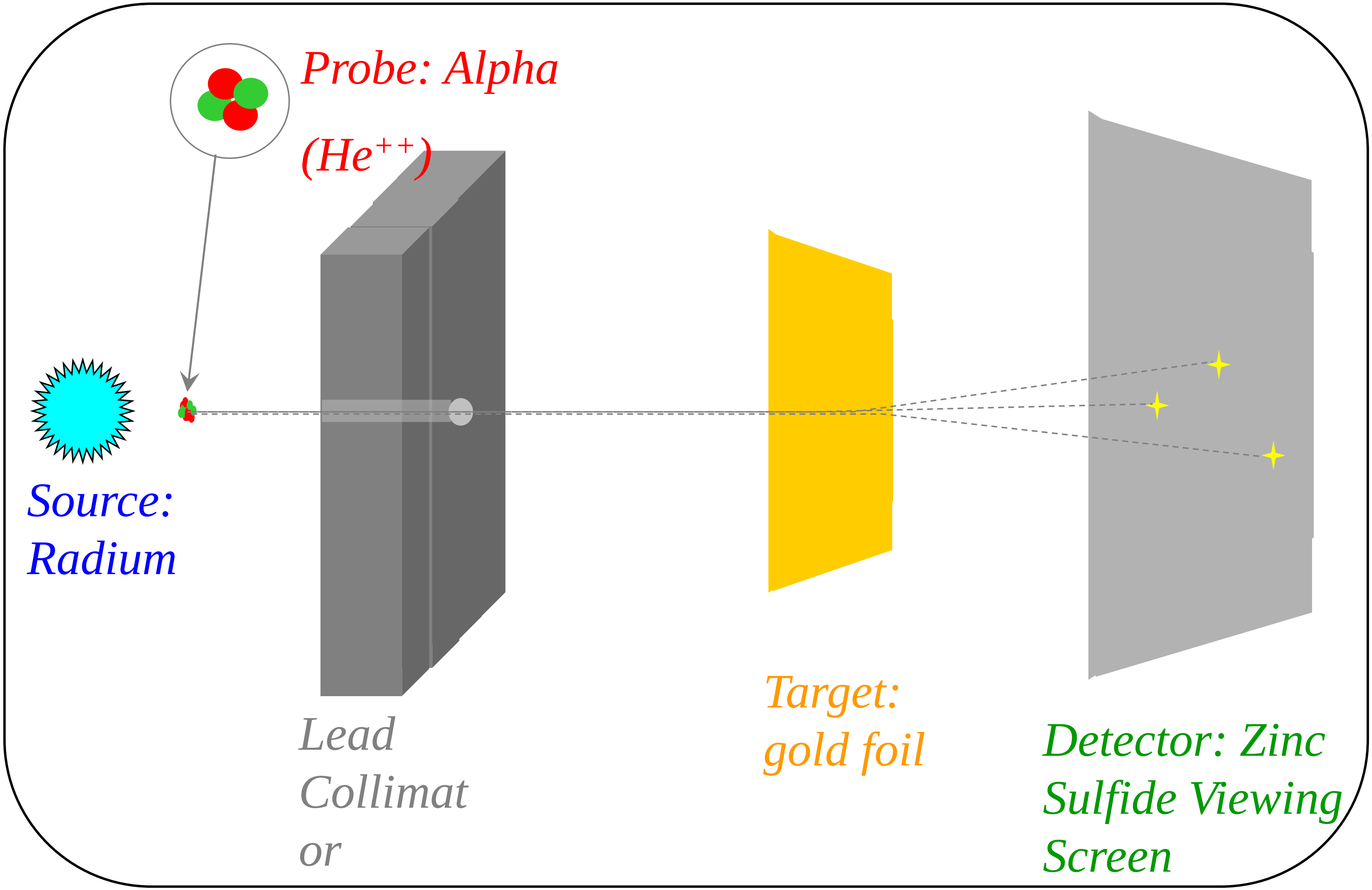
https://www.youtube.com/watch?v=UFiPWv03f6g

How to resolve q/m?

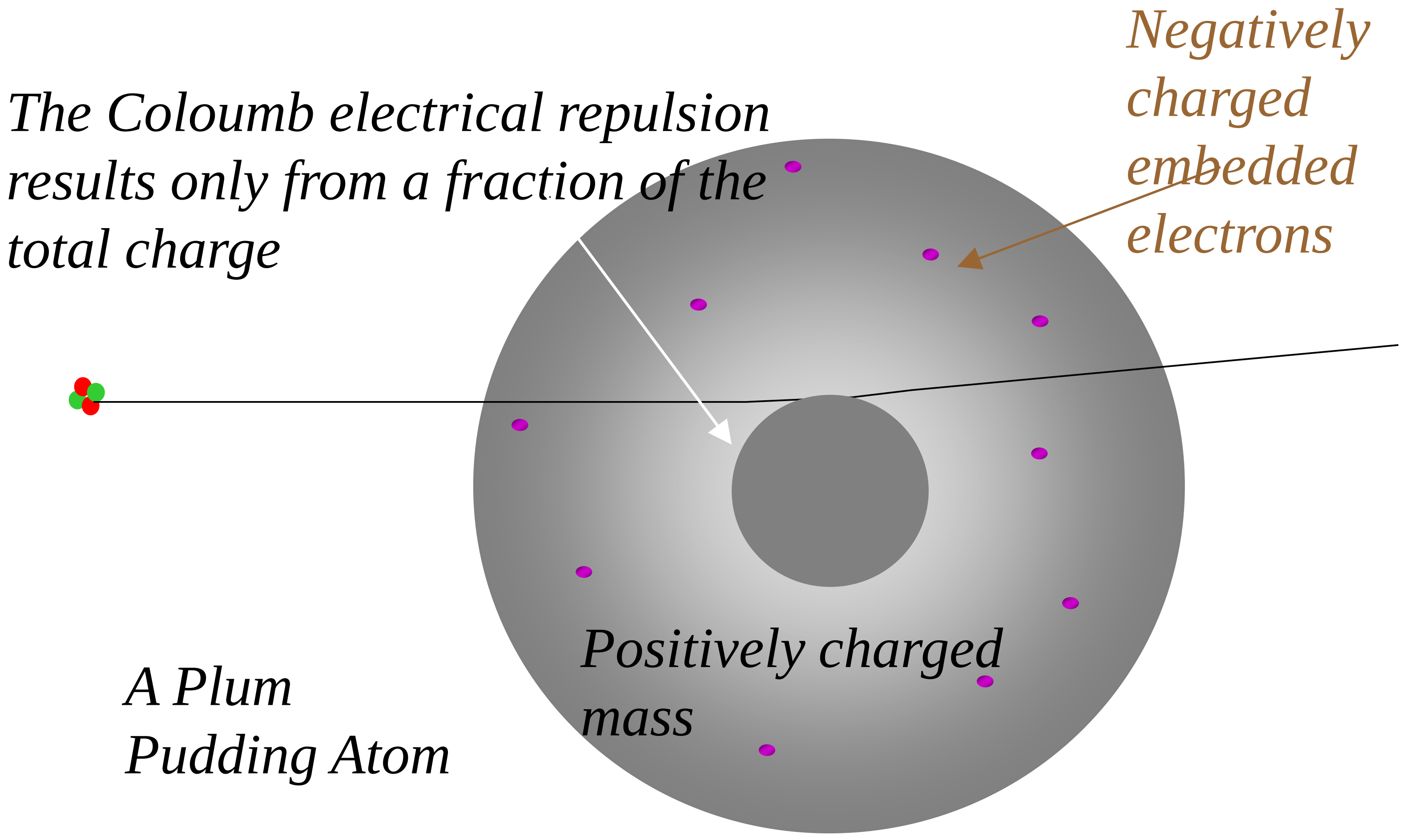
$$F_g = F_q;\ Mg = qE \Rightarrow \frac{q}{M} = \frac{g}{E} \Rightarrow q = \frac{Mg}{E}$$

$$F_{droplet} = Mg - \gamma v = Ma = M\frac{dv}{dt} \Rightarrow v = \frac{Mg}{\gamma} \Rightarrow M = \frac{\gamma v}{g}$$

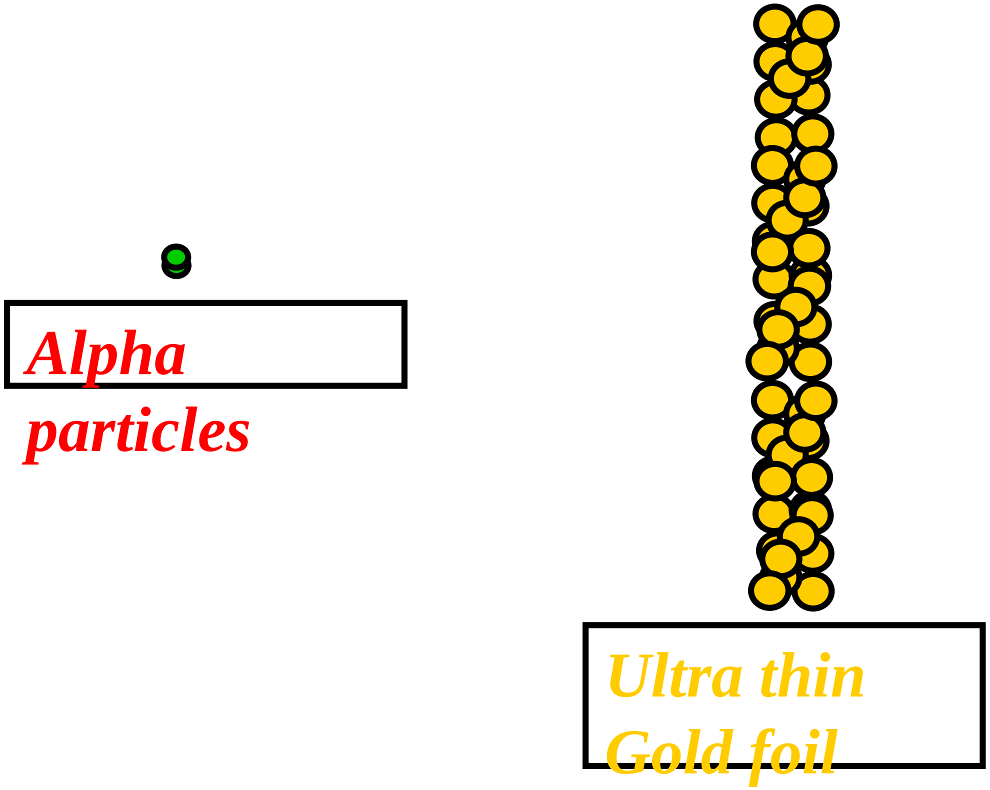
$$q = 1.6021773 * 10^{-19}\,C;\ m = 9.109390 * 10^{-31}\,kg$$


Probe: Alpha
(He++)
Source:
Radium
Lead
Collimat
or
Target:
gold foil
Detector: Zinc
Sulfide Viewing
Screen

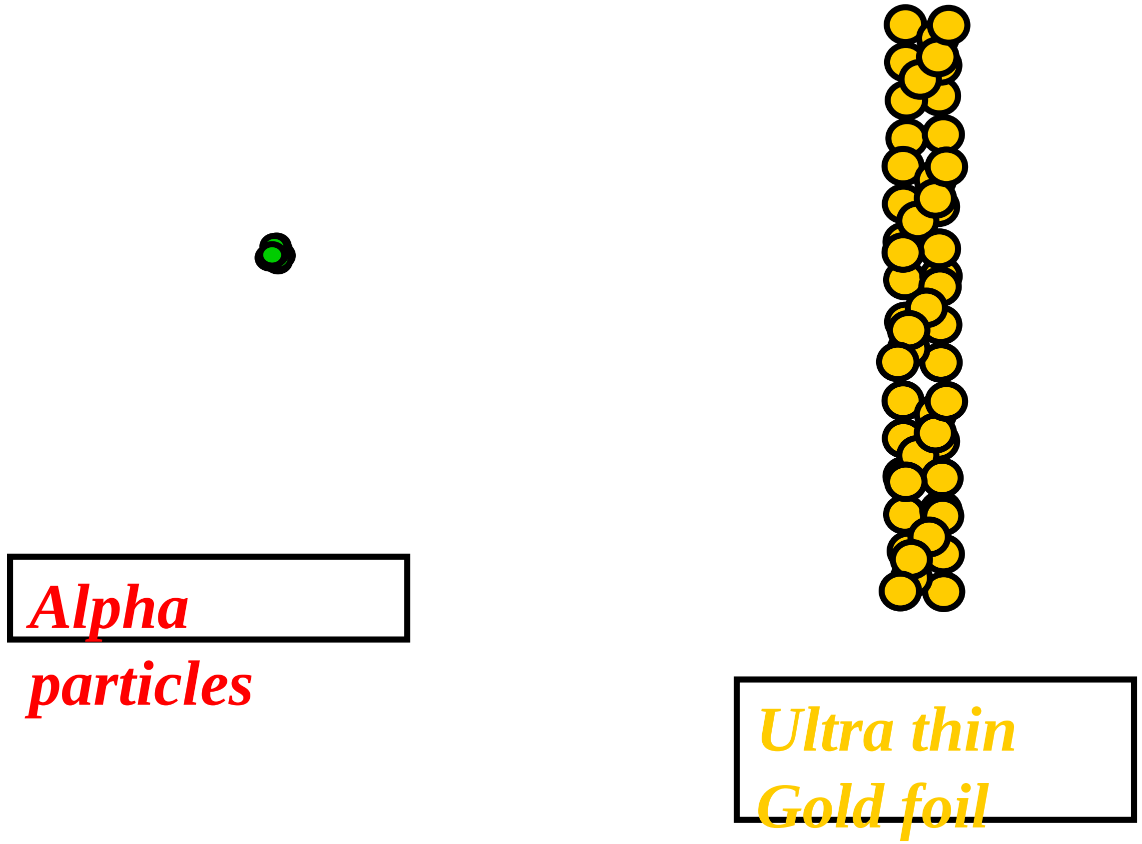
circa 1909: Prevailing atomic model is Plum Pudding.



They expected to see small deflections of the alphas as they barreled through the ultra-thin foil



Marsden instead observes many large angle scatters or ricochets.



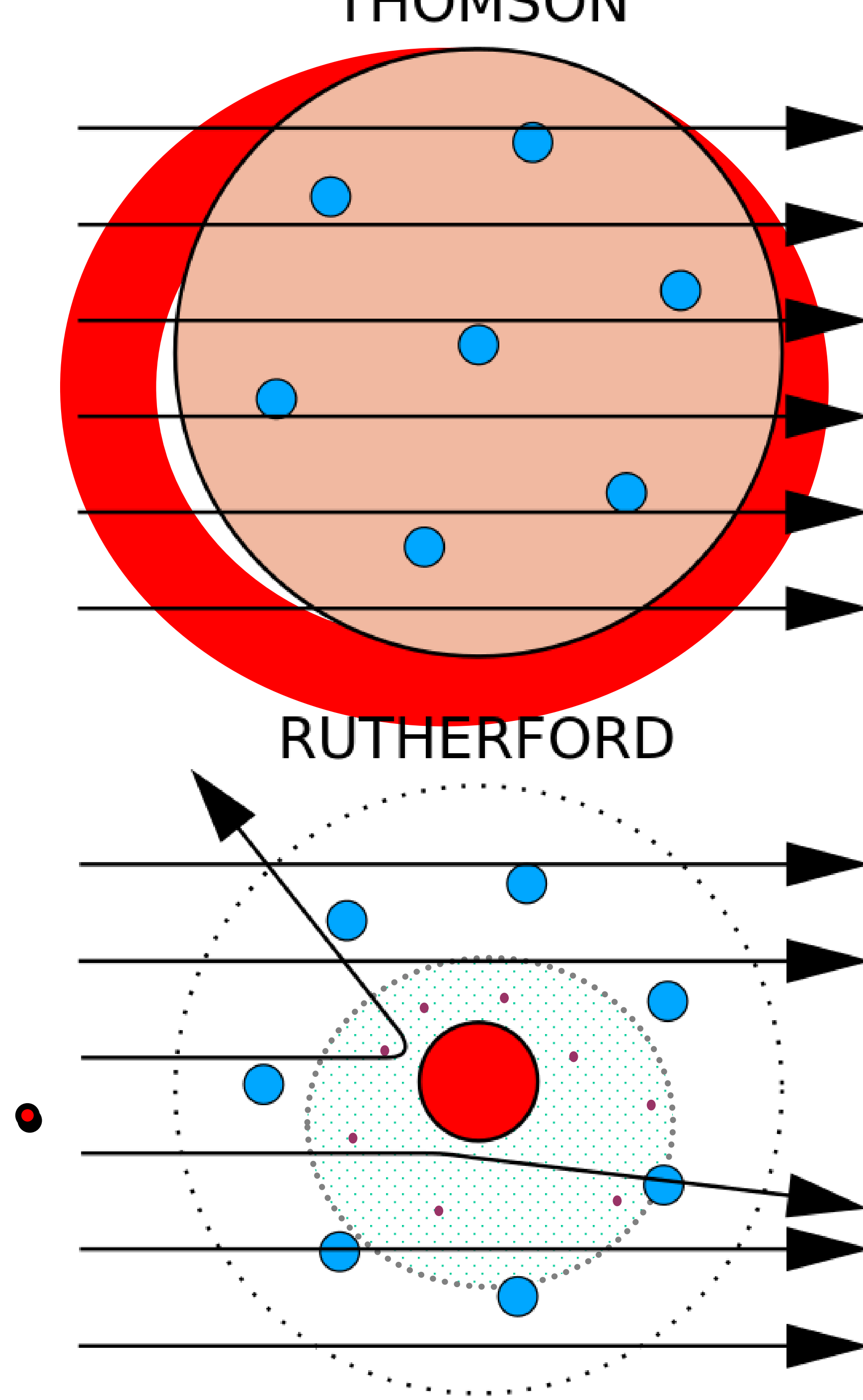
This scattering is contrary to the PP model!

From Marsden's observed scattering angles Rutherford calculates:

Charged mass is not distributed over whole atomic volume.

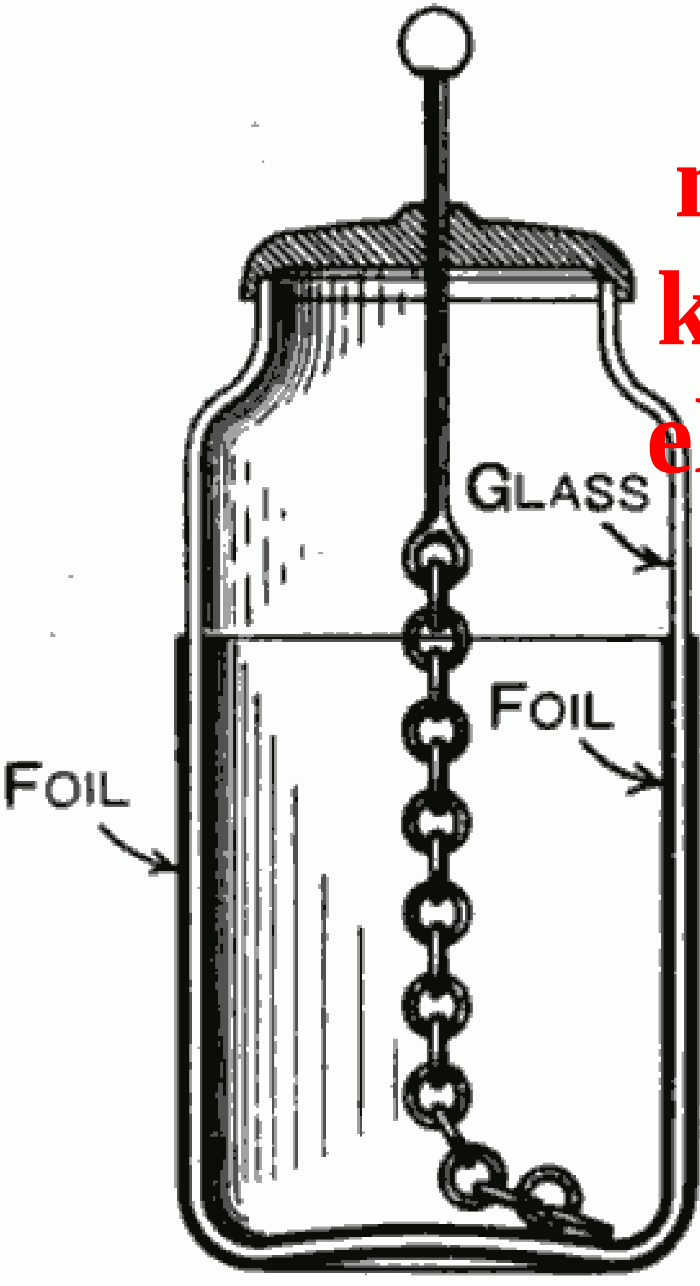
The observed scatters can occur when the charge is concentrated at the center in volume of 0.0001 atomic diameter

This was the death of plum pudding & birth of the nucleus.

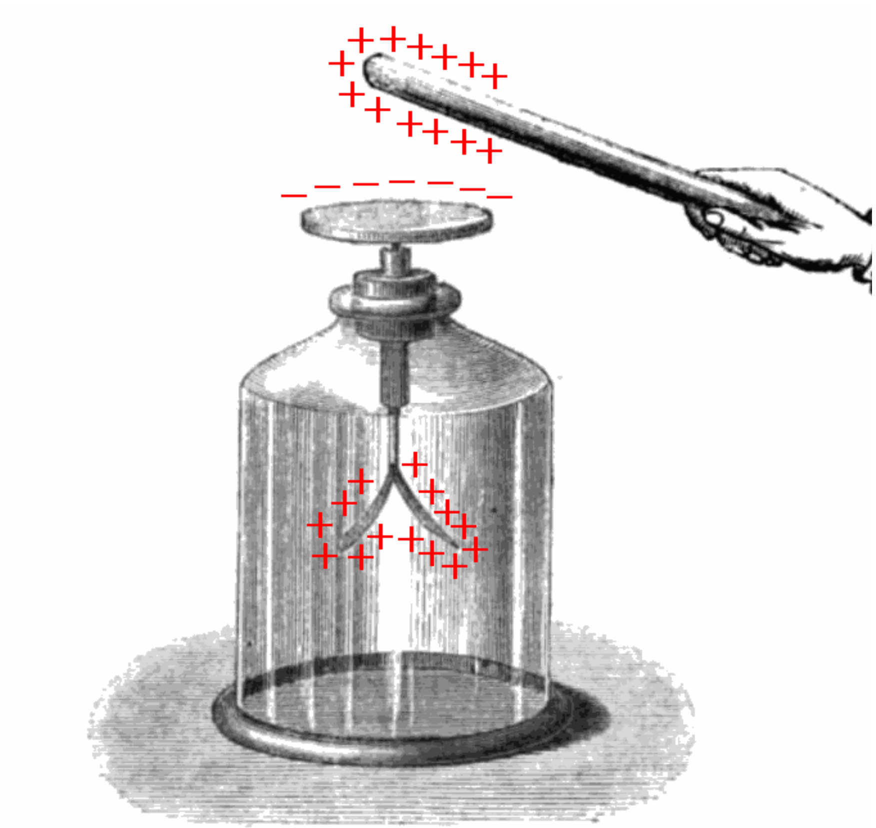


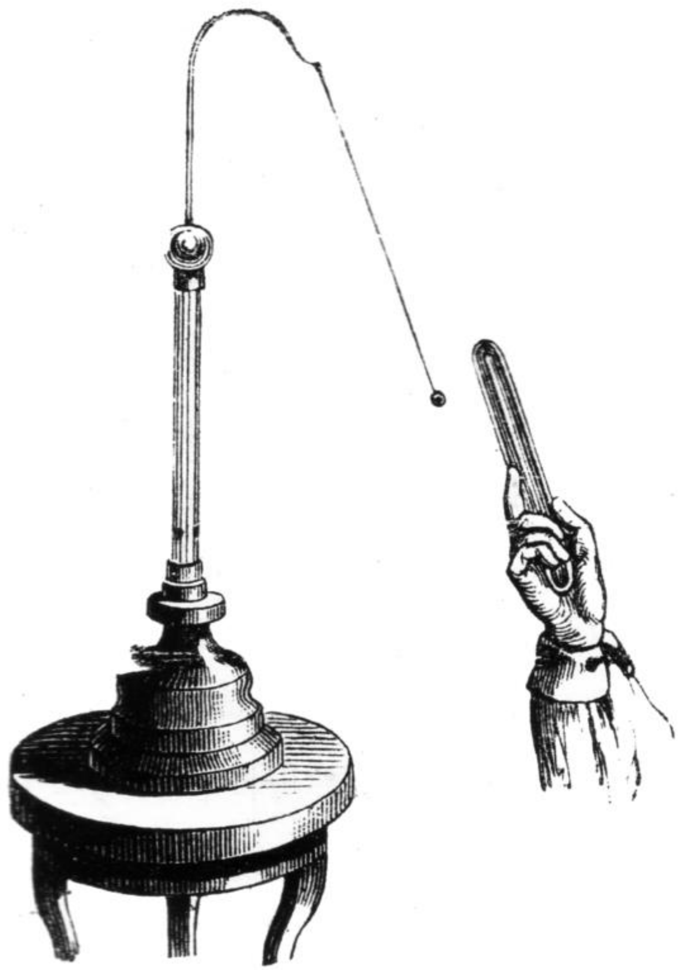
The experiment was carried out Franklin in June 1752, but using a kite. He attached a key to the kite string, which was connected to a Leyden jar. Although the kite was not struck by lightning, static electricity was conducted to the key, and Franklin felt a shock when he moved his hand near the key. Georg Wilhelm Richmann (Germany/Russia) was killed by electrocution while attempting to recreate the experiment in St. Petersburg in 1753.

How to make and keep static electricity?

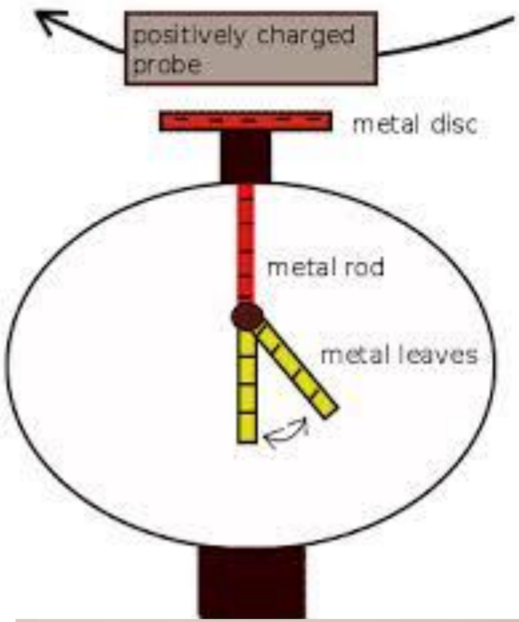


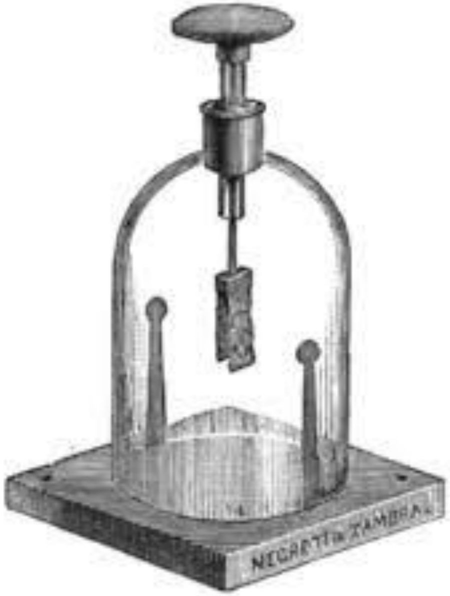
How to measure electric charge?






C
D
B
A


positively charged probe
metal disc
metal rod
metal leaves

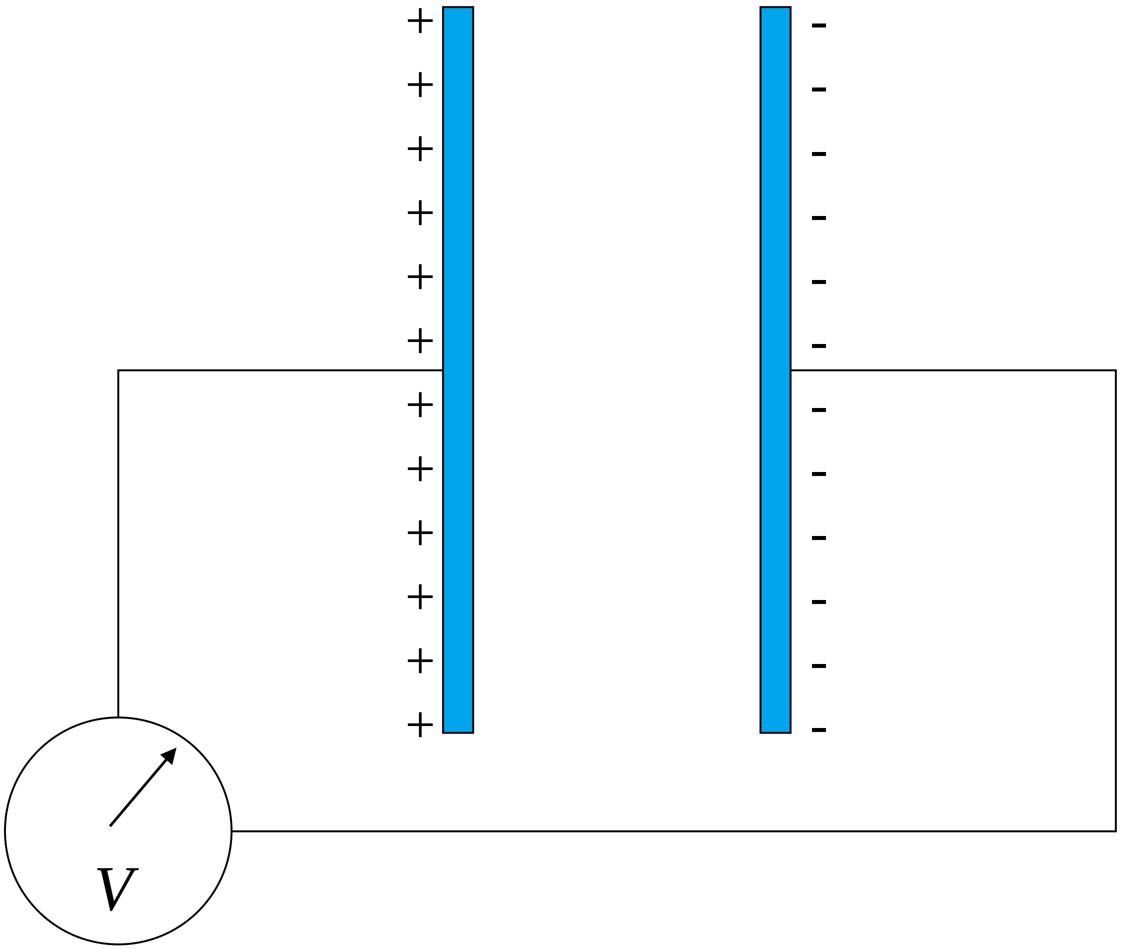

NEGRETTI & ZAMBRA


AstroParticelle

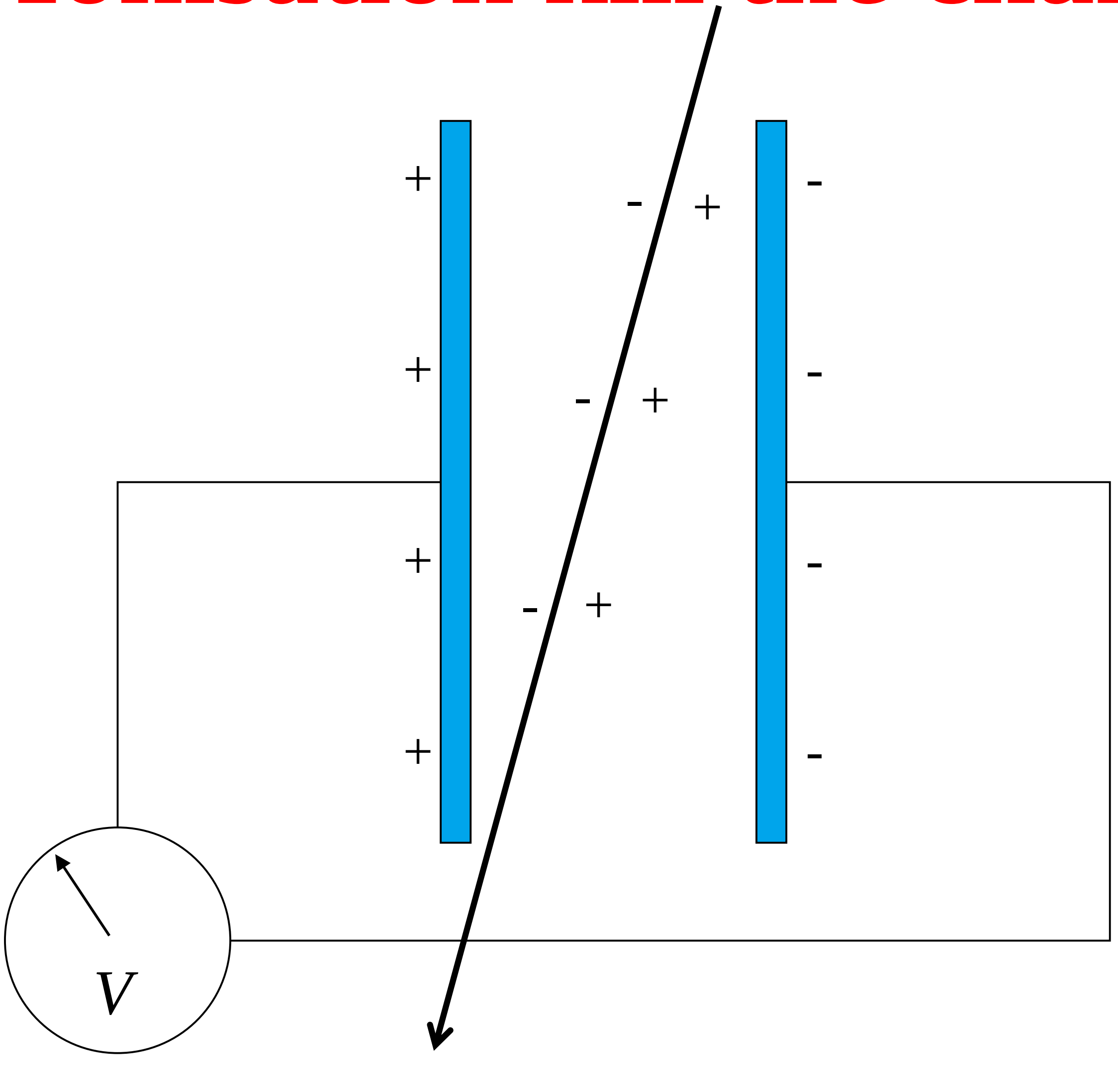
Electroscopes discharge spontaneously. Why?

- • 1785:Coulombfoundthat electroscopes can spontaneously discharge by the action of the air and not by defective insulation
- • 1835:Faradayconfirmsthe observation by Coulomb, with better insulation technology
- • 1879: Crookes measures that the speed of discharge of an electroscope decreased when pressure was reduced (conclusion: direct agent is the ionized air)

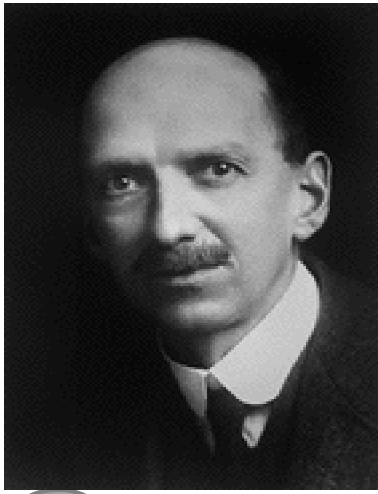
Charged capacitor



Ionisation kill the charge



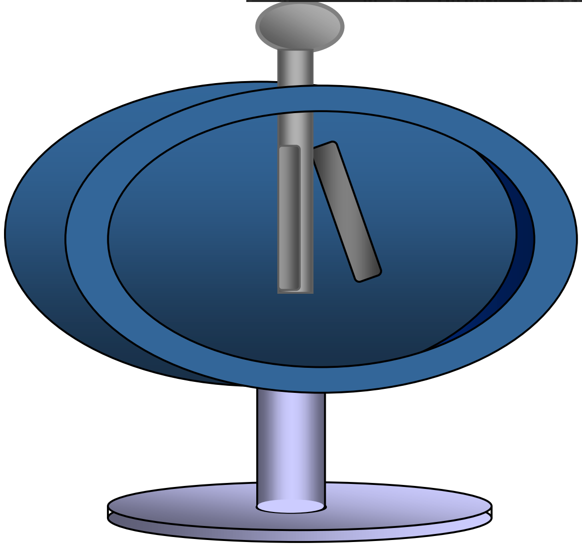
1900 While studying atmospheric electricity,
J. Estler *and* ***H. Geitel*** *note an unknown, but continuously present source of ions "in the air"*



Charles T. R. Wilson's ionization chamber

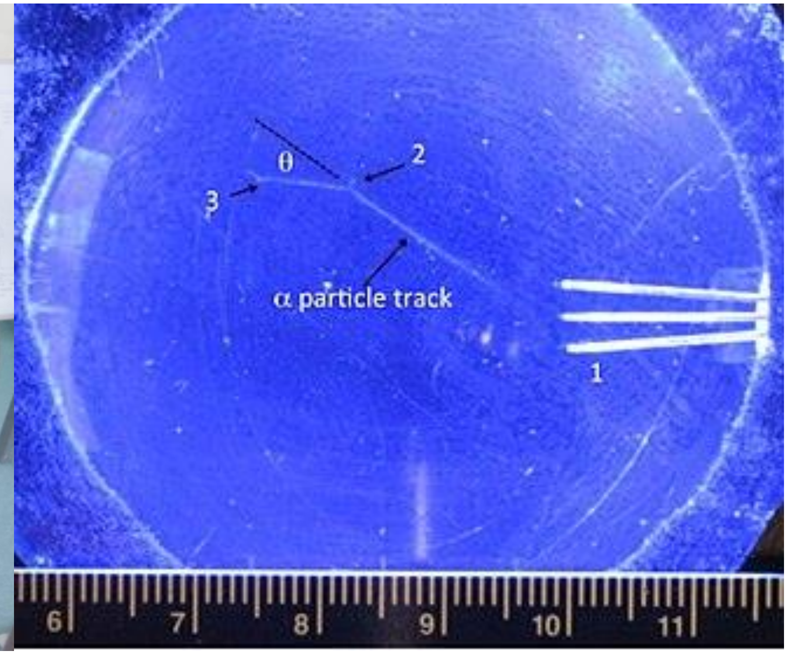
Electroscopes eventually discharge even when all known causes are removed,
i.e., even when ***electroscopes*** *are*

- *sealed airtight*
- *flushed with dry, dust-free filtered air*
- *far removed from any radioactive samples*
- *shielded with 2 inches of lead*



seemed to indicate an unknown radiation with greater penetrability than ***x-rays*** *or radioactive* ***γ rays***
Speculating they might be extraterrestrial, Wilson ran underground tests at night in the Scottish railway, but observed no change in the discharging rate.

Original of the first Wilson chamber



A cloud chamber consists of a sealed environment containing a supersaturated vapor of water or alcohol. An energetic charged particle (for example, an alpha or beta particle) interacts with the gaseous mixture by knocking electrons off gas molecules via electrostatic forces during collisions, resulting in a trail of ionized gas particles. The resulting ions act as condensation centers around which a mist-like trail of small droplets form if the gas mixture is at the point of condensation. These droplets are visible as a "cloud" track that persist for several seconds while the droplets fall through the vapor. These tracks have characteristic shapes. For example, an alpha particle track is thick and straight, while an electron track is wispy and shows more evidence of deflections by collisions.

1909 *Taking his ionization chamber first to the top of the Eiffel Tower (275 m)*

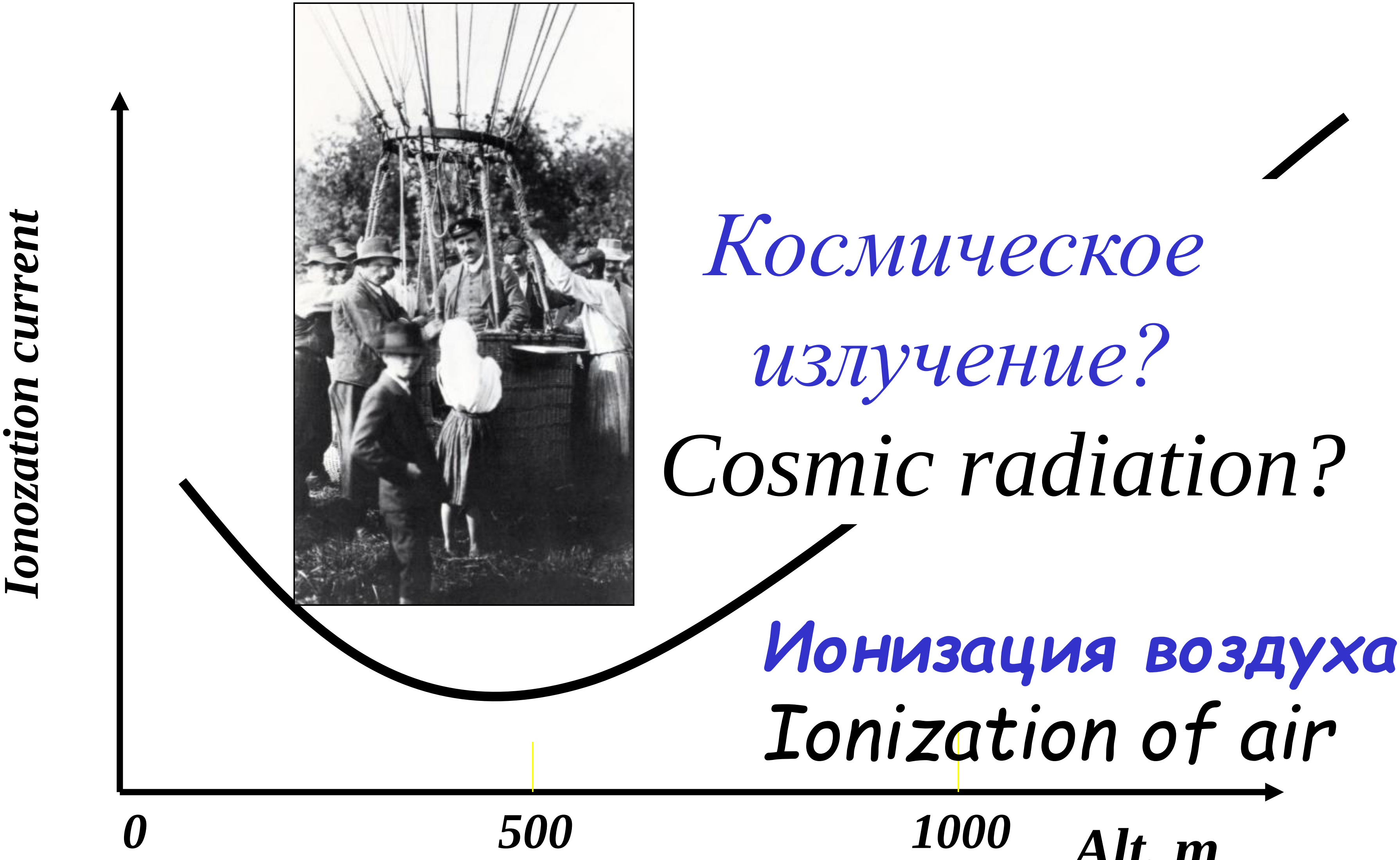
Wulf *observed a 64% drop in the discharge rate.*

Familiar with the penetrability of radioactive α, β, γ rays, Wulf expected any ionizing effects due to natural radiation from the ground, would have been heavily absorbed by the "shielding" layers of air.

В 1912 г. Виктор Гесс достиг высоты ~5км

In 1912 Victor Hess reached ~5 km

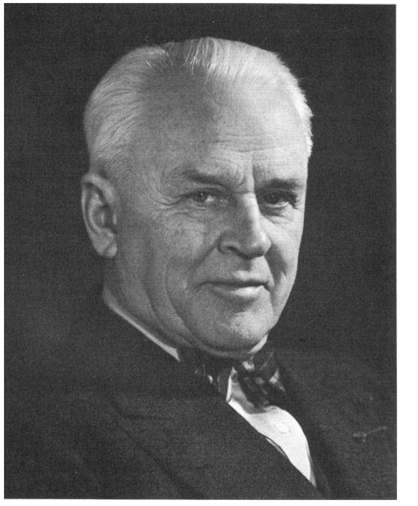
http://pamela.physik.uni-siegen.de/pamela/history.html



Who named Cosmic Rays?

Millikan's Experiment ★

(1925-1928)

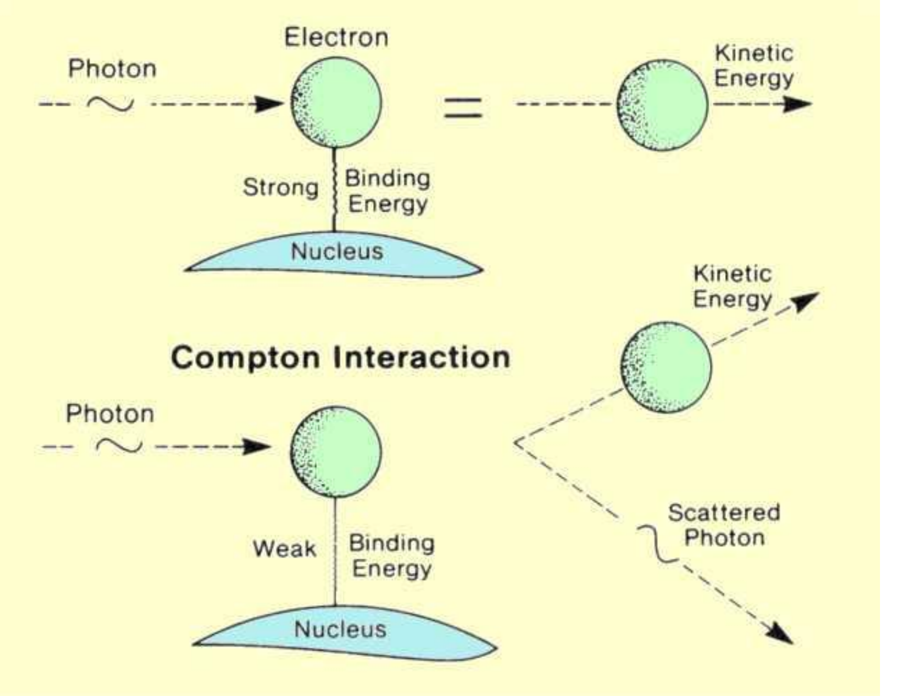


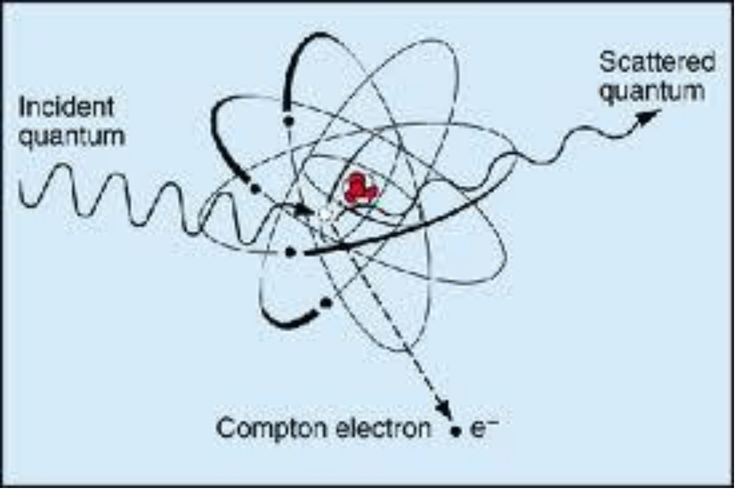
- The first experiment to use high altitude.
- The highest mountain of USA, Mt. Whitney(4418m), and Muir Lake(3540m) (except Alaska).

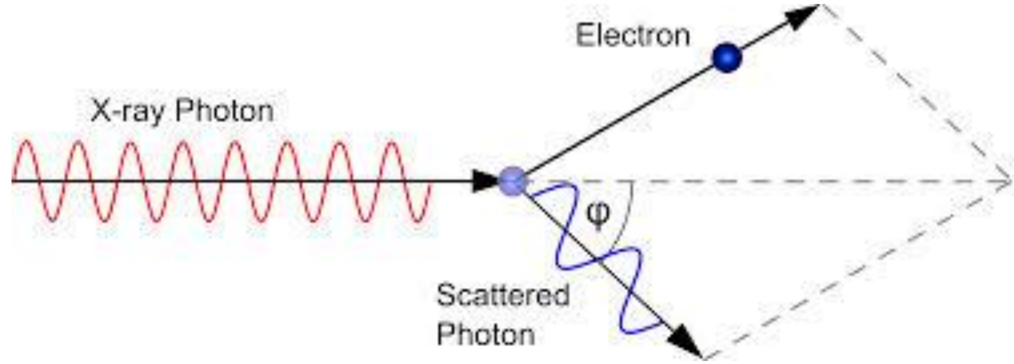
  (The experiment may be classified into very the first experiment

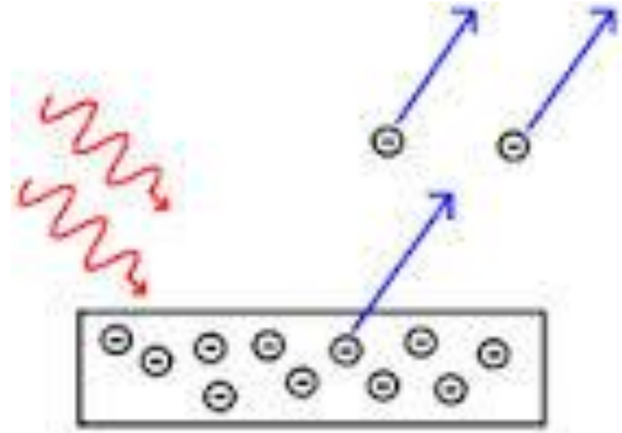
  at high altitude mountain laboratories.)
- In 1940, Hess agreed with the name, so everybody started

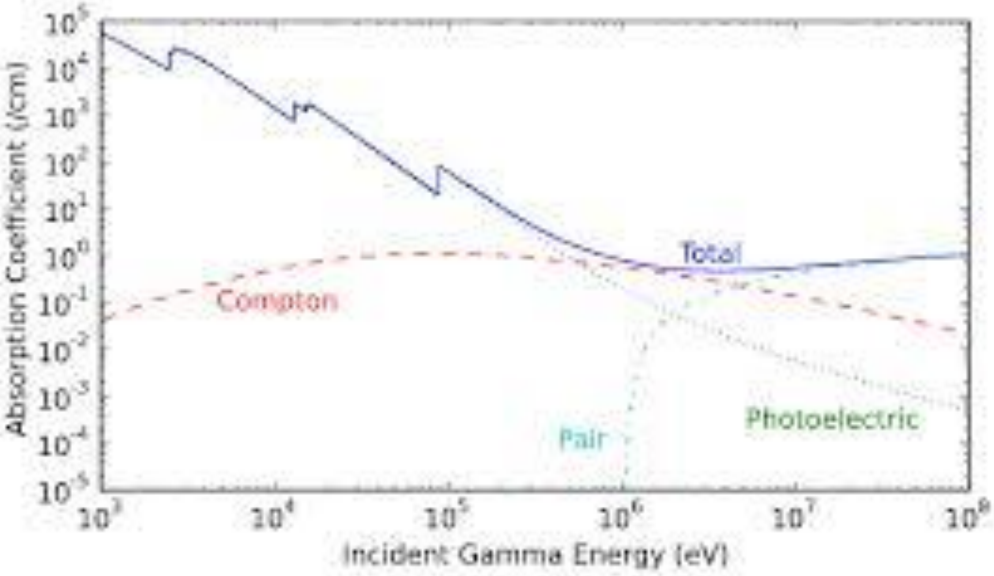
  to call Hohen-strahlung as **cosmic ray**

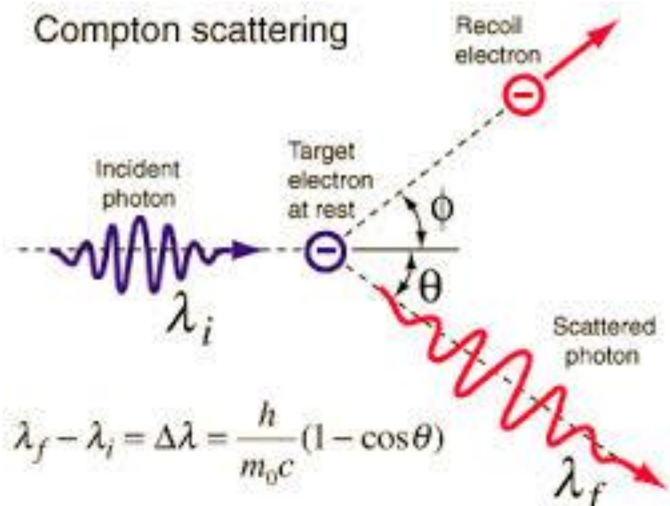



Incident quantum
Scattered quantum
Compton electron
e⁻


Electron
X-ray Photon
φ
Scattered Photon




Absorption Coefficient (/cm)
Incident Gamma Energy (eV)
Total
Compton
Pair
Photoelectric


Compton scattering
Recoil electron
Incident photon
Target electron at rest
Scattered photon
λ_i
λ_f
ϕ
θ
$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$

Attenuation of the gamma ray flux in the matter

Ослабление потока dI на длине dx : $dI = -I \cdot \alpha \cdot dx,$

$$\frac{dI}{I} = -\alpha \cdot dx$$

Интегрируем

$$lnI = -\alpha \cdot x + C$$

Используем начальные условия, находим C

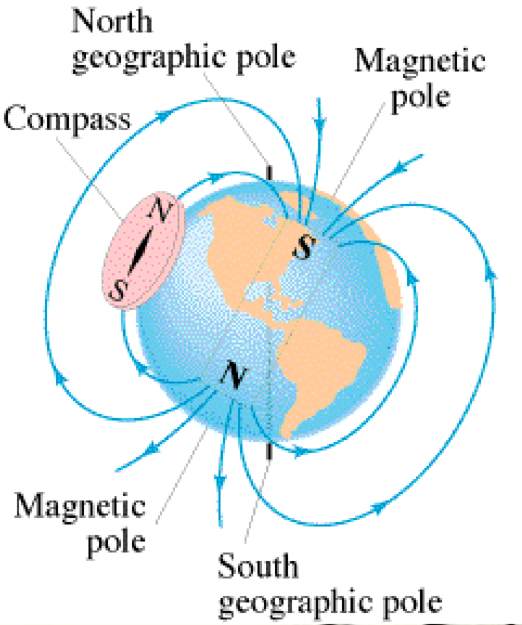
$$x = 0, \ I = I_0 \ , \ lnI_0 = C$$

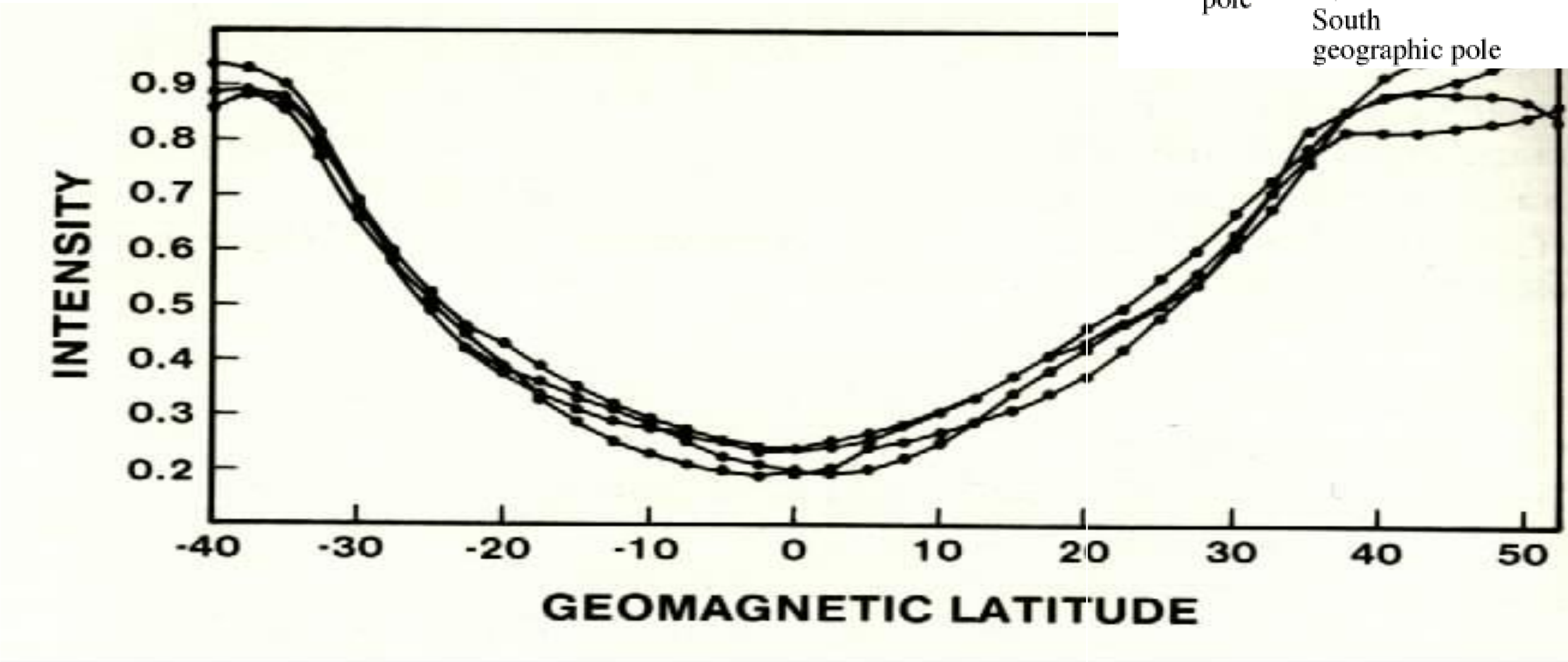
$$\ln I - ln \ I_0 = -\alpha \cdot x$$

$$\frac{I}{I_0} = e^{-\alpha x}$$

$$I(x) = I_0 \cdot e^{-\alpha x}$$

1930-33 ***Arthur Compton*** *(University of Chicago)*
conducts a worldwide sea- and mountain-level latitude
survey of cosmic ray intensities and confirms
the ***Latitude Effect****.*





The 4 curves correspond to 4 seasons

Influence on cosmic ray fluxes

The interaction between the Earth magnetic field and cosmic rays was seen by:

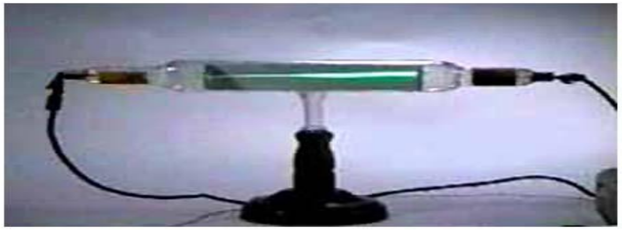
- **Latitude effect**: the CR flux depends on the latitude, is higher at the poles than at the equator.
- Conclusion: CR are mainly charged! They arrive from all directions and are deflected by the magnetic field. **Each latitude has a cut-off rigidity (p/z) below which no vertically arriving particles can penetrate.**

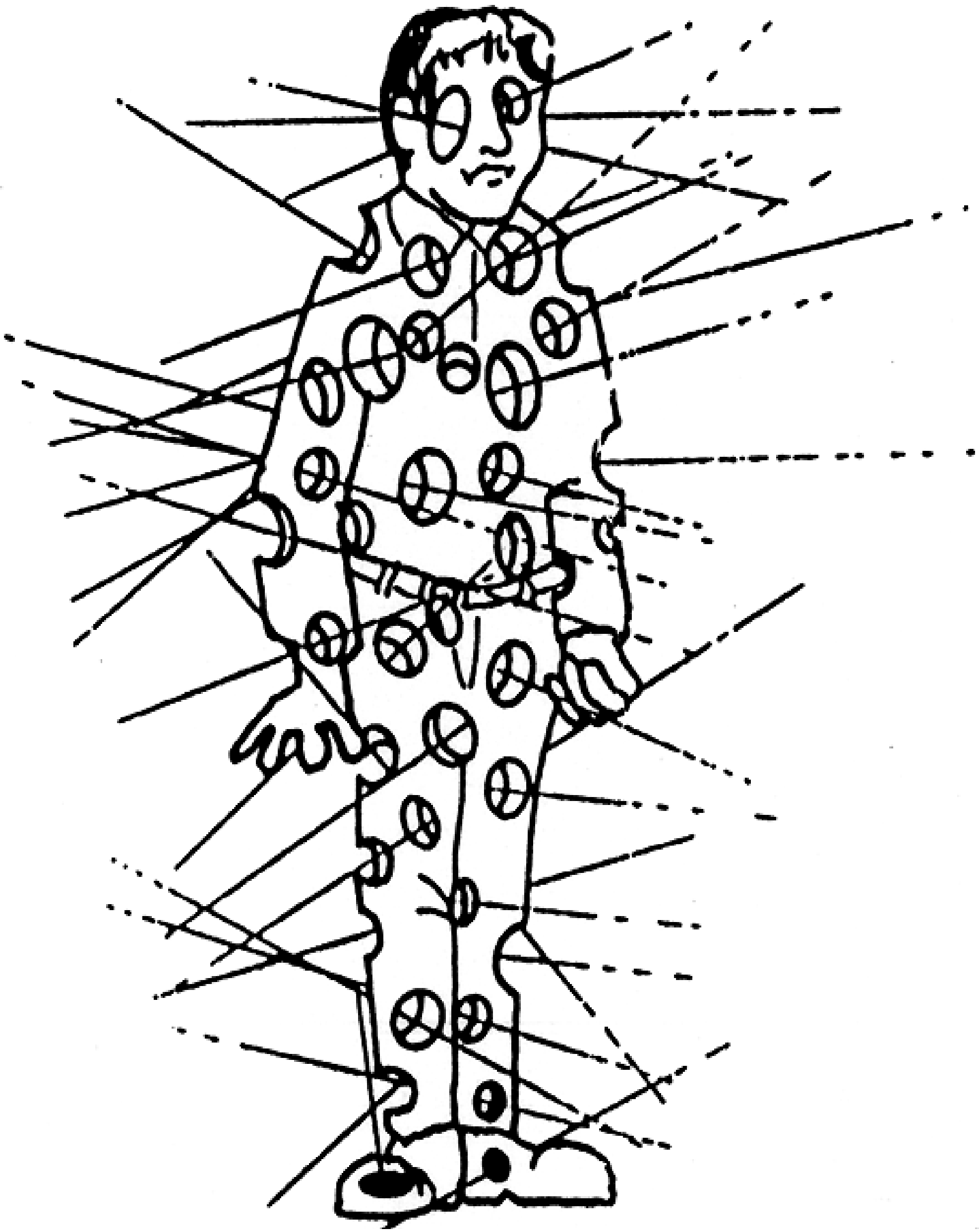
- ***East-West effect**:*

- *the cut-off rigidity depends on the arrival direction. Positive CRs are more abundant if they enter from West, negative if from East.*

East-West asymmetry (detected): cosmic rays are mainly positive!

- *inspired by the Norwegian mathematician* ***Carl Størmer****'s calculations explaining colleague* ***Kristian Birkland****'s theory of the* ***aurora***
- ***Birkland*** *experimented with electron beams and a phosphorous-painted globe of lodestone*

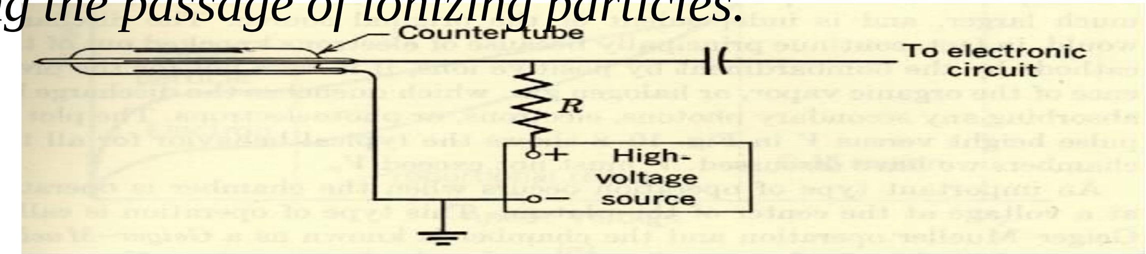




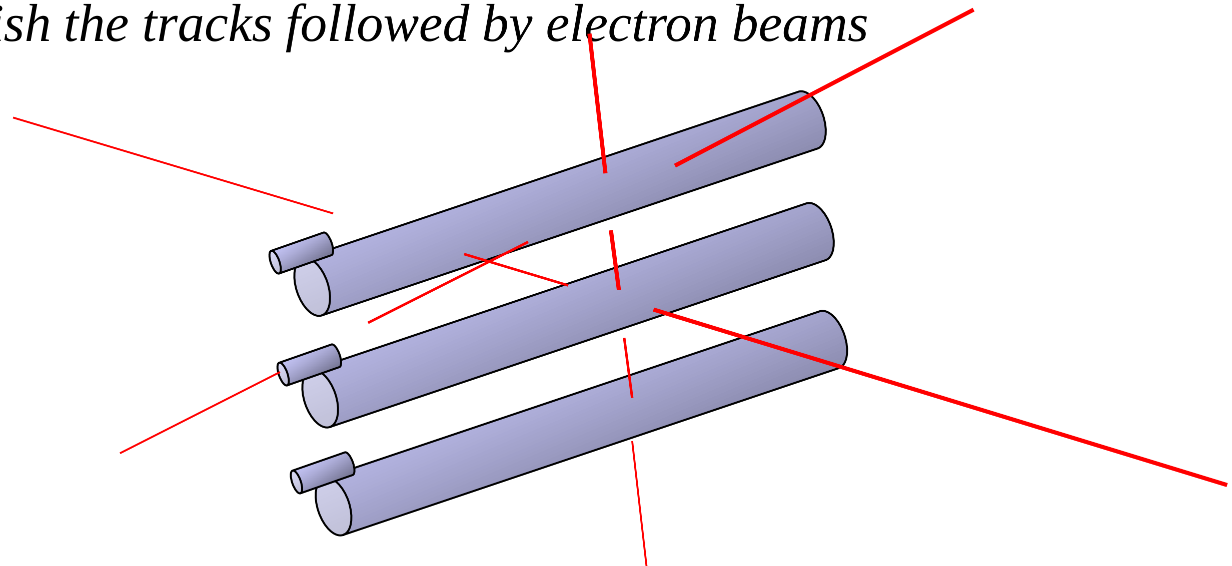
mmesons are plentiful at the Earth’s surface

~10^4 will hit you during this lecture.
To escape, go deep underground!

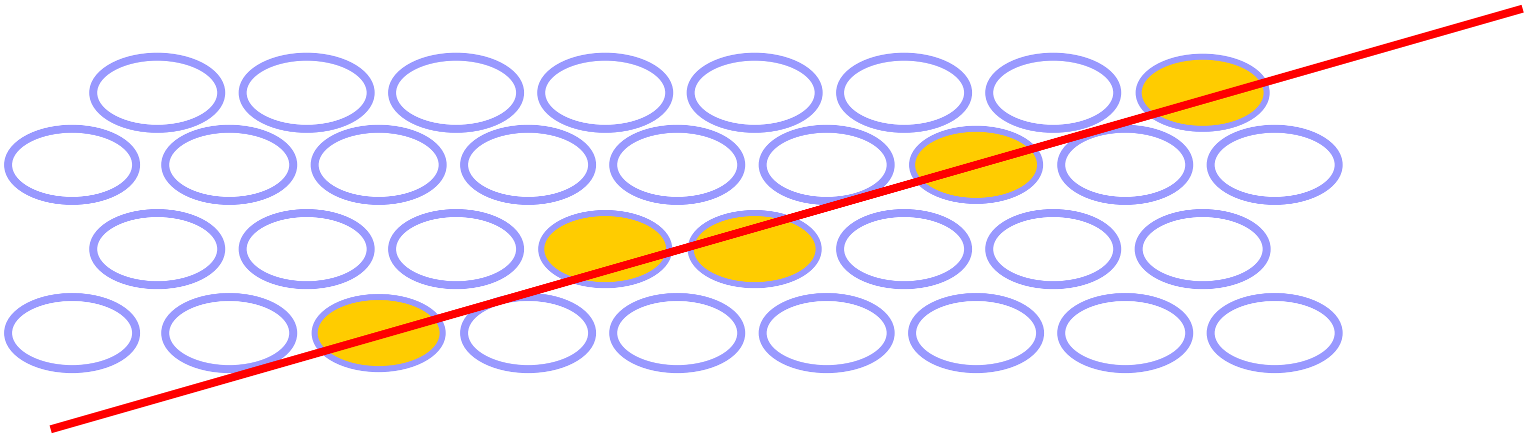
1911 Rutherford's assistant Hans Geiger develops a device registering the passage of ionizing particles.



1924 Walter Bothe and Geiger use multiple Geiger counters to establish the tracks followed by electron beams



1928-29 Bothe and Werner Kolhörster build Geiger telescopes and announce cosmic "rays" contain charged particles

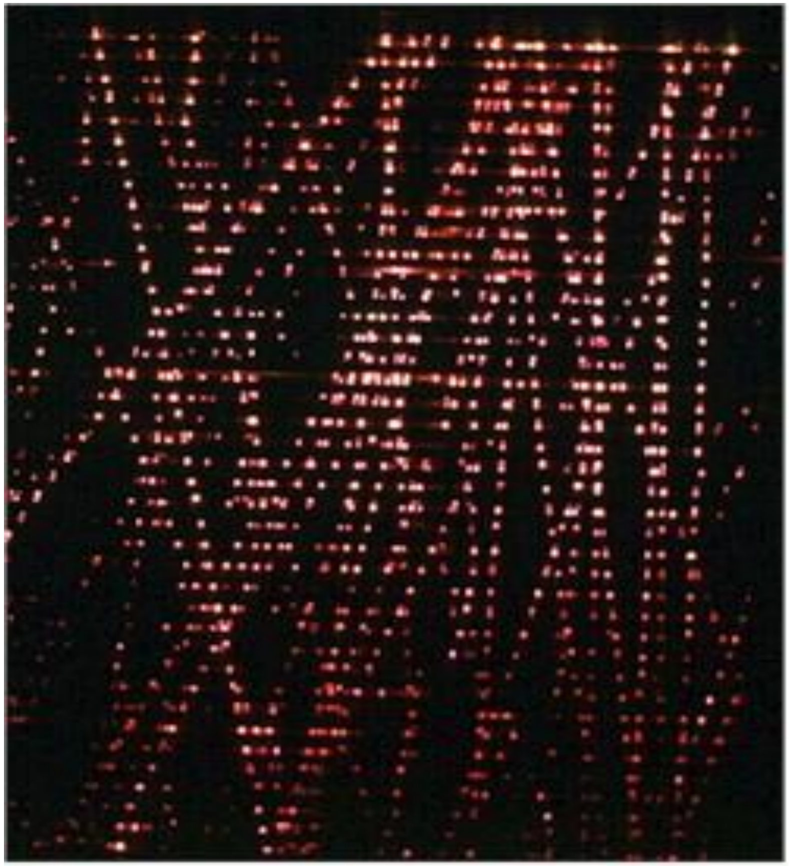


Although cosmic rays do come “from all directions”, at high altitudes near the equator the intensity is higher coming from the West than from the East!

1939 Johnson speculates primaries may be protons!

Wide spark chamber

In the 1960's spark chambers were common. When a charged particle ionizes gas between the plates, sparks fly along the track, marking the track of the particle.



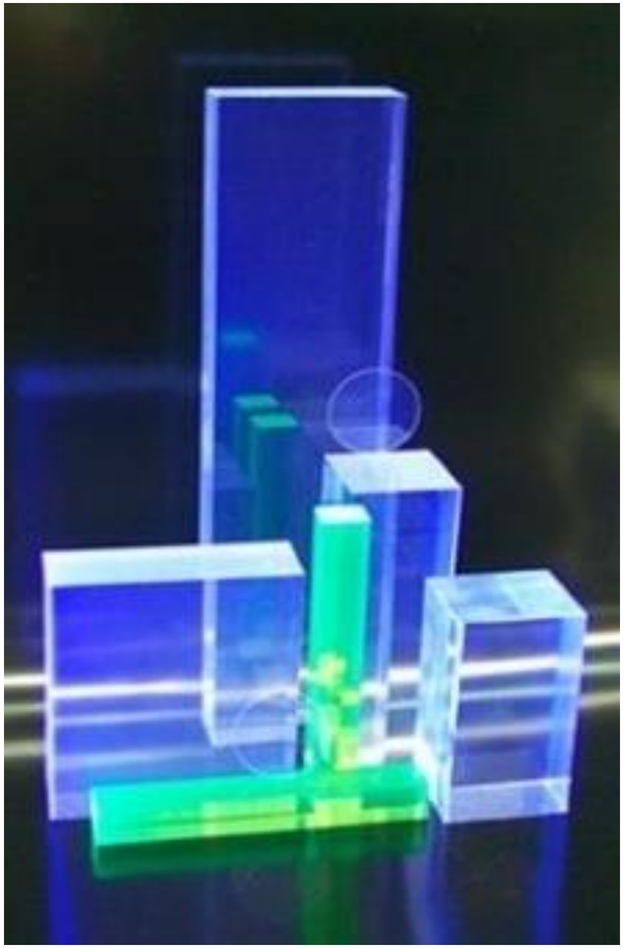
Particle detectors: our window to micro-world

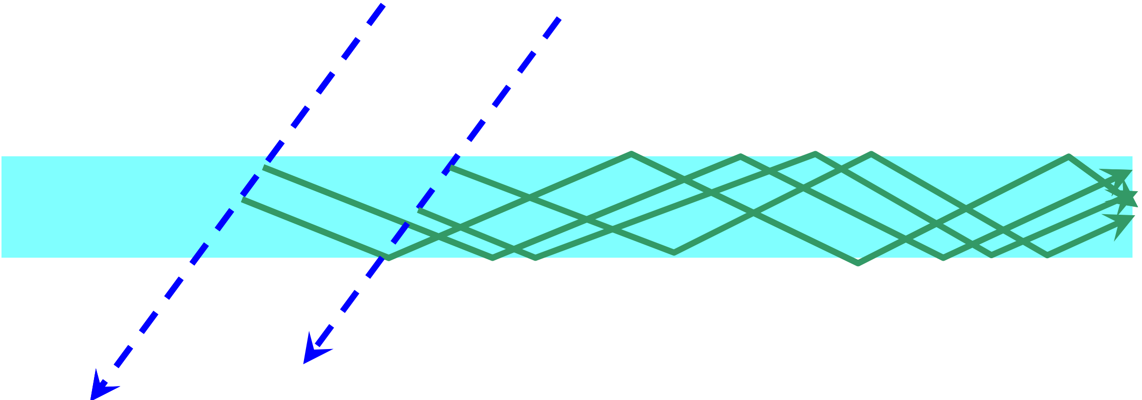
What are scintillators good for?

- Count particles
- Measure energy release
- measure time of particle passing
- measure location

How do they work?

- passing charge excite molecules in plastic
- as molecules de-excite, a small fraction release optical quanta
- this light propagates inside the plastic to the surface of the phototubes

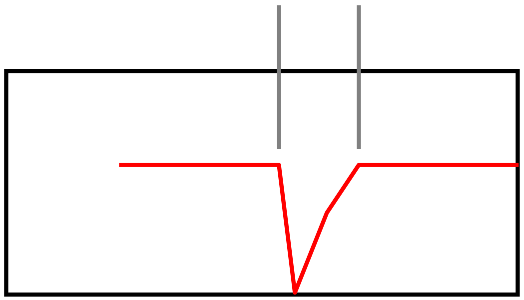


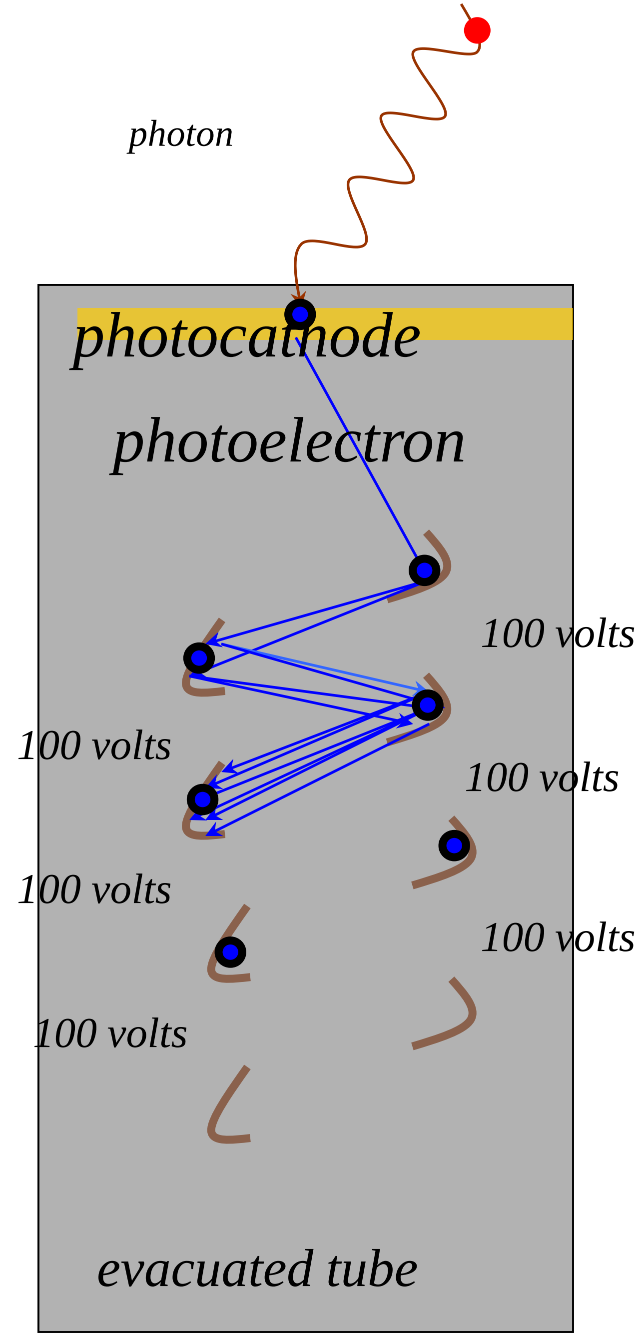


Phototubes: Electronic Retinas

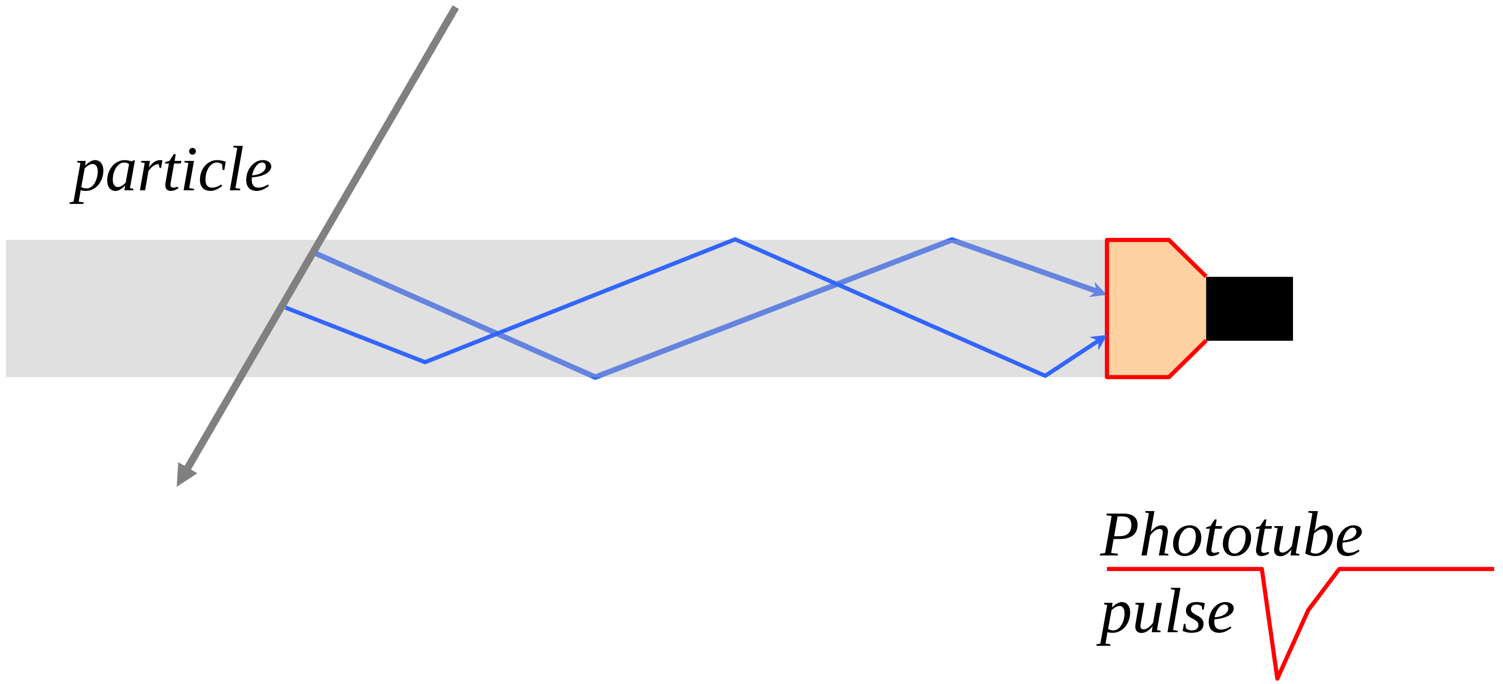
- See light pulse from scintillator
- Very sensitive
  - huge amplification
  - they can detect a single photon !
- Produce a signal quickly
  - important for **triggering**
  - precise timing

output pulse 20 ns





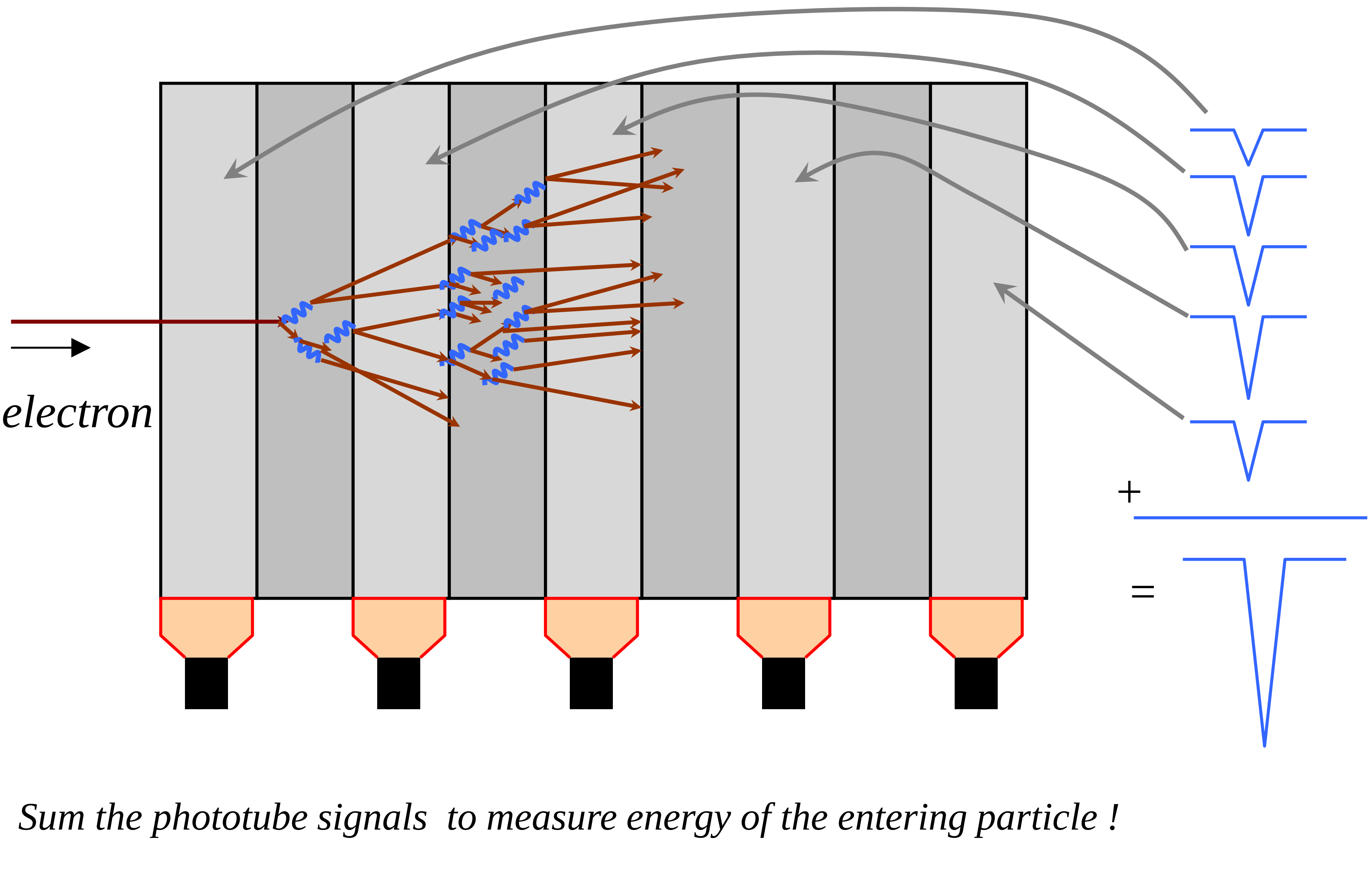
Put the phototube & scintillator together…



The pulse amplitude is proportional to the light intensity (number of photons)

The number of photons is proportional to the energy lost by the passing particle

Electromagnetic “Sampling” Calorimeter:
A layer cake of scintillator & lead



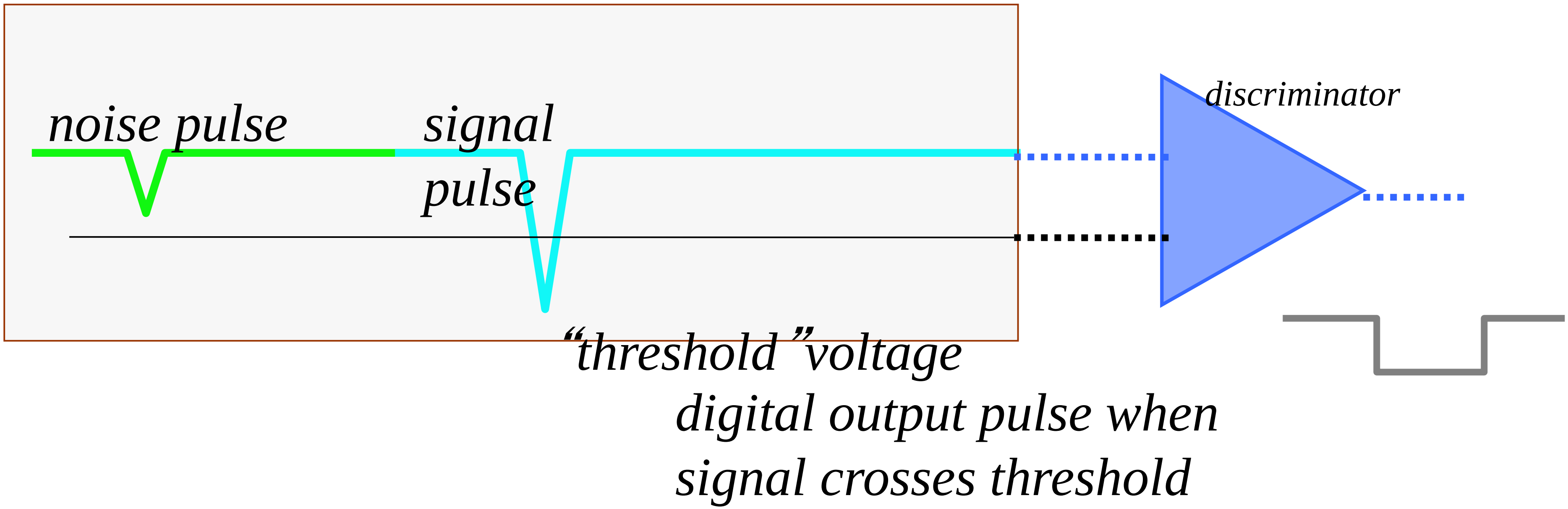
Sum the phototube signals to measure energy of the entering particle !

Separating signal from noise

Discriminators

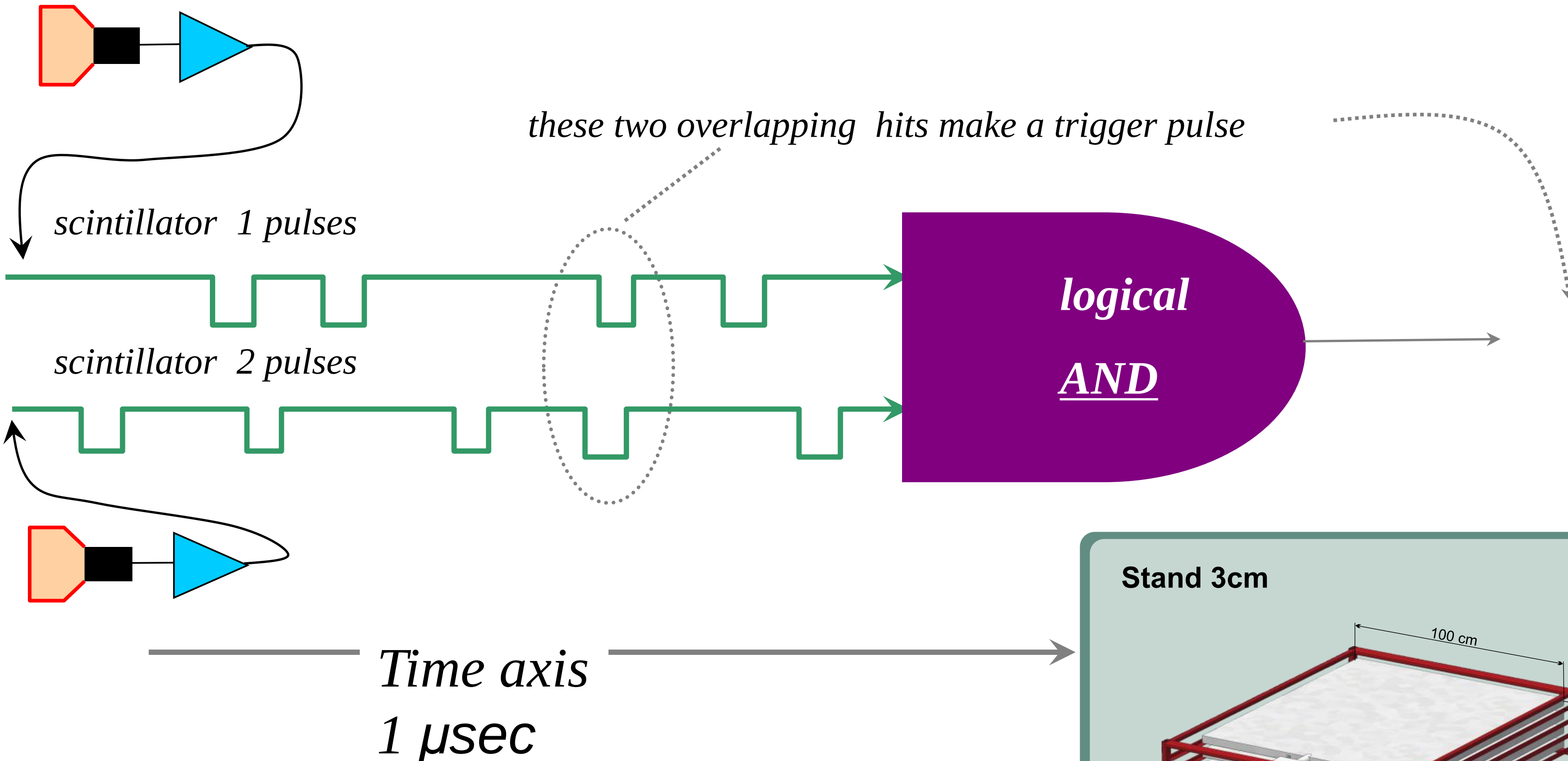
- not all pulses are made by a passing particle.
- there are also "noise" sources
- we use a discriminator to clean up the noise

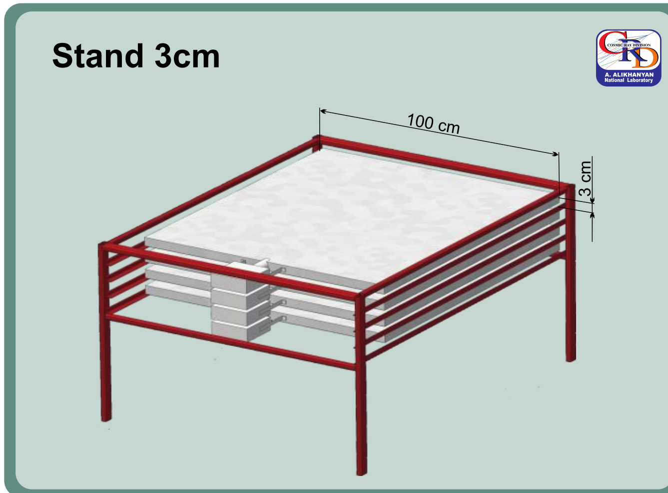
- If the pulse is larger than the discriminator threshold
  ➔ output is TRUE, otherwise FALSE



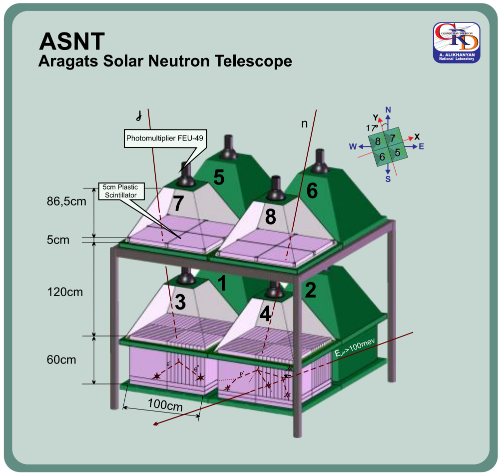
Coincidences techniques

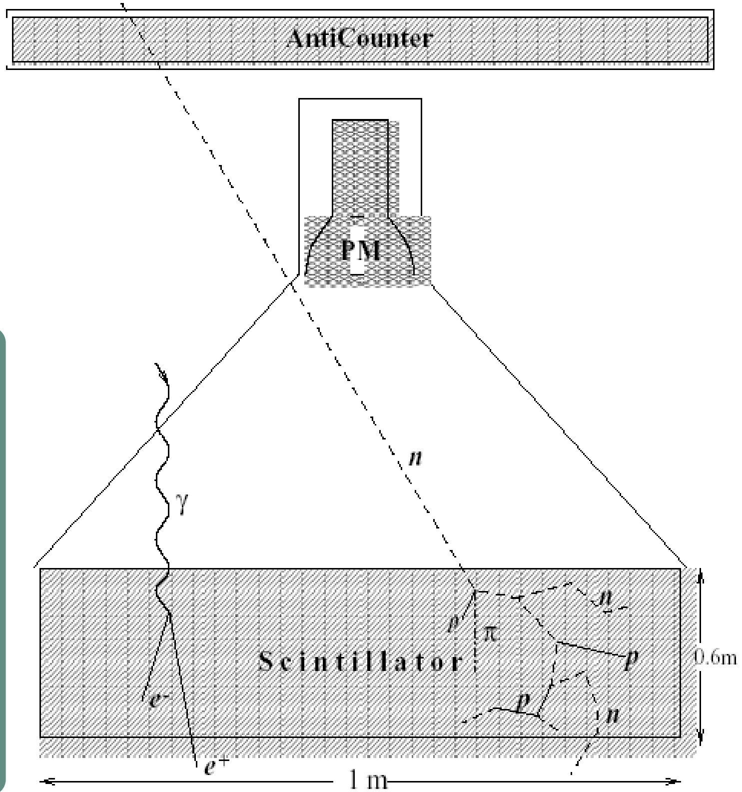
Phototube + discriminator

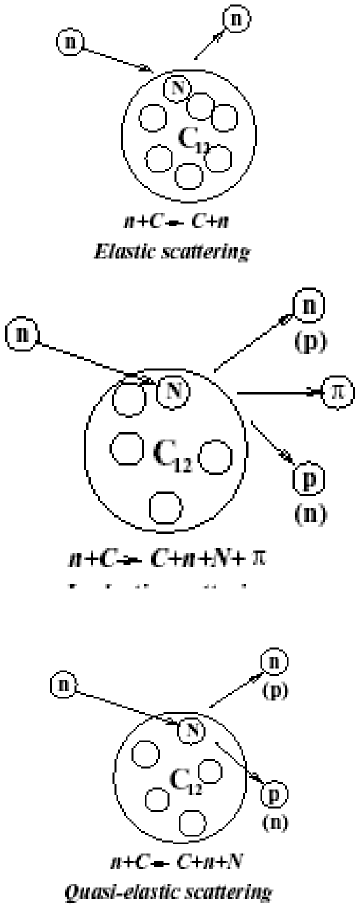




Aragats Solar Neutron Telescope ASNT

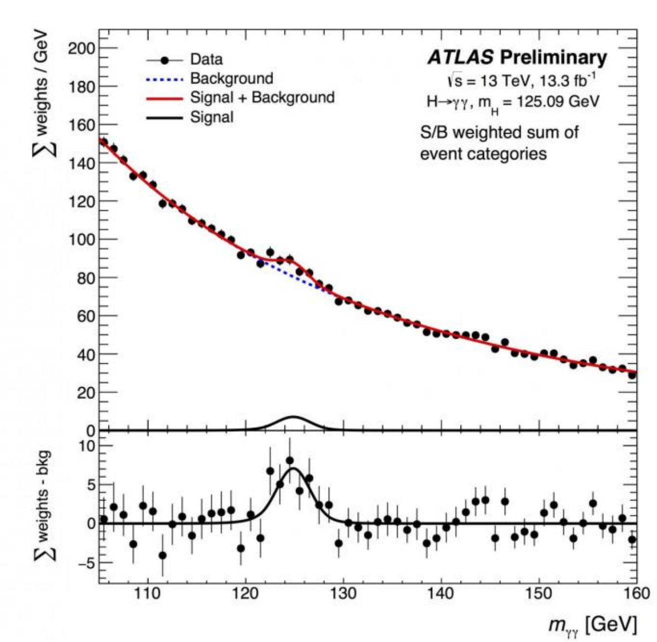


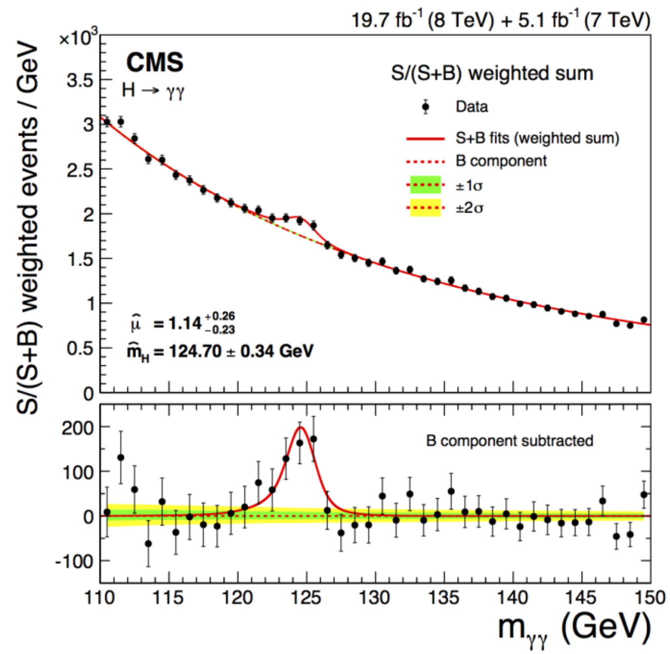




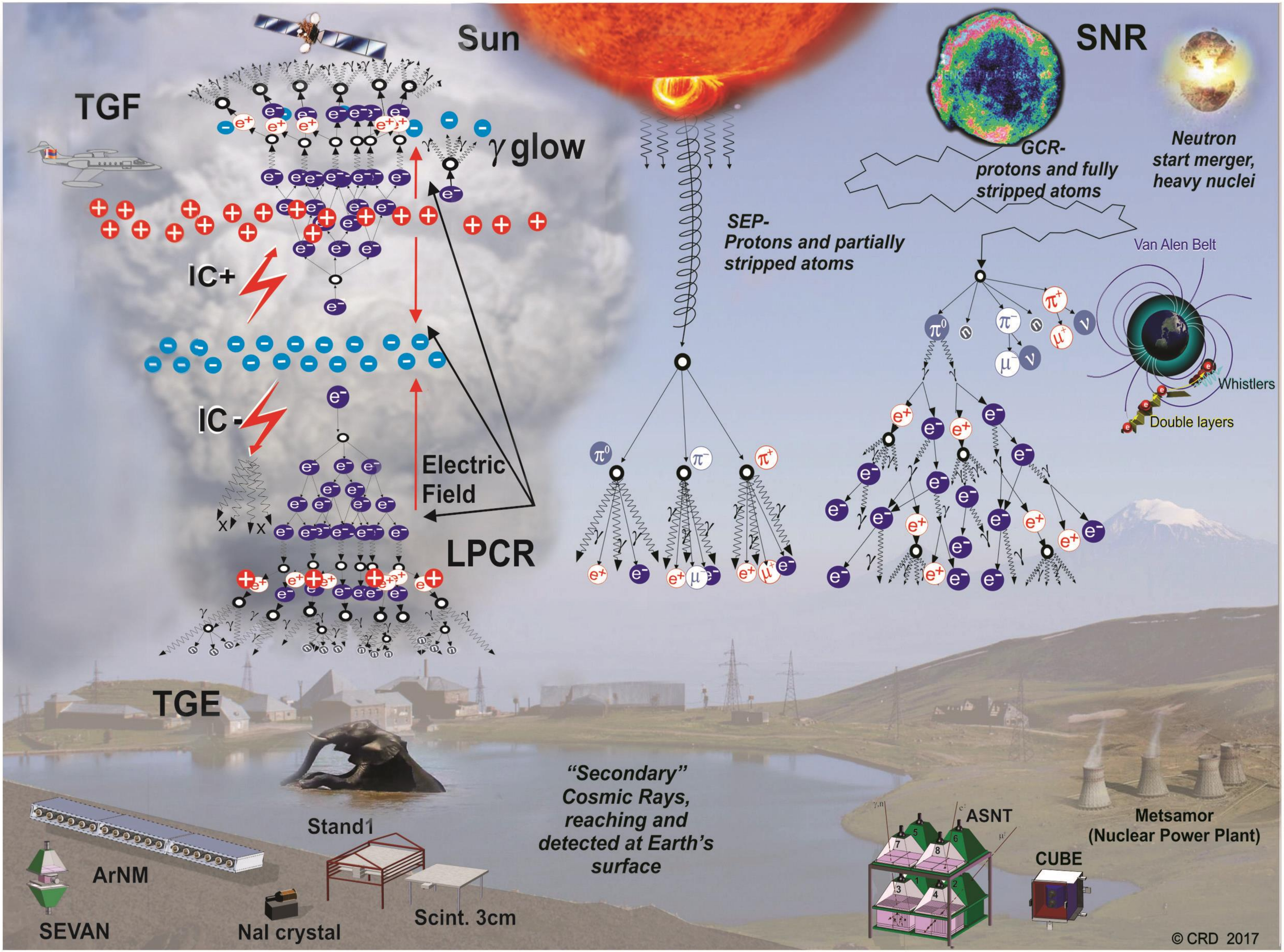
Samples space (10; 01; 11; 00)

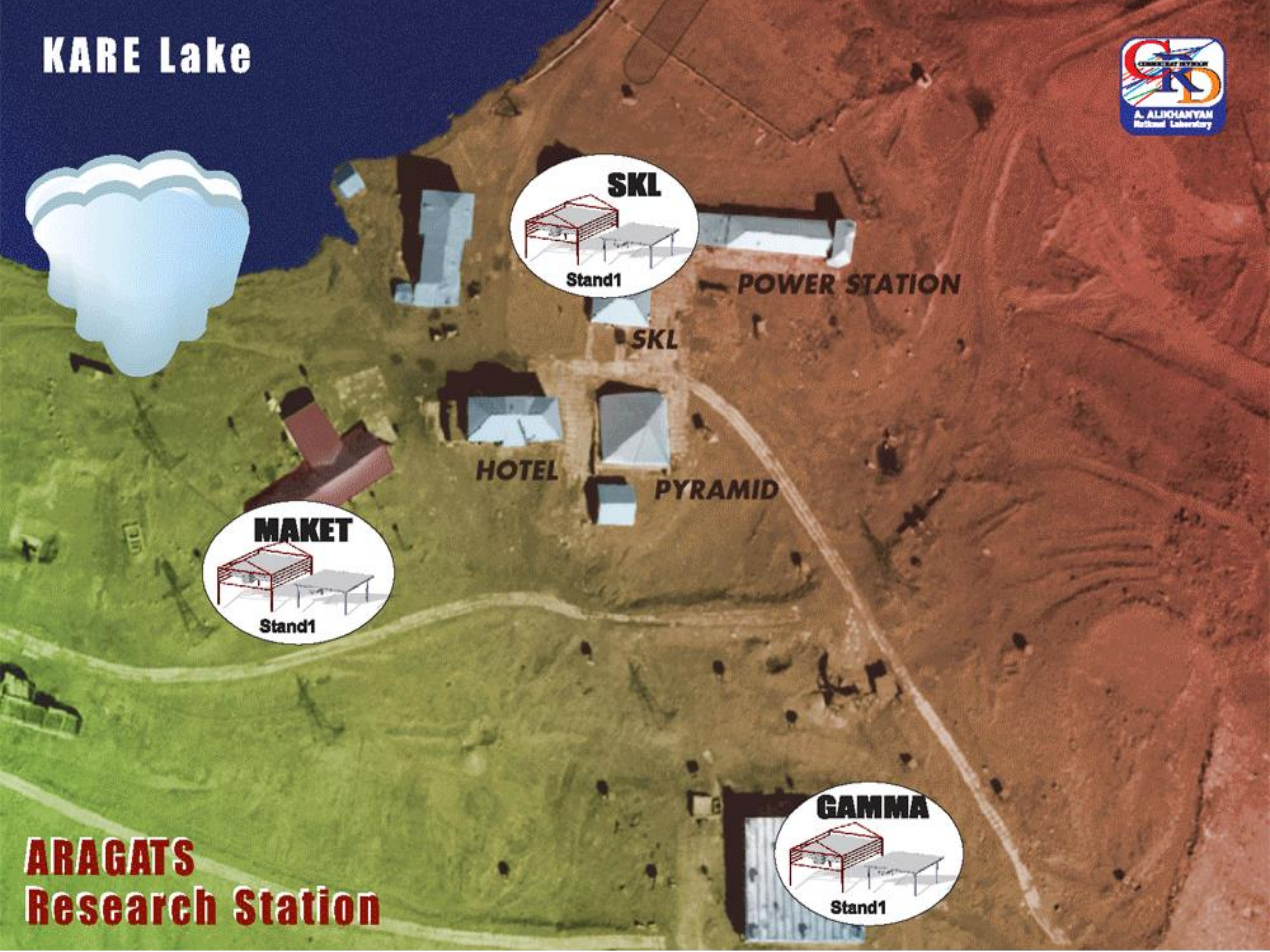
Higgs boson discovery at CERN LHC (ATLAS and CMS experiments)



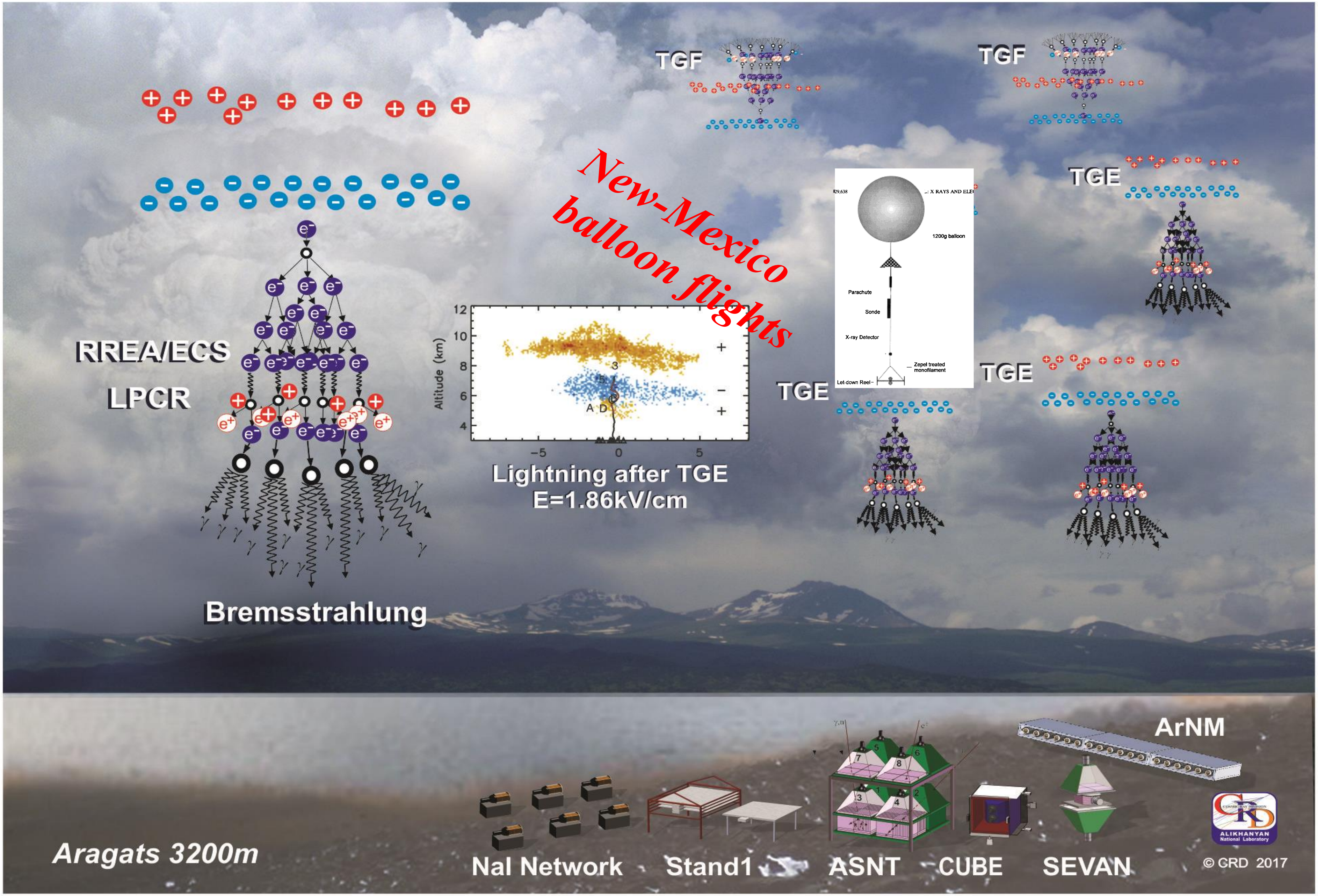


The distribution of the invariant mass of the two photons in the ATLAS measurement of H→γγ using the full 2015+2016 data set. An excess is observed for a mass of ~125 GeV


Sun
SNR
TGF
γ glow
GCR-
protons and fully
stripped atoms
Neutron
start merger,
heavy nuclei
SEP-
Protons and partially
stripped atoms
Van Alen Belt
IC+
IC -
Whistlers
Double layers
Electric
Field
LPCR
TGE
"Secondary"
Cosmic Rays,
reaching and
detected at Earth's
surface
Stand1
ASNT
Metsamor
(Nuclear Power Plant)
CUBE
ArNM
SEVAN
NaI crystal
Scint. 3cm
© CRD 2017


KARE Lake
SKL
Stand1
POWER STATION
SKL
HOTEL
PYRAMID
MAKET
Stand1
GAMMA
Stand1
ARAGATS
Research Station
A. ALIKHANYAN
National Laboratory

Only small fraction of RB/RREA become TGE, but many random emerging radiating regions in the cloud give raise to ionization and open path to the lightning leaders!



ARMENIAN GEOPHYSICAL NETWORK

COSMIC RAY DIVISION
A. ALIKHANYAN National Laboratory

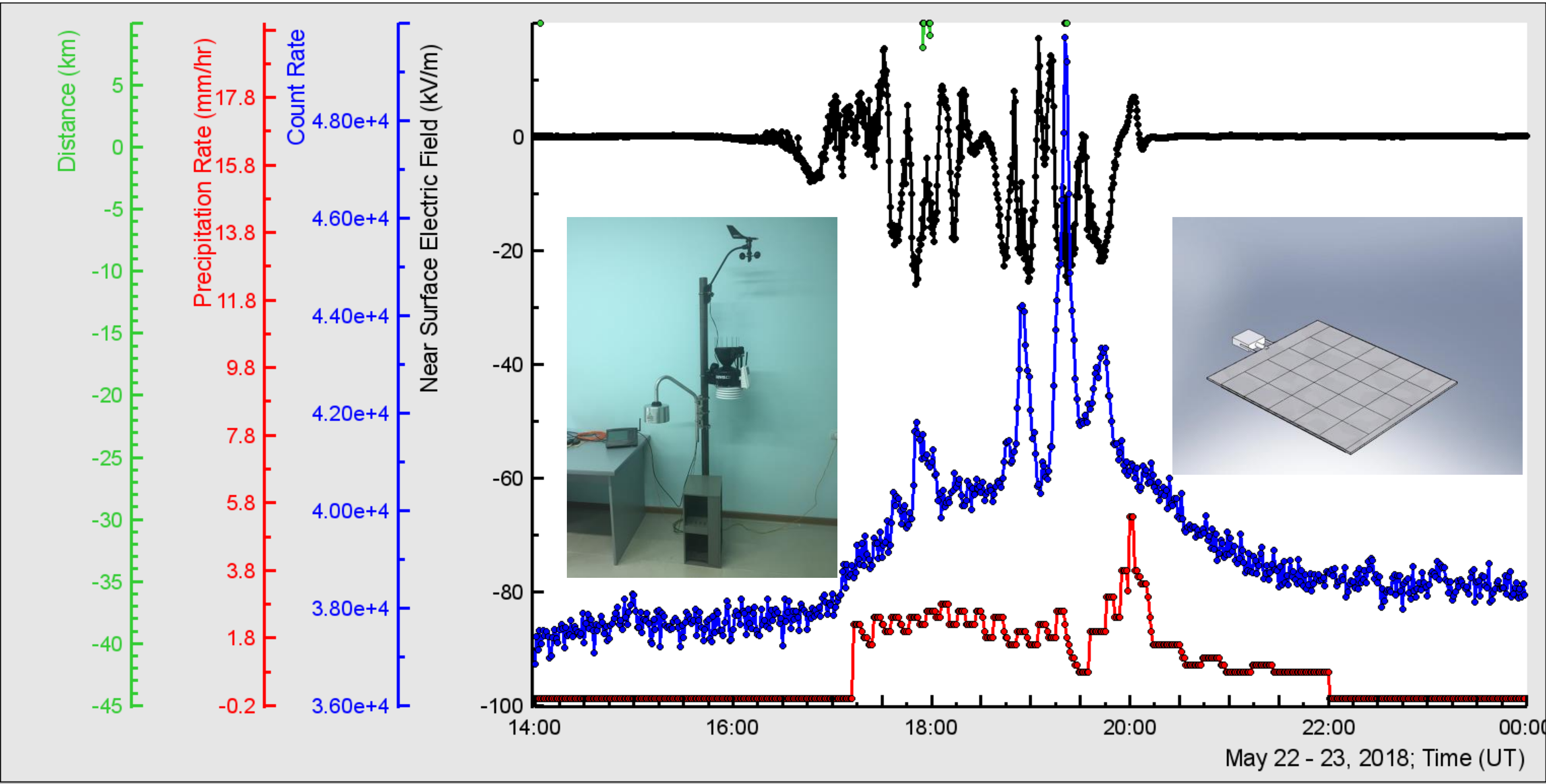
A. ALIKHANYAN National Laboratory

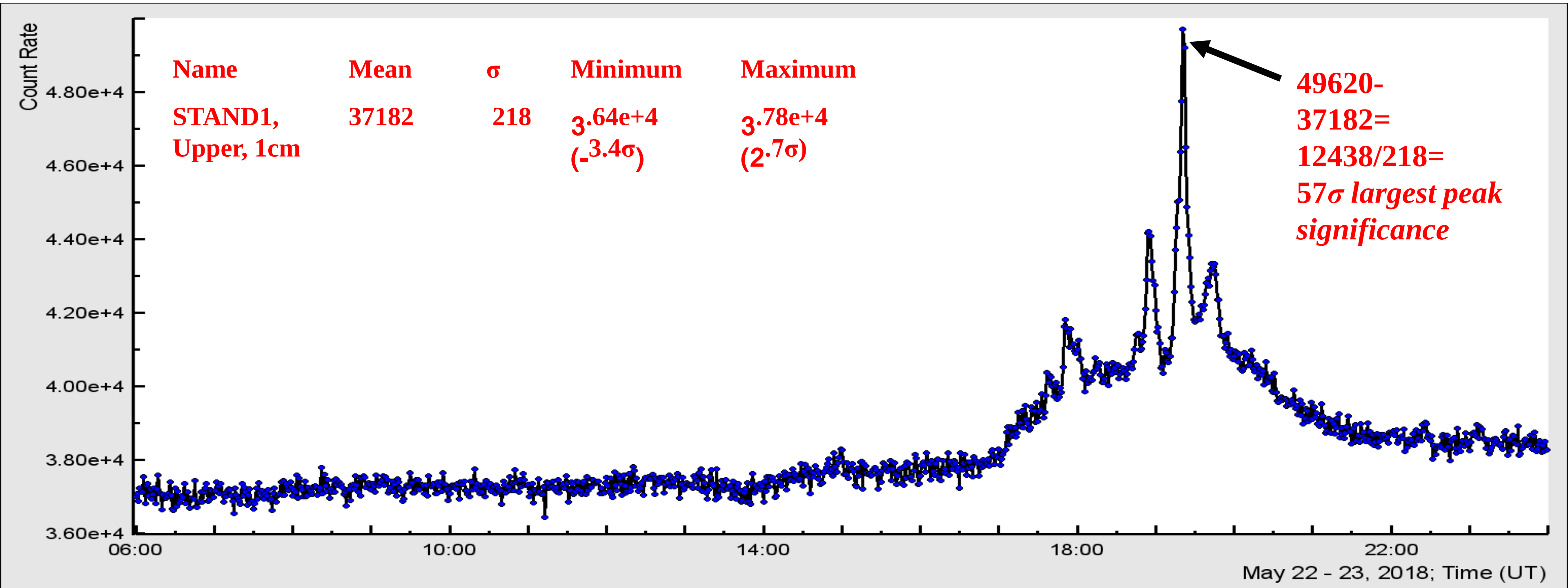
Space Environmental Viewing and Analysis Network (SEVAN)

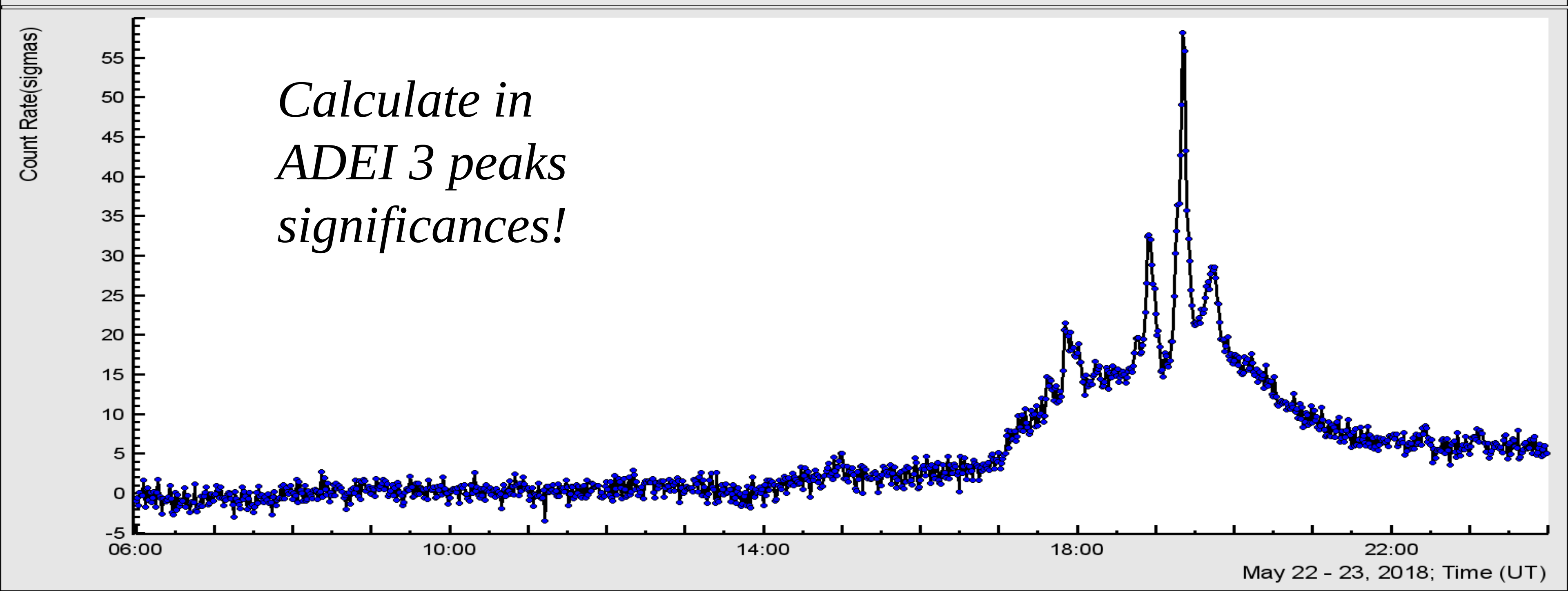
A network of middle to low latitude particle detectors called SEVAN (Space Environmental Viewing and Analysis Network) is planned in the framework of the International Heliophysical Year (IHY), to improve fundamental research of the Solar accelerators and Space Weather conditions. The program of TGE detection with SEVAN network started in 2016.

COSMIC RAY DIVISION
Alikhanyan Physics Institute,
Alikhanyan Brothers 2,
Yerevan 375036, Armenia

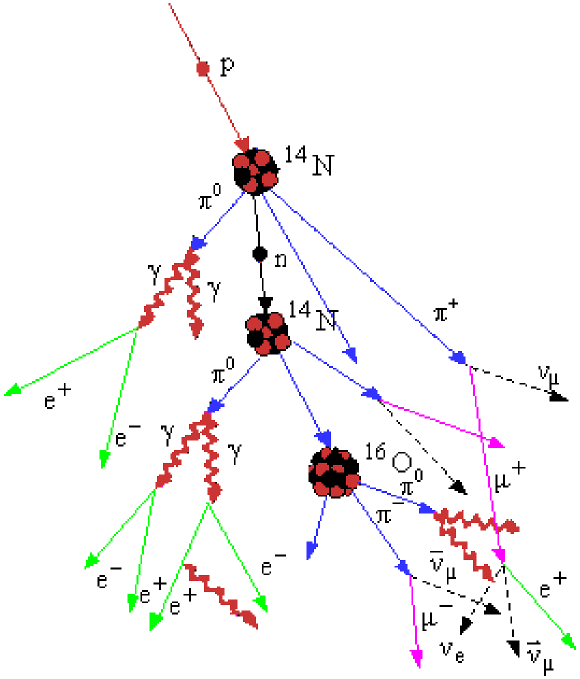
Measurements on Aragats: Particle fluxes; electric field, rain rate




Count Rate
4.80e+4
4.60e+4
4.40e+4
4.20e+4
4.00e+4
3.80e+4
3.60e+4
06:00
10:00
14:00
18:00
22:00
May 22 - 23, 2018; Time (UT)
Name
Mean
σ
Minimum
Maximum
STAND1, Upper, 1cm
37182
218
3.64e+4 (-3.4σ)
3.78e+4 (2.7σ)
49620-37182=12438/218=
57σ largest peak significance


Count Rate(sigmas)
55
50
45
40
35
30
25
20
15
10
5
0
-5
06:00
10:00
14:00
18:00
22:00
May 22 - 23, 2018; Time (UT)
Calculate in ADEI 3 peaks significances!

Counting particles



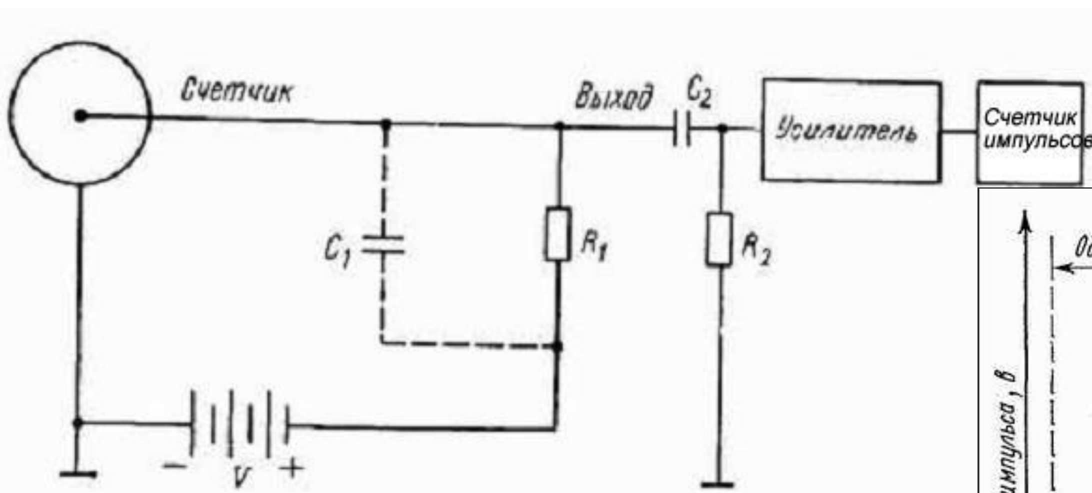
Распределение Пуассона

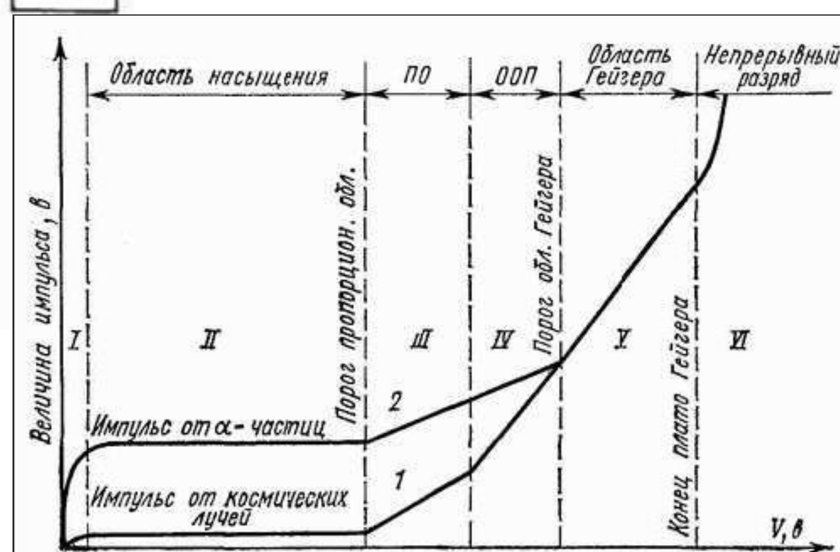
$$P_{\mu}(n) = \frac{\mu^n}{n!} e^{-\mu}$$

характеризуется всего одним параметром μ, представляющим собой среднее число отсчетов, которое мы ожидаем получить в случае многократного повторения измерений.

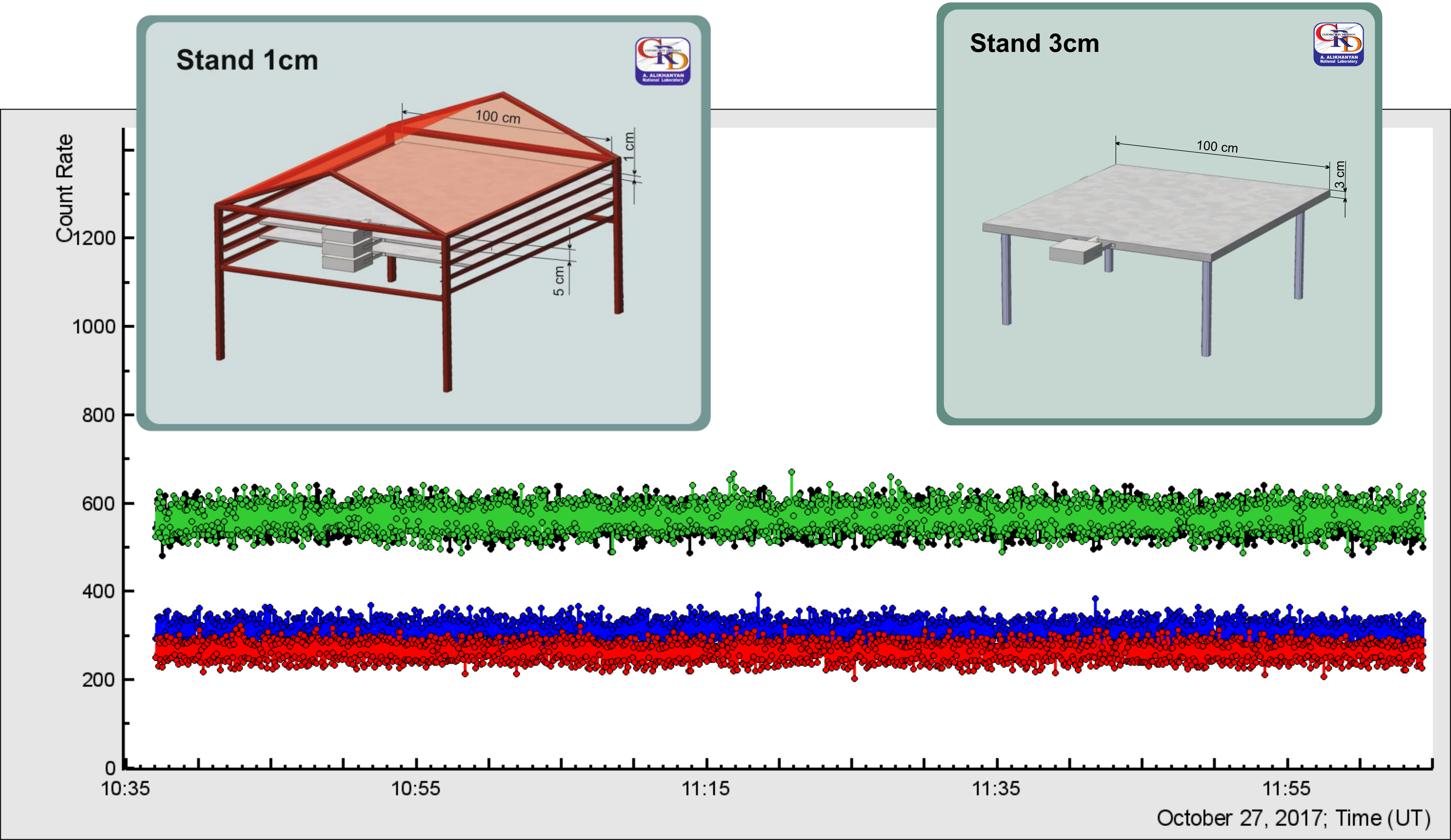
$$\mu = \overline{n} = \frac{\sum_{i=1}^{N} n_i}{N}$$

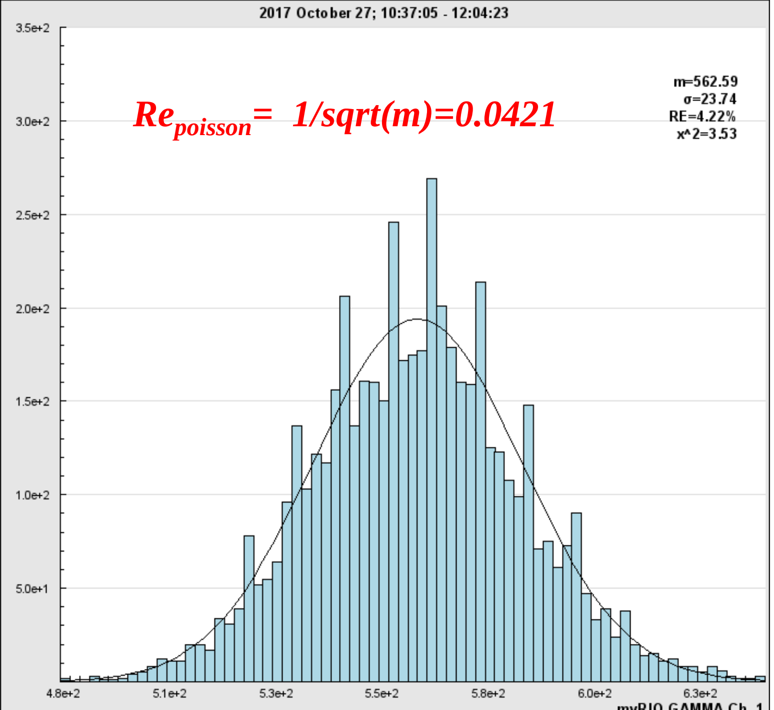
Дисперсия в случае распределения Пуассона равна среднему числу частиц $D = \overline{n}$, стандартное отклонение $\sigma = \sqrt{\overline{n}} = \sqrt{\mu}$.



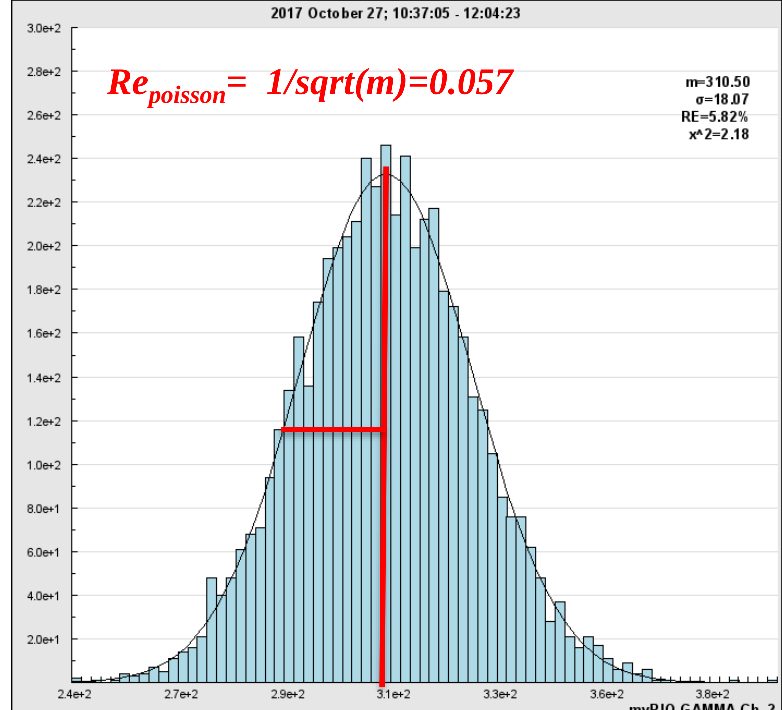


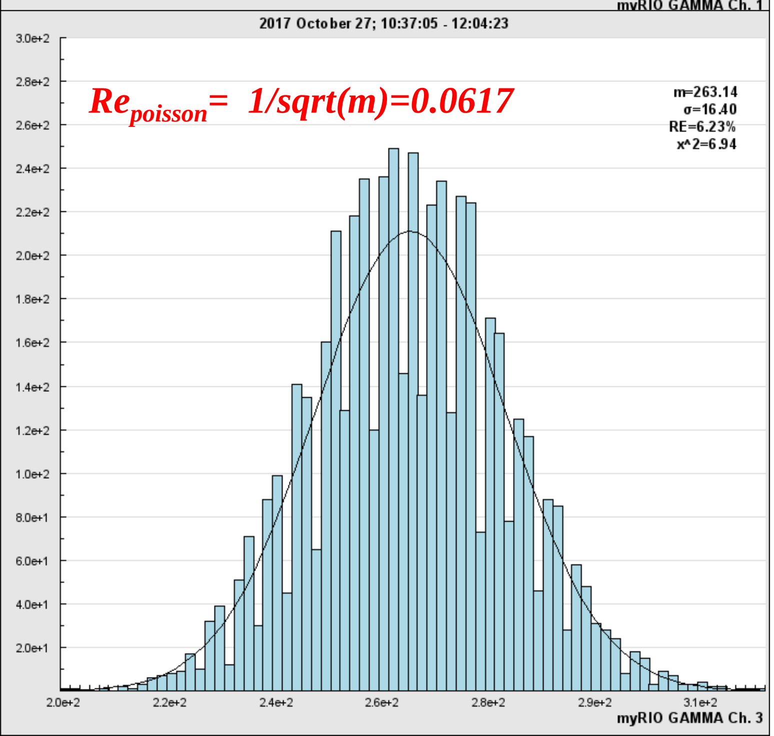
STAND1 (GAMMA) – what is the best count rate?

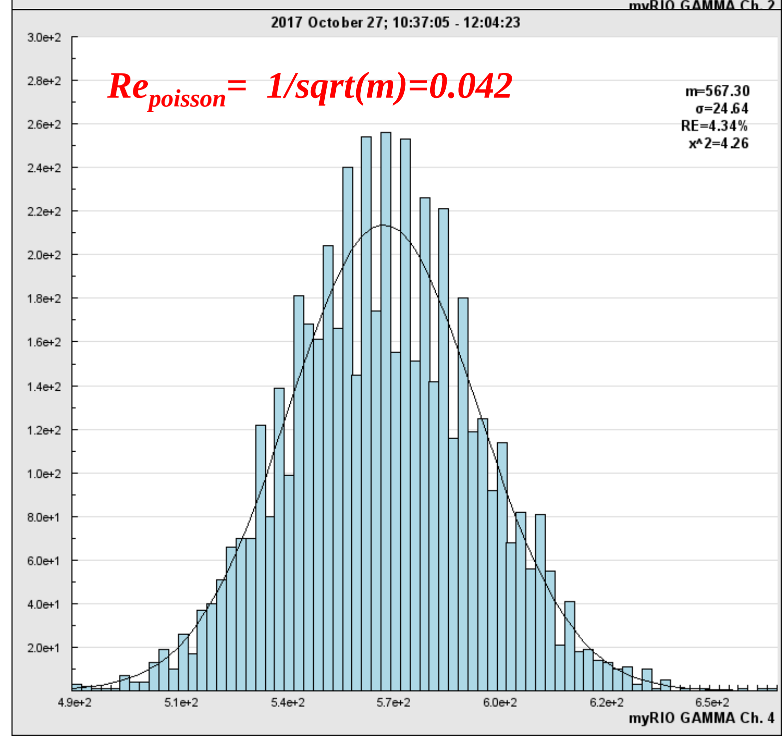



2017 October 27; 10:37:05 - 12:04:23
$Re_{poisson}$= 1/sqrt(m)=0.0421
m=562.59
σ=23.74
RE=4.22%
x^2=3.53
myRIO GAMMA Ch. 1

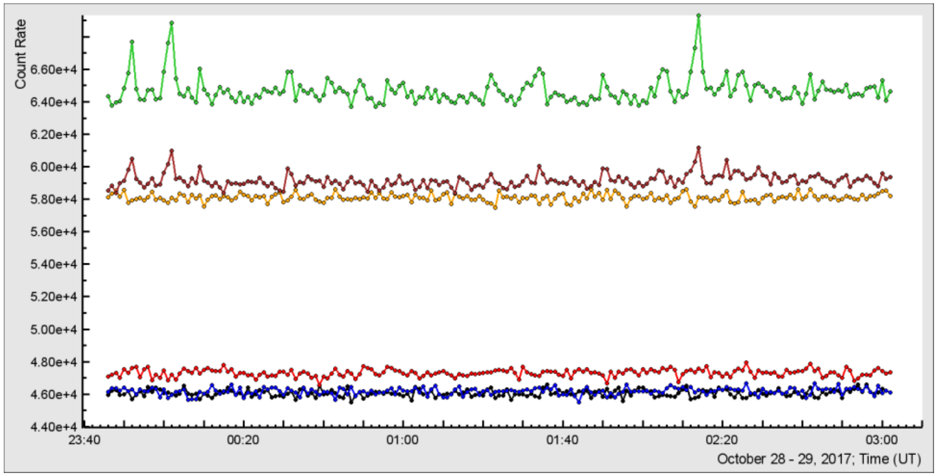
M=5238


2017 October 27; 10:37:05 - 12:04:23
$Re_{poisson}$= 1/sqrt(m)=0.057
m=310.50
σ=18.07
RE=5.82%
x^2=2.18
myRIO GAMMA Ch. 2

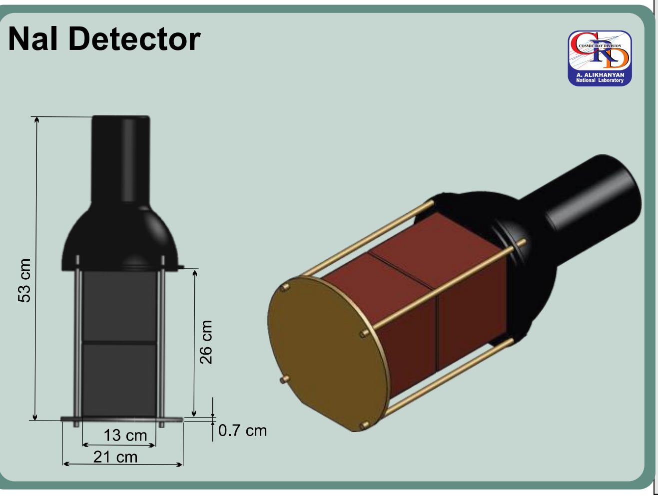

2017 October 27; 10:37:05 - 12:04:23
$Re_{poisson}$= 1/sqrt(m)=0.0617
m=263.14
σ=16.40
RE=6.23%
x^2=6.94
myRIO GAMMA Ch. 3

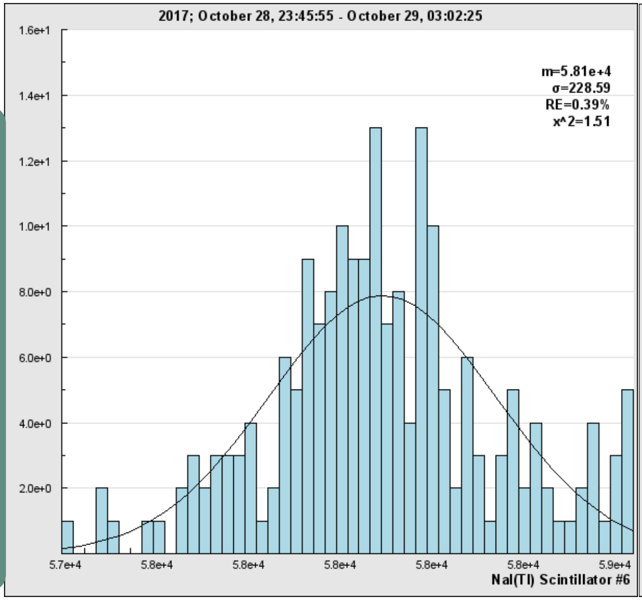

2017 October 27; 10:37:05 - 12:04:23
$Re_{poisson}$= 1/sqrt(m)=0.042
m=567.30
σ=24.64
RE=4.34%
x^2=4.26
myRIO GAMMA Ch. 4

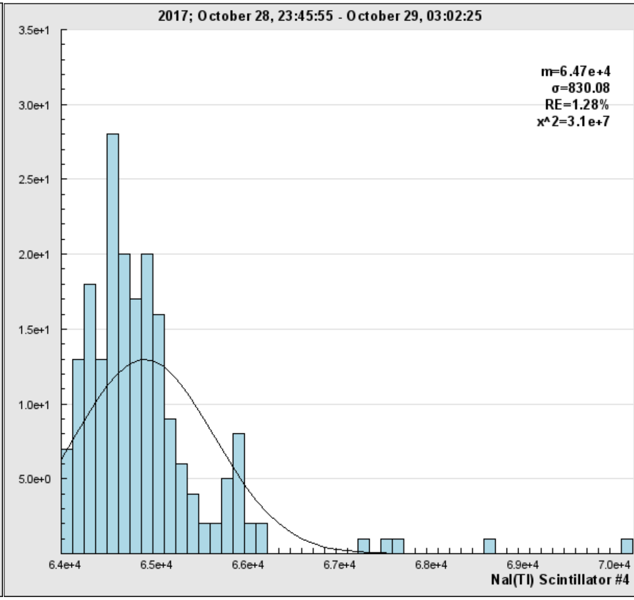
Simple method to select "GOOD" AND "BAD" DETECTORS by comparing calculated and Poisson relative errors (should coincide!)



Name	Mean	σ	Min	Max	RE%	1/SQRT(N)%
NaI(Tl) #1	46061	215	4.55e+4 (-2.56σ)	4.66e+4 (2.48σ)	0.47	0.47 GOOD
NaI(Tl) #2	46174	211	4.55e+4 (-3.28σ)	4.67e+4 (2.36σ)	0.46	0.46 GOOD
NaI(Tl) #3	47310	224	4.66e+4 (-3.33σ)	4.80e+4 (2.88σ)	0.47	0.46 GOOD
NaI(Tl) #4	**64690**	**830**	**6.37e+4 (-1.2σ)**	**7.05e+4 (7.06σ)**	**1.28**	**0.39 Vau!!!**
NaI(Tl) #6	**58106**	**229**	**5.75e+4 (-2.81σ)**	**5.86e+4 (2.2σ)**	**0.40**	**0.41 BEST!!!**
NaI(Tl) #7	59154	415	5.84e+4 (-1.83σ)	6.12e+4 (4.87σ	0.7	0.41 BAD







Questions for Summer school students

- Calculate RE and theoretical RE for Aragats detectors: STAND1 (MAKET, GAMMA and SKL) NAI, ASNT and others;
- Calculate barometric coefficients
- Calculated significances of TGE peaks


Video: Aragats Lightnings
Aragats CAMERA 1
2014-08-03
20:13:15-04
00:09 / 17:29


Video: Aragats Lightnings
Aragats CAMERA 1
2014-08-03
20:22:56-00
00:40 / 17:29


Aragats CAMERA 1
2014-08-03
20:28:31-03
01:11 / 17:29

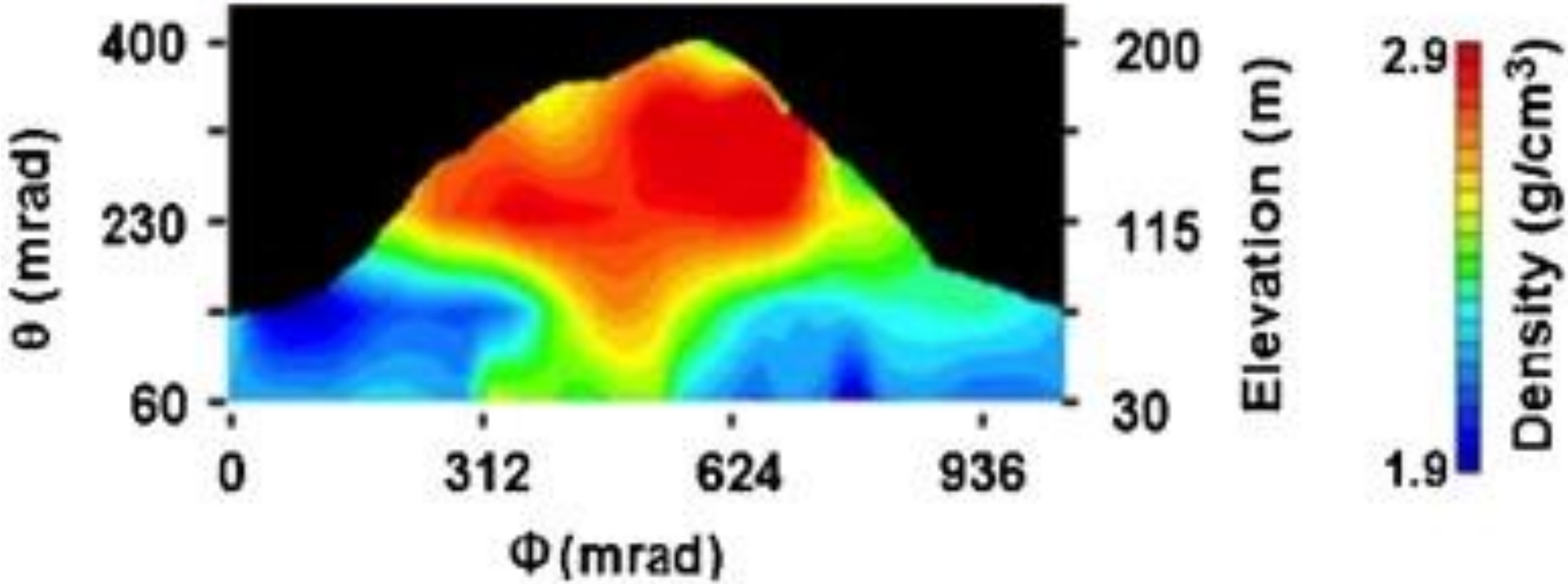

Aragats CAMERA 1
2014-08-03
20:31:31-01
01:35 / 17:29

Volcanoes, lightning flashes and Cosmic Rays

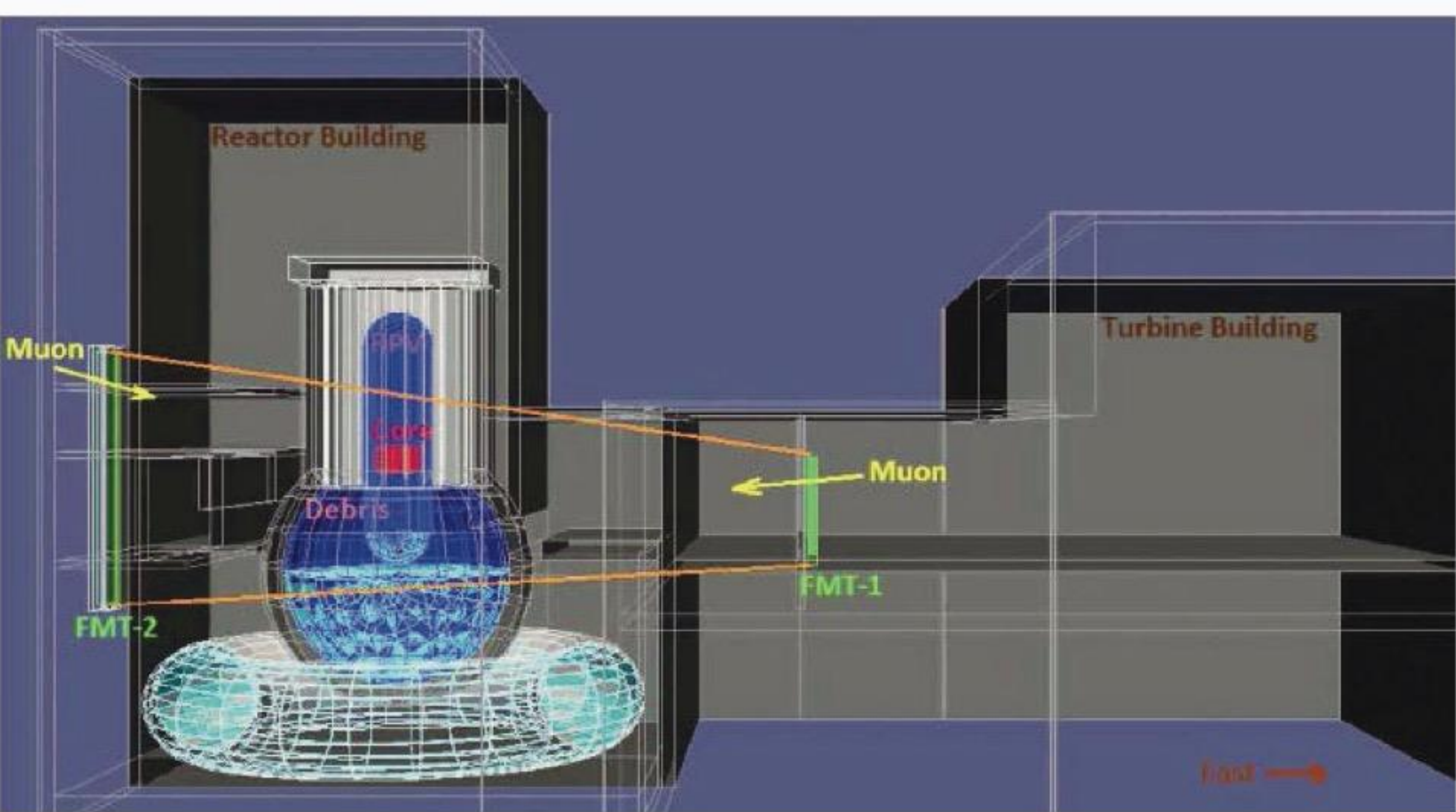
Muography principle is the same as for radiography: the measurement of the absorption of a radiation through a target will give access to its transmittance image and its integrated density. The muon on the Soufrière Hills volcano in Montserrat, an island near Guadeloupe.

https://news.cnrs.fr/articles/pr obing-volcanoes-with-cosmic-

View of the Showa-Shinzan lava dome. Bottom: average density distribution

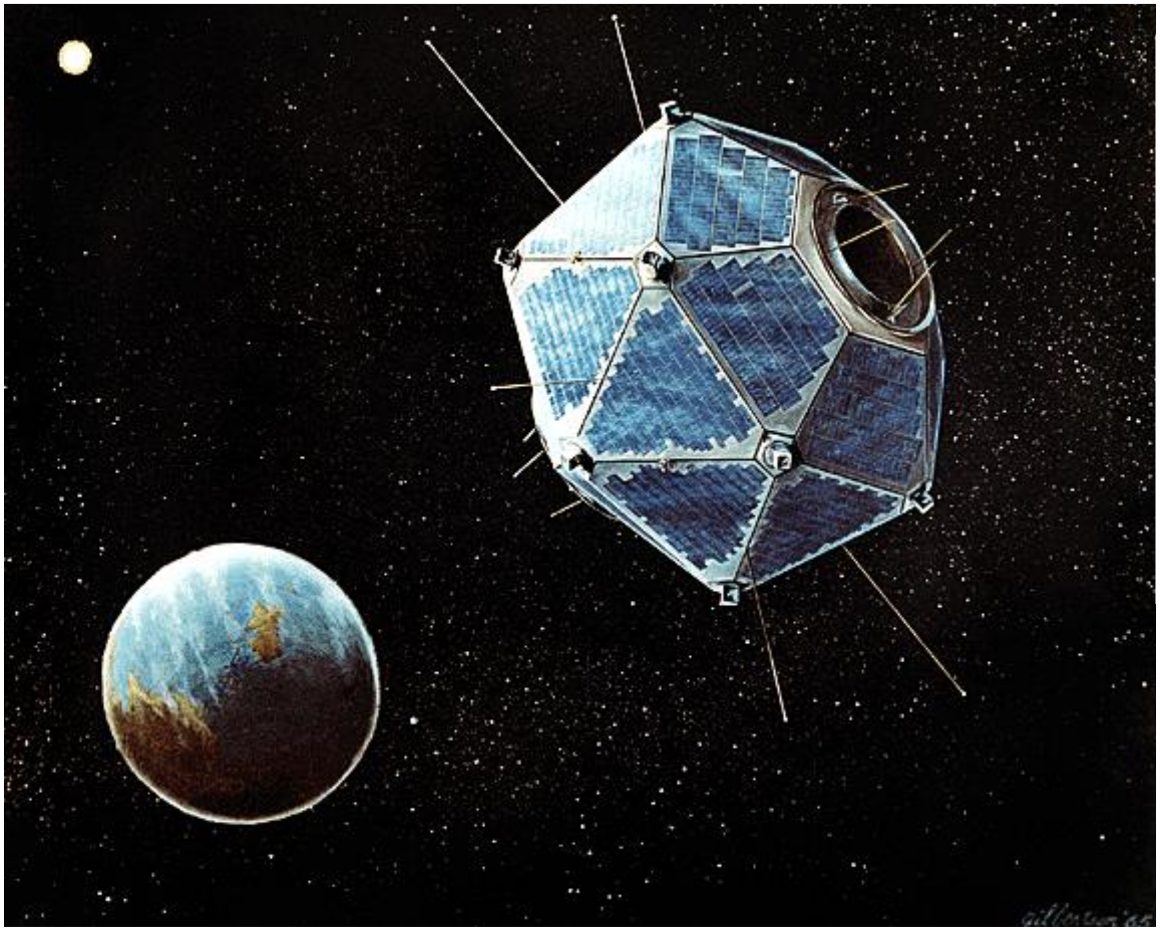


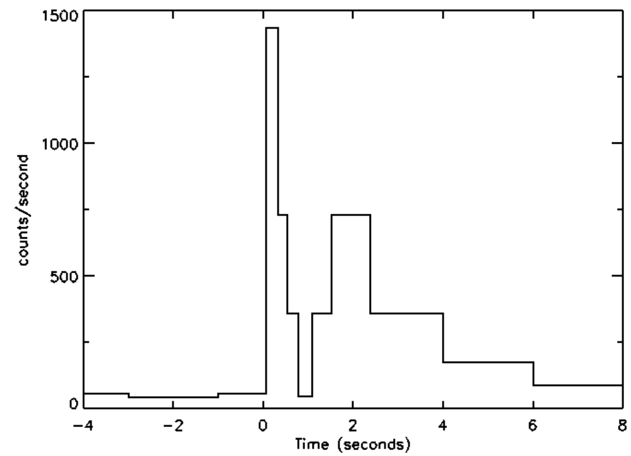
Muon muon scattering radiography for Fukushima is installed inside a concrete radiation shield in front of the reactor building. Typical muon scattering angles are a few degrees (also used to scan trailers and shipping containers for special nuclear material)



Nuclear Test Ban Treaty: On August 5, 1963, after more than eight years of difficult negotiations, the United States, the United Kingdom, and the Soviet Union signed the Limited Nuclear Test Ban Treaty.

Vela satellites designed to detect flashes of gamma-rays from nuclear bomb blasts, began to record bursts of gamma-rays -- not from the vicinity of the Earth, but from deep space!



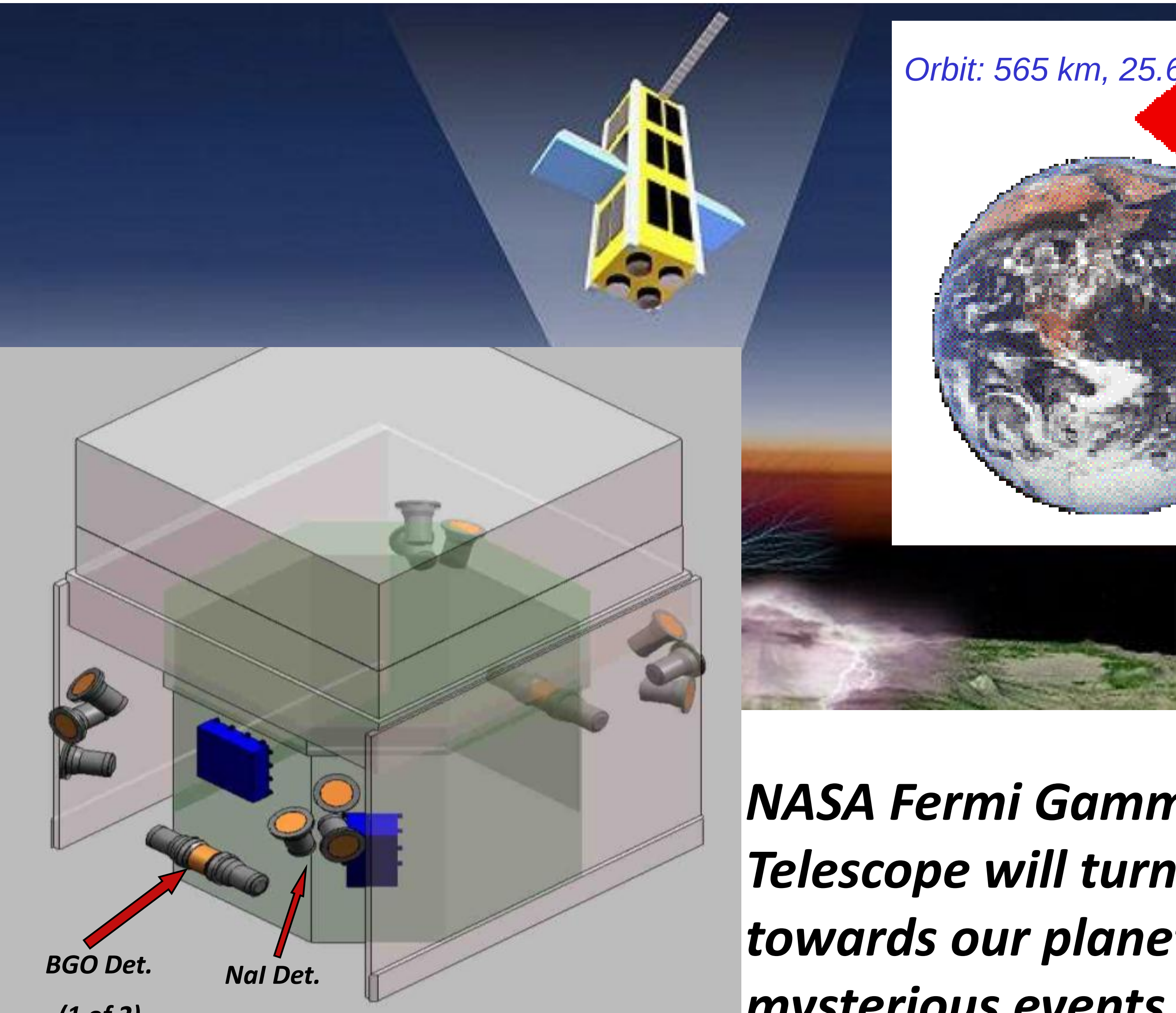


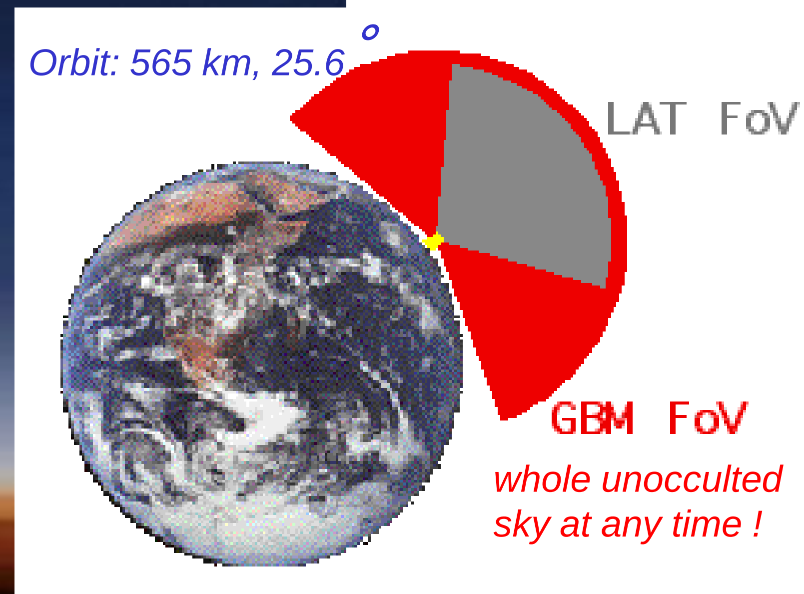
In 1973 discovery was announced in Ap.J. letters by Klebesadel, Strong, and Olsen. Their paper discusses 16 cosmic gamma-ray bursts observed by Vela 5a,b and Vela 6a,b between July 1969, and July 1972.

Although most of the energy of a bomb blast in space would be directly visible as an x-ray flash, a simultaneous indication by the gamma-ray detectors would provide a confirming signature of a nuclear event. A further confirmation would come from the detection of neutrons.

Direction angles for a single event observed by pairs of satellites could then be combined to determine one or two possible directions for the source of the event.

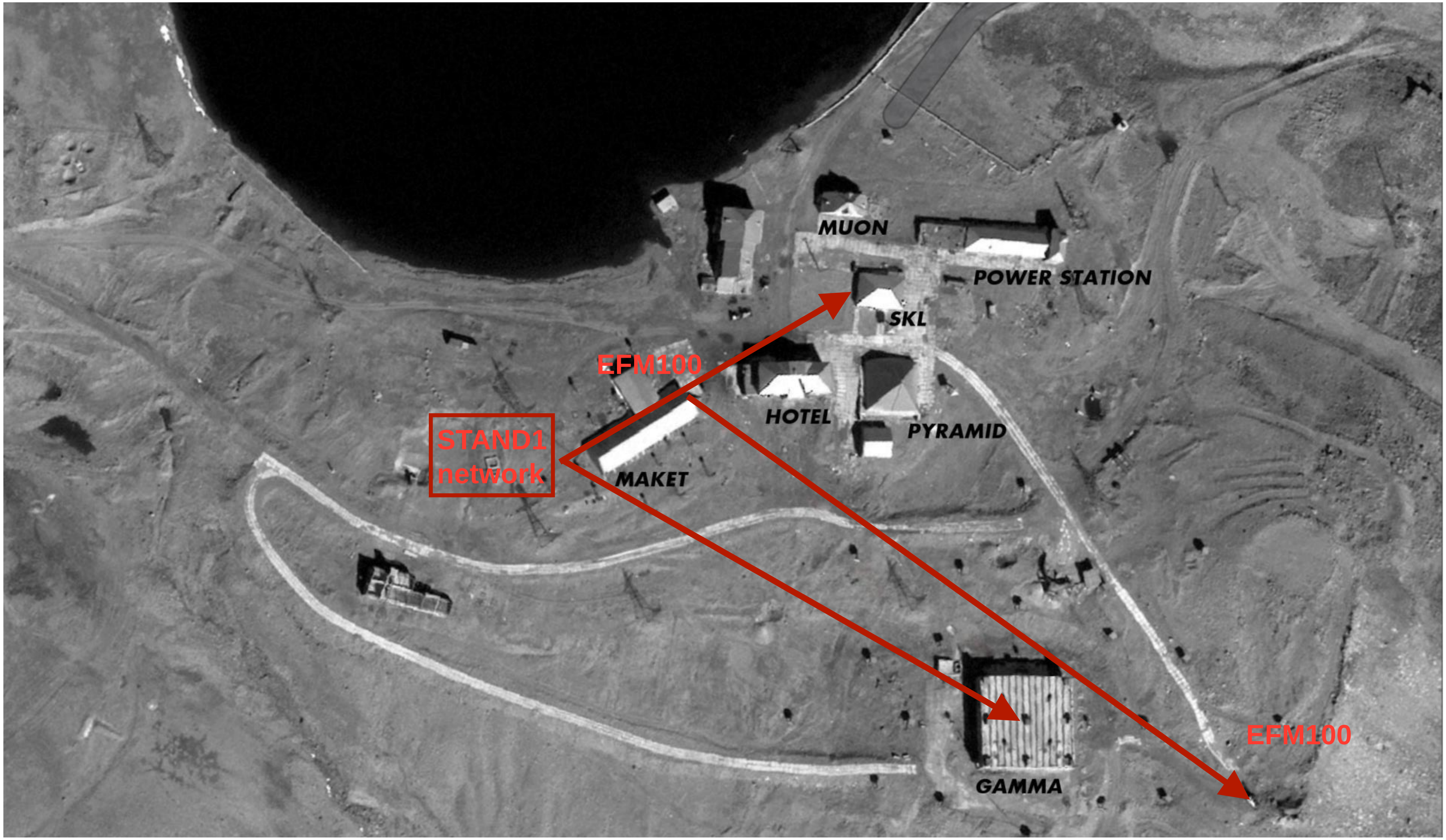
Fermi to Focus on Terrestrial Gamma Flashes (TGF)



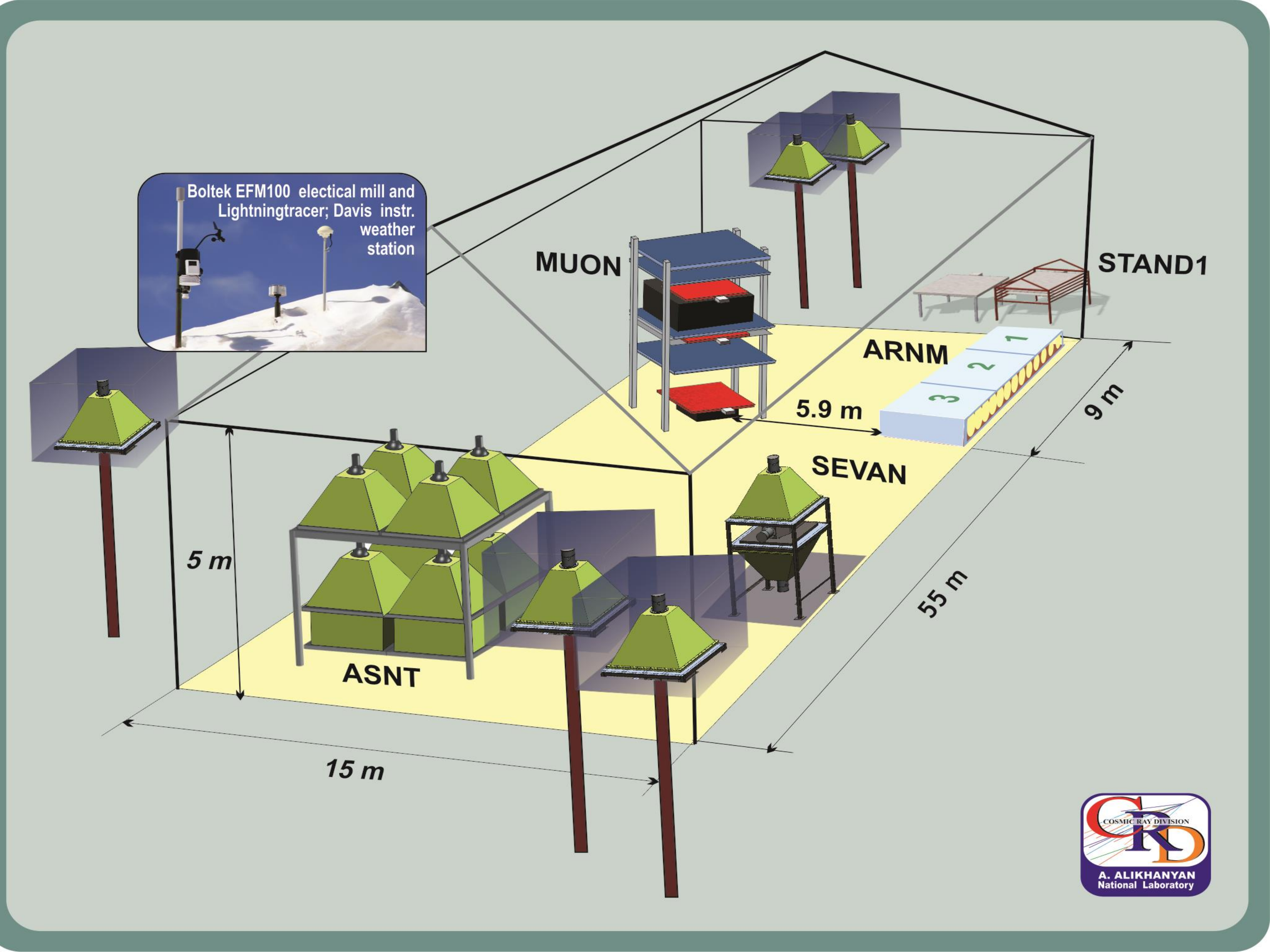


NASA Fermi Gamma-Ray Space Telescope will turn the observatory towards our planet, in a bid to study mysterious events terrestrial gamma-

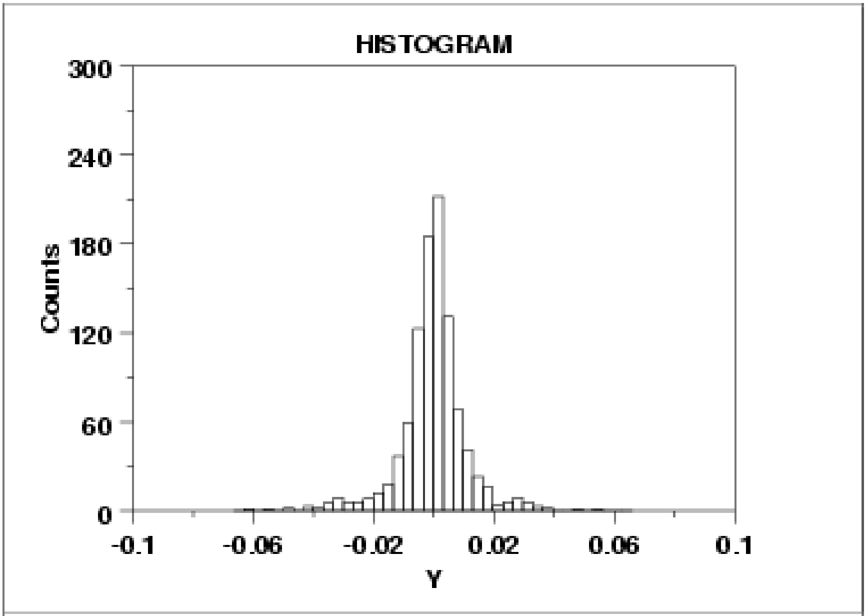
STAND1 and EFM networks



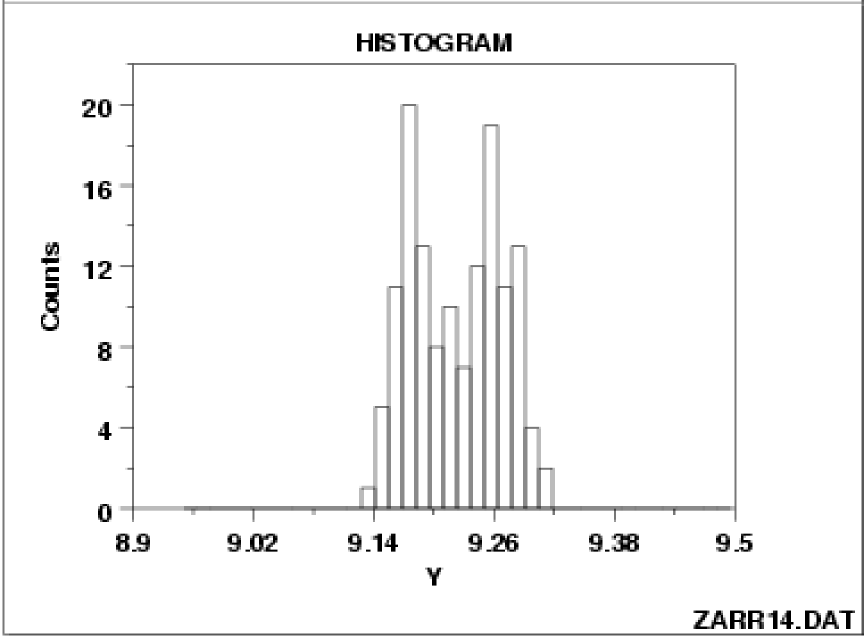
STAND1 detector network consisted of 4 scintillators and 3 field mills

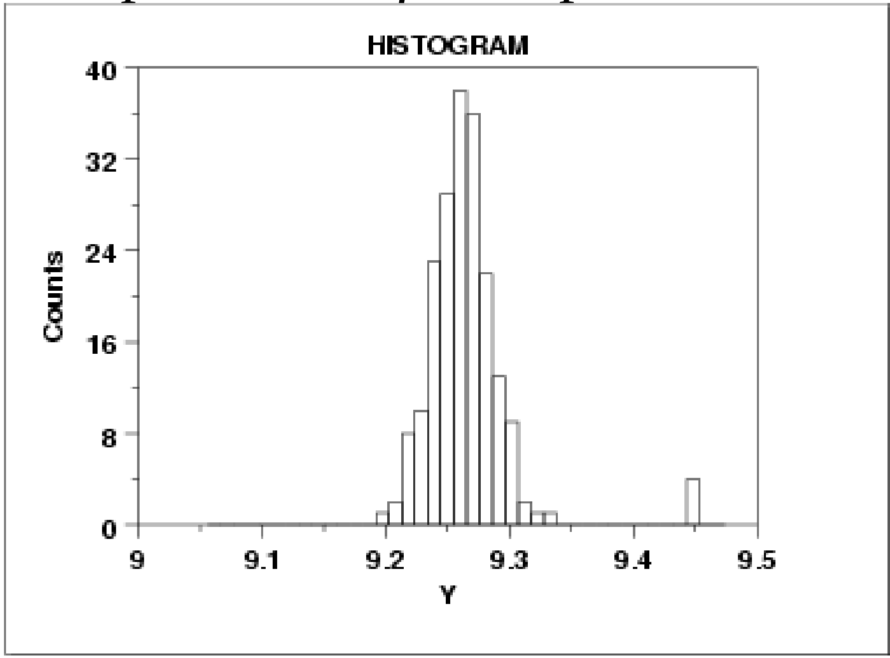

Boltek EFM100 electical mill and Lightningtracer; Davis instr. weather station
MUON
STAND1
ARNM
1
2
3
5.9 m
9 m
SEVAN
5 m
55 m
ASNT
15 m
COSMIC RAY DIVISION
A. ALIKHANYAN National Laboratory

Histogram

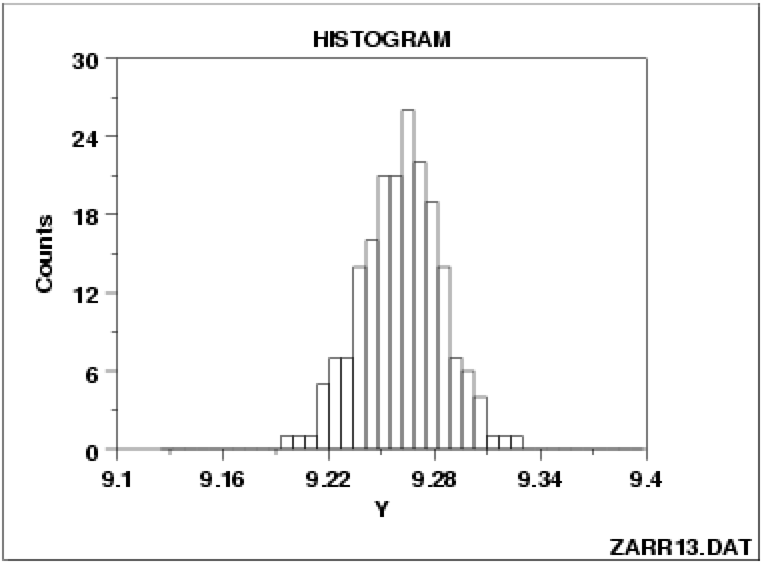


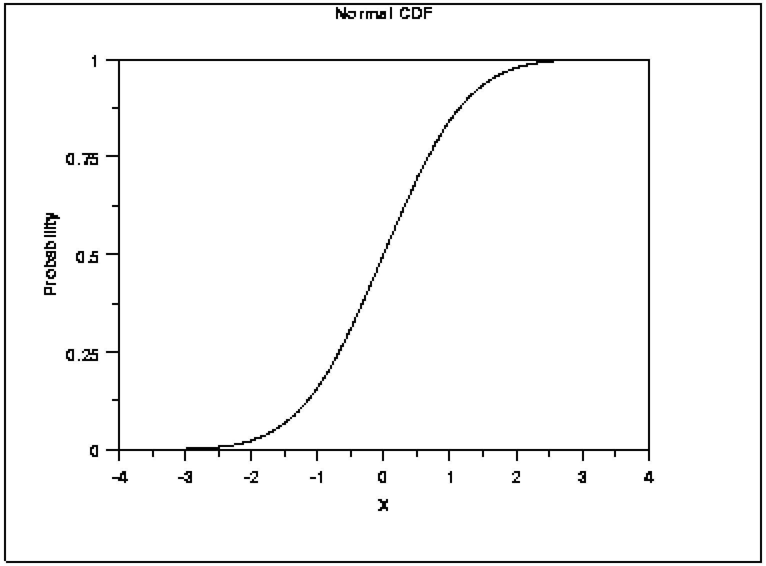
center (i.e., the location) of the data;
spread (i.e., the scale) of the data;
skewness of the data;
presence of outliers; and
presence of multiple modes

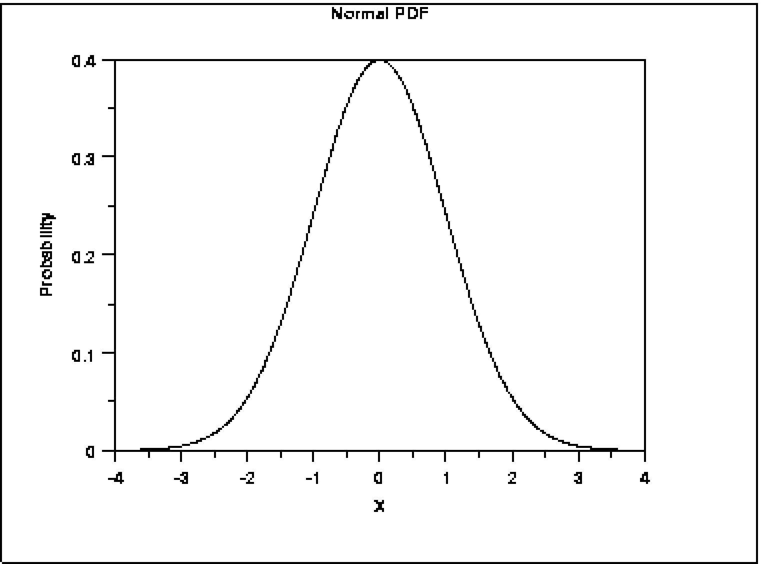


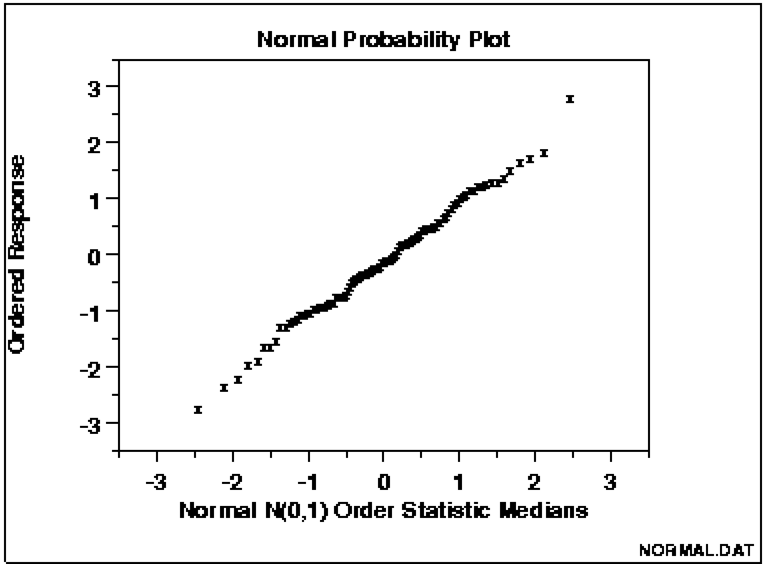


Standard (Normal) Gaussian Distribution

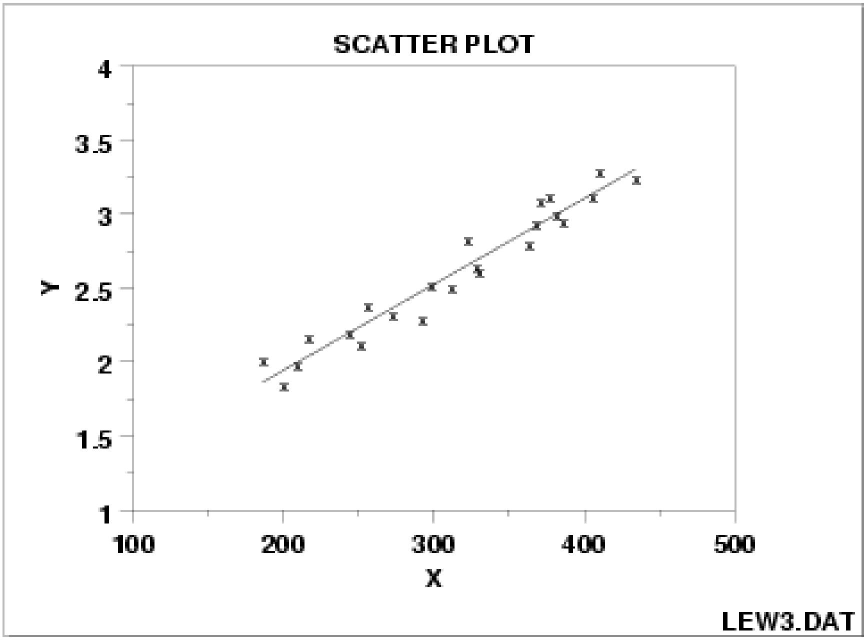




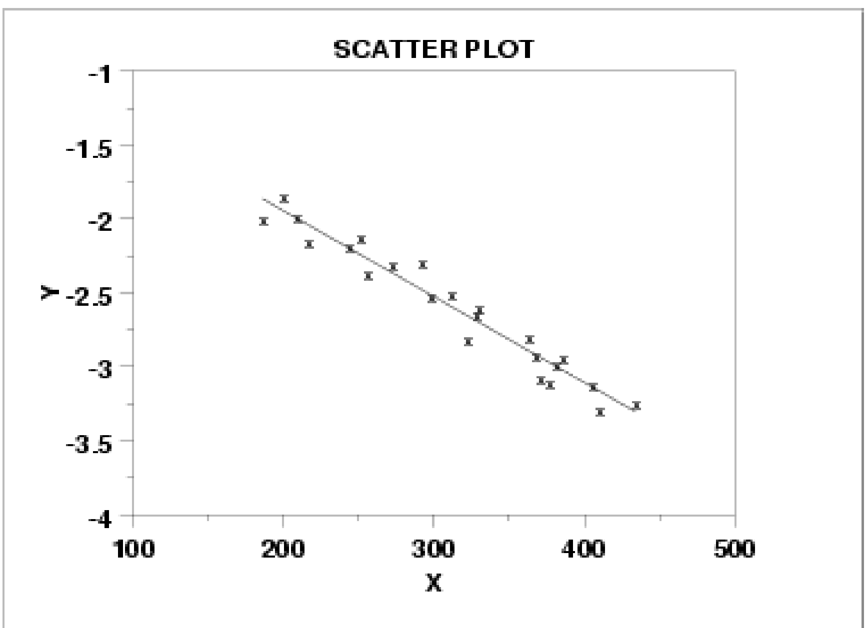


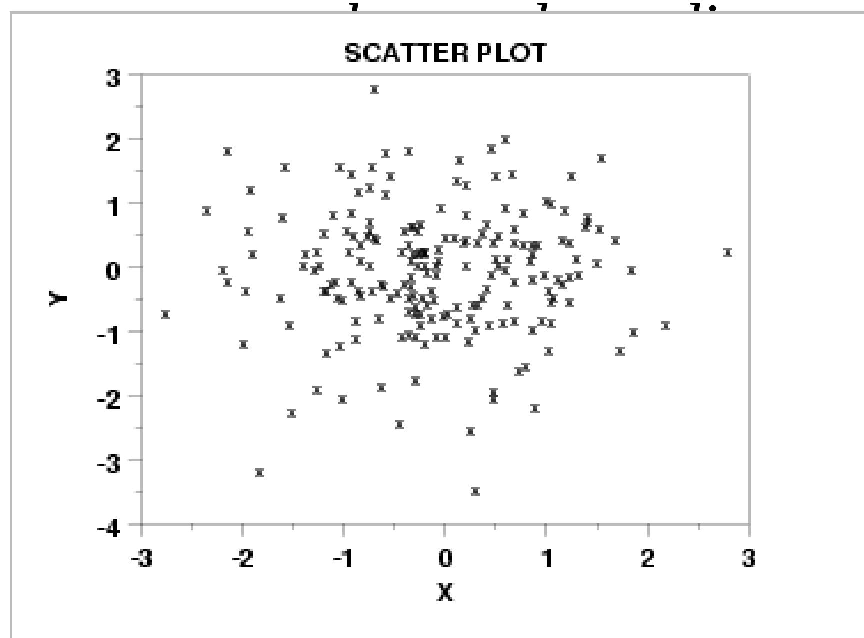


Scatter Plot (x,y)-Correlation

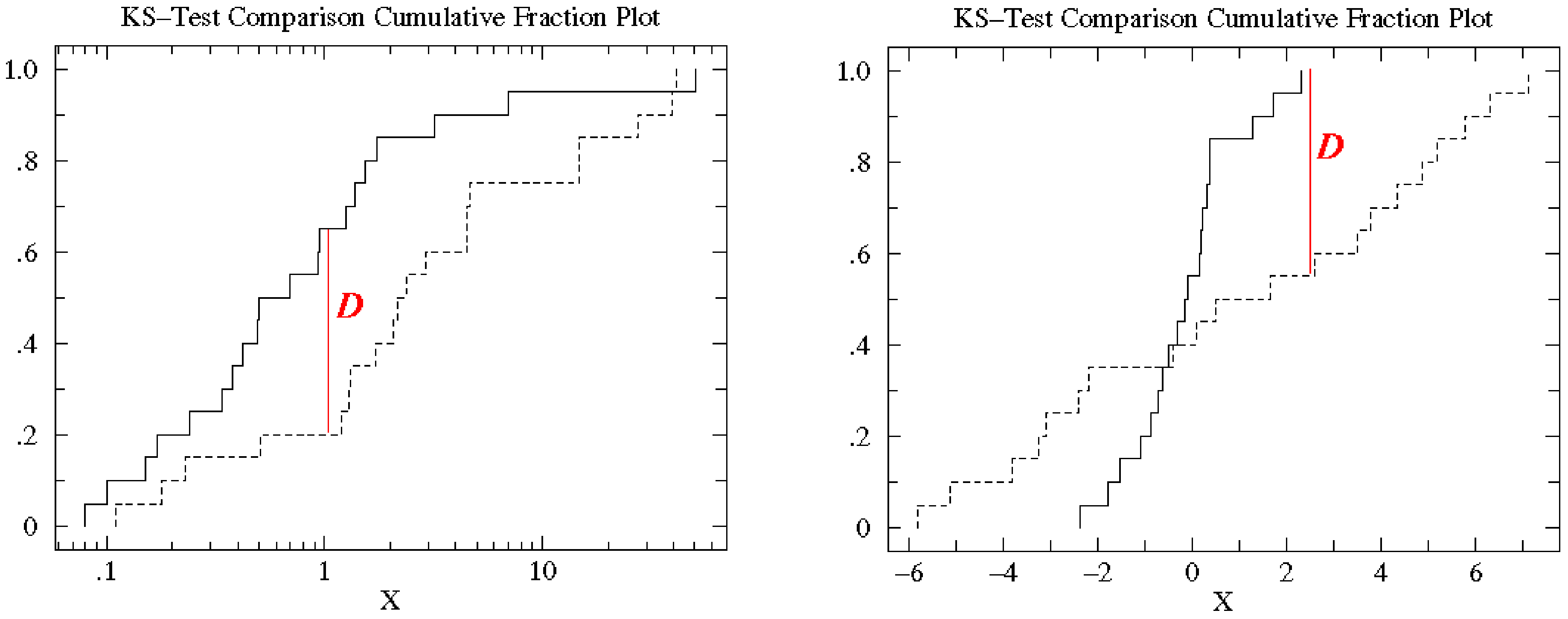


Are variables X and Y related?
Are variables X and Y linearly related?
Are variables X and Y non-linearly related?
Does the variation in Y

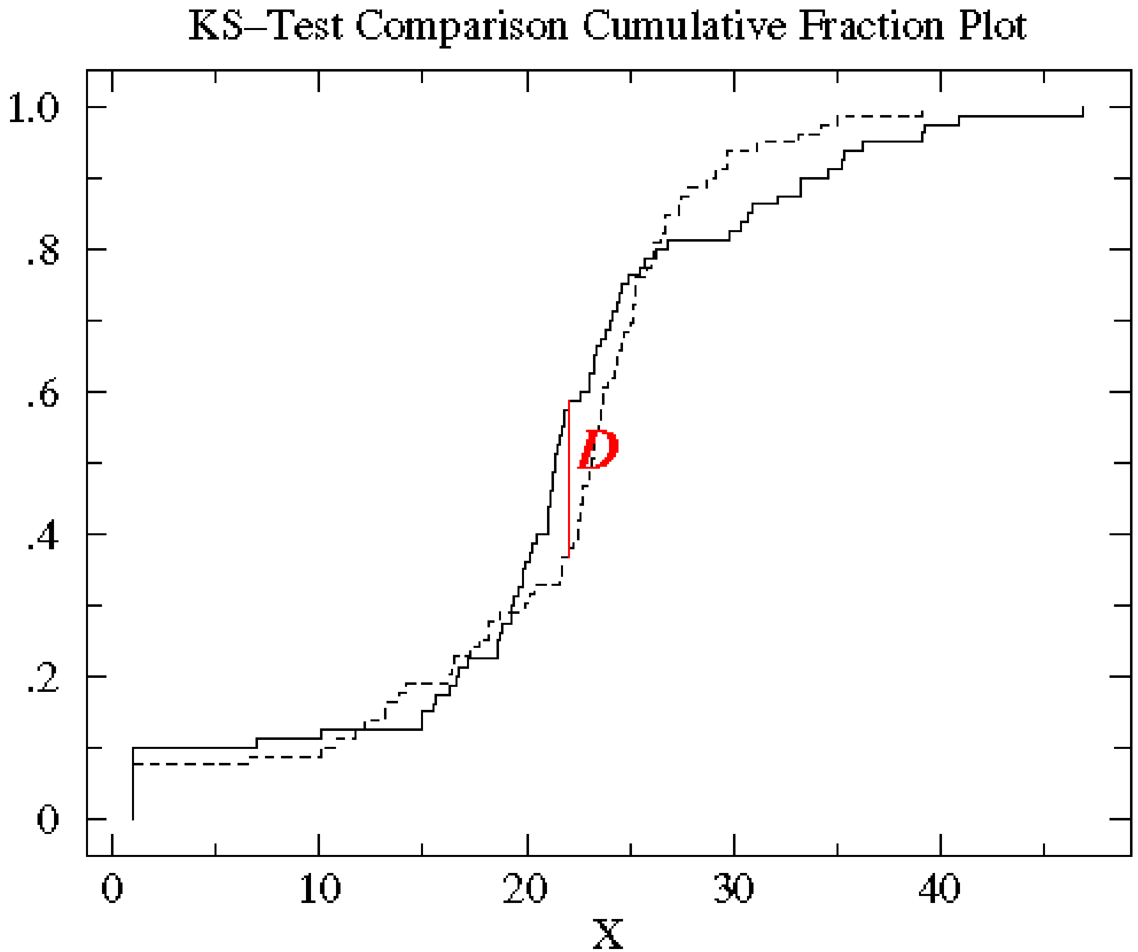




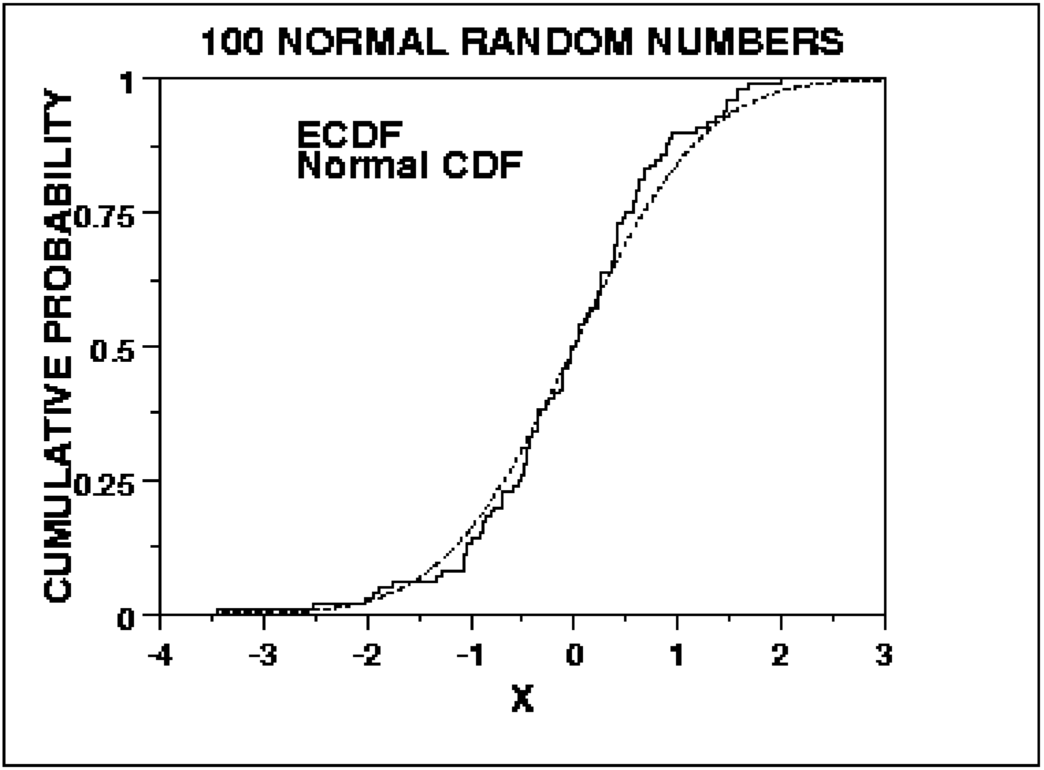
The Kolmogorov-Smirnov test (KS-test) tries to determine if two datasets differ significantly.



Two near-by apple trees are in bloom in an otherwise empty field. One is a Whitney Crab the other is a Redwell. Do bees prefer one tree to the other? We collect data by using a stop watch to time how long a bee stays near a particular tree. We begin to time when the bee touches the tree; we stop timing when the bee is more than a meter from the tree. (As a result all our times are at least 1 second long: it takes a touch-and-go bee that long to get one meter from the tree.) We wanted to time exactly the same number of bees for each tree, but it started to rain.



Kolmogorov-Smirnov Goodness-of-Fit Test



$$D = \max_{1 \le i \le N} \left| F(Y)_i - \frac{i}{N} \right|$$

An attractive feature of this test is that the distribution of the K-S test statistic itself does not depend on the underlying cumulative distribution function being tested. Another advantage is that it is an exact test (the chi-square goodness-of-fit test depends on an adequate sample size for the approximations to be valid). Despite these advantages, the K-S test has several important limitations:

It only applies to continuous distributions.

It tends to be more sensitive near the center of the distribution than at the tails.

Perhaps the most serious limitation is that the distribution must be fully specified. That is, if location, scale, and shape parameters are estimated from the data, the critical region of the K-S test is no longer valid. It typically must be determined by simulation.

Bernoulli (1654-1705, Bazel) process, probability distribution

$$P_n(m) = C_n^m p^m q^{n-m}$$

$$C_n^m = \frac{n!}{m!(n-m)!}$$

$$P_n(m) \approx \frac{1}{\sqrt{2\pi}\sqrt{npq}} e^{-x^2/2} = \frac{1}{\sqrt{npq}} \varphi_0(x)$$

$$\sqrt{npq} = \sqrt{80 \cdot \frac{1}{6} \cdot \frac{5}{6}} = \frac{10}{3}$$

$$x = \frac{m - np}{\sqrt{npq}} = \frac{20 - 80(1/6)}{10/3} = 2$$

$$\varphi_0(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$$

Poisson process: $\lambda = np \; p = \frac{\lambda}{n}$

$$P_n(m) = C_n^m \left(\frac{\lambda}{n}\right)^m \left(1 - \frac{\lambda}{n}\right)^{n-m} =$$

$$= \frac{\lambda^m}{n^m} \frac{n(n-1)\ldots(n-m+1)}{m!} \left(1 - \frac{\lambda}{n}\right)^n \left(1 - \frac{\lambda}{n}\right)^{-m} =$$

$$= \frac{\lambda^m}{m!} \cdot \frac{n-1}{n} \cdot \frac{n-2}{n} \cdot \frac{n-m+1}{n} \left(1 - \frac{\lambda}{n}\right)^n \left(1 - \frac{\lambda}{n}\right)^{-m} =$$

$$= \frac{\lambda^m}{m!} \left(1 - \frac{1}{n}\right)\left(1 - \frac{2}{n}\right) \cdots \left(1 - \frac{m-1}{n}\right)\left(1 - \frac{\lambda}{n}\right)^n \left(1 - \frac{\lambda}{n}\right)^{-m}.$$

$$P_n(m) = \frac{\lambda^m}{m!} \left(1 - \frac{\lambda}{n}\right)^n \qquad \lim_{n \to \infty} \left(1 - \frac{\lambda}{n}\right)^n = e^{-\lambda}.$$

$$P_n(m) = \frac{\lambda^m}{m!} e^{-\lambda}.$$