Making of Detector for HEP

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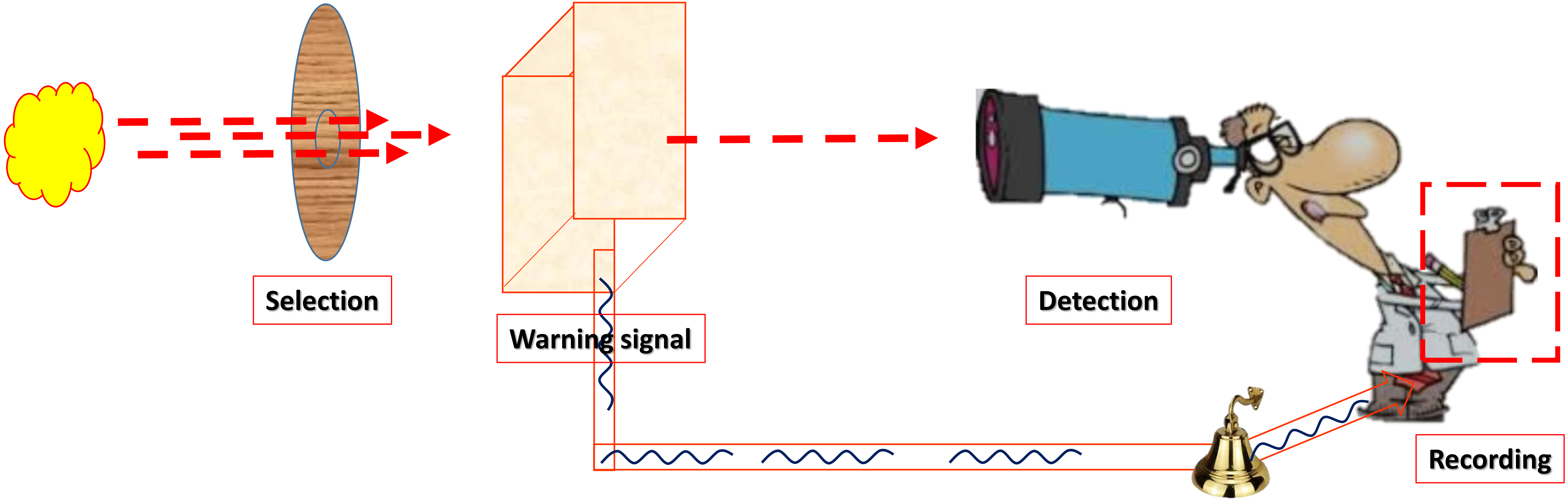
VECC

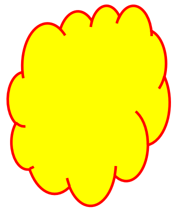
3rd ALICE-INDIA school on Quark Gluon Plasma

Lecture-1

What we will be discussing in next two classes !!



What we expect from the source?



No of particles

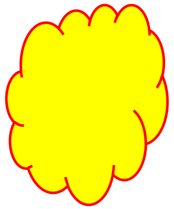
Type of particles (Mass, Charge, spin and so on..)

Momentum of particles

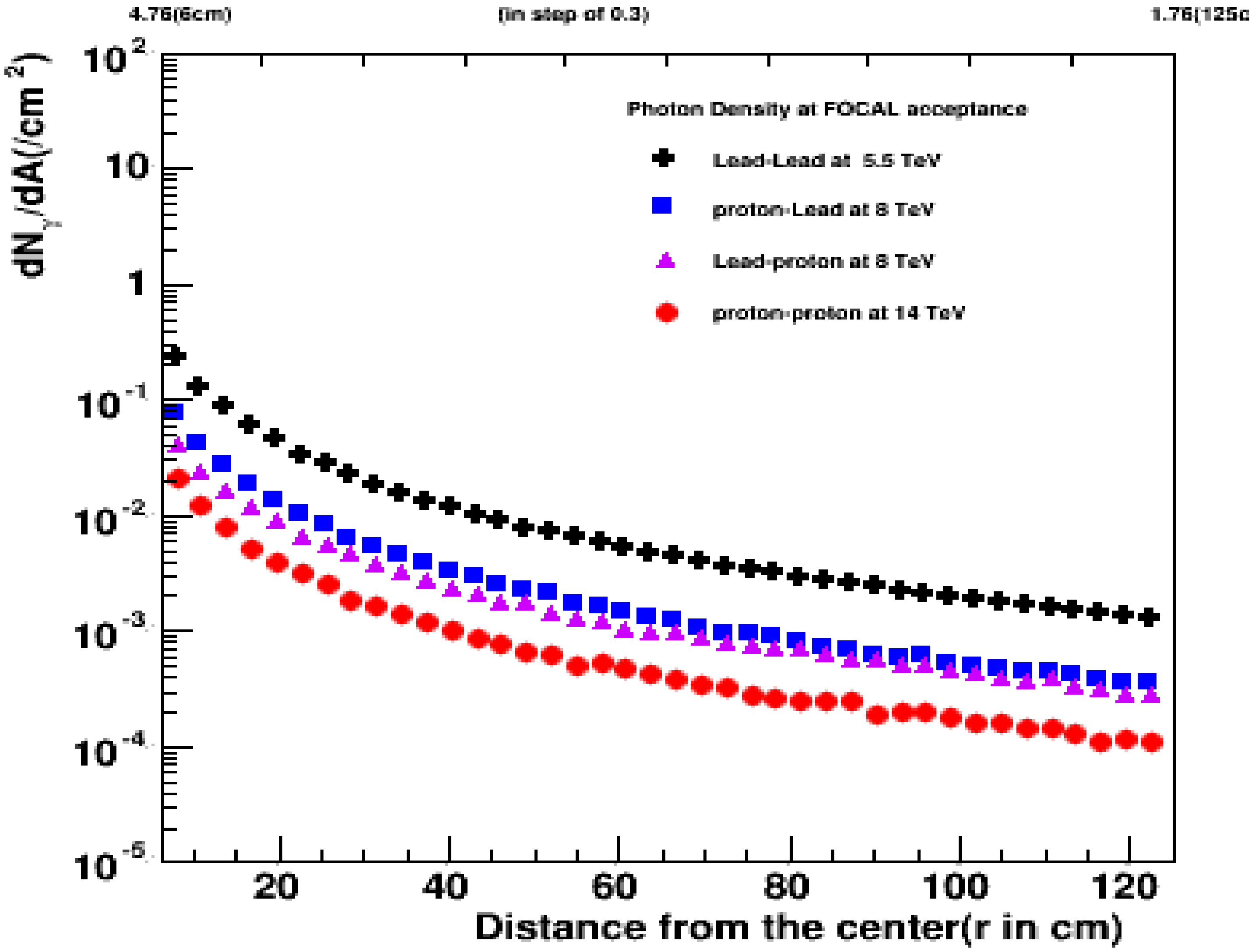
Energy / Energy Range of produced particles

Expected background from source?

What we expect from the source?



No of particles



What

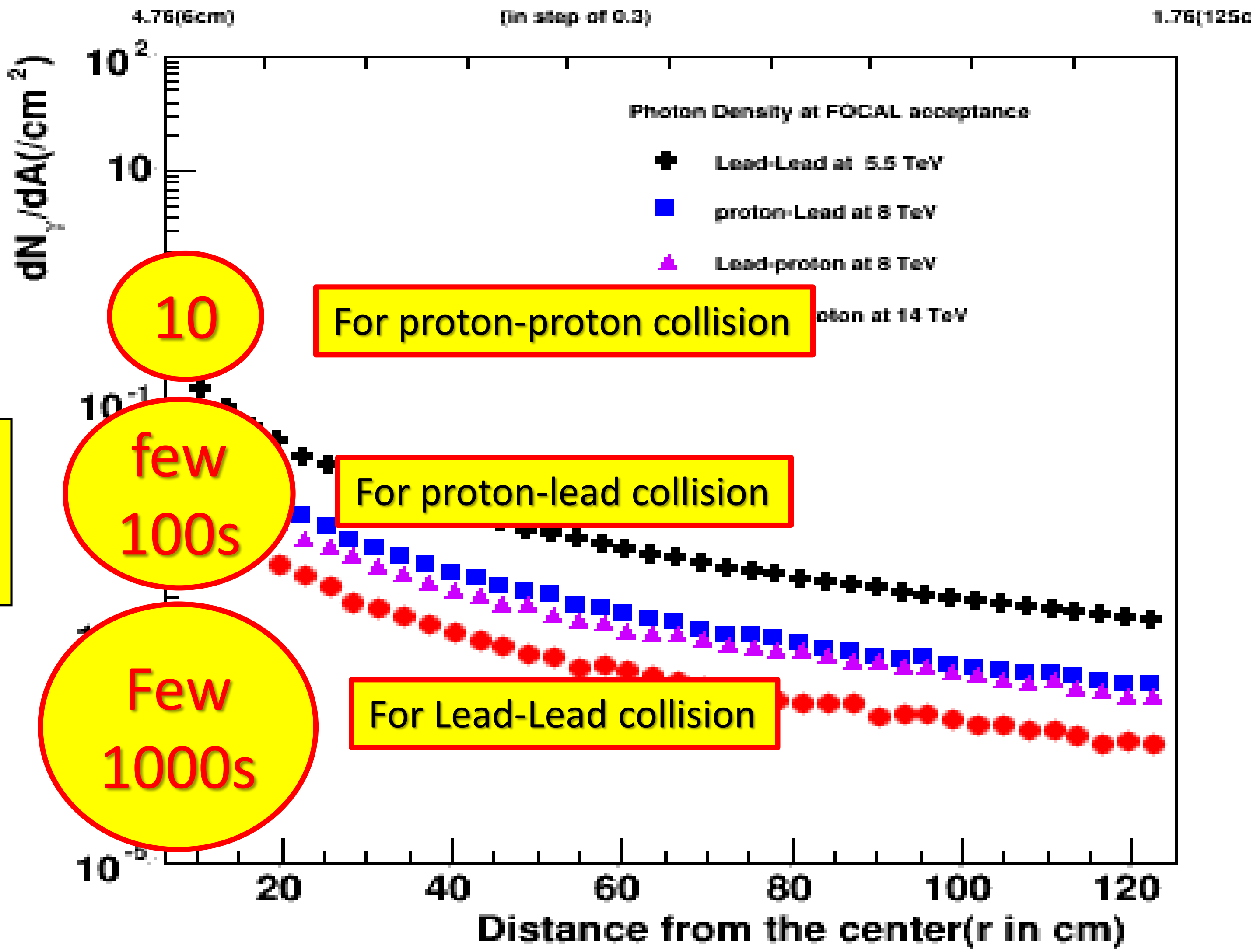
$dN_\gamma/dA(/cm^2)$

Tells?

What we expect from the source?

No of particles

$$\frac{dN_{ch}}{d\eta} \approx$$



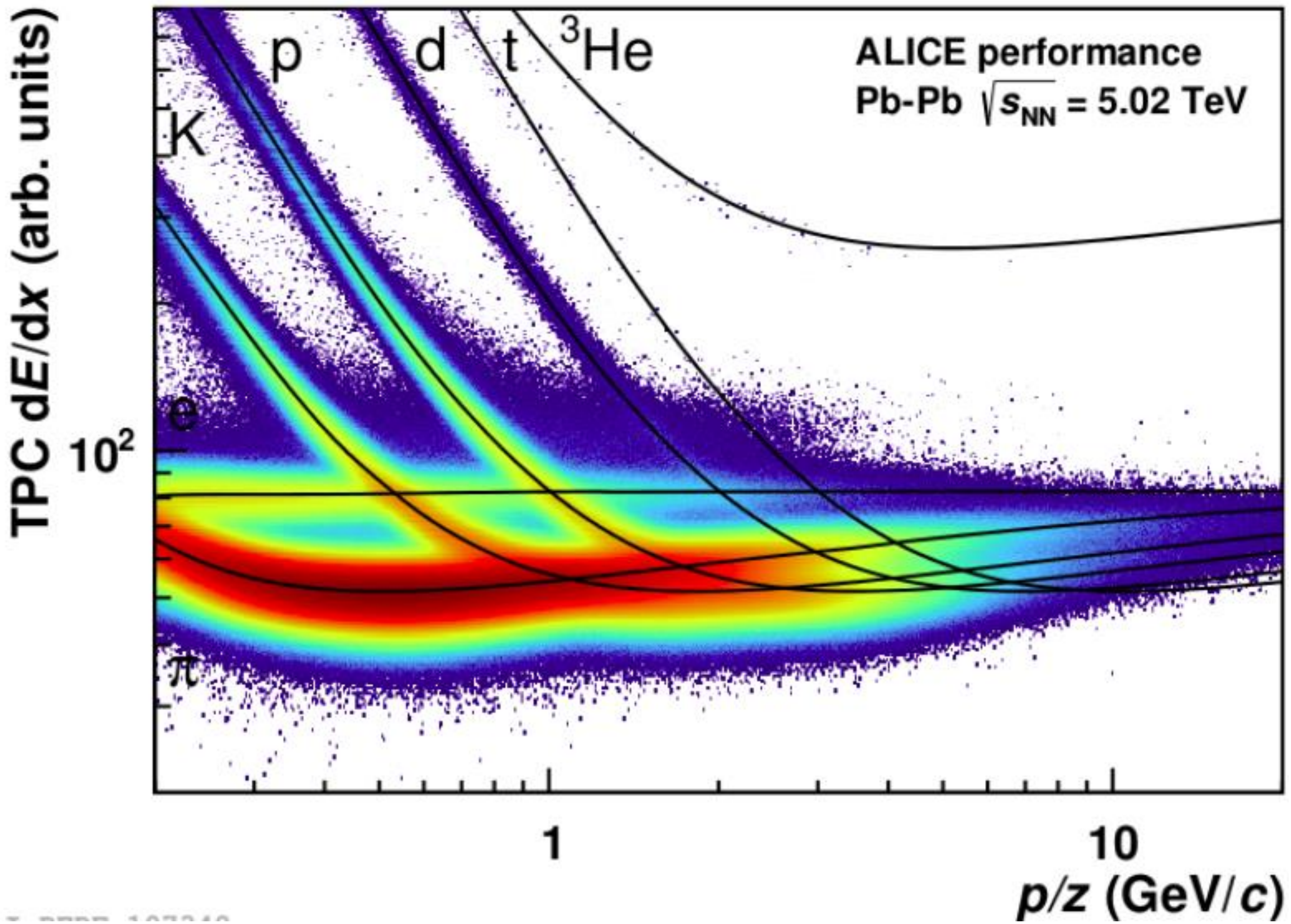
What

$dN_{\gamma}/dA(/cm^2)$

Tells?

What we expect from the source?

Type of particles (Mass, Charge, spin and so on..)



$$-\frac{dE}{dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

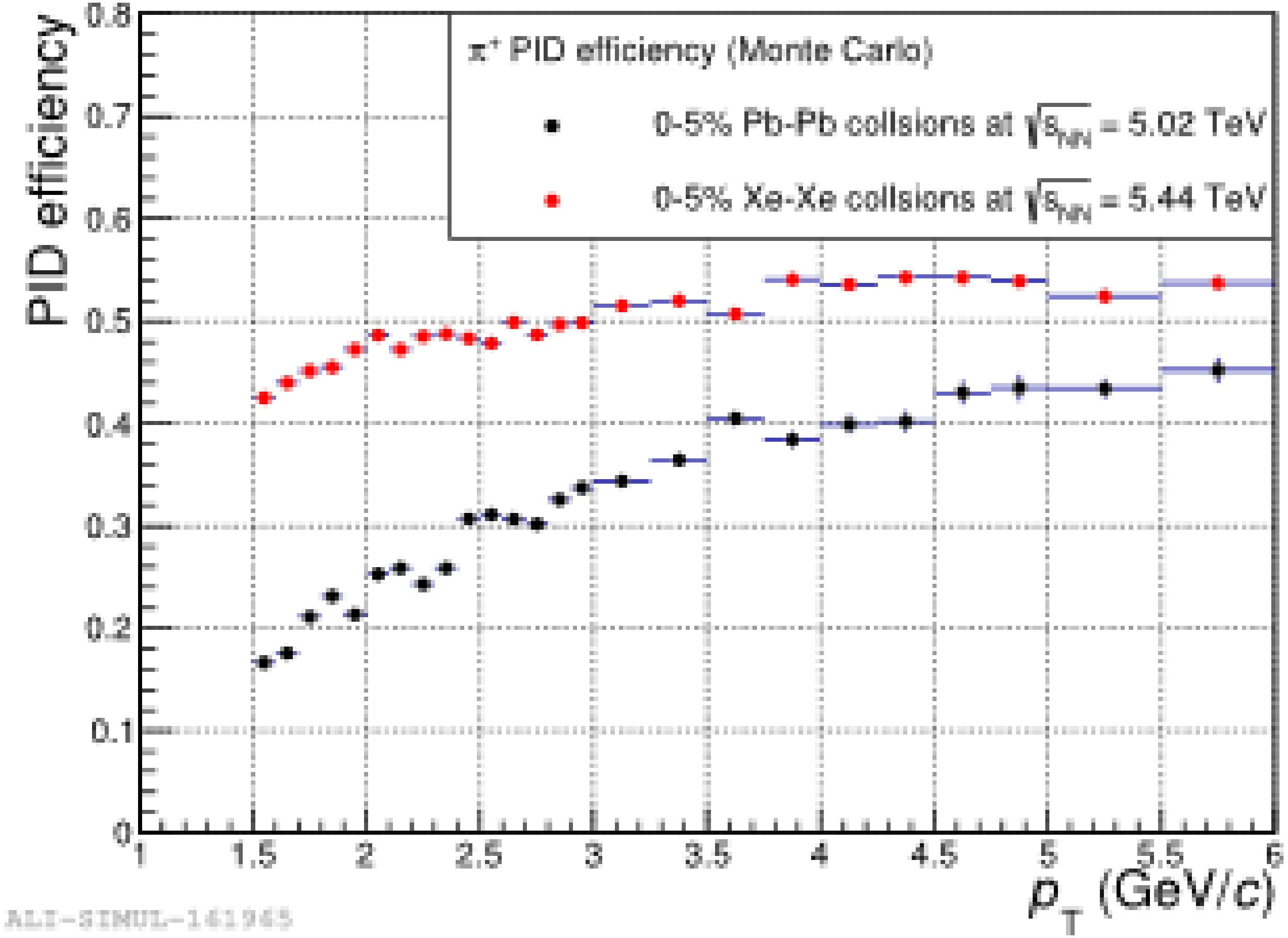
Information about type of particles has direct link to the choice of detection technique

We know (expect)
Whether it is electron/gamma/pion
Or something else!!

What we expect from the source?

Momentum of particles

Energy(Range) of produced particles



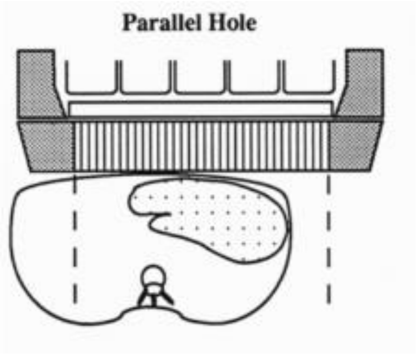
What we expect from the source?

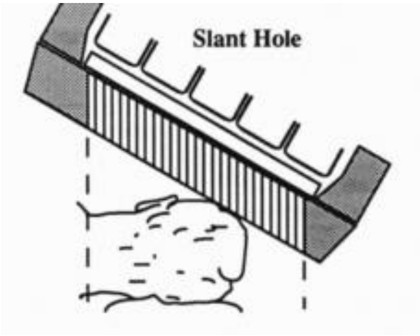
Information from the Source	Impact on Detector building
No of particle (Particle density) expected	Detector cell size
Particle type (Charge, mass and other)	Type of detector, material
Energy/Momentum range	Detector material
Type of measurement	Mode of measurement(Tracker/calorimeter)

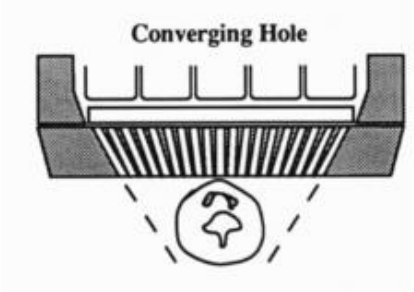
Event selection/collimeter

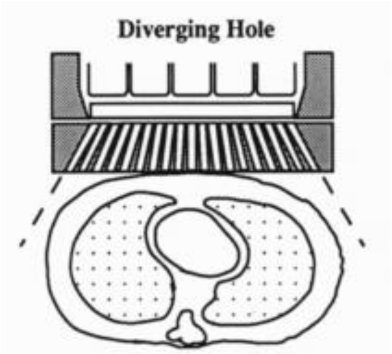
This is most relevant to test beam
For experiments in Heavy ion collision

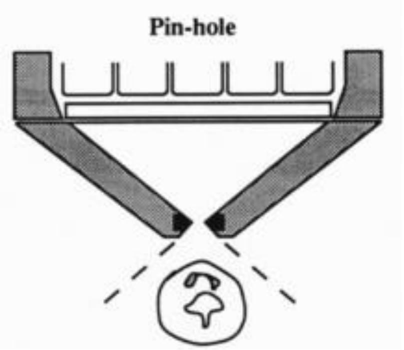
Collimation is a process to narrow a beam of particles/waves.
It will result a more directional beam or limit the spatial cross-section.











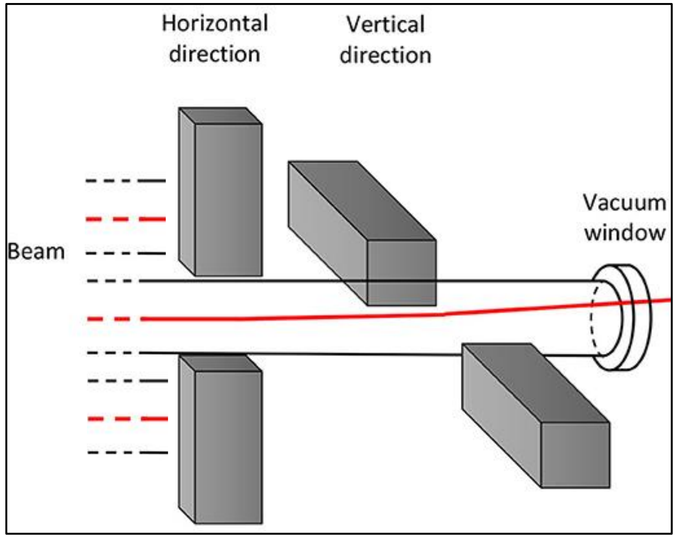
Trigger

Selection of proper particle and reject debris

This is responsible for the real time selection of the subset of data to be of choice

It can done both ON/OFF the detector.
It always introduce some kind of buffering.

Simplest schematic for the trigger detector



	Bubble chamber	Spark chamber	Proportional chamber	Drift chamber	Scintillator
Dead time	50 ms	100 ms	200 ns	100 ns	10 ns

Trigger

This is responsible for the real time selection of the subset of data to be of choice

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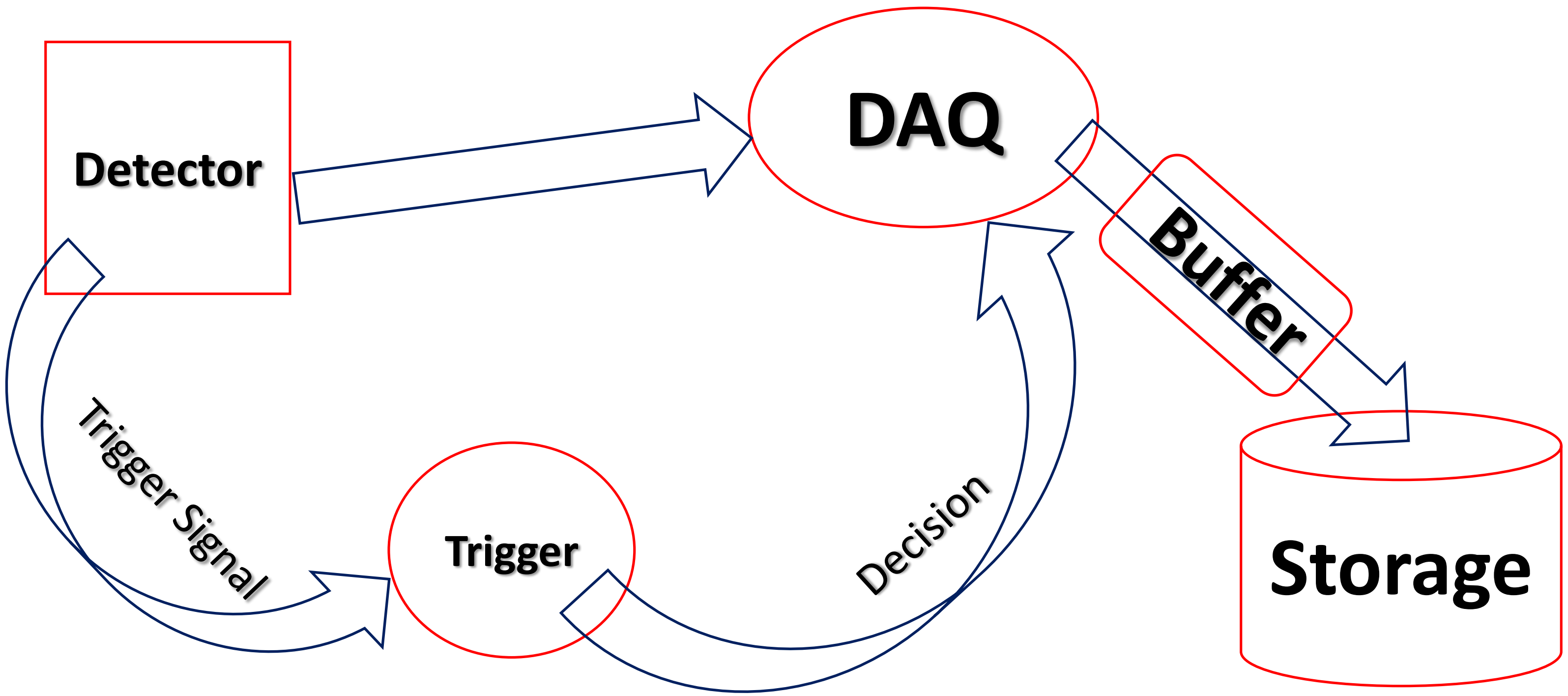


Detector

Particle detector is an instrument to measure properties of a particle

- position and direction (r)
- Momentum (p)
- Energy (E)
- Mass (m)
- transition radiation
- spin, lifetime

Particle Detection

Tracking (with/without) magnetic field, calorimetry, Spectroscopy, techniques of PID, Cherenkov radiation or time of flight

Non-Destructive measurement
Commonly known as spectrometric technique

Destructive measurement

Tracker

Calorimeters

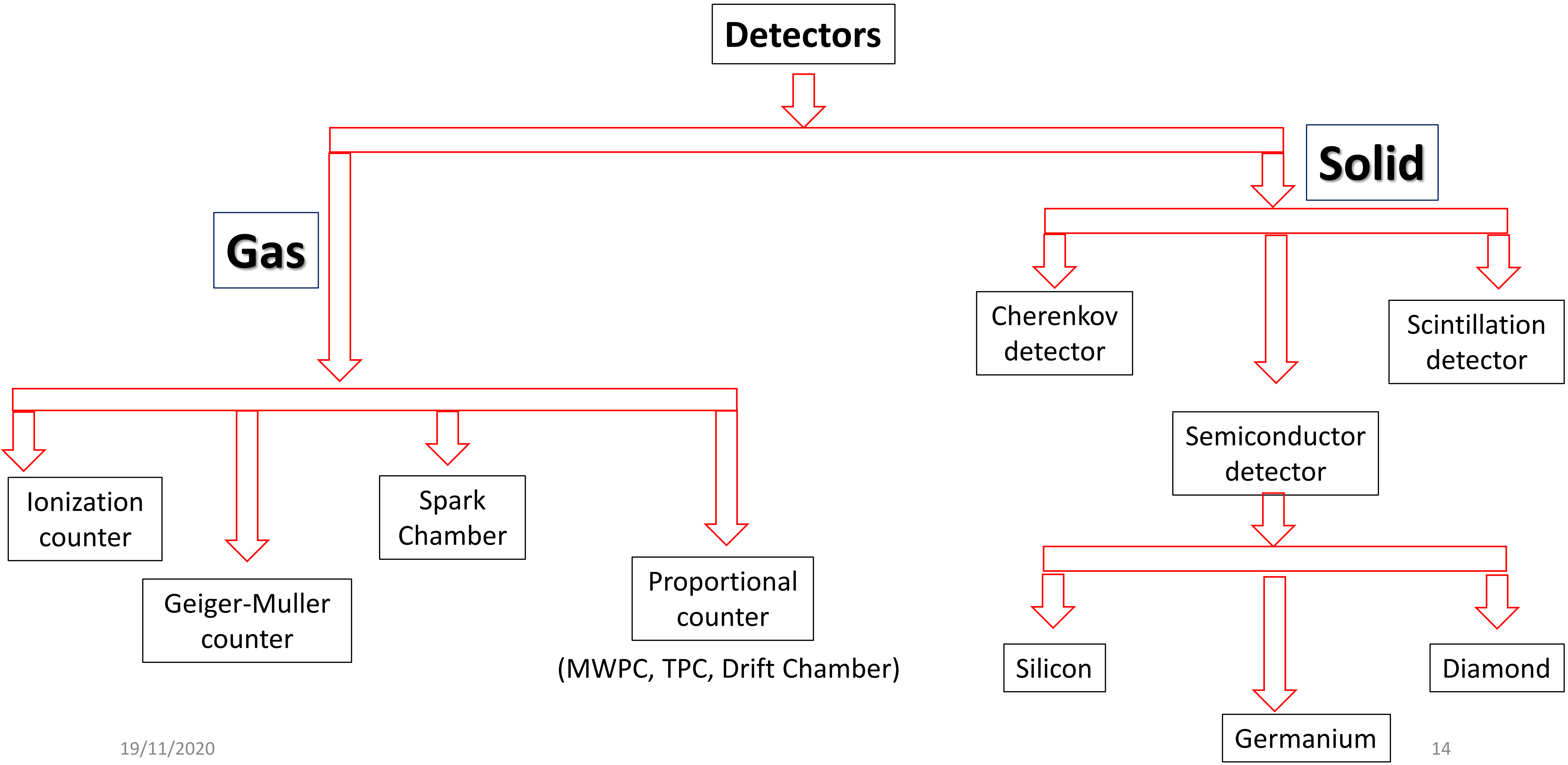
Adaptation of a particular detection technique depends on the purpose of the measurement

Detector

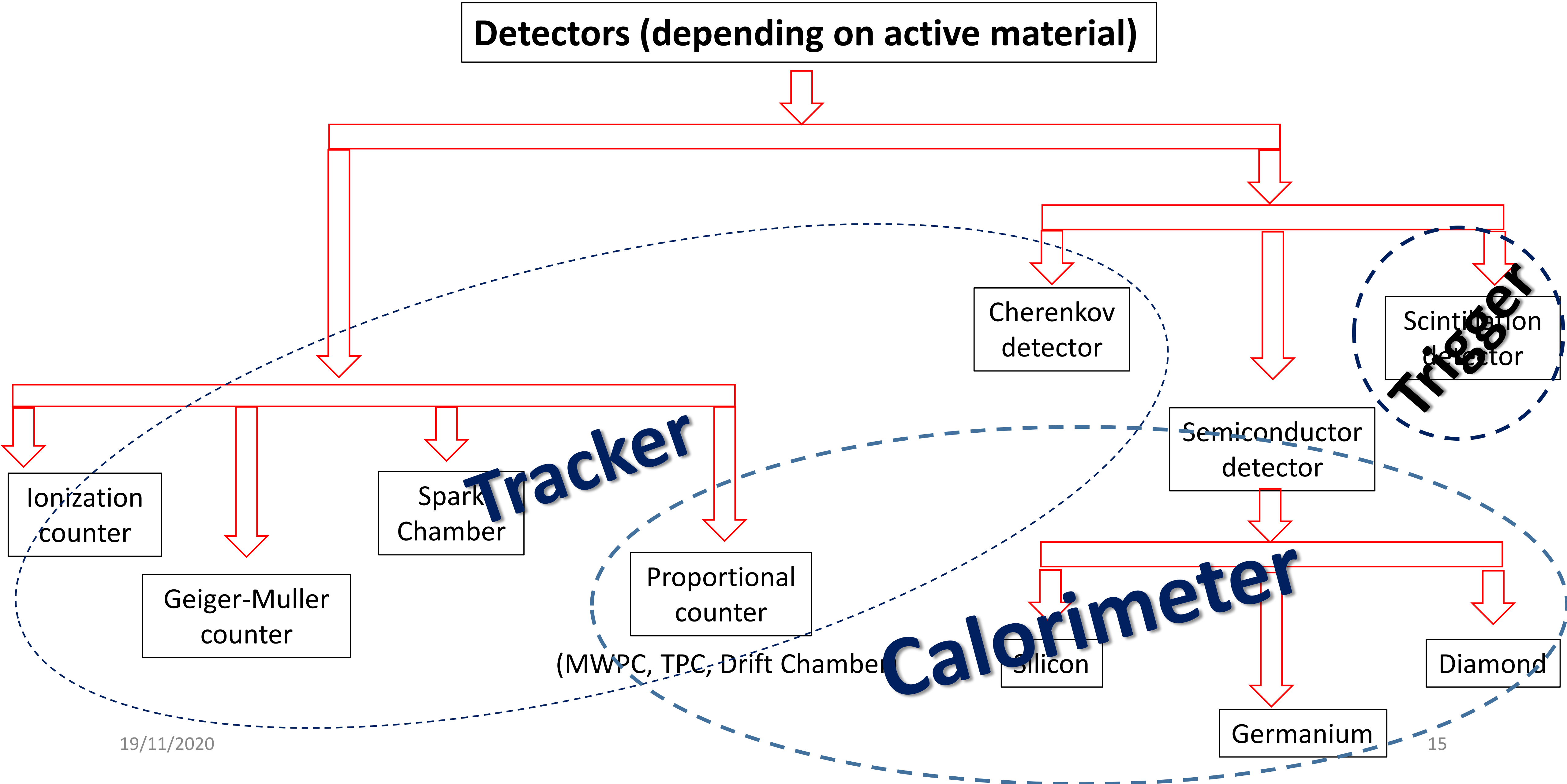
Particle Interaction

<u>Interaction of charged particle (except e^-)</u> ✓ **Multiple scattering** ✓ **ionisation and excitation** ✓ **Bremsstrahlung** ✓ **Other radiation losses** ✓ **Strong interaction (depending on the energy of the particle)**	**<u>Interaction of photons/e^-</u>** ❑ **Bremsstrahlung** ❑ **Pair production, Compton and photoelectric** ❑ **Multiple scattering, ionization loss** **Depending on the energy, Electrons are prone to EM-shower production**
<u>Interaction of neutral particles (m > 0)</u> depends on energies: from > 100 MeV to < 1 eV Interact only with nucleus via strong interaction	Choices of the detector (both spectrometer and calorimeter) material, size, shape and other physical parameter strongly depend on the type of targeted particles

Detector


Detectors
Solid
Gas
Cherenkov detector
Scintillation detector
Ionization counter
Spark Chamber
Geiger-Muller counter
Proportional counter
(MWPC, TPC, Drift Chamber)
Semiconductor detector
Silicon
Diamond
Germanium

Detector



Detectors (depending on active material)
Ionization counter
Geiger-Muller counter
Spark Chamber
Proportional counter
(MWPC, TPC, Drift Chamber)
Cherenkov detector
Semiconductor detector
Silicon
Germanium
Diamond
Scintillation detector
Tracker
Calorimeter
Trigger

Detectors (performance)

Important properties of the detector

- ✓ Sensitivity of the detector to lowest expected detection.
- ✓ The detector should work in linear domain for the range of measurement.

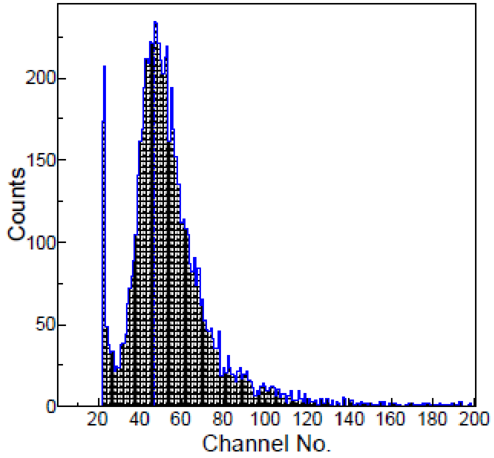
There are other parameters as well

- ✓ Time resolution
- ✓ Spatial resolution
- ✓ Energy resolution
- ✓ Detection efficiency
- ✓ Misidentification probability
- ✓ And so on…..

Detectors (performance)

Important properties of the detector

- ✓ **Sensitivity of the detector to lowest expected detection.**
- ✓ The detector should work in linear domain for the range of measurement.



$$\frac{S}{N} = \frac{mean}{standard\ deviation} = \frac{\bar{x}}{s}$$

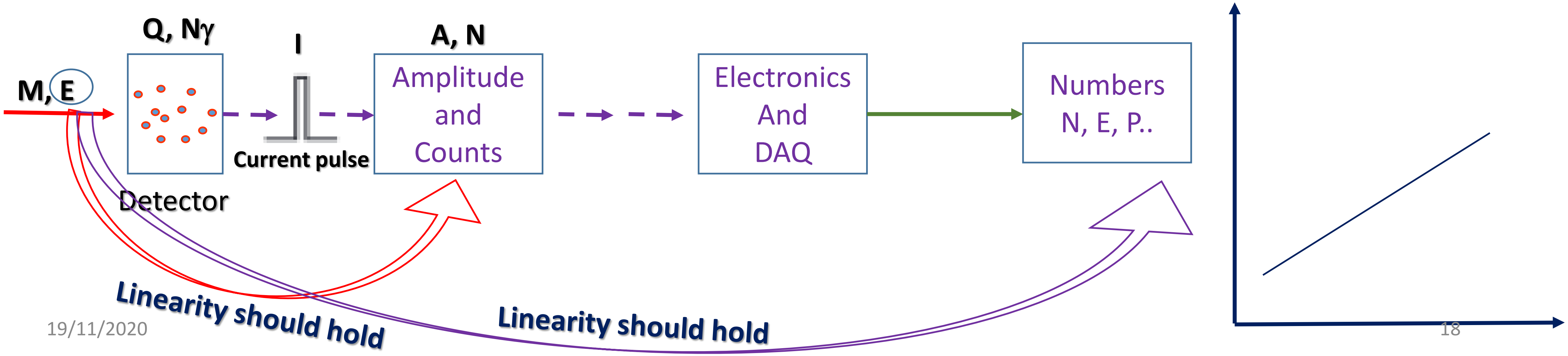
S => Mean of the signal
N => Standard deviation

General rule: S/N >3 for better signal signal detection

Detectors (performance)

Important properties of the detector

- ✓ Sensitivity of the detector to lowest expected detection.
- ✓ **The detector should work in linear domain for the range of measurement.**



Readout Electronics

Electrical pulse to number

The general aim is collect electrical signals
(a current pulse) from the detector and process it to

- ✓ Differentiate minimum detectable signal from back ground noise
- ✓ Measure the energy (from signal amplitude).
- ✓ Counts the incidence (multiplicity)
- ✓ Optimize the timing (to avoid overlapping events)

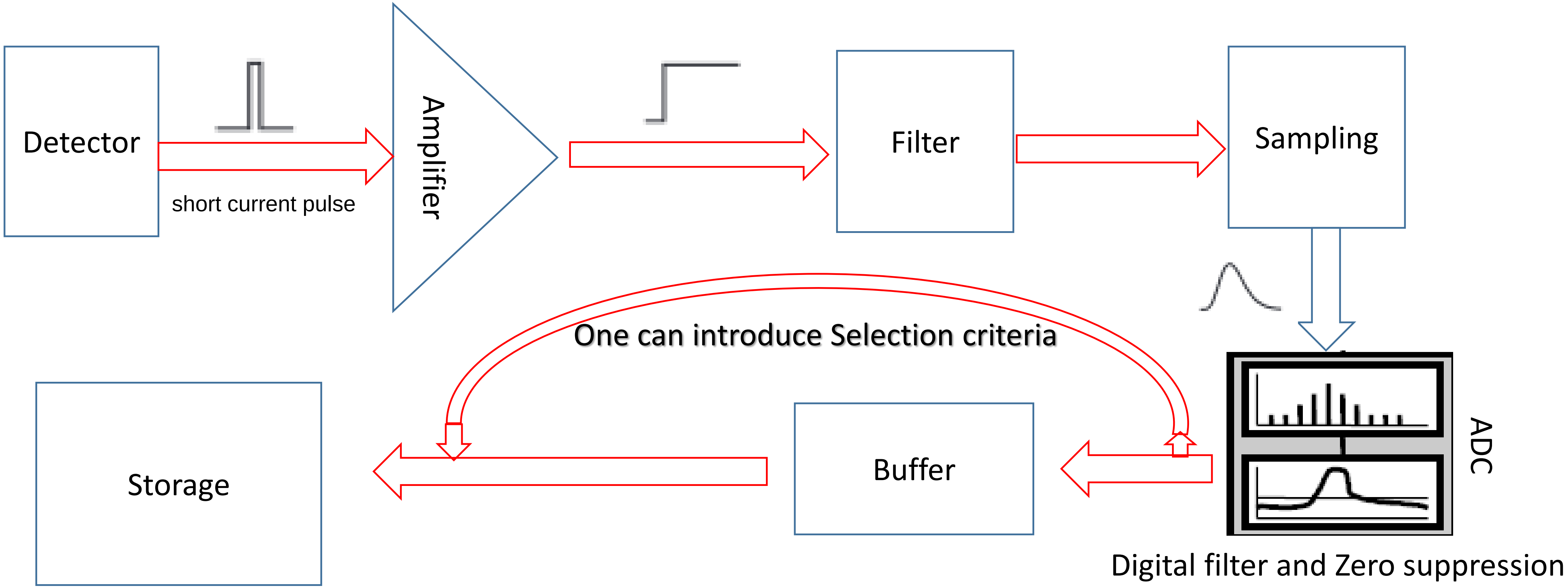
The next step consist of Digitization of the signal
and storing with (additional) conditions

- ✓ Analog to digital conversion
- ✓ Implementation of additional conditions
- ✓ Storing with all relevant information for offline use

Readout Electronics

Electrical pulse to number

Schematic of the steps for the readout electronics



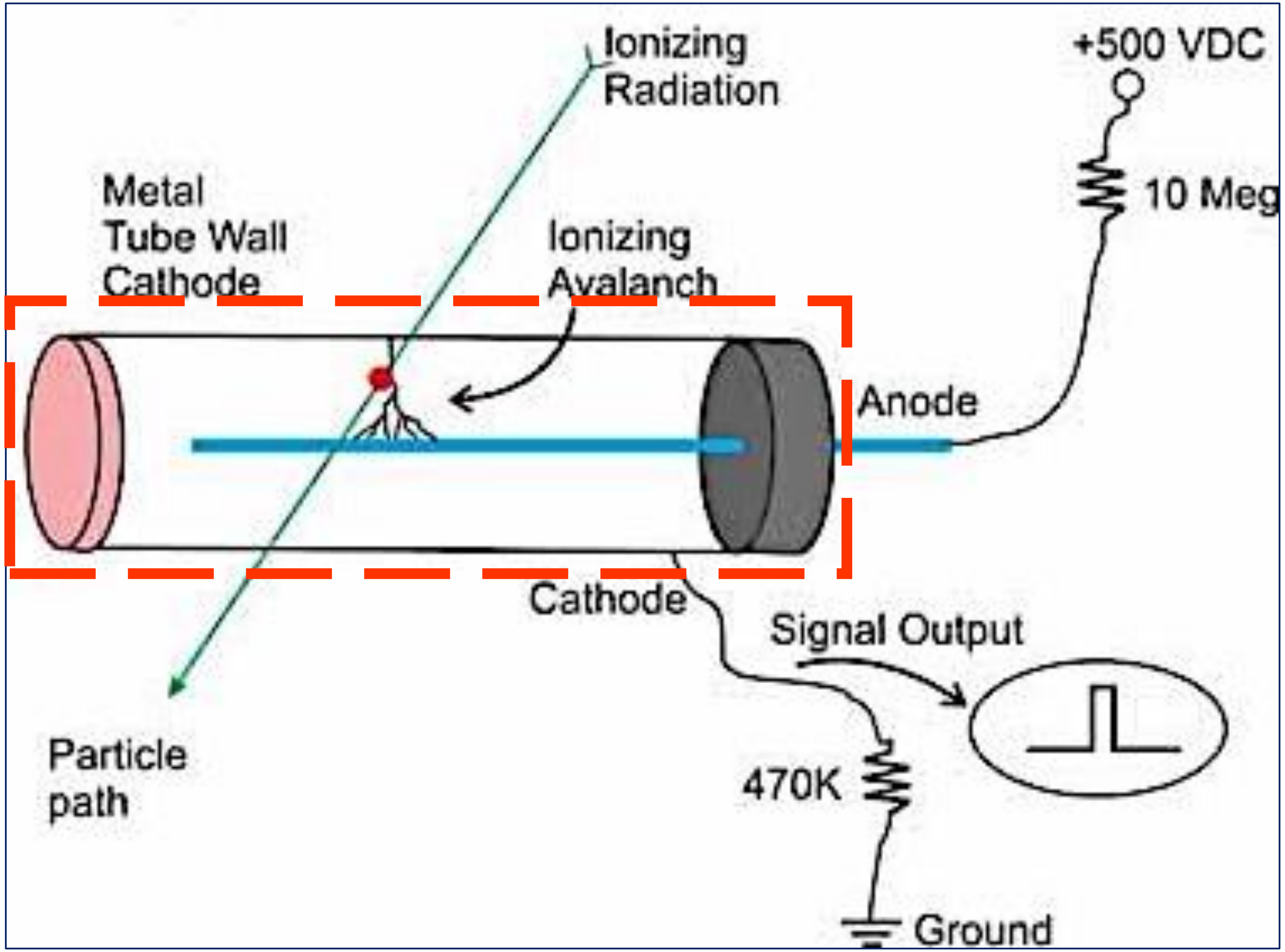
End of Lecture-1

How to Detect

Particles to be detected

❖ Decide what should be the detector

✓ Gas, Liquid or Solid
✓ Single layer OR Segmented



Measured quantities
Identity, mass, energy, momentum, track……

Creating the Bang

Few Numbers

6.5 TeV => 1.6 x 10^{-7} J

1000 times smaller compare to the energy of a Bee

1 GeV => 1.6 x 10^{-10} J

1.16 x 10^{13} Kelvin temperature

Table 35.1: Typical resolutions and deadtimes of common charged particle detectors. Revised November 2011.

Detector Type	Intrinsinc Spatial Resolution (rms)	Time Resolution	Dead Time
Resistive plate chamber	$\lesssim 10$ mm	1 ns (50 ps[a])	—
Streamer chamber	300 μm[b]	2 μs	100 ms
Liquid argon drift [7]	∼175–450 μm	∼ 200 ns	∼ 2 μs
Scintillation tracker	∼100 μm	100 ps/n[c]	10 ns
Bubble chamber	10–150 μm	1 ms	50 ms[d]
Proportional chamber	50–100 μm[e]	2 ns	20-200 ns
Drift chamber	50–100 μm	2 ns[f]	20-100 ns
Micro-pattern gas detectors	30–40 μm	< 10 ns	10-100 ns
Silicon strip	pitch/(3 to 7)[g]	few ns[h]	$\lesssim 50$ ns[h]
Silicon pixel	$\lesssim 10$ μm	few ns[h]	$\lesssim 50$ ns[h]
Emulsion	1 μm	—	—