Detection of cosmic rays

Some practical remarks

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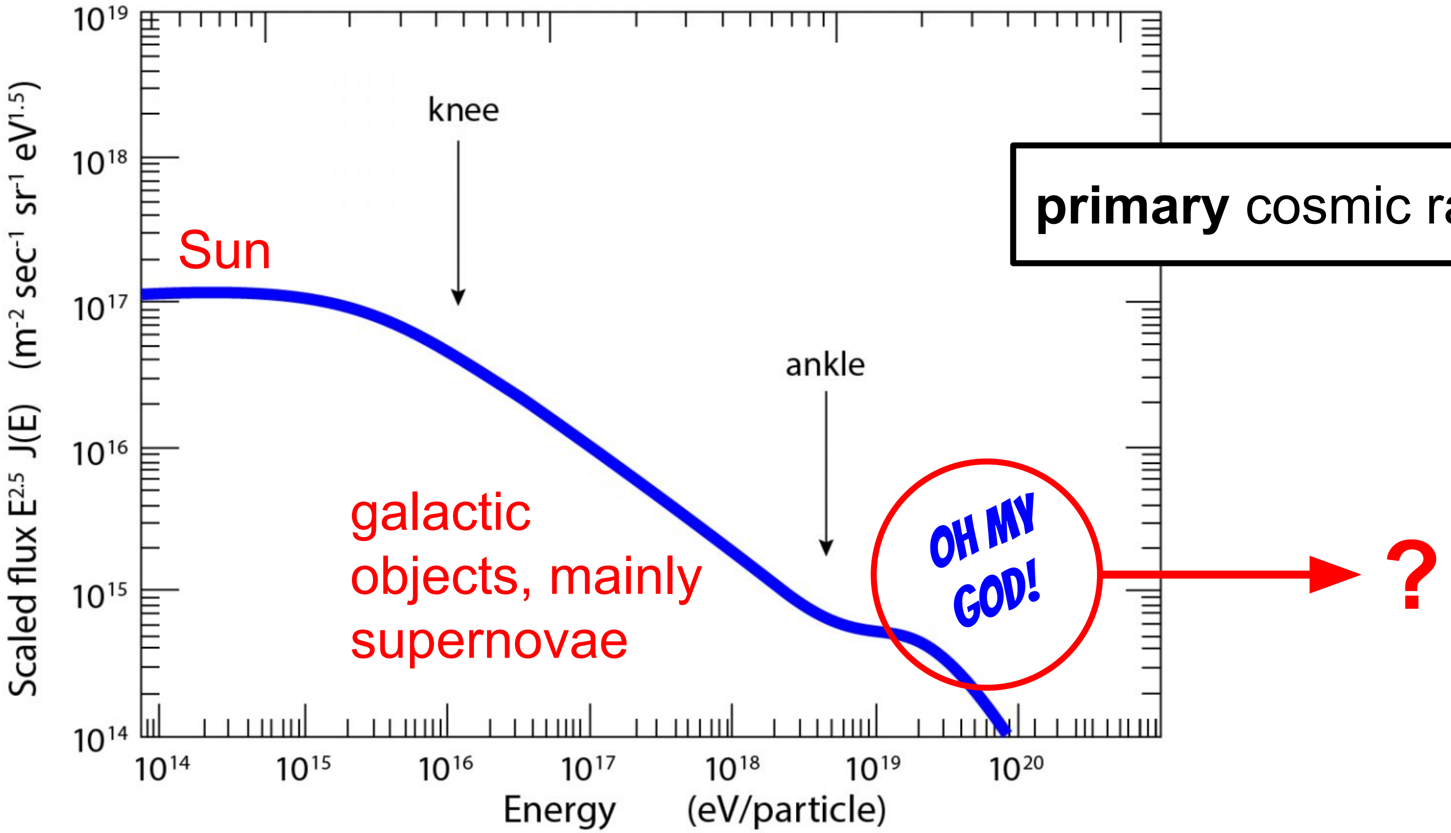
BULLETS FROM THE OUTER SPACE...

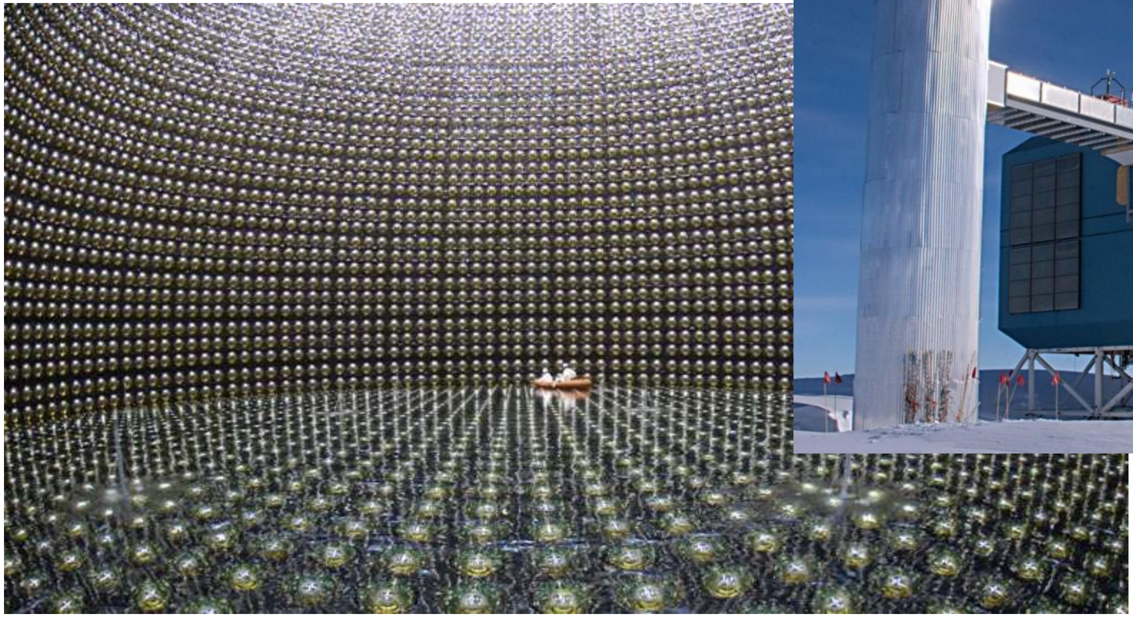
H (~95%), He (~4%) and heavier nuclei up to Fe (~1%) are generated and accelerated in various astrophysical sources - wide range of energies:



...EVEN SOME VERY ELUSIVE ONES...

neutrinos are way the most abundant particles reaching Earth from the outer space
(~10^{11} neutrinos per squared centimeter per second from the Sun only!)

however they are way the less interacting → they come, pass through and leave



...COME AND HIT OUR ATMOSPHERE

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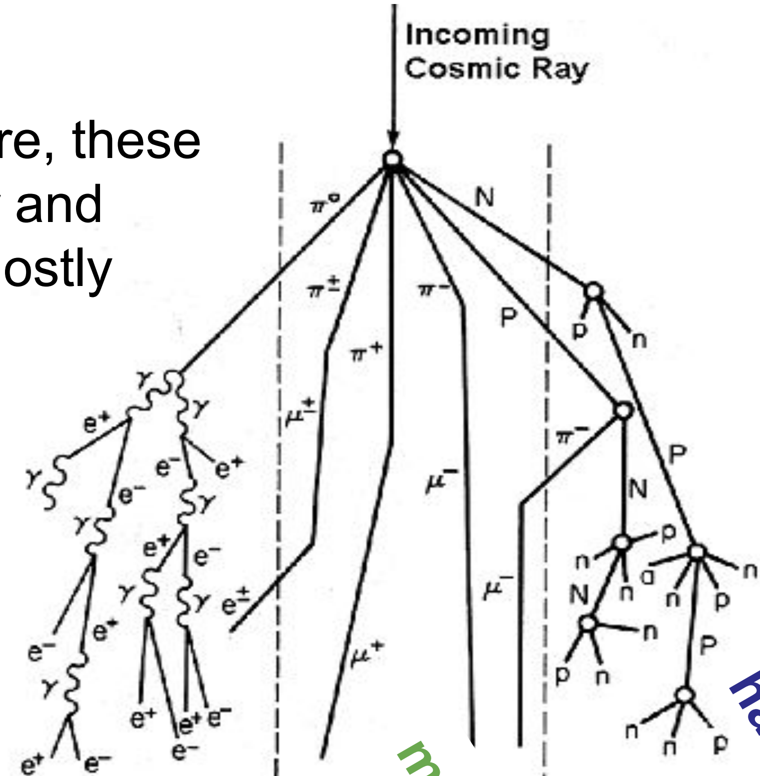
approaching the Earth atmosphere, these primary cosmic rays hit dense air and undergo spallation → mesons (mostly pions) and nucleons production

and then...

secondary cosmic rays

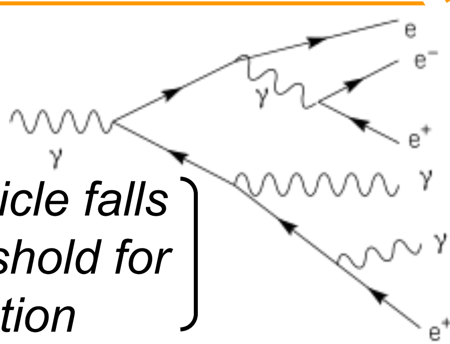


EM showers

meson decays

hadronic showers

$$\pi^0 \rightarrow \gamma\gamma$$

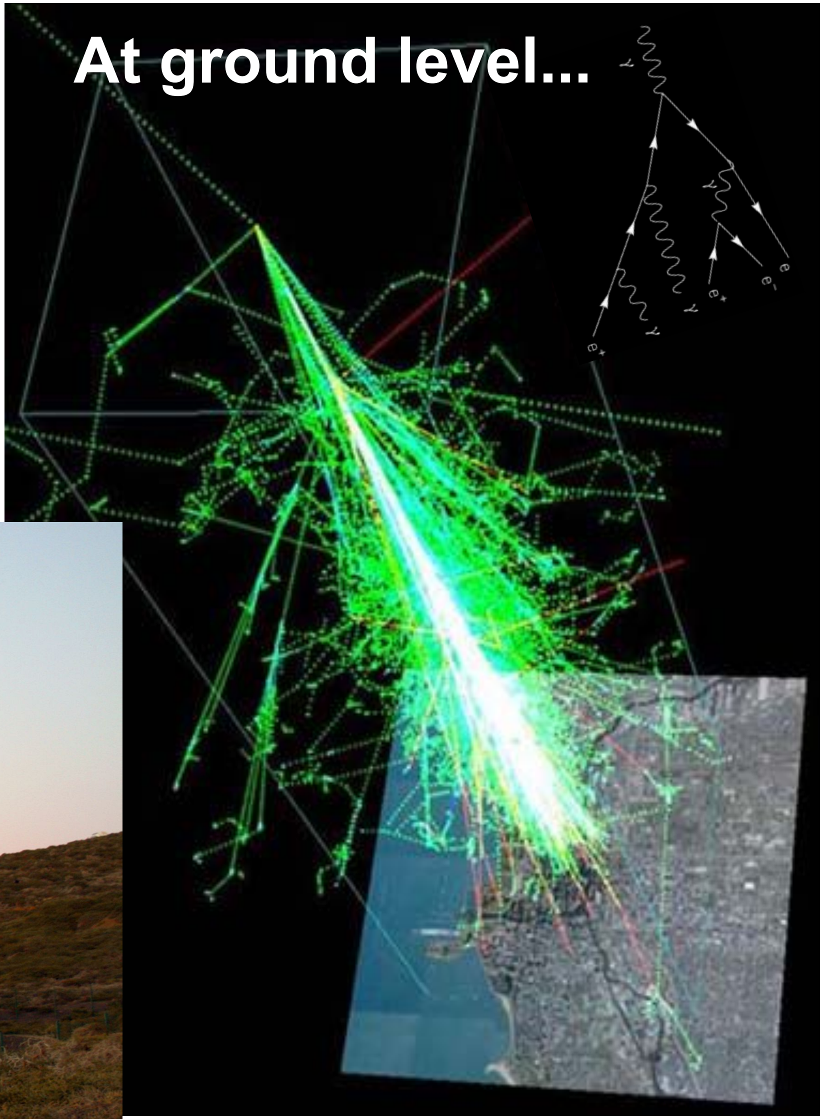


until energy per particle falls below ~1MeV - threshold for e^+e^- pair production

$$\pi^{\pm} \rightarrow \mu^{\pm} \overset{(-)}{\nu}_{\mu}$$

WHAT DO WE GET?

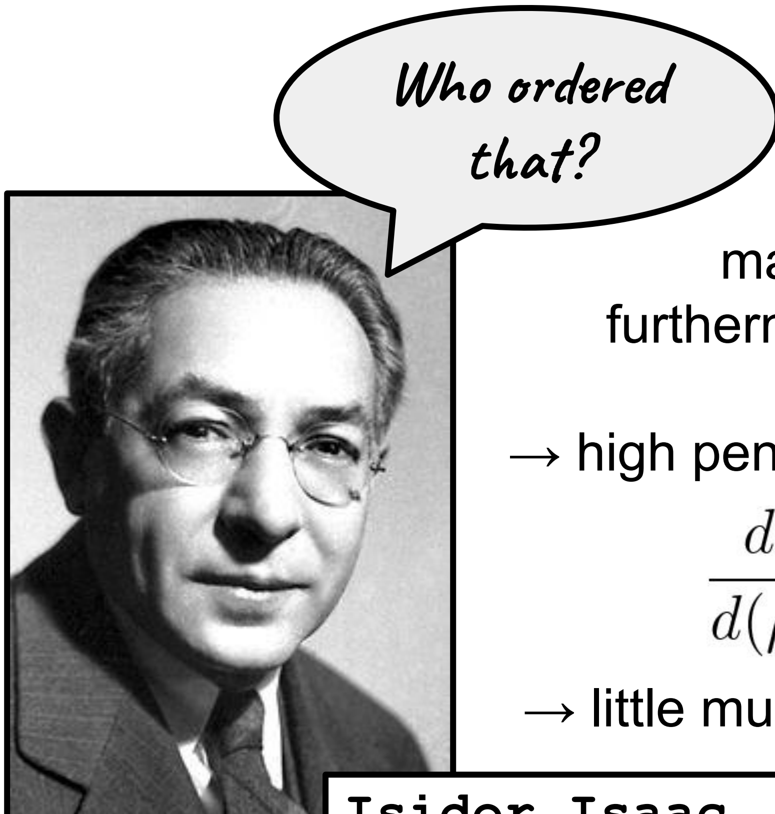
extensive air showers can develop in several kilometers → some of the electrons and gamma reach the ground level, leaving behind trails of scintillation and Cherenkov emissions (we'll talk about them later!)



WHAT DO WE GET?

but mostly few-GeV <u>muons</u> from charged pions decay

$$\pi^{\pm} \rightarrow \mu^{\pm} \overset{(-)}{\nu}_{\mu}$$



Isidor Isaac Rabi, 1936

mass of ~100MeV → no radiative emission
furthermore muons in this momentum range are Minimum Ionising Particles

→ high penetrating power

$$\frac{dE}{d(\rho x)} \sim 200 \frac{\mathrm{MeV}}{\mathrm{g/cm^2}}$$

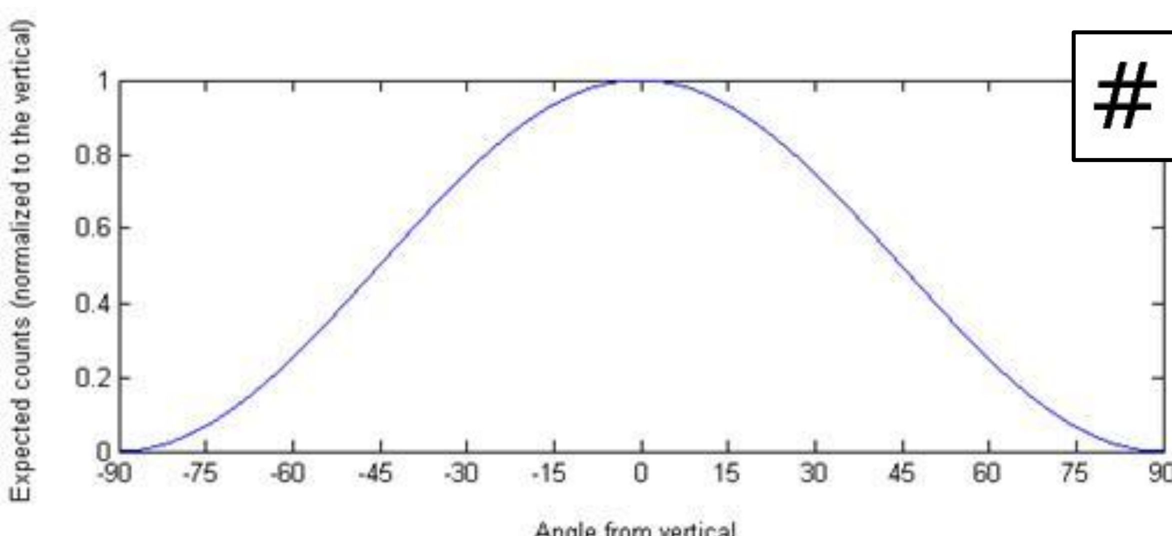
→ little multiple scattering contribution

WHAT DO WE GET?

how many bullets do we expect?

$$\frac{d\Phi_\mu}{d\Omega}(\text{at ground level}) \sim \frac{100}{s \cdot m^2 \cdot sr}$$

cosmic rays come with an angle with respect to the ground surface axis
→ the more the depth of atmosphere to travel through, the less the rate



$$\boxed{\# \propto \cos^2(\phi)}$$

WHAT DO WE GET?

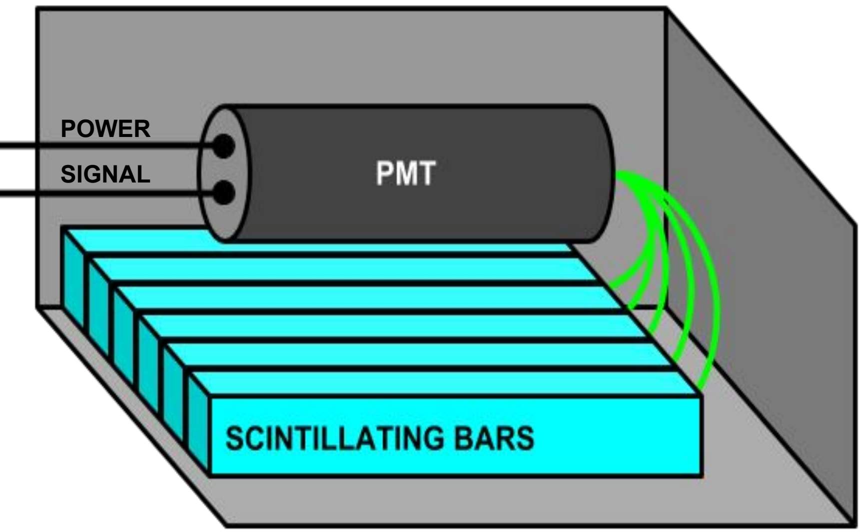
muons are themselves unstable: they undergo weak decay

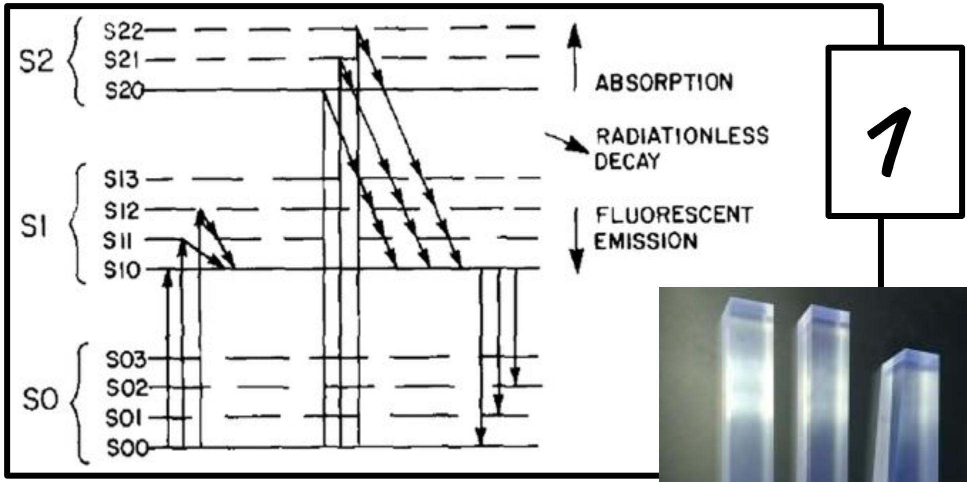
$$\mu^{\pm} \rightarrow e^{\pm} \overset{(-)}{\nu}_e \overset{(-)}{\nu}_\mu$$

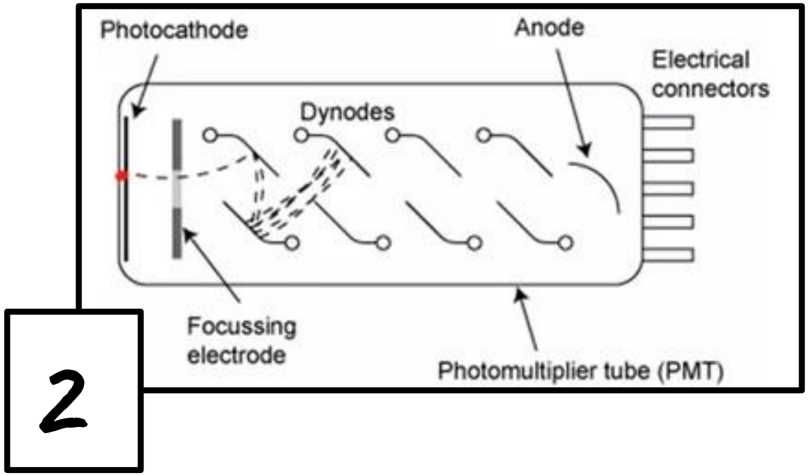
with a decay time of ~2μs → according to classical kinematics 10GeV muons should travel only 600m before decaying

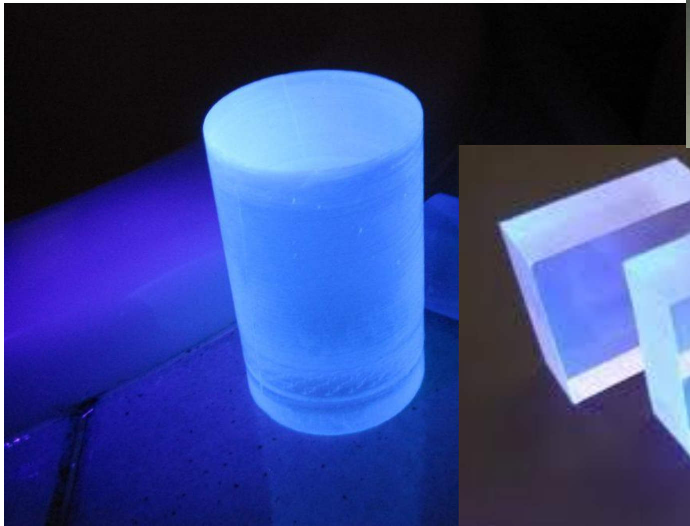
the trick: relativistic time dilation makes fast muons live longer in our reference frame *or equivalently* relativistic space contraction makes fast muons see shorter paths along the direction of their motion
→ *et voilà*, from 600m to 60km!
(Lorentz factor γ~100 at 10GeV)

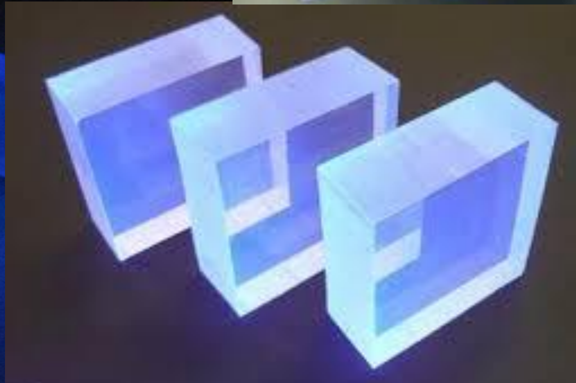
SCINTILLATION DETECTOR











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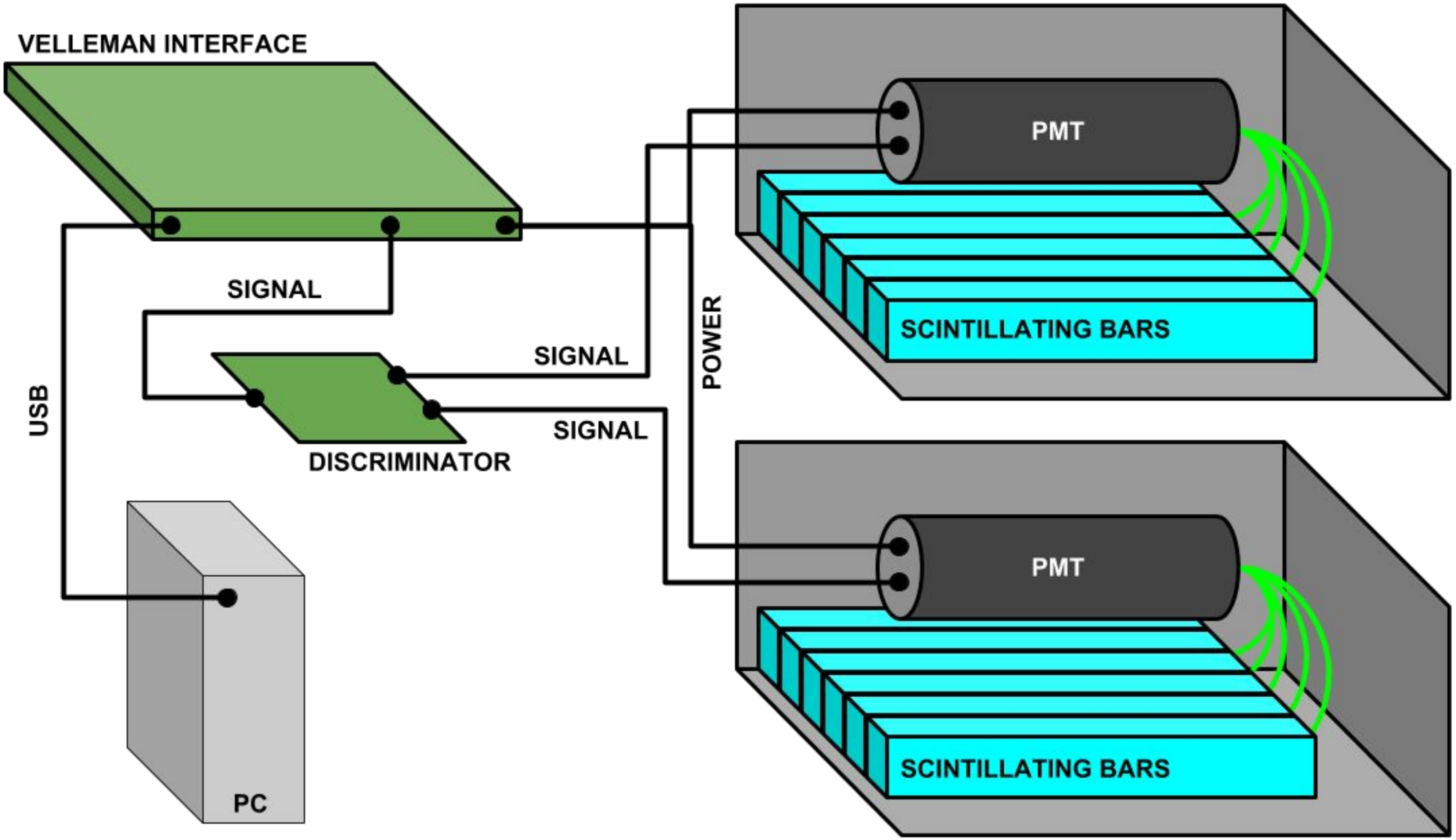

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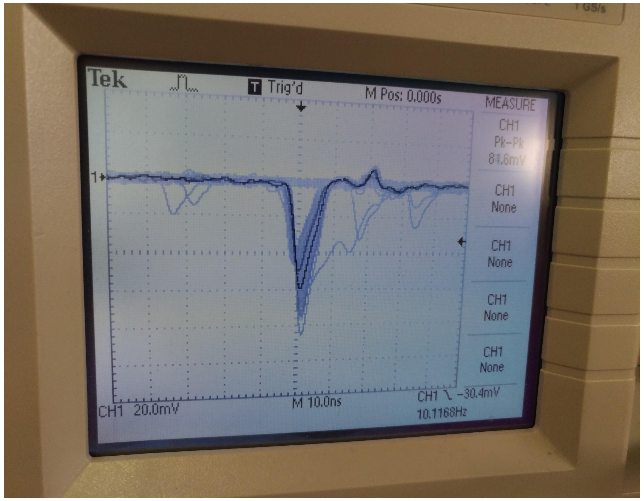
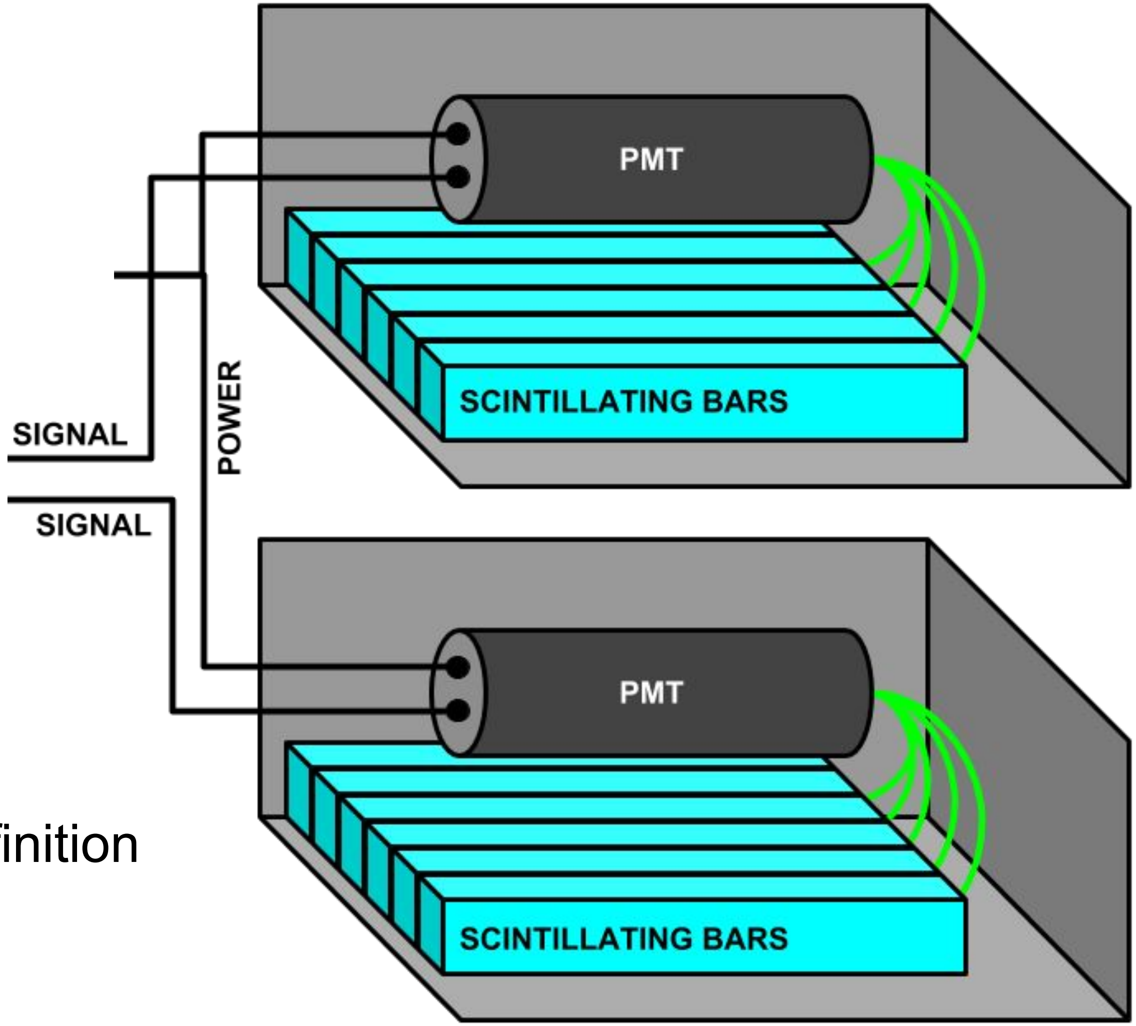
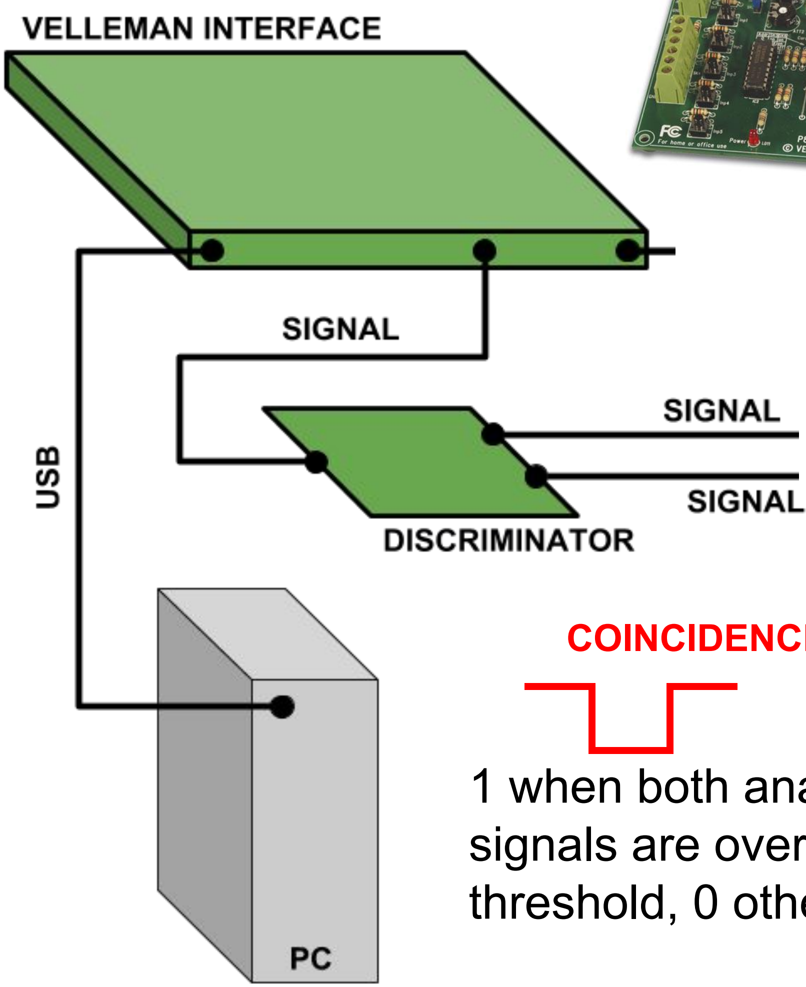
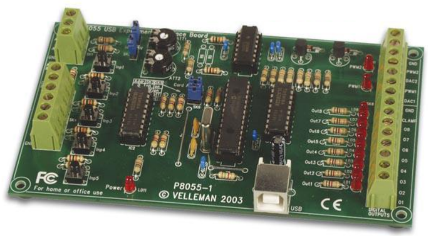




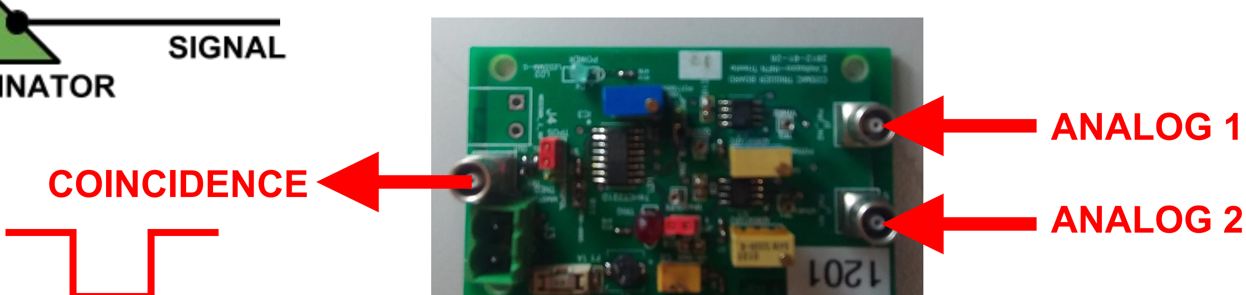
couple of analog signals → discrimination threshold definition

SCINTILLATION DETECTOR



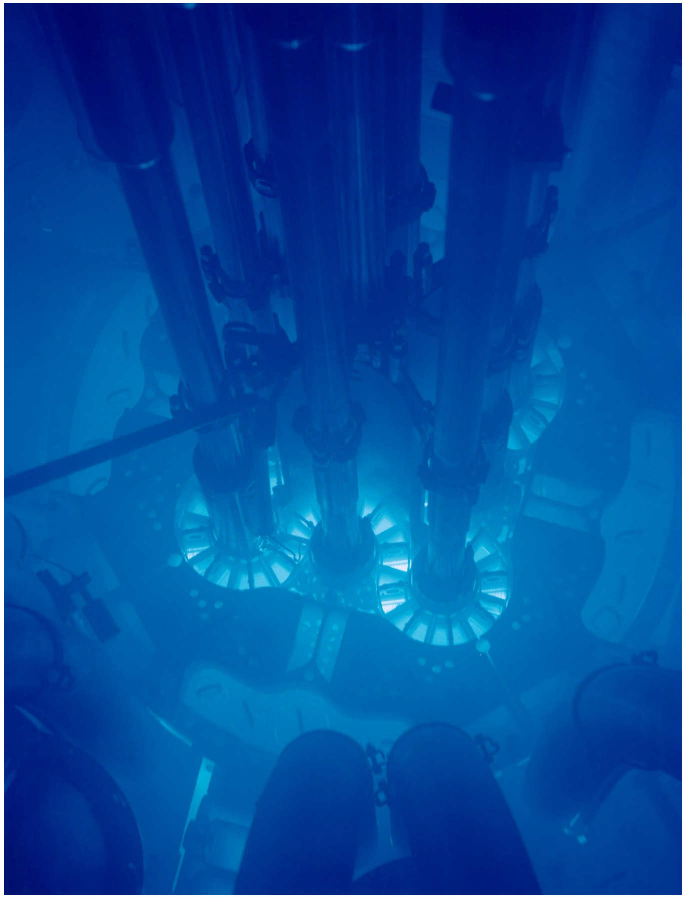


PC-PMT interface, manages both power supply and digital signal



1 when both analog signals are over threshold, 0 otherwise → event counter only!

CHERENKOV DETECTOR



high energy particles entering some medium can travel faster than light (in that medium!) for a bit → slowing down to $v < c$ results in the emission of blue photons at an angle

$$\theta = \mathrm{acos}\left(\frac{c}{nv}\right)$$

the faster the bullet, the more the light!

CHERENKOV DETECTOR

possible application to particle detection for media which are transparent to Cherenkov light → best media include

- water
  (Super-Kamiokande, IceCube)
- gaseous mixtures such as air
  (ACTs such as MAGIC)
- some transparent crystals such as PbO
  (extensive use in high energy physics calorimetry)

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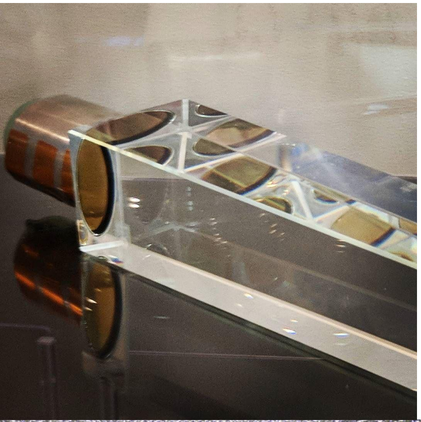
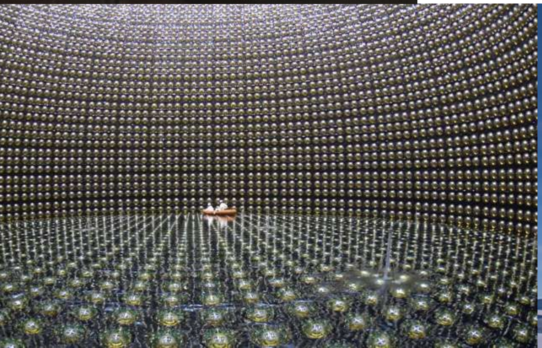

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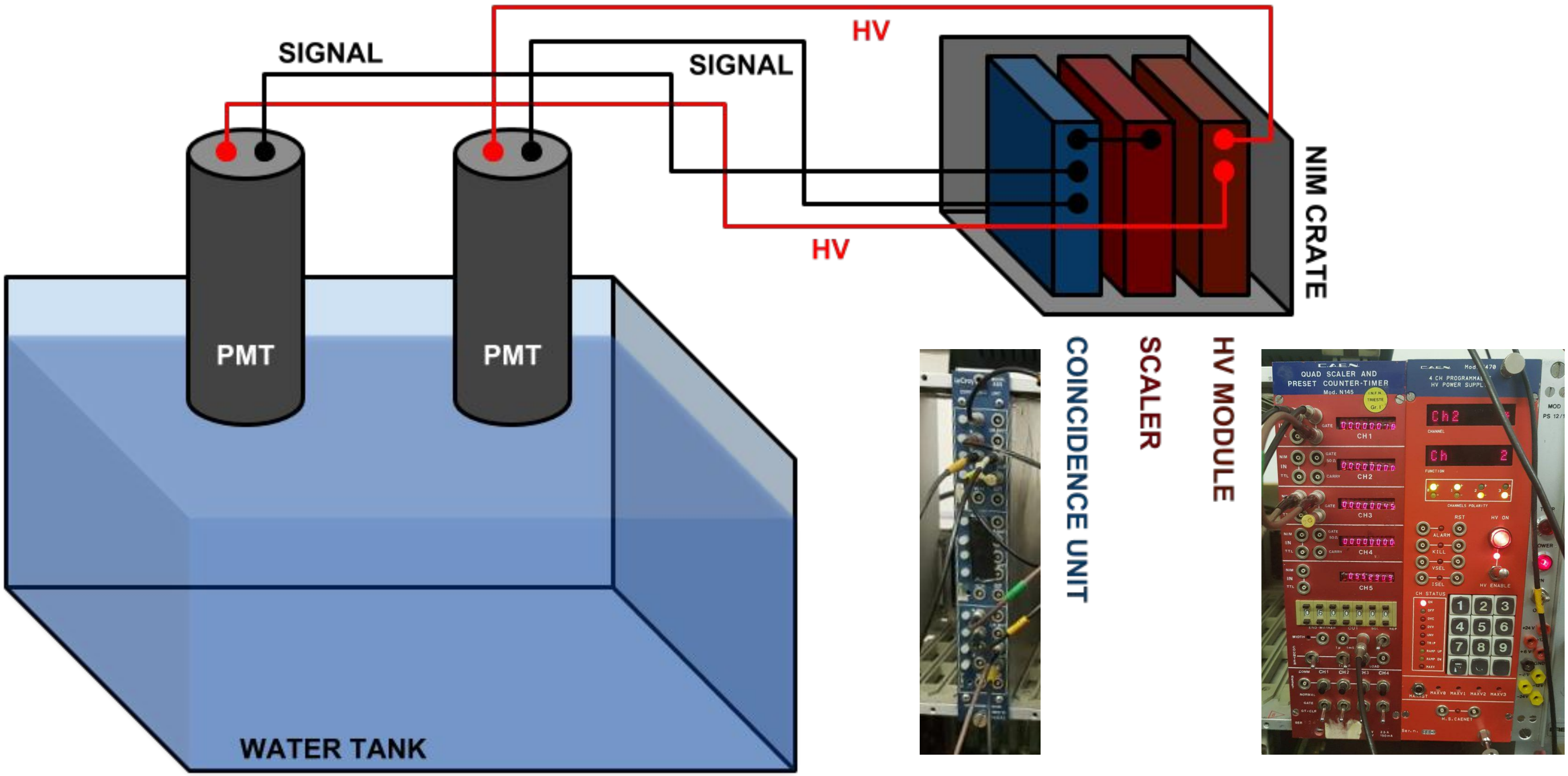
CHERENKOV DETECTOR

...a simple water tank will meet our needs!



thank you!