



THE CHERENKOV THRESHOLD DETECTOR (XCET)

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WHAT IS CHERENKOV RADIATION?



The Nobel Prize in Physics 1958

"for the discovery and the interpretation of the Cherenkov effect"



**Pavel Alekseyevich
Cherenkov**



Il'ja Mikhailovich Frank

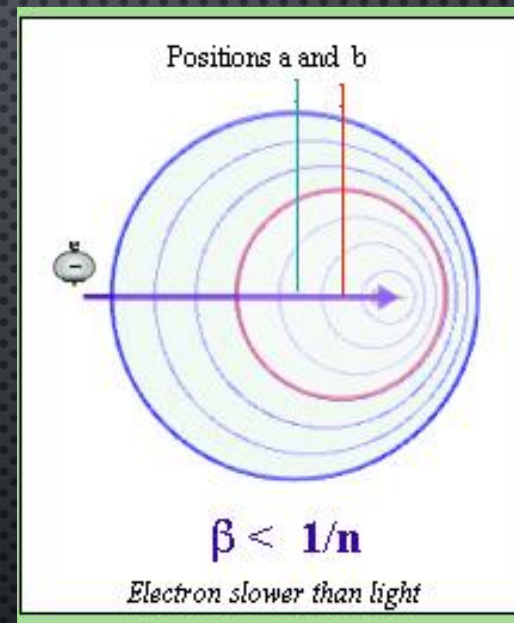
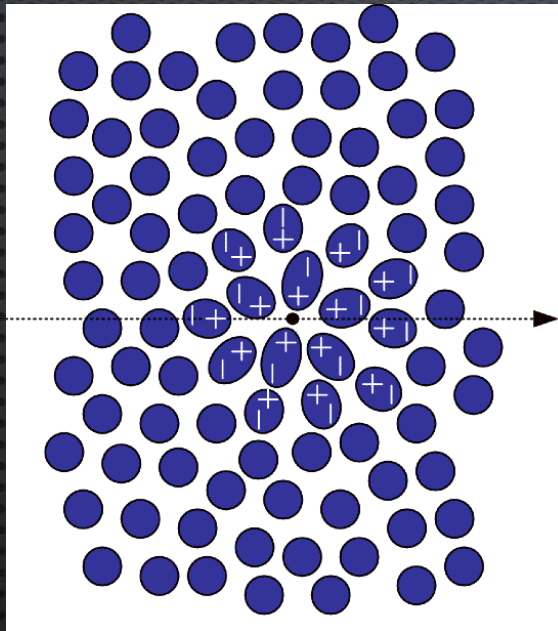


Igor Yevgenyevich Tamm

Experimentally observed by
Cherenkov in 1934

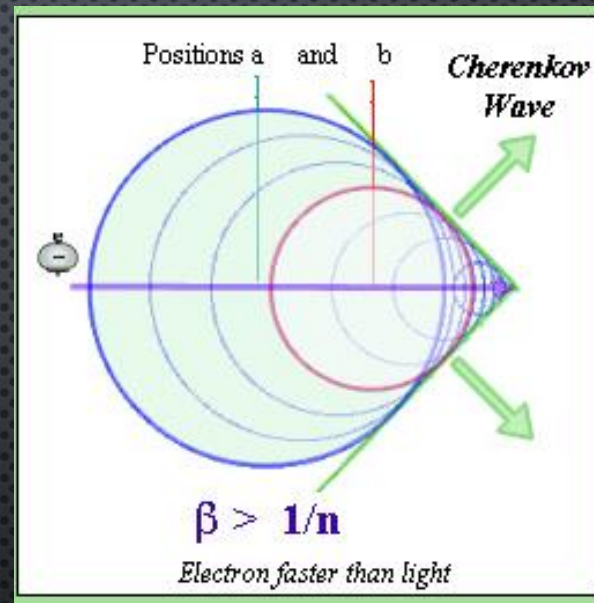
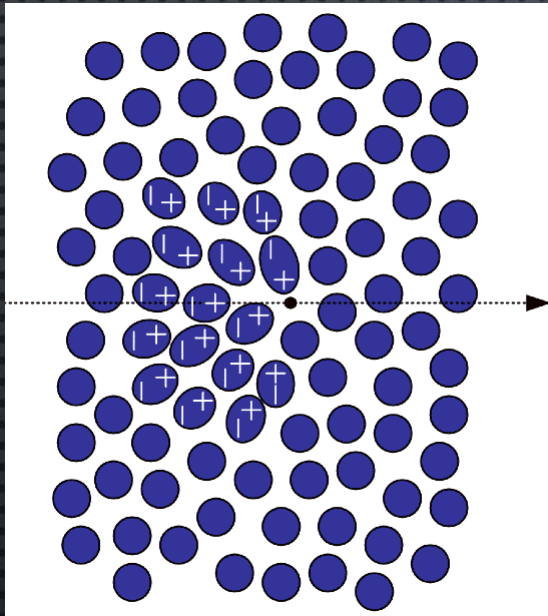
Theoretically explained by
Frank & Tamm in 1937

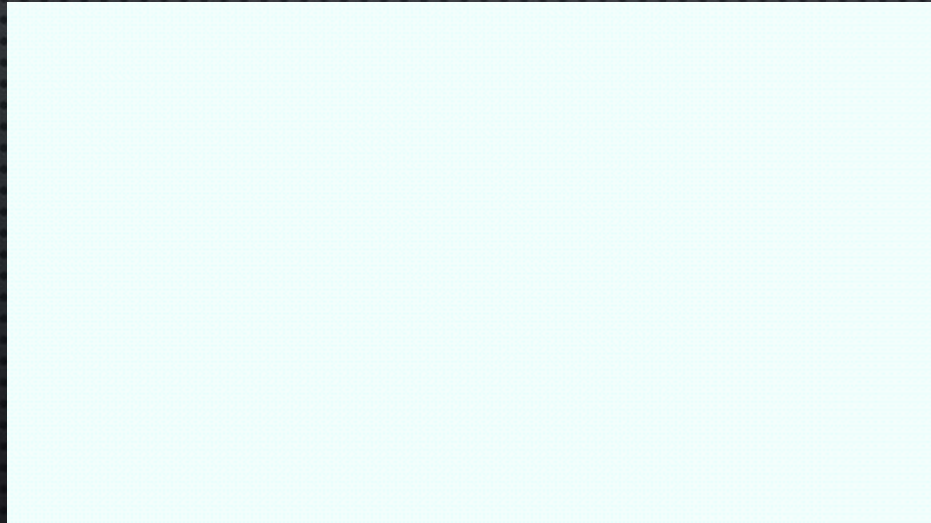
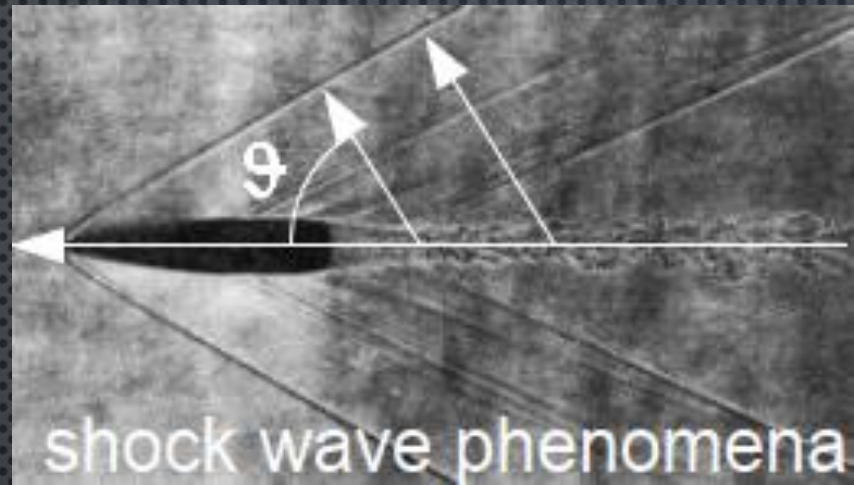
The Cherenkov effect occurs when the velocity of a charged particle travelling through a dielectric medium exceeds the speed of light in that medium.



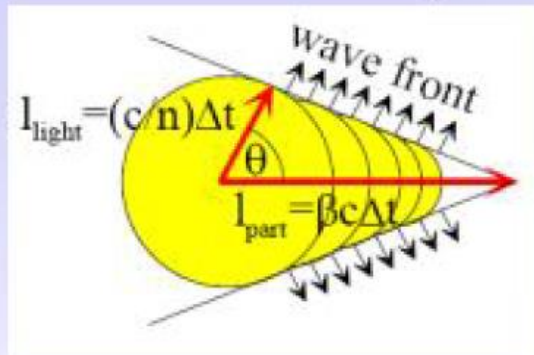
Local polarisation by a slow particle: $v < c/n$

Local polarisation by a relativistic particle: $v > c/n$



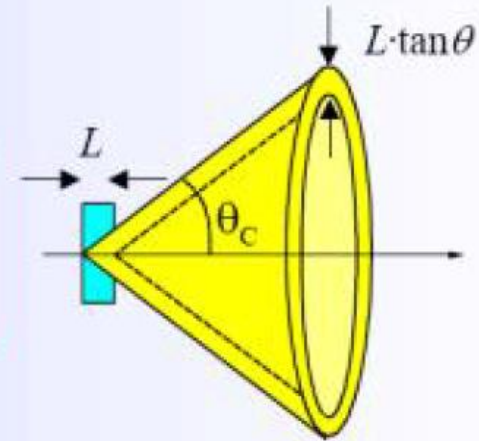


with velocity $\beta \geq \beta_{thr} = \frac{1}{n}$ n : refractive index



$$\cos \theta_c = \frac{1}{n\beta}$$

with $n = n(\lambda) \geq 1$



■ $\beta_{thr} = \frac{1}{n} \rightarrow \theta_c \approx 0$ Cherenkov threshold

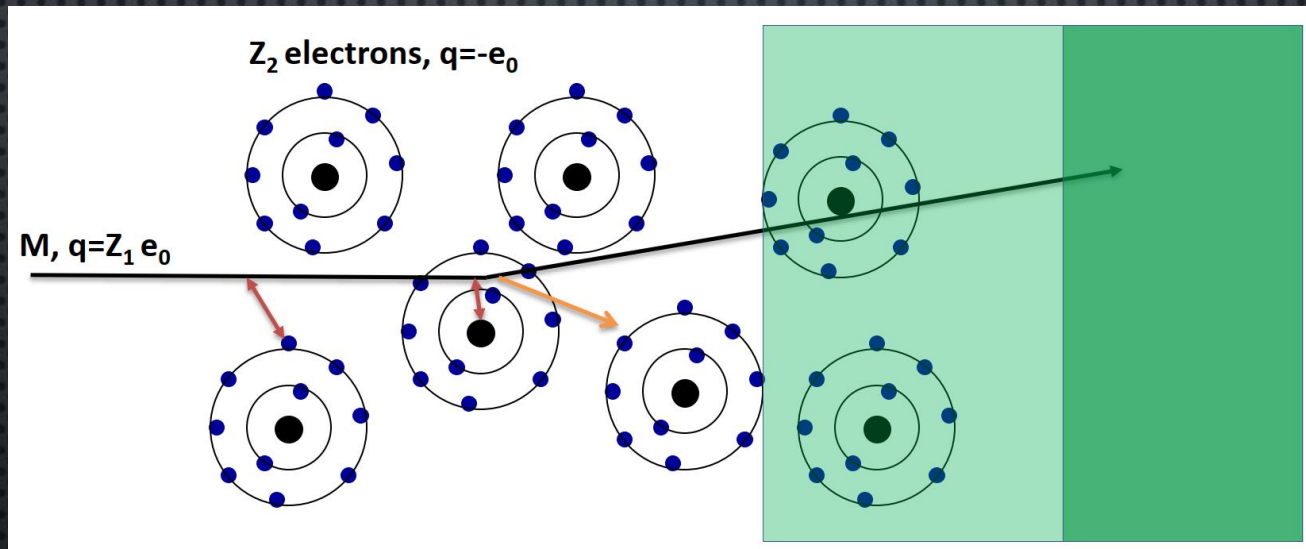
■ $\theta_{max} = \arccos \frac{1}{n}$ 'saturated' angle ($\beta=1$)

Some interesting properties:

- Fast emission ~pico seconds – very appreciated for timing
- Wavelength depends on $1/\lambda^2$ -> high emission in the UV and blue
- Number of photons emitted is proportional to Z^2 of the incoming particle
- Light is polarised

HOW TO DETECT INTERACTION WITH MATTER?

- Charged particles interact with matter and lose energy to the medium
 - By excitation, ionisation, Bremsstrahlung and Cherenkov radiation



- To detect the particle, we need the energy loss to translate into light or an electrical charge

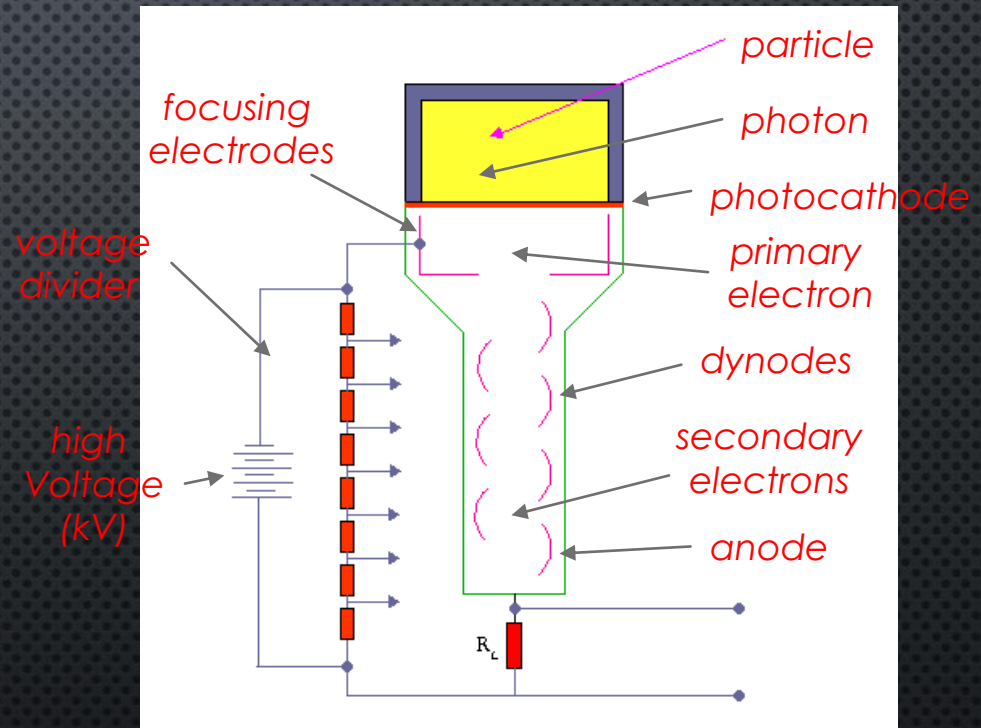
Photodetectors

Photomultiplier tubes: the oldest and widely used technology

- Individual photon detection
- High quantum efficiency (30%)
- High gain (10^6)
- Fast signals (ns)
- Low dark count rate (Hz)
- Different form factors



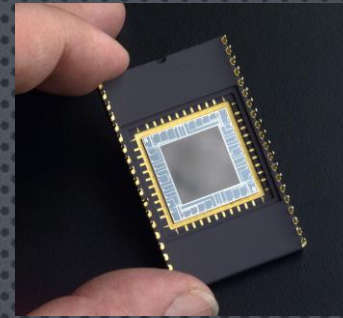
Photomultiplier tube



How a PMT works

Photodetectors

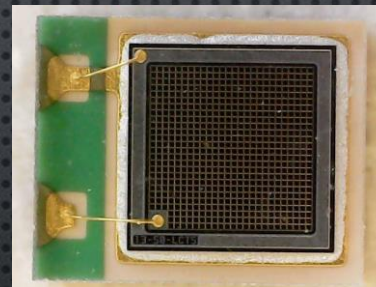
Silicon-based cameras: CCD, CMOS



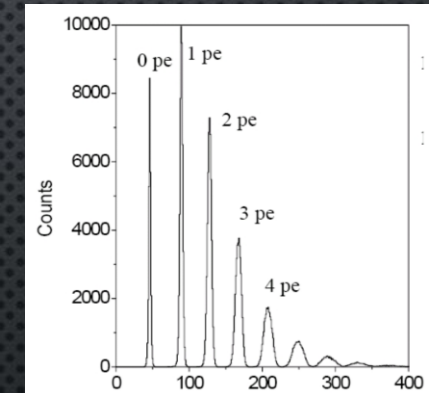
CCD sensor

Silicon photomultipliers: new technology developing very fast

- Individual photon detection
- High efficiency (50%)
- High gain (10^6)
- Fast signals (ns)
- Low voltage (50V)
- Compact (mm)
- High dark count rate (kHz/mm²)



~500 photodiodes
1.3mm × 1.3mm



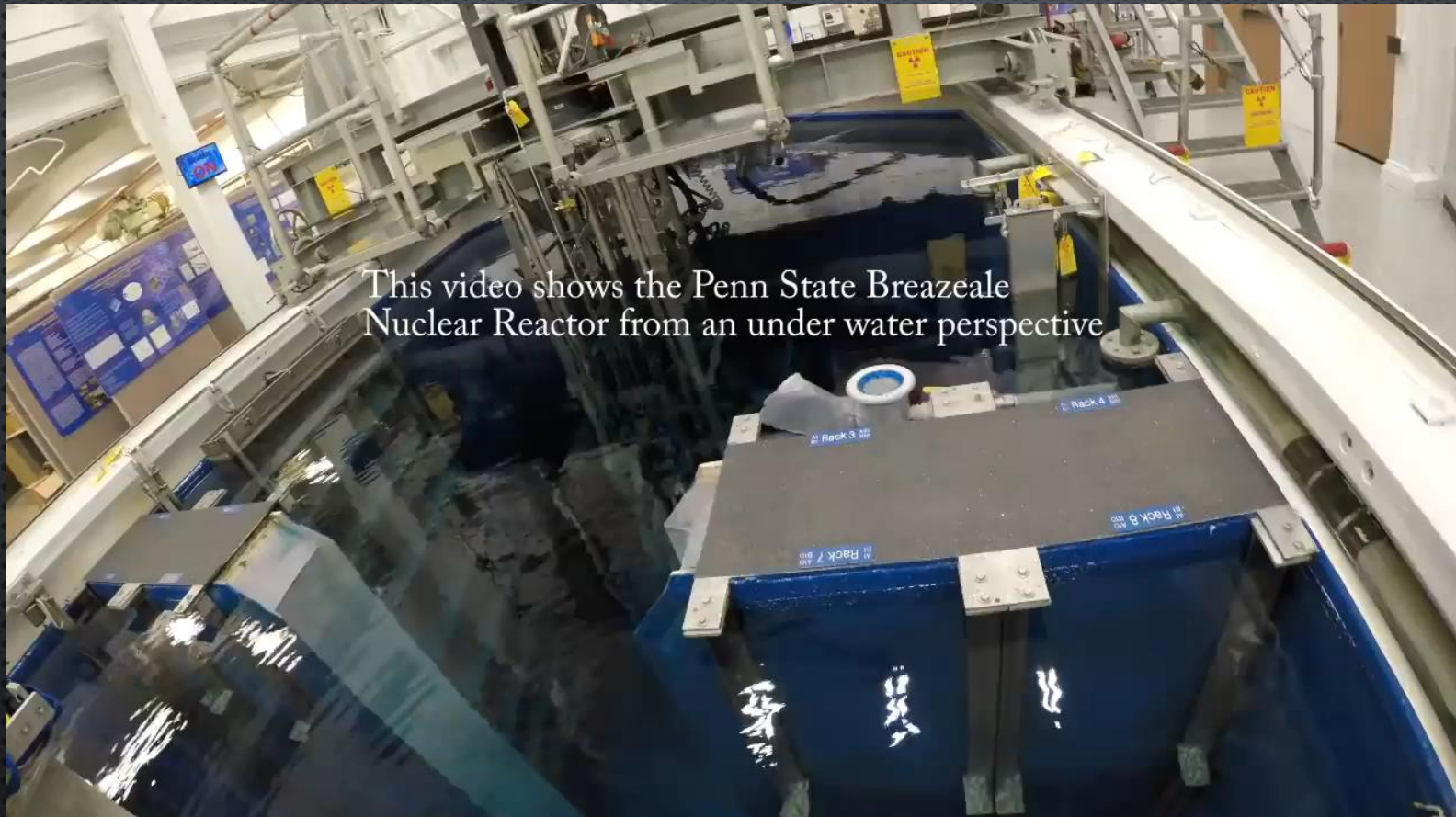
Individual photon
counting

Less common:

Gaseous photon detectors: exploit ionisation in gases

Hybrid photon detectors: a mix between PMT and silicon detectors

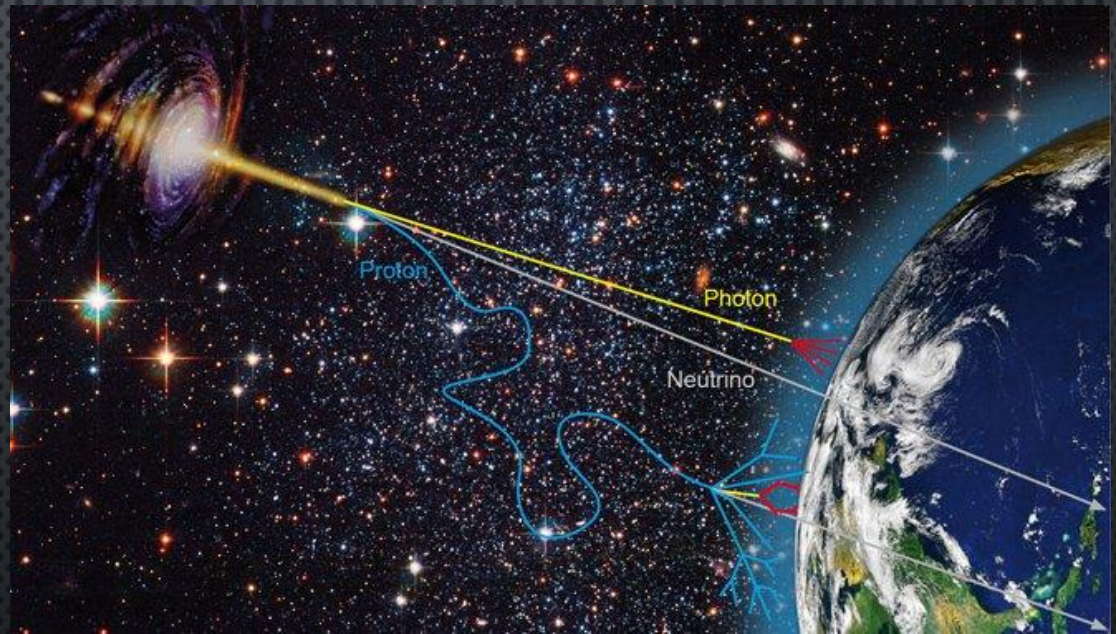
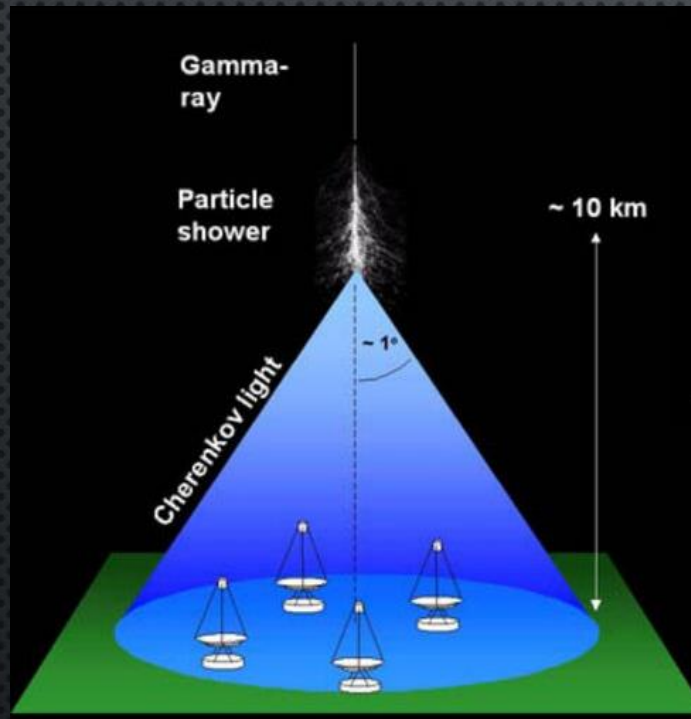
EXAMPLES OF CHERENKOV LIGHT



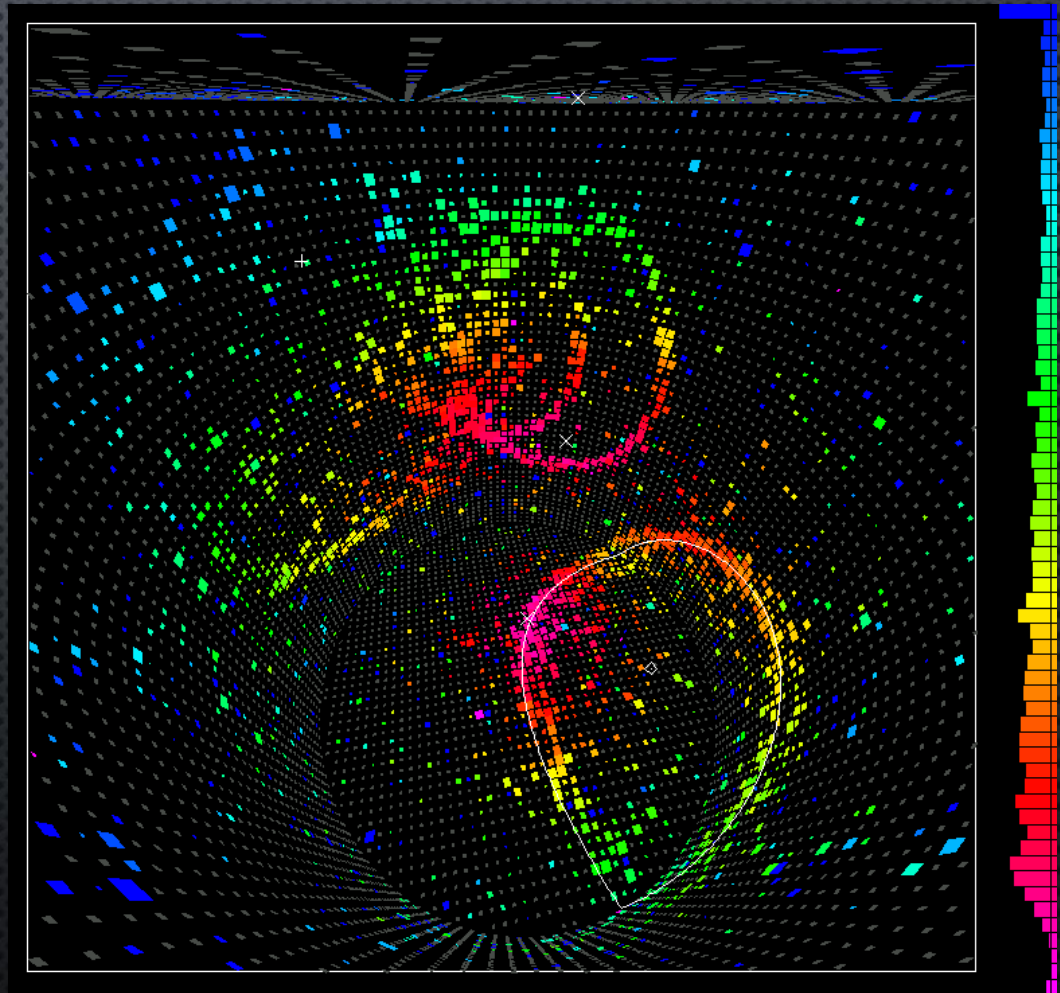
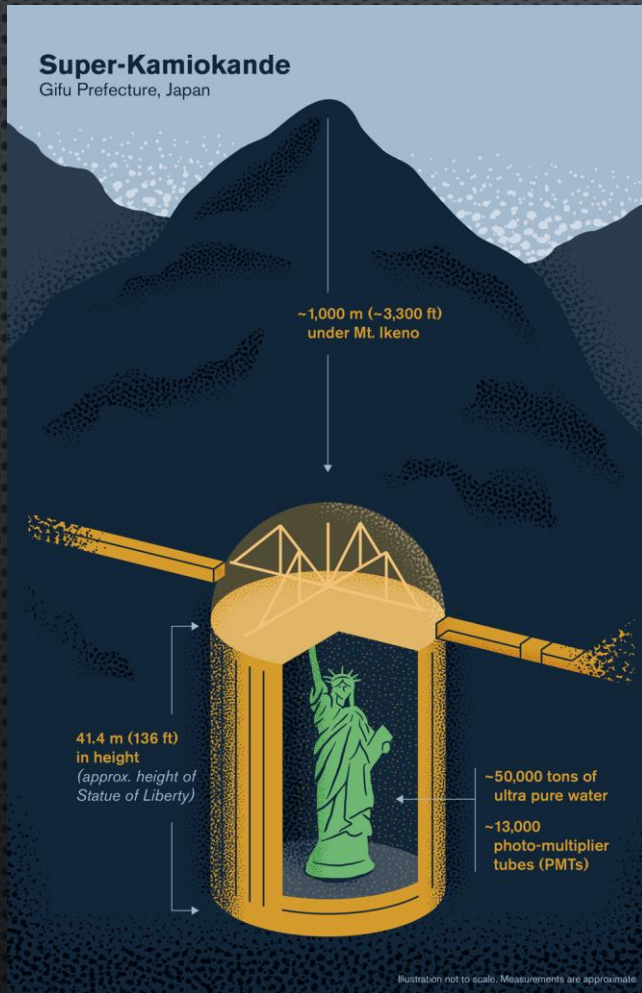
This video shows the Penn State Breazeale Nuclear Reactor from an under water perspective



CHERENKOV TELESCOPE ARRAY



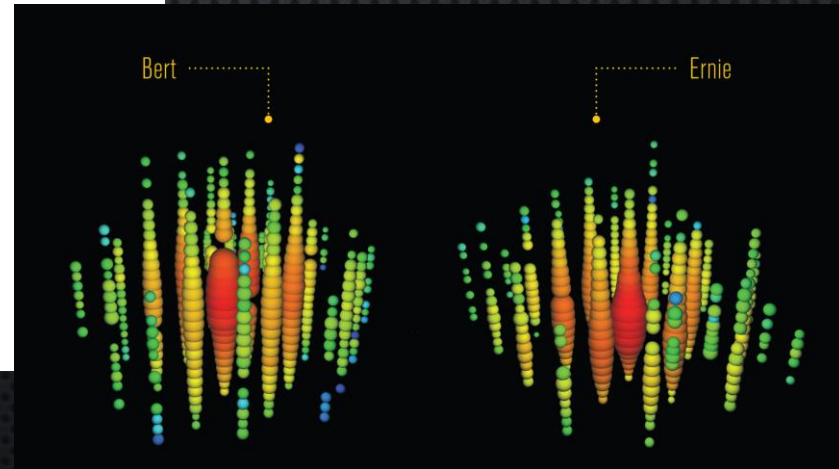
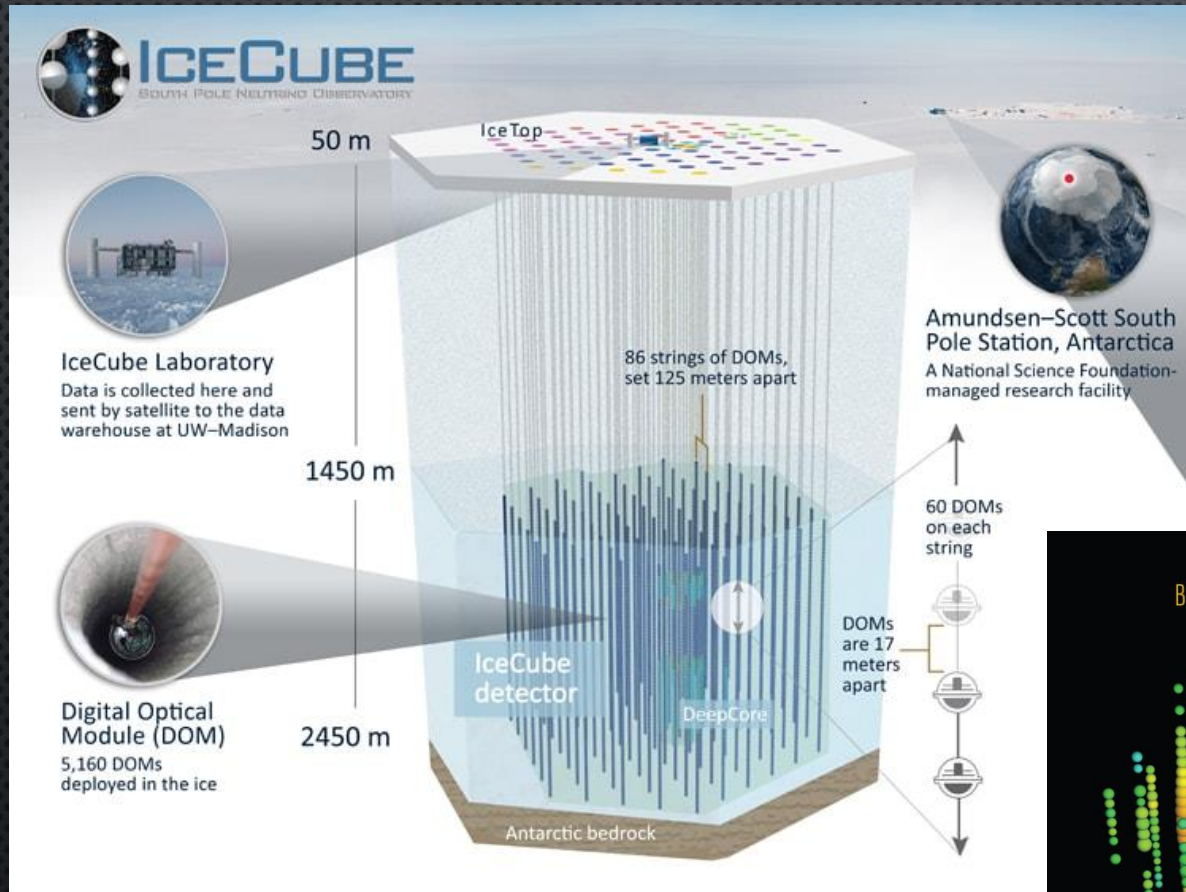
SUPER KAMIOKANDE



ICE CUBE



(not this one...)

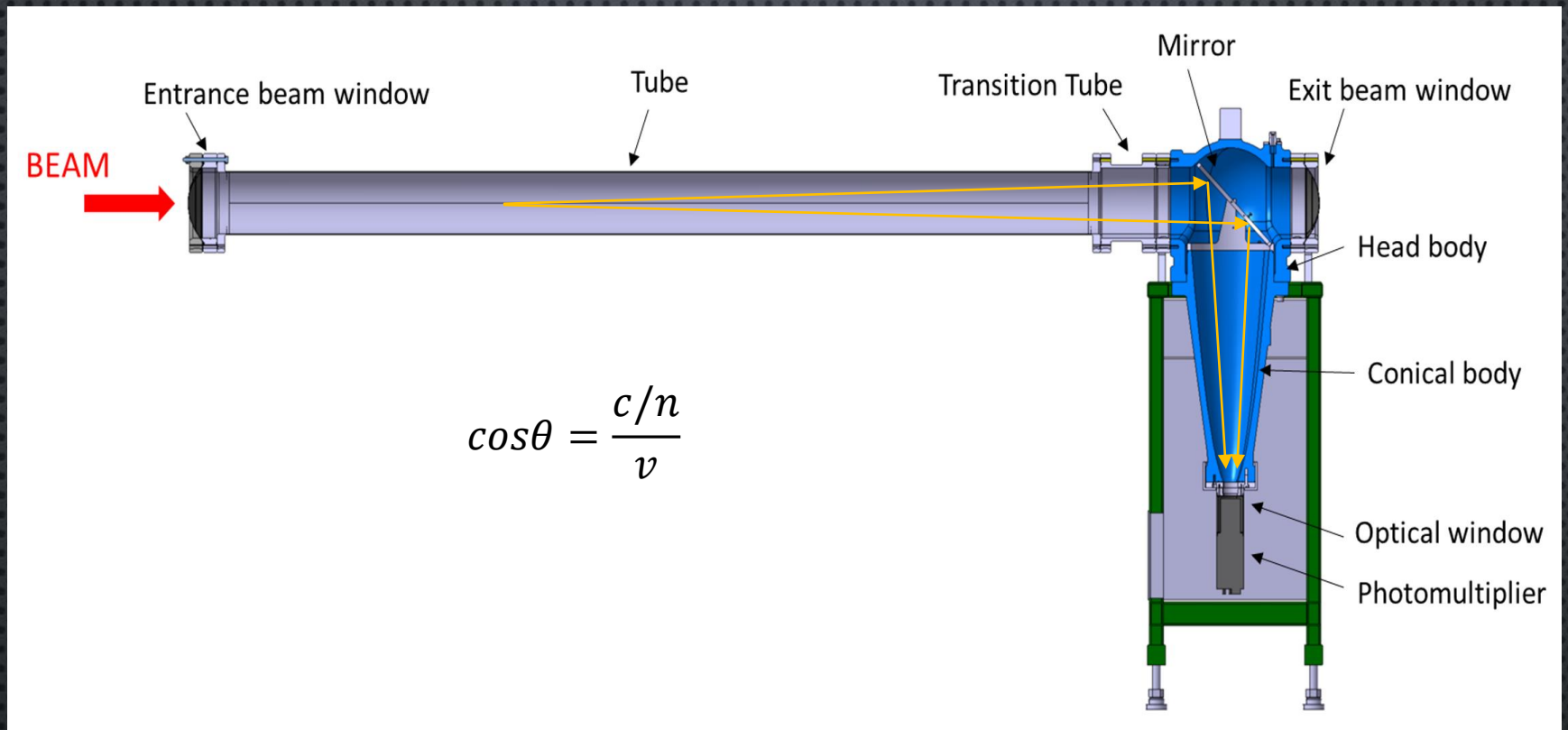


AND FINALLY: THE CHERENKOV THRESHOLD DETECTOR (XCET)

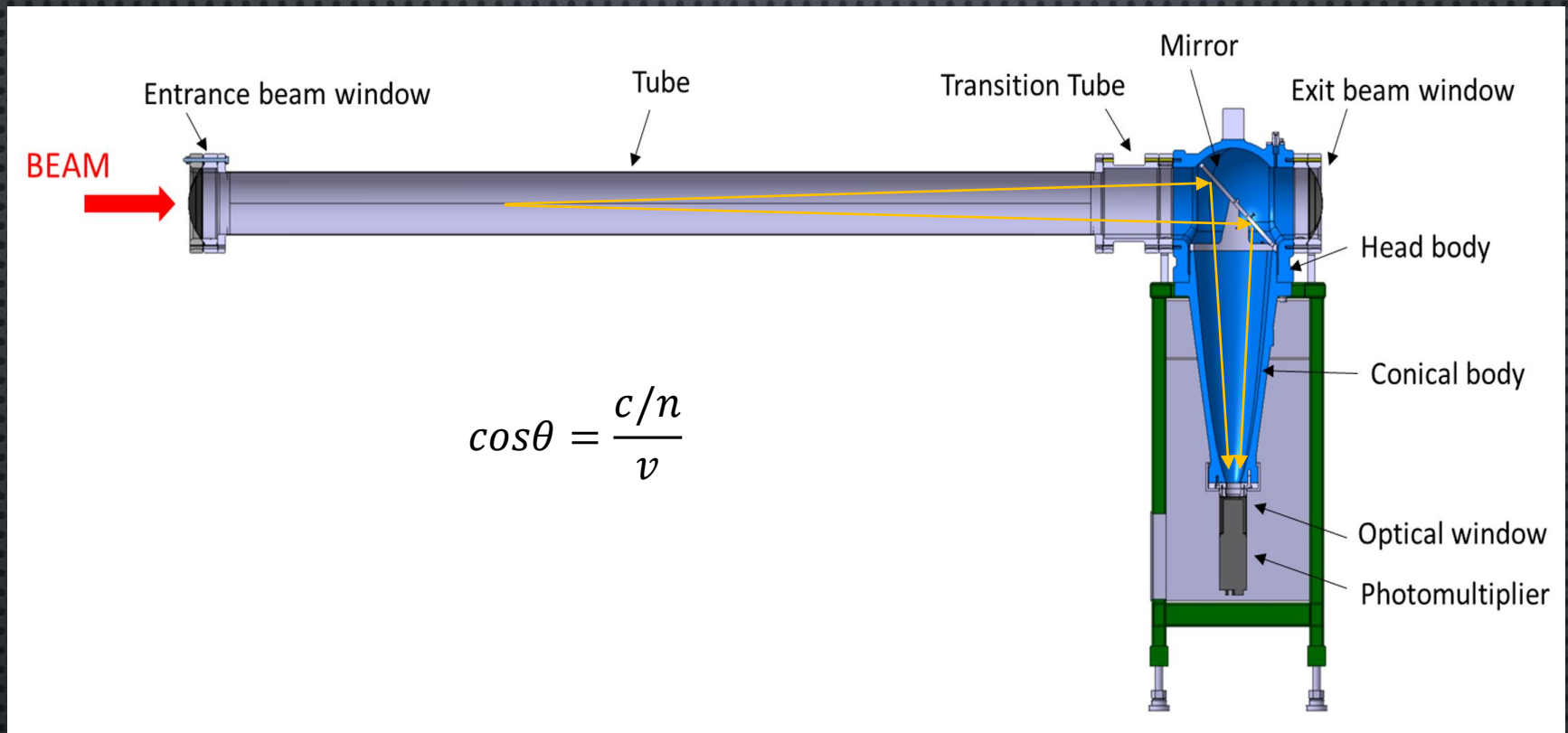


We exploit the Cherenkov effect to identify individual particles in the beam:
Proton? Kaon? Pion? Electron?

This information can be used to study the beam composition or by the experiments to know which particle enters their detector.

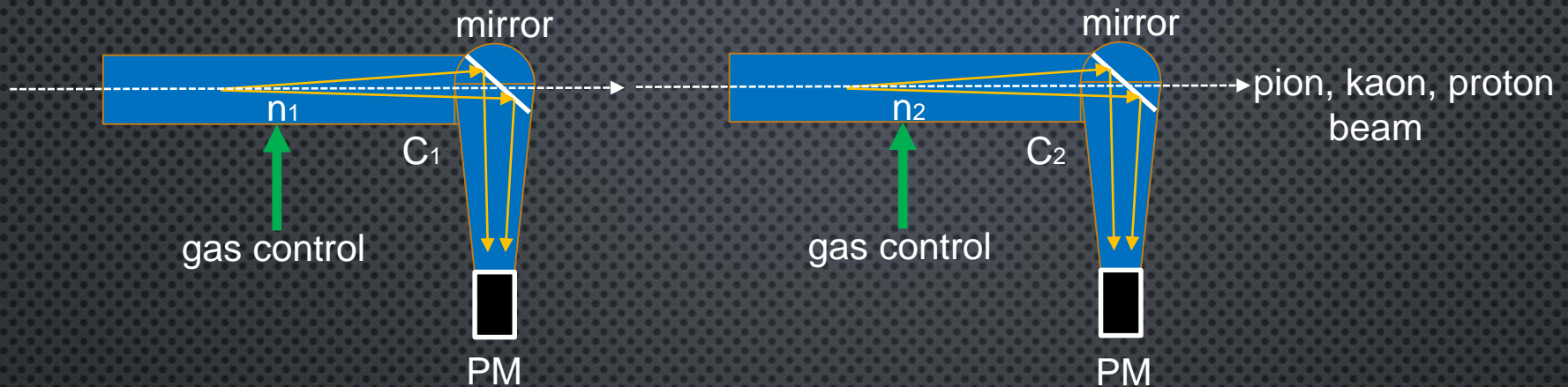


- A beam particle enters the beam pipe where there is a radiator gas
- If the threshold condition is fulfilled, $v > c/n$, it emits Cherenkov light
- If the angle of the Cherenkov cone is in the acceptance of the optics, it can be seen by the photomultiplier



- We can be sensitive to a wider range of particle velocities by modifying the refractive index of the gas 'n':
 - We can change the pressure: $n = 1 + k * P$
 - We can change gas: N_2 , CO_2 , He, special gases...

PARTICLE IDENTIFICATION



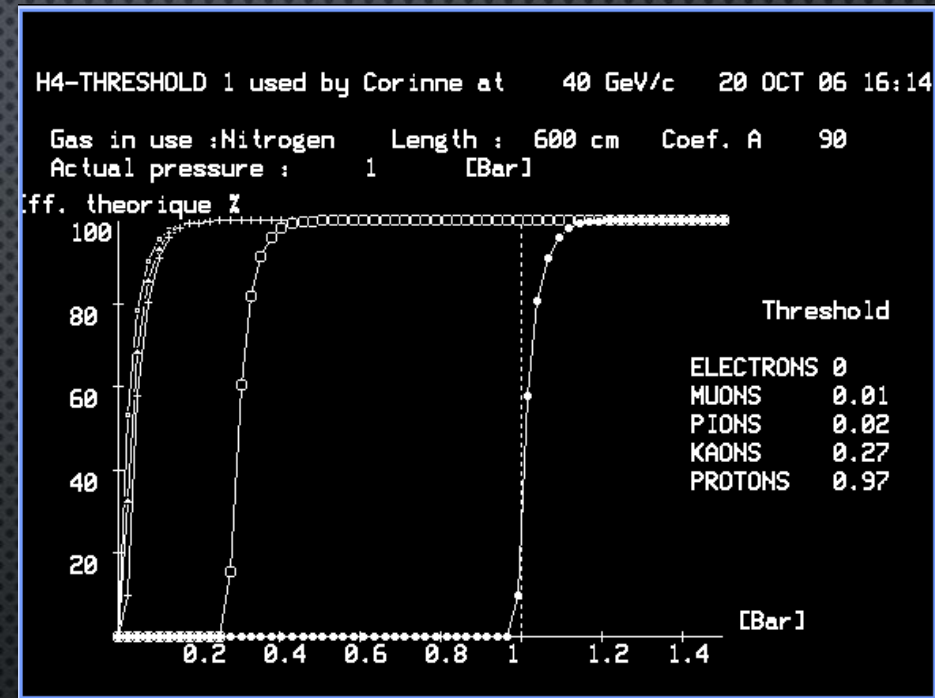
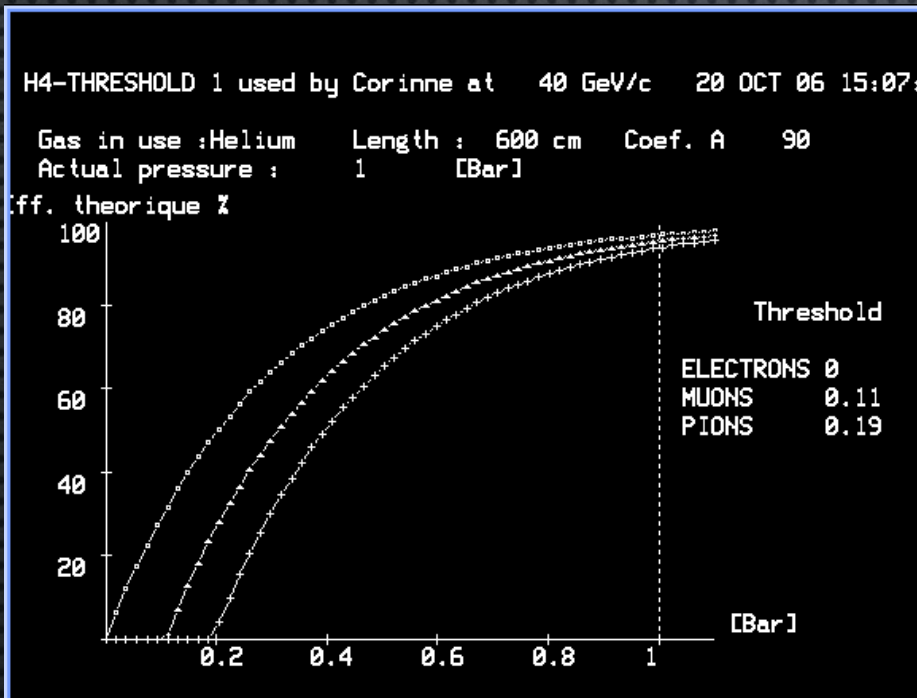
Choose n_1, n_2 in such a way that for:

$$n_2 : \quad \beta_\pi, \beta_K > 1/n_2 \text{ and } \beta_p < 1/n_2$$

$$n_1 : \quad \beta_\pi > 1/n_1 \text{ and } \beta_K, \beta_p < 1/n_1$$

Light in C_1 and C_2	→	identified pion
Light in C_2 and not in C_1	→	identified kaon
Light neither in C_1 and C_2	→	identified proton

Effect of different gases in the detection threshold



A FEW LAST NOTES



- We always install a scintillator close to an XCET and we put both detectors in coincidence to suppress noise (trigger)
 - The signals from the PMT typically are:
 - Fast: tens of ns
 - Small: tens of mV
- We can:
- Digitise them
 - Use a comparator

If you would like to go deeper into the physics of Cherenkov counters, this is a reference paper:

“Cerenkov Counter Technique in High-Energy Physics”, J. Litt and R. Meunier (CERN)

And you can contact me for questions or any further information:
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Thank you very much for your attention

I wish you success but, above everything, enjoy and have fun!!

Questions?

