Week 14: Chap. 19 Miscellaneous Detectors

Multidimensional Detector Systems

Miscellaneous Detectors
-- Cerenkov Radiation
-- Liquid-filled detectors … bubble chamber & rare gas
-- Thermal calorimeters … bolometer
-- Other solid-state materials:
films, TLDs, track-detectors

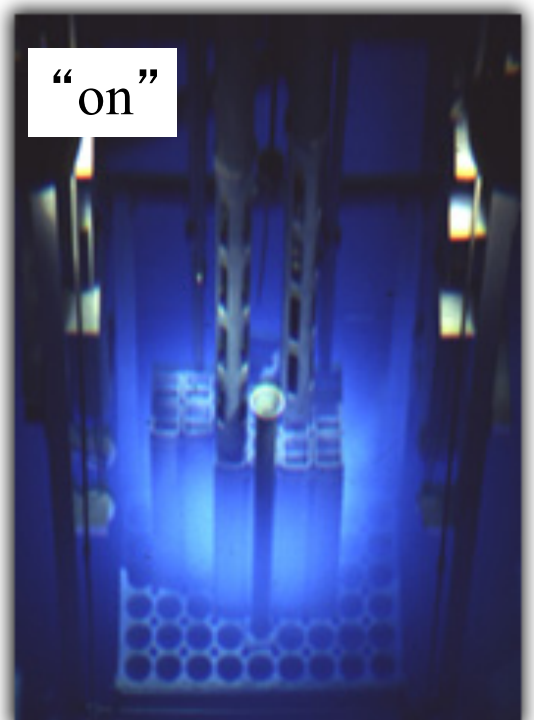
Summary/Overview Questions

"Big European Bubble Chamber", 35 m^3 of LH_2, (1973-85)

Miscellaneous Detectors: Cerenkov Light

Cerenkov light is emitted when a particle moves through a dielectric medium at a velocity that is faster than the phase velocity of light in that medium. (e.g. in water n=1.33, $c=0.75c_{vac}$) The effect is one of a shockwave caused by the electromagnetic interaction of the particle with the atoms. At low velocities (low energy) photons emitted during the displacement/replacement of the atoms can destructively interfere …the number of photons that are emitted is proportional to the square of the *velocity* of the particle and to the square of the frequency of the emitted light (N.B. n is a function of ν which cuts off the spectrum).

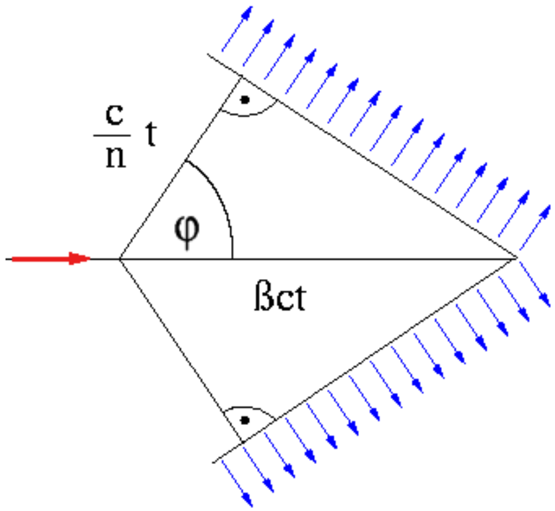
U.Missouri, Rolla
(200kW reactor)



$$n = \sqrt{\varepsilon_{rel}\mu_{rel}}$$

$$\mu_{rel} \sim 1 \quad \textit{nonmagnetic materials}$$

Miscellaneous Detectors: RICh's



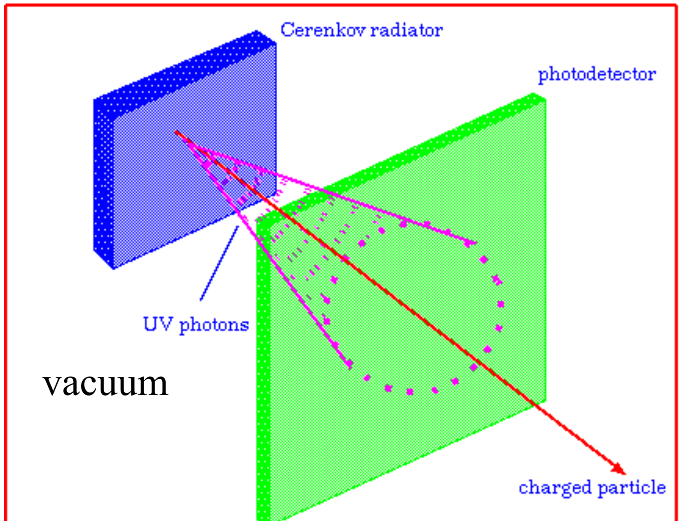
$$\cos\phi = \frac{1}{n\beta}$$

ϕ=42° at c in water

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha\, x}{c}\left(1 - \frac{1}{n^2\beta^2}\right)\frac{1}{\lambda^2}$$

n is the dielectric refractive index, α = 1/137
x is the path length in radiator
For a relativistic e^-
N ~390 photons/cm in water (at 300-700 nm)

Ring Imaging Cherenkov detector uses a "thin" radiator to form a pulse of light emitted like a smoke ring that is detected downstream. The characteristic angle is measured by the size of the ring.

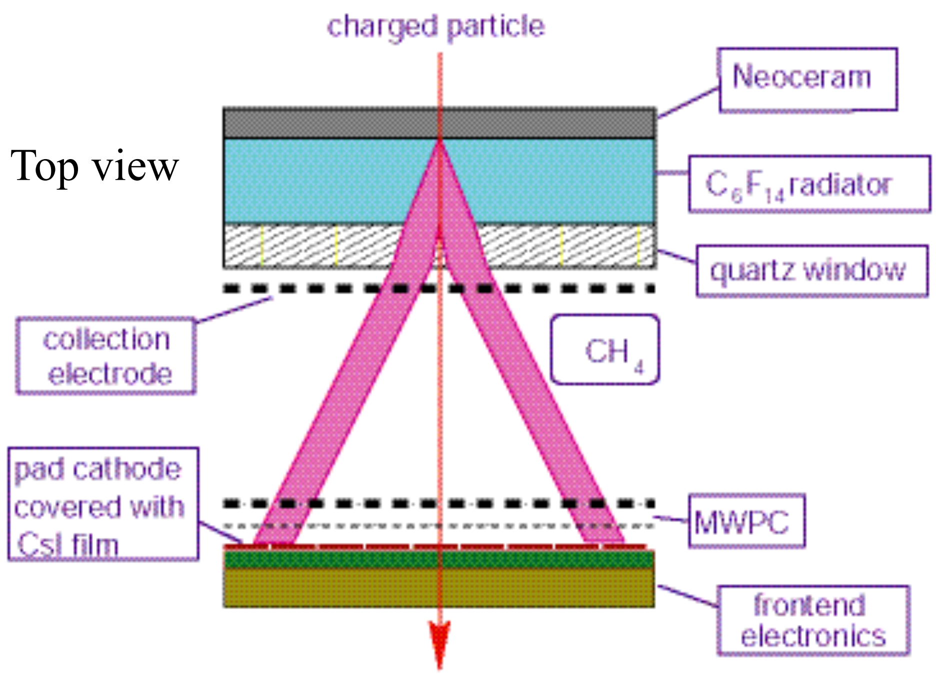


proximity focusing RICH detector scheme

Miscellaneous Detectors: RICh's

RICh detectors .. Many schemes in the high energy field

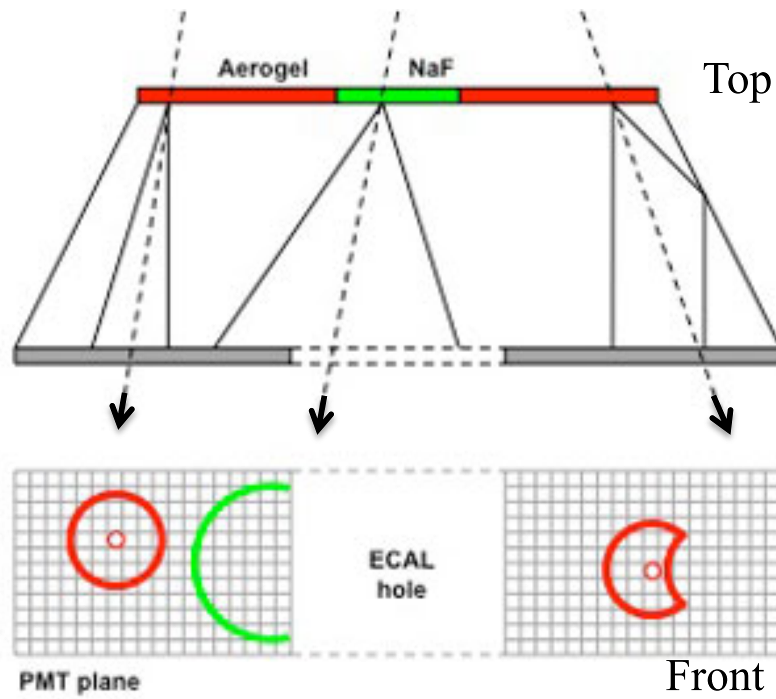
Top view



Combined trigger MWPC & RICh detector

http://alice-hmpid.web.cern.ch/alice-hmpid/

Top view



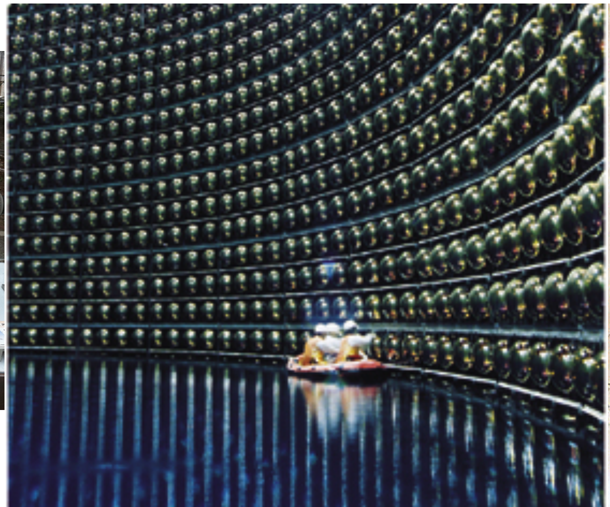
Front view

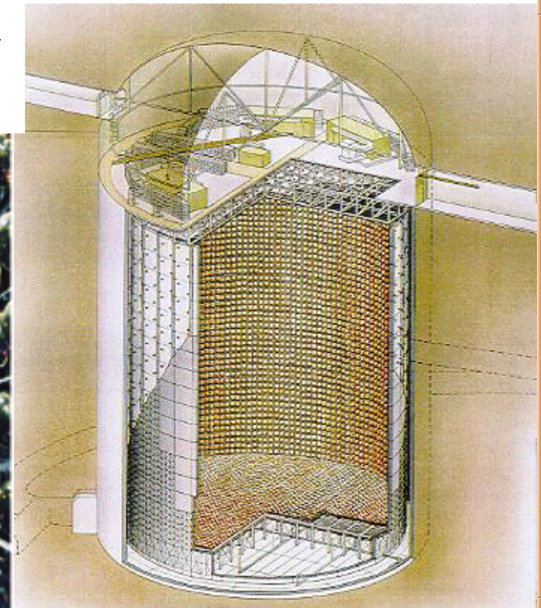
Part of Alpha-Magnetic Spectrometer on ISS

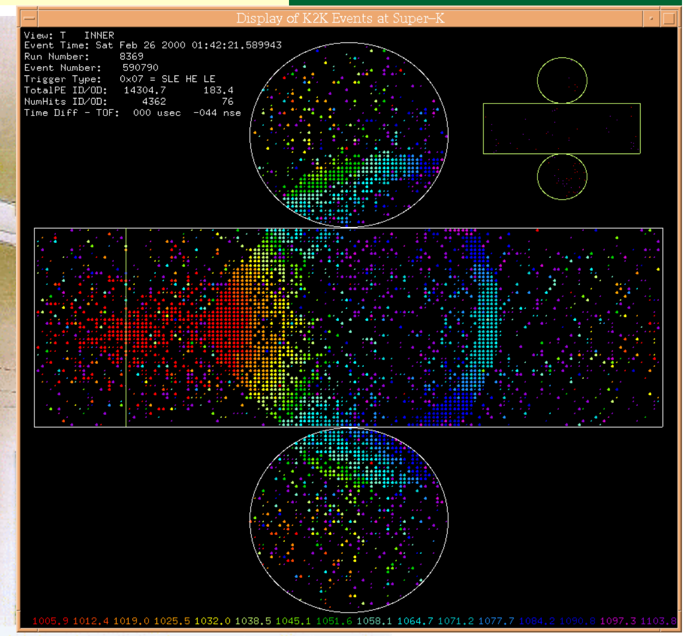
http://www.ams02.org/what-is-ams/tecnology/rich/

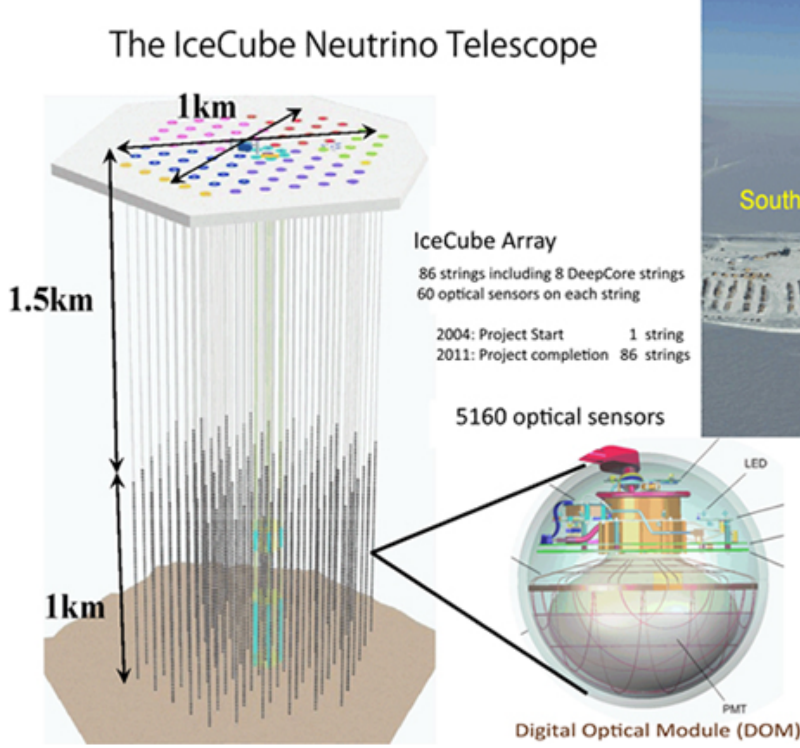
Miscellaneous Detectors: RICh’s w/ Condensed Matter

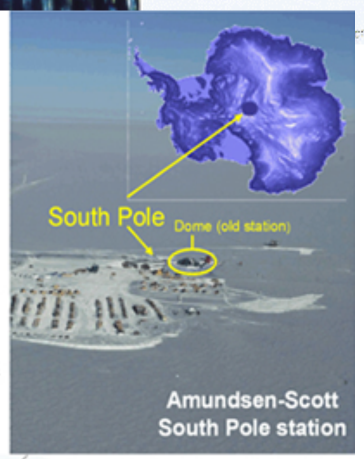
Super-K in Japan, 1km underground
32+18 kton H_2O, 11.2k PMTs

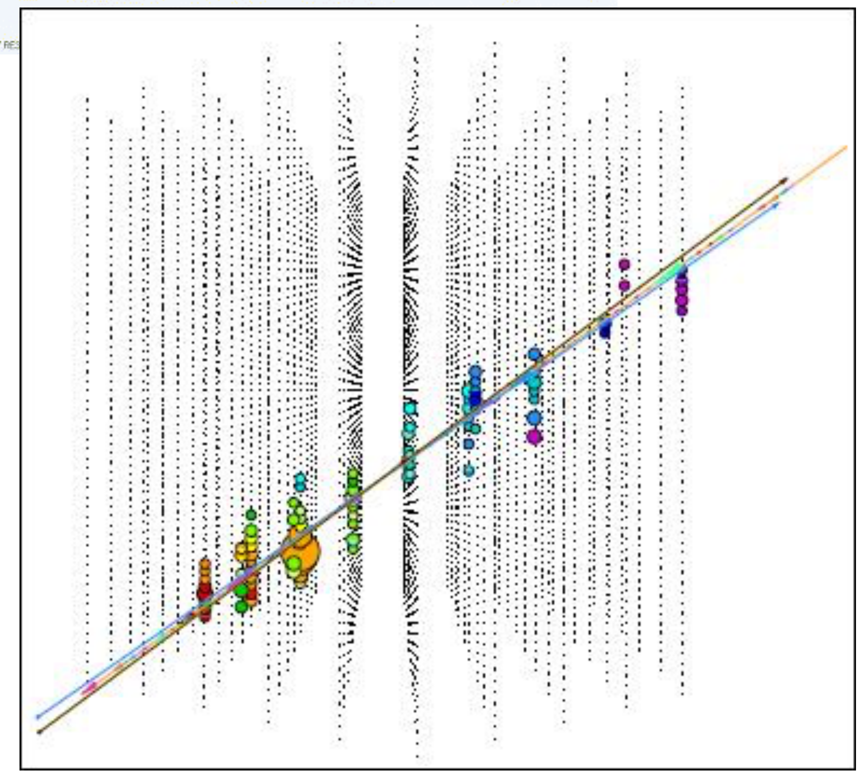










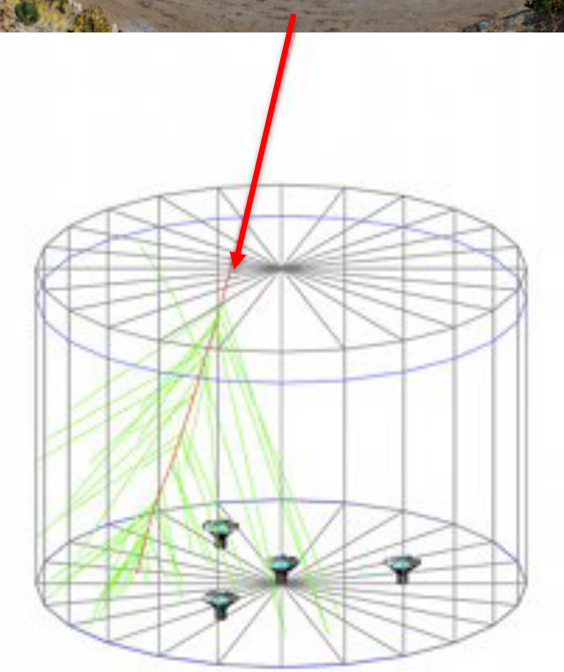


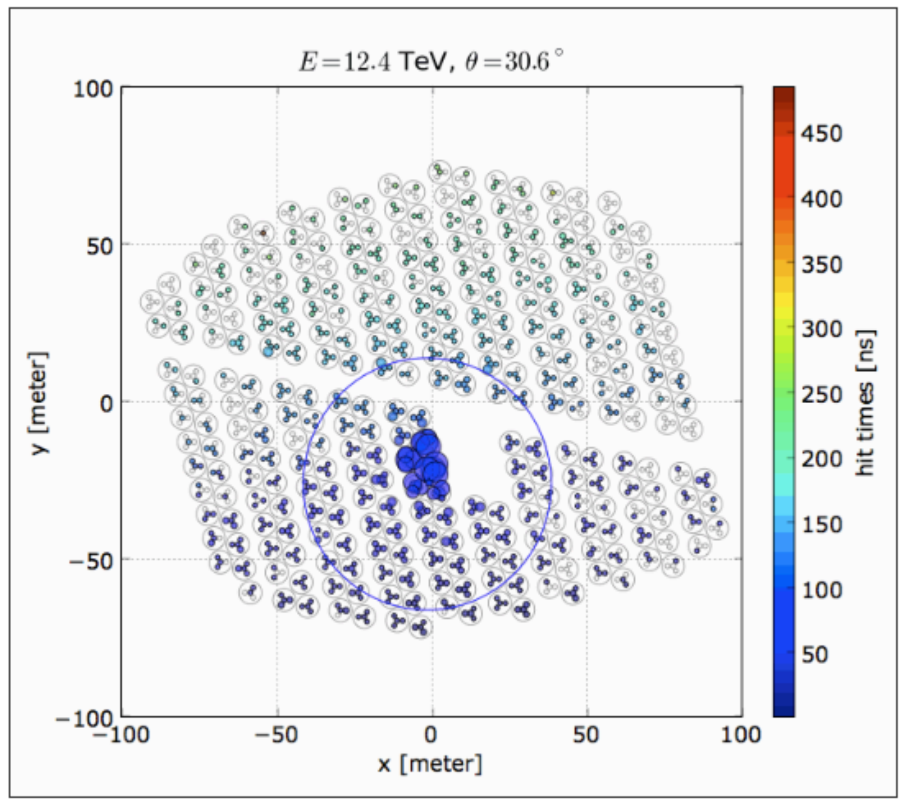
Miscellaneous Detectors: RICh's w/ Condensed Matter

MICHIGAN STATE UNIVERSITY

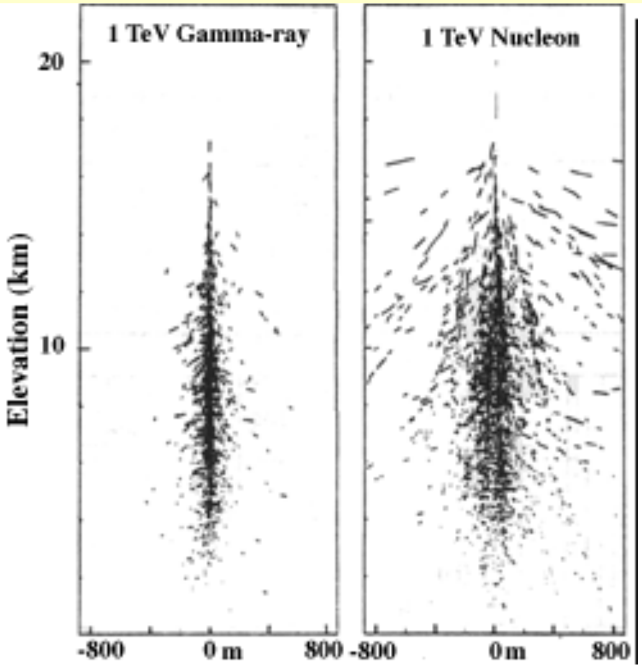
[High Altitude Water Cherenkov Gamma-ray Observatory]

HAWC is located on the flanks of the Sierra Negra volcano near Puebla, Mexico at an altitude of 4100 meters (13,500 feet). The detector has an instantaneous field of view covering 15% of the sky, and during each 24 hour period HAWC observes two-thirds of the sky. Using the HAWC Observatory, we are performing a high-sensitivity [synoptic] survey of the gamma rays from the Northern Hemisphere.

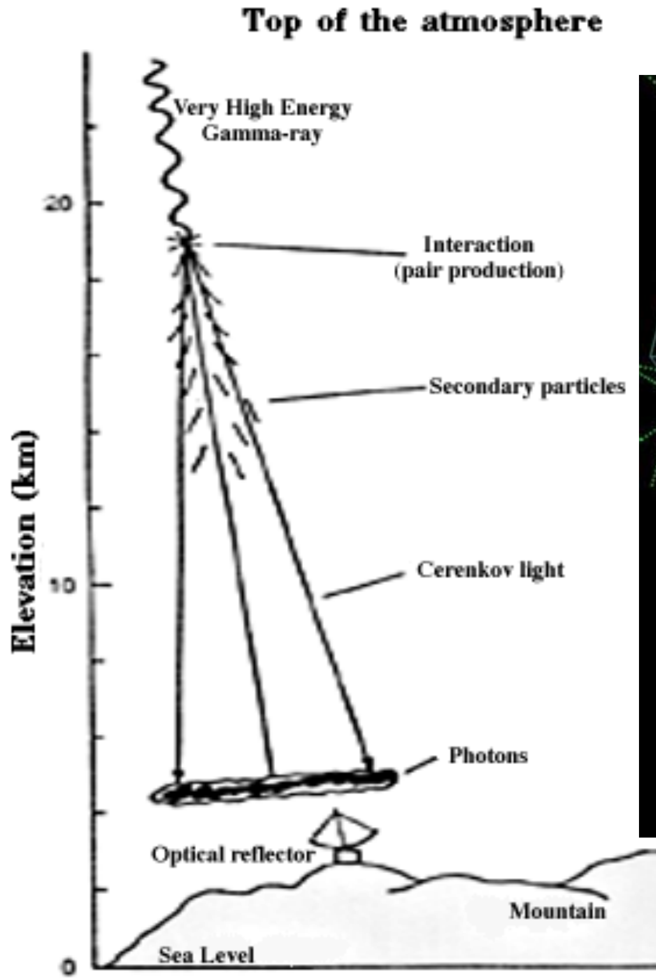


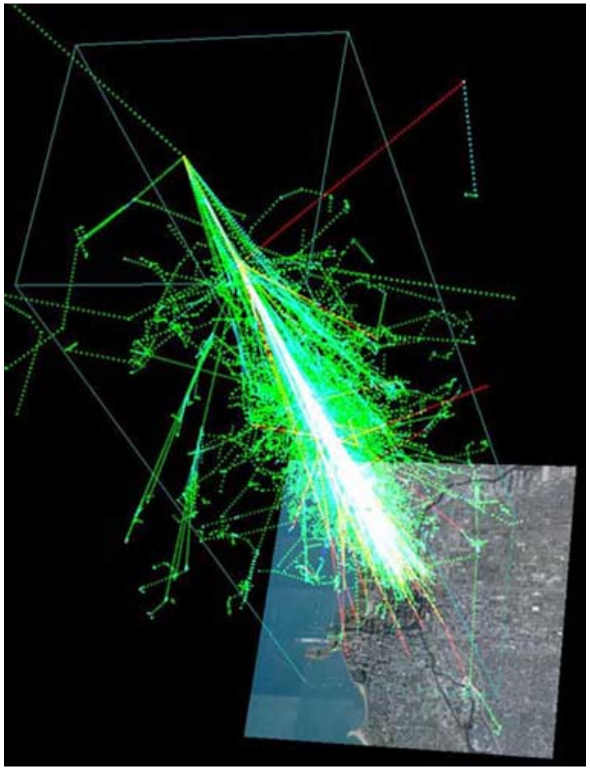


Miscellaneous Detectors: RICh's w/ gas



Extremely high energy γ-ray from space pair-produces at the top of the atmosphere and creates characteristic shower of secondaries.





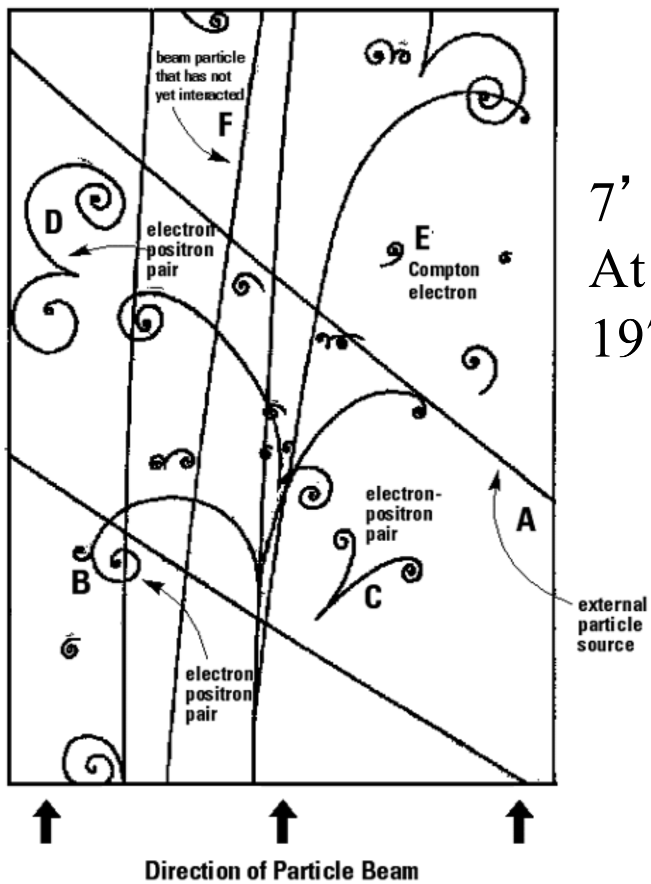
MAGIC at MPI-Munich
236 m^2 for cosmic rays

List of websites for various experiments:
http://www.mpi-hd.mpg.de/hfm/CosmicRay/CosmicRaySites.html

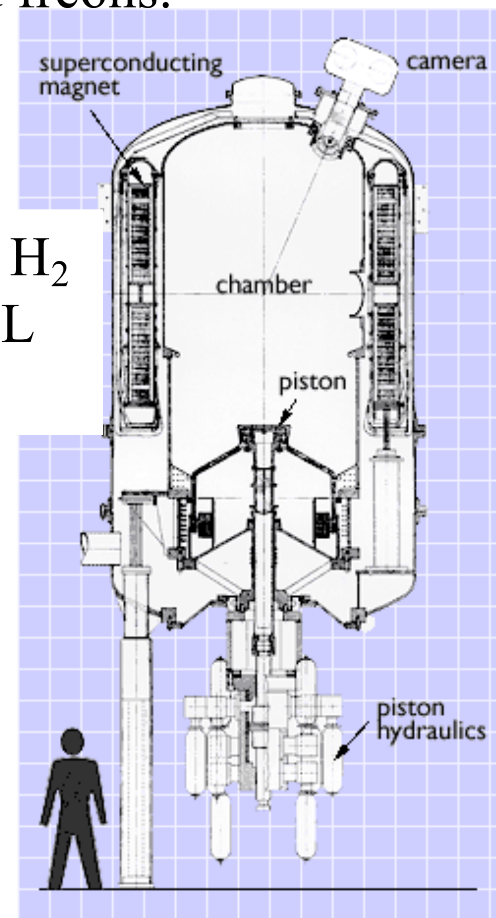
Misc. Dets. – Cloud & Bubble Chambers

Cloud chambers were first developed by Charles T.R. Wilson around 1911 for experiments on the formation of rain clouds. The supersaturated water vapour condensed around ions created by dE/dx of radiation passing through the vapor. The difficulty lies only in creating the supersaturation (vapor cooled below its boiling point).

Bubble chambers were developed by Donald Glaser (at UoM) based on the same principle but operating on superheated liquids like hydrogen and freons.

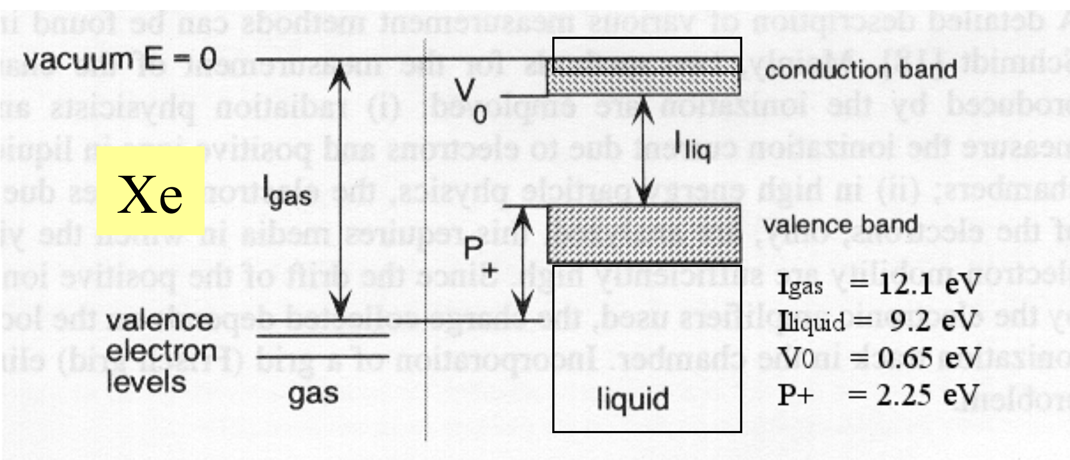


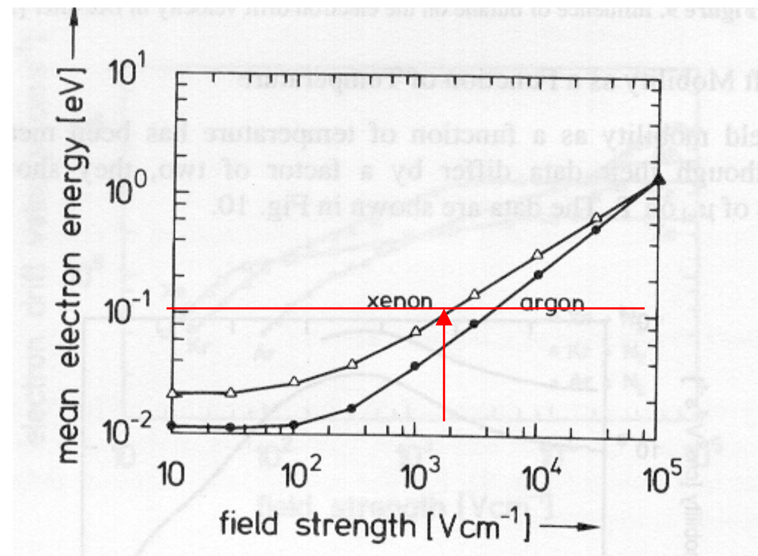
7’ liq. H_2
At BNL
1974

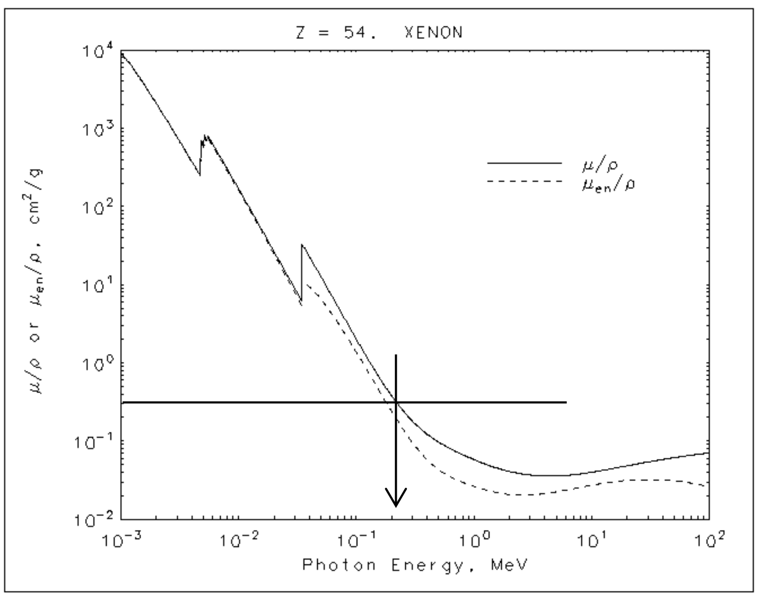


Miscellaneous Detectors: Liquid Ion-Chambers

Liquid noble gases, particularly Xe (highest density, lowest FIP of rare gases) and Ar (readily available) have been tested as ionization media. Overall, the charge carrier mobility is so low that the electrons can be lost to impurities before they are collected …







$$KE \sim 0.1eV \rightarrow v \sim \sqrt{\frac{2KE}{m}} \rightarrow \beta = \sqrt{\frac{2*0.1}{511x10^3}} = 6x10^{-4}$$

$$\sim 2x10^5 cm/s \quad vis. \quad 10^7 cm/s \ in \ Si \ and \ Ge$$

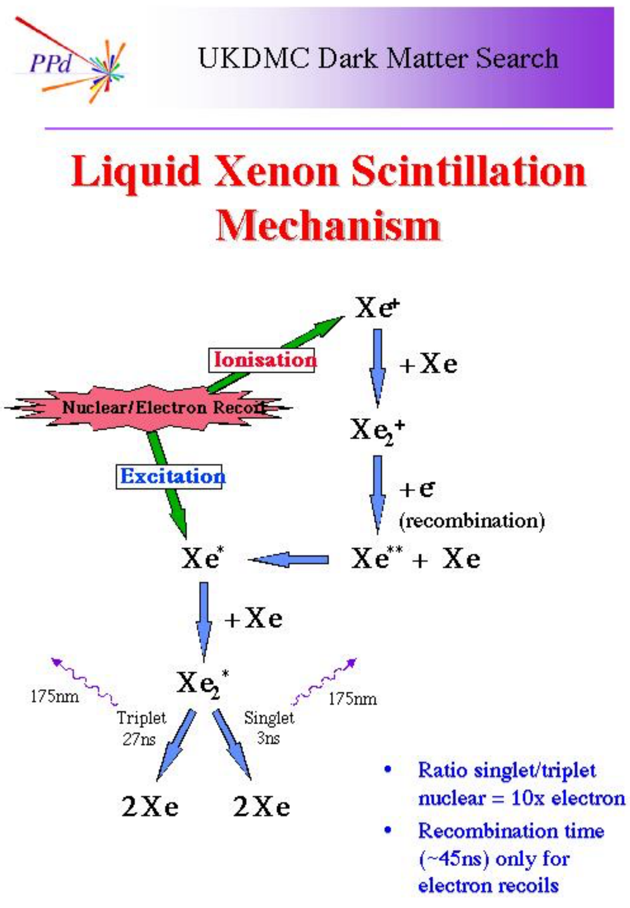
Try scintillation: pure liq-Xe scintillates at 178 nm (6.93 eV) with 61k photons/MeV , ρ = 2.953 g/cm^3 … μ ~ 1cm at 0.2 MeV

Miscellaneous Detectors: Liquid Ion-Chambers

MICHIGAN STATE UNIVERSITY

Try scintillation: pure liq-Xe scintillates at 178 nm (6.93 eV) with 61k photons/MeV , ρ = 2.953 g/cm^3 … μ ~ 1cm at 0.2 MeV

Purity remains an issue, Xe_2^+ strong oxidizer



NIM A505 (2oo3) 199

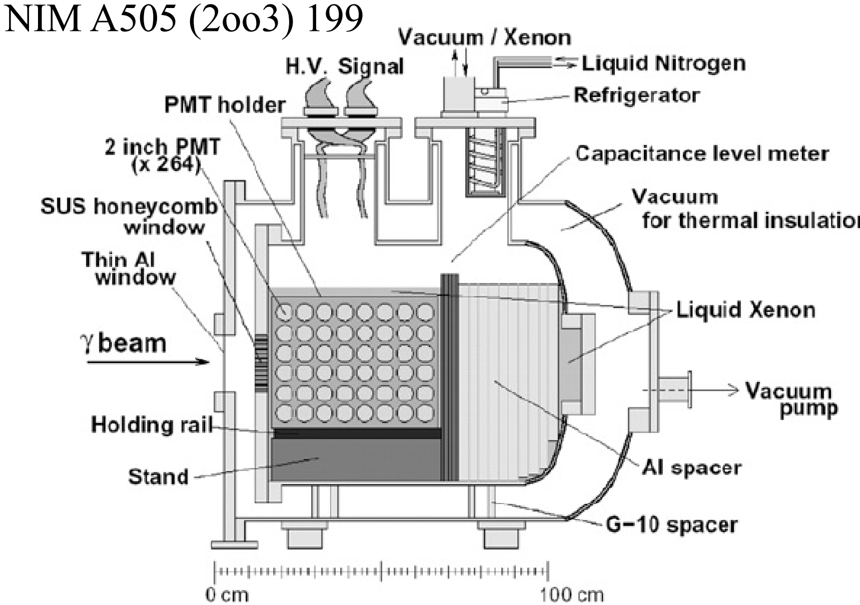
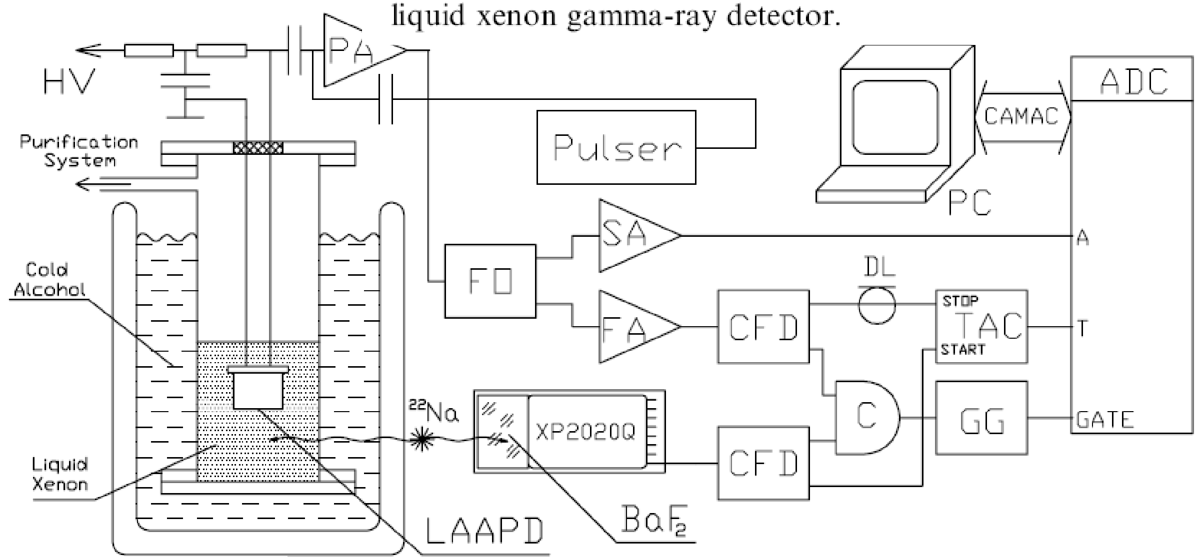


Fig. 2. Schematic view of the constructed prototype of the liquid xenon gamma-ray detector.



http://hepwww.rl.ac.uk/ukdmc/iop98njts/index.htm

http://arxiv.org/ftp/physics/papers/0203/0203011.pdf

http://www.pd.infn.it/~conti/LXe.html

Miscellaneous Detectors: Bolometer

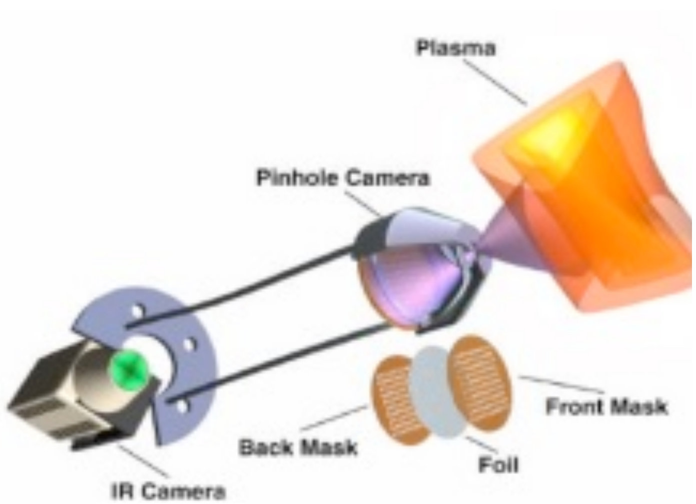
MICHIGAN STATE UNIVERSITY

One can measure the energy itself through a temperature rise in a calorimeter – the energy is tiny, the heat capacity has to be tiny to be visible.

$q = Cm\Delta T$ C, the (specific) heat capacity, ~ T^3 at cryogenic temperatures

Room temperature devices are used in plasma physics with sensitivities on the order of 1μW/cm^2 and a time constant of 10ms.

$$q/A = 10^{-6}\, W/cm^2 \; 0.01s = 10^{-8}\,\frac{J}{cm^2} \quad \rightarrow \quad 70.x10^9\,\frac{eV}{cm^2}$$



(100MeV/A ^{78}Kr is 8GeV)

The devices are very slow and thus have a large deadtime. They completely lack any discrimination, but they can be extremely efficient and are used in searches for exotica in nuclear and particle physics.

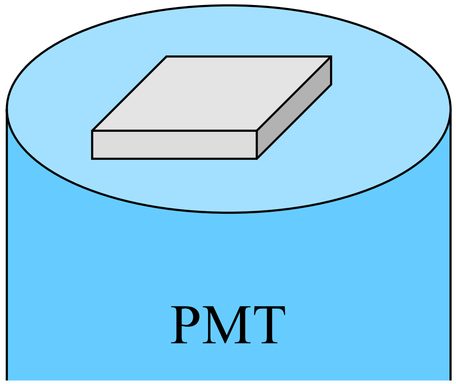
Miscellaneous Detectors: TLD

A TLD (thermo-luminescent detector) is a solid crystal phosphor when exposed to radiation at normal temperature, electrons in the normal crystal structure are released and trapped in lattice defects (traps) in the crystal structure producing a long-lived metastable energy state for the electrons. The electrons remained trapped for long periods of time at room temperature. When the crystal is heated (200-400^{o}C), the electrons are released from the traps and return to their original ground state, emitting a photon. (Scintillation for rapid decay, phosphorescence for slow decay.)

The number of photons is proportional to the number of electrons trapped, which in turn is proportional to the amount of radiation that was incident on the crystal.

Materials include LiF and CaF_2 in small chips with mm sizes. Newer technology uses optically stimulated emission from Al_2O_3 (next slide.)

Typical precision is ~15% at low doses dropping to ~3% at high doses.



Miscellaneous Detectors: OSL

MICHIGAN STATE UNIVERSITY

Note that the TLD can only be readout once. This is a problem for archival storage of information on dosimetry. A new readout technique has been developed that uses laser light to stimulate emission from the trapped electrons that leaves them in the traps. This is called optically-stimulated luminescence by the manufacturer Landauer.

Radiations Measured	Photon (X and Gamma Ray)	Beta Particle	Neutron
Detector	Al_2O_3 (Aluminum Oxide)	Al_2O_3 (Aluminum Oxide)	Optional Neutrak® 144 detector inside dosimeter (CR-39)
Analysis Method	Optically Stimulated Luminescence (OSL)	Optically Stimulated Luminescence (OSL)	Chemical etching followed by track counting (Track-Etch®)
Energies Detected	5 keV to in excess of 40 MeV	150 keV to in excess of 10 MeV (Expressed as Average Energy)	Fast: 40 keV to 40 MeV Thermal/ Intermediate: 0.25 eV to 40 keV
Dose Measurement Range	1 mrem to 1000 rem (10 µSv to 10 Sv)	10 mrem to 1000 rem (100 µSv to 10 Sv)	Fast: 20 mrem to 25 rem (200 µSv to 250 mSv) Thermal/ Intermediate: 10 mrem to 5 rem (100 µSv to 50 mSv)
Accuracy	**Deep Dose (Hp10)** ±15% at the 95% confidence interval for photons above 20 keV **Shallow Dose (Hp 0.07**) ±15% at the 95% confidence interval for photons above 20 keV and beta particles above 200 keV		
Accreditations, Approvals, Licenses	**NVLAP** (NVLAP Lab Code 100518-0) for Whole Body (ANSI HPS N13.11-2001) in the comprehensive subcategory "General" in all categories including VI when neutron component is added; and for extremity (ANSI HPS N13.32-1995). **HSE** (Health and Safety Executive) United Kingdom approved for Whole Body (OSL) and Whole Body Neutrons. **DOELAP** (Department of Energy Laboratory Accreditation Program).		

Miscellaneous Detectors: TLD Question

MICHIGAN STATE UNIVERSITY

"The number of photons is proportional to the number of electrons trapped, which in turn is proportional to the amount of radiation that was incident on the crystal.
Materials include LiF and CaF_2 … small chips with mm sizes
Typical precision is ~15% at low doses dropping to ~3% at high doses."

Question: How many photons are emitted by the TLD device to readout a "low dose"?