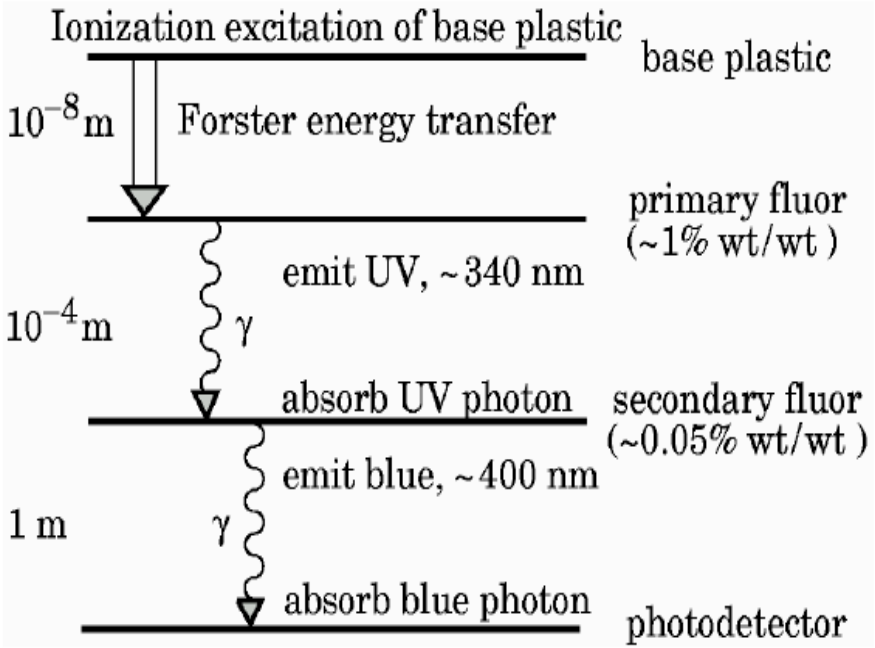
Organic scintillators

Scintillation mechanism



scintillation, followed by resonant dipole-dipole interaction with fluor; strong coupling increases

fluor shifts wavelength to where the base is more transparent; shortens the decay time of scintillation and increases yield

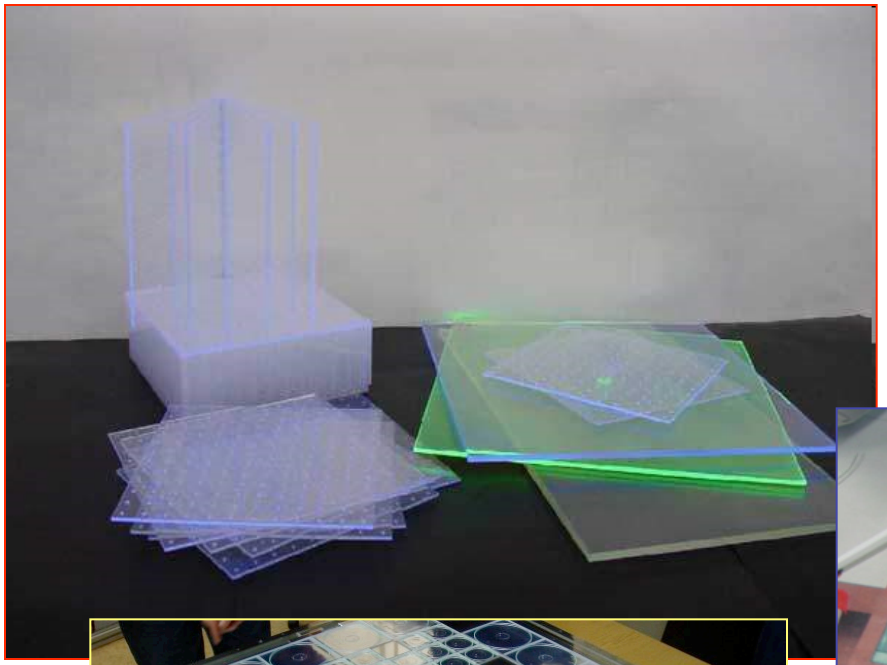
Cautions: aging and handling, radiation damage, ...

- they have low *Z*, being mainly made of H and C
  - low γ detection efficiency (≈ only Compton effect).
  - but high neutron detection efficiency via (n,p) reactions

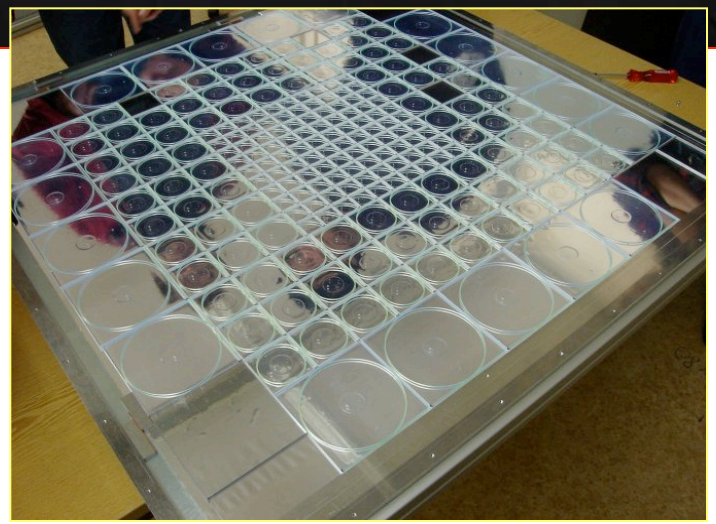
Organic scintillators – light yield

- Attenuation lengths are sensitive to optical clarity, surface quality (internal reflection) and impurities
  - often deal with >meter lengths of scintillators, so these optical effects are important
- Aging and crazing (microcracks in surface) diminish light yield
- Radiation damage is complex; it affects both light yield and attenuation

Examples of organic scintillators

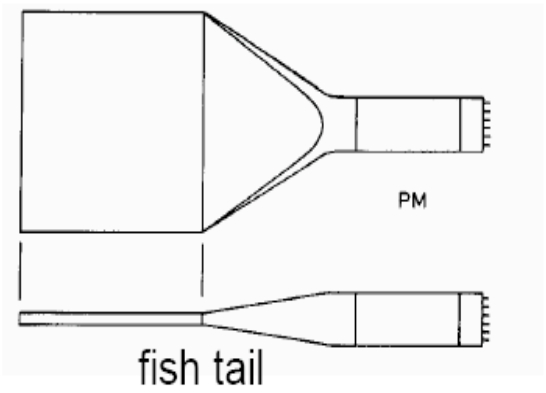


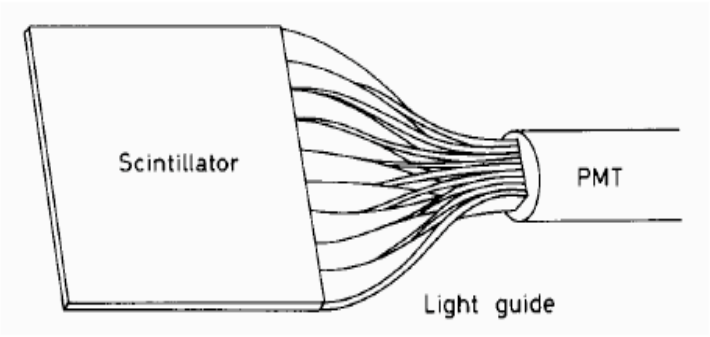
- Tiles are usually wrapped in reflective material and light-tight tape
- Light guide to couple to PMT
- Fiber readout also used



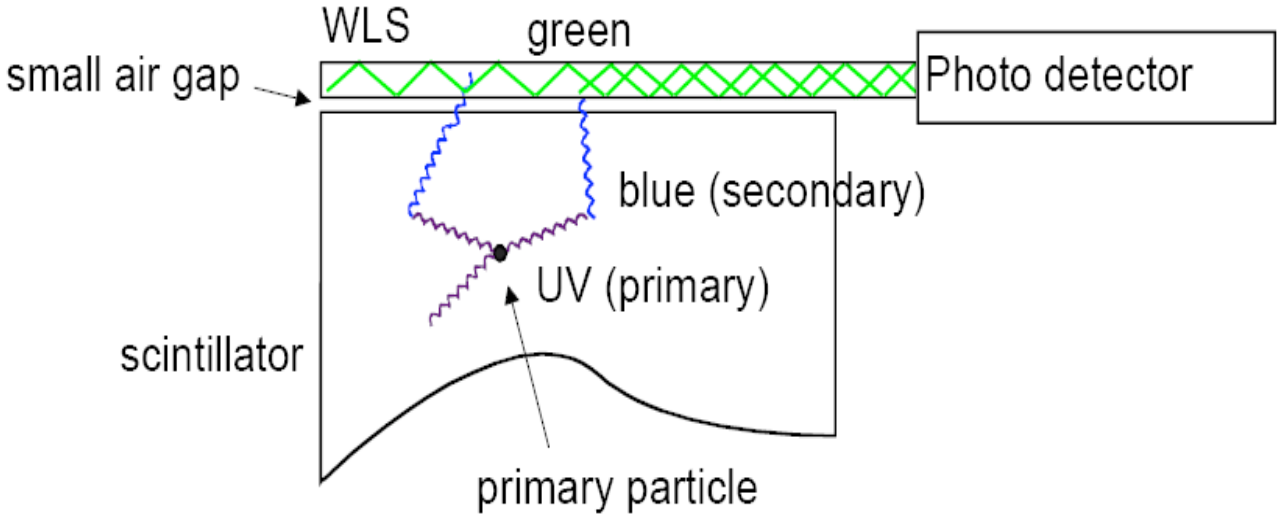
Scintillator readout

- light guides
  - transfer by total internal reflection (and reflector)





- wavelength shifter (WLS) bars

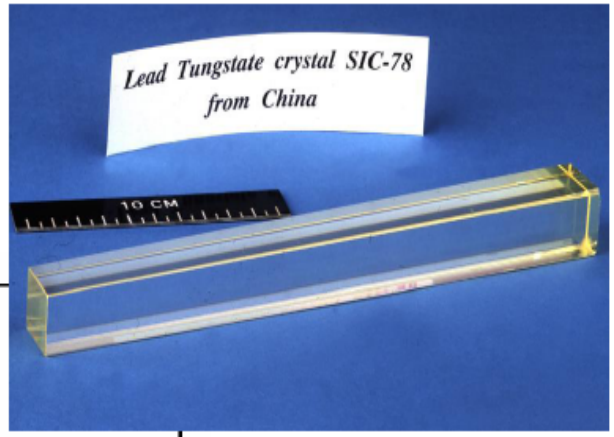


Inorganic scintillators

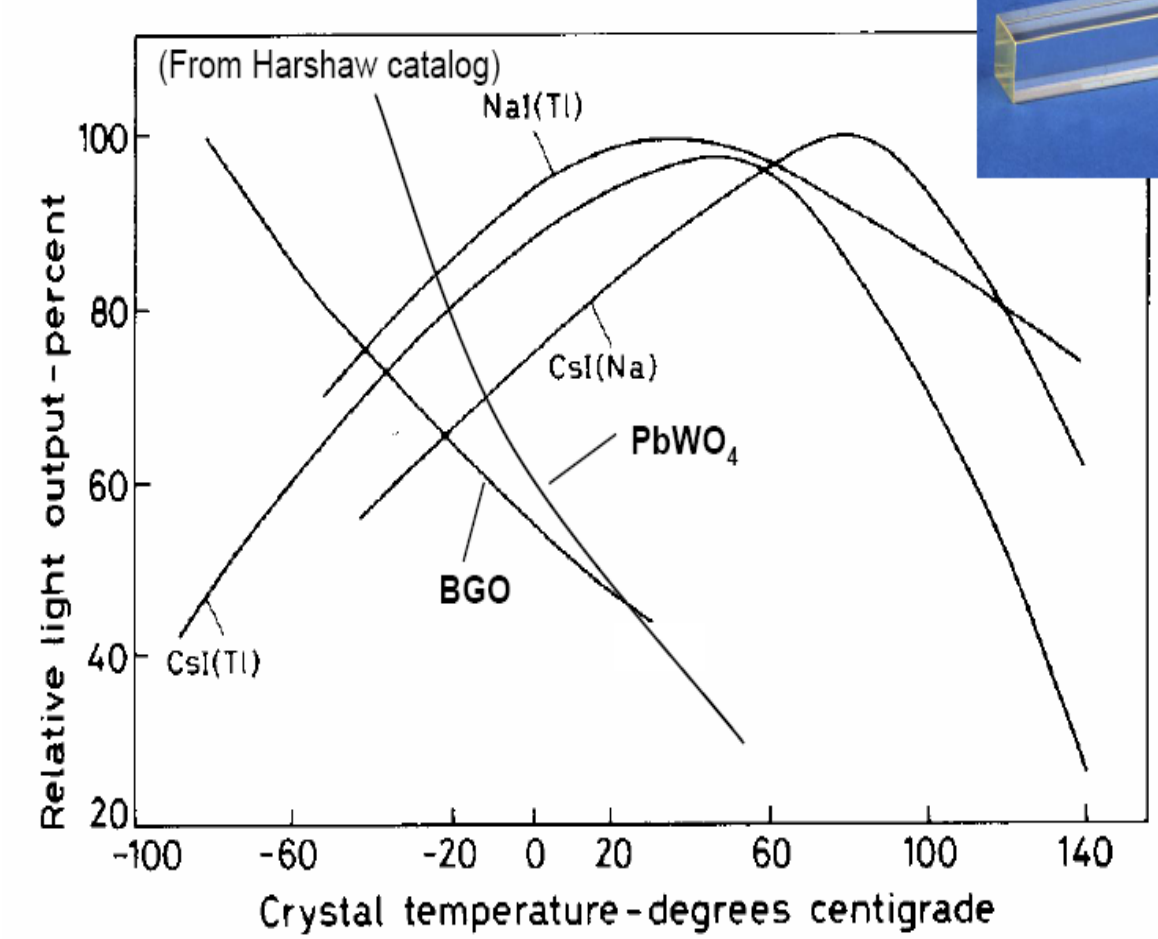
- Inorganic crystalline scintillators
  - Ionization by charged particles
  - NaI, CsI, BaF_2, $Bi_4Ge_3O_{12}$, $PbWO_4$,...
  - High density and high *Z*
  - well suited for detection of charged particle and γ
    - densities: between ~4 and ~8 g cm^{-3}
    - high *dE/dx*
    - high conversion efficiency for electrons and γ
    - often with very high light output
  - often more than two time constants
    - fast recombination from active centers (ns to μs)
    - delayed recombination due to trapping ($\approx$100 ns)

Inorganic scintillators

- light ouput has strong temperature dependence

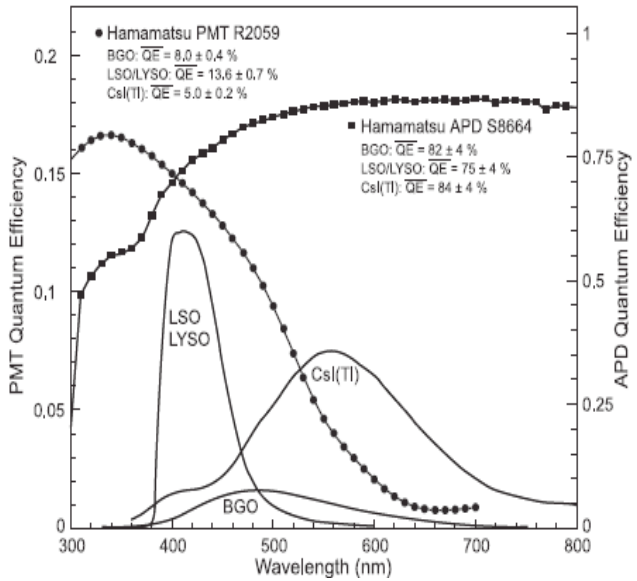


PWO4 final polished cristal for CMS calorimetry



Inorganic scintillators

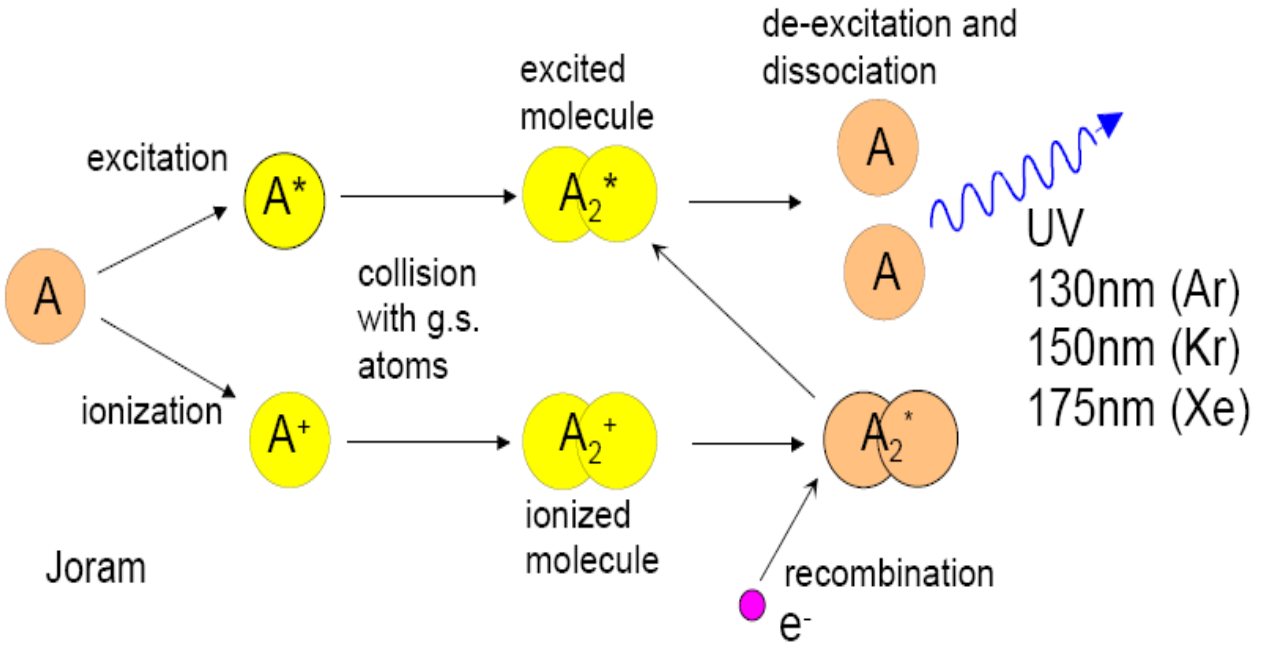
- Higher densities, lower light yields relative to organics
- Crystals – slow and expensive to grow
- Light collection efficiency – optical transparency, surface quality, scattering centres
- Signal development can be slow; 100s of ns



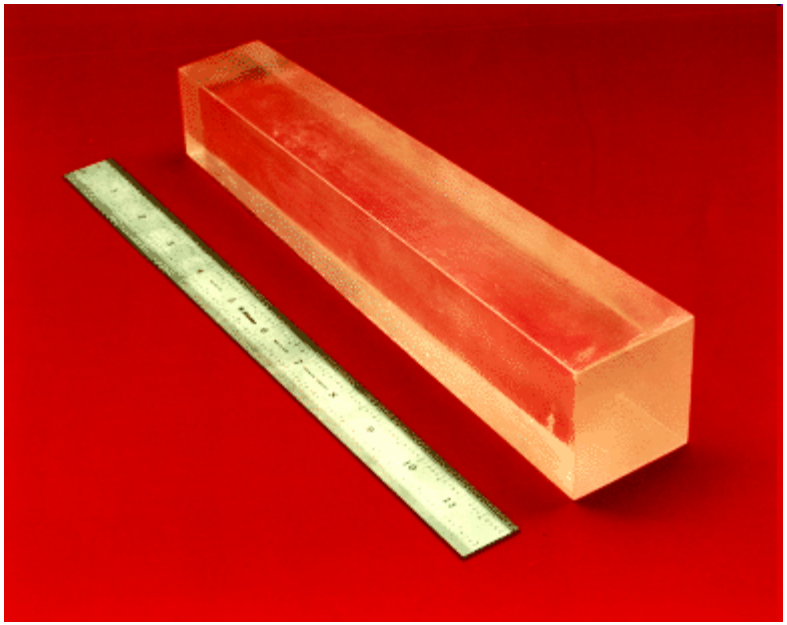
Parameter:	ρ	MP	X_0^*	R_M^*	dE/dx	λ_I^*	τ_{decay}	$\lambda_{\max}$	$n^\natural$	Relative output†	Hygro-scopic?	$d(\text{LY})/dT$
Units:	g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
NaI(Tl)	3.67	651	2.59	4.13	4.8	42.9	230	410	1.85	100	yes	−0.2
BGO	7.13	1050	1.12	2.23	9.0	22.8	300	480	2.15	21	no	−0.9
BaF_2	4.89	1280	2.03	3.10	6.6	30.7	630^s	300^s	1.50	36^s	no	-1.3^s
							0.9^f	220^f		3.4^f		$\sim 0^f$
CsI(Tl)	4.51	621	1.86	3.57	5.6	39.3	1300	560	1.79	165	slight	0.3
CsI(pure)	4.51	621	1.86	3.57	5.6	39.3	35^s	420^s	1.95	3.6^s	slight	−1.3
							6^f	310^f		1.1^f		
$PbWO_4$	8.3	1123	0.89	2.00	10.2	20.7	30^s	425^s	2.20	0.083^s	no	−2.7
							10^f	420^f		0.29^f		
LSO(Ce)	7.40	2050	1.14	2.07	9.6	20.9	40	420	1.82	83	no	−0.2
GSO(Ce)	6.71	1950	1.38	2.23	8.9	22.2	600^s	430	1.85	3^s	no	−0.1
organic	~1		~40		~2	~80	~2	tune		~25	no	

Inorganic scintillators

- Liquid noble gases (LAr, LKr, LXe)
  - also two time constants
    - few ns and 100 to 1000 ns, but same wavelegth

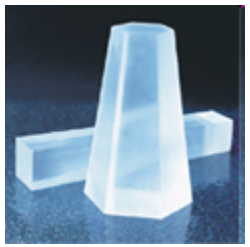


Examples of inorganic scintillators

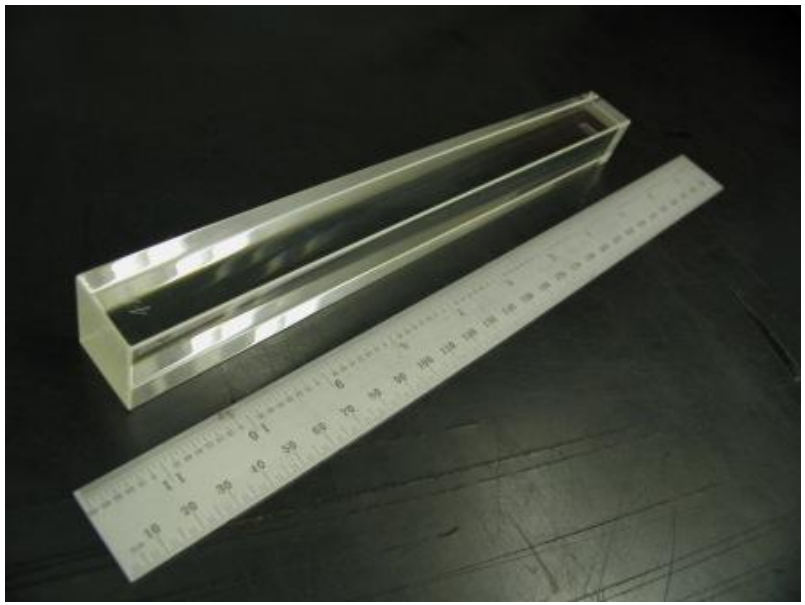


CsI(Tl)

BaF_2



NaI(Tl)

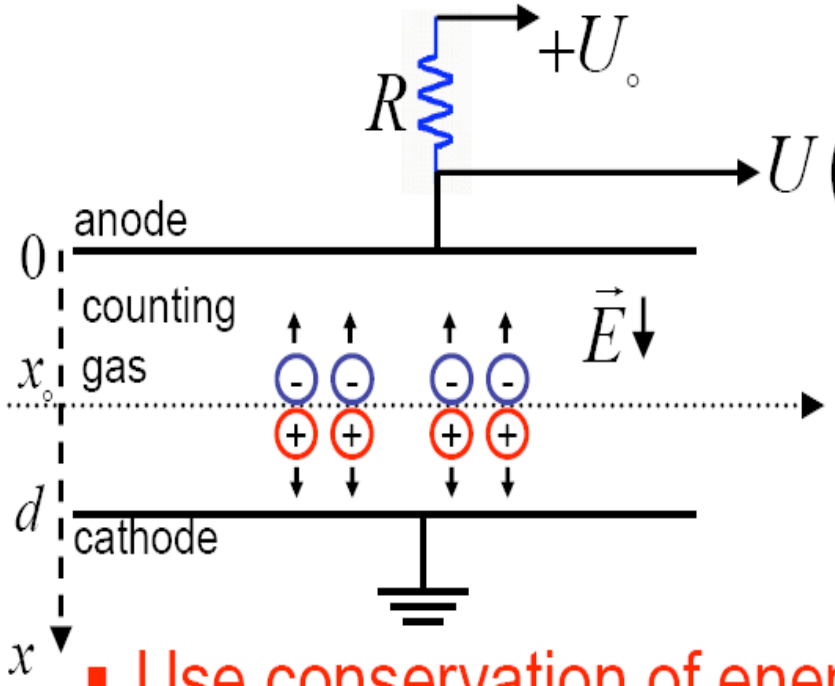


Lead Tungstate

Ionization chambers

Ionization chambers

Parallel electrodes



$$\left|\vec{E}\right| = \frac{U(t)}{d} \qquad C = \frac{\varepsilon A}{d}$$

$$\int_0^{t_d^-} v^- dt = x_\circ$$

$$\int_0^{t_d^+} v^+ dt = d - x_\circ$$

$v^+ < v^-$ drift velocities depend on the electric field

- Use conservation of energy in C

$\frac{1}{2}CU_\circ^2 = \frac{1}{2}CU^2(t)$ + work done by $\vec{E}$ on drifting charges

obtain $$-\frac{dU(t)}{dt} = \frac{Ne}{Cd}\left[v^- + v^+\right]$$ holds for $v = v\left(\left|\vec{E}\right|(t)\right)$

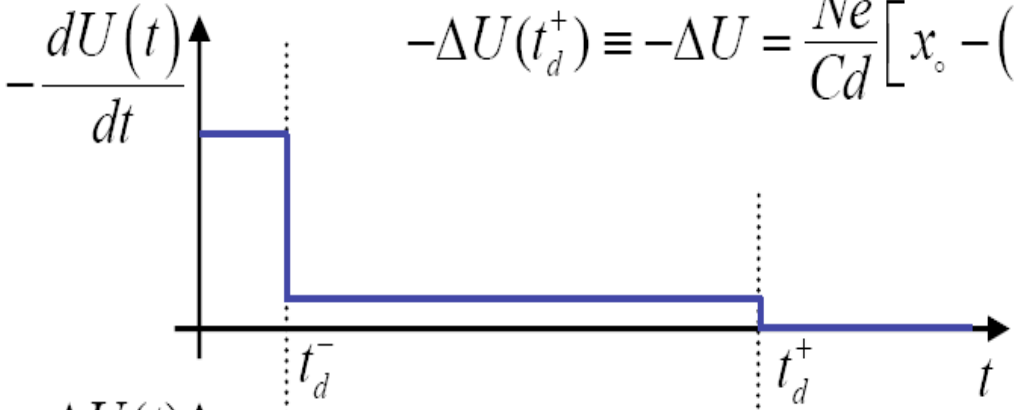
Ionization chambers

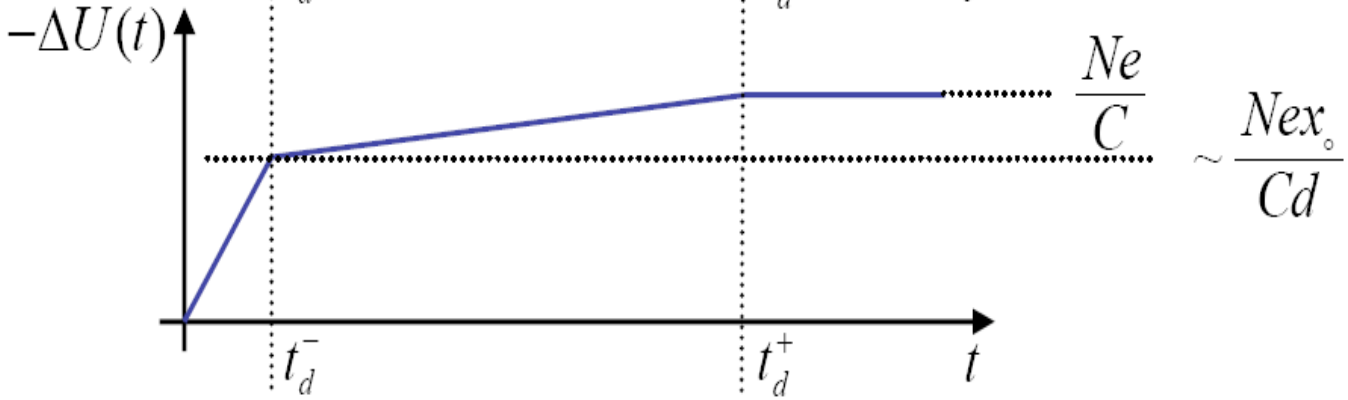
Signal

$$\Delta U(t) = U(t) - U_\circ = \Delta U^-(t) + \Delta U^+(t)$$

$$-\Delta U(t_d^+) \equiv -\Delta U = \frac{Ne}{Cd}\left[x_\circ - (d - x_\circ)\right] = \frac{Ne}{C}$$

$$\Delta Q = -Ne = C\Delta U$$



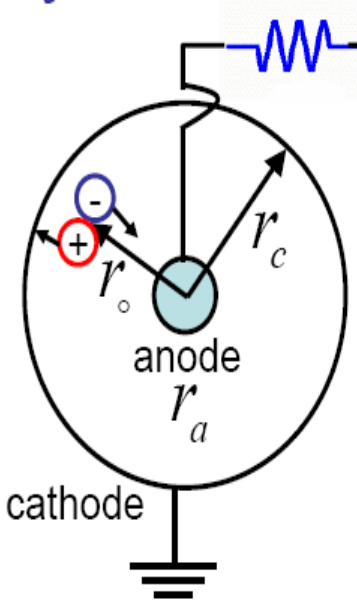


$$\frac{\Delta U^+}{\Delta U^-} = \frac{d - x_\circ}{x_\circ} \qquad \text{If } x_\circ = \tfrac{1}{2}d \quad \text{then} \quad \frac{\Delta U^+}{\Delta U^-} = 1$$

Ionization chambers

Cylindrical electrodes

$$\left|\vec{E}(r)\right| = \frac{U}{r \ln \frac{r_c}{r_a}} \propto \frac{1}{r}$$



If approximation $v^{\pm} \propto \left|\vec{E}\right|$ then

$$-\Delta U^- = \frac{Ne}{C}\frac{\left(\ln r_\circ - \ln r_a\right)}{\left(\ln r_c - \ln r_a\right)}$$

$$-\Delta U^+ = \frac{Ne}{C}\frac{\left(\ln r_c - \ln r_\circ\right)}{\left(\ln r_c - \ln r_a\right)}$$

$$\Delta U = \Delta U^- + \Delta U^+ = -\frac{Ne}{C}$$

$$\Delta Q = -Ne = C\Delta U$$

$$\frac{\Delta U^+}{\Delta U^-} = \frac{\ln r_c - \ln r_\circ}{\ln r_\circ - \ln r_a}$$

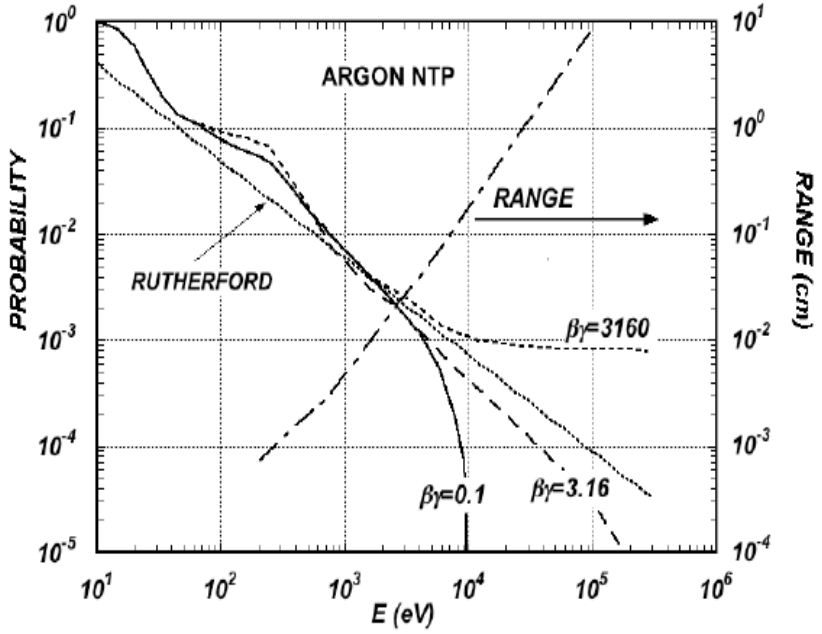
If $r_\circ = \frac{2}{3} r_c$ and $r_a \ll r_c$ then $\frac{\Delta U^+}{\Delta U^-} = \frac{\ln\frac{3}{2}}{\ln\frac{2r_c}{3r_a}} < 1$

for $r_c = 1$ cm and $r_a = 30$ μm then $\frac{\Delta U^+}{\Delta U^-} = 0.075$

- in general electrons contribute more to the signal
- discharging *C*: pocket dosimeter

Charge transport in gases

- Recall primary/total ionization (n_T ~ 2-3 x n_P)
- Distribution of ejected electrons ~ $1/E^2$ (E=electron energy)
- Ionization clusters form around energetic secondary electrons; can degrade time and position resolution



Probability of producing an electron of energy ≥E (left scale), and range of electrons in Argon at NTP (right scale)

Drift velocity

- Liberated electrons accelerated by applied field, but have small mean-time-between-collisions τ, so $v_d = e\,E\,\tau / m << v_{rms}$ (think Ohm's law)
- More sophisticated model (ω = Larmor freq eB/m):

$$\mathbf{v_d} = \frac{e}{m}\frac{\tau}{1+\omega^2\tau^2}\left(\mathbf{E} + \frac{\omega\tau}{B}(\mathbf{E}\times\mathbf{B}) + \frac{\omega^2\tau^2}{B^2}(\mathbf{E}\cdot\mathbf{B})\mathbf{B}\right)$$

- Drift velocity depends on τ, i.e. on collisional cross-sections; very sensitive to gas mixture, contaminants
- **ExB** force causes "Lorentz angle" (see above);

$$\tan\theta_B = \omega\tau$$