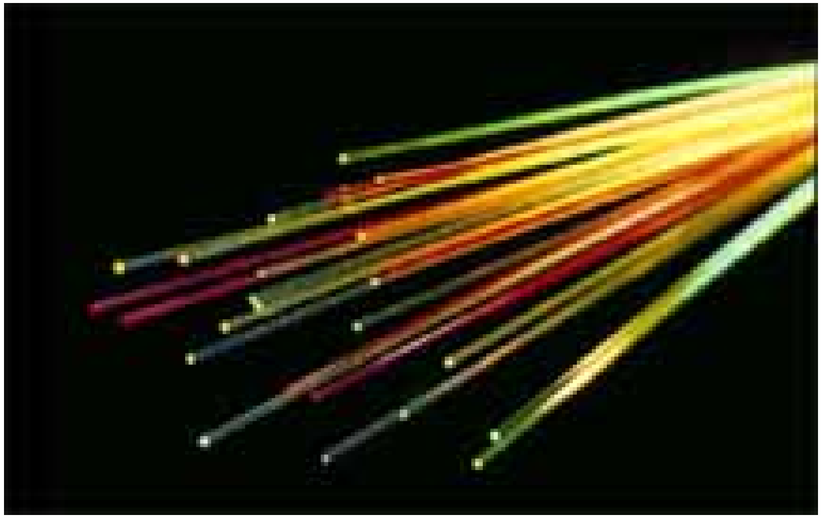
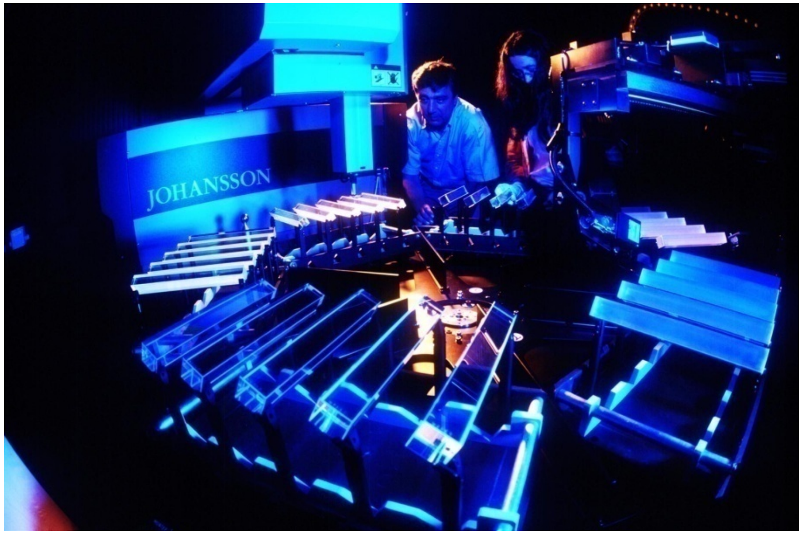
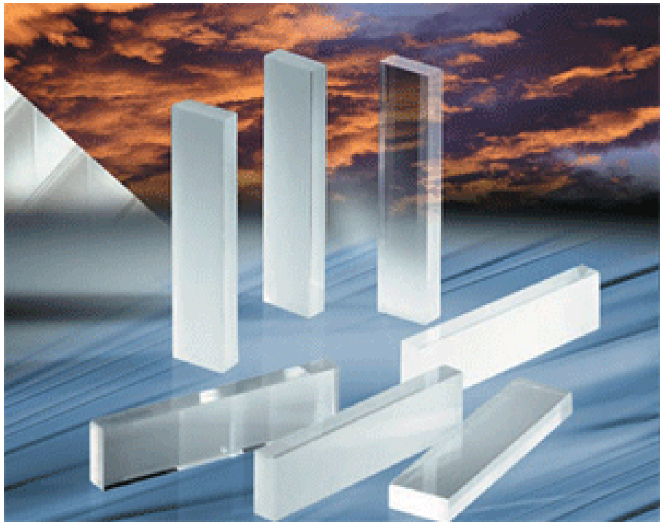
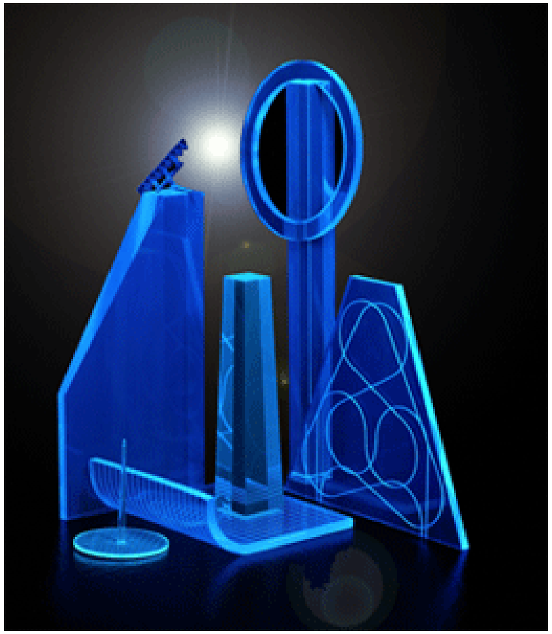




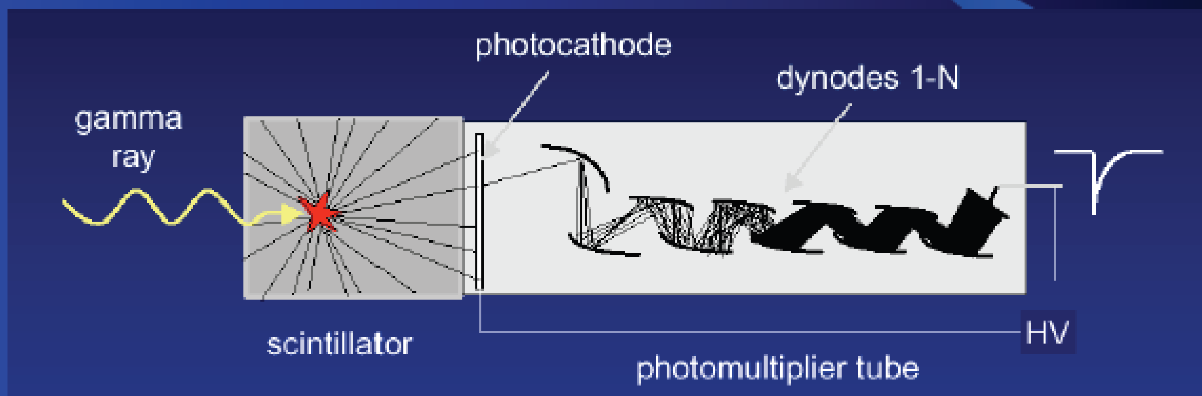
Detectores basados en el registro de átomos excitados → Centelladores





Centellador: en pocas palabras

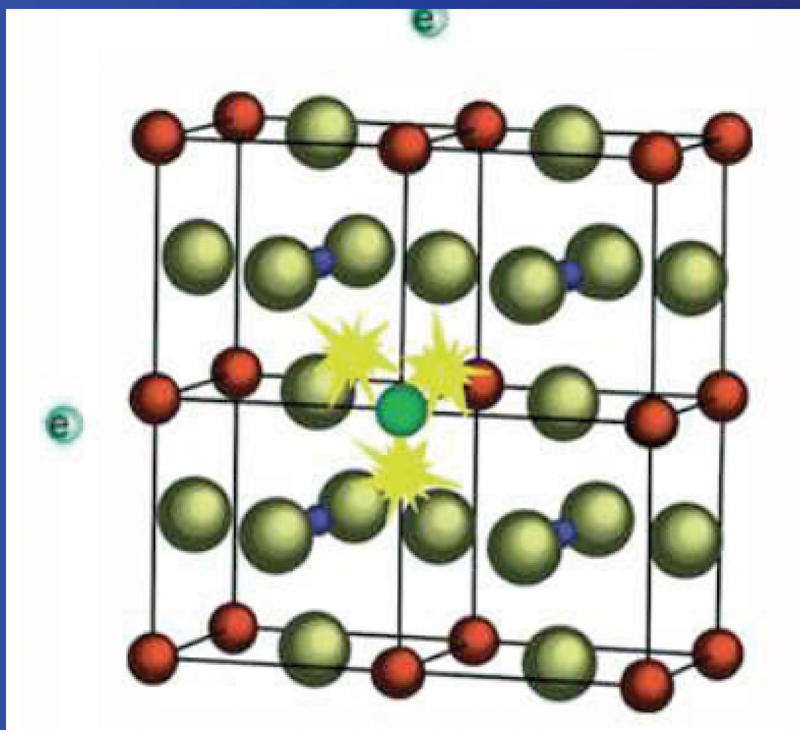
- To convert ALL the energy of the incident particle in to light
- Necessity to use dense materials

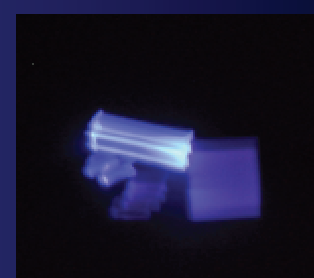


- Above certain minimum level most scintillators are linear with respect to the energy deposited
- Light output is directly proportional to energy deposited

Por qué un cristal?

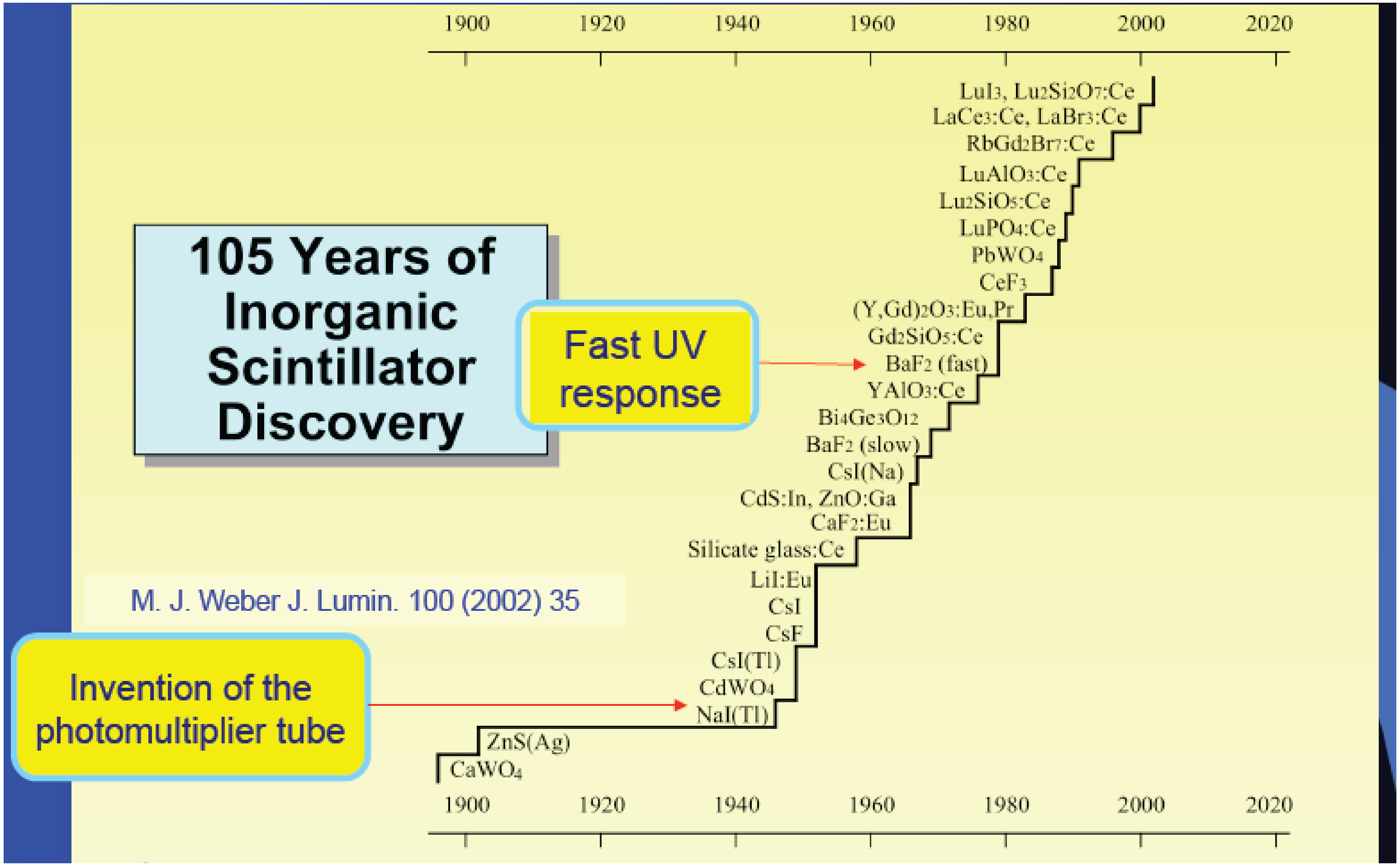
- Heavy material are rich in electrons, which interact strongly with light
- Only ordered system can confine electrons in well separated energy bands, so that the material is transparent to its scintillation light



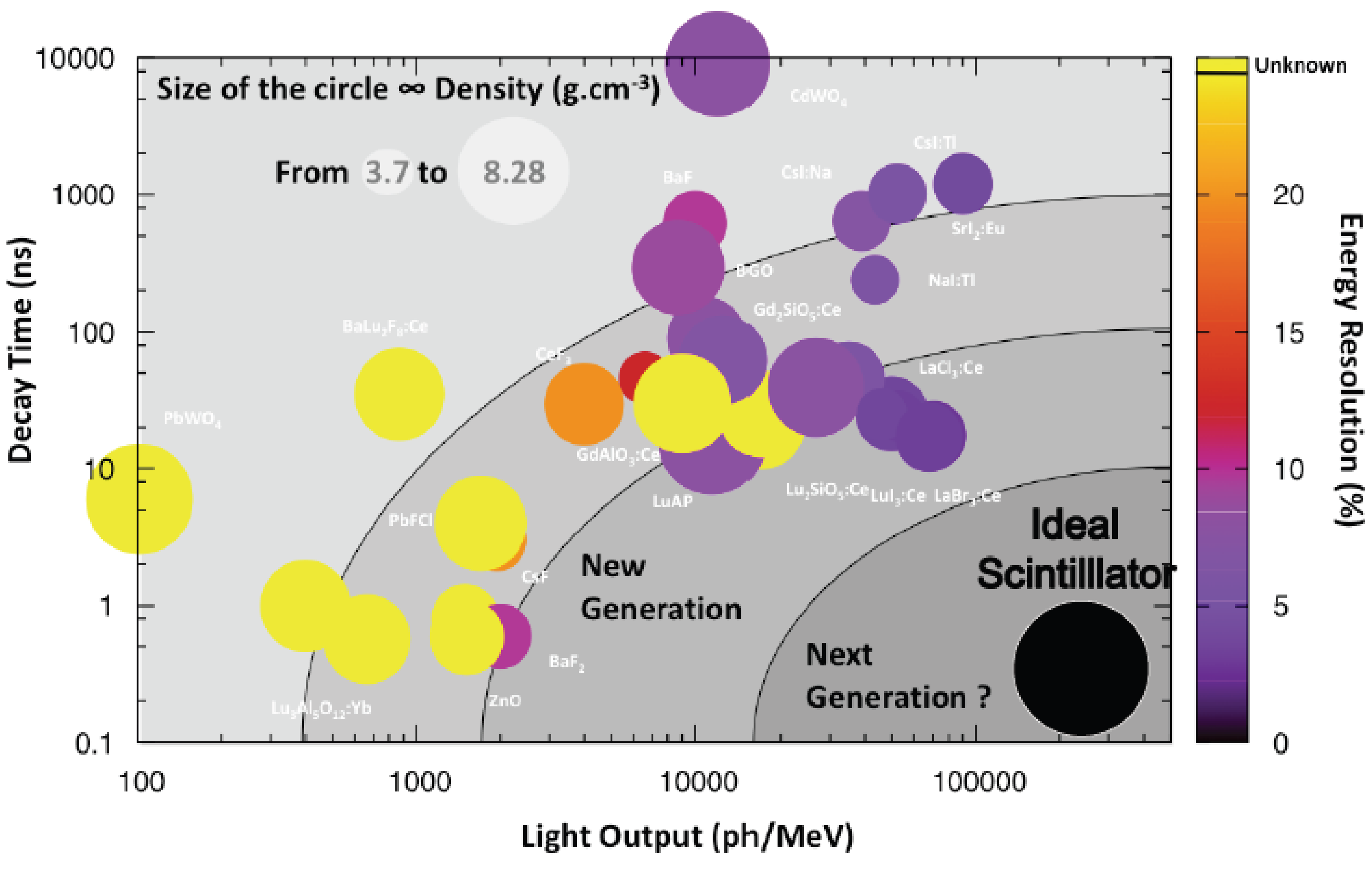


Ejemplos de cristales

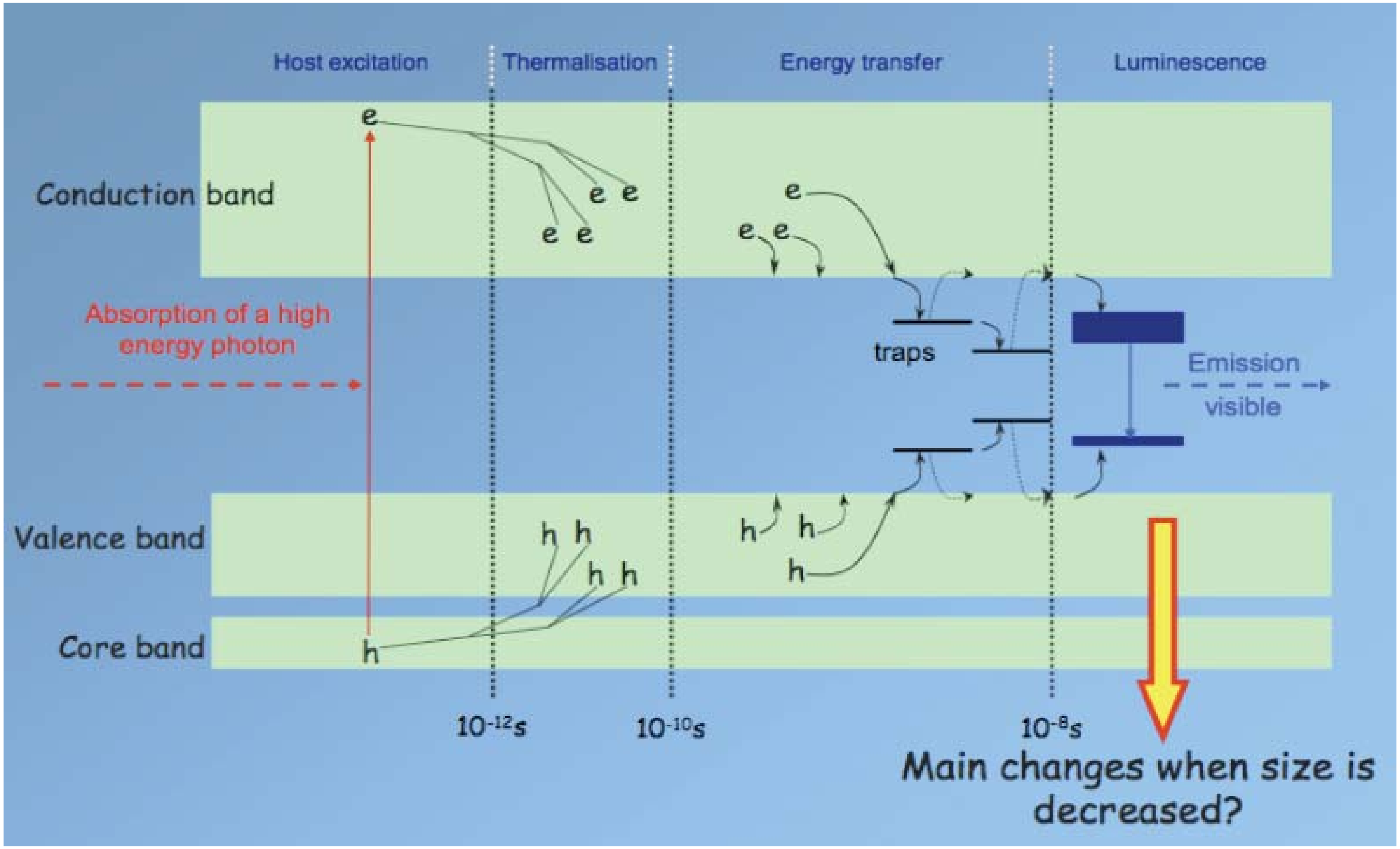
Erase una vez….



Clasificación

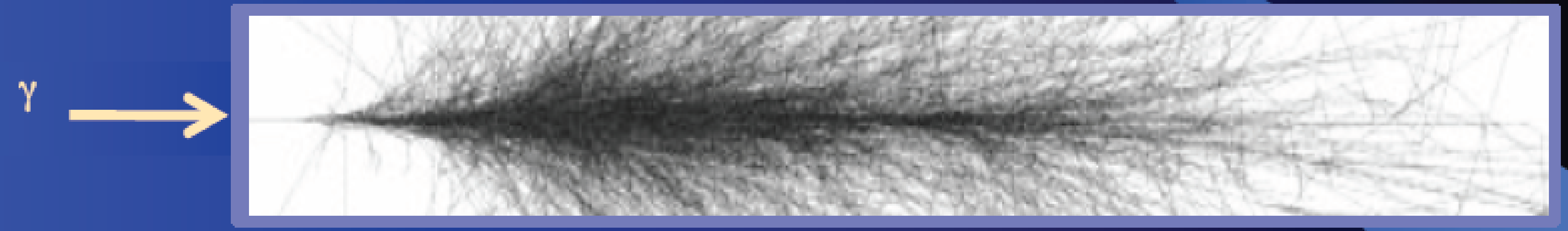


Proceso de centelleo



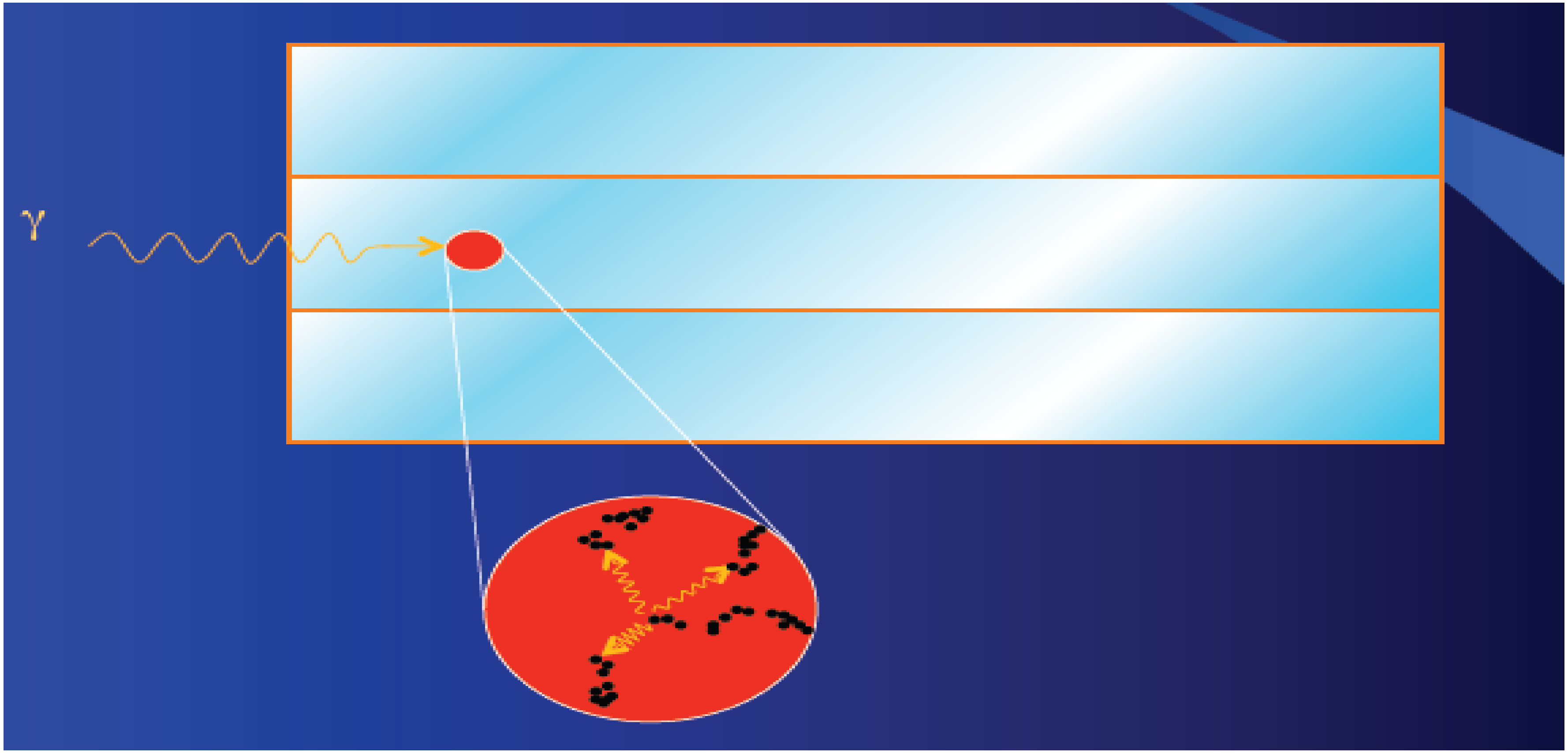
Zoom del proceso de conversión (alta energía)

- The energy conversion from incoming X or γ Rays is a complex process resulting from a cascade of events.

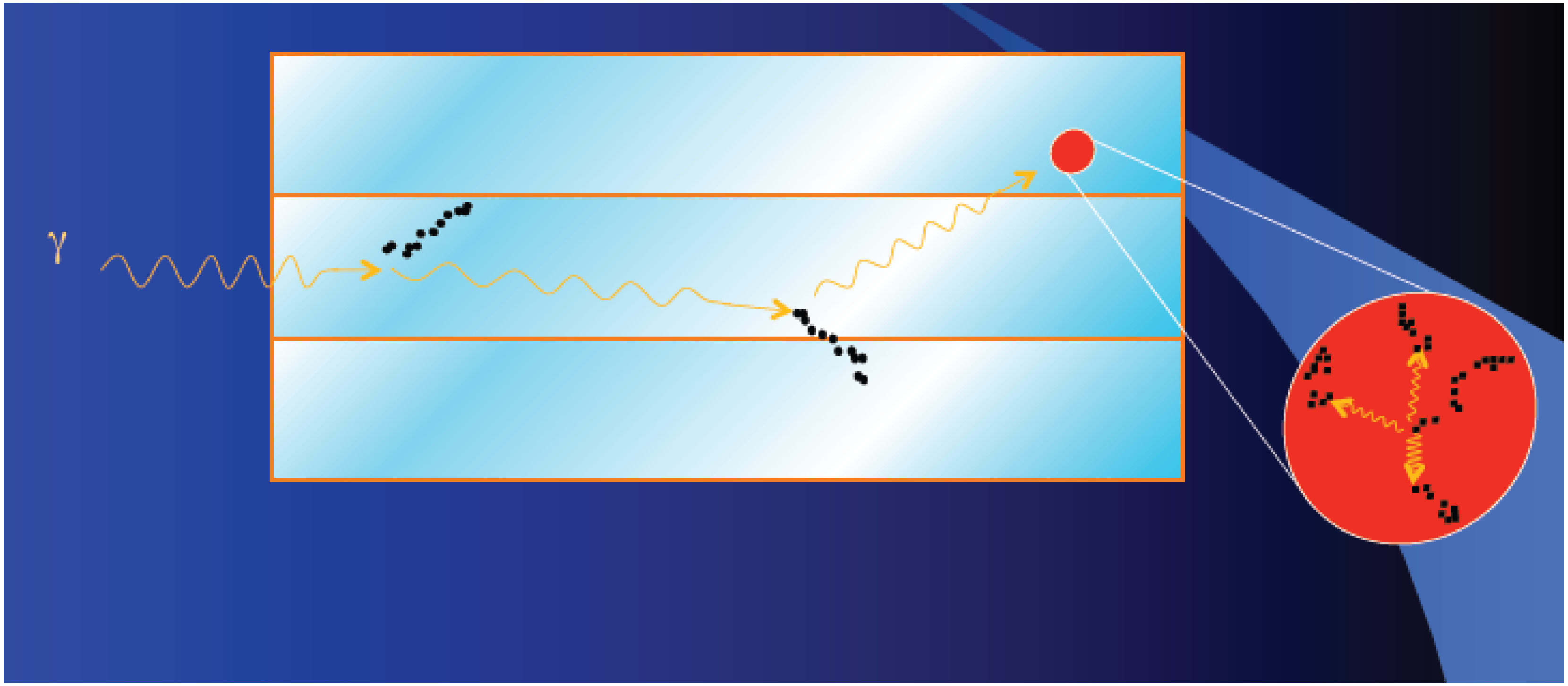


- Hadronic events are even more complex
  - Details of the full cascade for HEP with contributions from different conversion mechanisms: scintillation and Cerenkov, would lead to particle identification within the shower

Zoom del proceso de conversión (baja energía)

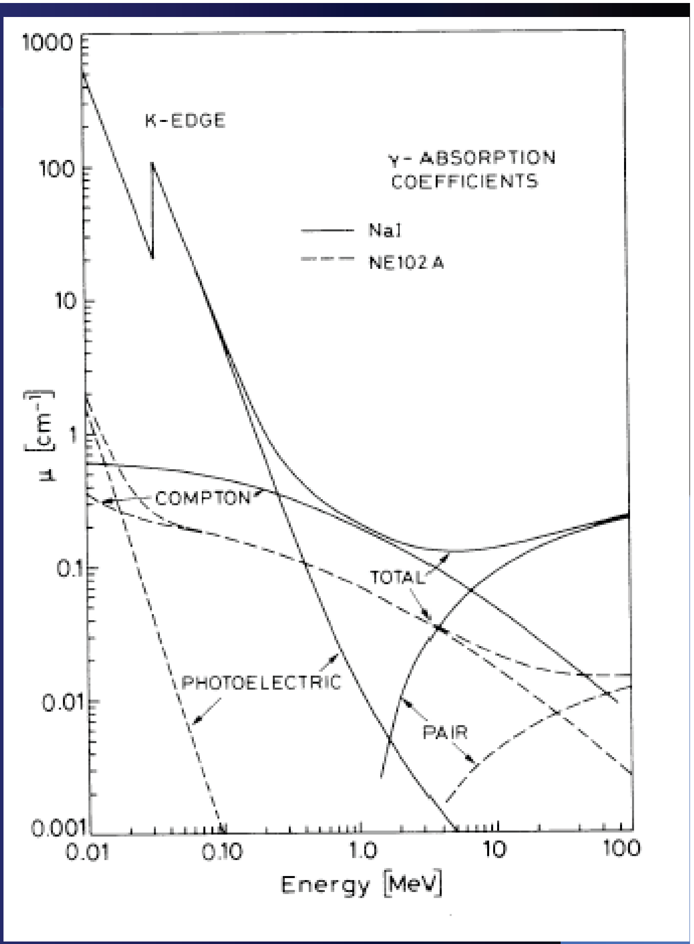


Zoom del proceso de conversión (baja energía)

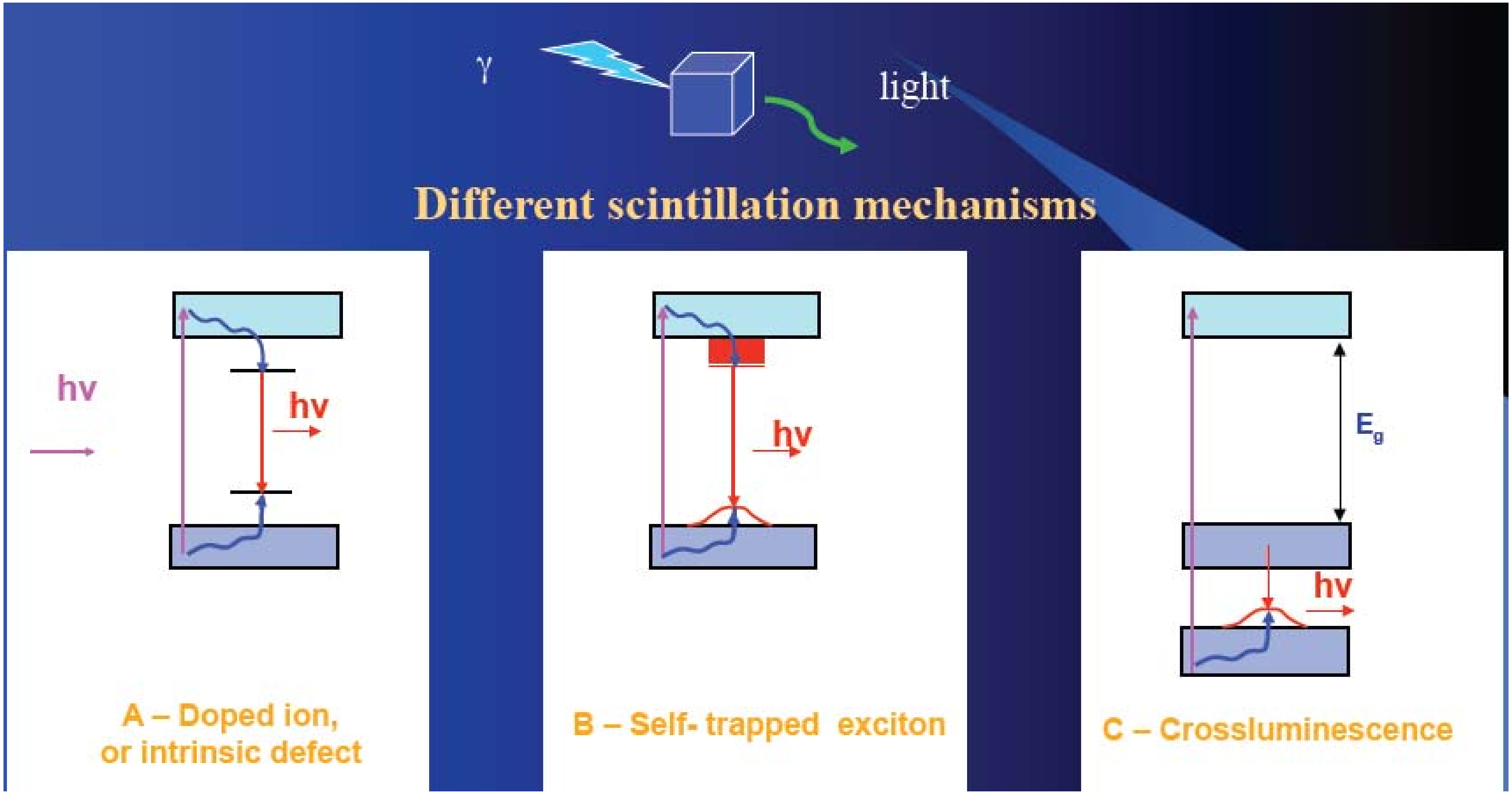


Qué centellador escojo?

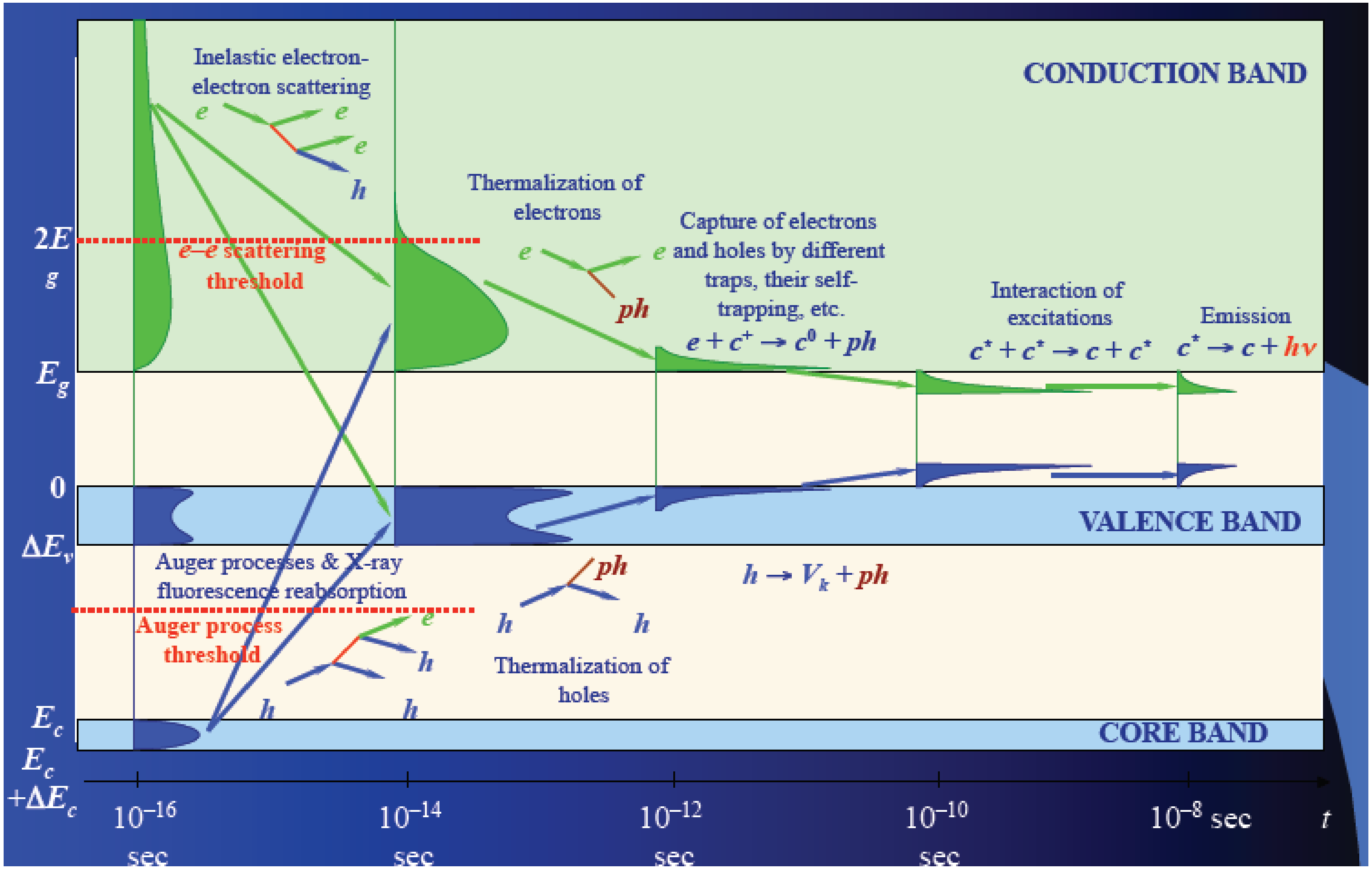
- For charged particles: high ρ materials to increase dE/dx
- For X and γ-rays (but also high energy electrons, which radiate γ-rays by bremstrahlung)
  3 mechanisms:
  - Photoelectric: $\sigma_{ph} \propto \frac{Z^5}{E_\gamma^{7/2}}$
  - Compton: $\sigma_c \propto Z$
  - Pair poduction: $\sigma_{pair} \propto Z^2 \ln(2E_\gamma)$
- At low energy high photoelectric cross-section is desired
- At high energy good shower containment requires
  - Small radiation length: $X_0 = \frac{A}{\rho}\frac{716.4\,gcm^{-2}}{Z(Z+1)\ln(287/Z)}$
  - Small Moliere radius: $R_M \approx X_0 \frac{Z+1.2}{37.74} \propto 1/\rho$



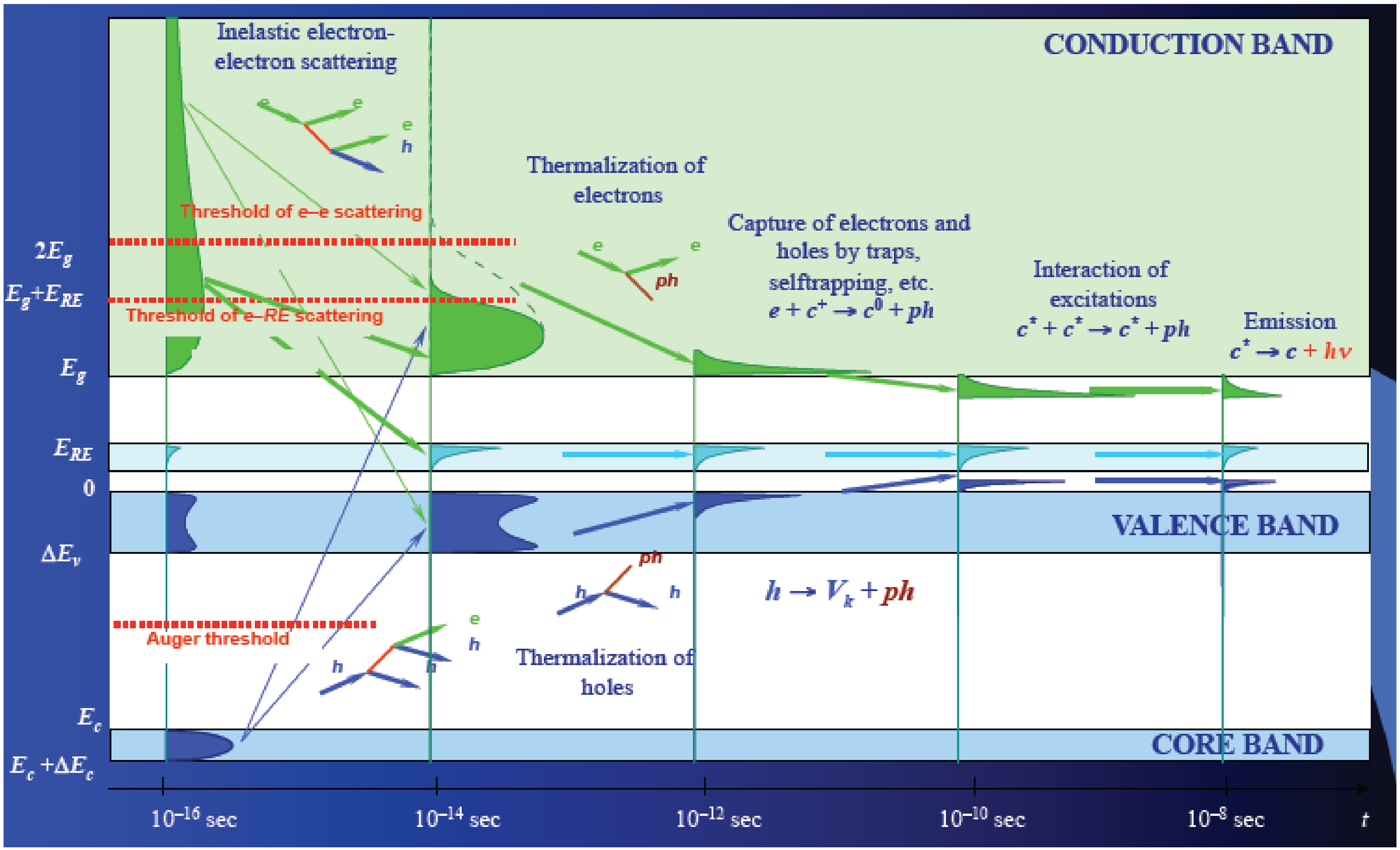
Aspectos fundamentales del centelleo



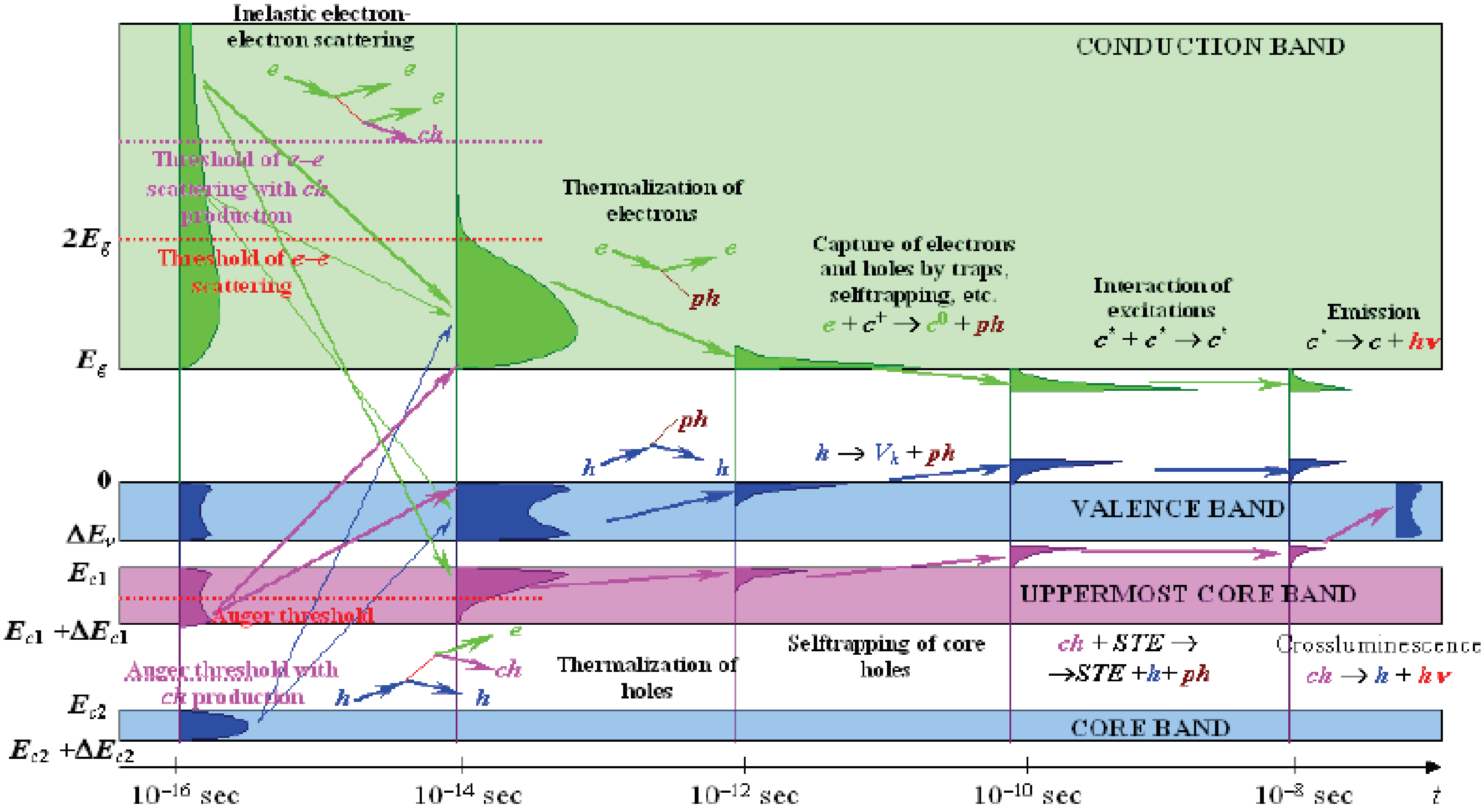
Relajación de las excitaciones electrónicas: luminiscencia intrínseca



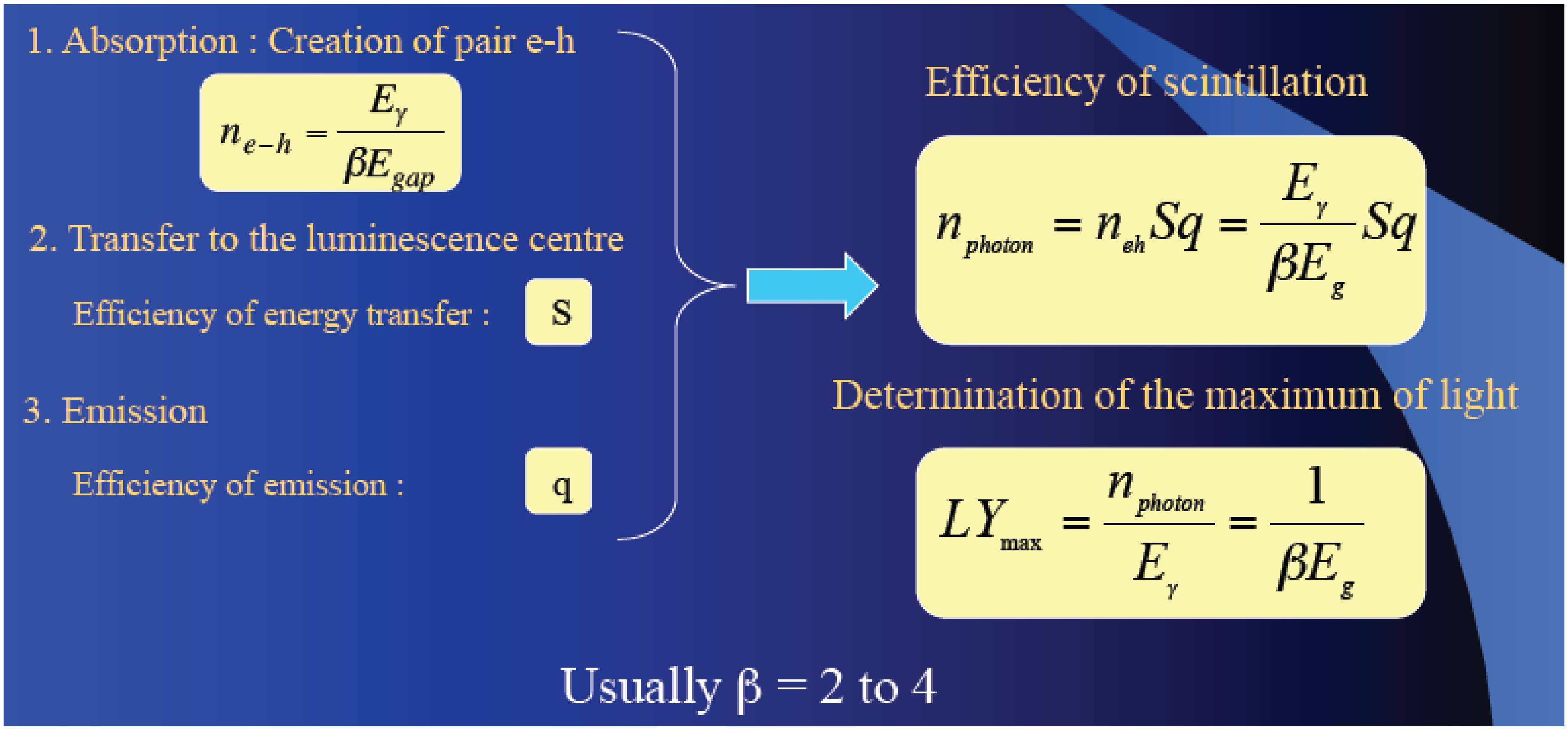
Relajación de las excitaciones electrónicas: luminiscencia extrínseca



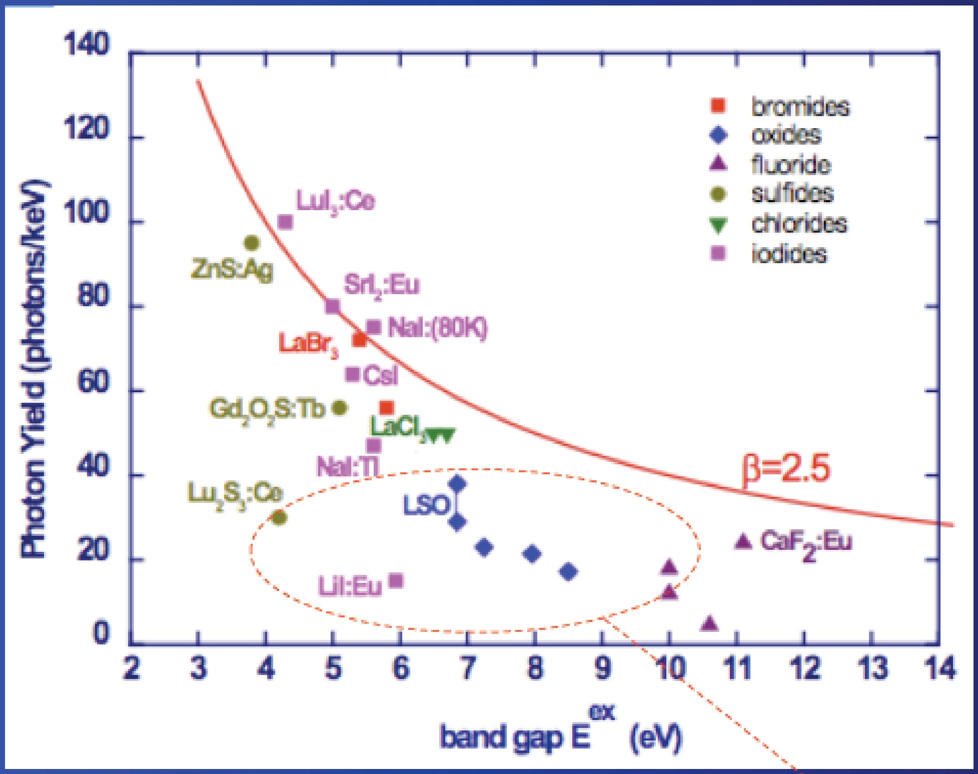
Relajación de las excitaciones electrónicas: luminiscencia cruzada



Las 3 fases del mecanismo de centelleo



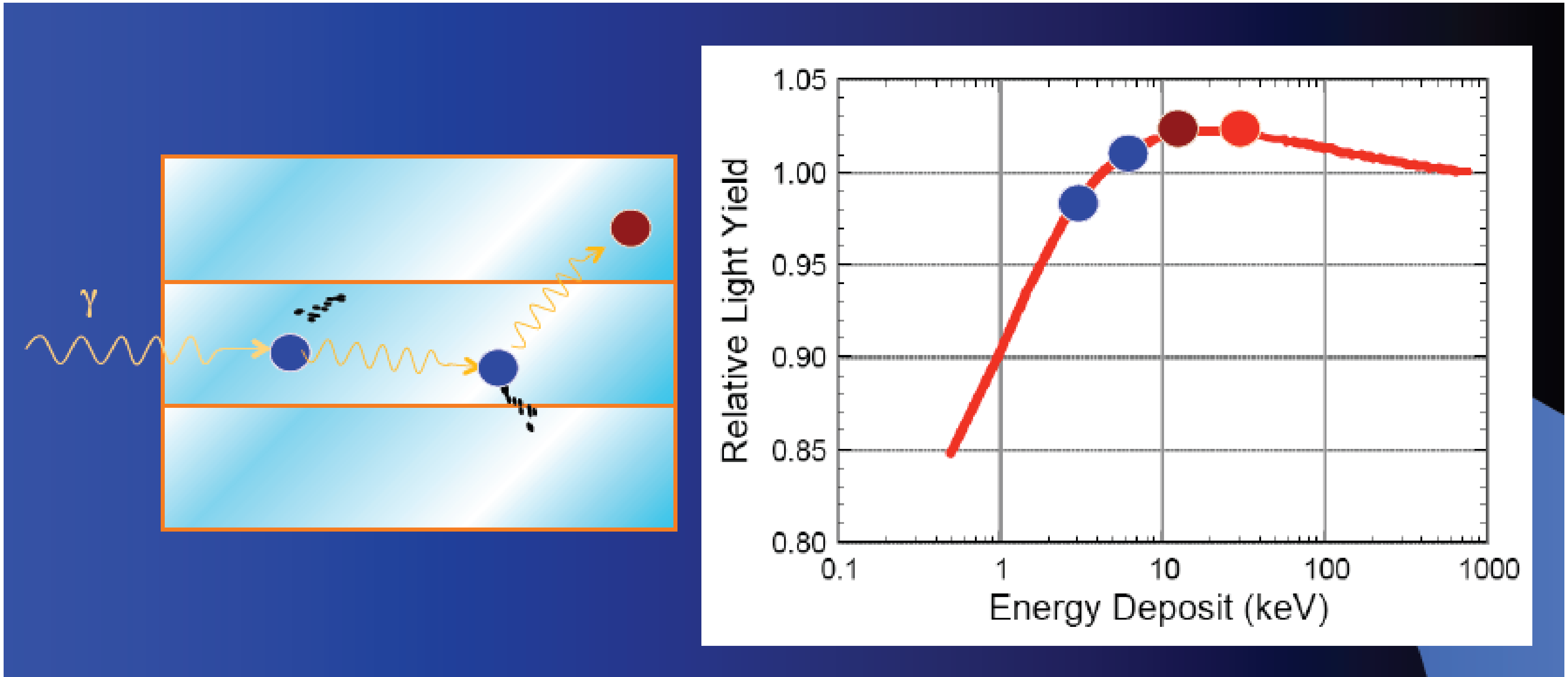
Límites para LY



$$N_{ph} \leq N_{eh} = \frac{E_{\gamma}}{\beta E_{gap}}$$

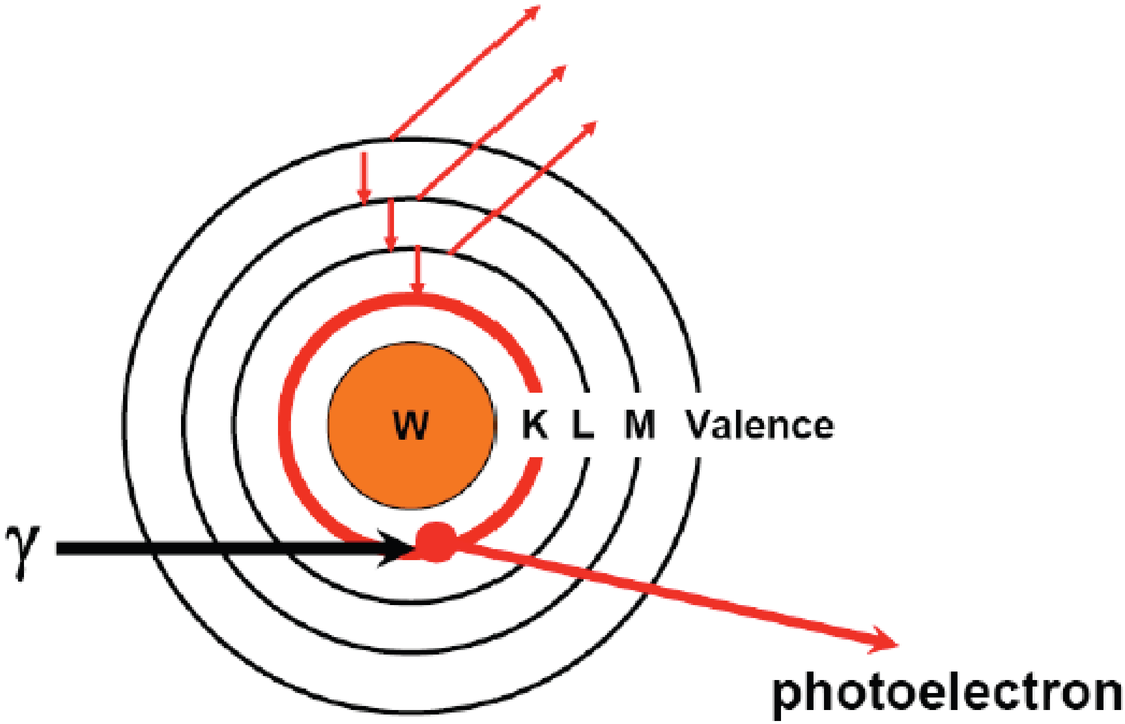
Why?

Interaccion inicial:
Compton vs Fotoelectrico



Non-Proportionality + Multiple Energy Deposit
⇒ Degraded Energy Resolution

Efecto fotoeléctrico



- Usually Occur with *Inner* Shell Electrons

  ⇒ Inner Shell Hole Filled via Cascade

Basics of photon detection

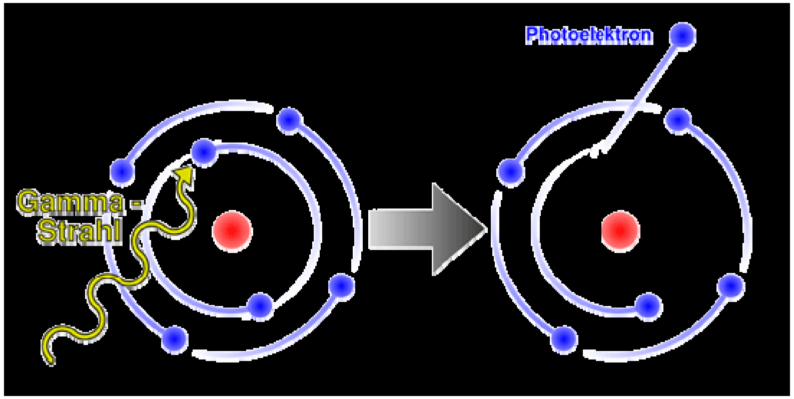
Purpose: Convert light into detectable electronic signal

(we are not covering photographic emulsions!)

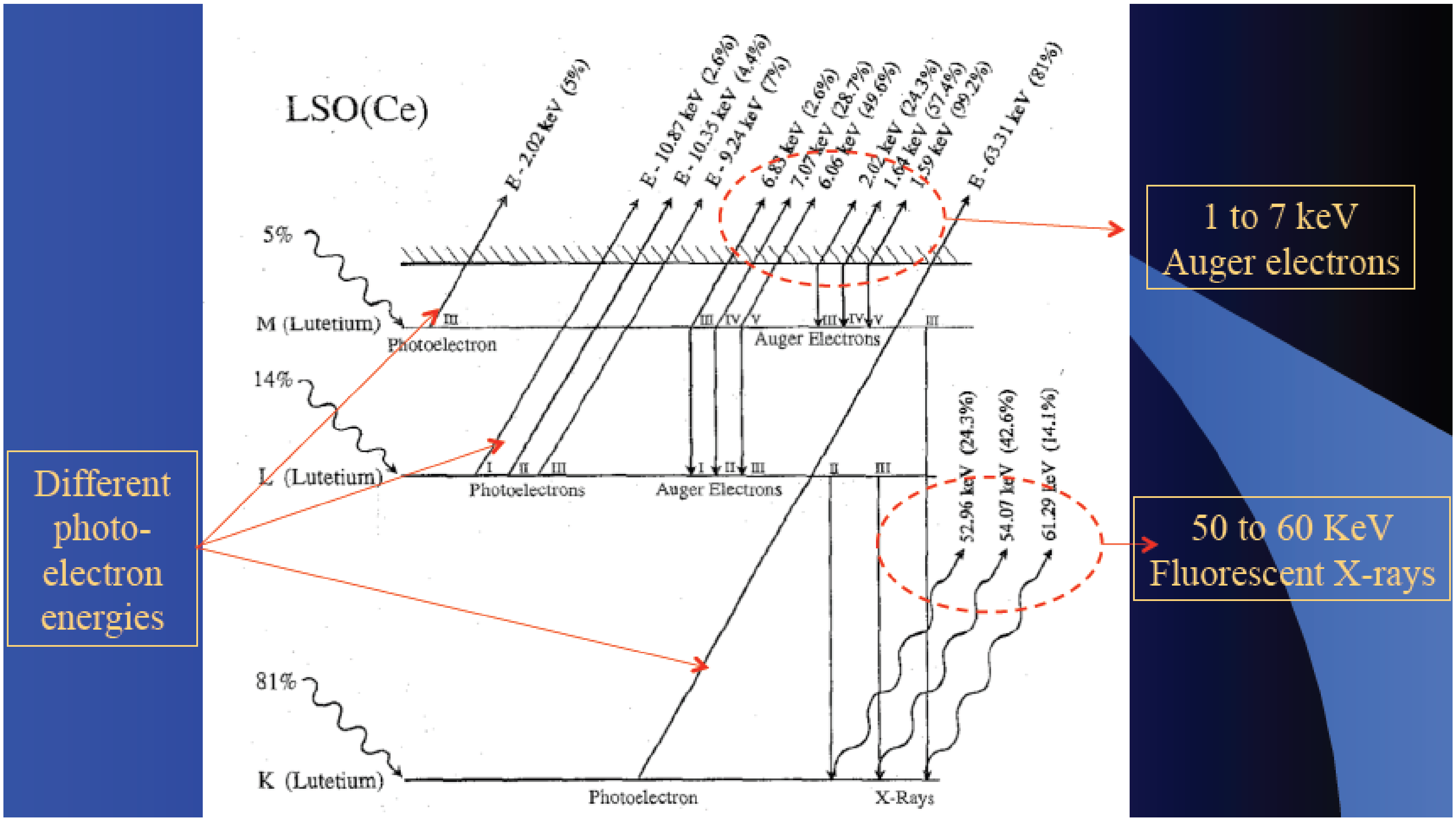
A. Einstein.
Annalen der Physik **17** (1905) 132–148.

Principle:

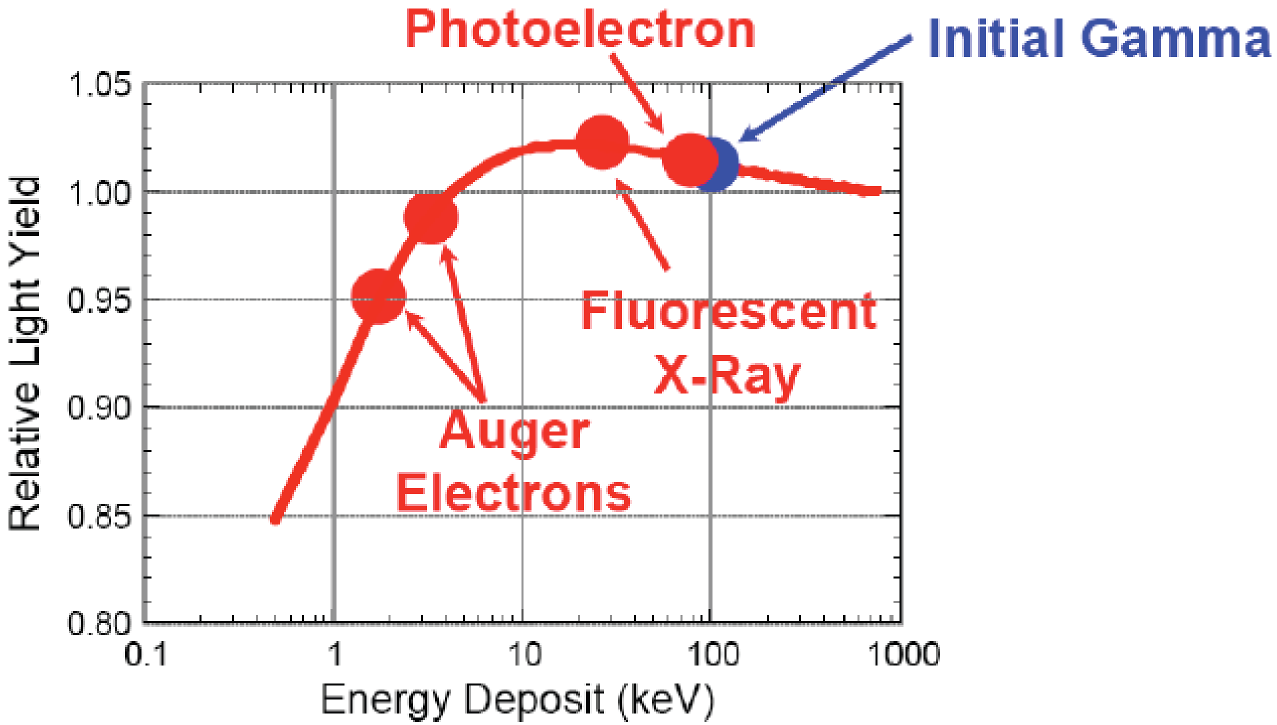
- Use photoelectric effect to ‘convert’ photons (γ) to photoelectrons (pe)
- Details depend on the type of the photosensitive material (see below).
- Photon detection involves often materials like K, Na, Rb, Cs (alkali metals). They have the smallest electronegativity → highest tendency to release electrons.
- Most photo-detectors make use of solid or gaseous photosensitive materials.
- Photo-effect can in principle also be observed from liquids.



Modelo simplificado de cascada



Interacción de la cascada fotoeléctrica



Non-Proportionality + Multiple Energy Deposit
⇒ Degraded Energy Resolution

Detectors based on Registration of excited Atoms → Scintillators

Emission of photons of by excited Atoms, typically UV to visible light.

a) **Observed in Noble Gases (even liquid !)**

b) **Inorganic Crystals**

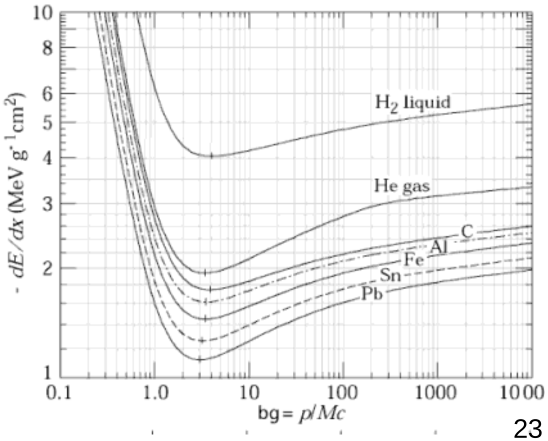
→ **Substances with largest light yield. Used for precision measurement of energetic Photons. Used in Nuclear Medicine.**

c) **Polyzyclic Hydrocarbons (Naphtalen, Anthrazen, organic Scintillators)**

→ **Most important category. Large scale industrial production, mechanically and chemically quite robust. Characteristic are one or two decay times of the light emission.**

Typical light yield of scintillators:

Energy (visible photons) ≈ few % of the total energy Loss.
z.B. 1cm plastic scintillator, ρ ≈ 1, dE/dx=1.5 MeV, ~15 keV in photons;
i.e. ~ 15 000 photons produced.



Detectors based on Registration of excited Atoms → Scintillators

Organic ('Plastic') Scintillators

Low Light Yield **Fast: 1-3ns**

Type	Light[a] output	λ_{max}[b] (nm)	Attenuation[c] length (cm)	Risetime (ns)	Decay[d] time (ns)	Pulse FWHM (ns)
NE 102A	58–70	423	250	0.9	2.2–2.5	2.7–3.2
NE 104	68	406	120	0.6–0.7	1.7–2.0	2.2–2.5
NE 104B	59	406	120	1	3.0	3
NE 110	60	434	400	1.0	2.9–3.3	4.2
NE 111	40–55	375	8	0.13–0.4	1.3–1.7	1.2–1.6
NE 114	42–50	434	350–400	~1.0	4.0	5.3
Pilot B	60–68	408	125	0.7	1.6–1.9	2.4–2.7
Pilot F	64	425	300	0.9	2.1	3.0–3.3
Pilot U	58–67	391	100–140	0.5	1.4–1.5	1.2–1.9
BC 404	68	408	—	0.7	1.8	2.2
BC 408	64	425	—	0.9	2.1	~2.5
BC 420	64	391	—	0.5	1.5	1.3
ND 100	60	434	400	—	3.3	3.3
ND 120	65	423	250	—	2.4	2.7
ND 160	68	408	125	—	1.8	2.7

LHC bunchcrossing 25ns

Inorganic (Crystal) Scintillators

Large Light Yield **Slow: few 100ns**

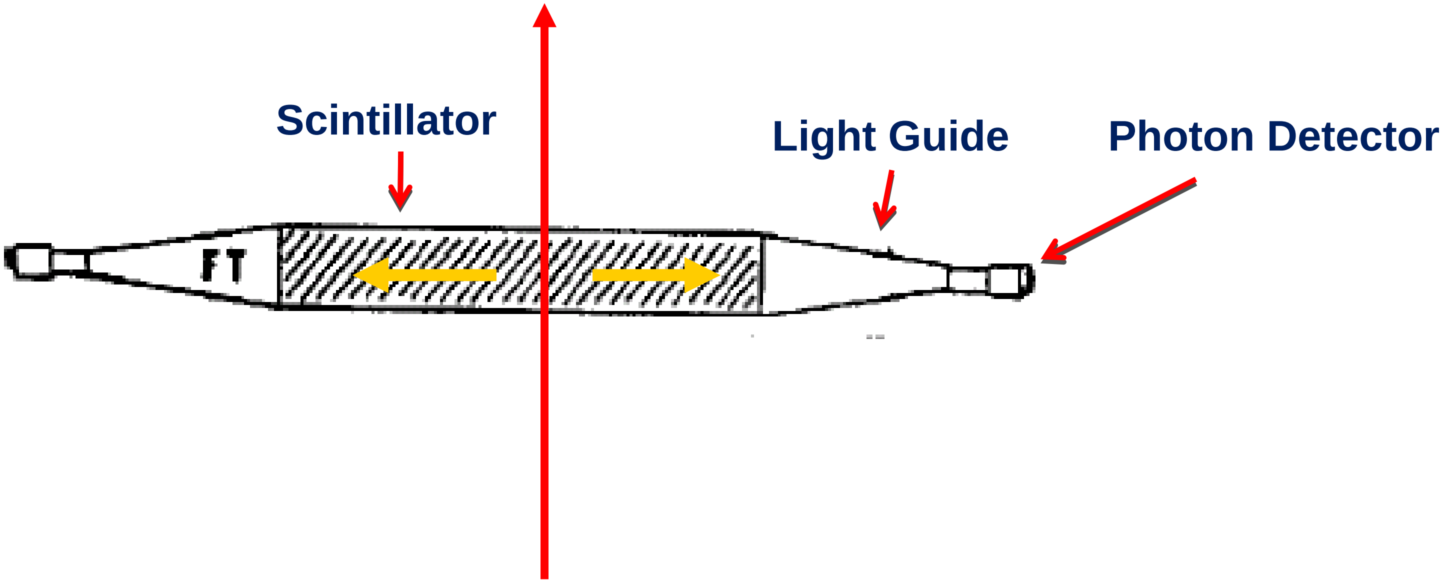
	Relative light output	λ_{max} emission (nm)	Decay time (ns)	Density (g/cm^3)
Inorganic crystals				
NaI(Tl)	230	415	230	3.67
CsI(Tl)	250	560	900	4.51
$Bi_4Ge_3O_{12}$ (BGO)	23–86	480	300	7.13
Organic crystals				
Anthracene	100	448	22	1.25
Trans-stilbene	75	384	4.5	1.16
Naphthalene	32	330–348	76–96	1.03
p,p'-Quarterphenyl	94	437	7.5	1.20
Primary activators				
2,5-Diphenyl-oxazole (PPO)	75	360–416	5[a]	
2-Phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole (PBD)	96	360–5		
4,4''-Bis(2-butyloctyloxy)-p-quaterphenyl (BIBUQ)	60	365,393	1.30[a]	

LEP bunchcrossing 25μs

Scintillators

Photons are being reflected towards the ends of the scintillator.

A light guide brings the photons to the Photomultipliers where the photons are converted to an electrical signal.

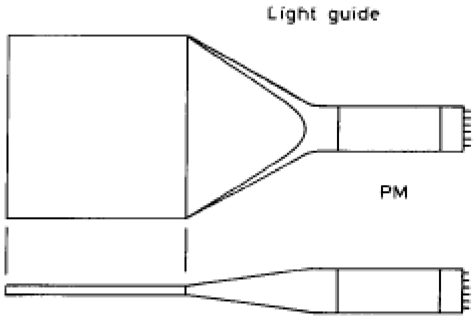


By segmentation one can arrive at spatial resolution.

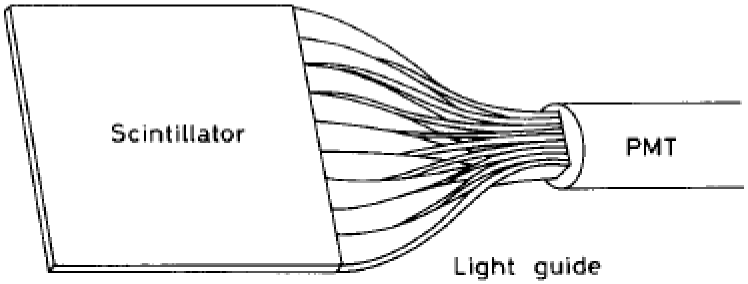
Because of the excellent timing properties (<1ns) the arrival time, or time of flight, can be measured very accurately → Trigger, Time of Flight.

Typical Geometries:

- Light guides: transfer by total internal reflection (+outer reflector)

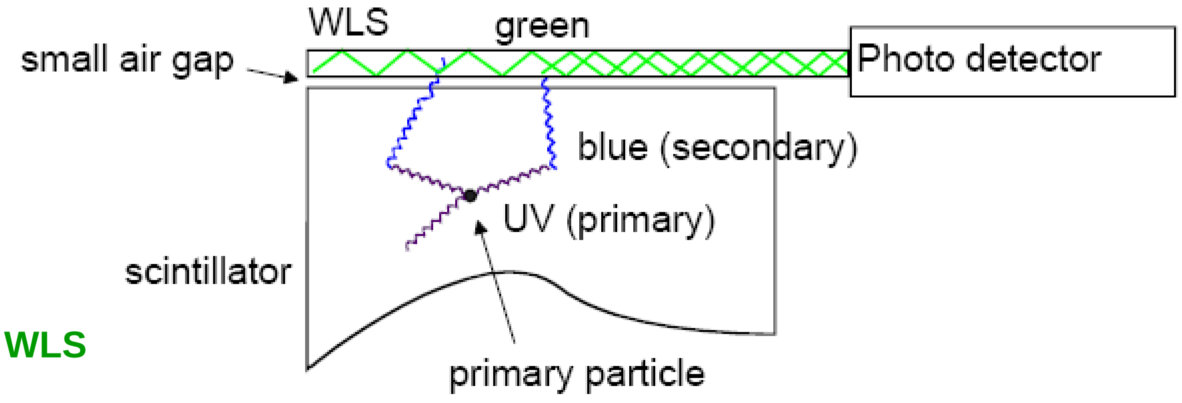


"fish tail"



adiabatic

- wavelength shifter (WLS) bars



UV light enters the WLS material
Light is transformed into longer wavelength
→Total internal reflection inside the WLS material
→ 'transport' of the light to the photo detector

The frequent use of Scintillators is due to:

Well established and cheap techniques to register Photons → Photomultipliers and the fast response time → 1 to 100ns

Schematic of a Photomultiplier:

- **Typical Gains (as a function of the applied voltage): 10^8 to 10^{10}**
- **Typical efficiency for photon detection:**
- **< 20%**
- **For very good PMs: registration of single photons possible.**
- **Example: 10 primary Elektrons, Gain 10^7 → 10^8 electrons in the end in T ≈ 10ns. I=Q/T = $10^8 \cdot 1.603 \cdot 10^{-19} / 10 \cdot 10^{-9}$ = 1.6mA.**
- **Across a 50 Ω Resistor → U=R*I= 80mV.**