Scintillator Detectors

Darren R Grant — June 2026

Canada Excellence Research Chairs
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Material References/Sources*

Scintillation Detectors - Particle Detection via Luminescence (W. Kolanoski — https://www.desy.de/~schleper/lehre/Det_Dat/SS_2018/02_Scintillators.pdf)

Scintillator Detectors (S. Leoni — https://www0.mi.infn.it/~sleoni/TEACHING/Nuc-Phys-Det/PDF/Lezione-partI-6-scint-det.pdf)

Introduction to Radiation Detectors and Electronics - III. Scintillation Detectors (H. Spieler, 1998 — https://www-physics.lbl.gov/~spieler/physics_198_notes/PDF/III-Scint.pdf)

Scintillation Detectors and Their Applications (C. Woody, 2019 — https://grids.triumf.ca/2019/lectures/Lecture7.pdf)

Scintillation Detectors (S. Xella, 2009 — https://www.nbi.dk/~xella/lecture_16Feb2009.pdf)

Scintillation Detectors (J. Yanez, 2025 — https://indico.triumf.ca/event/574/contributions/6081/attachments/4802/6978/scintillation_detectors_yanez_grids_2025.pdf)

Detector and detector systems for particle and nuclear physics I (J. Zmeskal, 2020 — https://www.oeaw.ac.at/fileadmin/Institute/SMI/PDF/Detectors_WS2020-21_part2.pdf)

* Alphabetically author last name

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Scintillators

Light Collection

Photodetectors

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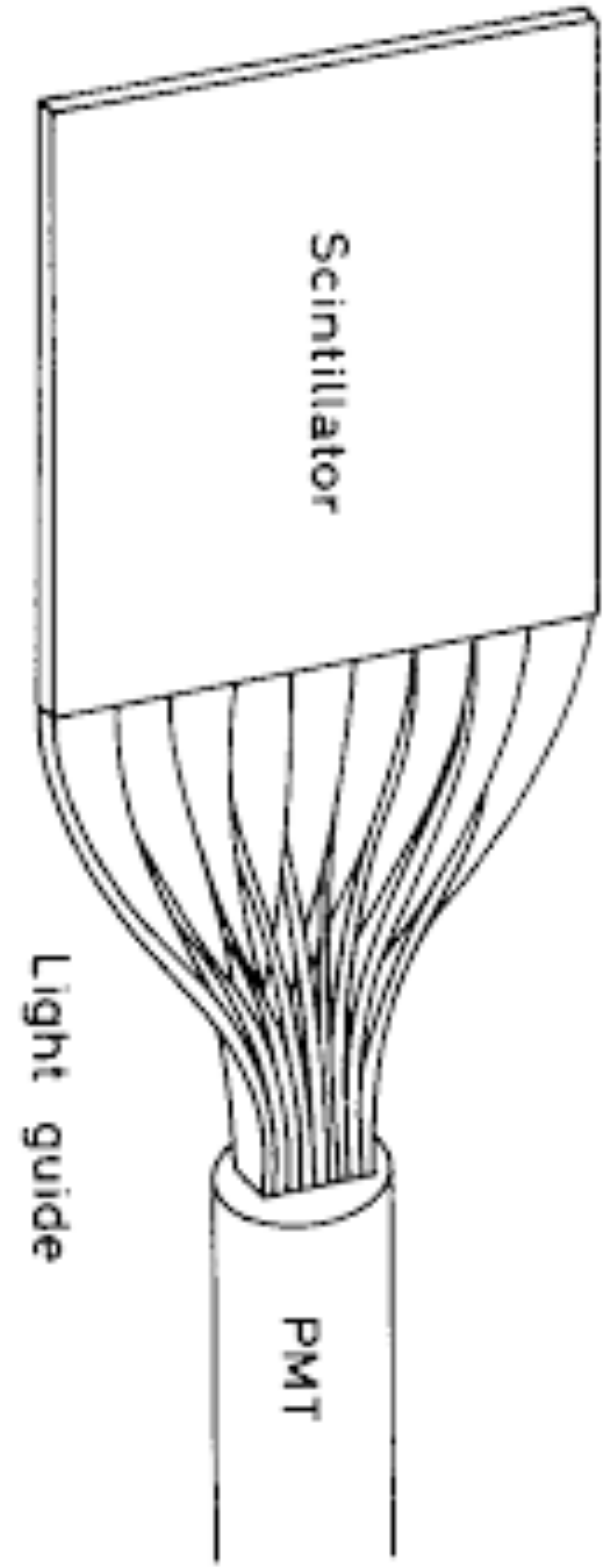
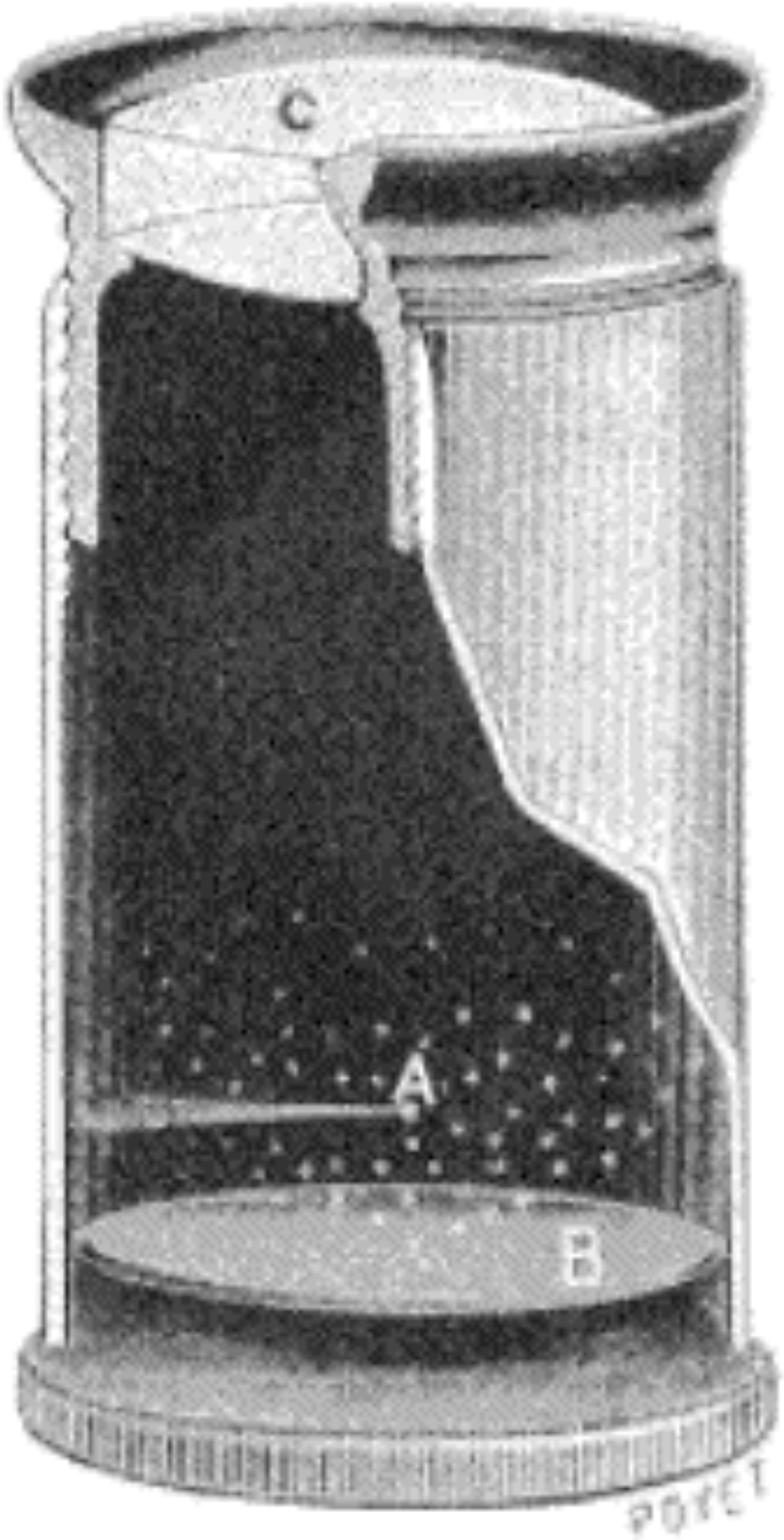


J. Zmeskal (SMI) 2020

Scintillation (aside) - brief history

W. Crookes (1903) first demonstrates the "spinthariscope", providing visual observations of individual scintillations (alpha particles impinging on a ZnS screen); precursor for scintillation counters.

Curran and Baker (1944) introduced the use of the photomultiplier tube in place of the naked eye, reviving the long-term use of scintillator detectors.

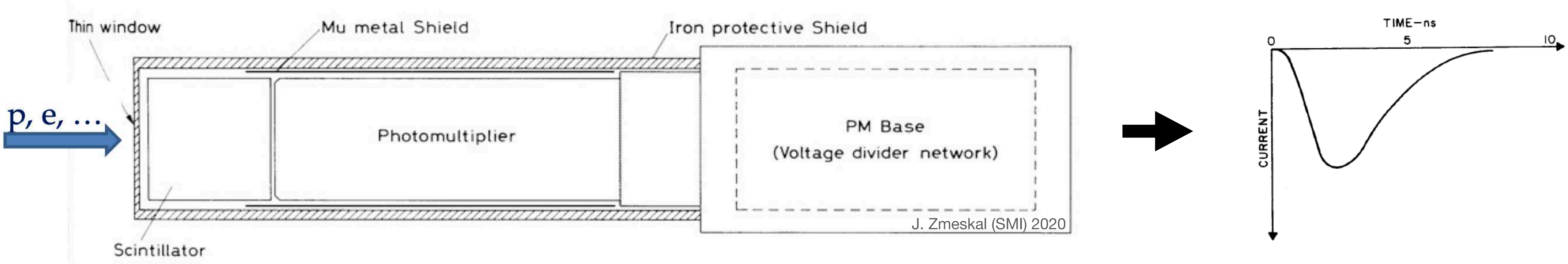


Artist's rendering of a spinthariscope from 1904.
Scale ~5cm. A: Ra-source; B: ZnS screen; C: Magnifying glass

Scintillation detectors - Introduction

General Principles

- Scintillator -> Luminescence via absorption of ionizing radiation (EM or particle)
  - Energy loss (dE/dx) is converted into light (hv).
- Light guide -> Collect and direct the scintillation light
- Photodetector -> Convert light to electrons and convert to digital signal



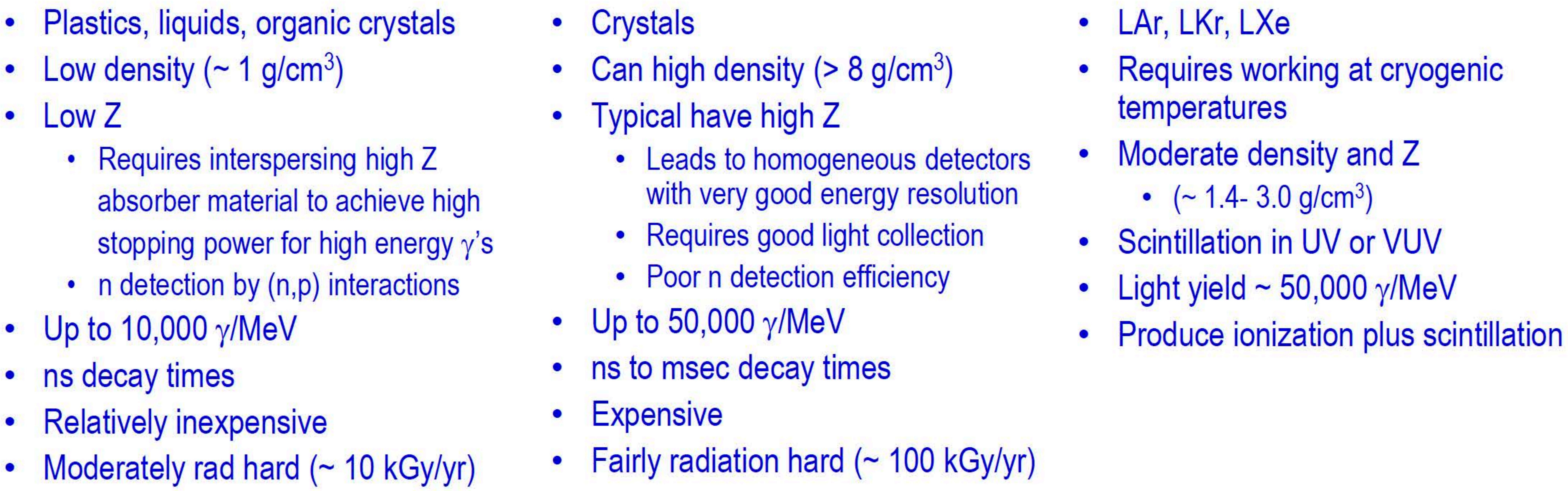
J. Zmeskal (SMI) 2020

Use cases

- Tracking detectors -> Trajectory
- Calorimetry -> Energy deposition
- Time of flight -> Velocity
- Trigger and veto systems -> Signature

Scintillation detectors - Materials

C. Woody (GRIDS 2019)



Organic

- Plastics, liquids, organic crystals
- Low density (~ 1 g/cm^3)
- Low Z
  - Requires interspersing high Z absorber material to achieve high stopping power for high energy γ's
  - n detection by (n,p) interactions
- Up to 10,000 γ/MeV
- ns decay times
- Relatively inexpensive
- Moderately rad hard (~ 10 kGy/yr)

Inorganic

- Crystals
- Can high density (> 8 g/cm^3)
- Typical have high Z
  - Leads to homogeneous detectors with very good energy resolution
  - Requires good light collection
  - Poor n detection efficiency
- Up to 50,000 γ/MeV
- ns to msec decay times
- Expensive
- Fairly radiation hard (~ 100 kGy/yr)

Noble gases

- LAr, LKr, LXe
- Requires working at cryogenic temperatures
- Moderate density and Z
  - (~ 1.4- 3.0 g/cm^3)
- Scintillation in UV or VUV
- Light yield ~ 50,000 γ/MeV
- Produce ionization plus scintillation

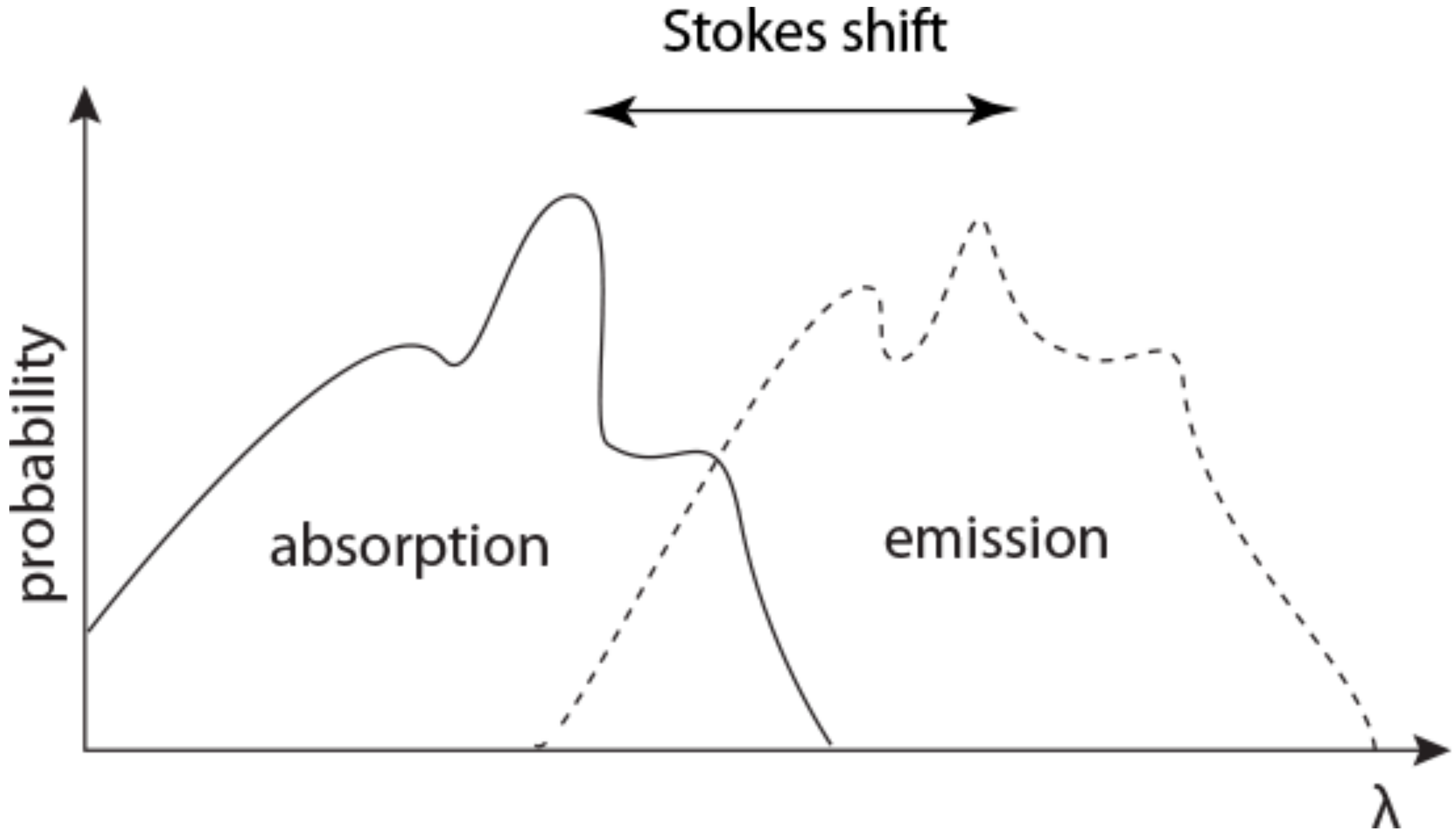
Key properties

- High conversion efficiency and (linear) light yield
- (Short) luminescence decay time
- **Medium transparency to emitted light**

Scintillation (aside) - Stokes shift

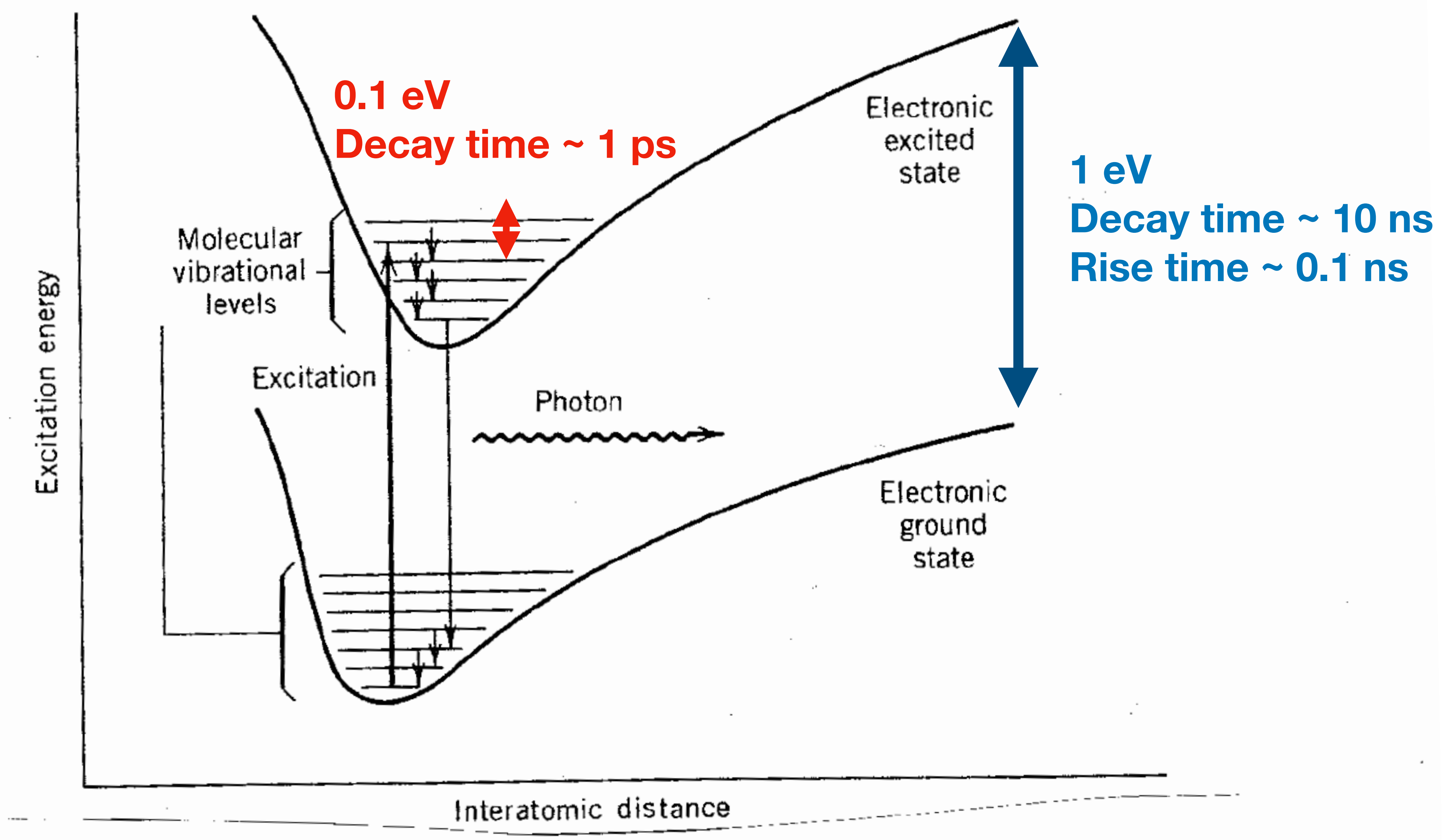
Scintillation medium should be transparent to the emitted light

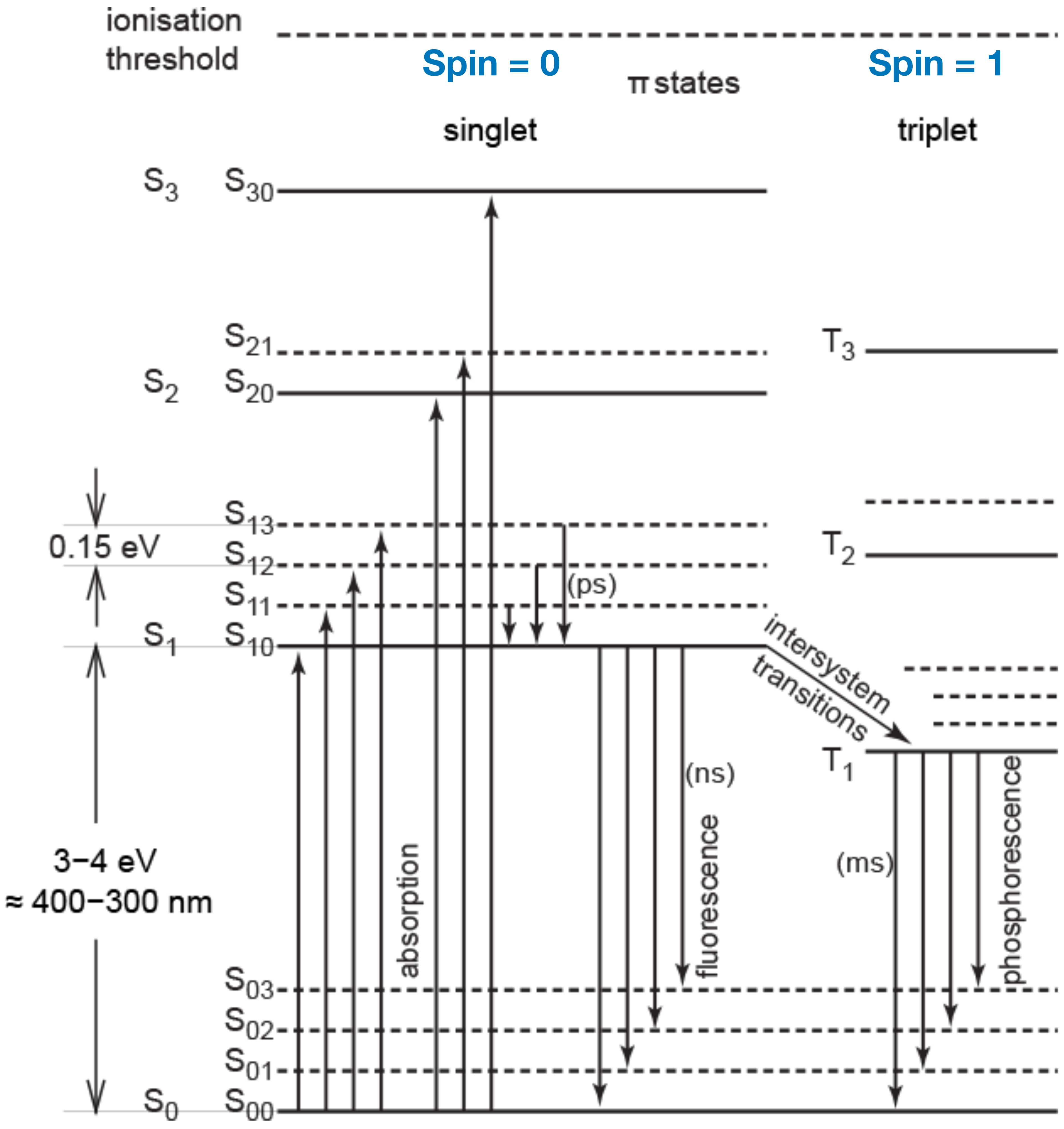
- In principle the light may be reabsorbed by the scintillator.
- For light to escape, the emission energy must be lower than the absorption energy, a phenomenon known as Stokes shift



Scintillators - Organic (Mechanism)

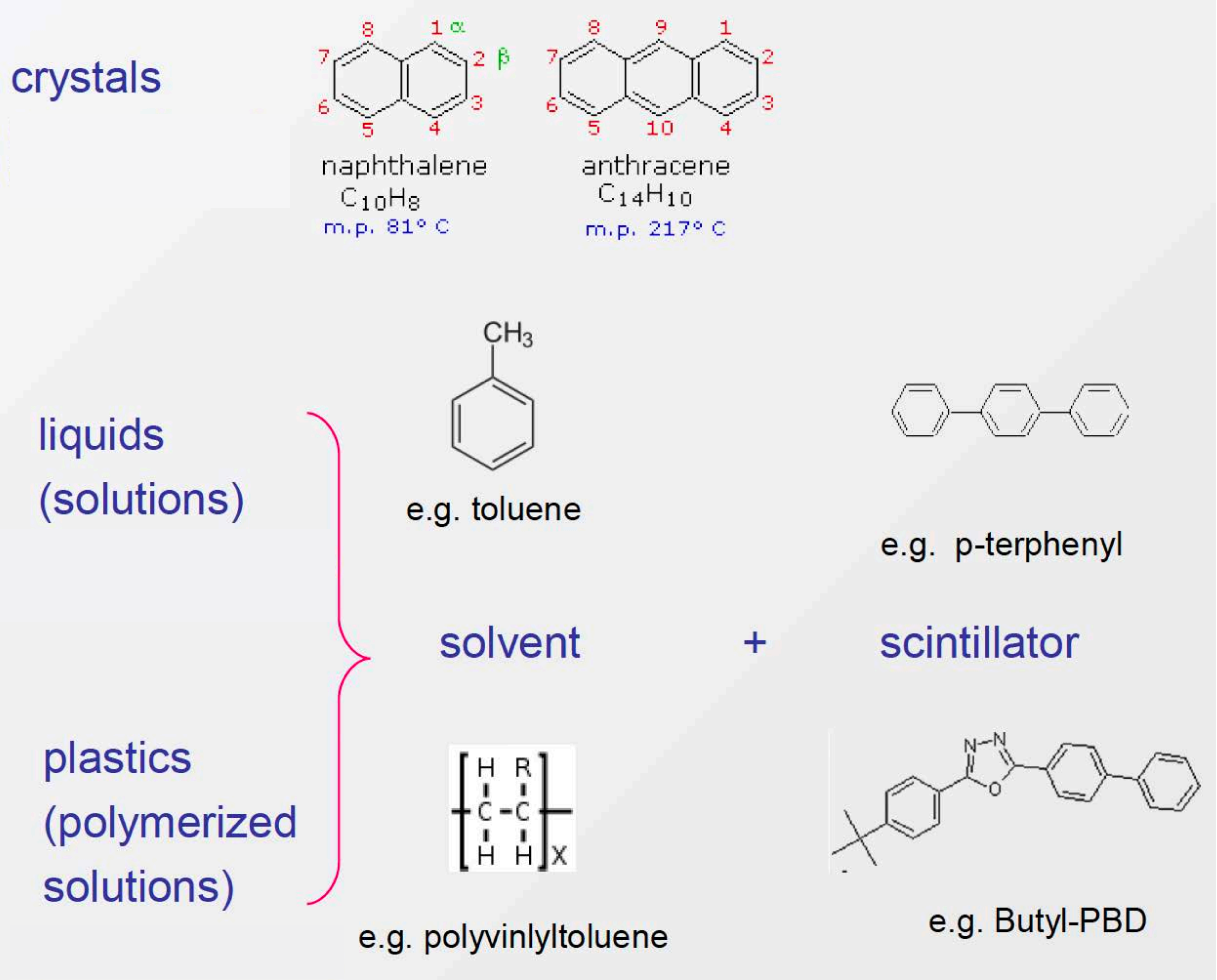
Solid or liquid hydrocarbons where the excited electrons are not strongly involved in bonding of the material





Low Z
Low conversion efficiency (~8 - 10 photons/keV)
Radiationless transitions (released via vibrations) produces Stokes shift
Fluorescence ~ e-8 s (Fast)
Phosphorescence ~ e-6 s (Slow - emission after intra-band transition)

Scintillators - Organic

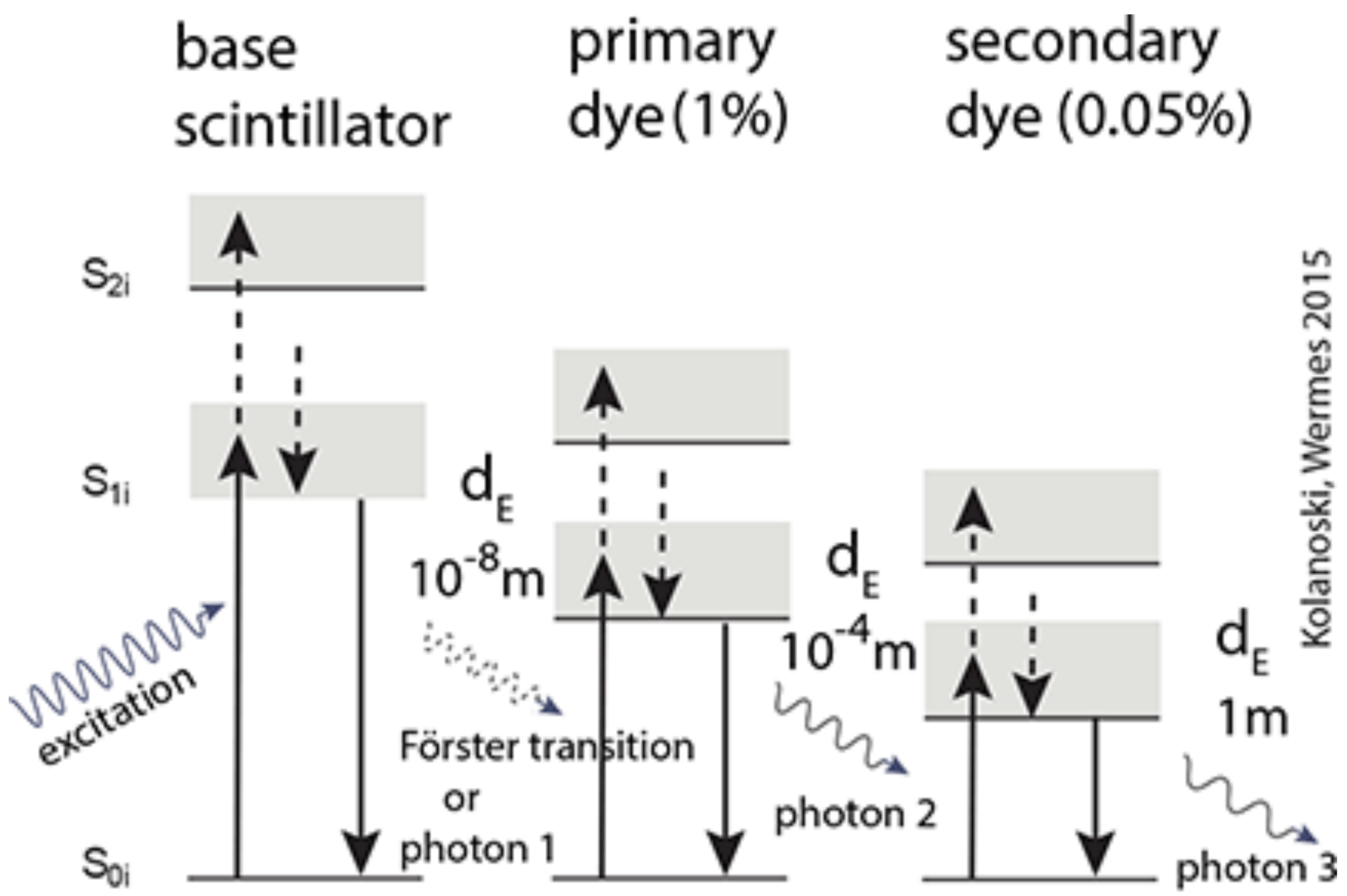


High light yield but fragile and challenging to scale; rarely used

Solvents scintillate with with low light yield; mix with a primary fluor (emitter) and secondary fluor (wavelength shifter).
Impurities quench light output.

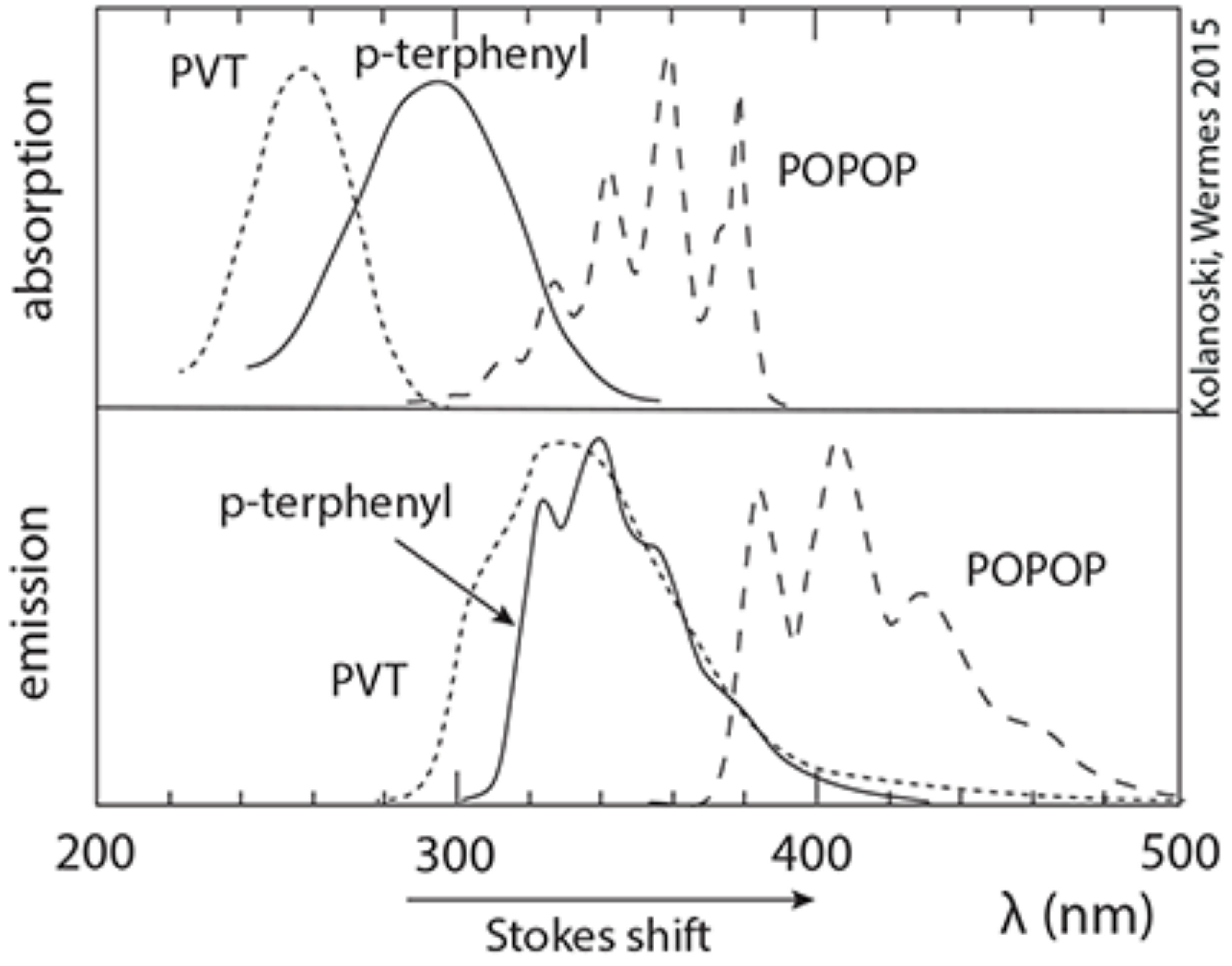
Cast in any shape for easy handling; Aging (solvents, grease, high temperature, ionizing radiation) impacts light yield

Scintillators - Organic (Liquid)

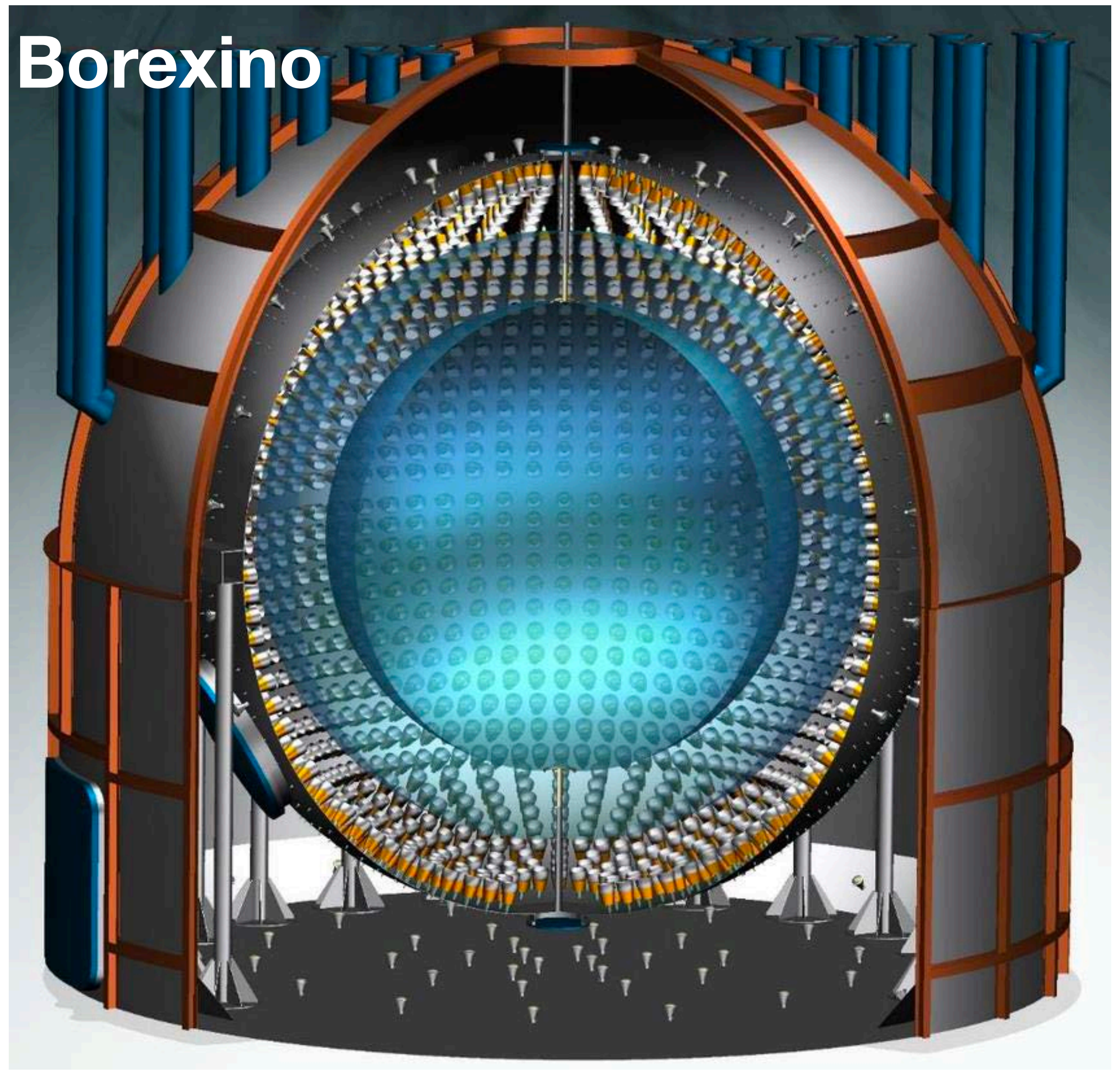


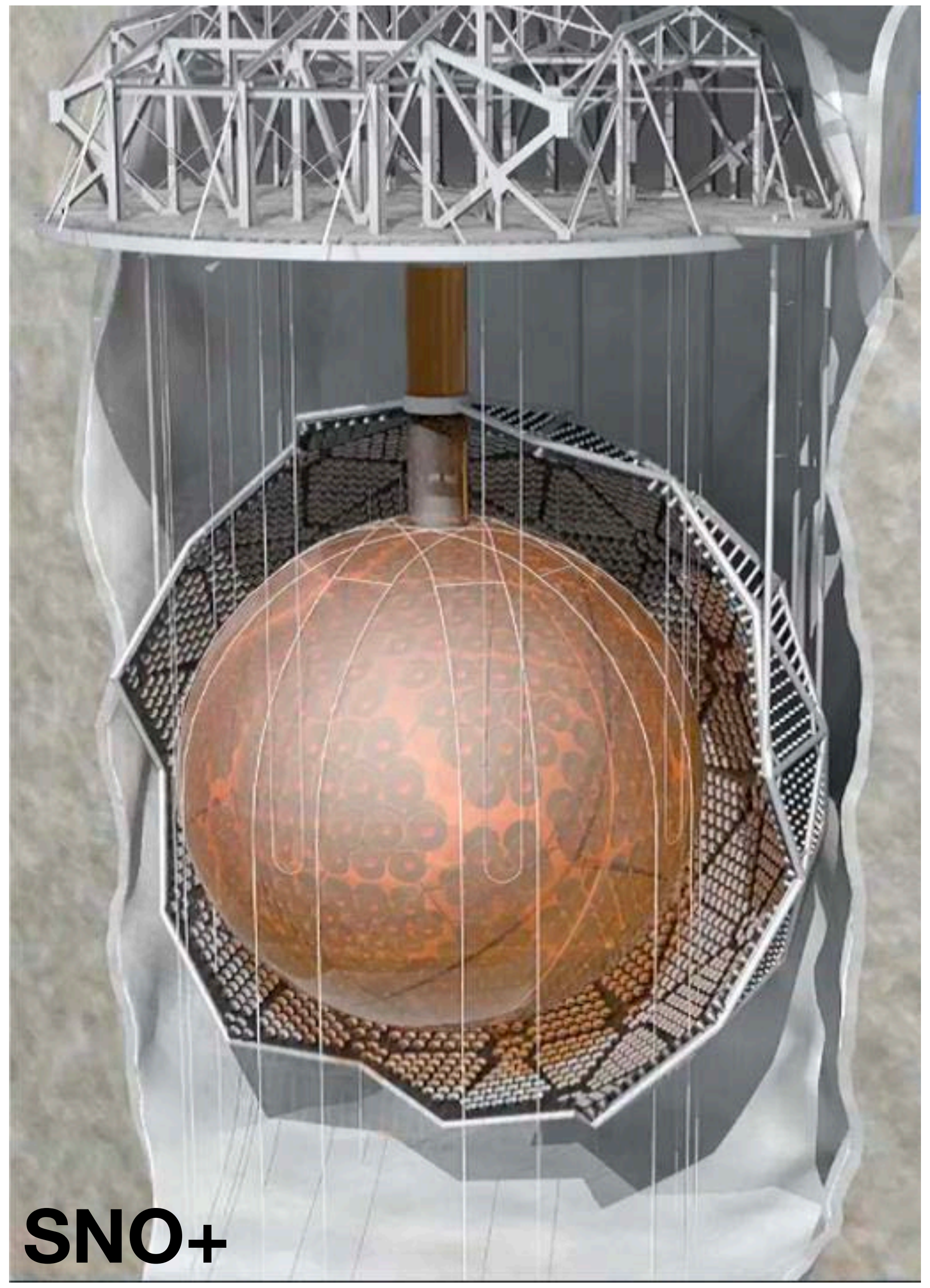
(a) Wavelength shifting: principle.

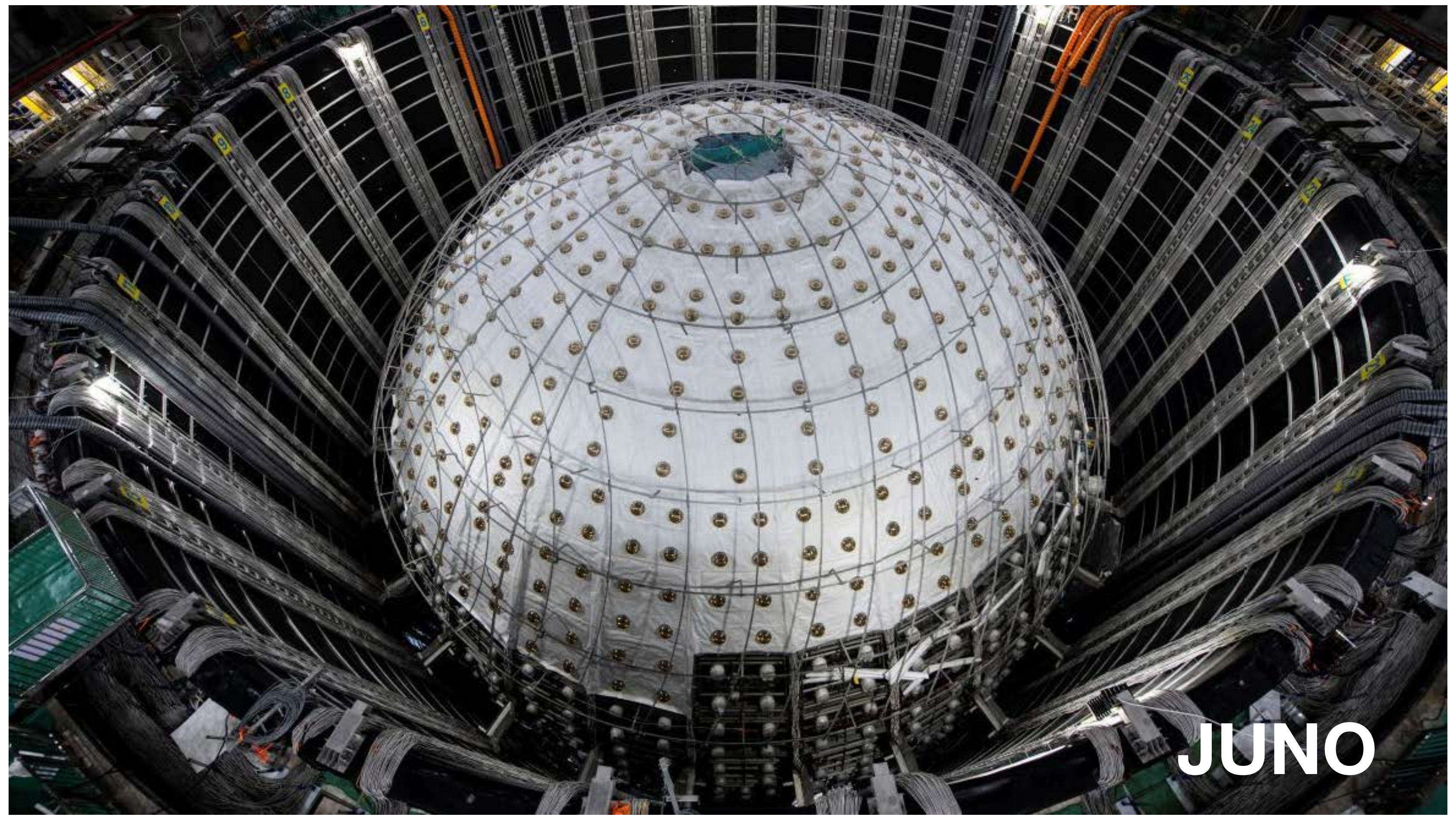
Solvents scintillate with with low yield; mix base (PVT) with a primary fluor (emitter) and secondary fluor (wavelength shifter). Impurities quench light output.



(b) Absorption and emission spectra.

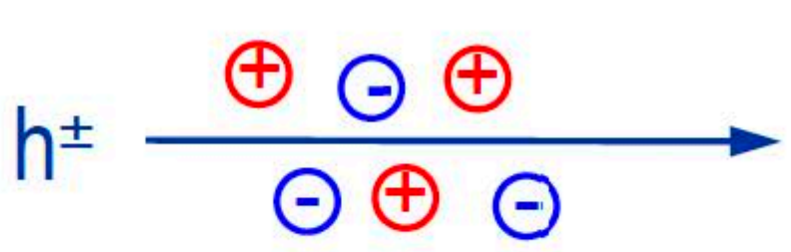


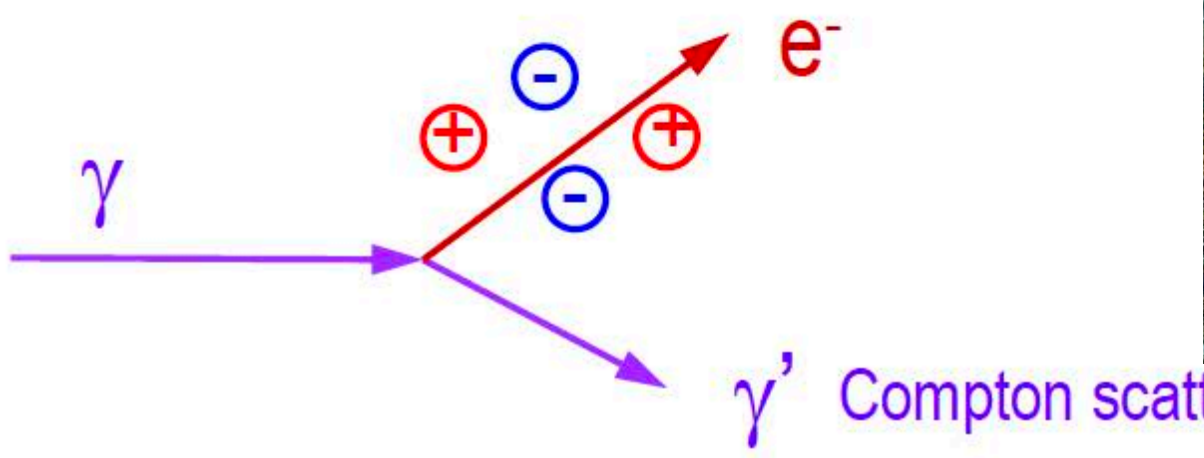


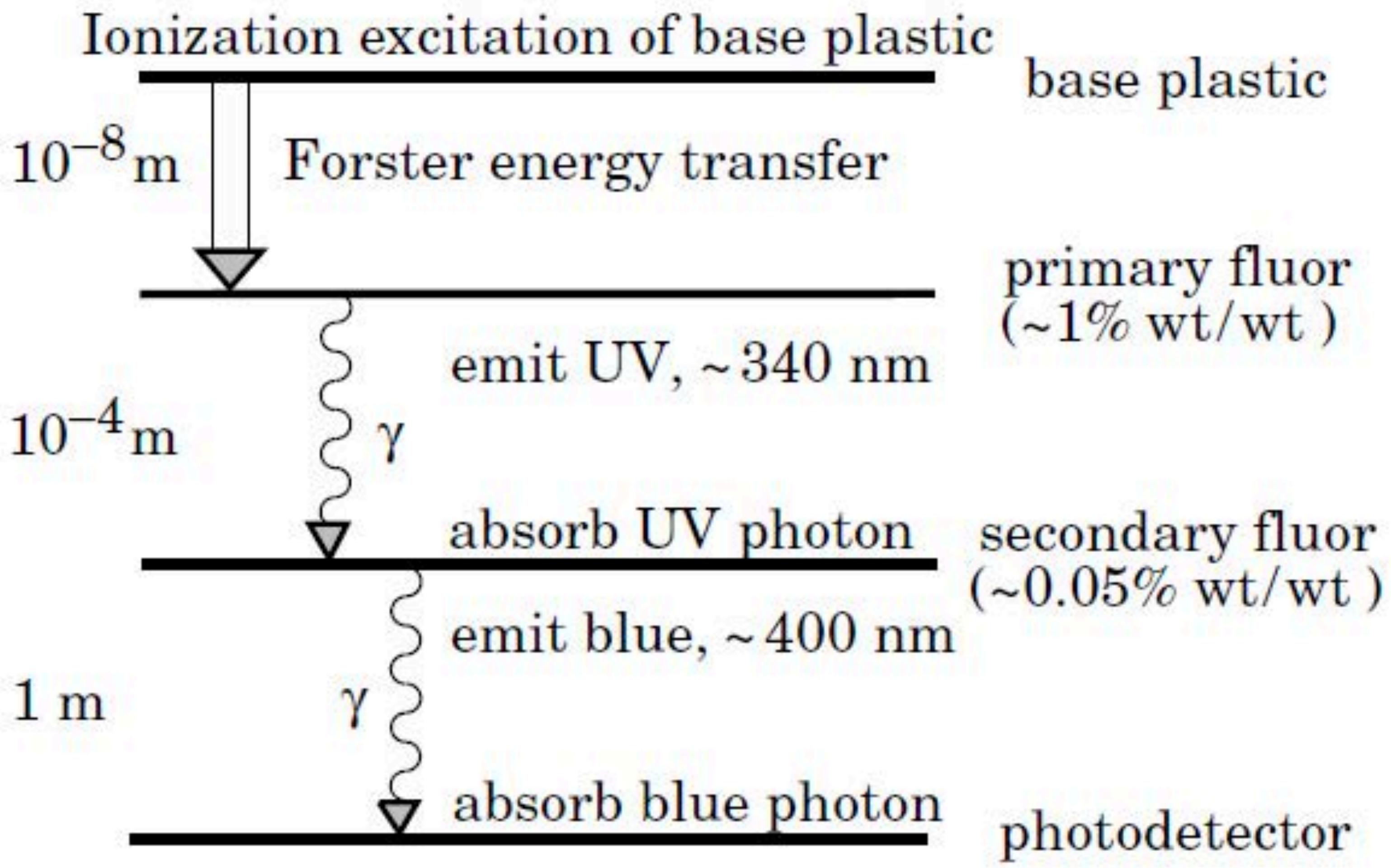


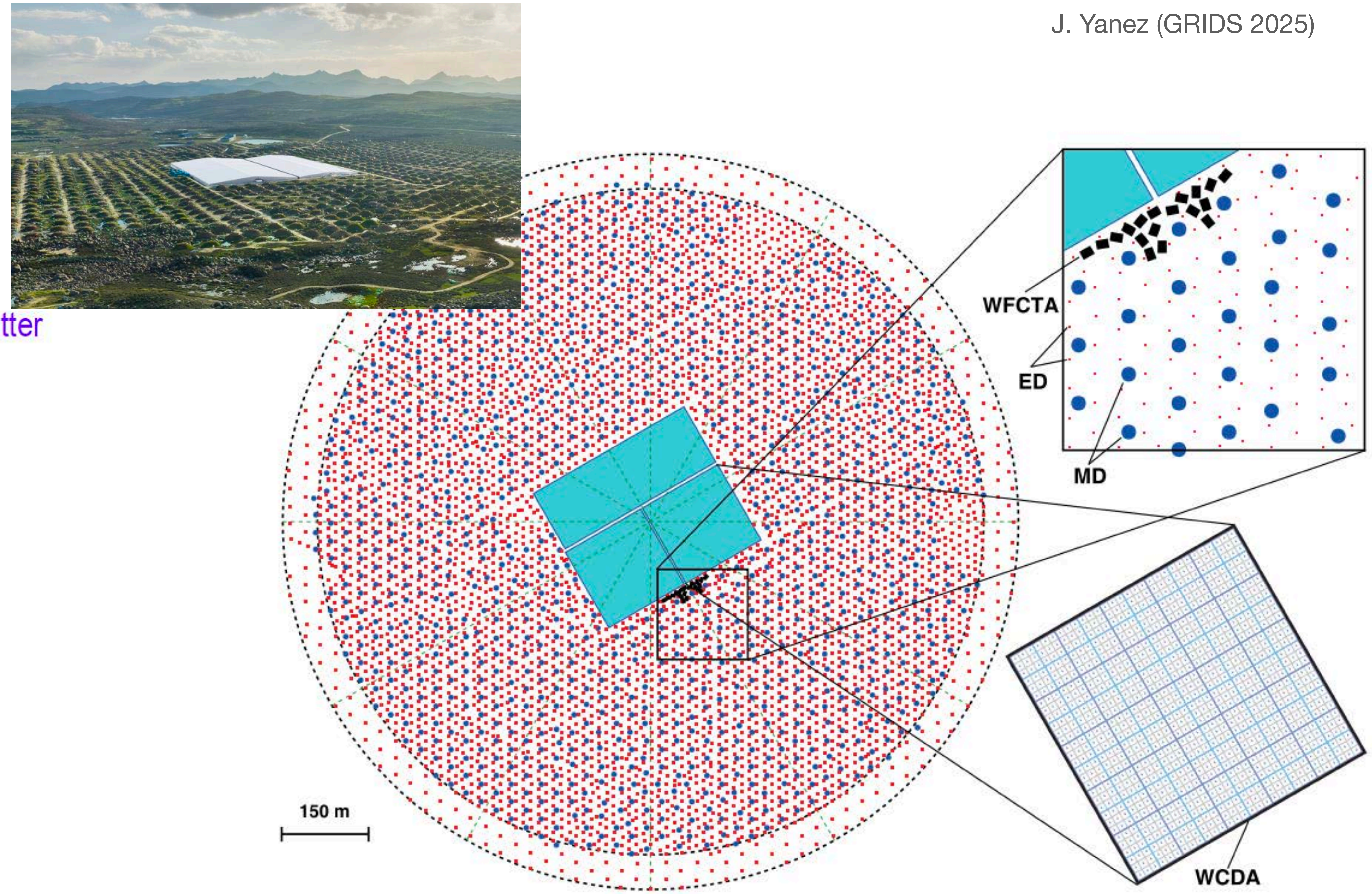
Scintillators - Organic (Plastic)

J. Yanez (GRIDS 2025)

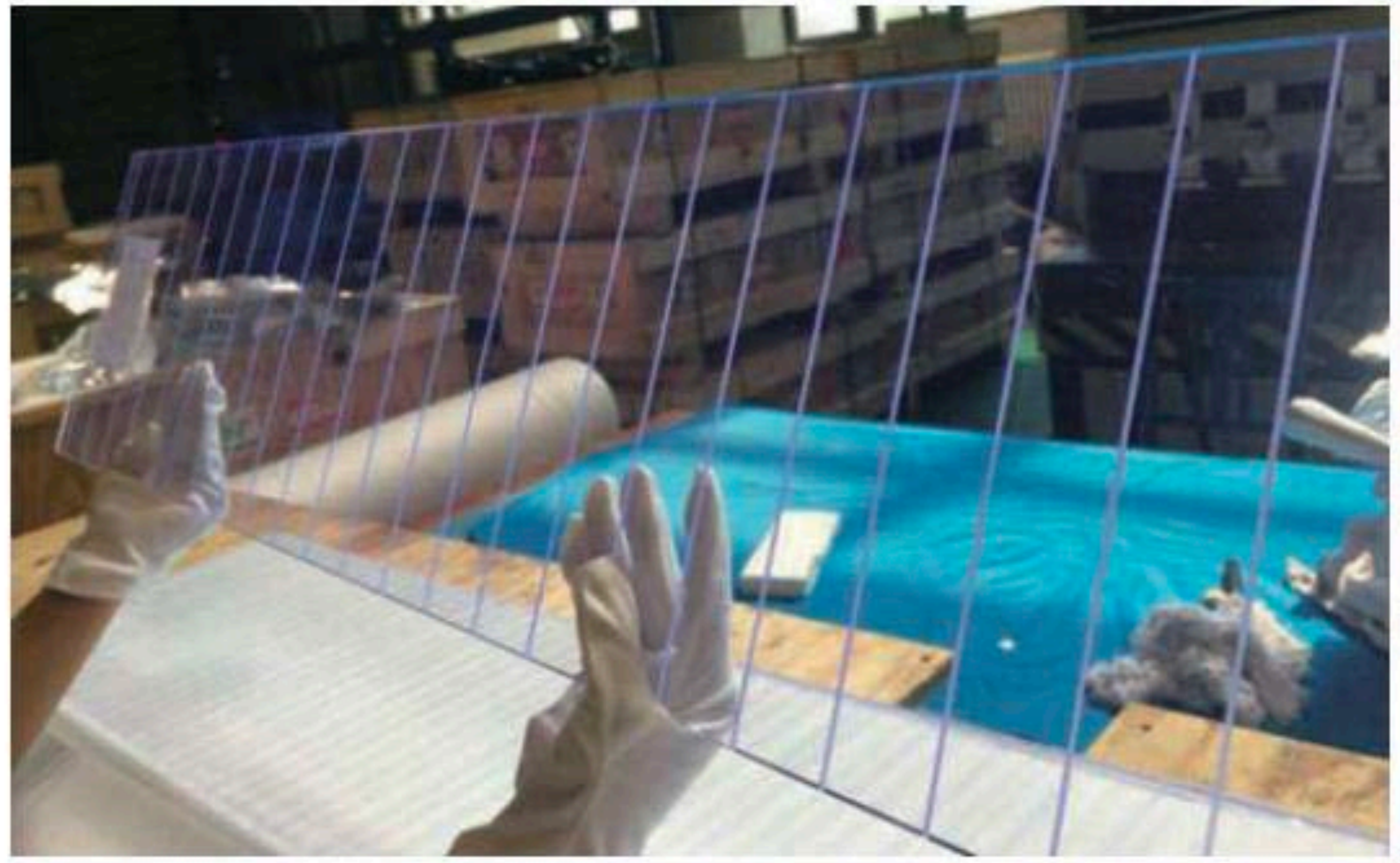


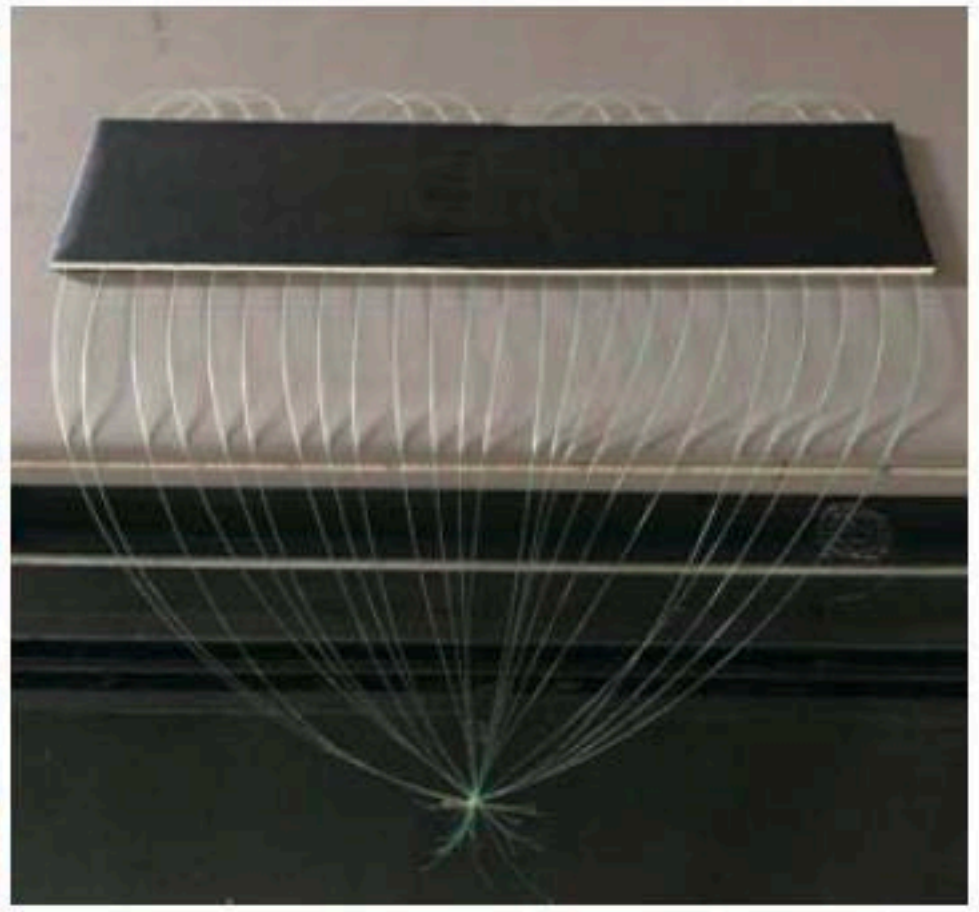






The LHASSO Gamma ray detector





Charged particles produce ionization that causes excitations in the medium

Gamma rays interact and produce electrons that can result in ionization

Each step in the process involves efficiency losses; overall light yield of approximately 1 photon per 100 eV of energy deposition.

C. Woody (GRIDS 2019)

Scintillators - Organic (Light Yield)

Follows Birk’s (semi-empirical) Law

$$\frac{dL}{dx} = \frac{S\frac{dE}{dx}}{1 + k_B\frac{dE}{dx}}$$

S is the scintillation efficiency

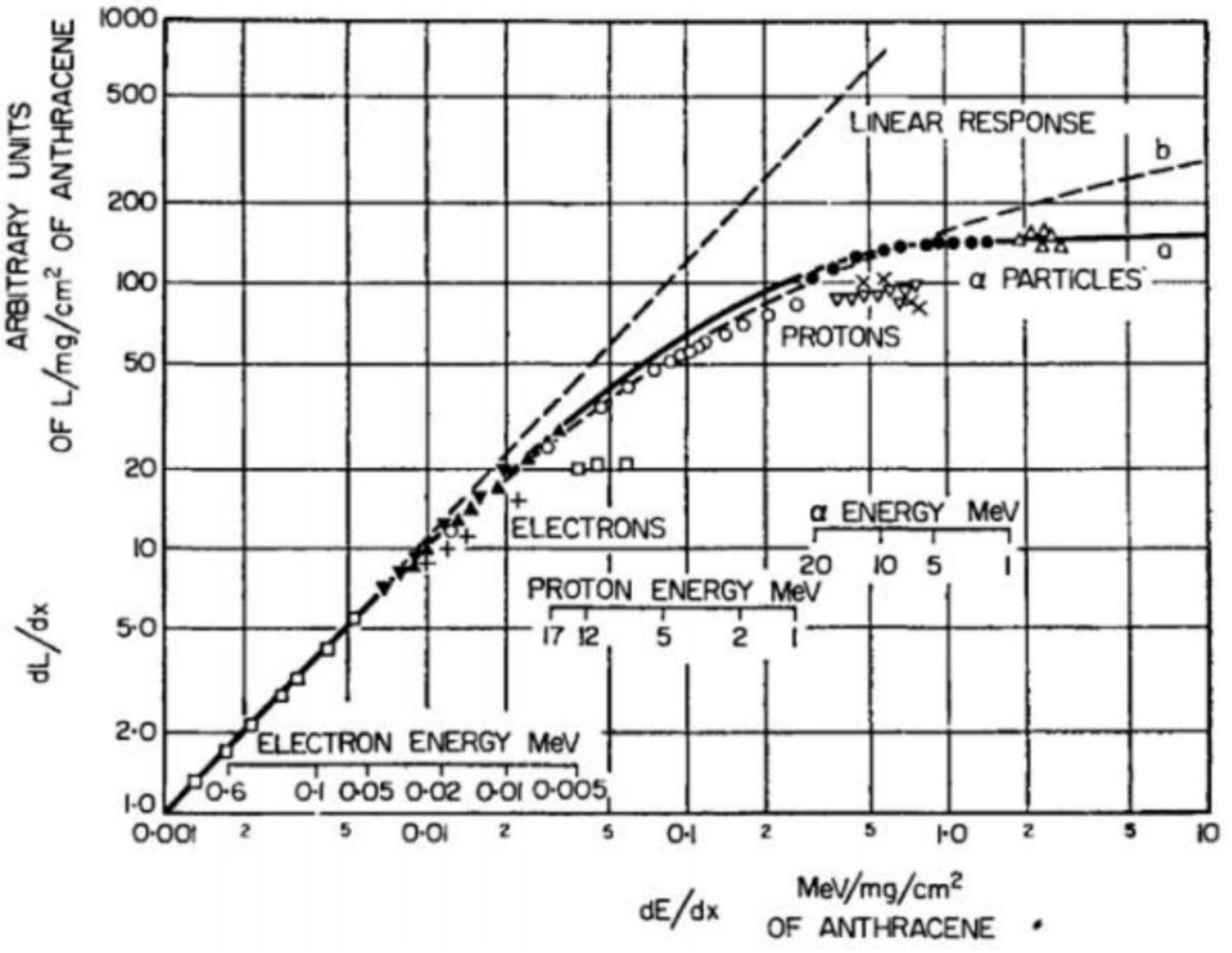
k_B is the quenching strength – ionization saturates

For minimum ionizing particles (GeV muons)

$$\frac{dL}{dx} = S\frac{dE}{dx}$$

For strongly ionizing radiation (MeV alpha particles)

$$\frac{dL}{dx} = \frac{S}{k_B}$$



The quenching strength must be determined experimentally.

Scintillators - Organic (Signal Timing Shape)

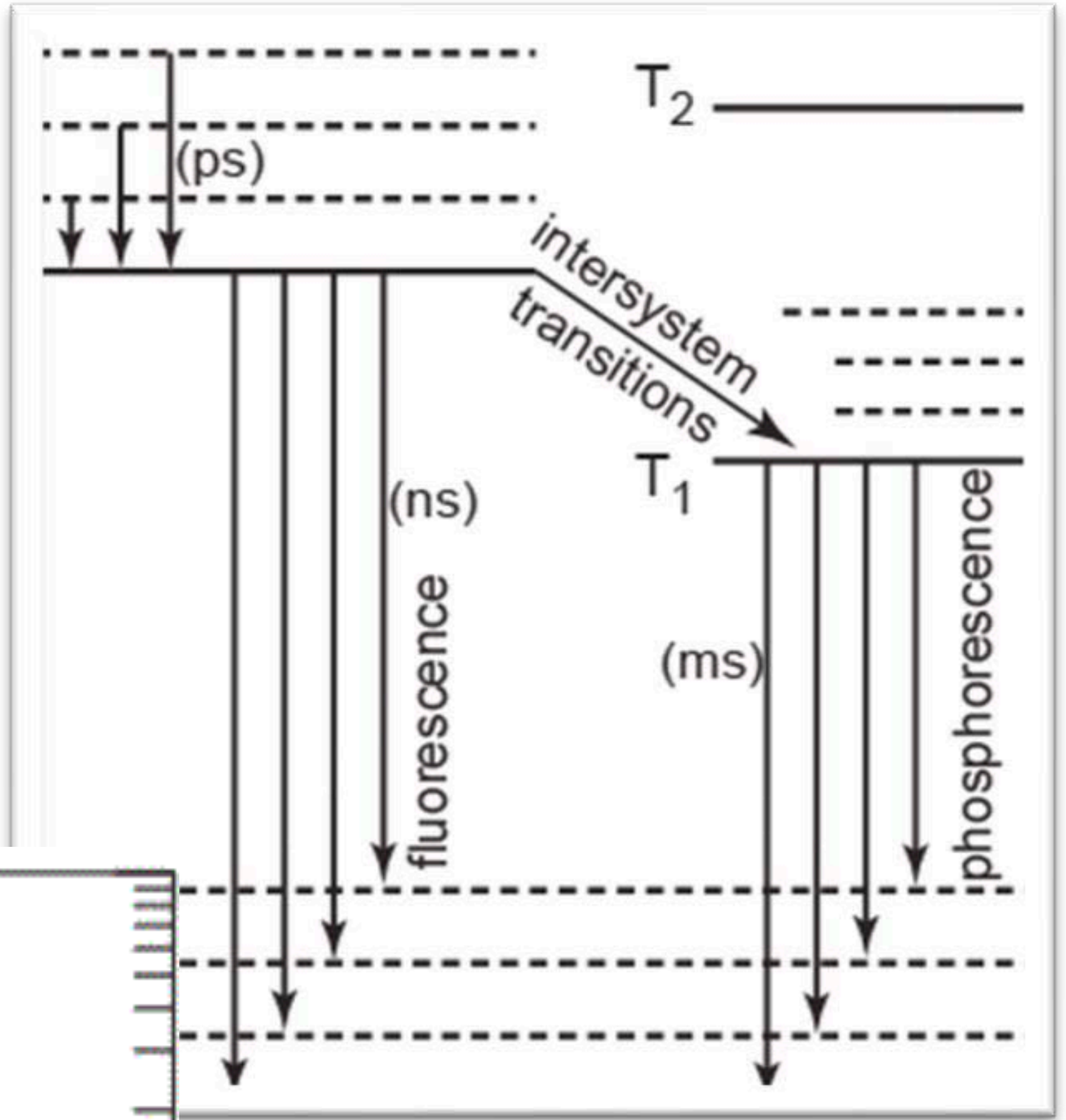
Prompt fluorescence emission follows a simple exponential decay; ie. For rise time:

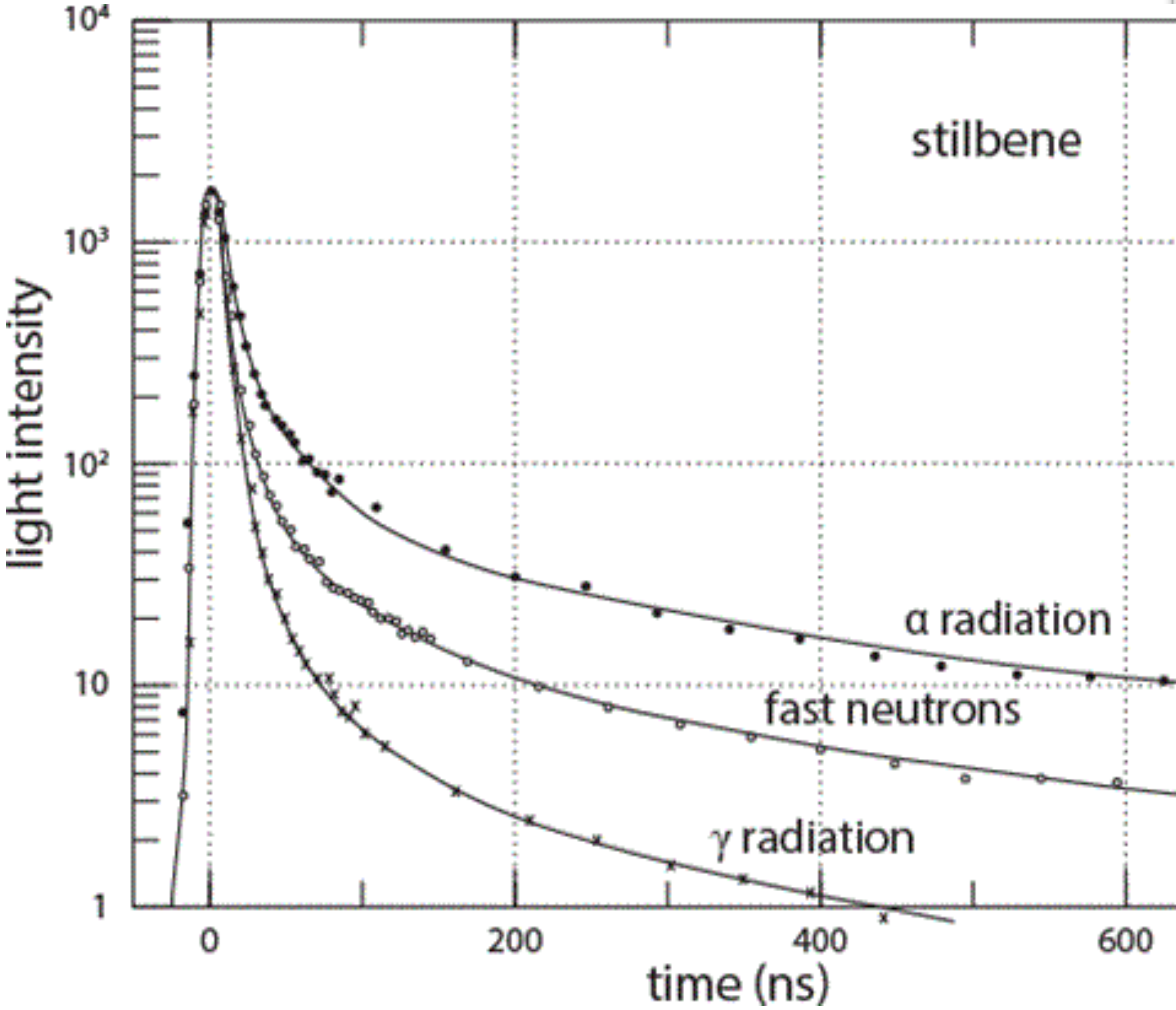
$$I(t) = I_0\, g(t)\, e^{-t/\tau_{dec}}$$

Many scintillators have a second component (with longer decay time)

$$I(t) = I_1\, g(t)\, e^{-t/\tau_f} + I_2 e^{-t/\tau_s}$$

Relative contribution of I_1 andI_2 depend on the ionization density of the incident particles -> leverage for pulse shape discrimination to distinguish particle types.





Scintillators - Inorganic (Mechanism)

Relies on the crystal lattice structure

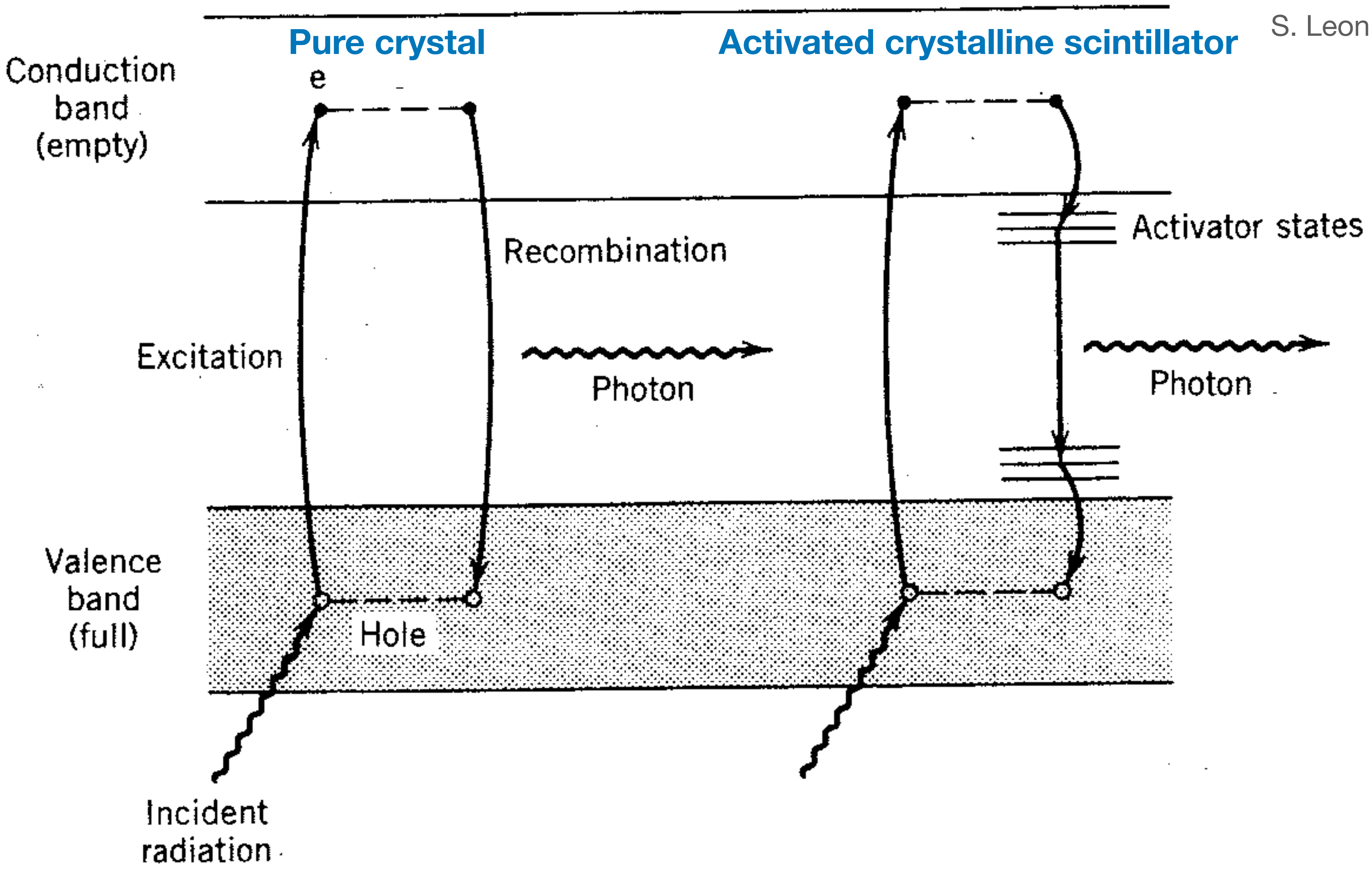
- Energy levels created by impurities in the band gap (luminescence centres)

Excited electrons move between atomic states, from the valence to the conducting band

Doping material changes the energy structure of the lattice; used to minimize re-absorption from the crystal as the emitted light has a lower energy than the energy-gap

eg. NaI(Tl) -> 4 eV with decay time of ~230 ns and rise time of ~10 ns

High Z (high stopping power -> total absorption calorimeters)
High conversion efficiency -> ~40 photons/keV (~40x better than plastic scintillators)



Scintillators - Inorganic (Mechanism)

S. Leoni (INFN)

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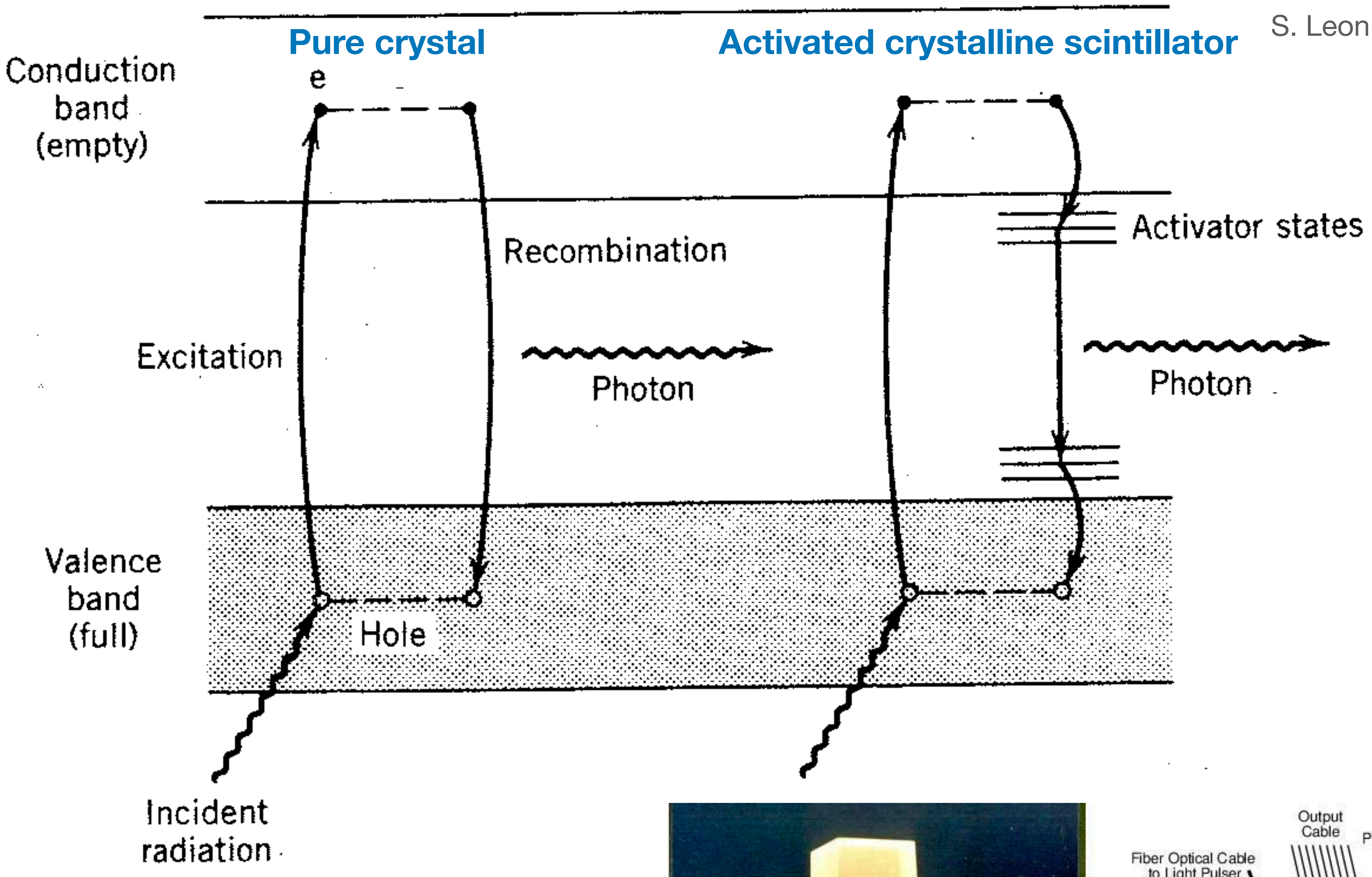
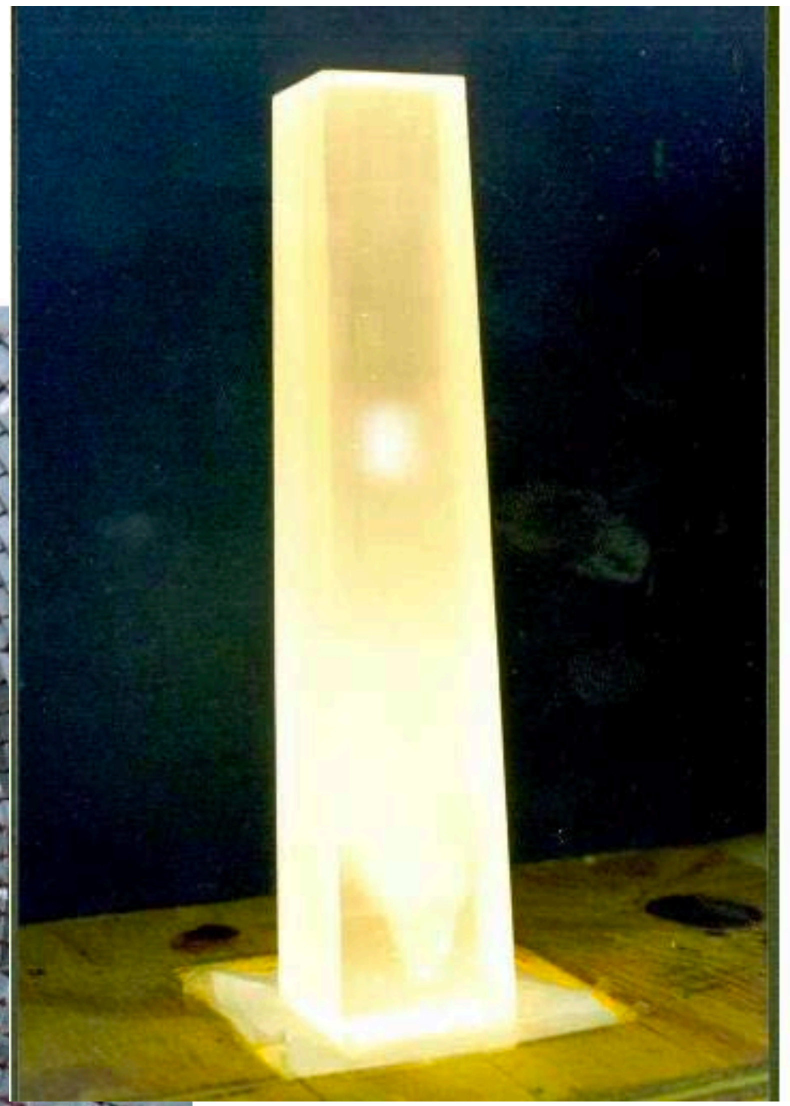
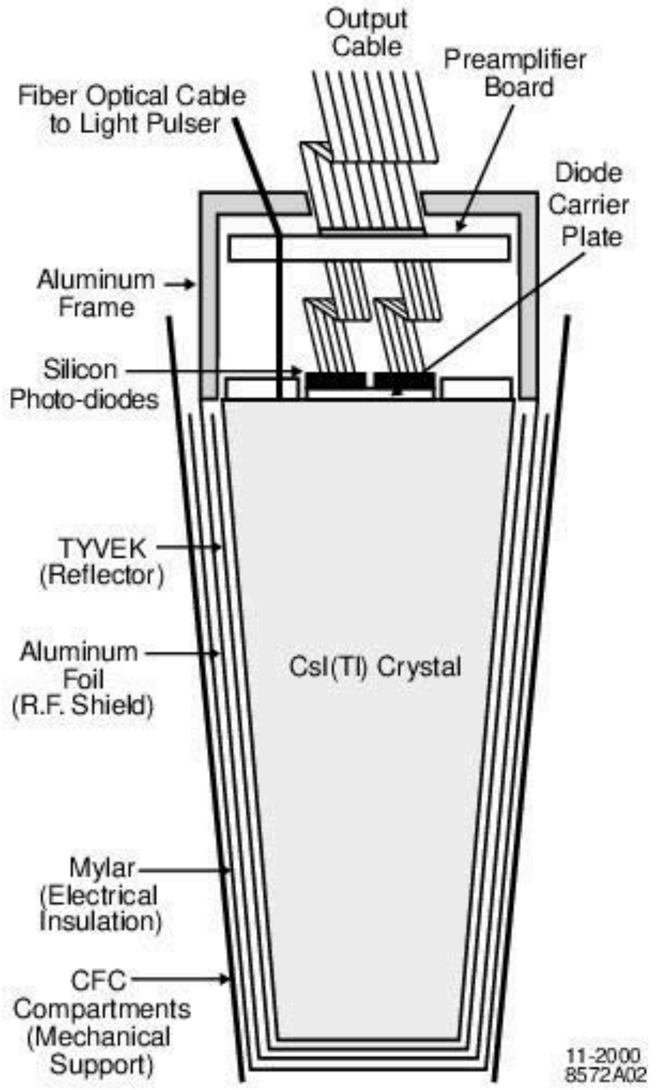






BaBaR calorimeter

Scintillators - Inorganic (Examples; Light Yield)

J. Yanez (GRIDS 2025)
J. Zmeskal (SMI) 2020

Light Yield depends on the absorbed energy and the electron-hole pair production average energy

$$L = \frac{E_{abs}}{w_{e/h}} S\, Q$$

S = transfer energy efficiency (thermalized pairs -> luminescence centres)
Q = quantum yield of the luminescence centre

Maximum theoretical yield approximately 140 photons/keV*

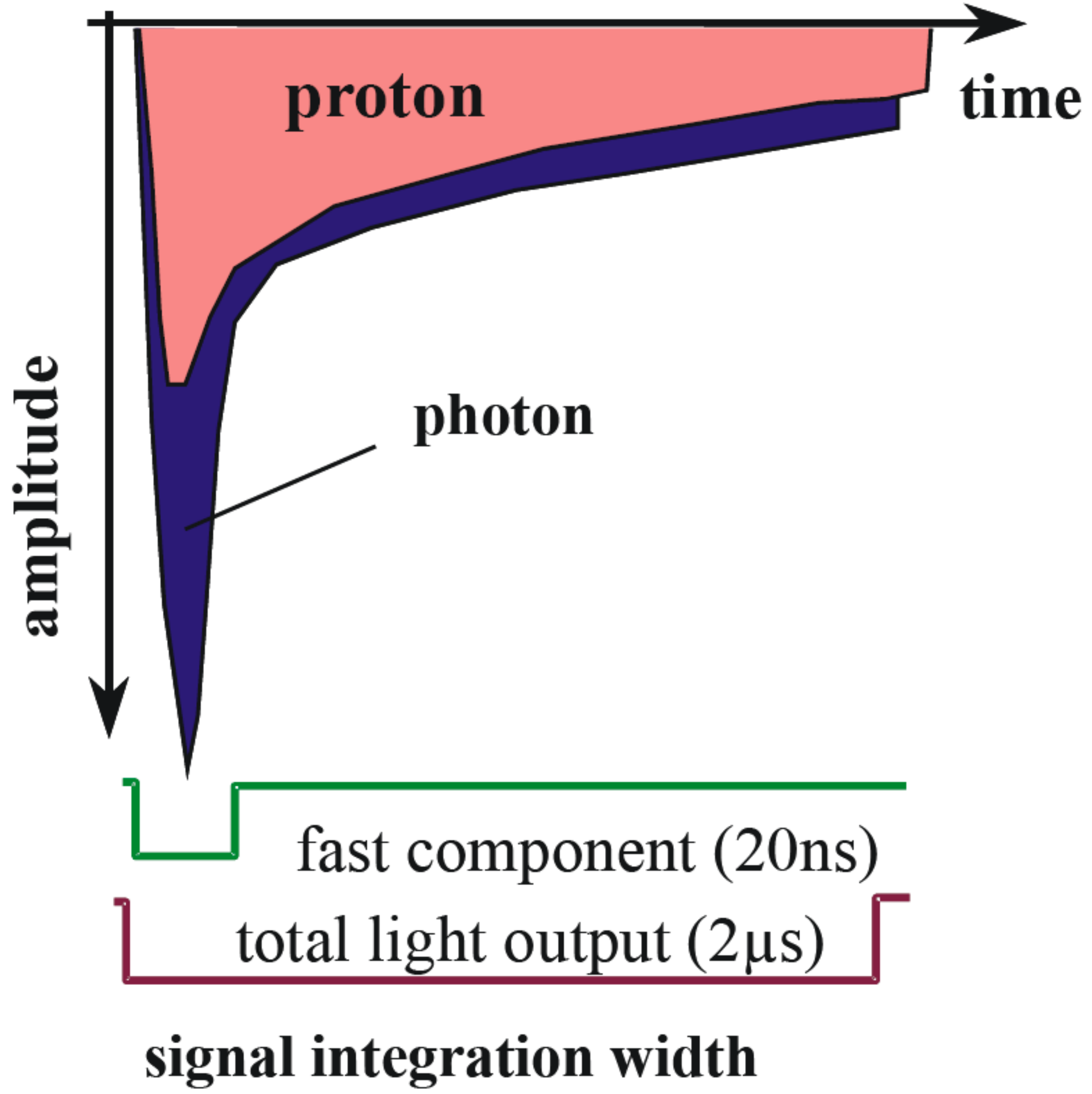
Scintillator composition	Density (g/cm^3)	Index of refraction	Wavelength of max.Em. (nm)	Decay time Constant (µs)	Scinti Pulse height$^{1)}$	Notes
NaI(Tl)	3.67	1.9	410	0.25	100	2)
CsI	4.51	1.8	310	0.01	6	3)
CsI(Tl)	4.51	1.8	565	1.0	45	3)
CaF_2(Eu)	3.19	1.4	435	0.9	50	
BaF_2	4.88	1.5	190/220 310	0,0006 0.63	5 15	
BGO	7.13	2.2	480	0.30	10	
$CdW0_4$	7.90	2.3	540	5.0	40	
$PbWO_4$	8.28	2.1	440	0.020	0.1	
CeF_3	6.16	1.7	300 340	0.005 0.020	5	
GSO	6.71	1.9	430	0.060	40	
LSO	7	1.8	420	0.040	75	
YAP	5.50	1.9	370	0.030	70	

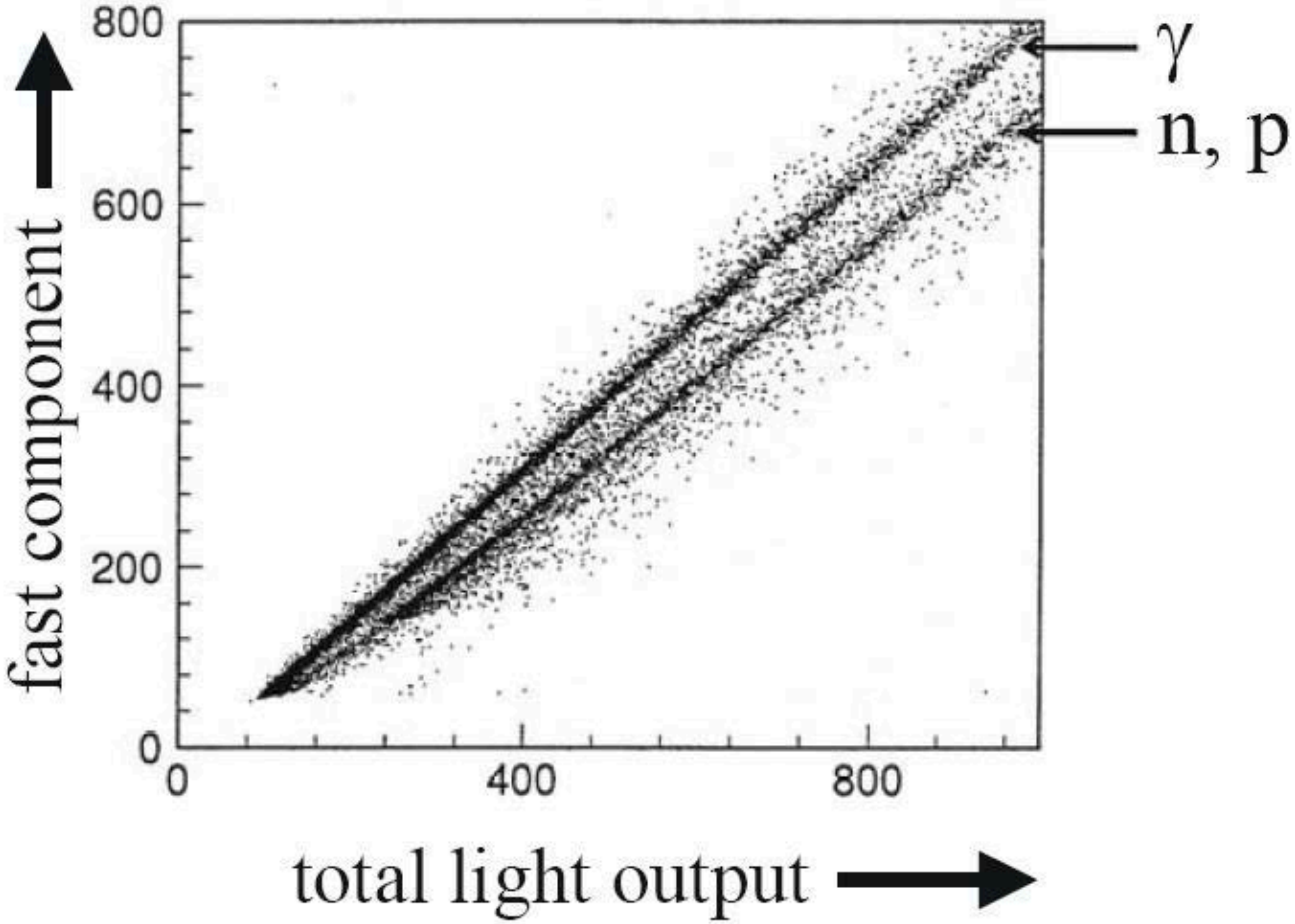
1) Relative to NaI(Tl) in %; 2) Hygroscopic; 3) Water soluble

* P. Lecoq et al. Inorganic Scintillators for Detector Systems: Physical Principles and Crystal Engineerin. Springer 2006

Scintillators - Inorganic (Signal Pulse Shape)

e.g. BaF_2 one of the fastest scintillators with an emission component with sub-ns decay time and a possible timing resolution of ~200 ps



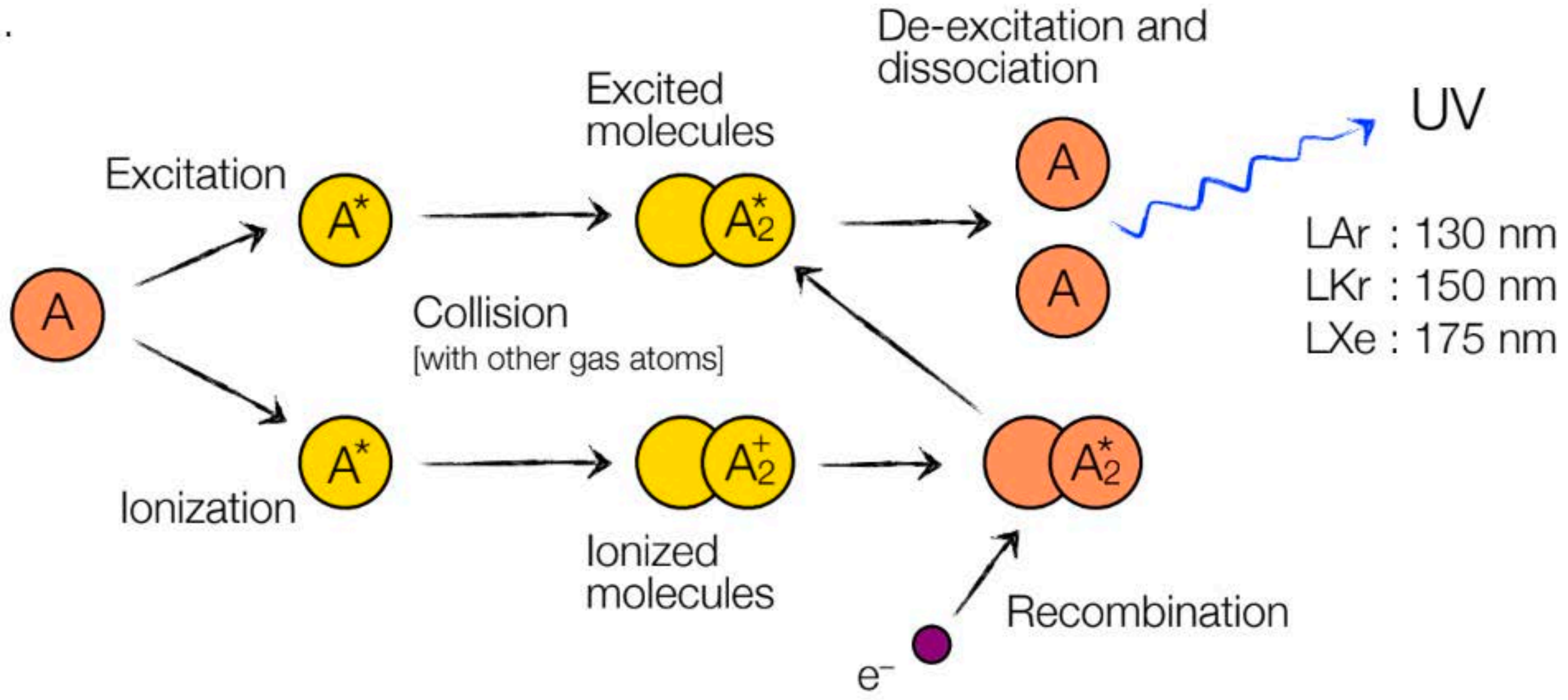


Scintillators - Noble Gas

High-purity inert gases may generation scintillation light via emission through decay of excited dimers to the ground state.

Emission typically in the far UV -> wavelength shifters

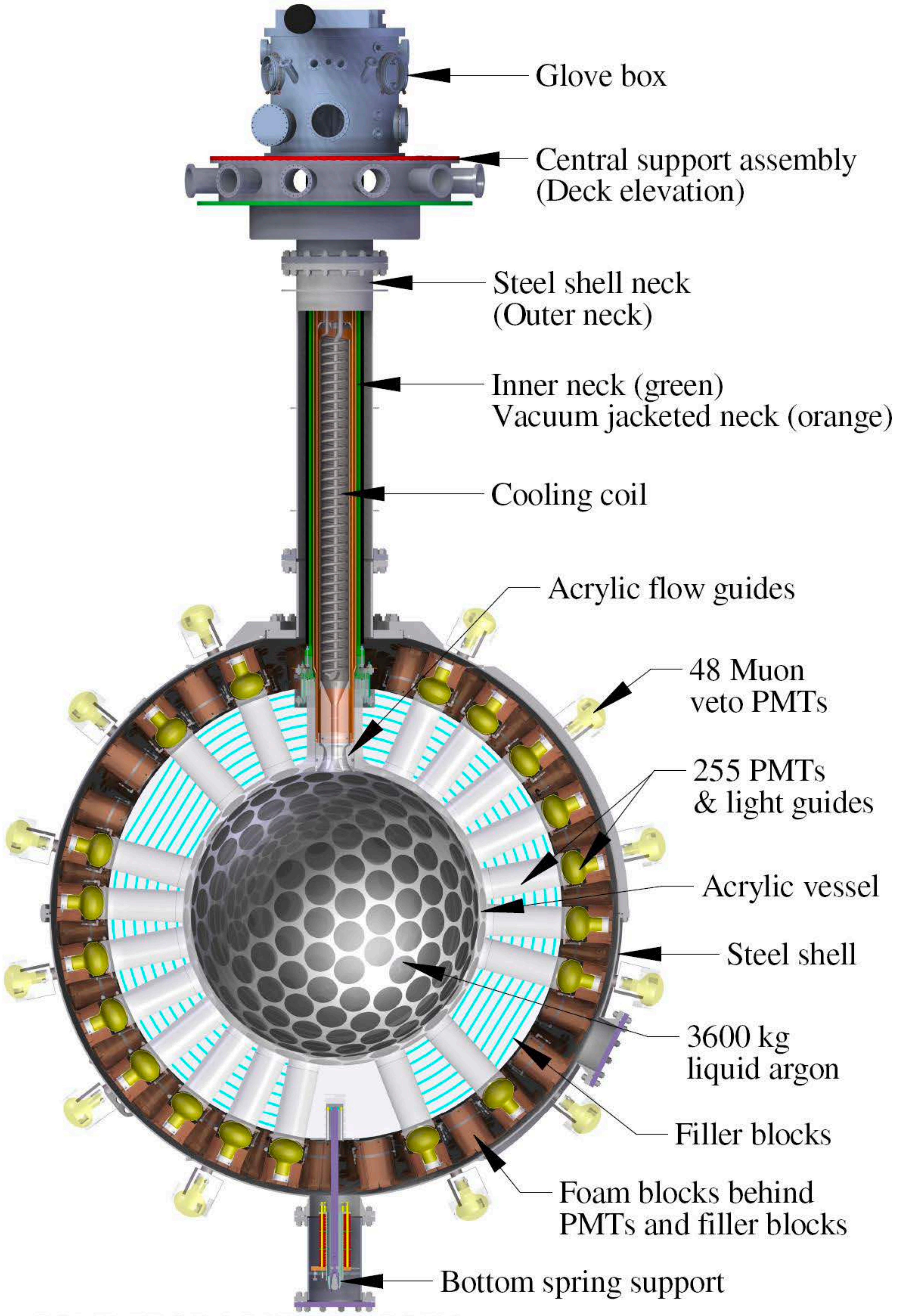
…



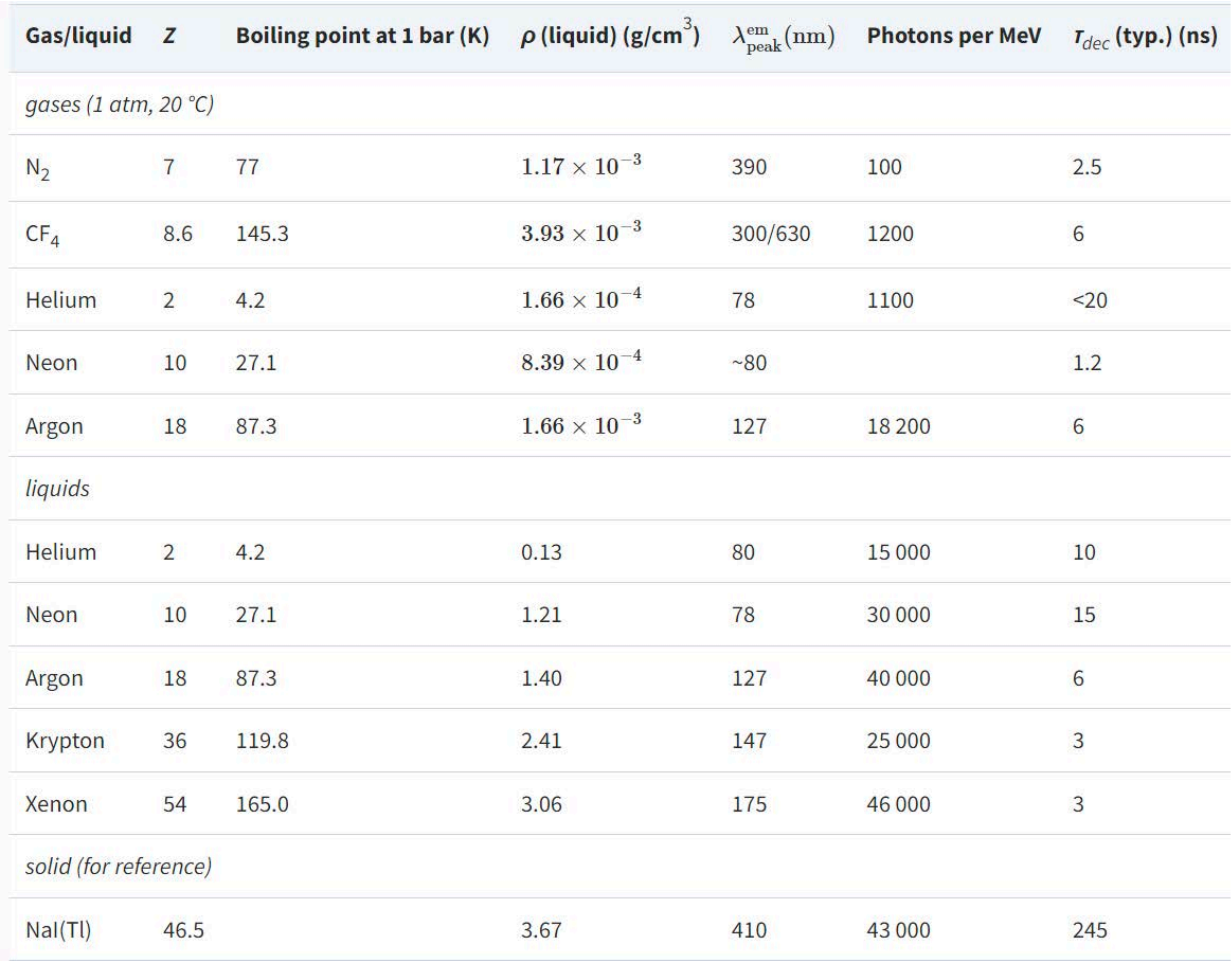
Pulse shape discrimination possible via measurement of ratio of single (fast) to triplet (slow) components that have separation for electromagnetic and nuclear recoils events.

DEAP-3600 Detector

J. Yanez (GRIDS 2025)



Scintillators - Noble Gas



Gas/liquid	Z	Boiling point at 1 bar (K)	ρ (liquid) (g/cm^3)	$\lambda^{\mathrm{em}}_{\mathrm{peak}}\,(\mathrm{nm})$	Photons per MeV	τ_{dec} (typ.) (ns)
gases (1 atm, 20 °C)						
N_2	7	77	1.17×10^{-3}	390	100	2.5
CF_4	8.6	145.3	3.93×10^{-3}	300/630	1200	6
Helium	2	4.2	1.66×10^{-4}	78	1100	<20
Neon	10	27.1	8.39×10^{-4}	~80		1.2
Argon	18	87.3	1.66×10^{-3}	127	18 200	6
liquids						
Helium	2	4.2	0.13	80	15 000	10
Neon	10	27.1	1.21	78	30 000	15
Argon	18	87.3	1.40	127	40 000	6
Krypton	36	119.8	2.41	147	25 000	3
Xenon	54	165.0	3.06	175	46 000	3
solid (for reference)						
NaI(Tl)	46.5		3.67	410	43 000	245

Very low Z
Fast decay times
Light yields that can reach similar levels to crystals

Scintillators - Initial Summary and additional thoughts

Organic Scintillators

Advantages
- Very fast
- Easily shaped
- Small temperature dependence
- Relatively inexpensive

Disadvantages
- Lower light yield (efficiency ~3%)
- Prone to radiation damage

Inorganic Scintillators

Advantages
- High light yield (efficiency ~13%)
- High density
- Good energy resolution

Disadvantages
- Crystal growth -> expensive
- Large temperature dependence

- In addition to Stokes Shift, attenuation lengths are impacted by: fluorine concentration and stabilizer additives (self-absorption); optical clarity and uniformity; surface quality

- Plastic scintillators age (exposure to solvent vapours, high temperature, flexing, irradiation) reducing the light yield. The surface is particularly fragile and can experience “crazing” (micro-fractures) in particular where there is surface contact with oils (including finger prints), solvents,…

- Long-lived luminescence (100s ns) may occur in plastic scintillators that does not follow an exponential decay.

- Radiation damage creates color centres that absorb more strongly blue/UV than longer wavelengths, reducing both light yield and attenuation length.

Light Collection

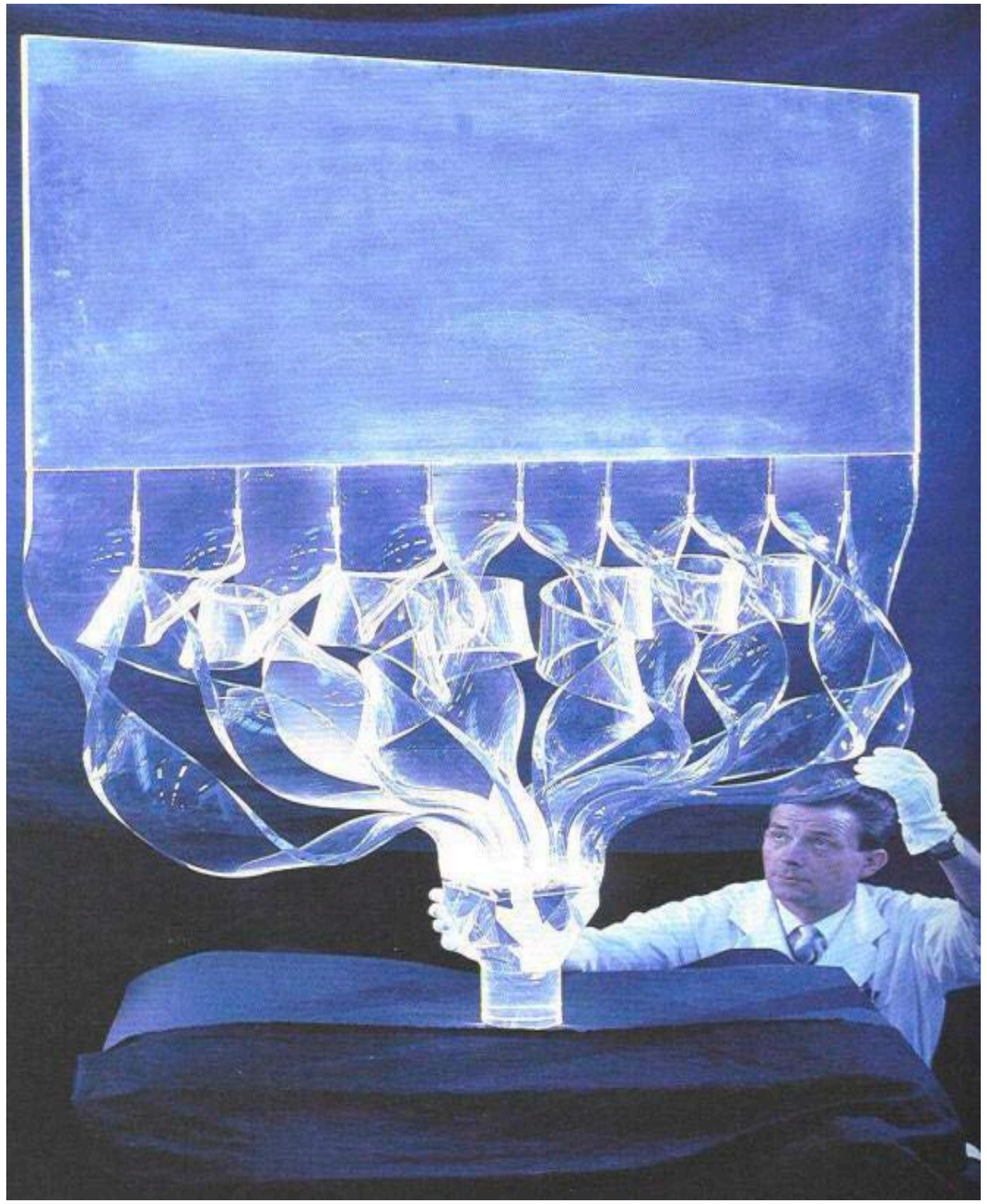
Scintillation light is produced isotropically

Establish the connection between the scintillator and the photoconductor

- high efficiency
- uniformity
- detector geometric constraints and matching to the readout device

General Approaches

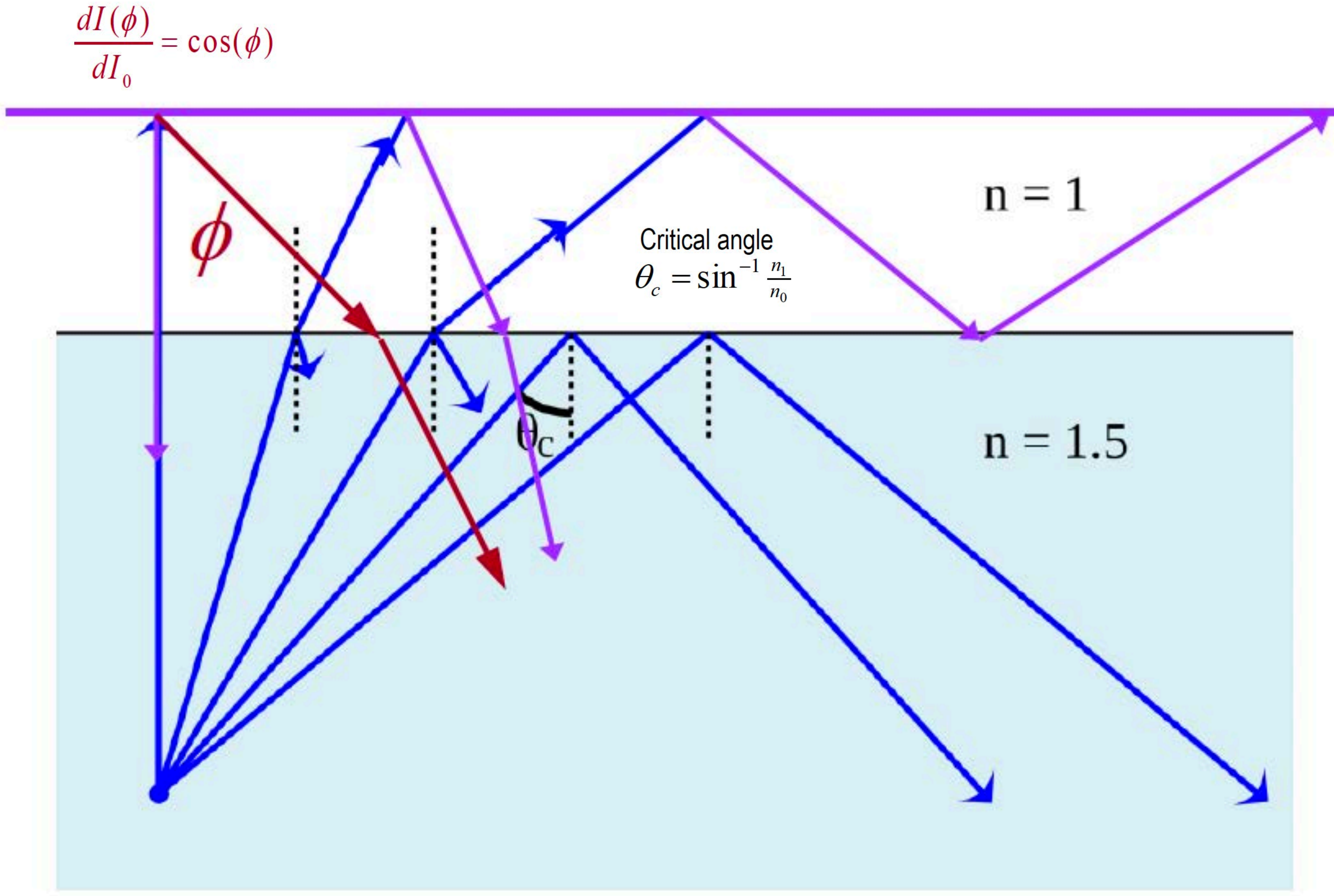
- Reflectors
- Light focusing guides
- Wavelength shifters
- Optical fibres



Light Collection - Reflectors

Total internal reflection (simplest approach can often be the best)

- Escape fraction
  - Can be reflected back into the scintillator by an external reflector
  - An air gap between the scintillator surface and reflector preserves the internal reflection
  - A specular reflector preserves the angles while a diffuse reflector (Lambert’s Law) will change the angle of the exiting rays and improve efficiency
- Trapped fraction (internal reflection)
  - requires highly polished surfaces
  - self-absorption can produce non-uniformities

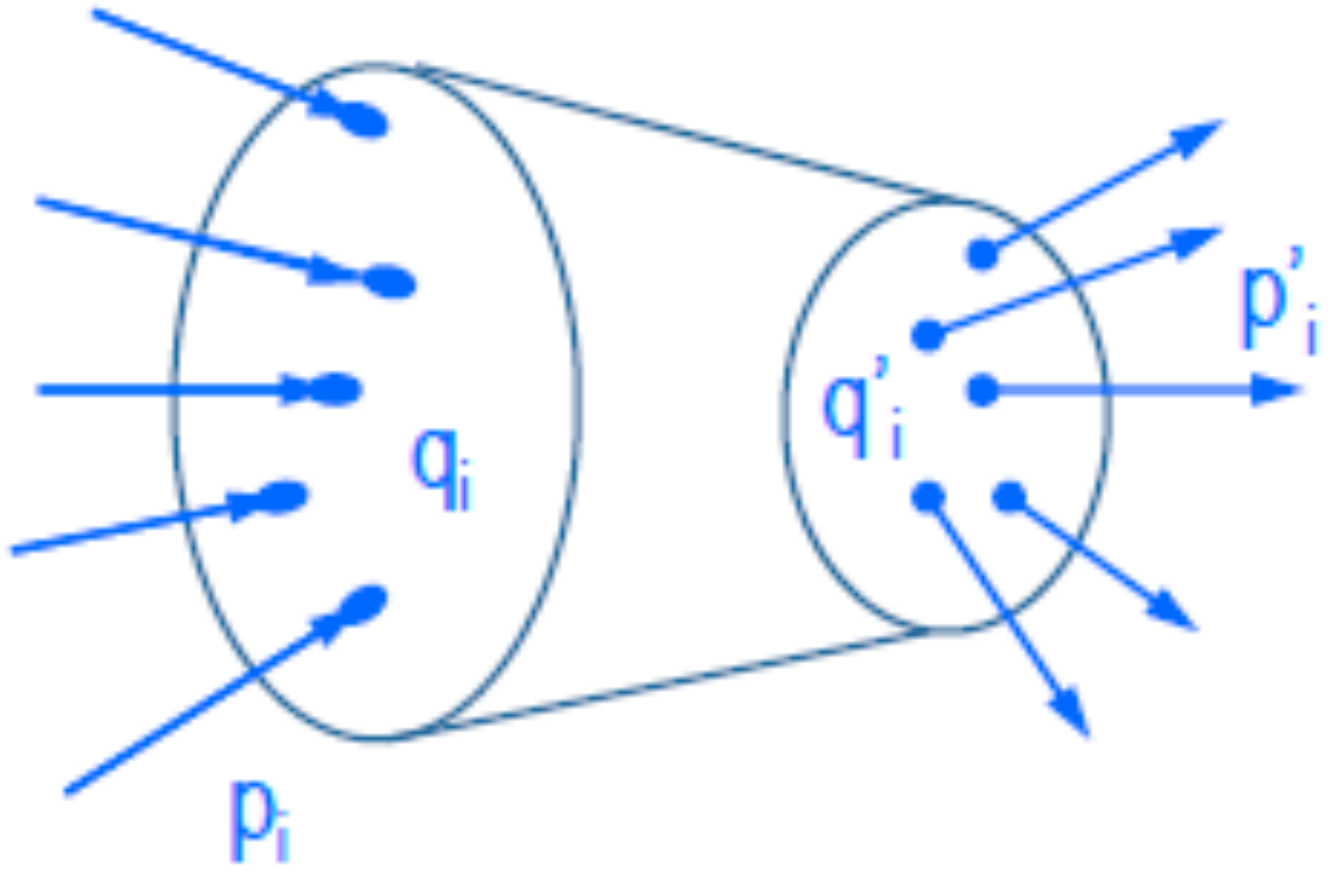


Light Collection - Focusing Guides

Light is concentrated while maintaining a constant phase space density with time

Louisville's Theorem

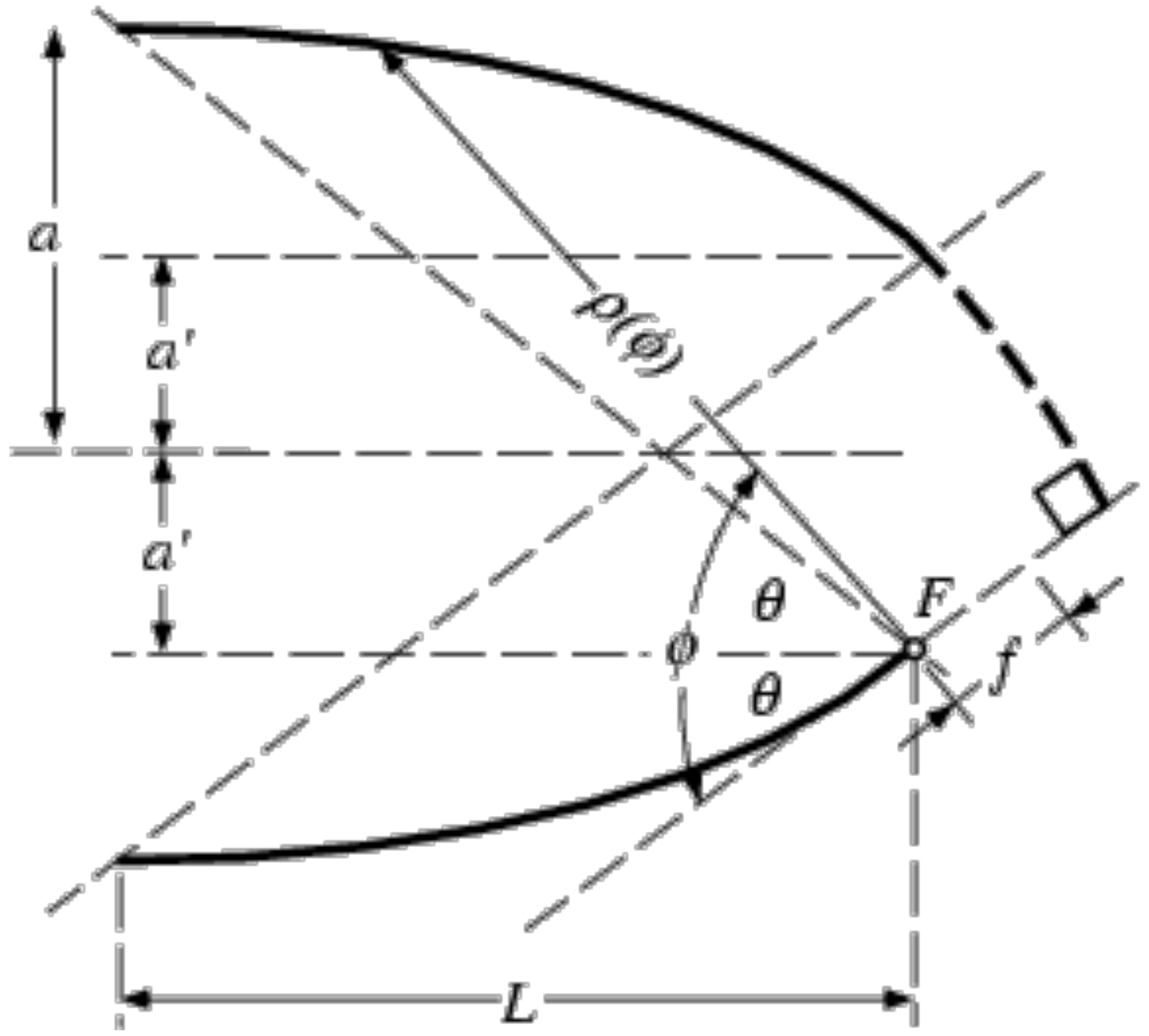
$$\frac{d\rho}{dt} = \sum_{i=1}^{n} \left(\frac{\partial \rho}{\partial q_i} \dot{q}_i + \frac{\partial \rho}{\partial p_i} \dot{p}_i \right) = 0$$



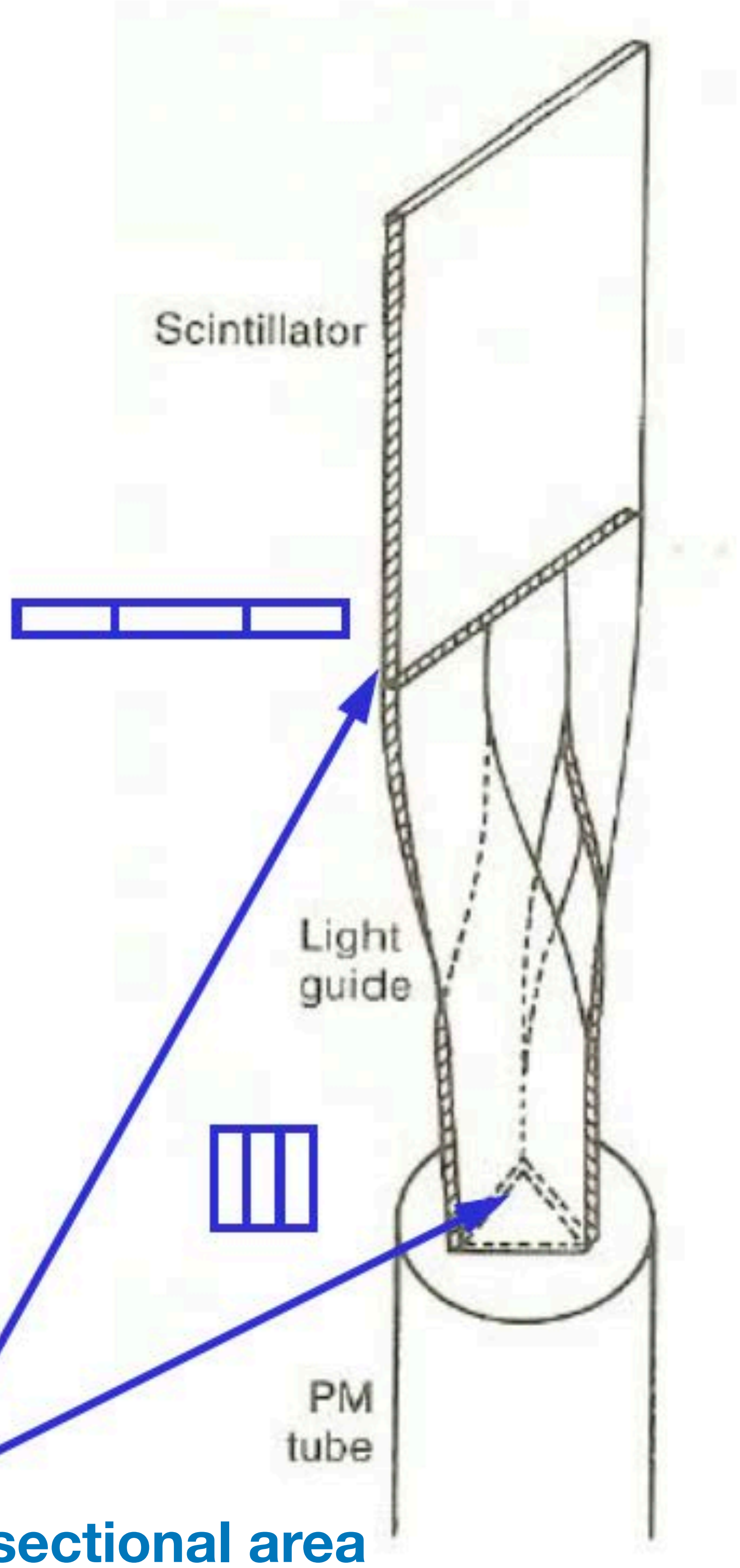
Area reduction increases divergence

Winston Cone*

Off-axis parabola of revolution
Focuses rays on exit aperture



Adiabatic Light Guide



Preserve initial cross-sectional area

G.Knoll, Radiation Detection and Measurement

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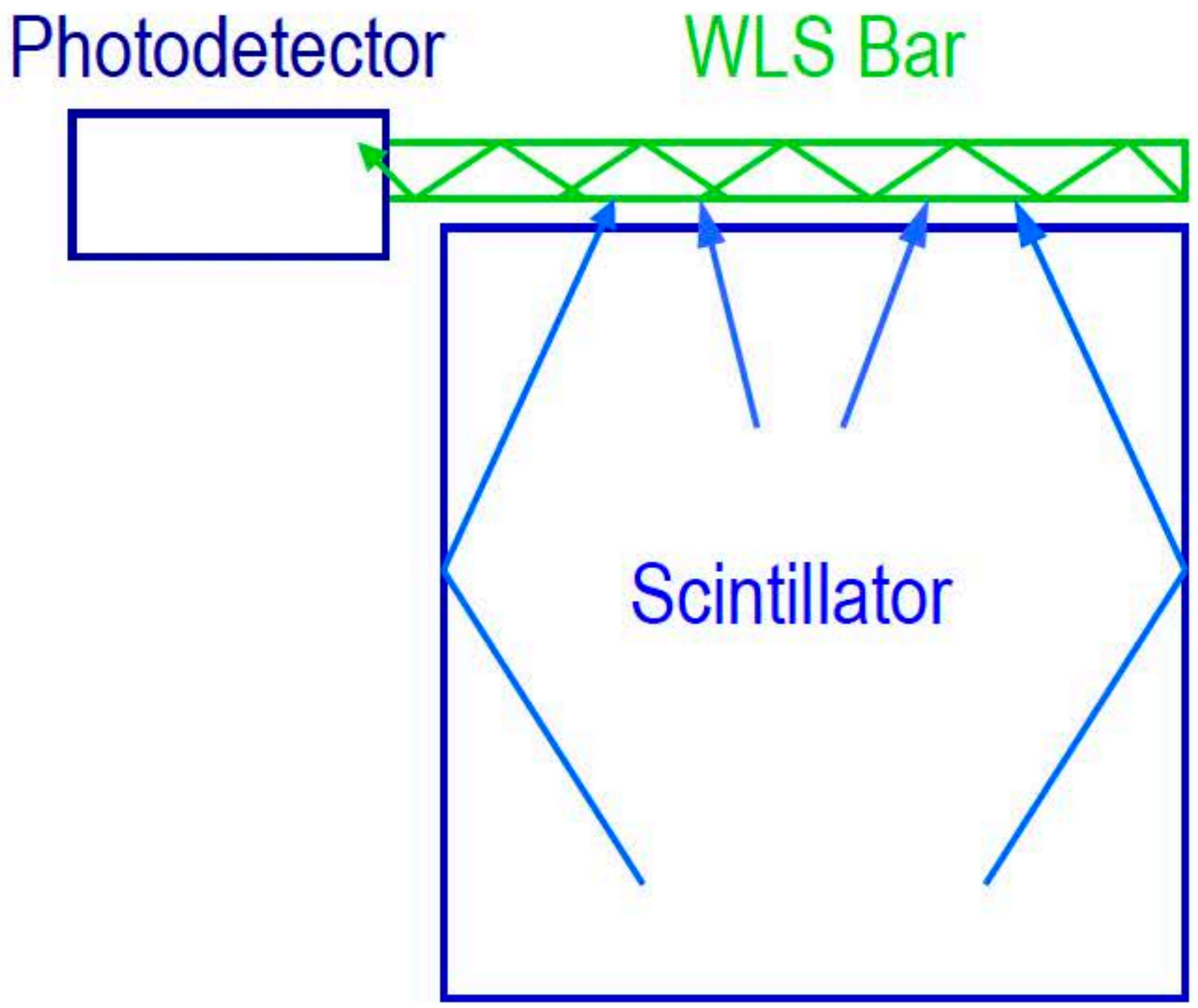
* R. Winston, J. Opt. Sci. Amer. 60 (1970) 245-247

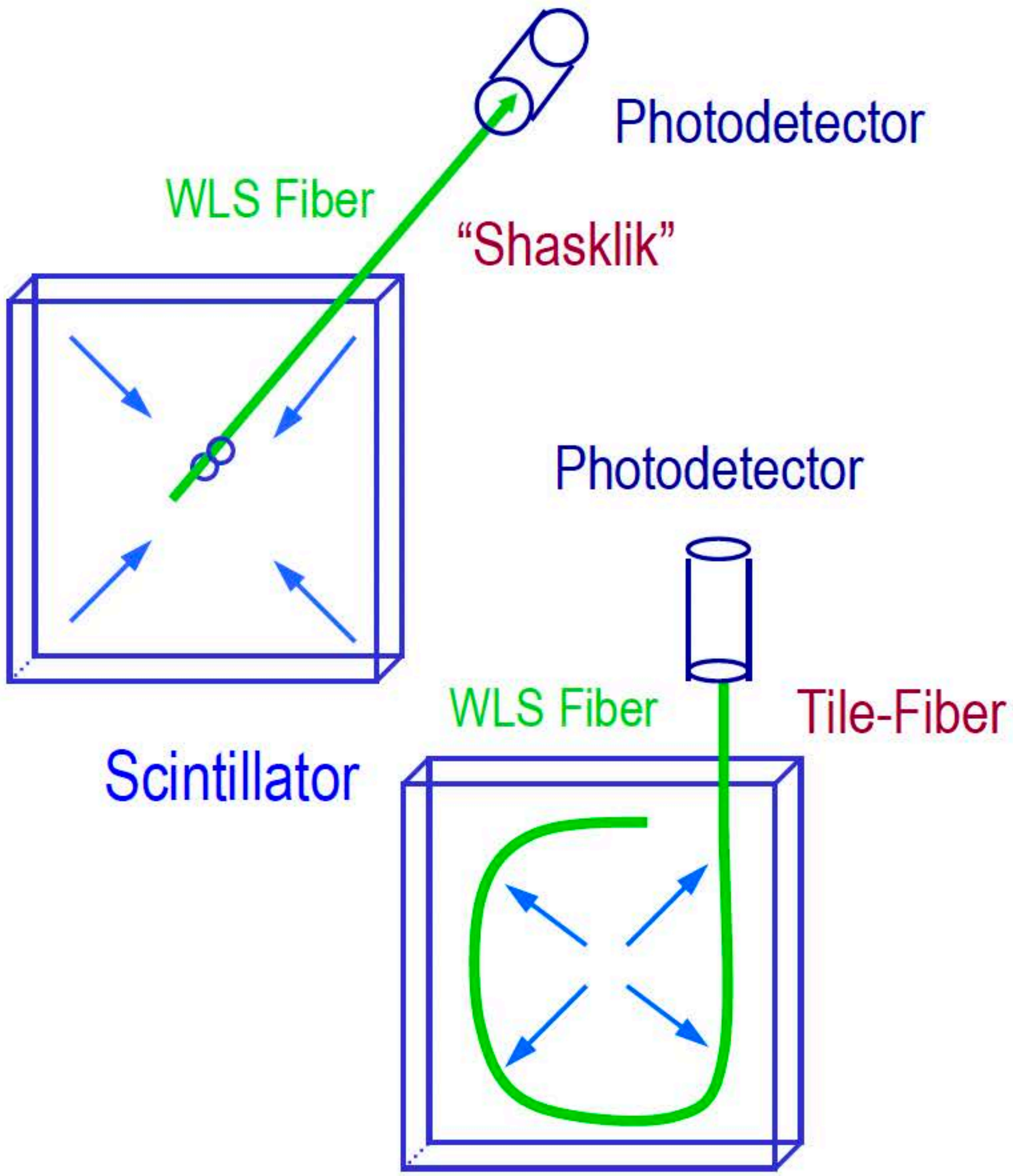
Light Collection - Wavelength Shifters

Wavelength shifter absorbs scintillation light and reemits light as a longer wavelength and in a different direction

Wavelength shifter element acts as its own light guide, bringing the shifted light to the photodetector

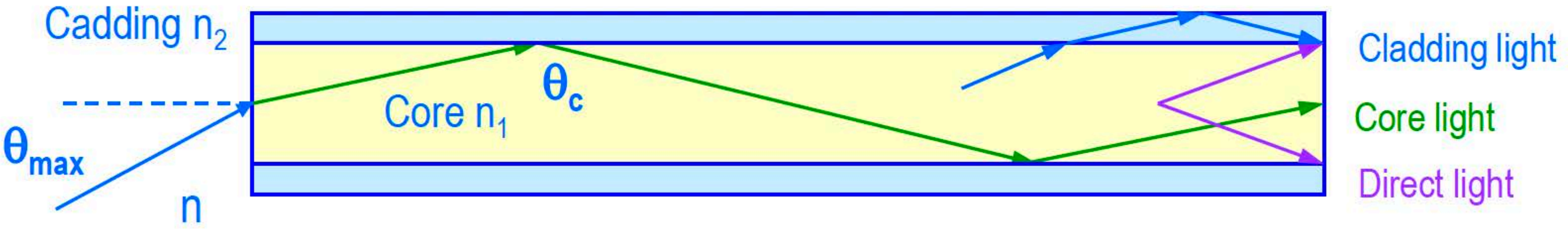
The transfer process may suffer from inefficiencies (scintillator -> wavelength shifter -> absorption -> re-emission -> collection -> photodetector)





Light Collection - Optical Fibres

Fibres may be used both as light guides and as an active (scintillator or Cherenkov) detector material



Small overall trapping fraction

- The light is trapped by internal reflection between the core and cladding ($n_1 > n_2$)
- The Numerical Aperture defines the maximum angle that can be trapped

$$N.A. = n \cdot \sin\theta_{\max} = \sqrt{n_1^2 - n_2^2}$$

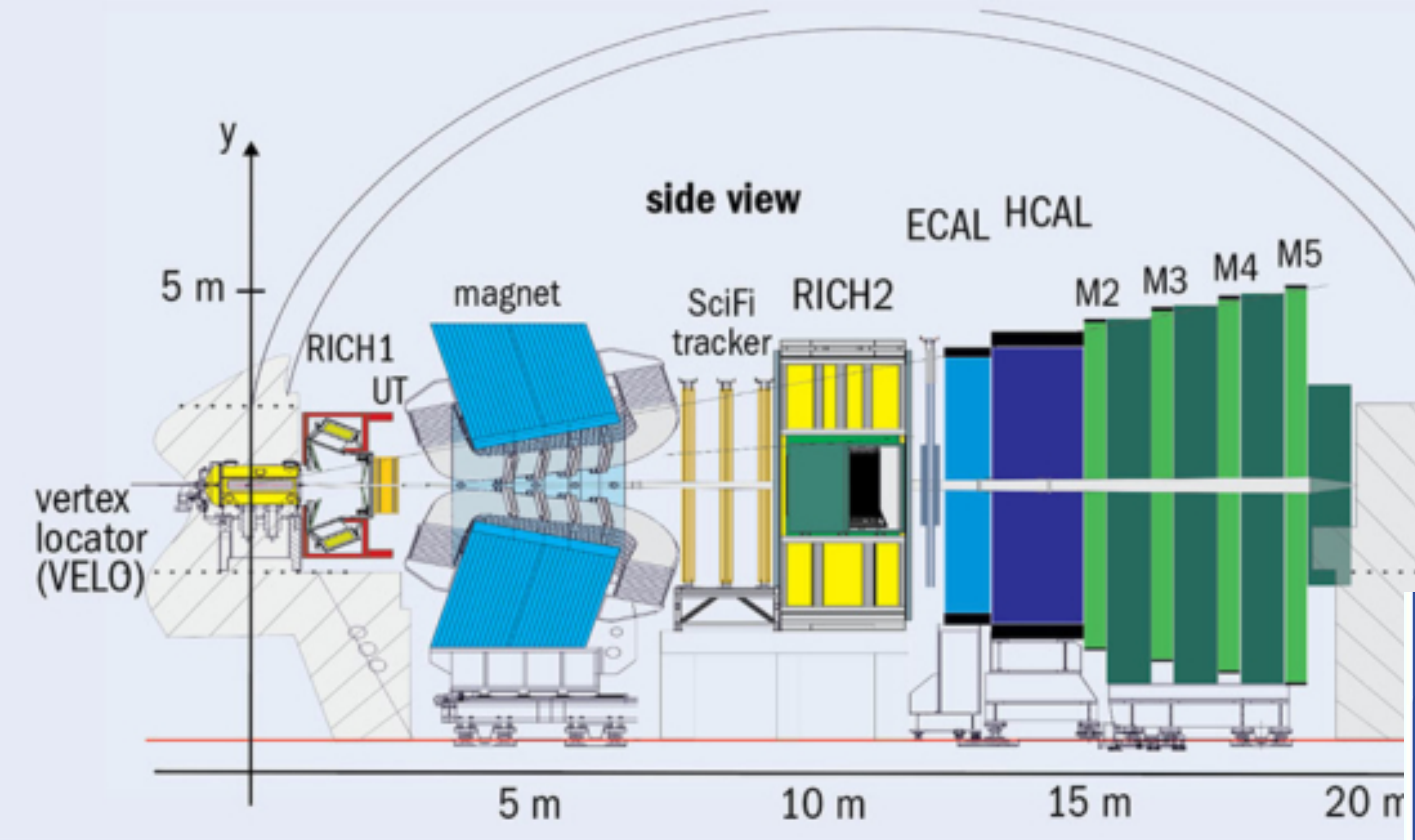
$$F_{fib} = \frac{1}{2}\left(1 - \frac{n_2}{n_1}\right)$$

G.Knoll, Radiation Detection and Measurement

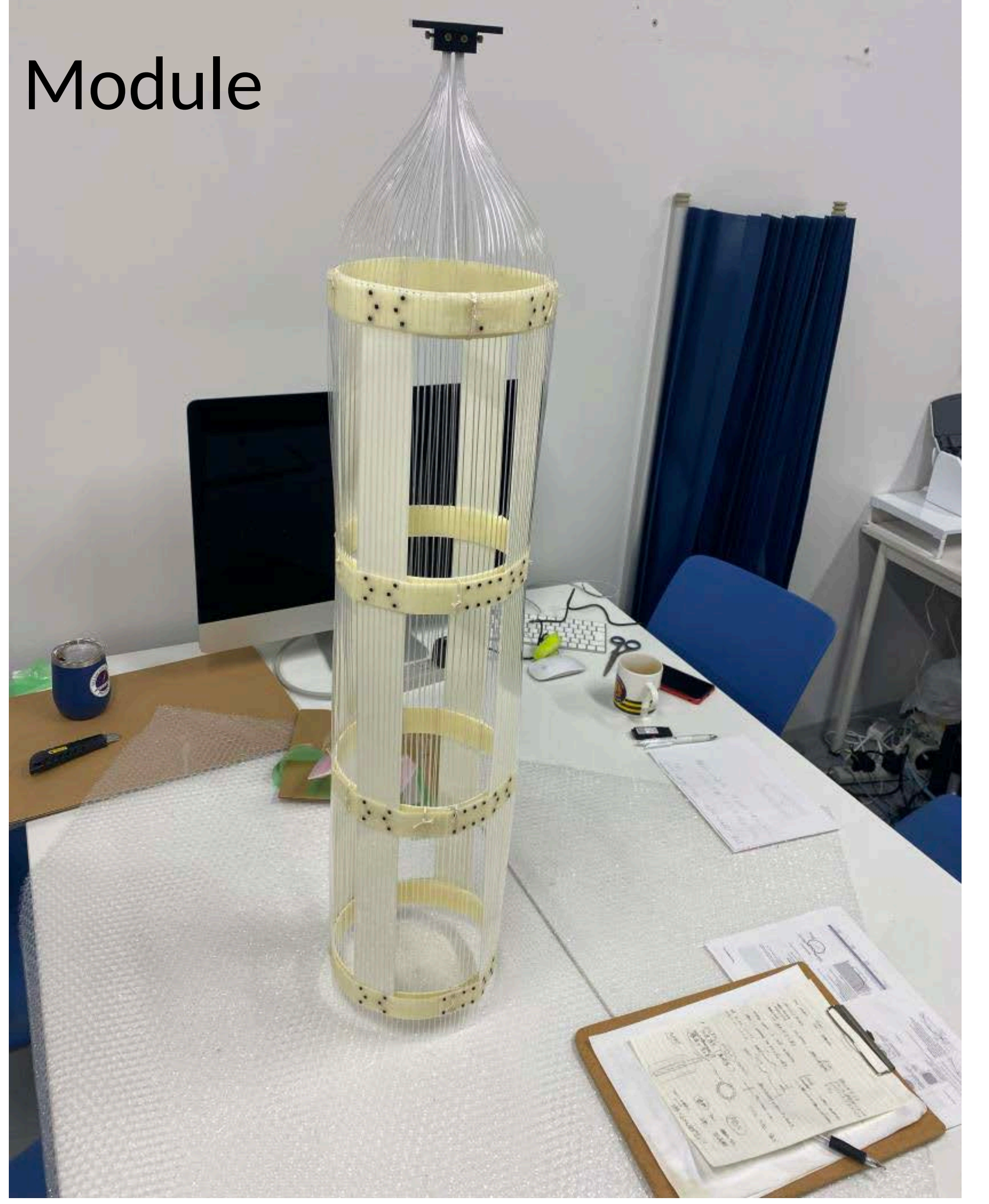
n_1=1.58 (polystyrene)
n_2=1.49 (PMMA)
F_{fib} ~ 3%
x2 ~ 6% if use reflector or read out both ends

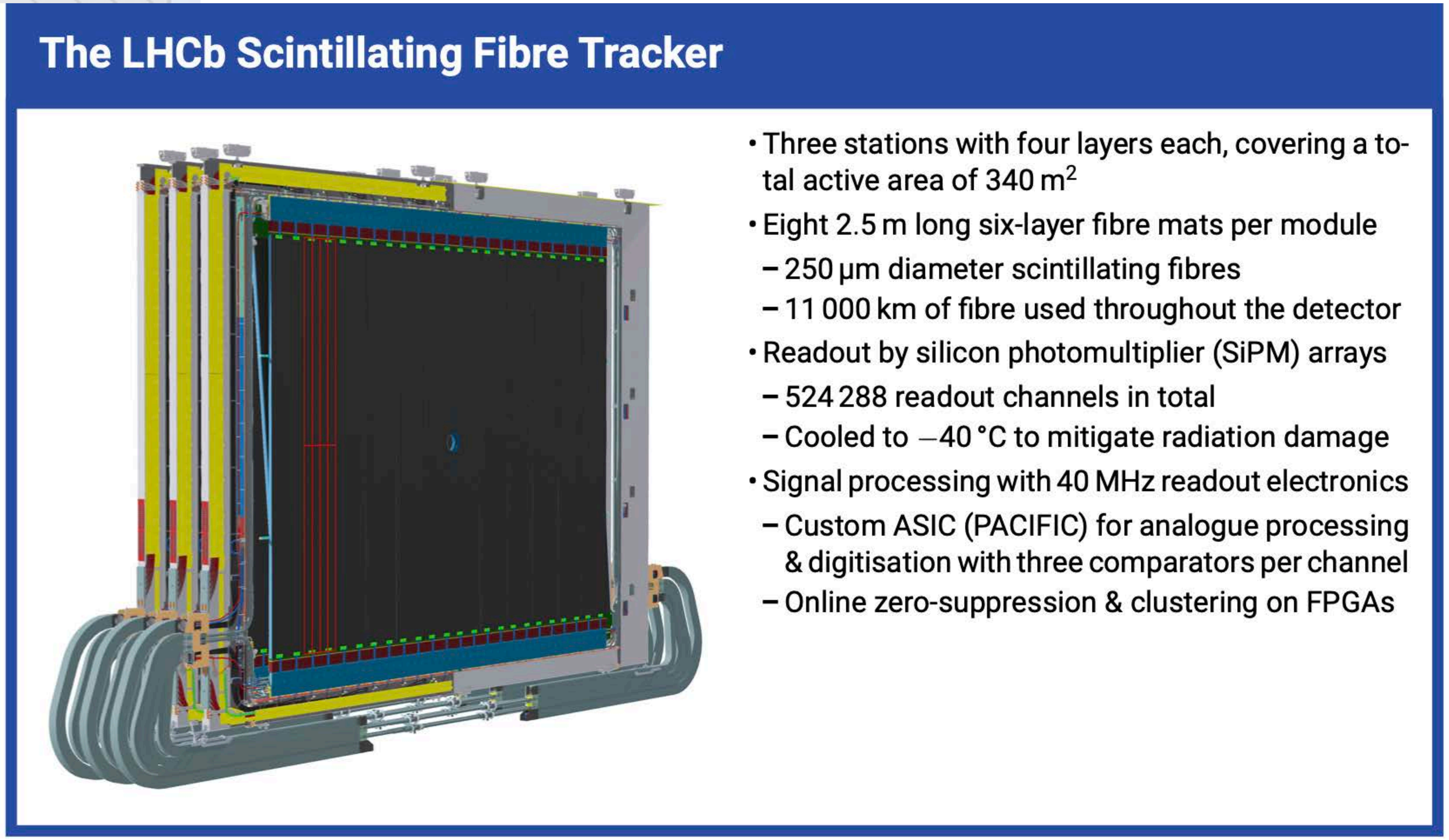
Attenuation length is wavelength dependent
Some direct light can escape; some escaping light can be trapped in the cladding

Light Collection - Optical Fibres



IceCube Fibre Optical Module





The LHCb Scintillating Fibre Tracker

- Three stations with four layers each, covering a total active area of 340 m^2
- Eight 2.5 m long six-layer fibre mats per module
  - 250 µm diameter scintillating fibres
  - 11 000 km of fibre used throughout the detector
- Readout by silicon photomultiplier (SiPM) arrays
  - 524 288 readout channels in total
  - Cooled to −40 °C to mitigate radiation damage
- Signal processing with 40 MHz readout electronics
  - Custom ASIC (PACIFIC) for analogue processing & digitisation with three comparators per channel
  - Online zero-suppression & clustering on FPGAs

Photodetectors

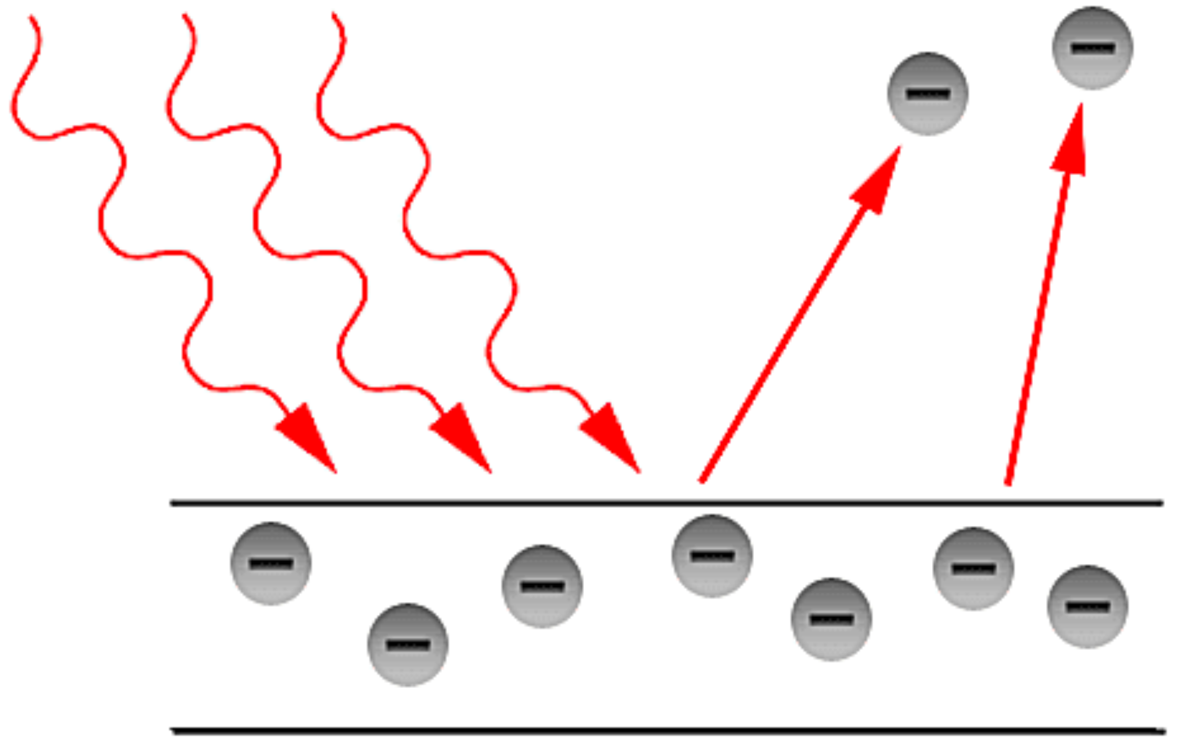
C. Woody (GRIDS 2019)
J. Yanez (GRIDS 2025)

Have reached the stage where we produced and collected light from an ionizing interaction we want to study

Final goal -> convert this to a digital signal.

Basic elements:

Photoelectric effect
- converts photons to photoelectrons
- performance driven by the quantum efficiency



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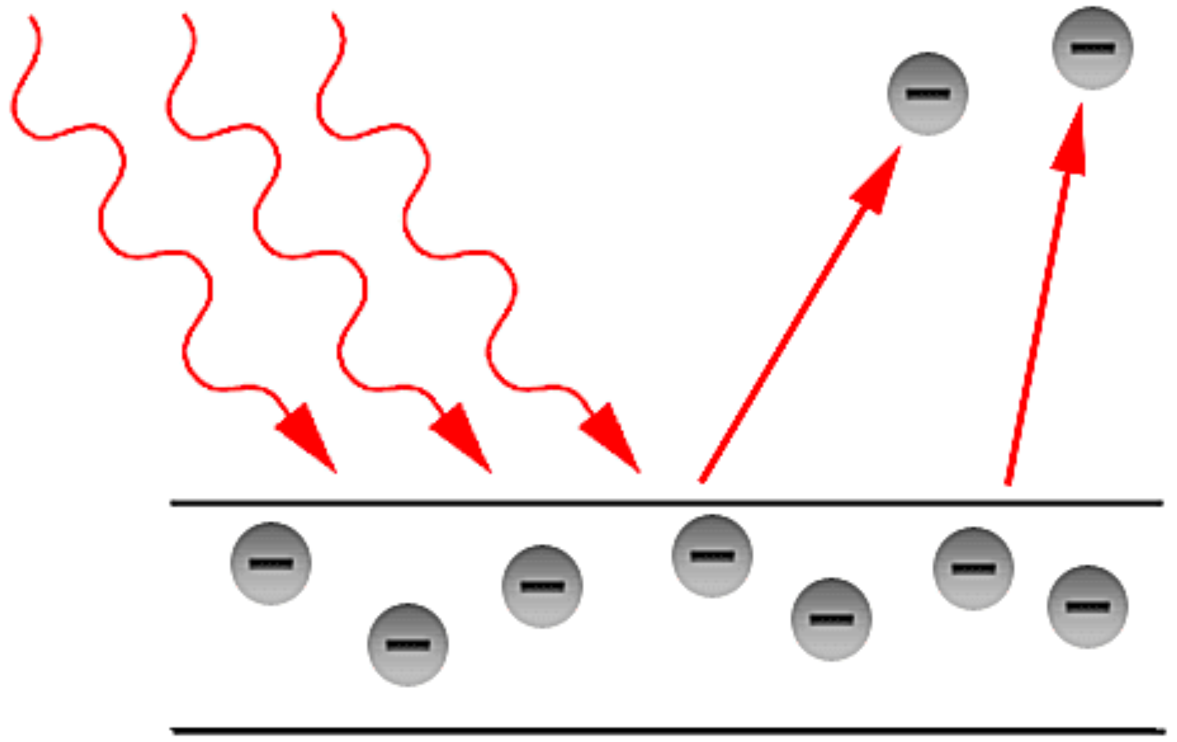

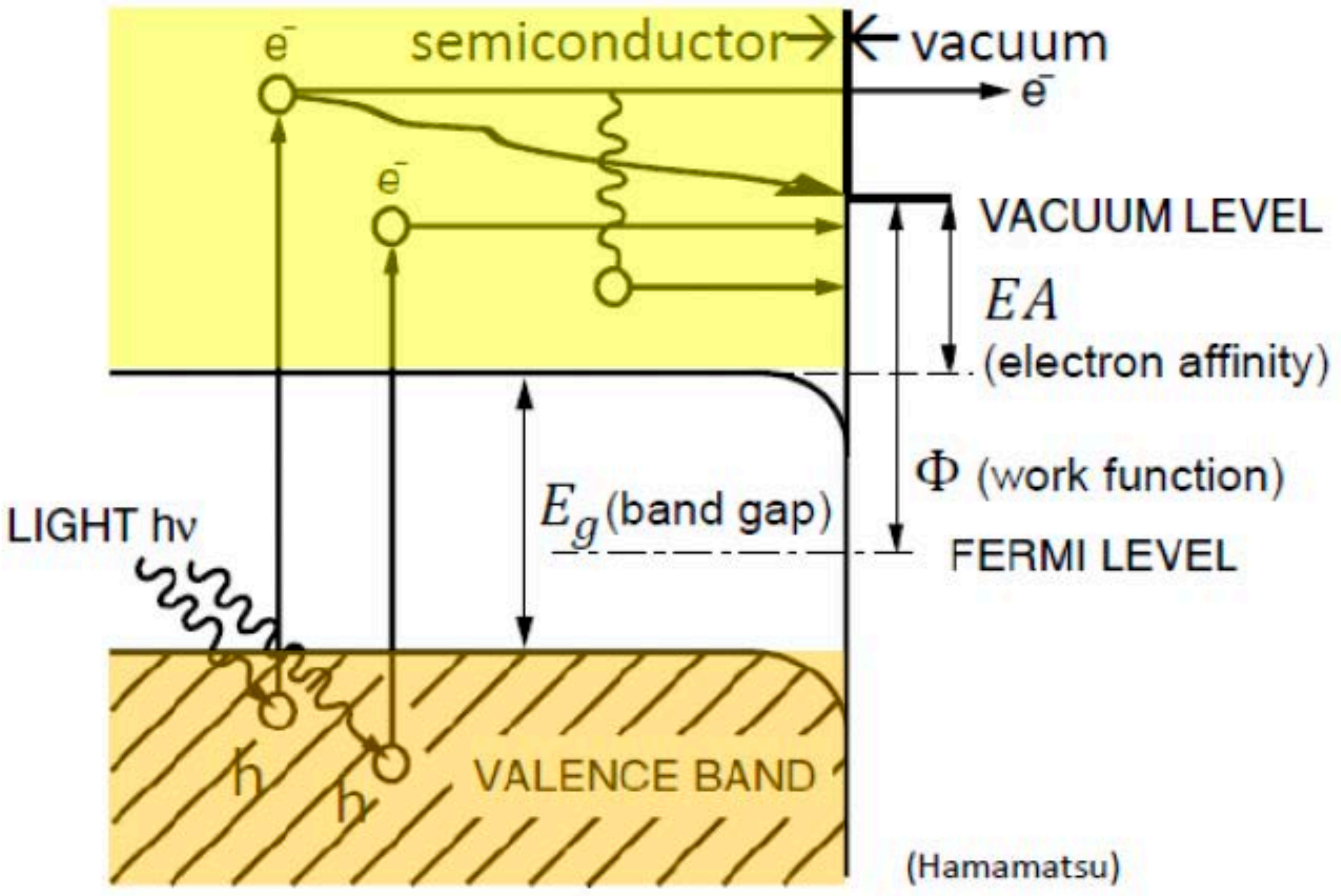

Photon energy:

$$E_\gamma = h\nu = \frac{hc}{\lambda} \approx \frac{1239\ \mathrm{eV}\cdot\mathrm{nm}}{\lambda}$$

Visible range 400 nm – 780 nm
→ 3.1 - 1.6 eV

Photodetectors

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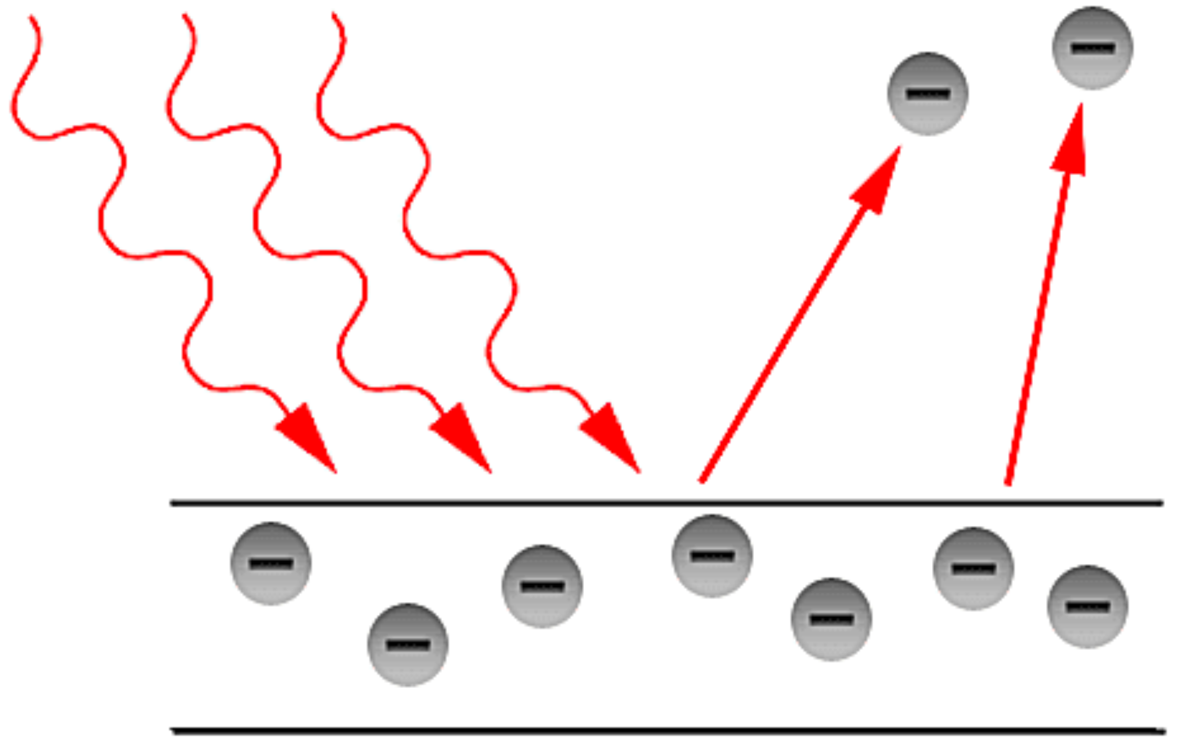
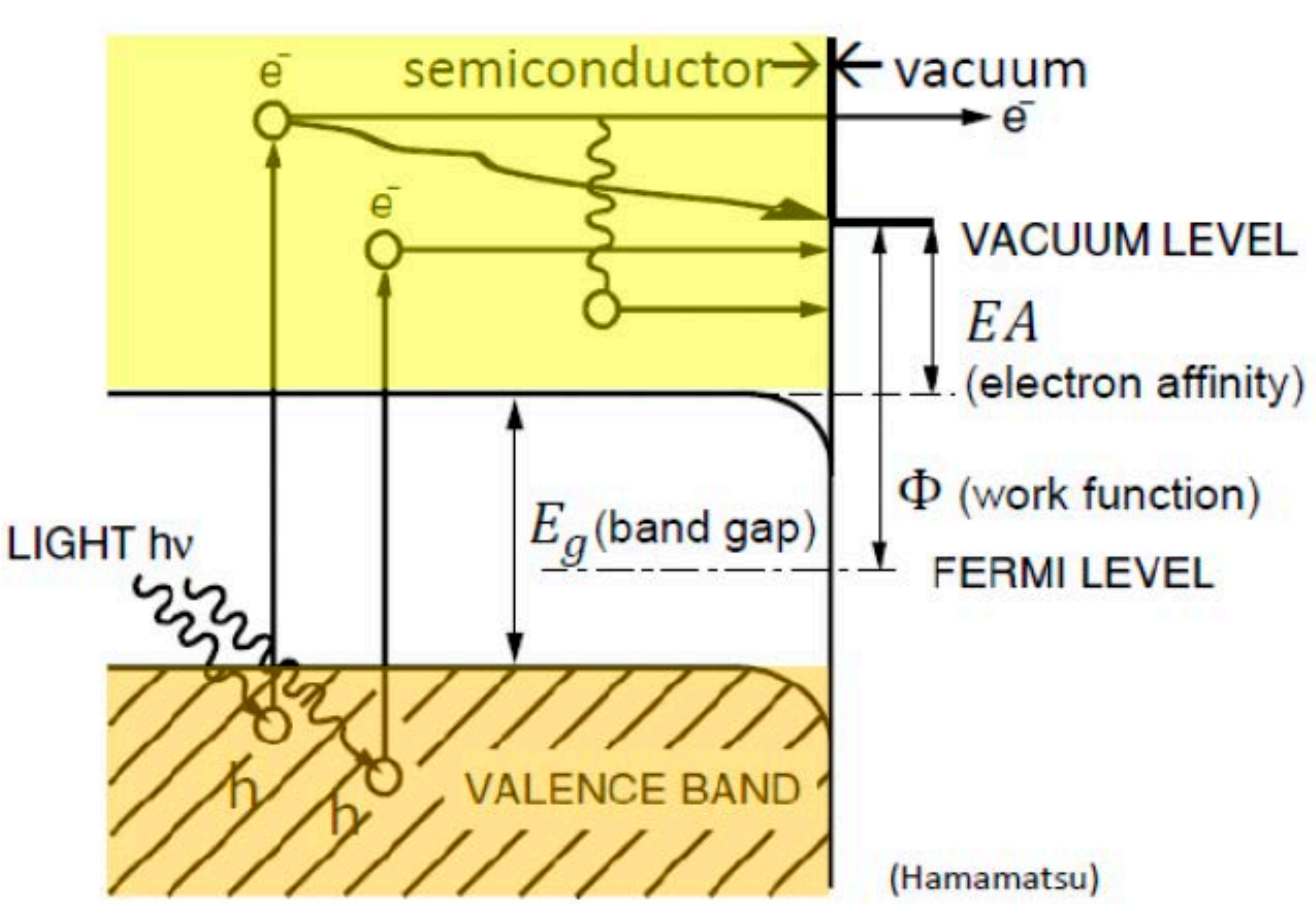


Charge amplification
- via gain or direct conversion (device dependent)
- driven by the signal-to-noise ratio

Photon energy:

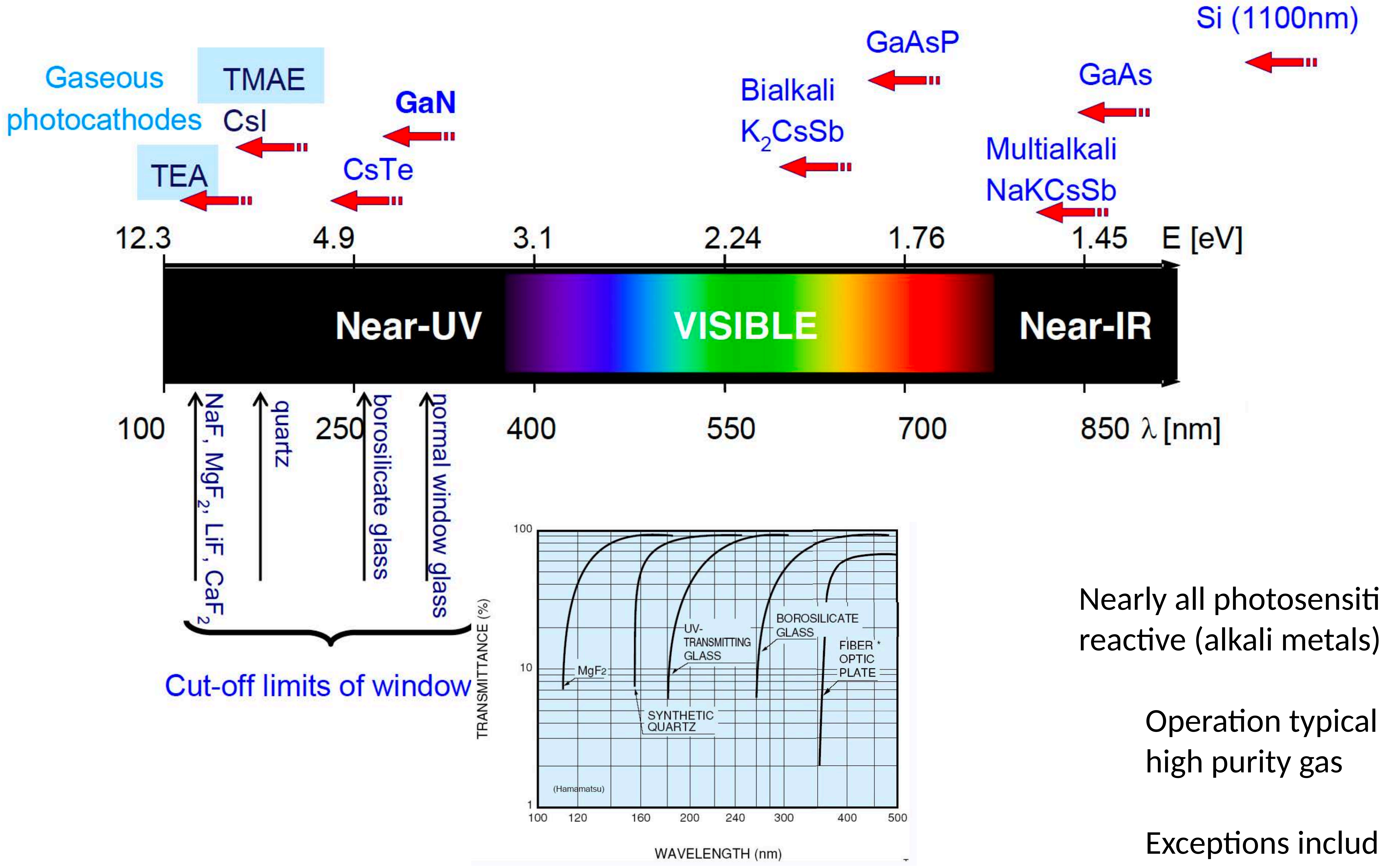
$$E_\gamma = h\nu = \frac{hc}{\lambda} \approx \frac{1239\ \mathrm{eV}\cdot\mathrm{nm}}{\lambda}$$

Visible range 400 nm – 780 nm
→ 3.1 - 1.6 eV



(Hamamatsu)

Photodetectors - Photocathodes



Nearly all photosensitive materials are very reactive (alkali metals)

Operation typically only in vacuum or high purity gas

Exceptions include CsI and Is

Photodetectors - Overview (types)

C. Woody (GRIDS 2019)

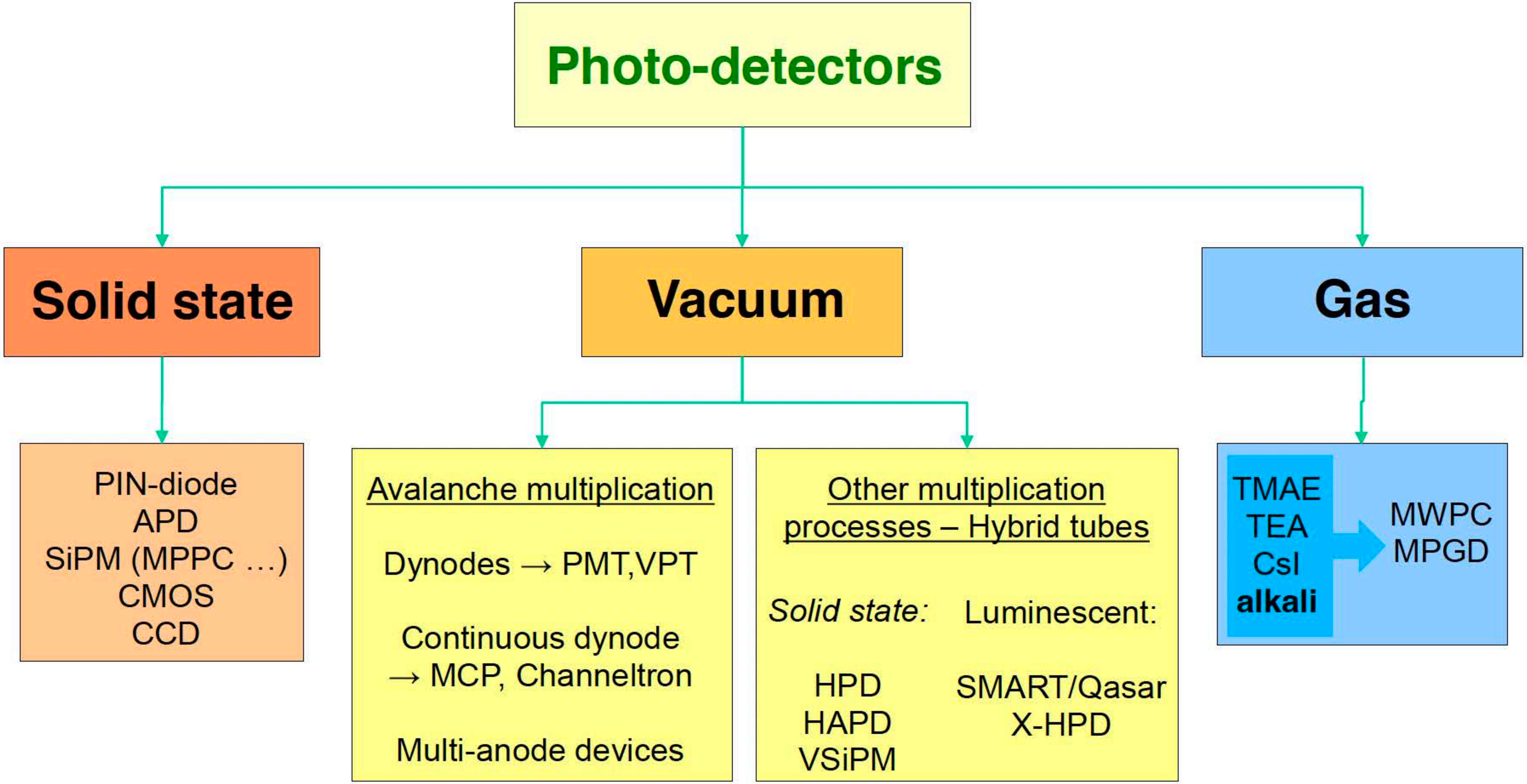


Photo-detectors

Solid state

PIN-diode
APD
SiPM (MPPC …)
CMOS
CCD

Vacuum

Avalanche multiplication

Dynodes → PMT,VPT

Continuous dynode
→ MCP, Channeltron

Multi-anode devices

Other multiplication processes – Hybrid tubes

Solid state:
HPD
HAPD
VSiPM

Luminescent:
SMART/Qasar
X-HPD

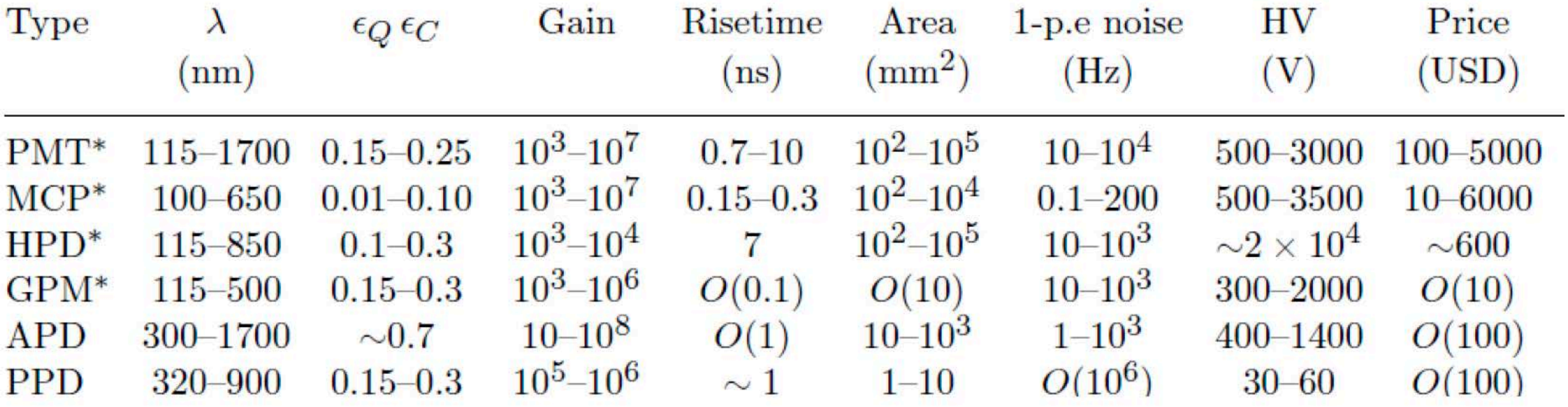
Gas

TMAE
TEA
CsI
alkali

MWPC
MPGD

Photodetectors - Overview (properties)

C. Woody (GRIDS 2019)



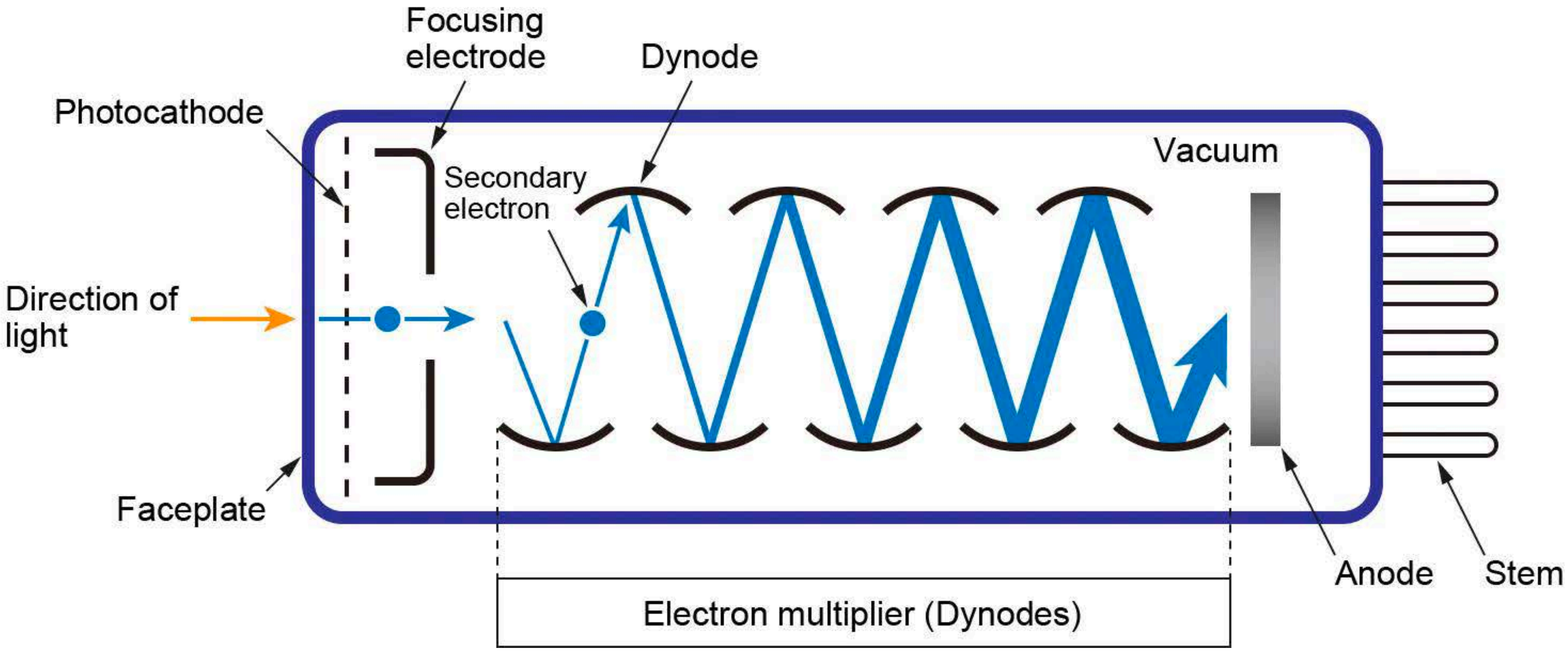
Type	λ (nm)	$\epsilon_Q \epsilon_C$	Gain	Risetime (ns)	Area (mm^2)	1-p.e noise (Hz)	HV (V)	Price (USD)
PMT*	115–1700	0.15–0.25	10^3–10^7	0.7–10	10^2–10^5	10–10^4	500–3000	100–5000
MCP*	100–650	0.01–0.10	10^3–10^7	0.15–0.3	10^2–10^4	0.1–200	500–3500	10–6000
HPD*	115–850	0.1–0.3	10^3–10^4	7	10^2–10^5	10–10^3	$\sim 2 \times 10^4$	~600
GPM*	115–500	0.15–0.3	10^3–10^6	$O(0.1)$	$O(10)$	10–10^3	300–2000	$O(10)$
APD	300–1700	~0.7	10–10^8	$O(1)$	10–10^3	1–10^3	400–1400	$O(100)$
PPD	320–900	0.15–0.3	10^5–10^6	~ 1	1–10	$O(10^6)$	30–60	$O(100)$

Review of Particle Physics
Journal of Physics G, Vol 37, No 7A (2010)

PMT = Photomultiplier tube (sensitive to magnetic fields)
APD = Avalance Photodiode
PPD = Pixellated Photon Detector (SiPM, GPMT, MPPC)
MCP = Multi-channel Plate Detector (dense, fast small diameter charge amplifiers)
HPD = Hybrid Photodiode Detector (vacuum PMT w/silicon sensor)
GPM = Gaseous Photon Detector (large area solid and gaseous photocathode)

Photodetectors - Photomultiplier tube (PMT)

C. Woody (GRIDS 2019)
J. Yanez (GRIDS 2025)



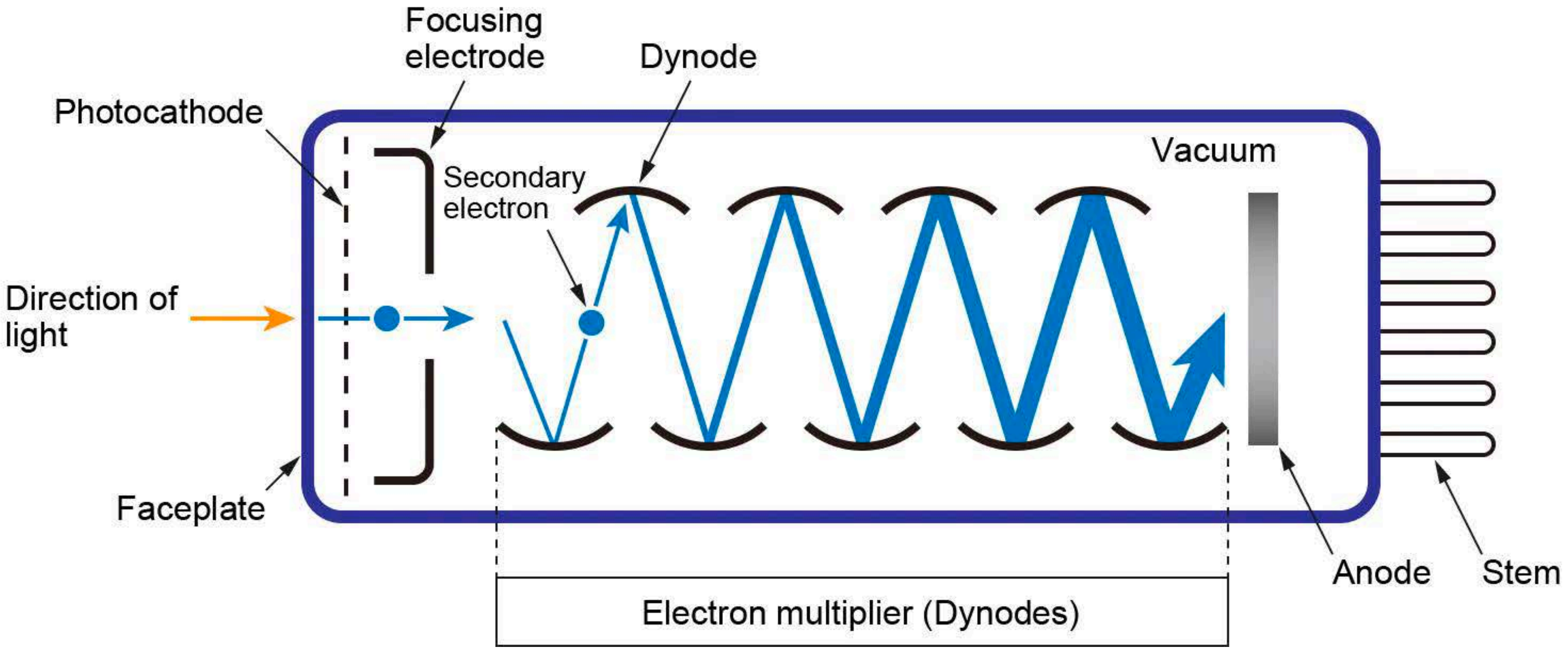
Photon releases an electron from the photocathode (quantum efficiency)

Collection of photoelectrons by the first dynode

Secondary emission from (N) dynodes in the chain (gain is a function of incoming electron energy)

Amplification factors of O(e6) achievable

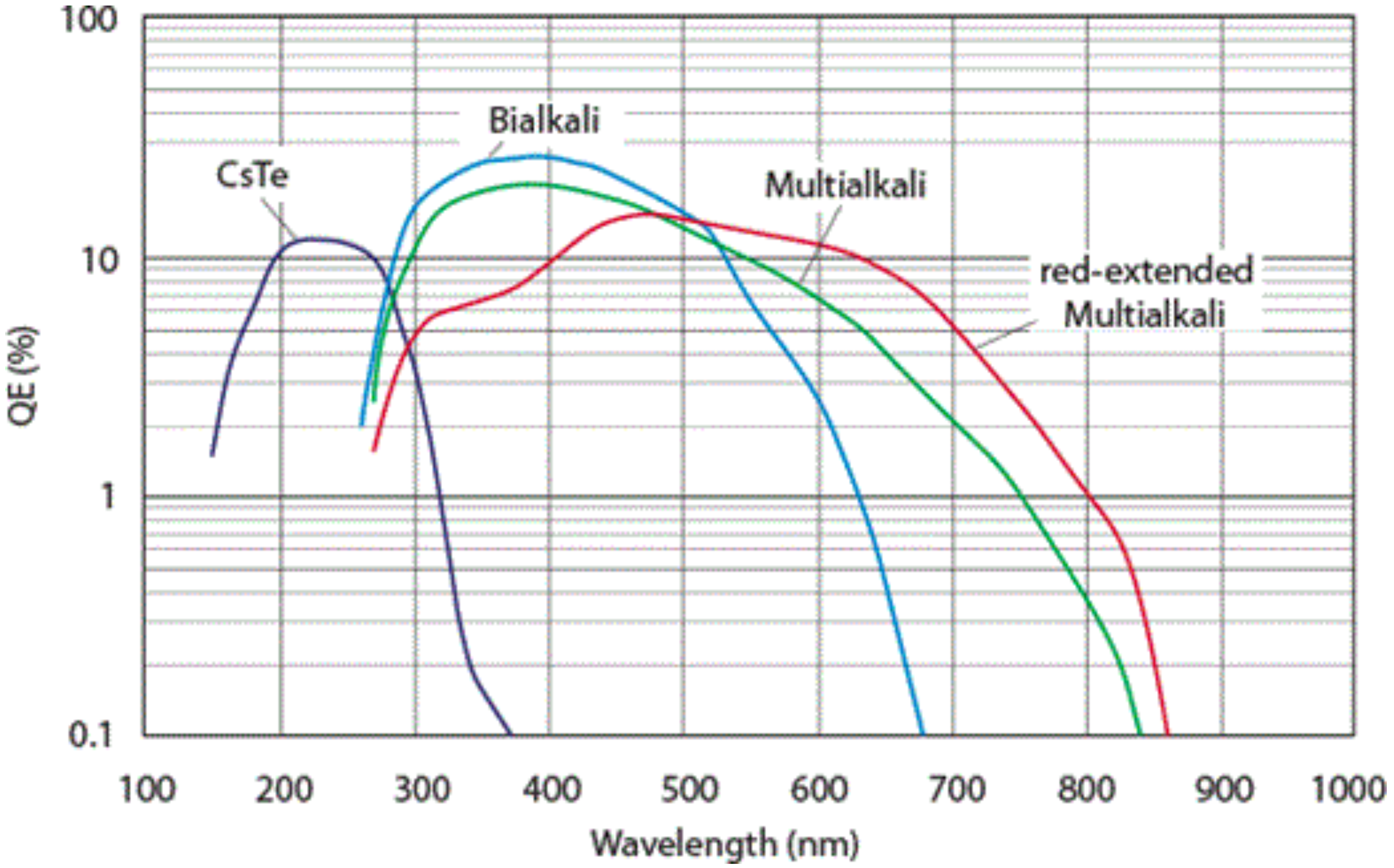
Photodetectors - Photomultiplier tube (PMT)



Monoalkali - CsI, CsTe, Kir

Bialkali - SbRbCs3

Mulitalkali - SbNaKCs3



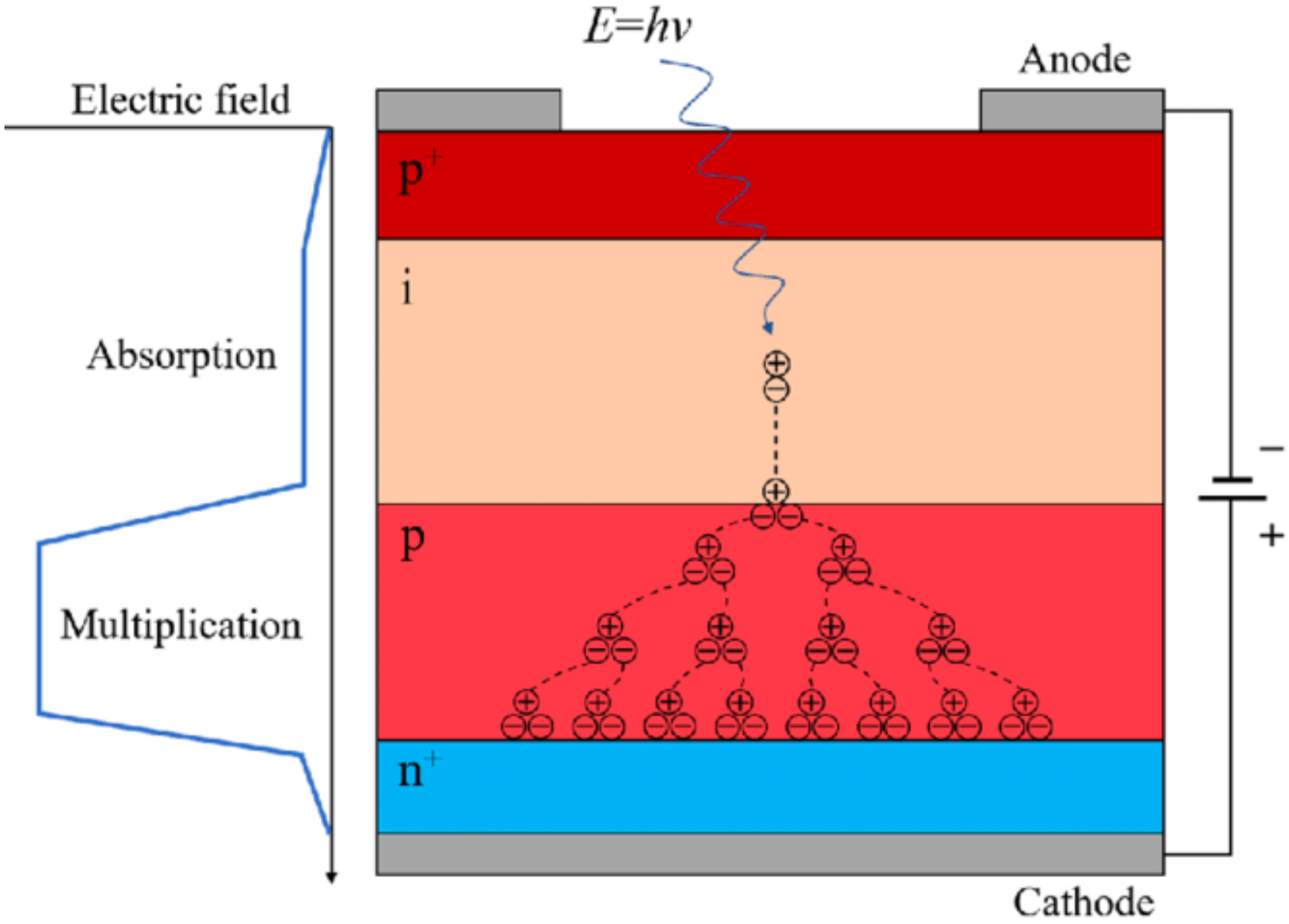
Photodetectors - Silicon (Avalanche Photodiodes - APDs)

Formed utilizing multiple p-n junctions ->
A modification of the traditional P (hole-rich)-I-N (electron-rich) photodiode where the (I)ntrinsic region typically acts as a large charge storage region. Operation in reverse bias this region instead behaves as a small capacitor = “open switch”)

In reverse bias, high doping creates a strong electric field

Electrons moved to the conduction band drift to the high-field region where an avalanche amplification takes place (50 - 500x)

Signal is obtained by an electric (can be further amplified.



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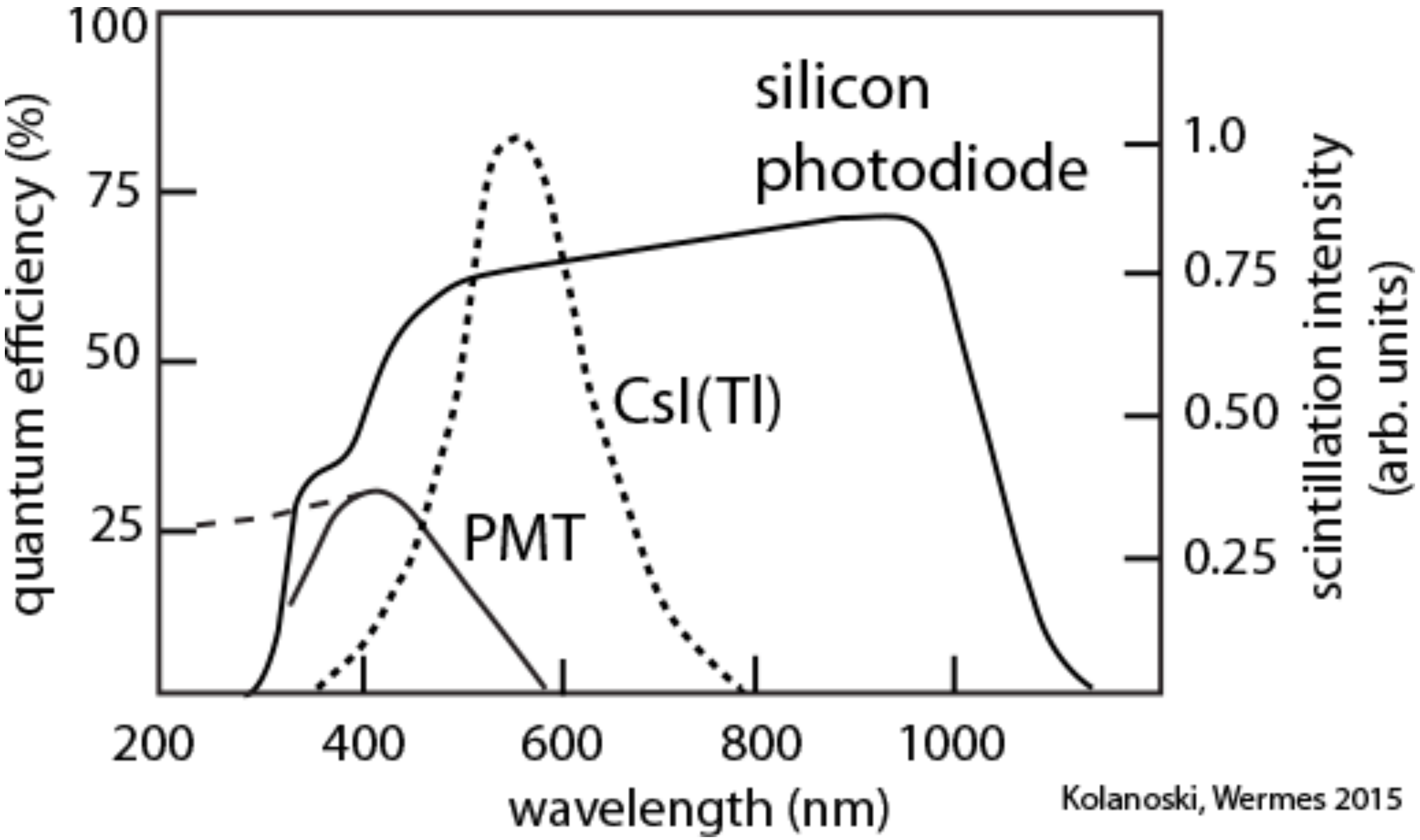

Kolanoski, Wermes 2015

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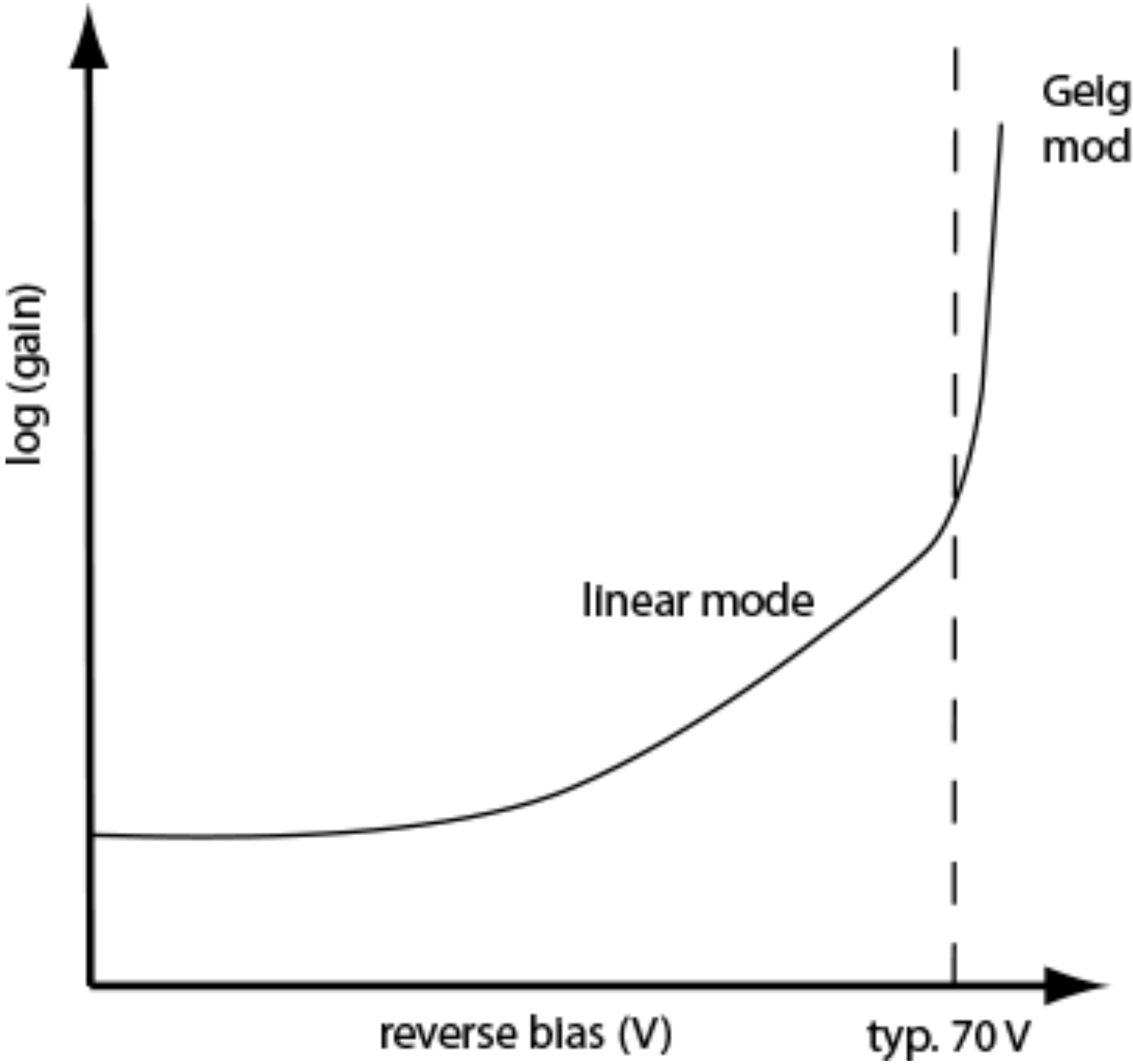


Photodetectors - Silicon (SiPMs)

C. Woody (GRIDS 2019)
J. Yanez (GRIDS 2025)

Arrays of Single Photon Avalance Diodes (SPADs) biased slightly above the breakdown voltage (Geiger mode)-> single particle (including photons) can trigger an avalanche.

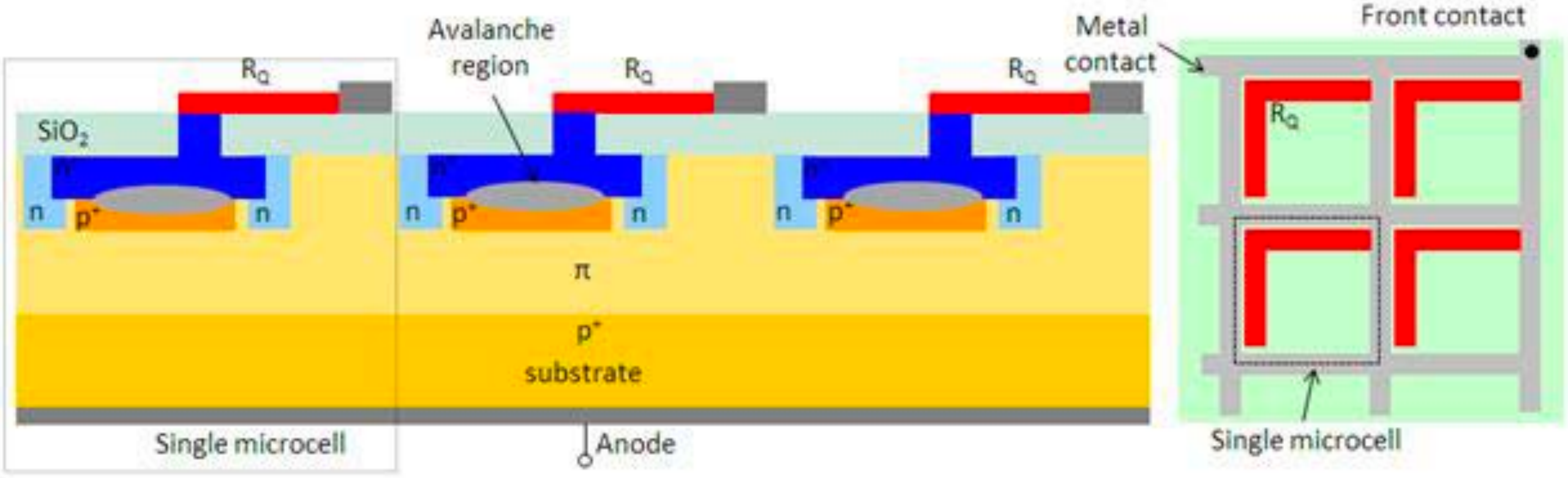
Cells are binary (yes/now); signal proportional to light intensity

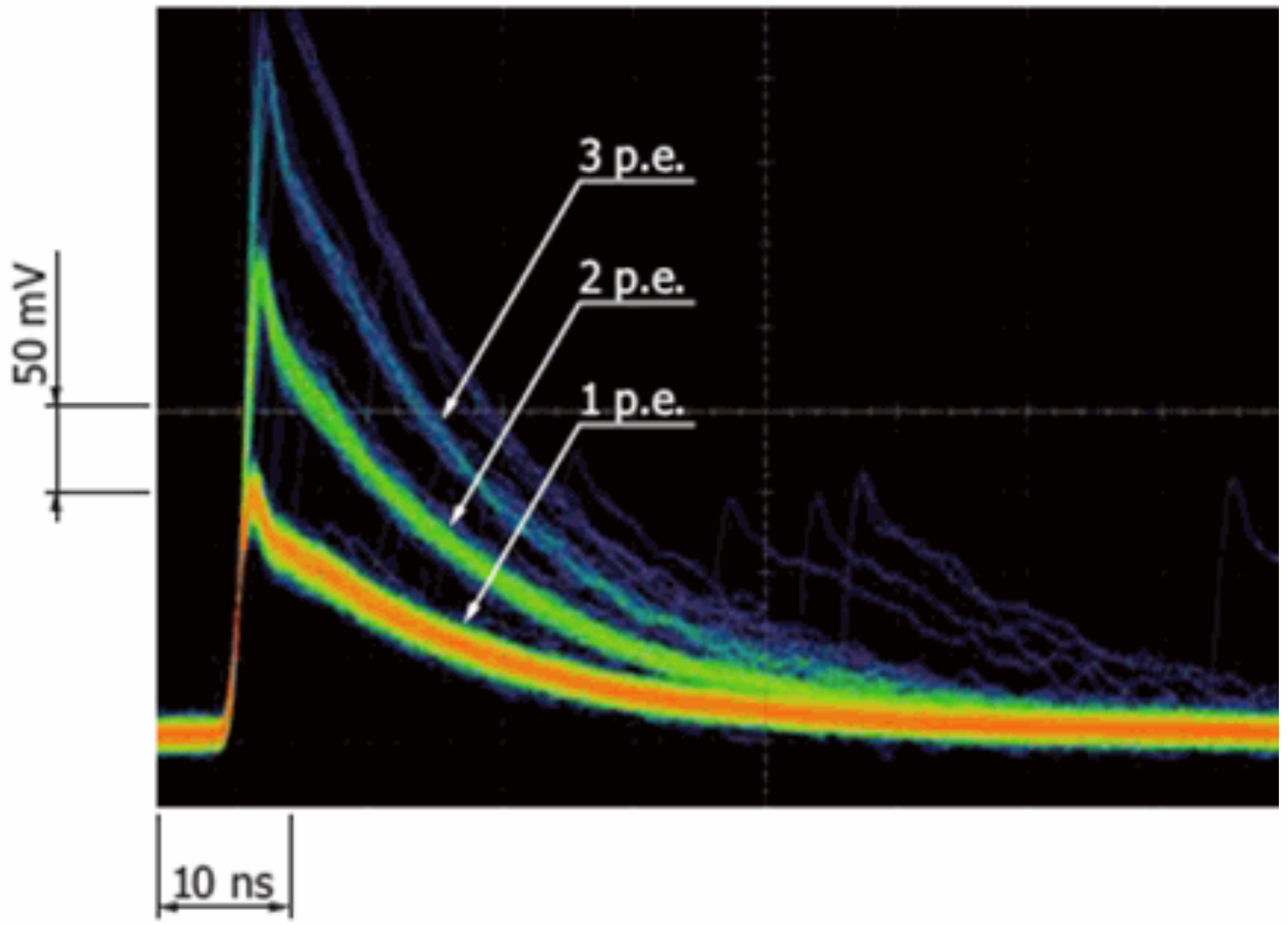
Advantages

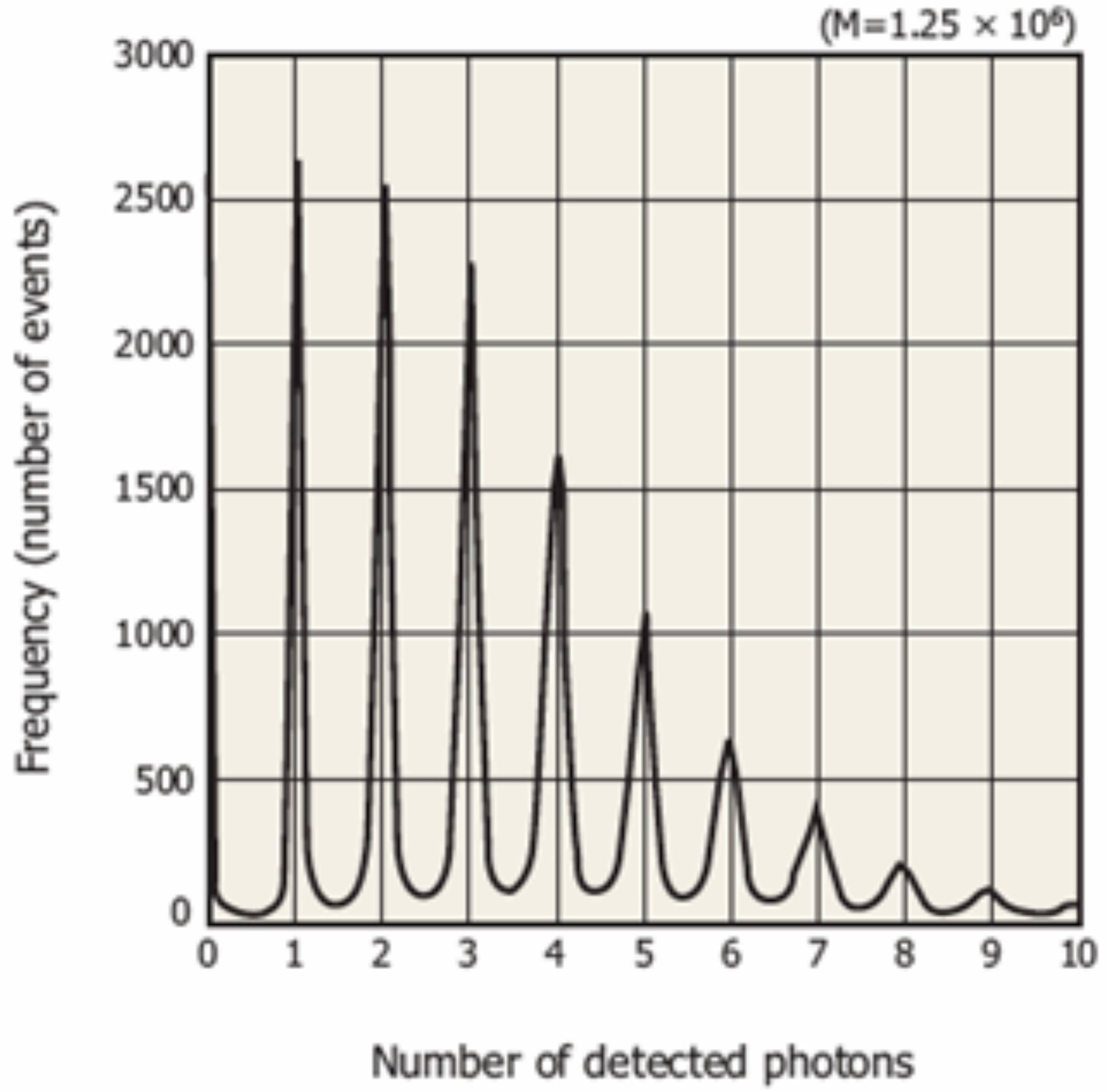
- High gains (similar to PMTs) can be realized
- Excellent single photon resolution
- Insensitive to magnetic fields

Disadvantages

- Non-linear output at high incident flux (pixel saturation)
- High noise rates (thermal carriers) ~100 kHz/sq-mm
- Large temperature dependence
- Susceptible to neutron damage







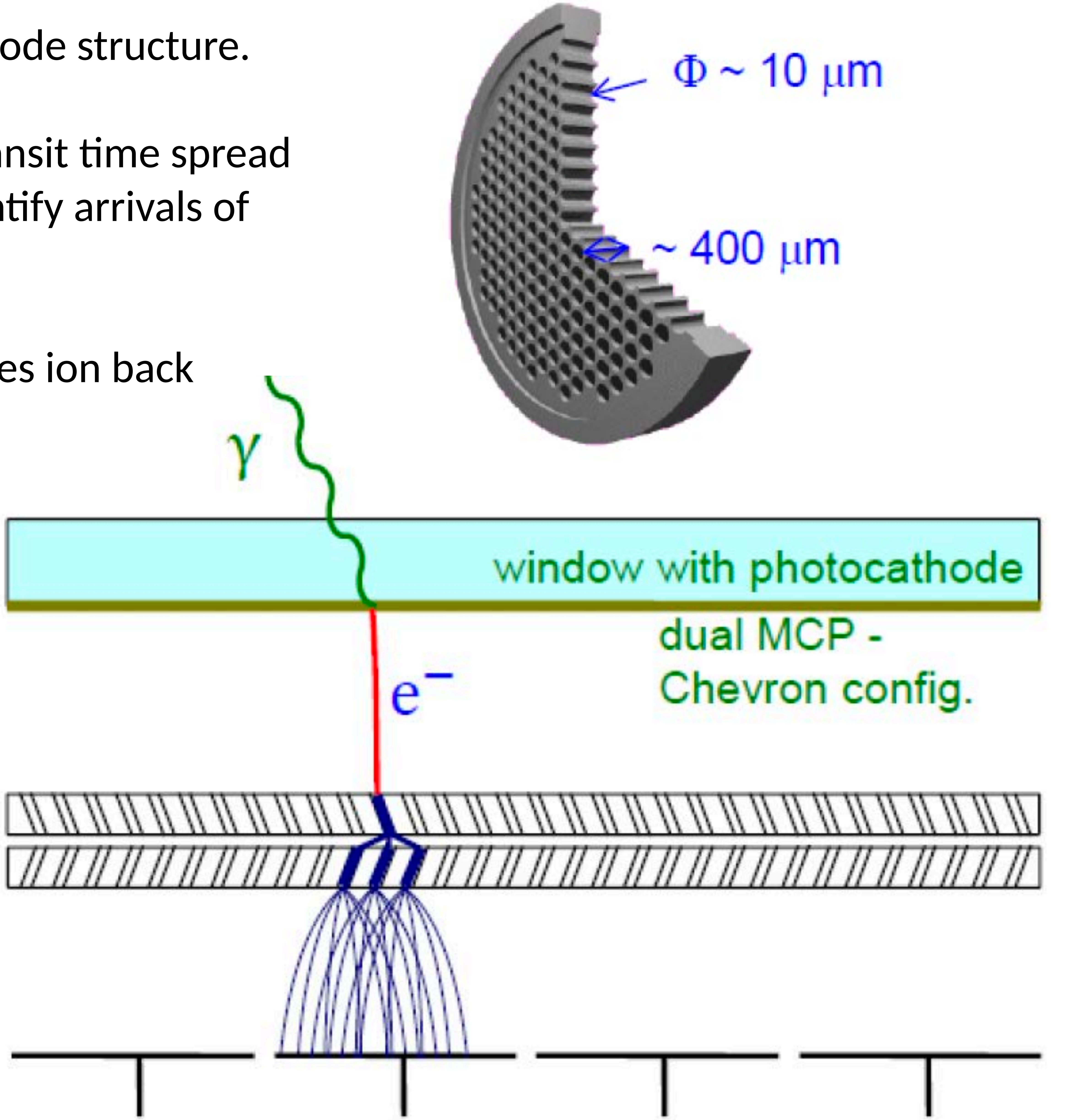
Photodetectors - Silicon (Multi-channel Plate Detectors - MCPs)

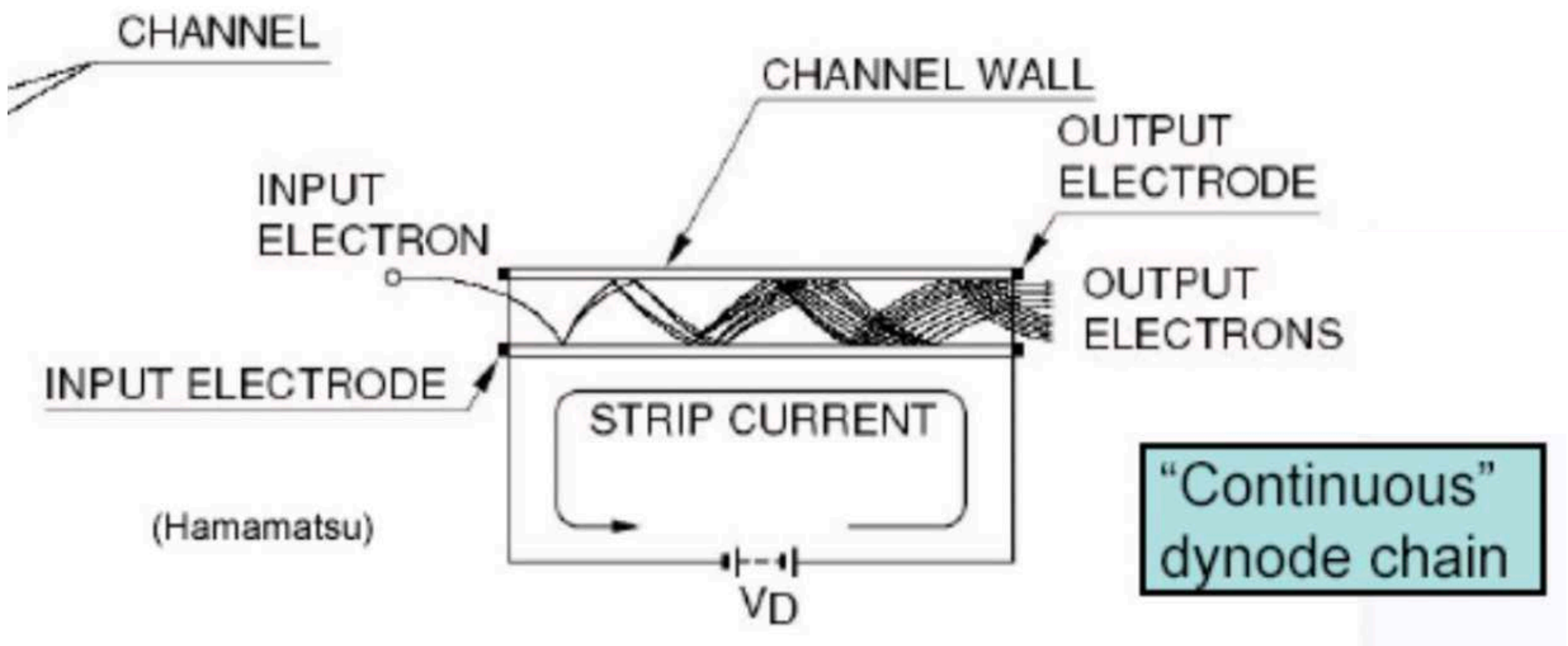
C. Woody (GRIDS 2019)
S. Leoni (INFN)

A thin (Pb-)glass plate with array of holes forming a continuous dynode structure.

The avalanche process is highly contained providing a very small transit time spread -> very fast timing and excellent timing resolutions (possible to identify arrivals of individual photoelectrons

“Chevron configuration” improves radiation hardness and suppresses ion back streaming -> improved gain

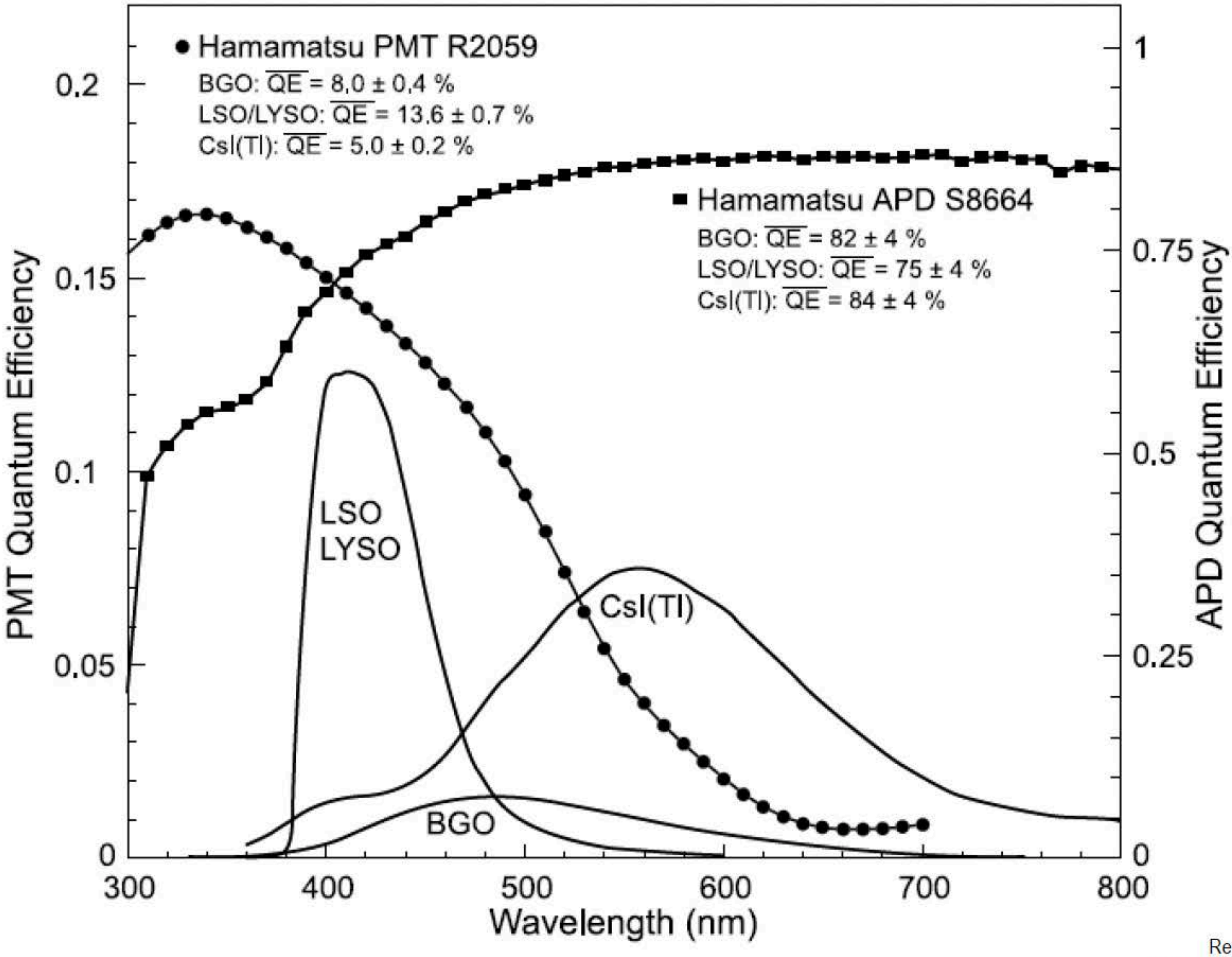




Scintillator Detector Systems - Quantum Efficiency

Optimization of the detector elements to harmonize the system

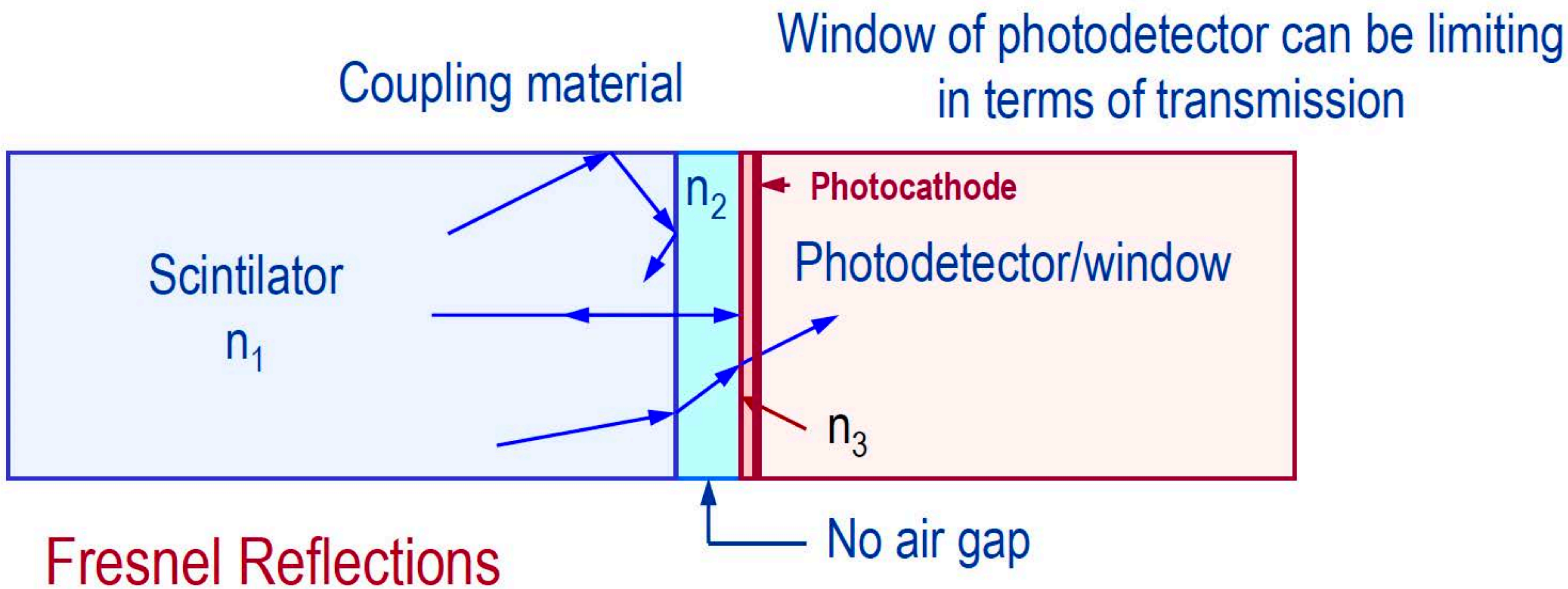
Emission Weighted Quantum Efficiency: $\overline{Q\,E} = \int QE_{PD}(\lambda)\cdot I_{em}(\lambda)\,d\lambda$



Review of Particle Physics
Journal of Physics G, Vol 37, No 7A (2010)

Scintillator Detector Systems - Optical Coupling

Optimization of the detector elements to harmonize the system



Window of photodetector can be limiting
in terms of transmission

Coupling material

Scintilator
n_1

n_2

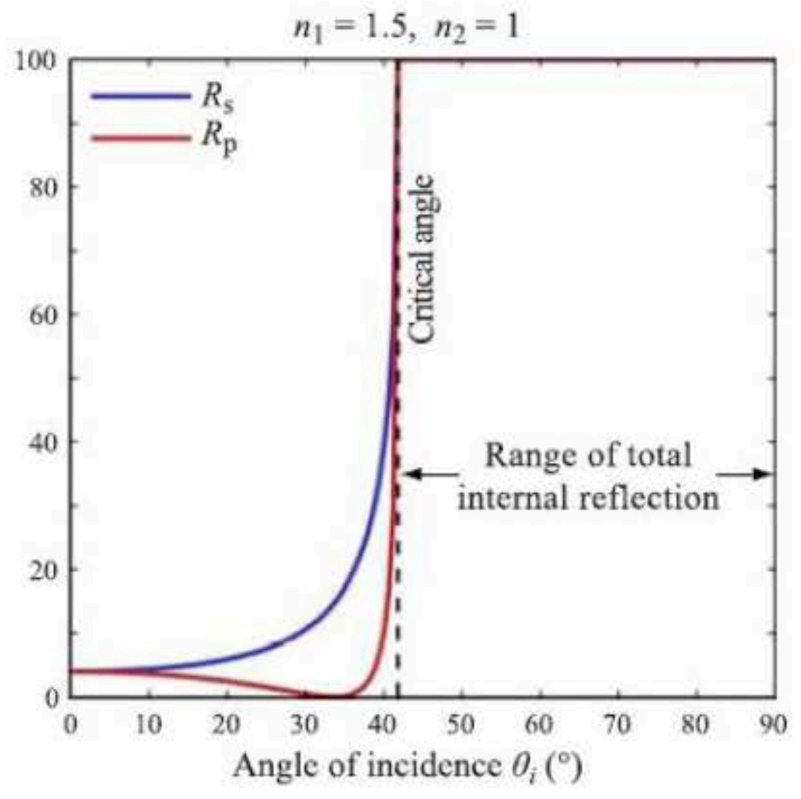
Photocathode

Photodetector/window

n_3

No air gap

Fresnel Reflections



Wikipedia

Normal incidence

$$R = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2$$

n_1=1.5, n_2=1.0

R ~ 4%

Coupling materials (n~ 1.4):
- Optical grease/glue
- Silicon “cookies”

⇒ n2 ~ n3

However, for heavy crystals $n_1 > n_2$

Scintillator Detector Systems - Applications

Nuclear and particle physics:

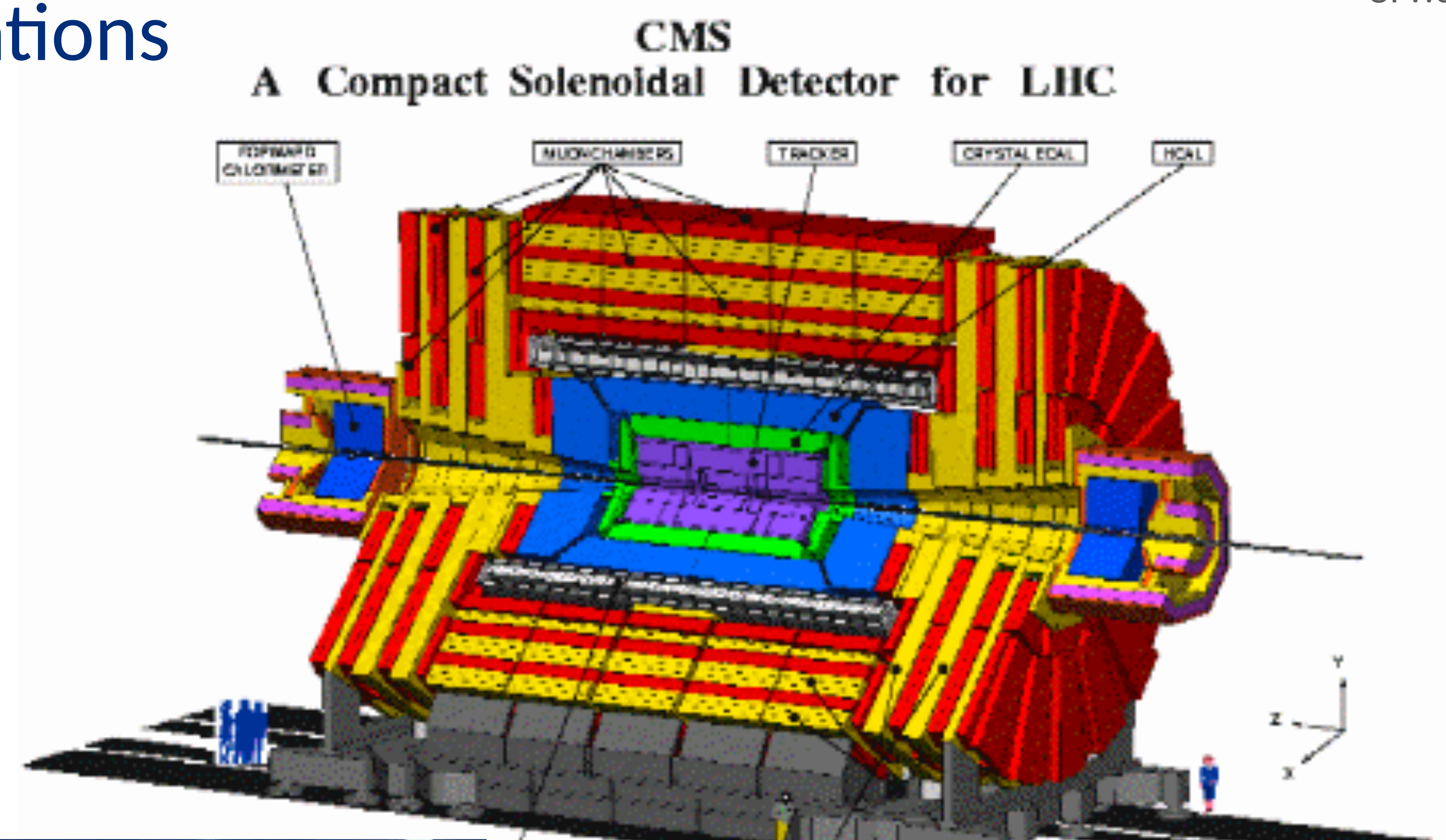
- Calorimetry
- Tracking
- Particle ID (Time of flight)

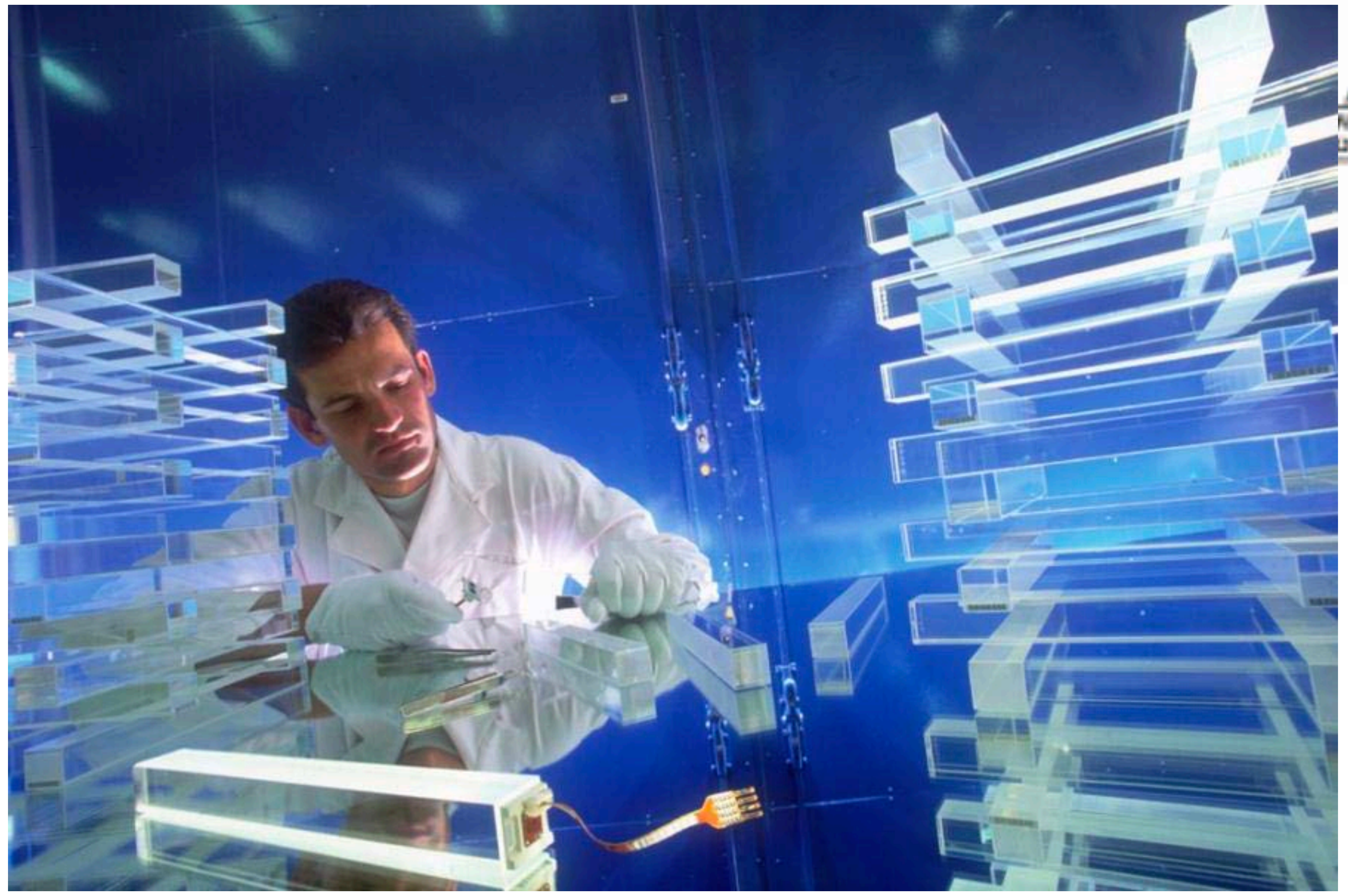
Astrophysics:

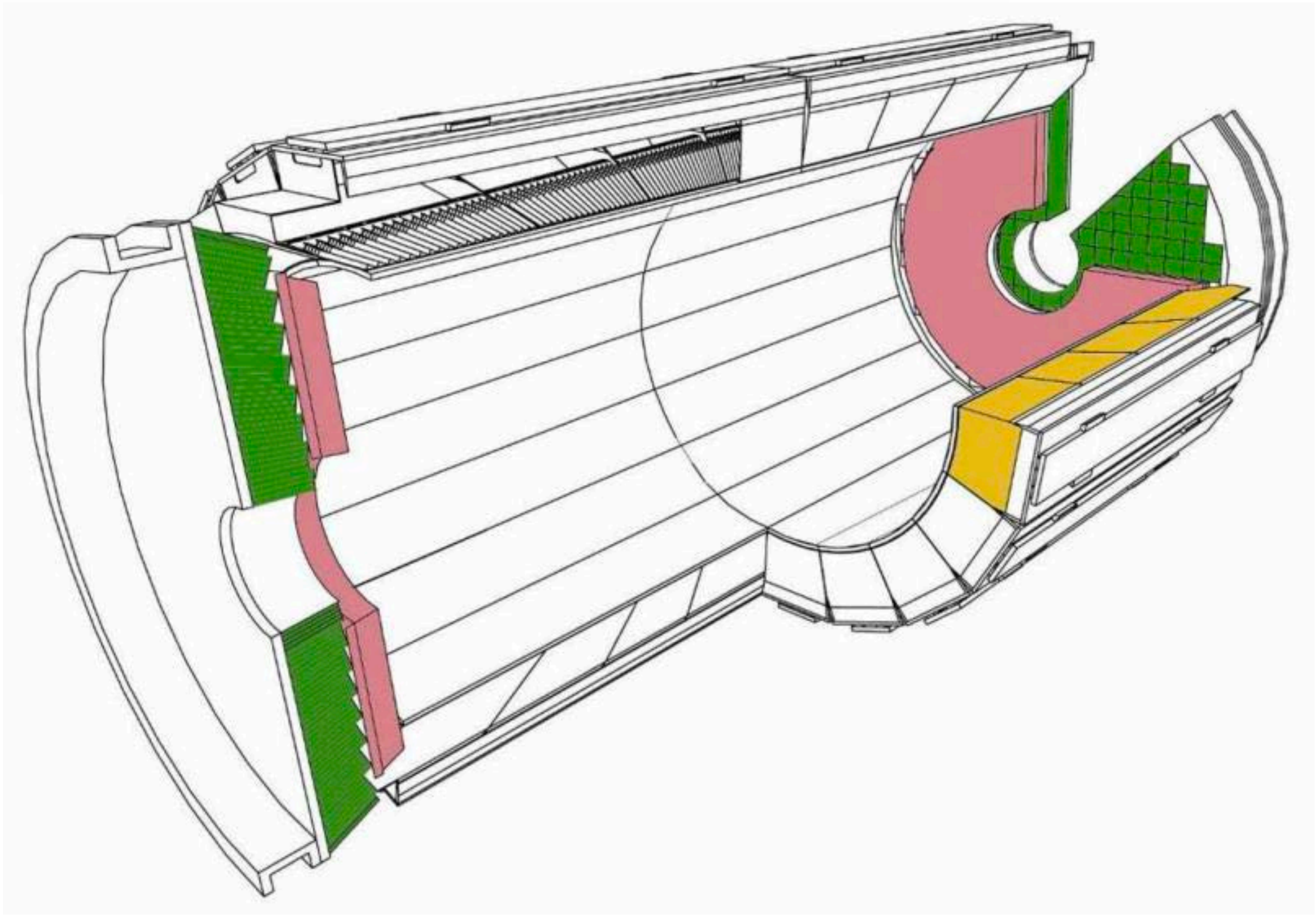
- Dark Matter

Medical Imaging

- PET







Order of 75k PbWO4 crystals crystals in the endcap (vacuum phototriodes) and barrel (APD) sampling calorimeters

Scintillator Detector Systems - Applications

J. Yanez (GRIDS 2025)

Nuclear and particle physics:

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Astrophysics:

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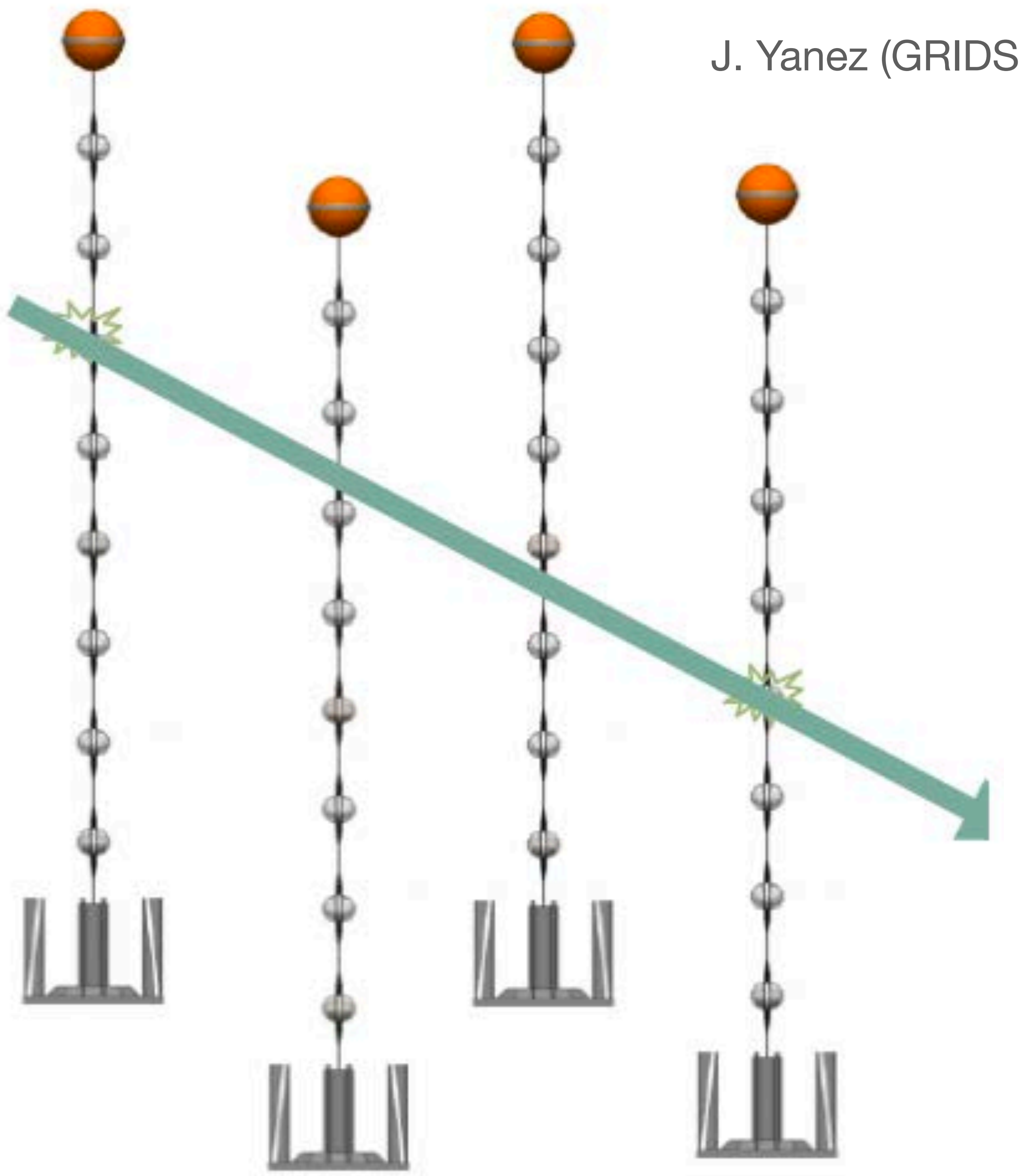
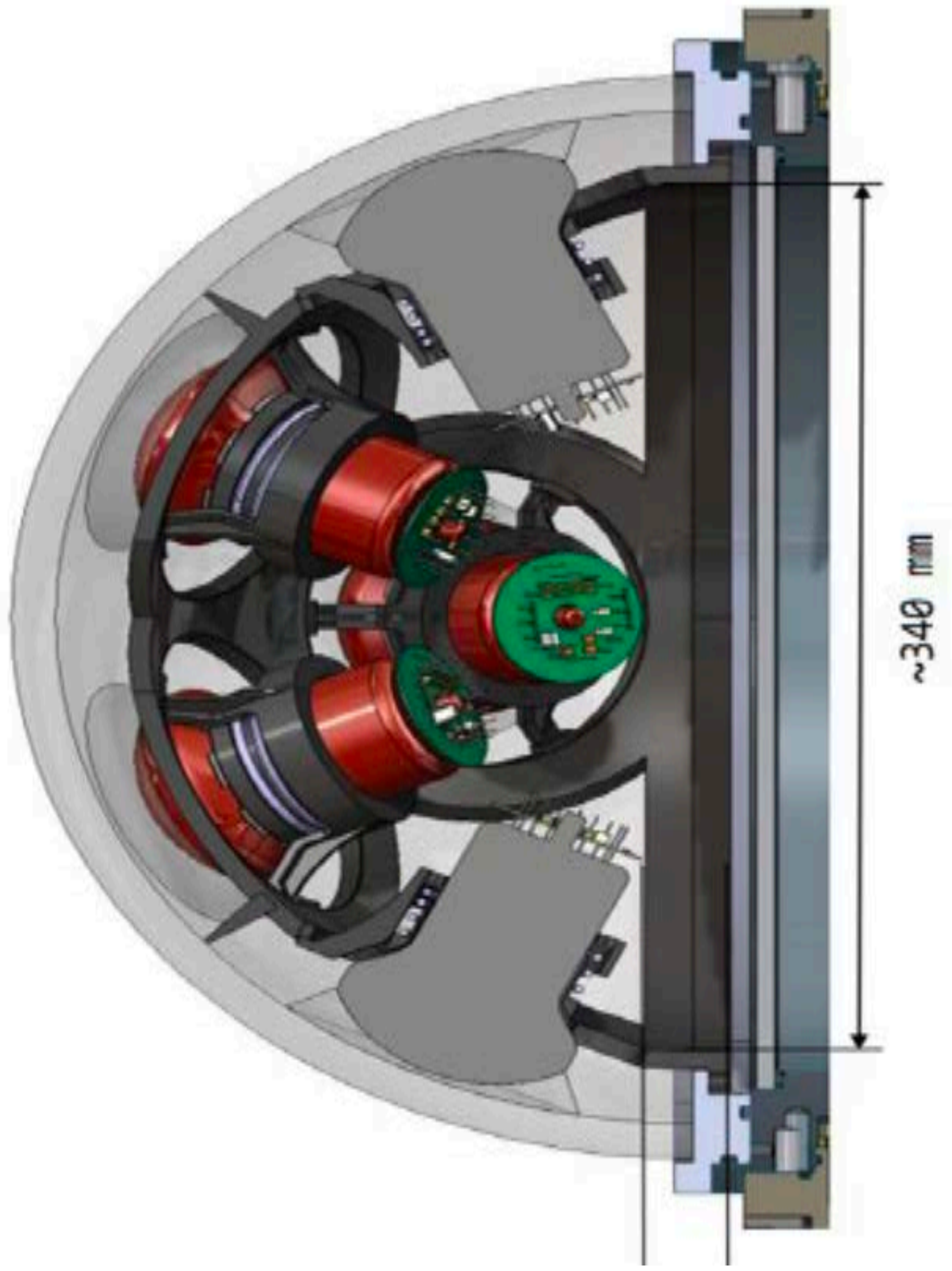
Medical Imaging

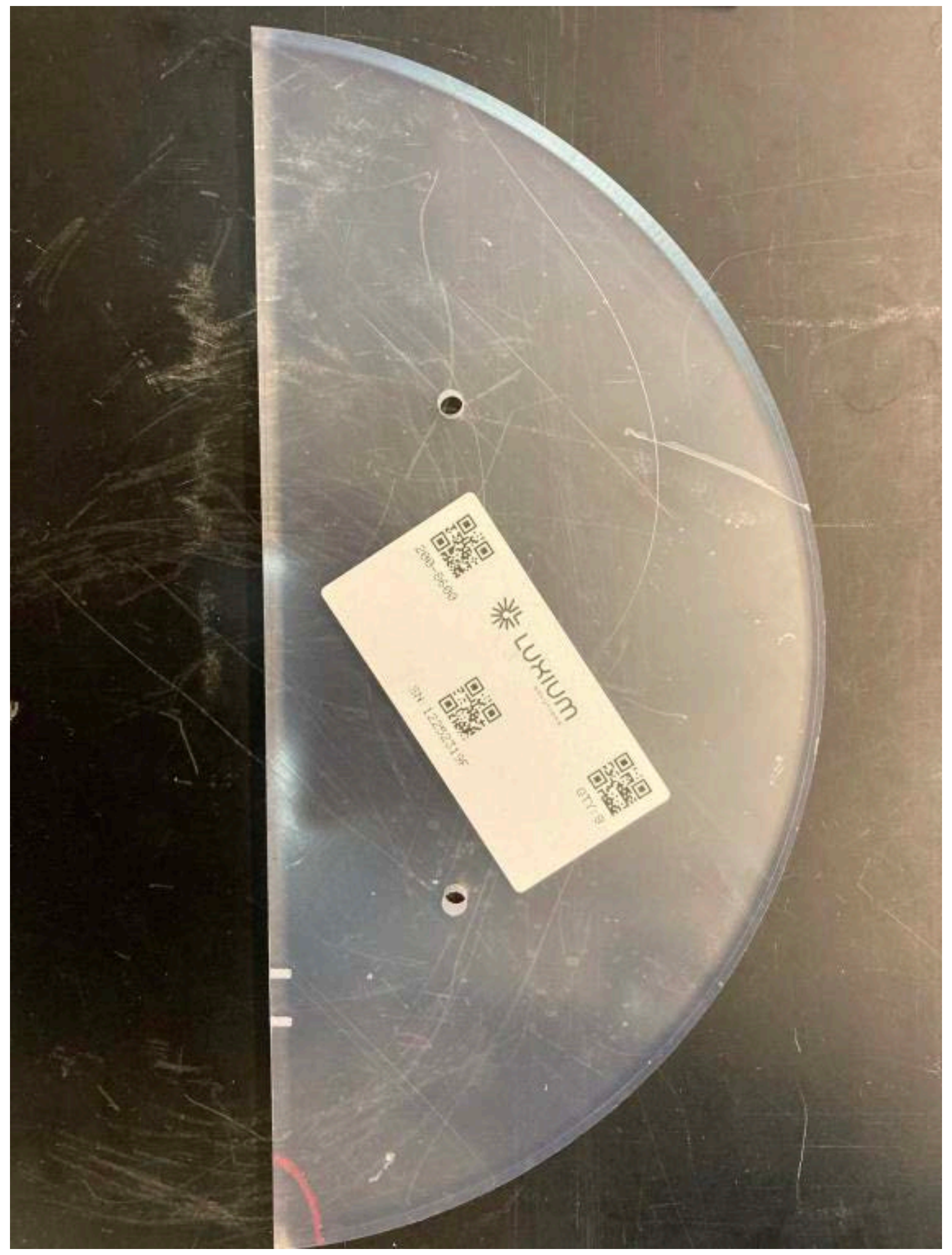
- PET

P-ONE



Atmospheric muon calibration w. Plastic scintillator and SiPM readout.





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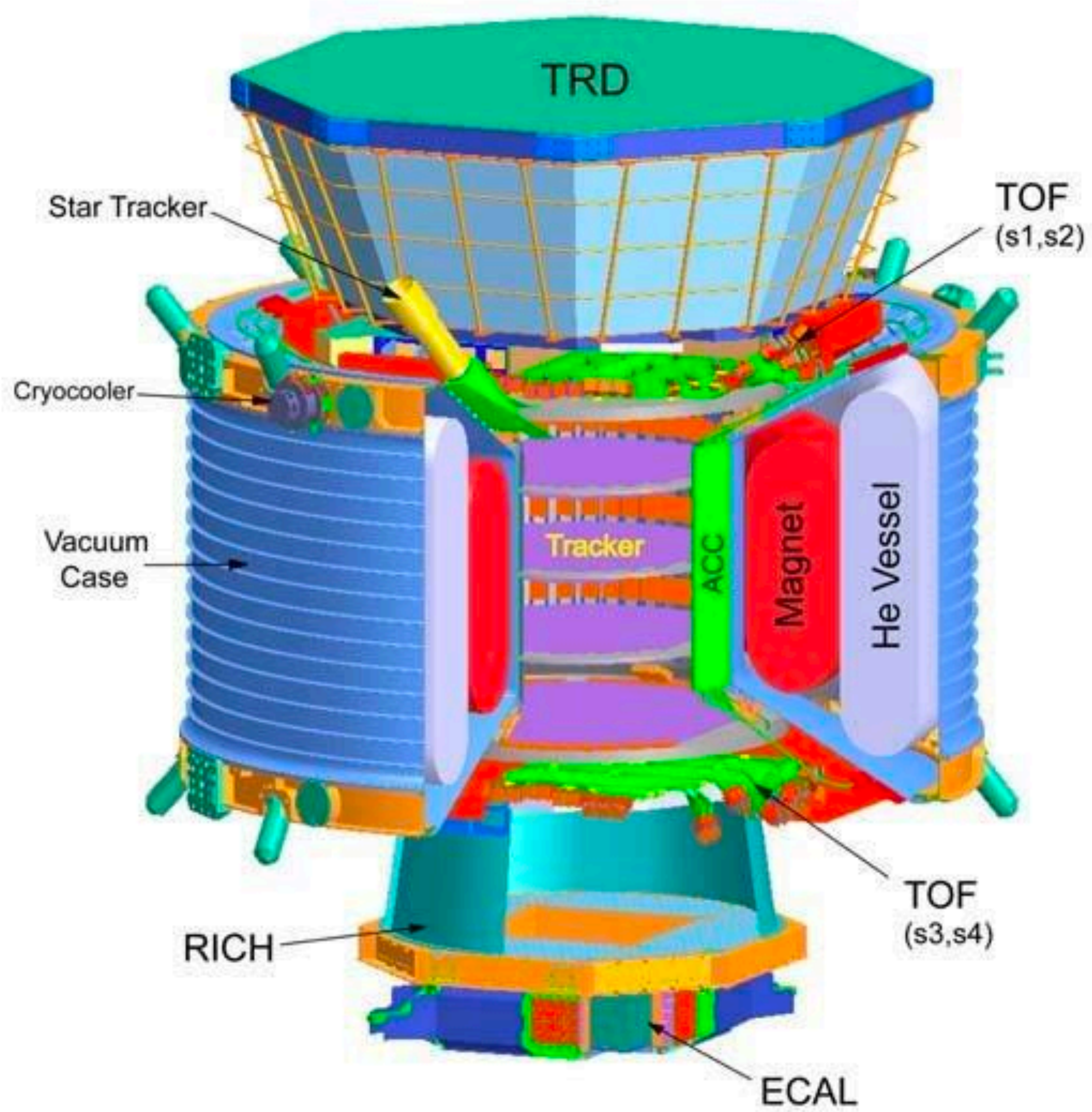

AMS-02

Scintillator Detector Systems - Applications

Nuclear and particle physics:

- Calorimetry
- Tracking
- Particle ID (Time of flight)

Astrophysics:

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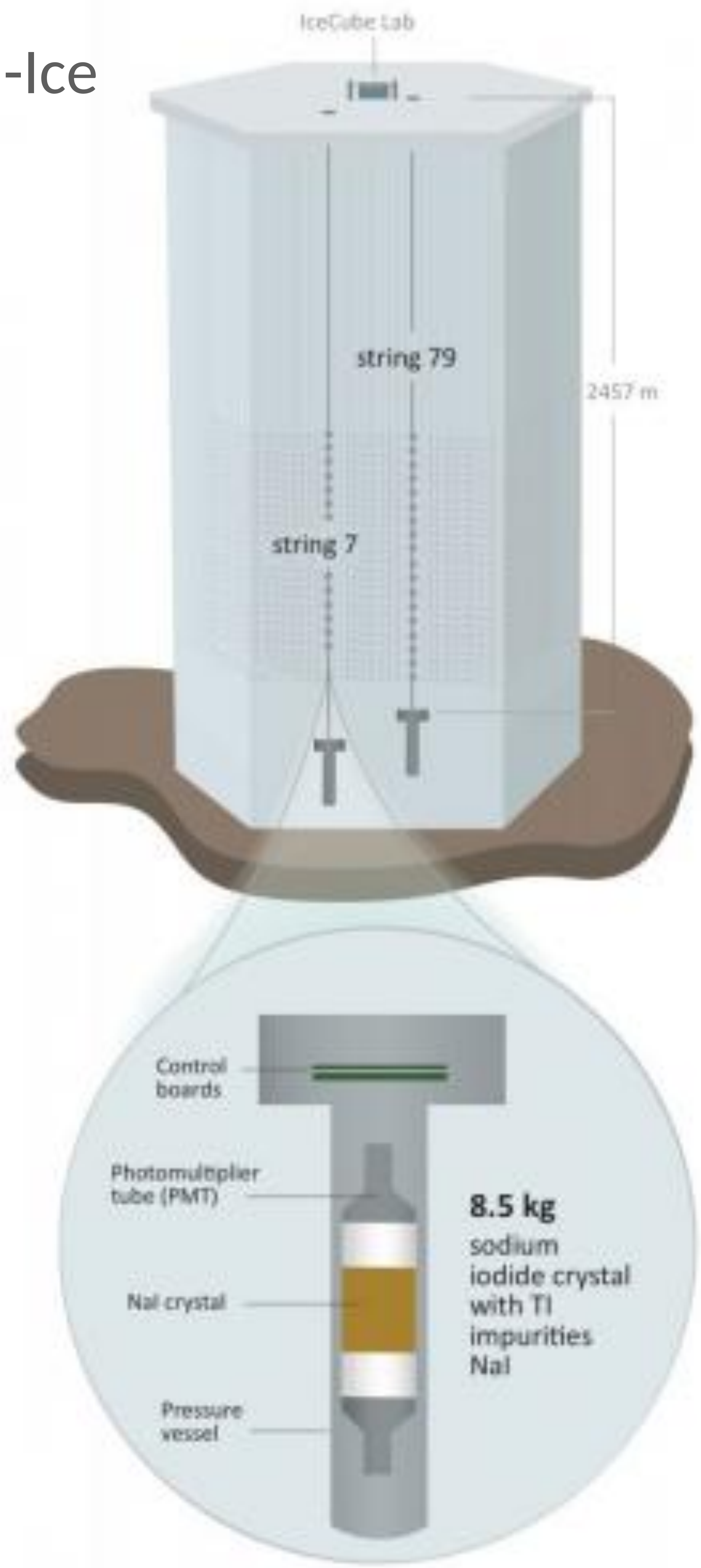
- PET

DM-Ice

High-purity NaI(Tl) crystals read-out by PMTs and deployed deep in the Antarctic ice sheet

Tl doping -> impurities on the crystal lattice that behave as activator sites for scintillation



Scintillator Detector Systems - Applications

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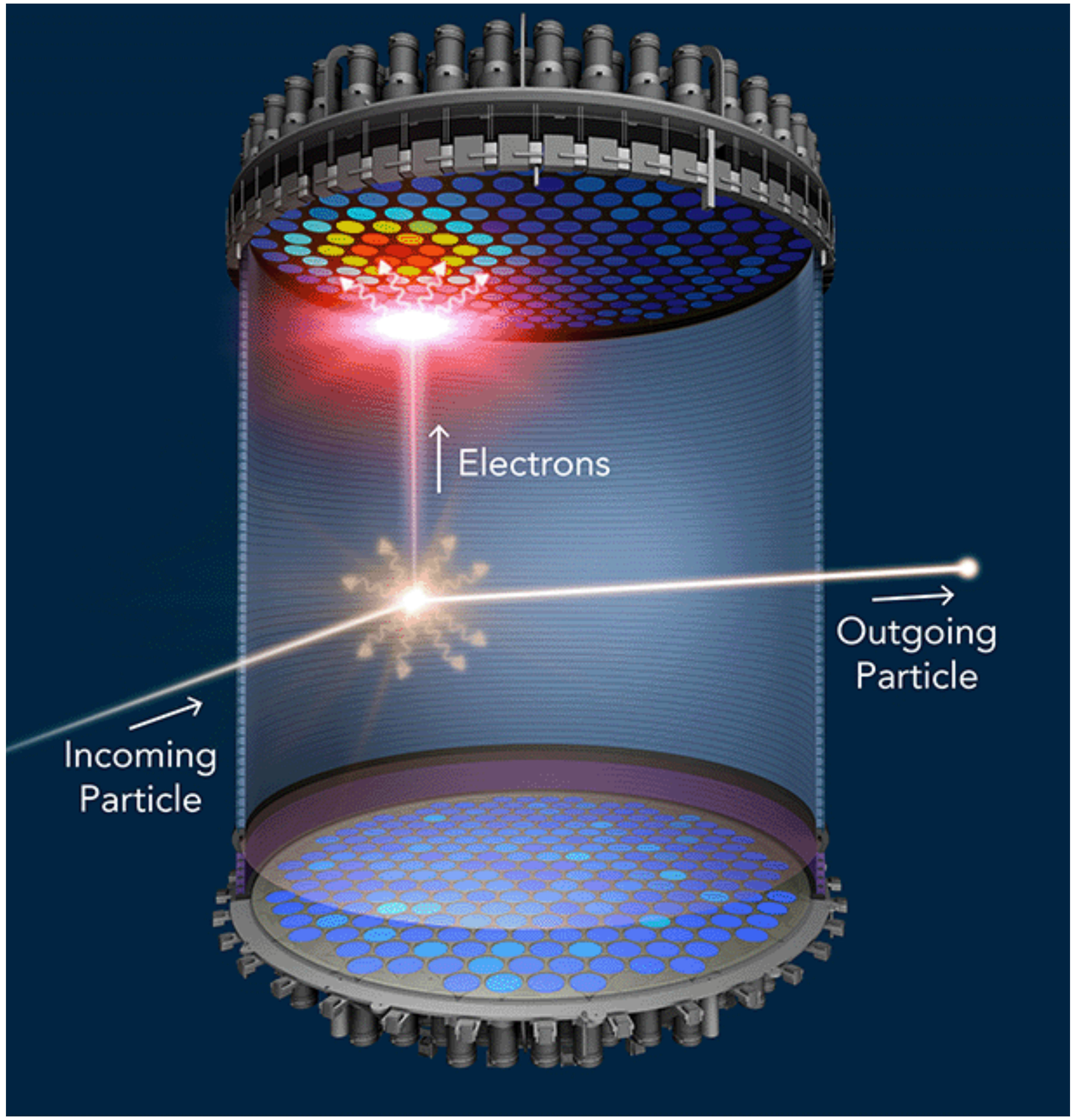
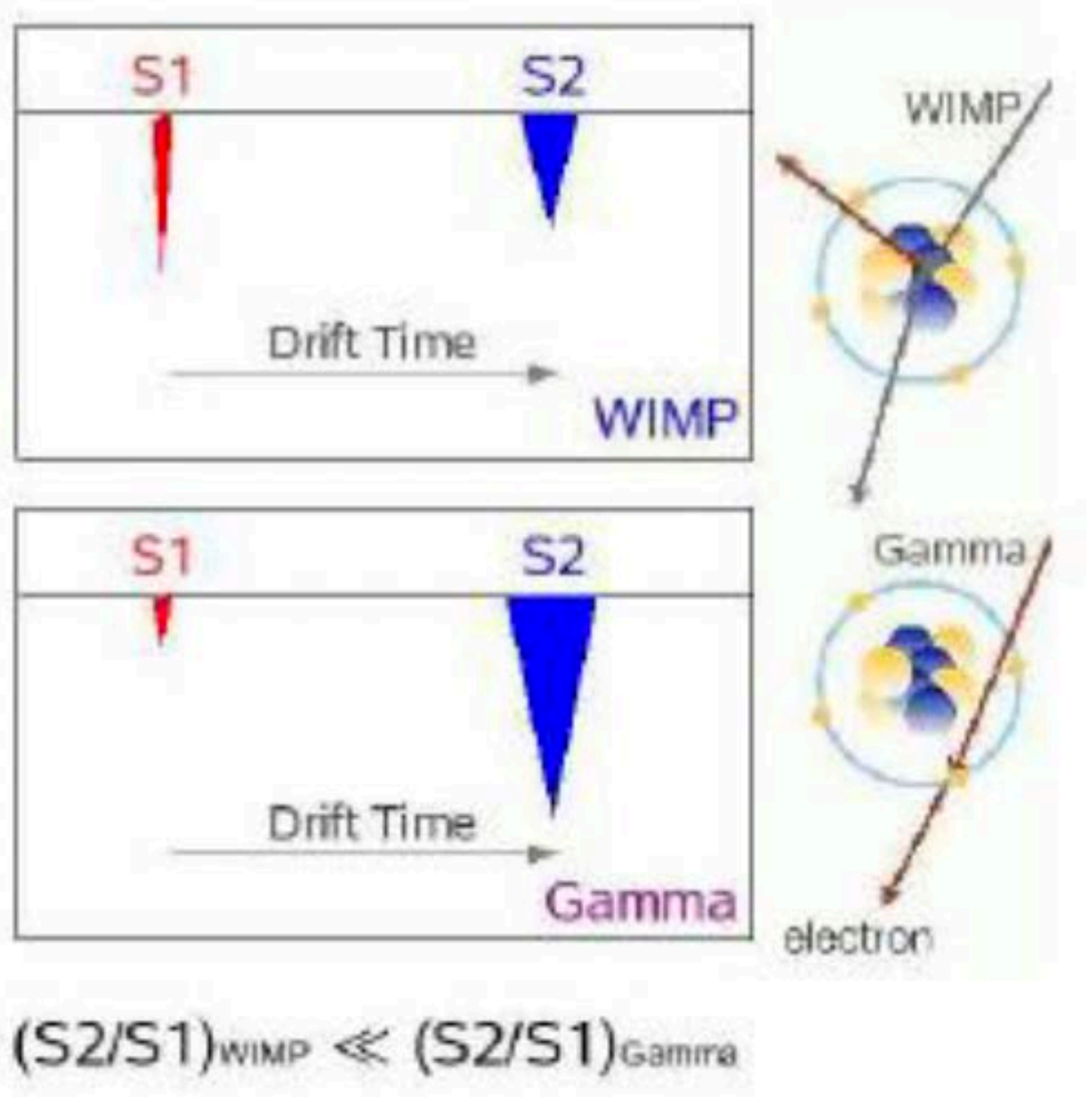


Dual-phase time projection chamber



$(S2/S1)_{WIMP} \ll (S2/S1)_{Gamma}$

WIMP interaction with nucleus -> nuclear recoil -> large scintillation signal in LXe, small ionization charge
Background (EM) interacts with electrons -> small scintillation signal, large charge
S1 = initial scintillation signal
S2 = ionization charge drifted to the gas phase via large elective field, amplified to produce 2nd delayed scintillation signal

Scintillator Detector Systems - Applications

Nuclear and particle physics:

- Calorimetry
- Tracking
- Particle ID (Time of flight)

Astrophysics:

- Dark Matter

Medical Imaging

- PET

XENON100, 62 kg

LUX, 375 kg

LZ, 10 ton

XLZD, 60–80 ton

* ask Thomas

Scintillator Detector Systems - Applications

Nuclear and particle physics:

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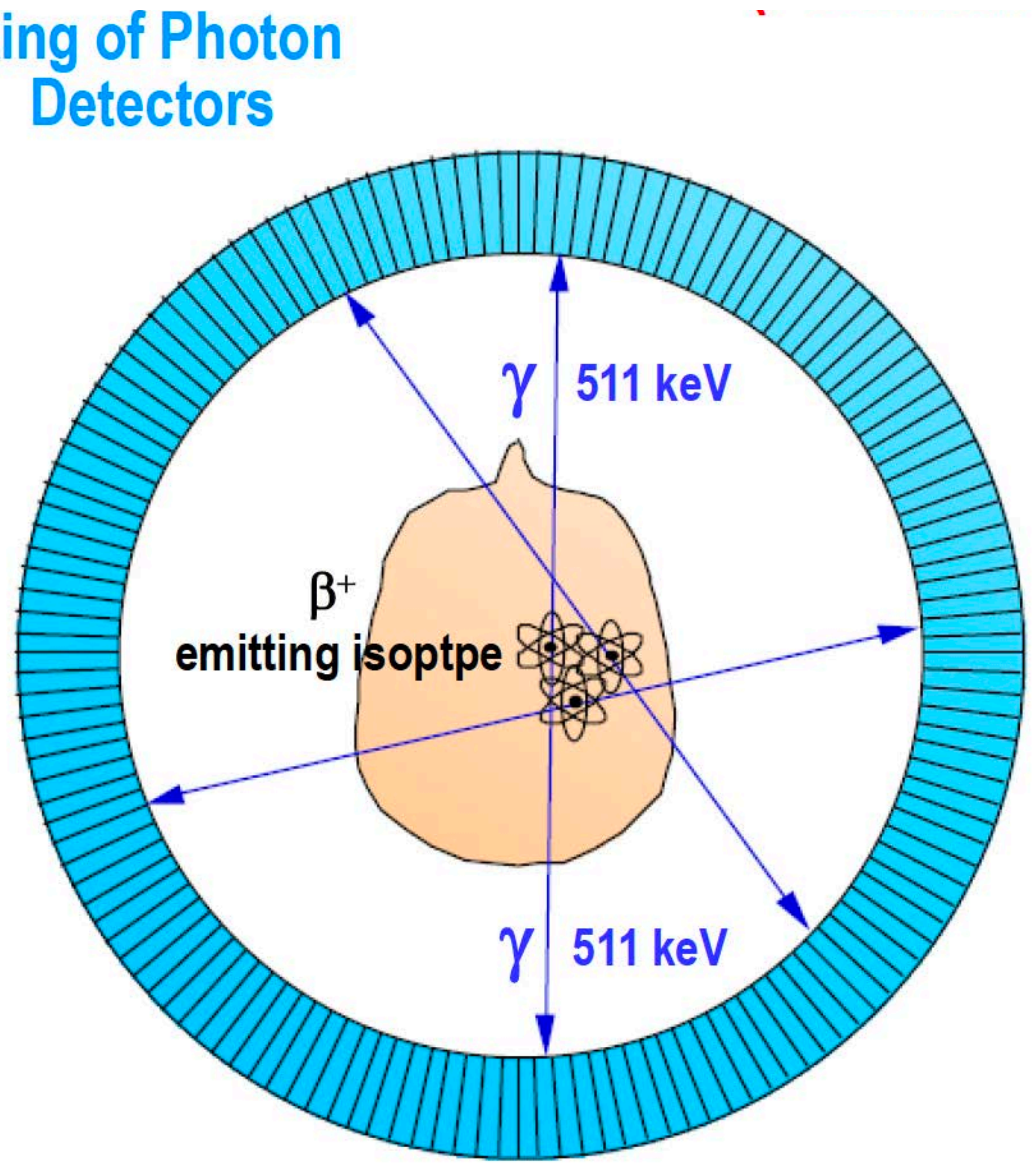
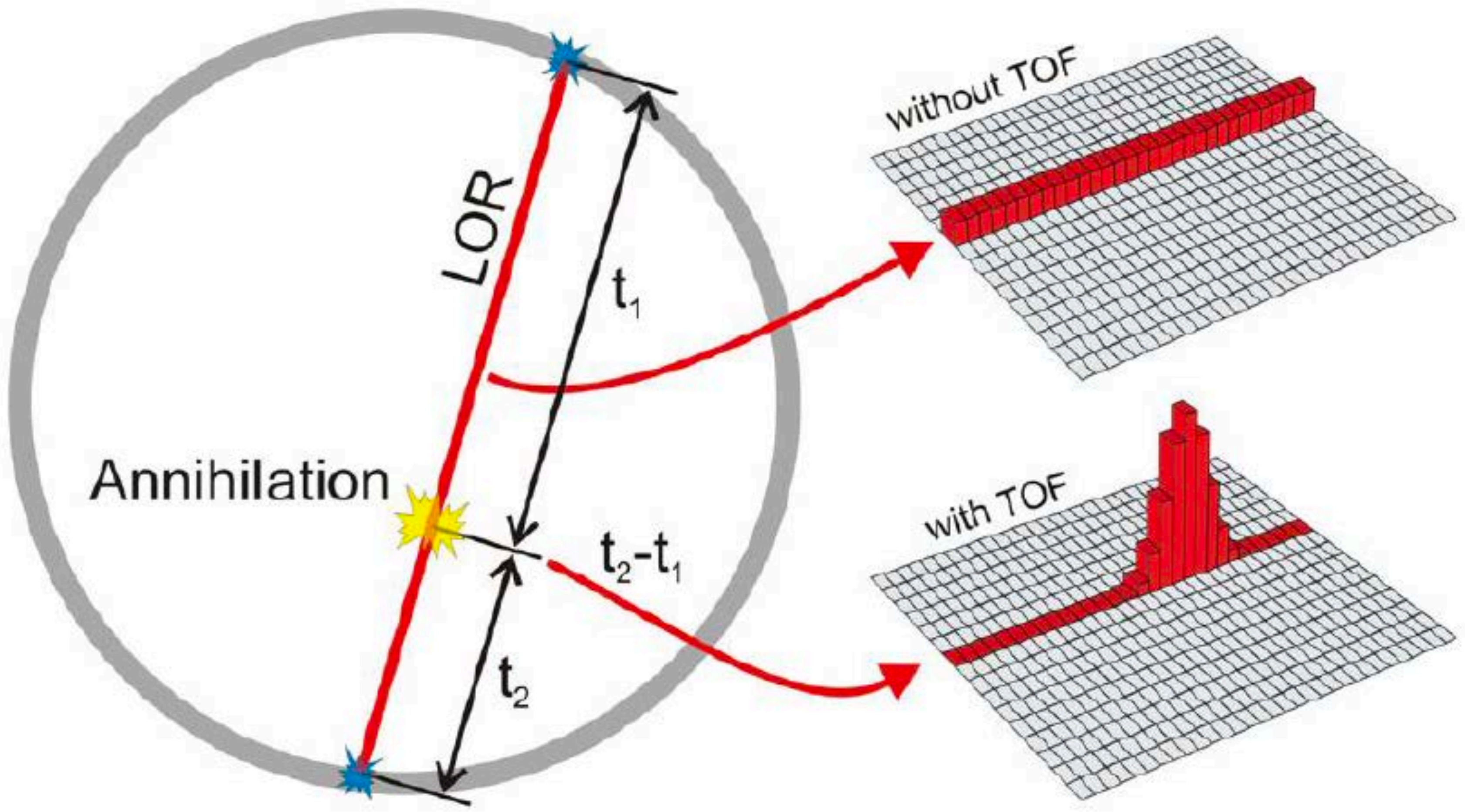
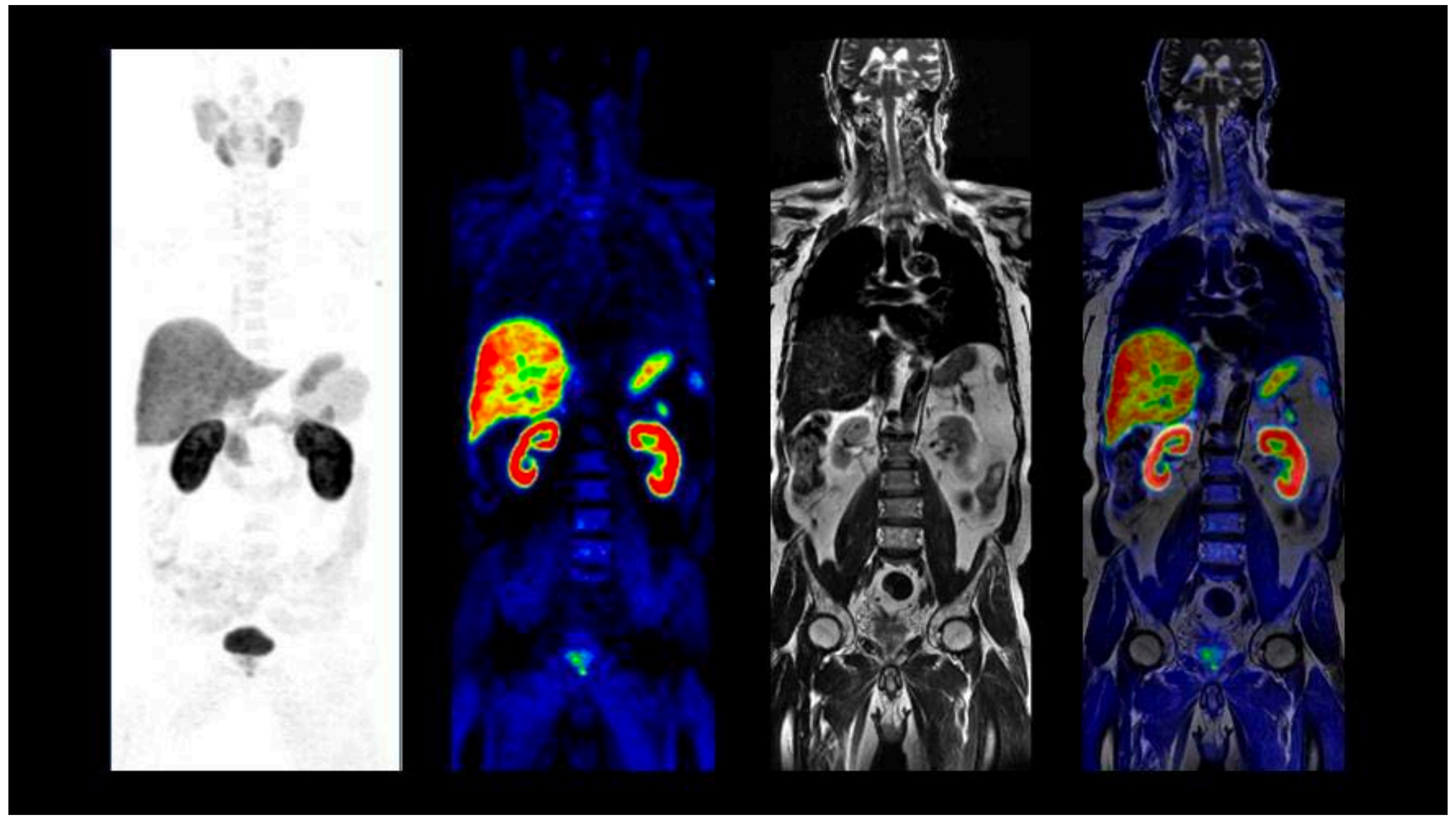


Figure courtesy of W.Moses





Timing is used to mitigate large random backgrounds
Requires fast, bright crystals

Reaching timing resolutions below 10 ps would improve image quality, reduce patient exposure and scan time (in particular for whole-body imaging).

σ_t < 100 ps
σ_E < 4% @ 511 keV

Summary

JUNO neutrino detector

Scintillators are an incredibly versatile particle detector medium

Adaptability provides opportunities for broad use across many areas

Photodetectors are a continuing area of exciting development

Detector design balances all of the factors that will impact performance:

- Interactions under observation
- Harmonizing the detector elements
- Optimizing signal to noise
- Geometry and scalability
- Environment
- …

Example - build your own at home - http://www.cosmicwatch.lns.mit.edu/

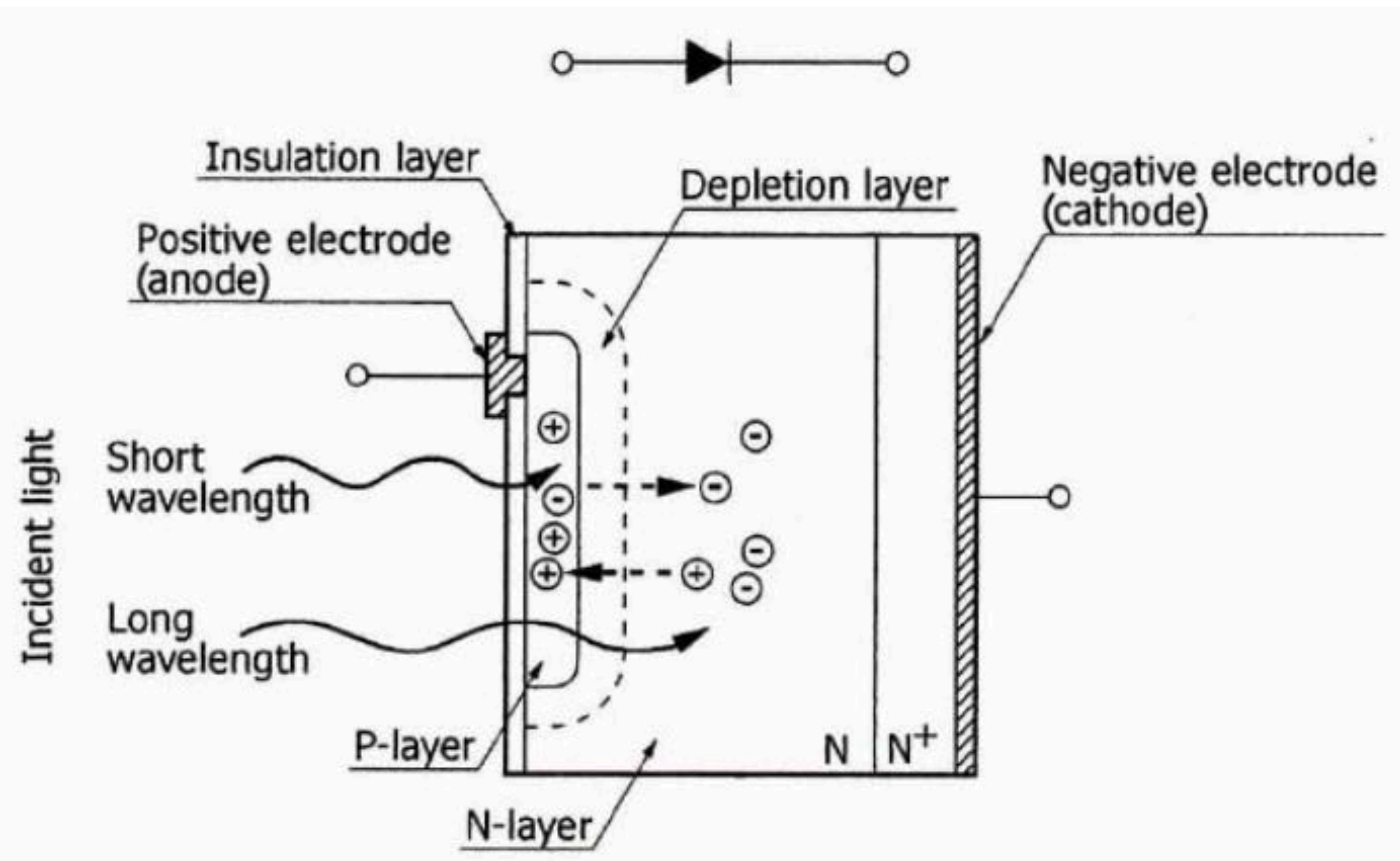
Backup slides

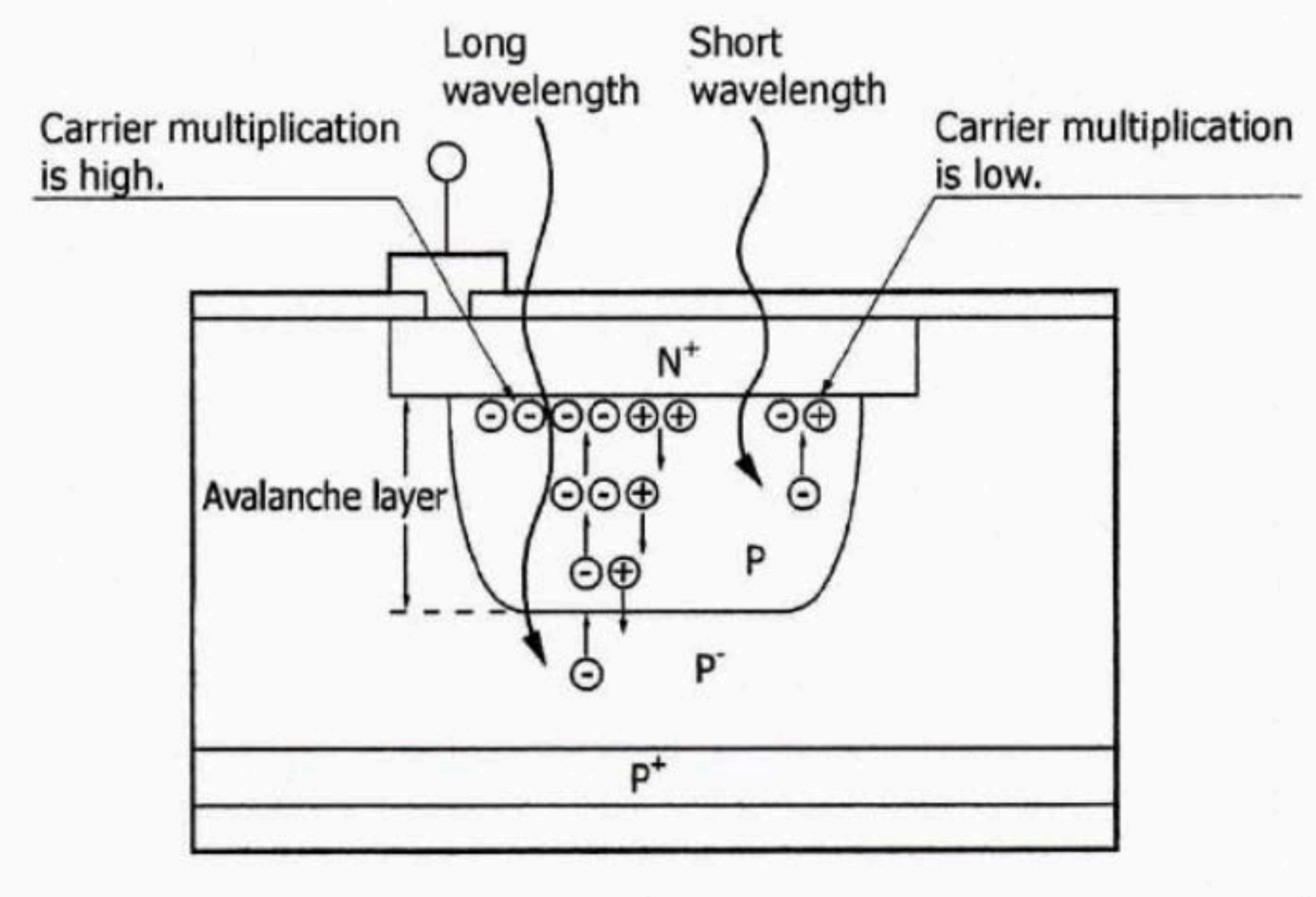
Photodetectors - Silicon (APDs)

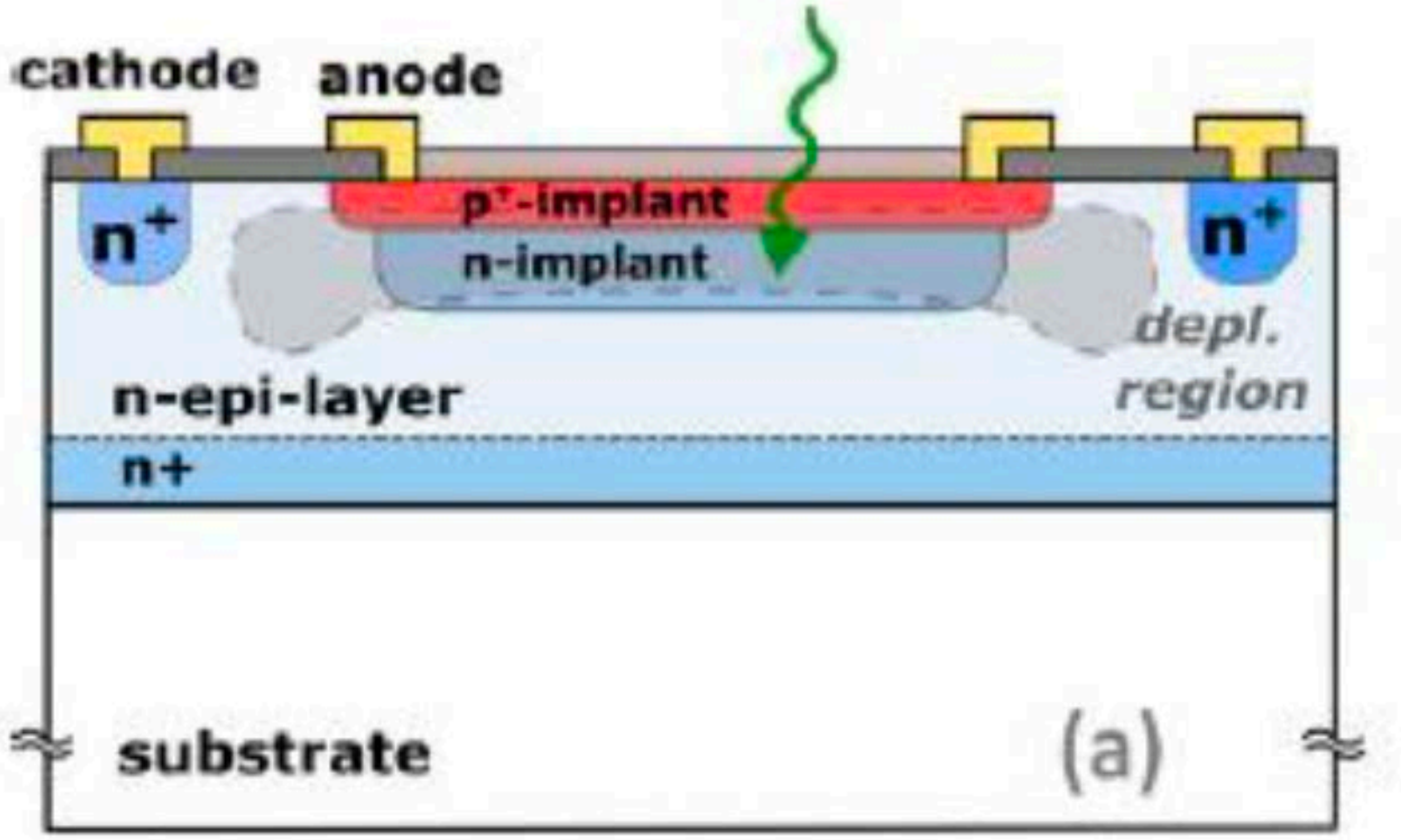
PIN photodiodes

Avalanche Photodiodes (APDs)

Geiger APDs (GAPDS)







Gain = 1
Linear output

Gain = 50 - 500
Bias voltage < Breakdown voltage
Linear output

Gain = 50 - 500
Bias voltage > breakdown voltage
“Quantized” output