UNIVERSIDAD
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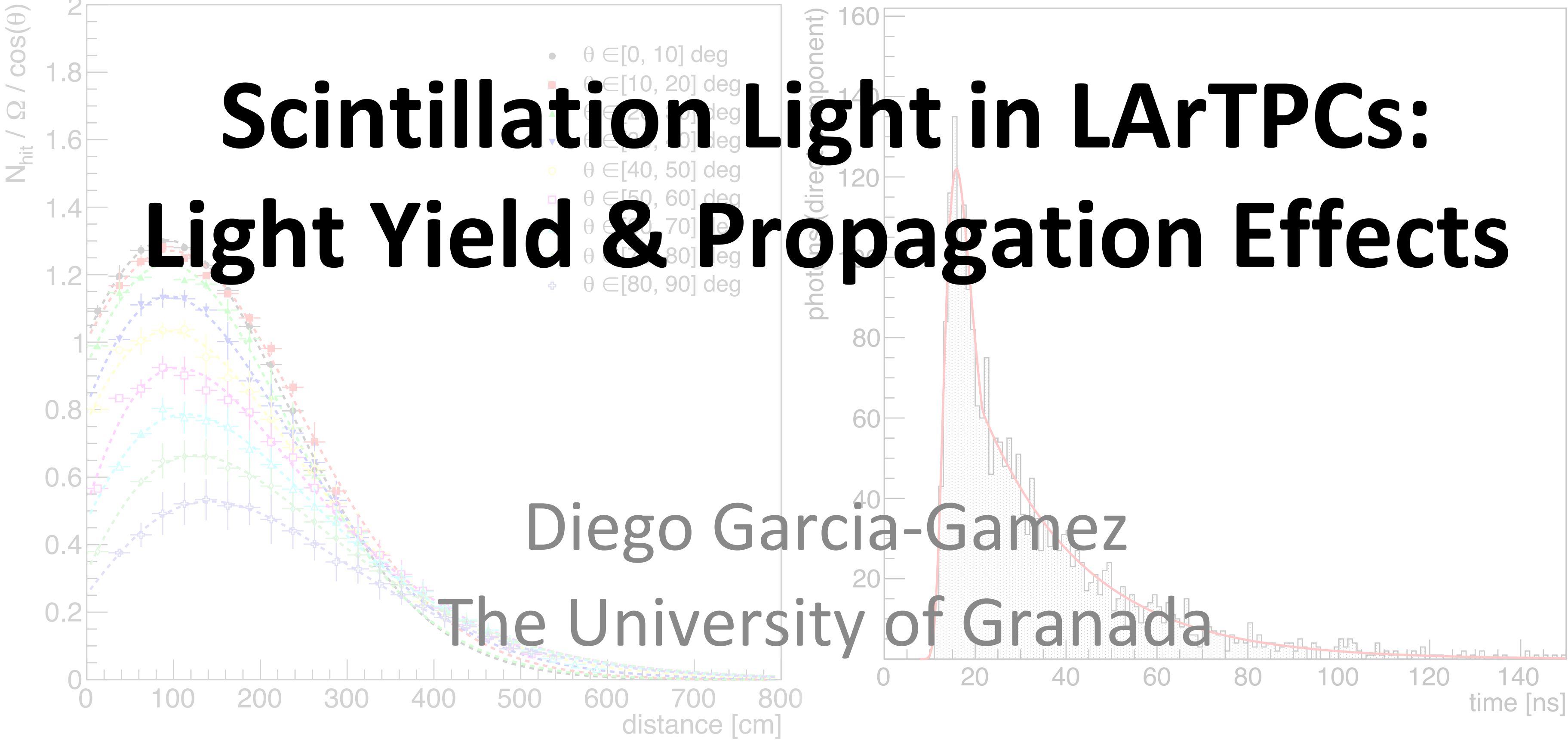
Scintillation Light in LArTPCs: Light Yield & Propagation Effects

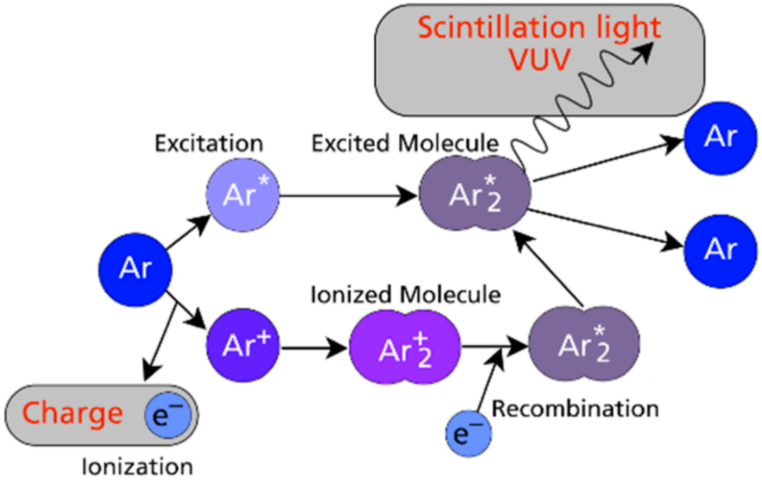


Diego Garcia-Gamez
The University of Granada

Outline

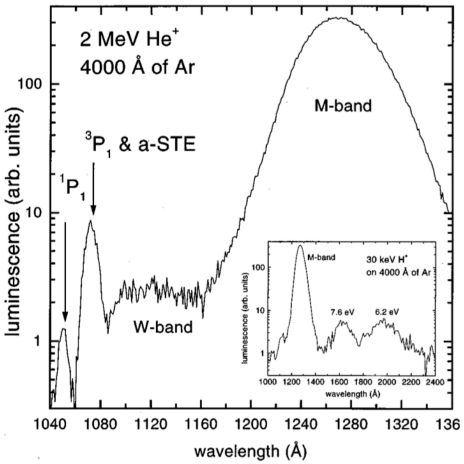
- Liquid argon scintillation light features
- Propagation effects in time and light yield
- Some examples for different detectors

LAr scintillation light features

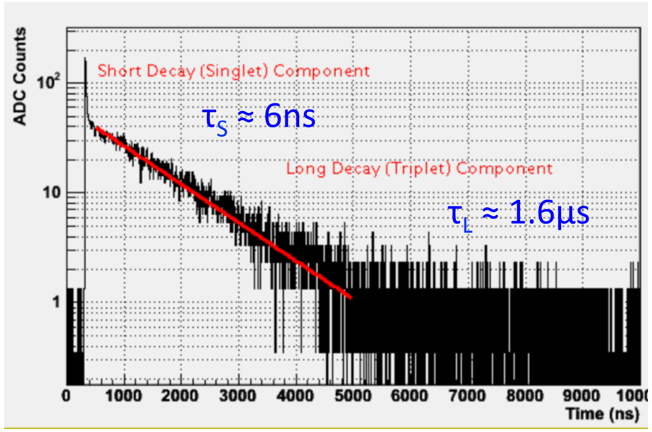


- In both ways, the Ar^*_2 should be de-excited to the dissociative ground state by emitting a UV photon
- The excimer states (excited structures with a short lifetime) formed in both cases are recognized to be singlet $^1\Sigma u$ and triplet $^3\Sigma u$ excimer states

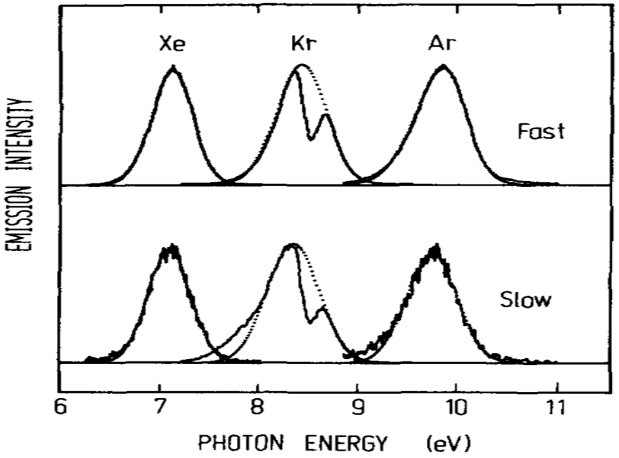
Ph. Rev. B 56 (1997), 6975



2010 JINST 5 P06003

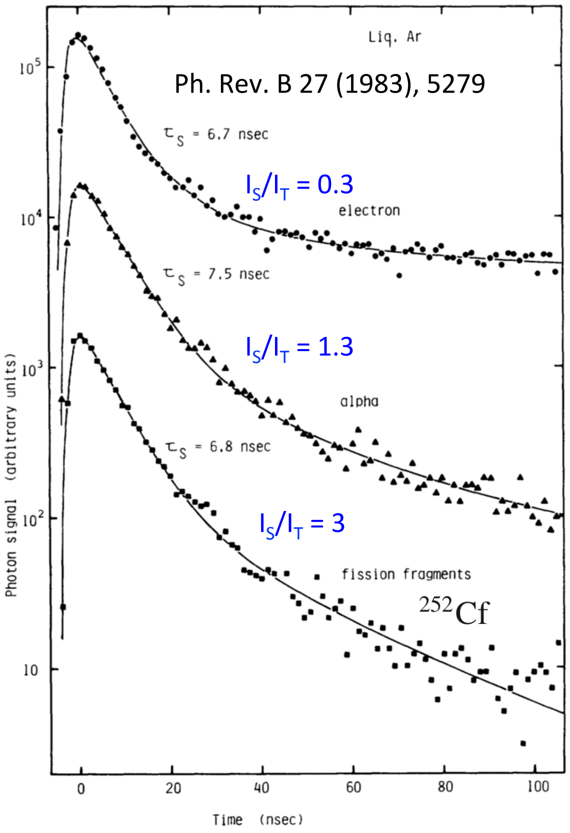


J Chem Phys vol 91 (1989) 1469



- Spectrum: Gaussian shape, peaking around λ=128 nm (FWHM ≈ 6 nm)
- Light emission exhibits double exponential decay characterized by two very different components
- Spectrum of both states basically coincide in width and wavelength

Scintillation time components & light yield



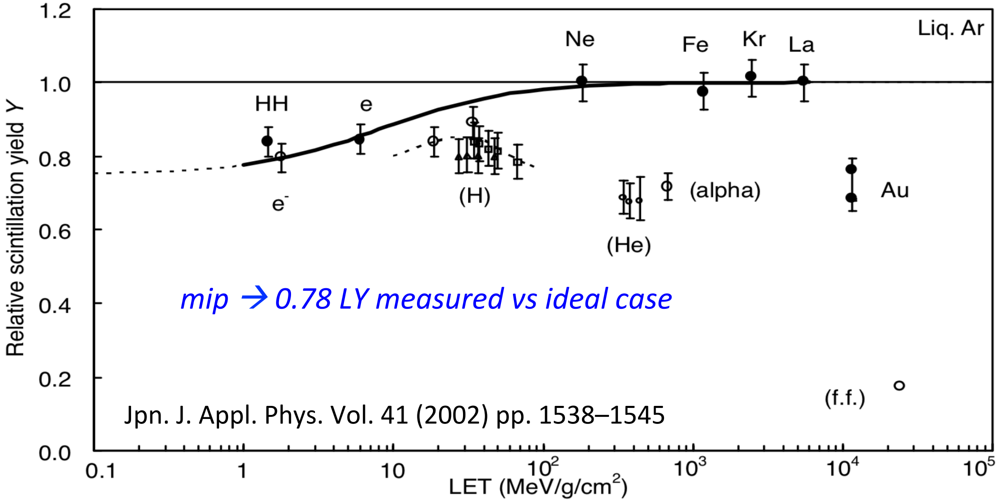
Ph. Rev. B 27 (1983), 5279

$I_S/I_T = 0.3$

$I_S/I_T = 1.3$

$I_S/I_T = 3$

- Time constants do not depend appreciable on the LET
- Light yield and fast/slow ratio depend on LET



mip → 0.78 LY measured vs ideal case

Jpn. J. Appl. Phys. Vol. 41 (2002) pp. 1538–1545

Relative to ideal case (response for relativistic heavy particles):

1. All the ions recombine
2. Each formed excimer produces one photon

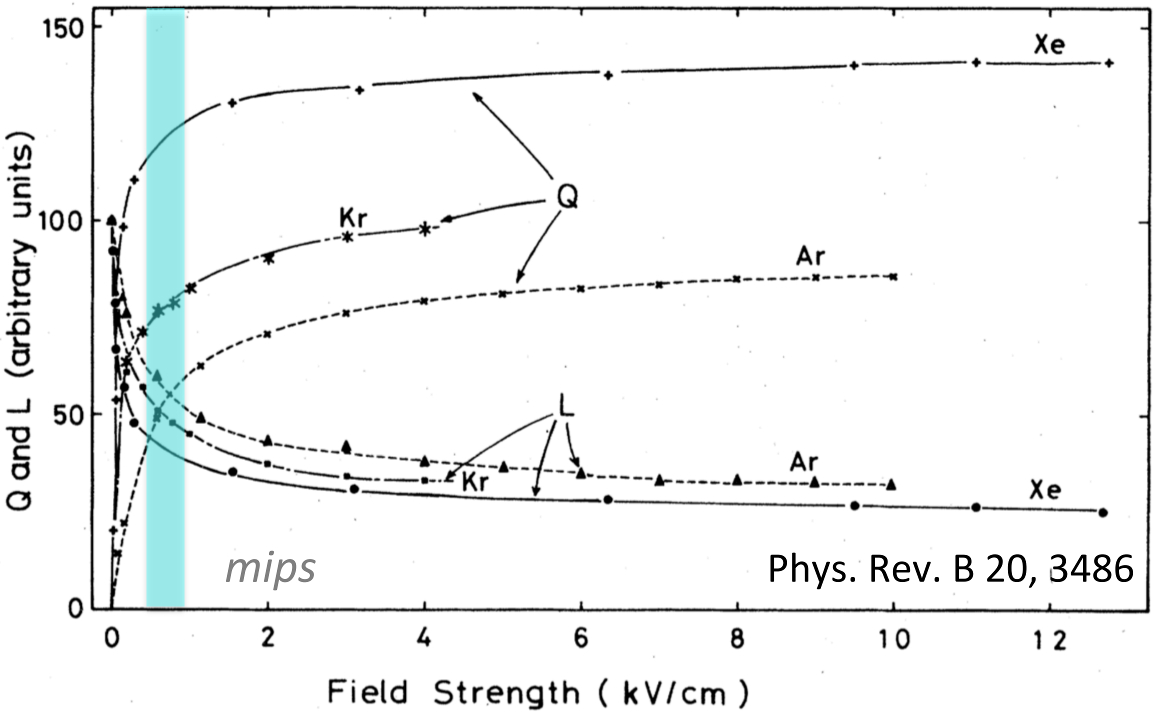
- The LET dependence of the relative scintillation yield in regions other than the flat top on the figure may be caused by

(i) the escape of electron from recombination (e^- beyond the Onsager radius)

(ii) the high density quenching of the scintillation photon ($Ar^* + Ar^* \rightarrow Ar + Ar^+ + e$)

Electric Field influence

- Electric Fields applied to the LAr medium also affect the intensity weights of the decay components



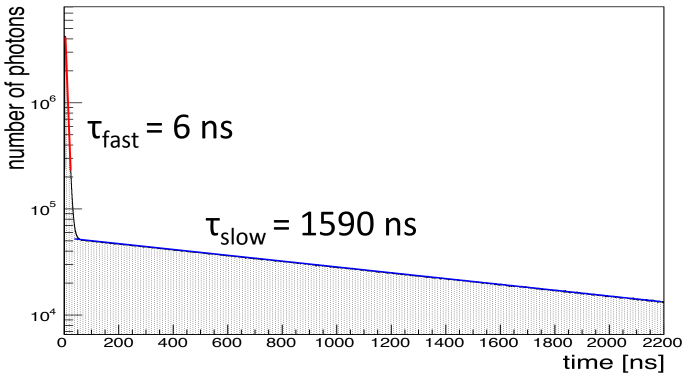
Phys. Rev. B 20, 3486

← Number of electrons (Q) and scintillation photons (L) per unit of absorbed energy vs electric field

- At high fields (e.g. EF≥ 15 kV/cm) the free-electron yield saturates and the scintillation intensity reaches a flat minimum

- The L minimum represents the field-independent contribution from decay of dimers formed by Ar* excited atoms, about 32% of the total light emitted at zero field for a *mip*)

Scintillation light propagation

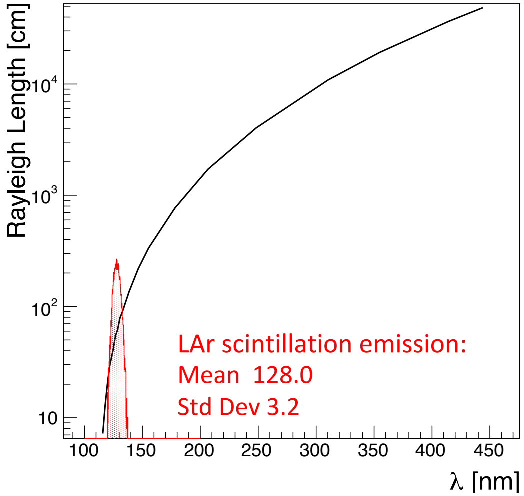


Summary @ emission:

- **dE/dx dependent scintillation yield**
- **dE/dx dependent intensity fast/slow ratio**
- **E-Field dependent scintillation yield**
- **Charge and light anti-correlation**

- Scintillation photons have energy lower than the first excited state of the Ar atom, therefore pure LAr is transparent to its own scintillation radiation
- However, during propagation through LAr VUV photons may undergo elastic interactions on Ar atoms → **Rayleigh scattering**

In LArSoft: Rayleigh scattering length @ 90K as a function of wavelength from arXiv:1502.04213



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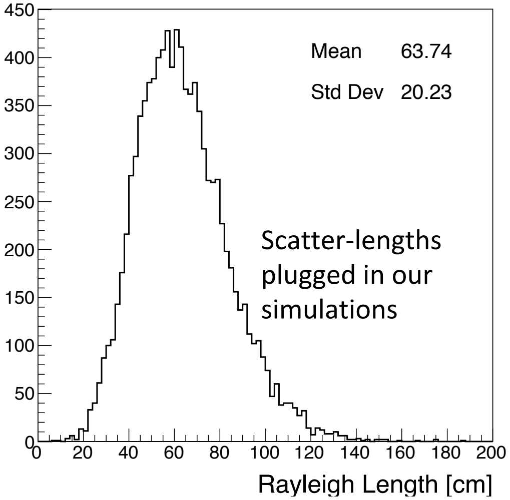
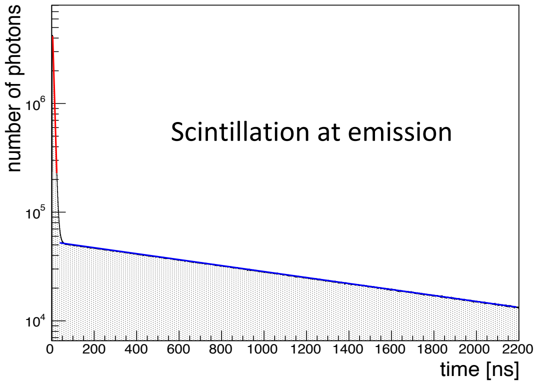


Scatter-lengths plugged in our simulations

Effects of propagation in time and LY

- Rayleigh Scattering affects, in a non negligible way, the light signals in our detectors in comparison with the “pure” emitted scintillation light

Arrival time distribution:



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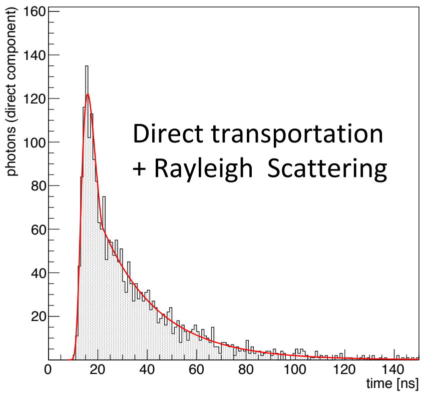

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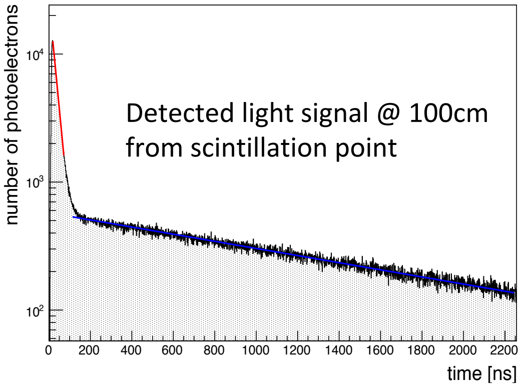
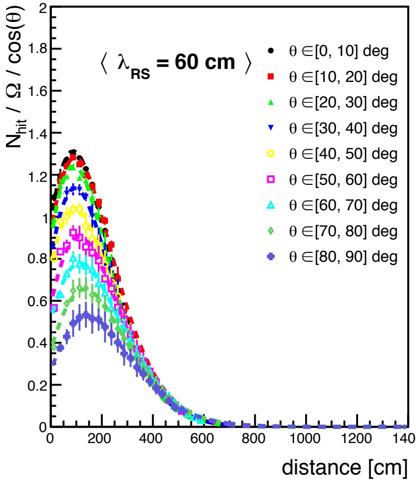
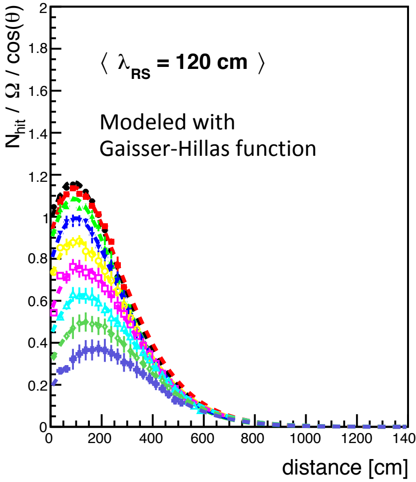
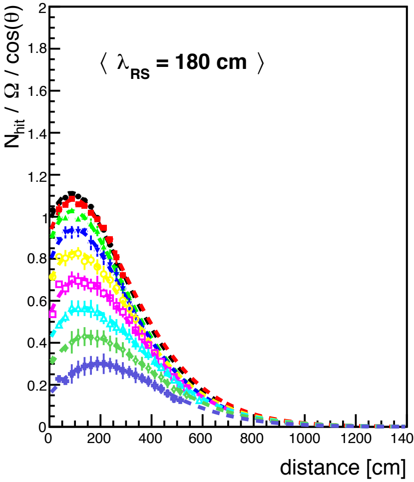


Light Yield:





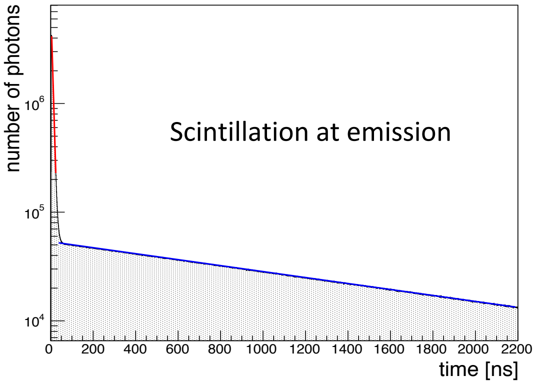


- It is important to understand/model it properly in liquid argon
- It depends on the Rayleigh scattering length

Effects of propagation in time and LY

- Rayleigh Scattering affects, in a non negligible way, the light signals in our detectors in comparison with the “pure” emitted scintillation light

Arrival time distribution:



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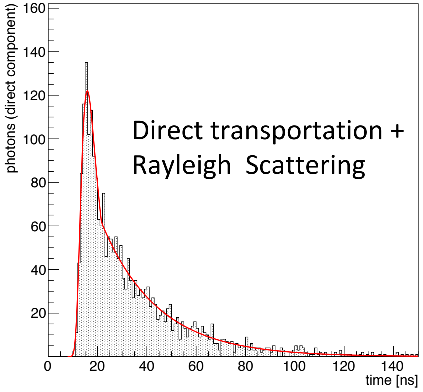

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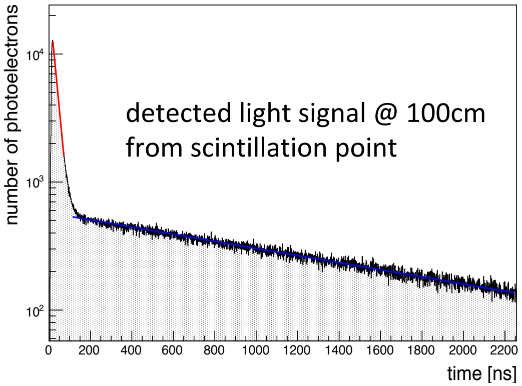
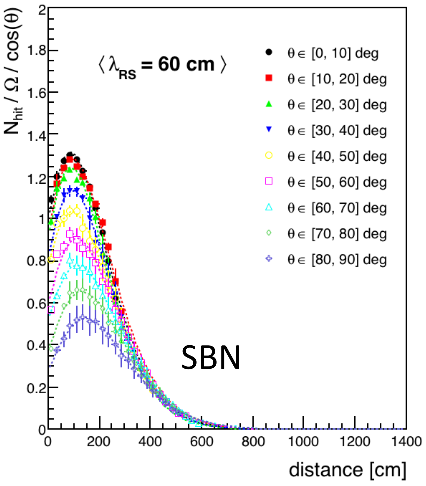
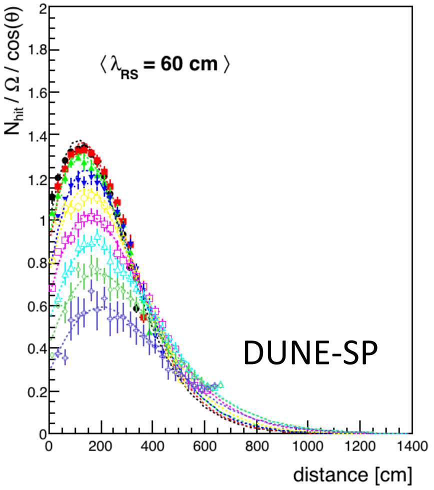
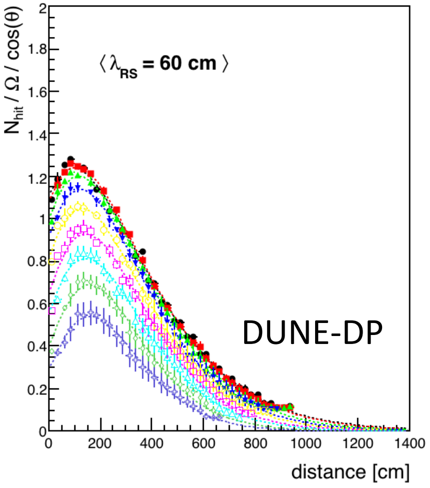


Light Yield:

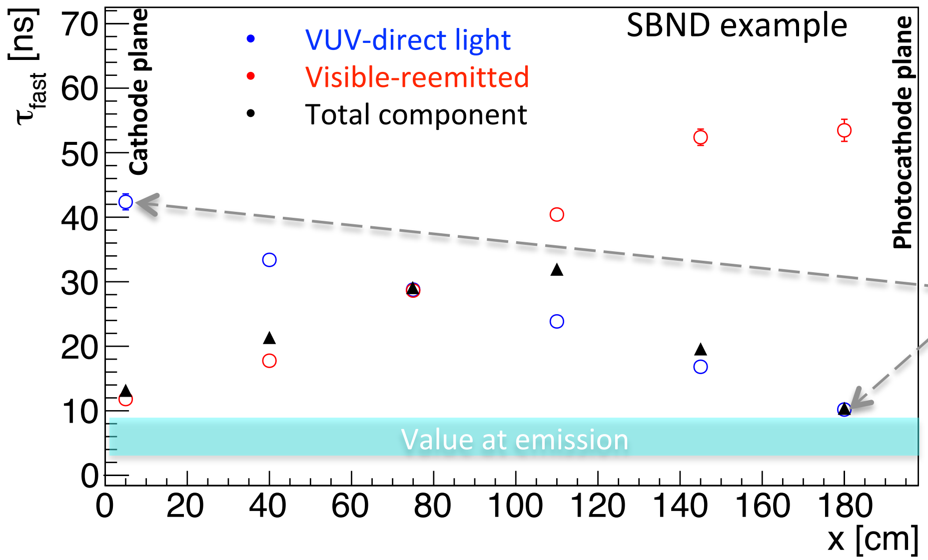


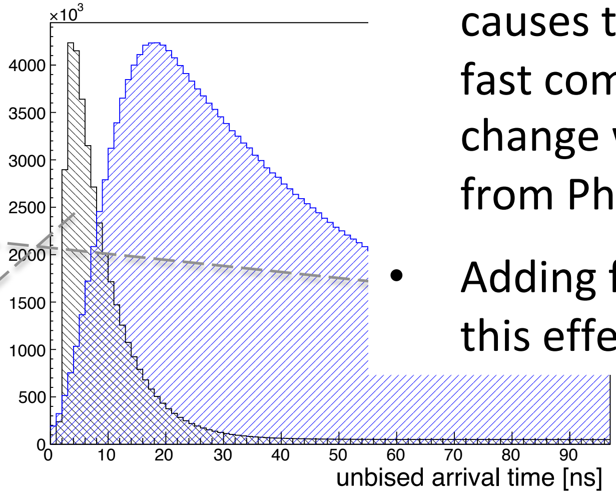




- It depends on the detector size

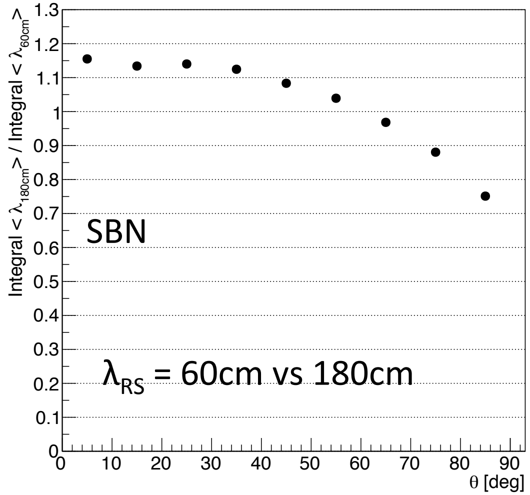
Quantifying these effects

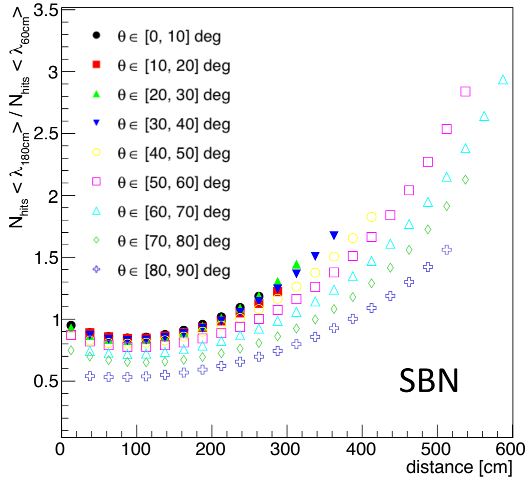




- Rayleigh scattering causes the "effective" fast component to change with distance from Photon-detectors
- Adding foils mitigates this effect

- That leads to the trigger efficiency differing with distance
- Rayleigh scattering length also affects the light yield: dependence on distance and offset angle





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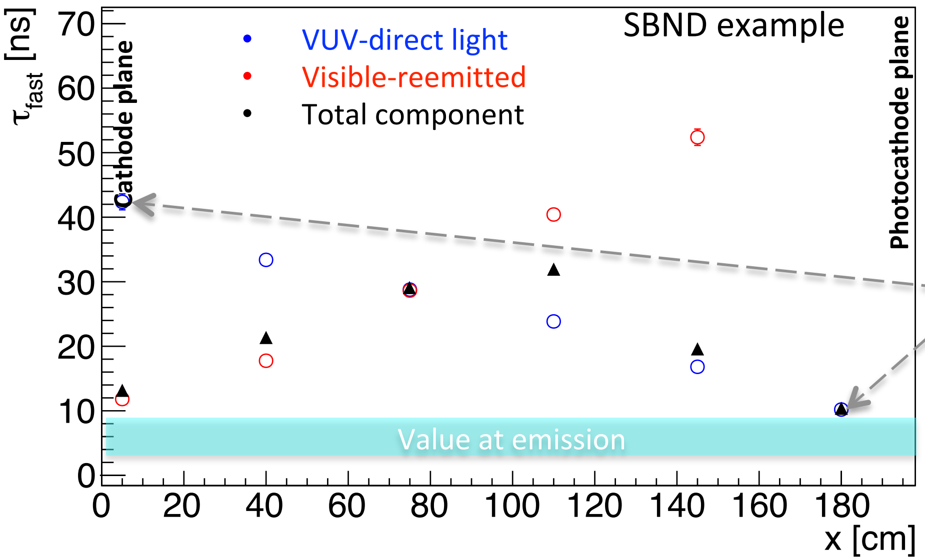

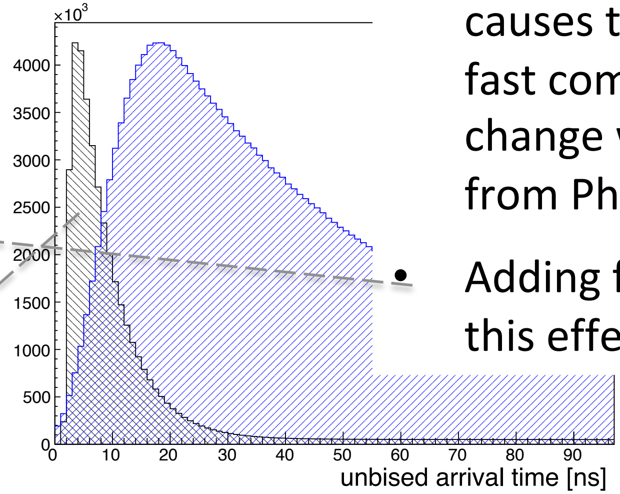

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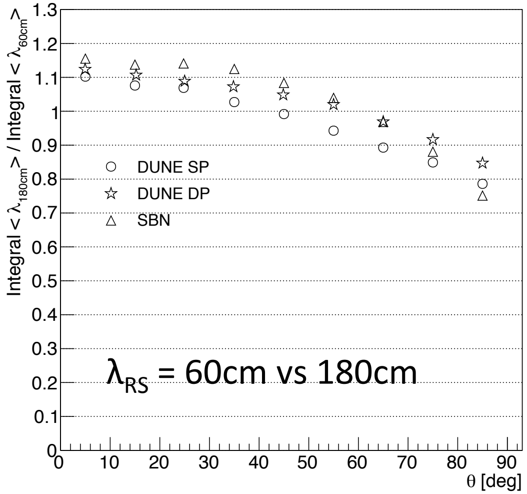
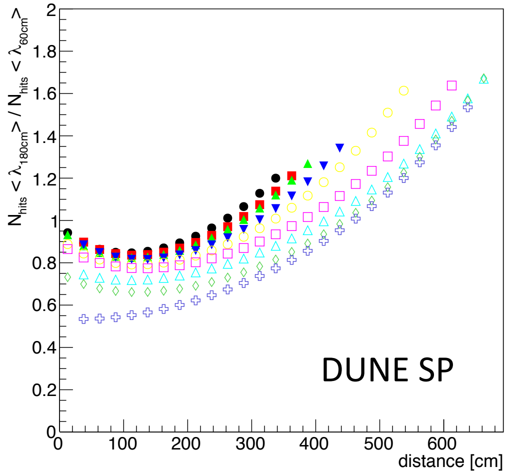
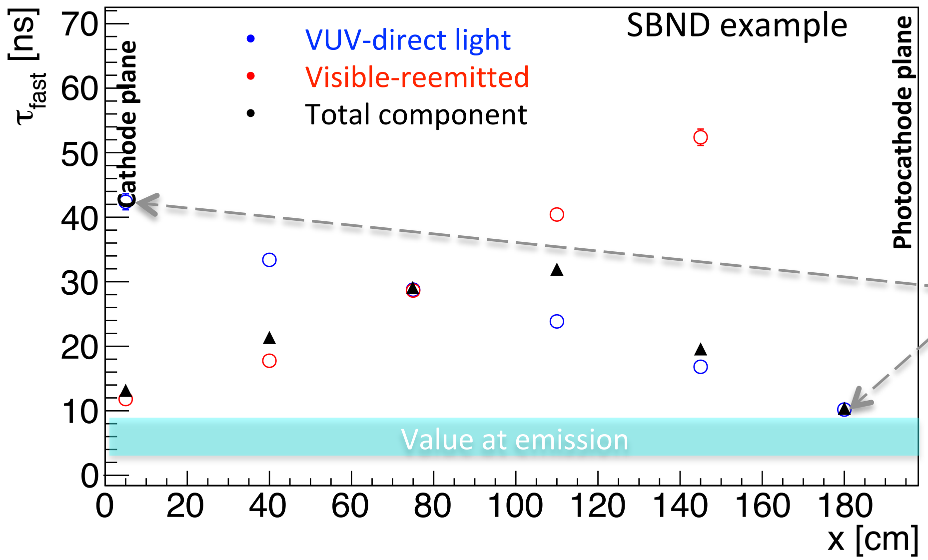
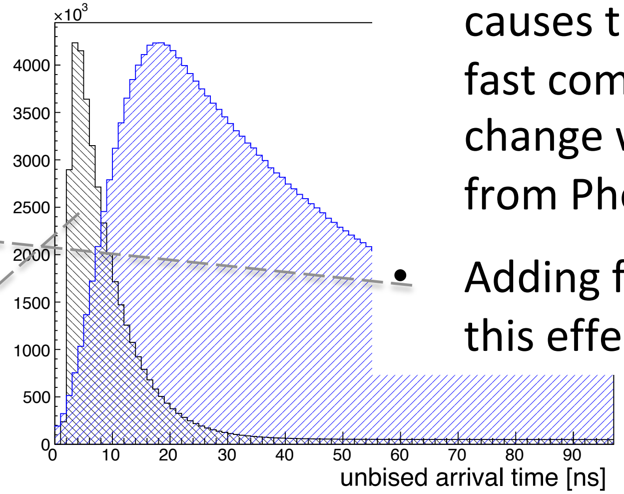




Quantifying these effects





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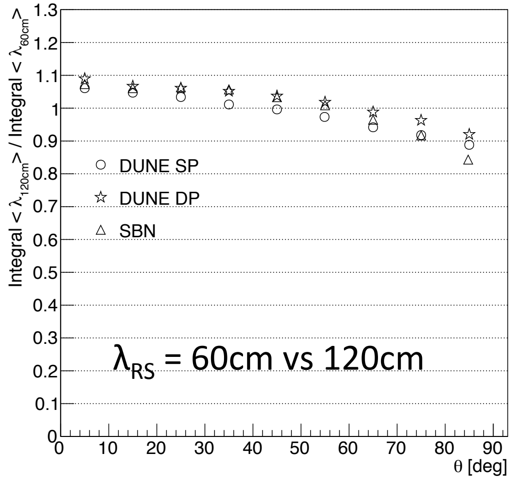
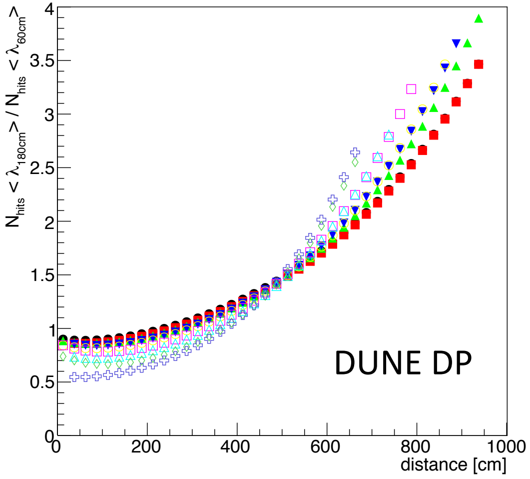
- Adding foils mitigates this effect

- That leads to the trigger efficiency differing with distance

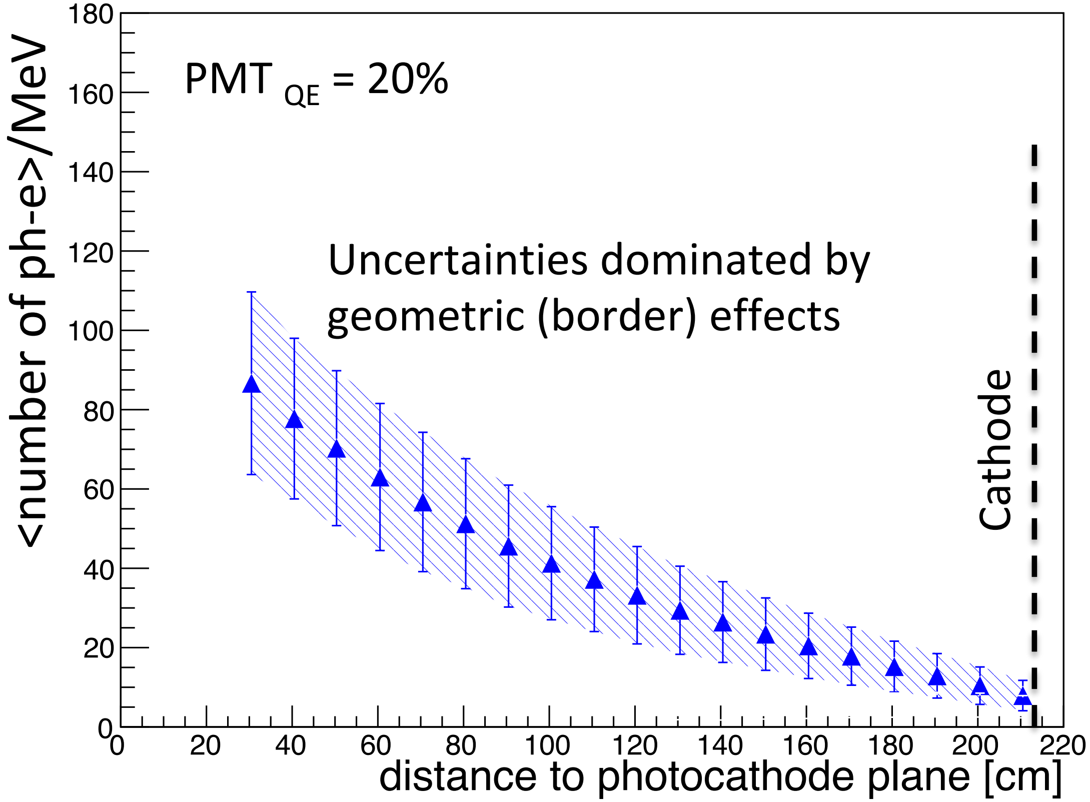
- Rayleigh scattering length also affects the light yield: dependence on distance and offset angle

→ Wrong assumptions of λ_{RS} can result in big differences in LY





Light Yield vs distance for different detectors (I)



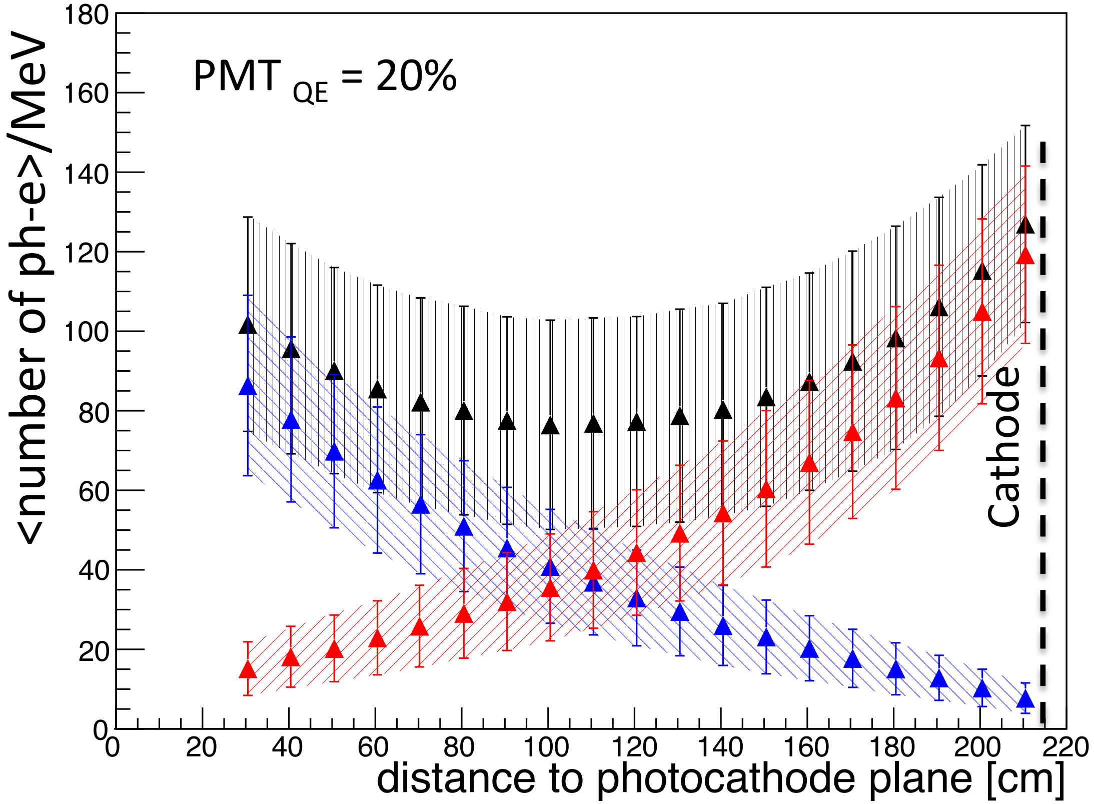
Scintillation points generated randomly in the active volume at different fixed drift distances

- VUV-direct light

← SBND case example (similar trend for other detectors)

Strong dependency of the light yield with the position (here drift distance) in the detector

Light Yield vs distance for different detectors (II)



Scintillation points generated randomly in the active volume at different fixed drift distances

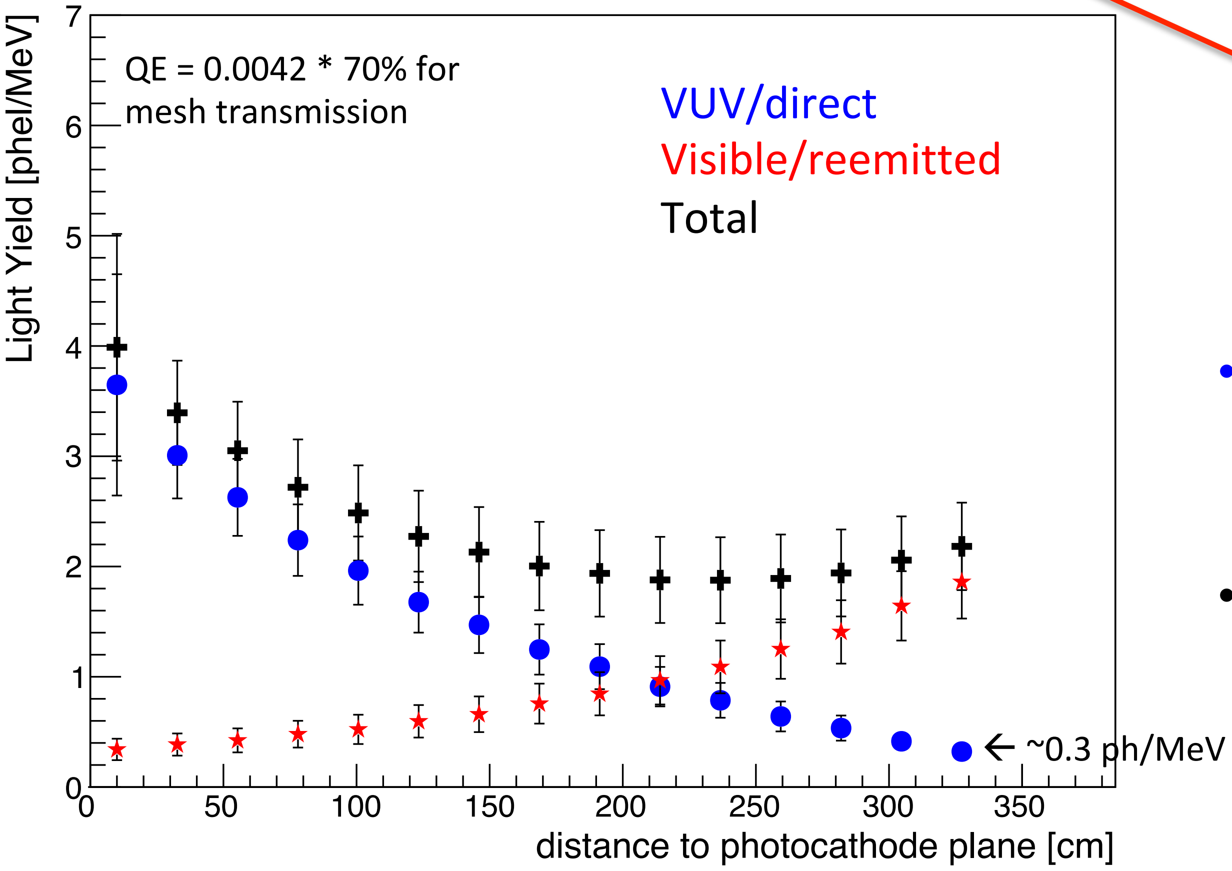
- VUV-direct light
- Visible-reemitted
- Total component

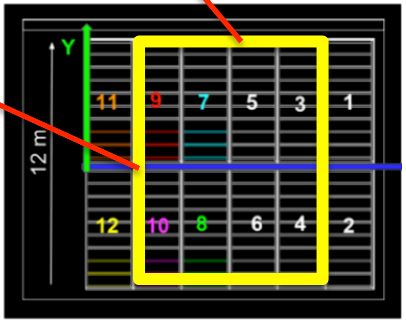
- More uniform light collection
- Improvement of the collection efficiency

Will lower the reconstruction threshold

Light Yield vs distance for different detectors (III)

Toy MC: 500 MeV point-like sources randomly generated at different distances from the photocathode plane y/cm = [-600,600] and z/cm = [300,1000]

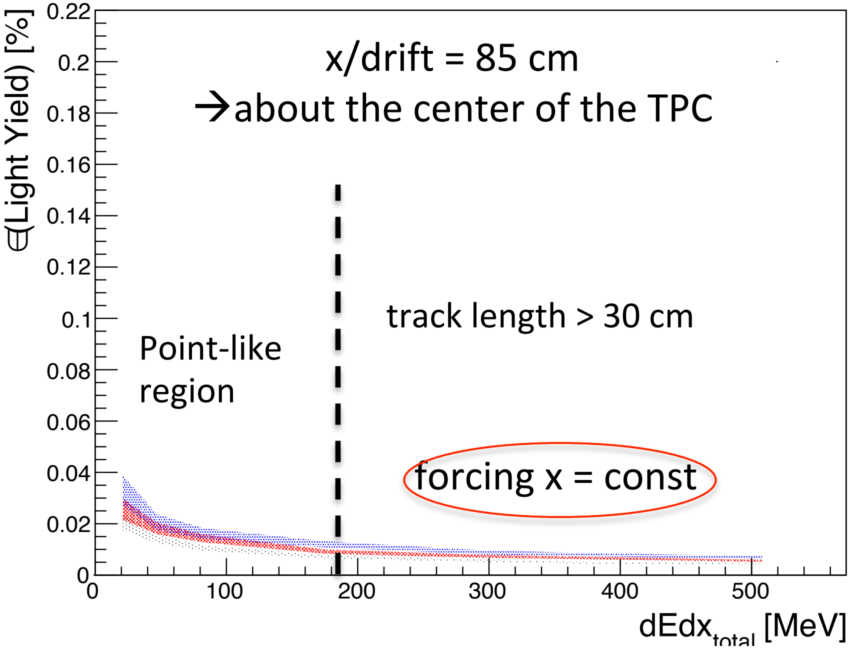


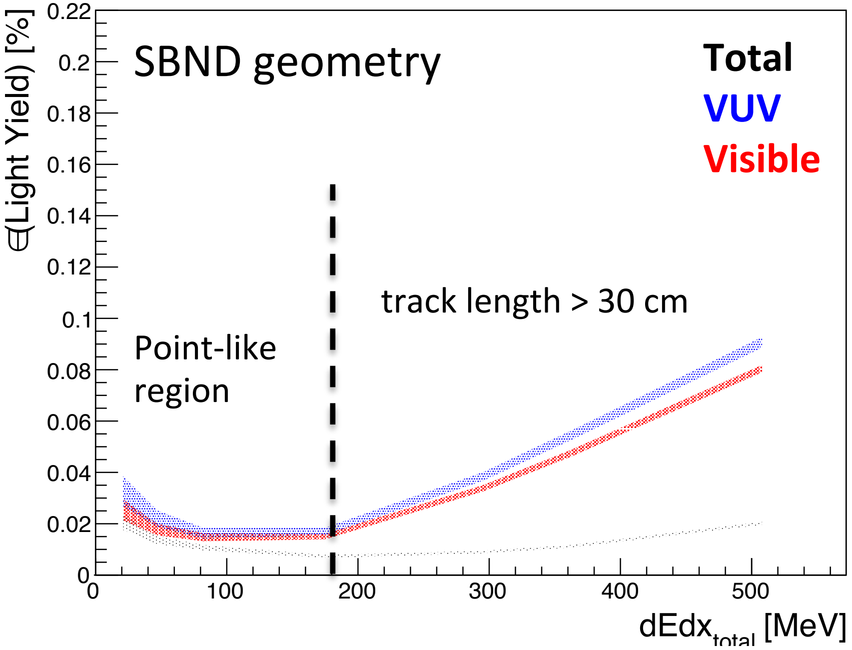


- **Assuming same efficiency for both components (needs to be investigated)**
- Attenuation on the bars also included (global effect ~0.46 light attenuation)

Effects of Light yield in Calorimetry

- The combination of charge and light information give a more compensating LAr calorimeter:
  - ➢ Can suppress fluctuations in the unavoidable recombination process
  - ➢ Responding in a more similar way to particles depositing different ionization densities
- <u>But uniformity is very important</u>





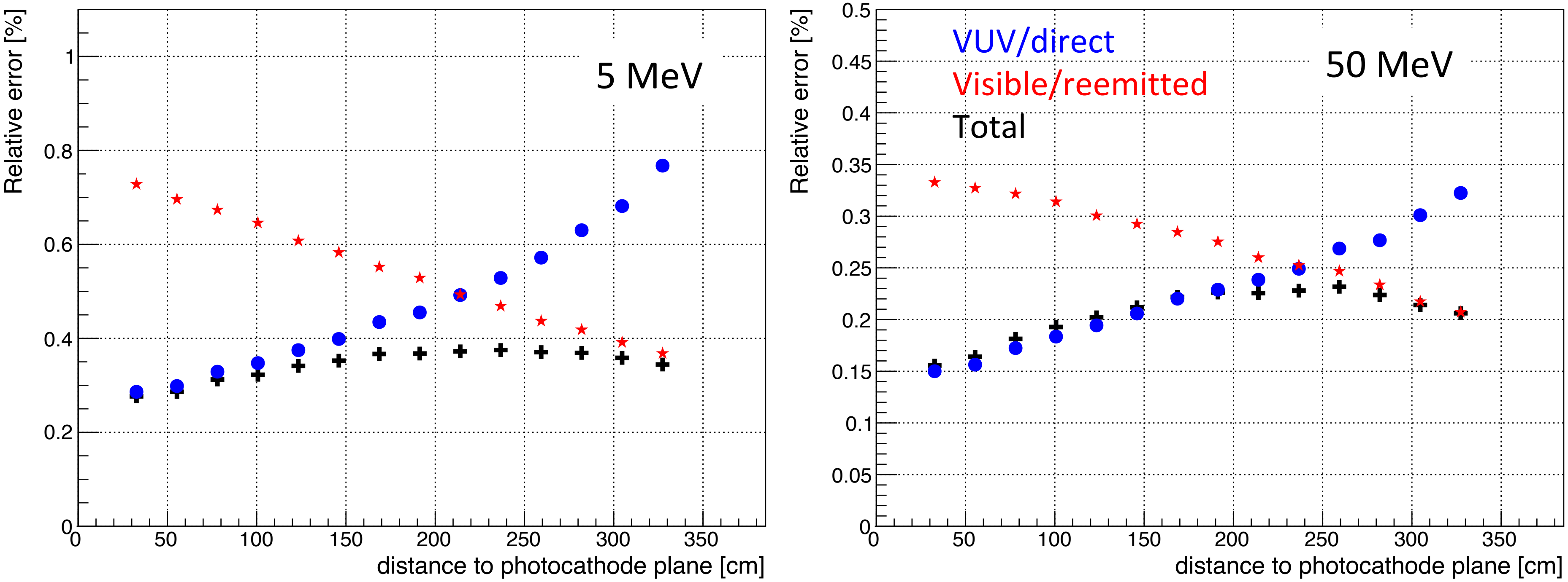
- Light yield uniformity crucial for a good calorimetric resolution

Calorimetry (DUNE example)

Toy MC: point-like sources randomly generated at different distances from the photocathode plane and y/cm = [-600,600] and z/cm = [500,1000]

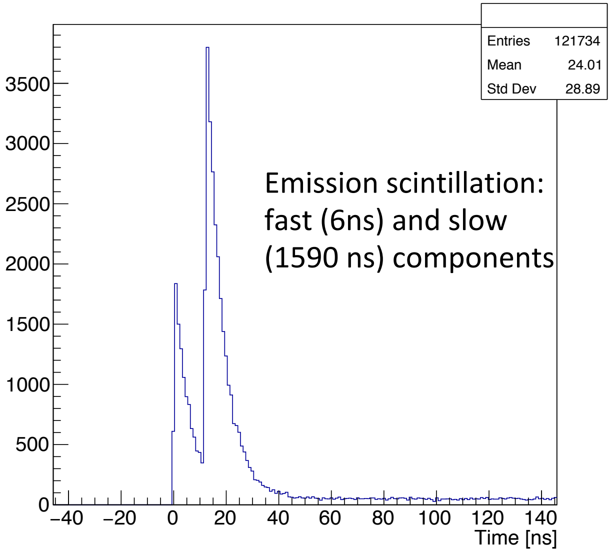
High LY makes a big difference for low energy events

Supernova like events

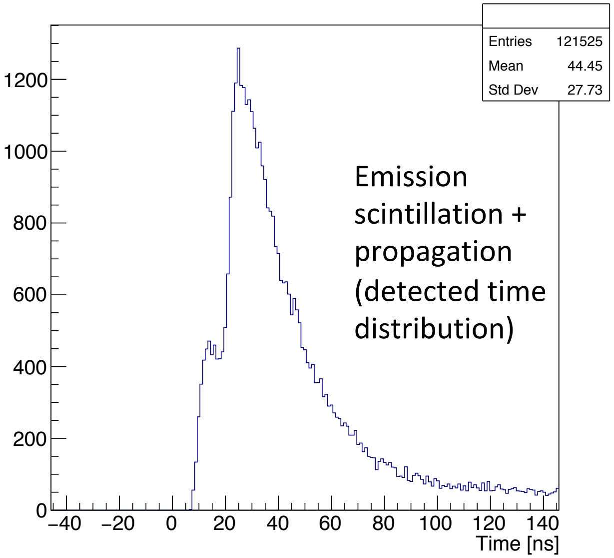


p → K + ν with light?

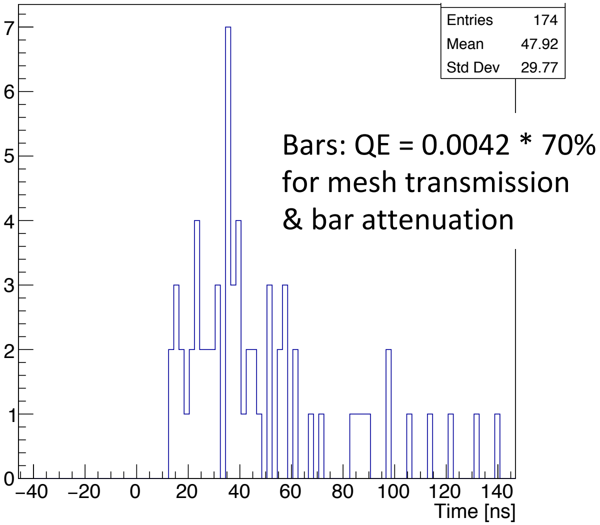
Toy-example case @ 150 cm from the photocathode plane: Kaon dE/dx = 100 MeV + Muon dE/dx = 200 MeV; Muon delayed 12 ns; w/o electronic effects



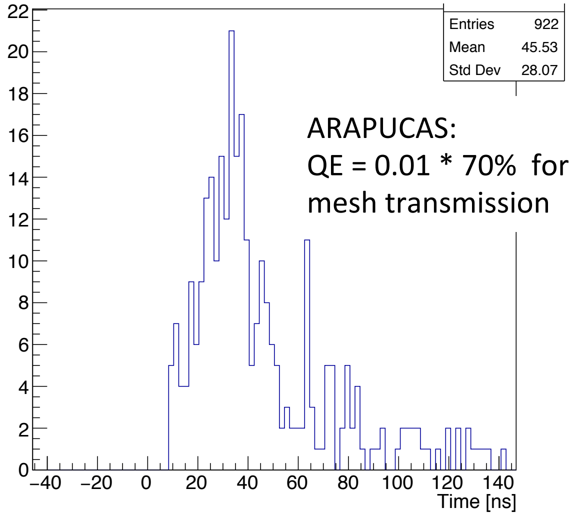
Emission scintillation: fast (6ns) and slow (1590 ns) components



Emission scintillation + propagation (detected time distribution)



Bars: QE = 0.0042 * 70% for mesh transmission & bar attenuation



ARAPUCAS: QE = 0.01 * 70% for mesh transmission

Conclusions

- In LArTPCs (PDS are in one plane) the light yield depends strongly on the position in the detector

  → Needs to be very well understood (for doing calorimetry)

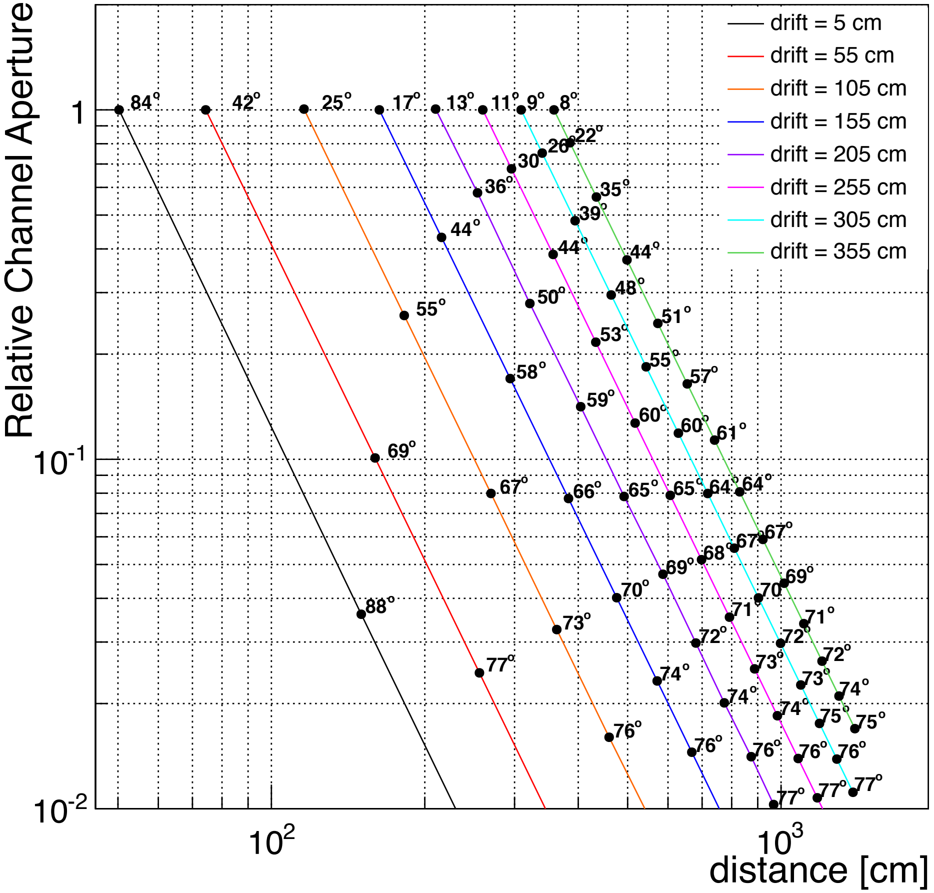
- In big LArTPCs (SBN detectors, DUNEs) propagation effects influence light detected signals

  → In both arrival times and amount of light (LY)

- Two previous points need to be well understood to understand our light signals and using them for doing physics

Back-Up

Relative geometric aperture

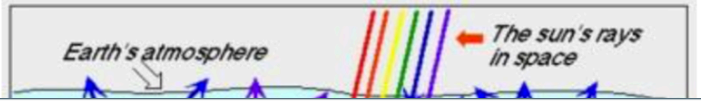


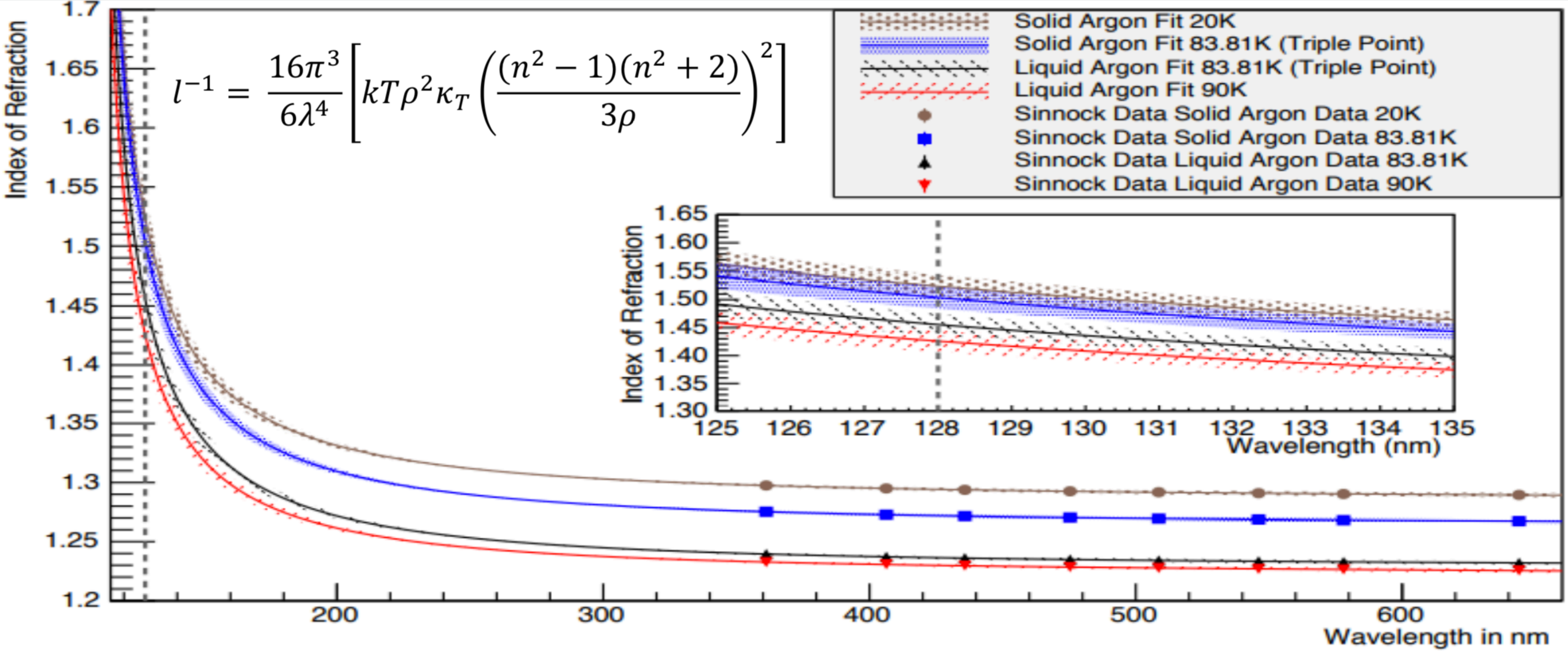
- Relative to the value of the hottest one
- We have assumed a distance between optical channels of 1m
- Scintillation points at the largest offset from the optical channel, 0.5m
- The points in each line represents the distance and angle (relative to the channel axis) of the consecutive channels

What is Rayleigh Scattering?

Slide stolen from V. Basque

- RS -> Elastic scattering of photon with medium of particle ~1/10 size of the wavelength; change of angle/direction (blue colour of the sky)
- Parametric process: initial state = final state





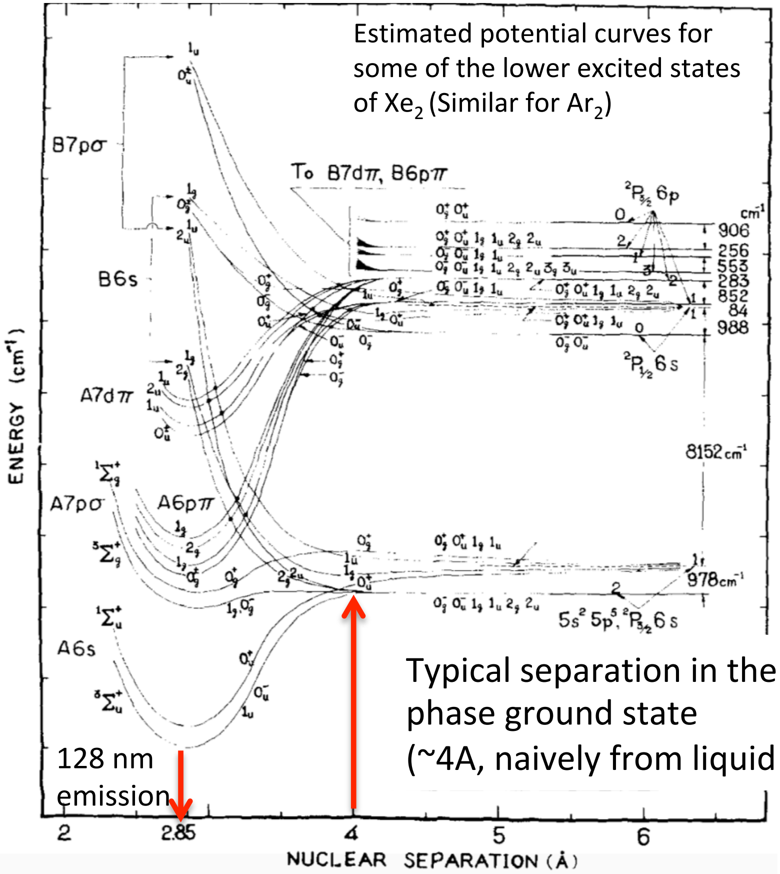
$$l^{-1} = \frac{16\pi^3}{6\lambda^4}\left[kT\rho^2\kappa_T\left(\frac{(n^2-1)(n^2+2)}{3\rho}\right)^2\right]$$

LArSoft)

- Late different measurements suggest a larger value < λ_{RS} ~ 100 cm >
- For a complete review see *sbn-doc-3590*

Wavelength Shifter: TetraPhenyl Butadiene (TPB)

J. Chem. Phys. 52, 5170 (1970)

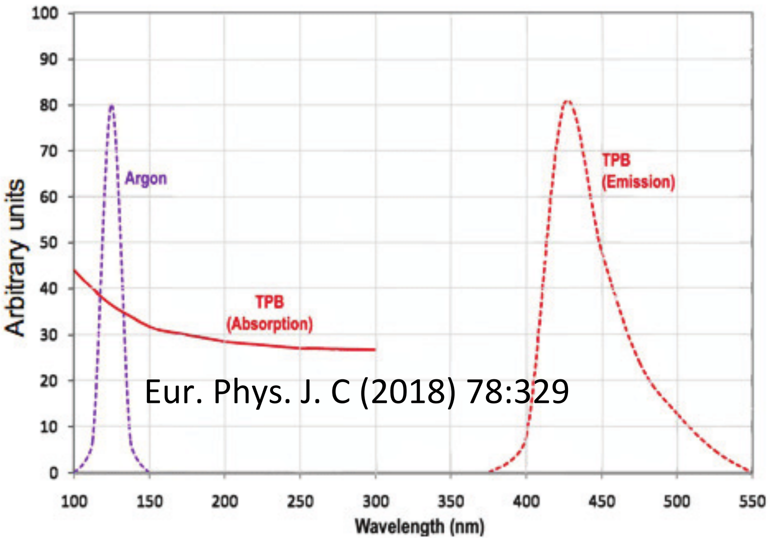


Estimated potential curves for some of the lower excited states of Xe_2 (Similar for Ar_2)

Typical separation in the liquid phase ground state (~4A, naively from liquid density)

128 nm emission

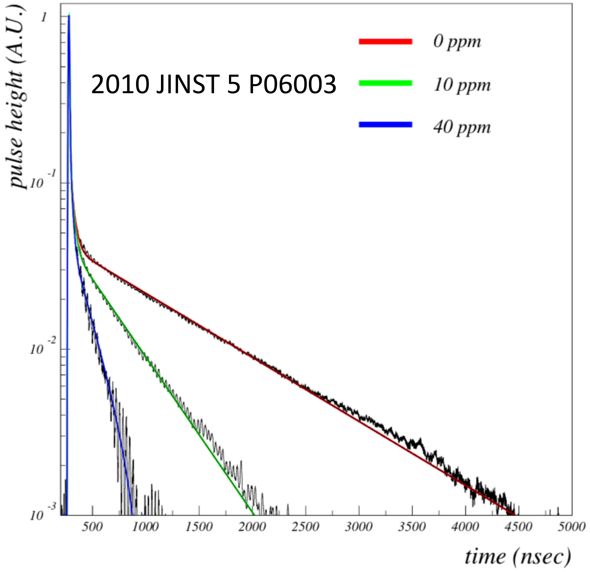
- Scintillation photons have energy lower than the first excited state of the Ar atom → pure LAr is transparent to its own scintillation radiation
- Detection is challenging (most other materials not) → most often need to use Wavelength shifting compounds, like TPB



Eur. Phys. J. C (2018) 78:329

- Can deposit WLS on Light detection components or inside the detector
- VUV sensitive SiPMs prototypes have appeared only recently

Argon purity and scintillation light



2010 JINST 5 P06003

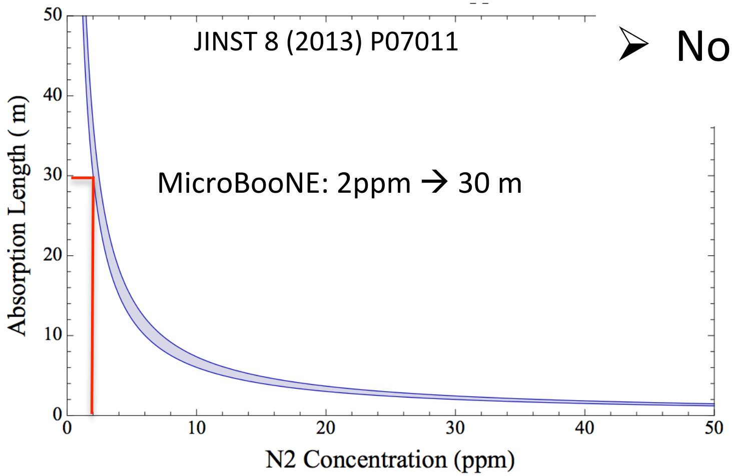
- Impurities affect differently charge and light
- H_2O and O_2 must/are controlled at a level (100-10 ppt) they are not a problem
- N_2 doesn't damage e^- lifetime, but light yes, and more difficult to remove

Before photon emission – Quenching → shape:

➢ Interaction of excimers with impurity molecules, resulting in an excimer dissociation with no photon produced → slow component ($^3\Sigma u$) more affected

$$Ar_2^* + N_2 \longrightarrow 2Ar + N_2$$

➢ Not a problem ≤ 2 ppm



JINST 8 (2013) P07011

MicroBooNE: 2ppm → 30 m

After photon emission – Absorption → yield:

➢ Loss of emitted photons by interaction with N_2 during propagation → $^1\Sigma u$ and $^3\Sigma u$ equally affected

➢ Is an important parameter for detector simulations and data analysis