Some considerations for timing photon detection

The time resolution of the drift coordinate: 400 ns (2.5 MS/s)
This sets the upper limit on time scale granularity needed for matching the light signal with charge
Two aspects for matching timing of light and charge:

- Knowing T_0 (relative to the start of the drift readout) of a SN neutrino, would allow to correct the reconstructed energy for impurity attenuation
- Help to determine if the nucleon decay candidates are within some fiducial volume

__Temporal resolution considerations__
E.g.,. positional based on TOF: the speed of light in LAr is 30 [cm/ns] / 1.38 [index of refraction] = 22 cm/ns. So with timing resolution for photon detection of 1 ns, the spatial resolution is on the order of 20 cm

Issues:

1. LAr is not a fast scintillator
2. Photon propagation is affected by Rayleigh scattering
3. PMT timing resolution (spread in transit time)
   - ➔ Transit time is mostly between photocathode and 1^{st} dynode

Properties of scintillation in LAr

Number of the photons (0.5 kV/cm, e- recomb ~ 0.7): ~22 000 γ/MeV
Maximal number of photons (all e- recombine) : ~51 000 γ/MeV

Primary scintillation (S1) consists of two components with massively different lifetimes:

- Fast component: $\tau_f = 6$ ns
- Slow component: $\tau_s = 1600$ ns
- The fraction of light going into fast / slow contribution depends on recombination effects, but for mip-like signals fast/slow ~ 30%,

See e.g., Hitachi et al., Phys. Rev. B27 5279 (1983))

Even if <u>all of the light</u> comes from the fast component, trying to get a timing resolution at a level of 1ns for photon arrival times will depend on the number of detectable photons

The resolution for TOF with scintillator emission probability $e^{-t/\tau}$ and n arriving photons is:

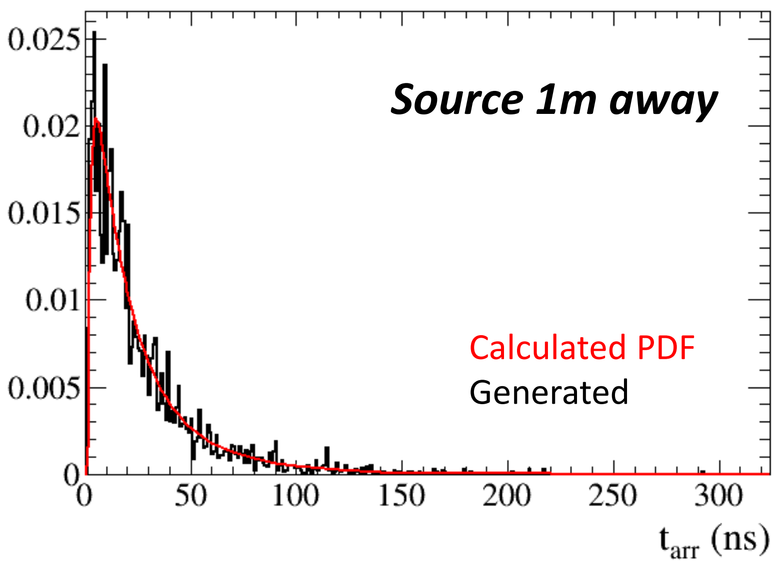
$$\sigma = \tau/n$$

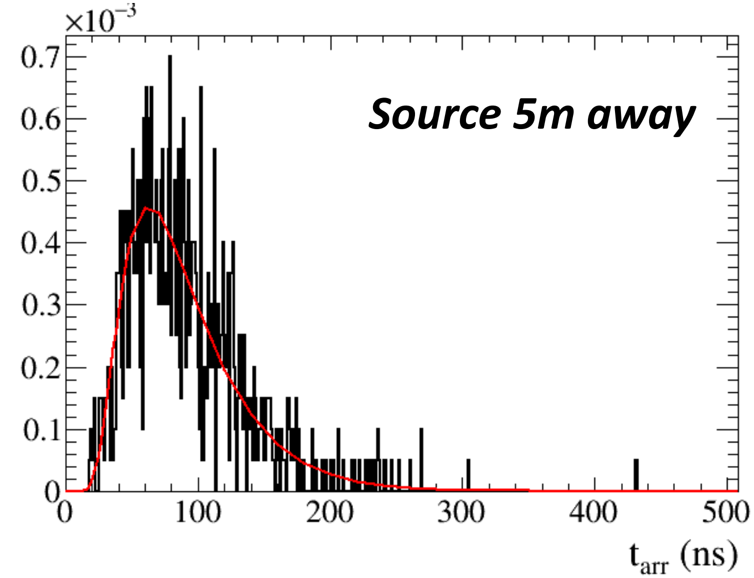
In case of single photon detection timing resolution is given by τ

Rayleigh scattering

- According the latest analyses: $\lambda_{RS} \sim 60$ cm
- The scattering is largely isotropic, i.e., photons are as likely to scatter in any direction
- For large source-detector distances the photon arrival time is not simply given by d/v, but is longer because of non-negligible path variations due to the RS scattering

Photon arrival time distributions $\lambda_{RS} = 55$ cm





For large distance RS could smear the photon transit time by tens of ns

Spread in transit time

HAMAMATSU

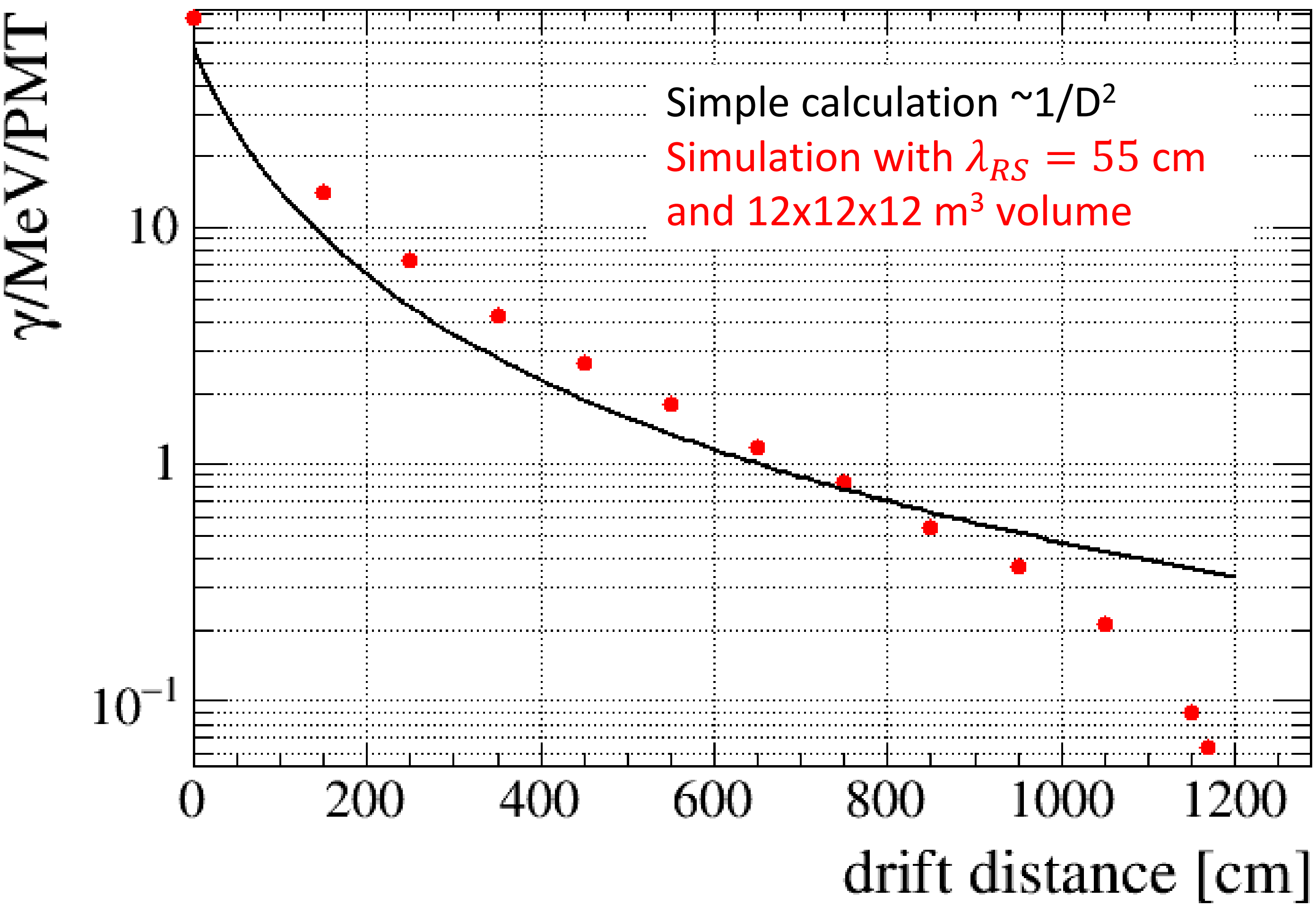
Anode Sensitivity (at +25 °C)

Dark Current (After 30 min storage in darkness)		Dark Count (After 15 hours storage in darkness)		Time Response			Single Photo-electron (Peak to valley ratio)		Pulse Linearity		Type No.
				Rise Time	Electron Transit Time	Transit Time Spread (FWHM)			at ±2 % Deviation	at ±5 % Deviation	
Typ. (nA)	Max. (nA)	Typ. (s^{-1})	Max. (s^{-1})	Typ. (ns)	Typ. (ns)	Typ. (ns)	Min.	Typ.	Typ. (mA)	Typ. (mA)	
50	700	4000	8000	3.8	55	2.4	1.5	2.5	20 (60)	40 (80)	R5912
1000	5000	6000	12 000	4	68	2.8	1.5	2.5	40	70	R5912-02

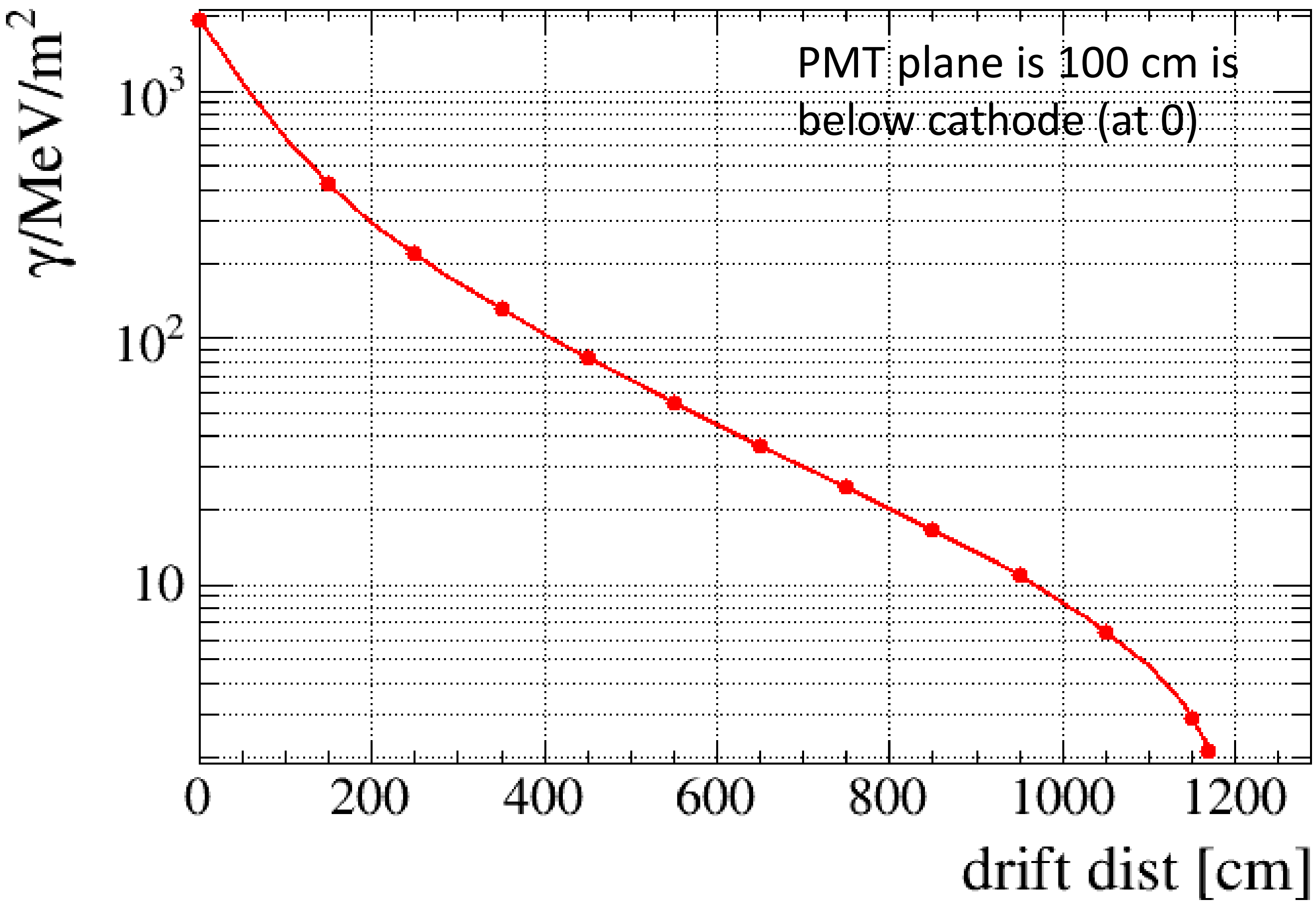
- The transit time is (surprisingly) long for R5912-mod2 → 68 ns
- The FWHM is ~3 ns → Sets a limit on a precision for photon timing measurements

Photons per 8” detector

No attenuation, no cathode opacity
PMT plane is 100 cm below the cathode plane



Photons / m^2 in detection plane



The number of PE that could be detected can be roughly estimated as

$$N_{pe} \approx N_d \times 0.0314 \times 0.5 \times 0.2 \times N_\gamma = N_d \times 3N_\gamma/1000$$

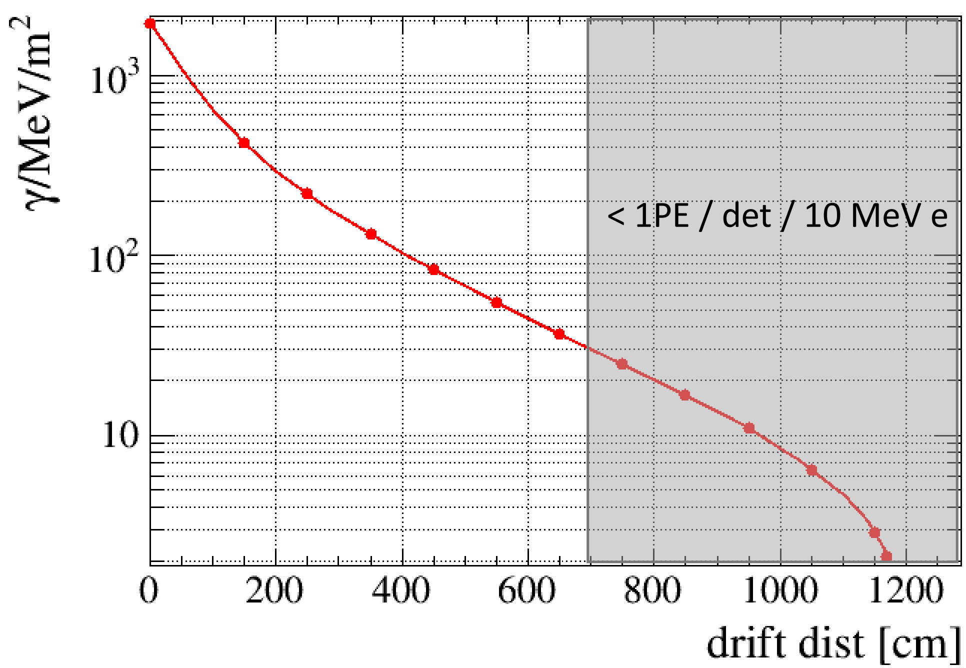
Number of detectors per / m2 x effective det area

WLS (1/2 of photons are emitted up)

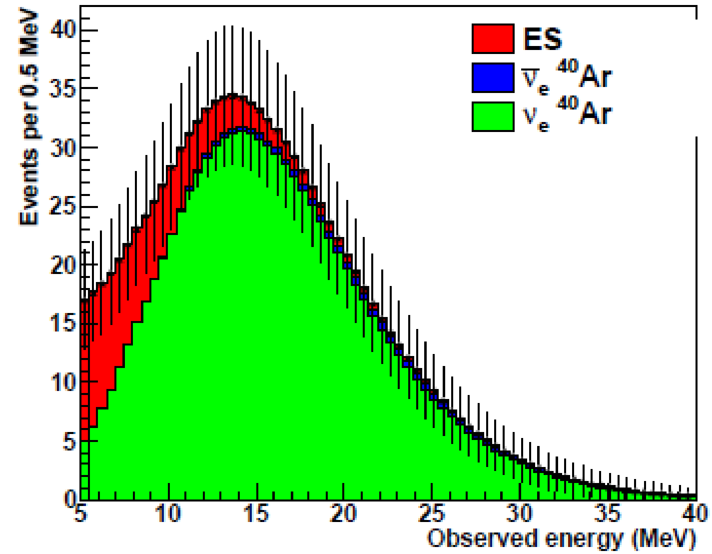
QE

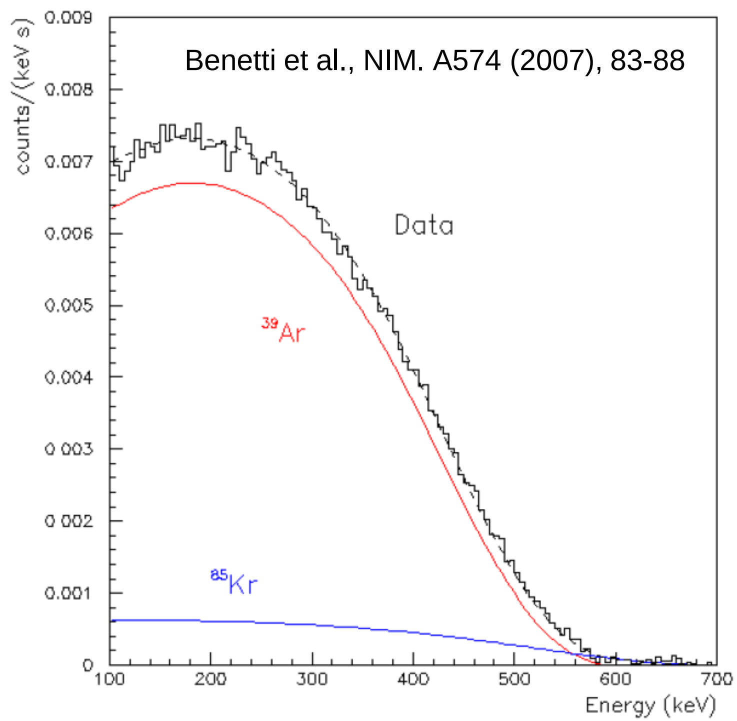
Photons / m2

Photons / m^2 in detection plane



SN neutrino spectrum





- Large variation in sensitivity to over the drift volume: O(100) variation
- Effect of radiological backgrounds? Ar39 is 1Bq/kg → 1400 Bq/m^3

Summary

- For light-charge signal association a timing resolution on light signals should not be greater than 400 ns = sampling of the charge readout

- Timing resolution for a detection at a few photon level is limited by physics of the light production and propagation in LAr and the time response of the PMT
- For large detector volumes RS would dominate achievable timing resolution