Simulation of optical processes

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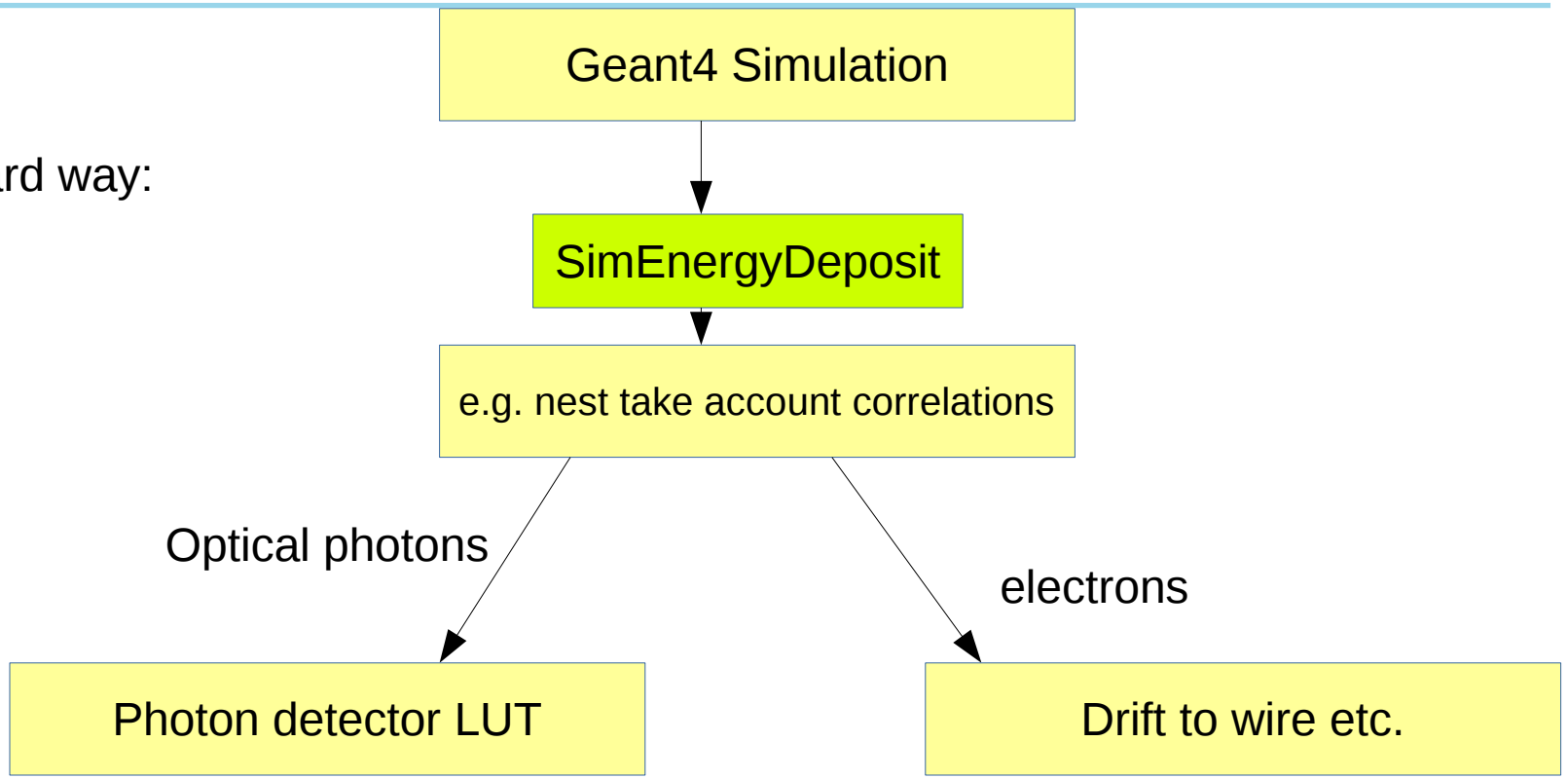
Outline

- **Three modes to run optical simulation**
- **Optical processes in Geant 4**
- **Liquid Argon TPC's:**
  - **Refraction index and propagation speed**
  - **Rayleigh scattering: effect on timing and imaging**
  - **Absorption length**

Three modes to run optical simulation.

1. Standard way:



2. Full simulation:
Enable optical processes and propagation in Geant4→ check LUT.
(very CPU expensive (>1000X) but might be replaced specialized ray tracers running on GPU's (OPTIX) geant4 optical processes have been implemented by Simon Bly)

3. Obtaining LUT:
Full Geant4 simulation currently done in a separate program (LightSim) → no reason not to integrate in LArSoft

Optical processes in Geant4

Production:

- Cerenkov Process
- Scintillation Process
- WLS
- Transition Radiation

Boundary Process:
Total internal reflection etc. at boundaries between materials with different refraction index.

Stepping:

- Absorption
- Rayleigh scattering
- Mie Scattering

Surface Process:
e.g. reflection on metallic surface needs Surface properties.

Optical physics in Geant 4

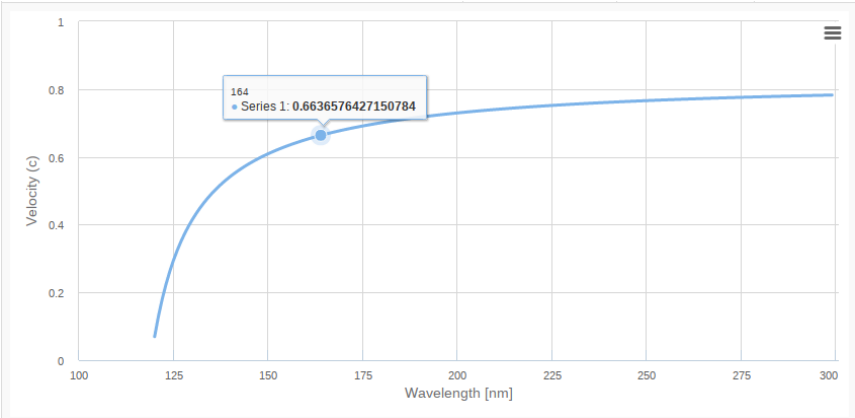
In Geant4, the optical physics has an exceptional position among the physics processes:
it adds:

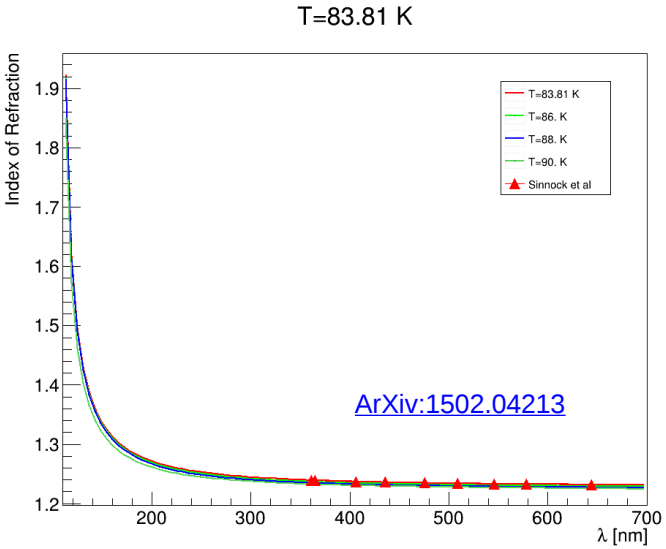
- **special particles (optical photons).**
  - The only particle that can be reflected or refracted at optical surfaces,
  - only particle created in optical processes like scintillation, Cherenkov radiation, and wavelength-shifting (WLS).
  - G4OpticalPhoton differs from the “usual” high-energy particle-physics photon (G4Gamma) in Geant4.
- **new properties for materials and optical surfaces.** Optical properties need to be assigned to the materials whenever optical physics processes are to be considered in the simulation. Every material needs at least a refractive index spectrum (which corresponds to the dispersion relation) and an attenuation length spectrum, though the attenuation length is by default set to infinity if it is not defined. Special optical materials, i.e. scintillating and WLS materials, additionally require the specification of the emission spectra as well as of the rise and decay times. More properties can be assigned to optical surfaces between volumes, e.g. the reflectivity of the surface.

arXiv:1612.05162

Peculiarities in the Simulation of Optical Physics with Geant4

Refraction index and propagation speed





group velocity is equal to the phase velocity
vp=c/n only
when the refractive index is a constant

$$v_g = \frac{c}{n + \omega \frac{\partial n}{\partial \omega}} = \frac{c}{n - \lambda_0 \frac{\partial n}{\partial \lambda_0}}$$
$$= v_p \left(1 + \frac{\lambda}{n} \frac{\partial n}{\partial \lambda}\right) = v_p - \lambda \frac{\partial v_p}{\partial \lambda} = v_p + k \frac{\partial v_p}{\partial k}.$$

n = c/vp = ck/ω.

```
root [0] .L LAr.C++
root [1] init();                    // initialize
root [2] sellmeierLAr();
root [3] rindextable();
```

```
<matrix name="RINDEX" coldim="2" values="1.7712*eV 1.23148
1.78626*eV 1.23154
1.80157*eV 1.2316
1.81715*eV 1.23166
.....
10.6975*eV 1.72744"/>
```

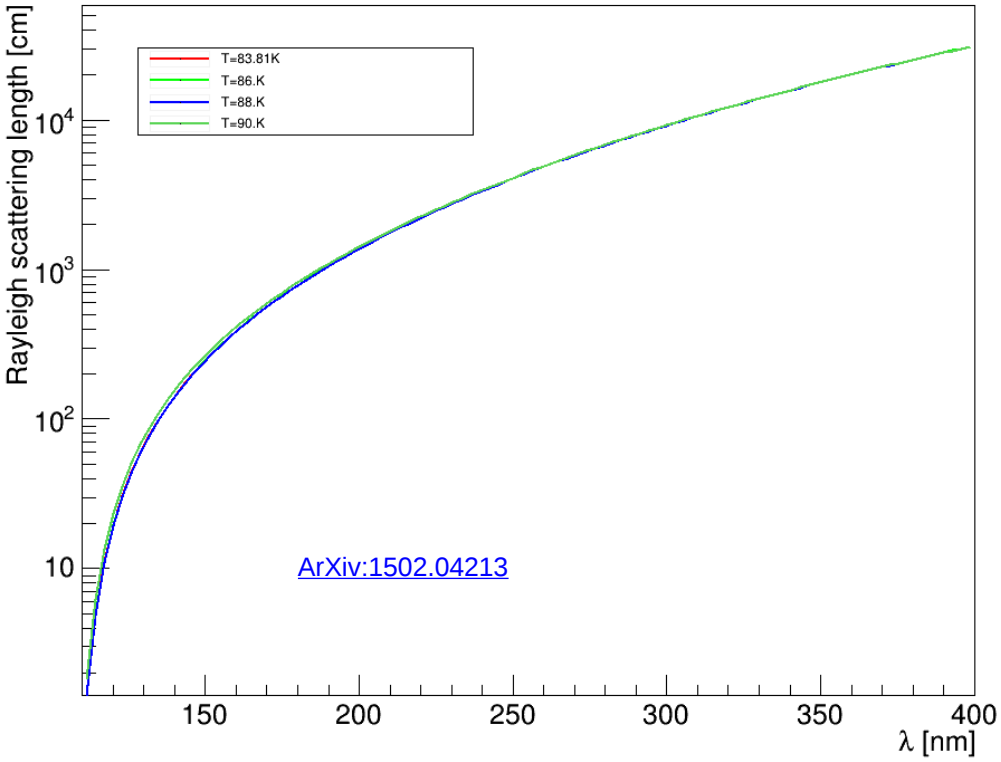
Fermilab

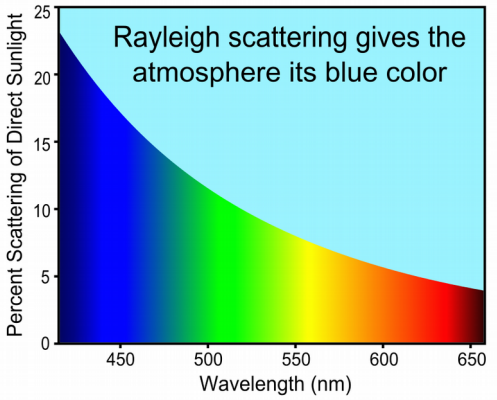
Rayleigh scattering

$$I = I_0 \frac{8\pi^4\alpha^2}{\lambda^4 R^2}(1+\cos^2\theta).$$

```
root [0] .L LAr.C++
root [1] init();
root [2] rayleigh();
root [3] rayleightable()
```

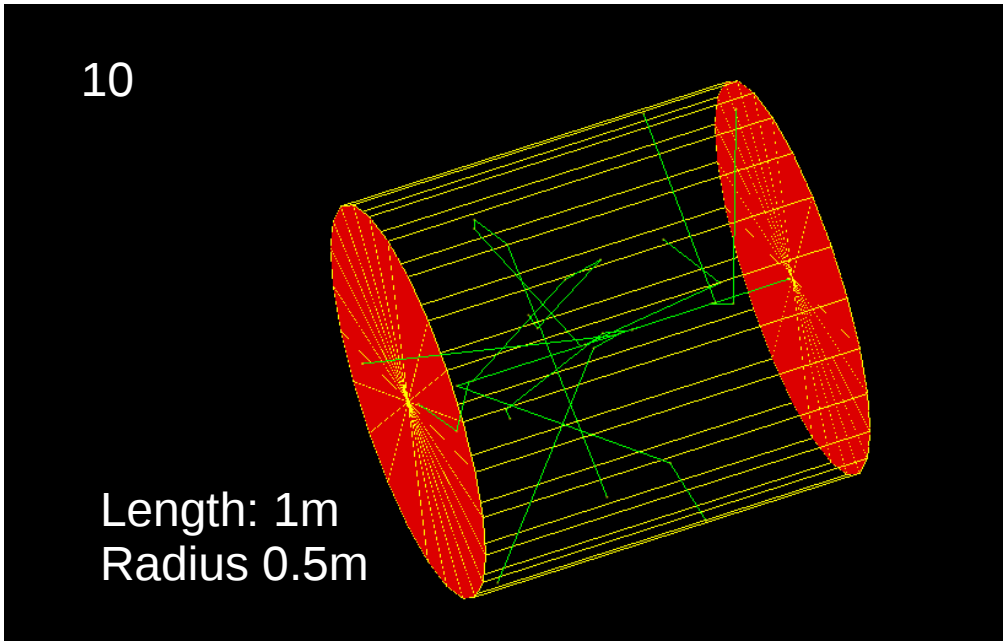
T=83.81K

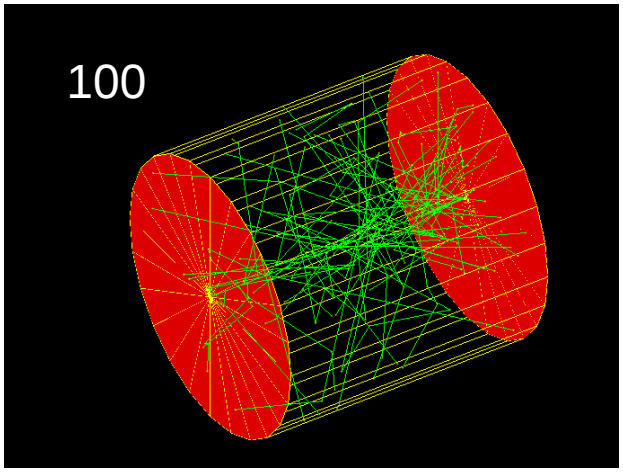


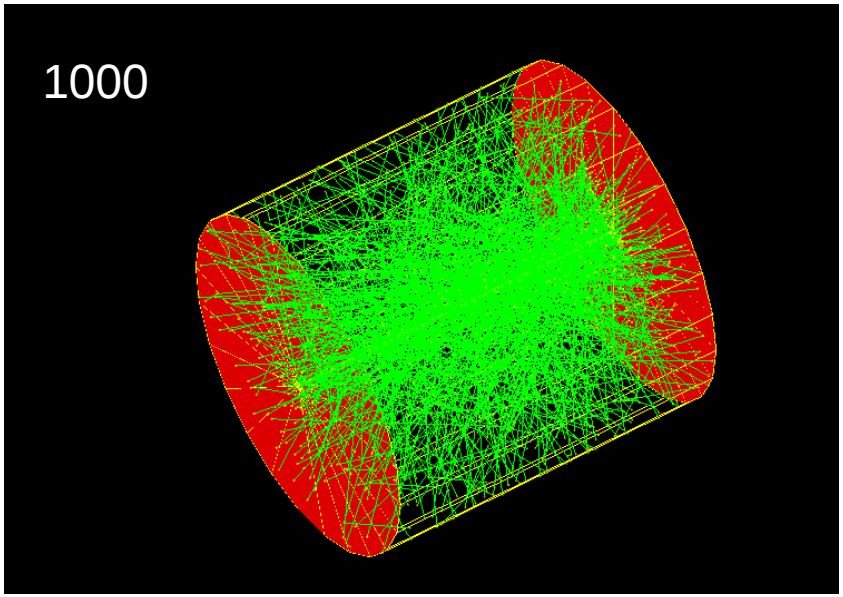


Fermilab

Rayleigh scattering

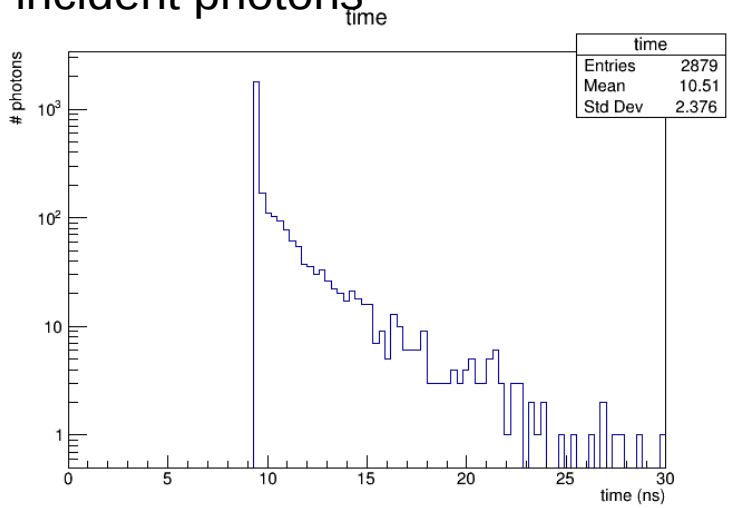


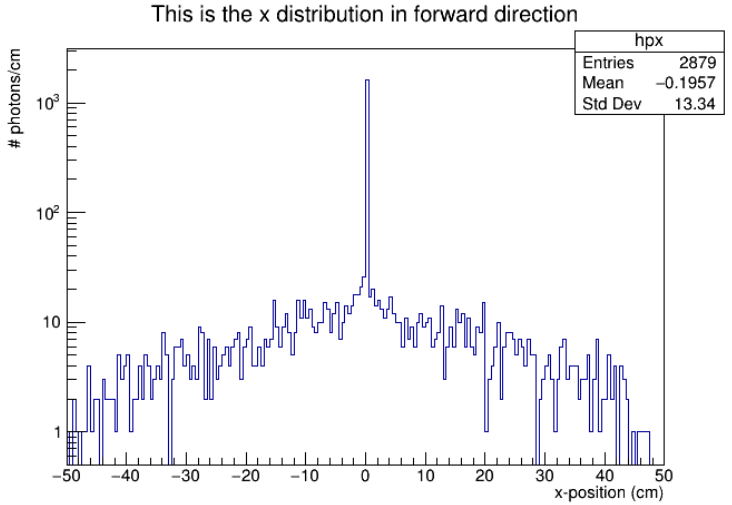


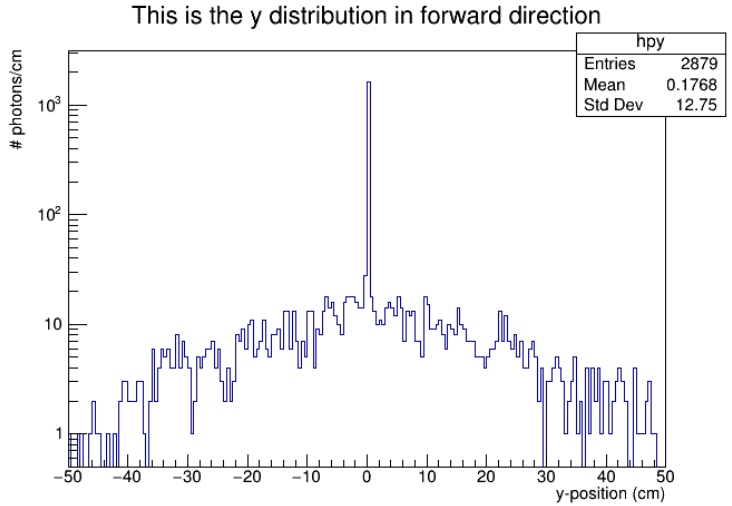


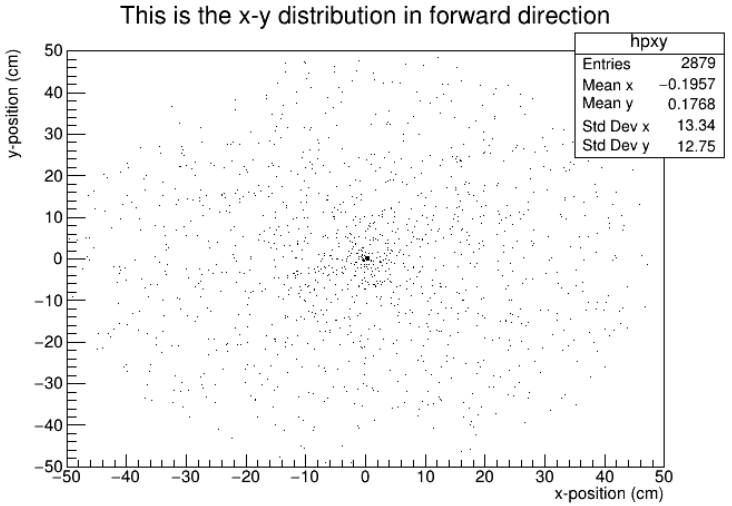
Rayleigh scattering: effect on timing and imaging

10000 incident photons





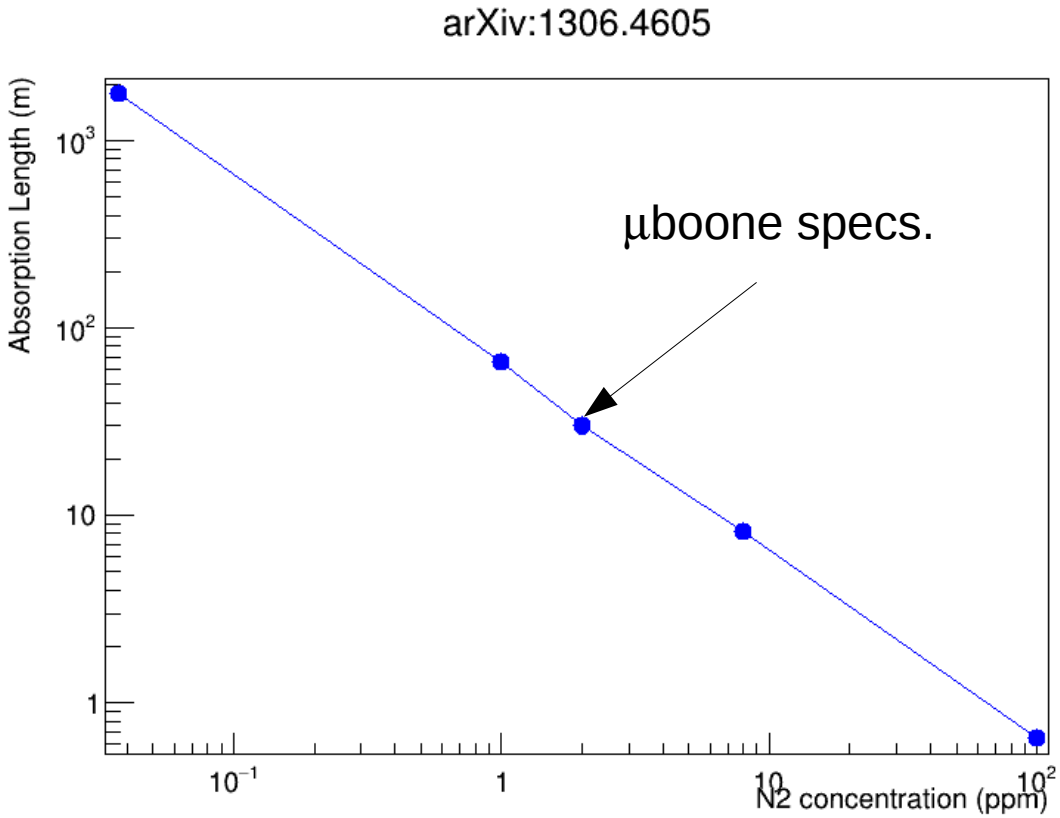




No scitillation time constant involved.

Fermilab

Absorption length



arxiv:1611.02481: 52.7 cm
arxiv:1502.04213: 60 +/- 6 cm
55 +/- 5cm