Scintillation Light in LArTPCs: Simulation and Reconstruction

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UK-LArSoft workshop, Edinburgh, October 2025

Outline

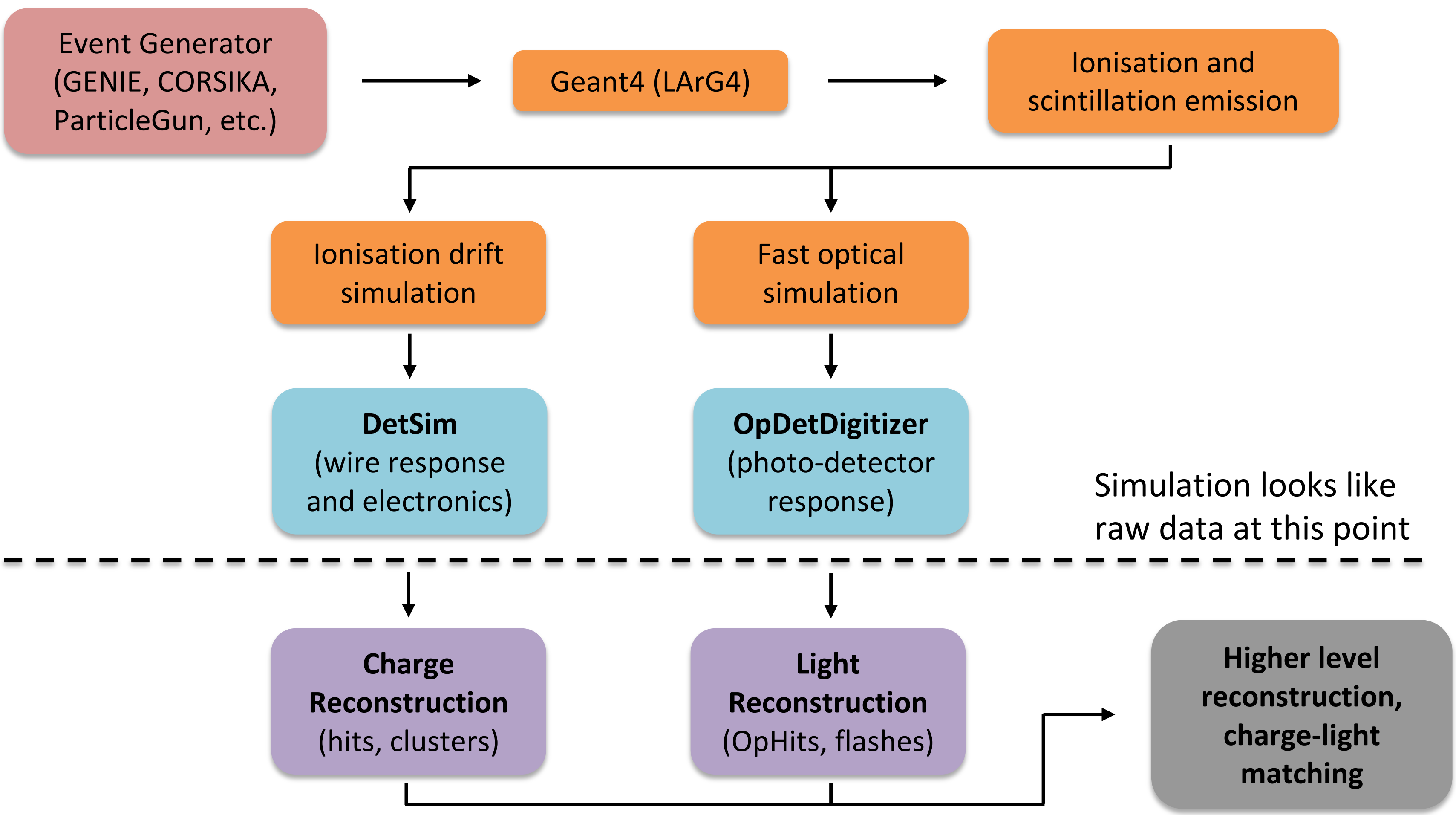
- This talk will give an overview of how LArSoft deals with simulating light and why it's hard
- I will also talk a bit about reconstruction
- Next, we will go through a few hands-on examples in the tutorial.

SBND, DUNE

Simulation Flowchart

Each stage is a module (or set of modules)

Each stage passes data products, “objects”, to the next stage

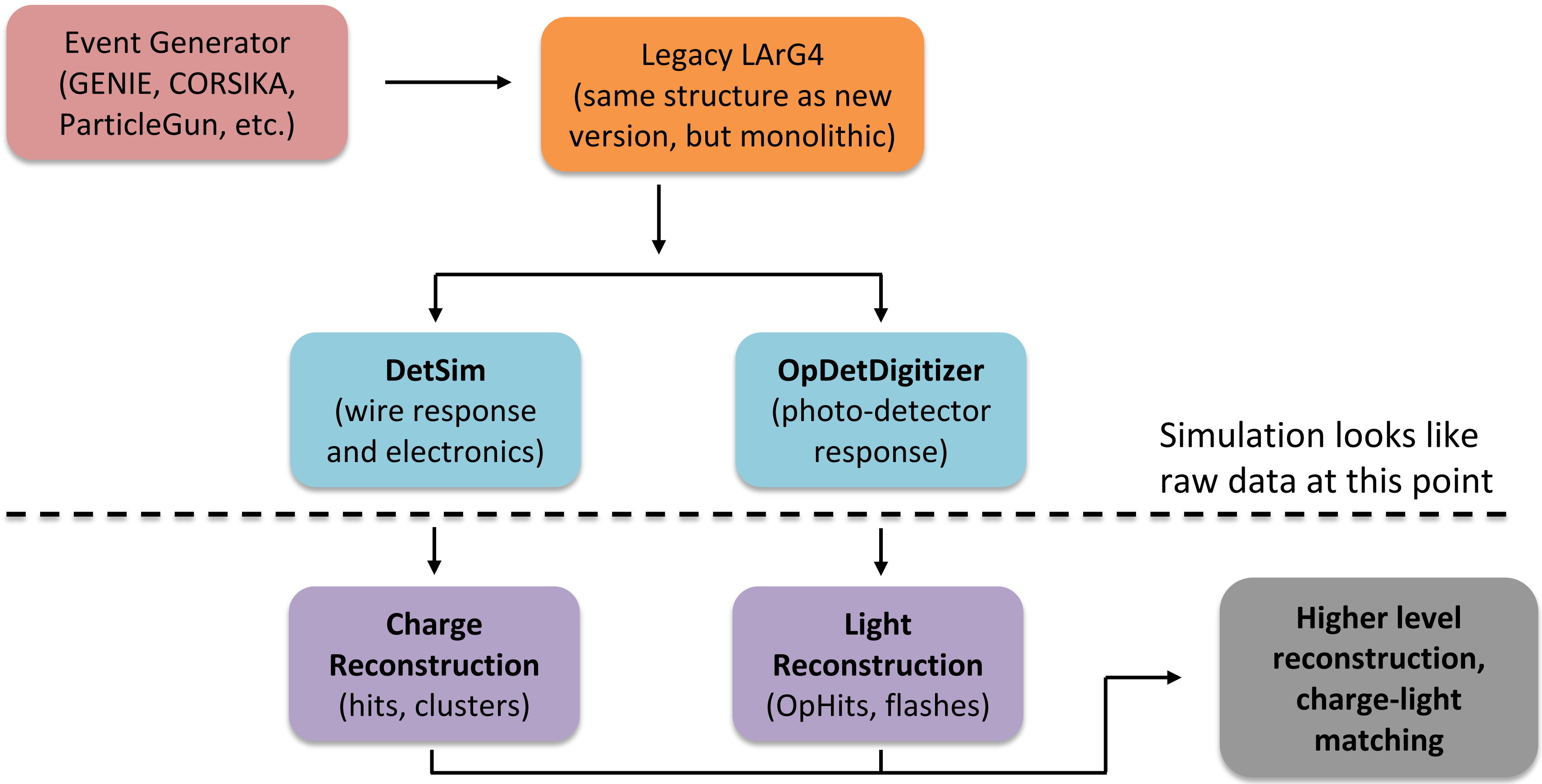


Simulation Flowchart (Legacy Version)

MicroBooNE

Each stage is a module (or set of modules)

Each stage passes data products, “objects”, to the next stage



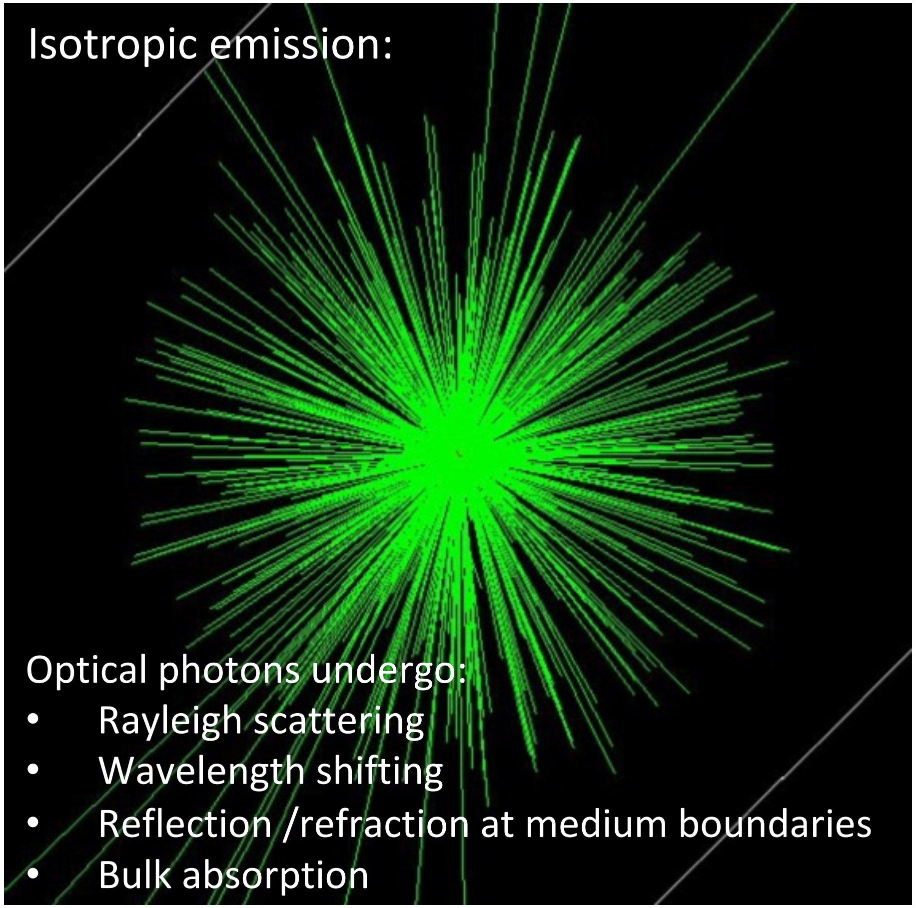
Elements of Light Simulation

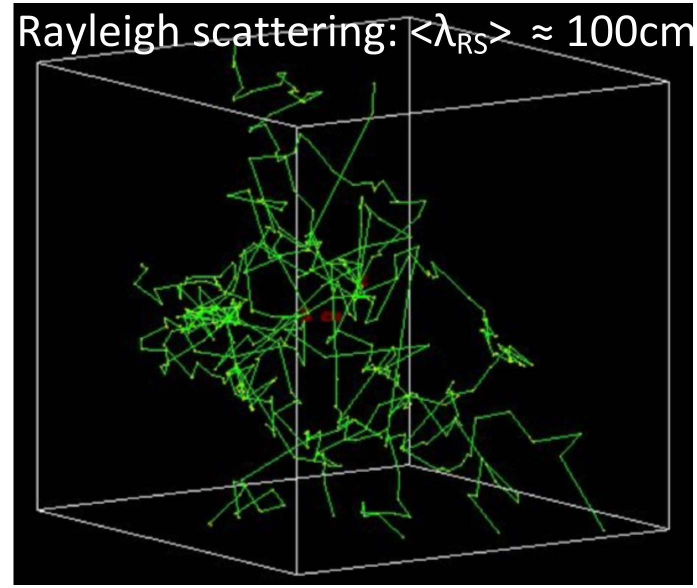
- **Light source:**
  - How many photons are generated?
  - What is their time distribution?
  - What is their wavelength?
- **Transport:**
  - How many photons make it to the detector?
  - How long does it take them?
  - Do they scatter / get absorbed / reflected etc?
- **Detection:**
  - What is our detection efficiency?
  - Does it depend on position on detector?
  - Are there any extra timing effects?

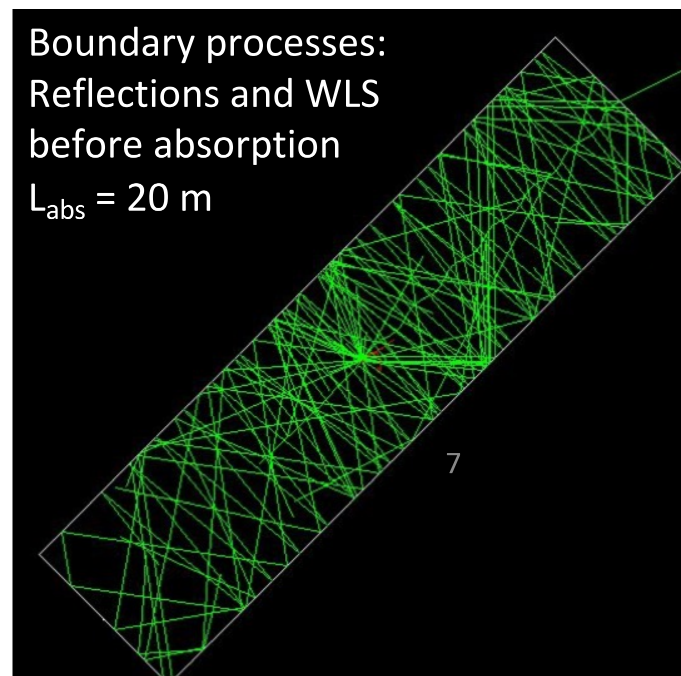
Different modes of simulation

- *Full optical simulation* (extremely slow)
  – requires definition of all optical properties.
- *Fast optical simulation* (faster, but less precise)
  – still need to run full optical at least once
  – majority of optical properties "burned in"
  – three primary methods exist: optical library, semi-analytical, generative neural network

Full optical light simulation







Scintillation yield ~24000 photons/MeV

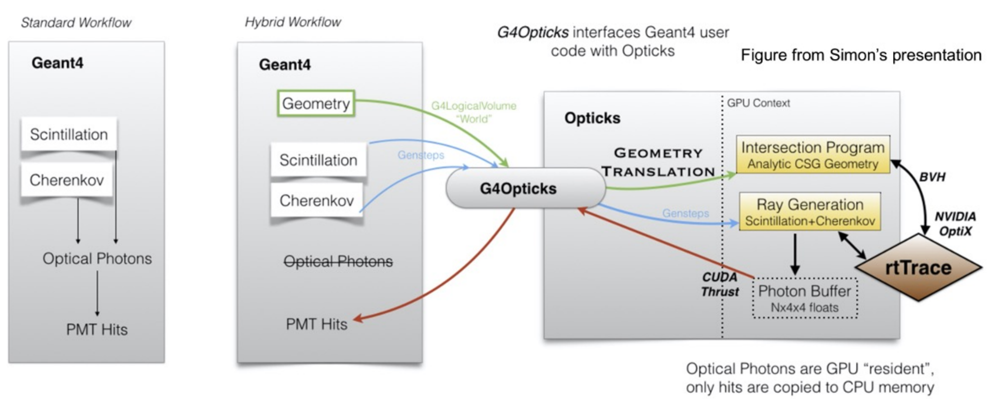
For GeV-scale interactions in large detectors, the tracking of each individual photon is prohibitively slow -> alternatives needed

(Aside): Using GPUs – NVIDIA OptiX

Some progress using GPUs for full optical simulation, but challenges remain

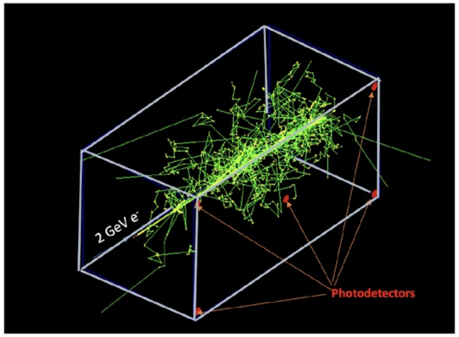
- GPU resources limited + using vendor specific tools (NVIDIA OptiX)

GPU based photon simulation



- simulation of photons within open detectors can be incredibly CPU intensive and limit event by event simulation
- often solved with voxel-ized lookup tables
- Opticks developed by Simon Blyth for JUNO, now part of GEANT4 releases

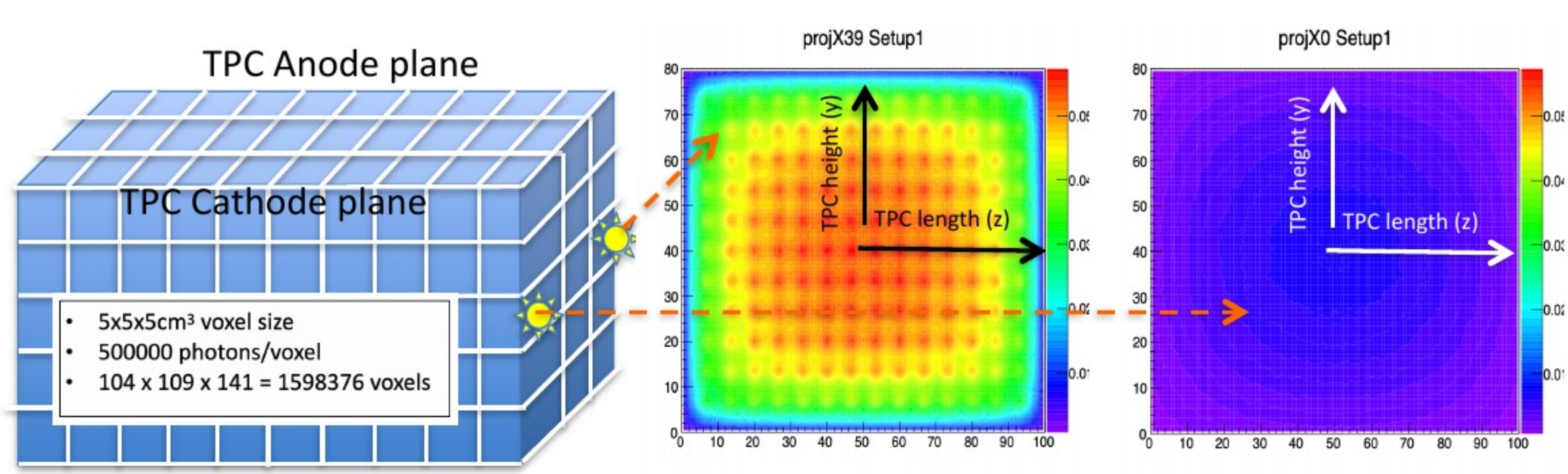
- CaTS: integrate GEANT4+Opticks in LArSoft for simplified LArTPC
- speedup of several 100 times for photon simulation
- also report that 1 core could saturate the GPU



Brookhaven National Laboratory

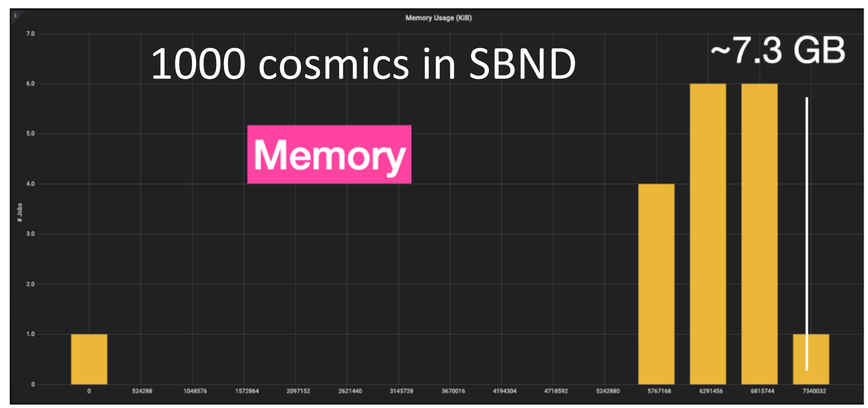
Slide stolen from Michael Kirby, NuFact 2024

Fast optical model: Optical Library



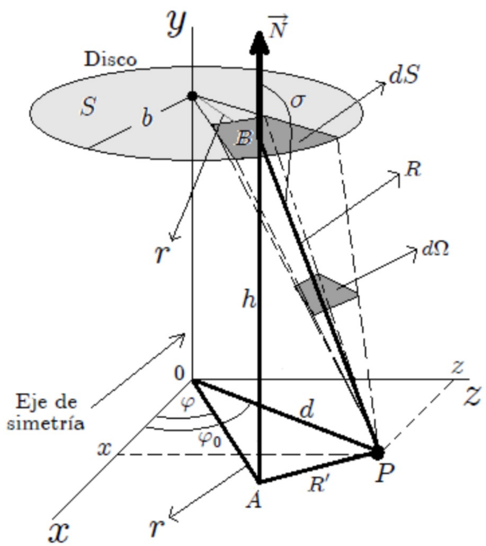
$$\langle N \rangle_{PMT-hits} = \left(\frac{dE}{dx}_{step} \cdot Length_{step} \right) \cdot LY \cdot visibility_{step}^{PMT}$$

- Resolution depends on voxel sizes: granularity effects at short distances
- Optical library size scales with detector size and number of photon detectors



- Prohibitive memory use for large detectors -- difficult to get working in SBND and DUNE, so different approaches currently used.

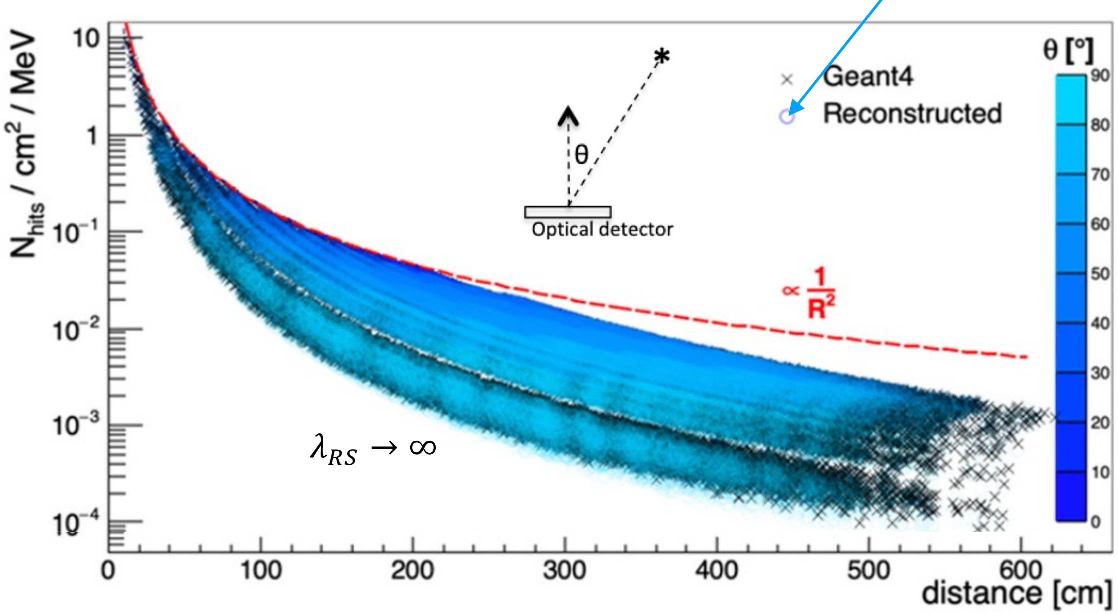
Fast optical model: Semi-Analytical



$$\Omega = h \int_0^{2\pi} \int_0^b \frac{r}{[h^2+r^2+d^2-2rd\,\mathrm{Cos}(\varphi_o-\varphi)]^{3/2}} dr d\varphi$$

- Given a dEdx in a point (x, y, z) we want to predict the number of hits in our optical detector (x_i, y_i, z_i)
- Isotropic scintillation emission makes the problem **"almost"** geometric

$$N_\Omega = e^{-\frac{d}{\lambda_{abs}}} \Delta E \cdot S_\gamma(\mathscr{E}) \frac{\Omega}{4\pi}$$



- "Almost" because we have Rayleigh scattering
- Need to correct for it, via parameterization
- Current approach used in SBND and DUNE

Eur.Phys.J.C 81 (2021) 4, 349

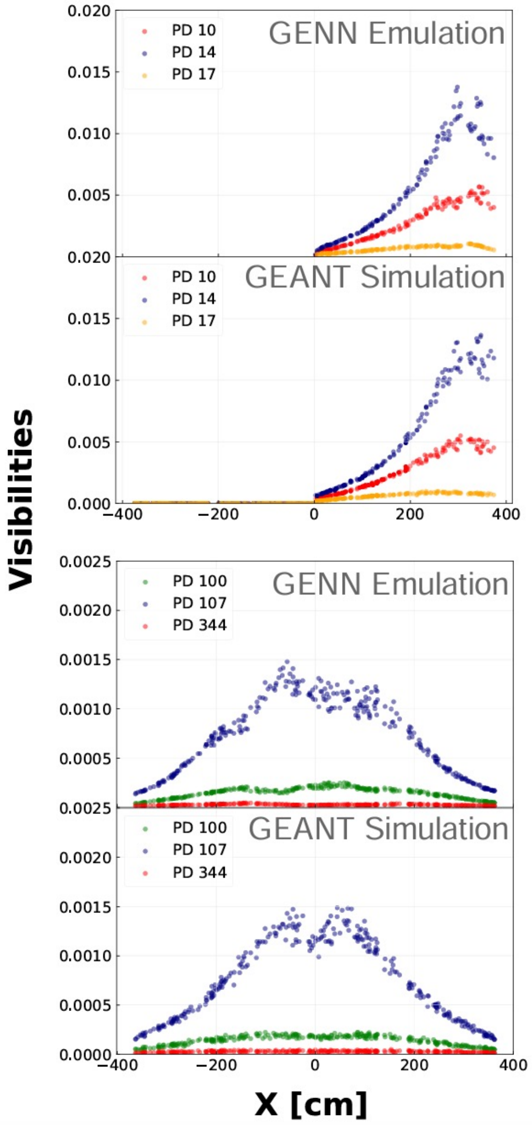
Fast optical model: Neural Networks

Generative neutral network (GENN):

- network trained on Geant4 simulation of voxelized detector, similar to library
- rather than storing visibilities in look-up table, use network to predict at run-time
- avoids memory limitation of library, at some CPU cost; available for some geometries in DUNE

Some ongoing attempts to train similar networks using data rather than simulation:

- no longer have to rely on often poorly known detector properties → could be more accurate / closer to data
- but challenging to get well understood training samples



Mach.Learn.Sci.Tech. 3 (2022) 1, 015033

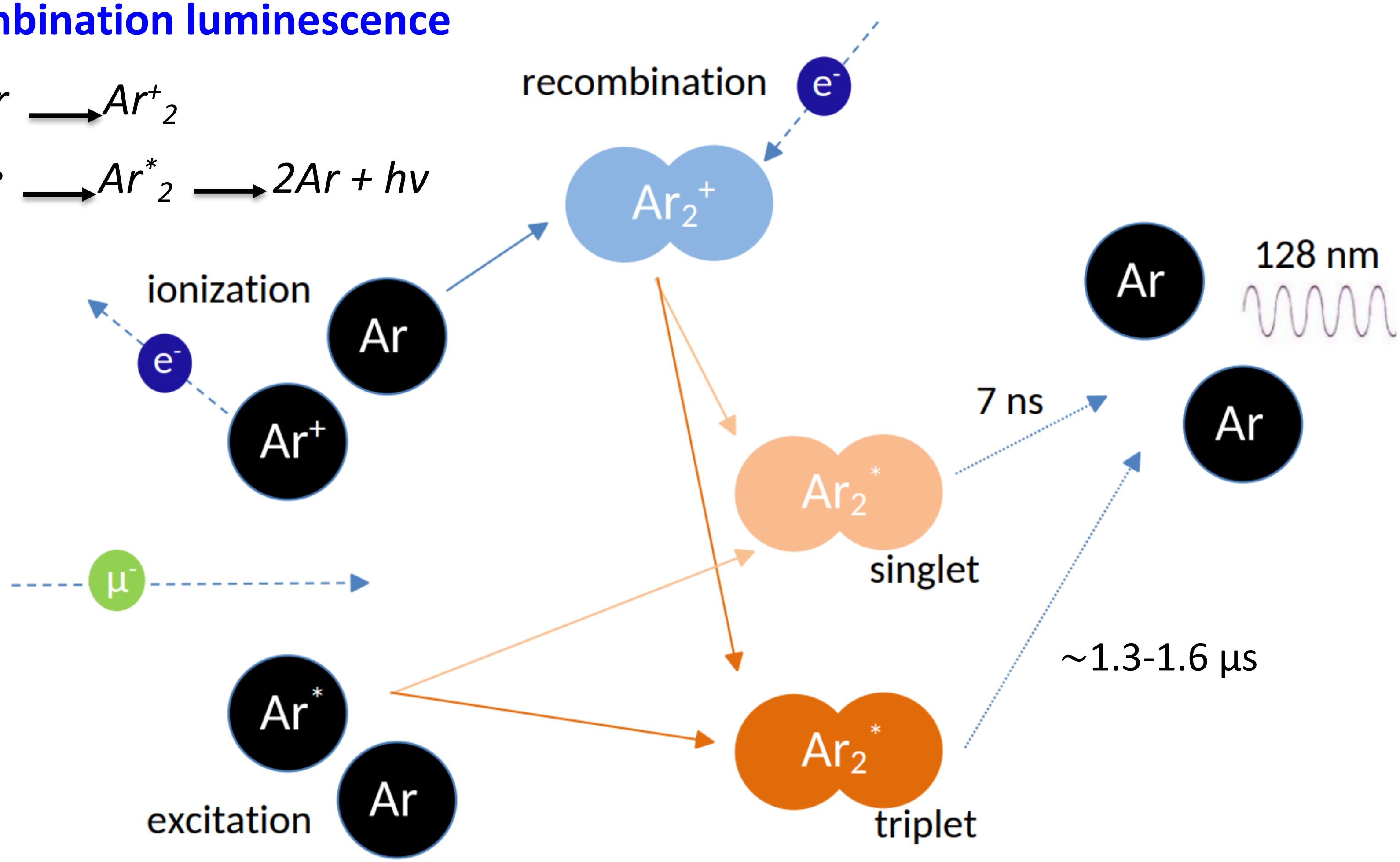
Emission

Scintillation mechanism in LAr

- **Recombination luminescence**

$Ar^+ + Ar \longrightarrow Ar^+_2$

$Ar^+_2 + e \longrightarrow Ar^*_2 \longrightarrow 2Ar + h\nu$



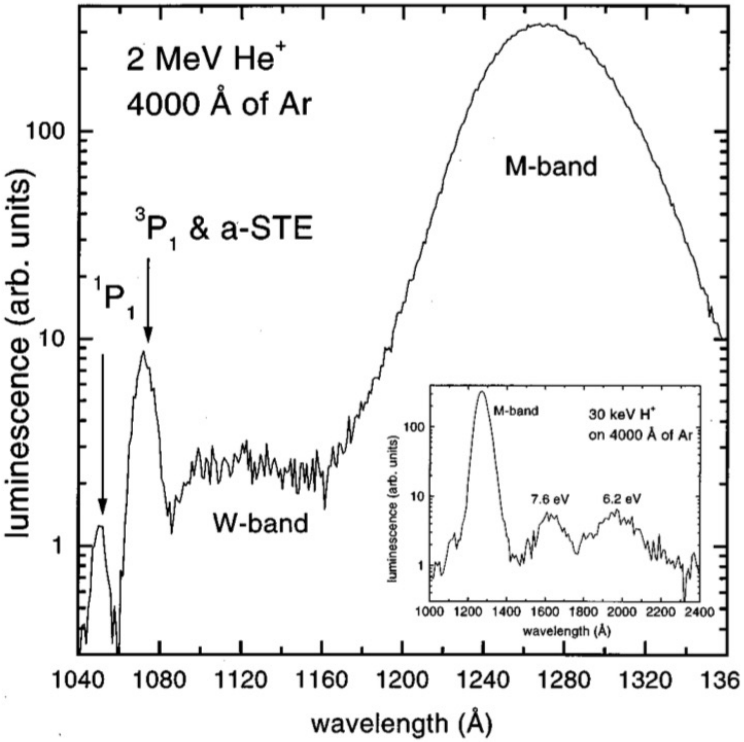
- **Self-trapped excitation luminescence**

$Ar^* + Ar \longrightarrow Ar^*_2 \longrightarrow 2Ar + h\nu$

Scintillation wavelength in LAr

In liquid argon, the overall emission spectrum is well represented by a gaussian shape peaking around:
λ = 128 nm (FWHM $\simeq$ 6 nm)

In LArSoft this is parameterised in larproperties.fcl



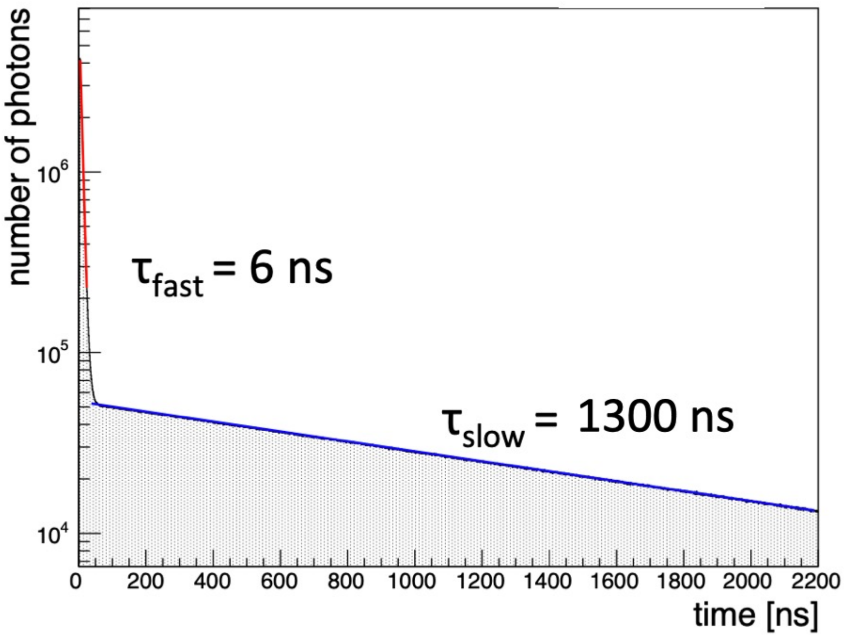
Ph. Rev. B 56 (1997), 6975

lardataalg / lardataalg / DetectorInfo / larproperties.fcl

```
# Fast and slow scintillation emission spectra, from [J Chem Phys vol 91 (1989) 1469]
FastScintEnergies:    [ 7.2,  7.9,  8.3,  8.6,  8.9,  9.1,  9.3,  9.6,  9.7,  9.8,  10,  10.2,  10.3,  1(
SlowScintEnergies:    [ 7.2,  7.9,  8.3,  8.6,  8.9,  9.1,  9.3,  9.6,  9.7,  9.8,  10,  10.2,  10.3,  1(
FastScintSpectrum:    [ 0.0,  0.04, 0.12, 0.27, 0.44, 0.62, 0.80, 0.91, 0.92, 0.85, 0.70, 0.50, 0.31, 0.:
SlowScintSpectrum:    [ 0.0,  0.04, 0.12, 0.27, 0.44, 0.62, 0.80, 0.91, 0.92, 0.85, 0.70, 0.50, 0.31, 0.:
```

Scintillation signal shape in LAr

- In all measurements the overall scintillation light emission exhibits a double exponential behavior in time
- This is a result of Ar excimer decays characterized by two very different components:
  a fast component, $\tau_S \approx$ 6ns,
  and a slow component, $\tau_T \approx$ 1.3µs



- Implementation in LArSoft:

lardataalg / lardataalg / DetectorInfo / larproperties.fcl

```
ScintFastTimeConst:   6.     # fast scintillation time constant (ns)
ScintSlowTimeConst:   1590.* # slow scintillation time constant (ns)
```

*Note:

- a slow time constant value convolved with the WLS-delay, results in a larger value ≈ 1.5-1.6µs

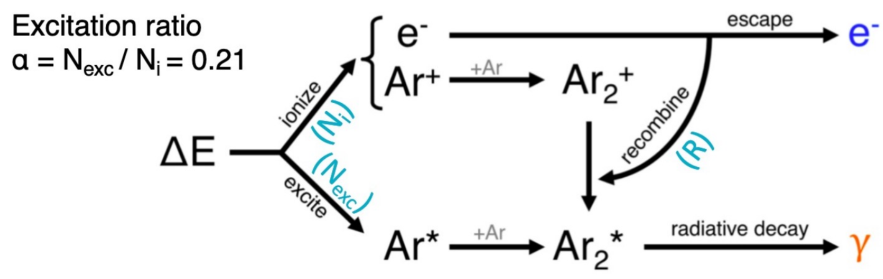
Scintillation Yields: E-field

Liquid Argon is a prolific scintillator:
~40000 photons/MeV @ zero electric field

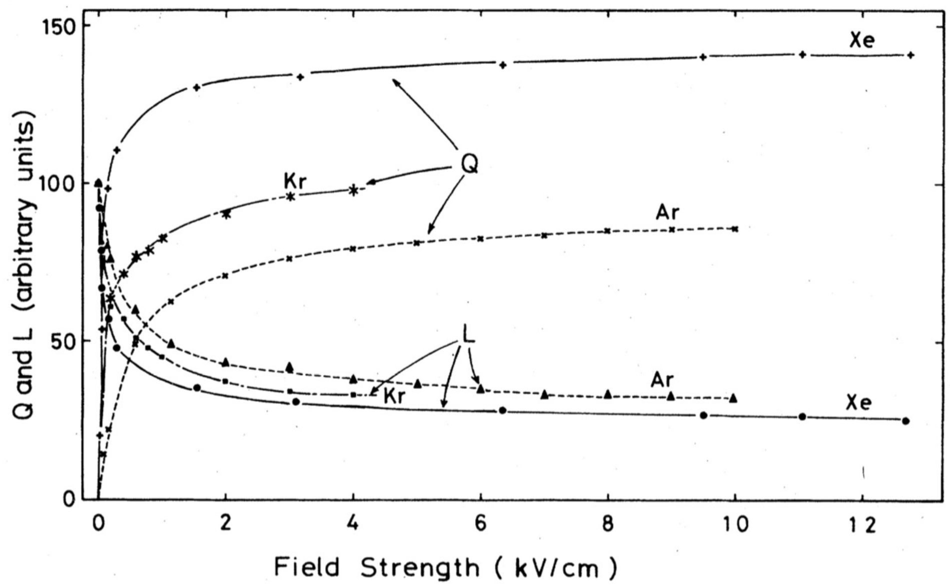
Strength of the electric field applied to the LAr impacts the amount of recombination
→ alters amount of charge (Q) and light (L)

Effect is (anti-)correlated, as electric field increases Q grows, L decreases. At 500 V/cm, energy deposit about equally divided between Q and L

This is modelled in LArSoft ISCalcCorrelated:



PHYSICAL REVIEW D 101, 012010 (2020)



Phys. Rev. B 20, 3486

larsim / larsim / IonizationScintillation / **ISCalcCorrelated.cxx**

```
// using this recombination, calculate number of ionization electrons
double const num_electrons = (energy_deposit / fWion) * recomb;

// calculate scintillation photons
double const num_photons = (Nq - num_electrons) * fScintPreScale;
```

Services.LArG4Parameters.IonAndScintCalculator: “Correlated”

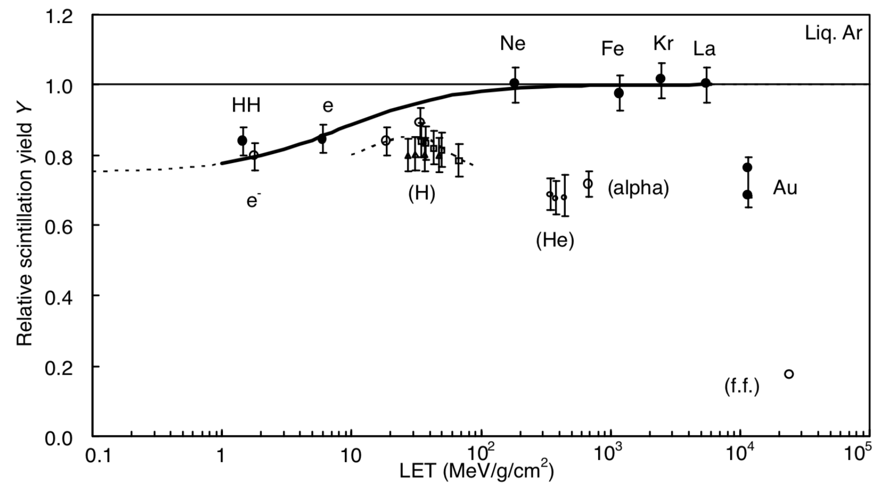
Scintillation Yields: Particle Type

Light yield and fast/slow ratio depend on how ionising the particles are:

- muons: ~24000 photons/MeV, ~ 25% prompt light
- alphas: ~16800 photons/MeV, ~ 60% prompt light

In LArSoft this is configured in larproperties.fcl, ScintByParticleType:

```
ScintByParticleType: true

# Scintillation yields and fast/slow ratios
MuonScintYield:            24000
MuonScintYieldRatio:       0.23
PionScintYield:            24000
PionScintYieldRatio:       0.23
ElectronScintYield:        20000
ElectronScintYieldRatio:   0.27
KaonScintYield:            24000
KaonScintYieldRatio:       0.23
ProtonScintYield:          19200
ProtonScintYieldRatio:     0.29
AlphaScintYield:           16800
AlphaScintYieldRatio:      0.56
```



Particle	τ_S	τ_T	I_S/I_T	Reference
Electron	6.3 ±0.2	1020±60	0.083	Kubota *et al.*[a]
	(5.0±0.2)	(860±30)	(0.045)	(E = 6 kV/cm)[a]
	4.6	1540	0.26	Carvalho and Klein[b]
	4.18±0.2	1000±95		Keto *et al.*[c]
		1110±50		Suemoto and Kanzaki[d]
	6 ±2	1590±100	0.3	This work
α	~5	1200±100		Kubota *et al.*[e]
	4.4	1100	3.3	Carvalho and Klein[b]
	7.1±1.0	1660±100	1.3	This work
F.F.	6.8±1.0	1550±100	3	This work

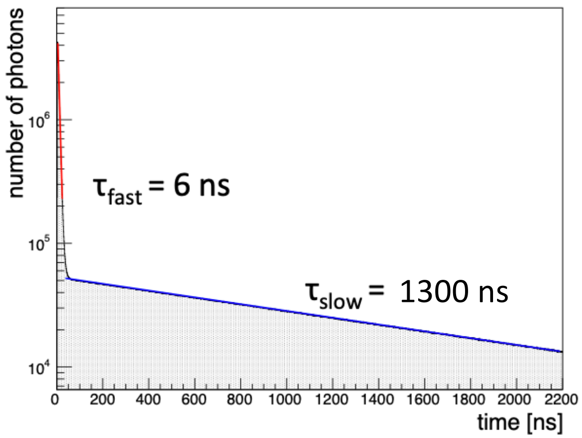
Jpn. J. Appl. Phys. Vol. 41 (2002) pp. 1538–1545;
Ph. Rev. B 27 (1983), 5279

Propagation

Scintillation light propagation

Scintillation (emission):

0.3 x τ_{fast}(6 ns) + 0.7 x τ_{slow} (1300 ns)



$$Q = N_e = N_\mathrm{i} R,$$

$$L = N_\gamma = N_\mathrm{ex} + N_\mathrm{i}(1-R),$$

$$Q + L = N_\mathrm{ex} + N_\mathrm{i} = \frac{\Delta E}{W_\mathrm{ph}}$$

Have properties at emission, now need to evaluate photons that reaches the optical detectors

⇒ **Transport effects**

- 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
- **Rayleigh Scattering affects, in a non negligible way, the light signals in our detectors in comparison with the "pure" emitted scintillation light**
- It is important to understand/model it properly in liquid argon

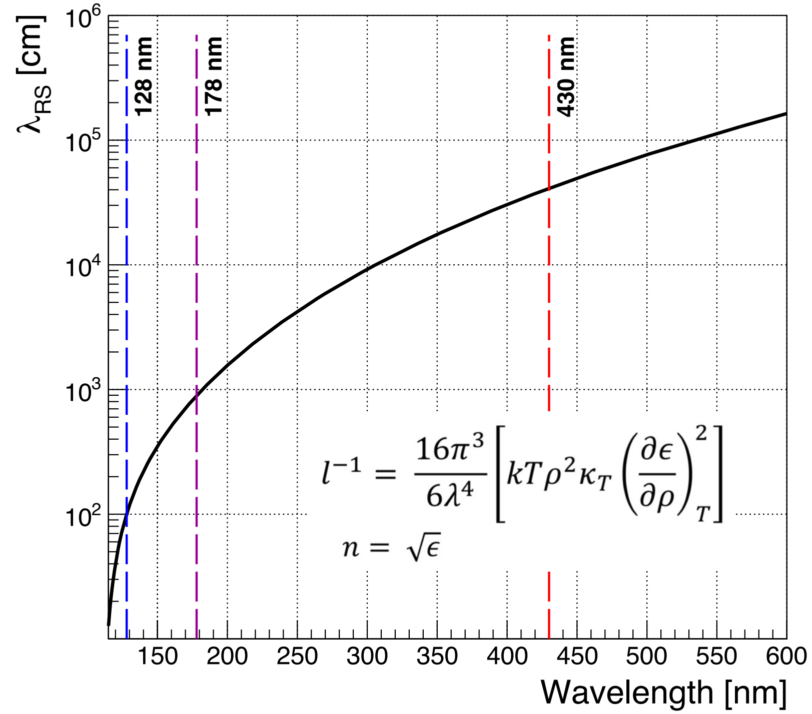
Rayleigh Scattering in Argon

Rayleigh scattering length for VUV photons in Ar measured variously between ~50 – 120 cm

- very hard to measure: small uncertainties in the index of refraction can drastically change the scattering length λ_{RS}
- most recent measurement around 100 cm, adopted by many LArTPC experiments

RS ~100cm < typical size of LArTPC detectors
→ has significant impact on light seen

In LArSoft, parameterized in larproperties.fcl



lardataalg / lardataalg / DetectorInfo / larproperties.fcl

```
# Refractive index as a function of energy (eV) from arXiv:2002.09346
RIndexEnergies: [ 1.18626, 1.68626, 2.18626, 2.68626, 3.18626, 3.68626, 4.18626, 4.68626, 5.18626,
RIndexSpectrum: [ 1.24664, 1.2205, 1.22694, 1.22932, 1.23124, 1.23322, 1.23545, 1.23806, 1.24116, 1

RayleighEnergies: [ 1.18626, 1.68626, 2.18626, 2.68626, 3.18626, 3.68626, 4.18626, 4.68626, 5.18626,
RayleighSpectrum: [ 1200800, 390747, 128633, 54969.1, 27191.8, 14853.7, 8716.9, 5397.42, 3481.37, 23
```

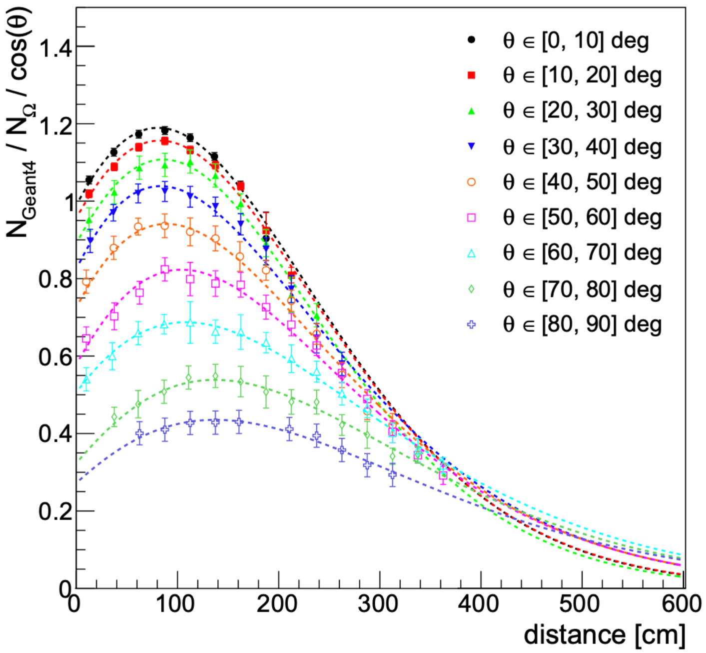
Modelling in fast optical simulation

Optical library / GENN network:

- Encoded in *visibilities* in each voxel directly (sort of) from full optical simulation

Semi-analytical model:

- Treated as a correction to the geometric prediction
- Parameterised based on difference between geometric prediction and full optical simulation
- Also correct for border effects in analogous way (reflections/absorption)



$$N_{\gamma} = N_{\Omega} \times GH'(d, \theta, d_T)/cos(\theta)$$

Eur. Phys. J. C (2021) 81:349

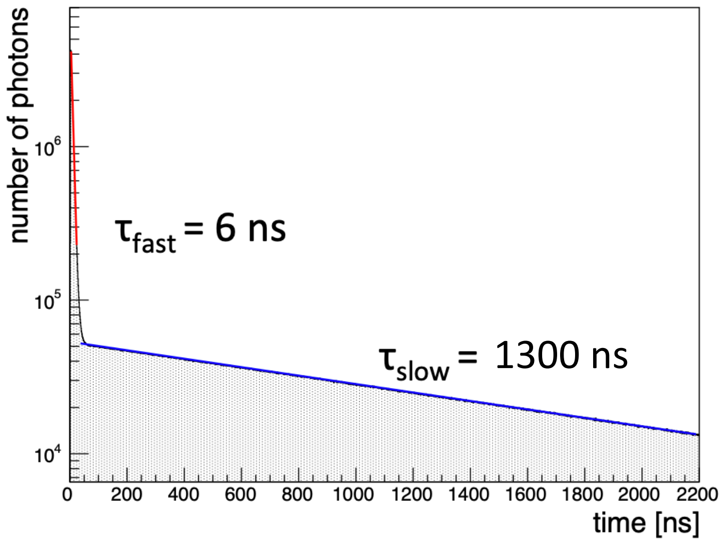
In LArSoft models implemented in larsim:

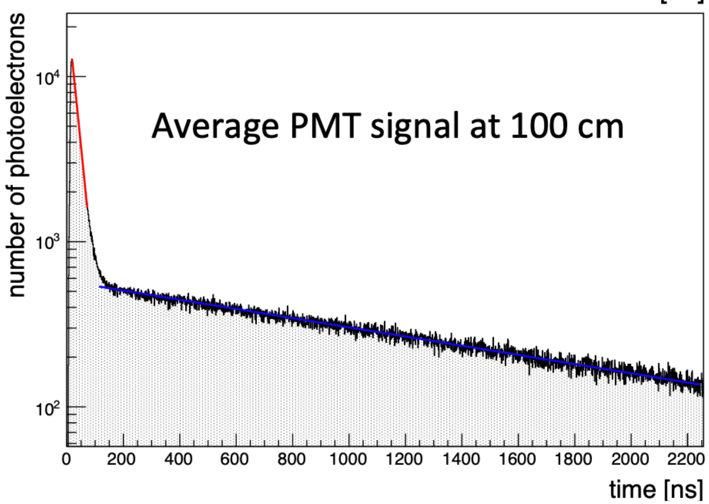
larsim/PhotonPropagation/PDFastSimPVS_module.cc (Library)
larsim/PhotonPropagation/PDFastSimPAR_module.cc (Semi-analytical)

Time structure of detected signals

Scintillation (emission):

$0.3 \times \tau_{fast}(6\ ns) + 0.7 \times \tau_{slow}(1300\ ns)$

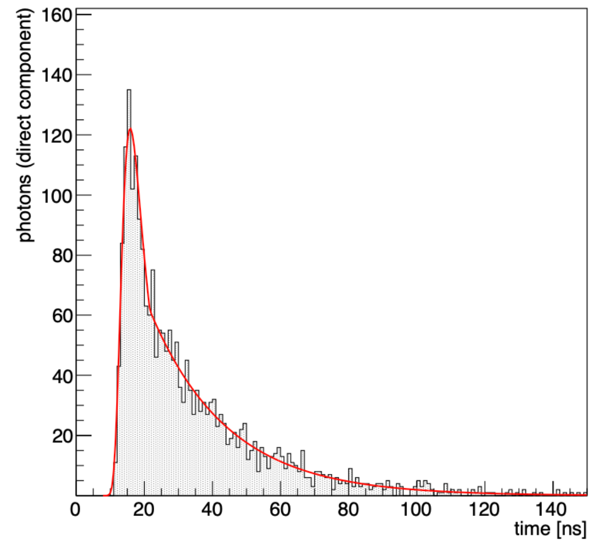




+

Propagation:

Direct transportation + Rayleigh Scattering



=

In "large" detectors transport effects will affect the effective time structure of the detected scintillation light

$$t_\gamma = t_E + t_t(d, \theta) + t_{WLS} + t_{det},$$

t_E = *emission time*

t_t = *transport time*

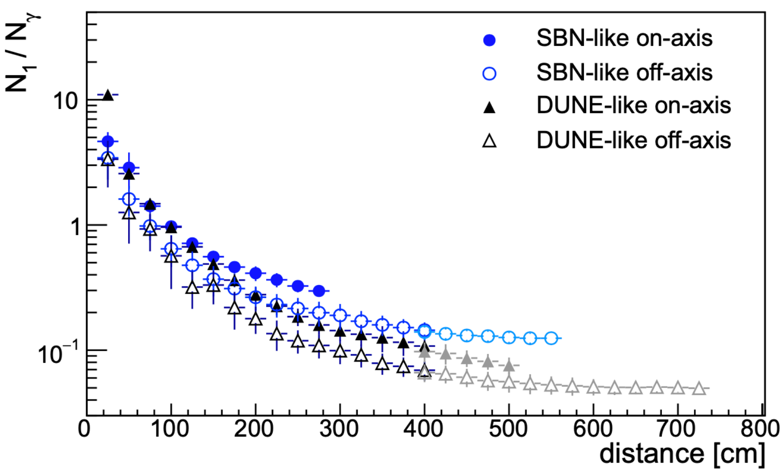
t_{WLS} = *WLS delay time*

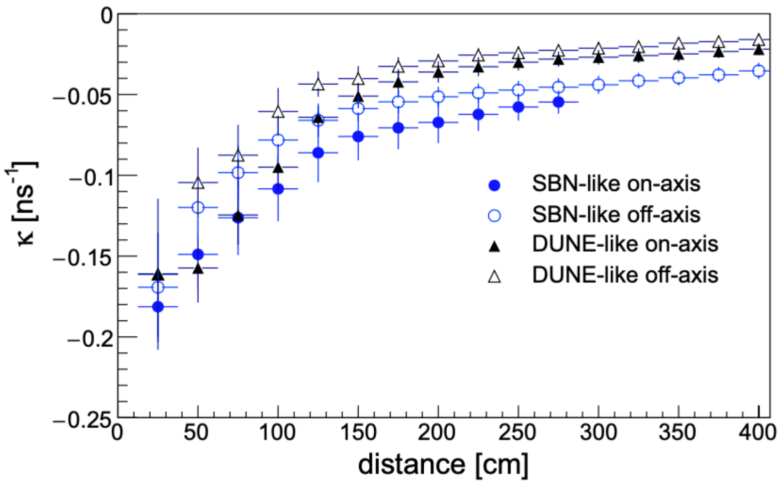
t_{det} = *detector time*

Time structure of detected signals

In fast optical simulation, modelled using parameterisations of Landau + Exponential fits to distributions from full optical simulation

- developed in conjunction with semi-analytical model, but can be used in combination with any approach to get number of photons (library, etc.)





$$t_t(x) = \underbrace{N_1 \frac{1}{\xi} \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} e^{\lambda s + s \log s} \, ds}_{Landau} + \underbrace{N_2 \, e^{\kappa x}}_{Exponential} ,$$

Eur. Phys. J. C (2021) 81:349

larsim / larsim / PhotonPropagation / **PropagationTimeModel.h**

larsim / larsim / PhotonPropagation / **PDFastSimPAR.fcl**

```
IncludePropTime:        true
```

Implementation in SBND

Detector specific

Hybrid approach used in SBND:

- semi-analytical model (hits + timing) inside TPC
- slimmed-down optical library outside TPC

Configuration in SBND:

sbndcode/sbndcode/LarSoftConfigurations/opticalsimparameterisations_sbnd.fcl

```
# ******************************************************************************
#          PARAMETERS SETS FOR SEMI-ANALYTIC SIMULATION ARE DEFINED HERE
# ******************************************************************************

# VUV/DIRECT LIGHT: TIMING PARAMETERISATION

# VUV/DIRECT LIGHT: NUMBER OF HITS CORRECTIONS

# ******************************************************************************
#  VIS semi-analytic model, specific to SBND
# ******************************************************************************

# VISIBLE/REFLECTED LIGHT: TIMING PARAMETERISATION

# VISIBLE/REFLECTED LIGHT: NUMBER OF HITS CORRECTIONS
```

Implementation in DUNE

Hybrid model default approach used in DUNE:

- semi-analytical model (hits + timing) inside TPC
- slimmed-down optical library outside TPC (only available for some geometries)

Detector specific

Configuration in DUNE:

duneopdet/PhotonPropagation/opticalsimparameterisations_dune.fcl

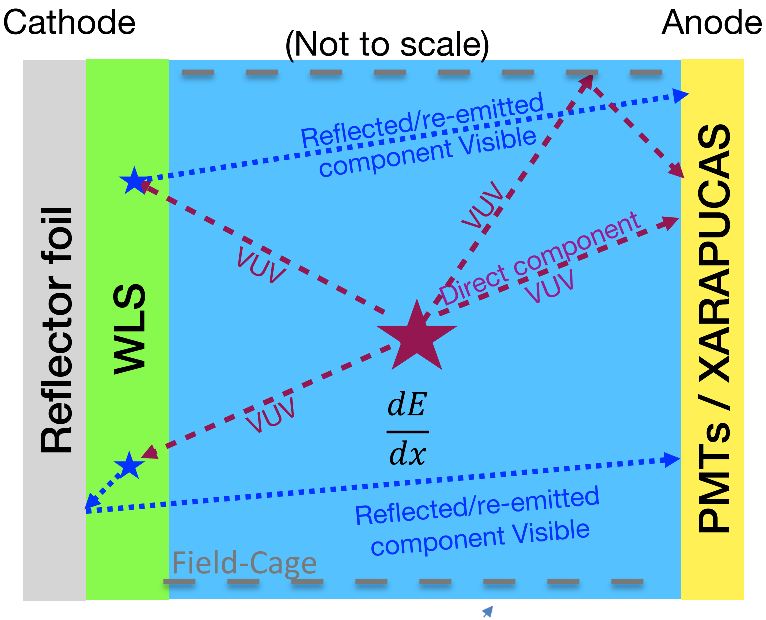
and

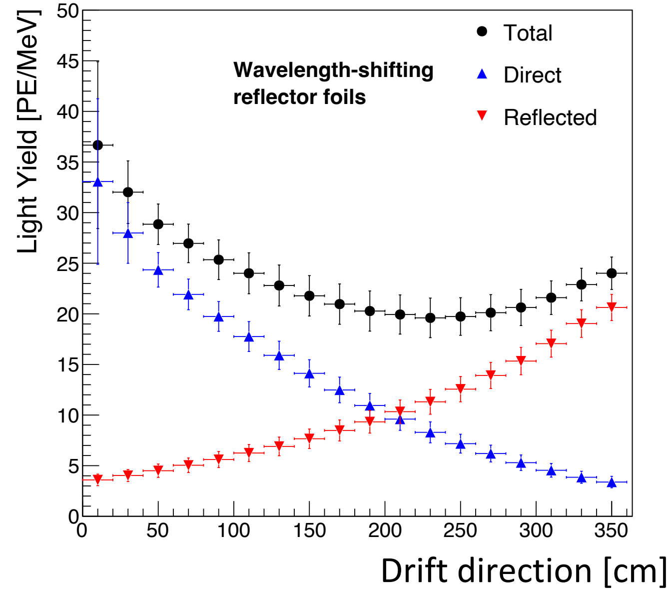
duneopdet/PhotonPropagation/PDFastSim_dune.fcl

```
# ******************************************************************************
#          PARAMETERS SETS FOR SEMI-ANALYTIC SIMULATION ARE DEFINED HERE
# ******************************************************************************

# VUV/DIRECT LIGHT: TIMING PARAMETERISATION

# VUV/DIRECT LIGHT: NUMBER OF HITS CORRECTIONS
```

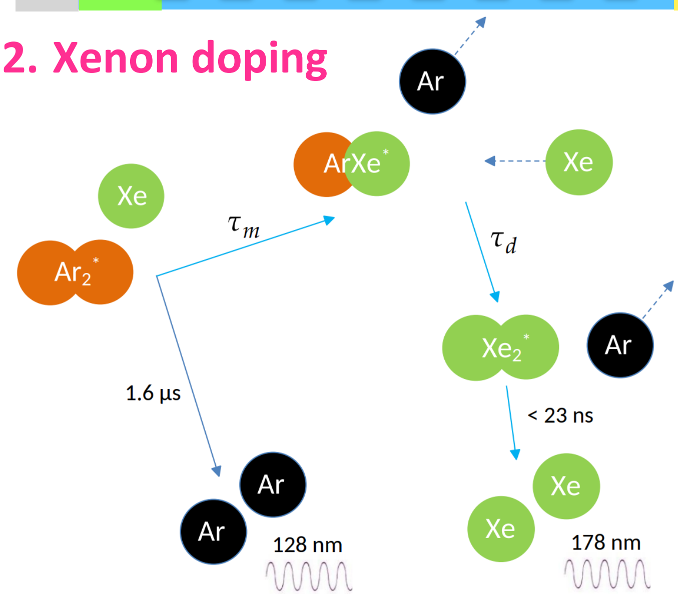
(Aside): Enhancing the Light Yield in LArTPCs

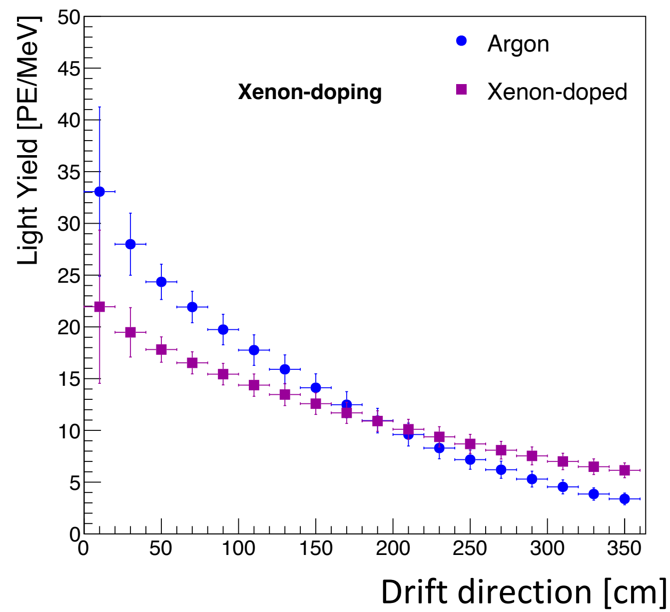
1. WLS-Coated reflector foils





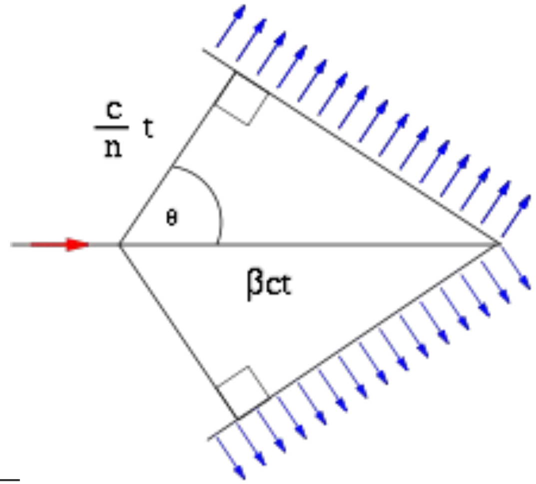
2. Xenon doping





(Aside): Cherenkov radiation in LAr

- A particle propagating in a medium with velocity greater than that of light in the medium produces an electromagnetic shock-wave with conic wavefront
- Photons are emitted with a precise angle with respect to particle direction



NIM A 516 (2004) 348–363

$$\frac{d^2N}{d\nu dx} = \frac{2\pi\alpha}{c}\sin^2\theta_{\check{C}} \qquad \cos\theta_{\check{C}} = \frac{1}{\beta \cdot n_{Ar}(\lambda)}$$

$$\Rightarrow \int_{109nm\,(LAr\ absorbed)}^{600nm\,(hard\ to\ detect)} \qquad R_{\check{C}} = \frac{dN_{\check{C}}/dx}{dN_{scint}/dx + dN_{\check{C}}/dx} = 2.4\%$$

$\Rightarrow$

→ Can be considered a second order effect with respect to scintillation light emission

dunesim/dunesim/Simulation/**larg4services_dune.fcl**

```
EnableCerenkovLight: false # Cerenkov light OFF by default
```

Beware enabling: no fast optical simulation exists, will use very slow full simulation!

Detection

Detecting light in LArTPCs

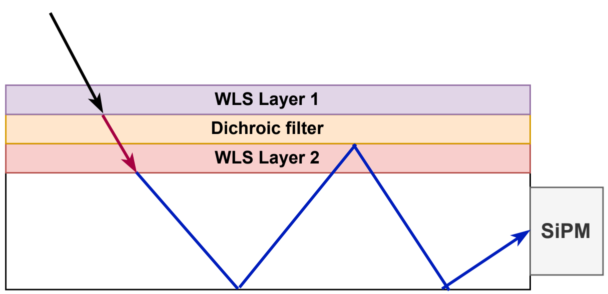
VUV LAr scintillation light is hard to detect directly, absorbed by most materials

- need to make use of wavelength shifters, e.g. TPB, PEN

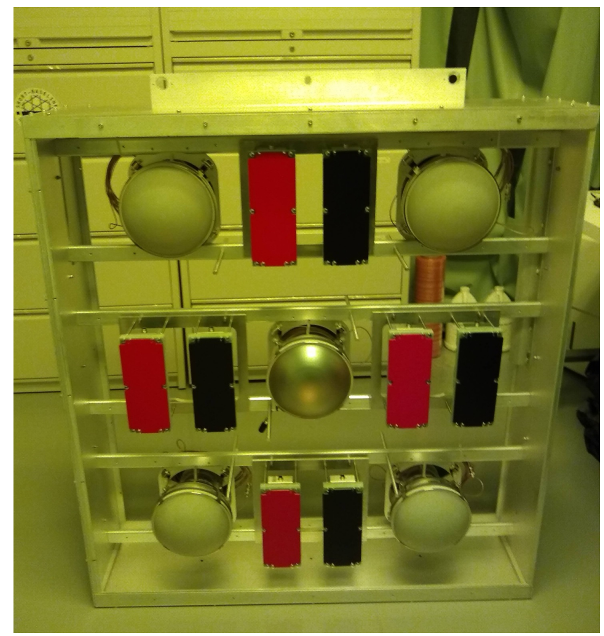
Photon detectors used:

- PMTs coated with WLS (SBND) or with WLS-coated plates in-front of them (MicroBooNE)
- Arapuca/XArapuca wavelength-shifting light traps using SiPMs (DUNE, SBND)

Wavelength shifters emit ~isotropically, lose 50% of light emitted away from photon-detectors



Arapuca operational principle



Photon detection system module in SBND, mixture of PMTs and XArapucas

Wavelength shifter in LArSoft

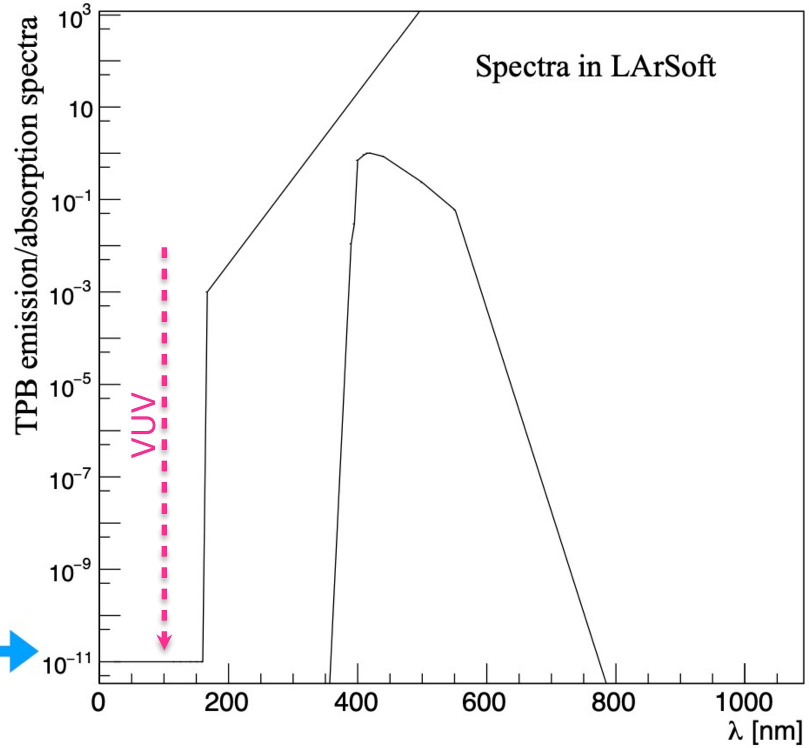
Processes handled by `G4OpWLS`:

- Initial photon killed and a new one created with different wavelength
- User must provide:

• Absorption length as function of photon energy

• Emission spectrum as function of photon energy

• Time delay between absorption and re-emission



The **WLSABSLENGTH** defines the absorption length which is the average distance travelled by a photon before it is absorbed by the TPB.

lardataalg / lardataalg / DetectorInfo / larproperties.fcl

```
# WLS - TPB properties original tpb [0.0, 0.0, 0.0, 0.0588,0.235, 0.853, 1.0,1.0,0.9259,0.704
TpbEmmisionEnergies: [0.05,1.0,1.5, 2.25, 2.481, 2.819, 2.952,2.988,3.024, 3.1, 3.14,3.1807,
TpbEmmisionSpectrum: [0.0, 0.0, 0.0, 0.0588,0.235, 0.853, 1.0,1.0,0.9259,0.704,0.0296,0.011,
TpbAbsorptionEnergies: [0.05,1.77,2.0675, 7.42, 7.75, 8.16, 8.73, 9.78,10.69, 50.39]
TpbAbsorptionSpectrum: [100000.0,100000.0, 100000.0,0.001,0.00000000001,0.00000000001, 0.000
```

Wavelength shifter time delay

TPB has complex time structure:

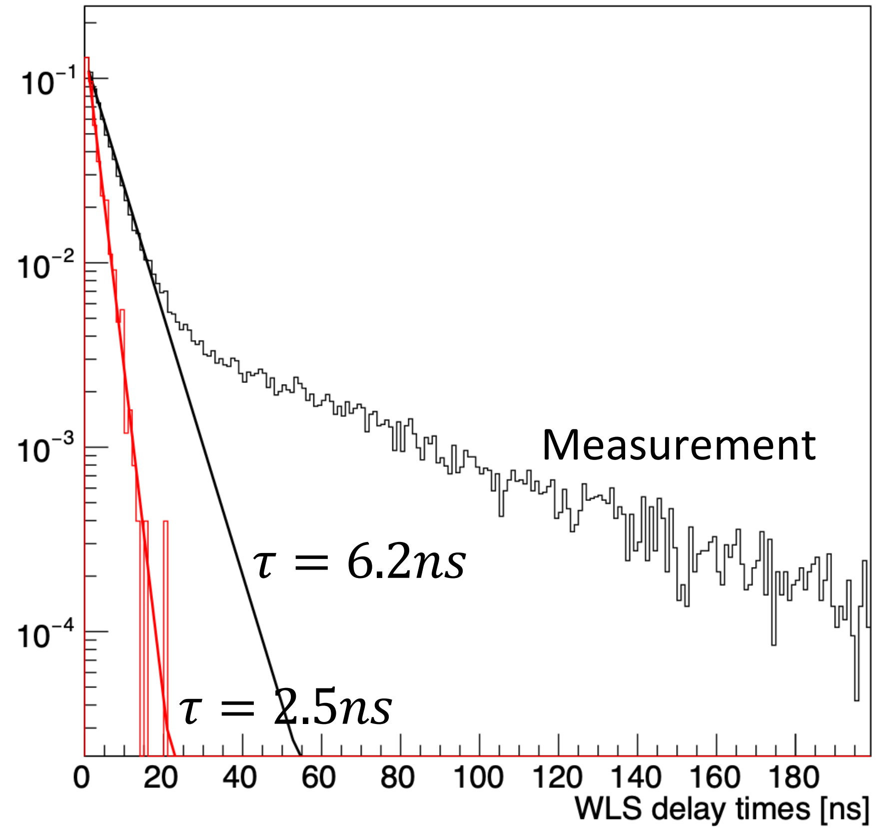
- bulk of light emitted promptly, but non-negligible longer components
- would non-negligibly alter time distribution

Geant4 (G4OpWLS class) only simulates Delta or Exponential model (neither is the case)

Instead, can simulate this separately in LArSoft:

- in SBND this is done in the at the optical detector digitizer stage (slightly hacky)
- sbndcode/sbndcode/OpDetSim/ DigiPMTSBNDAlg.cc
- not currently simulated in DUNE, instead approximated with longer late light time constant

	Decay time (ns)	Abundance (%)
Instantaneous component	1–10	60 ± 1
Intermediate component	49 ± 1	30 ± 1
Long component	3550 ± 500	8 ± 1
Spurious component	309 ± 10	2 ± 1



PHYSICAL REVIEW C **91**, 035503 (2015)

Photon simulation output objects

lardataobj / lardataobj / Simulation / SimPhotons.h

```
// This structure contains all the information per photon
 // which entered the sensitive OpDet volume.

 class OnePhoton
 {
 public:
   OnePhoton();

   bool           SetInSD;
   TVector3       InitialPosition;
   TVector3       FinalLocalPosition; // in cm
   float          Time;
   float          Energy;
   int            MotherTrackID;
 };
```

```
class SimPhotons : public std::vector<OnePhoton>
```

```
class SimPhotonsLite
{
  public:
    SimPhotonsLite();
    SimPhotonsLite(int chan)
      : OpChannel(chan)
    {}

    int   OpChannel;
    std::map<int, int> DetectedPhotons;

    SimPhotonsLite& operator+=(const SimPhotonsLite &rhs);
    const SimPhotonsLite operator+(const SimPhotonsLite &rhs) const;

    bool operator==(const SimPhotonsLite &other) const;
};

// Define a OpDet Hit as a list of OpDet photons which were
// recorded in the OpDet volume.

class SimPhotons : public std::vector<OnePhoton>
```

- `SimPhotons` objects (collections of OnePhoton) save detailed information about each detected photon
- `SimPhotonsLite` objects reduce memory and size at the price of keeping only the number of photons at a time-slot.
- The kind of object you want to save in your simulation is specified in the configuration file by the line:

```
services.LArG4Parameters.UseLitePhotons: true  # false to save SimPhotons
```

Full Optical Sim vs FastSim knobs

Full optical simulation offers full flexibly, but impractical for large scale use

Fast optical simulation inflexible, parameters burned in during training. Needs re-training if detector design / understanding of light changes

	Full Optical Simulation	Fast Optical Simulation
Emission Timing Constants	Tunable	Tunable
Emission Energy Spectrum	Tunable	Burned in, impacts transport
Scintillation Yield	Tunable	Tunable
Rayleigh Scattering	Tunable	Burned in
Transport Time Modeling	Not needed	Burned in, but separate
Material Properties	Tunable	Burned in
OnePhoton vs LitePhotons	Chooseable	Chooseable

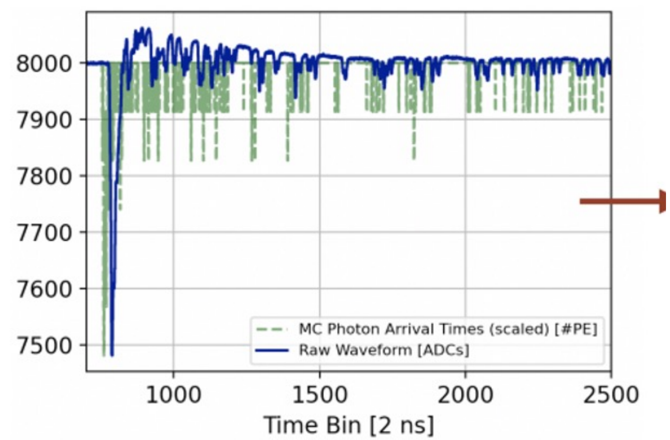
PMT digitisation (SBND example)

Finally, we simulate the resulting waveforms we'd see on the photo-detectors:

- each PE gets swapped for an electronics response, either constructed from parameters (idealised) or from a measured response
- the expected noise is also added to the waveforms

sbndcode / sbndcode / OpDetSim / digi_pmt_sbnd.fcl

```
# Parameters for ideal SER simulation
PMTRiseTime:            3.8        #ns
PMTFallTime:            13.7       #ns
PMTMeanAmplitude:       0.9        #in pC
TransitTime:            55.1       #ns
PMTChargeToADC:         -25.97     #charge to adc factor

# Parameters for test bench SER simulation
PMTSinglePEmodel:       true     #false for ideal PMT respons
PMTDataFile:            "OpDetSim/digi_pmt_sbnd_v2int0.root"
```



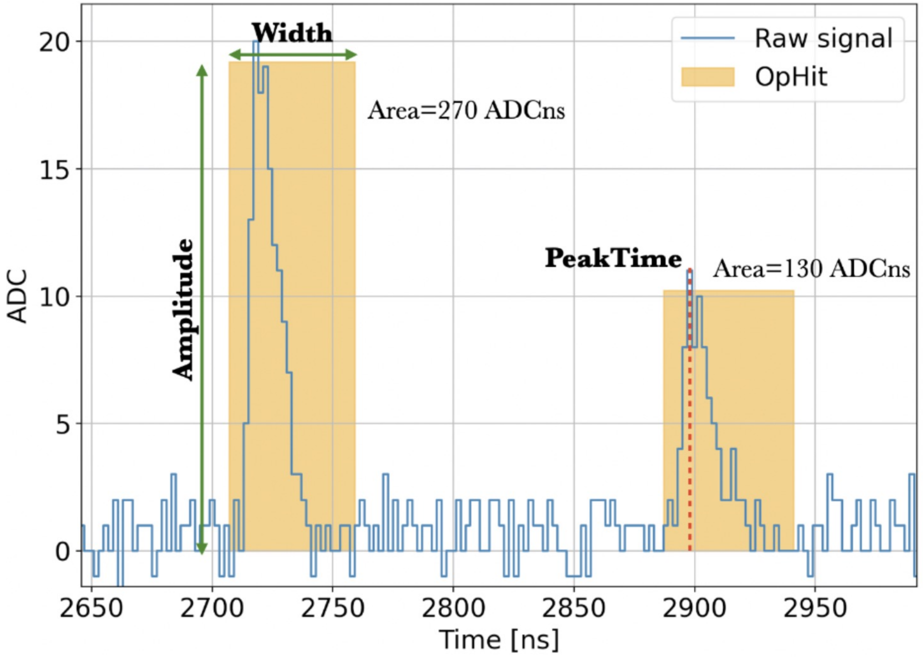
Example PMT waveform in SBND compared with MC photon arrival times:

- undershoot due to AC coupling → bipolar single electron response

Reconstruction

Optical Hits

- First, we look for pulses in the raw (or deconvolved) waveforms
- The light pulses in LArSoft are stored in objects called OpHits
- OpHits are found when the waveform goes above a certain threshold and are held while it continues to be so
- The OpHit Time is decided by the first arriving photon
- This can lead to the merging of visible separate optical signals, especially in the case of SiPMs (in the Arapucas)



lardataobj / lardataobj / RecoBase / OpHit.h

```
int             fOpChannel;
unsigned short  fFrame;
double          fPeakTime;
double          fPeakTimeAbs;
double          fWidth;
double          fArea;
double          fAmplitude;
double          fPE;
double          fFastToTotal;
```

Optical Flashes

Optical hits from different photon detectors that are time-coincident are combined into Optical Flashes:

- these are analogous to clusters in the charge reconstruction, but matched in time rather than space

Having a flash allows us to reconstruct the position of the particles that generated the light (roughly)

This can then be used to match the light signals to the reconstructed TPC tracks -- Flash Matching

lardataobj / lardataobj / RecoBase / OpFlash.h

```
private:

    double                 fTime { 0.0 }; ///< Time on @ref DetectorClocksHardware
    double                 fTimeWidth;    ///< Width of the flash in time [us]
    double                 fAbsTime;      ///< Time by PMT readout clock
    unsigned int           fFrame;        ///< Frame number
    std::vector< double >  fPEperOpDet;   ///< Number of PE on each PMT
    std::vector< double >  fWireCenters;  ///< Geometric center in each view
    std::vector< double >  fWireWidths;   ///< Geometric width in each view
    double                 fXCenter { NoCenter }; ///< Estimated center in x [cm]
    double                 fXWidth { NoCenter }; ///< Estimated width in x [cm]
    double                 fYCenter;      ///< Geometric center in y [cm]
    double                 fYWidth;       ///< Geometric width in y [cm]
    double                 fZCenter;      ///< Geometric center in z [cm]
    double                 fZWidth;       ///< Geometric width in z [cm]
    double                 fFastToTotal;  ///< Fast to total light ratio
    bool                   fInBeamFrame;  ///< Is this in the beam frame?
    int                    fOnBeamTime;   ///< Is this in time with beam?
```

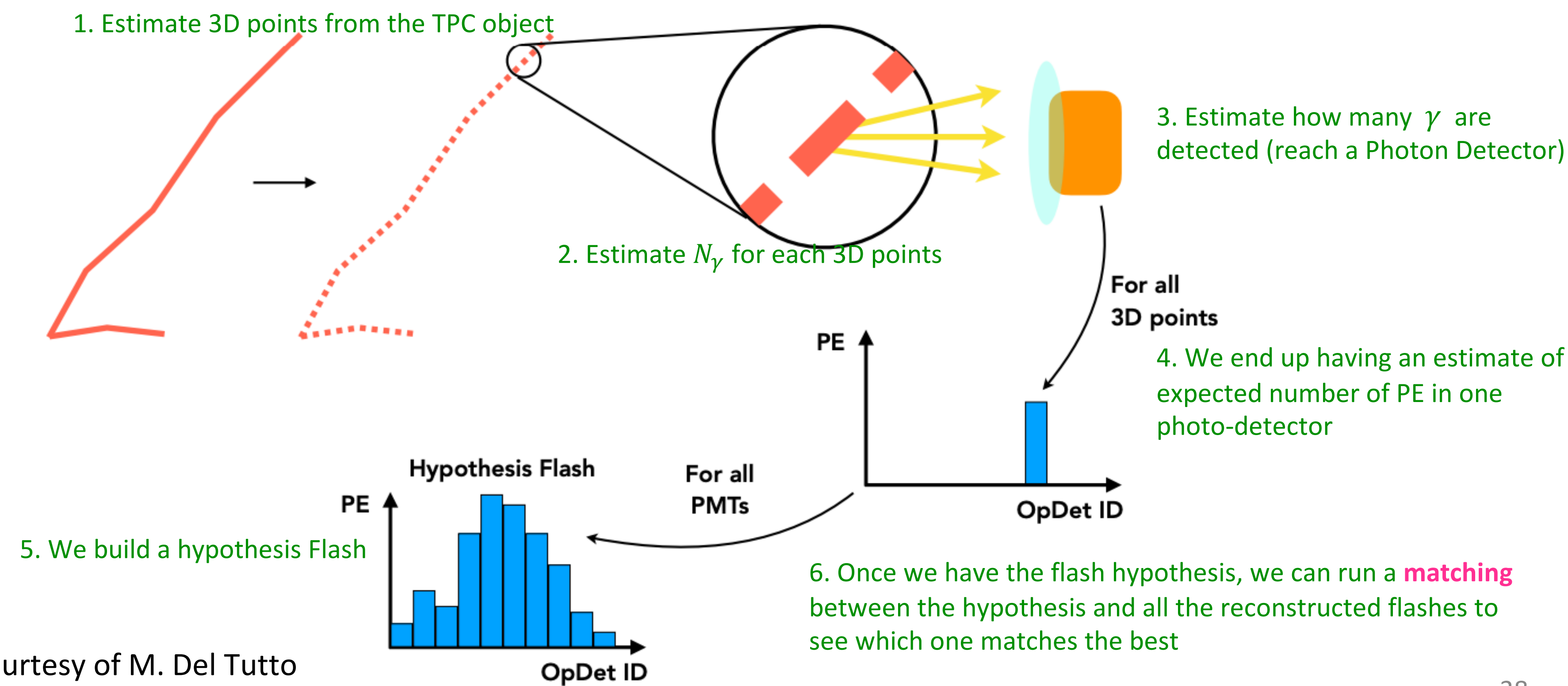
Flash Matching: `OpT0Finder` example

Flash matching goals:

- Distinguish a neutrino interaction from cosmic backgrounds
- Provide T_0 for each TPC interaction

The two ingredients for flash matching:

- Reconstructed Flashes
- TPC Objects (reconstructed objects in the TPC, i.e. Pandora's `recob::Slice`) ⇒ The flash matching code should match a TPC Object with its flash



Courtesy of M. Del Tutto

Summary

- Optical simulation is tricky, need to cut some corners to get it working in LArSoft with reasonable resource usage (size, number of photons -> Memory, CPU).
- Corners are cut, so there is always room for improvement.
- Applications of scintillation light in LArTPCs are not fully developed – always lots of opportunities to do new things.

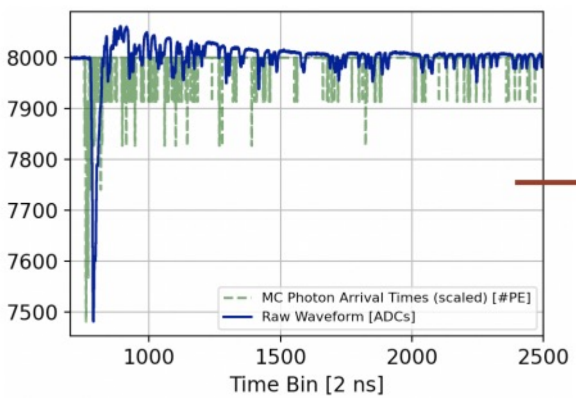
Backups

Light Signal Deconvolution

- In SBND we have PMT (and XARAPUCA) readout with **AC coupling**: bipolar SER ⇒ This makes accurate light reconstruction **a challenge** (by F.J. Nicolás)

➤ OpDeconvolution module (in brief): sbndcode / sbndcode / OpDetReco / **OpDeconvolution** /

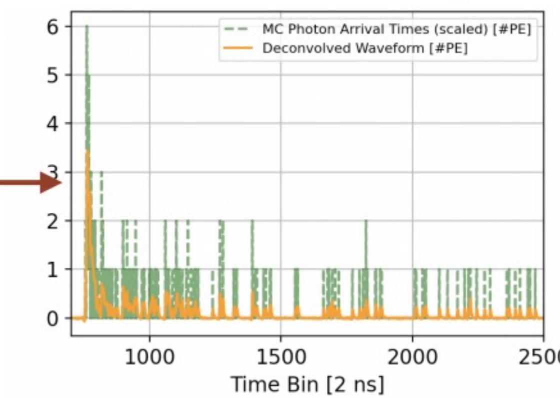
Starts with the **raw::OpDetWaveform** objects (from DetSim stage)



OpDeconvolution module

➤ Methods to:
- ➤ Perform deconvolution (using FFT)
- ➤ Baseline estimator
- ➤ Reduce noise (waveforms smoothing and filtering in the frequency domain)

Produces deconvolved signals (also **raw::OpDetWaveform** objects) to be fed to downstream reco algorithms

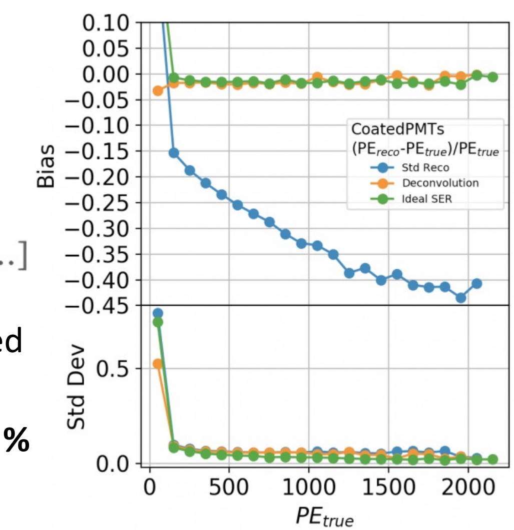


Downstream reconstruction chain:

- Use standard OpHit and OpFlash finder algorithms to recover pulses ⇒ #PE, t0… using the deconvolved signals

- OpHit and OpFlash configuration file with refined parameters for deconvolved waveforms

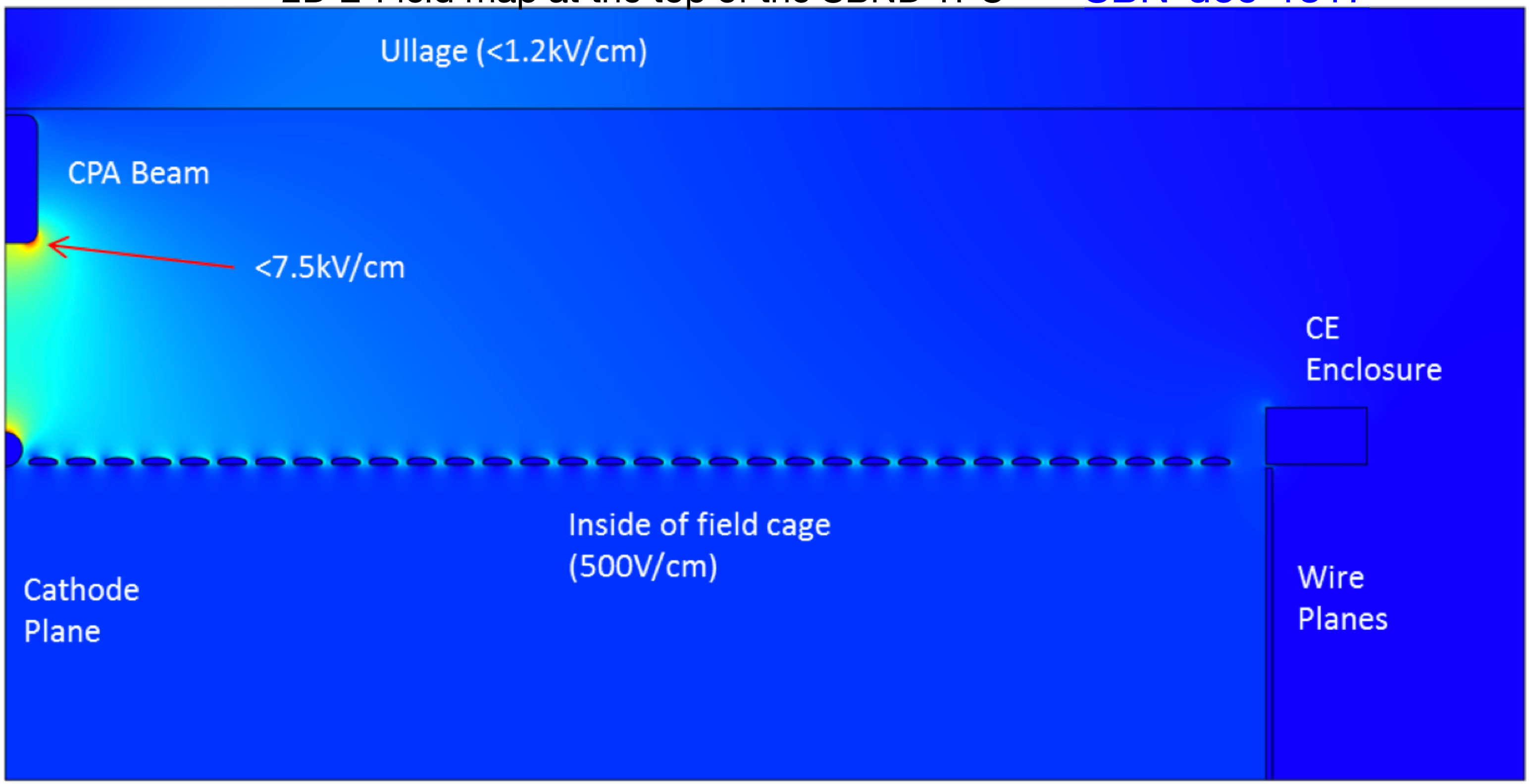
⇒ **Performance: resolution better than ~5% and unbiased at the level of few %**



E-Field map in a TPC (SBND case example)

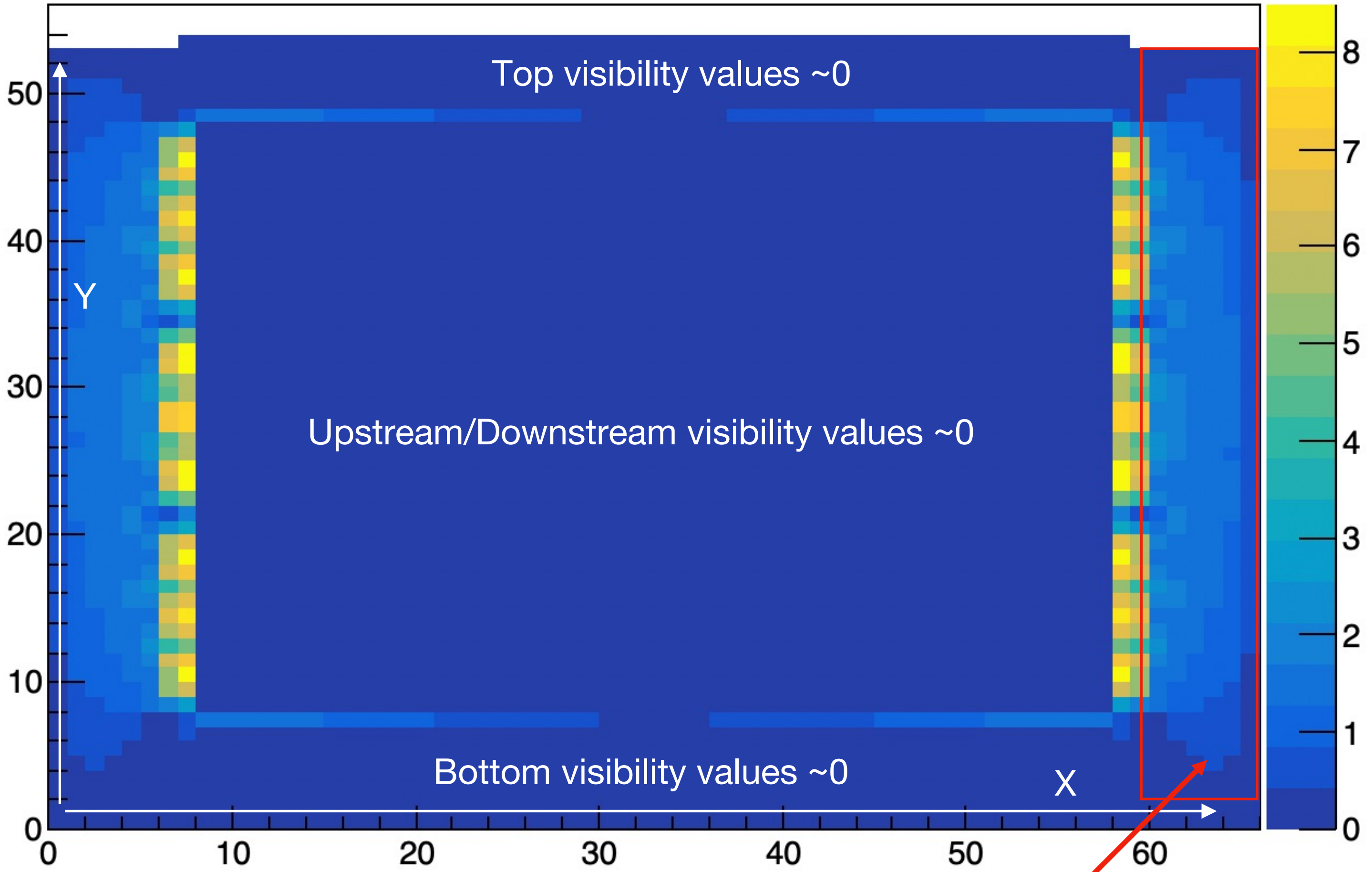
Warning: Light yield strongly depends on the Electric Field value

2D E-Field map at the top of the SBND TPC SBN-doc-1317



- Inside the active volume EF is constant @ 0.5 kV/cm (nominal)
- In the top of the TPC EF values range from few kV/cm at the CPA location decreasing to ~0 at the APA.
- Behind APA (PD-plane) EF = 0 is a good approximation (almost constant)

E-Field x Visibility map in a TPC (SBND case example)



- Only behind APA visibilities are significant
- Current EF model in the hybrid approach: **500V/cm inside the TPC & 0V/cm anywhere else**