PD Simulation Refactoring for new LArG4

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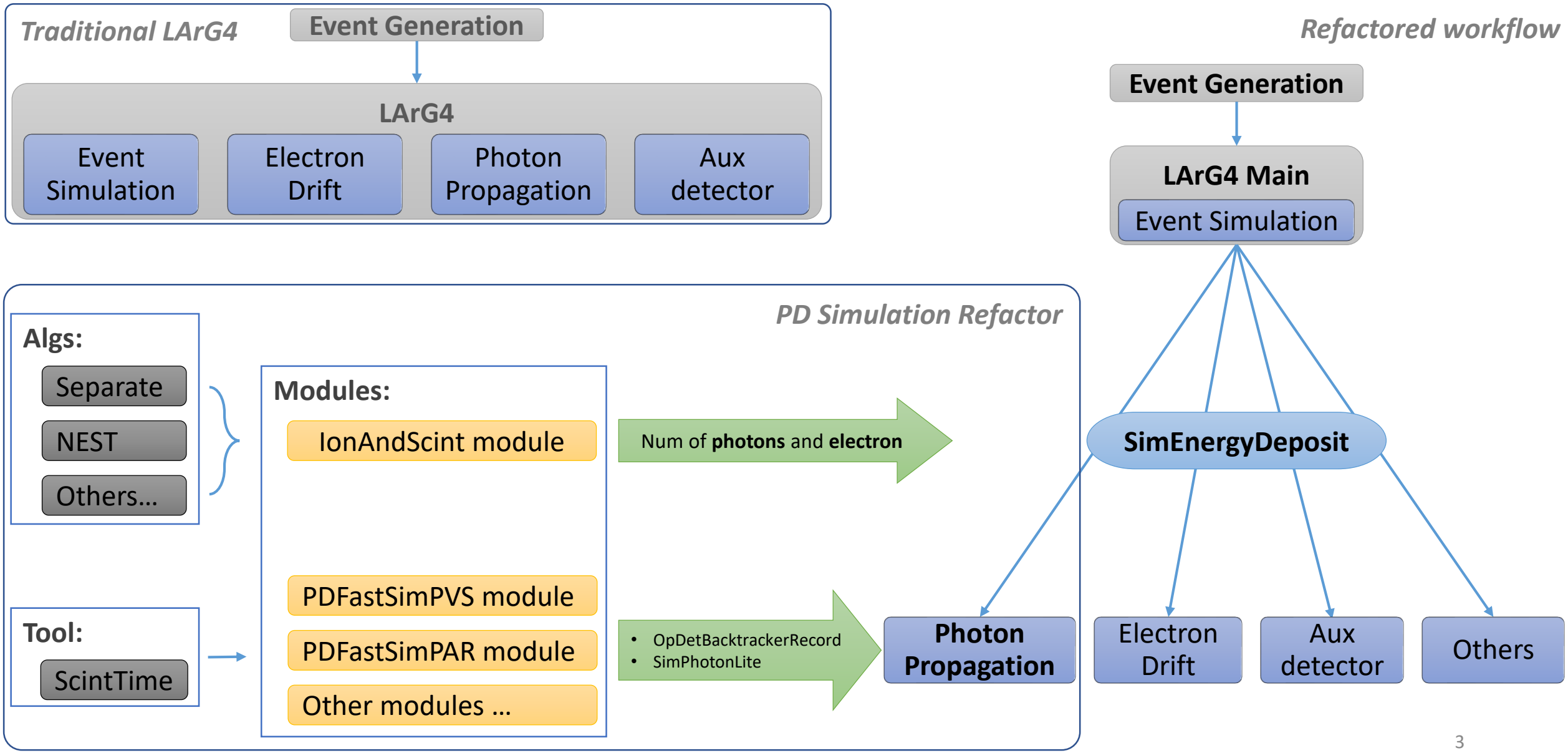
Outline

- Refactored simulation workflow
- Modification being made regarding the refactor
- Preliminary test for the refactored PD simulation modules

Simulation workflow – Refactored model



Status for the refactored PD simulation

feature/**muve_pdsim_refector**

Modified:

- lardataobj/Simulation/**SimEnergyDeposit.h**
- lardataobj/Simulation/classes_def.xml

Update:

- larsim/ElectronDrift/**ShiftEdepSCE_module**.cc
- larsim/ElectronDrift/**SimDriftElectrons_module**.cc
- larsim/LArG4/OpDetPhotonTable.cxx
- larsim/LArG4/OpDetPhotonTable.h
- larsim/LArG4/OpFastScintillation.cxx
- larsim/PhotonPropagation/**PhotonLibraryPropagation_module.cc**
- Larg4/Services/**SimEnergyDepositSD.cc**
- larwirecell/Modules/**BlipMaker_module.cc**

Within the scope of:
larsoft_suite, lardataobj, dunetpc

New

- larsim/IonizationScintillation/**IonAndScint_module.cc**
- larsim/IonizationScintillation/**ISCalcAna_module.cc**
- larsim/PhotonPropagation/**PDFastSimPAR_module.cc**
- larsim/PhotonPropagation/**PDFastSimPVS_module.cc**

- larsim/IonizationScintillation/ISCalc.cxx
- larsim/IonizationScintillation/ISCalc.h
- larsim/IonizationScintillation/ISCalcNESTLAr.cxx
- larsim/IonizationScintillation/ISCalcNESTLAr.h
- larsim/IonizationScintillation/ISCalcSeparate.cxx
- larsim/IonizationScintillation/ISCalcSeparate.h

- larsim/PhotonPropagation/ScintTimeTools/ScintTime_tool.cc
- larsim/PhotonPropagation/ScintTimeTools/ScintTime.h

- larsim/IonizationScintillation/*ISCalc_ana.fcl*
- larsim/PhotonPropagation/*PD_Sim_Chain_Ref.fcl*
- larsim/PhotonPropagation/*PD_Sim_Chain_Tra.fcl*
- larsim/PhotonPropagation/*scintillationtime_tool.fcl*

Status for the refactored PD simulation

feature/**muve_pdsim_refector**

SimEnergyDeposit

New attributes

- numFPhotons
- numSPhotons
- scintYieldRatio

Read: No impact
Write: **Attention** to the interface

New functions

- NumFPhotons()
- NumSPhotons()
- ScintYieldRatio()

```
SimEnergyDeposit(int np = 0,
        int nfp = 0,
        int nsp = 0,
        int ne = 0,
        double sy = 0,
        double e = 0.,
        geo::Point_t start = {0.,0.,0.},
        geo::Point_t end = {0.,0.,0.},
        double t0 = 0.,
        double t1 = 0.,
        int id = 0,
        int pdg = 0)
  : numPhotons(np)
  , numFPhotons(nfp)
  , numSPhotons(nsp)
  , numElectrons(ne)
  , scintYieldRatio(sy)
  , edep(e)
  , startPos(start)
  , endPos(end)
  , startTime(t0)
  , endTime(t1)
  , trackID(id)
  , pdgCode(pdg)
{
} « end SimEnergyDeposit »
```

Status for the refactored PD simulation

feature/**muve_pdsim_refector**

IonAndScint module

Modules

- IonAndScint
- ISCalc_ana

Algorithms

- ISCalcNESTLAr
- ISCalcSeparate

Template for new algorithm

- ISCalc

```
IonAndScint:
{
    module_type:            "IonAndScint"
    SimulationLabel:        "largeant:LArG4DetectorServicevolTPCActive"
    ISCalcAlg:              "NEST"
    ISCalcAlg:              "Separate"
}
```

```
class ISCalc
{
public:
    ISCalc();
    virtual ~ISCalc();
    virtual void      Initialize()                                          = 0;
    virtual void      Reset()                                               = 0;
    virtual void      CalcIonAndScint(sim::SimEnergyDeposit const& edep)    = 0;
    virtual double    EFieldAtStep(double efield, sim::SimEnergyDeposit const& edep)  = 0; //value

    double            EnergyDeposit() const                 {return fEnergyDeposit;}
    double            NumOfElectrons() const                {return fNumIonElectrons;}
    double            NumOfPhotons() const                  {return fNumScintPhotons;}
    double            NumOfFastPhotons() const              {return fNumFastScintPhotons;}
    double            NumOfSlowPhotons() const              {return fNumSlowScintPhotons;}
    double            ScintillationYieldRatio() const       {return fScintillationYieldRatio;}

protected:
    double  fEnergyDeposit;            // total energy deposited in the step
    double  fNumIonElectrons;          // number of ionization electrons for this step
    double  fNumScintPhotons;          // number of scintillation photons for this step
    double  fNumFastScintPhotons;      // number of fast scintillation photons for this step
    double  fNumSlowScintPhotons;      // number of slow scintillation photons for this step
    double  fScintillationYieldRatio;  // liquid argon scintillation yield ratio
} « end ISCalc » ;
```

Status for the refactored PD simulation

feature/**muve_pdsim_refector**

Photon Propagation

Modules

- PDFastSimPAR
- PDFastSimPVS

Tool

- ScintTime

```
PDFastSim:
{
   module_type:              "PDFastSimPVS"
   module_type:              "PDFastSimPAR"

   SimulationLabel:          "IonAndScint:NEST"
   SimulationLabel:          "IonAndScint:Separate"

   DoSlowComponent:          "true"
   ScintTimeTool:            @local::ScintTimeTool
}
```

```
ScintTimeTool:
{
    tool_type: ScintTime
    LogLevel:   1
    P1:         0.0          // PureLAr: rising time of fast scintillation
    P2:         6.0          // PureLAr: decay time of fast scintillation
    P3:         0.0          // PureLAr: rising time of slow scintillation
    P4:         1600.0       // PureLAr: decay time of slow scintillation
    P5:         1
    Material:   "PureLAr"
    Material:   "XeDopedLAr"
}
```

Status for the refactored PD simulation

feature/**muve_pdsim_refector**

```
class ScintTime
{
public:
    ScintTime(fhicl::ParameterSet const& pset);
    double GetScintTime(bool is_fast, CLHEP::HepRandomEngine& engine);

private:
    int           LogLevel;

    // parameters for the shape of argon scinitllation light time distribution
    double         par1;                        // PureLAr: rising time of fast LAr scinitllation;    XeDopedLAr:
    double         par2;                        // PureLAr: decay time of fast LAr scintillation;     XeDopedLAr:
    double         par3;                        // PureLAr: rising time of slow LAr scinitllation;    XeDopedLAr:
    double         par4;                        // PureLAr: decay time of slow LAr scintillation;     XeDopedLAr:
    double         par5;                        // reserved

    std::string    Mat;                         // scintillation medium: PureLAr or XeDopedLAr

    // general functions
    double single_exp(double t, double tau2);
    double bi_exp(double t, double tau1, double tau2);

    // functions for scintillation timing calculation
    double LAr_Scint(bool is_fast, CLHEP::RandFlat& randflatscinttime);

    // add more (customized) functions below
    double LAr_Xe_Scint(bool is_fast, CLHEP::RandFlat& randflatscinttime);
} « end ScintTime » ;
```

Add functions here:
Random number generation based on the time spectrum

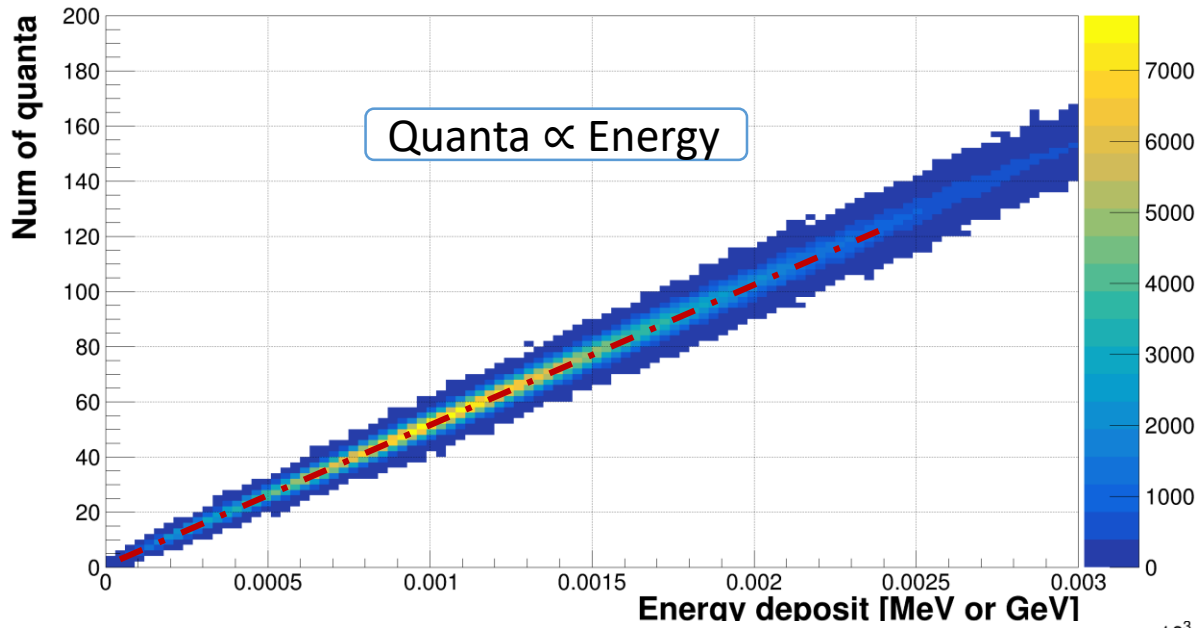
Verification of customized IS calculation - NESTLAr

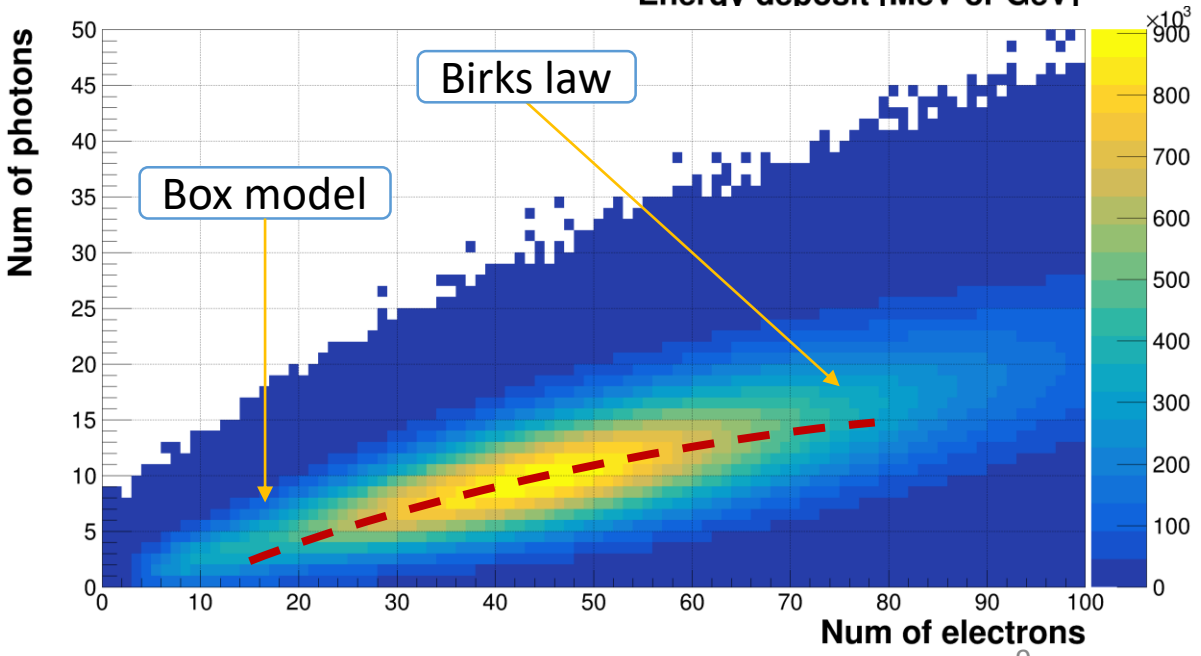
Function verification ← done

- ❑ Num of quanta proportional to energy deposit
- ❑ Correlation between electrons and photons

Accuracy verification ← to be measured

- ❑ Work function
- ❑ Quenching factor
- ❑ Anticorrelation between electrons and photons
- ❑ …





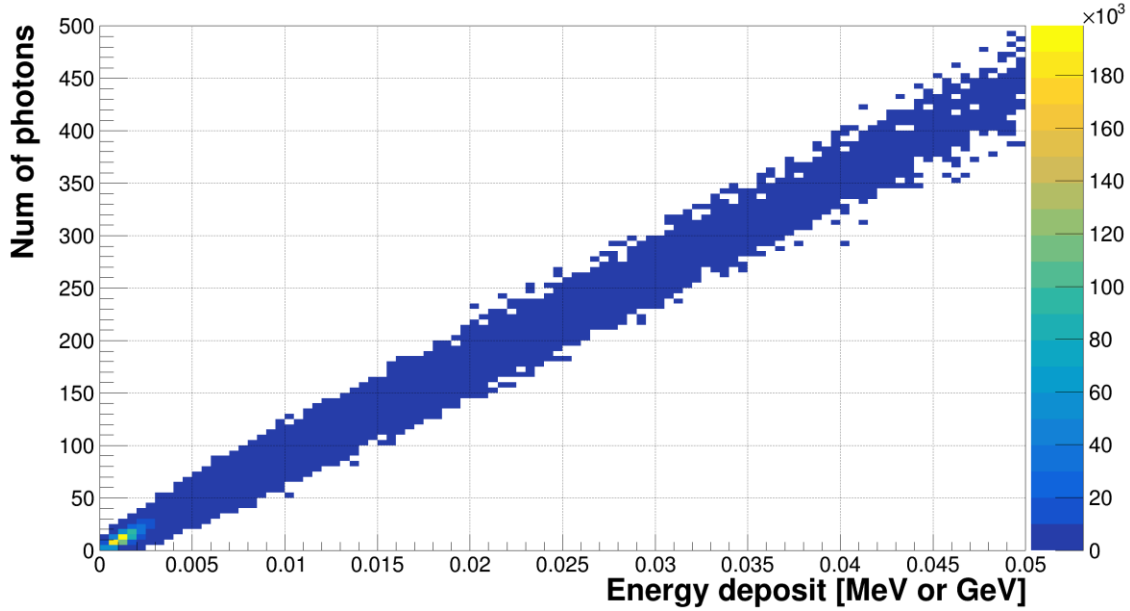
Verification of customized IS calculation - NESTLAr

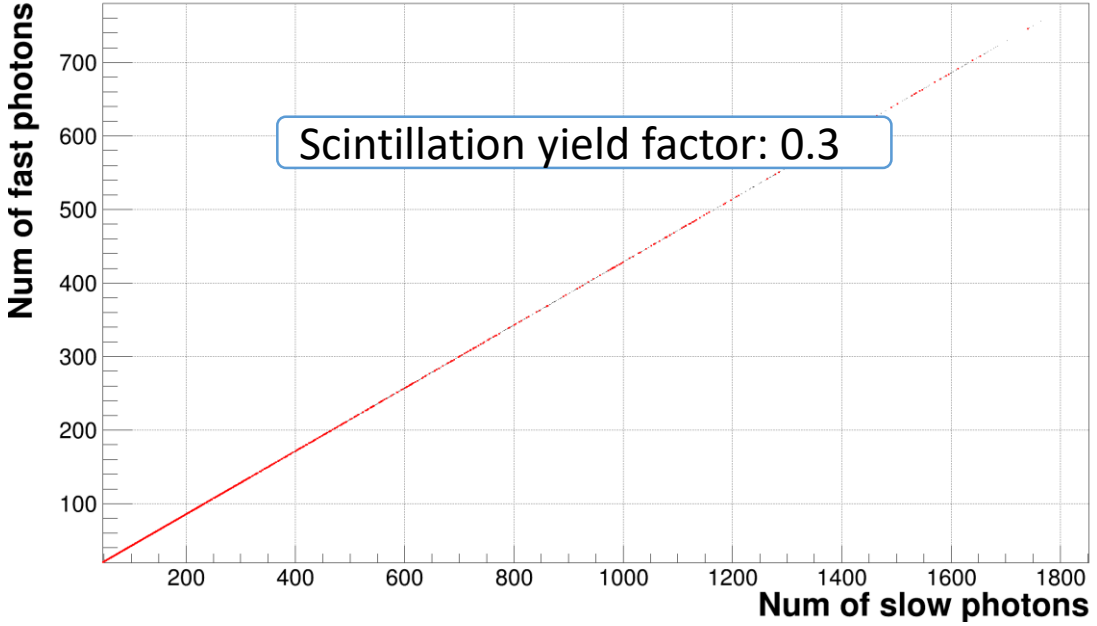
Function verification ← done

- ❑ Num of photons proportional to energy deposit
- ❑ Scintillation yield factor

To make it more accurate

- ❑ Scintillation yield factor based on LAr purity?
- ❑ …





Test of the PD simulation

Event generation: 6 GeV muons (/dune/data/users/wmu/output/protodune_muon.fcl)

Simulation

Refactored

- /fcl/PD_Sim_Chain_REF.fcl
- Geometry: protodune_v5_refactored_nowires
- Service: protodunev4_photonvisibilityservice

Event simulation: LArG4Main

IS calc: IonAndScint (***NESTLAr/Separate***)

PD simulation: PDFastSimPVS

Traditional

- /fcl/PD_Sim_Chain_TRA.fcl
- Geometry: protodune_v5_refactored_nowires
- Service: protodunev4_photonvisibilityservice
- IS calculation: ***NEST/Separate***
- PD simulation: photon visibility service

Data analysis:

- SimPhotonCounter module: **SimPhotonCounter**
- DumpOpDetBacktrackerRecords: **DumpOpDetBacktrackerRecords**

Refactored PD simulation workflow

```
services.PhotonVisibilityService:                    @local::protodunev4_photonvisibilityservice
services.LArG4Parameters.UseLitePhotons:             true
physics:
{
    producers:
    {
        //retain largeant name for compatibility
        largeant:
        {
            module_type:            "larg4Main"
            enableVisualization:     false
            macroPath:               ".:./macros"
            visMacro:                "vis.mac"
        }

        IonAndScint:
        {
            module_type:            "IonAndScint"
            SimulationLabel:         "largeant:LArG4DetectorServicevolTPCActive'
//            ISCalcAlg:               "NEST"
            ISCalcAlg:               "Separate"
        }

        PDFastSim:
        {
           module_type:             "PDFastSimPVS"
//           module_type:               "PDFastSimPAR"

//           SimulationLabel:           "IonAndScint:NEST"
           SimulationLabel:          "IonAndScint:Separate"

           DoSlowComponent:          "true"
           ScintTimeTool:            @local::ScintTimeTool
        }

        rns:
        {
            module_type:            "RandomNumberSaver"
        }

    }
```

Event simulation

IS calculation

IS calc algorithm

PD simulation

Scint time produce

Refactored

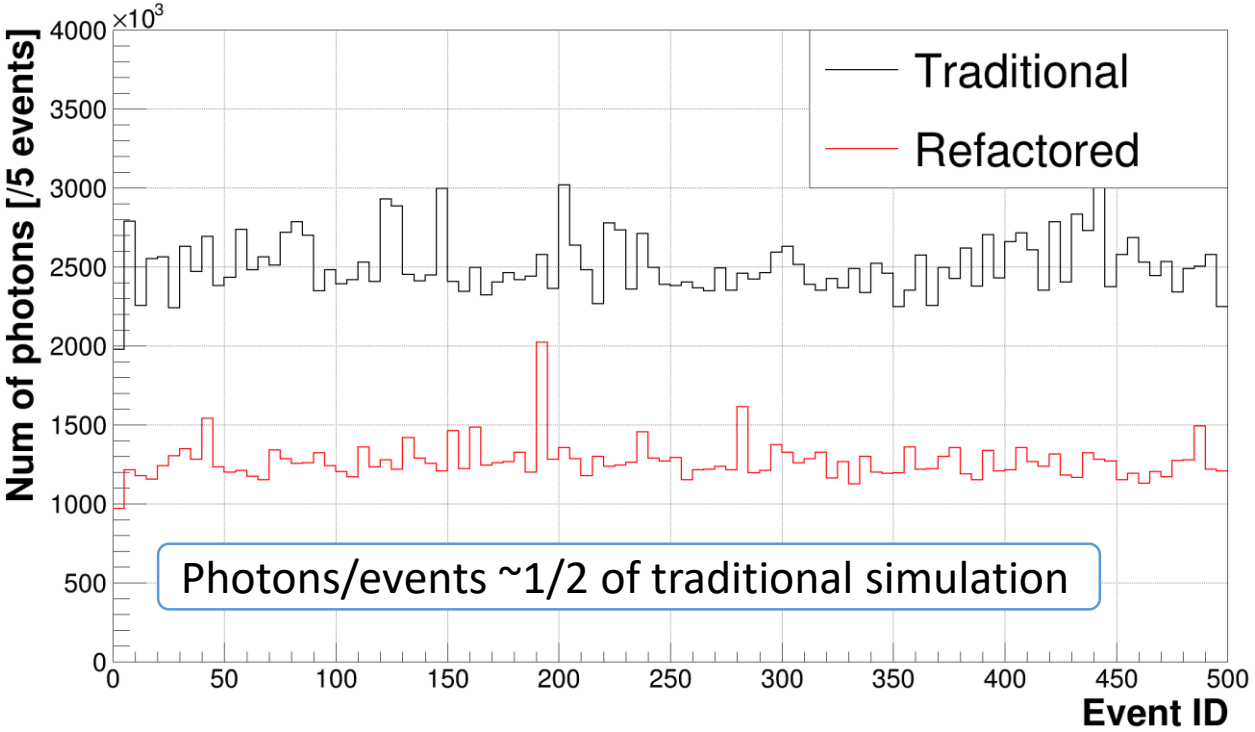
```
services.PhotonVisibilityService:                    @local::protodunev4_photonvisibilityservice
services.LArG4Parameters.FillSimEnergyDeposits:      true
services.LArG4Parameters.UseLitePhotons:             true
services.LArG4Parameters.IonAndScintCalculator:      "NEST"

physics:
{

    producers:
    {
        largeant: @local::standard_largeant
        rns:      { module_type: "RandomNumberSaver" }
    }
```

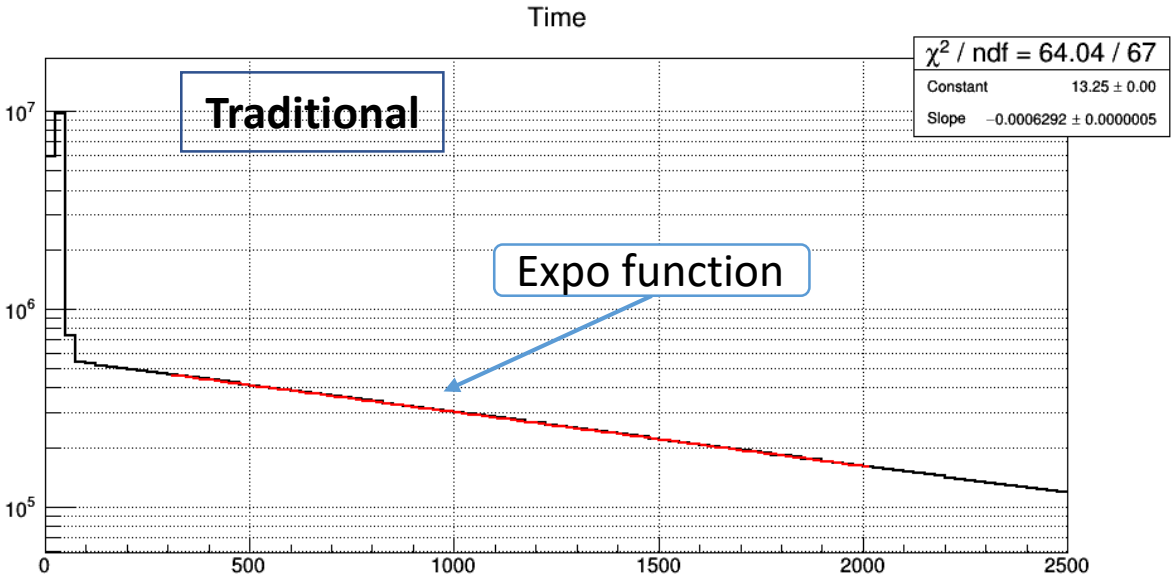
Traditional

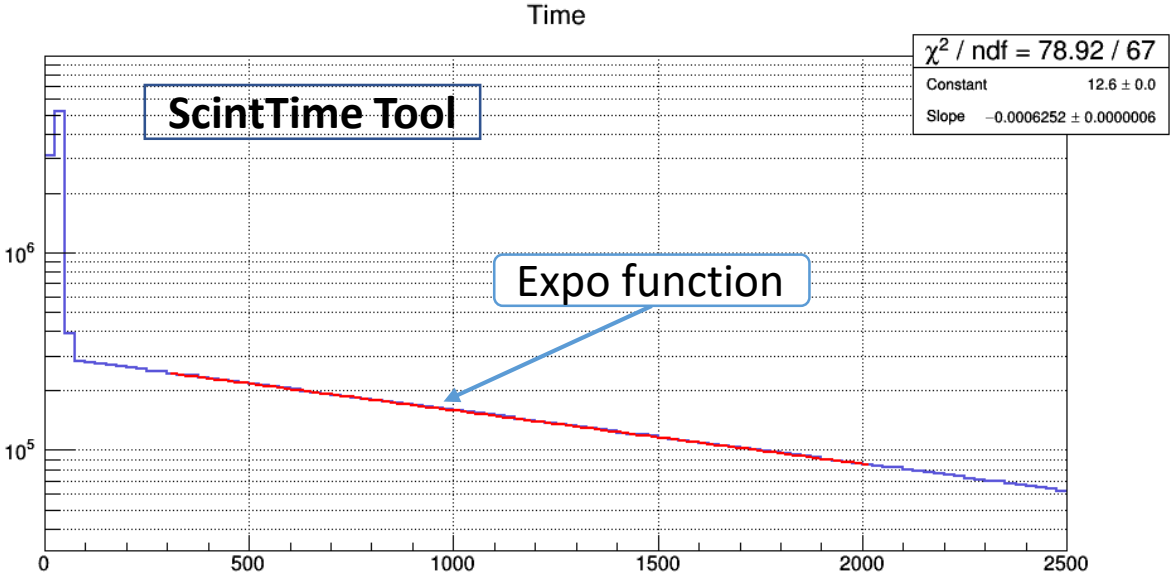
Event simulation
IS calculation
Photon simulation
Electron simulation
…

Comparisons - NEST

To check whether or not the refactored PD simulation behaves the same as the traditional PD simulation.

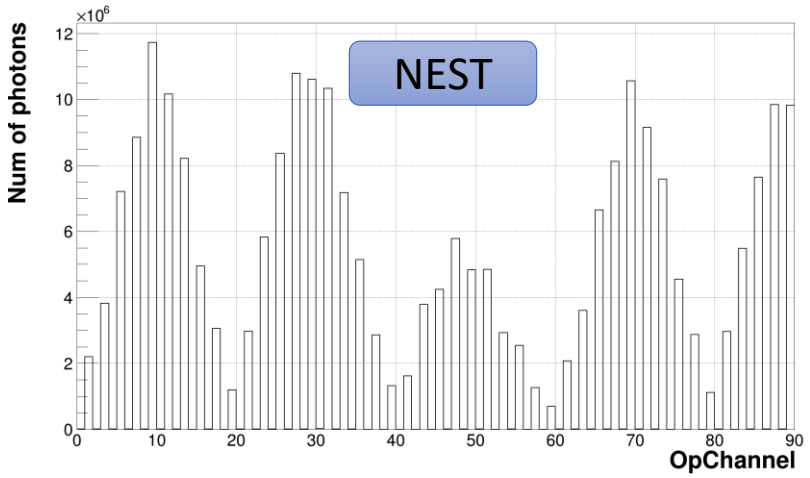






Comparisons - NEST

Traditional



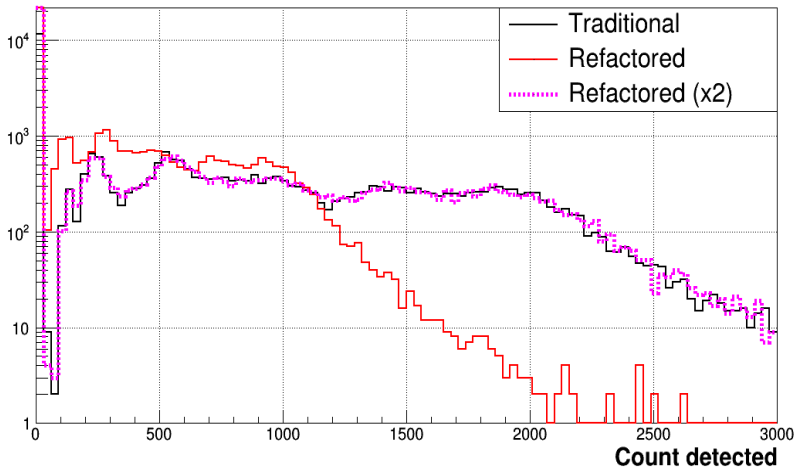
Different

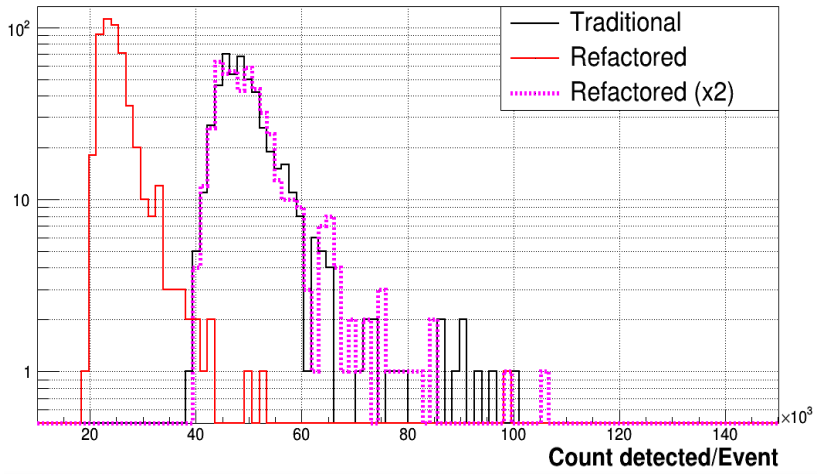
- ❑ Num of photons/channel ← *different IS calc algorithm*

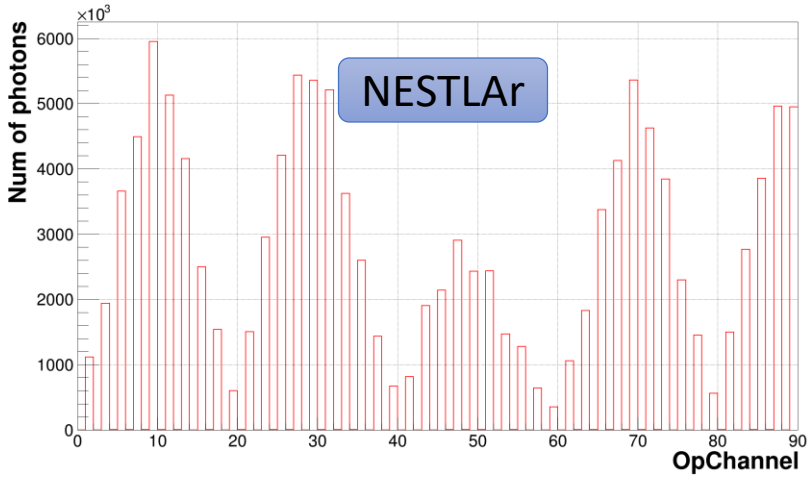
Identical

- ❑ Hit Pattern ← *same photon visibility service*

Refactored

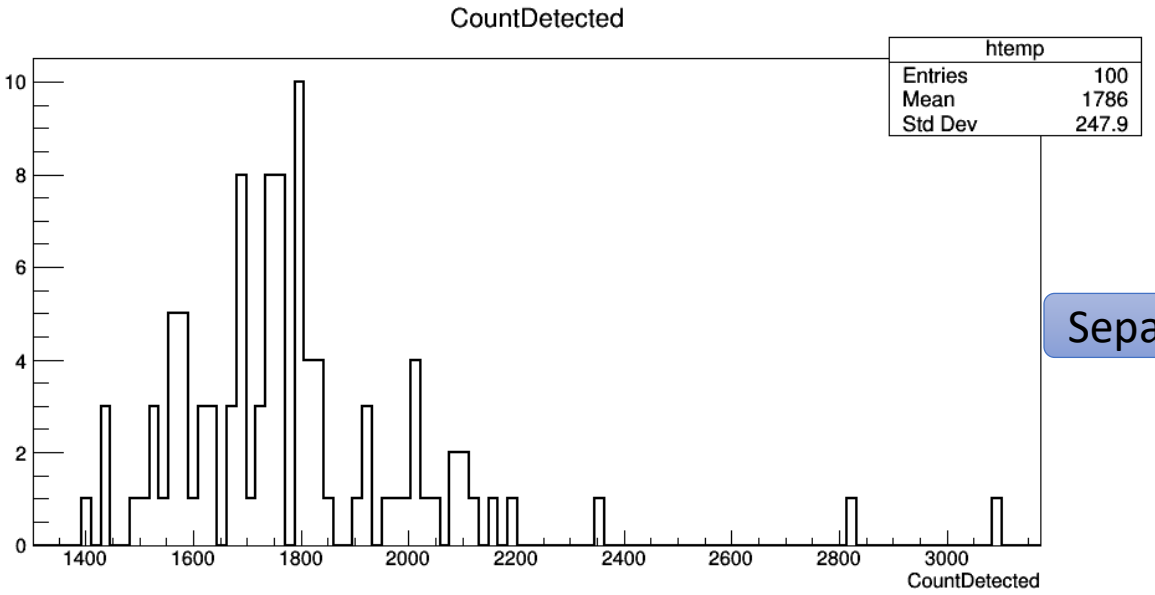




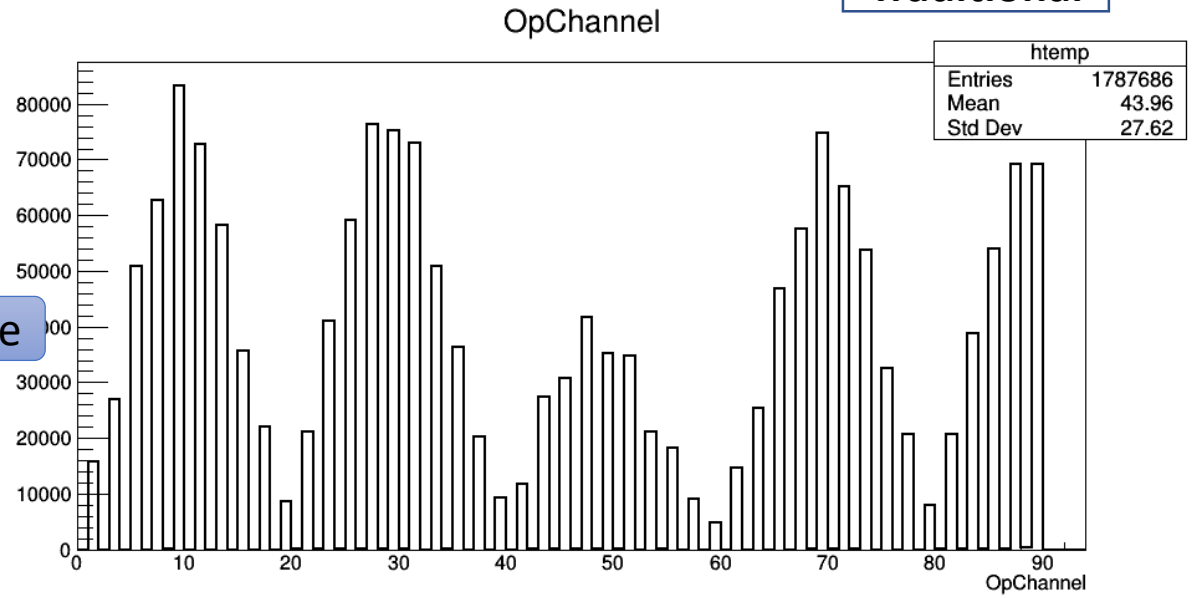


Comparisons - Separate

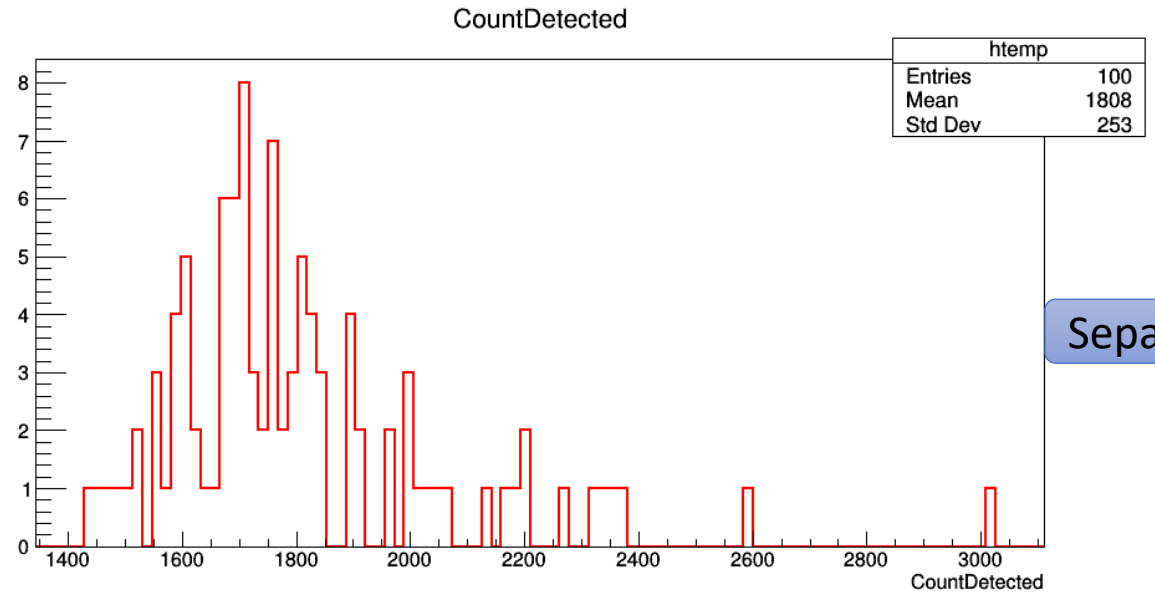
Traditional



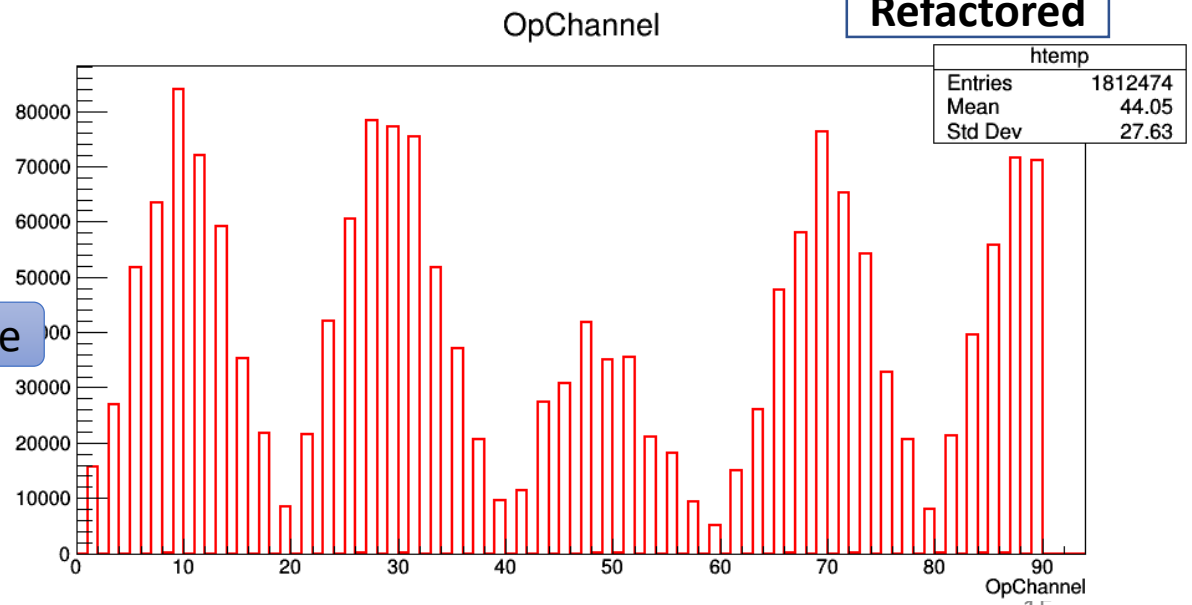
Separate



Refactored



Separate



Conclusion

- The general functions of refactored PD simulation are ready;
- The framework for ion/scint calculation algorithm based on customized scintillation and ionization process is setup, more features can be introduced based on the measurement;
- The framework for different scintillation time spectra customization is ready, more functions can be implemented based on theory or measurement

Performance

Traditional

TimeTracker printout (sec)	Min	Avg	Max	Median	RMS	nEvts
Full event	1.11353	**1.42688**	7.40342	1.35197	0.351473	500
source:RootInput(read)	0.000160229	0.000222149	0.00199898	0.000188864	0.000177647	500
simulate:rns:RandomNumberSaver	2.97E-05	4.27E-05	0.000255171	3.95E-05	1.24E-05	500
simulate:largeant:LArG4	0.960195	**1.24694**	7.22227	1.17688	0.334198	500
[art]:TriggerResults:TriggerResultInserter	1.55E-05	1.99E-05	8.99E-05	1.81E-05	7.08E-06	500
end_path:out1:RootOutput	4.02E-06	5.36E-06	3.25E-05	4.85E-06	2.00E-06	500
end_path:SimPh:SimPhotonCounter	0.0125384	0.0155078	0.0349295	0.0149767	0.00222159	500
end_path:out1:RootOutput(write)	0.129282	0.163927	0.311172	0.155701	0.027348	500

Refactored

TimeTracker printout (sec)	Min	Avg	Max	Median	RMS	nEvts
Full event	19.9151	**23.5643**	64.7467	22.654	3.41722	500
source:RootInput(read)	0.000353222	0.00103867	0.0117735	0.000931529	0.00072863	500
simulate:rns:RandomNumberSaver	3.34E-05	4.40E-05	0.000596761	3.90E-05	3.78E-05	500
simulate:largeant:larg4Main	4.99001	5.95891	12.2898	5.82788	0.601505	500
simulate:IonAndScint:IonAndScint	1.15368	1.4506	4.17135	1.38401	0.237032	500
simulate:PDFastSimPVS:PDFastSimPVS	5.22251	6.33678	18.8219	6.08039	1.00276	500
[art]:TriggerResults:TriggerResultInserter	1.72E-05	2.46E-05	0.000617209	2.05E-05	3.76E-05	500
end_path:out1:RootOutput	4.00E-06	5.64E-06	2.80E-05	5.13E-06	2.01E-06	500
end_path:ISCalcAna:ISCalcAna	2.00605	2.86237	7.88696	2.66712	0.532126	500
end_path:SimPh:SimPhotonCounter	0.109091	0.160912	0.5473	0.148256	0.0380358	500
end_path:out1:RootOutput(write)	5.51305	6.79283	21.028	6.45885	1.22719	500