

# ProtoDUNE-SP TPC analysis updates and paper status

Tingjun Yang (FNAL)

DUNE Collaboration Phone Call

Nov 8, 2019

# Introduction

- In this talk, I will give an update on the ProtoDUNE-SP TPC analysis. Flavio will cover the photon detector updates later.
- Forming of new task forces
  - Simulation TF
  - EM-shower TF
- Improved understanding of LAr properties
  - Diffusion
  - Electron lifetime
- Paper status (TPC sections)

# New Task Forces

- Simulation TF – convener: Wenqiang Gu
  - Integrate refactorized larg4
  - Integrate wire-cell simulation
  - Wenqiang give a nice report at this week's DRA meeting. Some results will be highlighted in this talk.
- EM-shower TF – convener: Aaron Higuera
  - Track/shower identification
  - Electron energy resolution
  - $\text{Pi}^0$  mass reconstruction
  - Great progress as well.

# Refactorized Larg4

- New interface to Geant4 developed by Hans Wenzel (FNAL)
  - Easy access to reference physics lists + extensions
  - Updated OpticalPhysics in G4
    - Scintillation properties are attached to the materials
    - Can have any number of scintillating materials (e.g. LAr and plastic scintillator)
- Simulation of all detector components is being migrated to the new framework
  - TPC: Dave Rivera
  - Photon detector: Wei Mu
  - CRT: Richie Diurba, Dave Rivera

## Configurable (fhicl) options in physics list service

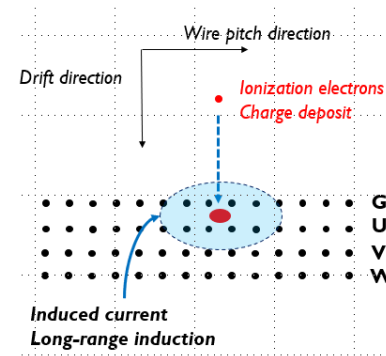
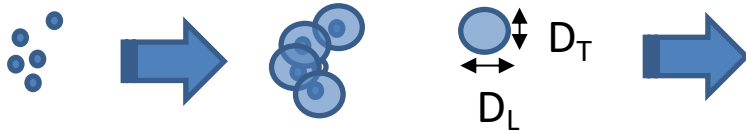
```
19 artg4tk::PhysicsListService::PhysicsListService(fhicl::ParameterSet const & p, art::ActivityRegistry &) :
20   PhysicsListName_( p.get<std::string>("PhysicsListName", "FTFP_BERT")),
21   DumpList_( p.get<bool>("DumpList", false)),
22   enableNeutronLimit_(p.get<bool>("enableNeutronLimit", true)),
23   NeutronTimeLimit_(p.get<double>("NeutronTimeLimit", 10. *microsecond)),
24   NeutronKinLimit_(p.get<double>("NeutronKinLimit", 0.0)),
25   enableStepLimit_(p.get<bool>("enableStepLimit", true)),
26   enableOptical_(p.get<bool>("enableOptical", true)),
27   enableCerenkov_( p.get<bool>("enableCerenkov", false)),
28   CerenkovStackPhotons_( p.get<bool>("CerenkovStackPhotons", false)),
29   CerenkovMaxNumPhotons_(p.get<int>(" CerenkovMaxNumPhotons", 100)),
30   CerenkovMaxBetaChange_(p.get<double>("CerenkovMaxBetaChange", 10.0)),
31   CerenkovTrackSecondariesFirst_( p.get<bool>("CerenkovTrackSecondariesFirst", false)),
32   enableScintillation_( p.get<bool>("enableScintillation", true)),
33   ScintillationStackPhotons_( p.get<bool>("ScintillationStackPhotons", false)),
34   ScintillationByParticleType_( p.get<bool>("ScintillationByParticleType", true)),
35   ScintillationTrackInfo_( p.get<bool>("ScintillationTrackInfo", false)),
36   ScintillationTrackSecondariesFirst_( p.get<bool>("ScintillationTrackSecondariesFirst", false)),
37   enableAbsorption_( p.get<bool>("enableAbsorption", false)),
38   enableRayleigh_( p.get<bool>("enableRayleigh", false)),
39   enableMieHG_( p.get<bool>("enableMieHG", false)),
40   enableBoundary_( p.get<bool>("enableBoundary", false)),
41   enableWLS_( p.get<bool>("enableWLS", false)),
42   BoundaryInvokeSD_( p.get<bool>("BoundaryInvokeSD", false)),
43   verbosityLevel_( p.get<int>("Verbosity", 0)),
44   WLSProfile_( p.get<std::string>("WLSProfile", "delta"))
```

} Ready to be tested

In progress

# WireCell TPC simulation

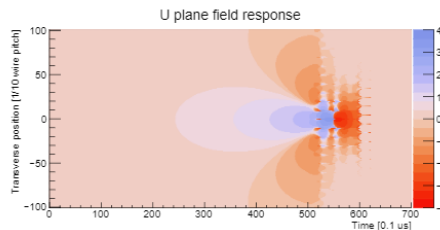
Wenqiang Gu



<SimEnergyDeposit>

\* x, y, z, t, # of e

- Ionized electron absorption (lifetime in LAr)
- Gaussian random diffusion (longitudinal/transverse)  $\sigma^2 = 2Dt$
- Fluctuation in electron absorption



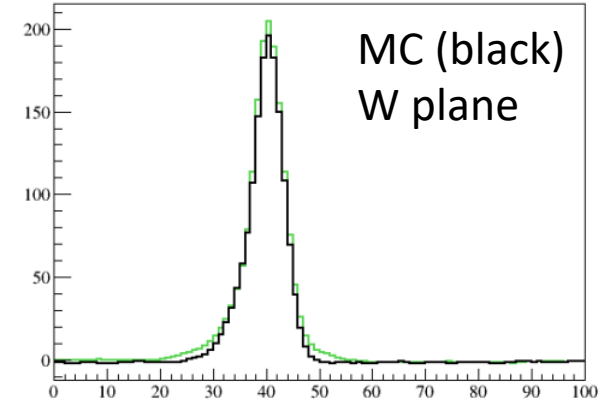
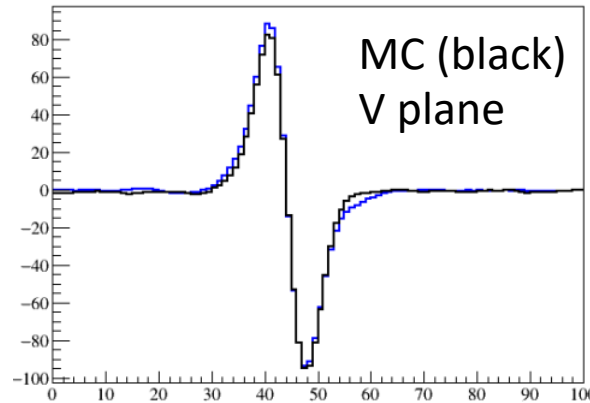
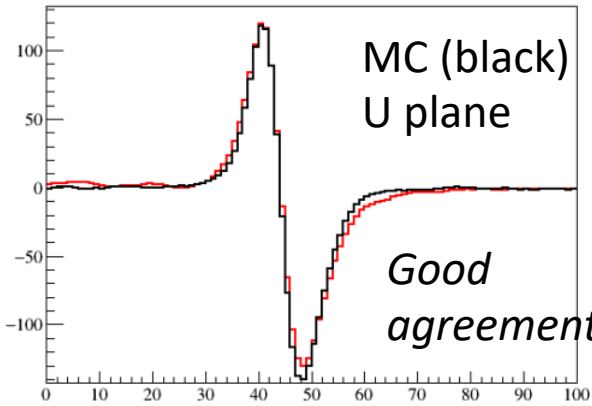
- Electronics response
- Preamp shaping
- AC coupling
- Noise
- Digitizer

[More reading: DUNE collaboration meeting, May 2019](#)

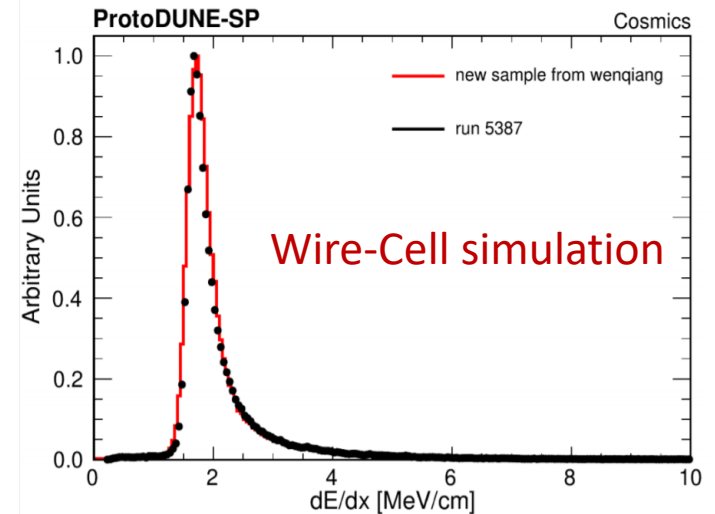
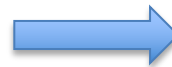
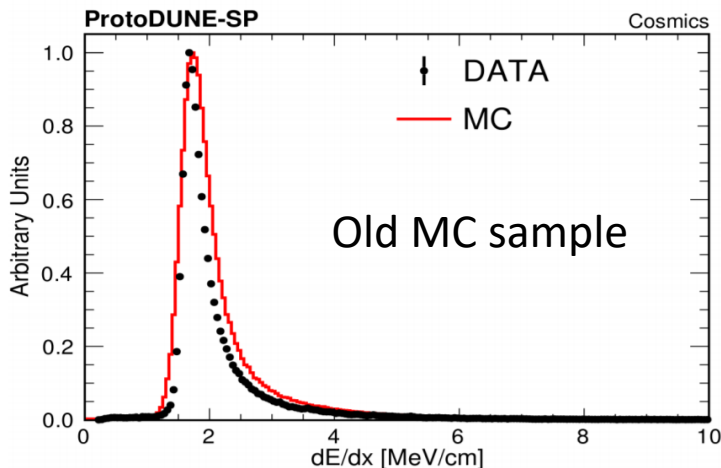
# Improved TPC signal simulation

Wenqiang Gu  
Ajib Paudel

Raw waveforms



Cosmic muon  $dE/dx$



# Diffusion studies

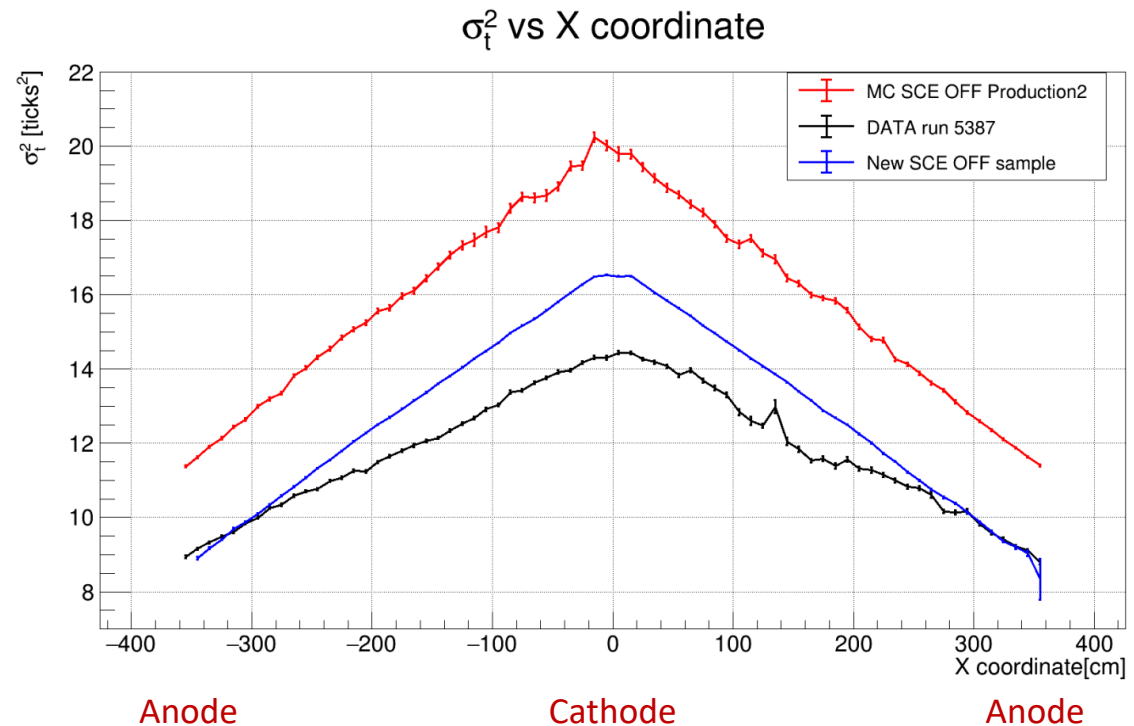
Ajib Paudel

- Diffusion smears the signal at longer drift distance.
  - Can be measured using  $\text{hit\_RMS}^2$  vs  $x$

$$\sigma_t^2 = \left( \frac{2D_L}{v_d^3} \right) x + \sigma_0^2$$

Annotations for the equation:

- Total time width of pulse →  $\sigma_t^2$
- Diffusion coefficient →  $D_L$
- Drift distance →  $x$
- Drift velocity →  $v_d$
- Inherent pulse width →  $\sigma_0^2$

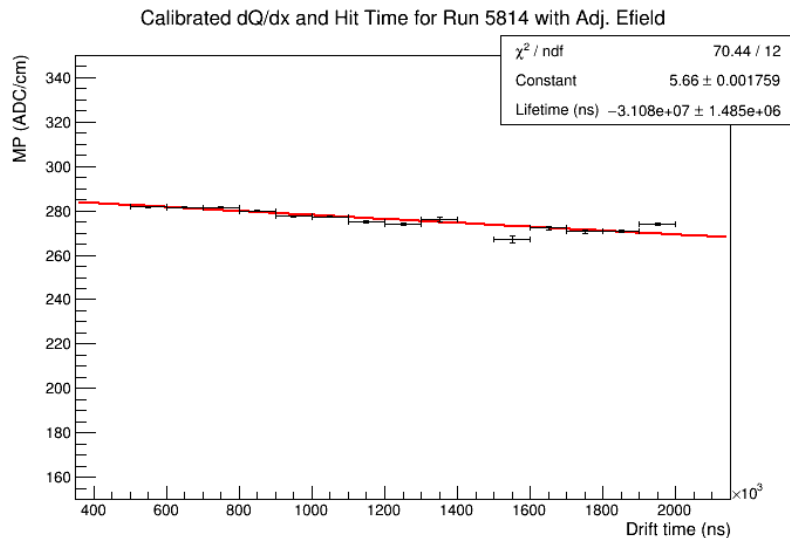


- New simulation improves the modeling of inherent pulse width ( $\sigma_0$ ).
- Diffusion constant can be tuned to improve the slope.

# Electron lifetime measurement

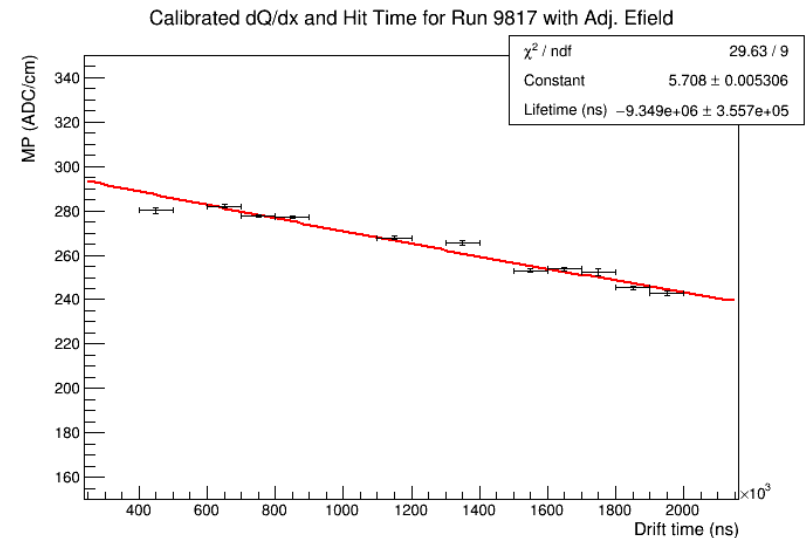
Richie Diurba

- Use CRT tagged horizontal cosmic tracks – parallel to the wire planes, drift distance provide by CRT.
- Using the track segment in the middle of TPC where spatial distortion in y,z caused by space charge is minimal.
- Use E-field map to correct for recombination effects (~2.5% over the full drift distance)



Run 5814: Nov 8, 2018

Lifetime:  $31 \pm 1$  ms



Run 9817: Oct 11, 2019

Lifetime:  $9.3 \pm 0.4$  ms



# Performance paper status (TPC sections)

Tom Junk, TY

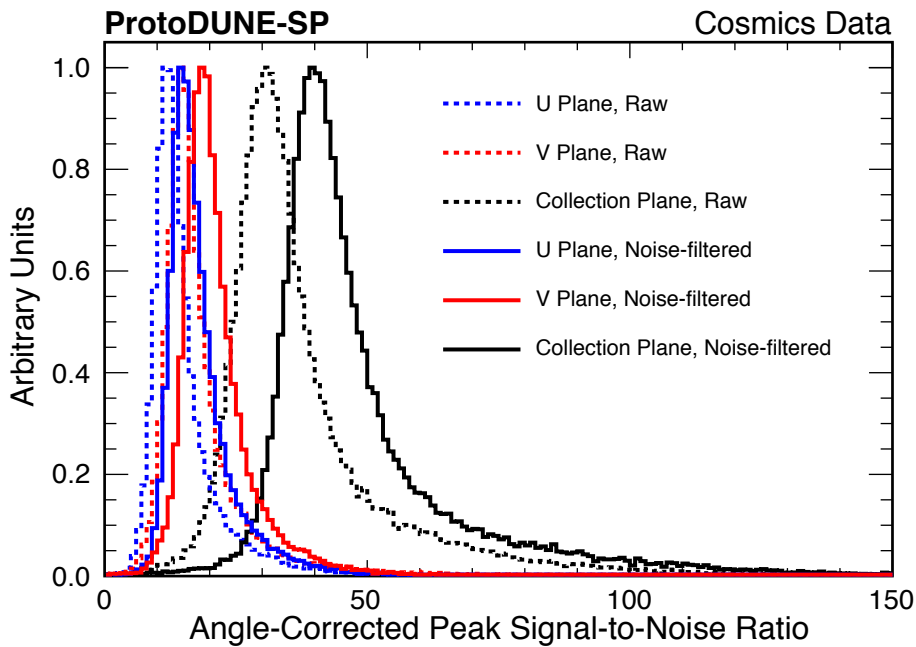
17	<b>4</b>	<b>TPC characterization</b>	<b>8</b>	<b>6</b>	<b>TPC Response</b>	<b>45</b>		
18	✓	4.1	TPC and Cold Electronics	8	✓	6.1	Imaging: beam event display gallery (2D and 3D)	45
19		4.1.1	TPC	8	✓	6.2	Space Charge Effects in ProtoDUNE-SP	45
20		4.1.2	Cold Electronics and Readout DAQ	11	✓	6.3	Cosmic-ray muon-based calibration	49
21	✓	4.2	TPC Data Preparation and Noise Suppression	12		6.3.1	Charge calibration	49
22		4.2.1	Pedestal evaluation	12		6.3.2	Energy scale calibration:	52
23		4.2.2	Initial charge waveforms	12	✓	6.4	Track Calorimetric Energy reconstruction and Identification	53
24		4.2.3	Sticky code identification	12		6.4.1	$dE/dx$ versus residual range for 1 GeV/c beam protons	53
25		4.2.4	ADC code mitigation	14		6.4.2	Identification and calorimetric energy reconstruction of 1 GeV beam pions and muons	56
26		4.2.5	Timing mitigation	14		6.4.3	$dE/dx$ for 1 GeV/c positrons	59
27		4.2.6	Tail removal	15				
28		4.2.7	Correlated Noise Removal (CNR)	16				
29	✓	4.3	Charge Calibration	16				
30	✓	4.4	TPC Noise Level	17				
31	✓	4.5	Signal Processing	22				
32	✓	4.6	Event Reconstruction	24				
33		4.6.1	Hit Finding	24				
34		4.6.2	Pattern Recognition with Pandora	25				
35	✓	4.7	Signal to noise performance	27				

✓ complete  
✓ Figures need to be updated

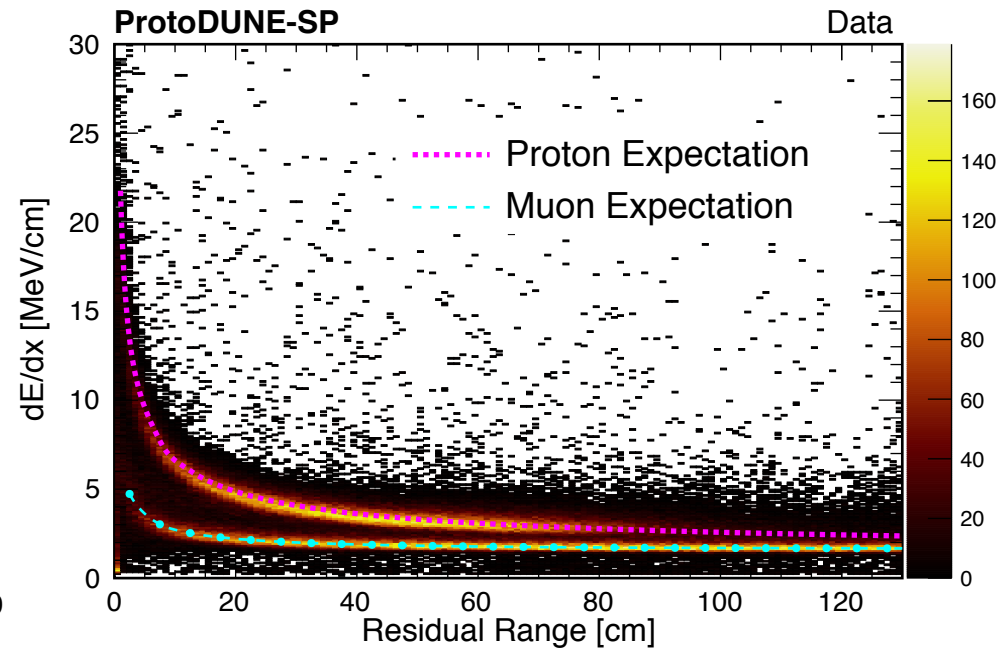
- Most of the subsections are in a good shape and ready to be reviewed.
- For details see my collaboration meeting talk:  
<https://indico.fnal.gov/event/21445/session/19/contribution/92/material/slides/0.pdf>

# Result highlights

Signal-to-noise ratios



Muon and proton dE/dx



- Now Flavio will show the photon detector results.