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Single pulse analysis using test beam data

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Meeting on cluster counting in drift chambers, 2023.03.20

Introduction

- The cluster counting method has a great potential for PID
- Precise simulation of the drift chamber is important, especially for the waveform simulation
- Currently, the waveform simulation is based on Garfield++. It stimulates the ionization process of charged particles passing through gas, the drift of ionized electrons (ions), the avalanche process, and the waveform signal. While other factors are not included, such as electronic response, noise, and space charge effect
- To obtain a more realistic waveform simulation, it is worth trying to get a single pulse shape from real data and then use it in the simulation

Dataset

- Using a dataset from the beam test at CERN SPS in July 2022

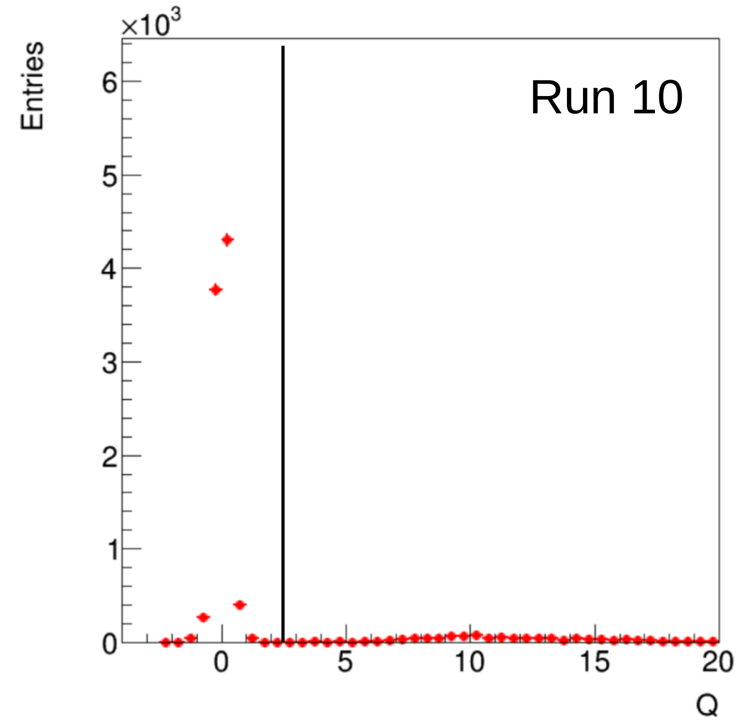
Run	Gas mix	Channel	HV tag	Sampling rate	Particle	Angle	events
10	90%He+10%C_4H_{10}	5	3	2GHz	μ:180 GeV	45	10000
11						0	10000
47						60	10000
49						30	5000

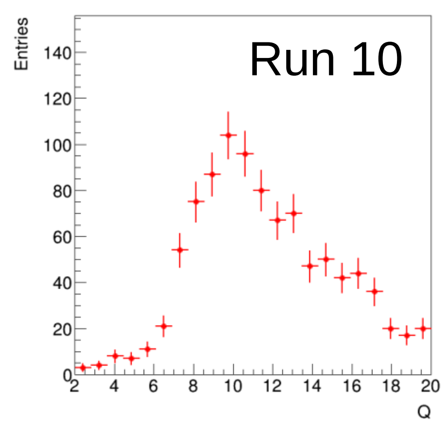
DRS channels	HV channels	Tubes
0	0	1.5cm-20μm
1	15	1.0cm-20μm
2	22	1.0cm-15μm
3	13	1.0cm-15μm
4	18	1.5cm-25μm
5	7	1.0cm-20μm
6	1	1.0cm-20μm
7	21	1.5cm-15μm
8	8	1.0cm-20μm
9	11	1.0cm-25μm
10	10	1.0cm-25μm
11	23	1.5cm-15μm
12		Upstream scintillator up
13		Upstream scintillator down
14		Downstream scintillator up
15		Downstream scintillator down

		HV tag	HV tag	HV tag	HV tag	HV tag
		0	1	2	3 (90/10)	4
Tubes	HV channels	Volt (V)	Volt (V)	Volt (V)	Volt (V)	Volt (V)
1cm-15mum	13.22	1280	1280	1280	1290	1310
1cm-20mum	1,7,8,15	1330	1350	1350	1350	1370
1cm-25mum	10.11	1390	1390	1390	1390	1410
1.5cm-15mum	21.23	1365	1340	1340	1340	1360
1.5cm-20mum	0	1430	1435	1450	1450	1470
1.5cm-25mum	18	1450	1450	1450	1480	1500

Event selection

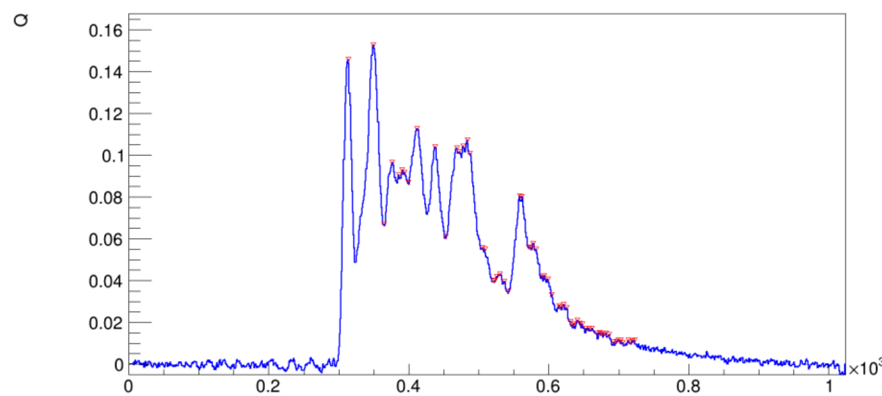
- Remove waveform which is noise dominated
- 1, each waveform is subtracted by its baseline (calculated from 5-50 ns)
- 2, apply cut on the integral charge of the waveform. Most values are close to 0 (almost noise)
  - Using cut 2.5 to select a good waveform (same as Shuaiyi Liu)

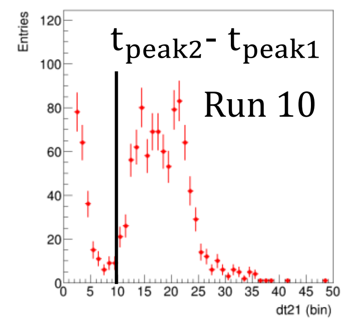


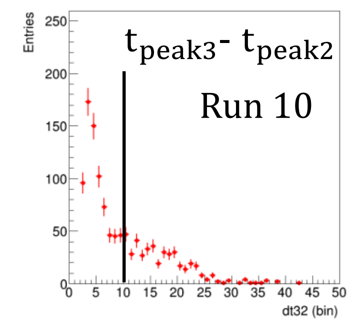


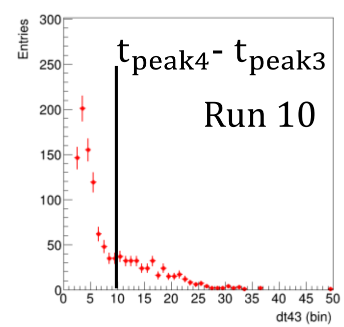
Event selection

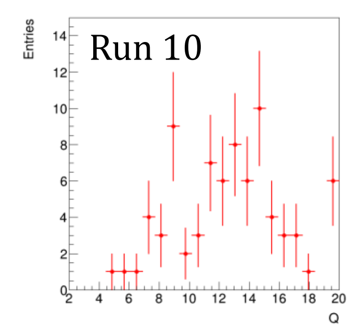
- Select waveforms that have good separation between the first, second, and third pulses
- Using *scipy.signal.find_peaks* to find peaks of each waveform (threshold 0.01)
- Apply cut:
  - $t_{peak2} - t_{peak1} > 10$
  - $t_{peak3} - t_{peak2} > 10$
  - $t_{peak4} - t_{peak3} > 5$





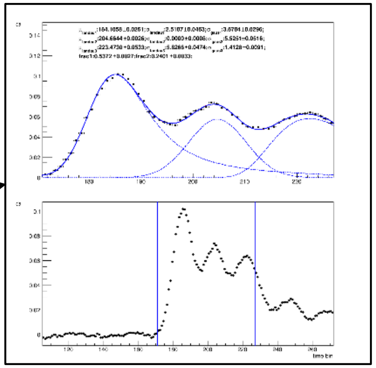


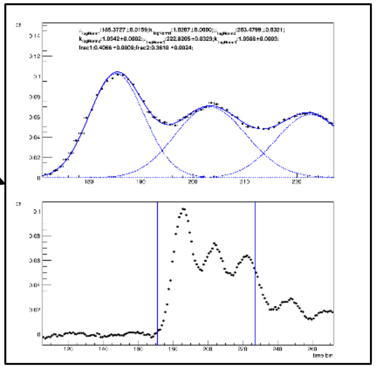


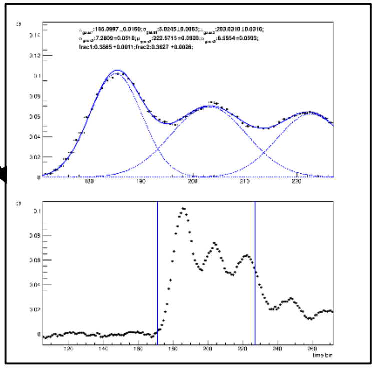


Fitting

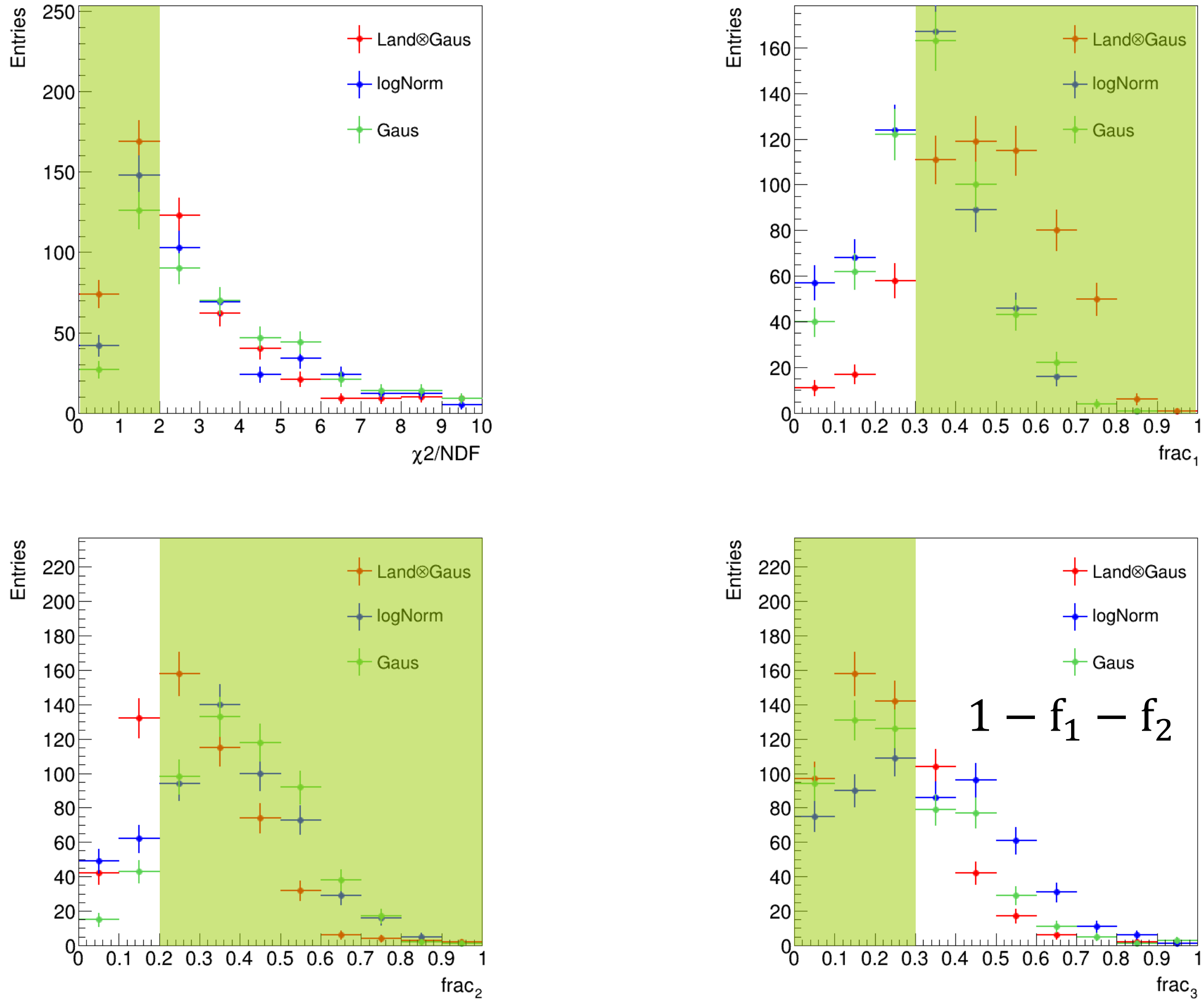
- The region of three pulses is fitted by the following function:
  - Landau⊗Gaus
    - $F = f_1 * \mathrm{Landau}_1 \otimes \mathrm{Gaus}_1 + f_2 * \mathrm{Landau}_2 \otimes \mathrm{Gaus}_2 + (1 - f_1 - f_2) * \mathrm{Landau}_3 \otimes \mathrm{Gaus}_3$
  - LogNormal
    - $F = f_1 * \mathrm{LogNormal}_1 + f_2 * \mathrm{LogNormal}_2 + (1 - f_1 - f_2) * \mathrm{LogNormal}_3$
  - Gaussian
    - $F = f_1 * \mathrm{Gaus}_1 + f_2 * \mathrm{Gaus}_2 + (1 - f_1 - f_2) * \mathrm{Gaus}_3$
  - The detailed fit range is [t_{peak1}-15, t_{peak3}+5]
- For statistic uncertainty of each bin: 0.5% is used



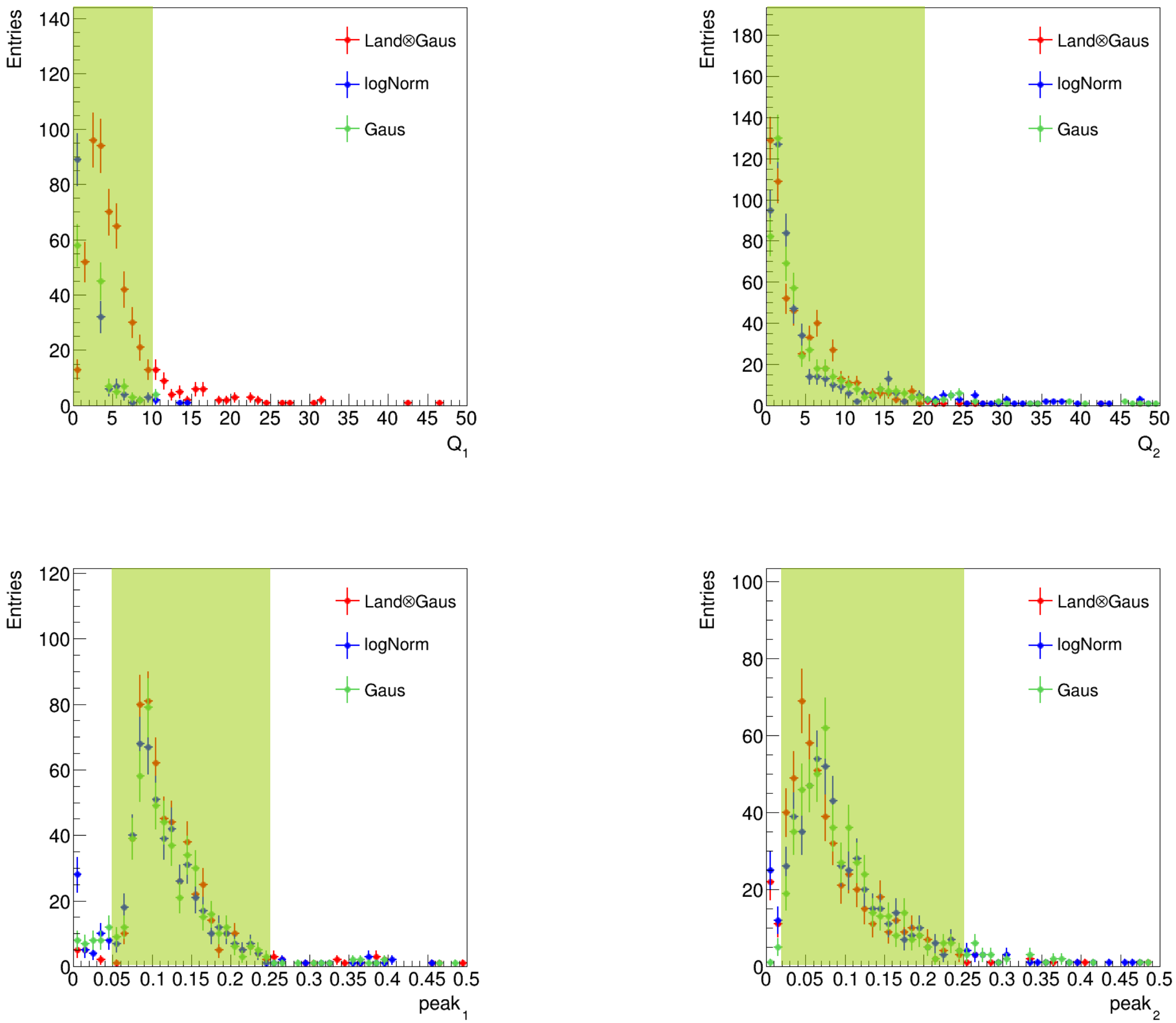




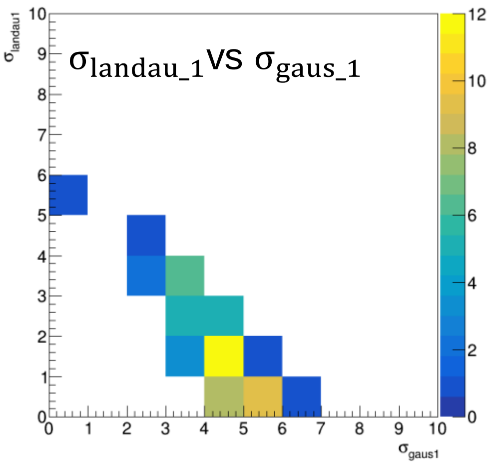
Fit quality selection

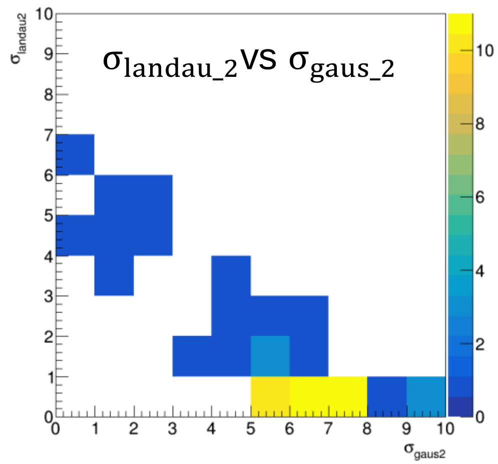


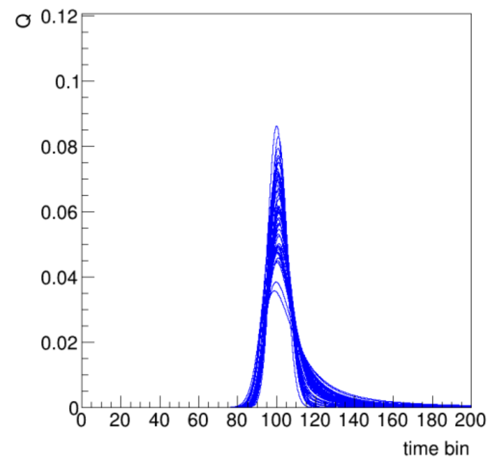
Fit quality selection

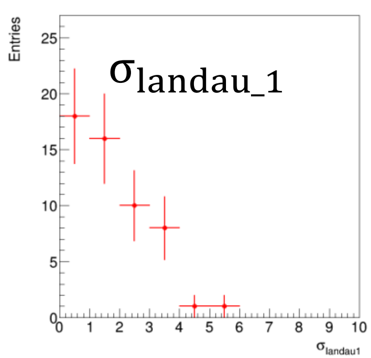


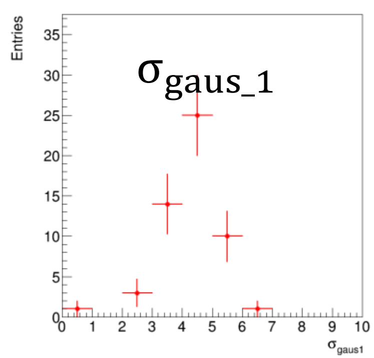
The fitted parameters(Landua⊗Gaus)

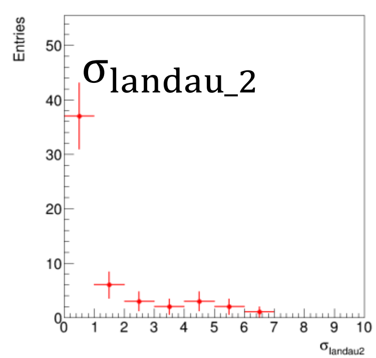


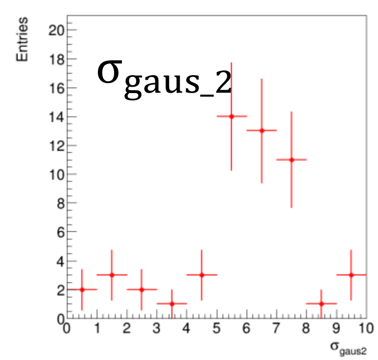




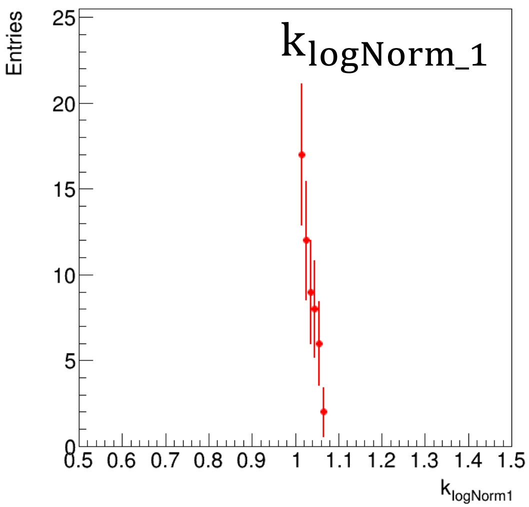


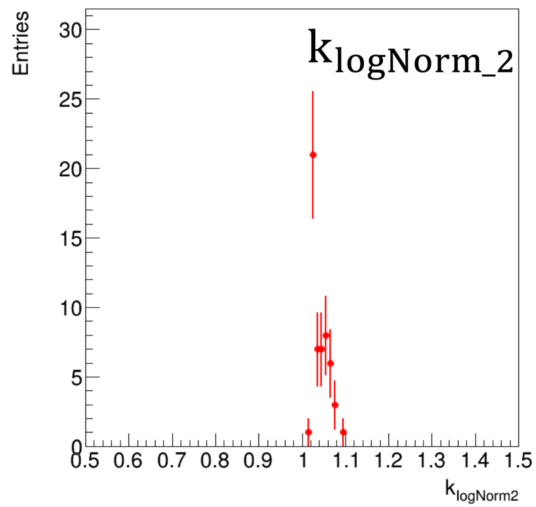


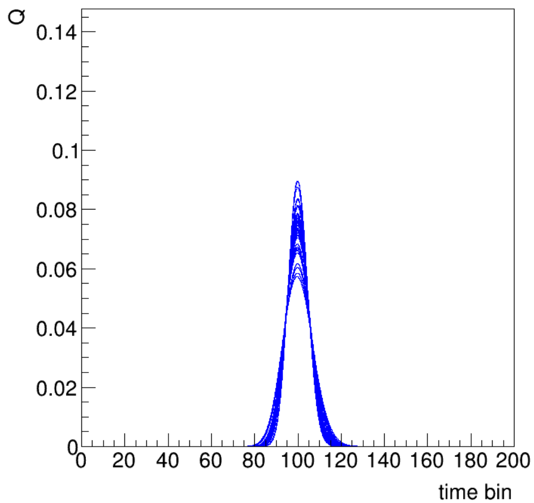




The fitted parameters (logNormal)

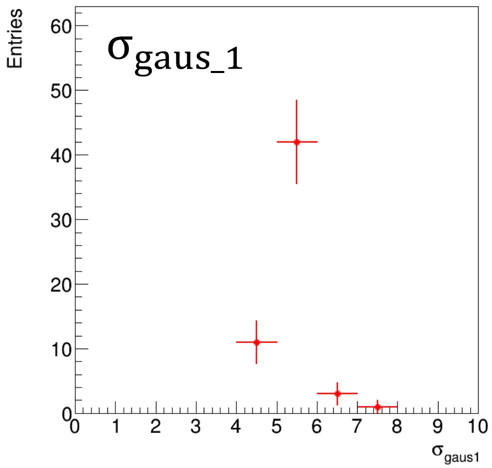


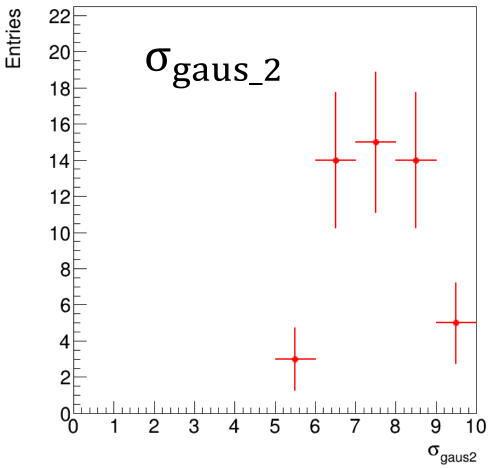


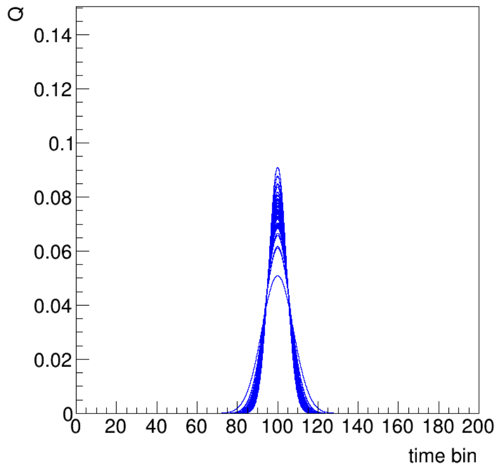


$$\mathrm{RooLognormal}(x\,|\,m_0,k) = \frac{1}{\sqrt{2\pi\cdot\ln(k)\cdot x}}\cdot\exp\left(\frac{-\ln^2(\frac{x}{m0})}{2\ln^2(k)}\right)$$

The fitted parameters (gaussian)







Summary

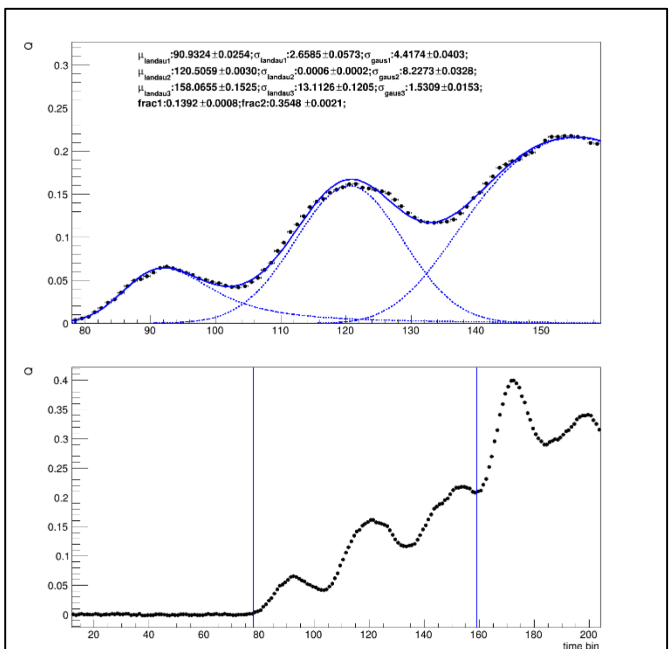
- The study of pulse shape from the test beam is performed
- Check the pulse shape of the first and second pulses, the pulse shapes are fitted by Landau$\otimes$Gaus, lognormal, and Gaussian
- All three fit functions seem to fit the pulse shape well. Not-trivial to decide which one is the best
- The distribution of the fitted parameters for the first and second pulses is different

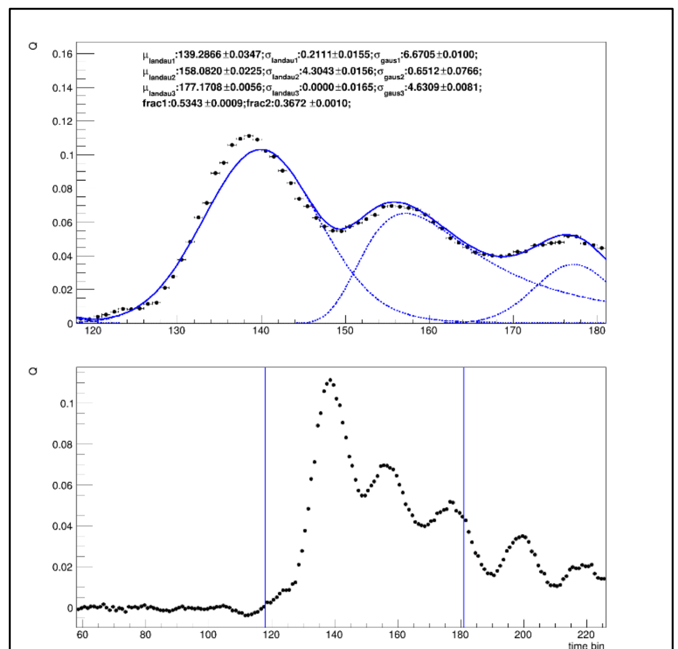
Back up

Thanks for your attention!

Fitting

- The region of three pulses is fitted by the following function:
  - $F = f_1 * \mathrm{Landau}_1 \otimes \mathrm{Gaus}_1 + f_2 * \mathrm{Landau}_2 \otimes \mathrm{Gaus}_2 + (1 - f_1 - f_2) * \mathrm{Landau}_3 \otimes \mathrm{Gaus}_3$
  - The detailed fit range is [t_{peak1}-15, t_{peak3}+5]
- For statistic uncertainty of each bin: 0.5% is used

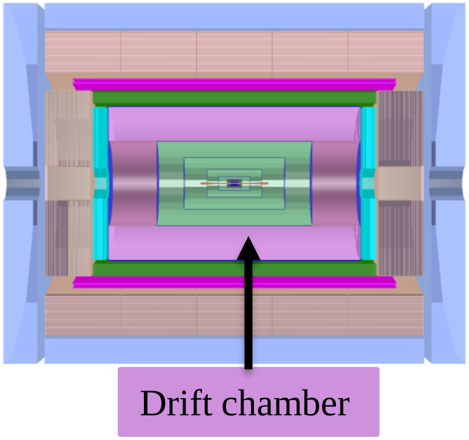




Introduction

- The CEPC experiment aims to measure the property of the Higgs boson precisely
  - Requirements: high track efficiency (~100%), momentum resolution (<0.1%), PID (2σ p/K separation at P < ~ 20 GeV/c), ...
  - Precise simulation is needed as it gives precise results

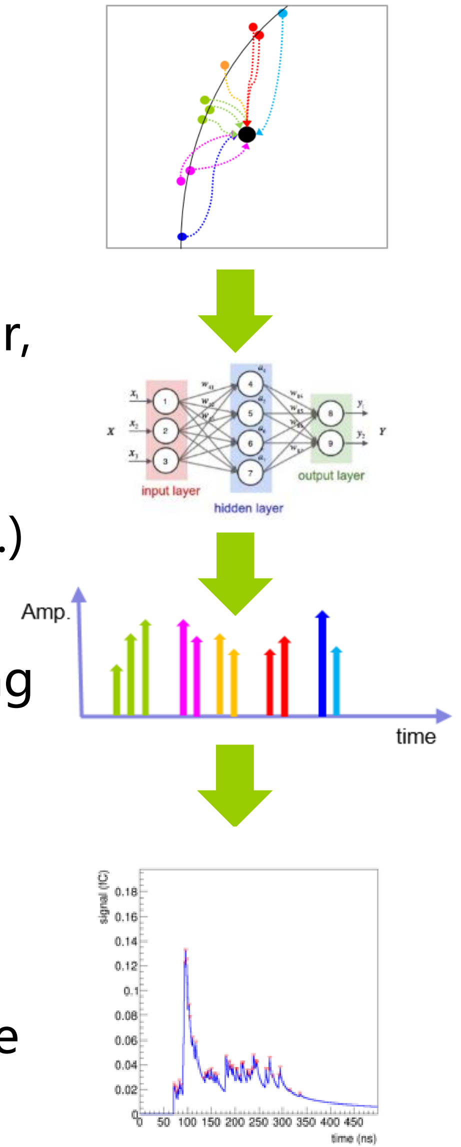
- The 4th conceptual detector design adopts silicon + drift chamber (DC) for tracking system
  - The DC: track reconstruction and PID (dN/dx+dE/dx)



- Performance of the DC needs to be studied with precise simulation

Towards precise DC simulation

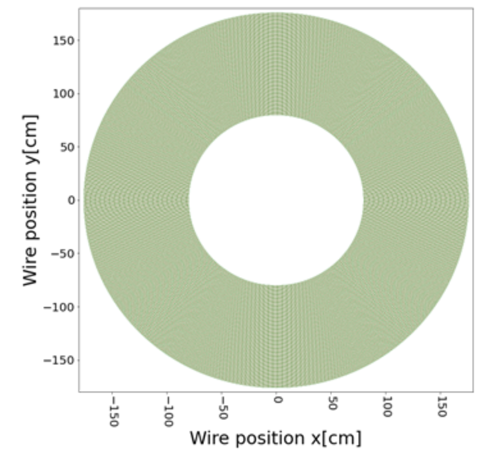
- Originally driven by the dN/dx study:
  - Needs precise ionization simulation, waveform simulation
  - Geant4 + TrackerHeed + NN model is adopted
  - Geant4: for particle propagation (decay) in the detector, interaction with detector material, …
  - TrackerHeed (from Garfield++): used for ionization process simulation for charged particles (e, μ, π, K, p, …)
  - NN model: is used for fast pulse simulation for each ionized electron (primary particle independent), training data is from Garfield++
  - More details in this [talk]
  - Shortcoming, the space charge effect can not be simulated
    - arXiv:2211.06361, RPC simulation with space charge effect (dynamic update of the electric field)

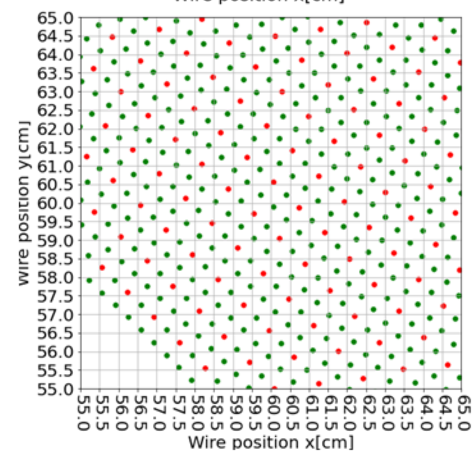


Drift Chamber Parameters in CEPCSW

- The baseline configuration of DC in CEPCSW

Half length	2980 *mm*
Inner and outer radius	800mm to 1800 *mm*
# of Layers	100/55
Cell size	~10mmx10mm/18mmx18mm
Gas	$He{:}iC_4H_{10}$=90:10
Single cell resolution	0.11 *mm*
Sense to field wire ratio	1:3
Total # of sense wire	81631/24931
Stereo angle	1.64~3.64 *deg*
Sense wire	Gold plated Tungsten ϕ=0.02*mm*
Field wire	Silver plated Aluminum ϕ=0.04*mm*
Walls	Carbon fiber 0.2 *mm*(inner) and 2.8 *mm*(outer)





Cell structure

Silicon detectors Parameters in CEPCSW

Silicon tracker	*Number of layer*	*Radius(mm)*	$\sigma_U\,(\mu m)$	$\sigma_V(\mu m)$
VXD	3 double layers	16-58	2.8/6/4/4/4/4	2.8/6/4/4/4/4
SIT	4 layers	230-770	7.2	86
SOT(SET)	1 layer	1815	7.2	86