Progress on PID Drift Chamber Study

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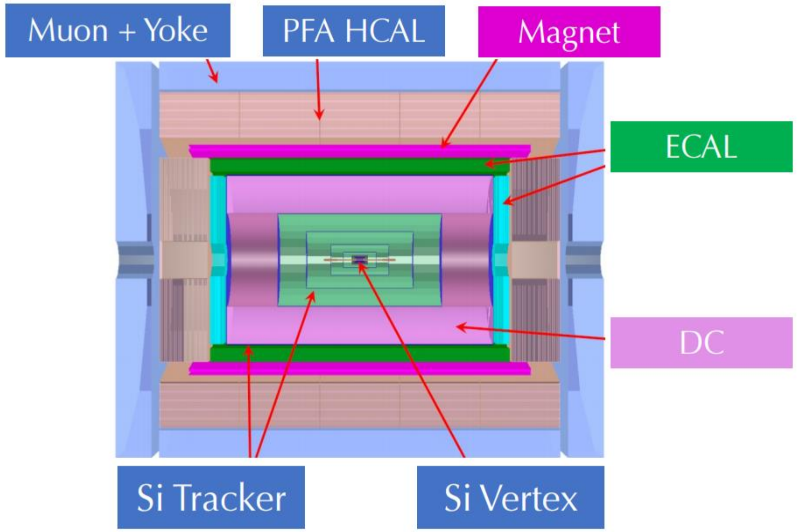
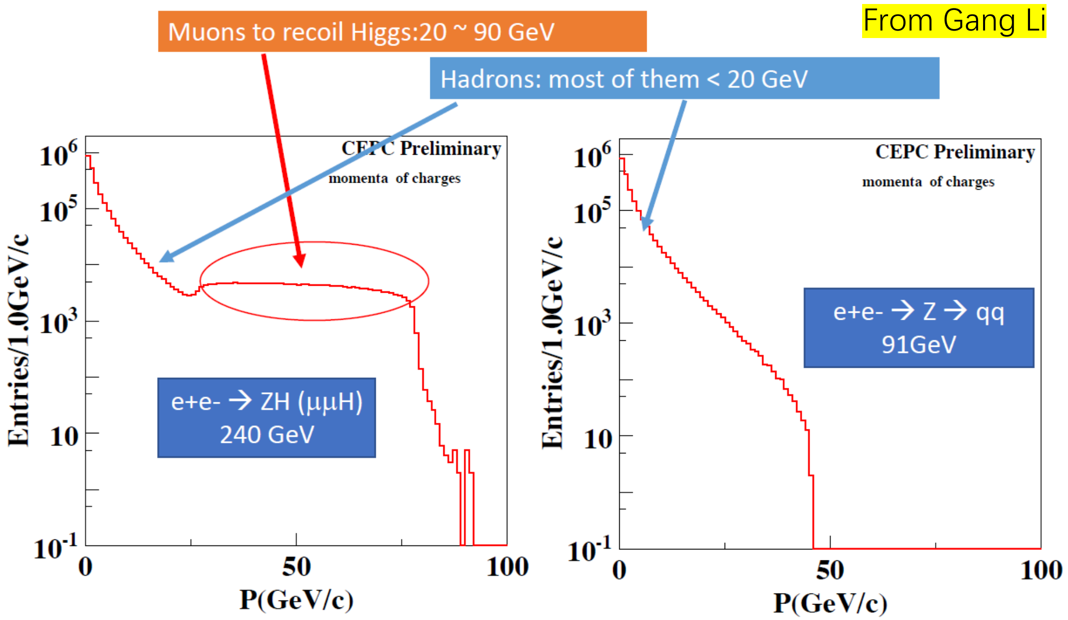
Outline

- **Introduction**
- **Updates in simulation**
  - Improvement of peak finding algorithm
  - Gas mixture comparison: He80 vs. He90
  - Updated PID performance
- **Status of experiment**
  - Test with different gas mixture
  - Beam test data analysis
- **Summary**

Introduction

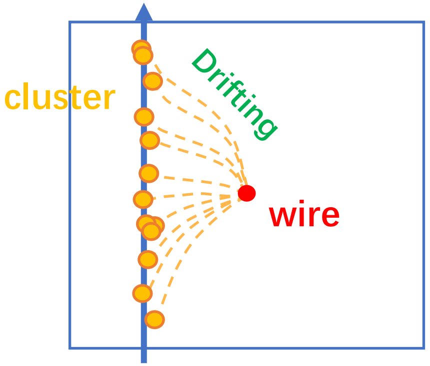
4th Conceptual Detector



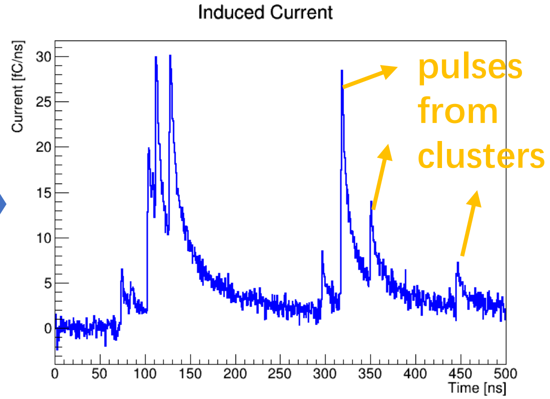


- Particle ID with a drift chamber is a key feature for the 4th conceptual detector
- Most hadrons from Higgs/Z pole data are below 20 GeV/c
- The drift chamber should have sufficient PID separation power for charged particles < 20 GeV/c

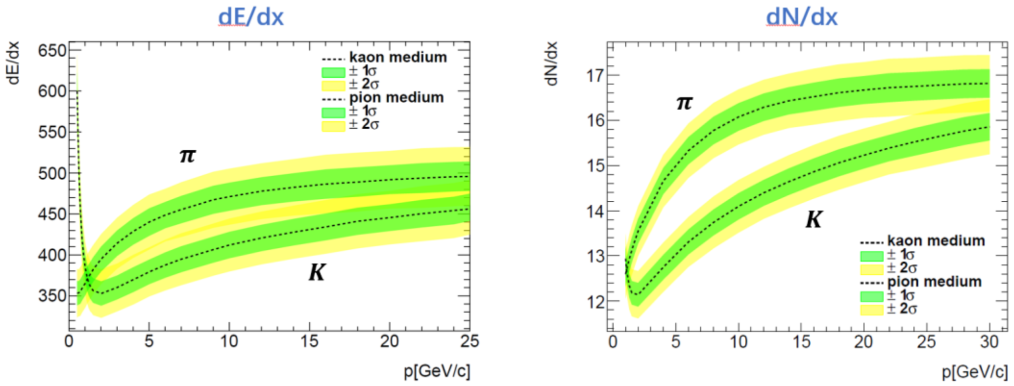
Introduction (II)



(for demonstration)



dE/dx vs. dN/dx (MC truth)

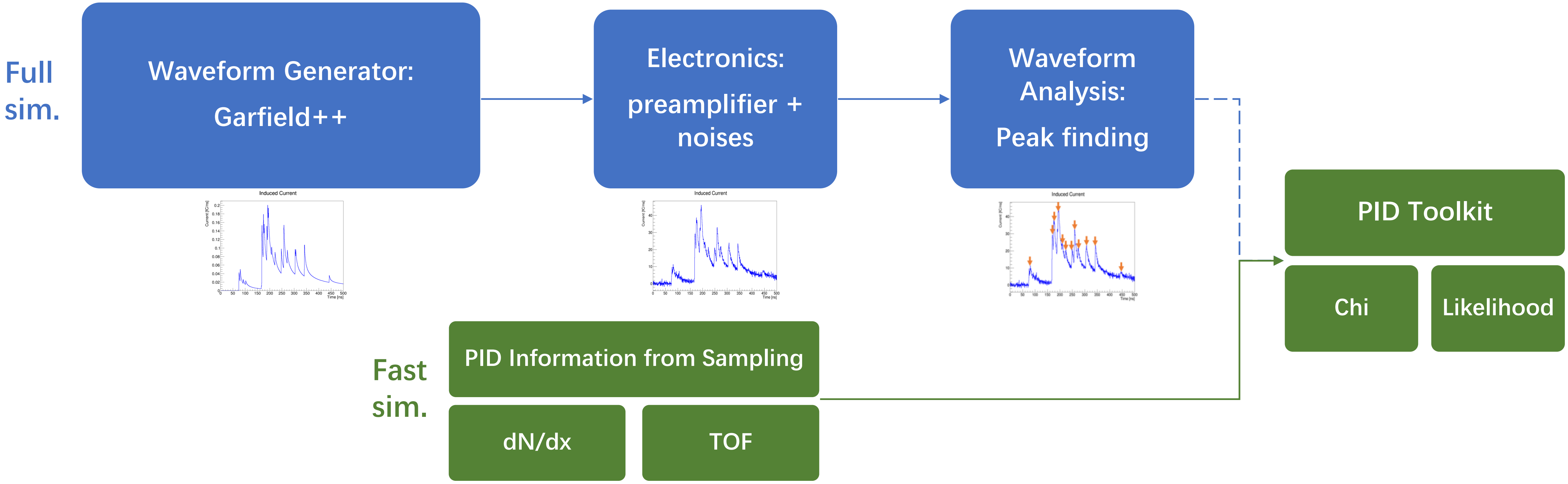


- The cluster counting technique count the number of primary ionizations (clusters) in the current signal (dN/dx)
- dN/dx is more powerful for PID due to small fluctuations, but is more challenging
- Simulation and experiment are essential for the feasibility and performance study

Simulations

- Improvement of peak finding algorithm
- Gas mixture comparison: He80 vs. He90
- Updated PID performance

The simulation workflow



Updates

- ✓ Peak finding algorithm
- ✓ Noise ratio definition
- ✓ Different gas mixtures
- ✓ Parametrization in fast simulation

Peak finding algorithm

- **Requirement**
  - **Fast:** Data size of waveform is huge. Fast online algorithm at the front-end is recommended
  - **Efficient:** Good ability to recover pile-up. High pulse detection efficiency

- **Peak finding using derivatives**
  - Not sensitive to the baseline
  - Good ability for pile-up recovery (especially for fast rising-edge signal)
  - Fast and easy to implement

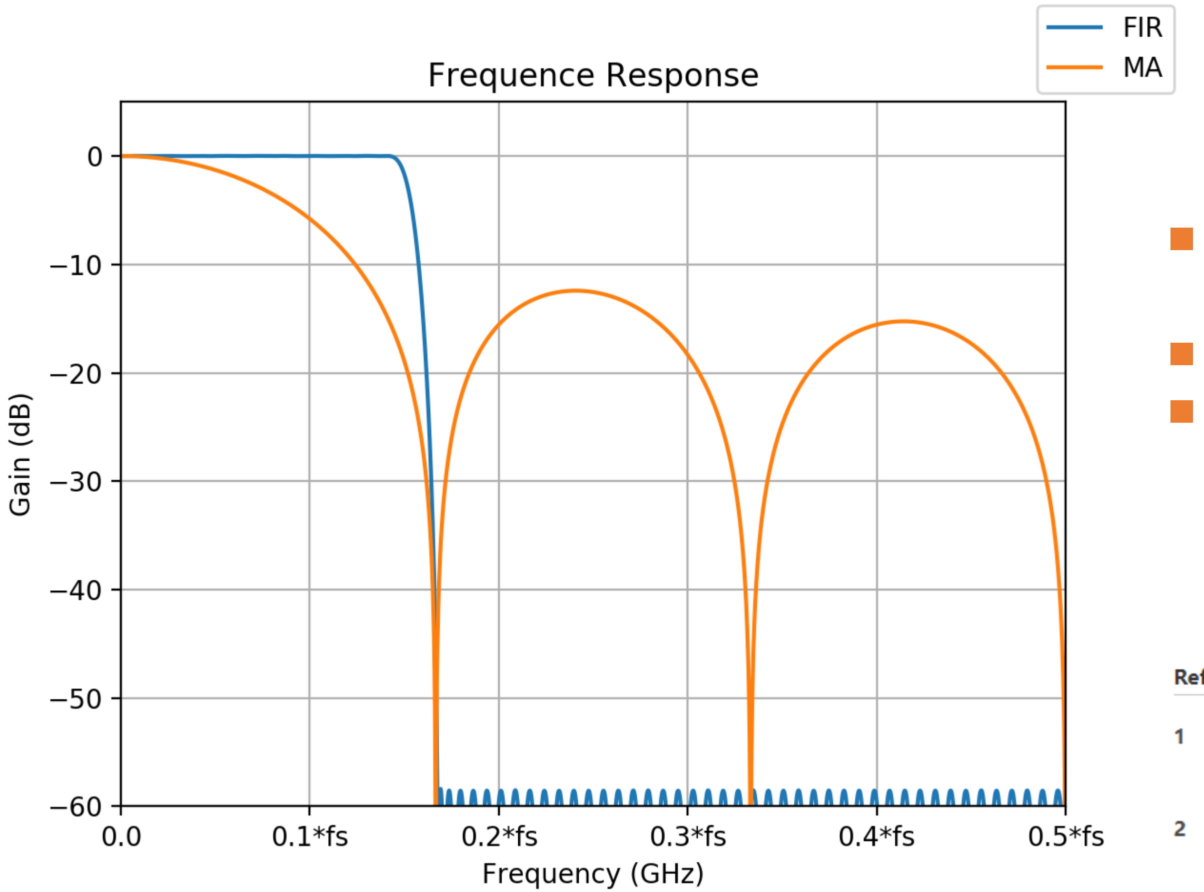
Peak finding algorithm (II)

- **Low pass filter (smoothing)**
  - Filter out high frequency noises in the waveforms in order to improve the S/N ratio
  - Finite impulse response (**FIR**) filter with a cutoff frequency (**F**): FIR[i] = a0*x[n] + a1*x[n-1] + …

- **Derivative (peak detection)**
  - First derivative (**D1**): D1[i] = FIR[i] – FIR[i – **G**]
  - Second derivative (**D2**): D2[i] = D1[i] – D1[i – **G**]
  - Hit detection: threshold passing (**T**)

The cutoff frequencies, derivative steps and thresholds have been optimized

Smoothing



- **Digital filter:** Reduce impact from noises with high frequencies
- **Moving average:** Poor frequency response
- **Optimal filter** with Remez exchange algorithm
  - Fast roll-off
  - Good stopband attenuation

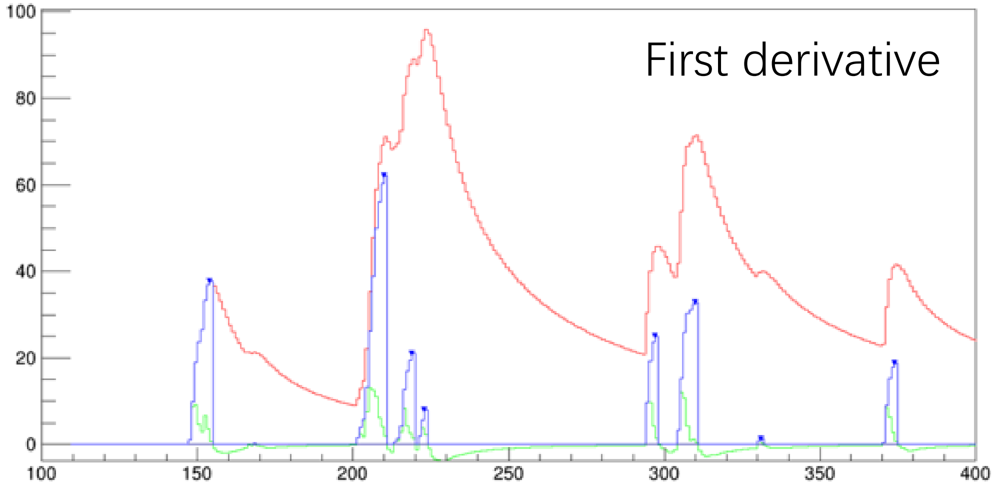
References

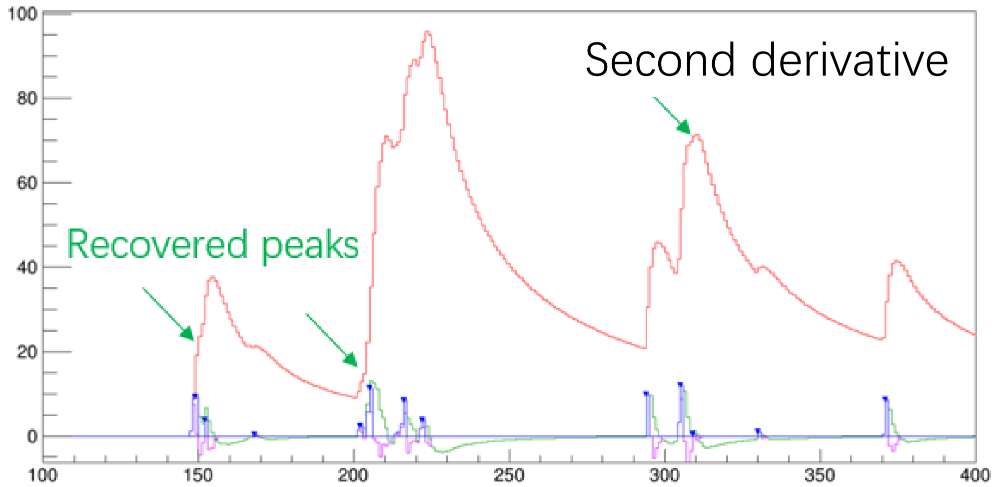
1 J. H. McClellan and T. W. Parks, "A unified approach to the design of optimum FIR linear phase digital filters", IEEE Trans. Circuit Theory, vol. CT-20, pp. 697-701, 1973.

2 J. H. McClellan, T. W. Parks and L. R. Rabiner, "A Computer Program for Designing Optimum FIR Linear Phase Digital Filters", IEEE Trans. Audio Electroacoust., vol. AU-21, pp. 506-525, 1973.

Derivative

- **Use second derivative instead of first derivative (rising-edge pile-ups recovery)**

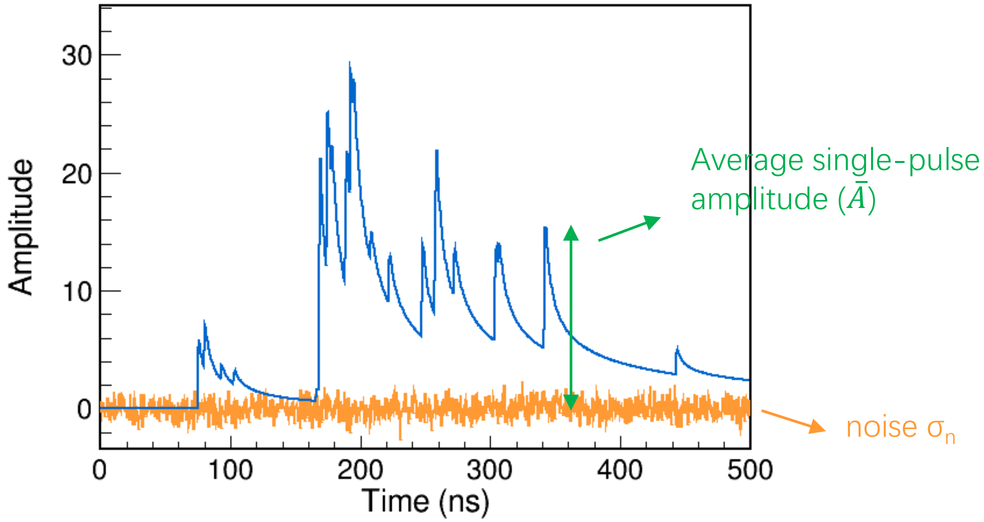




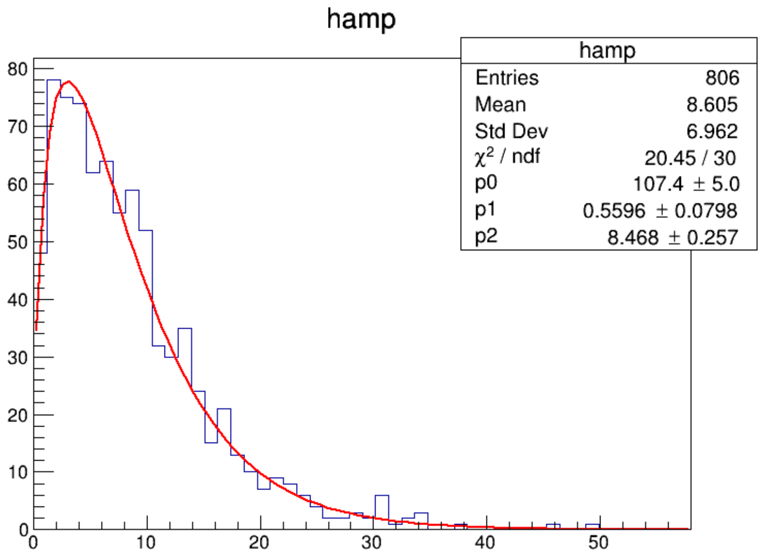
Pile-up on the falling edge is easier to recover. However, it is not the case for pile-up on the rising edge.

Noise definition

- **Noise ratio definition:** $\frac{\sigma_{Noise}}{\bar{A}_{signal}}$
  - $\bar{A}_{signal}$: Averaged single-pulse amplitude
  - σ_{Noise}: Noise RMS



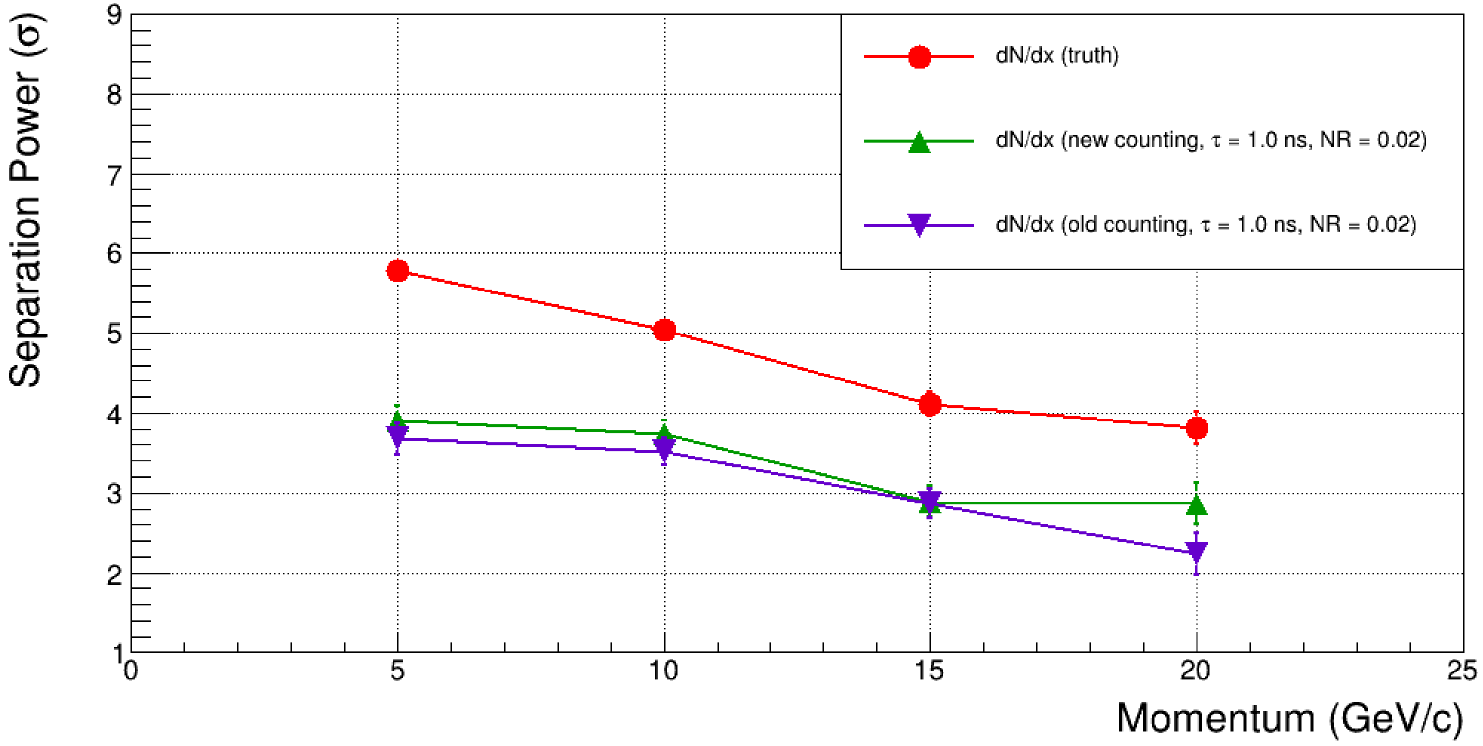
Fit to single-pulse amplitudes with a Polya function



More reasonable noise definition. Noise level is only dependent on the single-pulse amplitudes. (Previously use averaged charge to normalize)

K/pi separation power with the updated algorithm

He 90% + iC_4H_{10} 10%, track length = 1m

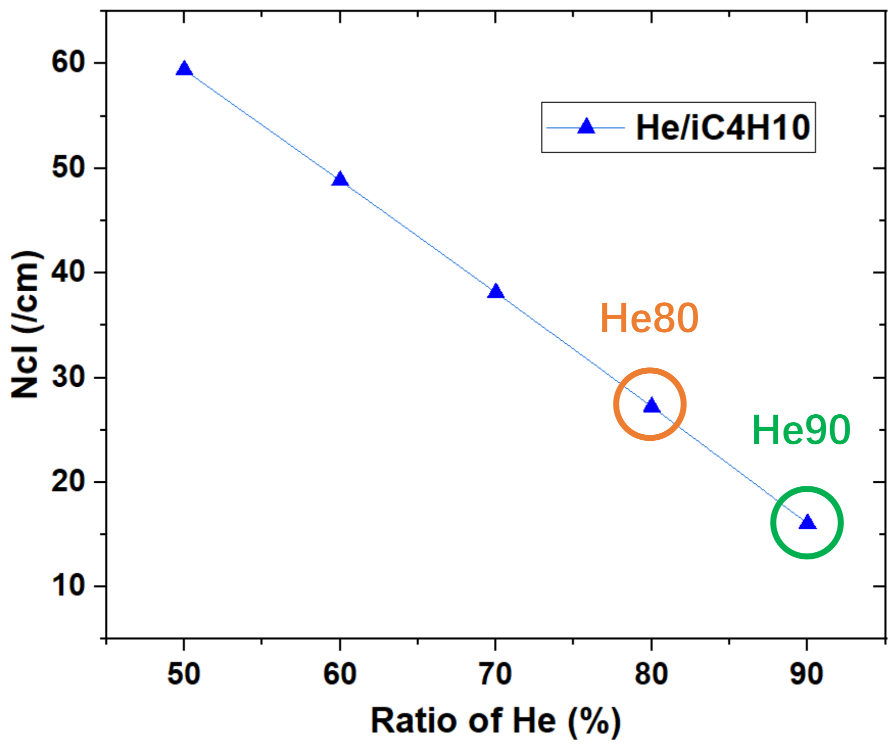


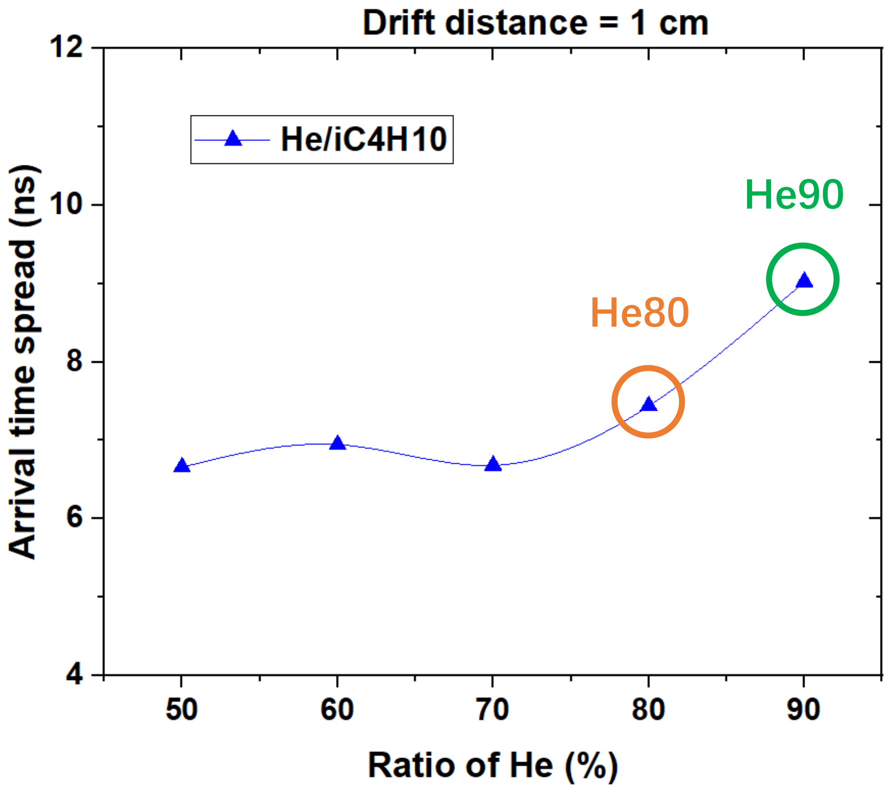
Separation power

$$\frac{\left|\left(\frac{dN}{dx}\right)_\pi - \left(\frac{dN}{dx}\right)_K\right|}{(\sigma_\pi + \sigma_K)/2}$$

Better separation power for the updated algorithm with tuned parameters

Properties of gas mixtures

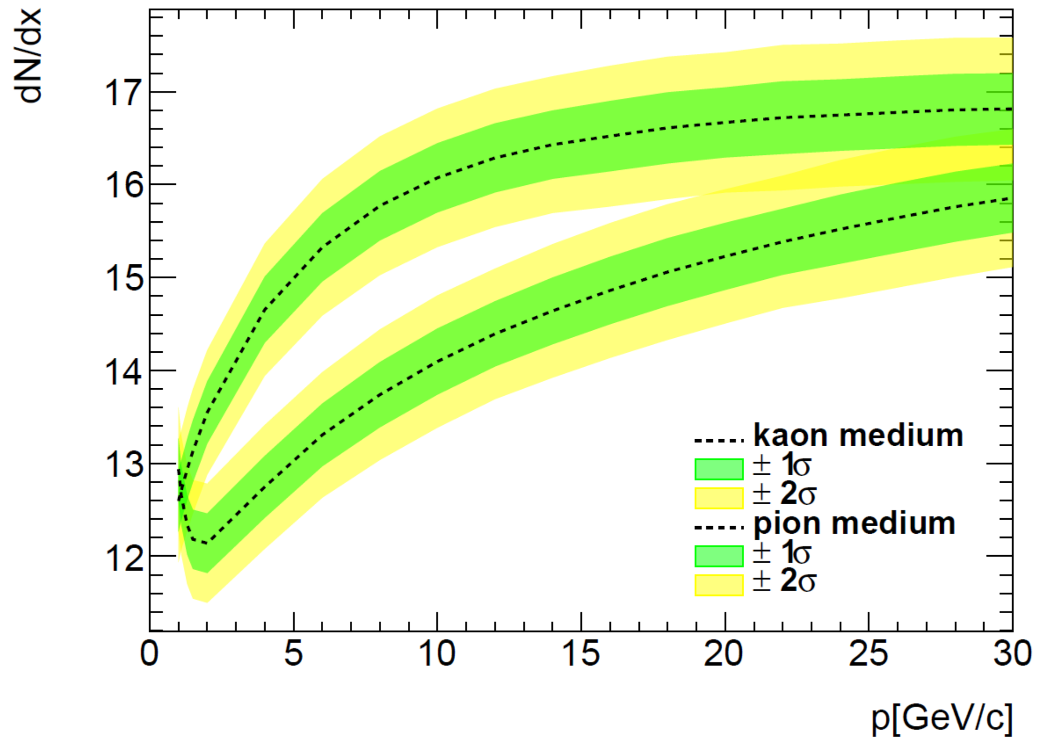




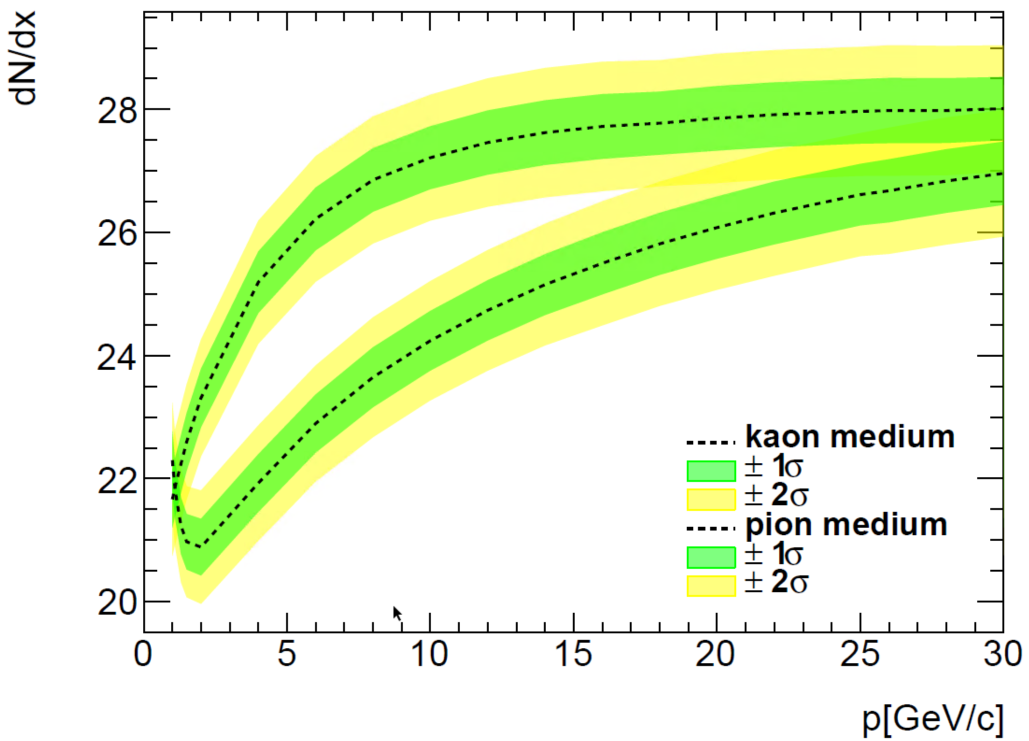
He80: Larger cluster density (more statistics, more pile-ups)
He90: Larger longitudinal diffusion (more pollution from the secondaries)

dN/dx from MC truth

He 90% + iC_4H_{10} 10%



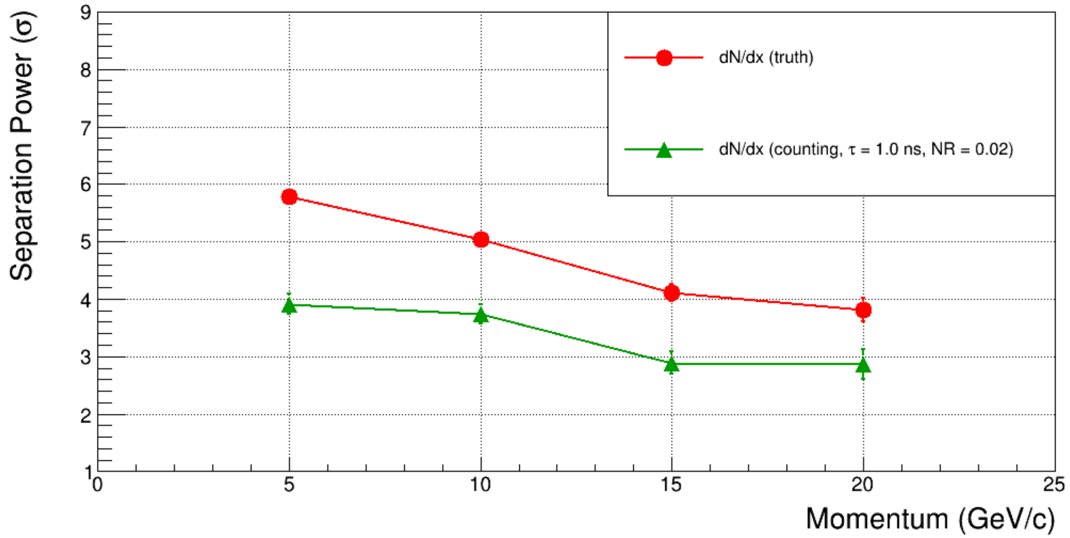
He 80% + iC_4H_{10} 20%



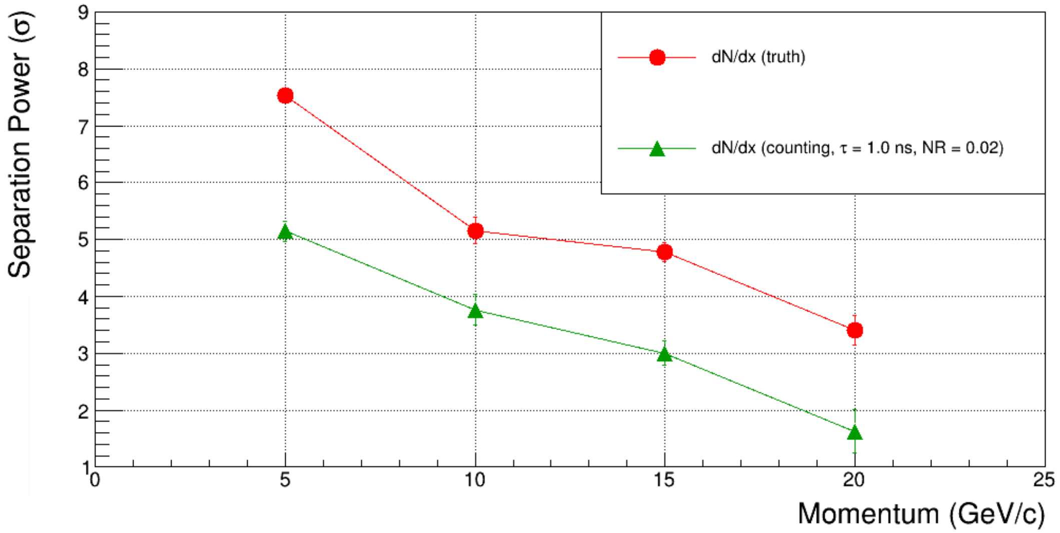
He 90% + iC_4H_{10} 10% mixture has better K/pi separation for high momentum

K/pi separation power for gas mixtures

He 90% + iC_4H_{10} 10%, track length = 1m



He 80% + iC_4H_{10} 20%, track length = 1m



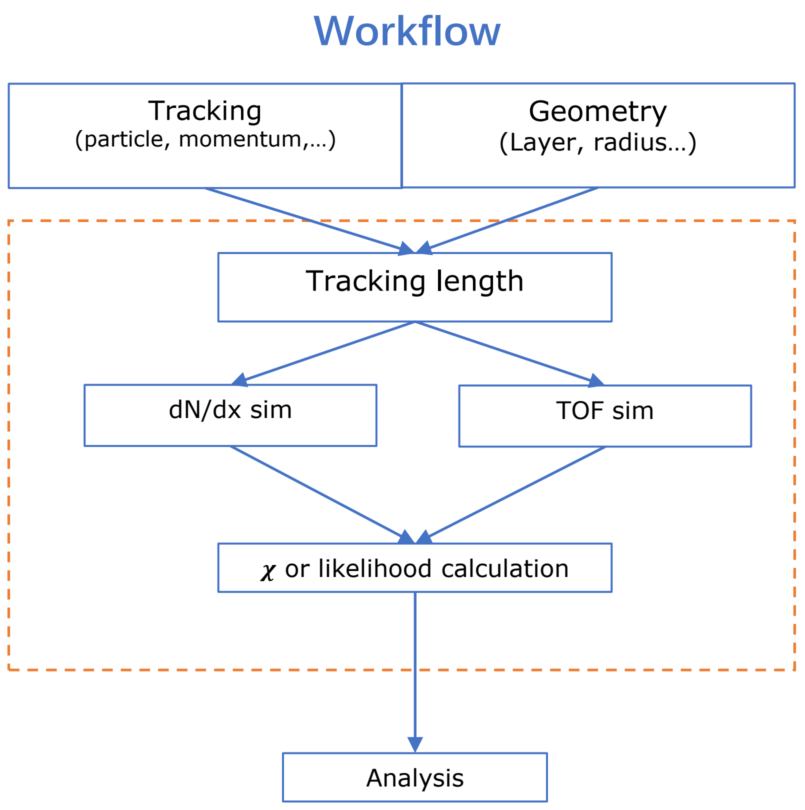
- He 90% + iC_4H_{10} 10% has better K/pi separation for high momentum
- He 80% + iC_4H_{10} 20% has better K/pi separation for low momentum
- PID in low momentum region can be covered by timing detector ➔ He 90% is more attractive

Fast simulation

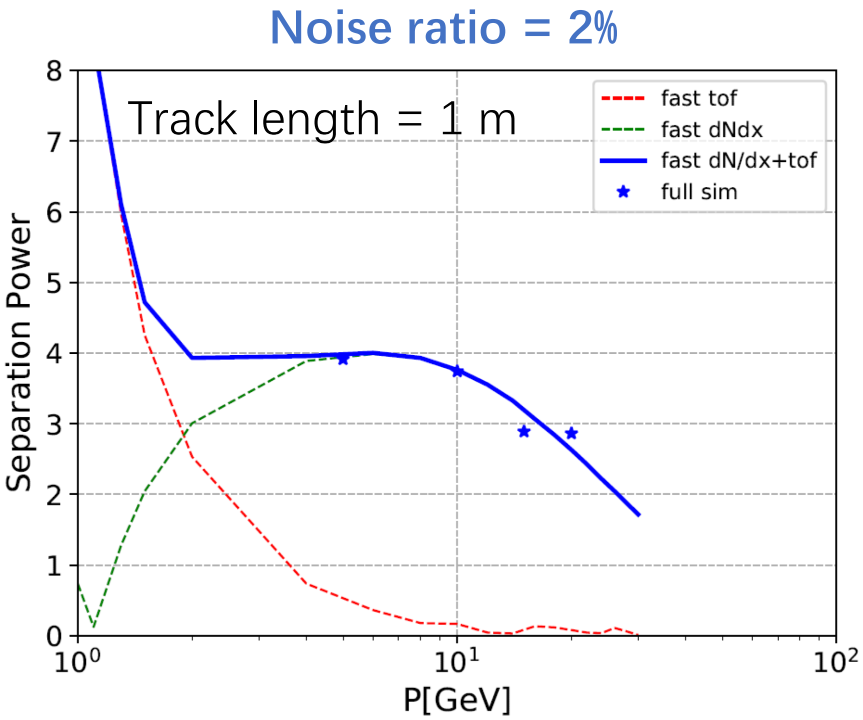
- **Fast simulation with sampling method can quickly provide PID information with**
  - wider momentum range: 0-20 GeV/c
  - timing information

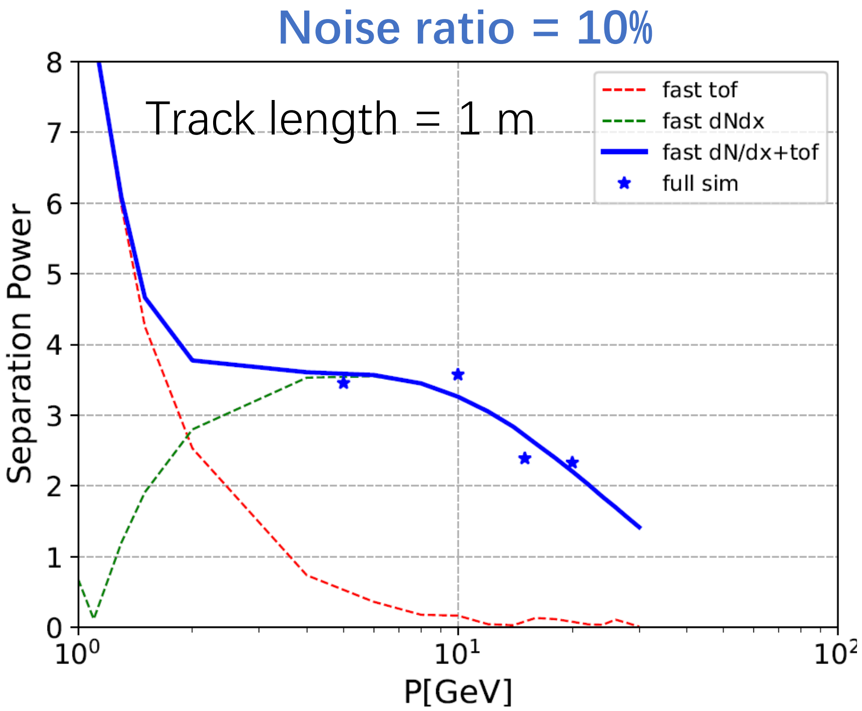
- **dN/dx model:**
  - $dN/dx_{meas} = \mathrm{d}N/dx_{truth} \times \epsilon$
  - dN/dx_{truth}: sampled from Garfield++
  - ϵ (counting efficiency): a function of cluster density and tuned from full sim.

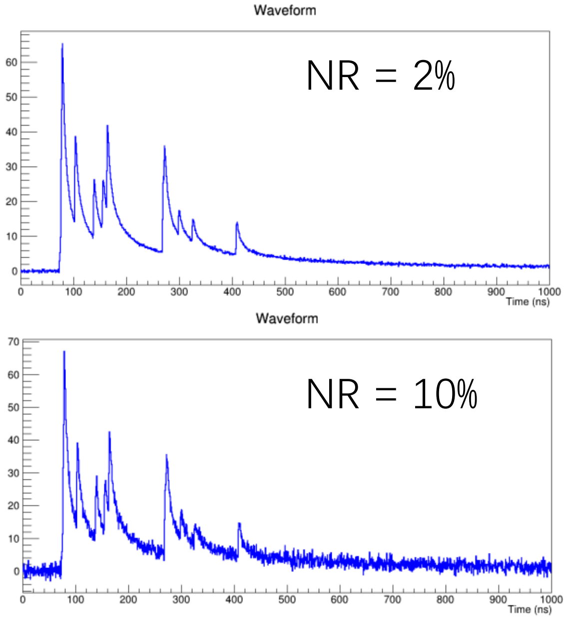
- **Timing detector model:**
  - R = 1.8m
  - Assuming a time resolution of 50 ps



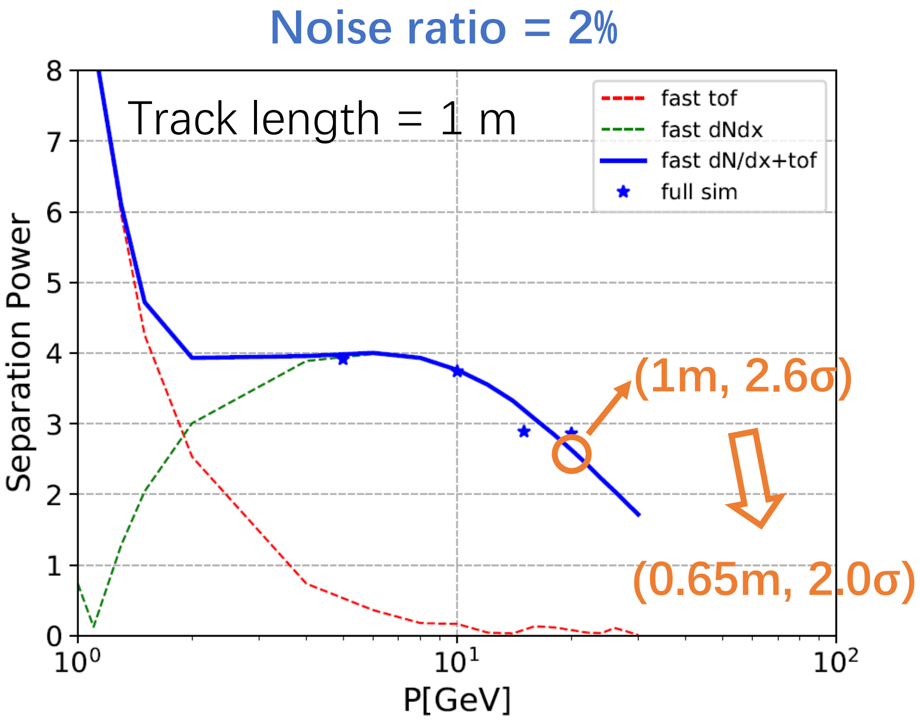
PID performance

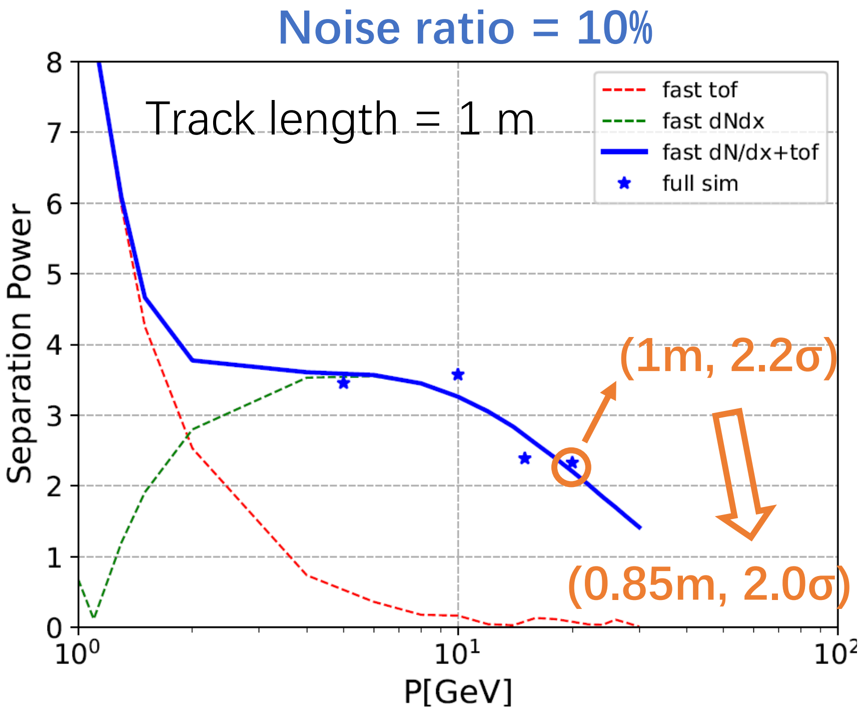


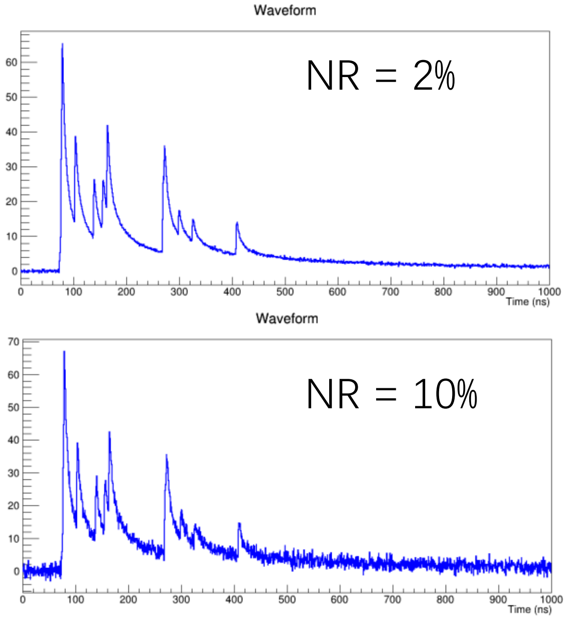




PID performance







2σ K/pi separation power up to 20 GeV/c requires

- thickness of DC > 65 cm for NR = 2%
- thickness of DC > 85 cm for NR = 10%

Experiments

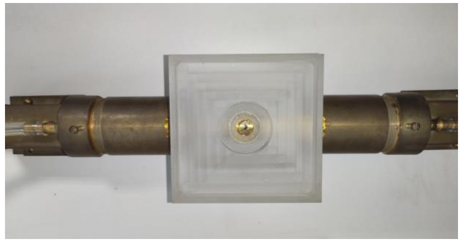
- Prototype test at IHEP
- Beam test data analysis

Test with different gas mixtures

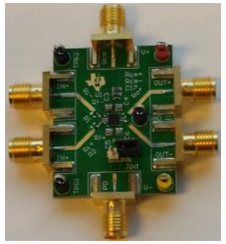
- **Test primary ionization signals with different gas ratios**
  - He/iC_4H_{10} = 90/10
  - He/iC_4H_{10} = 80/20
  - He/iC_4H_{10} = 70/30
- **High He ratio (@ the same HV) means high gas gain and high SNR, which is good for cluster counting**
- **Low He ratio requires preamplifiers with high gain bandwidth product (GBP)**

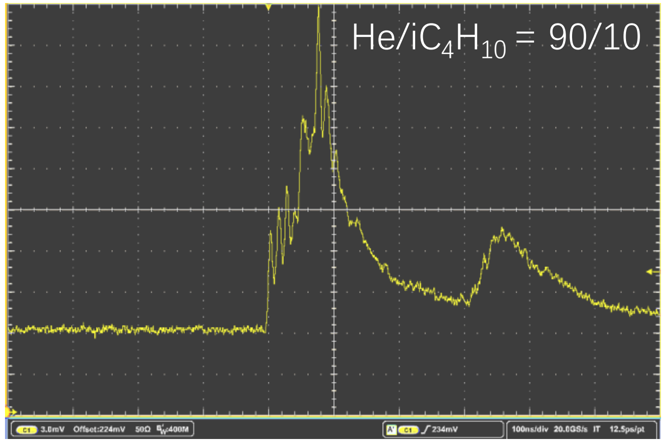
Prototype test @ IHEP

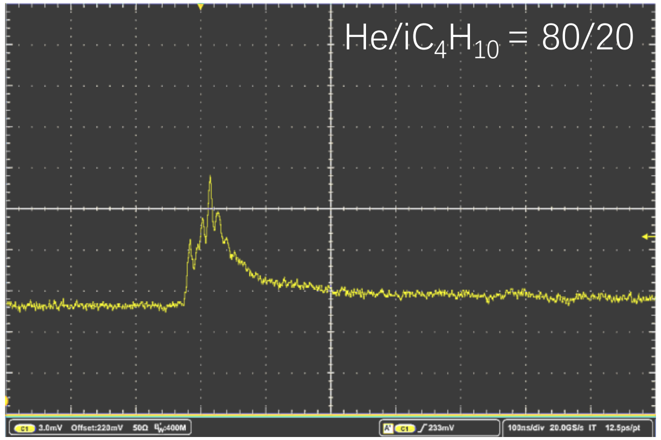
Proportional tube (φ=32mm)

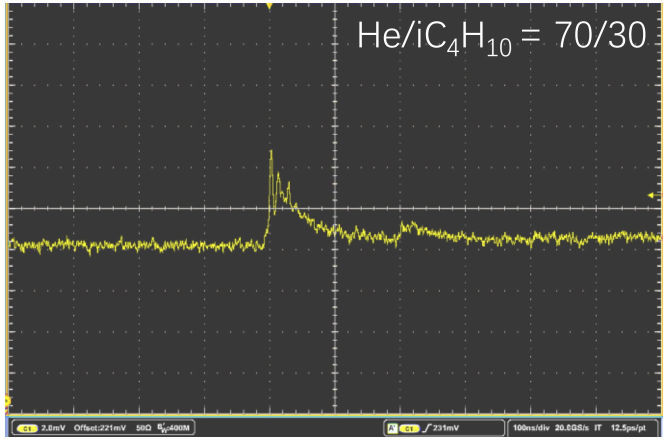


Preamplifier





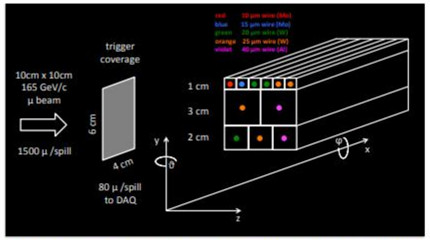


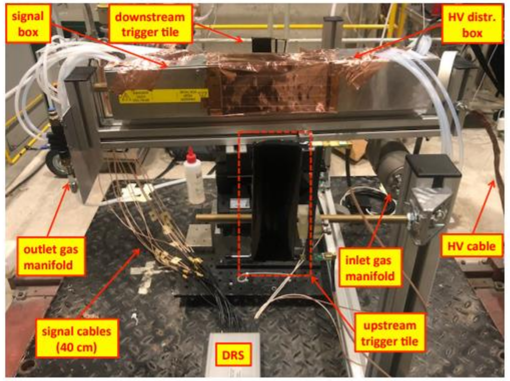


Beam test data analysis (preliminary)

Beam test @ CERN from F. Grancagnolo's group

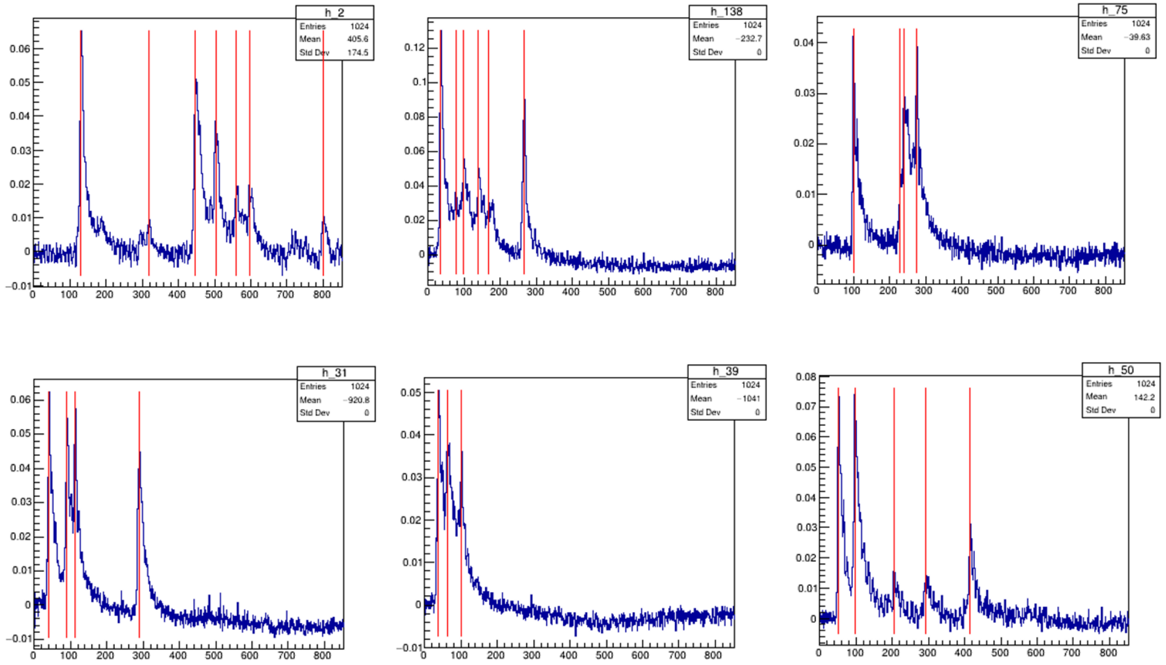
schematic





The test was performed during November 2021 at CERN on the H8 beam line in a **parasitic mode**. Main users on the same beam line was a team testing a tile calorimeter and, therefore, requesting for **large part of the time, beams of electrons and hadrons, at various energies,** needed for their calibration, but **useless for our purposes**. Only **sporadically**, a beam of **165 GeV/c muons** was available for us.

Preliminary peak finding with our algorithm



muons_165GeV_angle0_GSPS1p2_delay725ns_7Nov_0321

Ongoing activities:

- Binary file converter
- Outlier removal
- Event classification
- Tuning peak finding algorithm

See Franco's report in CEPC Physics and Detector Plenary Meeting:
https://indico.ihep.ac.cn/event/15676/contribution/2/material/slides/0.pdf

Summary

- **Updated simulation shows**
  - He 90% + iC_4H_{10} 10% gas mixture gives better K/pi separation at high momentum
  - It is possible to shrink the thickness of DC to less than 1m to satisfy 2σ K/pi separation up to 20 GeV/c

- **Experiment status**
  - Prototype test with different gas mixtures
  - Data analysis with the beam test data is ongoing

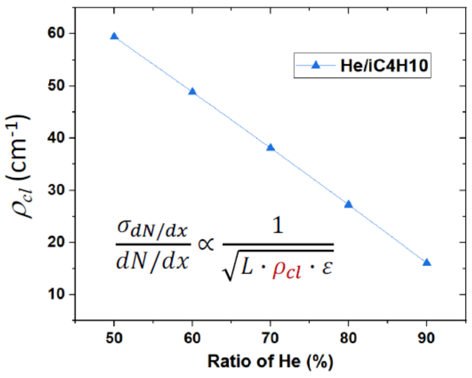
Thank you!

Backup

More study of gas mixtures

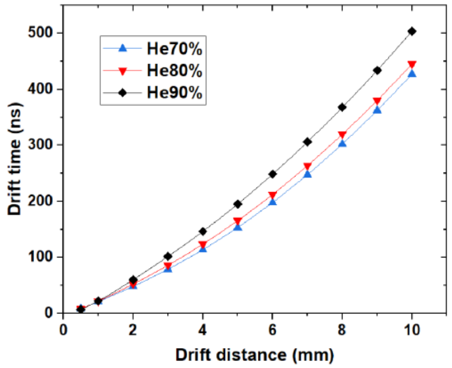
- choice of the gas mixture is essential
  - High cluster density compatibly with cluster counting efficiency
  - Low drift velocity helps to identify clusters in time
  - Small longitudinal diffusion is beneficial to both spatial resolution and dN/dx measurement
- Simulation of gas mixture performed to understand the gas property and optimize the working point

Cluster density vs ratio of He

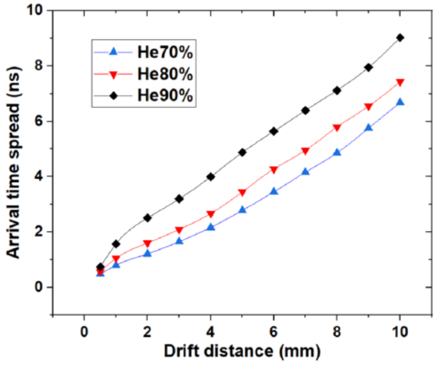


$$\frac{\sigma_{dN/dx}}{dN/dx} \propto \frac{1}{\sqrt{L \cdot \rho_{cl} \cdot \varepsilon}}$$

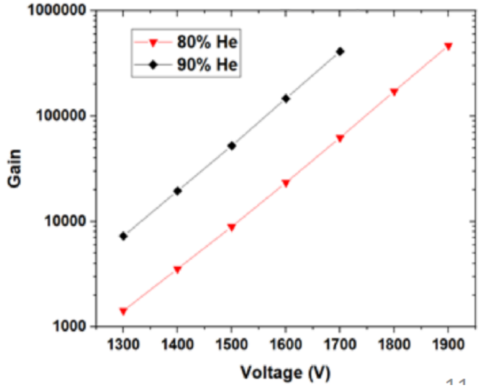
Drift time vs drift distance



Diffusion effect vs drift distance

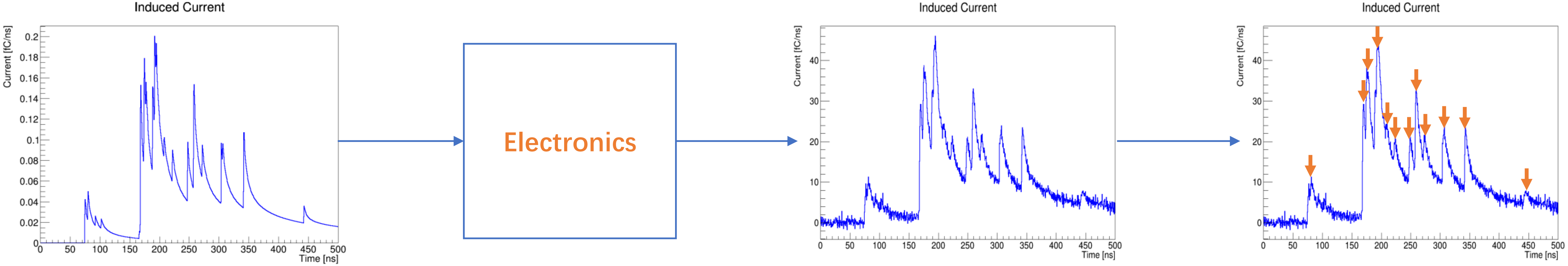


Gain vs H.V.



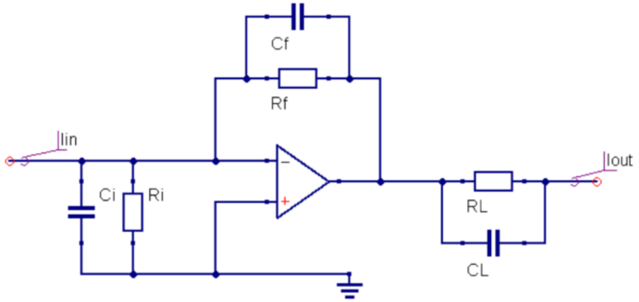
Full simulation

Induced current **Realistic waveform**



Signal generator (Garfield++):
- Heed: ionization process
- Magboltz: gas properties (drift/diffusion)

Electronics:
- Preamplifier
- Noises
- ADC



Peak finding algorithm:
- Low pass filter (smoothing)
- Second derivative (peak detection)

Prototype Experiment Setup

H.V.

^{90}Sr

Gas

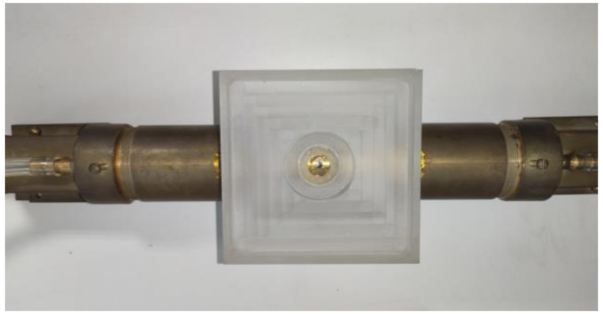
Detector prototype

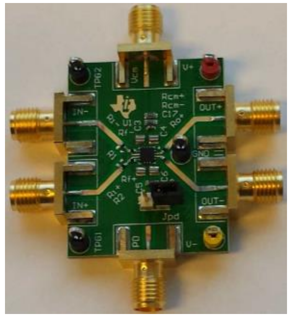
Power supply

Preamp

Oscilloscope

Sr Source





- ✓Proportional tube (φ32mm)
- ✓Gas: He + iC_4H_{10}

OR

Generator

Pulse or rectangular waveform

Waveform Generator

- ✓ **Pre-amplifier: LMH5401 evaluation module**
- ✓ Gain bandwidth product (GBP): 8 GHz
- ✓ Gain : 12 dB (4 V-V)
- ✓ R_f: 127 Ω