Status and plan for the dN/dx simulation and experiment

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CEPC Physics and Detector Meeting

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Outline

- Introduction
- Full simulation with the experiment
- Fast simulation
- Summary

Introduction

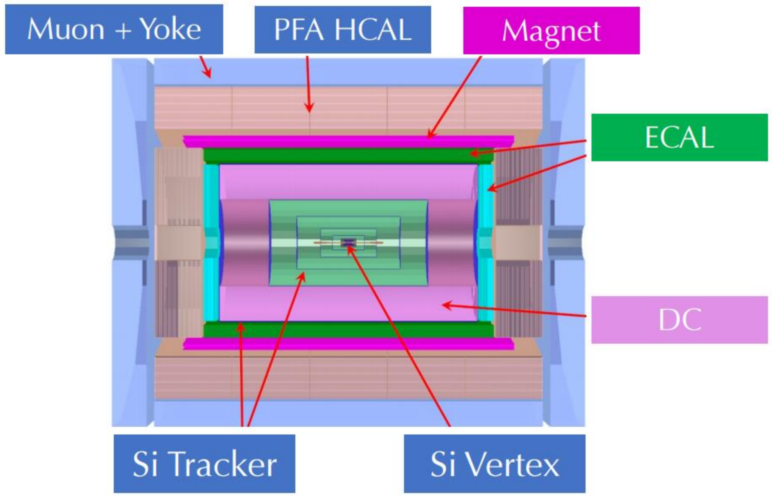
- **Particle ID with a drift chamber is a key feature for the 4th conceptual detector**

- **Ionization measurement using the cluster counting technique (dN/dx) can benefit from small fluctuations**

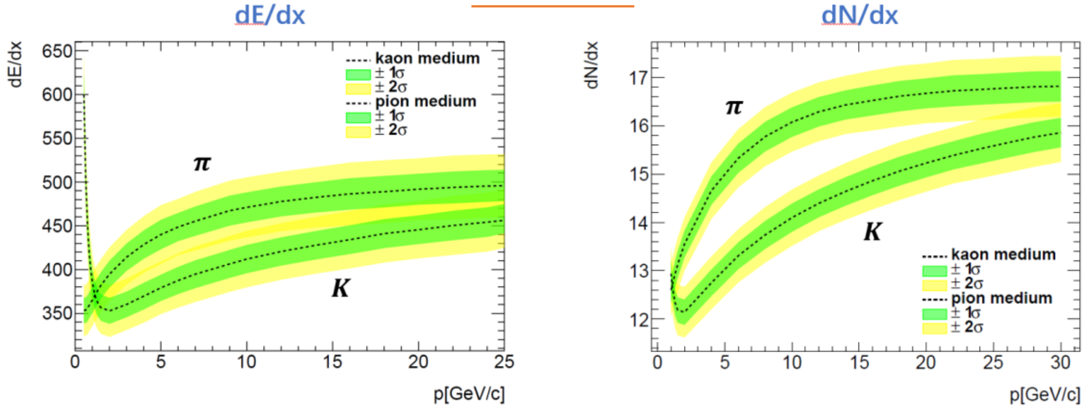
- **Need detailed simulation for the feasibility and performance study**

- **Input from experiment tests is important for simulation**

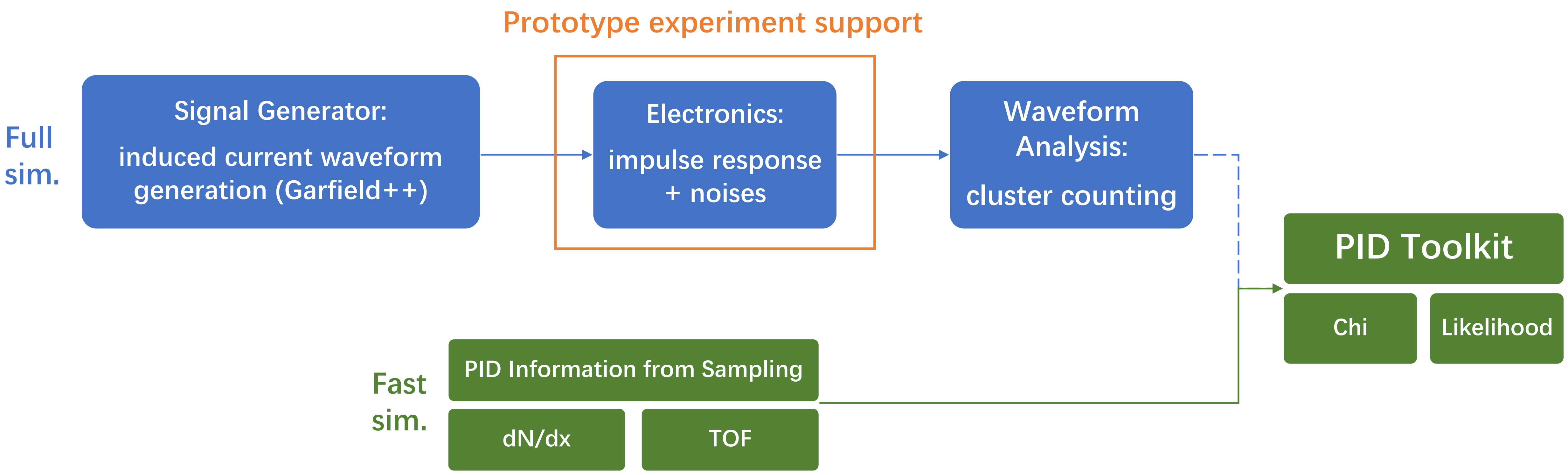
4th Conceptual Detector



MC truth



The simulation workflow

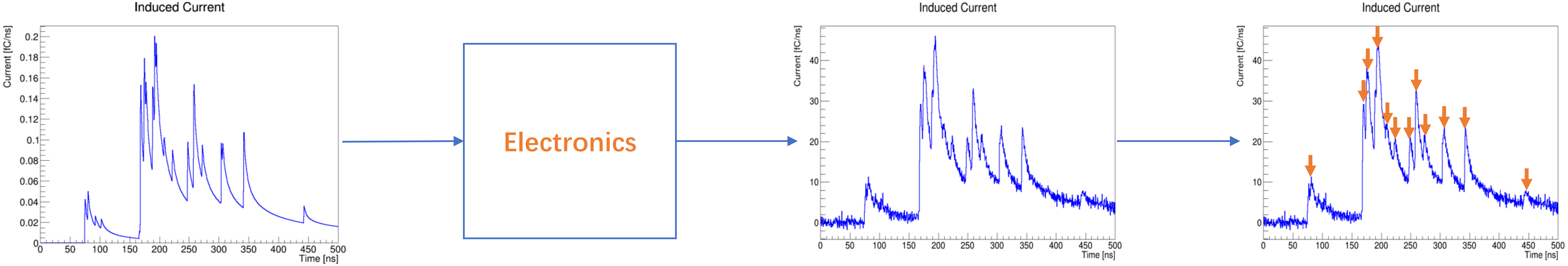


- A framework of dN/dx simulation is ready

Full simulation

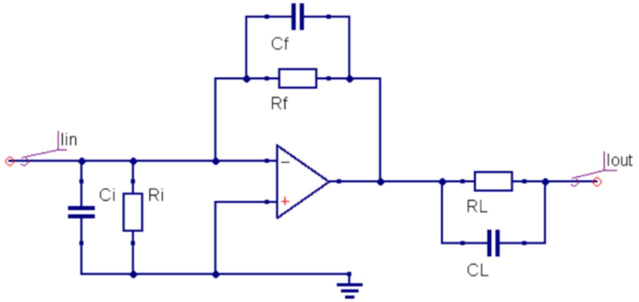
Induced current

Realistic waveform



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

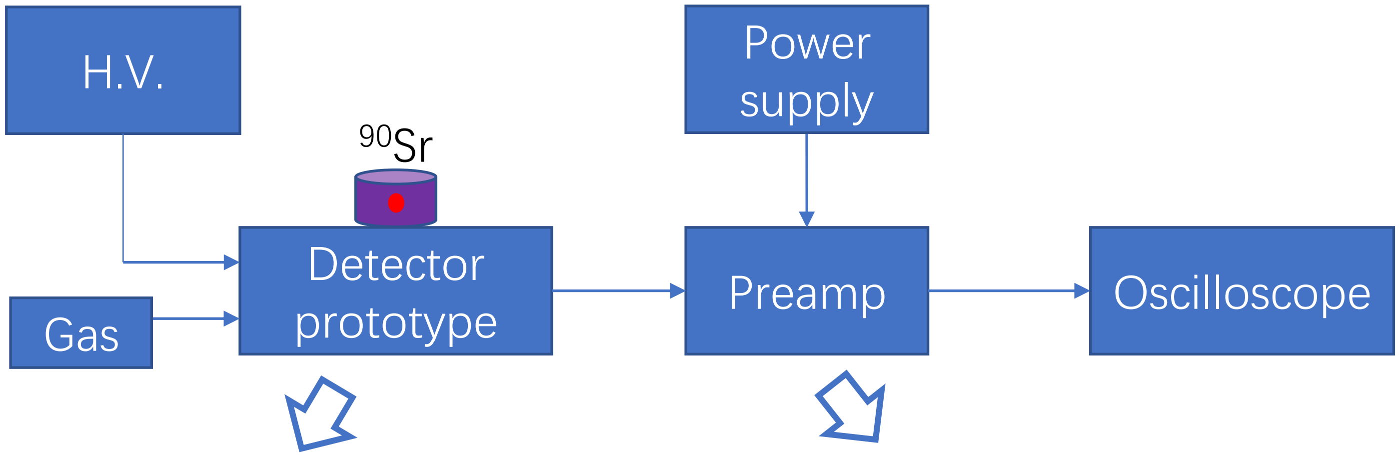
Electronics:
- Preamplifier
- Noises
- ADC

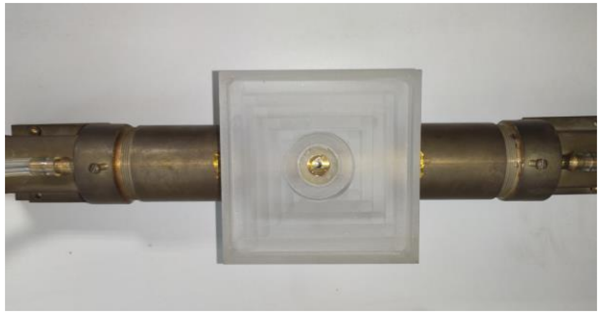


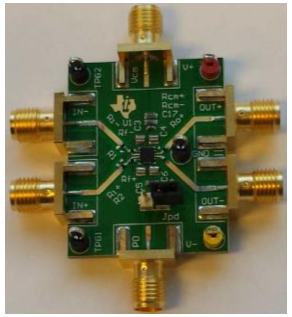
Counting method:
- Moving average (MA):
  - $\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} S[i-k]$
- First difference (D1):
  - D1[i] = MA[i] – MA[i – 1]

- **Need experiment to provide more realistic electronics information**
  - **Noises**
  - **Response function**

Experiment with a prototype detector





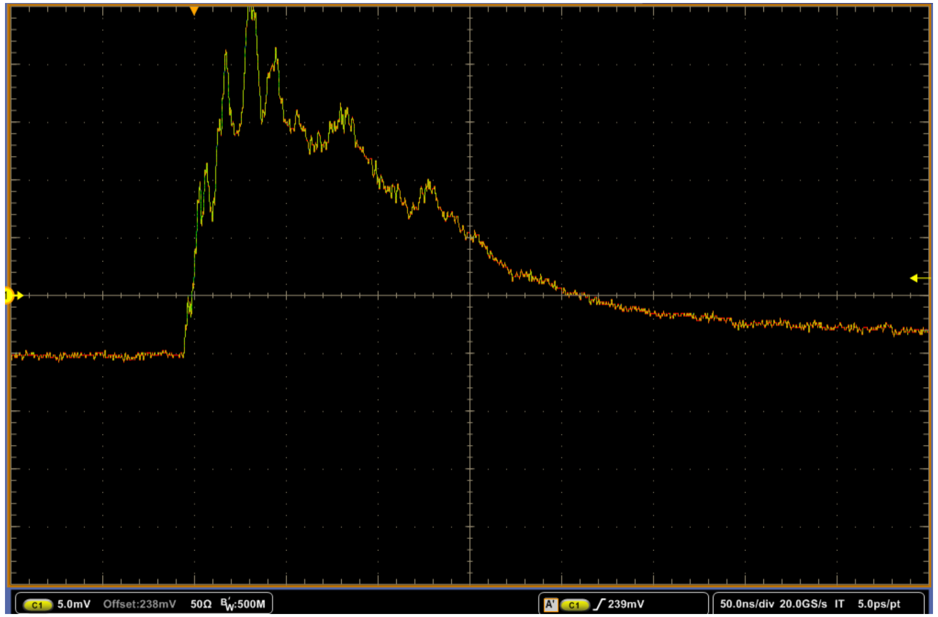


- ✓ **New amplifier: LMH5401 evaluation module**
- ✓ Gain bandwidth product (GBP): 8 GHz
- ✓ Gain : 12 dB (4 V-V)
- ✓ R_f: 127 Ω

- ✓ Proportional tube (φ32mm)
- ✓ Gas: 80% He + 20% iC_4H_{10}

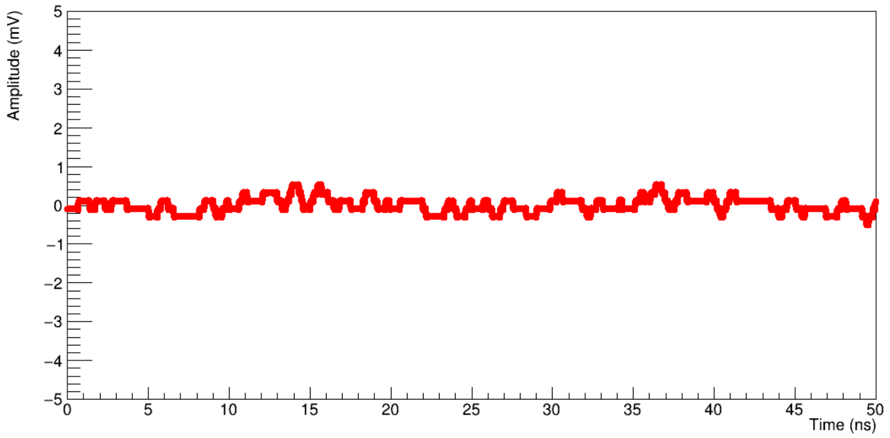
Waveform examples

- **Can observe peaks with fast rising edge in the waveforms**
- **Small gain and low noise**
  - Signal amplitude: ~10^1 mV (max. peak)
  - Noise amplitude: ~10^{-1} mV (sigma)



Noise extraction

Extract noise information from the baseline of the waveform



FFT analysis of noises

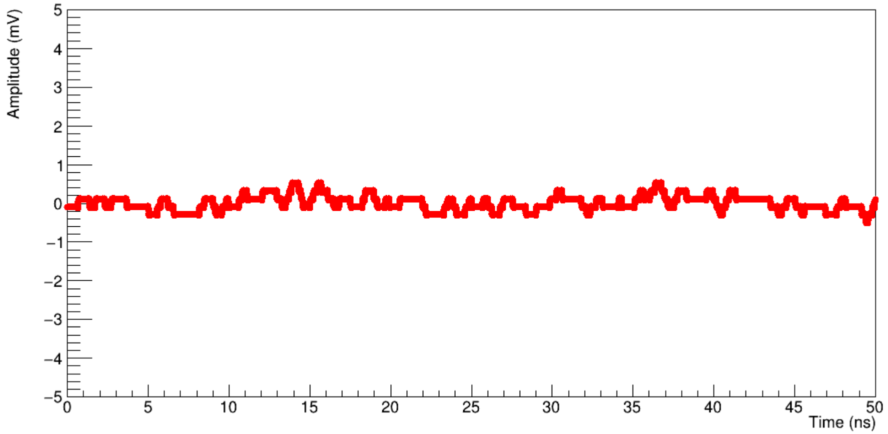
rectangular notation

$$x(t) = \sum_{k=0}^{+\infty} ReX[k]\cos(2\pi kt/T) - ImX[k]\sin(2\pi kt/T)$$

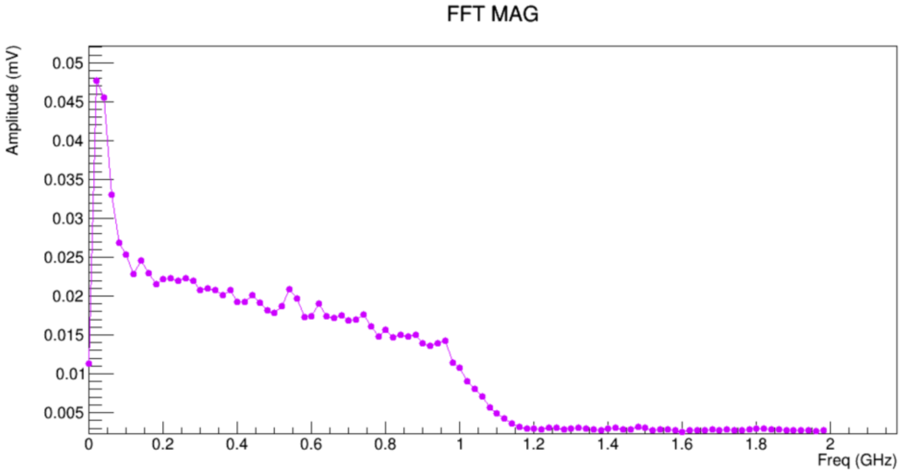
polar notation

$$MagX[k] = (ReX[k]^2 + ImX[k]^2)^{1/2}$$

$$PhaseX[k] = \arctan\left(\frac{ImX[k]}{ReX[k]}\right)$$



FFT

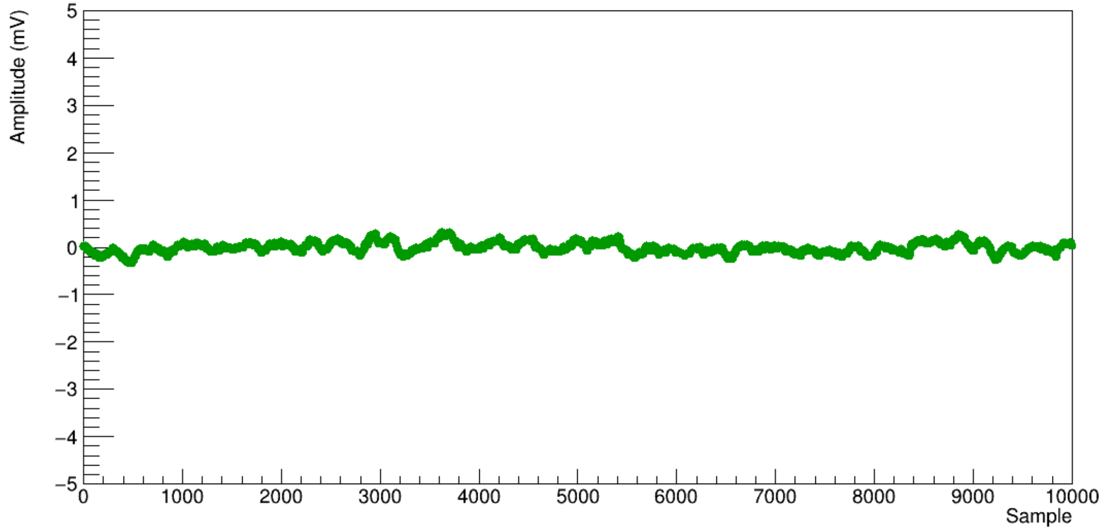


IFFT

- ✓ Average frequency spectra with 227 measurements
- ✓ Assume random phases

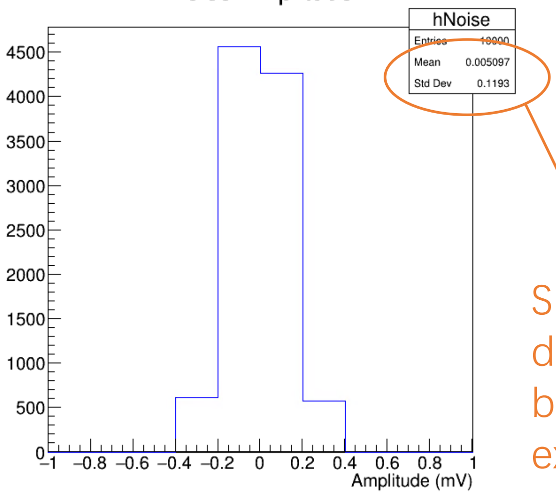
Noise generation

IFFT



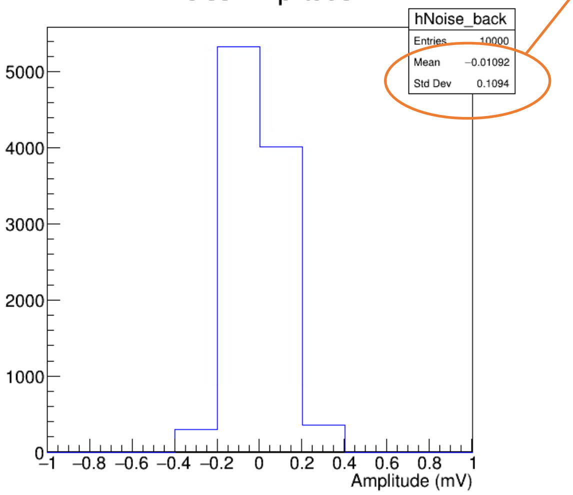
Noises are reproduced

Experiment

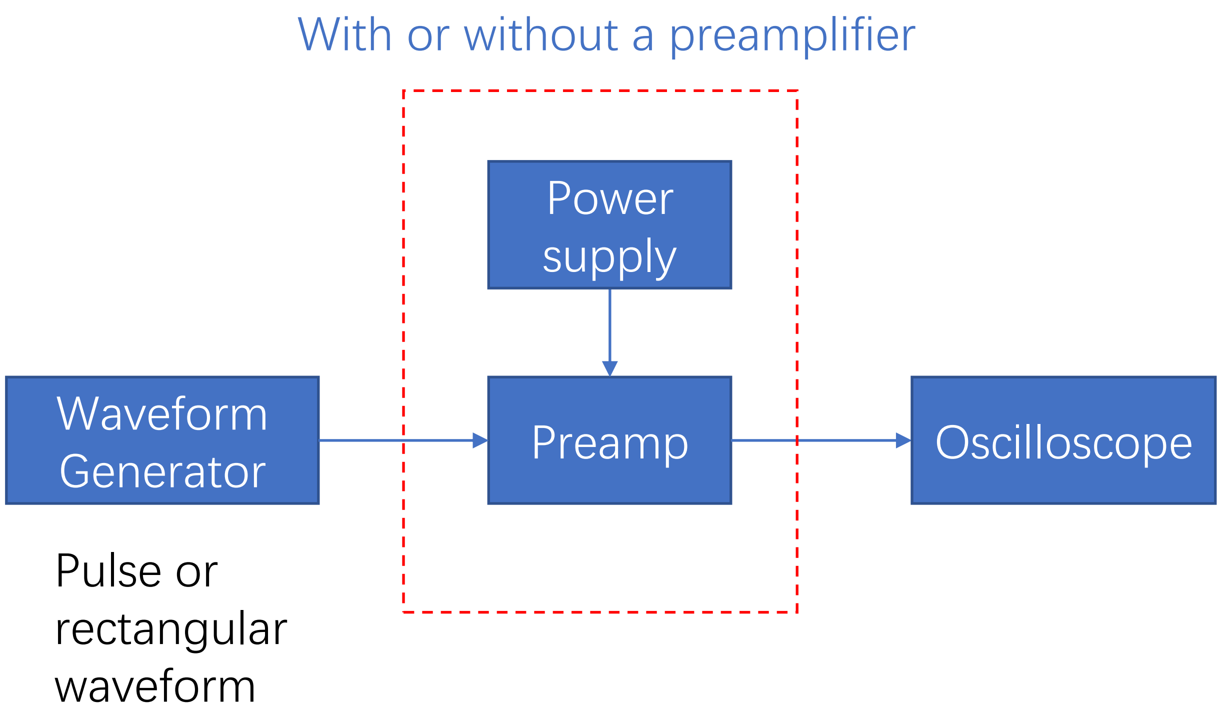


Similar distribution between experiment and simulation

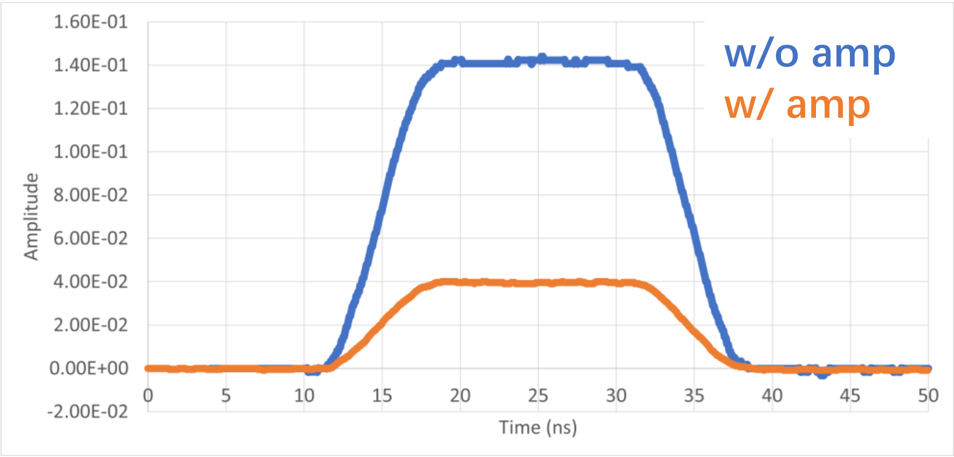
Simulation



Experiment with a signal generator

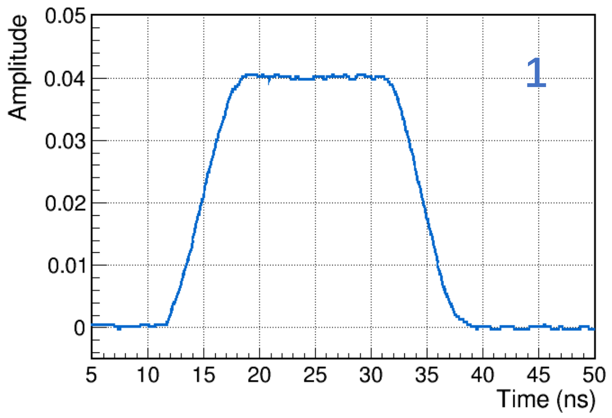


- Measure the signal with or without the pre-amplifier
- Try to extract the response of the pre-amplifier



Response function analysis (preliminary)

1: Signal w/o amp
2: Response function
3: Signal w/ amp



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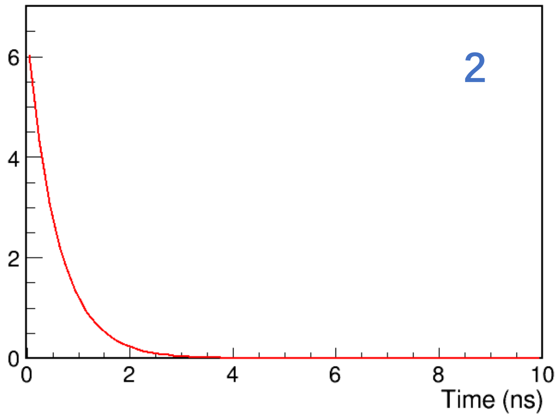

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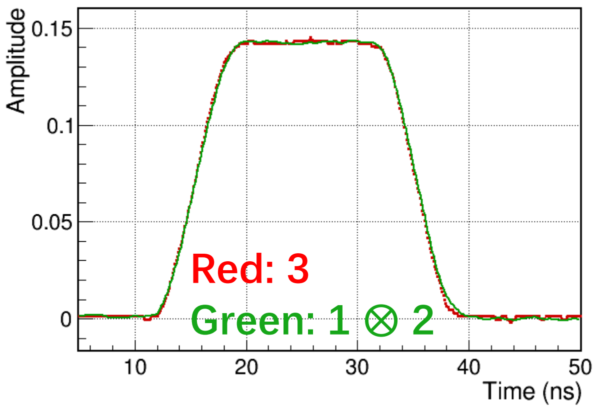
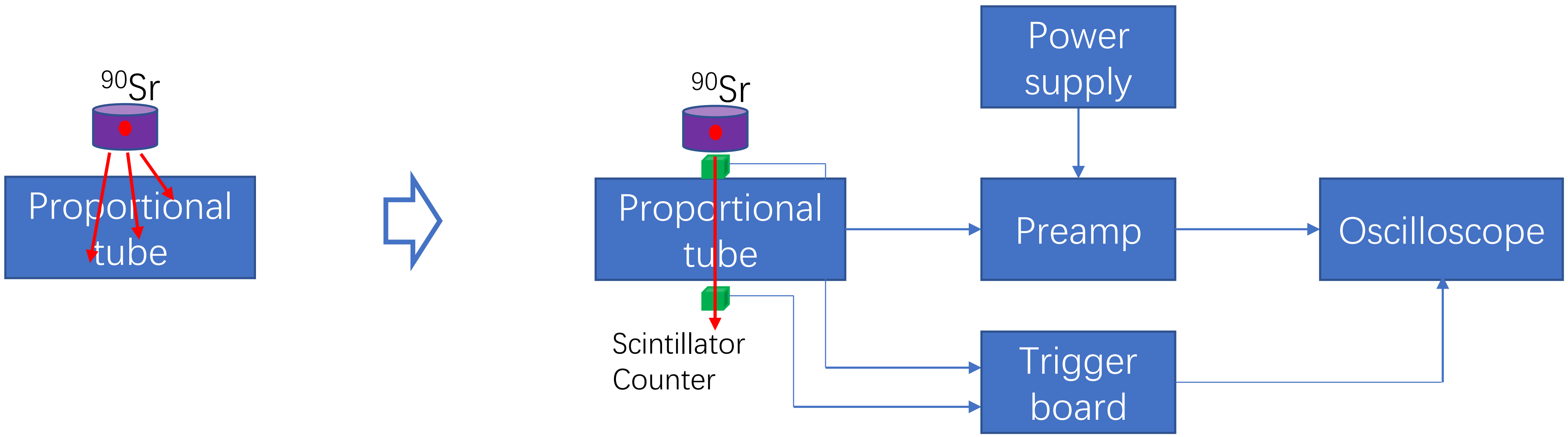


Extracted pre-amplifier response:

- Time constant ~0.6 ns (assume an exponential form)
- Risetime ~ 1ns: consistent with our previous simulation

- Check the response function by convoluting it to the signal w/o pre-amp.
- Show good consistency.

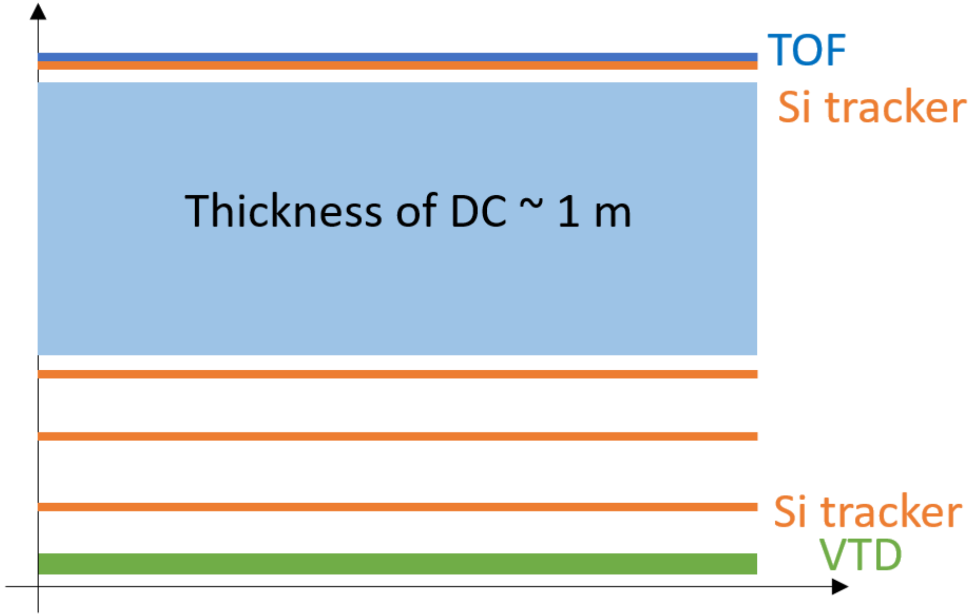
Plan: Prototype experiment with collimation



- **Constrain the entrance angle and track length of the emitted electrons from the Sr source**
- **Two scintillator counters with small active area will be used to provide trigger signals**

Fast simulation in CEPCSW

- **Main objective: Speeding up the simulation to enable the study of PID performance**
- **Method: Sampling dN/dx (truth) by a certain track length using Garfield.**
- **Geometry setup:**
  - Floating DC up to Rout =1.8m (1cm*100 layers)
  - A TOF detector surrounded at R = 1.8m
  - Can handle single particle in different angle.

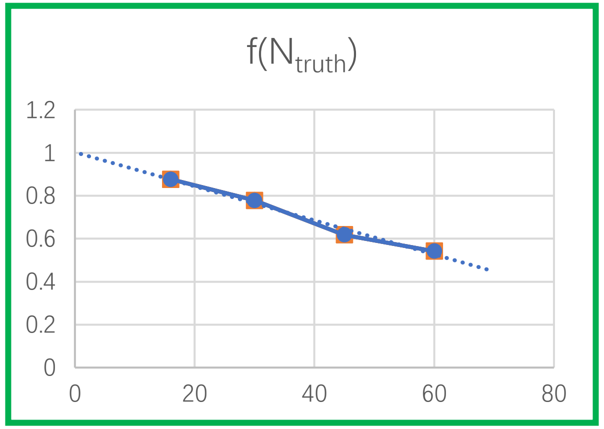


Current v1 configuration

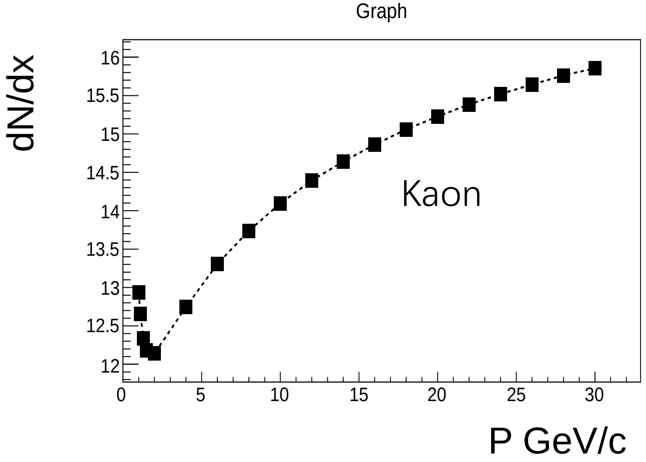
Fast simulation in CEPCSW (II)

- **dN/dx model:** $N = N_{truth} \times \epsilon = N_{truth} \times Gaus(f(N_{truth}), \sigma)$.
  - N_{truth}: Garfield sampling
  - ϵ: counting efficiency, tuned based on full simulation
- **TOF model:**
  - Assuming a resolution of 50 ps

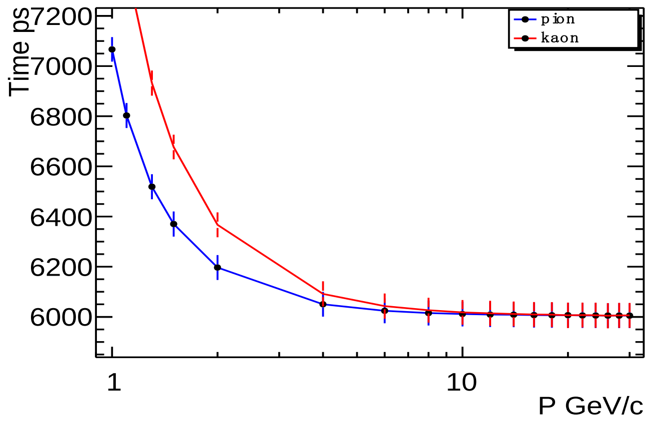
Tuned from waveform-based simulation



dN/dx model



TOF model

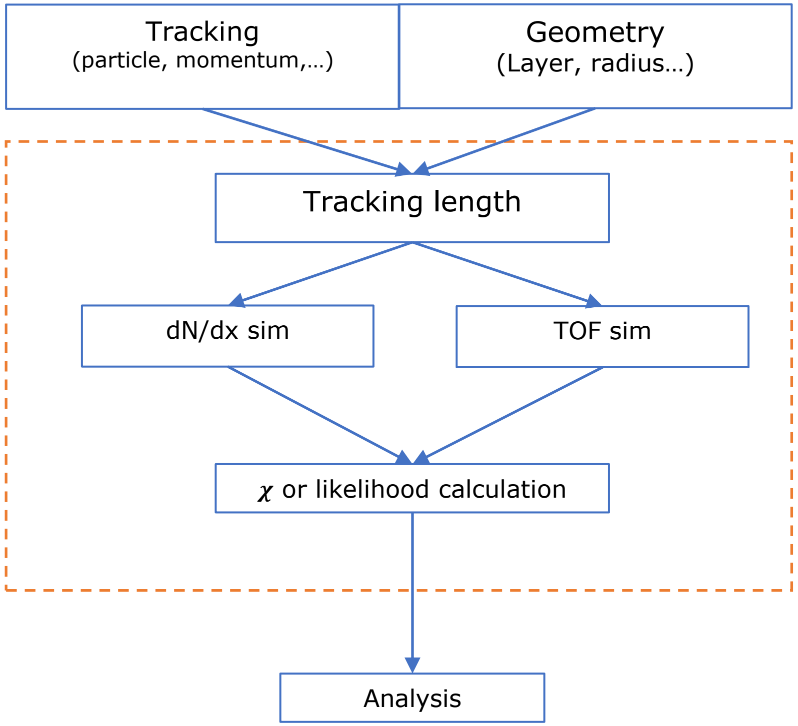


Fast simulation in CEPCSW (III)

- **Provide PID information:**
  - $\chi_t = \frac{t - t_{exp}}{\sigma_t}$, $\chi_{\frac{\mathrm{dN}}{\mathrm{dx}}} = \frac{dN/dx - dN/dx_{exp}}{\sigma_{\frac{dN}{dx}}}$
  - Likelihood: $\frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi_t^2} * \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi_{\frac{dN}{dx}}^2}$

- **A standalone package is also developed for physics analysis to do quick studies**
  - Input: basic track related parameter
    - angle, momentum, distance from initial point.
  - Output: the probability of assumption on each particle species, with dN/dx (and TOF, optional)
    - χ, likelihood

Structure of the fast simulation



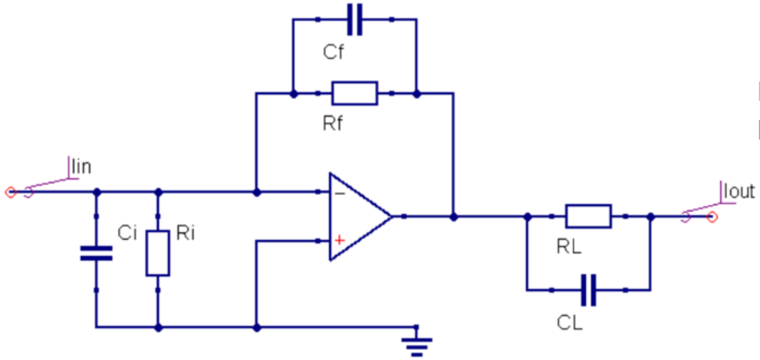
Summary

- **Initial prototype experiments are setup for the ionization measurement. The following information is extracted:**
  - Electronics noises
  - Response of the preamplifier (preliminary)
- **A fast simulation toolkit is developed for physics users to study the PID performance**
- **To do:**
  - Improve the experiment in several aspects
  - Import the results from the experiment to the full simulation

Thank you

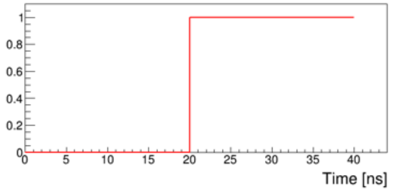
Backup

A simple current-sensitive preamplifier

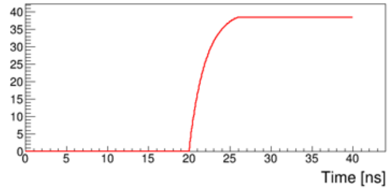


Time constants (τ) and risetime:

Step response:



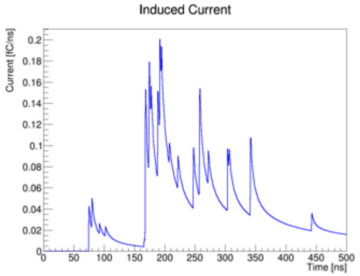
Response after preamplifier:



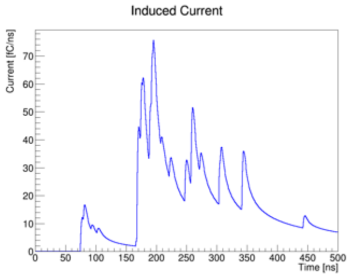
Time Constant (ns)	Risetime (ns)
0.5	0.95
1.0	1.85
2.0	3.70
3.0	5.50
4.0	7.35
5.0	9.20

Broaden of the waveforms with different time constants:

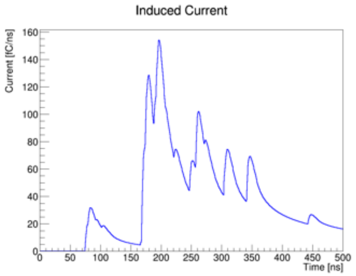
$\tau = 0\ ns$



$\tau = 2\ ns$



$\tau = 5\ ns$



Response function result from a pulse signal