Updated full simulation software

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Cluster counting meeting
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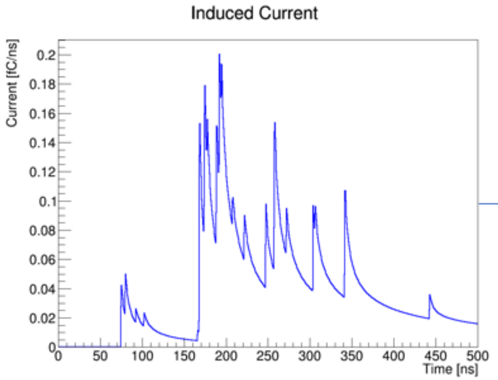
Introduction

- **Full simulation package is the foundation of dN/dx PID study**
- **Major challenges**
  - Full simulation with Garfield++ is computational expensive
  - Need more realistic model from the test beam data
- **A full simulation package is developed considering the challenges in 2021**
  - Fixed momentum track
  - Test beam 2021
- **Make extensions and updates to the original packages in order to perform CEPC DC studies and peak finding ML algorithm studies**

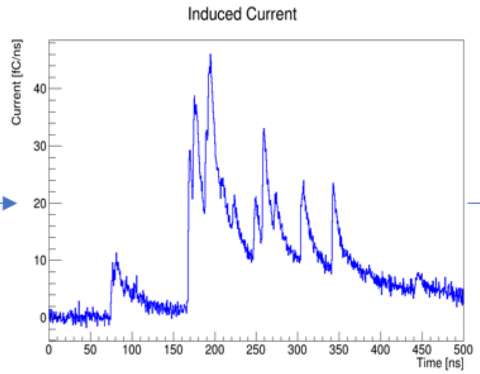
Full simulation

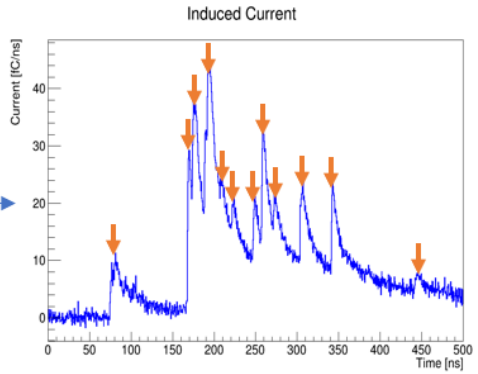
Induced current



Electronics

Realistic waveform





Signal generator (Garfield++):

- Heed: ionization process
- Magboltz: gas properties (drift/diffusion)

Electronics:

- Preamplifier
- Noises
- ADC

Peak finding algorithm:

- Second derivative

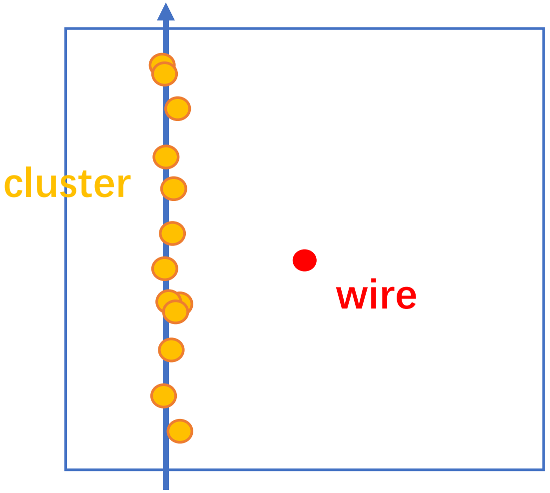
Signal generation

Digitization

Reconstruction

Amplification and signal creation is slow

Ionization process (by Heed)

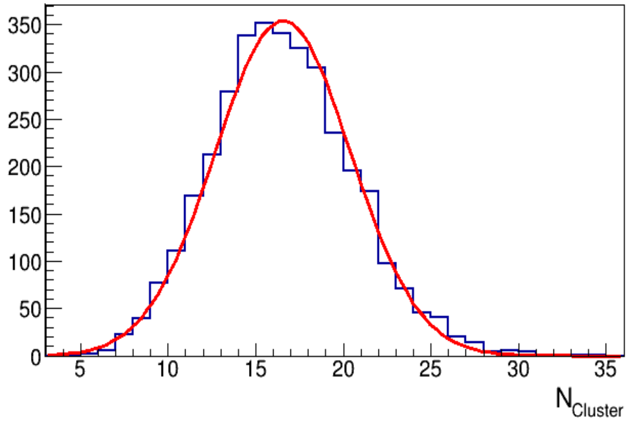


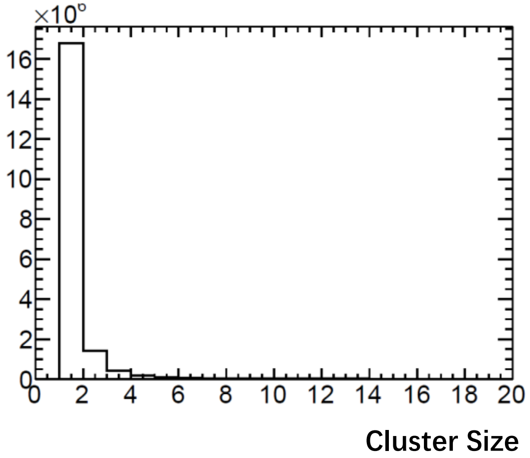
(for demonstration)

- **A sequence of primary interactions (clusters) along the track**
  - The # of clusters can be described by the Poisson distribution

$$P(\bar{N}_p, k) = \frac{\bar{N}_p^k}{k!} e^{-\bar{N}_p}$$

- **For each cluster, one or more electrons are released**



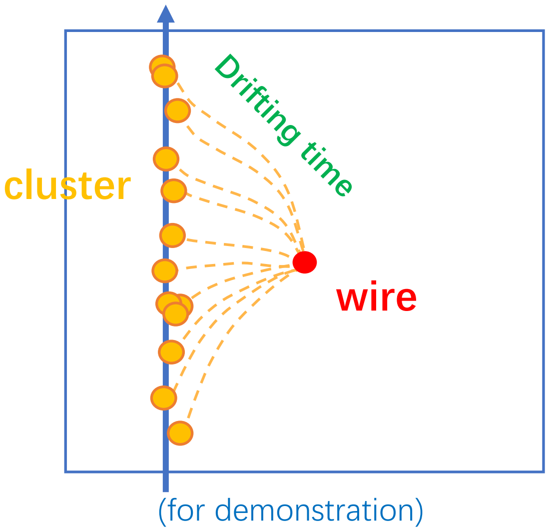


1 cm x 1 cm
He/iC_4H_{10}: 90/10

Update: Use Heed to simulate the ionization

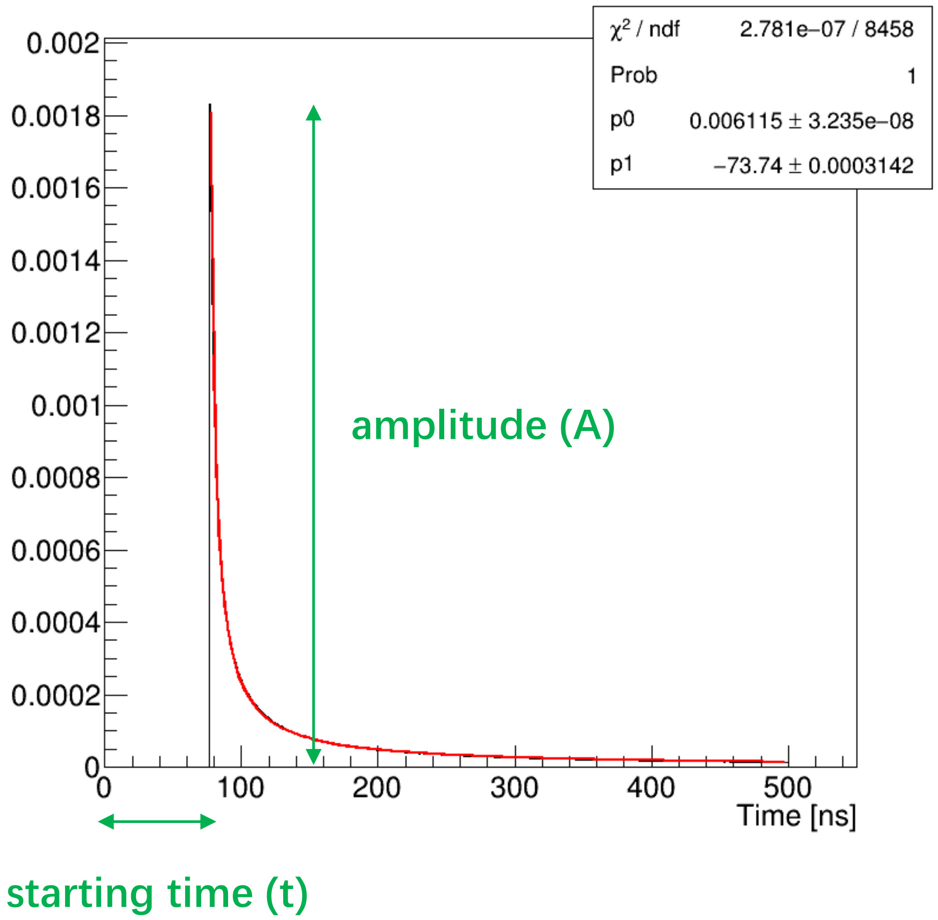
Effective models for signal generation

Electrons from ionization:
drift/diffusion ➔ avalanche ➔ induce current



Very time consuming in Garfield++
➔ Need parameterization

Single pulse: pulse(A, t)



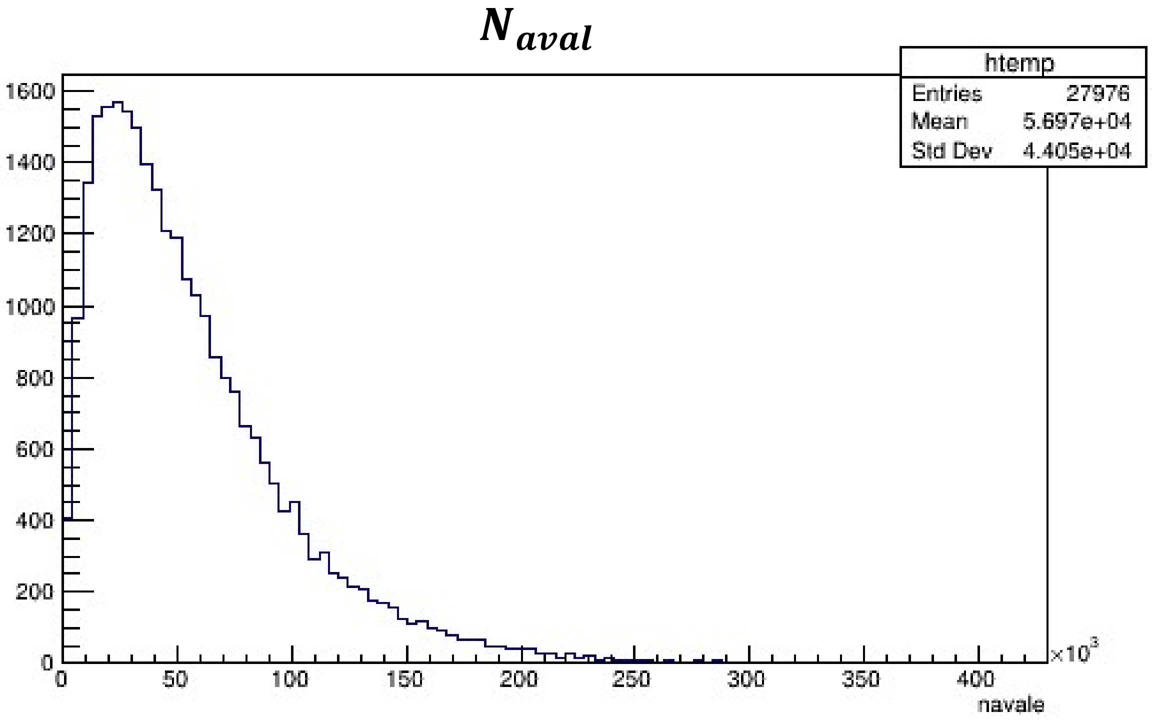
Parameterization:
- Amplitude
- Starting time
- Pulse shape

Need to extract information from Garfield++

Garfield++ simulation setup

- **Geometry and cell size**
  - Cubic cells with cell size of 1.8 cm x 1.8 cm
- **Gas mixture**
  - 90/10: He/Isobutane
- **High voltage**
  - 1630 volt

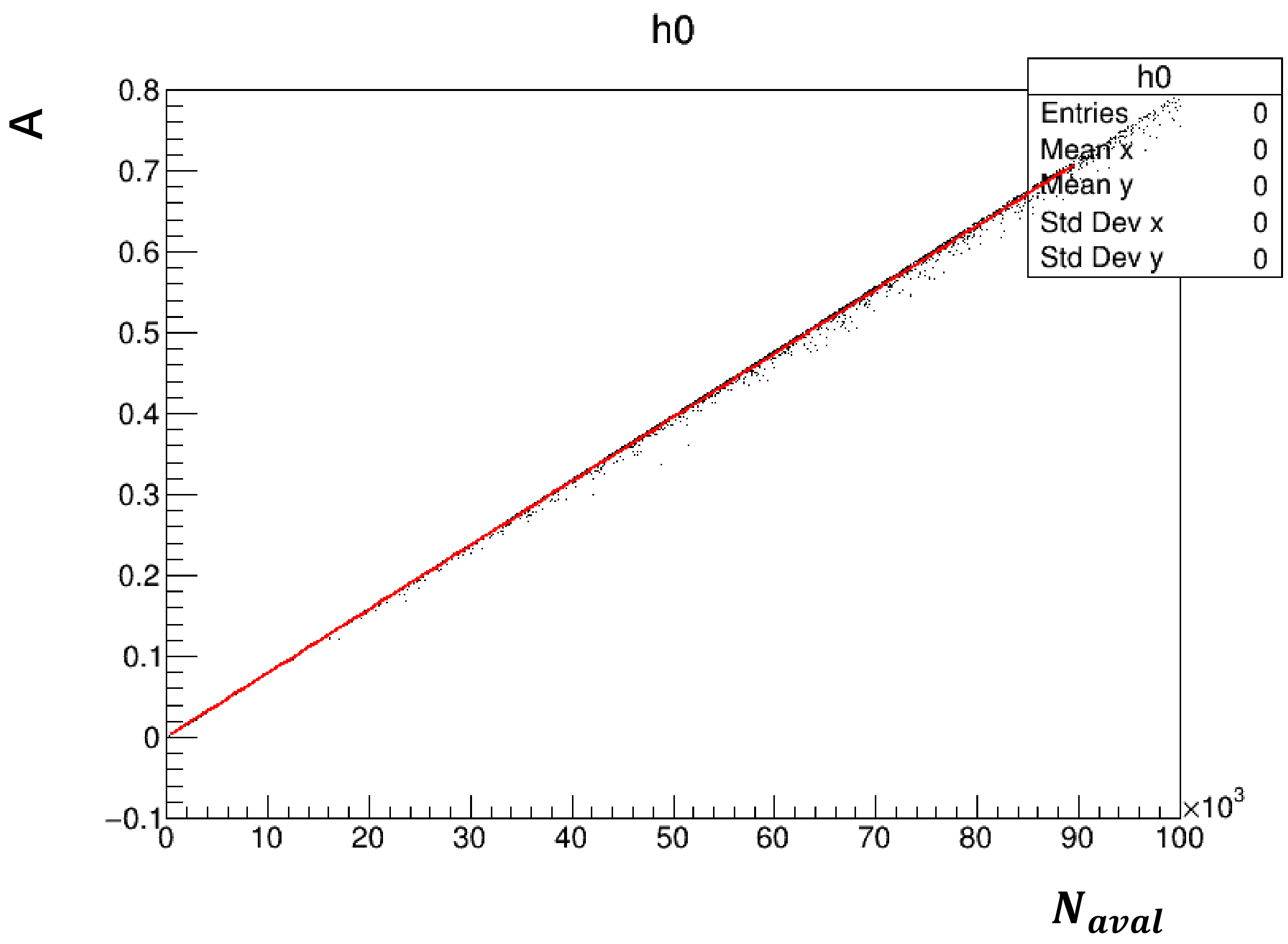
Pulse amplitude model



# of avalanche e-

- Strong inhomogeneous field around a thin wire yields **Polya** distributions
- Obtain N_{aval} distribution from Garfield simulation

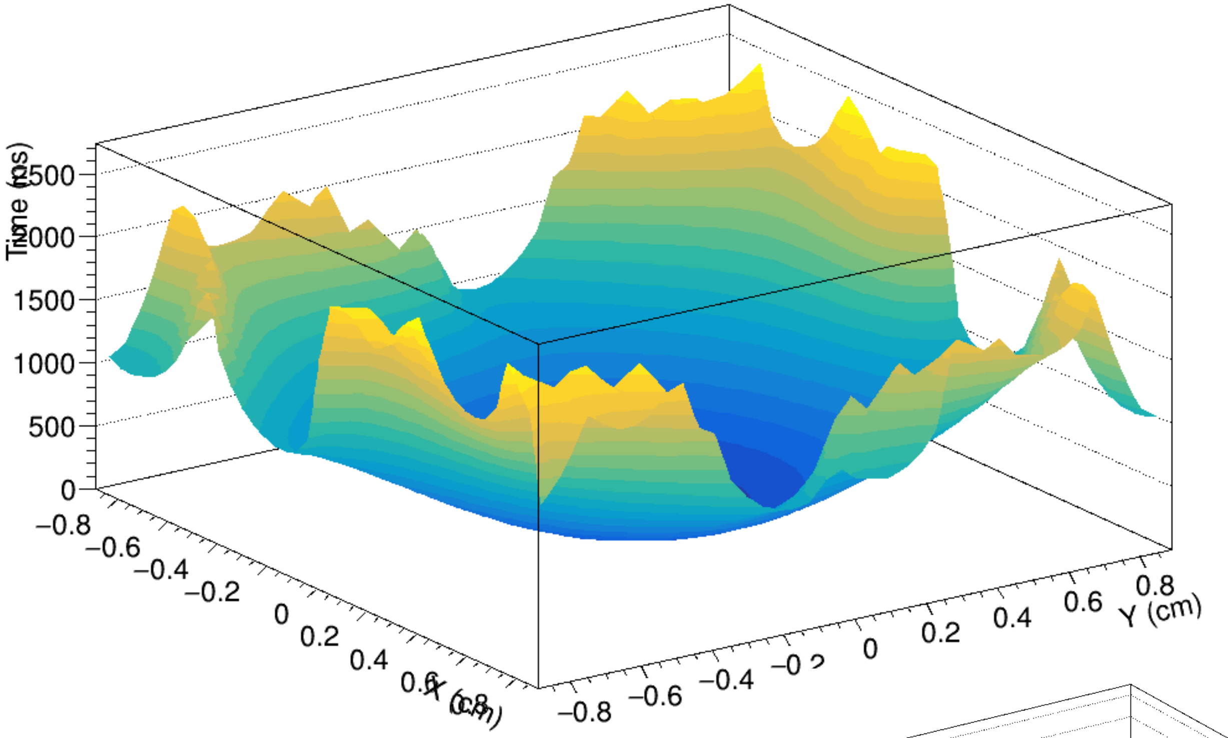
Pulse amplitude model (cont.)



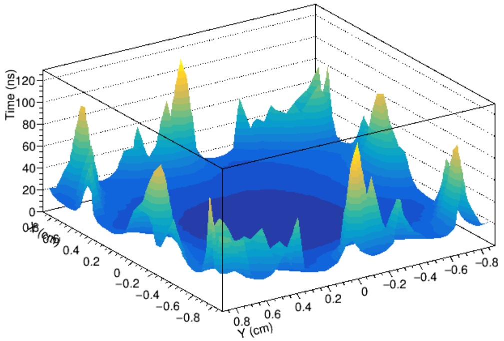
- Induced current $\propto -\frac{N_{aval}}{t+t_0}$
- Pulse height $A \propto N_{aval}$
- Linear fit:
  - $A(N_{aval}) = p_0 + p_1 \times N_{aval}$

Pulse time model

μ



σ

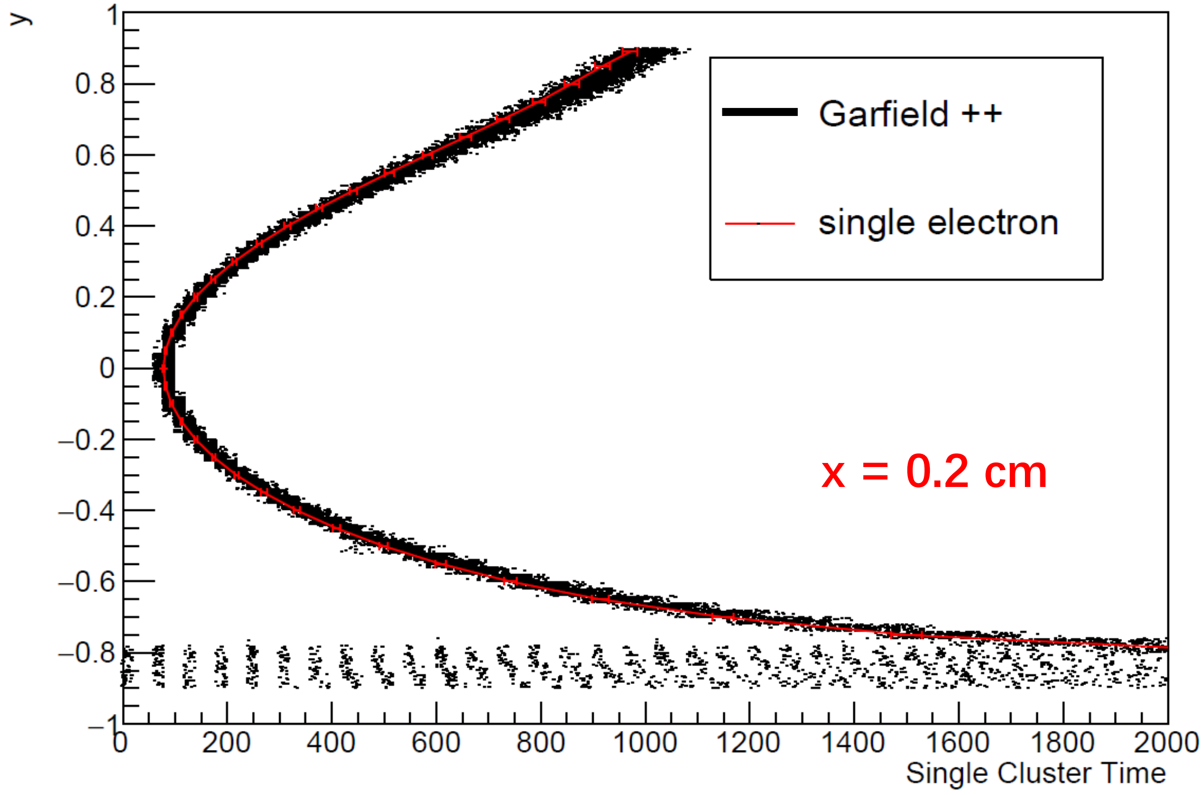


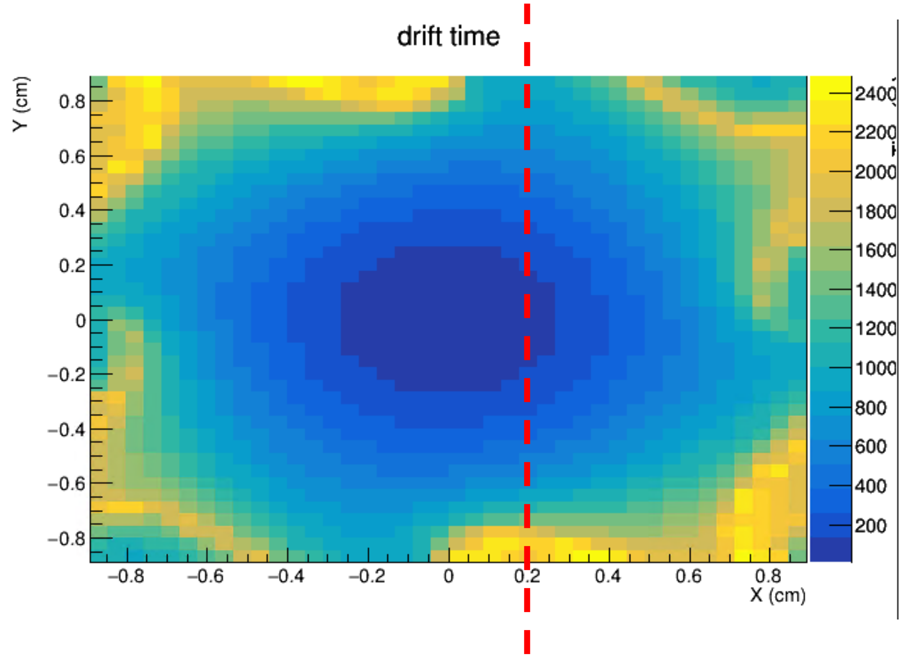
- For a fixed electric/magnetic field:
  - t is mainly determined by initial position of the electron
- Measure the relationship from Garfield++ simulation
  - $t(x,y) = Gauss(\mu(x,y), \sigma(x,y))$

Update: 2D measurement

Pulse time model (cont.)

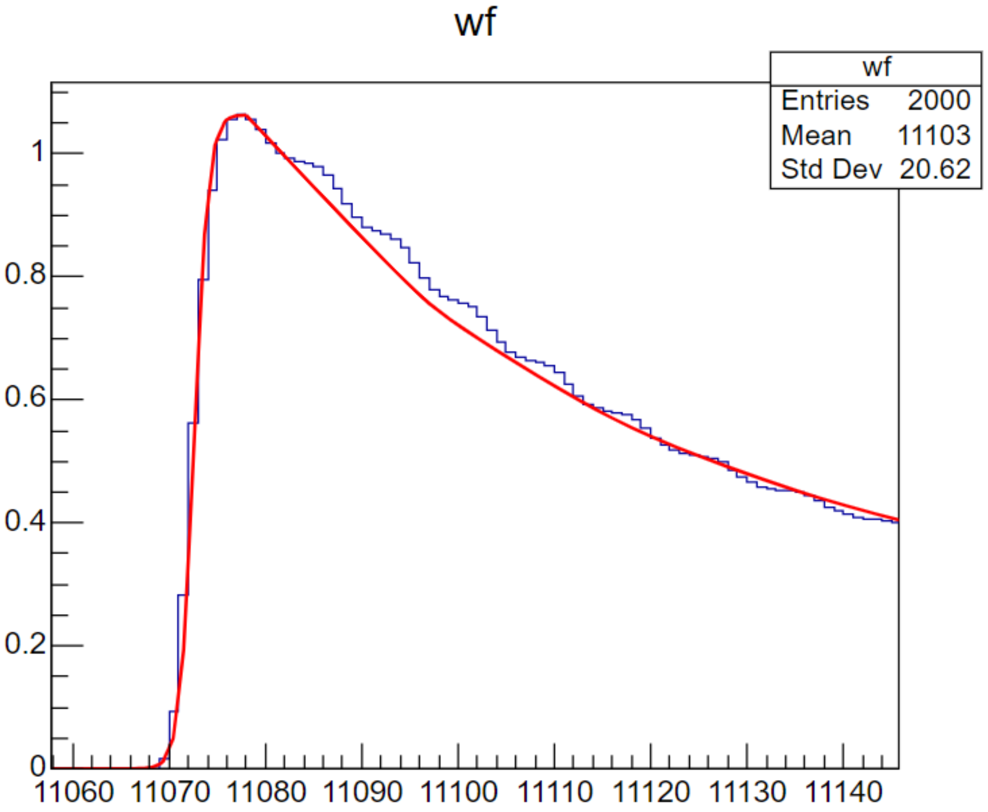
Comparison to Garfield++





Good consistency for track with x = 0.2 cm

Pulse shape model



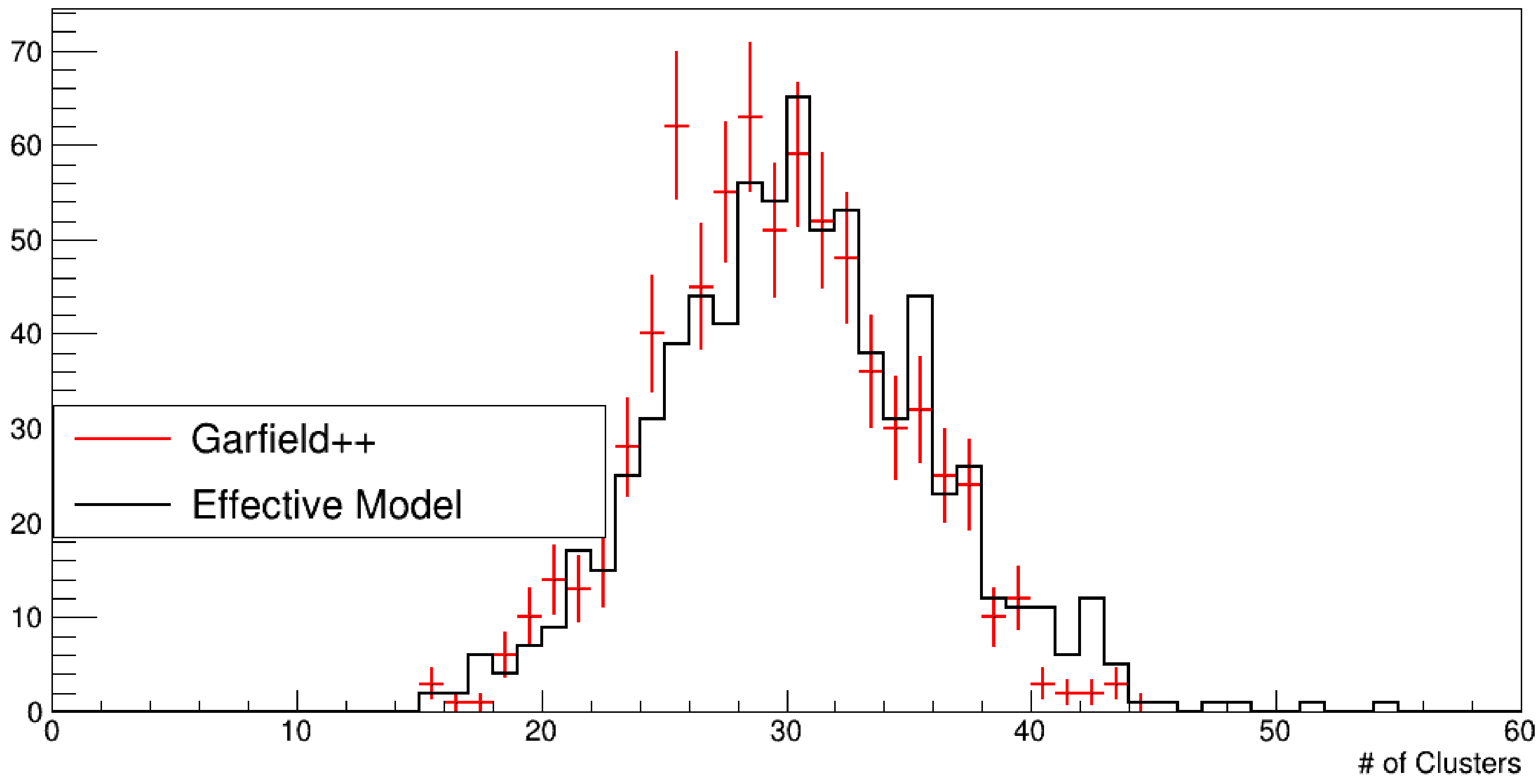
- Fit the Garfield pulse by:

- $$f(x|A,t) = \begin{cases} p_0 \times \dfrac{e^{-p_1(x-p_2)}}{1+e^{-\frac{t-p_3}{p_4}}}, x < t \\ A \times \dfrac{p_5^{p_6}}{(x-t)^{p_6}+p_5^{p_6}}, x \geq t \end{cases}$$

Model validation

- **Control the systematic error by the modelling**
  - Need to be consistent with Garfield++ simulation in an acceptable level
- **Compare basic distributions**
  - Ionization distribution
  - Single-pulse distribution: amplitude, time
  - (Multi-pulse) waveform distribution: charge
- **Garfield++ setup**
  - Cell size: 1.8 cm x 1.8 cm
  - Gas mixture: He/iC_4H_{10} (90/10)
  - Particle: 20 GeV/c pions

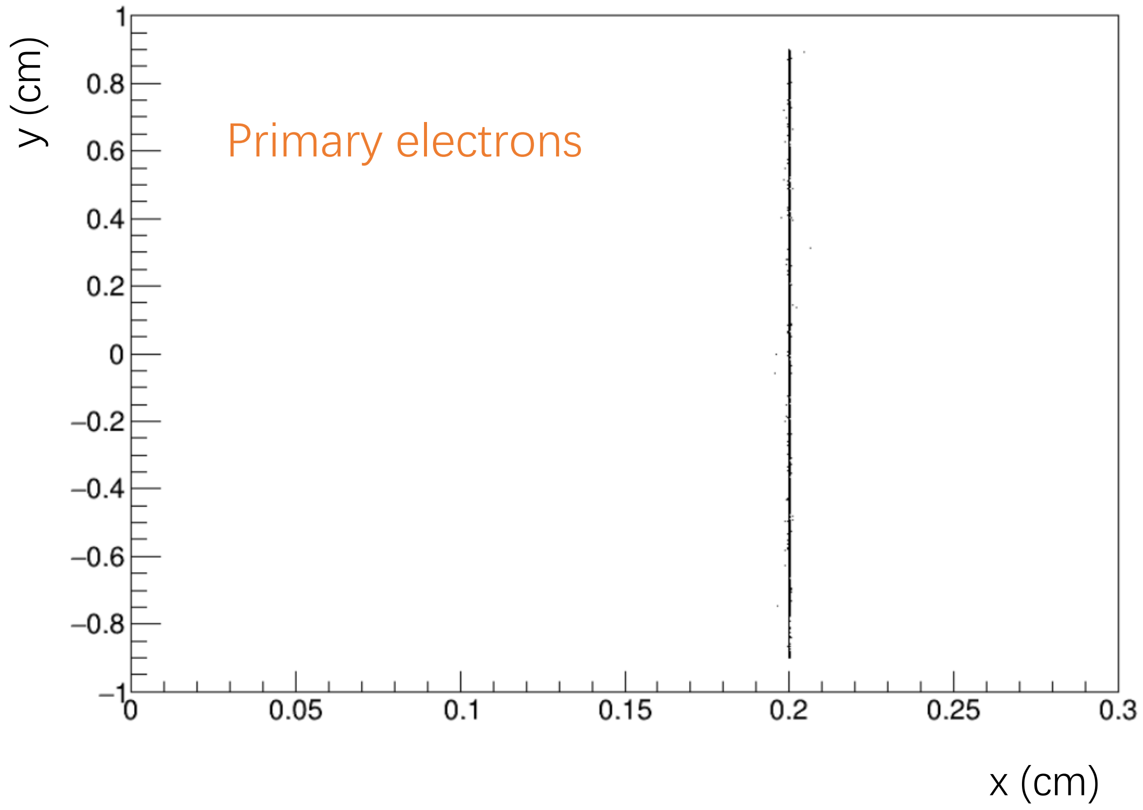
of primary ionizations

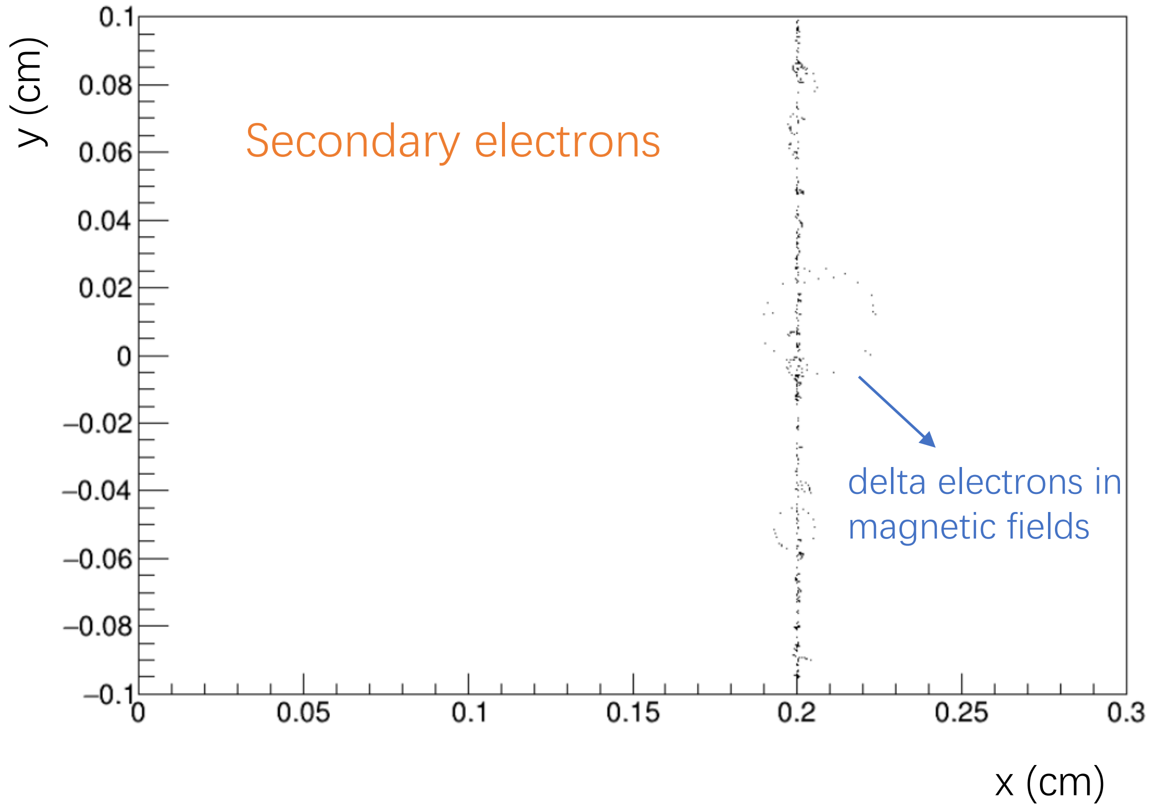


Be consistent very well

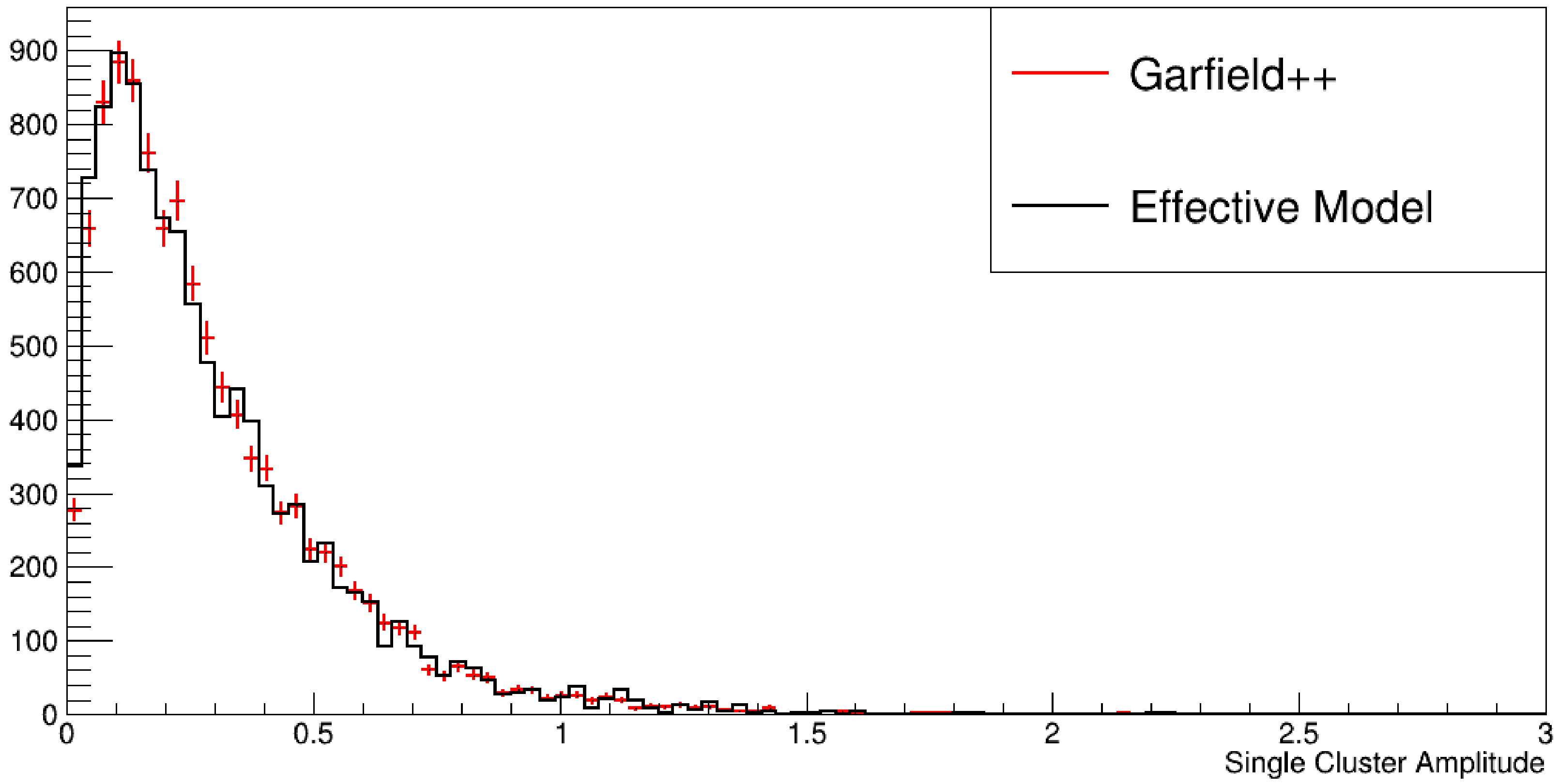
More ionization plots

Ionization positions



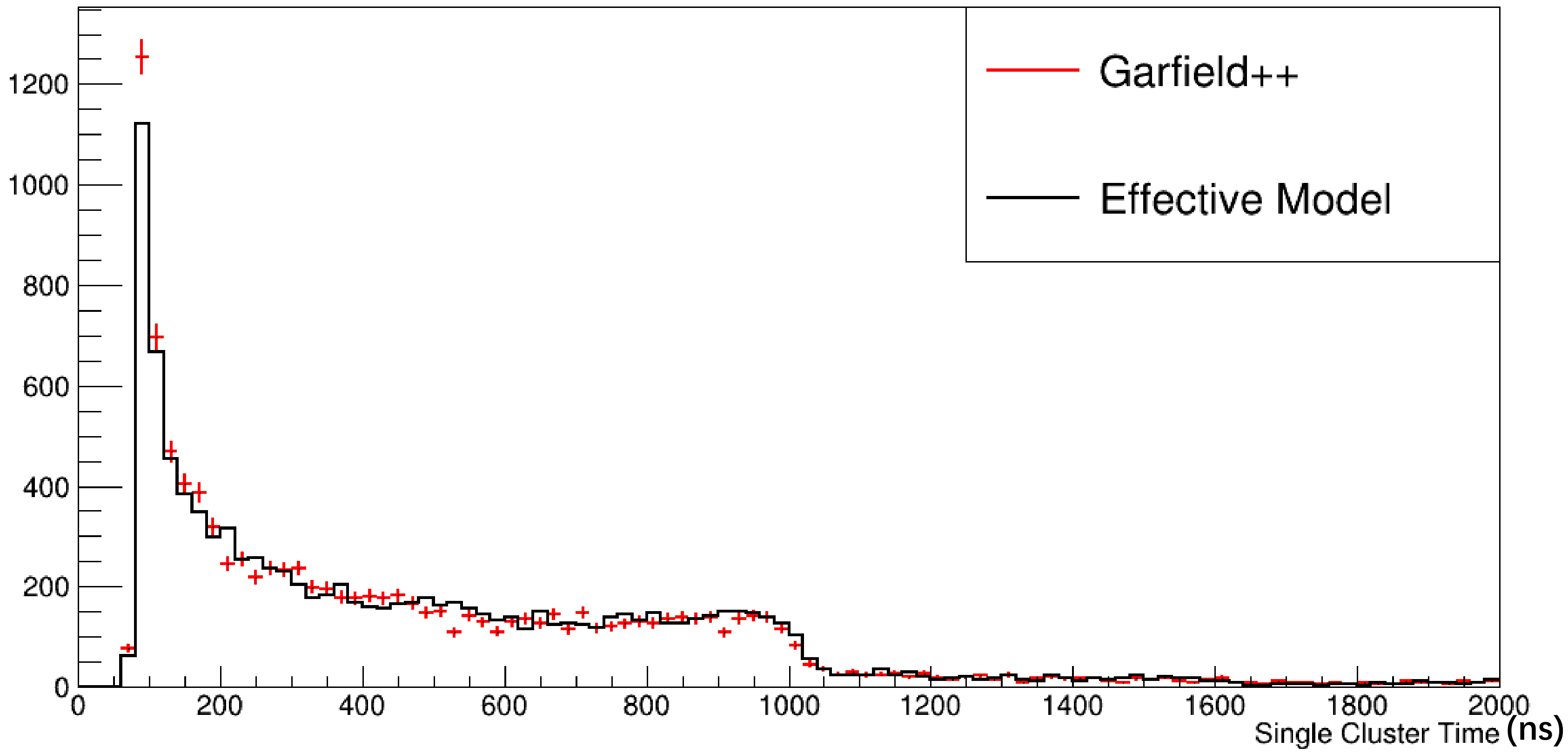


Single-pulse amplitude



Be consistent very well

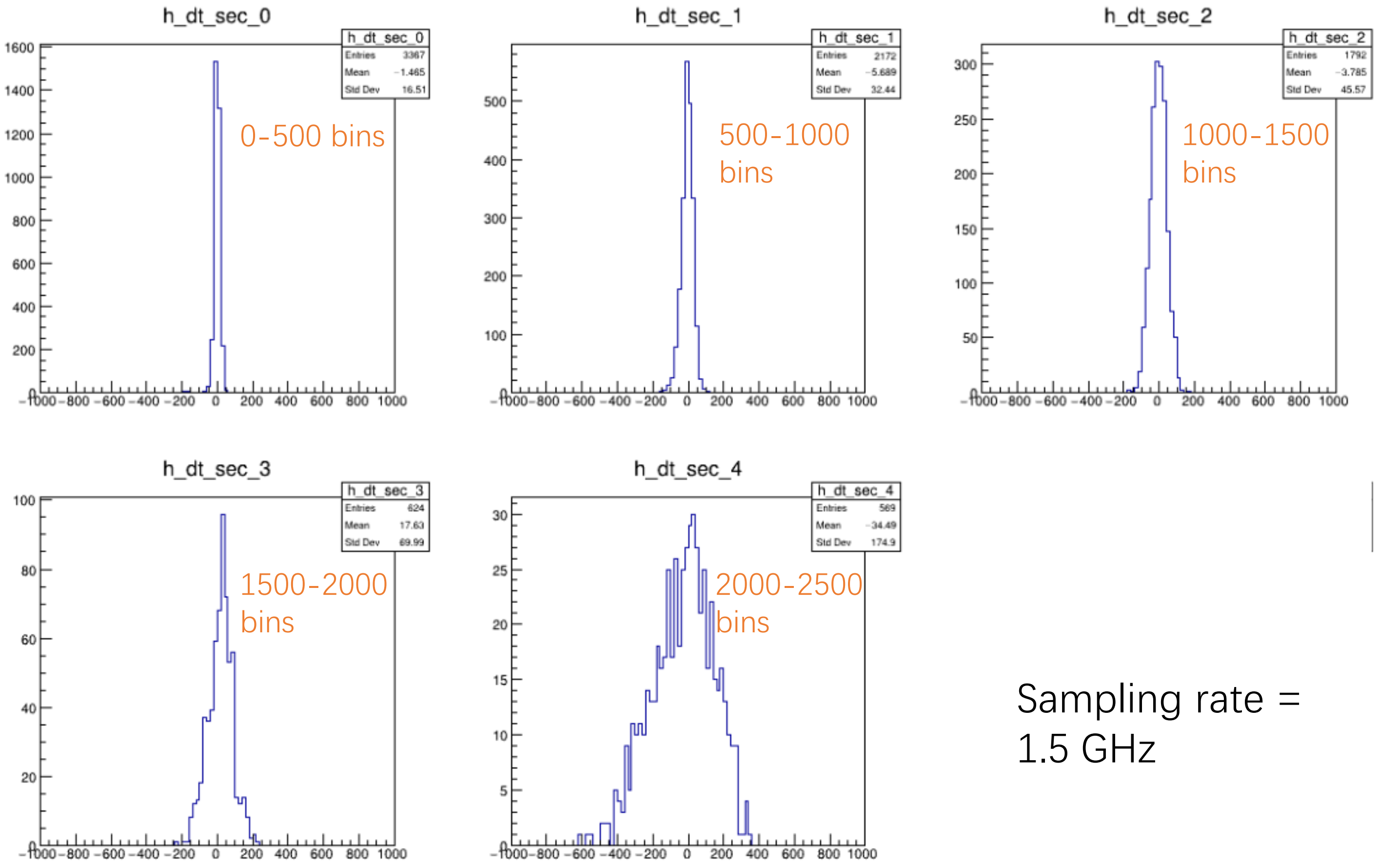
Single-pulse time



Be consistent very well

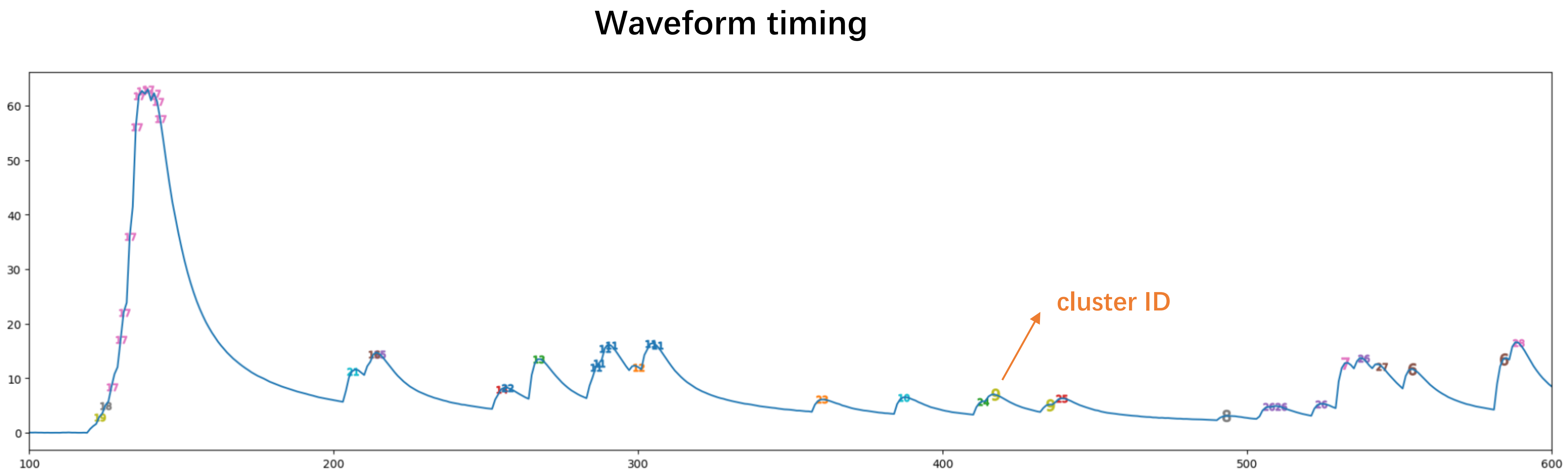
More timing plots

Δt from a cluster

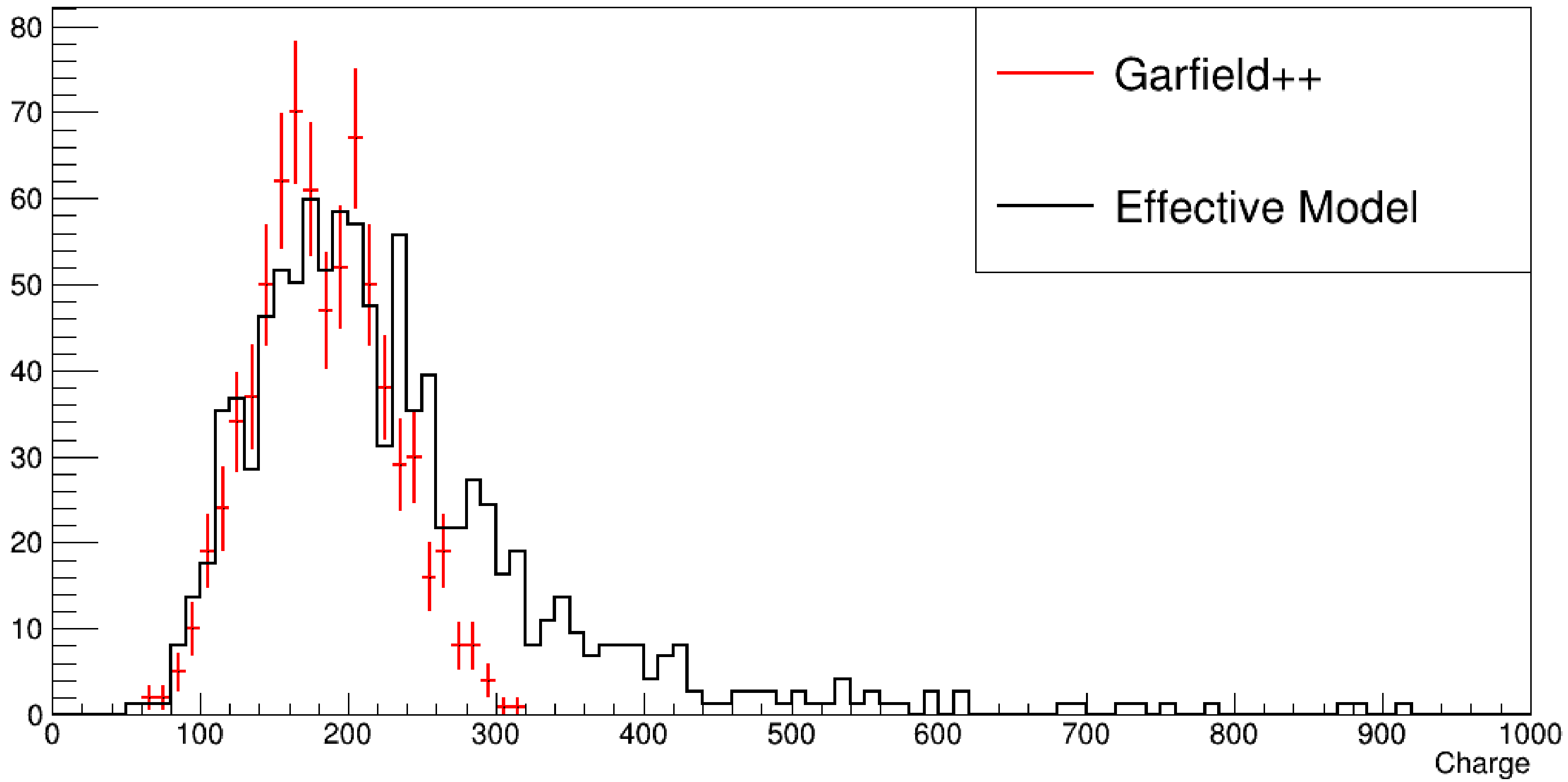


Sampling rate = 1.5 GHz

More timing plots



Waveform distribution: charge



Be consistent for the MPV (Lossing 25% events with large charge in Garfield simulation)

Realistic models from beam test data

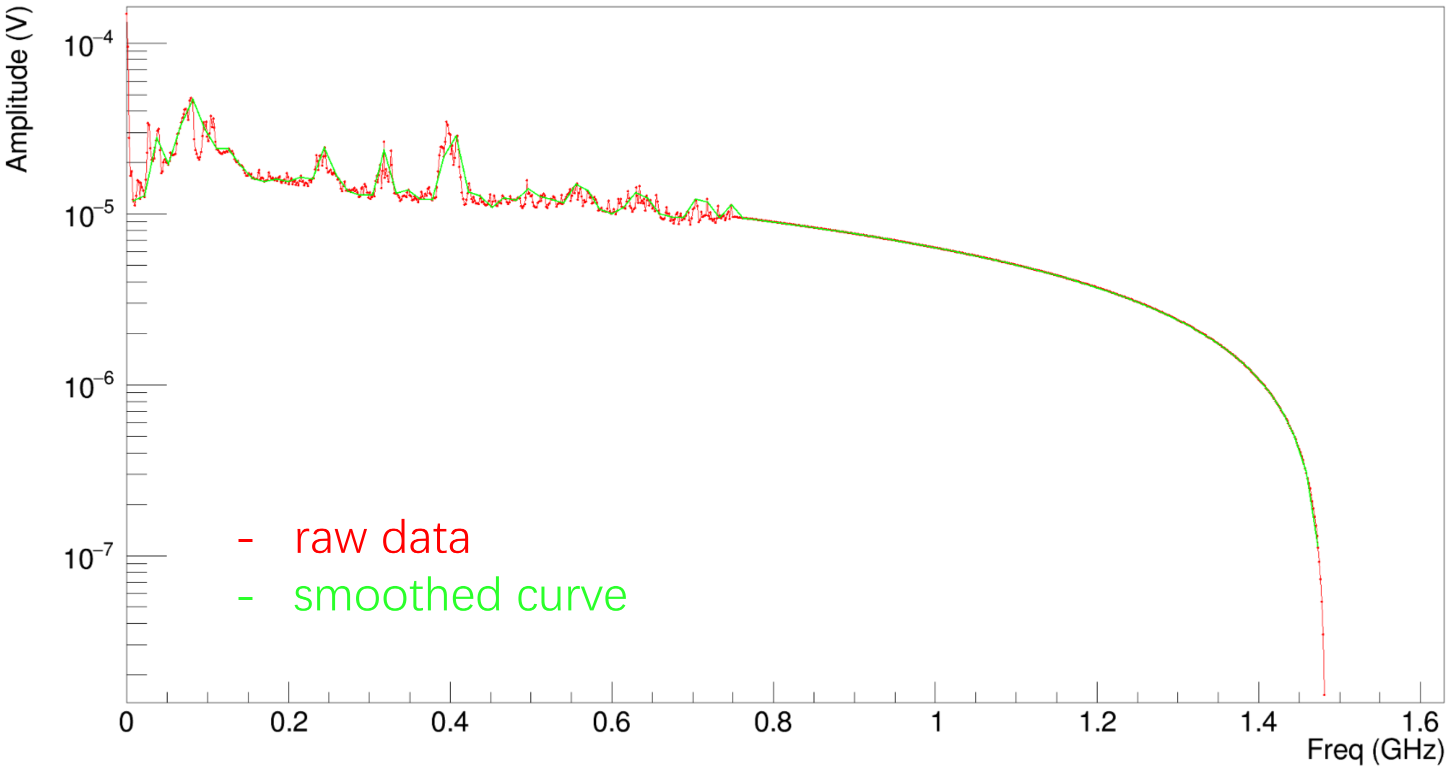
- **Noise model: correct frequency response**
  - Already done for beam test 2021
  - Update for beam test 2022

- **Preamplifier response: more realistic pulse shape**

Noise Generation

- **Test beam data 2022**
  - Run #: 16, 17, 18
  - Sampling rate: 1.5 GHz
  - Angle: 45 deg.
  - DRS Channel: 5 (1 cm)

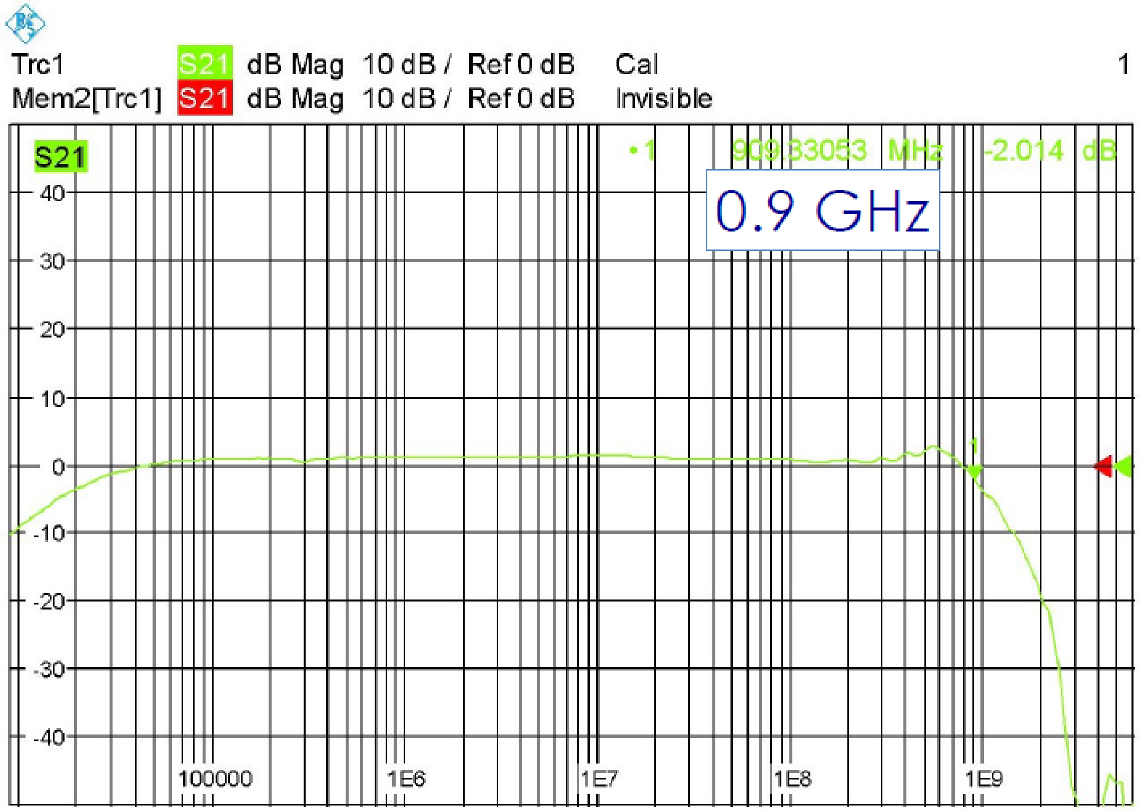
Magnitude in frequency domain



Averaged over 50k noise events

Frequency response of the preamplifier

Preamp channel – Gain 1

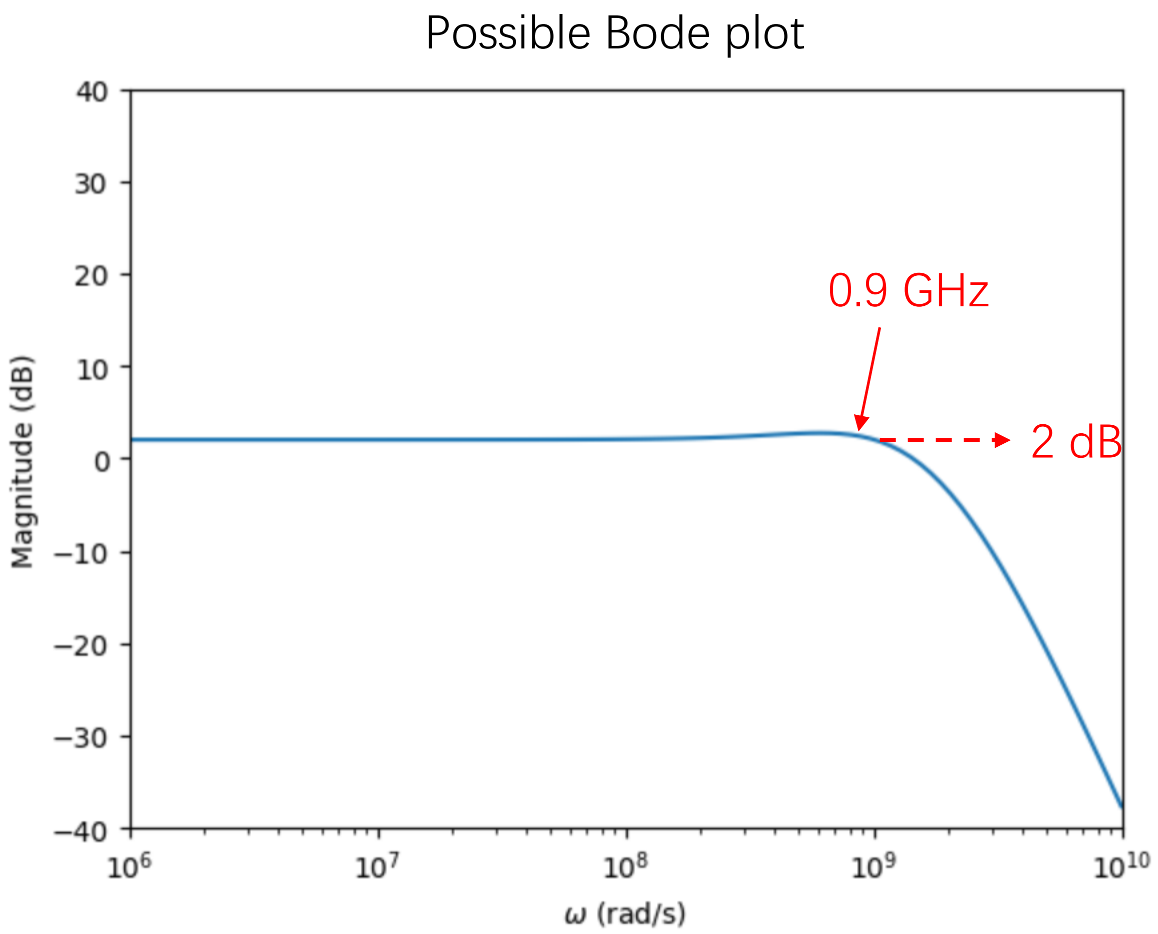


Transfer performance is flat up about 0.9 GHz and then down 40db in less than a decade

(Use gain 1 for beam test 2022 as suggested by Gianluigi)

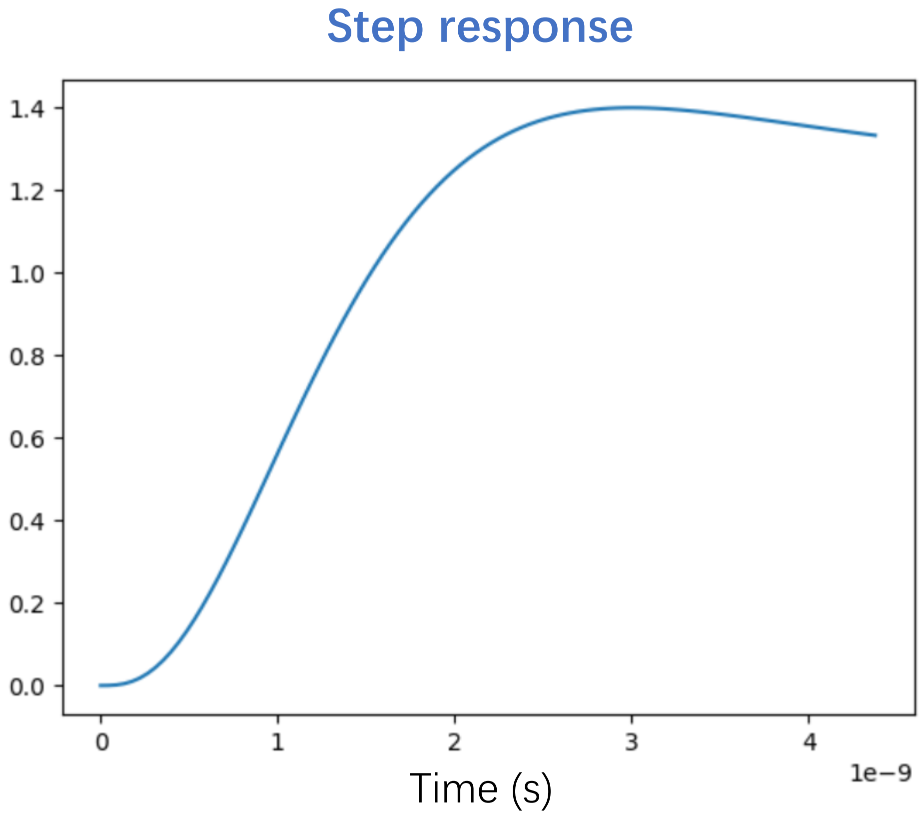
From Gianluigi's talk. Thanks a lot for providing the information

Possible Bode plot and the transfer function

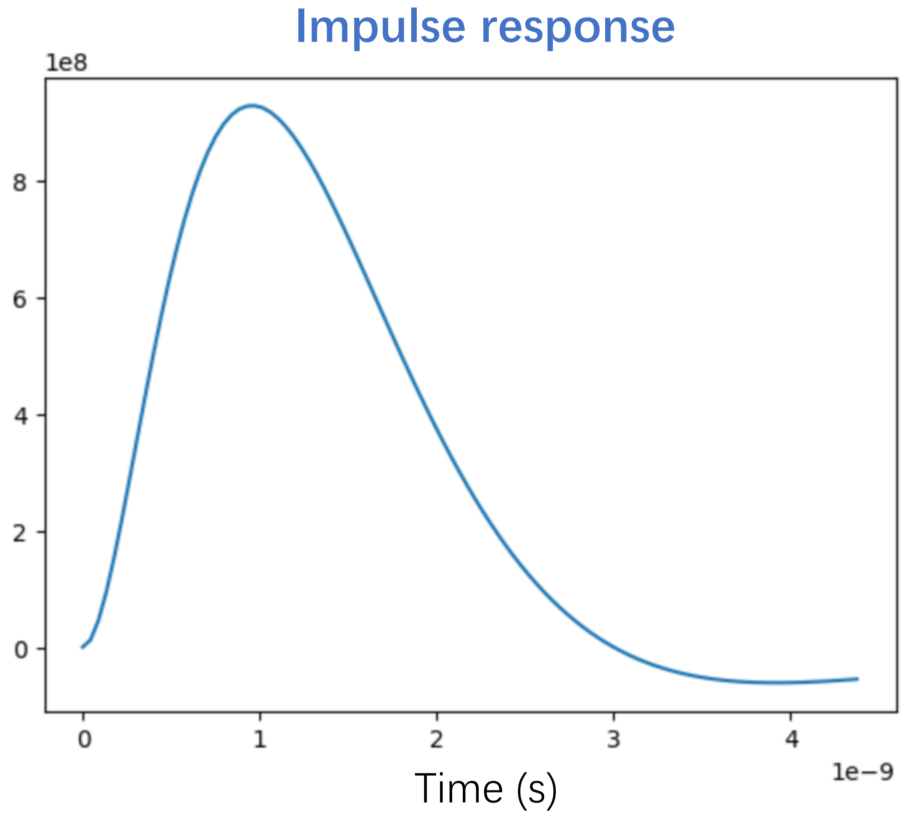


$$H(s) = \frac{1.4 \times 10^{28} \times (s + 6.0 \times 10^8)}{(s + 1.6 \times 10^9)^4}$$

Responses in time domain



Risetime 2-3 ns



Make convolution to the MC pulse

Conclusion

- **Have updated the full simulation with effective models. The model is generally consistent well to the Garfield++ simulation**

- **Have extracted the noise and preamplifier responses from the beam test data 2022**

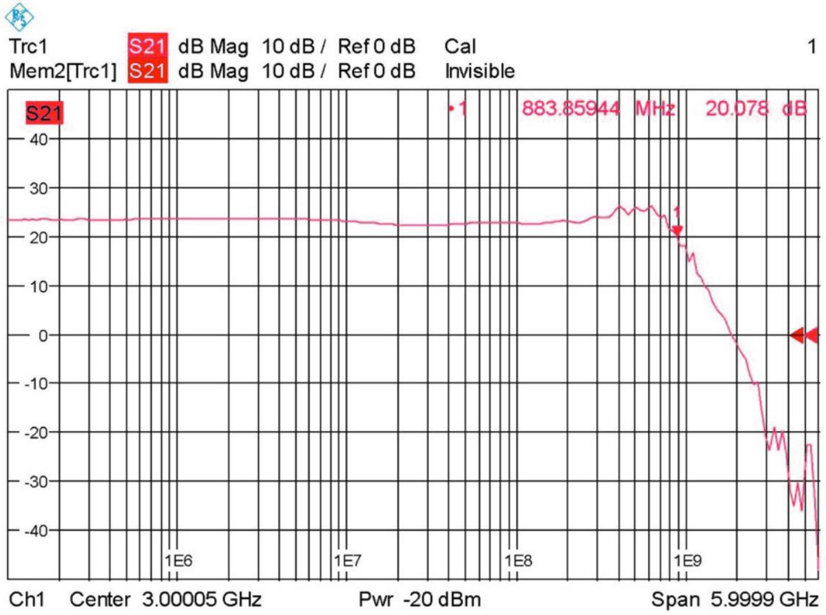
- **Next to do:**
  - Finalize the simulation code
  - Perform DC study with high statistics
  - Tune simulation with beam test data, and update the machine learning study

Backup

Preamplifier for test beam 2021

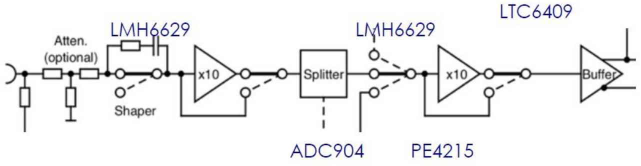
Preamp channel – Gain 10

Material from differt talk's of Stefan Ritt



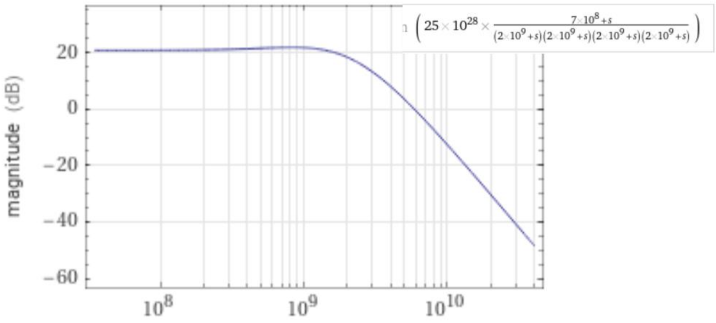
Gain	BW_{3db} (MHz)	Noise (mV)
1	940	0.37
10	880	0.40
100	300	1.2
100	500	1.7
100	800	3.3

Different compensations



For the 2021 test beam, this setup was used.

Possible Bode diagram



from Gianluigi

Single pulse amplitude