Updated full simulation software

Guang Zhao, Shuiting Xin, Shuaiyi Liu, Xu Gao, Linghui Wu
zhaog@ihep.ac.cn

Cluster counting meeting
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Introduction

- **Full simulation package is the foundation of dN/dx PID study**

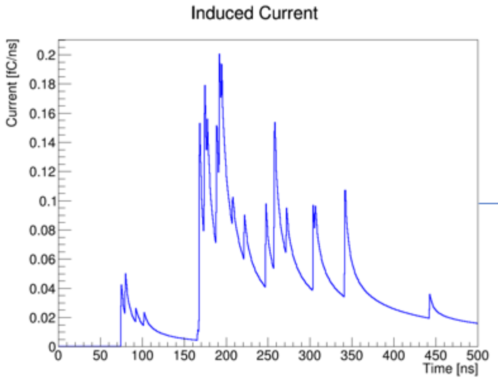
- **Major challenges**
  - Full simulation with Garfield++ is computational expensive
  - Need more realistic model from the test beam data

- **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



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

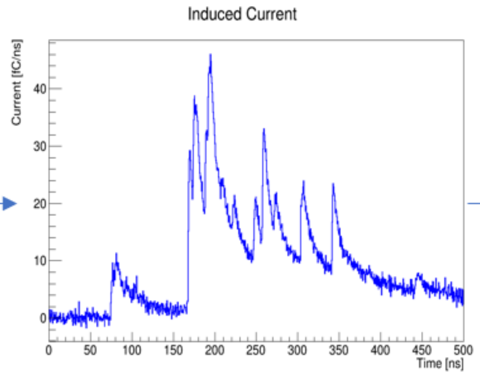
Signal generation

Amplification and signal creation is slow

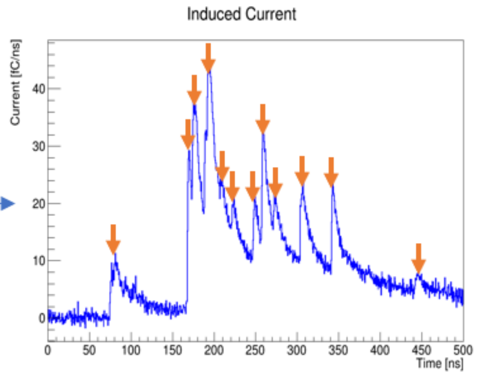
Electronics

Electronics:
- Preamplifier
- Noises
- ADC

Realistic waveform



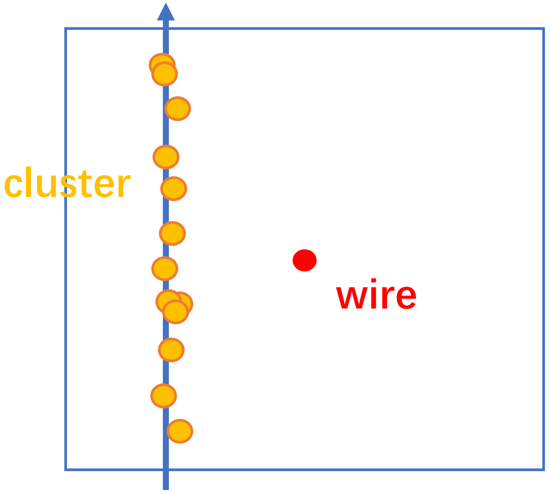
Digitization



Peak finding algorithm:
- Second derivative

Reconstruction

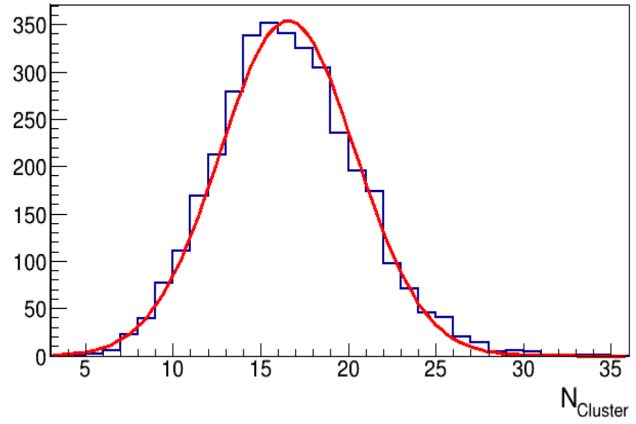
Ionization process (by Heed)

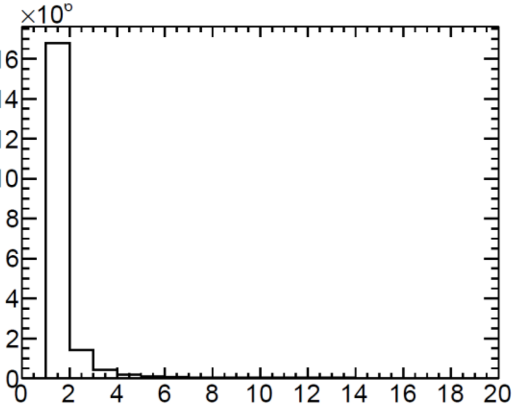


- **A sequence of primary interactions (clusters) along the track**
  - The # of clusters can be described by the Poisson distribution

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

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



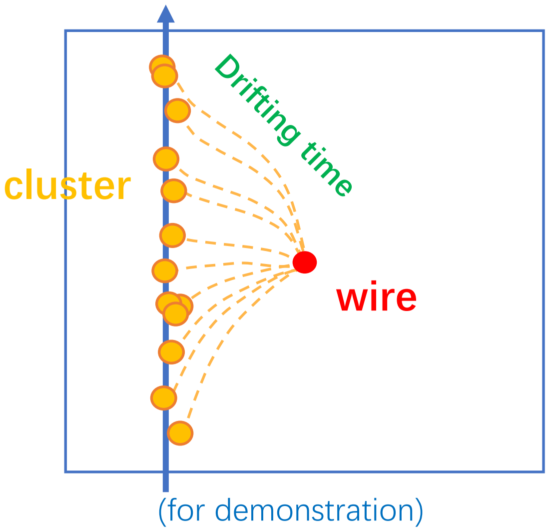


1 cm x 1 cm
He/iC_4H_{10}: 90/10

Update: Use Heed to simulate the ionization

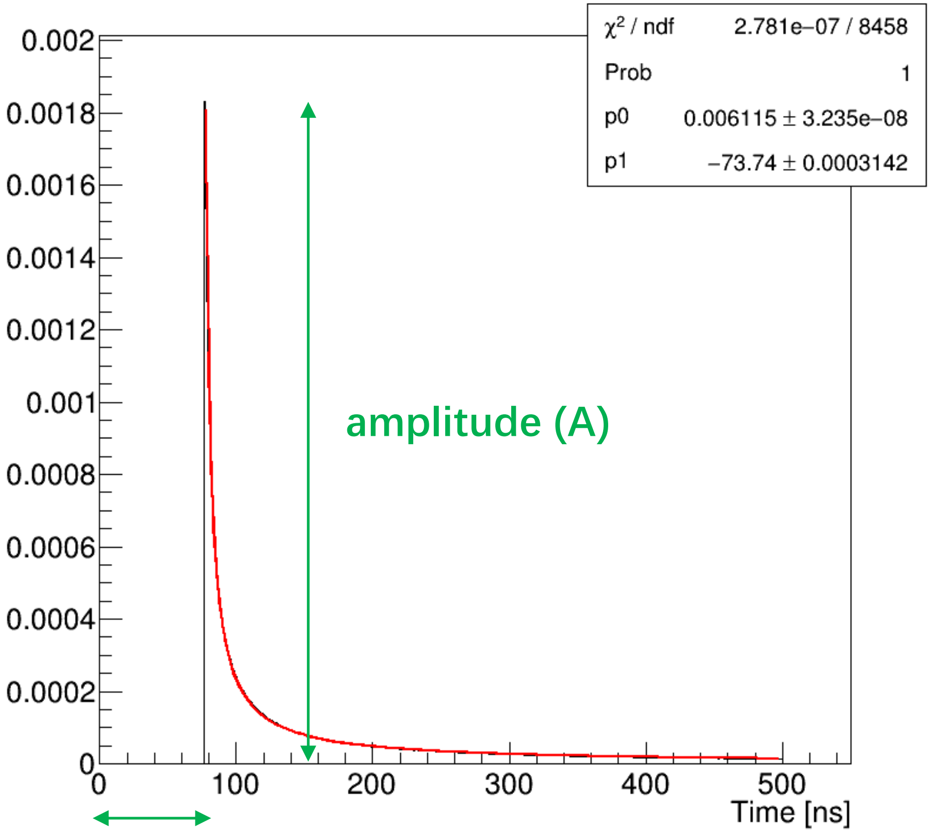
Effective models for signal generation

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



Very time consuming in Garfield++
➔ Need parameterization

Single pulse: pulse(A, t)



starting time (t)

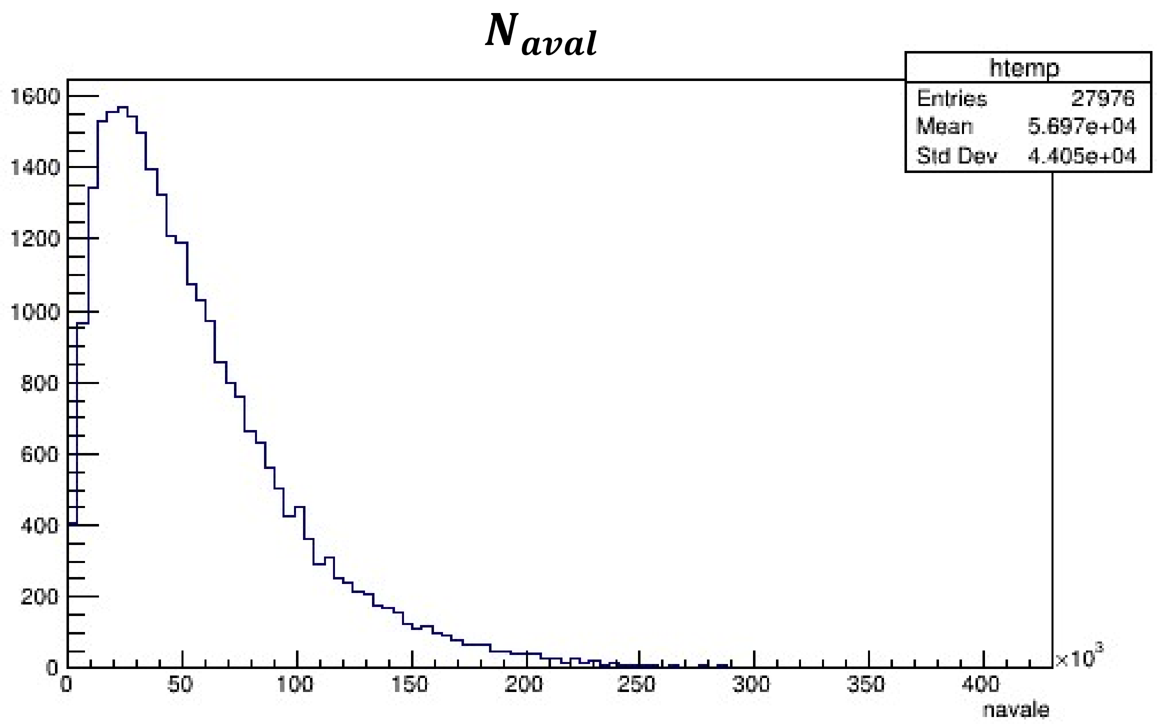
Parameterization:
- Amplitude
- Starting time
- Pulse shape

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

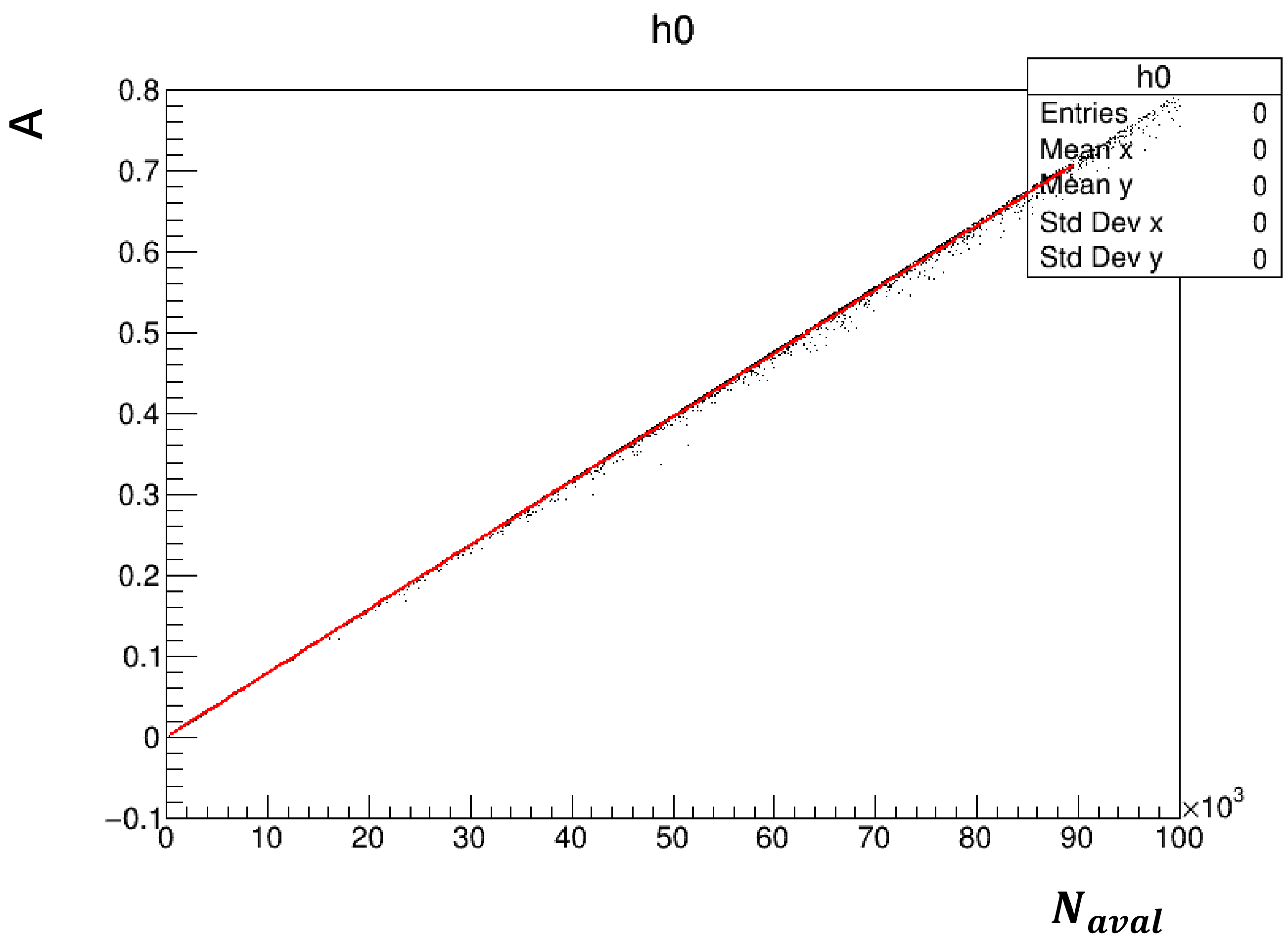
Pulse amplitude model



# of avalanche e-

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

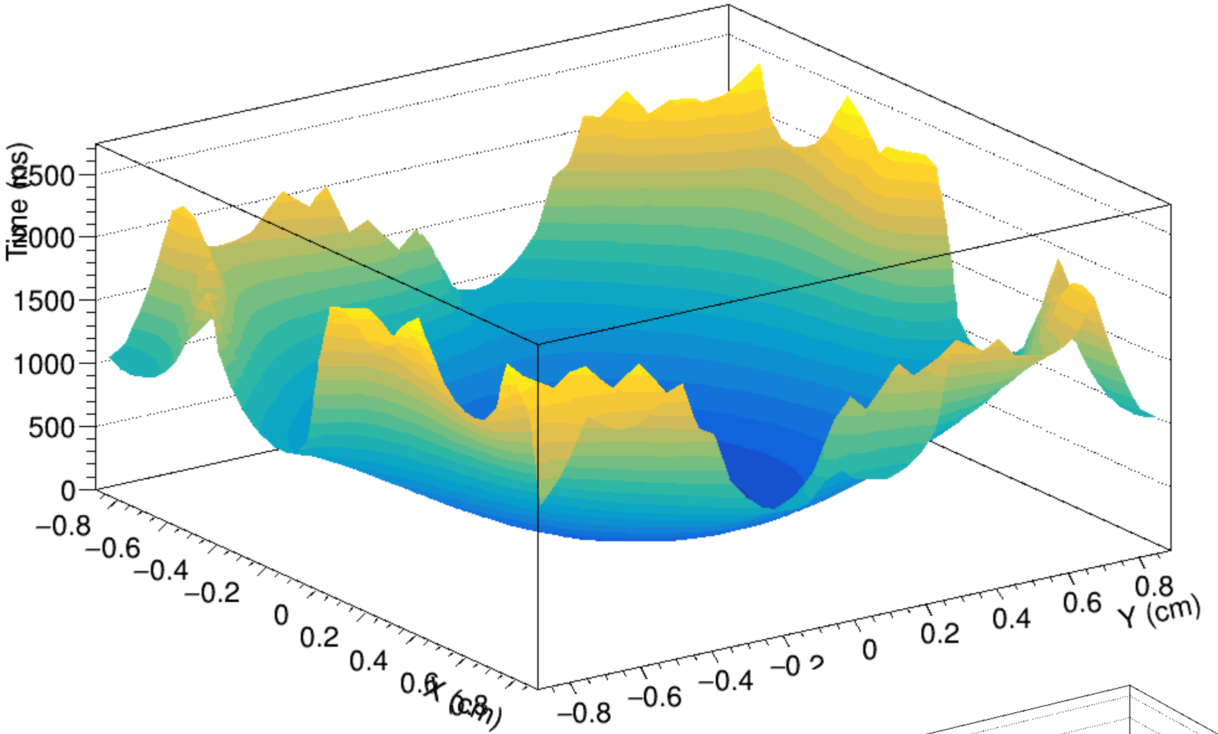
Pulse amplitude model (cont.)



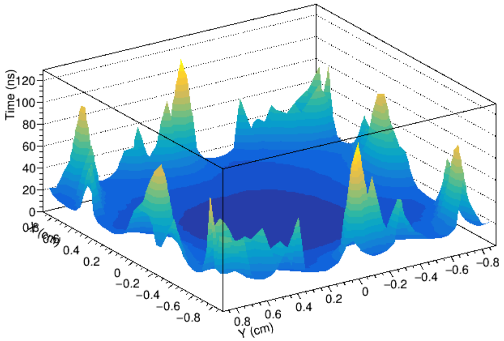
- Induced current $\propto -\frac{N_{aval}}{t+t_0}$
- Pulse height $A \propto N_{aval}$
- Linear fit:
  - $A(N_{aval}) = p_0 + p_1 \times N_{aval}$

Pulse time model

μ



σ

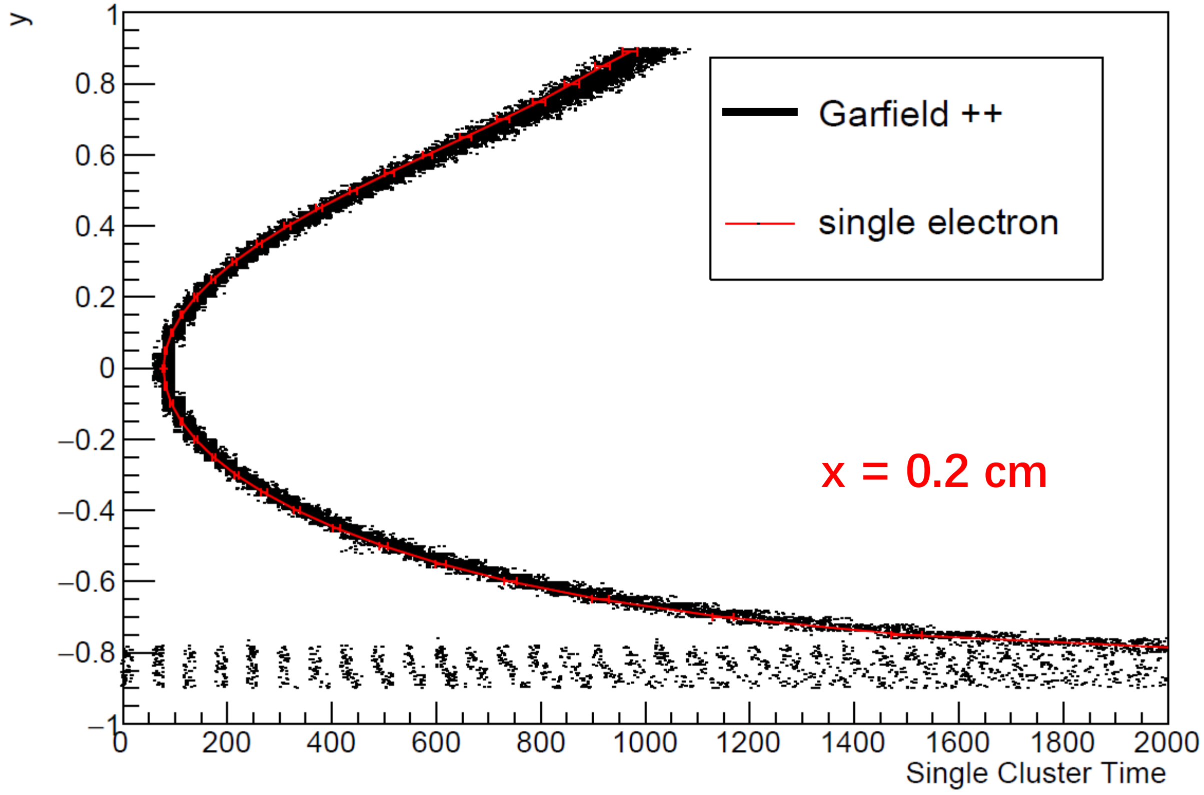


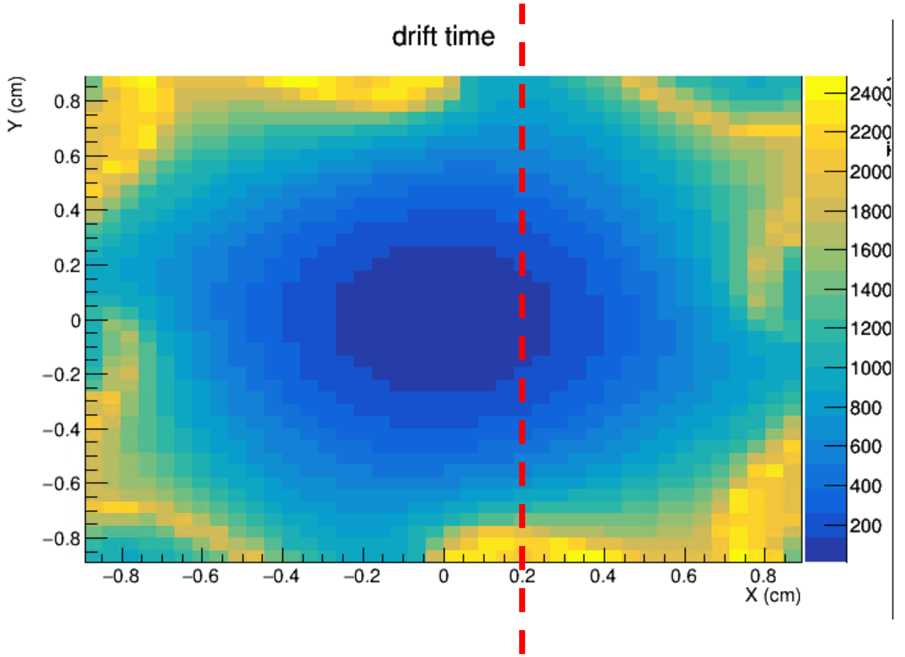
- For a fixed electric/magnetic field:
  - t is mainly determined by initial position of the electron
- Measure the relationship from Garfield++ simulation
  - $t(x, y) = Gauss(\mu(x, y), \sigma(x, y))$

Update: 2D measurement

Pulse time model (cont.)

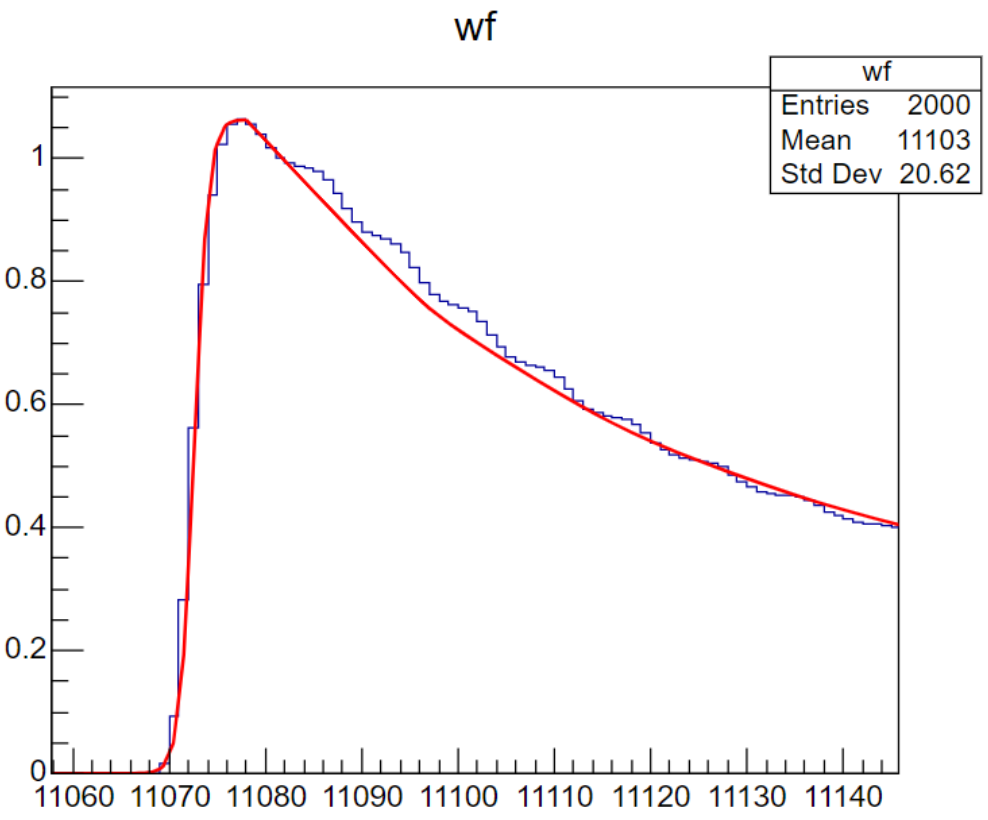
Comparison to Garfield++





Good consistency for track with x = 0.2 cm

Pulse shape model



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

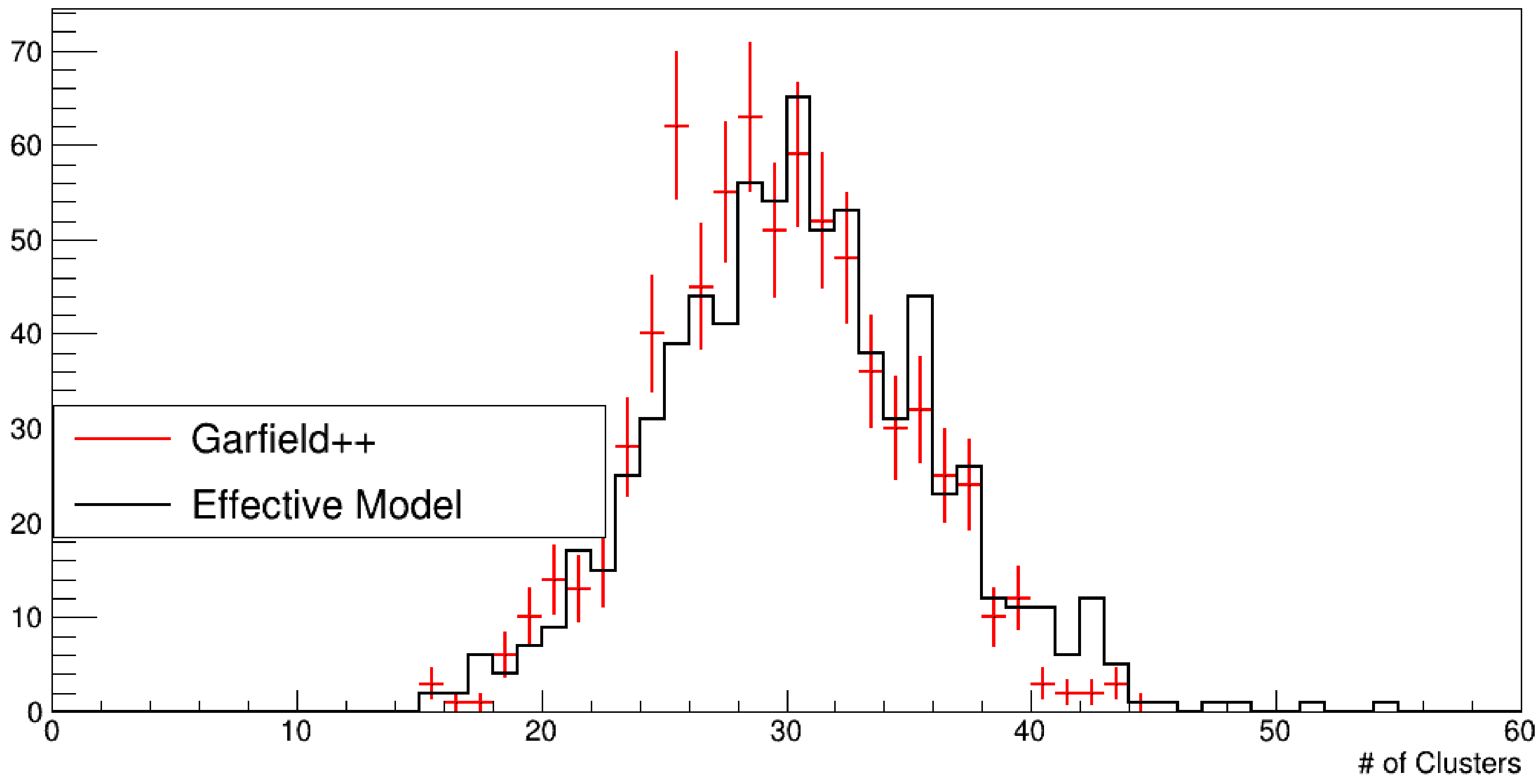
Model validation

- **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

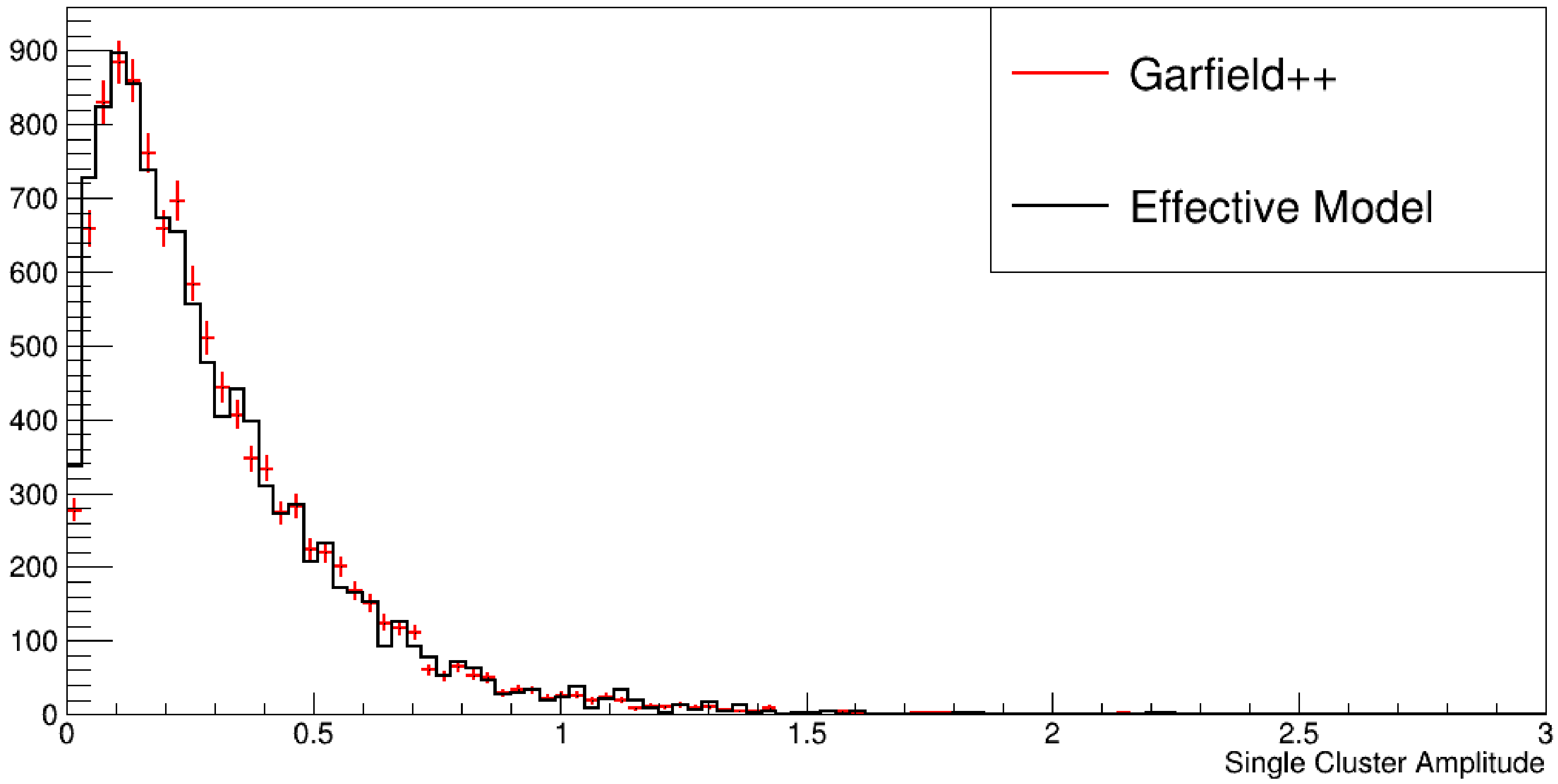
- **Garfield++ setup**
  - Cell size: 1.8 cm x 1.8 cm
  - Gas mixture: He/iC_4H_{10} (90/10)
  - Particle: 20 GeV/c pions

of primary ionizations



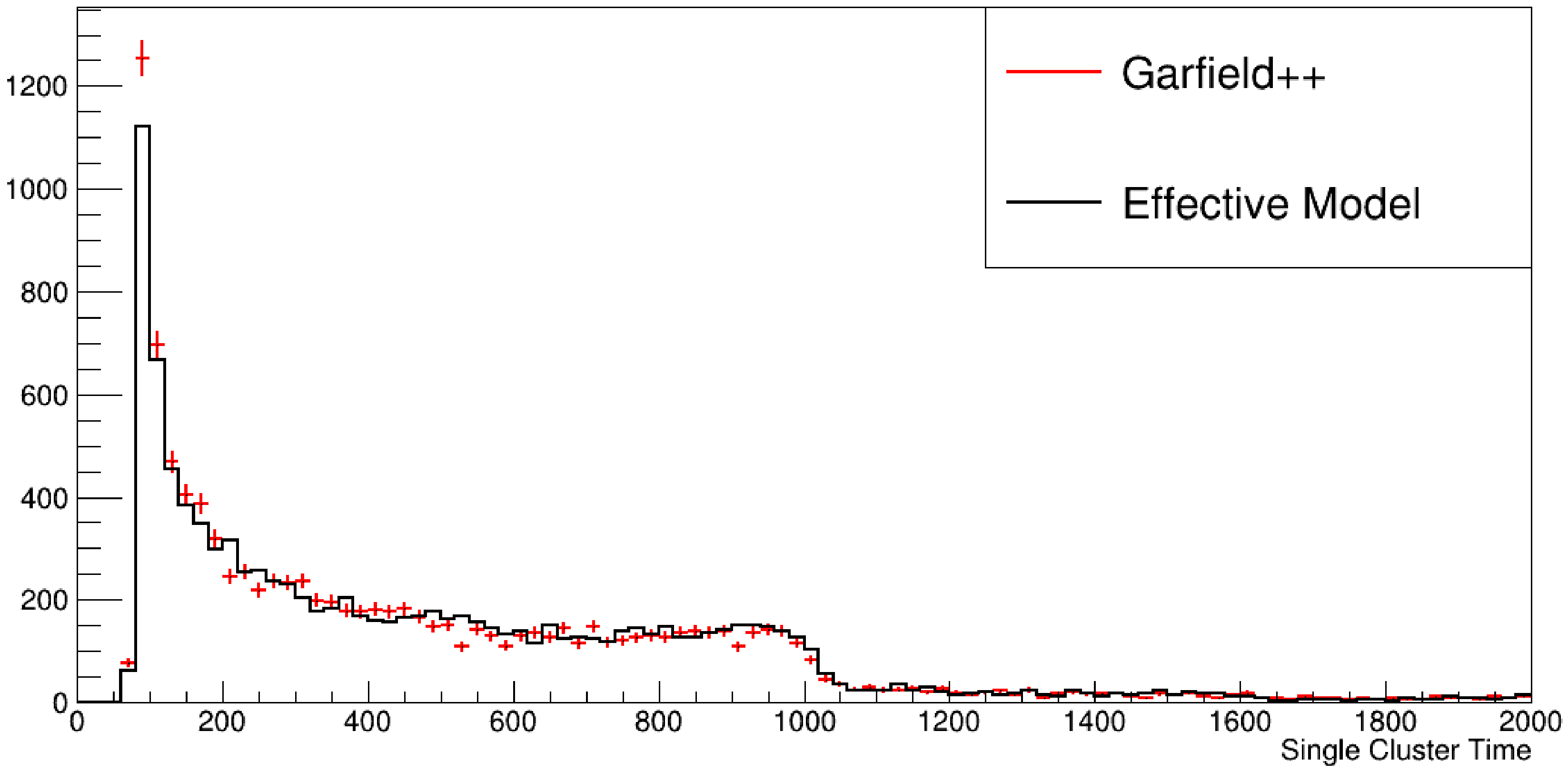
Be consistent very well

Single-pulse amplitude



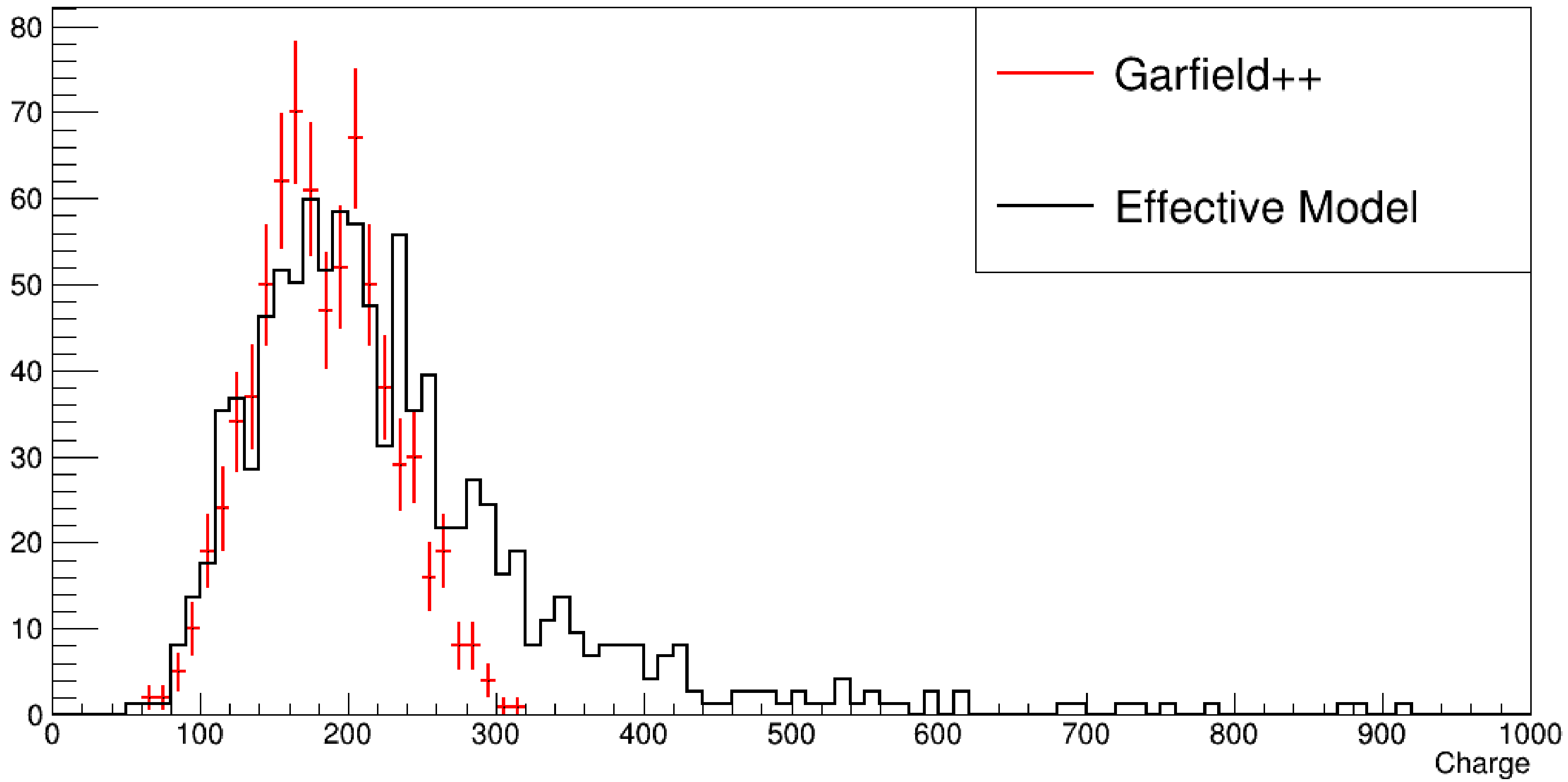
Be consistent very well

Single-pulse time



Be consistent very well

Waveform distribution: charge



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

Realistic models from beam test data

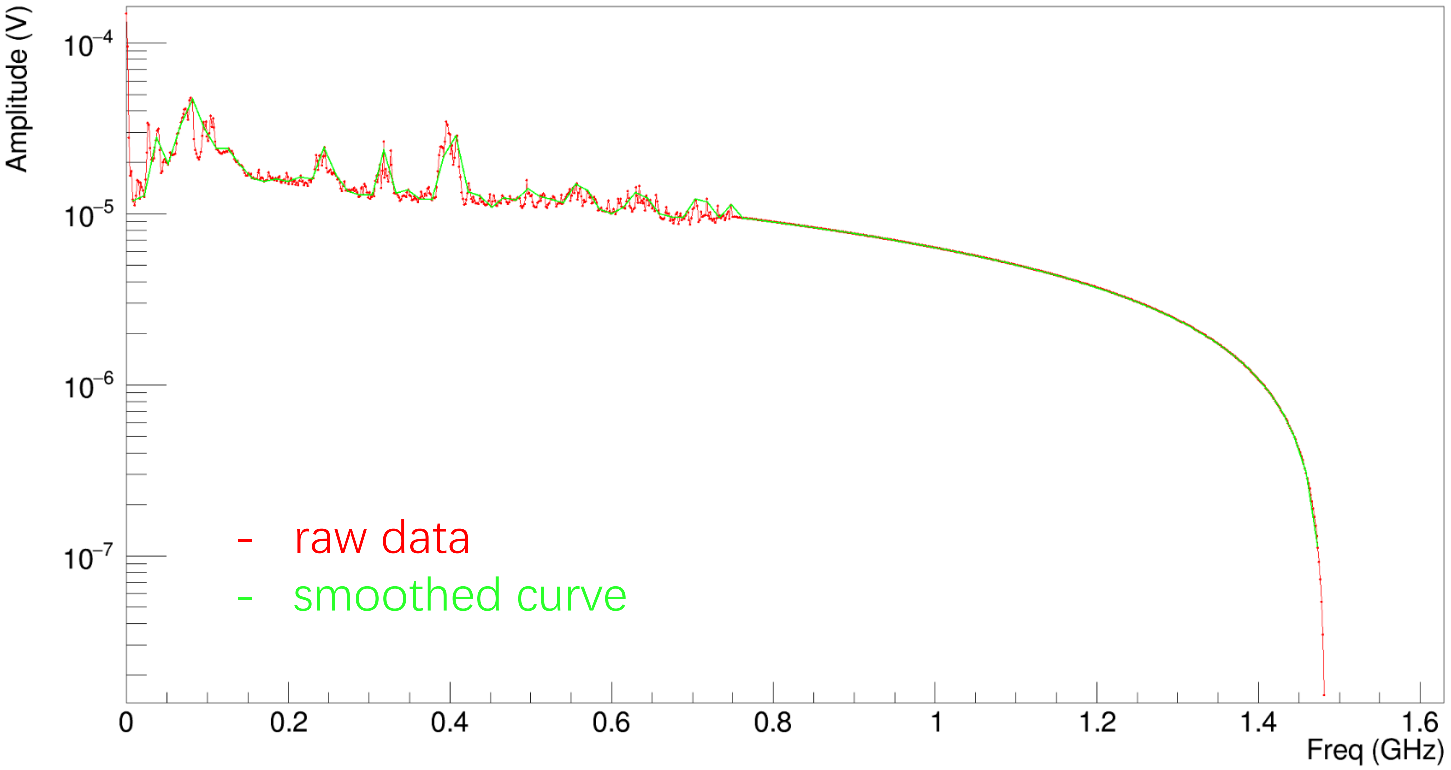
- **Noise model: correct frequency response**
  - Already done for beam test 2021
  - Update for beam test 2022

- **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)

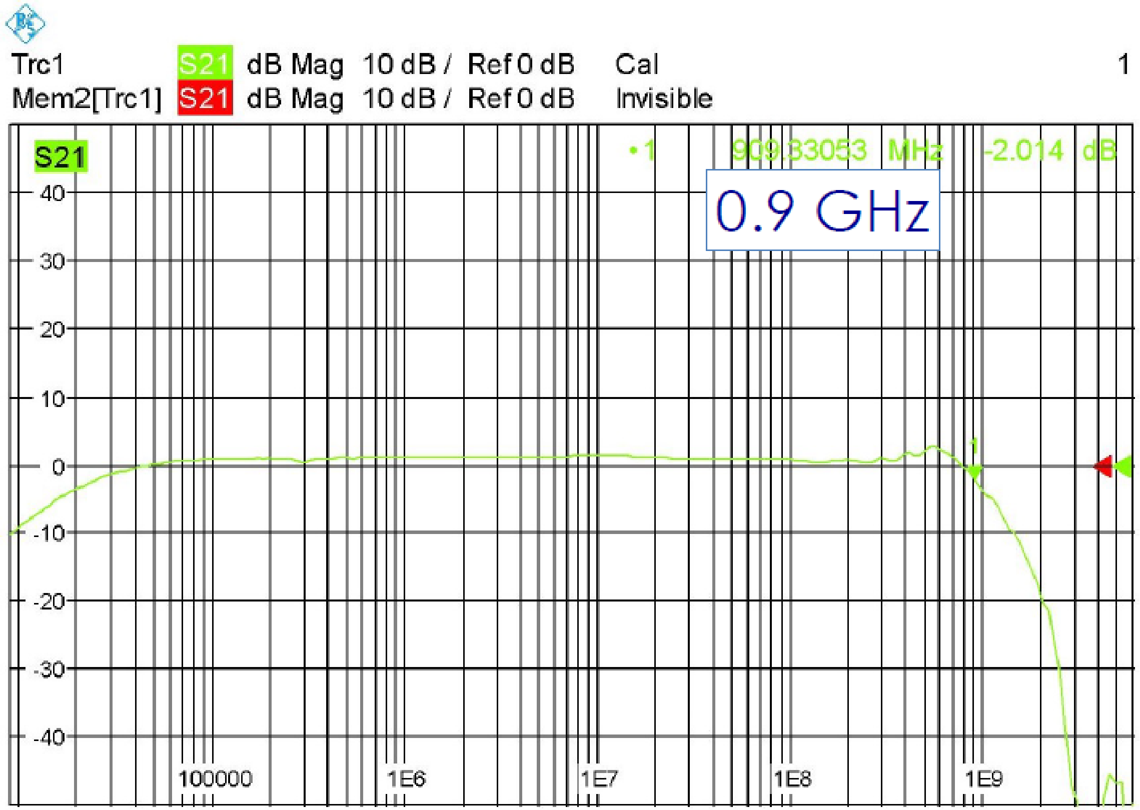
Magnitude in frequency domain



Averaged over 50k noise events

Frequency response of the preamplifier

Preamp channel – Gain 1

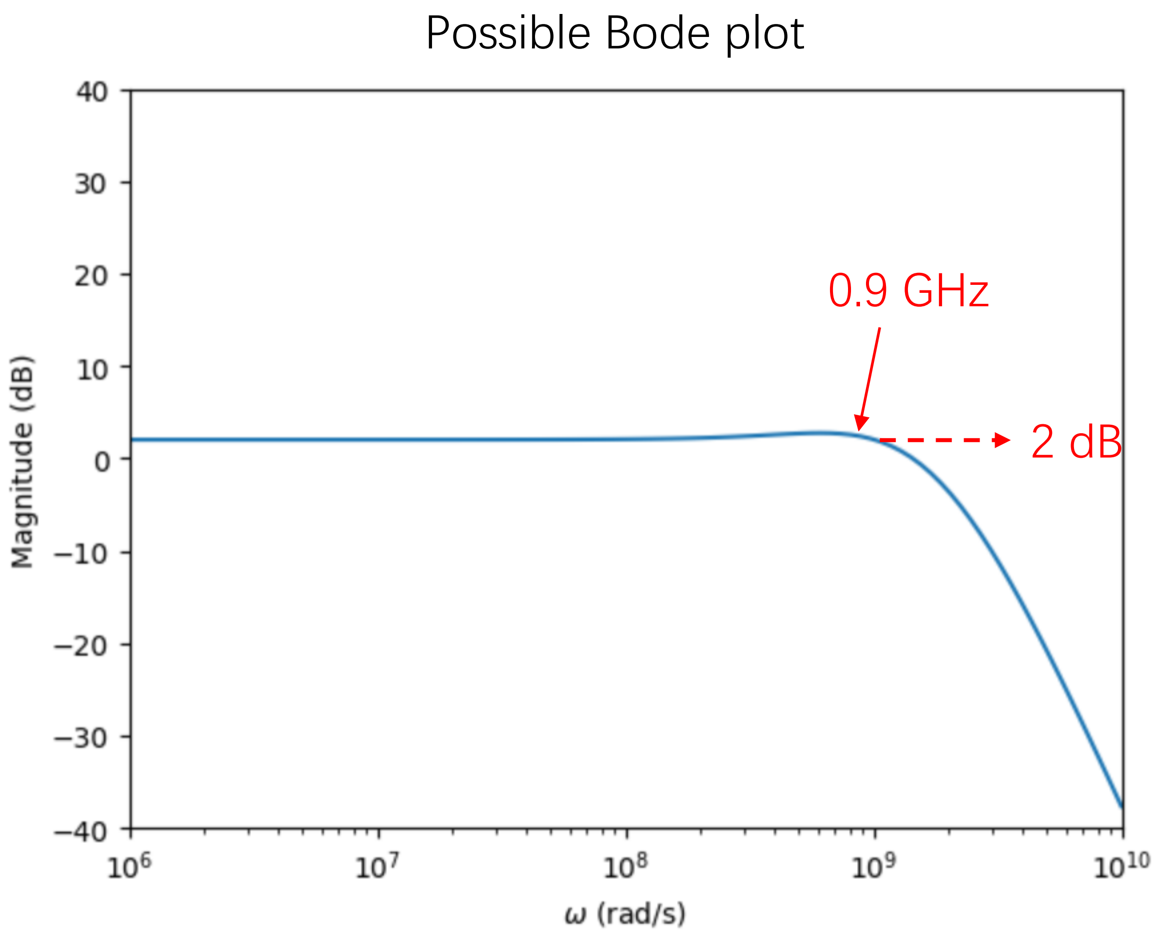


Transfer performance is flat up about 0.9 GHz and then down 40db in less than a decade

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

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

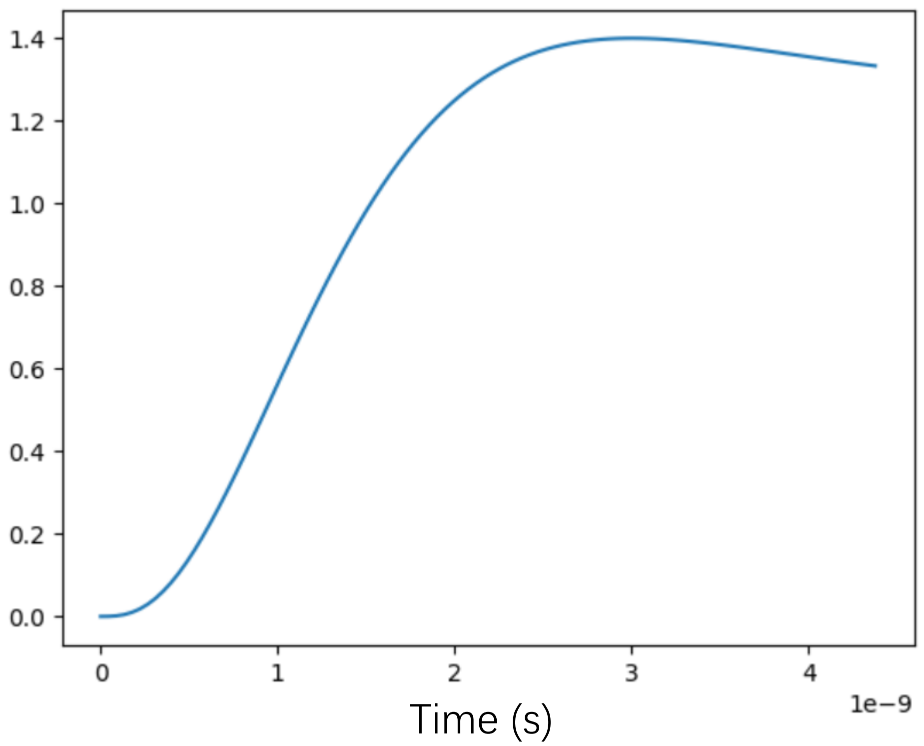
Possible Bode plot and the transfer function



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

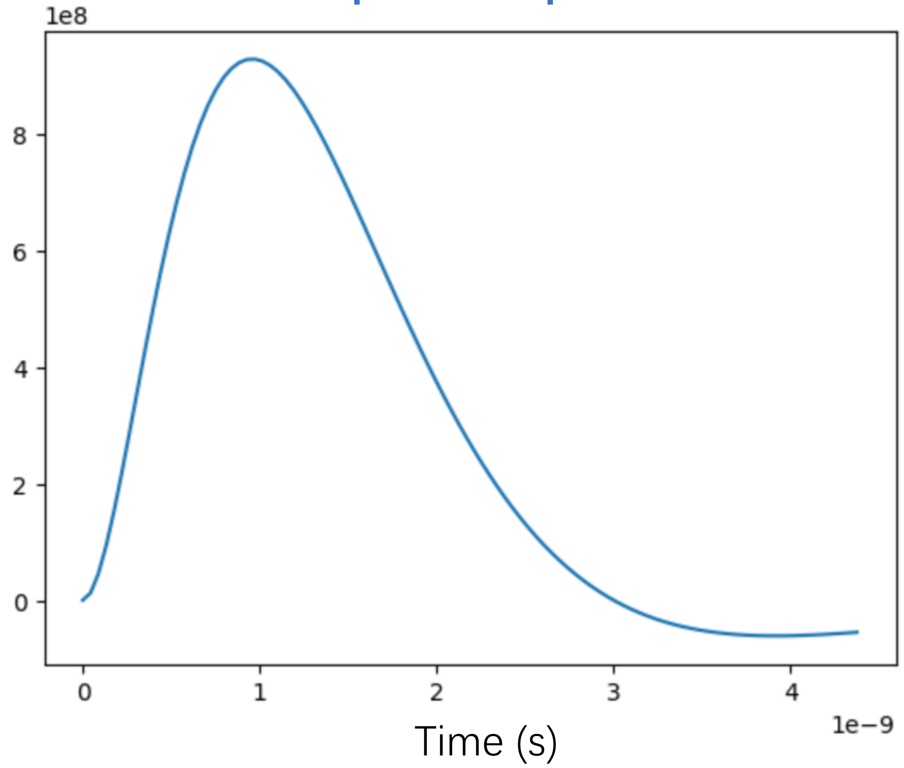
Responses in time domain

Step response



Risetime 2-3 ns

Impulse response



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**

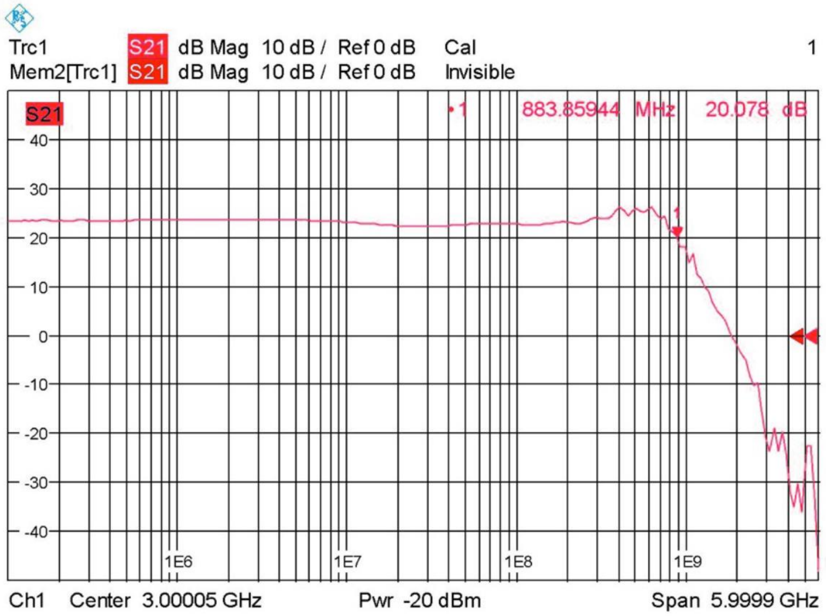
- **Next to do:**
  - Finalize the simulation code
  - Perform DC study with high statistics
  - Tune simulation with beam test data, and update the machine learning study

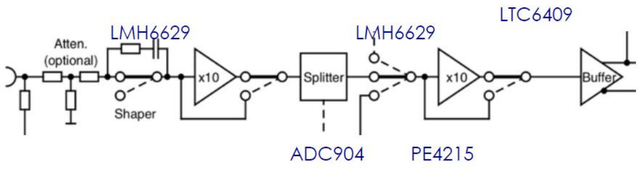
Backup

Preamplifier for test beam 2021

Preamp channel – Gain 10

Material from differt talk's of Stefan Ritt



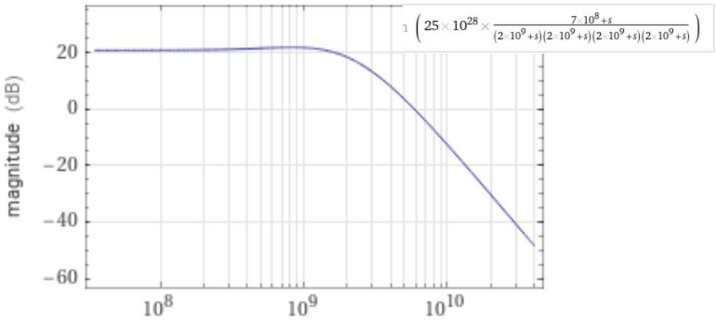


Gain	BW_{3db} (MHz)	Noise (mV)
1	940	0.37
10	880	0.40
100	300	1.2
100	500	1.7
100	800	3.3

Different compensations

For the 2021 test beam, this setup was used.

Possible Bode diagram



from Gianluigi