JÜLICH
FORSCHUNGSZENTRUM

Status of Waveform Reconstruction

DFG Meeting Hamburg
Forschergruppe JUNO

18th September 2017 | Michaela Schever

Gefördert durch
DFG Deutsche Forschungsgemeinschaft

Outline

- **Muon waveform reconstruction**
  - First hit time reconstruction
  - Charge reconstruction
  - Rise time

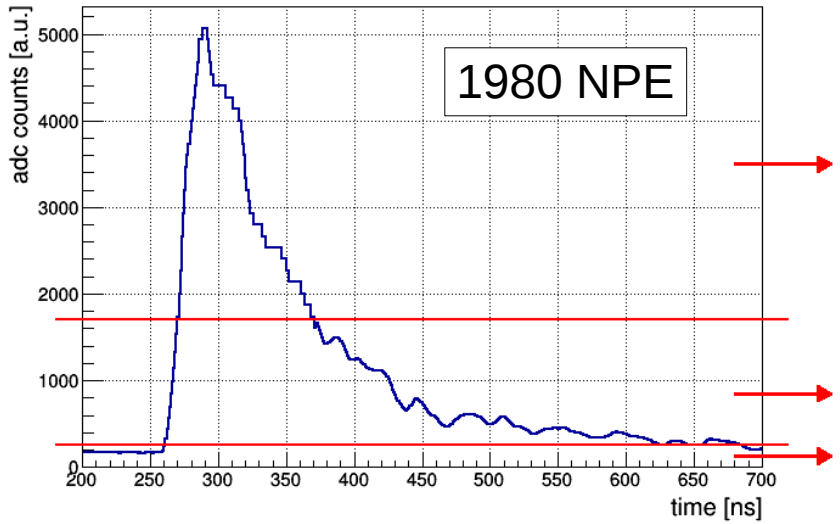
- **IBD waveform reconstruction**
  - Overview of deconvolution method and Wiener filter
  - Variation of common reconstruction method

Muon Waveforms

- **Muon waveform reconstruction**
  - First hit time reconstruction
  - Charge reconstruction
  - Rise time

Muon Waveforms
Motivation

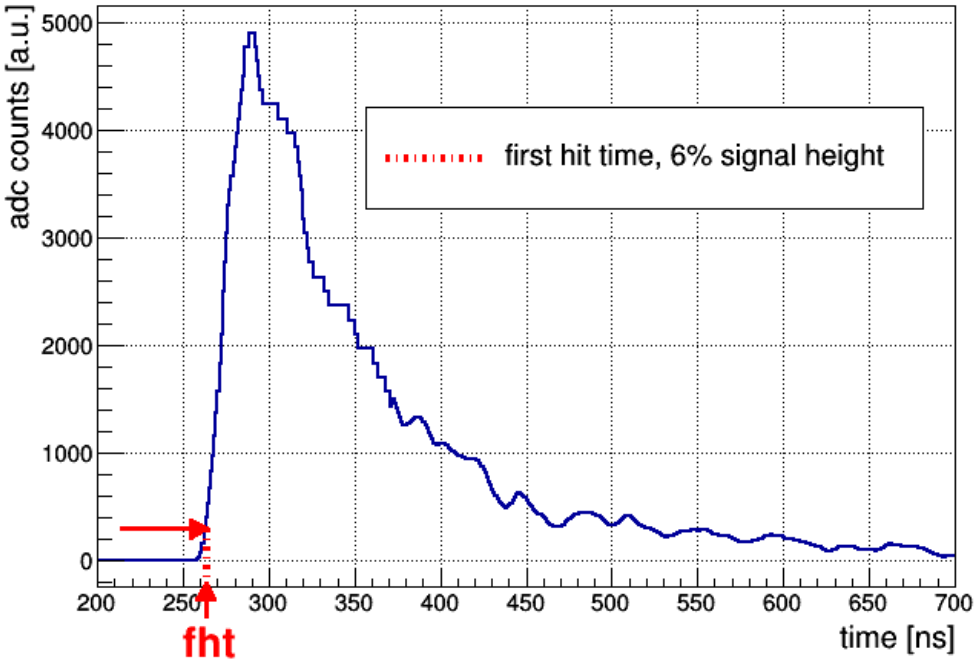
- Needed for muon track reconstruction
- Typical NPE for muon events: 500 – 5000
- Sampled with three regions differing in resolution
- New package: MuonWaveRec
- Quantities relevant for reconstruction:
  - First hit time (fht)
  - Charge
  - Rise time
- MuonWaveRec used in muon reco paper draft by Christoph [DocDB 2414-v2]



Waveform example of center muon event

Muon Waveforms: First Hit Time

Constant Fraction Discriminator: Method



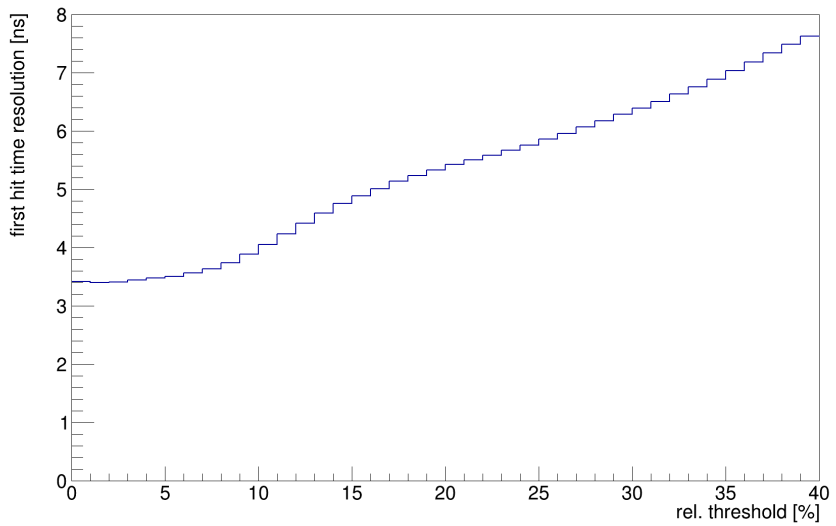
Example of fht determination by CFD

Constant Fraction Discriminator (CFD):

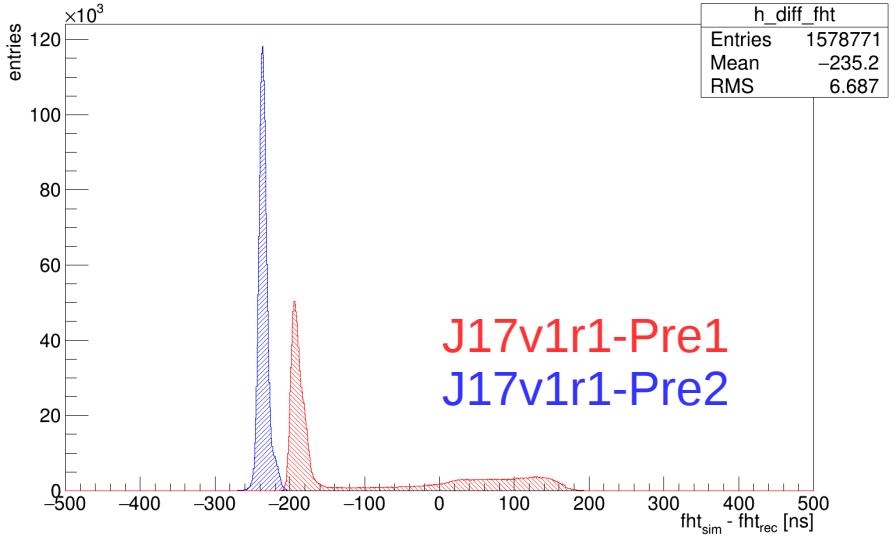
- Set first hit time when waveform passes a threshold
- Set threshold as relative fraction of waveform height

- Implementation: go from global maximum to earlier times until threshold is passed
- Other methods studied; this one yields best results

Muon Waveforms: First Hit Time
Constant Fraction Discriminator: Results



Averaged fht resolution (RMS) in dependence on threshold

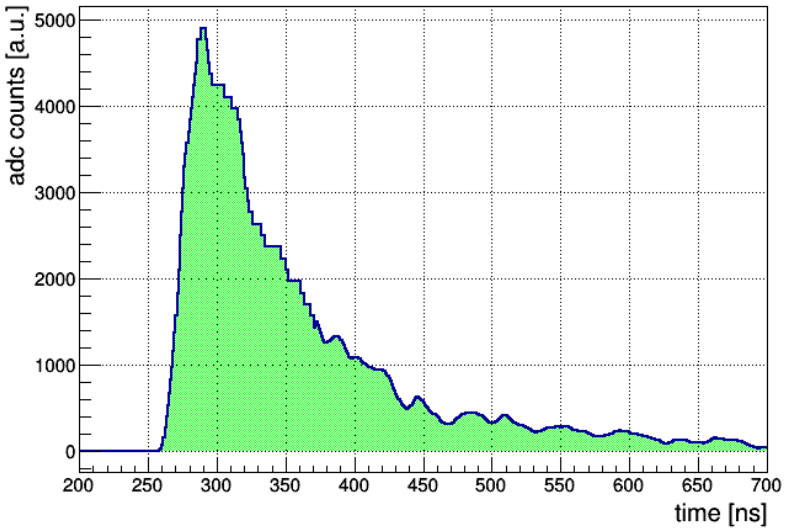


Comparison fht reconstruction from last validation run

[Christoph Genster]

- Fht resolution depends on relative threshold
- Best fht resolution: ~3.4 ns at threshold of 4% of signal height
- Rising edge of waveform influenced by distribution of arriving photons
  → worsens resolution obtained by CFD
- Best value of FadcOffset has to be determined
- CFD used in MuonWaveRec package
- MuonWaveRec used for muon track reco in validation since J17v1r1-Pre2

Muon Waveforms: Charge
Charge Integration: Method

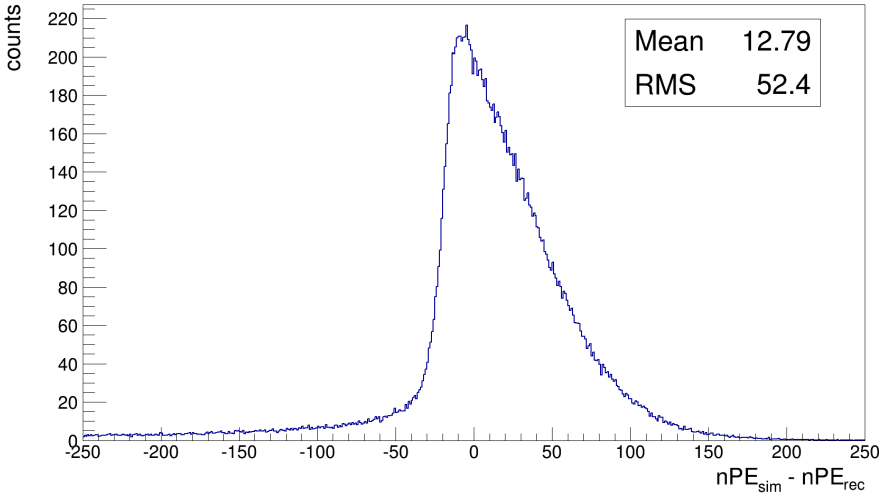


Example of charge reconstruction

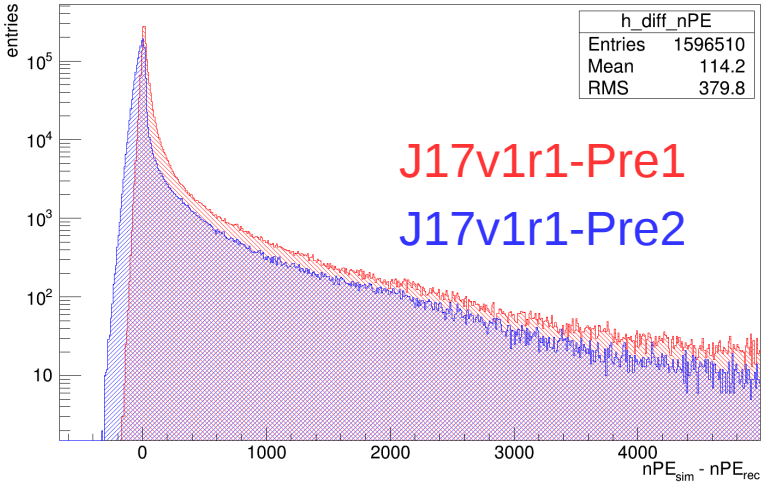
Charge integration:

- Perform baseline correction
- Integrate waveform area
- Integration area: entire readout window

Muon Waveforms: Charge
Charge Integration: Results

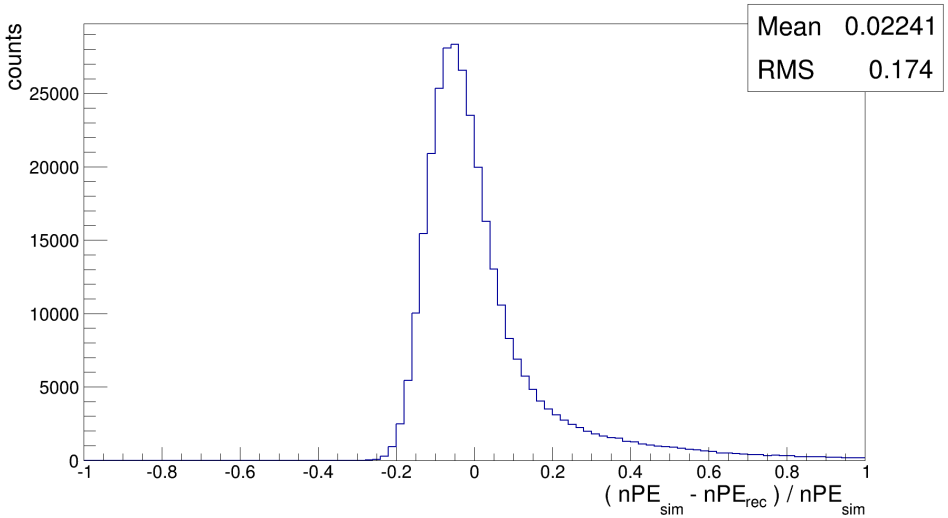


Distribution of true – reco charge



Comparison of charge reconstruction from last validation cycle and before

[Christoph Genster]

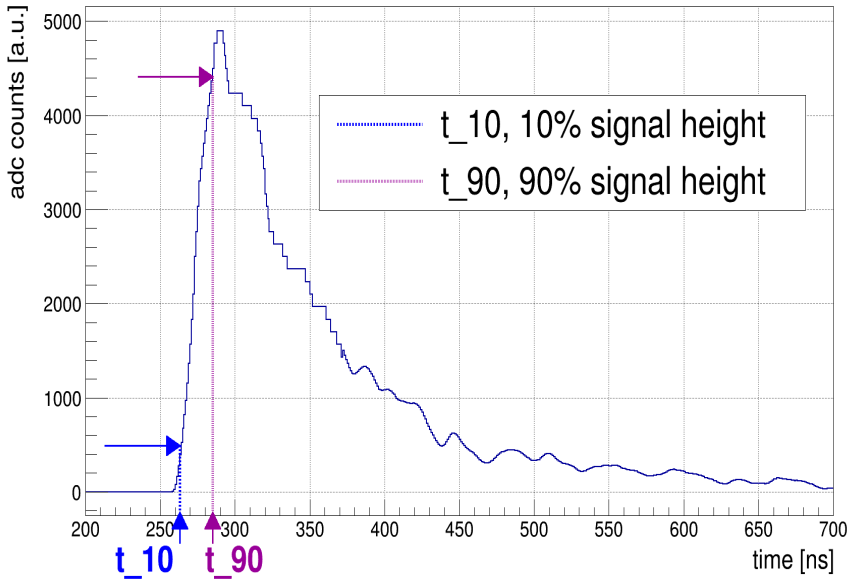


Distribution of true – reco charge relative to true charge

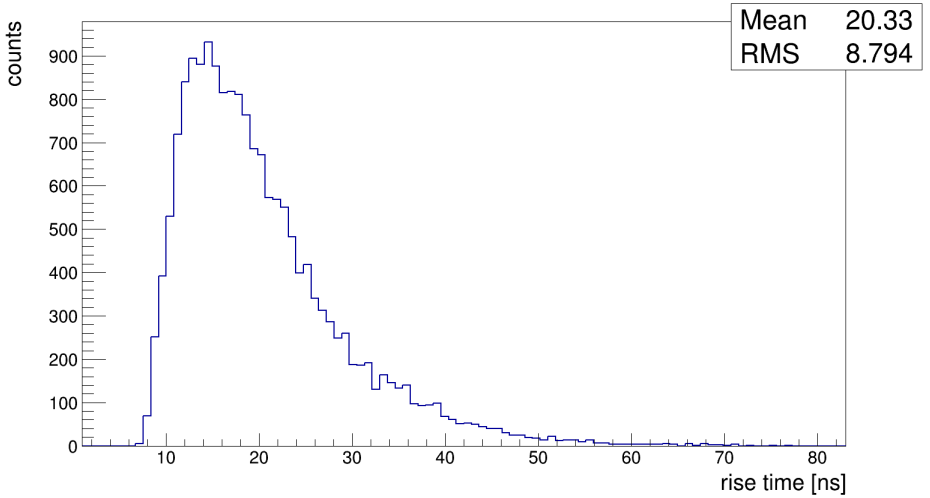
- Charge resolution with RMS ≈ 0.17
- Tendency to reconstruct too few nPE, especially for large charges

→ Needs improvement, especially for large charges

Muon Waveforms: Rise Time
Method & Results



Example of rise time reconstruction



Rise time distribution for center event

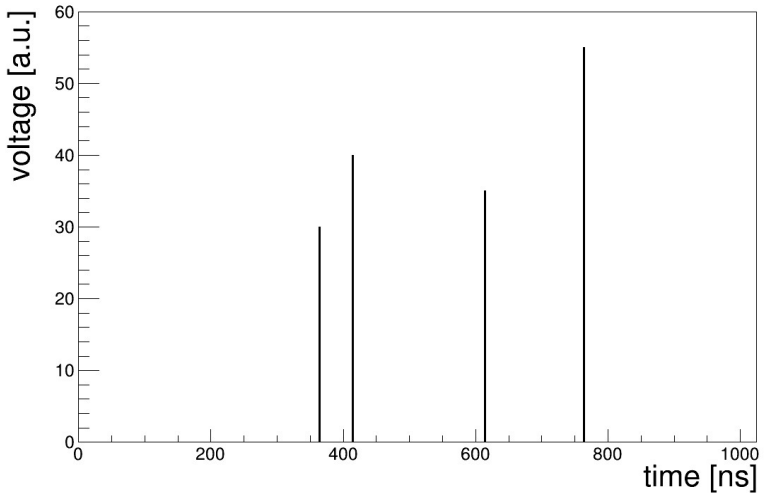
Rise time:

- Time waveform needs to rise from 10% to 90% signal height
- Recently introduced to DataModel

- **IBD waveform reconstruction**
  - Overview of deconvolution method and Wiener filter
  - Variation of common reconstruction method

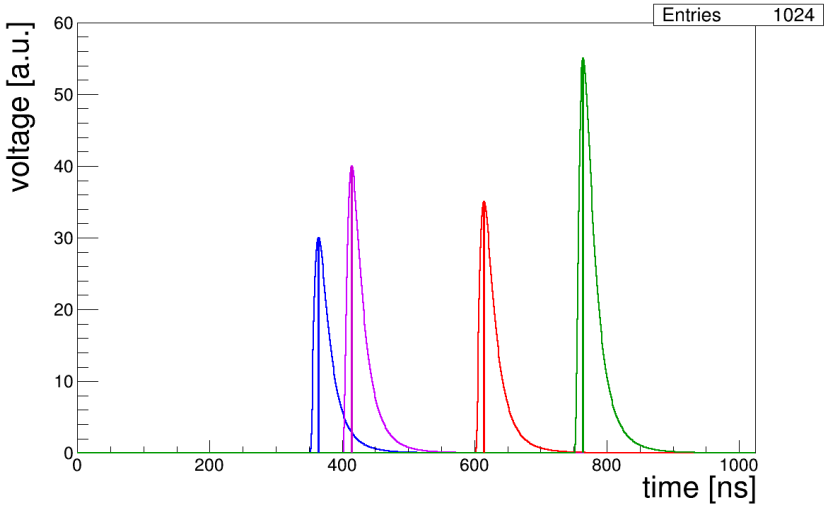
IBD: Wiener Deconvolution
The Deconvolution Method

- Quantities to reconstruct:
  charge and time of each photo-electron (PE)
- Charge and time information are included in hit distribution



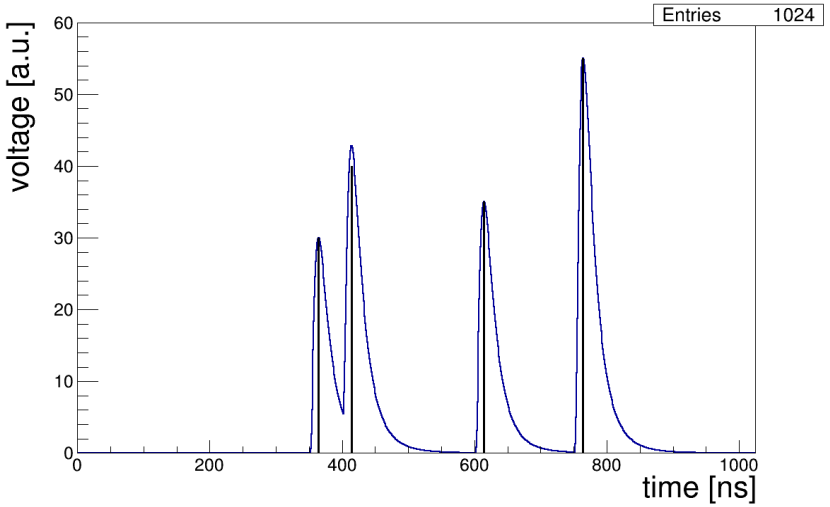
IBD: Wiener Deconvolution
The Deconvolution Method

- Quantities to reconstruct:
  charge and time of each photo-electron (PE)
- Charge and time information are included in hit distribution
- Each hit in hit distribution is convoluted with SPE response



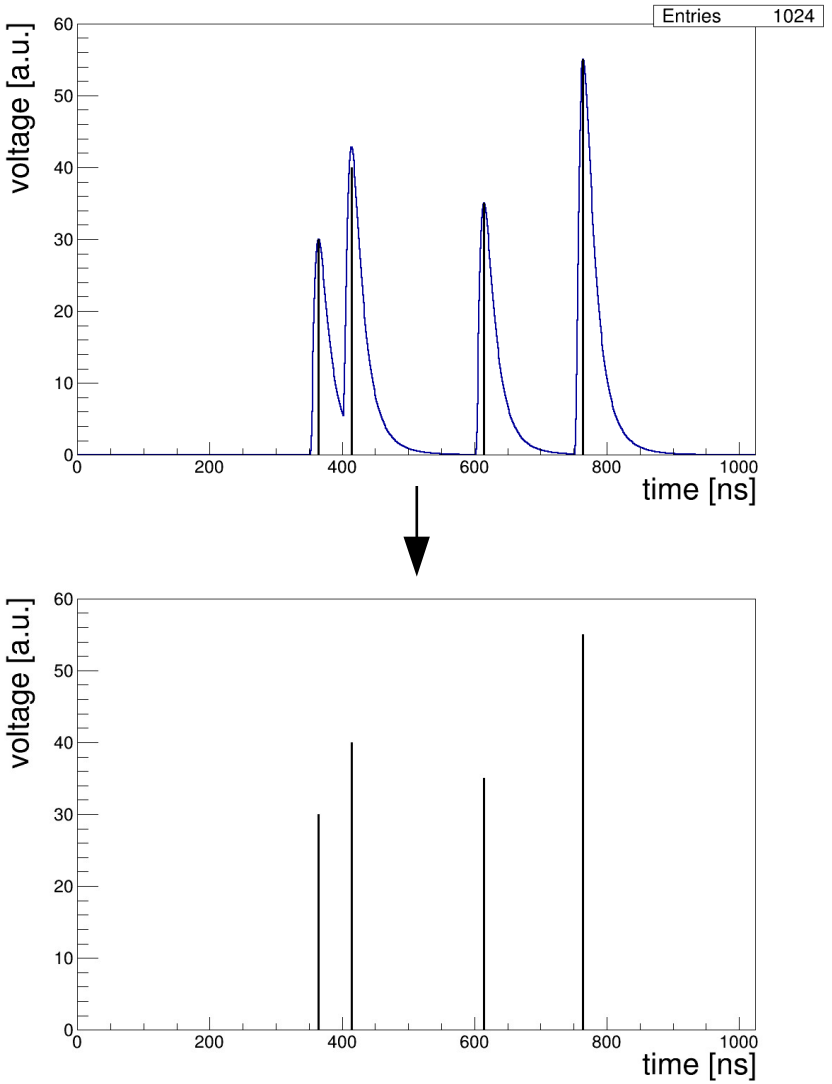
IBD: Wiener Deconvolution
The Deconvolution Method

- Quantities to reconstruct:
  charge and time of each photo-electron (PE)
- Charge and time information are included in hit distribution
- Each hit in hit distribution is convoluted with SPE response
- SPE responses add up to waveform



IBD: Wiener Deconvolution
The Deconvolution Method

- Quantities to reconstruct:
  charge and time of each photo-electron (PE)
- Charge and time information are included in hit distribution
- Each hit in hit distribution is convoluted with SPE response
- SPE responses add up to waveform
- Deconvolution method reconstructs hit distribution from waveform



IBD: Wiener Deconvolution

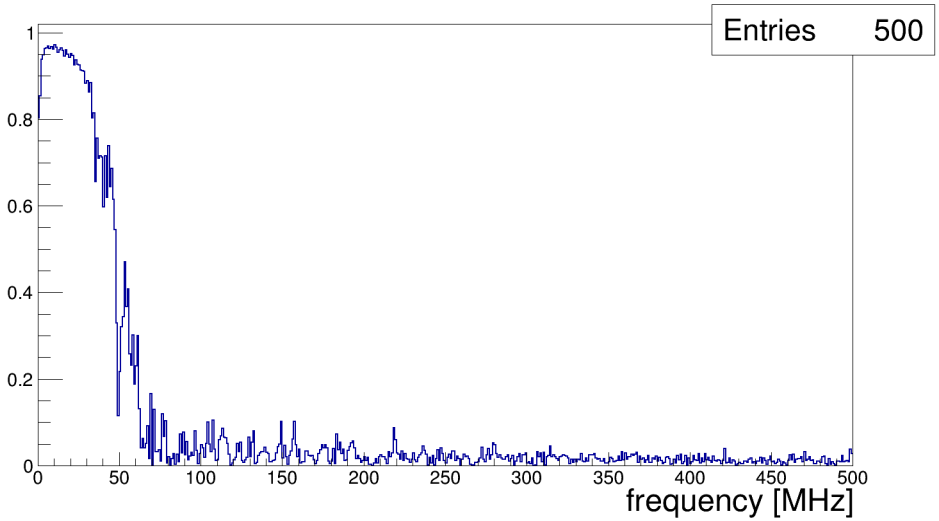
The Wiener Filter

- Deconvolution method requires noise filter if signal contains noise
- Filters should select signal part of measurement

- One possibility: Wiener filter:

$$\frac{|S|^2}{|S|^2 + |N|^2}$$

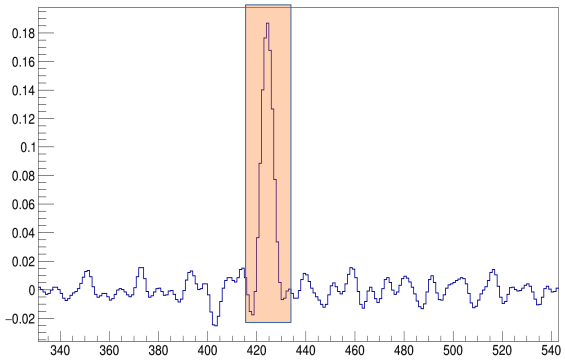
- Filtering in frequency domain
- Optimal filter from mathematical point of view
- Requires precise knowledge of expected signal and noise



Example of Wiener filter

IBD: Wiener Deconvolution
Variation of common method

- Method commonly results in charge reconstruction by integration
- Integration depends on integration limits

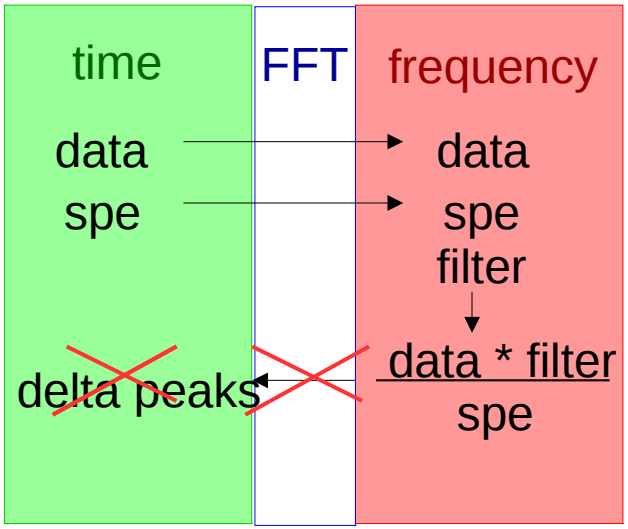


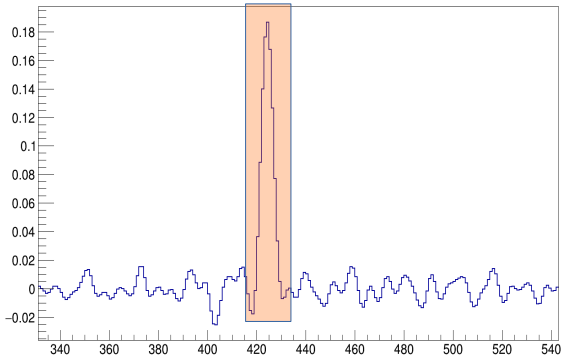
commonly: charge integration in time domain

IBD: Wiener Deconvolution
Variation of common method

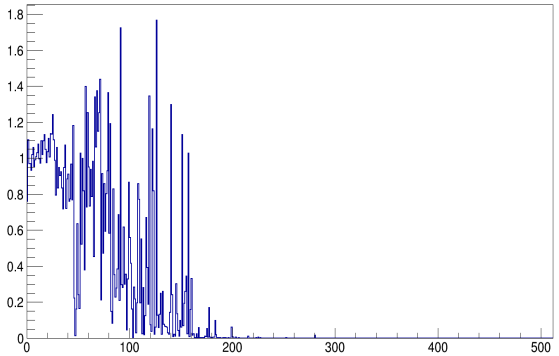
- Method commonly results in charge reconstruction by integration
- Integration depends on integration limits

- Idea: obtain both time and charge from frequency domain
- Principle of variation:





commonly: charge integration in time domain



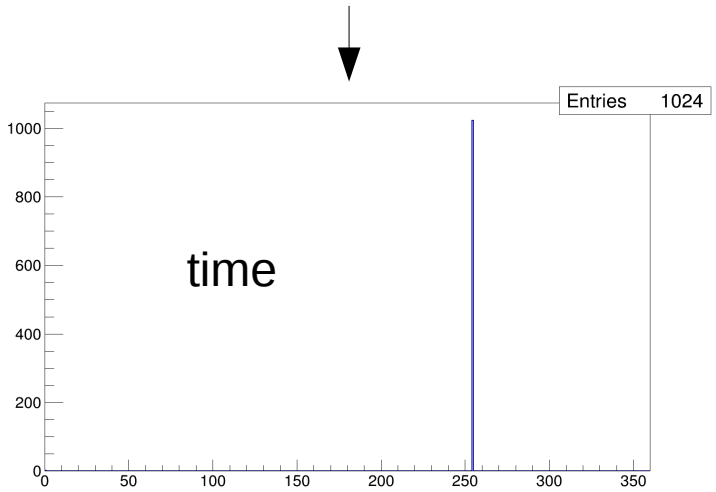
deconvoluted spectrum in frequency domain

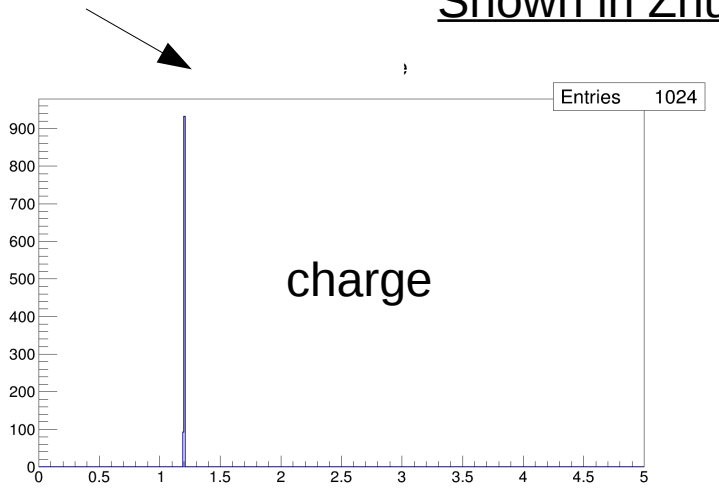
IBD: Wiener Deconvolution

Variation of Common Method – Principle

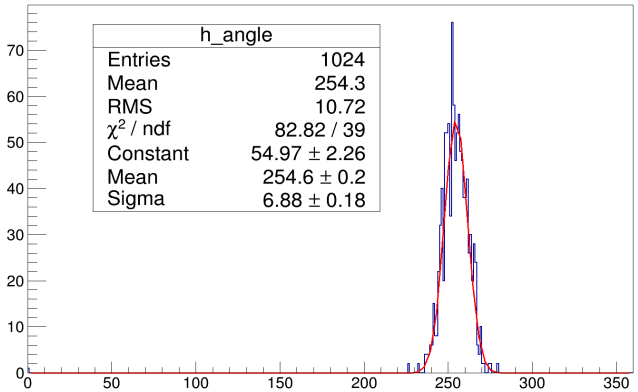
Plotting **phase differences Δφ** and **magnitude**:

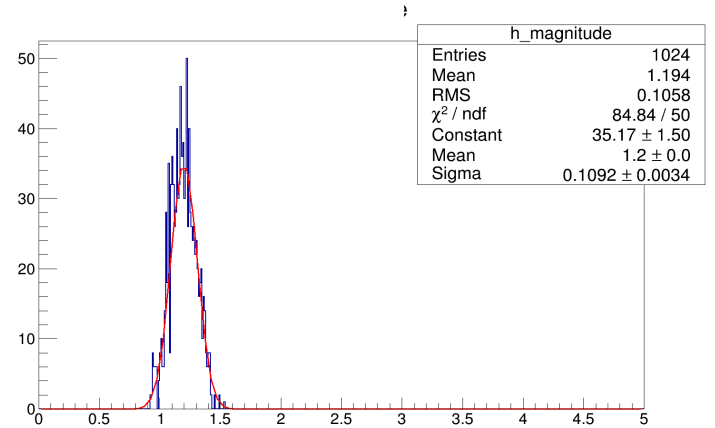
Shown in Zhuhai





without noise

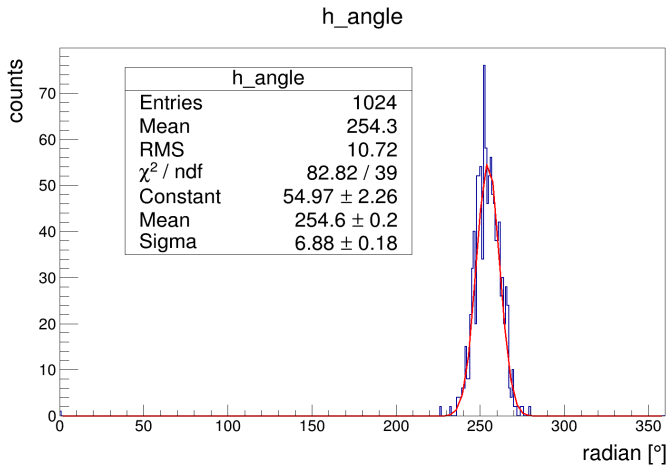




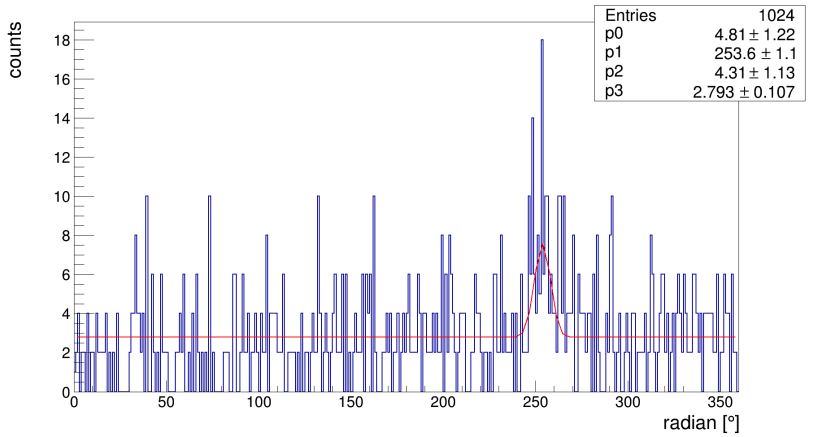
with statistical noise

IBD: Wiener Deconvolution
Variation of Common Method – Principle

Plotting **phase differences Δφ**:



with statistical noise



with systematic noise

- Distribution loses clarity when systematic noise is added
- Fit gets unstable
- Uncertainty of peak position increases

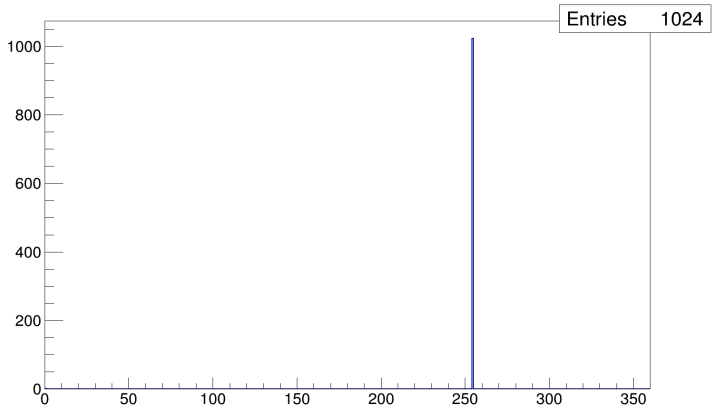
→ change method of time extraction

IBD: Wiener Deconvolution
Further Variation of Common Method

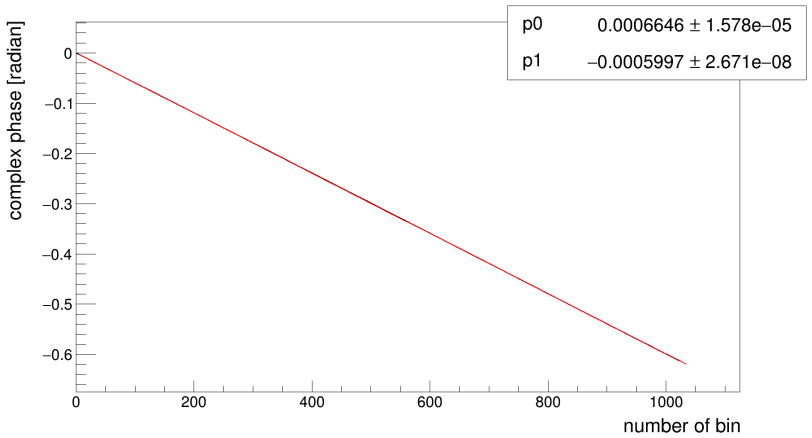
Solution:

- Replace Fourier transform $X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi kn/N}$ with $X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi kn/N^2}$

- Noiseless case:
  Fourier transform: time is given by position of delta peak
  altered transform: time is given by slope of straight line



Time extraction based on Fourier transform



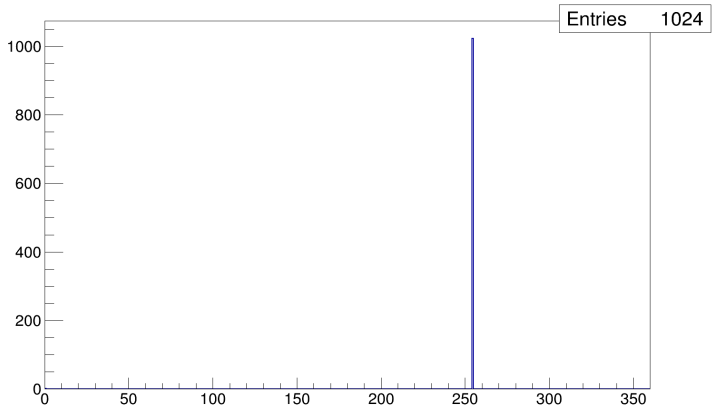
Time extraction based on straight line fit

Wiener Deconvolution
Variation of Common Method

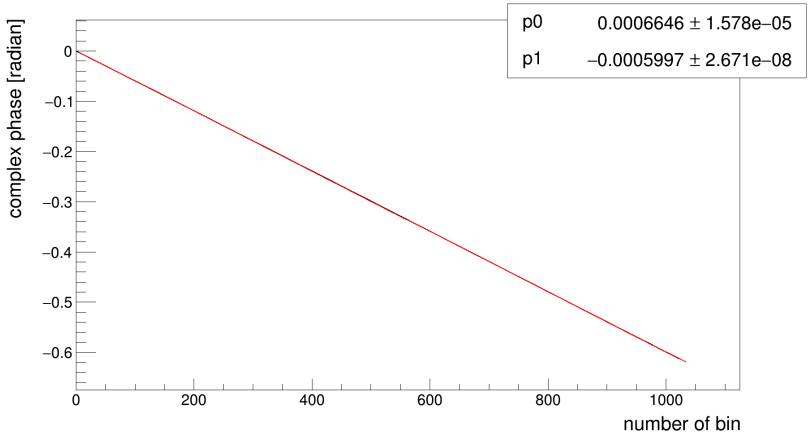
Solution:

- Replace Fourier transform $X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi kn/N}$ with $X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi kn/N^2}$

- Noiseless case:
  Fourier transform: time is given by position of delta peak
  altered transform: time is given by slope of straight line



Time extraction based on Fourier transform



Time extraction based on straight line fit

Work in progress ...

Summary & Outlook

- **Muon waveform reconstruction:**
  - First hit time studied by constant fraction discriminator approach and constant threshold: resolution: ~3.4 ns
  - Charge reconstruction by waveform integration
  - Rise time introduced
  - New Package: MuonWaveRec

- **IBD waveform reconstruction:**
  - Deconvolution method is studied based on the frequency domain spectrum
  - Fourier transform is altered to fit time
  - Focused on study of SPE waveforms until now
  - Continued by study of general waveforms of more PE