Study of the kinetics of the Undoped CsI Emission

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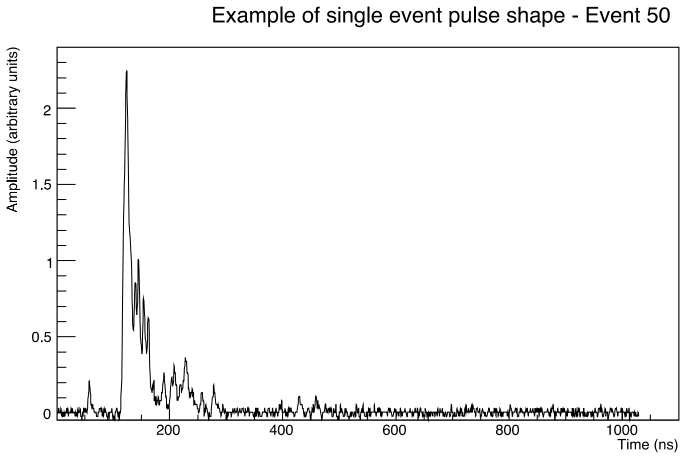
Outline

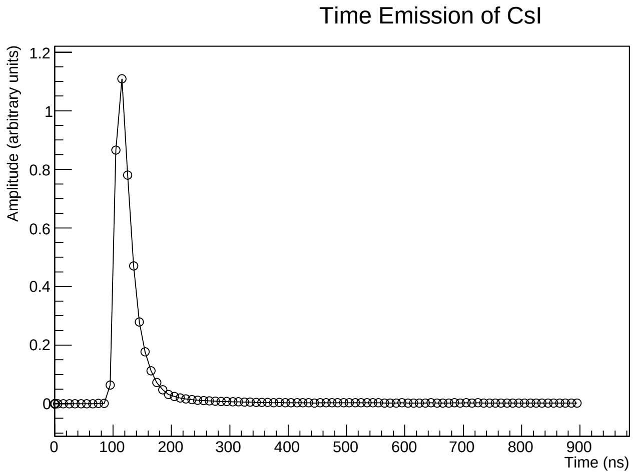
- Kinetics of the CsI
- Studying the pulse shape
- Mu2e: Results by Caltech and LNF groups
- Data analysis
- Results

Kinetics of the CsI crystal

The shape of crystal's emission waveform can affect:

- Energy Measurement
  - Pile up
  - Data Volume
- Expected performance parameters of calorimeter
  - Realistic Shape of Crystal convoluted with FEE



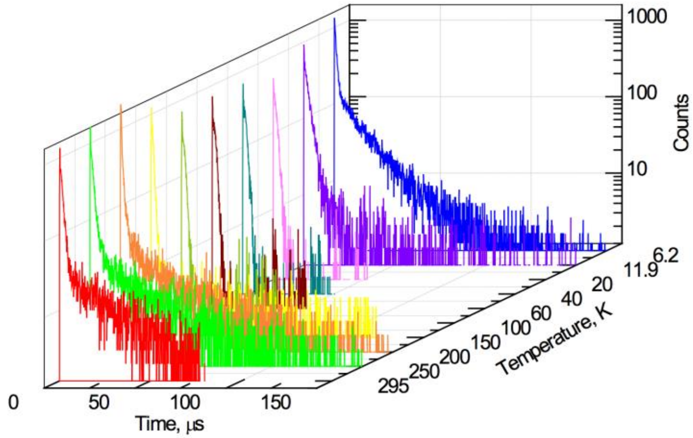


Example of pulse shapes: single and multiple events

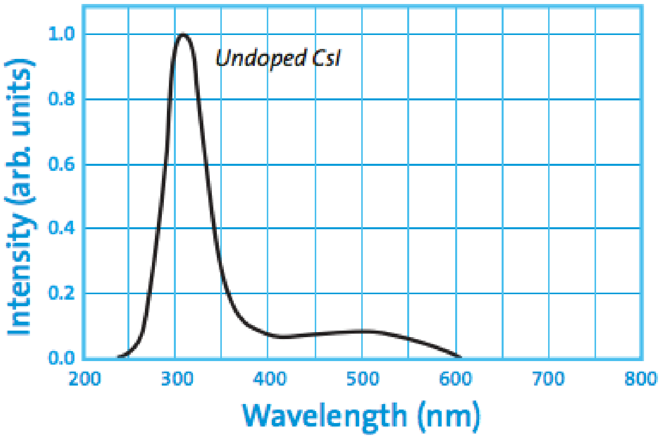
Waveform shape of the Crystal's emission

Different experiments during past years studied undoped CsI and it's emission giving us the following information:

- Emission is a function of the temperature
- Radiation hardness adequate for Mu2e experiment
- Emission peak of the fast component at 310 nm
- Emission peak of the slow component at 500 nm



(1) Isometric plot of decay curves of undoped CsI measured for α-particle excitation (^{241}Am) at different temperatures; Luminescence and scintillation properties of CsI: A potential cryogenic scintillator, (VB Mikhailik, V Kapustyanyk, V Tsybulskyi, V Rudyk, H Kraus)

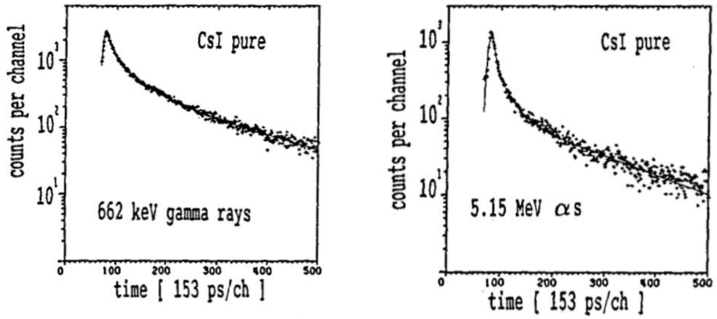


(2) Scintillation emission spectrum of undoped CsI; CsI Pure Data Sheet, Saint-Gobain Ceramics & Plastics

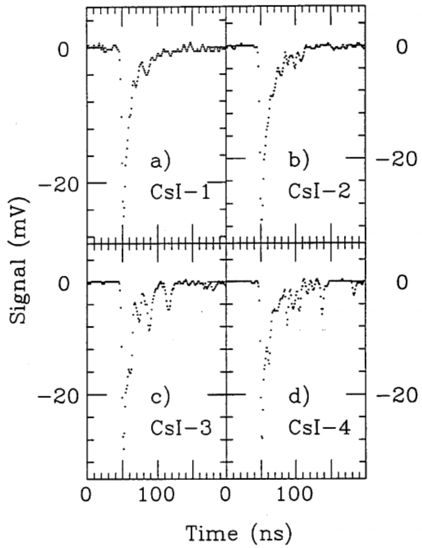
How many lines and uncertainties

- **Fast component**:

→ One component ~20 ns[3] or two components at ~6 and ~30ns[4]?



662 keV gamma-rays		5.15 MeV alpha particles
21.7 ± 1.8 ns (65 %)	fast	20.6 ± 1.3 ns (50 %)
2.1 ± 0.2 ns (35 %)		2.2 ± 0.2 ns (50 %)
1.0 μs (50 %)	slow	0.1 μs (100 %)
0.1 μs (50 %)		



Sample	F (%)	τ_F (ns)	S (%)	τ_S (ns)
CsI-1	33	6.1±1.2	67	30±8
CsI-2	29	6.6±1.7	71	27±5
CsI-3	22	7.2±1.0	78	41±6
CsI-4	27	6.8±1.1	73	43±6

(3) Decay spectra and times of pure CsI;
Scintillation characteristics of pure and Tl-doped CsI crystals, (P. Schotanus; R. Kamermans)

(4) Decay spectra and times of pure CsI;
A study on undoped CsI crystals (Zong-ying Wei, Ren-yuan Zhu)

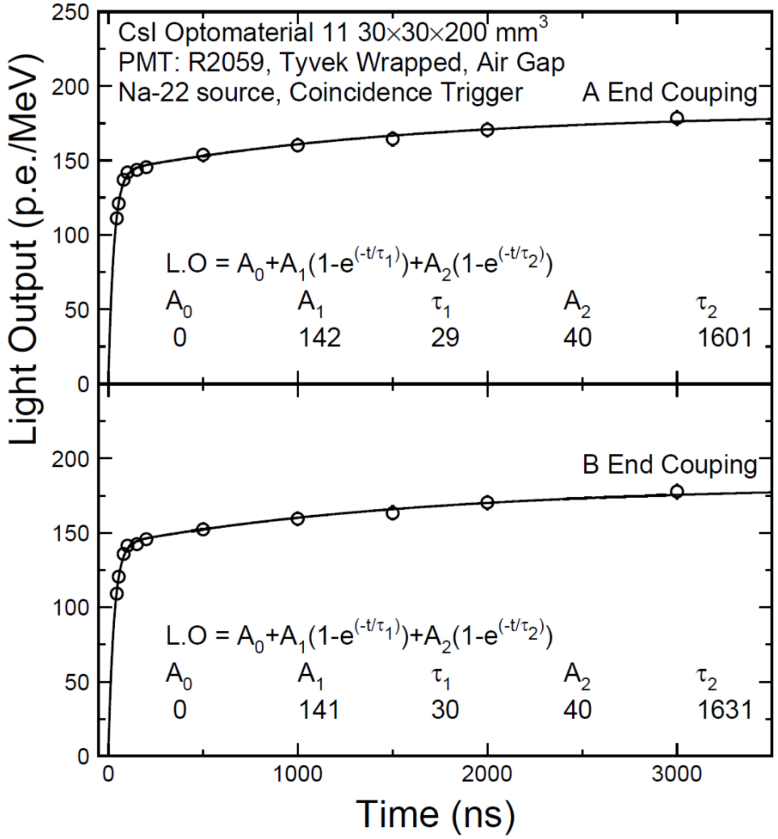
- **Slow Component**, dependent on contamination:

→ Large spread around the value of ~1 μs in decay times for different publications[3]

Results of Caltech Mu2e group

Data taken over 4000 ns with time bins of 50 ns:

- Raw data is the integrated charge, not the waveform
- Fast component ~30 ns
- Slow component of ~ 1600 ns, contribution can be small compared to fast component in some crystals

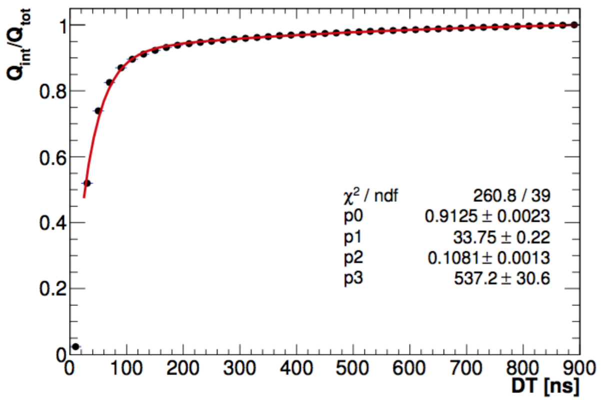


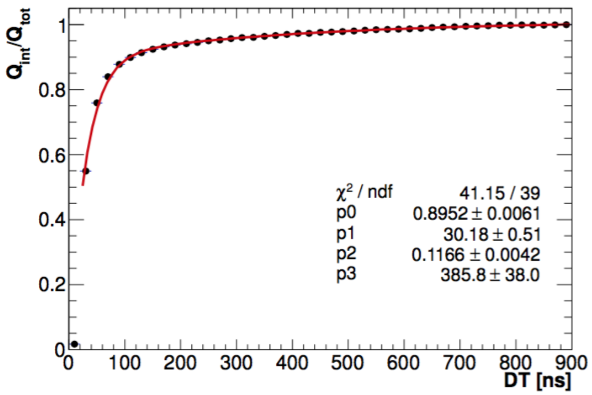
(5) Charge integrated from the signal start to 4000 ns for crystals from OPTOMATERIALS.

Results of LNF Mu2e group

Data taken over 1000ns with time bins of 1 ns subsequently integrated over 20 ns intervals to compare with Caltech results:

- fast component ~30 ns
- slow component between 500 and 1000 ns



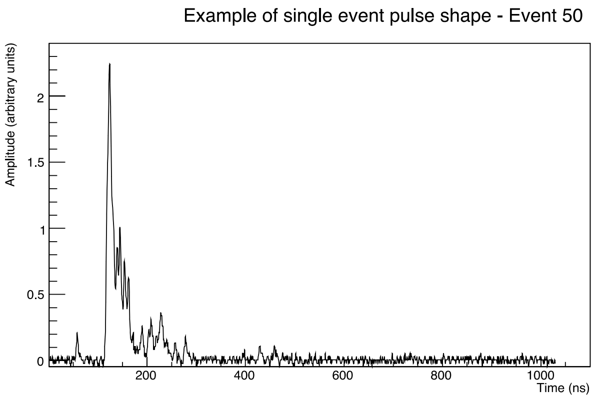


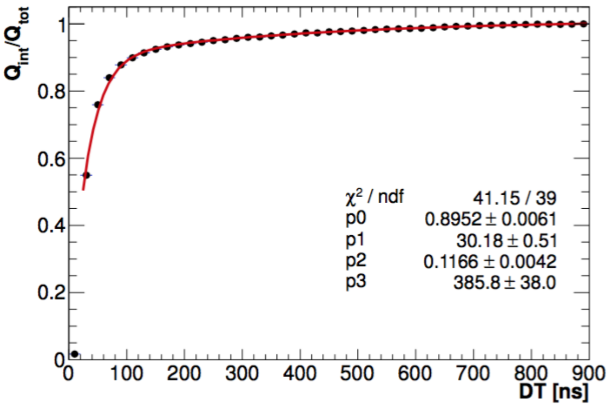
(6) Ratio between the charge integrated from the signal start (DT = −30 ns), Q_{int}, and the total integrated charge, Q_{tot}, as a function of the DT variable for crystals from OPTOMATERIALS.

$$p_0\left(1-e^{-\frac{x}{p_1}}\right)+p_2\left(1-e^{-\frac{x}{p_2}}\right)$$

Results of LNF Mu2e group

- Using a running integral makes uncertainties on different points all correlated
- Alignment of different signals made respect to the higher bin, noise can make it fluctuate
- Acquisition window of 1000 ns can affects fit results for the slow component





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Analyzed data from LNF

We have analyzed data taken with two crystal:

- Siccas CsI readout by an UV-extended PMT and tested with a ^{22}Na source (placed at different position w.r.t. the PMT on crystal longitudinal axis)

- ISMA CsI readout by PMT and tested with CRs

Data: counts converted in volts and pedestal already subtracted

Analyzing the pulse shape

Steps followed:

- Integration from 60 to 960 ns
- Integration from peak to 800 ns
- Normalizing and aligning all pulses
- Deriving an average pulse shape
  - Projecting the average and studying it in single 10 ns slices
  - Histogram made using the mean of Gaussian fit on each slice

Analyzing the pulse shape

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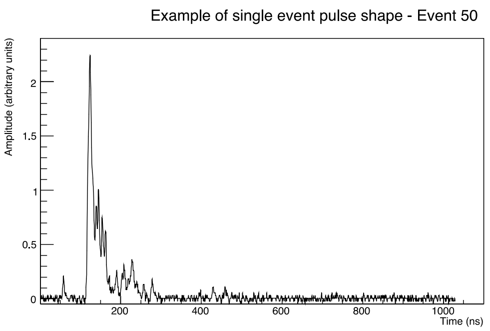

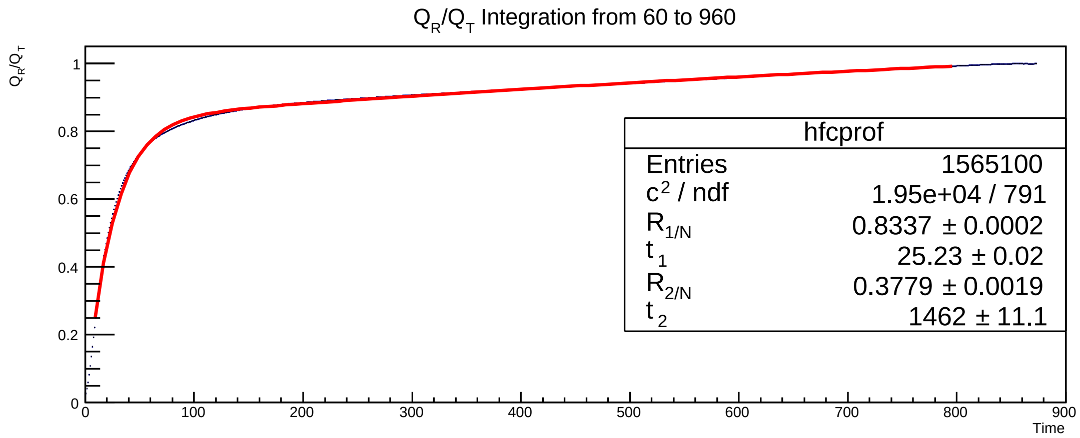

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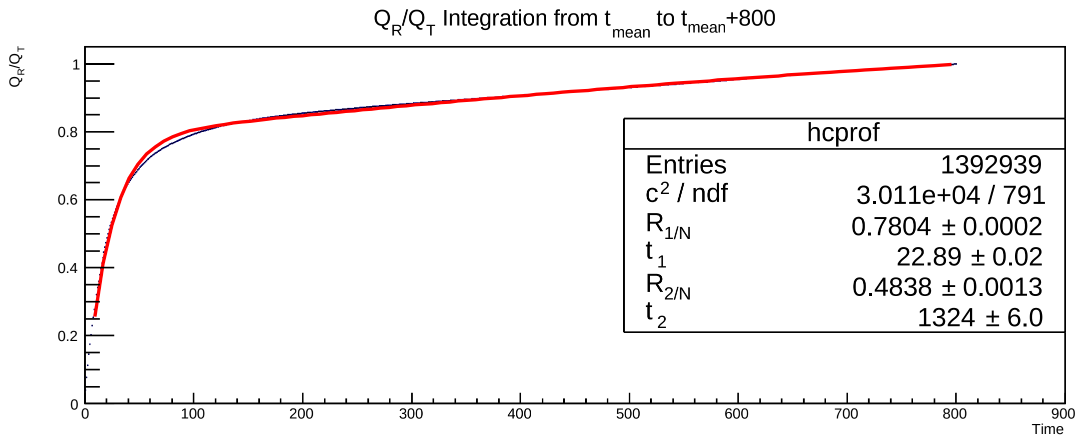

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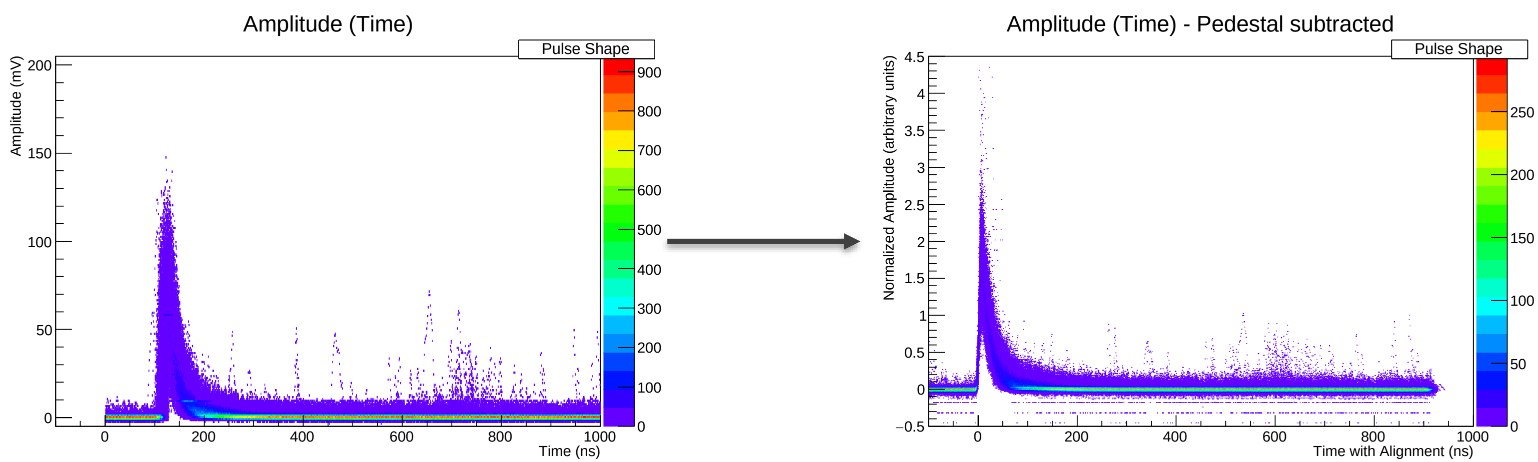
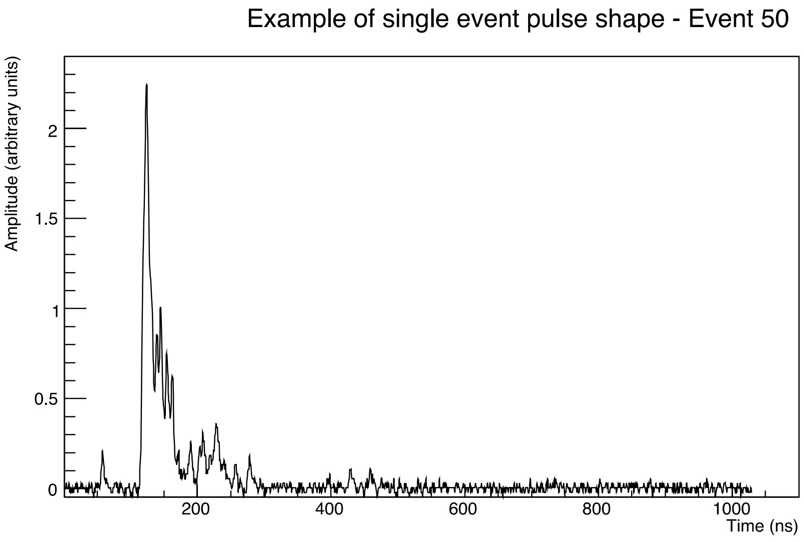
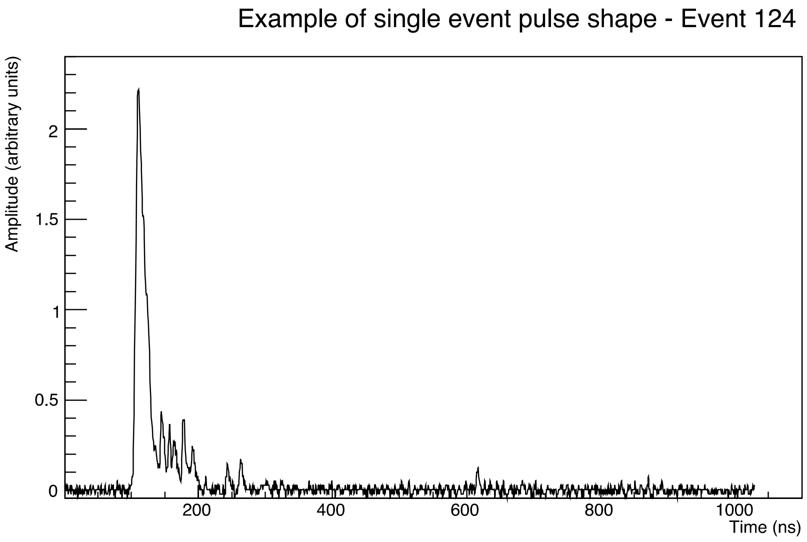


The Pulse Shape – Assumptions

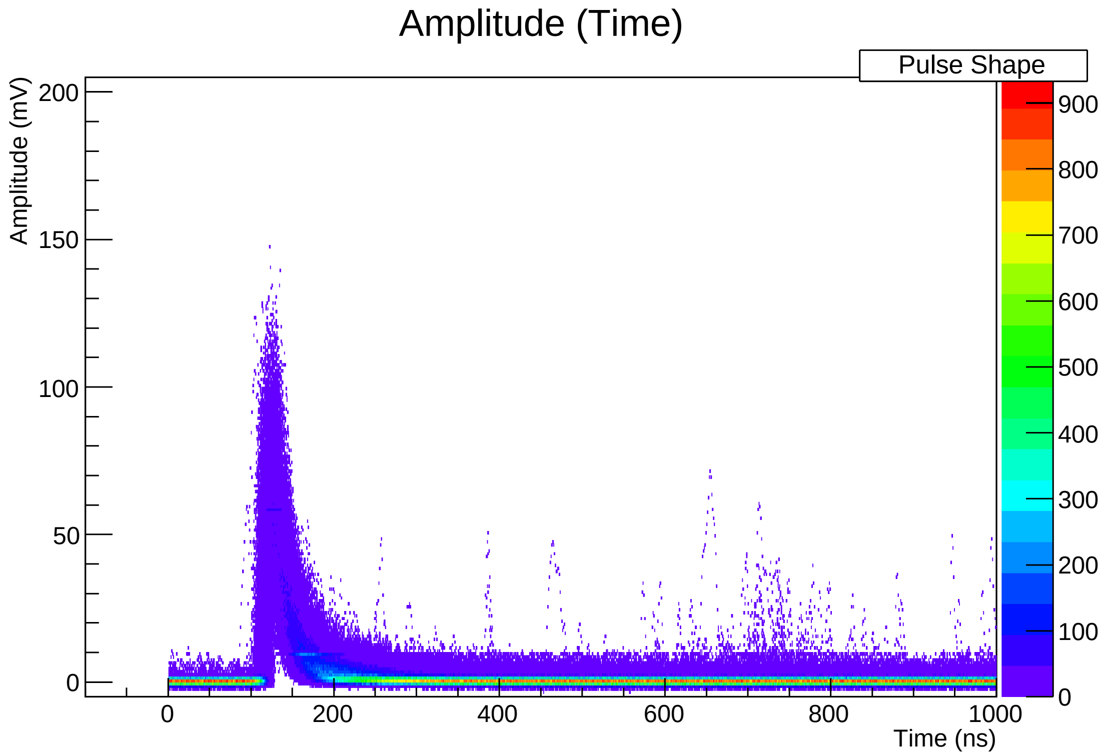
- All waveforms have the same shape
- All waveforms have the same rise time





The Pulse Shape – Deriving the average

- Normalize shape to the the integral
- New pedestal evaluated from first 50 ns
- Alignment with leading edge slope



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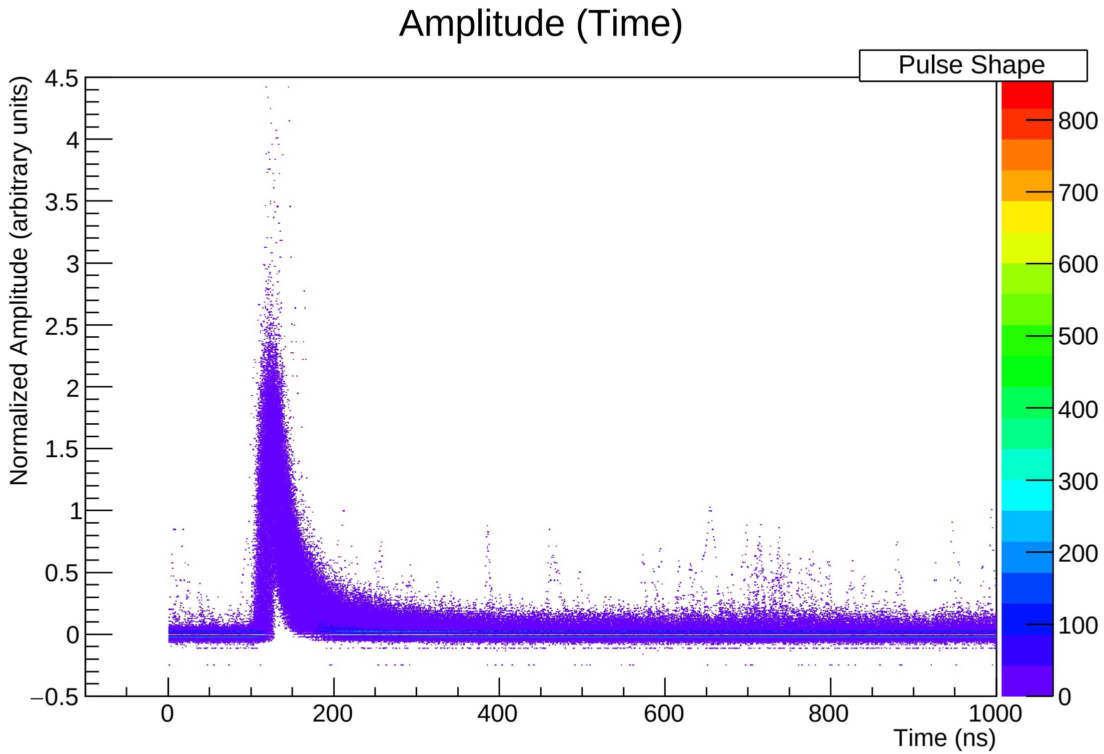

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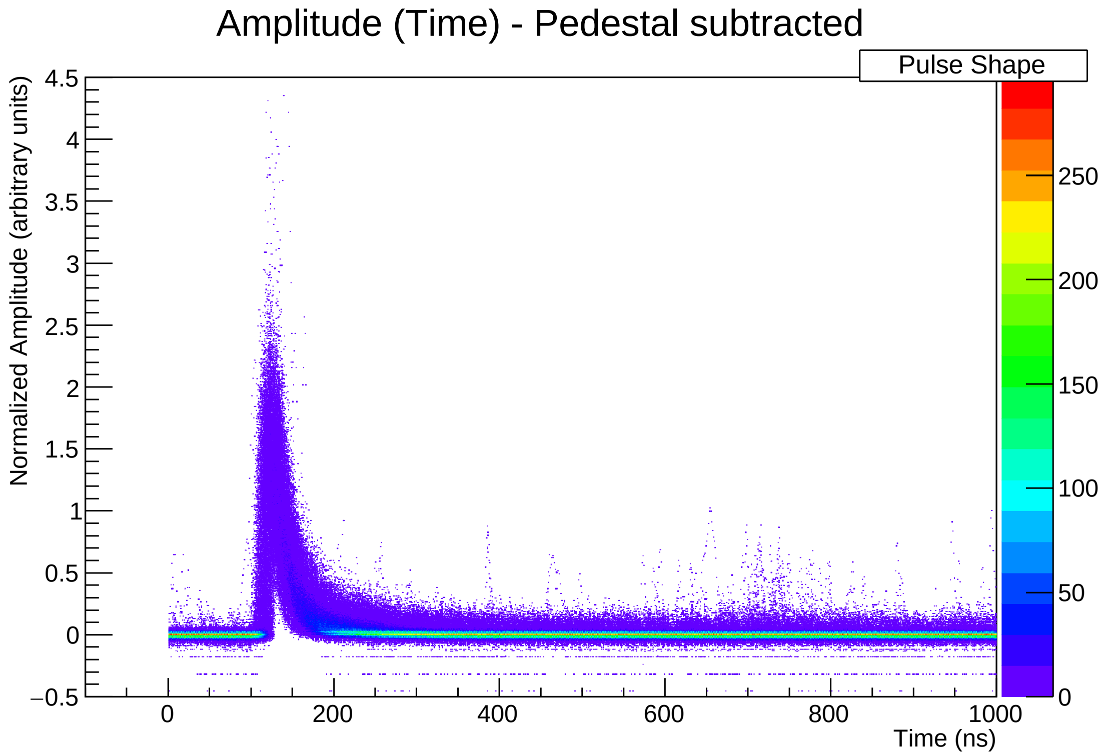

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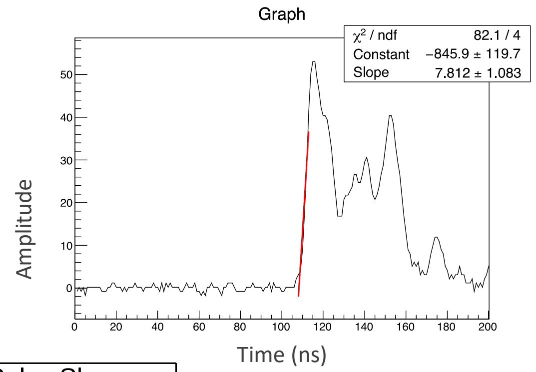

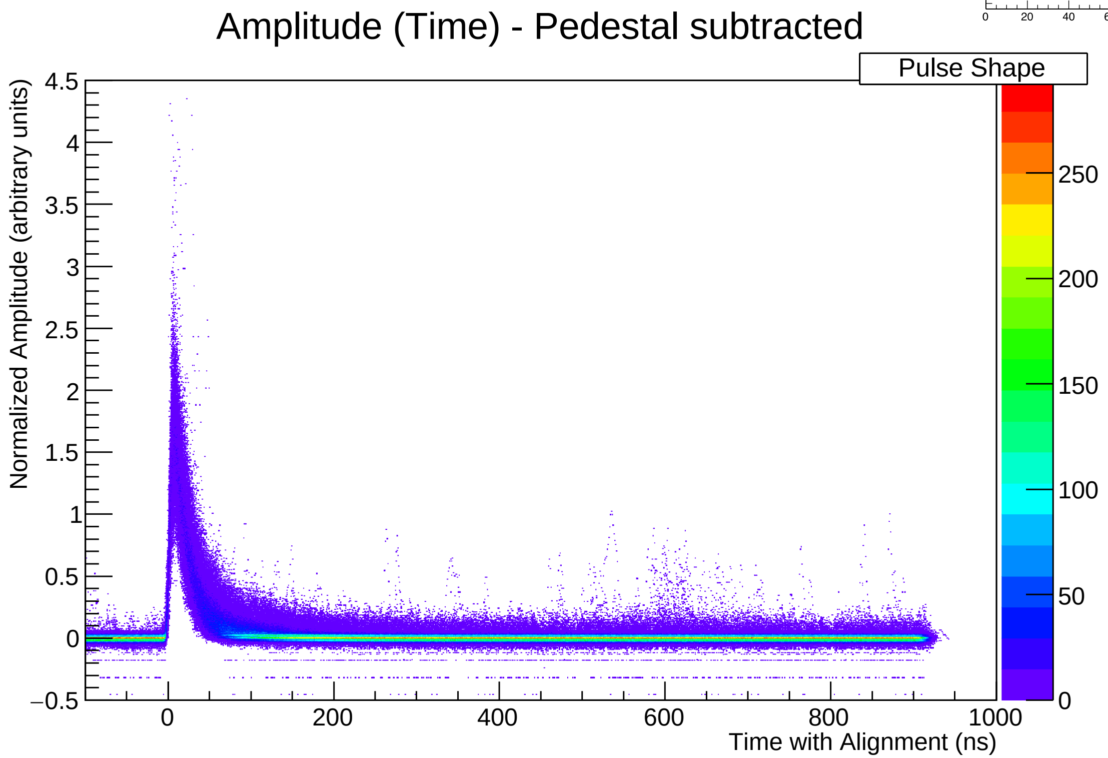

Analyzing the pulse shape

- Steps followed:
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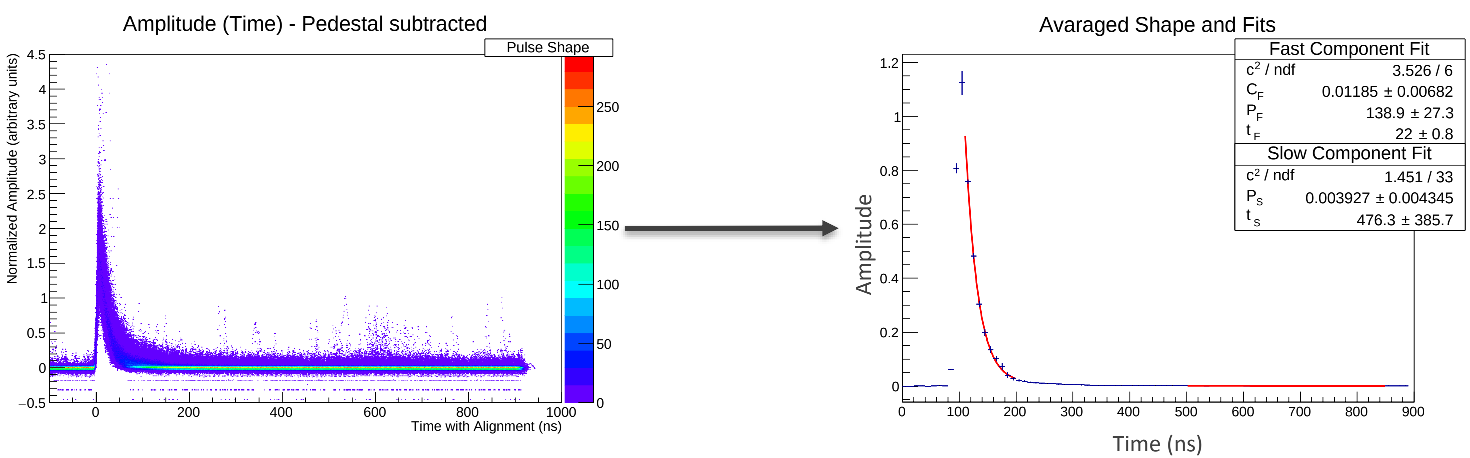
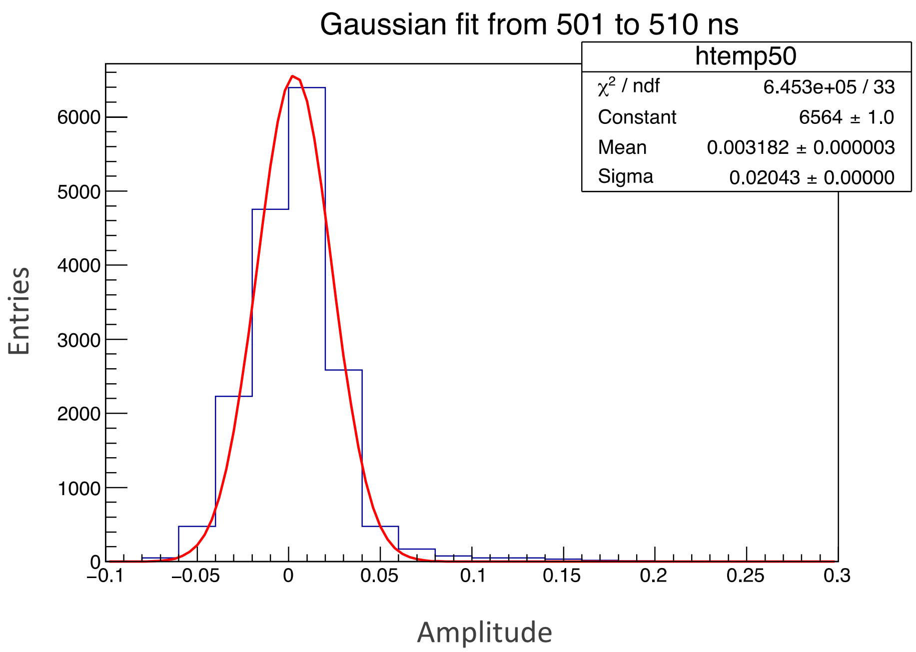
  - **Histogram made using the mean of Gaussian fit on each slice**

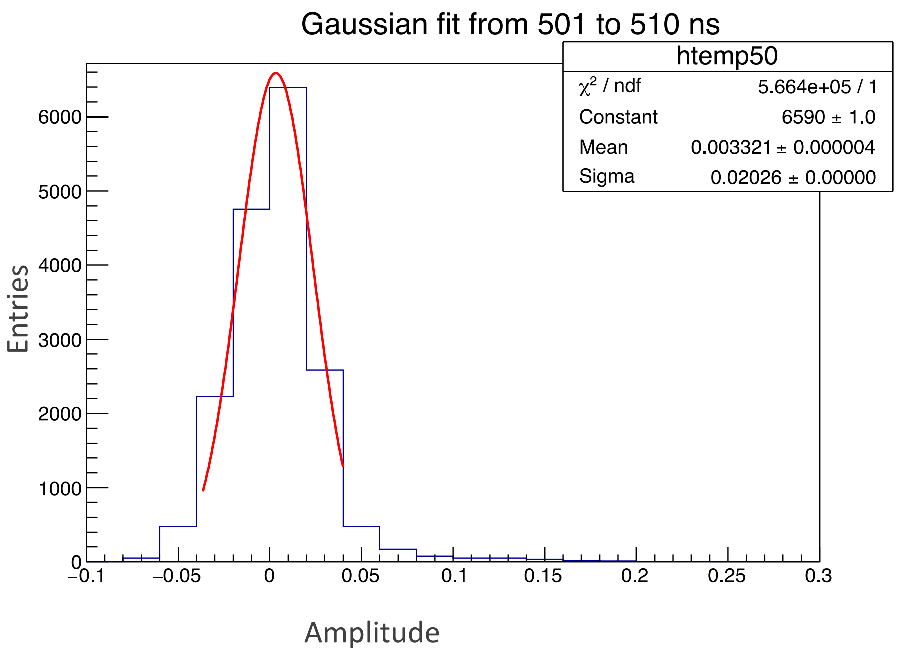


Example - Gaussian Fit of a 10 ns Slice

Siccas 13 crystal, ^{22}Na source 2 cm from PMT, Tyvek wrapping



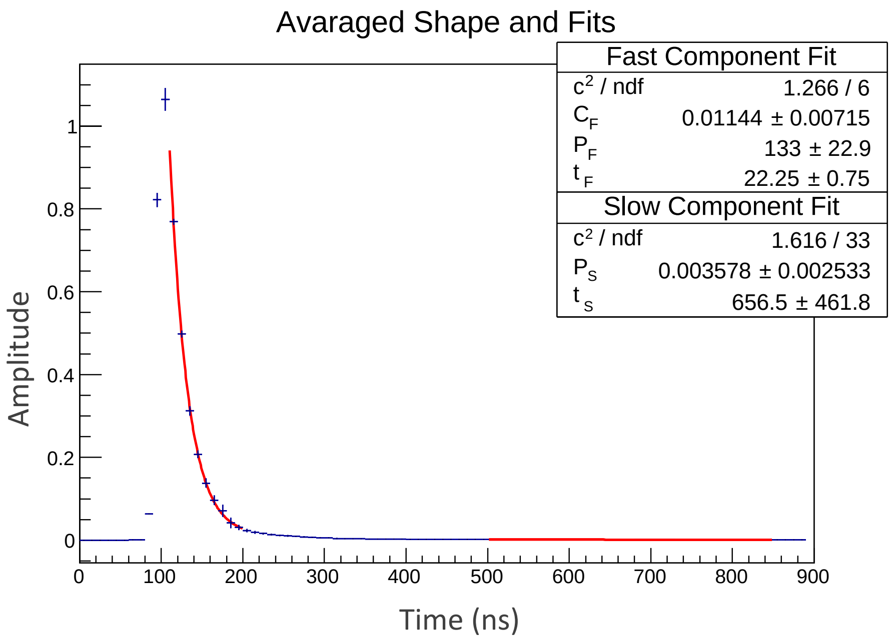
Gaussian fit including tales of a 2D histogram's slice.



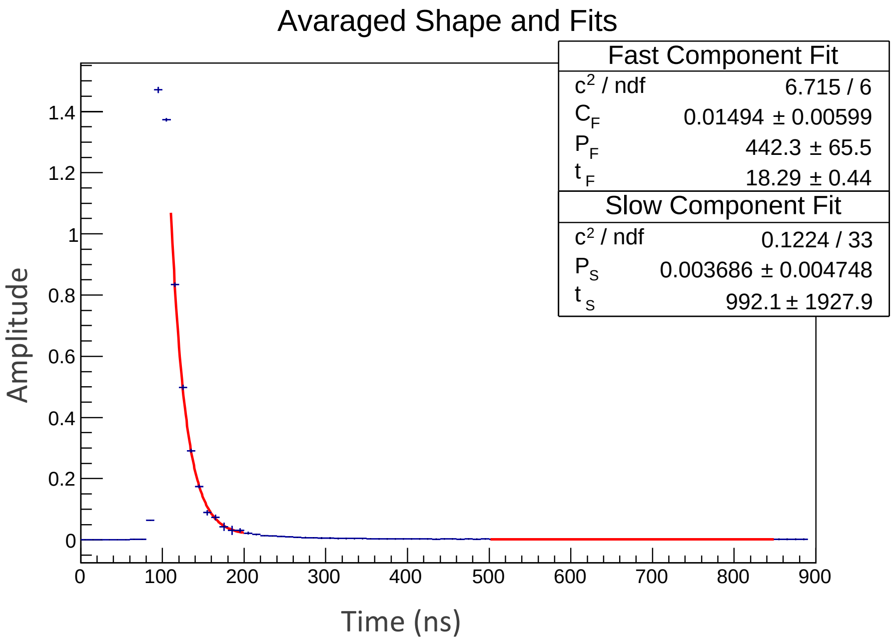
Gaussian fit excluding tails of a 2D histogram's slice.

Emission Shape – From slices Gaussian fit results

Siccas 13 crystal, ^{22}Na source 2 cm from PMT, Tyvek wrapping



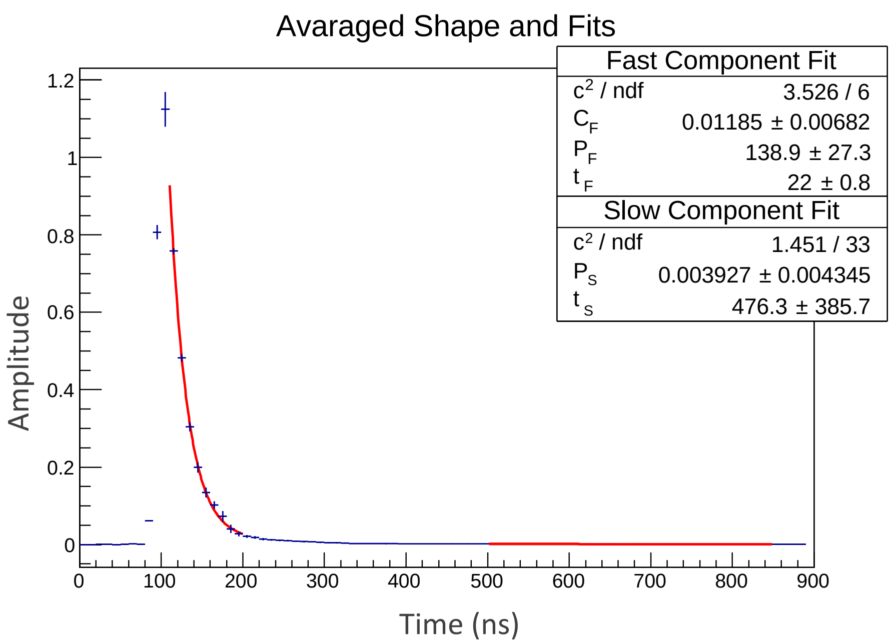
Points evaluated from Gaussian fit including tails



Points evaluated from Gaussian fit excluding tales

Emission Shape – From slices Gaussian fit results

Siccas 13 crystal, ^{22}Na source 10 cm from PMT, Tyvek wrapping



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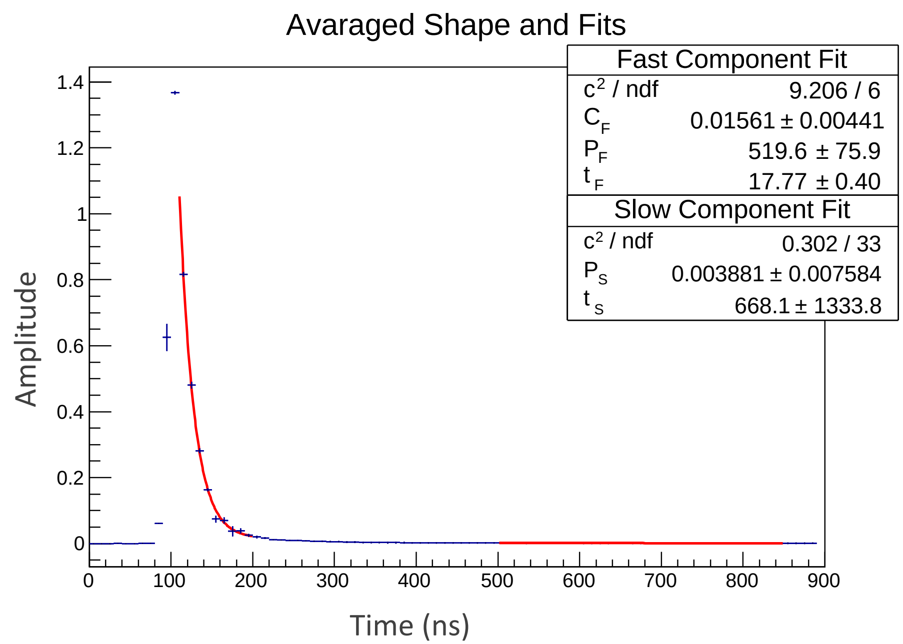
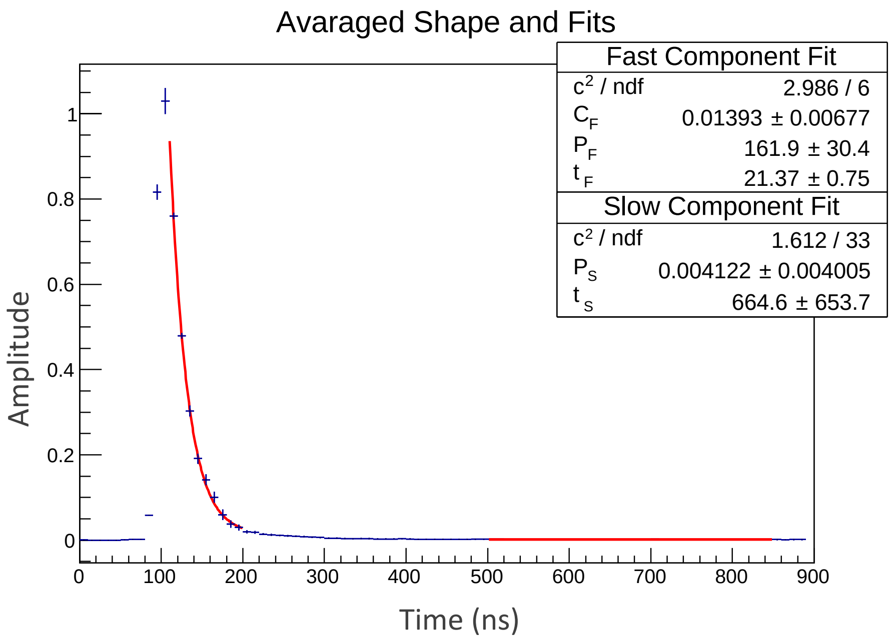


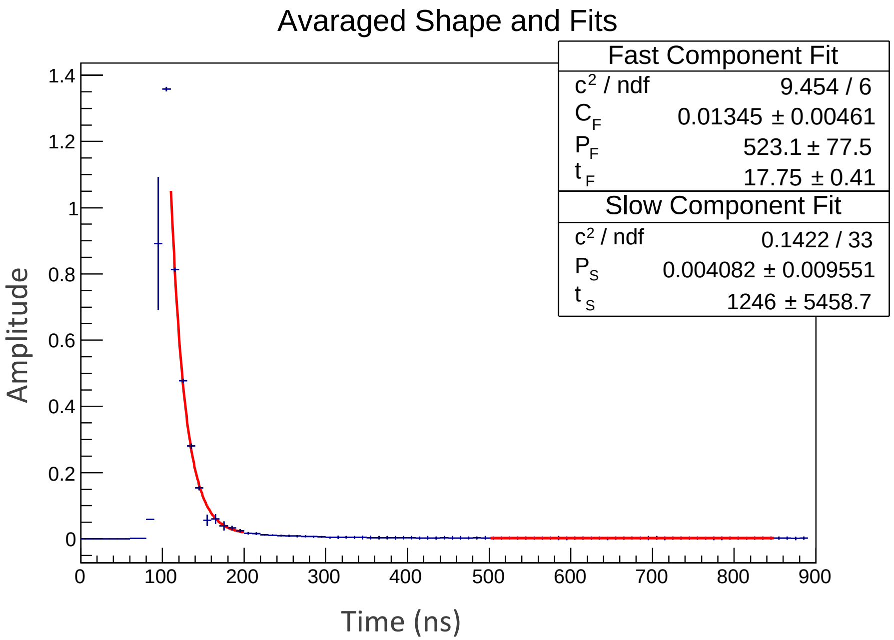
Points evaluated from Gaussian fit excluding tales

Emission Shape – From slices Gaussian fit results

Siccas 13 crystal, ^{22}Na source 16 cm from PMT, Tyvek wrapping



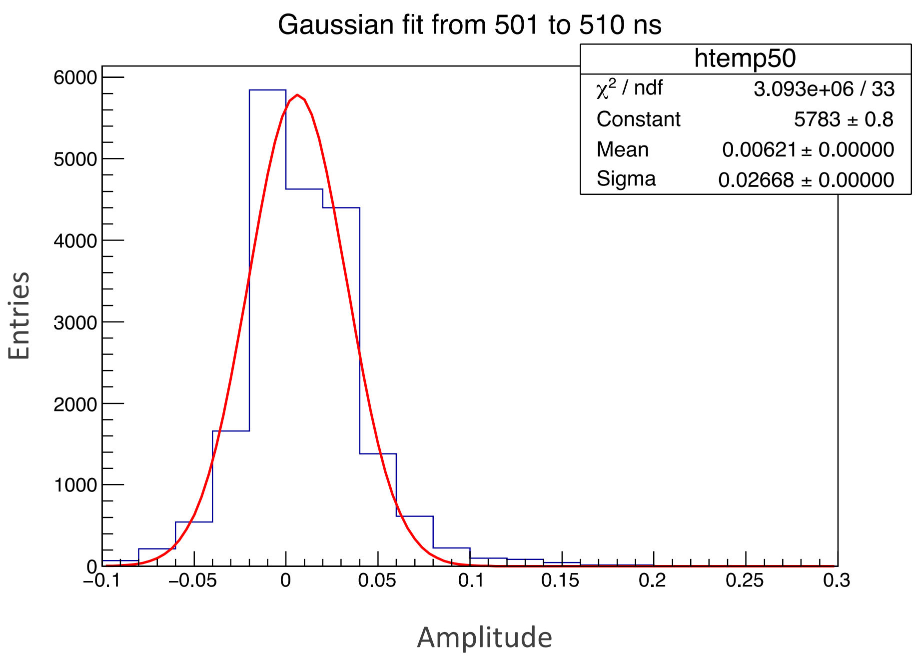
Points evaluated from Gaussian fit including tails



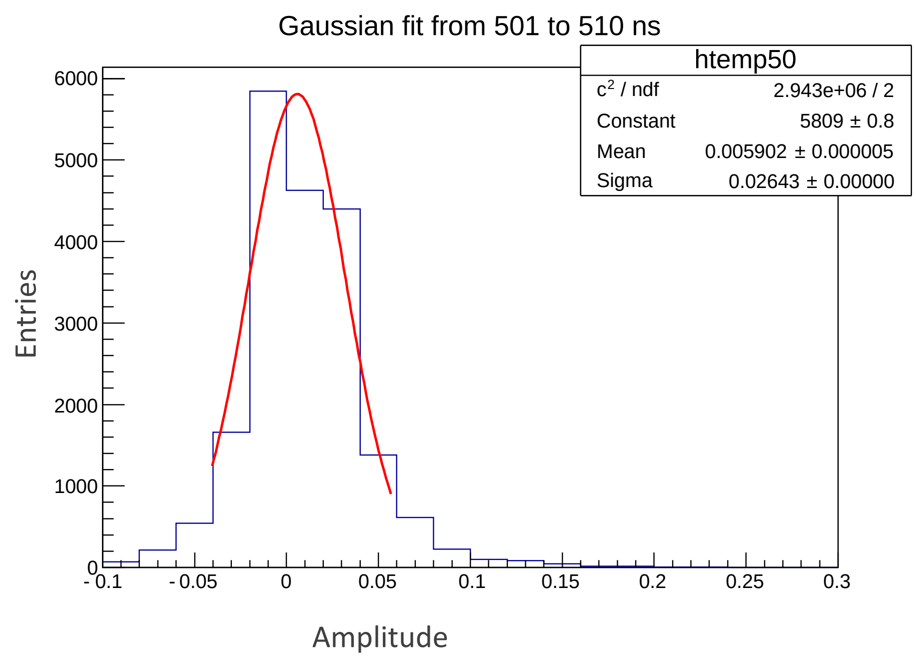
Points evaluated from Gaussian fit excluding tales

Example - Gaussian Fit of a 10 ns Slice - CRs

ISMA crystal, cosmic rays and PMT, Tyvek wrapping



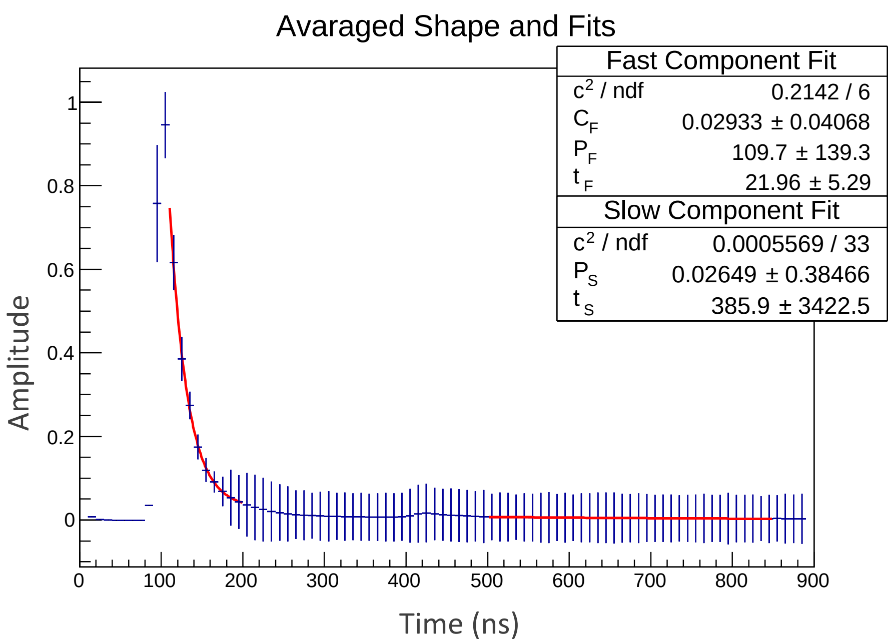
Gaussian fit including tales of a 2D histogram's slice.



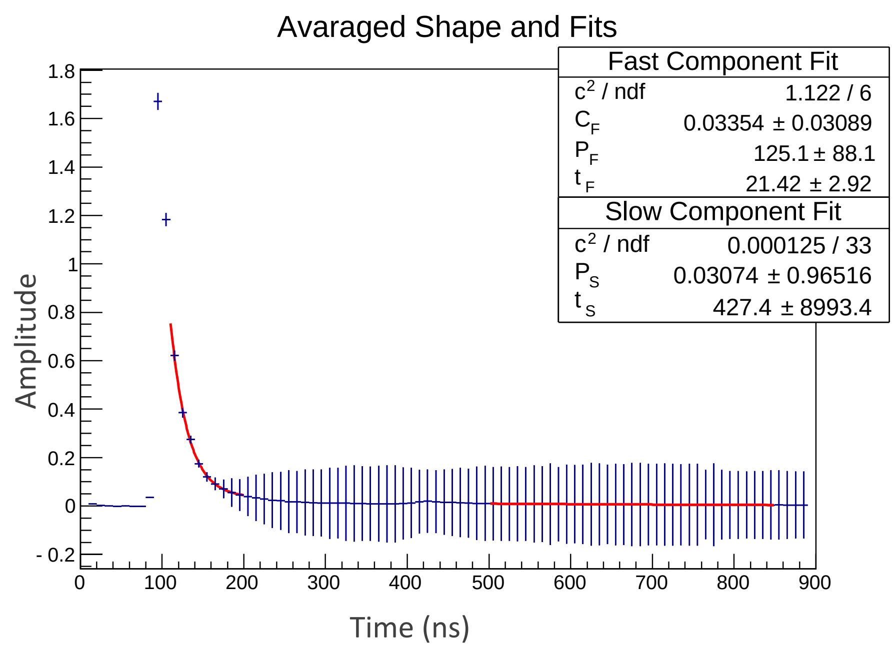
Gaussian fit excluding tails of a 2D histogram's slice.

Emission Shape – From slices Gaussian fit results

ISMA crystal, cosmic rays and PMT, Tyvek wrapping



Points evaluated from Gaussian fit including tails



Points evaluated from Gaussian fit excluding tales

Results – Slices Gaussian Fit with tales

Siccas Crystal with Source, 2 cm from PMT	
$\tau_F(ns)$	22.25 ± 0.75
$\tau_S(ns)$	656.5 ± 461.8
Siccas Crystal with Source, 10 cm from PMT	
$\tau_F(ns)$	22 ± 0.8
$\tau_S(ns)$	476.3 ± 385.7
Siccas Crystal with Source, 16 cm from PMT	
$\tau_F(ns)$	21.37 ± 0.75
$\tau_S(ns)$	664.6 ± 653.7
ISMA Crystal with Cosmic Rays and PMT	
$\tau_F(ns)$	21.96 ± 5.29
$\tau_S(ns)$	385.9 ± 3422.5

Results – Slices Gaussian Fit with tales

Siccas Crystal with Source, 2 cm from PMT	
$\tau_F(ns)$	18.29 ± 0.44
$\tau_S(ns)$	992.1 ± 1927.9
Siccas Crystal with Source, 10 cm from PMT	
$\tau_F(ns)$	17.77 ± 0.40
$\tau_S(ns)$	668.1 ± 1333.8
Siccas Crystal with Source, 16 cm from PMT	
$\tau_F(ns)$	17.75 ± 0.41
$\tau_S(ns)$	1246 ± 5458.7
ISMA Crystal with Cosmic Rays and PMT	
$\tau_F(ns)$	21.86 ± 9.57
$\tau_S(ns)$	398 ± 100360.3

Summary

- No evidence of a component with decay time close to ~ 6 ns
- Fast component decay time from pulse shape fit is ~ 20 ns, consistent with different publication but lower then the results from fitting the integrated charge
- Slow component decay time from pulse shape fit is between ~ 380 ns and 1200 ns but lower then the results from fitting the integrated charge

References

1. Luminescence and scintillation properties of CsI: A potential cryogenic scintillator (VB Mikhailik, V Kapustyanyk, V Tsybulskyi, V Rudyk, H Kraus) Physica Status Solidi B-Basic Solid State Physics 252 (2015) 804-810

2. CsI Pure Data Sheet, Saint-Gobain Ceramics & Plastics

3. Scintillation characteristics of pure and Tl-doped CsI crystals (P. Schotanus, R. Kamermans) IEEE Transactions on Nuclear Science 37 (1990) 177-182

4. A study on undoped CsI crystals (Zong-ying Wei, Ren-yuan Zhu) Nuclear Instruments and Methods in Physics Research A326 (1993) 508-512