Hit Reconstruction
Pulse Shape Fit Parameters

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Introduction

- APV25 channel response modeled with Four-Pole Fit Function
- Used UCSC testboard Calibration Pulse Scan data (ADC as function of 48 time bins) to calculate svt shape fit parameters values for 2021 slim sensors
- Parameter values very different from default values in conditions database
  - Default values lead to poor hit fitting, effects track and vertex reconstruction efficiency
  - All 2019 and 2021 analysis thus far use these default fit parameters
- No testboard calibration pulse data available for 2019 sensors, or 2021 “non-slim” sensors
- Calibration pulse run using DAQ taken at Jlab 2021 (run 014393), however error in script lead to only 6 (instead of 48) time bins for a given pulse being filled
  - Similar run taken in 2019 will be analyzed separately in future
- Successfully fit 99% of alive channels, using only 6 time samples
  - Dead channels and failed fits use nearest neighbor fit param values
- Local database updated with correct fit params, will compare reconstruction

APV Pulse Fit Functions

- **Hps-java pulse fit function does not match function referenced in Sho's thesis:**
  - **Function in hps-java stops at k=2 in summation, vs k=3 in thesis**
- Cam emailed Sho, and **Sho confirmed that both his thesis, and reference used for his thesis, have typos**
- **APV pulse fit function in hps-java is correct!**
- **Also noticed additional Four-Pole function ("3 Tau Function") in apv6_formfactors paper worth studying**

$$F_{4pole}(t) = \frac{\tau_1^2}{(\tau_1-\tau_2)^3}\left(e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}}\sum_{k=0}^{2}\frac{\left(\frac{\tau_1-\tau_2}{\tau_1\tau_2}t\right)^k}{k!}\right) \quad (4.2)$$

$$\frac{1}{(1+j\omega\tau_1)(1+j\omega\tau_2)^3} \xrightarrow{\text{F.T.}} \frac{\tau_1^2}{(\tau_1-\tau_2)^3}\left[e^{-\frac{t}{\tau_1}} - \sum_{k=0}^{2}\left(\frac{\tau_1-\tau_2}{\tau_1\tau_2}\cdot t\right)^k \frac{e^{-\frac{t}{\tau_2}}}{k!}\right]$$

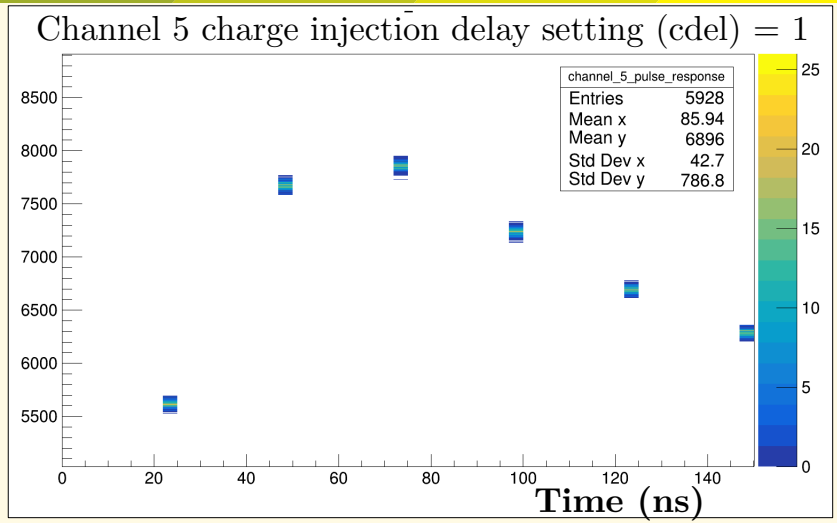
Parameterization of CMS silicon detectors pulse shape and Form Factors determination. A. Buffini, S. Busoni, M Meschini, G. Parrini

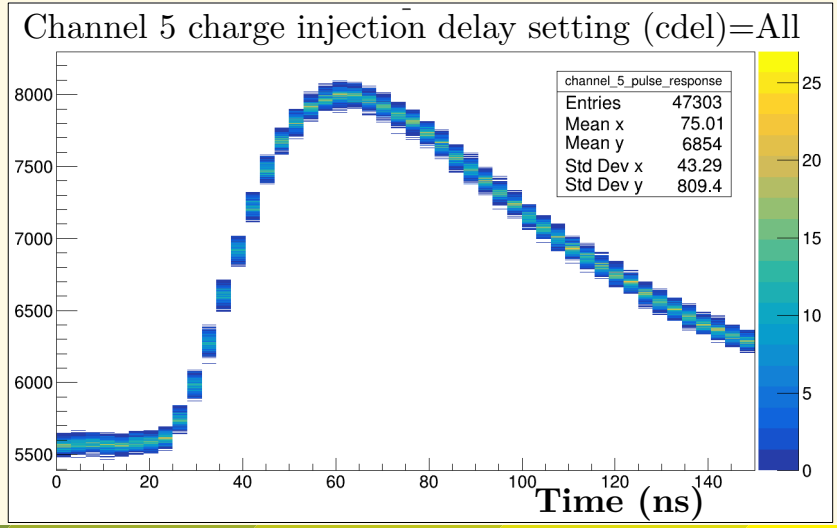
Paper shows 5 poles for a "4 pole function"...Correct values in red

$$\frac{1}{(1+j\omega\tau_1)(1+j\omega\tau_2)(1+j\omega\tau_3)^2} \xrightarrow{\text{F.T.}} A\cdot e^{-\frac{t}{\tau_1}} + B\cdot e^{-\frac{t}{\tau_2}} + (C+D\cdot t)\,e^{-\frac{t}{\tau_3}} \quad (13)$$

UCSC Calibration Cdel Scan

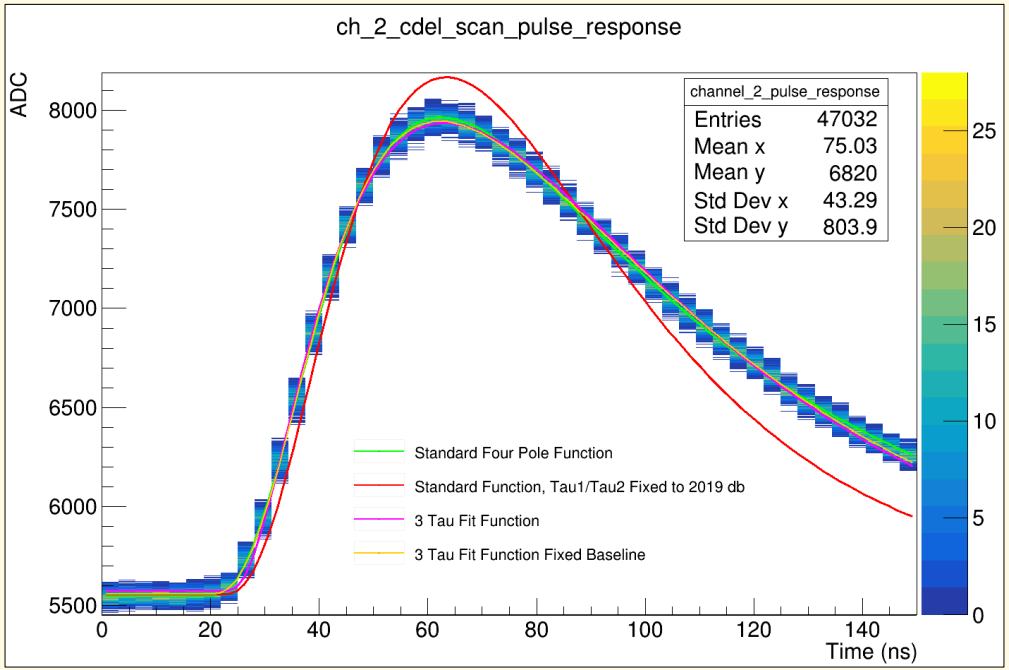
- Calibration pulse scans taken at UCSC on testboard for 2021 L0/Slim-sensor production
- APV25 internally injects charge into channels, reads out **6 time samples at 25ns intervals** (TOP)
- APV25 **"cdel" setting (1-8) changes the time delay on readout by 3.125ns*(8-cdel)** to provide more pulse time resolution (BOTTOM)
- **Fit data with pulse shape function** defined in hps-java to **get real pulse shape fit parameters**
- **This data only exists for 2021 slim sensors...**





Comparing Fit Functions/Params

- **Fitting pulse with Standard Fit Func using conditions database default values results in poor fit in general**
- **Fitting pulse with Standard Fit Func and allowing fit parameters to float results in good fit**
  - **Expect gains in reconstruction**
- Fitting using alternative "3 Tau" Fit Function results in similar fit quality
  - Ignore this function, **USE STANDARD FIT FUNCTION ONLY**
  - See backup for justification

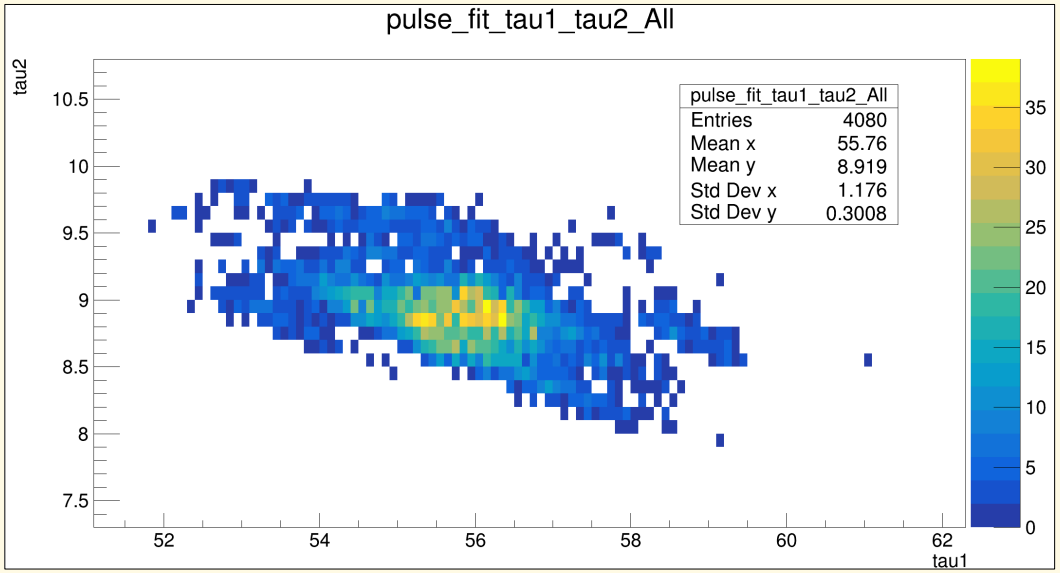


Fit channel pulse response using Four Pole Function

- **RED:** Using existing database params
- **GREEN:** Allow fit parameters to float
- **MAG**/**ORNG**: Alternative fit function, not used

APV Pulse Shape Fits

- Database default 2019/2021 values tau1=35.0, tau2=10.0
- **2021 slim sensor fit tau1 mean ~56 significantly different than database**
- **Current fit parameters in hps-java not representative of 2021 slim sensors, rawhit fit quality impacted**
  - Likely true for non-slim sensors
  - Likely true for 2019
- **Compare 2021 reconstruction using default fit parameters, and newly caluclated param values**



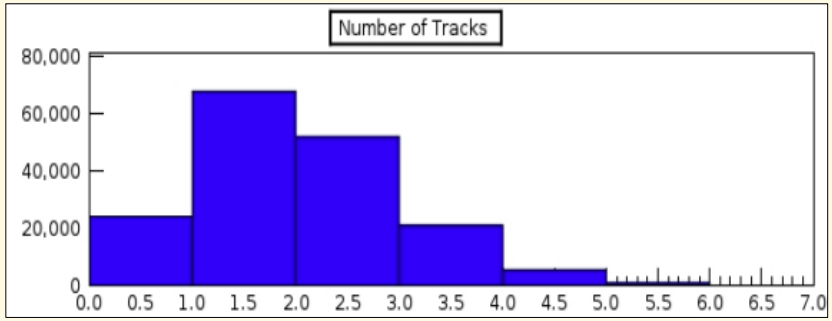
Standard Function fit results for floating tau1 and tau2 2021 Slim Sensors Only

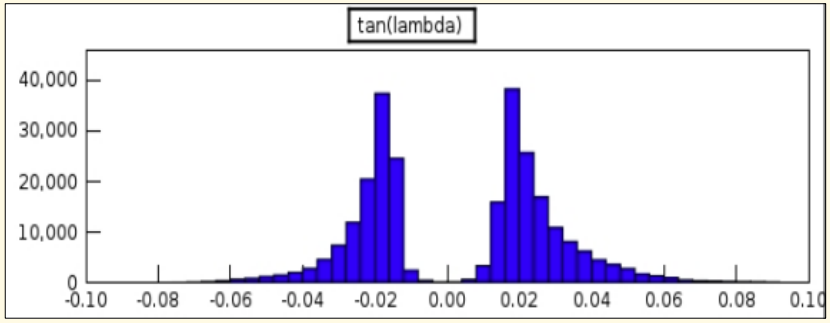
Track Reconstruction New Taus vs Database

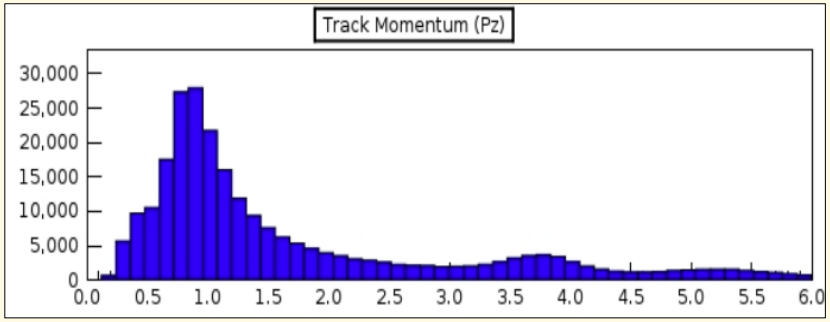
- Cameron ran standard reconstruction on 2021 Run 14191 using existing 2021 hps-java database APV channel pulse shape fit parameters
  - Default values (Tau1 = 35.0 and Tau2 = 10.0)
- Cam also ran standard reconstruction on same file, using Tau1=56.4 and Tau2 = 8.7 for all channel fit parameters
- Compare changes in hit/track reconstruction

Reconstruct more Tracks using New Tau Values

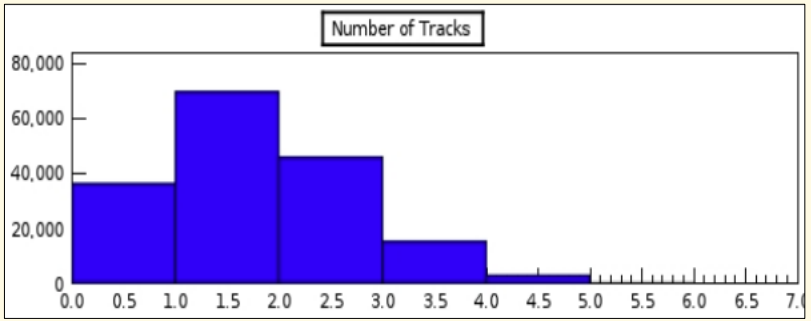
New Taus

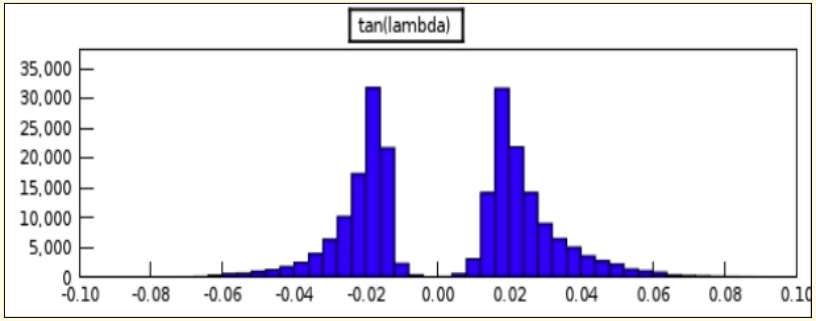


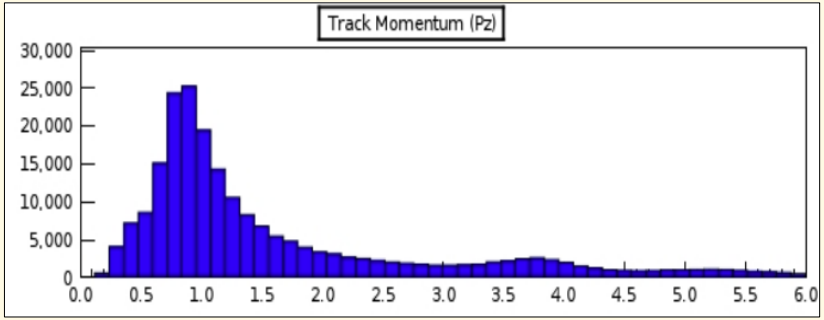




Database Taus

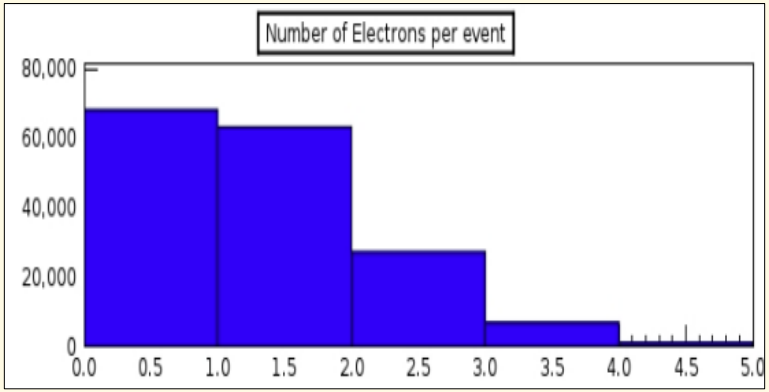


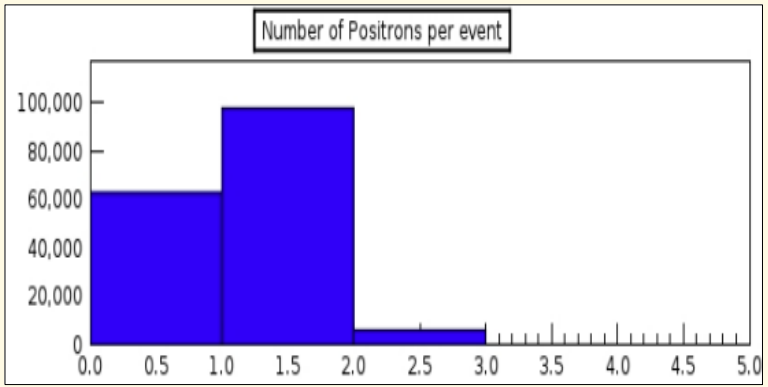




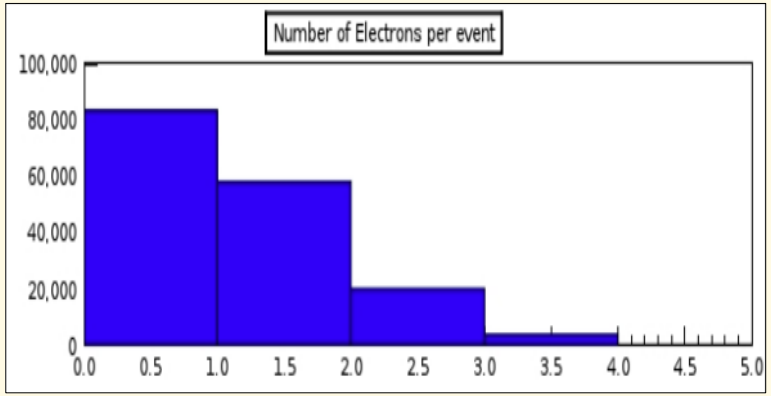
Reconstruct more electrons and positrons using New Taus

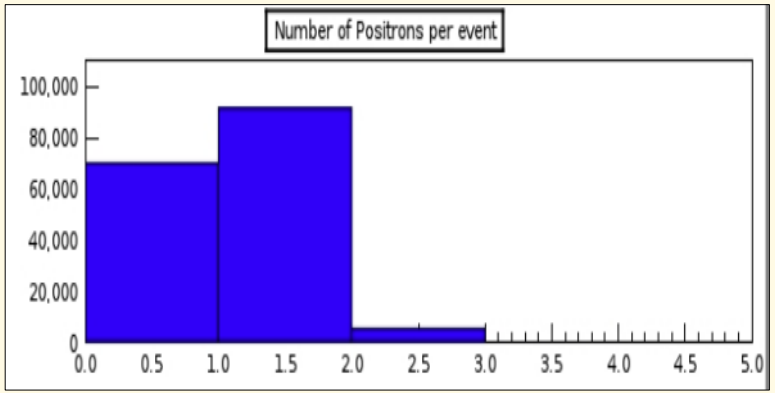
New Taus





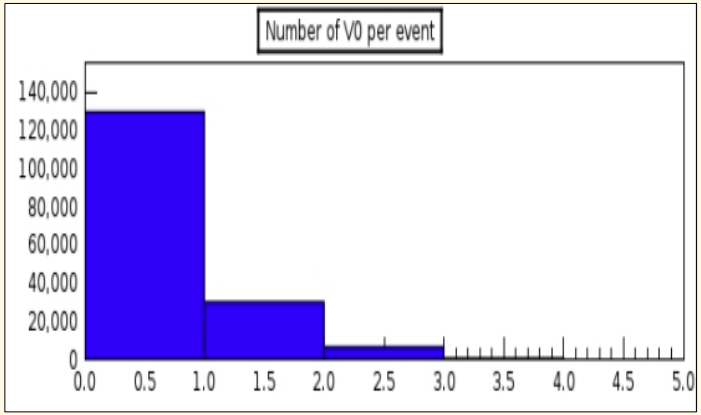
Database Taus

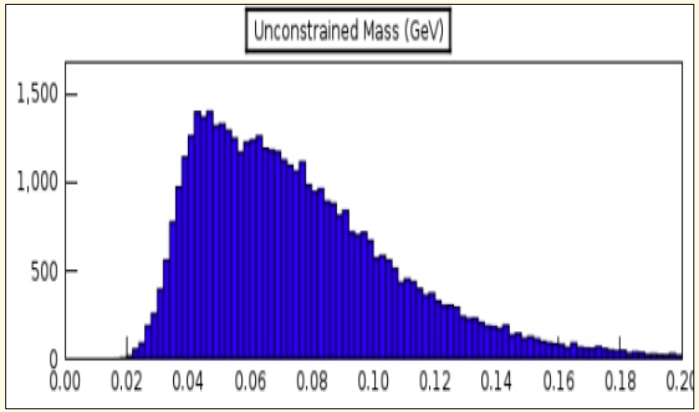




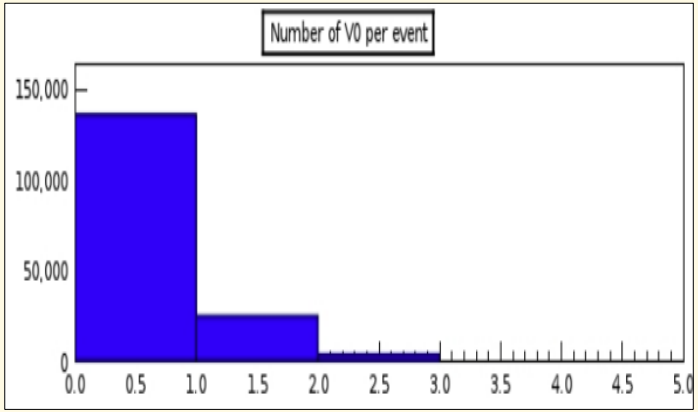
Reconstruct more Vertices using New Taus

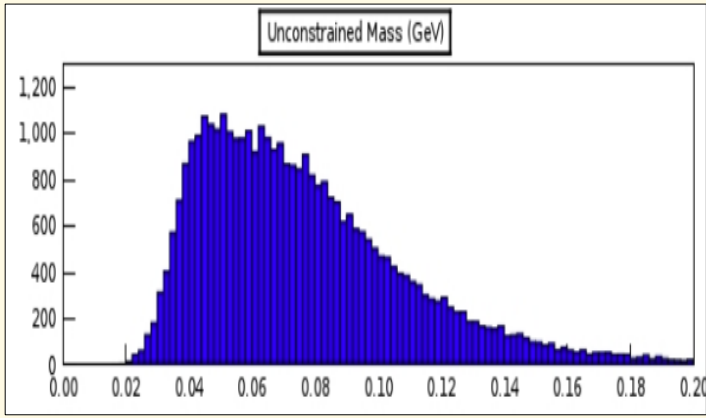
New Taus





Database Taus





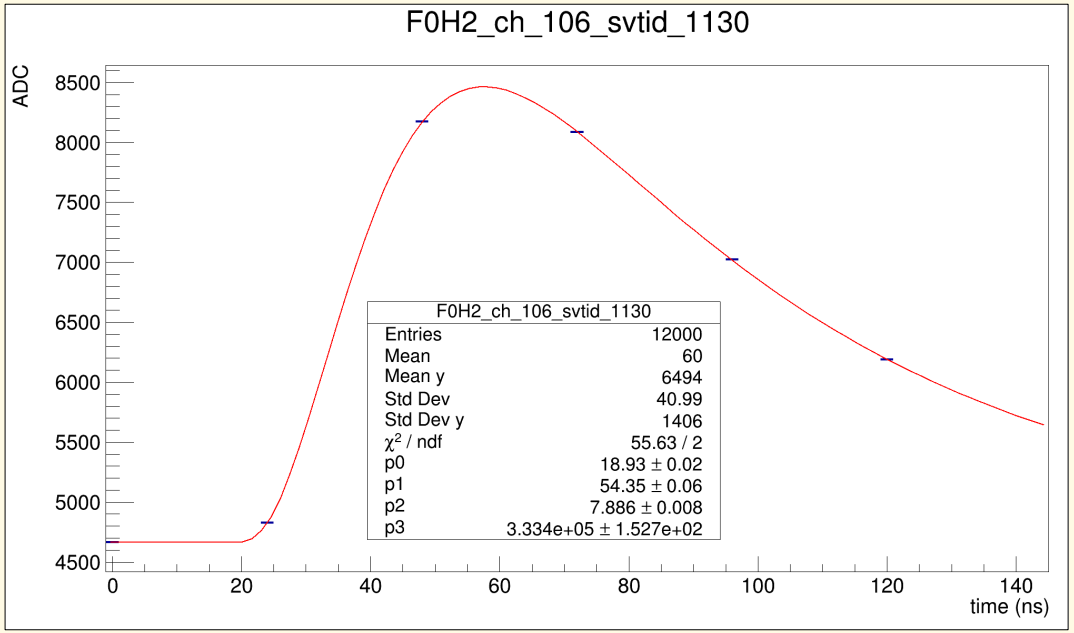
Track Reconstruction New Taus vs Database

- Improvement in Track reconstruction/more Tracks and Vertices using New Tau fit values compared to existing hps-java 2021 conditions database values
- While not investigated here, likely same gains in Tracking/Vertexing would be found for 2019 reconstruction (as conditions database holds same default values as 2021)
- **Need to update database with calibrated shape fit parameters for 2019 and 2021 as soon as possible!**
- Need calibration scan data for all 2019 and 2021 sensors

2021 JLAB SVT SHAPE FIT PARAMETERS

2021 Jlab Pulse Shape Fits

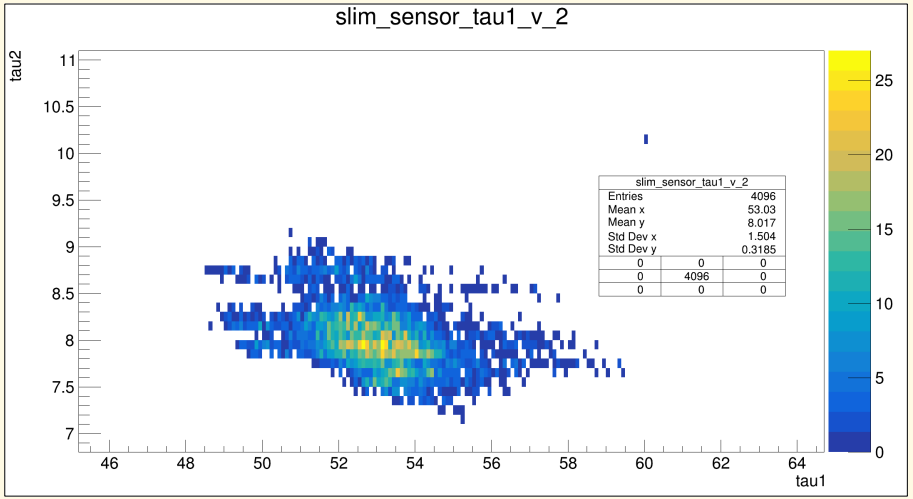
- Calibration pulse scan run taken at Jlab in 2021 (run 14393)
- However, scan script had error, so only 6 time samples available (instead of 48 with full scan)
- Made hpstr processor to read evio events, get all rawsvthits, and build Tprofile of hit amplitude vs time, for all channels
- Fit Tprofile with standard fit function to get shape parameter values amplitude, t0, tau1, tau2
  - Baseline parameter fixed and set equal to Mean of Bin(0)

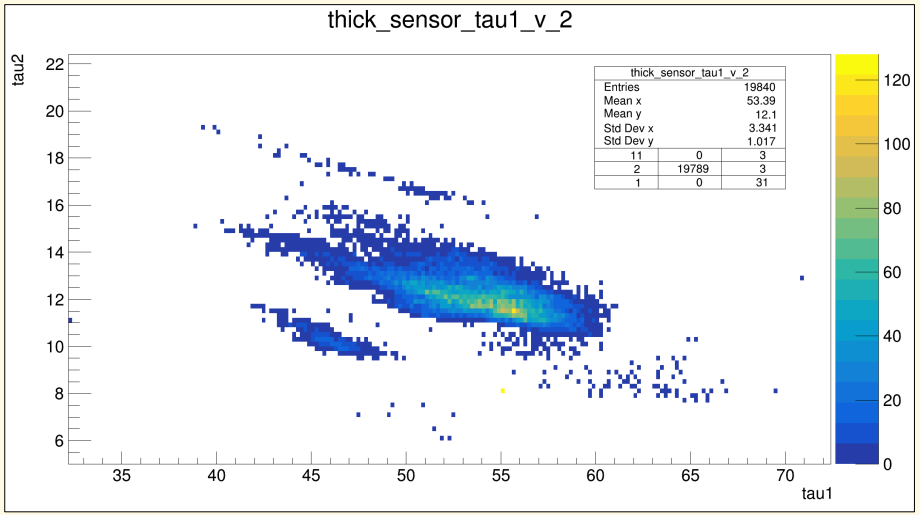


Tprofile of F0H2 channel 106 with 2000 Calibration Pulse events. Only 6 time bins available. Profile fit with standard shape fit function.

2021 Jlab Pulse Shape Fits

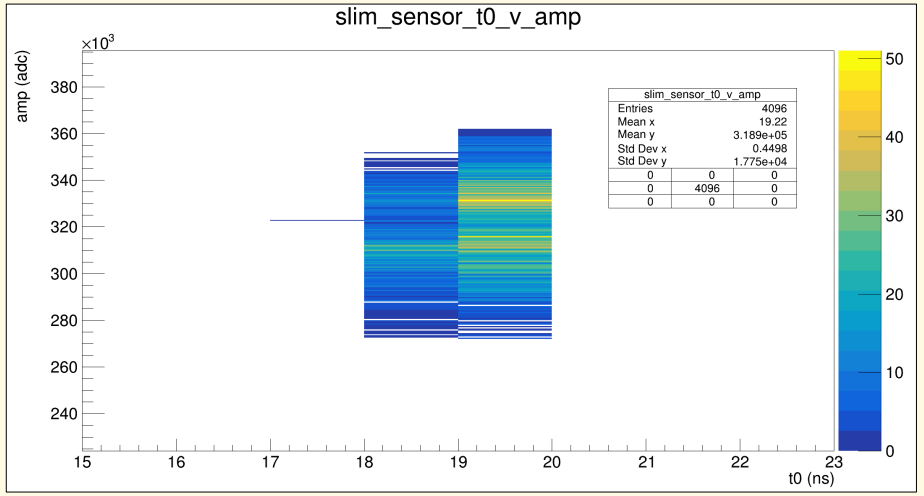
- Fit parameter results of Jlab calibration data
- **NO CUTS** yet on fit/pulse quality
- (TOP) slim sensor tau1 v tau2
  - Well grouped
  - Tau1 ~53
  - Tau2 ~8
- (BOTTOM) thick sensor tau1 v tau2
  - Multiple outlier channels
  - Large dispersion in taus
  - Distinct tau1/tau2 groups
- Check if outliers are bad calibration pulses or bad fits
- Check t0 and amplitude fits results

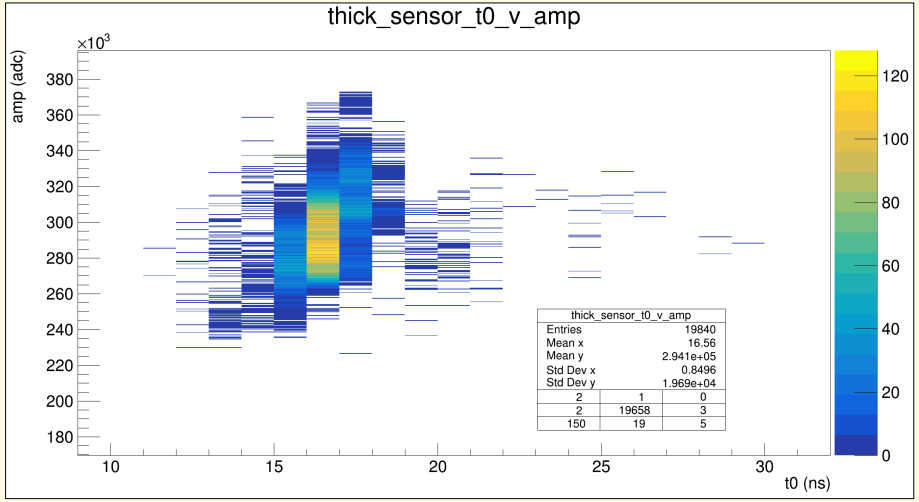




2021 Jlab Pulse Shape Fits

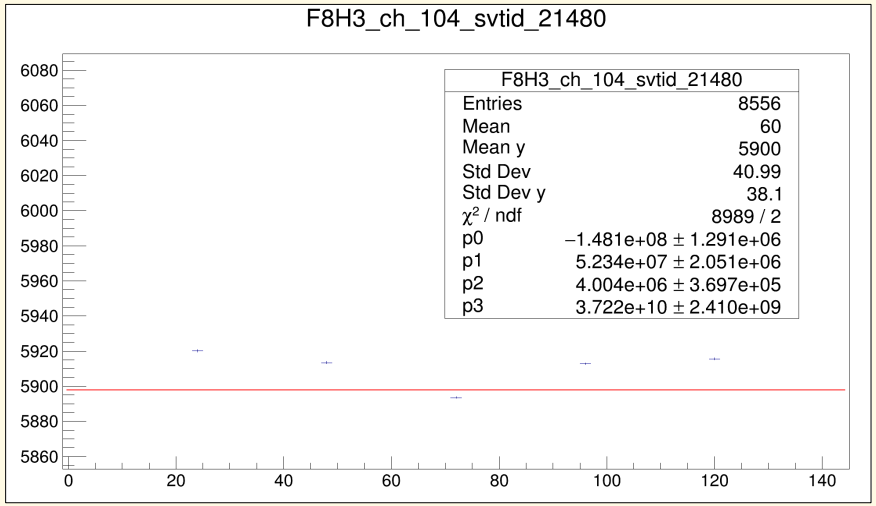
- Fit parameter results of Jlab Cdel = 1 calibration scan data
- NO CUTS on fit/pulse quality
- (TOP) slim sensor t0 v amp
- (BOTTOM) thick sensor t0 v amp
  - Many outier in t0 and amplitude

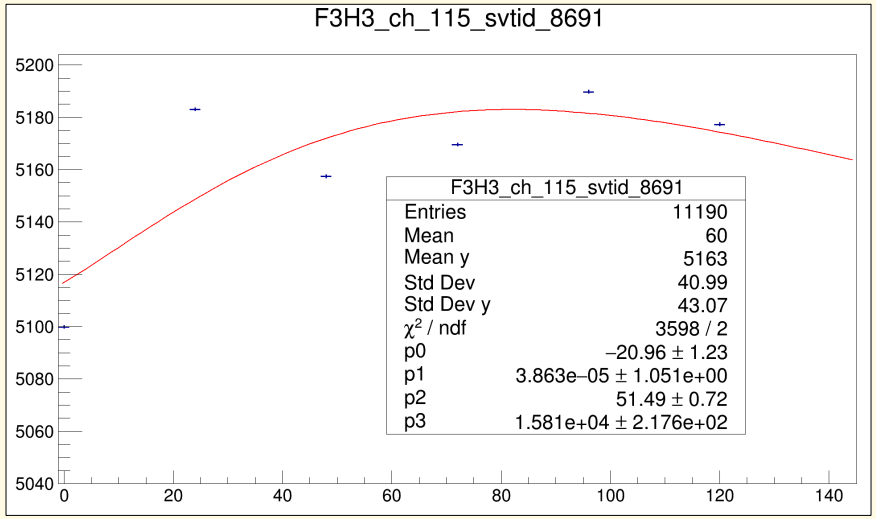




2021 Jlab Pulse Shape Fits

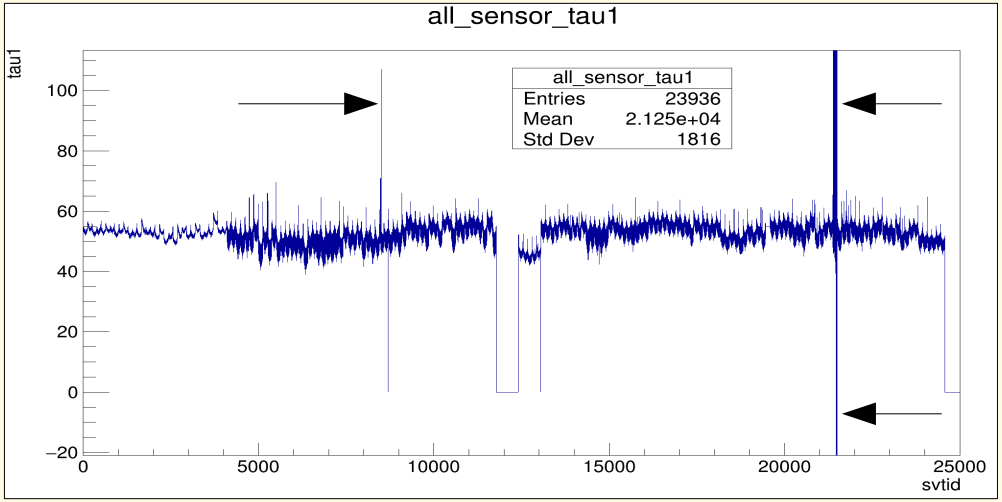
- Plots show examples of failed calibration pulse on channel
- Pulse should peak near time sample 3
- Bad pulses *largely* identified by checking if time_sample3 < (time_sample2 AND time_sample4)
- For channels with bad calibration pulse, use nearest neighbor shape fit parameters instead

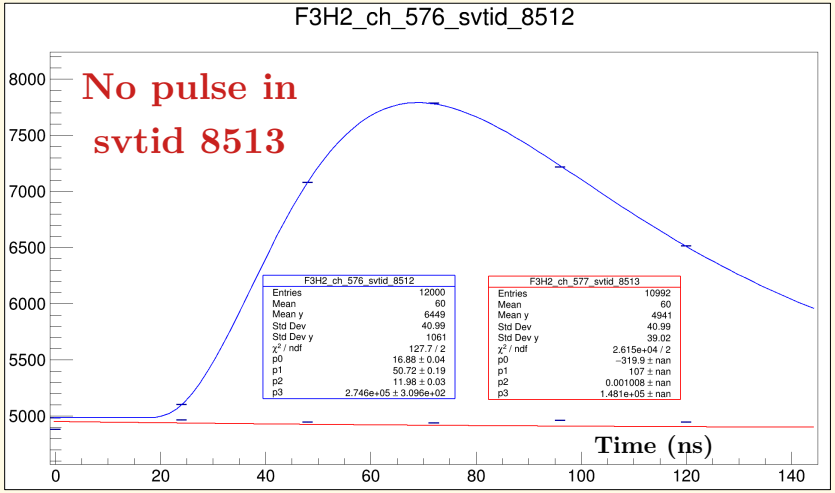


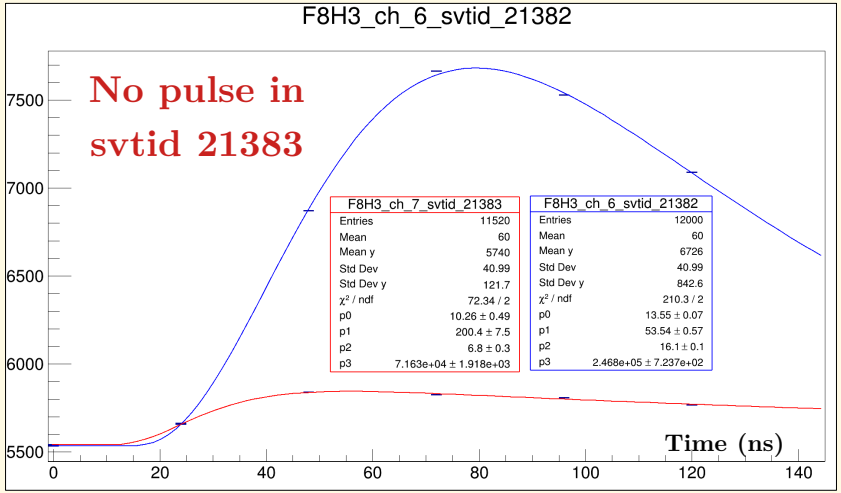


Tau1 Spikes

- (TOP) Plot of svtid vs fit tau1
- **tau1 = 0 represent "dead" channels**
- Large tau1 spikes (> 100) likely indicate poor fit
  - (Bottom) shows **calibration pulse missing/bad**
- **Cut fits with tau1 > 100**
- Use nearest neighbor channel shape fit parameters for database

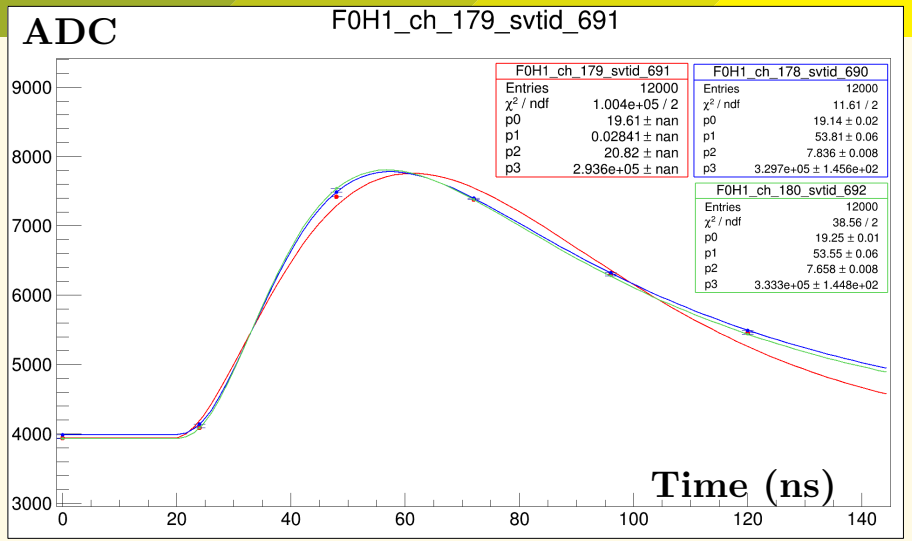


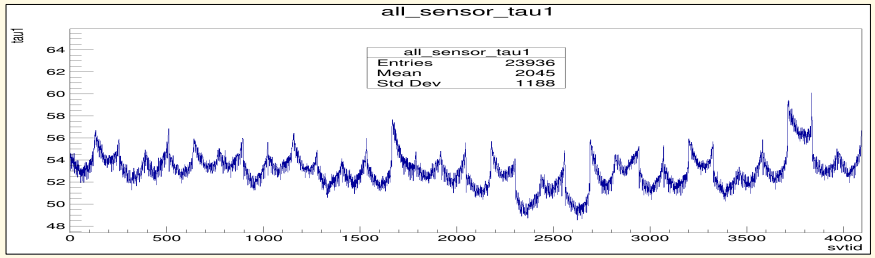


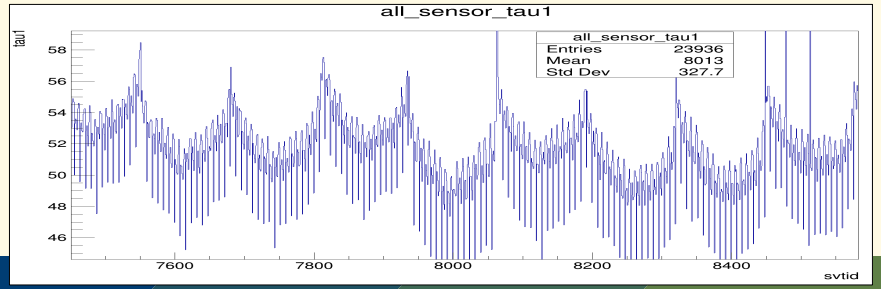


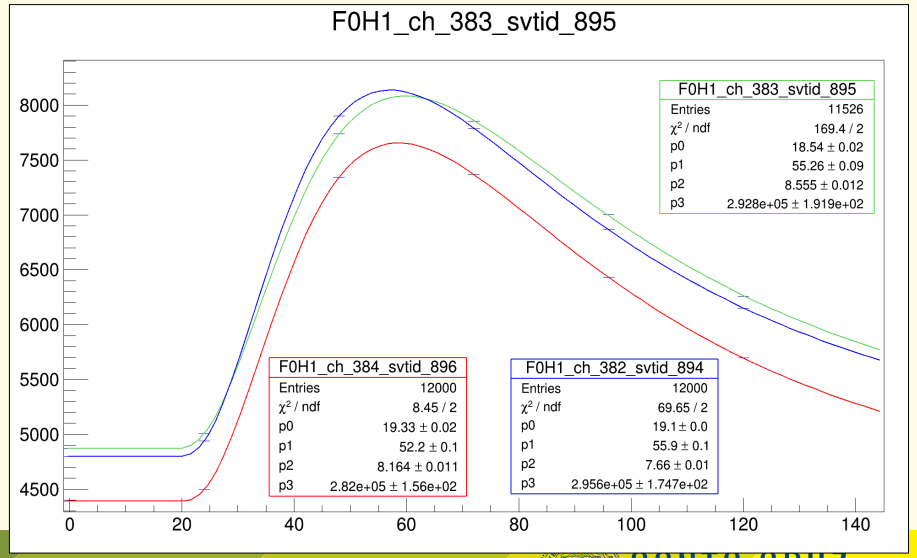
Low Tau1 Values

- (TOP RIGHT) Plot shows 3 neighboring channels,
  - svtid_691 has bad fit with tau1~1 , and “nan” errors on fit params
  - **Cut channels where errors are “nan”, use nearest neighbor fit params**
- (BOTTOM RIGHT) Plot shows 3 neighboring channels with good fits
  - Tau1 values vary between 52.2 – 55.26
  - (BOTTOM LEFT) shows oscillation in tau1
    - Fits look okay



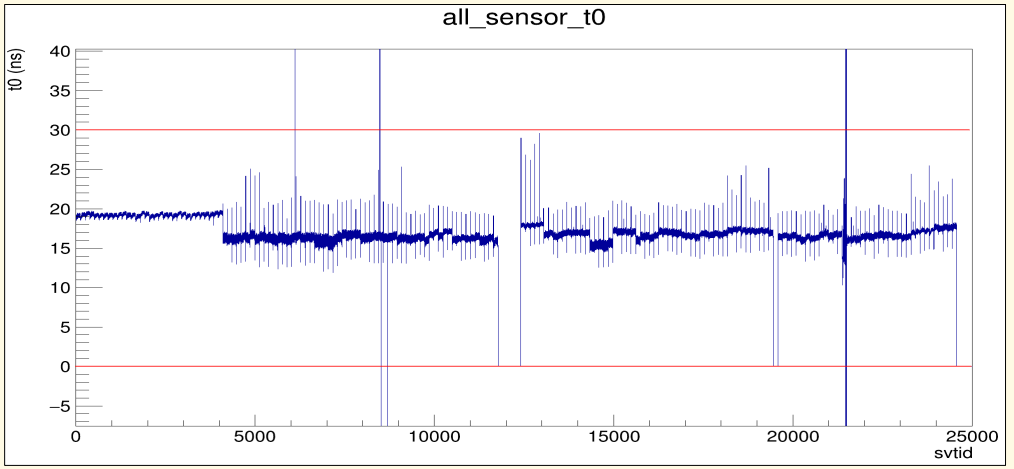


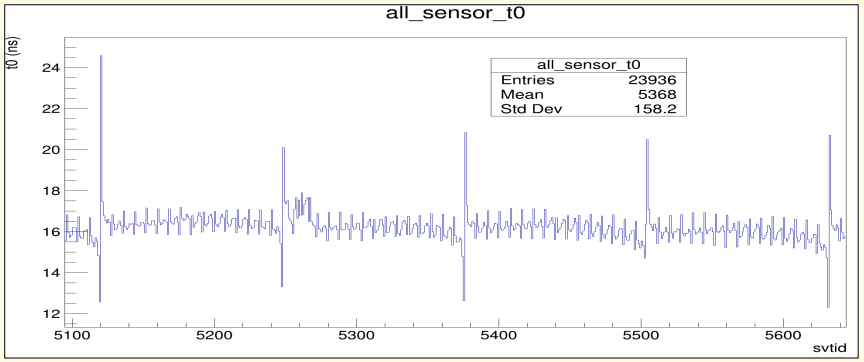


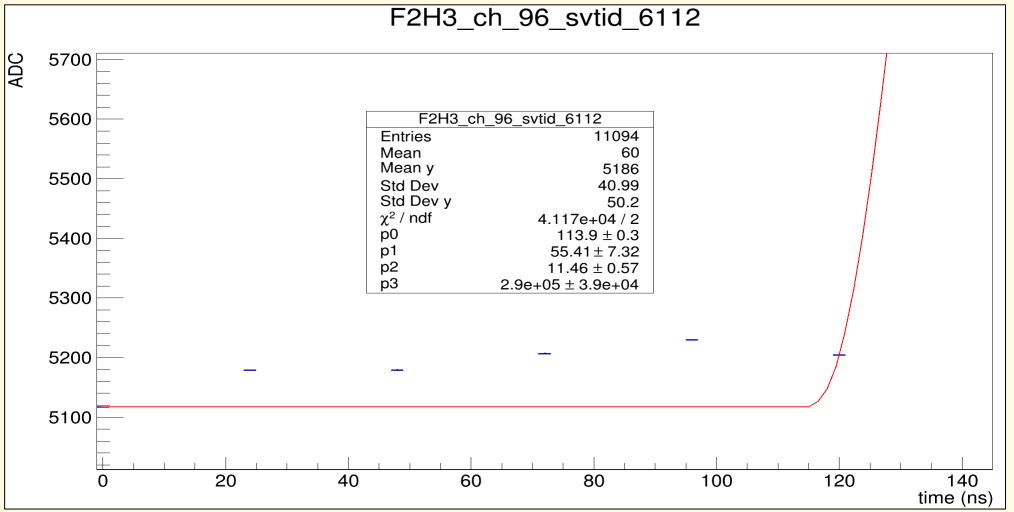


t0 Fit Parameter

- Plot shows svtid vs t0 fit param
- Slim sensors (svtid < 4096) have different average t0 than thick sensors
- (BOTTOM RIGHT) Large t0 spikes correlate to bad pulses...cut these channels
- (BOTTOM LEFT) Interesting t0 pattern as function of channel...
- **Cut t0 > 30**
- **Cut t0 <= 0**







2021 Jlab Pulse Shape Fits **POST CUTS**

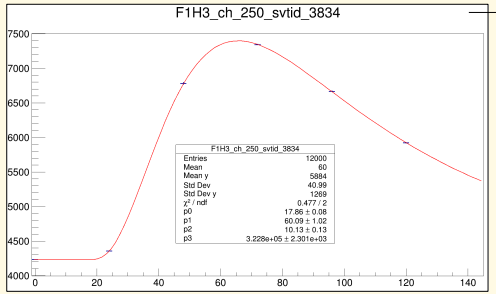
Checking svt shape fit parameters after cutting the following channels:

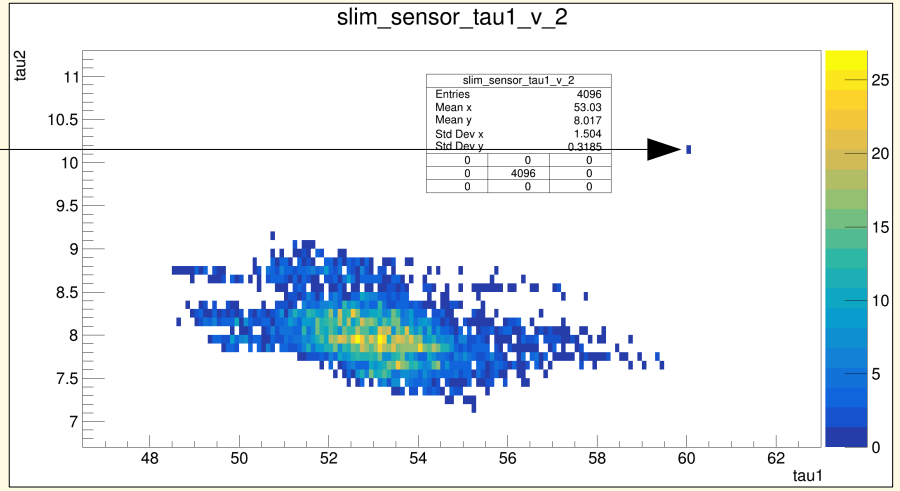
- No/bad calibration pulse
  - Fit errors are “nan”
    - tau1 > 100
- t0 > 30 ns and t0 $<= 0$ ns

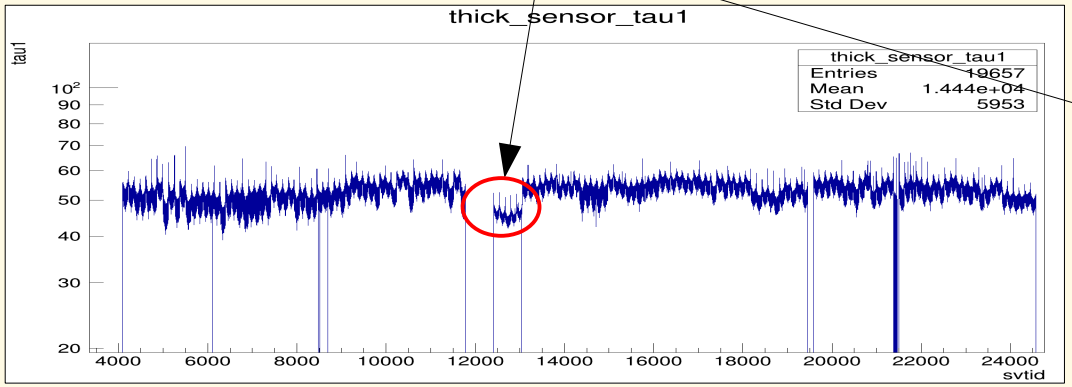
Channels that fail these cuts are assigned fit parameters of their nearest neighboring channel that is not cut

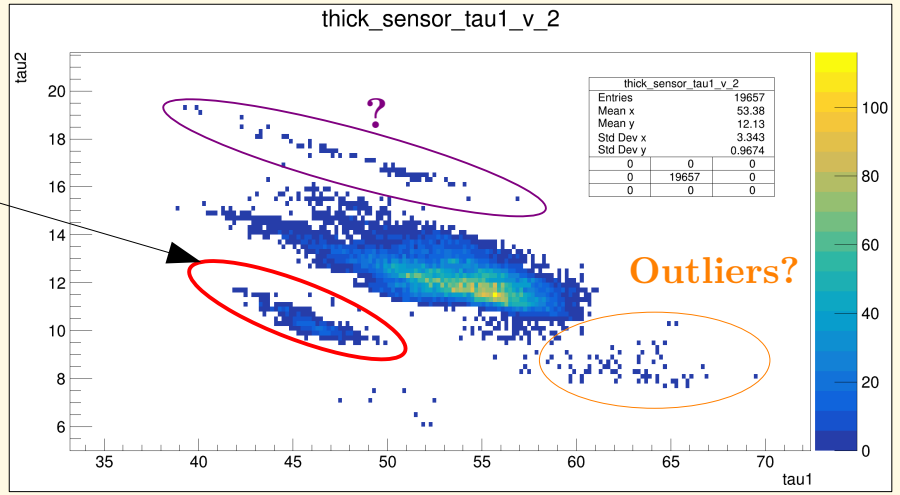
2021 Jlab Pulse Shape Fits

- (TOP) Slim sensor tau1 v tau2 shows good grouping with no severe outlier channels
- (BOTTOM) Thick sensor tau1 v tau2 shows no remaining severe outlier values
  - Bottom left group represents one hybrid



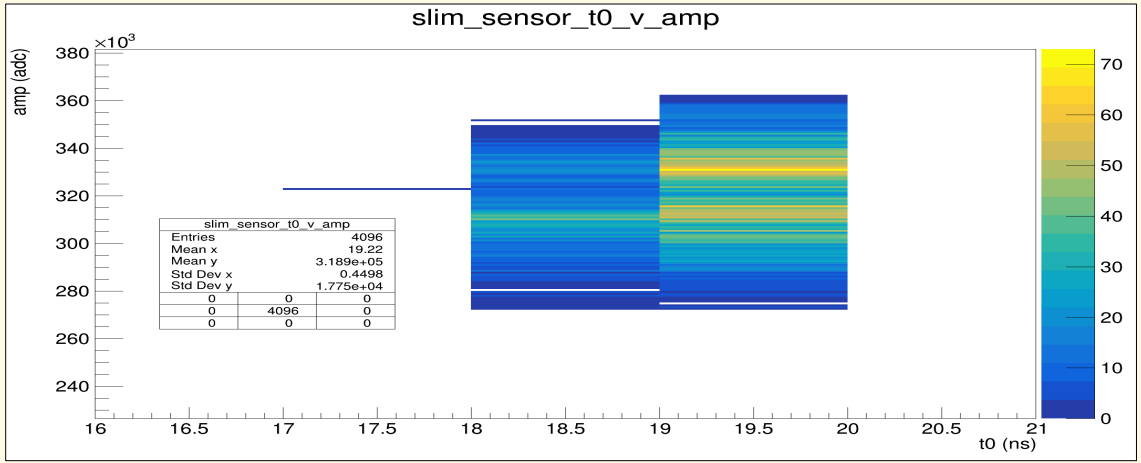


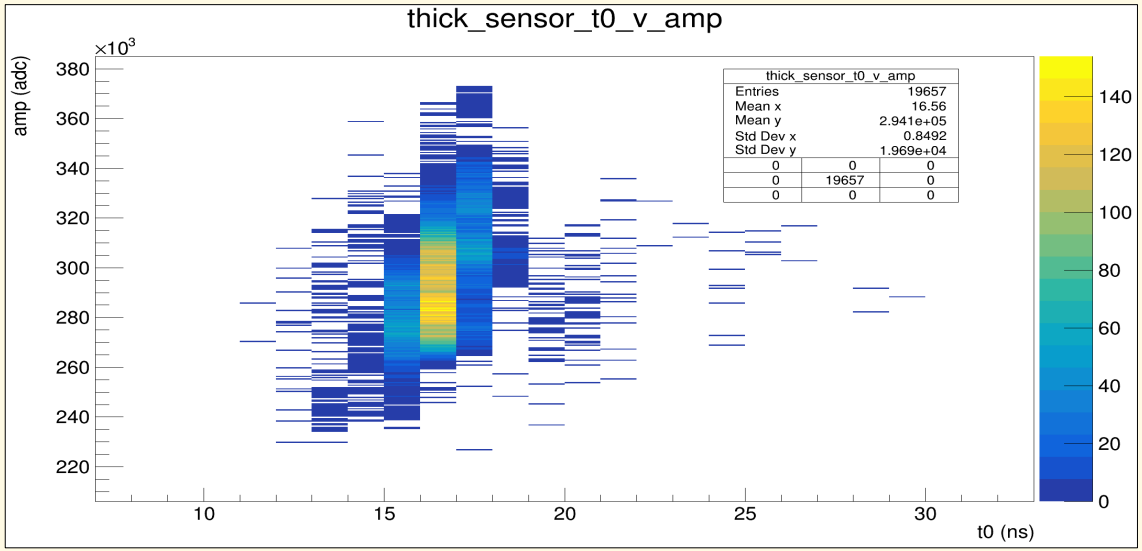




2021 Jlab Pulse Shape Fits

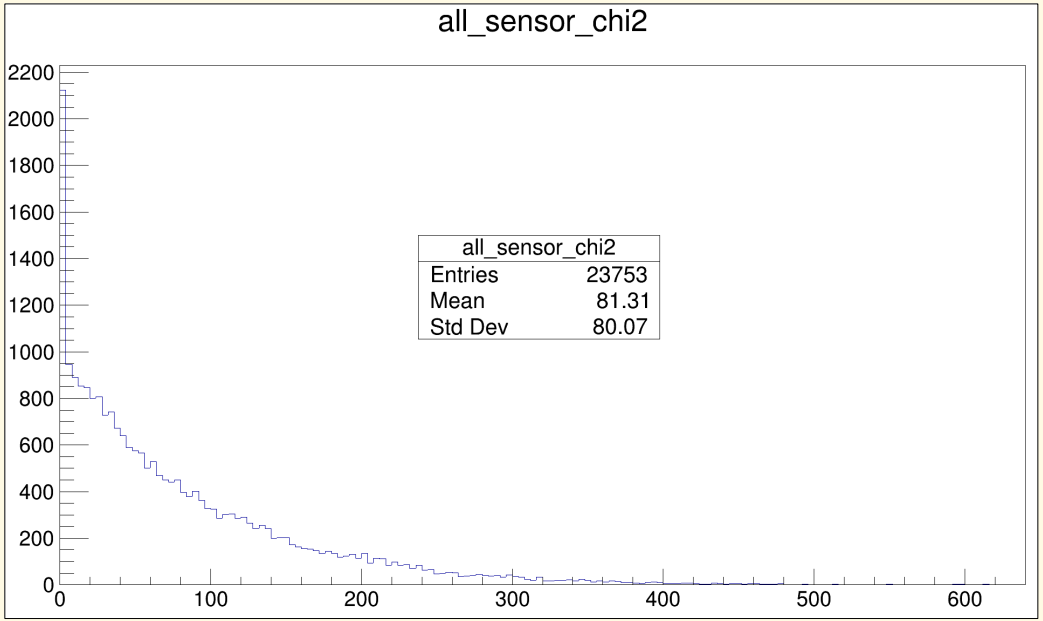
- (TOP) Slim sensor t0 width looks good
  - Two peaks in amplitude
- (BOTTOM) Thick sensor t0 improved…no severe outlier channels
  - Some scattered channels with larger t0 than expected…





2021 Jlab Pulse Shape Fits

- Calibration pulse shape fit parameters for 99% (23753/(24575-640)) of connected channels calculated
- Remaining channels (including disconnected) assigned fit parameter values of nearest "good" neighbor
- Fit parameters exported to local copy of conditions database for testing
- **Will compare DQM plots** using default database params (tau1 = 35.0, tau2 = 10.0, t0 = -10.0, amplitude = 2500), and new fit values



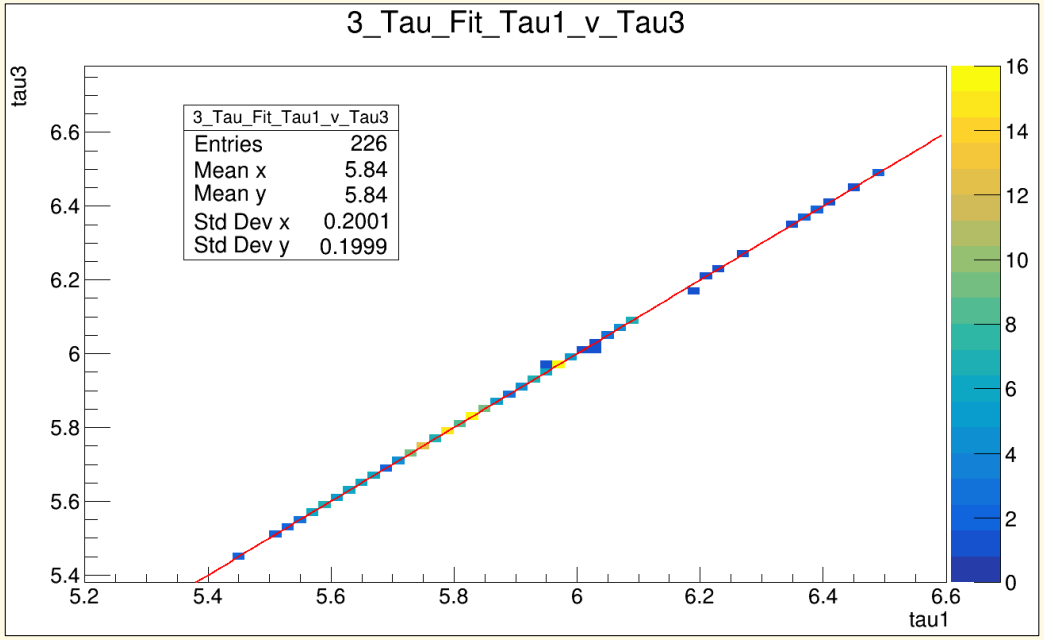
Summary

- Have calibrated svt pulse shape fit parameter values for 2021 SVT
  - Updated in local copy of database for now
  - Will compare tracking using new vals
  - Are we okay with using nearest neighbors for channels w/o calib pulse?
- Should decide if full calibration scan upon return to Jlab is necessary
- Similar 2019 run exists, but in different format, will require modified eivo processor
  - Will work on getting fit params soon
- Validate 2016 values as sanity check?

Backup

Current vs 3 Tau

- **Fit parmeter seeds for 3 Tau Shape are unreliable**
  - Some channels fail fits using same seeds
  - Sometimes fixing baseline gives a better fit...sometimes letting it vary gives better fit
- **When 3 Tau fit is good** (determined by checking errors on tau3 fit parameter), **tau1 and tau3 are ~equal**
- Looking at fit function definitions, **if tau1 = tau3, "3 Tau Fit Function" becomes equivalent to Current Fit Function**
- If 3 Tau Function only performs good fit when tau1 = tau3, it's no different from Current Fit Function, except more difficult to seed fit parameters
- **Conlusion: stick with Current Fit Function**



Current Fit Function

$$\frac{1}{(1+j\omega\tau_1)(1+j\omega\tau_2)^4} \xrightarrow{\text{F.T.}} \frac{\tau_1^3}{(\tau_1-\tau_2)^4}\left[e^{-\frac{t}{\tau_1}} - \sum_{k=0}^{3}\left(\frac{\tau_1-\tau_2}{\tau_1\tau_2}\cdot t\right)^k \frac{e^{-\frac{t}{\tau_2}}}{k!}\right]$$

3 Tau Fit Function

$$\frac{1}{(1+j\omega\tau_1)(1+j\omega\tau_2)(1+j\omega\tau_3)^2} \xrightarrow{\text{F.T.}} A\cdot e^{-\frac{t}{\tau_1}} + B\cdot e^{-\frac{t}{\tau_2}} + (C+D\cdot t)\,e^{-\frac{t}{\tau_3}}$$