IMPROVING ENERGY RESOLUTION FOR THE STAR FORWARD CALORIMETER SYSTEM

David Kapukchyan

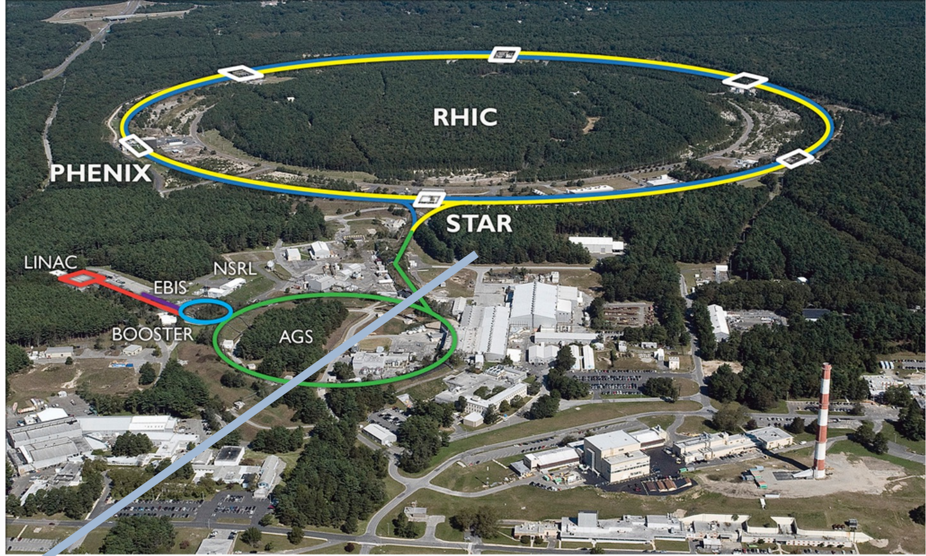
for the STAR Collaboration

Fall Meeting of APS Division of Nuclear Physics

October 2022, New Orleans, LA

Supported in part by: U.S. DEPARTMENT OF ENERGY

STAR FORWARD UPGRADE

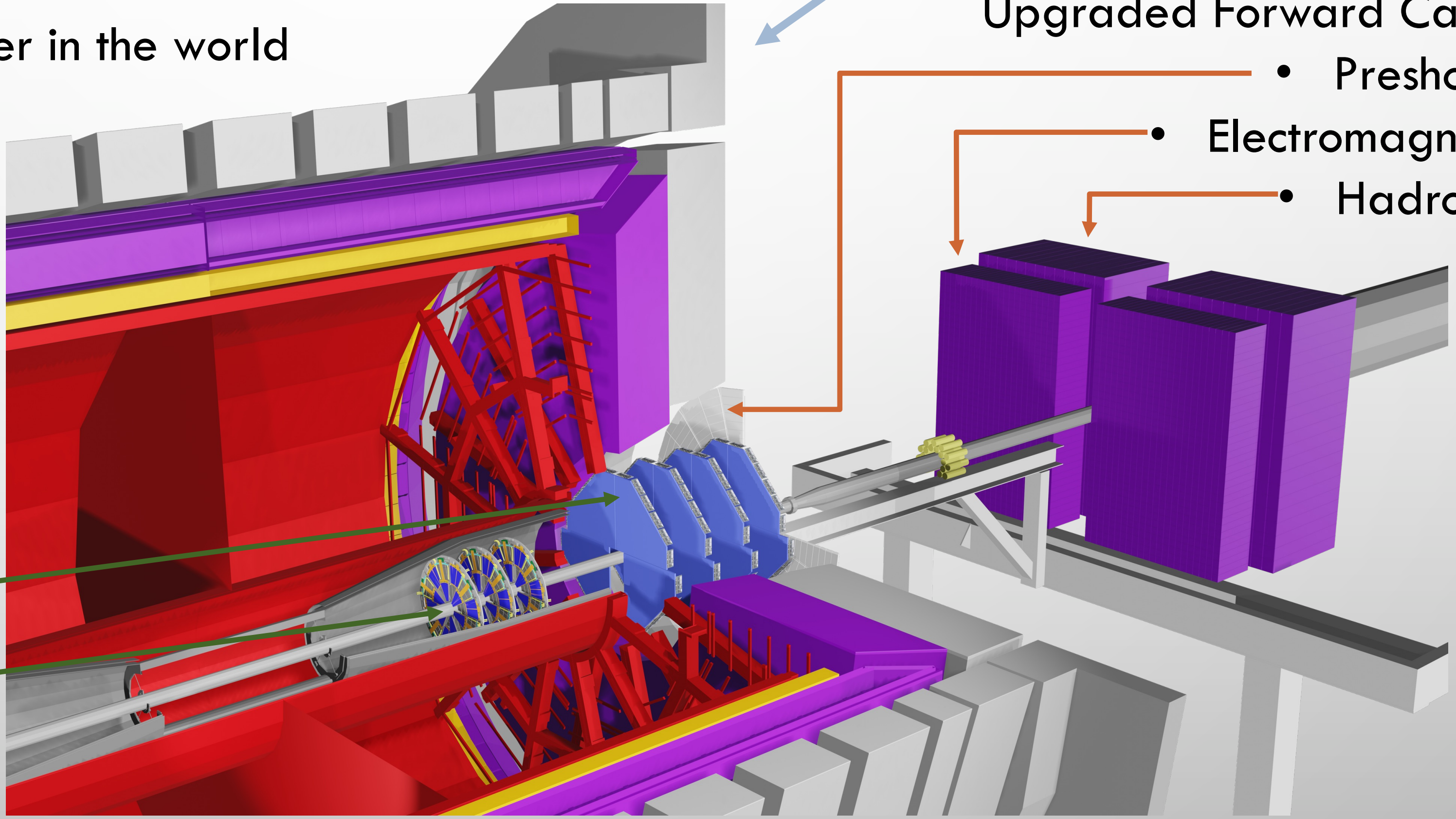


- STAR detector is located at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab on Long Island NY
- RHIC is the only polarized pp collider in the world

- Upgrades STAR capabilities in $2.5<\eta<4$
- Almost full 2π coverage in azimuth
- Tracking and Calorimetry will provide excellent PID

Upgraded Forward Calorimeters

- Preshower (EPD)
- Electromagnetic (ECal)
- Hadronic (HCal)

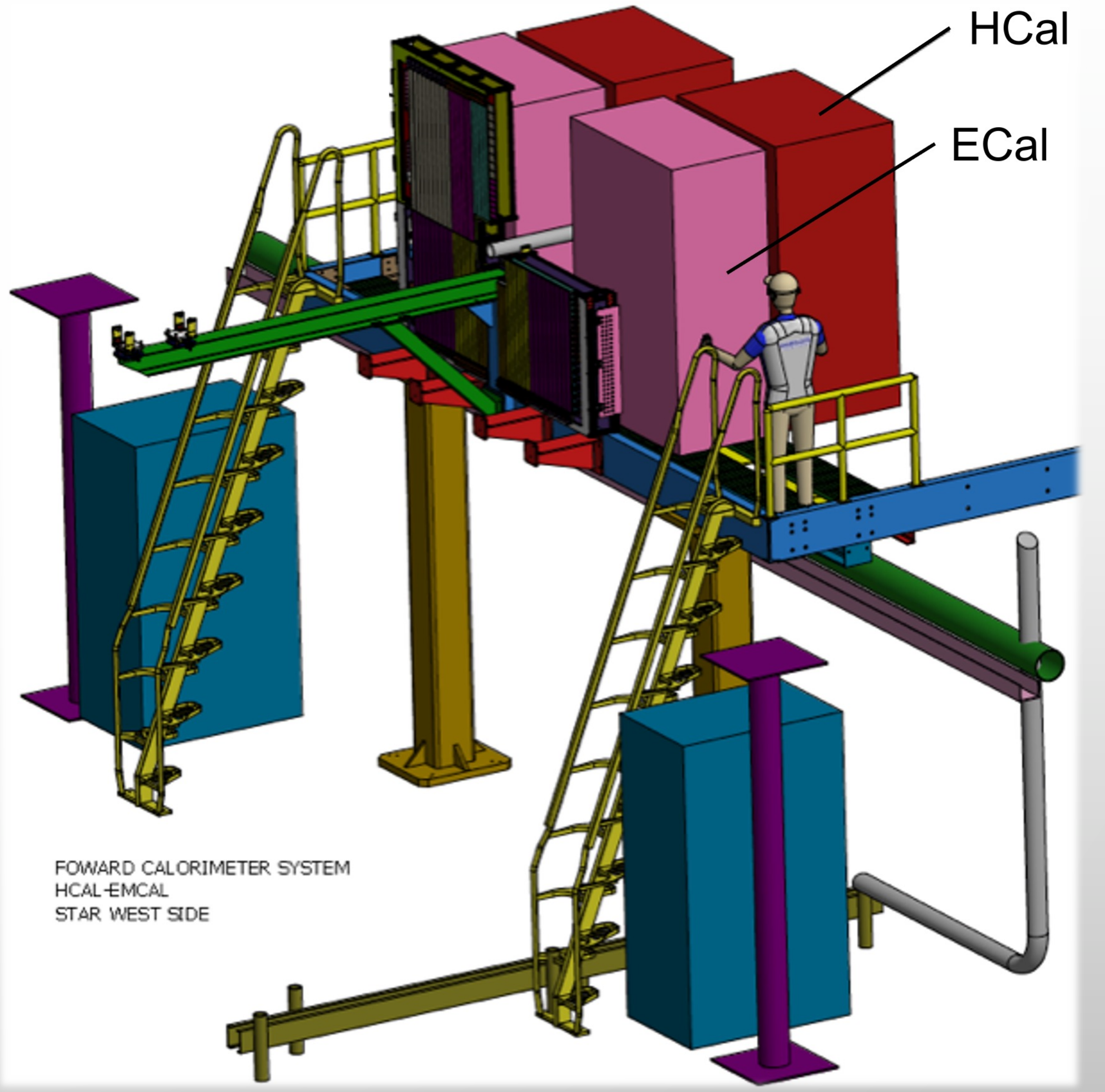


Tracking

- small strip Thin Gap Chambers
- Silicon Disks

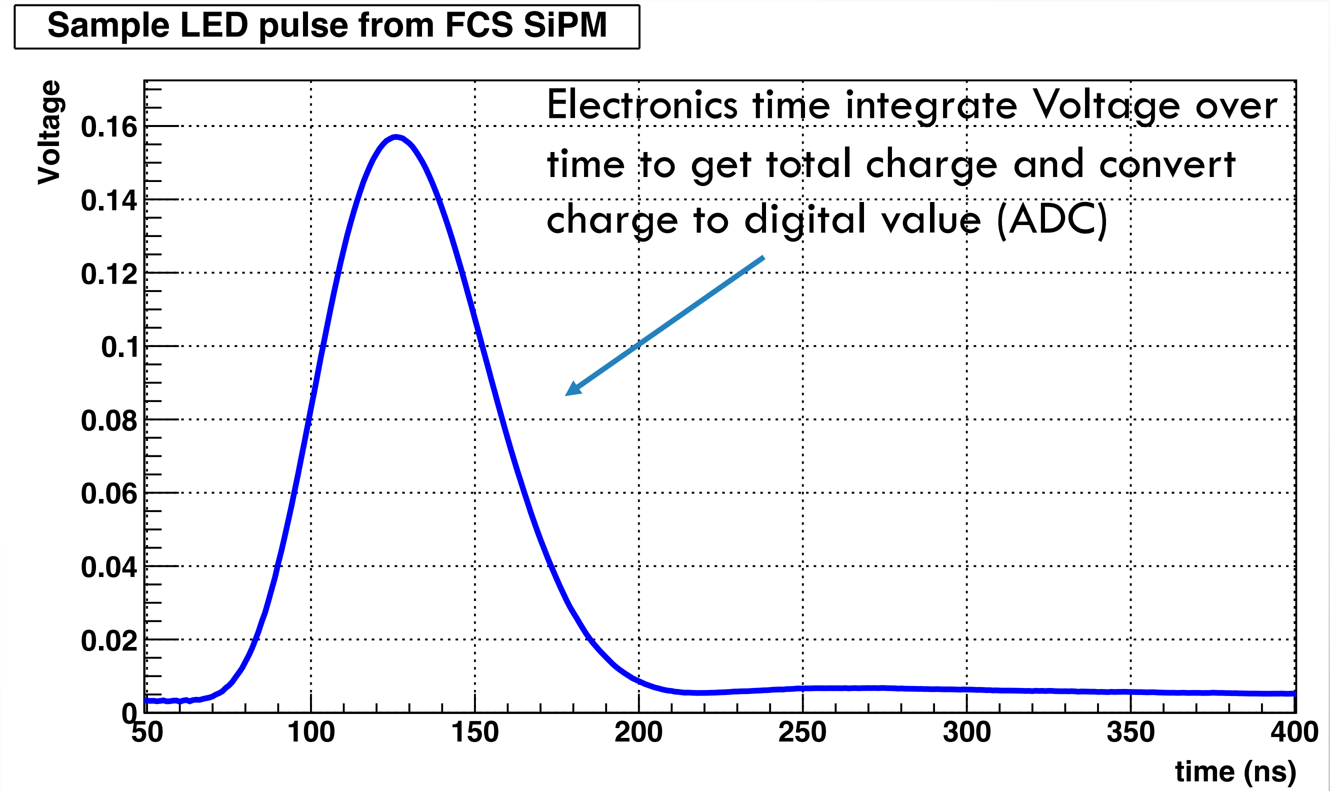
FORWARD CALORIMETER SYSTEM (FCS)

- Located ~ 7m from STAR IP on STAR west platform
- Both Ecal and Hcal split into two halves (North/South)
- Use SiPMs for readout
- ECal is Pb/Sc sandwich (from PHENIX)
  - $\sim 10\%/\sqrt{E}$
  - 5x5 cm^2 lateral size, ~18 X_0
- HCal is Steel/Sc sandwich built from scratch
  - $\sim 60\%/\sqrt{E}$
  - 10x10 cm^2 lateral size, ~4.5 λ
- Preshower is existing EPD detector (not shown)



GETTING THE ENERGY

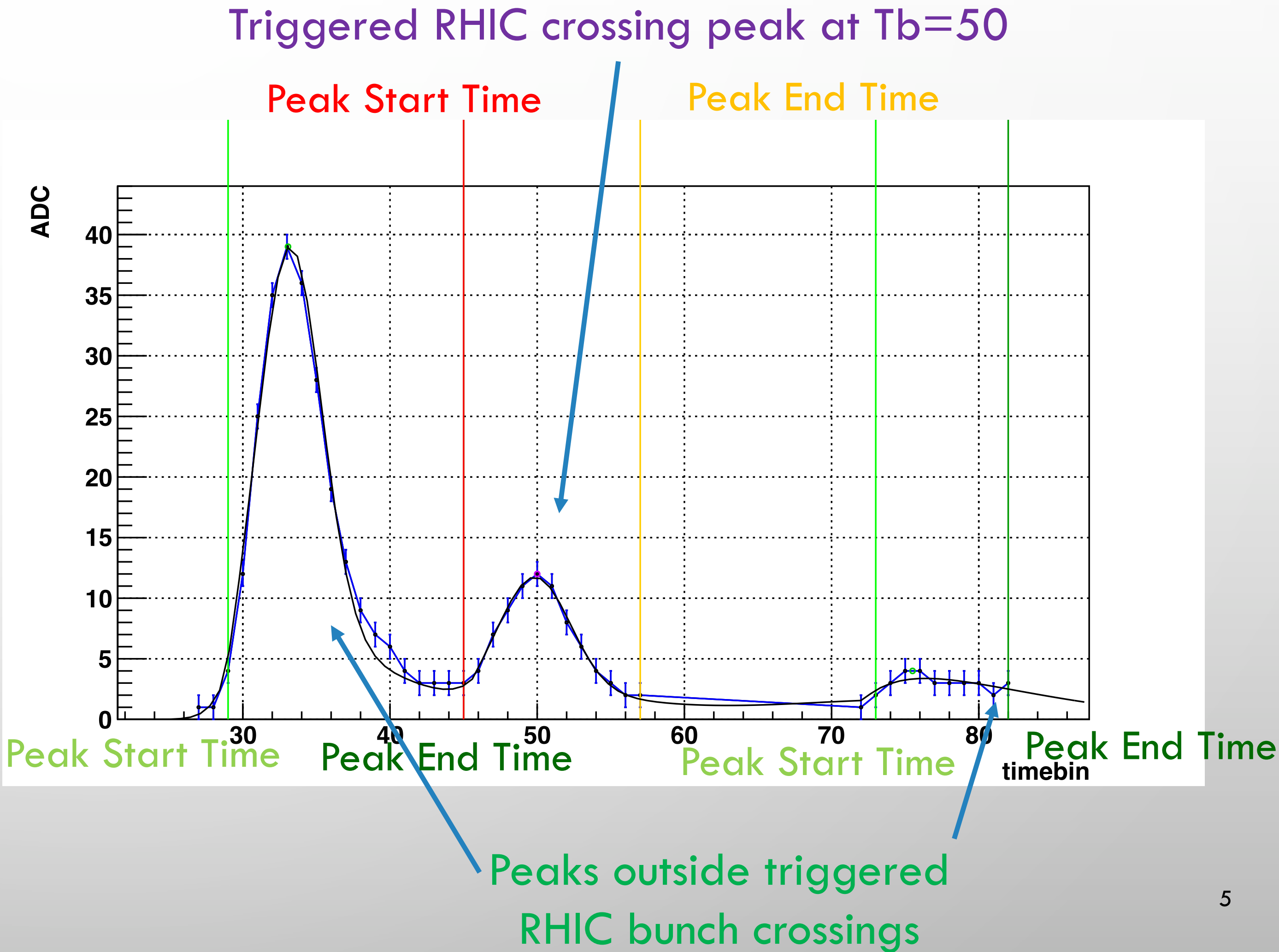
- Signals from a detector are digitized by time integrating the voltage (ADC) of the signal over the whole time of a trigger window
- STAR trigger windows are defined by the time between RHIC bunches (bunch crossing)
- The energy deposited in the detector (E)=ADC*Gain
  - Gain needs to be calibrated
  - See Xilin Liang's talk next



DIGITIZATION OF SIGNAL

- DEP boards digitize signal every ~13.5 ns
- This comprises 1 timebin (Tb)
- There are 8 Tb in 1 RHIC bunch crossing
- There is up to 100 Tb of data for every channel in every event
- Energy = (Fitted signal integral)*Gain
  - Each signal/peak is fitted to a Gaussian
  - Fitted signal to all peaks shown in black
  - Amplitude of Gaussian is proportional to integral
- Peaks found using discrete second derivative test

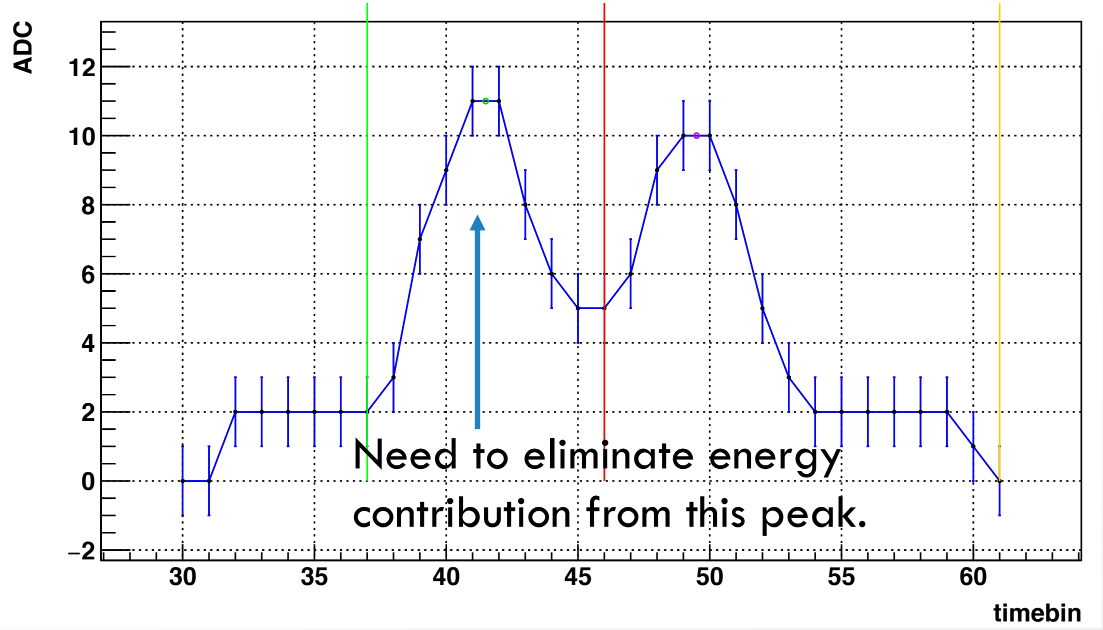
Sample Signal from DEP showing multiple RHIC bunch crossings



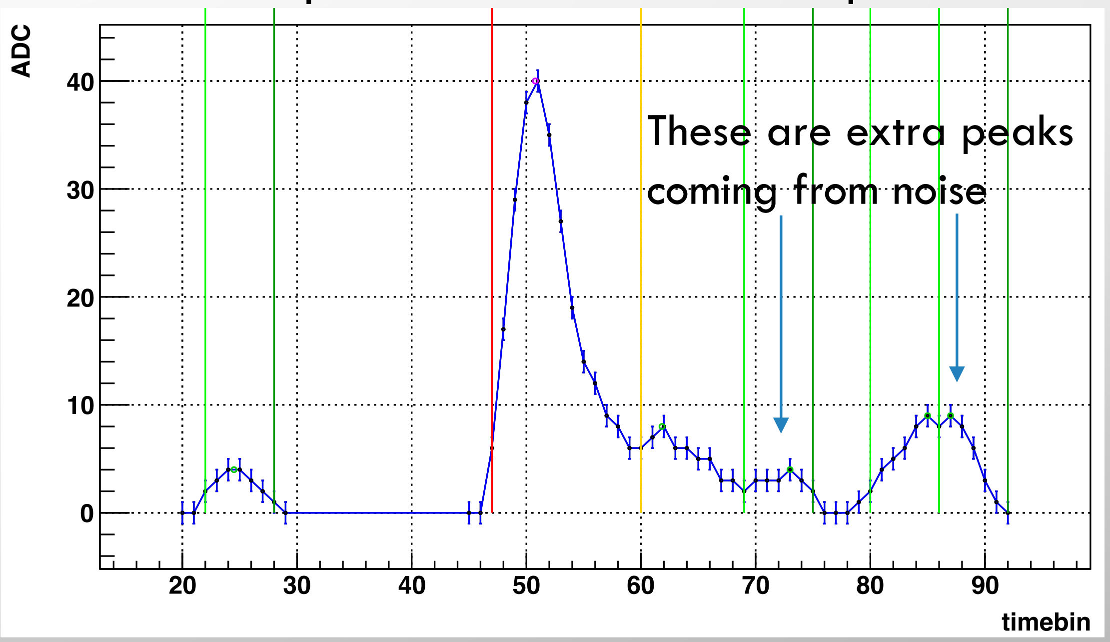
CHALLENGES

1. Fitting is time consuming and want to avoid fitting in cases where it is not needed
   - If only 1 peak in the triggered crossing adding up the ADCs is sufficient
2. Overlapping signals from untriggered RHIC crossing
   - Want to eliminate energy contribution coming from surrounding peaks
   - Fitting will help but need accurate count of peaks
3. Second derivative method can identify noise as peaks
   - Don't want to fit a signal to noise
   - More peaks → more fitting parameters → computation time

Example of Overlapping signals

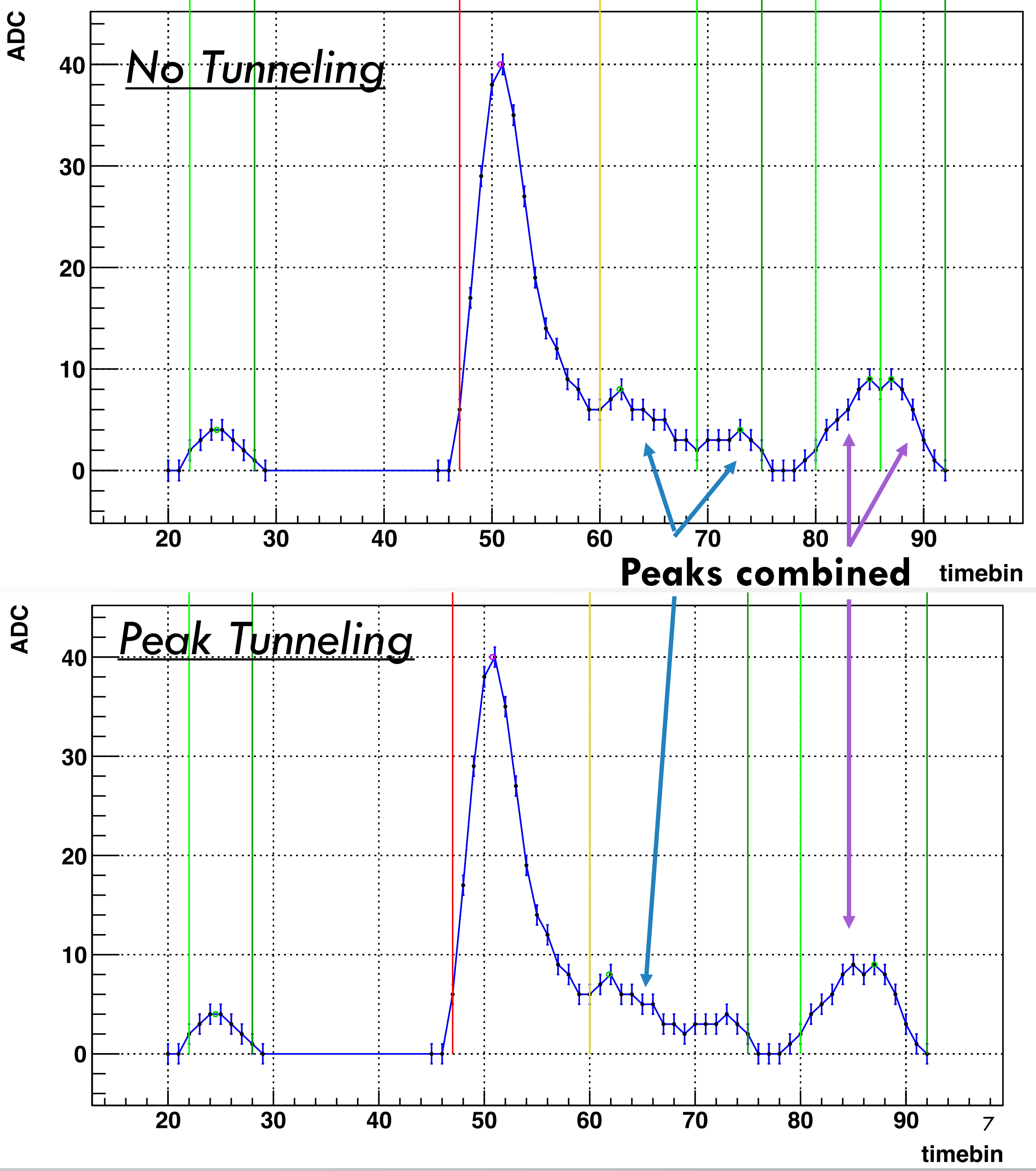


Example of noise identified as peaks



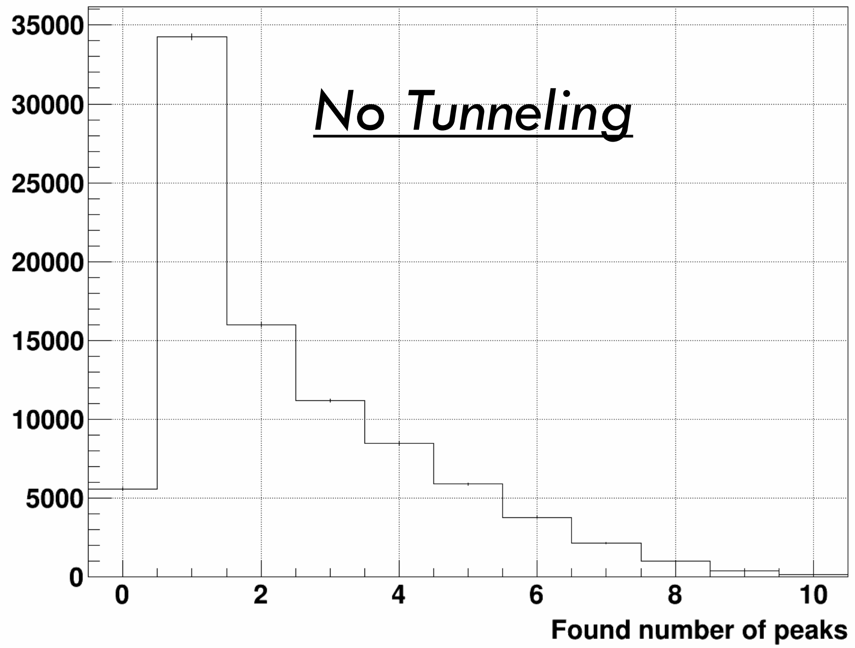
ELIMINATING PEAKS COMING FROM NOISE

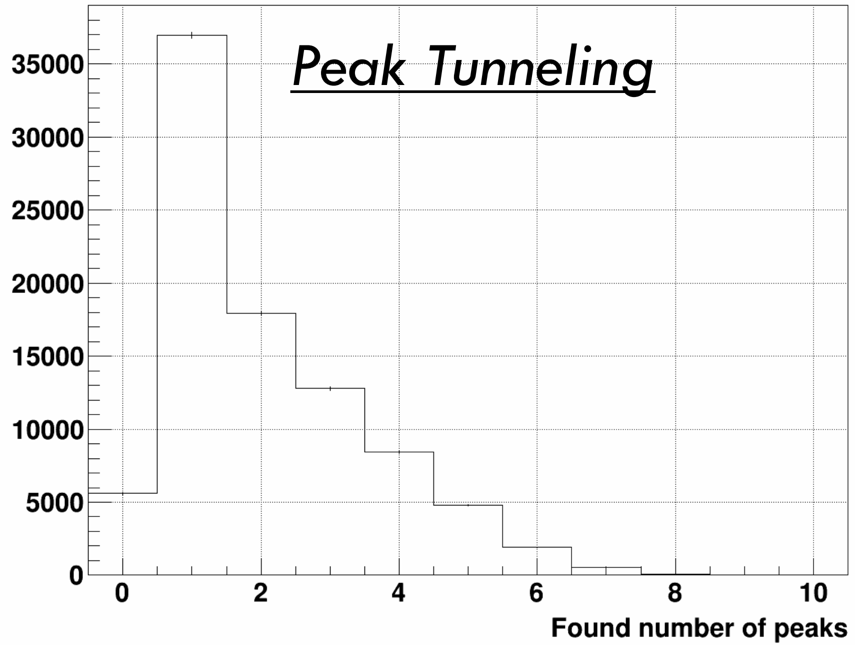
- Compute a probability a peak is a real peak or noise
  - Call this method peak tunnelling as it was inspired by quantum tunneling
- Assumes noise follows a Normal distribution
  - Parameters need to be tuned to data set
- Merge peaks that have low probabilities together
  - Higher probability peak is identified as peak position when merging



PERFORMANCE: NUMBER OF PEAKS

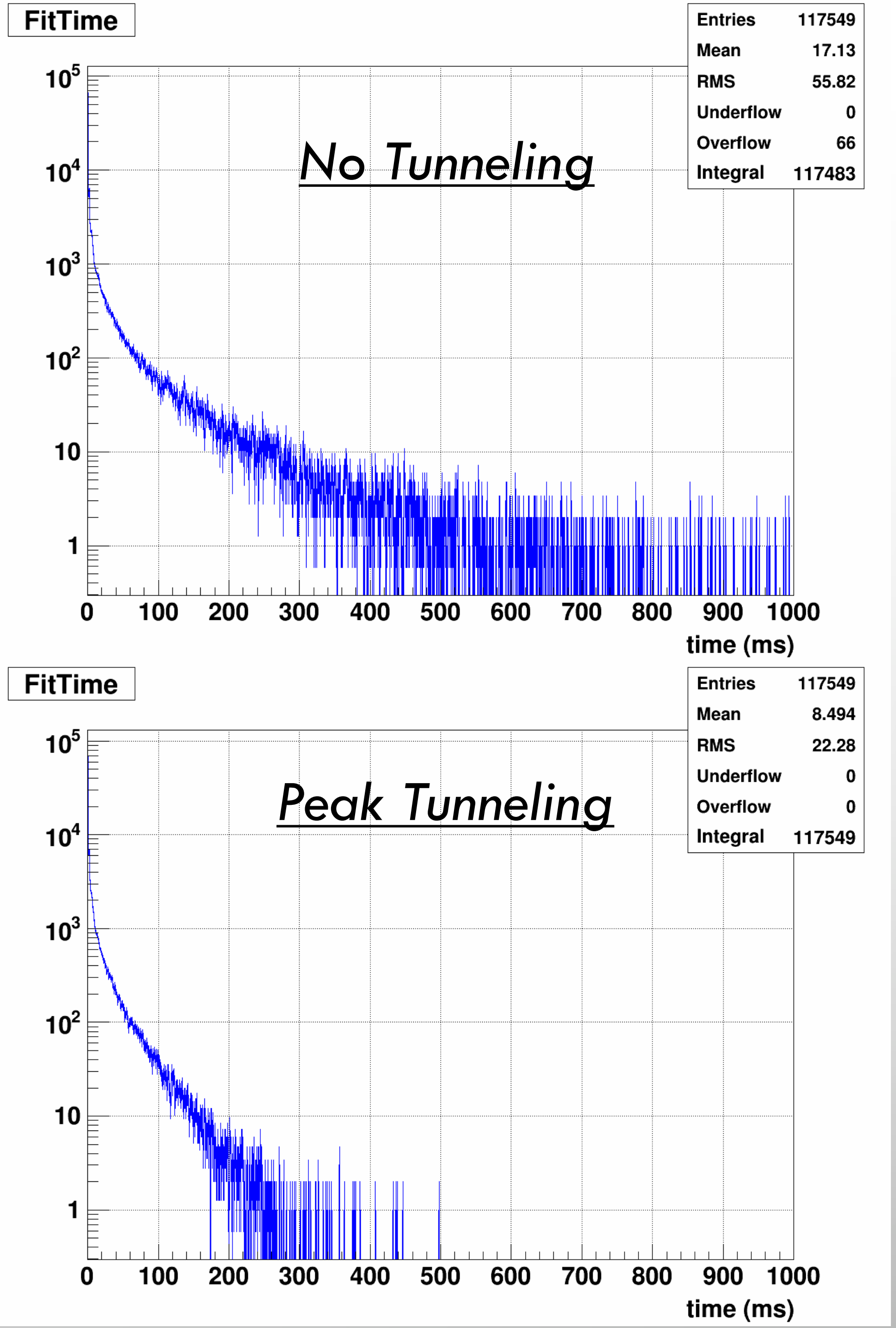
- Ran 100 events on RHIC run 22 pp data
- Plots show number of peaks with and without peak tunneling method
- Peak tunneling shows much lower number of peaks on average





PERFORMANCE: TIMING

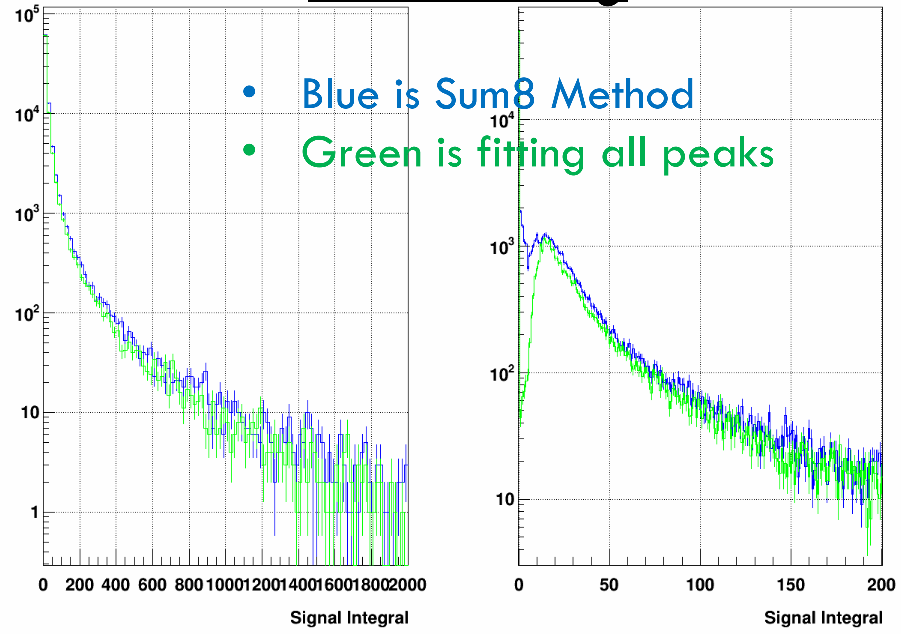
- Fitting all signals to known signal shape with a fixed number of peaks
- Timing with peak tunneling is twice as fast
- This is due to less peaks so fewer fitting parameters



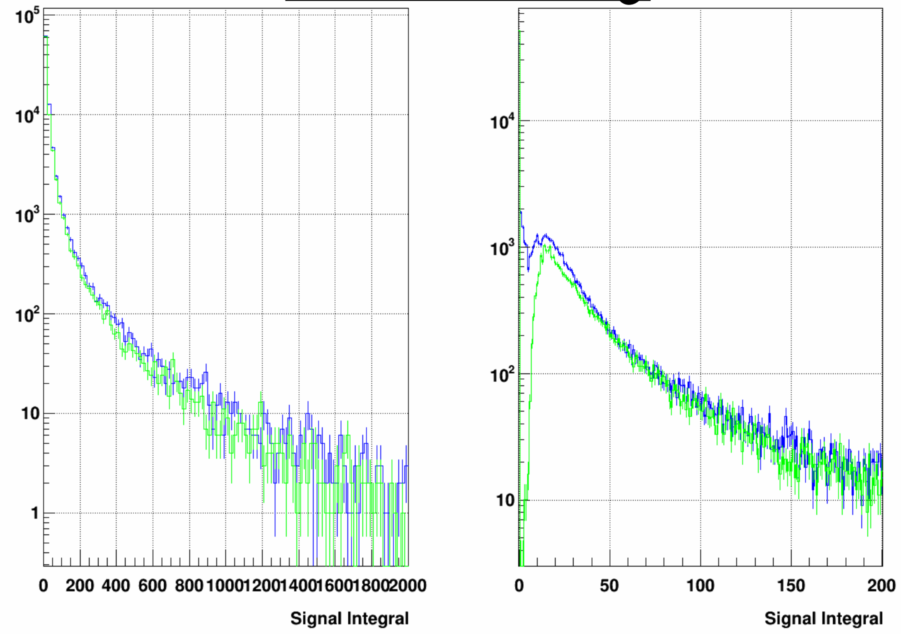
PERFORMANCE: ADC SUM

- Plots are comparing fitted signal integral with just summing ADCs with and without tunneling
- Sum8 method adds ADCs in 8 Tb of triggered RHIC crossing
    - Fastest method
    - Shown in Blue
- Sum8 method to fitting overestimates low side of energy compared to fitting
    - Shown in Green
- Very little difference in integral sum between with and without tunneling

No Tunneling



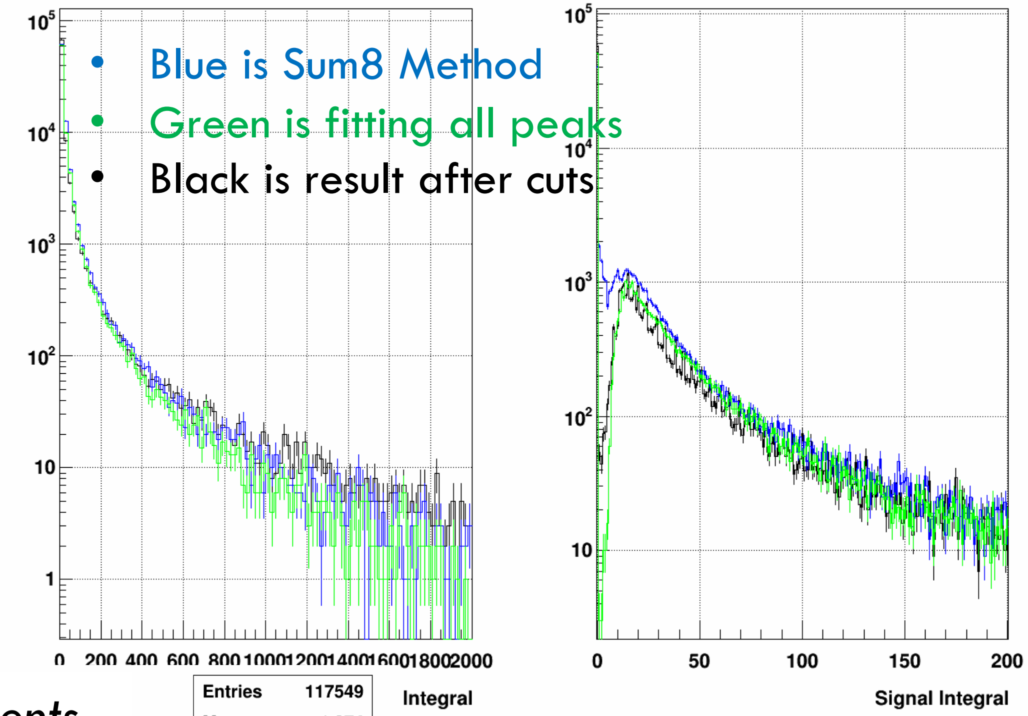
Peak Tunneling



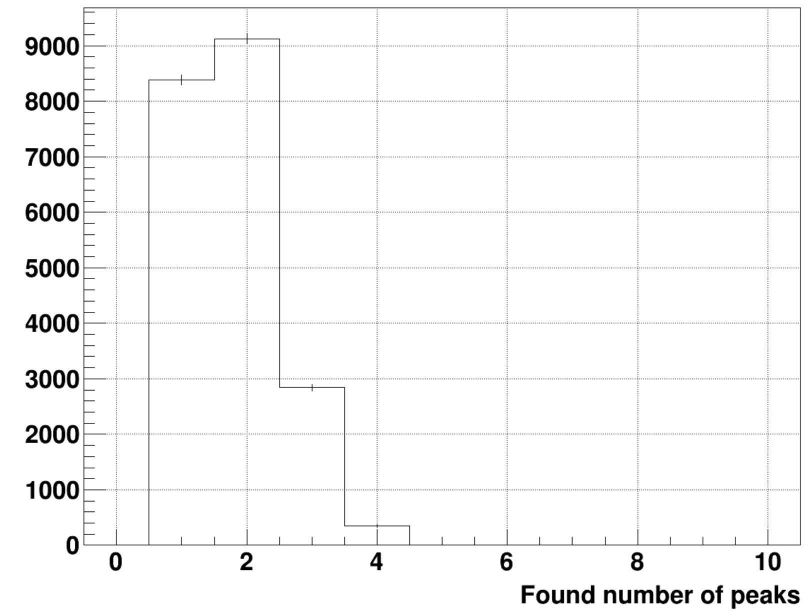
PUTTING IT ALL TOGETHER

- Final algorithm uses peak tunneling to determine number of peaks and their locations
- Cut out all peaks not within 3 RHIC bunch crossings
  - This ensures only overlapping peaks are fit
- Only fit peaks in those cases all other use Sum8 method

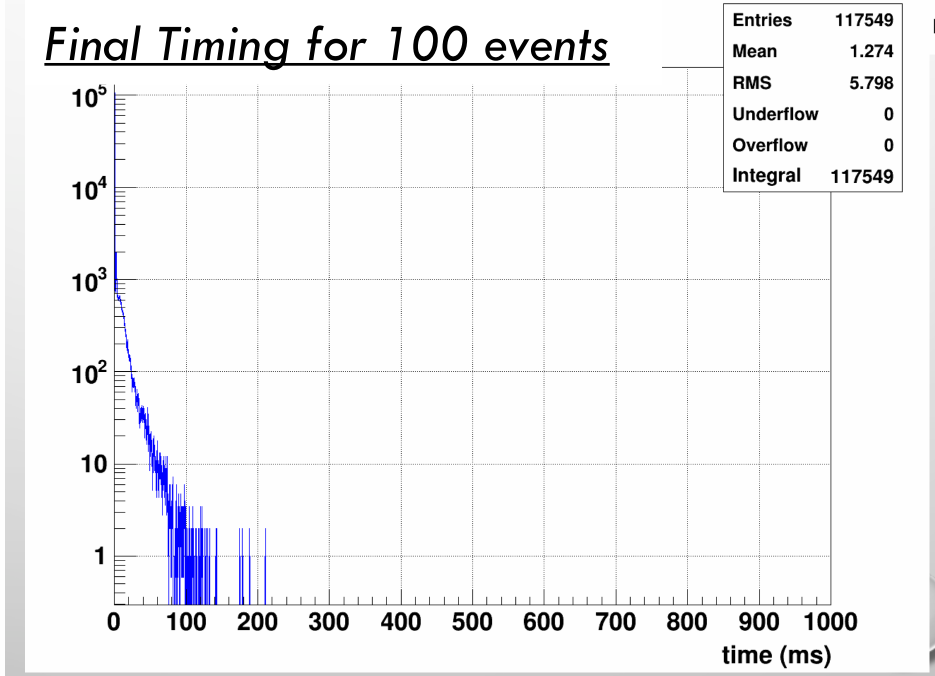
Final ADC sum



Final number of peaks



Final Timing for 100 events



- Accurate determination of peaks leads to faster computation time
- Aids in fitting overlapping peaks to correctly determine the energy

CONCLUSIONS

- STAR Forward upgrade greatly enhances capabilities of STAR in forward region
  - Upgrade will allow much better particle ID at STAR forward region
- The FCS uses latest technology to help improve energy determination
  - DEP boards have much finer digitization to record more details about the raw signal
  - More information means more analysis, which means more computation time to determine energy
- Developed robust algorithm to find peaks and determine energy quickly
  - Employed peak tunneling to reduce noise on found peaks
  - Cut out fitting peaks that don't overlap

BACKUP

FITTED SIGNAL SHAPE

- Signal shape $C + \frac{A_1}{\tau_1^2}(x - x_1)^{p_1} + e^{-(x-x_1)/\tau_1} + \frac{A_2}{\tau_2^2}(x - x_2)^{p_2} + e^{-(x-x_2)/\tau_2} + Ae^{-\frac{(x-x_0)^2}{2\sigma^2}}$
- C is a constant offset usually fixed to 0 unless there is a pedestal (baseline)
- A_1, A_2, τ_1, τ_2, p_1, p_2, x_1, x_2 are fixed constants to characterize size of tail
- A is the magnitude of the Gaussian and is also a fitting parameter
- x_0 is mean of Gaussian and is also a fitting parameter
- σ is the standard deviation of the Gaussian and is also a fitting parameter
- Multiple peaks just linearly sum this formula

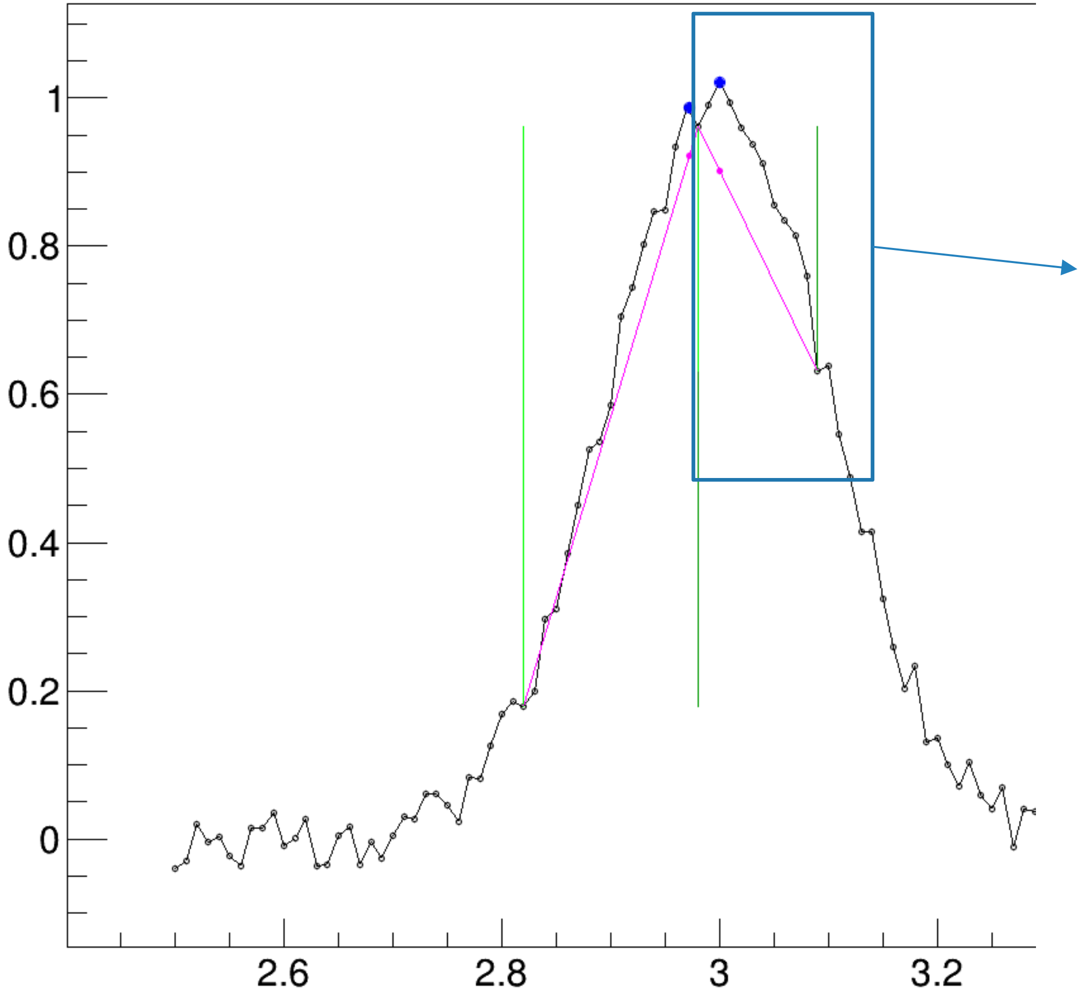
PEAK TUNNEL METHOD

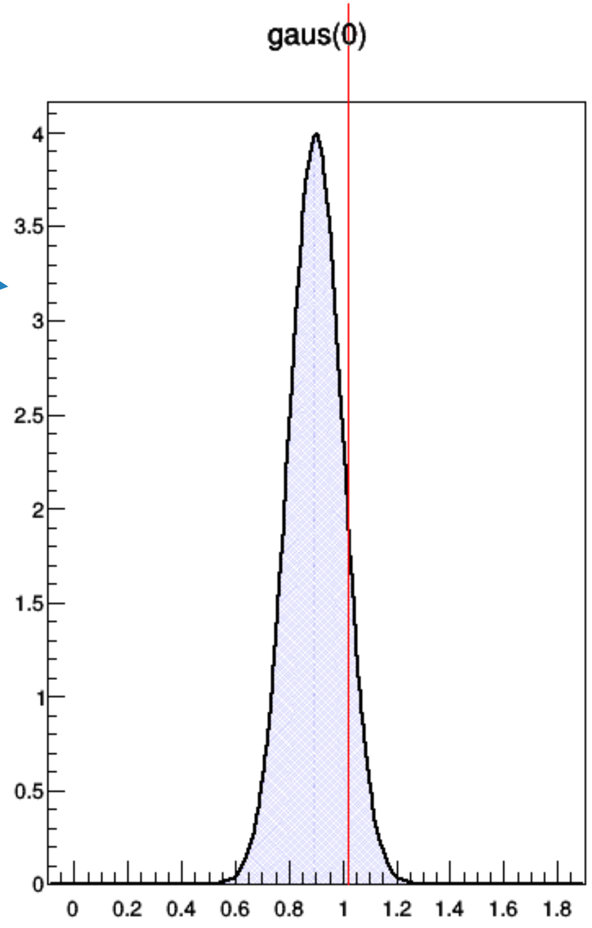
- Compute a probability that a given peak window contains a real peak or noise
- Probability considers two things: width of the window, size of the peak relative to the slope line

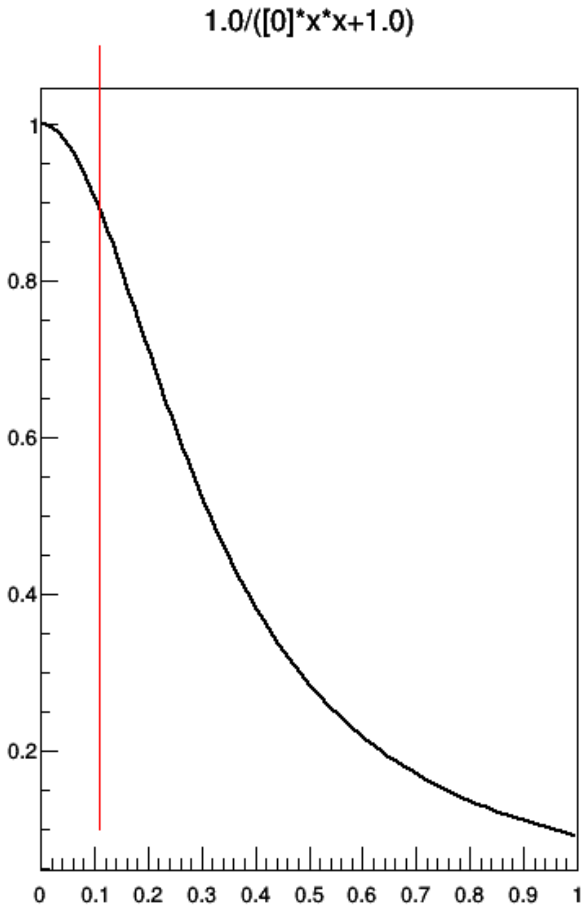
1. $P_{width}(x_s, x_e) = \frac{1}{a*(x_e - x_s)^2 + 1}$
2. $P_{height} = Erfc\left(\frac{heightdiff}{\sqrt{2}\sigma}\right)$
    - $heightdiff = p_y - yline(p_x)$
    - $yline\ is\ the\ line\ formed\ by\ the\ points\ x_s, y_s, x_e, y_e$

- x_s, y_s, x_e, y_e are the x,y points of the start and end of the found peak respectively
- $a\ and\ \sigma$ are two scale parameters that need to be set.
- The total probability is P_{width}*P_{height} ,with lower probability means more likely it's a peak
- If a peak has a probability higher than some threshold, then it is merged with the adjacent found peak with the lower probability peak dominating.

TUNNEL METHOD ILLUSTRATED







TUNNEL METHOD AT WORK