The STAR Forward Calorimeter Upgrade: Performance and Prototype

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For the STAR collaboration

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Outline

1. Overview
2. Fermilab Test
3. FCS Prototype Test at STAR

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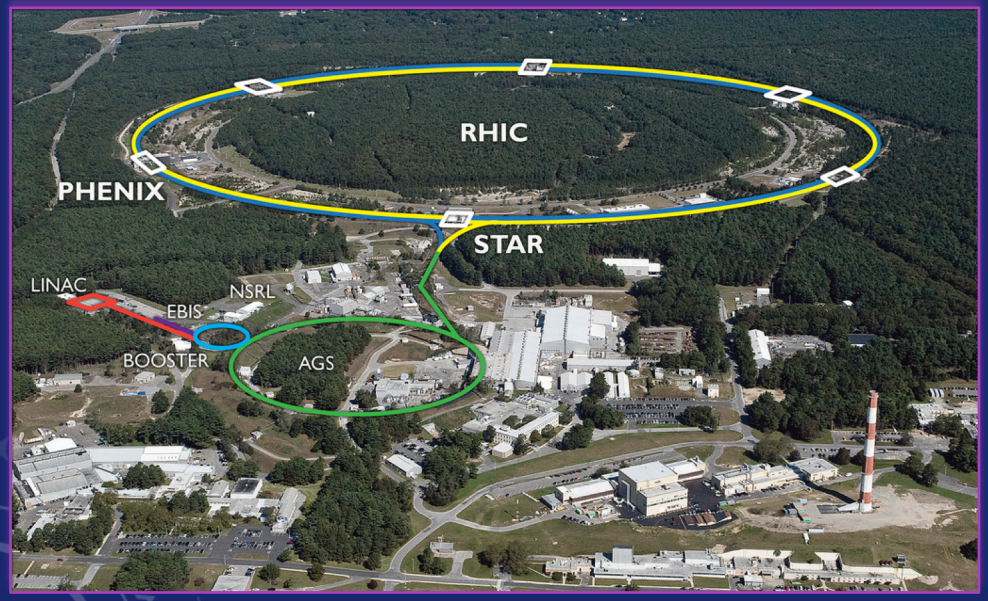
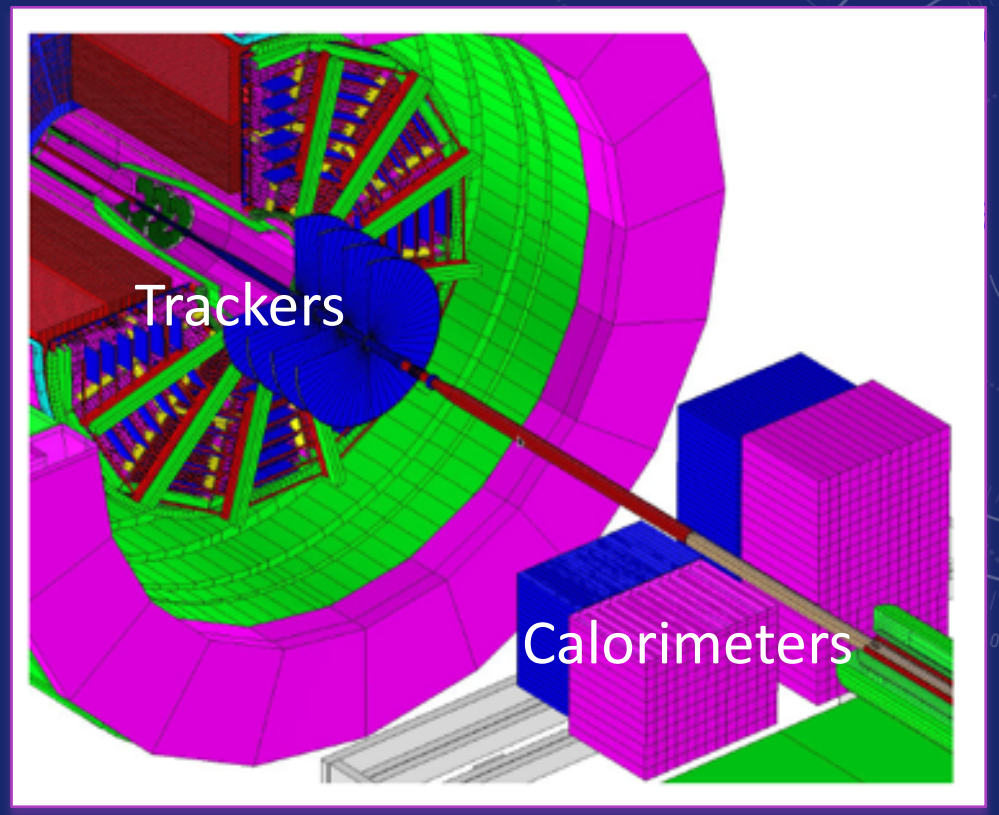
STAR Forward Upgrade

- STAR detector located at RHIC at BNL
- RHIC is the worlds only polarized proton collider
- One important measurement is the transverse single spin asymmetry in Drell Yan production
  - It requires good separation between photons, electrons, hadrons

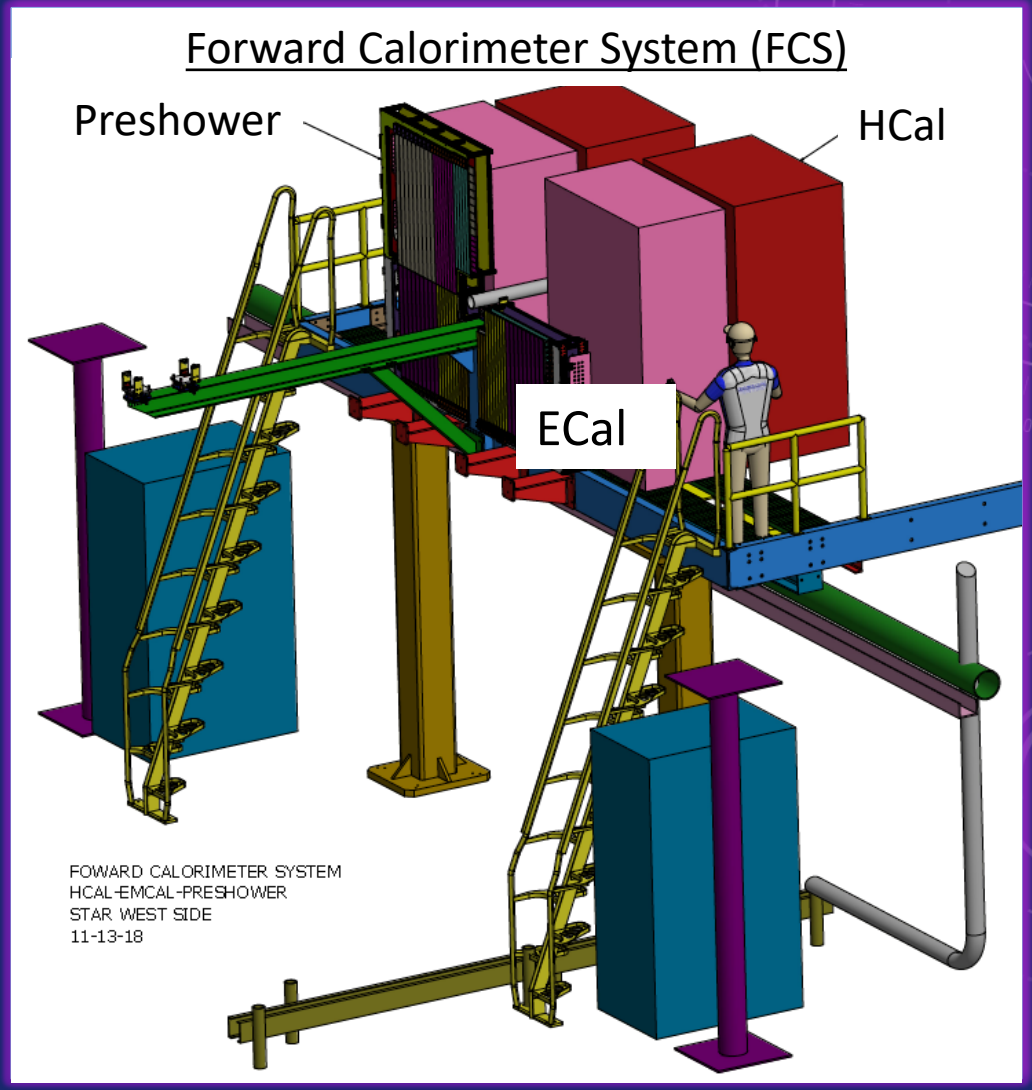




- The forward upgrade will achieve this capability by installing trackers and a calorimeter system
- Trackers consist of Silicon disks and small thin gap chambers (sTGC)
- This talk will discuss calorimeters in more detail
- Approved and needs to be ready for data taking in Fall 2021

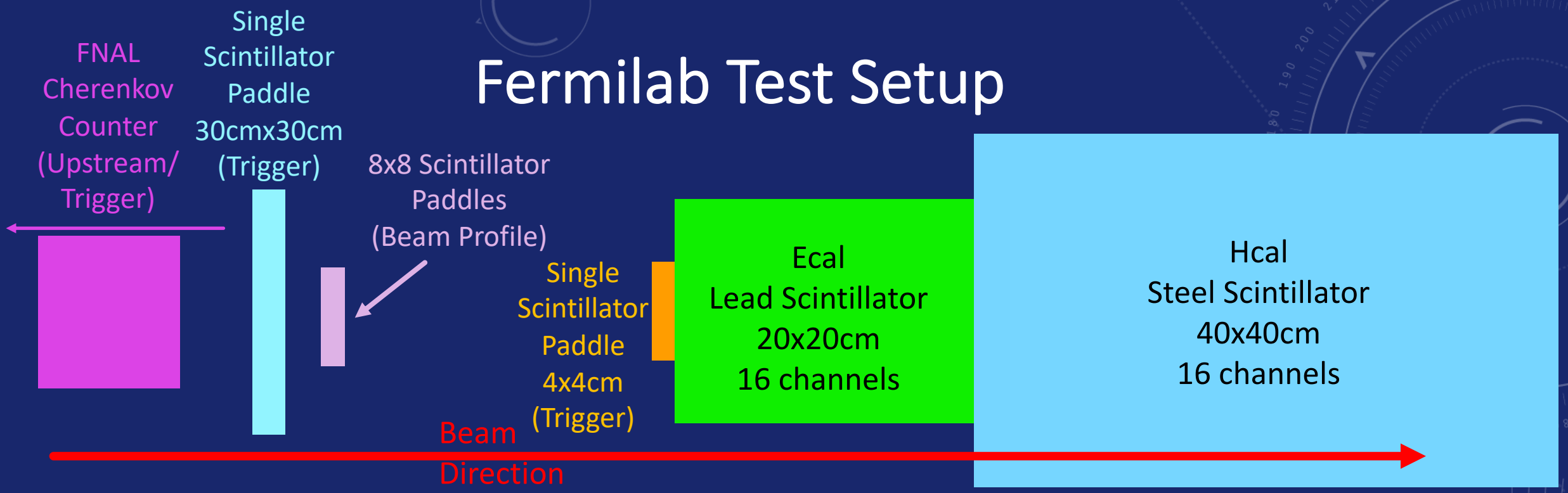
Forward Calorimeter System (FCS)

- Consists of Preshower (fPRE), Electromagnetic Calorimeter (Ecal), and Hadronic Calorimeter(Hcal)
- All detectors will use SiPM readout
- Preshower (fPRE)
  - Scintillator Hodoscope
  - Re-use an existing one at STAR
- ECal
  - Re-use Pb/Sc sandwich from PHENIX
- Hcal
  - Fe/Sc sandwich
  - Will be built from scratch



Fermilab Test

Fermilab Test Setup



- The proposed Hcal for the FCS underwent testing at Fermilab Test Beam Facility (FTBF)
- As can be seen from the diagram above the Test Setup contained multiple systems
- Main detector of this test was the Hadronic calorimeter (Blue)
- Three detectors could be used as trigger: both single scintillator paddles and the Cherenkov

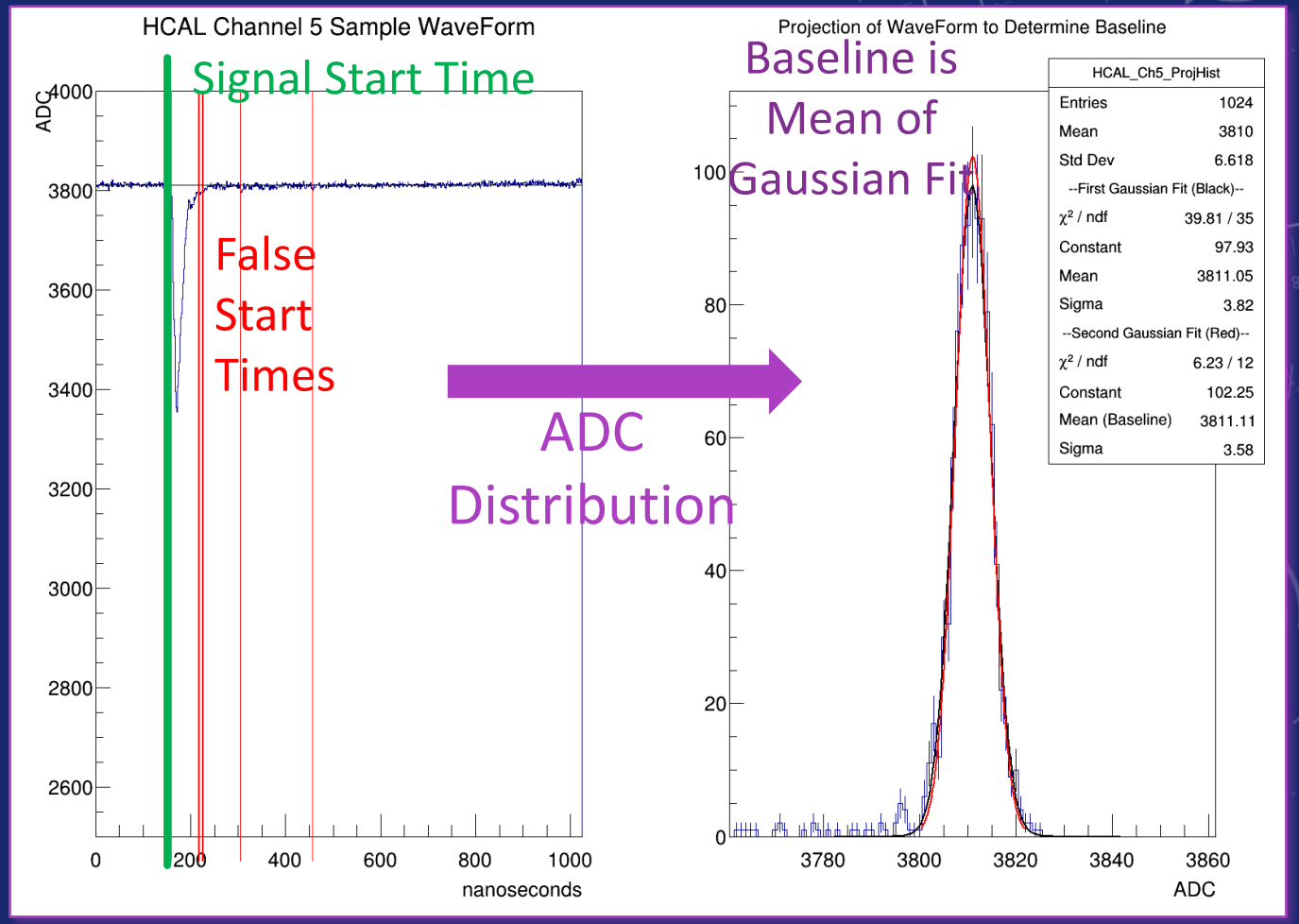
Hcal Channel Map
Inner 2x2 (Red)
Outer (Green)

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Electronics Readout

- New electronics system takes data by sampling signal over short times
- These short times are called timebins (tb)
  - Each tb corresponds to ~1ns
- Each tb returns a digitized number corresponding to size of signal (ADC)
  - This number ranges from 0-4095
- Two things now need to be determined the baseline of the signal and the signal start time
  - Baseline found from ADC distribution
  - Developed algorithm for finding start time

Sample Pulse showing baseline and start time determination

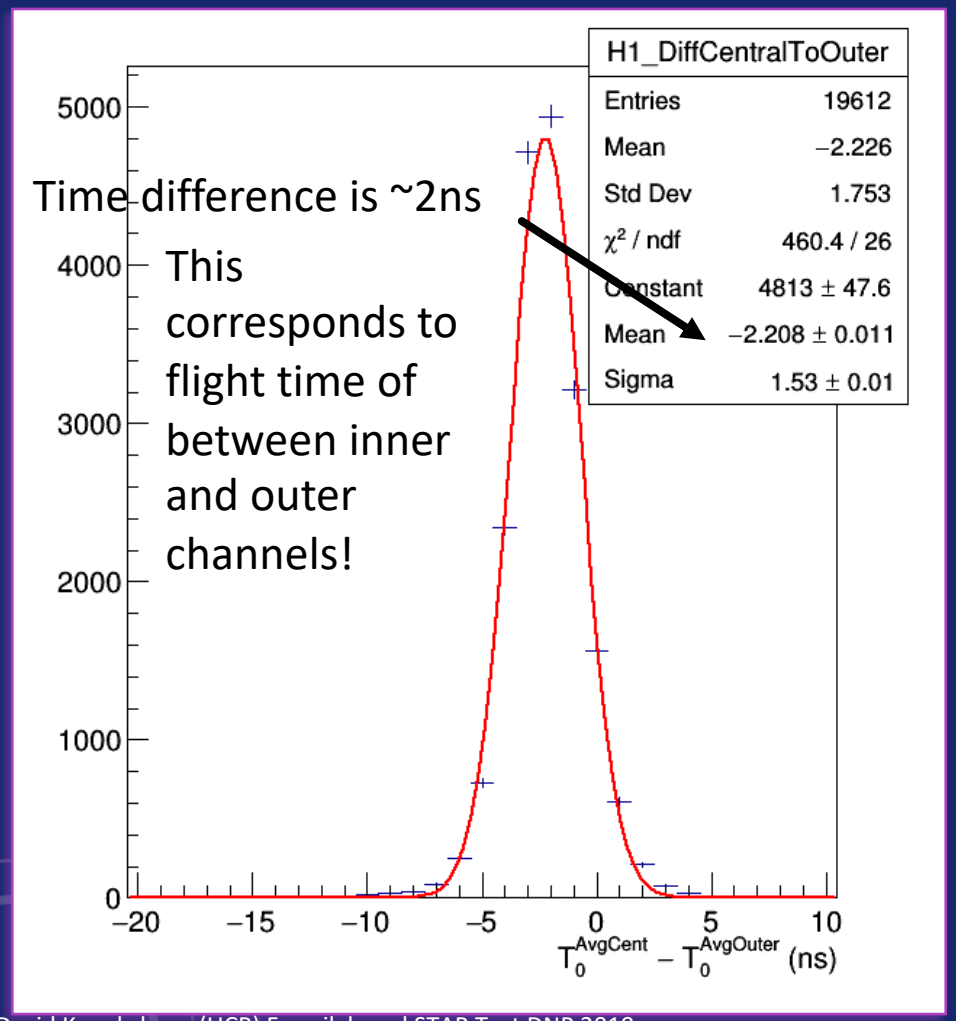


Interesting results

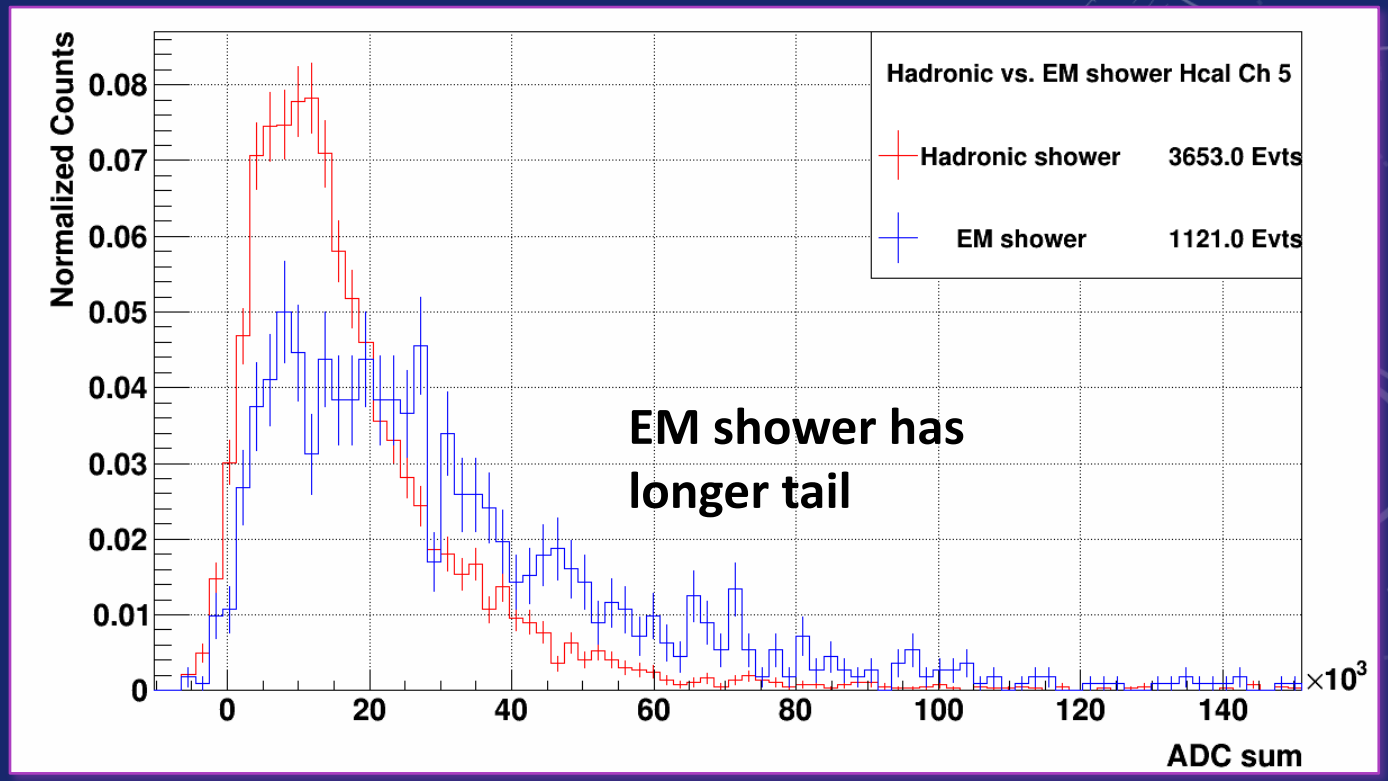
Hcal Channel Map
Inner 2x2 (Red)
Outer (Green)

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

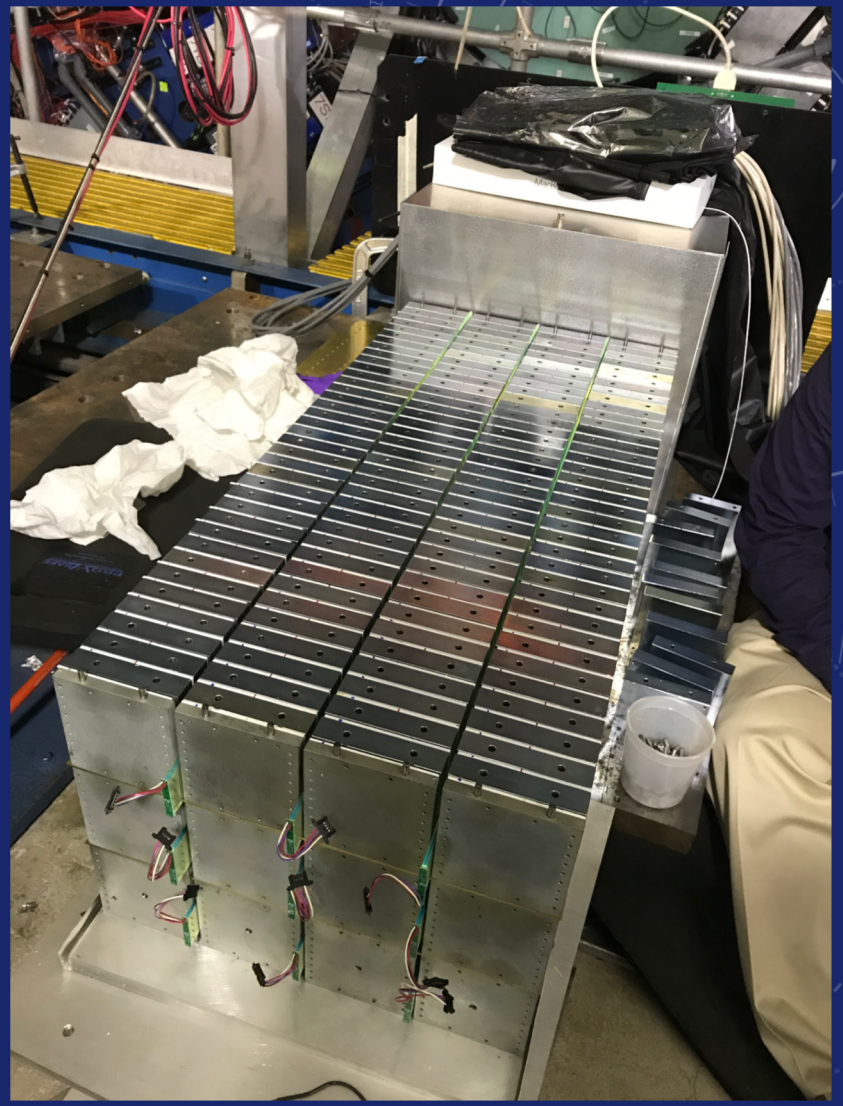
Look at the signal start time difference between inner and outer channels



Use the Cherenkov counter to trigger on electrons vs. hadrons and check to see if there are any differences between hadronic and EM showers.

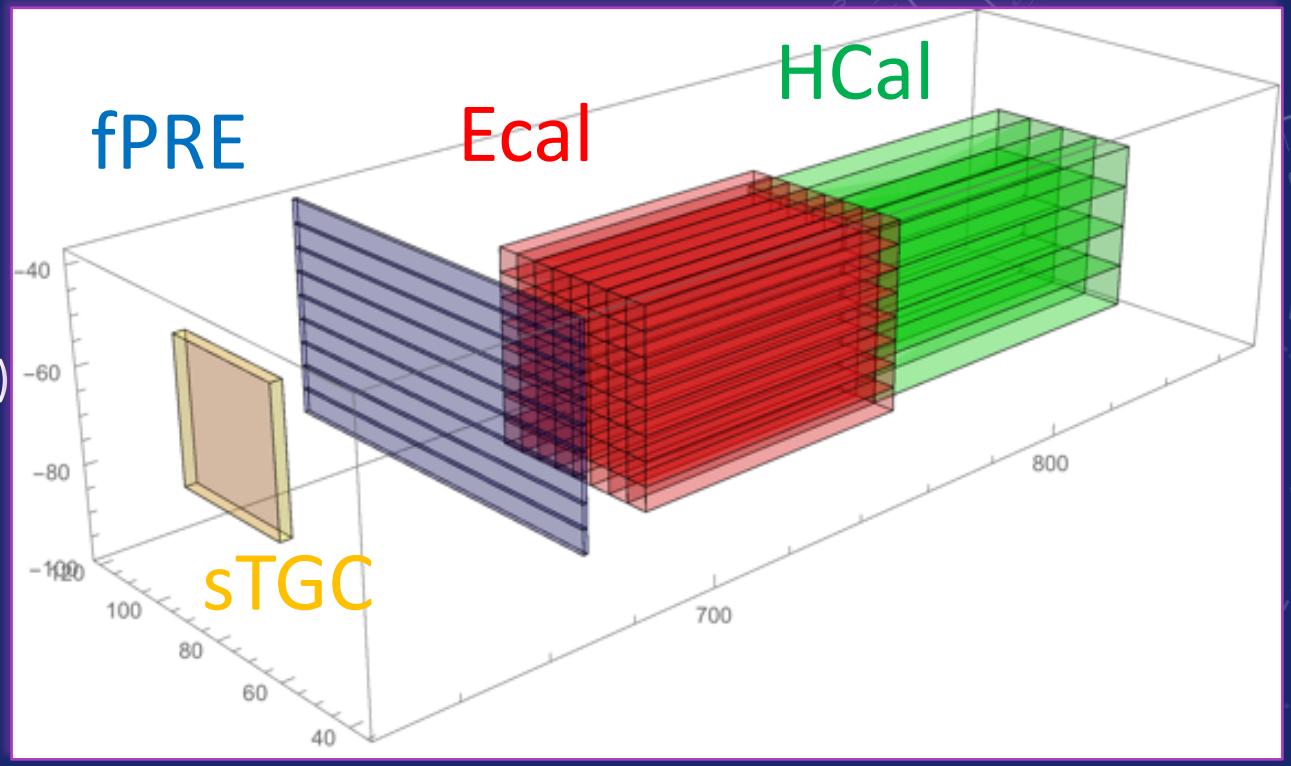


FCS Prototype at STAR

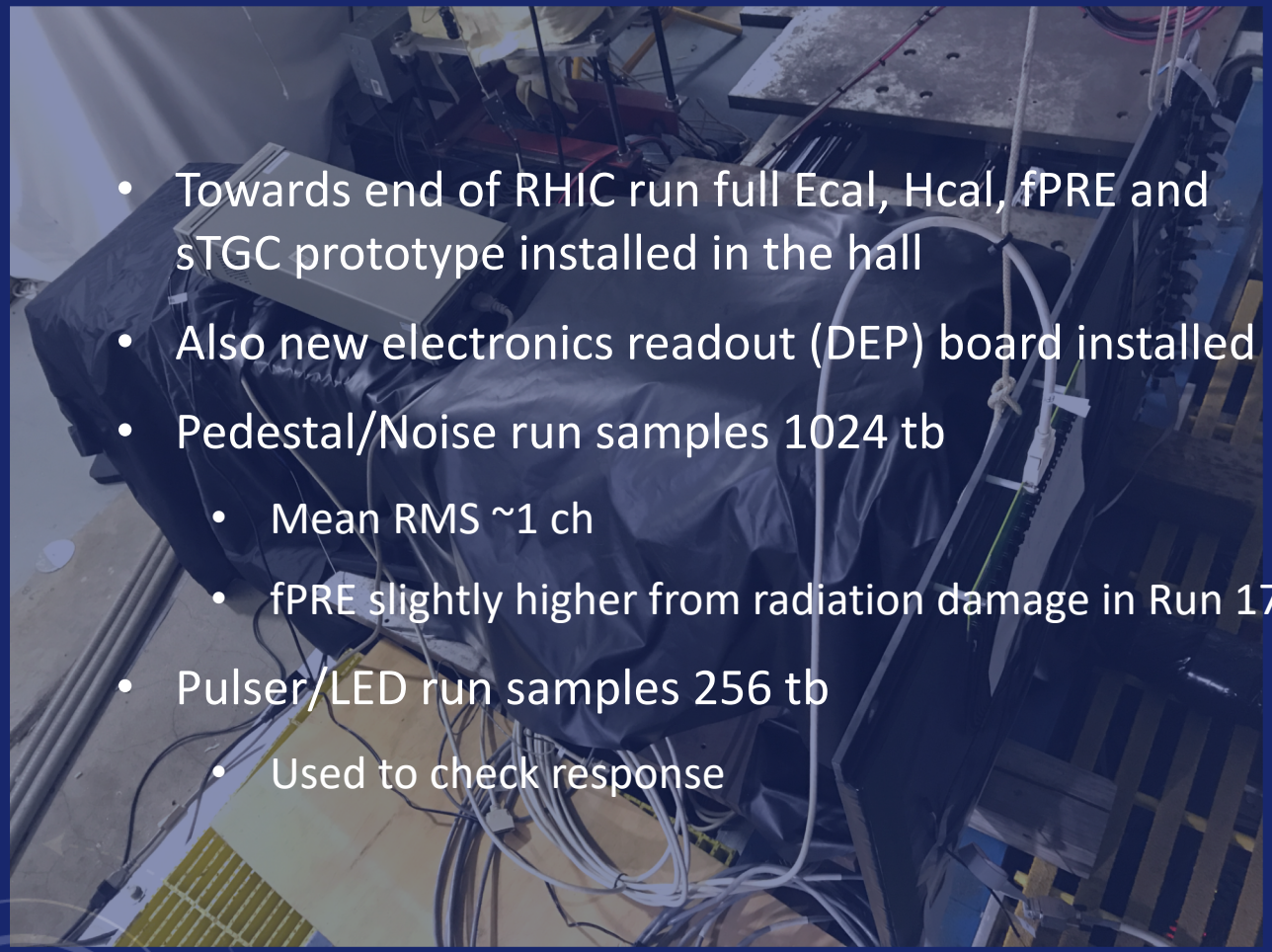


STAR FCS prototype in Run 19

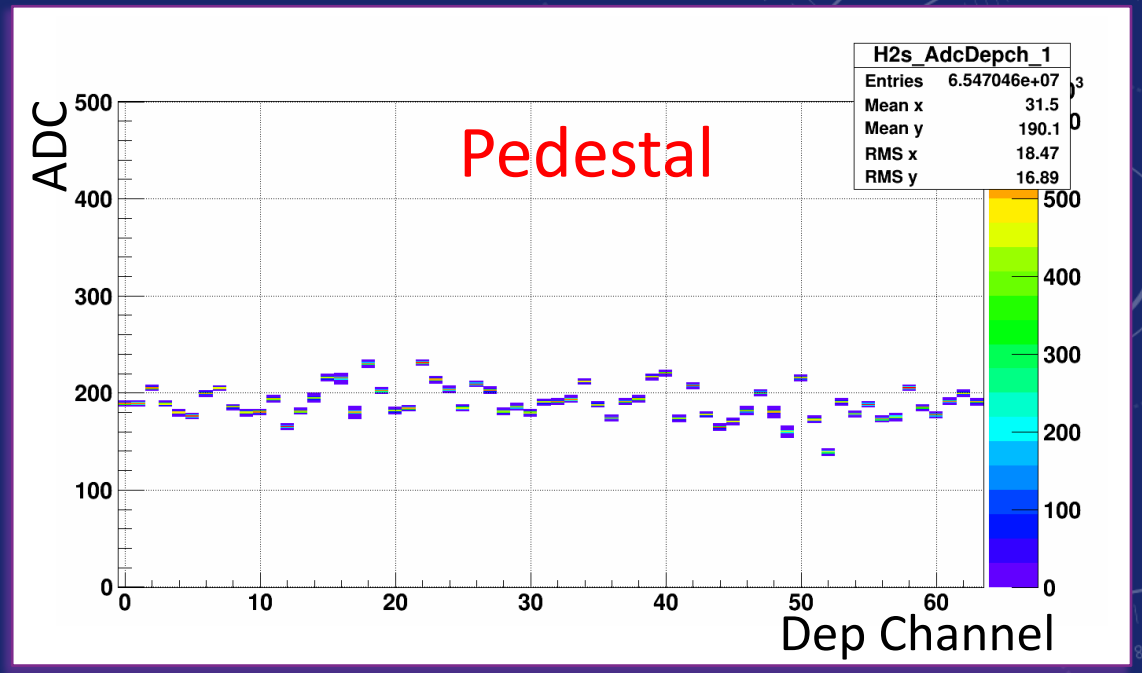
- FCS prototype consists of Ecal, Hcal, preshower (fPRE)
  - Ecal was 8x8 and similar material makeup to FNAL
  - Hcal was same as FNAL test
  - fPRE was 1 layer of 9 Scintillator slats
- Also one sTGC module installed for testing (tracker)
- Electronics board (DEP) for readout
  - Captured SiPM signal in real time
  - DEP boards have 32 channels each (4 total)
  - Each channel samples 1/8 of RHIC tick (~12ns/tb)
  - ADC is still 0-4095 per timebin (tb)

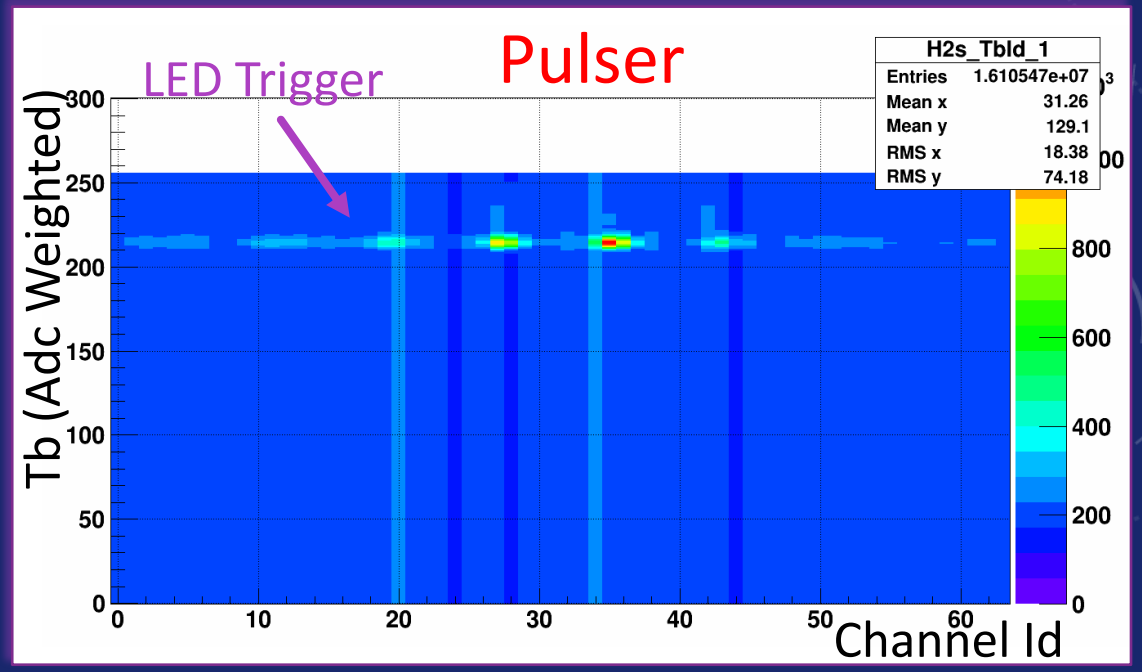


Commissioning and Testing



- Towards end of RHIC run full Ecal, Hcal, fPRE and sTGC prototype installed in the hall
- Also new electronics readout (DEP) board installed
- Pedestal/Noise run samples 1024 tb
  - Mean RMS ~1 ch
  - fPRE slightly higher from radiation damage in Run 17
- Pulser/LED run samples 256 tb
  - Used to check response

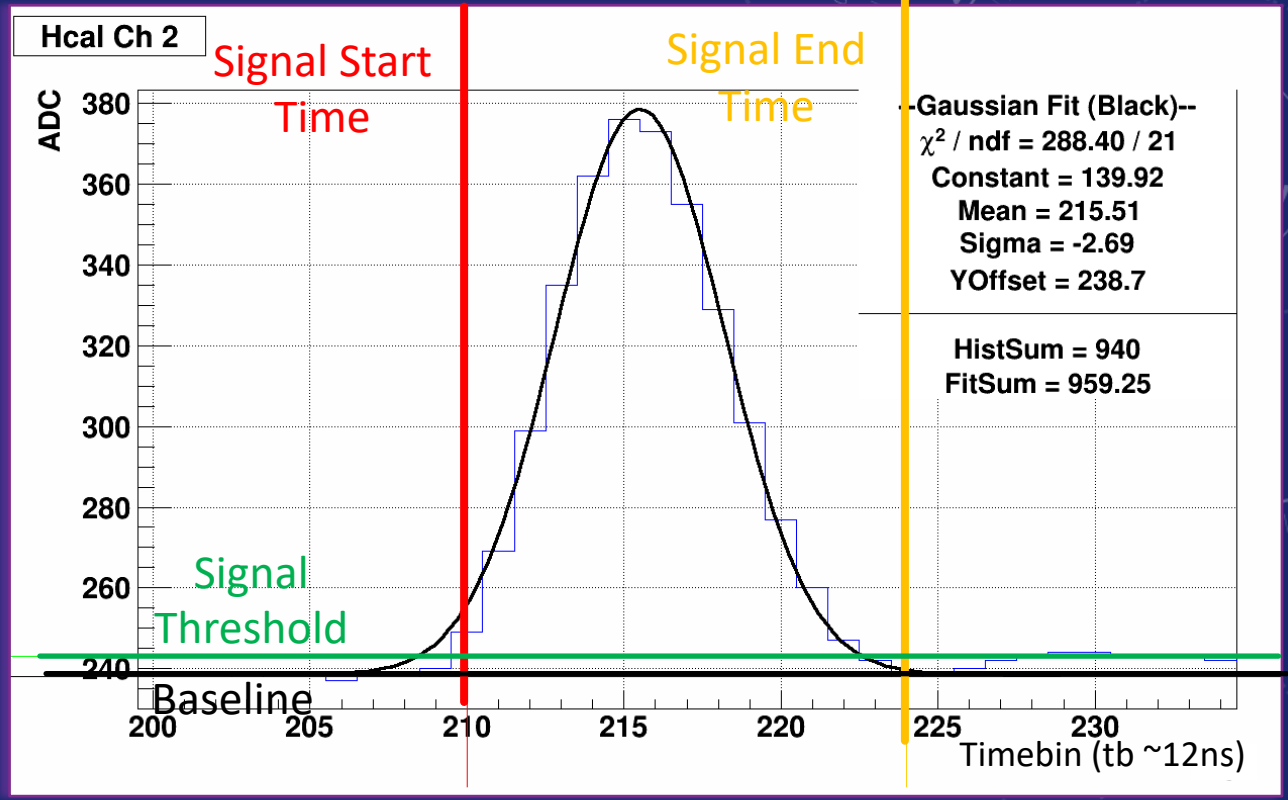


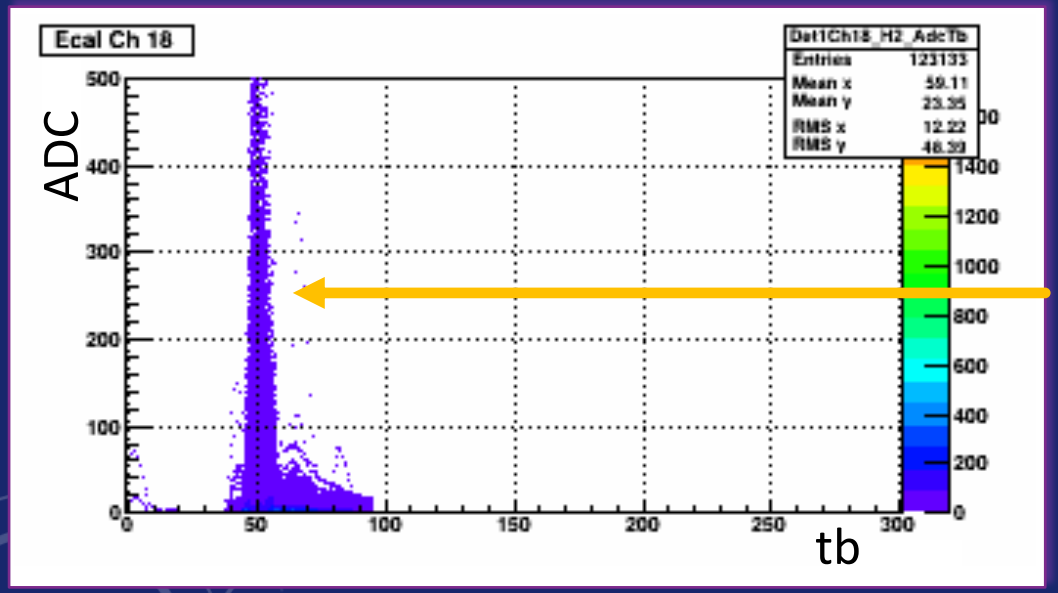


Physics Data

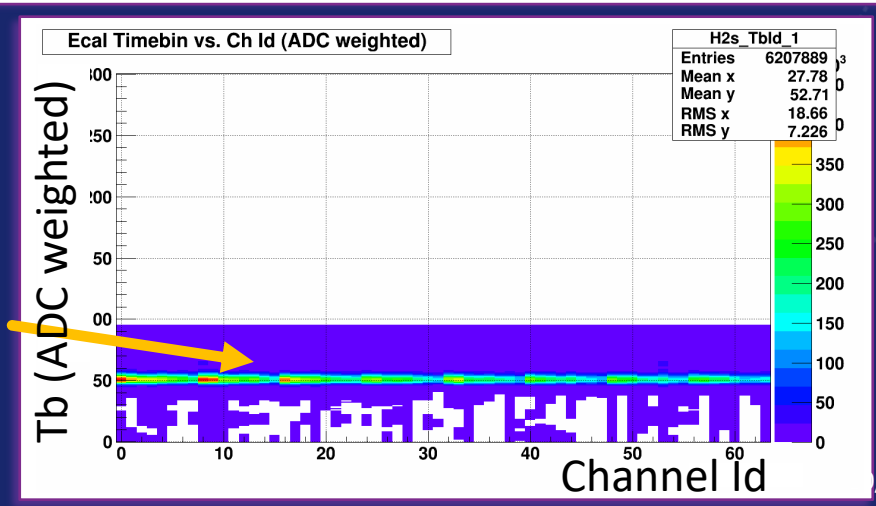
- Took data 200 GeV Au Au min bias data
- Signal from DEP board on plot on right
  - Taken from Pulser run to show signal with no pedestal subtraction
- Peak at triggered RHIC crossing in bottom two plots

Sample Signal and Signal Fitting using DEP boards (Hcal Channel)





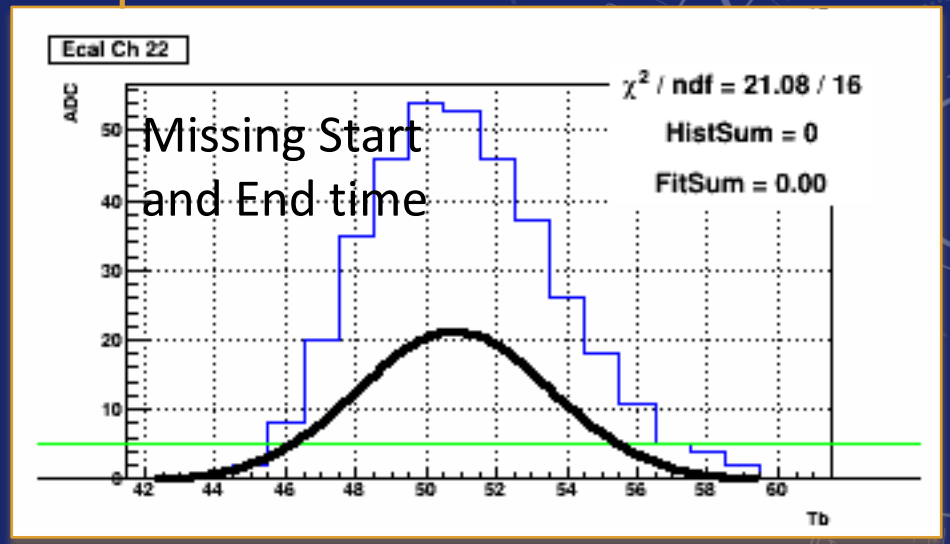
Triggered RHIC Crossing Roughly 50 tb (~600ns)



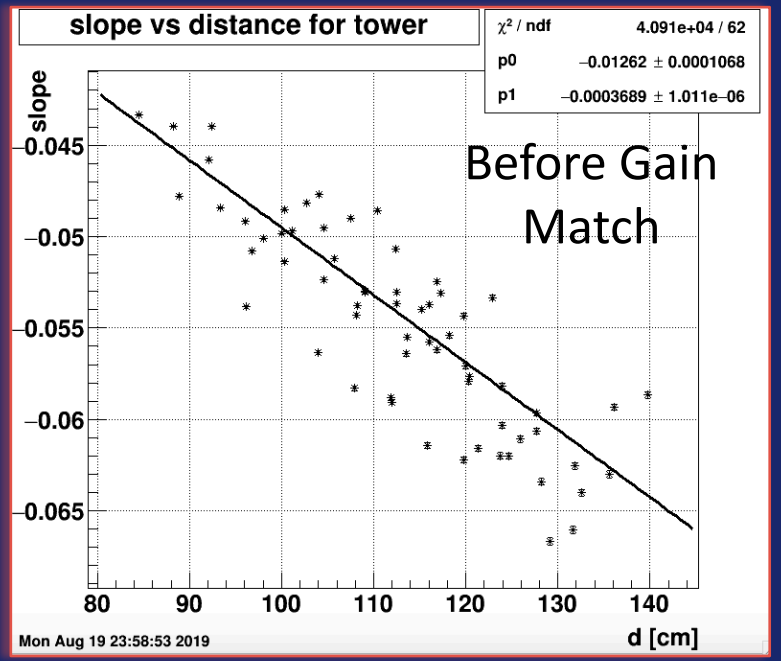
Ongoing Analysis of Data

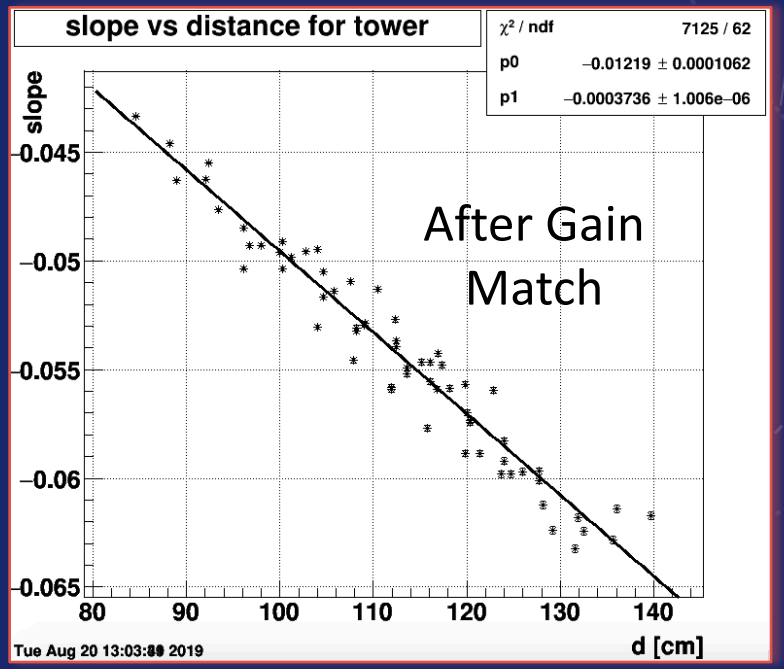
- Analysis of the Au Au data is ongoing
  - Refine signal fitting
  - Gain matching
  - Calibrations (Next slide)
- These analyses are to prepare for future running of the detector

Example of Peak find and Fit Failure



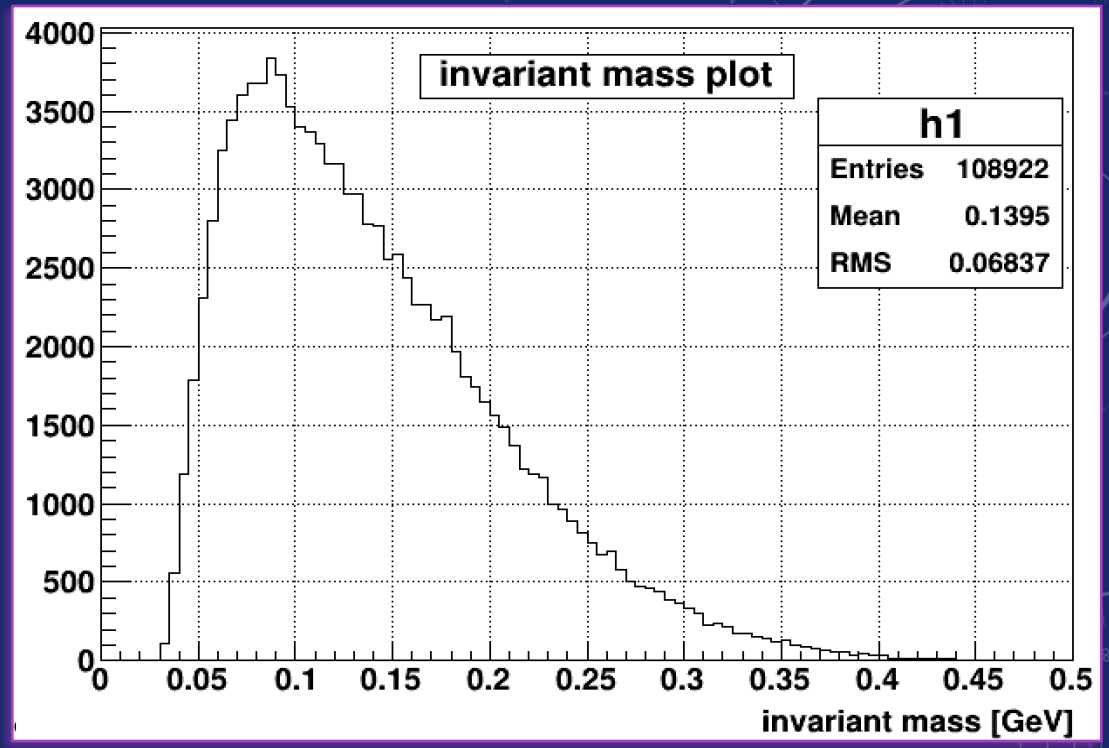
Gain Matching

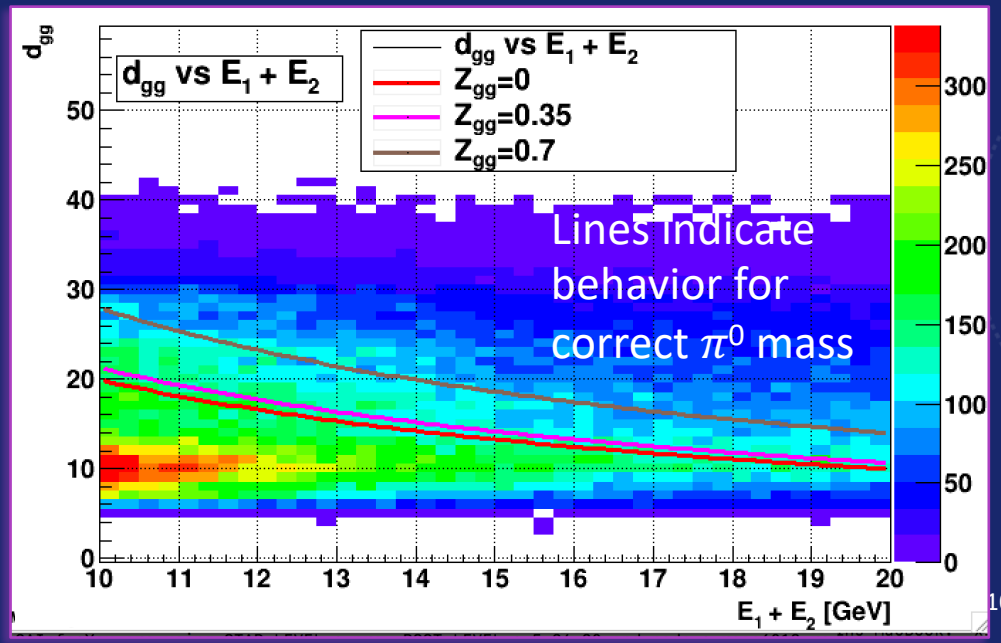




Calibration efforts

- Calibration focused on looking for π^0
  - Gain is adjusted so π^0 invariant mass peak is at correct position
- Invariant mass computed by forming clusters of Ecal cells and then taking two highest energy clusters
  - Energy(E) = ADC Sum from tb(35-60)*gain
  - ‘gain’ is rough estimate from Fermilab test
  - $d_{\gamma\gamma}$ = distance between cluster centers
- Invariant mass shows peak but not at π^0 mass
  - Still need some work to cut out backgrounds
  - Need to find correct gain factors





Conclusions

- STAR forward upgrade will extend STAR's forward physics capabilities
- It will allow the key measurements to aid our understanding of the spin of the proton
- Fermilab test showed very promising results
  - New electronics system working well
  - Successful signal start time algorithm developed
  - Hadron and EM showers show different behaviors
- Successful FCS prototype built, run, and data taking
- Analysis efforts ongoing
  - Refine fitting algorithm
  - Calibration
- Forward Upgrade has been approved and will be built for RHIC running 2021

Backup

Fermilab setup more details

Color indicates ADC block

HCal Steel Scintillator
40cmx40cm(10cmx10cm square cells)
20mm Fe layered with 3mm scintillator
36 layers
Length:~86.4cm
Square cells are arranged in 4x4 pattern
(total 16 channels)
ADC (Block) 1

ECal lead(Pb) Scintillator
20cmx20cm (5cmx5cm square cells)
Length:
Square cells are arranged in 4x4 pattern
(Total 16 channels)
ADC (Block) 2

Single Scintillaor Paddle
4cmx4cm
ADC (Block) 4
Channel 0 (Sc1)
Can be used to trigger

Scintillator Hodoscope
32cmx32cm
16 rectangular scintillators
(5mmx10cm)
Arranged so 8 vertical and
8 horizontal
(Total 16 channels)
(Total coverage 4cmx4cm)
ADC (Block) 3
Used for beam profile

Single Scintillator paddle
30x30cm
ADC (Block) 4
Channel 1 (Sc2)
Can be used to trigger
(Muon tests for MIP)

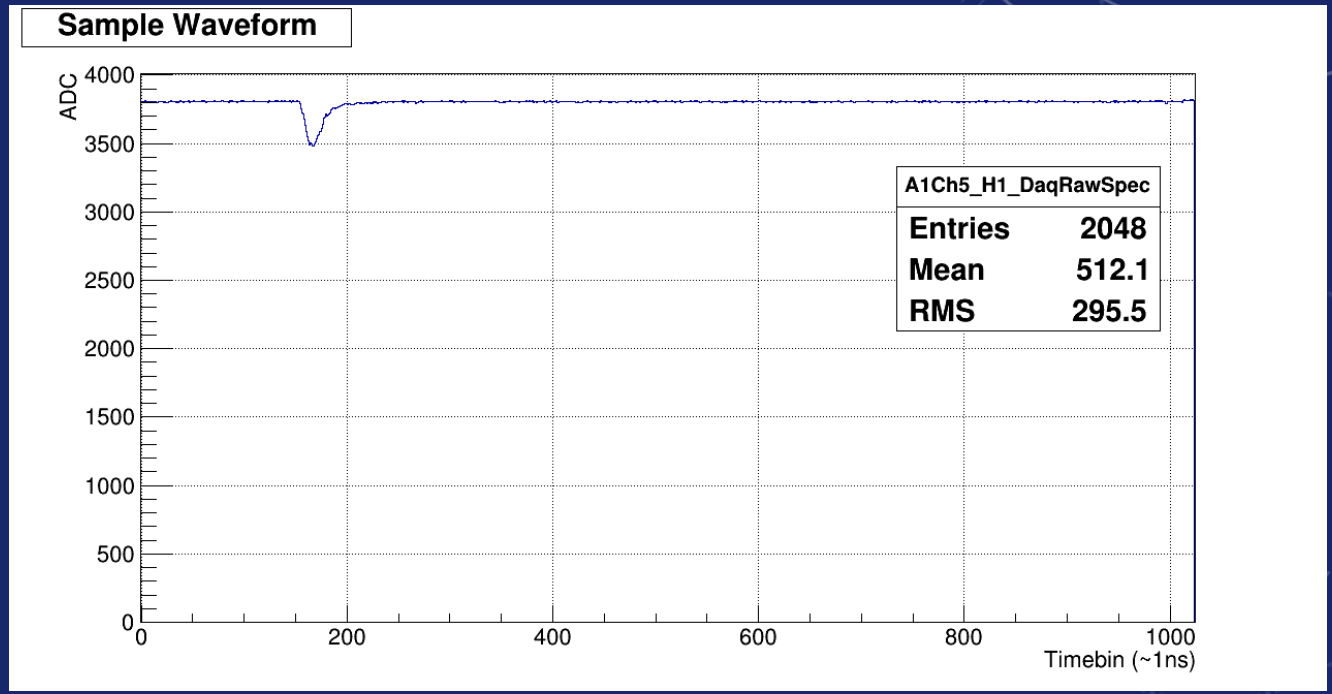
FNAL Chernkov Counter
ADC (Block) 4
Channel 2 (Ce1)
Channel 3 (Ce2)
(Unplugged at some point)

Channels 4-15
unplugged and used
to find correlated
noise

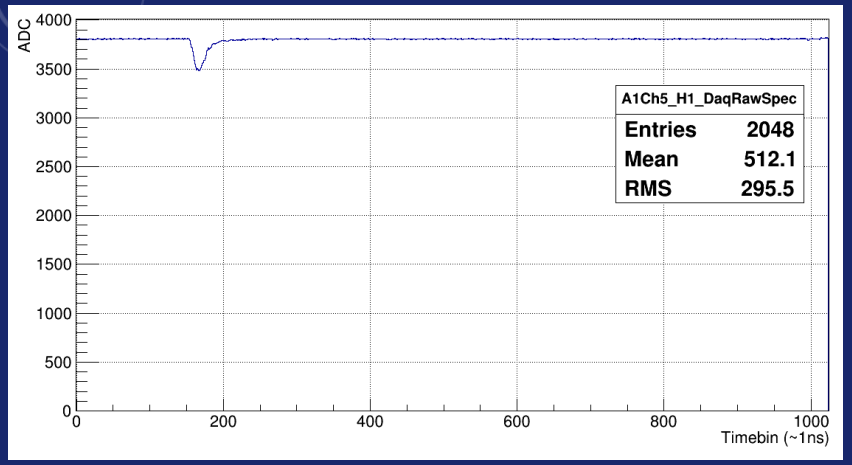
Description of Electronics System at Fermilab

- Electronics board capable of digitizing signal from SiPM/PMT in real time
- These boards have a 1024 capacitor array for each channel capable of 1GigaSample/sec
  - This means every timebin (tb) corresponds to ~1ns
  - Each tb gives one 12 bit ADC value (0-4095)
- Traditionally such charge integration happens over entire pulse (QT boards at STAR)
- With the raw signal itself there are two things which are now needed to be done by hand
  1. Find the baseline
  2. Find the signal start time
  3. Sum the signal to get the more traditional ADC value

Sample Pulse from using new electronics readout

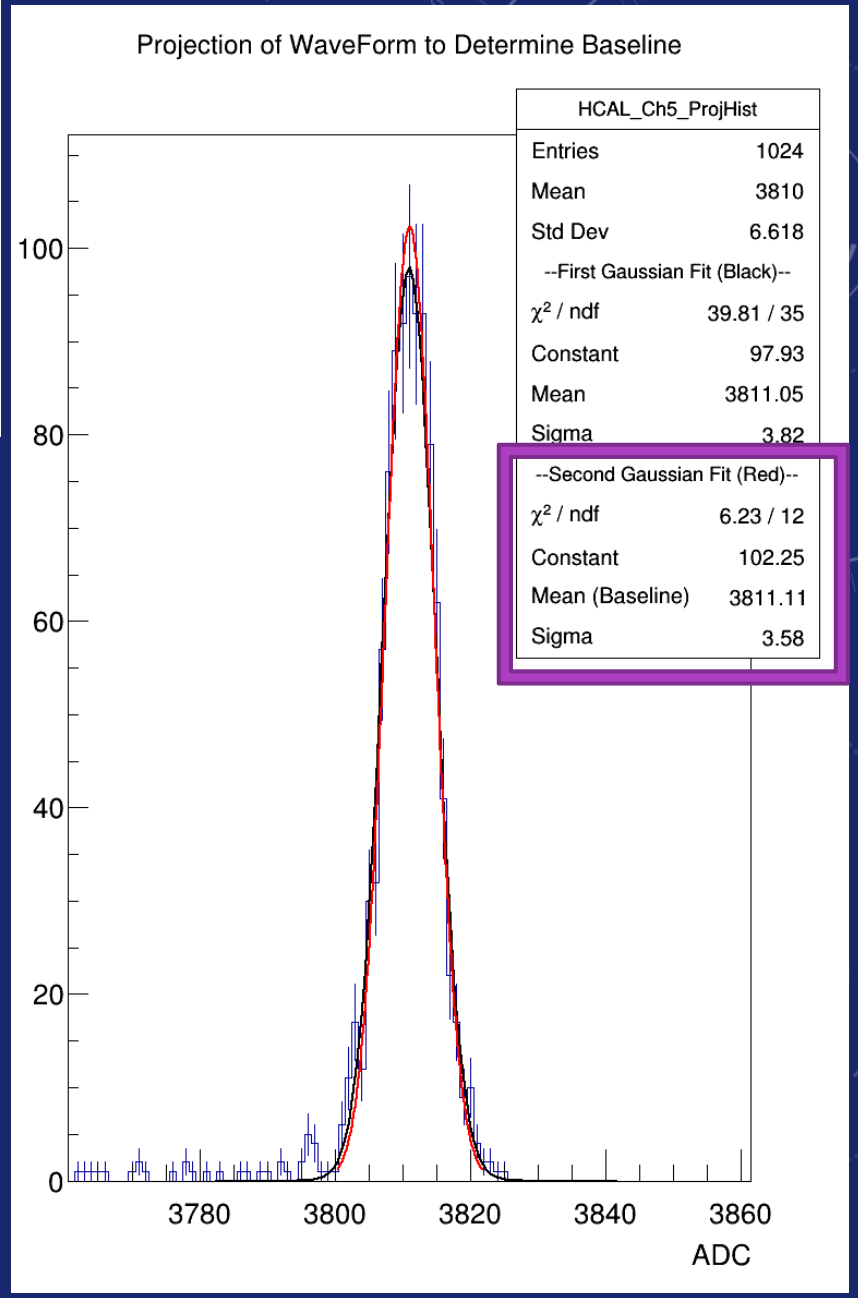


Finding the baseline



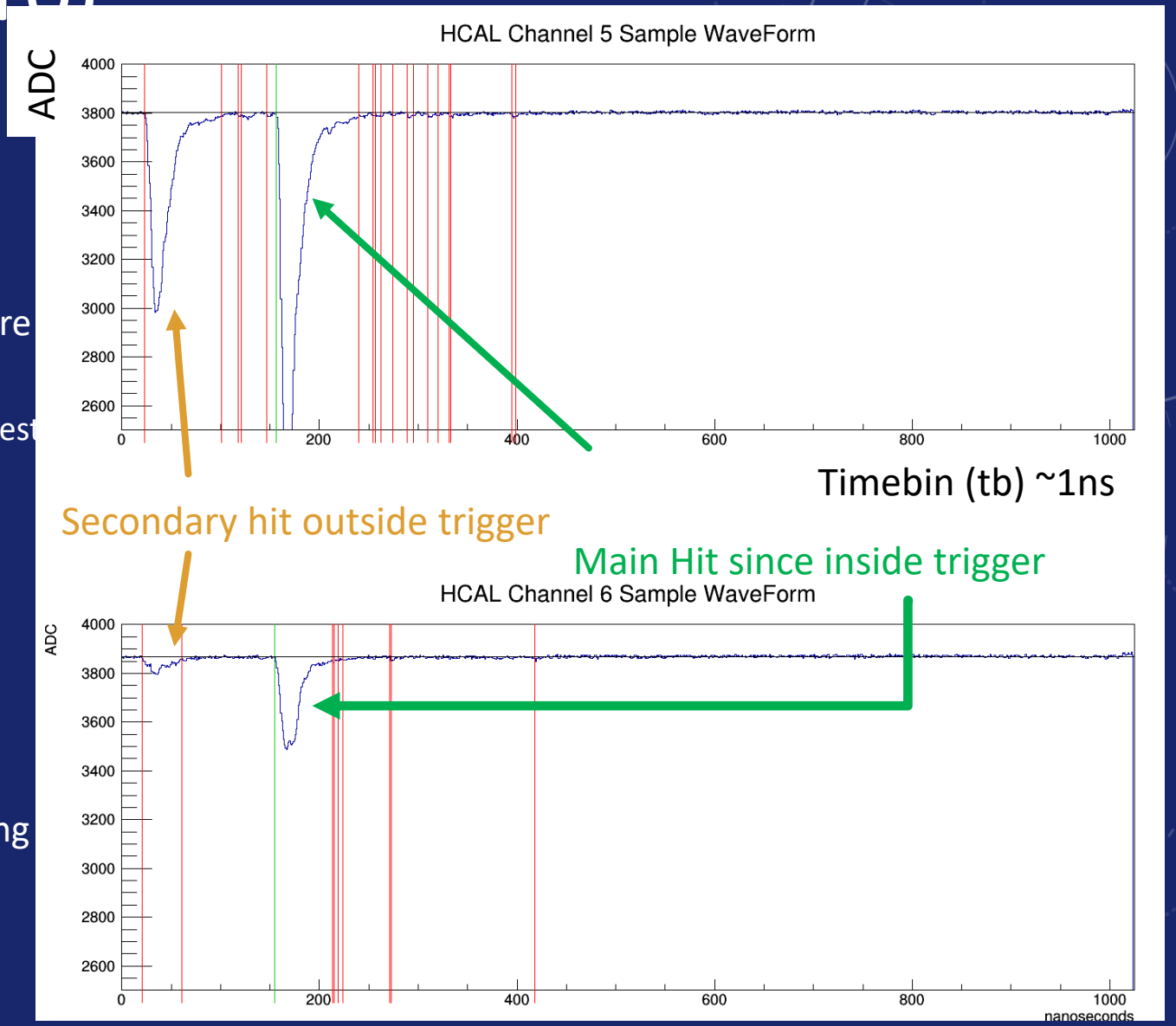
- This was done by projecting the pulse to the y-axis (ADC) and doing two gaussian fits
  - First fit was to max ± 30
  - Second fit was mean±2*sigma of first fit
- The mean of the second fit was the baseline
- This also gives a sigma to the baseline which will be important later in identifying the signal start time
- The plot on the top right shows one such example with its fit

Project along Y



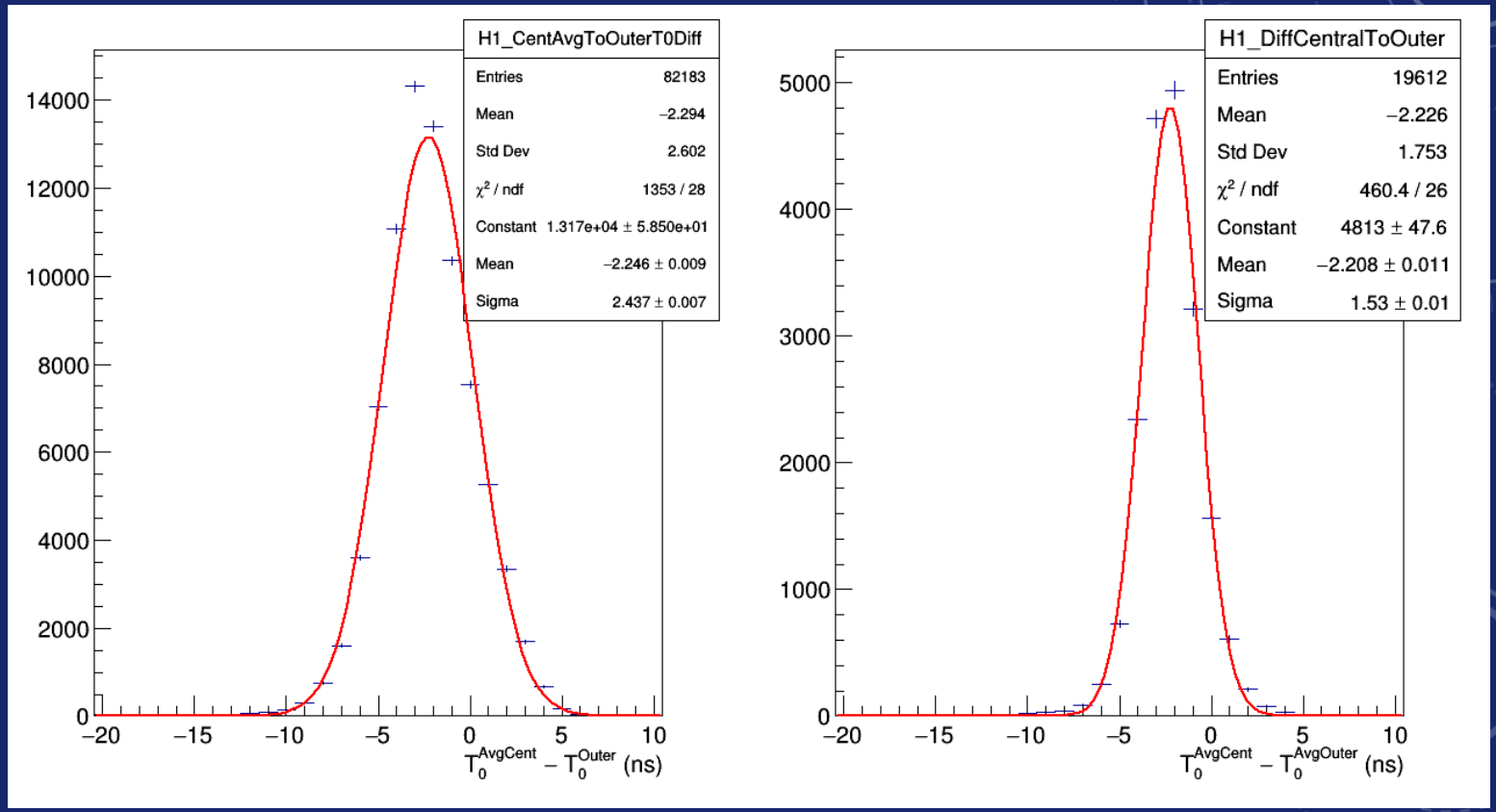
Finding the Start Time (T0)

- This is done by scanning the pulse and checking where it goes 5*sigma above baseline
  - The 5 was chosen after testing to see which worked best
- This could lead to lots of false positives (Red Lines) which were ruled out by the following method
  1. If a potential T0 was found do a linear fit using ±4 tb
  2. If the slope fit was close to zero then rule it out.
- Now this left only the double peak cases where two signals would appear in the full 1024 tb pulse
- To eliminate these we checked which of the remaining T0s were inside of our trigger window of 120-220 tb
- Final T0 is green line in plots on right



Comparing T0s To Detect Slow Neutrons

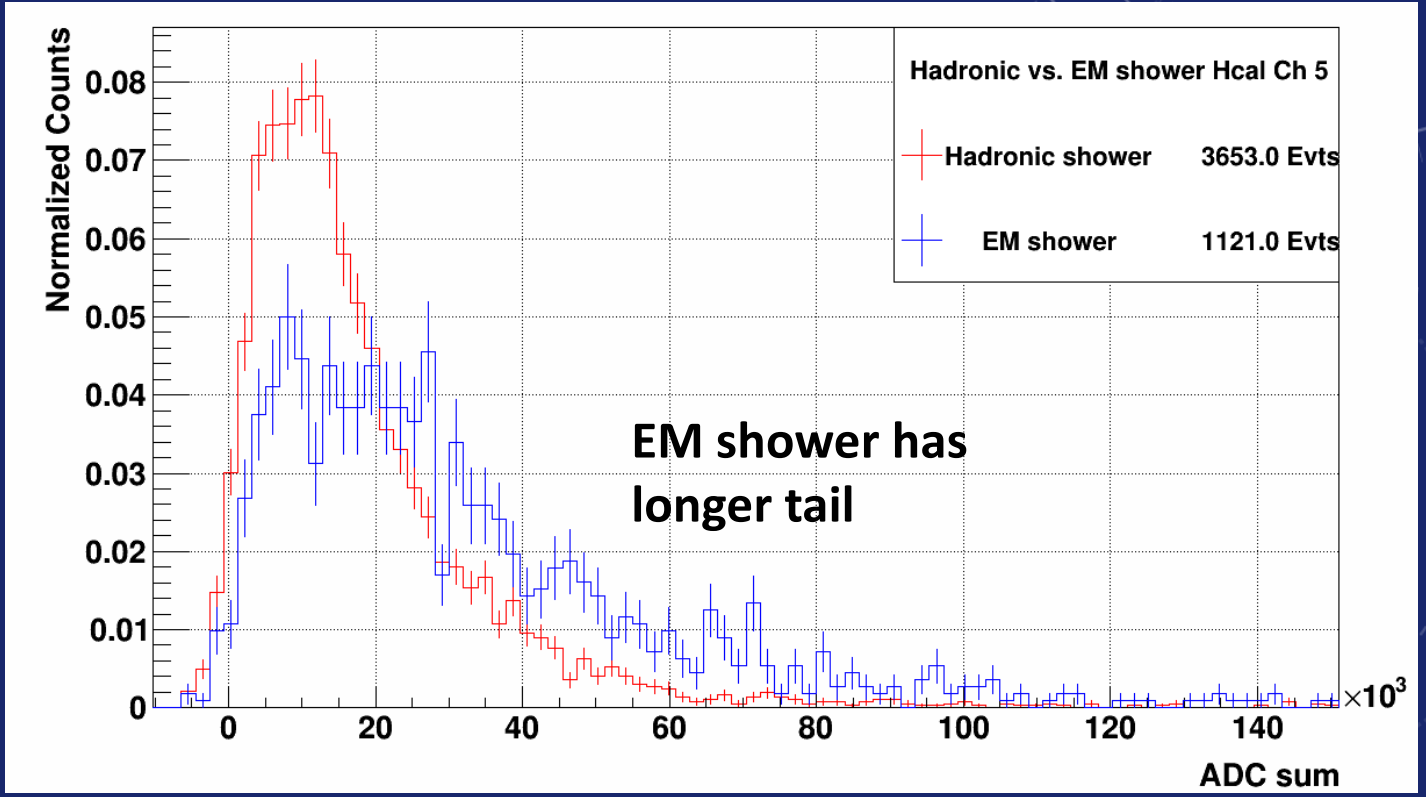
- Ecal was removed for this test and a 20cm lead block placed in front Hcal to induce showers
- Beam was 120 GeV mixed species of protons, pions, electrons
- The T0 for the inner 2x2 was averaged $T0^{AvgCent}$ was compared to the outer channels T0 ($T0^{Outer}$)
- Also the $T0^{AvgCent}$ was compared to the average T0 for the outer channels ($T0^{AvgOuter}$)



- As can be seen in both plots no there is no significant difference between signal times between outer and inner sectors
  - The 2ns shift is merely coming from travel time of shower from one cell to next

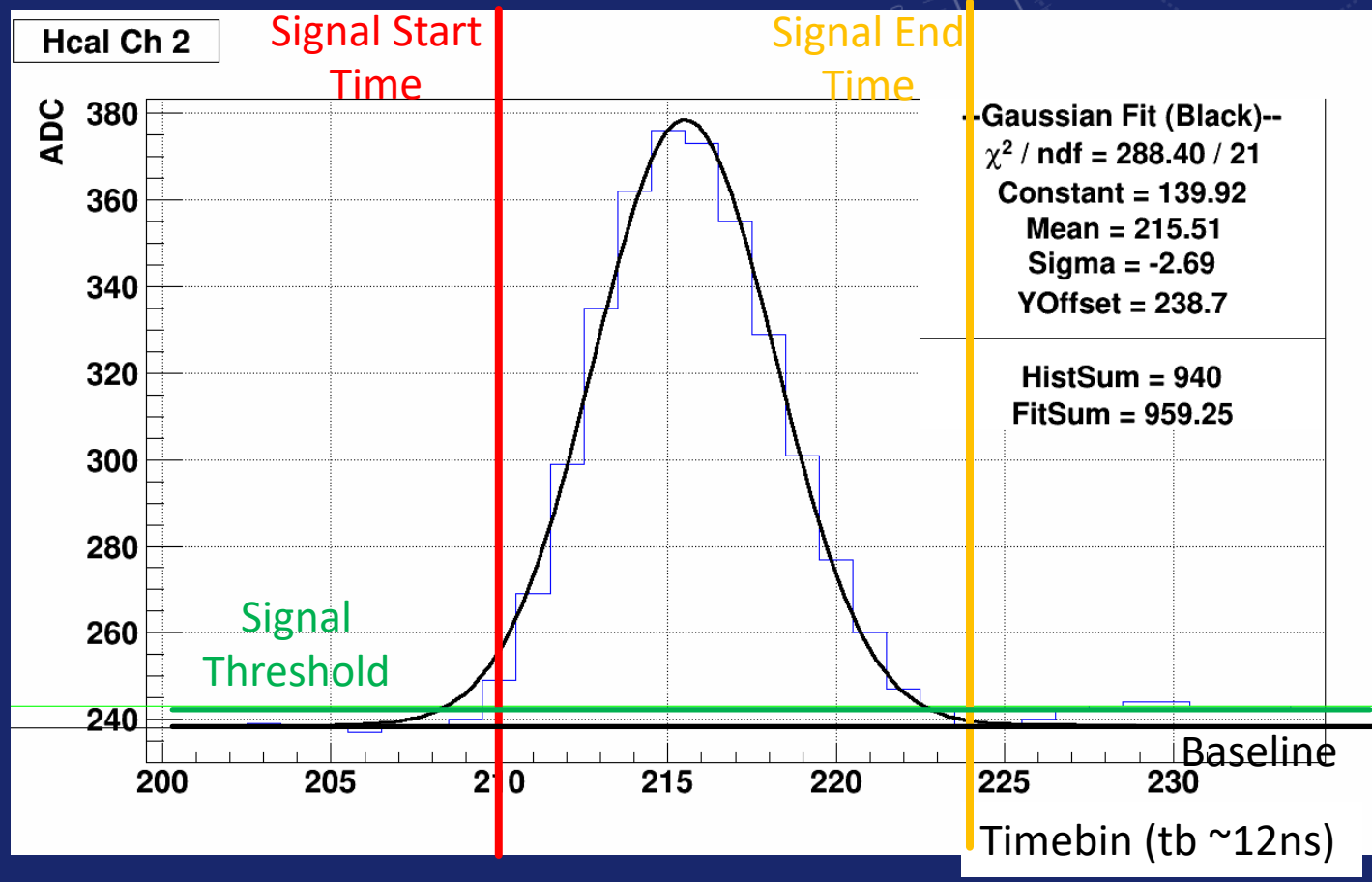
EM and Hadronic Showers

- The difference between electromagnetic showers and hadronic showers was also explored by UCR grad student Ding Chen
- The setup again included just the Hcal (no Pb) and the same mixed beam but at 20GeV
- Electron ID using FNAL Chernkov Counter tuned to electrons
- Compare the adc sum from EM shower to Hadronic showers
  - ADC sum was the found T0 plus 100 tb
- From plot it looks like Hadronic and EM showers do have different profiles

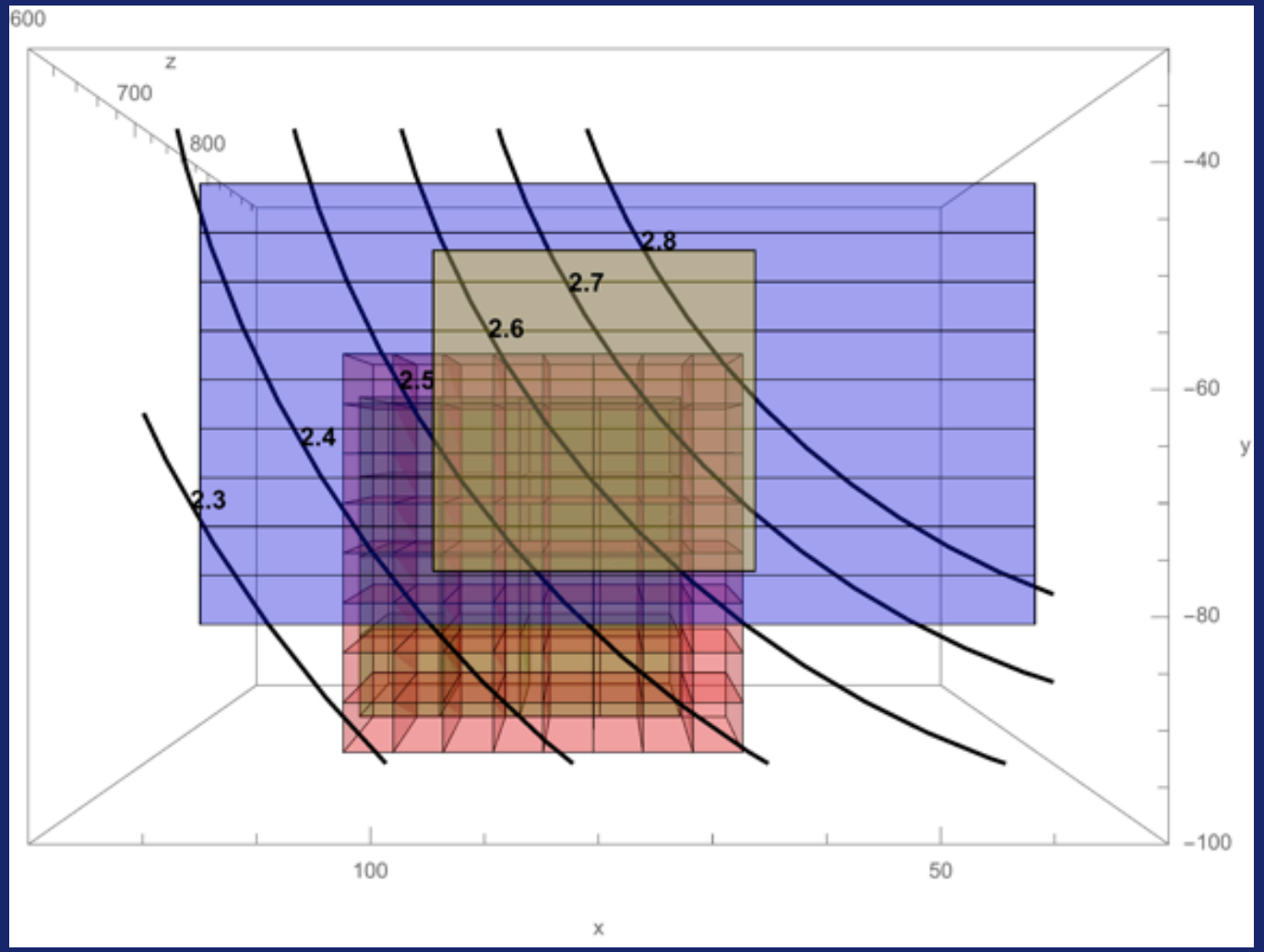


Pulser DEP signals and Signal Fitting

- Figure on right shows sample signal from Hcal
  - Blue histogram is signal
  - Black Gaussian line is Fit
  - Hcal and Ecal signal similar
- Algorithm first determines start and end time for signal based on signal threshold and ADC differences (derivative)
  - Modified FNAL algorithm
  - Ongoing development
- Start and End Tb are used for fit range
- Integration from summing ADC vs. Fit is also shown



Geometry with Eta Rings



Pedestal Data

- Ecal RMS ~ 1ch
- Hcal RMS ~ 1ch
- Pres RMS ~ 5ch