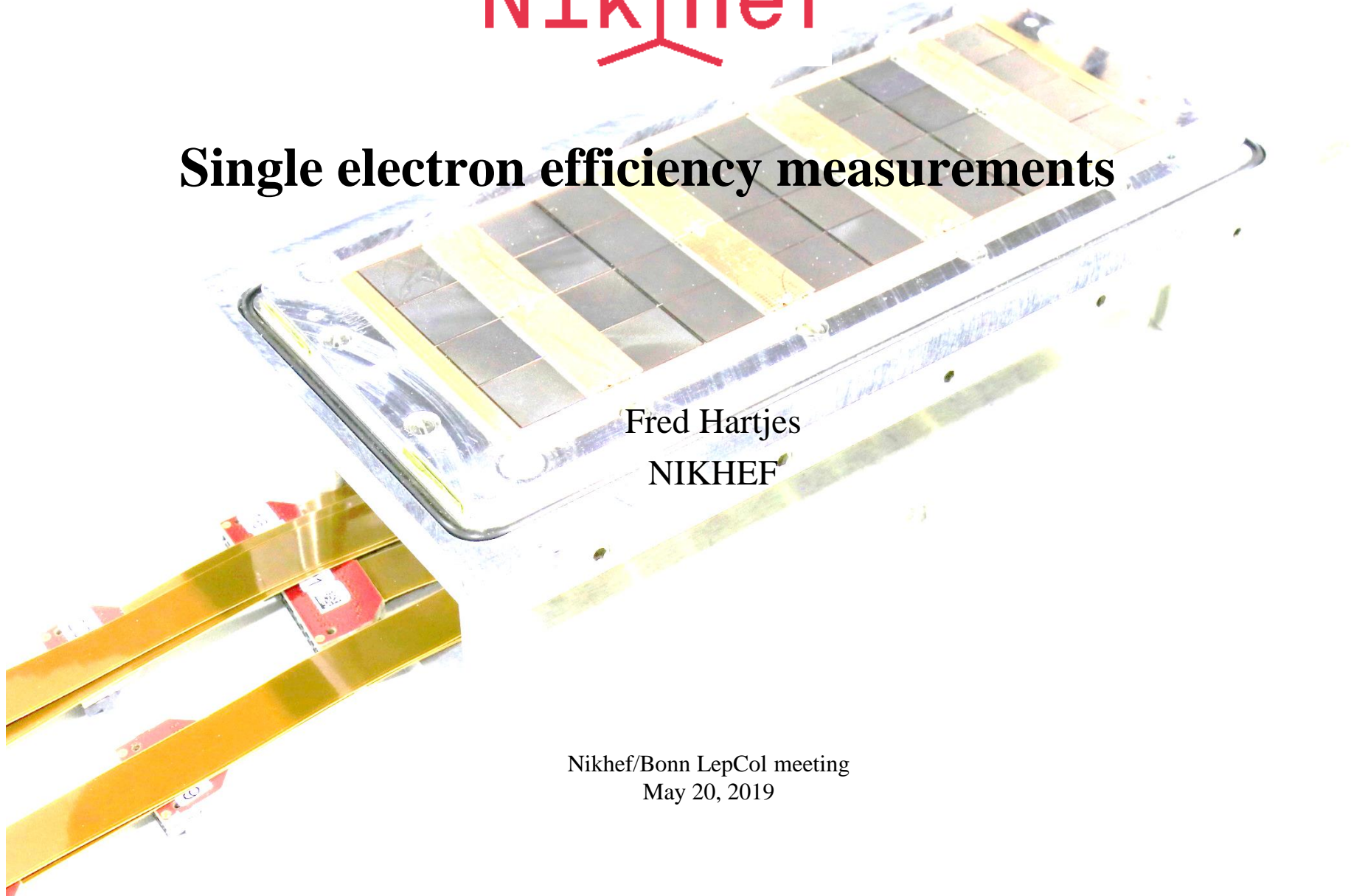




## Single electron efficiency measurements

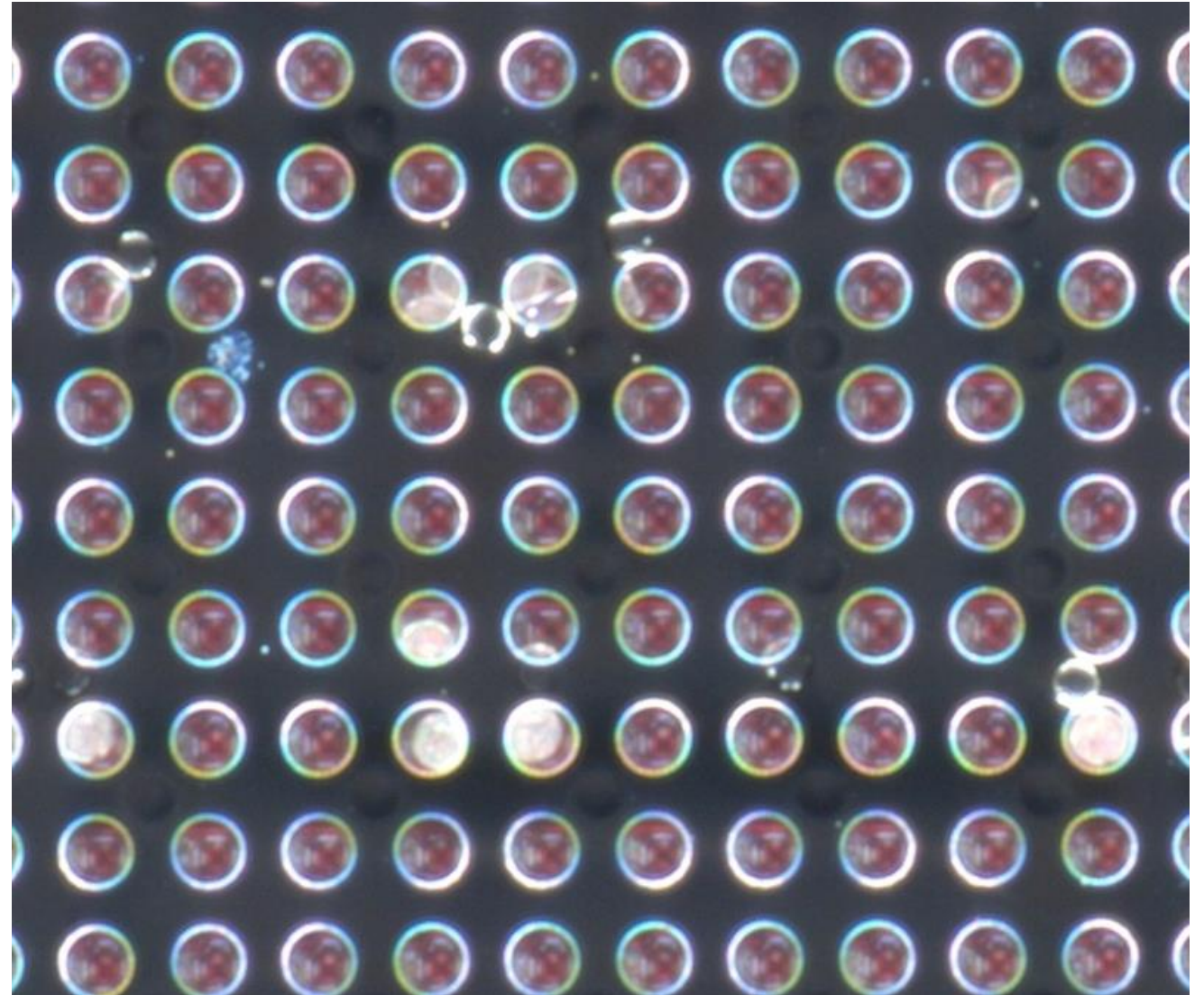
Fred Hartjes  
NIKHEF

Nikhef/Bonn LepCol meeting  
May 20, 2019



# HV problem

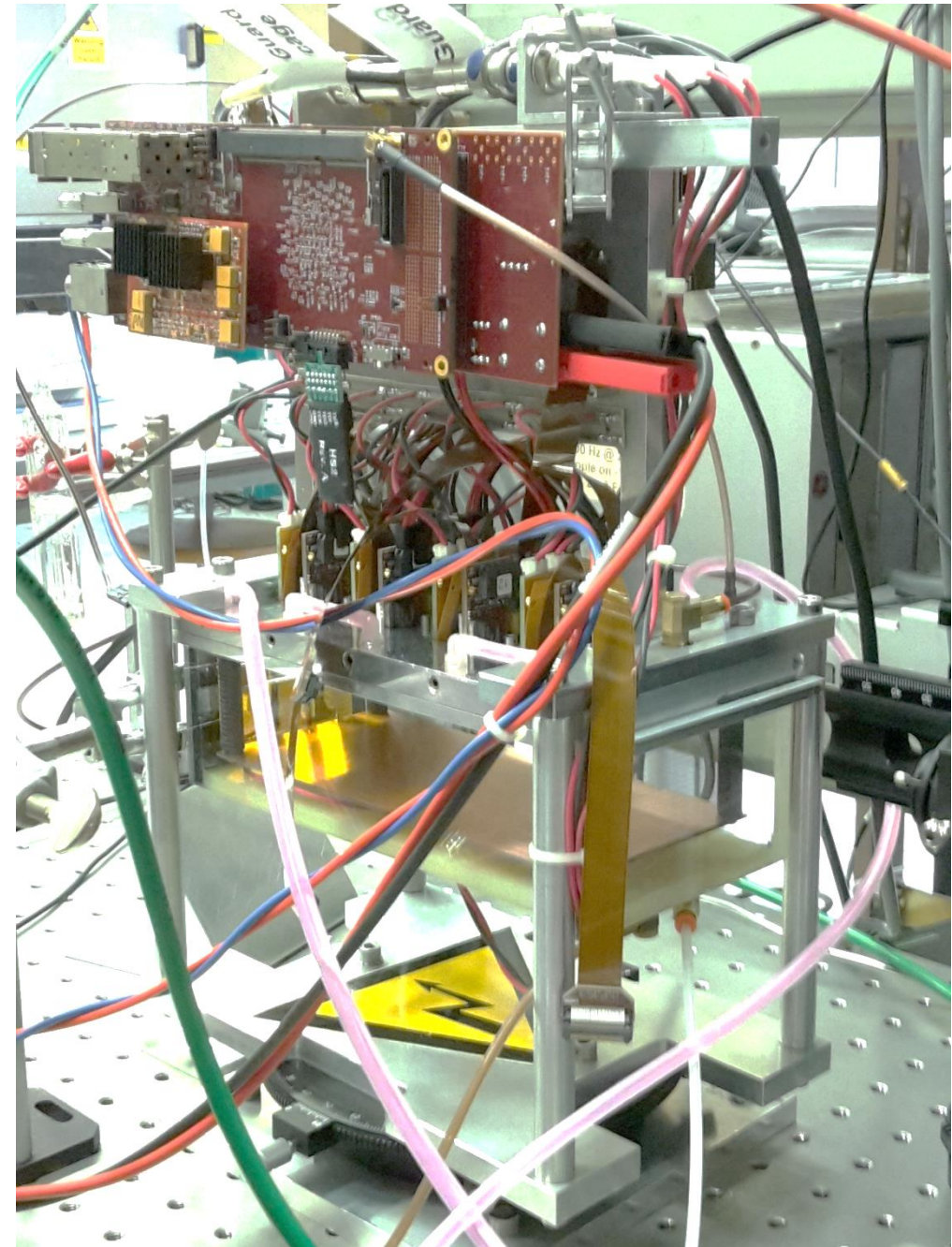
- Initially no HV problems with the textbox, but at  $V_{\text{grid}} = -360 \text{ V}$  suddenly a permanent hard short appeared
- The problems was caused by QUAD 17 where tiny disks in many of the holes of two chips
  - Chip 3: W30-E11
  - Chip 4: W30-C10
- In the textbox the QUAD was replaced
- Later on we have replace the chips on QUAD 17





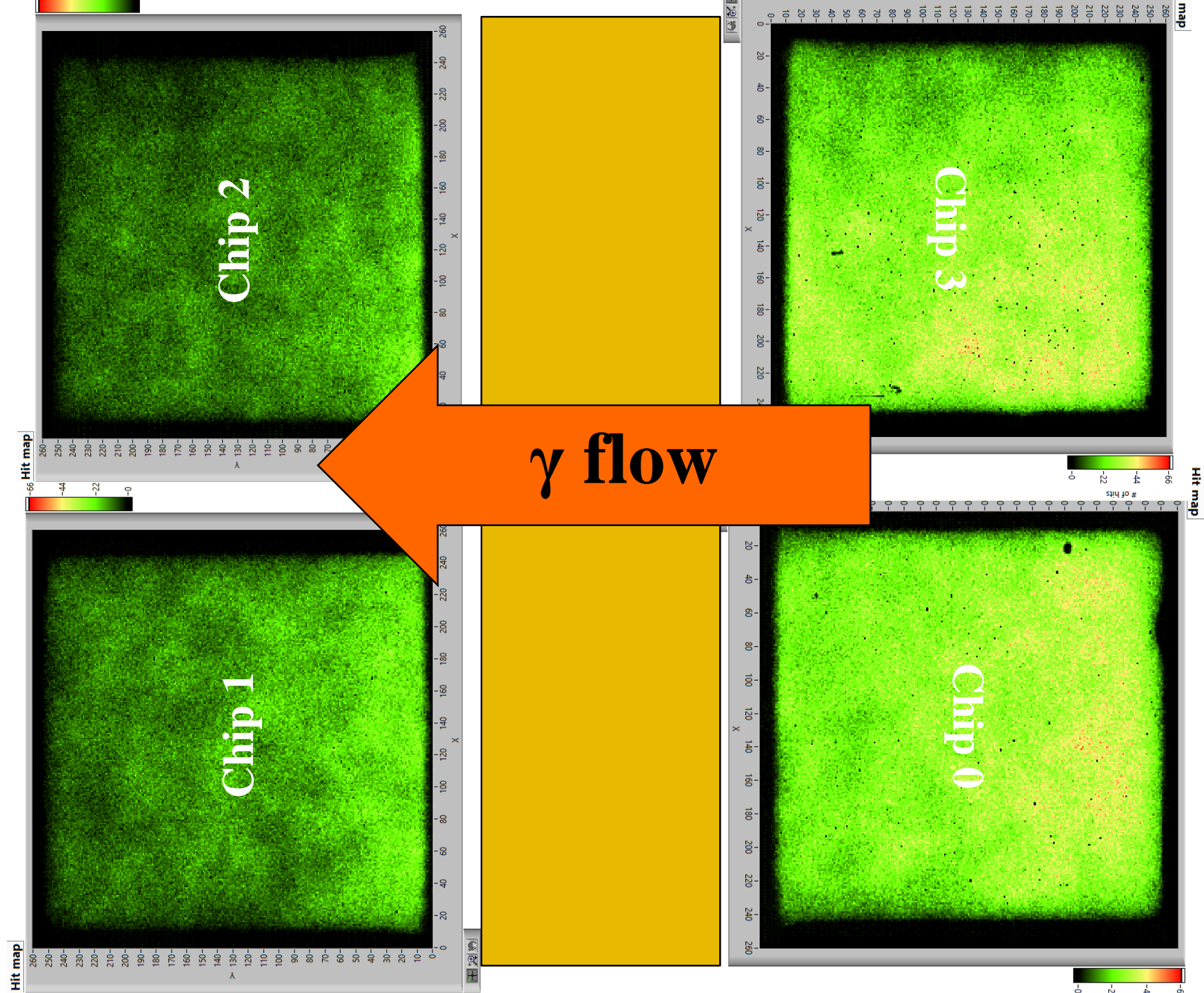
# Single electron efficiency with $^{55}\text{Fe}$ source

- Source Fe-55-04
  - 5.6 keV gamma
- Expecting with Ar the photon peak of  $\sim 220$  e- and the escape peak at  $\sim 110$  e-
- 3 gas mixtures tried
  - T2K
  - T3K (3% iC4H10)
  - 18% iC4H10 + Ar
- Done for 8 – 9 different grid voltages, 170 s per run
- Cluster tracing by finding hits within -40 to 400 ns window from 1<sup>st</sup> hit
- Cluster rate 25 – 100 Hz depending on chip position
  - $\Rightarrow I_{\text{grid}} \sim 10$  pA/chip
  - $\Rightarrow$  hardly voltage drop across the protection layer



# Hitmaps at $V_{\text{grid}} = -320 \text{ V}$

- T2K gas
- Using  $^{55}\text{Fe}$  source
- 5 micro discharges during 170 s
- Identical Z scale for all plots

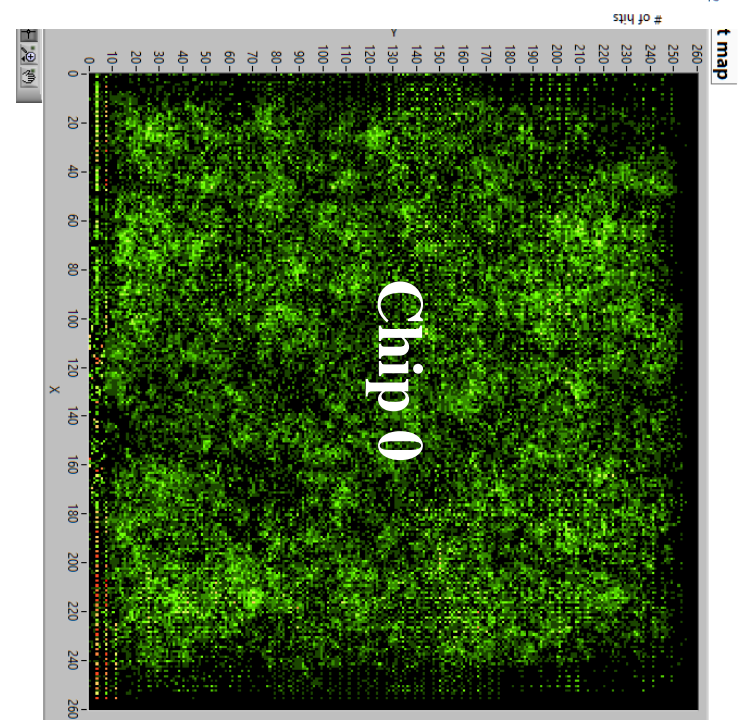
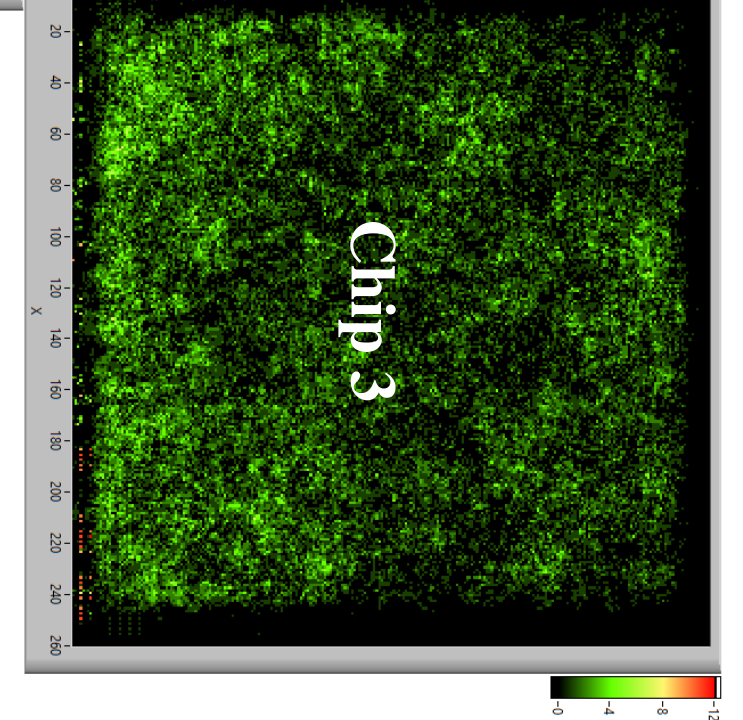
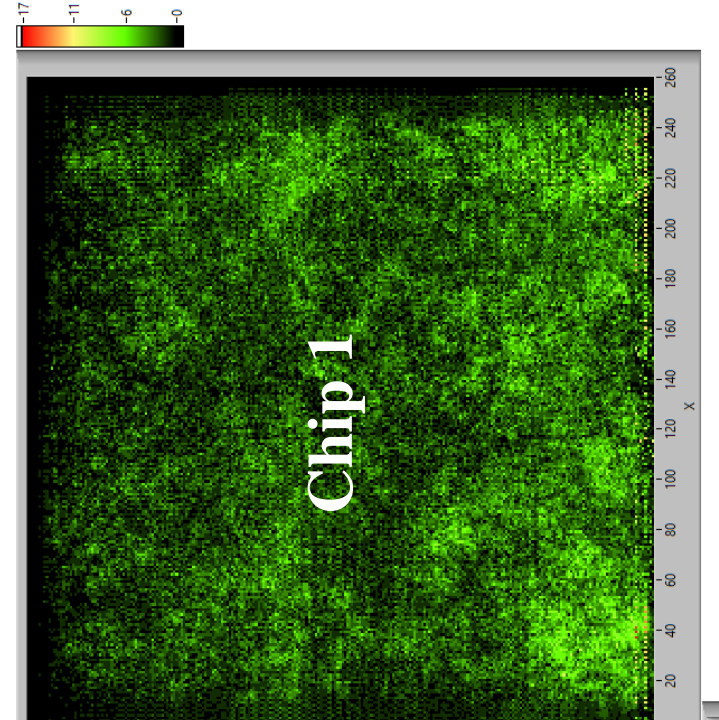
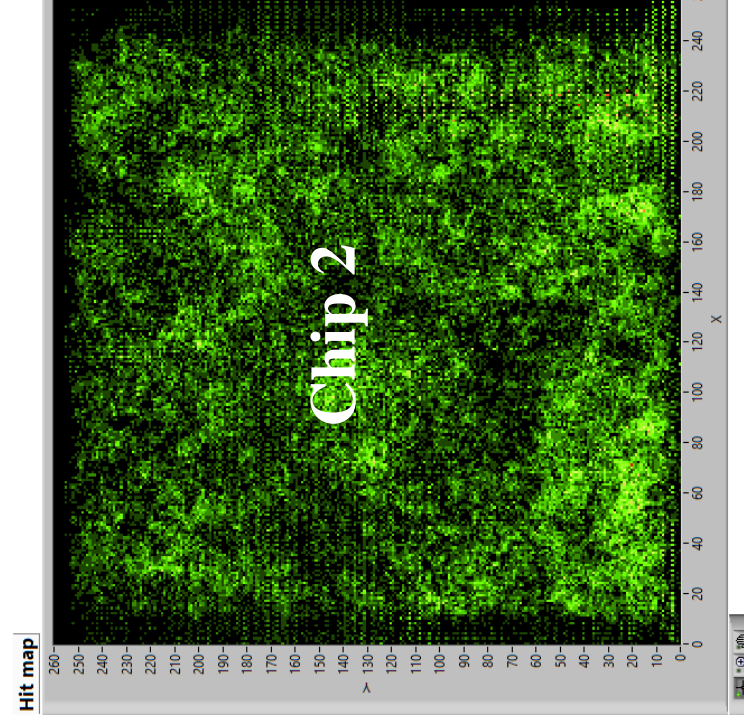




# Hitmaps at $V_{gid} = -350 \text{ V}$

■ No  $^{55}\text{Fe}$  source

■ 16 micro discharges during 170 s



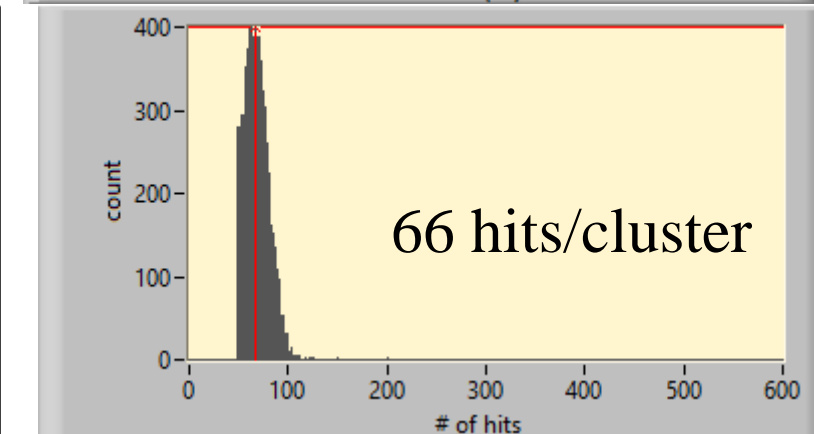
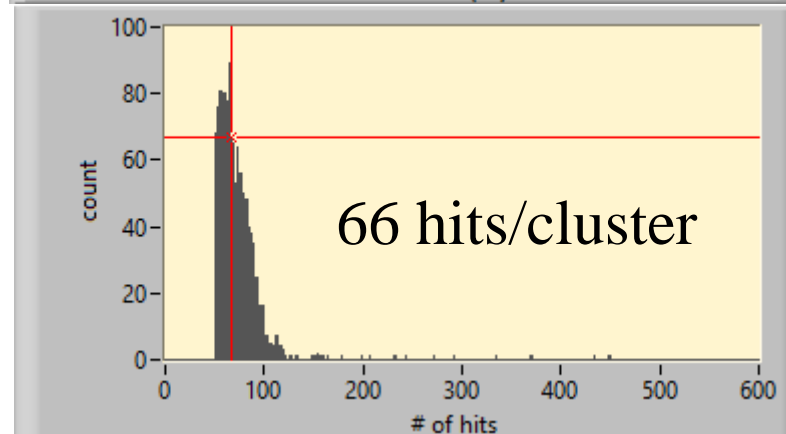
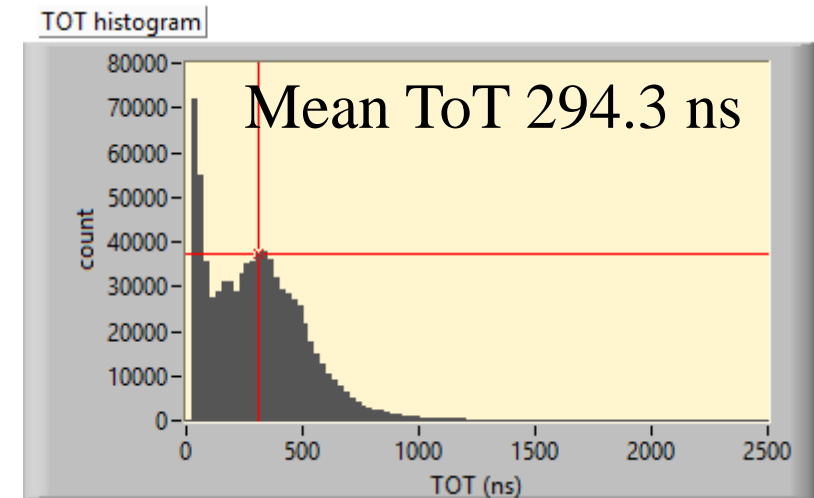
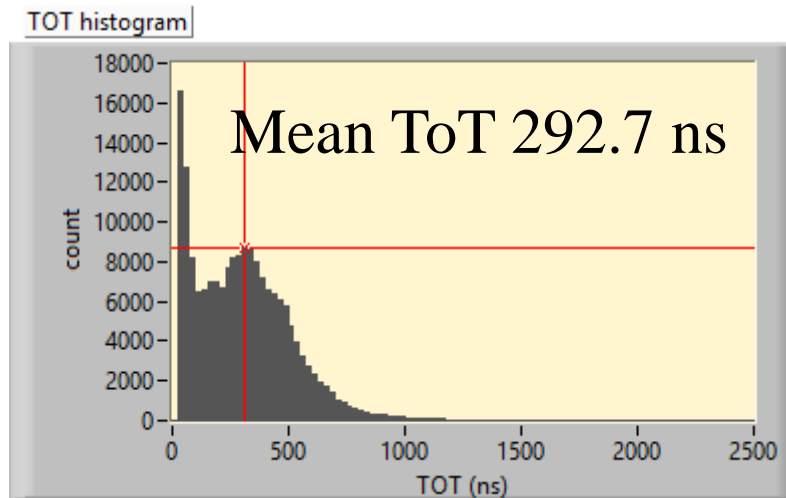
# Measurements with iC4H10/Ar 18/82

# $^{55}\text{Fe}$ measurements with Ar/ $i\text{C}_4\text{H}_{10}$ 82/18 $V_{\text{grid}} = -340 \text{ V}$

- One micro discharge

Chip 2

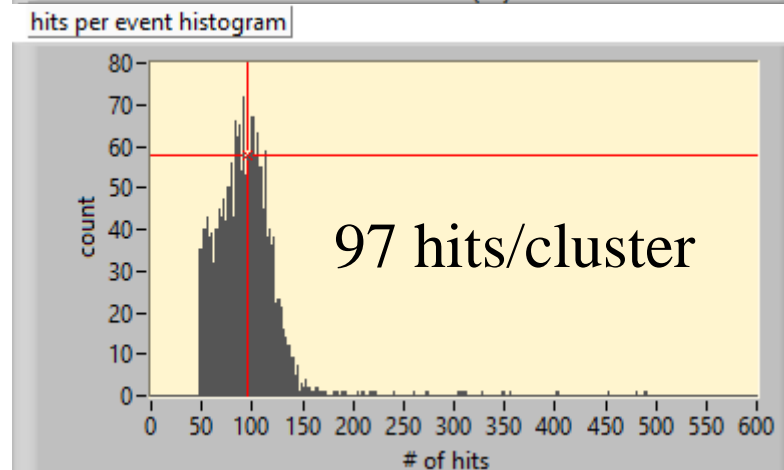
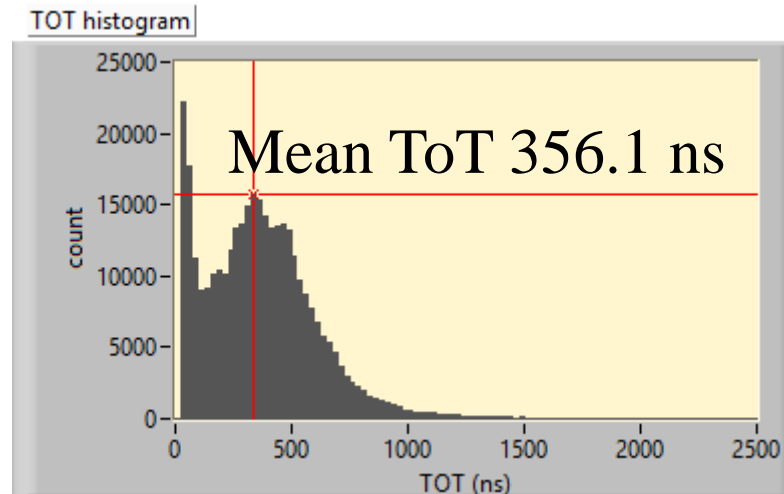
Chip 0



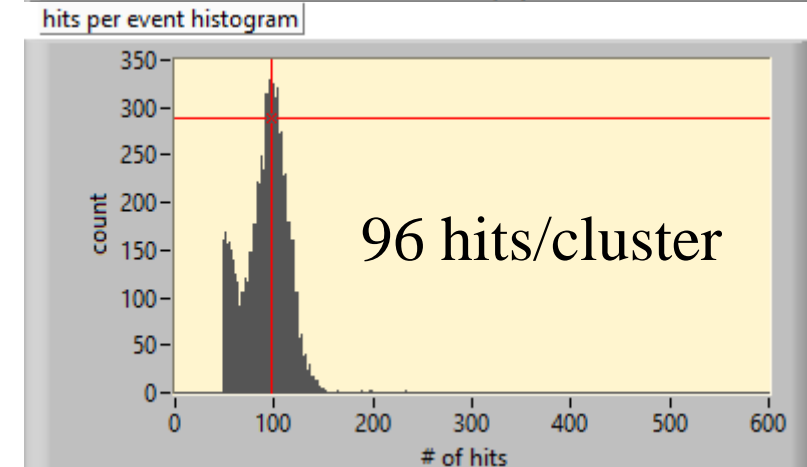
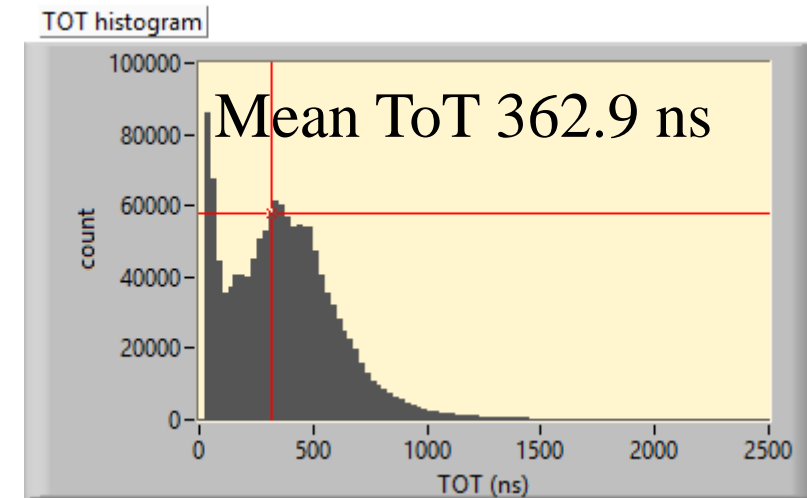
# $^{55}\text{Fe}$ measurements with Ar/ $i\text{C}_4\text{H}_{10}$ 82/18 $V_{\text{grid}} = -350 \text{ V}$

- No micro discharge

## Chip 2



## Chip 0



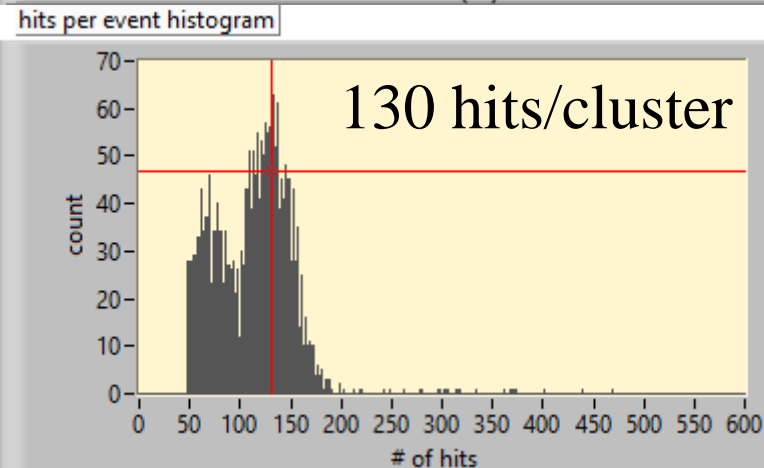
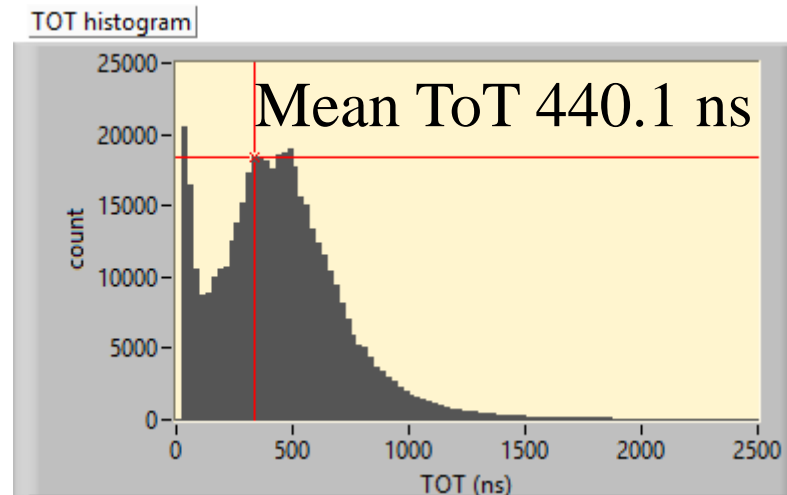


# 55Fe measurements with Ar/iC<sub>4</sub>H<sub>10</sub> 82/18

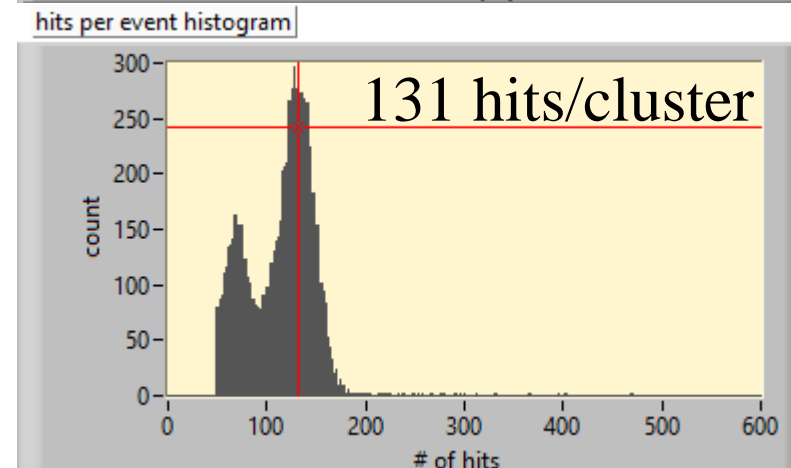
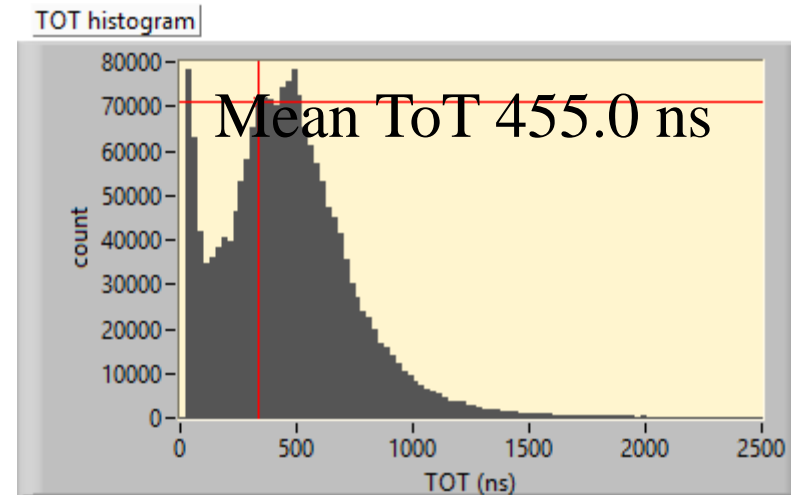
## Vgrid = -360 V

- No micro discharges

### Chip 2



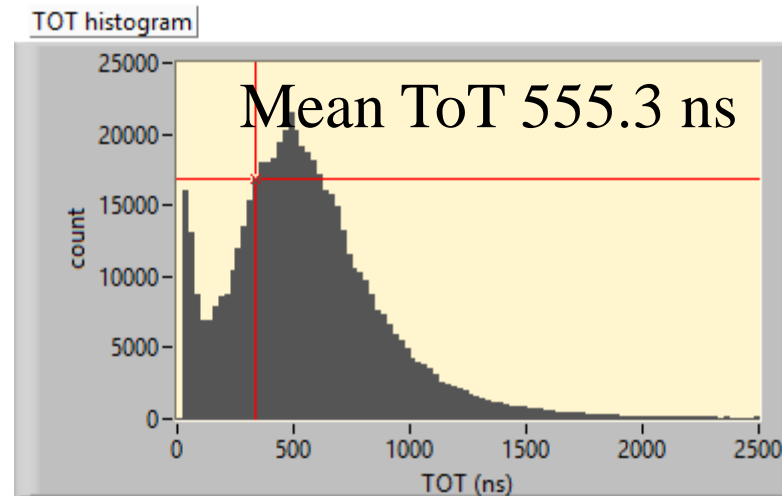
### Chip 0



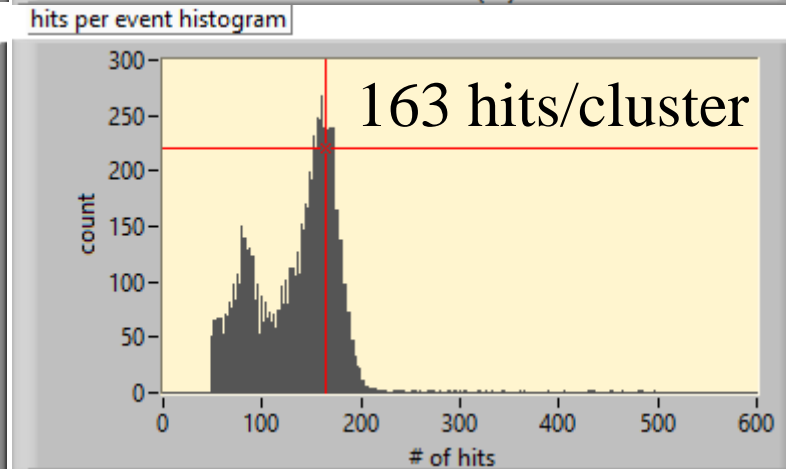
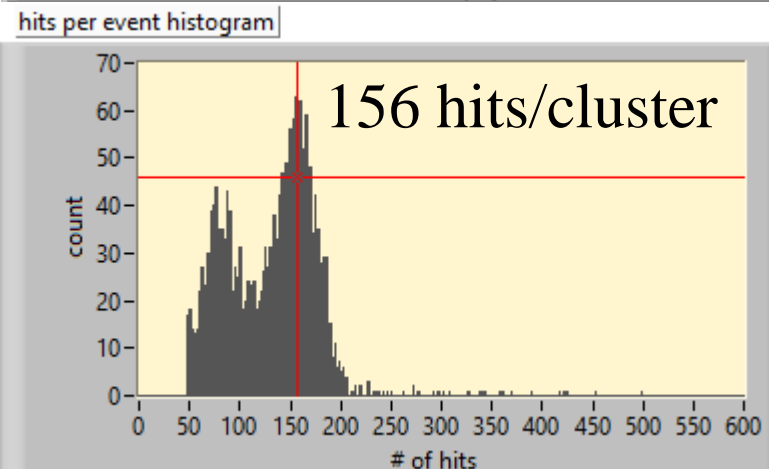
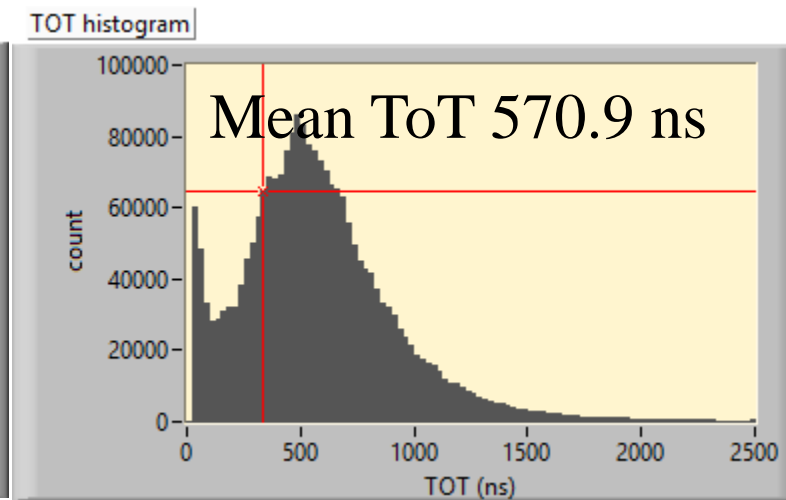
# $^{55}\text{Fe}$ measurements with Ar/ $i\text{C}_4\text{H}_{10}$ 82/18 $V_{\text{grid}} = -370 \text{ V}$

- No micro discharges

## Chip 2



## Chip 0

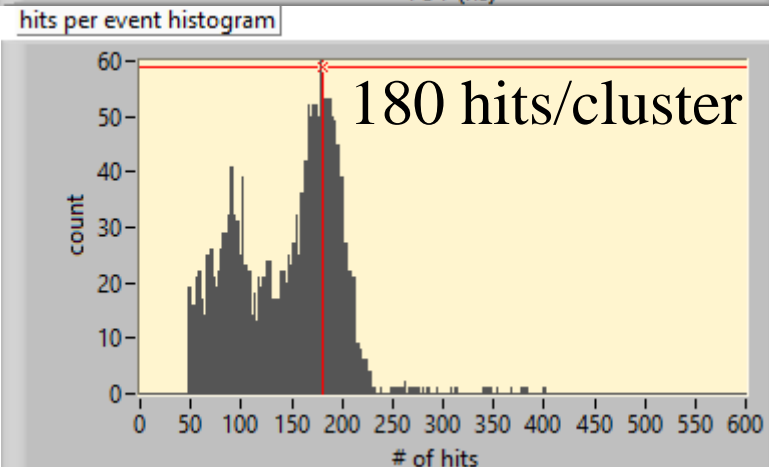
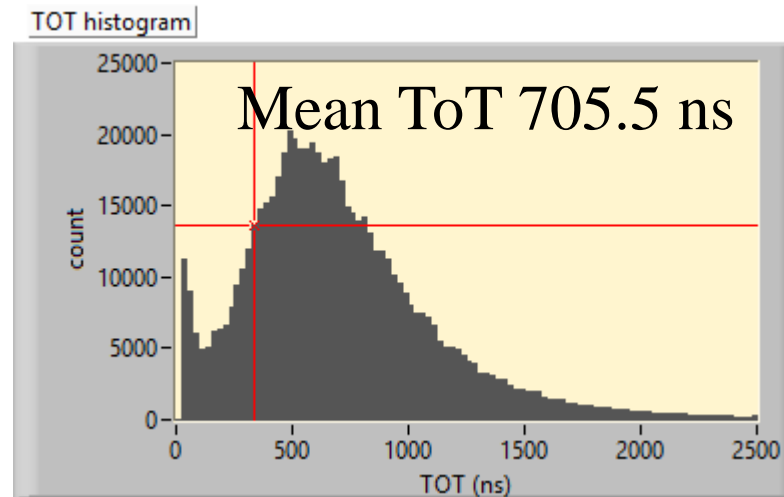


# 55Fe measurements with Ar/iC<sub>4</sub>H<sub>10</sub> 82/18

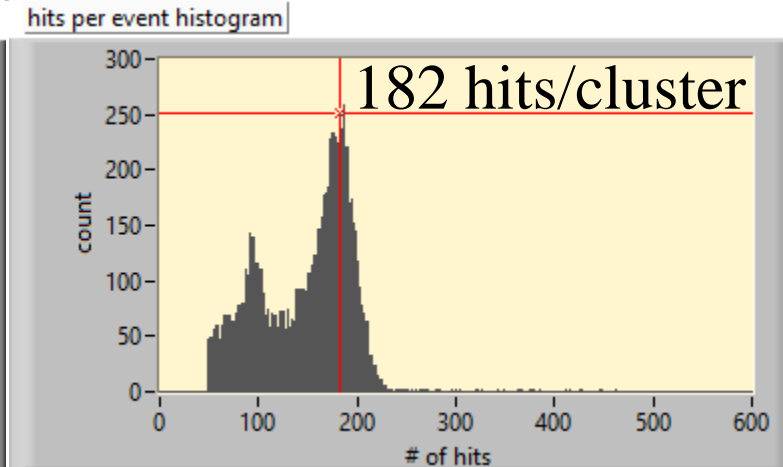
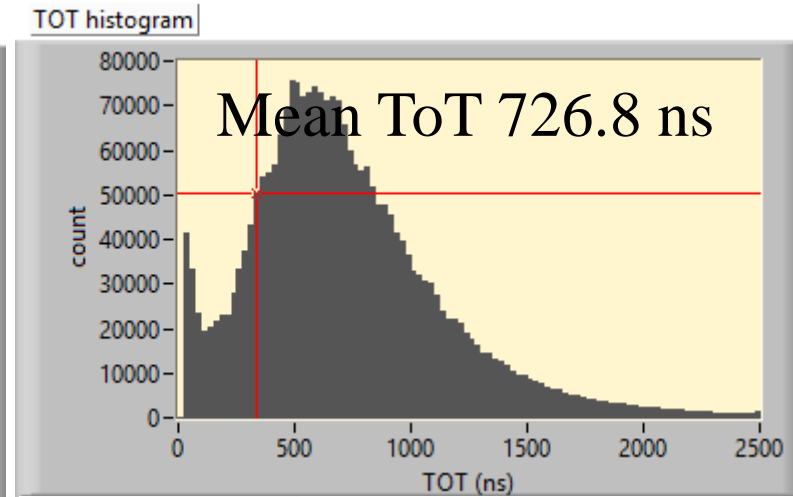
## Vgrid = -380 V

- No micro discharges

### Chip 2



### Chip 0





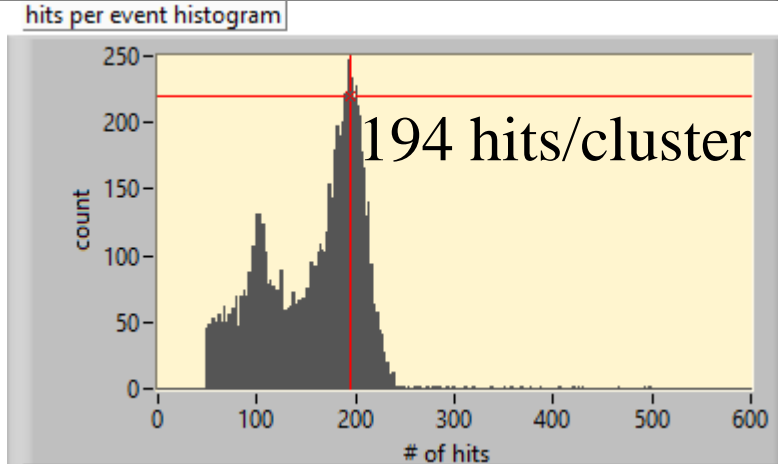
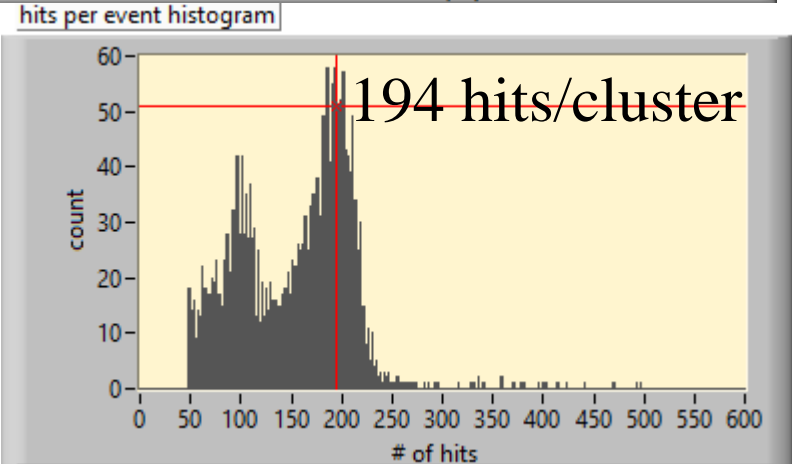
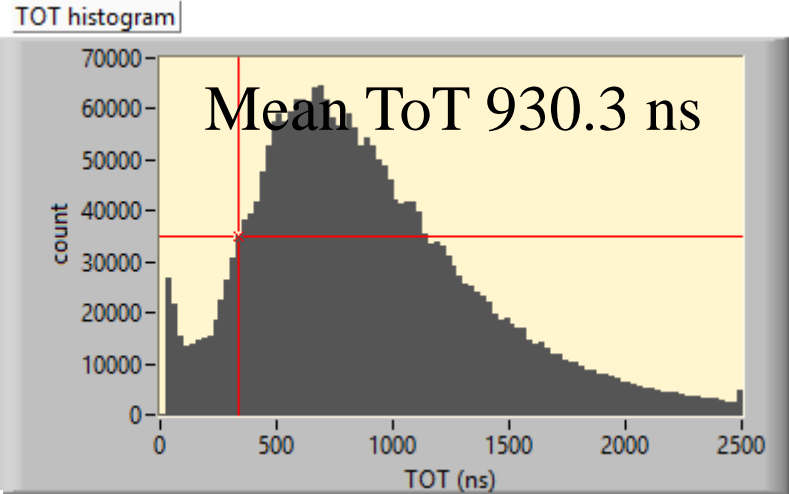
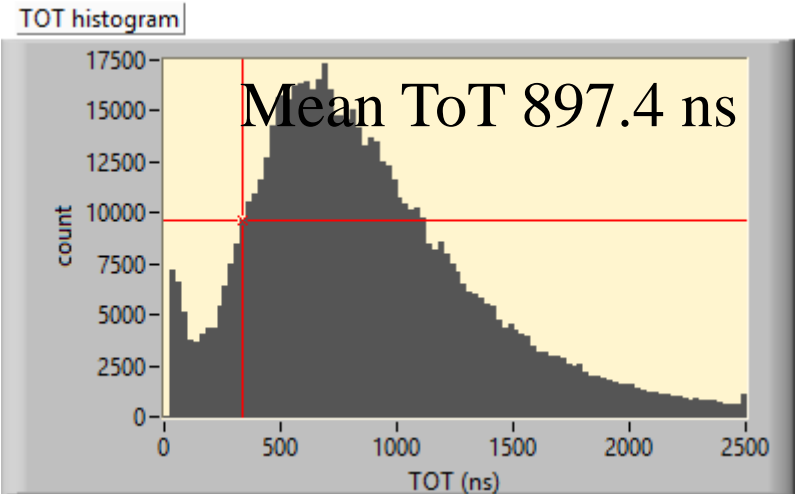
# 55Fe measurements with Ar/iC<sub>4</sub>H<sub>10</sub> 82/18

Vgrid = -390 V

■ One micro discharge

Chip 2

Chip 0

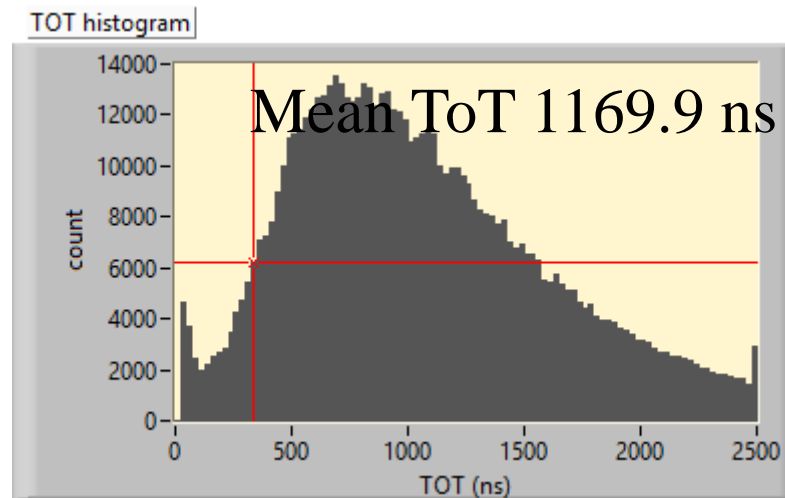


# $^{55}\text{Fe}$ measurements with Ar/ $i\text{C}_4\text{H}_{10}$ 82/18

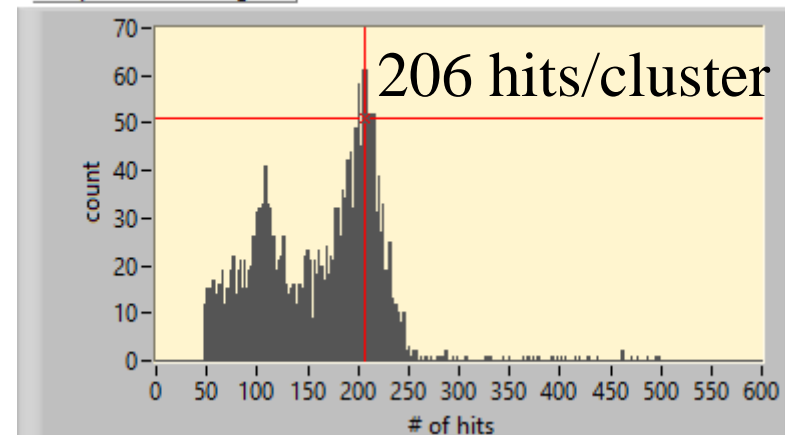
## $V_{\text{grid}} = -400 \text{ V}$

- One micro discharge

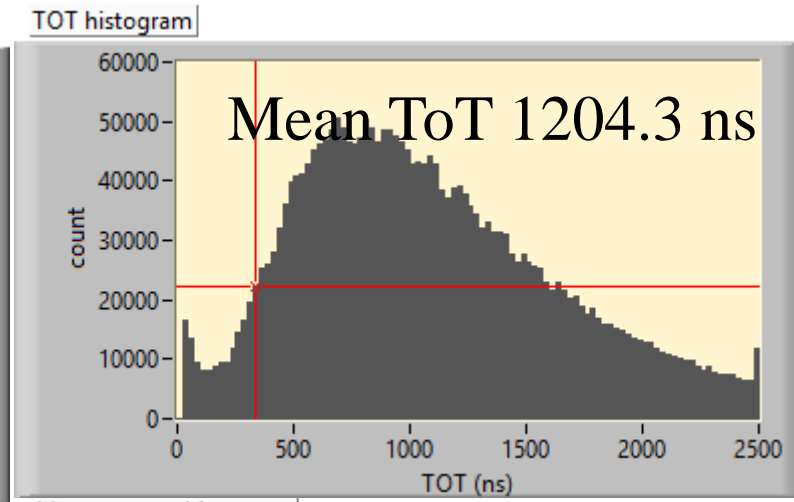
### Chip 2



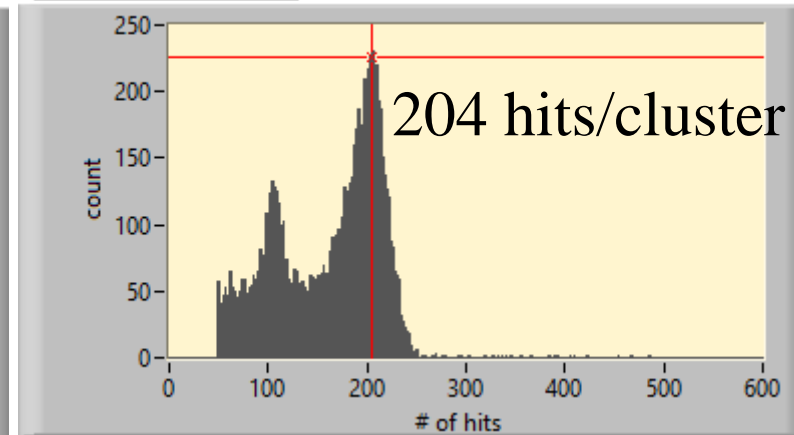
hits per event histogram



### Chip 0



hits per event histogram

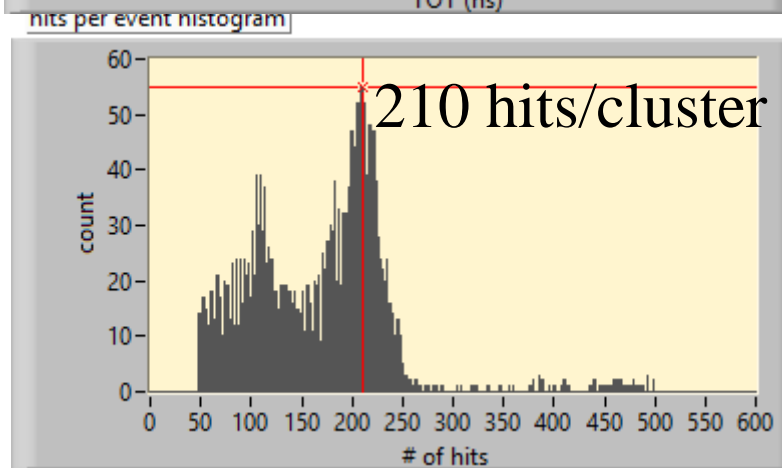
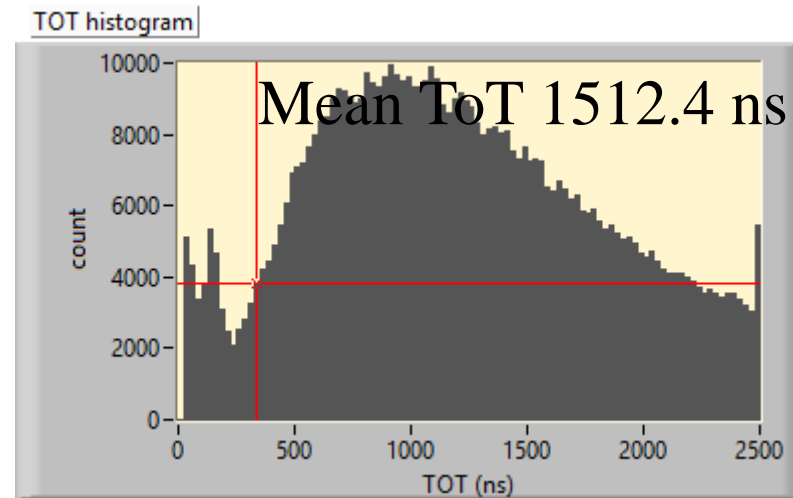


# $^{55}\text{Fe}$ measurements with Ar/ $i\text{C}_4\text{H}_{10}$ 82/18

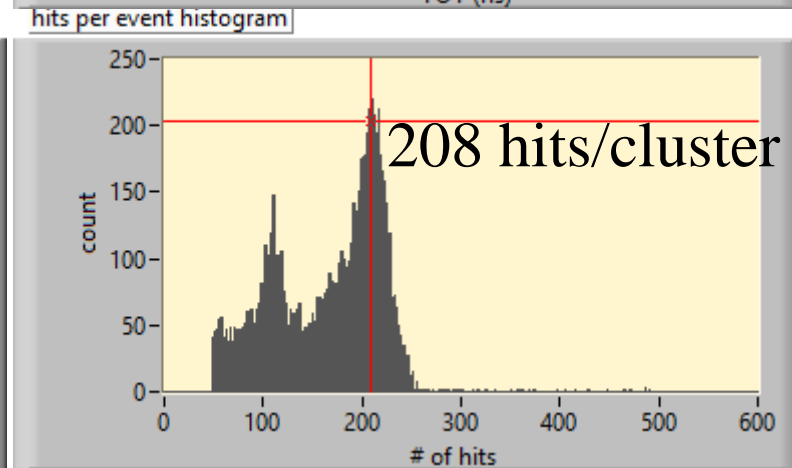
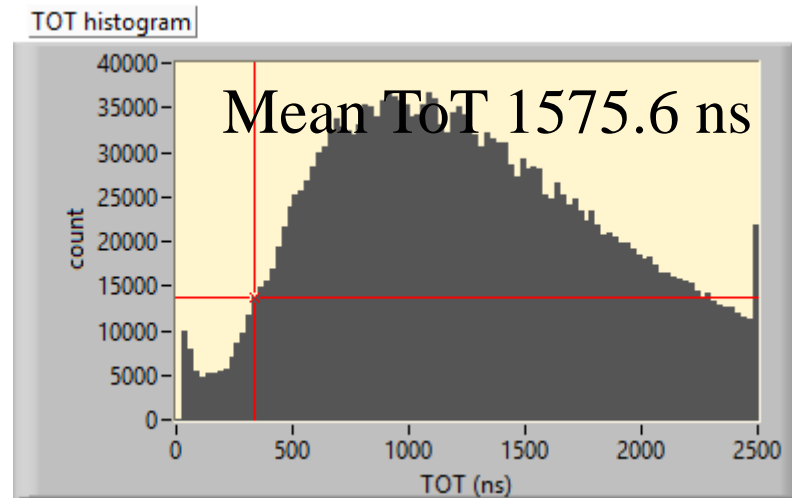
## $V_{\text{grid}} = -410 \text{ V}$

- Two micro discharges

### Chip 2



### Chip 0





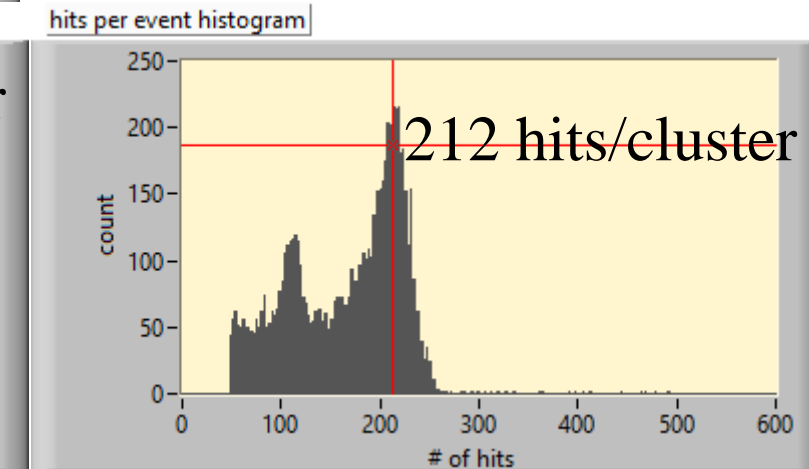
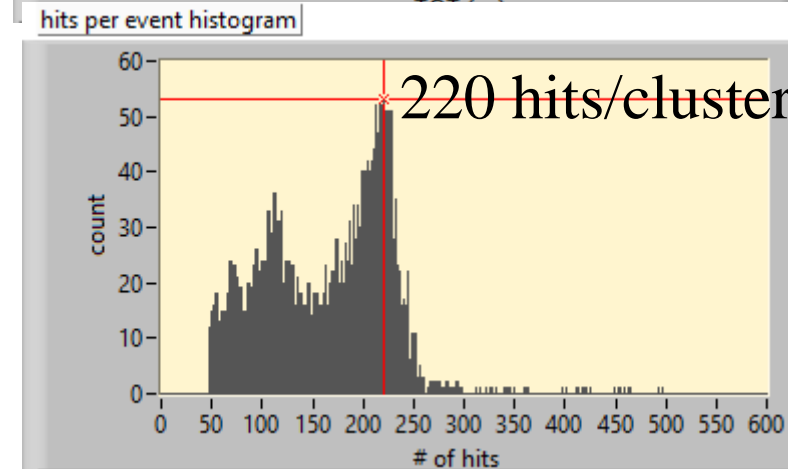
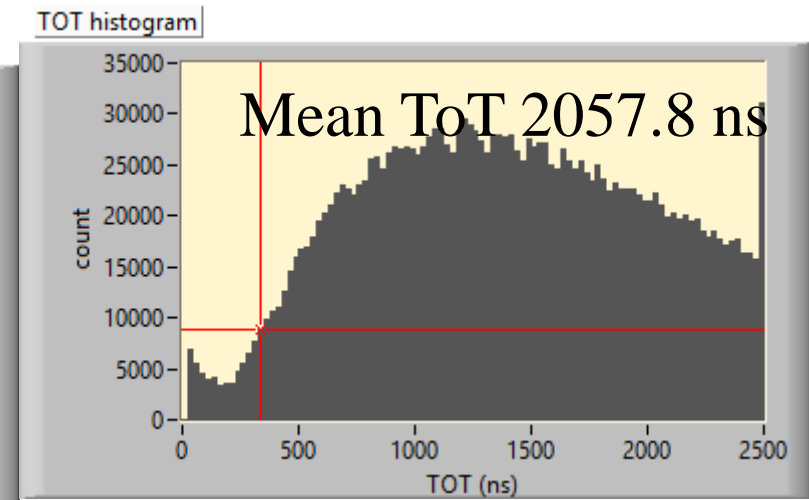
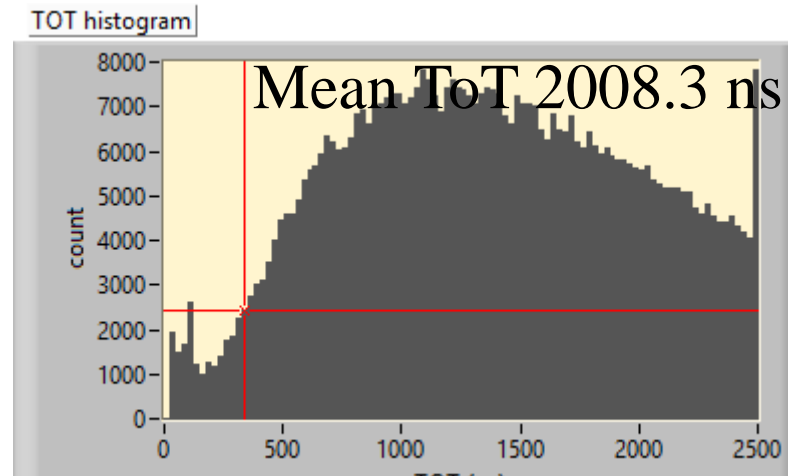
# 55Fe measurements with Ar/iC<sub>4</sub>H<sub>10</sub> 82/18

## Vgrid = -420 V

- No micro discharges

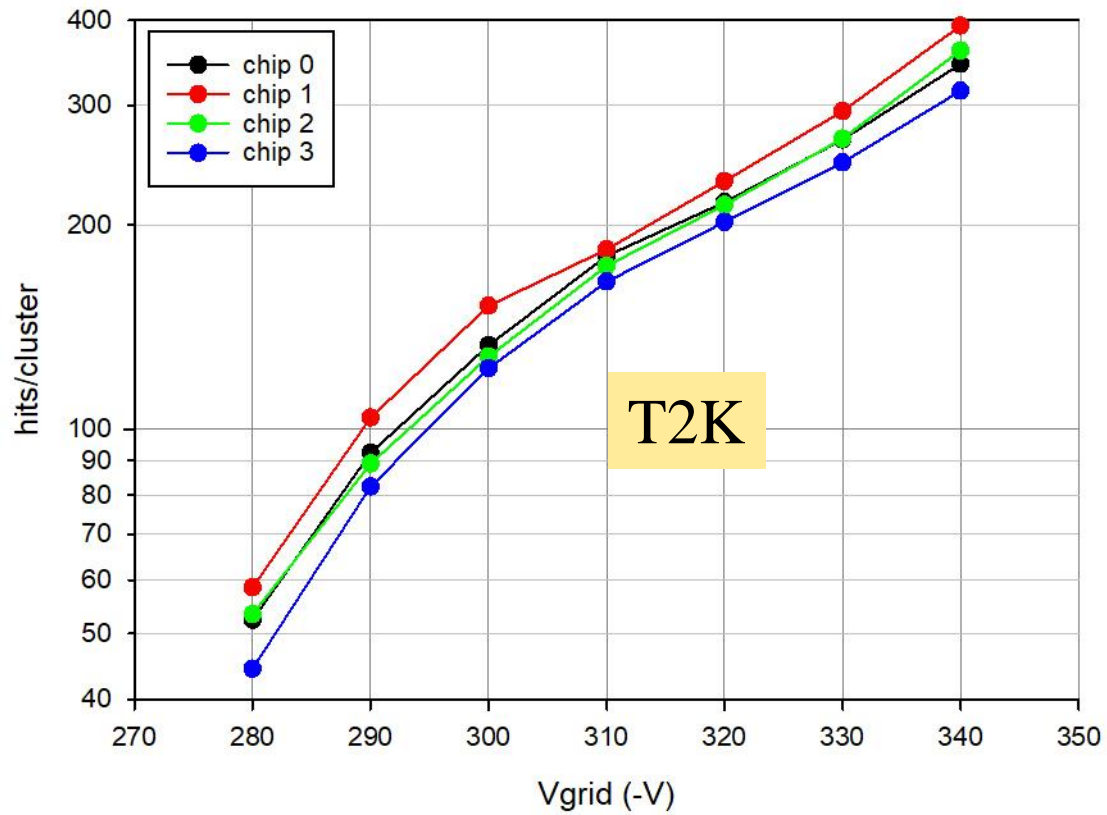
### Chip 2

### Chip 0



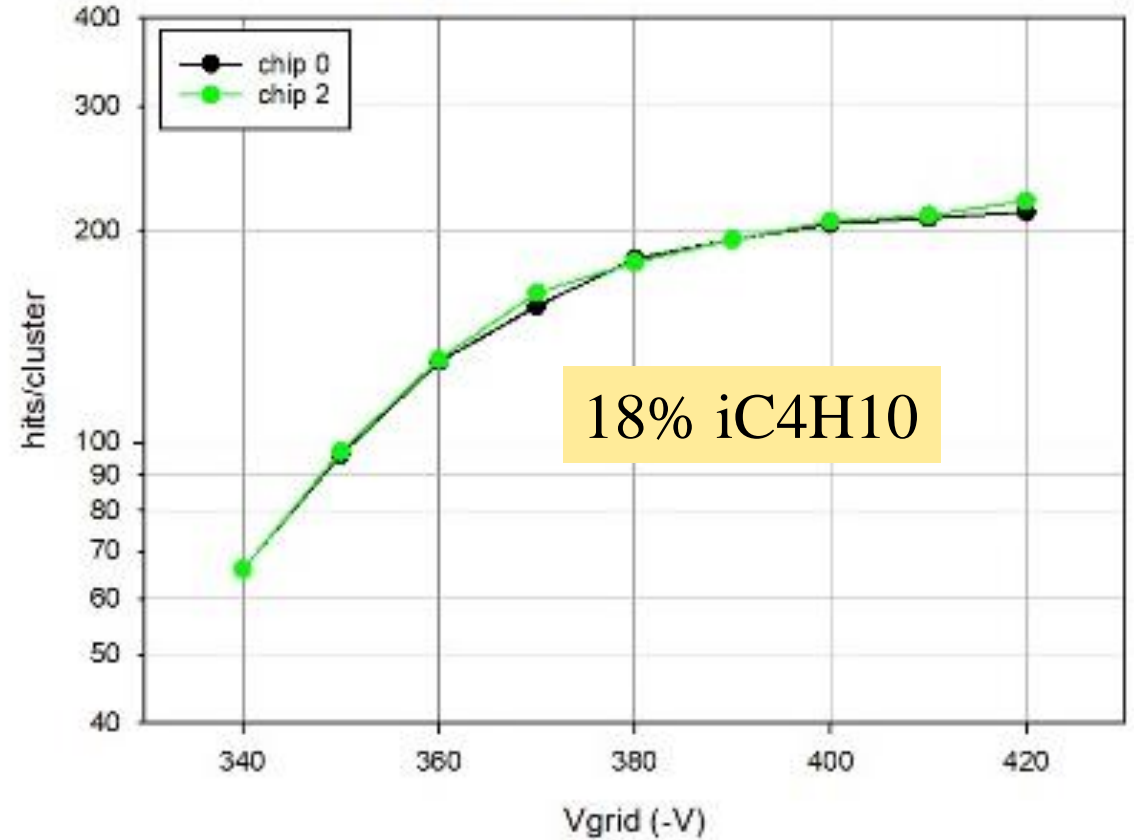
# Comparison hits/cluster

QUAD 13 hits/cluster vs Vgrid  
55Fe irradiation



QUAD 13 hits/cluster vs Vgrid  
55Fe irradiation

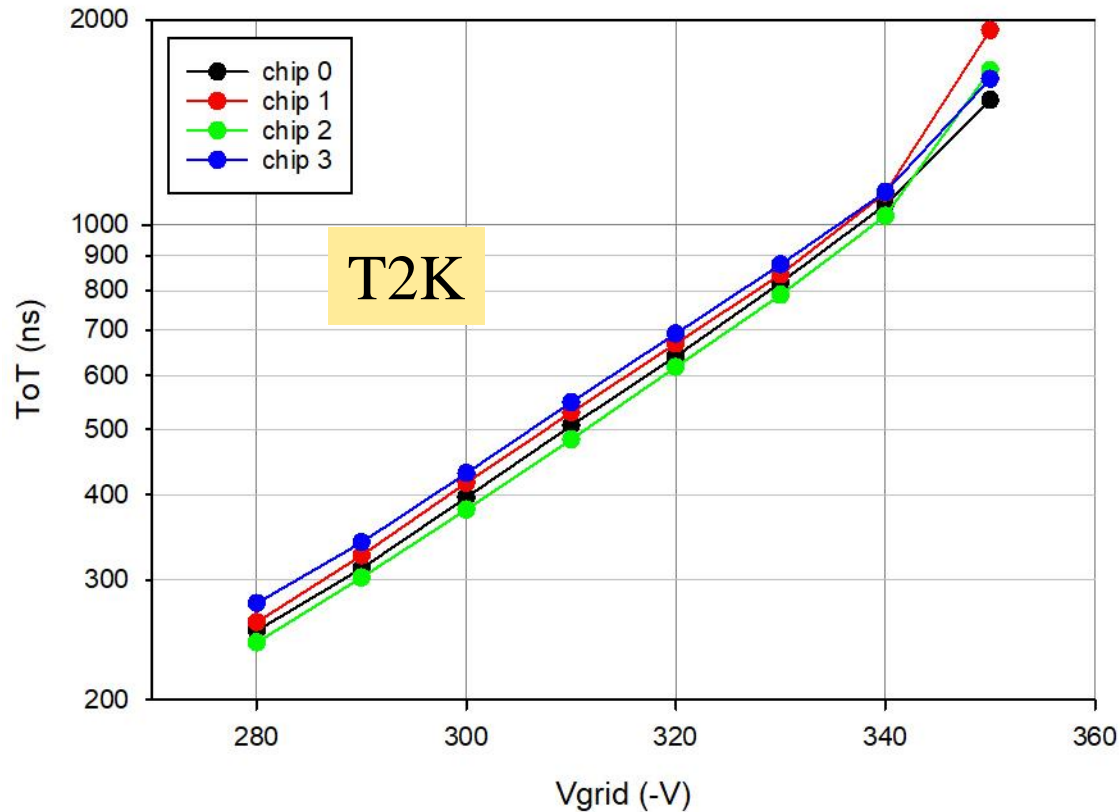
Data 30 - 4 - 2019  
Ar/iC4H10 82/18



# Comparison mean ToT

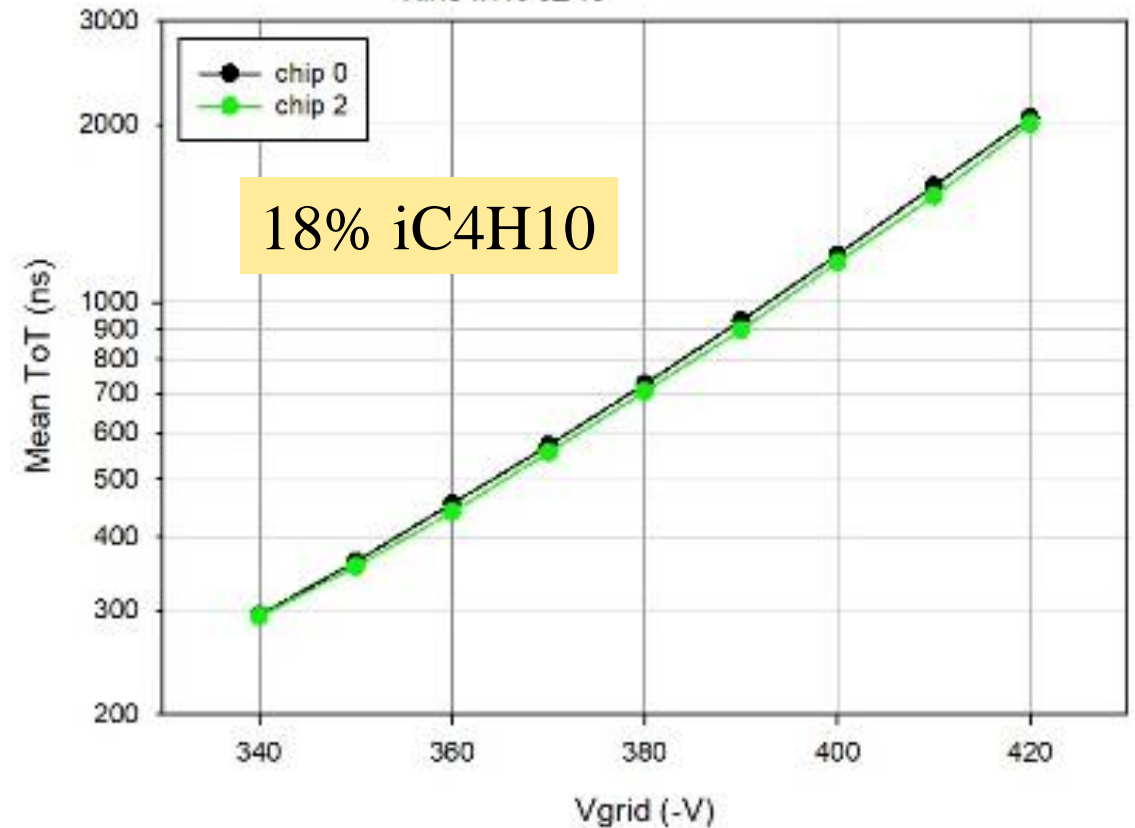
- ToT for laser measurements ~20% lower
  - $^{55}\text{Fe}$  values affected by pile-up?

QUAD 13 ToT vs Vgrid  
 $^{55}\text{Fe}$  irradiation



QUAD 13 ToT vs Vgrid  
 $^{55}\text{Fe}$  irradiation

Data 30 - 4 - 2019  
Ar/iC4H10 82/18





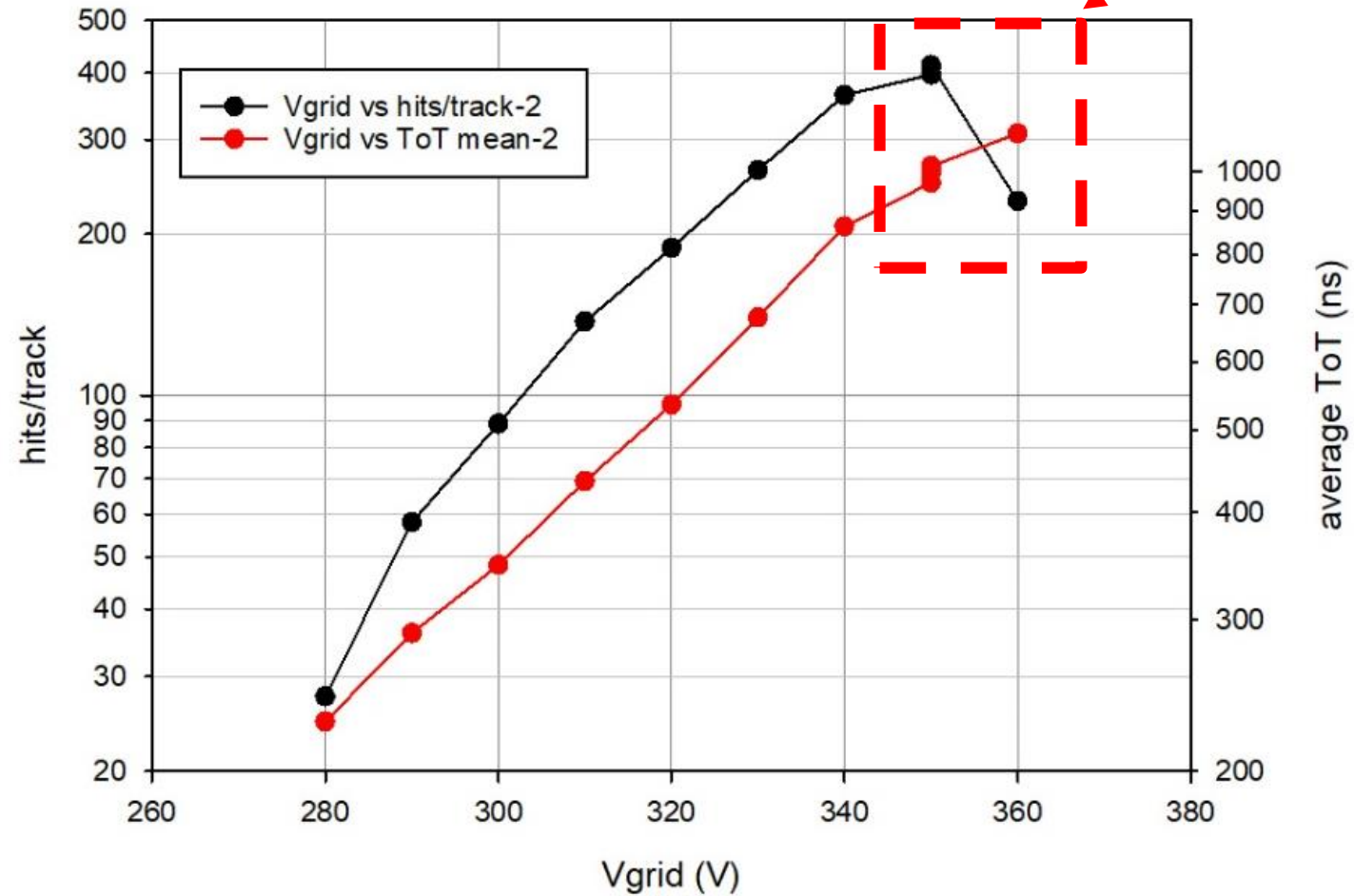
# Laser measurement using T2K gas

## Hits/track and ToT vs Vgrid

■ No plateau

2D Graph 1

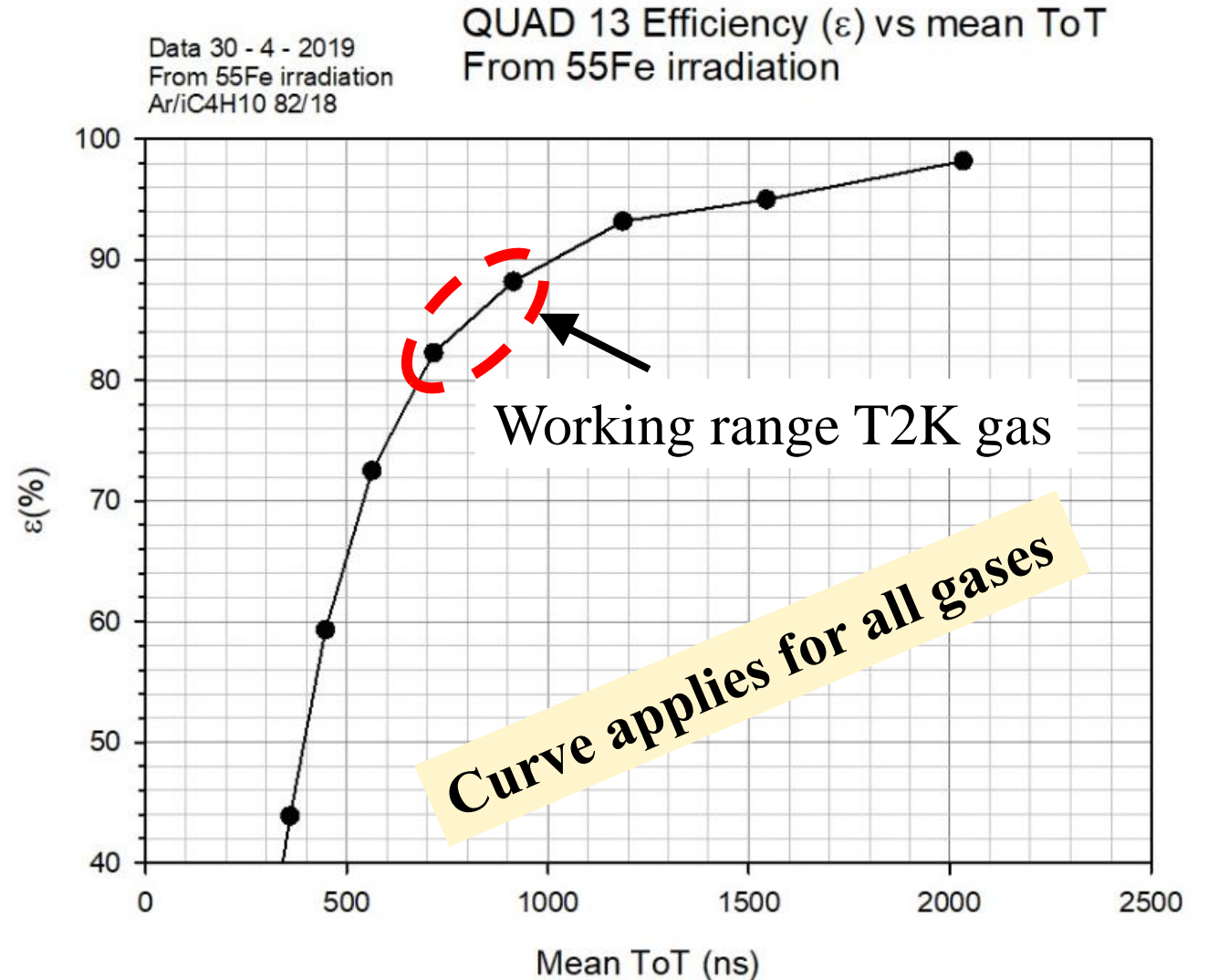
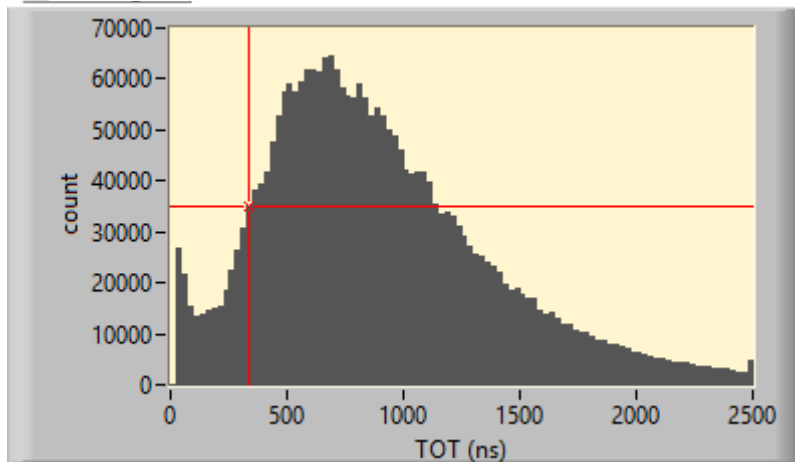
Messy region



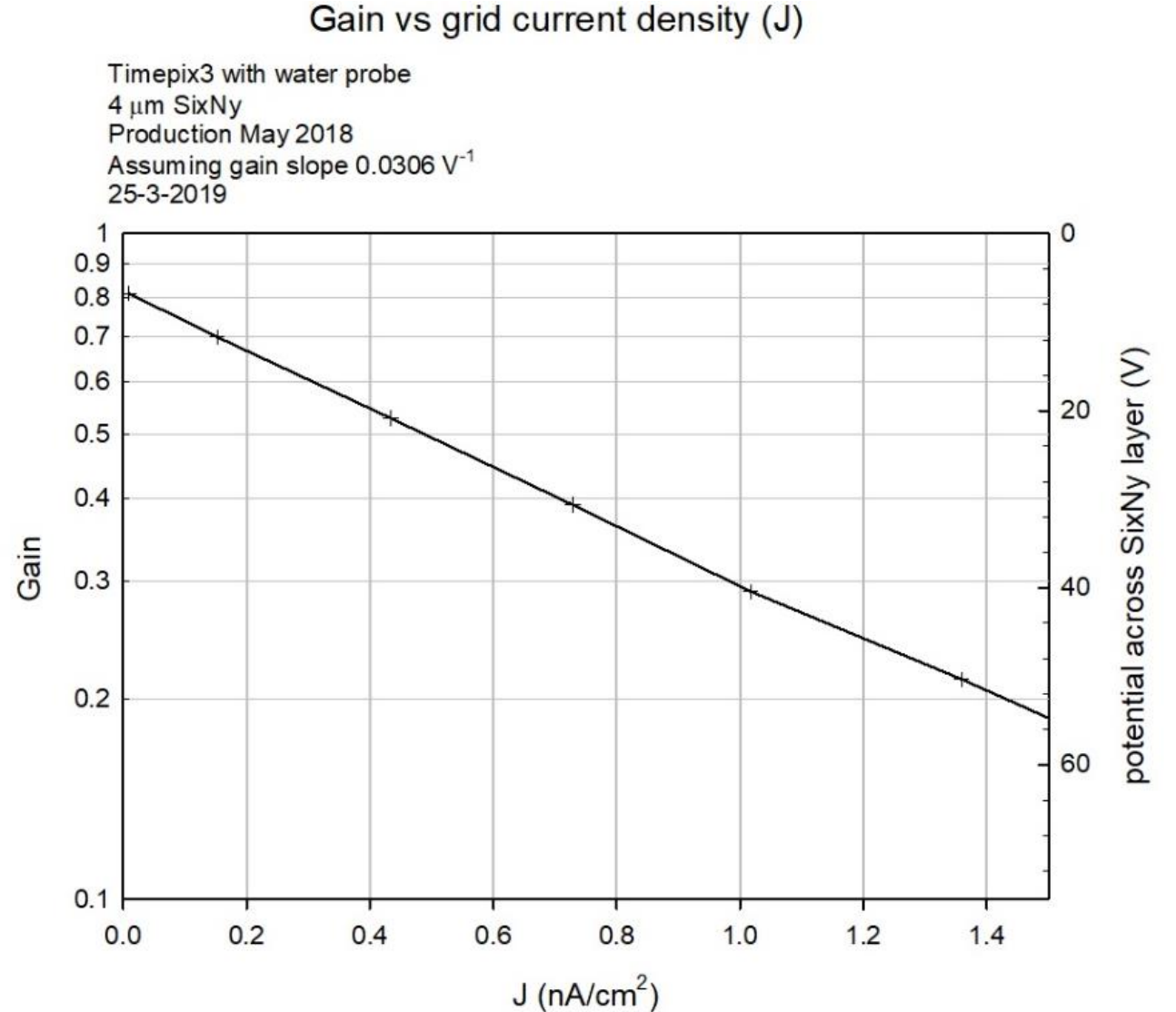
# Deduced from 18% $iC_4H_{10}$ measurements: Single electron efficiency vs mean ToT

- For Mean ToT = 1000 ns we have 90% SE efficiency
- During testbeam:
- **Look at mean ToT => SE efficiency**

TC Example ToT spectrum



- During testbeam we may easily have **30 – 40 V potential drop** across protection layer
- => we need an extended working range



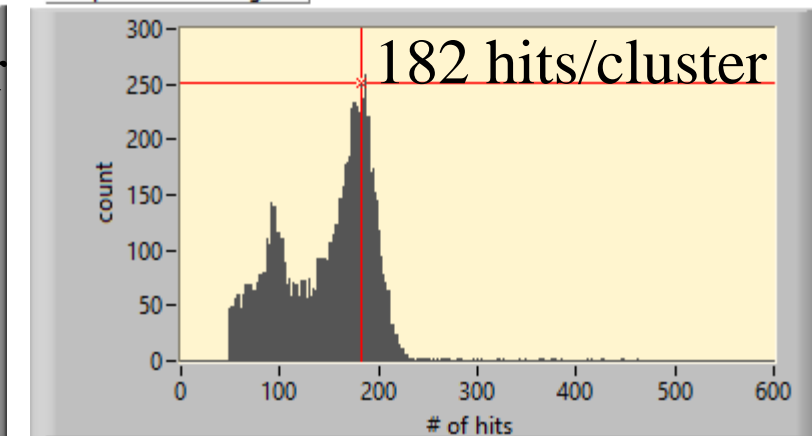
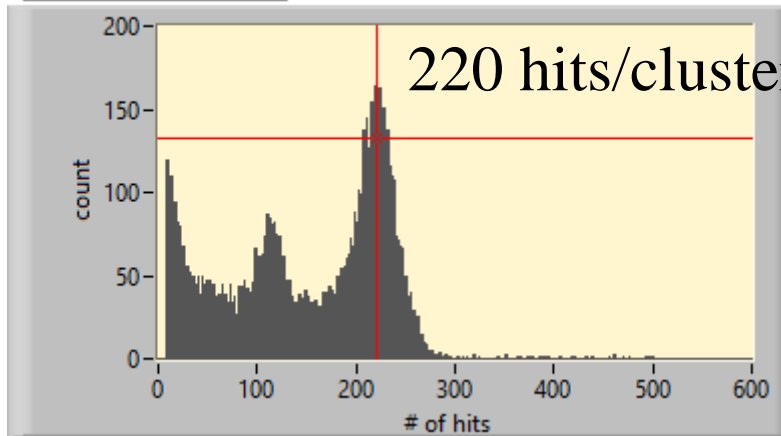
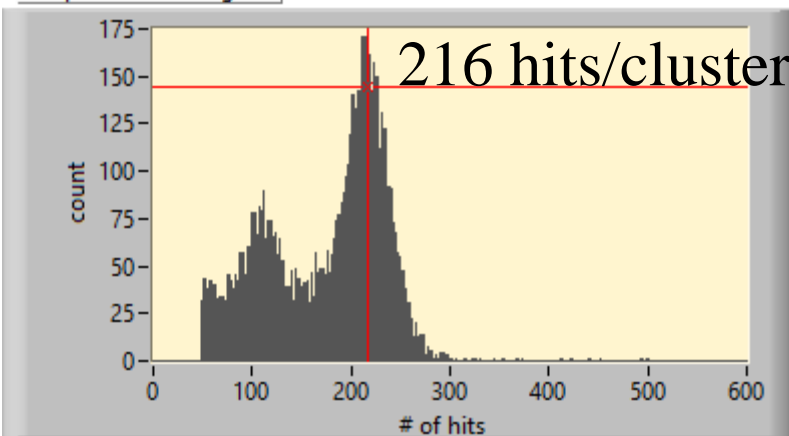
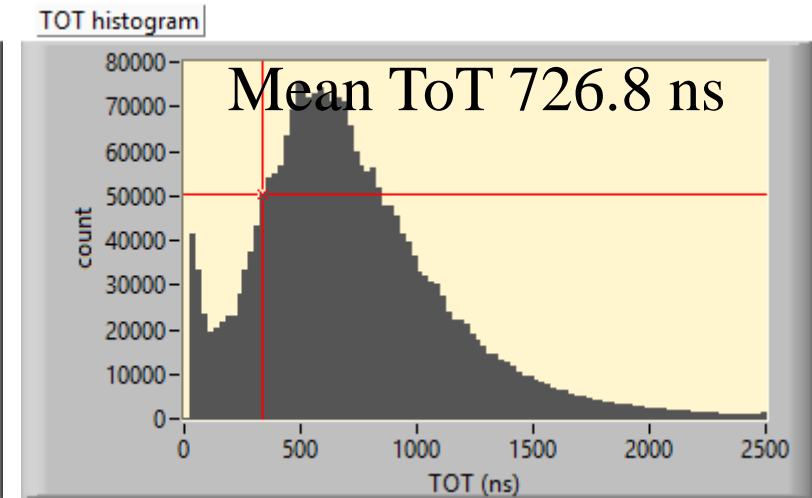
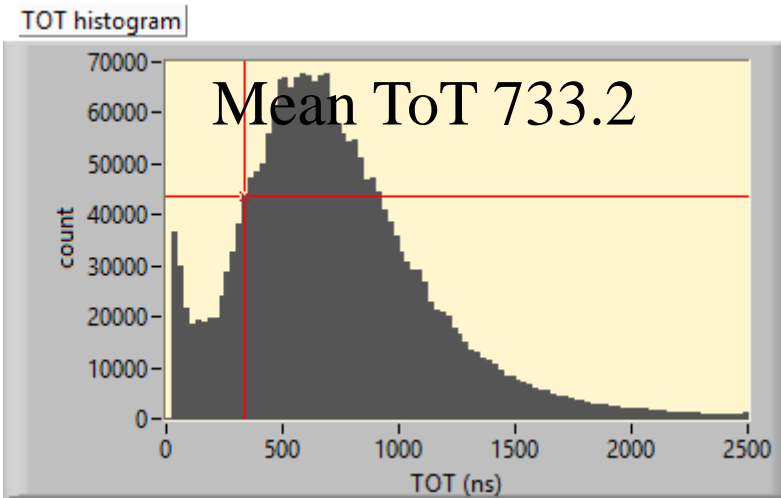
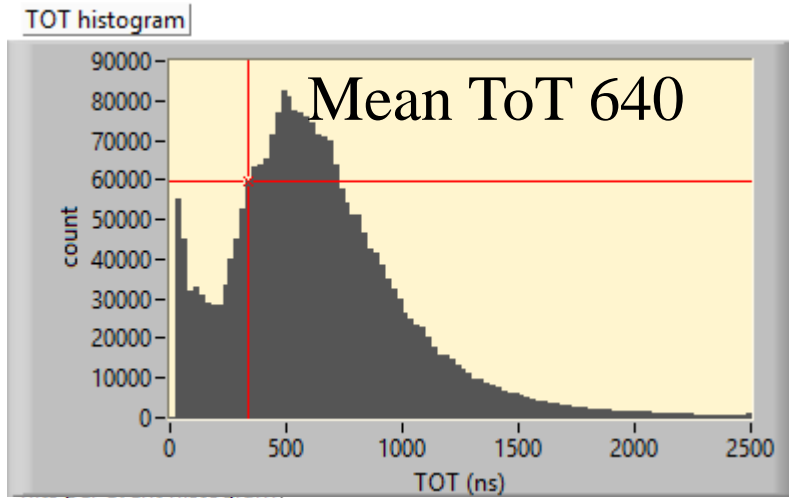
# Comparison of 3 different gases for chip 0 at mean ToT = 640 – 730 ns

■ => single electron efficiency 77 – 84%

## T2K -320 V

## T3K -320 V

## 18% iC4H10 -380 V



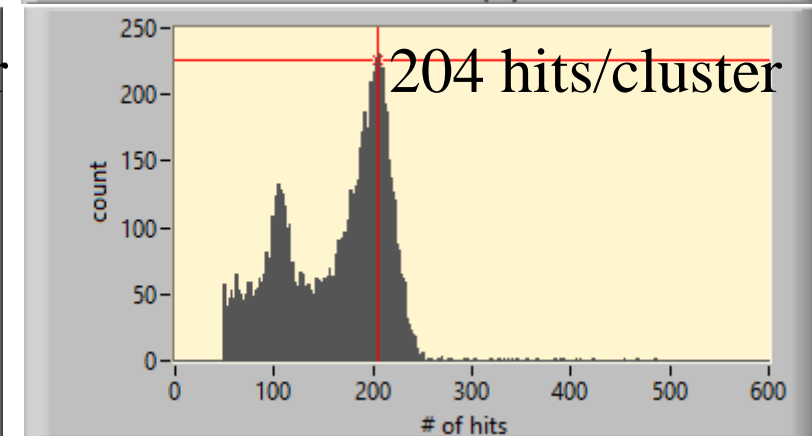
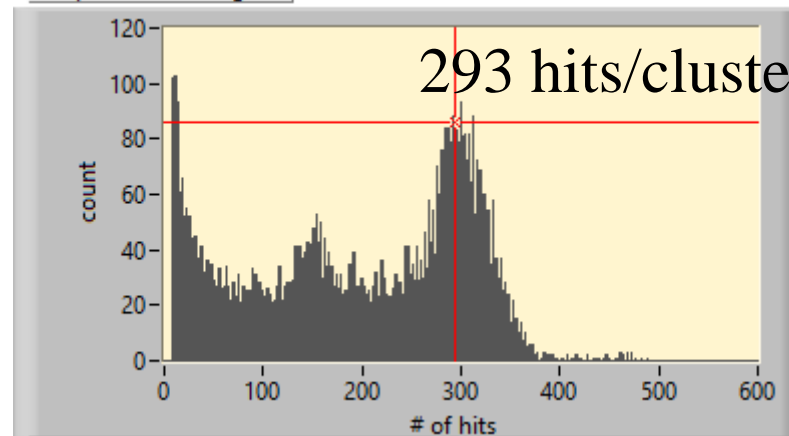
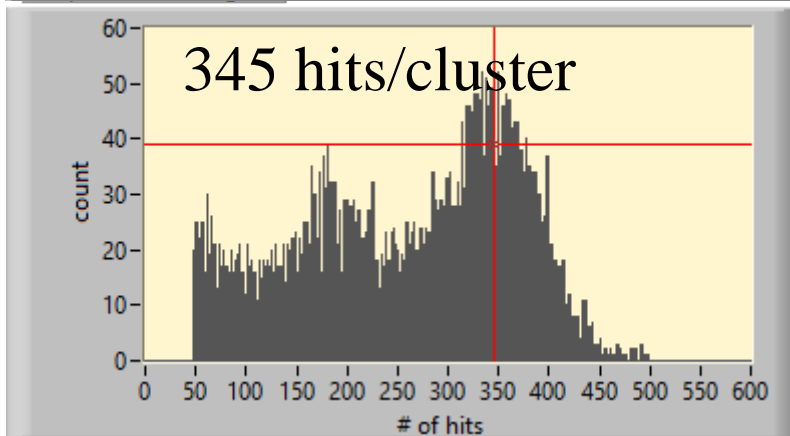
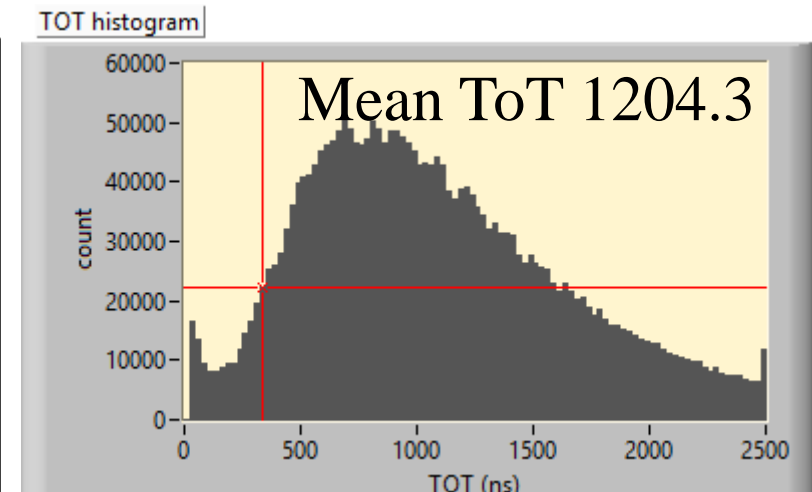
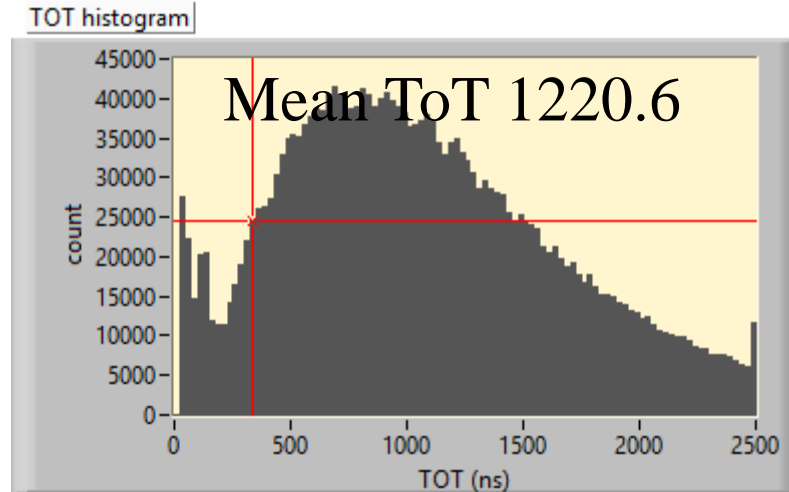
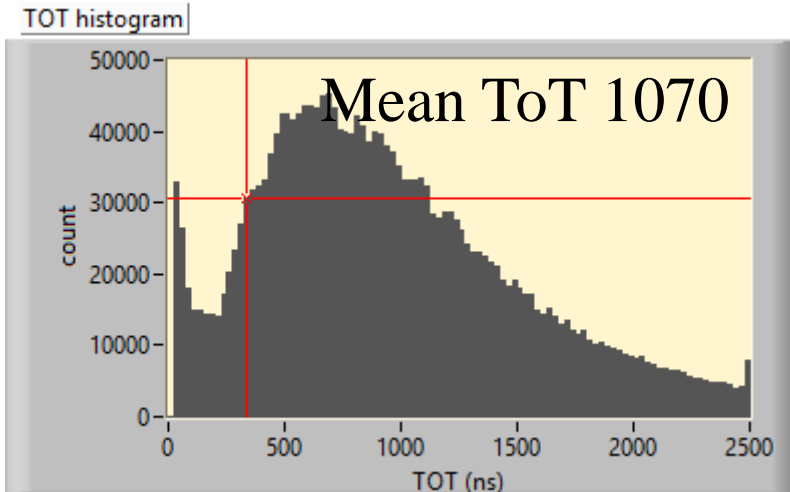
# Comparison of 3 different gases for chip 0 at mean ToT = 1000 – 1200 ns

■ => single electron efficiency 90 – 93%

## T2K -340 V

## T3K -340 V

## 18% iC4H10 -400 V

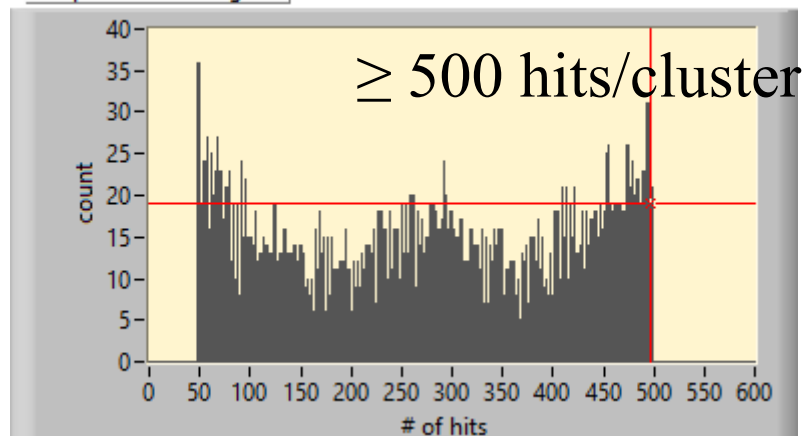
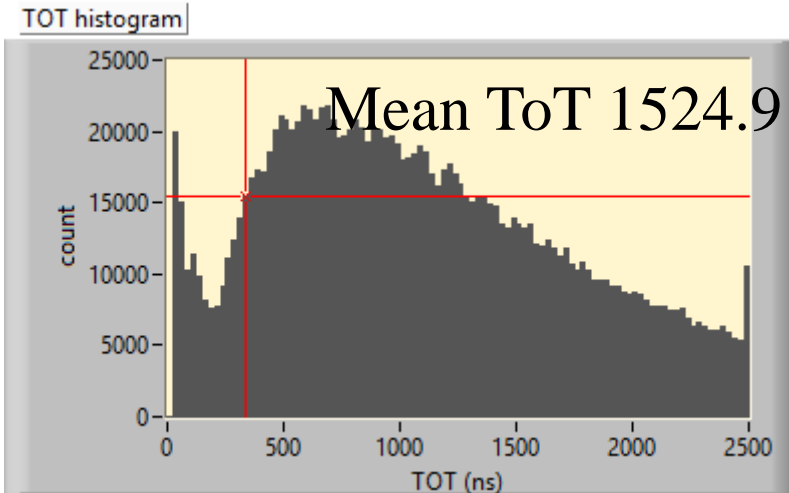




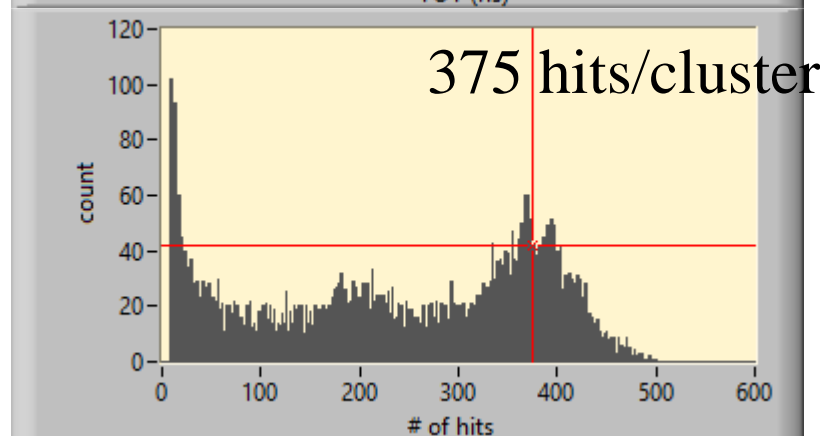
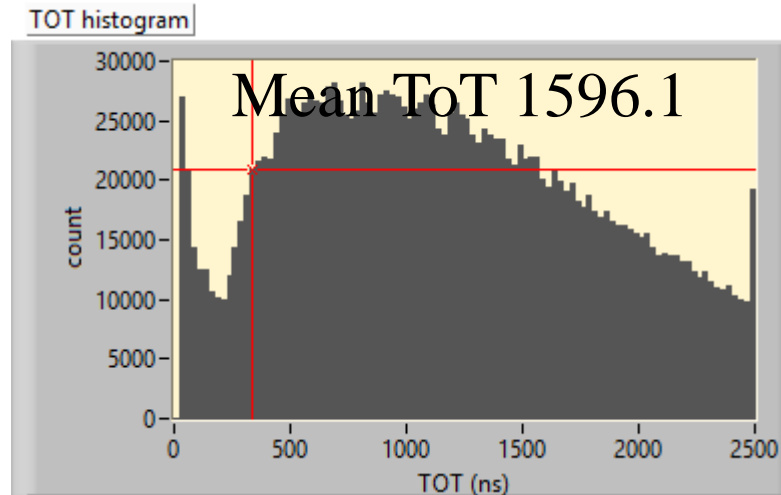
# Comparison of 3 different gases for chip 0 at mean ToT = 1525 – 1600 ns

■ => single electron efficiency 95 %

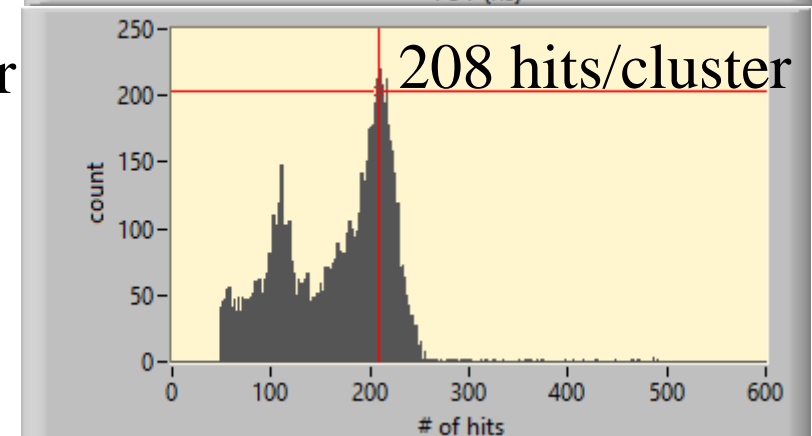
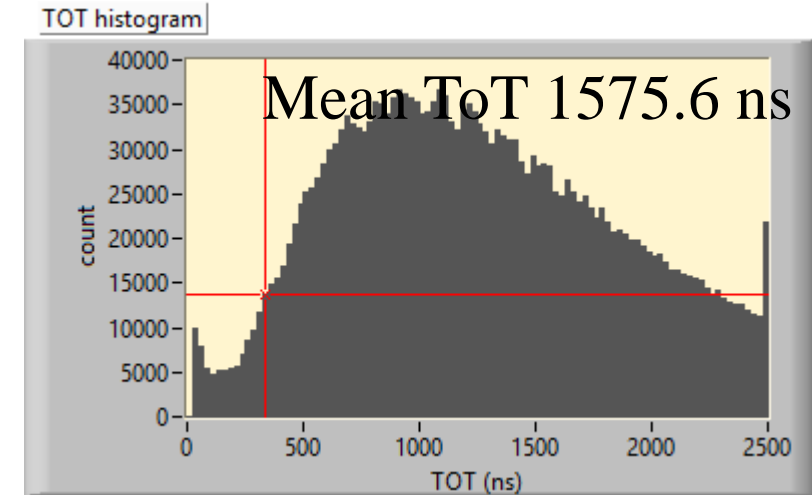
## T2K -350 V



## T3K -350 V

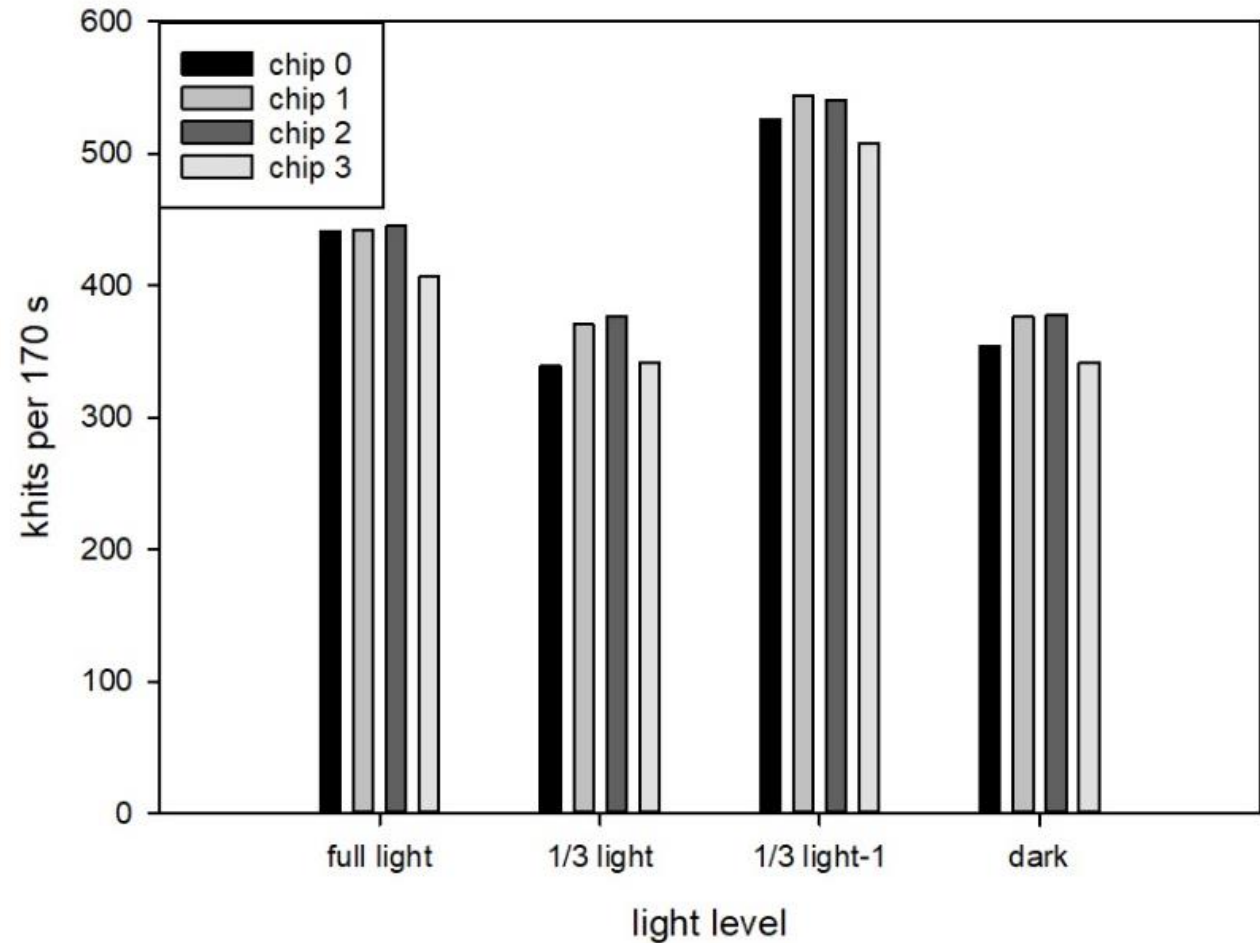


## 18% iC4H10 -410 V



# Sensitivity to environmental light

- Hit rate in T3K gas without source at  $V_{\text{grid}} = -340 \text{ V}$
- Measured with
  - All lights on
  - 1/3 lights on (the ones near the corridor wall)
  - In almost complete darkness
- => **no obvious correlation with environmental light level**

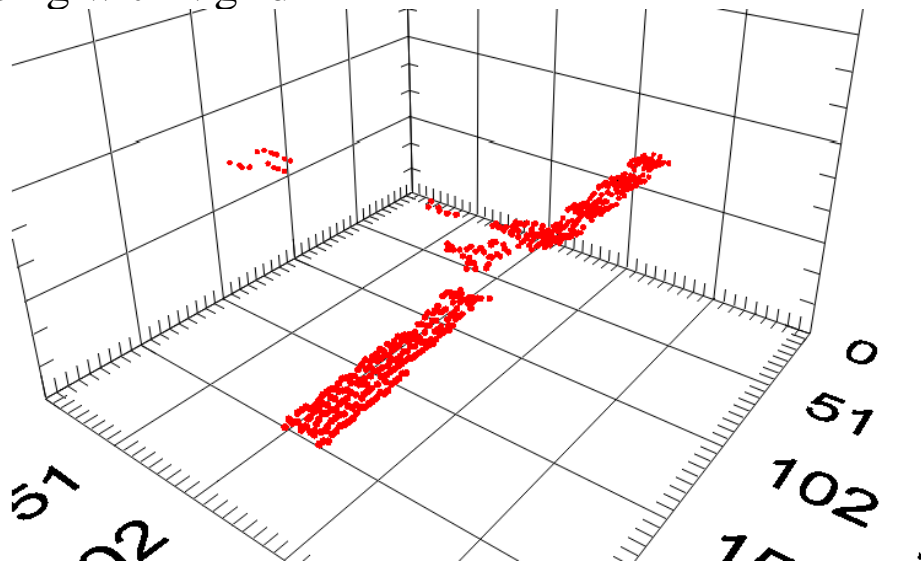


# Conclusions efficiency / secondary emission measurements

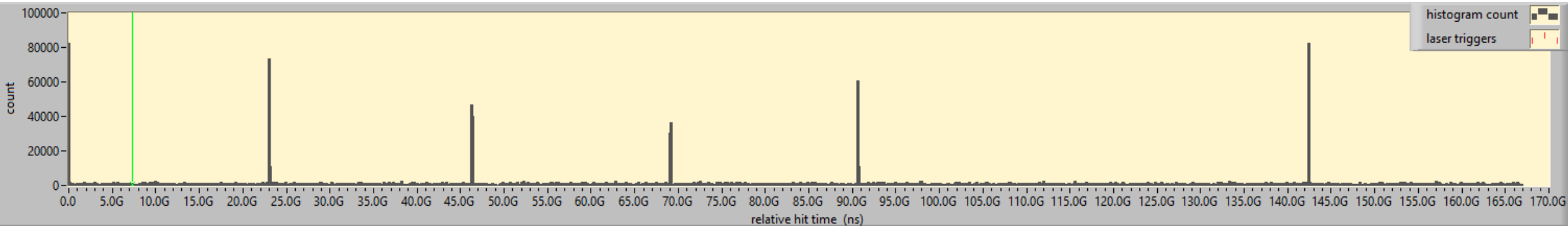
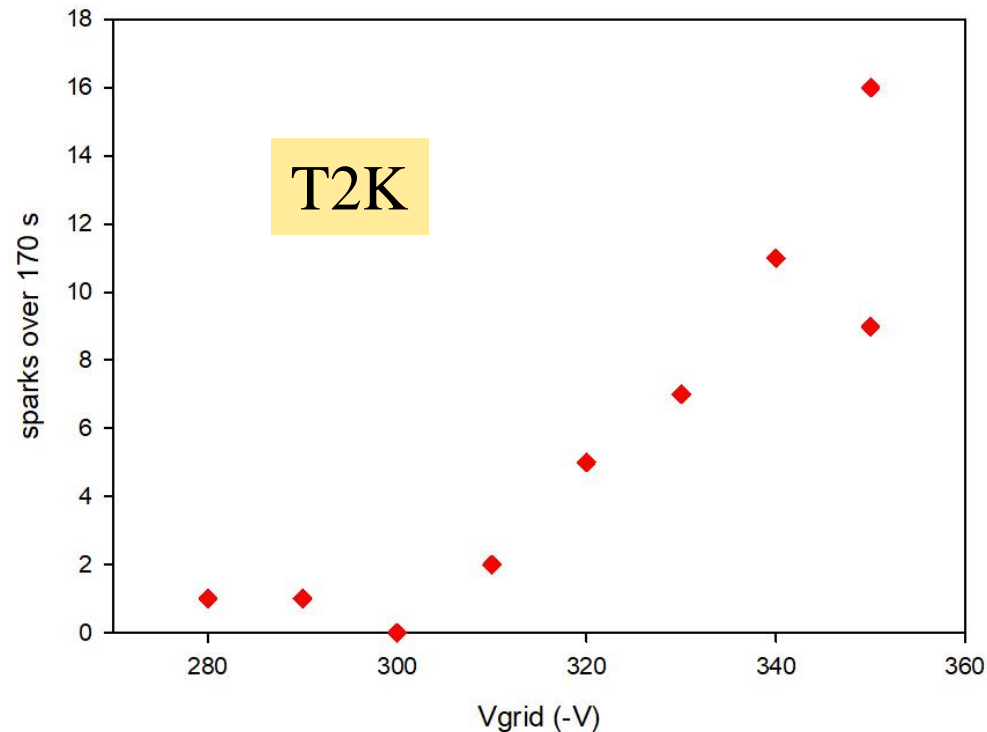
- **Using well quenched gas (18% iC<sub>4</sub>H<sub>10</sub>)** gives excellent results
  - Good plateau on expected level (210 e.) => comfortable working point
  - Good for dE/dX
- **Using T2K gas with 2% iC<sub>4</sub>H<sub>10</sub>** the performance of the present TPX3 with InGrid is problematic
  - Have to work on steep part of efficiency curve => very sensitive for rate effects
  - Many secondary emission hits, easily exceeding 100% at reasonable efficiency
  - Not suited for reliable dE/dX
- **Using T3K (3% iC<sub>4</sub>H<sub>10</sub>)** secondary emission is about reduced by a factor of 2
  - We would need ~ 10 % iC<sub>4</sub>H<sub>10</sub> to bring the secondary emission down to an acceptable level (T9K)
- **Secondary emission depends on**
  - Amount of quencher in the gas
  - Distance anode – grid
  - Material/surface treatment of the grid (Cu is much better than Al)

# Micro discharges

- Occurring quite frequently (36 x in 22 min at T2K gas)
- Show themselves as ~126 events of ~530 hits each, separated by  $409.6 \mu\text{s} \Rightarrow 52 \text{ ms}$  dead time
- **Not visible** on the current monitor of the HV supply
- Hitting all pixels on all 4 chips simultaneously
- Rate increasing with Vgrid



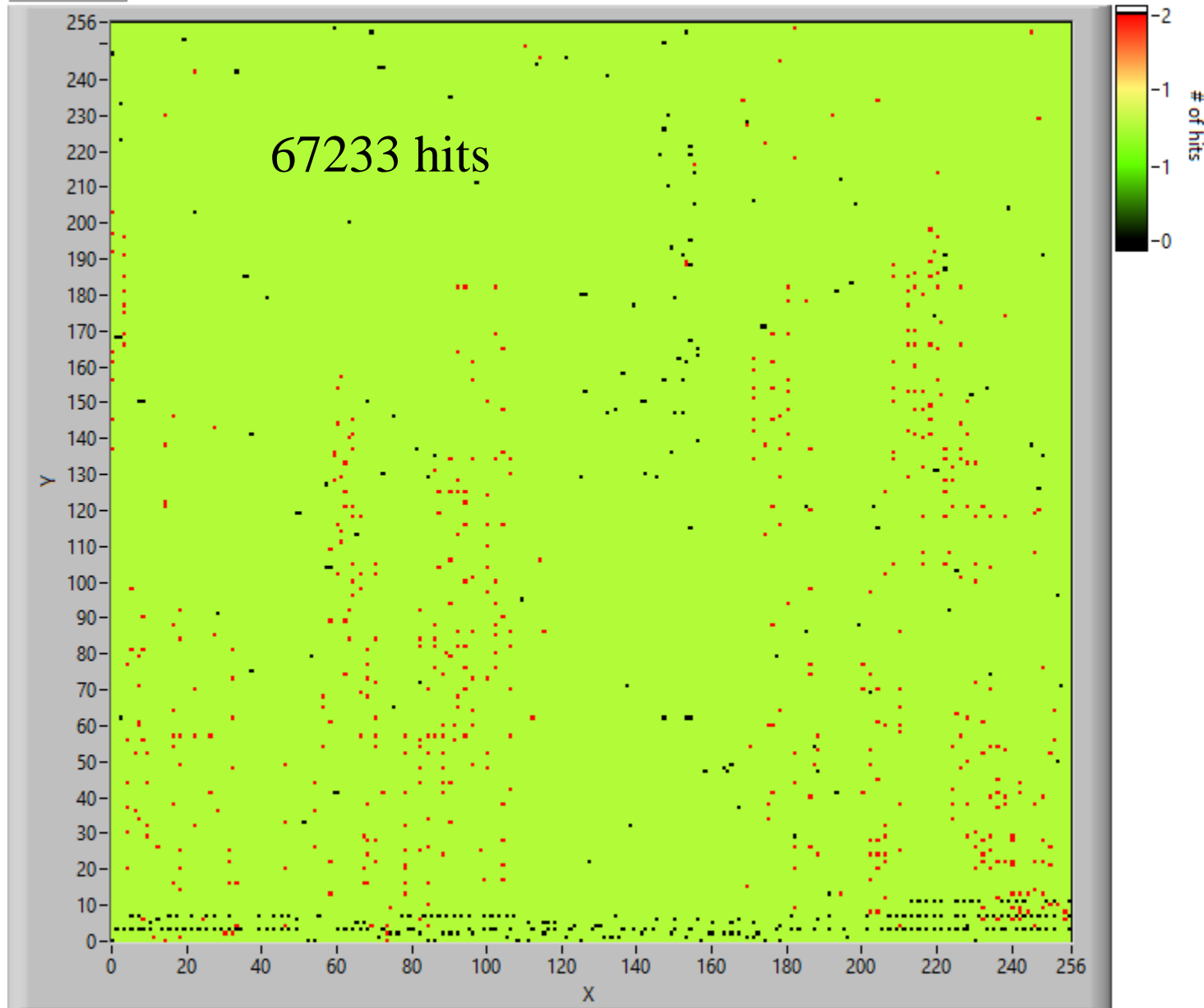
Spark frequency vs Vgrid  
QUAD 13



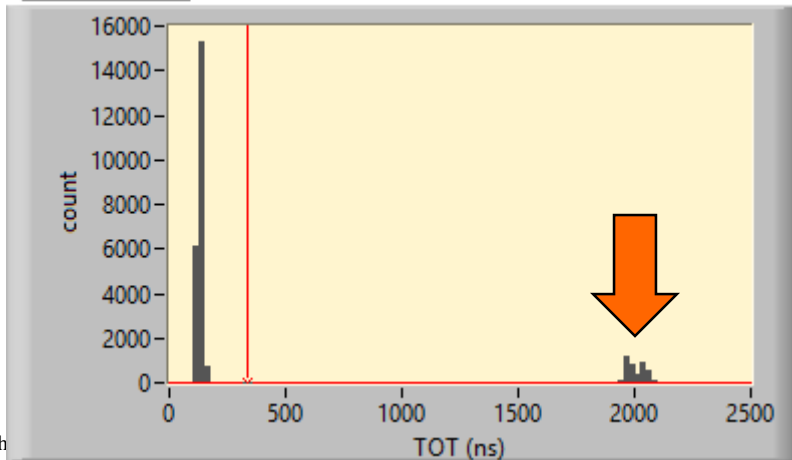
# Hitmap of a single discharge in chip 0

- T3K gas
- NO source
- Vgrid = -340 V, in total darkness
- **Data taken at one micro discharge in 52 ms**
  - => NO cosmics expected
- **Min 500 hits per cluster**
- **Most discharge hits are very small, but ~ 10% are peaked around 2000 ns**
- Almost all pixels fire, but a few fire twice

Hit map



TOT histogram

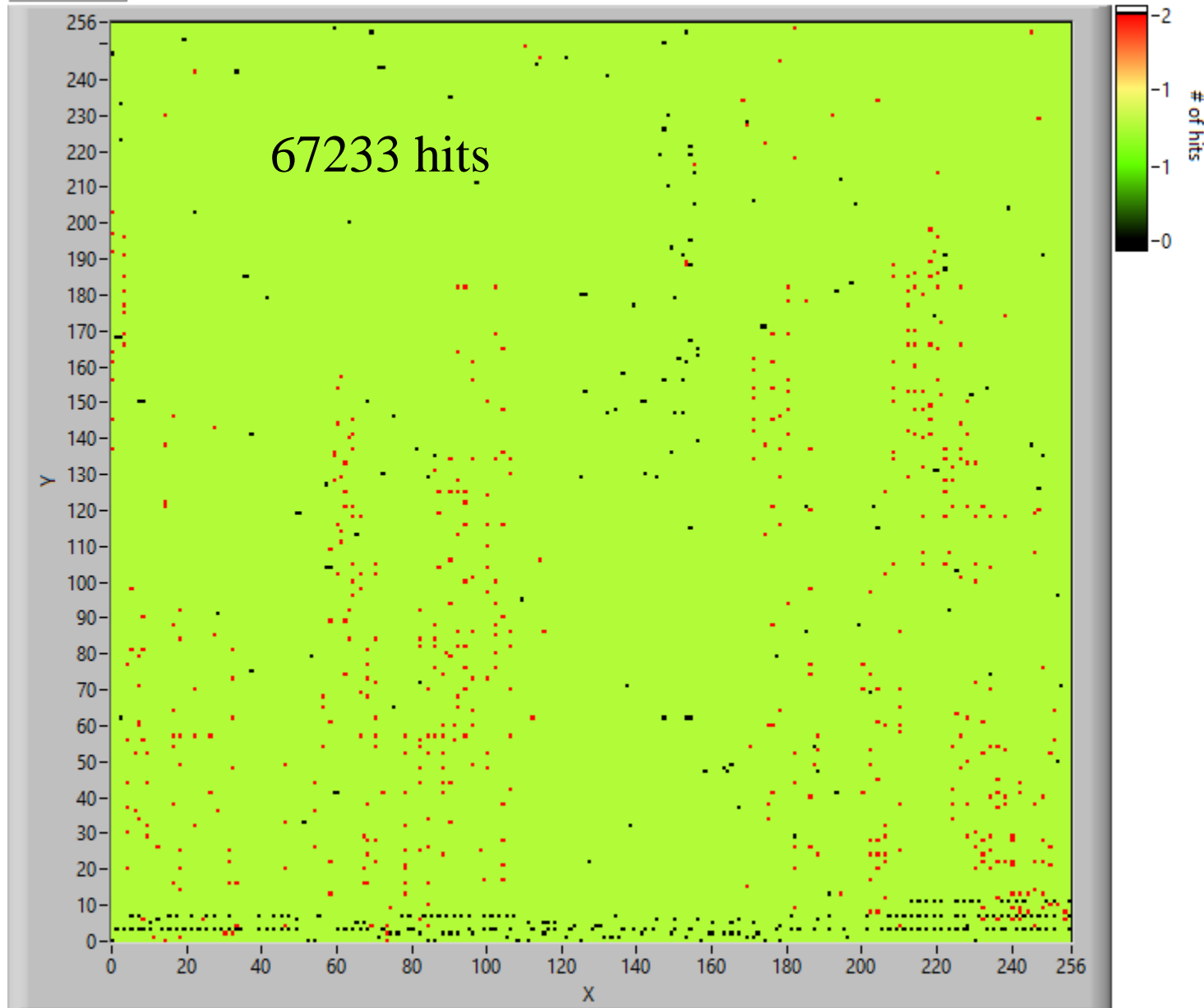




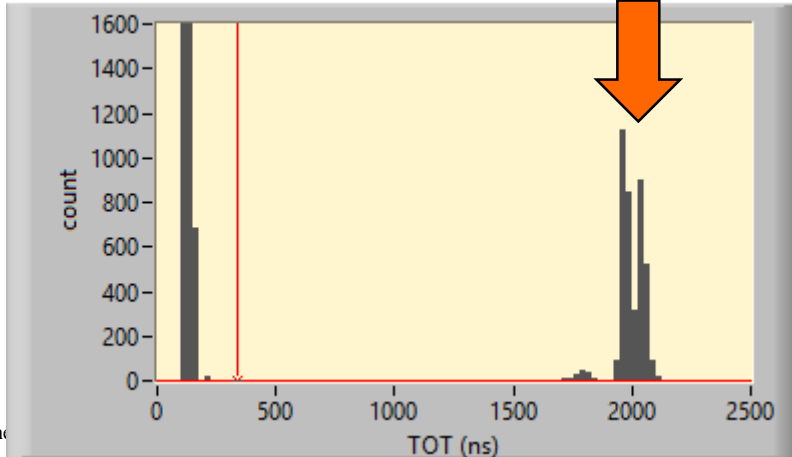
# Hitmap of a single discharge in chip 0

- T3K gas (3% iC<sub>4</sub>H<sub>10</sub>)
- NO source
- Vgrid = -340 V, in total darkness
- **Data taken at one micro discharge in 52 ms**
  - => NO cosmics expected
- **Min 500 hits per cluster**
- **Most discharge hits are very small, but ~ 10% are peaked around 2000 ns**
- Almost all pixels fire, but a few fire twice (red pixels)

Hit map

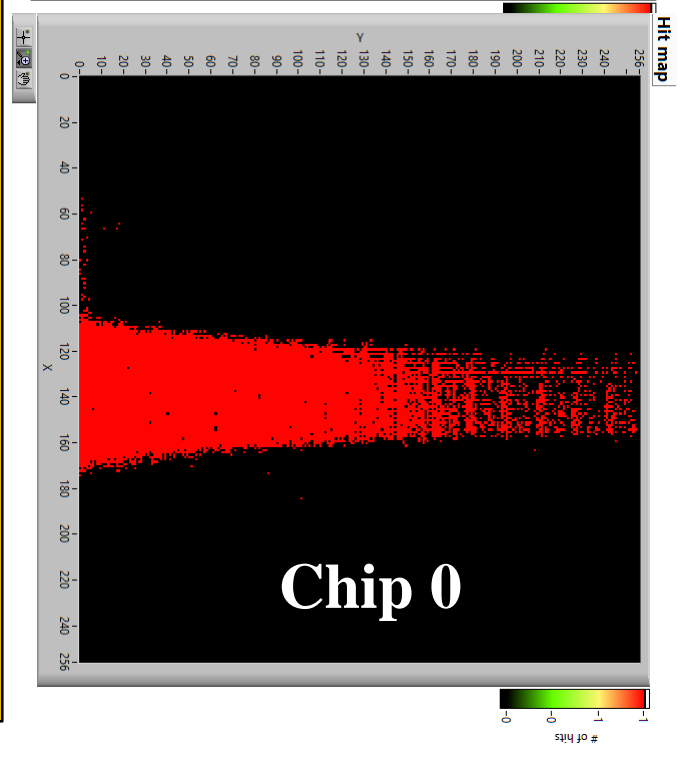
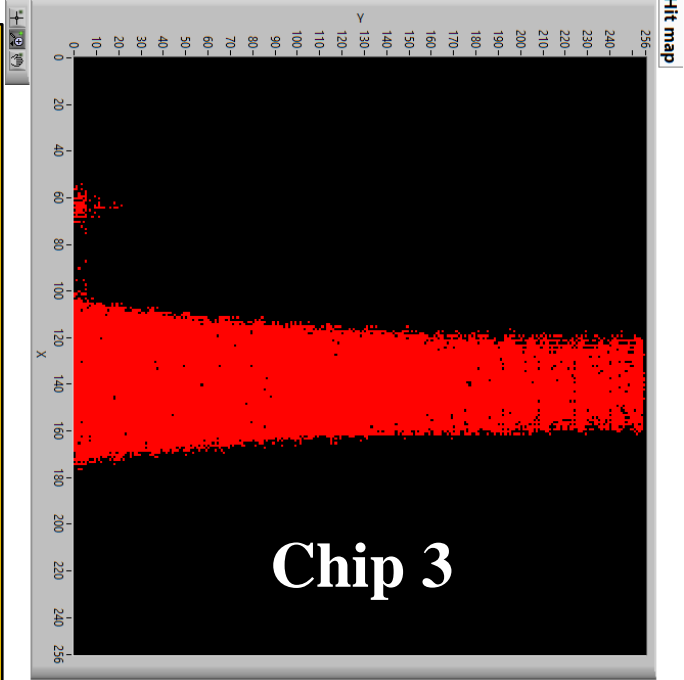
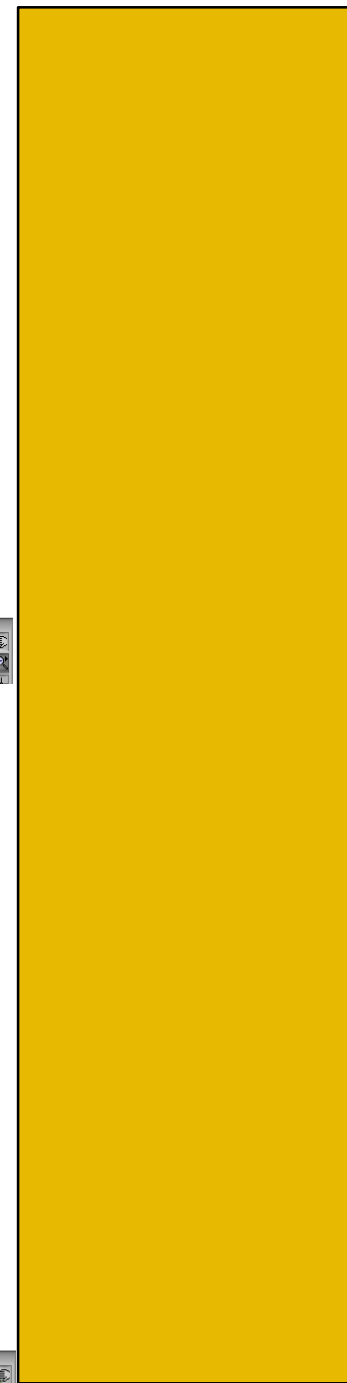
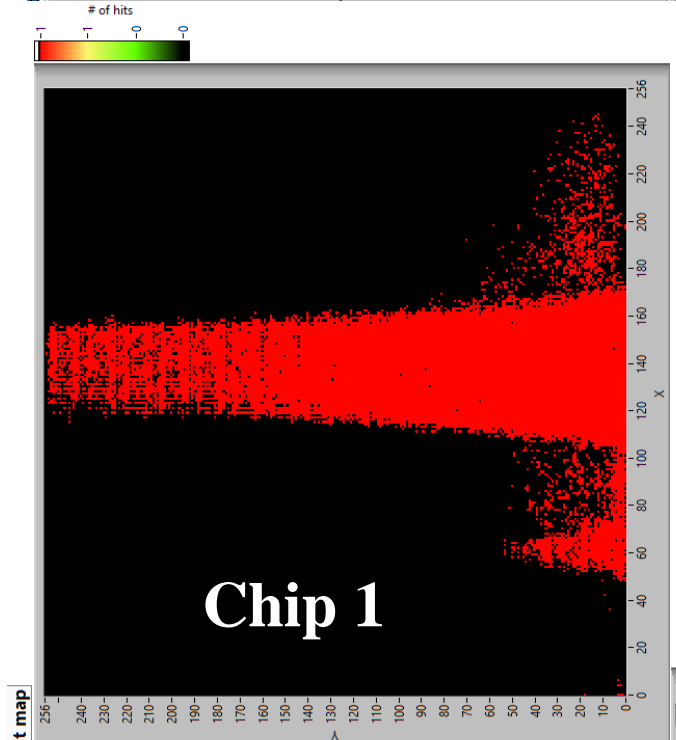
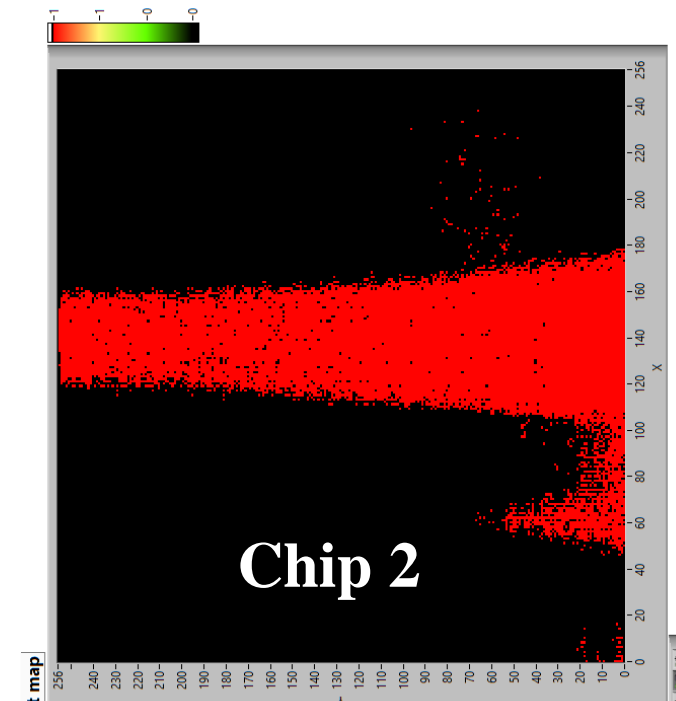


TOT histogram



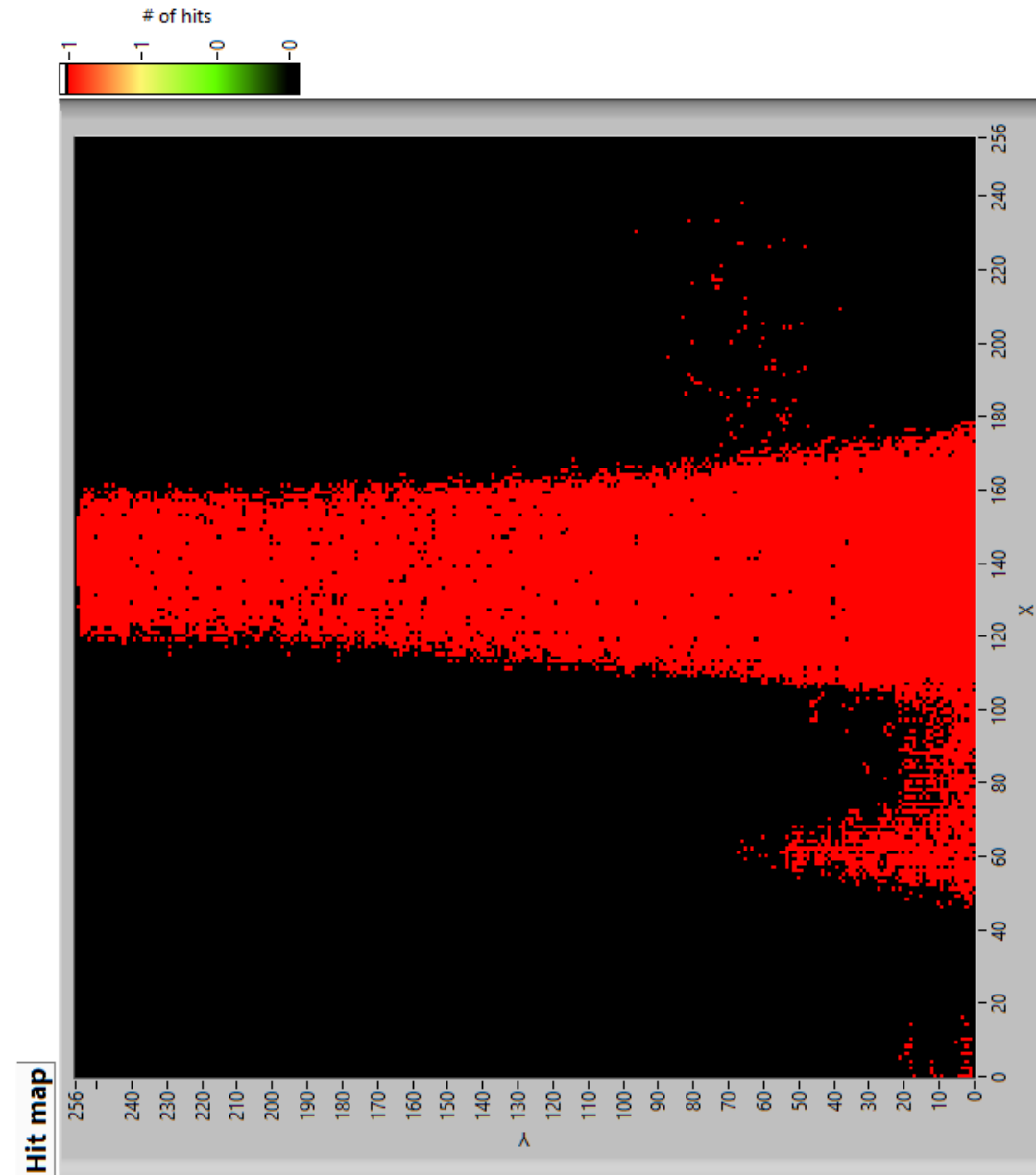
# Hitmaps at discharges

- T3K gas
- NO source
- In total darkness
- Vgrid = -340 V
- **Min ToT 1700 ns**
- Min 5 hits per cluster
- 3 micro discharges during 170 s
- Result: 50 – 60 hits per cluster



# Conclusions about micro discharges

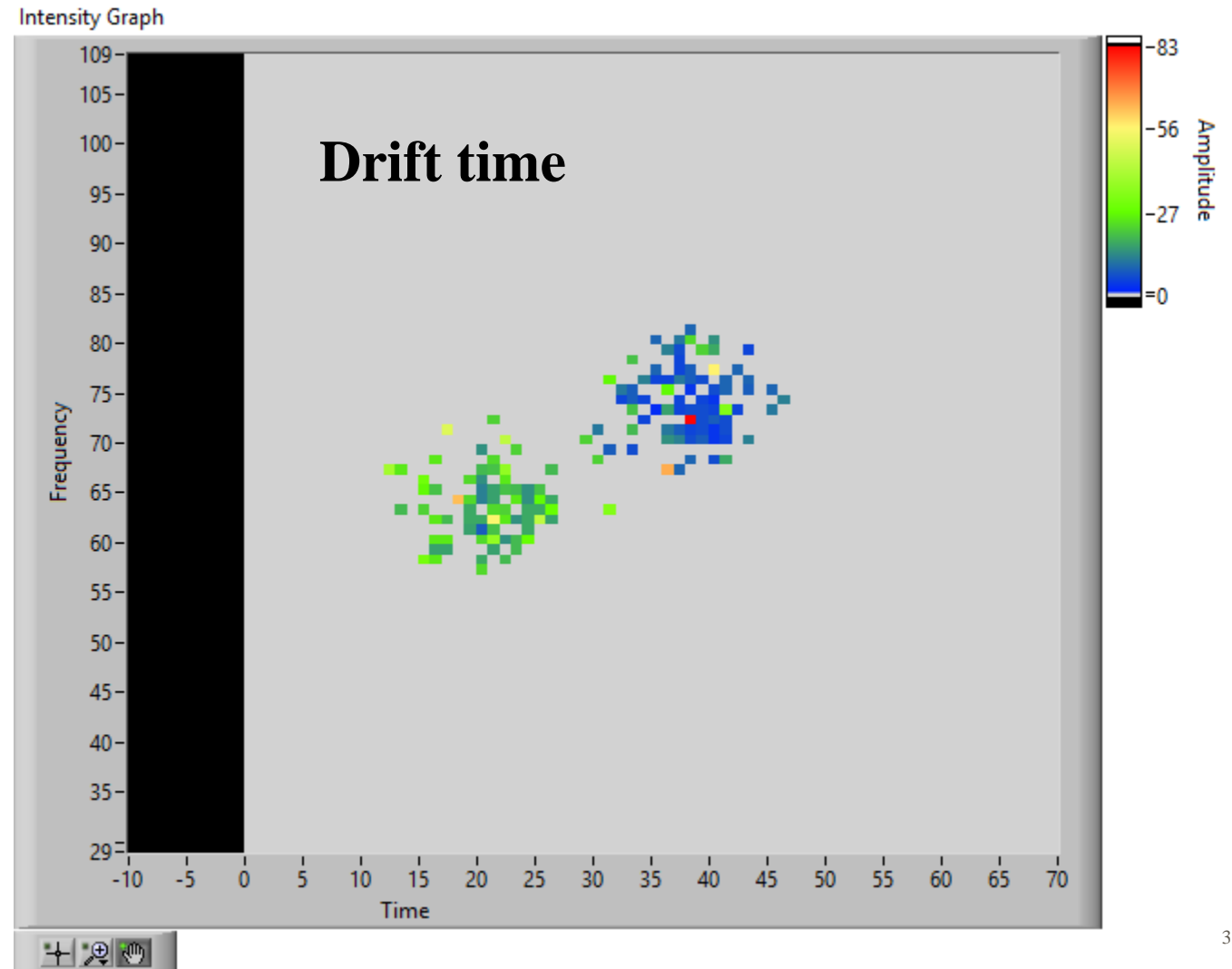
- Sparking **gas** dependent
  - T2K gas: frequent sparking: **36 micro-discharges** during Vgrid scan of 22 min
  - 18% iC4H10: limited sparking: **5 micro-discharges** during Vgrid scan of 25 min
- Sparking **Vgrid** dependent
  - Rate increasing with increased ToT
- Mostly very small ToT (50 – 175 ns)
  - But ~ **10% are huge (around 2000 ns)**
- Large discharge hits are located in a cone centered around **column 140**
- **No clue** on which chip started the discharge
  - All 4 chips show a comparable pattern
- Can we explain this from DAQ error (one significant ToT bit goes wrong??)
  - Specific problem of QUAD13 (bad contact in the flex)?
- Or are these really large signals??



# Reference

# Just some fun: two events almost simultaneously

- Event 982
- Ar/iC4H10 82/18
- Chip 2
- 400V
- Close to the grid



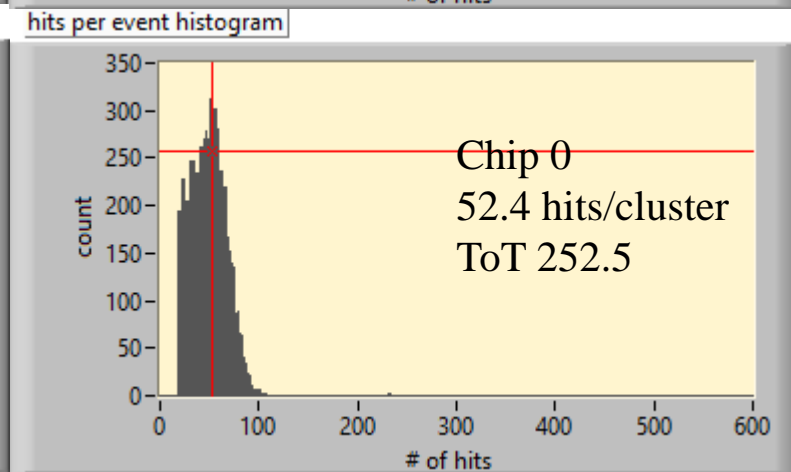
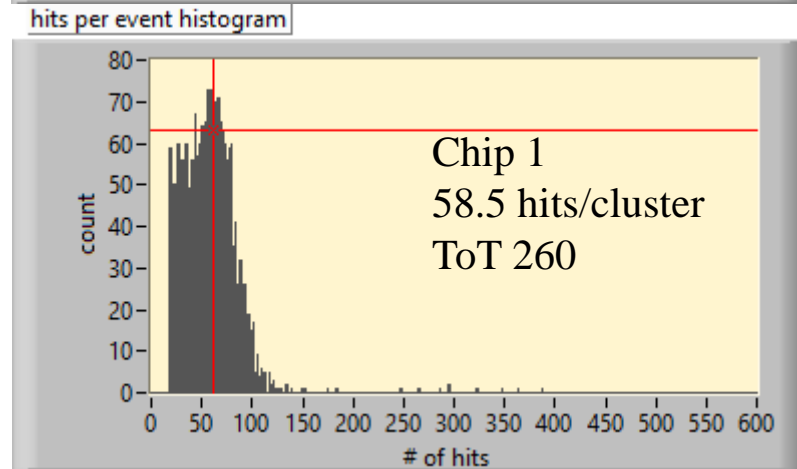
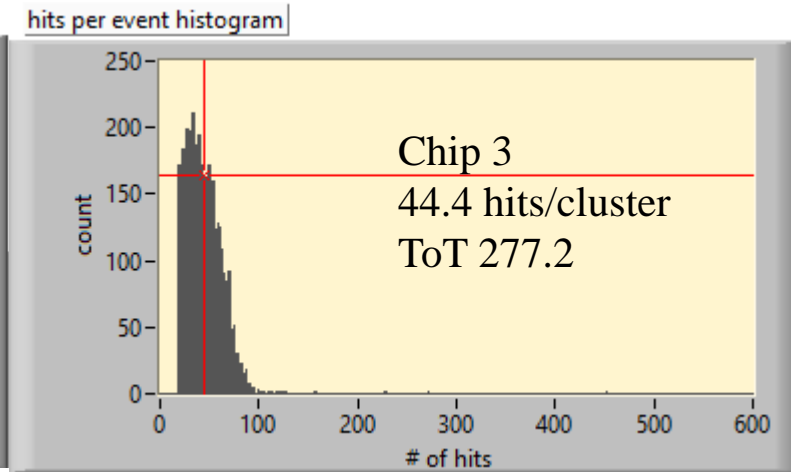
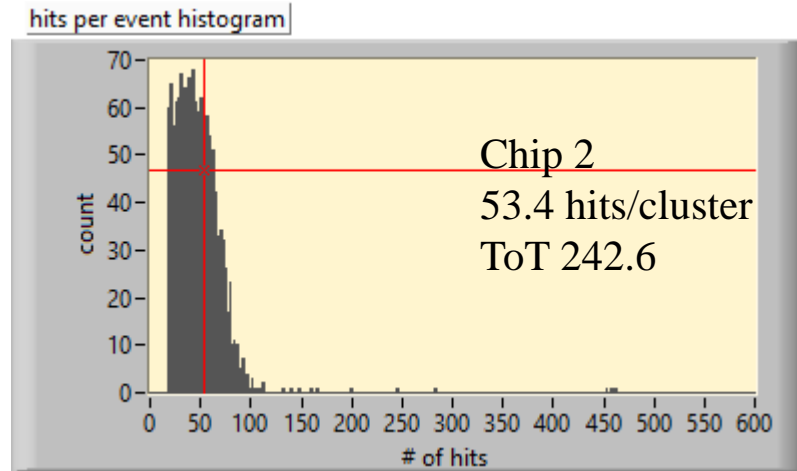


**T2K**

**(iC4H10/CF4/Ar 2/3/95)**

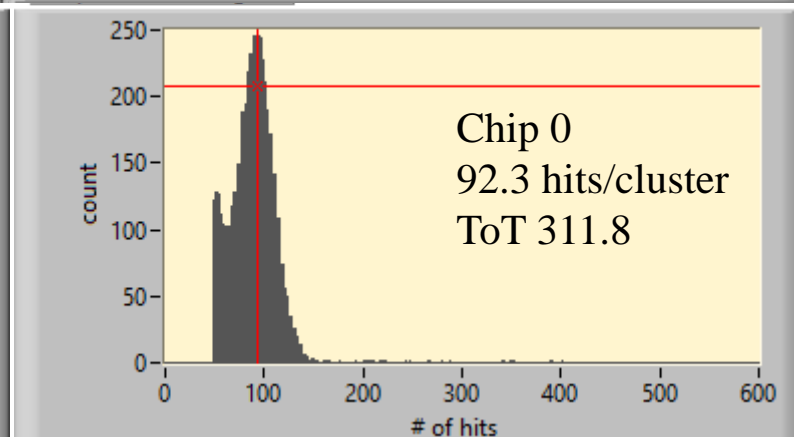
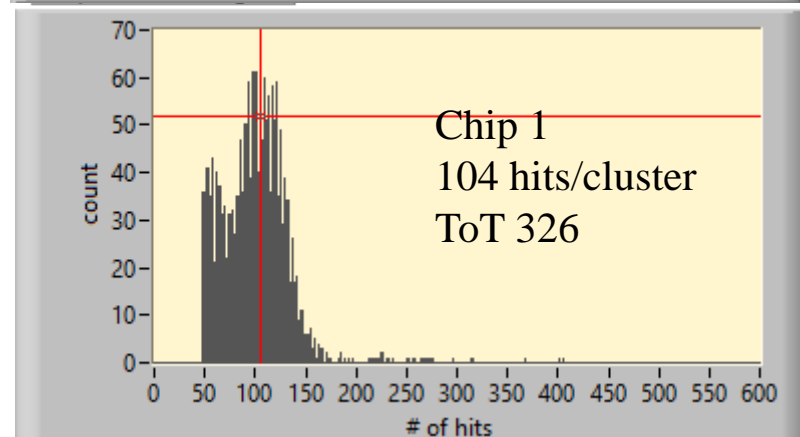
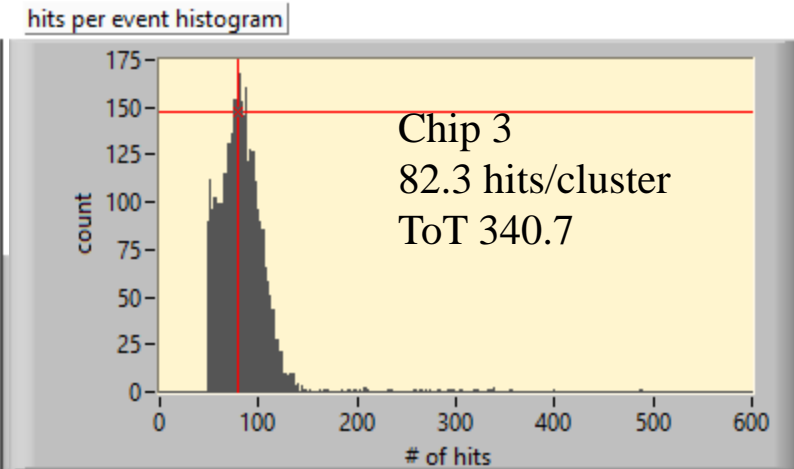
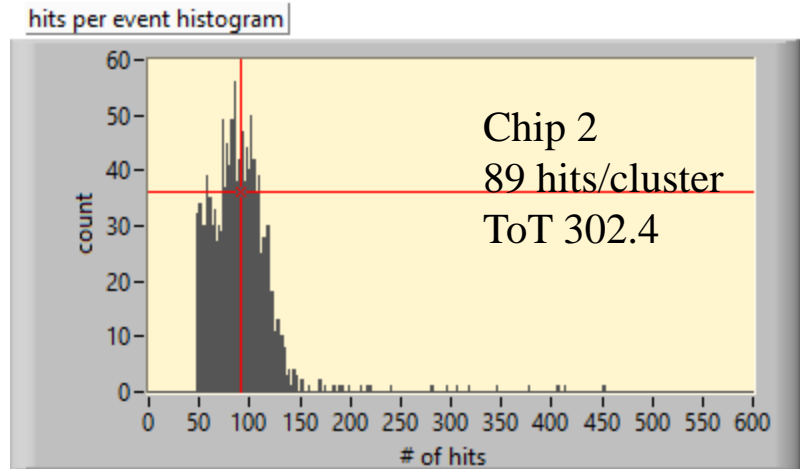
# 280 V

- 1 micro discharge



# 290 V

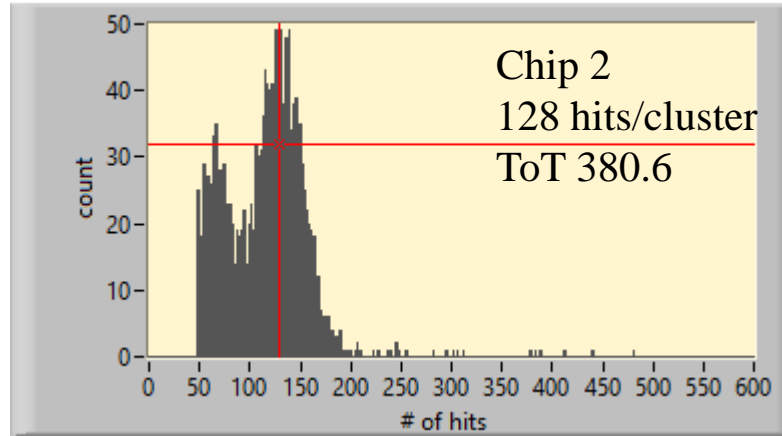
- 1 micro discharge



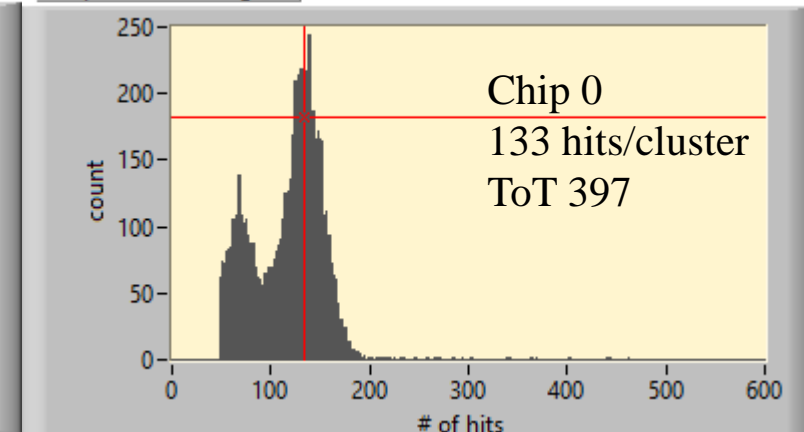
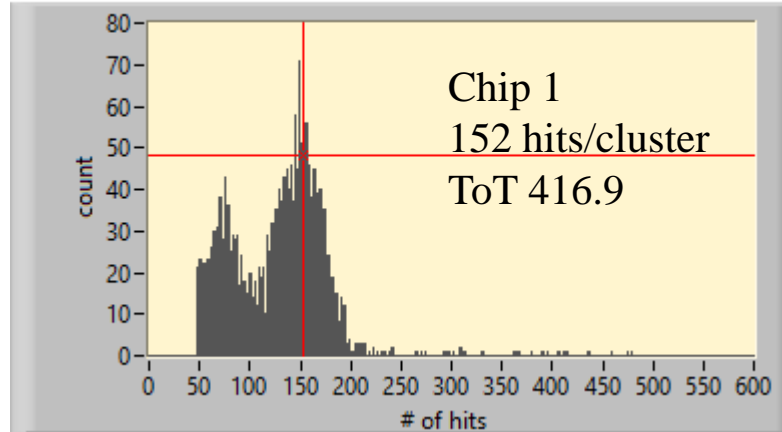
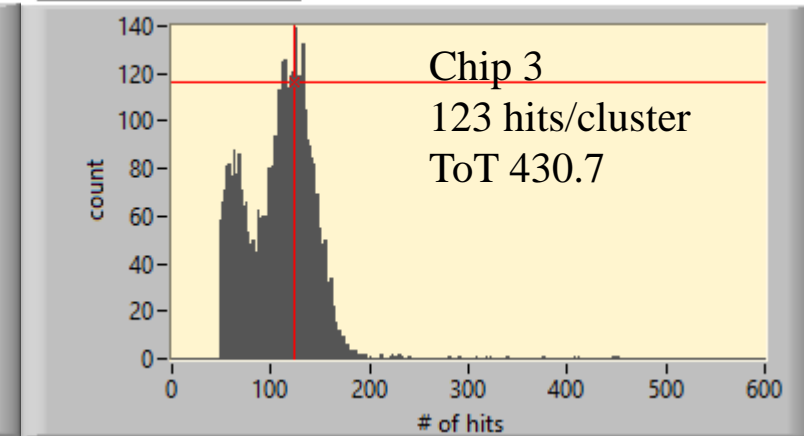
# 300 V

- No discharges

hits per event histogram

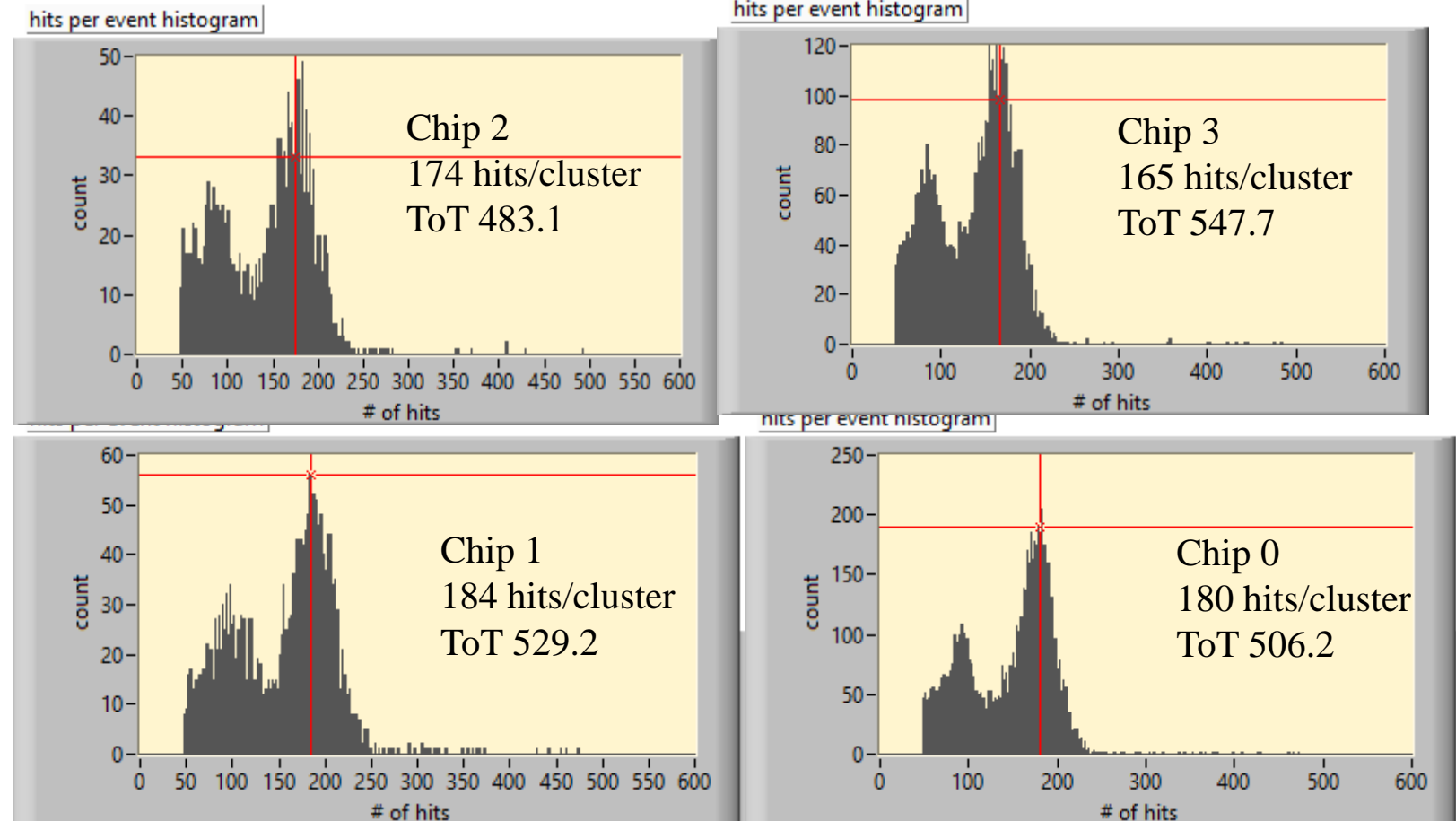


hits per event histogram



# 310 V

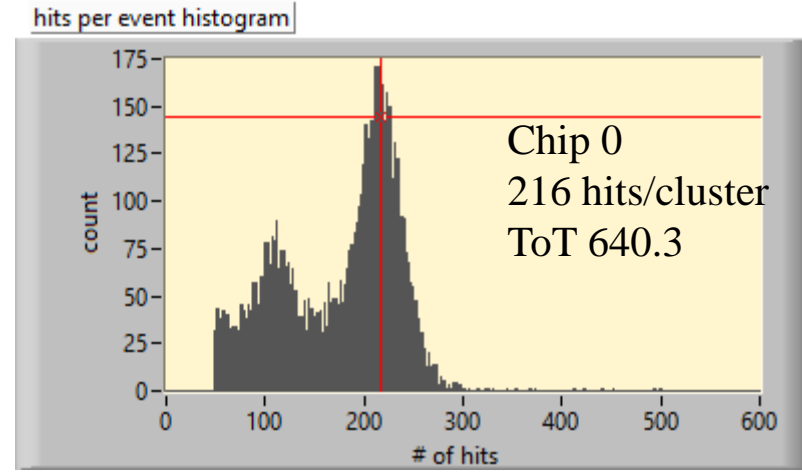
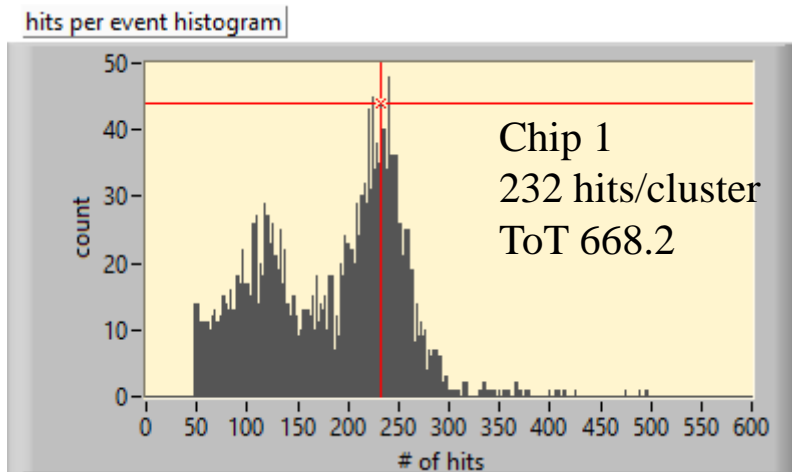
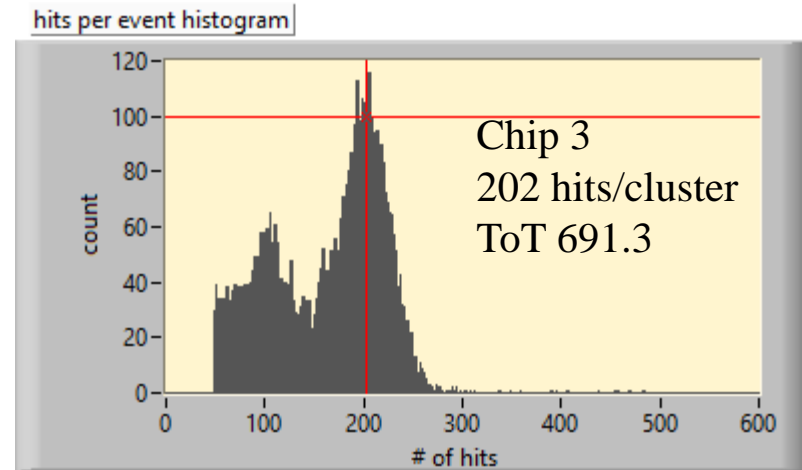
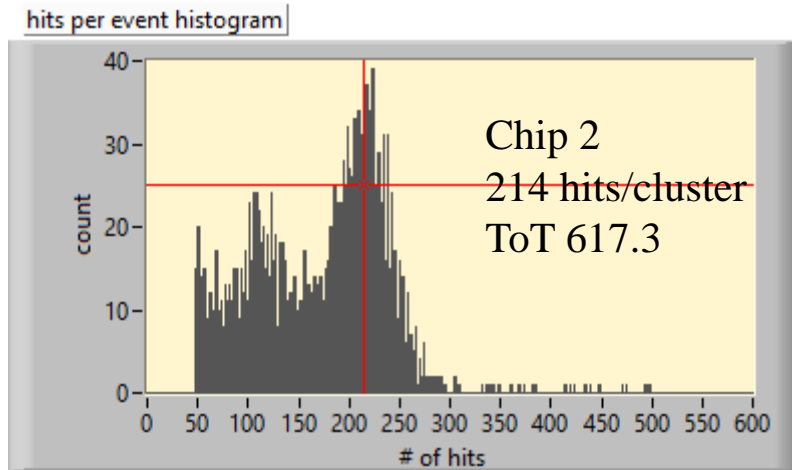
- 2 micro discharges





# 320 V

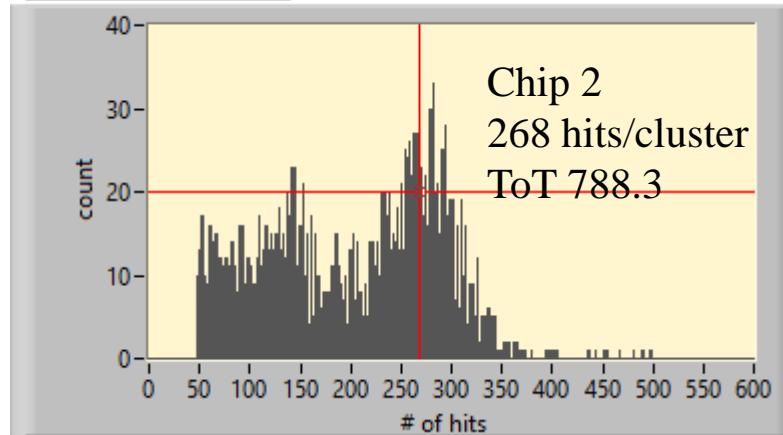
- 5 micro discharges



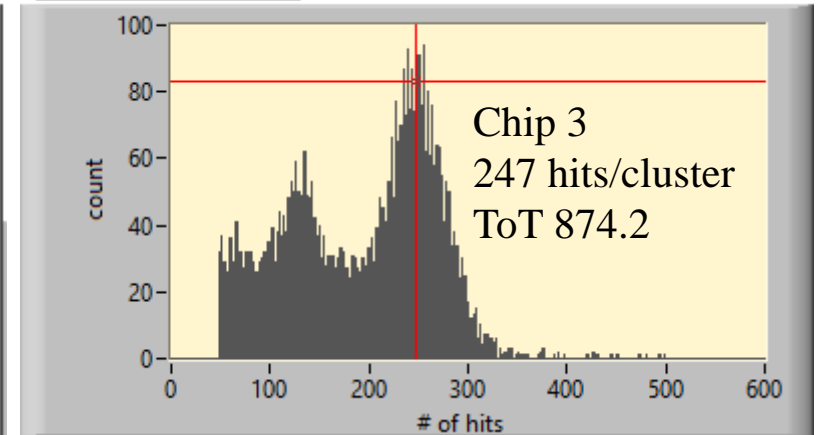
# 330 V

- 7 micro discharges

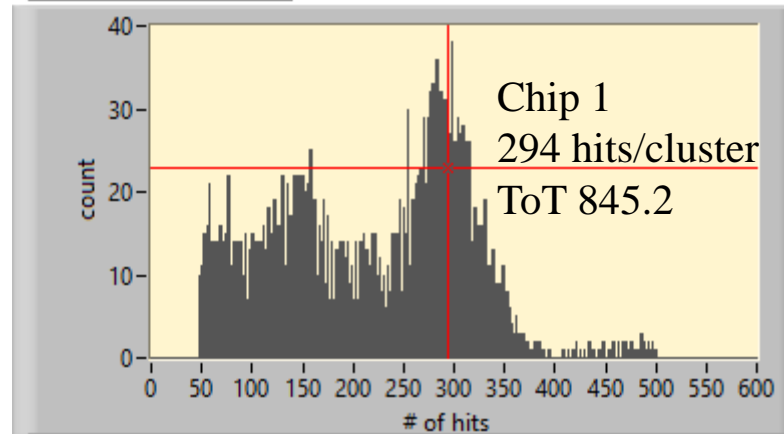
hits per event histogram



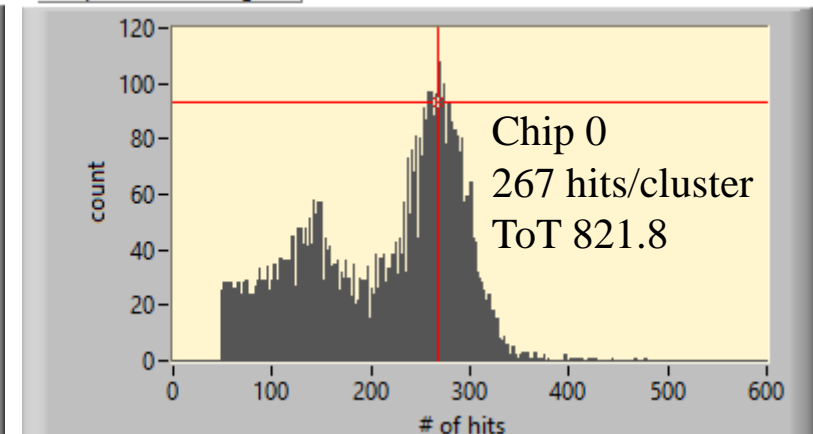
hits per event histogram



hits per event histogram



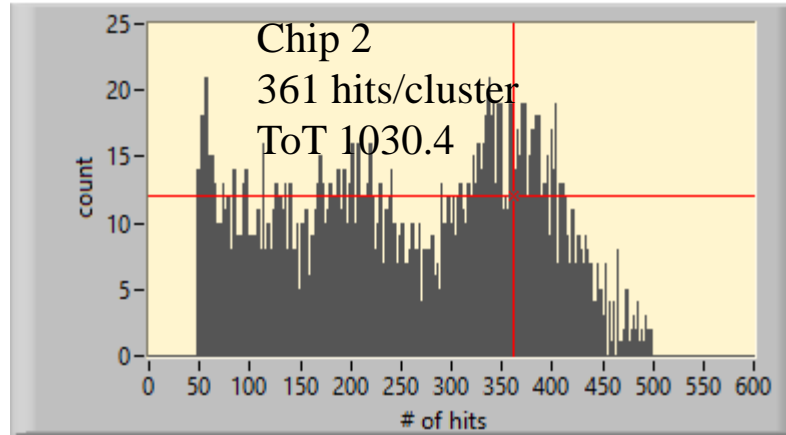
hits per event histogram



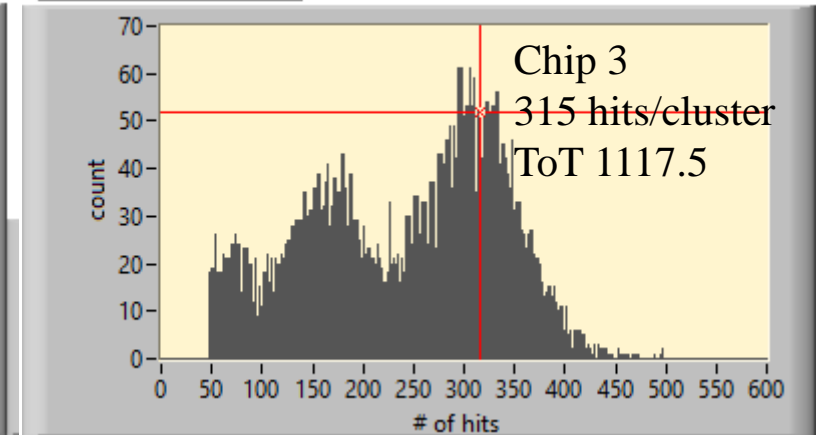
# 340 V

- 11 micro discharges

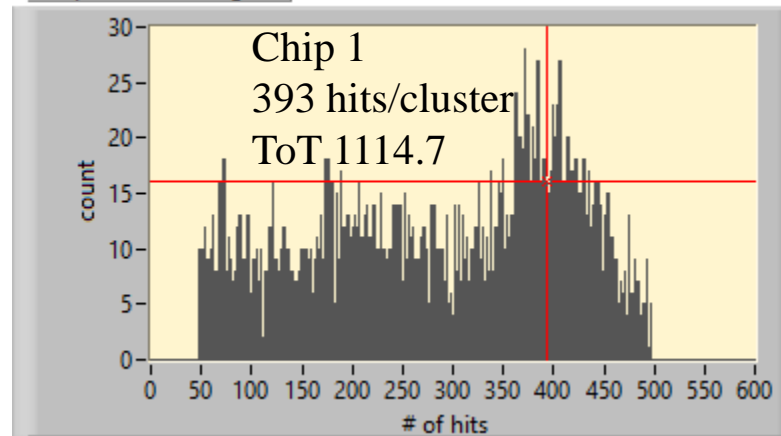
hits per event histogram



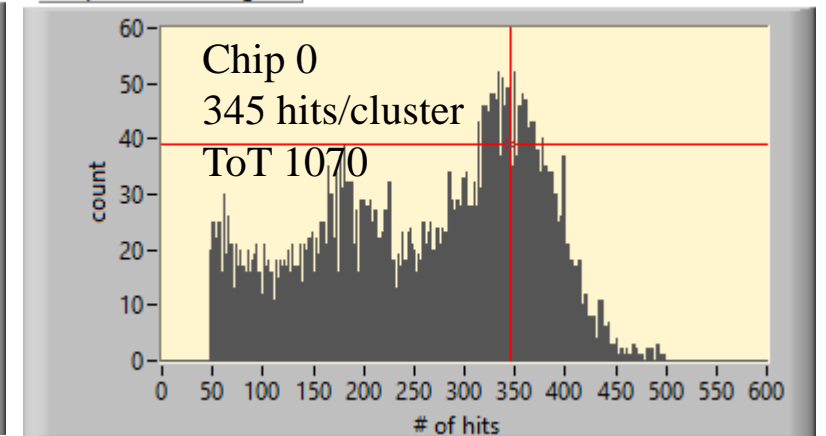
hits per event histogram



hits per event histogram

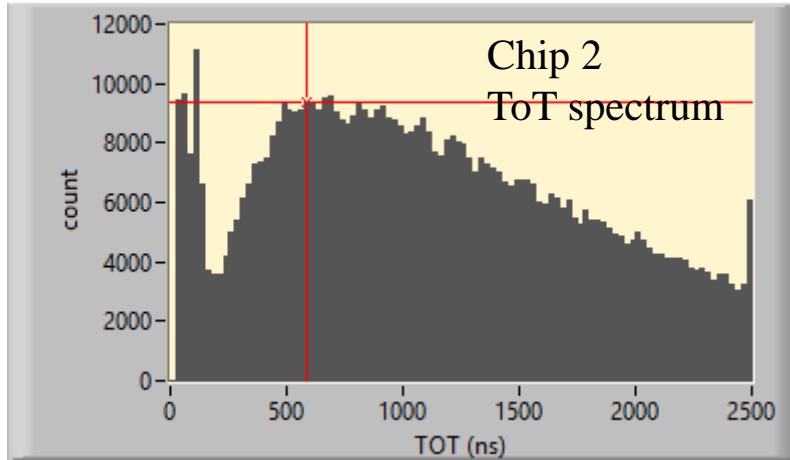


hits per event histogram

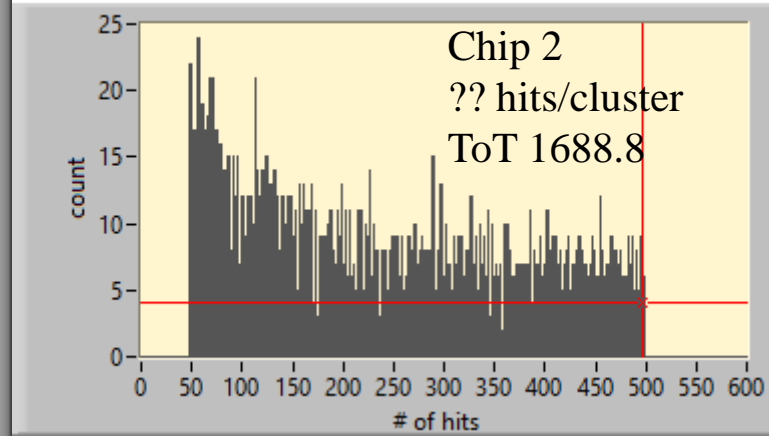


# 350 V

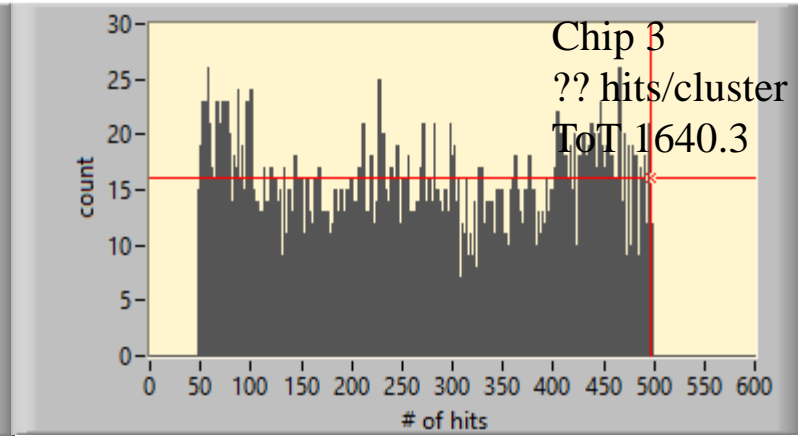
TOT histogram



hits per event histogram

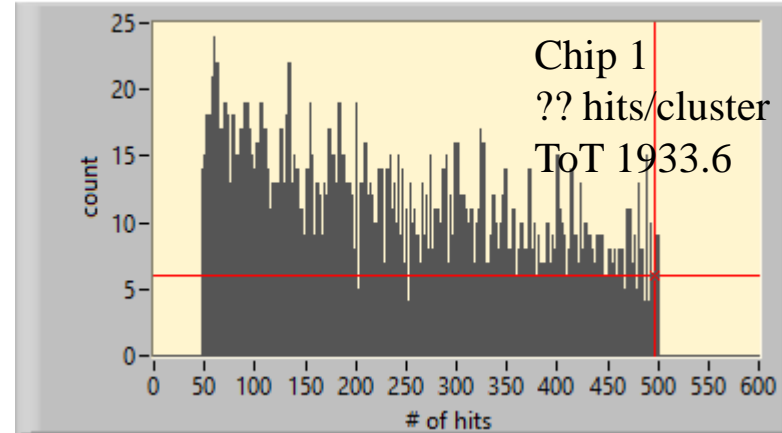


hits per event histogram

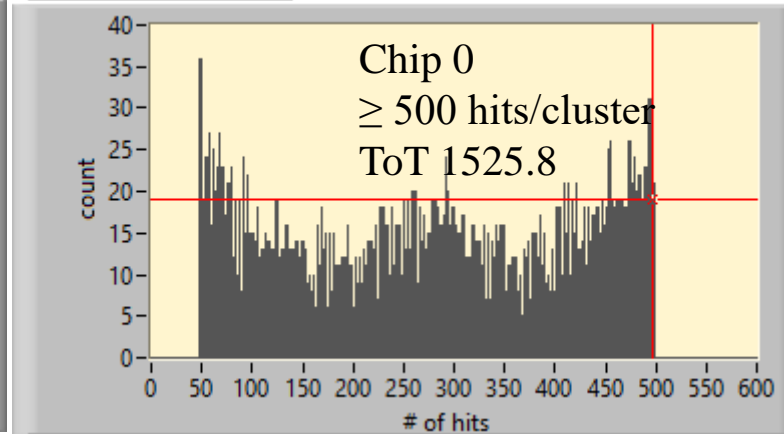


■ 9 micro discharges

hits per event histogram



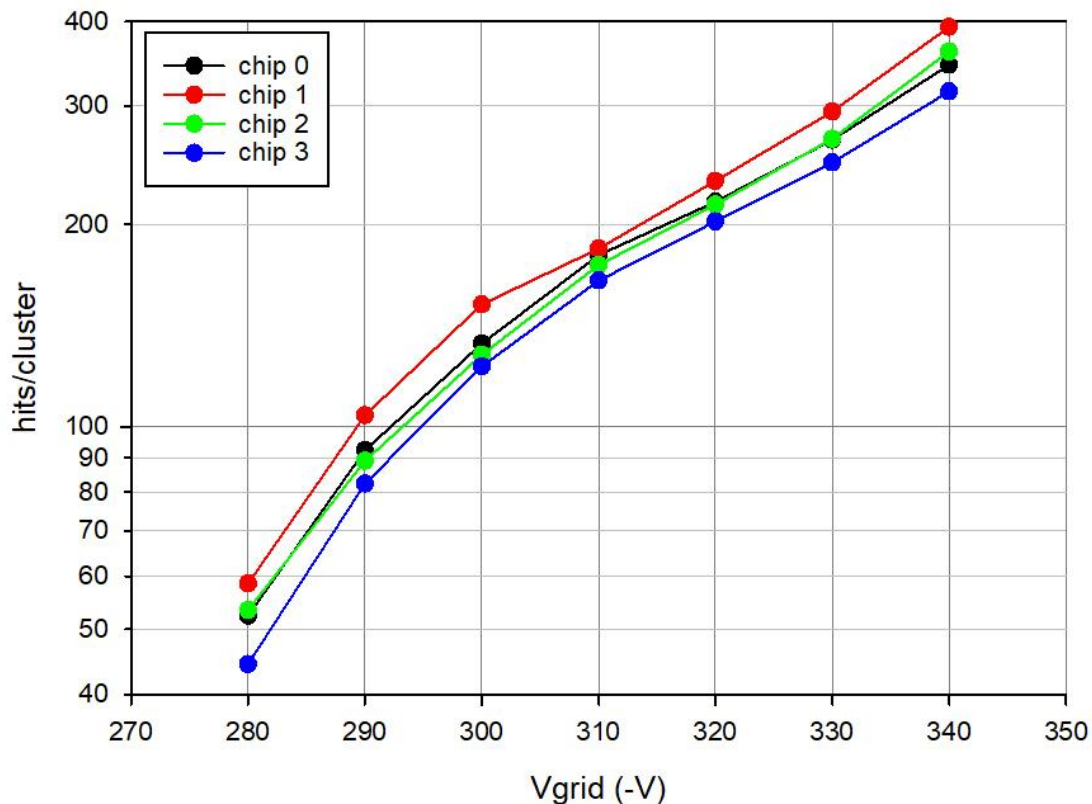
hits per event histogram



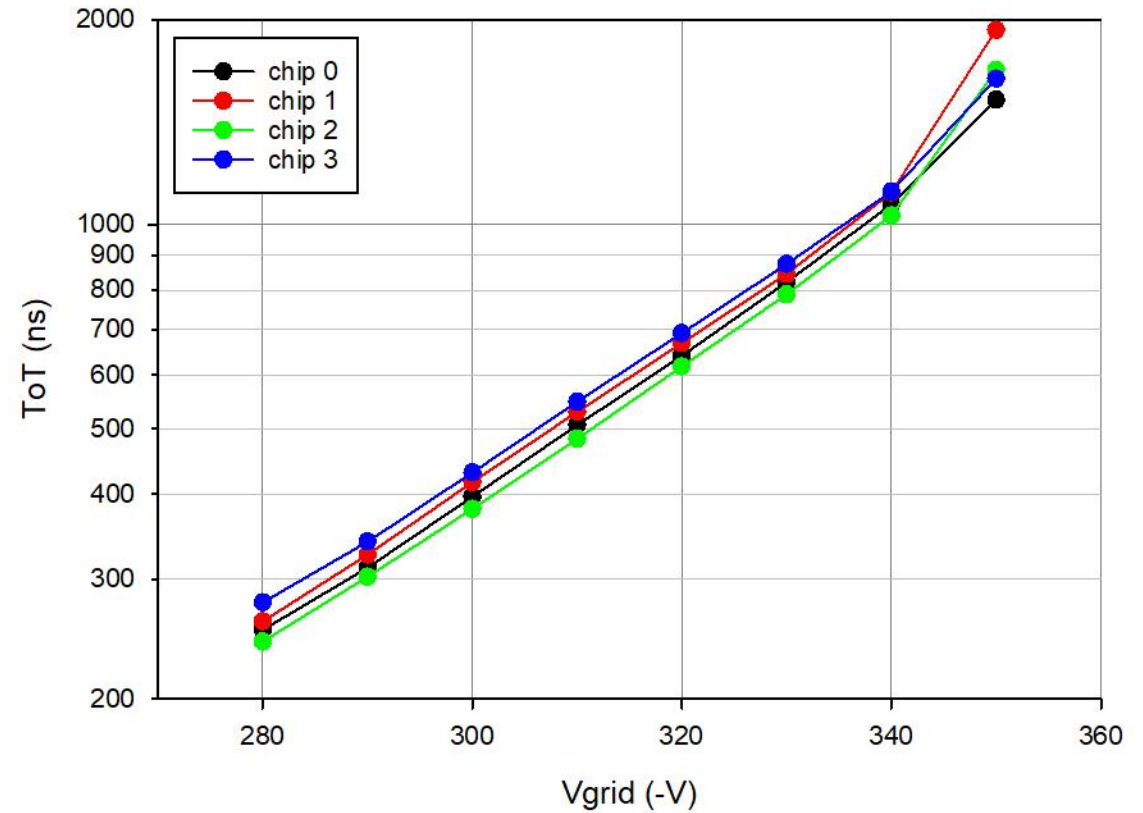
# No plateau visible in hits/cluster

- Results agree with laser measurements
- Above 320 V much more hits than the number of primary electrons
- Possible cause: **secondary emission** from the grid by UV light from the avalanche
- May be solved by more quencher in the gas (iC4H10)

QUAD 13 hits/cluster vs Vgrid  
55Fe irradiation

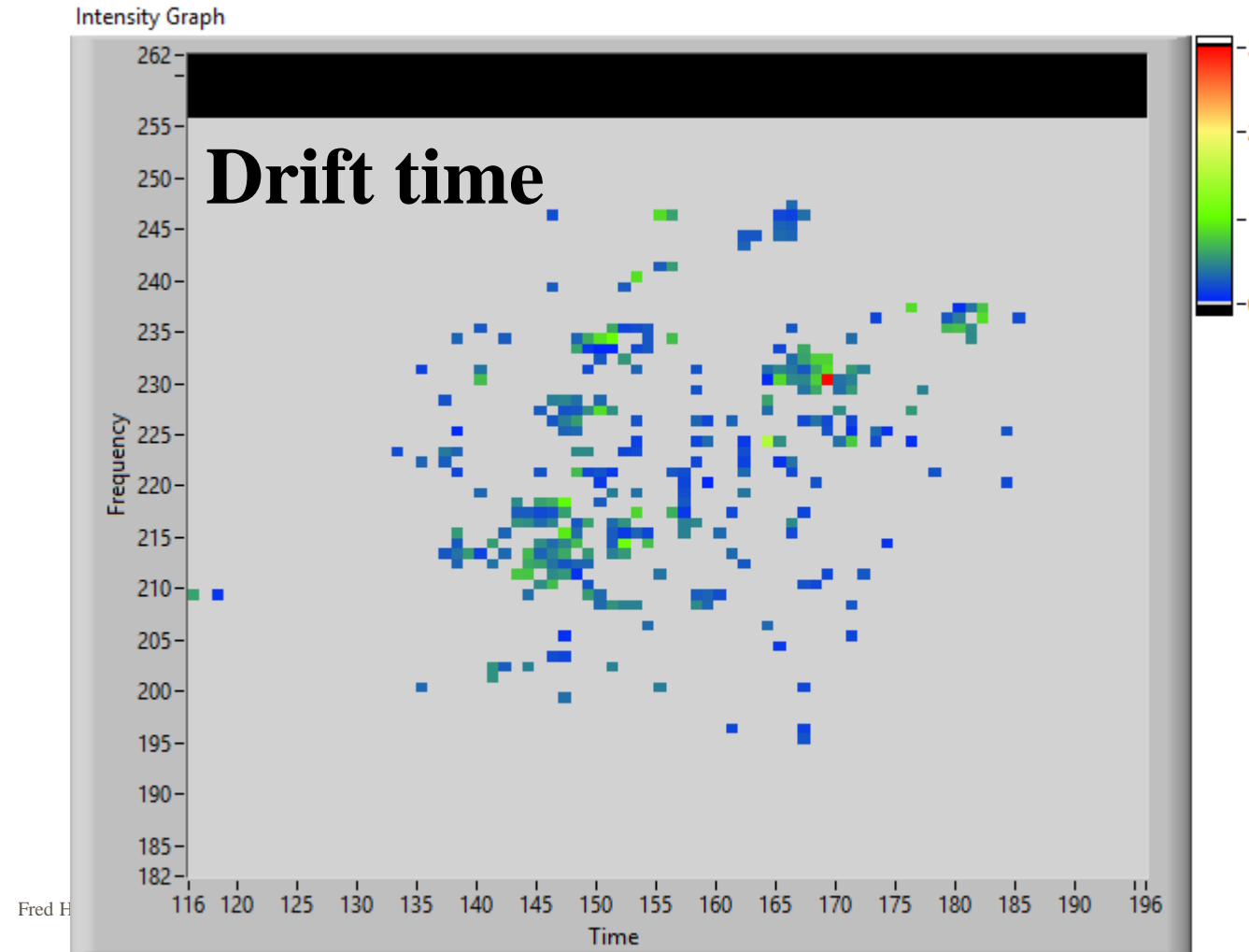
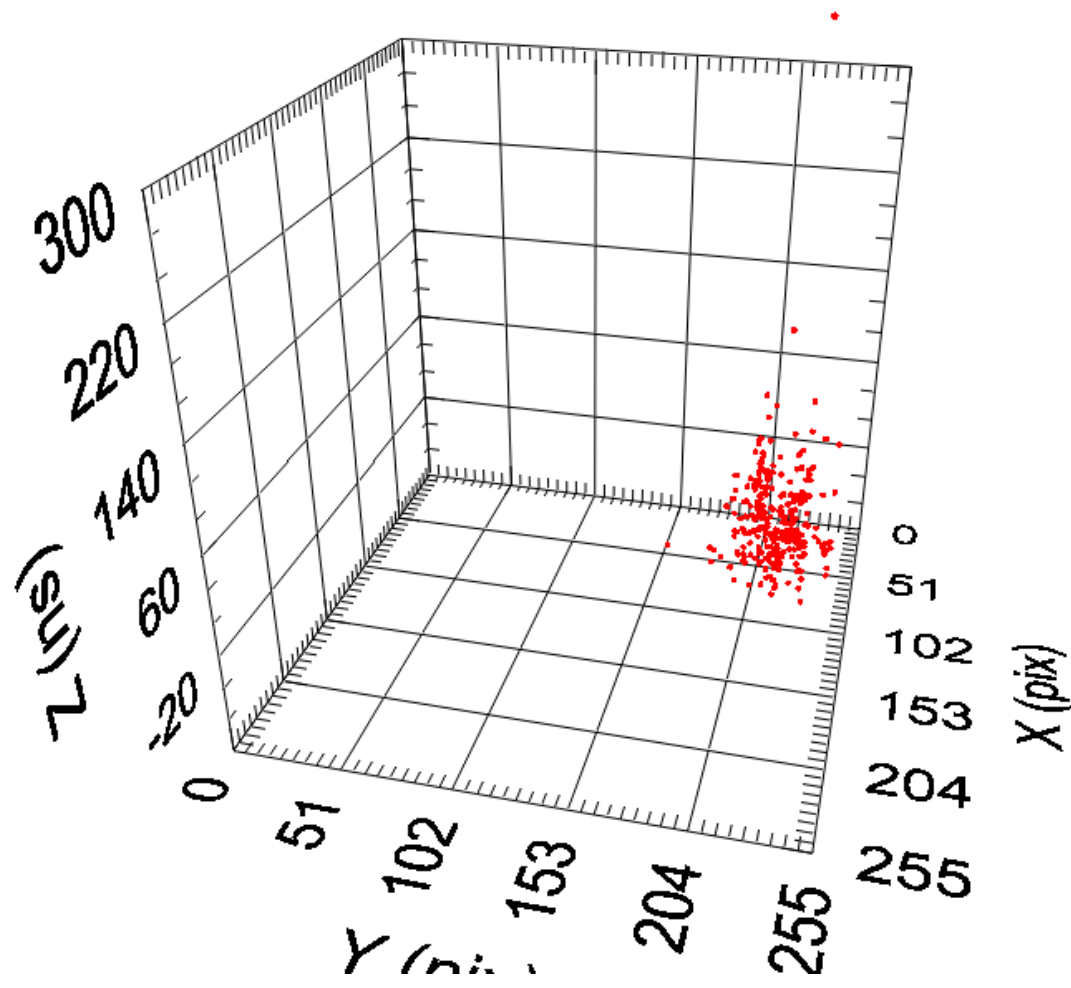


QUAD 13 ToT vs Vgrid  
55Fe irradiation



- NO ToT correction
- 288 hits
- 215 neighbours
- **Tendency of clustering**

## Event at $V_{grid} = -350$ V

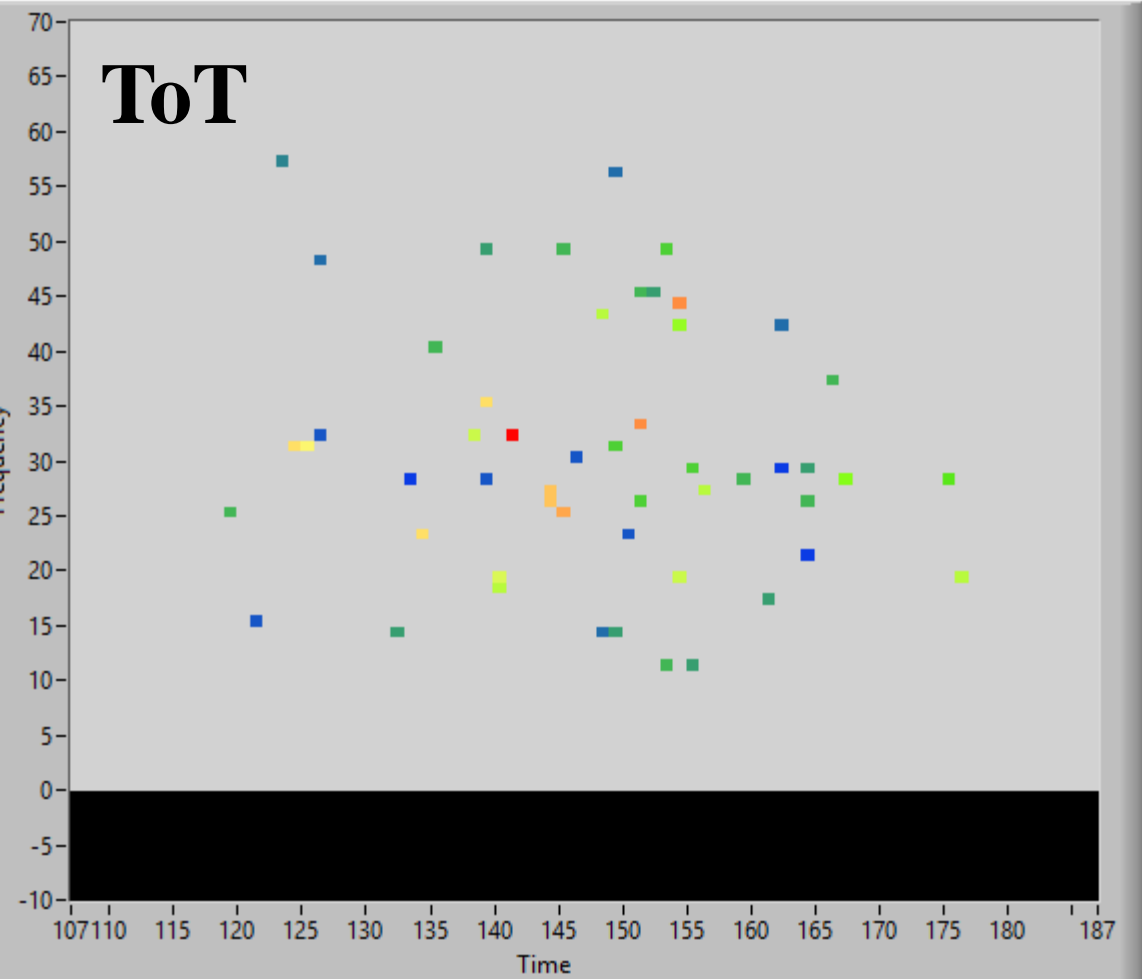


# Events

$V_{\text{grid}} = -280 \text{ V}$

52 hits, 5 neighbours

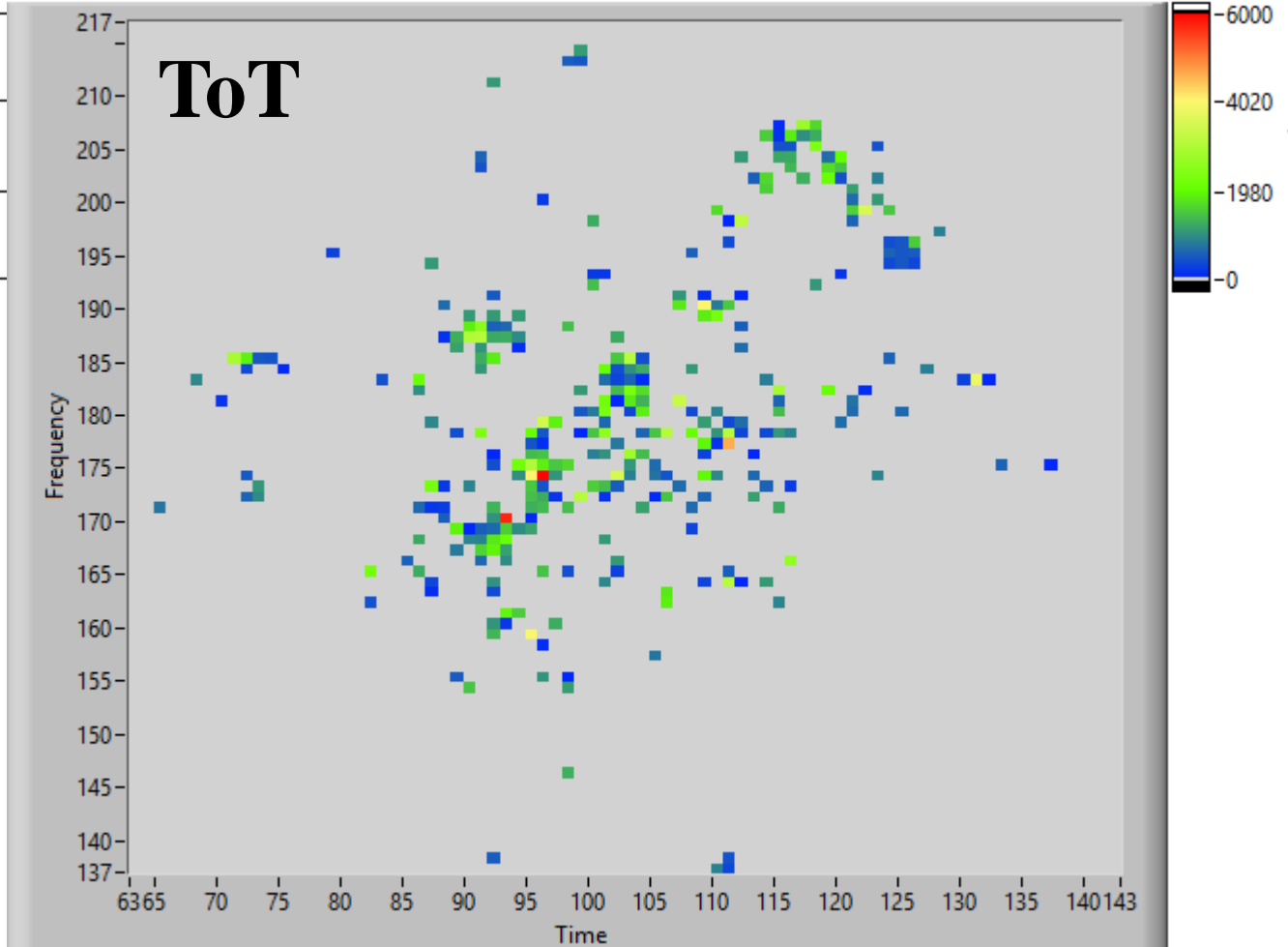
Intensity Graph



$V_{\text{grid}} = -350 \text{ V}$

338 hits, 239 neighbours

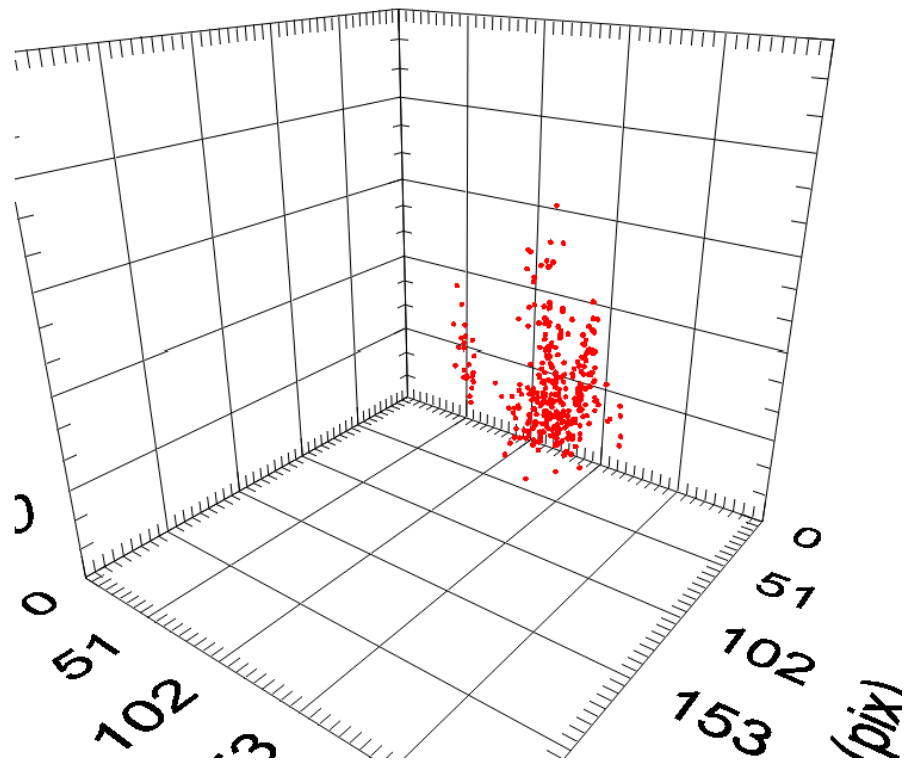
Intensity Graph





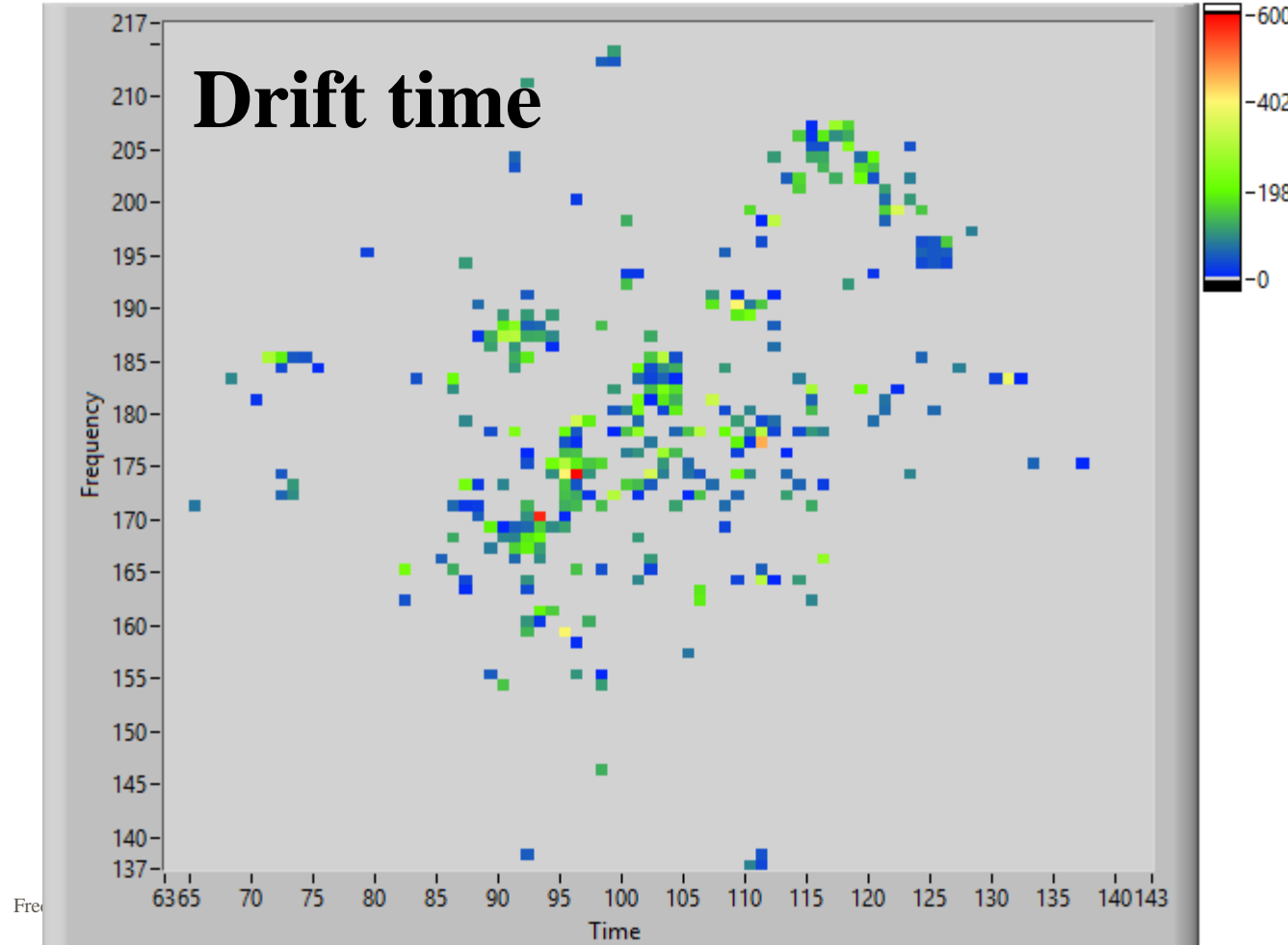
Vgrid = -350 V  
338 hits, 239 neighbours

Event display



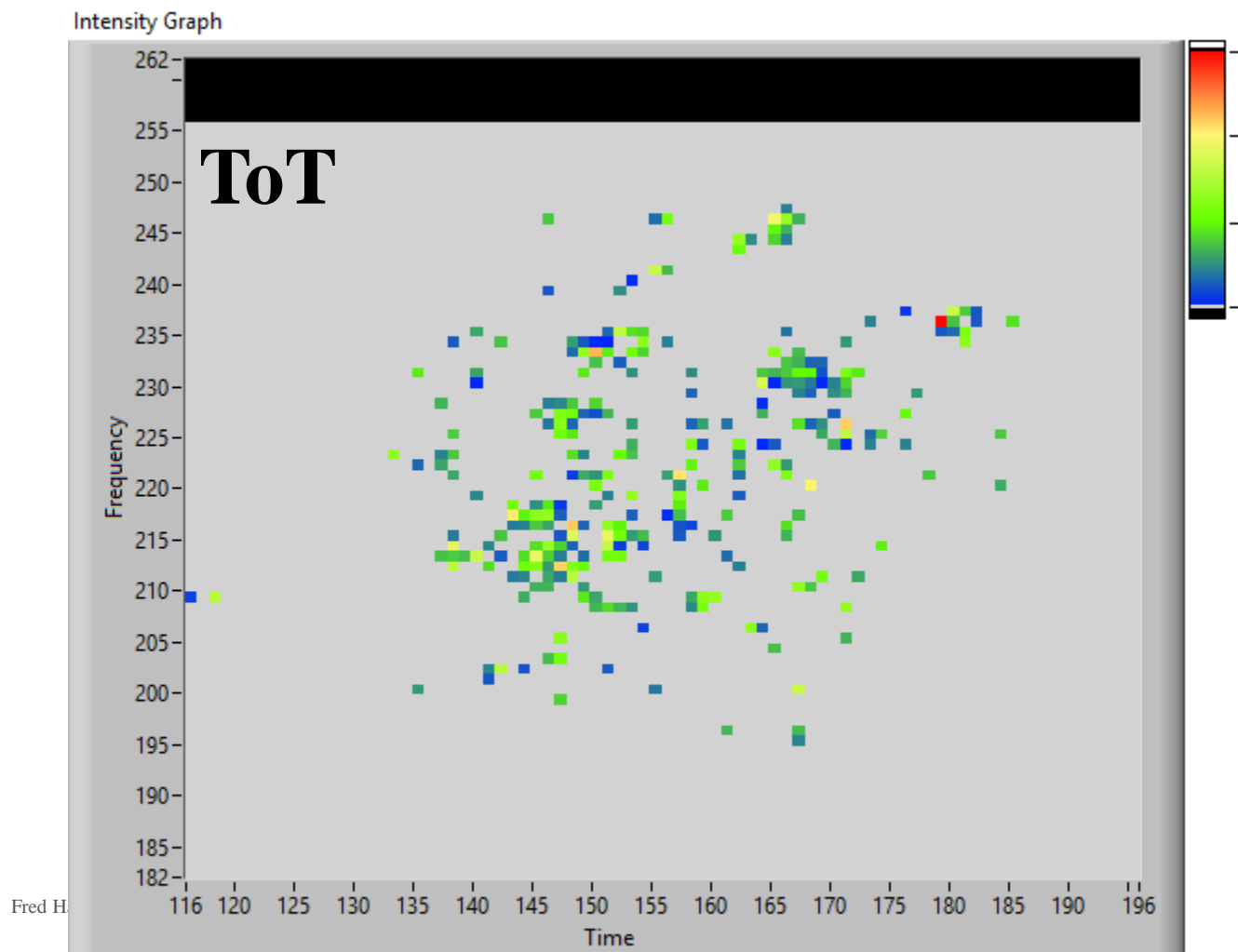
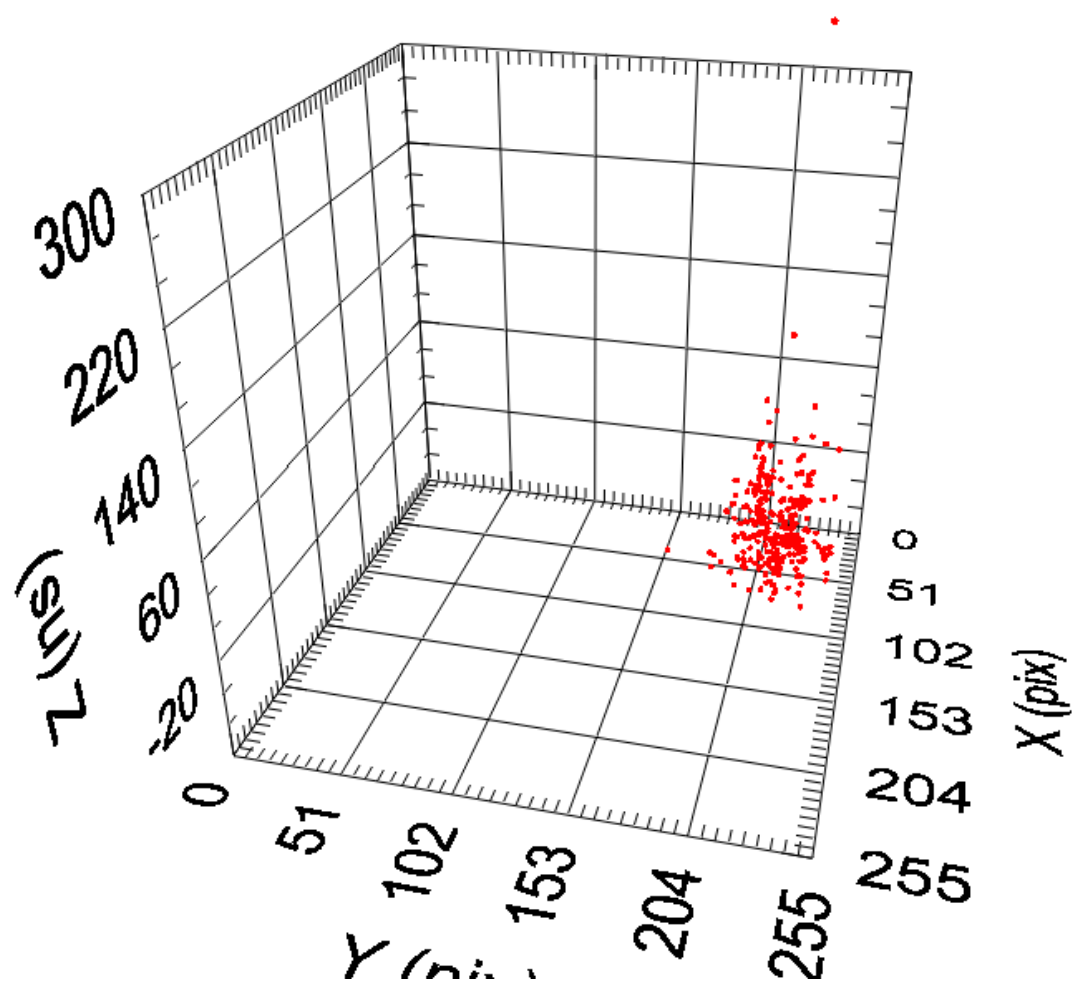
Vgrid = -350 V  
338 hits, 239 neighbours

Intensity Graph



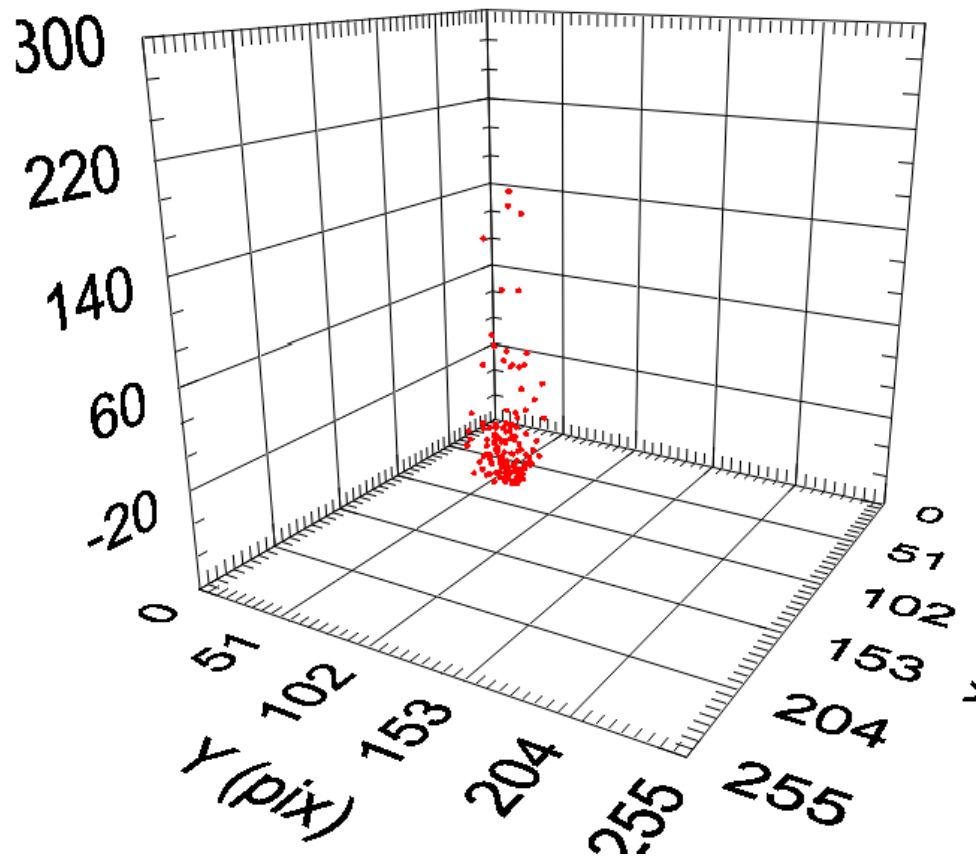
- NO ToT correction
- 288 hits
- 215 neighbours
- **Indication of clustering**

## Event at $V_{grid} = -350$ V

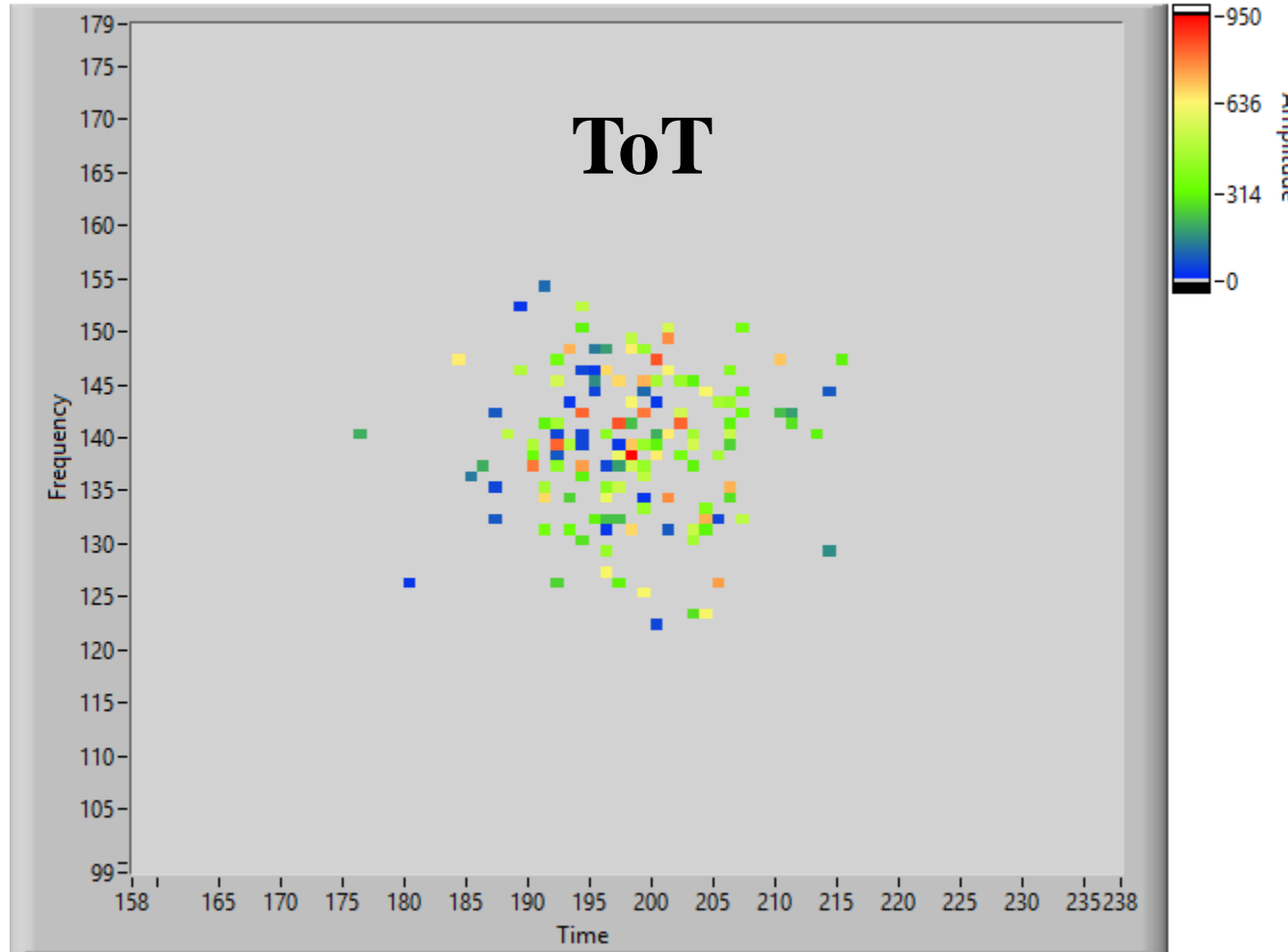


- NO ToT correction
- 134 hits
- 59 neighbours
- **NOT many pairs of high/low ToT**

## Event at $V_{\text{grid}} = -300 \text{ V}$

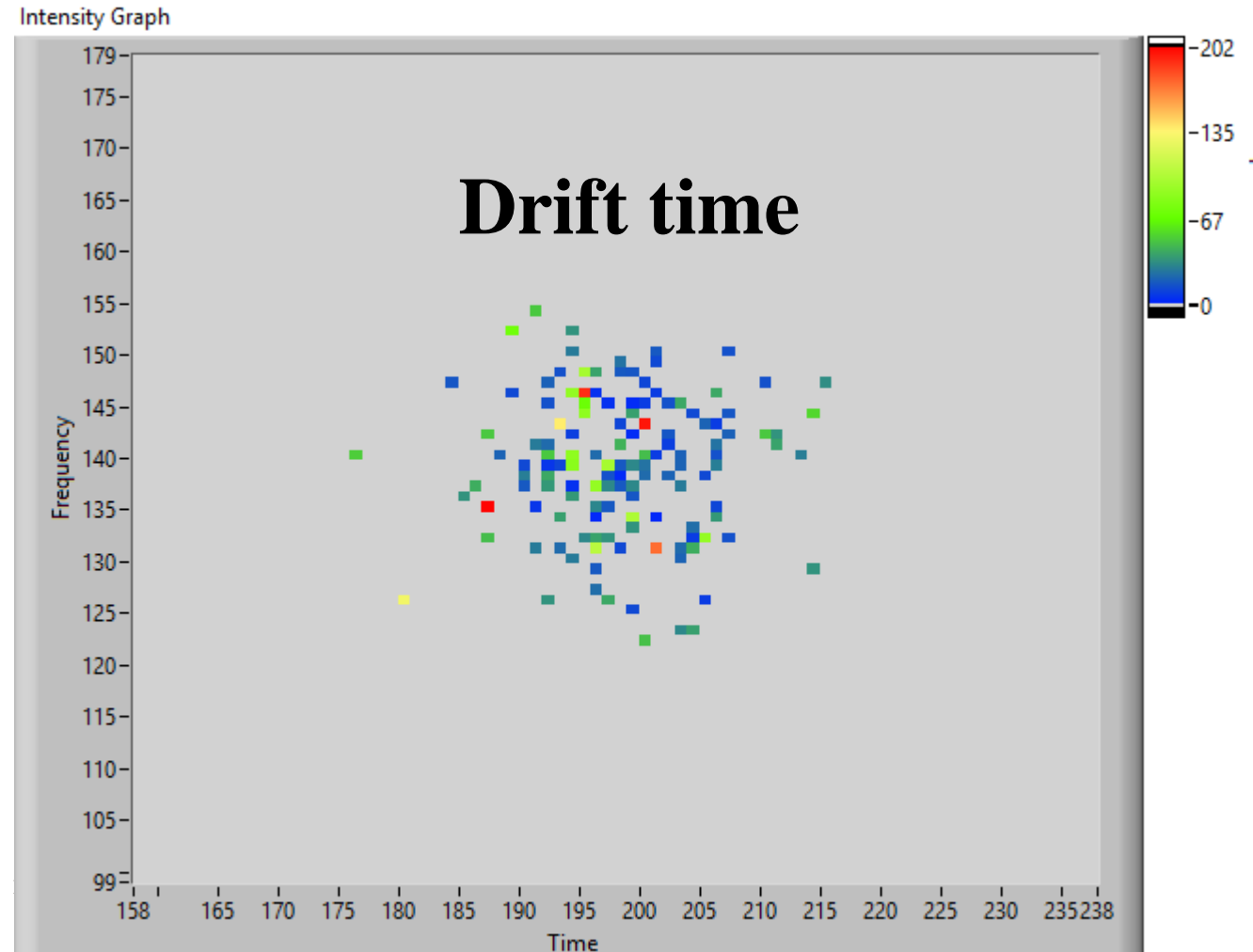
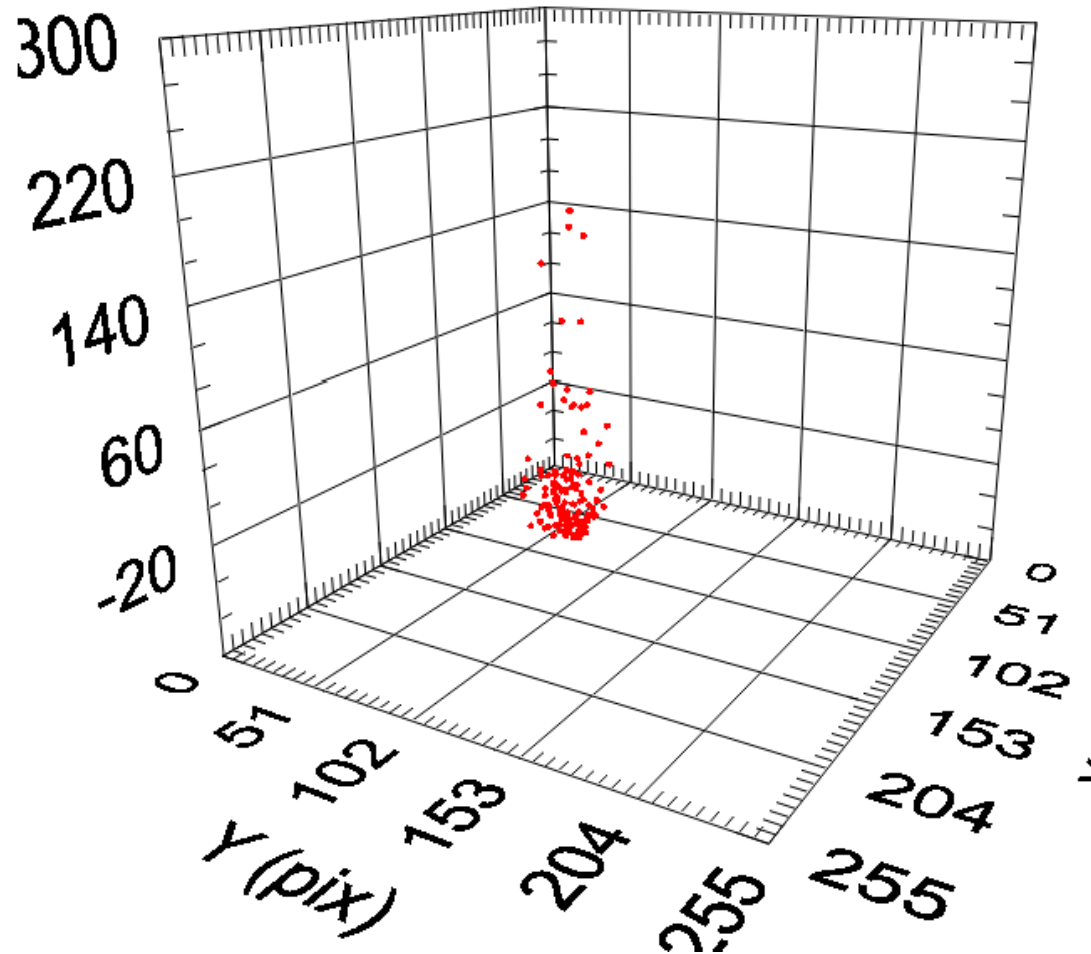


Intensity Graph



- NO ToT correction
- 134 hits, 59 neighbours
- No unexpectedly large drift times
  - Large drift times are related to small ToT

## Event at $V_{\text{grid}} = -300 \text{ V}$



**T3K**

**(iC4H10/CF4/Ar 3/3/94)**

# 55Fe measurements with T3K

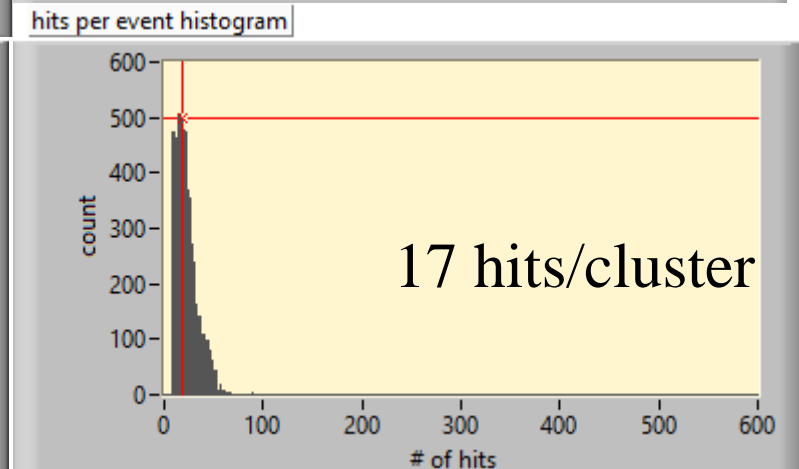
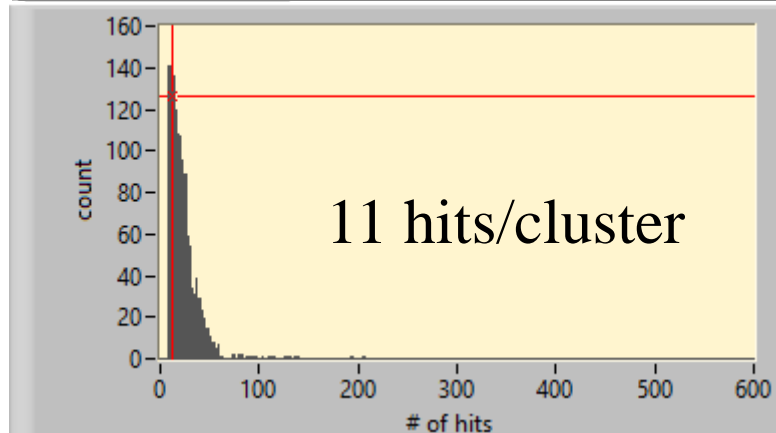
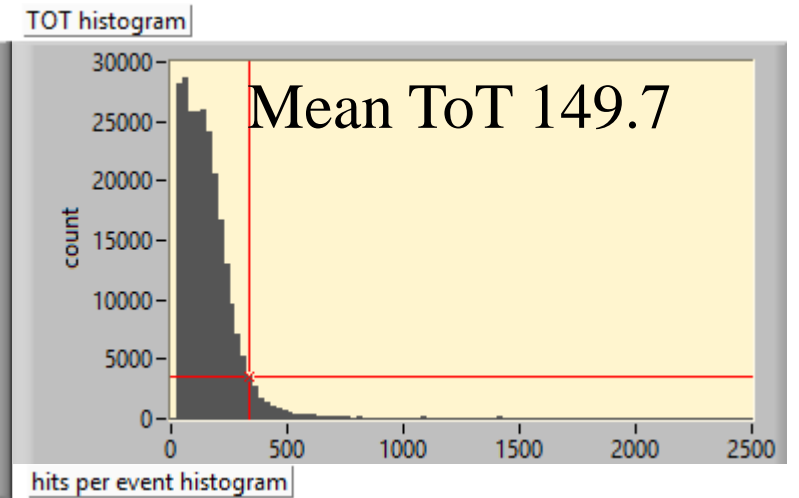
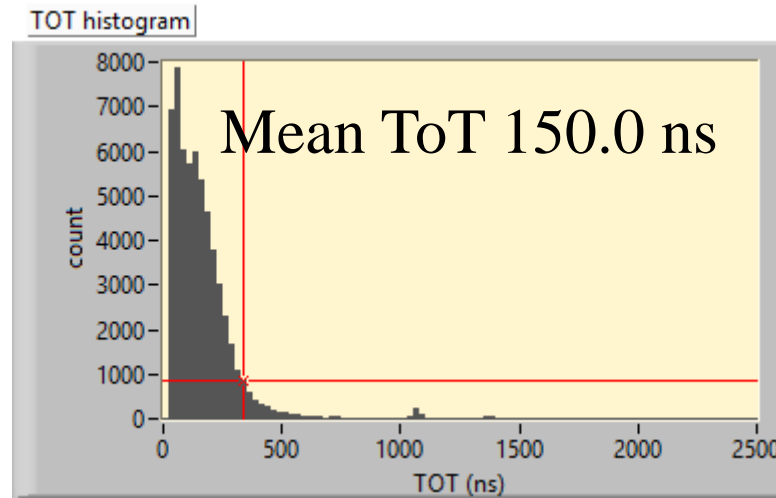
Vgrid = -280 V

- No micro discharges

Chip 2

Chip 0

Increased threshold



# 55Fe measurements with T3K

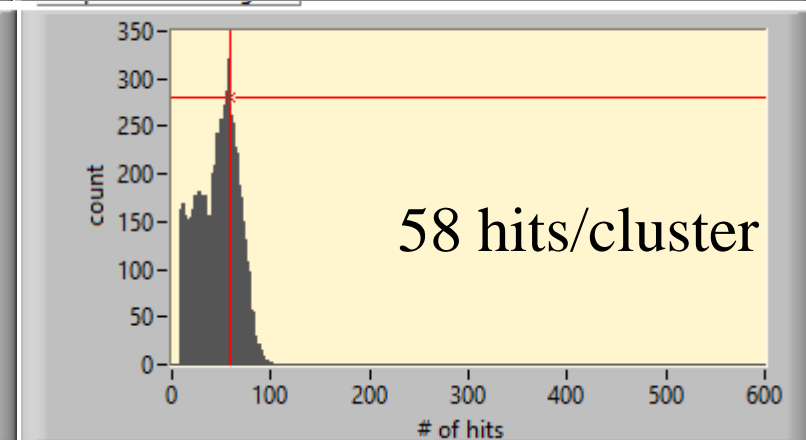
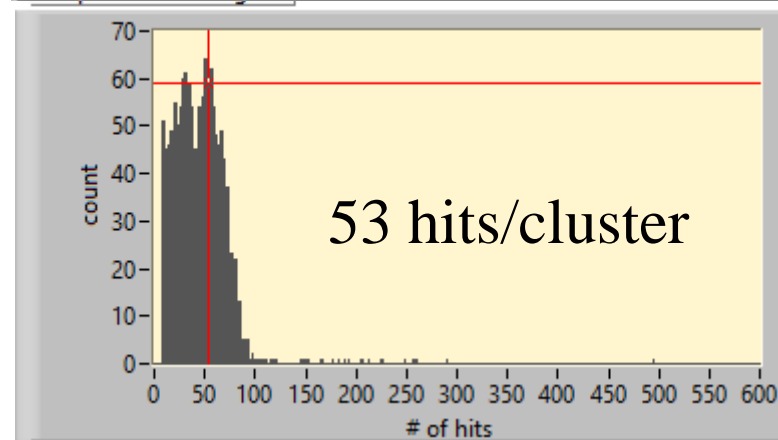
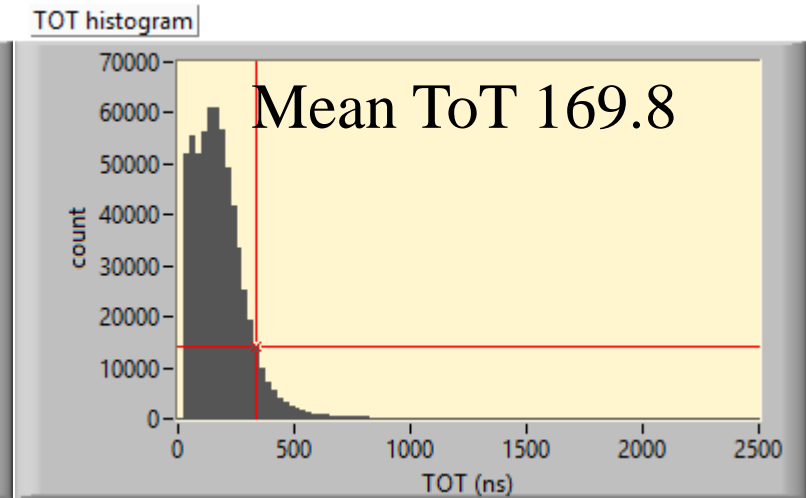
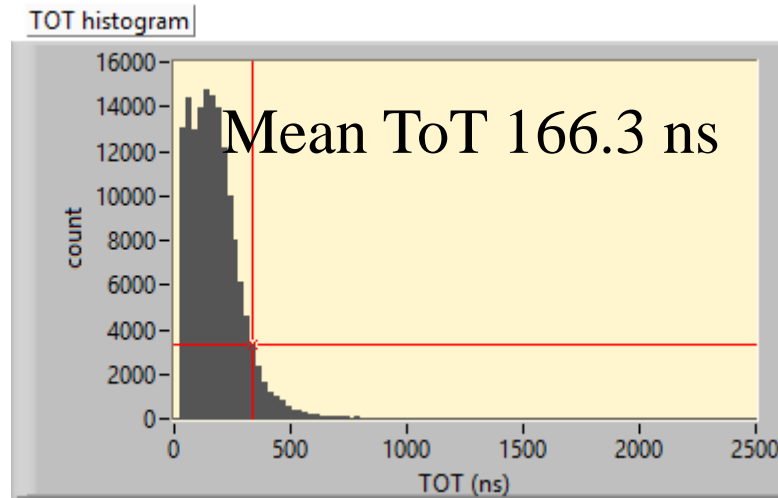
Vgrid = -290 V

- No micro discharges

Chip 2

Chip 0

Increased threshold





# 55Fe measurements with T3K

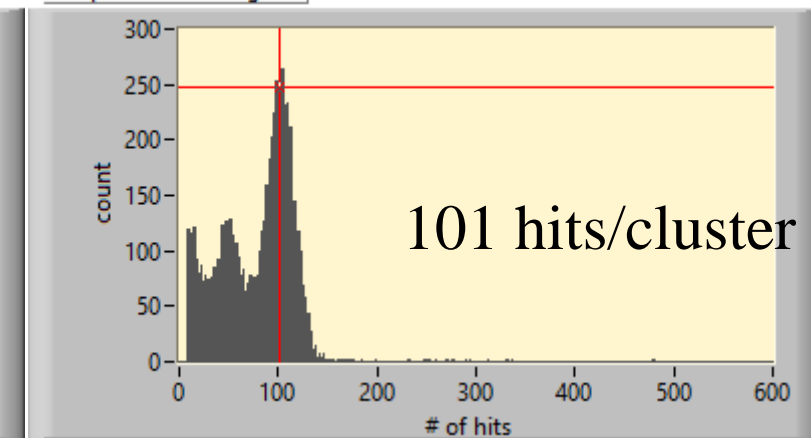
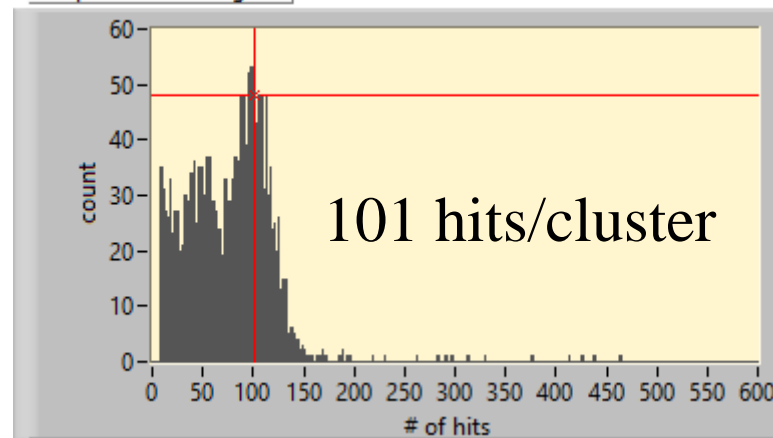
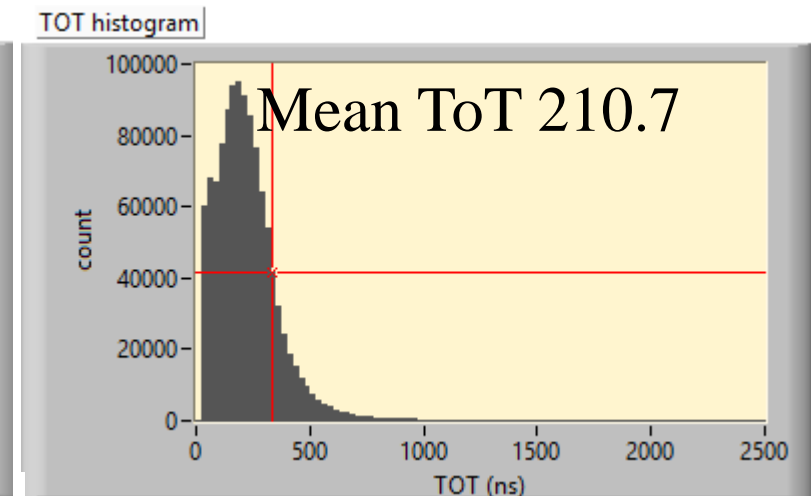
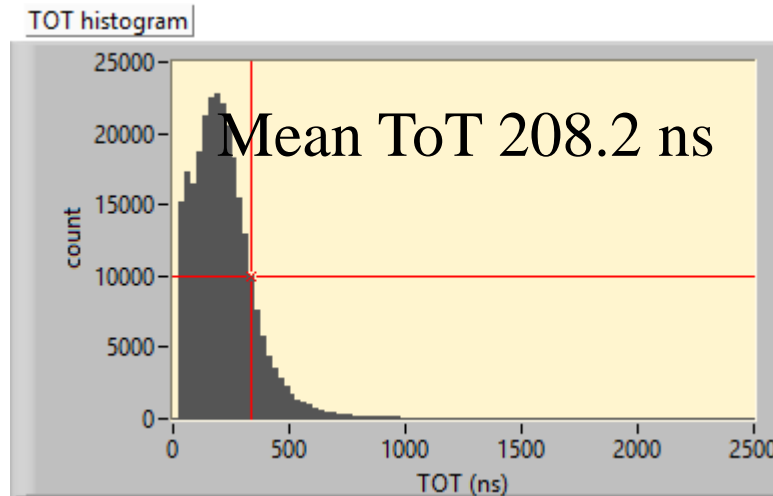
Vgrid = -300 V

- No micro discharges

Chip 2

Chip 0

Increased threshold



# 55Fe measurements with T3K

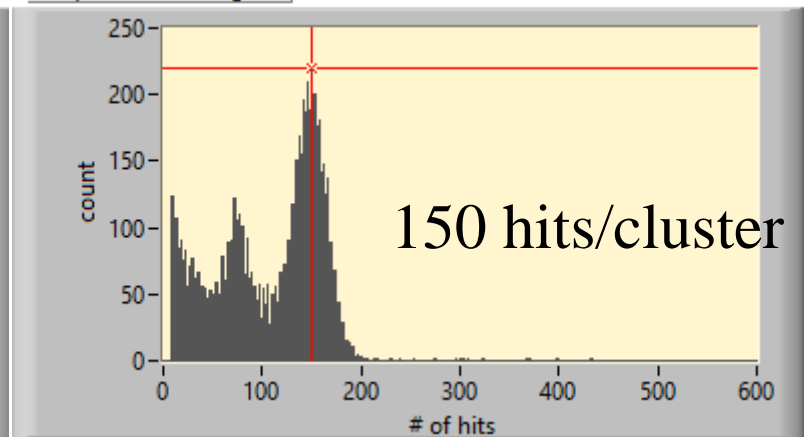
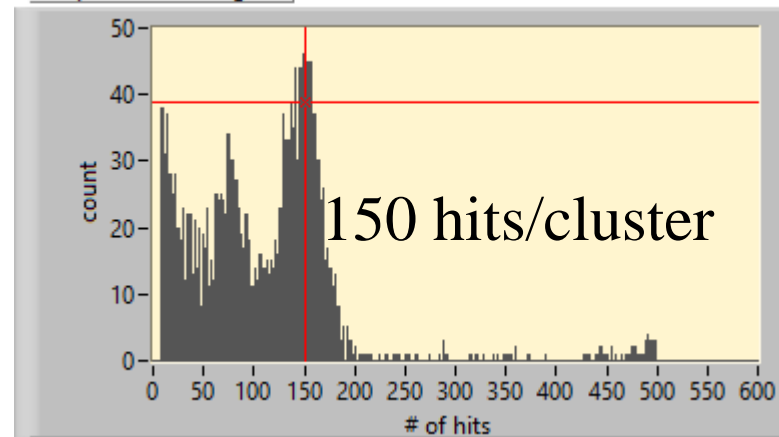
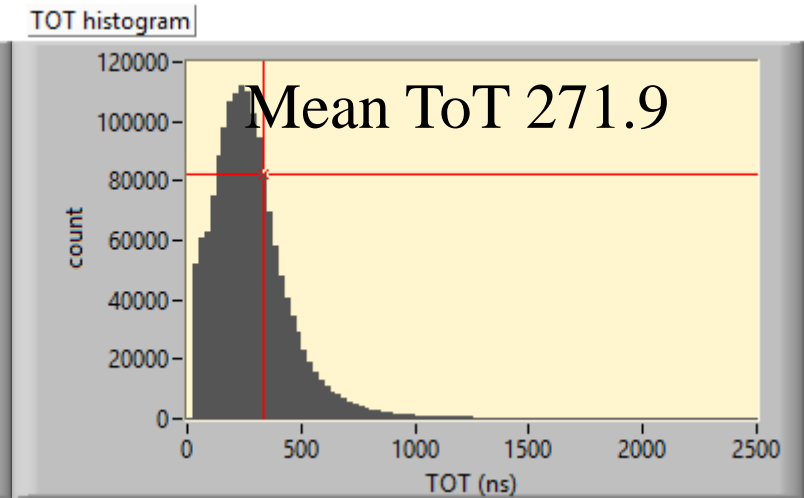
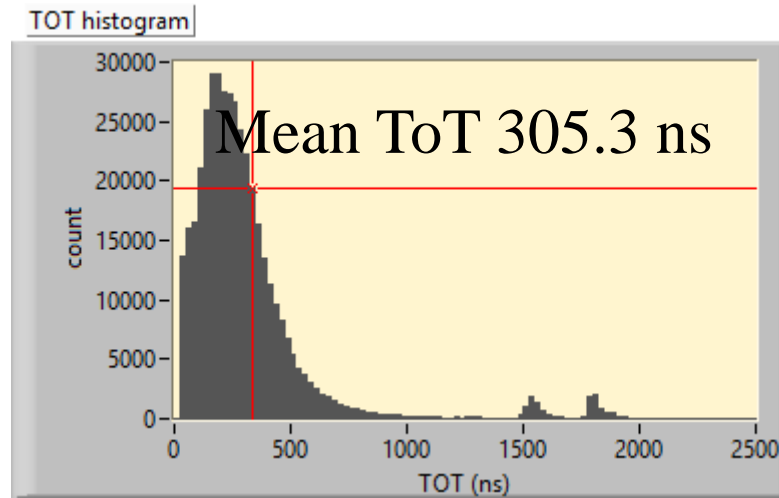
Vgrid = -310 V

- One micro discharge

Chip 2

Chip 0

Increased threshold



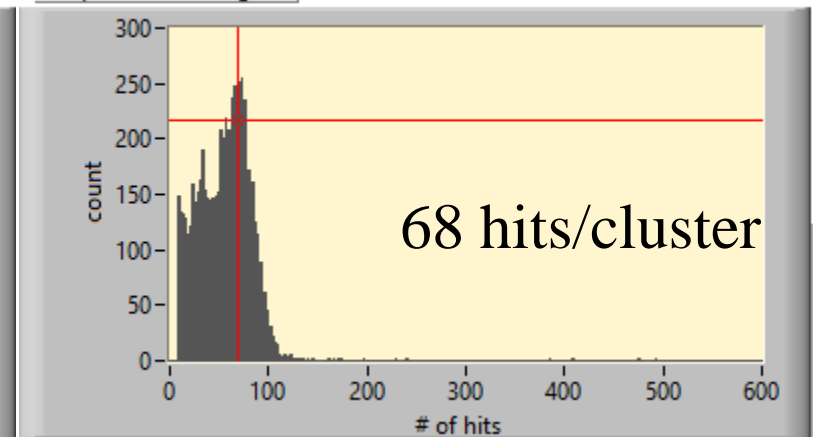
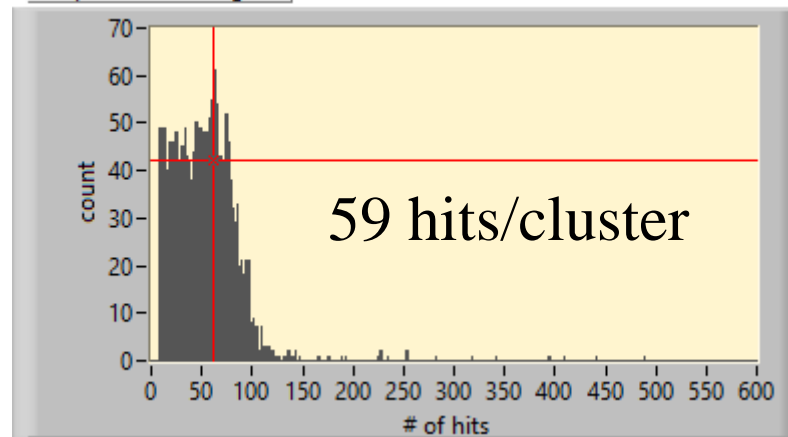
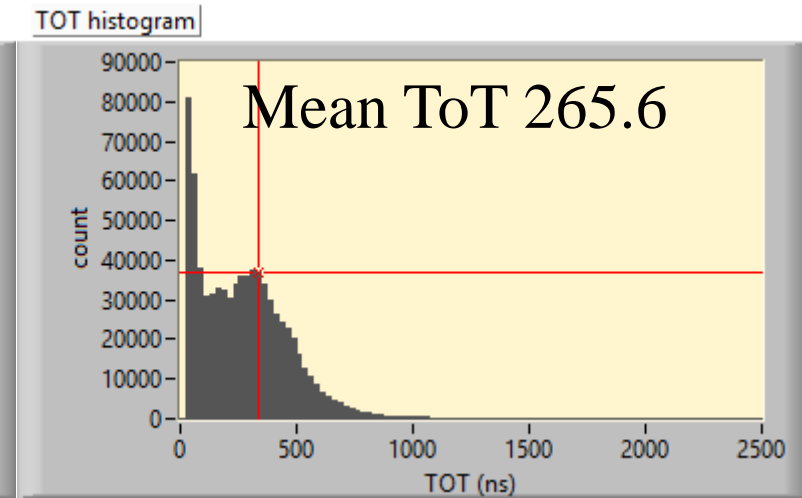
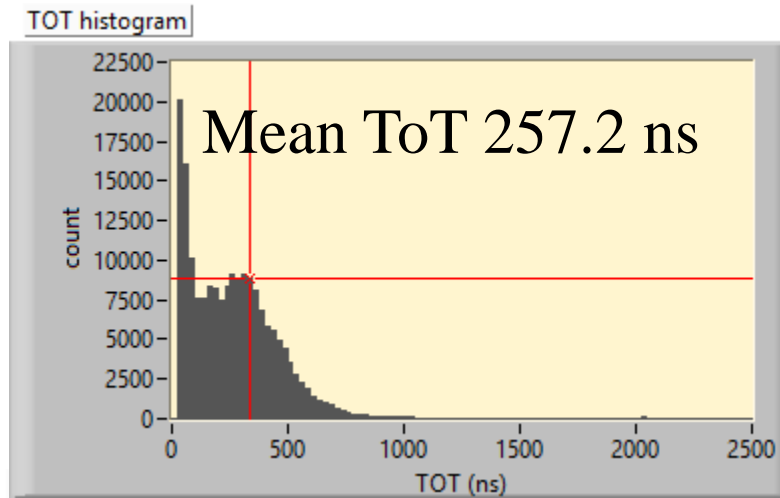
# **$^{55}\text{Fe}$ measurements with T3K**

**Vgrid = -280 V**

- One micro discharge

Chip 2

Chip 0



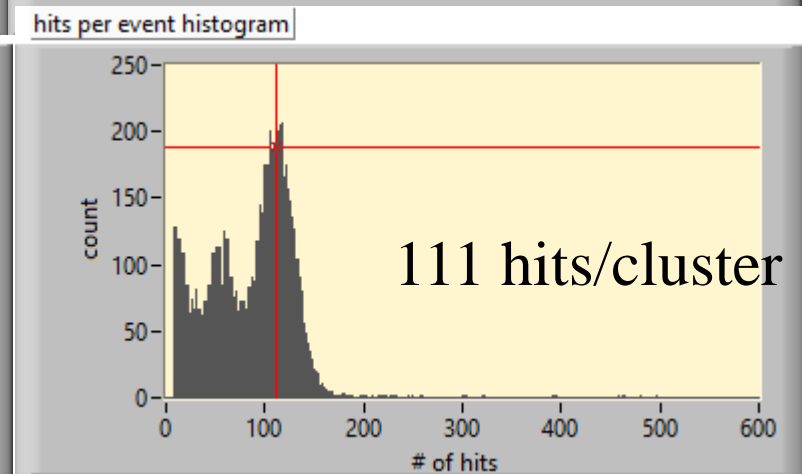
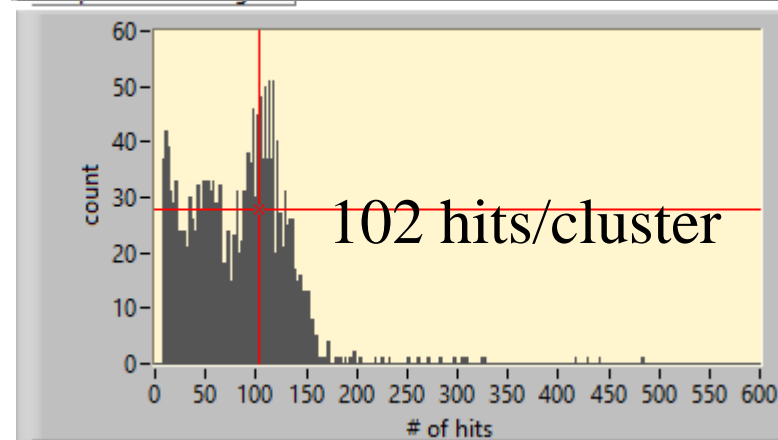
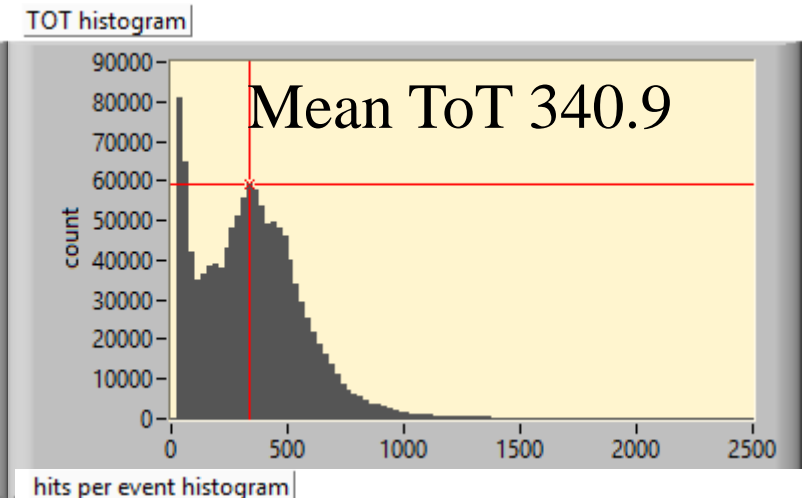
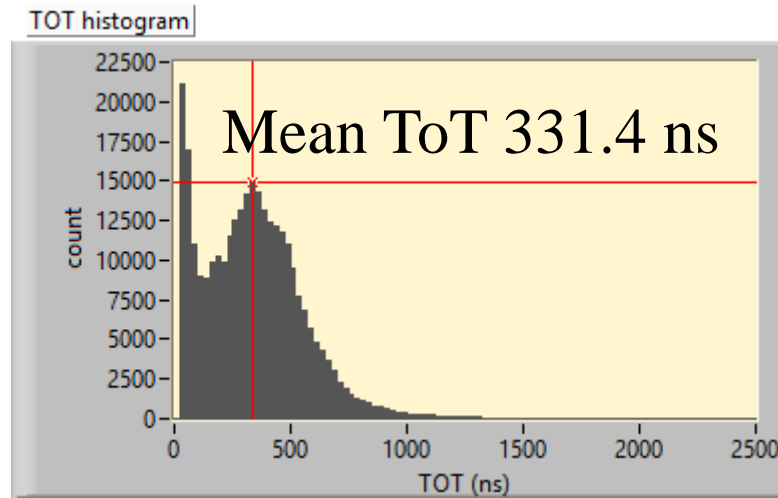
# $^{55}\text{Fe}$ measurements with T3K

$V_{\text{grid}} = -290 \text{ V}$

- Two micro discharges

Chip 2

Chip 0



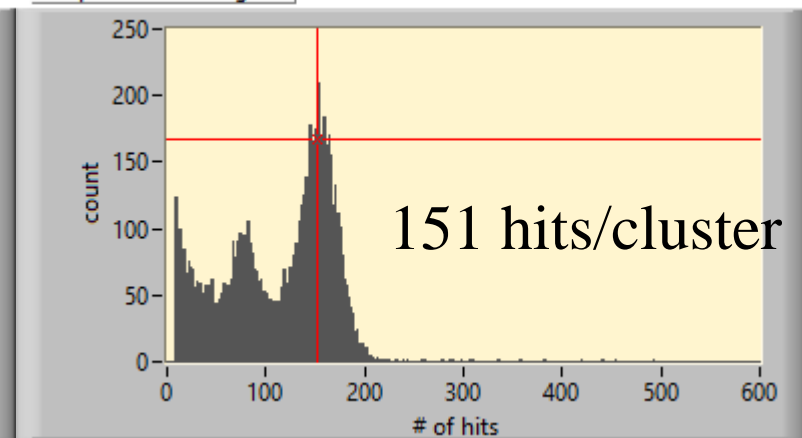
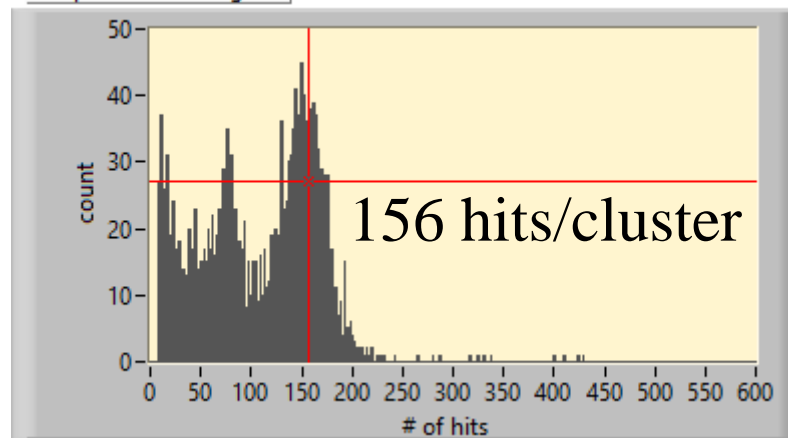
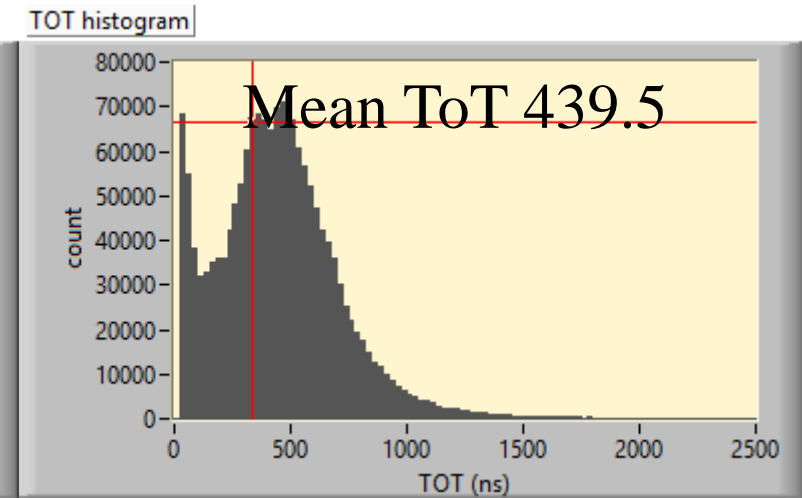
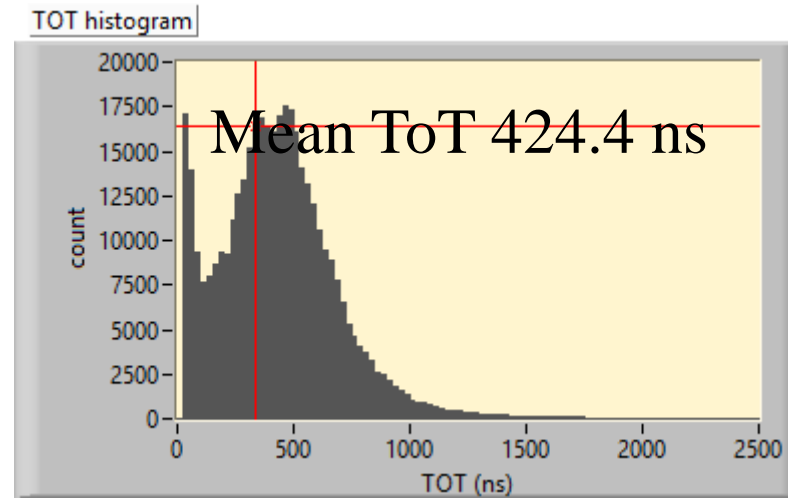
# **$^{55}\text{Fe}$ measurements with T3K**

**$V_{\text{grid}} = -300 \text{ V}$**

- No micro discharges

Chip 2

Chip 0



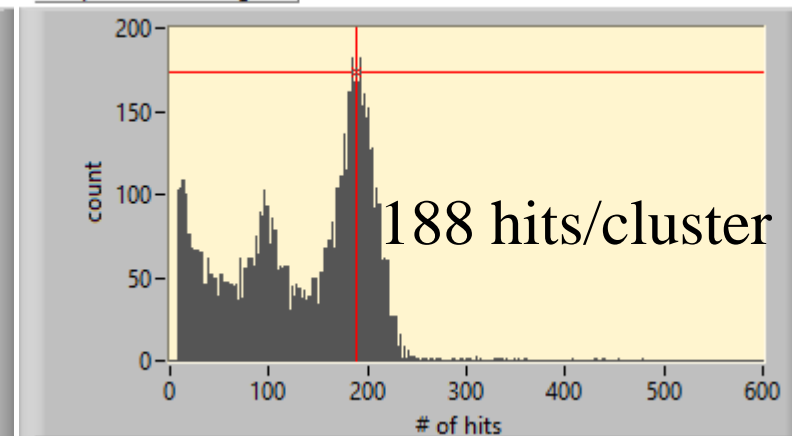
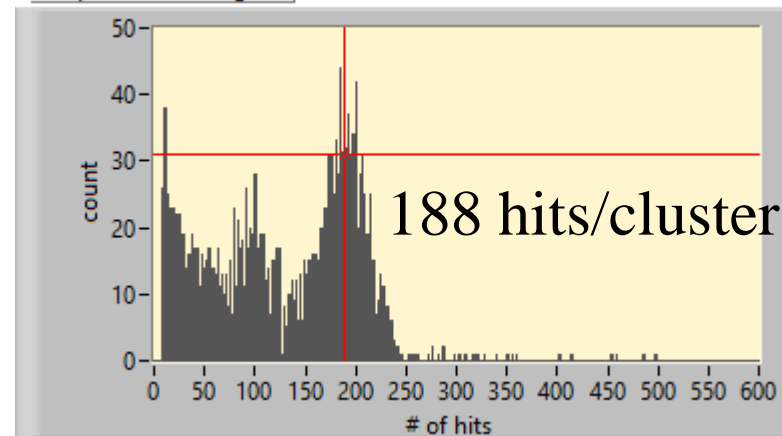
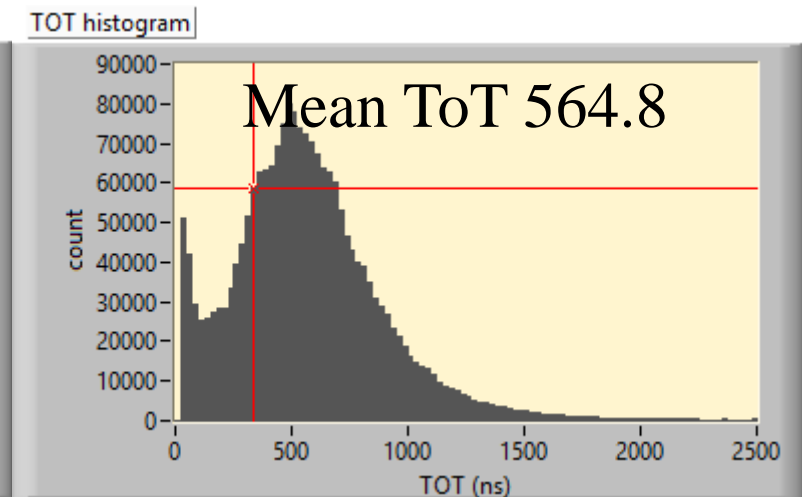
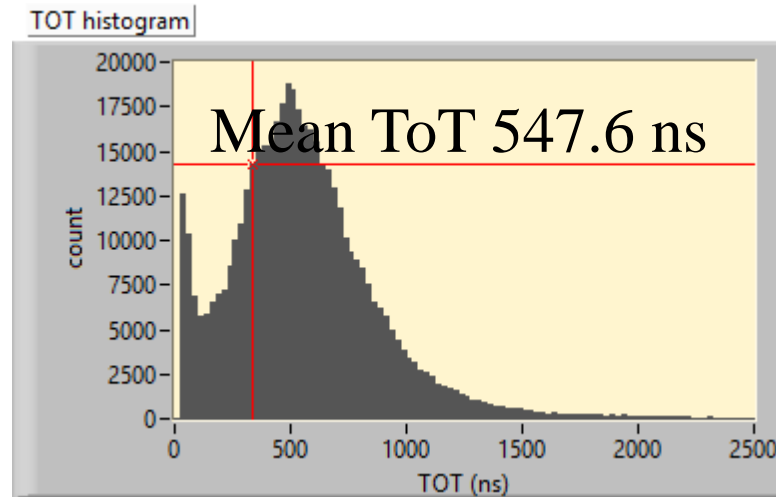
# $^{55}\text{Fe}$ measurements with T3K

Vgrid = -310 V

■ One micro discharge

Chip 2

Chip 0



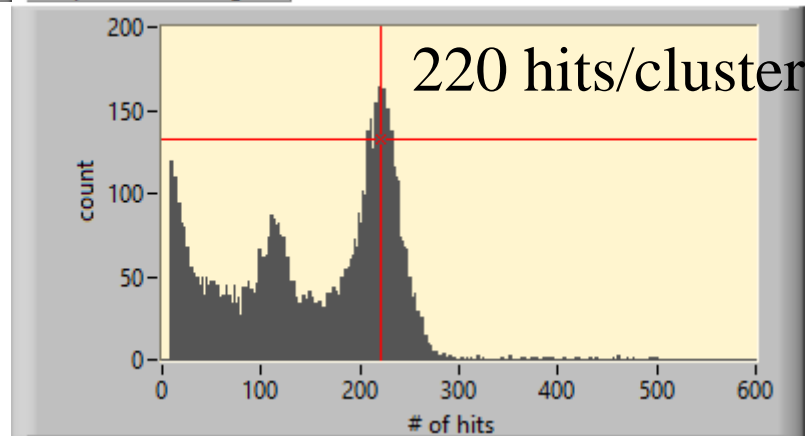
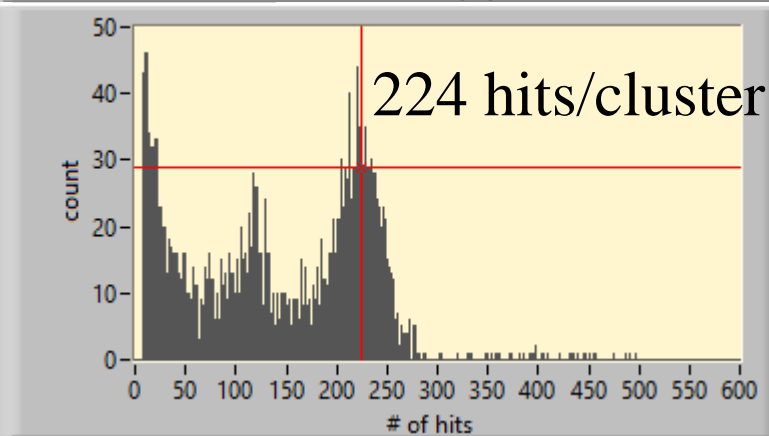
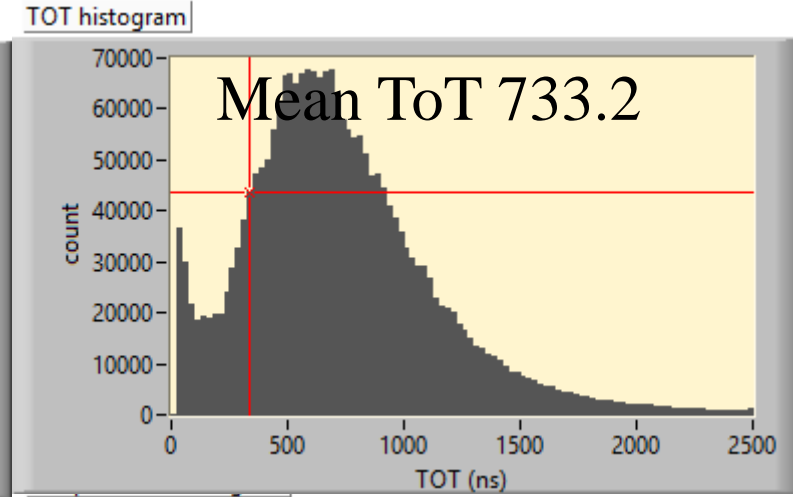
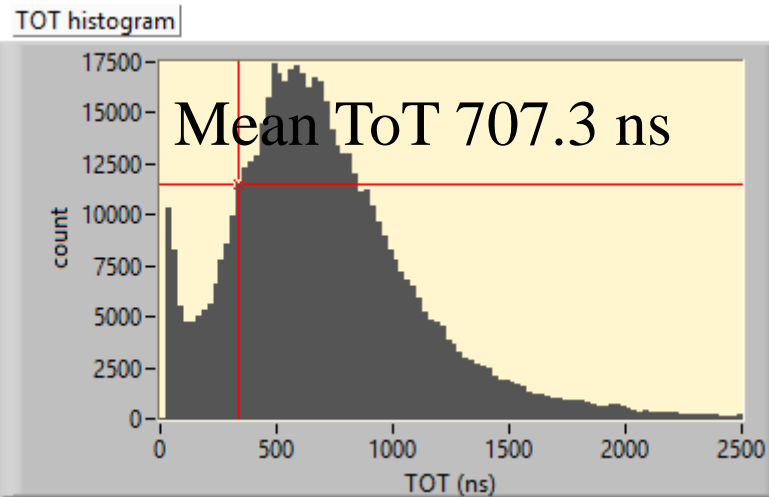
# $^{55}\text{Fe}$ measurements with T3K

$V_{\text{grid}} = -320 \text{ V}$

- Seven micro discharges

Chip 2

Chip 0





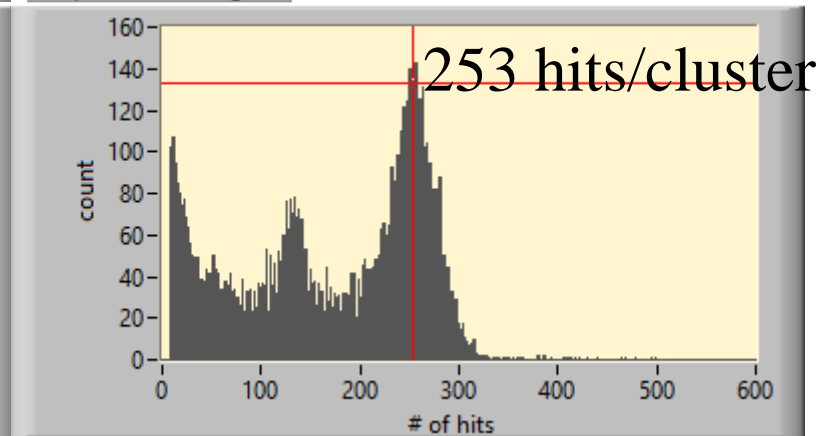
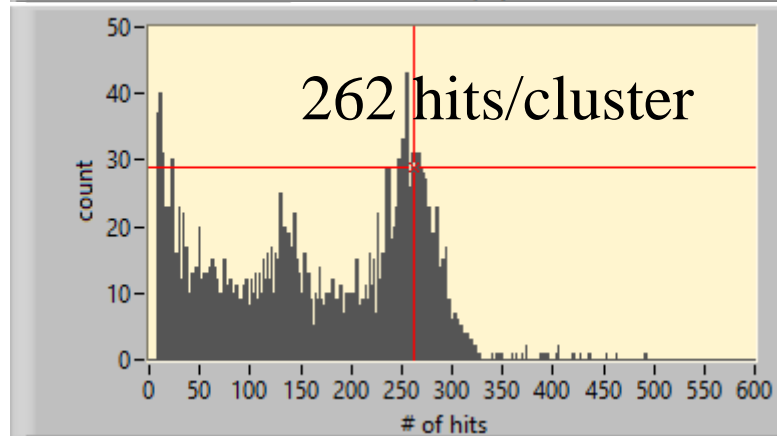
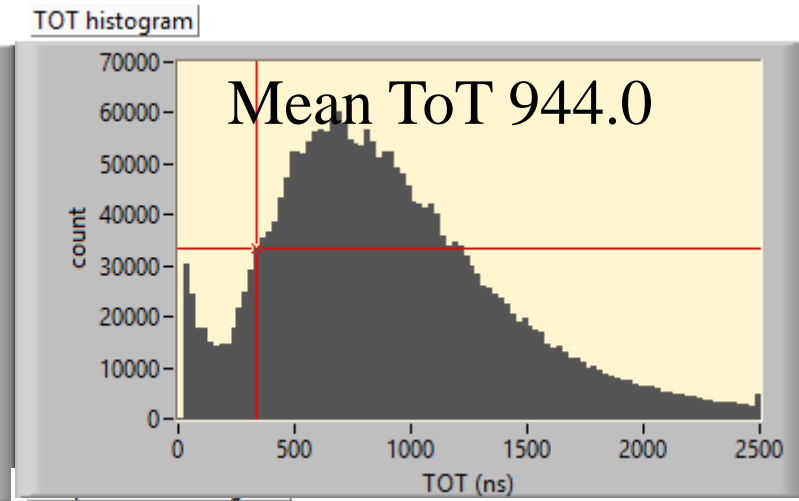
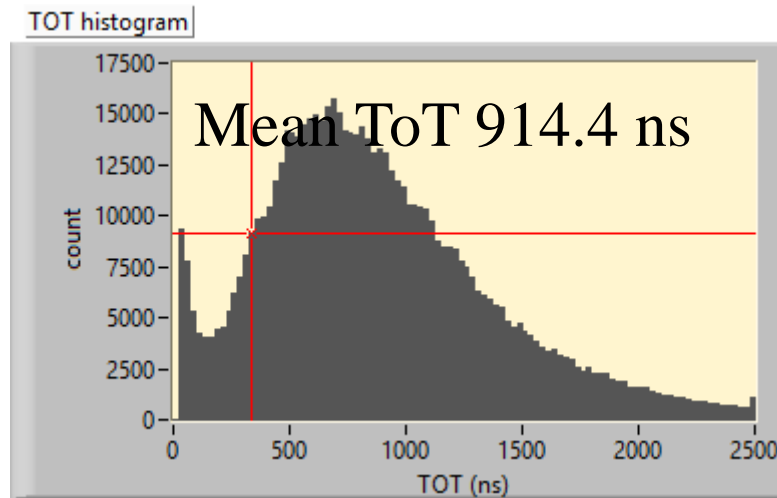
# $^{55}\text{Fe}$ measurements with T3K

Vgrid = -330 V

- Five micro discharges

Chip 2

Chip 0



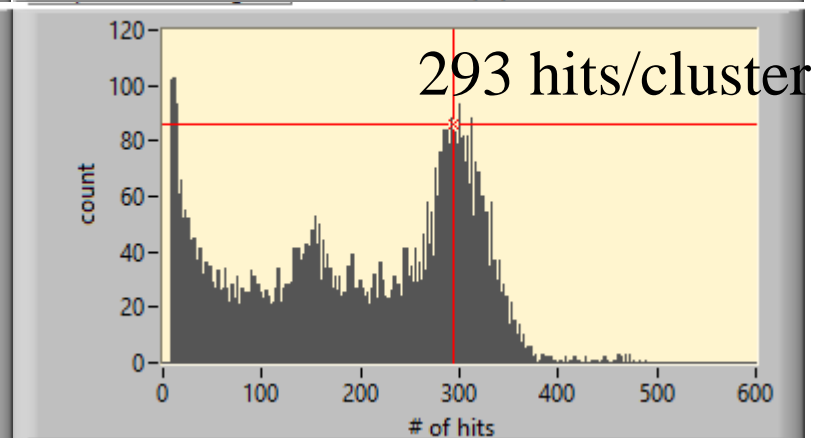
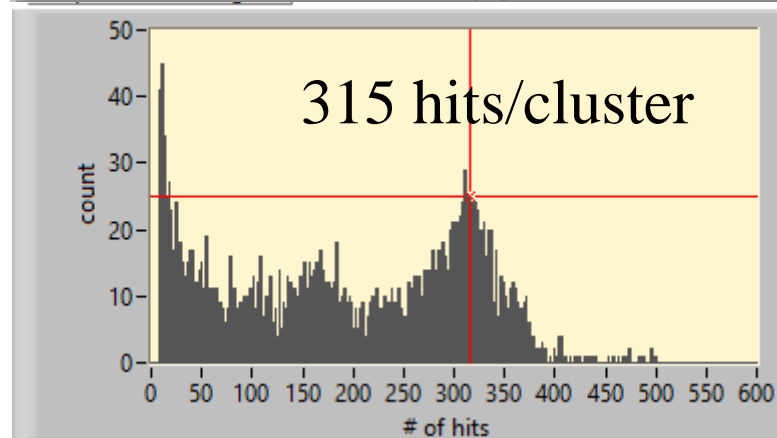
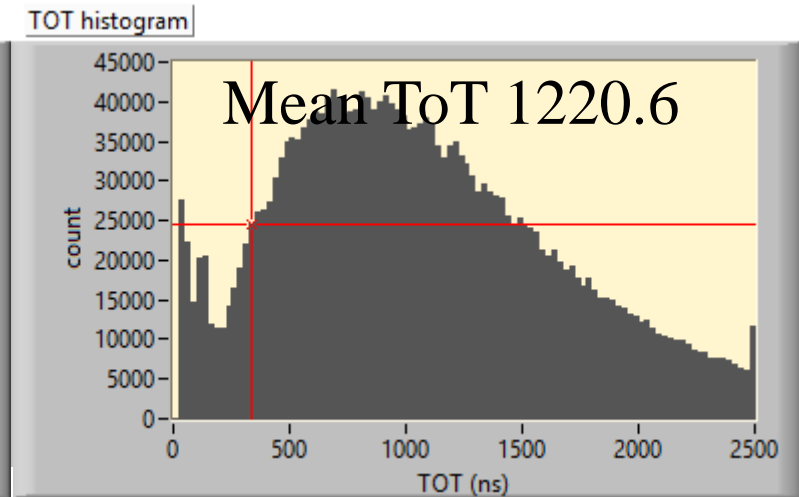
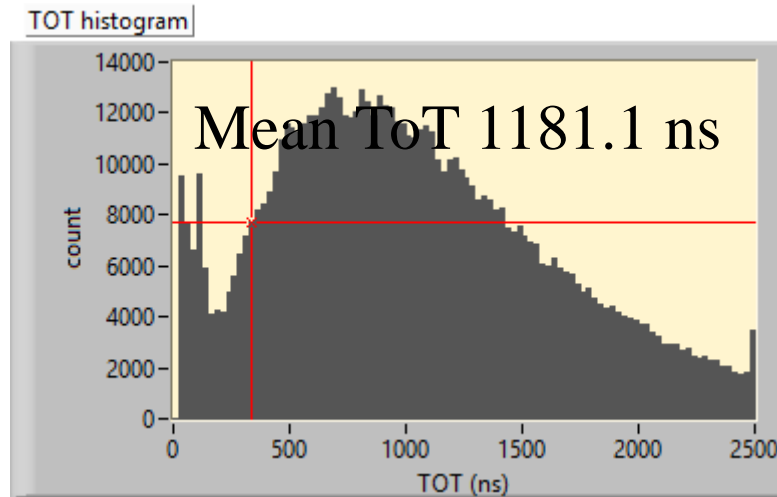
# 55Fe measurements with T3K

Vgrid = -340 V

- Five micro discharges

Chip 2

Chip 0



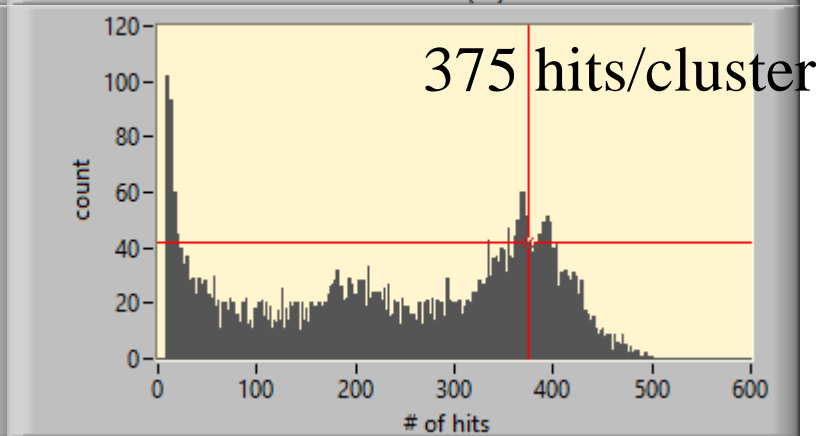
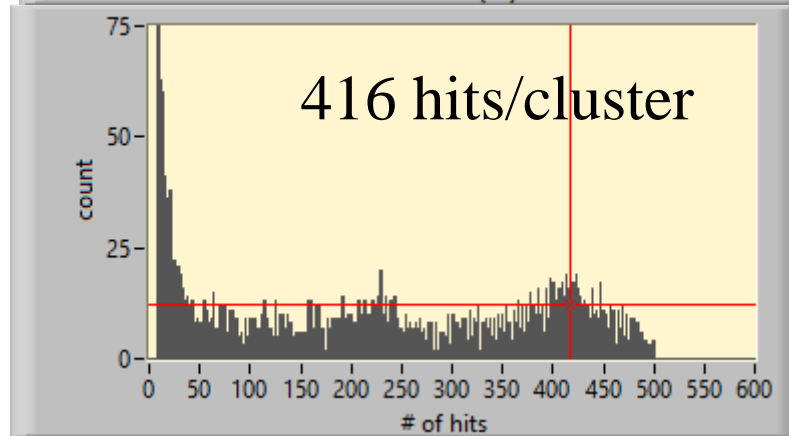
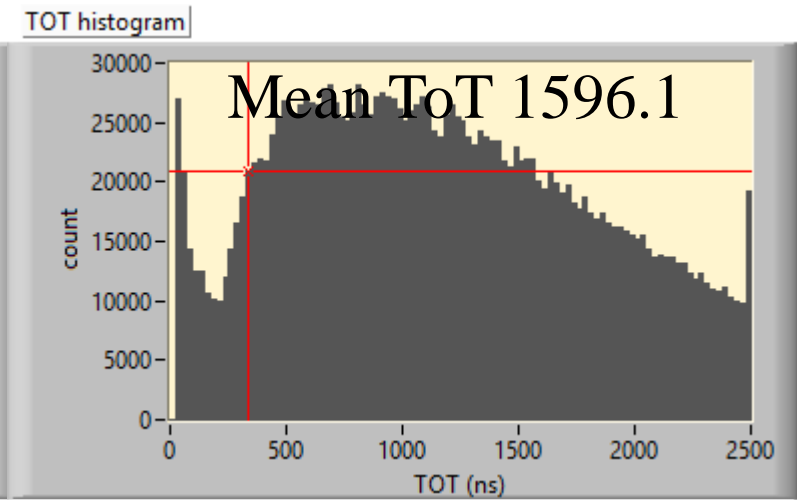
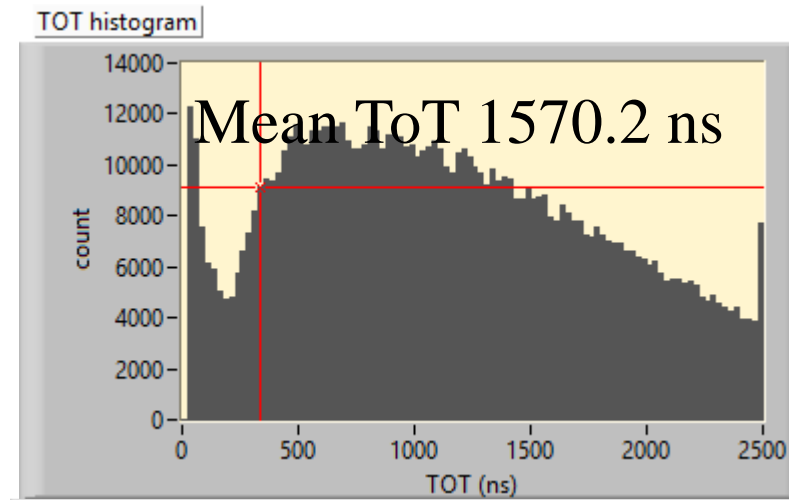
# $^{55}\text{Fe}$ measurements with T3K

$V_{\text{grid}} = -350 \text{ V}$

- Eight micro discharges

Chip 2

Chip 0

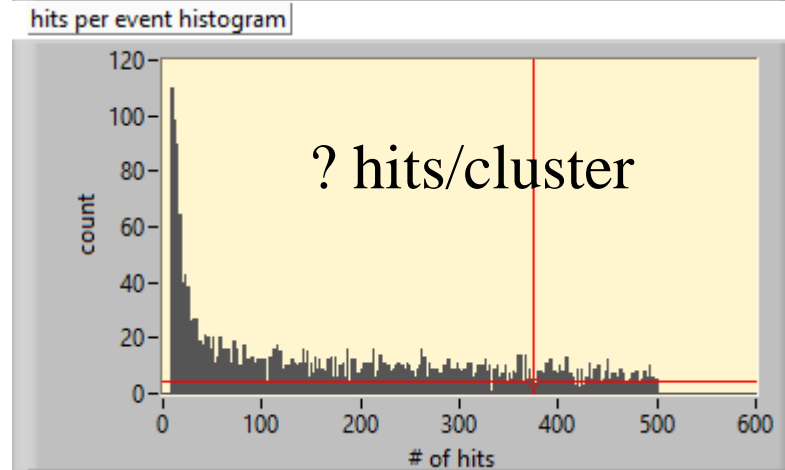
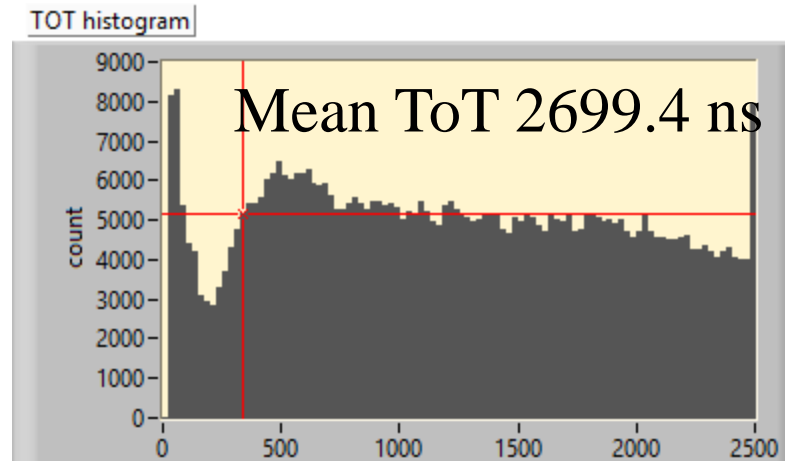


# $^{55}\text{Fe}$ measurements with T3K

$V_{\text{grid}} = -360 \text{ V}$

- Eleven micro discharges

### Chip 2



### Chip 0

