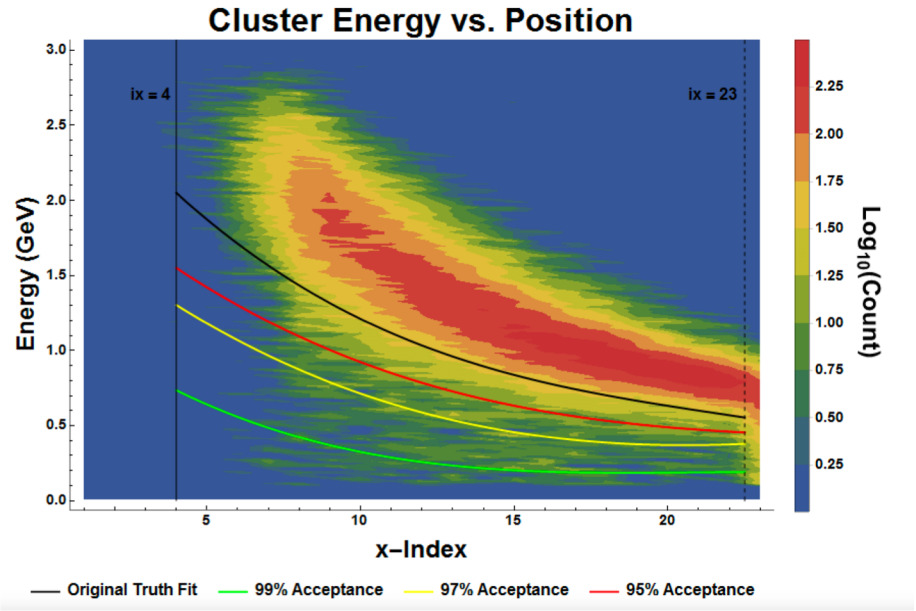
HPS Trigger

Valery Kubarovsky
Jefferson Lab

November 19, 2020



HPS 2019 Trigger Note

Description and Tuning of the HPS 2019 Trigger

S.K. McCarty, R. Paremuzyan
University of New Hampshire
Durham, New Hampshire 03824

V. Kubarovsky, B. Raydo
Thomas Jefferson National Accelerator Laboratory
Newport New, Virginia 23606

The Heavy Photon Search experiment is based in the Thomas Jefferson National Accelerator Facility and is designed to search for a prompt, electro-produced dark photon. This is done using both a resonance search analysis of the e^+e^- invariant mass spectrum for prompt-decay particles, and using a vertex analysis for delayed-decay particles.

Because the Jefferson Lab electron beam is very intense, data is produced a rate exceeding the ability of HPS to record it. As such, it is necessary to develop a trigger system to select only the data most likely to be useful during analysis. Building off the work of the 2015 and 2016 runs, a series of triggers are designed to enable this.

- Kyle wrote comprehensive detailed 37 pages Trigger analysis note
- We are all lucky to have such students in our collaboration
- Thank you Kyle!

HPS Trigger Detectors

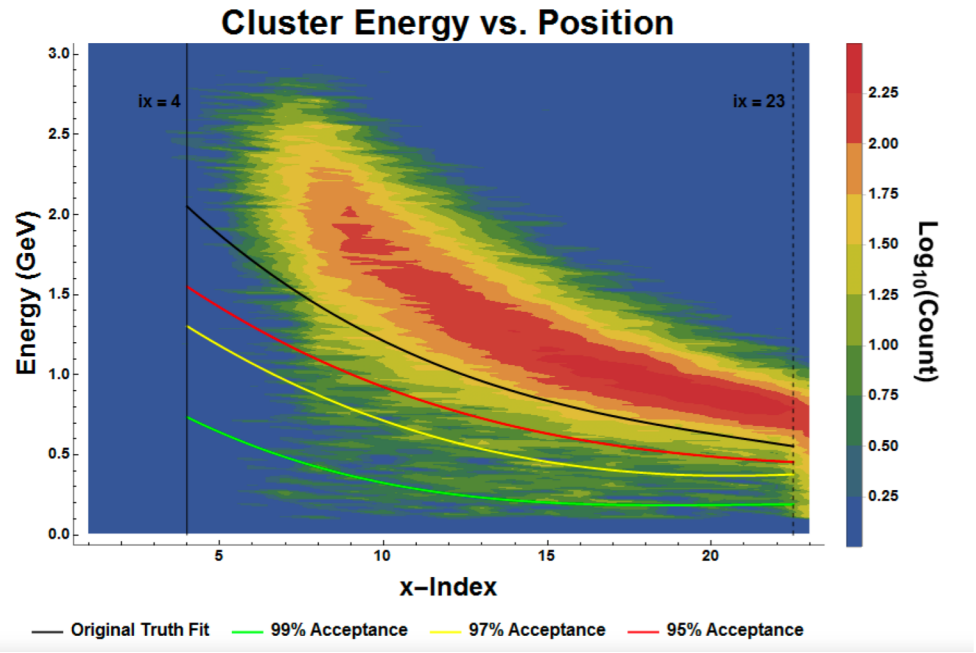
- Silicon vertex Detector (SVT) does not participate in the trigger
- The Calorimeter, 442 lead tungstate ($PbWO_4$) crystals
  - Split into two identical halves (top and bottom)
  - The main trigger primitives is a cluster (Energy, Coordinate) in a 3x3 crystal window
  - Position dependent energy cut (PDEC) was implemented for the positron trigger
- The Hodoscope
  - Split into two identical halves (top and bottom)
  - Located at the positron side only
  - Has two layers, layer1 and layer 2, with 5 tiles in each layer
  - The main trigger primitive is the hit (only coordinate)
  - Correlation matrix was used for the coincidence between layer1 and layer 2 hodoscope planes
- Correlation matrix between hodoscope hits and calorimeter clusters was implemented for the positron trigger

2019 HPS Triggers

- Positron trigger
  - 4 tops
  - 4 bottoms
- Pairs (top-bottom)
  - old 2016 trigger
  - Moller
  - 2 gamma
  - Muon trigger
- 2 gammas (anywhere in the calorimeter)
- 3 gammas (anywhere in the calorimeter
- FEE
  - Top
  - Bottom
- Special triggers
  - Pulser
  - Hodoscope
  - Cosmic
  - LED
  - Faraday Cup

Position Dependent Energy Cut (PDEC)

- 4 different versions to choose from
  - 99% acceptance
  - 97% acceptance
  - 95% acceptance
  - 93% acceptance
- Trident events were used for the tuning PDEC
- Beam energy dependent!



$$x_{\text{cluster}} \geq x_{\text{threshold}}$$

$$E_{\text{cluster}} \geq C_0 + C_0 x + C_1 x^2 + C_2 x^3$$

Positron Triggers

Top

- **#00 Singles-0.**
  - Low energy cluster (150-8191) MeV
  - Calorimeter iX index=(-23,+23). Full detector
- **#01 Singles-1** Positron.
  - Cluster energy= (200-3000) MeV
  - Calorimeter iX index=(+4,+23)
- **#02 Singles-2** Positron.
  - Cluster energy=(200-3000) MeV
  - Calorimeter iX index= (+4,+23)
  - Position Dependent Energy Cut
- **#03 Singles-3 Top** Positron.
  - Cluster energy=(200-3000) MeV
  - Calorimeter iX index= (+4,+23)
  - Position Dependent Energy Cut
  - Hodoscope

Bottom

- Symmetric to Top

Positron trigger

September, 2019 I=120 nA

			E_{min}	E_{max}	PDEC	Hodo	Rate	Pre scale
#00	Single-0	Top	150	8191			1.9M	20000
#01	Single-1	Top	200	3000			32K	0
#02	Single-2	Top	400	3000	93%		7.7K	2
#03	Single-3	Top	200	3000	99%	Geom	10K	1
#04	Single-0	Bot	150	8191			2.0M	20000
#05	Single-1	Bot	200	3000			31K	0
#06	Single-2	Bot	400	3000	93%		8.3K	2
#07	Single-3	Bot	200	3000	99%	Geom	10K	1

- Trigger version hps_v12_1.trg
- Current 120 nA
- Total trigger rate 25kHz,
- Lifetime 95%

Pair Triggers, FEE and others

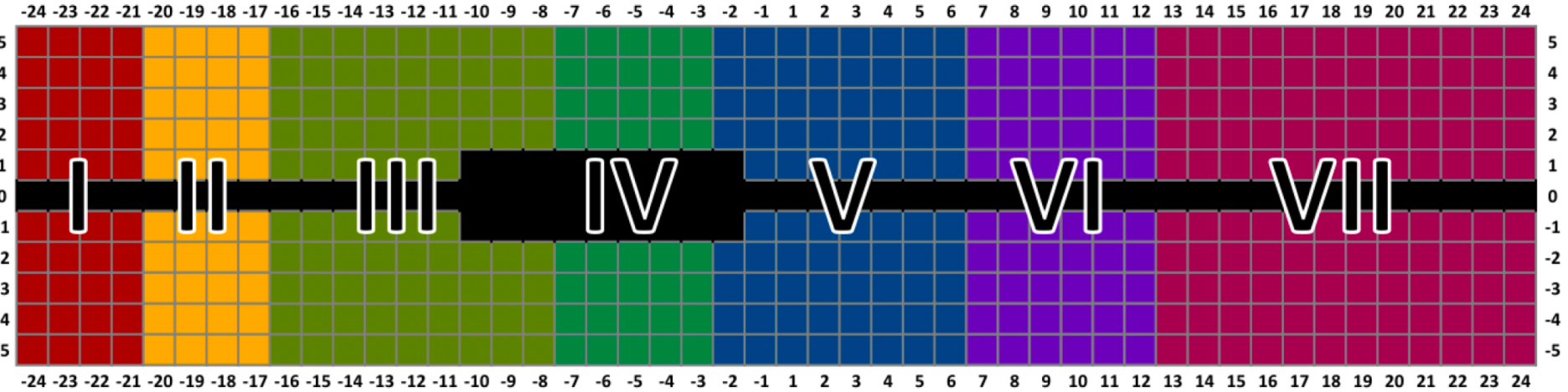
			E_{min}	E_{max}	Rate	Pre scale
#08	Pair-0	Old e^+e^-	300	3000	15K	100
#09	Pair-1	Moller	300	3000	120K	1000
#10	Pair-2	2 gammas Top-Bot	300	3500	80K	500
#11	Pair-3	Muons	80	300	730	1
#16	2 gammas	Top or Bot	150	8191	170K	20000
#17	3 gammas	Top+Bot	200	3000	8.7K	0
#18	FEE	Top	2600	5200	170	1
#19	FEE	Bot	2600	5200	161	1

Muons

No prescale

FEE

FEE prescales



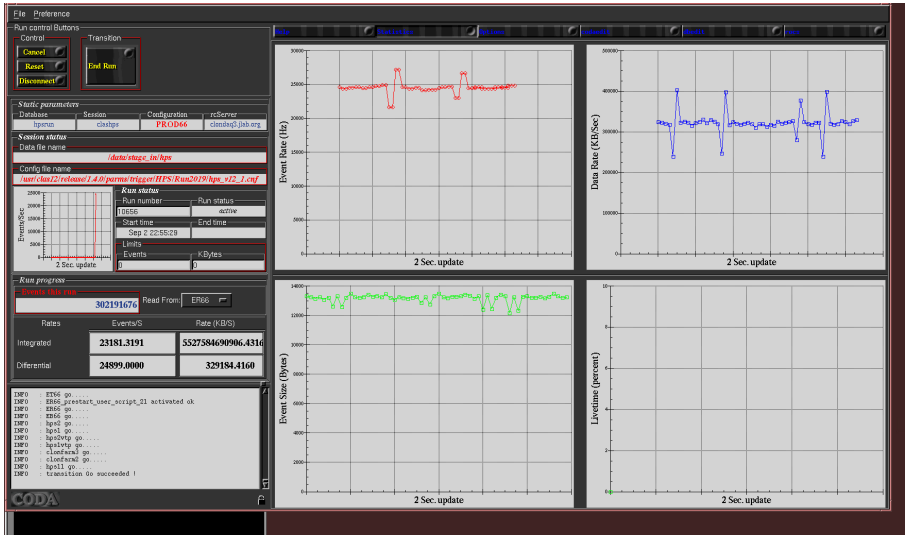

```
#                      prescale region
#                      |    region xmin
#                      |    |      region xmax
#                      |    |      |      prescale
#                      |    |      |      |
VTP_HPS_FEE_PRESCALE   0    -22    -20     0
VTP_HPS_FEE_PRESCALE   1    -19    -16     8
VTP_HPS_FEE_PRESCALE   2    -15     -7     128
VTP_HPS_FEE_PRESCALE   3     -6     -2     1024
VTP_HPS_FEE_PRESCALE   4     -1      6     512
VTP_HPS_FEE_PRESCALE   5      7     12     12
VTP_HPS_FEE_PRESCALE   6     13     23     0
```

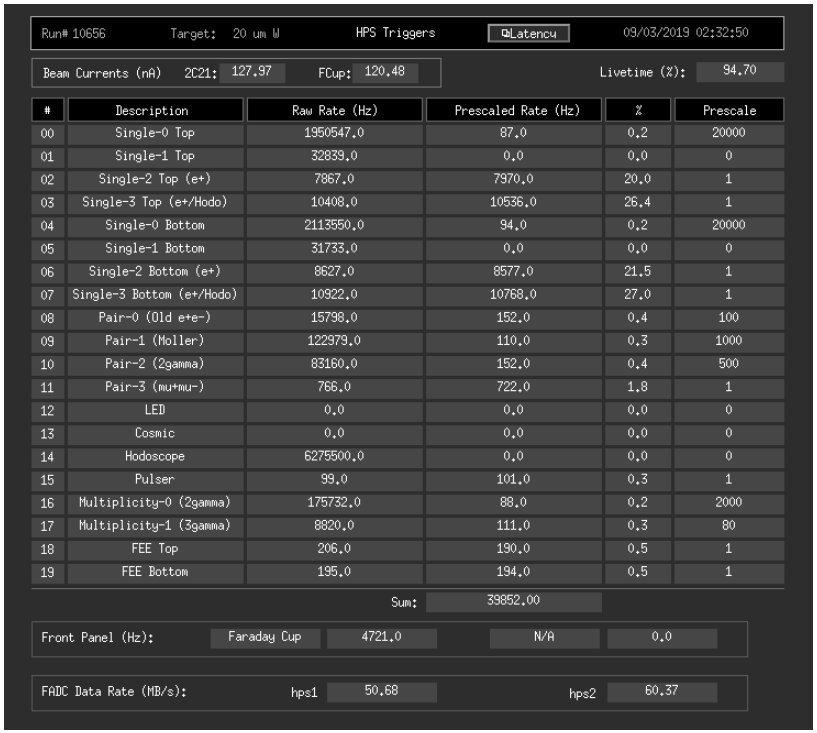
Region	Prescale
I	I
II	9
II	129
IV	1025
V	513
VI	13
VII	I

Special Triggers

			Rate	Prescale
#12	LED	Calorimeter	15K	0
#13	Cosmic	Calorimeter	120K	0
#14	Hodoscope		6.3M	0
#15	Pulser		100	1
#16 Front Panel	Faraday Cup		4648	5

DAQ and Trigger Performance





#	Description	Raw Rate (Hz)	Prescaled Rate (Hz)	%	Prescale
00	Single-0 Top	1950547.0	87.0	0.2	20000
01	Single-1 Top	32839.0	0.0	0.0	0
02	Single-2 Top (e+)	7867.0	7970.0	20.0	1
03	Single-3 Top (e+/Hodo)	10408.0	10536.0	26.4	1
04	Single-0 Bottom	2113550.0	94.0	0.2	20000
05	Single-1 Bottom	31733.0	0.0	0.0	0
06	Single-2 Bottom (e+)	8627.0	8577.0	21.5	1
07	Single-3 Bottom (e+/Hodo)	10922.0	10768.0	27.0	1
08	Pair-0 (Old e+e-)	15798.0	152.0	0.4	100
09	Pair-1 (Moller)	122979.0	110.0	0.3	1000
10	Pair-2 (2gamma)	83160.0	152.0	0.4	500
11	Pair-3 (mu+mu-)	766.0	722.0	1.8	1
12	LED	0.0	0.0	0.0	0
13	Cosmic	0.0	0.0	0.0	0
14	Hodoscope	6275500.0	0.0	0.0	0
15	Pulser	99.0	101.0	0.3	1
16	Multiplicity-0 (2gamma)	175732.0	88.0	0.2	2000
17	Multiplicity-1 (3gamma)	8820.0	111.0	0.3	80
18	FEE Top	206.0	190.0	0.5	1
19	FEE Bottom	195.0	194.0	0.5	1
		Sum:	39852.00		

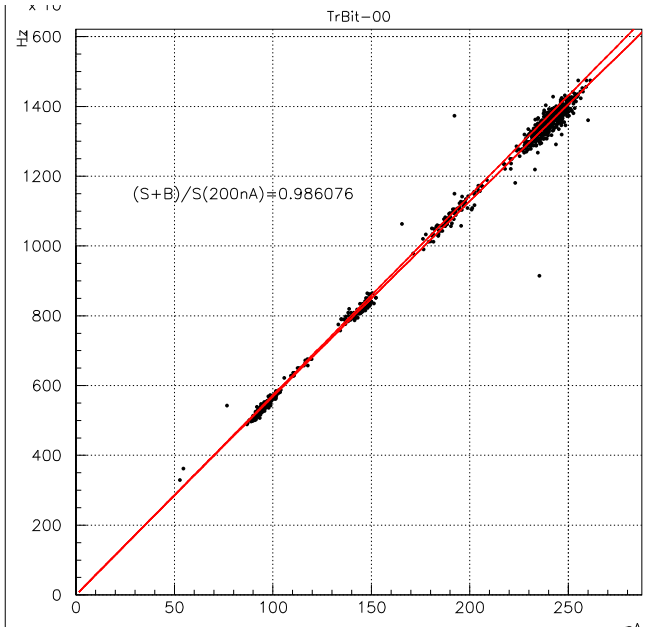
Front Panel (Hz): Faraday Cup 4721.0 N/A 0.0

FADC Data Rate (MB/s): hps1 50.68 hps2 60.37

- I=120 nA
- DAQ rate 25 kHz
- Data Rate 325 MB/s
- Event size 13 KB
- Lifetime 95%
- Trigger version hps_v12_1.trg

Trigger rate vs beam current

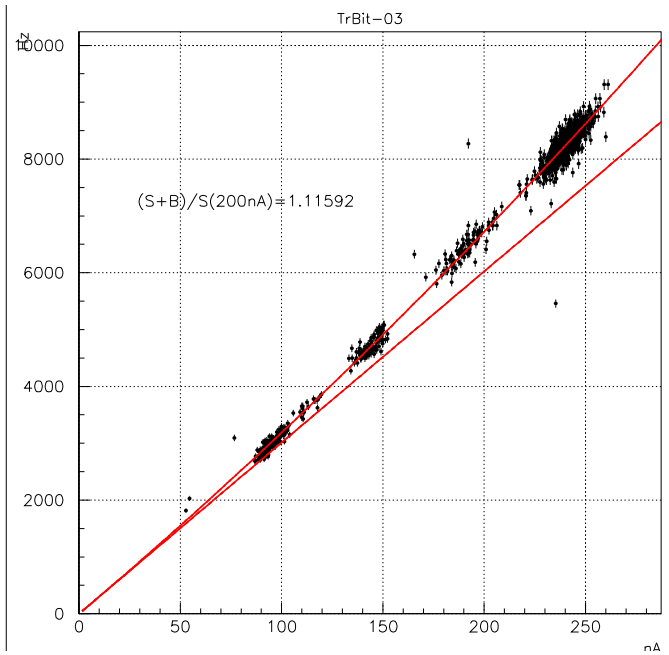
Low energy clusters only



0 250 nA

Linier dependence trigger rate with current

Positron: Cal & Hodo

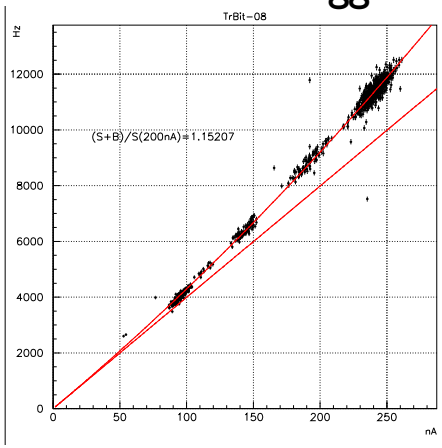


0 250 nA

Only 11% randoms at 200 nA

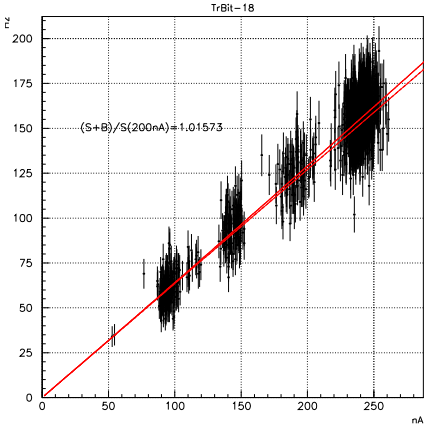
Pair, Muon and FEE

Pair: 2016 trigger



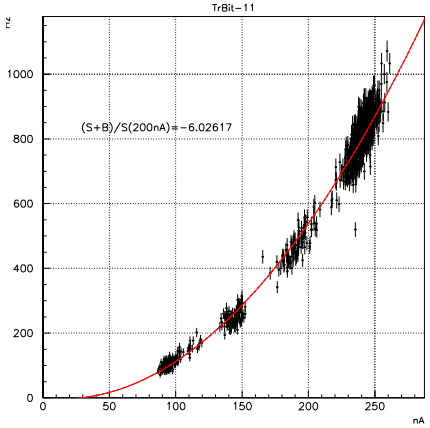
$$\frac{Signal + Bgrd}{Signal} = 1.15 \ @200nA$$

FEE



$$\frac{Signal + Bgrd}{Signal} = 1.01 \ @200nA$$

Muons



$$\frac{Signal + Bgrd}{Signal} \sim 6 \ @200nA$$

2% from total rate

Trigger Validation

- Validation of the trigger firmware performance
  - Random trigger data
  - Full simulation of the trigger firmware based on the FADC data
  - Selection of the events that satisfied the trigger conditions
  - Test the hardware trigger bits.
- Absolute trigger efficiency estimation
  - Random trigger data
  - Selection of the events that satisfied the trigger conditions
  - Test the hardware trigger bits.
  - Found some firmware bugs during validation (no clusters with 8 and 9 hits were accepted, fixed by Ben)
  - Adjusted Cal x Hodo coincidence matrix (remove 1% inefficiency)
  - Inefficiency less then 1.3% at the end of validation

To Do List

MC simulation

- New beam energy → adjust trigger parameters
- Positron calorimeter energy cuts
- Position dependent energy cut
- Elastic scattering cuts
- Neutral trigger cuts

Off-line reconstruction

- Fast data cooking
- Select events of interest
- Make trigger validation

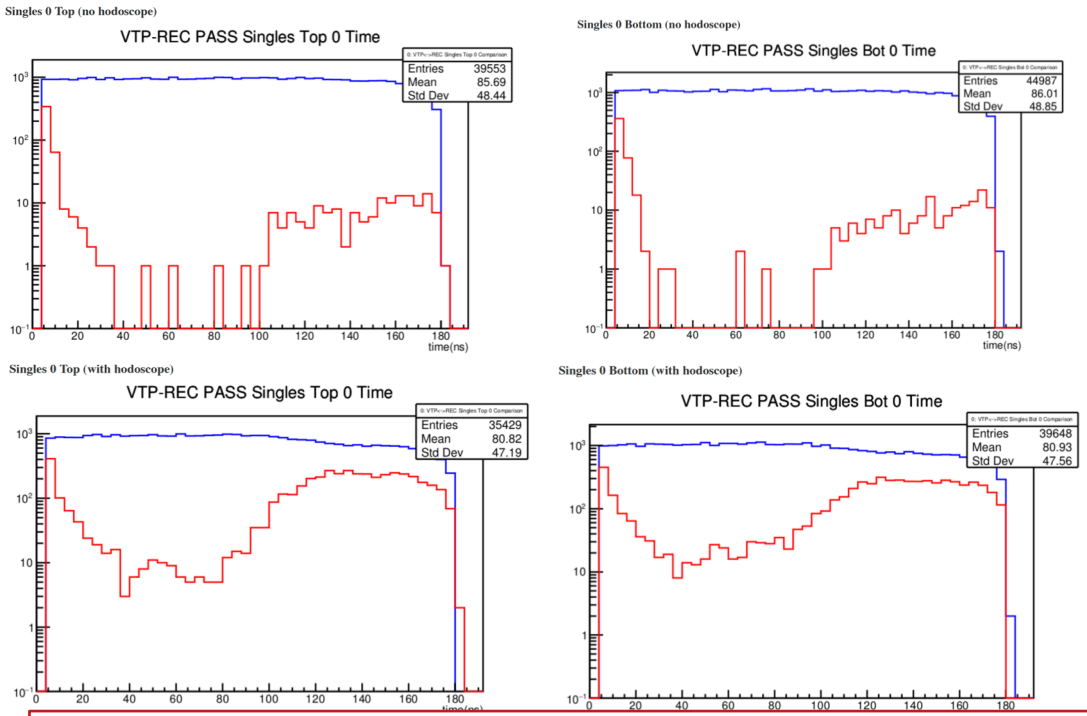
Conclusion

- 2019 HPS trigger was substantially modified
- This modification was successful
- The positron trigger was designed, implemented and validated
- Muon trigger was implemented
- FEE trigger was significantly improved
- Multiphoton triggers were added
- The trigger efficiency was at the level of 99% or better
- For the future 2021 run MC and off-line reconstruction program has to be ready well in advance the experiment will start

End of story

Trigger inefficiency due to the high hodoscope hit rate

Plots for each trigger bit show the successful reconstructed trigger to VTP bank matches **(Blue)** and failures **(Red)** as a function of time in the FADC window. It was plotted as a function of FADC time so that window edge effects could be seen and ignored from the overall efficiencies. You can see that times near the beginning and end of the FADC window tend to cause problems because the ECAL pulses are clipped. Mismatches in the middle of the window can happen due to pile-up where the FADC hits can be ignored by the trigger or due to a bug.



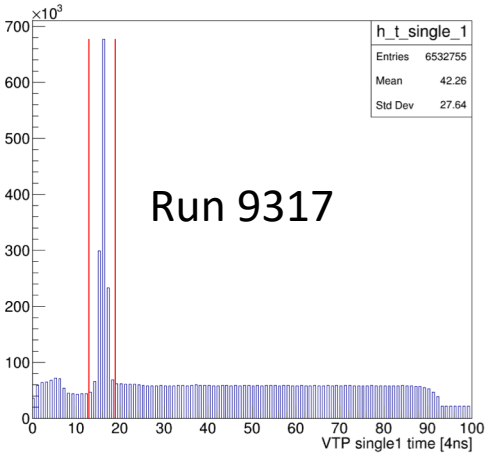
Effect of the high hit rates on the FADC on the trigger logic (pile up hits are missed by trigger when within 32ns of each other)
~1% loss effect (roughly consistent with the FADC hit rate seen from hodoscope).

Ben

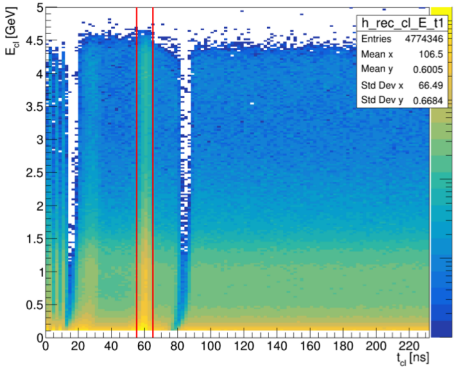
Change of persistency up to 64 ns (that was done after this study) eliminated any inefficiency due to the 32ns pileup feature.

ECal Efficiency

- Trigger with Hodoscope only
- Check the efficiency of the ECal PDEC trigger



Run 9317

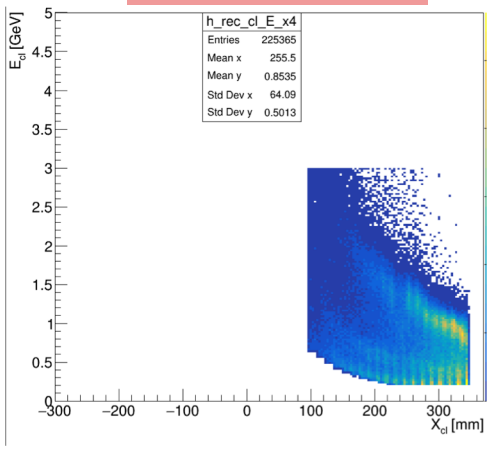


The offline ECal cluster should satisfy trigger conditions

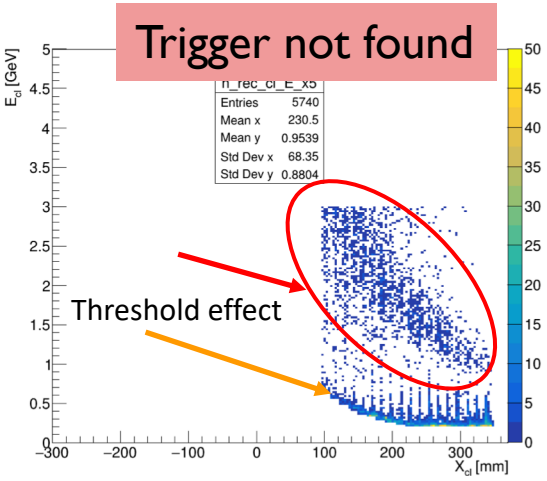
- X > 90
- E_cl < 3. GeV
- PDEC cut
- To be in time: t > 55 ns & t < 65 ns
- N_Hits > 1

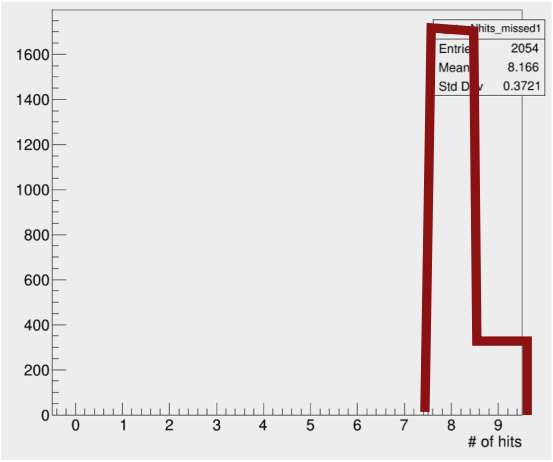
Events with E > 1 GeV
No cluster with 8 and 9 hits was accepted
Ben found a bug and quickly fixed!

Trigger found



Trigger not found





Rafo

Production Single-3 trigger efficiency

Data: single2 trigger (ECal only PDEC trigger)

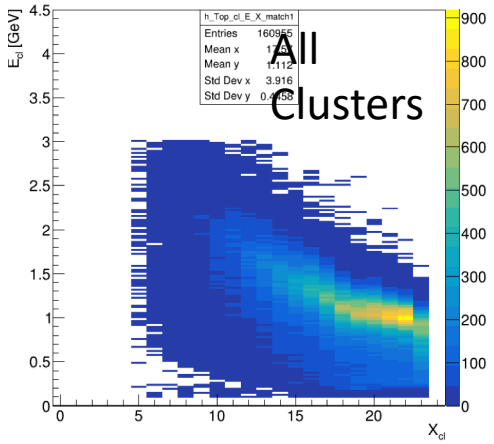
Single3 trigger (The production trigger)

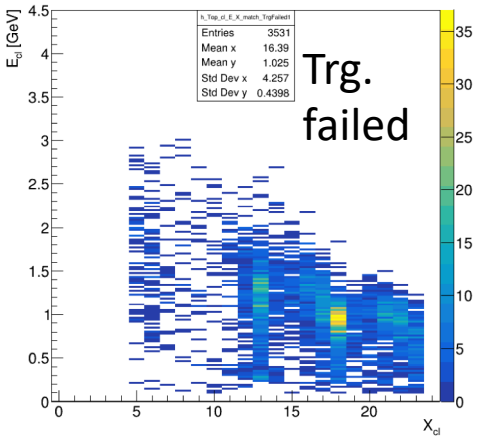
- Hit in L1 is above threshold
- Hit in L2 is above threshold
- L1xL2 geom and time matching
- L1xECal_X geom and time matching
- L2xECal_X geom and time matching
- ECal PDEC (validated earlier)

Event's Selection

Clusters
- In-time cluster
- $E_{cl} < 3$ GeV
- $X_{cl} > 105$

Tracks
- $P > 0.85$ GeV
- chi2/NDF < 5 (to avoid fake tracks)
- Positive charge
- Track-Cluster matched





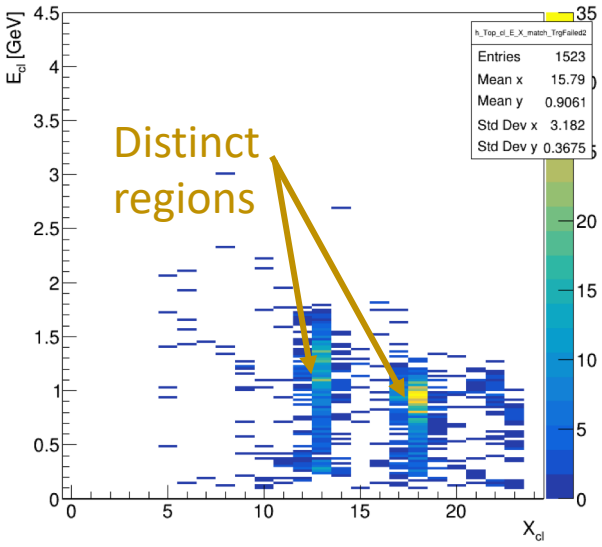
Rafo

About 2% failed
≈ half of failed events failed
"$X_{Hodo} \otimes X_{ECal}$"

See next slide for these failed events

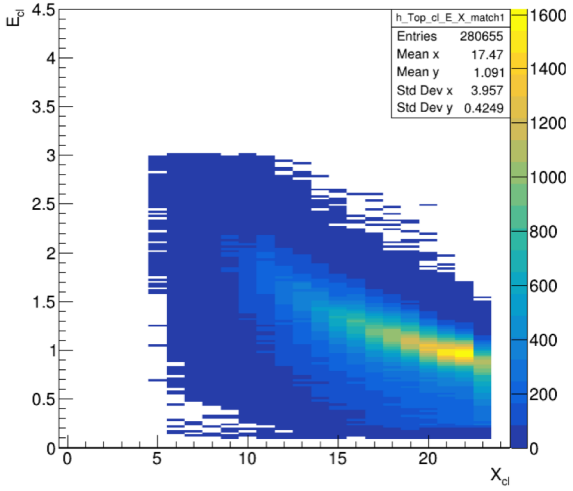
Production Single-3 trigger efficiency

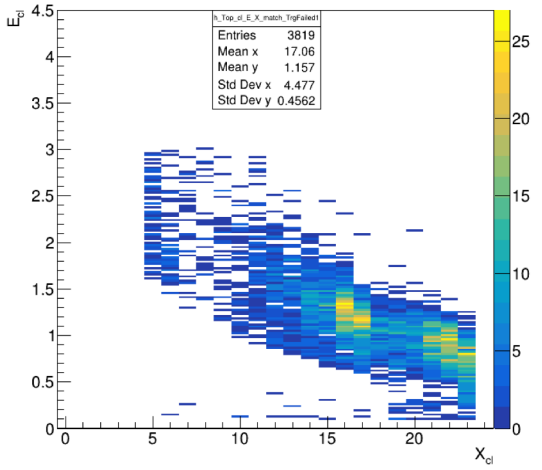
Events that failed "$X_{Hodo} \otimes$



This led to loosen a bit "$X_{Hodo} \otimes X_{ECal}$" matching cut

Trigger efficiency with new "$X_{Hodo} \otimes X_{ECal}$" table





<u>Inefficiency is 1.3%</u>

Rafo