HERD CALO Trigger Simulation

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Trigger Requirement

- HERD science
  - High energy CR (tens of GeV - PeV)
  - DM (photon smoking gun around several hundreds of GeV)
  - Gamma-ray survey (> 500 MeV)
- Calibration
  - CALO MIP calibration
    - penetrating charged particles to equalize the response of CALO cells
  - TRD response curve calibration
    - Low energy electrons (0.5-5 GeV)
- Trigger rate should not > 500 Hz, due to limited performance of readout CMOS chip

Trigger Goals

- Trigger high energy cosmic-rays
  - protons & nuclei
  - electrons
  - photons
- Trigger low energy photons
- Trigger low energy electrons
  - for TRD calibration
- Trigger MIP events
  - for CALO cell calibration

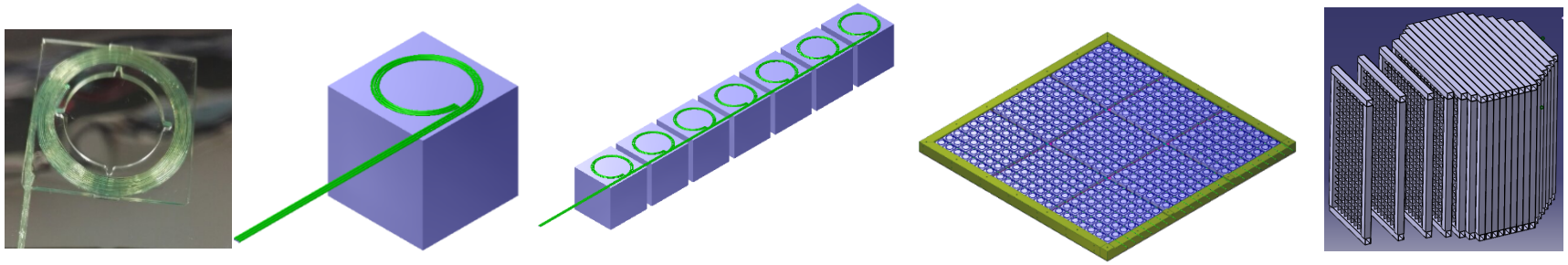
HERD Trigger System

- PSD:
  - all SiPM signals, energy (absolute charge) information, ~ 100ns delay
- TRD & TK:
  - ms delay, too slow as trigger signal
- CALO:
  - LYSO + PMT signals, energy information, ~100ns delay

Trigger Strategy

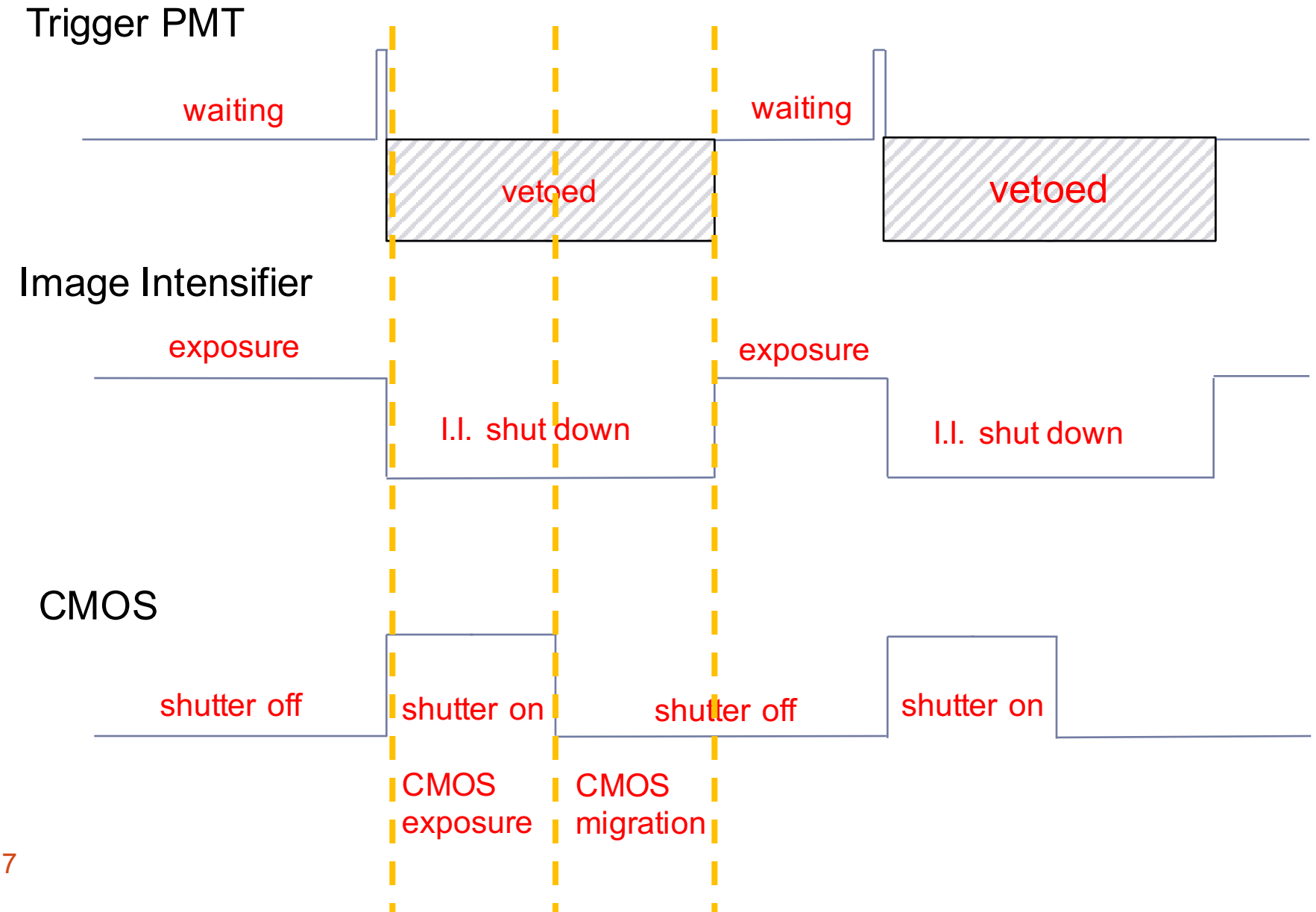
- The global trigger (GT) is obtained by using the logical AND/OR of PSD and CALO particle-dedicated triggers:
  - TK and TRD do not involved in GT
  - High Energy (HE) CR and photon trigger: high energy deposition CALO trigger
  - Low Energy (LE) photon trigger: low energy deposition CALO trigger AND PSD veto
  - Low Energy electron trigger: low energy deposition CALO trigger
  - Calibration trigger: low energy deposition CALO trigger

CALO – LYSO Array

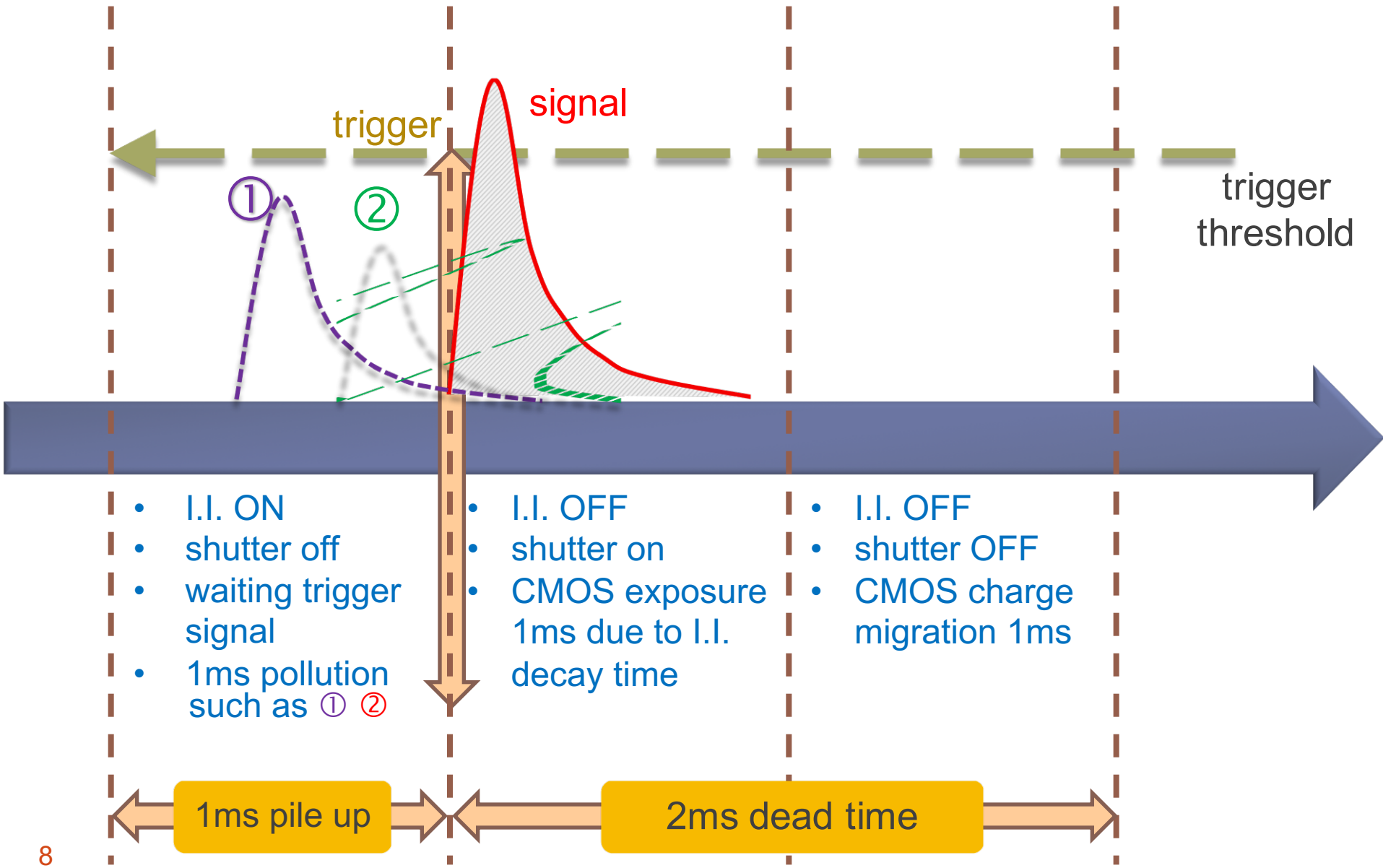


number of crystals	~7500	
crystal dimension	3cm*3cm*3cm	
readout	3WLSF / crystal	IsCMOS low range, IsCMOS high range, trigger PMTs

CALO Trigger Timing and IsCMOS



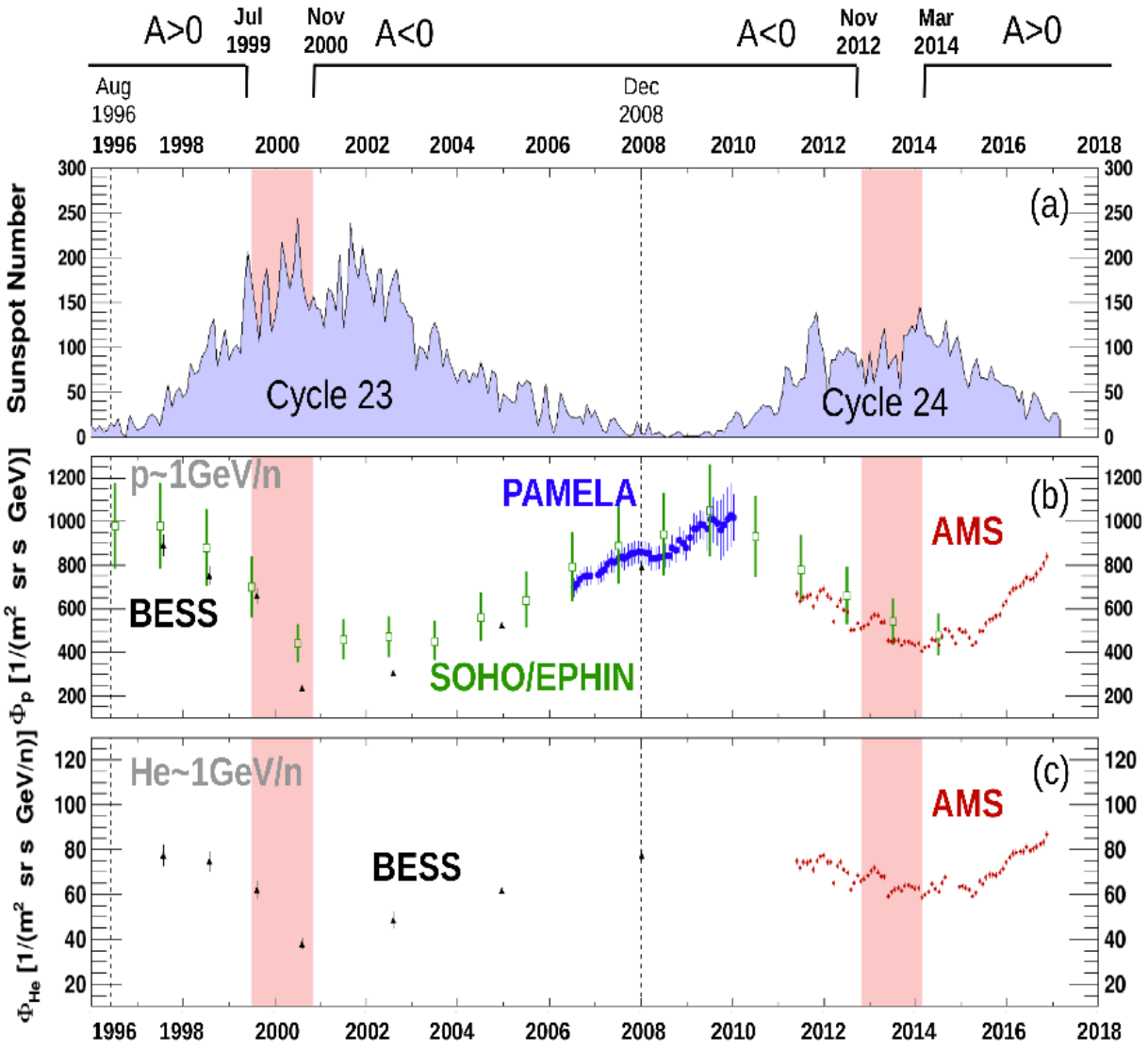
IsCMOS Working Mode



CALO Trigger Study

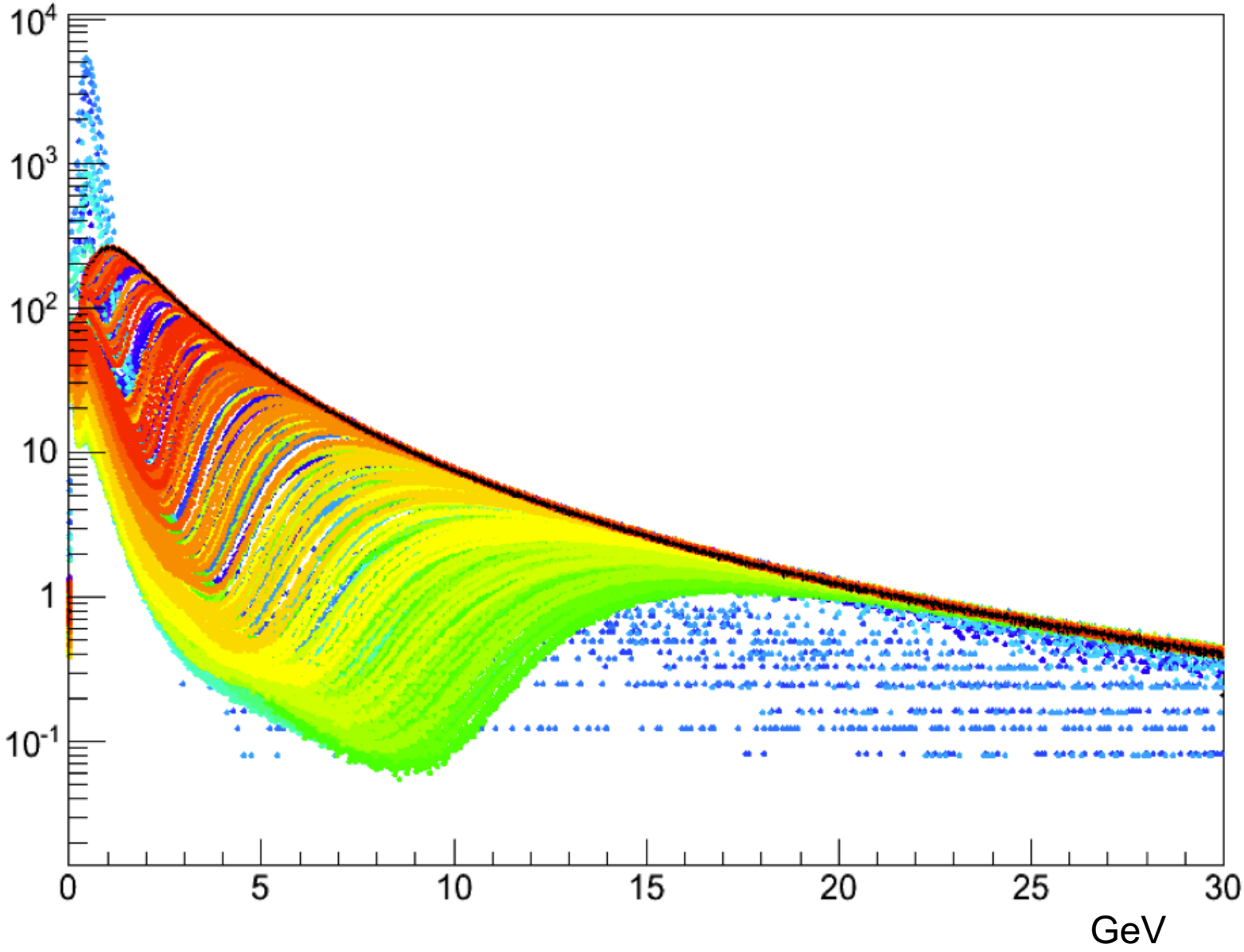
- Trigger threshold (HE & LE)
- Trigger rate
  - signal rate
  - background rate
- Trigger efficiency
- Main background is high flux CR proton. This study is based on the hard radiation environment
  - cosmic-ray (mainly proton) is signal at high energy, and is background at low energy
  - other components do not take into account
- Basic settings:
  - particle rate: AMS02 data of ISS orbit as reference
  - 2X0 STK, CALO geometry: 63*63*63 cm^3
  - Image Intensifier 1% decay time: 1 ms (τ=0.217 ms)

CR Rate vs Time

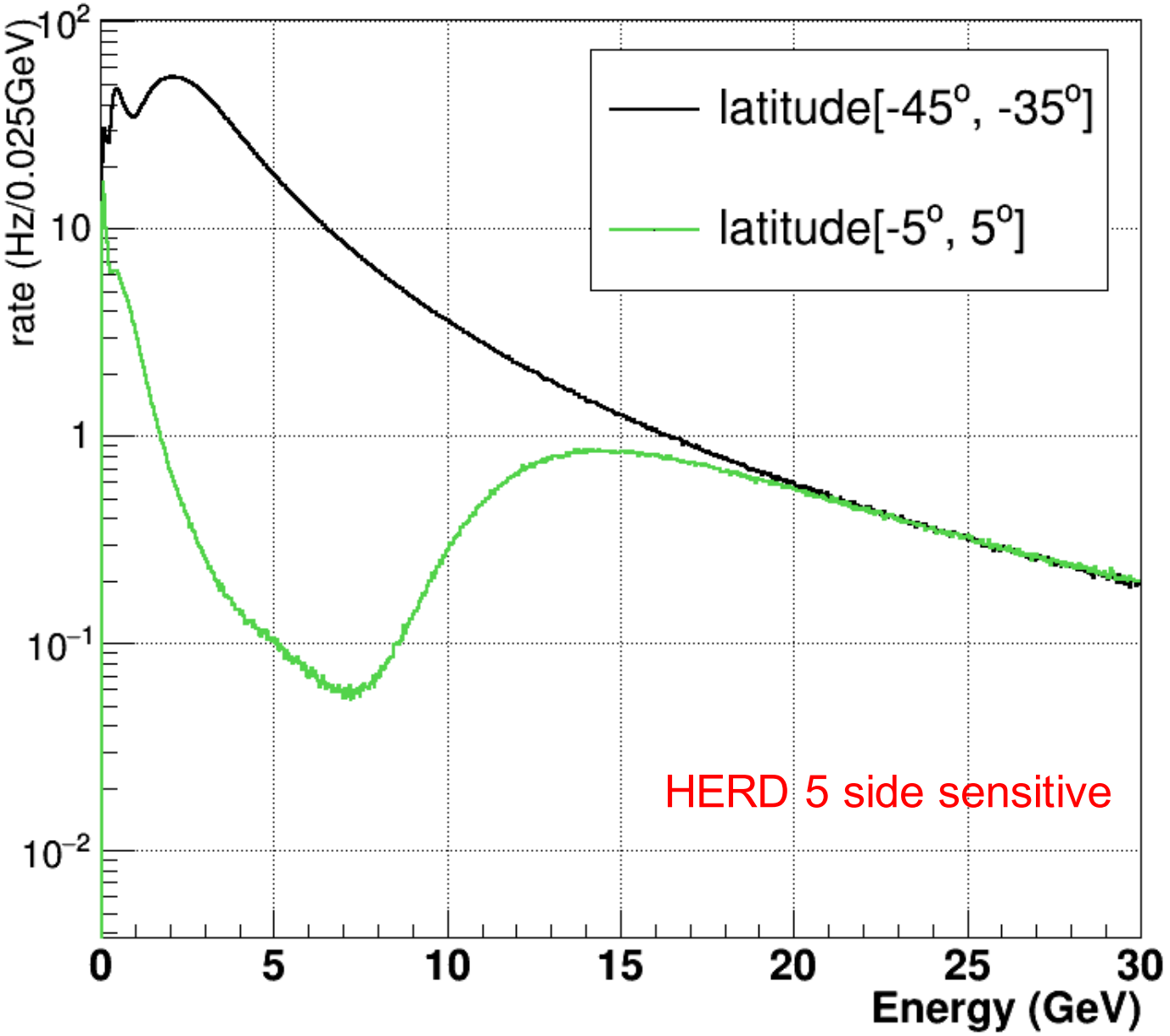


Flux of year 2011 used in this work as an estimation of year 2022

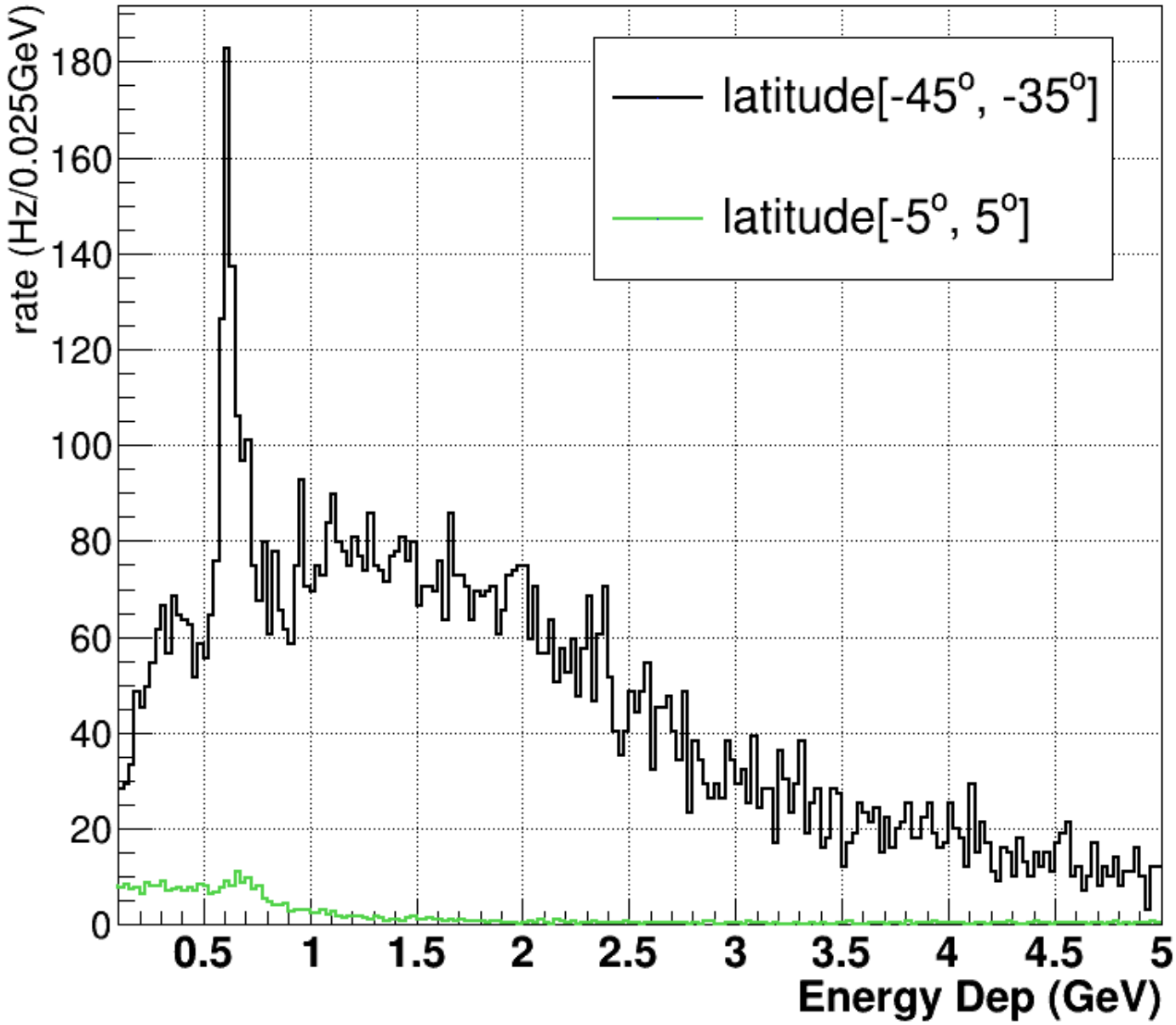
Example of Particle Rate in Different Geomagnetic Region



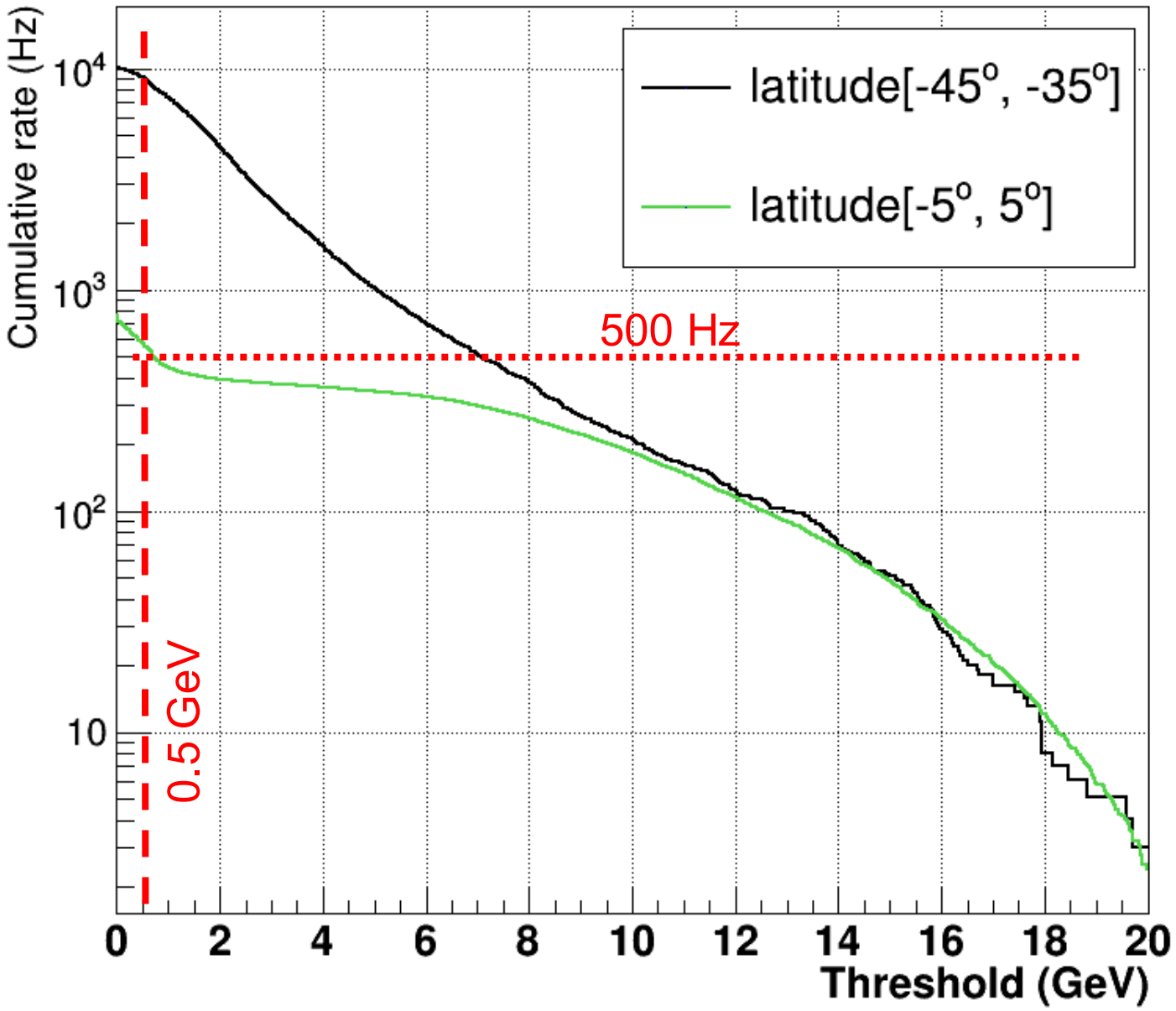
Particle Rate in Polar and Equator Region



CALO Count Rate vs Proton Energy Deposition



Accumulated Rate by Energy Deposition

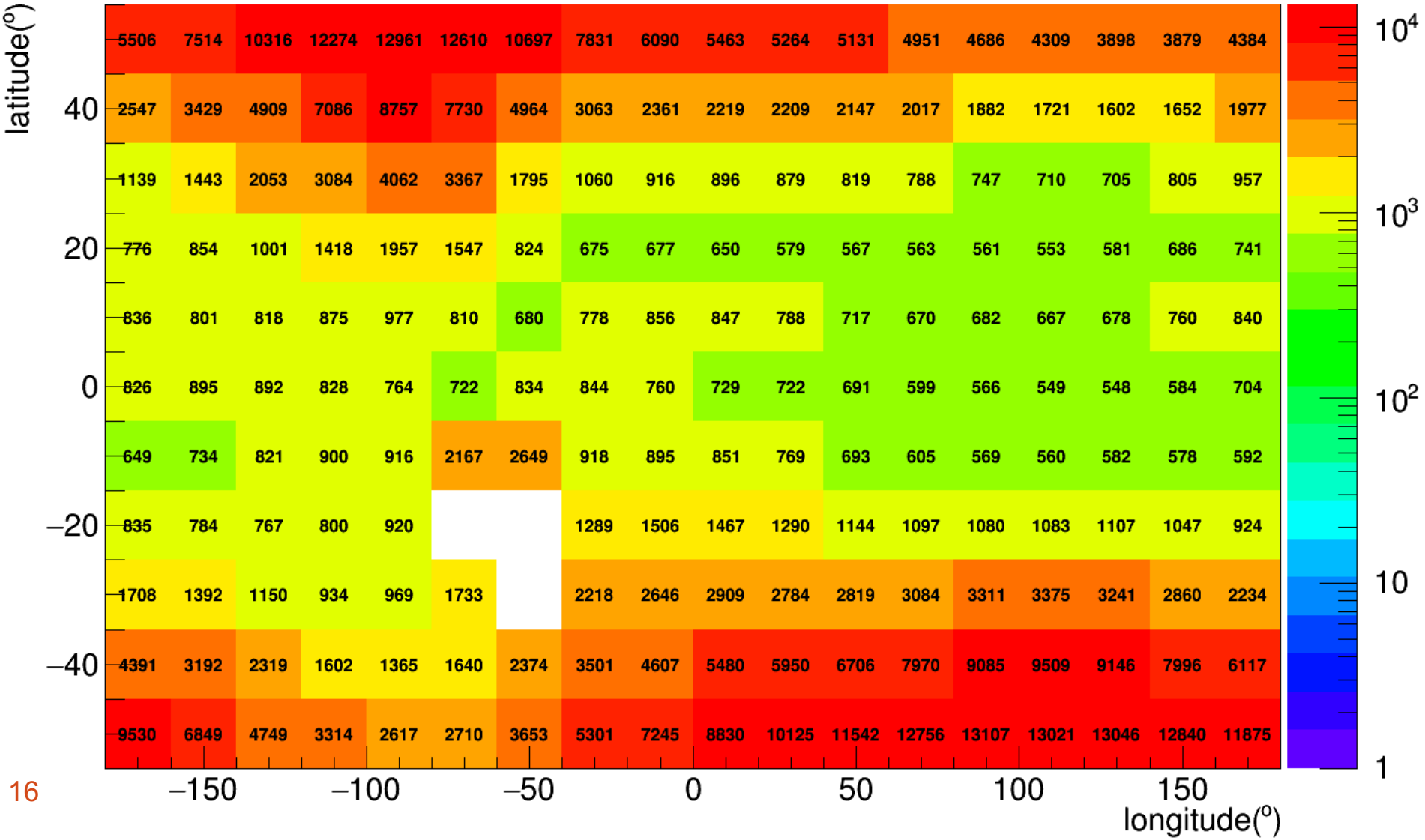


Trigger Threshold vs Trigger Rate

Trigger threshold (sum of all cell signals)	Trigger rate (Hz) Lat[-45°,-35°]	Trigger rate (Hz) Lat[-5°,5°]
0.5 GeV	10000	600
8 GeV	400	300
10 GeV	250	200
13 GeV	100	100

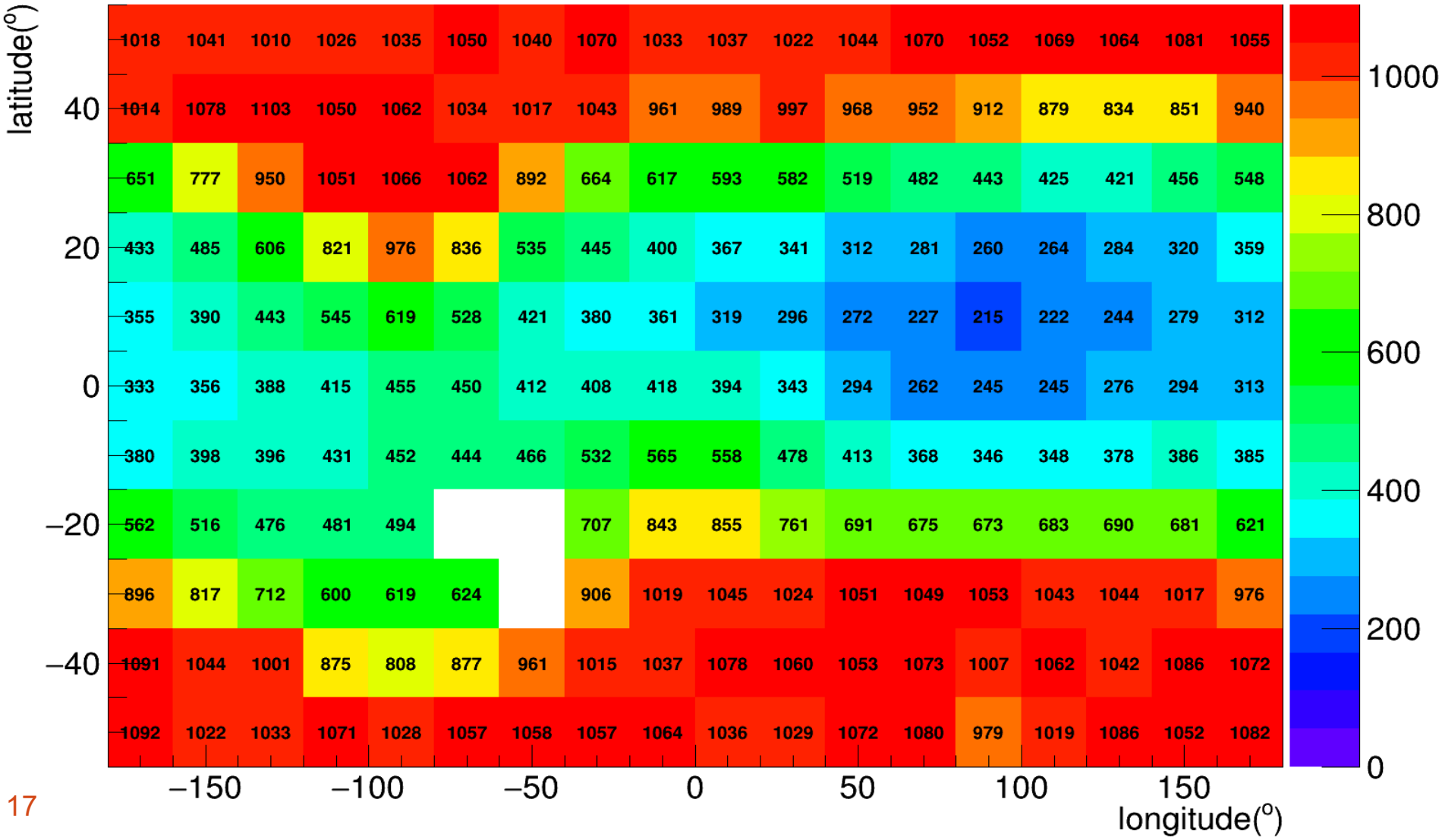
Event Rate Map (Threshold 0.5 GeV)

max event rate ~ 10000 Hz, average rate ~ 2960 Hz



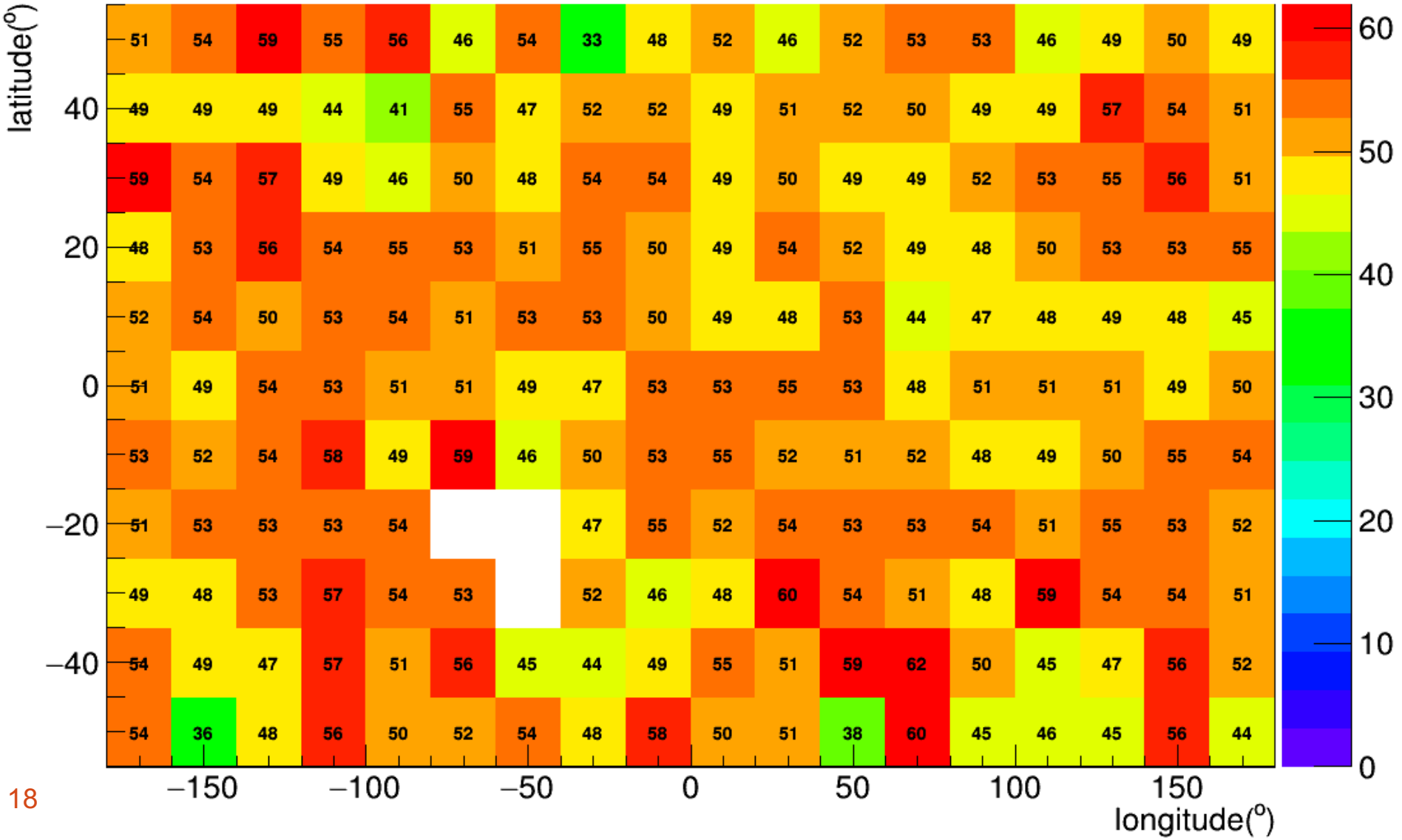
Event Rate Map (Threshold 5 GeV)

max event rate ~ 1100 Hz, average rate ~ 720 Hz



Event Rate Map (Threshold 15 GeV)

max event rate ~ 60 Hz, average rate ~ 50 Hz



Trigger Rate Estimation

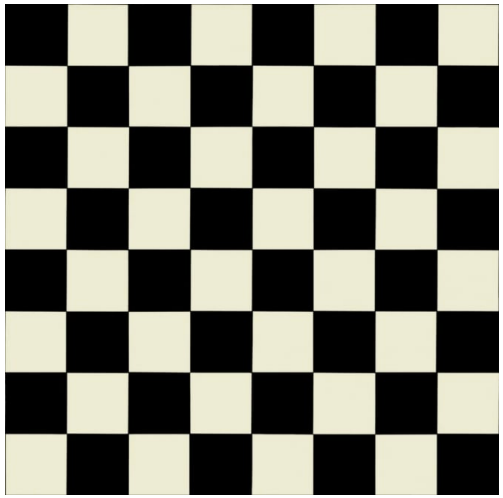
Channel	Threshold	Event Rate	
High energy trigger	5 GeV	200-1000 Hz	OK if increase threshold
LE photon trigger	0.5 GeV	600-10000 Hz	OK if veto eff > 99.9%
LE electron trigger			need simple shower shape requirement
LE MIP trigger			only allow near equator to avoiding peak shift

Proposal

- Use outer 3 layers as “shell” part and the rest as “core” part
  - LE electron and photon only fires shell
  - CR events fires both shell and core
- In practice there are 6 shell units and 1 core unit
- Each unit connect to PMTs for trigger
- Careful design of connection map and redundancy setup

Trigger Pattern

- The outmost 3 layer “shell” cells to several PMTs, serve as LE trigger
  - >85% trigger efficiency for 500MeV photon
  - LE electron simple shower selection
  - MIP events selection
- The rest of the “core” cells to several PMTs serves as HE trigger, and as VETO for LE trigger
- Chessboard readout pattern for both shell and core cells

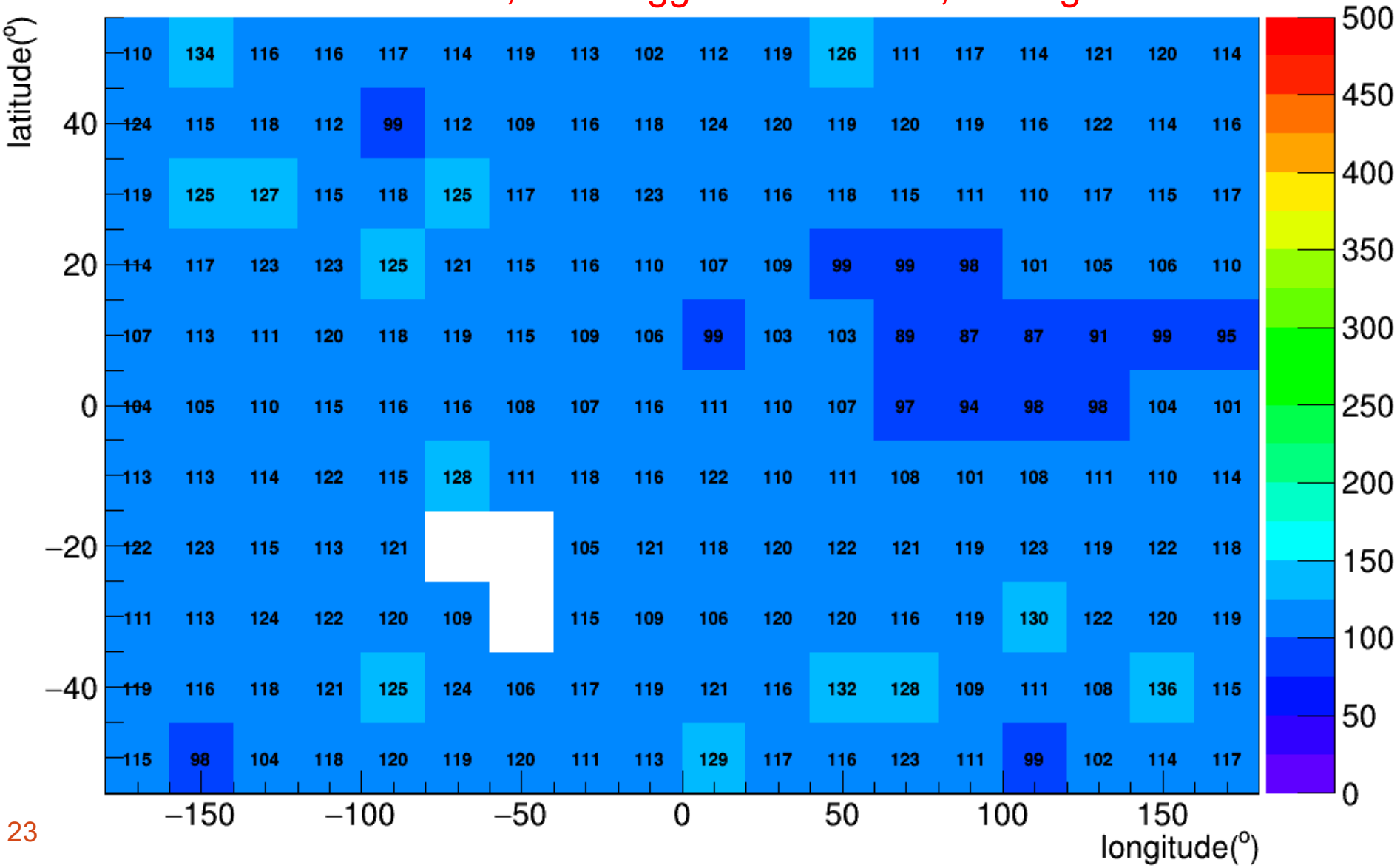


CALO Global Trigger (GT)

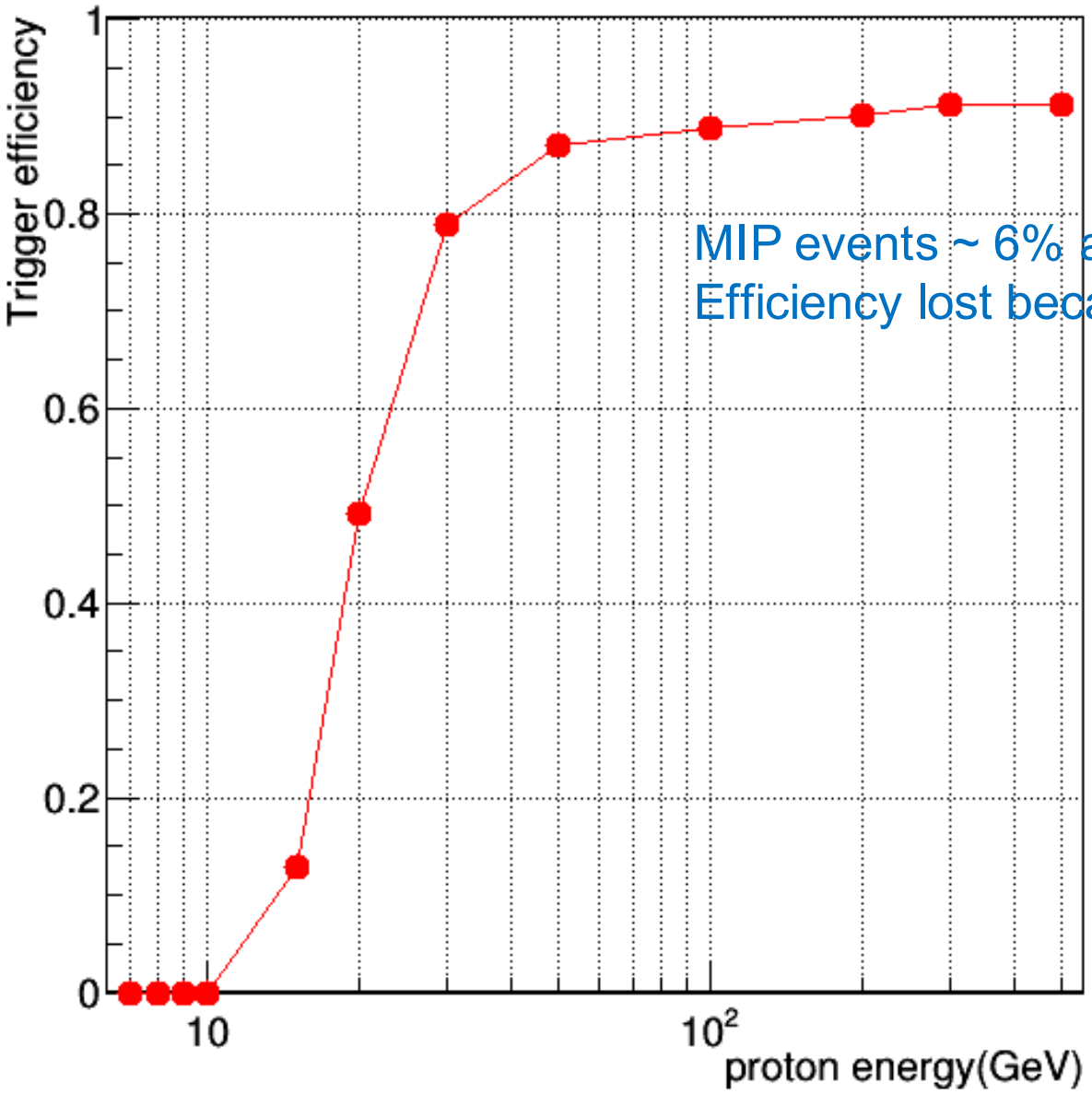
- GT is a combination (logical OR) of individual trigger channels
  - HE trigger channel
  - LE photon trigger channel
  - LE electron trigger channel
  - Unbiased (Etot > 0.5 GeV with 1000 pre-scale)
- Stand alone calibration trigger channel

HE Trigger Rate Map

Ecore threshold 10 GeV, max trigger rate 140 Hz, average rate 110 Hz



HE Trigger Efficiency for Proton



MIP events ~ 6% and not included
Efficiency lost because of MIP

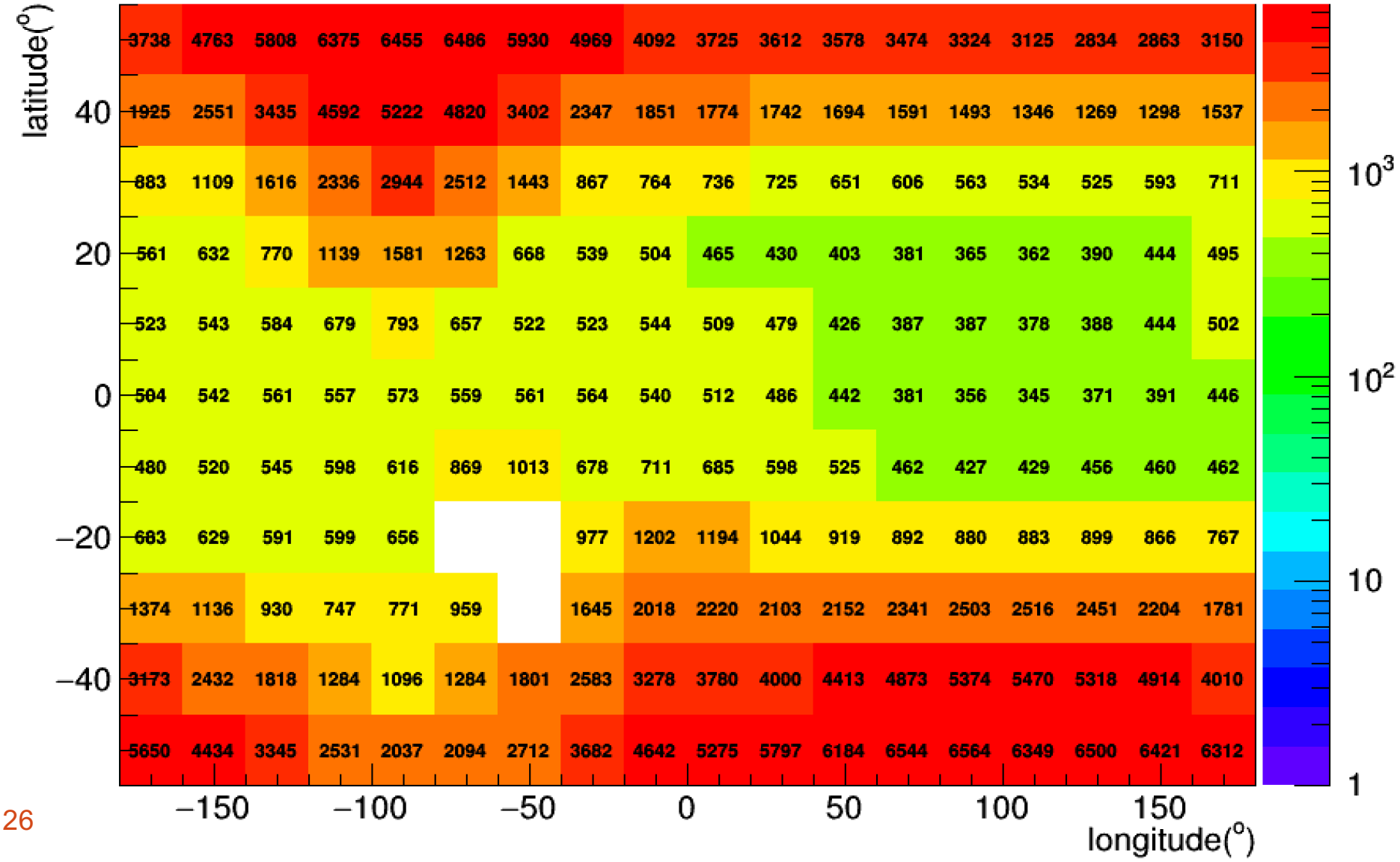
LE photon trigger

- CALO trigger threshold 0.5 GeV, max rate around 10000 Hz
- Roughly PSD geometry 1.6m*1.6m, count rate 30 times bigger than CALO
- PSD veto efficiency > 99.95%
- Trigger rate ~ 30*10000*0.05% = 150 Hz
- Or at least veto efficiency > 99.9% to ensure trigger rate < 500 Hz, the veto efficiency including:
  - PSD charged particle detection efficiency
  - Charged particle leakage(coverage) efficiency

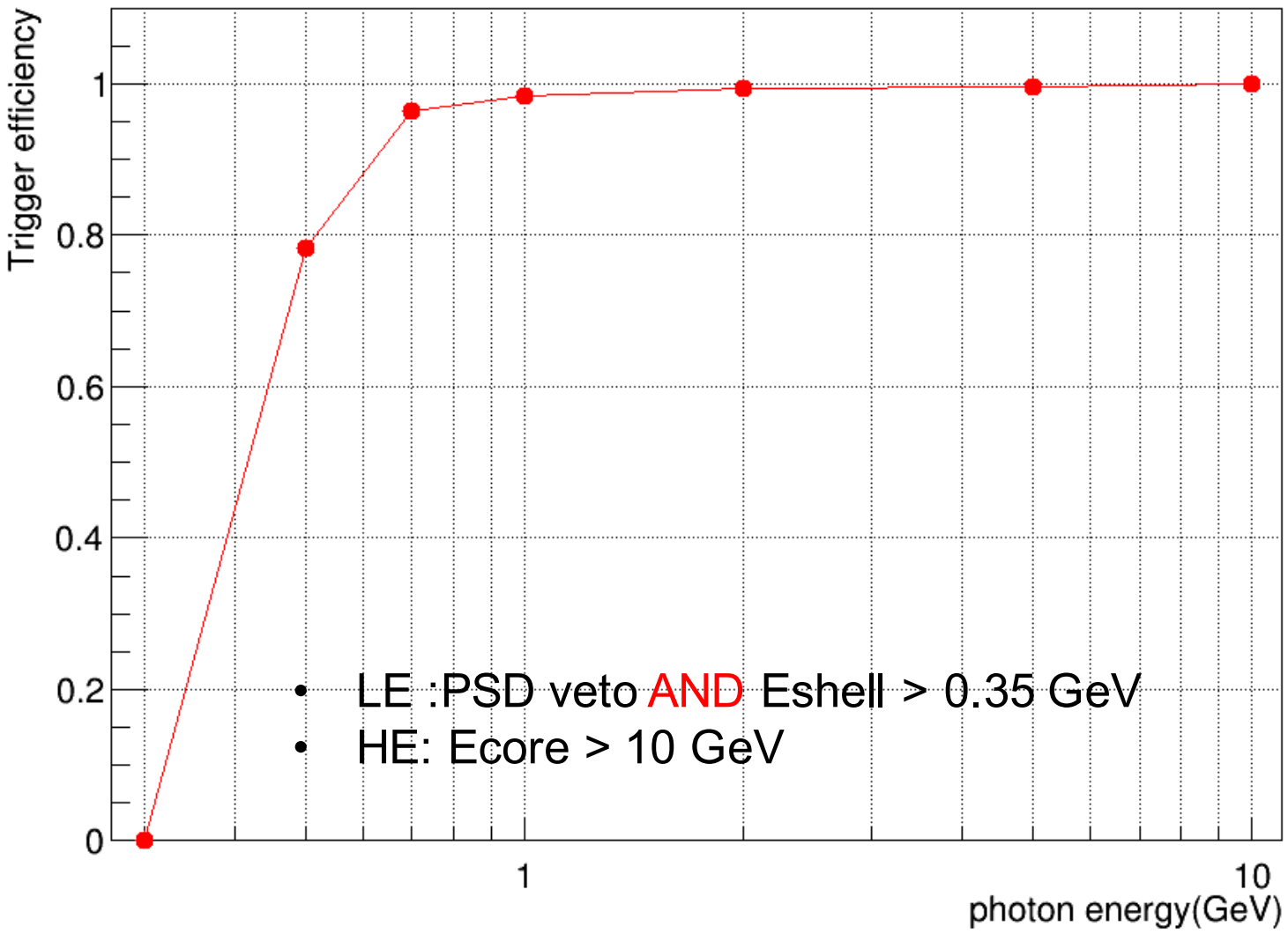
- Trigger timing under study

LE Photon Trigger: Event Rate Map

Eshell threshold 0.35 GeV, veto efficiency not included



Photon HE+LE Trigger Efficiency



LE Electron Trigger

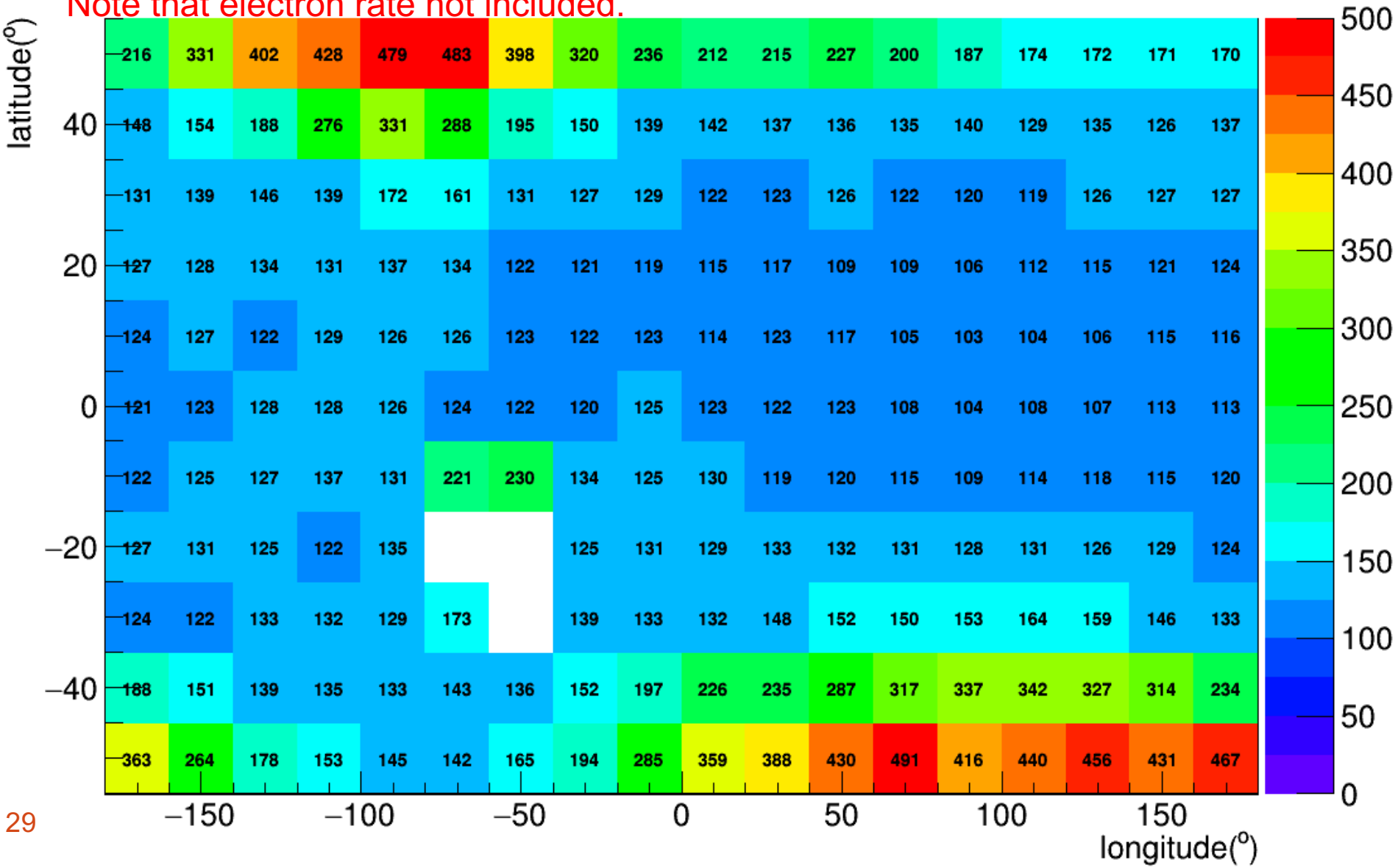
- 0.5 – 5 GeV electron is needed for TRD calibration
  - most energy deposited in the shell unit
  - only use shell unit near where TRD mounted to select electron passing through TRD firstly
  - (Eshell > 0.35 GeV AND Ecore < 0.06 GeV)

  OR (Eshell > 1 GeV AND Ecore> 0.6 GeV)

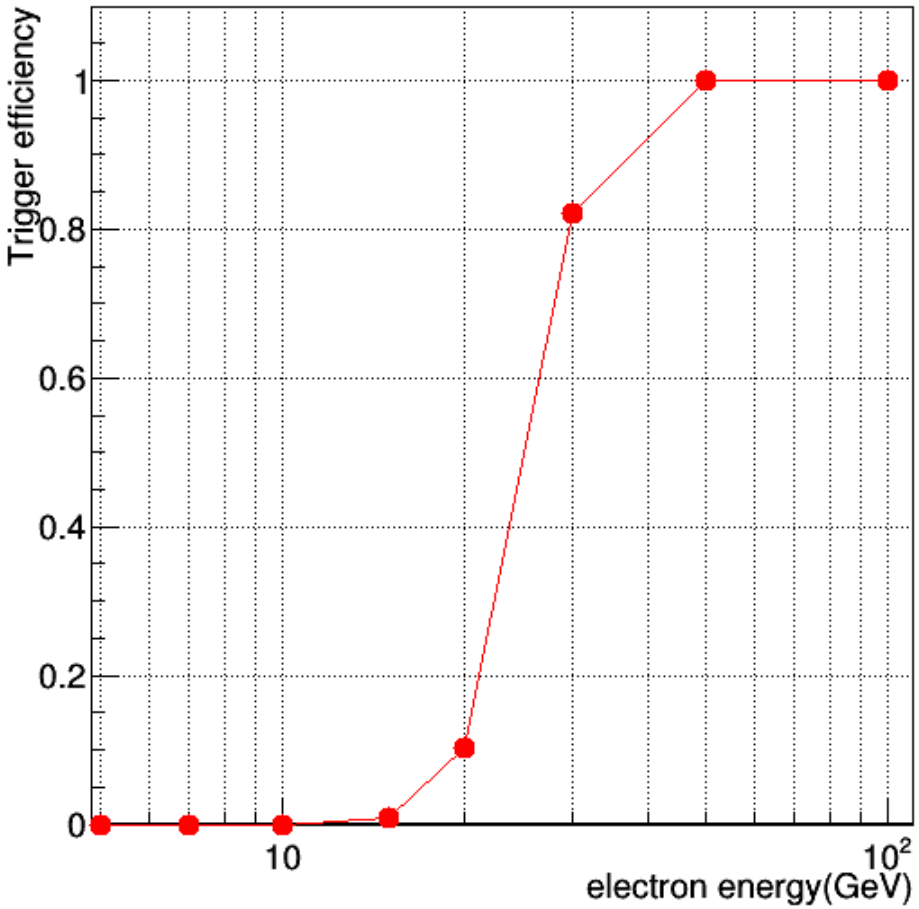
- TODO: electron rate per day per channel in TRD
  - improvements on threshold

HE Trigger + LE Electron Trigger Rate

Ecore > 10 GeV + Eshell selection, max rate 340 Hz, average rate 140,
Note that electron rate not included.

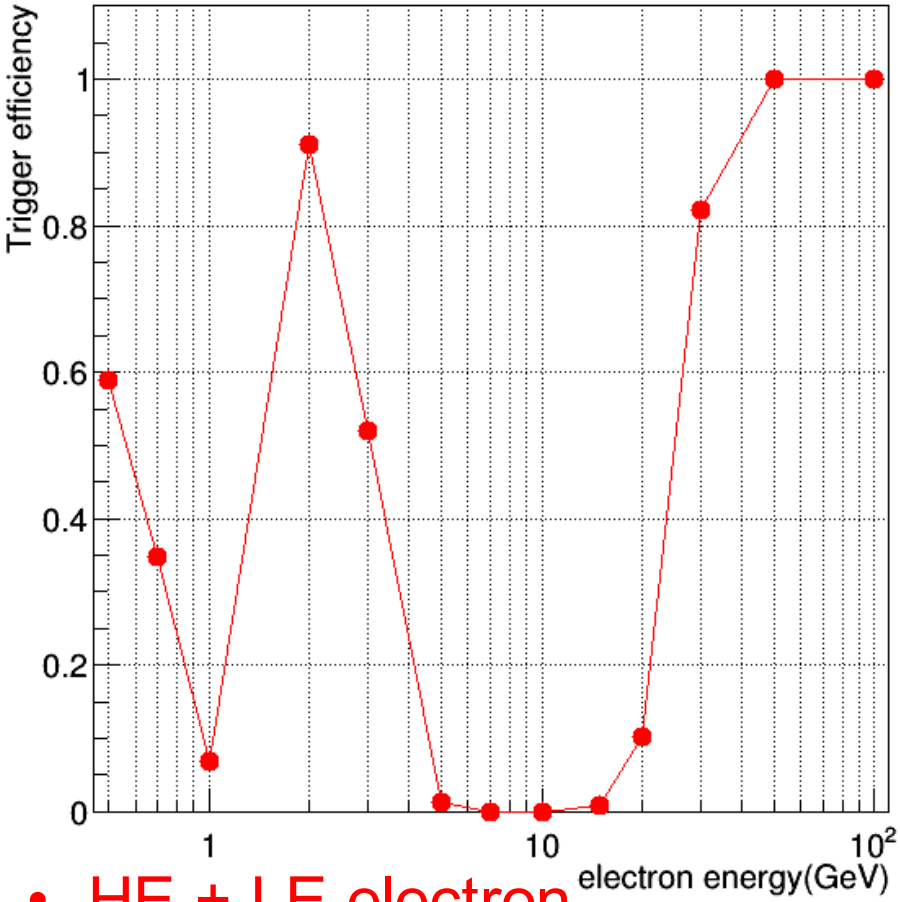


Electron Trigger Efficiency



HE only

- Ecore> 10 GeV



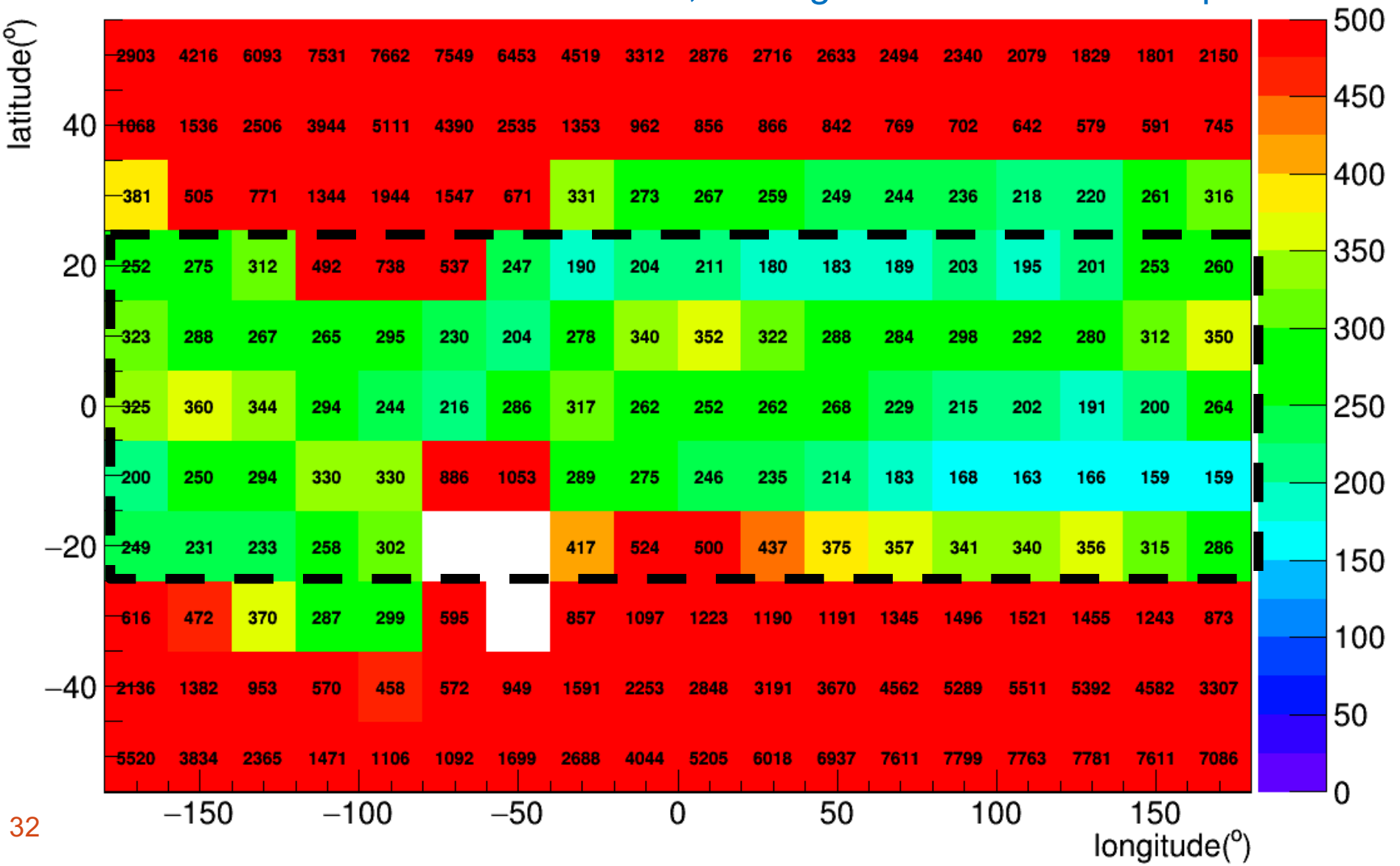
- HE + LE electron
  - Ecore> 10 GeV
  - OR (Eshell > 0.35 GeV AND Ecore < 0.06 GeV)
  - OR (Eshell > 1 GeV AND Ecore < 0.6 GeV)

Calibration Trigger Mode

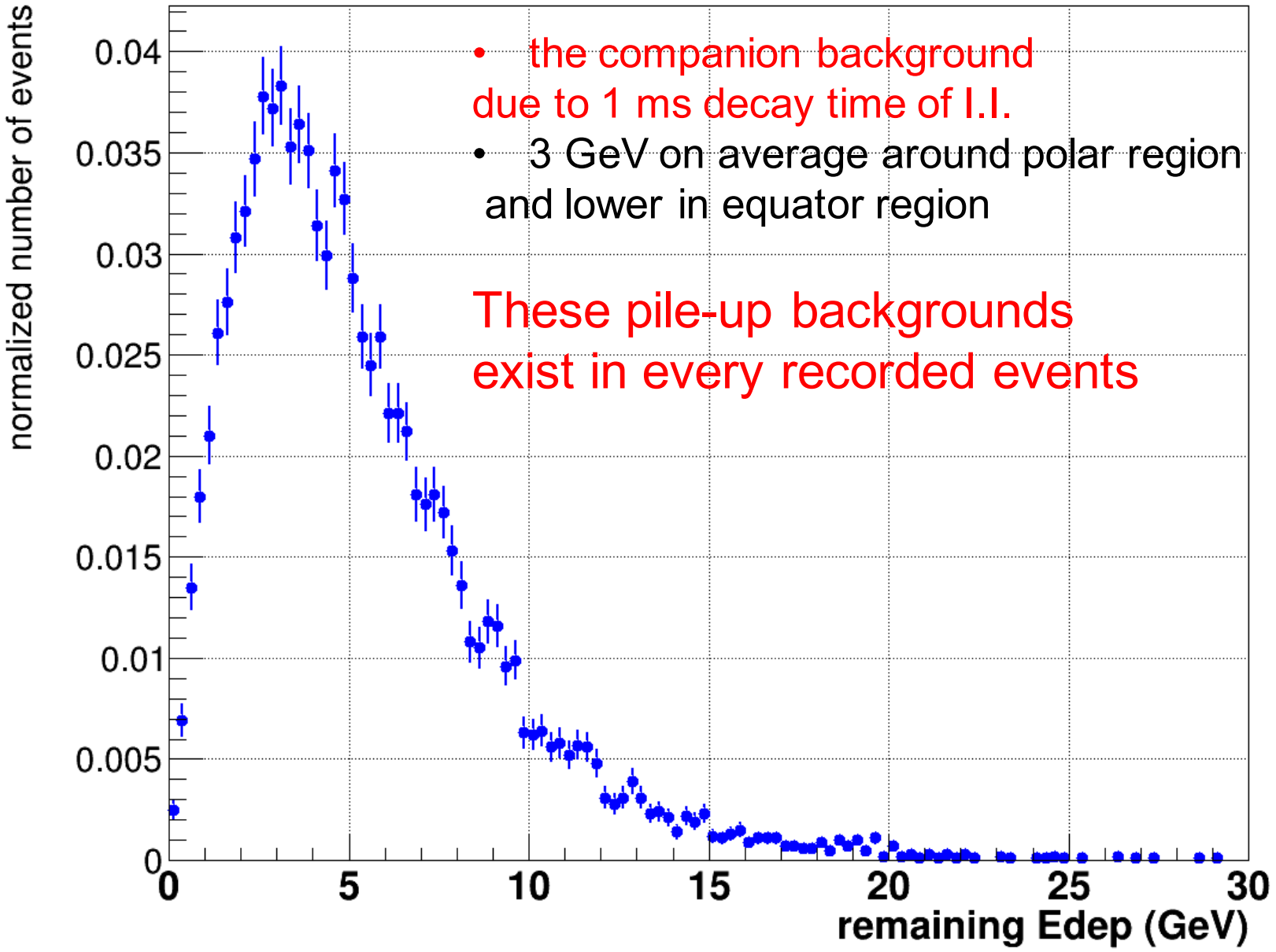
- Stand alone calibration runs
- 0.1 < Eshell < 0.8 GeV AND Ecore> 0.5 GeV
- AND geo latitude [-20^{o}, 20^{o}]
- AND exclude SAA

Calibration Mode Trigger Rate Map

Ecore > 0.5 GeV + Eshell selection, average rate 300 Hz near equator



Accumulated Pile-up Backgrounds



Dead Time & Detection Efficiency

Event rate(Hz)	Efficiency(%) dead time= 2 ms	Efficiency(%) dead time= 1 ms
50	92	95
100	85	92
200	73	84
300	64	78
400	57	72
500	51	68

Faster I.I. (10-100 us) will be necessary to kill pile up and increase efficiency

Summary

- Science data taking mode
  - HE trigger
    - 110 Hz trigger rate
    - Trigger efficiency > 90%, for proton > 50 GeV
  - HE + Low energy electron threshold
    - 130 Hz trigger rate
    - Trigger efficiency > 90%, for electron > 30 GeV
  - LE trigger with CALO shell threshold beyond 0.35 GeV and AND PSD veto
    - Trigger rate depends on veto efficiency
    - Trigger efficiency > 80%, for photon > 0.5 GeV
  - Unbiased with pre-scale
    - < 10Hz
- Calibration mode
  - CALO core trigger threshold > 0.5 GeV and CALO shell threshold to discard shower events
  - 300 Hz trigger rate near earth equator (-20^{o} , 20^{o}) and SAA exclude