Trigger Simulation Activities

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on behalf of
CIEMAT / INFN-Bologna

HERD 9th International Workshop, 22-23 February 2021

Introduction

- The aim of the trigger simulation work is to develop a **reliable trigger design** that is able to cope with **HERD science goals** and **capabilities.** This program requires
  - up-to-date modeling of the **expected fluxes** of the relevant particle species, including **charged** (protons, light nuclei, e-, e+) and **γ-rays**
  - A reliable modeling of the **detector materials** and **response**
  - Definition of an optimized **trigger logic** to maximize the HERD science reach
- Our **strategy** is to **develop this program** in close collaboration with the other institutes involved in this task and to **provide the tools** to the HERD collaboration
- This effort is coordinated within the **HERD Trigger Working Group**, which has held bi-weekly meetings since **April 2020**
- We have made use of **HerdSoftware** to produce the **simulated samples** and our goal is to integrate the **trigger algorithms** inside HerdSoftware for public use
- Our starting point has been the **baseline trigger definitions** developed at **IHEP** and included in the **HERD proposal**

Baseline Trigger Definitions

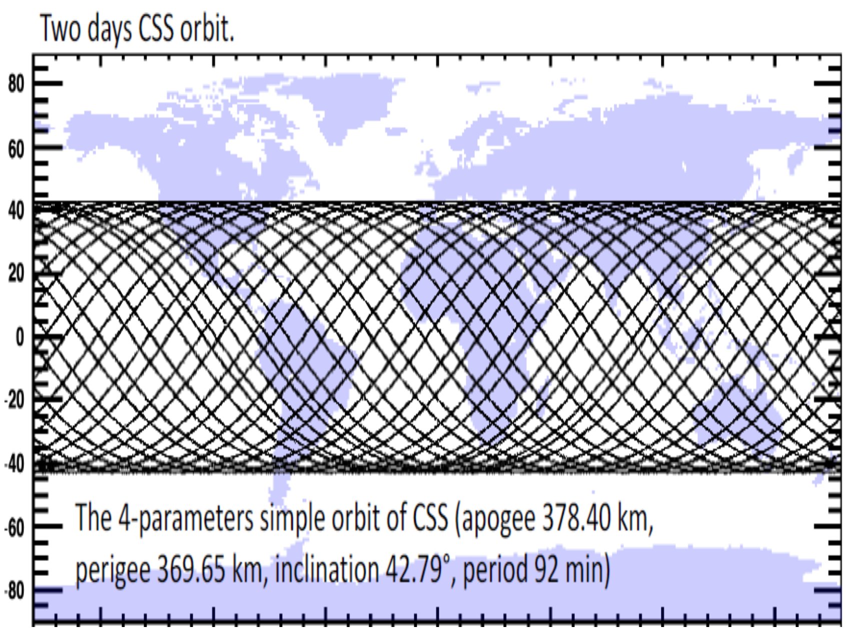
The **Global Trigger (GT)** is obtained from the logical combination of the particle-dedicated sub-triggers, built from the deposited energies in **CALO** and **PSD**

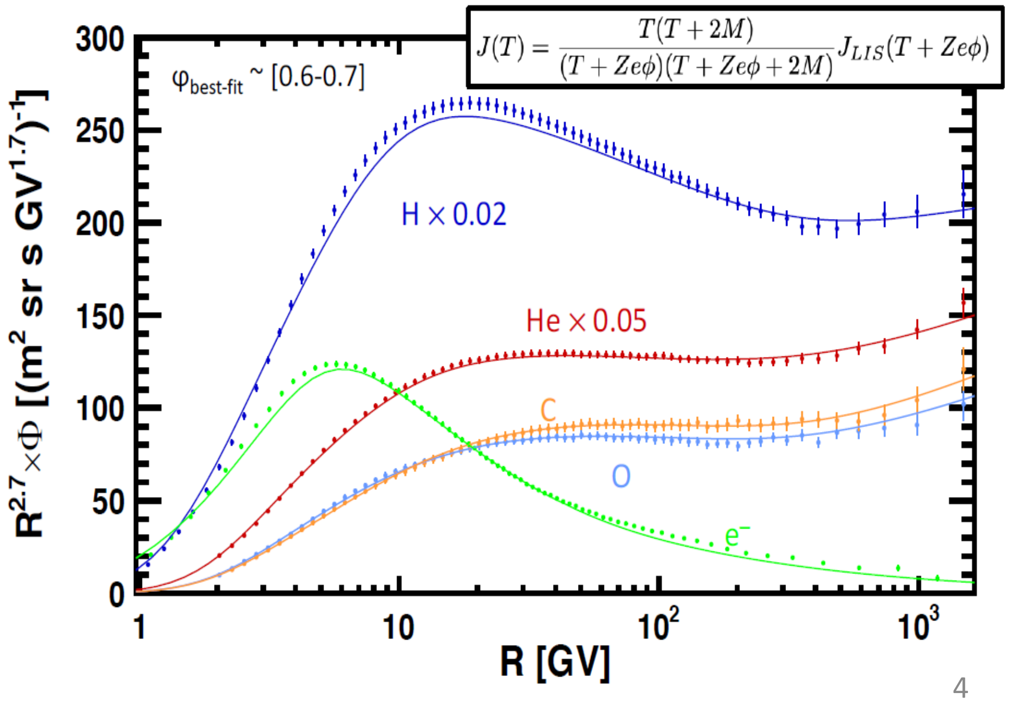
- ❑ **HE (High Energy particle)** requires high energy deposition in CALO
- ❑ **LEG (Low Energy photon)** low energy deposition in CALO and PSD veto
- ❑ **LEE (Low Energy Electron)** low energy deposition in CALO
- ❑ **Unbiased:** low energy in CALO, for trigger efficiency evaluation
- ❑ **Calibration Trigger:** low energy deposition in CALO.

Revision of Input Cosmic Ray Fluxes

Space Environment Simulator (https://gitlab.cern.ch/oliva/ses)

- Satellite Orbit (position and velocity vectors as function of time)
- Coordinate Transformation
- Particle Fluxes





Expected Rates

❑ Expected CR Rates and Global Trigger Rates

- ❑ The output of latest **SES orbit simulation release (v4)** is now available at https://srm.ciemat.es:2880/pnfs/ciemat.es/data/public/herd/fluxes_for_trigger/ses/v4/
- ❑ A simple **ROOT macro** to compute expected **trigger rates** using **SES outputs** & **trigger acceptances** for different particle species is also available at https://srm.ciemat.es:2880/pnfs/ciemat.es/data/public/herd/fluxes_for_trigger/ses/tools/

```
// Print the average trigger rates for individual particle
// species and subtriggers
void PrintTriggerRates(TString SESvers = DefaultSESvers,
                       TString SESsmod = DefaultSESsmod);
-UU-:----F1  SESRates.h     67% L108    (C/l Abbrev)----------
```

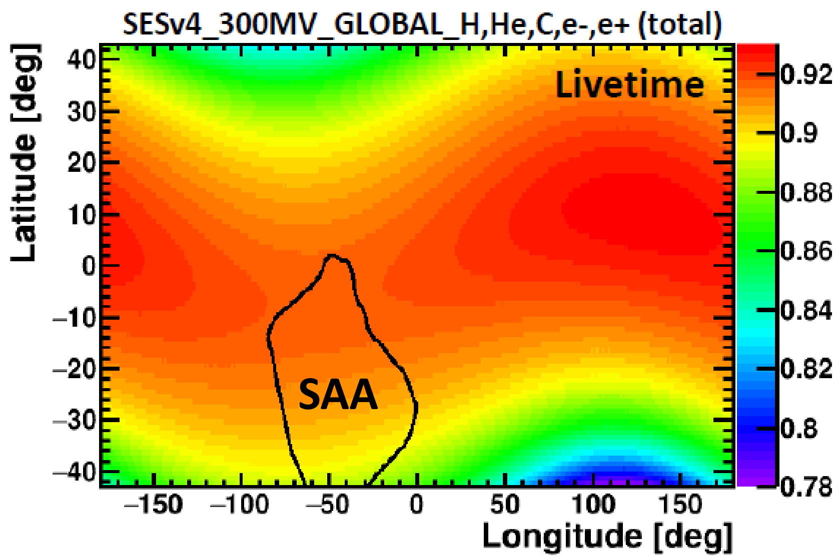
- ❑ **Average rate** for **GLOBAL** trigger including **H**, **He**, **C**, **e-**, **e+** contribs. and minimum solar modulation is **below 100 Hz**
- ❑ Under cutoff contribution is **5 Hz** dominated by **e-** contribution

```
root [2] PrintTriggerRates("v4","300MV")
>>>>>>>> SubTrigger : HE3 <<<<<<<<<<
               Total    Under    Above
        H :    36.67     0.00    36.67
       He :    19.17     0.00    19.17
        C :     2.27     0.00     2.27
 electron :     0.65     0.00     0.65
 positron :     0.02     0.00     0.02
ALL Part.  :   58.78     0.00    58.78
>>>>>>>> SubTrigger : LEE <<<<<<<<<<
               Total    Under    Above
        H :    23.41     0.10    23.31
       He :     6.05     0.00     6.05
        C :     0.23     0.00     0.23
 electron :     5.10     4.25     0.85
 positron :     0.49     0.45     0.04
ALL Part.  :   35.28     4.79    30.48
>>>>>>>> SubTrigger : LEG <<<<<<<<<<
               Total    Under    Above
        H :     0.01     0.00     0.01
       He :     0.01     0.00     0.01
        C :     0.00     0.00     0.00
 electron :     0.02     0.01     0.00
 positron :     0.00     0.00     0.00
ALL Part.  :    0.03     0.02     0.02
```

```
>>>>>>>> SubTrigger : UNB <<<<<<<<<<
               Total    Under    Above
        H :  1027.17     2.51  1024.66
       He :   279.40     0.00   279.40
        C :    10.45     0.00    10.45
 electron :   125.56   105.10    20.46
 positron :    13.80    12.82     0.98
ALL Part.  : 1456.38   120.43  1335.94
>>>>>>>> SubTrigger : CALIB <<<<<<<<<<
               Total    Under    Above
        H :   229.63     0.62   229.01
       He :    24.36     0.00    24.36
        C :     0.06     0.00     0.06
 electron :     7.45     6.78     0.67
 positron :     0.65     0.61     0.04
ALL Part.  :  262.15     8.00   254.15
>>>>>>>> SubTrigger : GLOBAL <<<<<<<<<<
               Total    Under    Above
        H :    61.08     0.10    60.97
       He :    25.48     0.00    25.48
        C :     2.50     0.00     2.50
 electron :     5.88     4.36     1.51
 positron :     0.53     0.46     0.06
ALL Part.  :   95.47     4.93    90.54
```

Expected Rates

❑ Expected CR Rates and Global Trigger Rates



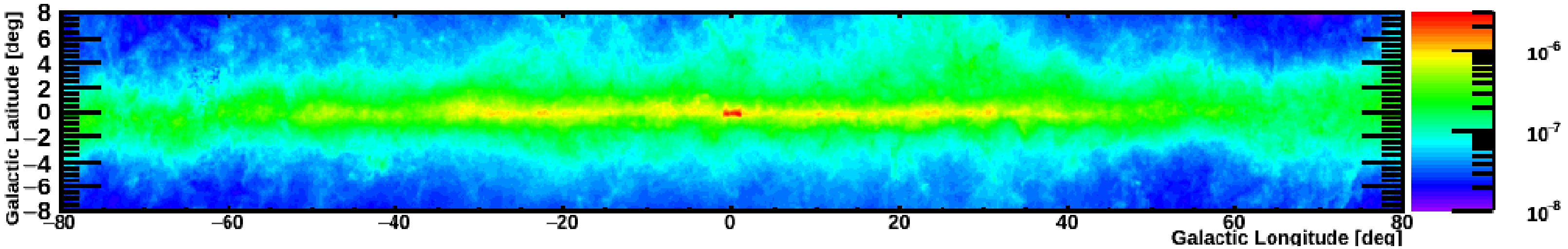

```
root [1] PrintLivetime(1.25e-3,"v4","300MV",1)
Open File : ./Rates_SESv4_300MV/H_GLOBAL.root
Open File : ./Rates_SESv4_300MV/He_GLOBAL.root
Open File : ./Rates_SESv4_300MV/C_GLOBAL.root
Open File : ./Rates_SESv4_300MV/electron_GLOBAL.root
Open File : ./Rates_SESv4_300MV/positron_GLOBAL.root
Open File : ./SAA/SAA.root

Average Trigger Rate        : 95.5 Hz
Average Rate (DT=1.25 ms)   : 84.5 Hz
Average Livetime            : 88.5%

Maximum Trigger Rate        : 222.6 Hz
Maximum Rate (DT=1.25 ms)   : 174.2 Hz
Minimum Livetime            : 78.2%

Minimum Trigger Rate        : 61.6 Hz
Minimum Rate (DT=1.25 ms)   : 57.2 Hz
Maximum Livetime            : 92.9%

>>> Exclude South Atlantic Anomaly <<<

Time Fraction Out of SAA    : 92.4%

Average Trigger Rate        : 96.4 Hz
Average Rate (DT=1.25 ms)   : 85.2 Hz
Average Livetime            : 88.4%

Maximum Trigger Rate        : 222.6 Hz
Maximum Rate (DT=1.25 ms)   : 174.2 Hz
Minimum Livetime            : 78.2%

Minimum Trigger Rate        : 61.6 Hz
Minimum Rate (DT=1.25 ms)   : 57.2 Hz
Maximum Livetime            : 92.9%

Effective Exposure Time     : 81.7%
```

- ❑ Excluding the of **time spent** in the **SAA (7.6%)**
- ❑ For **1.25 ms dead time** (800 fps), the **average livetime** out of the **SAA** is **88.4%** with a **minimum livetime** along the orbit of **78.2%**
- ❑ The overall **effective exposure time** is **81.7%**

Expected Rates

❑ Expected γ-ray Rates and LEG Trigger Rates:

- ❑ Compute **yearly averaged rates** to simplify the problem
- ❑ **Factorize** the ingredients:
  - ❑ **Differential Acceptance** in local coordinates evaluated for individual pixels within the field of view to account for specific trigger definition and/or event selection efficiencies.
  - ❑ **Exposure Maps** in galactic coordinates obtained from CSS orbit simulation for each individual pixel within the field of view
  - ❑ **Intensity Maps** in galactic coordinates **I(l,b,E)** encompassing all relevant contributions to the Galactic diffuse emission (Fermi-LAT model)
- ❑ This **factorized scheme** allows to easily reevaluate the expected average rates from diffuse γ-ray emission for different effective area and/or source models

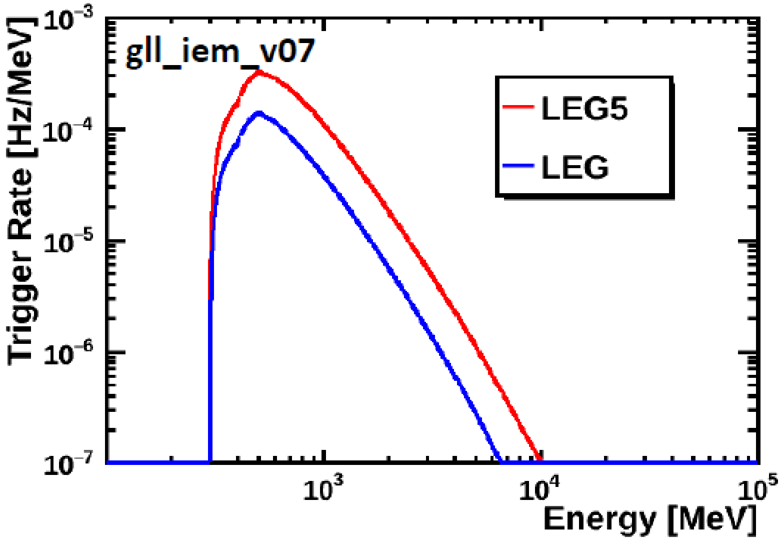


Expected Rates

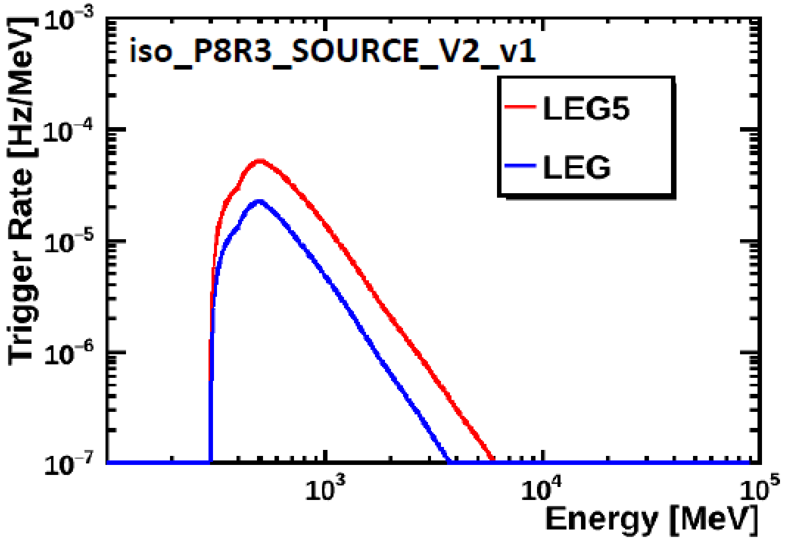
❑ Expected γ-ray Rates and LEG Trigger Rates:

- ❑ Evaluate expected **LEG trigger rate** using definitions based on HERD proposal
  - energy_in_**TOP**_shell > **350 MeV** AND energy_in_**ANY**_PSD_side < **1 MeV**
  - energy_in_**ANY**_shell > **350 MeV** AND energy_in_**ANY**_PSD_side < **1 MeV**
- ❑ Average trigger rates can be evaluated from the intensity and exposure time maps

$R(E) = 1/T \, \Sigma_i \, A_i(E) \, (\Sigma_{l,b} \, T_i(l,b) \, \phi(l,b,E) \, \Delta l \, \Delta b)$



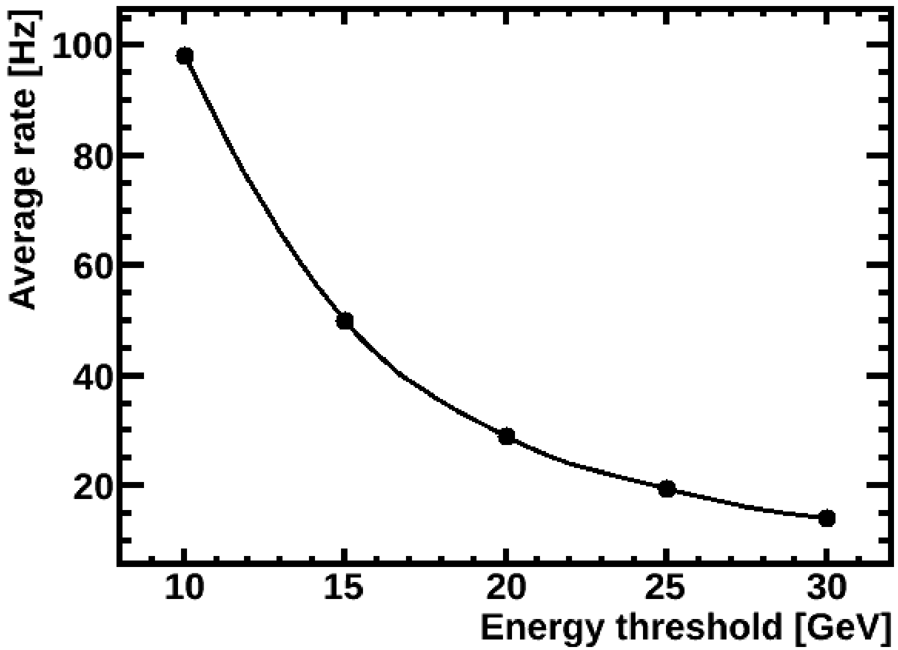
LEG : Average Rate = 0.08 Hz
LEG5: Average Rate = 0.21 Hz

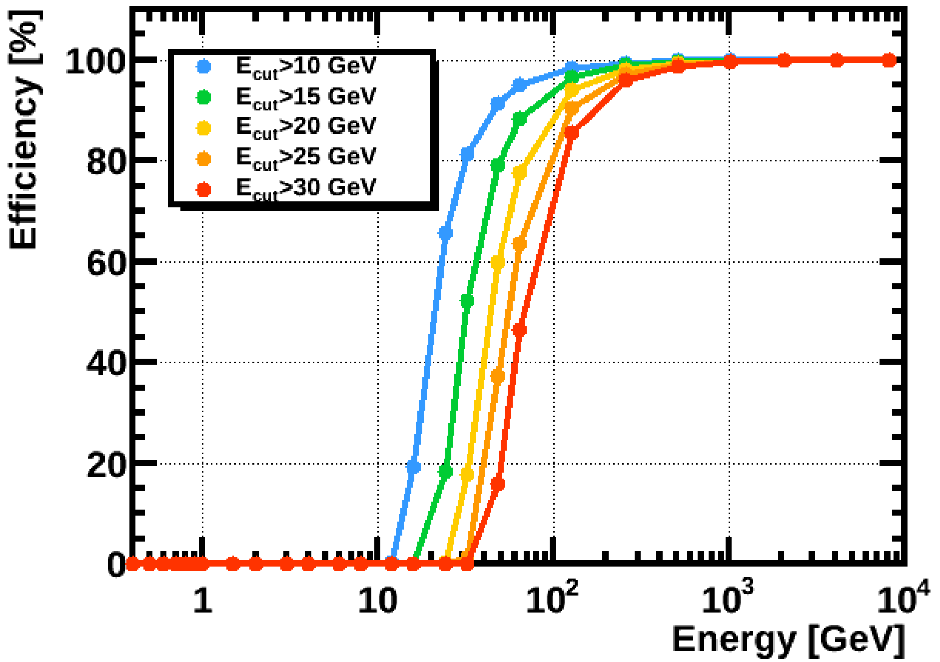


LEG : Average Rate = 0.01 Hz
LEG5: Average Rate = 0.03 Hz

HE Trigger Optimization: Acceptance

- Inspection of the HE trigger efficiency on proton samples with contained showers shows that current definition is optimized by extending the CALO core region to the full CALO
- HE trigger rate can be tuned by increasing the energy threshold

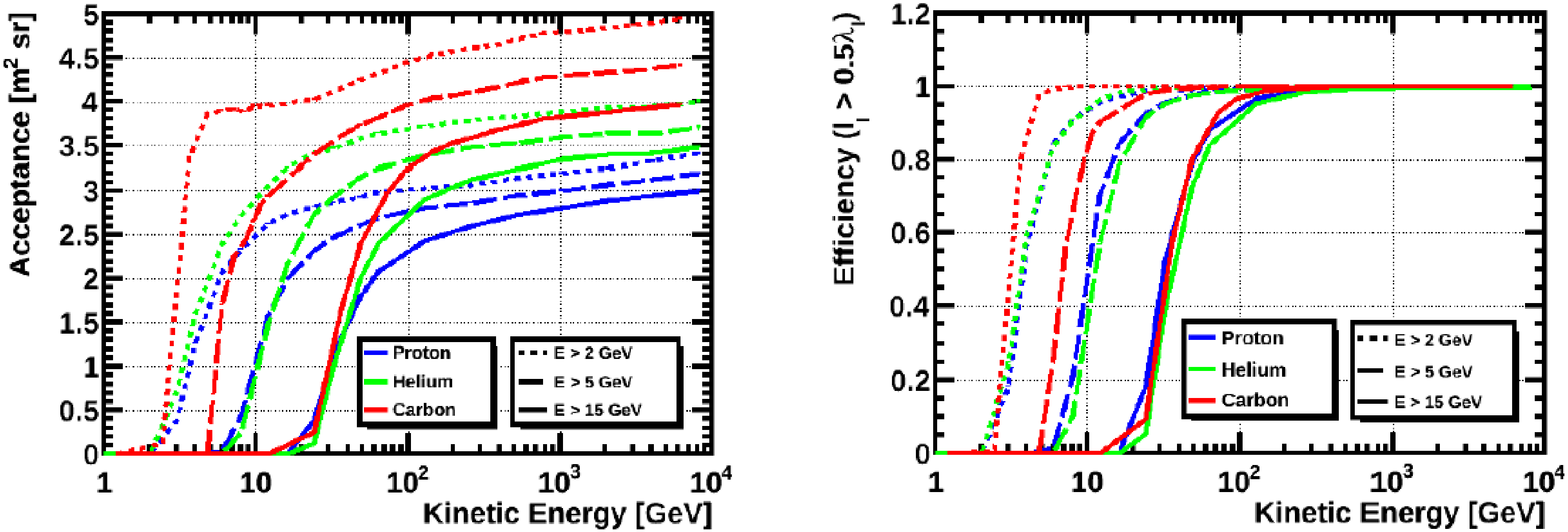




HE Trigger Optimization: Energy Range

► HE trigger extension to **lower energies** provides additional **calibration samples** and opens a window to **new science topics** with HERD

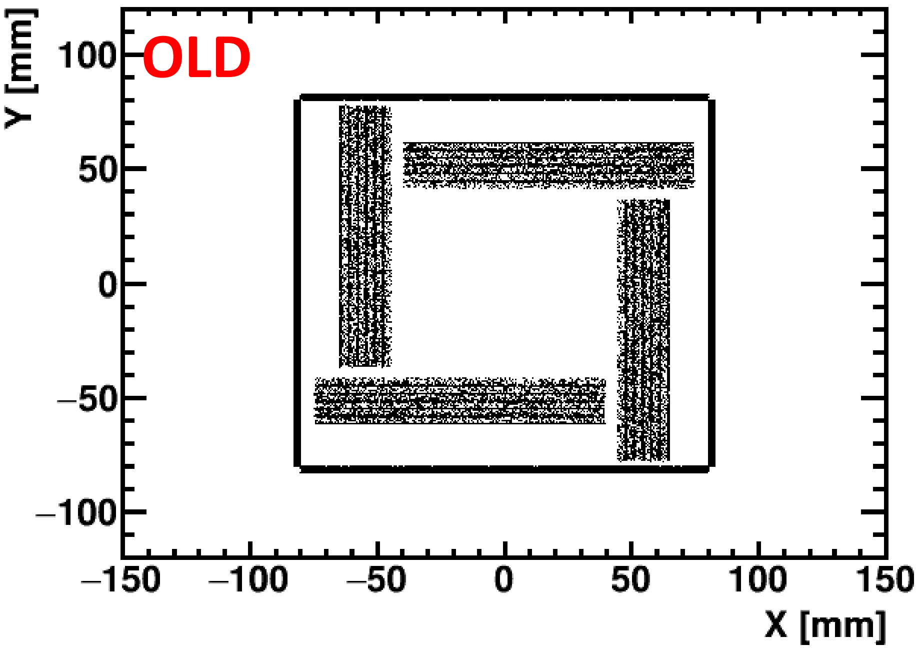
► HE trigger can be extended to lower energies by setting different **low energy thresholds**

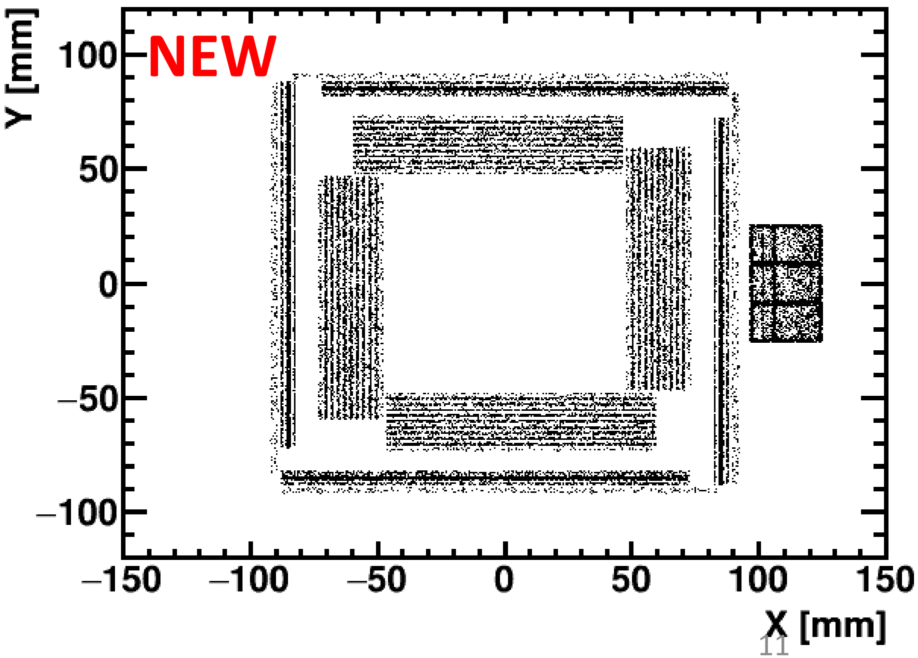


► Each **energy threshold** may define a **different sub-trigger**. The increase in the trigger rate can be regulated by setting different **prescaling factors** according to the science/operation constraints

Simulated HERD Geometry

- All previous studies of the **trigger performances** have been carried out on the simulation implementing the **original geometry** as described in **HERD proposal**
- Latest modifications in **HERD geometry** and a first **CSS description** have been implemented in **HerdSoftware**
- We have launched a small MC production to start a **systematic study** of the trigger performances with the **new geometry** compared to our previous results
- At this stage **CSS** simulation is **not enabled** so as to have a direct comparison with the results obtained with the old geometry





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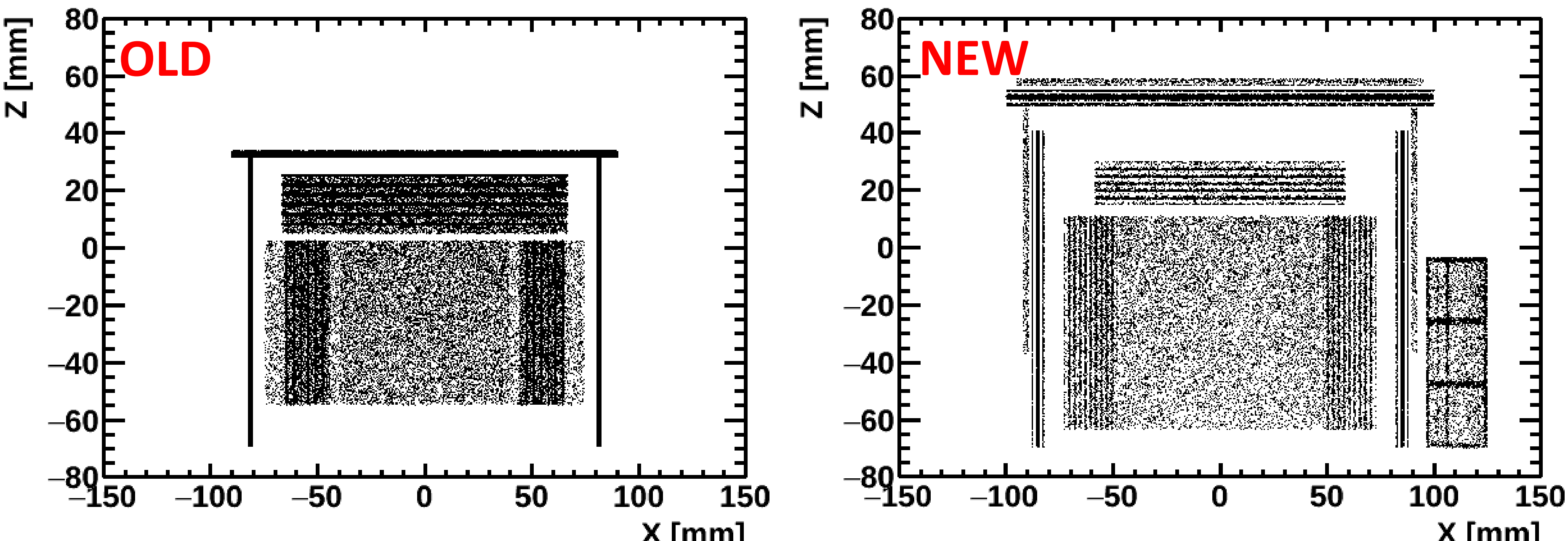


Trigger Acceptance

- The differences of **optimized trigger** definition on **new** *vs.* **old** geometries for the simulated particle species are consistent with
  - Small increase of upstream material budget (increased **UNB** threshold) and overall detector size (increased **LEE** and **CALIB** acceptances)
  - Less efficient PSD veto (1 layer + gaps between scintillator tiles) resulting in an increased **LEG** acceptance for all particle species
- Although trigger settings are still to be tuned for this geometry (e.g. PSD veto), the impact on the **GLOBAL** trigger rate is minor
- In particular, the contribution of charged particles to the **LEG** rate is ~1Hz [*]

OLD

>>>>>>>> SubTrigger : GLOBALOpt <<<<<<<<<<

	Total	Under	Above
H :	115.36	0.42	114.94
He :	44.43	0.00	44.43
C :	4.27	0.00	4.27
electron :	15.06	11.42	3.64
positron :	1.51	1.35	0.16
ALL Part. :	180.63	13.19	167.44

NEW

>>>>>>>> SubTrigger : GLOBALOpt <<<<<<<<<<

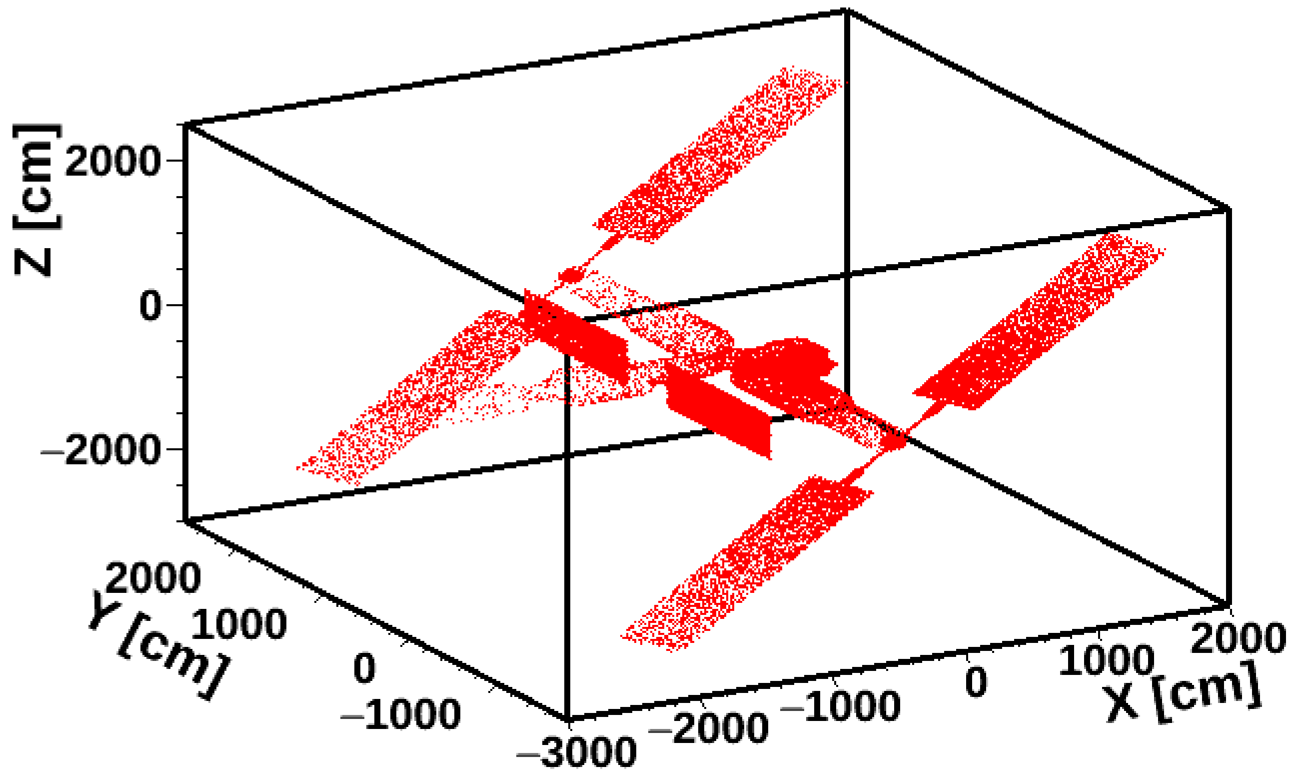
	Total	Under	Above
H :	118.69	0.41	118.29
He :	45.98	0.00	45.98
C :	4.30	0.00	4.30
electron :	16.18	12.43	3.74
positron :	1.64	1.48	0.16
ALL Part. :	186.79	14.32	172.47

(*) For consistency with baseline definition LEG trigger is defined for top side. Acceptance and expected rates should be multiplied by a factor ~3 if lateral sides are included

CSS Geometry Configuration

```
#### Add the CSS
/herd/geometry/parametric/general/spaceStation css

### Set the angles of the CSS solar panels
# The range of all rotation angles within [-180, 180) degree, and the angle increase with
# left-hand rule respect to the rotation axis. By default there's no rotation (all angles
# equal to zero degree), and all panels are in horizontal position (parallel to the XY
# plane).
/herd/geometry/parametric/css/spSpinAngleM1M2 90 deg    # Spin angle of all the panels on modu
/herd/geometry/parametric/css/spSpinAngleMC 90 deg      # Spin angle of both panels on module
/herd/geometry/parametric/css/spRevAngleM1M2 50 deg     # Revolution angle of both couples of
```



Trigger Rates

```
>>>>>>>> SubTrigger : GLOBALOpt <<<<<<<<<<

                          Total    Under    Above
CSS None -  2m    H :   118.06     0.32   117.74
CSS Nom. -  3m    H :   118.99     0.39   118.59
CSS Nom. - 45m    H :   117.24     0.37   116.87
CSS Max. - 45m    H :   114.88     0.34   114.55

>>>>>>>> SubTrigger : 020_GLOBALOpt <<<<<<<<<<

                          Total    Under    Above
CSS Nom. -  3m    H :   136.16     0.45   135.71
CSS Nom. - 45m    H :   132.97     0.42   132.55
CSS Max. - 45m    H :   131.41     0.39   131.02

>>>>>>>> SubTrigger : 035_GLOBALOpt <<<<<<<<<<

                          Total    Under    Above
CSS Nom. -  3m    H :   153.73     0.49   153.23
CSS Nom. - 45m    H :   149.77     0.44   149.33
CSS Max. - 45m    H :   147.86     0.42   147.44

>>>>>>>> SubTrigger : 4pi_GLOBALOpt <<<<<<<<<<

                          Total    Under    Above
CSS Nom. -  3m    H :   239.33     0.60   238.73
CSS Nom. - 45m    H :   233.90     0.53   233.37
CSS Max. - 45m    H :   232.20     0.51   231.69
```

- ❑ Evaluation with SES v4 shows **consistent results for down-going** proton rates
- ❑ Extension (*) down to ~11.5º below horizontal (**cos(θ) < 0.20**) shows **increase of 15%** in expected rate
- ❑ Extension (*) down to ~20.5º below horizontal (**cos(θ) < 0.35**) shows **increase of 30%** in expected rate
- ❑ Isotropic acceptance (only valid for **under cutoff flux**) shows **consistent increase** in proton rate

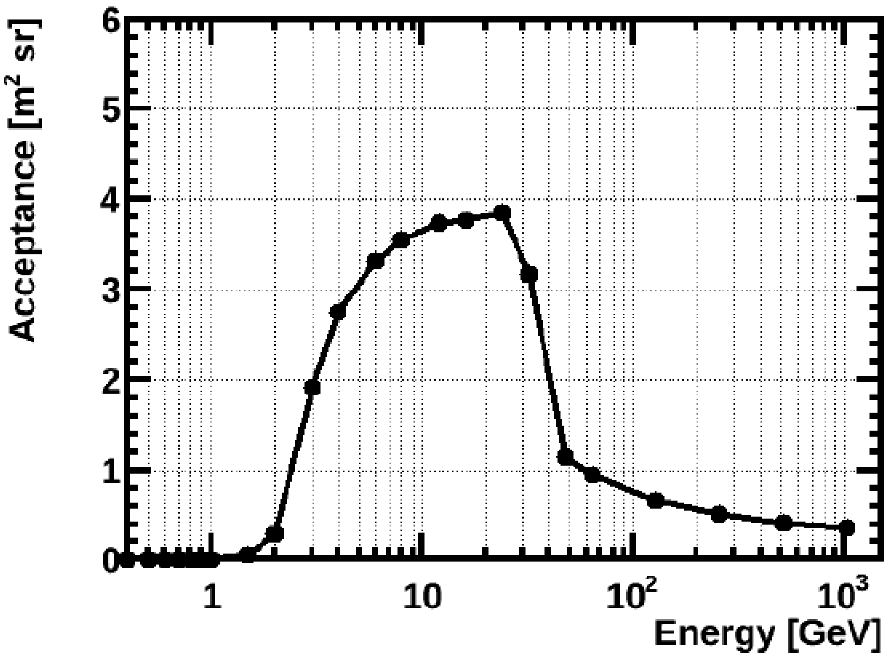
(*) Stoermer cuttoff transfer function evaluated for cos(q) < 0.20. Penumbra effects due to Earth blocking not included

Low Energy Topological Trigger

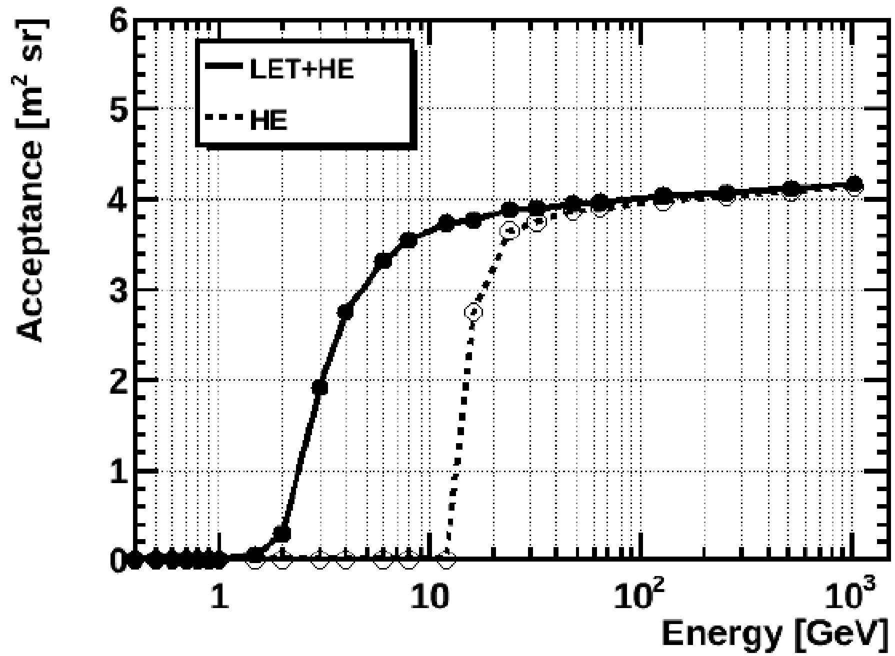
The self-trigger signal from **CALO PD readout** allows to define simple **topological triggers** based on the **total multiplicity and x,y,z-projection multiplicities** that complement the triggers built from the energy deposition in CALO

- A **topological trigger for low energy electrons (LET)** exploits the differences in the **electron and proton showers** in CALO

Electron LET Trigger



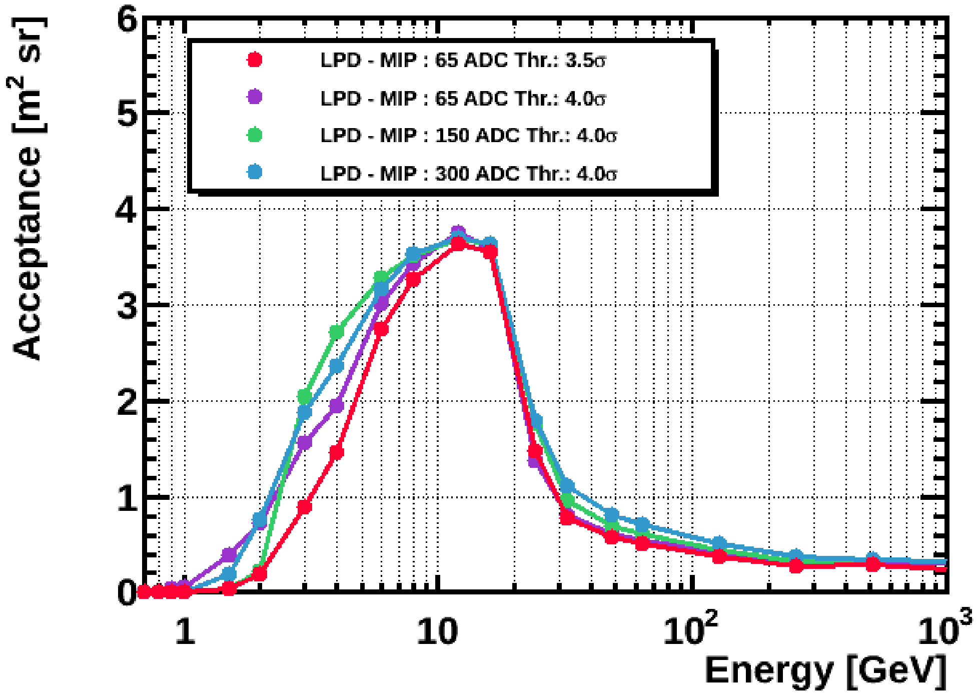
Electron LET+HE Trigger



✓ **High electron acceptance** with a continuous overlap with the HE trigger and **strong proton suppression** at low energies to have a reasonable trigger rate.

Low Energy Topological Trigger

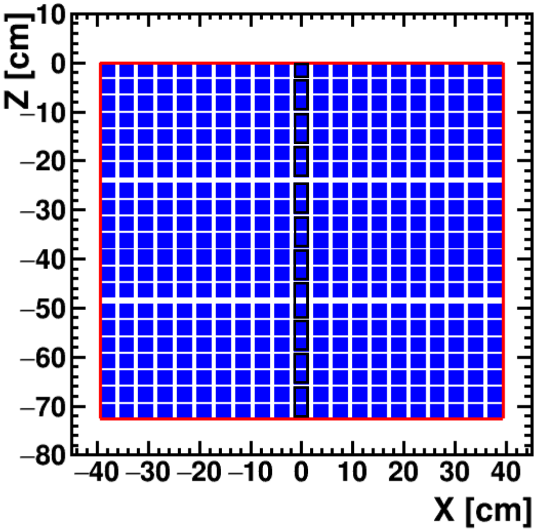
- The **performance of the LEET trigger** to a more realistic detector response has been investigated thanks to the **simulation of the PD readout**
  - The parameters of the trigger cuts have been optimized in 4 LPD configurations

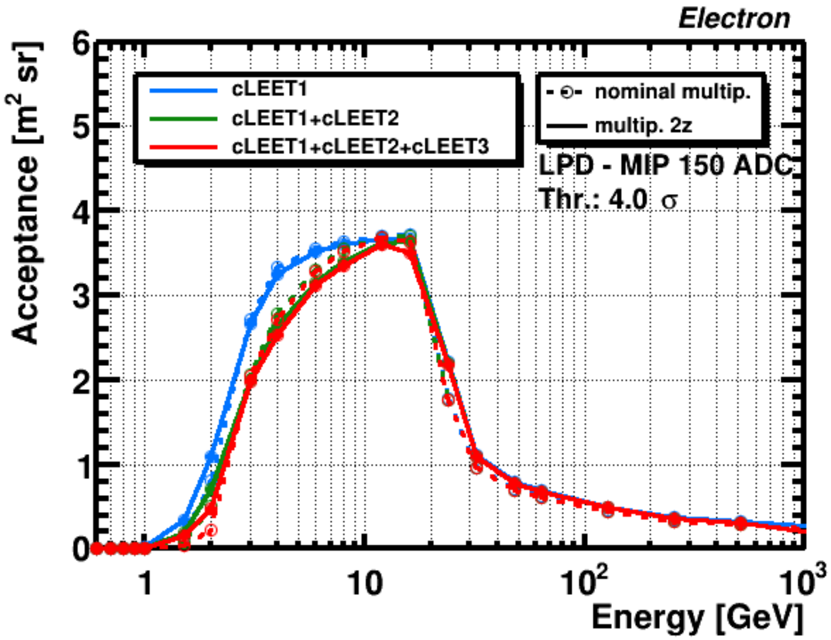


  - The stability of each configuration has been also verified when the response has a channel by channel variation

Low Energy Topological Trigger

- The impact of **a reduced number of trigger channels** (logical OR of 2 consecutive crystals in the same CALO column) in the HERD PD trigger system has been evaluated



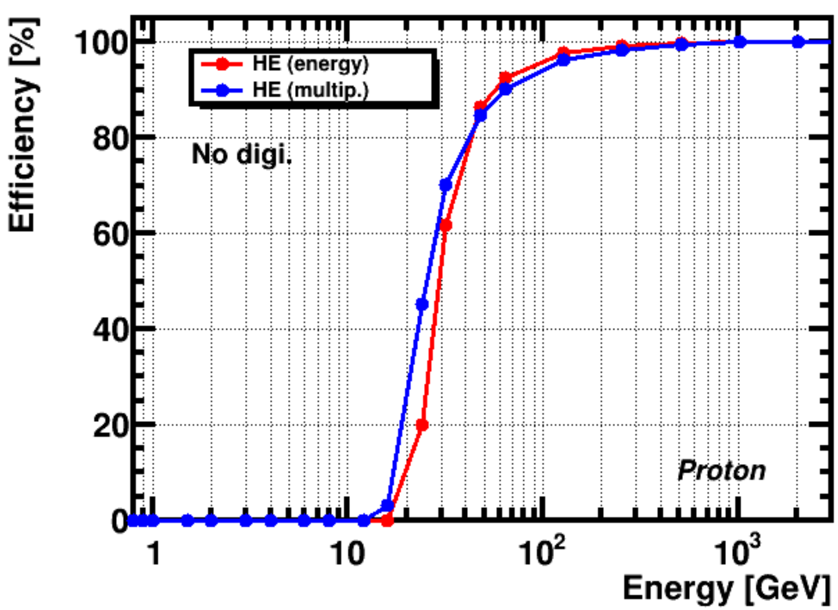


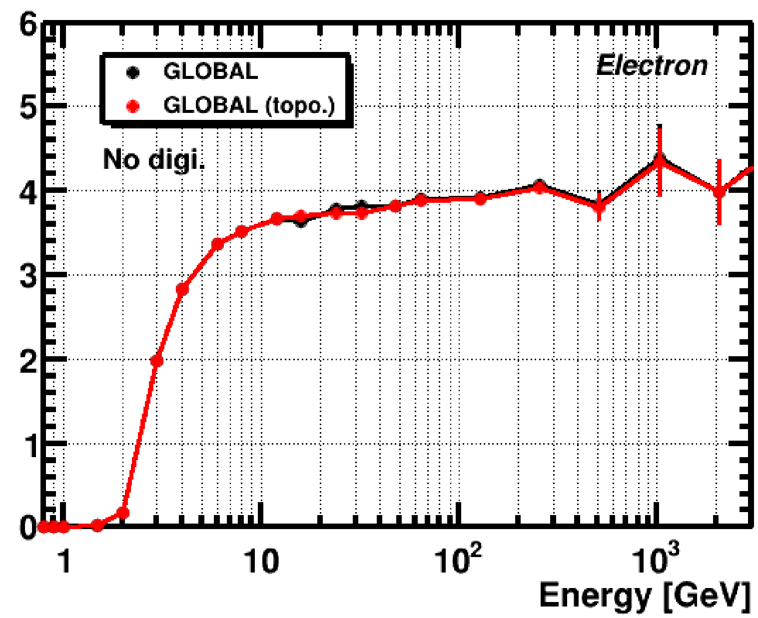
- **no significant degradation** in the **performances** is observed

More Topological Triggers

- Several **topological triggers** based on the **total multiplicity and x,y,z-projection multiplicities** of the CALO PD self-trigger signals have been investigated
  - High Energy based on multiplicity
  - High Energy Electron Trigger (HEET)
  - Low Energy Electron Trigger (LEET)
  - MIP Trigger

- Results show that **topological triggers** can **complement (extend)** the capabilities of those built from the energy deposition in CALO





Implementation in *HerdSoftware*

1. The **implementation of the trigger algorithms in HerdSoftware** is at an advanced stage. The scheme follows the architecture and design agreed with the developers team

2. The implementation has been done at a low level, i.e., implementation of the **dataobjects** containing the information and **algorithms** with the methods to calculate and fill them.

3. Currently, algorithms and dataobjects needed for the computation of the **High Energy**, **Low Energy Gamma** and **Unbiased** triggers have been developed

4. The **roadmap** includes:

- ❑ the steps needed before merging the current development into master (revision, documentation, wiki, tests…) so that the end-users can incorporate this feature to their analyses
- ❑ the addition of other subtriggers, e.g. low electron topological trigger, that requires information from the CaloPD.

Summary

- A progress report on the simulation work to **evaluate and optimize** the **HERD trigger** has been presented
- The studies are performed in close collaboration with the other institutes involved in this task, in particular with IHEP, and coordinated within the **HERD Trigger Working Group**
- Our current understanding is that the **baseline optimized design** should able to cope with the initial requirements in terms of **particle efficiency and rates**, but more detailed evaluations are ongoing
- **New possibilities** have been investigated (low energy extensions, topological triggers) and should be taken into consideration for the **final design**
- The **implementation** in **HerdSoftware** is now in an advanced stage
- Our plan is to keep **up-to-date evaluation** of the trigger performance with the latest modifications of the detector simulation and to **provide support** to new developments, e.g., low energy gamma trigger extension