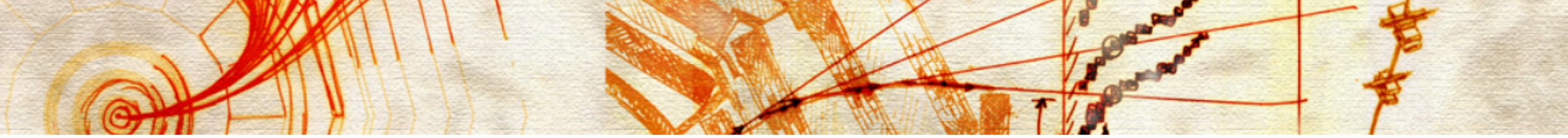


GEFÖRDERT VOM

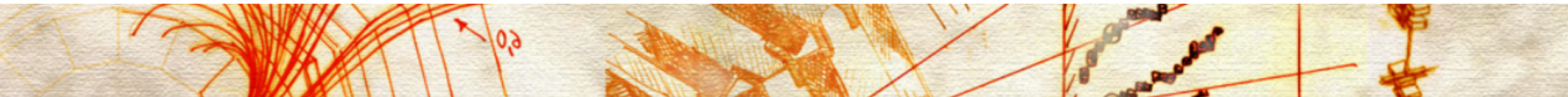
Bundesministerium
für Bildung
und Forschung

TRIGGERING ON ELECTRONS AND PHOTONS IN CMS IN PHASE-2 AND ITS PHYSICS IMPLICATIONS

Swagata Mukherjee, *on behalf of the CMS collaboration*

III. Physikalisches Institut A, RWTH Aachen University, Germany

Phenomenology 2021 Symposium **24-26 May 2021**

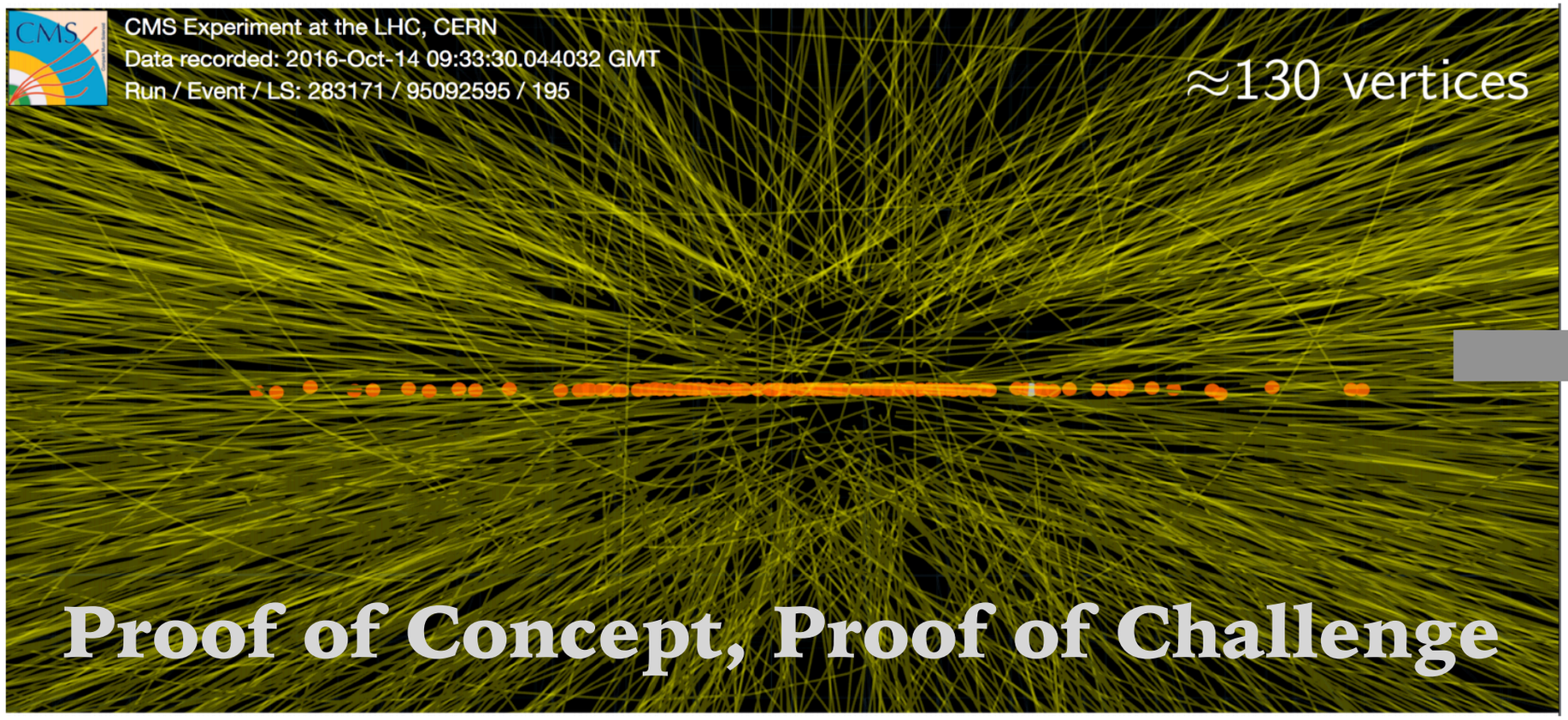


CHALLENGES IN HIGH LUMINOSITY LHC

HL-LHC (aka Phase-2) ~2027 onwards

Much higher pile-up (140-200 in Phase-2 vs ~40 in 2018)

More radiation damage, and increased event complexity



Real-life event with HL-LHC-like pileup from special run in 2016 with individual high intensity bunches

Despite this, **trigger thresholds should stay ~similar to Run-2**, so that physics is unaffected.

Moreover, maintaining thresholds is **NOT** the only motivation for trigger upgrade.

HL-LHC research program opens a door to the unknown, and the goal is to extend the physics reach by **increasing the available phase space.**

Huge challenge for Trigger and Data acquisition system.

CMS TRIGGER SYSTEM PHASE-2 UPGRADE

CMS keeps the 2-stage triggering approach

First stage: Level-1 (L1) trigger, hardware-based

How many events can L1 process per second

Time available to take L1 decision

	Run-2	HL-LHC
Bandwidth	~100 kHz	~750 kHz
Latency	~3.8 us	~12.5 us

tracking@L1, particle-flow@L1

Highly granular readout

Second stage: High level trigger (HLT), software-based

Keep 100:1 rejection factor w.r.t L1

How many events can HLT process per second

How much data can HLT write to disk per second

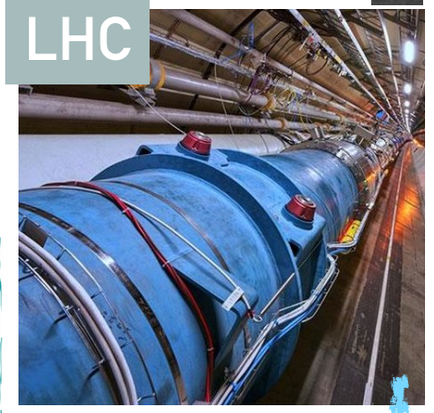
	Run-2 (2018)	HL-LHC
Bandwidth	~1 kHz	~7.5 kHz
Throughput	~2.5 GB/s	61 GB/s

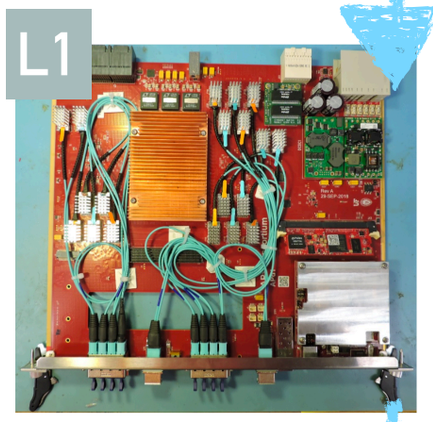
~300 ms average time to take HLT decision

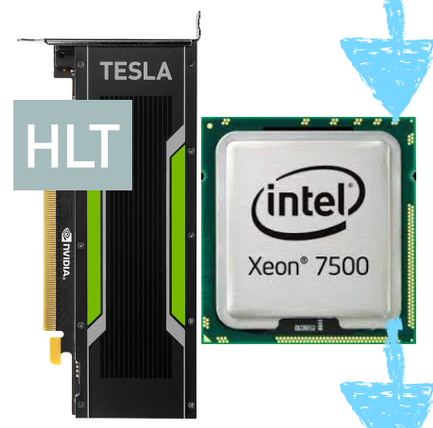
Heterogeneous (CPU+GPU) HLT farm

Readout detectors at full granularity.

Exploit multi-threading





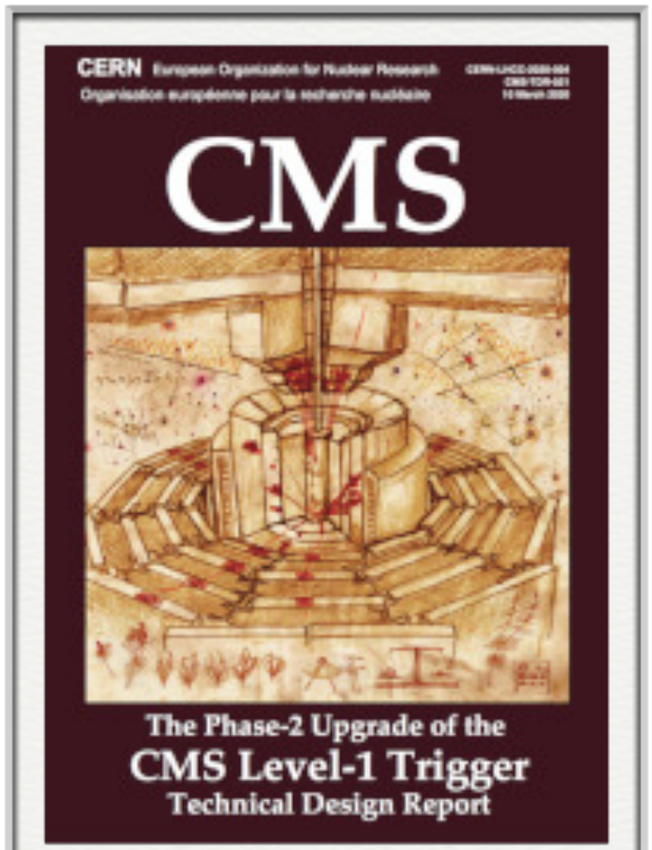


IT'S TDR TIME !

- Phase-2 triggering & reconstruction is very much a **work in progress**.
  - Expect many more improvements in coming years.
  - This talk is a **snapshot of where we are now**.
- CMS **L1 trigger technical design report (L1 TDR)** was written last year. Link to L1 TDR.
  - Improvements in electron and photon L1 triggers in phase-2 will be discussed in this talk.
- CMS collaboration is now writing the **HLT TDR.**
  - Expected to be public ~September this year.
  - A preview of electron & photon phase-2 HLT will be shown in this talk. Link to CMS DP-2021/009.

Huge amount of work being done in trigger side (L1+HLT) to ensure Phase-2 physics goals are met.

L1 TDR



CMS DETECTOR UPGRADE ASPECTS RELEVANT TO e/γ TRIGGERS

CMS detector upgrade in HL-LHC is a critical necessity, ensuring:

Radiation hardness

Mitigation of physics impact of high pileup

New Tracker

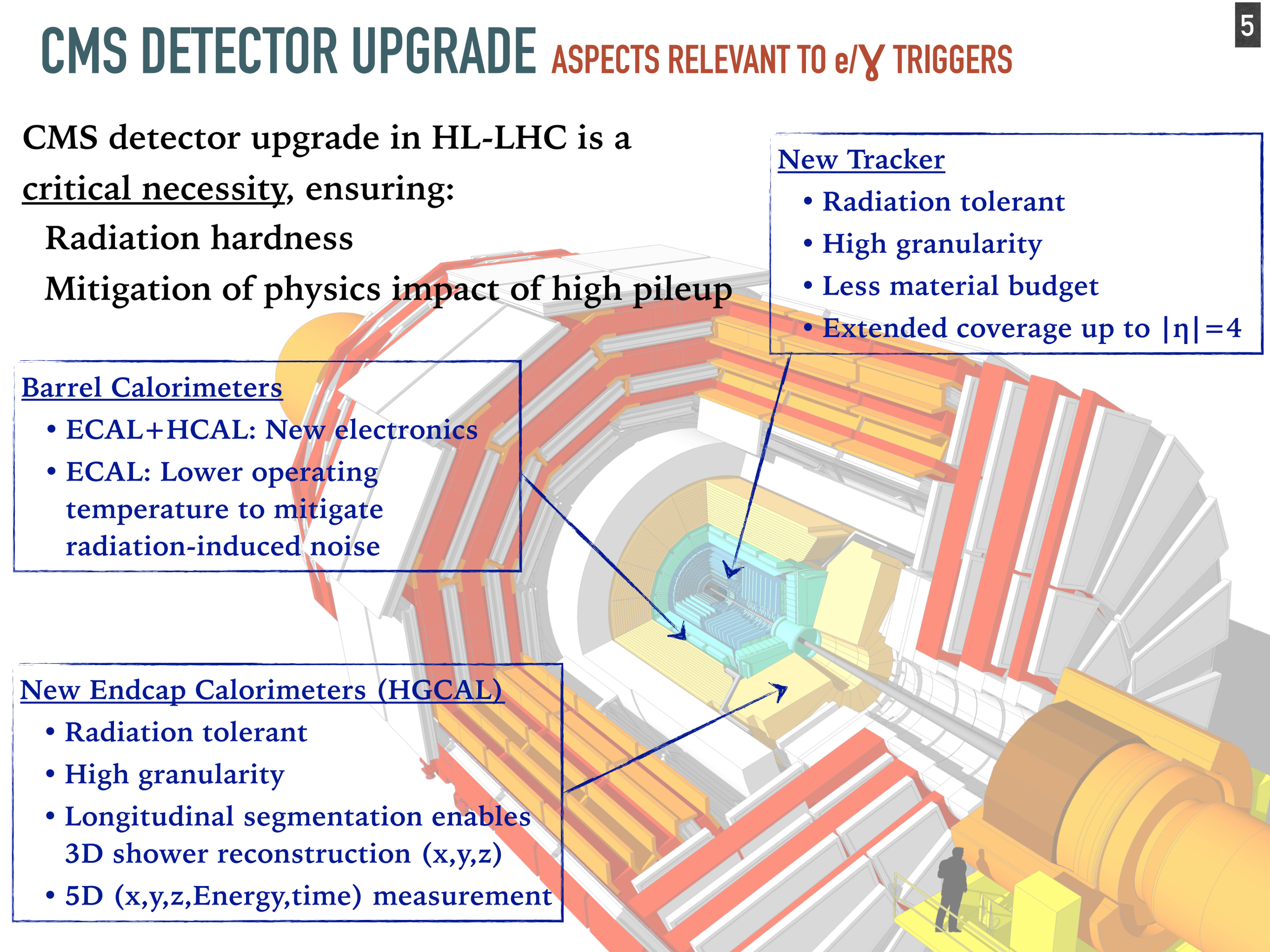
- Radiation tolerant
- High granularity
- Less material budget
- Extended coverage up to $|\eta|=4$

Barrel Calorimeters

- ECAL+HCAL: New electronics
- ECAL: Lower operating temperature to mitigate radiation-induced noise

New Endcap Calorimeters (HGCAL)

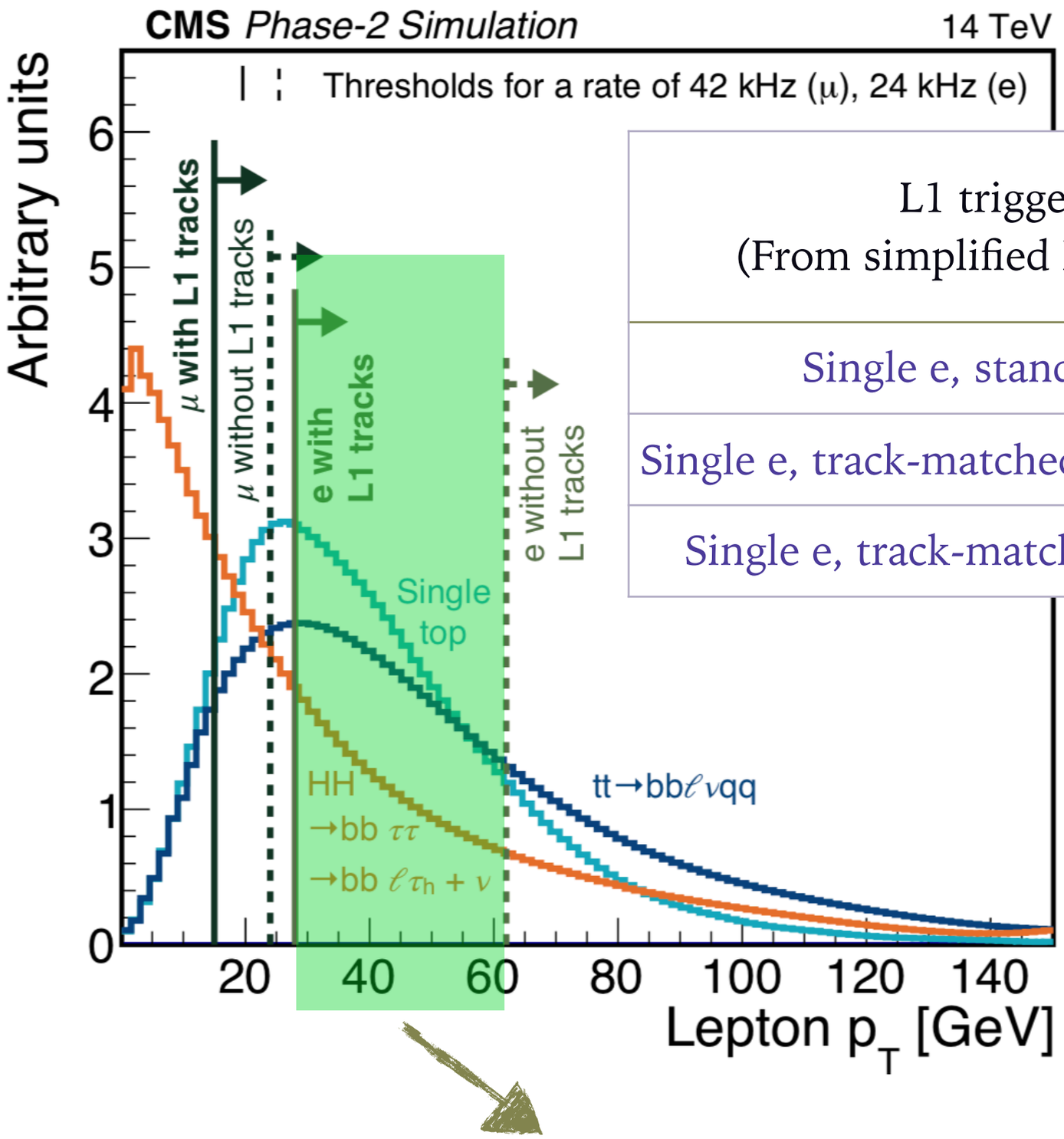
- Radiation tolerant
- High granularity
- Longitudinal segmentation enables 3D shower reconstruction (x,y,z)
- 5D (x,y,z,Energy,time) measurement



L1 TRIGGER ELECTRON & PHOTON

- e/ɣ performance @L1 in barrel will benefit from **crystal-level granularity.**
- e/ɣ identification @L1 is cut-based in barrel, BDT-based in HGCAL.
- **Tracking@L1** is a powerful handle against pile-up.
- Exploit complementarity of different object flavour
  - **Standalone e/ɣ objects:** robust L1 triggers based on independent sub-detectors (ECAL/HGCAL)
  - **Track-matched electrons**: Standalone objects with at least one matched track are promoted to track-matched electron candidates.
    - Significantly **reduces trigger rate, enabling lower trigger threshold**.
- L1 tracks also used to define **track isolation @L1** for e/ɣ objects.

ELECTRON L1 TRIGGER IMPROVEMENTS PHYSICS IMPACT



[CMS-TDR-021]

L1 trigger (From simplified L1 menu)	Threshold [GeV]	Efficiency at plateau	Rate in kHz
Single e, standalone	51	99%	25
Single e, track-matched, non-isolated	36	93%	24
Single e, track-matched, isolated	28	93%	28

Lower threshold achievable at a cost of efficiency

At HLT, we **use multiple L1 triggers in "OR"** to ensure best possible acceptance and efficiency

Acceptance gain due to tracking@L1

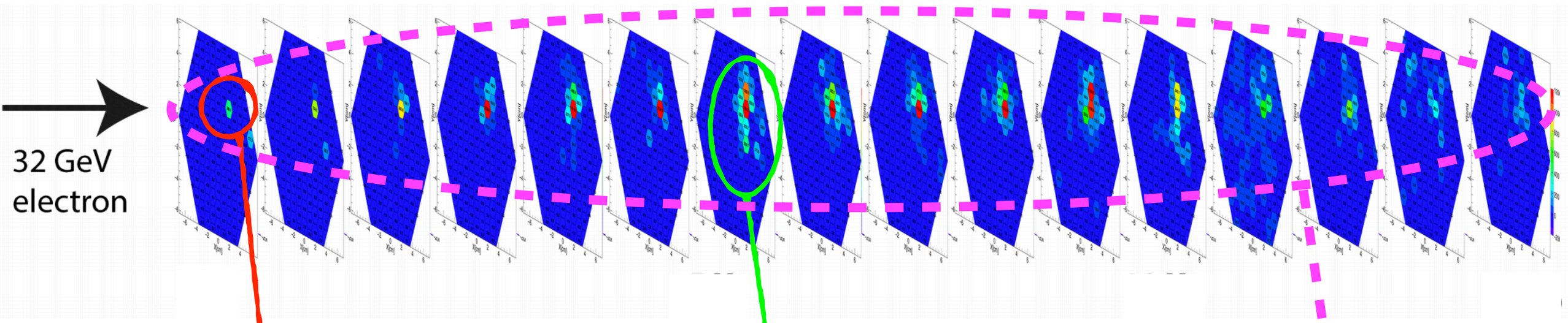
Similar for photon L1 triggers (in back-up)

e/γ RECONSTRUCTION @HLT

NOVEL CLUSTERING ALGORITHMS IN HGCAL

- Reconstruction/identification in barrel similar to Run-2.
  - Retuning/optimisations made to cope with pile-up.
- New endcap calorimeter (HGCAL) → **New reconstruction algorithms, new identification variables.**

CMS-TDR-019



RecHit (Reconstructed Hit)
Energy deposit in a single sensor of HGCAL

2D cluster
Groups of RecHits in the same layer of HGCAL

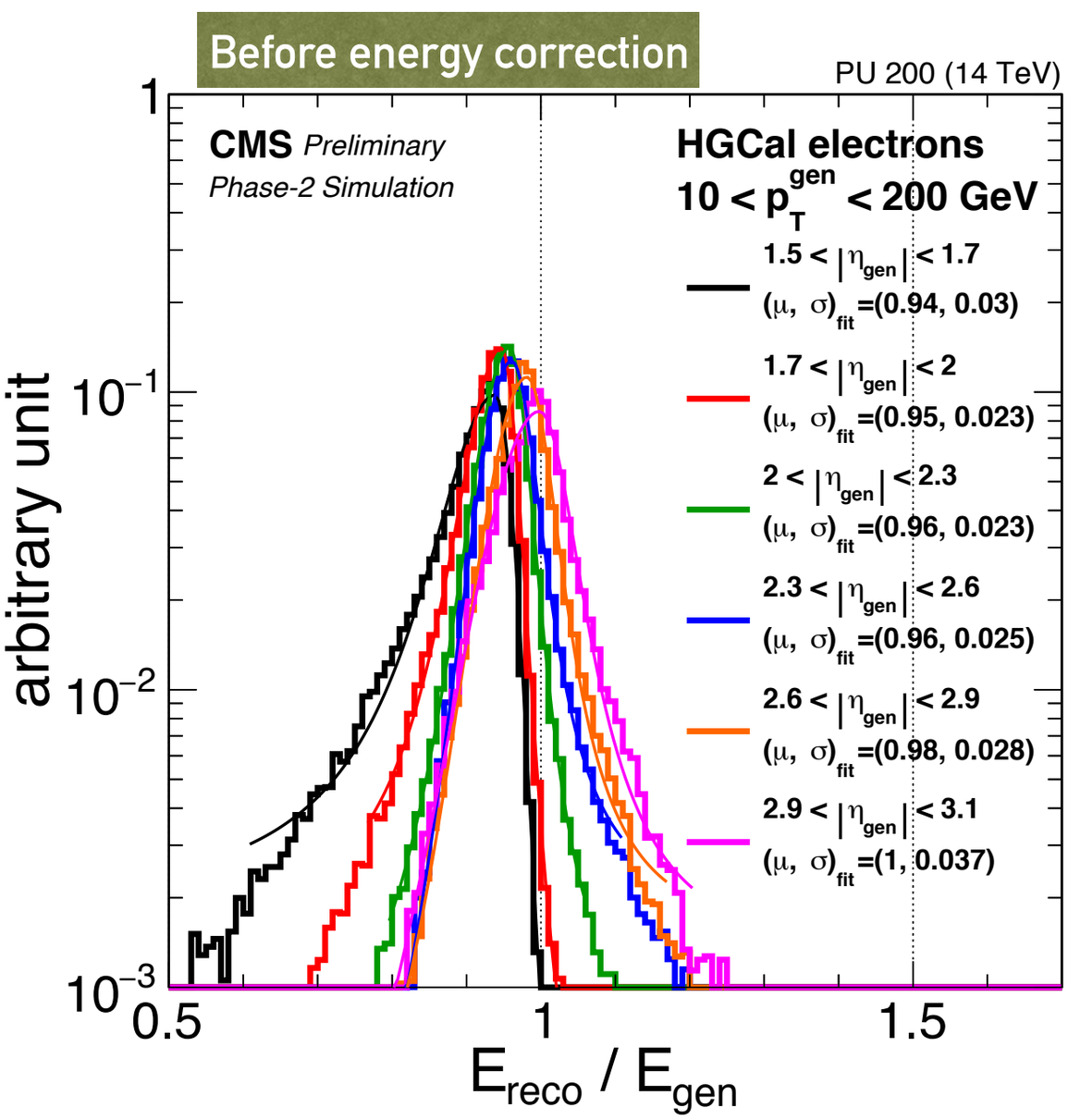
3D cluster
Linking of 2D clusters to form full 3D shower of e/γ

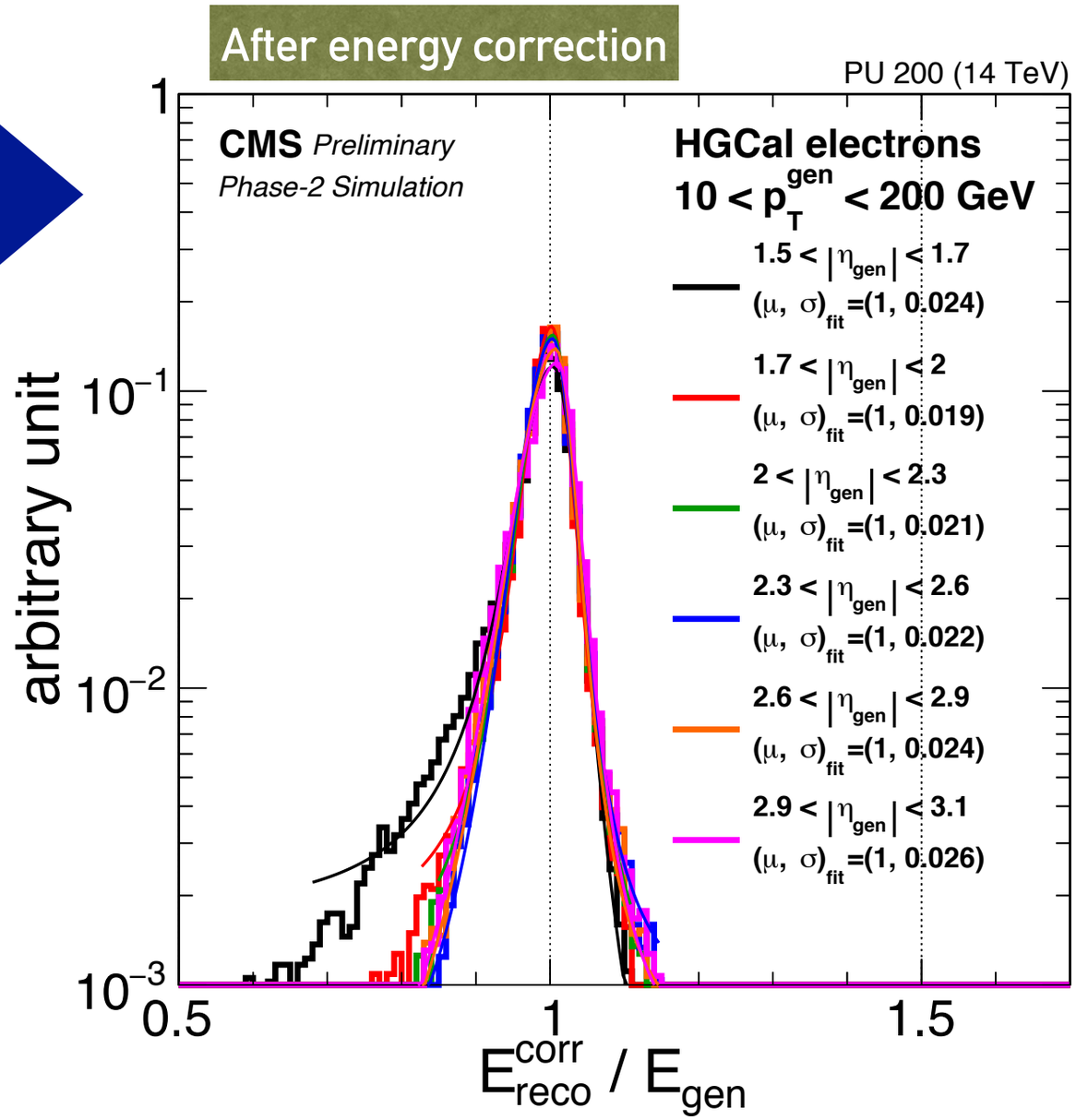
After that
- Clustering of 3D clusters: superclustering
- Electron track reconstruction

ELECTRON ENERGY RESPONSE AND RESOLUTION IN HGCAL

Multivariate energy regression, trained using variables related to energy and shape of electron energy deposit in HGCAL, and variables related to pile-up.

[CMS DP-2021/009]



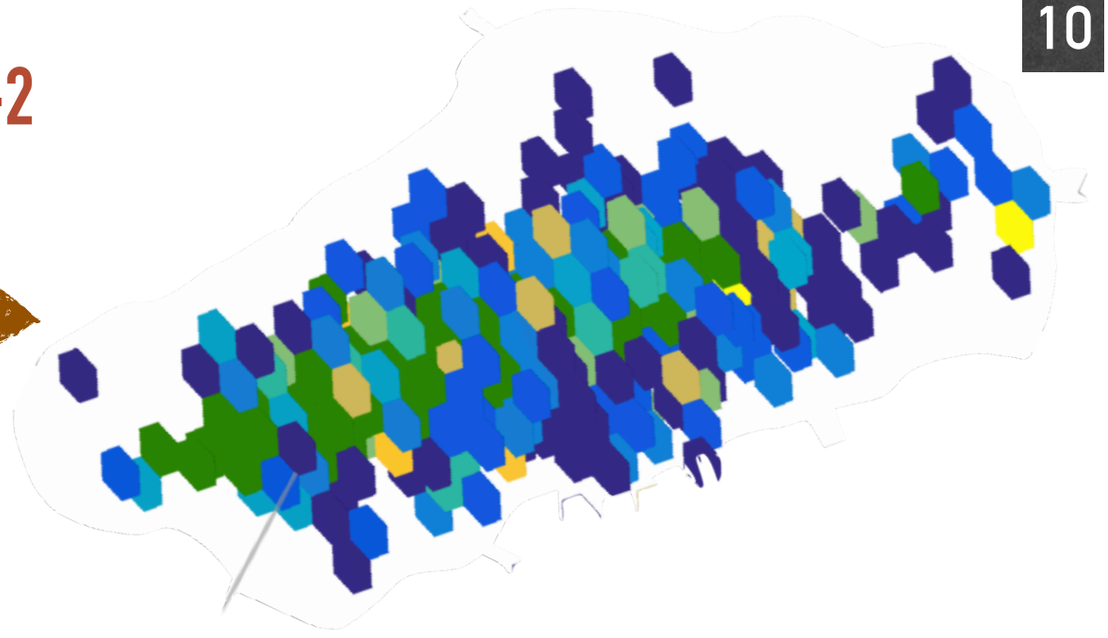


Satisfactory energy response and resolution after regression-based energy correction

Response & resolution stable across the whole |η| range of HGCAL.

RECONSTRUCTION IMPROVEMENTS IN PHASE-2

Once we have reconstructed energy deposit in HGCAL



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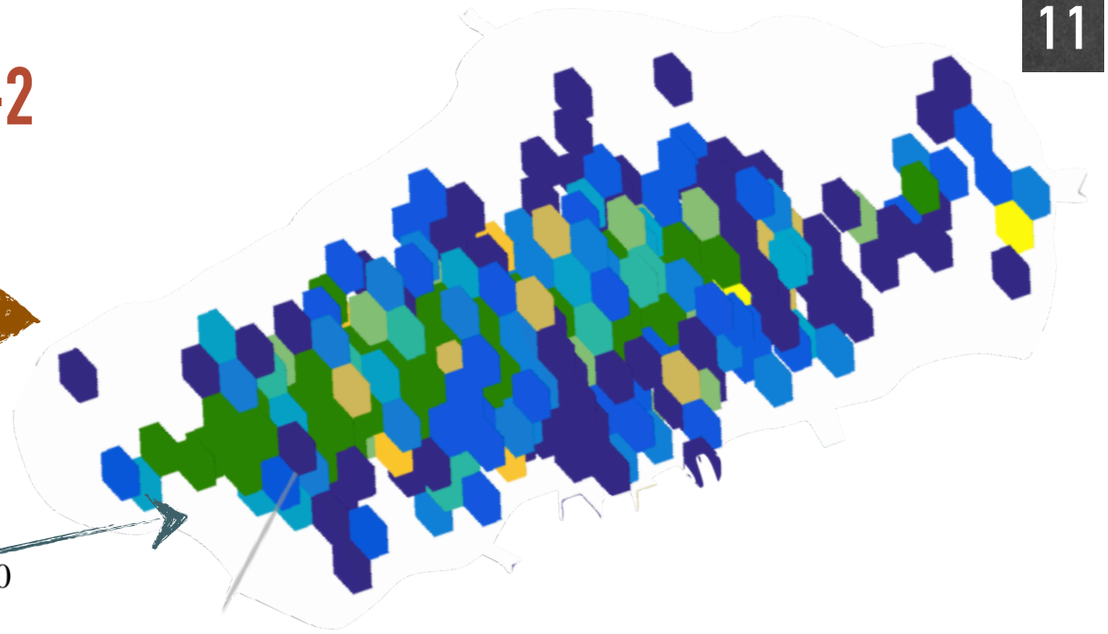
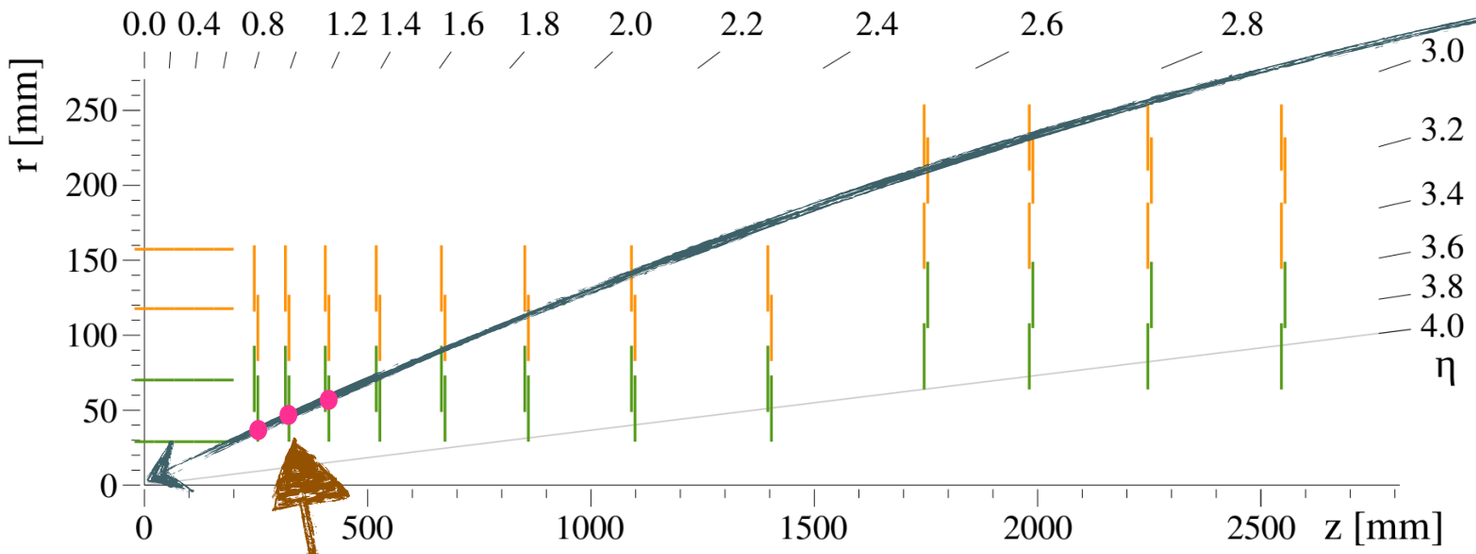




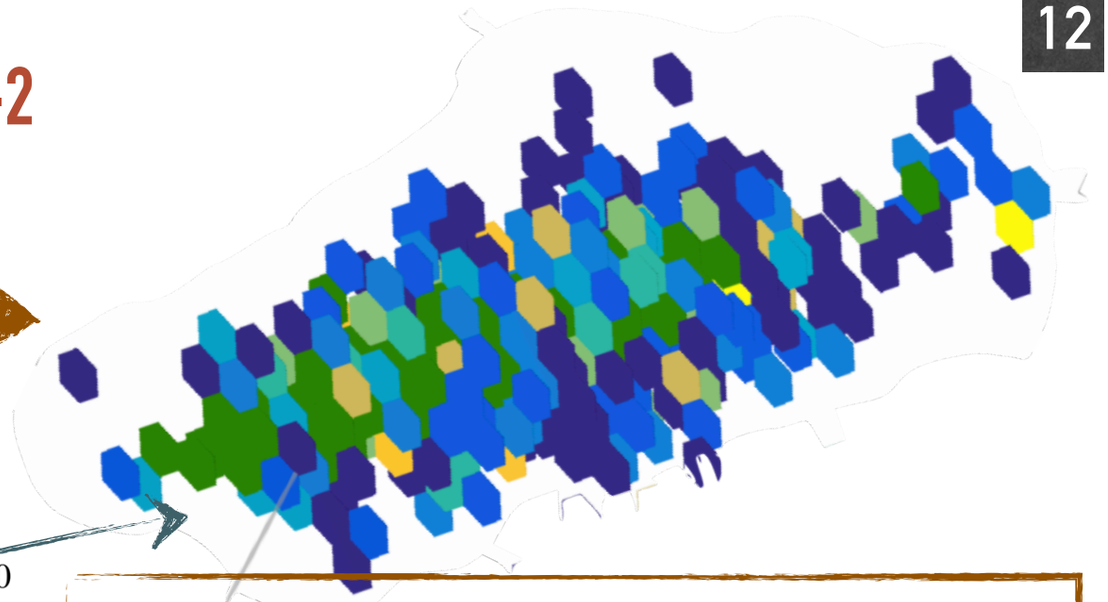
Next step is to find compatible hits in the inner tracker

Very important step for electron HLT

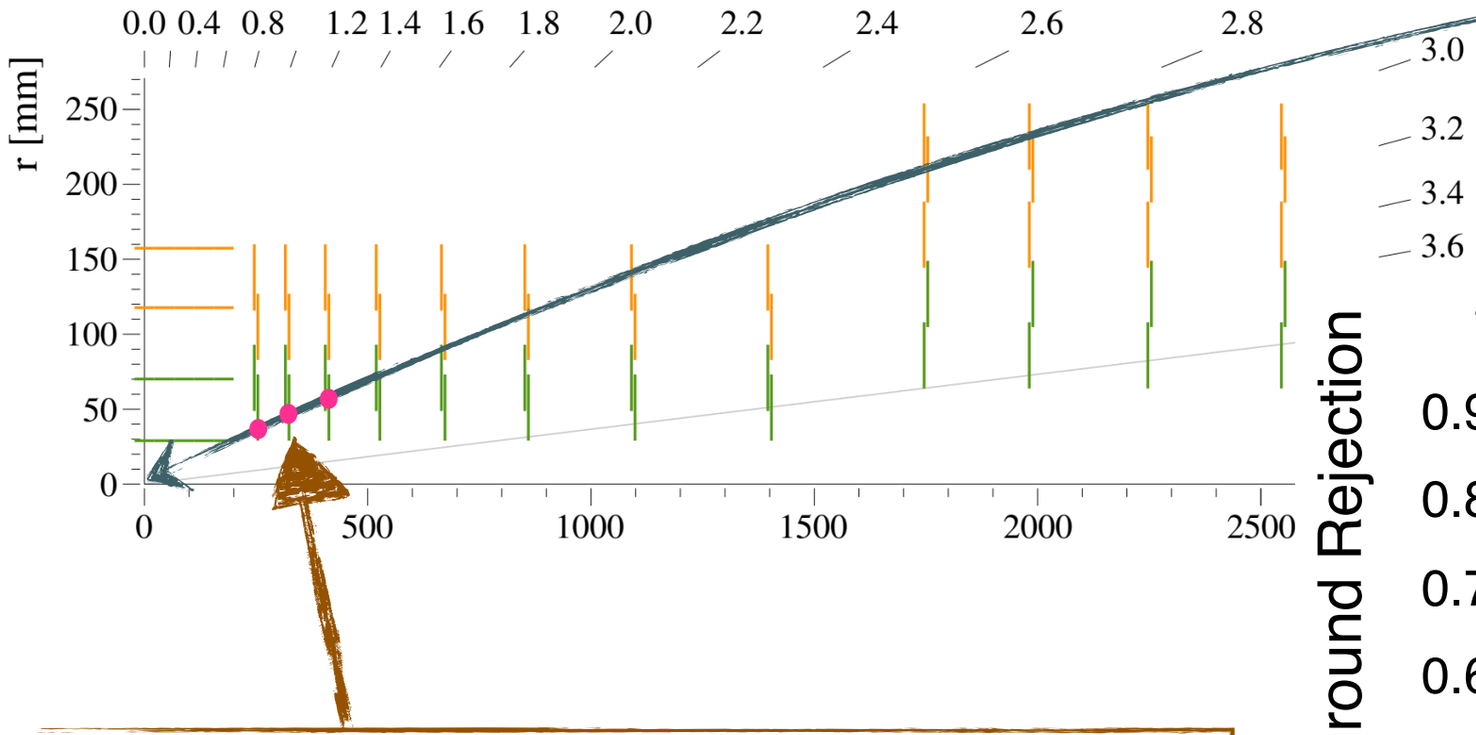
Known as '**pixel matching**'.

RECONSTRUCTION IMPROVEMENTS IN PHASE-2

Once we have reconstructed energy deposit in HGCAL



Retuning led to sizeable improvement in performance



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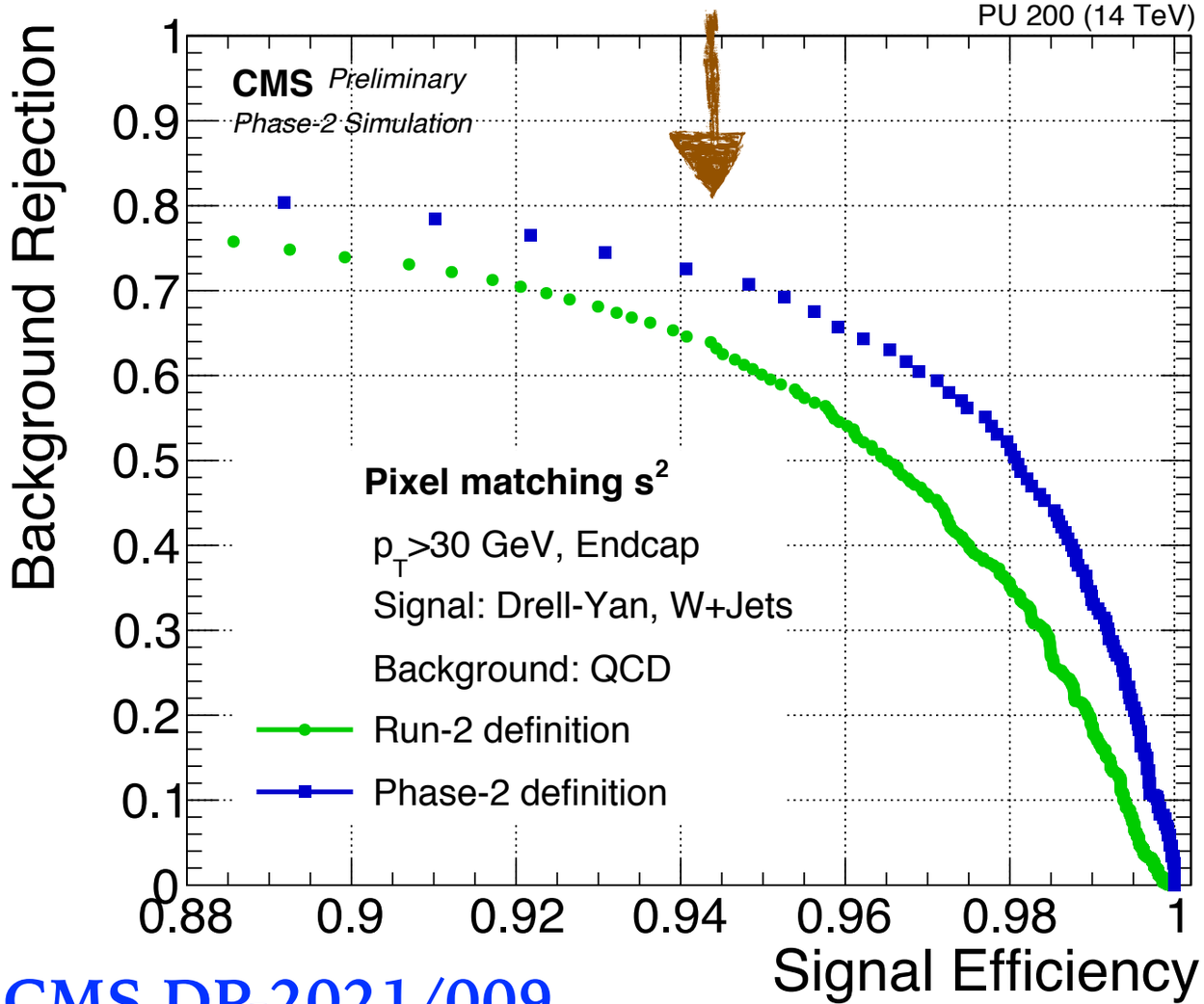


CMS DP-2021/009

ELECTRON & PHOTON HLT PATHS

A simplified HLT menu is made for the HLT TDR.

Just a demonstrator. We can and will have a lot more for actual Phase-2 HLT menu.

Achieved phase-2 HLT thresholds similar to Run-2

Single isolated electron HLT

Threshold=32 GeV.

Rate ~1 kHz at PU=200

Efficiency ~80% at PU=200

Generic HLT, serves many analyses, eg: **WɣɣcrossͲsection measurement, Measurements of the W boson rapidity, helicity, double-differential cross sections, charge asymmetry.**

Double isolated photon HLT

Designed to efficiently capture **photon and electron** both. No electron veto in photon HLT.

Threshold=30/23 GeV.

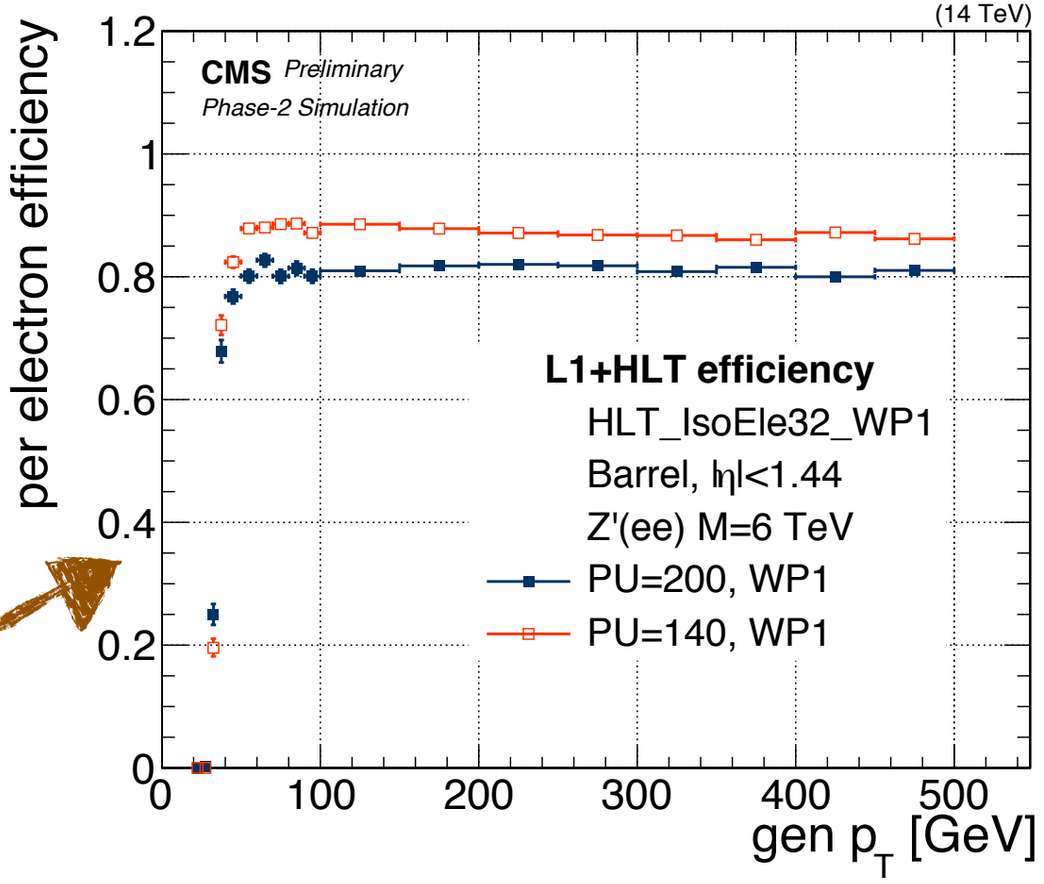
Rate ~180 Hz at PU=200.

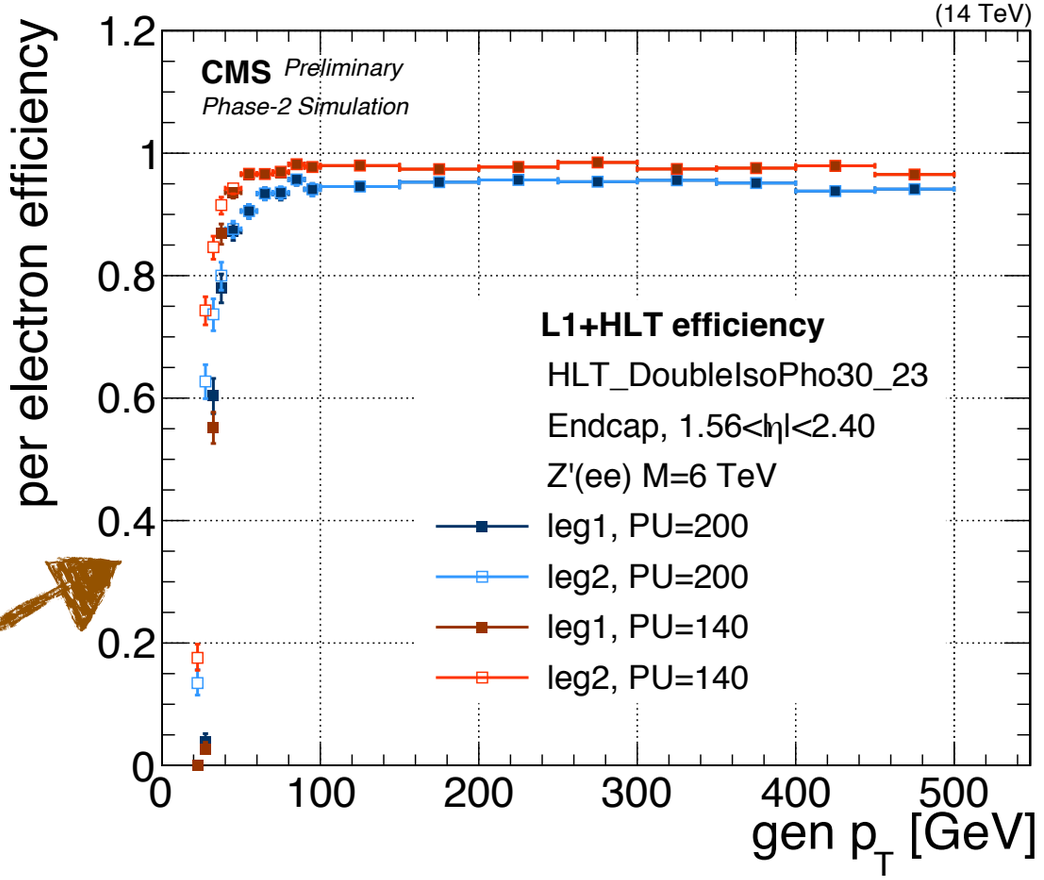
Object-level efficiency ~95% at PU=200.

Event-level efficiency ~85% at PU=200 for HH→bbɣɣ.

HLT found to be well-suited for **HH→bbɣɣ**.

[CMS DP-2021/009]





HETEROGENEOUS HLT FARM

CPU evolution is not able to cope with the increasing demand of performance.

Example: HGCAL has **unprecedented number of read-out channels**.

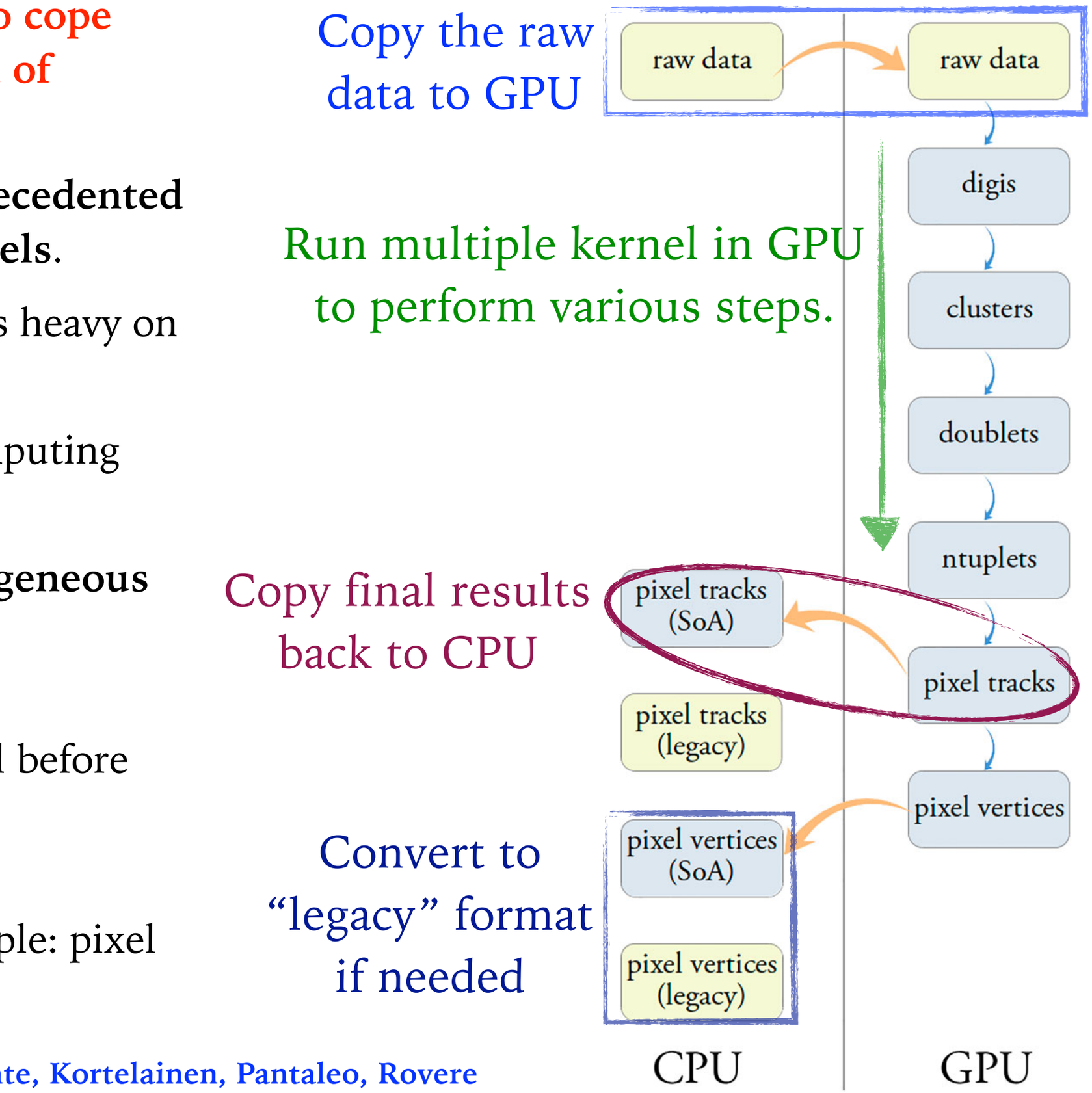
Reconstruction in HGCAL is heavy on computing resources.

Alternative approach in computing needed.

CPU & GPU based heterogeneous HLT farm.

CMS would like to exercise a Heterogeneous HLT farm well before HL-LHC

For Run-3, run some steps of reconstruction in GPU. Example: pixel tracks and pixel vertices



Reference: this paper by Bocci, Innocente, Kortelainen, Pantaleo, Rovere

STAY TUNED !

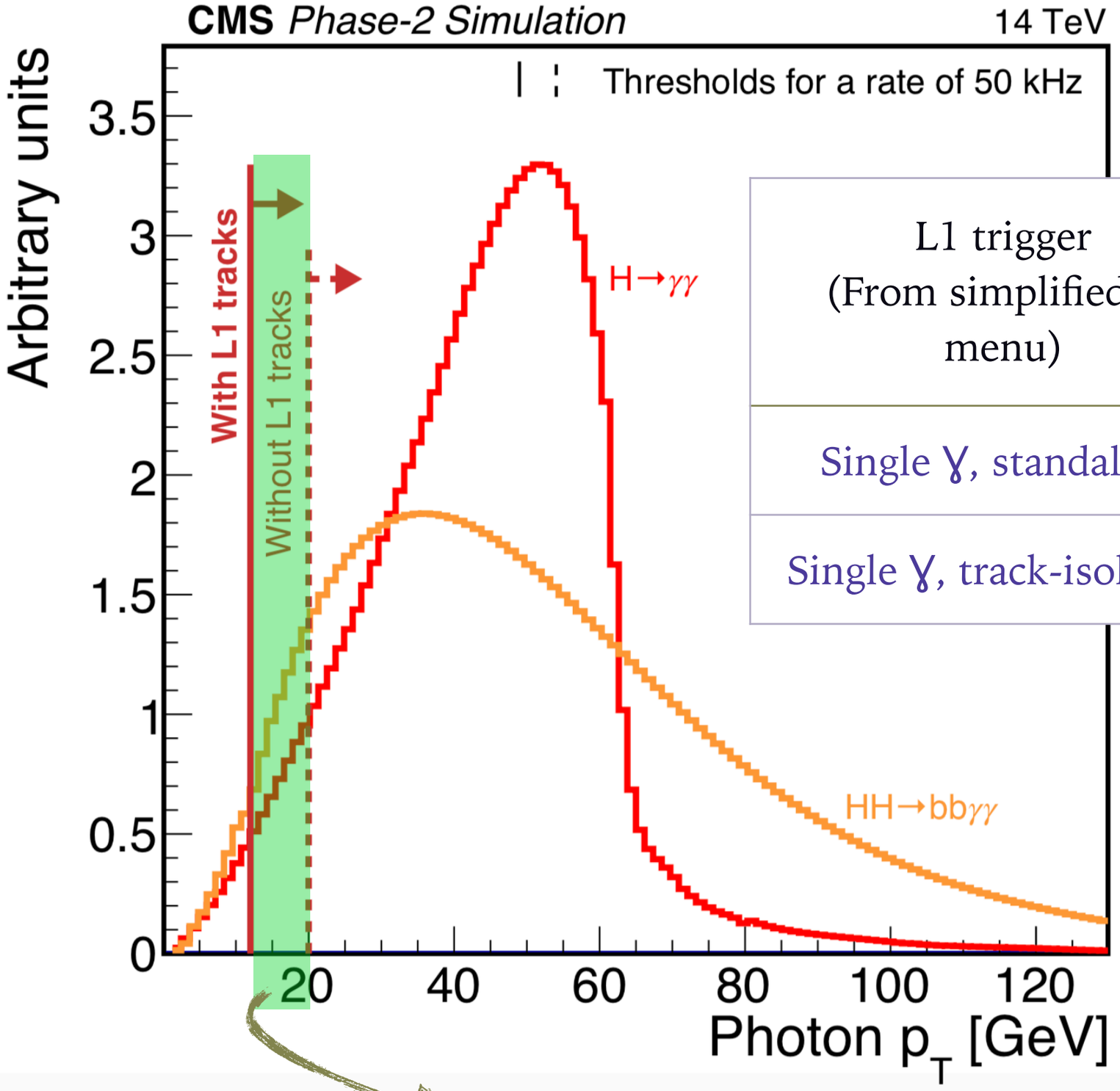
Triggering on electrons and photons in HL-LHC looks promising already, despite the challenges.

Presented a snapshot.

Expect more improvements @L1 and HLT in coming years.

EXTRA SLIDES

PHOTON L1 TRIGGER IMPROVEMENTS PHYSICS IMPACT



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[CMS-TDR-021]

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Single ɣ, standalone	51	99%	25
Single ɣ, track-isolation	36	97%	43

Lower threshold at a cost of efficiency

Use “OR” of multiple L1 triggers at HLT to ensure best possible acceptance and efficiency