# Préparation du déclenchement des événements à 4 leptons avec le détecteur CMS pour le Run II du LHC.

**Simon Regnard**

**Laboratoire Leprince-Ringuet – École polytechnique – Palaiseau**

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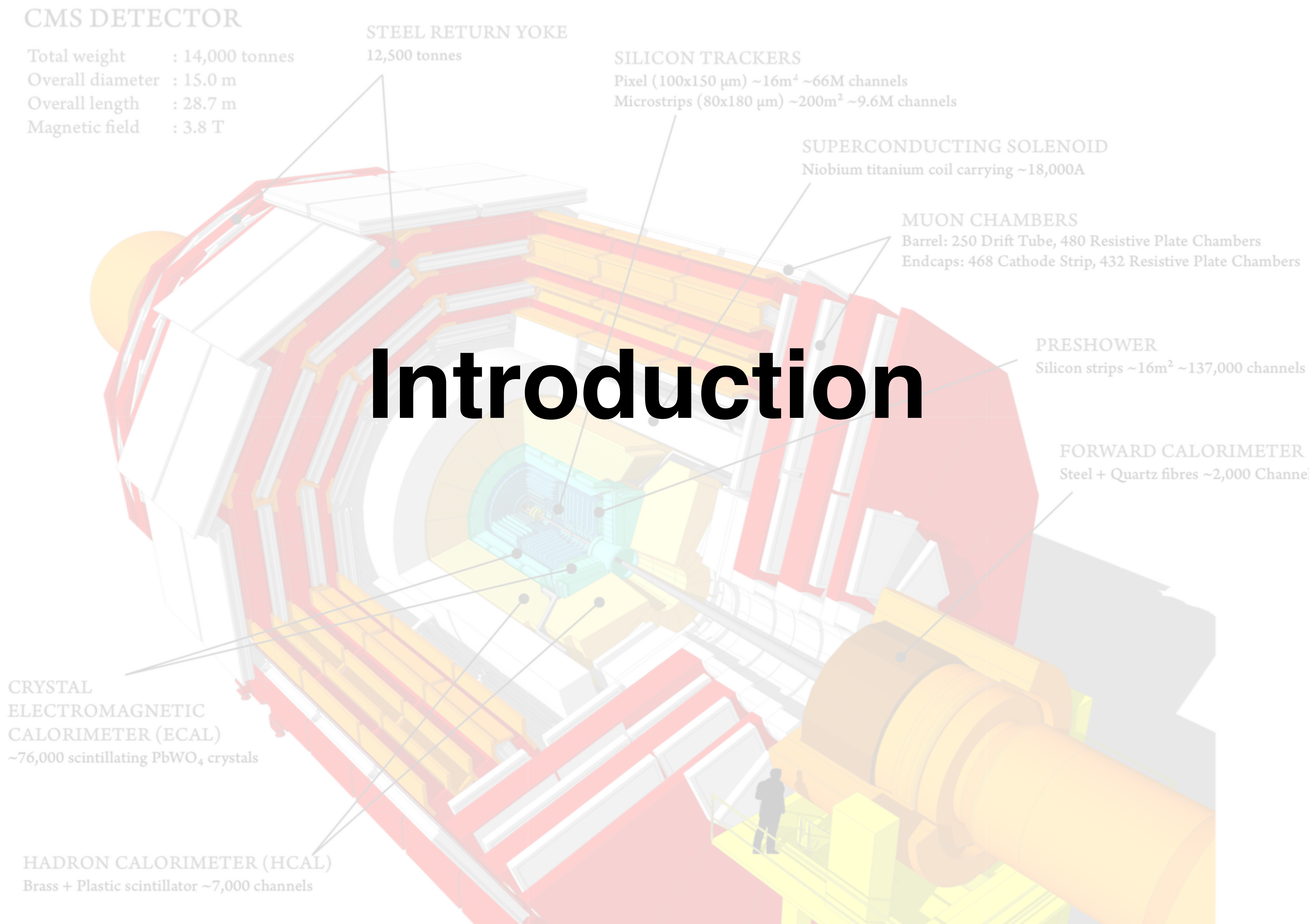
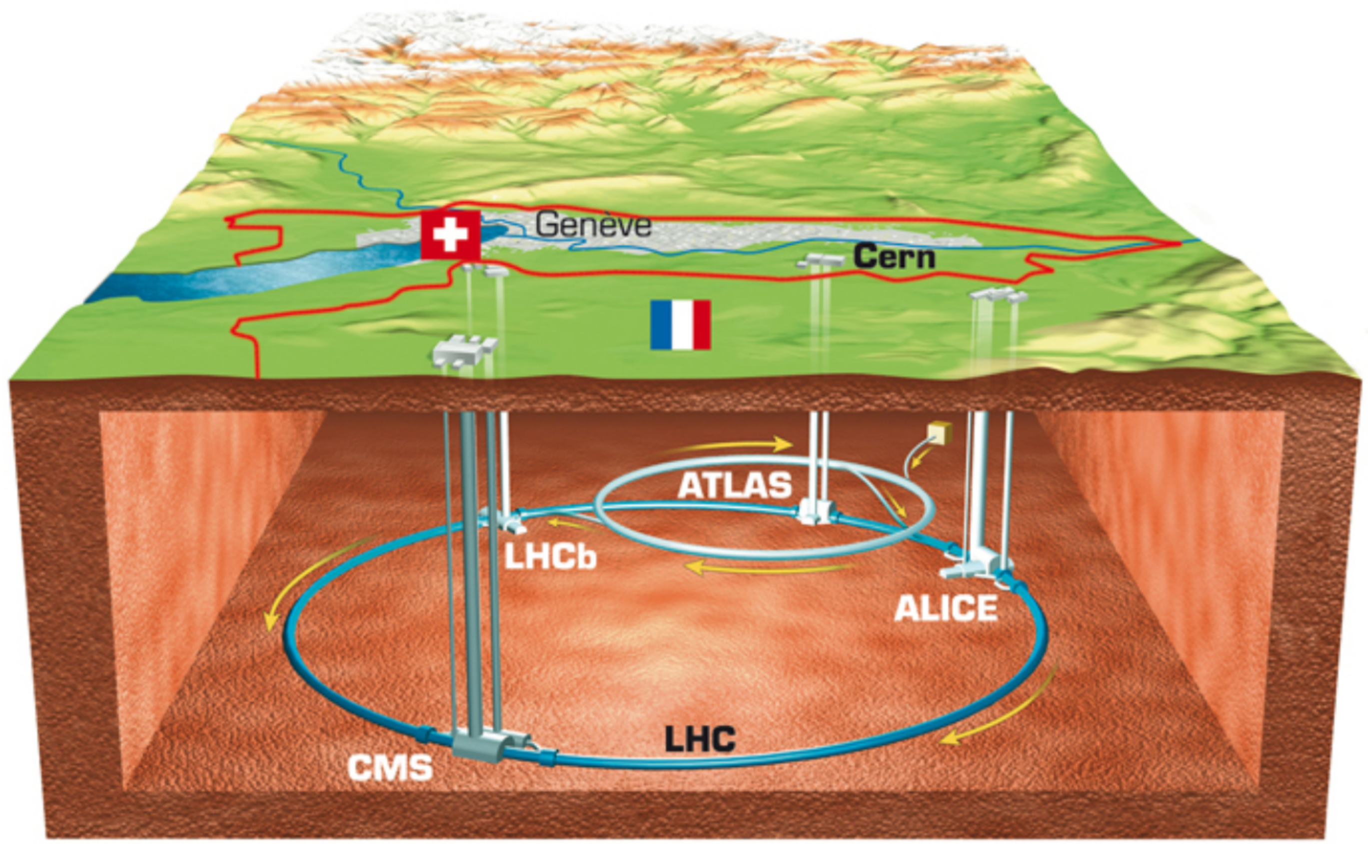
# Outline

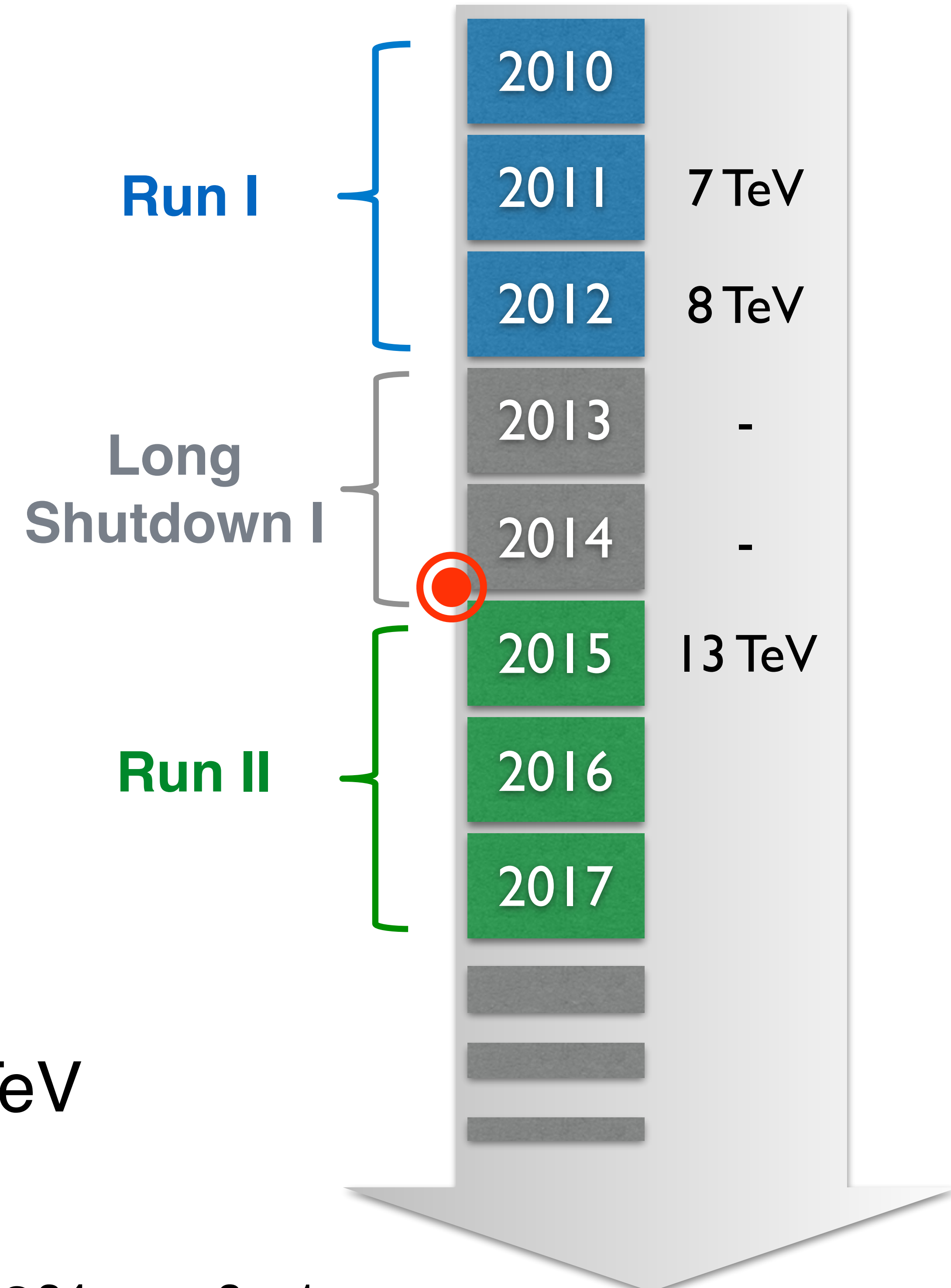
- Introduction
- Electrons in CMS
- The CMS trigger
- Improving the electron HLT
- Triggering H→4l events

# Introduction



# Restarting the Large Hadron Collider

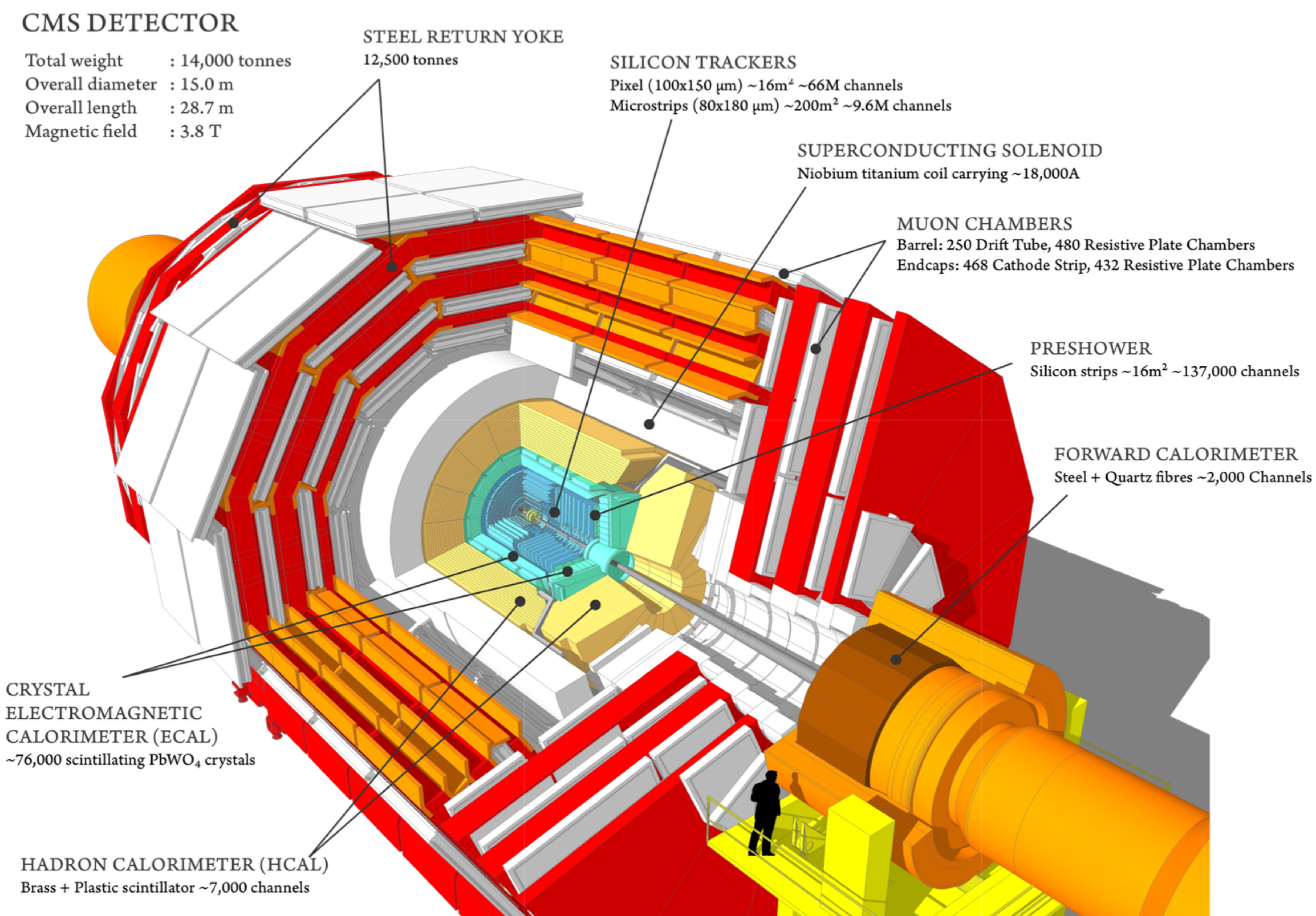



After a 2-year shutdown, proton beams will circle the LHC again as of March 2015.

- center-of-mass energy: 8 TeV → 13 TeV
- bunch spacing: 50 ns → 25 ns
- instantaneous luminosity: up to $1.5\times10^{34}$ $cm^{-2}s^{-1}$

# The CMS detector

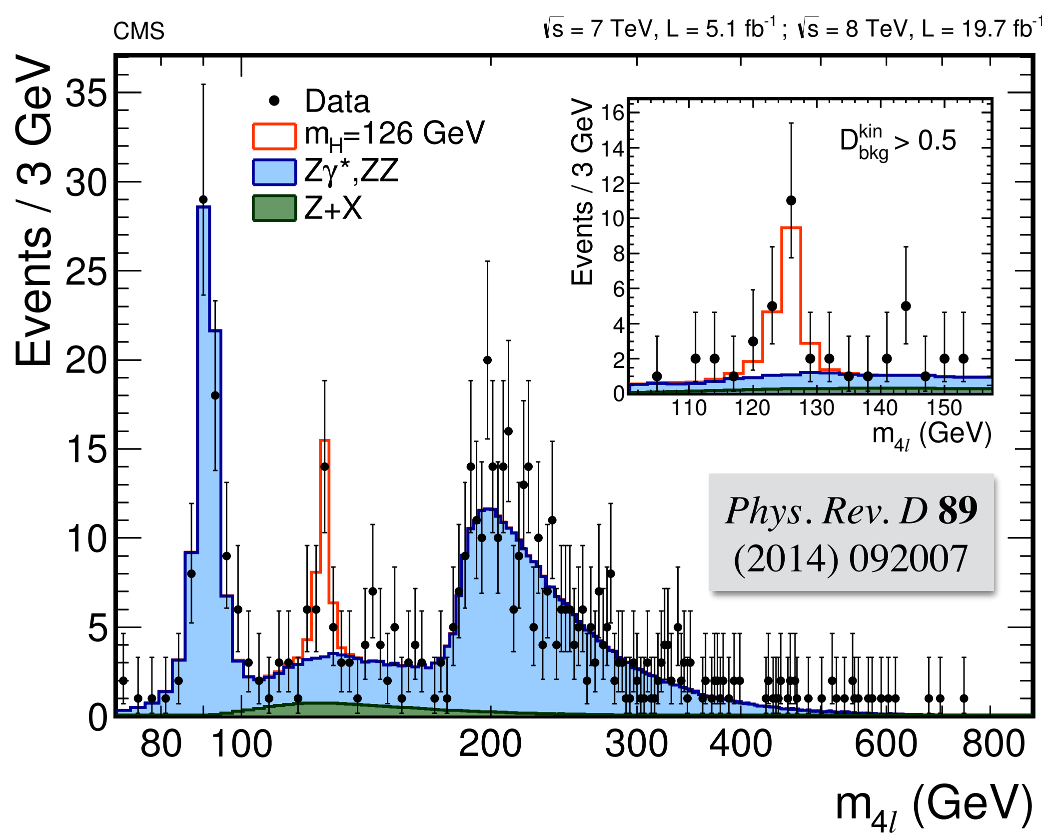


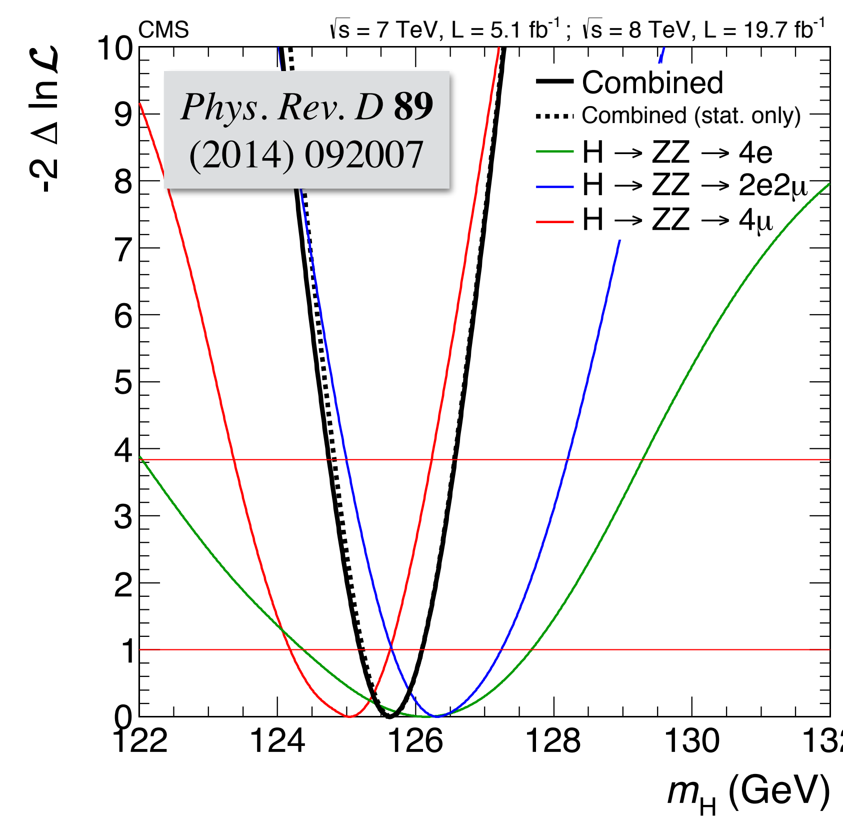
# H→ZZ*→4l, a golden channel

H→ZZ*→4l (l=e,μ) : a channel with low B.R. but high S/B, high resolution and full reconstruction of the Higgs decay products.

➔ Provided a wide set of results based on Run I data:

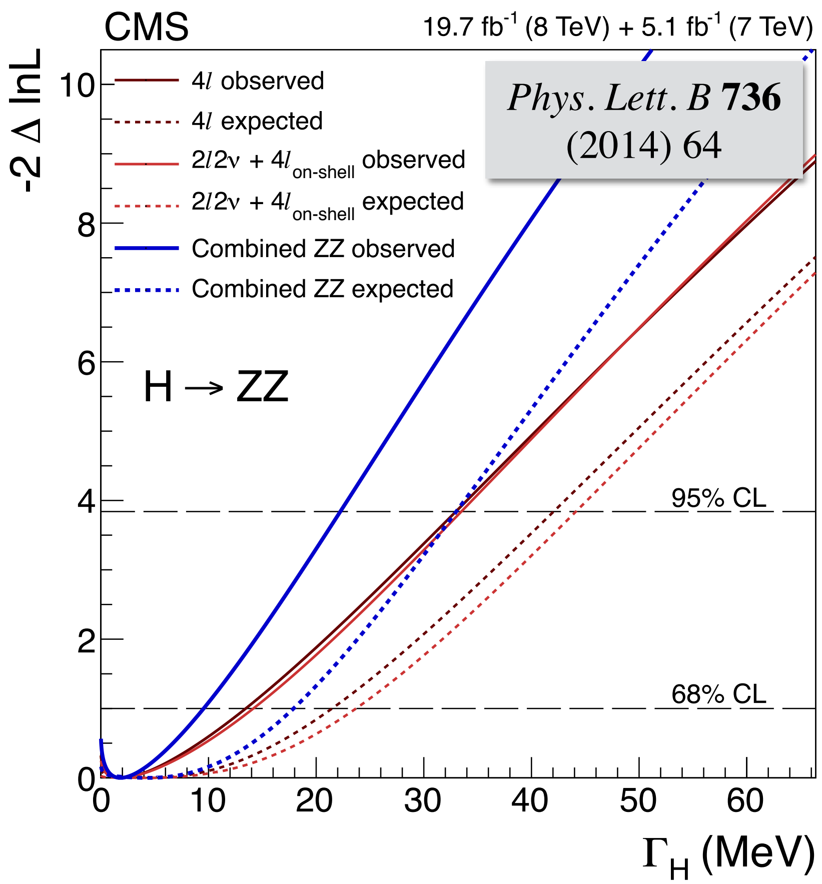
- Key contribution to the Higgs boson discovery
  - with the full Run I dataset: 6.8σ (6.7σ) obs. (exp.) local significance
- High resolution for the mass measurement
  - standalone H→4l result: $m_H = 125.6 \pm 0.4$ (stat.) $\pm 0.2$ (syst.) GeV

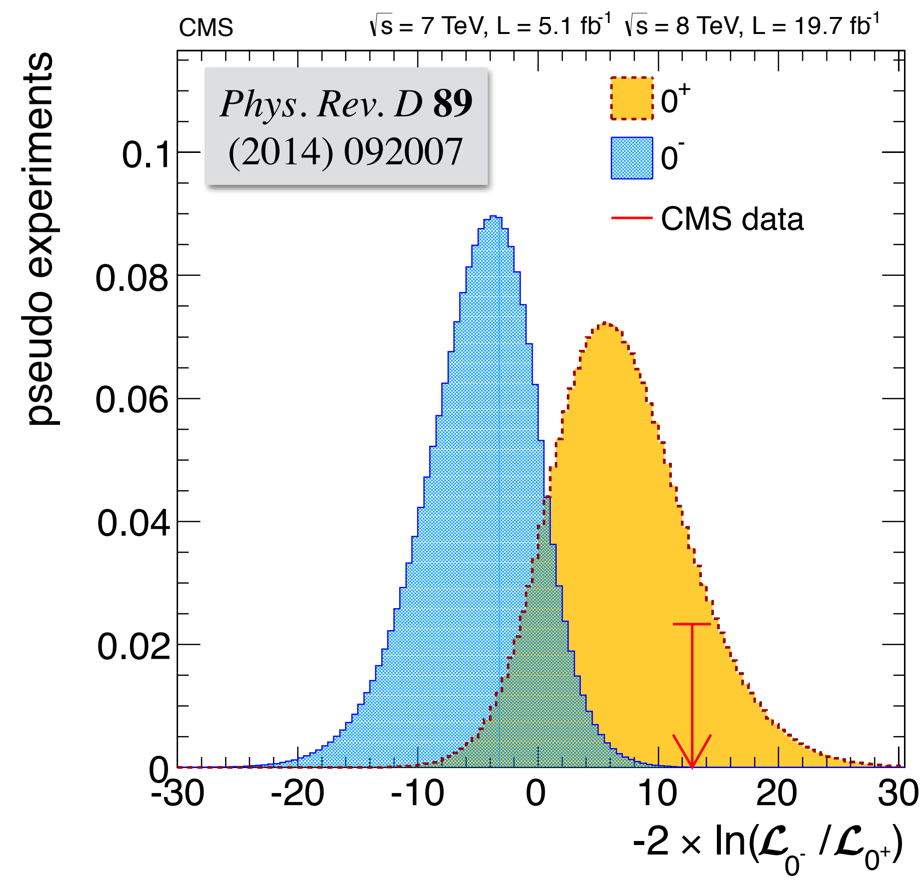


# H→ZZ*→4l, a golden channel (2)

- Measurement of the Higgs width from off-shell production
- Hypothesis tests of the spin-parity of the new boson
  - e.g. pseudoscalar boson hypothesis excluded at a 99.9% c.l.



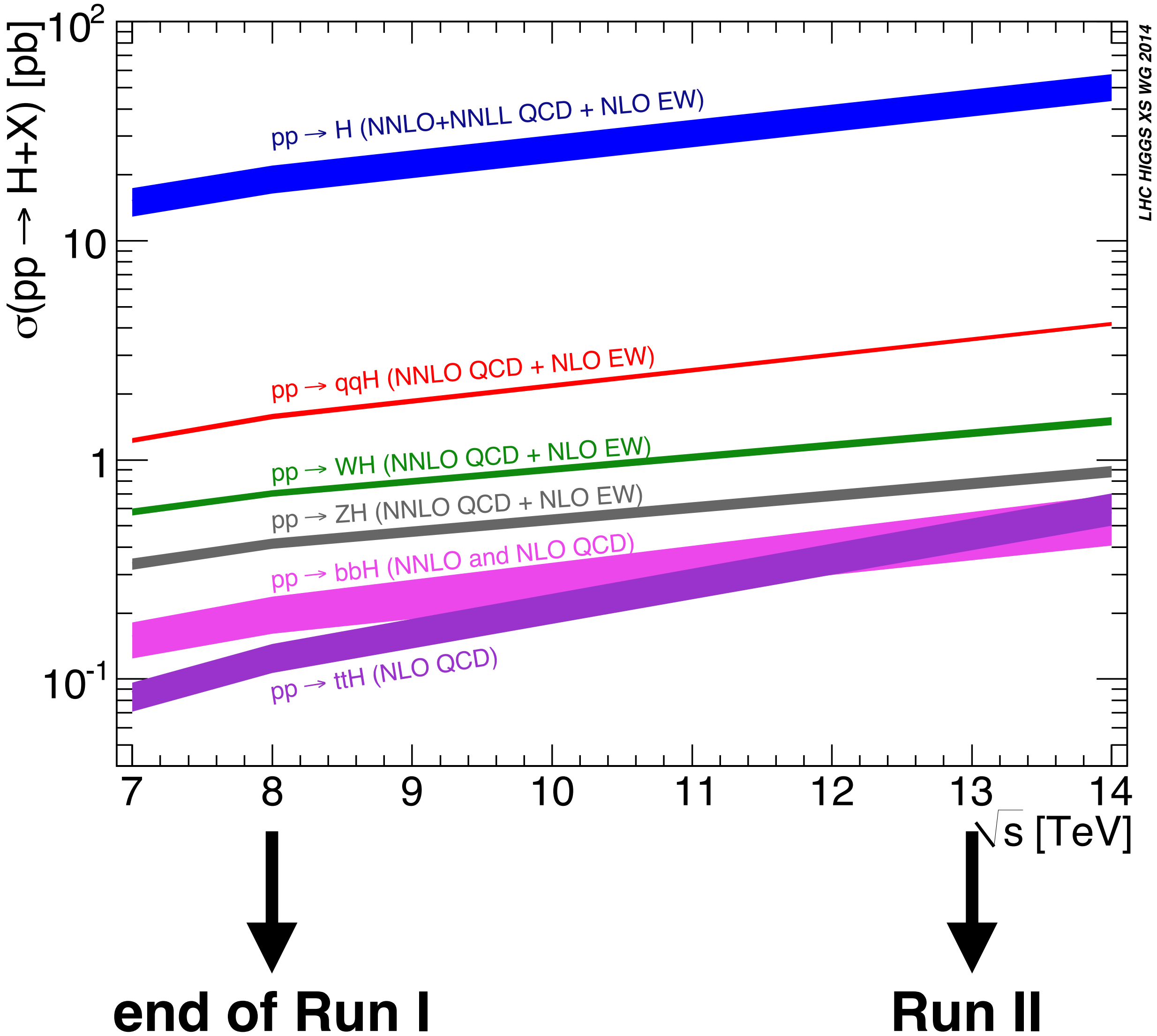

- Constraints on anomalous HZZ couplings

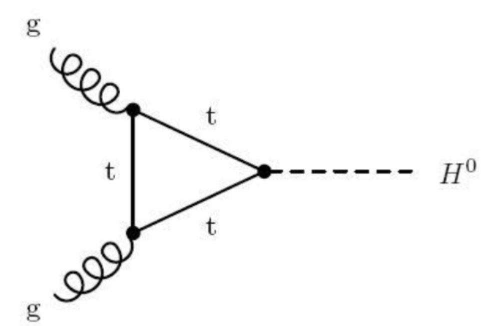
➔ Major role in showing that the new boson is very consistent with a standard model Higgs boson.

# H→ZZ*→4l in Run II

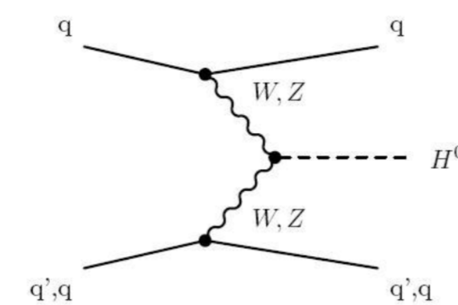
More challenges to come as of 2015:

- constrain couplings further, to look for deviations from SM predictions,
- unravel new **production modes** of the boson, besides gluon fusion.

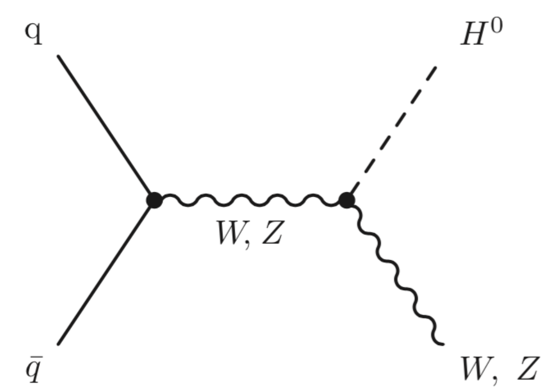


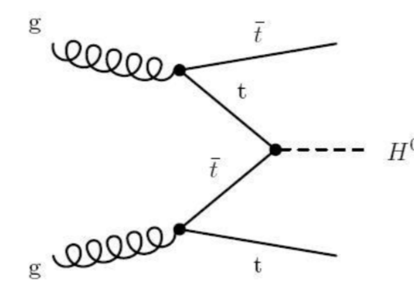

**gluon fusion**




**vector boson fusion**



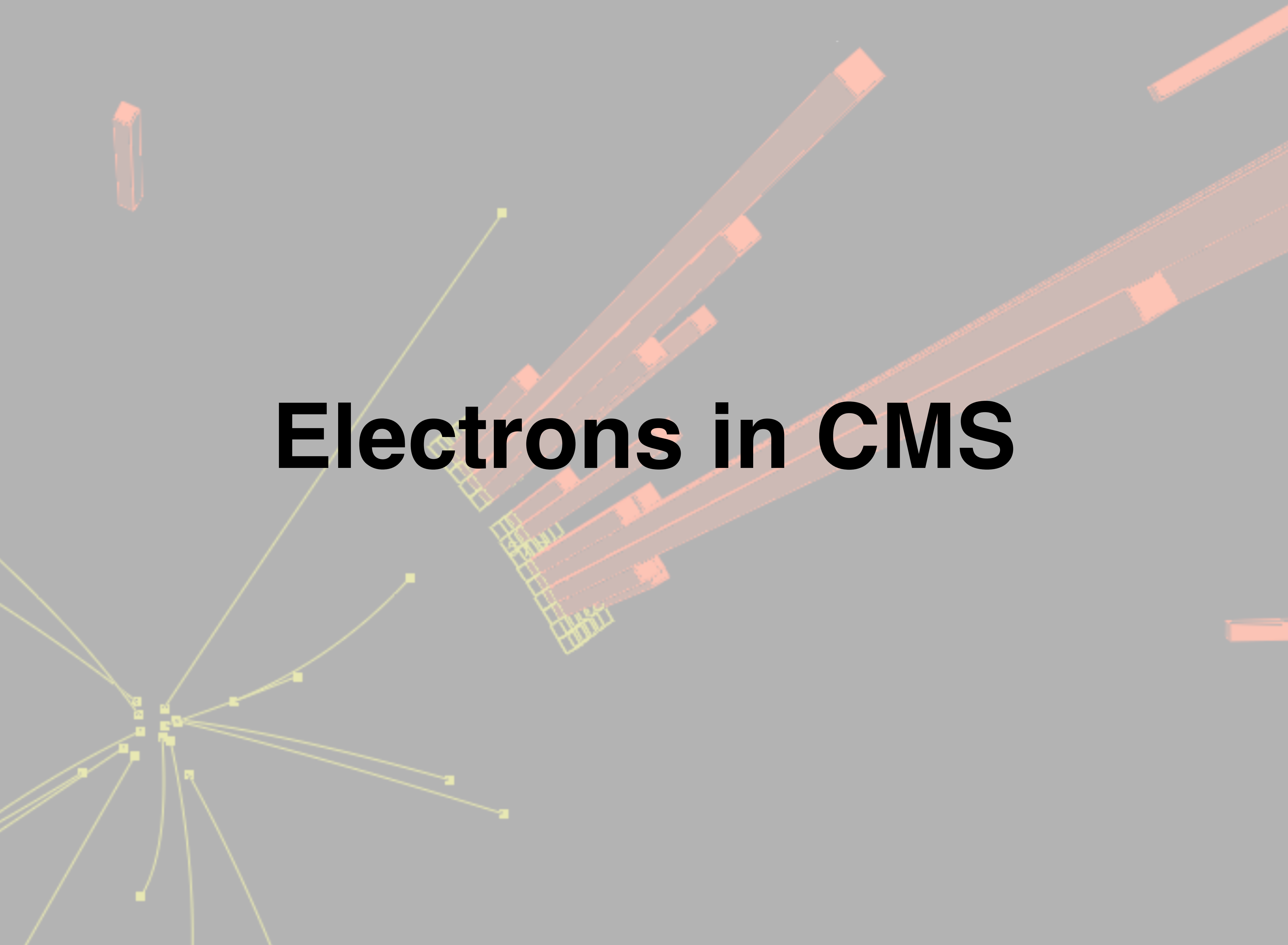

**associated VH production**



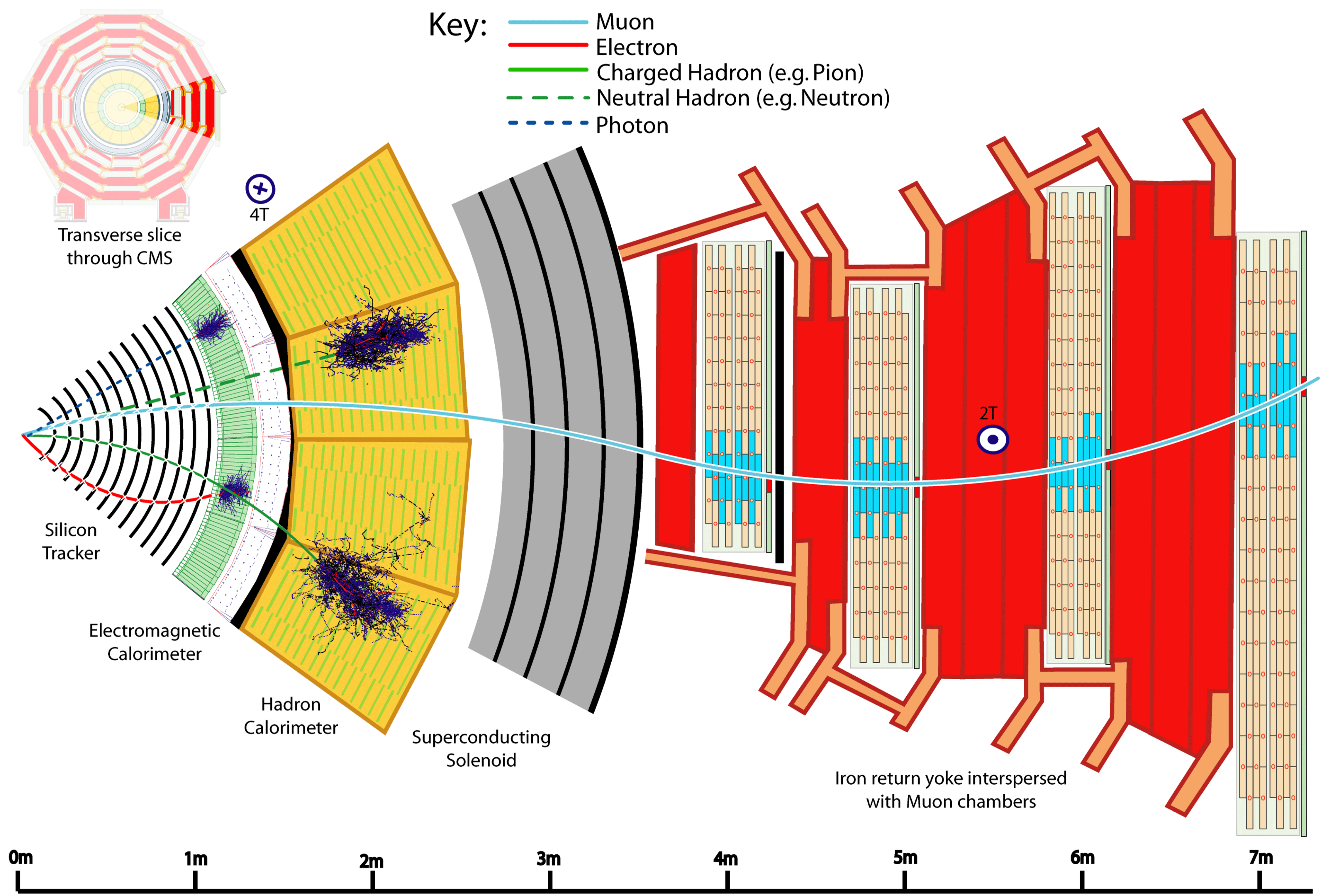

**associated ttH production**

➔ Need to redesign the analysis, and this starts with trigger and objects.

# Electrons in CMS



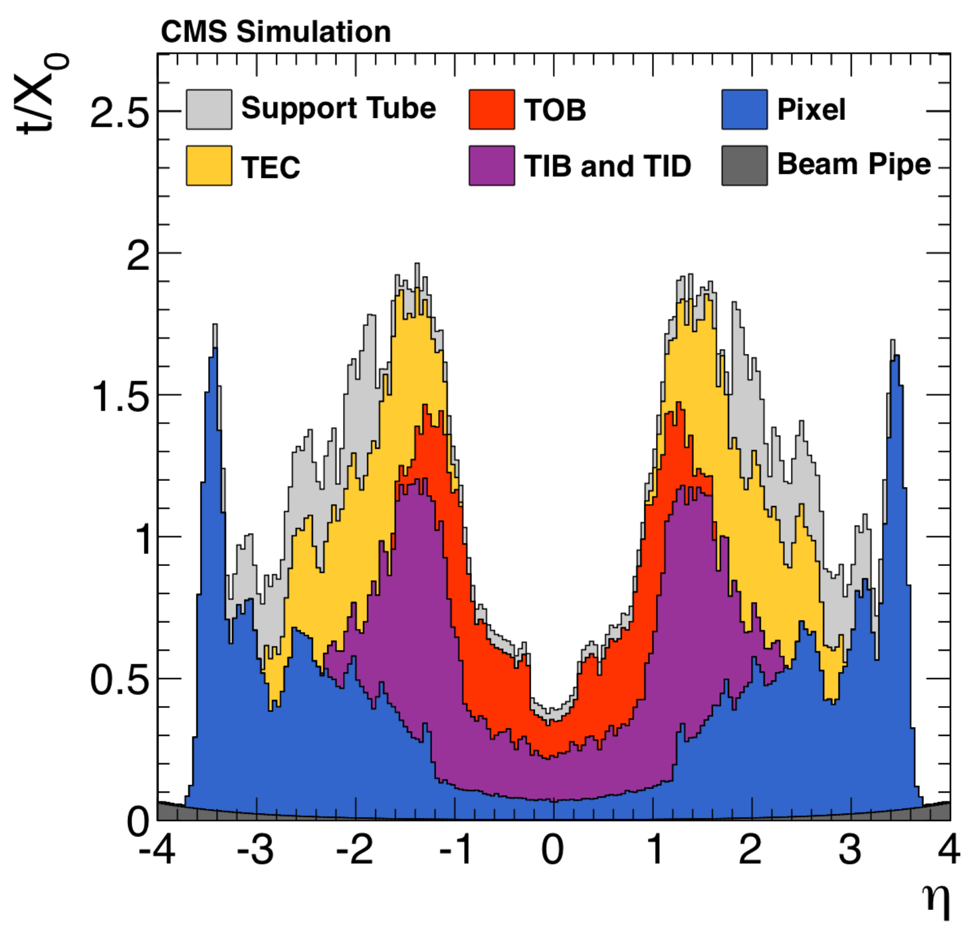
# A CMS slice

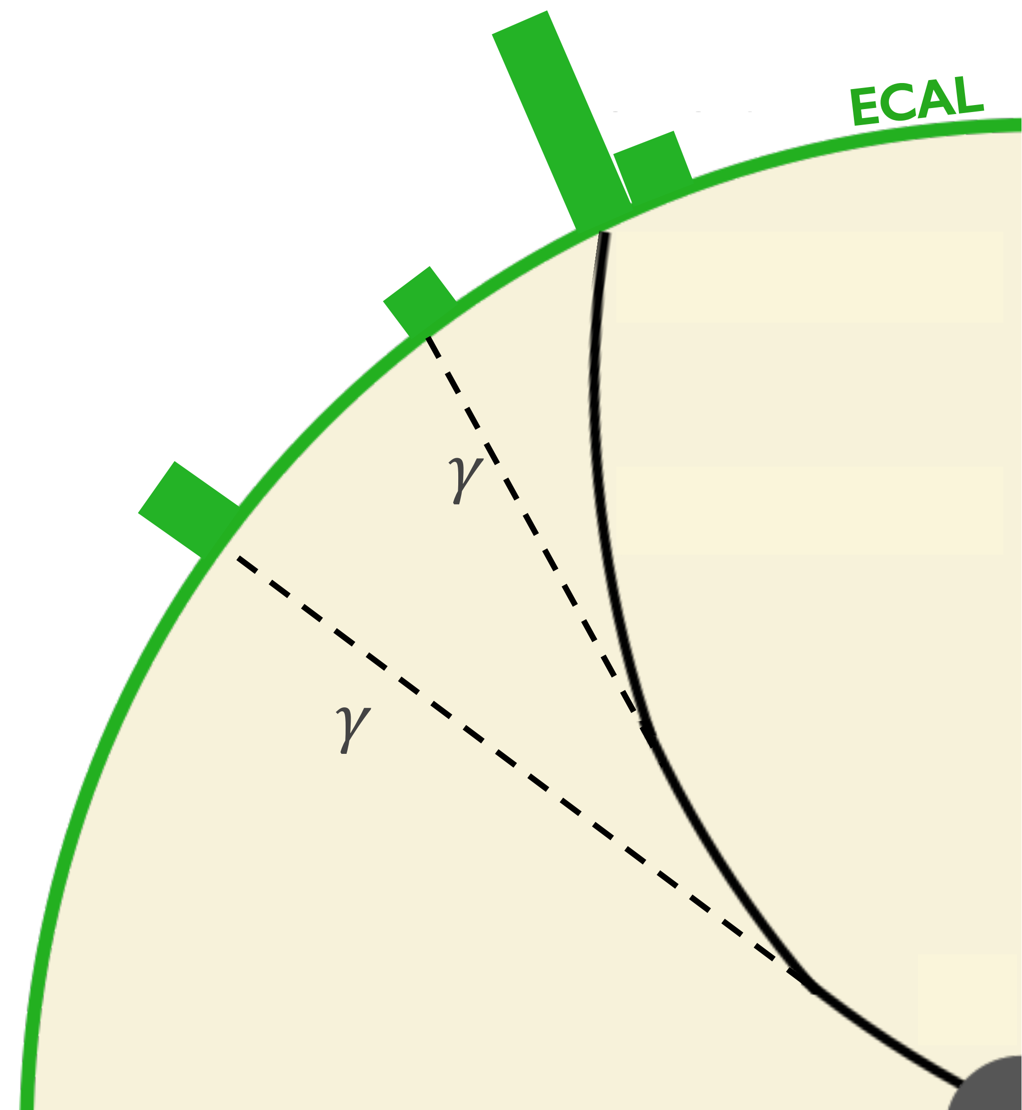

Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
Transverse slice through CMS
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0m
1m
2m
3m
4m
5m
6m
7m

# Peculiarity of electrons in CMS

Due to tracker material + magnetic field, electrons can undergo large **bremsstrahlung radiation** before reaching the ECAL.

⇒ spread electron energy over a wide area of ECAL in the Φ direction.

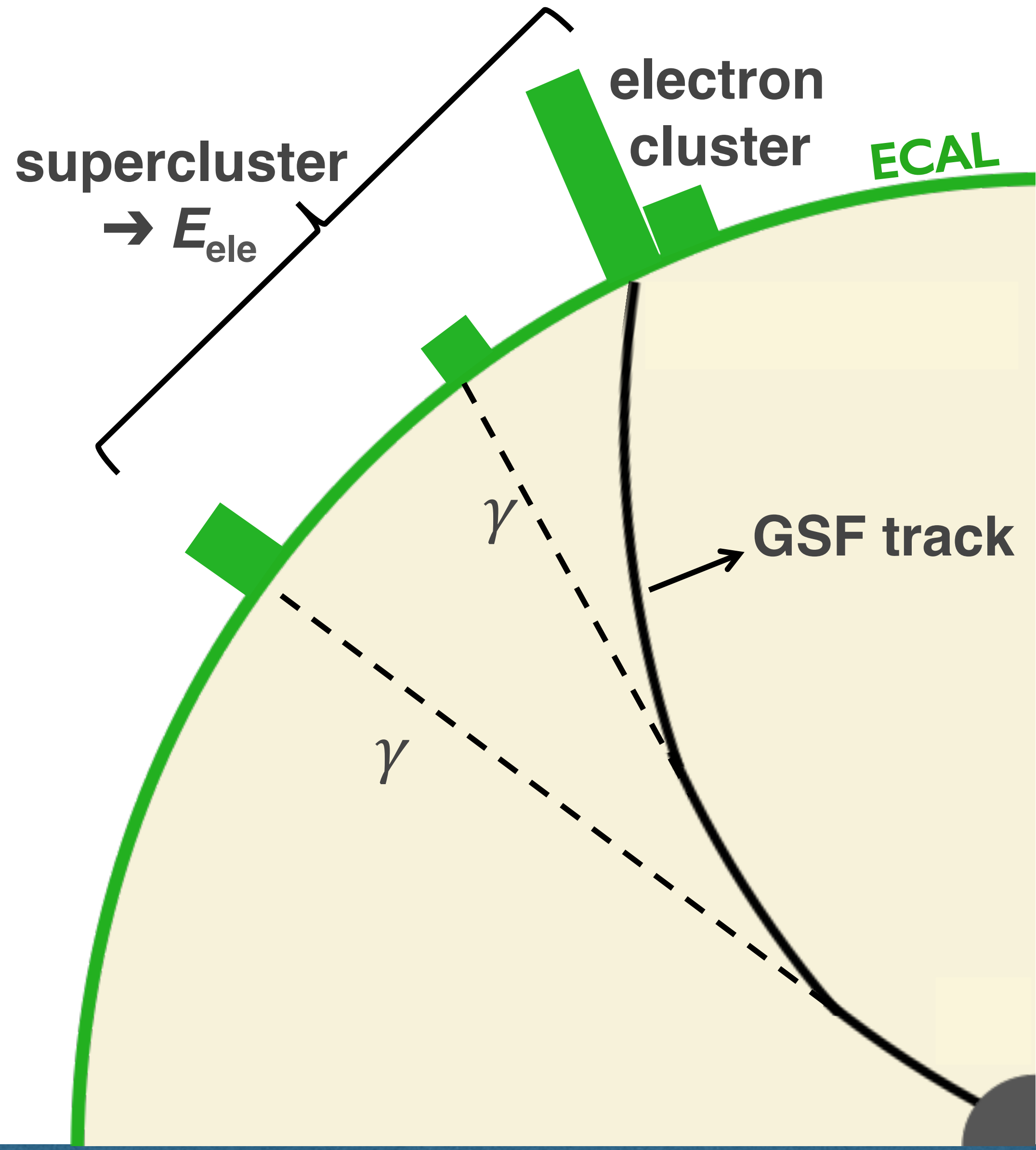


# Electron reconstruction

Main steps of reconstruction flow:

- **Cluster** ECAL energy deposits,
- Arrays of clusters in the Φ direction
  → **supercluster**
- Reconstruct the electron **track**, using the Gaussian Sum Filter algorithm,
- Ensure **track-cluster association**, resolve ambiguities,
- Estimate **electron energy**, combining ECAL and tracker information, and classifying electrons according to bremsstrahlung pattern.
  → energy resolution of 1.7-4.5 %



# Electron selection

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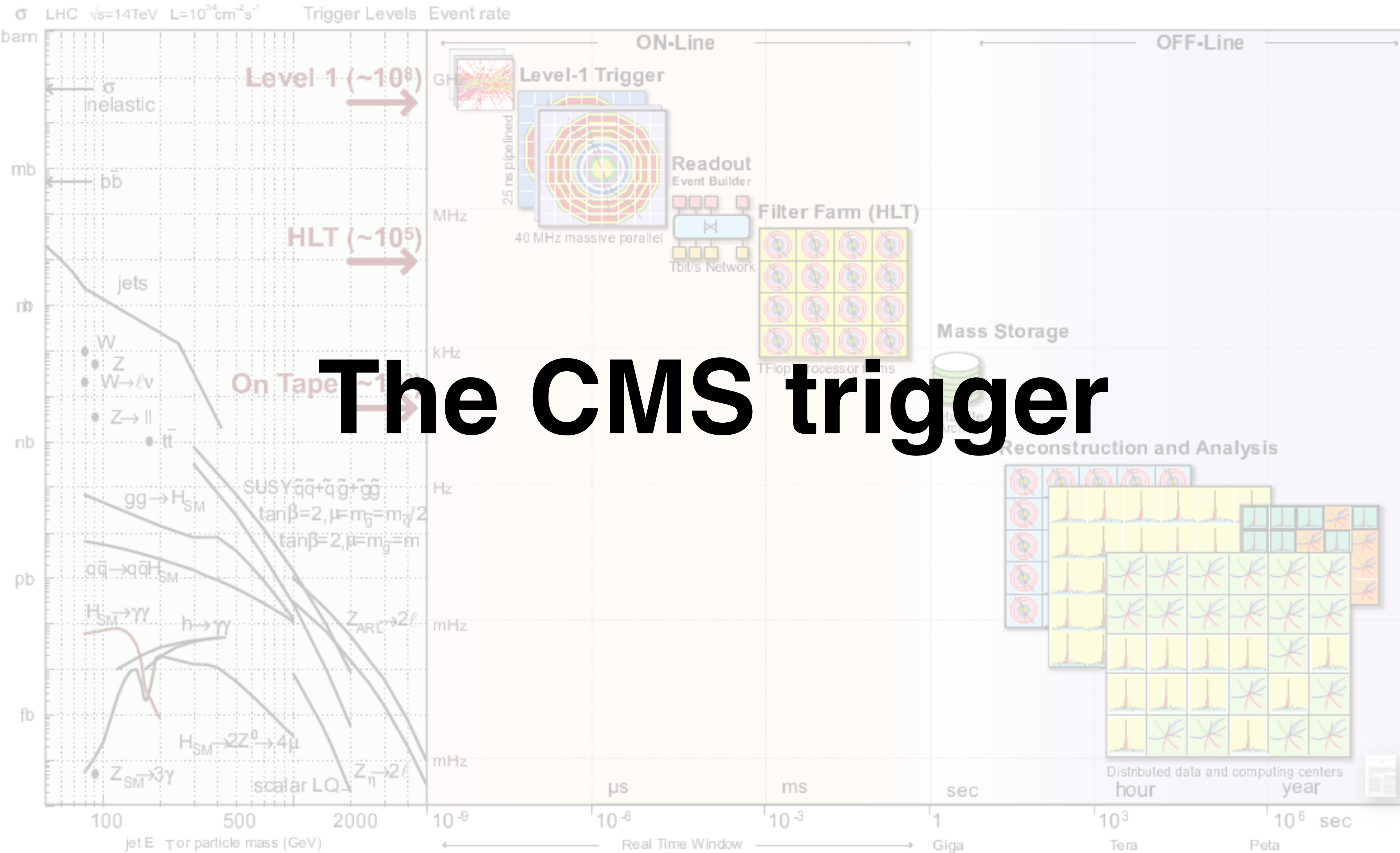
Selection techniques separate **primary signal electrons** from backgrounds (= jets, electrons from b/c decays or photon conversion…)

➢ **Identification:** multivariate discriminant, combines information relative to bremsstrahlung, track cluster matching, ECAL shower shape, etc.

➢ **Isolation**: reject electron candidates with significant energy flow near their trajectories.

# The CMS trigger



# The CMS trigger: a 2-level system

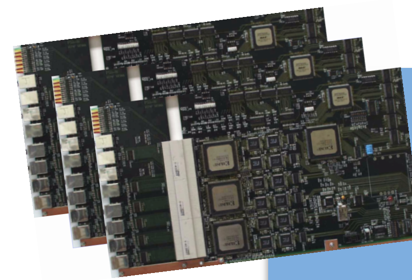
The role of the trigger is to:

- reduce the event rate from the LHC collision rate (~ 40 MHz) to what can be stored and analyzed offline (~ 1 kHz)
- while keeping the physics reach of the experiment.

CMS was designed with a **2-level** trigger system.

**LHC collisions**

**~ 40 MHz**



**L1 trigger**

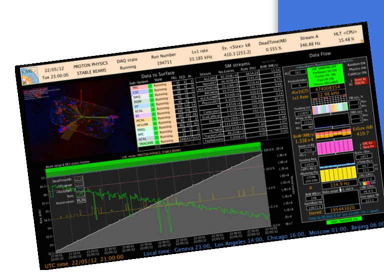
**hardware-based, fast readout of the detector with limited granularity**

**~ 100 kHz**

'Online'

**High-Level Trigger (HLT)**

**full detector readout, software, streamlined version of the CMS reconstruction algorithm**

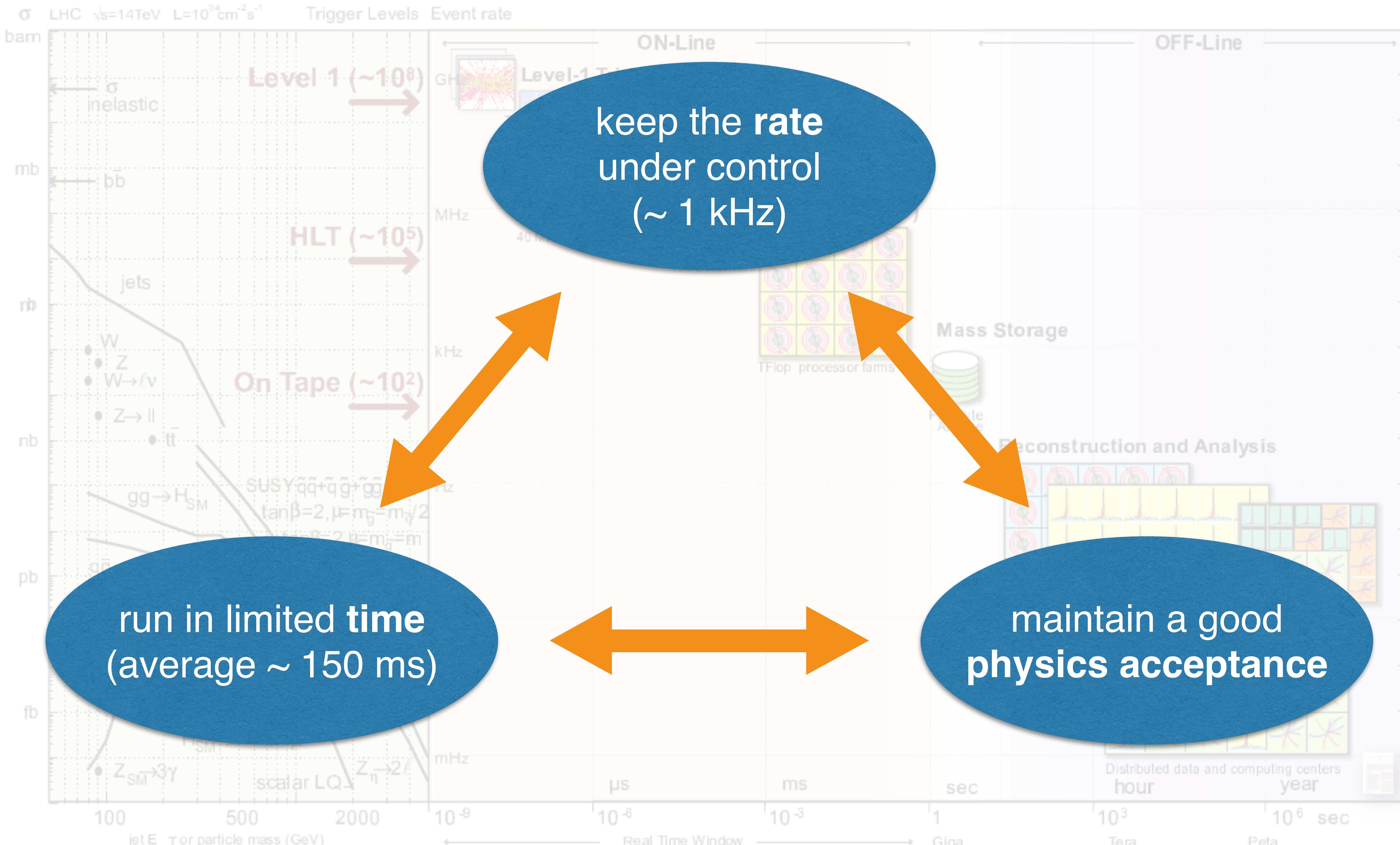


**~ 1 kHz**

'Offline'

**Data storage, full reconstruction, physics analyses**

# The trigger compromise




keep the **rate** under control (~ 1 kHz)

run in limited **time** (average ~ 150 ms)

maintain a good **physics acceptance**

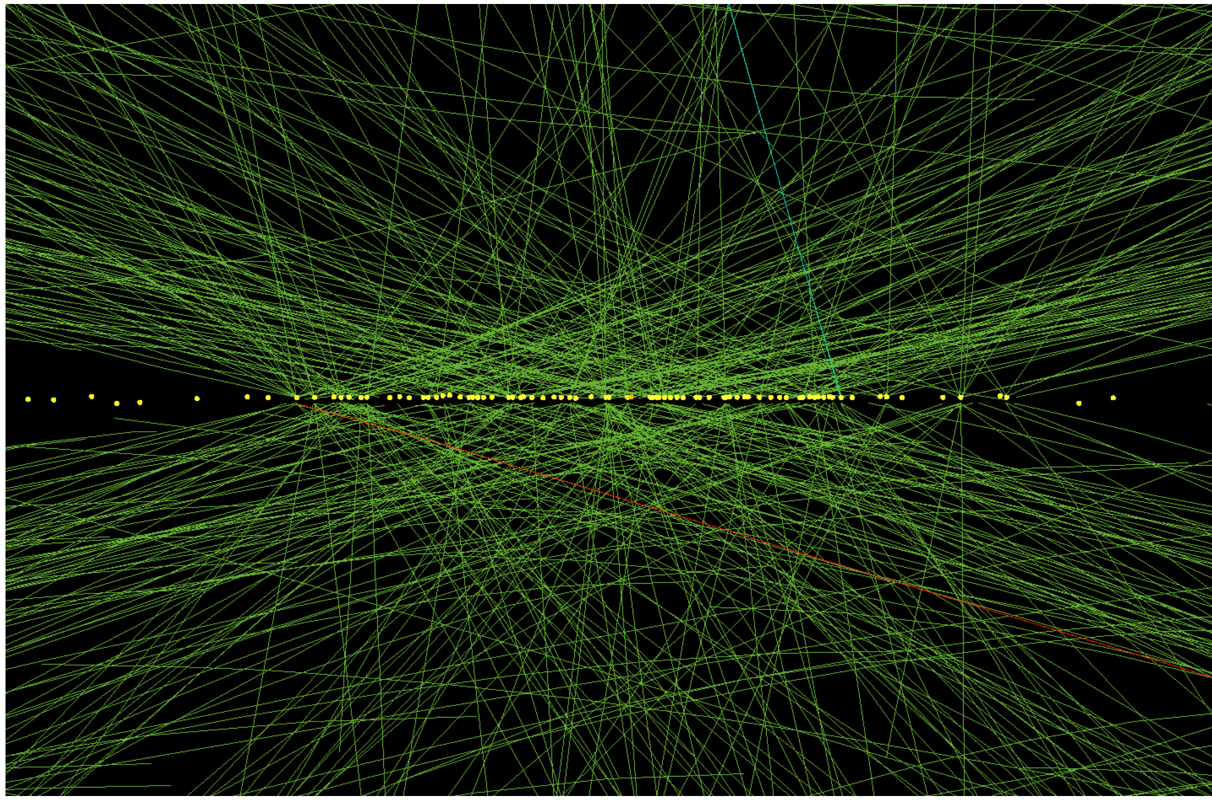
# Run II: a new challenge

Reminder : new conditions of Run II are

- $\sqrt{s}$ = 8 TeV → 13 TeV
- bunch spacing : 50 ns → 25 ns

→ Overall *L.σ* increases by a factor ~4, the allowed rate only by 2…

→ Increasing *pileup* disturbs selection algorithms.

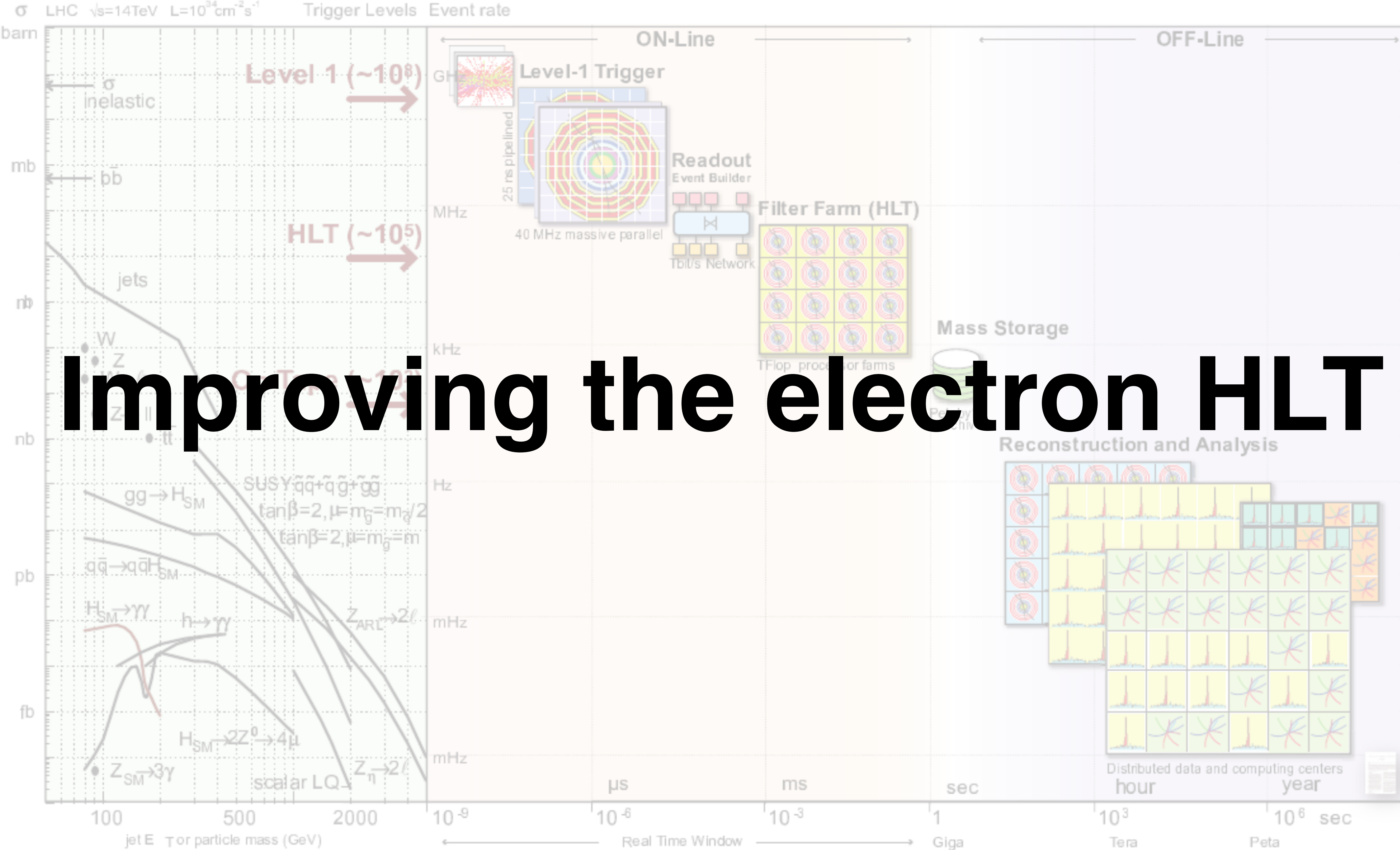


↳ ***Pileup*** = overlapping interactions from same (*in-time*) & nearby (*out-of-time*) bunch crossings (up to 45 interactions/crossing at $1.5\times10^{34}$ $cm^{-2}s^{-1}$)

**How can we contain the rate ?**

- Tighten pT thresholds and quality criteria ? Yes, but relying only on this would kill the physics acceptance !
- Be smarter: adapt for HLT the advanced algorithms that were successful in the offline world, and move HLT cuts closer to offline selection.

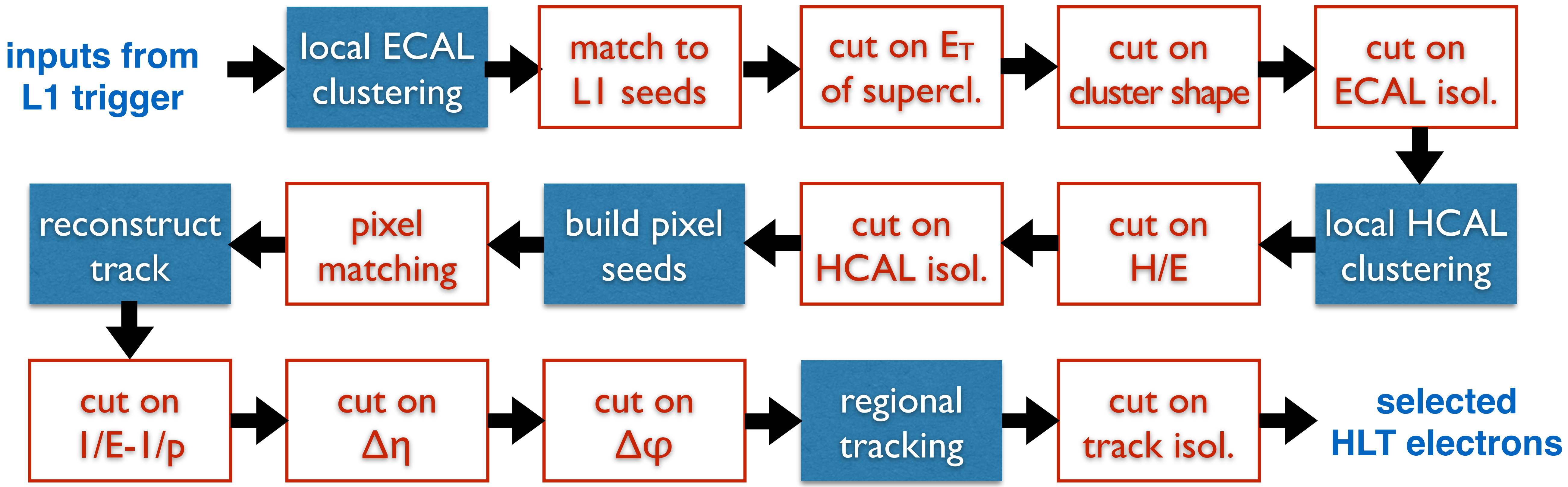
# Improving the electron HLT



# Electron HLT reconstruction

Among other objects, the HLT algorithm reconstructs electrons.
➔ **What is different from offline reconstruction ?**

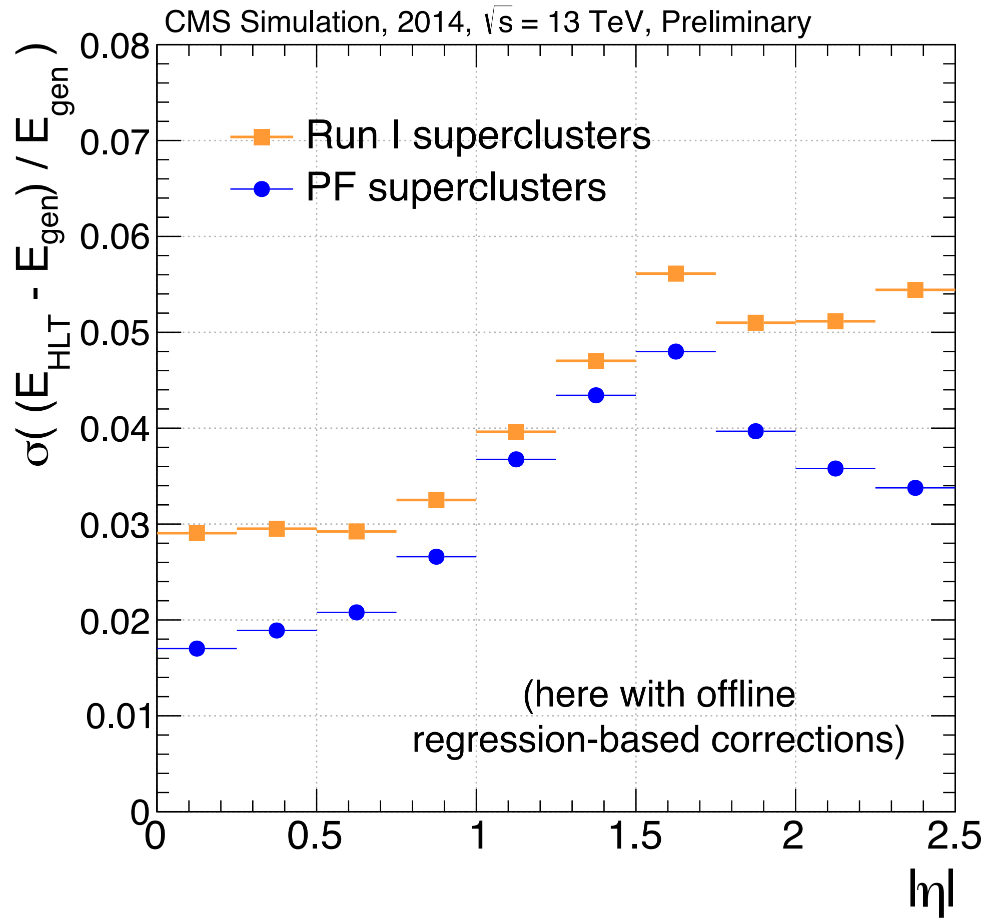
- Only look at what is needed → 'regional' reconstruction.
- As soon as you can build a discriminating variable, **cut on it** to already reject some electron candidates.
- Give priority to what is **least time-consuming**, and has **most background rejection power.**



# Clustering improvement

**Particle Flow (PF) clustering** = Iterative algorithm to cluster ECAL energy deposits

- Reconstructs individual showers.
- Handles energy overlaps.

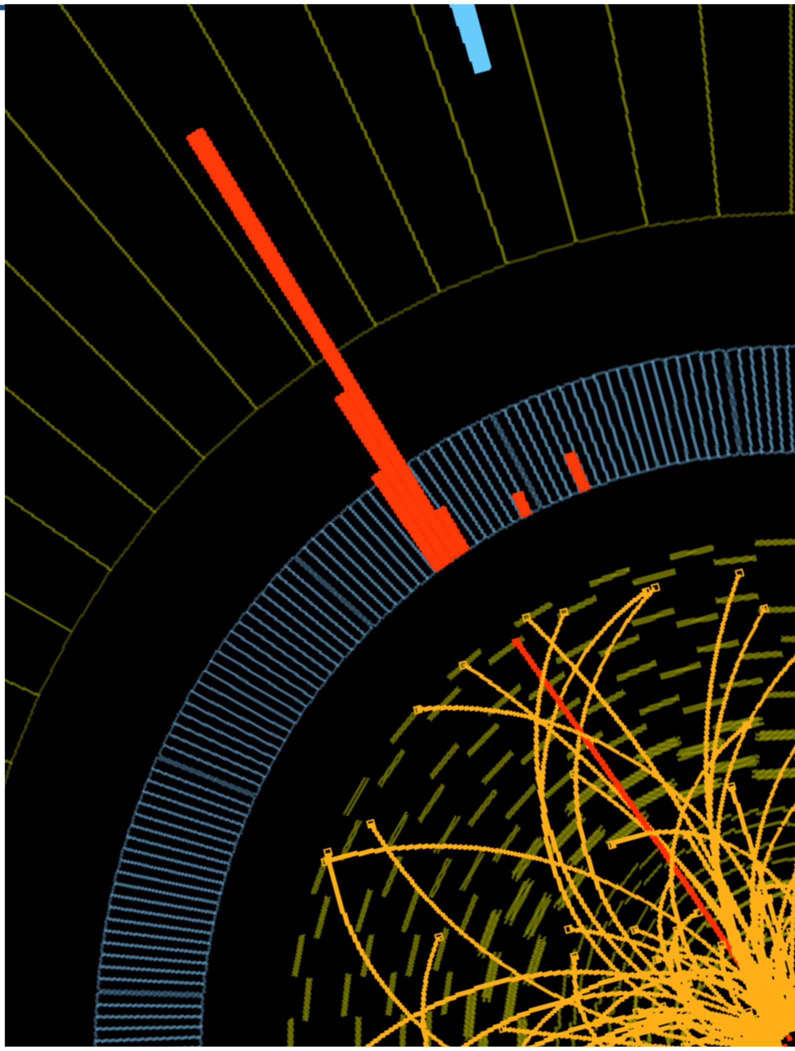



Porting this offline algorithm to HLT :

- preserves **efficiency** wrt. Run I,
- **synchronizes** the reconstruction flow with offline, e.g. cluster shape variables.

+ New regression-based energy corrections improve **energy resolution**, especially at high pileup.

# Tracking improvement

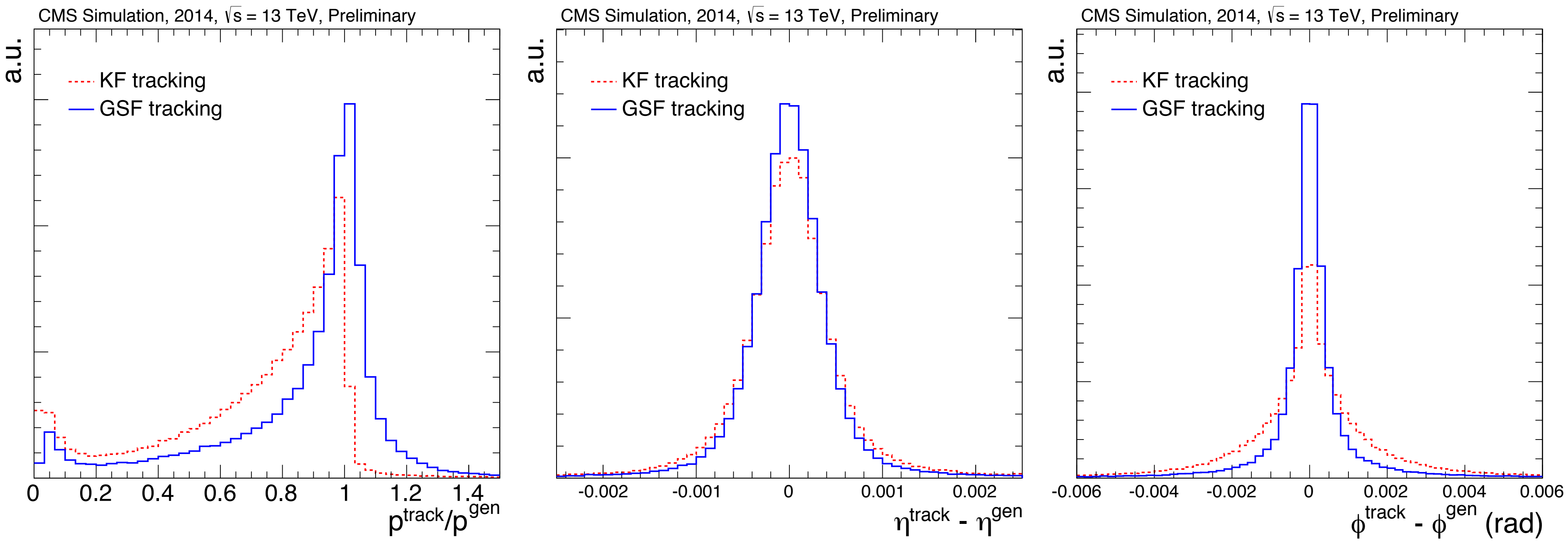


Standard Kalman Filter (KF) tracking, used at HLT in Run I, is suboptimal for electrons.

➔ Port to HLT the **Gaussian Sum Filter** (GSF) algorithm that accounts for bremsstrahlung effects:

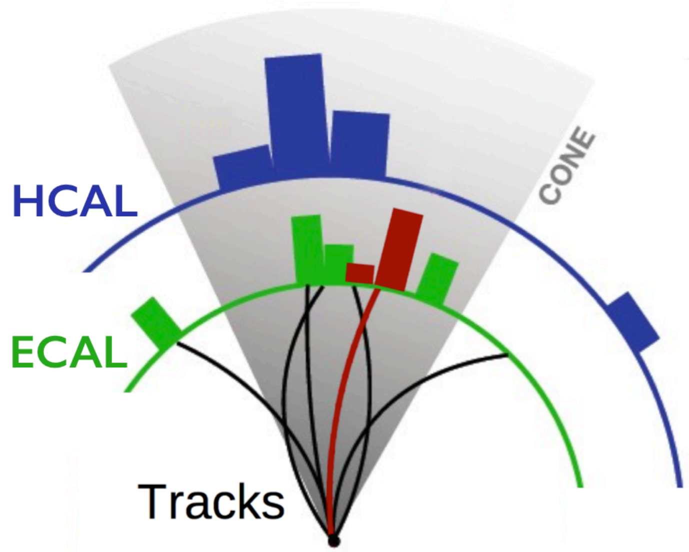
- relaxed $\chi^2$ to better collect tracker hits
- energy loss modeled as sum of Gauss functions

➔ Get a 25 % rate reduction with the same efficiency as KF tracking.




➔ Make momentum and position measurements more precise.

# Isolation strategies



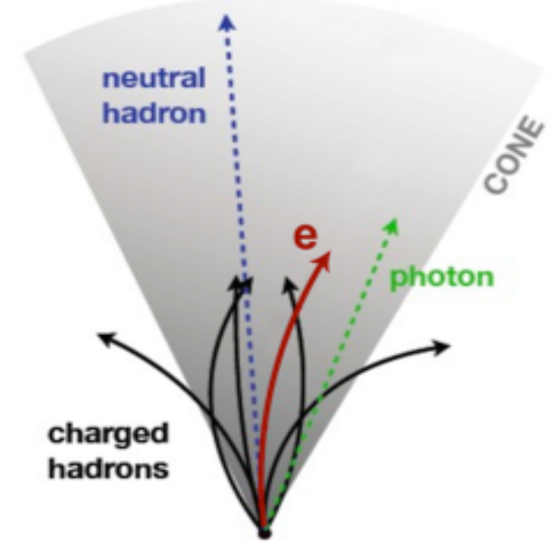

$$\text{iso} = \frac{1}{p_{\mathrm{T}}^{ele}}\left(\sum_{\text{ECAL}} E_{\mathrm{T}} + \sum_{\text{HCAL}} E_{\mathrm{T}} + \sum_{\text{tracks}} p_{\mathrm{T}}\right)$$

## Detector isolation

(used at HLT in Run I)

➢ Sum energy deposits and track momenta in a cone of ΔR = 0.3 around the electron.

At HLT, cut on 3 components separately.




$$\text{iso} = \frac{1}{p_{\mathrm{T}}^{ele}}\left(\sum_{\text{photons}} p_{\mathrm{T}} + \sum_{\substack{\text{neutral}\\\text{hadrons}}} p_{\mathrm{T}} + \sum_{\substack{\text{charged}\\\text{hadrons}}} p_{\mathrm{T}}\right)$$

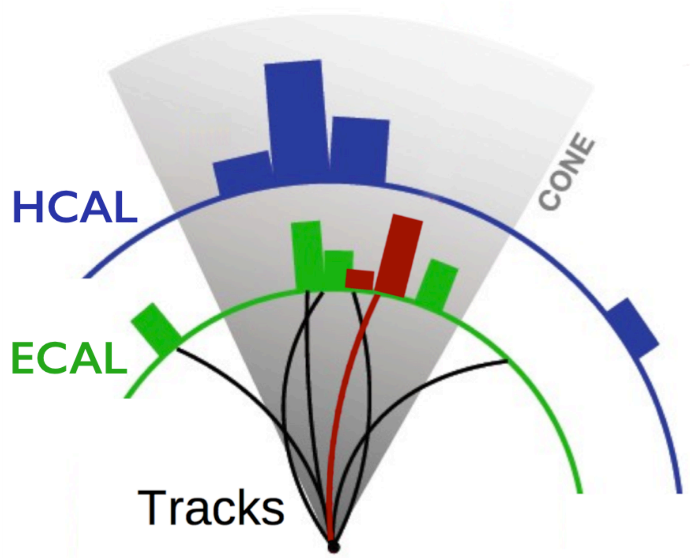
## Particle Flow isolation

(used offline in Run I)

➢ PF algorithm assembles PF clusters and tracks into particles ➞ Sum momenta of particles in the cone.

➢ Better handle detector noise, cleanly remove electron footprint.

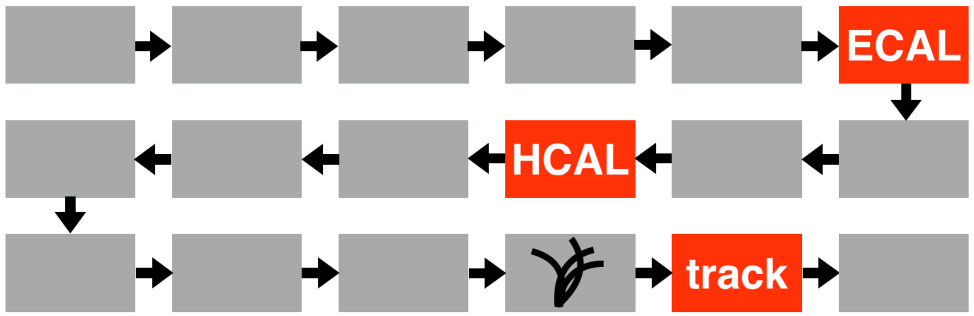
# Isolation strategies

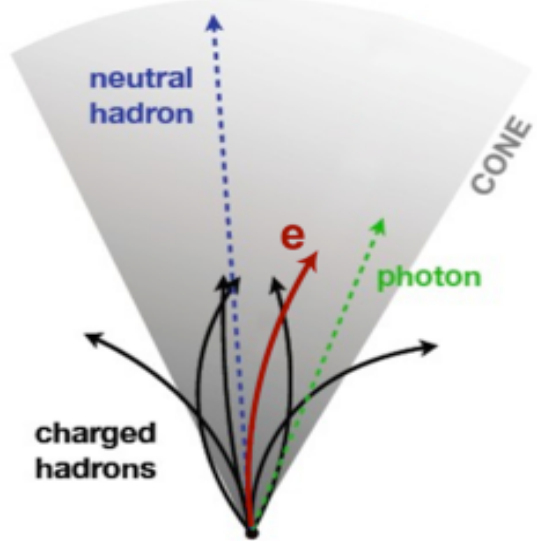



$$\text{iso} = \frac{1}{p_{\mathrm{T}}^{ele}} \left( \sum_{\text{ECAL}} E_{\mathrm{T}} + \sum_{\text{HCAL}} E_{\mathrm{T}} + \sum_{\text{tracks}} p_{\mathrm{T}} \right)$$

## Detector isolation
(used at HLT in Run I)

Good for HLT, because you can cut on ECAL & HCAL early in the flow.

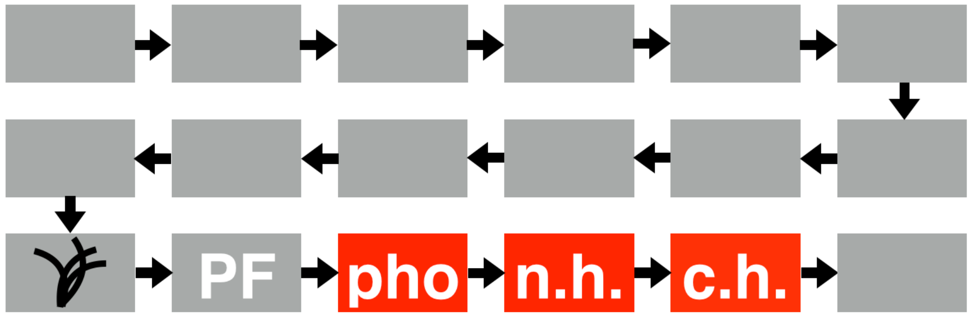



$$\text{iso} = \frac{1}{p_{\mathrm{T}}^{ele}} \left( \sum_{\text{photons}} p_{\mathrm{T}} + \sum_{\substack{\text{neutral}\\ \text{hadrons}}} p_{\mathrm{T}} + \sum_{\substack{\text{charged}\\ \text{hadrons}}} p_{\mathrm{T}} \right)$$

## Particle Flow isolation
(used offline in Run I)

Can't do any cut until you have run regional tracking ➞ time consuming.



# PF-cluster based isolation

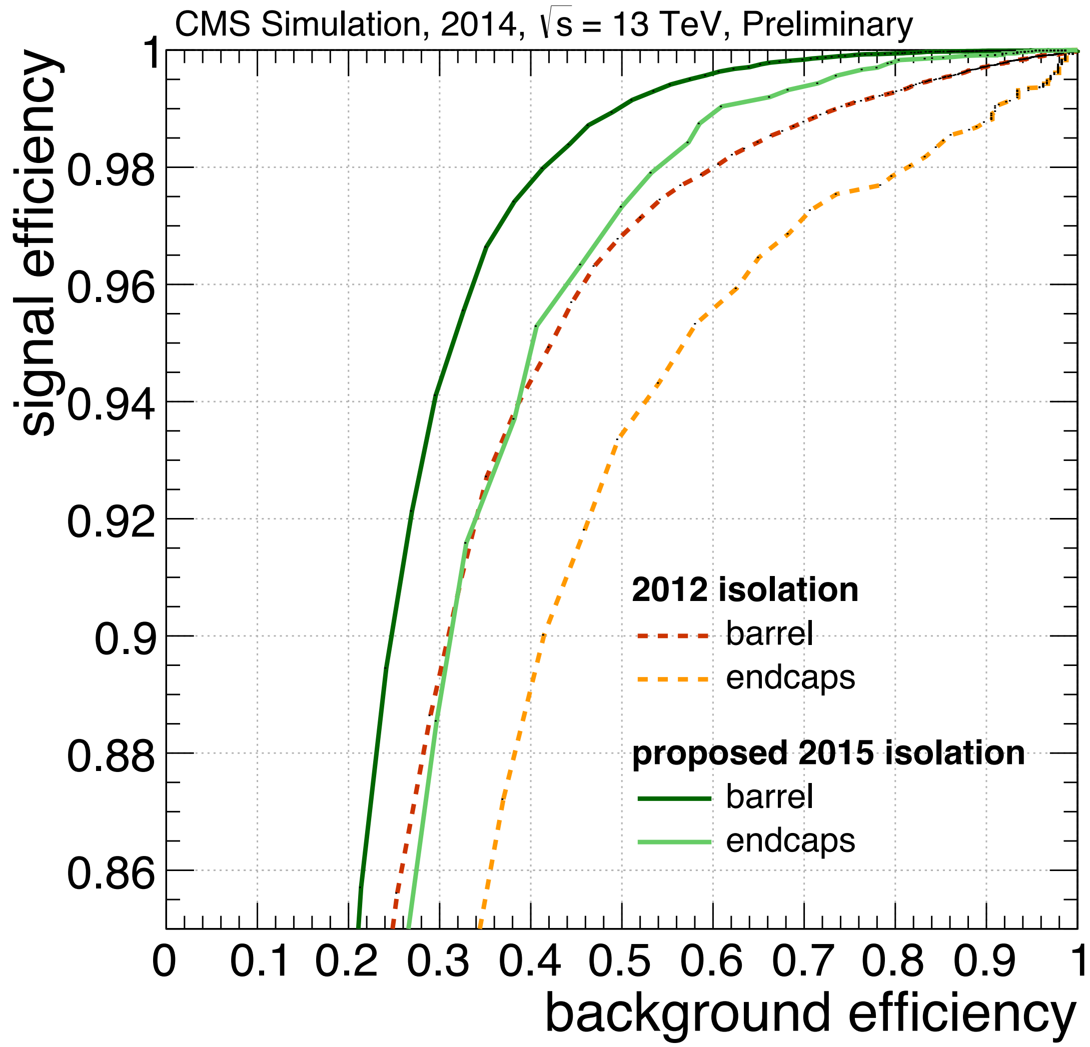
Need to adapt PF isolation to make it more HLT-compliant.

➟ **PF-cluster based isolation** = use PF intermediary blocks without assembling particles.

$$\text{iso} = \frac{1}{p_{\mathrm{T}}^{ele}} \left( \sum_{\substack{\text{ECAL} \\ \text{PF clusters}}} E_{\mathrm{T}} + \sum_{\substack{\text{HCAL} \\ \text{PF clusters}}} E_{\mathrm{T}} + \sum_{\text{tracks}} p_{\mathrm{T}} \right)$$

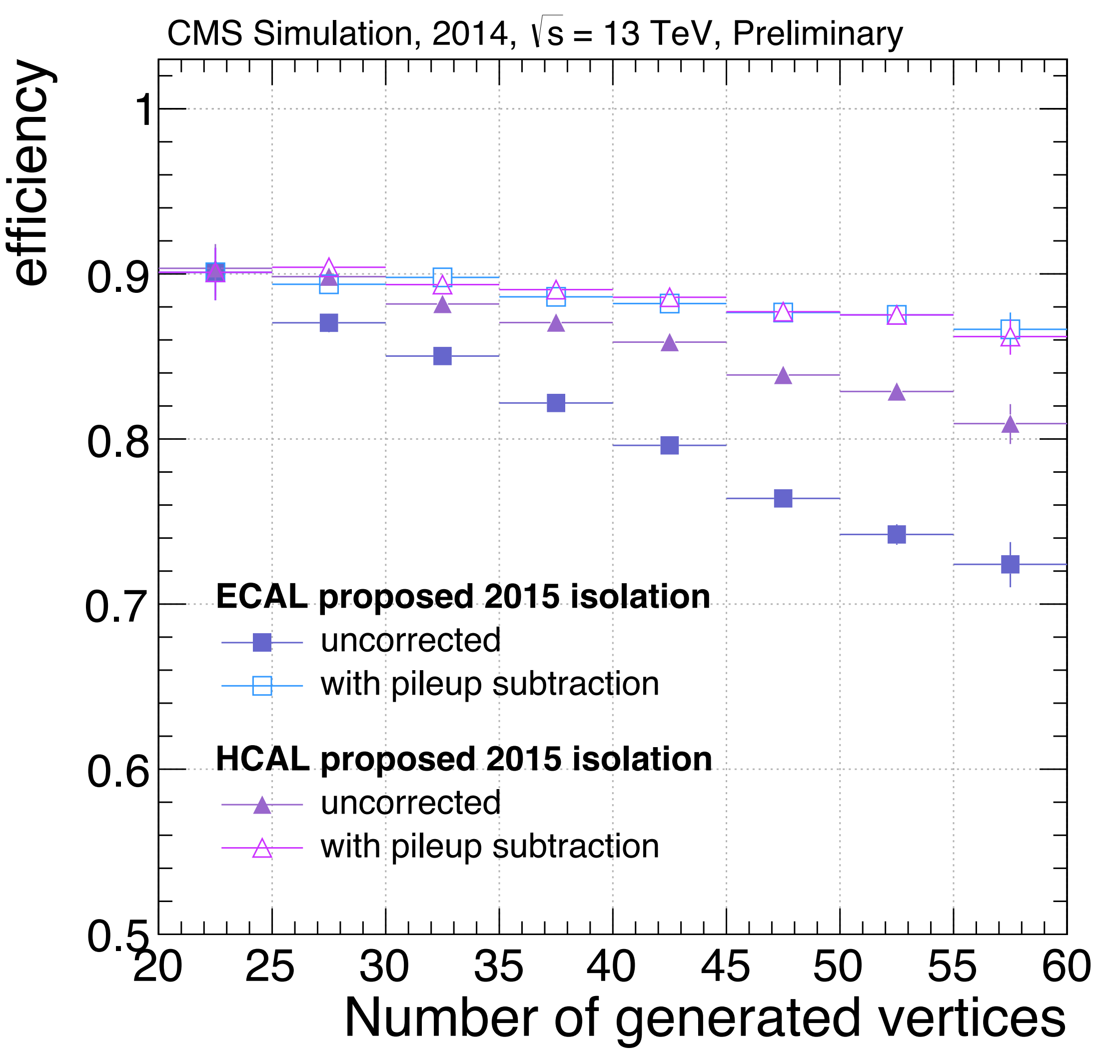
➢ Similar timing as detector-based isolation,

➢ Similar performance as PF isolation, i.e. neat progress wrt. detector based.



# Pileup subtraction

Isolation is very sensitive to additional energy deposits from pileup.
➟ port a pileup subtraction technique to HLT



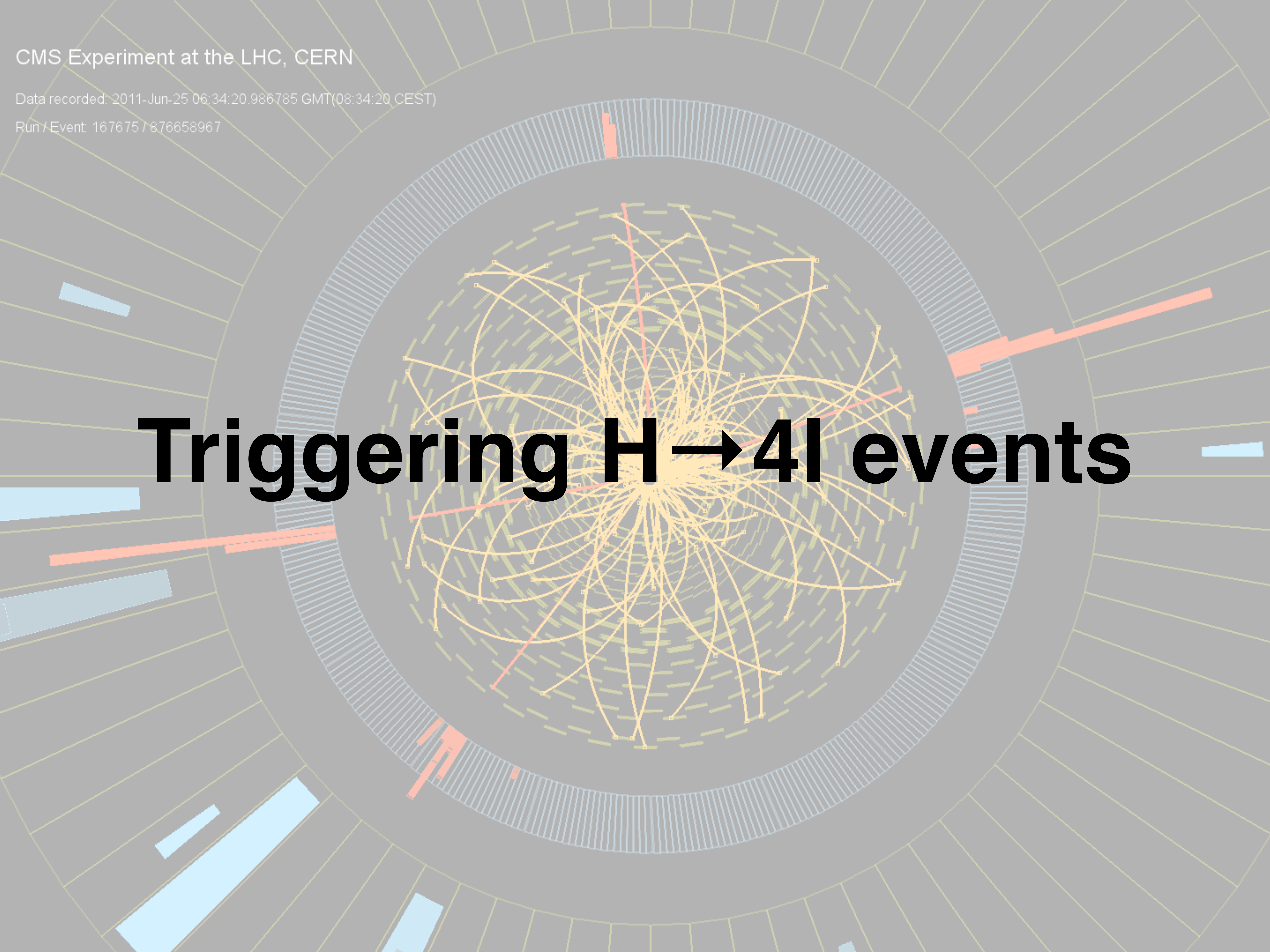

**FastJet technique:**

- Compute the average energy density $\rho$ in the event.
- $<$ iso $>$ and $< \rho >$ are linear functions of number of pileup vertices.
- Replace $\sum_{\textbf{PF clusters}} E_{\mathrm{T}} \longrightarrow \sum_{\textbf{PF clusters}} E_{\mathrm{T}} - \rho \, . \, A_{eff}$

  with well-chosen effective area $A_{eff}$ .

➔ makes isolation efficiency flat wrt. number of vertices.

# Triggering H→4l events



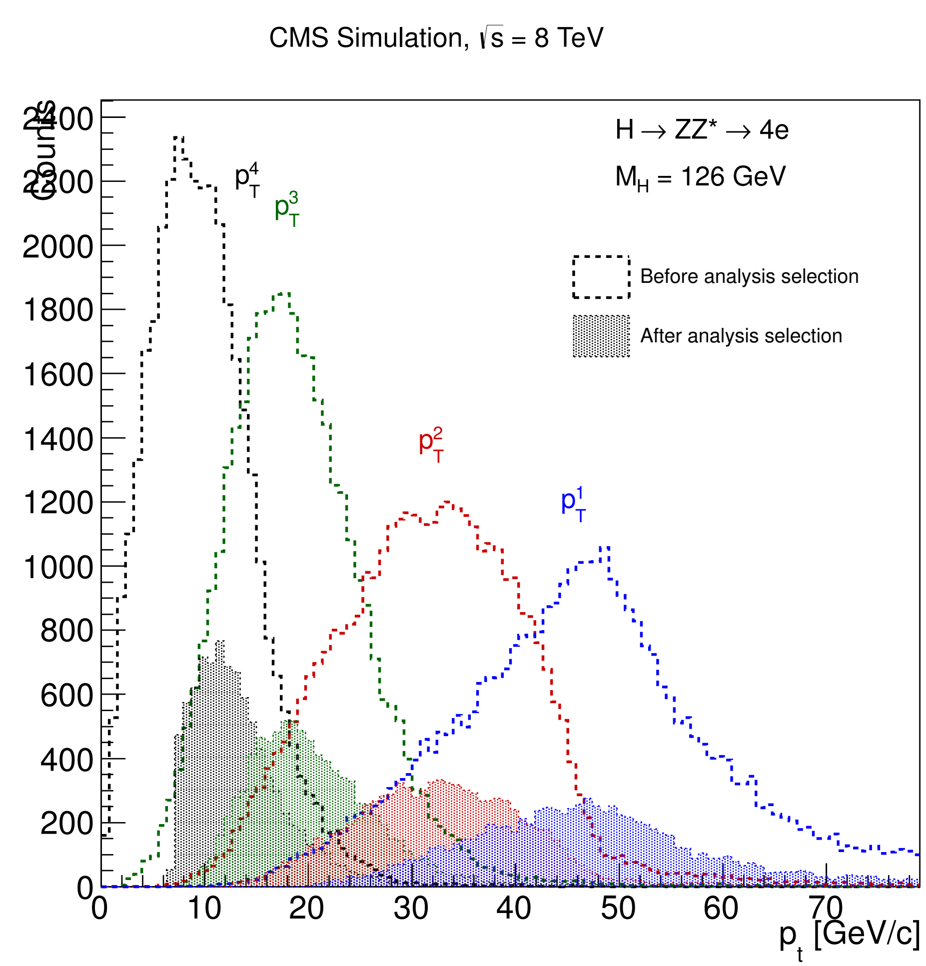
# From HLT objects to HLT paths

HLT algorithm is divided into pieces called ***paths***.
Each path reconstructs and selects a certain combination of **objects**: electrons, muons, jets, missing transverse energy, etc.

➔ It is up to analysts to build relevant paths to trigger the physics events they want to study (signals, control samples, etc.)

In the case of the H→ZZ*→4l channel:

- Many leptons in the final state: easier to trigger on.
- These leptons can be quite soft and fail the selection (problem both for offline and HLT).



# Optimizing selection thresholds

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Special care must be taken to tune selection working points (here: 7 variables of HLT electrons)

- Very little wiggle room, because this all has to fit into a given rate budget.
- Cut tightest on variables that have most background rejection power.
- Keep the selection looser than in offline analyses.

non-public material

# H→ZZ*→4l trigger strategy

Which paths to build for H→ZZ*→4l, maximizing <u>signal efficiency</u> while containing the <u>rate</u> ?

Achieve this by combining:

- paths with few objects and tight selection
- paths with more objects and loose selection

Here for a luminosity of $1.4\times10^{34}$ $cm^{-2}s^{-1}$:

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# Conclusion

- The CMS detector is ready for a new data taking period at a never-explored c.o.m. energy.
- New algorithms were included into the CMS trigger
  ➔ preserve trigger efficiency at high luminosity and high pileup.
- Currently preparing the hunt for rare production modes of the Higgs boson in the $H \rightarrow ZZ^* \rightarrow 4l$ channel.

non-public material


CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-25 06:34:20.986785 GMT(08:34:20 CEST)
Run / Event: 167675 / 876658967
Merci de votre attention !