Karlsruher Institut für Technologie

Bundesministerium
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# Trigger-Level Physics Analysis at the CMS Experiment

**Enhancing the Phase Space for the Analysis of Inclusive H → bb Production through Trigger-Level Analysis at the CMS Experiment**

**Adelina Lintuluoto**

Gentner day
April 24th 2024

# The Standard Model of particle physics is incomplete

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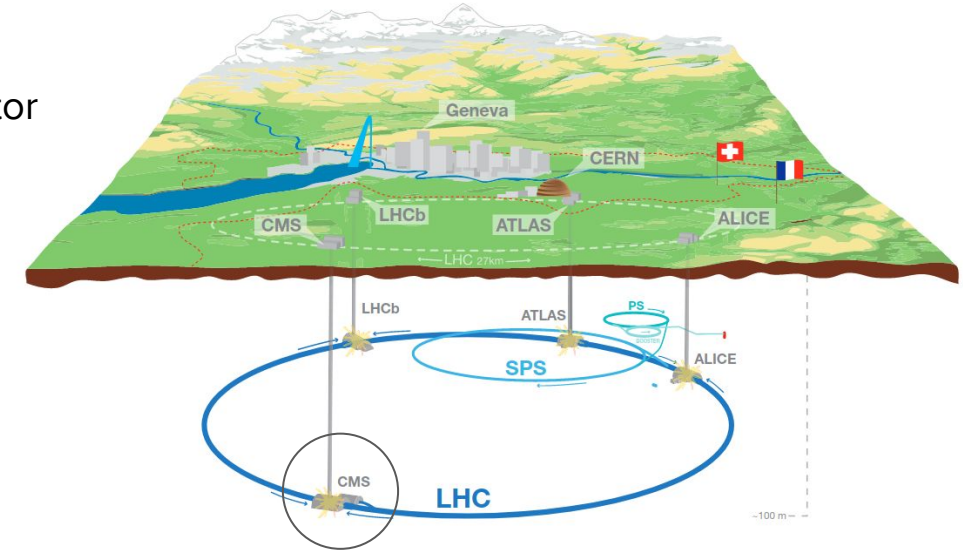
Protons collide in the center of experiments such as the CMS detector



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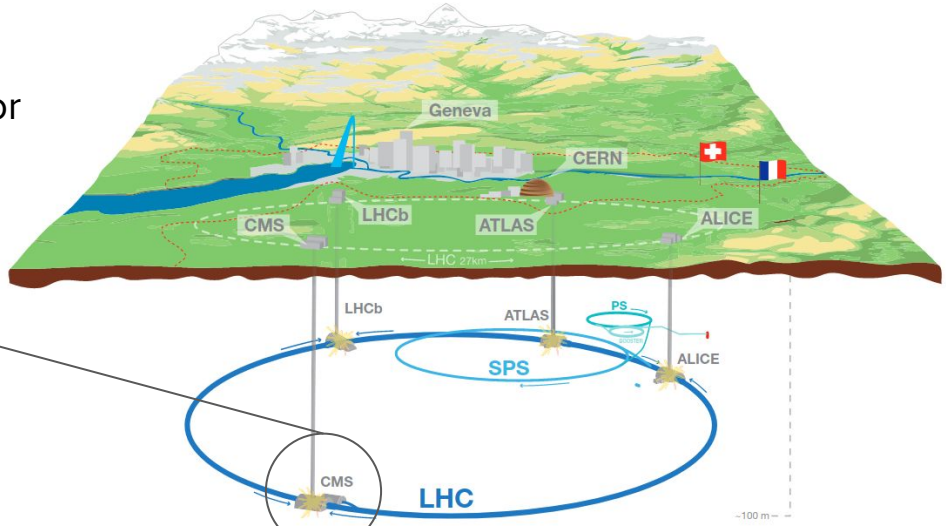
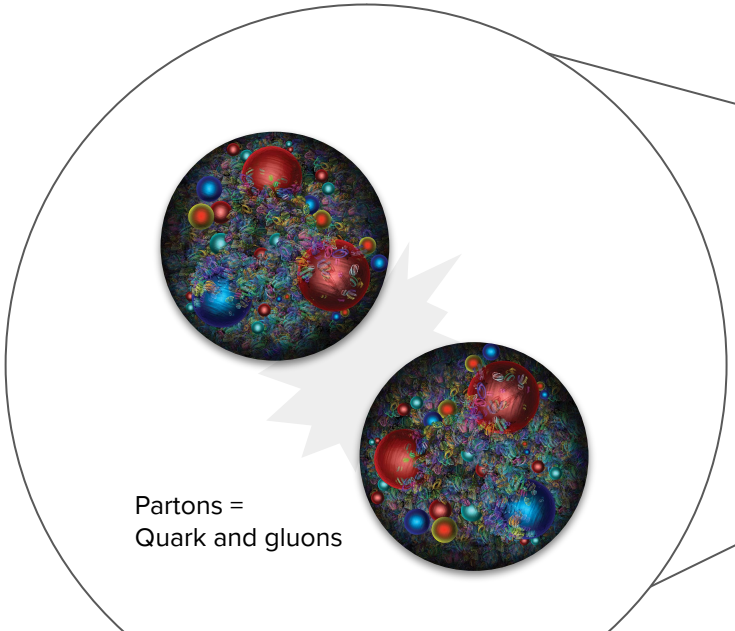


Partons =
Quark and gluons

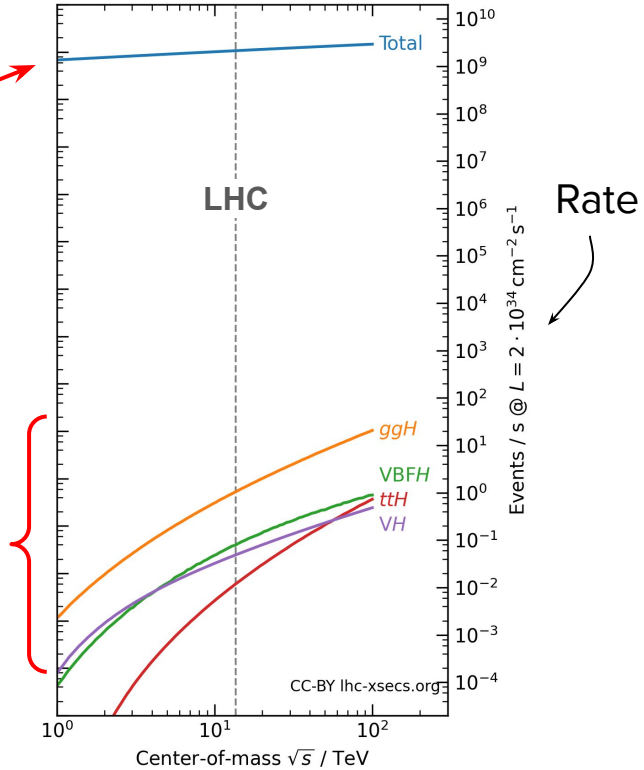
Collisions are dominated by parton interactions with low momentum transfers

# Higgs boson (H) production is rare at the LHC

~99% are soft QCD interactions

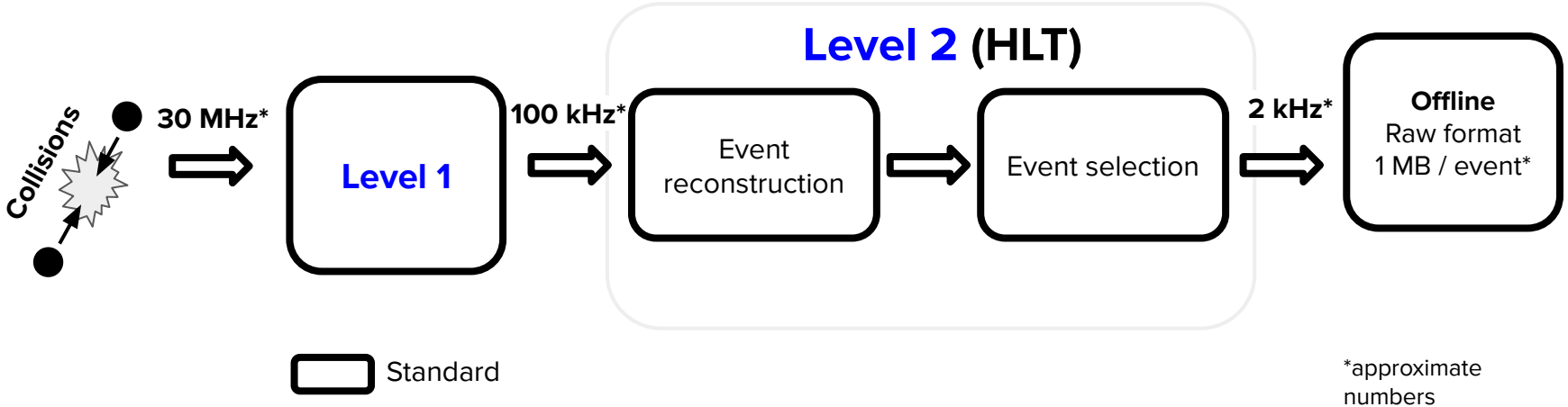
Rate of H production is ~10 orders of magnitude smaller

Algorithms (*triggers*) that try to identify and select H production are required

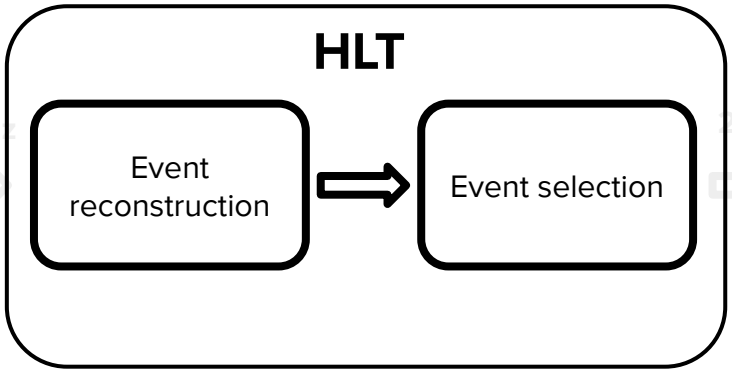



F. Sauerburger, LHC cross section plot, https://lhc-xsecs.org/

# At CMS, events are selected by a two-tiered trigger system

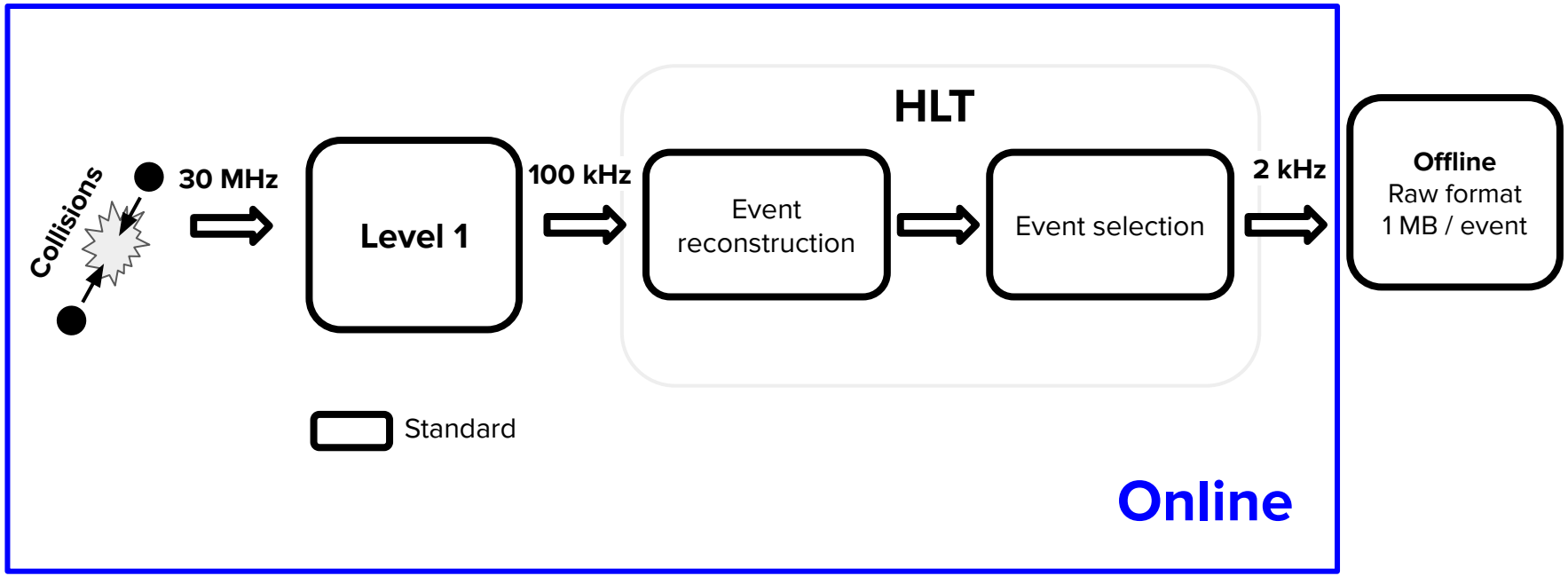


# The HLT hardware consists of CPU and GPU units

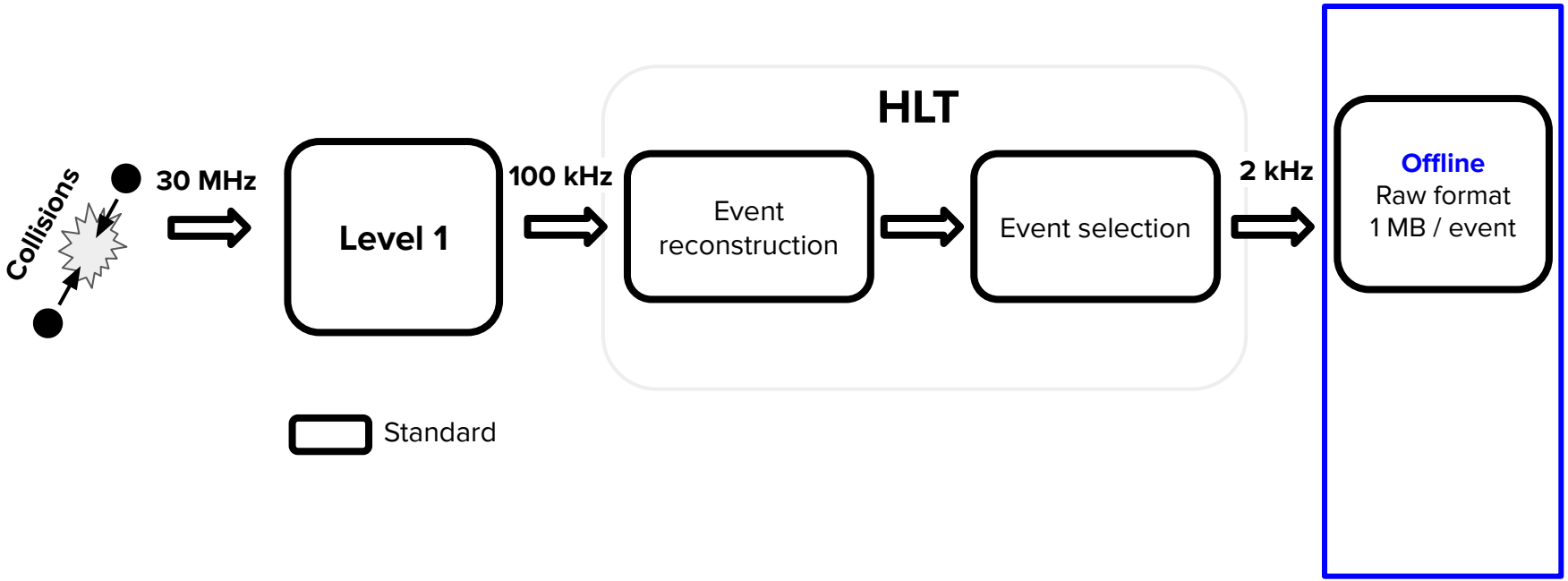



# of event processed / second
increased by 3 times since Run 2

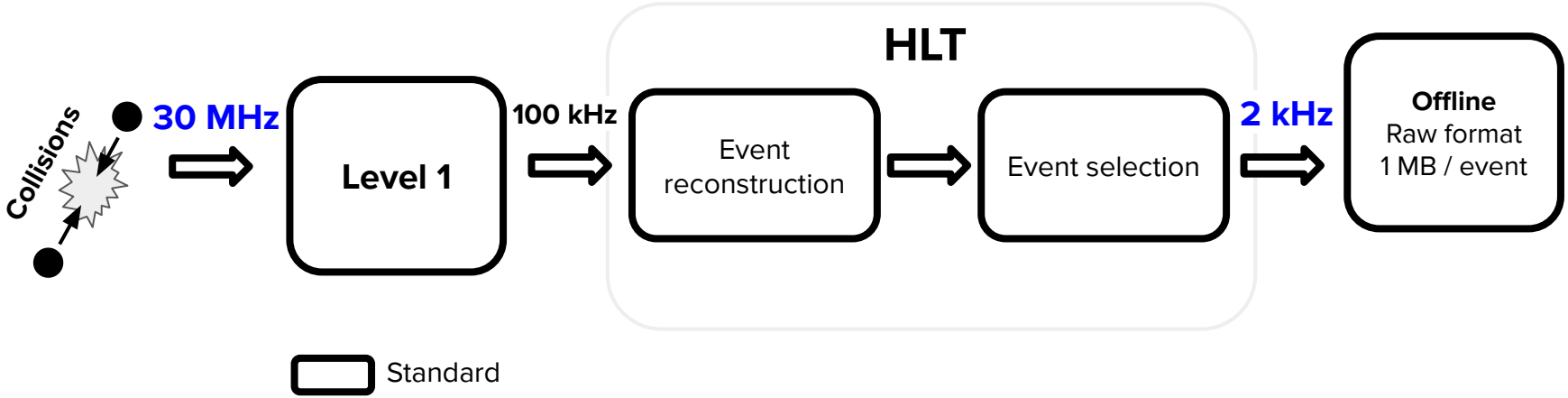
# Online reconstruction aims to provide low latency



# Offline reconstruction aims to provide the best physics objects for analysis

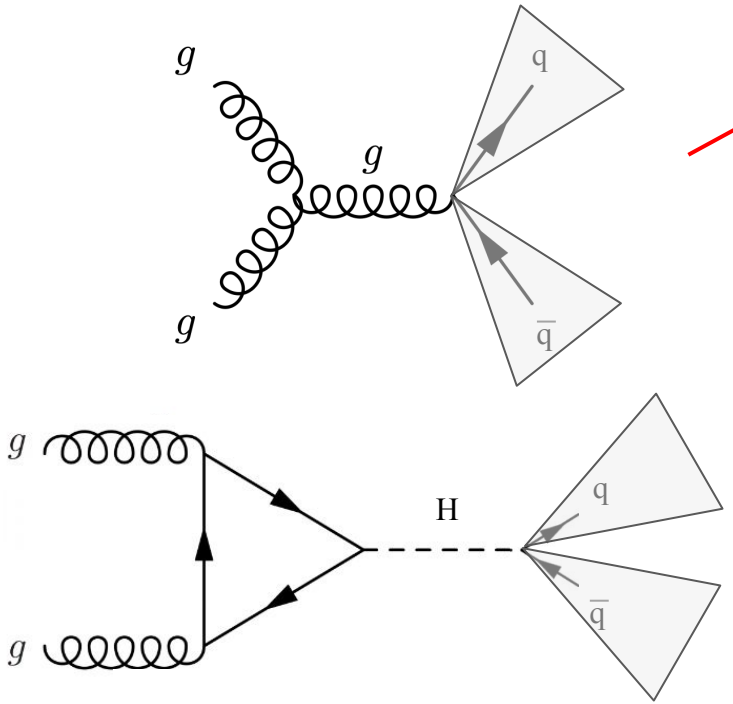


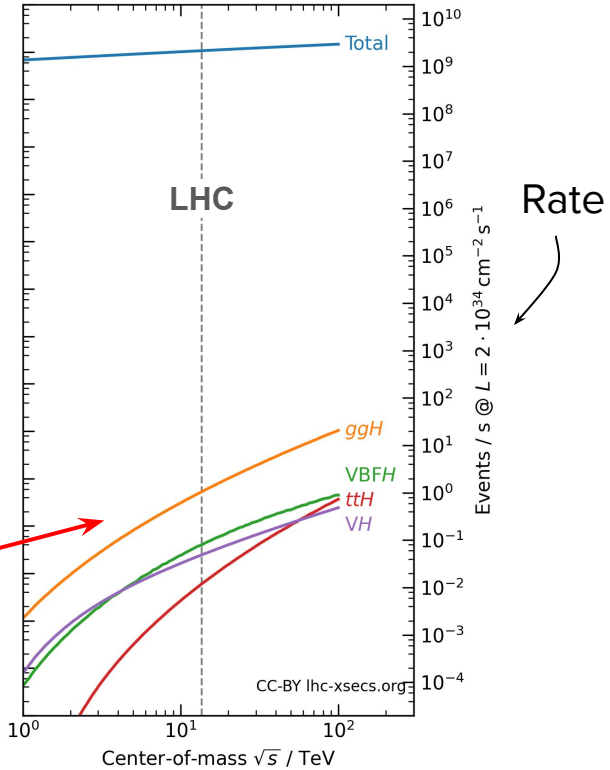
# The vast majority of events are permanently lost




**~99.99% reduction**

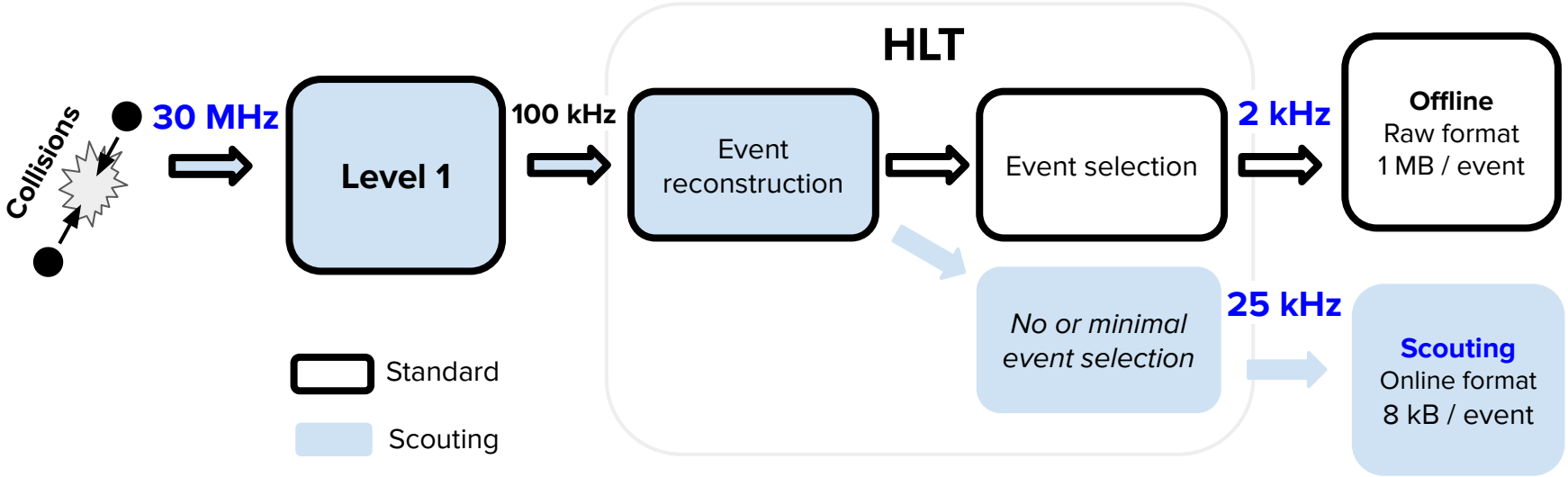
# It can be difficult to distinguish desired interactions from other processes



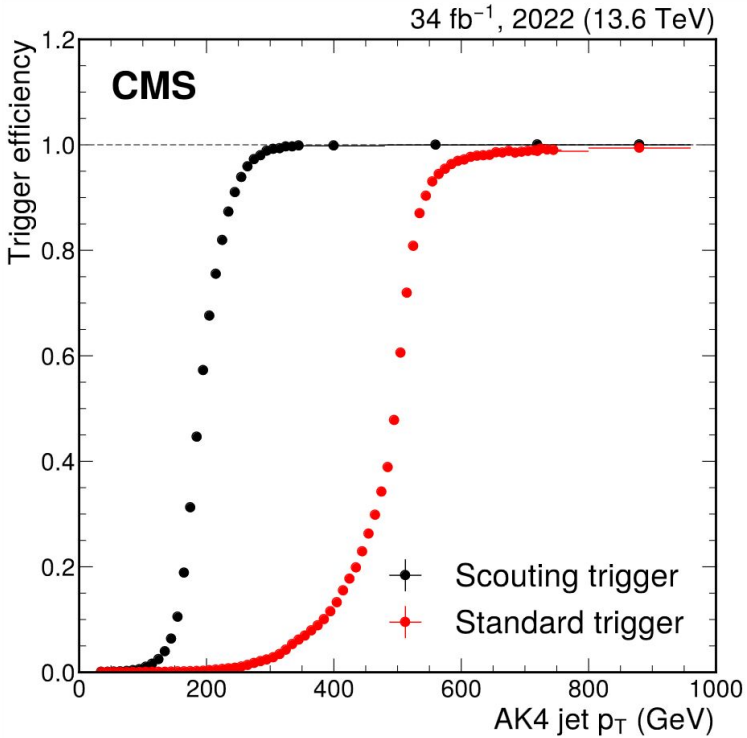




F. Sauerburger, LHC cross section plot, https://lhc-xsecs.org/

# **Scouting** increases the event rate — allowing analysis of previously unexplored phase spaces



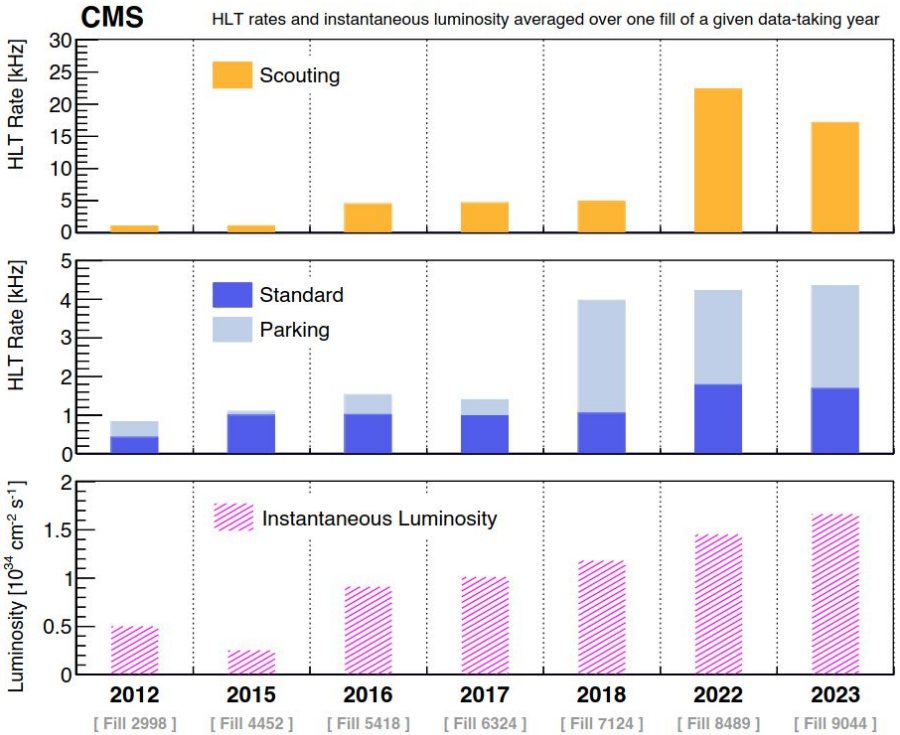
# Access to unexplored phase spaces is achieved by lowering the trigger thresholds




Scouting reaches full efficiency earlier

Potentially revealing new physics that was **previously overlooked** due to higher thresholds

# Scouting had a significant expansion in Run 3



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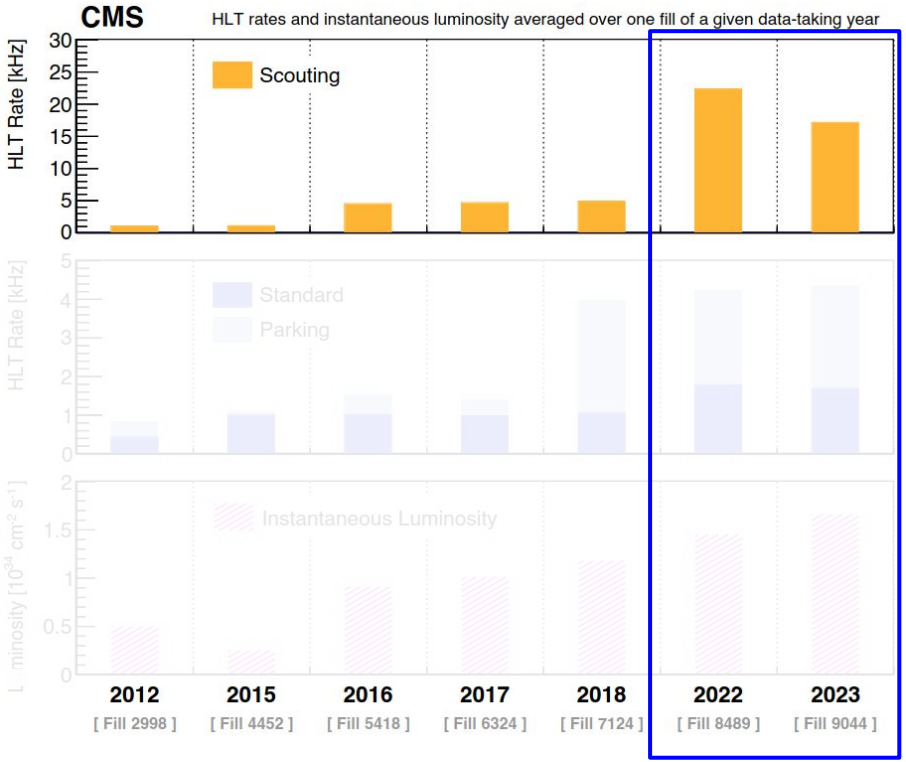

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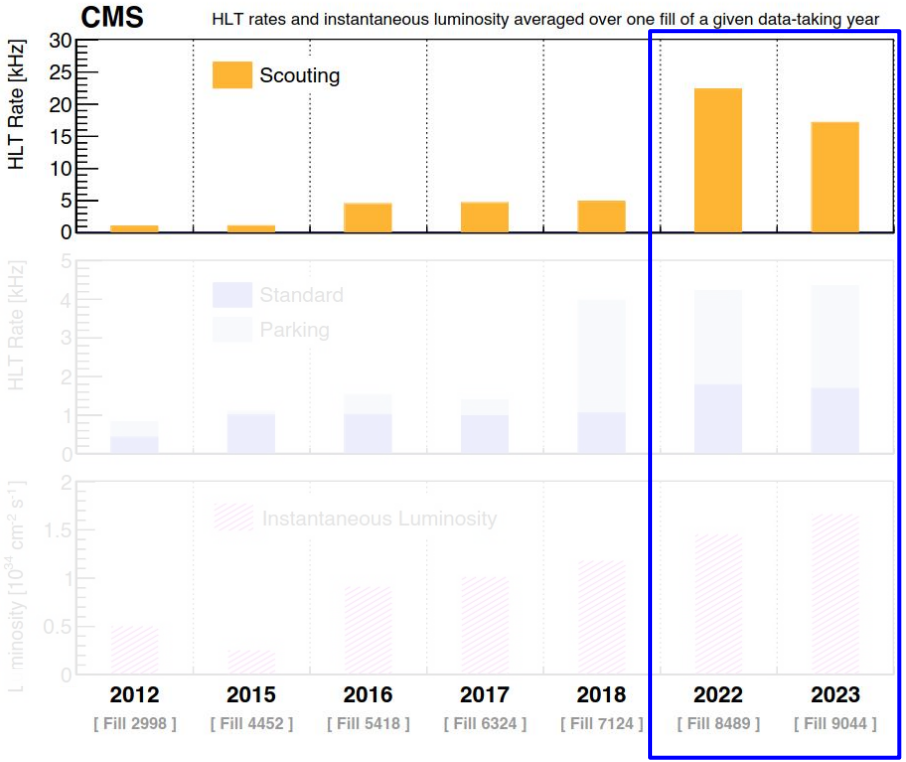


⬅️ More resources

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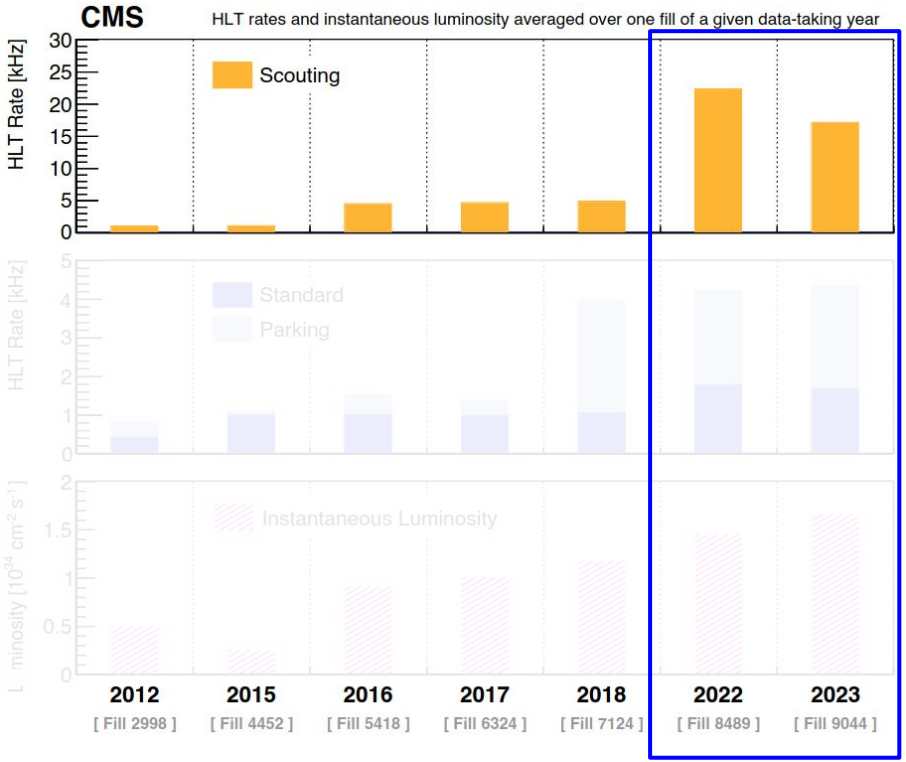


⬅️ More resources

⬅️ Offloading to GPU

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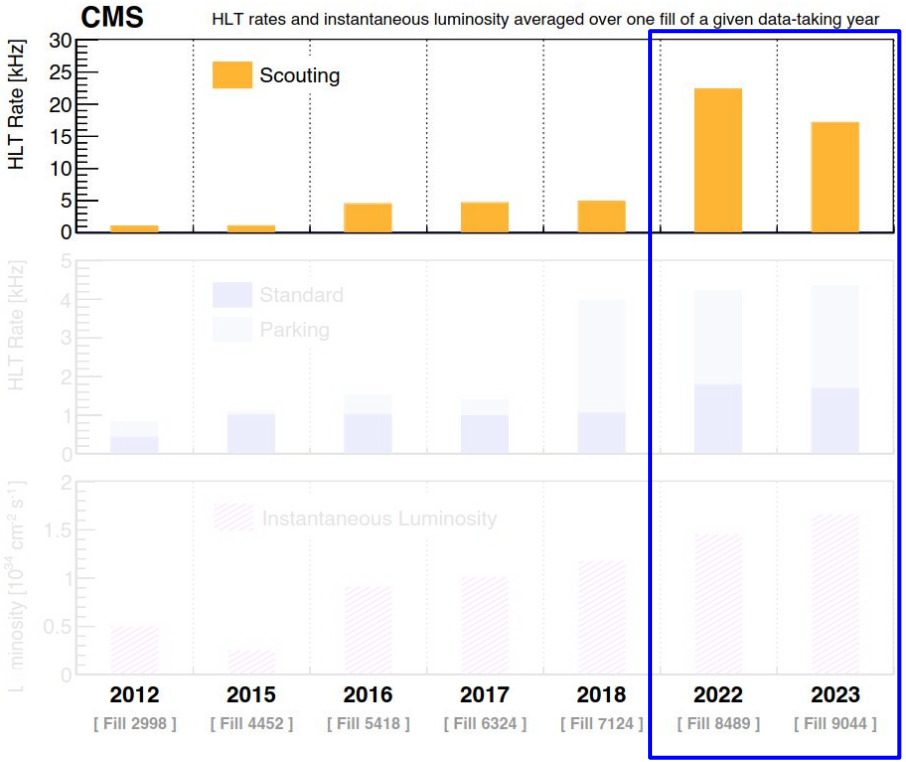
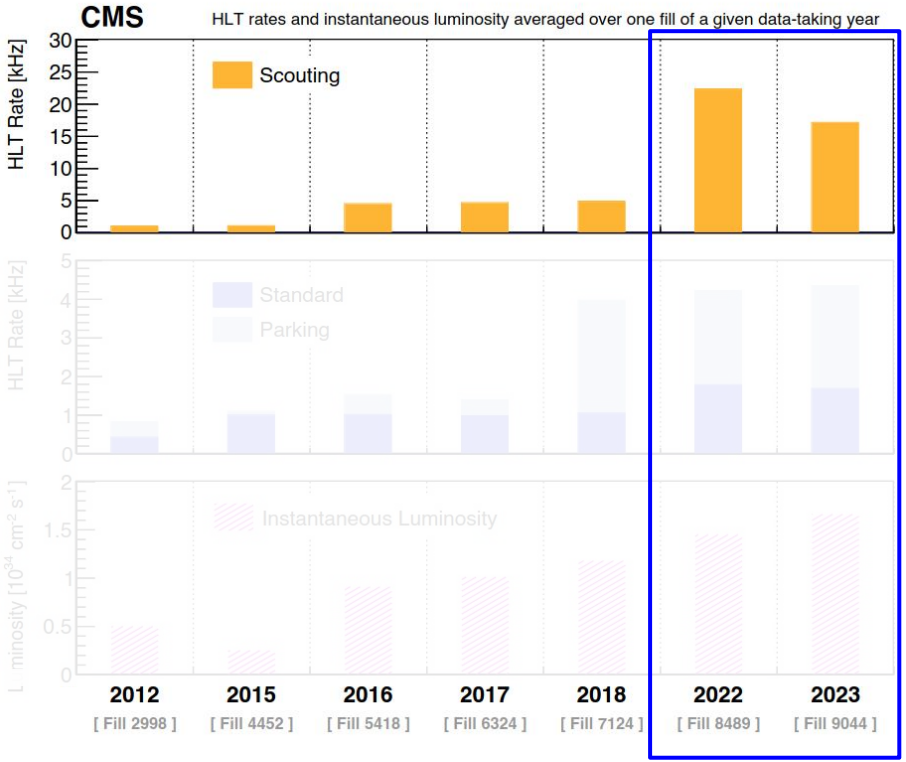


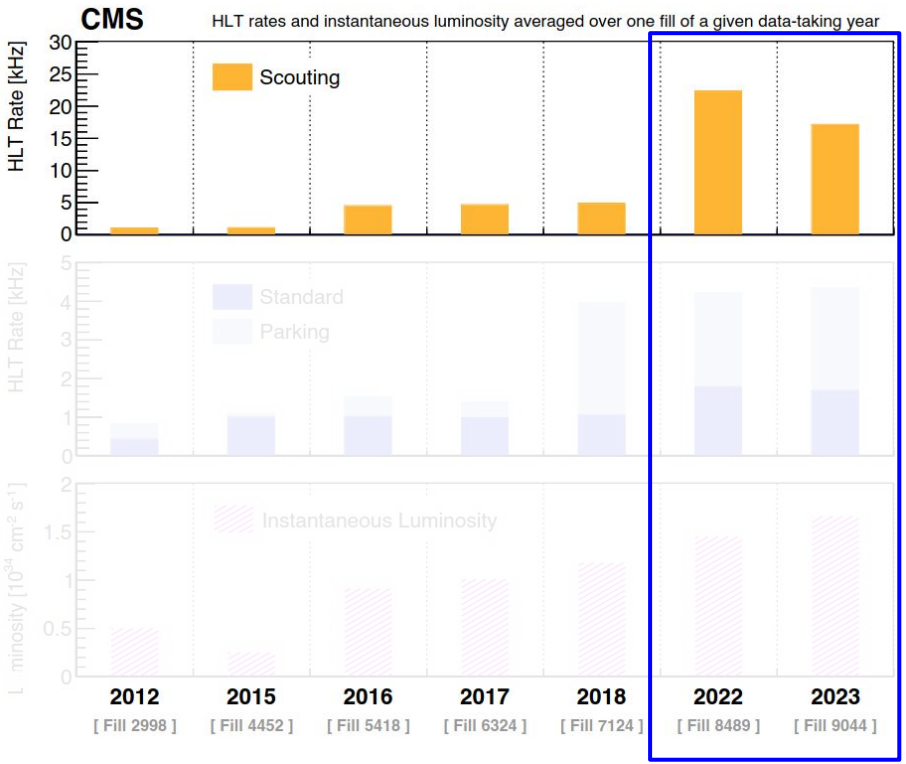

- ⬅️ More resources
- ⬅️ Offloading to GPU
- ⬅️ Advanced reconstruction

# Scouting had a significant expansion in Run 3




- ⬅️ More resources
- ⬅️ Offloading to GPU
- ⬅️ Advanced reconstruction
- ⬅️ Improved event content

# Scouting had a significant expansion in Run 3




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2024-068
2024/03/26

CMS-EXO-23-007

Enriching the physics program of the CMS experiment via data scouting and data parking

The CMS Collaboration*

**Abstract**

Specialized data-taking and data-processing techniques were introduced by the CMS experiment in Run 1 of the CERN LHC to enhance the sensitivity of searches for new physics and the precision of standard model measurements. These techniques, termed data scouting and data parking, extend the data-taking capabilities of CMS beyond the original design specifications. The novel data-scouting strategy trades complete event information for higher event rates, while keeping the data bandwidth within limits. Data parking involves storing a large amount of raw detector data collected by algorithms with low trigger thresholds to be processed when sufficient computational power is available to handle such data. The research program of the CMS Collaboration is greatly expanded with these techniques. The implementation, performance, and physics results obtained with data scouting and data parking in CMS over the last decade are discussed in this Report, along with new developments aimed at further improving low-mass physics sensitivity over the next years of data taking.

*To be submitted to Physics Reports*

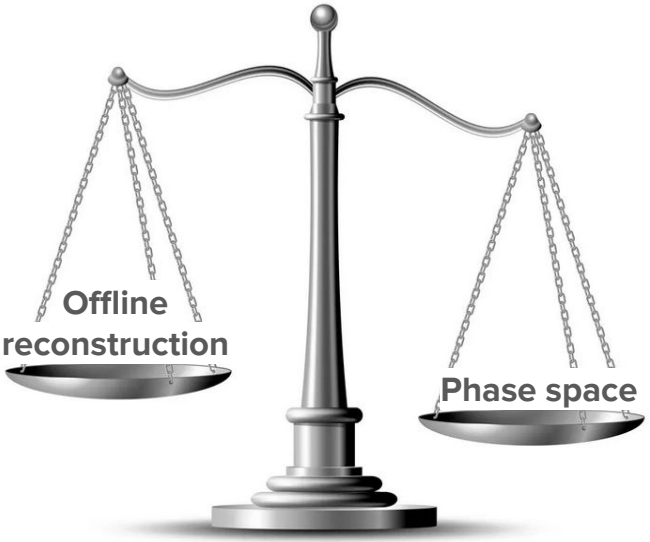


*See Appendix B for the list of collaboration members



arxiv.org/abs/2403.16134

# Trade-off: Offline reconstruction vs Unexplored phase spaces

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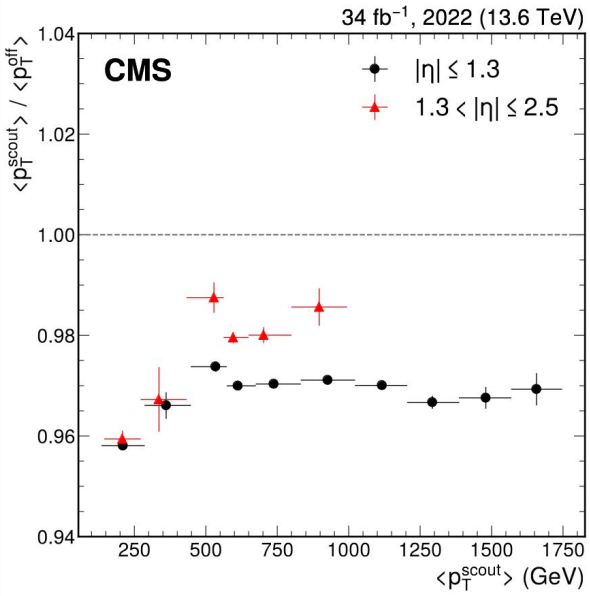
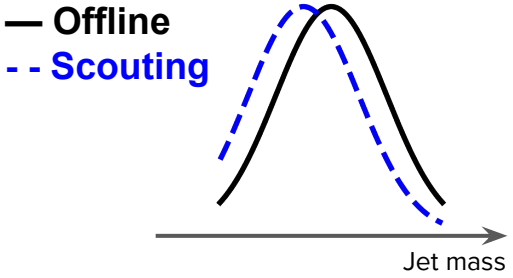
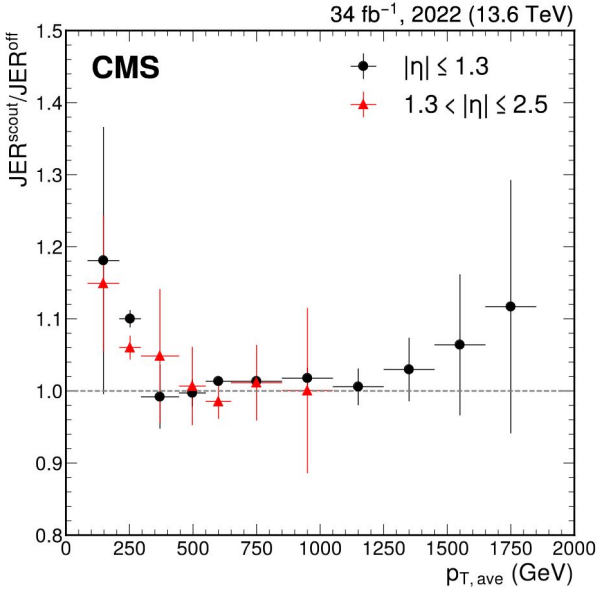
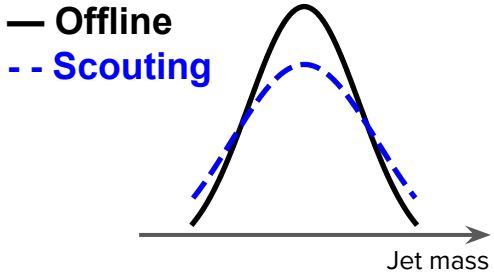
## Comparison of momentum




## Comparison of resolution

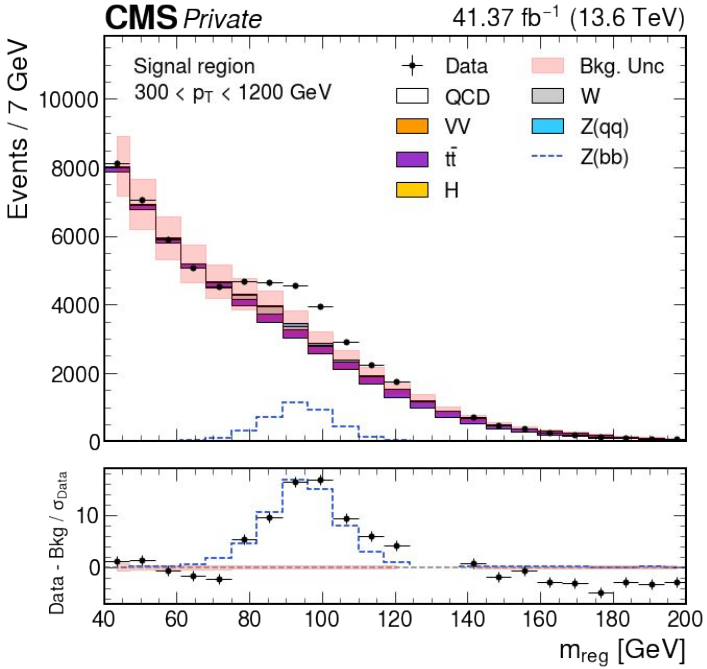



The scouting reconstruction is comparable with that achieved offline

# Validating the scouting strategy by searching for Z → bb production at high momentum transfer

Feasibility study — systematic uncertainties with greatest impact included



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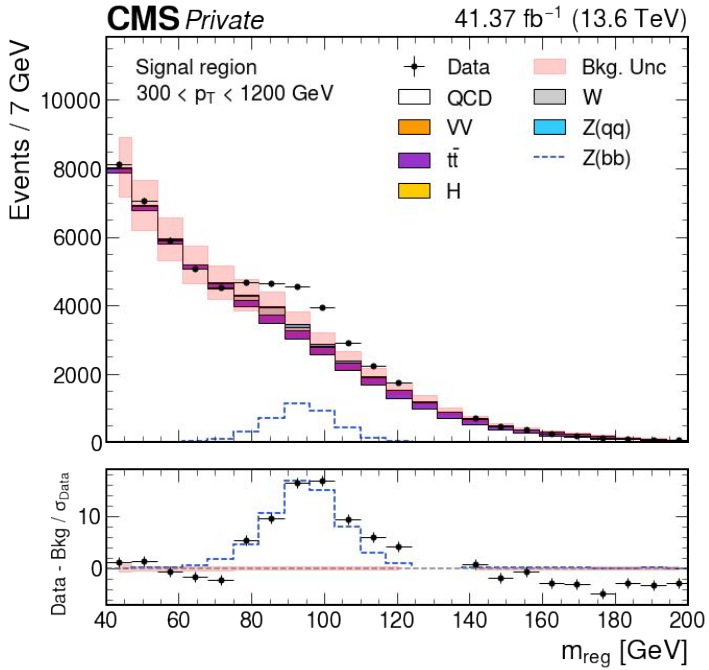
Feasibility study — systematic uncertainties with greatest impact included

$1.1^{+0.1}_{-0.1}$ x SM Z

**In agreement with SM**



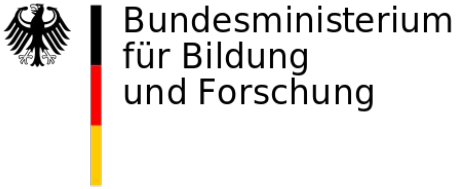
# Summary

- **Scouting broadens the range of events** that are captured by CMS, providing the potential to reveal new physics
- Resolutions of scouting objects approach those achieved by the offline reconstruction
- **Scouting jets are valuable** in searches for boosted boson decay into hadronic final states

**Thanks to Günter Quast, Clemens Lange, Paris Sphicas, the CMS Trigger Studies Group — Elisa Fontanesi & Patin Inkaew, the DAZSLE group — Jennet Dickinson and many more!**


Karlsruher Institut für Technologie


CERN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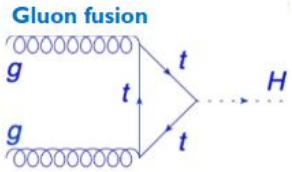
# BACKUP

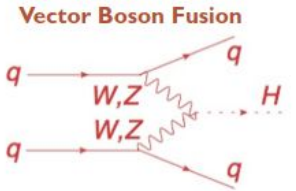
# Standard Model Higgs boson

observed



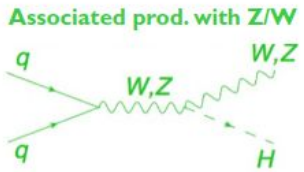

88% of the total

observed



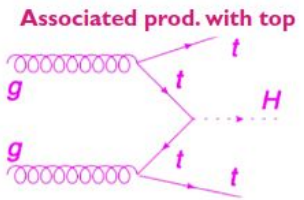

7% of the total

observed

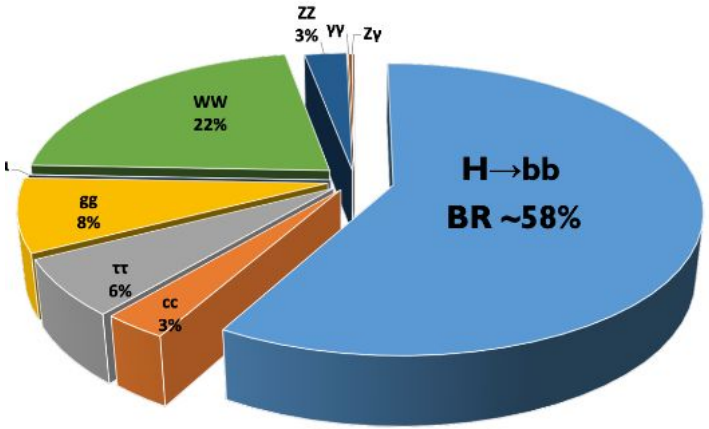



3% of the total

observed




1% of the total



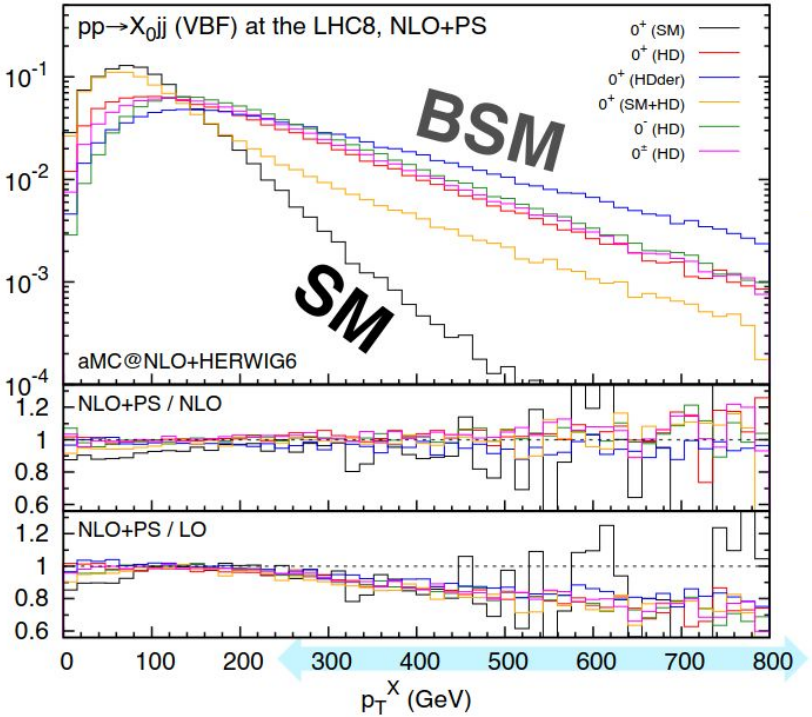

Observed (5$\sigma$) production modes:

- Gluon gluon fusion, VBF (Run-1)
- ttH, VH (Run-2)

Observed (5$\sigma$) decay modes:

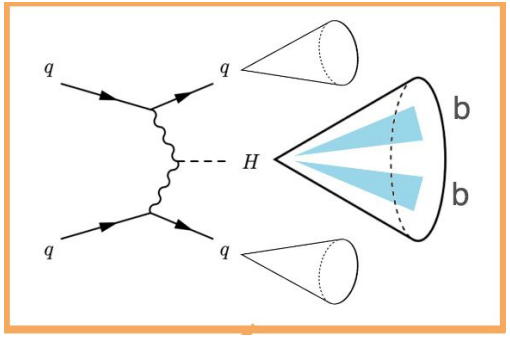
- To bosons: H→ZZ, H→WW, H→$\gamma\gamma$
- To fermions: H→$\tau\tau$, H→bb

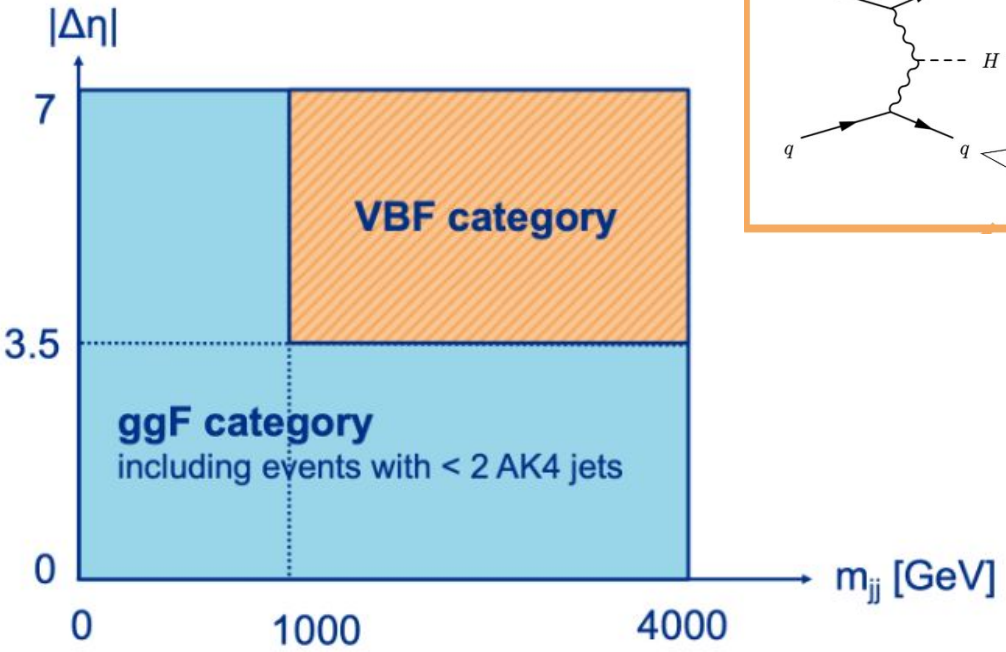
# The transverse momentum spectra is altered by EFT operators

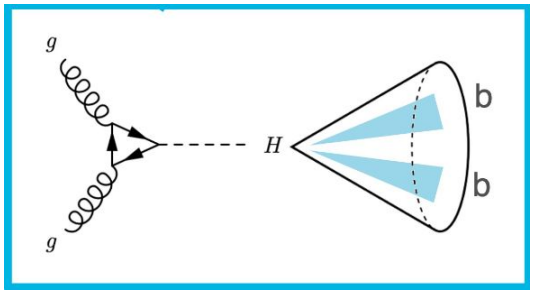


# Relative contribution from different production modes change with transverse momentum

# The VBF production mode is isolated by targeting the two forward going quarks



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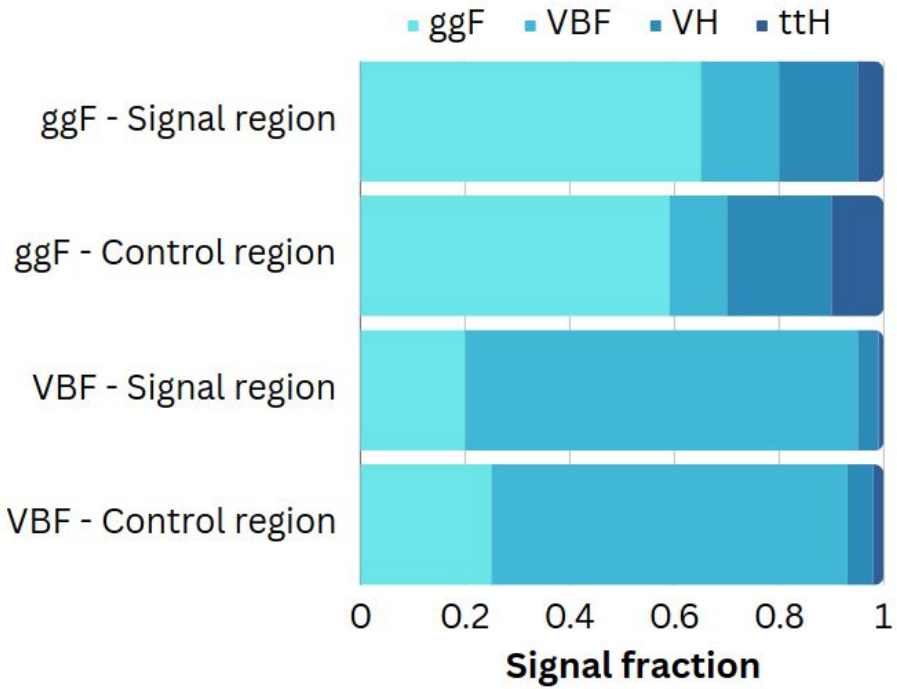
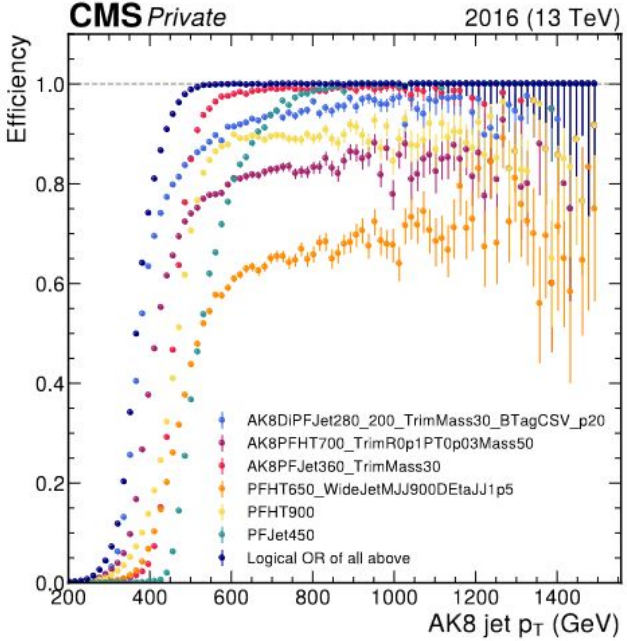
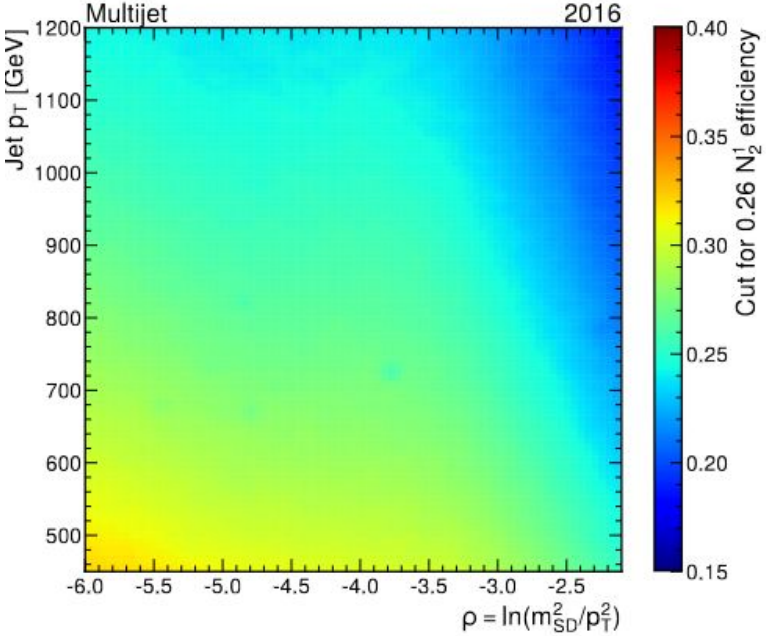


# VBF analysis strategy

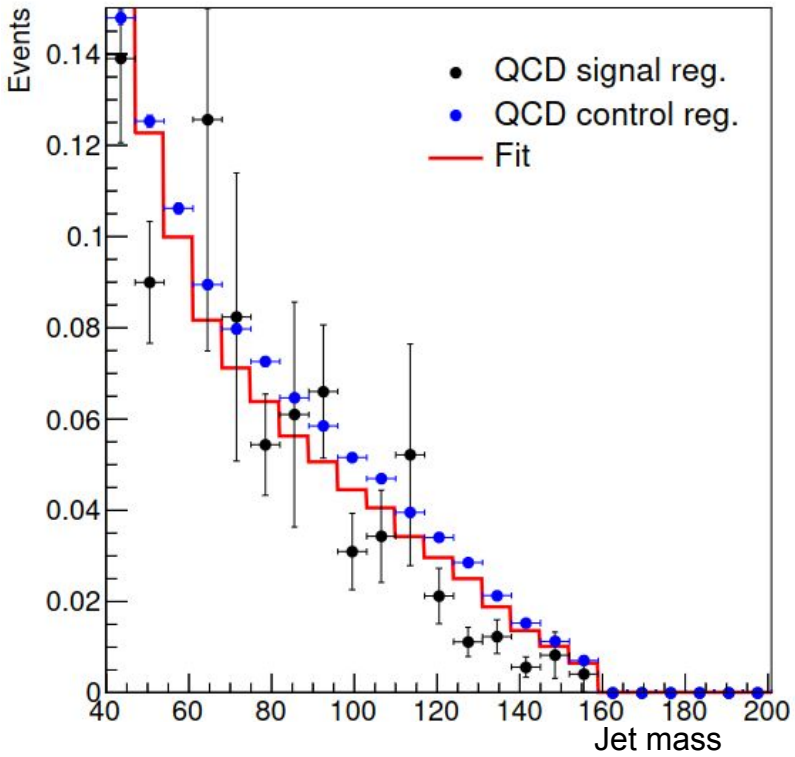
- Require H candidate jet with $p_T$ > 450 GeV and 2-prong substructure
  - Minimum $p_T$ set by trigger limitations
- Apply jet flavour tagger selection
  - Tagger is decorrelated from H candidate mass
- Events failing tag selection are used to estimate non-resonant background (soft QCD interactions)
- Fit to H jet soft drop mass distribution

# VBF analysis strategy



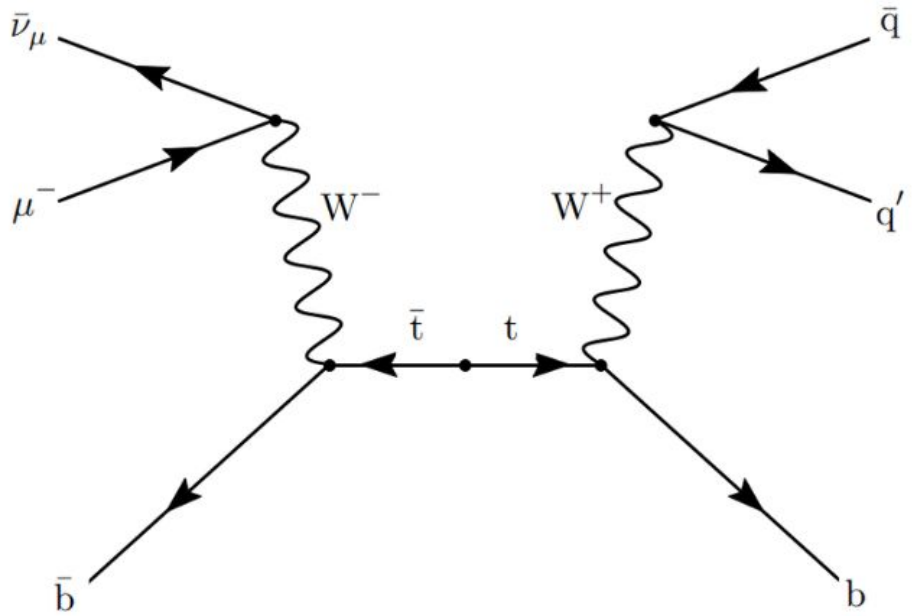



# QCD background estimation




- Control potential shape effects introduced by the tagger (simulation)
- Control discrepancies in tagger selection between data and simulation

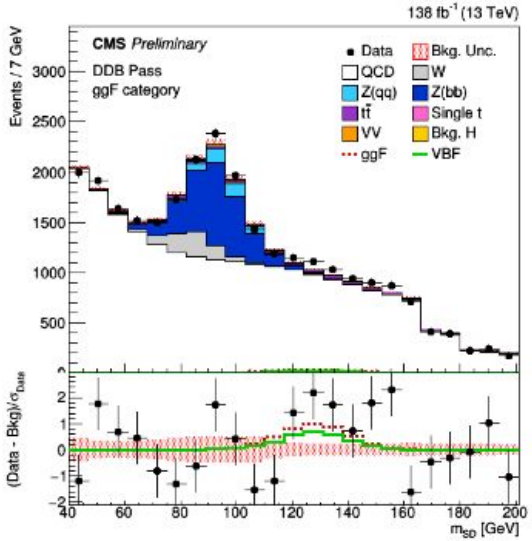
# Top quark background estimation



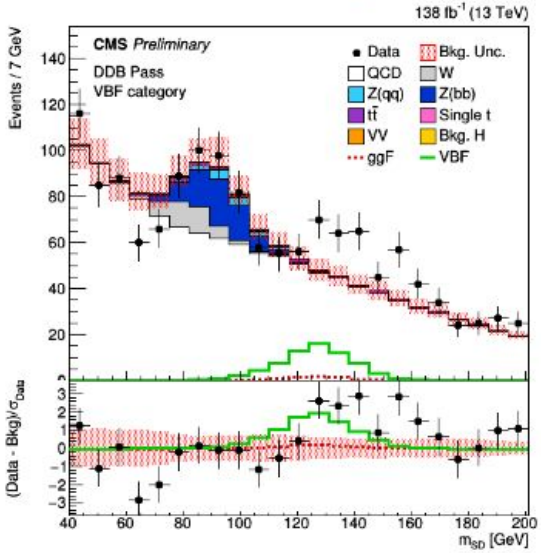

- Control for normalisation differences in data and simulation
- Control discrepancies in tagger selection between data and simulation

# Simultaneous fit of ggF and VBF

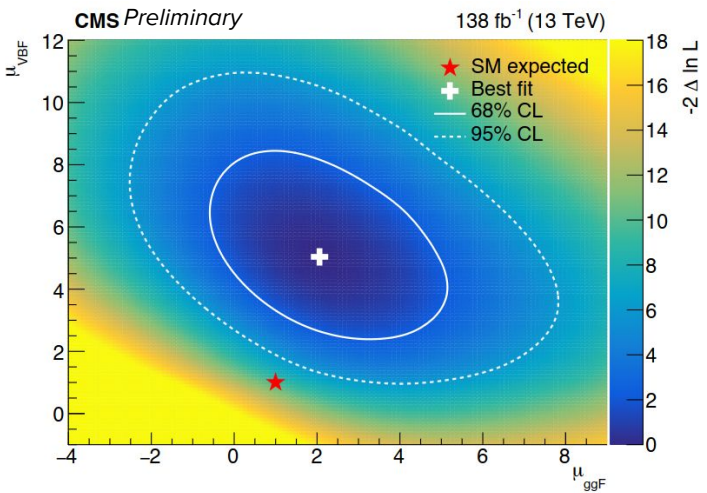
**ggF category**
summed over $p_T$ bins

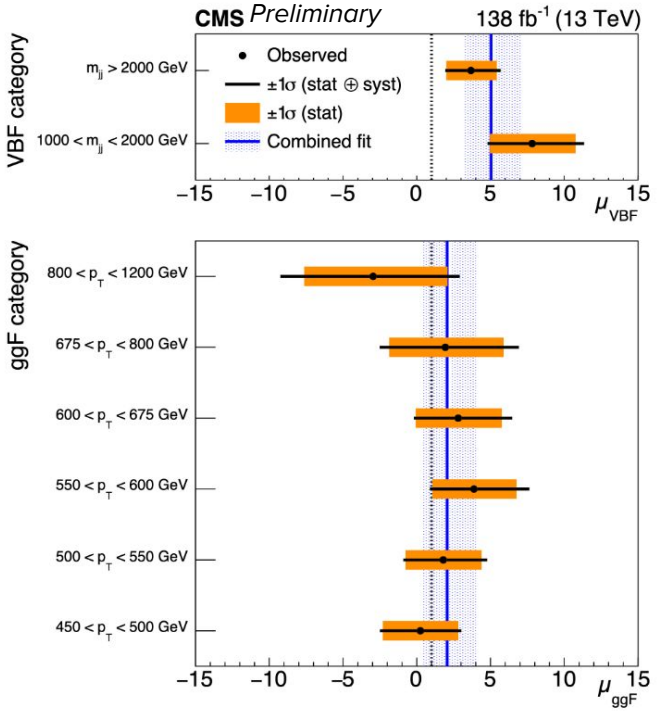



**VBF category**
summed over $m_{jj}$ bins

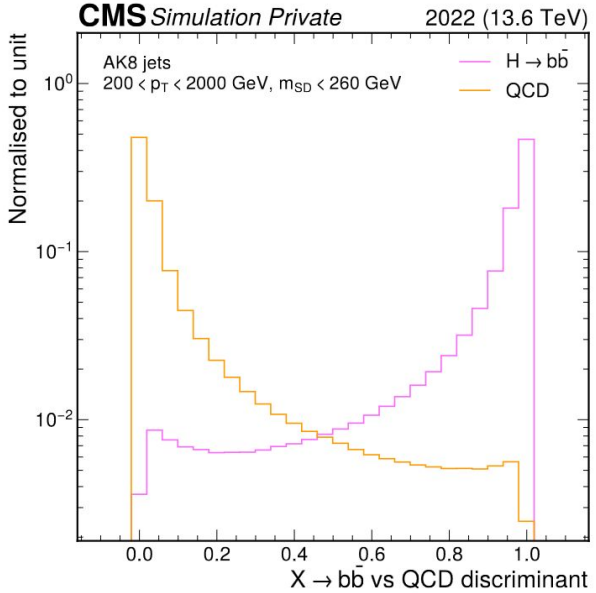


# Simultaneous fit of ggF and VBF

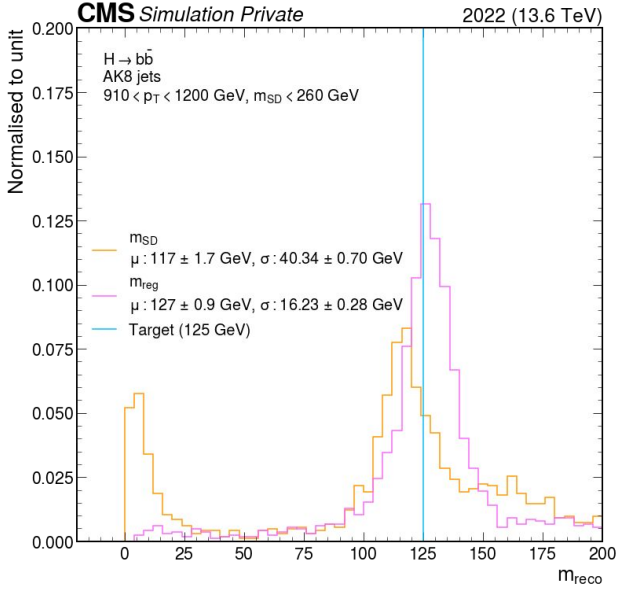


# Using the scouting strategy to search for boosted H production

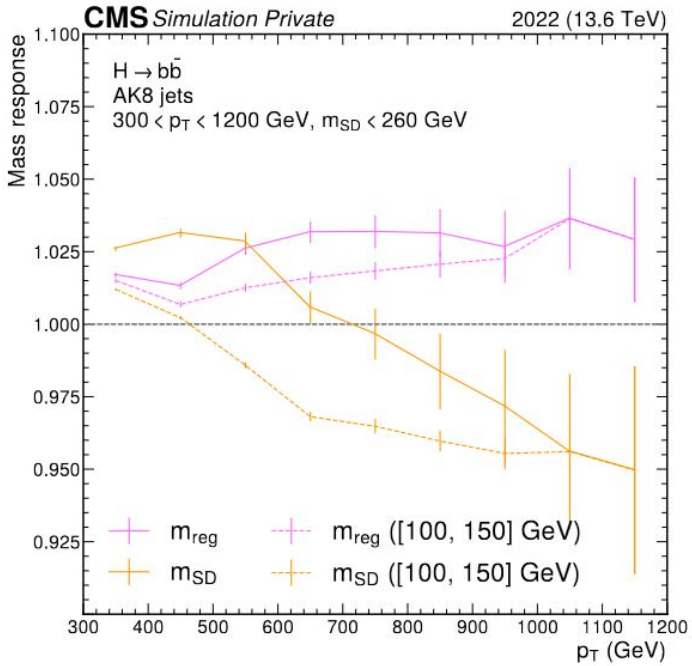


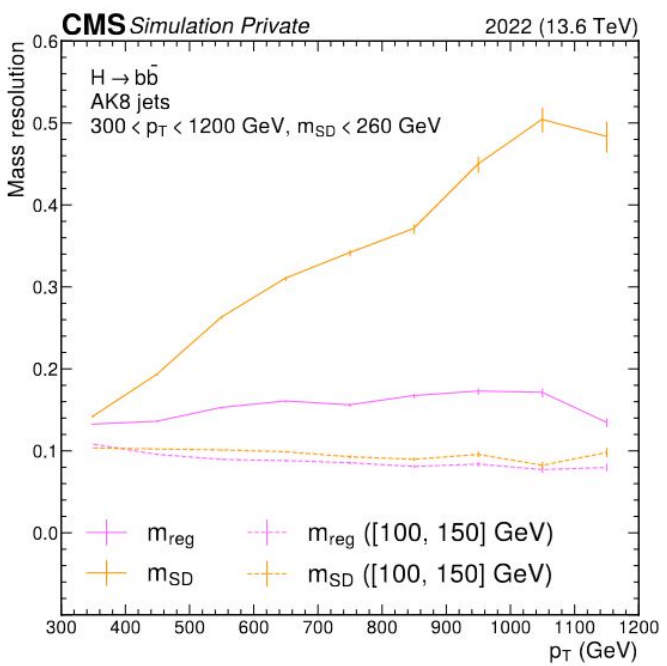

40% likelihood of correctly identifying signal jets
⟶0.6% likelihood of misidentifying QCD jets



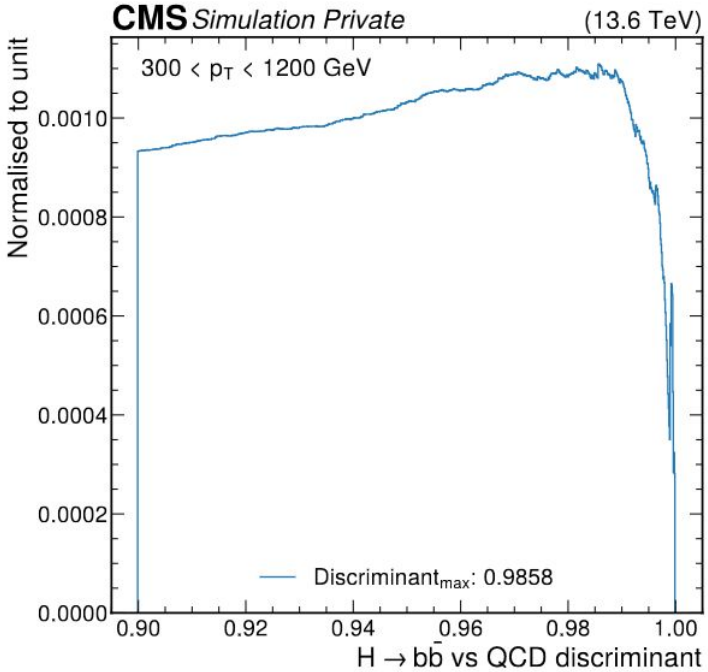

Jet mass resolution of roughly 10%

# Using the scouting strategy to search for boosted H production



# Using the scouting strategy to search for boosted H production

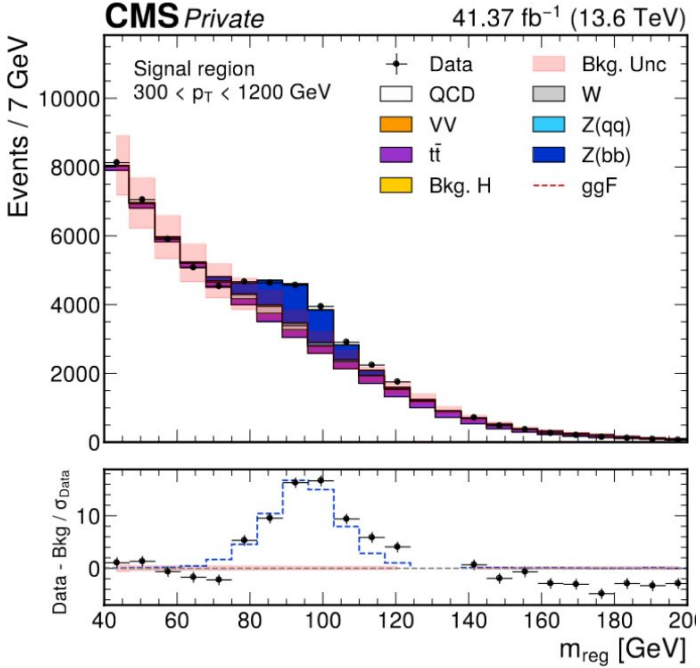


# Validating the scouting strategy by searching for boosted Z → bb production

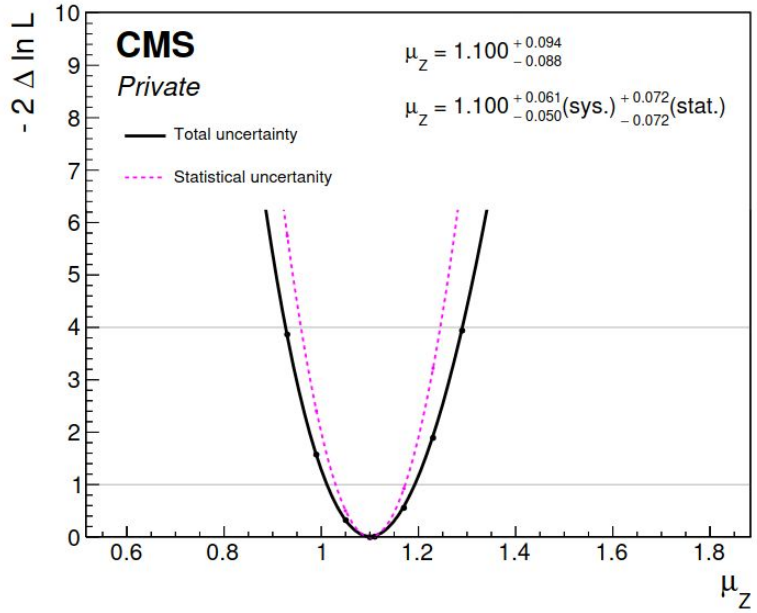
Feasibility study — systematic uncertainties with greatest impact included

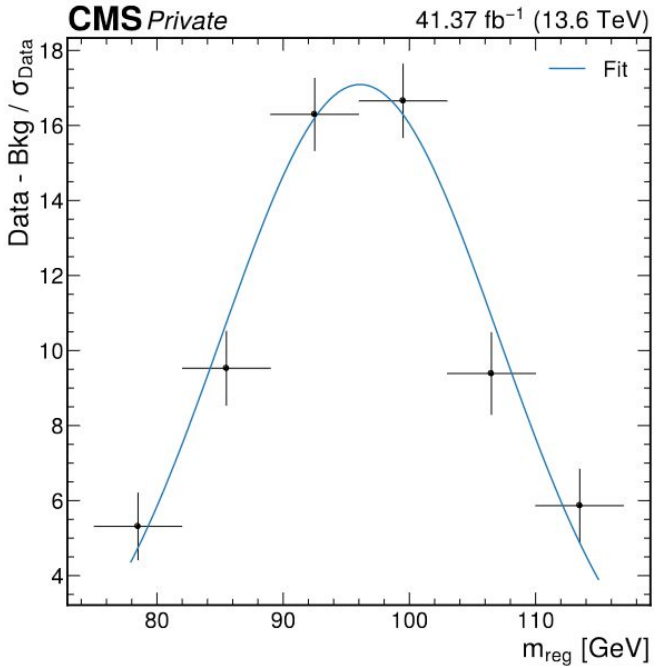
$1.1^{+0.1}_{-0.1}$ x SM Z

**In agreement with SM**



# Validating the scouting strategy by searching for boosted Z → bb production

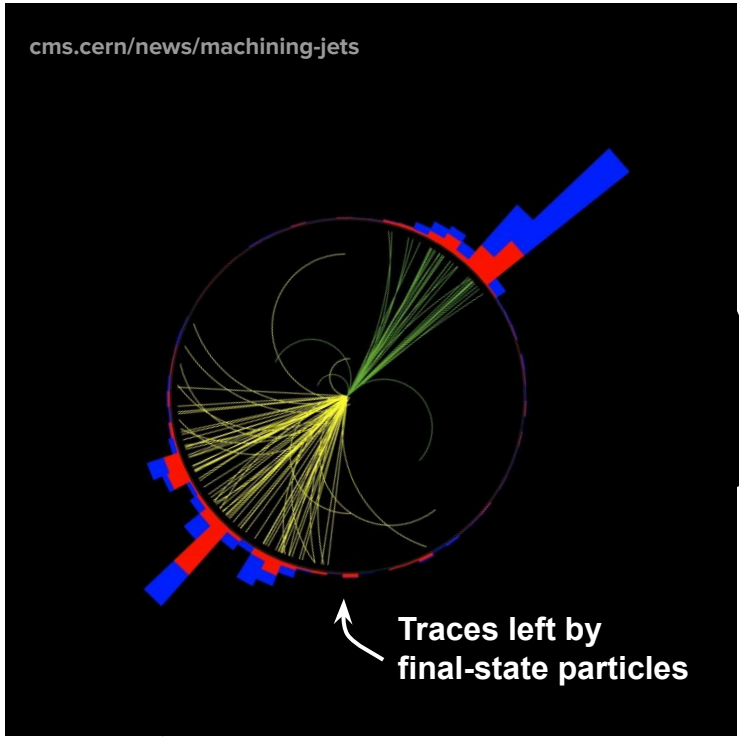


# Performing a more exploratory analysis of searching for inclusive boosted H production

- Work is still ongoing
- Expected significance exceeds that of Run 2 analysis, even with ⅓ the integrated luminosity cds.cern.ch/record/2721858

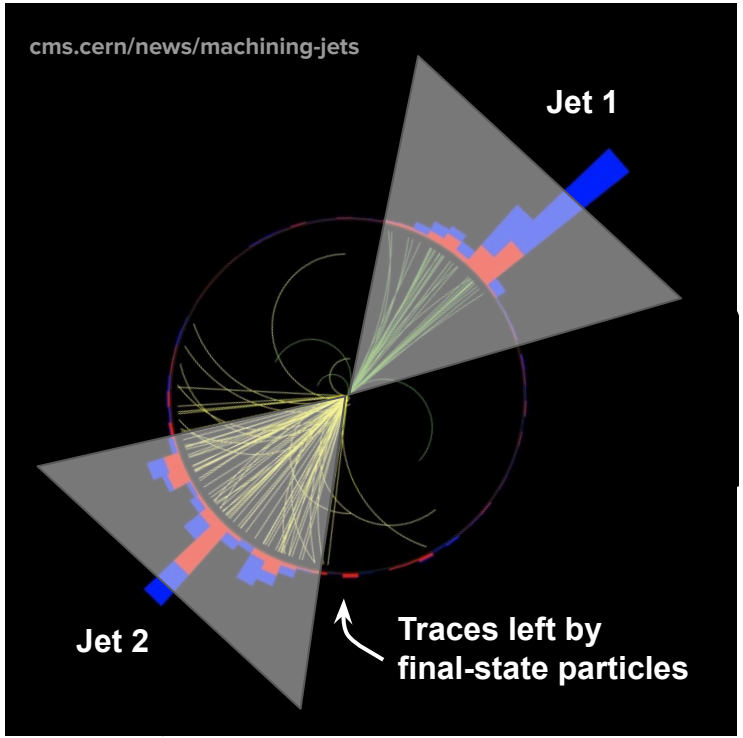
# Parton interactions often give rise to a cascade of quarks and gluons that form hadrons



# Parton interactions often give rise to a cascade of quarks and gluons that form hadrons

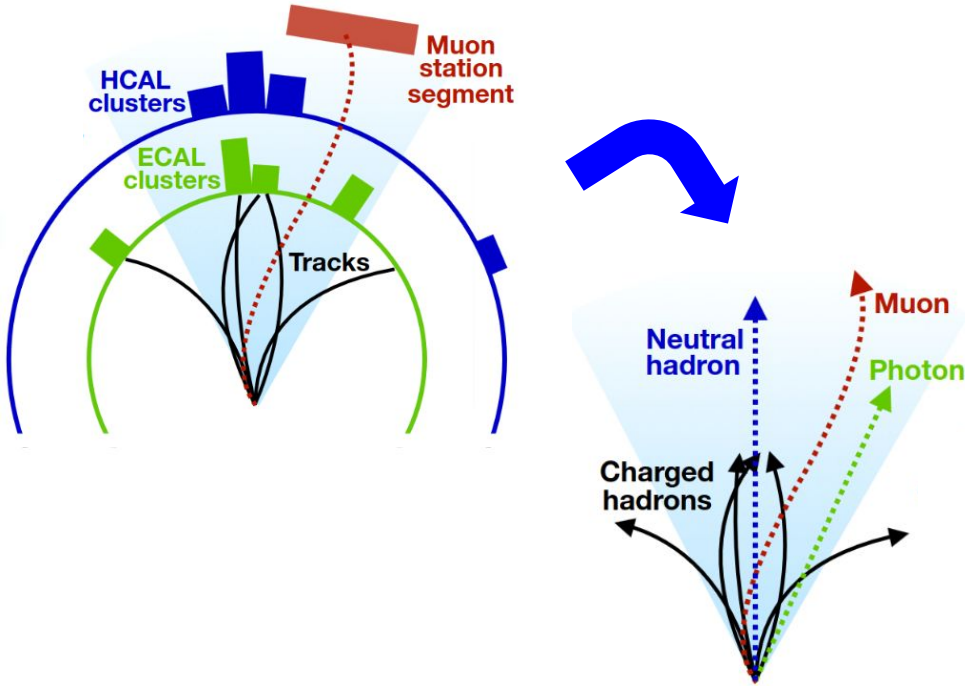
Final-state particles are clustered to reduce the complexity of the final-state

H decay also result in final-states involving jets



# Online reconstruction uses similar but simplified algorithms to the offline reconstruction

Traces of particles




PF reconstruction