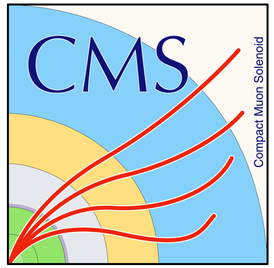


Science and Technology Facilities Council

Rutherford Appleton Laboratory

7 August 2024

Run 3 Trigger Level Scouting at the CMS experiment

A.R.SAHASRANSU

The Compact Muon Solenoid (CMS) experiment

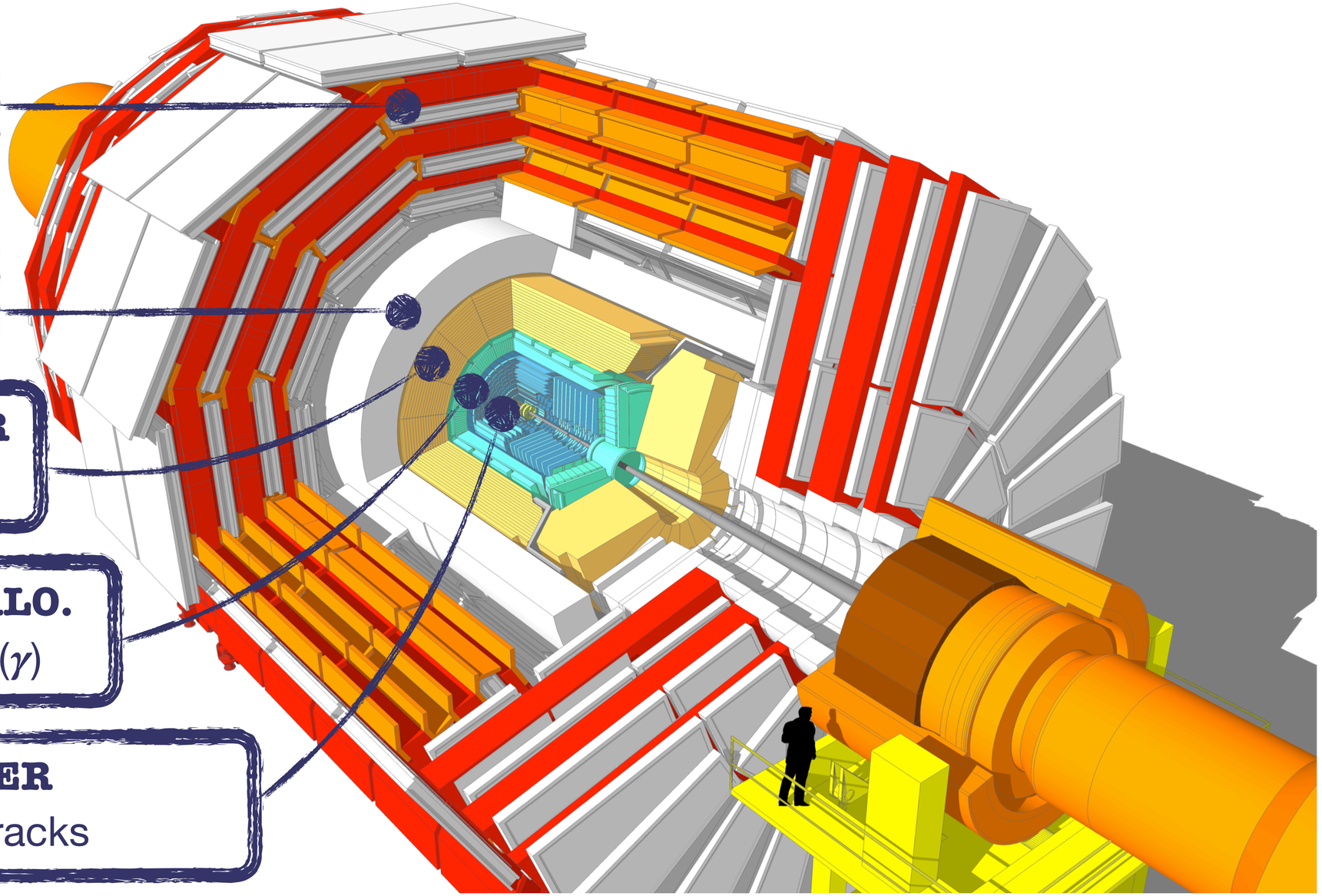
MUON CHAMBERS
Detect Muons (μ).

SOLENOID
3-momentum of Tracks

HADRON CALORIMETER
Jets

ELECTROMAGNETIC CALO.
Electrons (**e**) and Photons (γ)

SILICON TRACKER
All charged particle Tracks



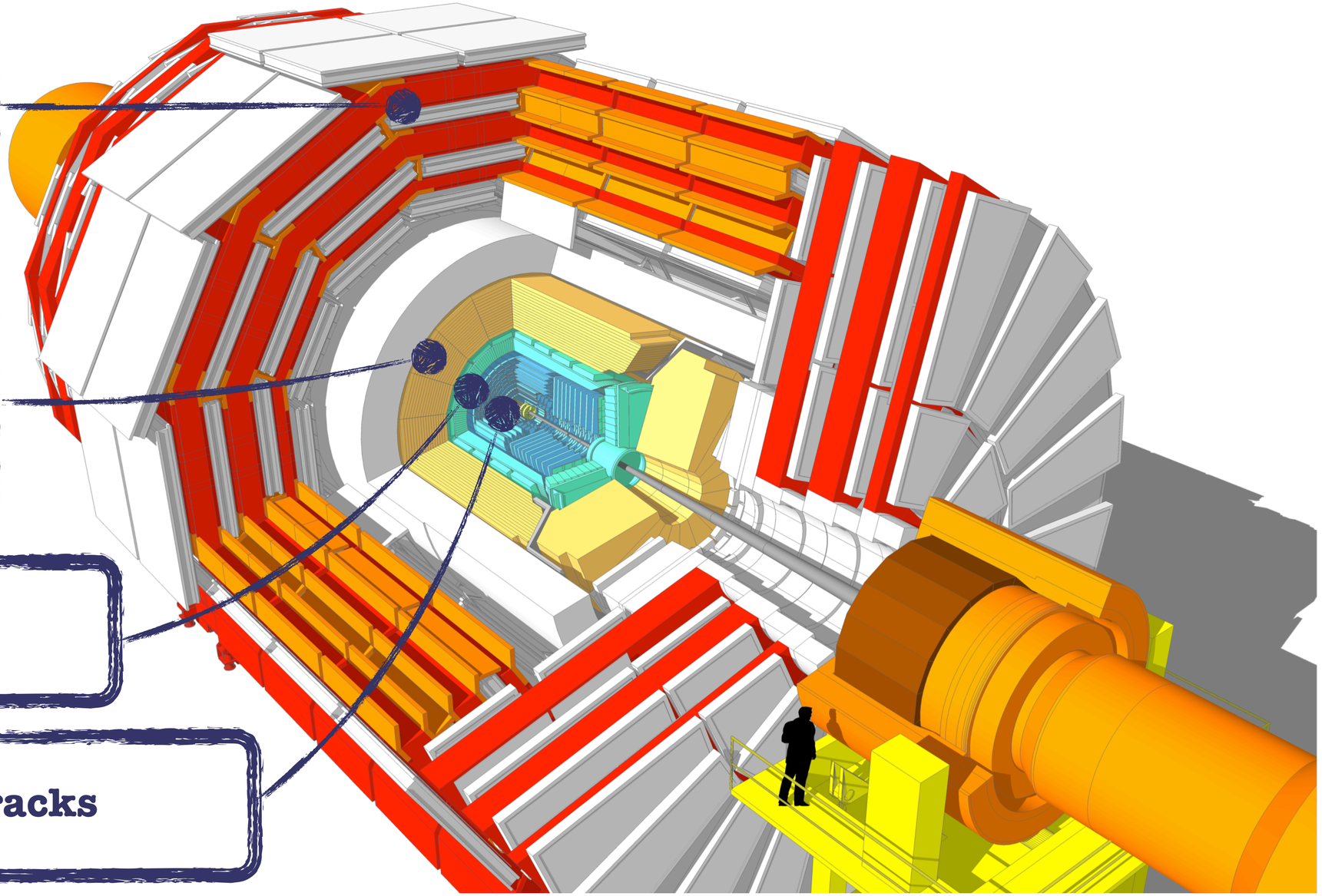
Reconstructed Physics Objects

μ

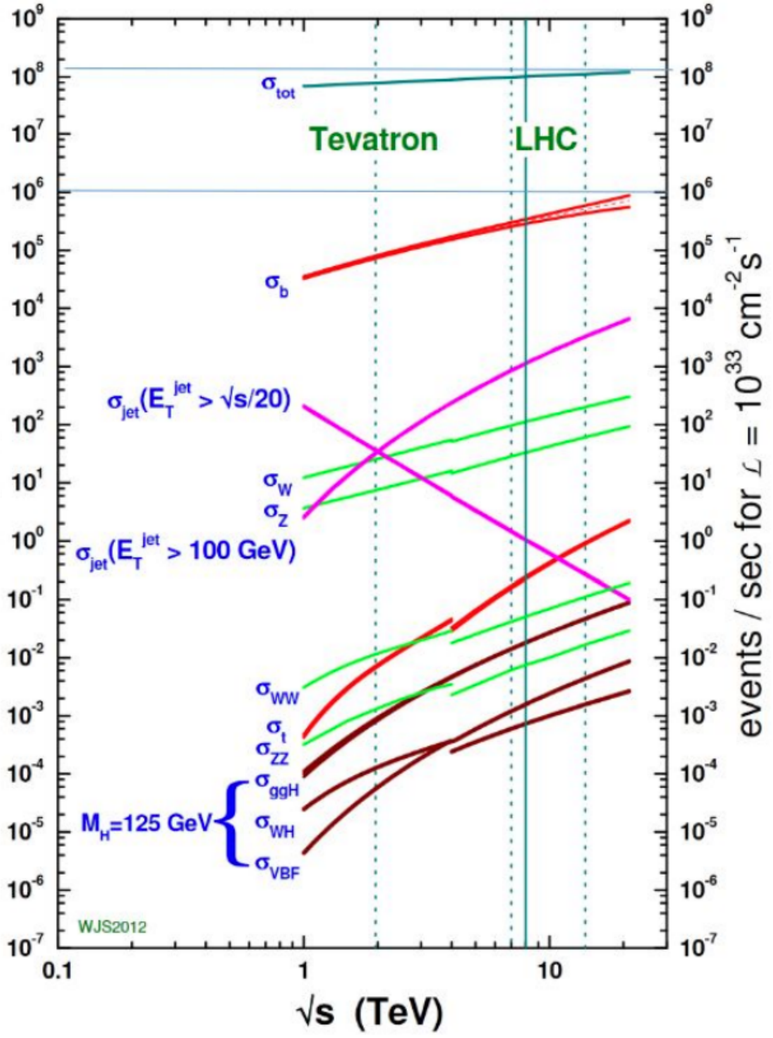
Jets,
Missing Transverse Energy (MET),
Scalar sum of energy deposit (HT)

e and γ

Charged Particle Tracks

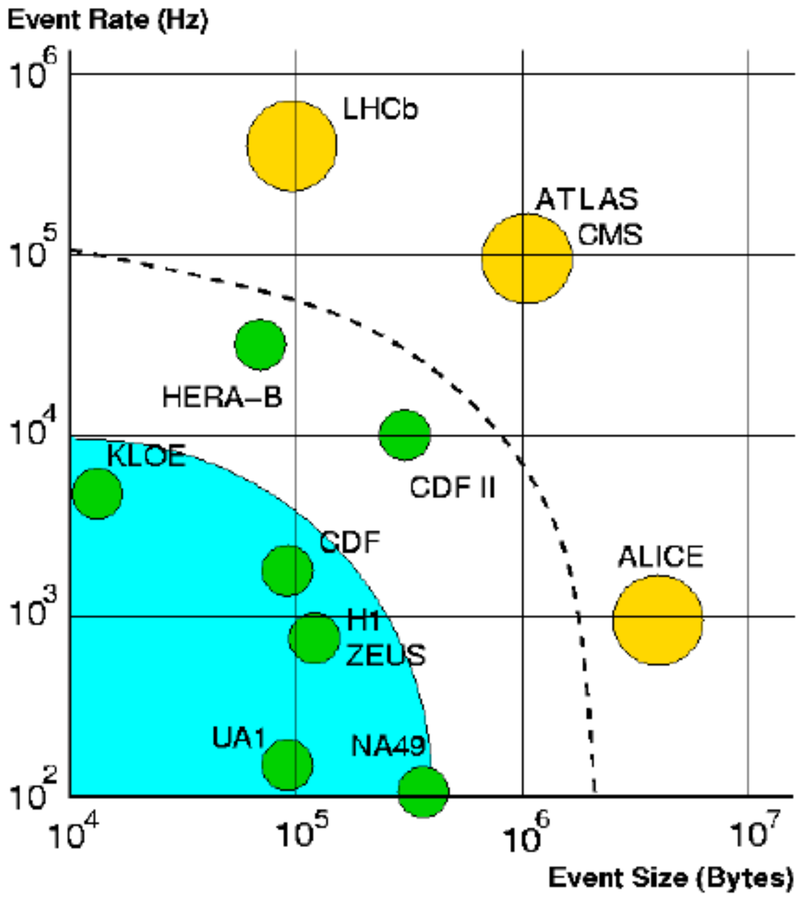


Triggering is essential at collider experiments



1206.7024

Rare physics ⇒ High Luminosity



GridPP collaboration

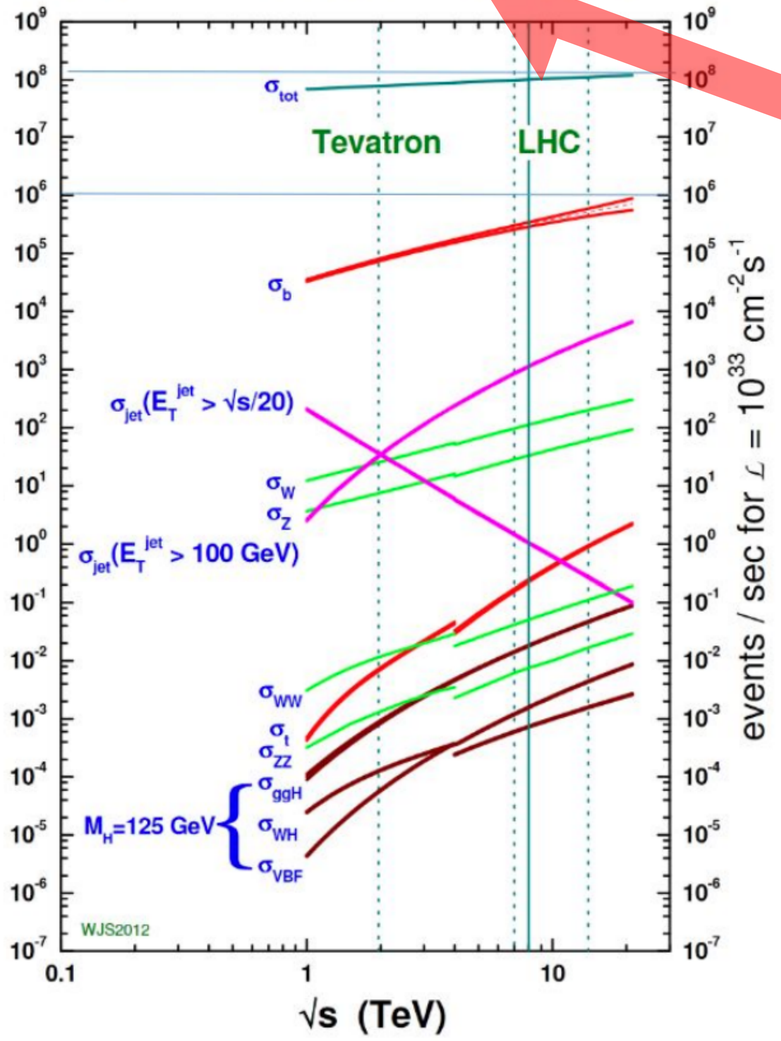
In 2018

- 1 million **H** bosons
- 1 billion **Z** bosons
- 10^4 trillion QCD

High Luminosity
⇒
Large Data

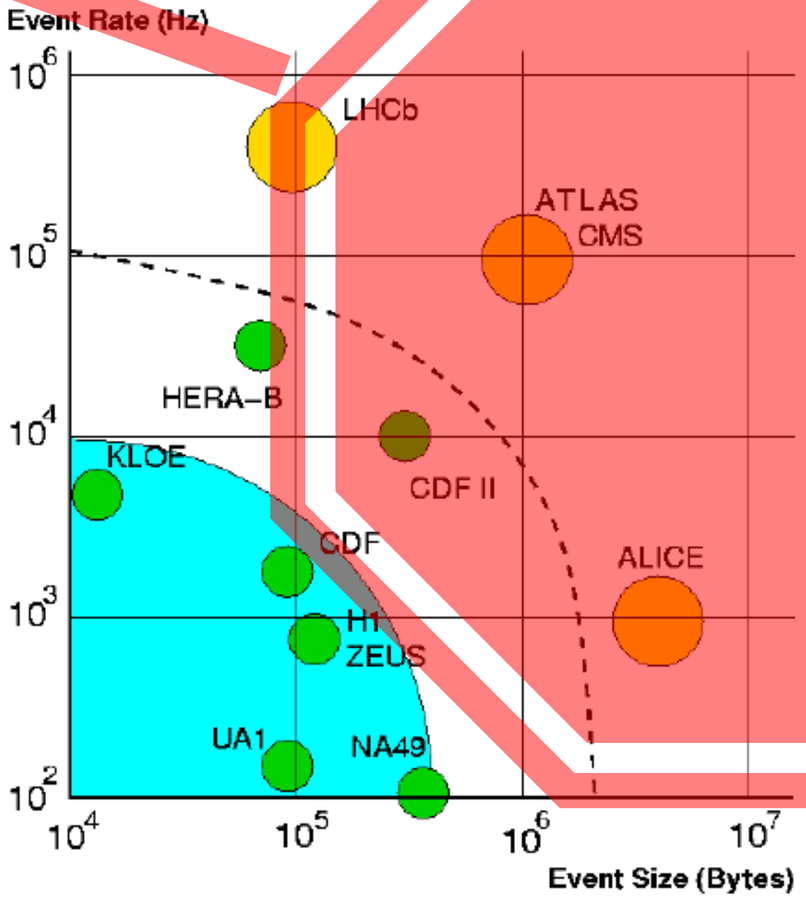
1 MB/s at 26 MHz
⇒ 26 TB/s ⇒
0.5 exa-byte / 9 mth

Triggering is essential at collider experiments



1206.7024

Rare physics ⇒ High Luminosity



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CMS Data Content

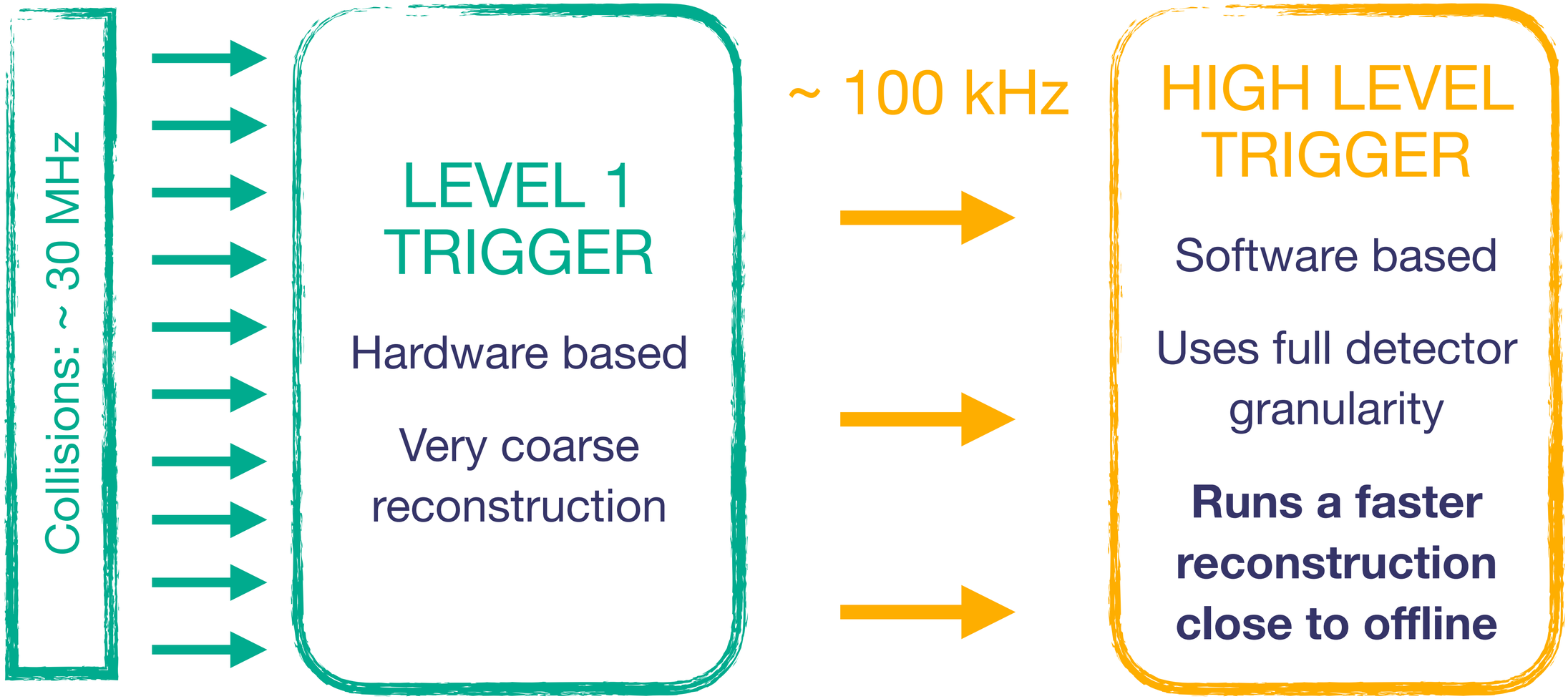
Sub-detector system	Run 2 (kB / event)	Run 3 (kB / event)
Tracker Strips	731	731
Tracker Pixels	259	259
Hadronic Calo.	170	391
Electromagnetic Calo.	128	128
Muons System	107.5	129.5
TOTAL	1400	1600

JINST 19 (2024) 05, P05064

- Data content observed at peak luminosities.
- Replace the full detector data with a summary.

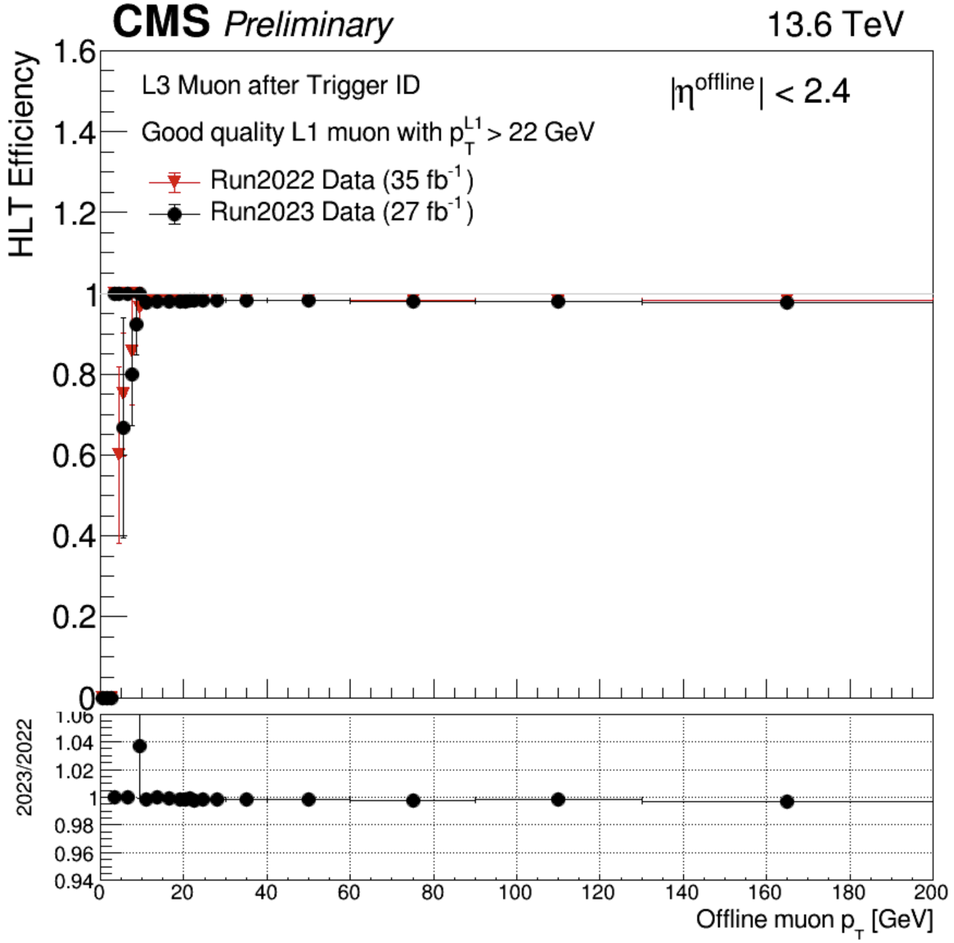
Reduce data:
O(1 MB)/event
⇒
O(10 kB)/event.

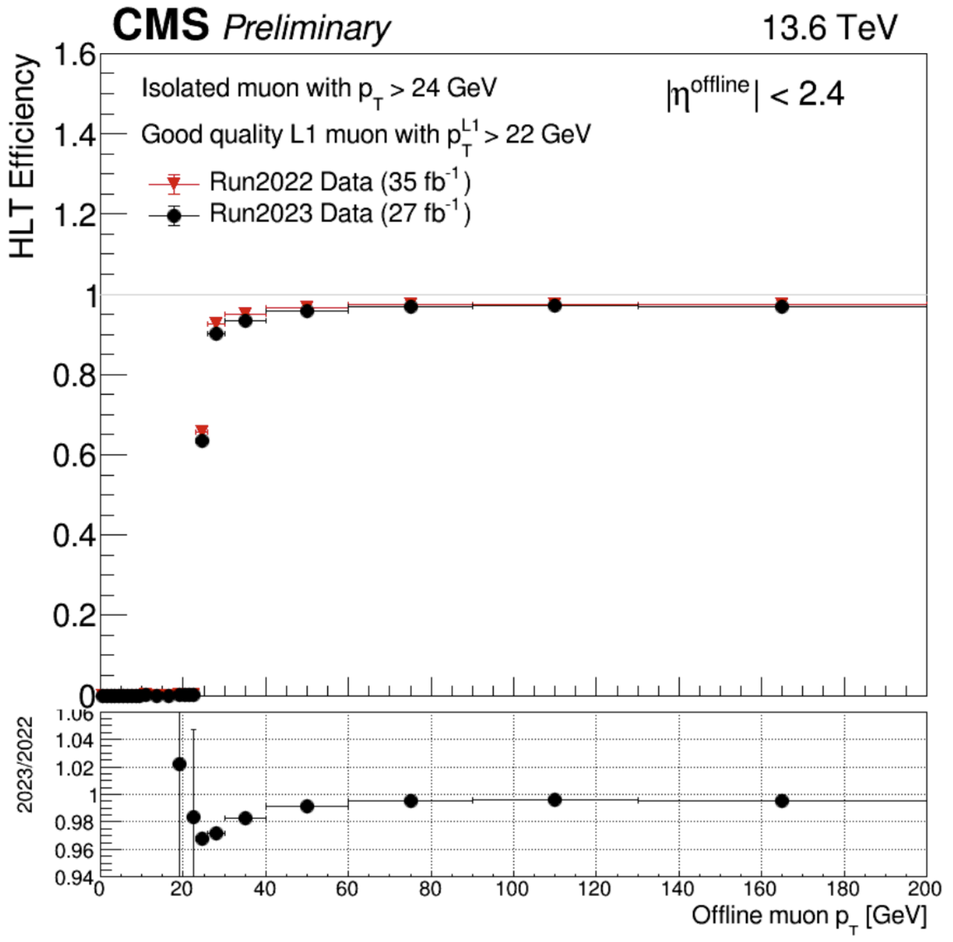
Use the HLT reconstruction



HLT reconstruction: Muons

Efficiency measured with respect to offline muons matched to an L1 muon.





HLT reconstruction: Muons

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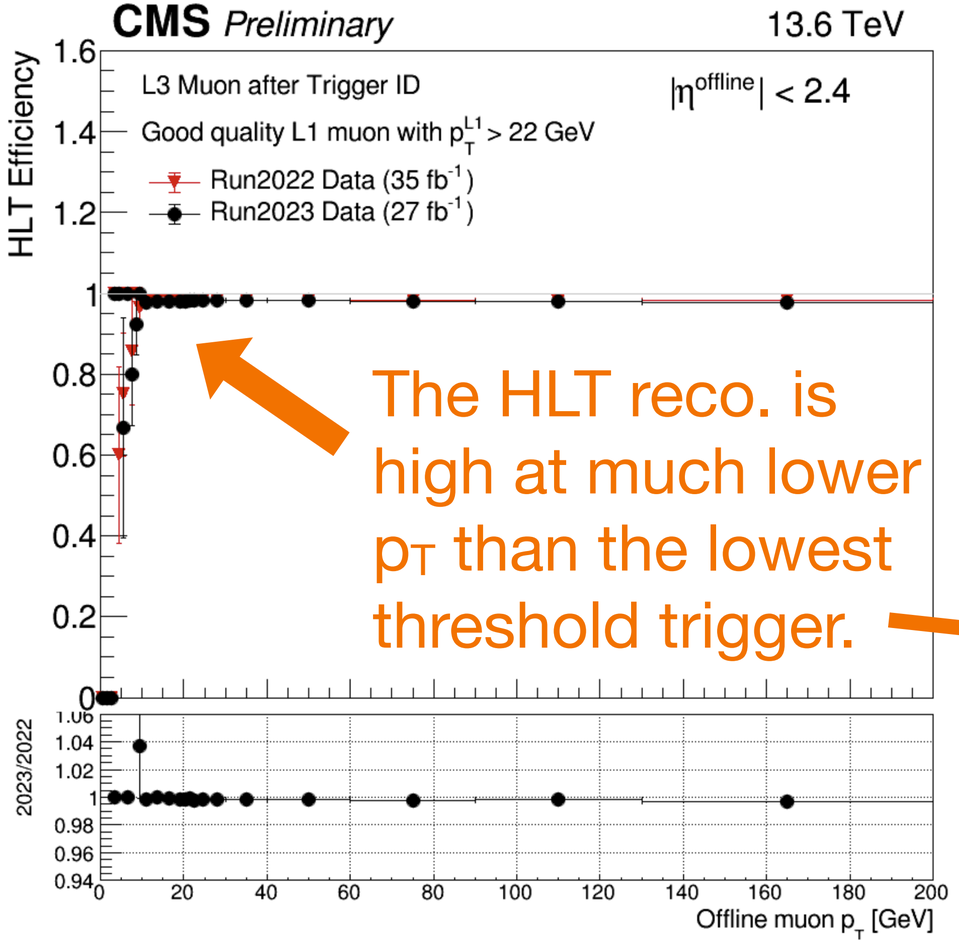
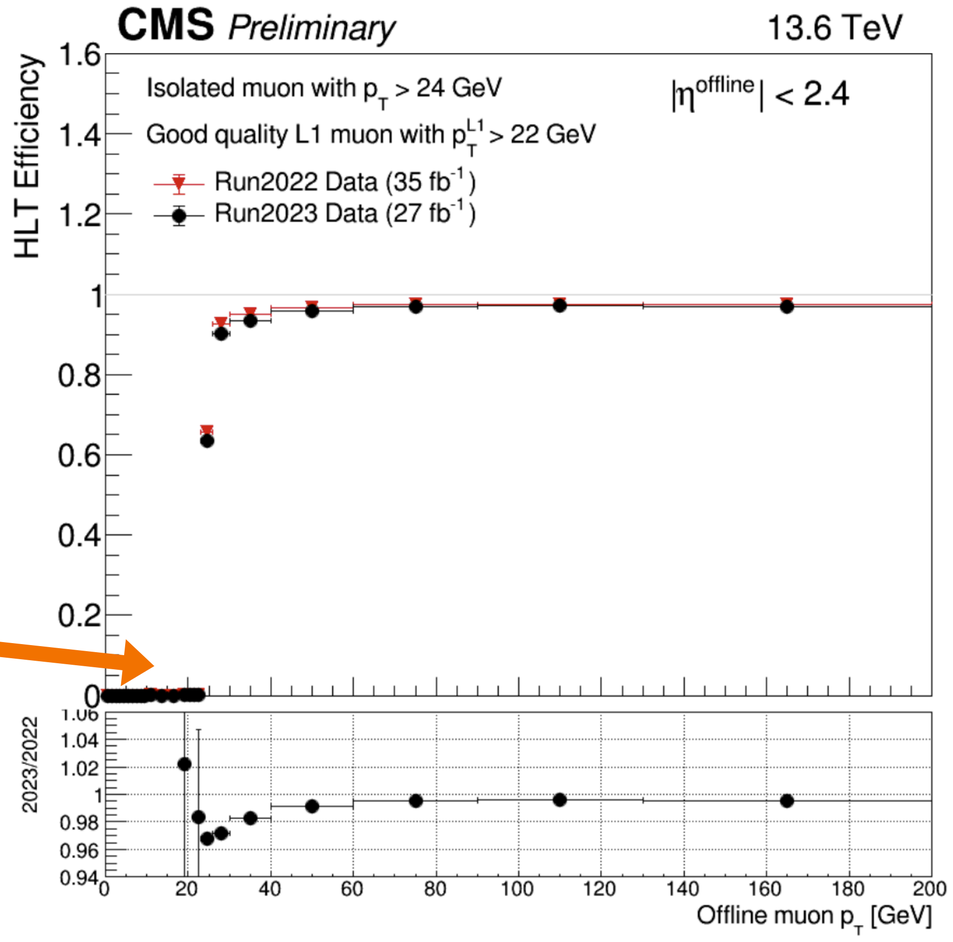


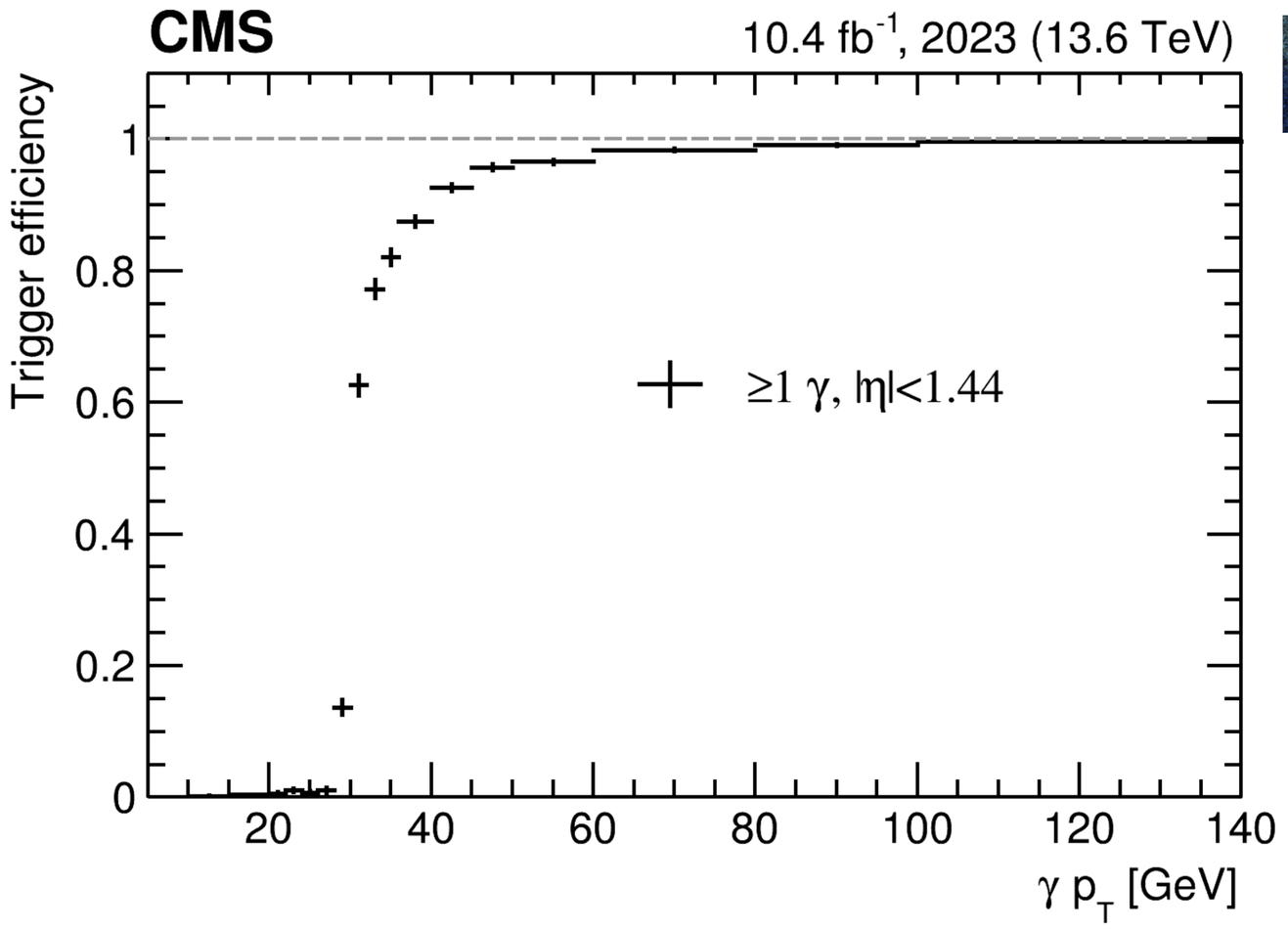
The HLT reco. is high at much lower p_T than the lowest threshold trigger.

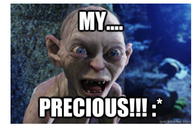


HLT reconstruction: Photons

Efficiency measured with offline photons matched to a scouting photon.

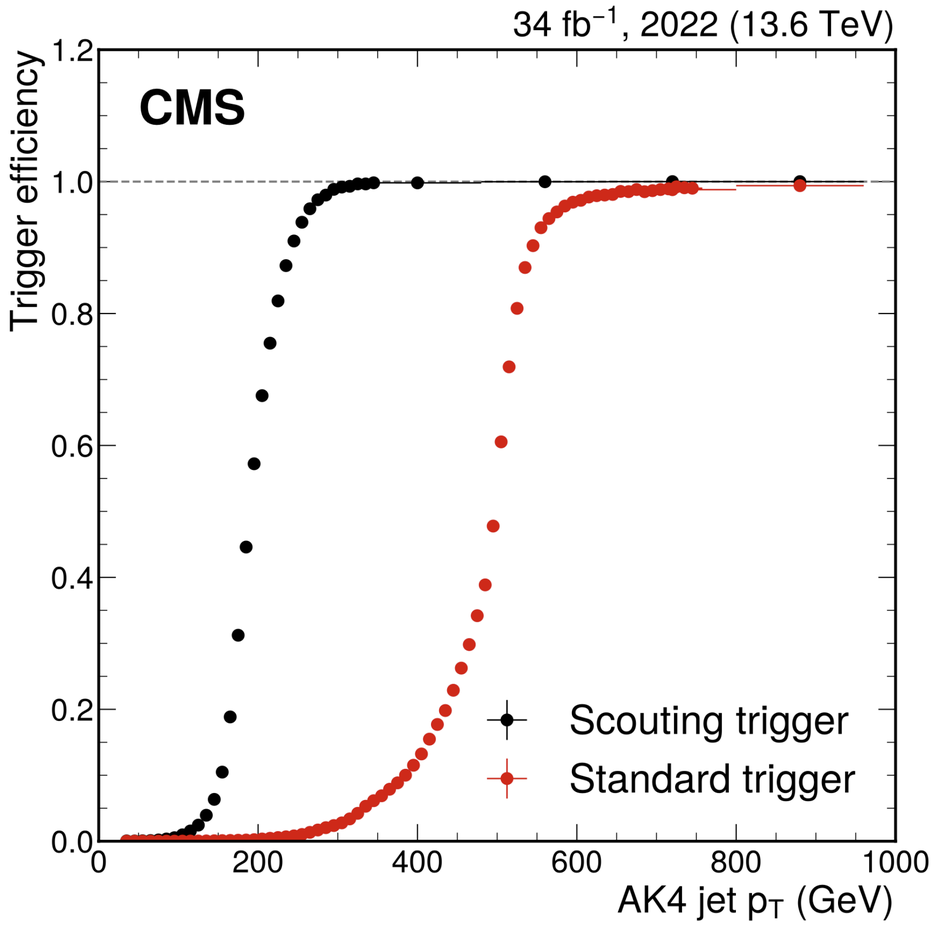
The scouting single photon efficiency with no other selection is at 30 GeV.

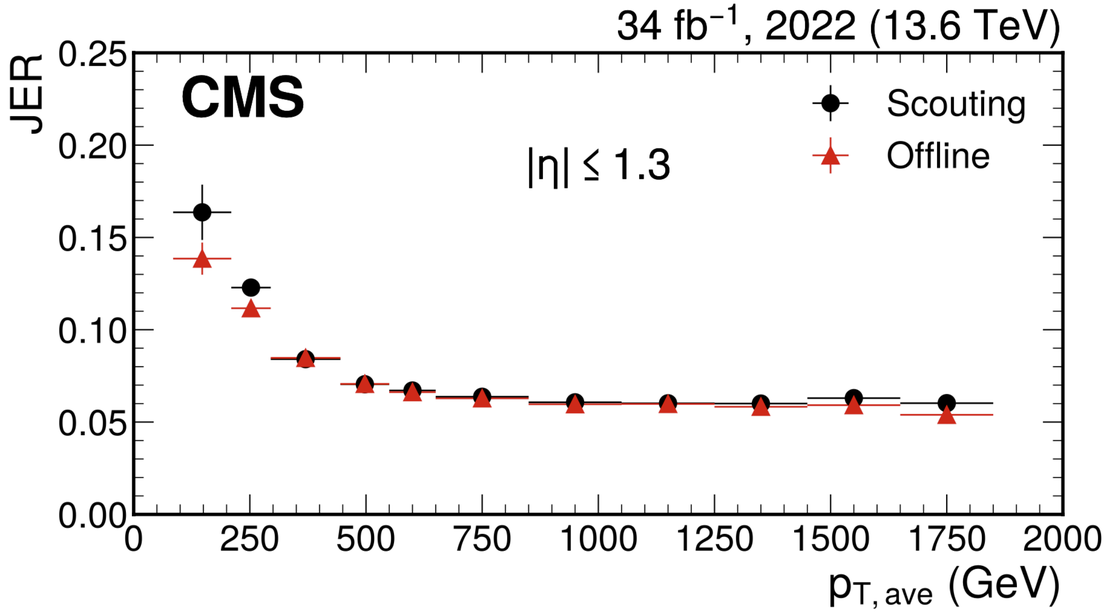




HLT reconstruction: Jets

Efficiency defined with respect to offline reconstructed jets in an unbiased sample.





Online and Offline performance is compatible.

What can be removed from CMS Data?

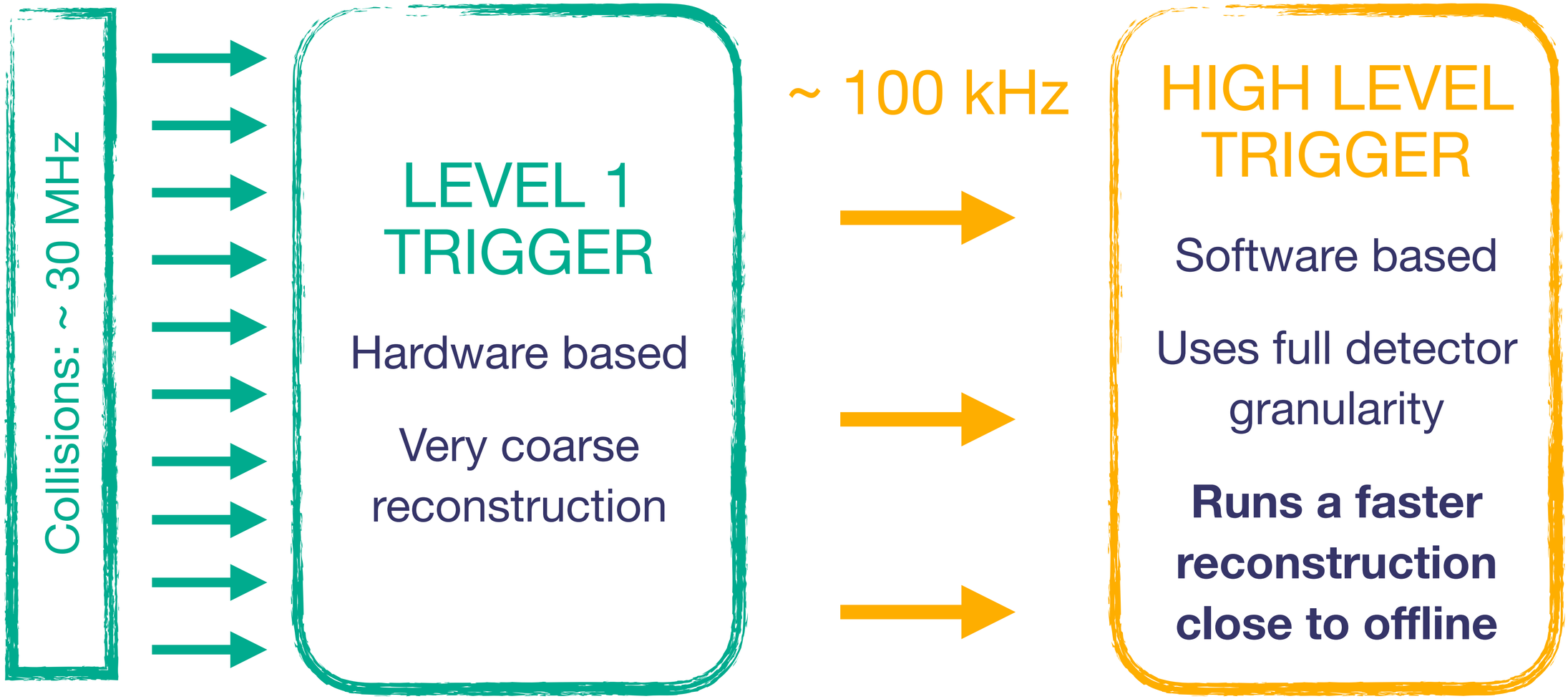
Sub-detector system	Run 2 (kB / event)	Run 3 (kB / event)
Tracker Strips	731	731
Tracker Pixels	259	259
Hadronic Calo.	170	391
Electromagnetic Calo.	128	128
Muons System	107.5	129.5
TOTAL	1400	1600

JINST 19 (2024) 05, P05064

- Data content observed at peak luminosities.
- Replace the full detector data with a summary.

Reduce data:
O(1 MB)/event
⇒
O(10 kB)/event.

Just store HLT Physics Objects



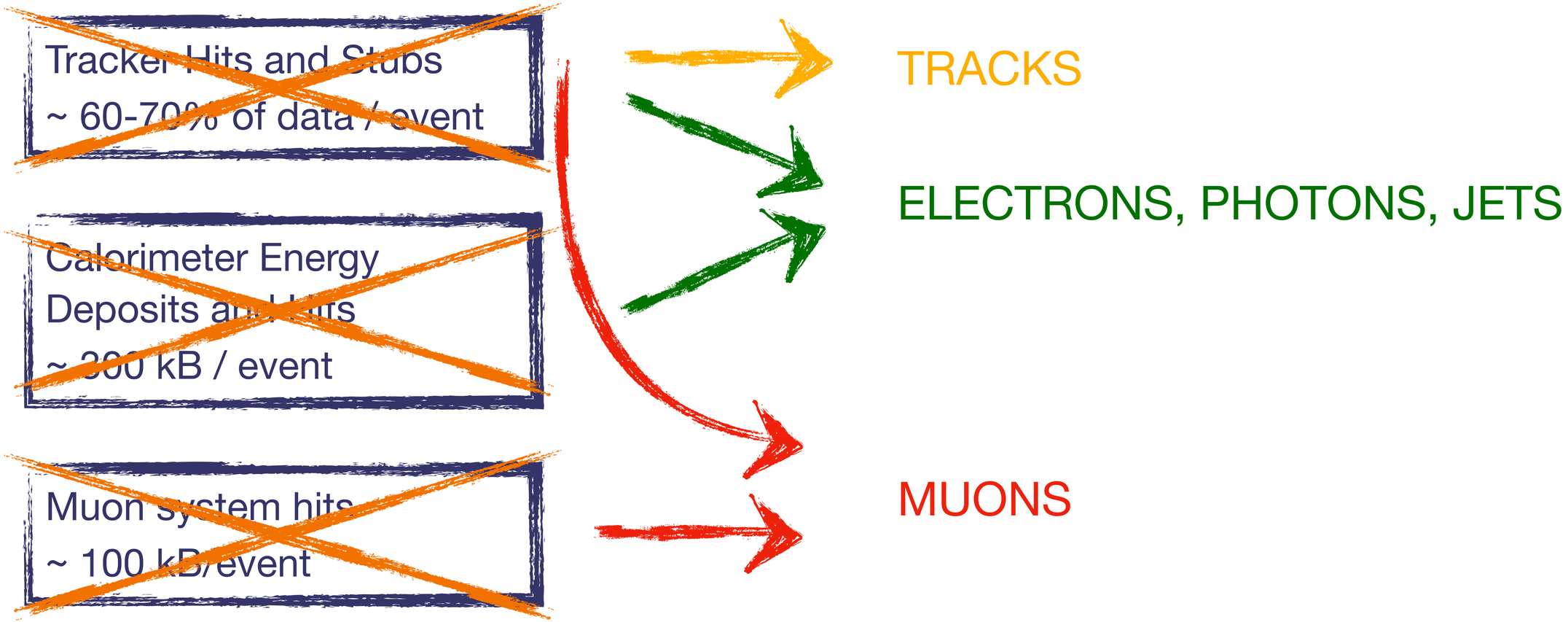
Scouting: New data format

Tracker Hits and Stubs
~ 60-70% of data / event

Calorimeter Energy Deposits and Hits
~ 300 kB / event

Muon system hits
~ 100 kB/event

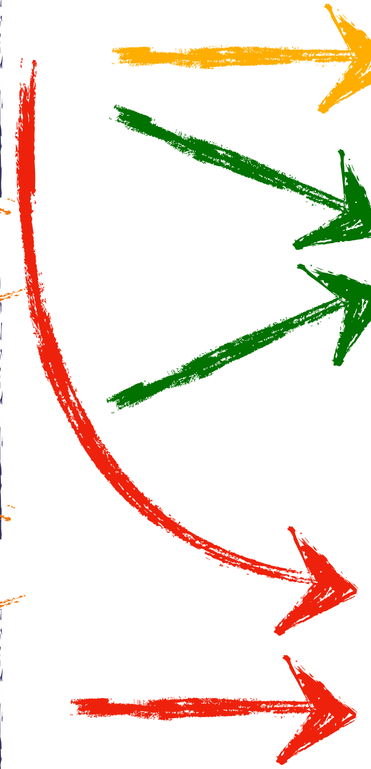
Scouting: New data format



Scouting: New data format

~~Tracker Hits and Stubs~~
~~~ 60-70% of data / event~~

~~Calorimeter Energy Deposits and Hits~~
~~~ 300 kB / event~~

~~Muon system hits~~
~~~ 100 kB/event~~



TRACKS

ELECTRONS, PHOTONS, JETS

MUONS

MERIT

O (10 kB) / event

DEMERIT

No offline processing
~~~

Scouting: New data format

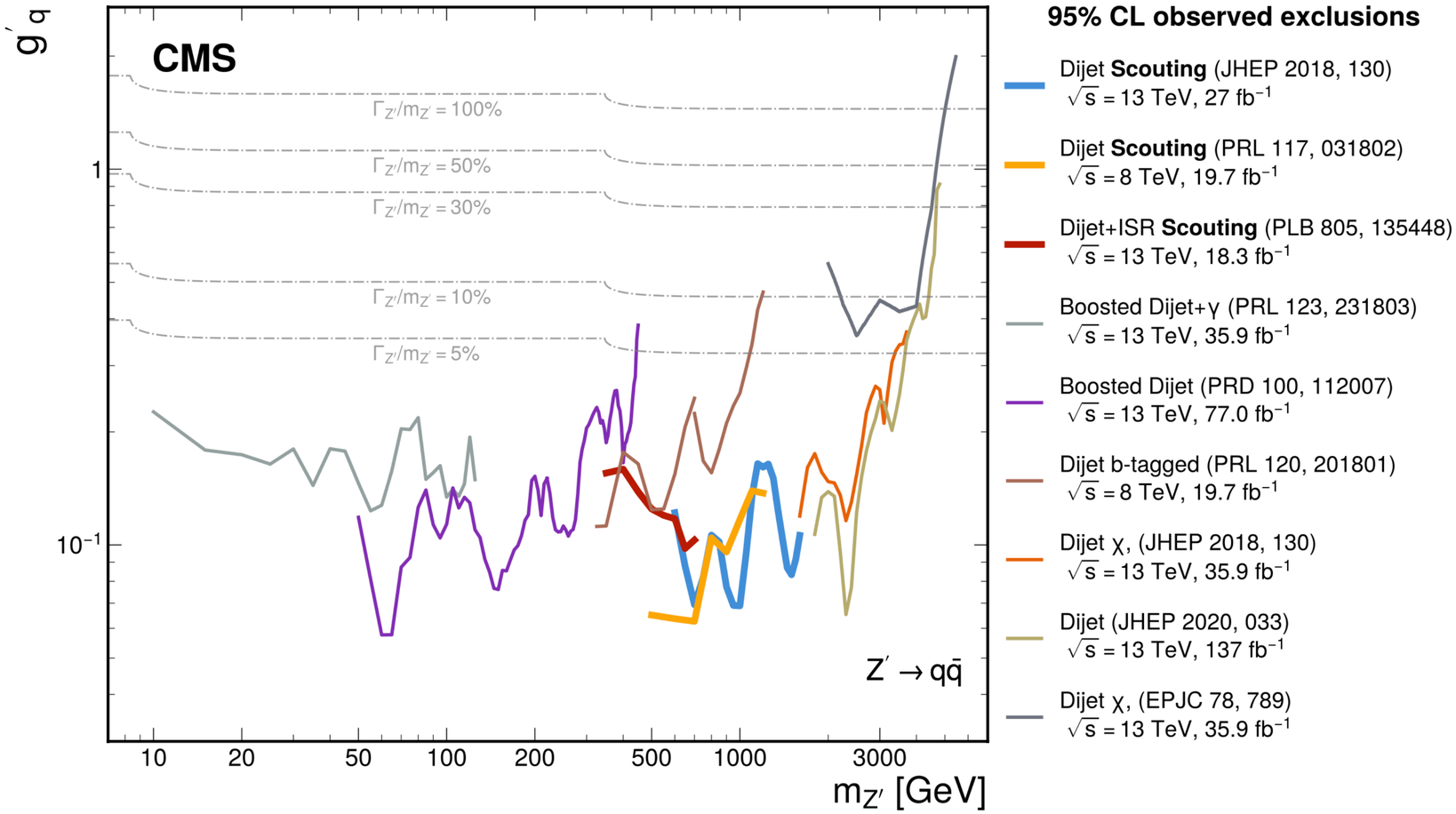
~~Tracker Hits and Stubs~~
~~~ 60-70% of data / event~~

~~Calorimeter Energy Deposits and Hits~~
~~~ 200 kB / event~~

~~Muon system hits~~
~~~ 100 kB/event~~

TRACKS

ELECTRONS, PHOTONS, JETS

Run 2

MUONS

Run 2

MERIT

O (10 kB) / event

DEMERIT

No offline processing
~~~

Run 2 Scouting Physics: Dark Matter search

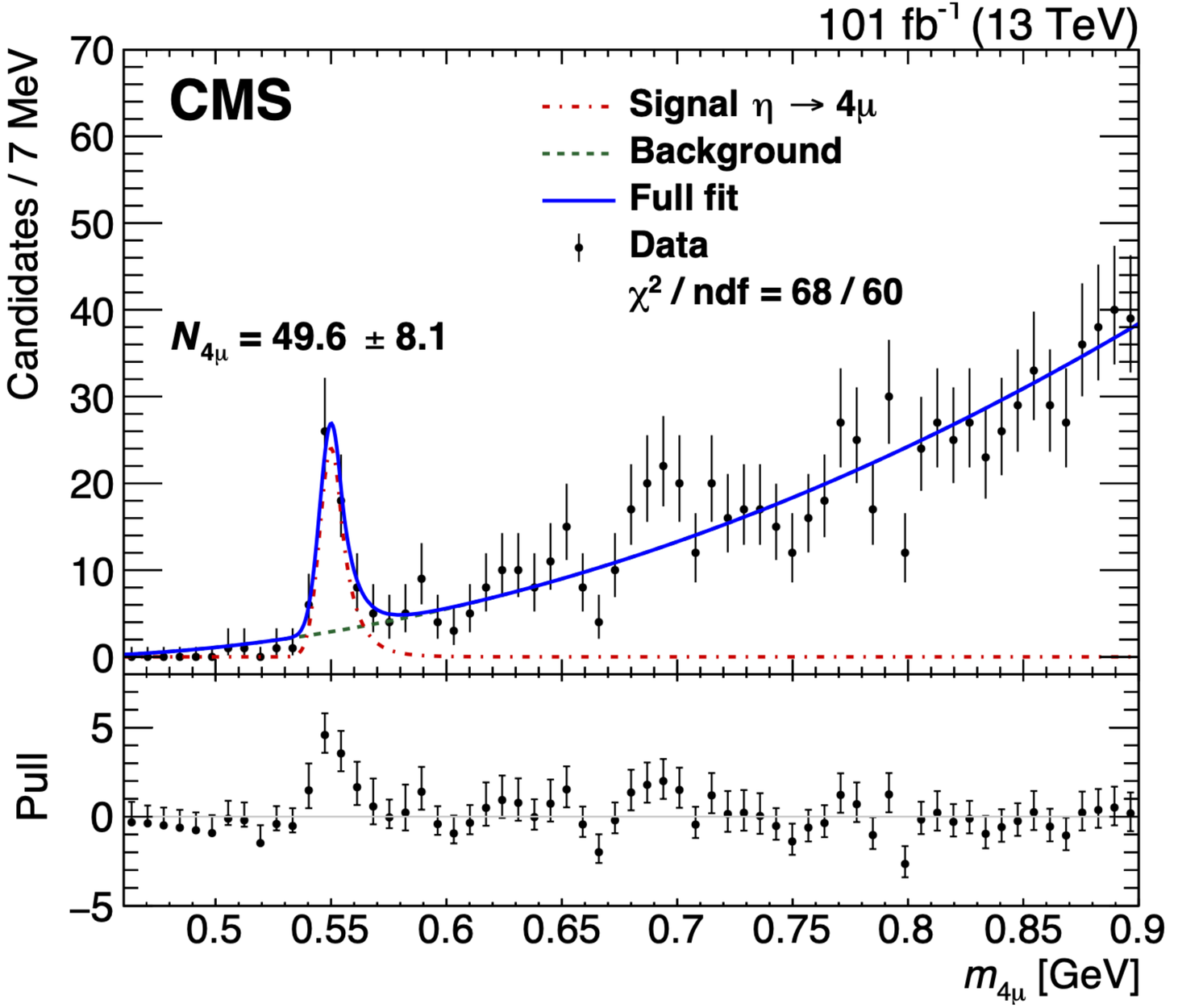
Observed limits on the universal coupling between a leptophobic Z’ boson and quarks.



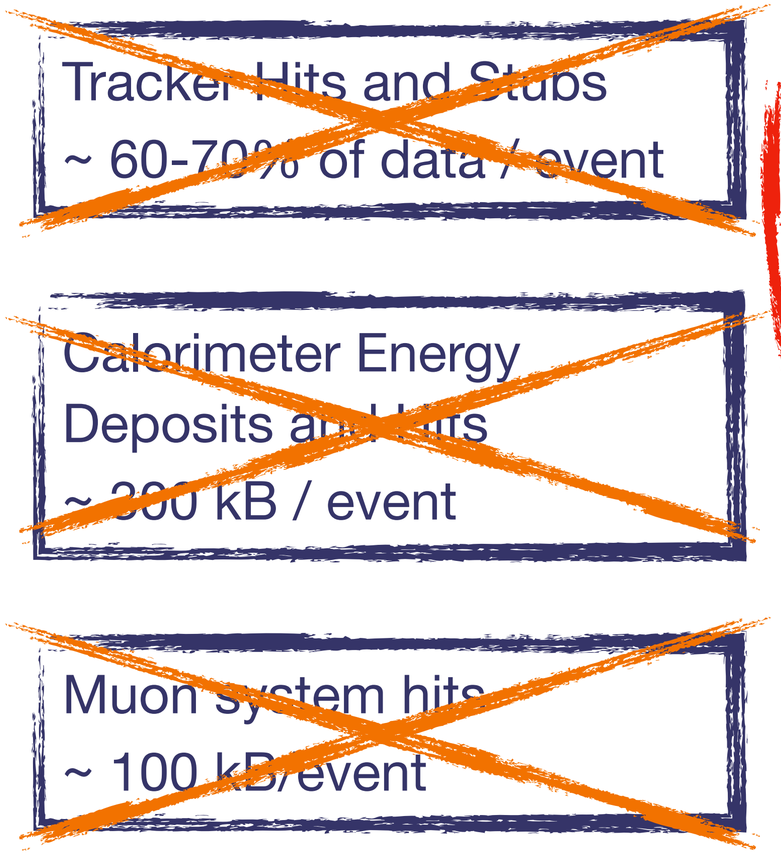
Run 2 Scouting Physics: SM physics

First observation of the decay of the η meson to 4 muons at

$$\mathcal{B}(\eta \to 4\mu) = 3.98 \times 10^{-9}$$



Run 3 has all physics objects



TRACKS

ELECTRONS, PHOTONS, JETS

MUONS

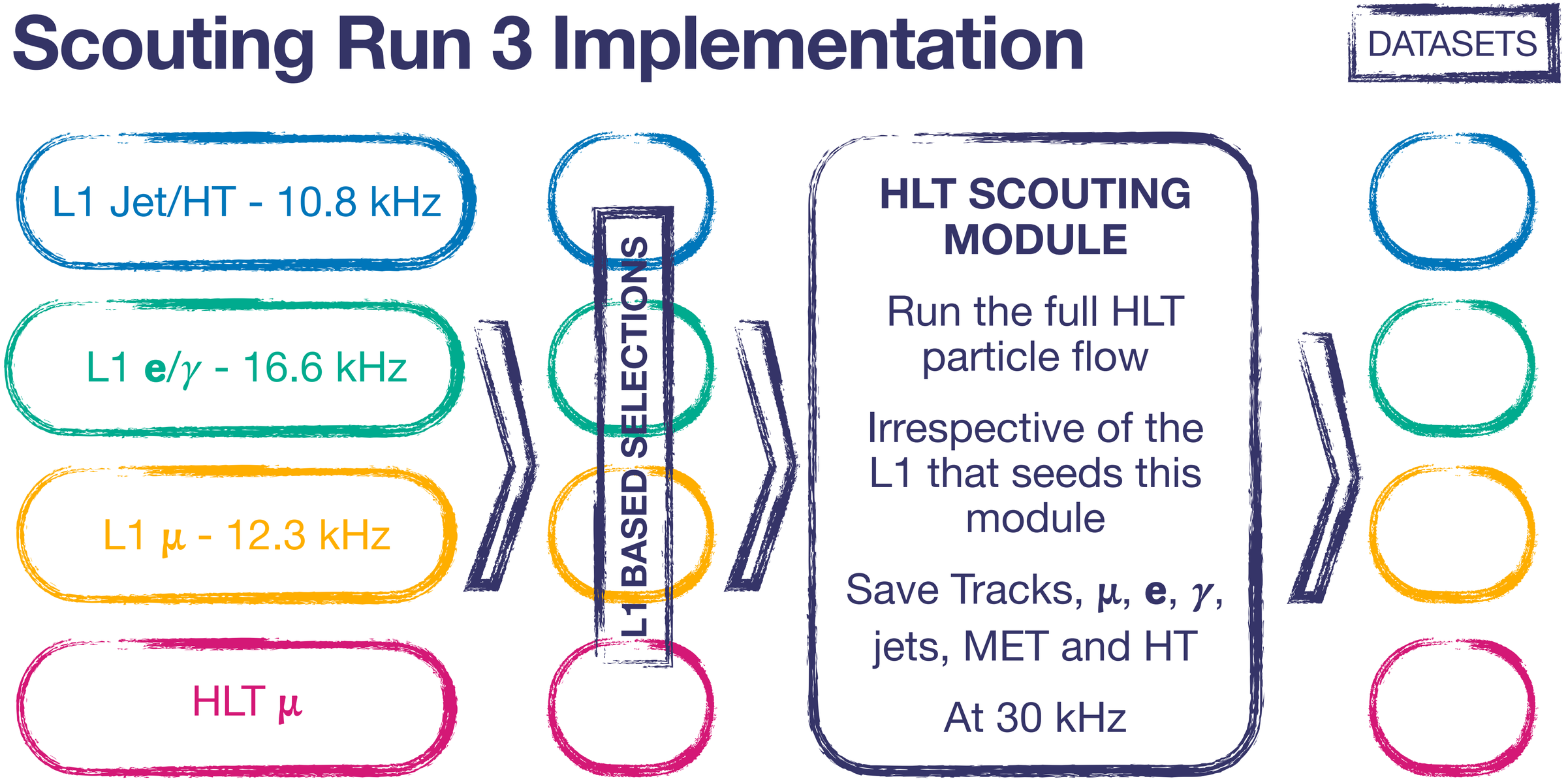
MERIT

O (15 kB) / event

DEMERIT

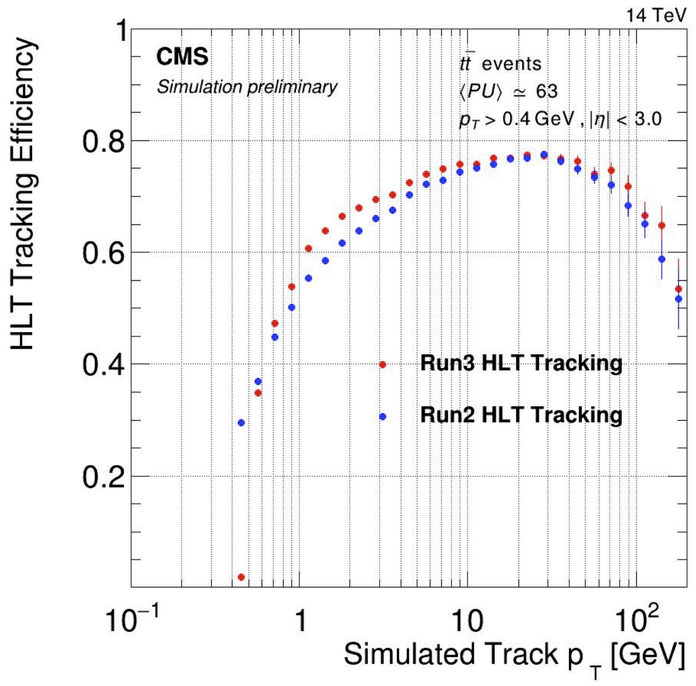
No offline processing

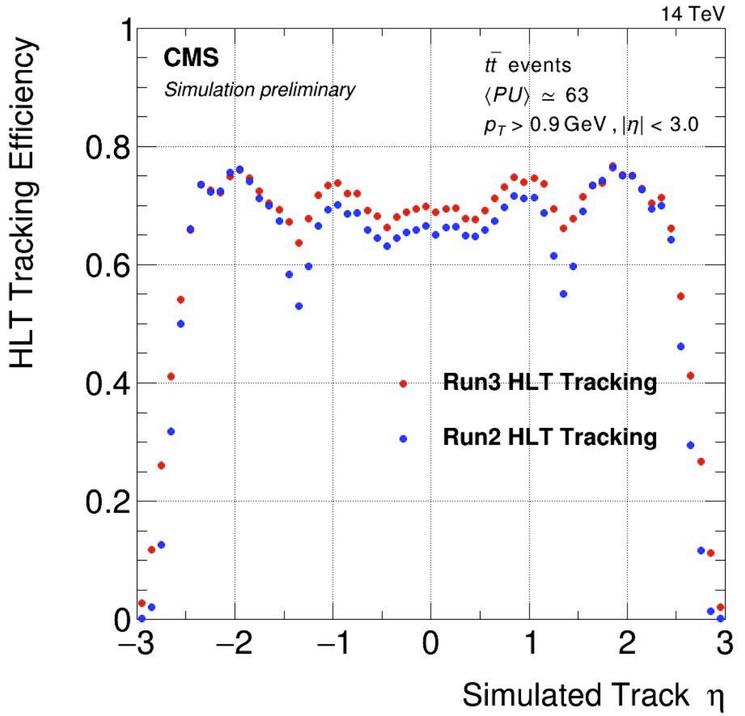
Scouting Run 3 Implementation

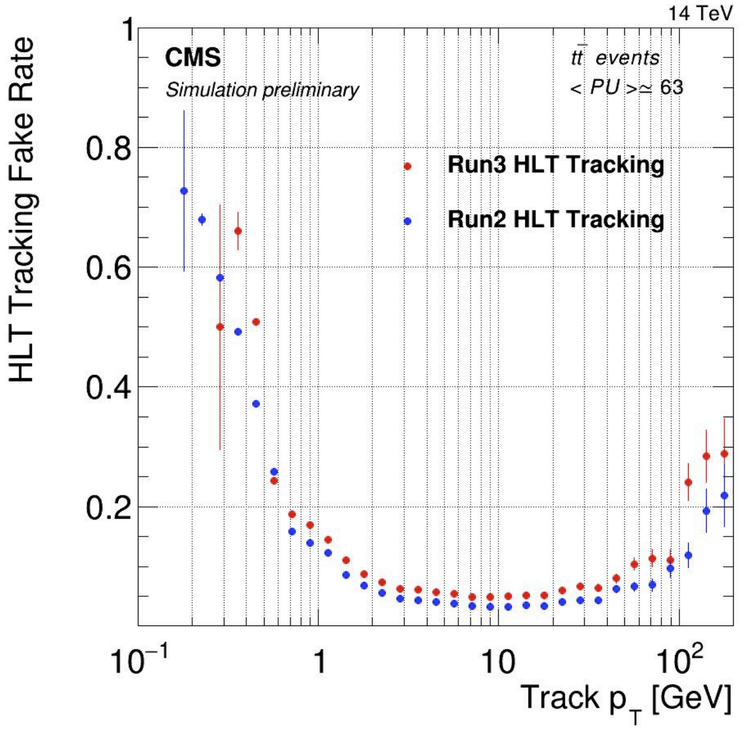


Reco. Improvement: Pixel Tracking

- Tracking performed at one go seeded by pixel tracks with $p_T > 0.3$ GeV and at least 3 pixel hits.
  - Pixel seed is required to match to one of the primary vertex.
- Better tracking performance and code optimised for GPUs.

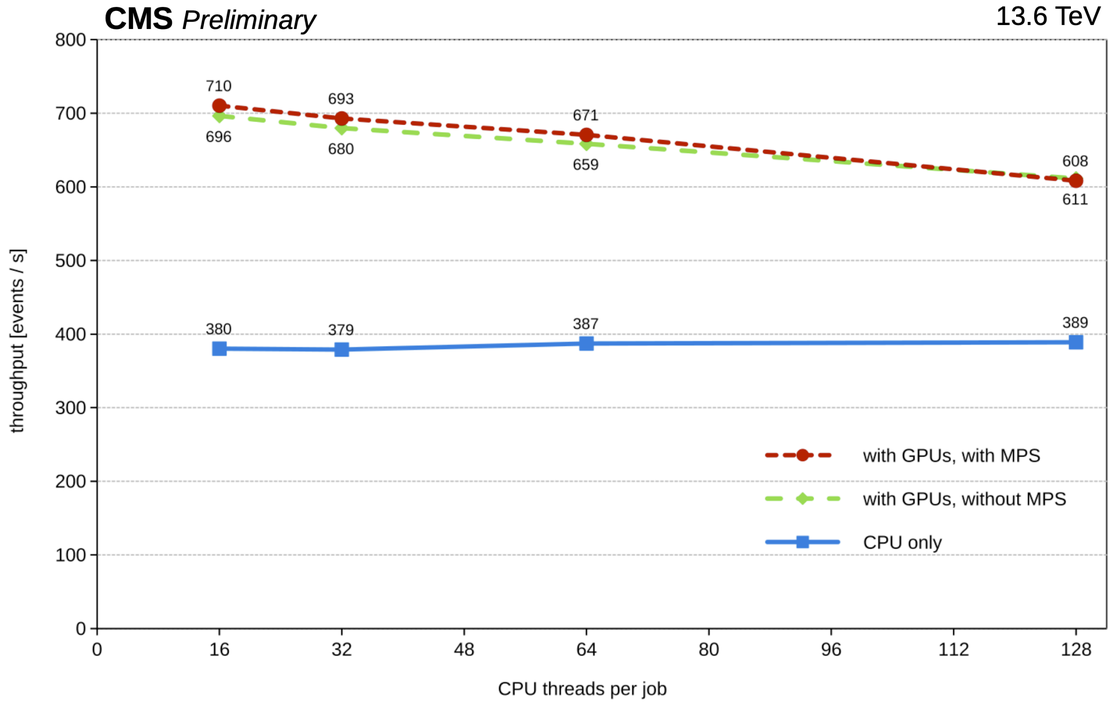


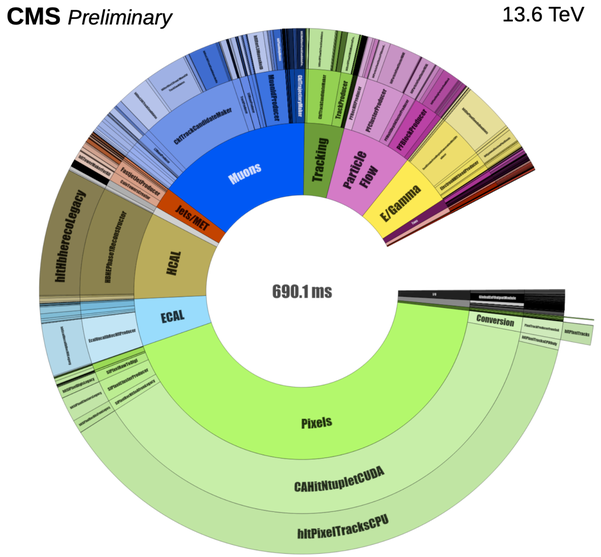


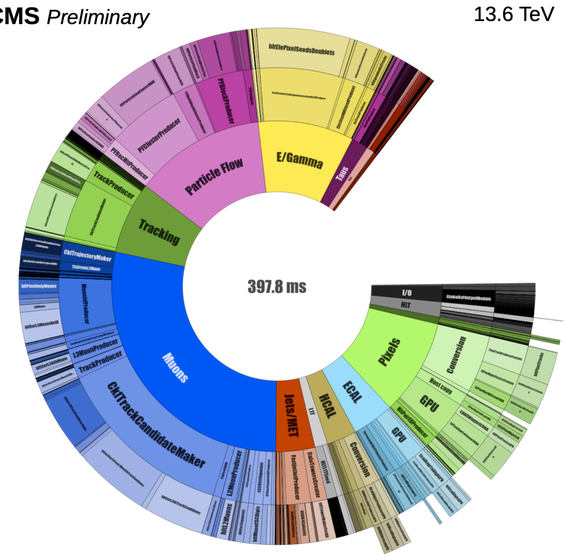


Reco. Improvement: Hybrid HLT farm

- 200 nodes with 2 AMD Milan 64-core CPUs and 2 Nvidia Tesla T4 GPUs each node.
- ECAL, HCAL and Pixel Track reco. (~40%) are now done in GPUs.







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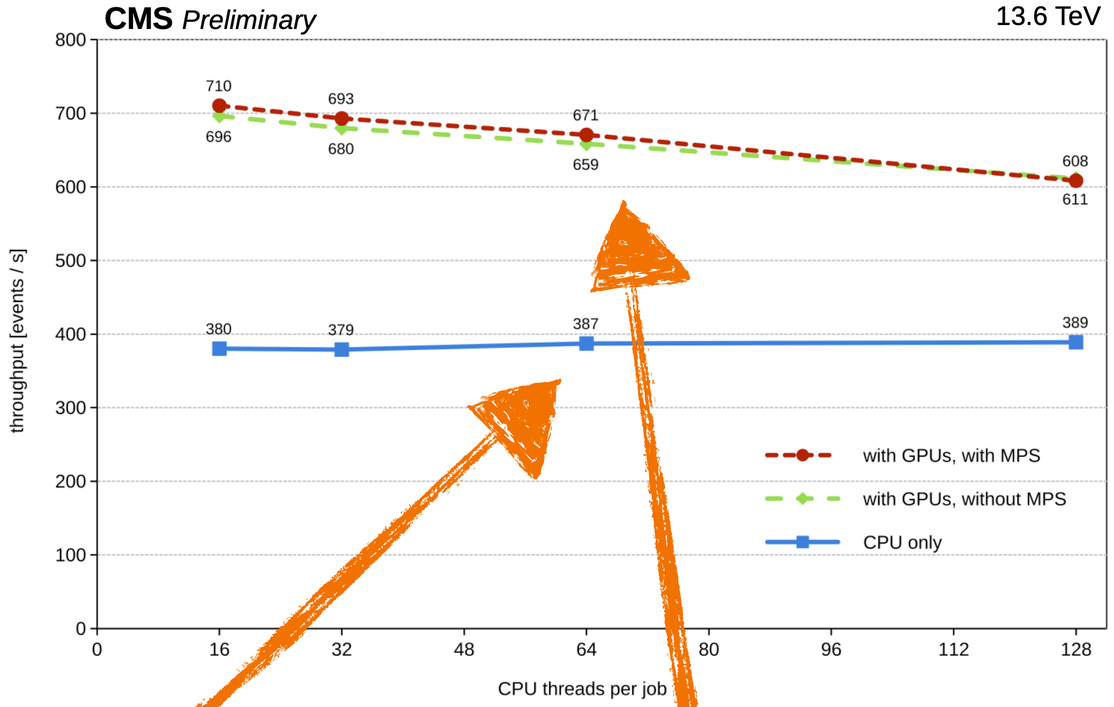

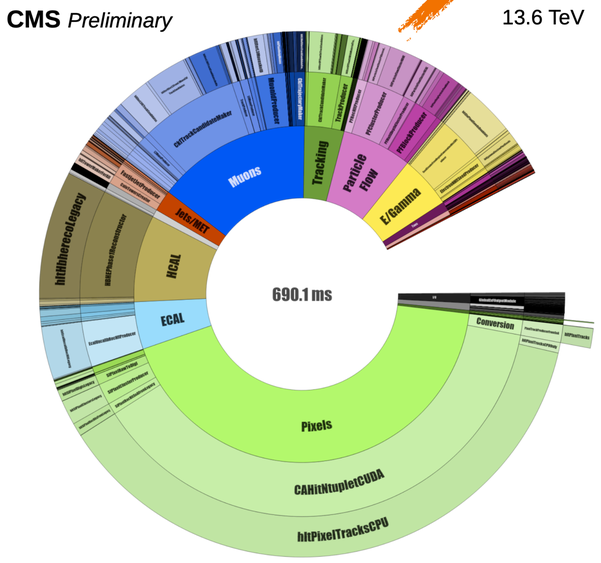

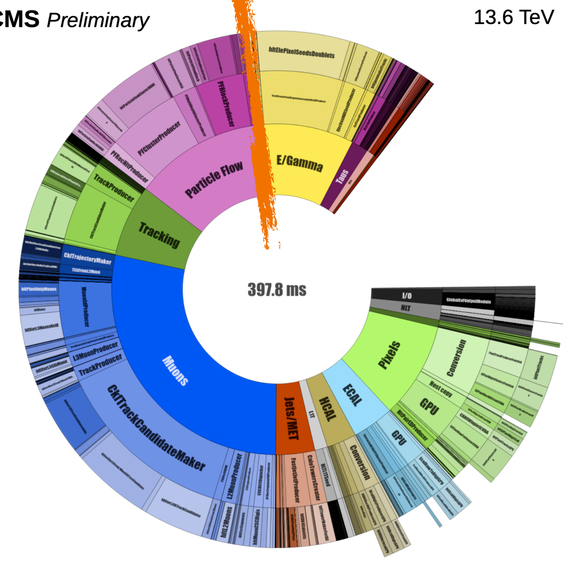

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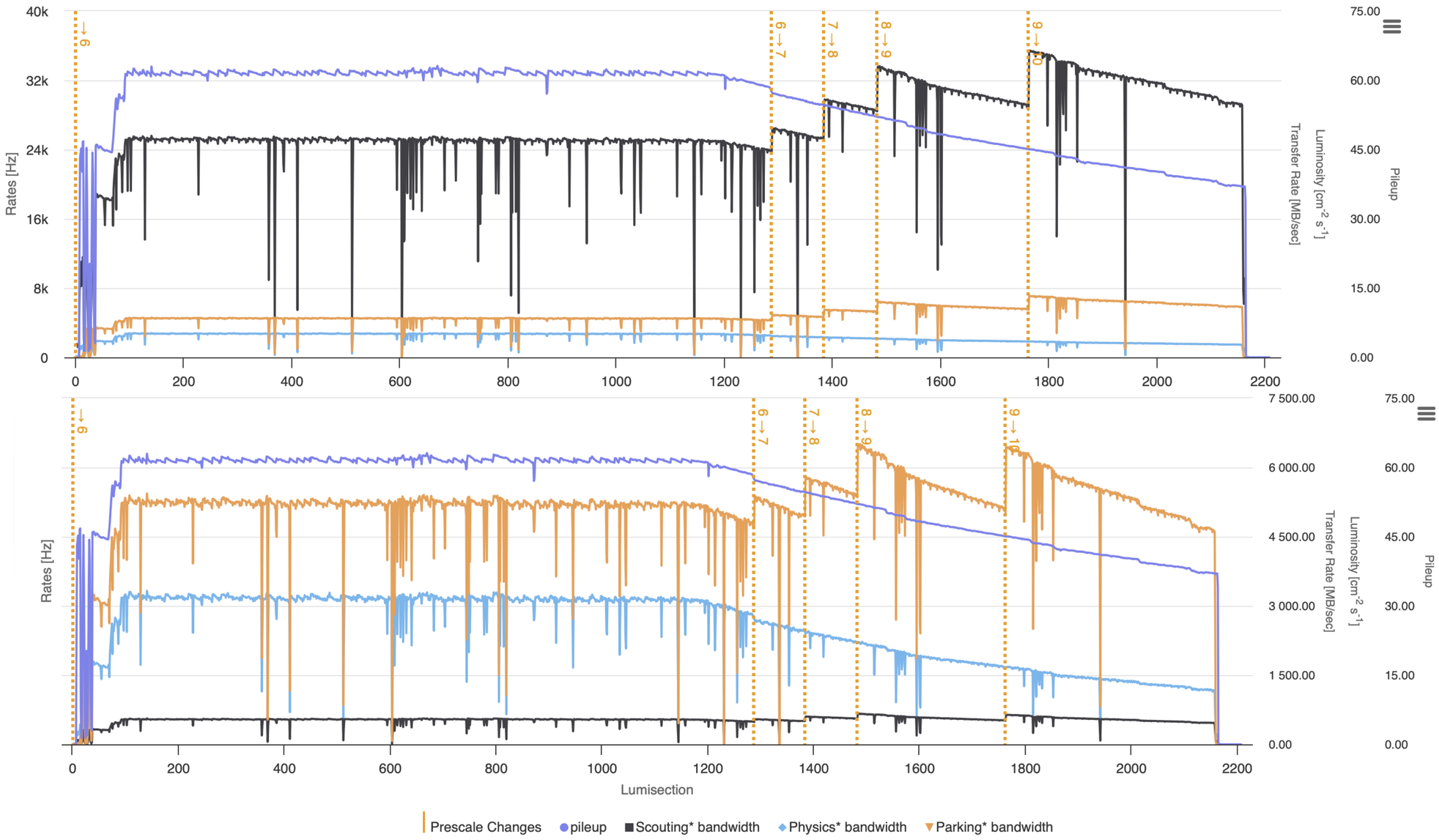
Run 3 Scouting parameters

Run 384052/ 2024

HLT RATES

DATASET BANDWIDTH



Jets/HT Scouting

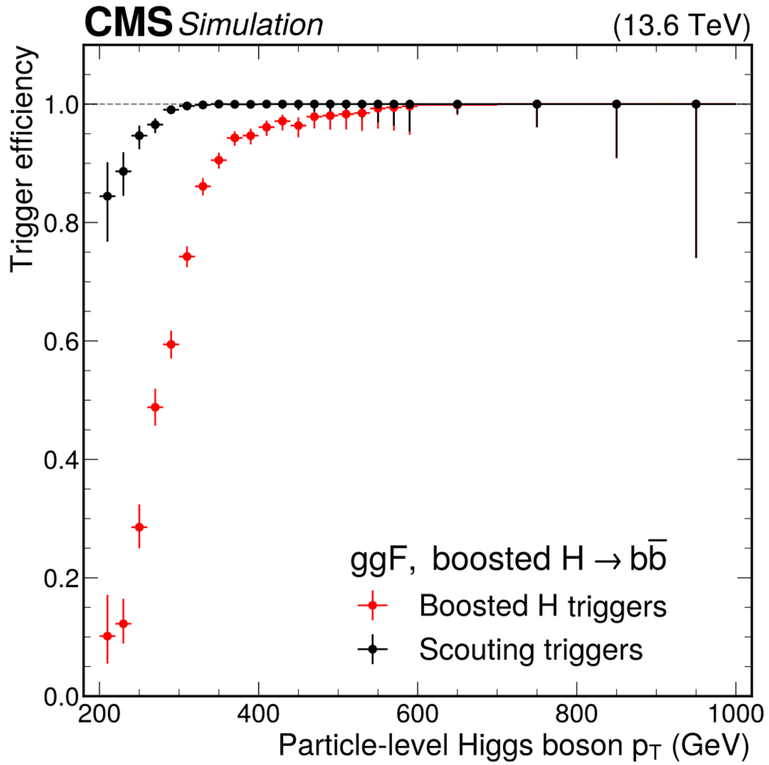
L1 INPUT

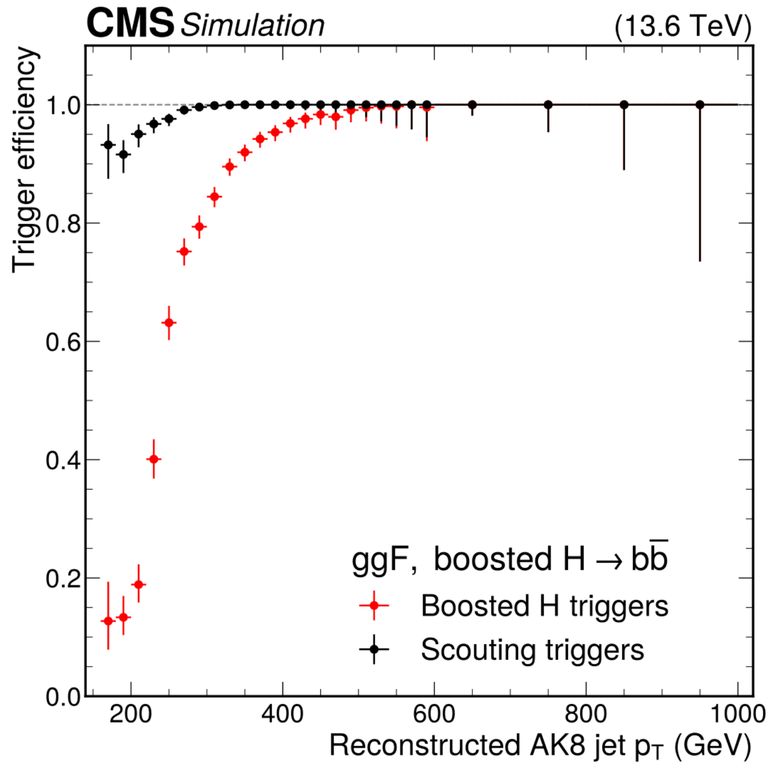
$H_T > 280$ GeV

1 jet, $p_T > 180$ GeV

2 jets, $p_T > 30$ GeV, $|\eta| < 2.5$, $\Delta\eta < 1.5$, $m_{jj} > 250$ GeV

No other selection



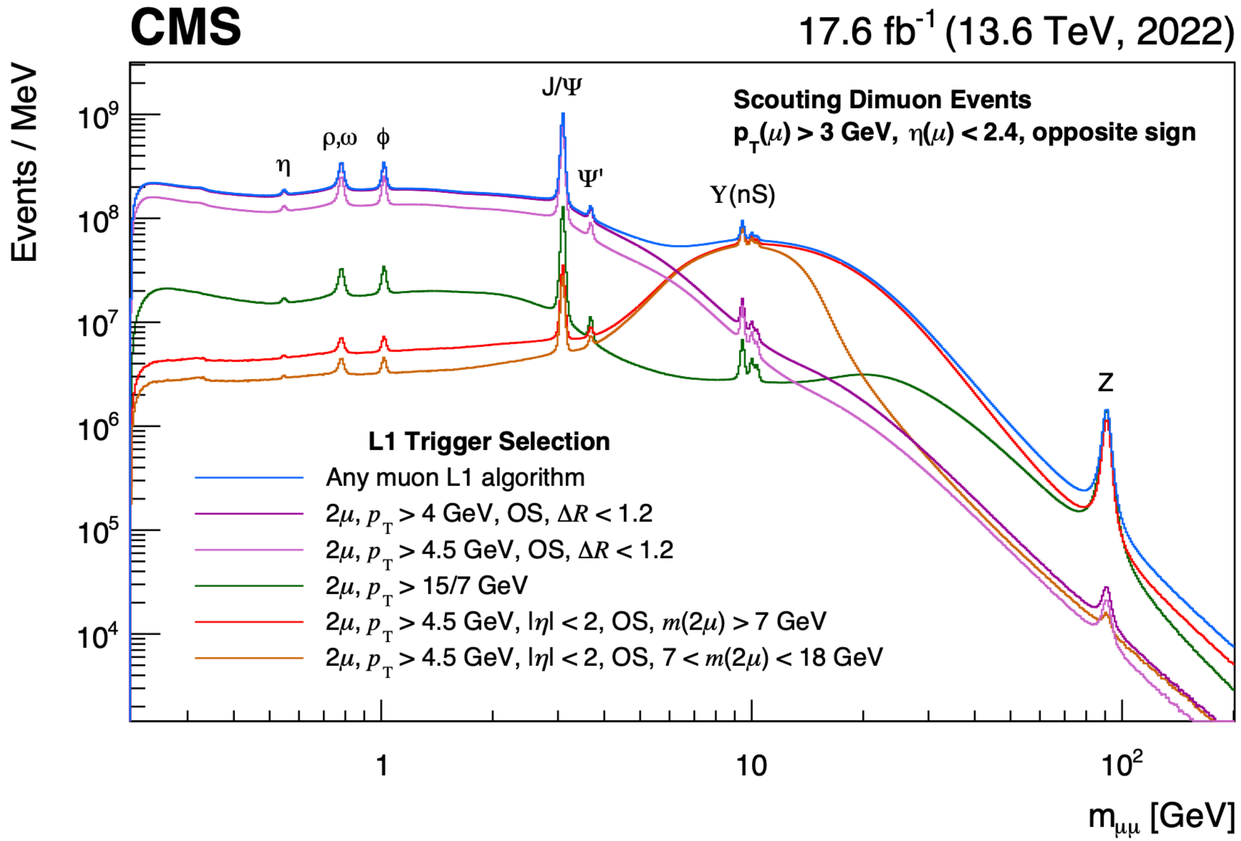


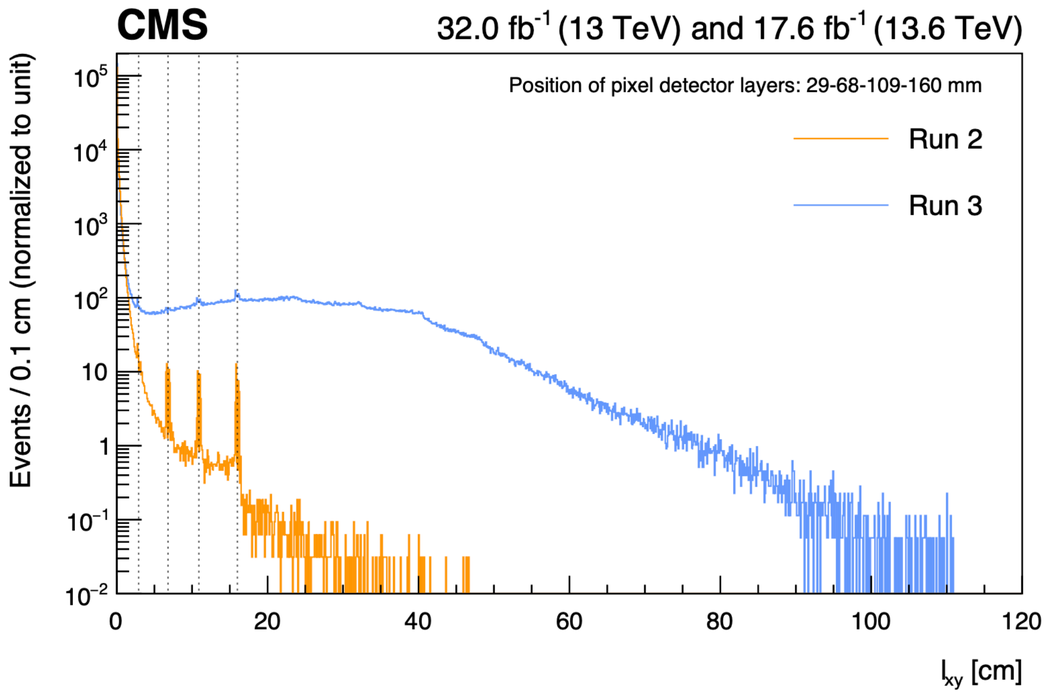
Significantly lower threshold for jets. Brings into focus multiple jets related physics. New possibility - jets+X analysis.

Muons Scouting

HLT SELECTION

2μ, p_T > 3/3 GeV





New and improved displaced muon reconstruction.

Completely new inclusion in Scouting. Low mass meson peaks observed.

e/γ Scouting

L1 INPUT

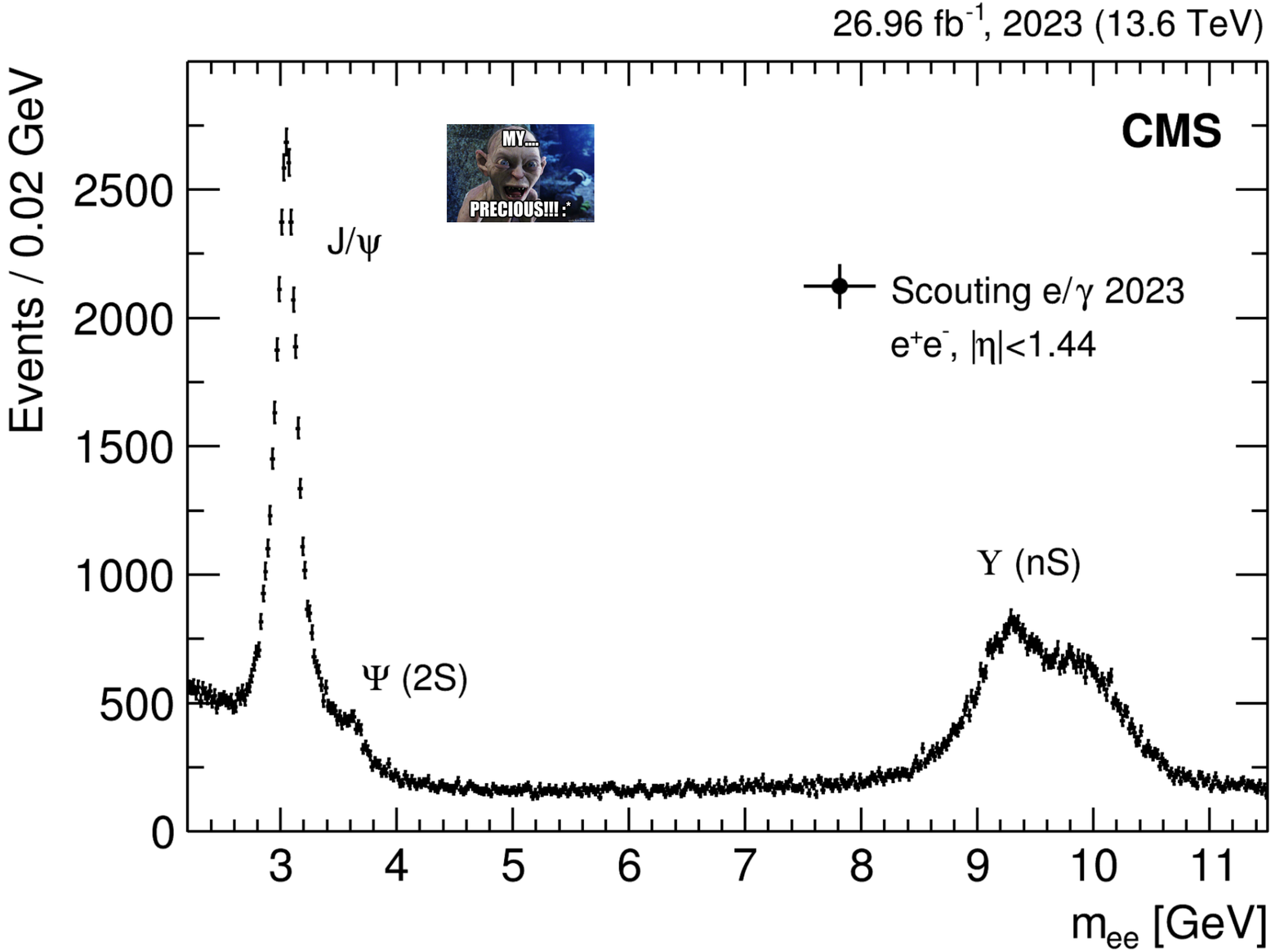
1 e/γ (tight), $p_T > 30$ GeV, $|\eta| < 2.1$

HLT: 1 ECAL, $p_T > 30$ GeV

L1 INPUT

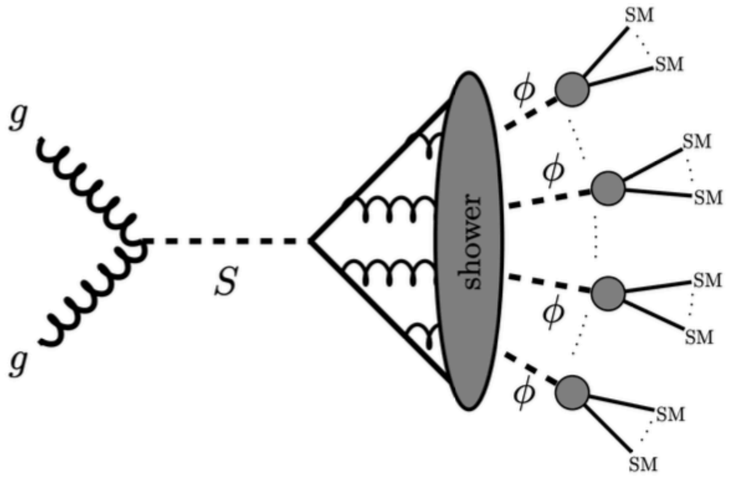
2 e/γ (loose), $p_T > 18/12$ GeV, $|\eta| < 1.5$

HLT: 2 ECAL, $p_T > 20/12$ GeV

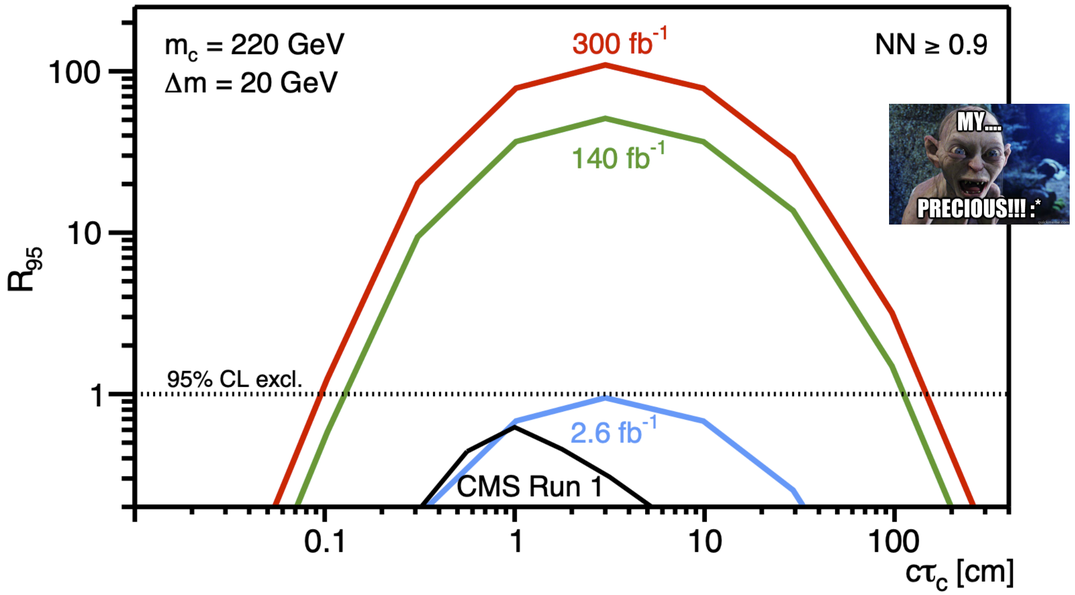


In the years to come :

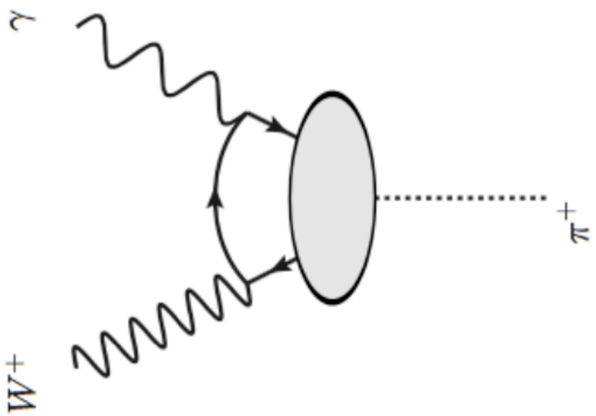
SUEPs



Soft Displaced Leptons



$W \to \pi\gamma$



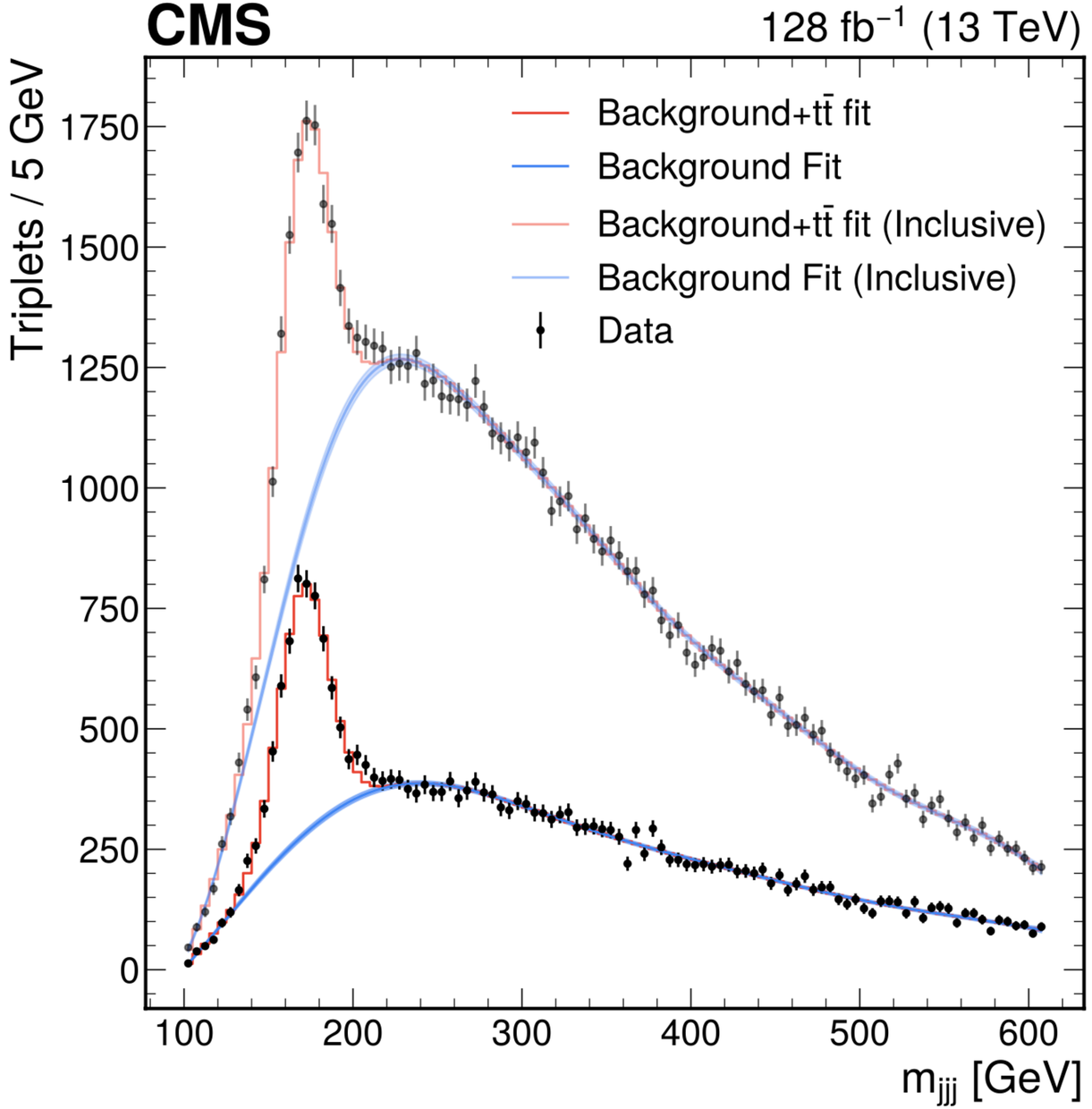
YOUR SEARCH FOR WEAK SCALE DARK PORTAL COUPLINGS WITH CROSS PHYSICS OBJECT ANALYSIS

QUESTIONS ??

MORE SLIDES FOLLOW…

Run 2 Jets: Three Jet Invariant Mass plot

Observation of fully hadronic top quark decays in the invariant mass of three jets with QCD multi-jet background with and without a NN discriminator.



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Run 2 Muons: Invariant Mass plot

Di-muon invariant mass spectrum and event rate of each L1 seed obtained with the scouting stream reconstructed at the HLT with $\mathcal{L} = 60\ fb^{-1}$.