UNIVERSITÉ DE LYON | Lyon 1

New analysis methods and physics prospects for HL-LHC

Maxime Gouzevitch on behalf of the CMS collaboration

24/09/2024

Introduction I

1) There were 4 major sets of projections (with updates in between)

   1.1) 2013 : First Snowmass process
   1.2) 2015-2017 : CMS Phase II TP and TDRs
   1.3) 2018-2019 : European Strategy (Yellow Report)
   1.4) 2021-2022 : Second Snowmass process

2) This talk is mainly based on (1.4) which includes updates based on Run 2 expertise and full picture of the expected Phase II CMS detector. Some information is taken from (1.2 – 1.3) when required.

3) I'll concentrate on the HL-LHC projections for Higgs physics :

   - Higgs Branching (example from $H \to \mu\mu$)
   - Higgs mass and width (example of $H \to 4l$)
   - HH production and Higgs self-coupling (example of $HH \to \gamma\gamma bb$)

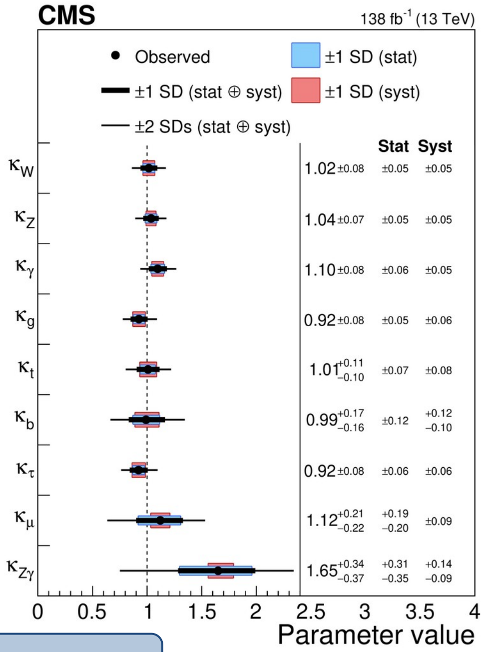
Introduction II

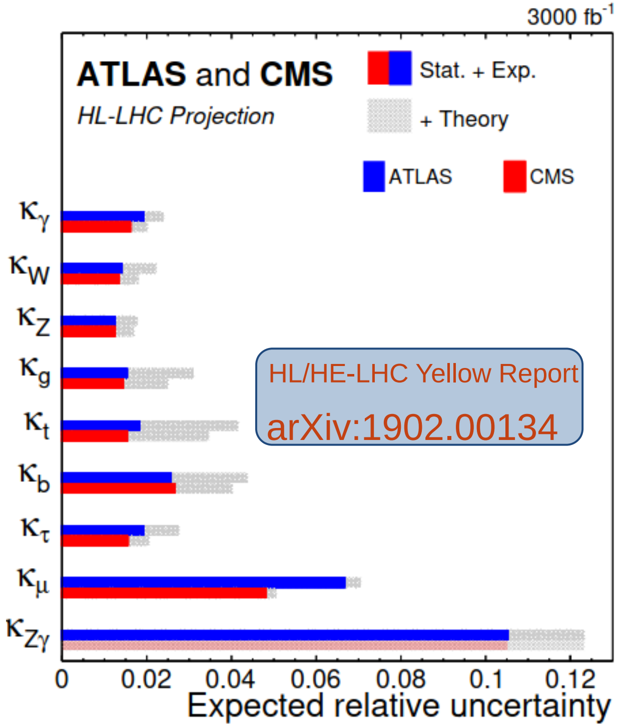
There are 2 main scenarios for systematic uncertainties for HL-LHC :

SCENARIO 1 (S1) : same systematics than measured in Run 2.

SCENARIO 2 (S2) : systematics scale down with luminosity (for data driven systematics) down to a floor.
Theoretical uncertainties are halved assuming progress in calculations.

2) Higgs BF





HL/HE-LHC Yellow Report
arXiv:1902.00134

Nature volume 607, pages 60–68 (2022)

- Rule of Thumb : to be sensitive to the TeV scale effect the Higgs BF shall be constrained at 1 % precision. CMS@HL-LHC : 5-10 %.

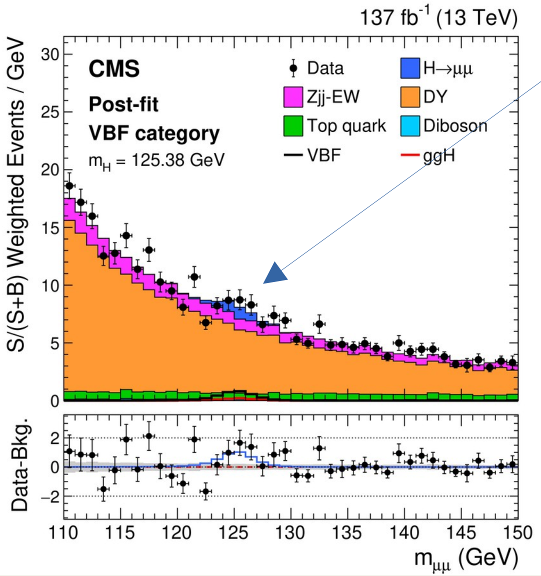
2.1) H → μμ : Run 2

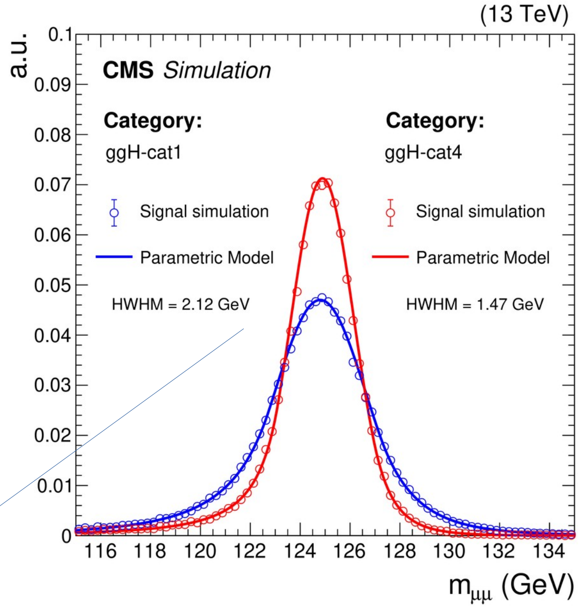
- Very small $BF_{SM}(H \rightarrow \mu\mu) = 2.18\ 10^{-4}$

- The first fermion to test the origin of masses of the 2nd generation. The $H \rightarrow cc$ coupling can be tested with a 100 % precision ().

- Evidence with Run 2 data. Search for a bump over an irreducible DY background.

- Sensitivity defined by 2 components :
  - Accumulated statistics.
  - Muon p_T resolution.



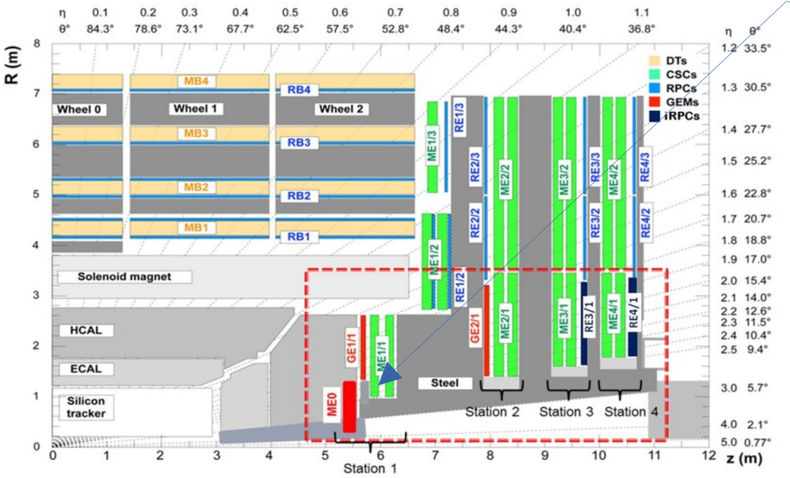


JHEP 01 (2021) 148

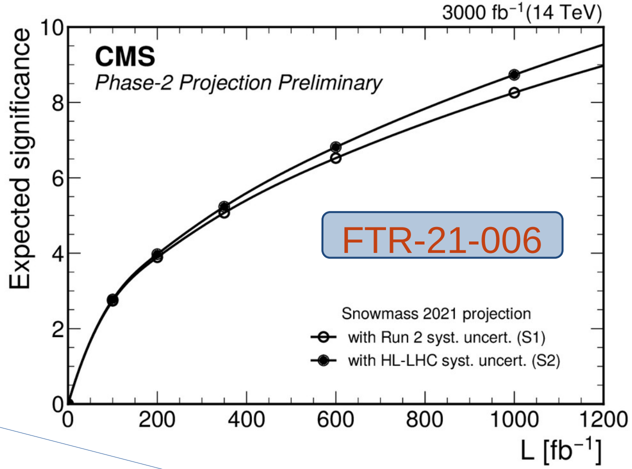
2.2) H → μμ : HL-LHC

- Luminosity wrt to Run 2 increases by factor 20.
- New extrapolation (Snowmass 2021) takes into account specificities of CMS HL-LHC detector.

Increased acceptance in forward region of the CMS Muon system (|η| < 2.4 → |η| < 2.8)



CMS-TDR-016

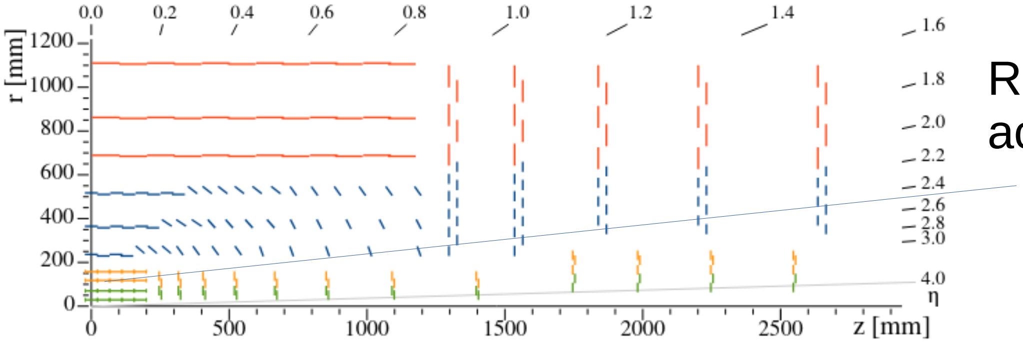


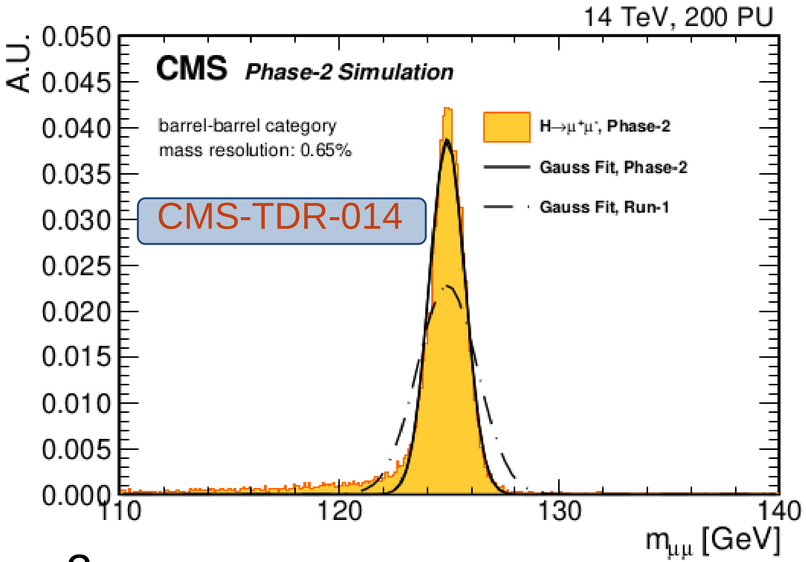
FTR-21-006

Process		Cross sections	Acceptance	Total yield change
Backgrounds	Drell-Yan	+7.8%	+16.0%	+25.0%
	$t\bar{t}$	+20.7%	+16.0%	+40.0%
	Zjj-EW	+9.6%	+18.3%	+29.6%
	Total background	+8.8%	+16.0%	+26.2%
$H \rightarrow \mu\mu$ signal	ggH	+12.3%	+10.7%	+24.5%
	VBF	+12.6%	+9.4%	+23.1%

2.2) H → μμ : HL-LHC

- Extended tracker acceptance with increased number of layers and reduced material budget





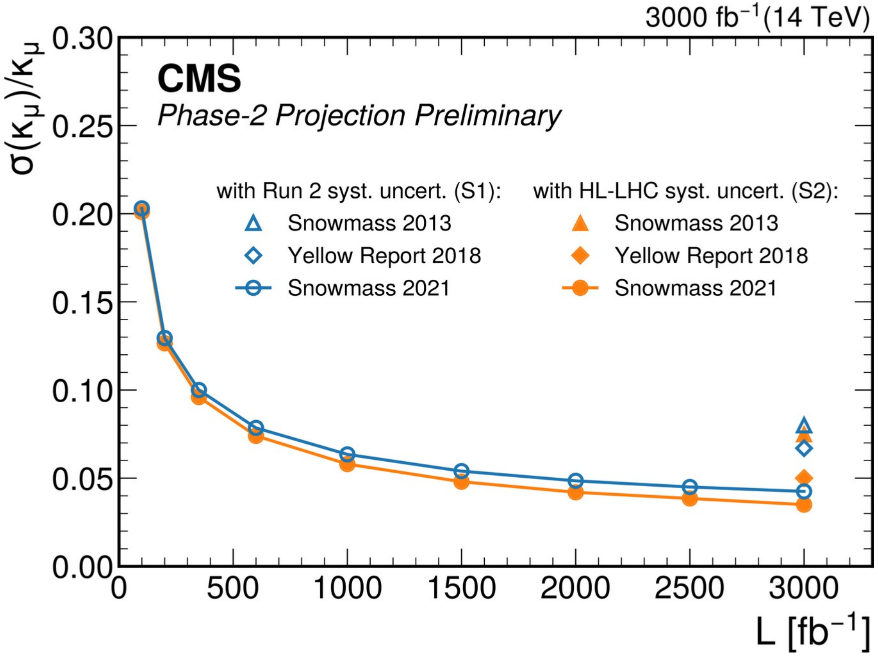
Run 2 acc.

2.2) H → μμ : HL-LHC

- Systematic uncertainties reduced using ML techniques for categorisation based on Run 2 developments.

- In conclusion :

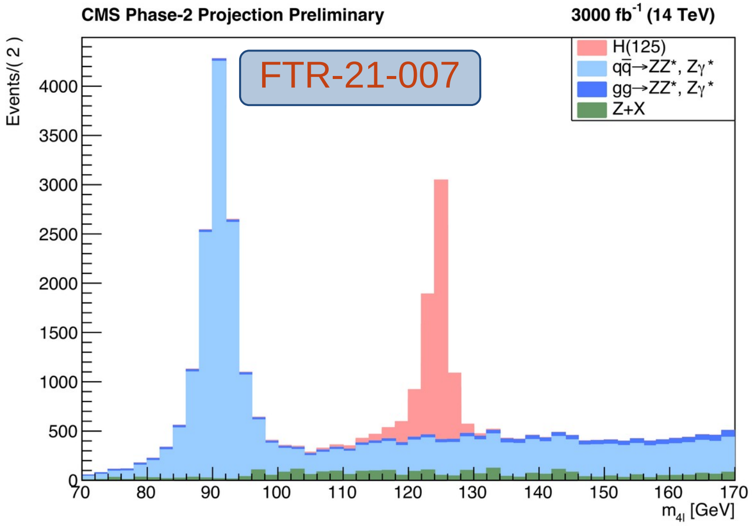
the H→ μμ discovery
is expected at the end of Run 3 or Run 4.
High precision measurement Run 5.

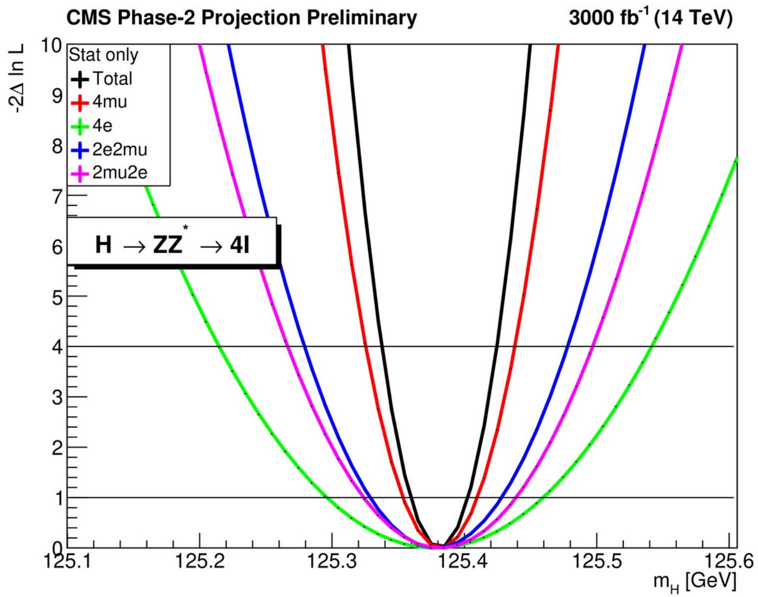


3) H mass and width

- A large and very clean sample of H$\rightarrow$ 4l will be available (6 k events).

- Possibility to constraint the Higgs boson mass with a precision of 25 MeV (140 MeV today).

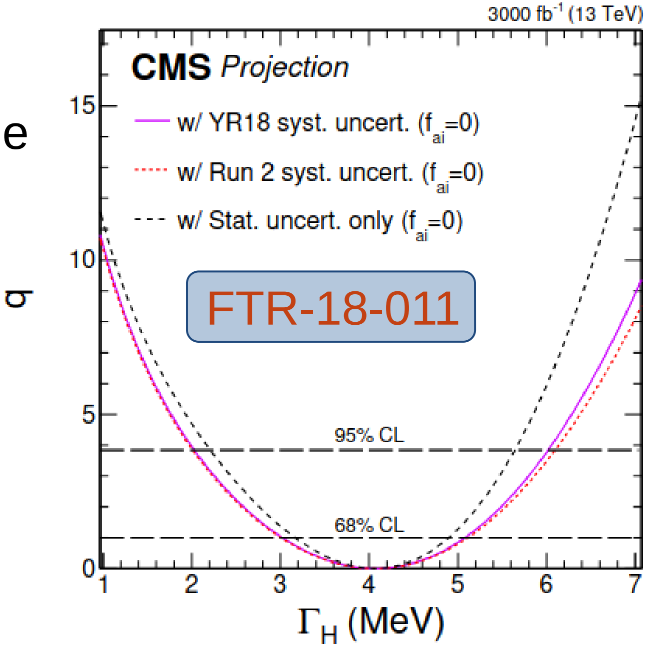




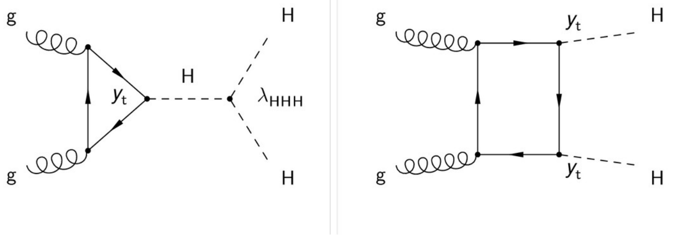
3) H mass and width

- The on-shell Higgs width measurement will never provide sufficient constraints on the natural Higgs width in an hadronic collider (180 MeV or ~44 x SM).

- The interference with off-shell production of on-shell ZZ pairs is a “model dependant” handle we have to use.
A constraint within 30 % can be achieved with this approach.

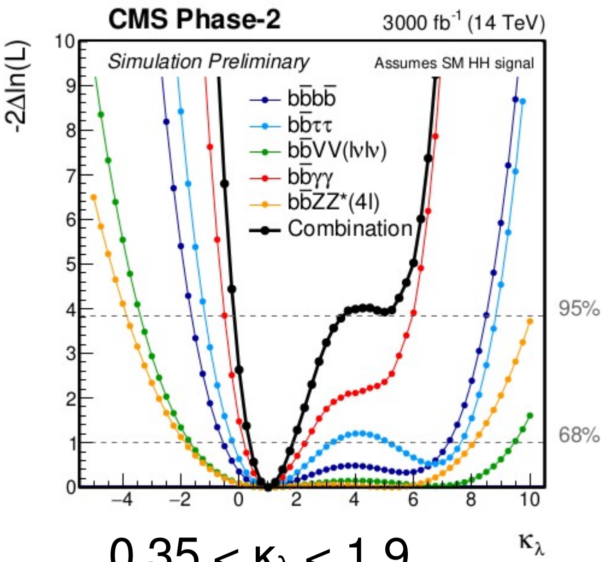


4) HH production



- HH production is the best handle to study the parameters of BEH potential. (postulated and not derived from first principles).
- Very challenging: 1000 times less events than single H production.

•

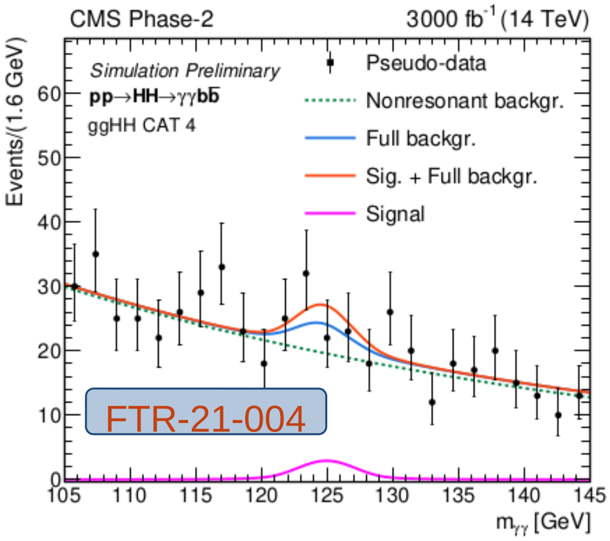


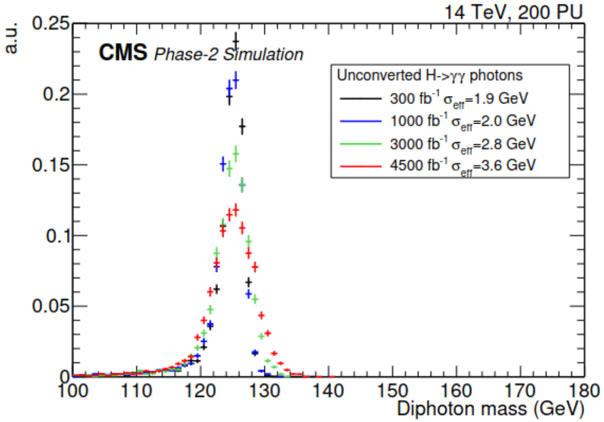
$0.35 < \kappa_\lambda < 1.9$

- Large common effort over many channels considered for Yellow Report, in particular for Self-coupling constraint.
- Best sensitivity for HH→γγbb (expected 1.8 σ)

4.1) HH→γγbb update

- The simplified analysis from Yellow Report (4 categories M_{HH} x MVA) updated with the best knowledge of Run 2
  - Including VBF HH
  - 8 categories (2 VBF HH, 6 ggHH) with much more evolved MVA
  - Removal of ttH using MVA
- The limiting factor for this analysis is slow degradation of Mγγ resolution with the darkening of ECAL barrel crystals.

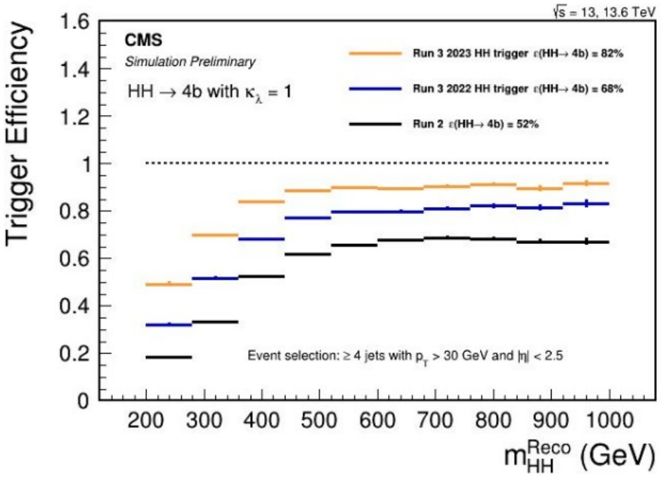




Expected significance
1.8 → **2.2 σ**

4.2) HH→bbbb update

- The 4b channel is particularly sensitive to the trigger efficiency.
- Different new strategies are developed to improve it :
  - Data parking : for Run 3 data with low pT b-jets are stored at 180 Hz with delayed reconstruction.
  - Dedicated L1 path followed by a dedicated HLT path.
  - During HL-LHC phase possibility of loose b-tagging on L1, making HLT b-jet triggers more efficient.



DP2023_050

Trigger	Requirement	Rates at HLT at 2x10^34 cm-2s-1
2023 HH trigger	HT > 280 GeV, 4 jets with pT > 30 GeV, PNet@AK4(mean 2 highest b-tag score) > 0.55	180 Hz
2022 HH trigger	4 jets pT > 70, 50, 40, 35 GeV, PNet@AK4(mean 2 highest b-tag score) > 0.65	60 Hz
2018 triple b-tag [2,3]	HT > 340 GeV, 4 jets pT > 75, 60, 45, 40 GeV, 3 b-tags with DeepCSV > 0.24	8 Hz

Summary and Conclusion

- The HL-LHC project is defined in the first place as a Higgs factory and will shape our knowledge of the Higgs sector for the next 25 years.

- The Phase II data will provide a very complete and global vision of Higgs physics with a maximal precision than can be reached with a hadron collider:
  - BF down to muon will be known with a precision of a few %.
  - The Higgs boson mass will be known with a nearly « ultimate » precision, while the Higgs boson width estimated in a model-dependent way.
  - The HH production and some hints about the direct measurement of the Higgs potential are within reach.

BACKUP

Danielle Monico, 2021

3) H mass and width

- The Higgs mass will be known with 25 MeV precision, mainly dominated by the $H \to 4\mu$. Here same source of improvement as for $H \to \mu\mu$.
- The absolute width may be contraint directly to 180 MeV (~44 x SM)