SIF 2015: 101° Congresso della Società Italiana di Fisica

Study of the performances of the $H \rightarrow ZZ^* \rightarrow 4l$ analysis with the CMS Phase-II Upgrade

Lisa Borgonovi, Sylvie Braibant,
Francesca Cavallo, Paolo Giacomelli, Luigi Guiducci, Simranjit Chhibra
Università and INFN Bologna
Nicola de Filippis
Politecnico and INFN Bari

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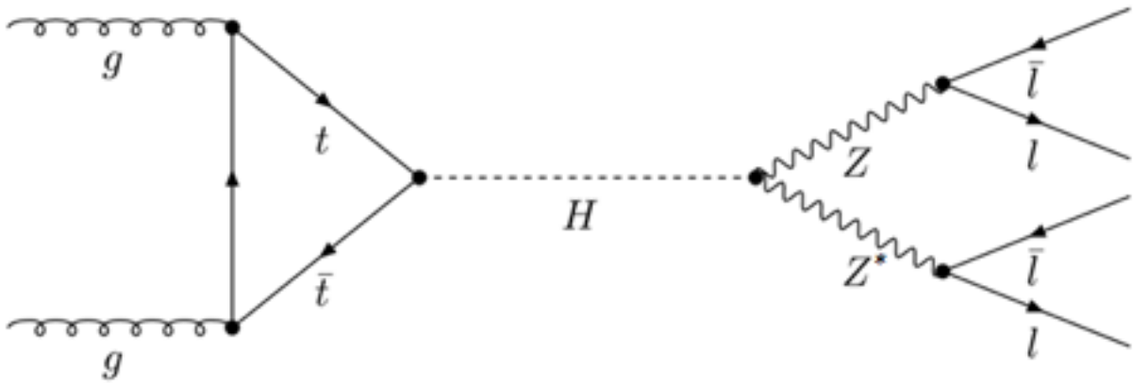
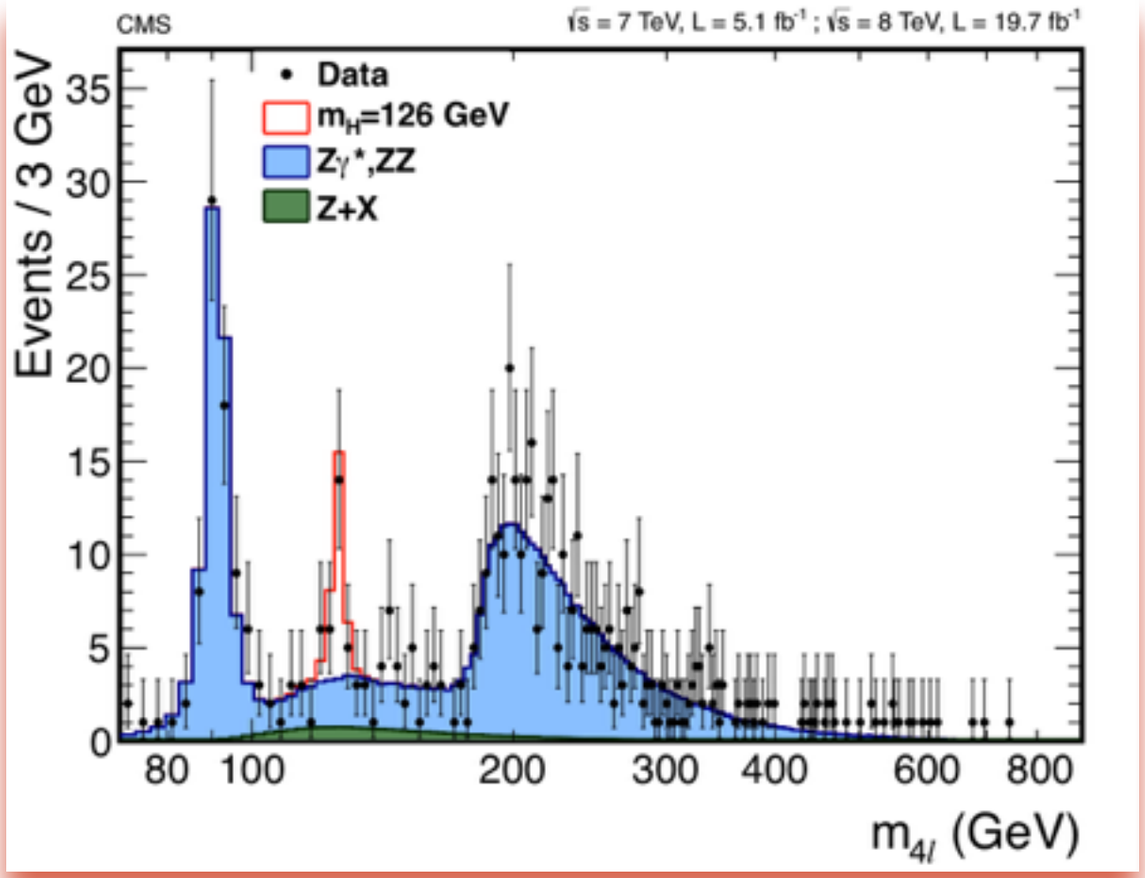
The Higgs boson

- 2012 @LHC (ATLAS - CMS): **Higgs discovery**
  Last missing piece of the SM!
- Higgs: fundamental for future studies: in particular
  $H \rightarrow ZZ^* \rightarrow 4l$ ($e^{\pm}$, $\mu^{\pm}$)
  - small background contamination
  - clean final state





LHC

LS2 ➡ Run3

$\mathcal{L} = 2 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\sqrt{s} = 14\ \mathrm{TeV}$

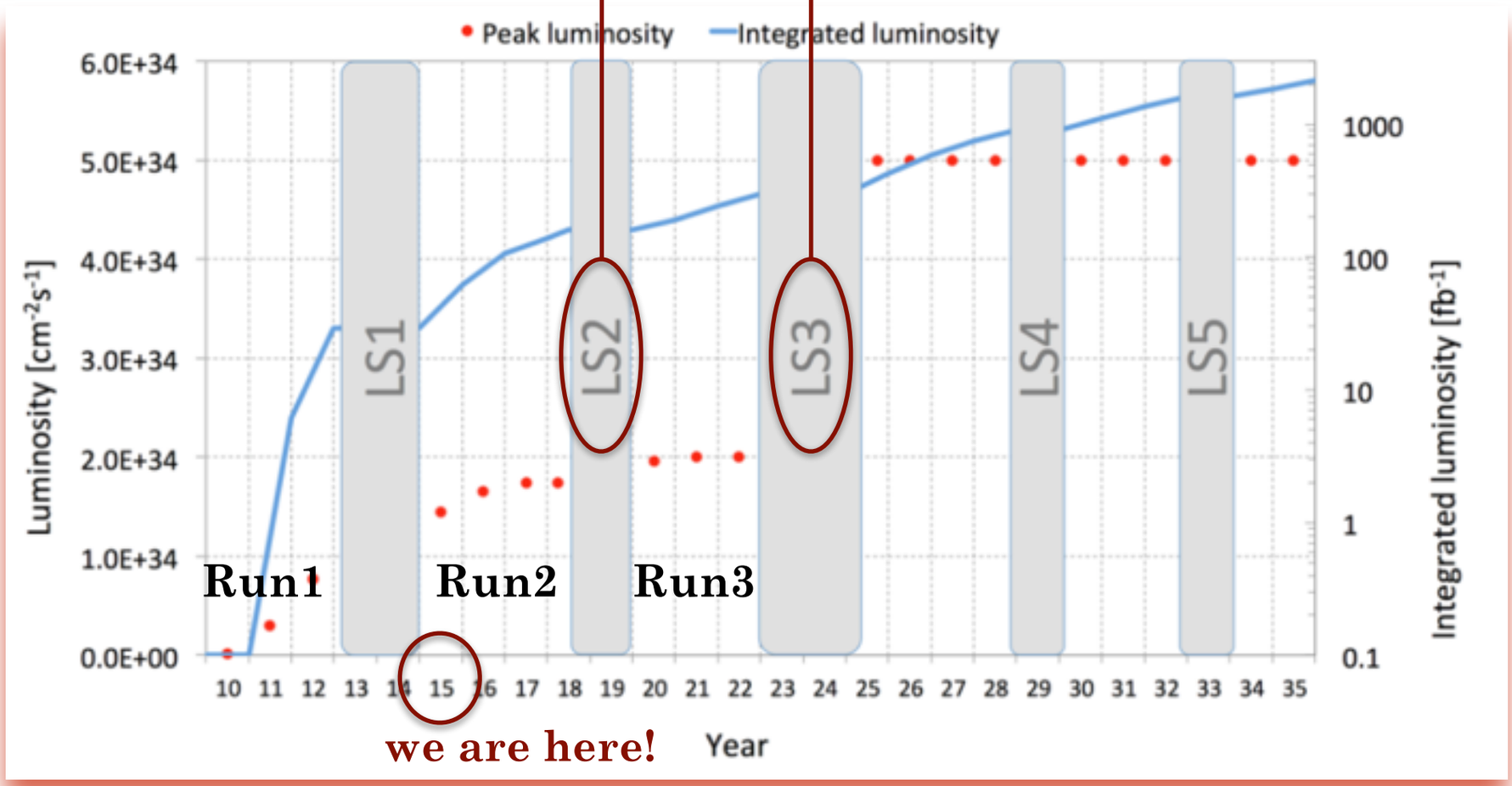
PU = 50

LS3 ➡ HL-LHC

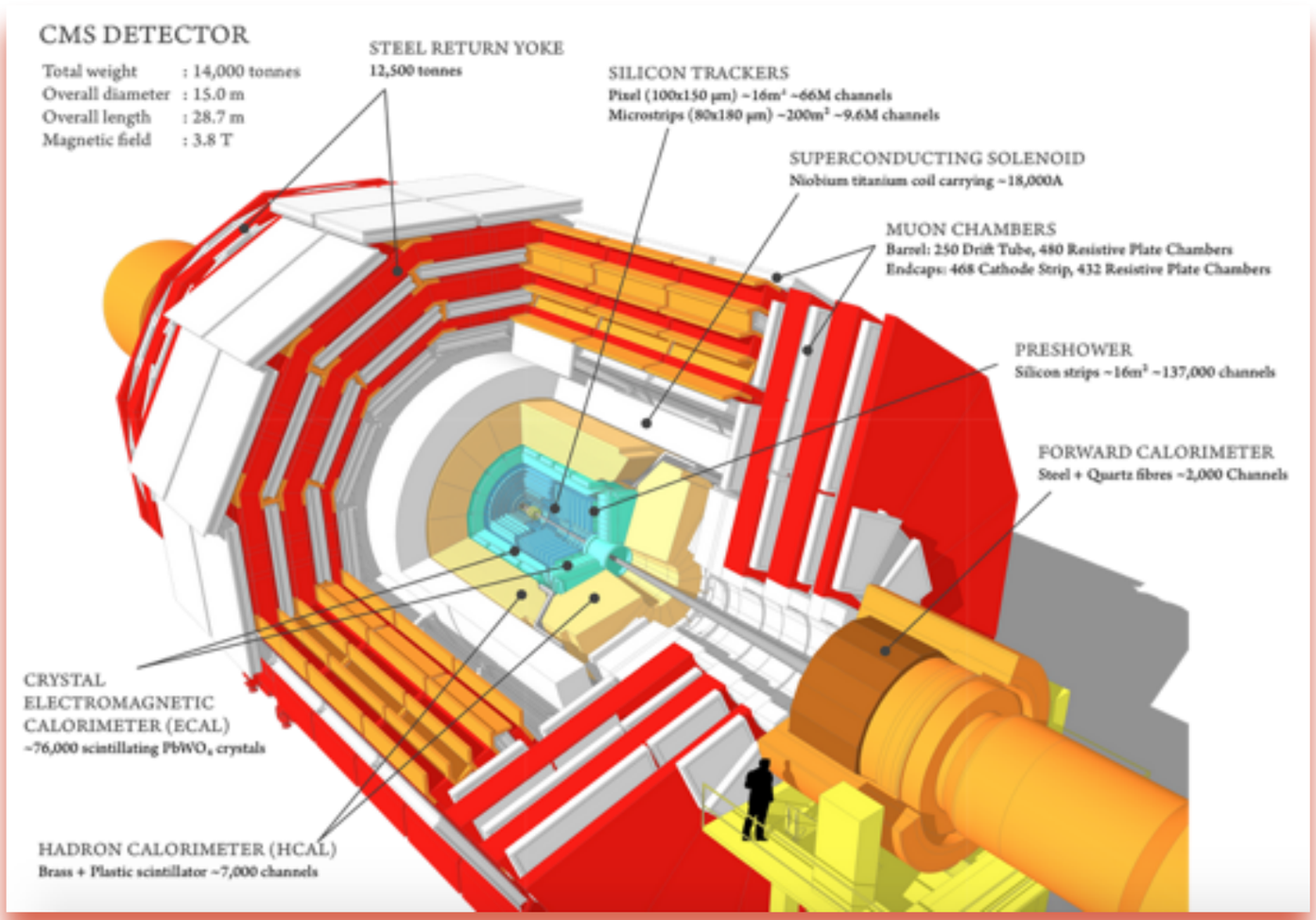
$\mathcal{L} = 5 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\sqrt{s} = 14\ \mathrm{TeV}$

PU = 140



CMS upgrades



Plan of upgrades:

Phase-I (2019):

- Pixel
  4th layer: better vertex reconstruction
- L1 Trigger
  Same rate and efficiency (in high PU and Lumi conditions)
- HCAL
  Electronics

Phase-II (2023): improvement (or substitution) of **ALL** sub-detectors

- New tracker and end-cap calorimeter
- **η** coverage extension (tracker + muon system) $\eta = 2.4 \rightarrow \eta = 3.0$

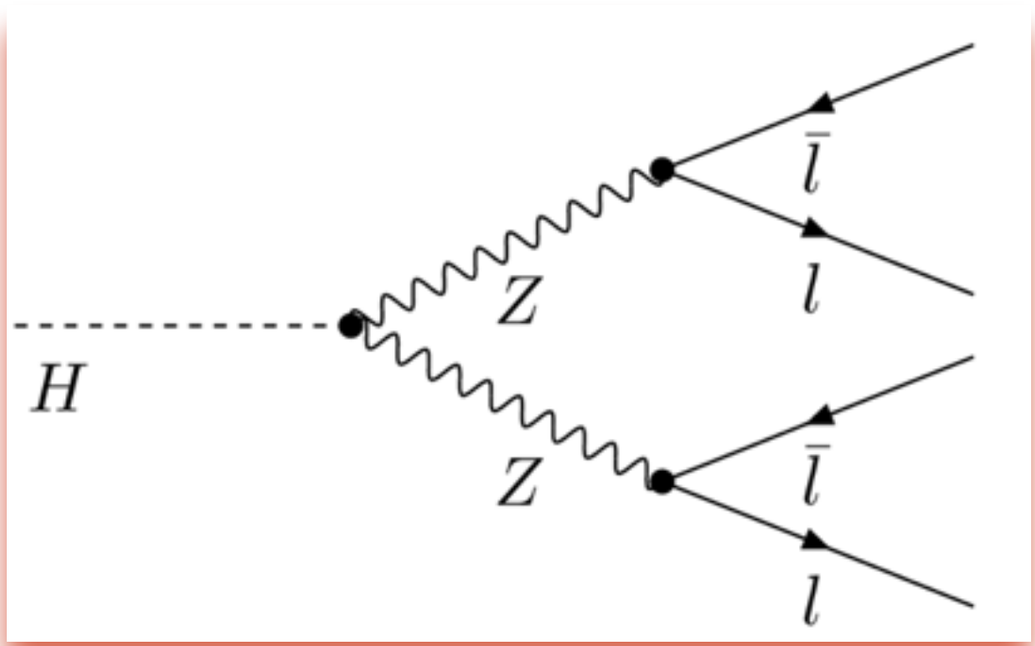
Signal - Backgrounds

- **Signal**:

  $H \rightarrow ZZ^* \rightarrow 4\mu$

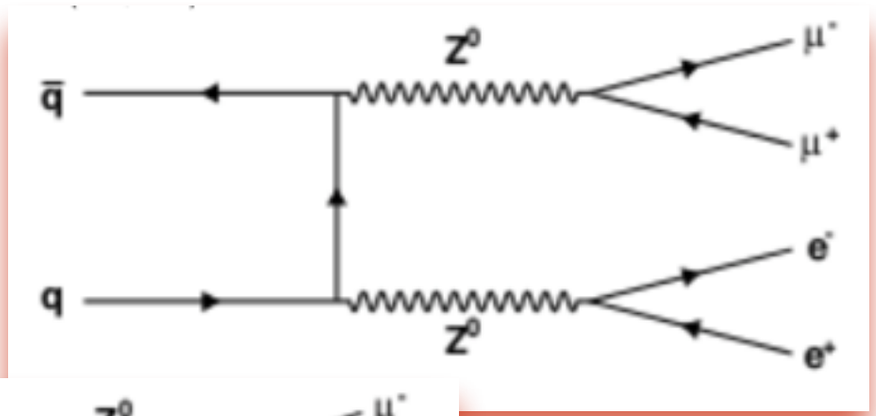
  $H \rightarrow ZZ^* \rightarrow 4e$

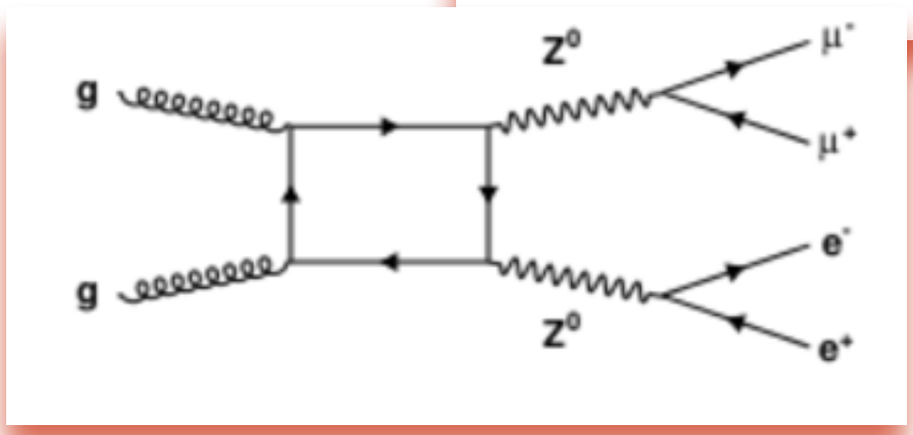
  $H \rightarrow ZZ^* \rightarrow 2e2\mu$



- **Irreducible Background**:

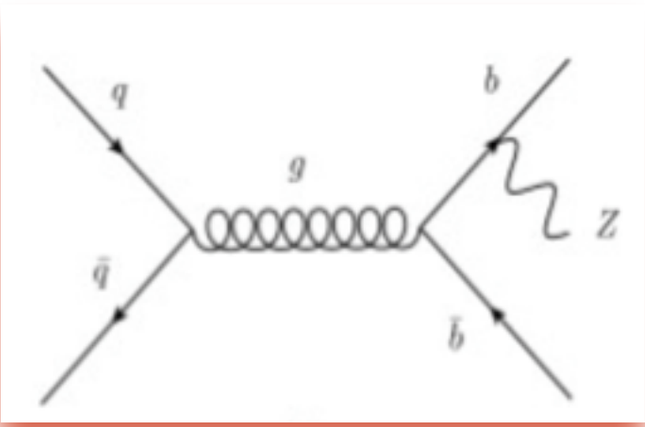
  $ZZ \rightarrow 4l$





- **Reducible Background**:

  Z+jets



This channel has been used to study the Phase-II upgrade performances

Upgrade Scenarios

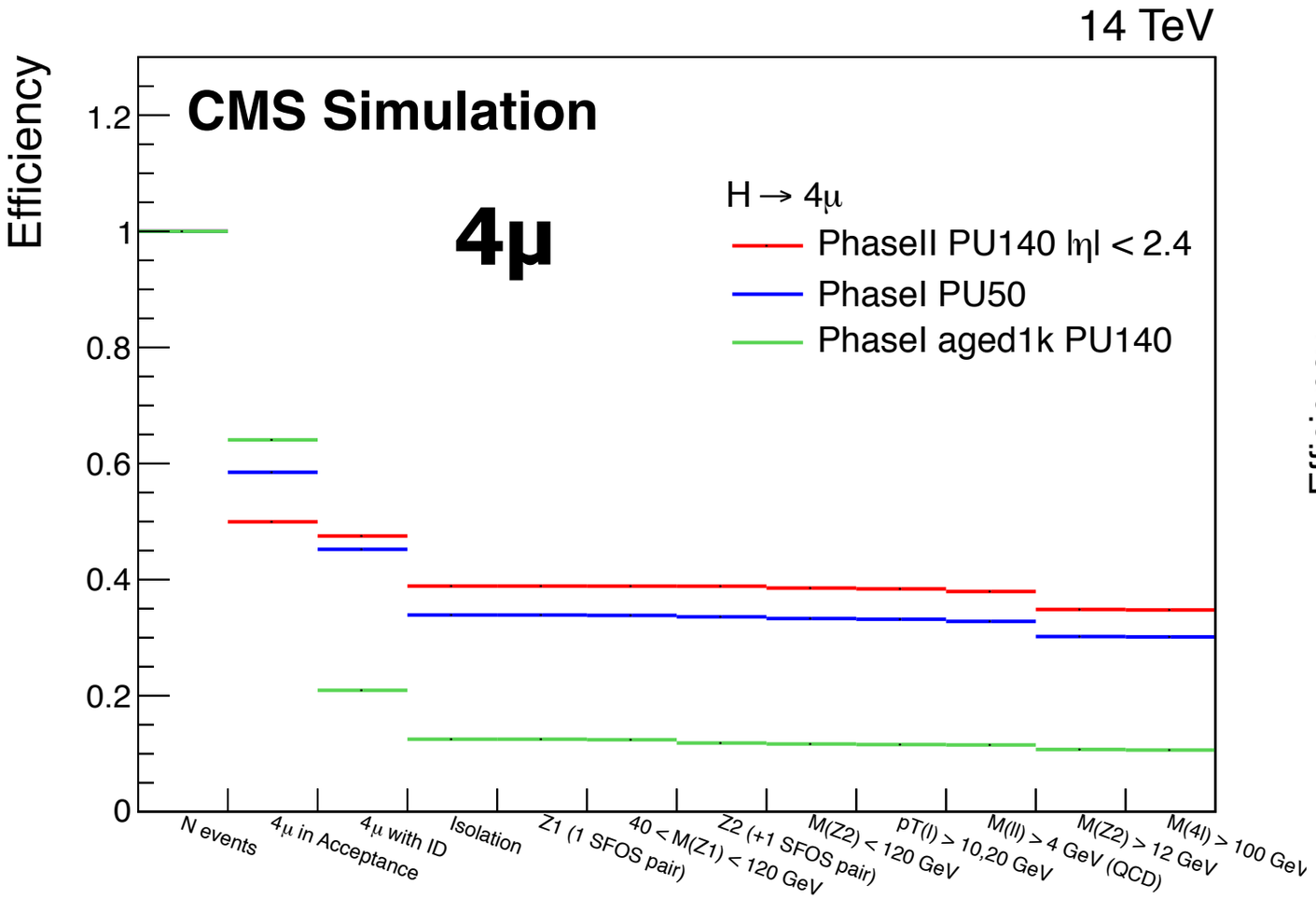
- **Phase-I (2019): reference**
  BX = 25 ns, PU 50, $\mathcal{L} = 2 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

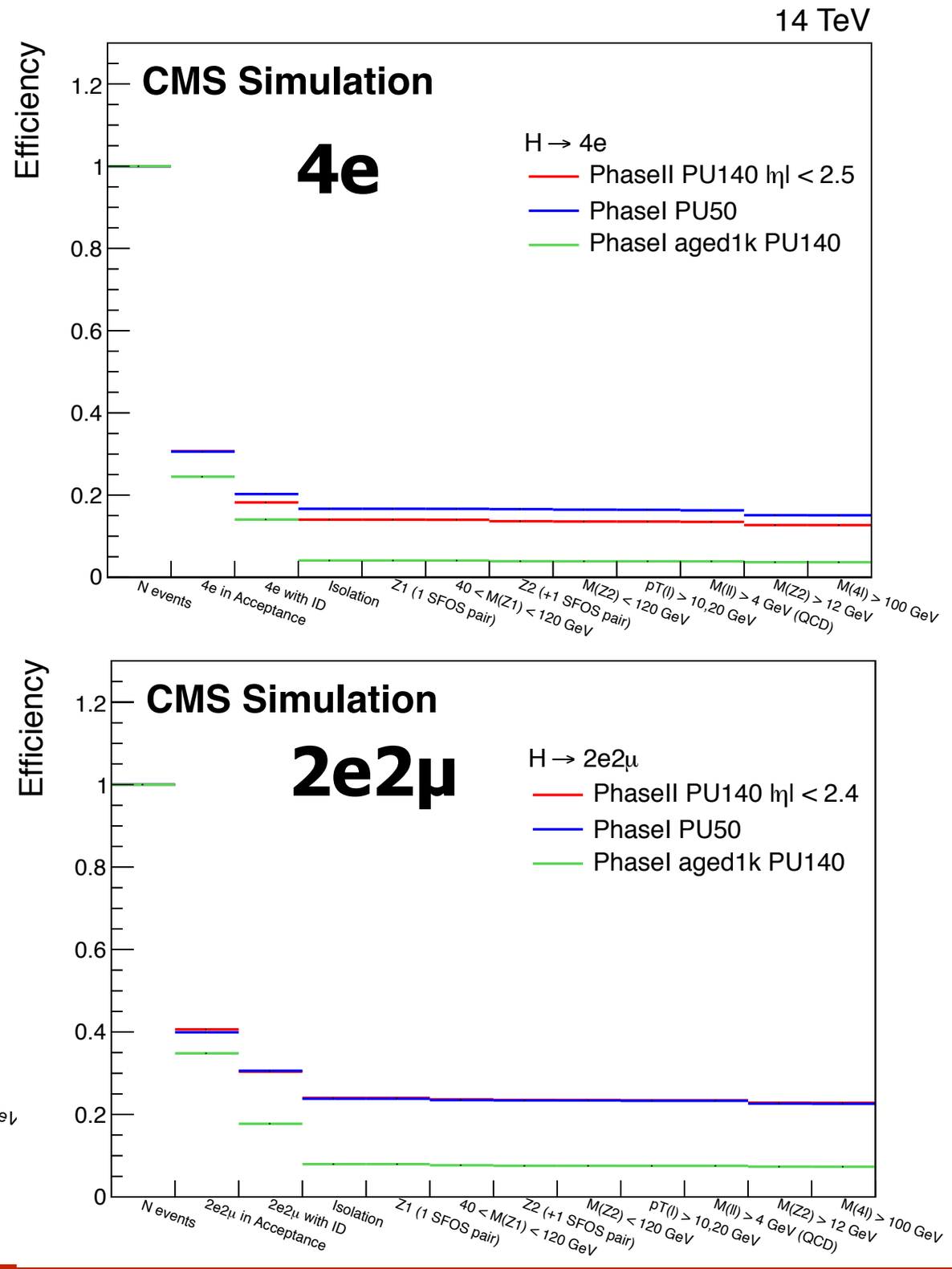
- **Phase-I "aged" (2019 geometry, 1000 fb^{-1} aging)**
  Phase-I geometry detector but in worse experimental conditions with no upgrades
  BX = 25 ns, PU 140, $\mathcal{L} = 5 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

- **Phase-II (2023)**
  Phase-II geometry detector WITH PLANNED UPGRADES
  BX = 25 ns, PU 140, $\mathcal{L} = 5 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Upgrade studies (1)

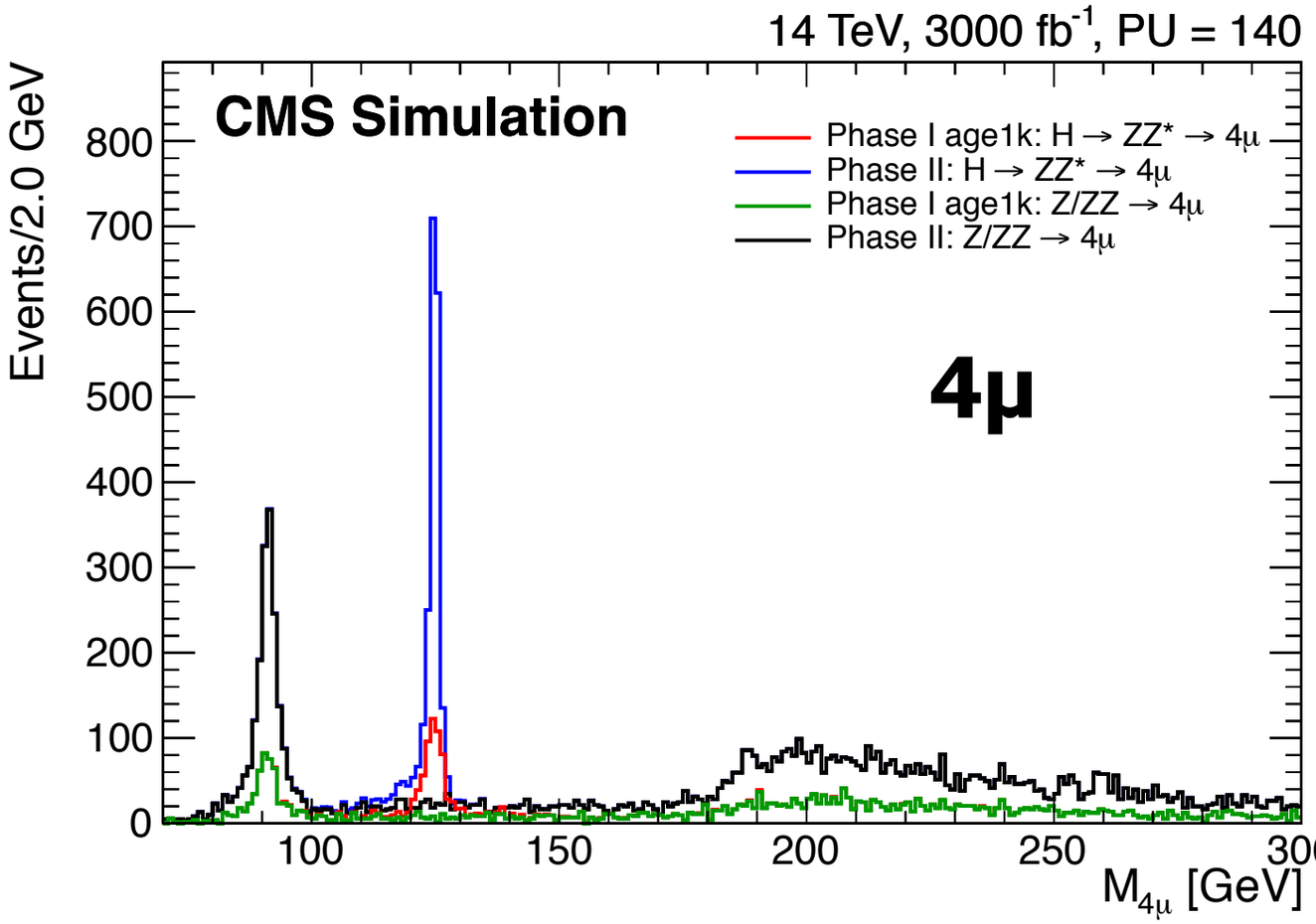
Cut flow tables
$|\eta| < 2.4$

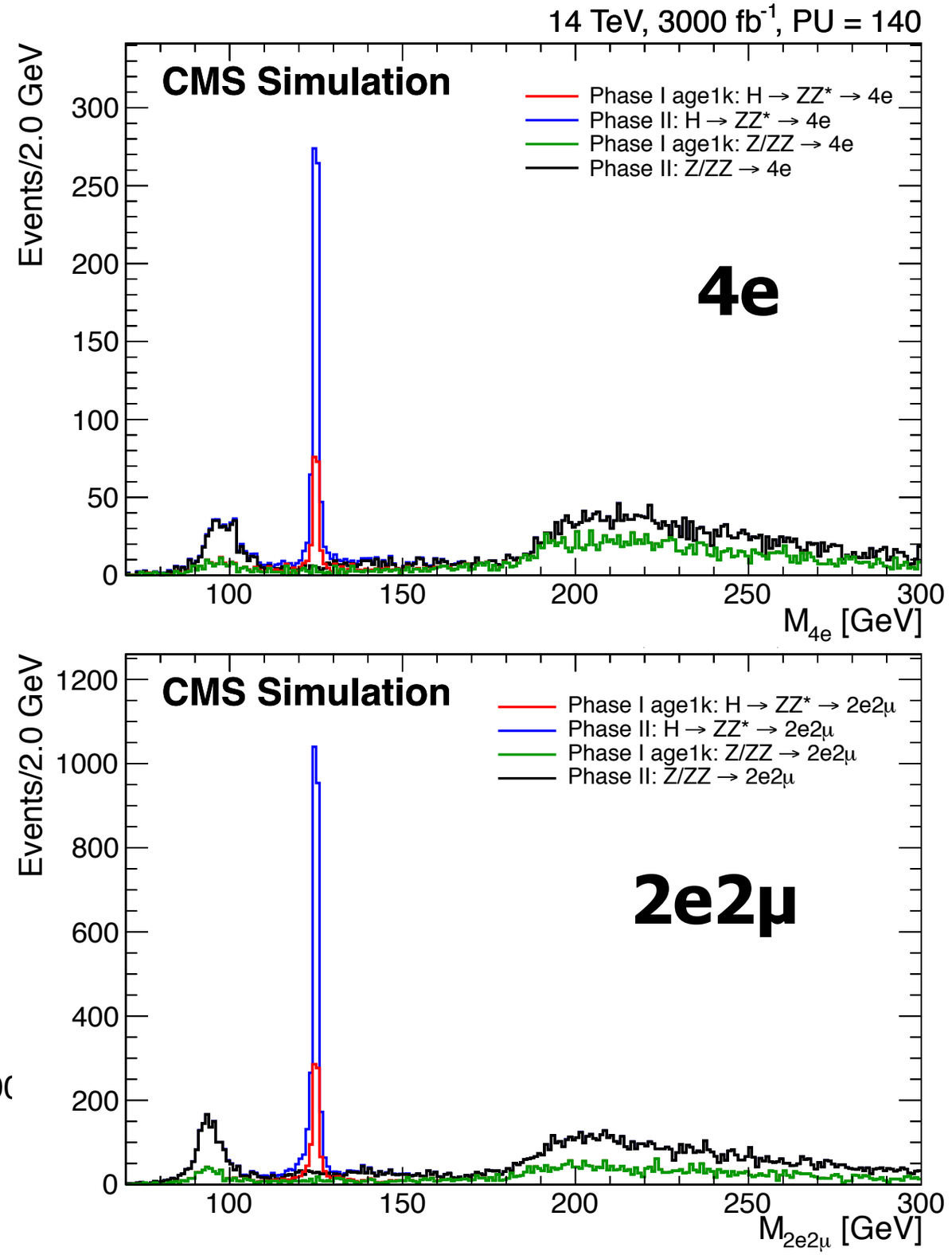




Upgrade studies (2)

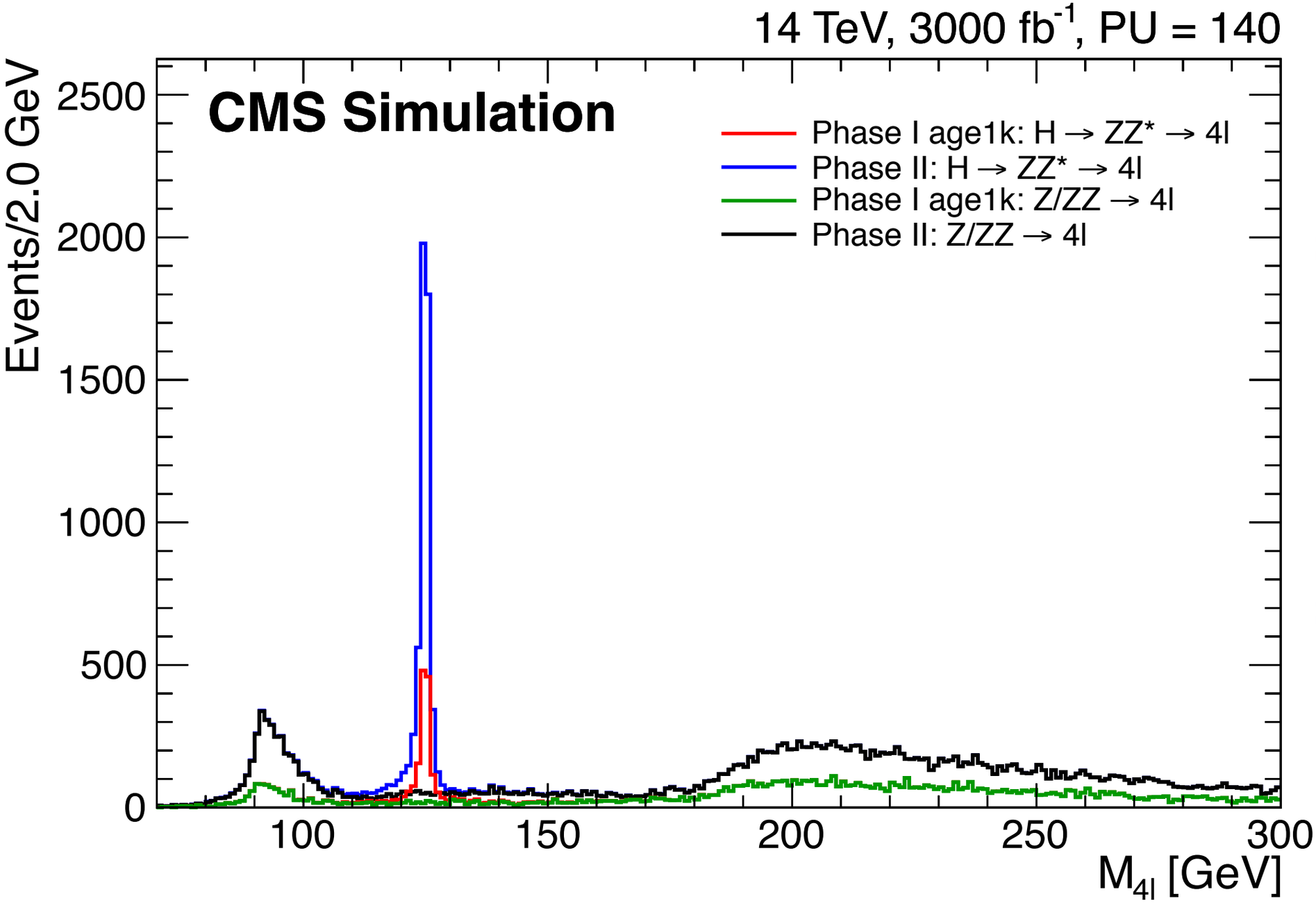
4-lepton invariant mass
$|\eta| < 2.4$





Upgrade studies (3)

4 leptons



Phase I "aged"

signal

background

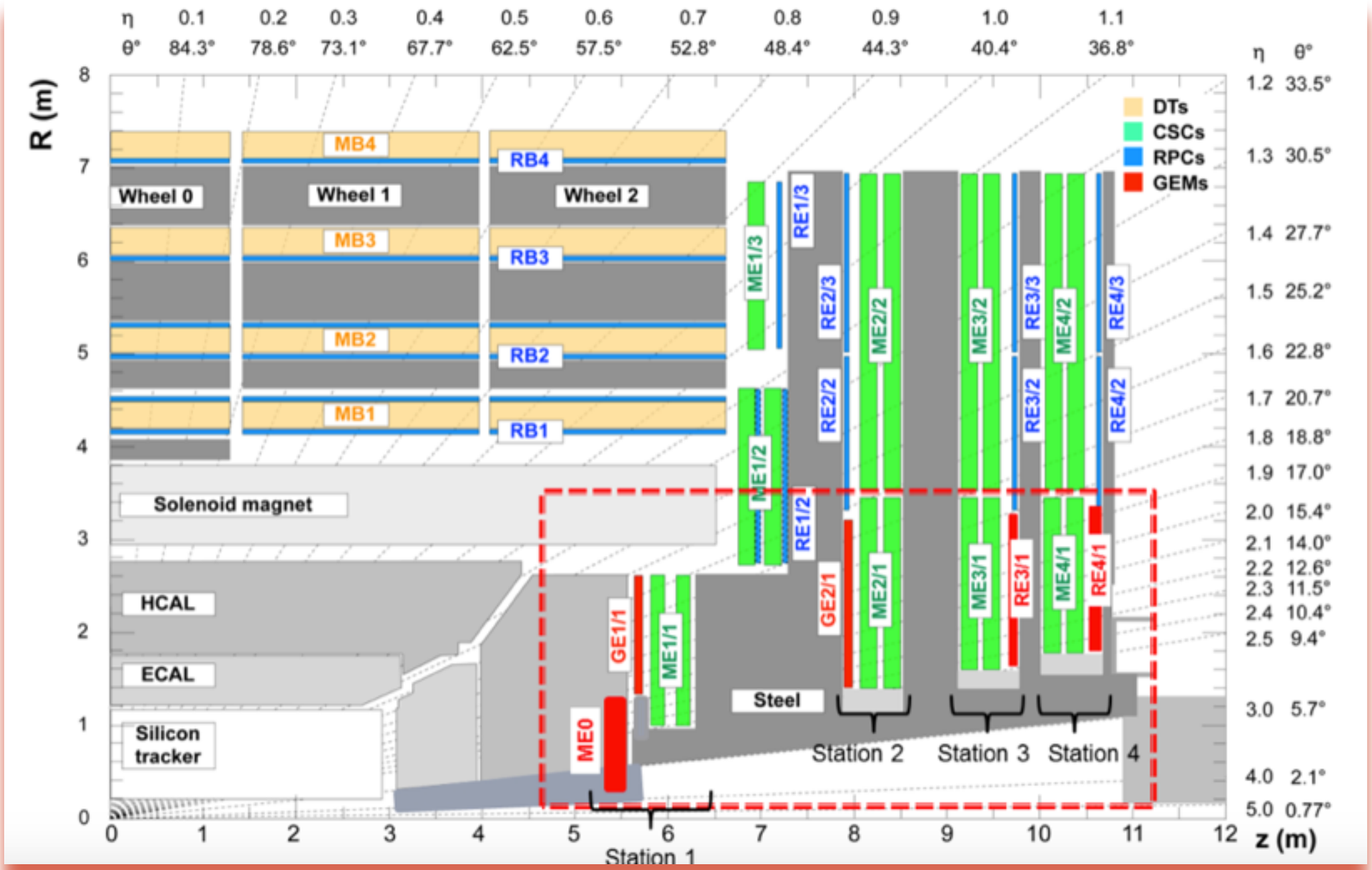
Phase II

signal

background

Upgrade: geometry extension

Plan of the geometry extension of the muon system



Delphes for Detector Simulation

Event Generator output (PYTHIA, MADGRAPH, POWHEG)

FullSimulation

- GEANT4
- **Complete** simulation of the detector (interaction particle-material)
- **Time** and **computing resources** consuming!

Delphes

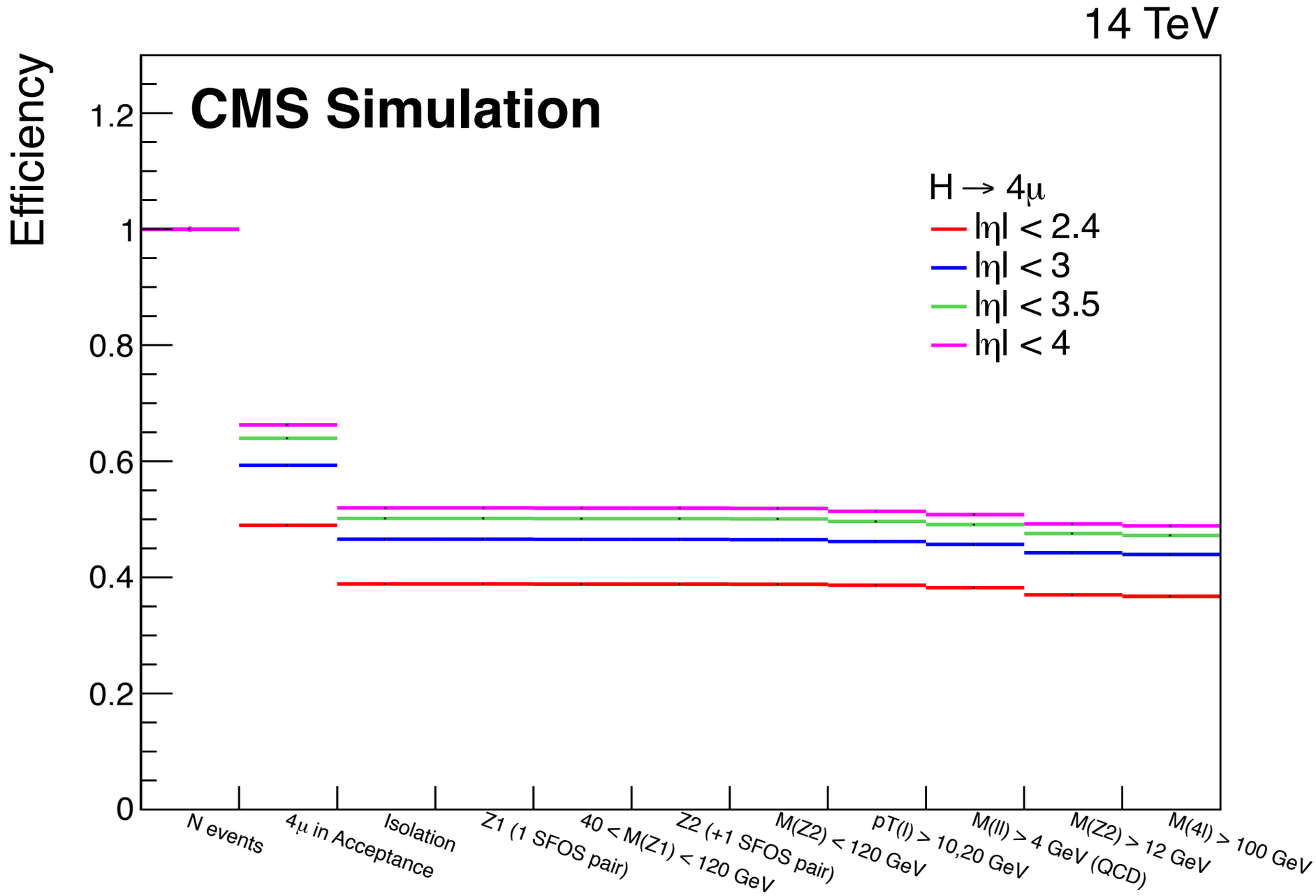
- C++ **modular** framework
- **Fast** and **parametrized** detector simulation
- Limitations

Validation needed!

η extension for muons (1)

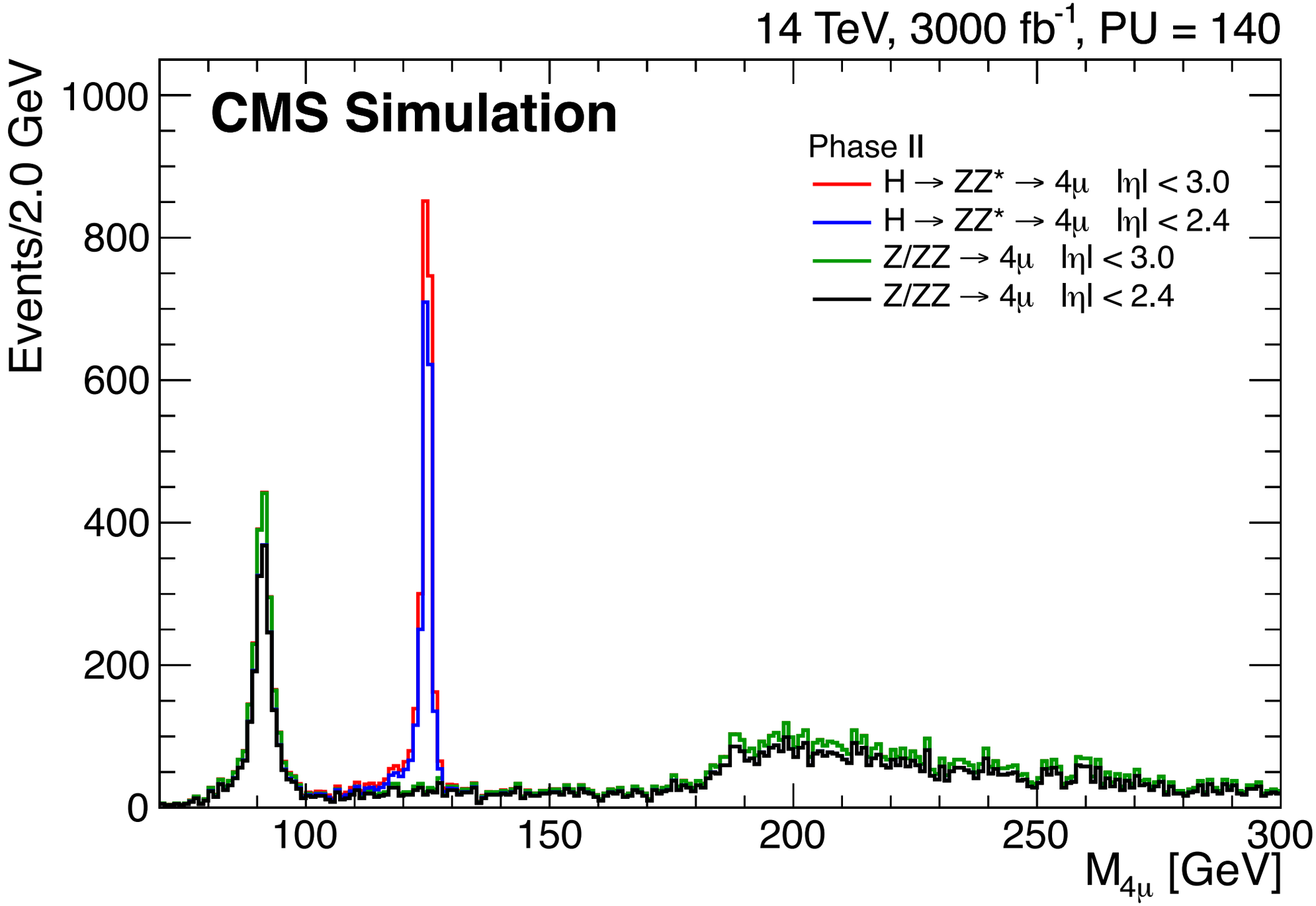
Phase-II:

4μ cut flow table for different acceptances



η extension for muons (2)

4μ invariant mass |η| < 3.0



Conclusions

- Performances of the **Phase-I "aged"** scenario significantly **worse** than the reference **Phase-I** scenario

- **Phase-II** scenario: better 4l mass reconstruction and event selection ➡ it copes with the challenging conditions of HL-LHC

- Geometry extension (|η| beyond 2.4) in the 4μ case increases the event selection efficiency

- These results are **part of the CMS Phase-II Upgrade Technical Proposal CMS-TDR-15-02**, June 2015

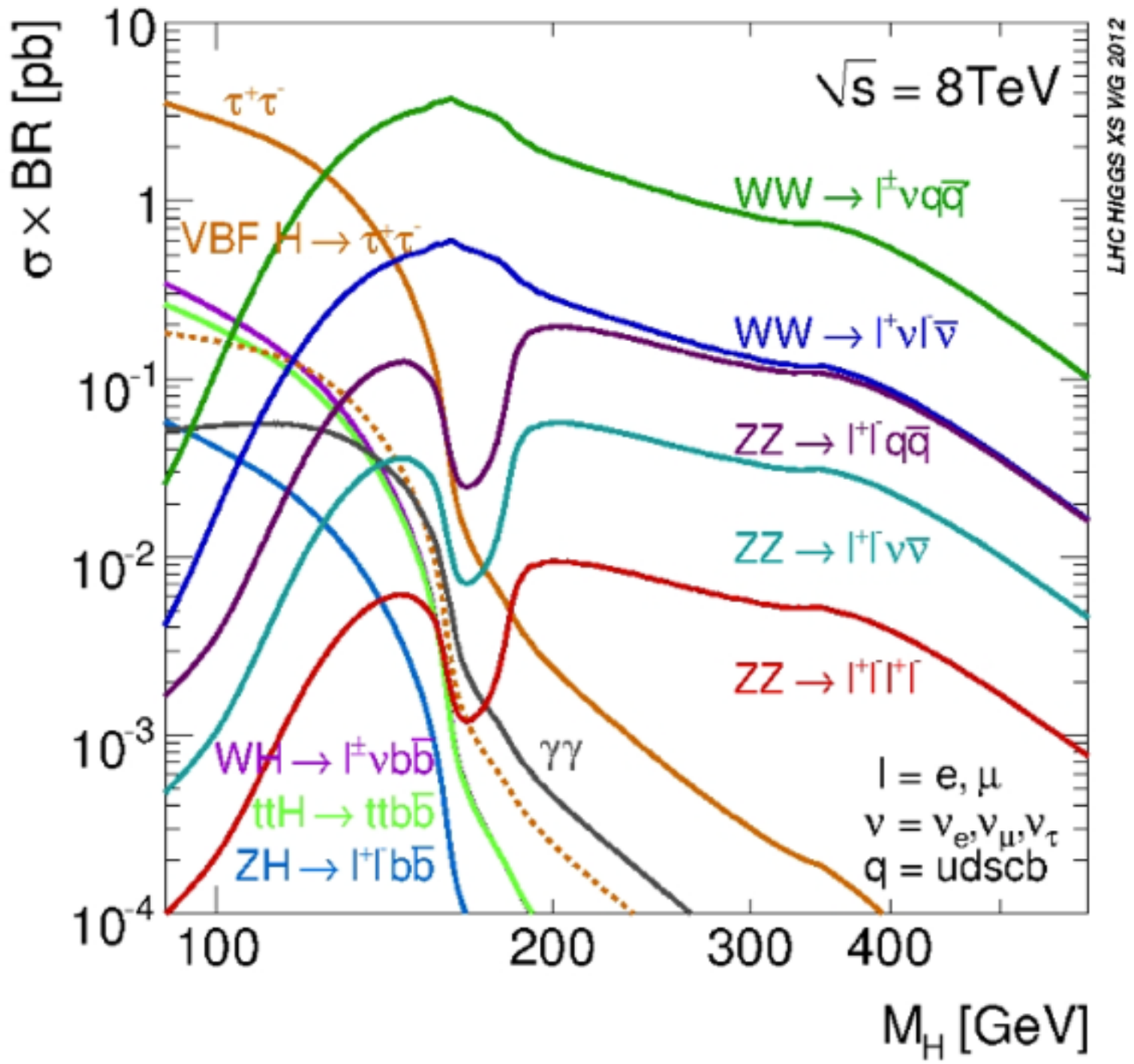
Backup

Cross-sections

m_H = 125 GeV	gluon-gluon fusion	vector-boson fusion	associated production (gauge boson)	associated production (ttbar+bbar)	total
√s = 8 TeV	19.27 pb	1.58 pb	1.12 pb	0.33 pb	22.30 pb
√s = 14 TeV	50.53 pb	4.17 pb	2.38 pb	1.19 pb	58.27 pb

Branching Ratios

m_H = 125 GeV	BR
H → bb	5.77 10^{-1}
H → ττ	6.32 10^{-2}
H → μμ	2.20 10^{-4}
H → cc	2.91 10^{-2}
H → gg	8.57 10^{-2}
H → γγ	2.28 10^{-3}
H → Zγ	1.54 10^{-3}
H → WW	2.15 10^{-1}
H → ZZ	2.64 10^{-2}
Γ_H (GeV)	4.07 10^{-3}



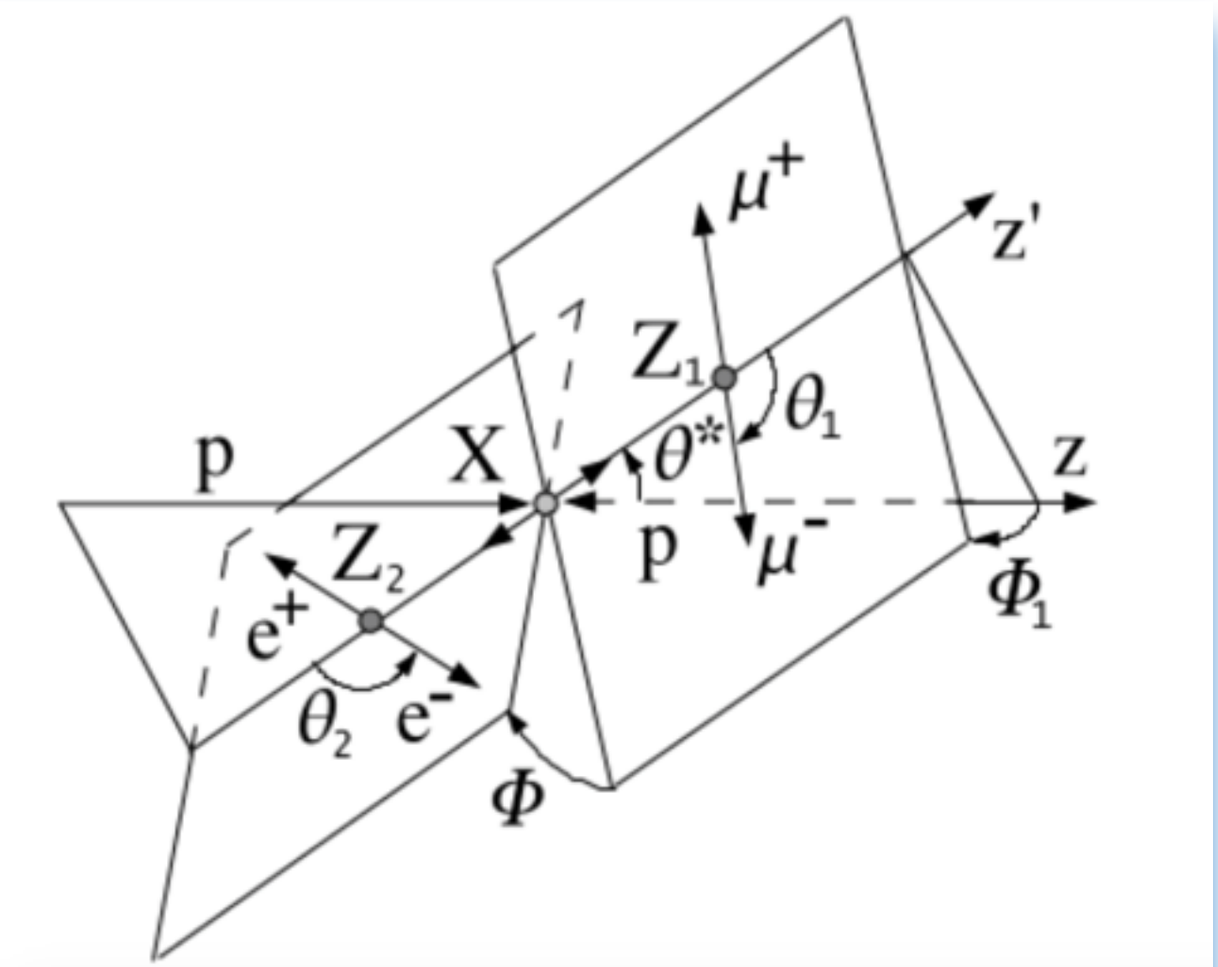
Phase-II Upgrade

Phase-II (2023):

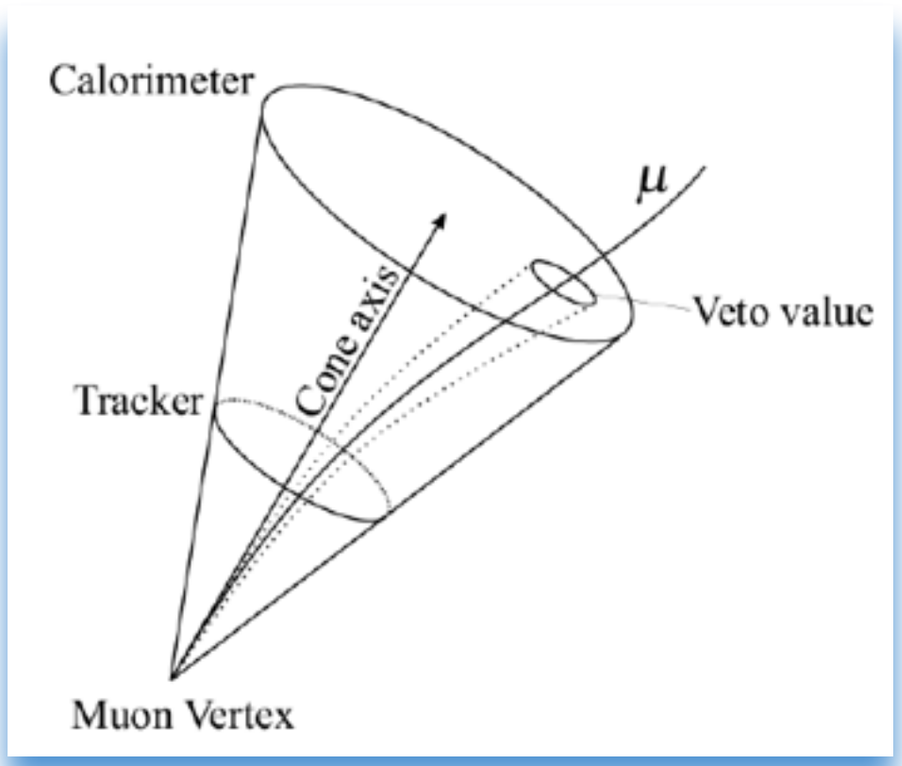
- **Tracker:** new Tracker, used for L1 Trigger
- **Calorimeter (endcap):** Shashlik vs High Granularity Calorimeter
- **Muon system:** redundancy improvement + η coverage extension
- **Trigger:** front-end electronics upgrade to maintain same rate and efficiency

Background Rejection

Kinematic Discriminant



Isolation



$$I(P) = \frac{\sum_{i \neq P} p_T^{charged}(i) + \max\left[\sum_{i \neq P} p_T^{neutral}(i) - I_C,\ 0\right]}{p_T(P)}$$