CMS PODAS
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CMS PO&DAS: Higgs Exercise

Matteo Bonanomi, Philip Keicher, Daniel Savoiu
(University of Hamburg)

CMS

KNOW THE CODE OF CONDUCT

HTTP://CERN.CH/GO/D9BT

IT'S EVERYONE'S RESPONSIBILITY TO:

Maintain a professional environment in an atmosphere of tolerance and mutual respect.

Abstain from all forms of harassment, abuse, intimidation, bullying and mistreatment of any kind.

This includes intimidation, sexual or crude jokes or comments, offensive images, and unwelcome physical conduct.

Keep in mind that behaviour and language deemed acceptable to one person may not be to another.

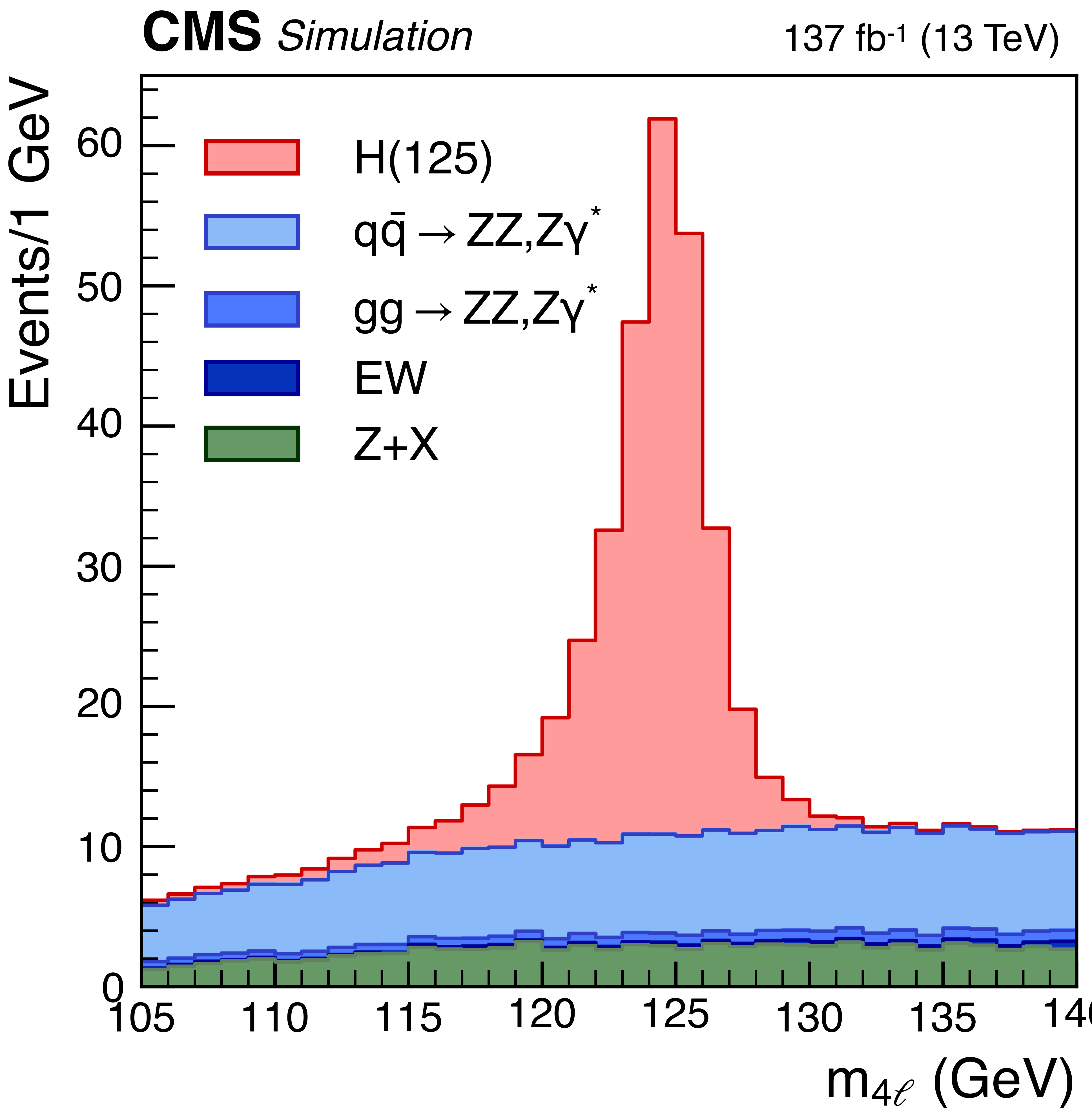
Help our community adhere to the code of conduct and speak up when you see possible violations.

The *golden channel*: H → ZZ → 4ℓ

Large S/B ratio: Good discrimination between signal $m_{4\ell}$ and approx. flat background shape under the peak

Excellent mass resolution: Optimal reconstruction of $m_{4\ell}$ shape thanks to the great resolution power of CMS

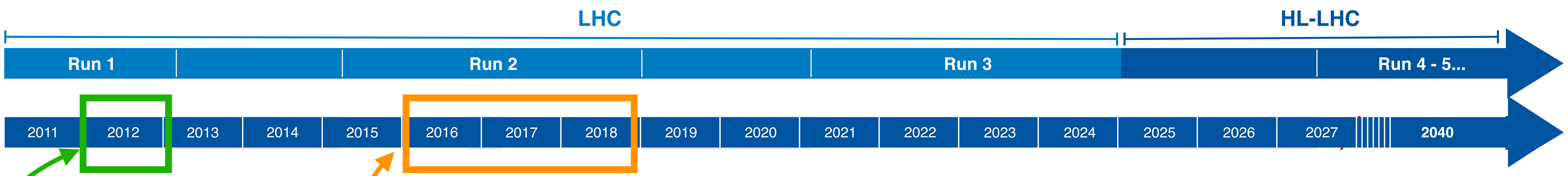
Resolved final state: Detection of the four leptons in the final state ensures good discrimination of signal and background



Fundamental for the discovery of the H but limited by the low branching fraction

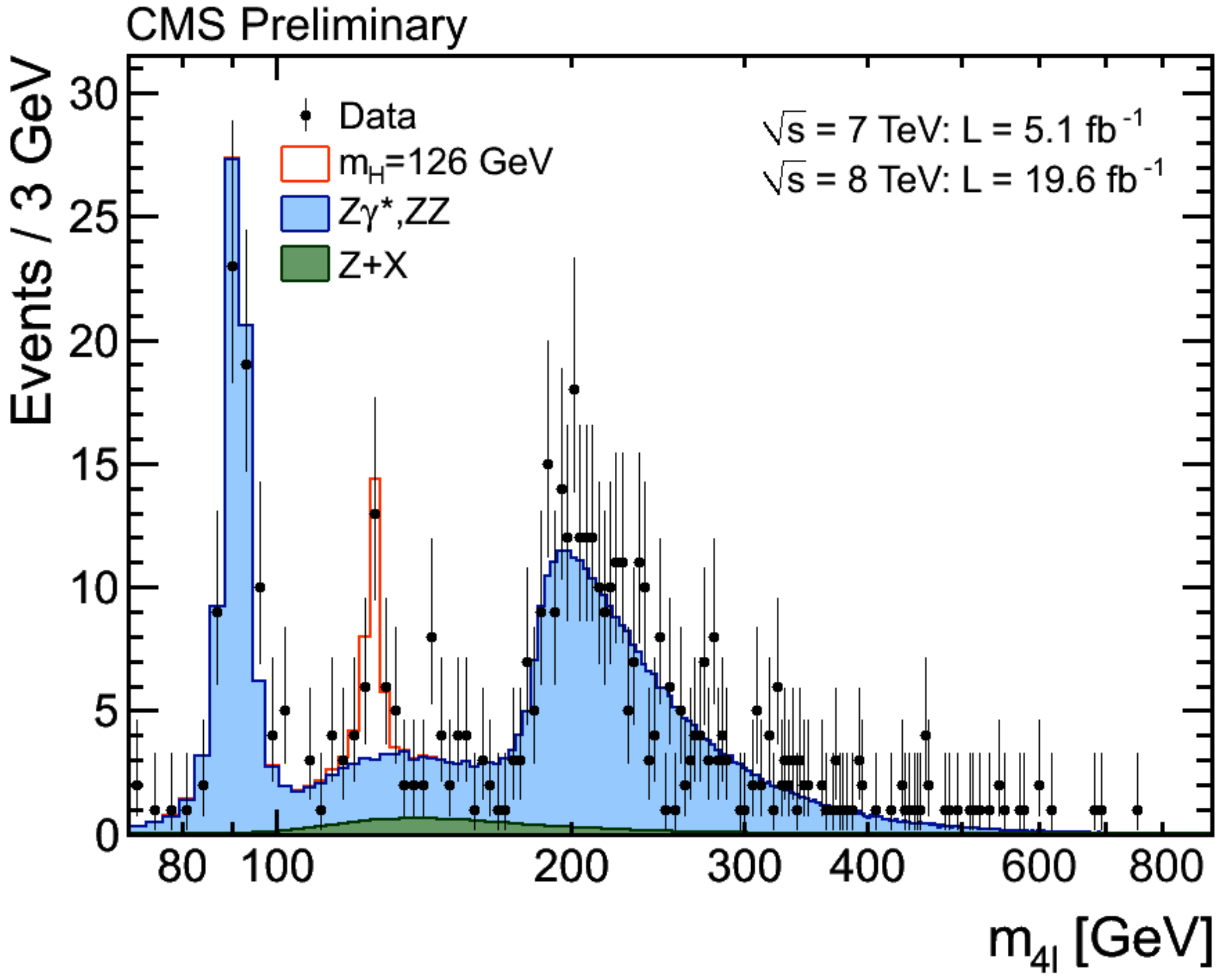
More data, more power

LHC / HL-LHC Plan



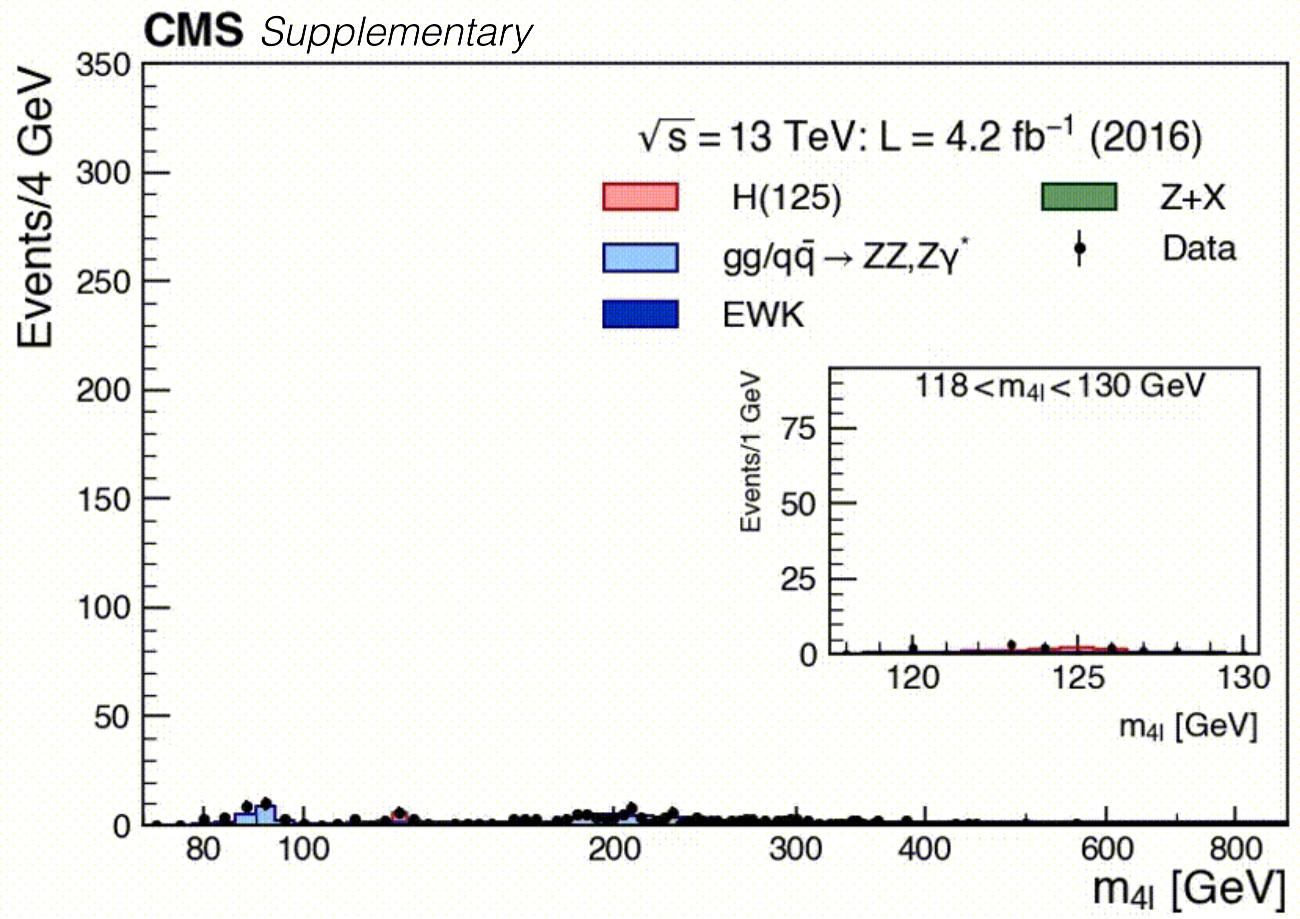
Discovery of the H boson

HZZ driving the sensitivity w/ $H\gamma\gamma$



Run-II (2016-2018)

precision physics era



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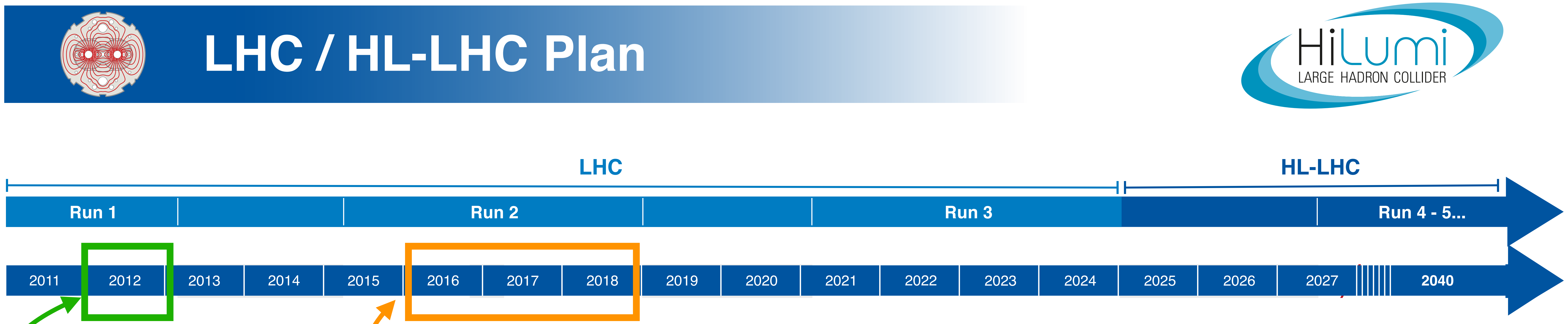

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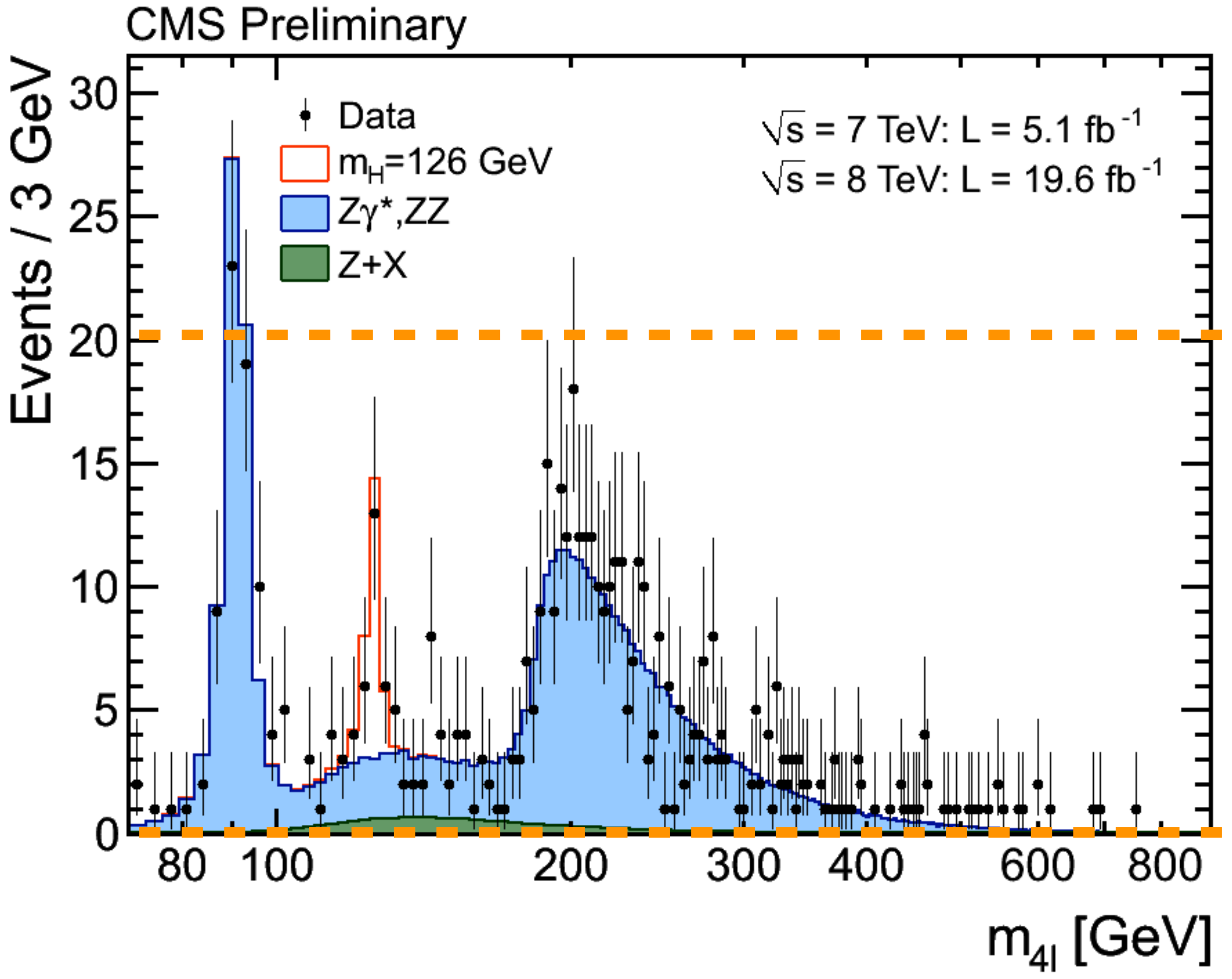

Run-II (2016-2018)

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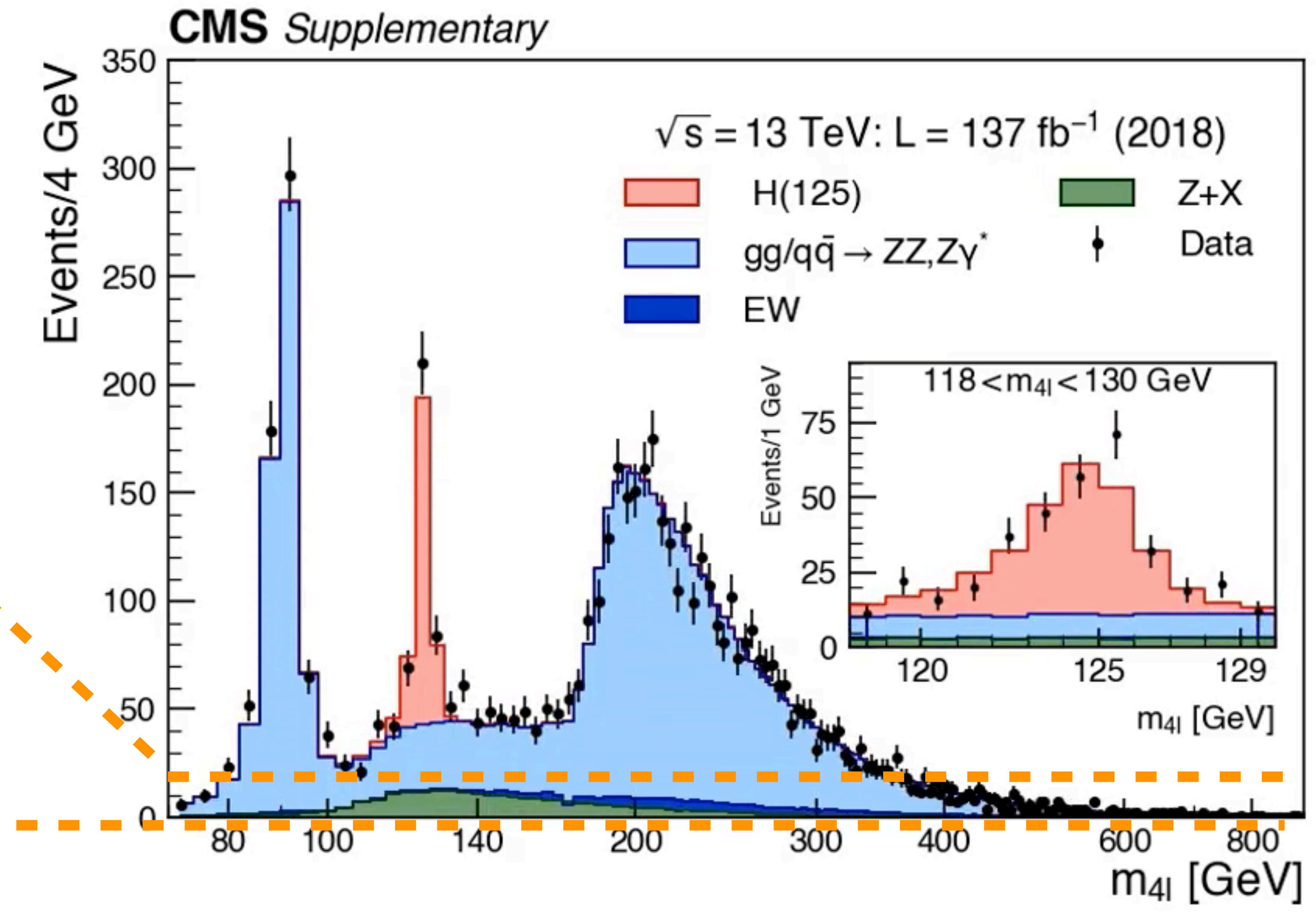
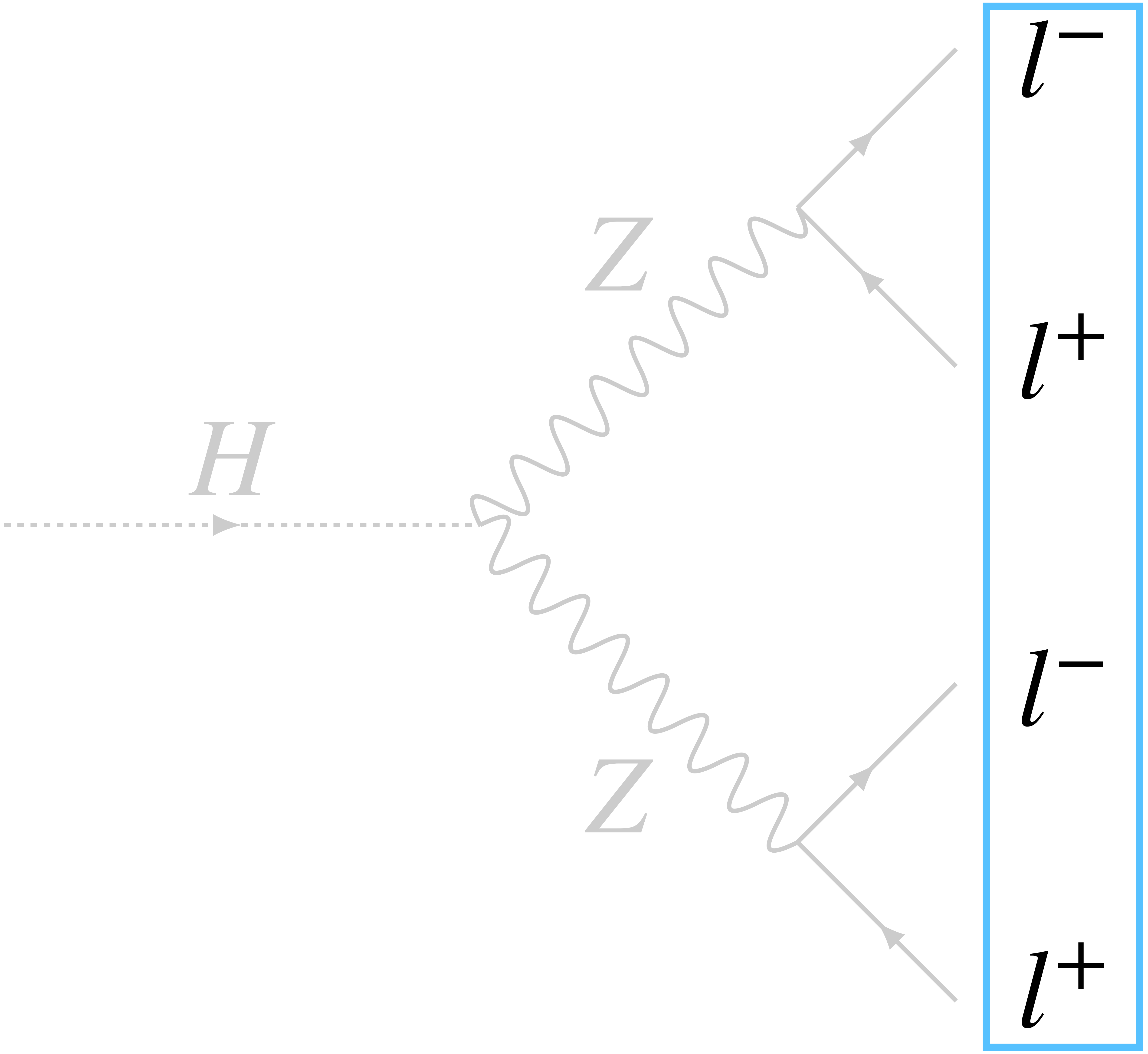


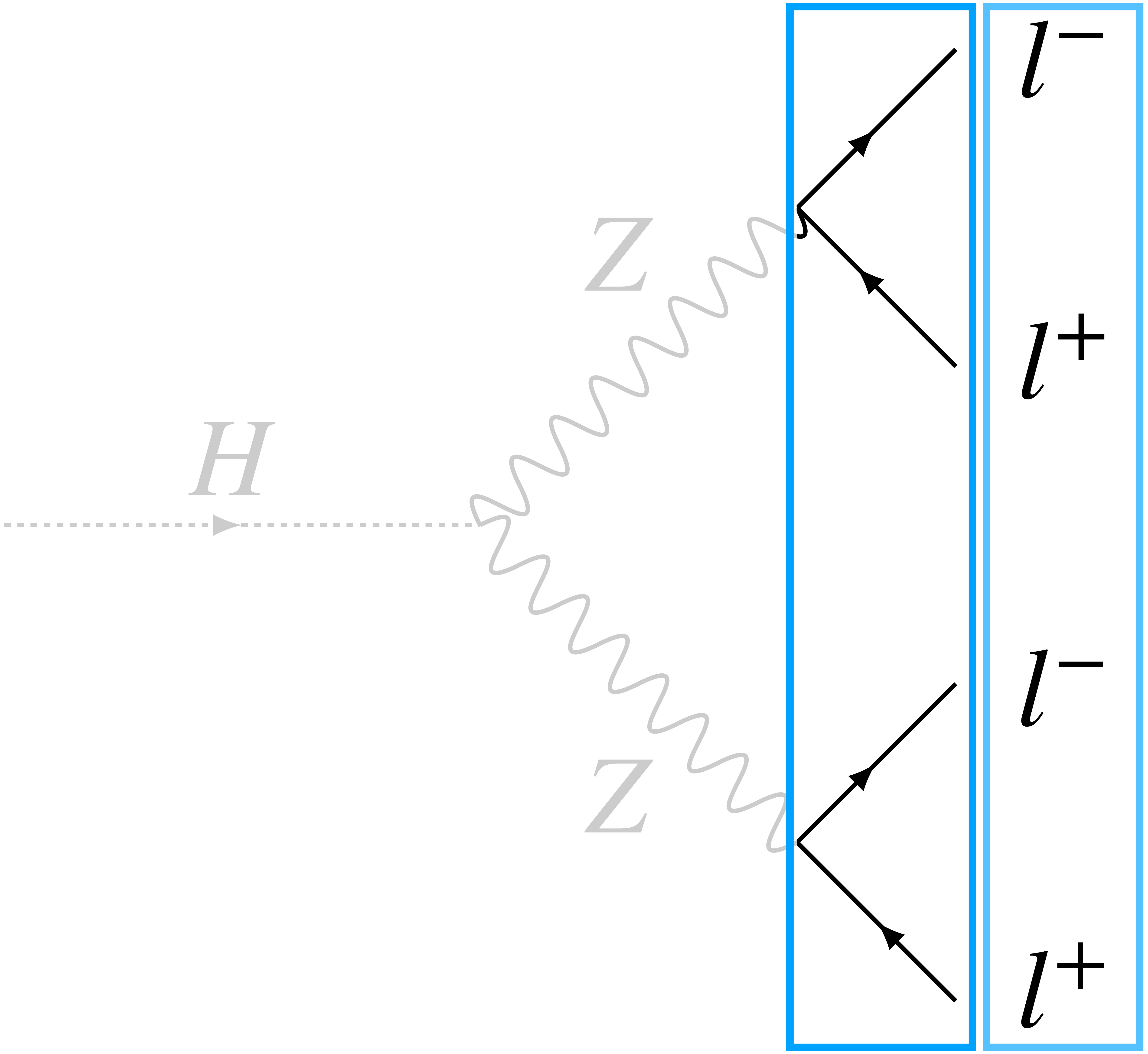
With **x40 more signal events** collected **in Run-II** the **golden channel** can be used to answer many questions…

The $H \to ZZ \to 4l$ analysis



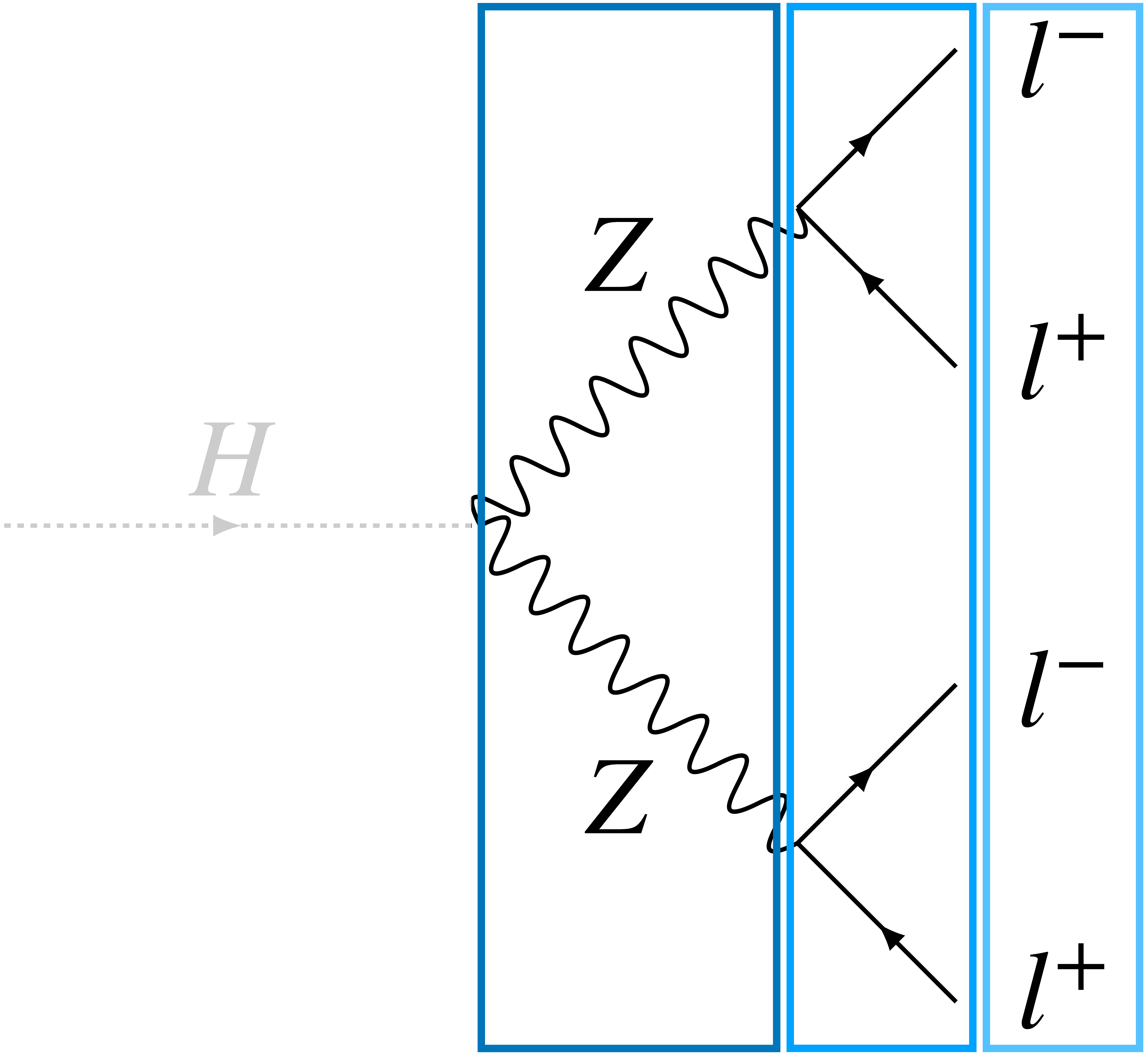
Leptons reconstruction

The $H \to ZZ \to 4l$ analysis



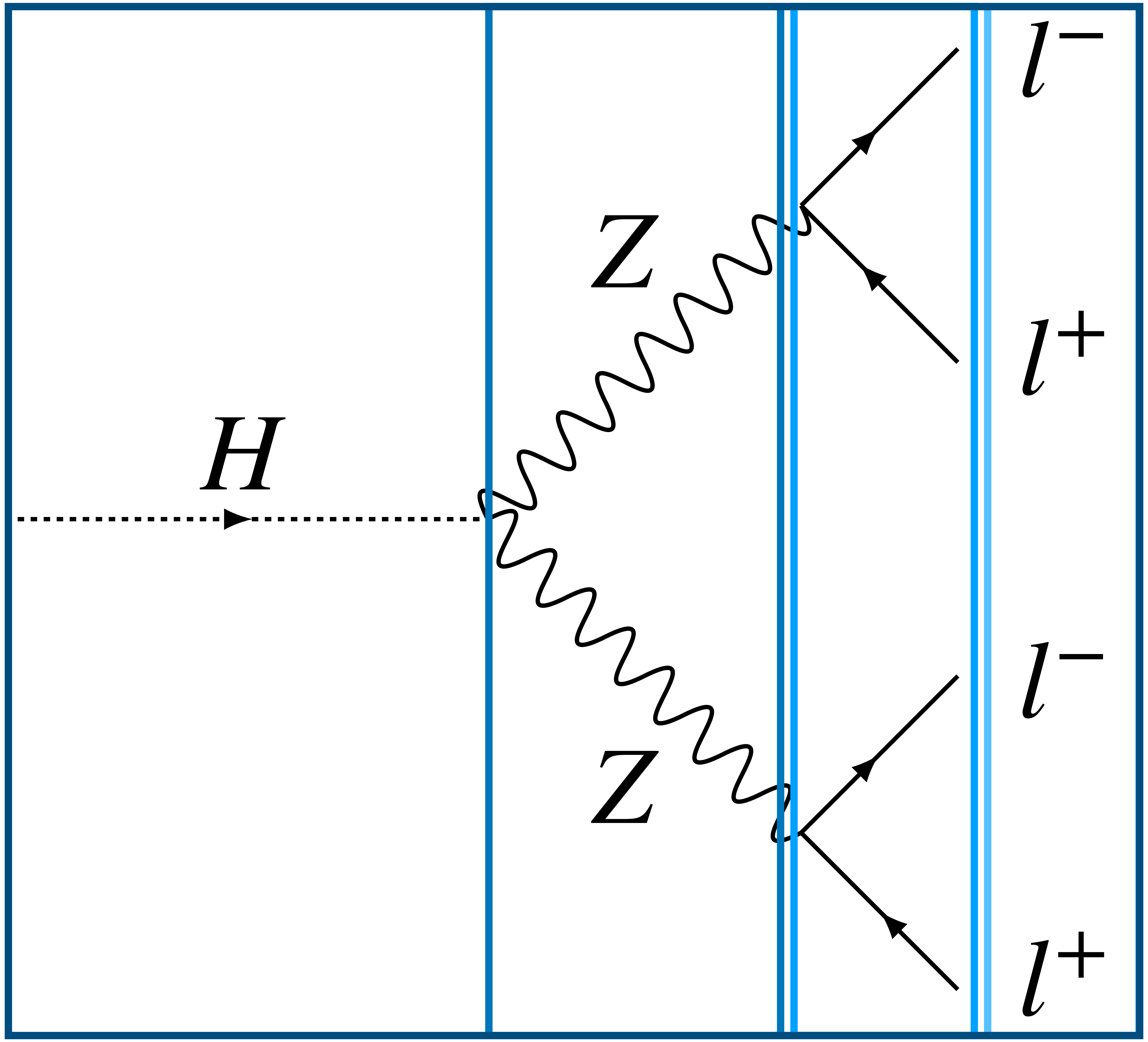
Leptons reconstruction & selection

The $H \to ZZ \to 4l$ analysis



Leptons reconstruction & selection = Z candidates

The $H \rightarrow ZZ \rightarrow 4l$ analysis



Leptons reconstruction & selection = Z candidates

H boson candidates

Measurements of properties of the Higgs boson in the four-lepton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV

From leptons to  boson

Electrons		Muons
Kinematic cuts $p_T^e > 7$ GeV, $\mid \eta^e \mid < 2.5$ **Vertex cuts** $d_{xy} < 0.5, d_z < 1$ cm, $SIP < 4$	**Loose leptons**	**Kinematic cuts** $p_T^\mu > 5$ GeV, $\mid \eta^\mu \mid < 2.5$ **Vertex cuts** $d_{xy} < 0.5, d_z < 1$ cm, $SIP < 4$
Isolation & ID Dedicated BDT targeting prompt electrons	**Tight leptons**	**Isolation & ID** Select only muons within a well defined cone (R=0.35)

Z Candidates: any OS-SF pair that satisfies $12 < m_{ll}(\gamma) < 120$ GeV/c^2

ZZ Candidates: from all ZZ pairs, defining $\mathbf{Z_1}$ the one with $m_{ll}(\gamma)$ closest to true Z mass

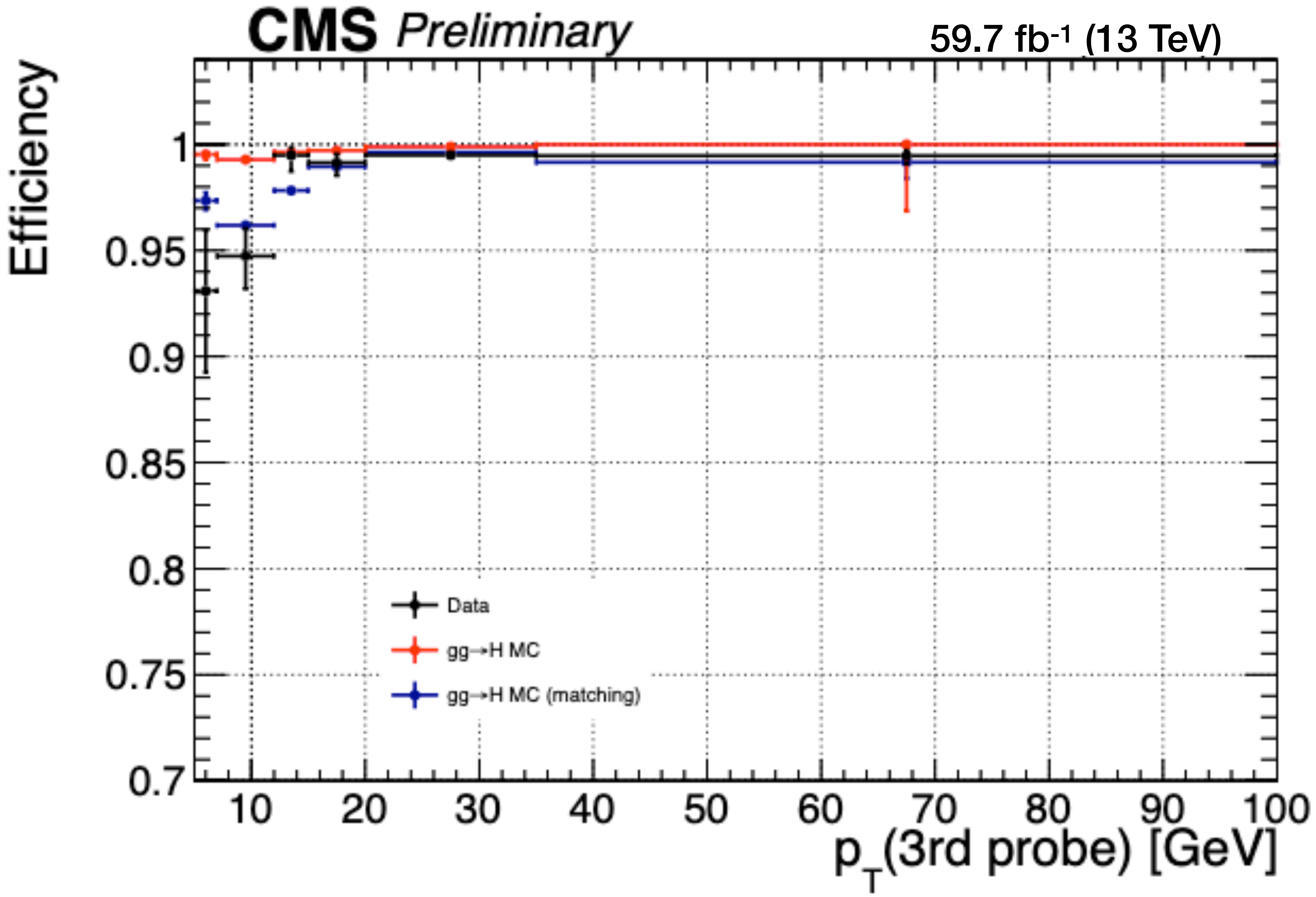
Trigger selection and efficiency

Events that **fire any HLT path** (2EG, 2Mu, MuEG, 1E, 1Mu): OR logic increases low p_T trigger efficiency

Efficiency measured with tag-and-probe method on $4l$ events, **applied to** both **Data** and **MC**

HLT path	prescale	primary dataset
HLT_Ele17_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	1	DoubleEG
HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ	1	DoubleEG
HLT_DoubleEle33_CaloIdL_GsfTrkIdVL	1	DoubleEG
HLT_Ele16_Ele12_Ele8_CaloIdL_TrackIdL	1	DoubleEG
HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL	1	DoubleMuon
HLT_Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL	1	DoubleMuon
HLT_TripleMu_12_10_5	1	DoubleMuon
HLT_Mu8_TrkIsoVVL_Ele17_CaloIdL_TrackIdL_IsoVL	1	MuonEG
HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL	1	MuonEG
HLT_Mu17_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL	1	MuonEG
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL	1	MuonEG
HLT_Mu23_TrkIsoVVL_Ele8_CaloIdL_TrackIdL_IsoVL	1	MuonEG
HLT_Mu8_DiEle12_CaloIdL_TrackIdL	1	MuonEG
HLT_DiMu9_Ele9_CaloIdL_TrackIdL	1	MuonEG
HLT_Ele25_eta2p1_WPTight	1	SingleElectron
HLT_Ele27_WPTight	1	SingleElectron
HLT_Ele27_eta2p1_WPLoose_Gsf	1	SingleElectron
HLT_IsoMu20 OR HLT_IsoTkMu20	1	SingleMuon
HLT_IsoMu22 OR HLT_IsoTkMu22	1	SingleMuon

Final State	$gg \to$ H MC	$gg \to$ H MC (matching)	Data (matching)
$4e$	$0.991^{+.002}_{-0.002}$	$0.948^{+.004}_{-0.004}$	$0.982^{+.005}_{-0.007}$
4μ	$0.997^{+.001}_{-0.001}$	$0.997^{+.001}_{-0.001}$	$1.000^{+.000}_{-0.001}$
$2e2\mu$	$0.995^{+.001}_{-0.001}$	$0.964^{+.002}_{-0.002}$	$0.983^{+.003}_{-0.004}$

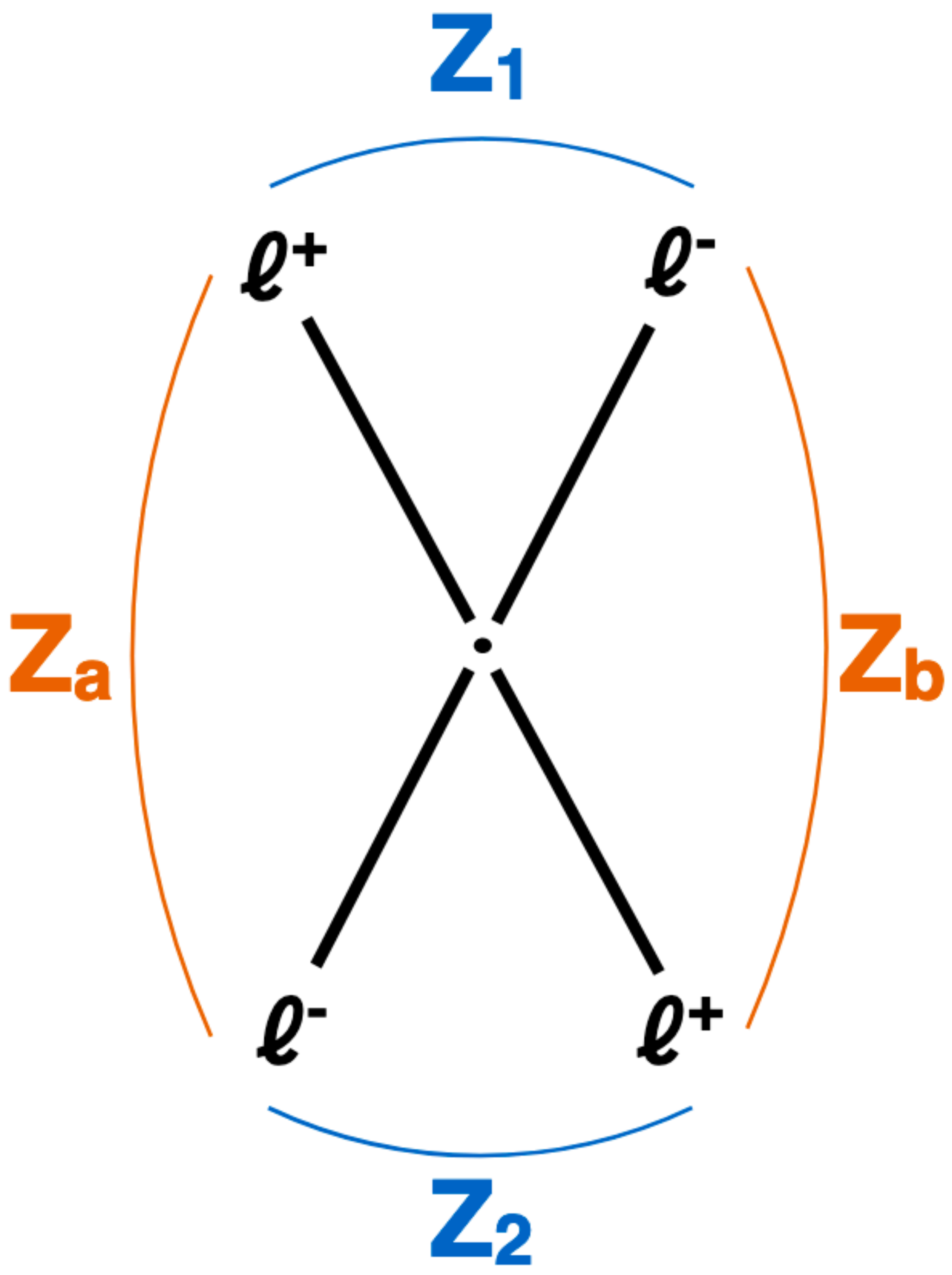


Selecting the best ZZ candidate

Z Candidates: any OS-SF pair that satisfies $12 < m_{ll}(\gamma) < 120$ GeV/c^2 firing any HLT path (2EG, 2Mu, MuEG, 1E, 1Mu)

ZZ Candidates: all possible ZZs are built, defining $\mathbf{Z_1}$ the candidate with $m_{ll}(\gamma)$ closest to the nominal Z mass

- $m_{Z_1} > 40$ GeV/c^2
- $p_{T(l_1)} > 20$ GeV, $p_{T(l_2)} > 10$ GeV ensures optimal trigger efficiency
- $\Delta R(\eta, \phi) > 0.02$ between each of the four leptons
- $m_{ll} > 4$ GeV for all OS pairs ensures QCD background suppression
- Reject 4μ and $4e$ candidates where the alternate pairing $\mathbf{Z_a Z_b}$ satisfies $| m(Z_a) - m_Z | < | m_{Z_1} - m_Z |$ AND $m_{Z_b} < 12$GeV/c^2
- $m_{4l} > 70$ GeV/c^2



If more than one **ZZ Candidate** passes the selection,
the one with he one with the largest scalar sum of transverse momenta of the two leptons defining the Z2 is retained.

In today's exercise

Selection

- Implement the definition of ID and Isolation for electrons and muons
- Implement trigger selection to pick only events interesting for the ZZ analysis

Calibration (advanced/optional exercise)

- Implement the FSR recovery for electrons and muons

Tasks

- Implement the reconstruction of the Z candidates to build the ZZ system
- Produce plots to validate the analysis selection steps
- Produce plots to check the properties of the ZZ system and validate Data/MC agreement

Some questions

- Plot the leading leptons transverse momentum and rapidity: do the plots reflect the cuts implemented in selection?
- For each event, reconstruct the two Z candidates and plot their invariant mass: how do they look like? If there is any difference, why?
- How does the invariant mass of the ZZ system look like? Can you explain which process is responsible of each contribution?
- *Advanced/optional:* What is the fraction of events affected by FSR recovery? Plot the invariant mass of the ZZ system for these events before and after FSR recovery

BACKUP SLIDES

Electrons selection

Kinematic cuts

$p_T^e > 7$ GeV, $|\eta^e| < 2.5$

Vertex cuts

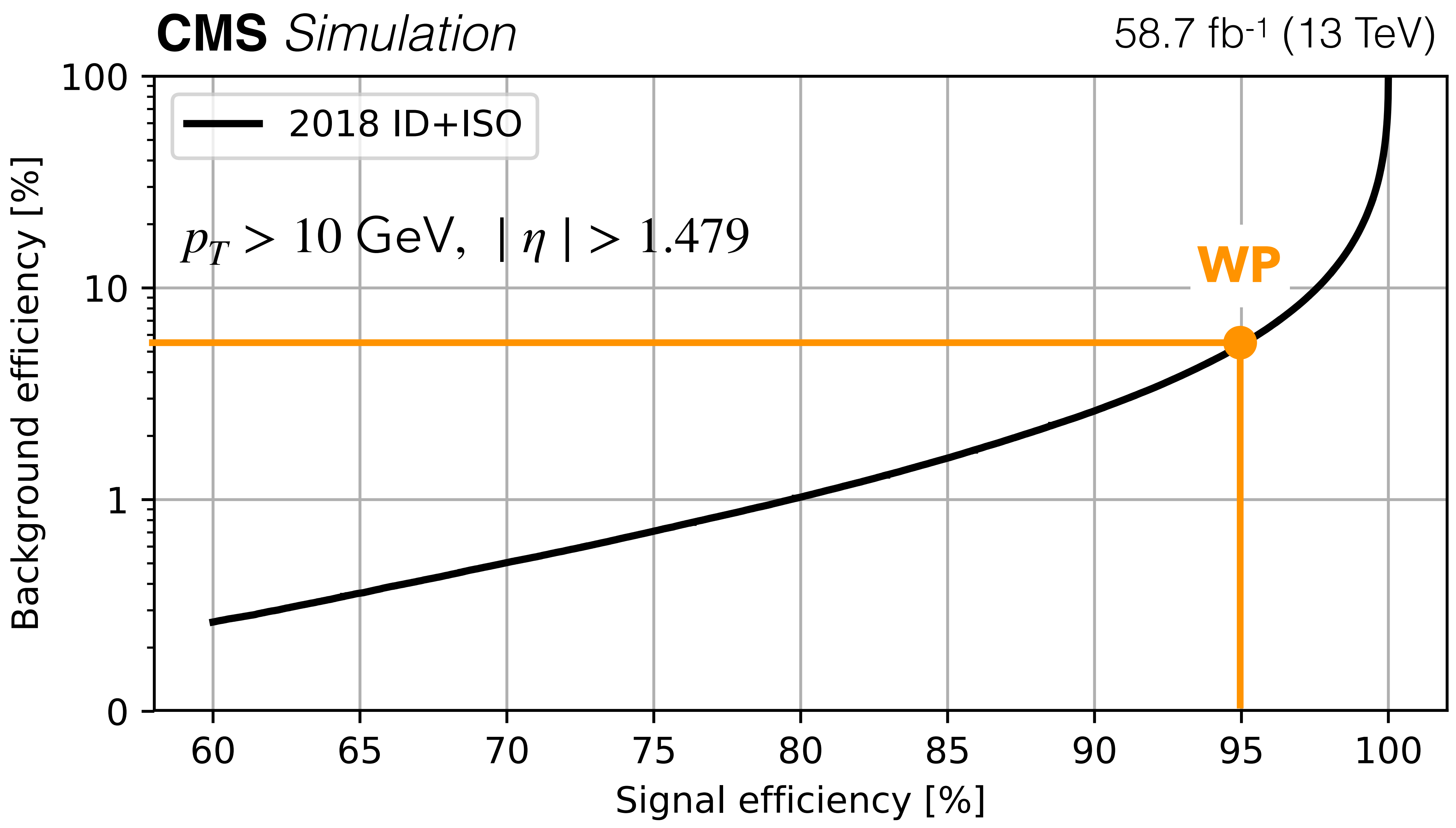
$d_{xy} < 0.5, d_z < 1$ cm, $SIP < 4$

Loose electrons

Isolation & ID

Dedicated BDT targeting prompt electrons

Tight electrons



- **BDT** trained in **6** $(|\eta|, p_T)$ **bins** to discriminate between prompt vs non-prompt electrons
- **Training** on Drell-Yan + Jets samples **separately on 3 years** to enhance overall performance
- **95% efficiency at high p_T, 80% (70%) efficiency at low p_T in barrel (endcap)**

Muons selection

Kinematic cuts

$p_T^\mu > 5$ GeV, $|\eta^\mu| < 2.5$

Vertex cuts

$d_{xy} < 0.5, d_z < 1$ cm, $SIP < 4$

Loose muons

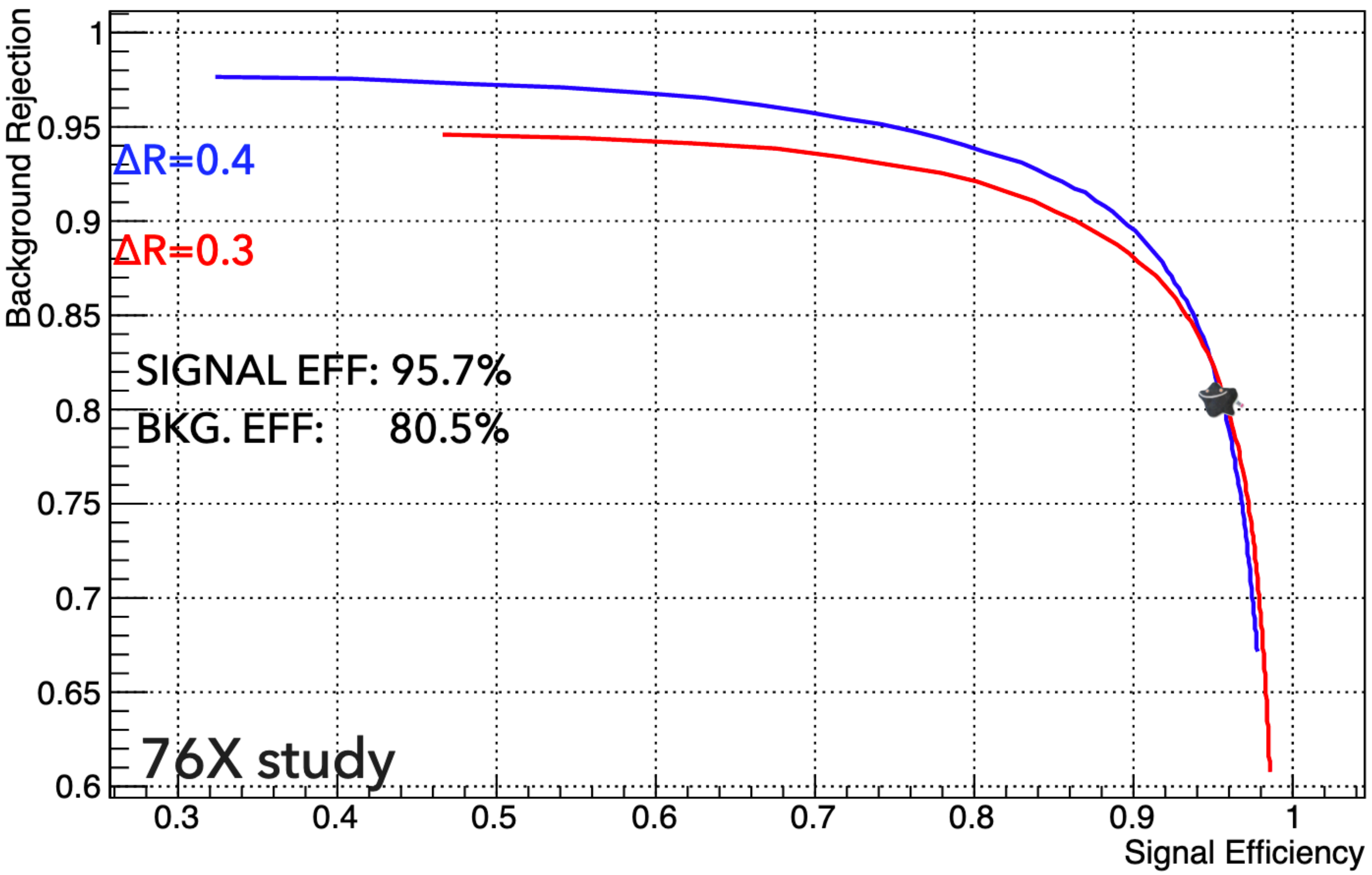
ID

PF ID and tracker high pT ID

Isolation

RelPFIso $(\Delta R = 0.3) < 0.35$

Tight muons



- **Isolation: FSR recovery and $\Delta\beta$** correction to **subtract PU contribution**

- ***Ghost cleaning*** performed: avoid single μ being reconstructed as 2 (or more) muons

Final State Radiation recovery

- **Radiation** of **high-energy photons** in decay with an **8% (15%) probability** for di-muon (di-electron)
- Isolated PF photons with $p_T^\gamma > 2$ GeV, $|\eta^\gamma| < 2.5$ discarded if: $\Delta R(\gamma, l)/E^2_{T,\gamma} < 0.012$, and $\Delta R(\gamma, l) < 0.5$
- **Small effect** on the full Run-II statistics **O(5.4%)**, comparable for signal and background processes