

aQGC2013:

Anomalous Quartic Gauge Couplings Helmholtz Alliance Workshop, 30 Sep-2 Oct 2013, Dresden
(Germany)

CMS: Studies for European Strategy and Snowmass relevant for Quartic Boson Interactions

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On behalf of CMS collaboration

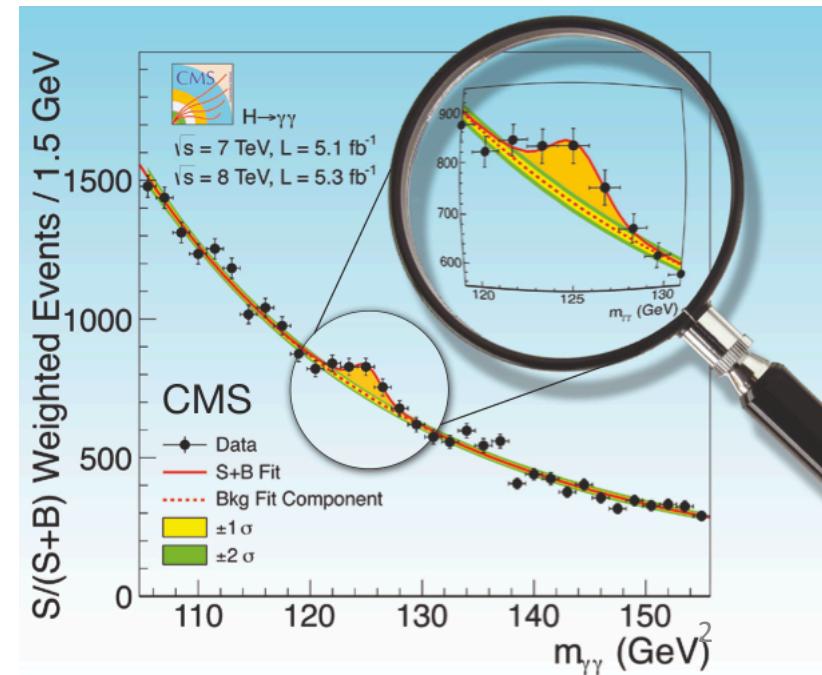
Vector bosons and EWSB

- Higgs boson was discovered by CMS and ATLAS
- Higgs mass is precisely measured
- Initial measurement of Higgs coupling is made
- Now we aim for better understanding of EWSB mechanism

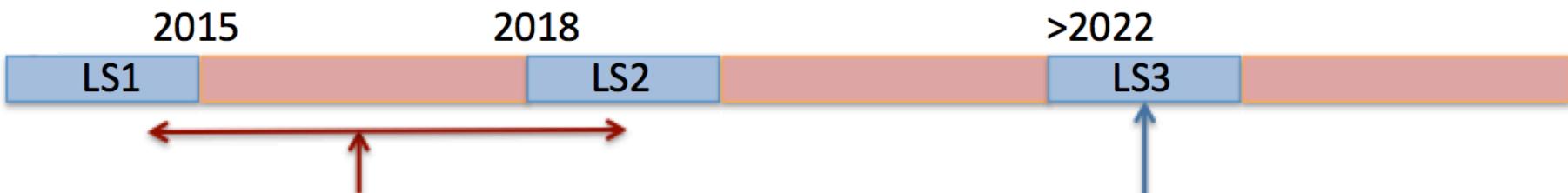
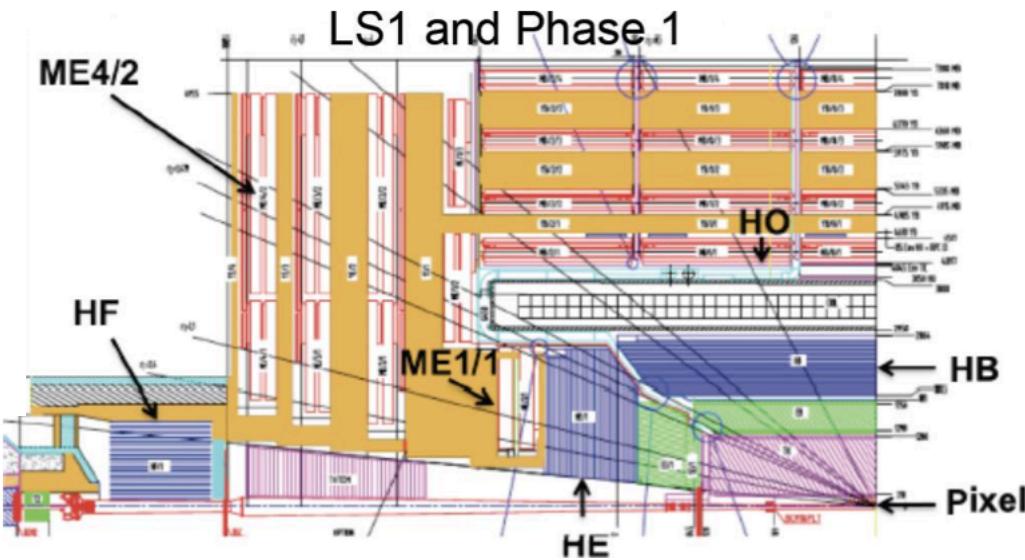
Deviations from SM ?

- Higgs coupling measurements
- Vector boson measurements
 - Diboson measurements
 - Triboson measurements
 - VV scattering

CMS future studies



CMS detector in the following years



Phase 1 Upgrades

- Pixel detector replacement (FPIX)
- HCAL electronics upgrade (HCAL)
- L1-Trigger upgrade (Trigger)

Proton-proton collisions at center of mass energy of 14 TeV

Phase 1:

- Data taking with integrated luminosity up to 300fb^{-1}
- Expecting 50 PU events

Phase 2:

- Data taking up to 3000fb^{-1}
- Expecting 140 PU events

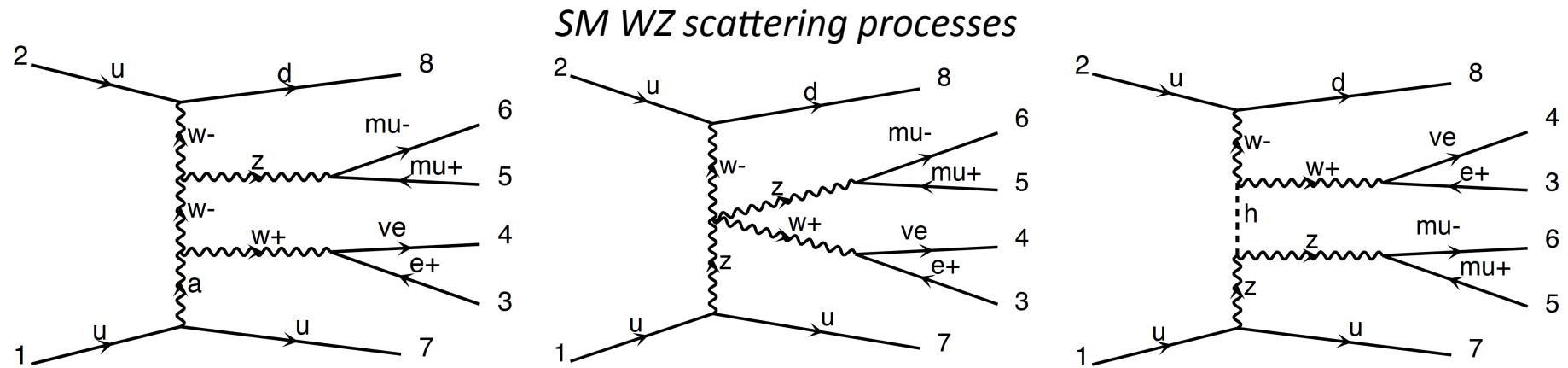
Phase 2 Upgrades (scope to be defined)

- Tracker Replacement, Track Trigger
- Forward Region: Calorimetry and Muons
- Further Trigger upgrade

WZ scattering

WZ \rightarrow l \bar{l} ll scattering process

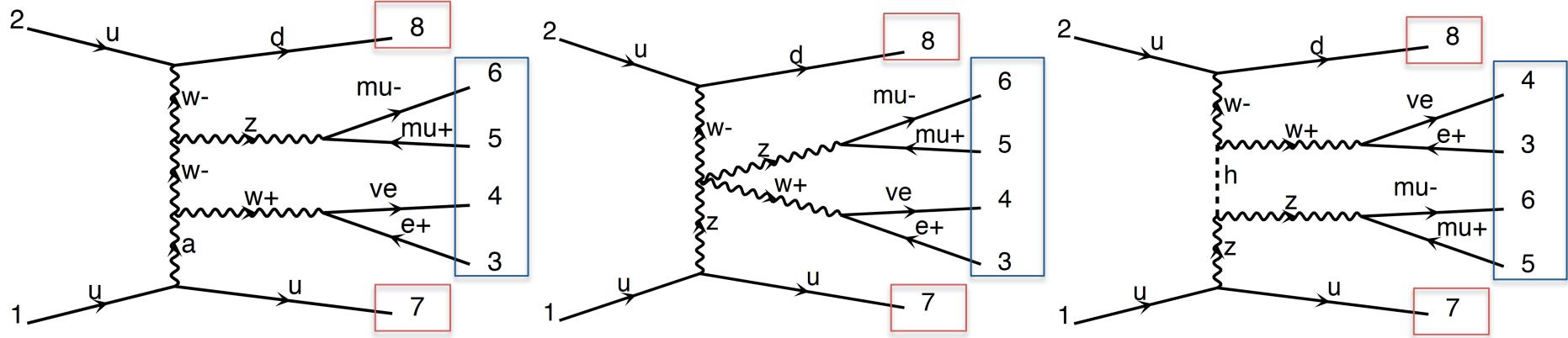
- Higher cross section than the cleanest ZZ \rightarrow 4l
- Cleaner signature than WW \rightarrow l \bar{l} ll



- Individually WZ scattering processes violate unitarity at high CM energies
- Strong interference among processes results with finite SM cross section
- Higgs mass is known \rightarrow allows precise prediction of cross section
- Sensitive to New Physics (NP) in the EWK symmetry breaking sector
- NP would cause increase of cross section at high scattering energies

WZ scattering signature

Central W and Z decay products

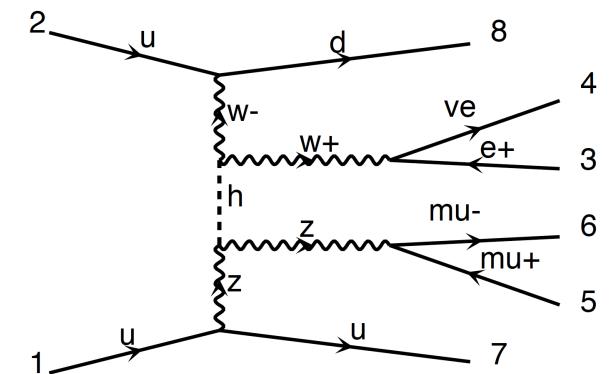
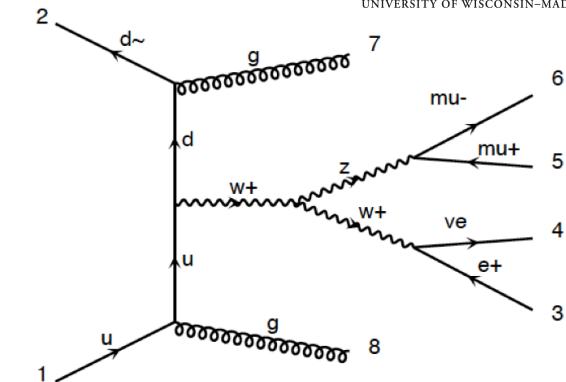
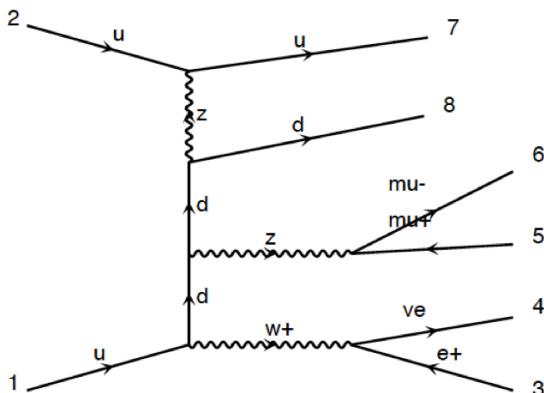
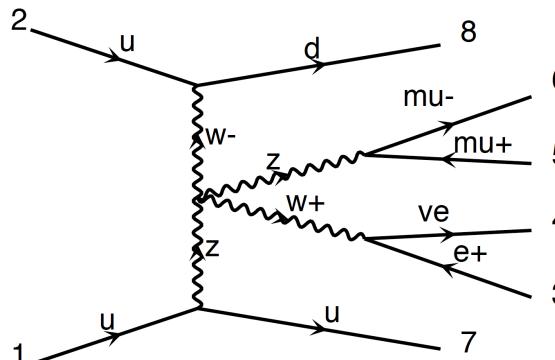
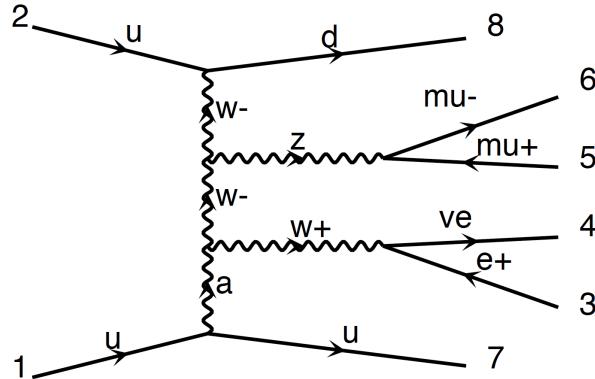


- Two energetic forward jets
- Large $\Delta\eta$, large invariant mass

Other WZ processes

QCD WZ, gluons in initial or final state

- Main background to WZ scattering
- Greatly reduced by applying vector boson scattering selection



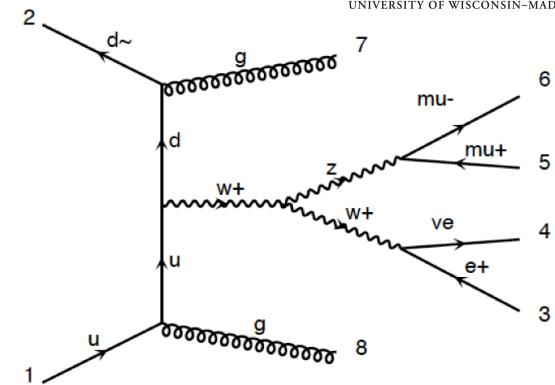
Radiative WZ emission

- Interferes with scattering processes
- Small contribution in phase space with two energetic forward jets

Backgrounds

QCD WZ, gluons in initial or final state

- Main background to WZ scattering
- Greatly reduced by applying vector boson scattering selection



Non WZ backgrounds:

- ZZ->4l (including ZZ scattering process)
 - One lepton is lost due to detector acceptance or efficiency
- Z+jets and ttbar
 - False lepton from jet activity
 - Expected to be small -> their contribution to total background is neglected

Signal and background simulation

Proton-proton collisions at center of mass energy 14 TeV

Integrated luminosities: 300fb^{-1} and 3000fb^{-1}

- MadGraph generator for signal and background processes
- Pythia for PS, hadronization and pileup
- Delphes for CMS simulation (phase 1 and phase 2 CMS detector)
- MadGraph cross sections in vector boson scattering phase space cross checked with VBFNLO (->uncertainty on signal: 5%)
- Uncertainty on background: 10%
 - Based on current cross section measurements in exclusive jet bins
-> dominated by systematic uncertainty (jet counting)

aQGC signal

Phys. Rev. D74 (2006) 073005

- Anomalous aQGC generated with MadGraph
 - D8 effective field theory approach
 - SU(2)xU(1) symmetry enforced, low mass Higgs

$$L_{T1} = \frac{f_{T1}}{\Lambda^4} Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}]Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$$

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA
$\mathcal{L}_{S,0}, \mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O
$\mathcal{L}_{M,0}, \mathcal{L}_{M,1}, \mathcal{L}_{M,6}, \mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O
$\mathcal{L}_{M,2}, \mathcal{L}_{M,3}, \mathcal{L}_{M,4}, \mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O
$\mathcal{L}_{T,0}, \mathcal{L}_{T,1}, \mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}, \mathcal{L}_{T,6}, \mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}, \mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X

Selection

Lepton selection

- 3 isolated leptons, two consistent with Z mass
 - $P_T(l) > 20 \text{ GeV}; |\eta| < 2.4$
- MET $> 30 \text{ GeV}$ (phase 1 only)

Jets selection

- Two energetic forward jets
 - $P_T(\text{jet}) > 50 \text{ GeV}; |\eta| < 4.7; M(\text{jet1}, \text{jet2}) > 600 \text{ GeV}$
- Large rapidity separation
 - $\Delta\eta(\text{jet1}, \text{jet2}) > 4.0;$
- $\Delta R(l, \text{jet}) > 0.4$

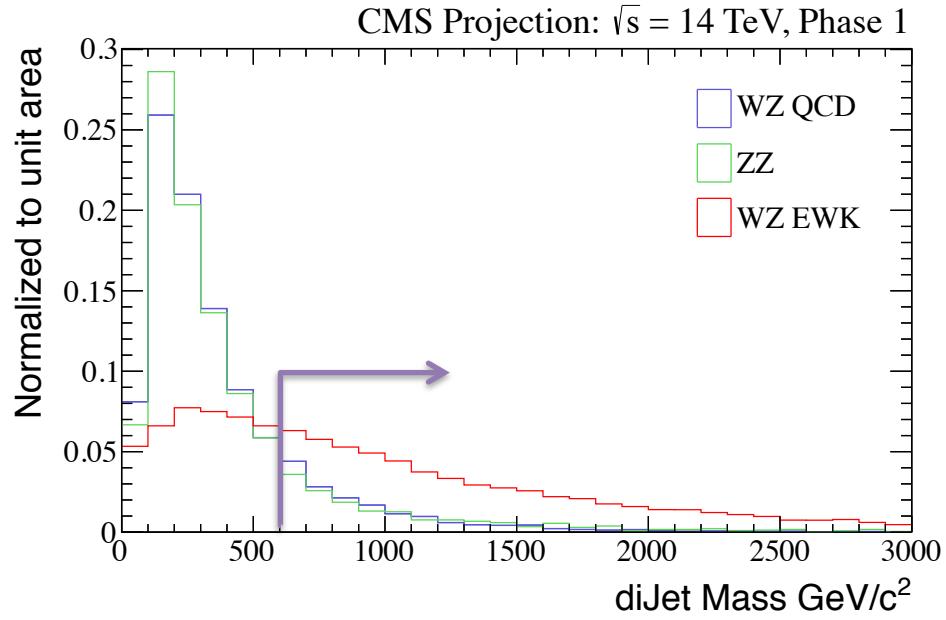
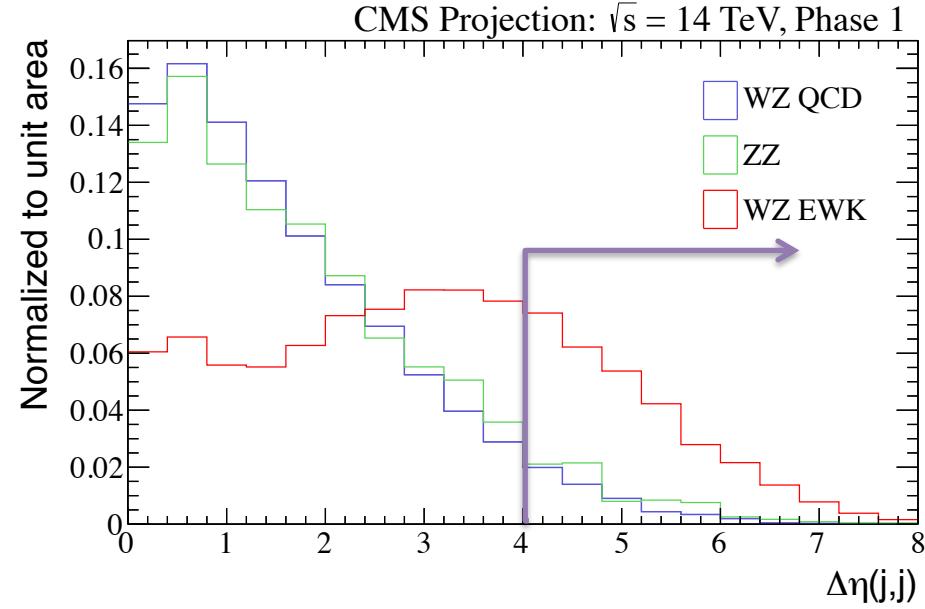
Cross sections [fb]

	WZ EWK	WZ QCD	ZZ	$L_{T1} = 1.0$
Total	7.7	270	16	3.1
Fiducial	0.69	0.96	0.038	0.57

- Background is significantly reduced
- WZ QCD still dominates

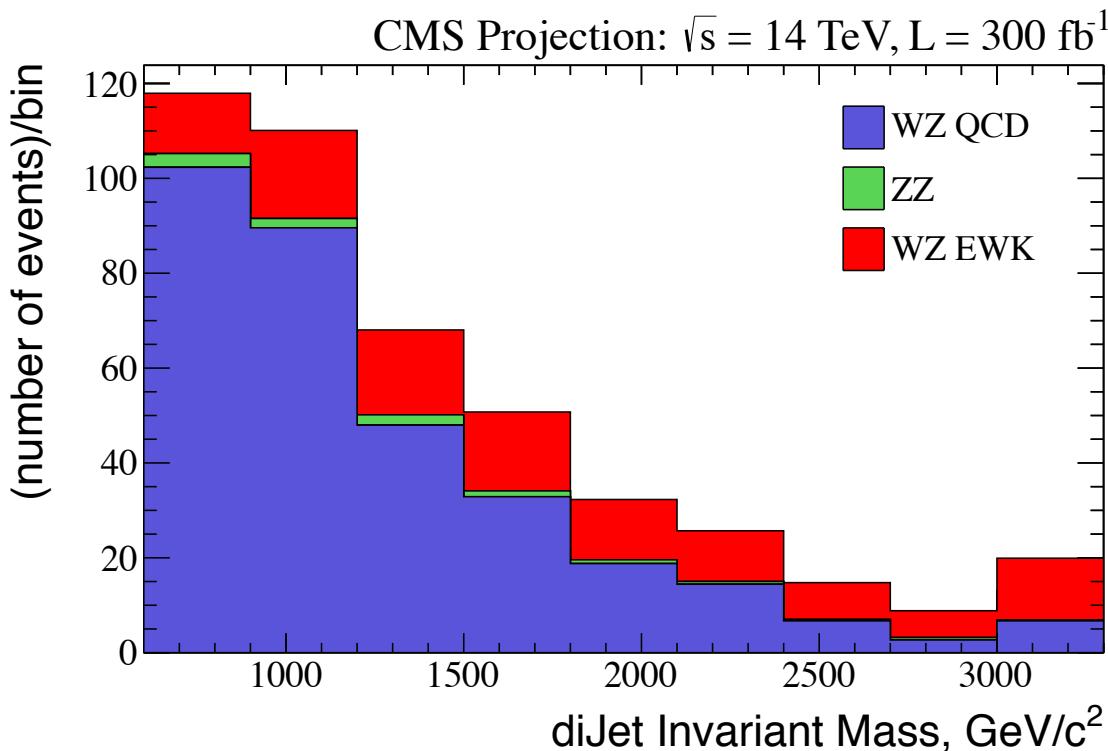
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFTR13006>

Scattering kinematics



- Scattering is characterized by high dijet mass and large difference in rapidity between jets
- Observables used for WZ scattering selection

WZ scattering discovery possibilities



- WZ scattering enhanced in high dijet mass region
- Counting experiment in $M(\text{jet1}, \text{jet2}) > 1.2 \text{ TeV}$ region
- 5σ discovery expected with integrated luminosity of 185 fb^{-1}

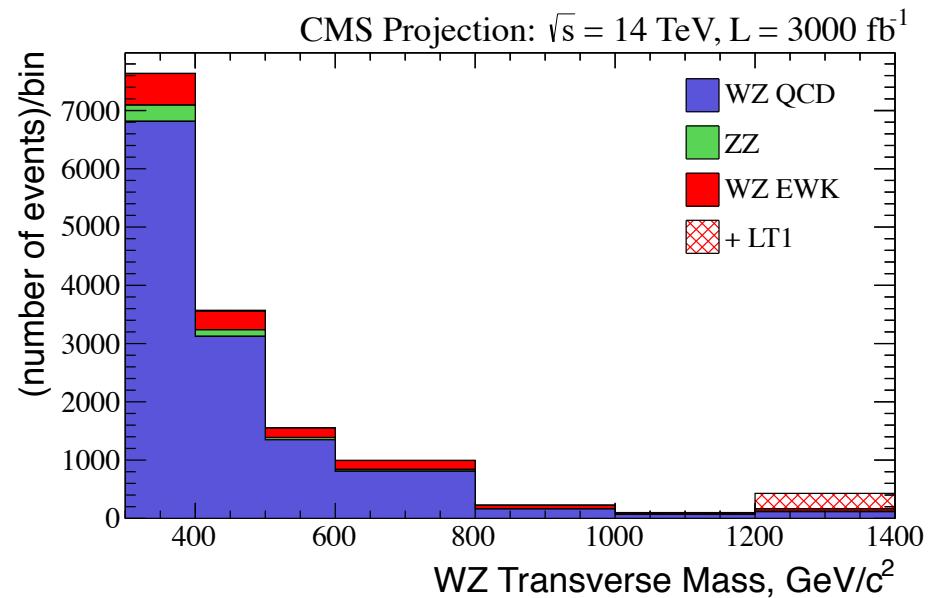
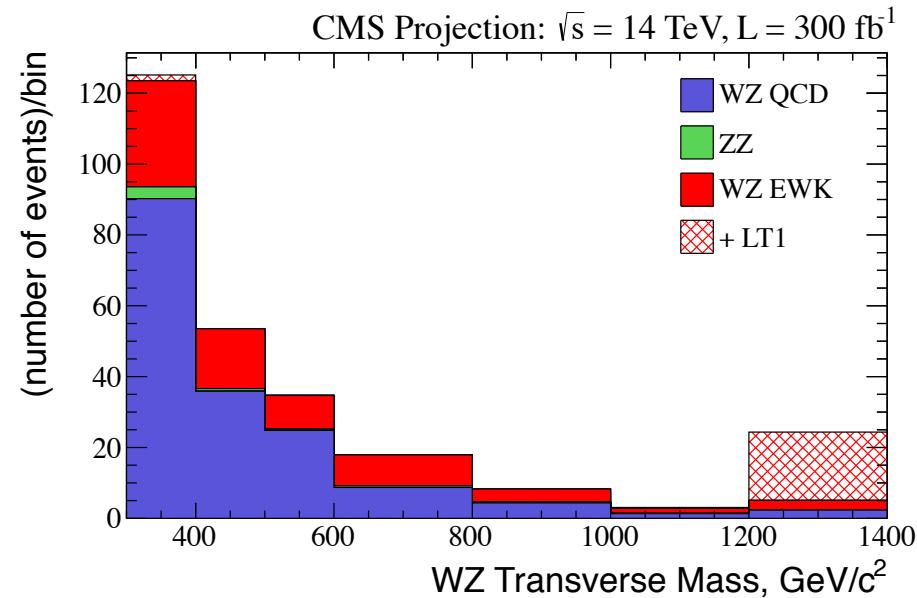
Significance	3σ	5σ
SM EWK scattering discovery	75 fb^{-1}	185 fb^{-1}

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFTR13006>

aQGC discovery possibilities



WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON



- Sensitivity for NP signal in high transverse mass of diboson system
- Counting experiment in $M_T(WZ) > 1(1.2)\text{TeV}$ for $300(3000)\text{fb}^{-1}$ scenario

Significance	3σ	5σ
$\frac{f_{T1}}{\Lambda^4}$ at 300 fb^{-1}	0.8 TeV^{-4}	1.0 TeV^{-4}
$\frac{f_{T1}}{\Lambda^4}$ at 3000 fb^{-1}	0.45 TeV^{-4}	0.55 TeV^{-4}

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFTR13006>

Anomalous couplings: Higgs and vector bosons

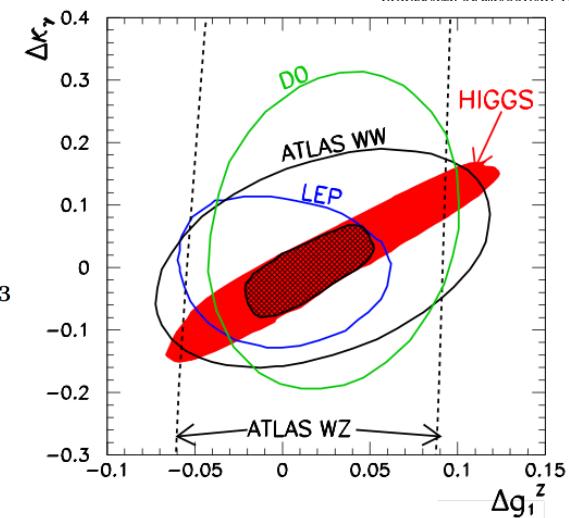
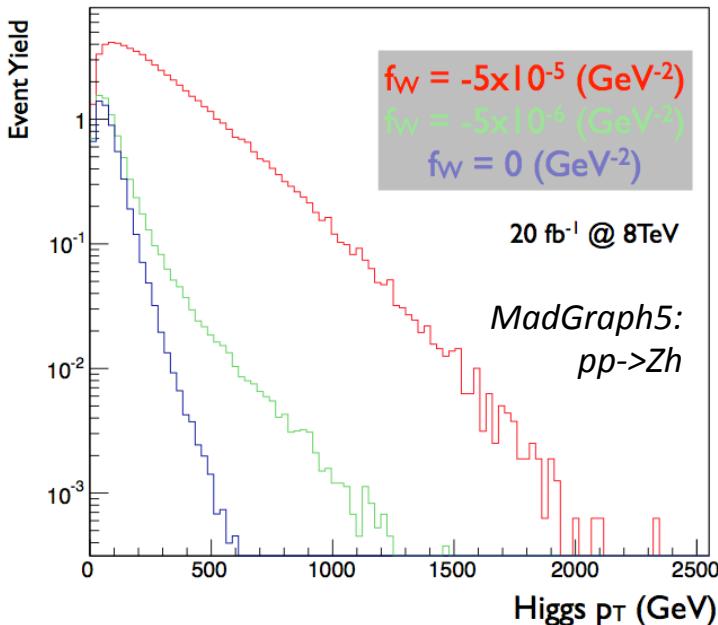
Limits on aTGC using Higgs cross section measurements

- Important to precisely measure cross sections
- Exploring Higgs P_T distribution

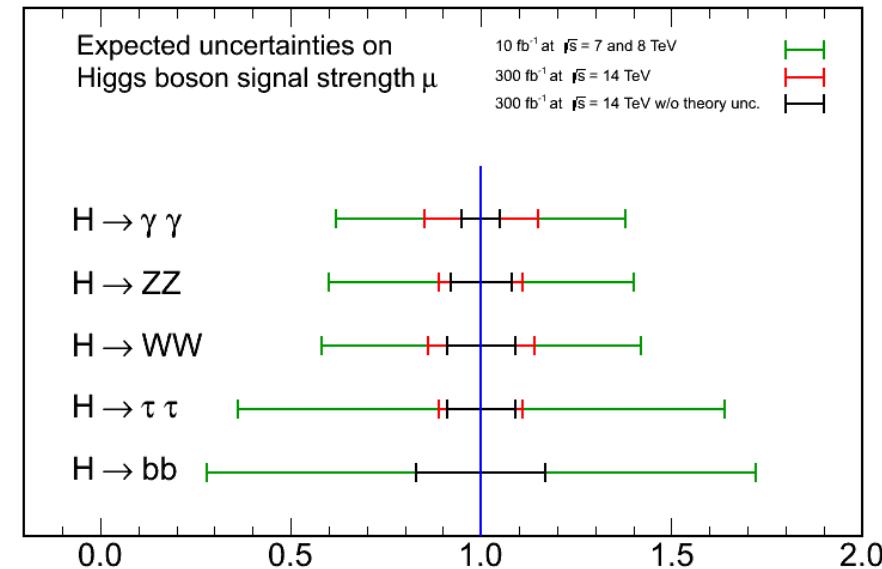
<http://arxiv.org/abs/1304.1151>

$$\mathcal{L}_{eff} = -\frac{\alpha_s v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_W}{\Lambda^2} \mathcal{O}_W + \frac{f_B}{\Lambda^2} \mathcal{O}_B + \frac{f_{bot}}{\Lambda^2} \mathcal{O}_{d\Phi,33} + \frac{f_\tau}{\Lambda^2} \mathcal{O}_{e\Phi,33}$$

D6 EFT: $\mathcal{O}_W = (D_\mu \Phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \Phi)$, TGC & Higgs Couplings
 $\mathcal{O}_B = (D_\mu \Phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \Phi)$, TGC & Higgs Couplings



CMS Projection



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/HigProjectionEsg2012TWiki>



Conclusion



Potential of CMS detector for WZ scattering observation in proton-proton collisions at center of mass energy of 14TeV is studied

- 3(5) σ observation of WZ scattering is expected with $\sim 75(185)$ fb^{-1} of data
- Indirect NP search is studied via $L_{T,1}$ EFT operator
- aQGC of the order of $L_{T,1}=1\text{TeV}^4$ are discoverable with 300fb^{-1} of data, corresponding to the Λ scale of $\sim 1\text{TeV}$
- With 3000fb^{-1} of data CMS provides the sensitivity to Λ scale $\sim 2\text{TeV}$

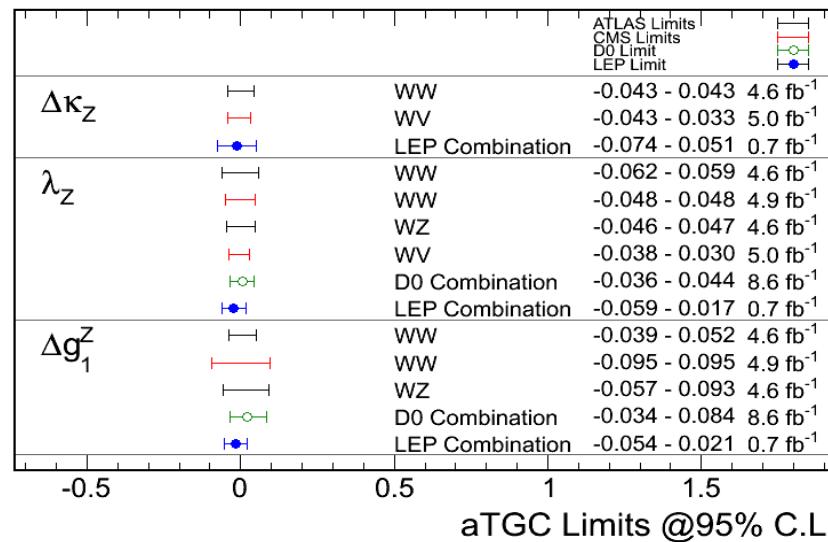
- Other VV scattering processes also provide important information about the nature of EWSB
- Measurements of VV processes together with direct Higgs measurements are important building blocks for NP constraint in the electroweak sector



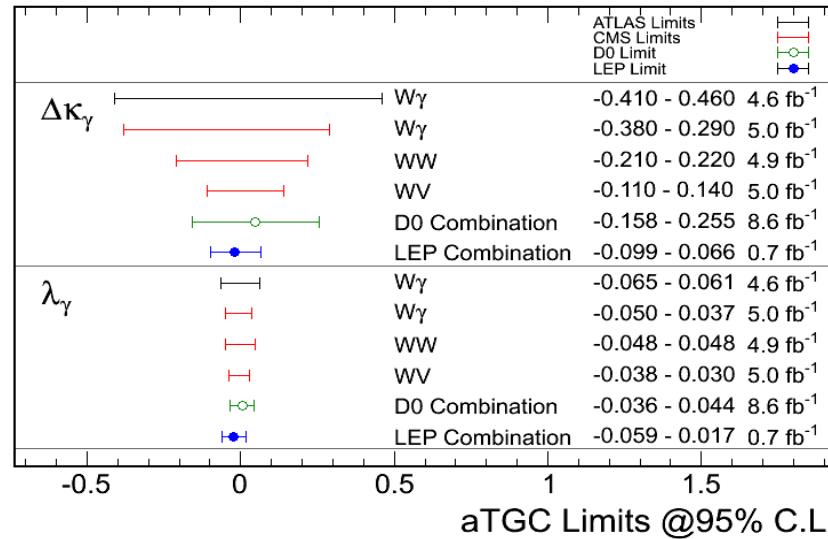
aTGC limits (summary)



Feb 2013



Feb 2013





Important input from theory community



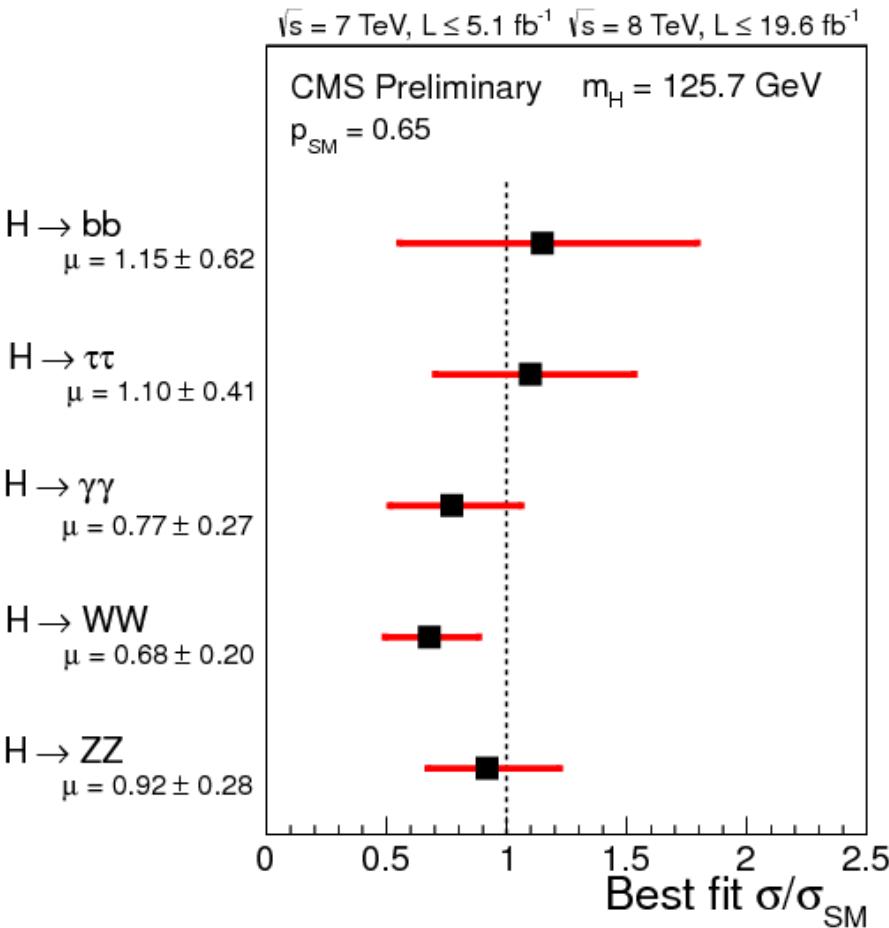
- Which basis of operators (parameters) are suggested to use for the anomalous vector boson couplings / anomalous Higgs couplings?
- For particular VV/VVV channel, which anomalous coupling parameters show the largest deviation from SM?
 - Which parameters to measure in particular channel?
- NLO VV(+2jets) MC, for event generation & also cross section calculation
- Additional work on improving the performance of VV+njet NLO MCs
- Differential predictions at NNLO for all relevant VV scattering and VVV states
- Suggestions for methods to separate and directly measure QGC and Higgs scattering



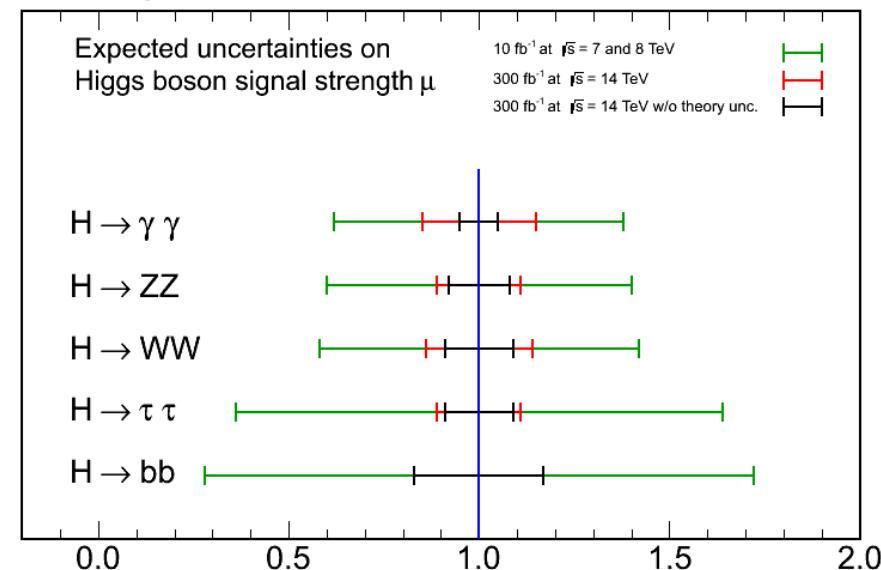
Backup



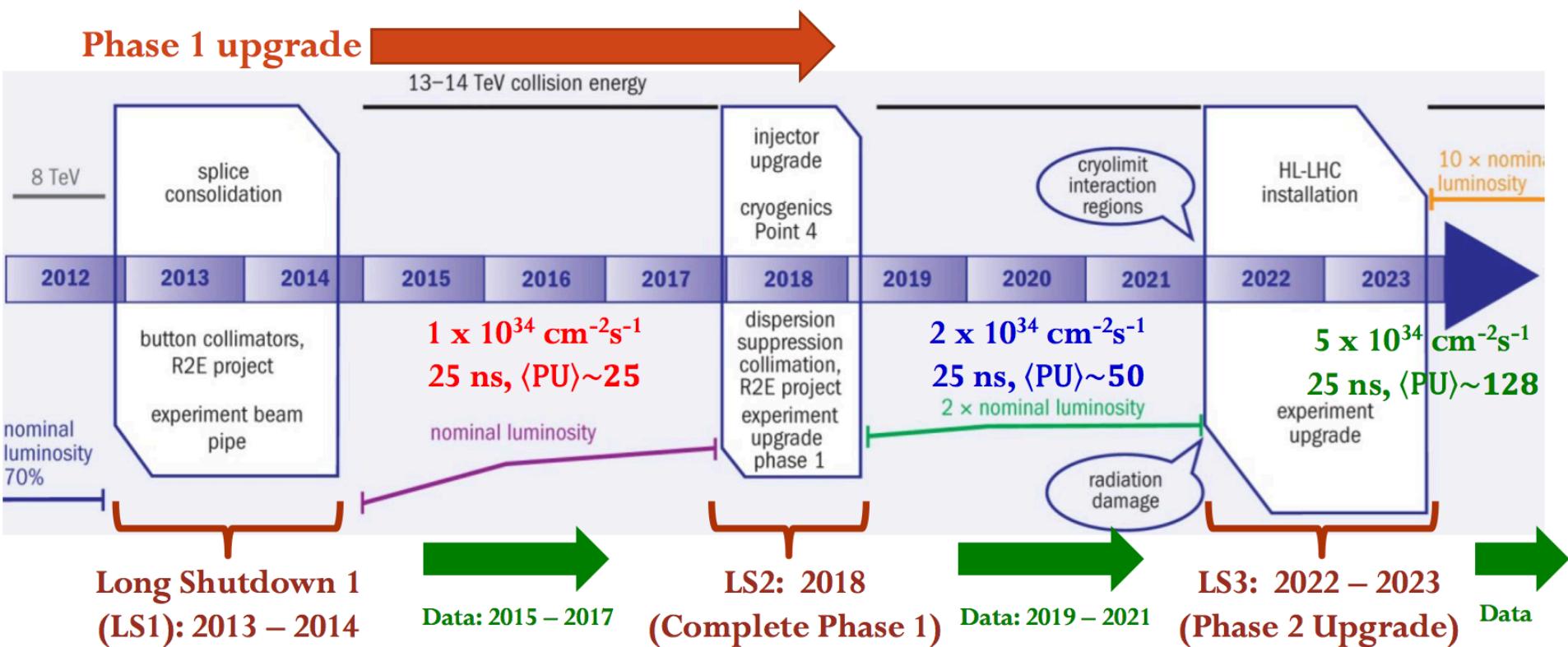
Backup



CMS Projection



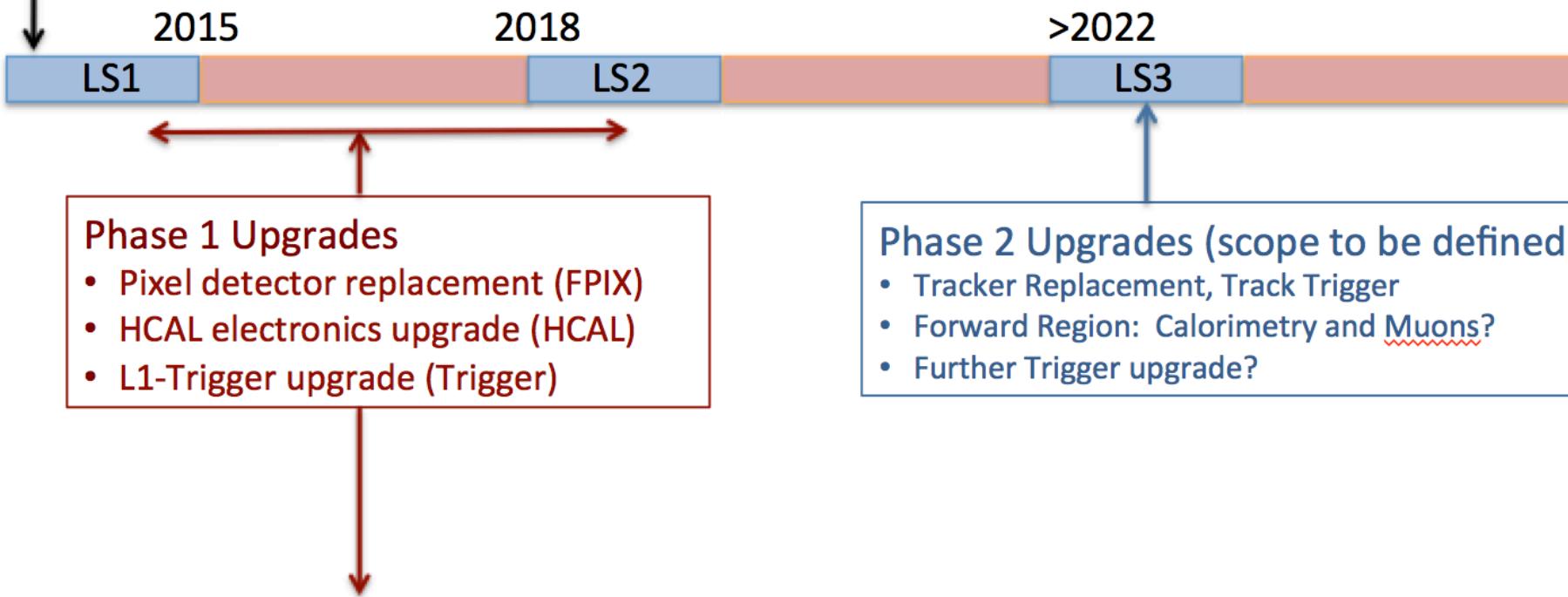
CMS upgrade plans



CMS upgrade plans

LS1 Projects: in production

- Complete muon coverage (ME4)
- Improve muon operation (ME1), DT electronics
- Replace HCAL photo-detectors in HF (new PMTs) and HO (HPD→SiPM)



Phase 1 Upgrades

- Pixel detector replacement (FPIX)
- HCAL electronics upgrade (HCAL)
- L1-Trigger upgrade (Trigger)

Phase 2 Upgrades (scope to be defined)

- Tracker Replacement, Track Trigger
- Forward Region: Calorimetry and Muons?
- Further Trigger upgrade?

Goal of Phase 1 Upgrades: achieve at least the same efficiency, and hopefully better, than we had at 7×10^{33} at 8 TeV with the LHC operating at 2×10^{34} at 14 TeV for 25 ns or 50 ns bunch spacing.