Prospects for Higgs Boson Measurements and Beyond Standard Model Physics at the High-Luminosity LHC with CMS

Rosamaria Venditti

Politecnico and INFN, Bari

On behalf of the CMS Collaboration

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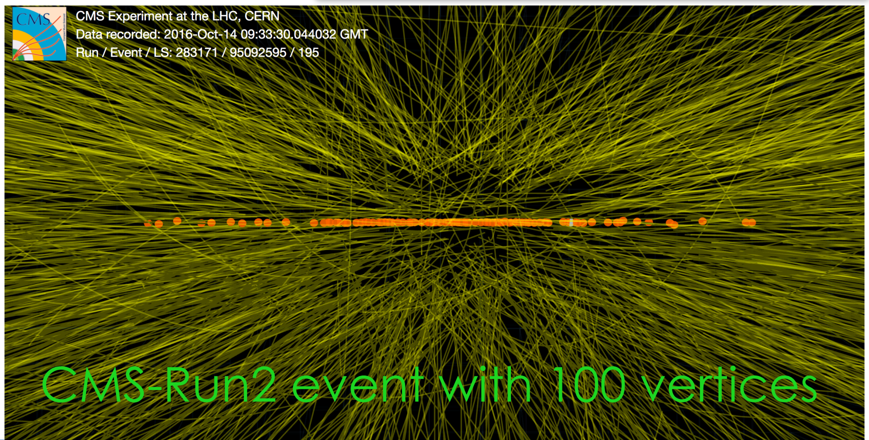
The HL-LHC Project

- To extend the sensitivity for new physics searches, a major upgrade of the LHC has been decided and is being prepared, **the High Luminosity LHC starting from 2023**.

	HL-LHC nominal	HL-LHC ultimate	LHC
instantaneous luminosity ($cm^{-2}s^{-1}$)	5×10^{34}	7.5×10^{34}	10^{34}
Pile-up collisions	140	200	30
integrated luminosity (fb^{-1})	3000	4000	60



The CMS Experiment and the Phase 2 Upgrade

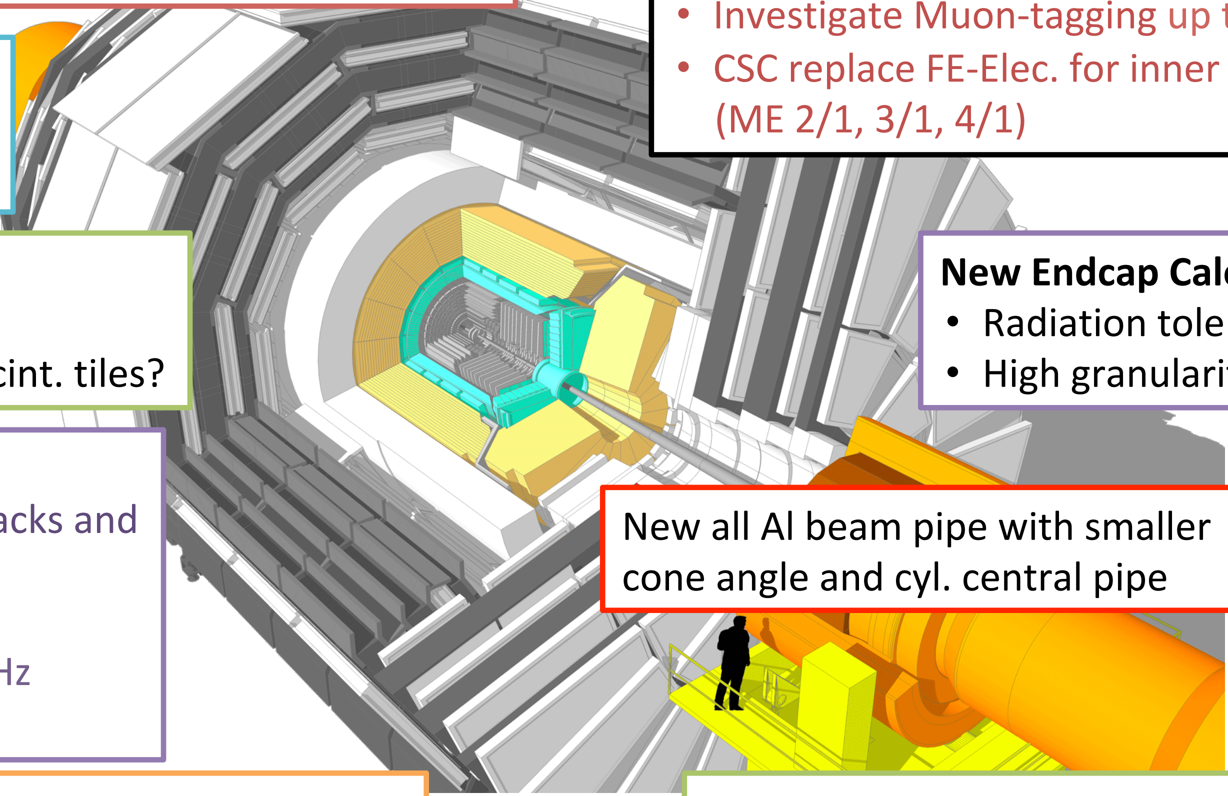
New Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

Barrel ECAL
- Replace FE electronics
- Cool detector/APDs

Barrel HCAL
- Replace HPD by SiPM
- Replace inner layers scint. tiles?

Trigger/DAQ
- L1 (hardware) with tracks and rate up ~ 750 kHz
- L1 Latency 12.5 µs
- HLT output rate 7.5 kHz
- New DAQ hardware

Other R&D
- Fast-timing for in-time pileup suppression



Muons
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 3
- CSC replace FE-Elec. for inner rings (ME 2/1, 3/1, 4/1)

New Endcap Calorimeters
- Radiation tolerant
- High granularity (**HGCAL**)

New all Al beam pipe with smaller cone angle and cyl. central pipe

Proposal for a Timing layer
- Timing resolution ~ 10 ps
- Space resolution ~ 10's of µm

The CMS Physics Program in the HL-LHC era

- **Precision SM physics with High Luminosity**
  - Electroweak Physics (VBF and VBS, Triboson production, Foward EW physics)
  - Strong Interactions (Photons and Jets, PDFs, Forward QCD physics)
  - Top physics (Cross section, properties, couplings, mass, FCNC)
- **Precision measurements in the (B)SM Higgs sector**
  - Couplings to ~5%, Cross Sections, Differential Distributions, Width, top Yukawa
  - Rare & Exotic decays
  - Di-Higgs Production→self coupling
  - BSM Higgs searches (extra scalars, BSM Higgs resonances, anomalous couplings)
- **More exotic models become accessible thanks to the detectors upgrades at HL-LHC**
  - Supersymmetry
  - Dark Matter Searches
  - Long Lived Particles, HSCP
  - Heavy Resonances, VLQ

Selected Examples in this talk

- **Flavor: Can we solve the puzzle of flavor with HL-LHC data?**
  - Flavour Anomalies, CKM and Metrology , Spectroscopy

Higgs Searches

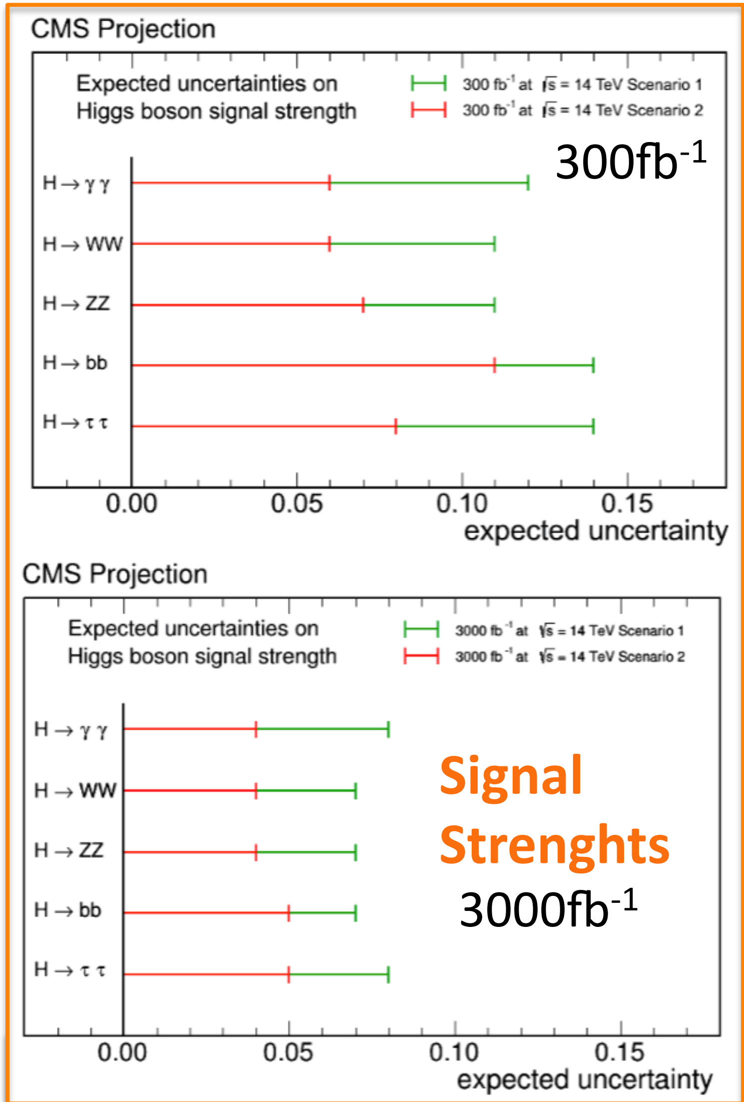
Higgs searches – the strategy

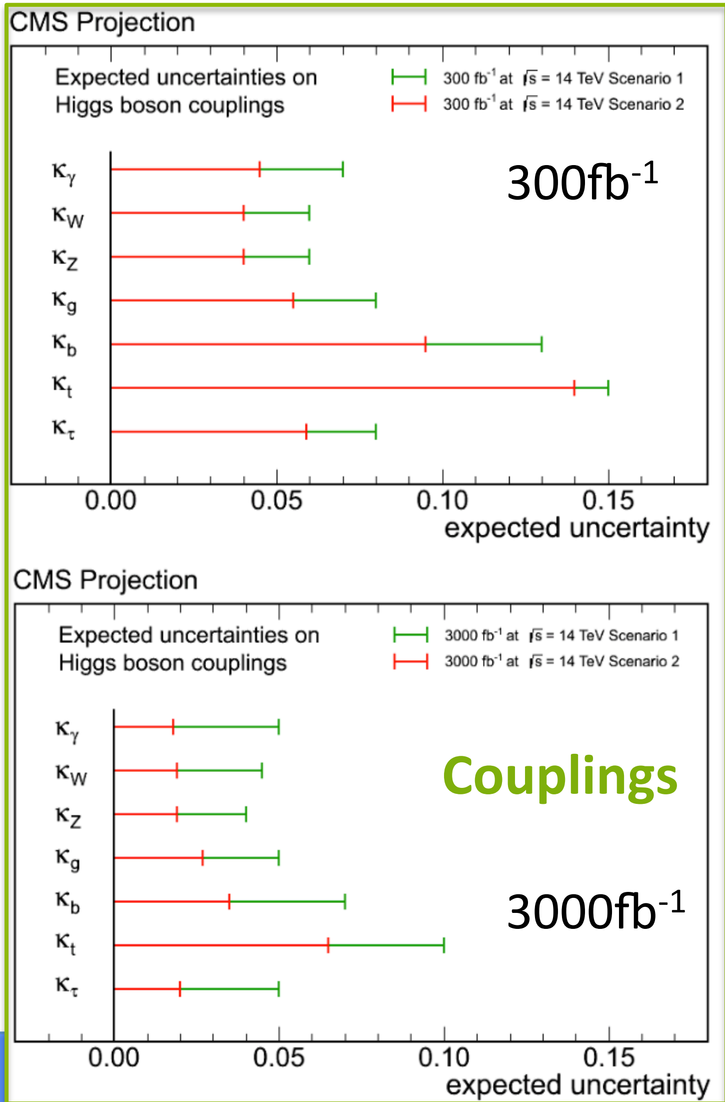
- **HL-LHC will be a Higgs factory: over 170 million Higgs bosons in 3000 fb^{-1}**
  - Achieve high precision measurements (down to the level of a few percents)
  - With this precision → any deviations from SM would reveal New Physics (additional particles in loop processes (gluon fusion, di-photon decay)
  - Reach sensitivity to coupling to 2nd generation ($H \rightarrow \mu\mu$)
- **Extrapolation Strategy:**
  - **Projections**: based on Run 1-2 at 7-13 TeV, extrapolate event yields and potentially systematic uncertainties using 1/sqrt(L)
  - **Simulation**: In 14 TeV MC, smear truth particles with resolutions expected with upgraded detectors in the Phase 2 collision conditions (200 pile-up interaction per BX)
- **Several assumptions made for the coupling determination**
  - **S1**: systematic uncertainties constant, unchanged detector performances
  - **S2**: theoretical uncertainties scaled by 0.5, experimental uncertainties scaled by luminosity

Higgs couplings and strenghts

arXiv:1307.7135
ECFA 2013

- Extrapolations based on **Run1 results, effect of high pileup and upgraded detector not considered**
- Precision on the **signal strength and couplings**: **5% for main channels, 10~20% on rare modes**





Deviations from the SM implemented as scale factors (κ's) of Higgs couplings relative to their SM values

Coupling with fermions

$$y_{F,i} = \kappa_{F,i}\frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i}\frac{m_{F,i}}{v}$$

Coupling with bosons

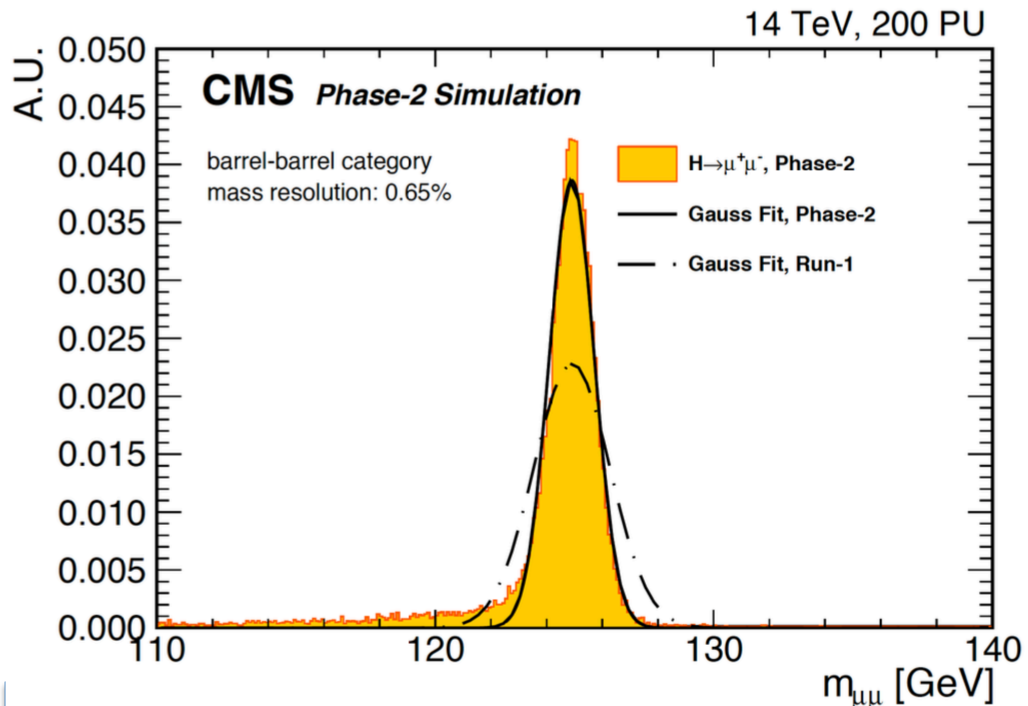
$$y_{V,i} = \sqrt{\kappa_{V,i}\frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}}\frac{m_{V,i}}{v}$$

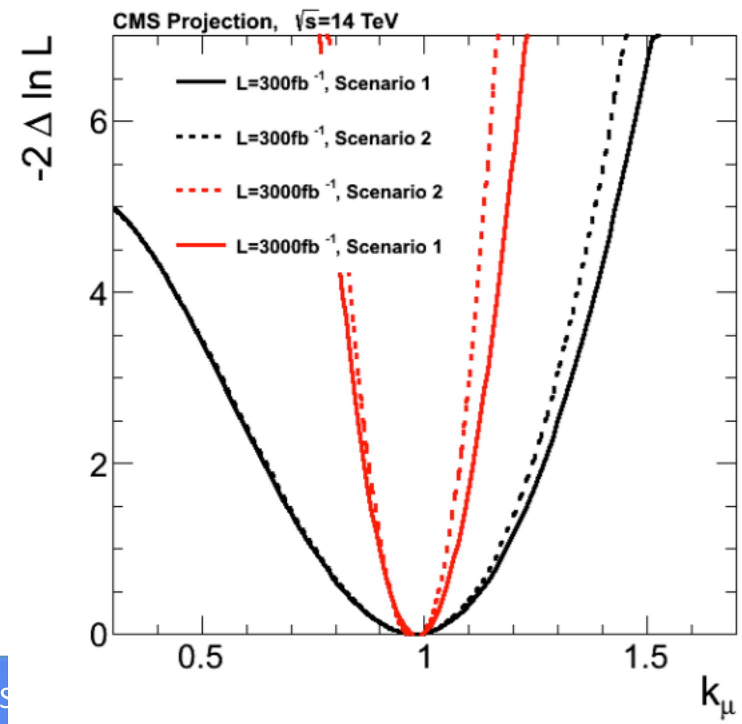
Rare decays: H→μμ

- HL-LHC will provide high statistics→rare decays become accessible [BR(H→μμ)=0.022]
- Probe coupling to 2nd generation of fermions
- H → $\mu\mu$ decays can be completely reconstructed and identified as a mass peak on top of the large background from Drell–Yan di-muon production.
  – The di-muon invariant mass resolution is critical to maximizing the sensitivity
- **Upgraded tracker allow to reach a mass resolution < 1% in Phase 2**

→Large impact on the analysis sentivity → **40% reduction of the systematics**

→Prospects for coupling measurement → **5% uncertainty @ 3000fb^{-1}**

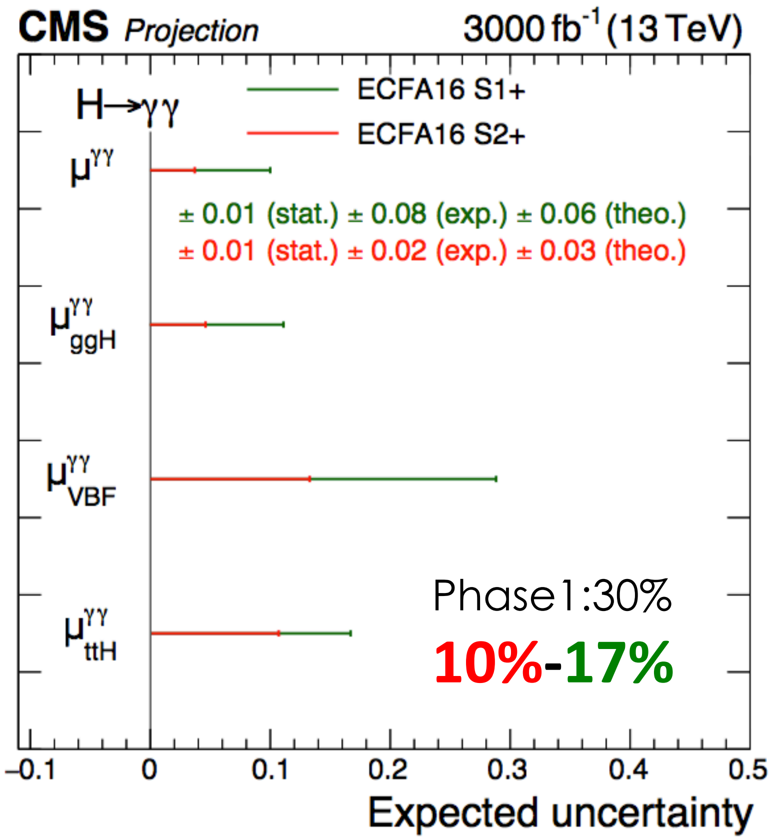


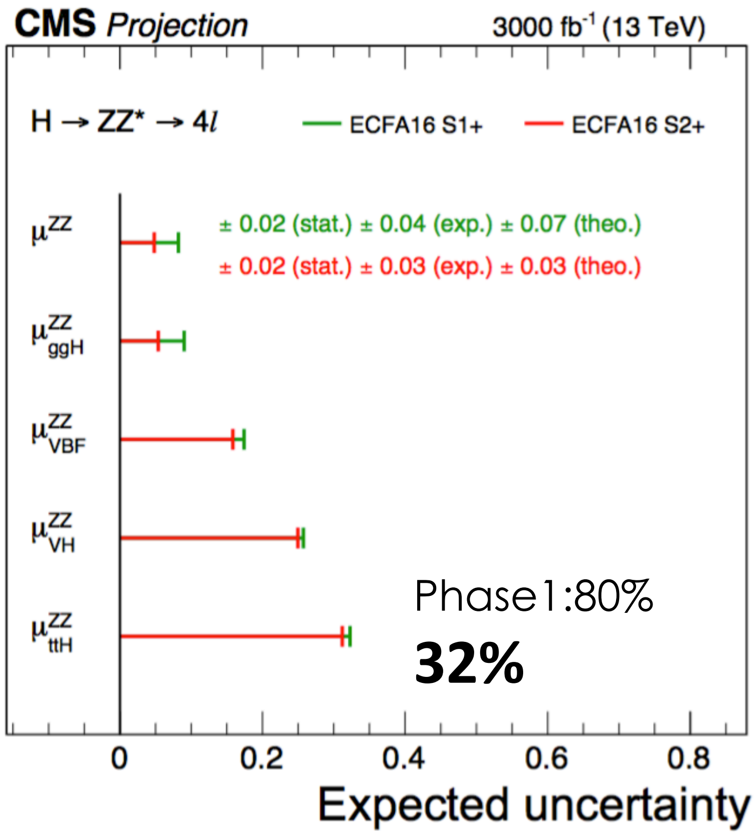


CMS-FTR-16-002

Top quark couplings

- Extrapolation performed from **12.9 fb^{-1} at 13 TeV** of the early Run 2 analyses, taking into account effect of upgraded detector and pile-up conditions
- Recent combination of Run 2 results (35fb^{-1}) allow to reach 10-20% uncertainty level
  - All of them (but k_μ and k_b) are systematics limited (theo and exp sys are now central)
- Statistics crucial in ttH (γγ, ZZ→4l) channels, although systematics also important
  - HL-LHC can bring uncertainty on tth rate down to 10% level
- Further improvement expected by incorporating features of recent Run 2 analyses (ttH)



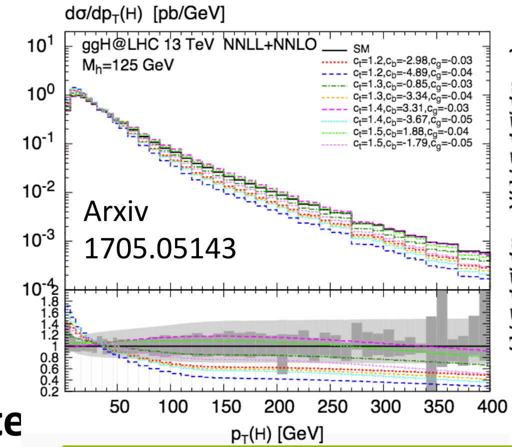


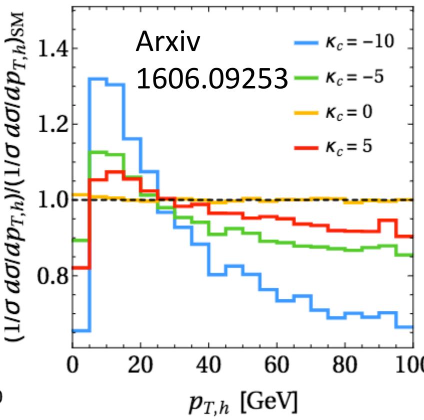
Scenario 1+:
All systematics are constant with luminosity + some detector effects included

Scenario 2+:
Experimental nuisances scale with √L, theory uncertainties halved + some detector upgrade effects included

Higgs differential Cross Section

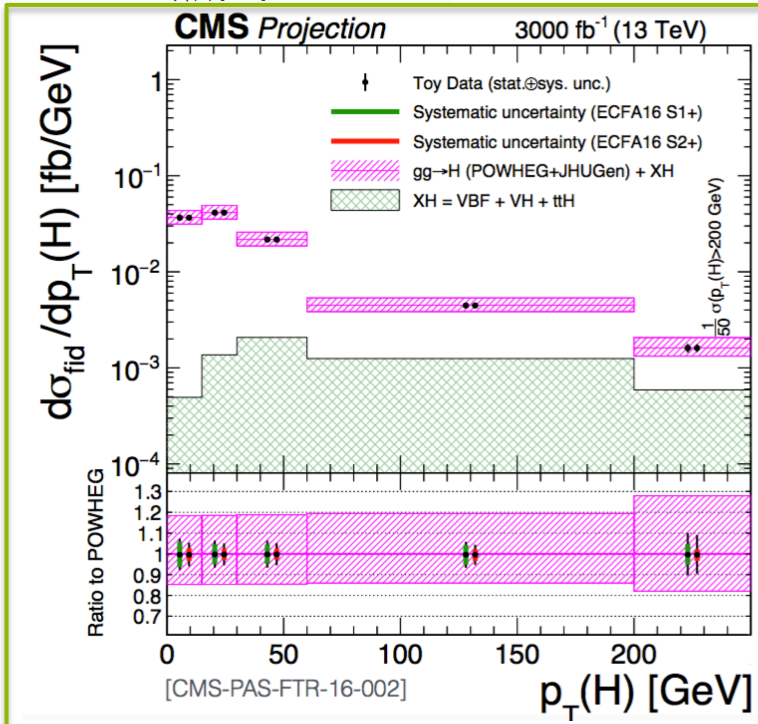
- Differential cross sections provide an interesting portal to a number of physical observables
  - The shape can be tested vs SM expectation: small variation of the couplings can lead to significant shape distortions
- p_T^H: Sensitivity to modifications of effective **Higgs Yukawa couplings** at low pT and to **finite top mass effects** at high pT
- **Jet multiplicity and first jet pT**→New physics in the loop, sensitivity at high pT
- **Rapidity $|y^H|$:** Theory distribution mostly determined by the **gluon PDF**; possible test
- Run2 results dominated by statistical uncertainties
- 3 ab^{-1} of data opens up possibilities for new measurements, and would provide competitive limits on Higgs couplings





p_T^H bin Statistical uncertainty		
Run2 ($36fb^{-1}$)	**Phase 1 ($300fb^{-1}$)**	**Phase 2 ($3000fb^{-1}$)**
30-40%	10-29%	4-9%

Can reach 3% precision if using the full Run2 combination

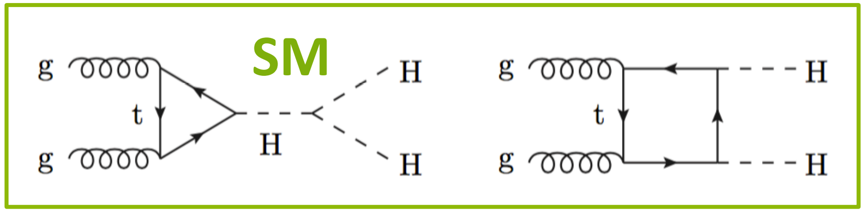


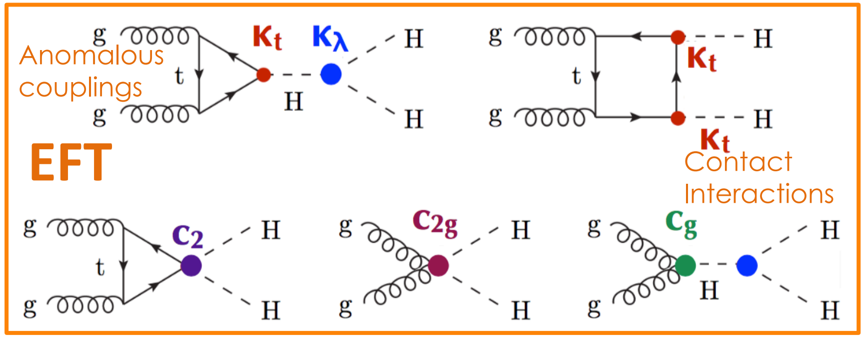
H→ZZ→4l
Extrapolation based on 12.9 fb^{-1}

Double Higgs Production

Arxiv: 1305.6397, 1505.05488
JHEP 04 (2016) 126

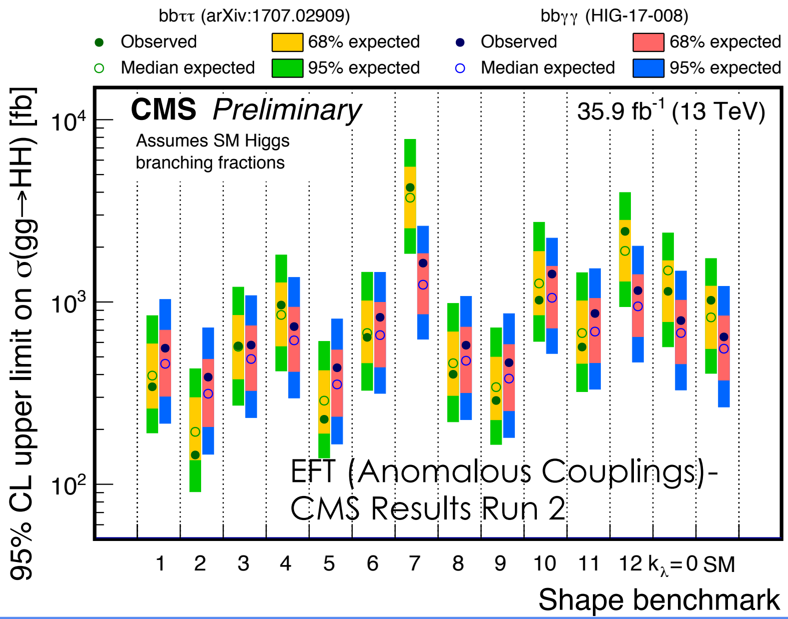
- The measurement of the Higgs boson **self coupling** is a **fundamental** test of the SM
- SM predicts a **extremely small cross section** for HH production (33.5 fb at 13 TeV→39 fb at 14 TeV)
- **Modified in many BSM scenarios**
  - Resonant Searches (MSSM, WED)
  - New Physics is in the ggF loop, anomalous couplings
- **Anomalous Higgs boson couplings**
  - Strong effect on cross-section and m(HH) shape
  - **EFT approach** parameterizes BSM theories
  - modifications to $\kappa_\lambda=\lambda/\lambda_{SM}$ and $\kappa_t = y_t/y_{t,SM}$ + three new interactions: **c2**, **c2g**, **cg** in the lagrangian





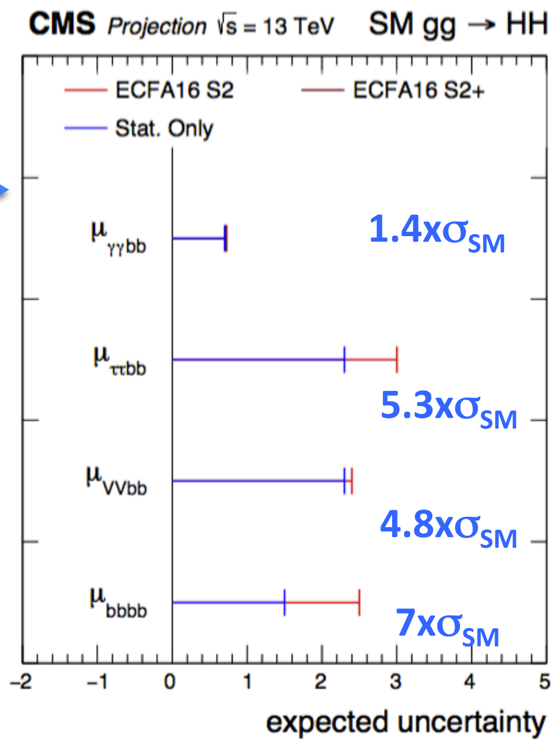
Run2 Results:

- Similar sensitivity from several channels to SM HH production → limits reach **20xSM (non-resonant)**
- Constraints set on anomalous Higgs boson couplings
  - 12 benchmarks of representative shapes
  - The different final states are complementary in different regions of BSM topologies
- Overall searches are limited by the statistics

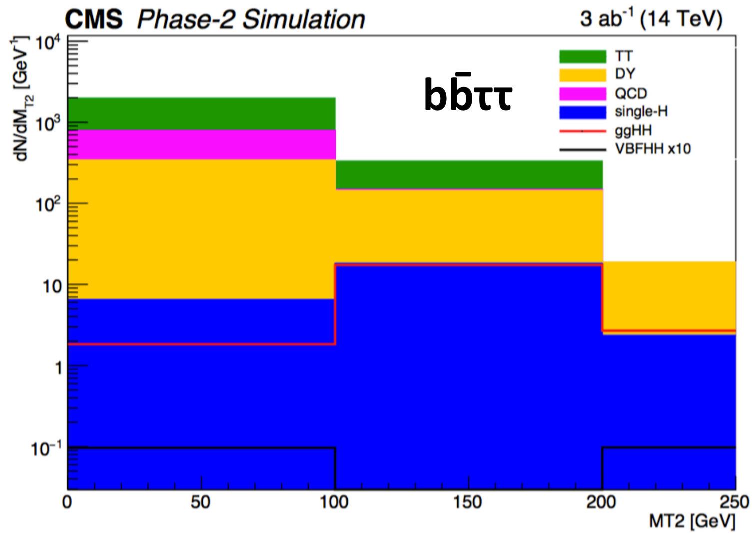


HH at HL-LHC

- **Extrapolation from Run II** to HL-LHC (3000 fb^{-1}) based on 2015 data, about 2.3-2.7fb^{-1}
  - Conservative and pessimistic, based on not optimized analyses
- Studies based on **full-sim/Delphes** are on going:
  - $b\bar{b}$ $b\bar{b}$, $b\bar{b}$ $\gamma\gamma$, $b\bar{b}$ VV, **$b\bar{b}$ $\tau\tau$**, and VBF for VVHH
- **In the HH→$b\bar{b}$ $\tau\tau$ performed: full analysis + projection based on full Run 2 dataset (35fb^{-1}) →**
  Results agree: UL at 95%CL on σ_{HH}/σ_{SM} ~1.5
  - This is just an estimate in the bbττ channel: combination of all channels (and with ATLAS) allow to reach the discovery sensitivity
  - SM benchmark considered in these estimates
- **Analysis improvements are faster than only luminosity gains**
  - New tracker with extended acceptance, new timing detectors, high granularity calorimeters
    - *30% improvement in light-jet discrimination*
  - x2 background reduction thanks to the enhanced object identification and analysis techniques



ECFA16 S2 reduced theory unc. and systematics
ECFA16 S2 + including future detector performance
Stat Only



HL-LHC can definitely be the test bench for double Higgs production

Beyond Standard Model

SUSY Searches

Present LHC has excluded large part of the natural SUSY parameter space

- Limits for strong SUSY production are above 1 TeV

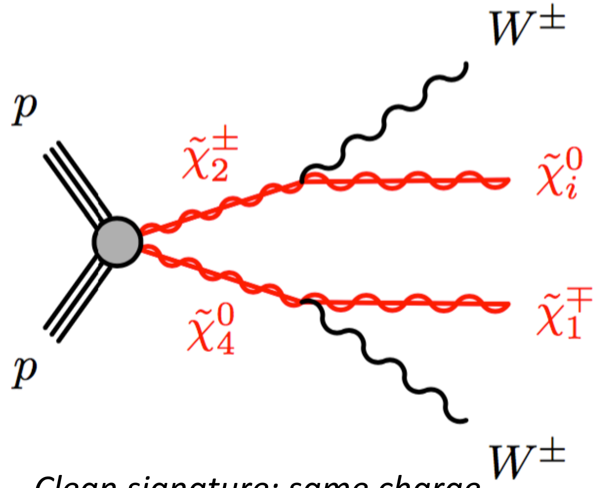
Still lots of opportunities in the electroweak sector

- May dominate if s-quarks and gluinos are heavy
- In most SUSY breaking scenarios EWK-ino masses are expected to be O(100 GeV) based on naturalness
- EWK-inos are produced via small EWK production cross sections → accessible to HL-LHC

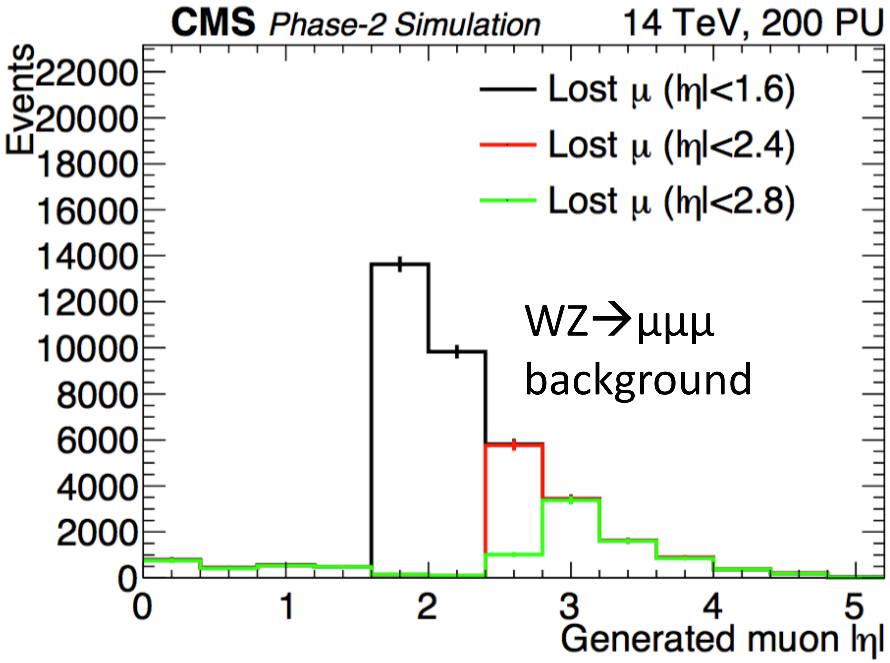
Search of EWK-inos into WW

arxiv 1310.4858
CMS-TDR-017, CMS-TDR-016

- Radiative Natural SUSY (RNS) with higgsino, bino, and wino at a few hundred GeV scale or below, and almost mass degenerate higgsino-like
- The associated production cross section of wino-like expected to be smaller than a few pb
  - Such processes can only be studied with the high luminosity
- In RNS $\chi 2\pm$ and $\chi 4$ are then expected to decay into higgsinos emitting same charge W bosons with a total branching ratio close to 25%



Clean signature: same charge leptons, large p_T^{miss} and modest jet activity

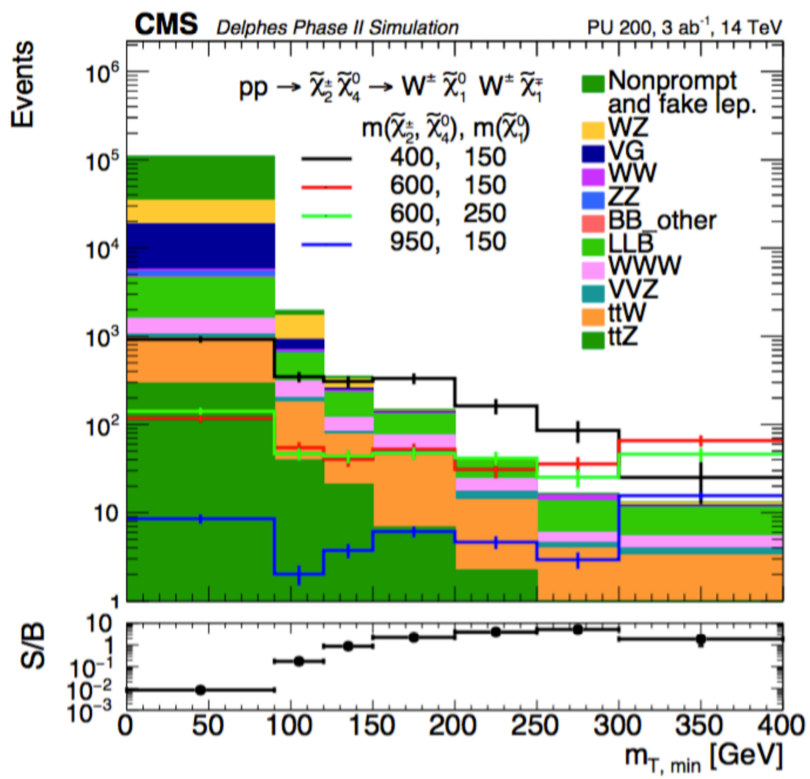


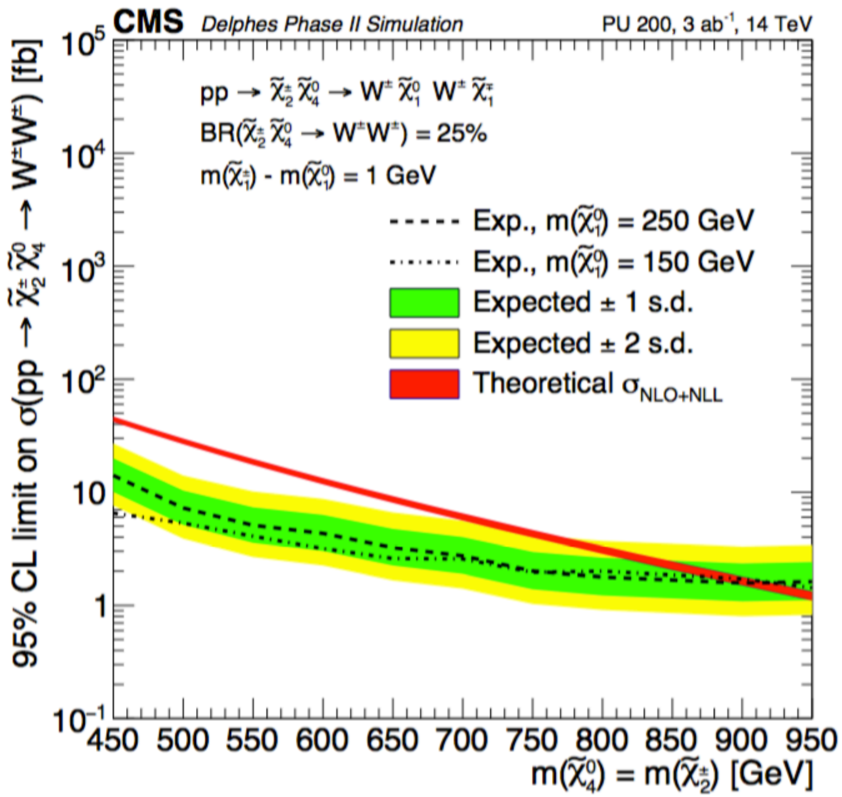
- Analysis performed using Delphes (fast simulation tool)
- Upgraded CMS detector simulation. Benefit from:
  - Upgraded high-granularity calorimeters→improved p_T^{miss} measurement
  - Extended Muon system acceptance →factor 3 reduction of the irreducible WZ background

Search of EWK-inos into WW

arxiv 1310.4858
CMS-TDR-017, CMS-TDR-016

- Two Higgisno mass (μ) scenarios considered:
  - $m(\chi_1)$ = 150 GeV is representative of the region of the parameter space outside the reach of the Run 2
  - $m(\chi_1)$ =250 GeV is outside the sensitivity reach of the same search when extrapolated to the HL-LHC
- Wino-like mass degenerate χ2,χ4 are excluded at 95% CL up to 900 GeV in the μ=150 and 250 GeV scenarios

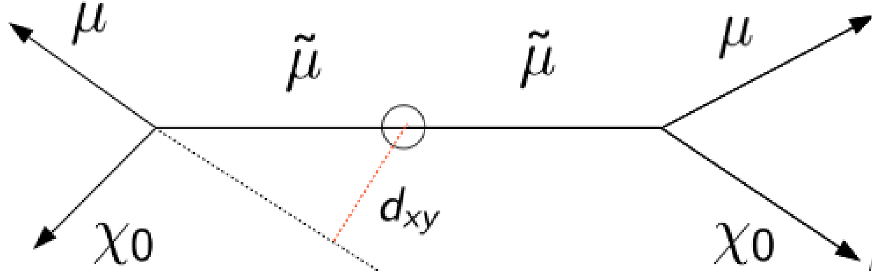


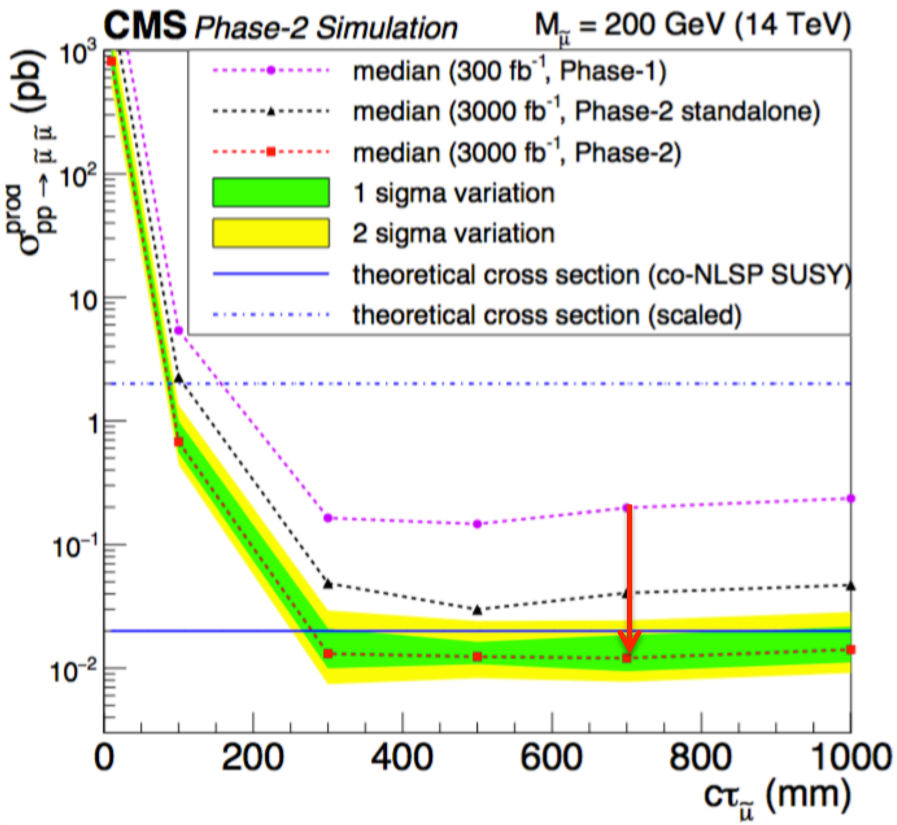


SUSY Long Lived Particles

CMS-TDR-016

- **Searches for the direct s-particles production with long lifetimes difficult in Run 2**
  - gauge-mediated SUSY breaking models where s-muons can be (co-)NLSPs and decay to a muon and a gravitino have been considered to quantify the HL-LHC discovery potential
  - small cross sections (~10^{-2} fb for 1 TeV s-muon)→become possible at the HL-LHC.
- **The sensitivity depends on *cτ:* the shorter the decay lengths the larger the SM bkg**
  - Discovery sensitivity of 3σ significance can be reached with 3000fb^{-1} of data with the trigger/reconstruction/analysis efficiency closer to the Run 2 in the PU200 environment
  - Key role of the muon system→additional station allow for an efficient reconstruction

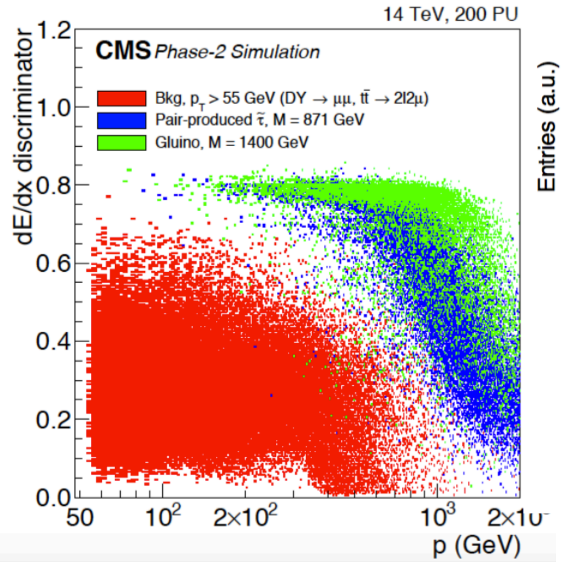


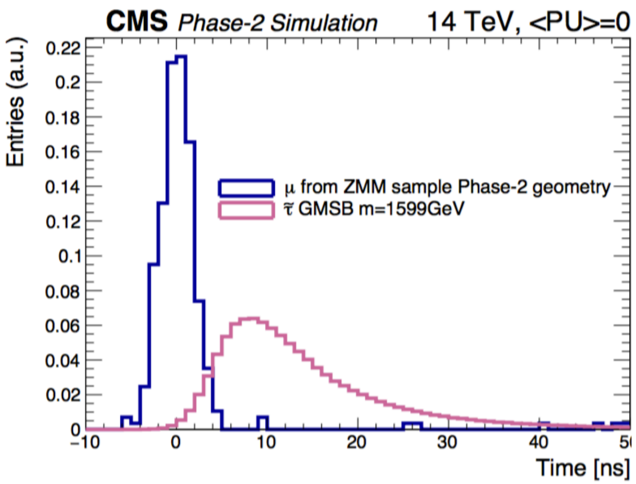


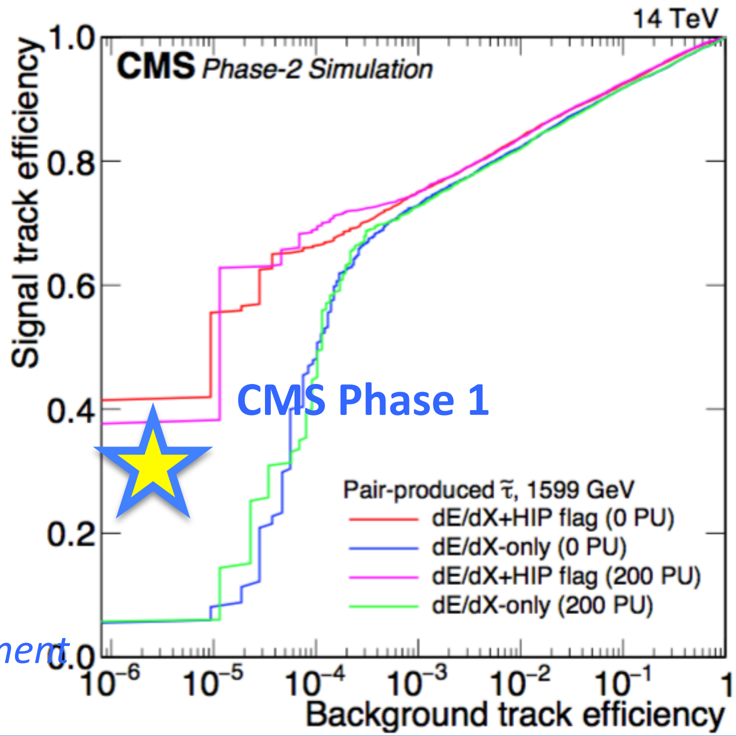
Heavy Stable Charged Particles

CMS-TDR-017,
CMS-TDR-016

- Several extensions of the standard model (Split SUSY) predict HSPC as NLSP
  - Lifetime larger than a few nanoseconds→travel through the detector before decaying
  - Mass ~ PeV scale→heavily ionizing the sensor material as they pass through.
  - Model independent searches have been investigated based on **TOF and d*E*/dx**
- Very small cross section →the HL-LHC will allow collecting large data sets needed to reach better sensitivity with respect to Run 2
- **Upgraded tracker, muon system are crucial for HSCP identification**







The Phase-1 sensitivity will be surpassed with the full expected integrated luminosity of the HL-LHC and suitable dE/dx measurement with tracker will be implemented.

Conclusions and Perspectives

- **HL-LHC will be the first Higgs factory. Potential to reach the percentage level in precision on the Higgs coupling modifiers and signal strengths.**
  - Thanks to the high statistics→ rare processes become accessible
  - Possibility to study the deviation from the Standard Model
  - Statistically-limited analyses can further combine ATLAS+CMS
  - Towards the high precision era: is important to reduce further the theoretical and experimental systematics
- **Rich BSM potential at HL-LHC. Looking forward to another discovery**.
  - Several projections and full analyses for a variety of existing benchmark channels.
  - With HL rare processes and low couplings become accessible. New models also welcome.
- **Large interplay between theoretical models, extrapolation and detector design for the HL phase**
- **Update of projections is on-going in view of the CERN Yellow Report that will be released at end of the year towards European Strategy in 2020**

Long-term exploration of Higgs sector and New Physics searches will have crucial impact on our understanding of nature

Backup

Triggering at HL-LHC

The goals:

- Maintain sensitivity to electroweak scale physics keeping acceptable rate even for low L1 pT thresholds.
- Add sensitivity to new physics scenarios, i.e. acceptance to displaced muons and HSCPs from long-lived particle decays

The HL-LHC challenges (induced pile-up and electronics):

- worse muon pT resolution
- increase of the trigger rate
- lack of redundancy in the forward region

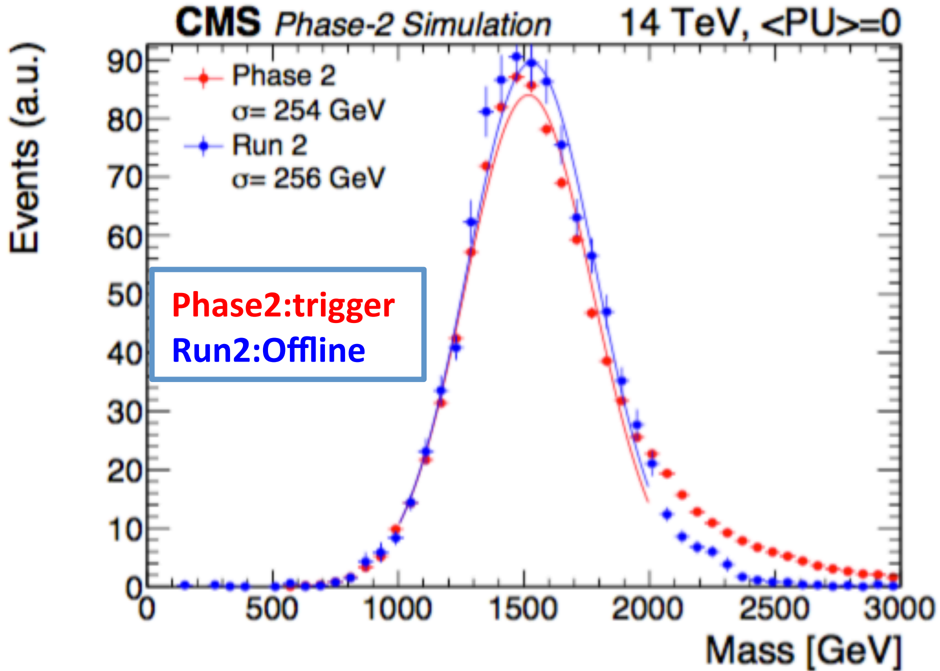
CMS will have new handle to cope these conditions

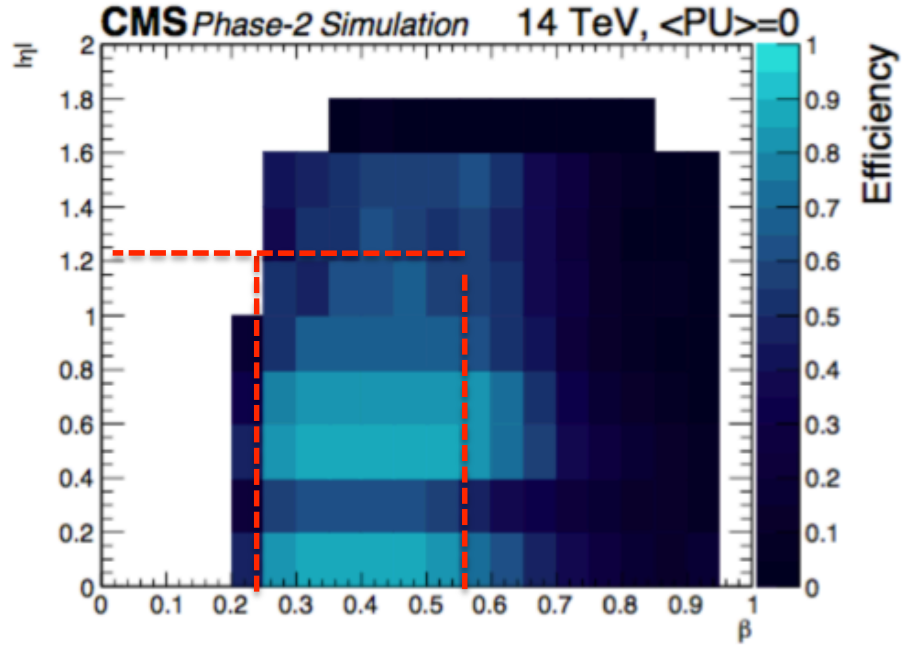
- New detectors in the forward region (ME0, GE21, RE31,RE41) →Additional bending angle measurement and improved time resolution
- L1 Track Trigger →require clever segmentation for the new detectors
- Increased latency and bandwidth →new on-detector electronic
- Add triggering capabilities in the forward region $2.4<|\eta|<2.8$

This implies a completly new design for phase 2 Muon trigger

BSM searches: HSCP

- Split SUSY predict the existence of new heavy particles with long lifetimes
  - it can travel through the majority of the detector before decaying and therefore appear as stable
- HSCPs can move much more slowly than muons→identified using **time-of-flight (TOF)** from the center o CMS to the muon systems.
- Particles moving slowly through the muon systems leave hits with a linear pattern in hit-position versus time. The **hits can be spread across several bunch crossings.**
  - **muon detectors with precise timing can provide important information for the HSCP signal searches→exploit RPC time resolution with the upgraded linkboard**



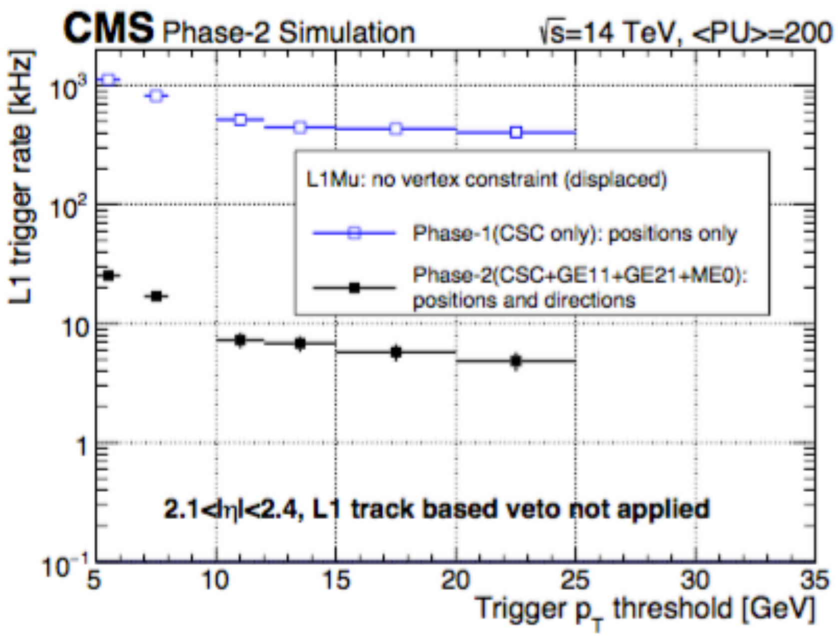


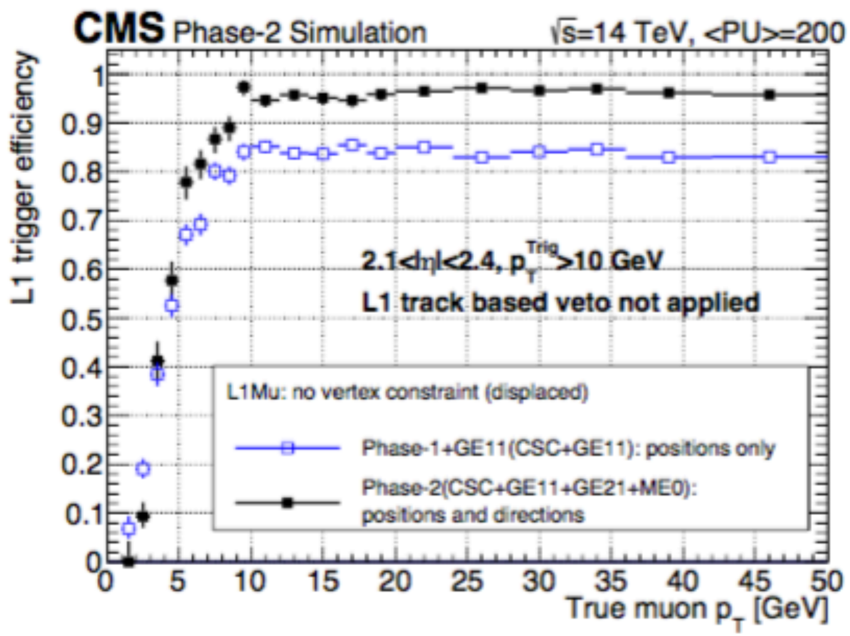
Phase2 trigger allows to reach same mass resolution at trigger level as in run2 offline analysis

With the Phase-2 upgrade events with $\beta < 0.5$ can be triggered with nearly 90% efficiency for $\eta < 1.2$

Displaced Muon trigger performance

Very fwd region





L1 muon trigger rate vs trigger pT threshold (left) and trigger efficiency vs true muon pT (right) for the endcap displaced muon algorithm in the region and 2.1 < |η| < 2.4. The track veto is not applied here yet.

HL LHC science goals
(and guide-lines for experiment upgrade)

Precision measurement of the Standard Model

- EWK Bosons and fermions couplings
- Differential distributions

Search for new physics in SUSY and exotic scenarios

- Characterized by small cross sections and/or challenging final state signatures
- displaced tracks and HSCP are probe of new physics

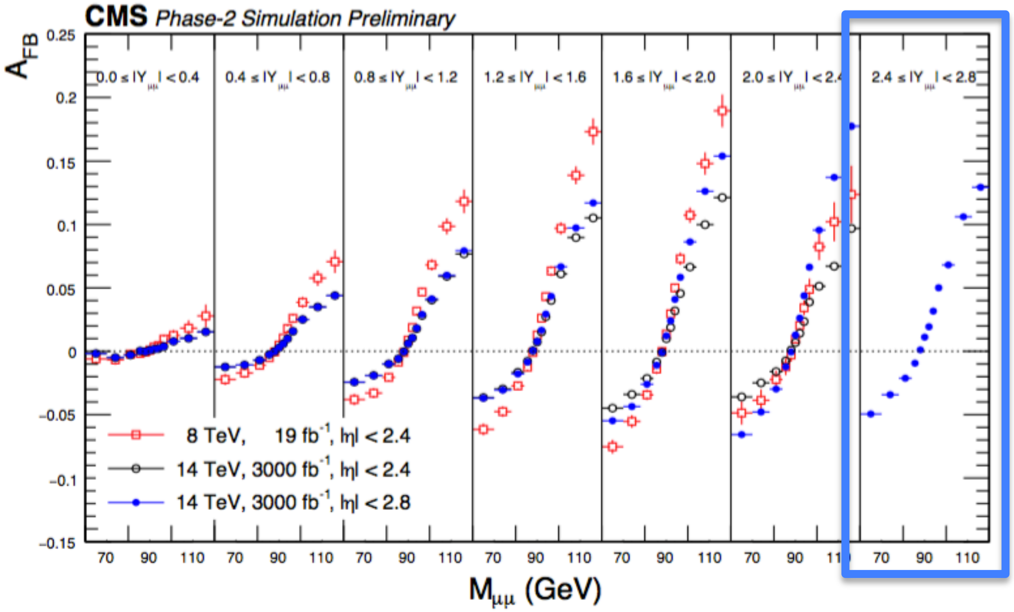
Maintain sensitivity to electroweak scale

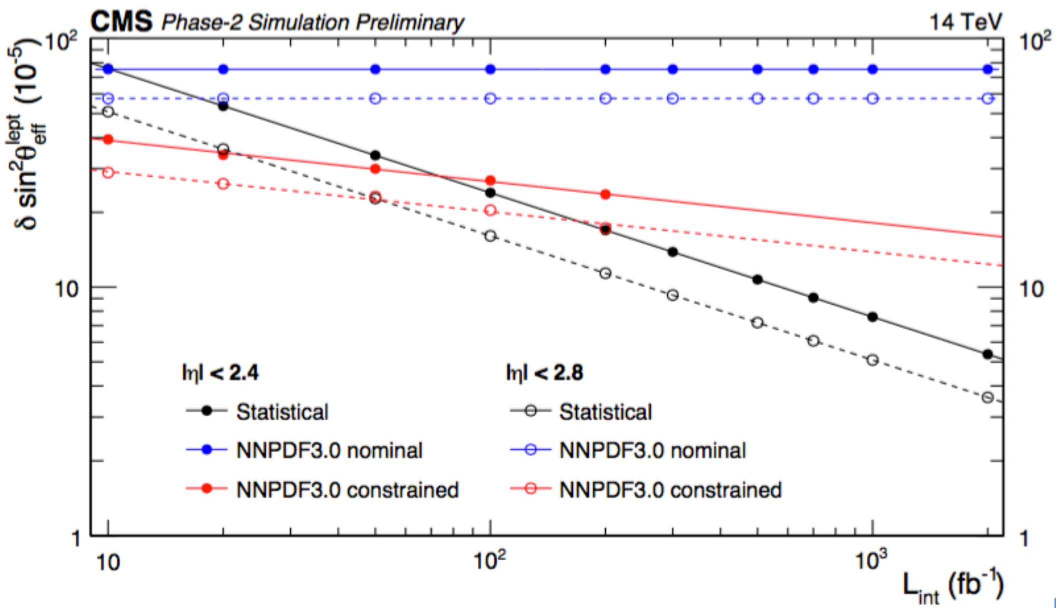
- keeping accetable rate even for low L1 pT thresholds.
- Ensure robust reconstruction/ID at L1 and offline

Add sensitivity to new physics scenarios

- Restore TrackTrigger ineff. for d_{xy} >2 mm
- Improve pT assignment for displaced tracks
- Use timing info for HSCP triggers

Effective weak mixing angle measurement





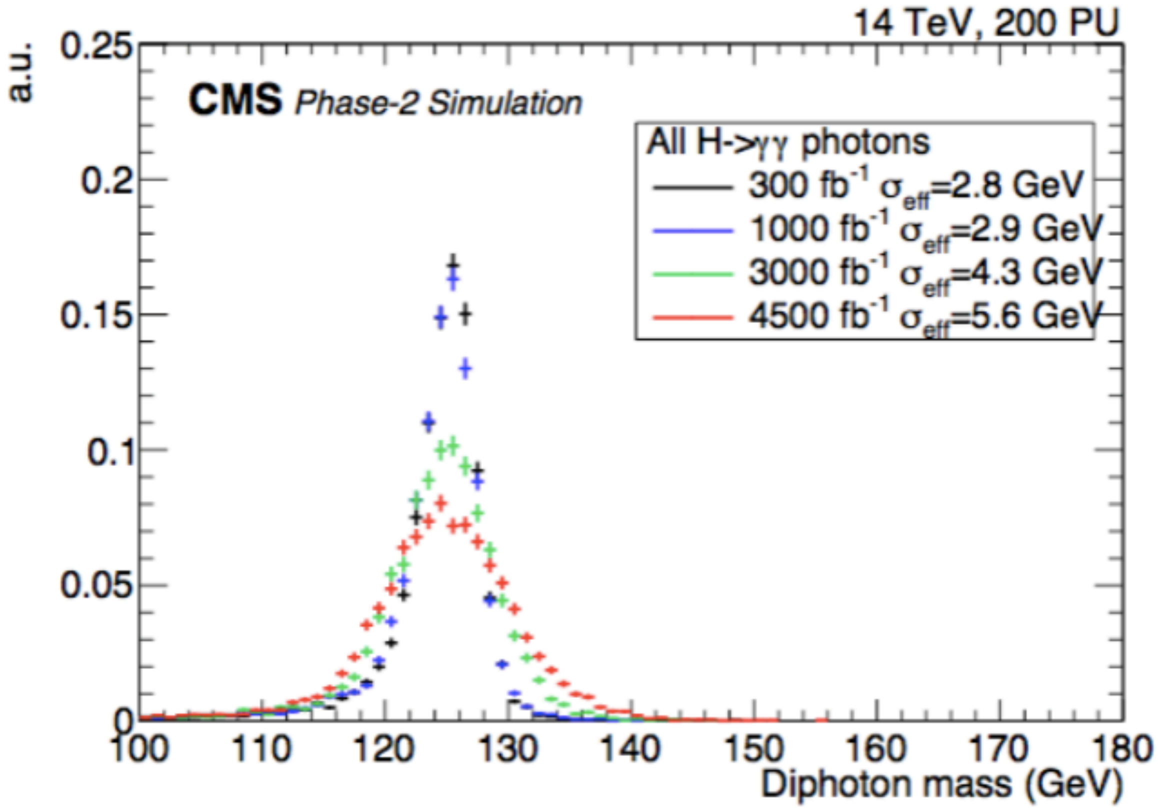
- Measurement of the effective weak mixing angle using the forward-backward asymmetry in Drell-Yan events
  - Generator level study with detector effect smearing
- Significant improvement brought by the extended eta coverage→

significantly increase of the coverage for larger *x*-values of colliding partons→

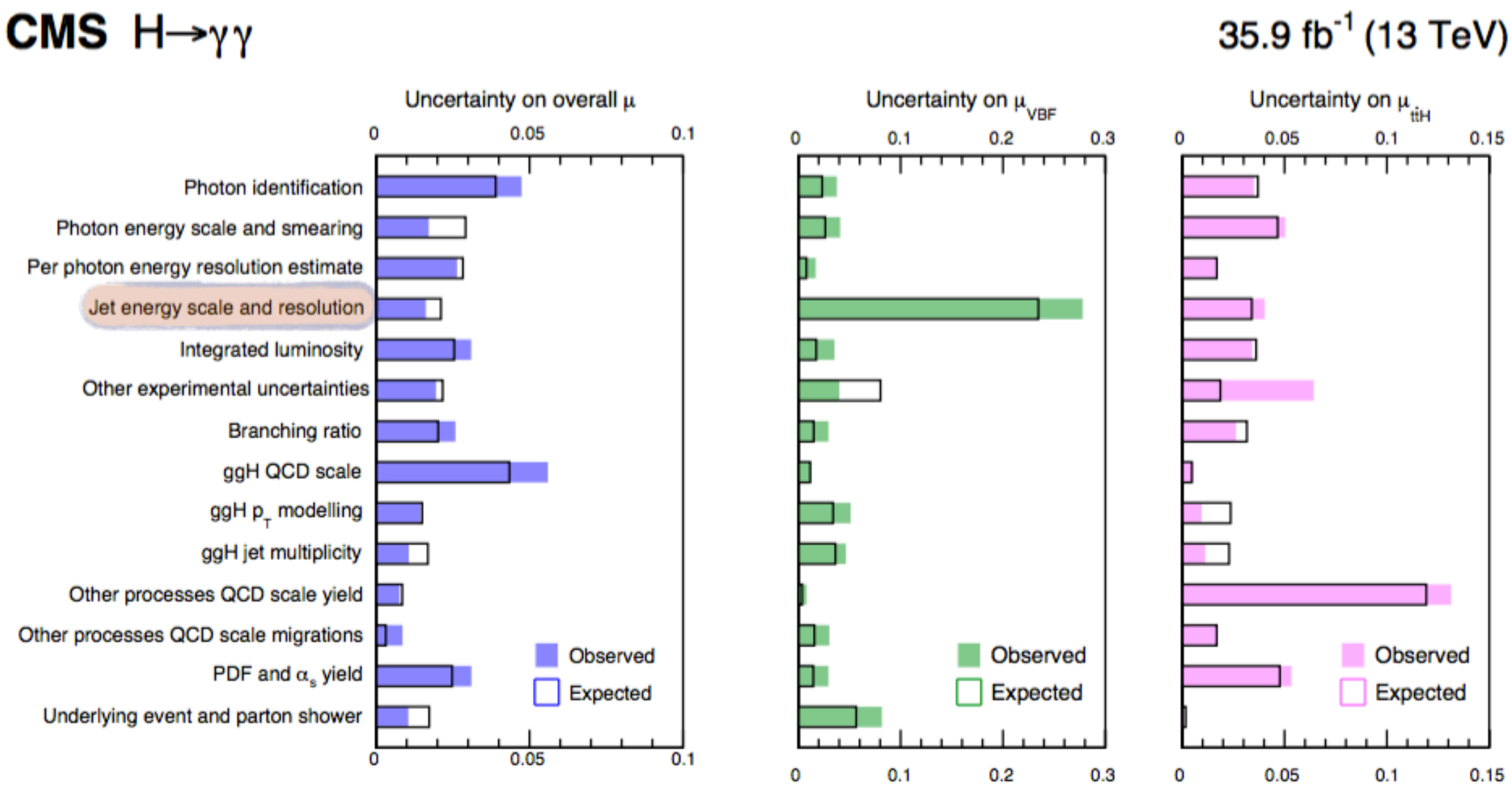
- **30% reduction of the statistical uncertainties**
- **20% reduction of the pdf uncertainties**

H→γγ

• H→γγ: the di-photon mass resolution is mostly driven by photon energy and vertexing resolutions
• Mass resolution is worsened in the different radiation ageing scenarios of the barrel calorimeter



H→γγ Systematics Breakdown



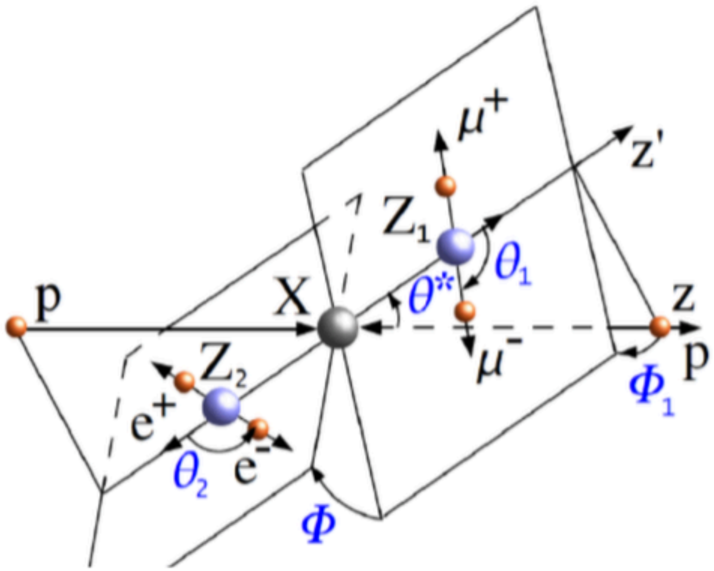
Current dominant uncertainties for overall μ:
uncertainty on **photon identification BDT**
overall theory uncertainties (due to QCD scale variations, primarily on ggH)

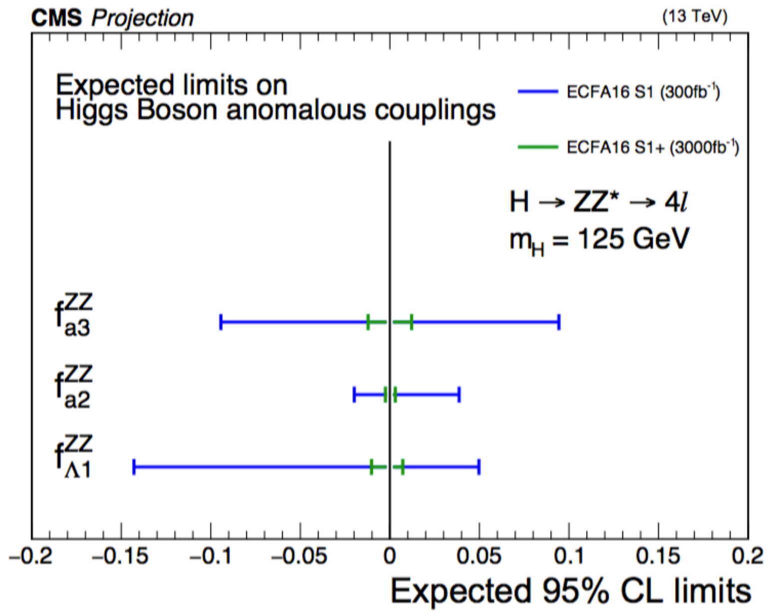
Higgs charge-parity

- H→ZZ→4l gives sensitive test of charge-parity
- Angular and mass distributions of leptons and Z bosons
- **Statistics-limited:** Precision in CP-odd fraction all way down to 1% level even with current systematics
- CMS detector will be much improved, and systematics decrease with more data

SM — leading momentum expansion — higher order cp-even — cp-odd

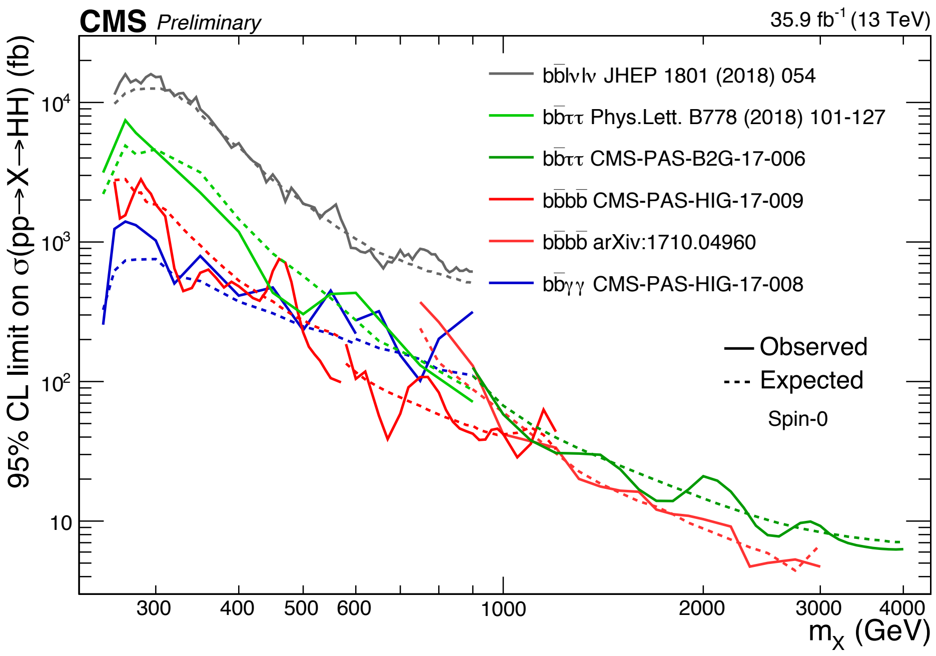
$$A = \frac{1}{v}\left[a_1^{VV} + \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{\left(\Lambda_1^{VV}\right)^2} + \frac{\kappa_3^{VV} (q_1+q_2)^2}{\left(\Lambda_Q^{VV}\right)^2} \right] m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* + a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

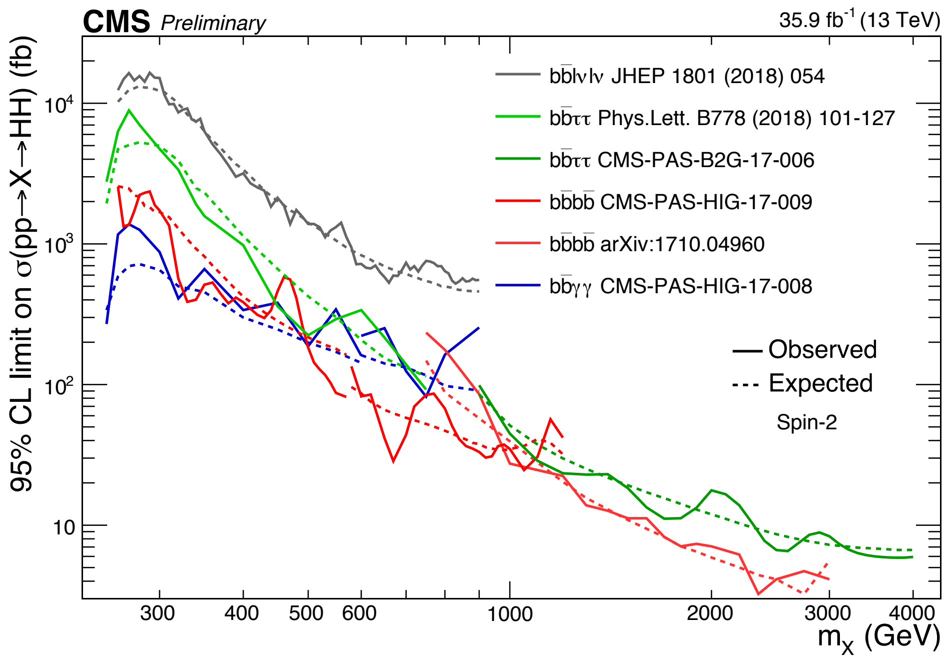




Double Higgs Production Upper Limits-Run2

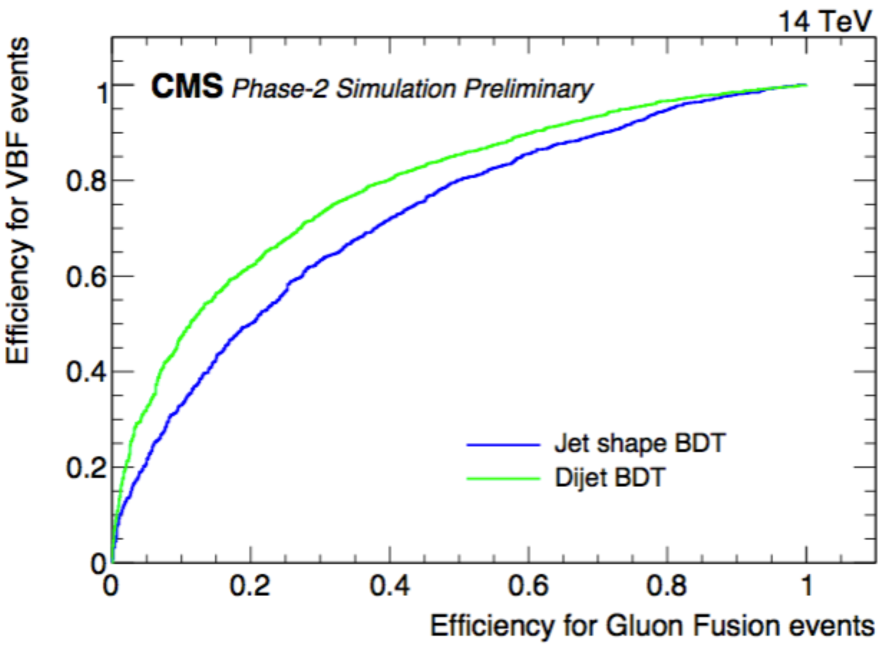
Resonant Searches





VBF tagging: $H \rightarrow \gamma\gamma$

- $H \rightarrow \gamma\gamma$: CMS High-Granularity Calorimeter allows inclusion of photons up to $|\eta| = 3.0$
  - increase in efficiency of the analysis by 12% in the barrel only
  - The resolution of endcap-endcap diphoton pairs is found to be very similar to the barrel one
- High granularity and precision timing capabilities of the HGCAL
  - improvement in pileup suppression in primary vertex reconstruction, isolation, jet shape observables and missing energy
  - improved reconstruction and identification of the forward jets in VBF production
- Analysis performed using a multivariate discriminator (BDT), combining photons and jets variables
- Precision in coupling measurment in Run2 analysis limited by JES, Photon ID, Theoretical uncertainties→further room for improvement



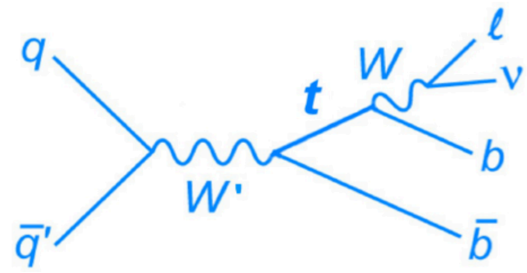
Signal and background yields for BDT working points (WP)

Event Categories	SM 125GeV Higgs boson expected signal			Background
	Total	ggH	VBF	per GeV
WP 0	750	25.4 %	74.6 %	678
WP 1	1275	35.9 %	64.1 %	876
WP 2	1926	45.8 %	53.2 %	1353
Run 2 WP	3878	42.0 %	58.0 %	1984

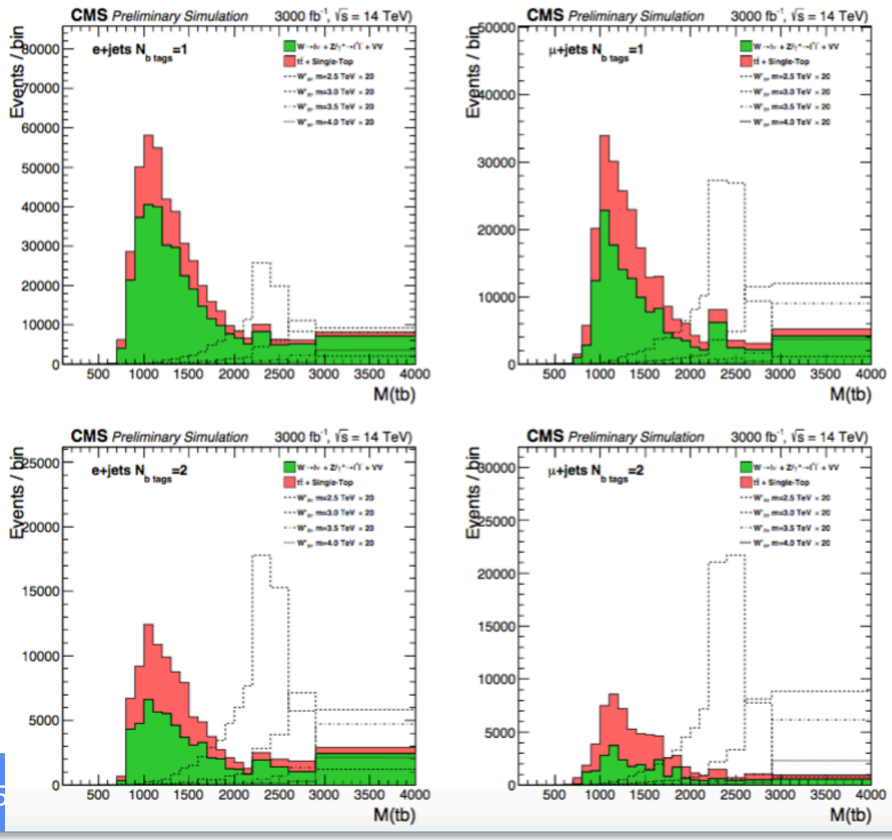
The discriminating power between ggH and VBF is comparable to Run 2 despite the increase in amount of pileup→conservative result considering that the analysis has not been optimized

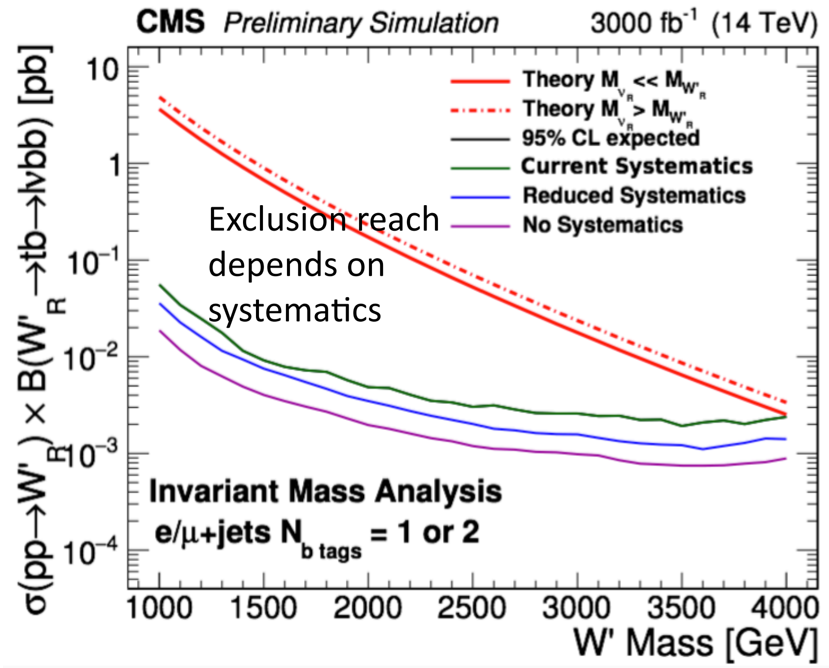
New heavy bosons: W’→tb

CMS FTR 16-005
Full simulation ongoing



- Many SM extensions require additional heavy gauge bosons.
  - SSM predicts the existence of a new massive charged boson, W’ (SM W like)
  - additional decay channel W'→tb opening up if the new boson is sufficiently massive.
- In a scenario $M(\nu_R)>m(W')$ →the decay to leptons is forbidden
- Projections using the baseline analysis at √s=13 TeV with 12.9 fb-1 data that excludes W' up to 2.67 TeV @ 95% CL



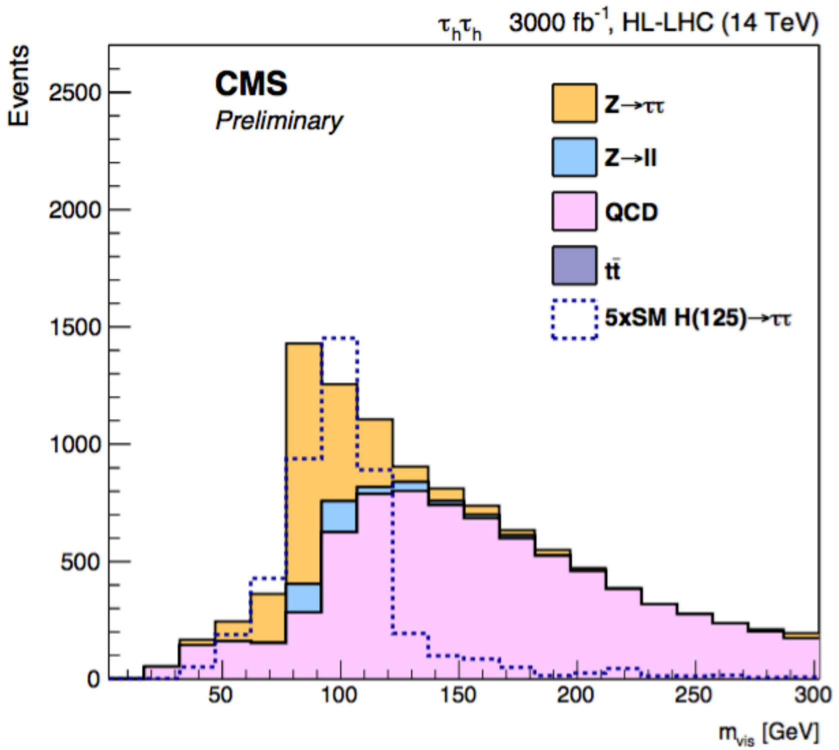


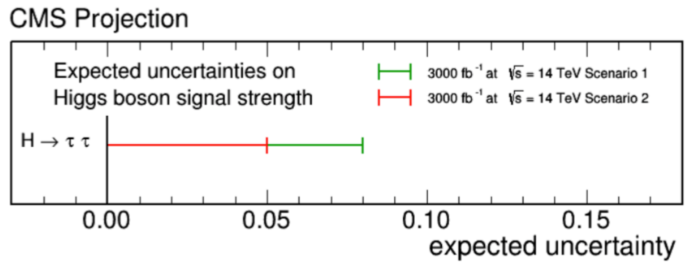
W’R masses up to 4 TeV can be excluded.
The sensitivity increases beyond 4 TeV

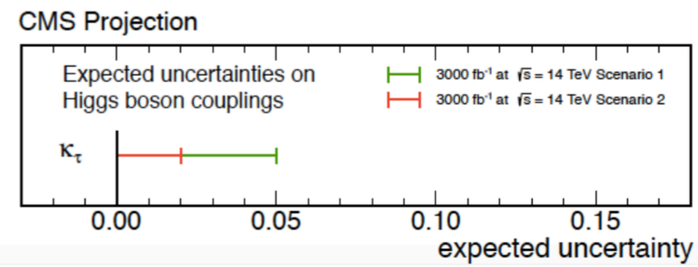
VBF tagging: $H \rightarrow \tau\tau$

CMS TDR-017-007

- The VBF production mode offers a higher signal purity compared to the dominant gluon-fusion production mechanism.
- During the HL-LHC operation O(1M) VBF $H \rightarrow \tau\tau$ events will be produced.
- Highest Sensitivity to the Yukawa couplings between the Higgs boson and the tau leptons
  - An **excellent mass resolution** is required, at HL-LHC almost the same as in Run2 → **a good measurement of the MET** is crucial for pileup mitigation
- Full simulation performed to account for the new tracker and upgraded calorimeters
  - **+10% increase in signal acceptance** thanks to the tracker and calorimeter extensions
  - Up to a **factor 2 in QCD multijet bkg suppression** thanks to the precise association of VBF jets to the PV

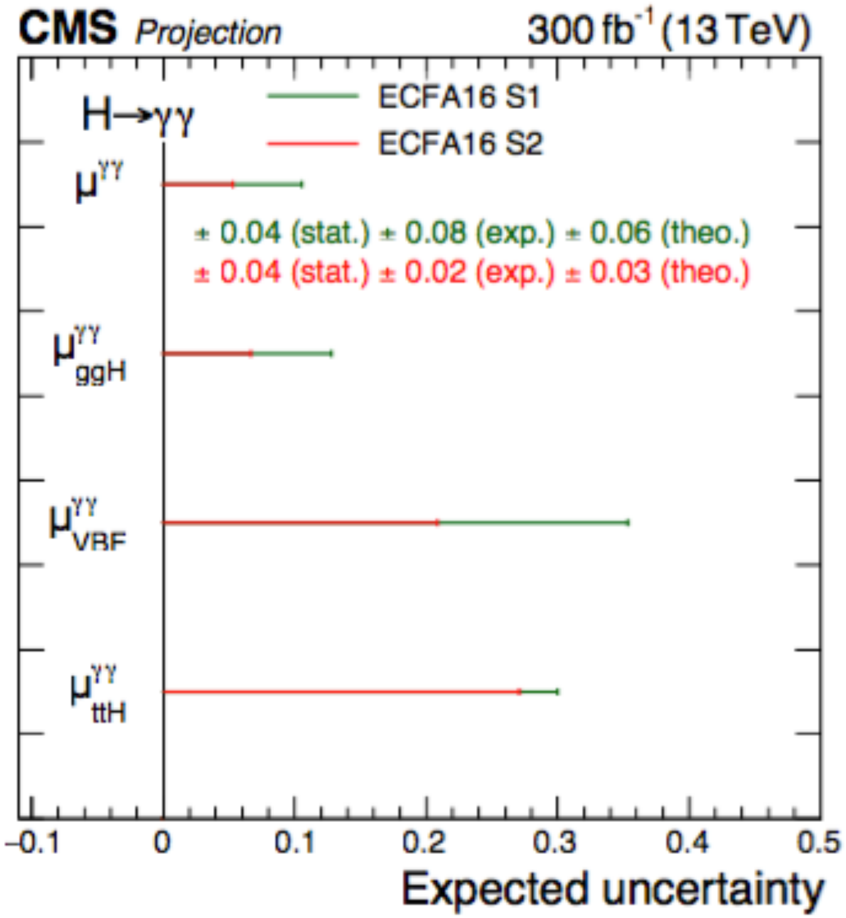


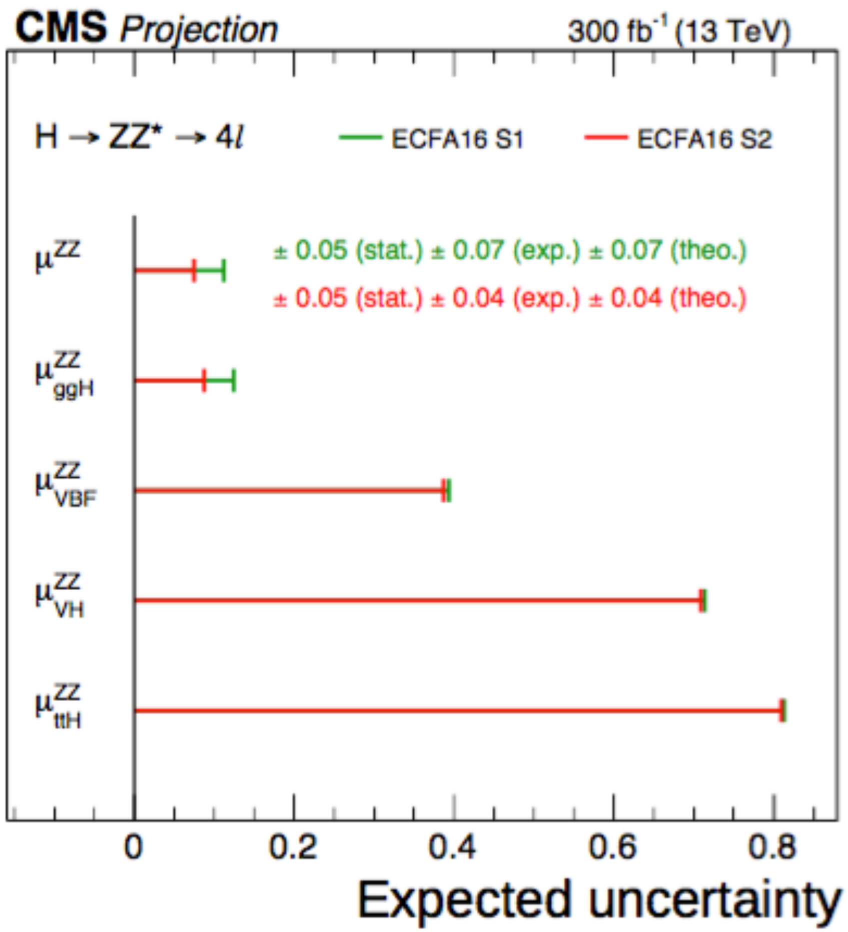




CMS projected precision at $3ab^{-1}$ for [S1-S2] scenarios:
[5-8]% level on the signal strength
[2-5]% level on the coupling modifiers $\kappa\tau$
→The full simulation results confirm the predictions

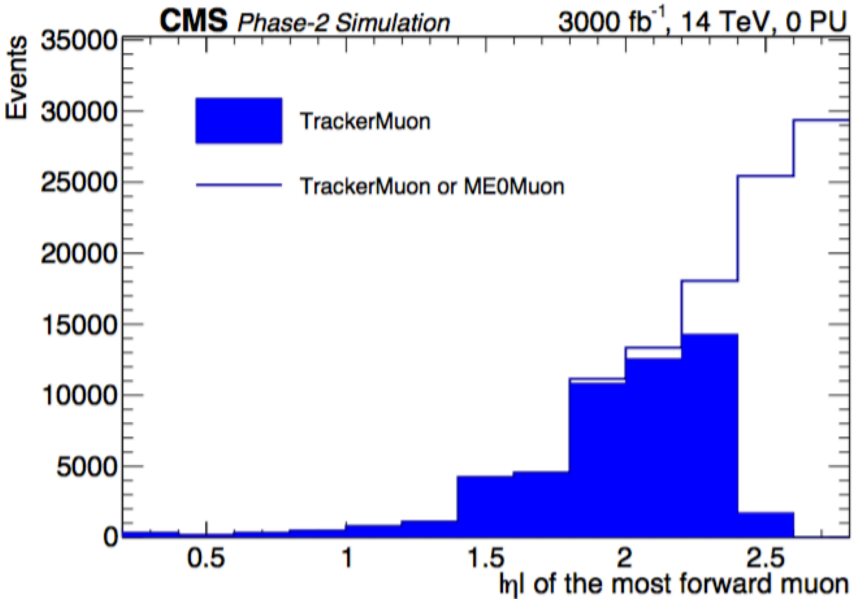
ECFA 2016- Phase 1 Projections

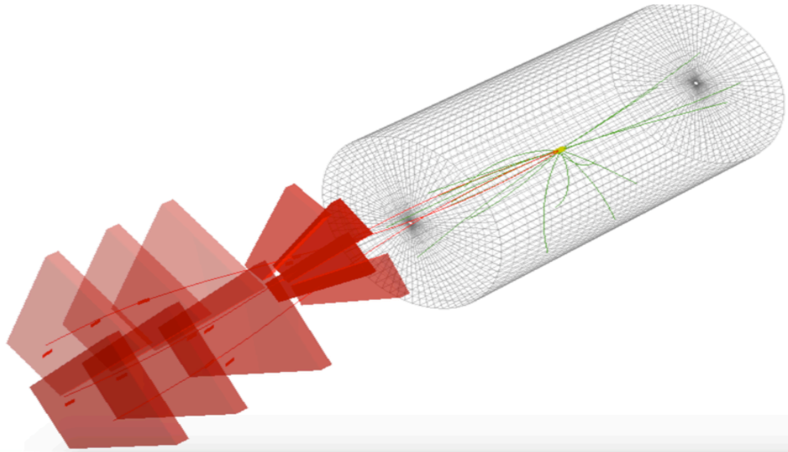




LFV Tau→3μ: a test of the SM

- Extremely low cross-section also in BSM models→ accessible at HL-LHC
- The main source of τ leptons in pp collisions is $Ds \rightarrow \tau\nu$ decays.
  - Muons with very low momenta and boosted in the forward direction.
- The upgraded muon system increases the signal fiducial acceptance by a factor of 2 but
  - worse trimuon mass resolution at high $|\eta|$ →event categorization
  - Optimal Momentum measurement not yet implemented
- Projected exclusion limit for 3000 fb^{-1}
  - **B(τ→3μ) is 4.3×10^{-9} at 90% without ME0**
  - **B(τ→3μ) is 3.7×10^{-9} at 90% CL with ME0**



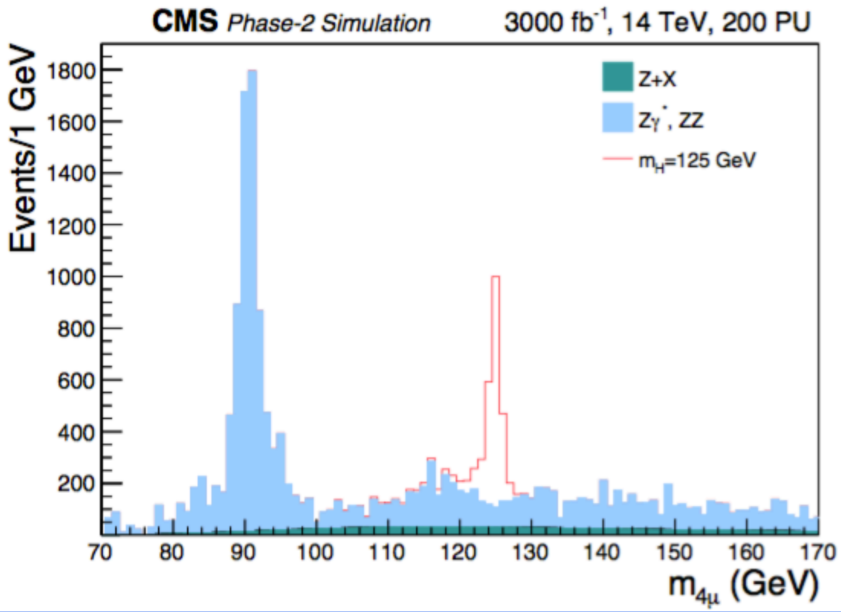


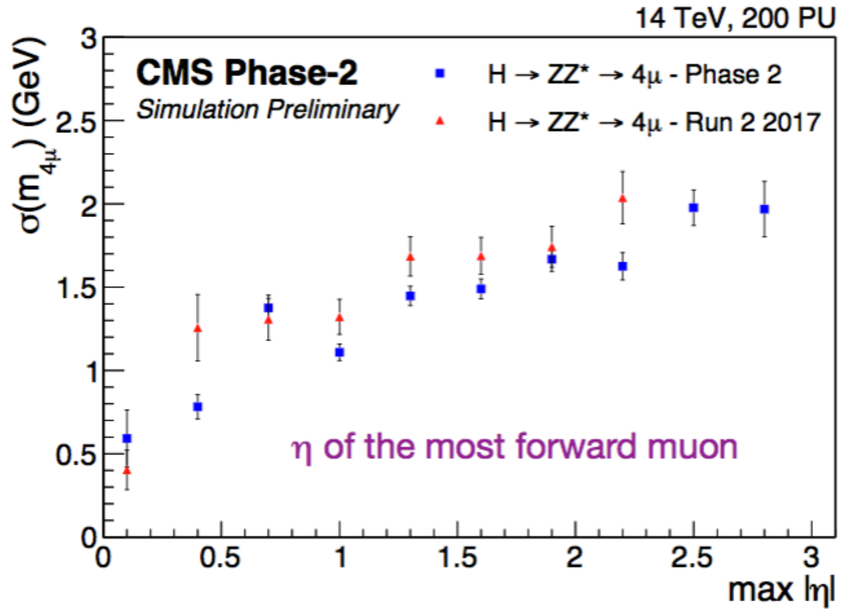
The difference can be re-interpreted as an effective gain in integrated luminosity ~1.35 →from 3000 to ~ 4000 fb^{-1} due to the muon extension

H→ZZ*→4ℓ

CMS TDR-017-002, CMS TDR-017-003

- During the HL-LHC period gluon fusion is expected to give rise to about 20k H→ ZZ* → 4ℓ decays, and vector boson fusion will add another ~1550
- Upgraded detectors bring significant improvements:
  - increased acceptances (Tracker+Muon System) →+15%
  - new EM/μ trigger
  - higher reconstruction efficiency and momentum resolution
- **Challange: control the experimental uncertainties**
  - **theoretical uncertainty on the total signal cross section does not play a role.**
- **Signal acceptance and mass resolution <u>fairly immune to the pile-up conditions</u>**
- The increase of acceptance in this channel is relevant in differential measurements, CP measurements, the Higgs mass measurement, and studies of anomalous couplings.

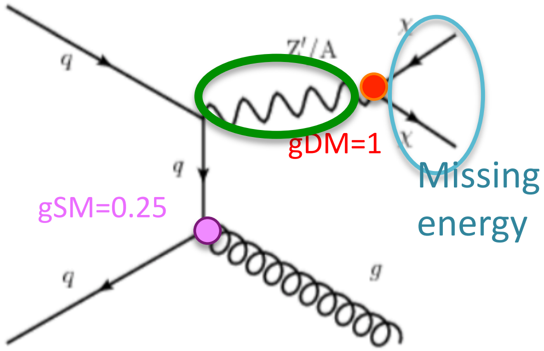




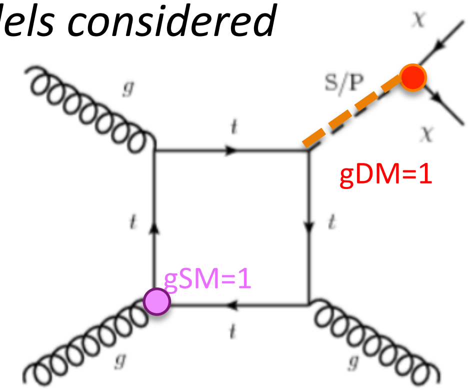
Dark Matter Searches

- The DM in the form of WIMPs will be one of the top priorities of the HL-LHC.
- Colliders can set competitive constraints on spin-dependent interactions
  - For the pseudoscalar mediated model, the LHC is uniquely place to probe this interaction
- DELPHES fast simulation tool, with parametrization close to the Run2 analysis

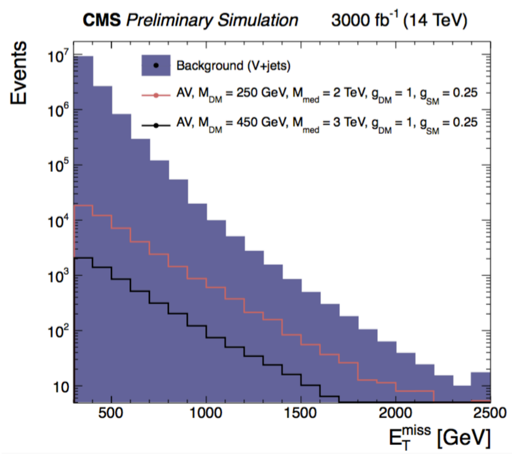
Two benachmark models considered

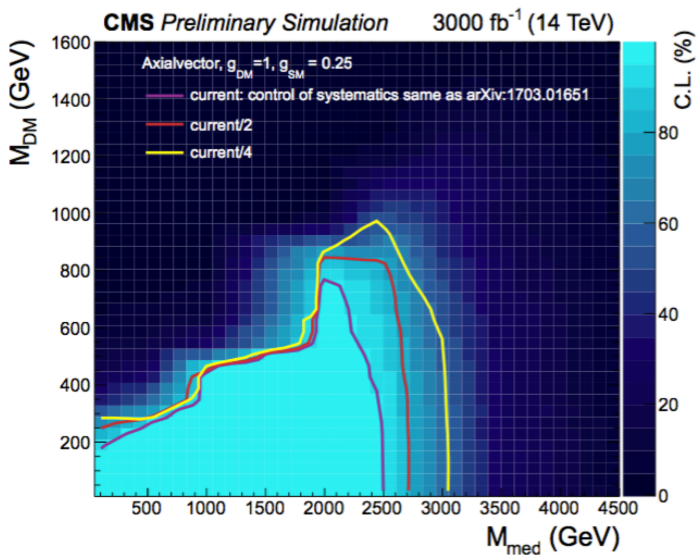


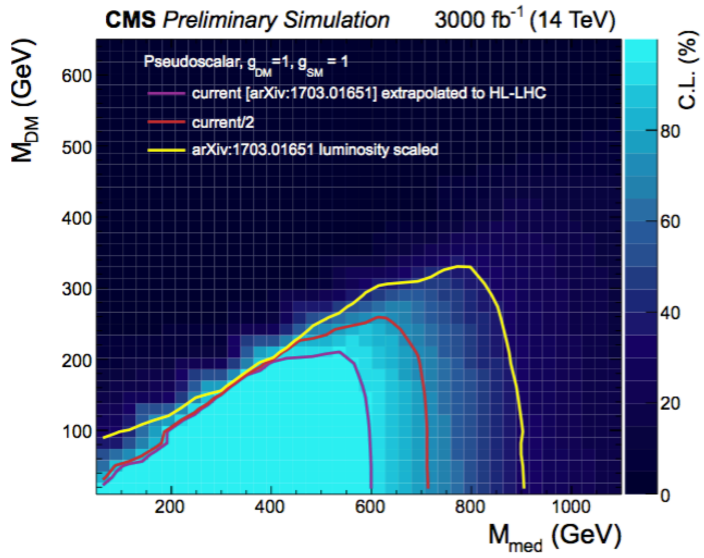
axial vector mediator



pseudoscalar mediator





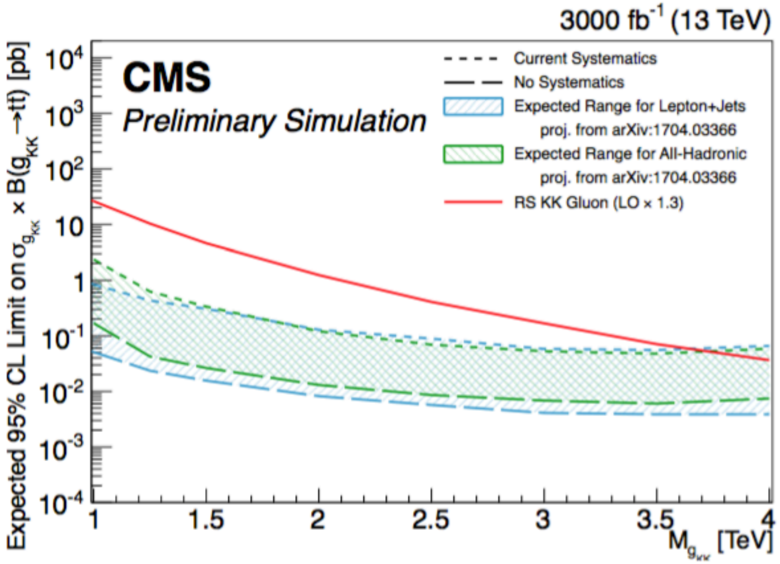


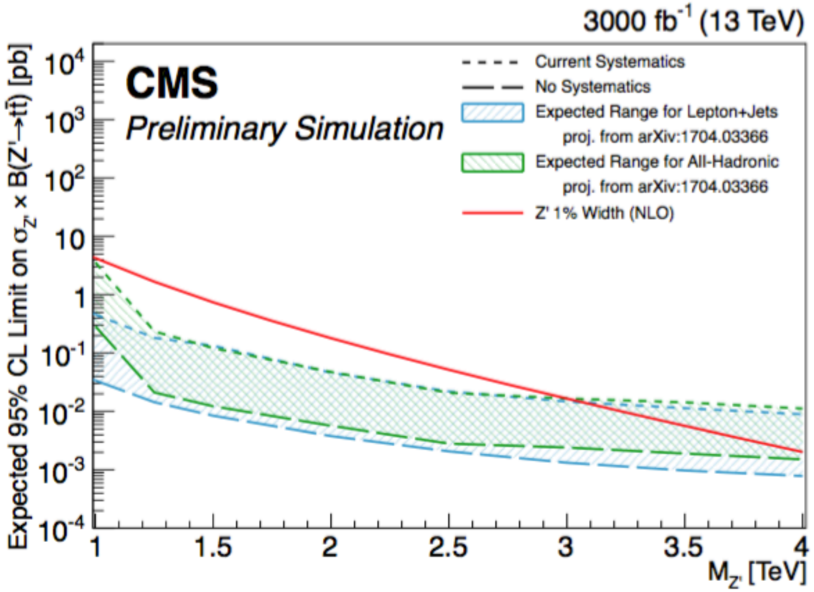
The projected exclusion reach for 3000 fb^{-1} at 95% confidence level (3 sys scenario)
Sensitivity up to 2.5 TeV for the AV-model and 600 GeV for the PS-model
Limits in the best "scaled" uncertainty scenario: 3 TeV (AV) and 900 GeV (PS)

New heavy bosons: Z'→ttbar

- Projections are performed for two signal models:
  - Narrow Z' signal hypothesis: width of the resonance is set to 1% of the resonance mass
  - Randall-Sundrum Kaluza- Klein gluon resonance where the resonance width is 16% of the resonance mass.
- CMS published Z'→tt in two channels l+jets (B2G-15-002), all-hadronic (B2G-15-003)
- Projections for HL-LHC are performed using two scenarios
  - S1: Same systematic uncertainties @13 TeV
  - S2: Remove all systematic uncertainties, only stat considered
  - The realistic case should be in between since reduction in systematic uncertainties is expected
    - QCD multijet background is derived from data and scales with L, ttbar cross section, jet energy scale and resolution, lepton ID efficiencies

CMS FTR 16-005
Full simulation ongoing





Exclusions projections at 95% C.L.
S1:expectation is to exclude the narrow Z' model up to 3.3 TeV, and the RS KK Gluon model up to 4 TeV.
S2:signal models are excluded to well beyond the 4 TeV limit of this analysis.

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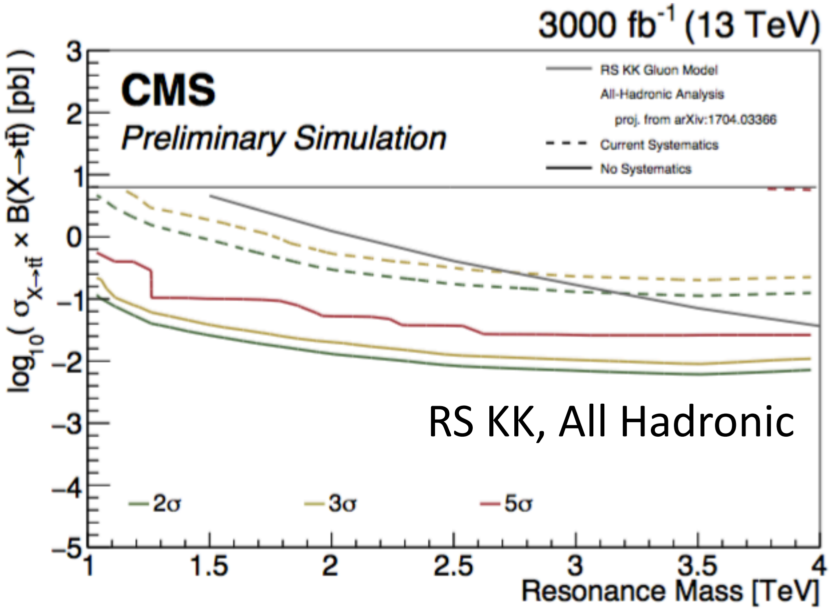

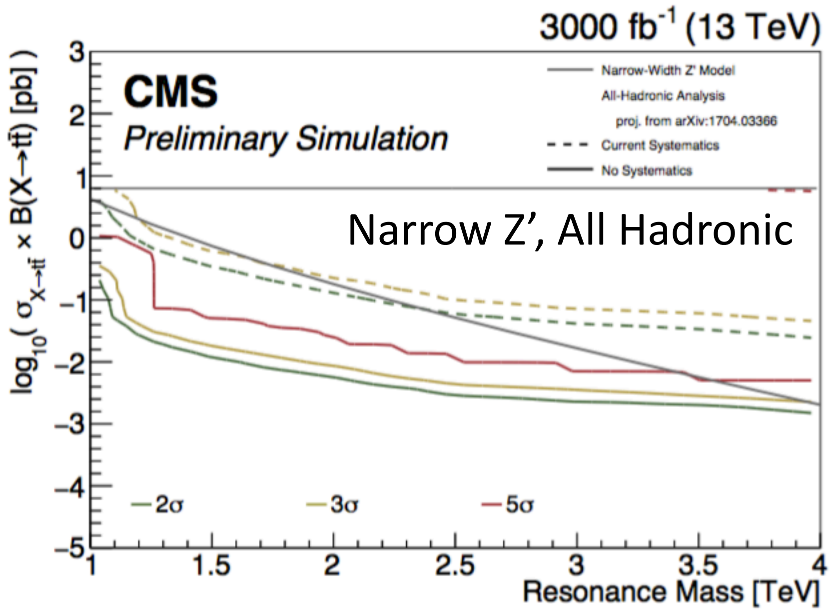

Discovery sensitivities in the possible presence of a new physics signal estimated by using toy datasets with different amounts of injected signal. The p-values are used to compute expected significances, reported as the number of standard deviations.