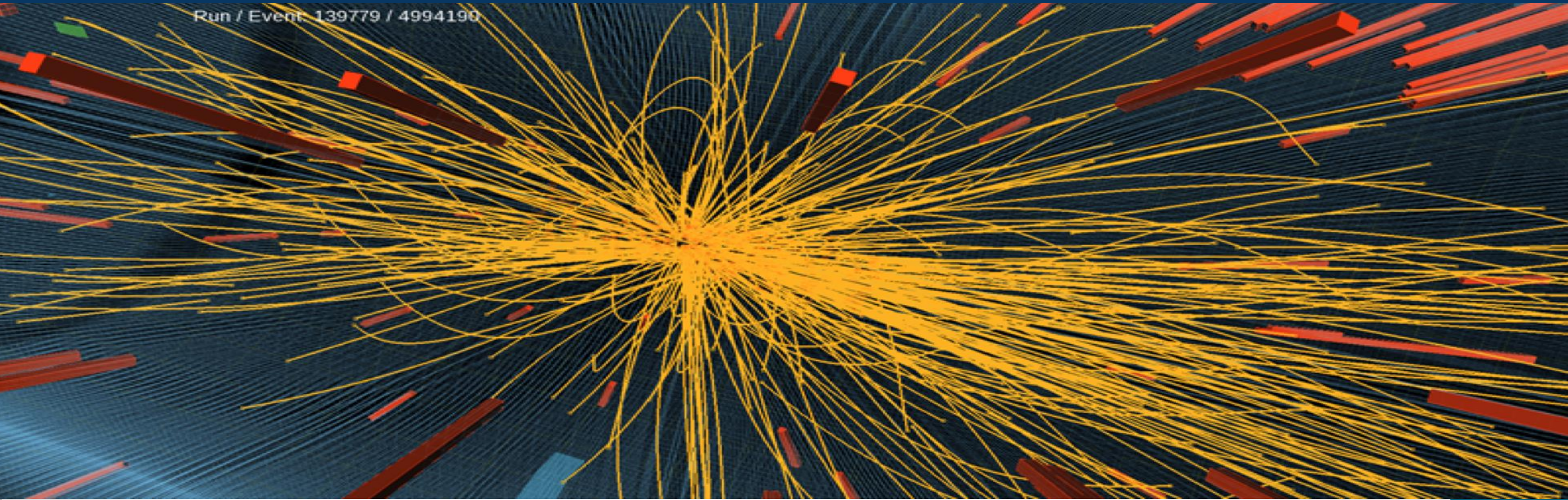
Searches for Heavy Resonances in Fermionic Final States at HL

Summary of existing ATLAS & CMS results for yellow-report-kickoff meeting

Kerstin Hoepfner (RWTH Aachen)

on behalf of the ATLAS and CMS collaborations

HLHE-LHC2017: Workshop on the physics of HL-LHC, and perspectives at HE-LHC, 30 Oct-1 Nov 2017, CERN



Analysis Techniques

ATLAS

- Generate truth-only 14 TeV event
- Overlay with jets (full sim) from pileup library, <PU> = 140 or 200
- Reconstruct particles from truth+overlay
- Smear their energy and p_T using **appropriate smearing functions,** incl. Eff for genuine objects and rates from mis-identified objects.

CMS (two types, projections and full analyses)

Projections from a present analysis

- Existing signal and background samples (simulated at 13 TeV) scaled to higher luminosity and sqrt(s)=14 TeV. Different uncertainty scenarios.
- Analysis steps (cuts) from present analyses.

Full analyses with parametrized detector performance

- DELPHES with up-to-date phase-2 detector performance and <PU> = 200
- Analysis steps guided by present analysis. Limited optimization for HL conditions. Cross checks with present analyses.
- Dedicated simulation of signal and bkgr samples

ATLAS Dijet (bump hunt)

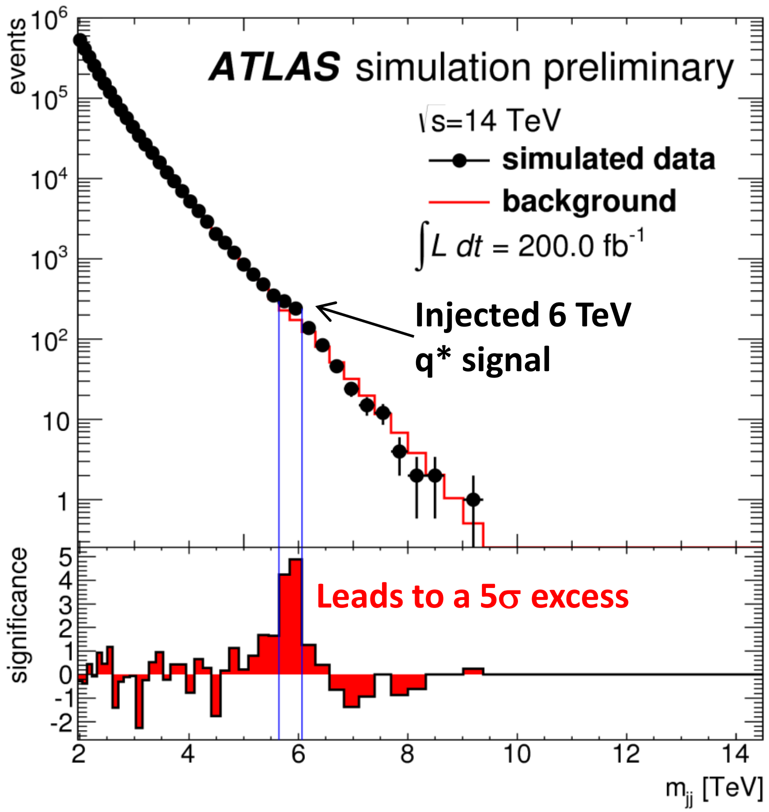
Powerful search technique for new physics, **model-independent** as long as a sharp resonance. Many interpretations possible.

Bump-hunter algorithm

- Discriminating variable = m(jj)
- Simulated bkgr = QCD (PYTHIA 8). No beam bkgr or detector bkgr. Fit bkgr shape with a smooth 4P-function, normally done to „data“
- No significant PU dependence, used <80>.

- Jets are smeared according to projected Phase-2 performance. Reconstructed with anti-kT, R=0.4

- Bump hunter scans all m(jj) bins with variable window size. Searching for bin with largest deviation from bkgr fit. Signals injected.



ATL-PHYS-PUB-2015-004

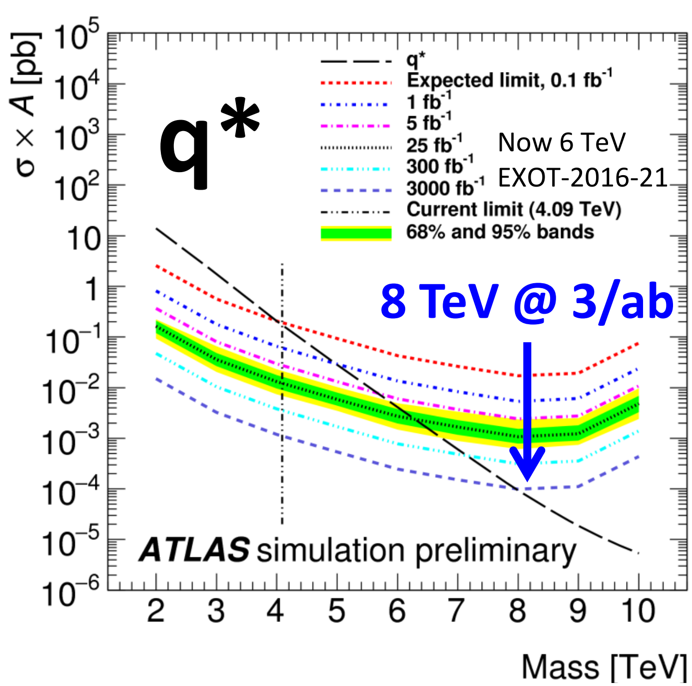
ATLAS Dijet (bump hunt)

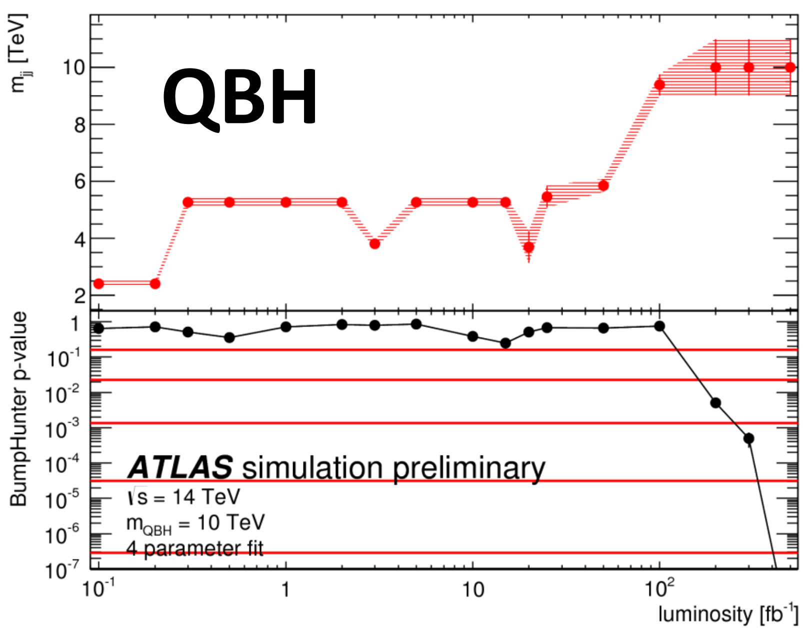
Reach for excited quarks (q*) and quantum black holes (QBH)

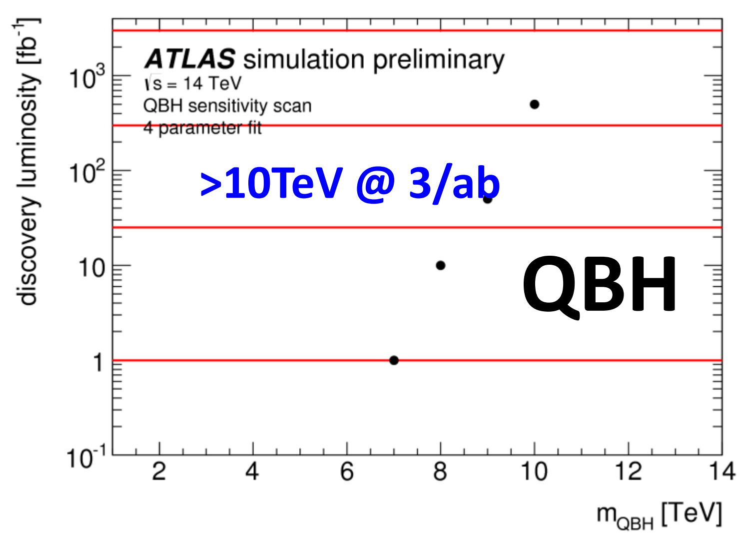
Possible NP signals simulated and injected

- **q*** → qV (V=g in 83% of the cases) with c=1
  PYTHIA 8, m(q*)= 2 – 13 TeV

- **QBH → jj** (BlackMax)
  Planck scale M_D = threshold mass for BH
  ADD model with 6 ED





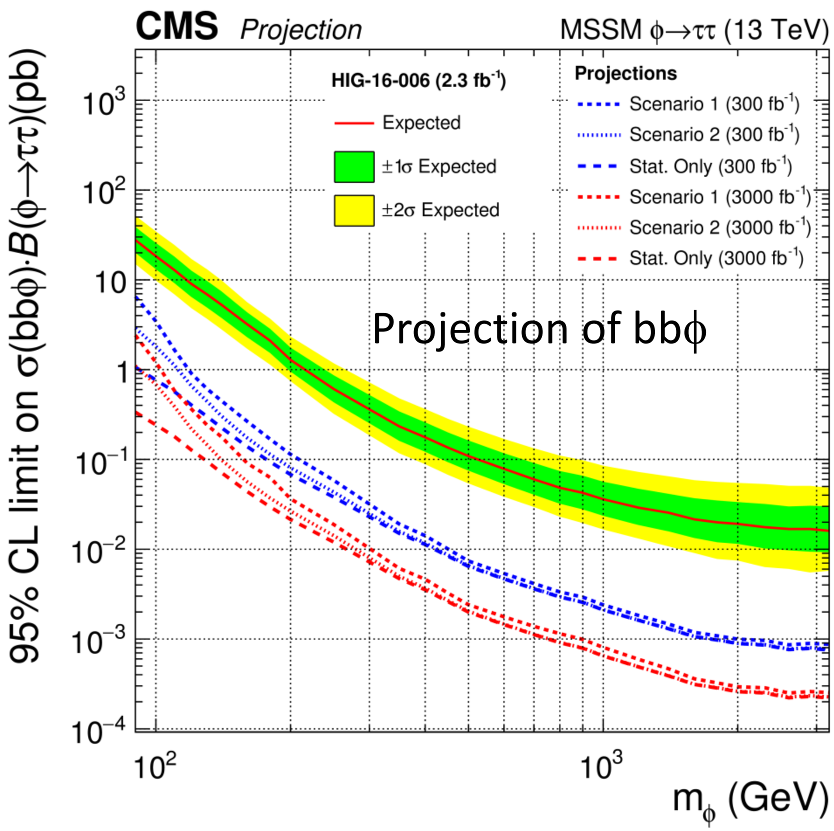


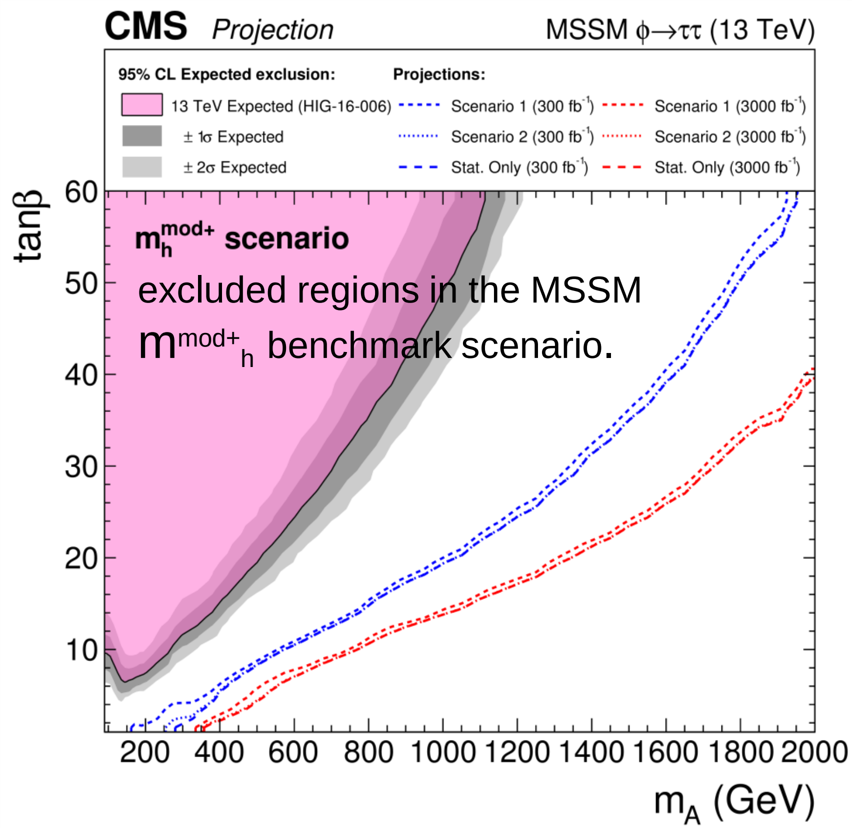
ATL-PHYS-PUB-2015-004

MSSM $\phi \rightarrow \tau\tau$

H->ttbar (including interference) is an important channel for next year.

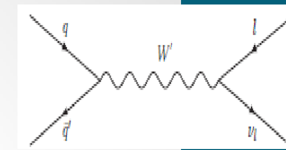
- MSSM ϕ (=h, H, A) from ggϕ and bbϕ production with decays $\tau\tau \rightarrow \mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$. Discriminating variable $M(\tau\tau)$
- Di-tau channel most sensitive direct search for additional Higgs'es
- Projection to 3000/fb based on 2015 result with 2.3/fb with two interpretations





Based on CMS-PAS-HIG-16-006
Projection in CMS-PAS-FTR-16-002

W´ Projected Discovery Reach

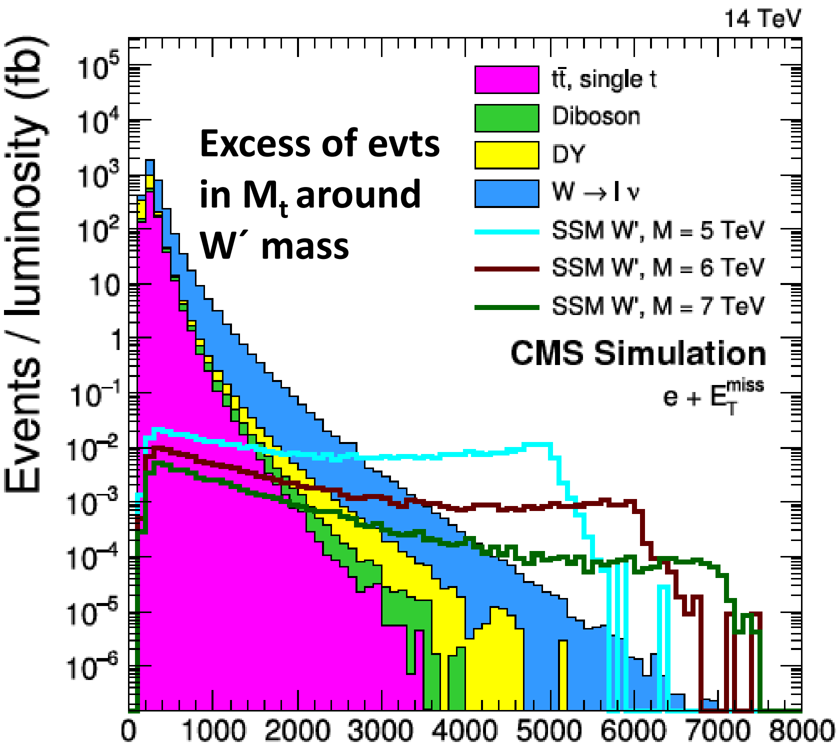


Benchmark analysis with max discovery sensitivity. DELPHES analysis.

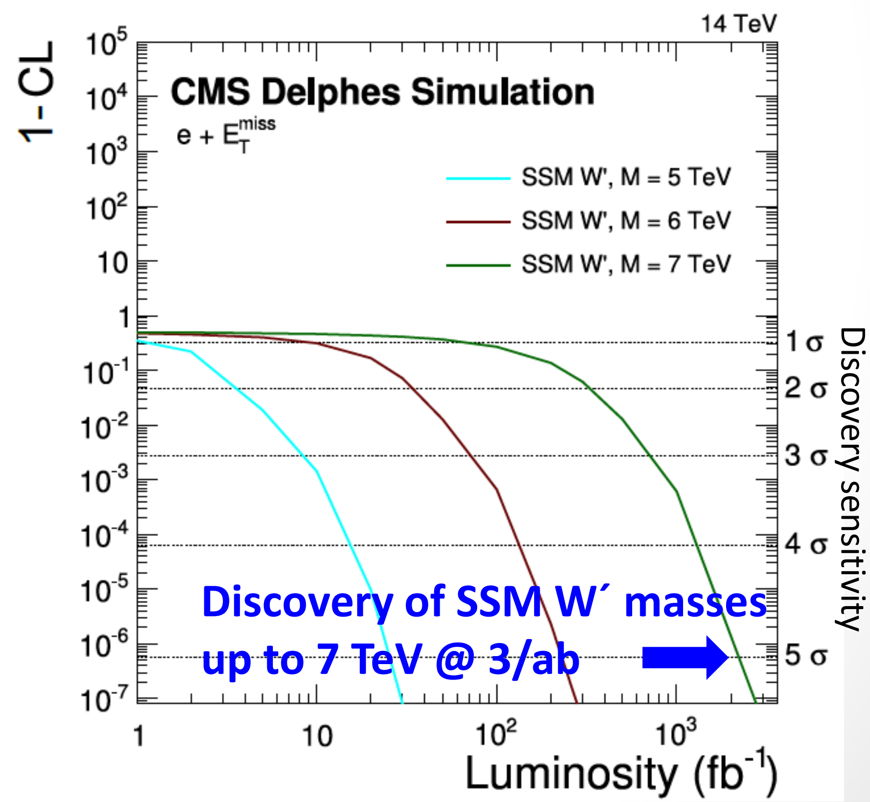
W´→eν Electron channel with good **resolution at very high mass** and rather constant resolution. Discriminating variable = M_t from (e, MET)

Key: understand the M_t tail and performance of high p_T leptons.

Assume systematics from run-2.



$$M_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos[\Delta\phi(\vec{p}_T^{\,l}, \vec{p}_T^{\,miss})]}$$

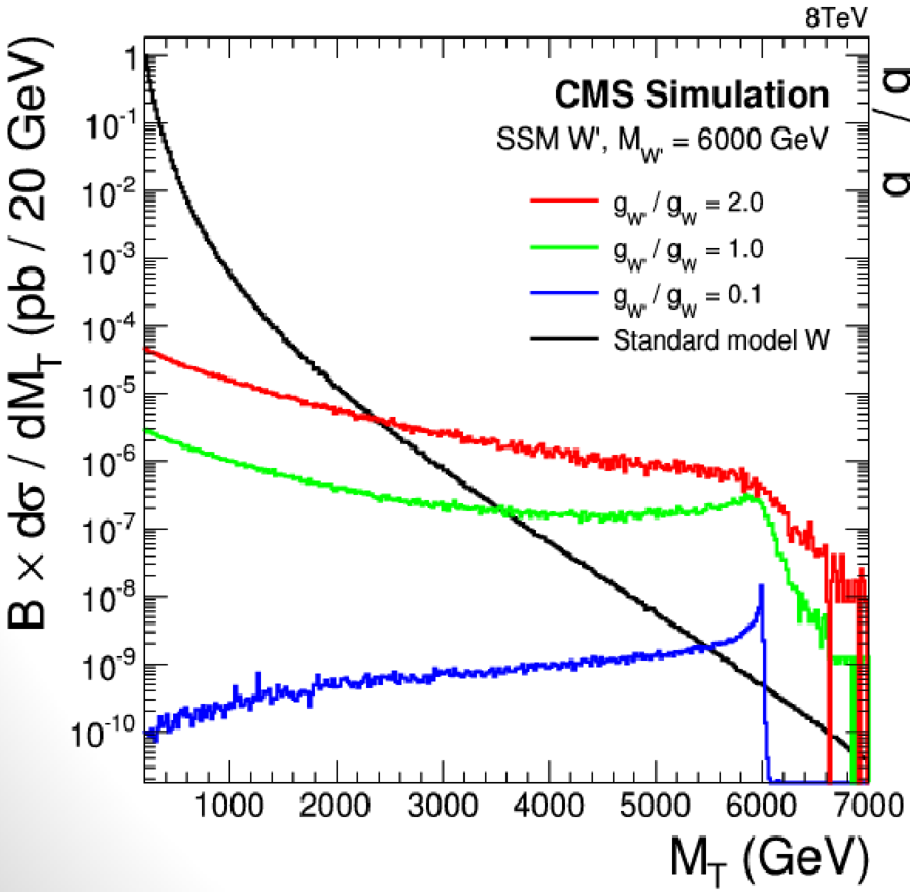


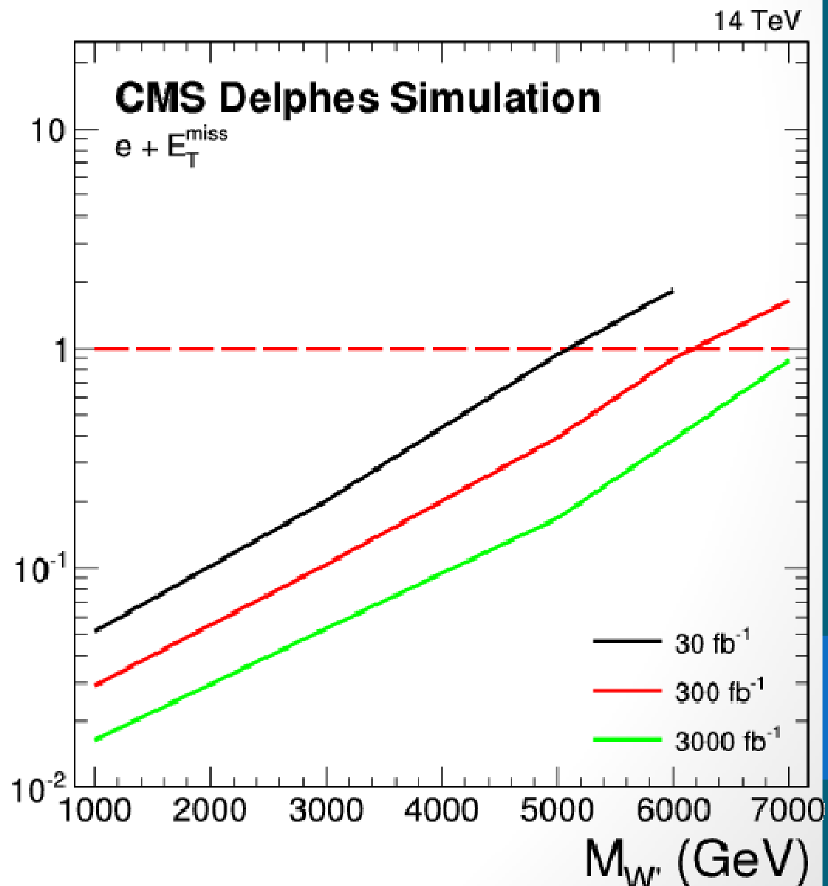
CMS-PAS-EXO-14-007

Study Weak Couplings

Weaker couplings is a domain of high luminosity. Example of W´ shown here, would work equally well for other models.

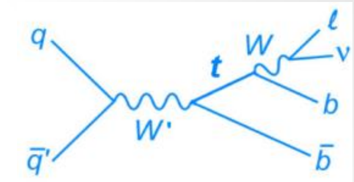
Coupling strength impacts widths, reweighted at GEN level. Detector performance from DELPHES (TP performance)





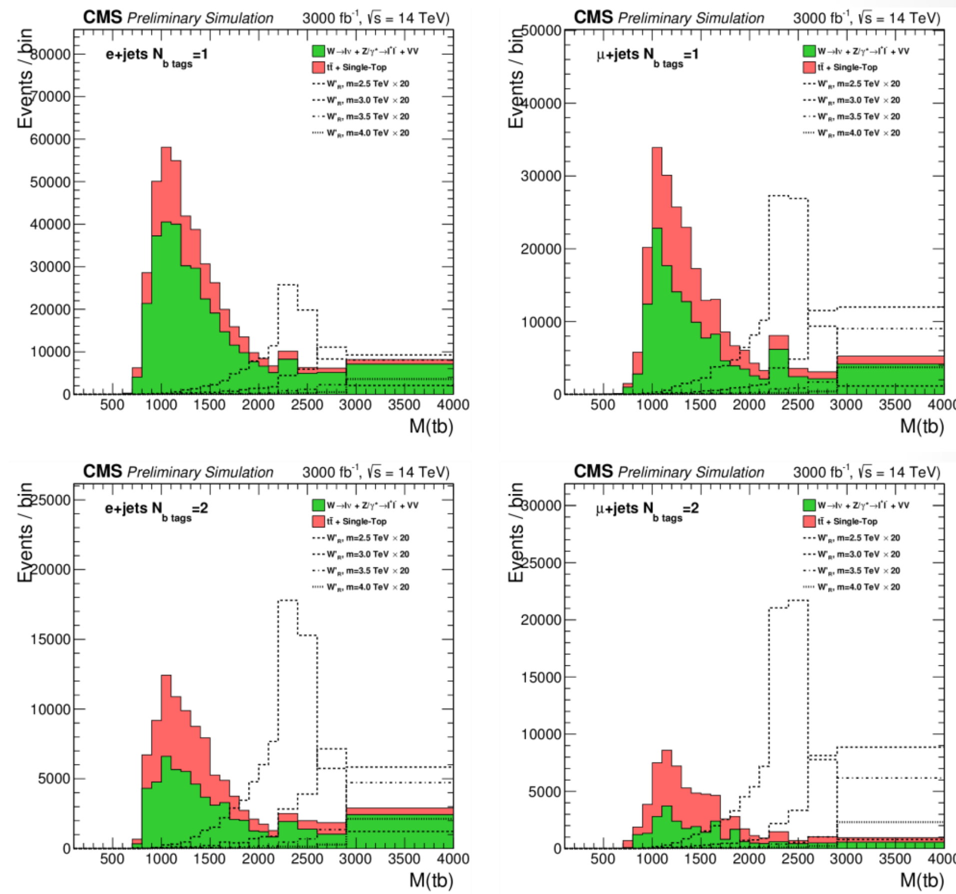
CMS-PAS-EXO-14-007

CMS W′→tb



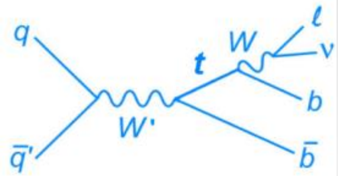
Probe scenarios such $m(\nu_R) > m(W')$ → forbidden for W′→lν

- Projection from 12.9/fb
- Four search categories in leptonic decays: e/mu plus 1 or 2 bjets
  - Use standard lepton IDs
  - Jets are reconstructed with anti-kT, R=0.4, $|\eta|<2.4$
  - B-tagging eff = 80% with 10% mistagging probability
- Discriminating variable M(tb)
- Trigger threshold O(1 TeV)



Baseline analysis tb at 13 TeV B2G-15-004, B2G-16-017.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

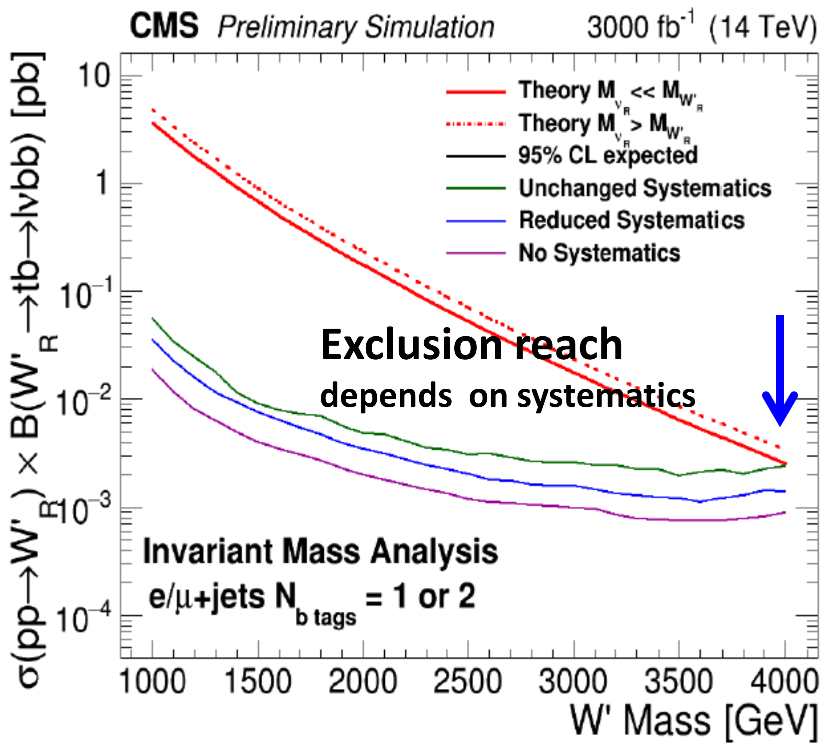
W′→tb Impact of Systematics

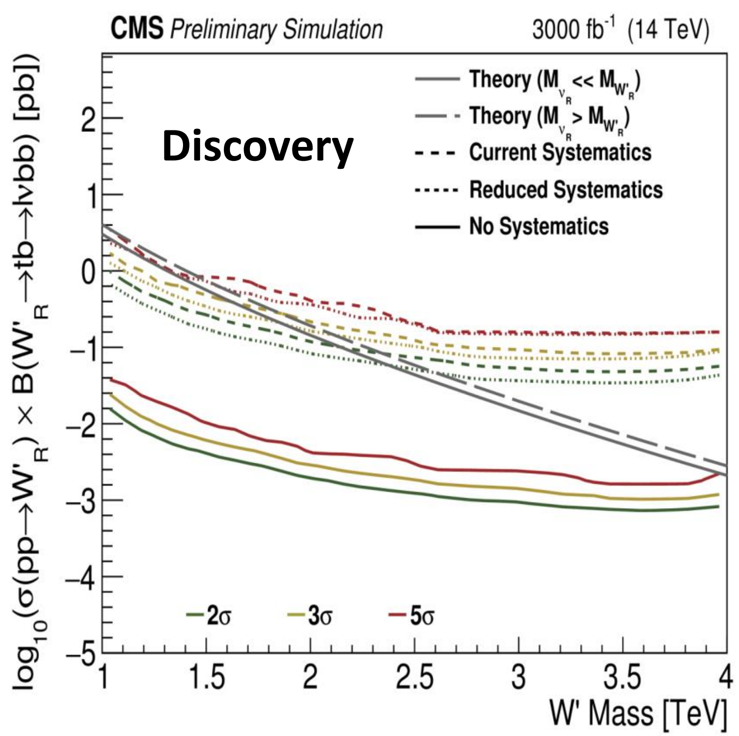


Three scenarios to extrapolate systematics from 12.9/fb to 3/ab

1) Leave **systematics unchanged**, simply scale templates with lumi
2) **Reduce** most experimental to percent level, theoretical uncertainties by factor 2, top p_T reweighting by factor 3
3) No systematics (best possible limit)

→Impact on projected exclusion limit: 4(4.4) TeV for case 1(3)





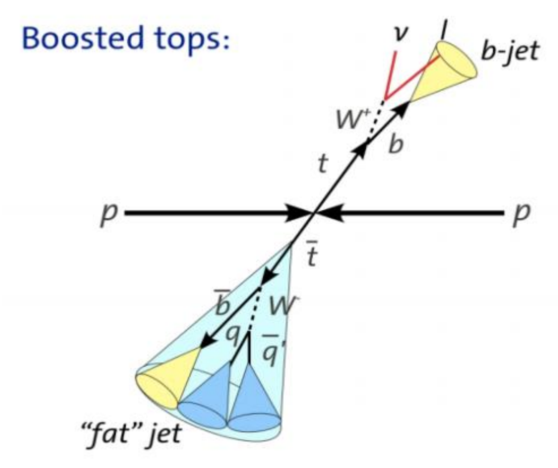
Baseline analysis tb at 13 TeV B2G-15-004, B2G-16-017.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

CMS Z′→tt Projection from 2.6/fb to 3/ab

Z′→ttbar studied in two dinstinct channels distinguished by decay of W (from t→Wb)

- Semileptonic (l + b-jet + jet + MET)
- All-hadronic channel (jets)

12 orthogonal categories



Pure projection

- Scale existing run-2 signal and bkgr expectations to 14 TeV and 3000/fb
- Discriminating variable = m(tt)

Two scenarios of systematic uncertainties:

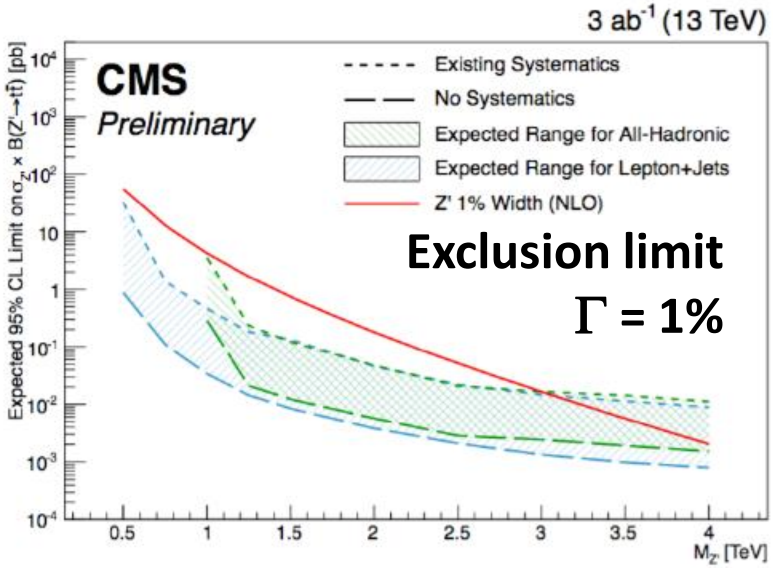
- Current Run-2 baseline analysis without scaling of uncertainties
  - E.g. Non-top multijet bkgr (dominant bkgr in all-hadronic) derived from data, should improve with L
  - Uncertainties on ttbar simulation (10-20%). Uncert. on other xsec's will improve.
  - JES, resolution and lepton ID efficiencies should improve
- Without any systematics, include only statistical uncertainties = best case

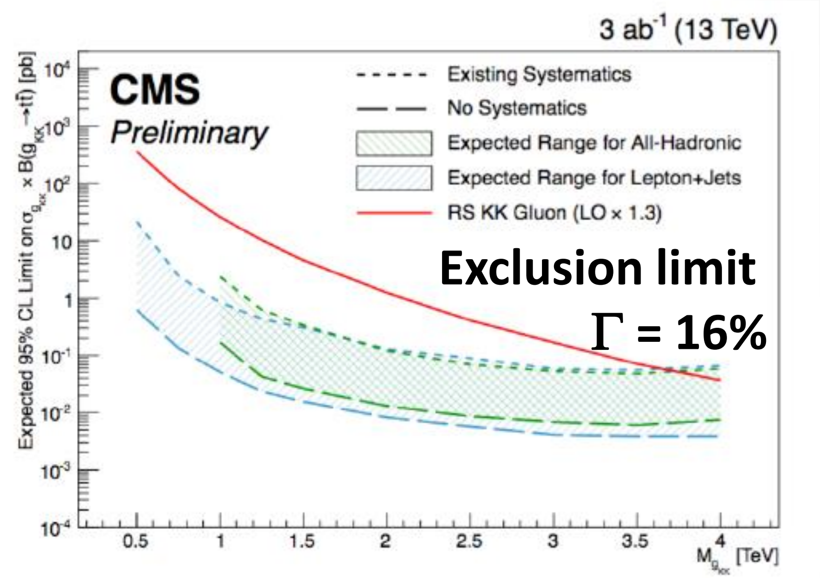
Baseline analyses at 13 TeV B2G-15-002, B2G-15-003.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

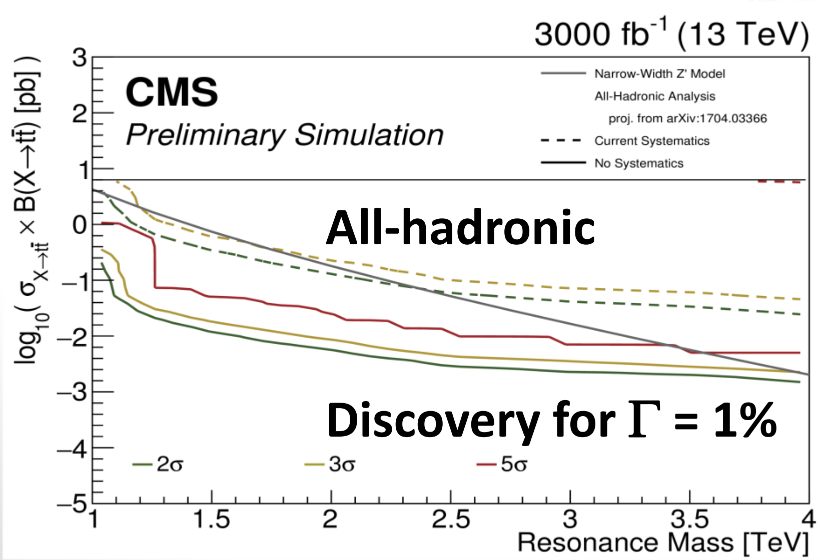
Z′→tt Projected Sensitivity

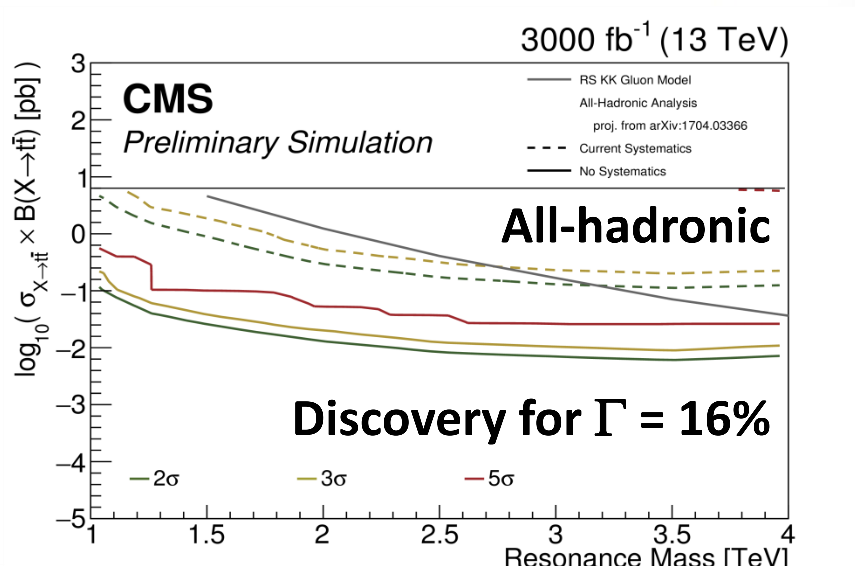
Two signal models: Narrow resonance (Z′) with 1% width

RS KK gluon resonance with width ~16% of mass







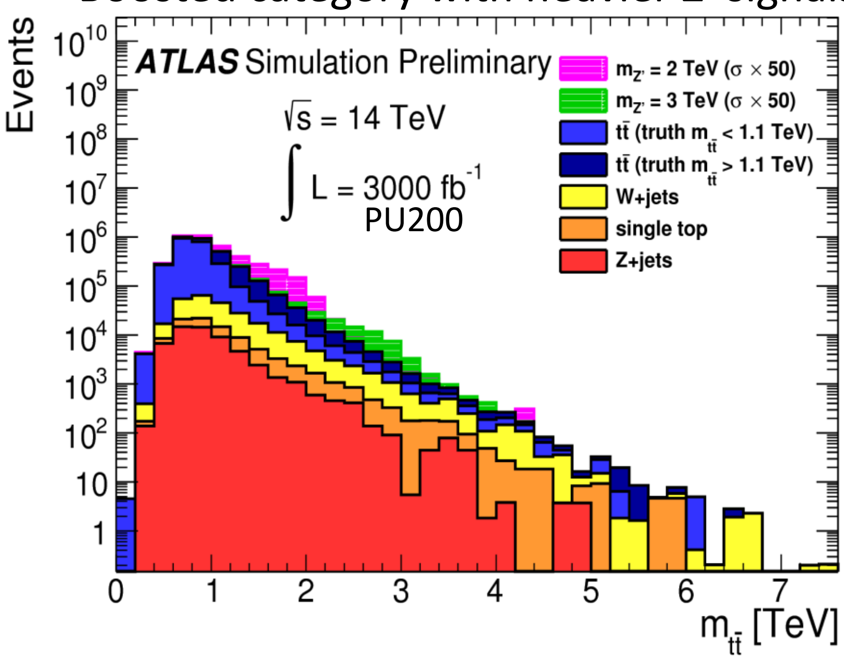


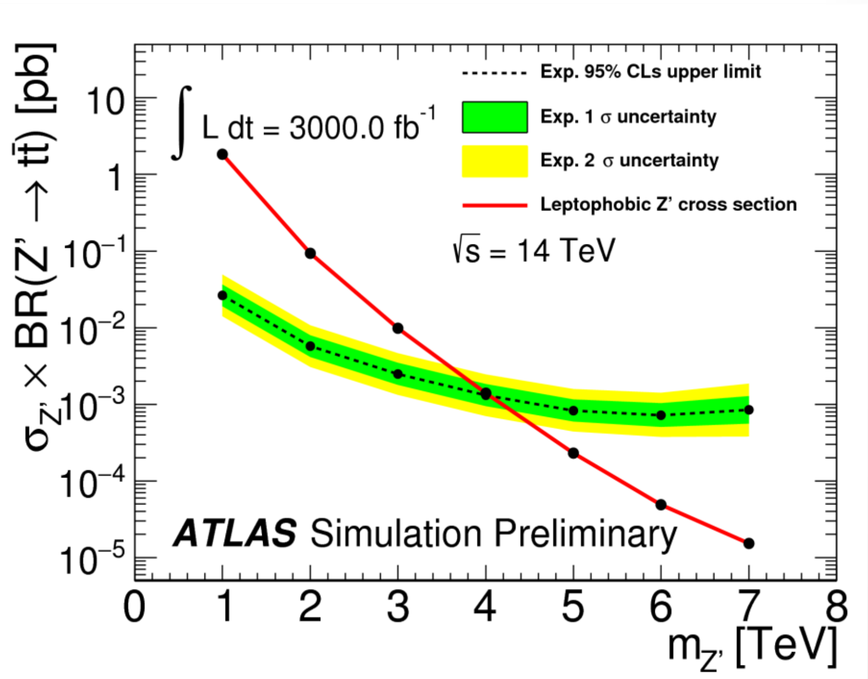
Baseline analyses at 13 TeV B2G-15-002, B2G-15-003.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

ATLAS Z′→tt→WbWb→lνbqqb

- Selection steps derived from run-2, simplified. Discriminating variable = m(tt)
- Two categories: resolved and boosted , l = e, μ
- Signal model: topcolor model with spin-1 Z′ boson, width 1.2%. PYTHIA 8. LO xsec * 1.3 (k-factor), Interference signal-bkgr neglected.
- Backgrounds simulated to NNLO

Boosted category with heavier Z' signals



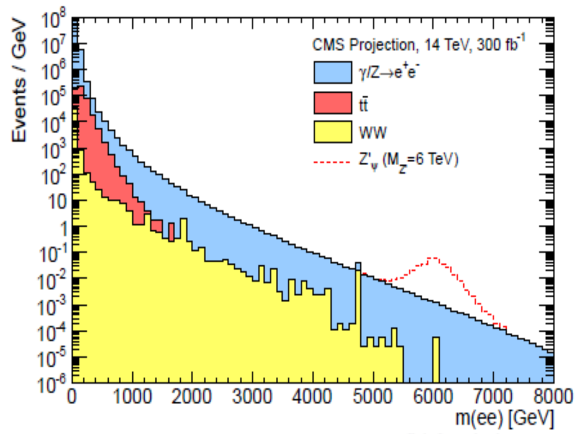


Detector effects: parametrized performance estimate of Phase-2 Det

Gain from HL: 3 TeV (300/fb) → 4 TeV (3000/fb)

What if we discovered something in Phase-I ?

Example of Z´→ ee

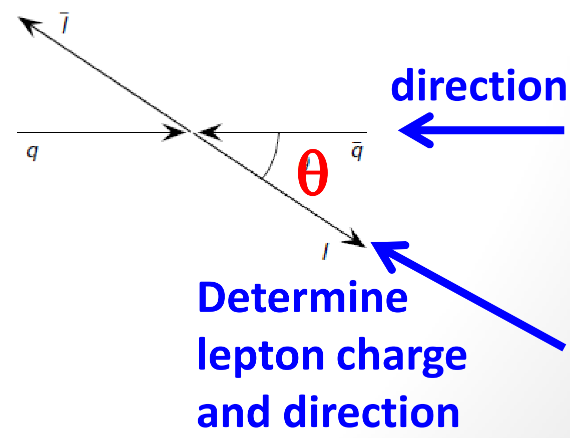


Case-1: assume a hint of a signal has been seen at the end of Phase-I and its properties are studied in Phase-II.

E.g. spin or production mode, A_{FB}

Case-2: model-independent search for a deviation of the A_{FB} asymmetry in the high-mass

$$A_{FB} = \frac{\sigma_{\theta<\pi/2} - \sigma_{\theta>\pi/2}}{\sigma_{\theta<\pi/2} + \sigma_{\theta>\pi/2}}$$



DY AFB = + 0.6

BSM AFB might be anything between -0.75… +0.75,

e.g. Z´_SSM AFB ≈ 0.08, Z´_I ≈ - 0.75

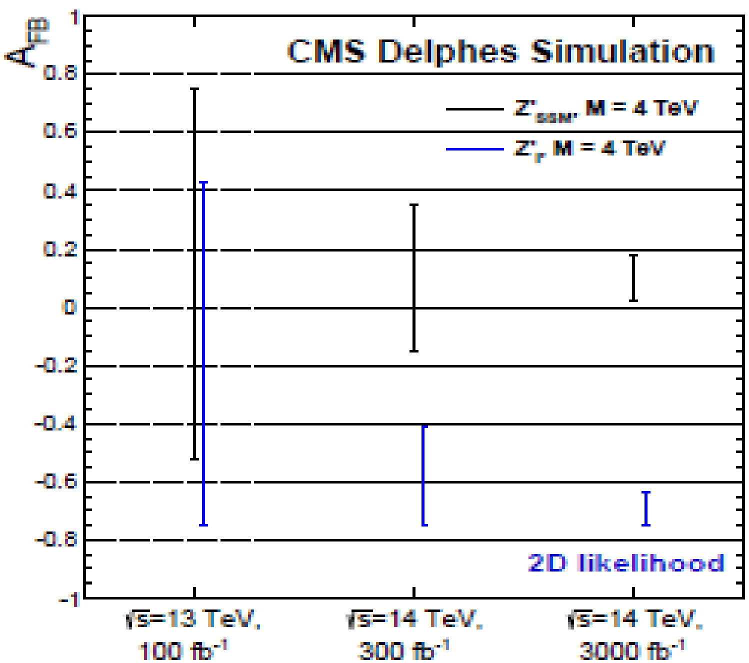
Used fullsim samples with knowledge of ~2013 (no HGCAL yet) and tuned electron ID.

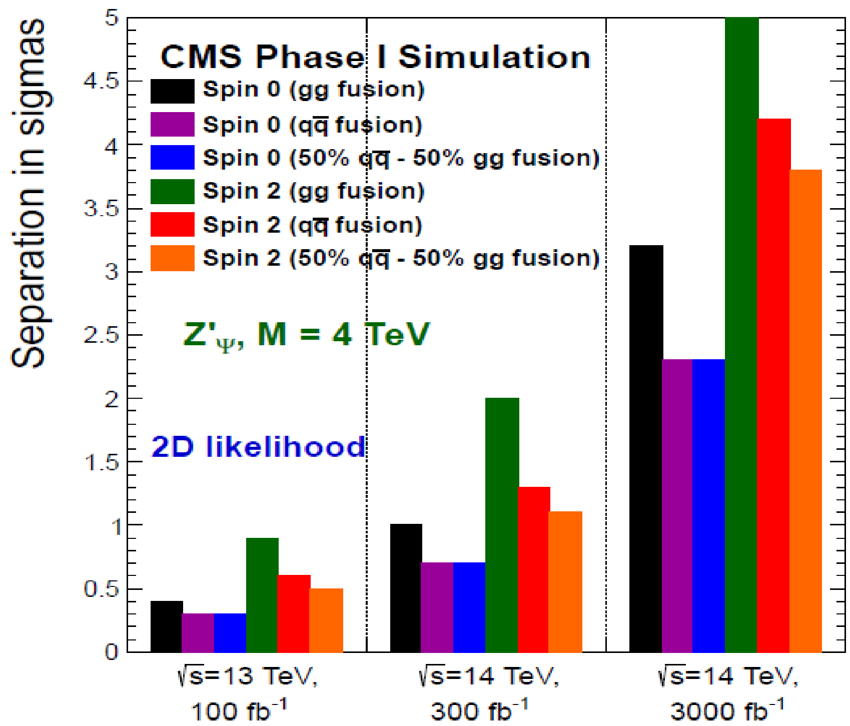
CMS-PAS-EXO-14-007 and TP

Property Measurements

New heavy spin-1 resonance. Little theoretical constraints on A_{FB} value → any value between -0.75 and +0.75. Experimentally determine lepton charge and direction of incoming quark.

Characteristic Property	Benchmark Model
Spin	Z'_ψ, G_{RS}
A_{FB}	Z'_{SSM}, Z'_ψ
Production mode	G_{RS}





	A_{FB} up quarks	A_{FB} down quarks	A_{FB} $\sqrt{s} = 13$ TeV pp collisions
Z'_Ψ	0	0	0
Z'_I	(no coupling)	-0.75	-0.75
Z'_{SSM}	0.075	0.105	0.08

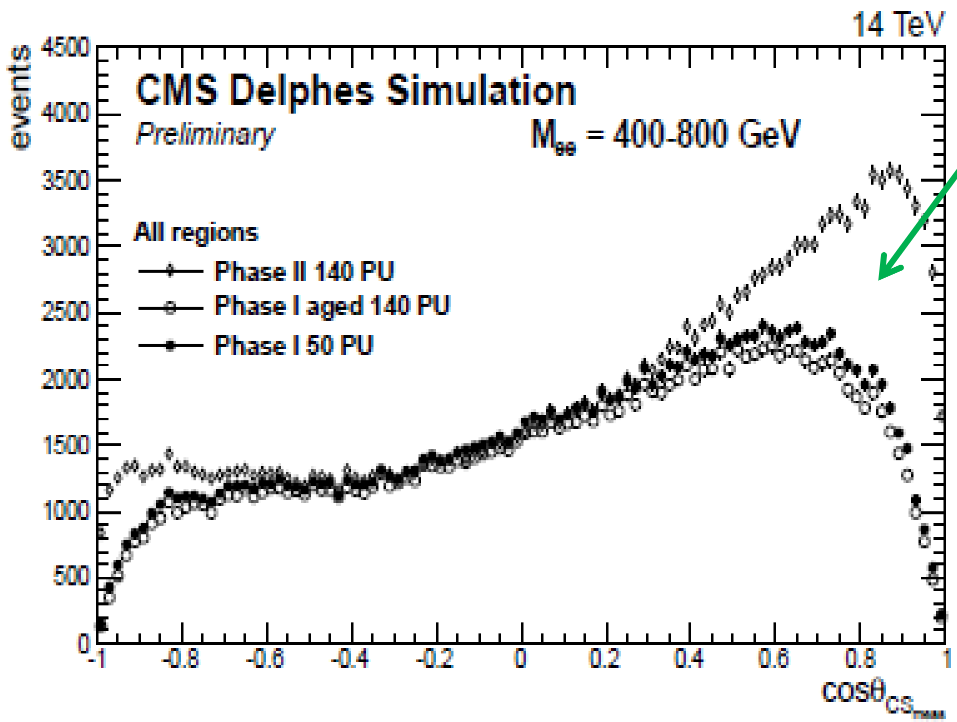
Measure cosθ. Its shape depends on production mode (gg, qq) and spin (0,1,2). CLs test of hypotheses.

Right: ECFA 2014 additional material.
Left: CMS-PAS-EXO-14-007 and TP

Model-Independent Search for New Physics Using DY A_{FB}

Concept: Measure DY A_{FB} with high precision. Search for deviation from new physics. At low masses high SM bkgr, at high masses nearly bkgr free.

Expect A_{FB} to be affected by performance of forward regions, maximum sensitivity for events cosθ ≈ ±1. With phase-2 detector extended coverage and improved performance in forward.



Gain in Phase-II from extended acceptance

For low masses, M(ee) < 500 GeV, about 5% of events recovered with upgraded tracker → **very important forward region!**

A_{FB} uncertainty reduced by ≈ 40% at 500 GeV and by ≈ 15% at 2 TeV, based on recovered events (plot in backup).

Some Thoughts on High Energy

- High energy will be VERY beneficial for new physics, significantly increased reach for new & heavy particles. Much more than HL.
- Not yet many projections of BSM studies.

- Likely needs new detectors, as ours will be too old by then.
- Detector performance has to be considered. E.g. expected mass range would yield leptons (e, mu) where saturation effects come into effect.
  - Electron energy saturation (for CMS in the ballpark O(2-3 TeV)
  - Muon momentum measurement becomes difficult for p_T>>2 TeV (bending too small with present magnetic field)

Summary

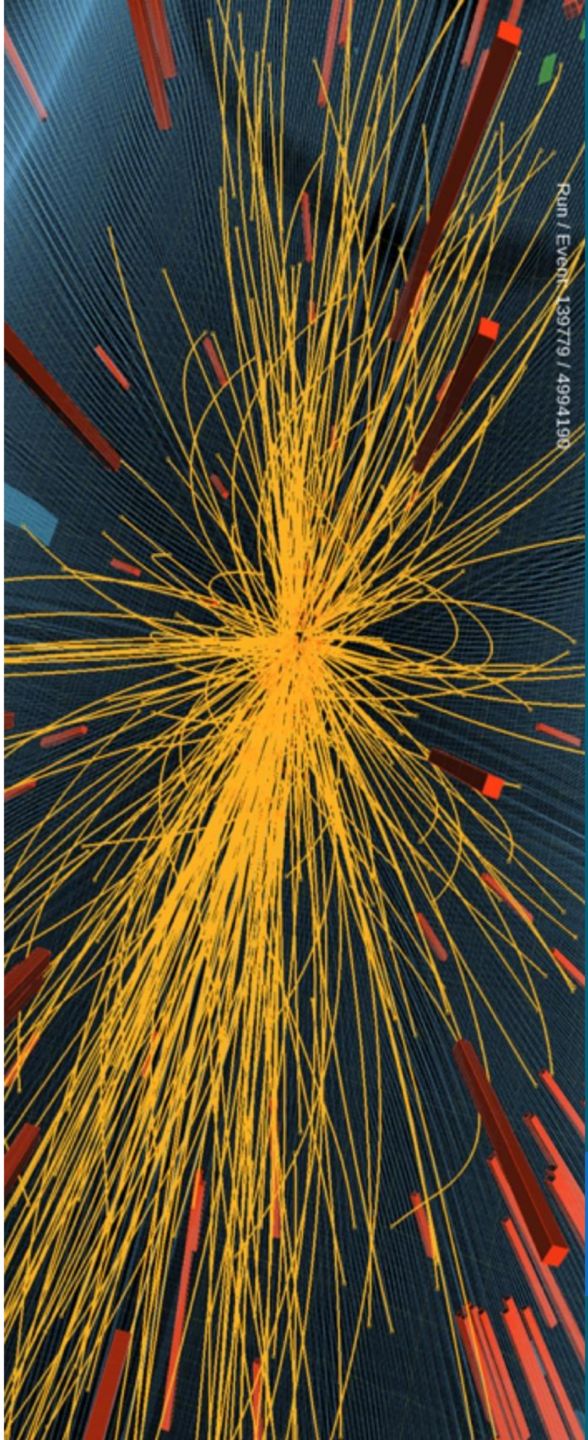
Rich BSM potential at HL-LHC. Looking forward to another discovery.

Poked just here and there. Many more potential studies which would be interesting.

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.

Reducing systematic uncertainties impacts sensitivity.

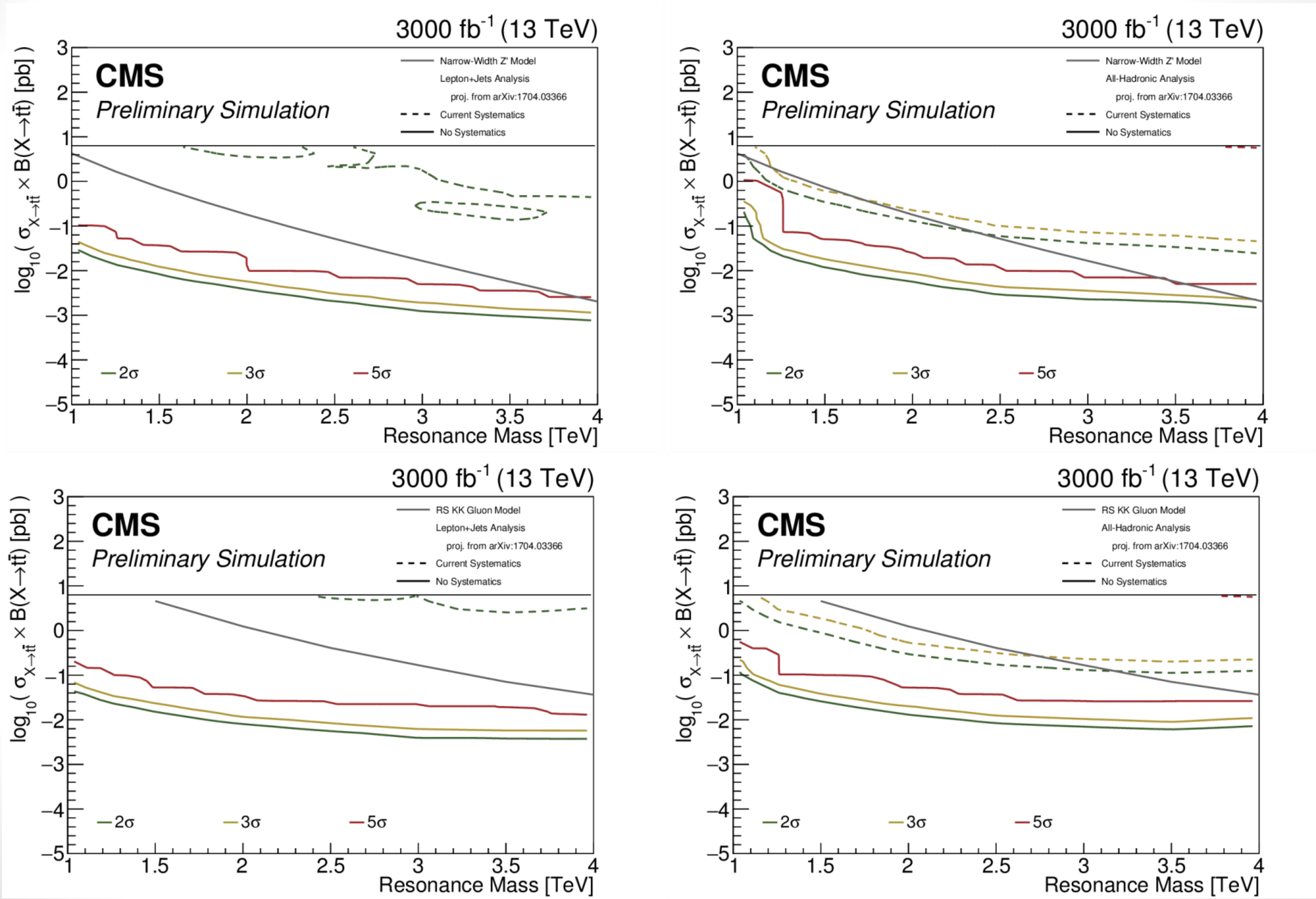


References

- [ATL-PHYS-PUB-2017-002] Study on the prospects of a $t\bar{t}$ resonance search in events with one lepton at a High Luminosity LHC
- [ATL-PHYS-PUB-2015-004] Dijet resonance searches with the ATLAS detector at 14 TeV LHC

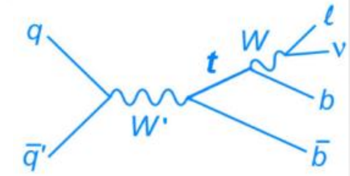
- [CMS-PAS-EXO-14-007] Enhanced scope of a Phase 2 CMS detector for the study of exotic signatures at the HL-LHC
- [CMS-PAS-FTR-16-002] Projected performance of Higgs analyses at the HL-LHC for ECFA 2016
- [CMS-PAS-FTR-16-005] Estimated Sensitivity for New Particle Searches at the HL-LHC
- Additional material for ECFA 2014

CMS Z′→tt Discovery Sensitivity



Baseline analyses at 13 TeV B2G-15-002, B2G-15-003.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

W′→tb Impact of Systematics

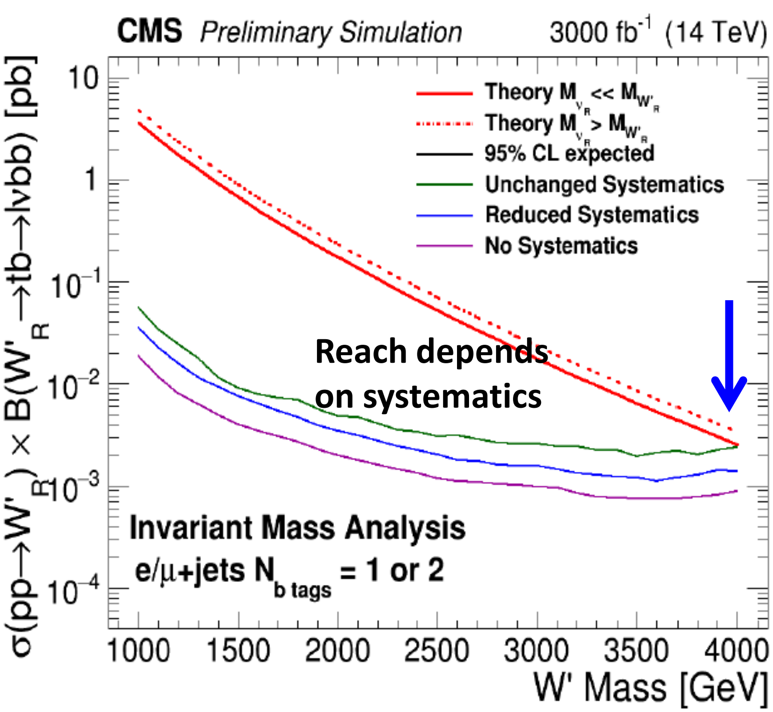


Three scenarios to extrapolate systematics from 12.9/fb to 3/ab

1) Leave **systematics unchanged**, simply scale templates with lumi
2) **Reduce** most experimental to percent level, theoretical uncertainties by factor 2, top p_T reweighting by factor 3
3) No systematics (best possible limit)

→Impact on projected exclusion limit: 4(4.4) TeV for case 1(3)

Source	Rate Uncertainty (Flat)	Rate Uncertainty (Scaled)
Luminosity	6.2%	1.5%
Trigger Efficiency (e/μ)	2%/5%	1%/1%
Lepton ID Efficiency (e/μ)	5%/2%	1%/1%
Jet Energy Scale	3.8%	1%
Jet Energy Resolution	1%	0.07%
b/c-tagging	2.7%	1%
light quark mis-tagging	1.2%	1.2%
W+jets Heavy Flavor Fraction	2.3%	1.1%
Top p_T Reweighting	18%	6%
Pileup	1.3%	0.09%
PDF	6.1%	3%
Matrix element Q^2 scale	18.9%	9.5%
$t\bar{t}$ Parton matching Q^2 scale	1.7%	0.9%
Top cross section	15%	7.5%
Bosonic cross section	10%	5%



Theoretical uncertainties comparable to experimental

Exclusion limit m(W′) >4 TeV @3/ab

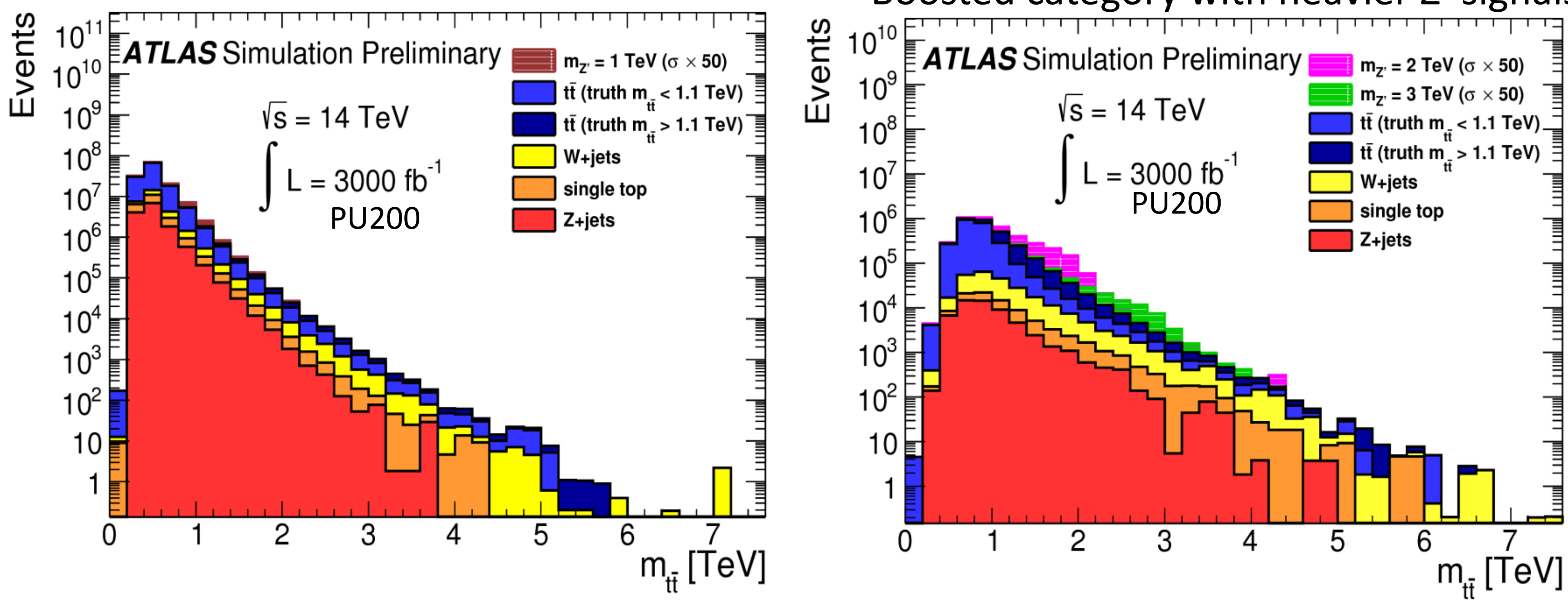
Baseline analysis tb at 13 TeV B2G-15-004, B2G-16-017.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

ATLAS Z′→tt→WbWb→lvbqqb

- Selection steps derived from run-2, simplified. Discriminating variable = m(tt)
- Two categories: resolved and boosted
- Backgrounds simulated to NNLO

Resolved category with 1 TeV Z‘ signal

Boosted category with heavier Z‘ signals



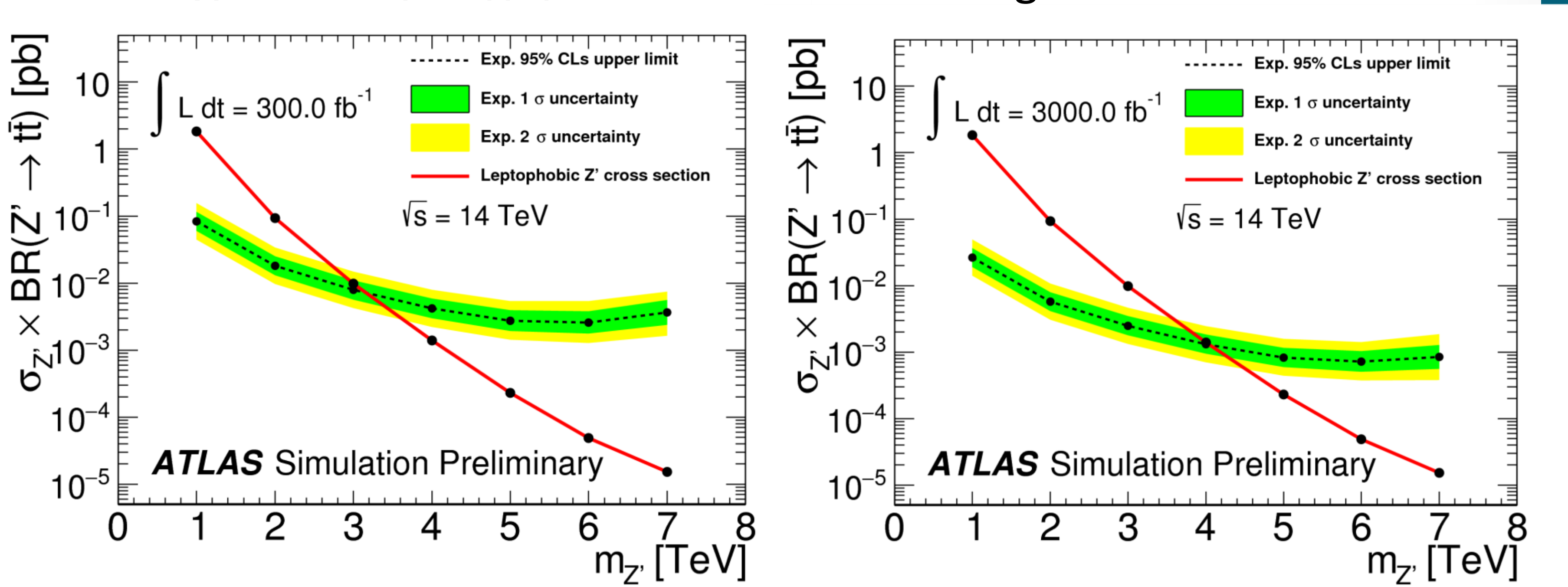
- Detector effects: parametrized performance estimate of Phase-2 Det

ATLAS Z′→tt

Signal model: topcolor model with spin-1 Z′ boson, width 1.2%.

PYTHIA 8. LO xsec * 1.3 (k-factor), Interference signal-bkgr neglected.

For limits: LLH function based on binned ttbar mass spectrum with two hypothesis (s+b)(b). For each simulated signal mass.



Gain from HL: 3 TeV (300/fb) → 4 TeV (3000/fb)

Same upgraded detector and PU for 300/fb and 3000/fb.

Property Measurements – Tools and Methods

- Fullsim samples with knowledge of ~2013 (no HGCAL yet)
- For phase-2 tuned the high-E_T electron ID to an efficiency comparable to run-1 with fake rate below 2x run-1 fake rate → reduced electron efficiency, especially in endcaps
  - Extended acceptance increases forward sensitivity
  - Charge-misID in forward regions would suffer from aging while opposite charge is required for AFB study

- Consider different models (all with sharp resonance) with their typical properties .
- Statistical method: CLs test between two hypothesis H1 and H0. Dice pseudo-experiments for each.

Model-Independent Search for new physics in high-mass DY tail

Concept:

- Measure DY AFB with high precision.
- Search for deviation from new physics
- At low masses high SM background. High masses nearly background free.

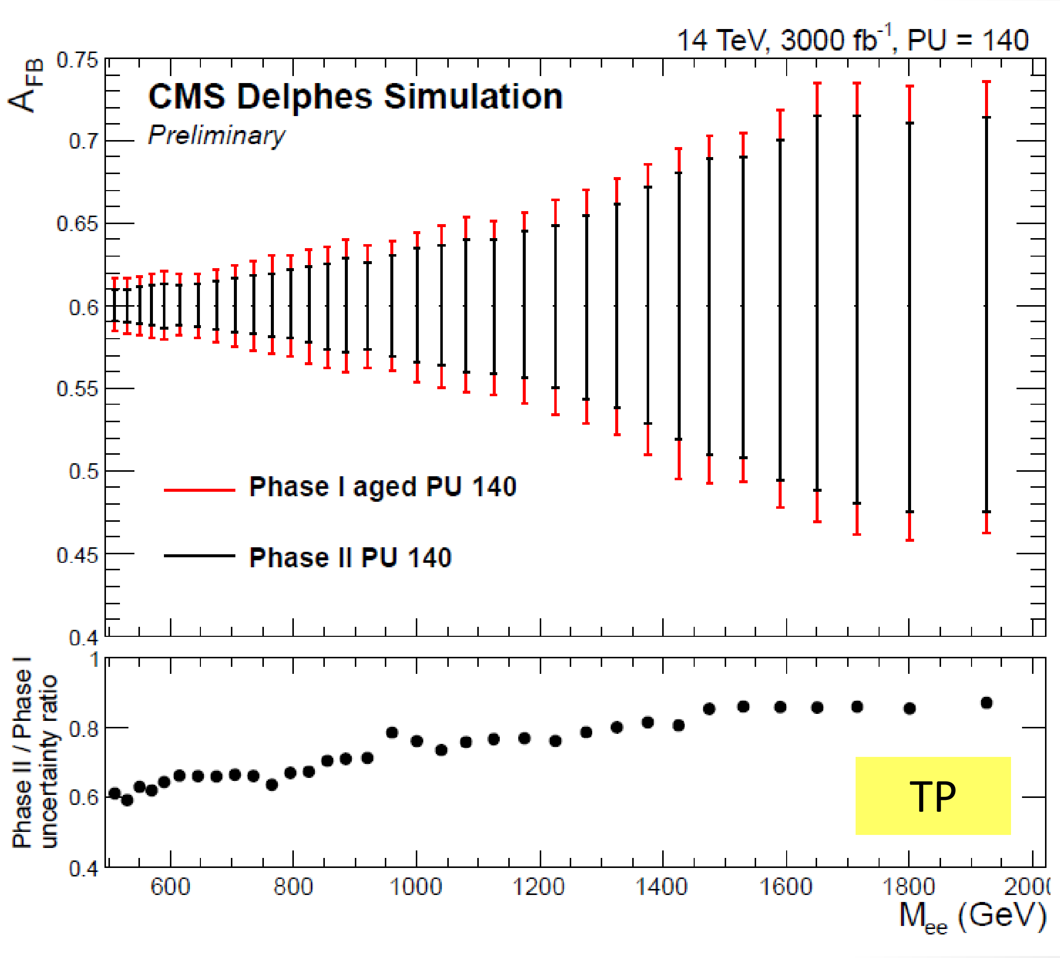
Some nubers:

DY A_{FB} = + 0.6

BSM A_{FB} might be anything between -0.75… +0.75,

e.g. Z´_SSM AFB ≈ 0.08,

Z´_I ≈ - 0.75



Large impact: AFB uncertainty reduced with phase-II geometry by ≈ 40% at 500 GeV and by ≈ 15% at 2 TeV. Based on recovered events.