Experimental searches at high p_T in view of flavour anomalies (WG3+4, ATLAS+CMS)

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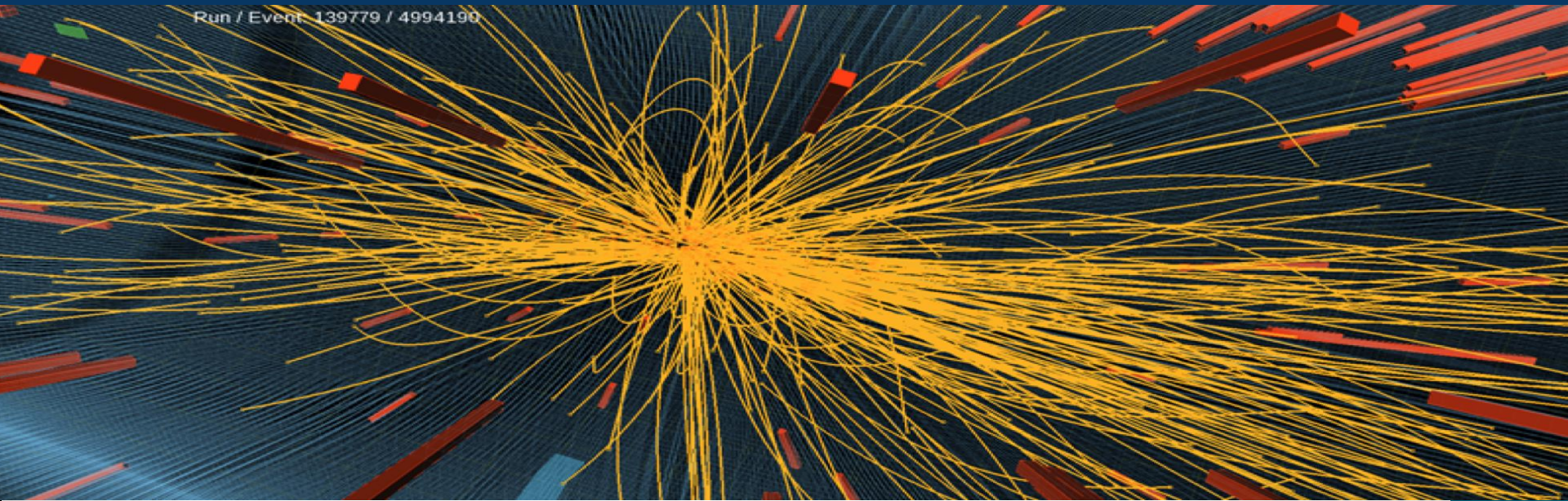
on behalf of the ATLAS and CMS collaborations

HL/HE - LHC Workshop at FNAL
April 4-6 2018



This talk

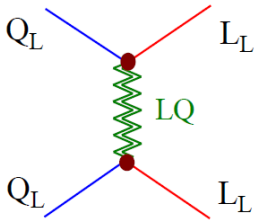
Observed anomalies in B-physics

Complementary searches in other channels

Many Run-2 searches in all final states. Some projections for HL-LHC. So far without dedicated flavor interpretations.

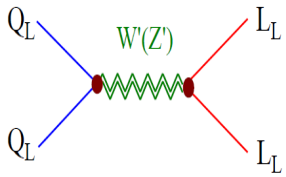
Models interpreting B-physics anomalies favor 3rd generation

→ Leptoquarks (LQ) pair and singly produced.
LQ3 -> τ + t ($\tau\tau$tt) and τ + b ($\tau\tau$bb).
At TeV singly produced might be dominant.

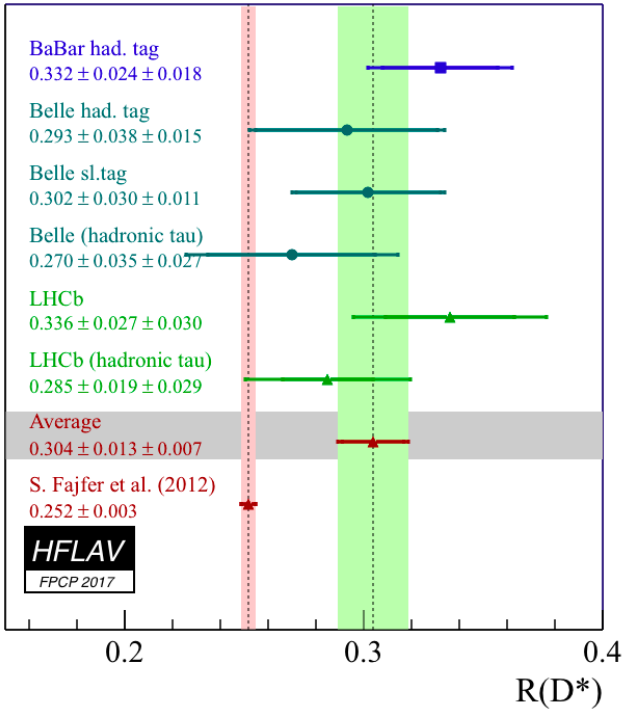


→ Z´ searches in 3rd generation Z´-> $\tau\tau$ and Z´-> tt.

→ W´ searches in 3rd generation, W´->tb and W´->$\tau\nu$



LQ and B-physics anomalies



Quark level transition $b \to c\ell\bar{\nu}$

R_D, R_{D^*}: combined $\sim 4\sigma$ deviation

$$R^{\tau/\ell}_{D^{(*)}} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell\bar{\nu})}$$

Quark level transition $b \to s\ell\bar{\ell}$

R_K, R_{K^*}: $\sim 2.5\ \sigma$ deviation (LHCb)

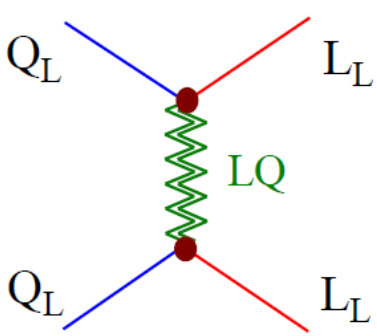
$$R_{K^{(*)}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}e^+e^-)}$$

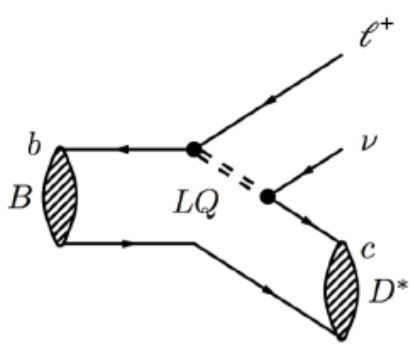
$B^0 \to K^{*0}\mu^+\mu-$ angular analysis:
3.4 σ deviation (LHCb) (Cli

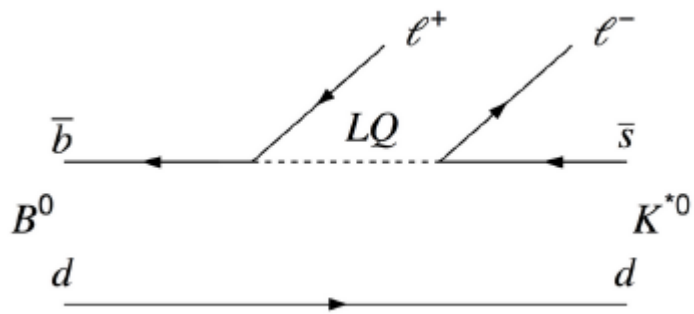
With lower precision BELLE, CMS, ATLAS

Possible explanation are LQ-like mediators. TeV scale and 3rd generation favored.

LQ couple to leptons and quarks, with a coupling λ





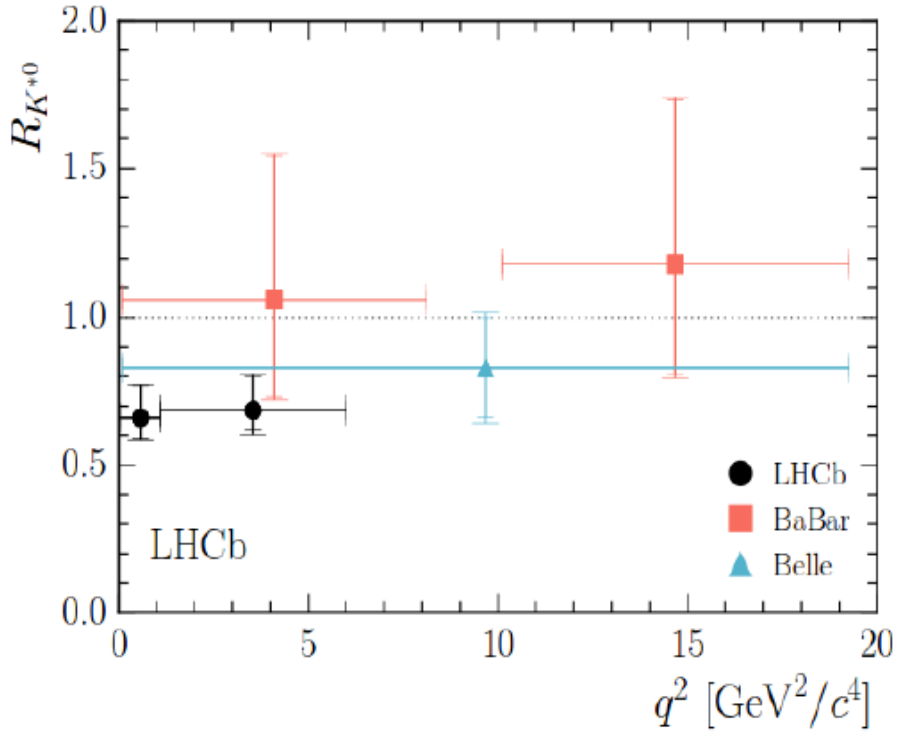


With material from talk by G.Isidori at CMS week Dec 6th 2017

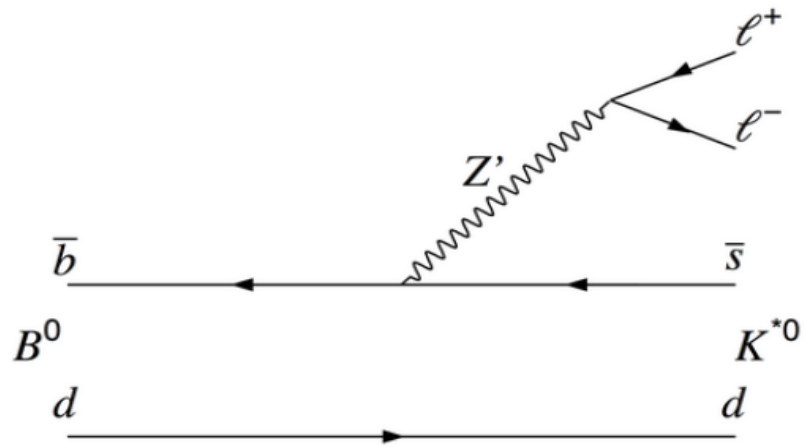
Z´ and B-physics anomalies

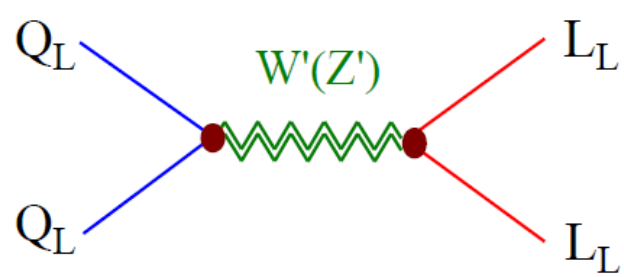
R_{K^*}

JHEP 08 (2017) 055



Possible new contribution in the $b \to s\ell\ell$ transition in BSM scenarios involving Z'





With material from talk by G.Isidori at CMS week Dec 6th 2017

Analysis Techniques for HL Studies

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

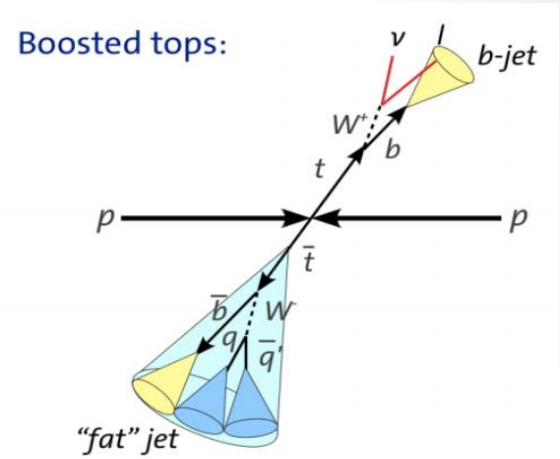
- DELPHES with up-to-date phase-2 detector performance and <PU> = 200
- Analysis steps guided by present analysis. Limited optimization for HL conditions. Cross checks with present analyses.
- Dedicated simulation of signal and bkgr samples

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) PU=140

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 luminosity
  - Uncertainties on ttbar simulation (10-20%) is leading. Uncertainties on other xsec's will improve.
  - JES, resolution and lepton ID efficiencies should improve.
- Without any systematics, include only statistical uncertainties = best case

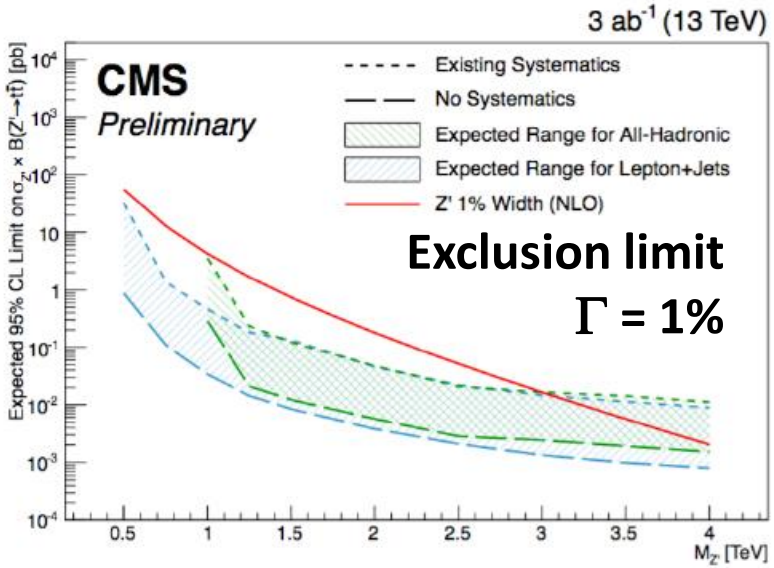
Baseline analyses at 13 TeV B2G-15-002, B2G-15-003. Projection in DP-2016/064 and CMS-PAS-FTR-16-005

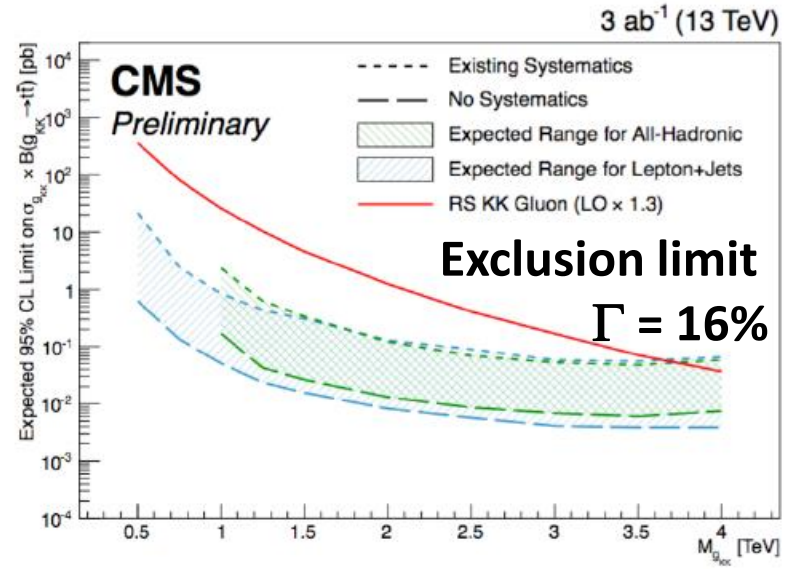
Z´→tt Projected Sensitivity

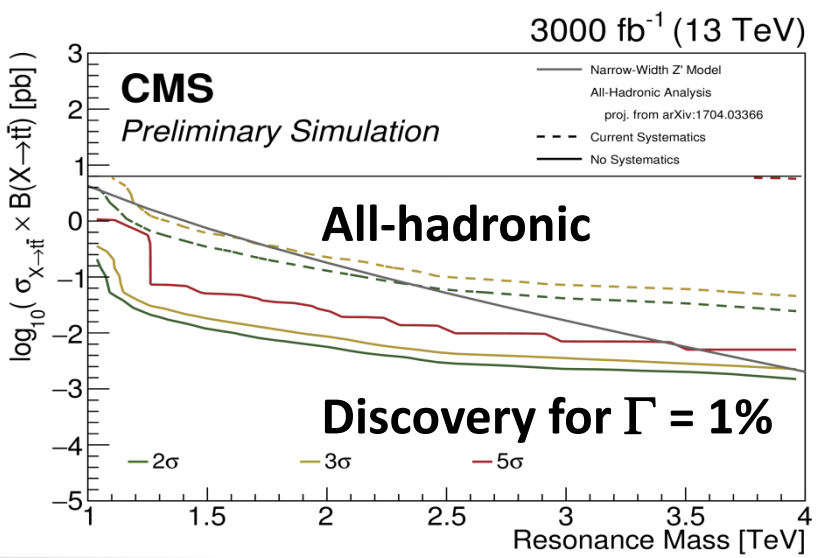
PROJECTION

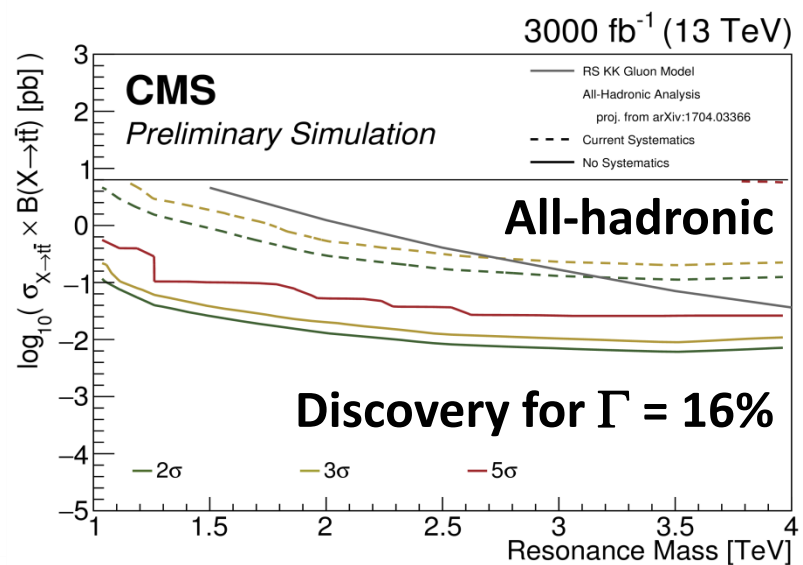
Two signal models: Narrow resonance (Z´) with 1% width

RS KK gluon resonance with width ~16% of mass









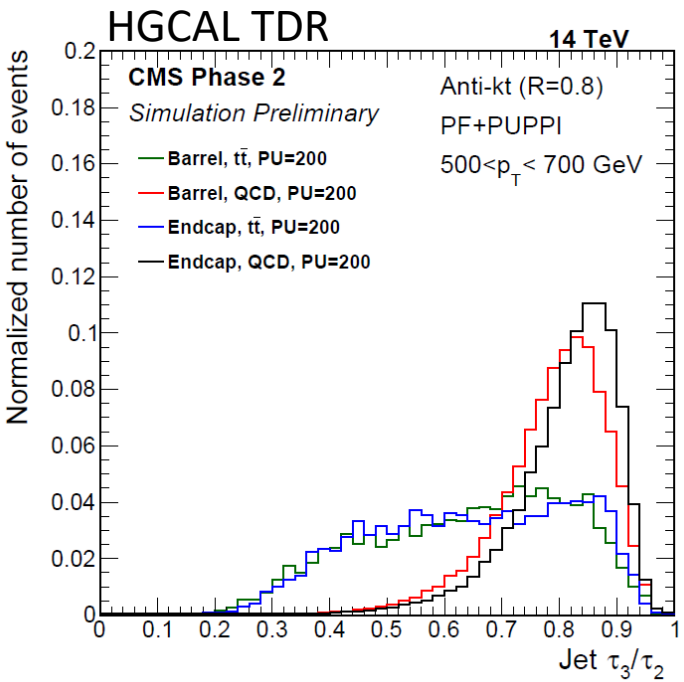
Baseline analyses at 13 TeV B2G-15-002, B2G-15-003.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

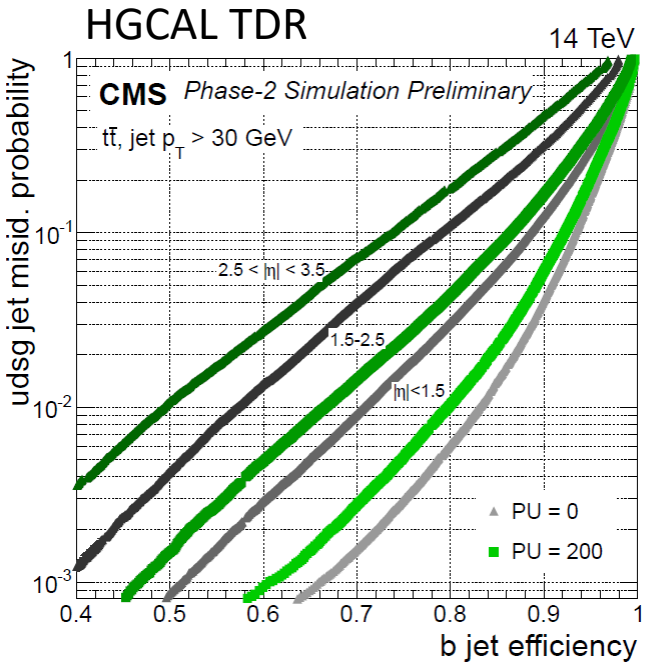
CMS Plan: Re-do tt Resonances

PLAN, DELPHES

Plan to redo the Z´ projections updating:

- Not a projection but DELPHES, incl. state-of-the-art Phase-2 performance from recent TDRs, e.g. high-granularity endcap calorimeter (HGCAL)





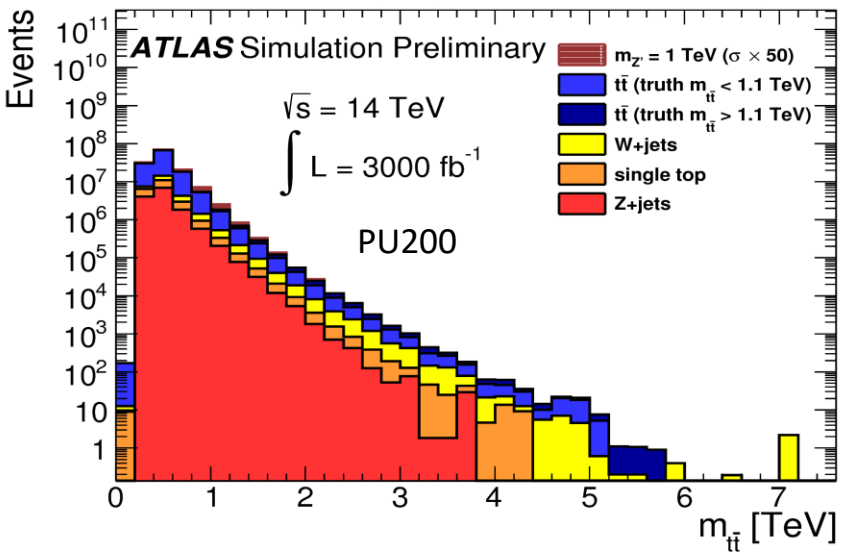
- Combine lepton+jets and all-jets channels
- Adapt analysis strategy for Z´ masses above 4 TeV where off-shell production becomes important. Use PU200.
- Adapt systematics uncertainty scenarios to better understanding (ongoing)

HGCAL TDR CMS-TDR-17-007

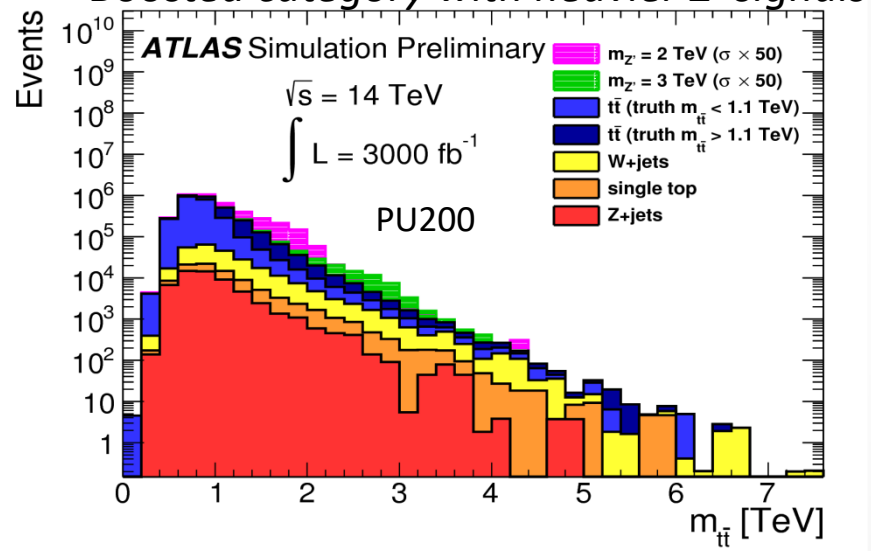
ATLAS Z′→tt→WbWb→lvbqqb

- **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 Detector
- Applied systematics (derived from Run-1)
  - Luminosity 3%
  - On event yield in resolved category: 8.8% (signal), 10.8% (background)
  - On event yield in boosted category: 18% (signal), 13.4% (background)

ATL-PHYS-PUB-2017-002

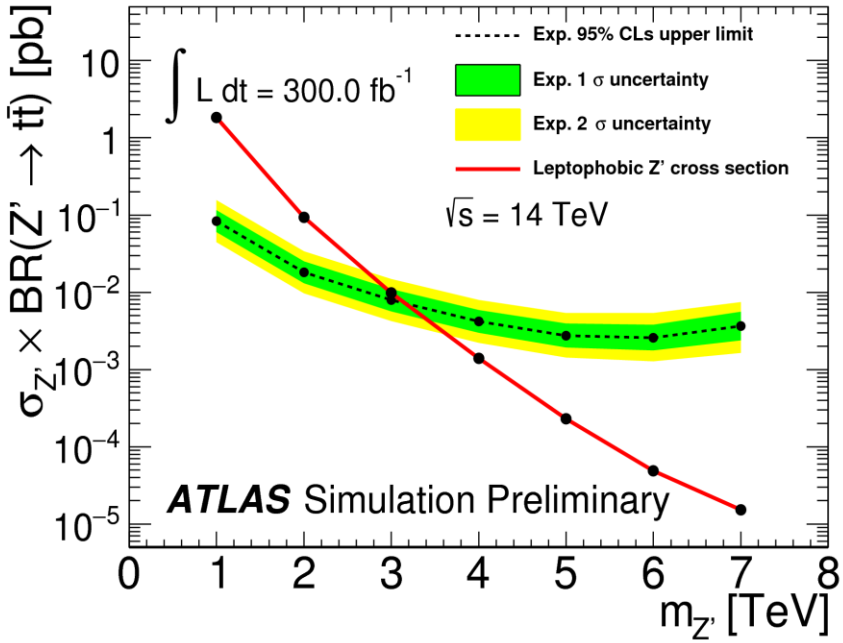
ATLAS Z´→tt

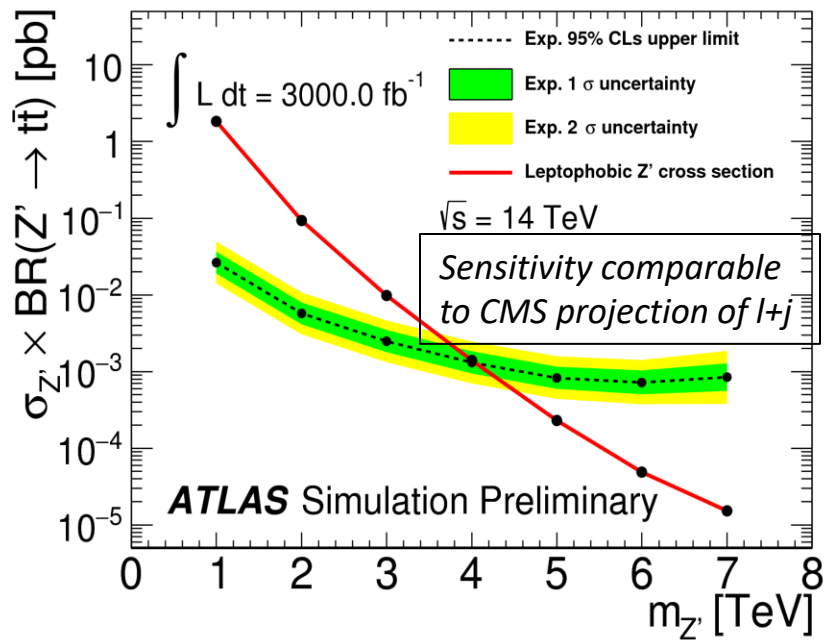
SIMPLIFIED ANALYSIS

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.



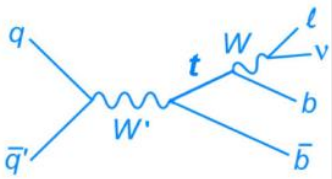


Gain from HL: 3 TeV (300/fb) → 4 TeV (3000/fb)

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

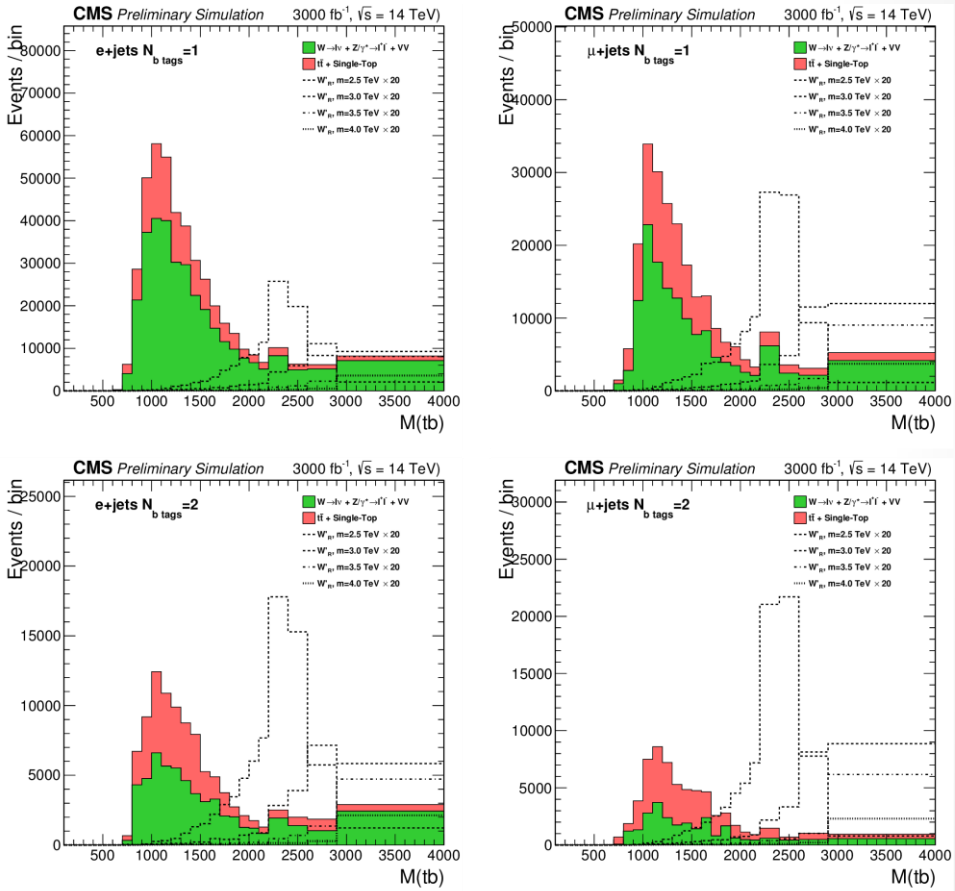
ATL-PHYS-PUB-2017-002

CMS W´→tb Projection



Probe scenarios such $m(\nu_R) > m(W') \rightarrow$ forbidden for $W' \rightarrow l\nu$

- 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

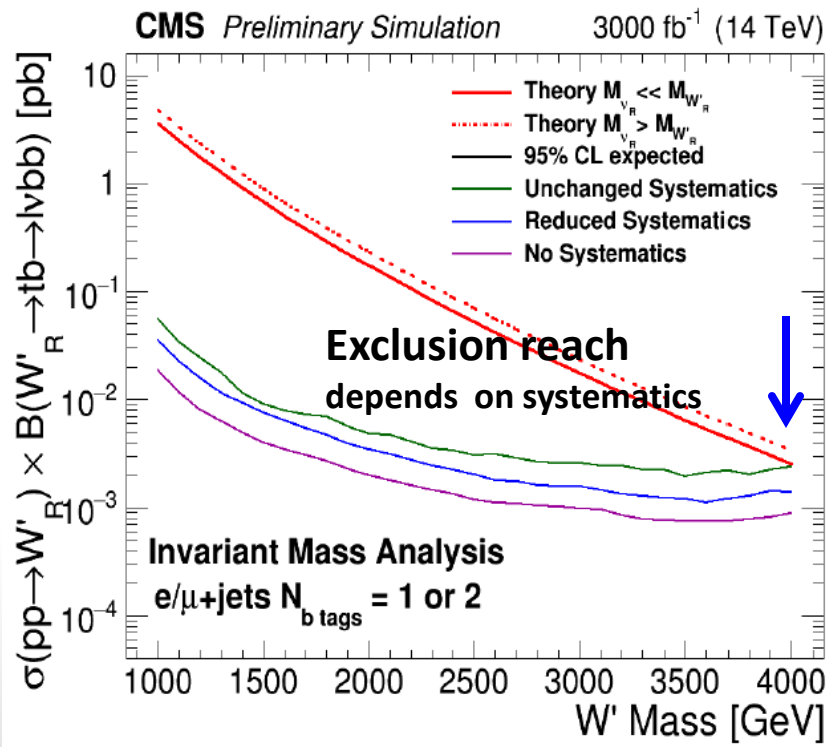
PROJECTION

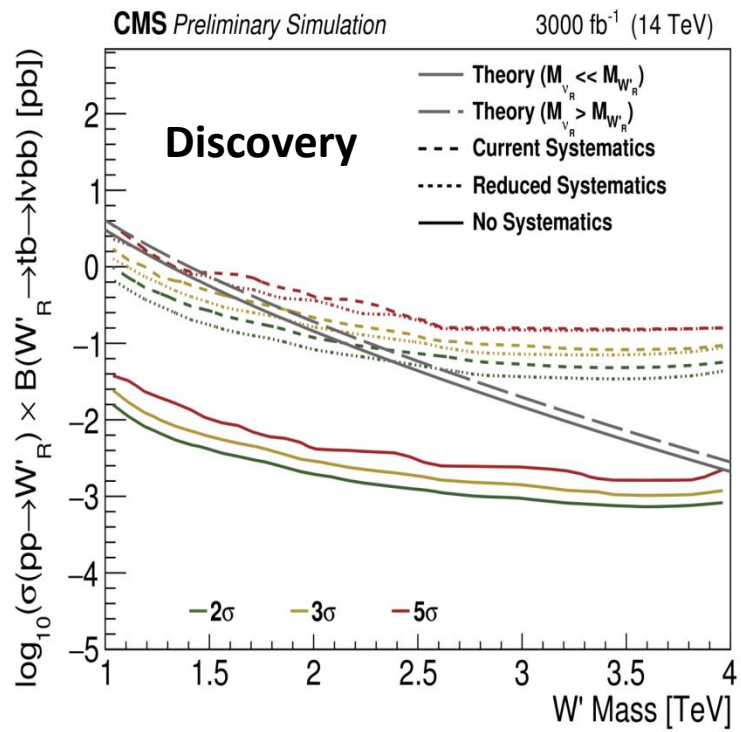
Three scenarios to extrapolate systematics from 12.9/fb to 3/ab

1) Leave **systematics unchanged**, simply scale templates with lumi
2) **Reduce** most experimental to percent level, theoretical uncertainties by factor 1/2, 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)

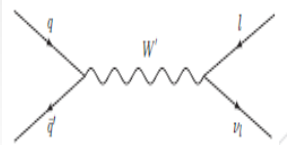
Detailed Table in backup





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

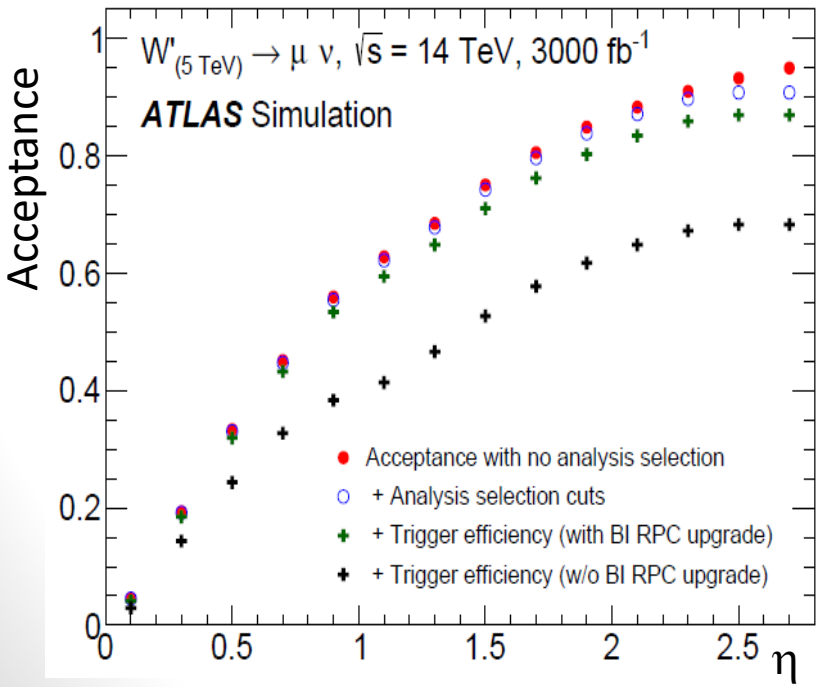
Other Searches for Heavy Bosons

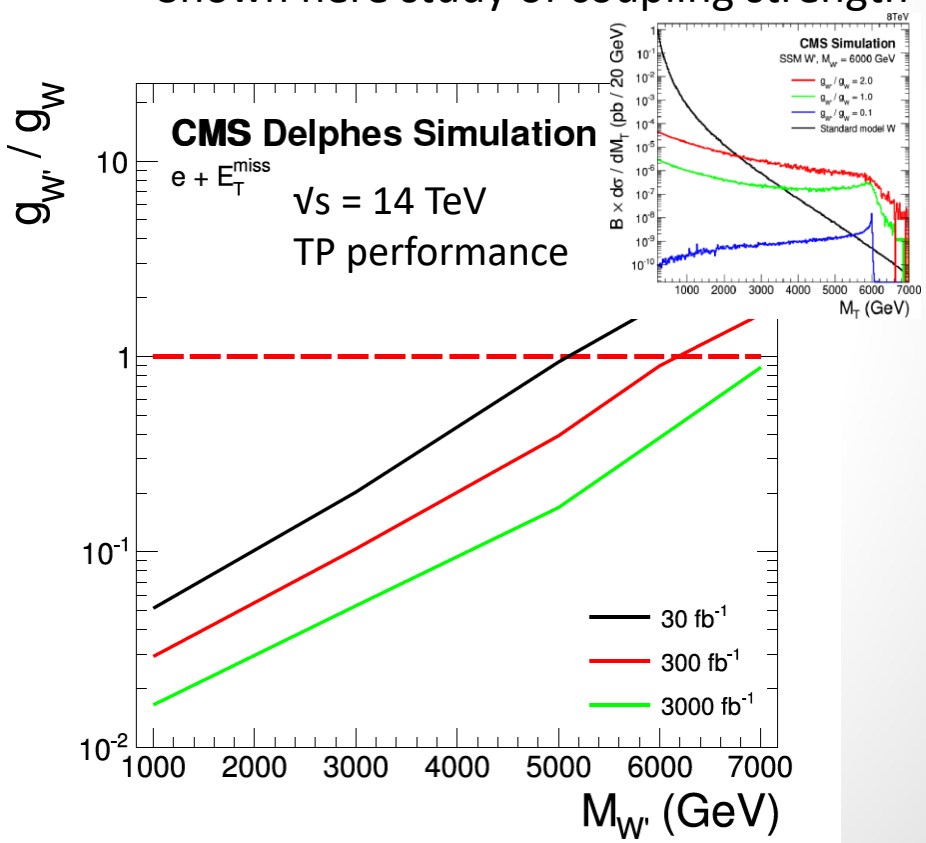


ATLAS and CMS are working on Z´/W´ searches in general. See talks on heavy resonances at this workshop, by Sarah Demers (ATLAS) and Sadia Kalil (CMS).

W´ →μν (ATLAS Muon TDR)
Cumulative acceptance as fct(η) with upgraded detector. With additional RPC gain in trigger efficiency 70% -> 90%.

W´→eν (CMS-PAS-EXO-14-007)
Discovery reach for SSM W` up to m(W´) = 7 TeV @ 3/ab
Shown here study of coupling strength





ATLAS Muon TDR CERN/LHCC/2017/077
CMS-PAS-EXO-14-007

Property Measurements

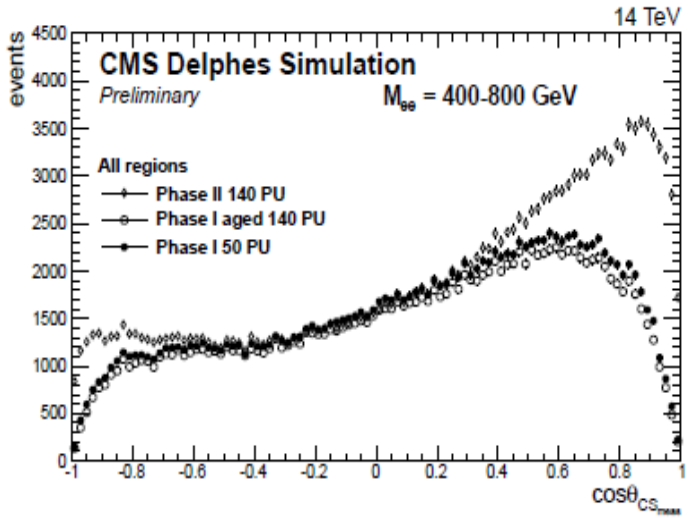
EXAMPLE

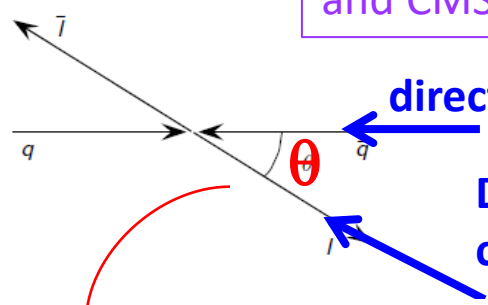
What if we see a hint of a signal in Phase 1?

→ **Study properties of „excess“ with HL-LHC**

CMS example: study new physics properties with high statistics in characteristic distributions, e.g. A_{FB}

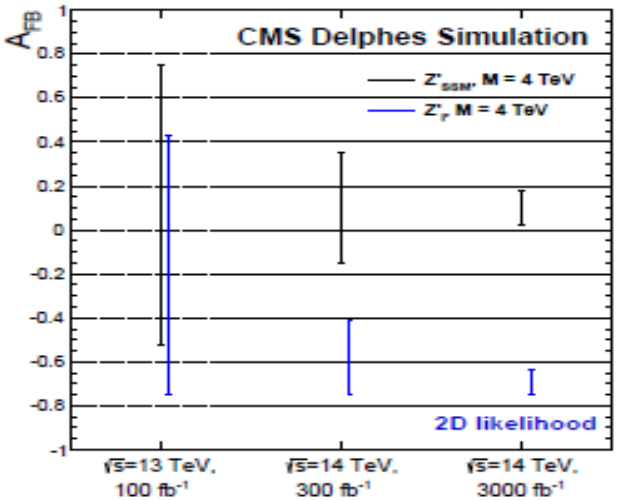
More A_{FB} studies by ATLAS and CMS from SM point





direction

Determine lepton charge and direction



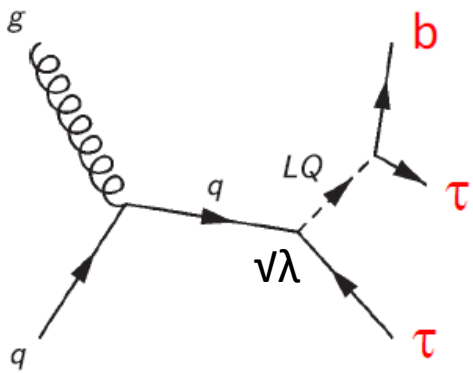
New heavy spin-1 resonance (dilepton channel). Little theoretical constraints on A_{FB} value → any value between -0.75 and +0.75.

	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

CMS-PAS-EXO-14-007 and TP
PhD thesis Laurent Thomas (Bruxelles)

CMS Plan: $LQ_3 \rightarrow \tau + b$

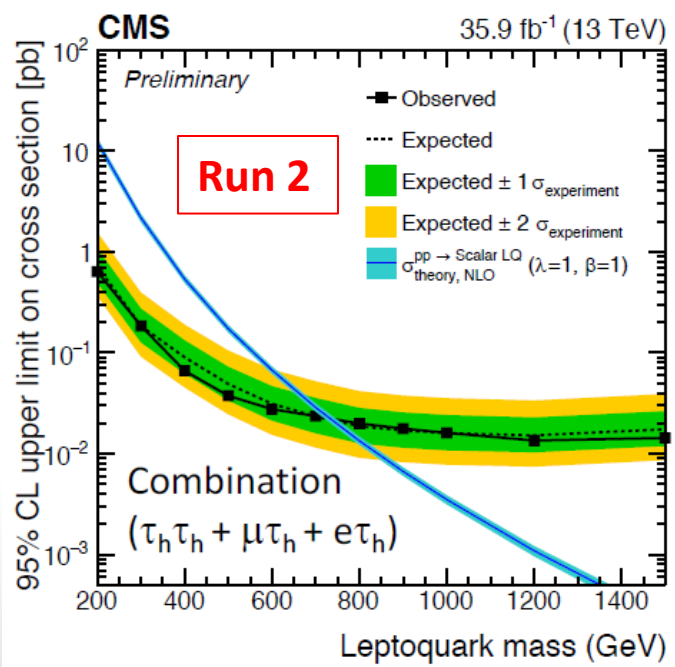
PLAN, DELPHES

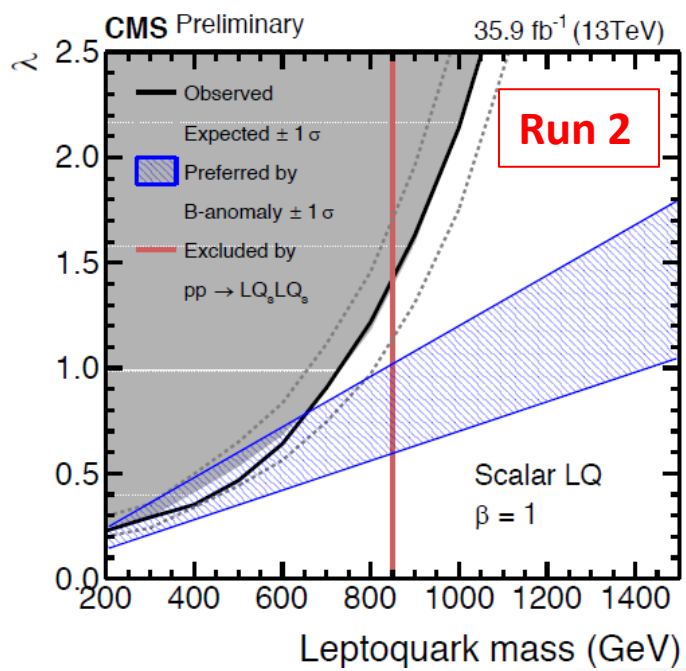


Model R_2~ as described in Phys. Rept. **641** (2016)
Signal xsec and k-factor from theorist
Signals simulated in LO with MG

- LQ always decays into τ + b (β = Br(LQ → τb) = 1)
- Unknown LQ-τ-b coupling λ (LQ-τ-b) = 1

Plan redo these two plots from existing Run-2 result





Single LQ3 sensitive to high-mass/ coupling region

Based on CMS-PAS-EXO-17-029

Idea: W´ → τ + ν

USEFUL?

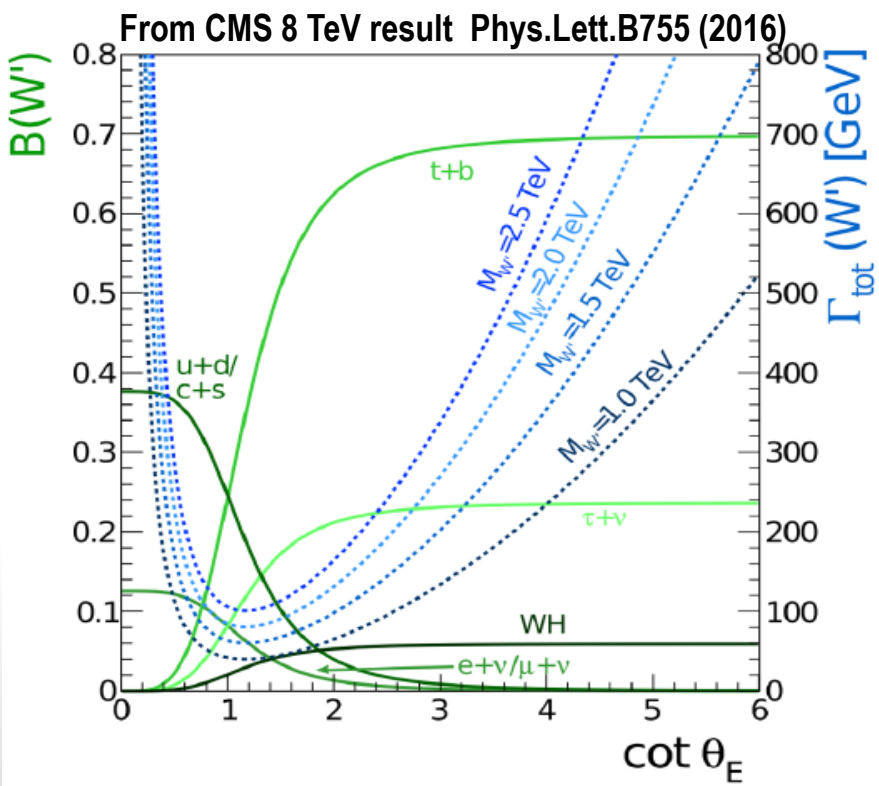
NUGIM
Phys.Rev.D.81.015006,
Phys.Lett.B 706 (2012)
arXiv: 1408.0914

Is it worth to project the NUGIM result in W'-> τν?

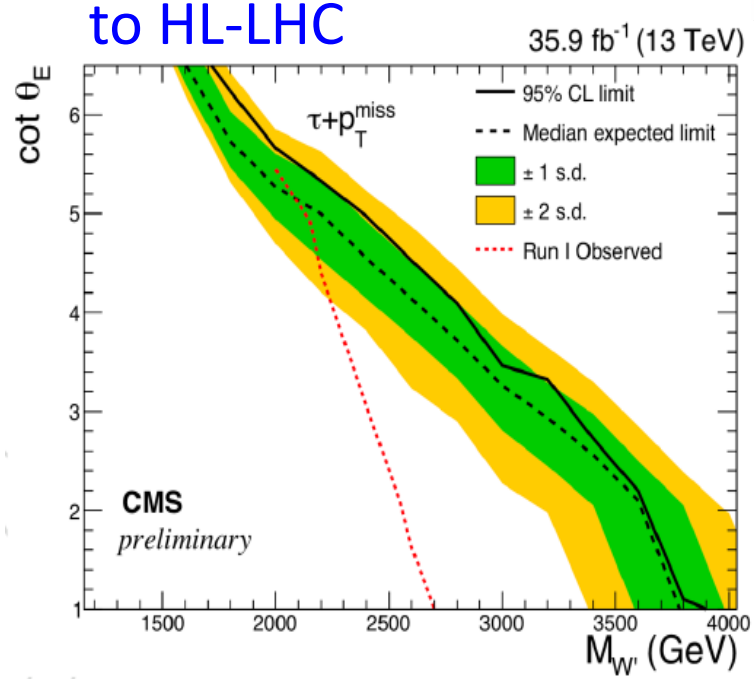
Complementary to W´->tb

NUGIM (non-universal gauge interaction model) = enhanced coupling to 3rd generation. BR depends on mixing angle cot θ_E

$$SU(2)_l \otimes SU(2)_h \rightarrow SU(2)_{SM} \otimes SU(2)_{extended}$$



Plan: project this result to HL-LHC



Based on CMS-PAS-EXO-17-008

Channel Matrix

FOR DISCUSSION

Several possibilities proposed to explain the flavor anomalies. For 3rd generation **mostly projections**. Ongoing efforts, rather full analyses.

Studies of systematics to be considered?

Question for theorists: where should we focus our efforts? Suggestions?

Channel	ATLAS	CMS
Z´ → ttbar	Recent results from semi-leptonic channel, more in progress	Projection for l+j and jj channels. Plans to re-do with DELPHES and TDR-performance
Z´ → ττ	ATLAS and CMS are working on Z'/W' searches in general. Question for theorists: is it worth focusing on Z´->ττ more ?	
W´ → tb	Result from ECFA2016. Run-2 driven analysis, simplified. Studies on systematics impact to be considered?	Projection from 12.9/fb for ECFA2016.
W´ → τν		Interesting?
LQ	Suggestions of necessary studies?	DELPHES based analysis of LQ3→tau+b planned for summer.

Summary

Several possibilities proposed to explain the flavor anomalies.

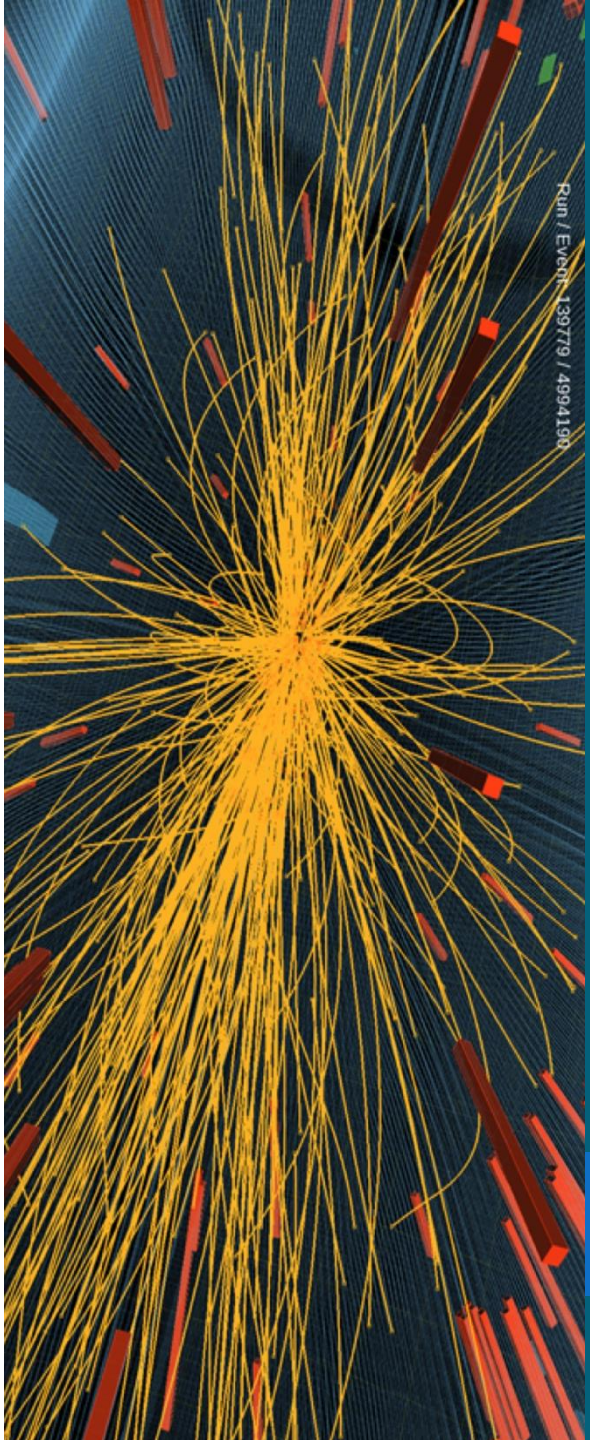
Existing studies with 3rd family in final state mostly projections.

More ongoing, DELPHES-based study of LQ3 and Z´→ttbar.

Studies of systematics to be considered?

Cover all interesting channels?

Something missing?



References

Public upgrade analyses

Z´→ttbar

- [ATL-PHYS-PUB-2017-002] Study on the prospects of a tt^{-} resonance search in events with one lepton at a High Luminosity LHC
- [CMS-PAS-FTR-16-005] Estimated Sensitivity for New Particle Searches at the HL-LHC
- CMS-TDR-17-007 HGCAL performance for high-mass tt resonances

W´→tb

- [CMS-PAS-FTR-16-005] Estimated Sensitivity for New Particle Searches at the HL-LHC

Other searches for heavy bosons (more in talks about heavy resonances):

- [CERN-LHCC-2017-017] W´→$\mu\nu$ projection of acceptance gain
- [CMS-PAS-EXO-14-007] W´ projected discovery reach for mass, couplings

Plans based on

- CMS-PAS-EXO-17-029 LQ3 -> tau + b
- CMS-PAS-EXO-17-008 W´-> tau + v

Talk by Gino Isidori at CMS week December 6th 2017

BACKUP MATERIAL

ATLAS Strategy for HL Studies

Overall strategy = generator-level truth with smeared detector response

- In general, use generator-level (truth) 14 TeV MC samples
- Overlay with jets (full sim) from pile-up 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.

Assumptions on systematics

- Evolvement of systematic + theoretical uncertainties: several scenarios based on how uncertainties will develop
- Detector upgrades designed to (at least) compensate degradations due to high pile-up
- Three uncertainty scenarios:
  - Unchanged (as in current analyses, mostly Run-2, some Run-1)
  - Reduced ×½
  - No systematic uncertainties

CMS Strategy for HL Studies

Projections from a present analysis (mostly this for 3rd family analyses)

- Existing signal and background samples (simulated at 13 TeV) scaled to higher luminosity and √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

Assumptions on systematics

- Evolvement of systematic + theoretical uncertainties
- Detector upgrades to compensate degradations due to high PU
- Three scenarios:
  - Unchanged, systematics kept as in current analyses
  - Reduced: Theoretical uncertainty ×½, experimental systematic uncertainty ∝1/√L until detector-driven lower limit is reached.
  - No systematic uncertainties

CMS Z´→ tt Projection Systematic Uncertainty Scenarios

Two scenarios to extrapolate systematics:

1. **Current run-2 systematics:** certainly pessimistic approach. E.g. QCD is derived from data, errors reduce with larger dataset.

2. **No systematics,** corresponding to max sensitivity.

If applicable to both event categories, uncertainties are treated as correlated.

Uncertainty	Semileptonic	All-Hadronic
Z+jets σ	✓	
W+jets σ	✓	
$t\bar{t}$ σ	✓	✓
Single t σ	✓	
VV σ	✓	
t-tagging Efficiency	✓	✓
t-mistagging Efficiency	✓	
Pileup reweighting	✓	✓
Parton Distribution Functions	✓	✓
Muon ID	✓	
Muon Trigger	✓	
W+jets Q^2 Scale	✓	
$t\bar{t}$ Q^2 Scale	✓	✓
$t\bar{t}$ Parton Shower Scale	✓	✓
NTMJ Jet Kinematics		✓
NTMJ Closure Test		✓
Luminosity Measurement	✓	✓
Jet Energy Resolution	✓	✓
Jet Energy Scale	✓	✓
Electron ID	✓	
Electron Trigger	✓	
b-tagging (HF) Efficiency	✓	
b-tagging (LF) Efficiency	✓	
Subjet b-tagging Efficiency		✓

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

CMS W´→ tb Projection Systematic Uncertainty Scenarios

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

1) **Current:** Leave **systematics unchanged** w.r.t. run-2 baseline analysis
2) **Reduced:** scale most experimental to percent level, theo uncertainties by factor 2, top p_T reweighting by factor 3, lumi uncertainty to 1.5%

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%
Theoretical top cross section	15%	7.5%
Theoretical bosonic cross section	10%	5%

Current = Run 2 systematics

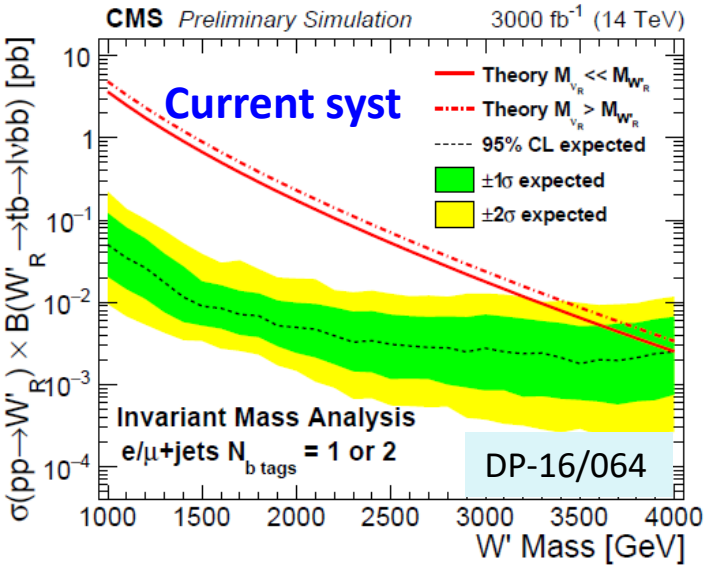
Reduced systematics

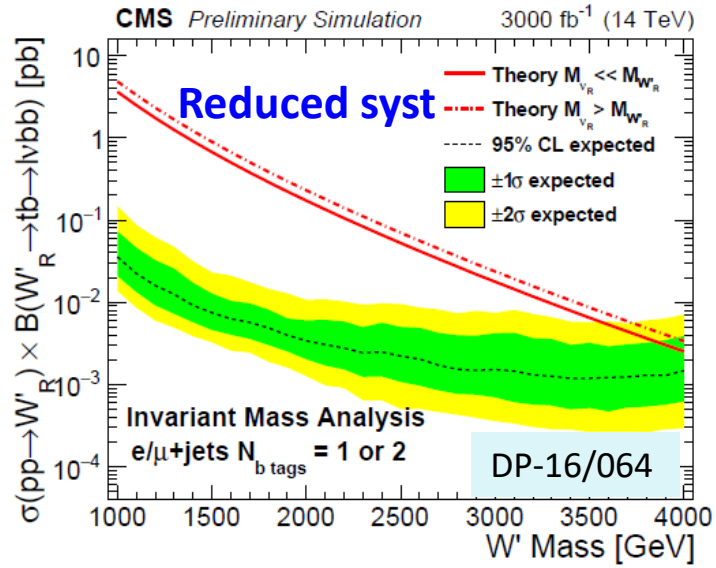
3) Also „**no systematics scenario**“, corresponding to maximum sensitivity

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 Projected Exclusions

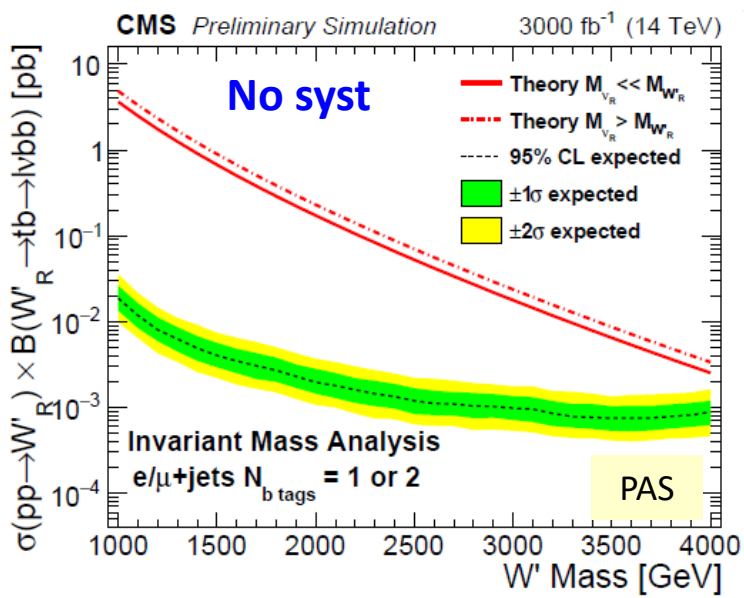
Exclusion for 3/ab. Impact of systematic uncertainties on sensitivity





Current (run-2) systematics = worst case. Expect improvements from phase-2 detector and better theorical calculations.

With „reduced syst“ and „no syst“ exclusion for m(W´)>4 TeV. Such high masses require analysis optimization (not done for this study).



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