Experimental Beyond-the-SM projects at the HL-LHC

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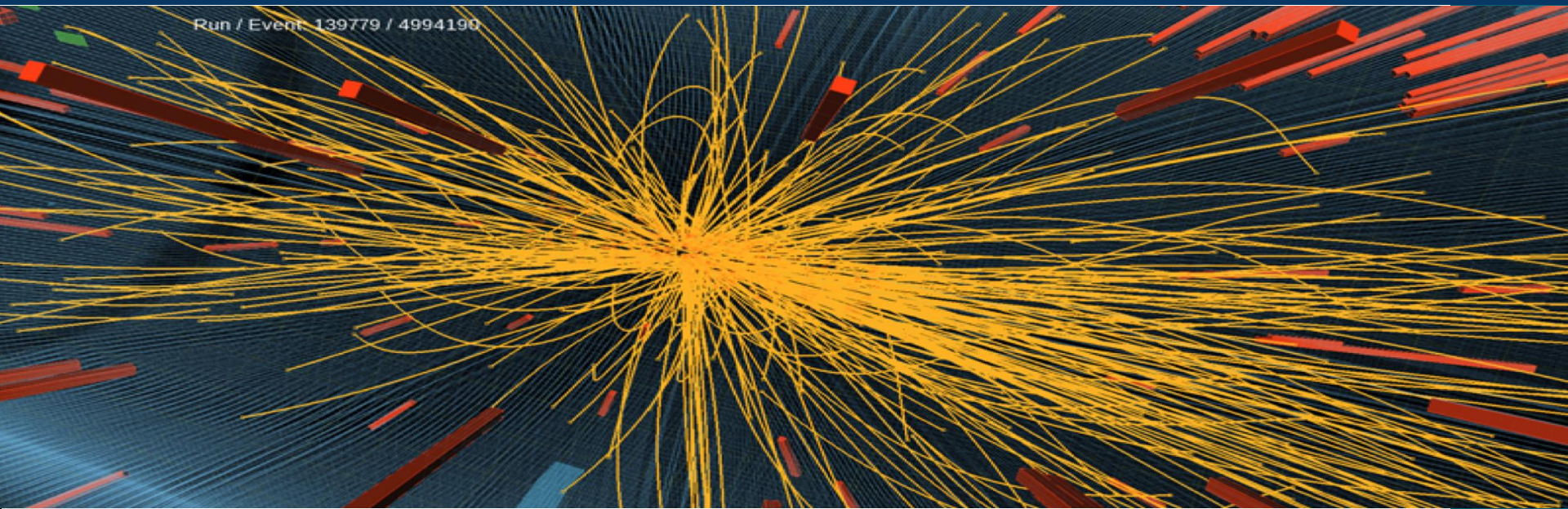
on behalf of the ATLAS and CMS collaborations

LHCP 2018, Bologna, June 8th 2018



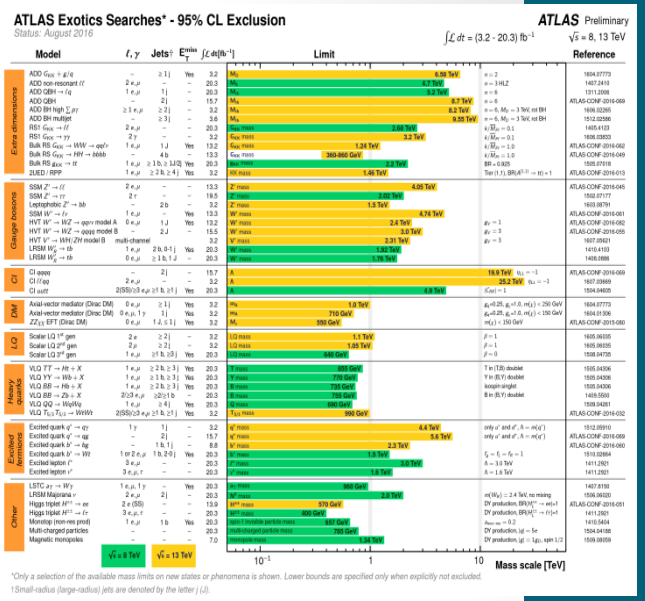
Motivation

Many ongoing searches at present LHC.

Indications here and there but no conclusive sign of new physics yet.

BSM searches at HL not a linear extrapolation from presence. Rather **widen the scope**, e.g.:

- Rare processes, weaker couplings
- New models upcoming including observed LHC results
- Go more model-independent not to miss something



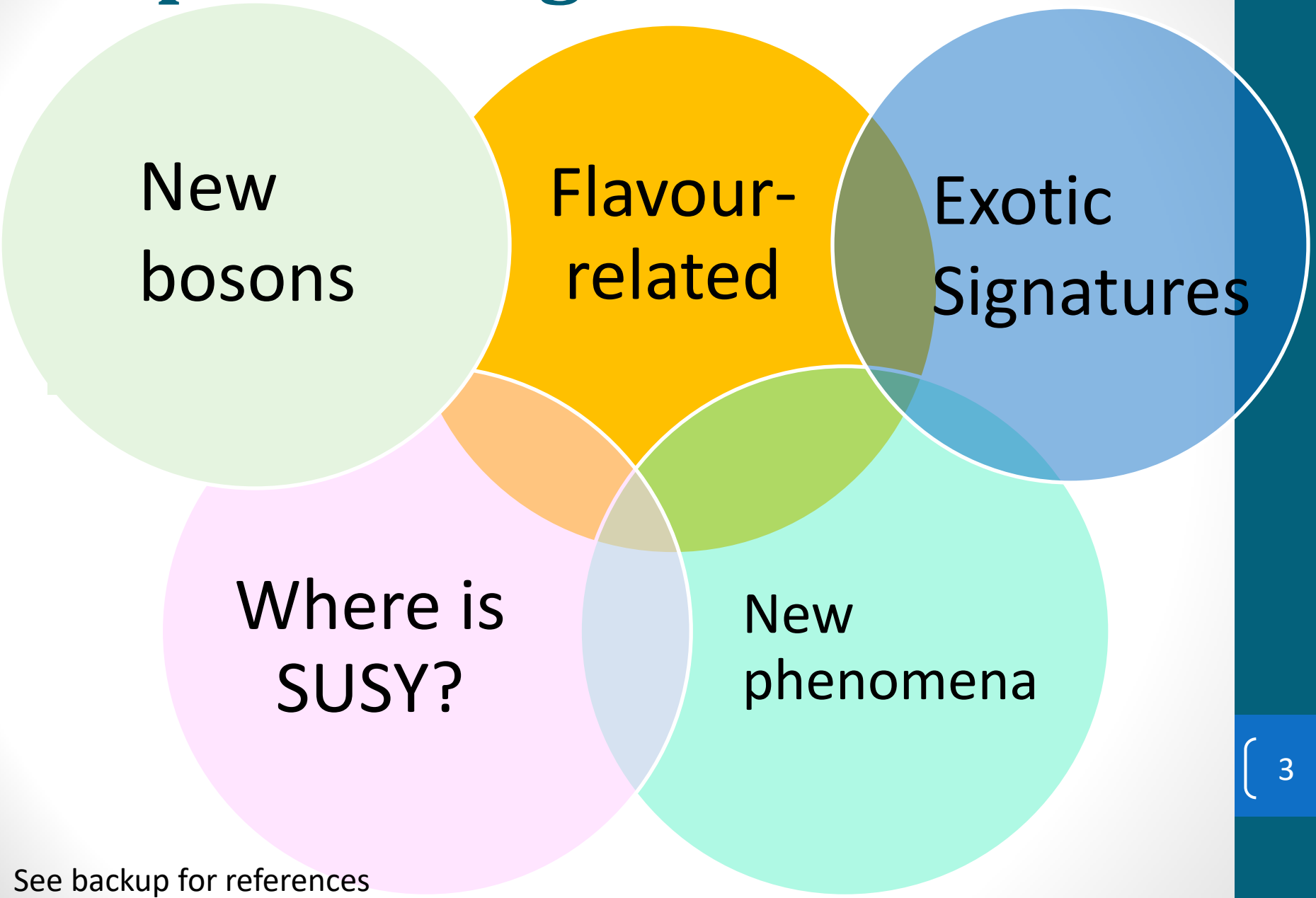
How to prepare for phase-2 physics?

→ Continue benchmark analyses

→ Develop new analysis strategies

SCOPE of this talk: show selected examples

Keep Searching



See backup for references

Analysis Techniques

ATLAS

- Generate truth-only 14 TeV event
- Overlay with jets (full sim) from pileup library, <PU> = 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

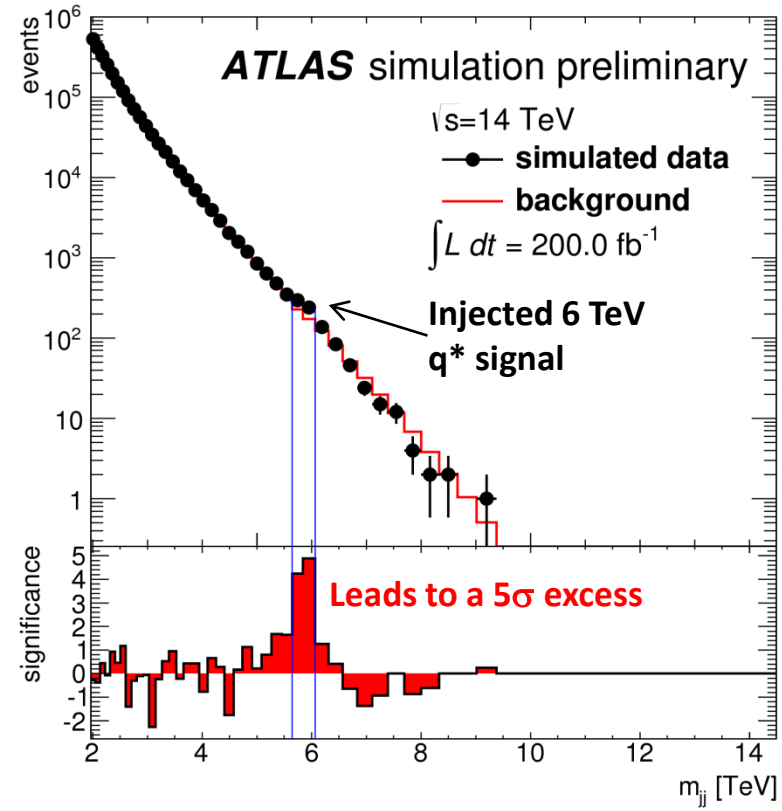
- DELPHES with up-to-date phase-2 detector performance and <PU> = 200
- Analysis steps guided by present analysis. Limited optimization for HL conditions. Cross checks with present analyses.
- Dedicated simulation of signal and bkgr samples

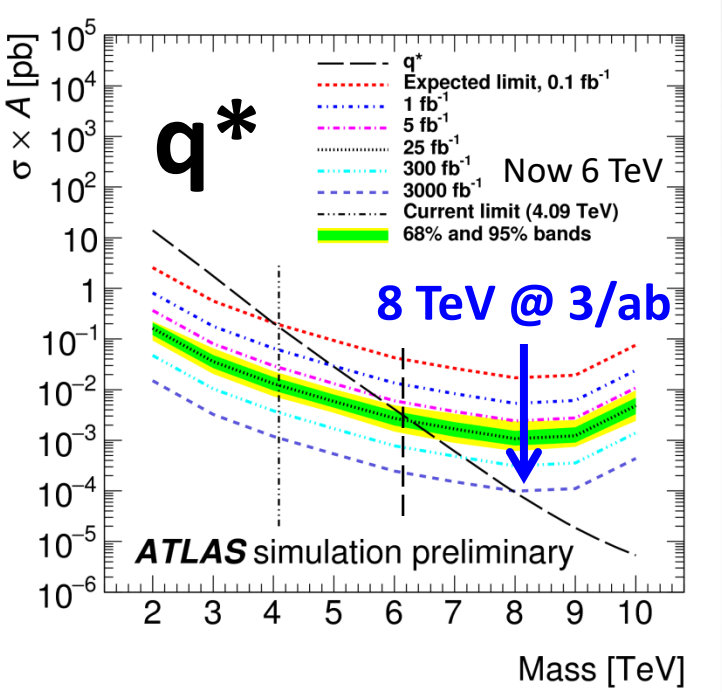
Dijet (bump hunt)

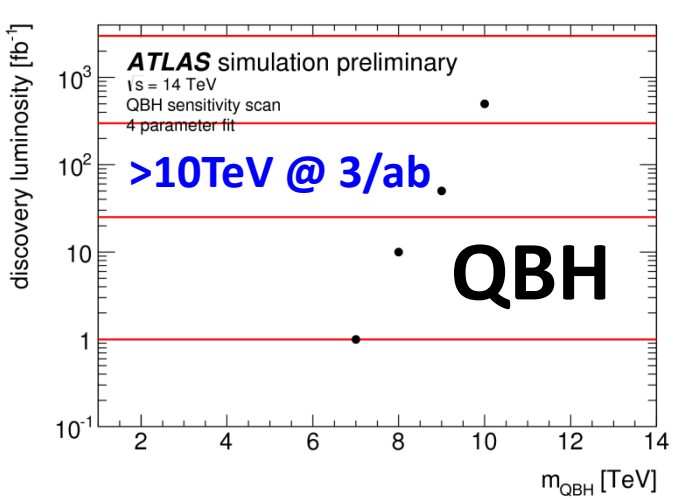
Discovery reach for excited quarks (q*) and quantum black holes (QBH)

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

Bump-hunter algorithm (Similar technique for other analyses)

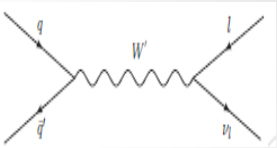






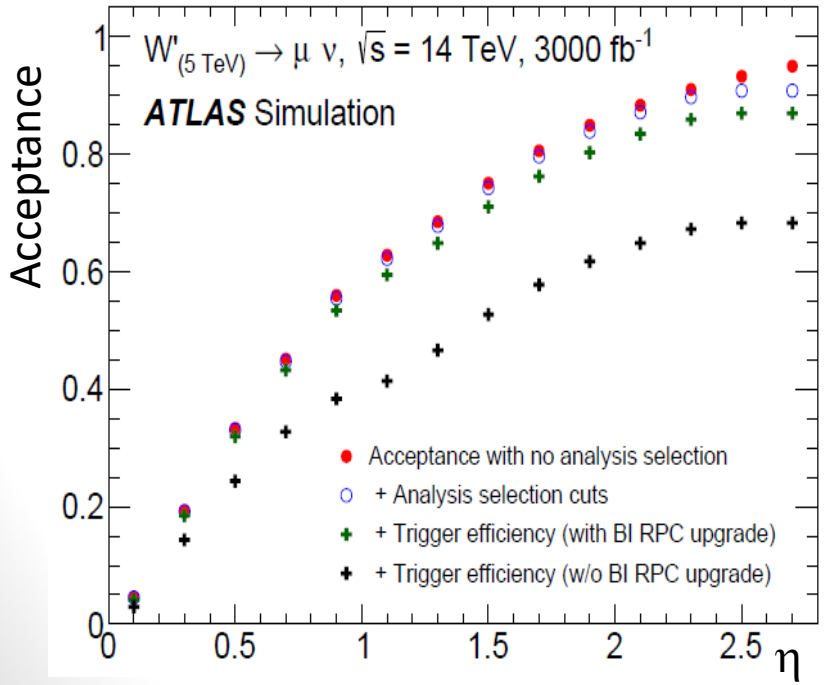
ATL-PHYS-PUB-2015-004

Searches for Heavy Bosons



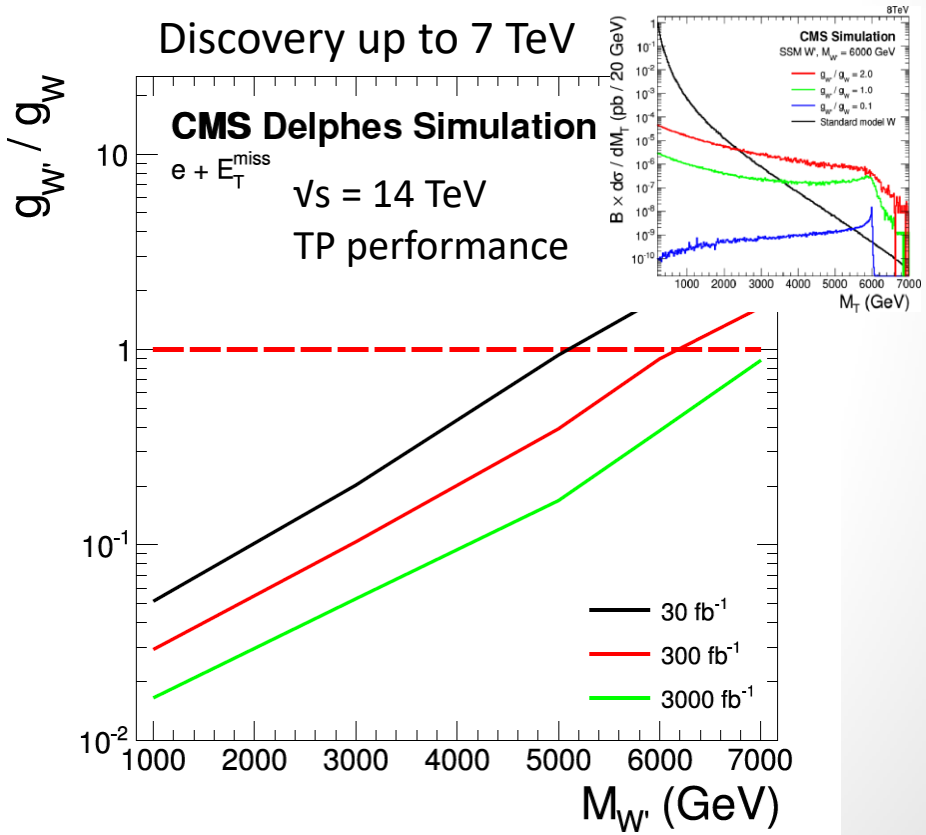
ATLAS and CMS are working on Z´/W´ searches in general.

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)
Weaker coupling are domain of HL
Shown here study of coupling strength

Discovery up to 7 TeV



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

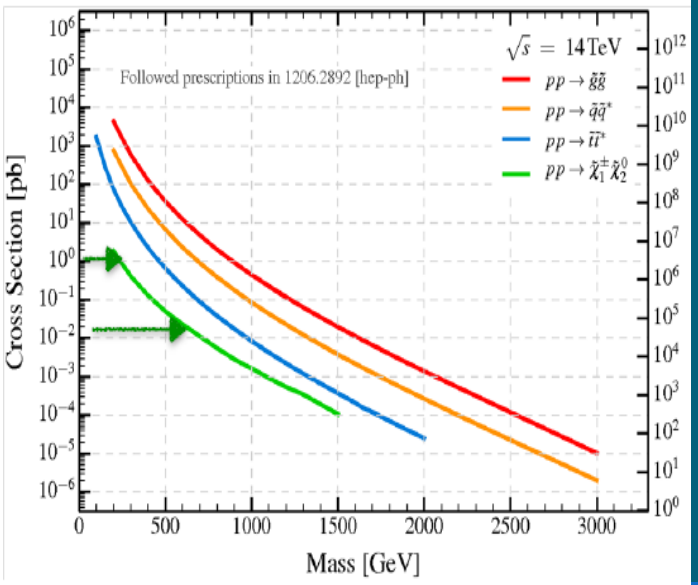
Where is SUSY?

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

- Limits for strong SUSY production are above 1 TeV
- Top and bottom squarks highly constrained

Still lots of opportunities in the electroweak sector

- May dominate if squarks and gluinos are heavy
- In most SUSY breaking scenarios EWK-inos are expected O(100 GeV) mass based on naturalness
- EWK-inos are produced via EWK production → small cross sections. HL-LHC has potential to increase sensitivity by 3000/80 ~40x



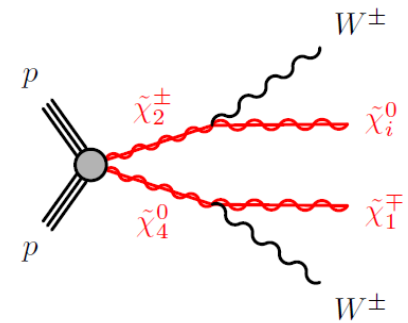
Search of EWK-inos into WW

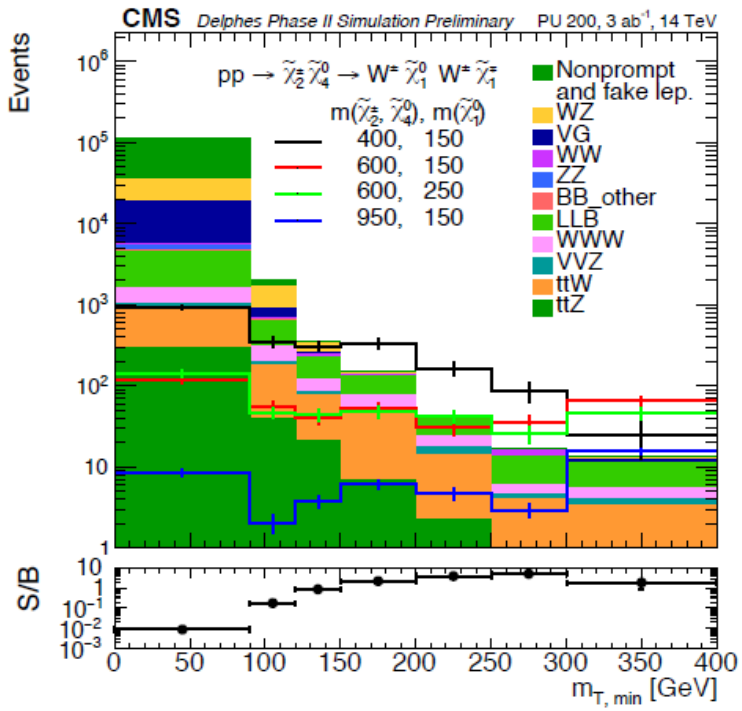
Search for $\tilde{X}_2^{\pm}\tilde{X}_4^0$ decaying to **same-sign WW.**

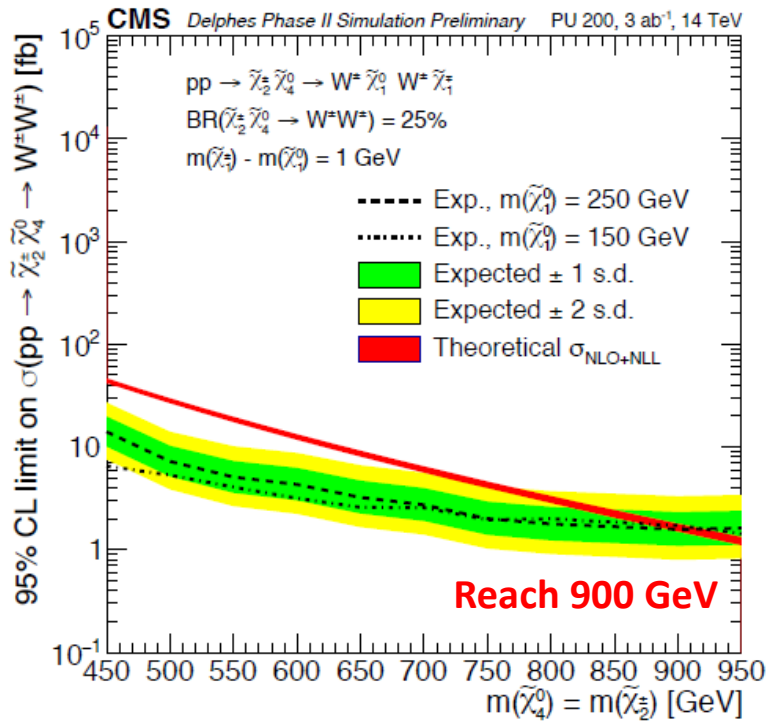
In some models large visible cross section (25%).

Signature: same-sign leptons. Small mass difference yields soft W and soft leptons.

Baseline SR binned into 7 $m_{T,min}$ based regions.



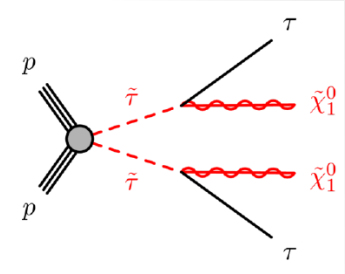




$$m_{T,min} = \min[m_{T(lep_1, p_T^{miss})}, m_{T(lep_2, p_T^{miss})}]$$

Direct Production of stau Pairs

If chargino and neutralino NLSP are heavy, direct stau pair production can become dominant EWK production
Assume 100% BR to SM tau and LSP.

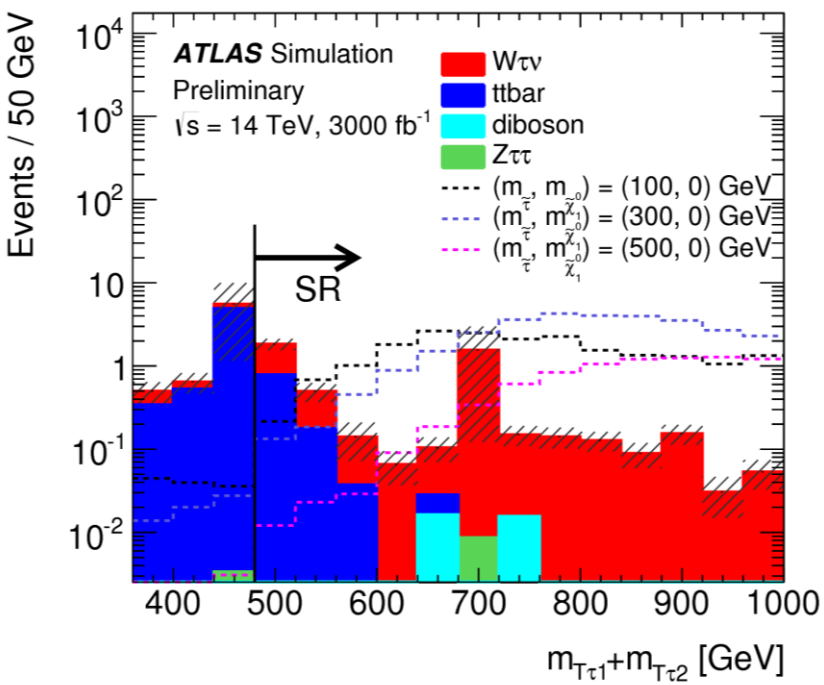


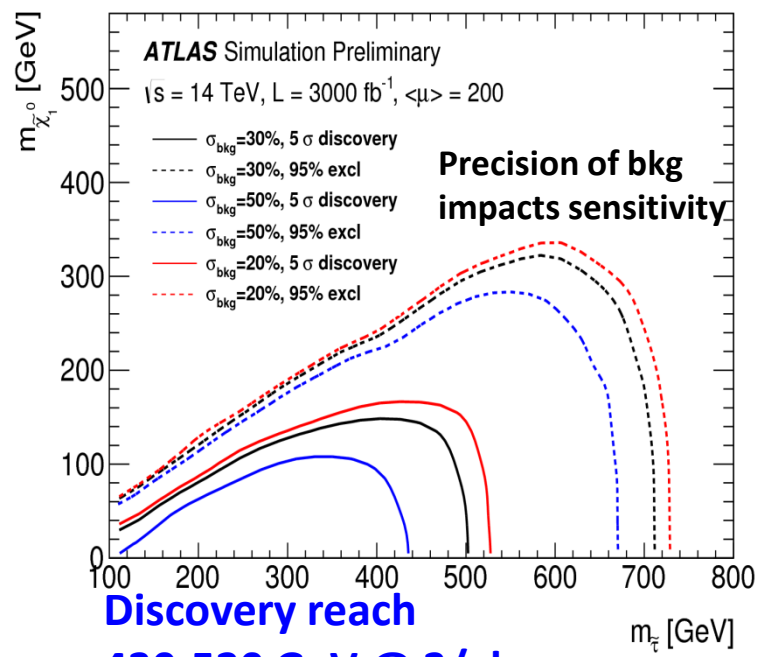
Signature:

- 2 tau jets (hadronically decaying tau)
- Large MET (from $\tilde{\chi}_1^0$)

Main background: W+jets, ttbar

Selection: 2 OS taus, loose jet and Z-veto, MET>280 GeV
Define signal region (SR) in $m_T(\tau 1) + m_T(\tau 2)$





Discovery reach
430-520 GeV @ 3/ab depending on bkg

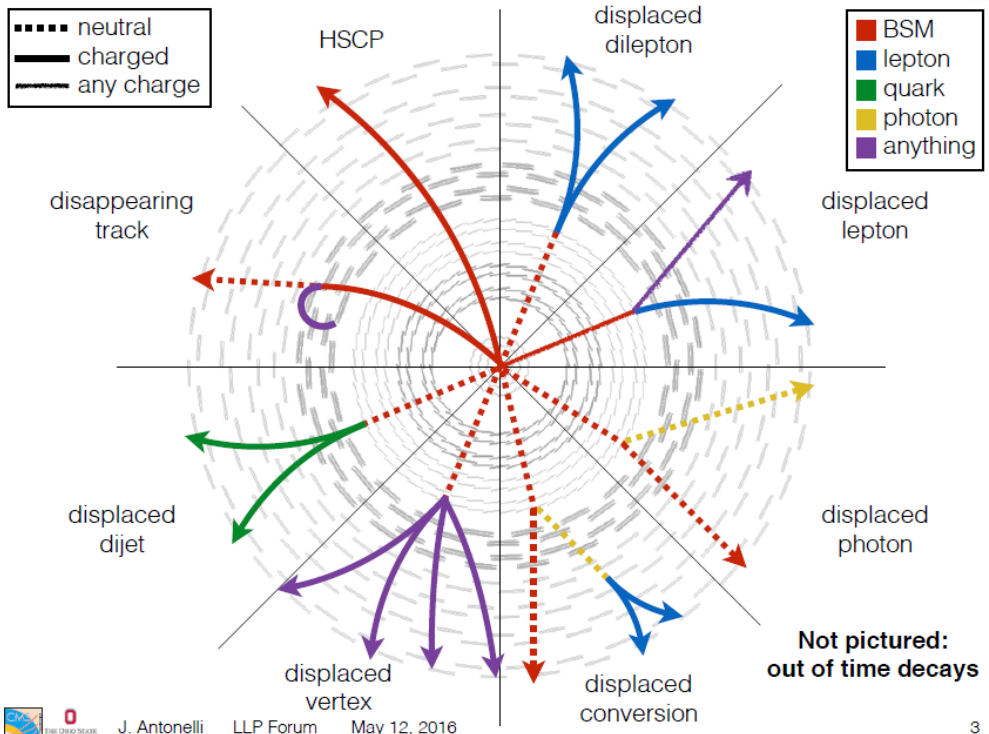
ATL-PHYS-PUB-2016-021

Exotic Signatures

- More and more models with **long-lived particles**
- One signature can originate from different models → search signature-based rather than model-driven
- Experimental issues: needs dedicated triggers and algorithms to detect these **non-standard signatures**. Efficiencies depend on kinematics, decay length, etc.

What is exotic?

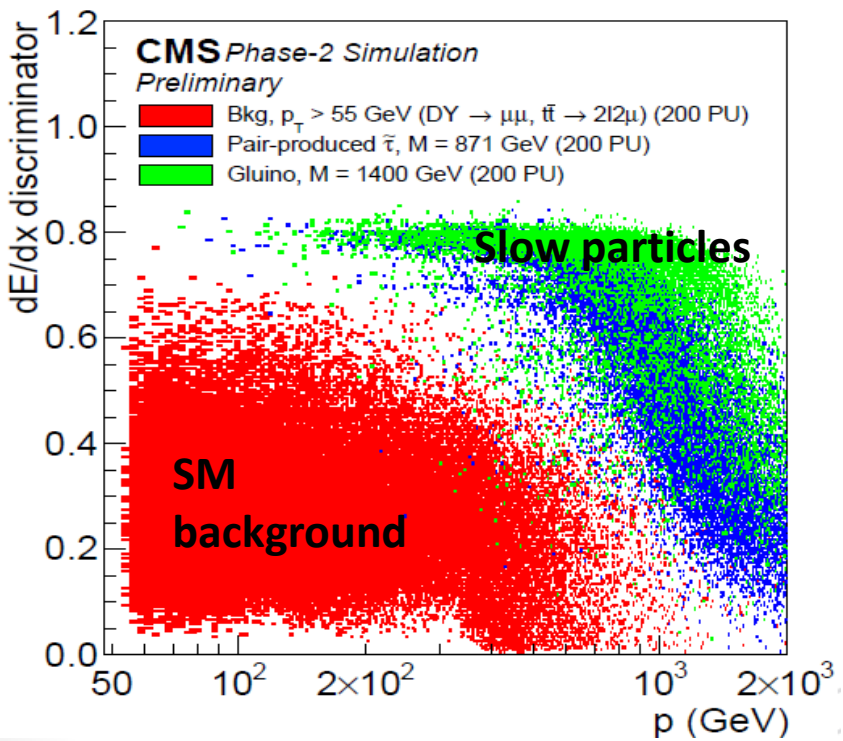
- Anomalous dE/dx
- Decay after long lifetime
- Appearance of tracks
- Timing measurements

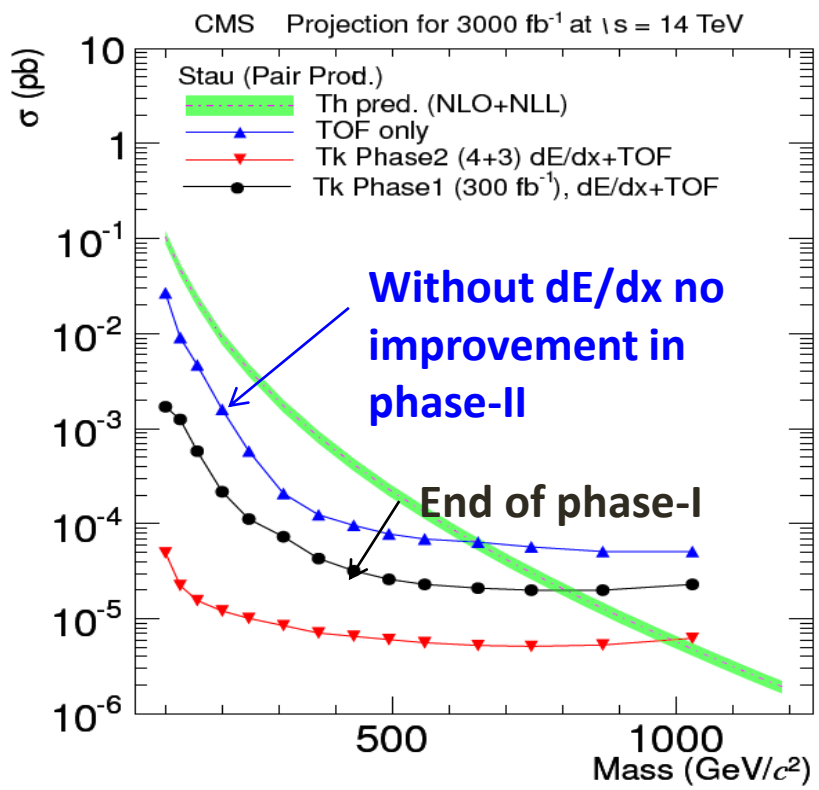


Detection via Anomalous dE/dx

Slow moving particles ($\beta << 0.9$) can be identified from their anomalous dE/dx

Similar method for fractionally and multiply charged particles

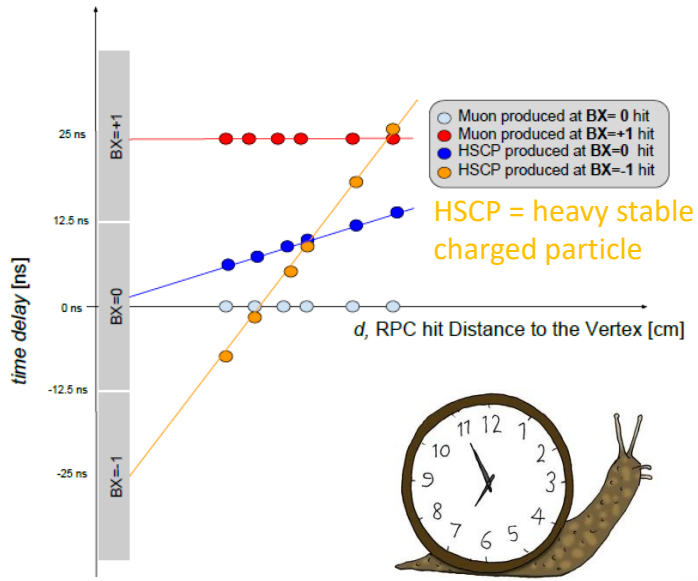


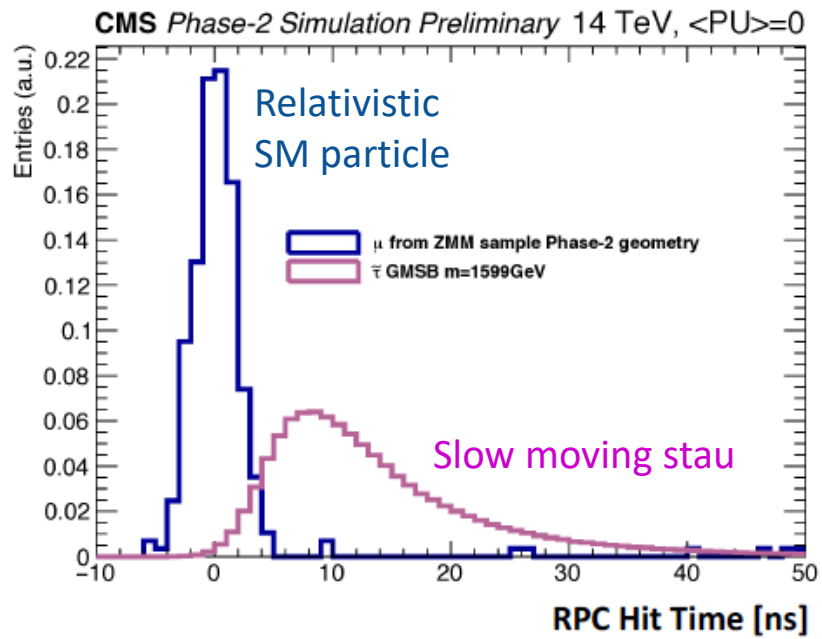


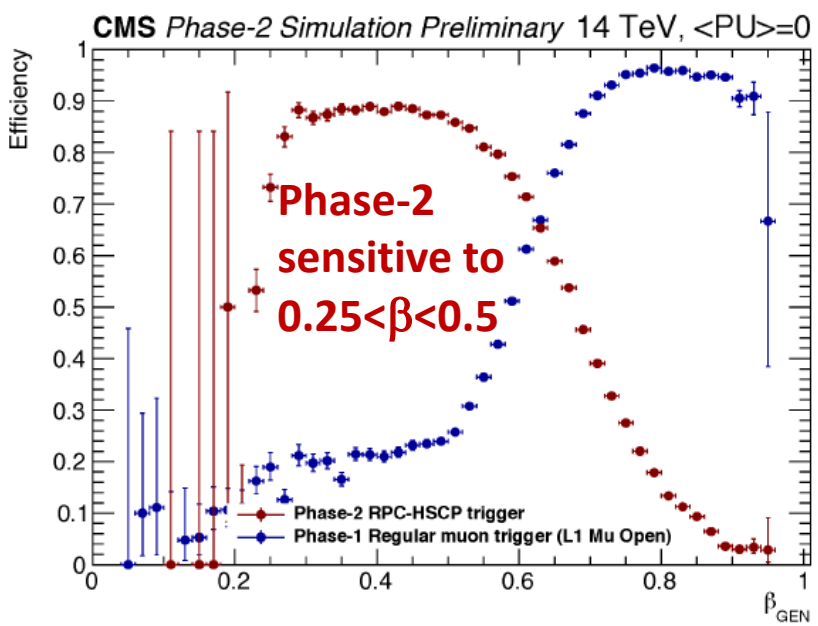
CMS upgrade tracker TDR TDR-17-001
CMS-PAS-EXO-14-007

Detection via Time-Of-Flight

Slow moving particles deviate sufficiently from relativistic TOF → allows to target low beta at **trigger level**

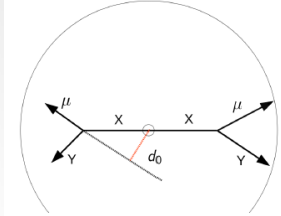






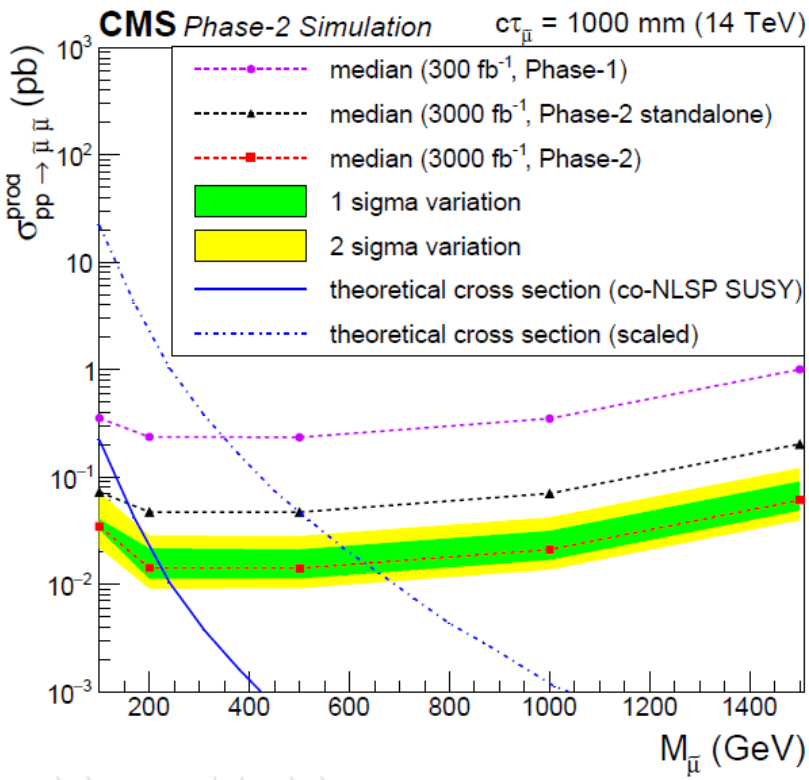
CMS TDR-17-003 (Muon TDR)

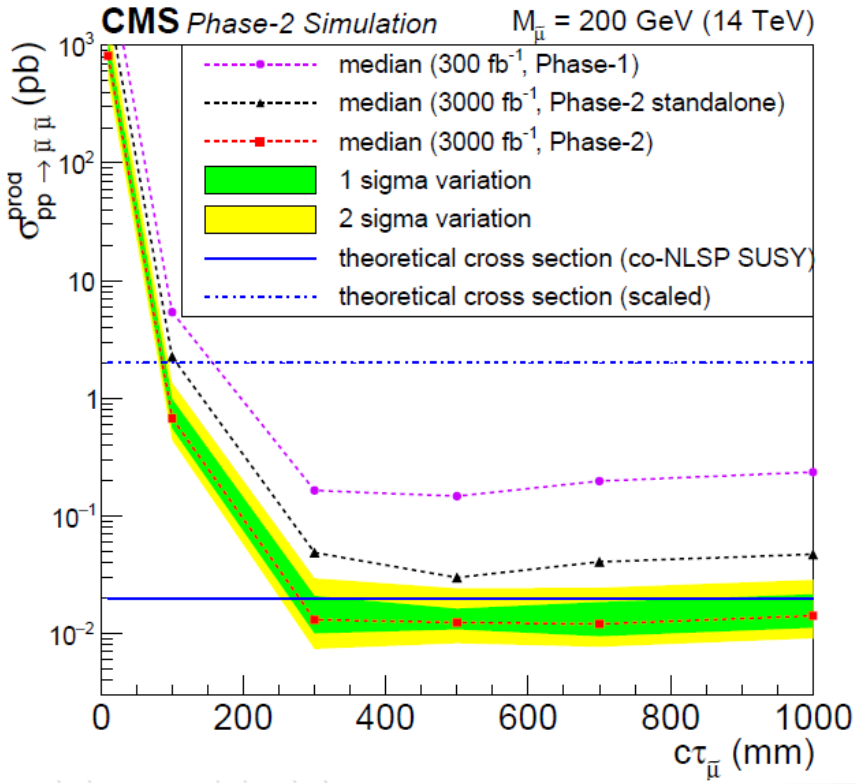
Sensitivity for Displaced Muons



$q\bar{q} \to \tilde{\mu}\bar{\tilde{\mu}}, \tilde{\mu} \to \mu\tilde{G}$

Search for muons with large displacement O(1-10 m) such that tracker does not contribute → trigger and reconstruction only in muon system.





Particular SUSY model with TeV smuons with production cross section $\sigma_{prod} < 10^{-2}$ fb
Exclude masses $m(\tilde{\mu}) < 220$ GeV with 3000/fb, Phase-2 detector.

Sensitivity in terms of decay length $c\tau$
Also discovery sensitivity.
More interpretations in other models ongoing.

Flavour puzzle

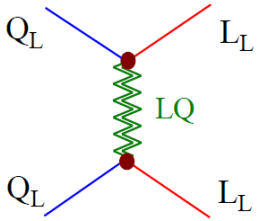
Observed anomalies in B-physics

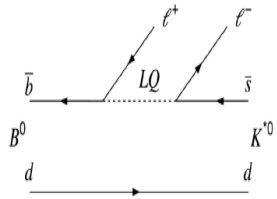
Complementary searches in other channels

Many Run-2 searches in all final states. Some projections for HL-LHC.

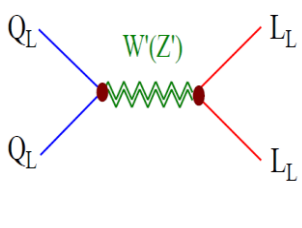
One possible explanation are leptoquark (LQ)-like mediators. TeV scale and 3rd generation favored.

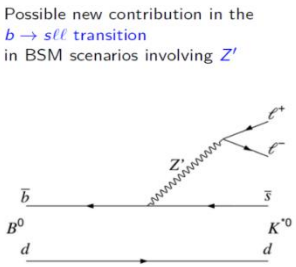
- Experimentally: LQ pair and singly produced. LQ3 -> τ + t ($\tau\tau$tt) and τ + b ($\tau\tau$bb).





Another possible explanation are Z´-like mediators. Also here 3rd generation favoured.





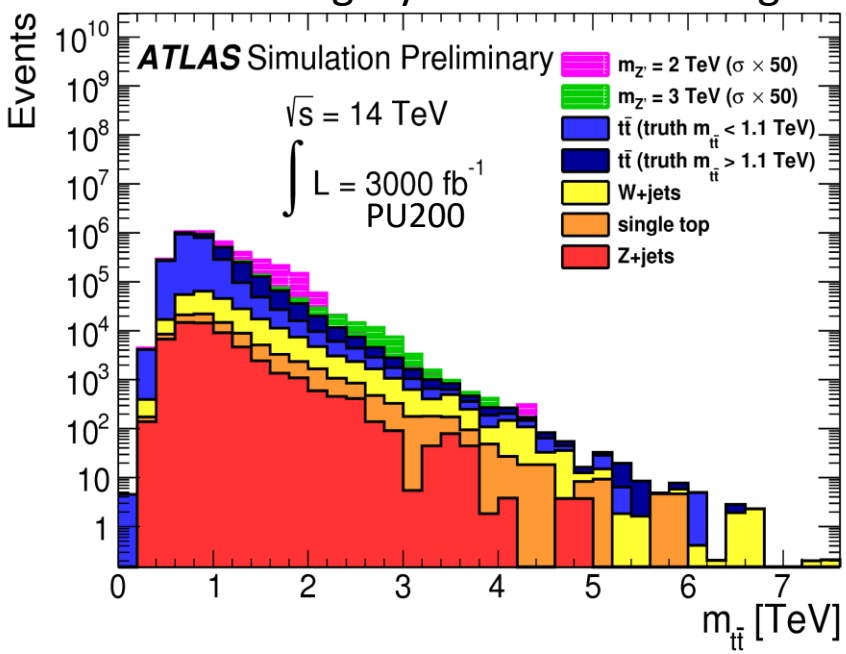
Ongoing projections for HL-LHC

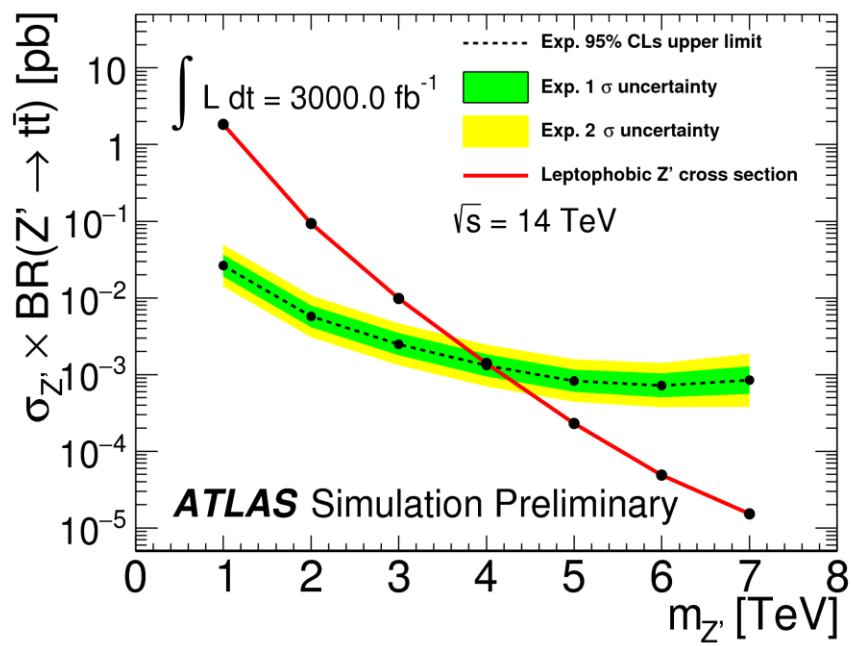
With material from talk by G.Isidori at CMS week Dec 6th 2017

Z´→tt→WbWb→lvbqqb

- 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-background neglected.
- Backgrounds simulated to NNLO

Boosted category with heavier Z' signals



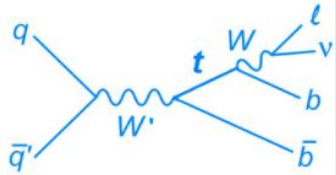


Detector effects: parametrized performance estimate of Phase-2 Det

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

ATL-PHYS-PUB-2017-002
Similar projection by CMS on Z´→tt

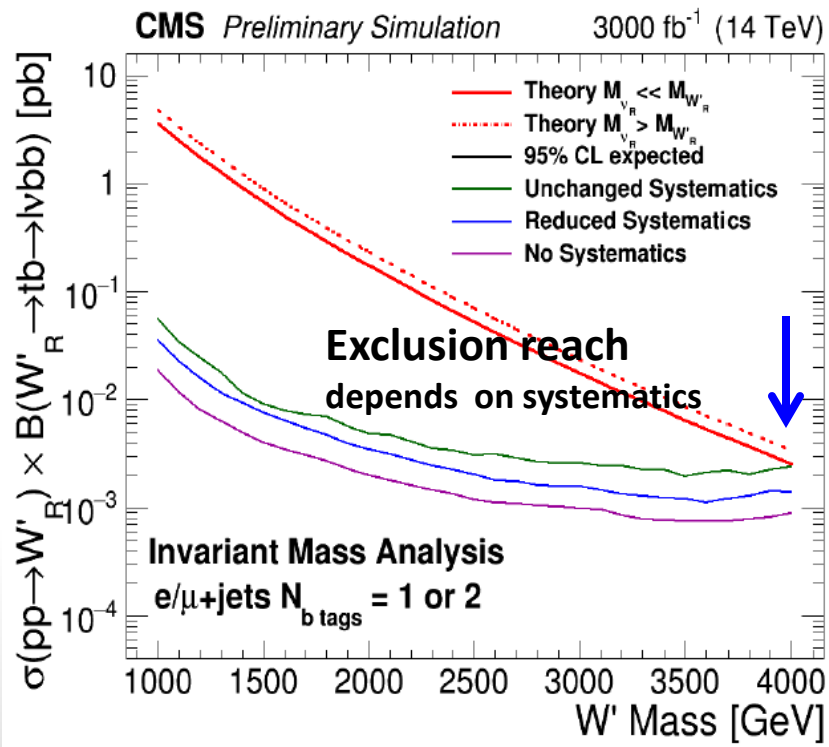
W′→tb →e/μ + b-jet(s)

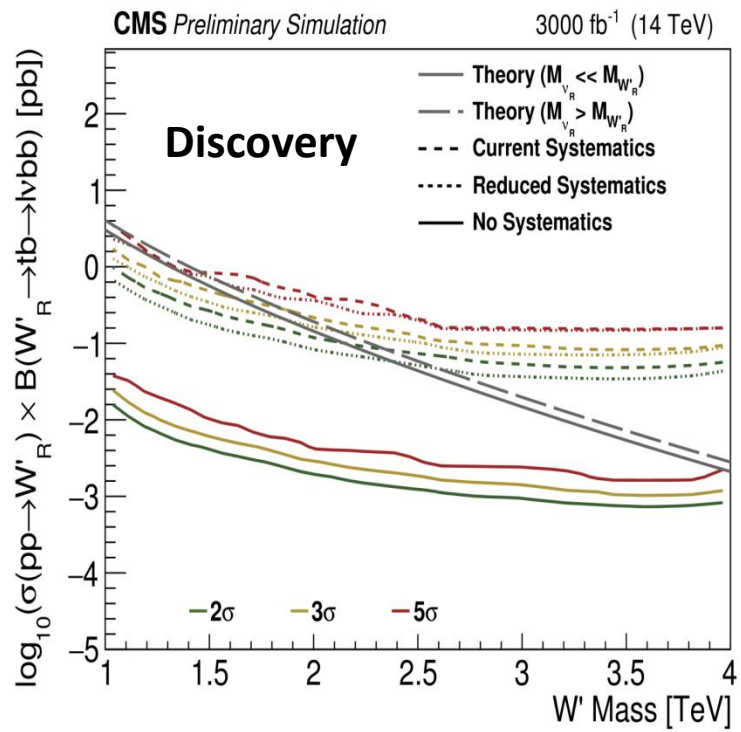


Three scenarios to extrapolate systematics from 12.9/fb to 3/ab

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

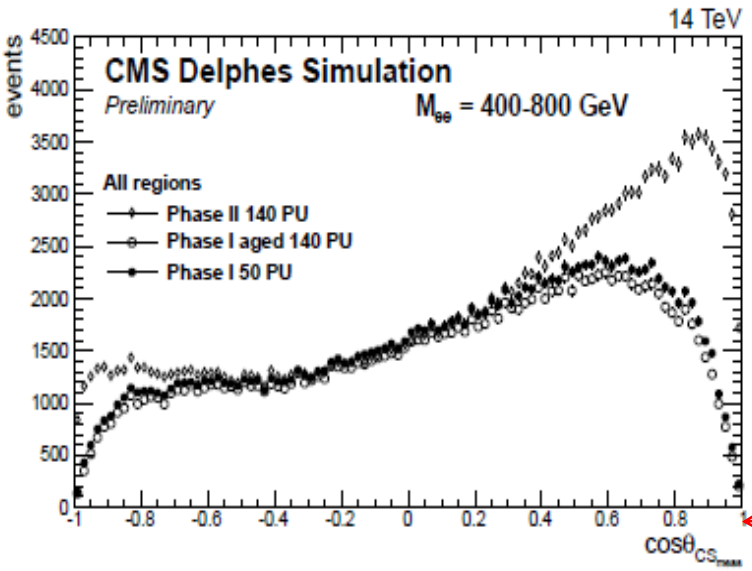
See something

What is it?

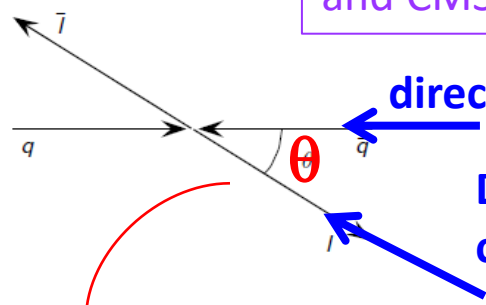
Study properties of „excess“ in phase-2

Property Measurements

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

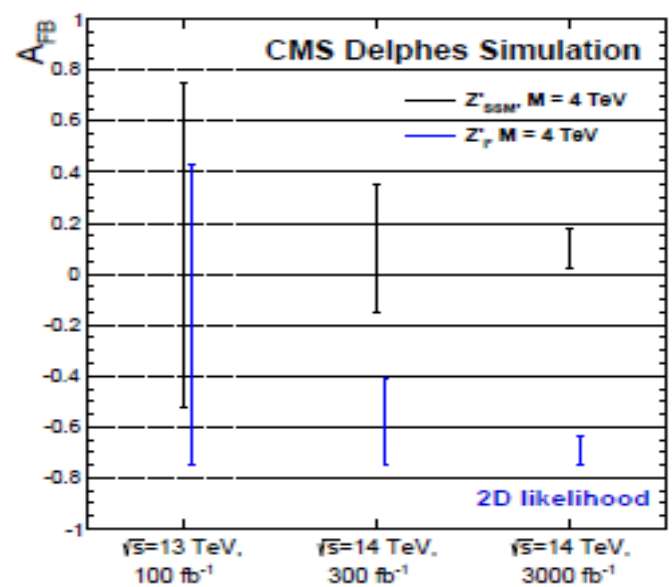


direction

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



Summary

Future is bright

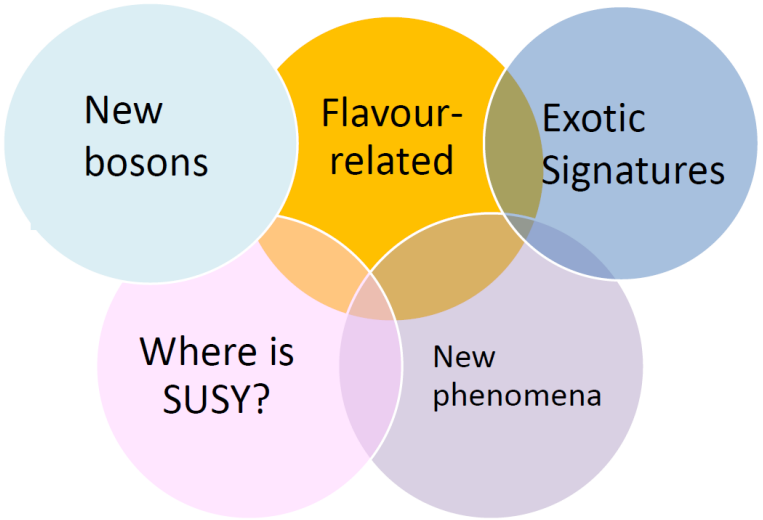
Rich BSM potential at HL-LHC.

Looking forward to another discovery ☺

Poked just here and there. Many more ongoing studies. Several projections and full analyses for a variety of benchmarks.

With HL rare processes and low couplings become accessible, also new models, signature-driven searches.

More details in references next page

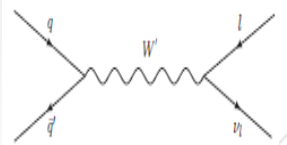


References

- [ATL-PHYS-PUB-2017-002] Study on the prospects of a tt^{-} 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-FTR-16-005] Estimated Sensitivity for New Particle Searches at the HL-LHC
- CMS-TDR-17-007 HGCAL performance for high-mass tt resonances
- [CMS-PAS-FTR-16-005] Estimated Sensitivity for New Particle Searches at the HL-LHC
- [CERN-LHCC-2017-017] ATLAS Muon upgrade TDR
- [CMS-PAS-EXO-14-007] Enhanced scope of a Phase 2 CMS detector for the study of exotic signatures at the HL-LHC
- CMS-TDR-17-003 CMS Muon upgrade TDR
- CMS-TDR-17-006 CMS ECAL barrel TDR
- CMS-TDR-17-007 CMS Forward calorimeter TDR

Talk by Gino Isidori at CMS week December 6th 2017

W´ Projected Discovery Reach

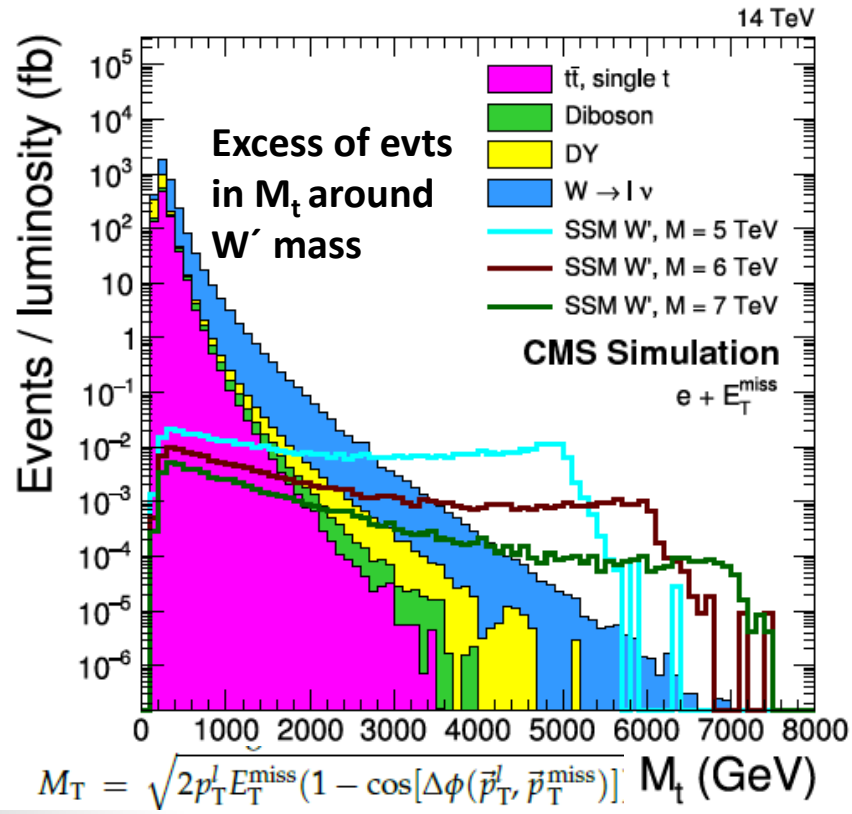


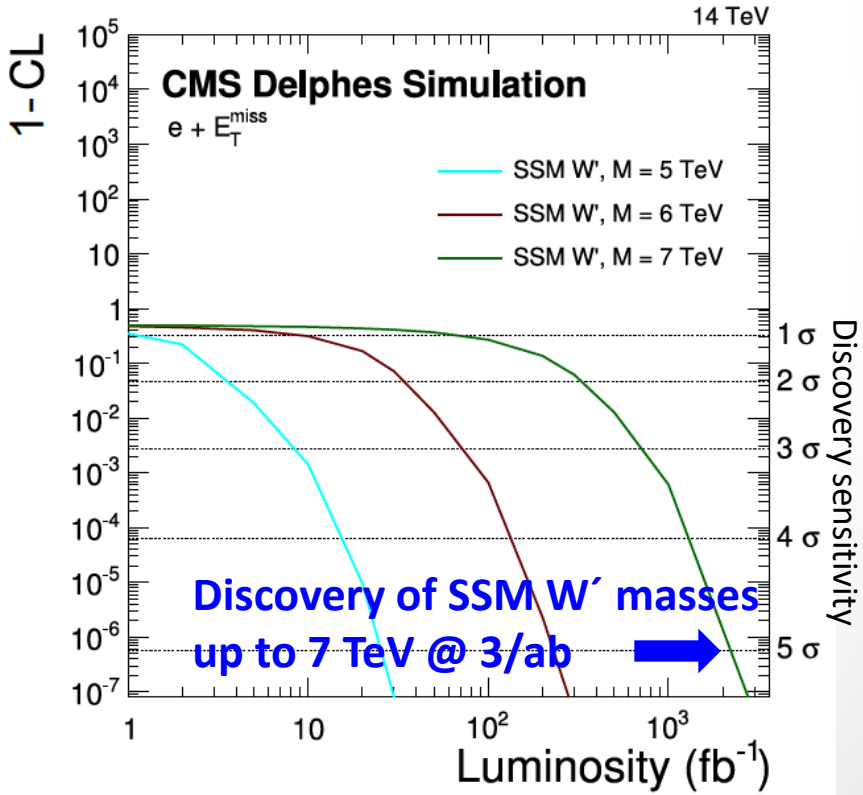
Benchmark analysis with max discovery sensitivity. DELPHES analysis.

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.





CMS-PAS-EXO-14-007

Exotic states of HH to bbbb

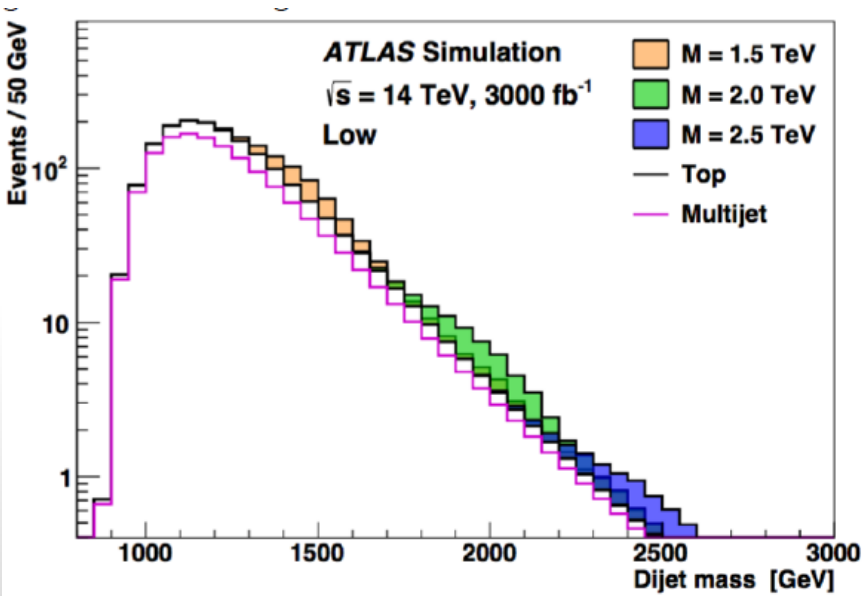
High-Mass Kaluza-Klein gravitons with each of the Higgs bosons decaying to $b\bar{b}$.

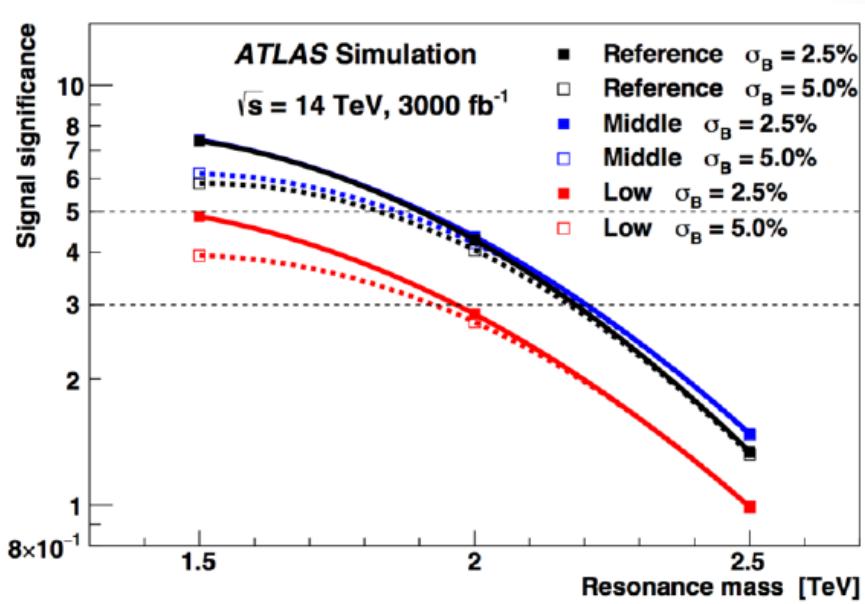
- Large Jet: anti-Kt R=1.0
- Track Jet: anti-Kt R=0.2. Used as proxy for "track jet" that are b-tagged.
- Trigger Jet anti-Kt R=0.4

Dominant background from QCD production.

Needs b-tagging → impact from upgrade scenario for medium masses

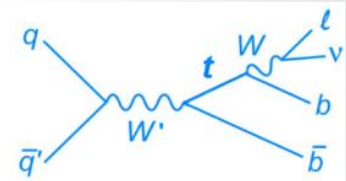
Technique similar to dijet analysis, looking for bump from a sharp resonance in spectrum. Sliding mass window around resonance mass for each signal mass point.





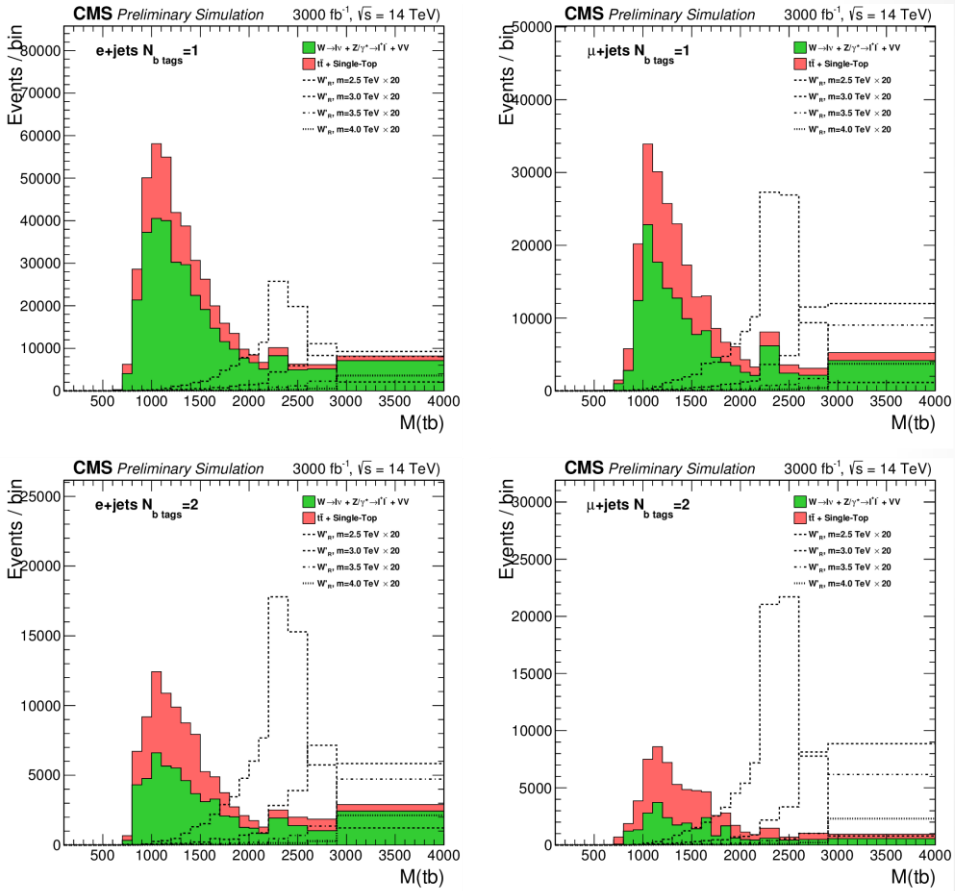
http://cds.cern.ch/record/2055248/files/LHCC-G-166.pdf

CMS W´→tb



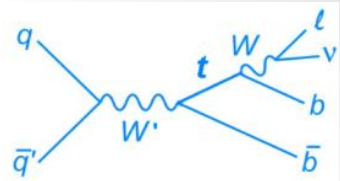
Probe scenarios such $m(\nu_R) > m(W') \rightarrow$ forbidden for $W' \rightarrow l\nu$

- 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

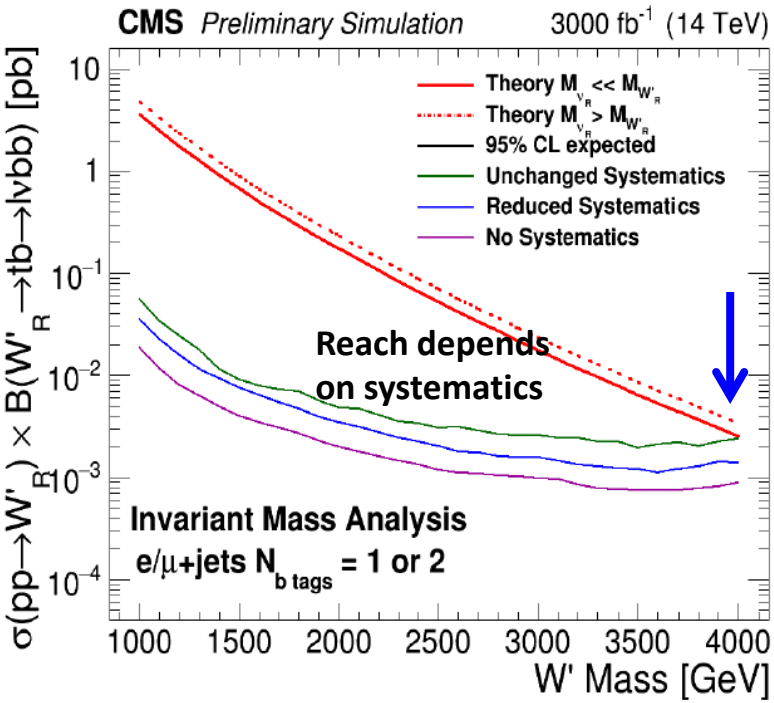


Three scenarios to extrapolate systematics from 12.9/fb to 3/ab

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

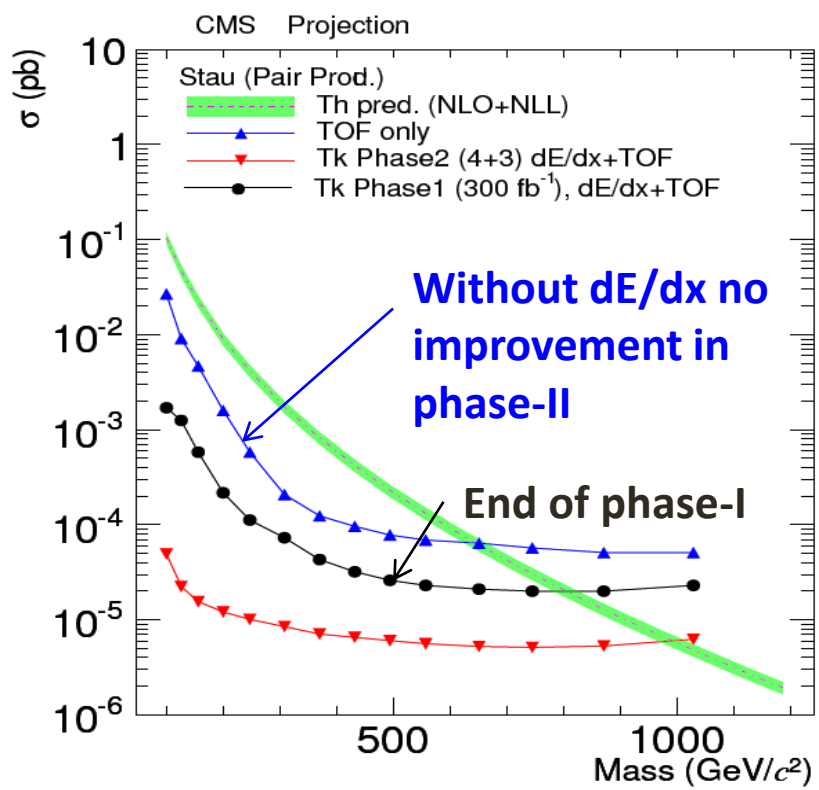
Exclusion limit m(W´) >4 TeV @3/ab

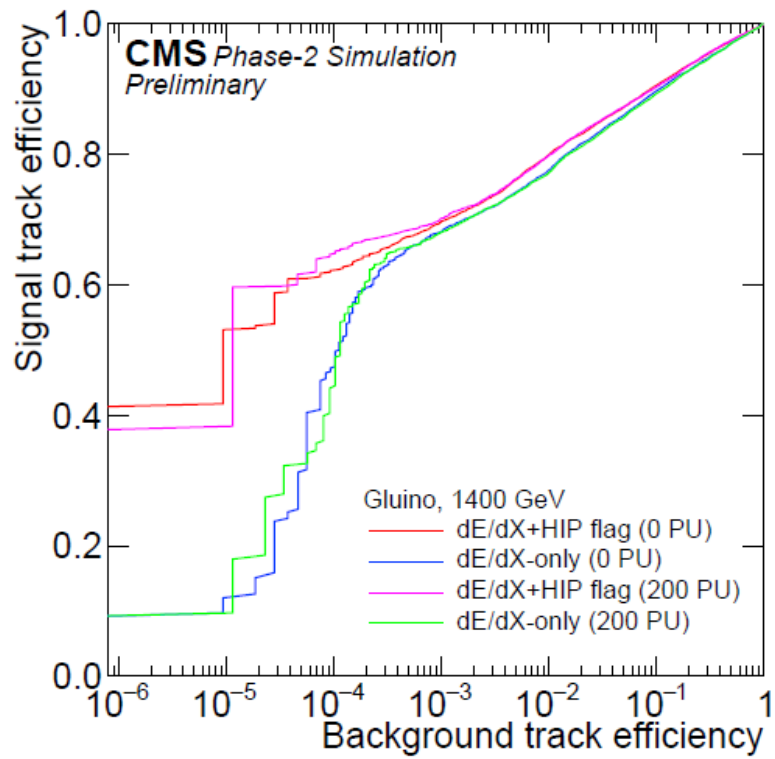
Baseline analysis tb at 13 TeV B2G-15-004, B2G-16-017.
Projection in DP-2016/064 and CMS-PAS-FTR-16-005

Detection via Anomalous dE/dx

Slow moving particles ($\beta << 0.9$) can be identified from their anomalous dE/dx

Similar method for fractionally and multiply charged particles





CMS upgrade tracker TDR TDR-17-001
CMS-PAS-EXO-14-007