BSM Physics at the HL-LHC

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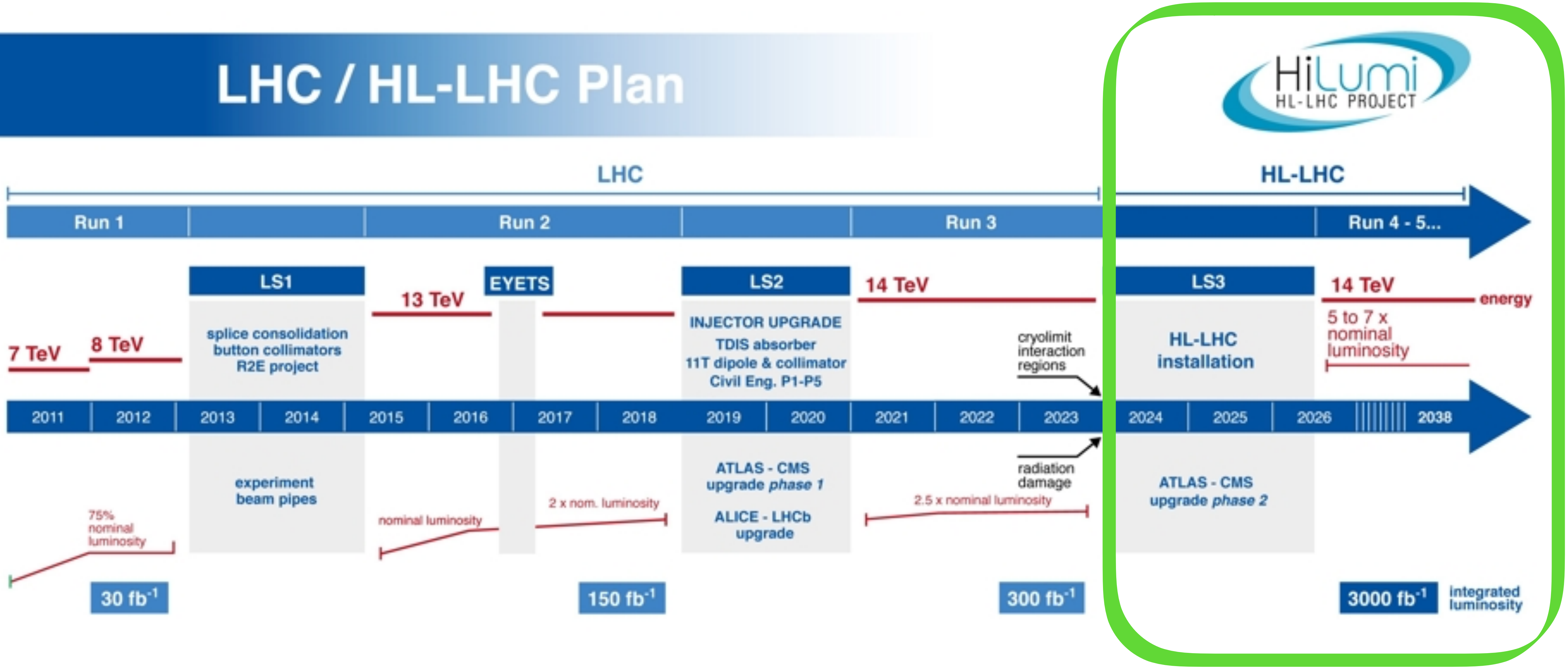


Improved detectors

- High pile up
- High beam-induced background
- High radiation

versus

- Higher granularity tracking & calorimetry
- Extended η coverage for tracker and muons
- Improved triggering (tracks, vertices, muons)
- Improved timing
- Improved readout
- Improved radiation hardness

Dark sectors

◆ Long lived particles

◆ Dark matter

Flavor

Others

◆ Vector-like quarks

◆ Heavy resonances

◆ SUSY

◆ in this talk

BSM searches at HL-LHC

- Continue and improve current searches to extend sensitivity
- Design new searches exploiting the new detector improvements.
- Develop new analysis strategies.

—> access scenarios with lower cross sections, lower acceptance.

—> open new search channels

  - e.g., in SUSY: focus on EWK sector, staus, compressed scenarios
  - e.g., long lived particles: explore improvements in muon systems, tracking, triggers and dedicated timing detectors to expand searches.

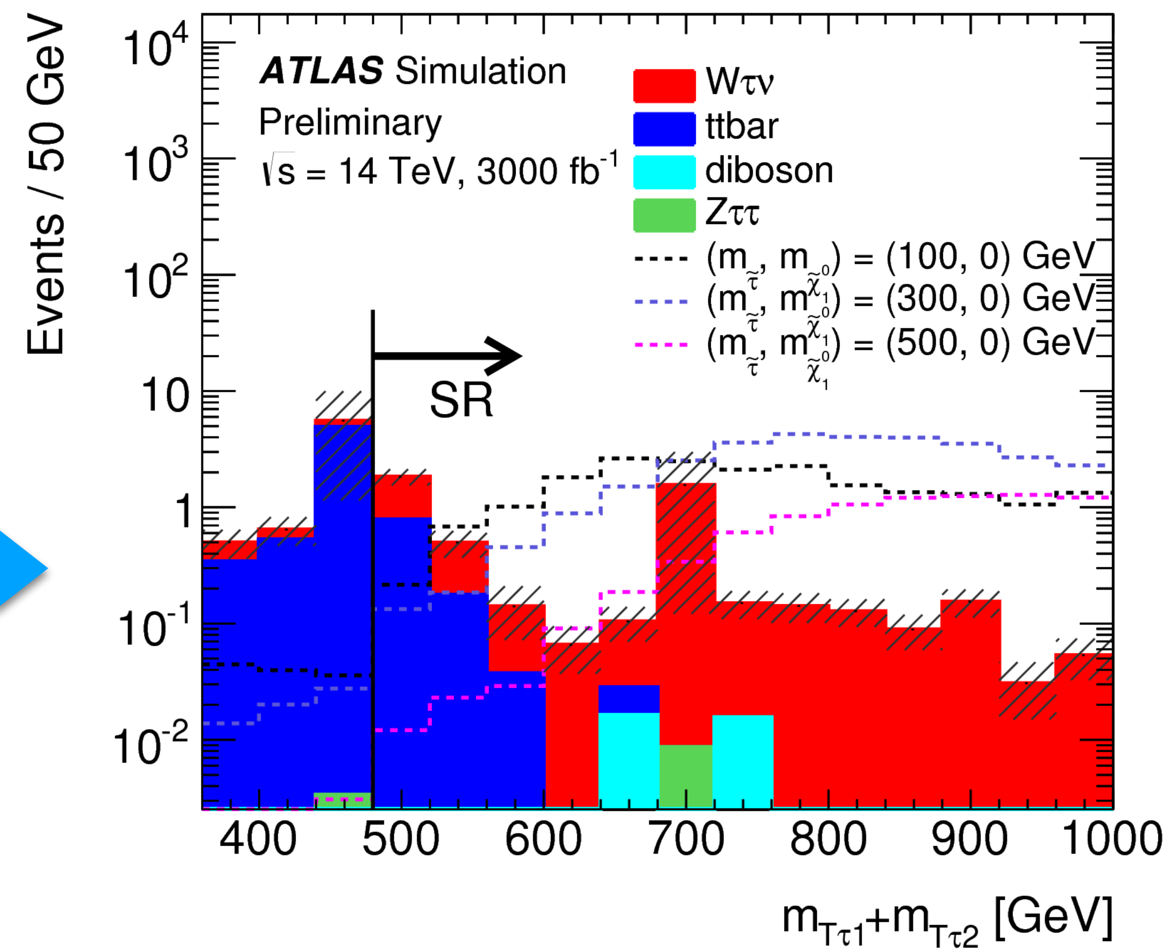
2 current methods to establish sensitivity

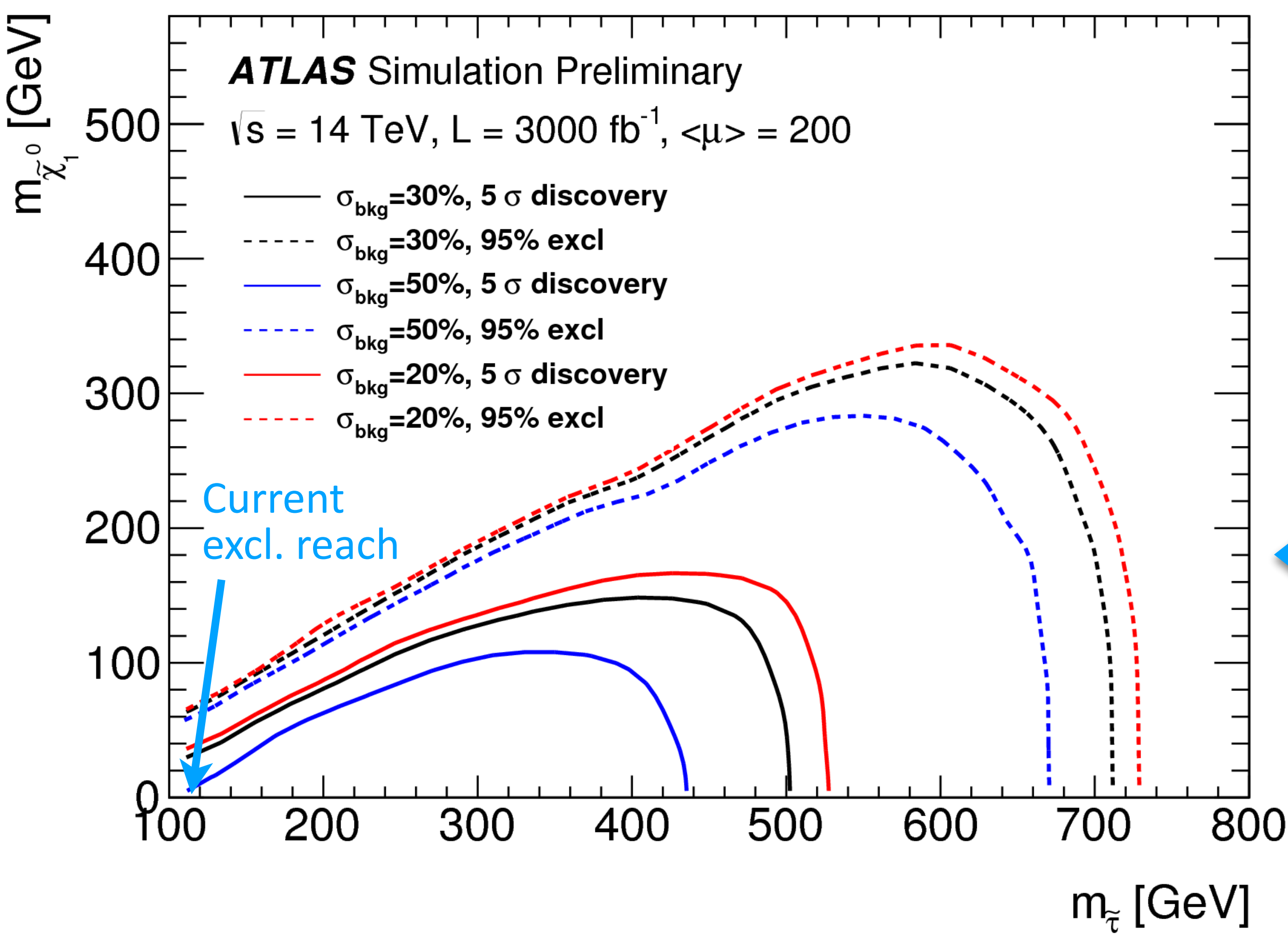
- Projections from a present analysis
  - Use existing samples, scale results to a higher luminosity considering different systematic scenarios
- Full analysis with parametrized detector performance
  - New simulation of the detectors, new/improved analysis design

Stau pair searches

ATL-PHYS-PUB-2016-021
Full anl.

- Direct $\tilde{\tau}\tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0\tau\tilde{\chi}_1^0$
- $m(\tilde{\tau}) \sim m(\tilde{\chi}_1^0)$ —> $\Omega_{\tilde{\chi}_1^0}h^2$ ~ observed.
- Low cross sections, low acceptance
- 2 OS τ_{had} + E_T^{miss} final state.
- Used $\Delta R(\tau_1, \tau_2)$, m_{T2}, $m_{T(\tau 1)} + m_{T(\tau 2)}$.





Current reach, $\tilde{\tau}_L\tilde{\tau}_L, \tilde{\tau}_R\tilde{\tau}_R$ combined:

- Excl: $m(\tilde{\tau}) <$ 109GeV for $m(\tilde{\chi}_1^0) = 0$.

HL-LHC reach, $\tilde{\tau}_L\tilde{\tau}_L, \tilde{\tau}_R\tilde{\tau}_R$ combined:

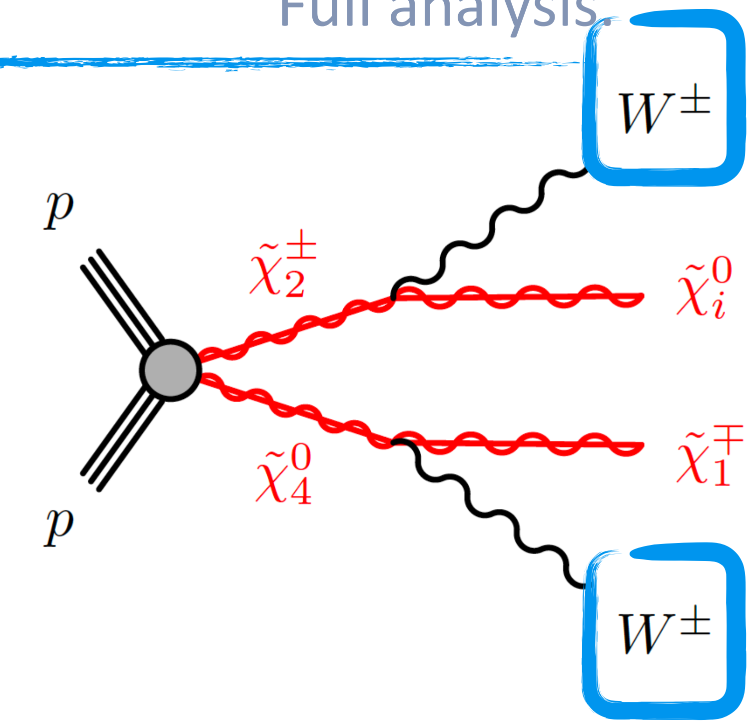
- 5σ disc: ~400 - 500GeV
- Exclusion: ~700GeV

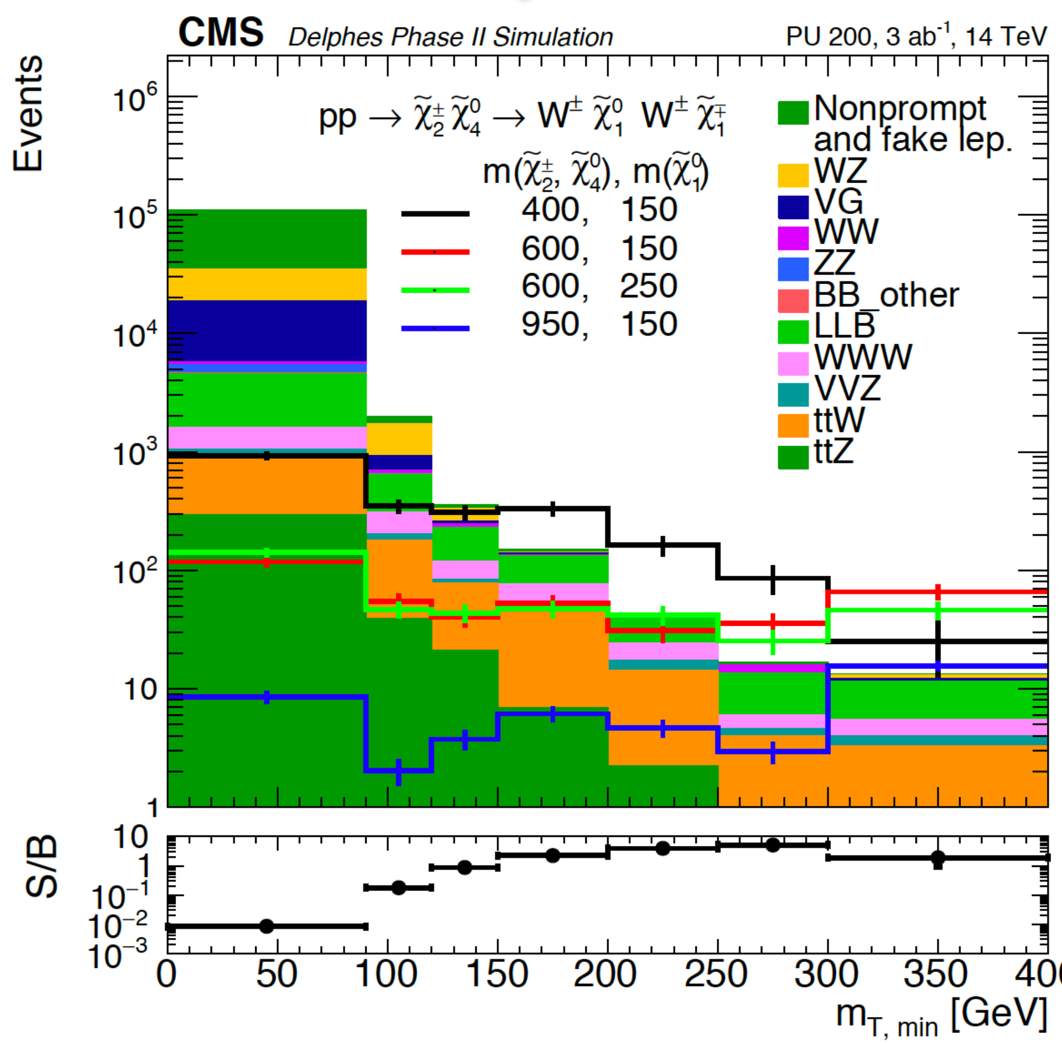
depending on systematics.

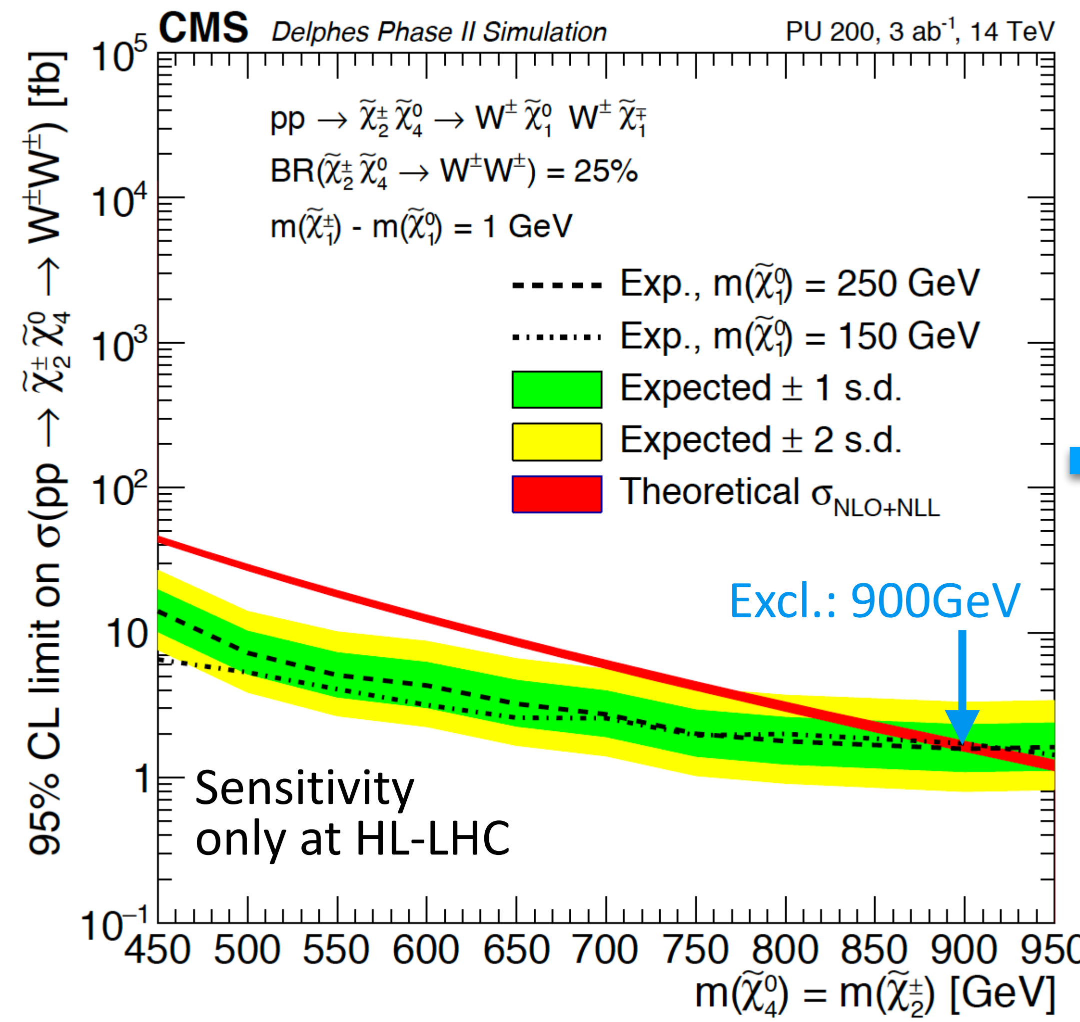
C2N4 in same sign dilepton search

CMS TDR-019
Full analysis

- SUSY EWK sector with $\mu < M_1 < M_2$.
  —> wino like degenerate $\tilde{\chi}_2^{\pm}\tilde{\chi}_4^0$ mass ~ M_2.
- 2 SS Ws (leptons) + E_T^{miss} final state.
  <— NEW search channel.
- Used $m_{T,\min} = \min[m_{T(lep_1,p_T^{miss})}, m_{T(lep_2,p_T^{miss})}]$.





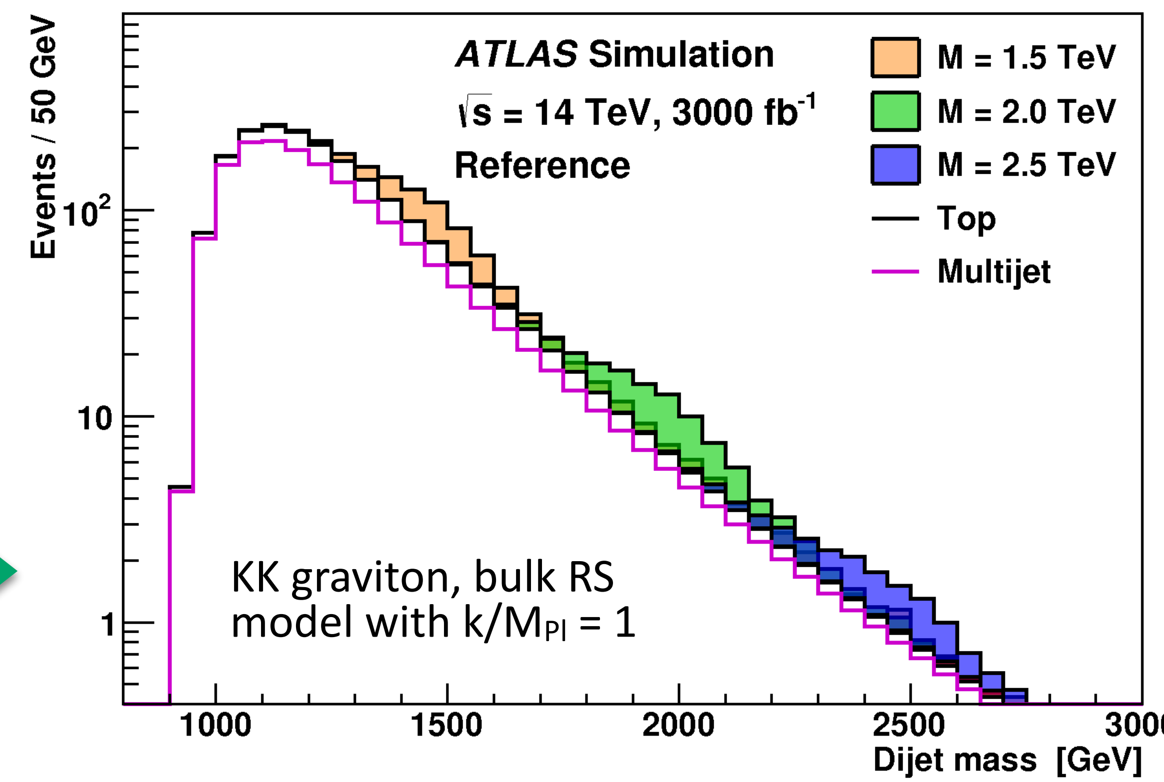


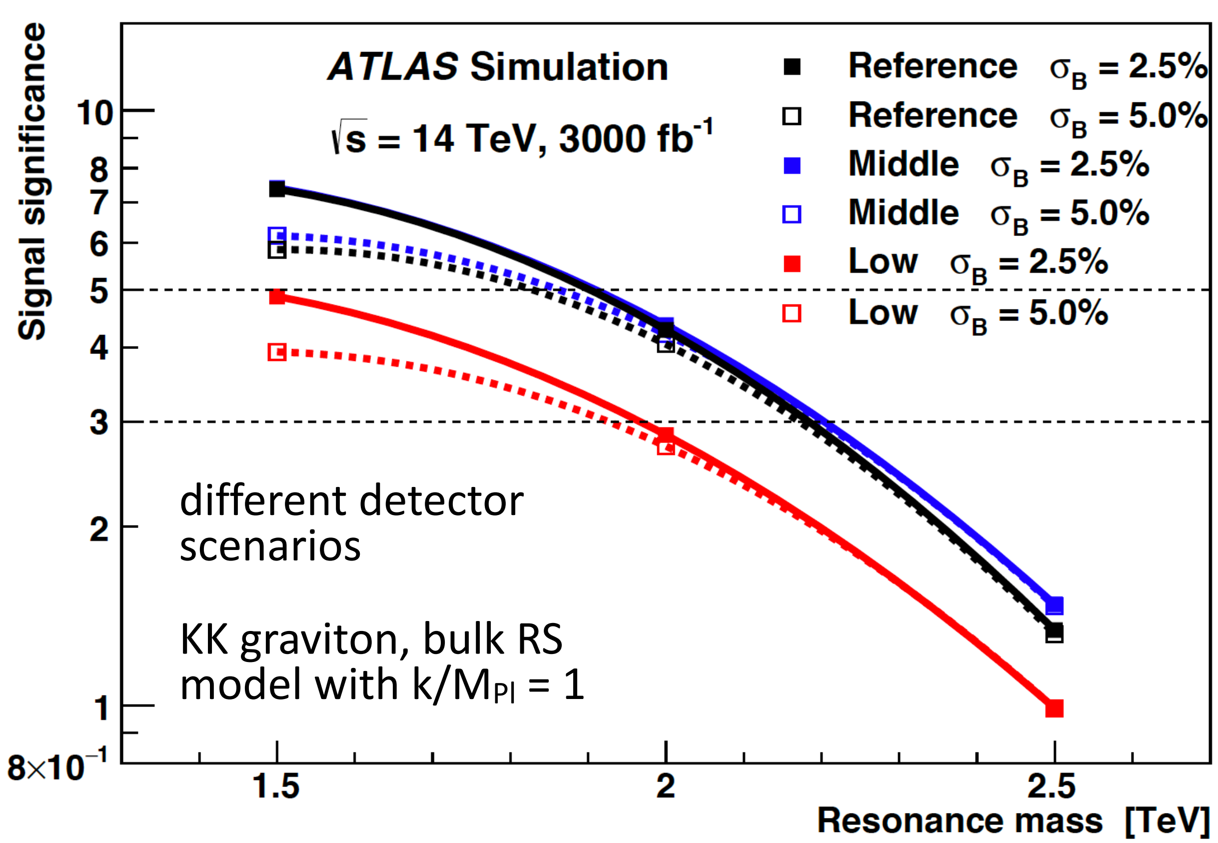
HL-LHC has potential to probe most of natural SUSY space with EW naturalness $\Delta EW < 30$.

Exotic states with HH —> bbbb

ATLAS LHCC-G-166 Projection

- Heavy resonances $X \to HH \to b\bar{b}b\bar{b}$
  - KK excitation of graviton in bulk RS
  - heavy neutral Higgs in 2HDMs
- Tag boosted $H \to b\bar{b}$ using jet mass, finding sujets, and subjet b-tagging.
- Look for bumps in di-boosted jet invariant mass distribution.





Sensitivity to bulk gravitons: ~2.5TeV.

Current excl.: 500-720 GeV.

CMS FTR-18-003 Projection

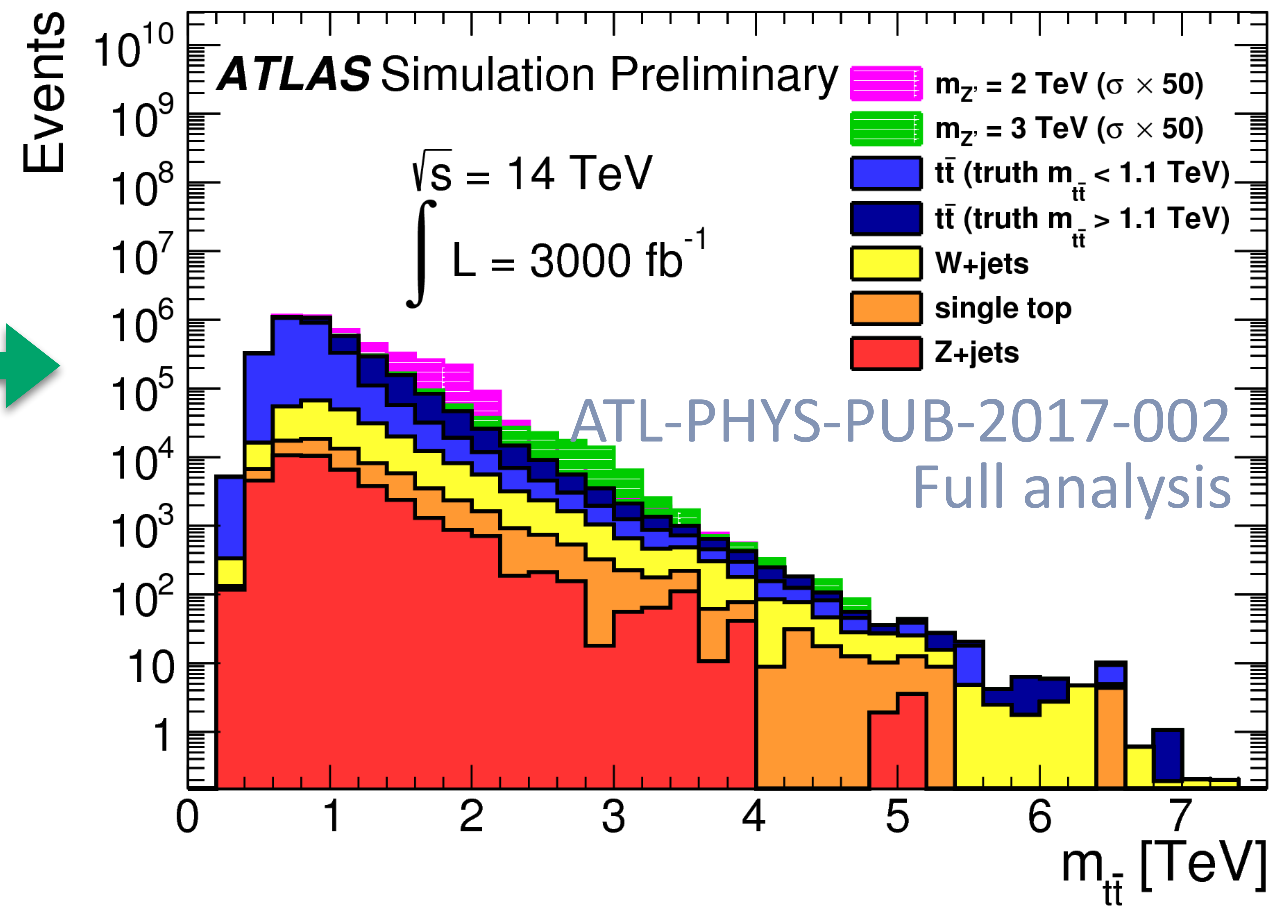
Similar CMS study studied VBF production of $X \to HH$

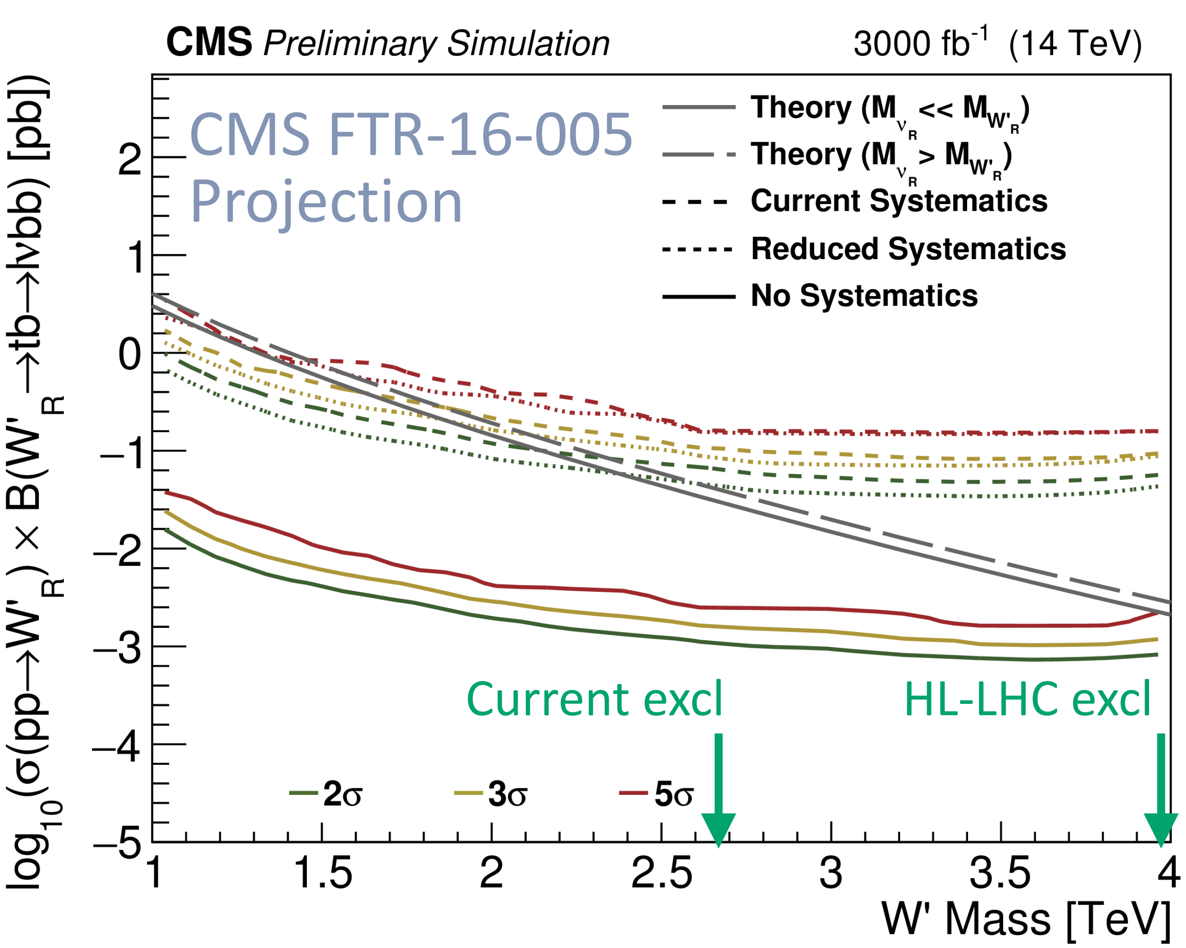
Used forward jets, and found sensitivity up to m_G ~ 3TeV.

heavy resonances

Z' and W' searches

- $Z' \to tt \to WbWb \to l\nu bqqb$. TopColour model with a spin-1 Z'.
- Boosted t or resolved t with 1e/μ.
- Reconstruct tops and check m_{tt}.
- Current/300fb^{-1} excl.: $m_{Z'}$ ~2.1/3TeV.
- HL-LHC excl.: $m_{Z'}$ ~4TeV. (boosted search dominates)



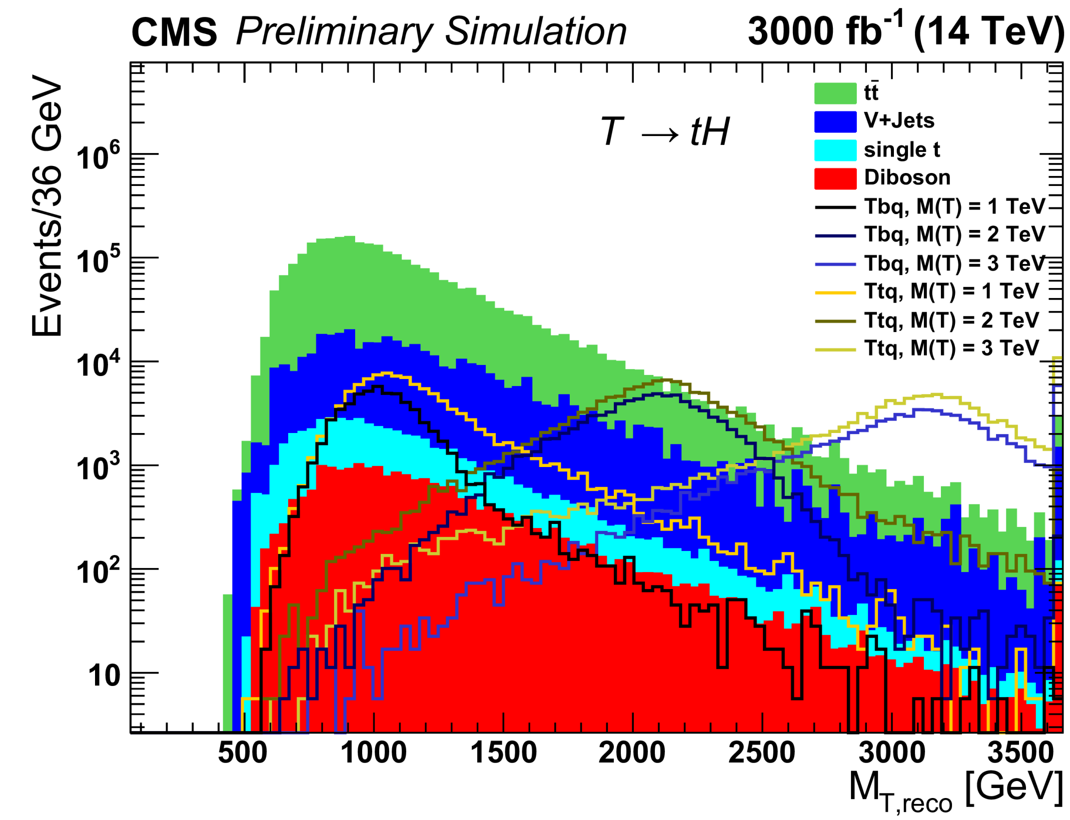


- Heavy $W' \to tb \to e/\mu + \nu bb$
  - e.g. sequential SM.
- e/μ + jets + b jets + E_T^{miss}.
- Search for signal in inv mass m_{tb}.
- Current excl: 2.7TeV.
- HL-LHC excl: $m_{W'}$ beyond 4TeV.
- HL-LHC discovery: $m_{W'}$ up to 4TeV.

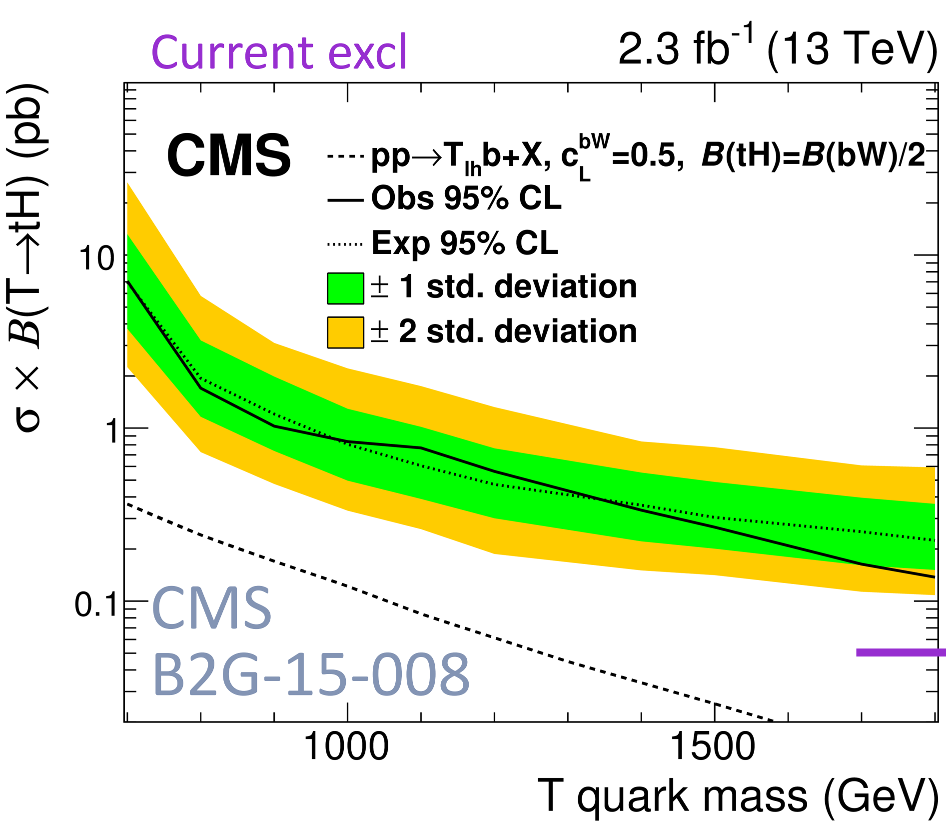
VLQ top partner search

CMS FTR-16-005
Full analysis.

- EWK production (Wb/Zt fusion) of VLQ top partner $gq \rightarrow Tbq'/Ttq$ with $T \rightarrow tH$.
- 1lep + jets + b jet(s) + boosted H + E_T^{miss}. + forward jet.
- Reconstruct m_T with a χ^2 minimization.
- HL-LHC greatly extends sensitivity and opens access to these models.

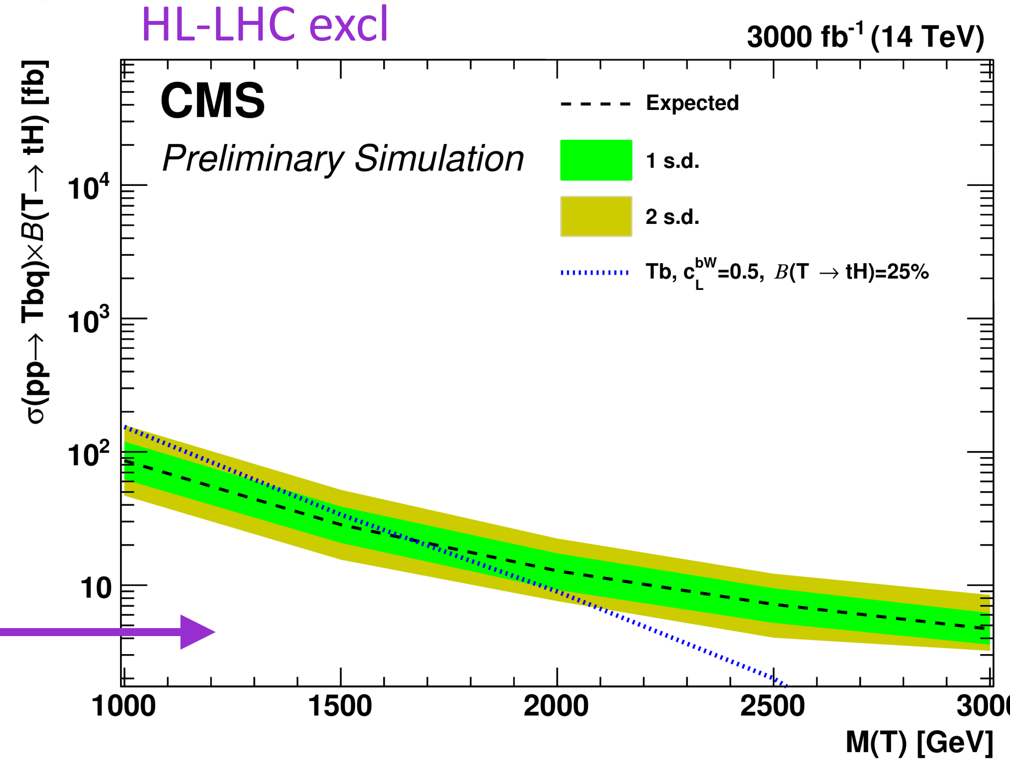


Current excl



CMS B2G-15-008

HL-LHC excl



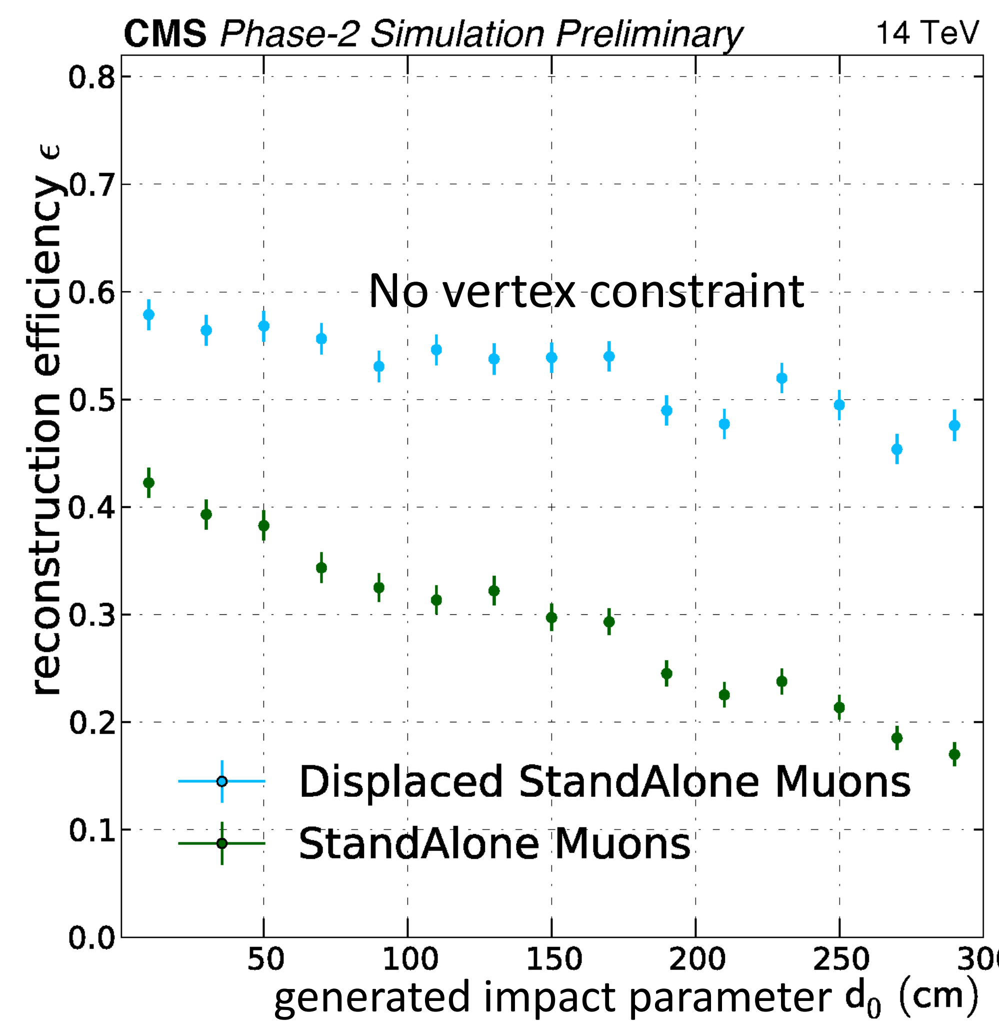
A versatile HL-LHC VLQ and VLL search program being designed:

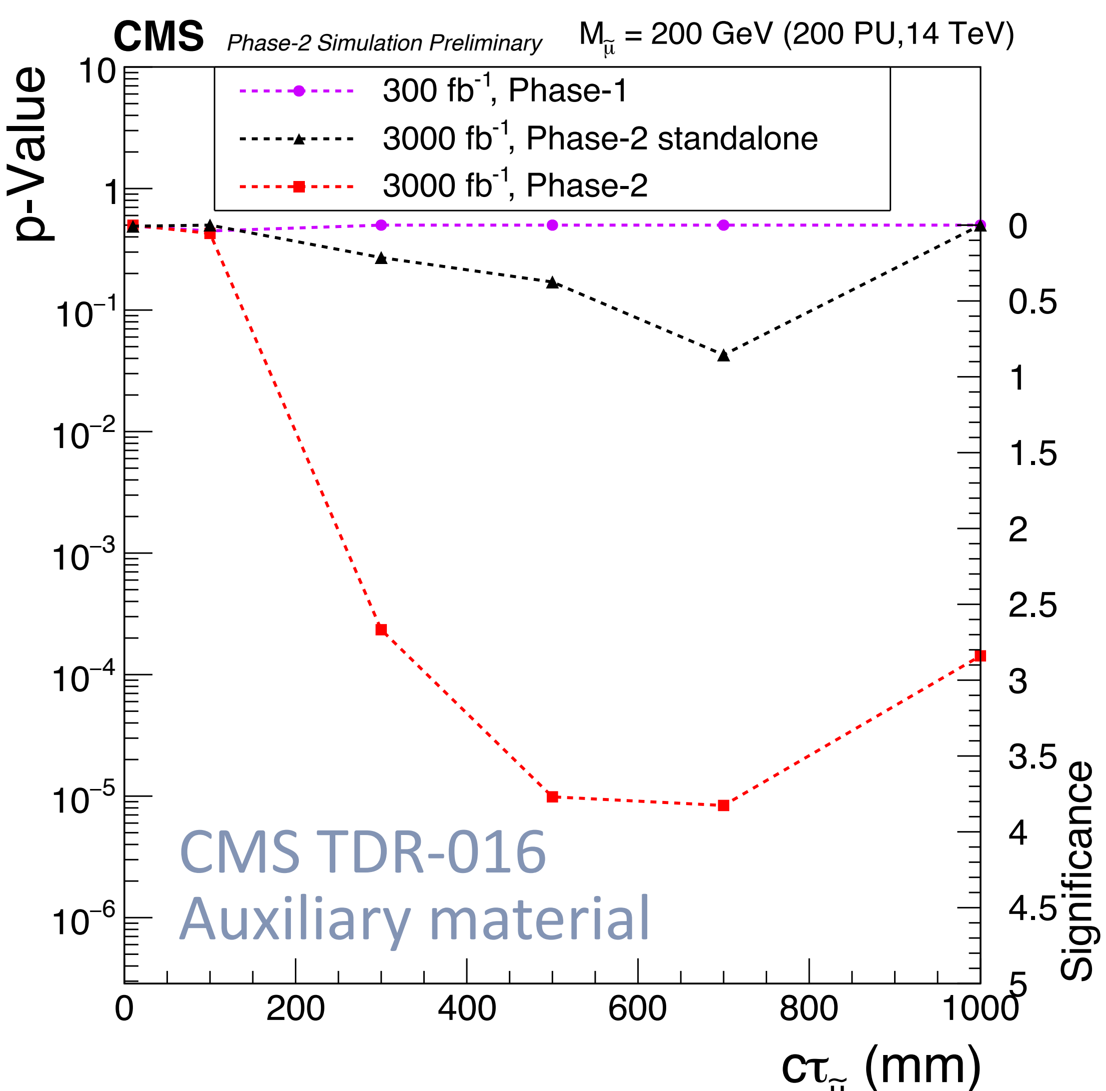
Production in heavy Higgs decays, measurement of chiral structure, …

Displaced muon search

CMS TDR-016
Full analysis

- Model independent search for displaced muons decaying outside the tracker.
- Trigger and reconstruction only in the muon system (standalone muons)
  - Additional hits in new muon layers + improved algorithms improve efficiency.



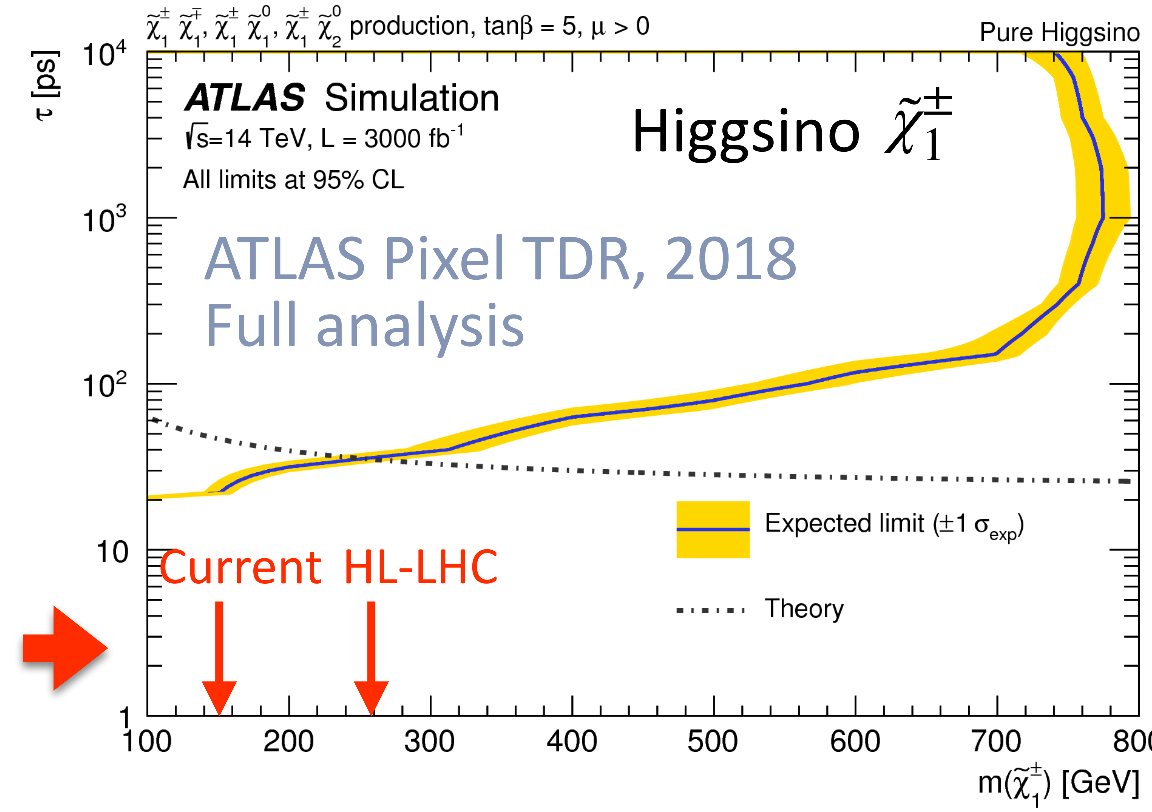


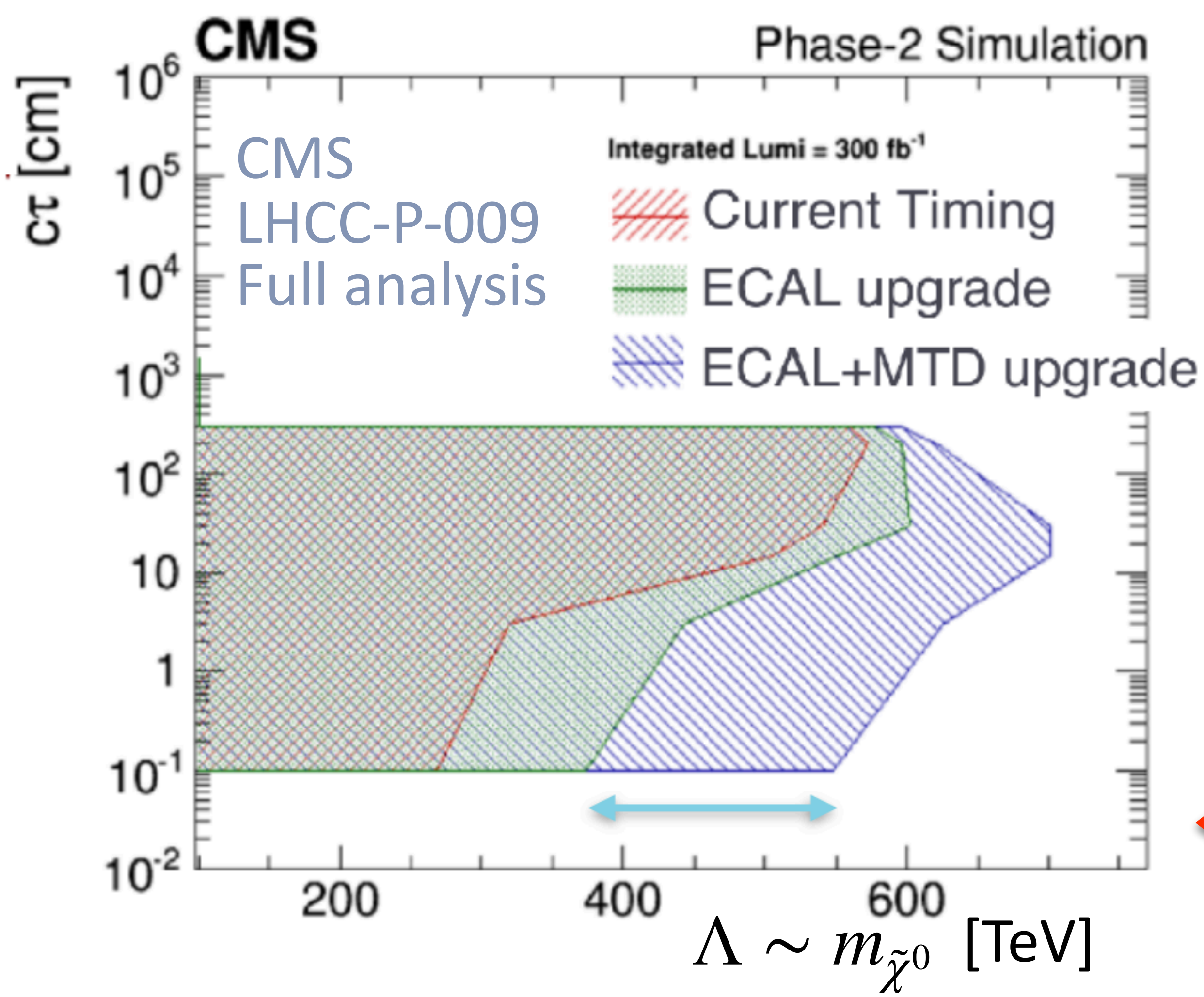
- Interpretation in terms of GMSB smuons: $\tilde{\mu} \rightarrow \tilde{G}\mu$ (low cross sections)
- Exclude smuons with mass < 220GeV.
- Discovery wrt cτ significantly improved.
- Interpretations ongoing for other models (e.g. dark photons).

long lived particles

Disappearing tracks, displaced vertices

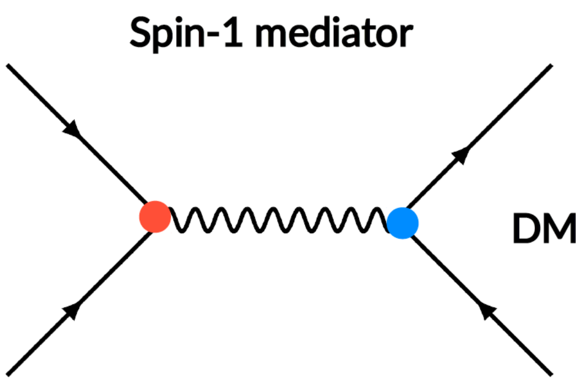
- Long lived $\tilde{\chi}_1^{\pm}$ when $m(\tilde{\chi}_1^{\pm}) \simeq m(\tilde{\chi}_1^0)$
  —> $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + \pi^{\pm}$ (very soft $\pi^{\pm}$)
- Disappearing track + E_T^{miss}.
- ATLAS: Benefit greatly from the new inner tracker strip detector (ITk).
- Wino $\tilde{\chi}_1^{\pm}$ excl: 400 (Run2) —> 800GeV.
- Pure higgsino $\tilde{\chi}_1^{\pm}$: 150 (Run2) —> 260GeV.

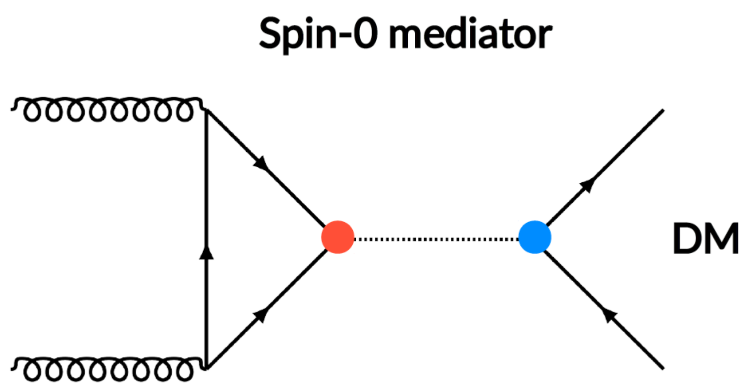




- Displaced photons from $\tilde{\chi}^0 \to \tilde{G} + \gamma$
- CMS MTD: MIP timing with 30ps precision. Acceptance of |η| < 3 for p_T, p < 0.7 GeV in barrel/endcap.
- Use time of arrival of photons to MTD to discriminate signal —> determine $\tilde{\chi}^0$ time of flight.
  —> increased sensitivity with MTD to short lifetimes and high masses.

Dark matter searches





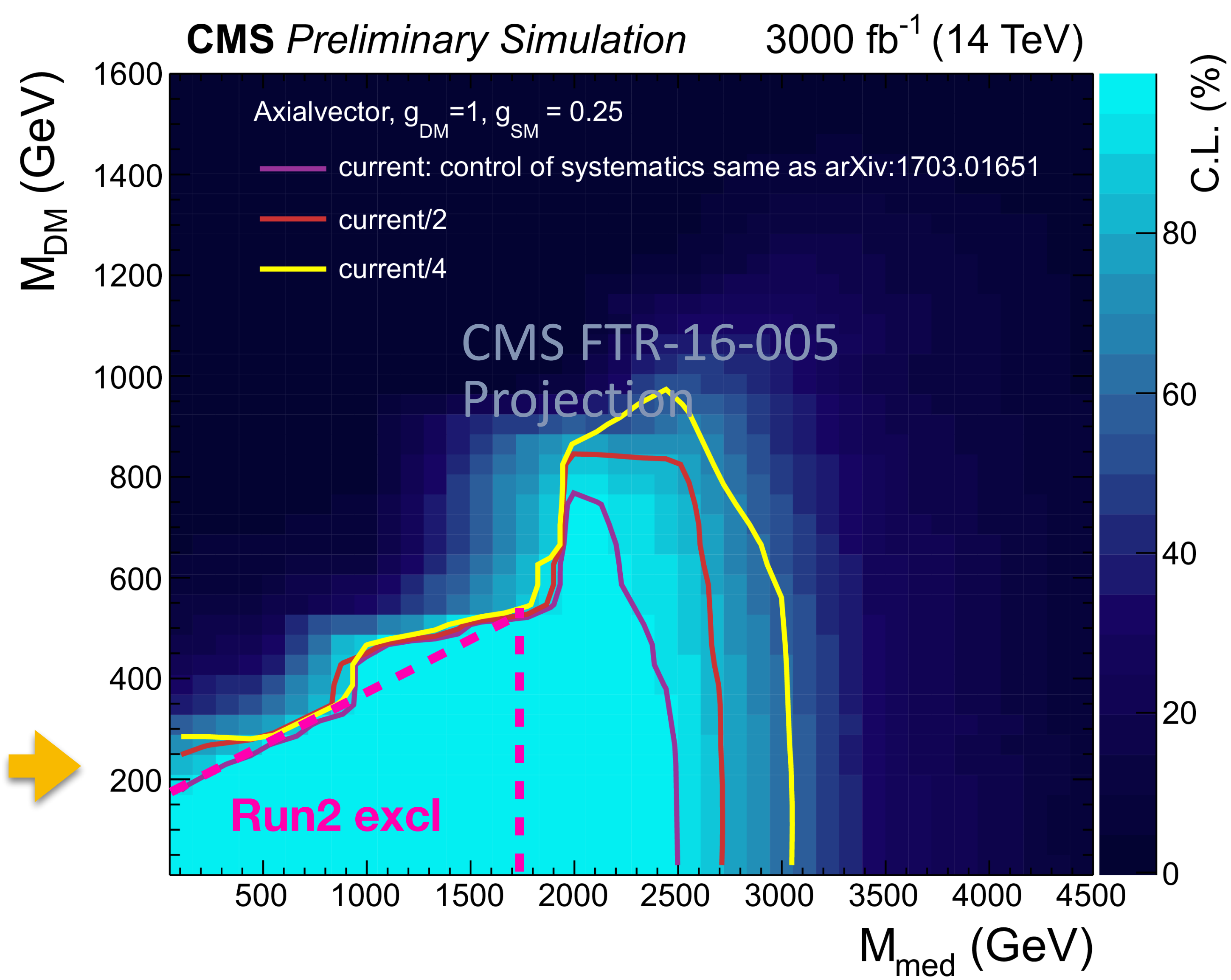
Simplified models with few free parameters:

$m_{mediator}$, m_{DM}, couplings $g_{mediator\text{-}SM}$, $g_{mediator\text{-}DM}$.

DM at HL-LHC:
Mainly projection studies

- Monojet
- DM + heavy flavor (DM+t, tt, bb, tttt)
- DM + mono Z, γ, VBF DM
- …

Example: Monojet + E_T^{miss} search



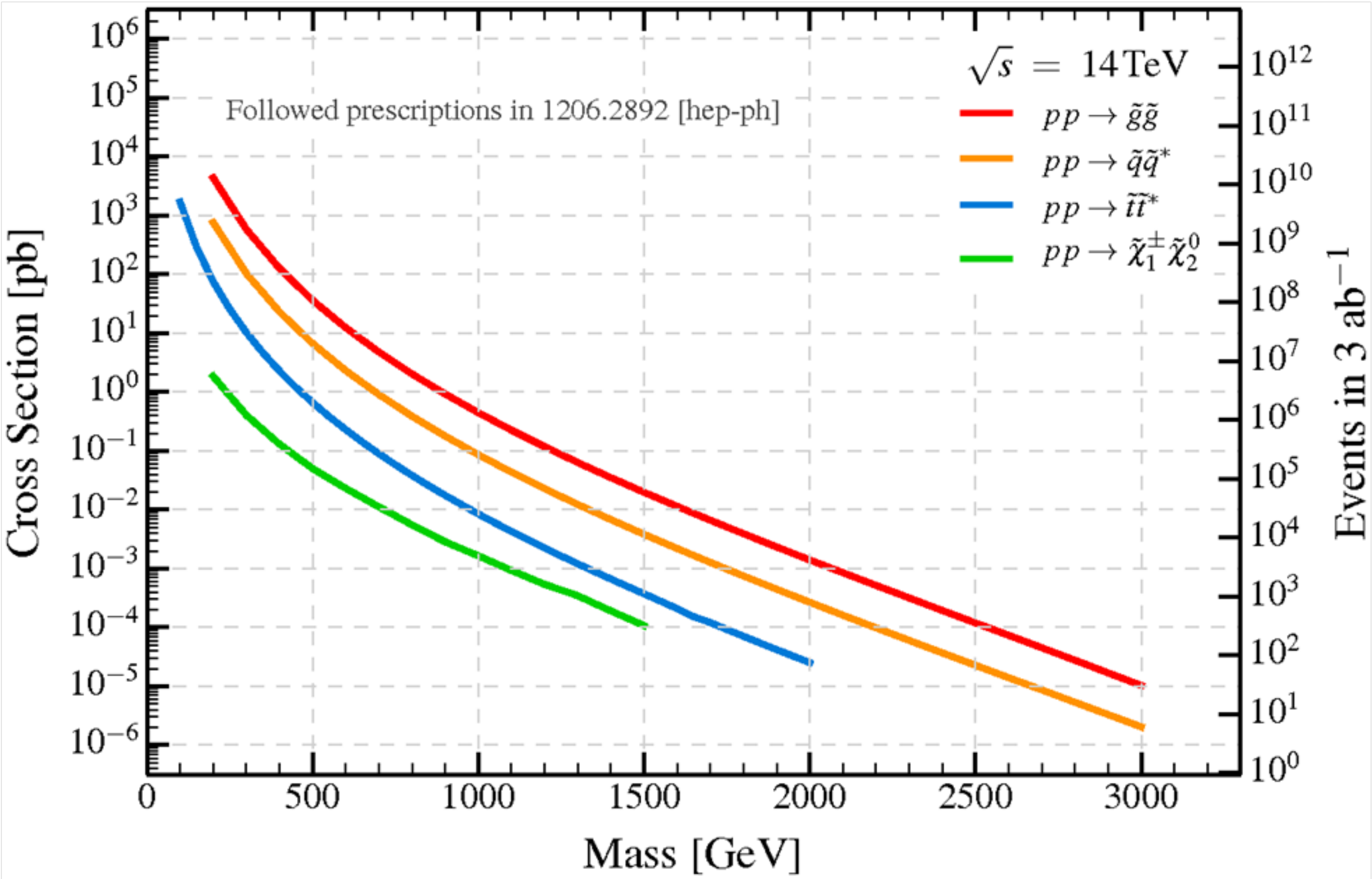
Summary

- HL-LHC offers an unprecedented amount of data and novel detector capabilities.
- BSM reach to be extended and new models and signatures to be explored.
- Rare processes become accessible.

- Many projection studies and full analyses are ongoing.
- A CERN yellow report including all recent studies by the LHC experiments and theorists being prepared for the end of 2018 as input to the European Strategy Group.

The SUSY saga will continue

- Gluinos and squarks have the highest cross sections.
  —> 5σ discovery reach up to ~2.5 and ~2 TeV.
- Conventional sbottom and stop searches
  —> 5σ discovery reach up to ~1.3 and ~1 TeV.
- Improving searches with refined methods.



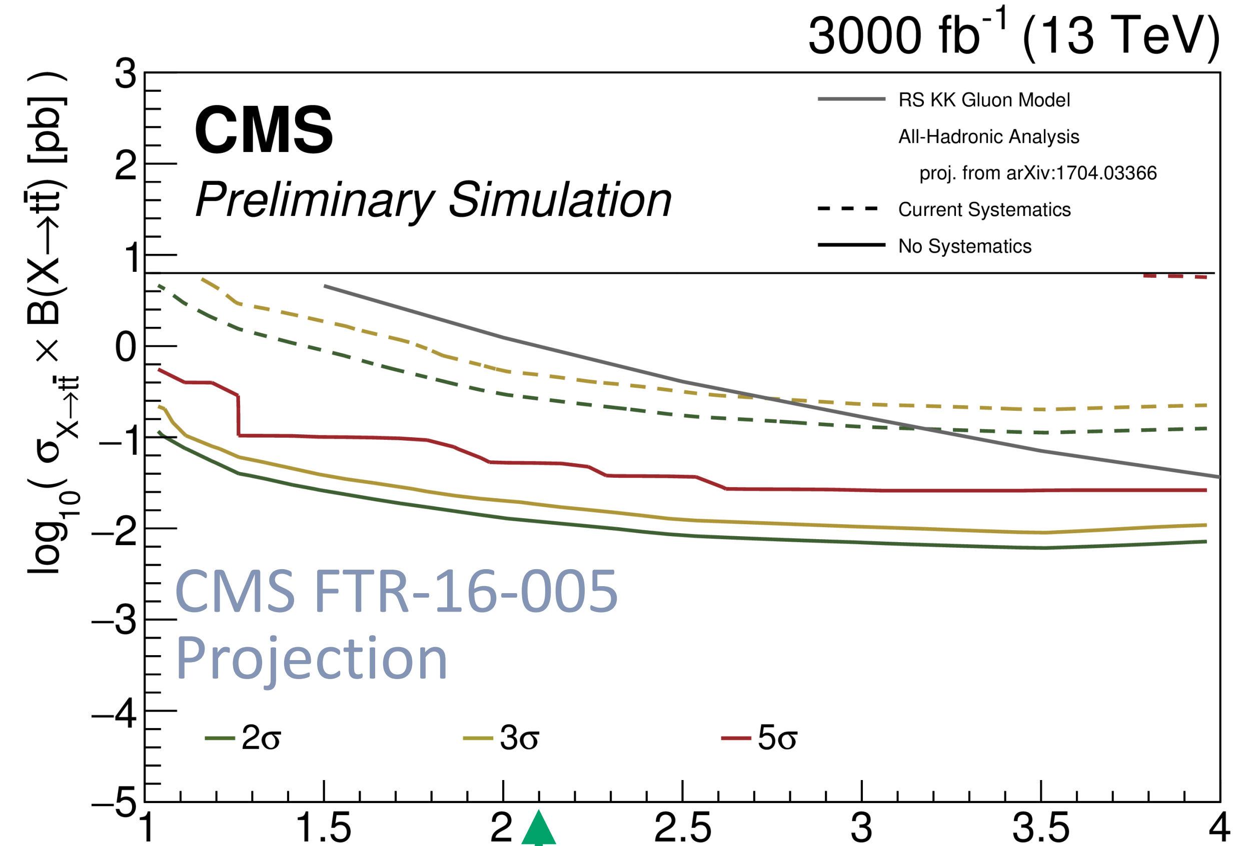
Focus on difficult scenarios:

- EWK gauginos in various decays
- Compressed EWK gauginos, sleptons
- Chargino pair production
- Light Higgsinos
- Stau pair production
- Compressed stop
- Heavy stops/sbottoms
- …

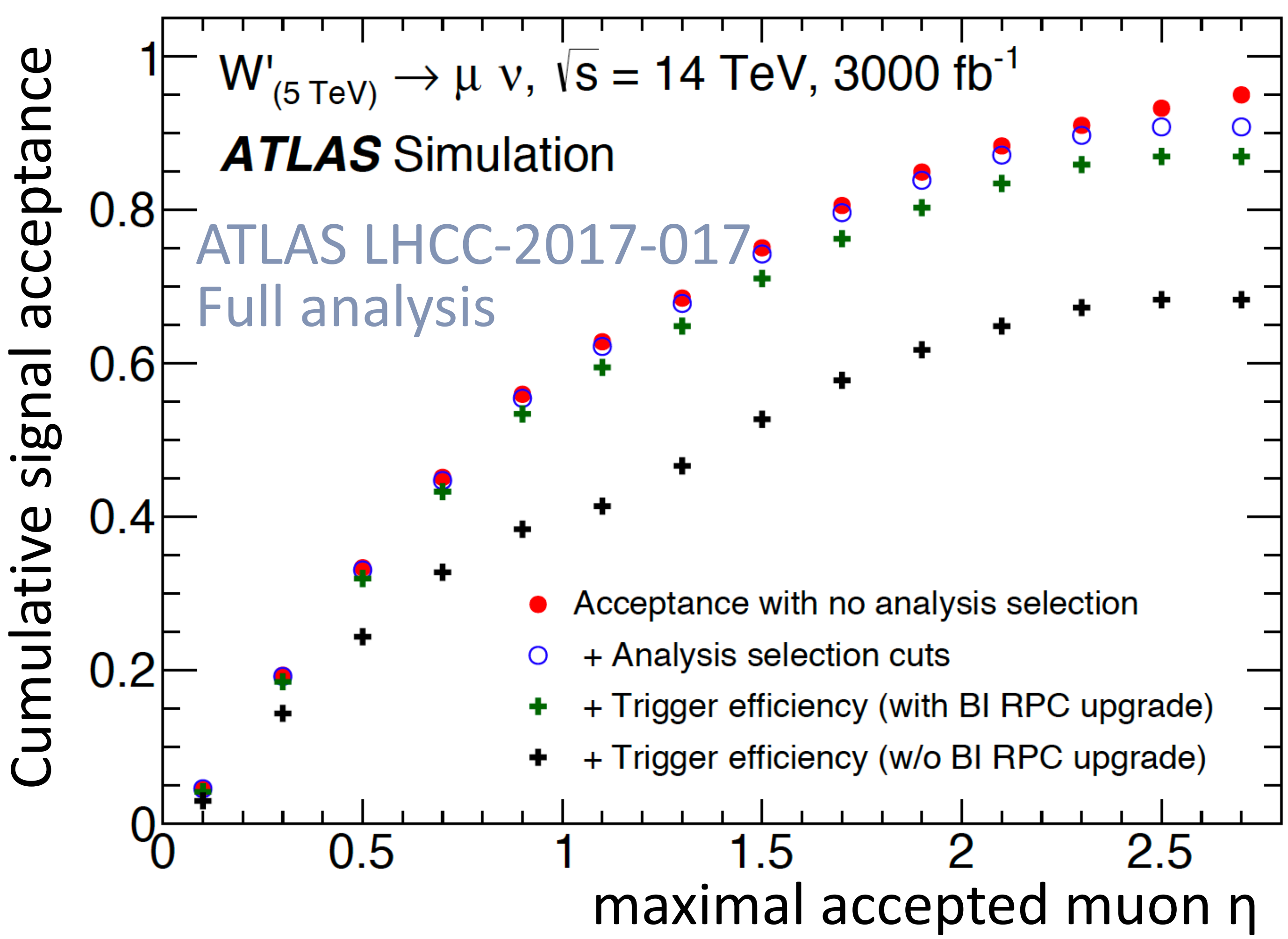
heavy resonances

Z' and W' searches

- Z' —> tt, t —> leptonic and hadronic
- Narrow width Z' ; RS KK graviton.
- Discovery sensitivity for hadronic channel on RS KK graviton.
- HL-LHC excl: 3.3TeV (narrow Z'), 4TeV (RS KK graviton)



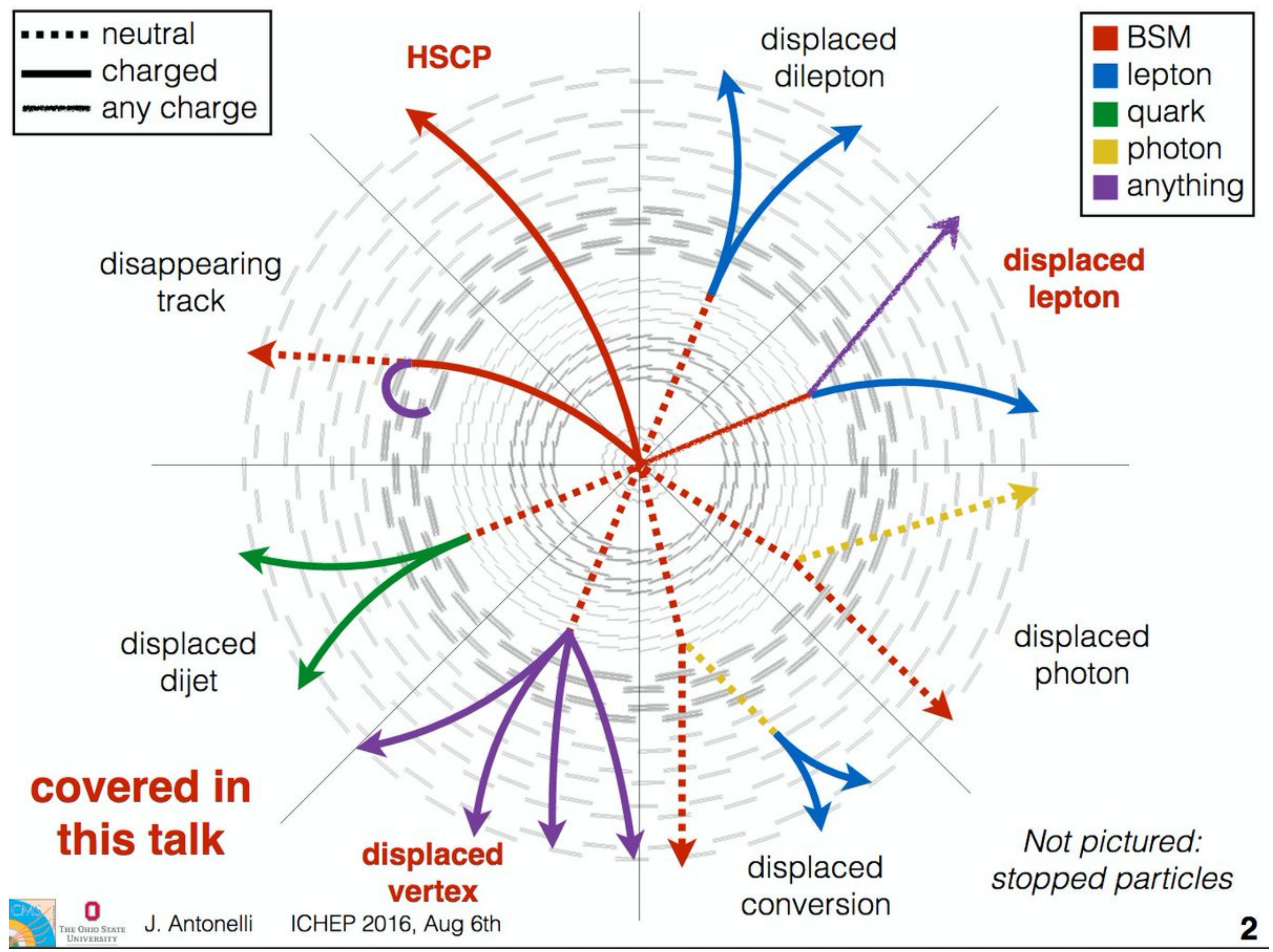
Current excl



- W' —> μν
- Assessed the impact of upgrade of ATLAS trigger system, i.e. addition of barrel inner RPCs.
- Increase in muon trigger acceptance gain: 70% —> 90%.

Long lived particle signatures

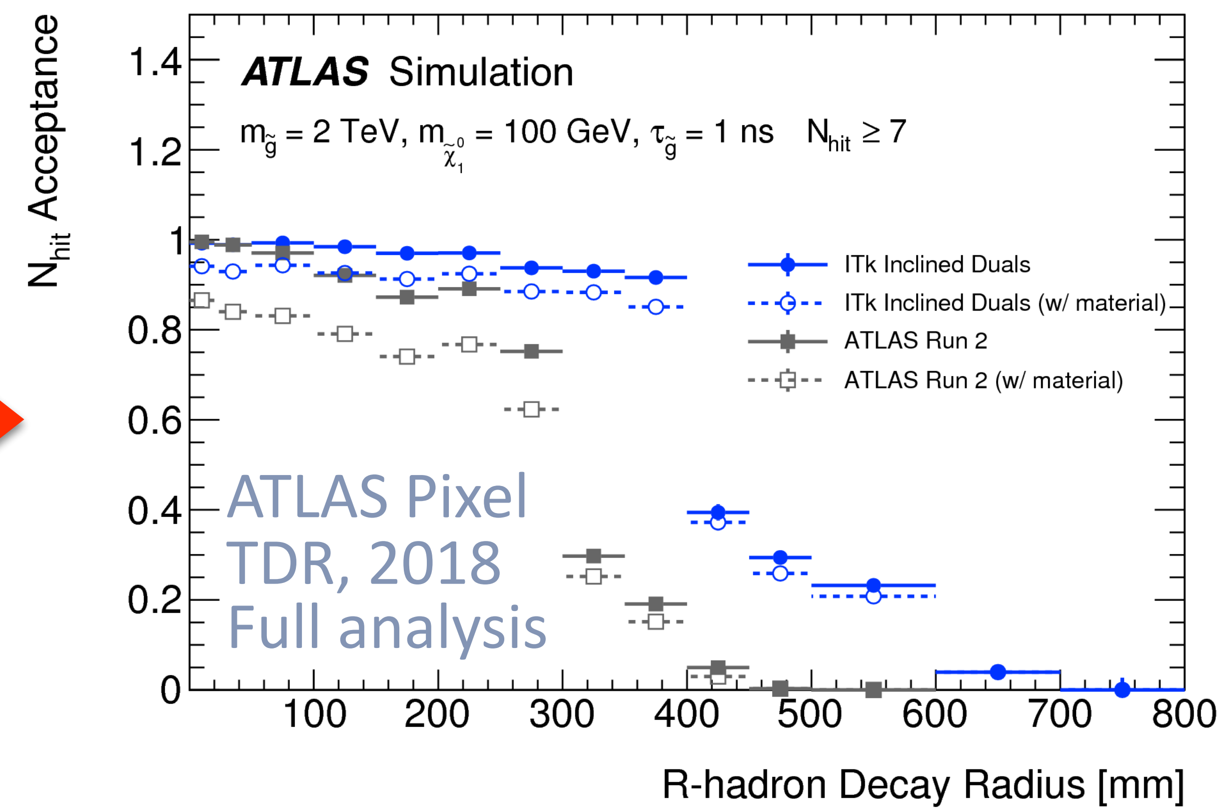
- Neutral or charged particles decaying a macroscopic, measurable distance away from the interaction point.
- Many models with LLPs.
- Non standard signatures, non standard objects.
- Signature based searches
- Need dedicated triggers and algorithms.
- Track triggers, improvement in muon systems and dedicated timing detectors will improve sensitivity.

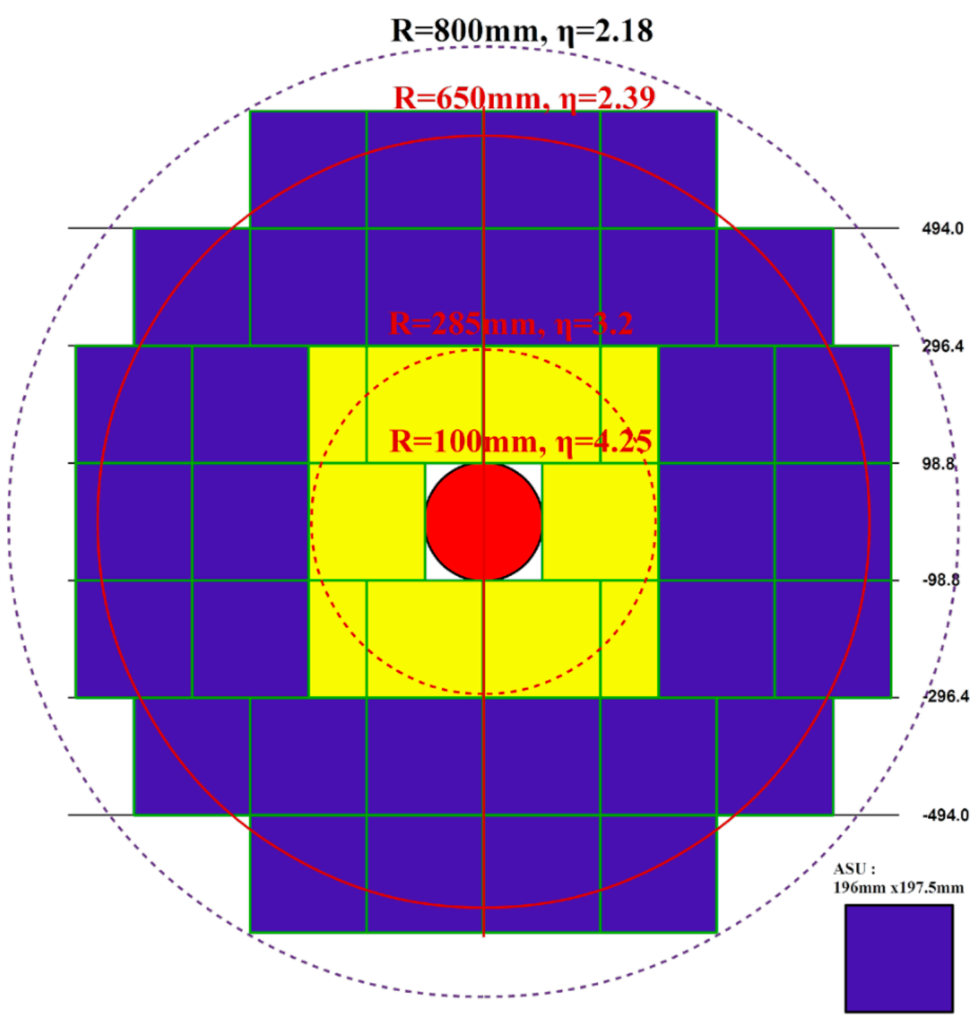


long lived particles

Disappearing tracks, dispaced vertices

- LLP decaying in inner tracker to stable particles forming displaced tracks / vertices.
- Larger volume and increased number of silicon layers in ITk significantly improve displaced vertex acceptance for an R hadron case study.





- ATLAS High granularity timing detector.
- Located at $z = 3.5$m, $2.4 < |\eta| < 4$.
- 30ps/track timing resolution.
- Improves sensitivity to slow forward charged long lived particles.