Beyond-Standard-Model Physics at the High-Luminosity LHC

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on behalf of the ATLAS and CMS collaborations

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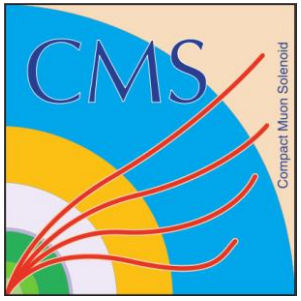
SUSY 2018, Barcelona



(HL-)LHC: Present and Future

- LHC with its experiments has shown great sensitivity (e.g. Higgs discovery)
- Along with LHC, detectors will be upgraded:
  - Maintain/Improve trigger/reconstruction capabilities (especially in forward region)
  - High granularity tracking & calorimetry
  - Longevity of detectors/electronics/readout to ensure operation during full HL-LHC period

BSM searches: HL-LHC prospects

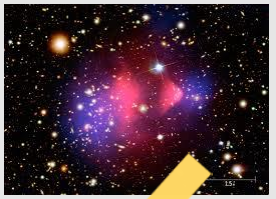
Theory

Hierarchy problem

Unification of gauge interactions

…

Experiment



Dark Matter/Energy

…

- Continue current effort of searches with higher sensitivity
- Open new search windows for models with low cross section, low acceptance
- How do we estimate physics potential of the HL-LHC?
  - Analysis: Complete/parametrized (Delphes) simulation of upgraded detector and HL-LHC environment (e.g. pileup interaction)
  - Projection: Scale results of current analysis to HL-LHC era

BSM searches: HL-LHC prospects

Theory

Hierarchy problem

Unification of gauge interactions

...

Ex

Matter/Energy

...

In this talk, I can only present a subset of current studies
(Only upgrade analyses shown here, no projections)

- Continue current eff s with higher sensitivity
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- Ho ate physics potential of the HL-LHC?
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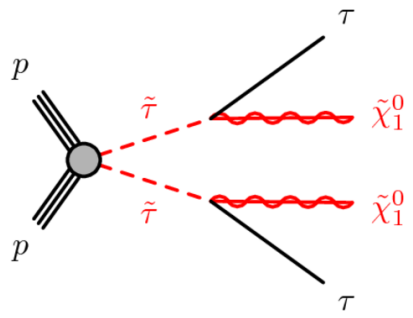
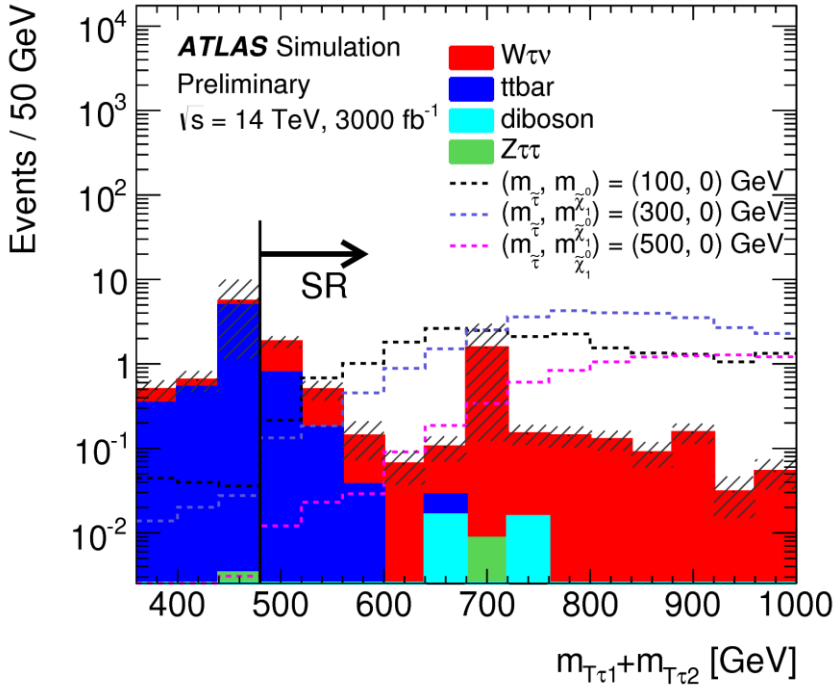
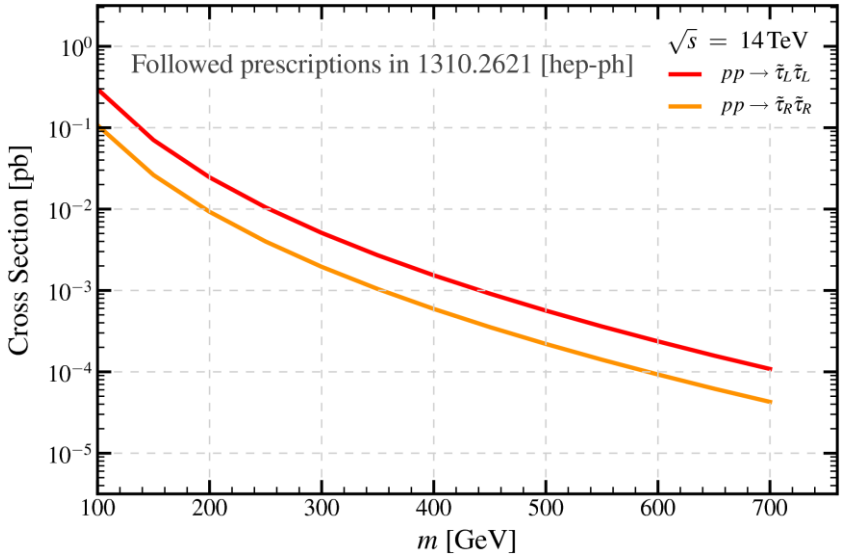
ATL-PHYS-PUB-2016-021

Stau Pair Search

- Direct stau production with low cross section
- Final state of at least two opposite sign τ_{had}+ $E_{T,miss}$
- Triggering on hadronic taus key challenge
- Selection based on $\Delta R(\tau$ pair) and transverse masses

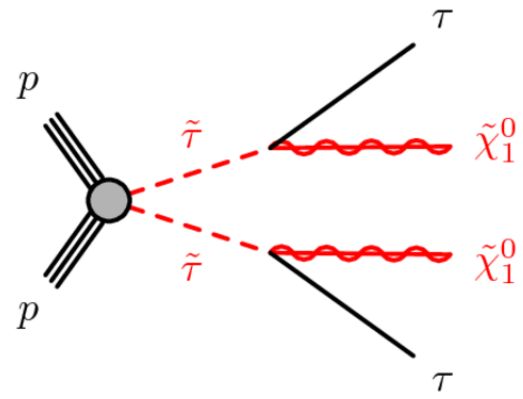


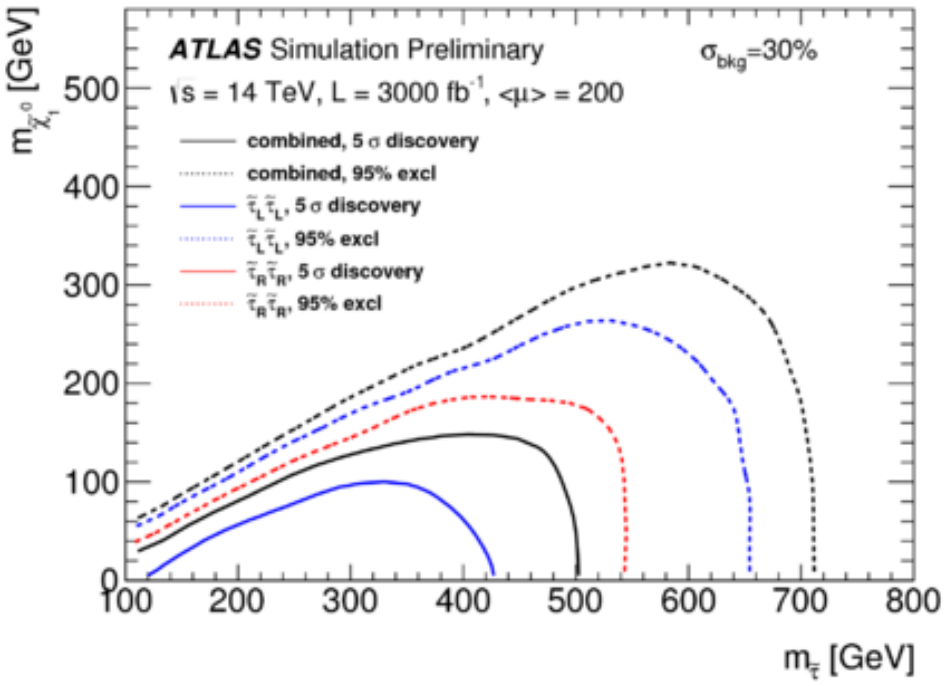




Stau Pair Search

- Sensitivity for current searches
  - Excluded up to 109 GeV
    (Run-2 8TeV,arXiv:1509.07152)
- Prediction for HL-LHC
  - 95% CL exclusion contour up to ~700 GeV
  - Discovery potential up to 500 GeV

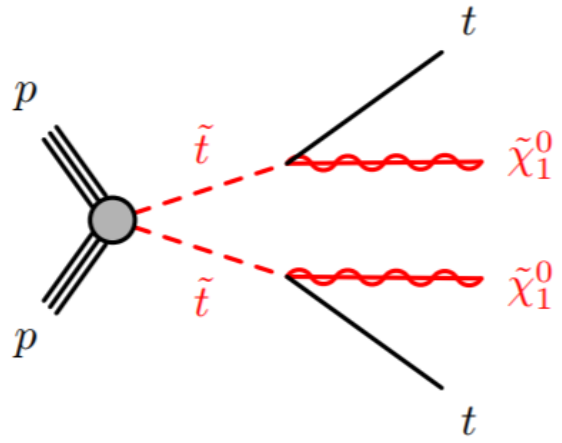


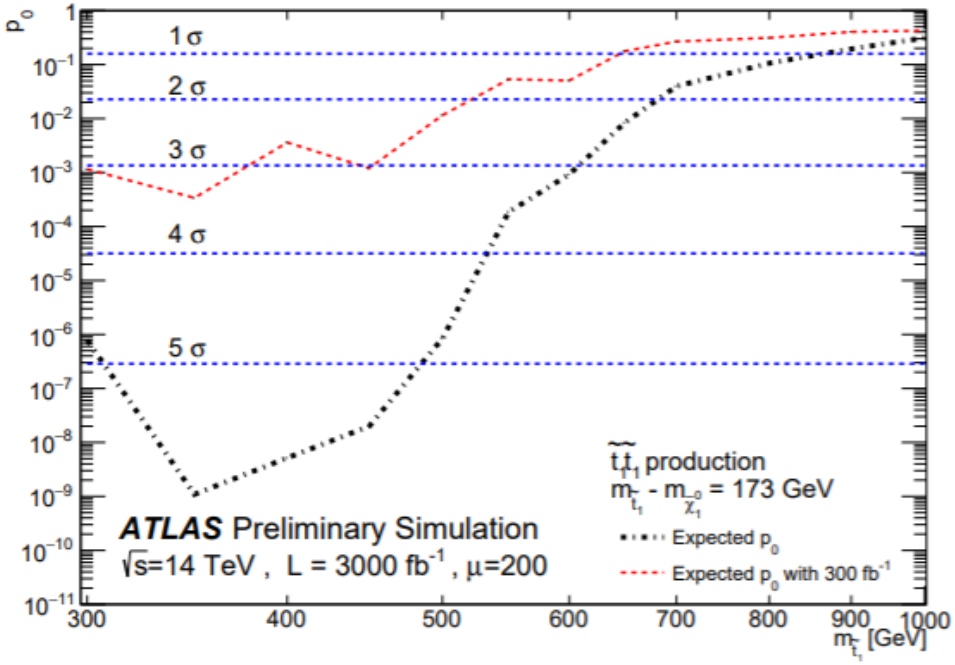


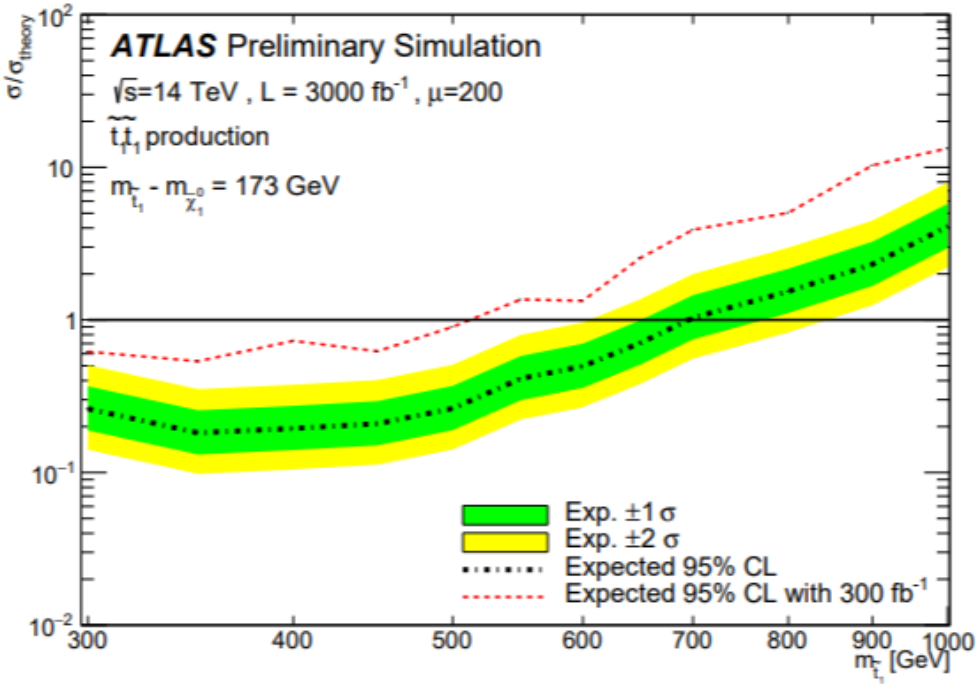
Largely benefiting from HL-LHC data period

Search for pair of top squark

- Top squarks decaying to top quark and neutralino (LSP)
- Compressed scenario with $m_{\tilde{t}} \approx m_t + m_{\tilde{\chi}_1^0}$
- 2 b-jets and exactly two good leptons (eμ,ee,μμ)
- Discovery potential up to 500 GeV in stop mass
- Exclusion up to 700 GeV



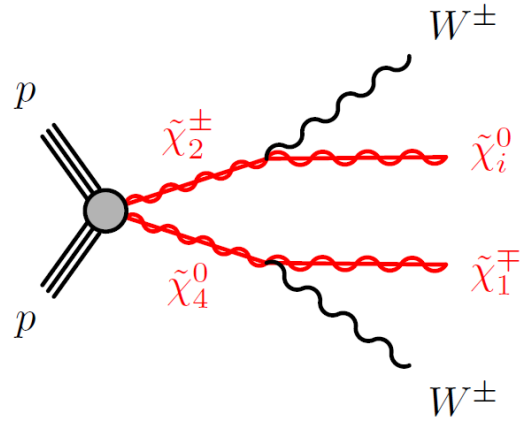


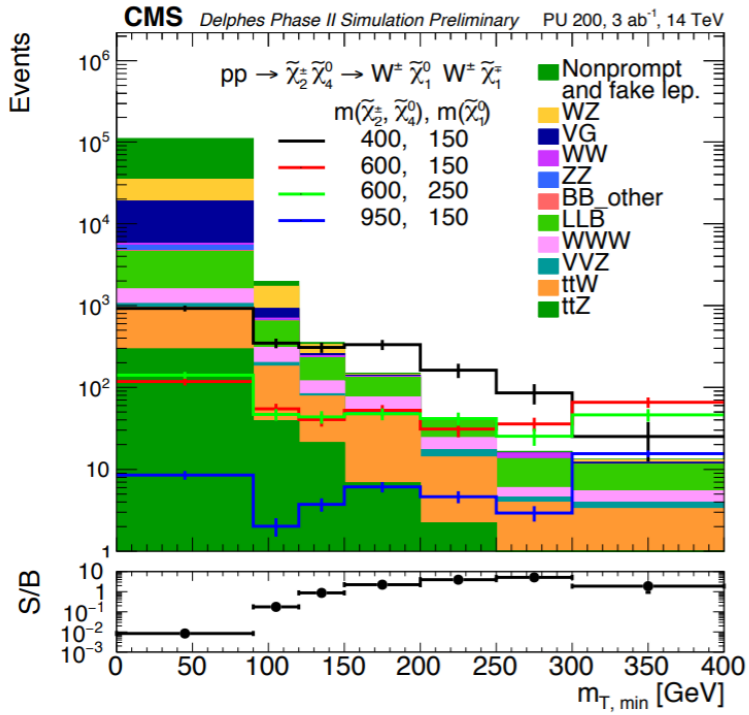


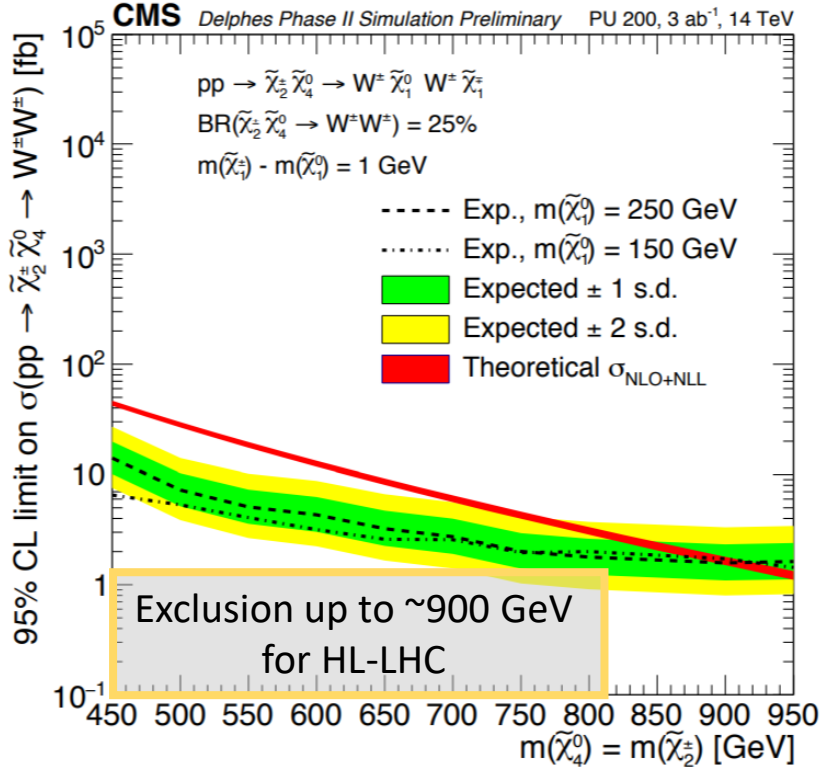
CMS-TDR-019

EWK SUSY in same-sign dileptons

- Electroweak production of SUSY particles
- Two same-sign W's (leptonically) + $E_{T,miss}$
- Select two same charge and well-isolated leptons
- Reject events with additional leptons, b-jets and high-p_T jets to suppress backgrounds

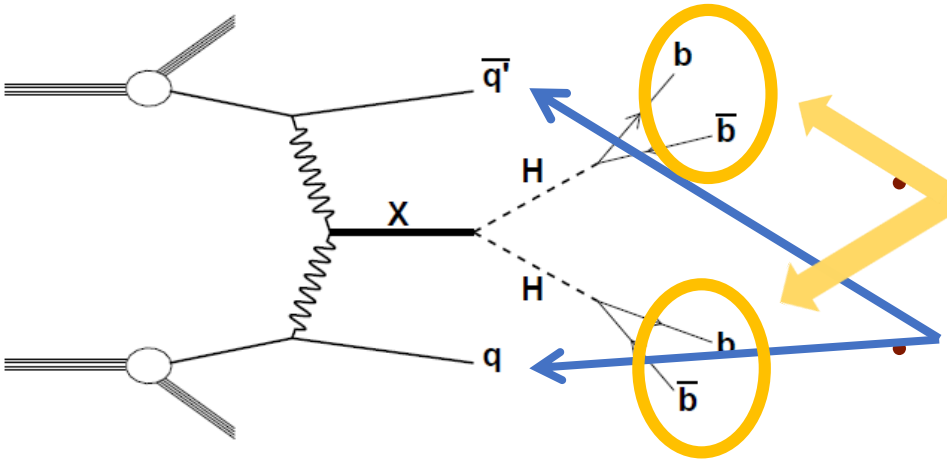






$$m_{T,min} = \min[m_{T(lep_1, p_T^{miss})}, m_{T(lep_2, p_T^{miss})}].$$

4b Resonances



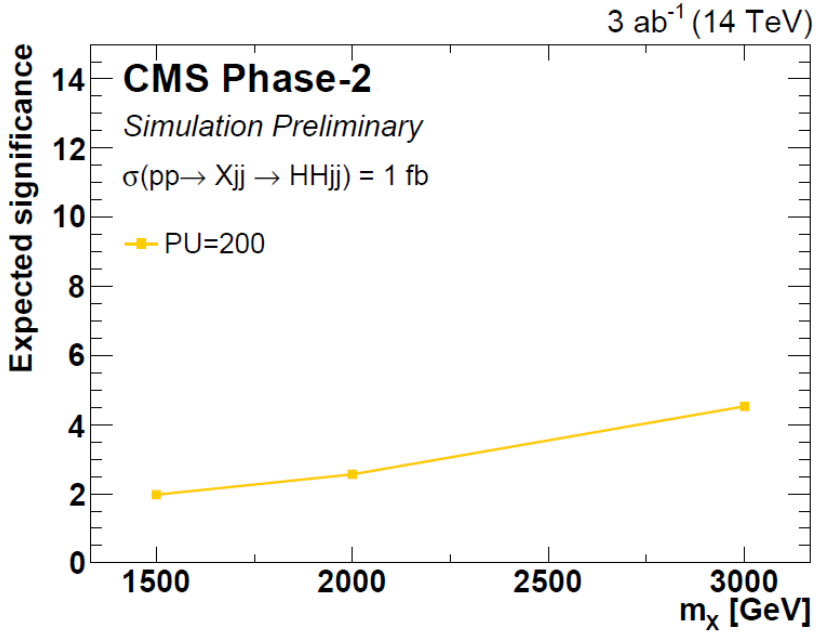
- VBF production of heavy resonance:

  $X \rightarrow HH \rightarrow 4b$

- Two high-p_T jets (either 3 or 4 b-tagged subjets) from Higgs bosons
- Two additional 2 jets (well separated from Higgs jets)

- KK Bulk Graviton from warped extra dimensions (WED) as heavy resonance
- For Run-2 analyses, BG masses of up to 3 TeV excluded (s-channel production)
- With HL-LHC data VBF mode of BG with its low cross section can be explored

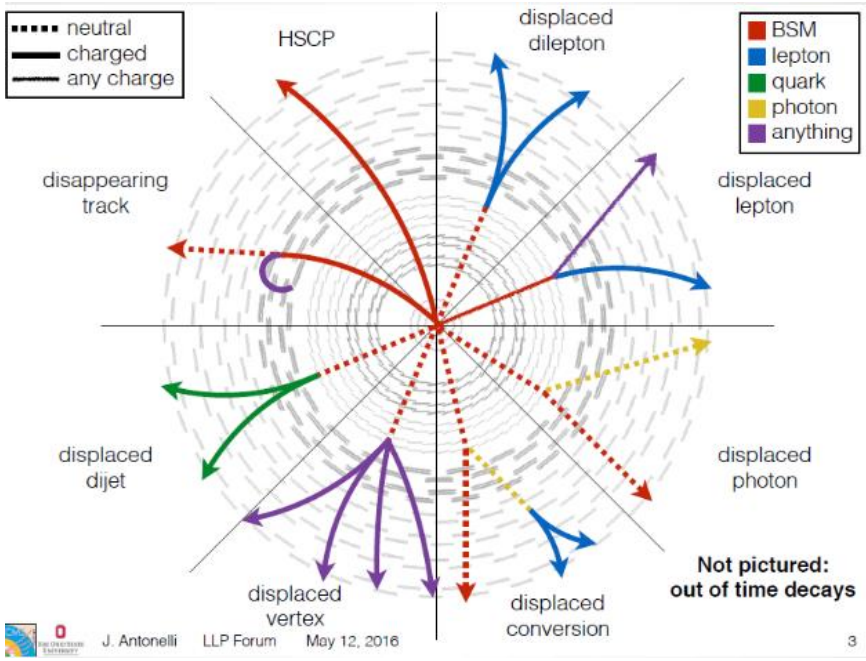
Similar study in ATLAS LHCC-G-166 (Projection)

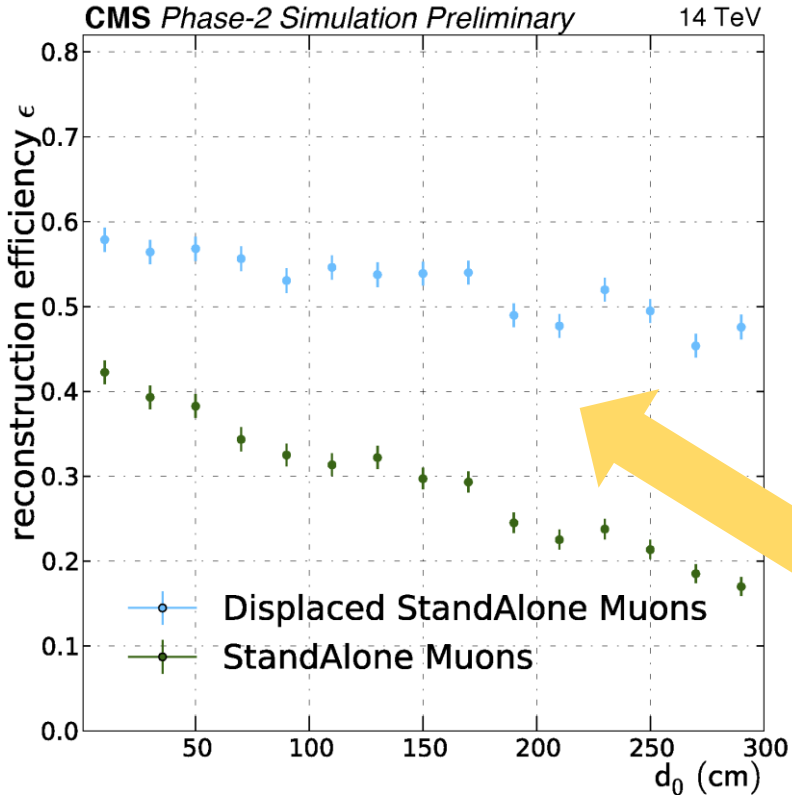


CMS-TDR-016

Long-lived Particles: Starting with Displaced Muons

- Large parameter space unexplored for long-lived signatures
- Large variety of detector signatures
- Model-independent search for displaced muons from long-lived particles (LLP)

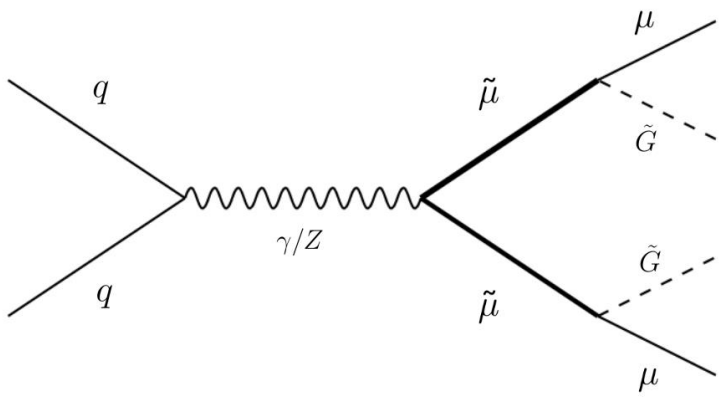


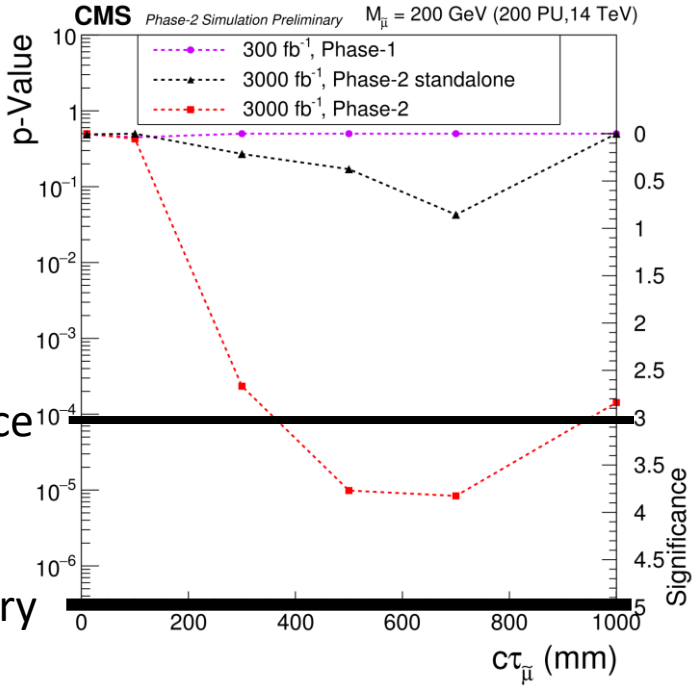


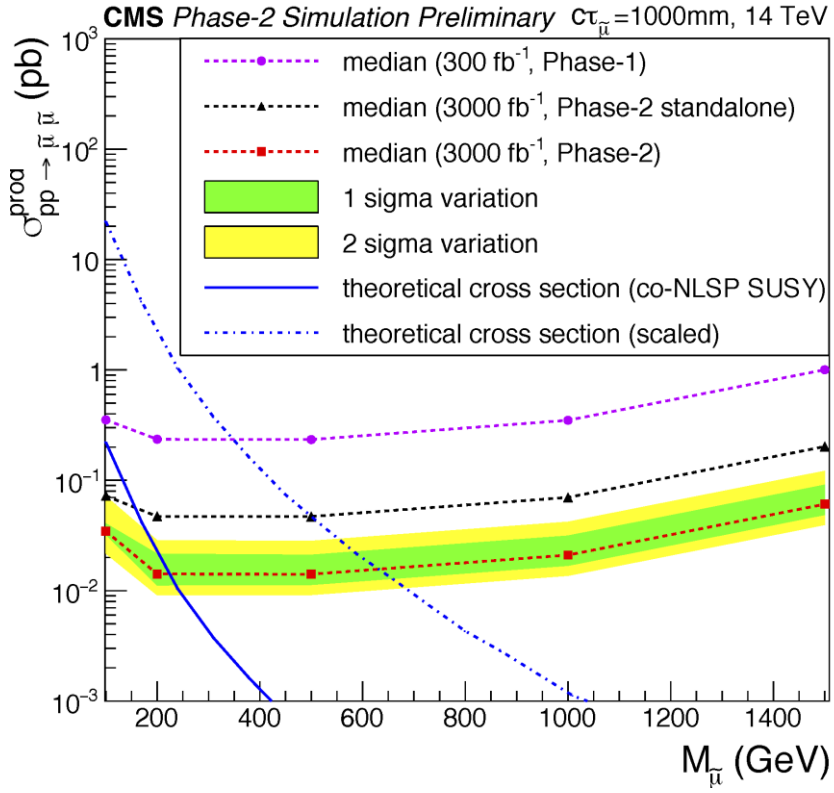
- Sensitive to large decay length of LLP using only muon system information
- Dedicated reconstruction to enhance sensitivity to largely displaced muons

Displaced Muons

- Explore sensitivity with GMSB smuons
- Typically low production cross section
- Exclusion for smuons up to 200 GeV
- 3σ evidence below masses of 200 GeV
- Other interpretations (dark photons) ongoing

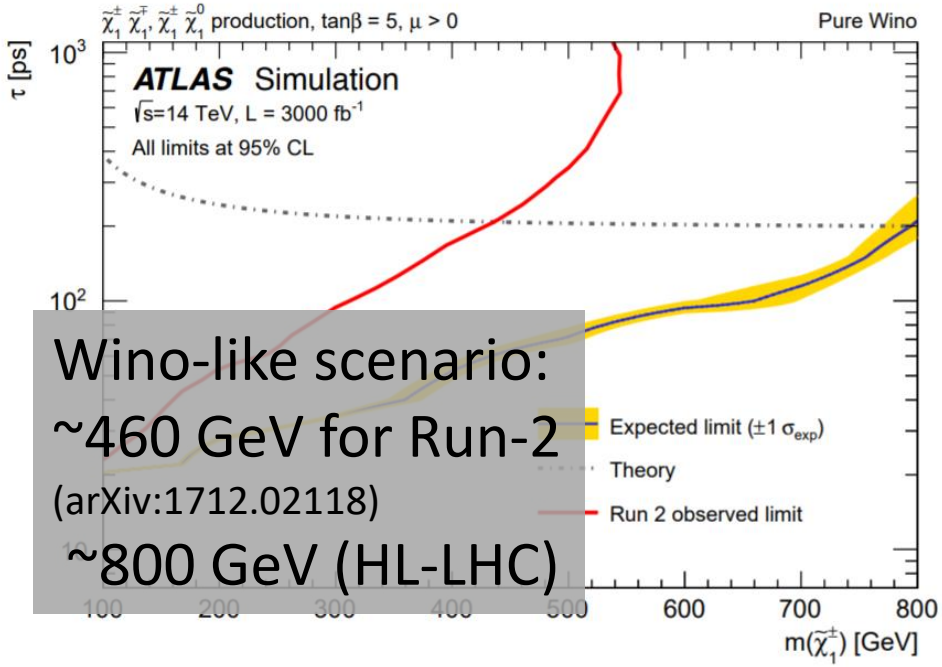




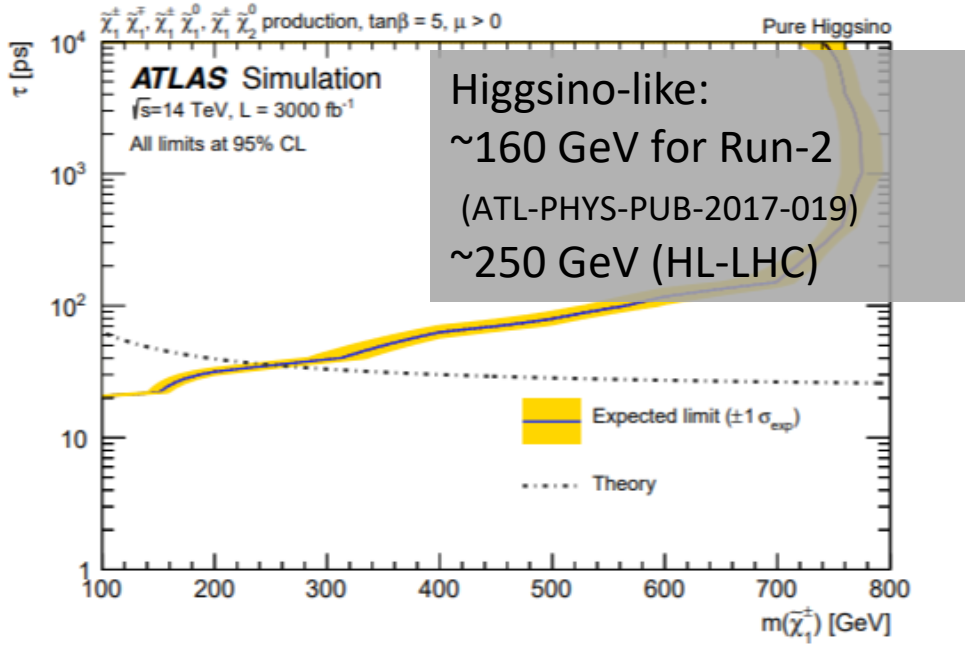


Disappearing Tracks

- In AMSB SUSY, lightest states can be nearly mass degenerate chargino and neutralino
- Chargino can be long-lived and decay to neutralino and pion in tracker volume
- Analysis based on reconstructing short tracks in tracker volume, benefiting from the new inner tracker strip detector of ATLAS to identify disappearing tracks



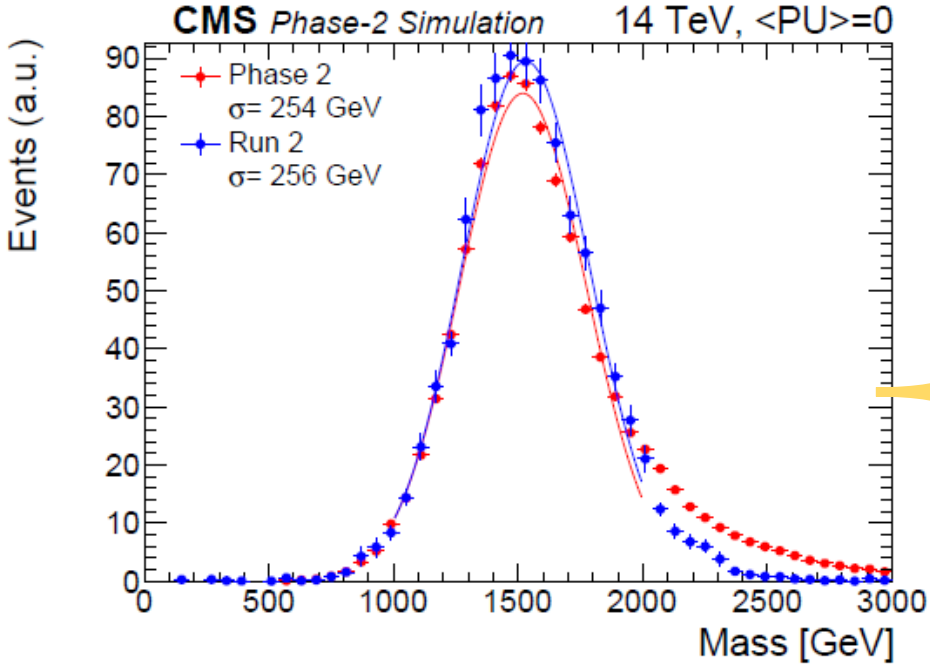
Wino-like scenario:
~460 GeV for Run-2
(arXiv:1712.02118)
~800 GeV (HL-LHC)

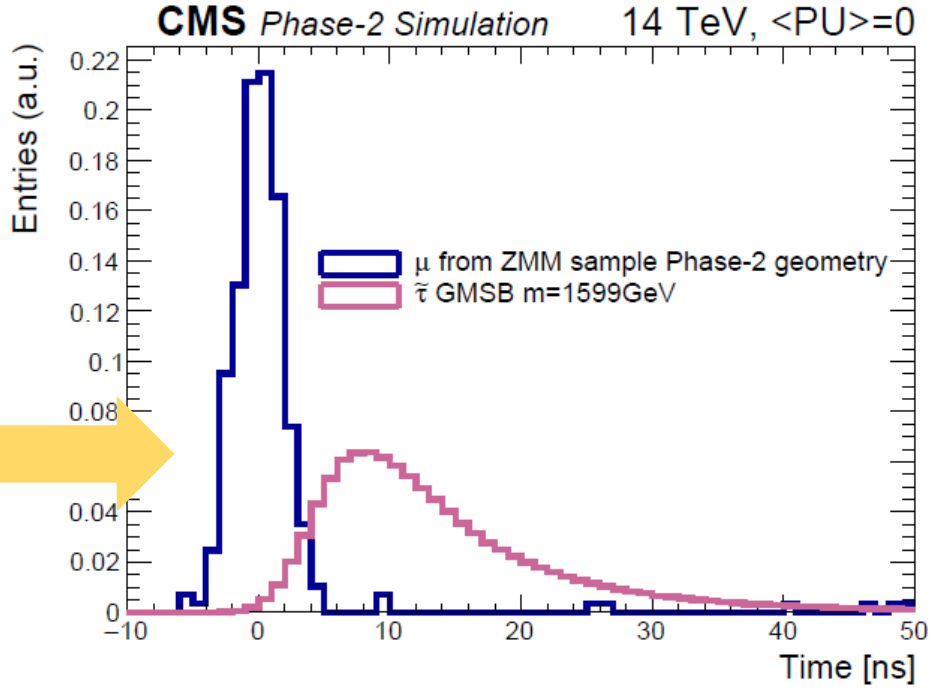


Higgsino-like:
~160 GeV for Run-2
(ATL-PHYS-PUB-2017-019)
~250 GeV (HL-LHC)

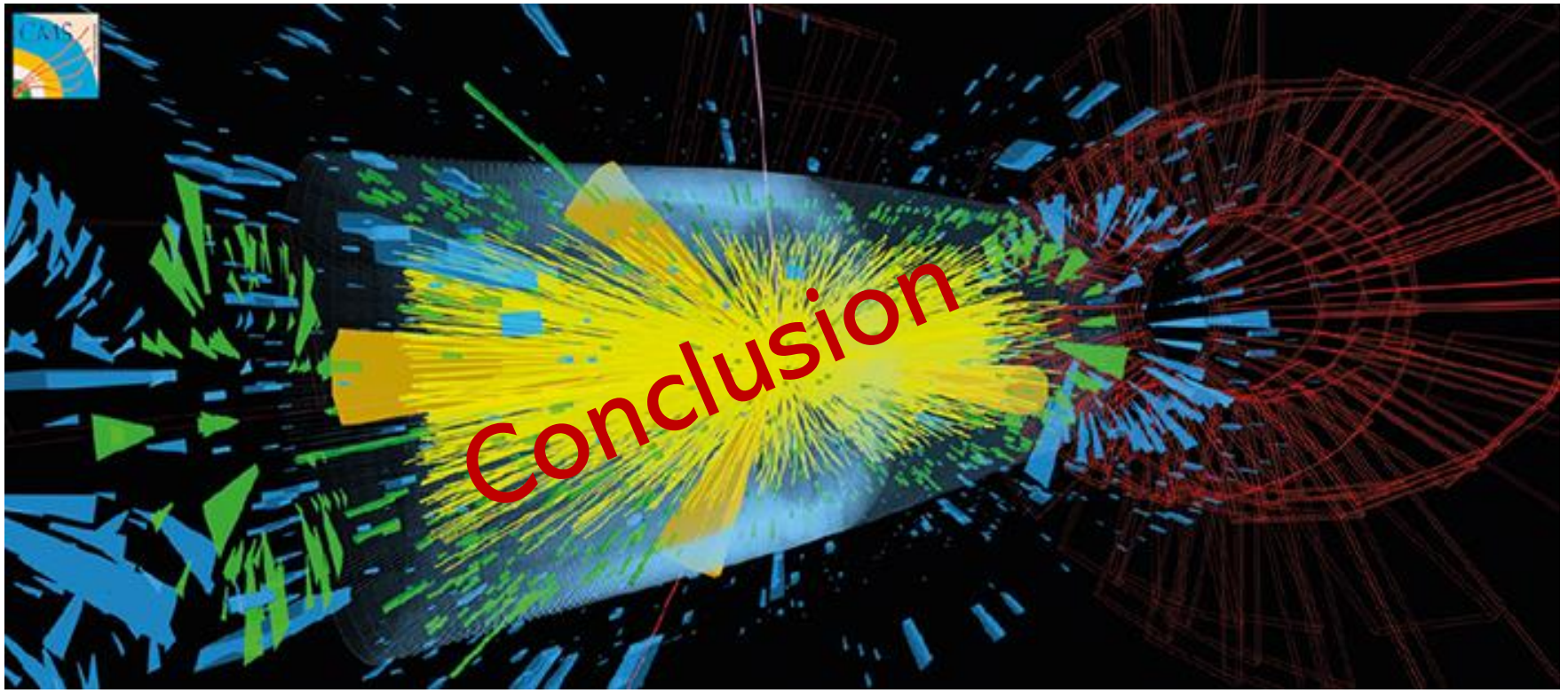
HSCPs with ToF

- Several extensions of the Standard Model (e.g. Split SUSY) predict HSCPs.
- HSCPs leave signals in the tracker and muon system while traversing the detector
- With a time-of-flight (ToF) measurement, one can distinguish HSCPs from muons





- Mass resolution for a 1.6 TeV stau
- Comparison between
  - ToF from offline DTs and CSCs (Run-2)
  - ToF from RPC trigger-level (Phase-2)
- Upgraded RPC electronics provide current offline resolution already at trigger level



- HL-LHC era (together with detector upgrades) provides a unique opportunity to search for new physics
- BSM searches? Yes, they are still alive!
  - Opening window to rare processes (SUSY)
  - Chance to search for unconventional signatures (displaced muons, disappearing tracks)
- Currently, there are many analyses/projections ongoing
- Ongoing studies from all LHC experiments will contribute to a yellow report (end of 2018)

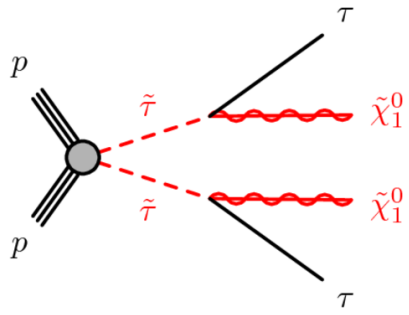
BACKUP

Selected upgrade physics analyses

- BSM searches at ATLAS:
  - Stau pair (ATL-PHYS-PUB-2016-021, Delphes)
  - Stop pair (ATL-PHYS-PUB-2016-022, Delphes)
  - Disappearing track (ATLAS Pixel TDR, 2018, CERN-LHCC-2017-021, ATLAS-TDR-030, Full-Sim)
- BSM searches at CMS:
  - C2N4 in same sign dilepton (HGCAL TDR, CMS-TDR-019, CADI: CMS-TDR-17-007, Delphes)
  - HSCP with RPC ToF (CMS-TDR-016, CADI: TDR-17-003, FullSim)
  - 4b Resonances (CMS-FTR-18-003, Full-Sim)
  - Displaced Muons (CMS-TDR-016, CADI: TDR-17-003, Full-Sim)

Stau Pair Search - Backup

- Triggering on hadronic taus
  - Di-tau + $E_{T,miss}$ or di-tau + ΔR are used
  - Efficiency of 80% for leading and sub-leading tau with 50 and 40 GeV
- Loose jet veto (pT >60 GeV -> safe against pileup)
- Delphes simulation includes di-tau trigger and c-jets and other light jets misidentified as b-jets



SR Definition
≥ 2 OS taus
loose jet-veto
Z-veto
$\Delta R(\tau 1, \tau 2) < 3.5$
$E_T^{miss} > 280$ GeV
$m_{T2} > 40$ GeV
$m_{T\tau 1} + m_{T\tau 2} > 480$ GeV

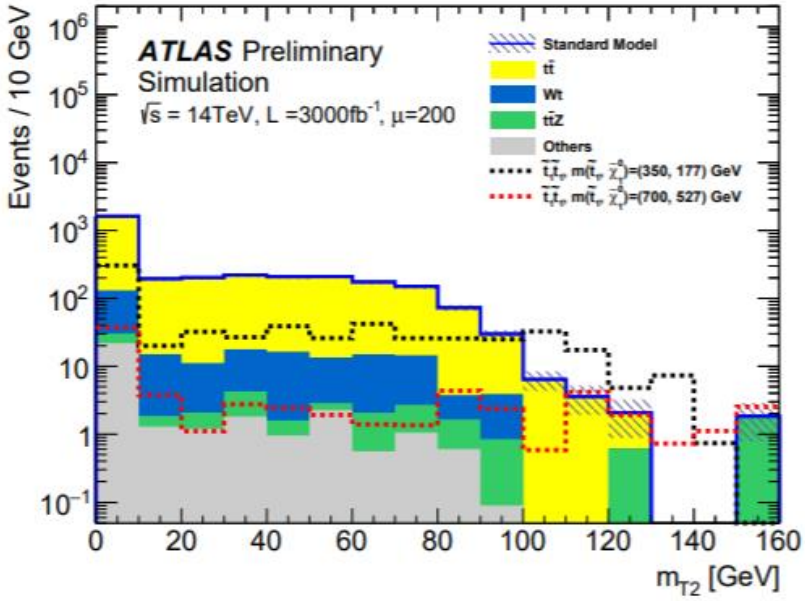
Transverse mass: $$m_T(\vec{p}_T, \vec{q}_T) = \sqrt{2(p_T q_T - \vec{p}_T \cdot \vec{q}_T)}.$$

„Stransverse“ mass: $$m_{T2} = \min_{\vec{q}_T} \left[\max \left(m_T(\vec{p}_T^{\tau 1}, \vec{q}_T), m_T(\vec{p}_T^{\tau 2}, E_T^{miss} - \vec{q}_T) \right) \right],$$

Top squark pair - Backup

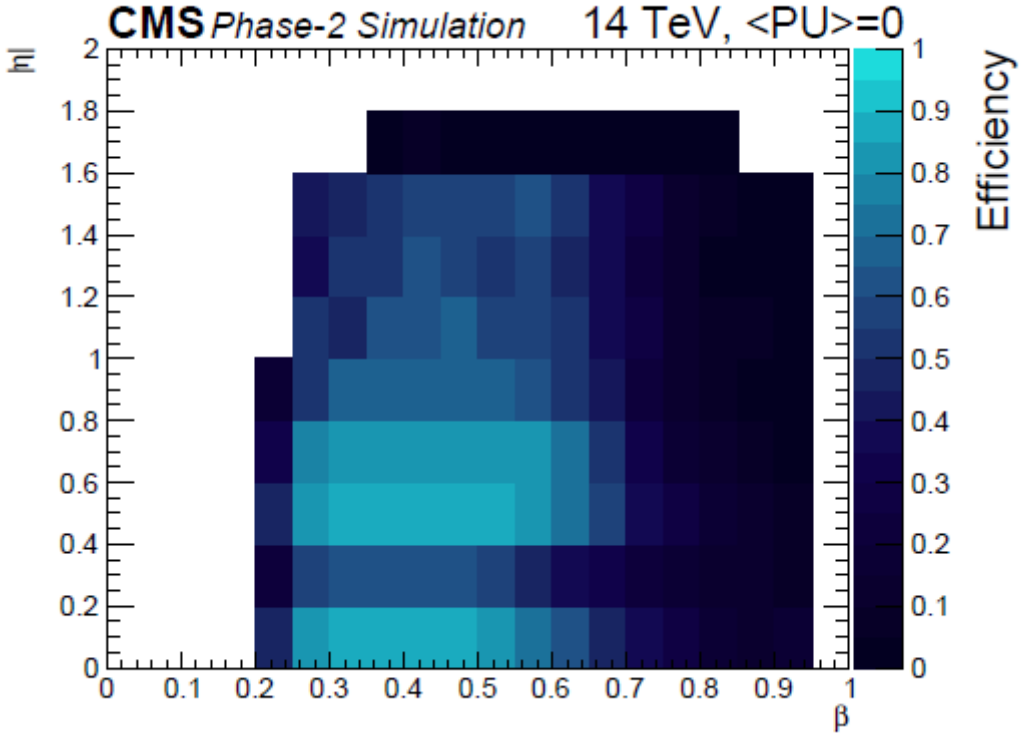
- Event Selection based on ISR jets
  - Recoil to have high momentum top quark and neutralino

	SR
$m_{\ell\ell}$ [GeV] (SF lepton pairs only)	$81.2 < m_{\ell\ell} < 101.2$
$\min\{\Delta\phi(\text{jet}_{\text{ISR}}, E_{\text{T}}^{\text{miss}})\}$	> 0.4
$\Delta\phi(\text{jet}_{\text{ISR1}}, E_{\text{T}}^{\text{miss}})$	> 2
$R_{\ell\ell}$	> 6
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 350
Leading ISR jet p_{T} [GeV]	> 300
m_{T2} [GeV]	> 100



HSCPs - Backup

- Efficiently trigger on slow moving particles at HL-LHC with beta < 0.5 and |eta| < 1.4

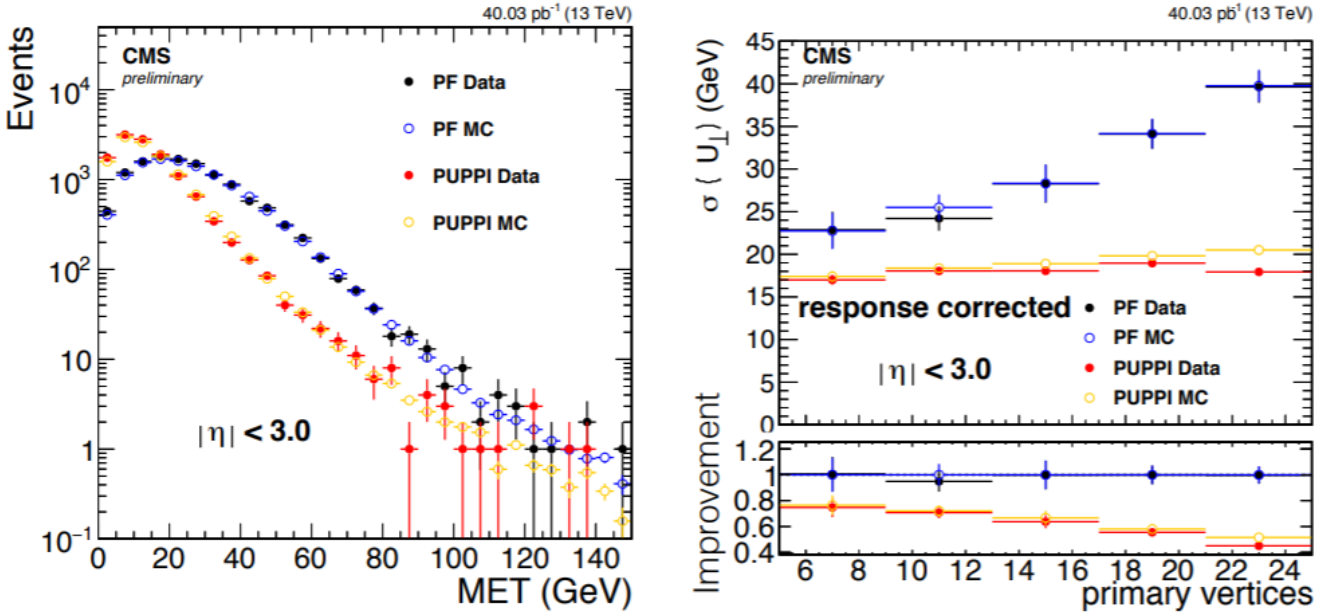


MET at HL-LHC

Pileup mitigation of Missing ET

the first missingET performance study with 13 TeV data

Performance was evaluated with DY events.



Good agreement between data and MC was seen in both.

The stable performance of PUPPI was confirmed with data.

https://indico.cern.ch/event/382815/contributions/910602/attachments/1139397/1631642/satoshi_BOOST2015.pdf