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Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

Searching for SUSY at the upgraded LHC

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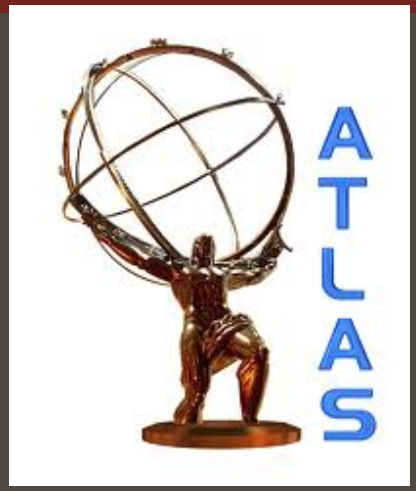
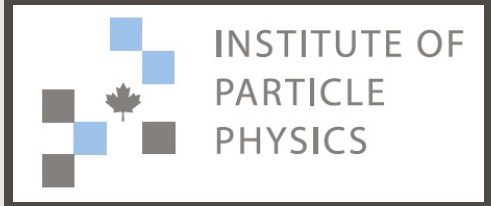
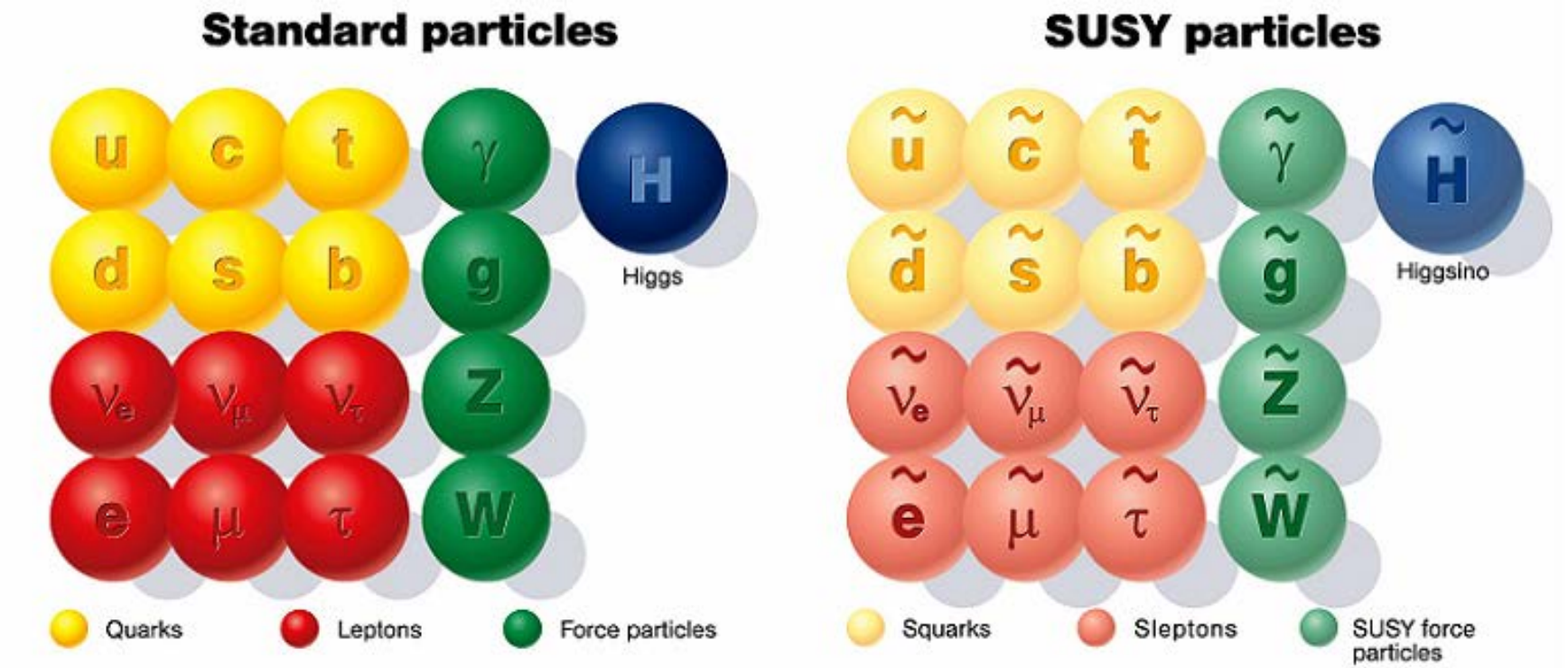




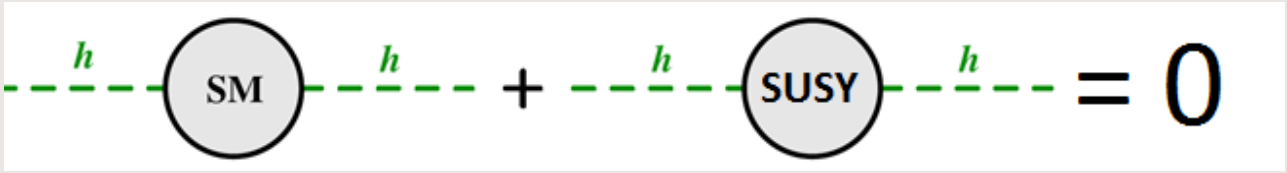
Minimal SUSY SM (MSSM)

- Every SM particle has a super-partner with spin-1/2 difference.
  - Every SM fermion (boson) is associated to a supersymmetric boson (fermion)
  - Charged higgsinos and winos mix to form **Charginos** $\left(\tilde{\chi}_1^{\pm}\right)$
  - Neutral higgsinos, winos, and binos mix to form **Neutralinos** $\left(\tilde{\chi}_2^0\right)$

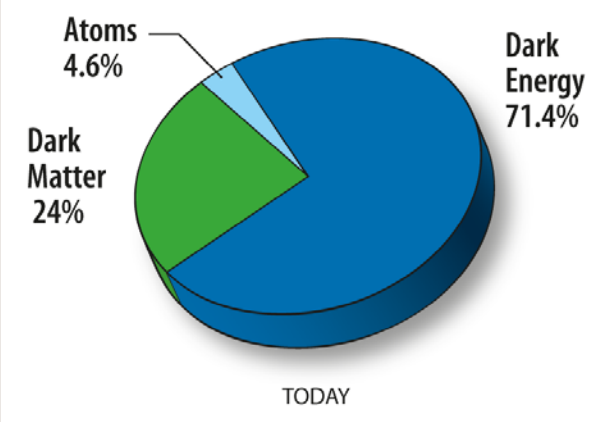


Why SUSY?

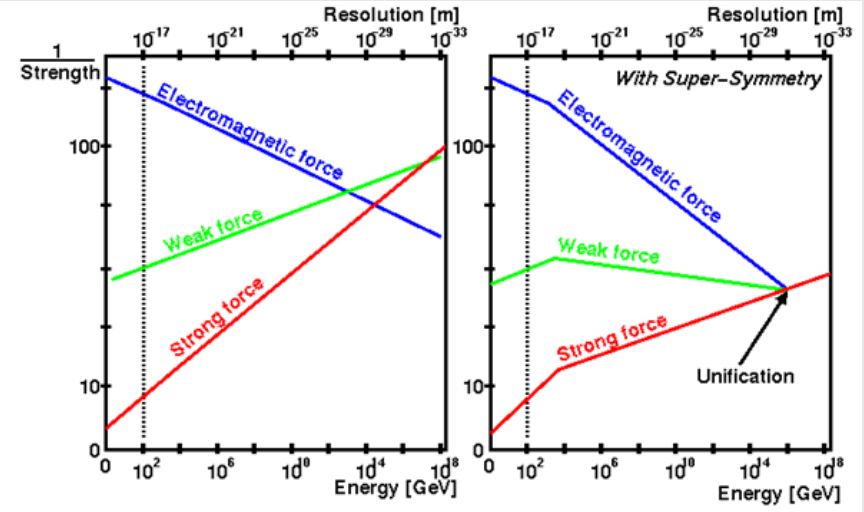
- No fine-tuning for the Higgs mass (quantum fluctuations requires fine tuning up to the 34th digit!)



- Lightest SUSY Particle (LSP): Neutral, weakly interacting → viable Dark Matter candidate if stable

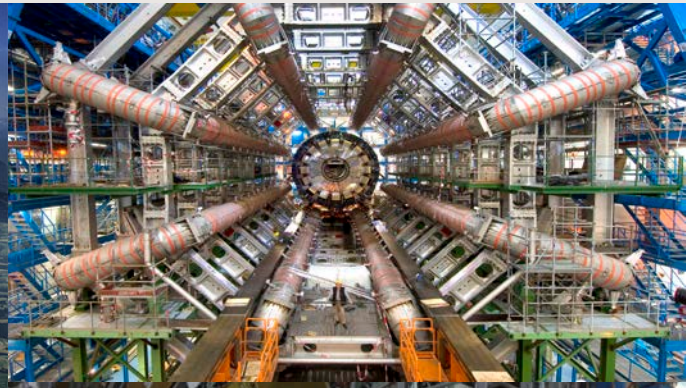


- Equality of Strong, Weak and EM couplings at ~10^{16} GeV



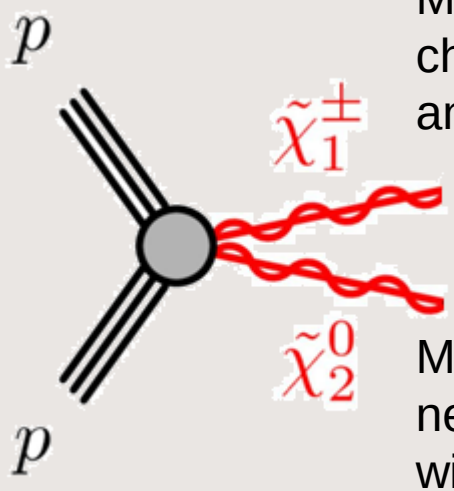
Searching for SUSY

- The LHC is a proton-proton collider that ran up to 8 TeV center-of-mass energy and collected 20/fb of data
- Planned upgrade in ~2020 will bring this up to 14 TeV and collect 3000/fb of data



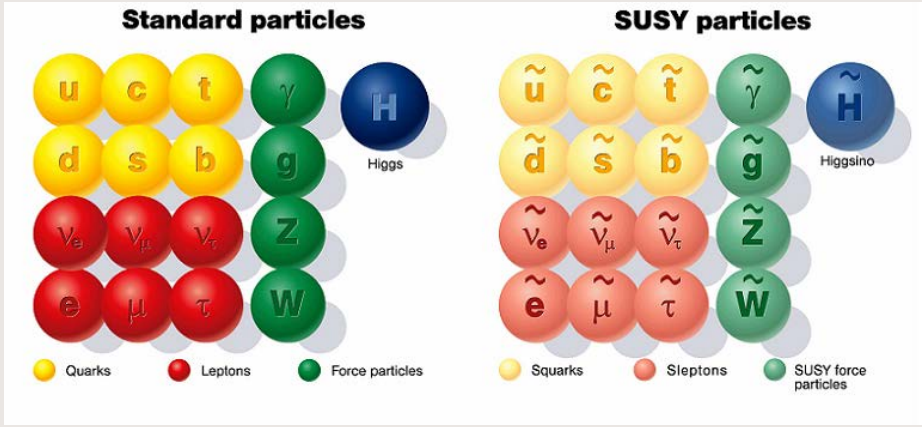
Searching for SUSY

- There are many ways to search for SUSY particles.
- →Search for strongly produced SUSY: stop pair production or 1st/2nd generation squarks and gluinos.
- **→Search for weakly produced SUSY: pair production of charginos and neutralinos.**



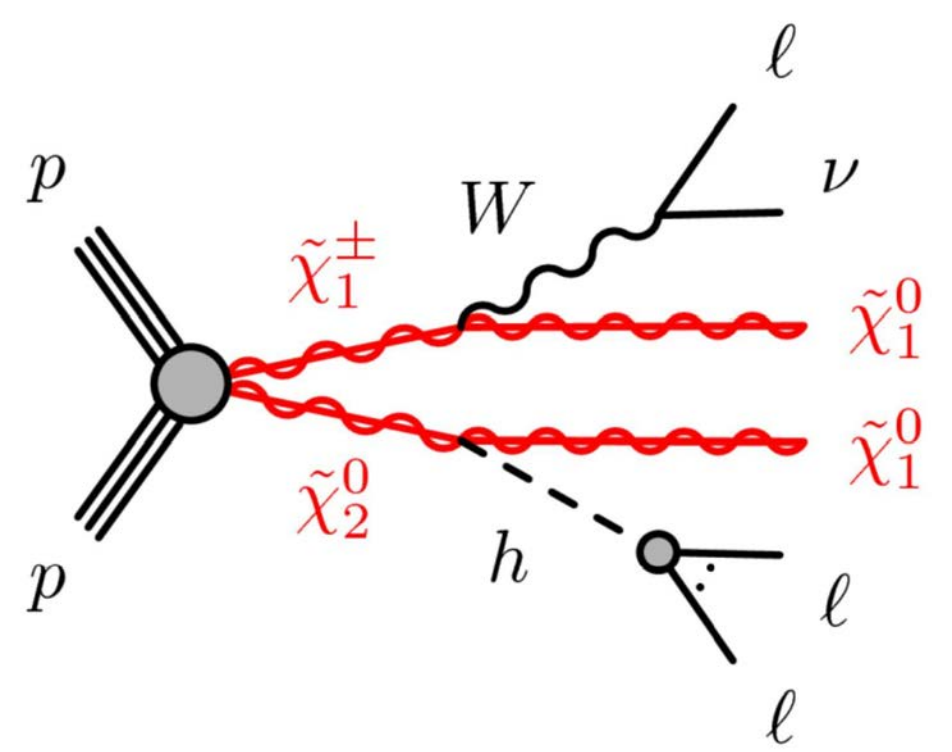
Mixed state of charged higgsinos and winos

Mixed state of neutral higgsinos, winos and binos



Signal

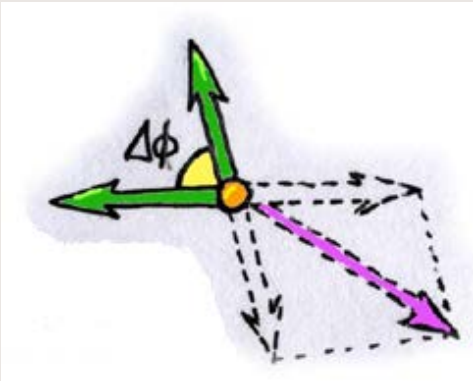
- 3 leptons + neutrinos + neutralinos
  - Signal cross-sections on the order of hundreds of fb
  - Cross-sections change depending on the masses of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$
- Many SM backgrounds
  - ttbar is the dominant background with a cross-section of ~900 pb
- Define a set of selection criteria (cuts) aiming at improving the sensitivity, which is roughly (#Signal/#Background)
  - Signal contains neutralinos (stable, neutral, and weakly interacting). Can we detect them to discriminate signal from background?



Observables

- **Missing Transverse Momentum (E_T^{miss})**
- Helps in "detecting" invisible particles → neutrinos and neutralinos
- Proton beams are along the z-direction; momentum is 0 in the xy plane. By momentum conservation, the momentum must also be 0 in the xy plane after the collision
- Sum of transverse momenta of invisible particles can be inferred using transverse momenta of visible particles using

$$E_{\mathrm{T}}^{\mathrm{miss}} = \sqrt{{E_{\mathrm{x}}^{\mathrm{miss}}}^2 + {E_{\mathrm{y}}^{\mathrm{miss}}}^2}$$



- **Invariant and transverse mass**
- Helps in measuring the mass of the W and Z bosons
- Z boson can decay into two leptons → we can determine the mass of the Z boson from the measured momenta of the leptons using $M_Z^2 = (E_{l_1} + E_{l_2})^2 - (\vec{p}_{l_1} + \vec{p}_{l_2})^2$
- W boson decays into a lepton and a neutrino; we cannot measure the z-component of the momentum of the neutrino, so we can only calculate the transverse mass of the W boson using

$$m_{\mathrm{T}} = \sqrt{2 * p_{\mathrm{T}}^{l} * E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\phi)}$$

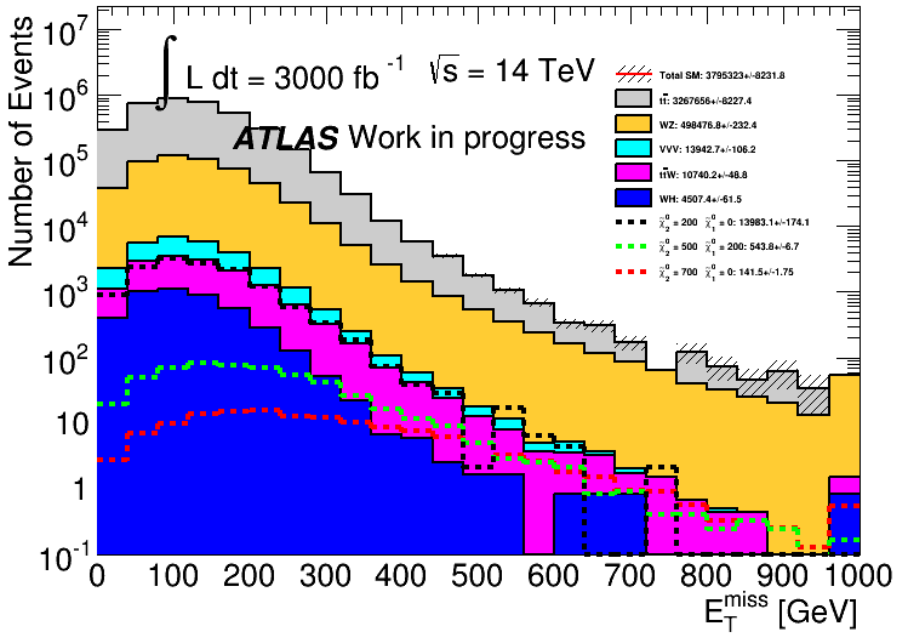
Signal Region

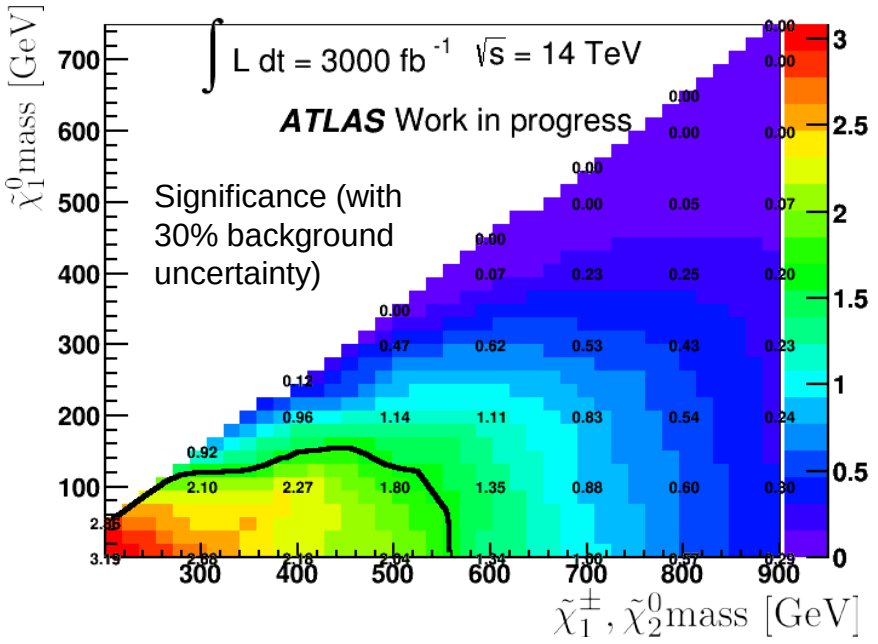
- Require 3 leptons (muons or electrons) such that 2 leptons (expected to come from the Higgs) have a small opening angle
- Veto events with b-quarks; supresses the top-quark backgrounds
- Veto events with same flavour, opposite sign pairs ($e^{\pm}e^{\mp}$or $\mu^{\pm}\mu^{\mp}$); supresses the WZ background
- Require E_T^{miss} > 100GeV
- Transverse mass cuts
  - mT1 > 150GeV
  - mT2 > 150GeV
  - mT3 > 200GeV

Current sensitivity

Total SM Backgrounds	Signal point ($m\chi_1^{\pm}$=200, $m\chi_1^0$=0)	Signal point ($m\chi_1^{\pm}$=500, $m\chi_1^0$=200)	Signal point ($m\chi_1^{\pm}$=700, $m\chi_1^0$=0)
9.52 ± 2.67	19.5 ± 6.5	6.44 ± 0.73	5.65 ± 0.35

→ Uncertainties above are statistical only





Summary

- SUSY is a promising theory for physics beyond the SM
- It is important to look for chargino neutralino pair production at the HL-LHC; investigated their decay mode via Higgs boson using leptonic final states
- Achieved 3 sigma for 200 GeV $\chi_1^{\pm}/\chi_2^0$ mass point.
- Future work:
  - Finalize the background estimate
  - Write the public note and incorporate the results into the ATLAS White Paper (supporting material for the upgrade)

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Thank you!
Merci

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Backup

What is an inverse femtobarn?

- Measurement of particle-collision events per femtobarn; a measure of both the collision number and the amount of data collected.
- One inverse femtobarn corresponds to approximately 100 trillion (10^{12}) proton-proton collisions.

Weight Calculations (Background)

	N_{gen}	σ	Efficiency	L_{MC}	Weight	$\sqrt{s}$ [TeV]
WZ (157953)	13250k	478.4 fb	1.0	27696.48 fb^(-1)	0.108317	14
WH (161105)	100k	269.44 fb	0.10384	3574.15 fb^(-1)	0.839360	14
WWW* (167006)	50k	$5.0961*(1.8)^2$ fb	1.0	3028.22 fb^(-1)	0.9906818	8
ZWW* (167007)	50k	$1.5546*(1.8)^2$ fb	1.0	9926.73 fb^(-1)	0.302214	8
ZZZ* (167008)	50k	$0.33239*(1.8)^2$ fb	1.0	46427.69 fb^(-1)	0.06461662	8
ttbar (105200)	14990k	953600 fb	0.54272	28.96406839 fb^(-1)	103.5766095	14
ttbarW (119353)	3500k	258.5 fb	1.0	13539.65184	0.221571429	14

- 8TeV samples rescaled to 14TeV.

Weight Calculations (Signal)

	N_{gen}	σ	Efficiency	L_{MC}	Weight	Corrected Weight
Signals (178474-178592)	50k	Theoretically Calculated	Taken from AMI	$\frac{N_{Gen}}{\sigma * \text{Eff}}$	$\frac{3000\ \text{fb}^{-1}}{L_{MC}}$	$\frac{\text{Weight}}{3.2641337}$
C1=N2=200GeV N1=0GeV (178474)	50k	1854 fb	0.063604	424.01fb^(-1)	7.075	2.1676
C1=N2=500GeV N1=200GeV (178485)	50k	50.1 fb	0.089607	11137.57 fb^(-1)	0.269358	0.08252071
C1=N2=1000GeV N1=0GeV (178518)	50k	1.646 fb	0.11828	256820.0 fb^(-1)	0.01168133	0.00357869

Signal Correction Factor

- The MC supressed several Higgs decay channels.
- Correct this by penalizing our signal by dividing the number of signal event by ~3.

Process	Theoretical Value	Simulation Input	Correction
h → c cbar	0.02910	0.0000000000	3.2641337
h → b bbar	0.57700	0.0000000000	
h → μ- μ+	0.00022	0.0007181094	
h → τ- τ+	0.06320	0.2062932498	
h → W- W+	0.21500	0.7017887453	
h → g g	0.08570	0.0000000000	
h → γ γ	0.00228	0.0000000000	
h → Z Z	0.02640	0.0861731297	
h → Z γ	0.00154	0.0050267659	

Event Selection

1) PRESELECTION
   1) Selects all electrons and muons in event with pt greater than 5 GeV.
   2) Selects jets with pt greater than 10 GeV.
2) APPLY SMEARING
   1) Smear lepton and MET information to simulate reco using TruthToRecoFunctions package.
3) OBJECT DEFINITION
   1) Electrons: pT>10GeV and |η|<2.47.
   2) Muons: pT>10GeV and |η|<2.50.
   3) Jets: pT>20GeV and |η|<2.50.

Event Selection (continued)

4) OVERLAP REMOVAL

1) Discard lowest Et electron if dR_ee<0.1 (duplicated electron).
2) Discard jet if dR_ejet<0.2 (duplication of objects across electron, jet containers).
3) Discard electron if dR_ejet<0.4 (discard electrons within remaining jets).
4) Discard muon if dR_mujet<0.4 (discard muons within remaining jets).
5) Discard both electron and muon if dR_mue<0.1 (discard overlapping electrons and muons from muonstraahlung).

Event Selection (continued)

5) TRIGGER

Require at least one of the following

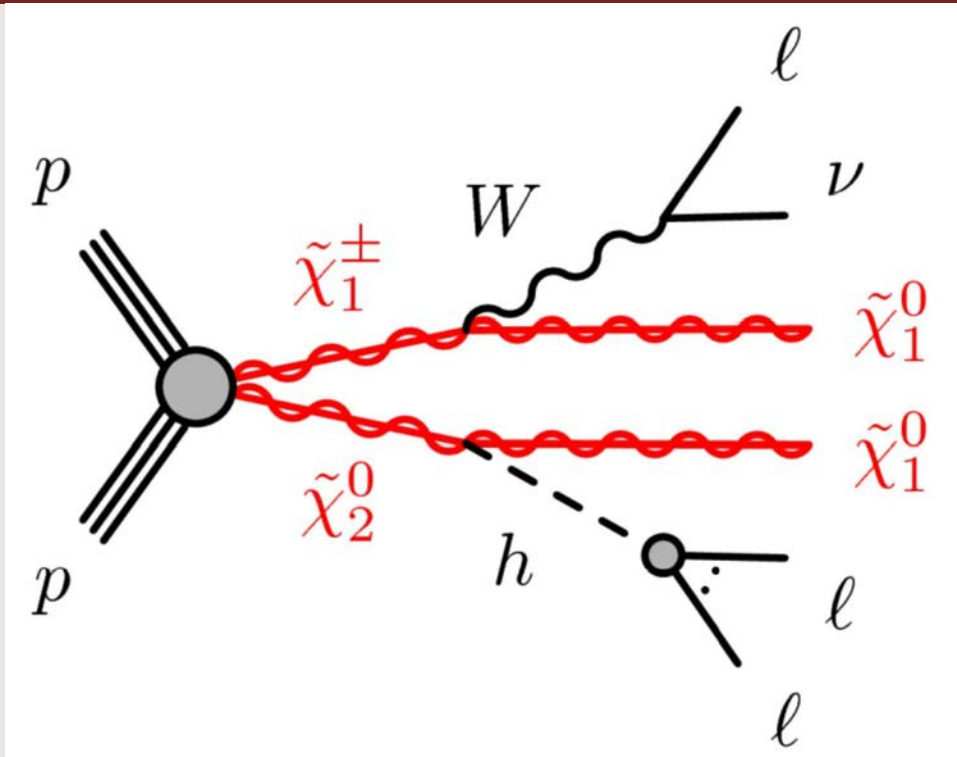
1) Electron: pT>25GeV and |η|<2.47.
2) Muon: pT>25GeV and |η|<2.40.

6) Calculate the jet flavors.

1) Look at every unstable quark, gluon and particle with pdgId = 0 within the jets dR=0.4 cone.
2) Choose highest energy parton within the jet to determine the flavor.
3) Apply b-tagging efficiency.

Signal

- 3 leptons + Missing transverse momentum (MET)
  - Signal cross-sections on the order of hundreds of fb
- Main backgrounds:
  - WZ (478.4 fb)
  - WH (269.44 fb)
  - ttbar (953,600 fb)
  - ttbarW (258.5 fb)
  - Triboson
    - WWW* (16.51 fb)
    - ZWW* (5.04 fb)
    - ZZZ* (1.08 fb)



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