Expermintal Searches for Physics Beyond the Standard Model

Steve Muanza

CPPM Marseille, CNRS-IN2P3
Aix Marseille University
FRANCE

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Outline

Steve Muanza's Personal Informations (Links are clickable)

Curriculum Vitae

Version in English
Version in French

Website

Personal Homepage

Summary of the SM

Where we stand for now

Passport

- Name: « Standard Model » of Particle Physics
- Date of Birth: 1967
- Parents: S. Glashow, A. Salam, S. Weinberg
  - Birth certificates:
    - Nucl. Phys 22 (1961) 579
    - Phys. Rev. Lett. 19 (1967) 1264
    - Conf. Proc. C 680519 (1968) 367
- Pediatricians: G. t'Hooft, M. Veltman
  - First pediatric examination: renormalizable (despite SSB)
- Particle Content:
  - Fermions: quarks & leptons (x3 generations)
  - Bosons:
    - Gauge: photon, W, Z, gluons
    - EWSB: Higgs
- External Symmetries:
  - Space-time structure: 3-D space, 1-D time, Minkowski metric
  - Poincaré group
    - Lorentz group: space-time rotation, boost
    - Space-time translation
- Discrete Symmetries: $C \cdot P \cdot T$
- Internal Symmetries:
  - Gauge group: $G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y$
- Visa exemptions: particles dynamics from low energy up to the EWK scale

Extending the Gauge Symmetries of the SM

Search for Grand Unified Theories

- New Particles: Z', $W'^{\pm}$, LQ,...
- New Phenomena: $Z - Z'$ mixing, $sin^2\theta_W$ (value and evolution), proton lifetime,...

Passport

- Name: « Grand Unified Theories »
- Date of Birth: 1974
- Parents:
  - S. Glashow, H. Georgi
  - J. Pati, A. Salam, ...
  - Birth certificates:
    - Phys. Rev. Lett. 32 (1974) 438,
    - Phys.Rev. D10 (1974) 275-289, ...
- Particle Content:
  - Includes the SM
  - In addition:
    - Leptoquarks
    - Possible Z' and/or W'
    - Possible ν_R
- Internal Symmetries:
  - Ex. of Gauge groups:

$$G_{GUT} = E_6 \rightarrow SO(10)\times U(1)_\psi \rightarrow SU(5)\times U(1)_\psi \times U(1)_\chi$$
$$G_{SM}$$

$$G_{Pati-Salam} = SU(4)\times SU(2)_R \times SU(2)_L \rightarrow SU(3)_C \times SU(2)_R \times SU(2)_L \times U(1)_{B-L}$$
$$G_{SM} \times SU(2)_R$$

- Visa exemptions: particles dynamics from low energy up to the GUT scale

Extending the Space-Time Symmetries of the SM

Search for Supersymmetry

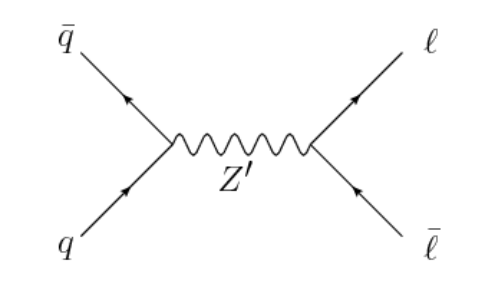
- New Particles: Higgs bosons (A^0, H^0, $H^\pm$), Super-partners ($\tilde{\ell}^\pm$, $\tilde{\nu}$, $\tilde{q}$, $\tilde{g}$,...)
- New Phenomena: Dark Matter ($\tilde{\chi}_1^0$ or $\tilde{G}_{3/2}$), natural M_h^{corr}, quantum gravity,...

Passport

- Name: « Minimal Supersymmetric Standard Model » of Particle Physics
- Date of Birth: 1983s
- Grand Parents: Y. Golfand, E. Likhtman, D. Volkov, V. Akulov, P. Ramond, P. Fayet, J. Iliopoulos,...
- Parents: H. Georgi, S. Dimopoulos
  - Birth certificate:
    - Nucl. Phys. B 193 (1983) 150
- 4-D Pediatricians: J. Wess, B. Zumino
- Particle Content:
  - Includes the SM (5 Higgs bosons)
  - Sfermions: squarks, sleptons
  - Gauginos: chargino, neutralinos, gluinos
  - SUGRA: graviton, gravitino
- Extended External Symmetries:
  - Space-time structure: 3-D space, 1-D time, Minkowski metric
  - Super-Poincaré group
    - Q: SUSY fermionic operators
    - Algebra w/ commuting & anti-commuting relations
- Internal Symmetries:
  - Low-E Gauge group: $G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_Y$
  - High-E Gauge Group: $G_{GUT} = E_8 \; or \; E_6 \; or \; SO(10) \; or \; SU(5)$
- Visa exemptions: particles dynamics from low energy up to the GUT scale

Search for New Resonances at the LHC

Search for Z': Principles



- Event Topology: "Charged dilepton" ($\ell = e/\mu$), i.e. all visible decay products
- Distinctive feature: signal peaks at $M_{\ell^+\ell^-} \approx M_{Z'}$ over a smooth background (search for resonance)
- Mass reconstruction:
  - Easy if FS is only made of visible decay products
  - In this case, one can rely exclusively on the Final State (FS)!
  - Invariant mass for N-body decay:

$$M = \sqrt{\left(\sum_{i=1}^{N} E_i\right)^2 - \left(\sum_{i=1}^{N} \vec{p}_i\right)^2} \tag{1.a.}$$

  - Ref: A. Einstein, Ann. d. Phys., vol.18, n13 (1905) 639-641
  - Comments:
    - Full Lorentz invariant
    - This is how the Z mass is measured at collider experiments

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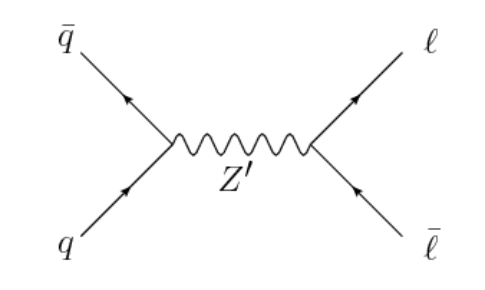
Search for Z': Principles



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Search for Z': Typical Analysis $\longrightarrow$ Link

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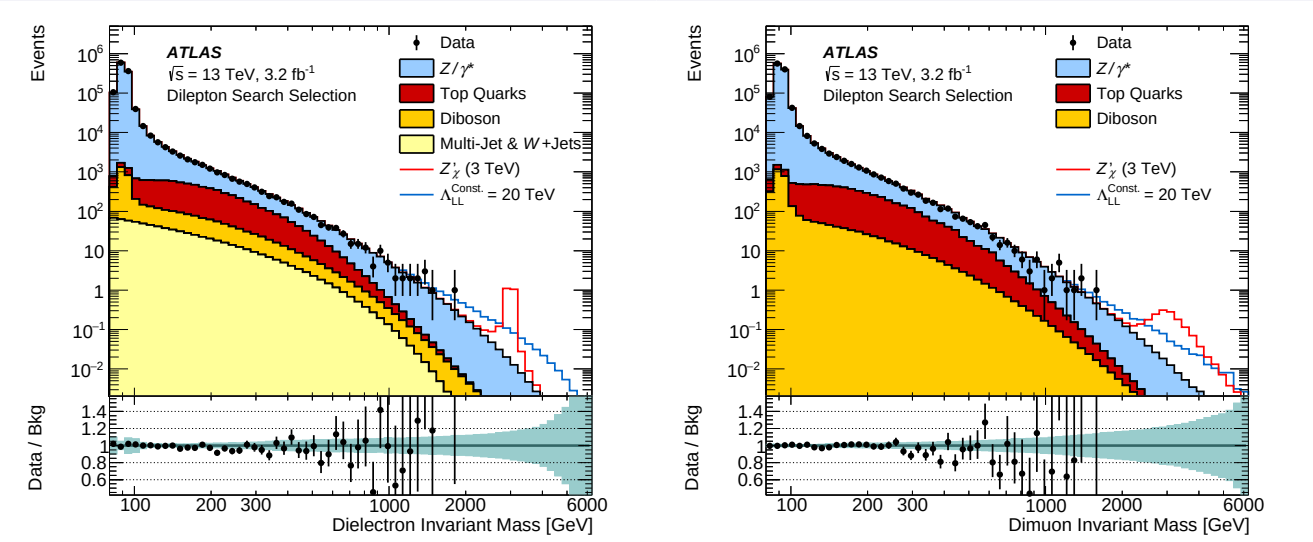
- Data sample: $\int \mathcal{L}dt = 3.2\ fb^{-1}$ of ATLAS pp collisions at $\sqrt{s} = 13$ TeV (2015)
- Event Selection:
  - Trigger: di-electron with $p_T(e^{\pm}) > 17$ GeV & single muon with $p_T(\mu^{\pm}) > 26/50$ GeV
  - Offline: 2 OS-SF isolated leptons with $p_T > 30$ GeV
- Final discriminant: Dilepton Mass
- Sensitivity to signal: depends crucially on
  - Signal natural width: $\Gamma_{Z'}$ (model dependent)
  - Dilepton mass resolution: mainly resulting from $\frac{\sigma_E}{E}(e^{\pm})$ or $\frac{\sigma_p}{p}(\mu^{\pm})$



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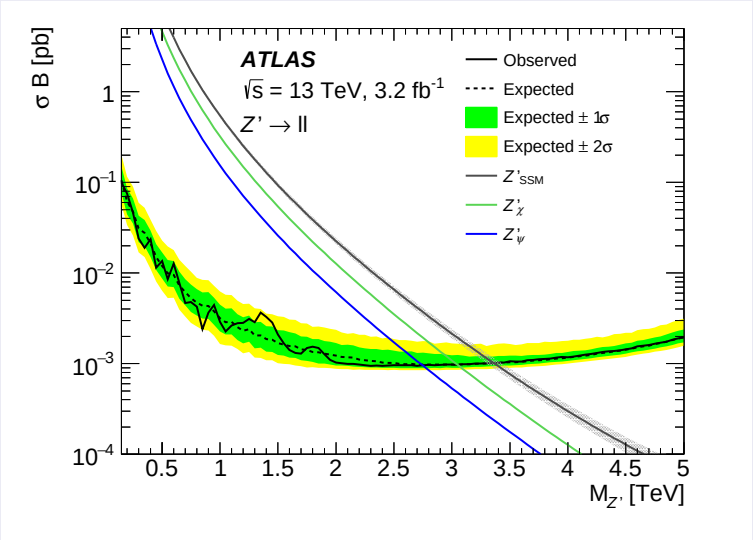
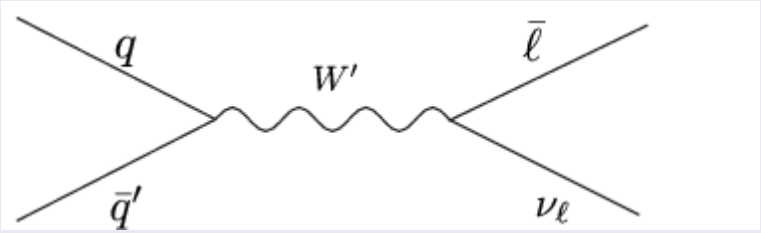


Search for New Resonances at the LHC

Search for W': Principles (1)



- Event Topology: $1\ell^{\pm} + \not{E}_T$
- Distinctive feature: signal displays a Jacobian peak at $M_T \approx M_{W'}$ over a smooth background (search for resonance)
- Mass reconstruction:
  - More complicated:
    - Can measure the full $4-p$ of the charged lepton
    - But ν escapes detection $\Rightarrow$ both $E(\nu)$ and $p_z(\nu)$ are unkown!
    - Full event reconstruction: not possible!
  - Transverse mass for N-body decay:

$$M_T = \sqrt{\left(\sum_{i=1}^{N} E_{T_i}\right)^2 - \left(\sum_{i=1}^{N} \vec{p}_{T_i}\right)^2} \tag{2.a.}$$

  - Ref: V. Barger et al., Z.Phys. C21 (1983) 99
  - Comments:
    - Not fully Lorentz invariant (only along longitudinal boosts)
    - This is how the W mass is measured at hadron collider experiments

Search for New Resonances at the LHC

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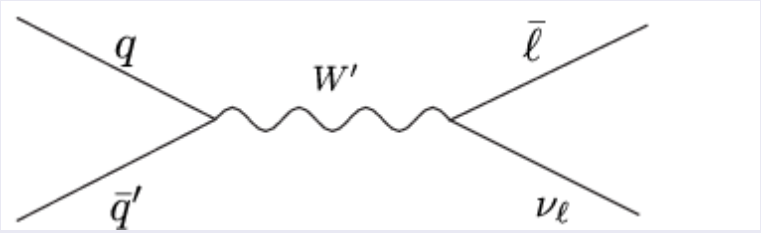

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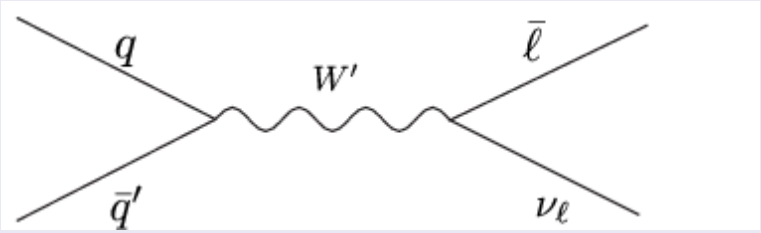

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- Data sample: $\int \mathcal{L} dt = \ fb^{-1}$ of CMS pp collisions at $\sqrt{s} = 13$ TeV (201?)
- Event Selection:
  - Trigger: 1 $e^\pm$ w/ $p_T(e^\pm) > 105/115$ GeV or 1 $\mu^\pm$ w/ $p_T(\mu^\pm) > 45/50$ GeV
  - Offline: 1 isolated $e^\pm/\mu^\pm$ (reject events w/ 2 leptons), $0.4 < \frac{p_T(\ell^\pm)}{\not{E}_T} < 1.5$
- Final discriminant: Transverse Mass
- Sensitivity to signal: depends crucially on
  - Signal natural width: $\Gamma_{W'}$ (model dependent)
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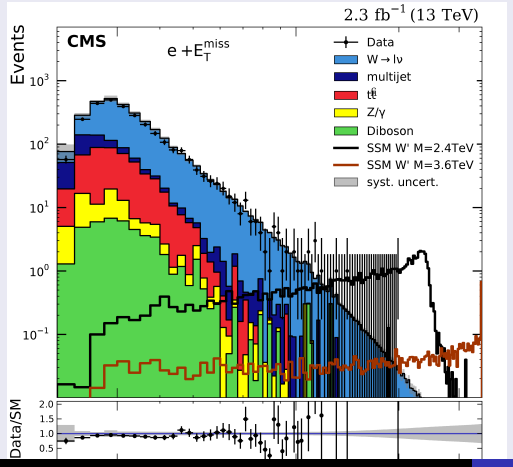

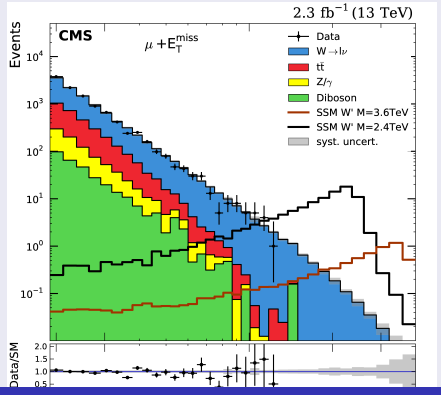

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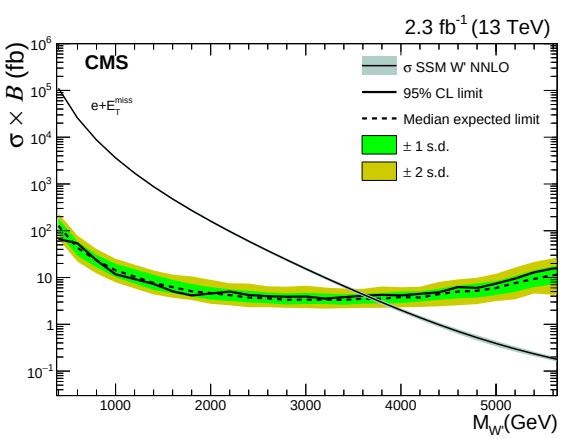

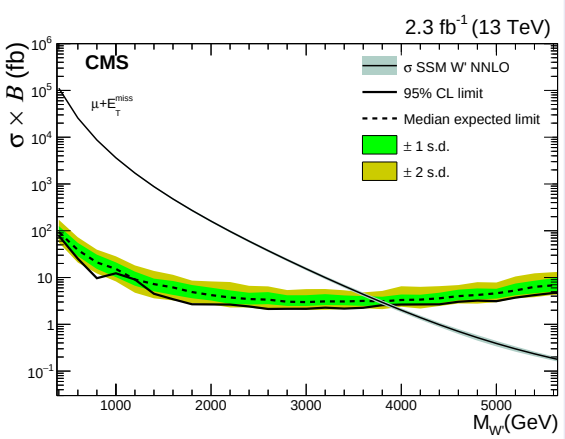

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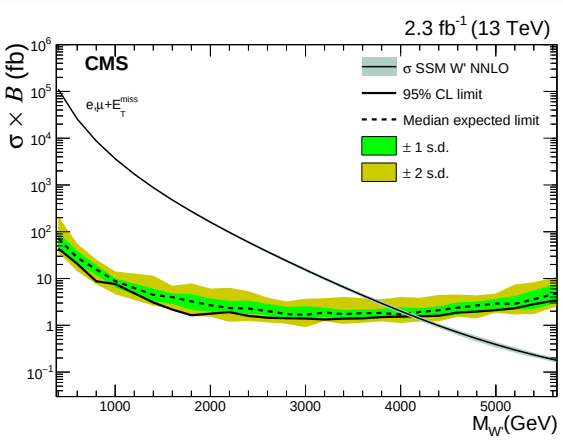


Search for New Resonances at the LHC

Missing Transverse Momentum at Hadron Colliders

- Definition: (sum over visible particles)
  - Ideally,

$$\not{\vec{p}}_T = \sum_{i=1}^{Invis.Part.} \vec{p}_{T_i} = -\sum_{i=1}^{Vis.Part.} \vec{p}_{T_i} \tag{1}$$

  - In practice,

$$\begin{cases} \not{p}_x = -\sum_{j=1}^{Reco.Objects} p_{x_j} - \sum_{j=1}^{SoftTerms} p_{x_j} \\ \not{p}_y = -\sum_{j=1}^{Reco.Objects} p_{y_j} - \sum_{j=1}^{SoftTerms} p_{y_j} \end{cases} \tag{2}$$

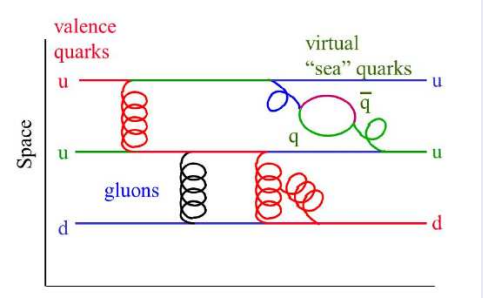
  - Usual language and notations: "Missing Transverse *Energy*" ($\not{E}_{x,y} \equiv \not{p}_{x,y}$)

$$\begin{cases} \not{E}_T = \sqrt{\not{E}_x^2 + \not{E}_y^2} \\ \phi(\not{E}_T) = Atan\left(\frac{\not{E}_y}{\not{E}_x}\right) \end{cases} \tag{3}$$

Search for New Resonances at the LHC

Restriction to the transverse plane for $\not{E}_T$

- At hadron hadron colliders the kinematics of the hadron collision is fully known (4-momenta of hadrons is known)
- However since these are not elementary, there are two (correlated) parts in the collision



  - "Hard Scatter": violent collision of 2 partons (quarks or gluons); of interest to us
  - "Underlying Event": debris of hadrons (plus possible secondary Hard Scatter); a background for us

Search for New Resonances at the LHC

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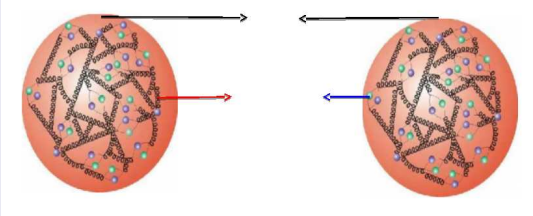

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$$P(p_1) = (E = 7000, p_x = 0, p_y = 0, p_z = 7000)\ \text{GeV},\ P(p_2) = (7000, 0, 0, -7000)\ \text{GeV},$$
$$\Rightarrow \sqrt{s} = 14\ \text{TeV}$$

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$$P(q_1) = (x_1 \cdot 7000, 0, 0, x_1 \cdot 7000) \text{ GeV},$$
$$P(q_2) = (x_2 \cdot 7000, 0, 0, -x_2 \cdot 7000) \text{ GeV} \Rightarrow \sqrt{s} = \sqrt{x_1 x_2}\sqrt{\hat{s}} \approx 0.1\text{-few TeV}$$

Search for New Resonances at the LHC

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$0 < x_i < 1,$

often $x_1 \neq x_2$ BOTH UNKNOWN $\Rightarrow$ possible boost along $\pm$z-axis

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Even though (E,$\vec{p}$) conservation fully holds, we do not know the partonic Initial State (I.S.)

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All we know is

$p_{x_i}^{I.S.} \approx 0$ and $p_{y_i}^{I.S.} \approx 0$

Search for New Resonances at the LHC

Restriction to the transverse plane for $\not{\vec{E}}_T$

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Therefore we can only apply $\vec{p}$ conservation in the TRANSVERSE PLANE

Extending the Space-Time Symmetries of the SM

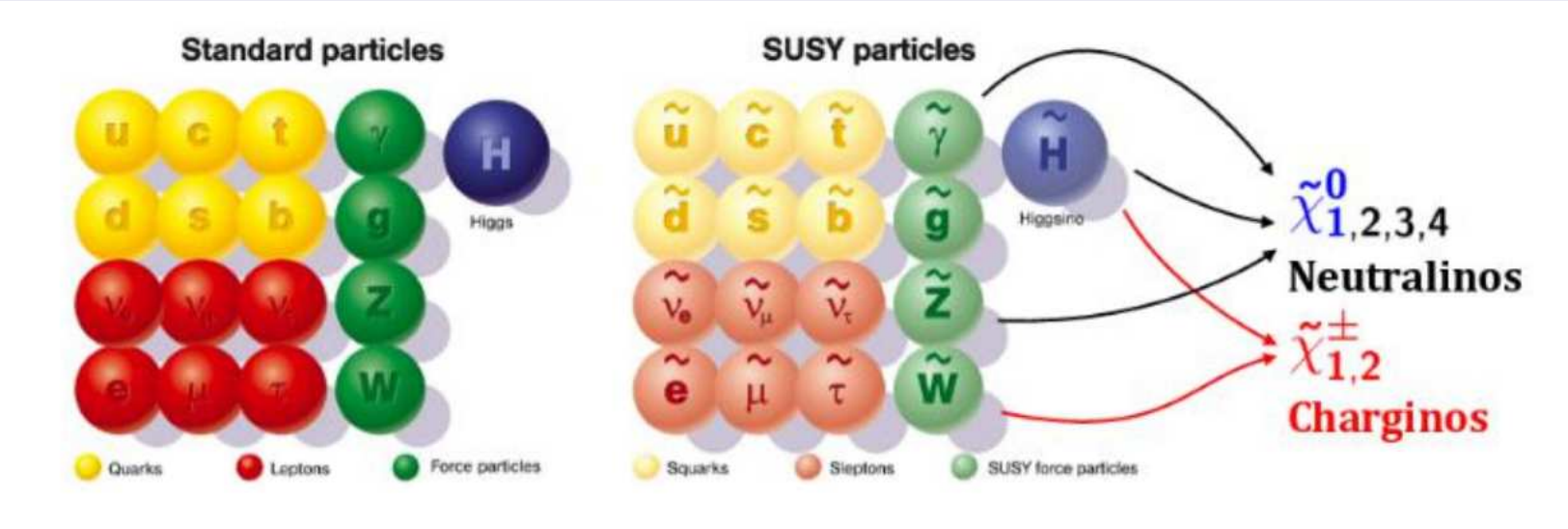
Reminders about Supersymmetry

- Definition:

$$\mathbf{Q|S>=|S\pm 1/2>} \tag{4}$$

$$\begin{cases} Q|B>=|F> \\ Q|F>=|B> \end{cases} \tag{5}$$

- MSSM: "Minimal Supersymmetric Standard Model"
  - $\mathcal{N}=1$ (SUSY is a broken symmetry)
  - $G_{MSSM}=G_{SM}=SU(3)_C\otimes SU(2)_L\otimes U(1)_Y$
  - Minimal particle content (but with 5 Higgs bosons, not 1)



Extending the Space-Time Symmetries of the SM

Reminders about Supersymmetry

- R-Parity:

$$\mathbf{R_P} = (-\mathbf{1})^{\mathbf{L+2S+3B}} \tag{6}$$

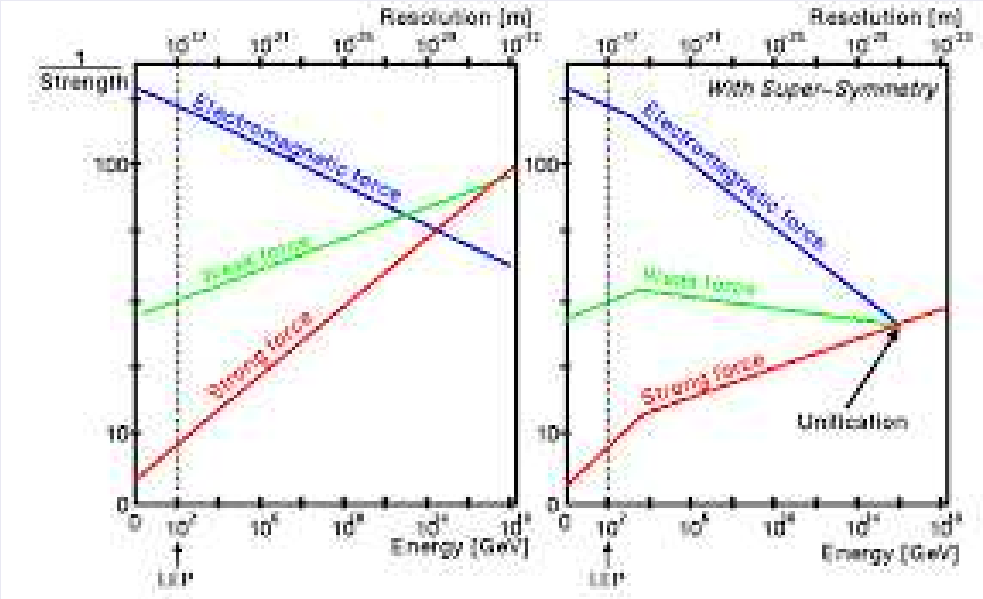
$$\begin{cases} R_P = +1(SM) \\ R_P = -1(SUSY) \end{cases} \tag{7}$$

- R_P Conservation (RPC):
  - SUSY particles are pair-produced
  - any SUSY particle decays into SM particles + a lighter SUSY particle
  - $\Rightarrow$ the lightest SUSY particle (LSP) is STABLE
  - The proton lifetime not excluded by data (Super-Kamiokande experiment)
  - In gravity-mediated SUSY breaking models, $\tilde{\chi}_1^0$ is the LSP
  - $\tilde{\chi}_1^0$ interacts weakly *Rightarrow* invisible in LHC detectors
  - $\tilde{\chi}_1^0$ is massive
  - Hence it's an excellent candidate for Cold Dark Matter (DM)

Extending the Space-Time Symmetries of the SM

SUSY Mass Spectrum

- Full SUSY models depend on 19 (SM) + 105 (soft-SUSY breaking) free parameters
- Once these parameters are set
  - Masses: of all SUSY particles can be calculated
  - Couplings: of all SUSY particles can be calculated
  - These masses & couplings determine how:
    - the Sparticles are produced
    - the Sparticles decay
    - the Sparticles (long-lived and LSP) interact in the detectors



Extending the Space-Time Symmetries of the SM

SUSY Mass Spectrum

- Full SUSY models depend on 19 (SM) + 105 (soft-SUSY breaking) free parameters
- Once these parameters are set
  - Masses: of all SUSY particles can be calculated
  - Couplings: of all SUSY particles can be calculated
  - These masses & couplings determine how:
    - the Sparticles are produced
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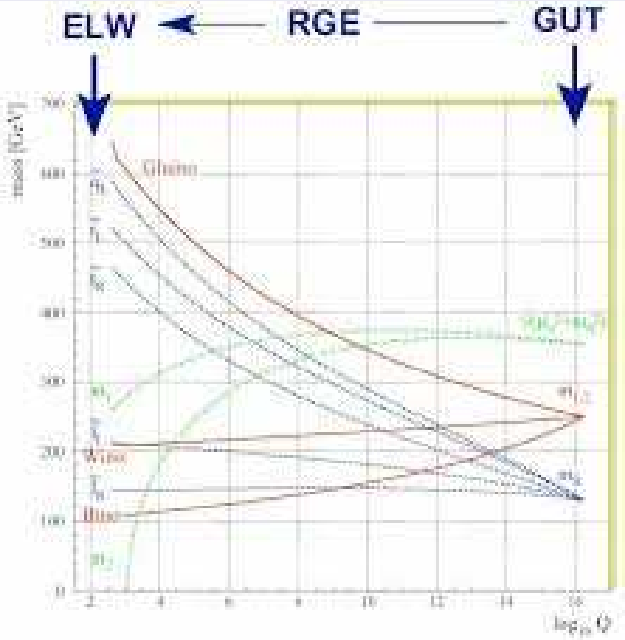

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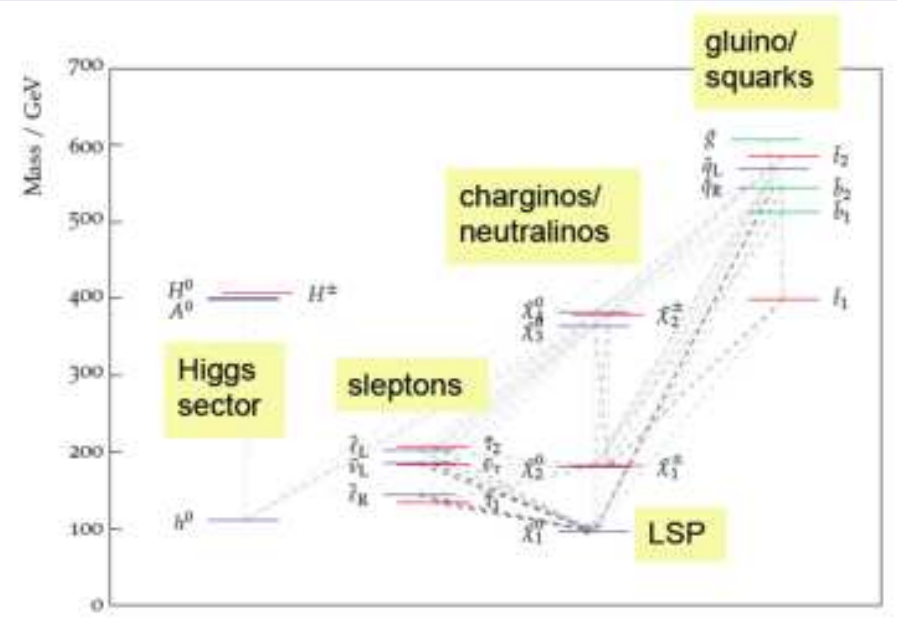
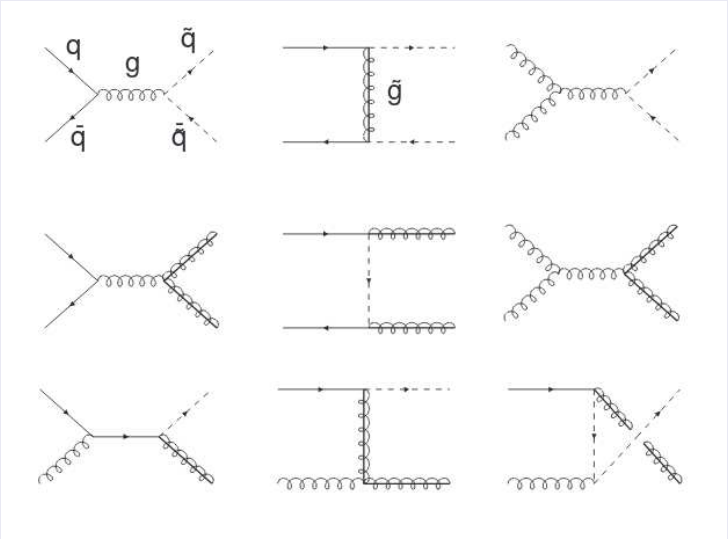


Extending the Space-Time Symmetries of the SM

SUSY Strong Production at LHC

- Shortname: "SUSY QCD"
- Sparticles:
  - 1st & 2nd generation squarks $\tilde{q}$: scalar u, scalar s,...
  - 3rd generation squarks $\tilde{Q}$: stops ($\tilde{t}_{1,2}$), sbottoms ($\tilde{b}_{1,2}$)
  - gluinos $\tilde{g}$
- Cross section: $\sigma(pp \to \tilde{q}\tilde{q}/\tilde{q}\tilde{g}/\tilde{g}\tilde{g})_{LO} \propto \alpha_3^2$



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    neutral (sneutrinos $\tilde{\nu}$)
  - "electroweakinos":
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    neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$
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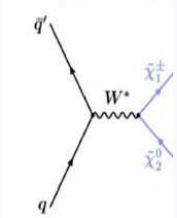

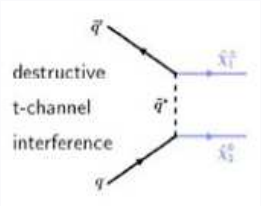

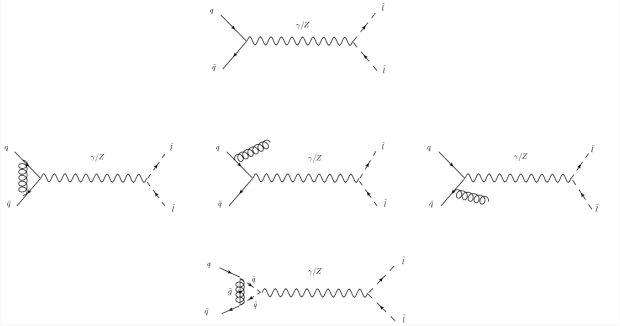

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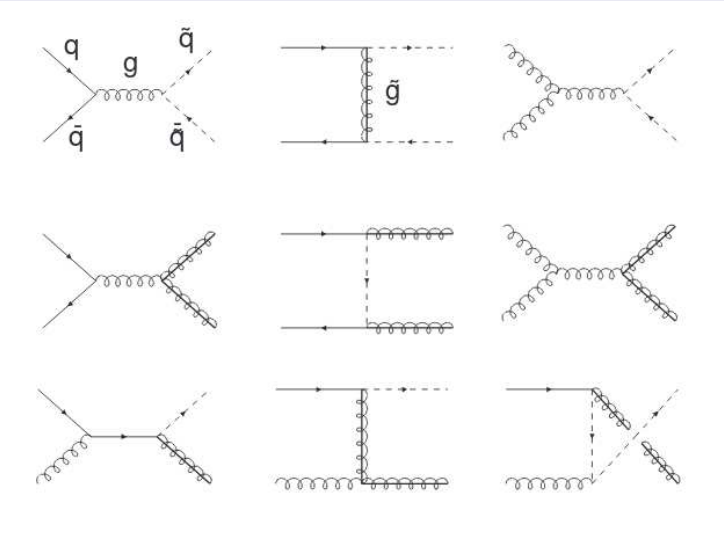

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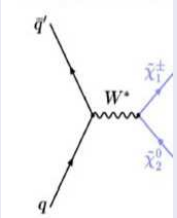

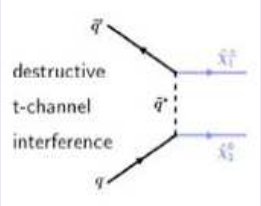

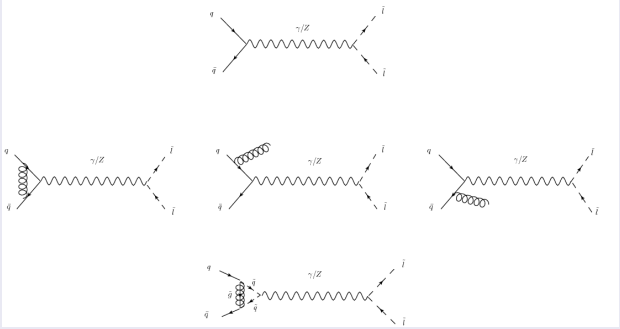

SUSY Searches at the LHC

Decay of Strong SUSY Particles

- State-of-the-art theory prediction:
  - Matrix Elements (MEs): σ_{NLO} (Next-to-Leading Order: "1-loop" QCD corrections)
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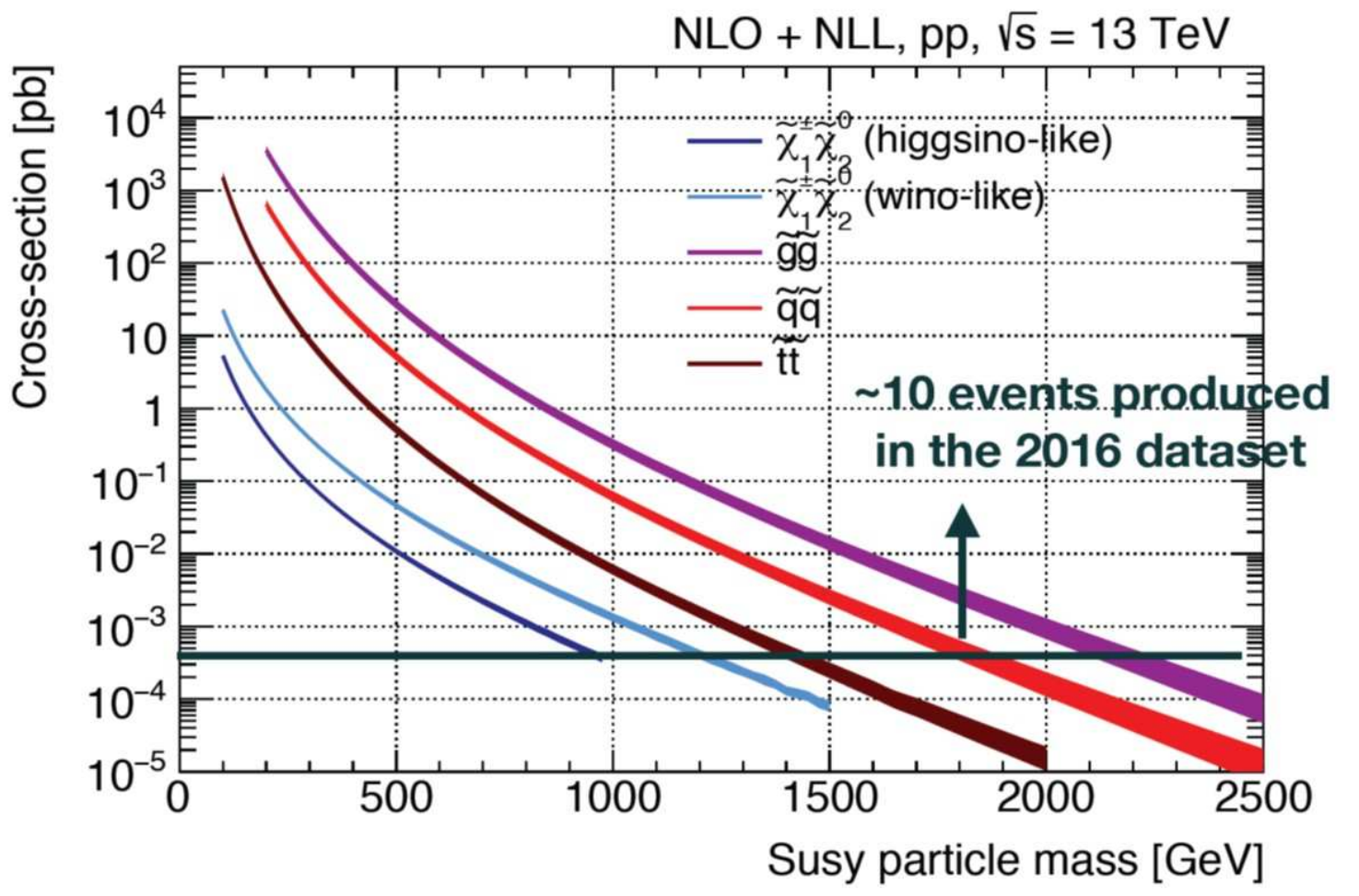

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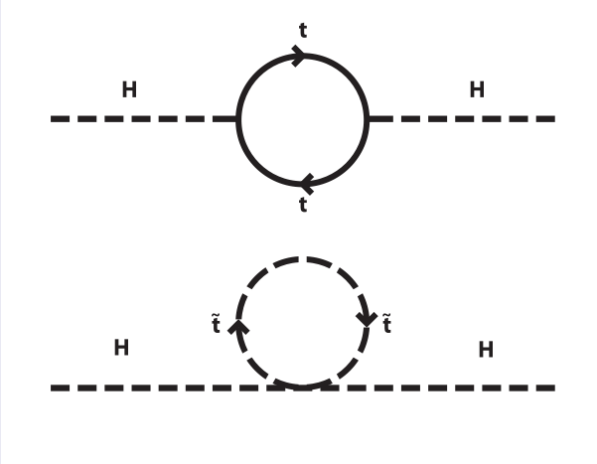
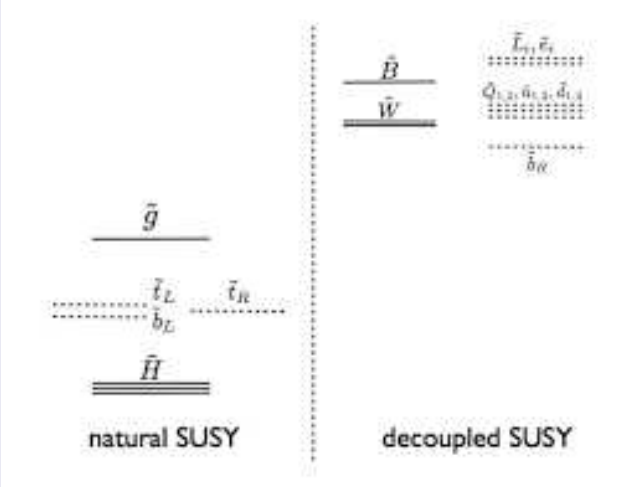
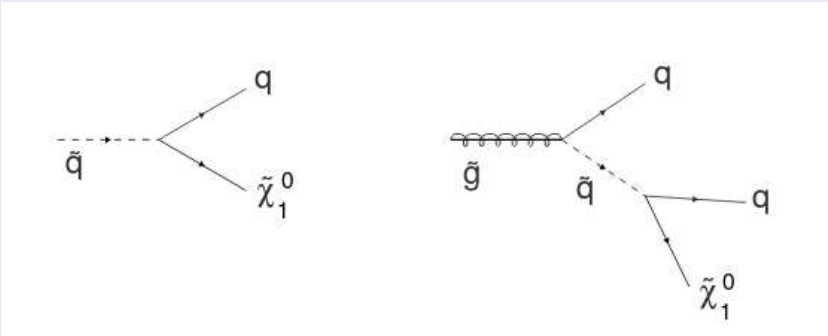
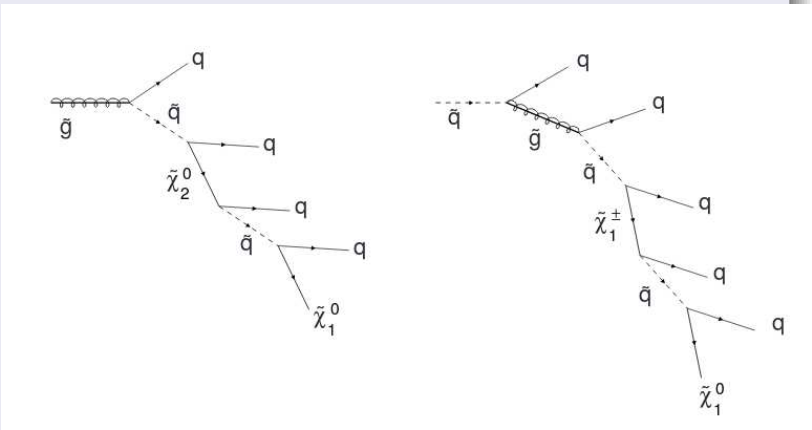




Extending the Space-Time Symmetries of the SM

Decay of Strong SUSY Particles





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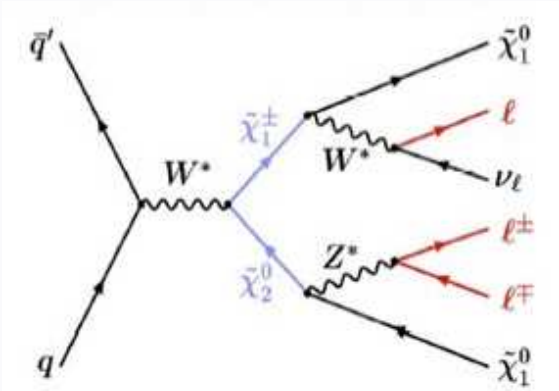

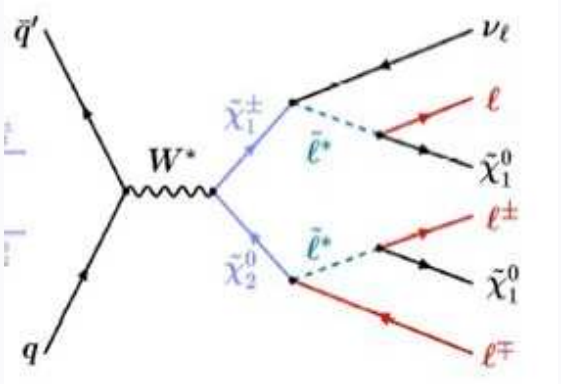

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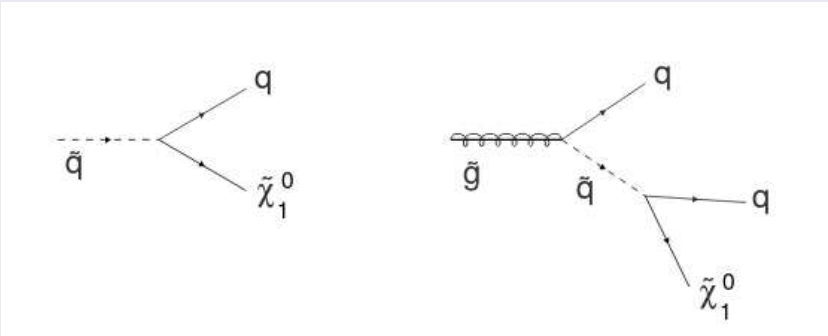

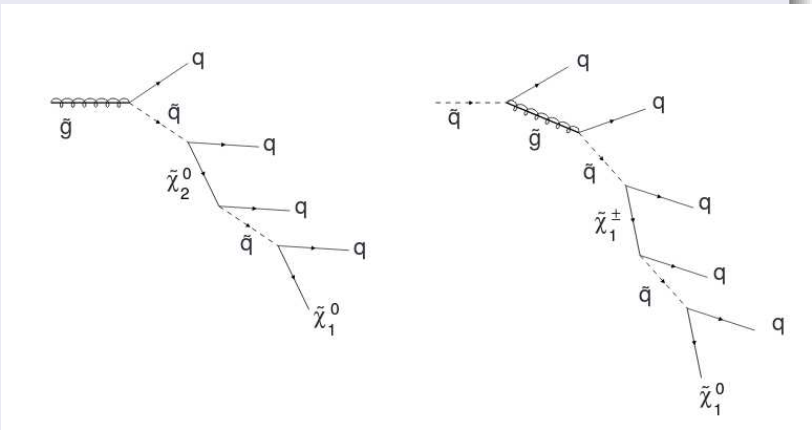

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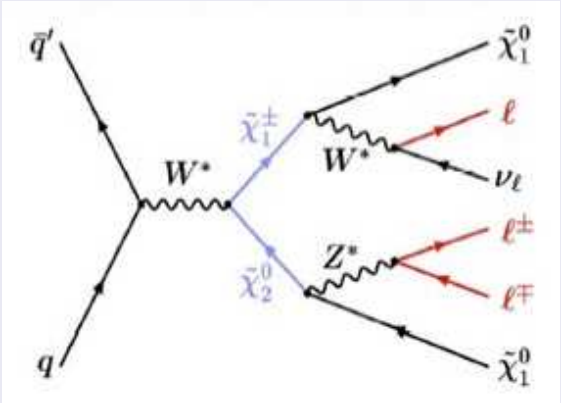
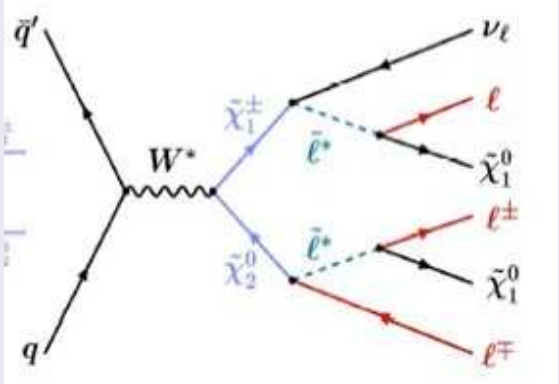
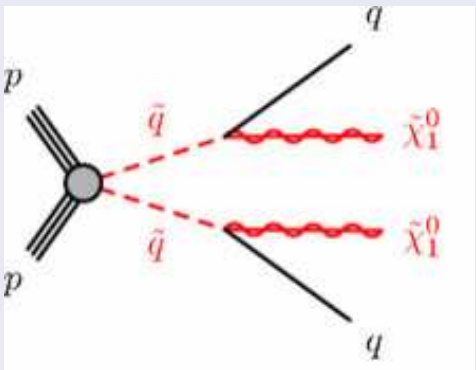


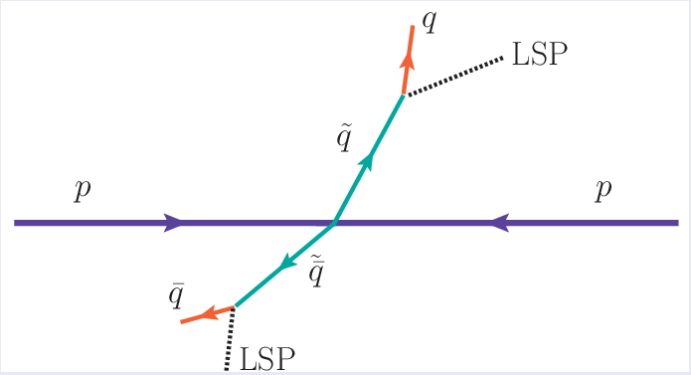


Extending the Space-Time Symmetries of the SM

Relation between Decay Chain & Search Topology

- Simple example:
  squarks pair production searched for in the acoplanar $2j + \not{E}_T$ event topology





- General case: $(n)j + (m)\ell^{\pm} + (p)\gamma + \not{E}_T$ event topology
  - w/ different the jets flavours: $b - jets$, $c - jets$, $\tau - jets$, $LF - jets$ (LF: u/d/s/g)
  - $\ell^{\pm}$ stands for $e^{\pm}$ or $\mu^{\pm}$

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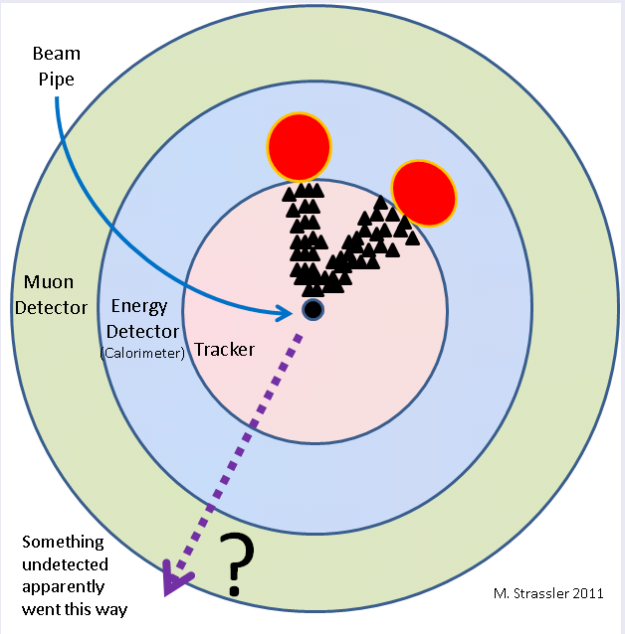

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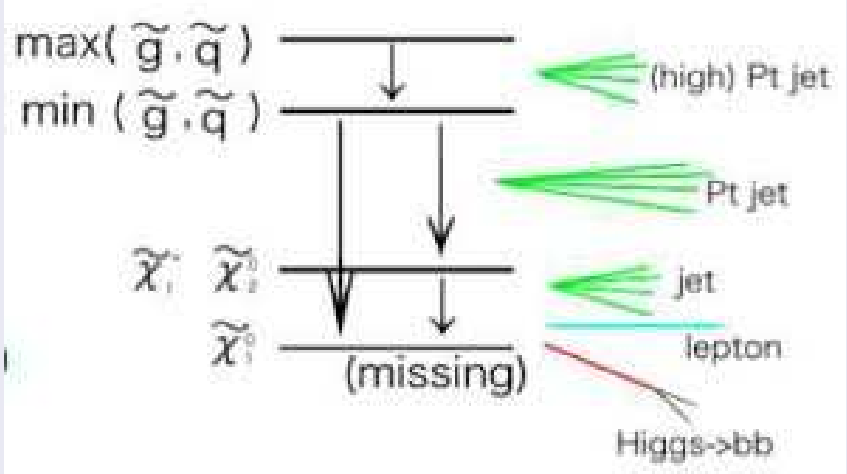
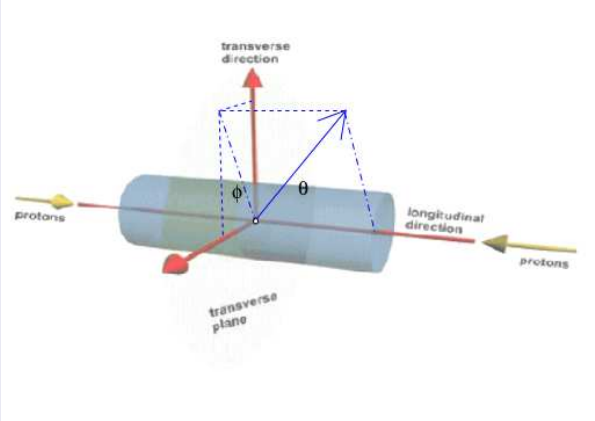


Search for SUSY at the LHC

Search for squarks & gluinos: Specific Variables

- Event Topology: products$(n)j + (m)\ell^{\pm} + \not{E}_T$ ($p \neq 0$ for GMSB)
- No obvious distinctive features over the large QCD background
- Usual Angular Variables:



$$\begin{cases} y = \frac{1}{2} Log \frac{(E+p_z)}{(E-p_z)} \\ \eta = -Log\left(tan\frac{\theta}{2}\right) \\ \Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \\ \Delta\phi_{min}(jets, \not{E}_T) \end{cases} \tag{8}$$

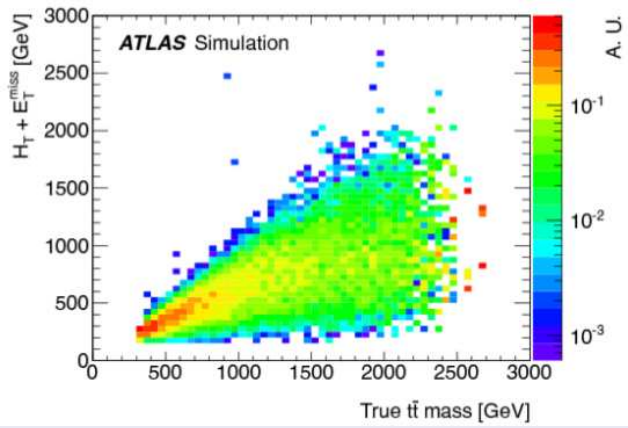
Search for SUSY at the LHC

Search for squarks & gluinos: Specific Variables

- Effective Mass:

$$M_{eff} = \sum_{i=1}^{N} p_{T_i}^{jets} + p_{T_i}^{leptons} + \not{E}_T \tag{9}$$

  - Not Lorentz invariant
  - But, sensitive to mass scale
    - $pp \rightarrow \tilde{g} + \tilde{q}$: $M_{eff}\, Min(M_{\tilde{g}}, M_{\tilde{q}})$
  - Yet, not precise and slightly biased
  - Ref: F. Paige, in A. Bartl et al., Proc. of Snowmass (1996) 693, [hep-ph/9612359]
  - Ref: F. Paige, in I. Hinchliffe et al., Phys. Rev. D55 (1997) 5520, [hep-ph/9610544]



Search for $Z' \rightarrow t\bar{t}$

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- Stransverse Mass:
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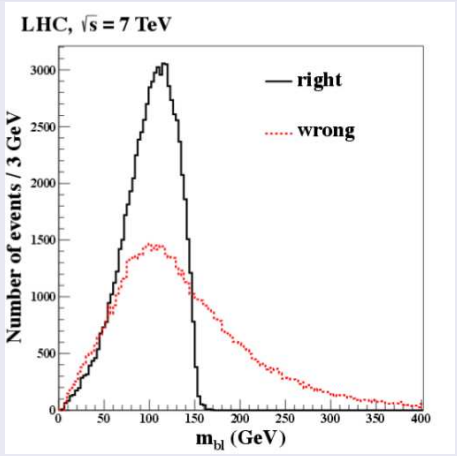

$t\bar{t}$ dilepton channel

$$M_{T2}\left[vis^{(A)}, vis^{(B)} | M_{\chi}^{trial}\right] =$$

$$\min_{\vec{\not{E}}_T = \vec{\not{E}}_T^{(A)} + \vec{\not{E}}_T^{(B)}} Max\left[M_T(\vec{p}_T^{vis(A)}, \vec{\not{E}}_T^{(A)} | M_{\chi}^{trial}), M_T(\vec{p}_T^{vis(B)}, \vec{\not{E}}_T^{(B)} | M_{\chi}^{trial})\right] \quad (10)$$

$$M_T^{2(A)} = M^{2(A)} + M^{2(\chi_A)} + 2\left[E_T^{(A)} E_T^{(\chi_A)} - \vec{p}_T^{(A)} \vec{p}_T^{(\chi_A)}\right] \quad (11)$$

$$M_{T2} \leq M_{Parent} \text{ and } \mathrm{M_{T2}^{Edge}} \approx \mathrm{M_{Parent}}$$

$$(\text{ provided } \mathrm{M}_{\chi} = M_{\tilde{\chi}_1^0})(12)$$

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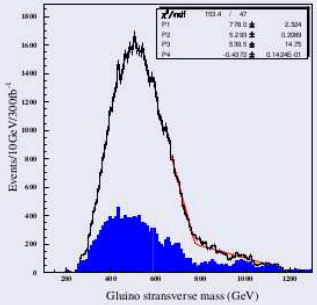
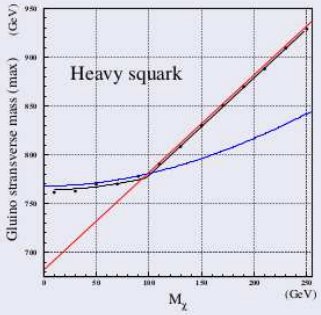


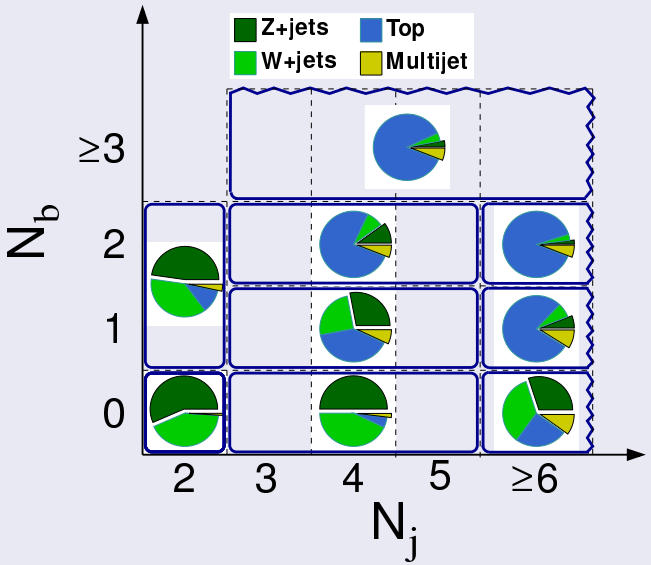


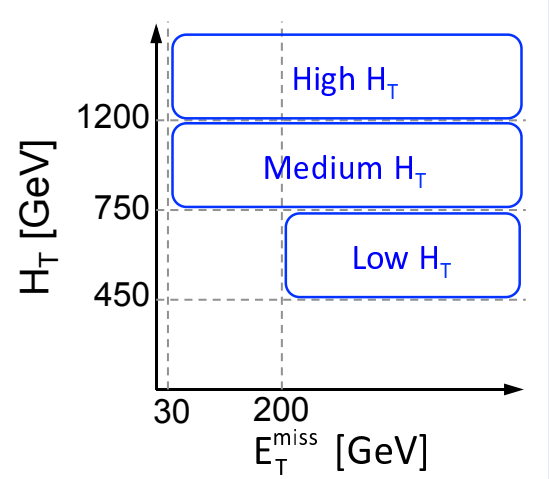
Properteis of Stransverse Mass

Search for SUSY at the LHC

Search for squarks and gluinos: Typical M_{T2}-based Search $\longrightarrow$ Link

- Event Topology: "$(n_{LF})j + (n_b)j + (0)\ell^{\pm}\not{E}_T$"
- Main background process: $Z(\rightarrow \nu\bar{\nu}) + jets$, $W^{\pm}(\rightarrow \ell^{\pm}\nu) + jets$, $t\bar{t}$ and QCD
- Data sample: $\int \mathcal{L}dt = 19.5\ fb^{-1}$ of CMS pp collisions at $\sqrt{s} = 8$ TeV (2012)
- Event Selection: $H_T = \sum_{i=1}^{N_j} p_{T_i}$
  - Trigger: $H_T > 650$ GeV OR $\not{E}_T > 150$ GeV OR $H_T > 350$ GeV& $\not{E}_T > 100$ GeV
  - Offline: 2 jets with $p_T > 100$ GeV and $|\eta| < 3.0$
    $H_T > 750$ GeV, OR $H_T > 450$ GeV, AND $\not{E}_T > 200$ GeV
    suppress QCD: $\Delta\phi_{min}(jets, \not{E}_T) > 0.3$ rad
- Final discriminant: events are clustered into 2 fat jets, $M_{T2} > 100 - 200$ GeV





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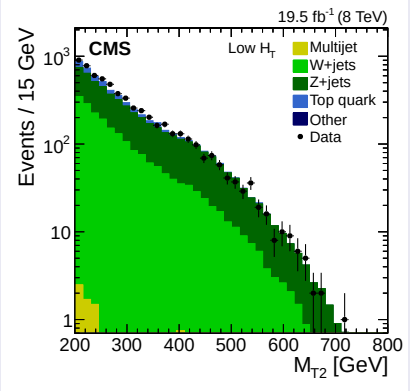
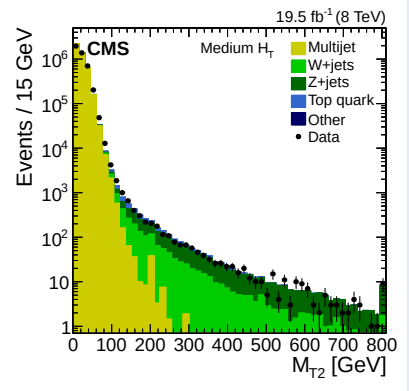
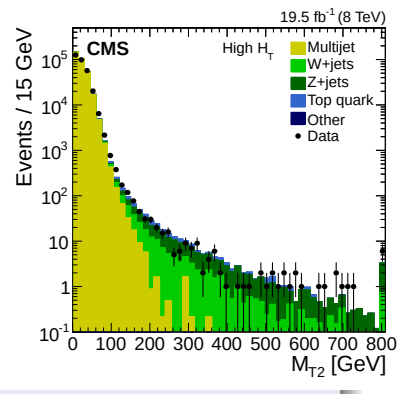


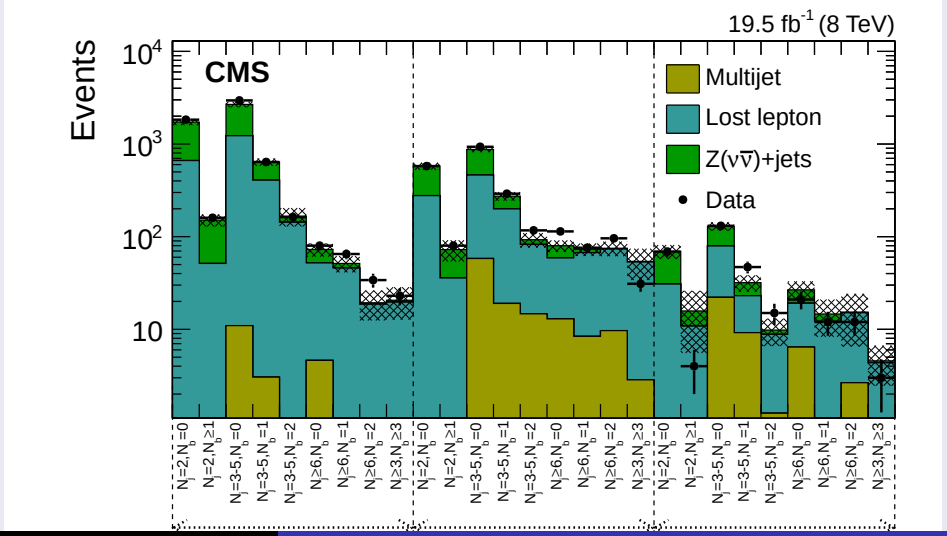




Search for SUSY at the LHC

Search for squarks and gluinos: Typical M_{T2}-based Search $\longrightarrow$ Link

- Event Topology: "$(n_{LF})j + (n_b)j + (0)\ell^{\pm}\not{E}_T$"
- Main background process: $Z(\rightarrow \nu\bar{\nu}) + jets$, $W^{\pm}(\rightarrow \ell^{\pm}\nu) + jets$, $t\bar{t}$ and QCD
- Data sample: $\int \mathcal{L}dt = 19.5\ fb^{-1}$ of CMS pp collisions at $\sqrt{s} = 8$ TeV (2012)
- Event Selection: $H_T = \sum_{i=1}^{N_j} p_{T_i}$
  - Trigger: $H_T > 650$ GeV OR $\not{E}_T > 150$ GeV OR $H_T > 350$ GeV& $\not{E}_T > 100$ GeV
  - Offline: 2 jets with $p_T > 100$ GeV and $|\eta| < 3.0$
    $H_T > 750$ GeV, OR $H_T > 450$ GeV, AND $\not{E}_T > 200$ GeV
    suppress QCD: $\Delta\phi_{min}(jets, \not{E}_T) > 0.3$ rad
- Final discriminant: events are clustered into 2 fat jets, $M_{T2} > 100 - 200$ GeV



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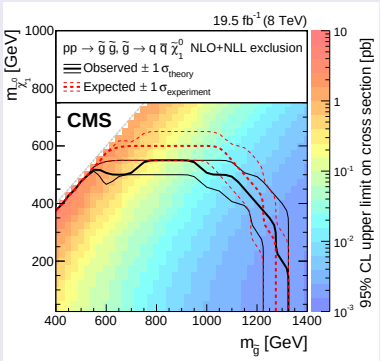

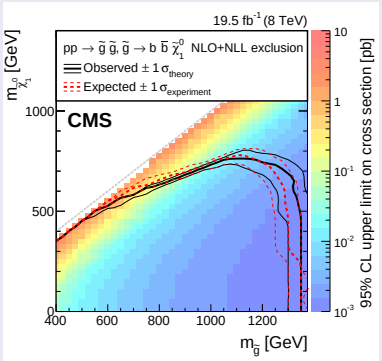

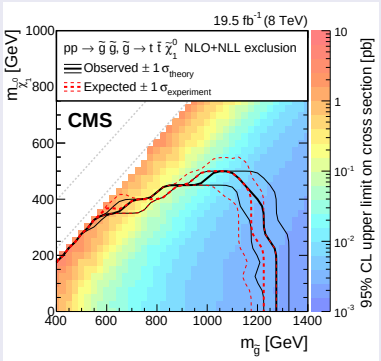

Search for SUSY at the LHC

Search for Direct Production of Electroweakinos: Specific Variables

- Dilpeton Mass Edge:
  - Lorentz invariant
  - Sensitive to mass difference
  - Very accurate
    - $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3\ell^{\pm} + \not{E}_T$
    - 2-body DK:

$$M^{max}_{\ell^+\ell^-} = M_{\tilde{\chi}_2^0} \times \sqrt{\left(1 - \frac{M^2_{\tilde{\ell}_2^{\pm}}}{M^2_{\tilde{\chi}_2^0}}\right)\left(1 - \frac{M^2_{\tilde{\chi}_1^0}}{M^2_{\tilde{\ell}_2^{\pm}}}\right)} \quad (13)$$

    - 3-body DK:

$$M^{max}_{\ell^+\ell^-} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} \quad (14)$$

- Ref: H. Baer et al., Phys. Rev. D 50 (1994) 4508 [hep-ph/9404212]

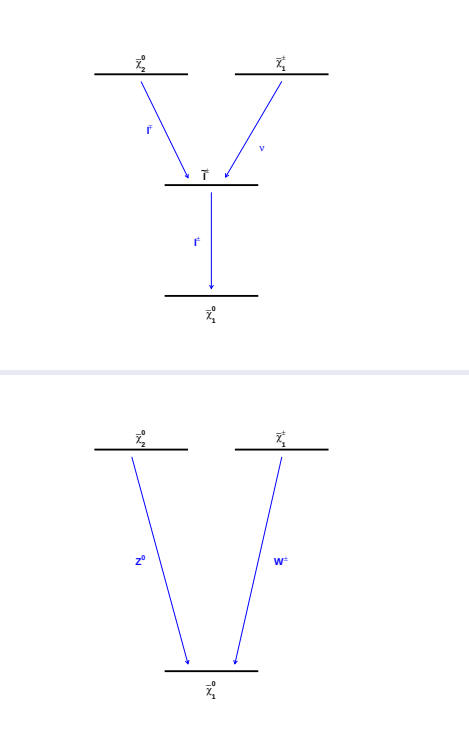

Figure: $\tilde{\chi}_2^0$ 2-body (top) and 3-body (bottom) leptonic decay

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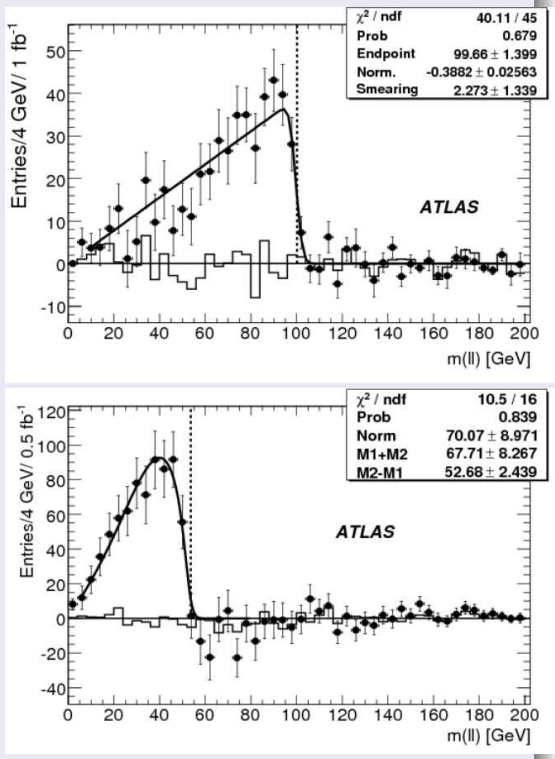

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Search for SUSY at the LHC

Search for Direct Production of Electroweakinos: Specific Variables

- Integral Charge Asymmetry:
  - Statistical variable (not event variable)
  - Sensitive to mass scale
  - Moderately accurate
  - Almost model-independent (relies on PDFs)
  - $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3\ell^{\pm} + \not{E}_T$

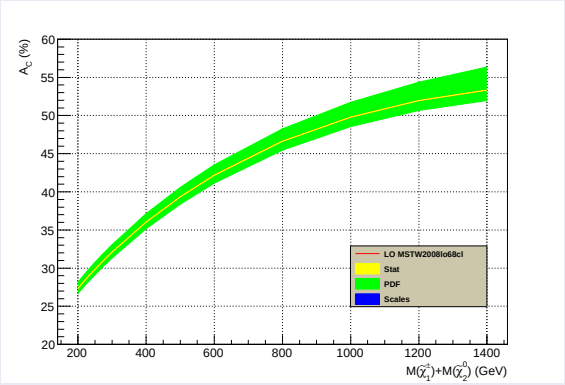
$$A_C = \frac{N_{\ell+} - N_{\ell-}}{N_{\ell+} + N_{\ell-}} \qquad (15)$$

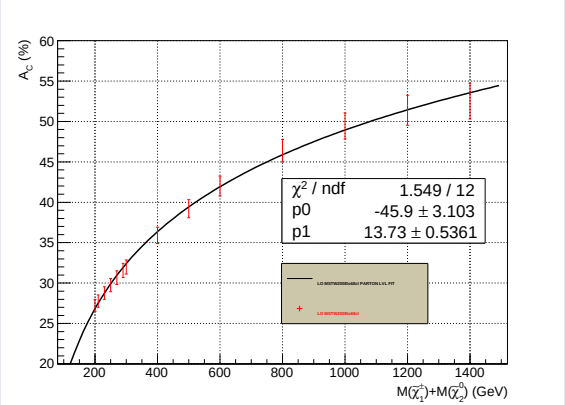
  - Enables to measure $M_{\tilde{\chi}_1^{\pm}} + M_{\tilde{\chi}_2^0}$
  - Complementary of other techniques that access mass differences
    Evolution of A_C is driven by the DGLAP evolution of the PDFs and parametrized as follows:

$$A_C[M_{\tilde{\chi}_1^{\pm}} + M_{\tilde{\chi}_2^0}] =$$

$$\sum_{i=0}^{N} A_i \times \left[Log\left[Log\left[M_{\tilde{\chi}_1^{\pm}} + M_{\tilde{\chi}_2^0}\right]\right]\right]^i \qquad (16)$$

  - Ref: S. Muanza, T. Serre, JHEP 1604 (2016) 179, arXiv:1412.6695 [hep-ph]





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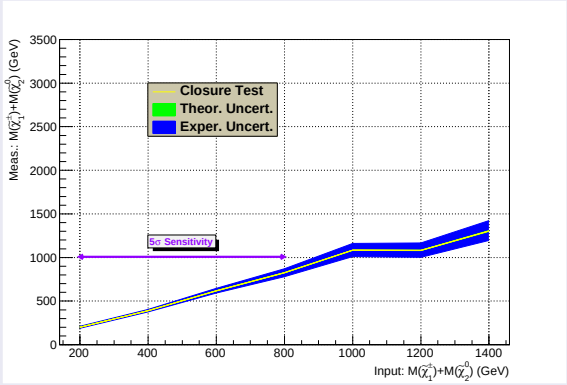
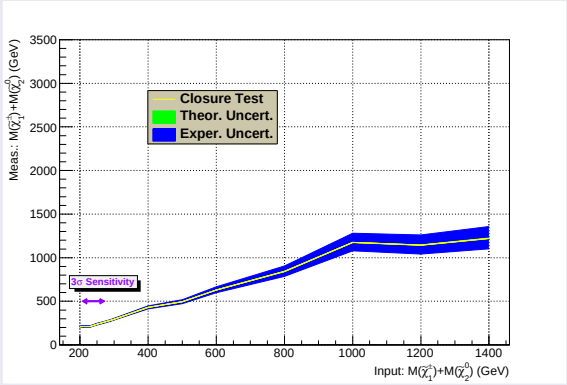
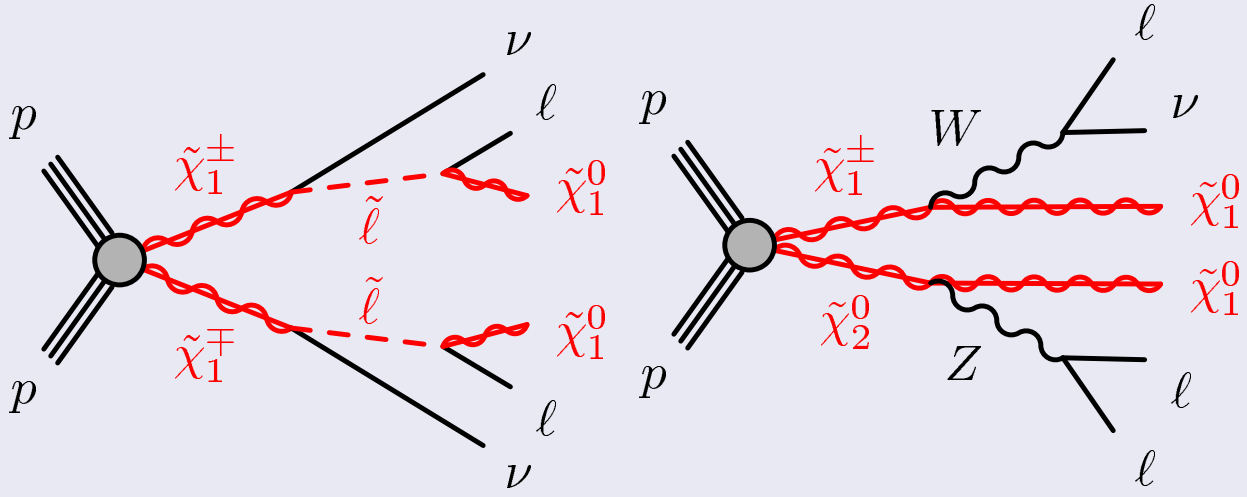




Search for SUSY at the LHC

Search for chargino-neutralino pairs: Typical Search $\longrightarrow$ Link



Search for SUSY at the LHC

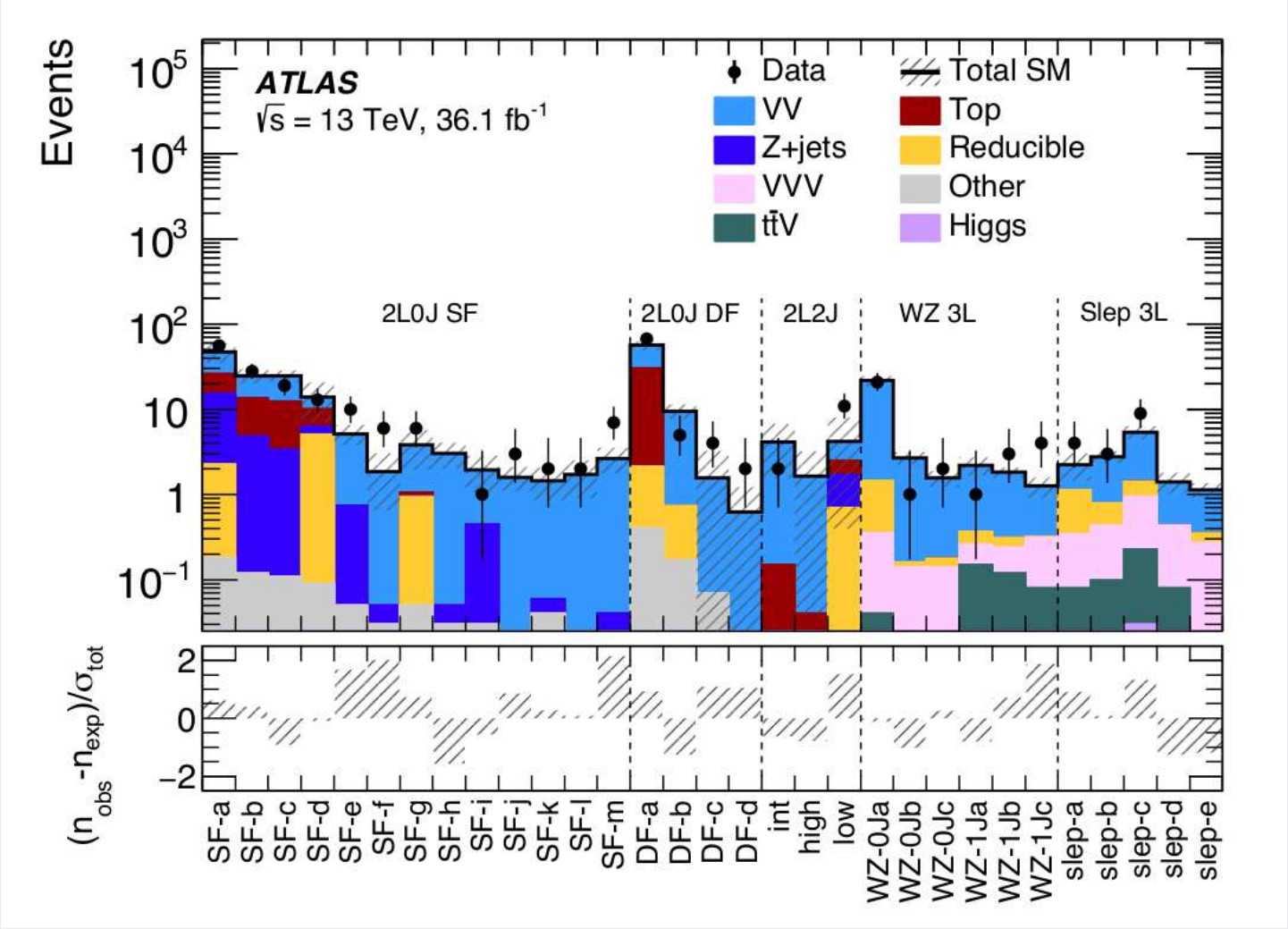
Search for chargino-neutralino pairs: Typical Search $\longrightarrow$ Link

- Event Topology: "$3\ell^{\pm} + \not{E}_T$"
- Main background process: $W^{\pm}(\rightarrow \ell^{\pm}\nu) + Z(\rightarrow \ell^{+}\ell^{-})$
- Data sample: $\int \mathcal{L}dt = 36.1\ fb^{-1}$ of ATLAS pp collisions at $\sqrt{s} = 13$ TeV (2015-2016)
- Event Selection:
  - Trigger: dilepton
  - Offline:

3ℓ exclusive signal region definitions							
m_{SFOS} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$p_{\mathrm{T}}^{\ell_3}$ [GeV]	$n_{\text{non-}b\text{-tagged jets}}$	$m_{\mathrm{T}}^{\mathrm{min}}$ [GeV]	$p_{\mathrm{T}}^{\ell\ell\ell}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{jet1}}$ [GeV]	Bins
<81.2	> 130	20–30		> 110			SR3-slep-a
		> 30					SR3-slep-b
>101.2	> 130	20–50		> 110			SR3-slep-c
		50–80					SR3-slep-d
		> 80					SR3-slep-e
81.2–101.2	60-120		0	> 110			SR3-WZ-0Ja
	120–170						SR3-WZ-0Jb
	> 170						SR3-WZ-0Jc
81.2-101.2	120–200		≥ 1	> 110	< 120	> 70	SR3-WZ-1Ja
	> 200	> 35		110–160			SR3-WZ-1Jb
				> 160			SR3-WZ-1Jc

Search for SUSY at the LHC

Search for chargino-neutralino pairs: Typical Search ⟶ Link



Search for SUSY at the LHC

Search for chargino-neutralino pairs: Typical Search $\longrightarrow$ Link

Signal channel	Region	$N_{\rm obs}$	$N_{\rm exp}$	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	$p(s{=}0)$	Z
2ℓ+0jets	DF-100	78	68 ± 7	0.88	32	27^{+11}_{-8}	0.22	0.77
	DF-150	11	11.5 ± 3.1	0.32	11.4	12^{+5}_{-4}	0.5	0
	DF-200	6	2.1 ± 1.9	0.33	12.0	$10.3^{+2.9}_{-1.9}$	0.06	1.5
	DF-300	2	0.6 ± 0.6	0.18	6.6	$5.6^{+1.1}_{-0.9}$	0.10	1.3
	SF-loose	153	133 ± 22	2.02	73	53^{+21}_{-16}	0.16	1.0
	SF-tight	9	9.8 ± 2.9	0.29	10.5	12^{+4}_{-3}	0.5	0
2ℓ+jets	SR2-int	2	$4.1^{+2.6}_{-1.8}$	0.13	4.5	$5.6^{+2.2}_{-1.4}$	0.5	0
	SR2-high	0	$1.6^{+1.6}_{-1.1}$	0.09	3.1	$3.1^{+1.4}_{-0.1}$	0.5	0
	SR2-low	11	$4.2^{+3.4}_{-1.6}$	0.43	15.7	12^{+4}_{-2}	0.06	1.6
3ℓ	WZ-0Ja	21	21.7 ± 2.9	0.35	12.8	14^{+3}_{-5}	0.5	0
	WZ-0Jb	1	2.7 ± 0.5	0.10	3.7	$4.6^{+2.1}_{-0.9}$	0.5	0
	WZ-0Jc	2	1.6 ± 0.3	0.13	4.8	$4.1^{+1.7}_{-0.7}$	0.28	0.57
	WZ-1Ja	1	2.2 ± 0.5	0.09	3.2	$4.5^{+1.6}_{-1.3}$	0.5	0
	WZ-1Jb	3	1.8 ± 0.3	0.16	5.6	$4.3^{+1.7}_{-0.9}$	0.18	0.91
	WZ-1Jc	4	1.3 ± 0.3	0.20	7.2	$4.2^{+1.7}_{-0.4}$	0.03	1.8
	slep-a	4	2.2 ± 0.8	0.19	6.8	$4.7^{+2.3}_{-0.5}$	0.23	0.72
	slep-b	3	2.8 ± 0.4	0.14	5.2	$5.1^{+1.9}_{-1.2}$	0.47	0.08
	slep-c	9	5.4 ± 0.9	0.29	10.5	$6.8^{+2.9}_{-1.3}$	0.09	1.4
	slep-d	0	1.4 ± 0.4	0.08	3.0	$3.6^{+1.2}_{-0.6}$	0.5	0
	slep-e	0	1.1 ± 0.2	0.09	3.3	$3.6^{+1.3}_{-0.5}$	0.5	0

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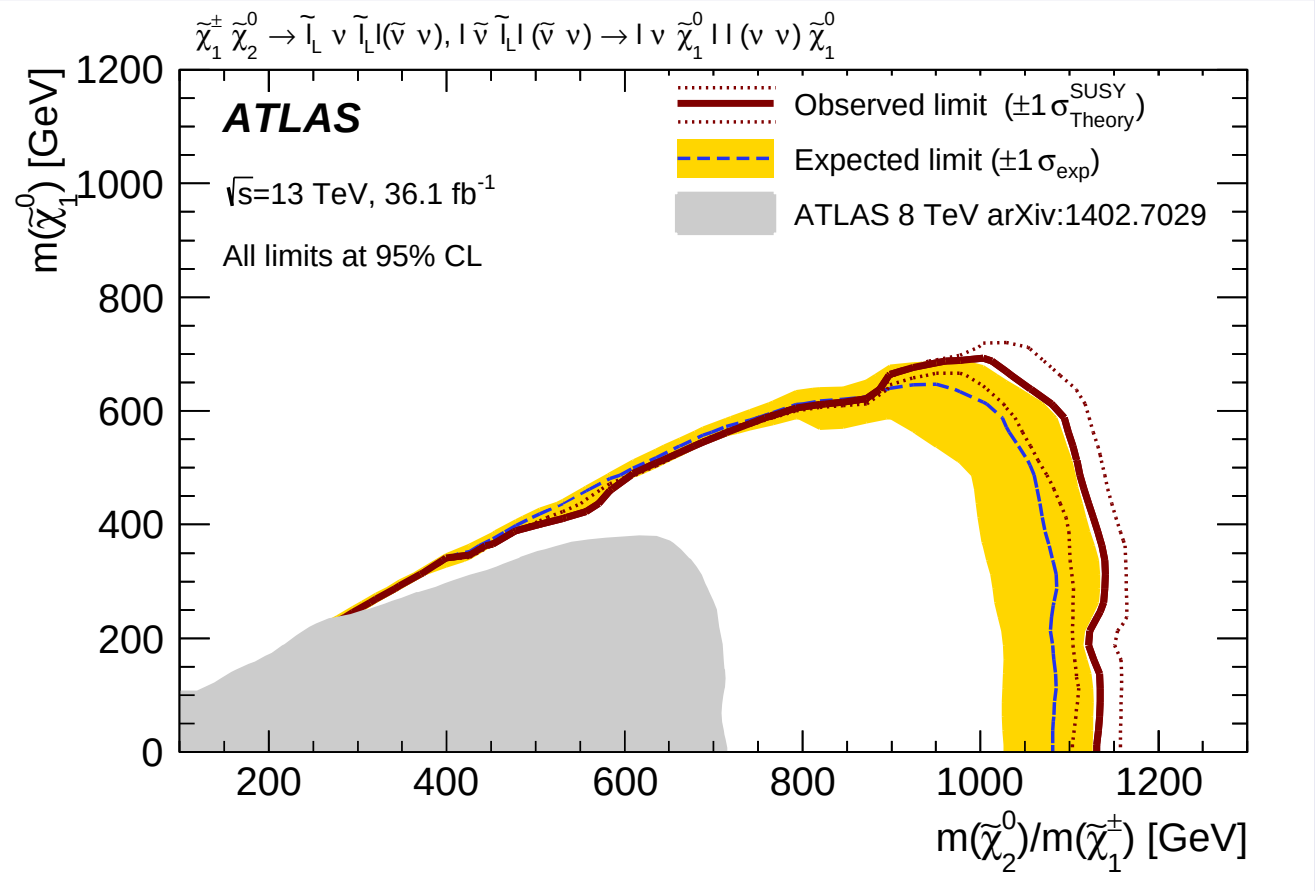

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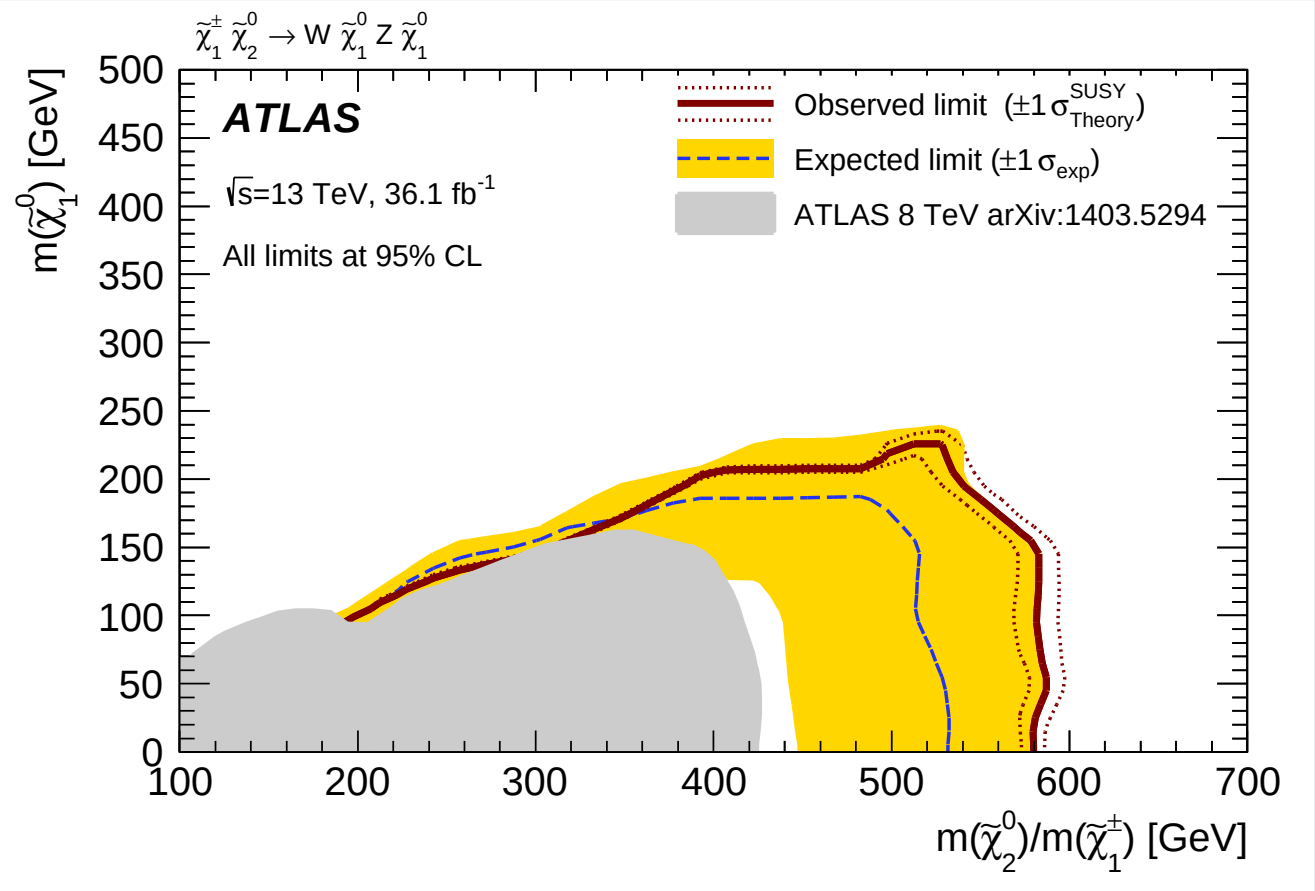

Search for BSM at the LHC

ATLAS and CMS Latest Limits

ATLAS
CMS