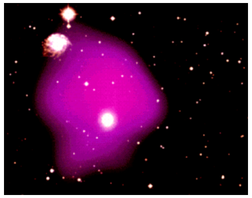
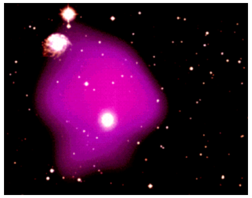
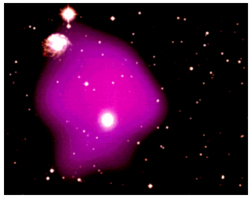




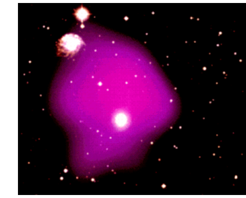
Searching for EWK SUSY and Stops with Vector Boson Fusion at the LHC

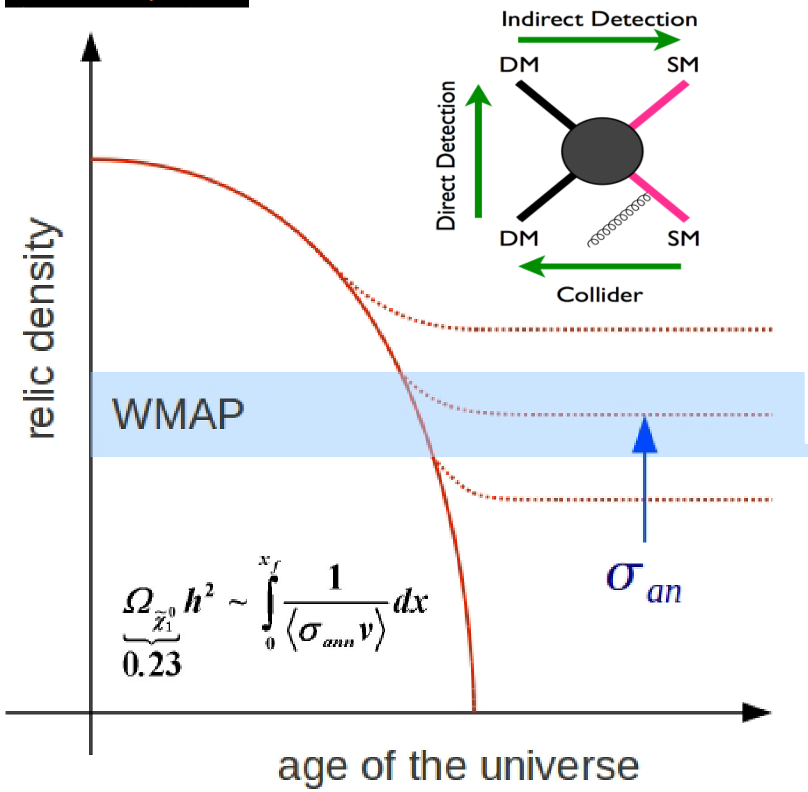
Alfredo Gurrola (Vanderbilt University)

SUSY 2013 Conference



Particle Physics & Cosmology





to Probe Ωh^2

$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

$s_W = \sin(\theta_W) \qquad c_W = \cos(\theta_W)$

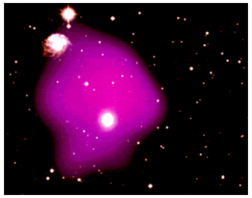
$s_\beta = \sin(\beta) \qquad c_\beta = \cos(\beta)$

$M_1 << M_2,\ \mu \Rightarrow \tilde{\chi}_1^0 \approx \tilde{B}$ → *pure Bino*

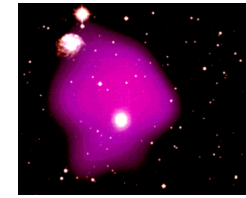
$M_2 << M_1,\ \mu \Rightarrow \tilde{\chi}_1^0 \approx \tilde{W}$ → *pure Wino*

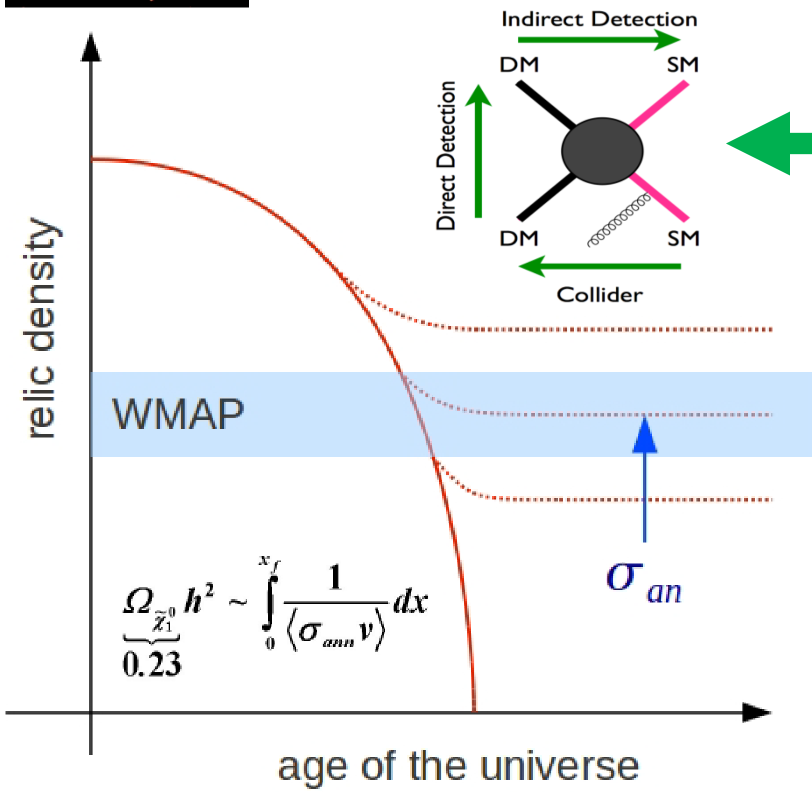
$\mu << M_1,\ M_2 \Rightarrow \tilde{\chi}_1^0 \approx \tilde{H}_h + \tilde{H}_d$ → *pure Higgsino*

The identity of dark matter is one of the most profound questions at the interface of particle physics and cosmology.

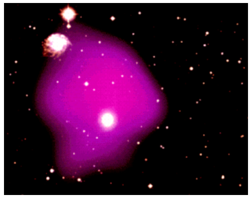


Particle Physics & Cosmology

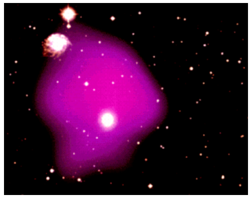


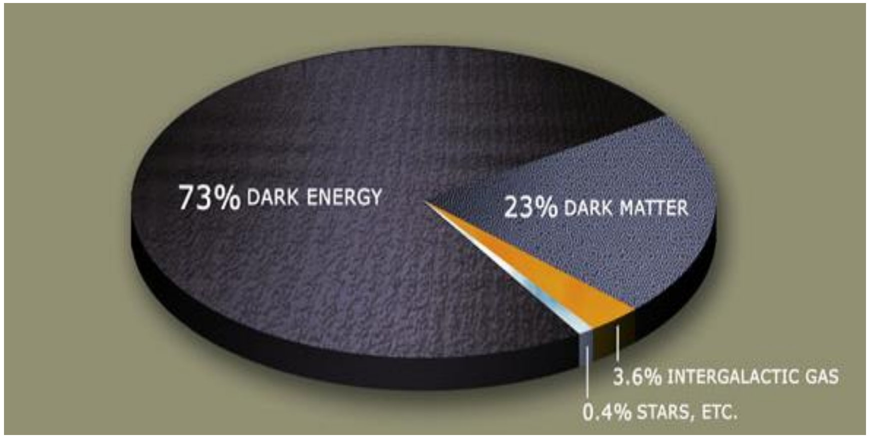


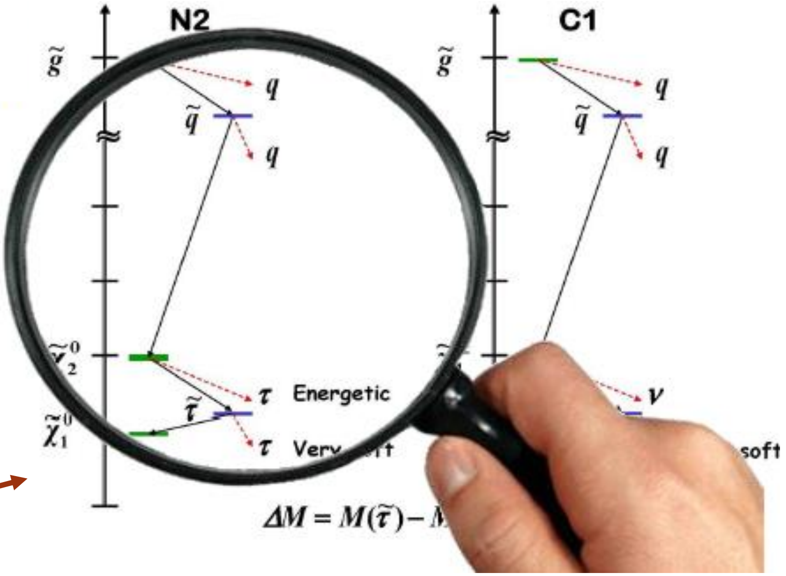
It is important to "directly" probe the EWK SUSY sector in order to determine their DM connection

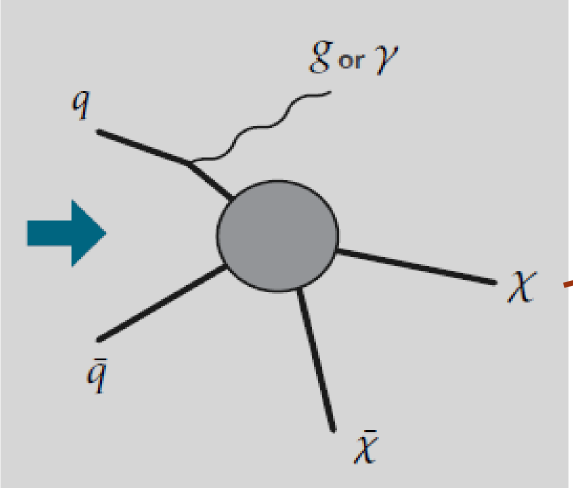


Current Dark Matter Searches







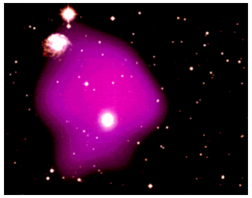


Cascade decay of heavier particles to the DM particle

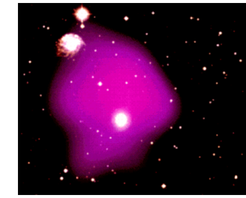
→ Signature: Large MET + jets (+ leptons) (+ photons)

DM particles directly produced in pairs after ISR

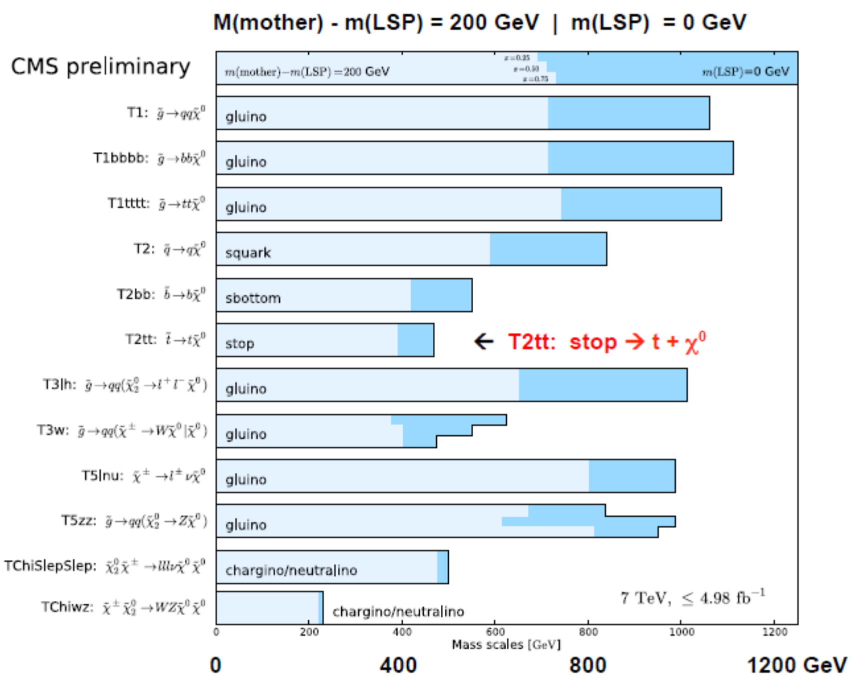
→ Signature: Large MET + mono-jet (mono-Z, etc.)

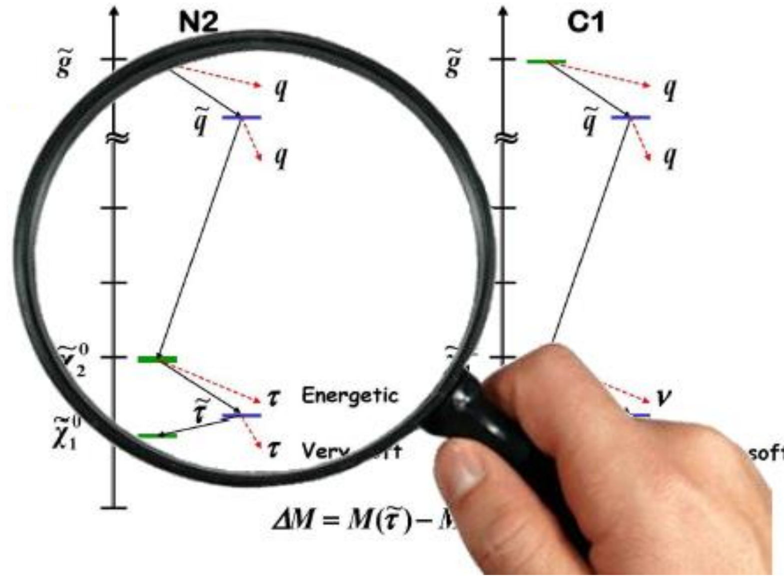


Classic SUSY DM Searches

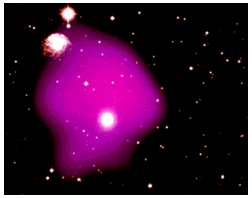


Determining the mass and content of the LSP requires model dependent correlations between colored and non-colored sector (e.g. grand unification in mSUGRA)

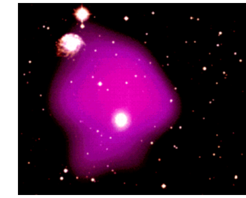




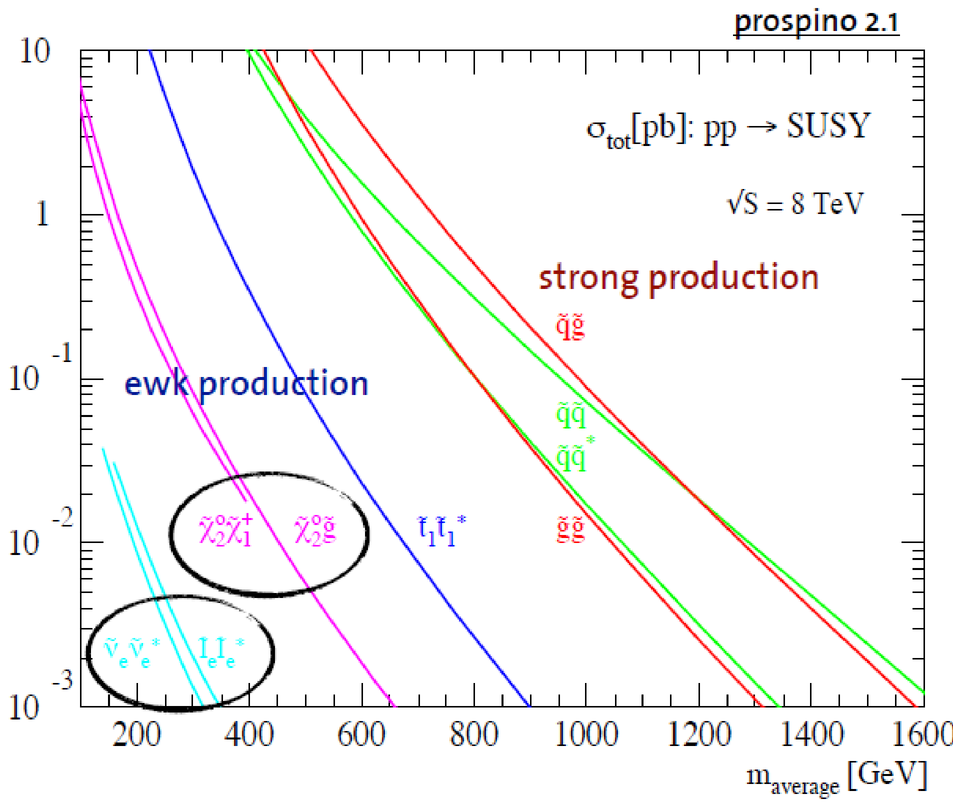
ATLAS and CMS pushing limits on 1st / 2nd squarks and gluinos to ~ 1.5 TeV

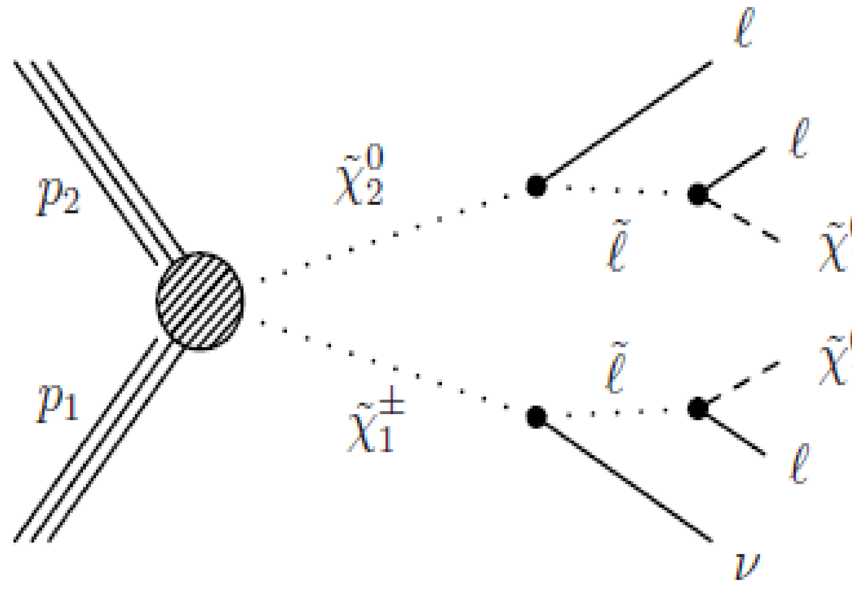


Classic SUSY DM Searches

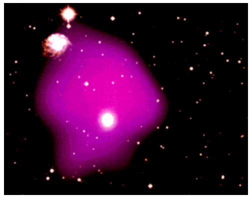


Colored objects heavy and the cross-section is small

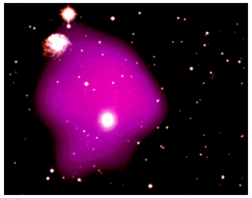




Started to look at direct production of EWKinos & 3rd generation

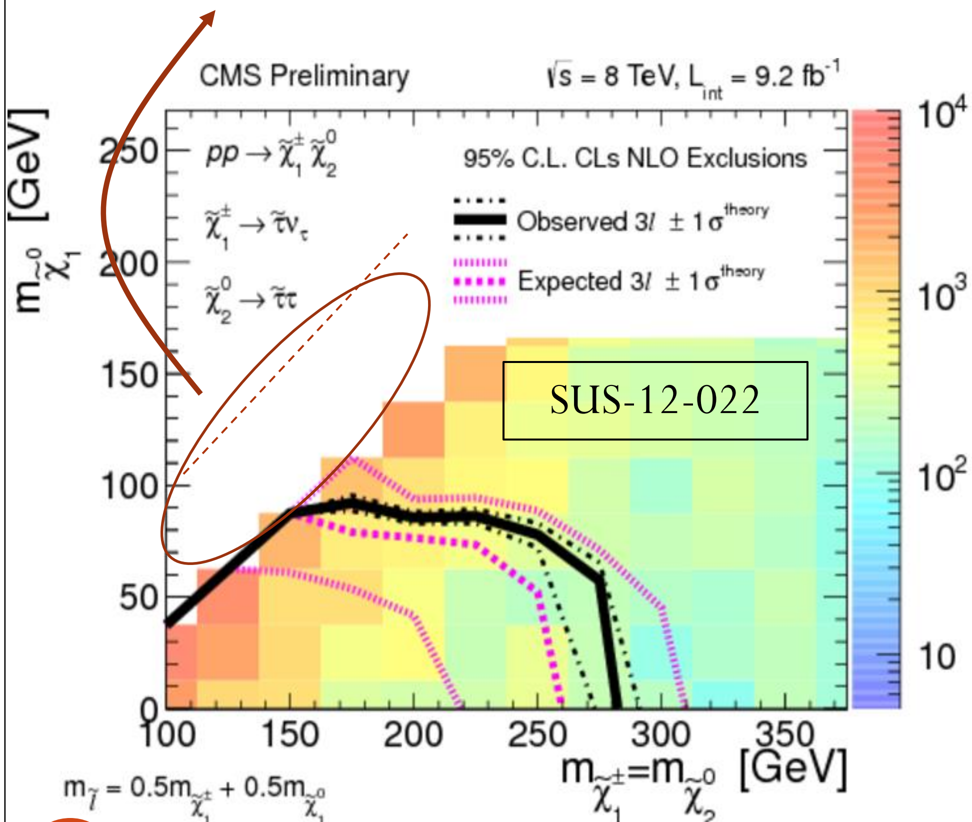


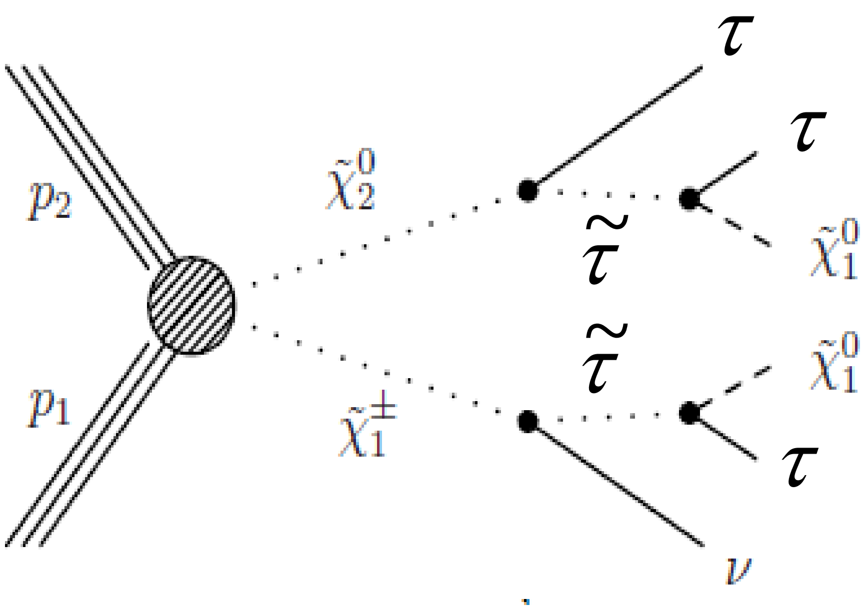
Classic SUSY DM Searches



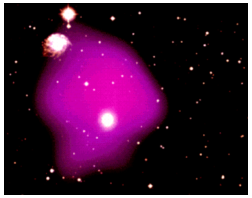
No sensitivity in cases with 3rd gen and compressed spectra

<u>VERY important for cosmology</u>

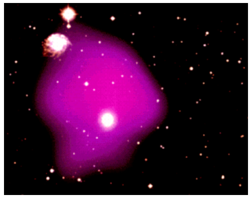


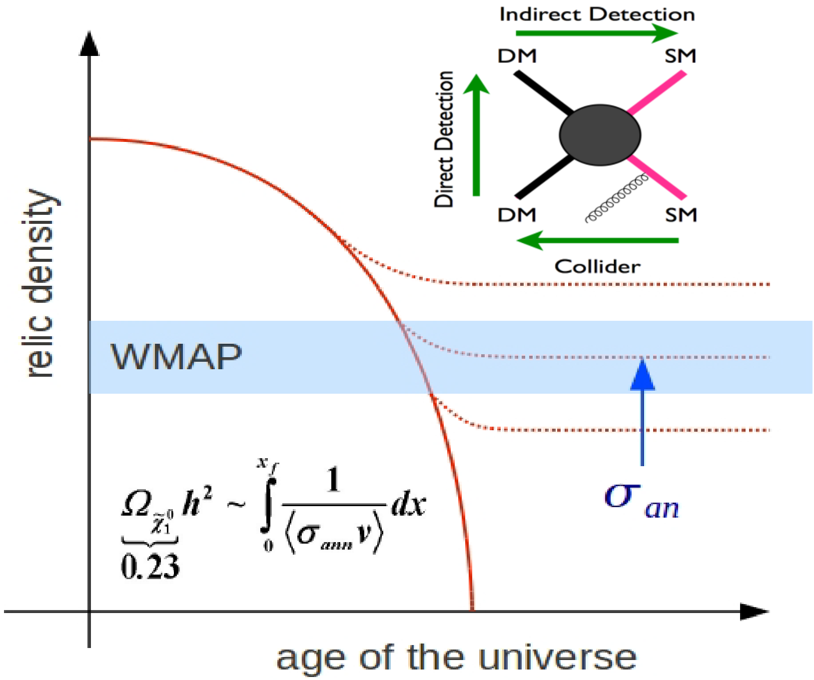


Tackling these scenarios is a very tall tall task at the LHC



VBF DM → Cosmology

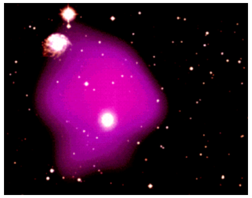




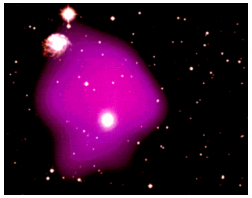
- LSP has large Wino/Higgsino component
  - LSP annihilation cross section is too large to fit observed DM relic density
- LSP is mostly Bino
  - LSP annihilation cross section is too small to fit observed DM relic density

Some problems can be solved if the DM is non-thermal. For thermal DM, some problems can be solved by adding coannhilation, resonance effects, etc.

Determining the composition of the LSP for a given mass is *very important* to understand early universe cosmology



Classic SUSY DM Searches



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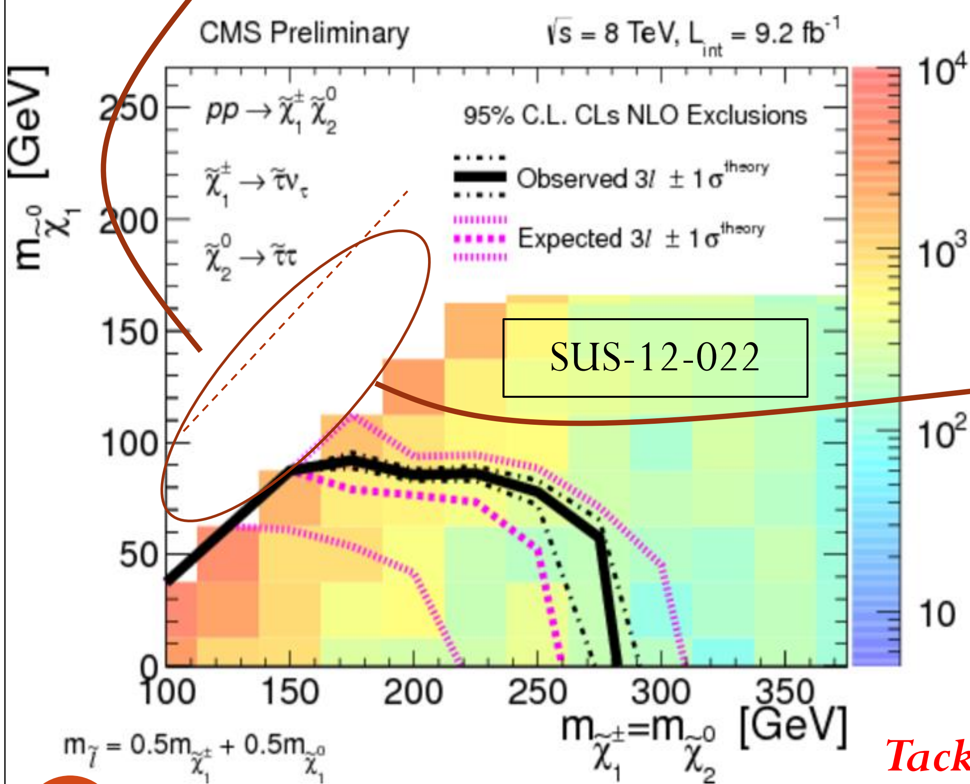
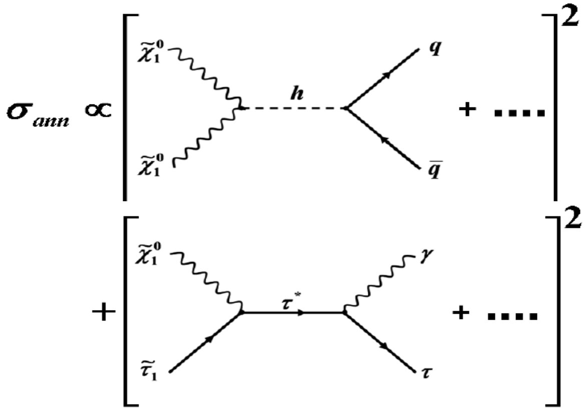
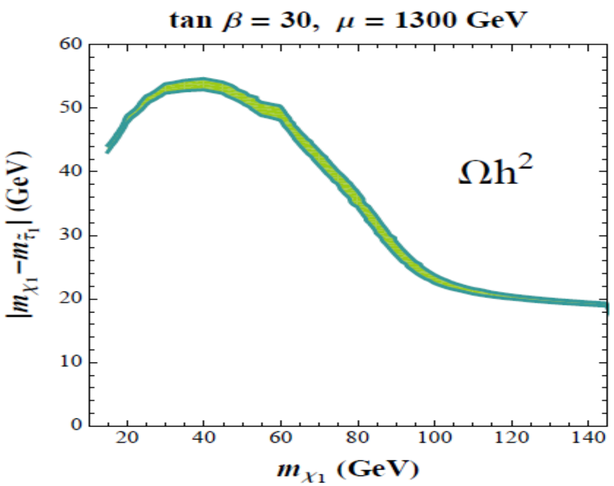




http://arxiv.org/pdf/1205.5842v1.pdf



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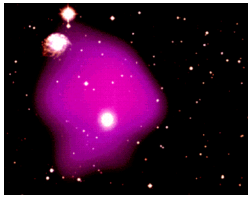
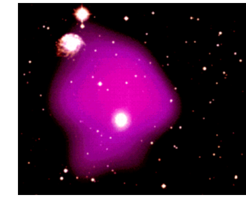
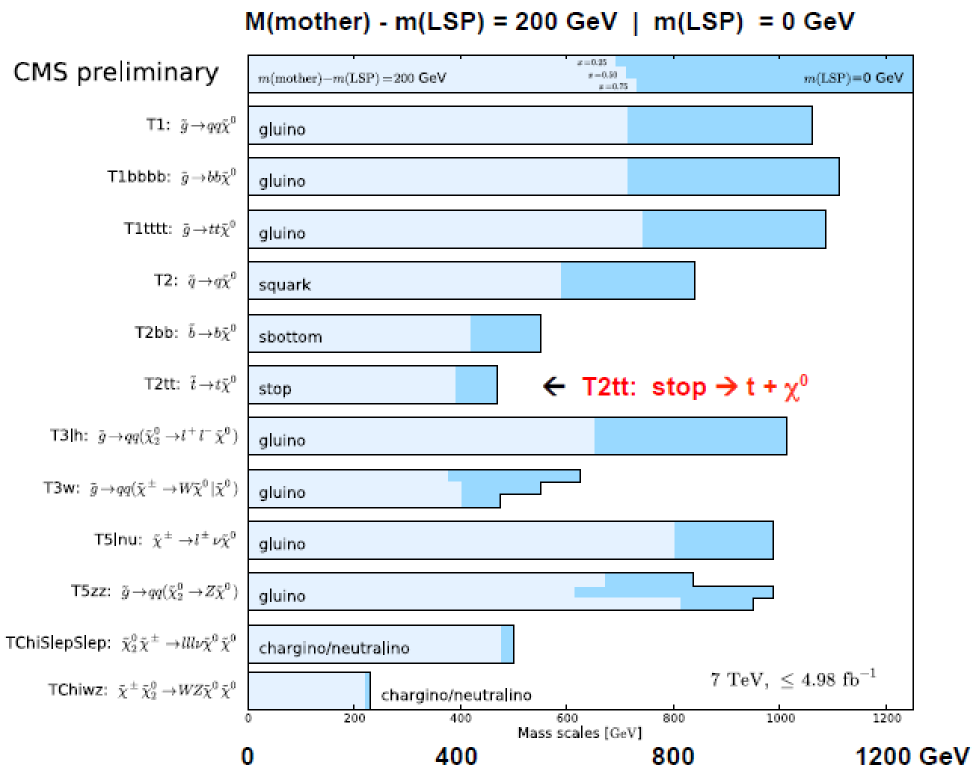
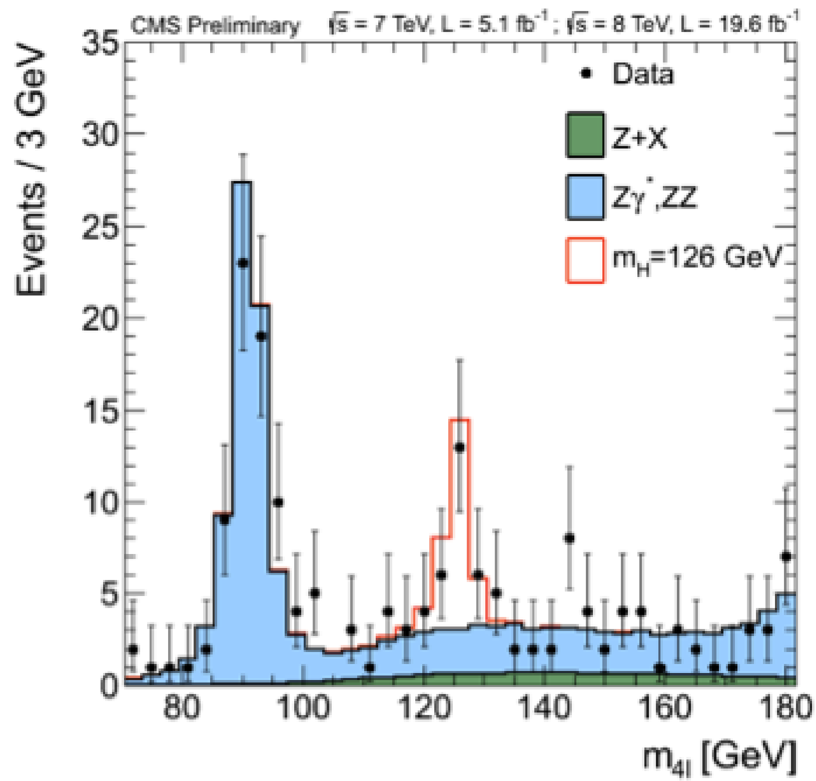


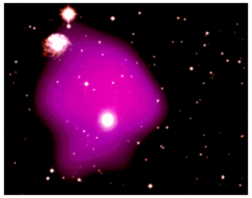
What do we know so far?



Key points: No SUSY yet & 126 GeV Higgs







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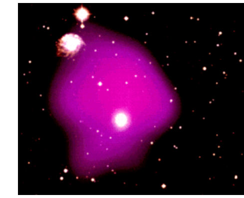
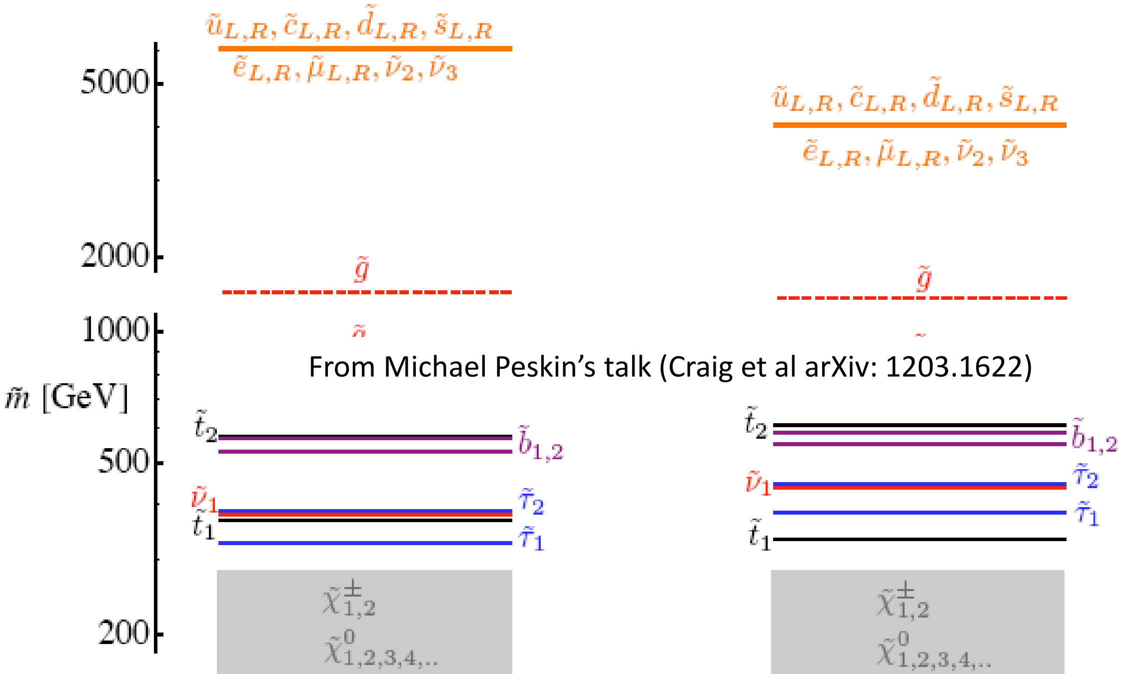
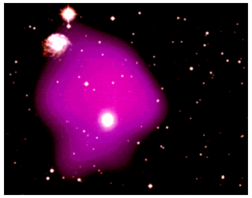




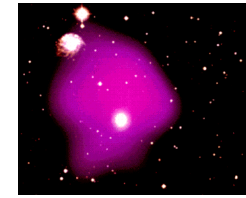
From Michael Peskin's talk (Craig et al arXiv: 1203.1622)

"Nightmare compressed scenario" is starting to look like the actual scenario

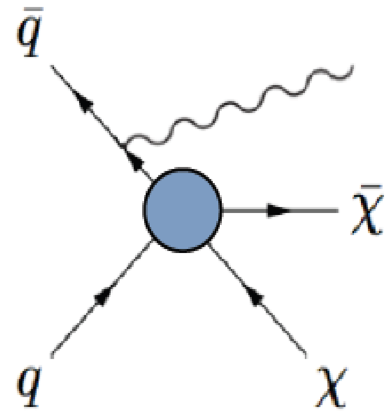
Becoming experimentally difficult to search for dark matter & EWK sector using "standard" searches (e.g. how to trigger?)



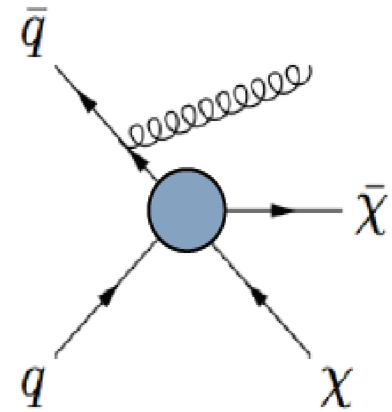
Classic Monojet DM Searches



Monojet searches probing QCD production of WIMPs → limits what one can say about its Wino, Bino, or Higgsino composition in the case of SUSY

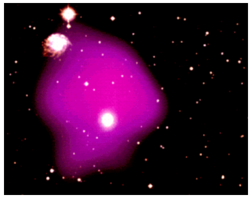


monophoton +MET

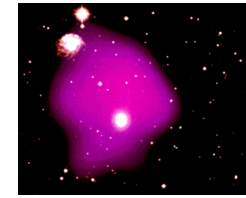


monojet +MET

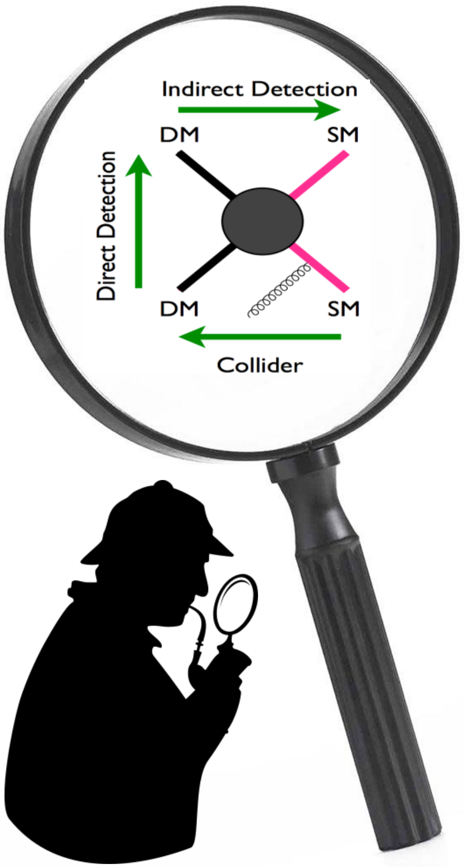
$$\mathcal{L} = \underbrace{\mathcal{L}_{SM}}_{\text{SM Lagrangian}} + \underbrace{i\bar{X}\gamma^{\mu}\partial_{\mu}X - M_X\bar{X}X}_{\text{kinetic terms for DM}} + \underbrace{\sum_{q}\sum_{i,j}\frac{G_{qij}}{\sqrt{2}}\left[\bar{X}\Gamma_i^X X\right]\left[\bar{q}\Gamma_q^j q\right]}_{\text{set of 4-Fermion interactions between DM and SM quarks}},$$

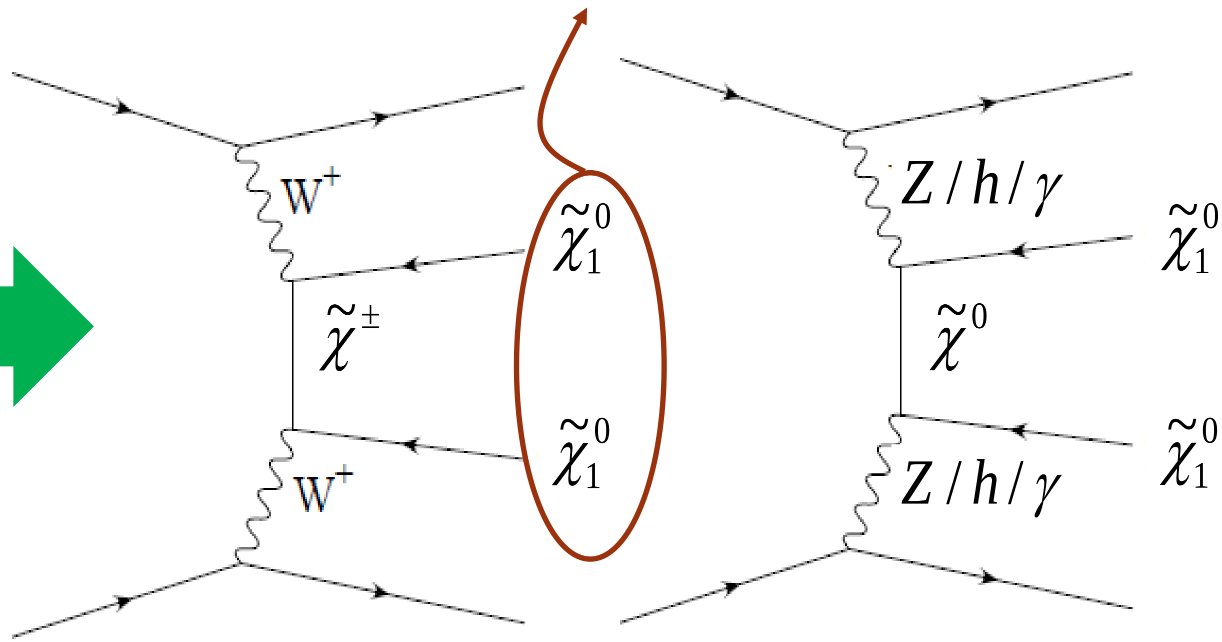


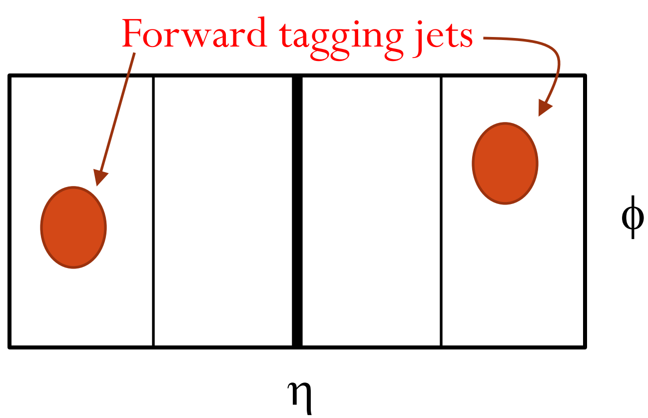
Probing SUSY DM with VBF



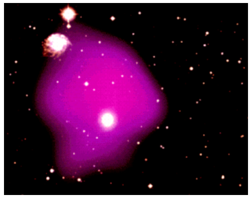
Cold dark matter candidate



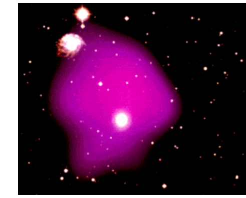




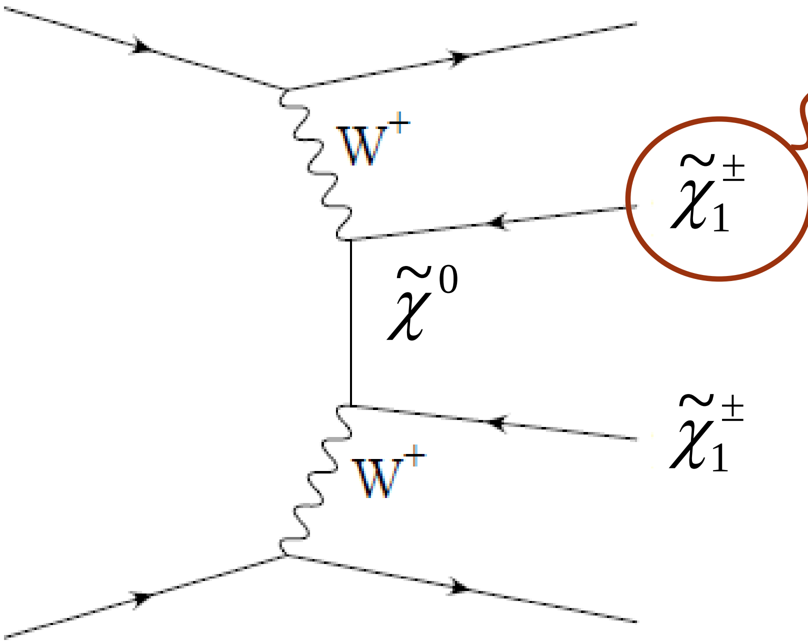
MET + jj



Probing DM with VBF



Pure Wino/Higgsino dark matter scenarios are special



$$\Delta M = M(\tilde{\chi}_1^\pm) - M(\tilde{\chi}_1^0) \sim 100\ MeV$$

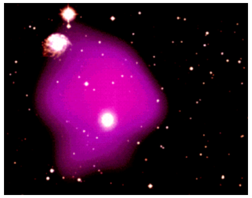
$$\Rightarrow Br(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \pi^\pm) \sim 100\%$$

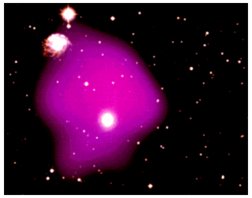
$$P_T(\pi^\pm) \sim \Delta M \sim 100\ MeV$$

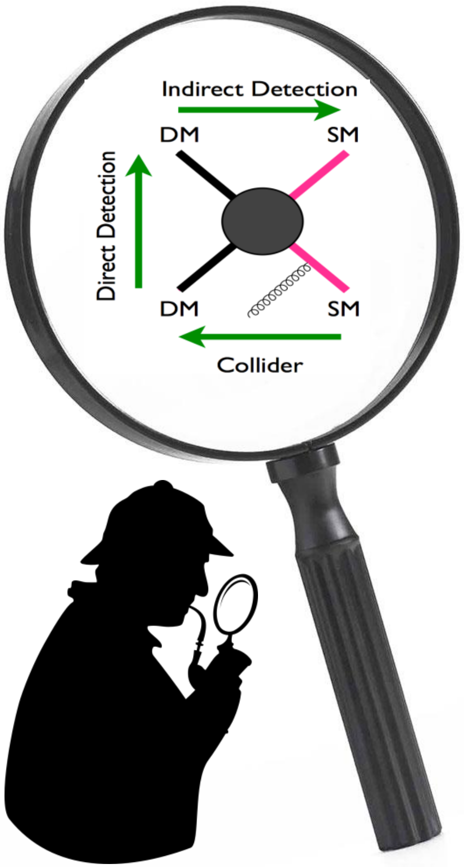
$\Rightarrow$ ***Final state once again jj+MET!***

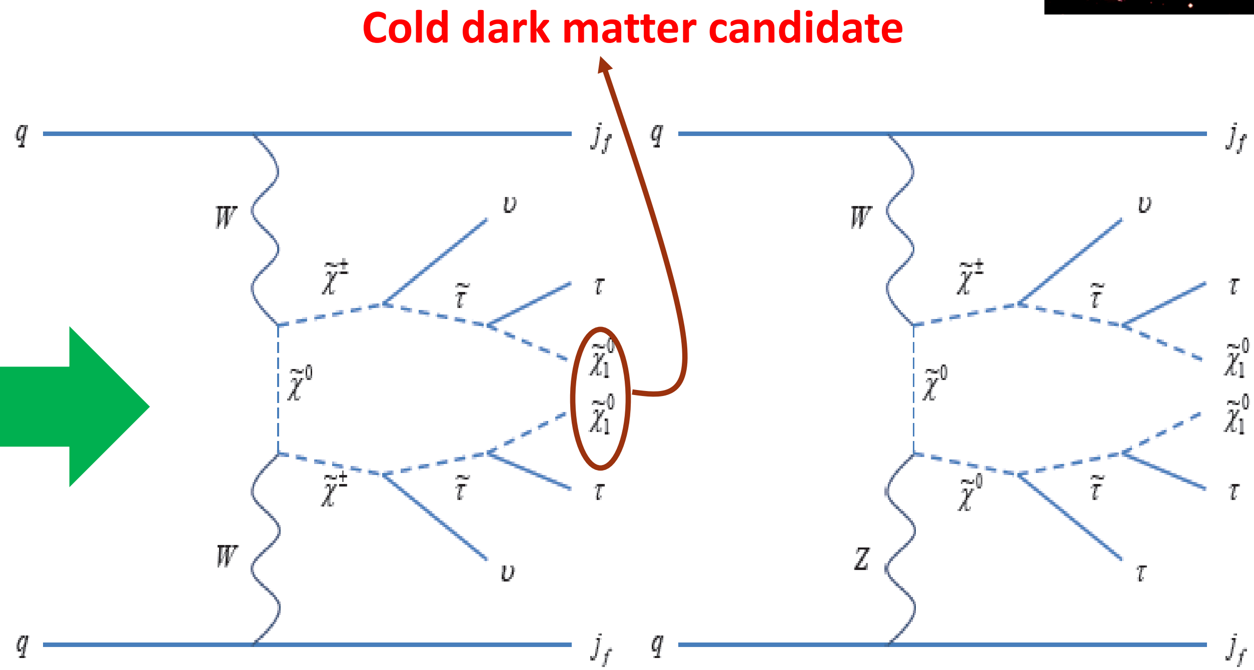
$\tilde{\chi}_1^\pm \tilde{\chi}_1^0\, jj,\ \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp\, jj$ ***also contribute!***

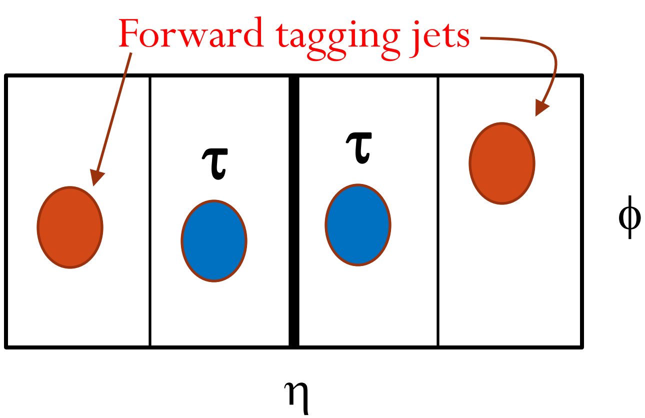
Probing EWK SUSY with VBF



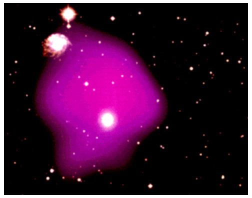








MET + jj + leptons



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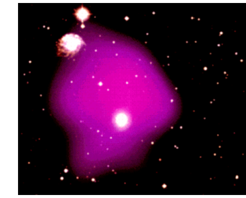


Vector Boson Fusion Processes as a Probe of Supersymmetric Electroweak Sectors at the LHC

Bhaskar Dutta[1], Alfredo Gurrola[2], Will Johns[2], Teruki Kamon[1,3], Paul Sheldon[2], and Kuver Sinha[1]

[1] *Mitchell Institute for Fundamental Physics and Astronomy, Department of Physics, Texas A&M University, College Station, TX 77843-4242, USA*

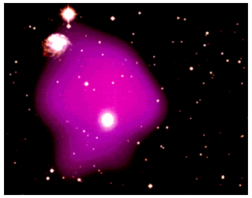
[2] *Department of Physics and Astronomy, Vanderbilt University, Nashville, TN, 37235*

[3] *Department of Physics, Kyungpook National University, Daegu 702-701, South Korea*

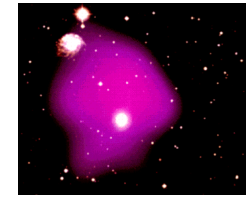
Vector boson fusion (VBF) processes offer a promising avenue to study the non-colored sectors of supersymmetric extensions of the Standard Model at the LHC. A feasibility study for searching for the chargino/neutralino system in the $R-$parity conserving Minimal Supersymmetric Standard Model is presented. The high E_T forward jets in opposite hemispheres are utilized to trigger VBF events, so that the production of the lightest chargino $\tilde{\chi}_1^{\pm}$ and the second lightest neutralino $\tilde{\chi}_2^0$ can be probed without a bias by experimental triggers. Kinematic requirements are developed to search for signals of these supersymmetric states above Standard Model backgrounds in both τ and light lepton (e and μ) final states at $\sqrt{s} = 8$ TeV.

http://arxiv.org/pdf/1210.0964v2.pdf

Phys. Rev. D 87, 035029 (2013)



Probing SUSY DM with VBF



Probing Dark Matter at the LHC using Vector Boson Fusion Processes

Andres G. Delannoy[2], Bhaskar Dutta[1], Alfredo Gurrola[2], Will Johns[2], Teruki Kamon[1,3], Eduardo Luiggi[4], Andrew Melo[2], Paul Sheldon[2], Kuver Sinha[1], Kechen Wang[1], and Sean Wu[1]

[1] *Mitchell Institute for Fundamental Physics and Astronomy, Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843-4242, USA*

[2] *Department of Physics and Astronomy, Vanderbilt University, Nashville, TN, 37235, USA*

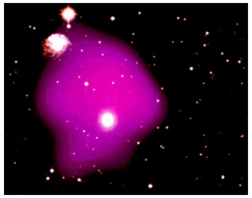
[3] *Department of Physics, Kyungpook National University, Daegu 702-701, South Korea*

[4] *Department of Physics, University of Colorado, Boulder, CO 80309-0390, USA*

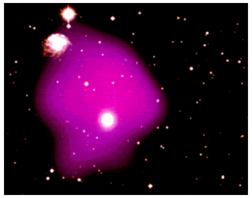
Vector boson fusion (VBF) processes at the Large Hadron Collider (LHC) provide a unique opportunity to search for new physics with electroweak couplings. A feasibility study for the search of supersymmetric dark matter in the final state of two VBF jets and large missing transverse energy is presented at 14 TeV. Prospects for determining the dark matter relic density are studied for the cases of Wino and Bino-Higgsino dark matter. The LHC could probe Wino dark matter with mass up to approximately 600 GeV with a luminosity of 1000 fb^{-1}.

http://arxiv.org/pdf/1304.7779v1.pdf

Phys. Rev. Lett. 111, 061801 (2013)



Probing DM with VBF



http://arxiv.org/pdf/1210.0964v2.pdf

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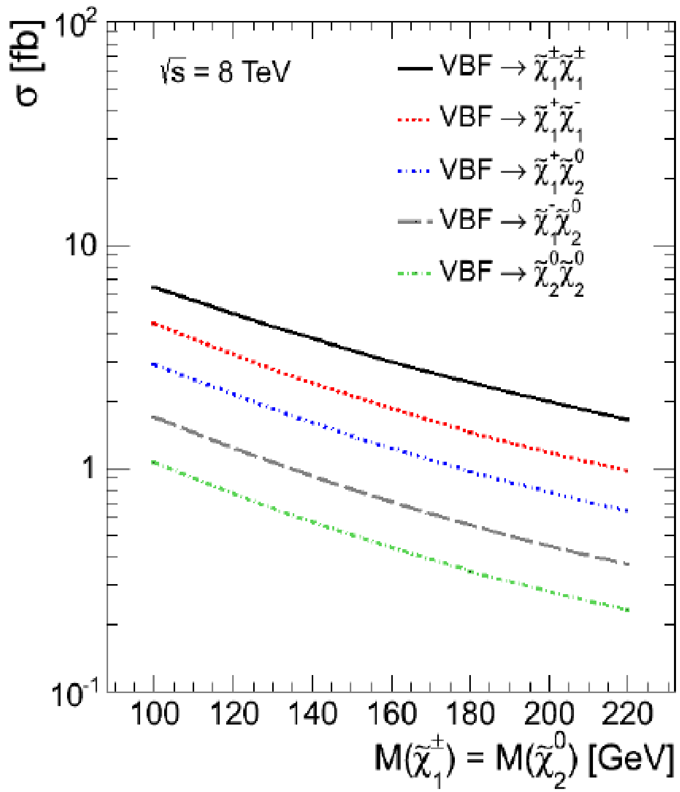
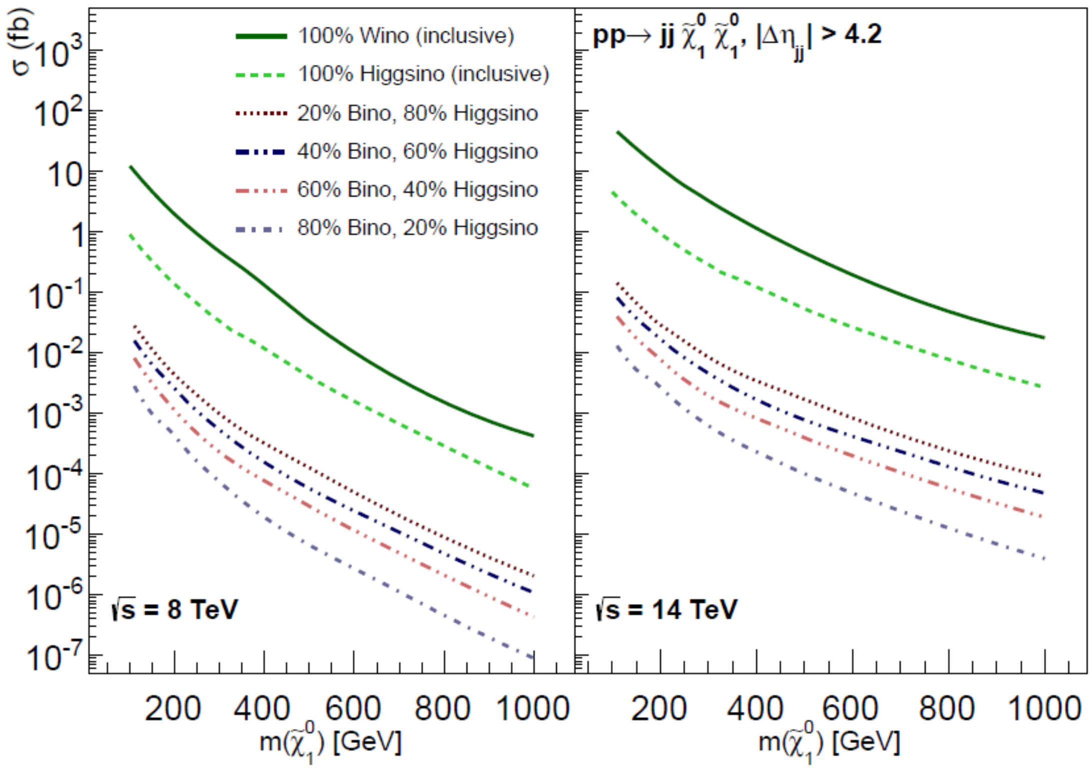
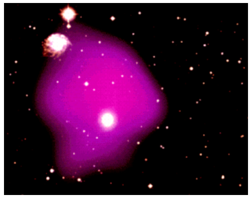


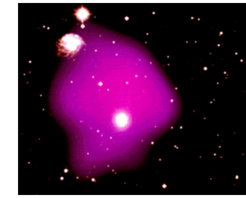
MET + jj + leptons

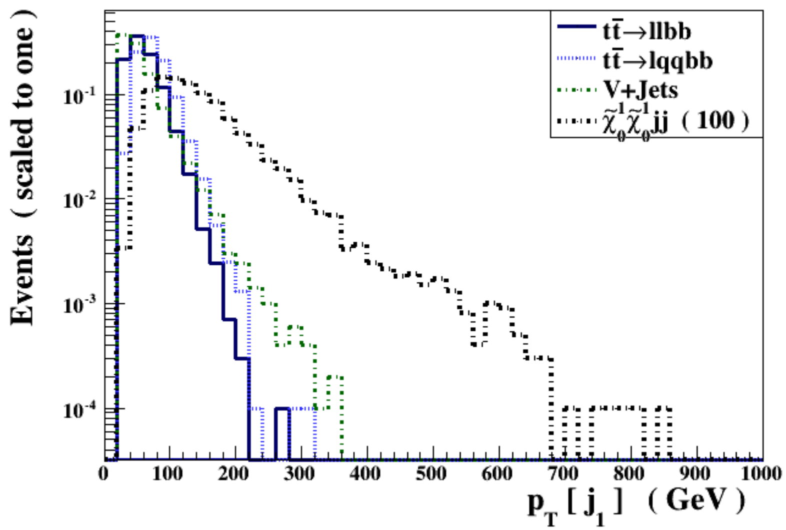


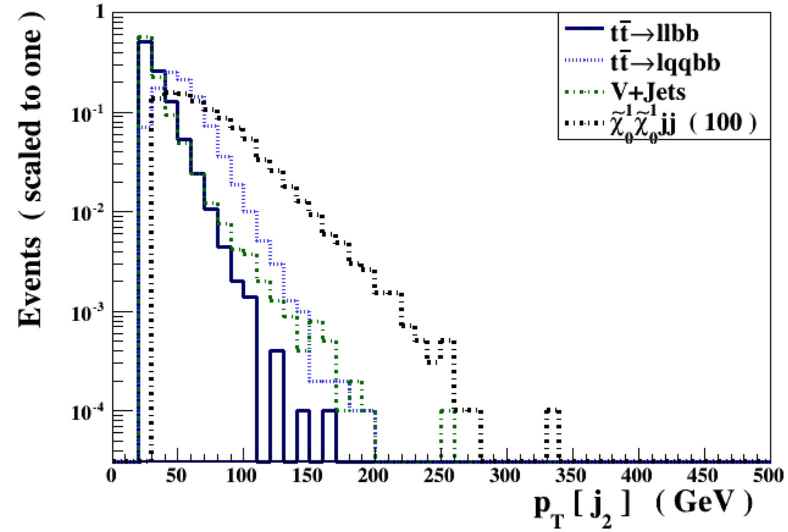
MET + jj

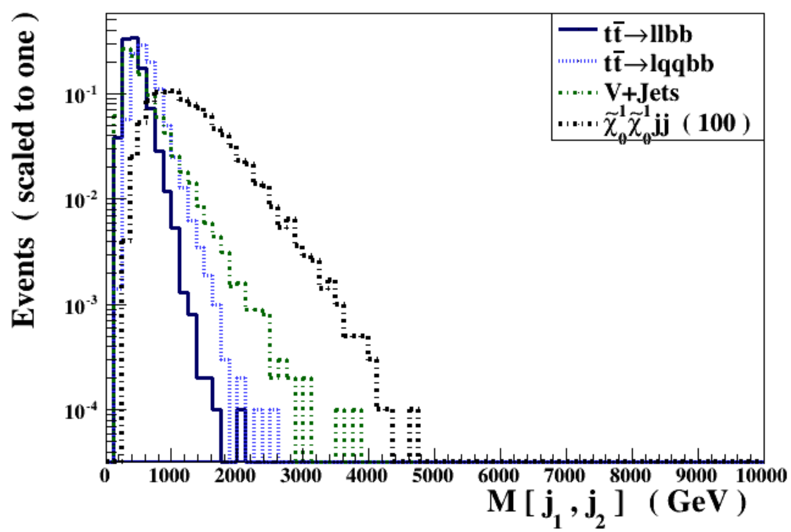


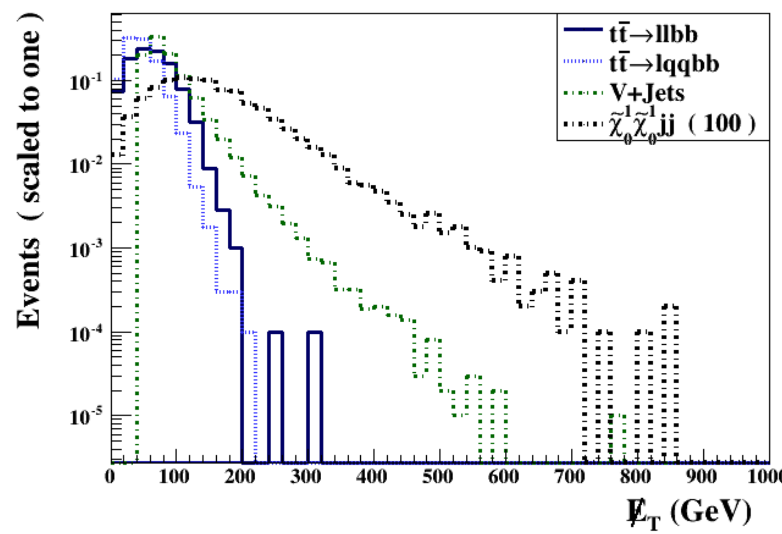
VBF SUSY Kinematics

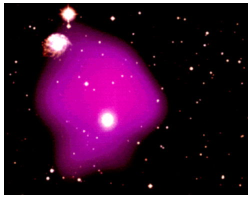




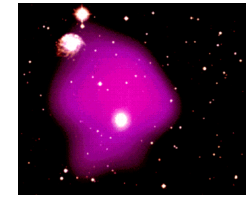




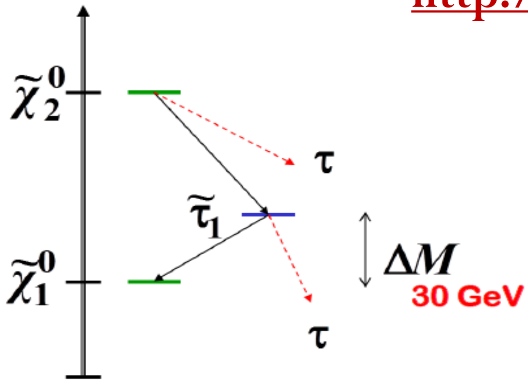




VBF SUSY Phenomenology



http://arxiv.org/pdf/1210.0964v2.pdf

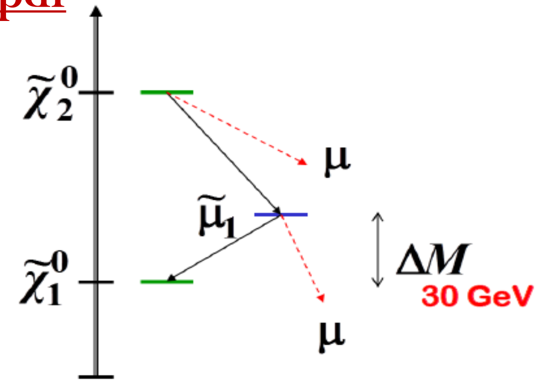


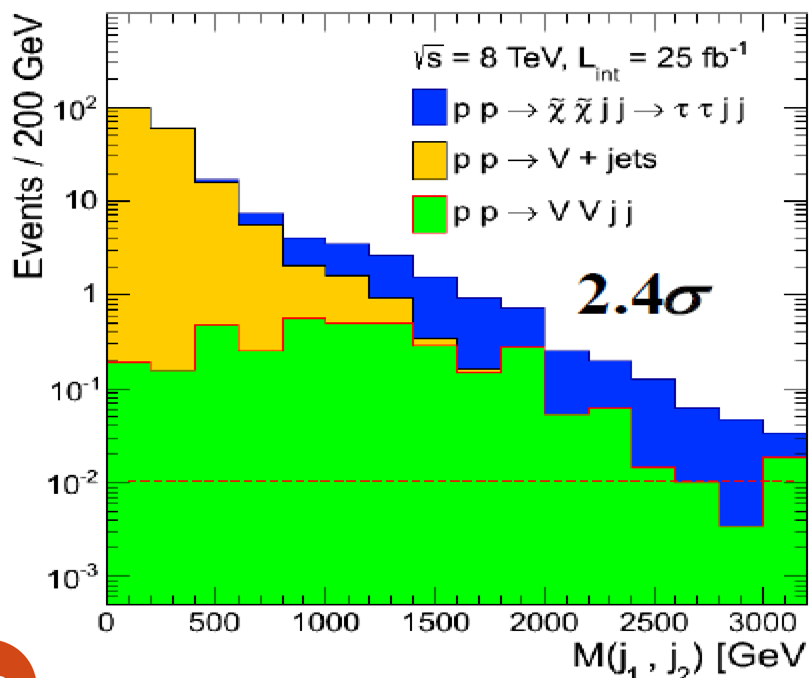
Benchmark Point:

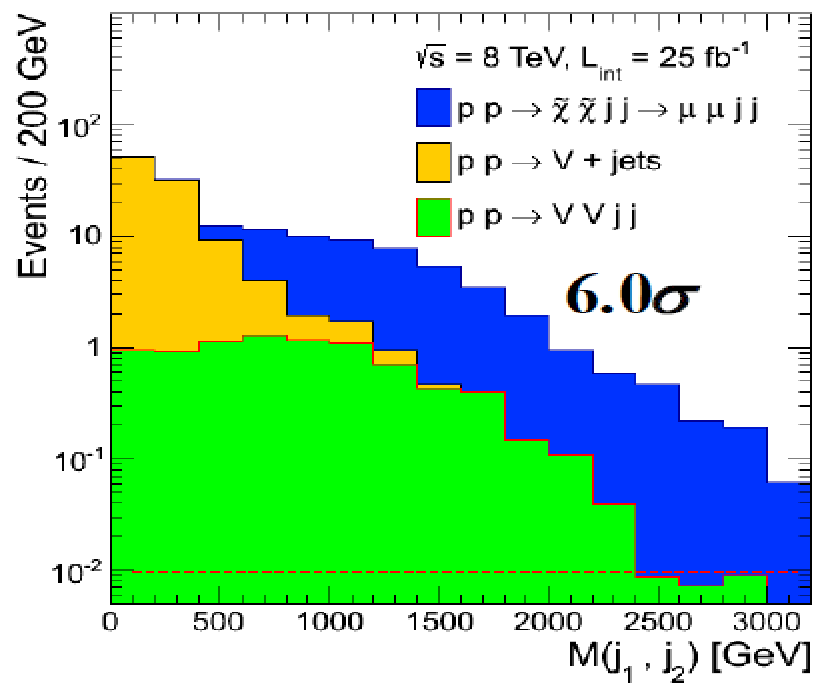
$M(\tilde{\chi}_1^+) \sim M(\tilde{\chi}_2^0) = 180$ GeV

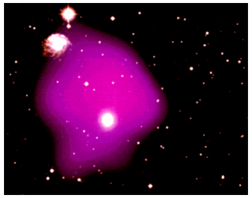
$M(\tilde{\chi}_1^0) = 90$ GeV

$M(\tilde{\tau}_1^+) - M(\tilde{\chi}_1^0) = 30$ GeV

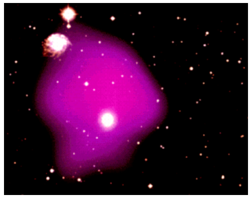








VBF SUSY Phenomenology



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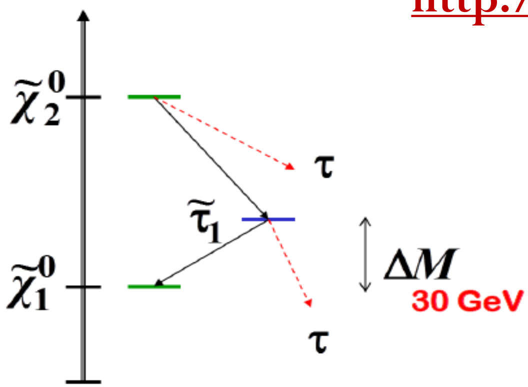
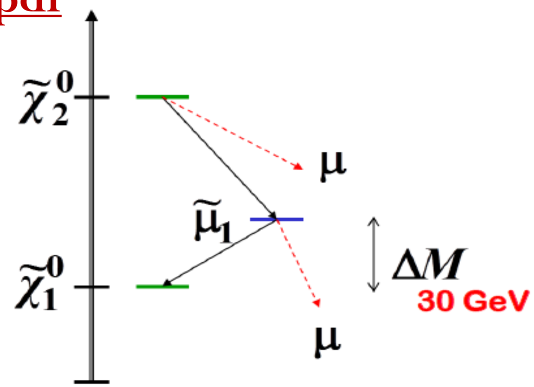
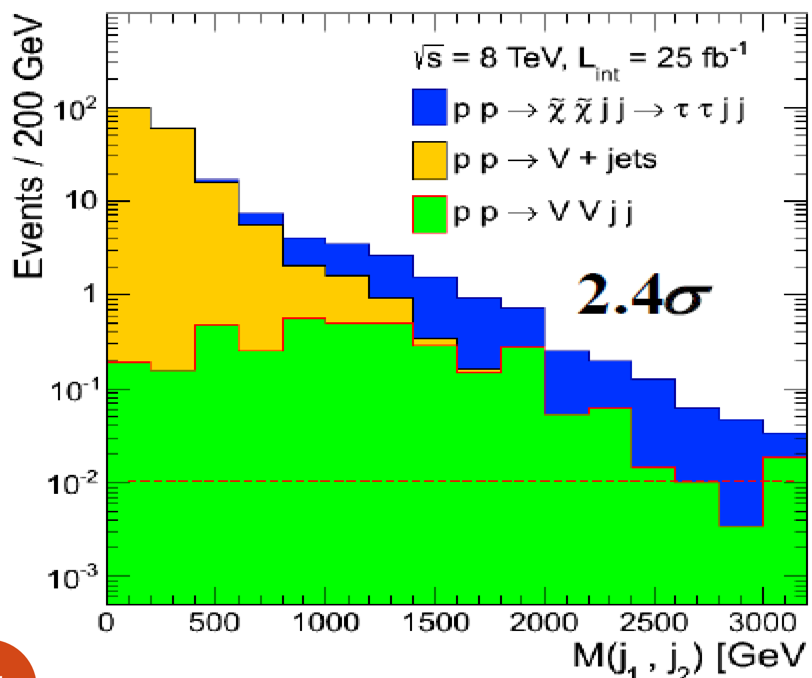
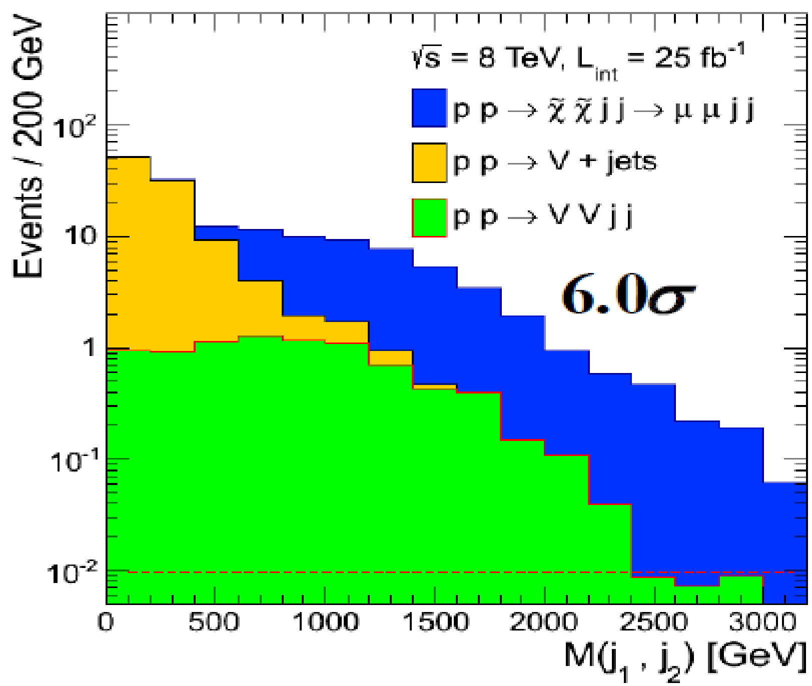
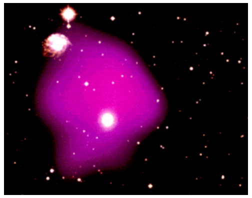


- Jets w/ pT > 50, |η| < 5
- |Δη(j,j)| > 4.2
- M(j,j) > 700
- Veto on events with b-jets
- Select at least two leptons
- MET > 75 GeV

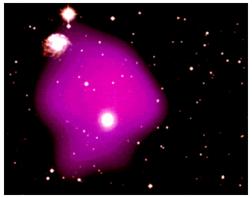


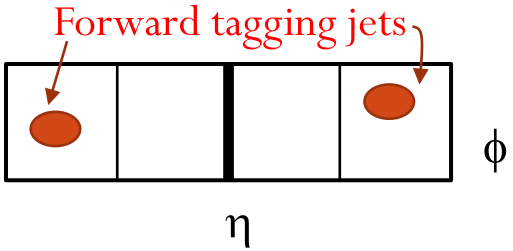






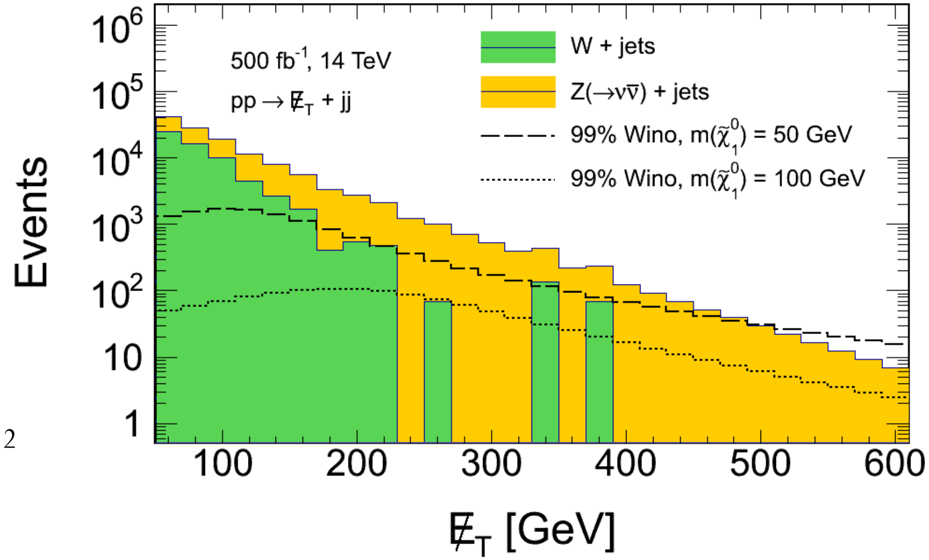
VBF DM Feasibility & Reach

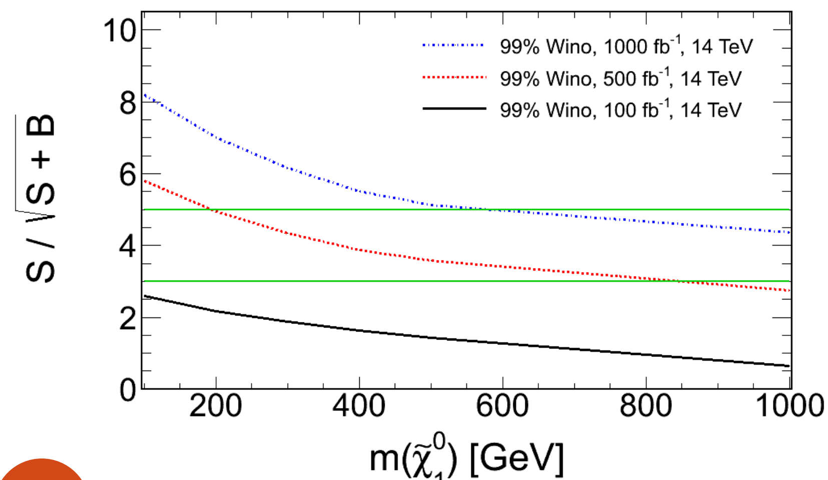




http://arxiv.org/pdf/1304.7779v1.pdf

- Two lead jets w/ pT > 50, $|\eta| < 5$
- $|\Delta\eta(j,j)| > 4.2$ & $M(j,j) > 1500$
- Veto on leptons (e,μ,τ) & b-jets
- Central jet veto: no 3[rd] jet w/ $\eta_1 < \eta_3 < \eta_2$
- MET > X optimized for each mass



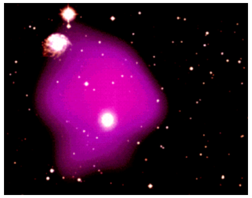


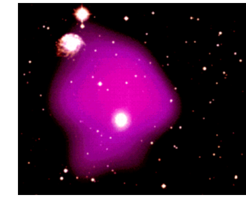
Real sensitivity is at 14 TeV

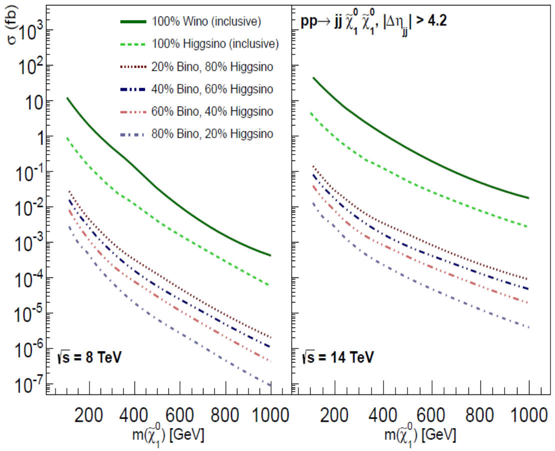
8 TeV reach is ~< 100 GeV

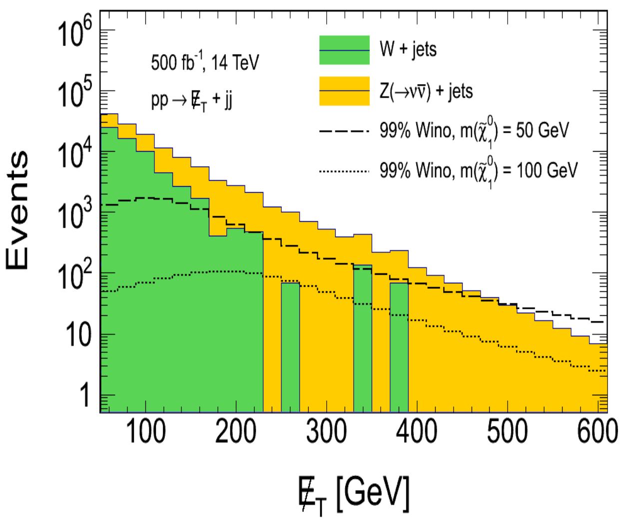
@ 1000 fb^{-1}, 5σ obtained up to a Wino mass of ~ 600

DM Relic Density

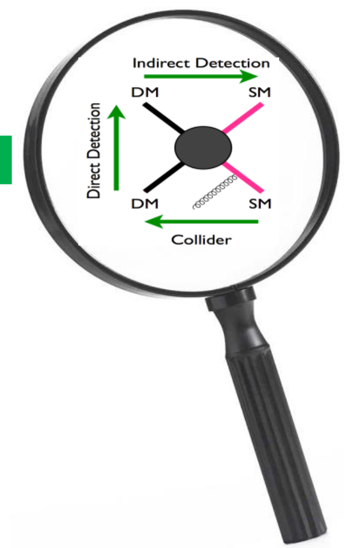




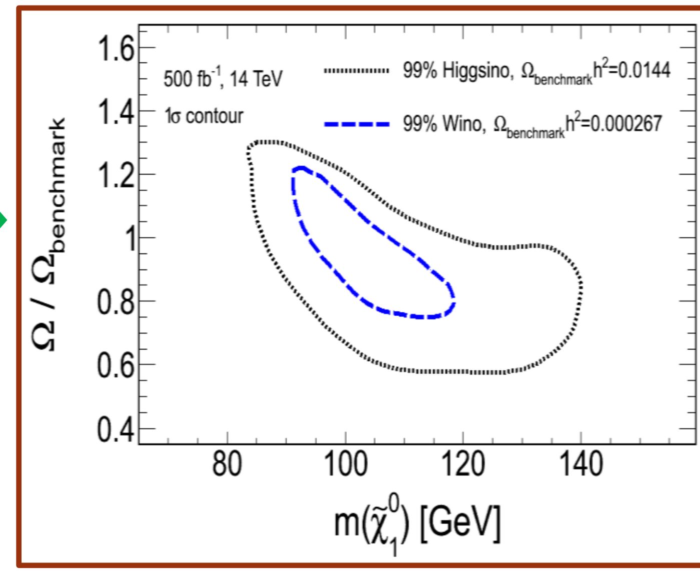




Simultaneously fit the MET shape and observed rate in data to extract the mass and composition of the LSP



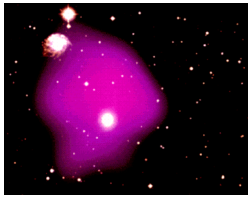
DarkSUSY

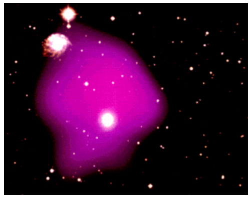


$$\Omega_{LSP} h^2 = f[F\%, m(LSP)]$$

Mass and composition of the LSP used to determine the LSP relic density

MET Performance w/ Pileup





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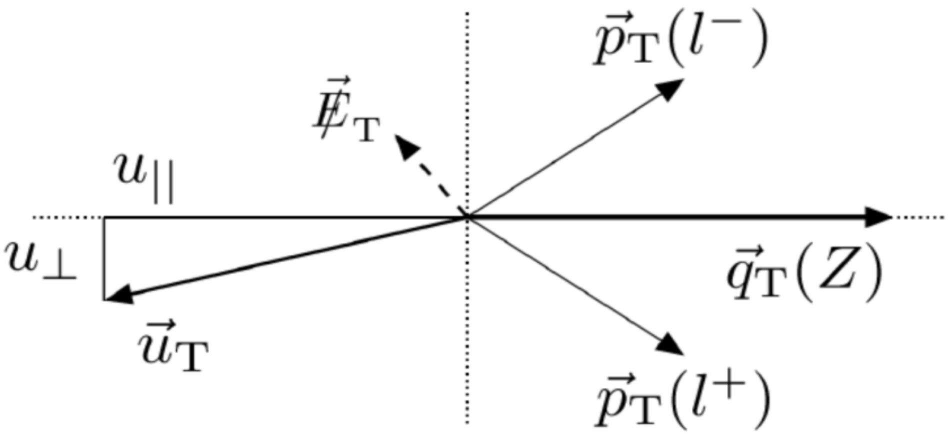
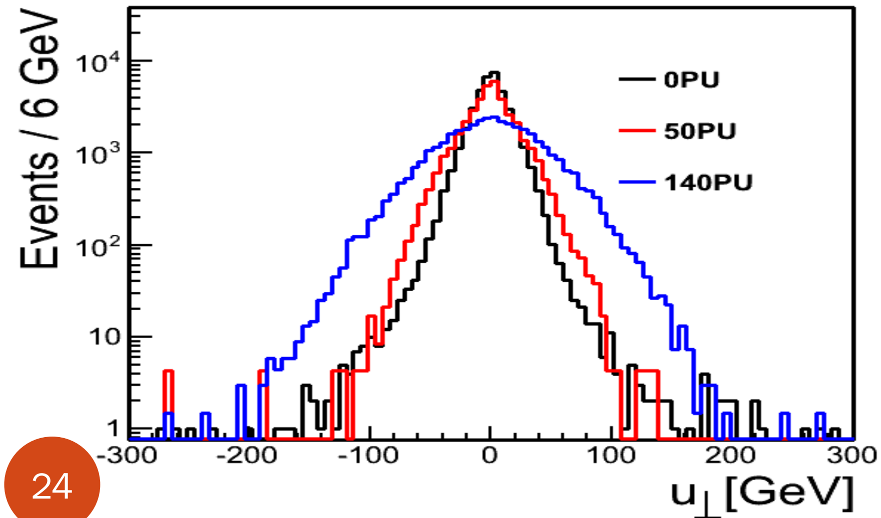
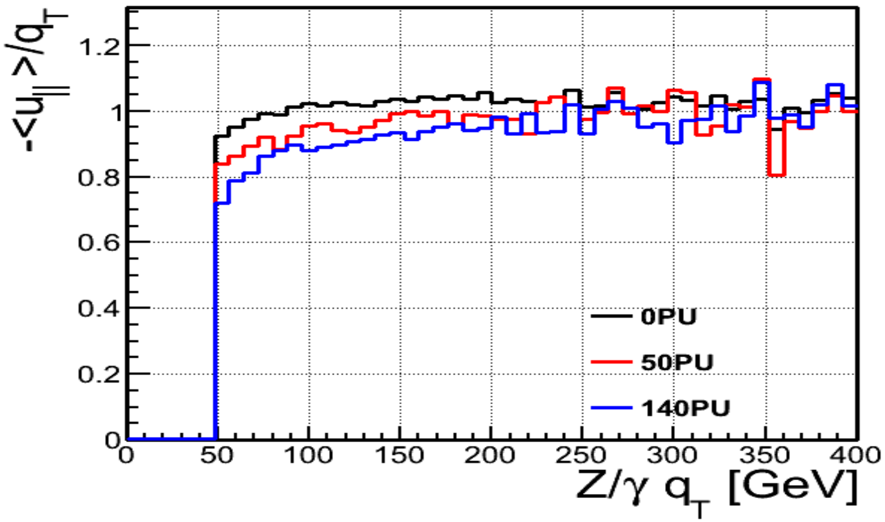
Use Delphes samples to study MET degradation with pileup



Select Z + jets events and study the perpendicular and parallel components of the hadronic recoil

$$E\!\!\!/_T \text{ energy scale} = -\langle u_{||} \rangle / q_T$$





MET Performance w/ Pileup

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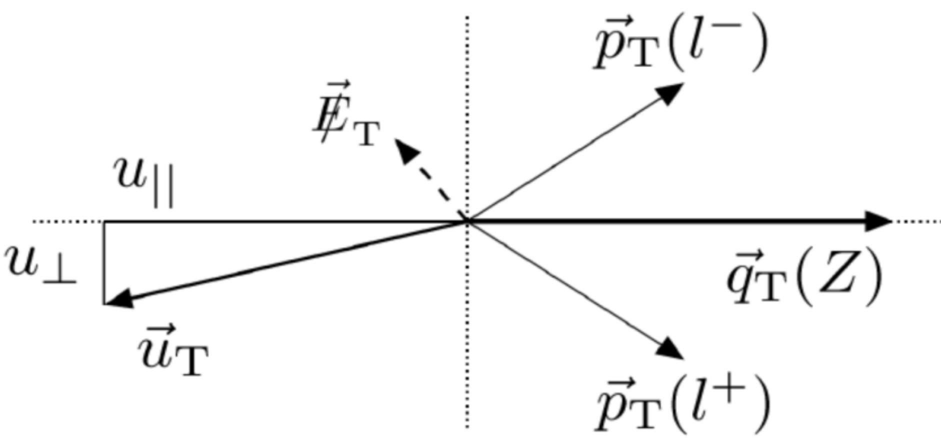
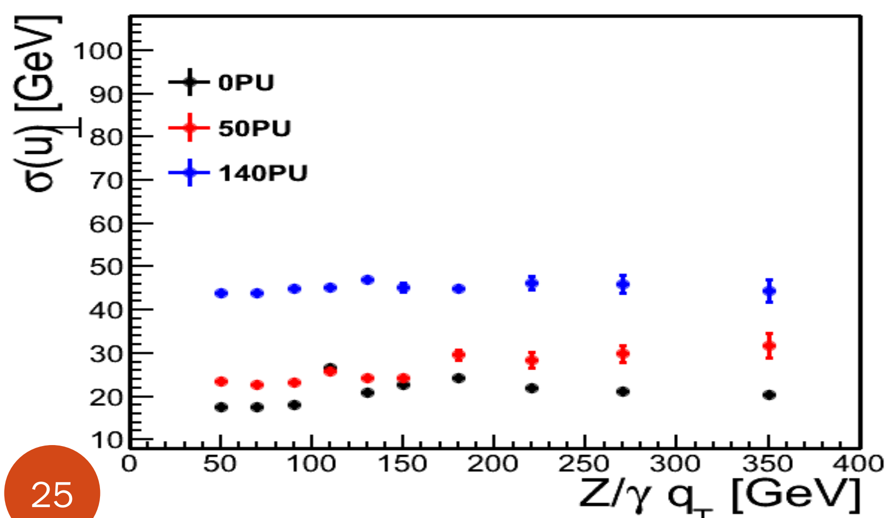
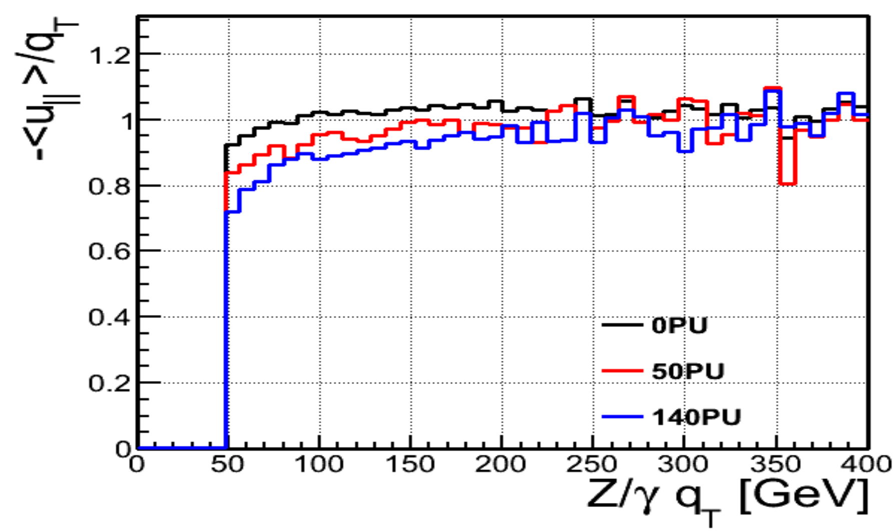
Preliminary: ~ 10% effect on energy scale and 50 GeV on resolution (PU=140)

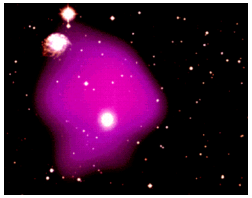
Minimal effect on mass reach (e.g. 20% energy scale → 4% in signal significance)

Ongoing study: effect on the mass reach due to pileup effects on the vetoes

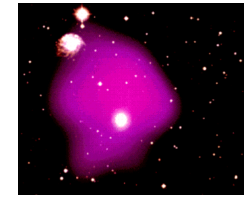




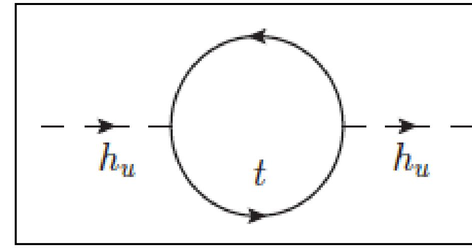


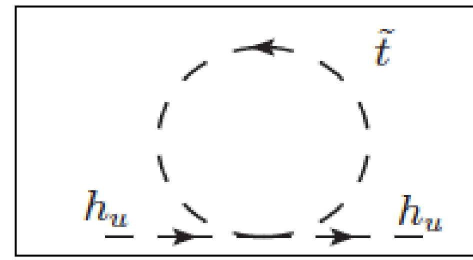


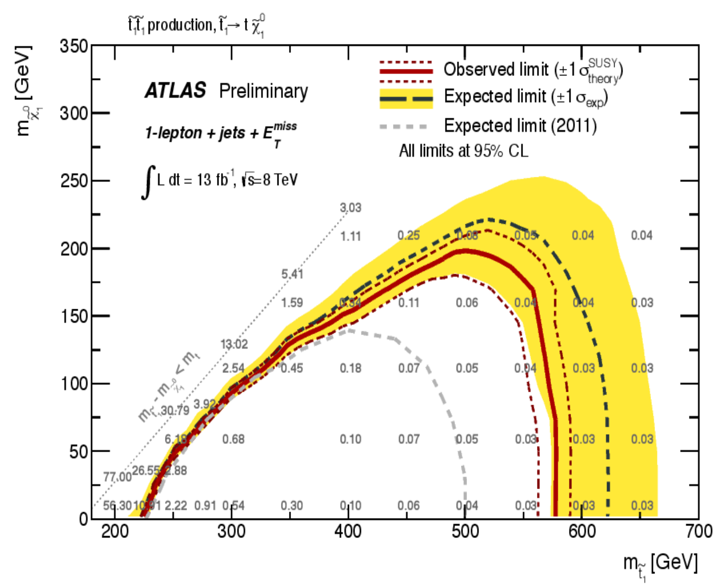
Motivation for Stops

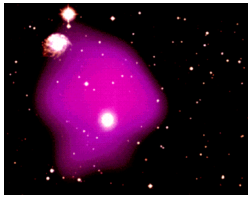


- Theoretical motivation ("Naturalness")
  - ***Cancel top loop corrections to the Higgs mass if the stop is light enough***
  - Mixing proportional to mass
    - ***Stop mass eigenstates can be light***
  - $\tilde{t}_1$ searches so far: LSP bino, $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$ wino → $Br(\tilde{t}_1 \to t\tilde{\chi}_1^0) \sim 100\%$
    - limited sensitivity to $m(\tilde{t}_1) \sim m(t) + m(\tilde{\chi}_1^0)$
    - limited sensitivity to $m(\tilde{t}_1) < 250$
    - Bino dark matter often does not satisfy the dark matter relic density constraints
      - need other effects, e.g Bino-Higgsino or stop-LSP coannihilation, etc.
  - Light stops and/or compressed spectra important for Higgs and cosmology

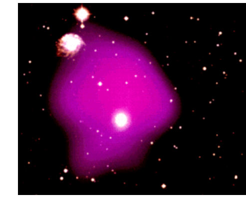


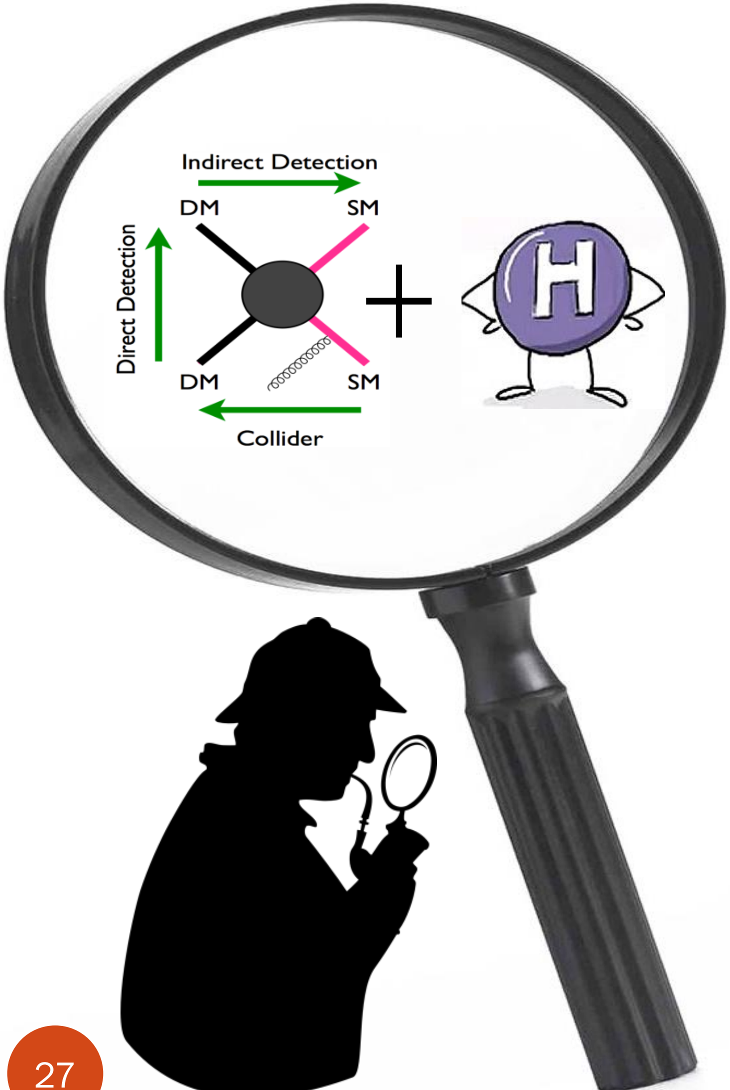


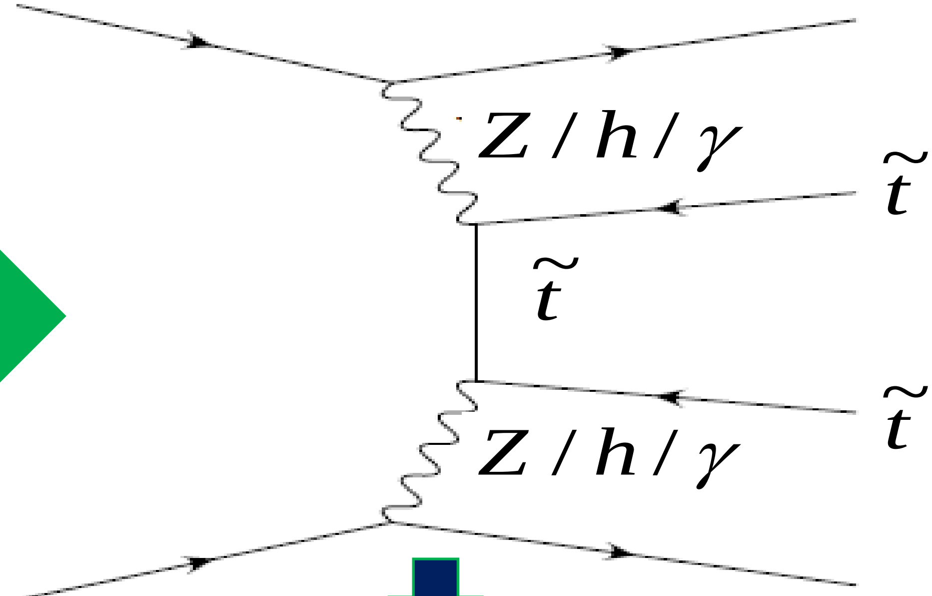


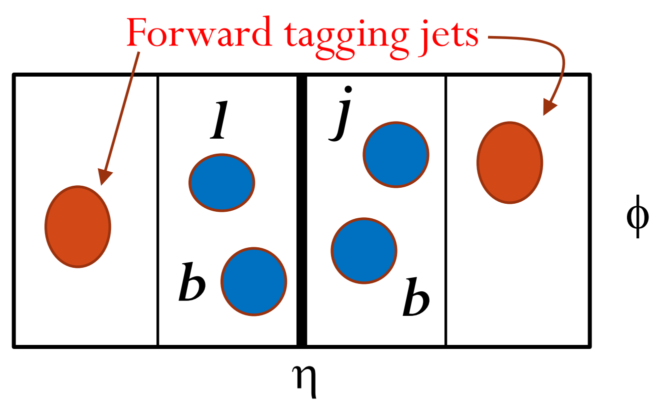


Probing Stops with VBF

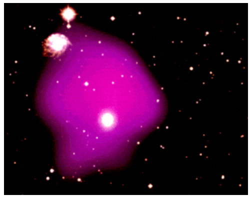




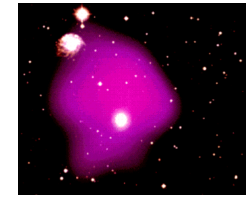


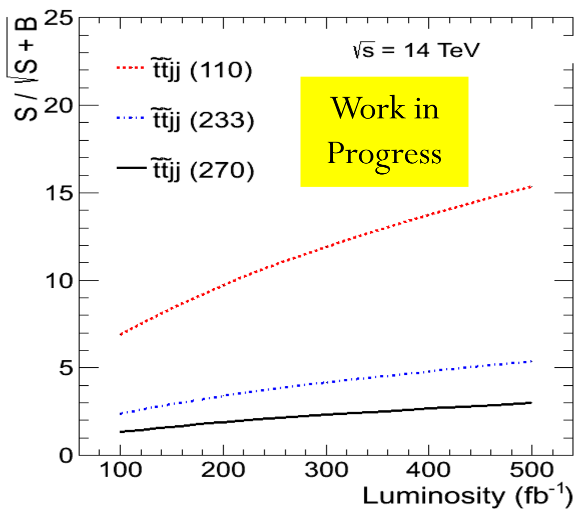


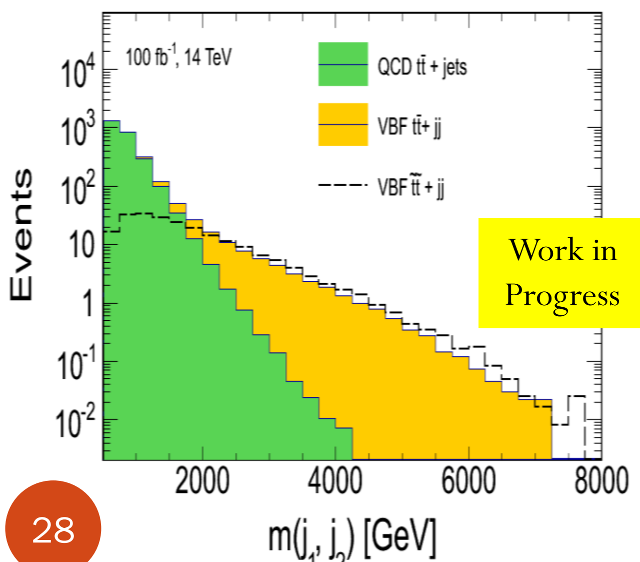
MET + $j_f j_f$ + leptons + 2b



Probing Stops with VBF

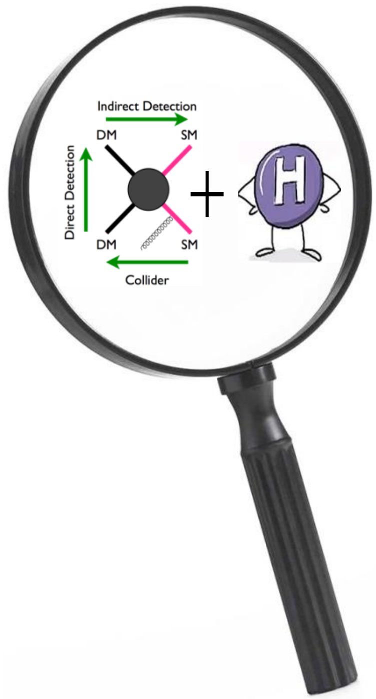




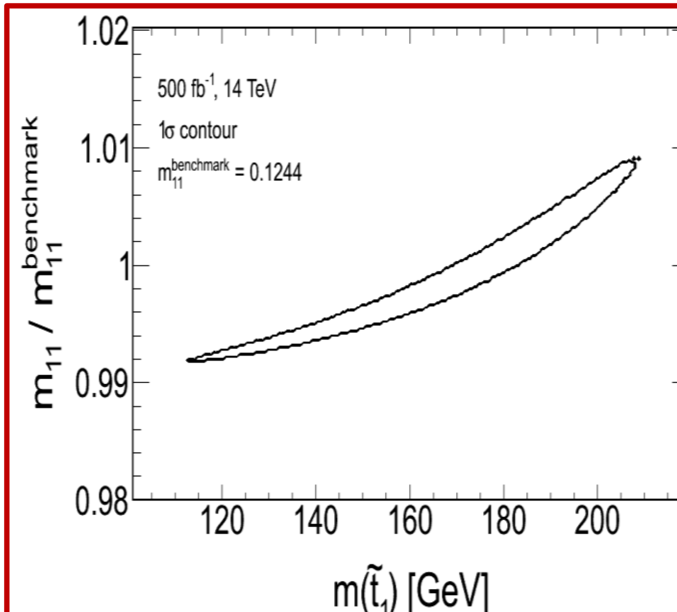


Benchmarks

- Stop (LSP) = 110 (50)
- Stop (LSP) = 233 (50)
- Stop (LSP) = 277 (90)

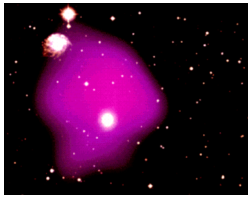


Simultaneously fit the dijet mass shape and observed rate in data to extract the mass and mixing

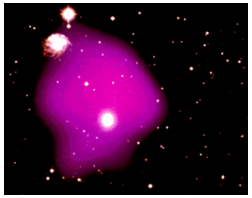


Work in progress → we are studying QCD stop

Authors: A. Delannoy, B. Dutta, W. Flanagan, A. Gurrola, W. Johns, T. Kamon, A. Melo, P. Sheldon, K. Sinha, K. Wang, S. Wu



Summary



- VBF offers a powerful way to *"directly" probe SUSY & DM* at the LHC
- **Compliments** current SUSY searches and has some advantages:
  - Probing EWK sector is largely *agnostic about the colored sector*
  - Direct window to determination the composition of the LSP
  - Unique tool at the LHC to directly access DM, light stops, and compressed spectra with an *experimentally plausible trigger*
- Pheno study shows that we can *probe e.g. Wino masses up to ~ 600 GeV at the 5σ level with 1000 fb^{-1} of 14 TeV data*
- *Relic density can be determined to ~20% (40%) accuracy at 500 fb^{-1}* for the pure Wino (Higgsino) dark matter scenario
- In progress: probe stops & compressed scenarios to ~ 300 GeV at 5σ w/ HL-LHC
- Validations with DELPHES have reproduced similar results
- Ongoing MET performance studies w/ Delphes shows ~10% energy scale degradation with a 50 GeV effect on resolution
  - Linearity has small effect on mass reach (linearity can also be corrected), while the effect on the reach due to resolution is minimal (~ 4%)
  - Details in the snowmass whitepapers/reports as well as ECFA workshop