SUSY Searches for EWK Production of Gauginos and Sleptons at the LHC

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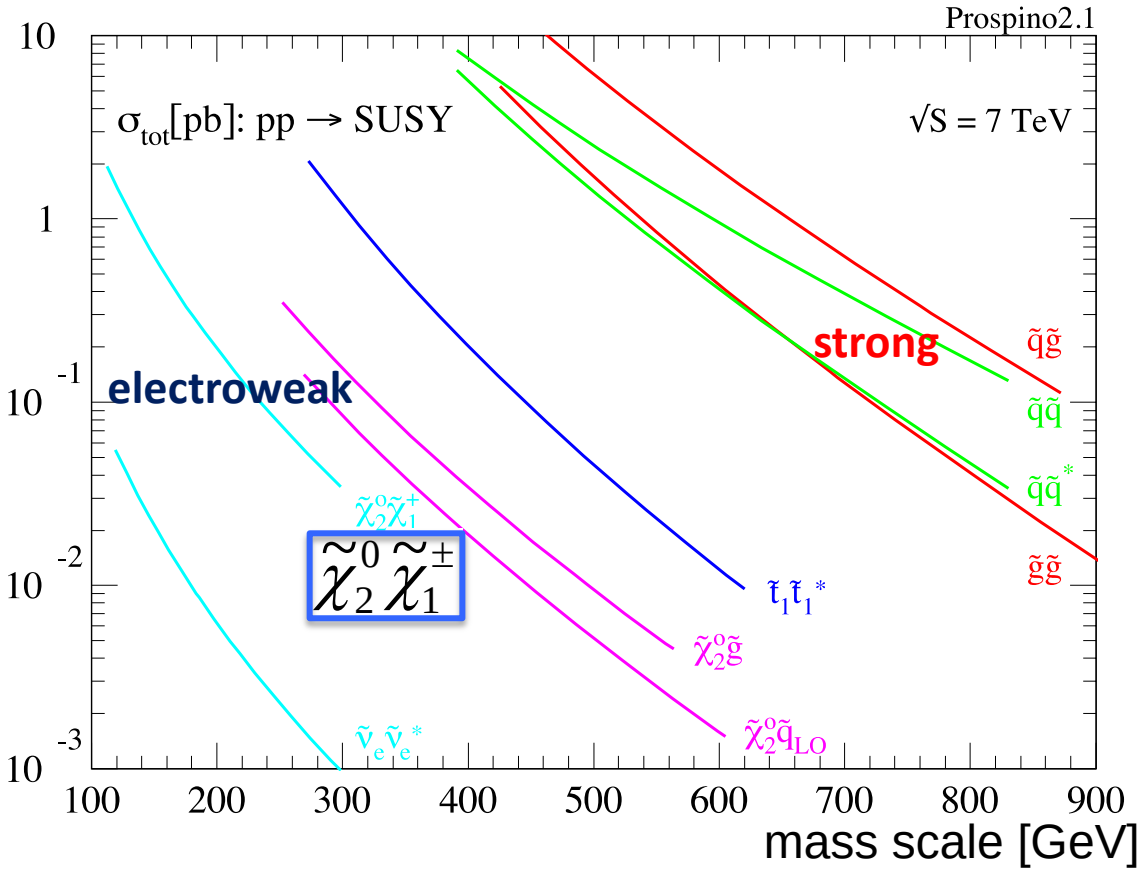
Motivation

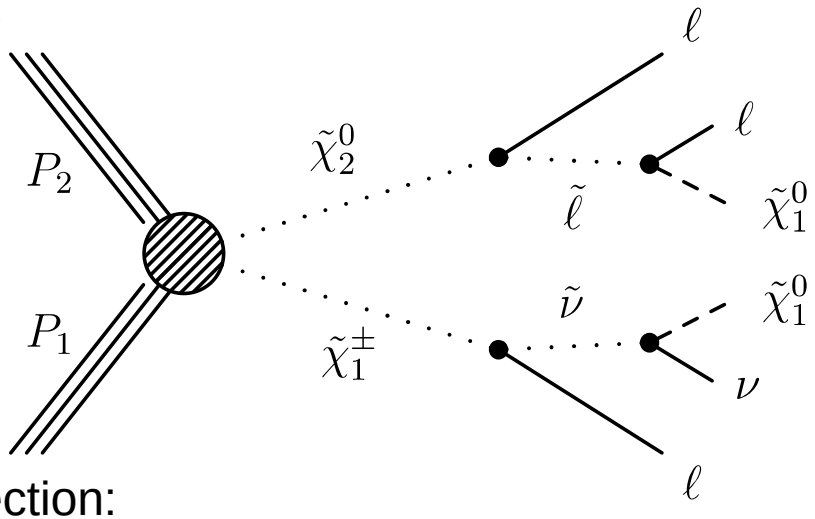
- Most SUSY searches have focused on strong production, which has the largest cross section



- Limits on these models probe masses of strongly-interacting particles up to ~1 TeV
  - Similar cross-sections to EWK gaugino's of 300-400 GeV
- Interesting when squarks and gluino's are heavy, but EWKinos are light

General strategy

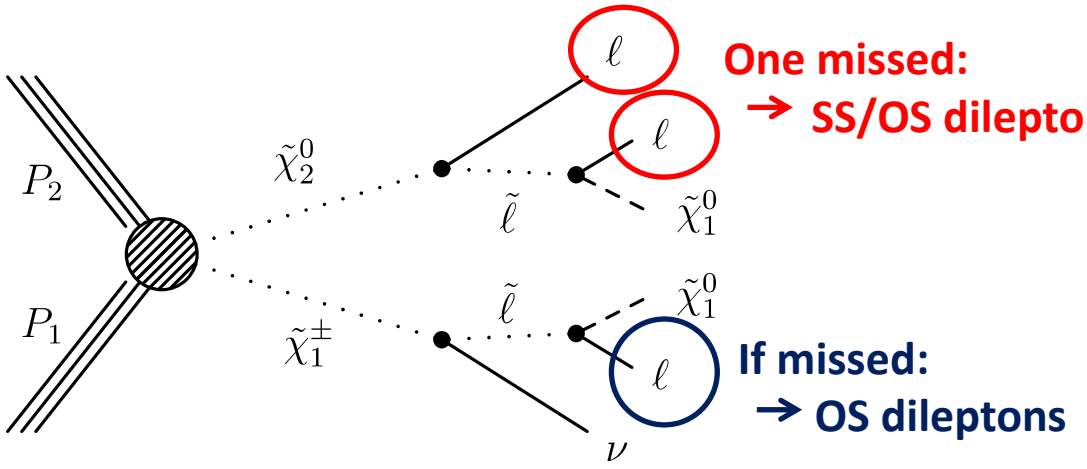
- Look for direct pair production of gaugino's and sleptons:
  - Very clean multi-lepton signatures
  - Low hadronic activity



- Main backgrounds and rejection:
  - Diboson backgrounds: apply Z mass cut
    - Not for intermediate vectorboson searches
  - ttbar: apply b-jet veto (or jet-veto)
  - Binning in MET or other kinematic variable (m_{T2}, m_{CT})
- Background estimation:
  - Non-prompt backgrounds: data-driven techniques
  - Diboson backgrounds: validated MC, with data-driven corrections
- Main focus on 8 TeV results

Chargino-neutralino production

chargino-neutralino production: light sleptons and sneutrinos



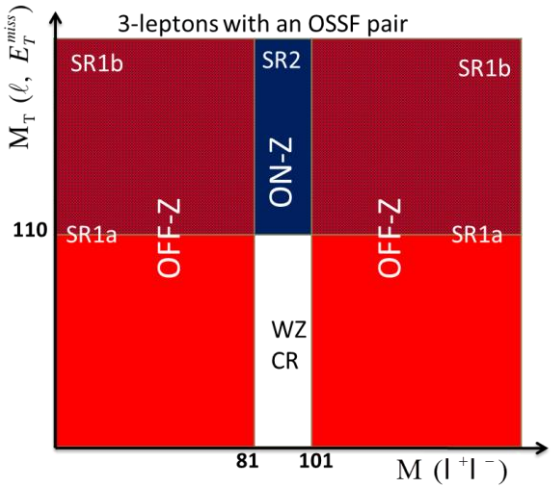
- **Model naturally gives 3ℓ (off-Z) signatures, but can give 2ℓ or 3ℓ (on-Z) signatures, depending on mass spectrum**
  - flavor-democratic or tau-enriched

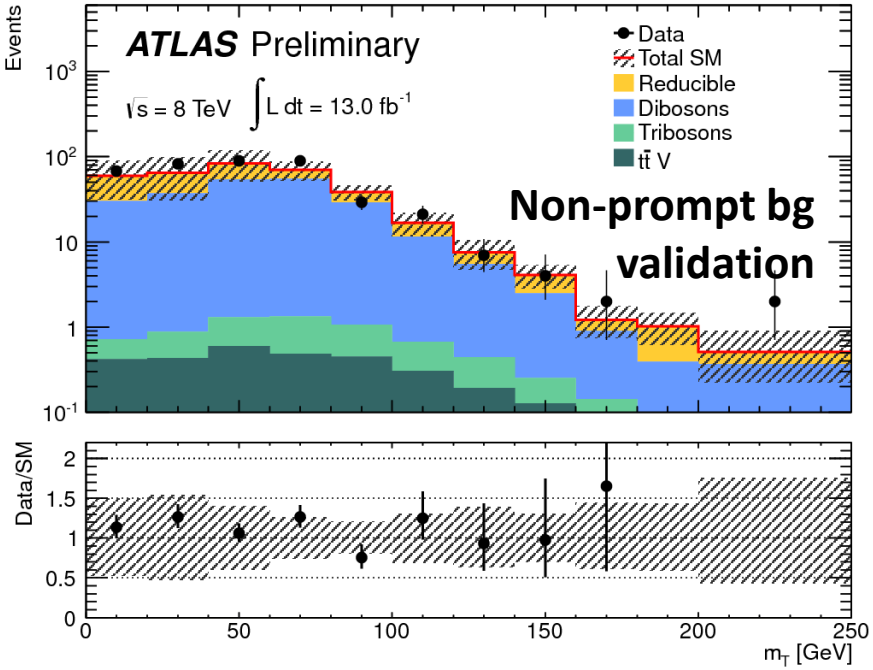
- Dedicated analyses:
  - 3-lepton searches (ATLAS+CMS, 8 TeV)
  - CMS: same-sign di-lepton analysis (Veto third lepton, fully exclusive)
  - ATLAS: same-sign and opposite sign jet-veto analysis (7 TeV)

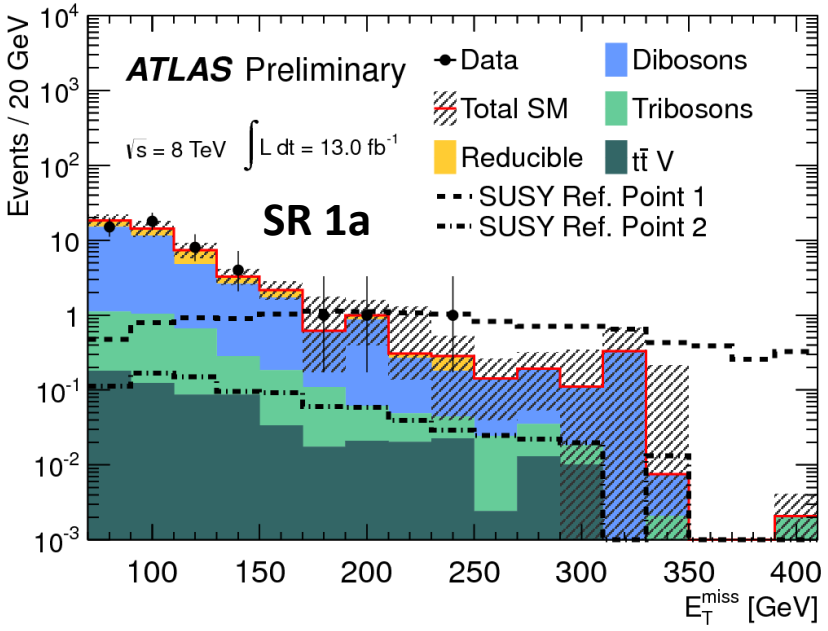
Three lepton analysis

ATLAS-CONF-2012-154

- 3 main search regions, targeted for specific models, with :
  - SR 1a: MET>75 GeV, Z-veto and b-jet veto
  - SR 1b: same as SR1a + m_T>110 GeV, lepton p_T>30 GeV
  - SR 2: Z candidate, m_T>110 GeV, MET>120 GeV
- Normalize WZ simulation to WZ control region
- Data-driven non-prompt prediction





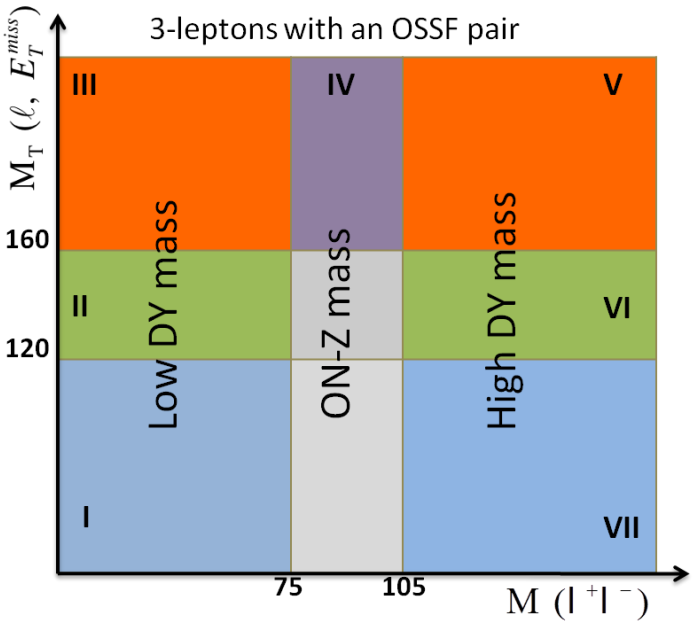


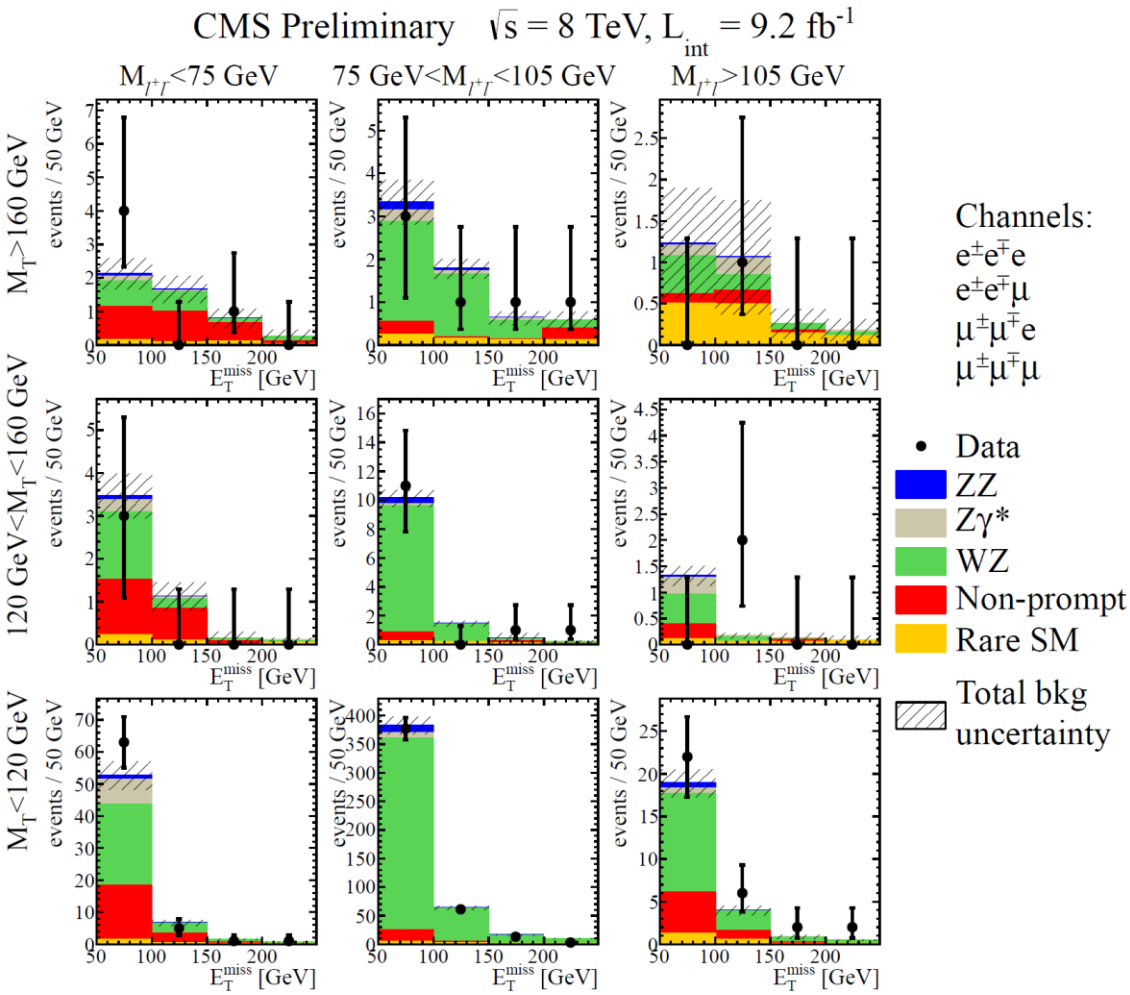
Three lepton analysis

SUS-PAS-12-022

- Use 3D binning : MET, m_T and dilepton mass
  - 50 GeV MET bins
- b-jet veto to suppress ttbar
- Correction to WZ MC MET resolution
- Also hadronic taus and no OS same-flavor pairs
  - Tau-enriched models

8 TeV

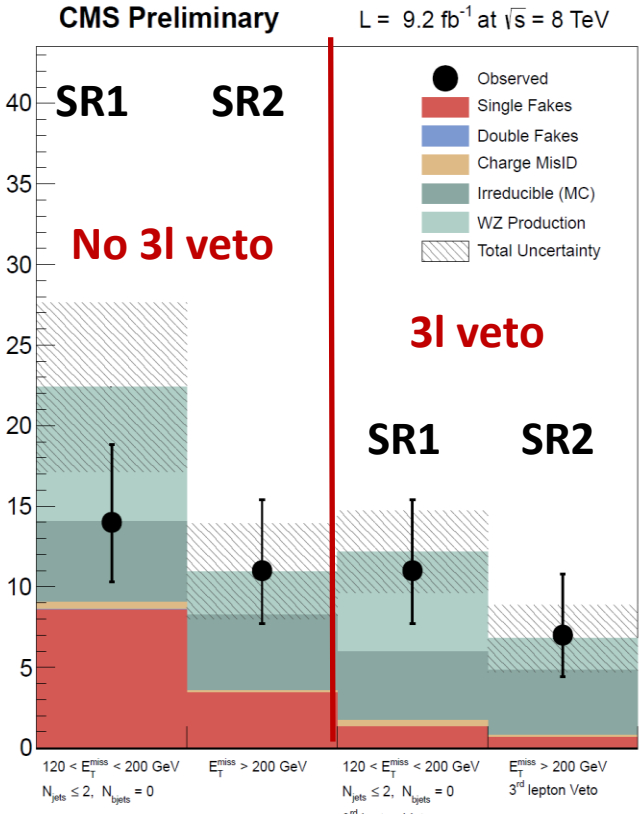




Same-Sign dilepton analysis

SUS-PAS-12-022

- Small mass splittings can lead to soft leptons and missing one of the leptons
- Tighter cuts needed because of larger backgrounds.
- SS dileptons, Z veto, cut on small hadronic activity or large MET:
  - SR1: MET>120 GeV, $N_{jets} \leq 2$, b-veto
  - SR2: MET>200 GeV



8 TeV

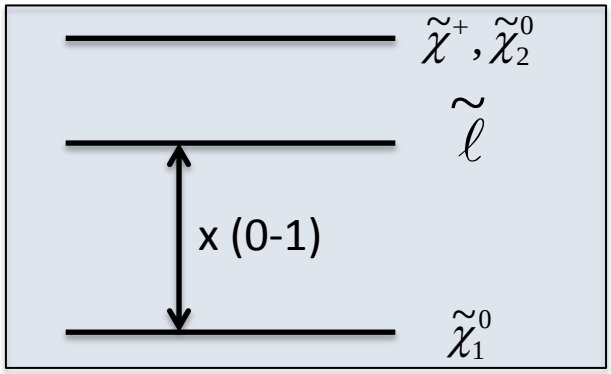
Similar 7 TeV ATLAS dilepton analysis (back-up slides)

Chargino-neutralino production

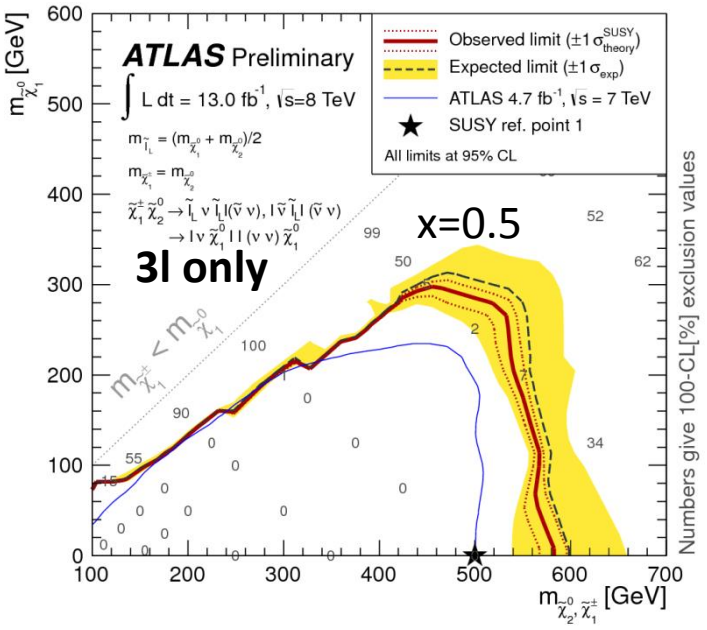
SUS-PAS-12-022

ATLAS-CONF-2012-154

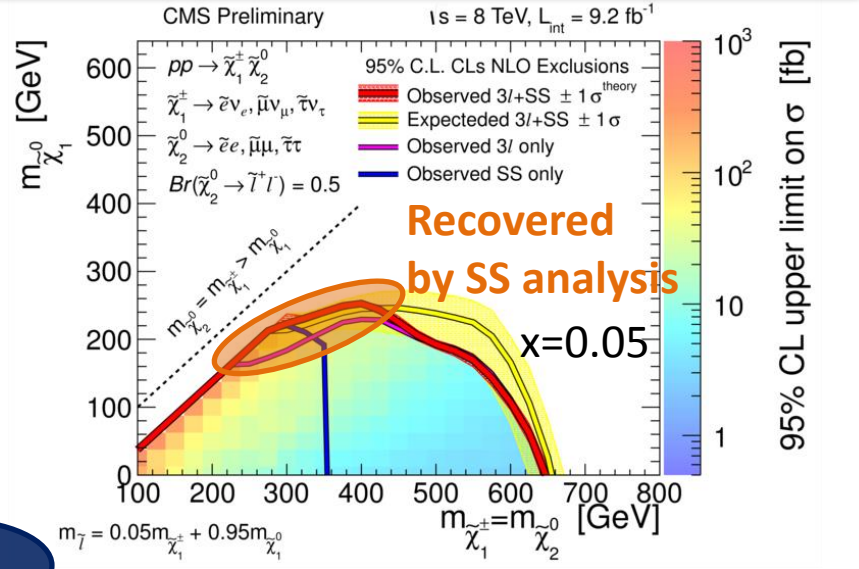
Same branching fraction to e,μ,τ

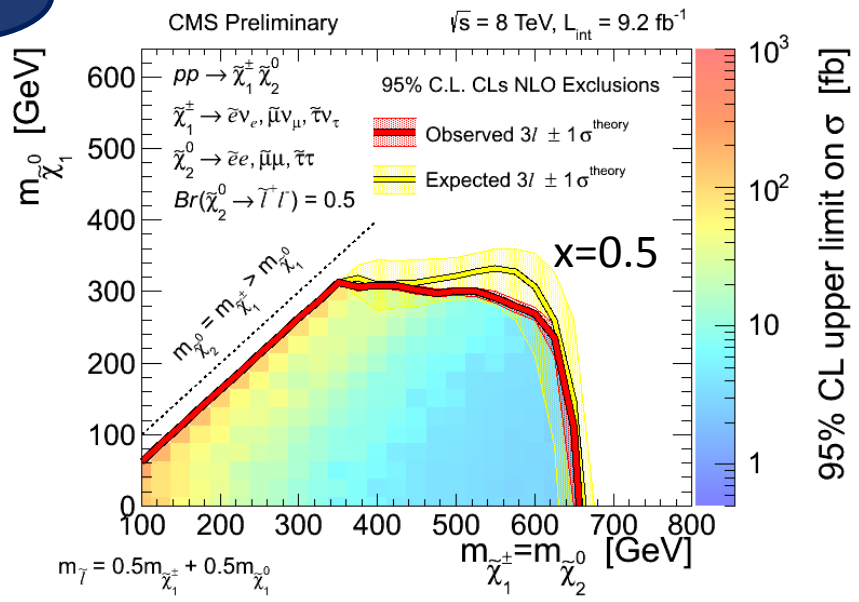


$m_{slep} = x \cdot m_{\chi^+} + (1-x) \cdot m_{LSP}$



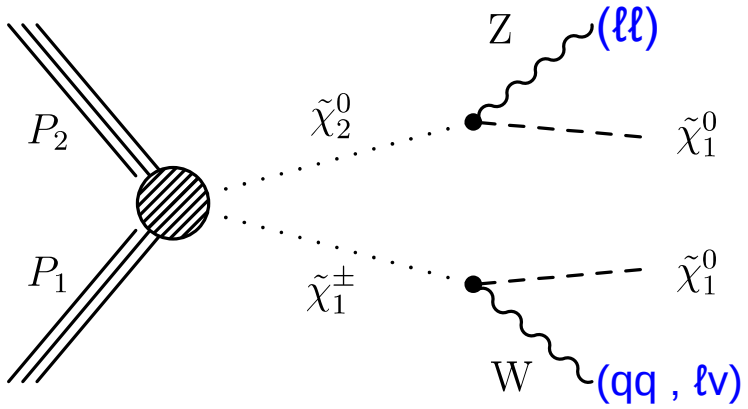
8 TeV

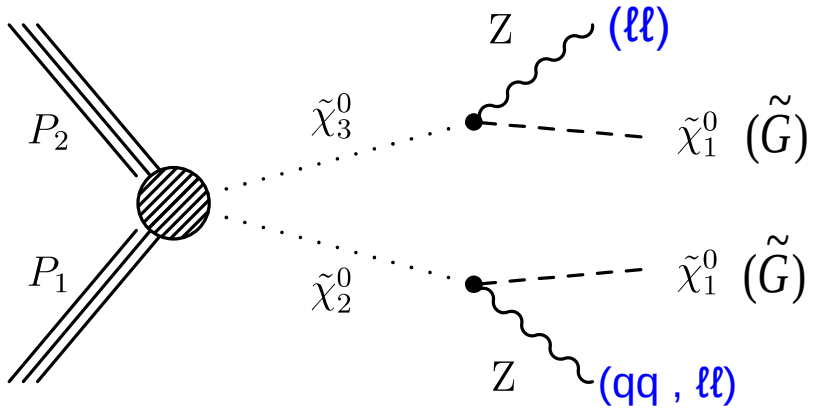




Chargino-neutralino production

chargino-neutralino production: direct decays to W/Z bosons (heavy sleptons)





- **Model naturally gives 3ℓ and 4l (on-Z) and 2l (on-Z) + jets signatures**
  - Neutralino pair production suppressed, use GMSB model

- Dedicated analyses:
  - 3-lepton + M(ll) + MT
  - 2-lepton + di-jet + MET

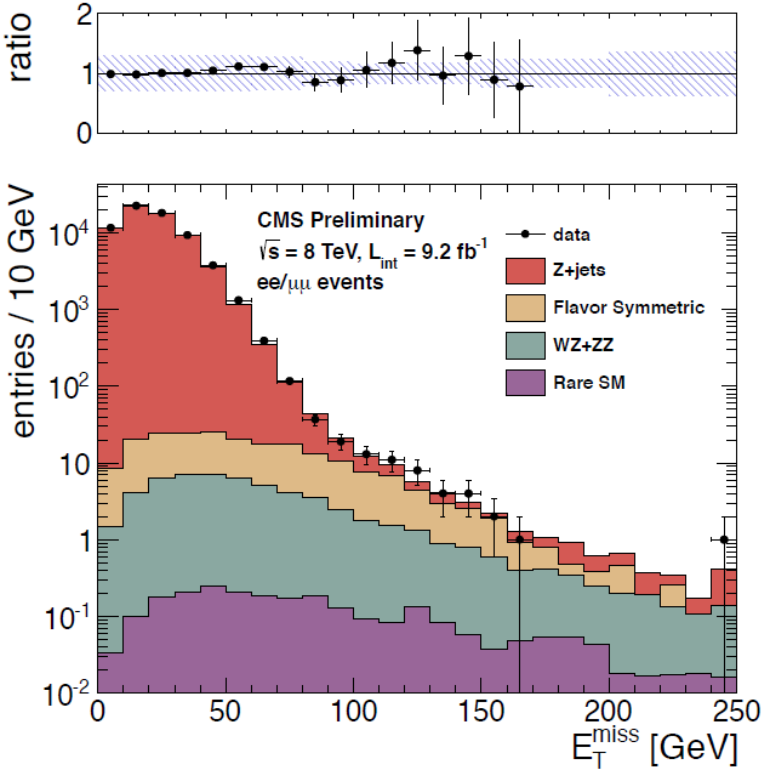
- Dedicated analyses:
  - 4-lepton + MET
  - 2-lepton + di-jet + MET

Z+dijet and four lepton analysis

SUS-PAS-12-022

- Z candidate, third lepton veto, b-veto
  - W/Z compatible dijet mass
- MET binning

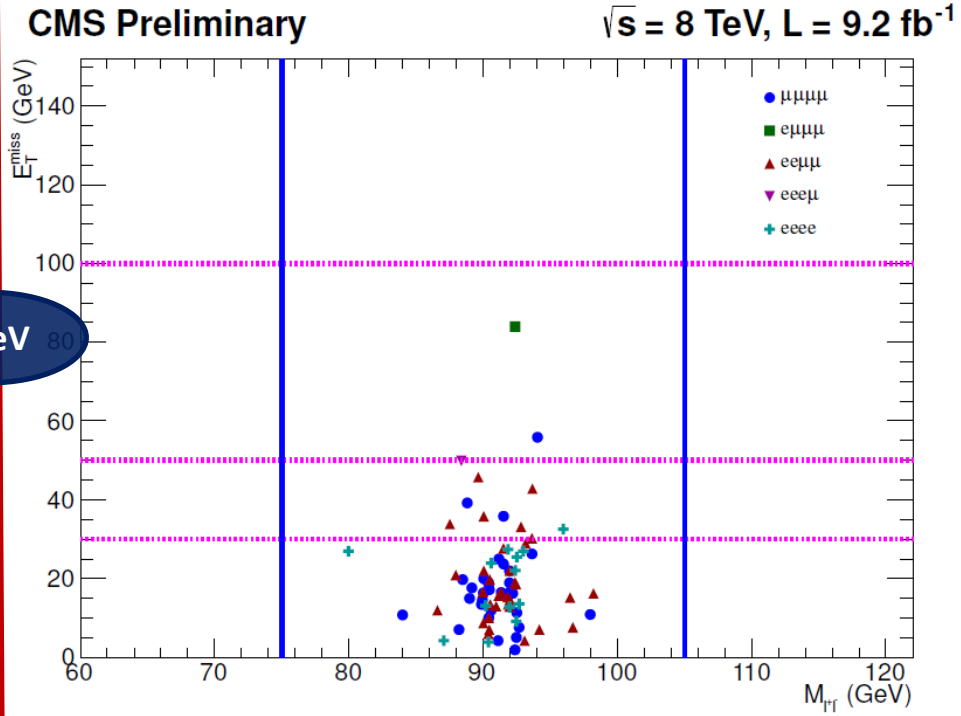
Similar 7 TeV ATLAS analysis



- Z+jets MET modeled with γ+jets templates
- Flavor symmetric backgrounds from eμ

8 TeV

- 4 e/μ or 3e/μ+τ
- Bin in number of opposite-sign same-flavor pairs, dilepton mass and MET
- b-jet veto to suppress ttbar



- Same background techniques as 3l analysis

Chargino-neutralino (WZ)/ GMSB Higgsino

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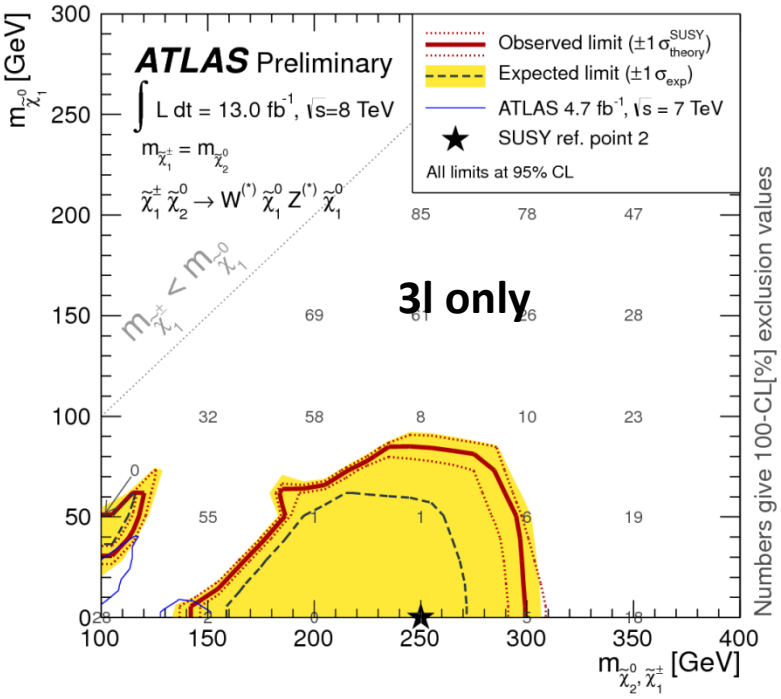
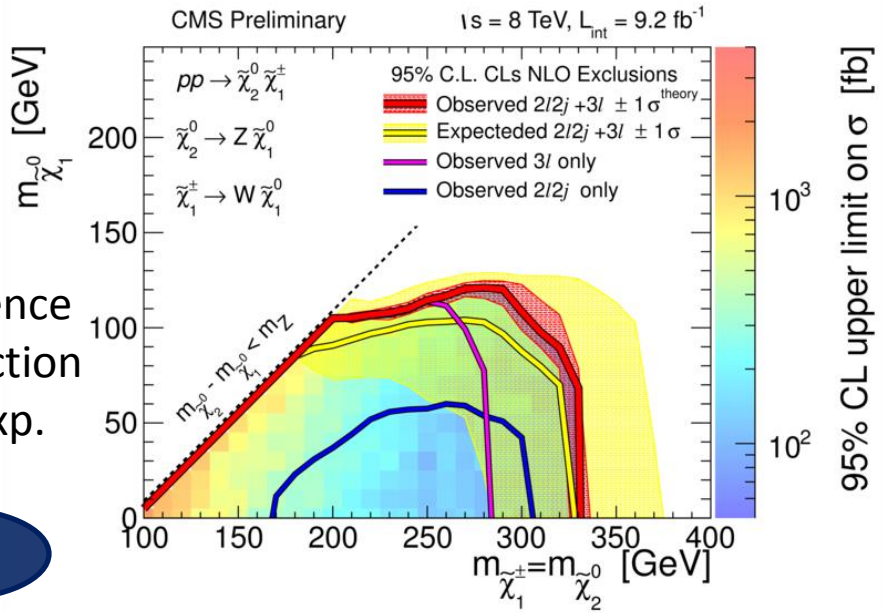
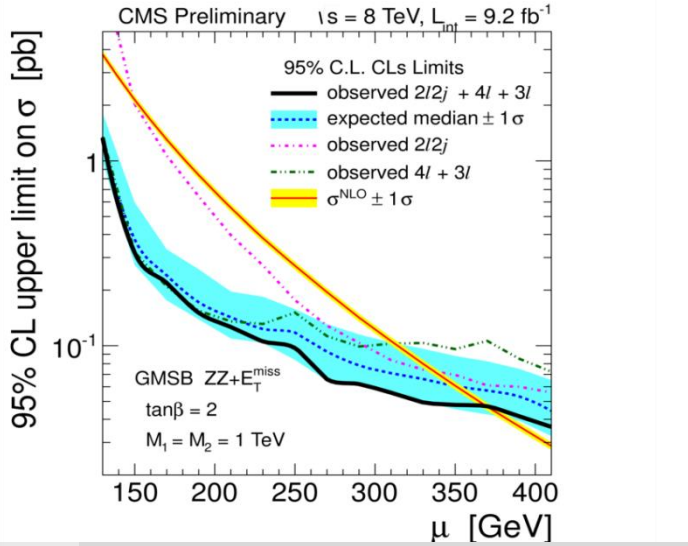
SUS-PAS-12-022



10% difference in cross-section between exp.

8 TeV



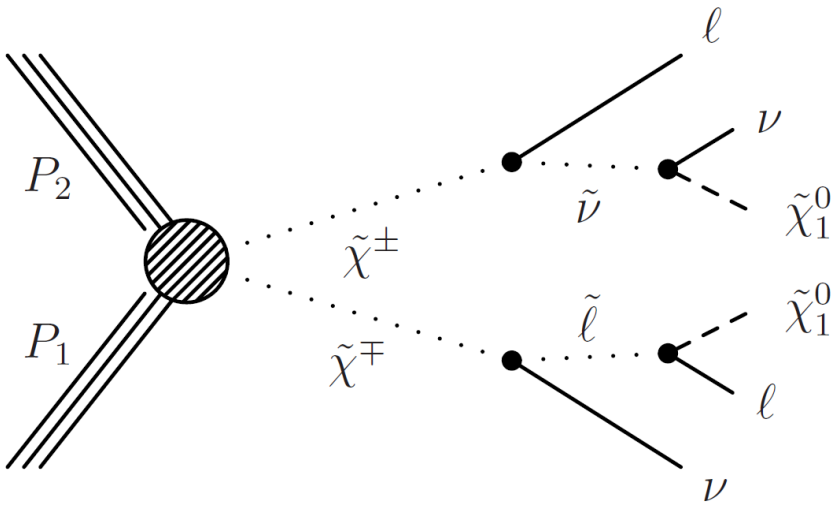


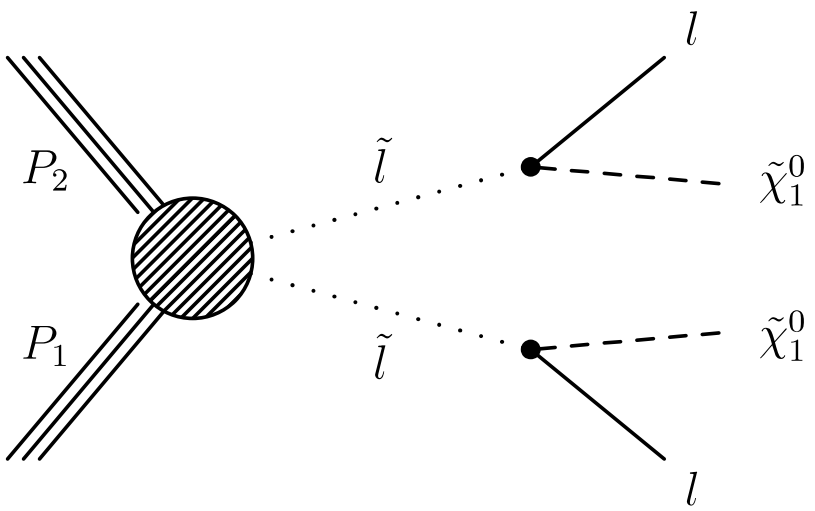
- Neutralino pair production in gauge-mediated symmetry breaking (GMSB) higgsino model
  - Exclusion in terms of parameter (μ) that controls the masses for Chargino and LSP

$$m_{\tilde{\chi}_1^{\pm}} \approx m_{\tilde{\chi}_1^0} \approx \mu$$

ATLAS Z+jets analysis: similar search in cascade decay

Chargino and slepton pair production





- **Model naturally gives 2ℓ (off-Z) signatures**

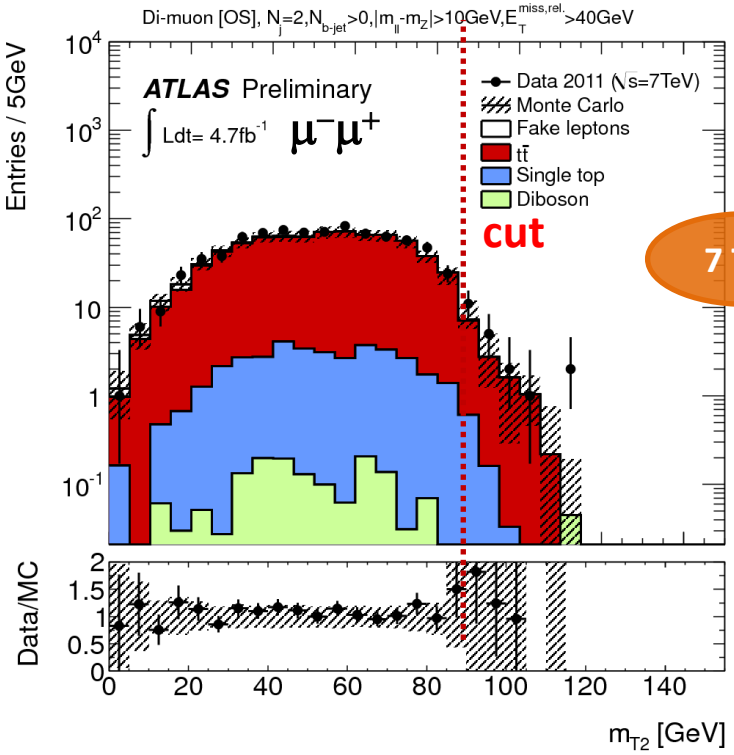
- Dedicated analysis:
  - opposite -sign di-lepton analysis

OS dilepton analysis

SUS-PAS-12-022

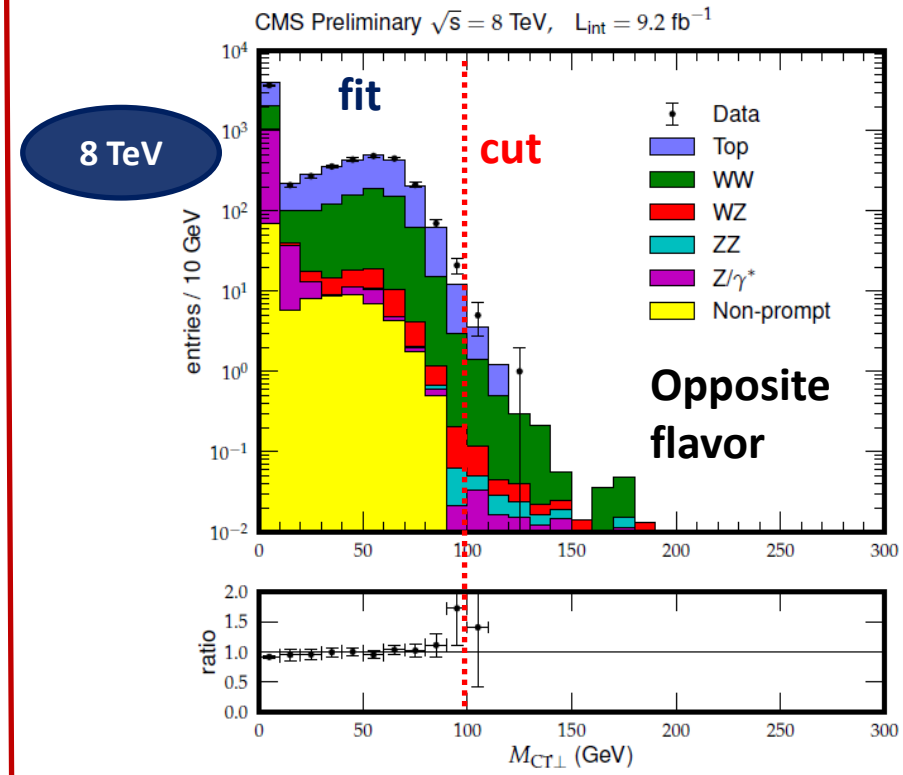
ATLAS-CONF-2012-076

- 2 OS leptons, Z-veto, jet veto, MET>40 GeV
  - Use M_{T2}-variable
  - Kinematic endpoint for WW, ttbar,...



7 TeV

- 2 OS leptons, Z-veto, b-jet veto, MET>60 GeV
  - Use $MC_{T,Perp}$-variable (back-up)
  - Kinematic endpoint for WW, ttbar,...



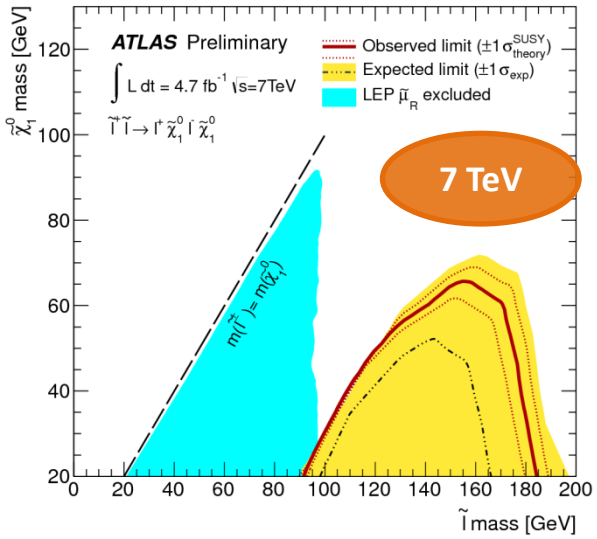
8 TeV

- Template fit for background estimates

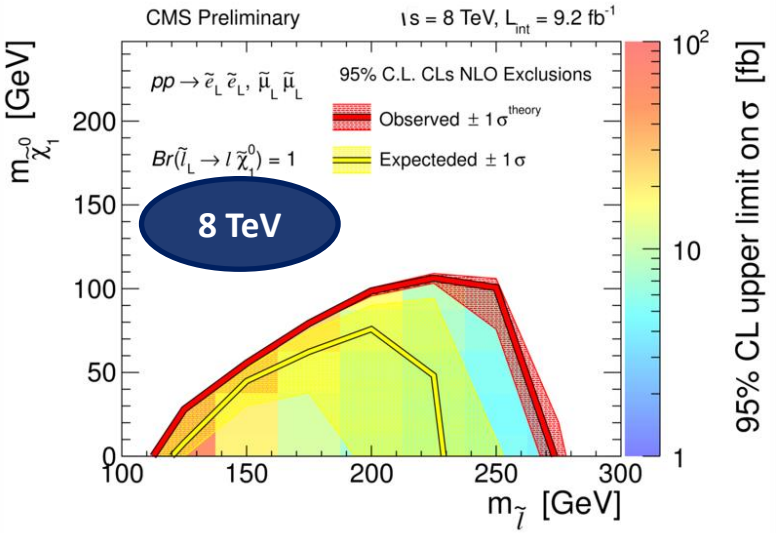
Chargino and slepton pair production

SUS-PAS-12-022

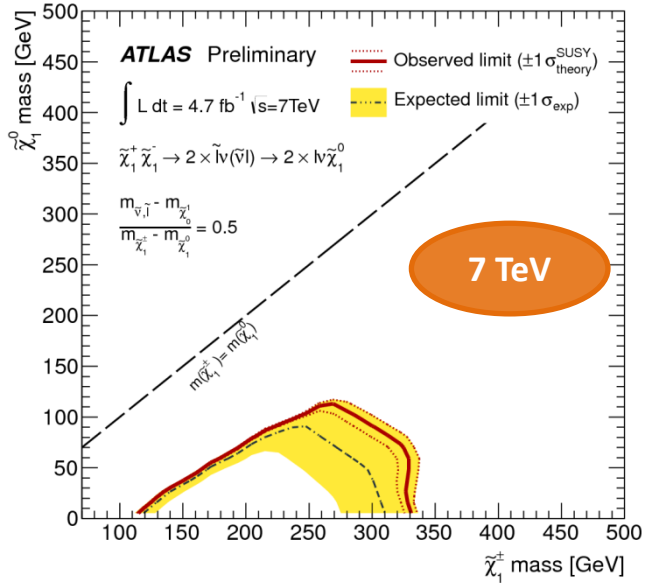
ATLAS-CONF-2012-076

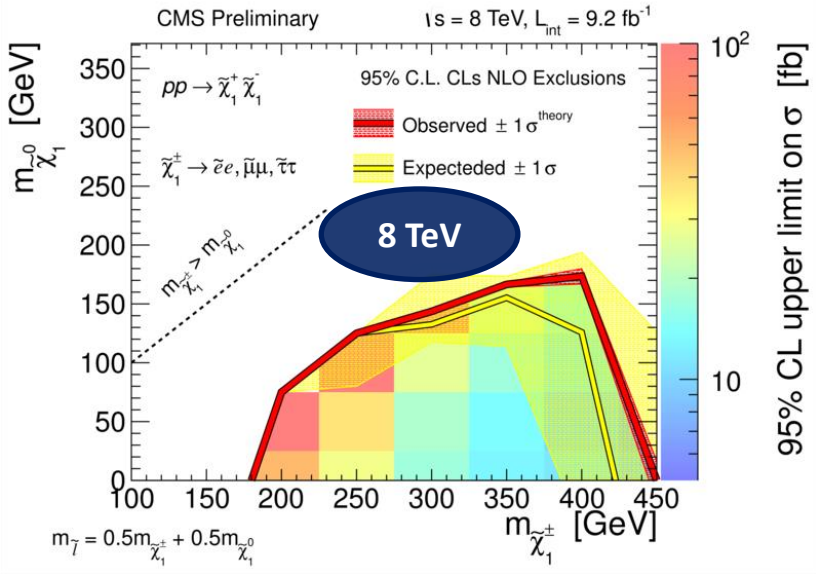


sleptons



charginos

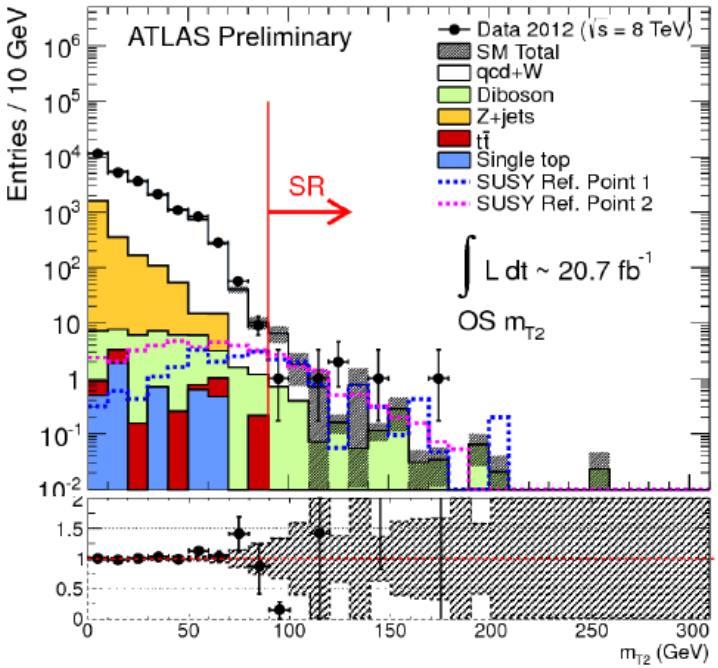


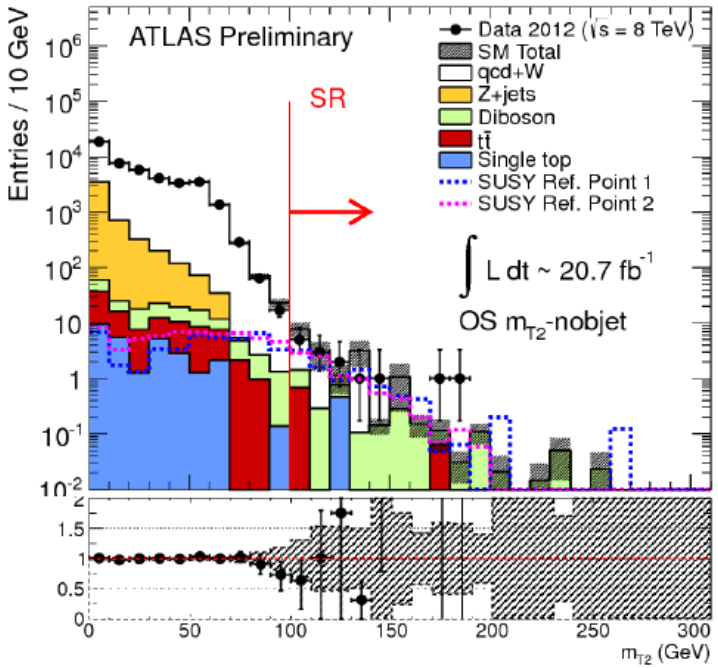


Intermediate staus

ATLAS-CONF-2013-028

- Chargino/neutralino pair production or chargino pair production only through intermediate staus
- SR 1: OS hadronic tau, Z-veto, jet-veto, MET>40, m_{T2}>90 GeV
- SR 2: OS hadronic tau, Z-veto, b-jet-veto, MET>40, m_{T2}>100 GeV



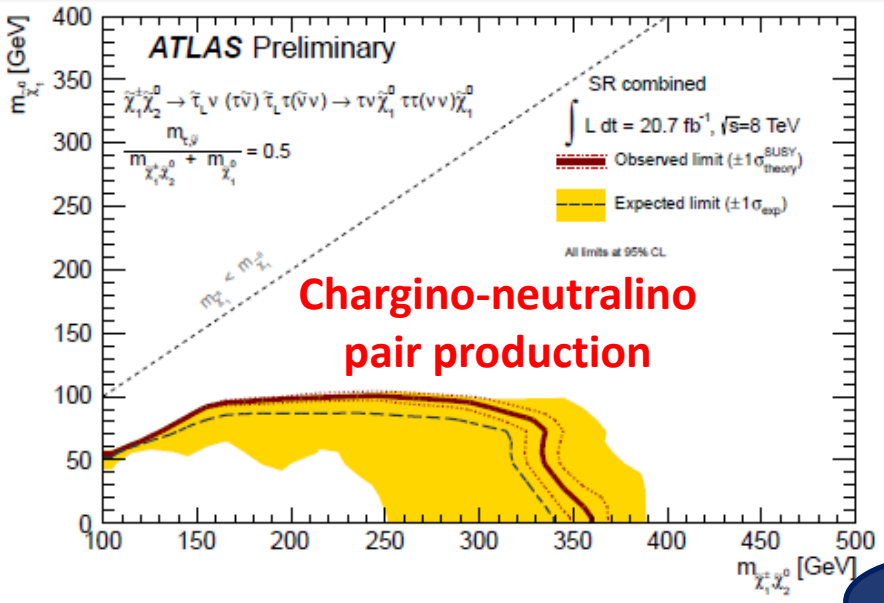


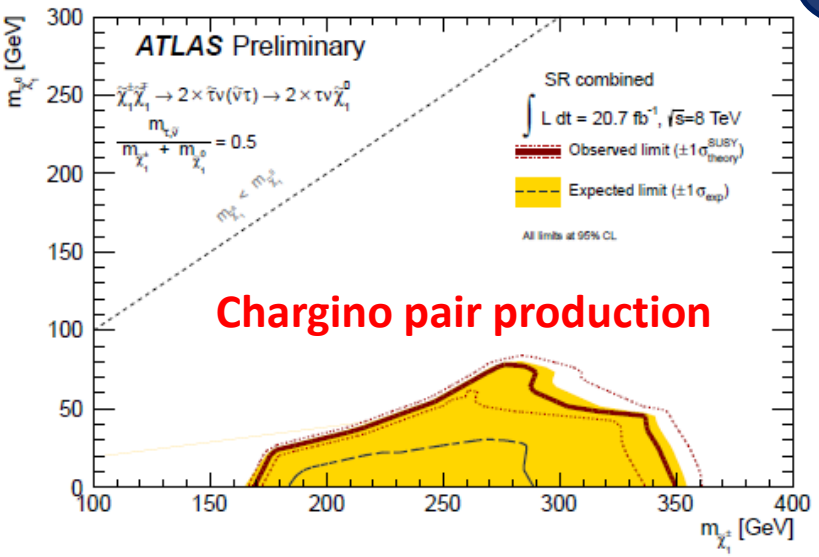
8 TeV

- ABCD technique for multi-jet and W+jet backgrounds

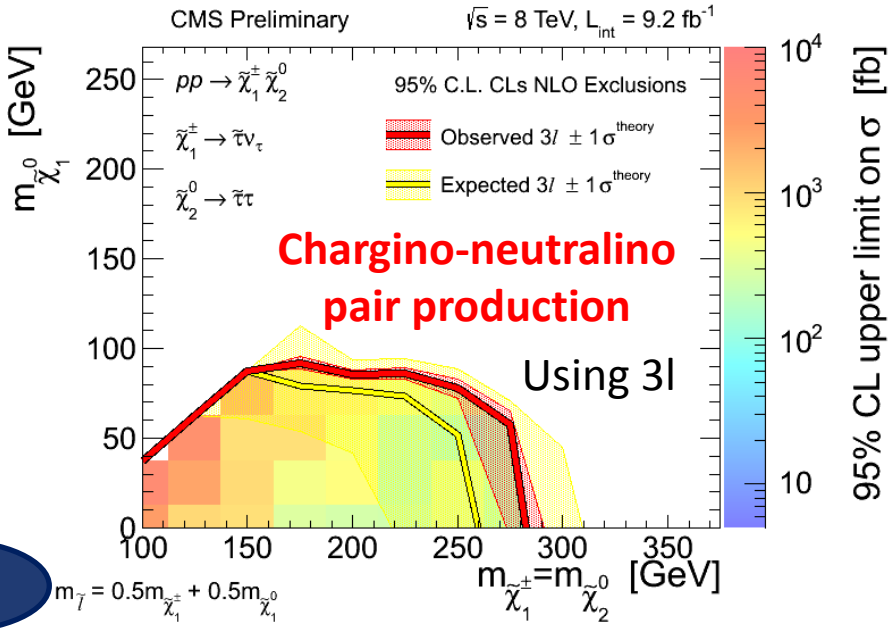
Intermediate staus

SUS-PAS-12-022
ATLAS-CONF-2013-028





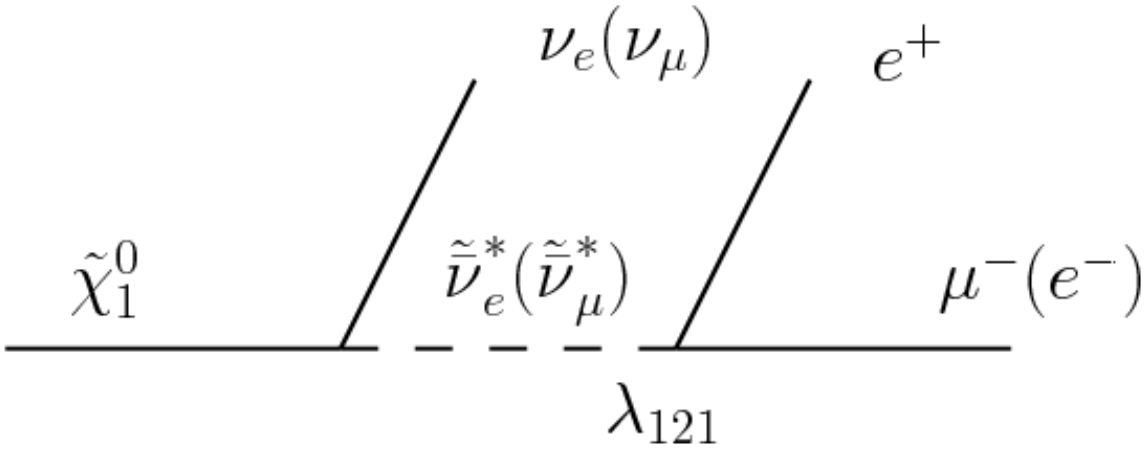
8 TeV



- **First result for chargino pair production with decays through intermediate staus**

R-parity violation SUSY searches

- LSP is not stable but will decay to two leptons
  - Low MET, multi-lepton signatures



- nLSP can be wino, L-slepton, sneutrino, gluino

- **Model naturally gives 4ℓ (off-Z) signatures**

- Dedicated analysis:
  - four lepton analysis

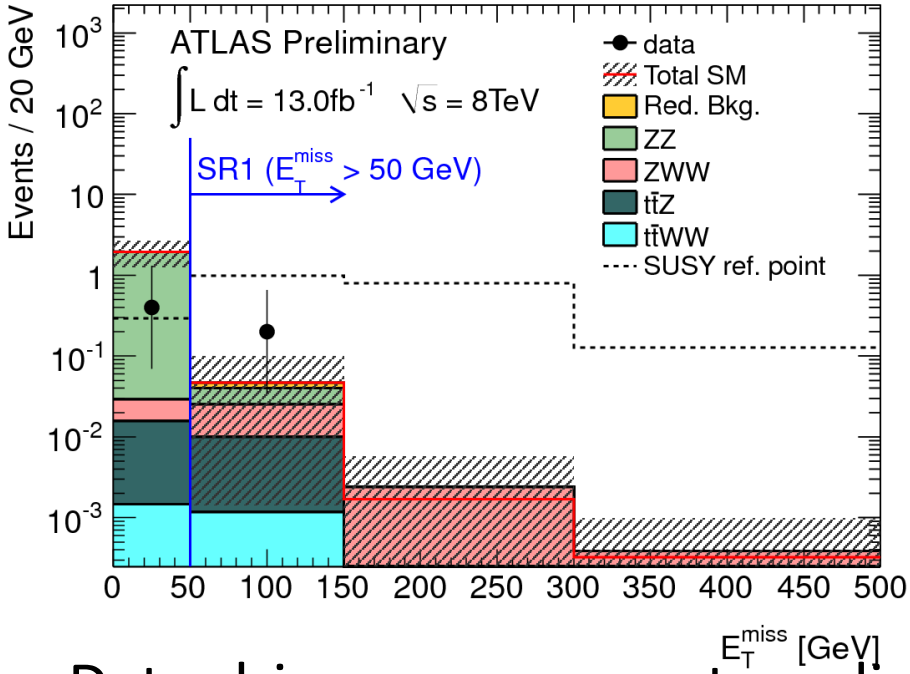
Four lepton analysis: RPV

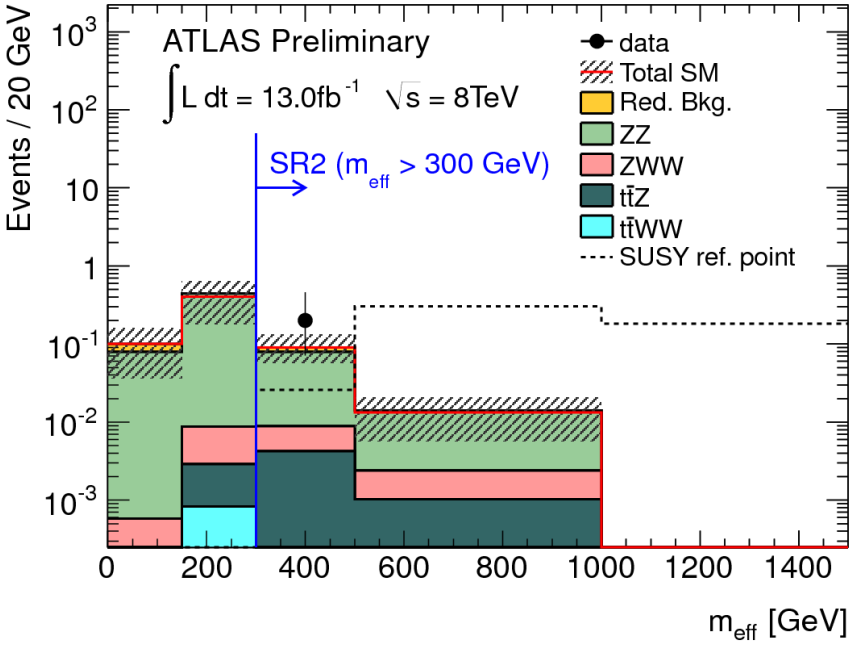
ATLAS-CONF-2012-153

- 2 search regions:
  - SR 1: 4 leptons, Z-veto and MET>50 GeV (neutrinos in final state)
  - SR 2: 4 leptons, Z-veto and m_{eff}>300 GeV

$$m_{\text{eff}} = E_{\text{T}}^{\text{miss}} + \sum_{\mu} p_{\text{T}}^{\mu} + \sum_{e} E_{\text{T}}^{e} + \sum_{j} E_{\text{T}}^{j}$$

8 TeV





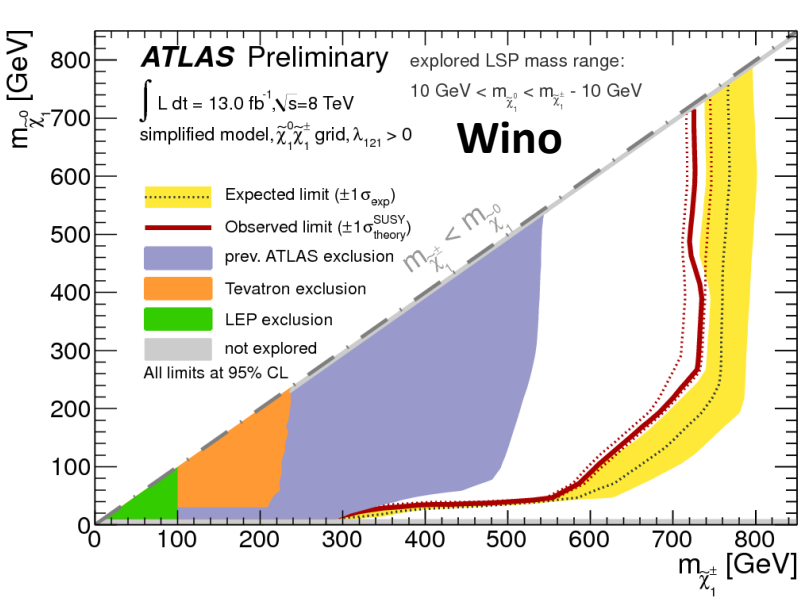
- Data-driven non-prompt prediction
- 3 validation regions (ttbar, ZZ, off-shell Z)

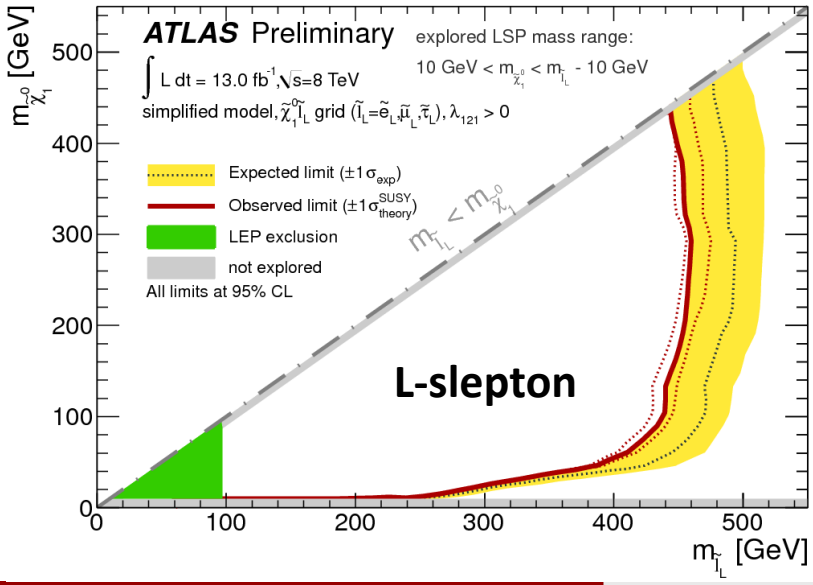
R-parity violating SUSY searches

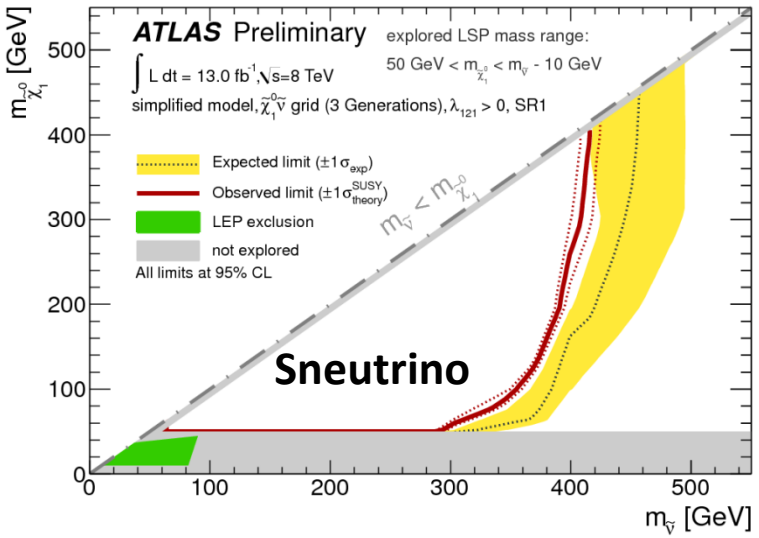
ATLAS-CONF-2012-153

- Results shown for Wino, left-slepton and sneutrino models
  - Only results for $\lambda_{121}>0$ shown, results for $\lambda_{122}>0$ similar

8 TeV



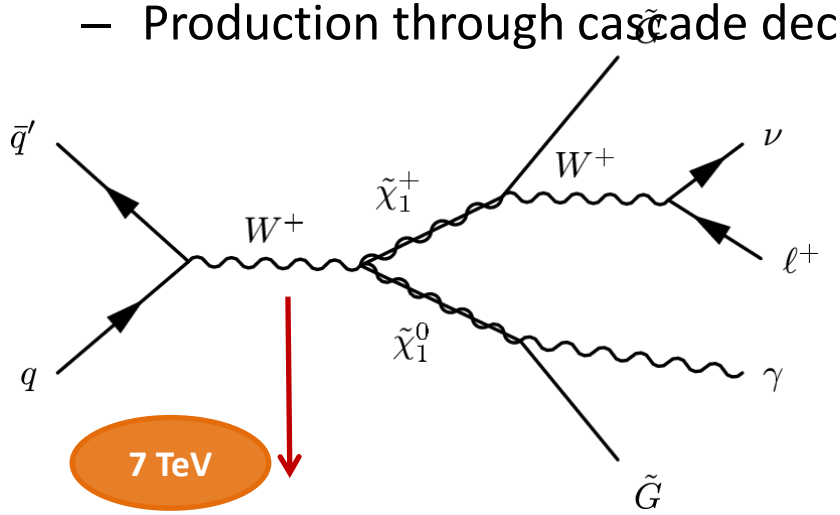




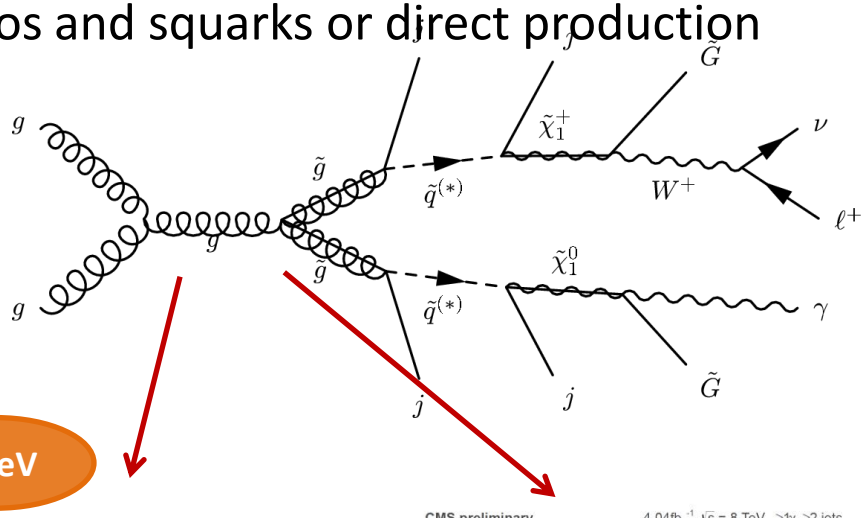
General Gauge-Mediated SUSY breaking

ATLAS-CONF-2012-144
CMS-PAS-SUS-12-018
Phys. Lett. B 719, 261-279

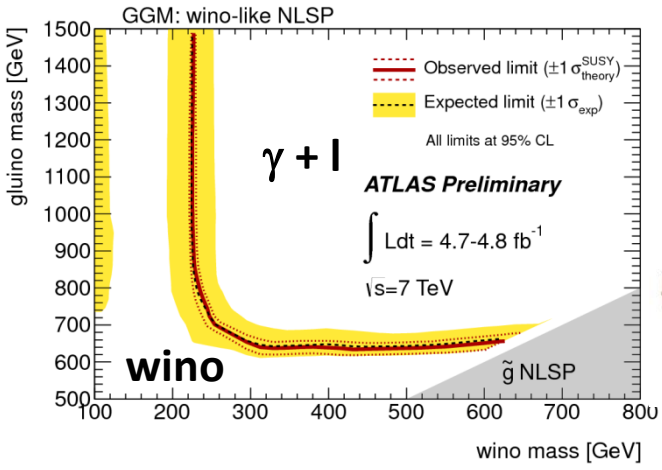
- Gravitino as LSP, nLSP is a neutralino, can be wino-, bino- or higgsino-like
  - Search in final states with photons, leptons and (b-)jets
  - Production through cascade decays gluinos and squarks or direct production

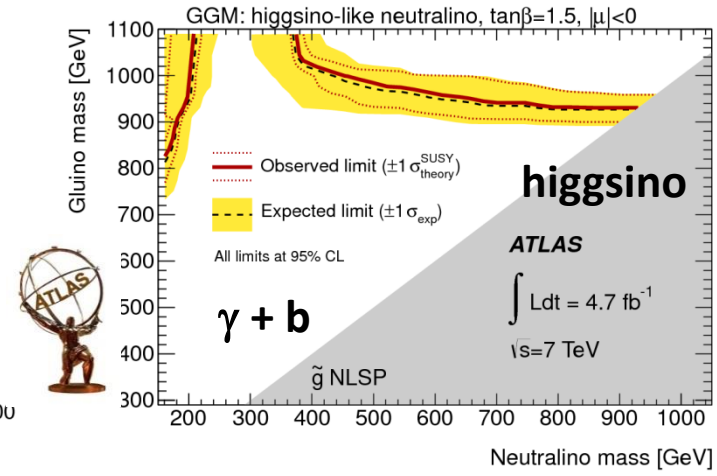


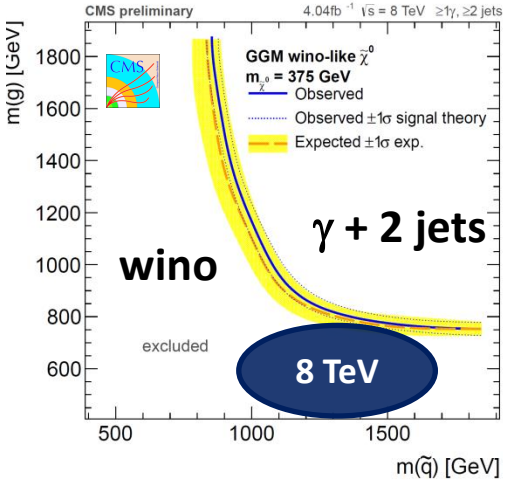
7 TeV



7 TeV

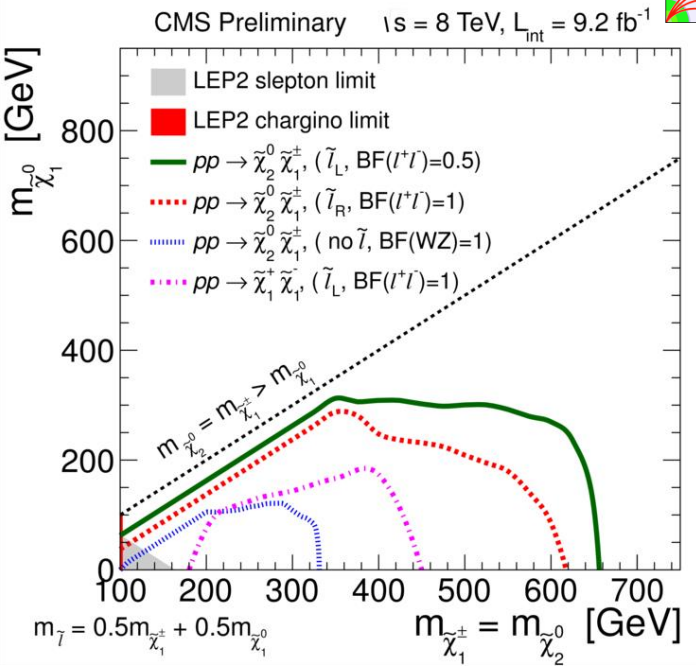


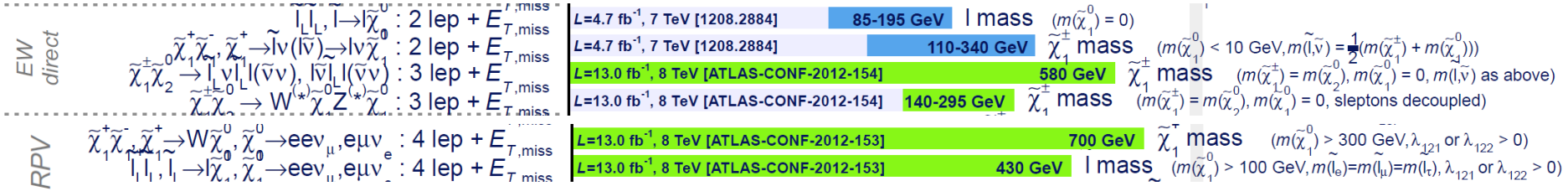




Conclusions

- Wide variety of searches for EWK SUSY
  - No SUSY found
  - Stringent constraints on masses of gauginos and sleptons
- Probing chargino-neutralino masses up to 600 GeV and slepton masses up to 250 GeV
- In R-parity violating models, wino masses up to 700 GeV and slepton masses up to 430 GeV





Back-up

Documentation

- Direct EWKino production
  - ATLAS-CONF-2012-154 (8 TeV)
  - ATLAS-CONF-2012-076 (7 TeV)
  - ATLAS-CONF-2013-028 (8 TeV)
  - CMS-PAS-SUS-12-022 (8 TeV)
- GGM models
  - ATLAS-CONF-2012-152 (8 TeV)
  - ATLAS-CONF-2012-147 (8 TeV)
  - ATLAS-CONF-2012-144 (7 TeV)
  - *Phys. Lett. B 719 (2013) 261-279*
  - CMS-PAS-SUS-12-018 (8 TeV)
  - CMS-PAS-SUS-12-013 (7 TeV)
- RPV violating models:
  - ATLAS-CONF-2012-153 (8 TeV)

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- chargino-neutralino production
  - through sleptons and sneutrinos
  - through vector bosons
- Slepton and chargino pair production
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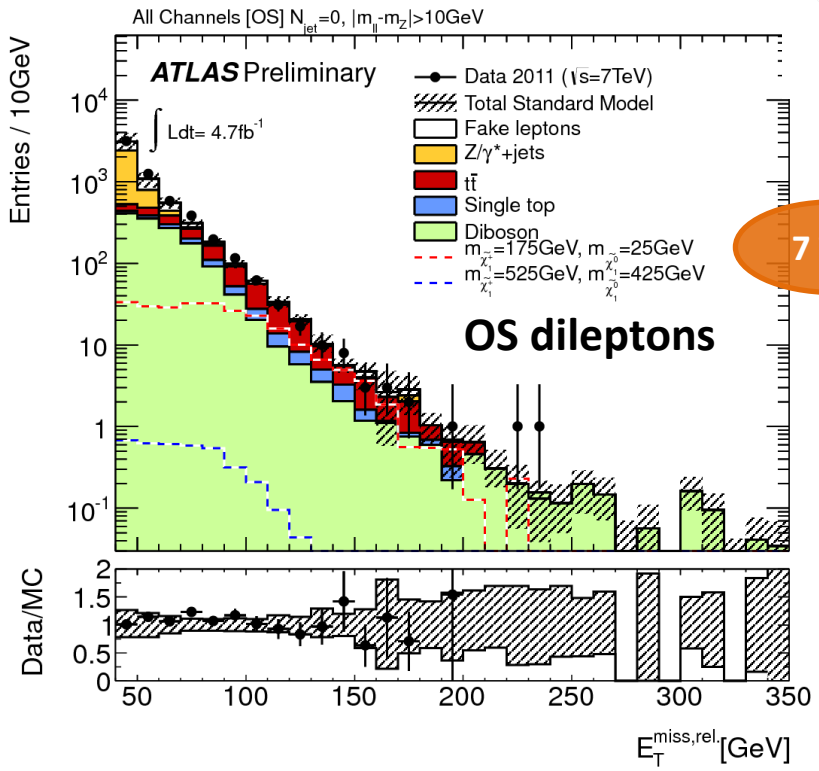
- General Gauge Mediated SUSY breaking
- Conclusions

Opposite-Sign and Same-Sign dilepton analysis

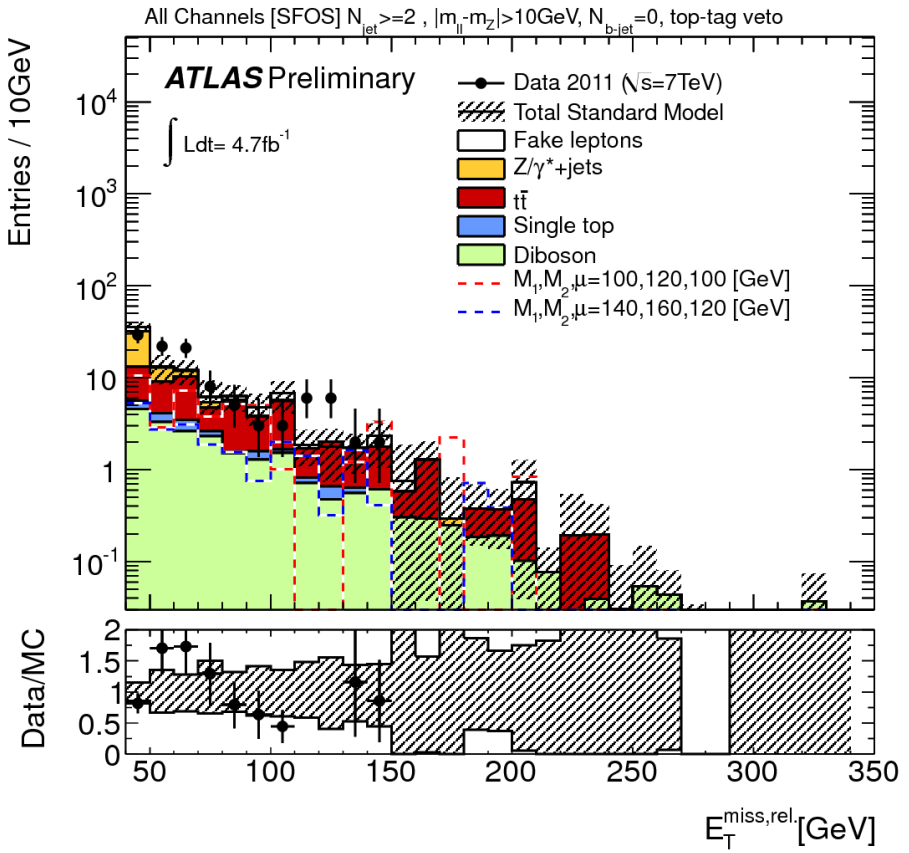
- Use both OS and SS dileptons:
  - Z veto, jet veto, MET>100 GeV



7 TeV

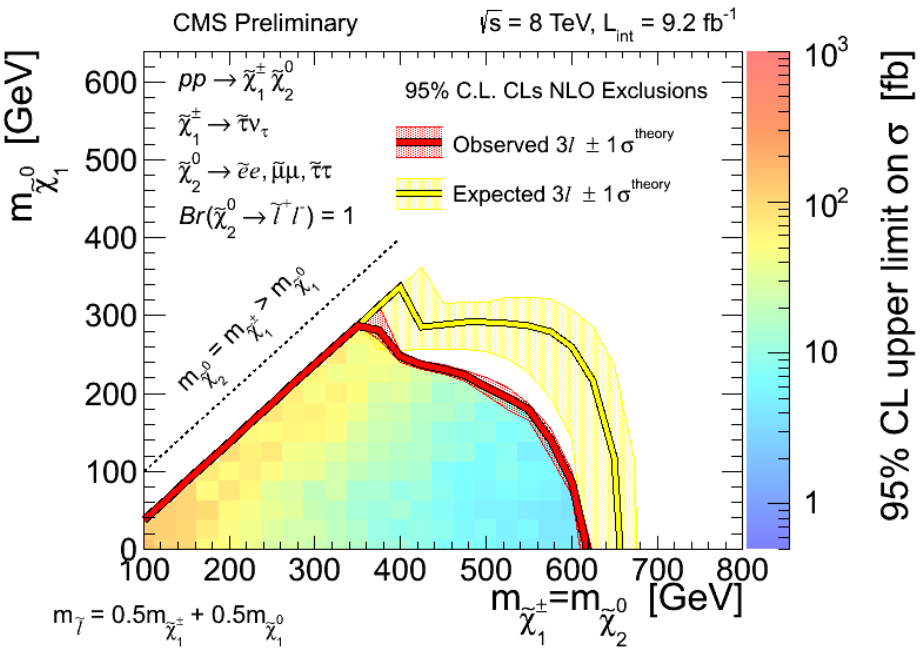
- Opposite sign dileptons, b-veto, top veto, at least 2 jets, MET>50 GeV
  - Off-Z, not targeting intermediate vectorbosons

7 TeV

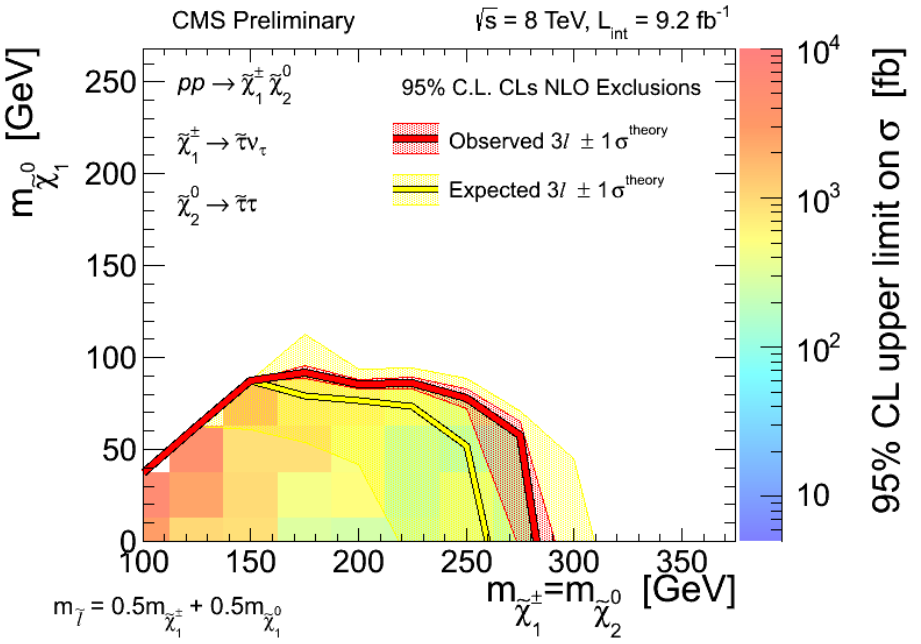


Tau-enriched and tau-dominated results

- Tau-enriched: chargino decays to taus
- Tau-dominated: chargino and neutralino decay to taus



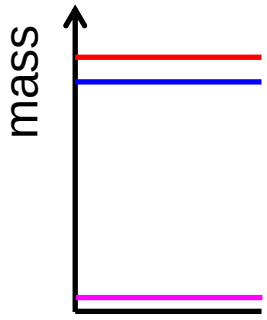
Tau-enriched



Tau-dominated

GSMB model (ZZ)

- Cross section of $\chi^0\chi^0$ is suppressed w.r.t. $\chi^\pm\chi^0$ → no sensitivity to models with only $\chi^0\chi^0$ production
- Interpret results using GMSB model with large BF to ZZ+MET



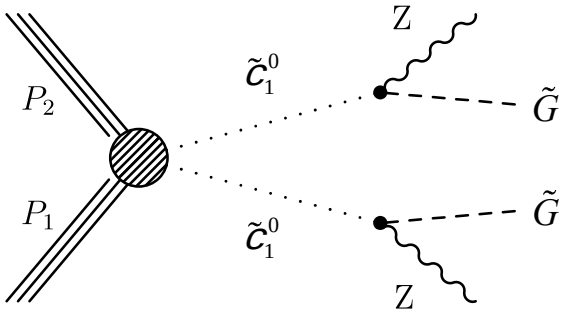
$\tilde{\chi}_1^\pm$ $\chi^\pm$ nearly mass-degenerate with NLSP: $\chi^\pm \rightarrow \chi^0$ + low p_T $\ell\nu$ / $q\bar{q}$

$\tilde{\chi}_1^0$ Z-enriched higgsino NLSP → large BF to Z + G

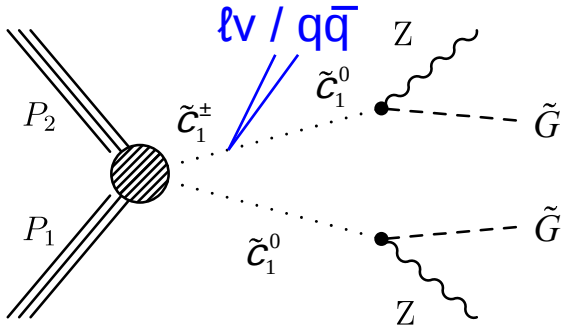
$\tilde{G}$ gravitino LSP

- **3 diagrams enhance σ × BF to ZZ+MET final state**

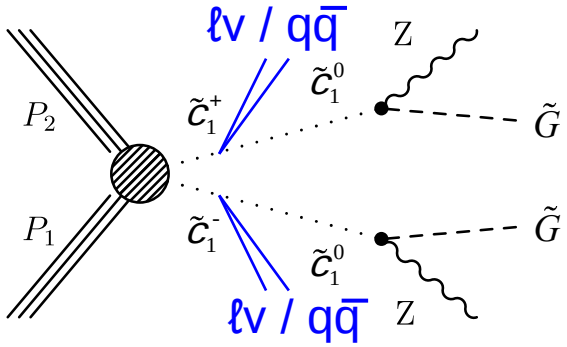
neutralino-neutralino



chargino-neutralino



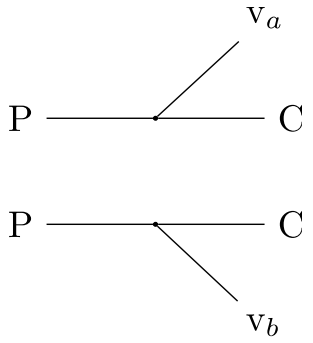
chargino-chargino



$M_{CT,Perp}$

$$M^2_{\mathrm{CT}} = m^2(\mathrm{v}_a) + m^2(\mathrm{v}_b) + 2\left[E_{\mathrm{T}}(\mathrm{v}_a)E_{\mathrm{T}}(\mathrm{v}_b) + \mathbf{p}_{\mathrm{T}}(\mathrm{v}_a)\cdot\mathbf{p}_{\mathrm{T}}(\mathrm{v}_b)\right]$$

$$M^{\max}_{\mathrm{CT}} = \frac{m^2(P) - m^2(C)}{m(P)}$$



- Endpoint only holds if PP are back-to-back (no ISR)
- Project visible momentum in direction perpendicular to ISR or other visible upstream objects
  - Implemented as $\vec{p}_{\mathrm{Up}} = -\left(\vec{p}_{\mathrm{T,miss}} - \vec{p}_{\mathrm{T1}} - \vec{p}_{\mathrm{T2}}\right)$

$$M^2_{\mathrm{CT}\perp} = m^2(\mathrm{v}_a) + m^2(\mathrm{v}_b) + 2\left[E_{\mathrm{T}\perp}(\mathrm{v}_a)E_{\mathrm{T}\perp}(\mathrm{v}_b) + \mathbf{p}_{\mathrm{T}\perp}(\mathrm{v}_a)\cdot\mathbf{p}_{\mathrm{T}\perp}(\mathrm{v}_b)\right]$$

arXiv:0910.1584

where

$$E_{\mathrm{T}\perp}(v) = \sqrt{m^2(v) + \mathbf{p}^2_{\mathrm{T}\perp}(v)}$$

if $m(v) = 0$,

$$M^2_{\mathrm{CT}\perp} = 2p_{\mathrm{T}}(\mathrm{v}_1)p_{\mathrm{T}}(\mathrm{v}_2)\left(|\sin\phi_1||\sin\phi_2| + \sin\phi_1\sin\phi_2\right)$$

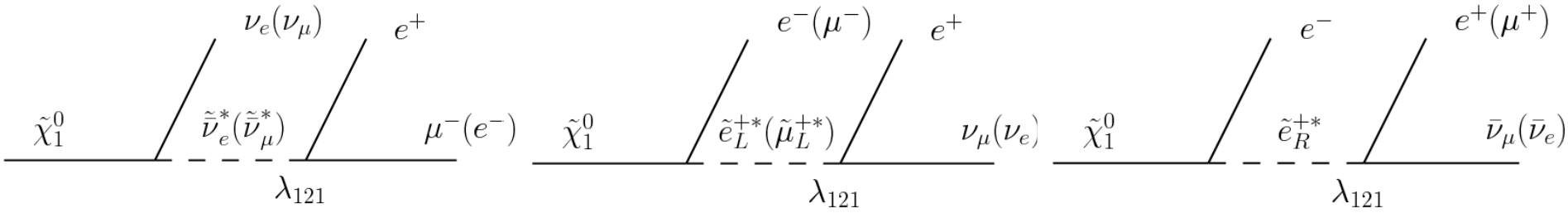
ϕ_i is the angle between $\mathbf{p}_{\mathrm{T}\perp}(v_i)$ and $\mathbf{p}_{\mathrm{Up}}$

R-parity violation SUSY searches

R-Parity violating SUSY searches

$$W_{\mathrm{RPV}} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_2 + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Proton stability forbids simultaneous violation of **lepton** and **baryon** number
LSP is Bino-like neutralino, nLSP can be wino, L-slepton, sneutrino, gluino



- **Model naturally gives 4ℓ (off-Z) signatures**

- Dedicated analysis:
  - four lepton analysis