Displaced RPV SUSY & Baryogenesis

Yanou Cui

Perimeter Institute

Long-lived BSM particles @ LHC workshop
UMass-Amherst, Nov 12, 2015
Displaced SUSY

- **Gauge mediation**: NLSP → gravitino + SM decay suppressed by $1/F^2$, displaced with $F \gtrsim 10^4$ TeV
- **Anomaly mediation**: co-LSP winos decay suppressed by mass degeneracy $\Delta m \sim m_{\tilde{\tau}}$ ⇒ long disappearing track
- **Mini-split spectrum**: NLSP → SM + LSP (RPC) decay suppressed by $1/(m_0)^4 + 3$-body
- **R-parity violation**: decay suppressed by tiny RPV couplings (UDD, LLE, QDL...) (or with mini-split spectrum)
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**Generically motivated by cosmology: baryogenesis!**
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  decay suppressed by $1/F^2$, displaced with $F \gtrsim 10^4 \text{TeV}$

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  decay suppressed by mass degeneracy $\Delta m \sim m_{\Psi}$
  $\Rightarrow$ long disappearing track

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  (or w/mini-split spectrum)

- **Generically motivated by cosmology**: baryogenesis!

(see Brock’s talk for more!)
Cosmological Concern with RPV Natural SUSY
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• Light stop with RPV ($\mathcal{B}$) *prompt* decay: An important channel of natural SUSY search at the LHC

prompt $\Rightarrow \lambda^{ij} \gtrsim 10^{-7}$ ($L_{\text{decay}} \approx 1 \text{ mm}$)
Cosmological Concern with RPV Natural SUSY

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  \[ \text{prompt} \Rightarrow \lambda^{ij} \gtrsim 10^{-7} \quad (L_{\text{decay}} \approx 1 \, \text{mm}) \]

• Assume conventional baryogenesis at $T \gtrsim T_{EW}$
  
  \[ \text{pre-existing baryon abundance efficiently erased by } \mathcal{B} \text{ scatterings, e.g. } \tilde{H}_u t \rightarrow \tilde{d}_i \tilde{d}_j,, \text{ if } \lambda^{ij} \gtrsim 10^{-7} ! \]
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$\mathcal{B}$-pre-existing baryon abundance efficiently erased by $\mathcal{B}$ scatterings, e.g. $\tilde{H}_u t \rightarrow \tilde{d}_i \tilde{d}_j$, if $\lambda_{ij} \gtrsim 10^{-7}$!

★ Estimate of washout: exponential reduction if $\Gamma_w \approx H (T_{\text{EW}})$

$$Y_B(0) = Y_B^{\text{init}} e^{-\int_{T_{\text{ini}}}^{T} \frac{\Gamma_w(T)}{H(T)} \, dT} \sim Y_B^{\text{init}} e^{-\frac{\lambda_{ij}^2 y^2}{g_{*}^{1/2}} \frac{M_{\text{pl}}}{m_{\text{EW}}}}$$
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★ Estimate of washout: exponential reduction if \(\Gamma_w \approx H (T_{\text{EW}})\)

\[ Y_B(0) = Y_B^{\text{ini}} e^{-\int_0^{T_{\text{ini}}} \frac{\Gamma_w(T)}{H(T)} \, dT} \approx Y_B^{\text{ini}} e^{-\frac{\lambda^{ij} y_f^2}{g_*^{1/2}} \frac{M_{\text{pl}}}{m_{\text{EW}}} \, \frac{1}{10^7}} \]
Cosmological Concern with RPV Natural SUSY

• Light stop with RPV (B) prompt decay: An important channel of natural SUSY search at the LHC
  \[ \lambda^{ij} \geq 10^{-7} \ (L_{\text{decay}} \approx 1 \ mm) \]

• Assume conventional baryogenesis at \( T \approx T_{EW} \)
  pre-existing baryon abundance efficiently erased by B scatterings, e.g. \( \tilde{H}_u t \rightarrow \tilde{d}_i \tilde{d}_j \), if \( \lambda^{ij} \geq 10^{-7} \)!

★ Estimate of washout: exponential reduction if \( \Gamma_w \approx H \ (T_{EW}) \)

\[
Y_B(0) = Y_B^{\text{init}} e^{-\int_0^{T_{\text{init}}} \frac{\Gamma_w(T)}{H(T)} \frac{dT}{T}} \sim Y_B^{\text{init}} e^{-\frac{\lambda^{ij} y_t^2}{g^* m_{EW}^2} M_{\text{pl}}}
\]

What are possible solutions to this problem?
Avoid the Problem: Suppress RPV Washout

• To ensure successful baryogenesis at $T \gtrsim T_{EW}$ … (?)
Natural SUSY with $\lambda^i \lesssim 10^{-7}$ ⇒ Displaced Stop at LHC!

(Barry, Graham and Rajendran 2013)

★ Good coverage up to $m \sim 1\text{TeV}$ w/recent development at
ATLAS/CMS! (colored, low bkg)

Liu and Tweedie, 2015
Solve the Problem: Baryogenesis from RPV

- Baryogenesis at $T \approx T_{EW}$, after all washout processes decouple ($\Gamma_w \approx H$) ?
  - RPV reset/regenerate $\Omega_B$!? (new ideas...)
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- Could SUSY shed light on prominent puzzles in modern cosmology?

  $\Omega_{DM} \approx 23\%$, $\Omega_B \approx 5\%$, $\Omega_B \sim \Omega_{DM}$

- Familiar/well-studied case: (RPC) LSP WIMP dark matter, MET+X search @LHC
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$\Omega_{DM} \approx 23\%, \Omega_B \approx 5\%, \Omega_B \sim \Omega_{DM}$

- Familiar/well-studied case: (RPC) LSP WIMP dark matter, MET+X search @LHC
- Potential addressing $\Omega_B, \Omega_B \sim \Omega_{DM}$ w/RPV?

$\Rightarrow$ (again) Displaced vertices @LHC!
Let’s start a journey beyond SUSY, then come back…
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Mini-Review of Baryogenesis

• Origin of $\Omega_B$? = Where do we ourselves come from?

Initial $B - \bar{B}$ asymmetry

$$\eta_B = (n_B - n_{\bar{B}})/n_\gamma \sim 10^{-10}$$

symmetric component annihilated away

Asymmetric $\Omega_B$ today
Let’s start a journey beyond SUSY, then come back…

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- Origin of $\Omega_B$? = Where do we ourselves come from?

**Sakharov Conditions (1967):**
- Baryon number violation
- C- , CP-violation
- Out-of equilibrium (CPT)

\[ n_B^{eq} = n_{\bar{B}}^{eq}, \quad \langle B \rangle_{eq} = 0 \]
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**Mini-Review of Baryogenesis**

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  \]

  **Sakharov Conditions (1967):**
  - Baryon number violation
  - C-, CP-violation
  - Out-of equilibrium (CPT) \( n^\text{eq}_B = n^\text{eq}_{\bar{B}}, \langle B \rangle_{\text{eq}} = 0 \)

  **Asymmetric \( \Omega_B \) today**

  **\( \Omega_B \approx 5\%: \)**
  - Need BSM Physics!

\(- \text{provided by RPV SUSY ?…} \)
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**Sakharov Conditions** (1967):

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  (- provided by RPV SUSY ?…)
- Out-of equilibrium (CPT)
  $$n_B^{eq} = n_{\bar{B}}^{eq}, \quad \langle B \rangle_{eq} = 0$$

- Existing baryogenesis mechanisms: (leptogenesis, EWBG…)
  Most involve high $M$ or/and $T$, *direct* experimental test impossible (c.f. WIMP DM for $\Omega_{DM}$)

$\Omega_B \approx 5\%$:

Need BSM Physics!
Baryogenesis from Out-of-Equilibrium Decay

**A general class of baryogenesis models** (e.g. leptogenesis)

- Assume a massive neutral particle $\chi$
- Baryon asymmetry can be produced in its decay (B-, CP-violating)

\[
\Gamma(\chi \to f) \neq \Gamma(\chi \to \bar{f})
\]

\[
n_f - n_{\bar{f}} \neq 0
\]

- Typically, the inverse processes efficiently erase the asymmetry
- But, if $\chi$ is **long-lived**, and **decays only after** $T_f < M_\chi$:

  **Inverse decay:** Boltzmann suppressed

  \[
e^{-M_\chi/T_{\text{decay}}}\]

  **Out-of-equilibrium decay** \rightarrow **Sakharov conditions ✓**
Baryogenesis from Out-of-Equilibrium Decay

- Asymmetry is **robustly preserved** if \((H: \text{Hubble expansion rate})\)
  \[ \Gamma_\chi < H(T = M_\chi) \]  Weak washout scenario

**An intriguing observation** (YC, Sundrum 2012; YC, Shuve, 2014)

- If \(\chi\) has mass at **weak scale** (the new energy frontier LHC is exploring!), numerology gives
  \[ c \tau_\chi^{-1} < H(T_{EW}) \sim 10^{-13} \text{ GeV} \]

- Converting to decay length:
  \[ c \tau_\chi \gtrsim \text{mm} \]  Displaced vertex regime @LHC!
Displaced Vertices Motivated by Baryogenesis

\[ \Gamma_\chi < H(T = M_\chi) \quad \text{and} \quad c\tau_\chi \gtrsim \text{mm} \]

- A generic connection between cosmological slow rates at \( T \sim 100 \text{ GeV} \) and displaced vertices at colliders.
- The universe around EW phase transition was just slightly bigger than LHC tracking resolution!

\[ H(100 \text{ GeV}) \sim 10^{-14} \text{ GeV} \sim (1.3 \text{ cm})^{-1} \]
\[ 10 \text{ GeV} \rightarrow (1.3 \text{ m})^{-1} \]
\[ 1 \text{ TeV} \rightarrow (0.13 \text{ mm})^{-1} \]
Displaced Vertices Motivated by Baryogenesis

• Production at the LHC?

No conflict between a small decay rate and a large production rate

• Long lifetime due to approximate symmetry (e.g. $Z_2$ parity)

• Recover MET signal for DM in the limit of exact symmetry!
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*Concrete, motivated baryogenesis models as example?*
Baryogenesis from WIMPs

- YC, JHEP 1312 (2013) 067
• The familiar story of a stable WIMP

WIMP DM $\chi$  

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X  

X
• The familiar story of a stable WIMP

\[ \text{WIMP DM } \chi \rightarrow \text{X} \rightarrow \text{thermal freeze out} \rightarrow \Omega_{\text{DM}} \rightarrow \text{out-of-equilibrium} \]
• The familiar story of a stable WIMP

WIMP DM $\chi$ \rightarrow X, thermal freeze out \rightarrow $\Omega_{DM}$, out-of-equilibrium

• A different story of a (general) WIMP?

WIMP $\chi$ \rightarrow X, thermal freeze out, out-of-equilibrium, Stable $\chi_{DM}$, $\Omega_{DM}$
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WIMP $\chi$ $\rightarrow$ X $\rightarrow$ thermal freeze out $\rightarrow$ ? $\rightarrow$ Metastable $\chi_B$?

Diverse lifetimes: generic in nature

(symmetry, mass/coupling hierarchy)

e.g. long lifetime of b-quark, muon

($m_W \gg m_b, m_\mu$), SUSY WIMP w/RPV
• The familiar story of a stable WIMP

WIMP DM $\chi$  

X

thermal freeze out

out-of-equilibrium

WIMP DM $\chi$

X

$\Omega_{DM}$

• A different story of a (general) WIMP?

WIMP $\chi$

X

thermal freeze out

out-of-equilibrium

WIMP $\chi$

X

$\Omega_{DM}$

Stable $\chi_{DM}, \Omega_{DM}$

Metastable $\chi_{B}$?

(later decay)

 Kü

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YC and Sundrum 2012;
YC 2013
Baryogenesis from Metastable WIMP Decay

- A new baryogenesis mechanism w/weak scale new physics:
  A WIMP miracle for baryons, can occur well below $T_{EW}$

- If + A stable WIMP DM
  new path addressing $\Omega_B \sim \Omega_{DM}$
- A generalized WIMP miracle!

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- A generalized WIMP miracle!

\[ \Omega_B = \epsilon_{CP} \frac{M_p}{M_{WIMP}} \Omega_{WIMP} \to \infty \]
A Minimal Model Example
(easy embedding in RPV natural SUSY!)

- We add to the Standard Model Lagrangian \((\mathcal{B}, \mathcal{CP})\):

\[
\Delta \mathcal{L} = \lambda_{ij} \phi d_i d_j + \varepsilon_i \chi \bar{u}_i \phi + M_{\chi}^2 \chi^2 + y_i \psi \bar{u}_i \phi + M_{\psi}^2 \psi^2 \\
+ \alpha \chi^2 S + \beta |H|^2 S + M_S^2 S^2 + \text{h.c.}
\]

\(\phi\): di-quark scalar w/same charges as SM u-quark;

\(\chi, \psi\): SM singlet Majorana fermions;

\(\varepsilon_i \ll 1\): small breaking of a \(\chi\)-parity \(\Rightarrow\) long-lived \(\chi\)

\(\chi \equiv \chi_B\), the WIMP parent for baryogenesis.

\(S\): singlet scalar, mediate WIMP annihilation \(\chi\chi \rightarrow \text{SM}\) via h-portal.
A Minimal Model Example

• Out-of-equilibrium decay of $\chi \rightarrow \Omega_B$

• Interference of tree- & loop-level decay

$\rightarrow$ CP asymmetry $\epsilon_{CP} \equiv \frac{\Gamma(\chi \rightarrow \phi^* u) - \Gamma(\chi \rightarrow \phi \bar{u})}{\Gamma(\chi \rightarrow \phi^* u) + \Gamma(\chi \rightarrow \phi \bar{u})}$

• Check other constraints ($n \rightarrow \bar{n}$ oscillation, neutron EDM...)

$\rightarrow$ With weak scale masses, new particles couple mostly to heaviest quarks (b, t) (just like the Higgs boson!)
Coming back to RPV SUSY vs. baryogenesis…

Meeting Particle Physics Frontier — Embedding in Supersymmetry (SUSY)

- Our mechanism: **generic** low scale baryogenesis
  Embed in motivated theory framework, e.g. SUSY?

Favored viable SUSY models after LHC runs:

- “Natural” SUSY: light stop \( m_{\tilde{t}} \ll m_{\tilde{q}_{1,2}} \) and/or B-(L-) violation
- (Mini-)Split SUSY \( m_{\text{gauginos}} \ll m_{\text{sfermions}} \)
Embedding in Natural SUSY: Model

Our minimal model: direct “blueprint”

- Promote singlets $\chi, S$ to chiral superfields, add to the MSSM. $B$ superpotential:
  \[ W = \lambda_{ij} T D_i D_j + \epsilon' \chi H_u H_d + y_t Q H_u T + +\mu \chi^2 \]
  \[ + \mu H_u H_d + \mu_S S^2 + \alpha \chi^2 S + \beta S H_u H_d. \]

- Assume SUSY pattern: scalar $\chi$ and $\tilde{q}_{1,2}$ heavy, decoupled, as in “natural SUSY”

- Mapping: (minimal model $\rightarrow$ SUSY model)
  - Diquark $\phi \rightarrow$ light $\tilde{t}_R$ in superfield $T$
  - Baryon parent singlet $\chi \rightarrow$ fermion singlet $\chi$
  - Majorana $\psi \rightarrow$ MSSM gaugino
  - Singlet scalar $S \rightarrow$ singlet $S$, mixes with $H_u$, enables $\chi$ annihilation
  - Small parameter $\varepsilon \rightarrow \varepsilon'$, enables late decay $\chi \rightarrow \tilde{t}\tilde{t}$ via $\chi - \tilde{H}_u$ mixing
Embedding in Mini-Split SUSY
(Cui, JHEP 1312 (2013) 067)

Interesting (surprising) finding: successful baryogenesis from minimal SUSY standard model (WIMP decay)!

\[ \tilde{B} \rightarrow \Delta B \]

Sakharov\#1: out-of equilibrium \( \checkmark \)

Split SUSY+ O(1) RPV: Natural long life-time of gauginos

Split spectrum \( \mathcal{O}(100 - 1000) \text{TeV} \sim m_{\text{scalar}} \gg m_{\text{gaugino}} \sim \text{TeV} + \text{RPV} \)

Late decay automatic! e.g. \( \chi \rightarrow udd \) (heavy mediator, 3-body...)

\[ \begin{array}{c}
\tilde{B} \\
\tilde{d}^+ \\
u_k
\end{array} \rightarrow 
\begin{array}{c}
d_i \\
d_j
\end{array} \]
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$\tilde{B} \rightarrow \Delta B$!
Embedding in Mini-Split SUSY

★ Sakharov #2, #3 (CP-, B/L-violation) ✓
rich CPV sources in SUSY (e.g. Majorana gaugino masses), $\mathcal{B} (\mathcal{L})$ from RPV couplings (safer w/ heavy scalars)

★ WIMP parent $\chi$ for baryons with “would-be” over-abundance ✓: Bino $\tilde{B}$! (not desirable if it is DM in RPC SUSY...)

★ Nanopoulos-Weinberg Theorem for Baryogenesis:

additional $\mathcal{B}$ source in the interference loop ✓
Another Majorana fermion in MSSM? $\tilde{W}, \tilde{g}$!

Minimal model (MSSM+RPV) gives everything needed for baryogenesis!
Embedding in Mini-split SUSY

- **Key processes:**

  **Thermal annihilation:**

  \[ \tilde{B} \rightarrow \text{--} \rightarrow \text{--} H \]

  \[ \tilde{B} \rightarrow \tilde{H} \rightarrow \text{--} \rightarrow \text{--} H^* \]

  **Tree-level RPV decay:**

  **Interference loop:**

  (RPC decays also included in analysis)
Numerical Results, examples

Include cosmological constraints: \( \Omega_{\Delta B} \) …

\[ \text{mini-split: } m_{\text{scalar}} \sim O(100 - 1000) \text{TeV} \]

Figure 7: Cosmologically allowed regions of parameter space for (a) baryogenesis and (b) leptogenesis models. We set RPV couplings \( \lambda' = \lambda'' = 0.2, \phi = \frac{\pi}{2} \). Cyan region provides baryon abundance \( 10^{-2} < \Omega_{\Delta B} < 4 \cdot 10^{-2} \).

In the case of leptogenesis the brown region is excluded by decay after EWPT at \( T_c \approx 100 \text{ GeV} \). The pink region is excluded by our simple basic assumption that bino decays after freezeout. Yellow region is excluded by requiring that washout processes are suppressed \( (T_d < M_{\tilde{B}}) \). Yellow region is in fact all included in the pink region (so appear to be orange in the overlapped region).
Baryogenesis from Out-of-equilibrium Decays

— Collider Phenomenology

YC and Shuve, arxiv:1409.6729, JHEP

★ Strategy/results generally applicable to other new physics search via displaced vertices
Simplified Models

- Classify parity-invariant production modes (analogy to DM search @LHC!), e.g.

- Classify decay modes (unlike DM search), e.g.
Simplified Models

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  **Charged under SM gauge interactions:**
  - wino/gluino-like (state in interference loop)

![Diagram](image)

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  $$g/W/Z$$

- Classify decay modes (unlike DM search), e.g.

  **Higgs portal:**
  singlet-like (e.g. $$M_\chi = 150 \text{ GeV}$$)
Simplified Models

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  - fixed coupling, study mass reach

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  ![Diagram showing charged state under SM gauge interactions](attachment:diagram.png)

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  **Baryon number violating:**
  \[ \chi \rightarrow u_i d_j d_k \]

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  ![Diagram showing Higgs portal](attachment:diagram.png)
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  **Lepton number violating:**
  \[ \chi \rightarrow L_i Q_j \bar{d}_k \]
  \[ \chi \rightarrow L_i L_j \bar{E}_k \]
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  **Baryon number violating:**
  - $\chi \rightarrow u_i d_j d_k$

  **Lepton number violating:**
  - $\chi \rightarrow L_i Q_j \bar{d}_k$
  - $\chi \rightarrow L_i L_j \bar{E}_k$

Later comprehensive analyses in RPV SUSY: Liu, Tweedie 2015; Csaki et.al 2015; Zwanne 2015
Experimental Searches

• Focus on displaced decay in tracking volume
  - Near lower bound $c\tau_x \gtrsim \text{mm}$ & better sensitivity, easier to model!
    (decay in other parts of detector important too…)


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Experimental Searches

• Focus on displaced decay in tracking volume
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• Two concrete examples (light-flavour only):

  **Baryon number violating:**
  $$\chi \rightarrow 3q$$
  displaced jets (all-hadronic)
  
  CMS, arXiv:1411.6530
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  CMS, arXiv:1411.6530

  **Lepton number violating:**
  \[ \chi \to \ell + 2q \]
  displaced muon + hadrons
  ATLAS-CONF-2013-092
Experimental Searches

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  \[ \chi \to 3q \]
  displaced jets (all-hadronic)
  CMS, arXiv:1411.6530

  **Lepton number violating:**
  \[ \chi \to \ell + 2q \]
  displaced muon + hadrons
  ATLAS-CONF-2013-092

• Goal of our analysis:
  - What is the coverage for our simplified models based on benchmarks chosen by the collaborations?
  - What advice can we provide for general experimental improvement?
Fully hadronic displaced vertices

**wino**

8 TeV:

\[ \sigma_{\chi\chi} \text{ CL (fb)} \]

- \[ <L_{xy}> = 3 \text{ cm} \]
- \[ <L_{xy}> = 30 \text{ cm} \]
- \[ <L_{xy}> = 300 \text{ cm} \]
- \[ \sigma_{\chi\chi} \text{ (NLO)} \]

CMS displaced dijet, arXiv:1411.6530
Fully hadronic displaced vertices

**8 TeV:**

![Graph showing wino production](image)

- wino → 3j, $\sqrt{s} = 8$ TeV
- $L_{xy} = 3$ cm
- $L_{xy} = 30$ cm
- $L_{xy} = 300$ cm
- $\sigma_{\chi \chi}$ (NLO)

(we study a challenging case: $M_\chi = 150$ GeV, moderately off-shell!)

CMS displaced dijet, arXiv:1411.6530

**singlet-like (Higgs portal)**

No bound @ 8 TeV 20 fb$^{-1}$!
Fully hadronic displaced vertices

**wino**

*8 TeV:*

\[\text{wino} \rightarrow 3j, \sqrt{s} = 8 \text{ TeV}\]

\[\begin{align*}
\langle L_{xy} \rangle &= 3 \text{ cm} \\
\langle L_{xy} \rangle &= 30 \text{ cm} \\
\langle L_{xy} \rangle &= 300 \text{ cm}
\end{align*}\]

\[\sigma_{\chi\chi} \text{ (NLO)}\]

\[\begin{align*}
\sigma_{\chi\chi} &\text{ 95\% CL (fb)} \\
M_{\chi} &\text{ (GeV)} \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000
\end{align*}\]

No bound @ 8 TeV 20 fb\(^{-1}\)!

*13 TeV:*

\[\text{wino} \rightarrow 3j, \text{ 2 DV, luminosity for 3 events, } \sqrt{s} = 13 \text{ TeV}\]

\[\begin{align*}
2 \text{ DV} \\
1 \text{ DV, 10\% syst.} \\
1 \text{ DV, 30\% syst.}
\end{align*}\]

\[\begin{align*}
\text{luminosity (fb}^{-1}) \\
M_{\chi} &\text{ (GeV)} \quad 1000 \quad 1500 \quad 2000 \quad 2500
\end{align*}\]

\[\begin{align*}
m_{\chi} &= 150 \text{ GeV} \\
\lambda_{S\chi\chi} \sin(2\alpha) \quad 0.5 \quad 1.0 \quad 1.5 \quad 2.0
\end{align*}\]

(we study a challenging case: \(M_{\chi} = 150 \text{ GeV, moderately off-shell!}\))

**singlet-like (Higgs portal)**

CMS displaced dijet, arXiv:1411.6530
Displaced muon + hadrons

wino

wino $\rightarrow \mu +$ tracks, $\sqrt{s} = 8$ TeV

8 TeV

13 TeV: M~2.5 TeV
**Displaced muon + hadrons**

**8 TeV**

**wino**

\( \text{wino} \rightarrow \mu + \text{tracks} \), \( \sqrt{s} = 8 \text{ TeV} \)

- \( <L_{xy}> = 0.3 \text{ cm} \)
- \( <L_{xy}> = 3 \text{ cm} \)
- \( <L_{xy}> = 30 \text{ cm} \)
- \( \sigma_{\chi\chi} \) (NLO)

\[ \sigma_{95\% \text{ CL}} \text{ (fb)} \]

\[ \text{vs. } M_{\chi} \text{ (GeV)} \]

**singlet (Higgs portal)**

(singlet-like, \( M_{\chi} = 150 \text{ GeV} \))

No bound @ 8 TeV 20 fb\(^{-1}\)

- 13 TeV: \( \sigma_{S} \sim 10 \text{ ab for } L_{xy} \sim 1 \text{ cm}! \)

**13 TeV:**

\( M \sim 2.5 \text{ TeV} \)

Higgs portal \( \chi \rightarrow \mu + \text{tracks}, 1 \text{ DV, luminosity for 3 events, } \sqrt{s} = 13 \text{ TeV} \)

\[ \text{luminosity (fb}\^{-1}) \]

\[ \text{vs. } M_{\chi} \text{ (GeV)} \]

\[ m_{\chi} = 150 \text{ GeV} \]

\[ \text{luminosity (fb}\^{-1}) \]

\[ \lambda_{S_{xy}} \sin(2\alpha) \]
Conclusion/Outlook-1

- A general conflict between RPV natural SUSY with prompt decay vs. conventional baryogenesis at $T \gtrapprox T_{EW}$

- Passive solution: suppress RPV $\Rightarrow$ displaced stop (good coverage)

- Natural alternative: (new) baryogenesis at $T \lessapprox T_{EW}$

- WIMP baryogenesis ($\Omega_B (+)\Omega_B \sim \Omega_{DM}$) & RPV SUSY $\Rightarrow$ displaced singlino/wino (sample high multiplicity DV, improve trigger/sensitivity for all-hadronic final states...)
• Baryogenesis from metastable weak scale particle decay:
  • A robust cosmological motivation for DV searches at the LHC
  • Exciting opportunity to reproduce the early universe BG @LHC! (cf. WIMP DM search)
• w/ATLAS displaced jets working group: working on implementing our simplified models as a benchmark example in official analysis w/LHC Run 2 data…