Exotic Signatures of New Physics at the LHC

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Exotic

Intriguingly Unusual or Excitingly Strange

- Stable and Late decaying Particles
  - Within Context of SUSY

Shouldn't necessarily Think of Exotic as Unlikely

often Assume New Particles
→ Rapid Decay over μ-scopic Distance

- Approximately Conserved Quantum #
→ Slow Decay over macroscopic Distance

(Accidental) Global Sym -
Viol. by Non-Renorm Op of $U(1)_B$, $U(1)_L$

In SUSY

1) R-parity Viol. only at Non-Renorm Level

$$\frac{1}{M}\int d^4\theta\, Q_L \bar{D} \supset \frac{1}{M}\, \psi_Q \phi \psi_d \phi_L$$

$$\Gamma(\phi_L \to \psi_Q \psi_d) \sim \frac{m_\phi^2 m_{\phi_L}}{M^2}$$

2) R-parity: Low SUSY Scale

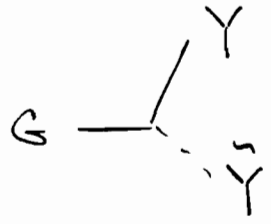
Lightest SM Superpartner - Metastable

Goldstino:

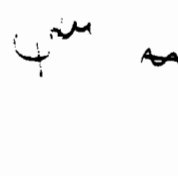
- Spontaneously Broken Global Sym => Goldstone

$$\delta G^\alpha = F \xi^\alpha$$

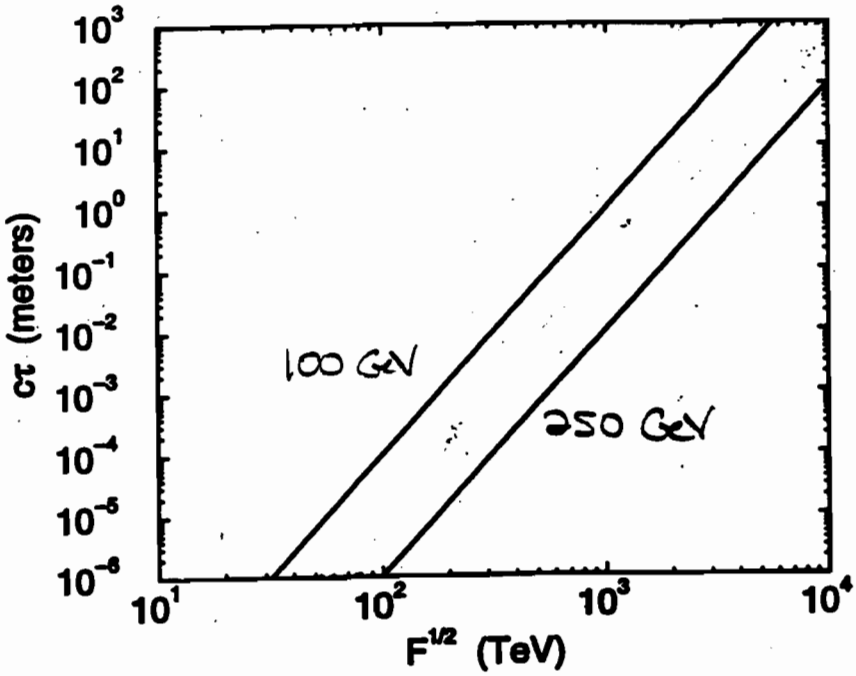
$$\frac{1}{F} \partial_\mu G_\alpha J^{\mu\alpha}$$



- Spontaneously Broken Local Sym => Gauge Particle Eats Goldstone



$$m_{3/2} = \frac{F}{\sqrt{3} M_p} \sim 2\ eV \left(\frac{\sqrt{F}}{100\ TeV} \right)^2$$


10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
cτ (meters)
100 GeV
250 GeV
10^1
10^2
10^3
10^4
$F^{1/2}$ (TeV)

- For $\sqrt{F} \gg m_{\lambda,\phi}$ with R-parity Conserved

Rapid Cascade Decays { $\rightsquigarrow W, Z, h, \ell, \ldots$; $\tilde{\gamma}$

Slow Decay to Gobstino $\tilde{\gamma} \longrightarrow \gamma$; G

$\tilde{\gamma}$: Lightest SM superpartner. NLSP (important in determining signatures)

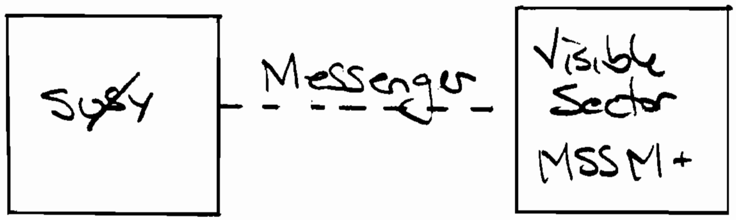
G : LSP

- For $\sqrt{F} \sim 10^{11}$ GeV $m_{3/2} \sim 100$ GeV

↳ often Assumed: And That LSP χ_1^0

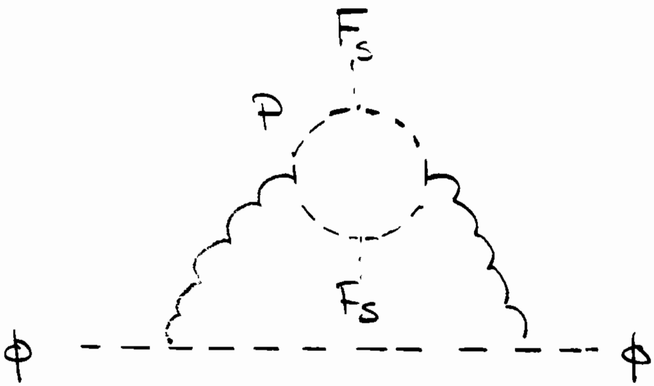
(DM Candidate)

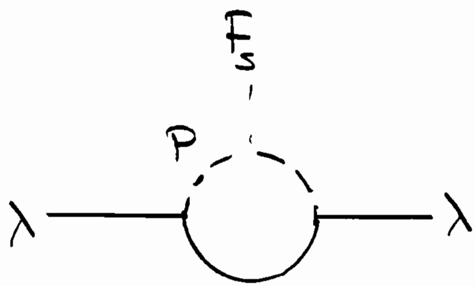
- For $\sqrt{F} \lesssim 10^{11}$ GeV   Sspectrum/ NLSP



- Gauge Mediation:

$$W = \lambda S P \bar{P}$$





$$m_\phi^2 \sim N\left(\frac{\alpha}{4\pi}\right)^2 \frac{|F|^2}{M^2} \qquad m_\lambda \sim N\left(\frac{\alpha}{4\pi}\right)\frac{F}{M}$$

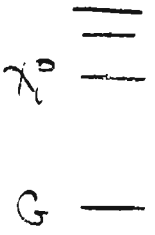
$c\tau$ (NLSP):

Long Lived	$c\tau \gg$ Detector
Macroscopic	$c\tau \sim$ Detector
Prompt	$c\tau \ll$ Detector

Note: Superpartners Produced in Pairs
(R-parity Conserved)
(Not badly Broken)

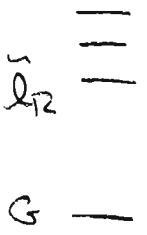
Long Lived:

χ_1^0:



$X + \not{E}$

$\tilde{l}_R^{\pm}$:



$X + \tilde{l}\tilde{l}$

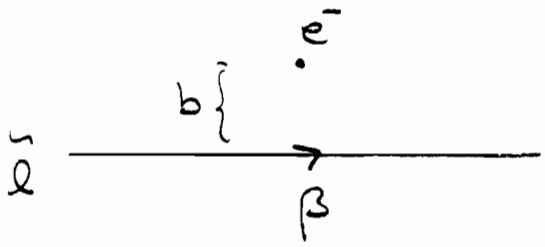
Charged Particles
(No $\not{E}_T$)

Non-Relativistic $\beta\gamma \leq 1$

1) Ionization

2) Time of Flight

- dE/dx Ionization $\beta\gamma \leq 1$



$$\vec{F} = \alpha \frac{\hat{r}}{r^2} \qquad \Delta p_\perp = \int F\,dt$$

$$= \int \frac{\alpha}{r^2}\,\frac{b}{r}\,\frac{dx}{\beta}$$

$$= \frac{2\alpha}{\beta b} \longleftarrow \text{Note}$$

$$\Delta E = \frac{\Delta p_\perp^2}{2m_e}$$

$$\frac{dE}{dx} \sim \frac{1}{\beta^2}$$

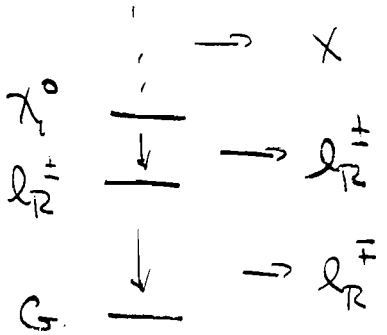
Bethe-Block

$\beta\gamma \leq 1$: Highly Ionizing Track. (HIT)

- Time of Flight.

$\beta\gamma < 1$ - - - (too Slow. Not Recorded)

Cascade Decays to $\tilde{l}_R^{\pm}$:



χ_1^0 Majorana

Superpartners Produced in Pairs:

$\times\ \tilde{l}_R^{\pm}\, l_R^{\mp}$

$\times\ l_R^{\pm}\, l_R^{\pm}$

} Both Occur

Like Sign HITs

Slepton Masses

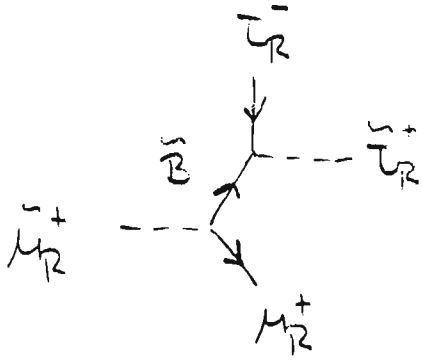
$$m_{\tilde{e}}^2 = \begin{pmatrix} m_{e_L}^2 + m_e^2 & m_e(A - \mu\tan\beta) \\ m_e(A - \mu\tan\beta) & m_{e_R}^2 + m_e^2 \end{pmatrix}$$

LR Mixing - Level Repulsion $\Delta m_{\tilde{e}_R} \sim \frac{m_e^2(\mu - A\tan\beta)^2}{2m_{e_R}(m_{e_L}^2 - m_{e_R}^2)}$

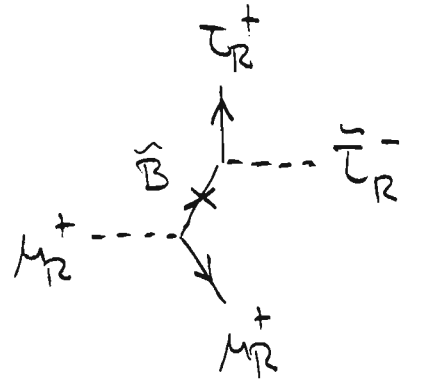
If Messenger Sector Flavor Blind

$m_{\tilde{e}_i}^2(M) = $ Equal

Then $m_{\tilde{e}} > m_{\tilde{\mu}} > m_{\tilde{\tau}}$ - Splittings can be $> m_e$ if $\tan\beta$ large



$$\frac{i m_B}{p^2 - m_B^2}$$



$$\frac{i \not{p}}{p^2 - m_B^2}$$

$$P(\tilde{\mu}_R^\pm \to \tilde{\tau}_R^\mp \tau_R^\pm) = \frac{m_B^2}{m_B^2 + m_{\tilde{\mu}_R}^2}$$

1) Another Source of $\bar{\tau}^{\pm}\bar{\tau}^{\pm}$ Like-Sign HITs

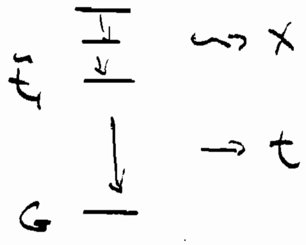
a) $\Gamma(\bar{\mu} \to \bar{\tau}\tau\mu) \sim \frac{g^2 \Delta m^3}{64\pi^2 M_B^2}$

Cu- Macroscopic
Possible

Charge-Changing Track (cc-HIT)

Might be Rejected
by track fitter

• $\tilde{t}_1$



Hadronizes: $\tilde{t}\bar{q} = M$ Heavy Mesino (sbaryon)

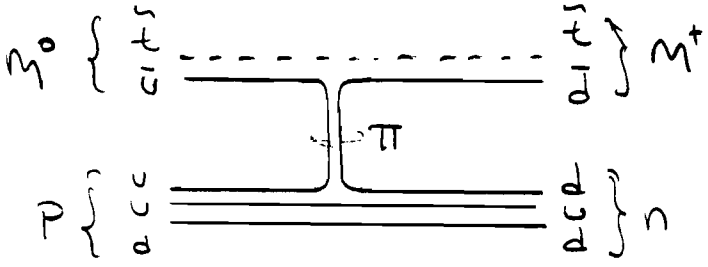
$\bar{q} = (\bar{u}, \bar{d})$ M doublet of SU(2) isospin

$M^{0,+}$, $\bar{M}^{0,-}$

↳ charged or neutral

Charge Exchange / Intermittent Tracks

(CE-HITs)



Exchange isospin / charge with Nuclear Matt

$\sigma \sim 100$ mb $\lambda_I \sim 130 \frac{gm}{cm^2}$

Inner Tracker	Transparent.
ECAL	165 gm/cm²
HCAL	655 gm/cm²

- Can leave track in Inner Tracker
  No Track in Muon System / Vice-Versa.

  Might not be Recognized

- Strongly interacting fermion - Some
  Even charged $\vec{\mu} \sim \frac{q}{m}$

Stopping Heavy Charged Particles

$\frac{dE}{dx} \sim \frac{1}{\beta^2}$ Eventually Ranges Out

For 800 gm/cm^2 { 100 GeV $\beta\gamma \leq 0.4$ Stops in HCAL
1 TeV $\beta\gamma \leq 0.25$ " "

$\tilde{\ell}^-$ Captured on Nucleus
$\tilde{\ell}^+$ Captures e^-

If $c\tau \gg$ few m:

Decay After Capture: Out of Time with Event of origin. ($\tau_{bunch} \sim 25$ ns.)

1) If decays During later Beam Crossing Can Look like $\not{E}_T$

2) Could Also search for Such Events After machine off

Decay Within Detector / Macroscopic

- $\tilde{l} \to l G$ HIT-MIT KnK

c.f. LEP Search

Might not be Recognized - $\not{E}_T$

- $\chi_1^0 \to (\gamma, Z, h) G$

  i) $\chi_1^0 \to \gamma G$

  Displaced γ-Vertex

  Photon-Pointing

7-8 cm

  ii) $\chi_1^0 \to Z G$

  Displaced Z-Vertex

  $\hookrightarrow ee, \mu\mu$ Good pointing

  c.f. CDF Search

  $c\tau$ - too large - might not pass Track trigger

(iii) $\chi^0 \to h G$

Displaced h Vertex

↳ bb

$c\tau(b) = 500\,\mu m$

$\cos\phi = \frac{\vec{p}_j \cdot \vec{n}}{|\vec{p}_j|}$

b - background $\cos\phi \geq 0$

Signal - Uniform $\cos\phi$

(Large) Negative Impact Parameter

$c\tau$ too large - No b-jet id

- Stable, Late Decaying Particles →
  Exotic Signatures

  Susy Signatures: Include + Beyond
  Standard $\not{E}_T$

  Many Signatures Require Specialized Analysis

- Homework: Think of other Exotic Signals which
  Detectors May be Capable of Seeing
  But Which Require Specialized Analysis

  It would be a Shame if Exotic Physics
  were Buried in the Data But
  No one Knew to Look !!