The Implication of F-theory GUTs for LHC

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arXiv:1001.4084, w/ J. Heckman and C. Vafa
arXiv:0903.3609, w/ J. Heckman, G. Kane and C. Vafa

SVP meeting, KITP  May 2010
$p_T(\mu^+) = 29 \text{ GeV}$
$\eta(\mu^+) = 0.66$
$E_{T \text{ miss}} = 24 \text{ GeV}$
$M_T = 53 \text{ GeV}$

W$\rightarrow$\mu\nu candidate in 7 TeV collisions
The more phenomenological approach:

- New Physics Scenario + Ingredient from string compactification + Pheno. Constraints is already stringent

- Focusing on models which could be seen and tested in near future
Focus on the F-theory GUT model

[C. Beasley, J. Heckman and C. Vafa]

Plan of my talk

- What are the ingredients for F-GUT
- SUSY breaking and $U(1)_{PQ}$ deformation
- LHC signals and searching strategy
Focusing on the UV motivated gauge theories -- Local models gravity can be decoupled 
\[ M_{GUT} / M_{pl} \sim 10^{-3} \]

Requiring GUT and decoupling limit severely restrict the model
### F-theory Ingredients for Model Building

- **Gauge fields** --> ADE Singularity $S^4 \times C^2 / \Gamma_{ADE}$
- **Matter fields** --> Curve with enhanced symmetry
- **Yukawa** --> Point with enhanced symmetry

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Hierarchical CKM matrices

µ term from the vev of a GUT singlet

U(1)\textsubscript{PQ} symmetry

Right-handed Neutrino

E\textsubscript{8} breaking pattern

\[ E_8 \supset SU(5)_{\text{GUT}} \times SU(5)_{\perp} \]

broken by U(1) flux to

\[ SU(3) \times SU(2) \times U(1) \]

broken to U(1)s by geometry

E\textsubscript{8} enhanced symmetry

min. number of geometric ingredients necessary

Heckman and Vafa, arXiv:0811.2417
Heckman, Tavanfar and Vafa, arXiv:0906.0581
**E8 Point Unification**

- **Majorana Neutrino Scenario**
  - Only one U(1) survive, PQ charge fixed

- **Extra matter** $10 \oplus \overline{10}$

- **Dirac Neutrino Scenario**
  - Two U(1)'s: $U(1)_{PQ}$, $U(1)_\chi$

<table>
<thead>
<tr>
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<th>$\bar{5}_M$</th>
<th>$10_M$</th>
<th>$5_H$</th>
<th>$\bar{5}_H$</th>
<th>$X^\dagger$</th>
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<td>+1</td>
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<td>−3</td>
<td>+5</td>
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Note that the field $S$ whose vev gives rise to the $\mu$-term is related to our field $X$ by $S = \frac{D_2 X^\dagger}{\Lambda_{UV}}$. 

In the context of Majorana neutrino scenarios, there is a unique PQ symmetry available with charge assignments $[v]$ on $\bar{5}_H$ and $\bar{5}_R$. For simplicity, note that the field $S$ whose vev gives rise to the $\mu$-term is related to our field $X$ by $S = \frac{D_2 X^\dagger}{\Lambda_{UV}}$. 

In the case of Dirac neutrino scenarios, there is a certain degree of flexibility. For simplicity,
Minimal E8 Model

Figure x: Depiction of an E8 theory GUT in which all of the necessary interaction terms descend from a single point of E8 enhancements. In all but one Dirac neutrino scenario, accommodating messenger fields in the gauge-mediated supersymmetry breaking sector turns out to force the messengers \( Y_{10} \) and \( Y'_{10} \) to transform in the \( \mathbf{10} \oplus \mathbf{10} \) of \( SU(5)_{GUT} \). GUT singlets such as the right-handed neutrinos \( N_R \) and \( X \) field localize on curves normal to the GUT sevenbranes. Here we have also included a dark matter candidate \( D \) which is localized on a curve. Neutrino scenarios seem further details of this classification. A remarkable feature of the classification is that in all but one scenario, it forces the messengers to transform in the \( \mathbf{10} \oplus \mathbf{10} \) of \( SU(5)_{GUT} \). After commenting on some of the implications of this for phenomenology, we next discuss potential "semirevisible" dark matter candidates corresponding to electrically neutral components of nontrivial \( SU(5)_{GUT} \) multiplets.

5.1 Flux and Monodromy

Before reviewing the main elements of the classification, we first discuss some of the necessary conditions on matter curves and fluxes which a monodromy group action must respect in order to remain consistent with the assumptions spelled out at the beginning of this section.

Recall that the chiral matter is determined by the choice of background fluxes through the matter curves of the geometry. In particular, we must require that if a zero mode in a representation localizes on a curve, then the conjugate representation cannot appear in it.
Extra GUT multiplet + Singlet \rightarrow Gauge mediation is natural in F-GUTs.

- Basic Picture

\[
\mathcal{L} \sim \int d^2 \theta XYY' \quad \langle X \rangle = M + \theta^2 F
\]

- Soft mass

\[
m_{soft} \sim \frac{\alpha}{4\pi} \frac{F}{M}
\]

- In almost all cases, messengers are in \( 10 \oplus \bar{10} \)
\( \mu / B\mu \ \text{PROBLEM} \)

- EWSB in MSSM \( B, \mu \sim M_{EW} \)
- In F-GUTs, PQ charge of X forbid \( \int d^2 \theta X H_u H_d \)

- D-term contribution to \( \mu \) term
  \[ \int d^4 \theta \frac{X^\dagger H_u H_d}{M_X} \]  
  (from integrating out KK modes of X)
  \[ \Rightarrow \mu \sim \frac{F}{M_X}, \quad \text{require } \mu \sim 10^2 \text{GeV} \Rightarrow F \sim 10^{17} \text{GeV}^2 \]

- \( B\mu \) term:
  \[ \int d^4 \theta \frac{XX^\dagger H_u H_d}{M_X^3} \Rightarrow B\mu \sim \frac{M|F|^2}{M_X^3} = \frac{M}{M_X} \left| \frac{F}{M_X} \right|^2 \]

\[ \frac{B\mu}{\mu} \sim \frac{M}{M_X} \mu \quad \text{smaller than } \mu \text{ if } M < M_X \]

J. Marsano, N. Saulina S. Schafer-Nameki, J. Heckman and Vafa
......
**U(1)\textsubscript{PQ} and Axion**

- U(1)\textsubscript{PQ} gauge boson can obtain mass through Stueckelberg mechanism.
- Below $M_{PQ}$, global U(1)\textsubscript{PQ} is broken by $\langle X \rangle = M$.
- $M$ set the axion decay constant $10^9$ GeV $< M < 10^{12}$ GeV.
- Take soft mass to be $\sim$TeV: $\frac{F}{M} \sim 10^5$ GeV $\rightarrow M \sim 10^{12}$ GeV.
- In fact both $M$ and F-term can be generated through Fayet-Polonyi potential --Mild tuning of the flux needed to achieve necessary hierarchy.

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J. Marsano, N. Saulina S. Schafer-Nameki, J. Heckman and Vafa
**U(1)\text{PQ} Induced Soft Masses**

Integrate out heavy PQ gauge boson

\[ \mathcal{L} \supset -g_{PQ}^2 e_X e_\Psi \int d^4\theta \frac{X^\dagger X \Psi^\dagger \Psi}{M_{PQ}^2} \]

Additional contribution to the scalar mass

\[ m_{soft}^2 = m_{GMSB}^2 + q_\Psi \Delta_{PQ}^2 \]

\[ \Delta_{PQ}^2 \sim g_{PQ}^2 \frac{F_X^2}{M_{PQ}^2} \]

\[ \Delta_{PQ} \sim \mathcal{O}(100) \text{ GeV} \]

Cosmological constraint

\[ \Delta_{PQ} \gtrsim 50 \text{ GeV} \]

<table>
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<tr>
<th>$q_{\text{Majorana}}$</th>
<th>$10_M$</th>
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<th>$5_H$</th>
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Negative sign -> Lower $m_{\tilde{q}}, m_{\tilde{\ell}}$
### Soft terms at low energy

- **GMSB + PQ deform. set BC @ \( M_{\text{mess}} \)**

- **Effective Parameters for Pheno Study:**
  - \( \Lambda (\Lambda \equiv F/M) \) and \( \Delta_{\text{PQ}} \)
  - \( N_{10} = 1, 2 \) (\( N_5 = 3, 6 \))
  - \( B\mu = 0 @ M_{\text{mess}} \sim 10^{12} \) GeV
    - fix \( \tan \beta \) at low scale

- **RG evolving of soft parameters down to TeV scale**
**Detail Feature in Soft Terms**

- **Gaugino Mass**
  
  \[ m_{\text{gaugino}} \sim N_{10} \frac{\alpha}{4\pi} \Lambda \]

  No PQ shift

- **Scalar Mass**
  
  \[ m_{\text{scalar}}^2 = \hat{m}_{\text{scalar}}^2 + e_\Phi \Delta_{PQ}^2 \]
  
  \[ \hat{m}_{\text{scalar}} \sim \sqrt{N_{10}} \frac{\alpha}{4\pi} \Lambda \]

  \[ m = \hat{m} \sqrt{1 - \frac{\Delta_{PQ}^2}{\hat{m}^2}} \]

- Small for squark

- Large for sleptons -&gt; largest for lightest stau
The LSP

- Gravitino mass: \(m_{\tilde{G}} \sim \frac{F}{M_p} \sim 10 - 100 \text{MeV}\)

  Heckman, Tavanfar and Vafa, arXiv:0812.3155

- NLSP decay to Gravitino

  \[\Gamma(\tilde{\psi} \rightarrow \tilde{G} + \psi) \sim \frac{m_{NLSP}^5}{F_X^2}\]

- NLSP is quasi-stable, lifetime: one sec - an hour
Figure 5: Mass spectrum of the sleptons and lightest chargino and two lightest neutralinos with $N_{10}=1$, $\Lambda = 50$ TeV as a function of $\Delta_{PQ}$. At values of $\Delta_{PQ} \sim 90$ GeV, the stau becomes the NLSP. At somewhat larger values of the PQ deformation, the sneutrinos become lighter than $\tilde{\chi}_2^0$ and at larger values, the right-handed selectron and smuon become lighter than the bino. The dashed grey line denotes the lower bound on the masses of quasi-stable staus of 100 GeV.
$\Delta_{PQ}$ and Slepton Mass

$N_{10} = 2, \Lambda = 53$ TeV

Figure 6: Mass spectrum of the sleptons, lightest chargino and two lightest neutralinos with $N_{10} = 2$ and $\Lambda = 53$ TeV as a function of $\Delta_{PQ}$. The dashed grey line denotes the present bound of 1 TeV on quasistable staus. Masses of the sparticles still depend on $\Delta_{PQ}$, so that changes in the branching fractions still persist.

3.3 Benchmark Models

In the previous sections we have studied how the mass spectrum depends on the parameters of an F-theory GUT. For $N_{10} = 1$ messengers we have seen that there are three qualitatively different orderings of masses which can be achieved for the lightest sleptons relative to the binos. Proceeding from smaller to larger PQ deformation, we have seen that at low values of the PQ deformation, the bino is the NLSP, while at moderate values of $\Delta_{PQ}$, the stau is the NLSP, but the right-handed selectron and smuon are heavier than the bino. Moreover, the remaining sleptons are all heavier than the second neutralino and lightest charginos. At maximal PQ deformation, the right-handed selectron and smuon become lighter than the bino, and all of the remaining sleptons are lighter than the second neutralino and lightest charginos. We have also seen that for $N_{10} = 2$ models, however, that there is less variation in the mass spectrum, so that the primary qualitative differences are well represented by $\Delta_{PQ}$ and slepton mass.
Figure 2: The relative masses of the binow lightest stau and right-handed selectron depend on the value of $\Delta PQ$ and $M_{mess}$. There are three qualitatively different regions for the Fytheory GUT Majorana neutrino scenario with $N_{10}=1$ and $\Lambda = 50$ TeV with separated by the two lines where the bino is equal in mass to either the stau upper line or slectron lower line. Here we also indicate the bino NLSP upper orange region and stau NLSP lower cyan region of parameter space.
Figure 4: As a function of $\Delta PQ$ and $\Lambda$, the masses of the sleptons will change relative to the gauginos. For F-theory GUTs with $N_{10} = 1$ messengers, as $\Delta PQ$ increases, there are three qualitative crossing regions where the stau becomes lighter than the bino, the right-handed selectron and smuon become lighter than the bino, and the remaining sleptons become lighter than the second neutralino and lightest charginos. In the plot, the orange region to the left denotes the range of parameter space where the bino is the NLSP, and the cyan region to the right indicates the region of the stau NLSP.

$N_{10}=1$, $M_{\text{mess}}=10^{12}$ GeV
The Whole spectrum

$N_{10}=1, \Lambda = 50 \text{ TeV}$ (Benchmark 1)

Figure 1: Spectrum of an Fwtheory GUT Majorana neutrino scenario with $N_{10}=1, \Lambda = 50 \text{ TeV}$ for minimal red left columns and maximal blue right columns PQ deformation of order 200 GeV. At small values of the PQ deformation, the bino is the NLSP, whereas for larger values this transitions to the staux. Further note that at larger PQ deformation, the right-handed selectron and smuon are also lighter than the binos, and all of the sleptons are lighter than the second neutralino and lightest charginos.
Effects on Sparticle Decay

- Squarks and gluino decay not sensitive to $\Delta_{PQ}$
- Neutralino and chargino decay change significantly

Figure 8: Dominant branching fractions of the $\tilde{\chi}^0_2 \rightarrow X$ as a function of $\Delta_{PQ}$ with $N_1 = 1$ and $\Lambda = 50$ TeV. As the mass of the sneutrinos becomes lower than the charginos, additional decay channels open up.
Difference From Other Models

- Although a deformation of mGMSB, it is narrow and less studied region of parameter space
- Qualitative comparison with mGMSB and mSUGRA

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<tr>
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<td>Gravitino</td>
<td>Gravitino</td>
<td>$\chi_1$</td>
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<tr>
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<td>short-live $\chi_1$ or stau</td>
<td>long-lived stau</td>
<td>short-live $\chi_2$ or stau</td>
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<tr>
<td>Signal</td>
<td>$\gamma +E_t+{\text{jets}}$</td>
<td>heavy “muon”</td>
<td>$E_t+{\text{jets}}$</td>
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</table>
What can we see at LHC?

Rest of the Talk: Focus on stau NLSP scenario

Main Questions:

- How staus are produced and detected at LHC?
- What are the signals? How they depend on F-GUT parameters?
- What is the prospect for discovery?
- Can we identify F-GUTs?
Long-lived Stau Search in the PAST

or Charged Heavy Massive Particle (CHAMP)

LEP II: $m > 100 \text{GeV}$

LEPSUSYWG/02-05.1

D0: 2 isolated $\mu$ w/ $p_t > 20 \text{ GeV}$

PRL 102, 161802(2009)

No Mass limit on stau!

CDF: 1 isolated $\mu$ with $p_t > 40 \text{ GeV}$

T. Aaltonen et al. PRL103, 021802 (2009)

$\sigma < 10 \text{fb at 95\% C.L}$

Limit on the stau mass is model dependent (depend on other sparticle mass)

For FGUTs, $m > 100 \text{ GeV}$

Stau Production in LHC

- Superpartners are produced in pair 
  \( \leftarrow \text{R-parity} \)

- Cascade Decays

- All SUSY events: 2 stau + X

- NO LARGE MISSING ENERGY
PRODUCTION RATE @ LHC

LO cross section from Pythia

\[ \Sigma_{g\bar{g}} \]

\[ \Sigma_{q\bar{q}} \]

\[ \Sigma_{\chi^0_2 \chi^\pm_1} \]

\[ \Sigma_{\chi^{\pm}_1 \chi^{-}_1} \]

\[ \Sigma_{\tau_1 \bar{\tau}_1} \]

\[ \Sigma_{l\bar{l}} \]

\[ N_{10} = 1 \]
\[ \Lambda = 50 \text{ TeV} \]
\[ \Delta_{PQ} = 140 \text{ GeV} \]

\[ \sigma_{\text{tot}} \sim 0.3 \text{ pb} \]

\[ \sigma_{\tilde{\chi}^0_{\pm} \tilde{\chi}^-_{\pm}} \sim 0.07 \text{ pb} \]

\[ \sigma_{\tilde{\tau}_1 \tilde{\tau}_1} \sim 0.3 \text{ pb} \]

\[ \sigma_{g\bar{g}} \]

\[ \sigma_{q\bar{q}} \]

\[ \sigma_{\tilde{\chi}^{\pm}_1 \tilde{\chi}^{-}_1} \]

\[ \sigma_{\tilde{\chi}^0_2 \tilde{\chi}^\pm_1} \]

\[ \sigma_{\chi^0_2 \chi^\pm_1} \]

\[ \sigma_{\chi^{\pm}_1 \chi^{-}_1} \]

\[ \sigma_{l\bar{l}} \]
Muon trigger (efficiency drop very fast below $\beta = 0.8$)

Muon w/ low velocity ($\beta < 0.6$) are not trigger by Muon trigger would reach the muon chamber too late, out of Bunch Crossing time 25ns

Jet + $\not{E}_T$ trigger (independent of the stau velocity)

Low velocity stau can be explored using MDT (Monitored Drift Chamber) data in off-line analysis
How to Isolate Staus

- Triggered as a muon, but much more energetic!
- Heavy --> expect low velocity ($\beta$)
- Time-of-flight measurement in muon chamber
- $dE/dx$ measurement in Calorimeter $\frac{dE}{dx} \propto \left(\frac{Q}{\beta}\right)^2$

Muon and Stau can be isolated using $\beta$ cut

recently using fast-moving stau also proposed
Jie Chen and T. Adams
Consider stau candidate with $0.6 < \beta < 0.91$, pass the muon trigger with 100% efficiency

Detector resolution of stau velocity and momentum

$$\frac{\sigma_\beta}{\beta} = 0.028\beta, \quad \frac{\sigma_p}{p} = \frac{k_1 p}{\text{GeV}} \oplus k_2 \sqrt{1 + \frac{m_{\tilde{\tau}}^2}{p^2}} \oplus \frac{k_3 \text{GeV}}{p}$$

$k_1 = 0.0118\%$, $k_2 = 2\%$ and $k_3 = 89\%$

Event Generation - Pythia + basic detector effects

- leptons: e/mu w/ Pt > 10 GeV and $|\eta| < 2.5$ + stau with $\beta > 0.91$
- jets: Pt >50GeV and $|\eta| < 2.5$
1. At least one stau candidate

2. ≥1 jet w/ Pt >50GeV and Et >50GeV (Trigger-level)

3. Effective Mass > 800 GeV

$$m_{eff} = \sum_{i=1}^{\min(4,N_{jet})} p_{T}^{jet,i} + \sum_{i=1}^{\min(2,N_{\mu})} p_{T}^{\mu,i}$$.
Cross section contours in \((\Lambda, \Delta_{PQ})\)

- SM bkg negligible (take to be 1)
  - discovery \(\Leftrightarrow \sigma L > 5\)
- For the best case, only need \(\sim 10 \text{ pb}^{-1}\)
- For CM Energy 7 TeV, need \(\sim 100 \text{ pb}^{-1}\)
Cross section contours in $(\Lambda, \Delta_{PQ})$

SM bkg negligible (taken to be 1) discovery $\Rightarrow \sigma L > 5$

For the best case, only need $\sim 10 \text{ pb}^{-1}$

For CM Energy 7 TeV, need $\sim 100 \text{ pb}^{-1}$
Other Channels - ($\tilde{\tau} + \text{leptons}$)

- Lots of leptons from cascade decay
  \[
  \chi_2^0 \rightarrow \tilde{l} + l \rightarrow 2l + \tau + \tilde{\tau}, \\
  \tilde{\nu} + \nu \rightarrow 2\nu + \tau + \tilde{\tau}, \\
  \tilde{\tau} + \tau
  \]

- Increase with PQ deformation
  \[
  \chi_1^\pm \rightarrow \tilde{\tau} + \nu, \\
  \tilde{\nu} + \tau \rightarrow \tilde{\tau} + 2\tau + \nu
  \]
Other Channels - $(\tilde{\tau} + \text{leptons})$

- Lots of leptons from cascade decay
  \[ \chi^0_2 \rightarrow \tilde{l} + l \rightarrow 2l + \tau + \tilde{\tau}, \]
  \[ \tilde{\nu} + \nu \rightarrow 2\nu + \tau + \tilde{\tau}, \]

- Increase with PQ deformation
  \[ \chi^\pm_1 \rightarrow \tilde{\tau} + \nu_\tau, \]
  \[ \tilde{\nu} + \tau \rightarrow \tilde{\tau} + 2\tau + \nu \]


**INCLUSIVE “MUON”**

- Hard leptons + jets, where no isolation of stau is necessary.
  - SM Background can reduced by hard cuts
    - At least two hard leptons with $p_T > 100$ GeV
    - At least two hard jets with $p_T > 150$ GeV.
  - $\beta > 0.67$, $p_T > 20$ GeV and $|\eta| < 2.5$
    - SS: A pair of same-sign isolated leptons.
    - $3l$: Three isolated lepton candidates.
    - $4l+$: Four or more isolated lepton candidates.
Is it F-GUTs?

Once long-lived stau is confirmed (from the tau rich events), there are only few possible scenarios, e.g. minimal GMSB models

Two major ways:

- superpartner masses
  - measurement can be done at the LHC

- very few number of parameters
  - measuring mass of squark and gluino fix $N_{10}$ and $\Lambda$; measuring other mass give additional checks

- susy breaking scale
  - measure the lifetime of stau
  - very challenging at LHC

Non-collider approach: staus produced by neutrino-nucleon interaction and detected by Neutrino telescope

Generally much easier compare to conventional SUSY model -- No $\not{E}_T$

Stau mass can be constructed from the measured momentum and velocity. Better precision if selecting low velocity stau

$$m_{\tilde{\tau}_1} = \frac{p}{\beta \gamma}$$

$$m_{\tilde{\tau}}^{\text{fit}} = 175.59 \pm 0.47 \text{ GeV}$$

$$m_{\tilde{\tau}}^{\text{true}} = 175 \text{ GeV}$$

Hinchliffe Paige '98, Ellis et al '06
Other masses can be constructed by selecting proper final-state particles

Construct Invariant Mass distribution

With 30 inv fb, the following precision can be achieved

\[ \Delta m_{\tilde{\tau}_1} = 0.021 \text{ GeV}, \quad \Delta m_{\tilde{\nu}_\tau} = 1.2 \text{ GeV}, \quad \Delta m_{\tilde{t}_L} = 2.0 \text{ GeV} \]

\[ \Delta m_{\tilde{\chi}_1^0} = 0.9 \text{ GeV}, \quad \Delta m_{\tilde{\chi}_2^0} = 2.0 \text{ GeV}, \]

\[ \Delta m_{\tilde{q}_R} = 2.8 \text{ GeV}, \quad \Delta m_{\tilde{q}_L} = 3.7 \text{ GeV}, \quad \Delta m_{\tilde{b}_1} = 57.7 \text{ GeV}. \]
\[ \text{N}_{10}=1, \quad \Lambda = 50 \text{ TeV} \]
\[ \Delta_{PQ}=140 \text{ GeV} \]

- Compare F-GUT Benchmark with mGMSB

- Vary mGMSB parameters:
  
  \[ M_{mess}, \quad \Lambda, \quad \sqrt{F}, \quad \tan \beta \]

- Distinguishing models is possible -- require large luminosity

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<td>( 372.5 )</td>
<td>( 412.1 )</td>
<td>( 371.6 )</td>
</tr>
<tr>
<td>( m_{\tilde{e}_R,\tilde{\mu}_R} )</td>
<td>( 214.3 )</td>
<td>( 246.9 )</td>
<td>( 204.9 )</td>
</tr>
<tr>
<td>( m_{\tilde{\tau}_1} )</td>
<td>( 175.0 )</td>
<td>( 174.8 )</td>
<td>( 174.7 )</td>
</tr>
<tr>
<td>( m_{\tilde{\nu}_\tau} )</td>
<td>( 366.1 )</td>
<td>( 400.4 )</td>
<td>( 367.7 )</td>
</tr>
<tr>
<td>( m_{\tilde{\tau}_2} )</td>
<td>( 384.0 )</td>
<td>( 422.3 )</td>
<td>( 385.1 )</td>
</tr>
<tr>
<td>( m_h )</td>
<td>( 1143 )</td>
<td>( 1143 )</td>
<td>( 1138 )</td>
</tr>
<tr>
<td>( m_A )</td>
<td>( 693.1 )</td>
<td>( 614.2 )</td>
<td>( 623.4 )</td>
</tr>
</tbody>
</table>
**Stopped Stau?**

- Low velocity stau can be stopped

- Inside detector: stau decay not correlated with the bunch crossing, difficult to trigger (with normal trigger)
  with modified trigger see Asai, Hamaguchi and Shirai, Phys.Rev.Lett.103:141803,2009

- Outside detector:

  - External detector, e.g. Water Tank -- require lifetime long enough
  - Stau trapped in Cavern Material decaying back to detector

  Buchmuller et al ’04
  Feng and Smith ’04
  De Roeck et al ’05
  Hamaguchi et al ’04, ’06,’09
The fraction of low velocity stau is small --> need large luminosity
Conclusion

- F-GUTs is a rigid frameworks for SUSY GUTs -- just enough to fit various aspects of phenomenological ingredient

- Embedding of GMSB in the framework is natural and predicative

- It can be tested at the LHC within a few years

- It also interesting to see if these local construction can be globally consistent.