Perspective on EF08 & the pMSSM scan

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Snowmass Day

EF08: Model Specific Explorations

- Models give concrete examples to compare scenarios
  - E.g. inclusivity of leptons colliders vs. reach of hadron colliders
- Sensitivity to specific models is of intrinsic interest!
- Top-down motivations can suggest viable parameter ranges
- For exploring complex, multi-parameter models (e.g. SUSY), a major challenge is how to balance the tradeoff between
  - Maintaining generality
    - Make as few assumptions as possible
  - Presenting clear, concise results
    - Be as consistent as possible in our assumptions

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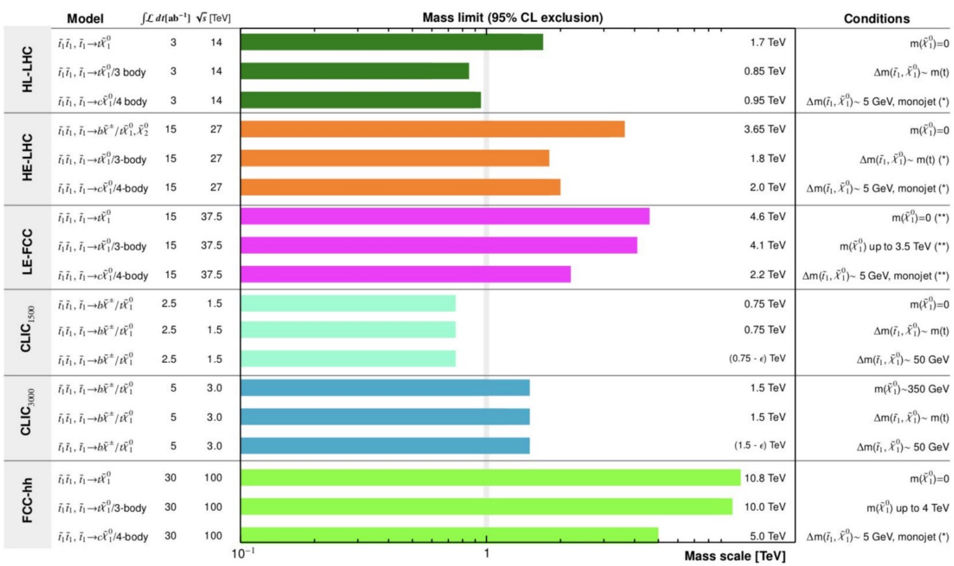
- For exploring complex, multi-parameter models (e.g. SUSY), a major challenge is how to balance the tradeoff between
  - Maintaining generality ➜ why we do the pMSSM scan
    - Make as few assumptions as possible
  - Presenting clear, concise results ➜ goal of Snowmass
    - Be as consistent as possible in our assumptions

Target results

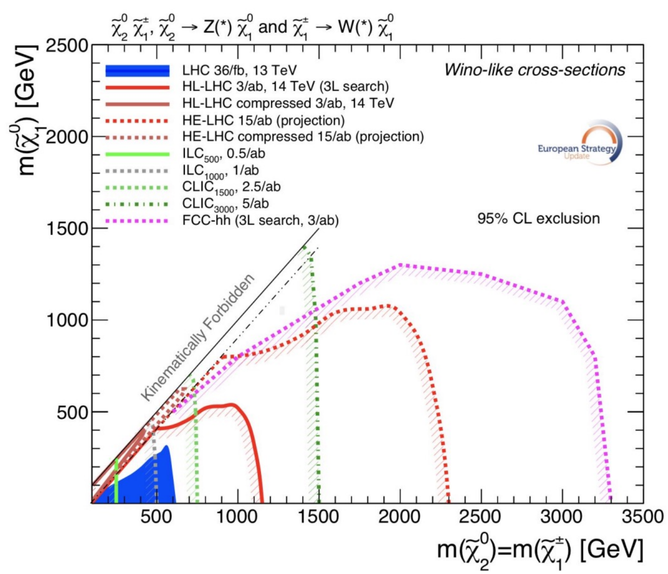
Examples from European Strategy Update

- Compare coverage of future colliders
  - Consider both reach and complementarity
  - Must add muon collider! Gaining a lot of traction…

Limits on squark mass



Limits on EWKino mass



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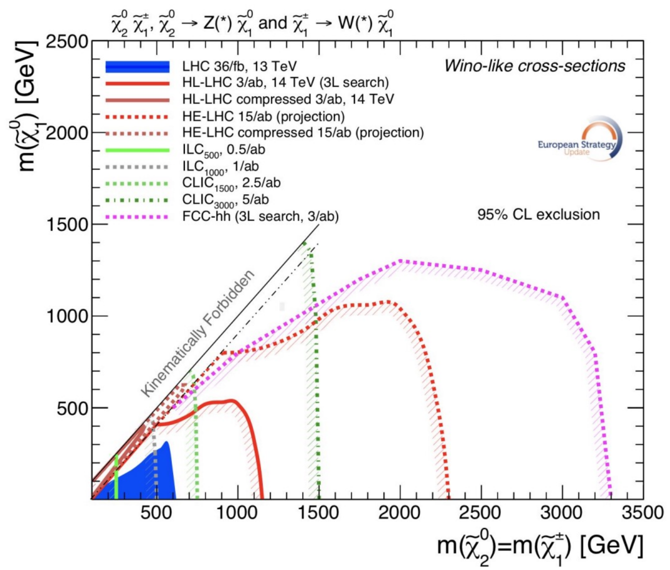
Beyond simplified models

- pMSSM uses well motivated assumptions to reduce to 19D, while preserving interesting phenomenology
- Vision: use the pMSSM scan to systematically quantify the dependence of these 2D contours on other SUSY parameters
  - Generate A LOT of model points, guided by existing measurements (flavor physics, Higgs and EW sectors, heavy quark masses, etc.)
  - Cover the range of many collider scenarios, up to 100 TeV pp
  - Draw bands or multiple contours per collider indicating what fraction of models are excluded / discoverable



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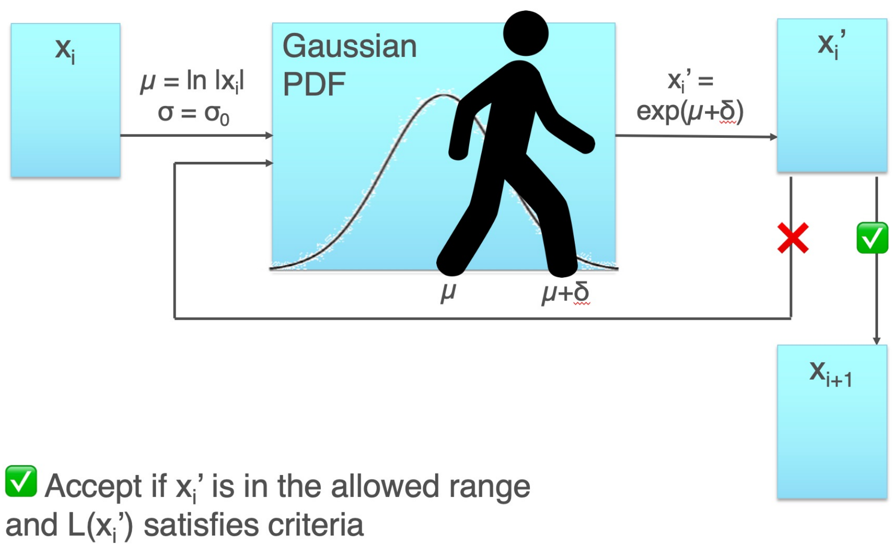
Overview of pMSSM scan strategy

- **1. Sample points** in the 19D pMSSM space
  - Most progress so far has been on this step
- **2. Focus in** on interesting regions of phase space
  - E.g. not excluded by LHC, near the measured muon g-2 and DM relic density, satisfying naturalness criteria, etc.
- **3. Generate** signal events
- **4. Perform analyses** for each collider scenario
- **5. Compare performance** of different future experiments

Sample points in the 19D pMSSM space

- Huge parameter space!
- Use a **Markov chain Monte Carlo** to step through the space in a smart way
  - **Likelihood** based on existing experimental results
  - **Logarithmic stepping** to populate low values of mass parameters more densely than high values



mass ~degeneracy between SUSY and SM → challenging signatures

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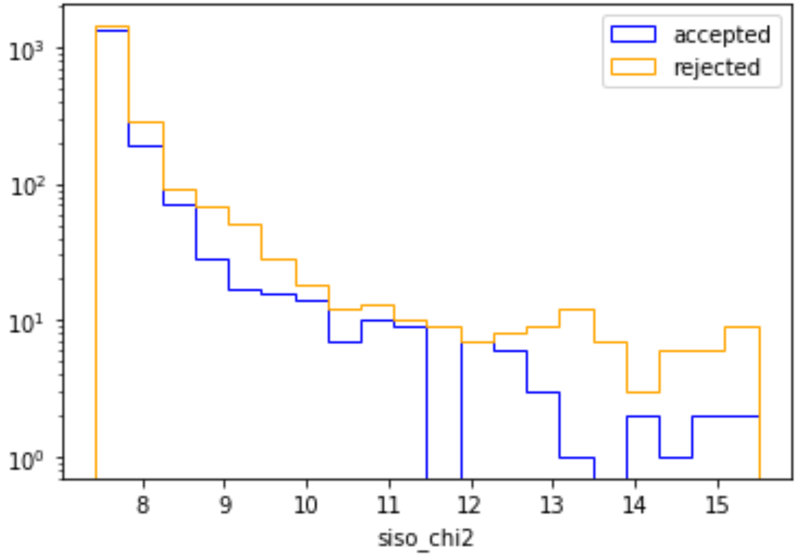
McMC likelihood

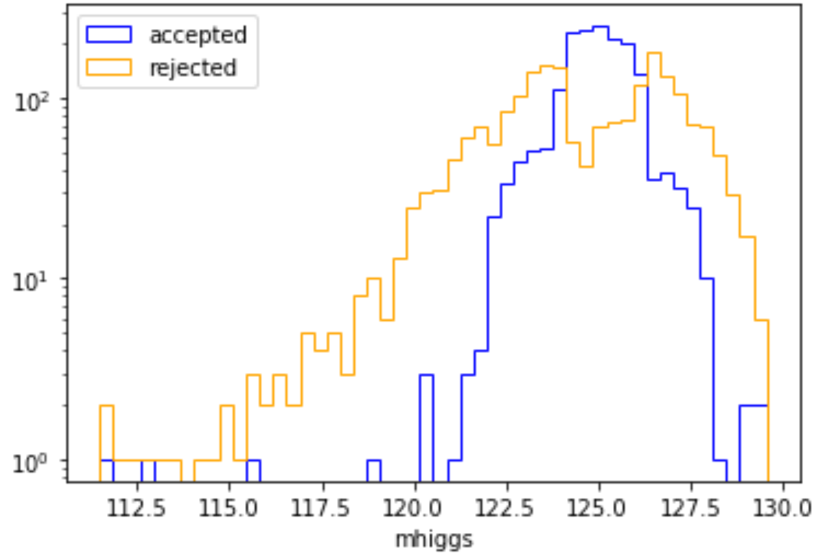
- Calculate the **likelihood** of each pMSSM point based on its agreement with existing measurements
  - The McMC prefers to take steps to new points with higher likelihood (better agreement with measurements)

Example 4000 point scan:

B-physics observables χ^2



Higgs boson mass



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McMC likelihood

- Contributions from **SPheno** and **FeynHiggs**: Gaussian with mean/width = experimental value/uncertainty
- Contributions from **Superiso**, **HiggsSignals**, and **HiggsBounds**: χ^2 is calculated directly by the program

Superiso 4.0	SPheno 4.0.4	FeynHiggs 2.18.0	Higgs Signals 2.6.0	Higgs Bounds 5.9.1
$\Delta_0(B \to K\gamma)$	$BR(B^+ \to \tau\nu)$	m_W	LHC Higgs meas.	LHC Heavy $H(\tau\tau)$
$BR(b \to s\gamma)$	$BR(D_s \to \tau\nu)$	$\Delta(\rho)$		
$BR(B_s \to \mu\mu)$	$BR(D_s \to \mu\nu)$	m_H, H properties		
$BR(B_d \to \mu\mu)$	α_S			
$BR(b \to s\mu\mu)$	m_{top}			
$BR(b \to see)$	m_{bottom}			
$BR(B0 \to K^{*0}\gamma)$				

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Perform analyses

- **Generate signal events** in Pythia + Delphes
  - pMSSM points and generated signal events will be made available to everyone
- Analysis of pMSSM points will rely on **crowdsourcing**
  - We encourage you to include the pMSSM points as signal in your analyses
- More groups using the scan points for studies = more complete comparison as the final product
  - **Speak up** if you want a particular collider setup for generated signal events, etc.
  - Want to extend this effort beyond EF (dark matter, rare, etc.)

Compare performance

- **How do interesting observables depend on pMSSM parameter values?**
  - Especially interesting for this scan, which extends ranges far beyond those performed for LHC studies
- **Compare the sensitivity of different colliders**
  - Quantify the dependence of 2D contours on other SUSY parameters
  - How do the different scenarios **complement each other**? Are there **uncovered regions**?
  - What is coverage like in experimentally interesting regions, e.g. near the measured muon g-2?

Conclusions

- **Tradeoffs** between generality and simplicity
  - pMSSM scan helps to bridge the gap
- Technical implementation is in place for a **pMSSM grand scan** using Markov chain Monte Carlo
- Signal events will be generated for you all to use!
- Early ideas for summary plots are similar to European Strategy Update (+ muon collider)
  - Bands/multiple contours from pMSSM scan add some nuance
  - New ideas are welcome, please share yours

Additional material

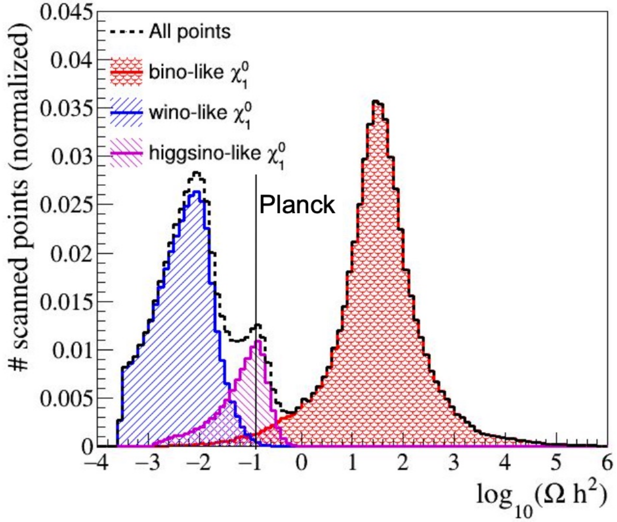
Parameter ranges

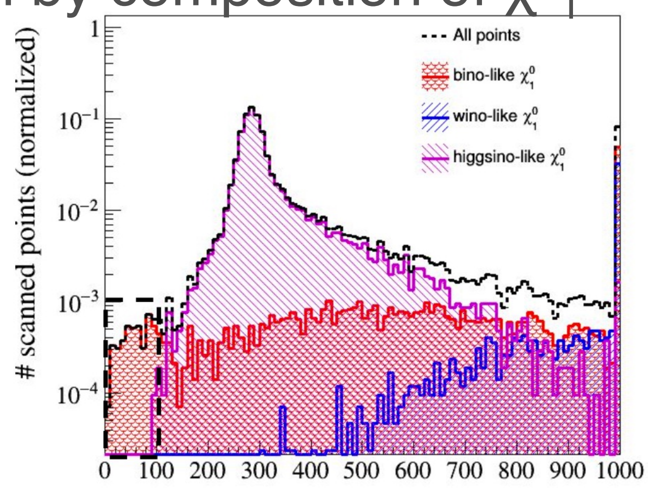
- Aim to cover parameter space accessible at many colliders, up to 100 TeV pp

Param.	Definition	Range
M_A	mass of psuedoscalar Higgs boson	100 GeV - 25 TeV
$\tan\beta$	ratio of Higgs vevs	1 - 60
$\lvert\mu\rvert$	Higgs-higgsino mass parameter	80 GeV - 25 TeV
$\lvert M_1\rvert$	bino mass parameter	1 GeV - 25 TeV
$\lvert M_2\rvert$	wino mass parameter	70 GeV - 25 TeV
M_3	gluino mass parameter	200 GeV - 50 TeV
$m_{\tilde{L}^{1,2}}$	$1^{st}/2^{nd}$ gen. left-handed slepton mass	90 GeV - 25 TeV
$m_{\tilde{R}^{1,2}}$	$1^{st}/2^{nd}$ gen. right-handed slepton mass	90 GeV - 25 TeV
$m^3_{\tilde{L}}$	3^{rd} gen. left-handed slepton mass	90 GeV - 25 TeV
$m^3_{\tilde{R}}$	3^{rd} gen. right-handed slepton mass	90 GeV - 25 TeV
$m_{\tilde{q}^{1,2}}$	$1^{st}/2^{nd}$ gen. left-handed squark mass	200 GeV - 50 TeV
$m_{\tilde{u}^{1,2}}$	$1^{st}/2^{nd}$ gen. right-handed u-type squark mass	200 GeV - 50 TeV
$m_{\tilde{d}^{1,2}}$	$1^{st}/2^{nd}$ gen. right-handed d-type squark mass	200 GeV - 50 TeV
$m_{\tilde{q}^3}$	3^{rd} gen. left-handed squark mass	100 GeV - 50 TeV
$m_{\tilde{u}^3}$	stop quark mass	100 GeV - 50 TeV
$m_{\tilde{d}^3}$	sbottom quark mass	100 GeV - 50 TeV
$\lvert A_\tau\rvert$	τ trilinear coupling	1 GeV - 7 TeV
$\lvert A_b\rvert$	bottom trilinear coupling	1 GeV - 7 TeV
$\lvert A_t\rvert$	top trilinear coupling	1 GeV - $3(m_{\tilde{q}^3} m_{\tilde{u}^3})^{1/2}$

5. Compare performance

- **How do interesting observables depend on pMSSM parameter values?**
- Inspiration plots from M. Mroweitz, CMS pMSSM team:
  - Observables broken down by composition of χ^0_1



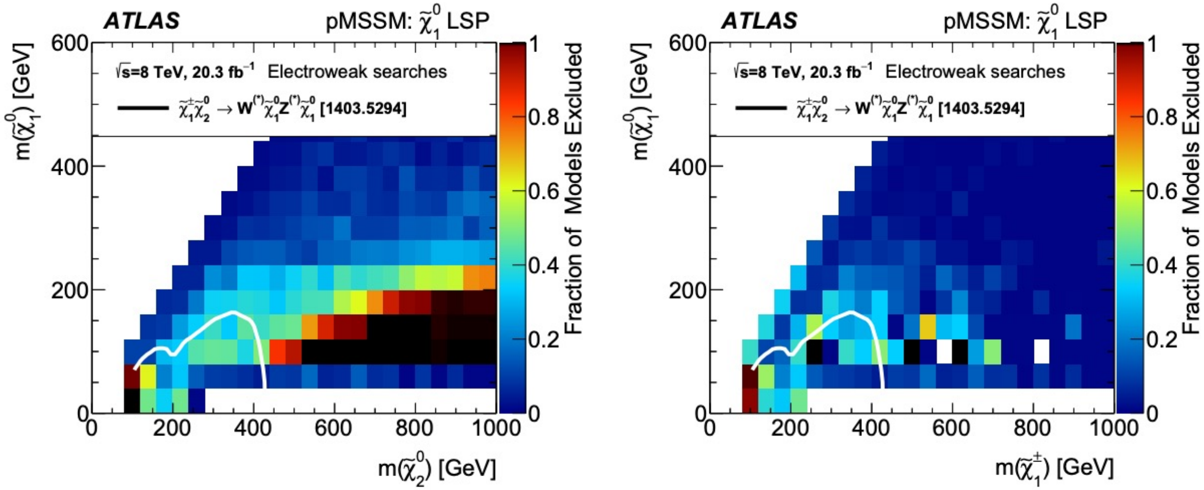


EW fine-tuning parameter

- Can look at many observables (e.g. muon g-2) for different ranges of pMSSM parameters

5. Compare performance

- **Compare the sensitivity of different colliders**
- Inspiration plots from [ATLAS Run 1 pMSSM scan](#):



(a) Neutralinos (b) Chargino–neutralino

Excluded region is actually not well covered in terms of pMSSM

- Can calculate e.g. contours of constant fraction of models excluded and overlay collider scenarios
- Can look at scanned points excluded by > 1, =1, or no future collider scenarios