

# pBSM Topical Meeting: pMSSM SUSY

Date: October 31, 2025

Indico: <https://indico.cern.ch/event/1602088/>

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## Key Takeaways (Post-Meeting Summary)

*Will fill in after the meeting (summary of the most important outcomes and decisions.) Detailed real-time minutes at the end of the document / agenda.*

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## Your input goes here!

**What would people like to see written down in the *first public guidelines document* from the pMSSM task force?**

[Name] [Comment]

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## Community Interest & Contact List

*Add your name and email if you want to be kept informed, participate in future meetings, or help organize community efforts.*

Name	Email	Institution / Role	Interest (Participation, Organization)
Judita Mamuzic	judita.mamuzic@cern.ch	Institute Jozef Stefan, Ljubljana	pMSSM liaison for ATLAS
Ben Hodkinson	ben.hodkinson@cern.ch	University of Oxford / post-doc	ATLAS pMSSM analyser



Name	Email	Institution / Role	Interest (Participation, Organization)

## Discussion Summary (so far)

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## Minutes & Key Points

### 1. Opening and Meeting Goals

- First topical meeting dedicated to **pMSSM** within the Prompt BSM WG.
- Goals of the topical meeting series:
  - Brainstorm what has been done so far, next steps, and perspectives.
  - Form task forces to agree on:
    - Data preservation & reinterpretation
    - Uncertainties
    - Results presentation
    - Benchmarks and validation tests
  - Collect inputs and define guidelines to be summarized in a public document.

#### Action Items:

- Contact conveners if interested in leading task forces on specific topics.
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### 2. Theoretical Overview – Emanuele Angelo Bagnaschi

#### Higgs mass and stops

- Updated Higgs-mass predictions require state-of-the-art tools; theory uncertainty matters.

- In simple scenarios, the observed Higgs mass points to stop scales from just below  $\sim 2$  TeV up to  $\sim 10$  TeV.
- Current LHC limits only begin to touch the low end. HL-LHC improves reach; FCC-hh needed for the heavy regime.
- Conclusion: stop searches remain a priority in realistic pMSSM settings.

### Extended Higgs sector

- Interplay between heavy Higgs bosons ( $H/A/H_{\pm}$ ) and SUSY states can open channels like  $H/A \rightarrow \tilde{\chi}\tilde{\chi}$  and  $H \rightarrow \tilde{\tau}\tilde{\tau}$ .
- These modes weaken standard  $\tau\tau/b\bar{b}$  searches but create new, largely unexplored signatures.
- Proposed next steps: reinterpret existing analyses with leptons/soft objects; design dedicated searches for these decays.

### Light electroweakinos and staus

- Viable light-ewkino and light-stau scenarios persist, often with significant mixing or compression.
- Possible effects on  $h \rightarrow \gamma\gamma$  rates; parameter regions at moderate  $\tan\beta$  remain interesting.
- Emphasis on coverage beyond 100% BR simplified topologies and fixed mass patterns.

### Recasting and combinations

- Theory-side recasts of the ATLAS pMSSM EWK scan show:
  - Single-analysis recasts roughly match collaboration sensitivities.
  - Combining approximately uncorrelated analyses strengthens exclusions, especially for bino-like LSPs.
  - Gaps remain where disappearing-track inputs are outdated.
- Message: light SUSY is still viable; many points with moderate  $r$  are testable in Run-3/HL-LHC.

### Probing SUSY in “SM phase space”

- Use SM precision/measurement regions with excellent systematics control (W mass, top, diboson) to constrain BSM production that contaminates these regions.
- Example strategy: assess shape distortions (e.g.,  $m_T$ ,  $p_T$ ,  $m_{bl}$ ) from SUSY processes and recast SM measurements accordingly.
- Complementary to direct searches; may close holes left by simplified-model assumptions.

### SMEFT and EFT matching

- Two-way synergy:

- Use SMEFT to import indirect constraints typically absent from global pMSSM fits.
- Inform SMEFT operator choices with MSSM-inspired priors rather than fully democratic scans.
- Caveat: consistent matching depends on which MSSM states are light (e.g., split SUSY, 2HDM-like limits).
- Practical note: when using SMEFT for MSSM, include proper matching for the Higgs quartic; Higgs-mass consistency is essential.

## Outlook

- Keep conventional searches for stops and heavy Higgses, but extend to SUSY decay modes of  $H/A/H^\pm$ .
- Prioritise light-ewkino coverage with realistic BRs and non-trivial decay chains.
- Expand reinterpretations and cross-analysis combinations; update disappearing-track inputs.
- Leverage SM measurement phase space for complementary sensitivity.
- Coordinate with SMEFT efforts using consistent MSSM→EFT matching.
- Explore trigger and detector-level innovations at HL-LHC that improve sensitivity to soft objects and long decay chains.

## Q&A

### T. Lari – Higgs-mass uncertainty

*Question:* How reliable are current theoretical uncertainties on the MSSM Higgs-mass prediction?

*Answer:* The old  $\pm 3$  GeV rule is outdated and too conservative. Modern tools such as FeynHiggs  $\geq 2.19$  or FlexibleSUSY provide point-by-point uncertainties that better reflect parameter-space dependence. Theoretical errors remain larger than experimental ones, typically  $\sim 1$  GeV, making this a theory-limited constraint.

### Samuel L. Bein – W-mass correlations

*Question:* Can current tools reliably connect MSSM parameters to  $m_{WmW}$  predictions, especially after the CDF 2022 result?

*Answer:* No major new theoretical calculations exist. FeynHiggs and Phoenix remain the main options. Within the MSSM, light electroweakinos or sleptons produce too small effects to explain CDF. Larger effects from stop–sbottom splitting conflict with Higgs-mass constraints. Realistic  $m_{WmW}$  shifts are small; precision future machines (ILC/FCC-ee) will be needed for sensitivity.

### Judita Mamuzic – NMSSM vs pMSSM

*Question:* Is it worthwhile to extend to the NMSSM given similar final states?

*Answer:* Possibly, depending on focus. The NMSSM adds a singlet scalar and singlino, which

can modify Higgs phenomenology and electroweakino spectra, yielding softer or altered leptonic signatures and relaxed Higgs-mass–stop correlations. Differences are model-dependent but can change phenomenology enough to justify study.

### **Lukas Heinrich – pMSSM scans**

*Question:* Which collaborations (MasterCode, GAMBIT, etc.) are still running full 19-parameter pMSSM scans?

*Answer:* GAMBIT has shifted to non-SUSY models; activity on SUSY scans is minimal. MasterCode still works on smaller setups (~11 parameters) but full 19D scans are computationally and manpower-limited—year-long runs, small teams, and high turnover. SUSY interest has cooled, so progress is slow compared to Run-2, though some SMEFT–fit projects continue at low pace

### **Yuchen Cai – Vacuum stability**

*Question:* Does vacuum stability exclude any significant part of the pMSSM parameter space?

*Answer:* Only specific regions are affected, mainly with large trilinear couplings (A-terms) or light stops and large mixing (XtXt). These can cause unstable vacua, but most of the pMSSM parameter space is not excluded. Dedicated tools exist to check this when needed.

### **Roberto Franceschini – Electron/muon excess**

*Question:* Can the reported electroweakino excess be linked to MSSM predictions or motivate new searches?

*Answer:* Possibly, but no strong correlation established. MSSM or NMSSM points fitting such excesses could alter  $H \rightarrow \gamma\gamma$  or Higgs properties, yet deviations are small or absent at current precision. Dedicated re-optimised searches around the relevant mass range might help, but no concrete new signal is predicted.

*Follow-up (M. Goodsell):* Agreed—it's a good idea but not yet pursued. The focus has been on completing existing analyses (e.g. monojet). Tests with non-SUSY or extended models have not outperformed MSSM cases; NMSSM behaves similarly but offers no clear improvement in explaining the excess.

### **Sabine Kraml – LLPs and combined signatures**

*Comment:* Sabine noted that parts of the pMSSM parameter space predict long-lived charginos, which can modify decay signatures of other SUSY particles. For example, stop decays could mix prompt and long-lived topologies, creating hybrid final states that are largely unexplored. She stressed that pMSSM studies should involve both prompt and LLP working groups.

*Answer:* Agreed—LLP effects must be integrated into future pMSSM efforts.

### **Tina Potter – Experimental sensitivity**

*Comment:* The shown mass spectra sit near current LHC sensitivity limits for simplified models (sleptons, gluinos). Complex decay chains or mixed branching ratios are not excluded, just close to reach. Suggested more data may suffice rather than redesigning analyses.

*Answer:* those spectra came from older studies, now likely near exclusion. Still, partial signal

acceptance was observed in simplified recasts (e.g. SModelS-like), implying some sensitivity remains.

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### 3. ATLAS Overview – Ben Hodkinson

#### Scope

- ATLAS Run-2 pMSSM work focused on **electroweakinos** (EWKinos); pipeline, results, and lessons.
- Standard RPCons. signatures:  $\tilde{\chi}/\tilde{g}/\tilde{q}/\tilde{\ell}$  pair production  $\rightarrow$  leptons/jets/ $\gamma$  + MET.
- Simplified-model contours are optimistic; full pMSSM has mixing, mixed BRs, cascades.

#### Pipeline

- Random uniform sampling ( $\approx 2 \times 10^4$  EWK points; future scans  $\times 10$ ).
- Spectra/decays via state-of-the-art tools (custom FeynHiggs chain + Savvy spectrum/decay codes).
- Two-stage evaluation:
  1. Truth level (MG5 + SimpleAnalysis + JSON likelihoods + pyhf).
  2. Detector level only near the CLs boundary (AtIIFastII + RECAST;  $O(10^3-10^4)$  jobs via REANA).
- External constraints (flavour, EWPO, DM relic, direct detection) shown with/without application.

#### Key Run-2 EWK results

- **Coverage is incomplete:** viable EWKinos persist **down to  $\sim$ LEP limits**; only isolated bins reach 100% exclusion.
- **Compressed** regions can be probed indirectly via **heavier EWKino** cascades feeding sensitive searches.
- **LSP type:** good reach for **wino-like** (disappearing tracks); **bino/higgsino** remain broadly viable at low mass.
- **DM complementarity:** ATLAS vs direct detection cover different regions; bino funnels mostly covered, **compressed co-annihilation** still open.
- Gaps: (i)  $\sigma$  suppression from **higgsino vs wino** production, (ii) **mixed BRs** dilute single-analysis reach  $\rightarrow$  need combinations, (iii) **radiative**  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$  unaddressed, (iv) longer **cascades** and **H/A  $\rightarrow$  EWKino** not exploited.

#### Beyond EWKinos

- Strong production: generic **0-lepton** searches give broad coverage; dedicated **3rd-gen squark** interpretations planned to handle complex chains.

### What to improve for Run-3

- Treat **LLPs** properly (beyond XS limits); include **small  $\Delta m$**  regions, **sleptons**, and **heavy-Higgs**→**EWKin** production in generation.
- Perform **statistical combinations** (not only best-expected-CLs).
- Faster, smarter sampling: **active learning/MCMC** to target boundaries and rare regions.
- Operational: reduce detector-level bottlenecks; adopt **rolling** interpretations while analysis experts are available.
- Harmonise with theory: agree **shared model samples/benchmarks**; benchmark **speed vs accuracy** (RECAST vs fast recasters).

### Bottom line

- Run-2 established meaningful but **non-exhaustive** coverage of EWKin.
- Priority targets: **compressed, mixed-BR, radiative**, and **heavy-Higgs-mediated** scenarios—plus LLPs and proper combinations in Run-3.

## Q&A

### Zeynep Demiragli – Reducing Monte Carlo workload

*Question:* Could analytical scaling or template-based parameterisation reduce the need for full MC generation in the pMSSM scans, as done in some dark matter studies?

*Answer (Ben Hodkinson):* Conceptually interesting; would like to see the reference.

*Follow-up (Jonas Wurzinger):* Similar efficiency gain achieved through **active learning**, where a **ML proxy** predicts CLs across parameter space to avoid generating events for clearly excluded models. The method is being tested in an ATLAS PubNote (linked to a Master's thesis), aiming to focus MC production on **non-excluded, high-interest regions**.

### Sabine Kraml – Using ML to accelerate scans

*Comment:* Previous work using a **random forest classifier** to predict Higgs masses in a pMSSM-like model greatly sped up scans by identifying likely viable points.

*Answer (Ben Hodkinson):* Acknowledged; related ideas are being explored to predict observables such as **relic density** within active-learning frameworks. The approach could further improve scan efficiency.

### Jeff Shahinian – Value of full detector simulation

*Question:* Given that SModelS reproduces ATLAS exclusions reasonably well, is full detector simulation always necessary? Has there been a systematic study comparing truth-level vs. full RECAST CLs results?

*Answer (Ben Hodkinson):* No full systematic study yet. For most models, truth- and reco-level

CLs agree closely; only a few show large deviations. These outliers do not alter the qualitative exclusion maps—truth-level tends to be slightly more optimistic. Identifying features of those discrepant models could be an interesting next step.

*Follow-up (Jeff Shahinian):* Suggested prioritising detector simulation only for signatures where it matters, to reduce computational load.

### **Lukas Heinrich & Mark Goodsell – Public pipelines and collaboration**

*Lukas:* Most of the ATLAS pMSSM pipeline (up to RECAST) could run publicly using tools like **GAMBIT**. Encouraged coordination between ATLAS and the theory community to share workloads and publicise pipelines.

*Mark:* Confirmed related work through his **BeSmart** framework, automating all pre-recast steps and integrating with **SModels**. Suggested collaboration with Lukas and Jonas to link BeSmart with Gaussian-process algorithms used in active learning.

### **Roberto Franceschini – Clearer physics messaging**

*Comment:* Supported targeted scans to answer simple but crucial questions (e.g. “*What is the lightest allowed stop or gluino mass in the MSSM?*”). Such clear benchmarks would counter pessimism around SUSY by providing sharp, interpretable results.

*Answer (Ben Hodkinson):* Agreed. Proposed including **pMSSM interpretation plots** directly in analysis papers alongside simplified model contours, through **rolling interpretations** performed while analyses are active.

*Follow-up (Sabine Kraml):* Supported the idea; once full scans exist, analyses could state explicitly which pMSSM regions each search excludes. With ATLAS public data, theorists can already generate such plots.

*Follow-up (Jonas Wurzinger):* Highlighted the benefit of continuous reinterpretation not only for exclusion but also **optimisation of sensitivity** to realistic models. Proposed modernising searches to maximise **pMSSM coverage** rather than simplified-model reach.

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## **4. CMS Overview – Samuel Louis Bein**

### **Scope and Objective**

Presented the CMS approach to the *pMSSM19* reinterpretation. The work covers both the electroweak and strong sectors in a single “grand scan.” The goal is to map CMS Run-2 sensitivity, including constraints from direct searches, dark matter, and naturalness.

### **Scan Setup**

A flat-prior MCMC was used over the full pMSSM19 parameter space, incorporating LEP, Higgs, and flavour constraints. About **20 million** valid model points were generated; **500,000** were selected for simulation. Oversampling targeted light stop regions, high naturalness ( $\Delta EW <$

100), and dark-matter-compatible points. Over-dense and excluded regions were down-weighted.

### Event Generation and Simulation

Events were generated with **Pythia LO inclusive mode**, filtered to emulate trigger efficiency (~50% rejection). Fast Simulation was used ( $\approx 10\times$  faster than Geant4). Each point received an effective integrated luminosity of **4× Run-2**, with 100–60 000 events per point. Two datasets were produced — *Legacy* and *Ultra-Legacy* — totalling about **20 billion events**, stored in NanoAOD format.

### Analyses and Likelihoods

Seven analyses were included:

- Soft opposite-sign leptons
- Ultra-soft lepton + track
- On-Z and edge dileptons
- Direct stau
- Single lepton
- Disappearing tracks
- 0-lepton + jets + MET

Likelihoods were computed in three modes:

1. **Full** – using full background models (signal scaled  $\pm 50\%$ ).
2. **Simplified** – independent bins, for statistics-dominated analyses.
3. **Binary** – for non-orthogonal analyses.  
Posterior densities, survival fractions, and Bayes-factor maps were built to assess exclusion and discovery potential.

### Main Findings

- Electroweakino models remain viable down to  $\approx 100$  GeV, consistent with LEP.
- Disappearing-track analyses dominate compressed wino regions; 0-lepton + jets + MET covers the strong sector.
- Dark-matter constraints isolate **Z/h funnels** and co-annihilation regions; with  $\Delta EW < 100$ , survivors are mainly **higgsino-like LSPs** with few bino-funnels.
- Variations of  $\pm 50\%$  in signal cross-section have little impact on qualitative results.
- Bayes-factor maps show only localised fluctuations, **no global excess or discovery hint**.

### Future Prospects and Improvements

- Extend trilinear-coupling range; increase bino-funnel sampling.
- Integrate newly available ultra-soft and displaced-track analyses.
- Release full **per-point and combined likelihoods** publicly.
- Explore **machine-learning regression** for fast 19D likelihood inference.

- Apply framework to **Run-3** data and incorporate **SMEFT** and **extended-Higgs-sector** constraints.

### **Takeaway**

CMS delivers a high-resolution, statistically consistent pMSSM interpretation. The Run-2 results confirm large surviving electroweak regions and motivate refined Run-3 searches focused on compressed and natural SUSY scenarios.

### Q&A

#### **Zeynep Demiragli – Trigger strategy follow-up**

*Question:* Asked Sam Bein to comment on his backup slides related to trigger studies and their connection to future searches.

*Answer (Samuel Louis Bein):* Explained that new **soft-track** and **ultra-soft lepton** analyses are not yet included in the CMS scan. Including them would remove part of the low-mass electroweakino space but leave a surviving **Higgsino-like** population. Phase-2 luminosity gains alone will not close this gap. Proposed a **low-pT (1–10 GeV) track-based Level-1 trigger**, expected to increase signal acceptance by about a factor 10 compared to current MET triggers, crucial to probe the remaining compressed Higgsino region. Implementation foreseen for **CMS Phase-2 (~2030)**.

#### **Sabine Kraml - Task force plans**

Stressed that pMSSM reinterpretation should be a **cross-group effort** involving ATLAS, CMS, and theory within the **Interpretation Task Force**.