CONNECTION OF SMALL EXCESSES IN ATLAS SUPERSYMMETRY SEARCHES USING ML

Judita Mamužić (ISJ) in collaboration with Ciril Bohak (UL FRI), Andrej Filipčić (IJS), Nishant Gaurav (Vanderbilt University), Lukas Alexander Heinrich (TUM), Aurelio Juste (IFAE), Brian Petersen (CERN), Roberto Ruiz De Austri Bazan (IFIC), Jonas Würzinger (TUM)

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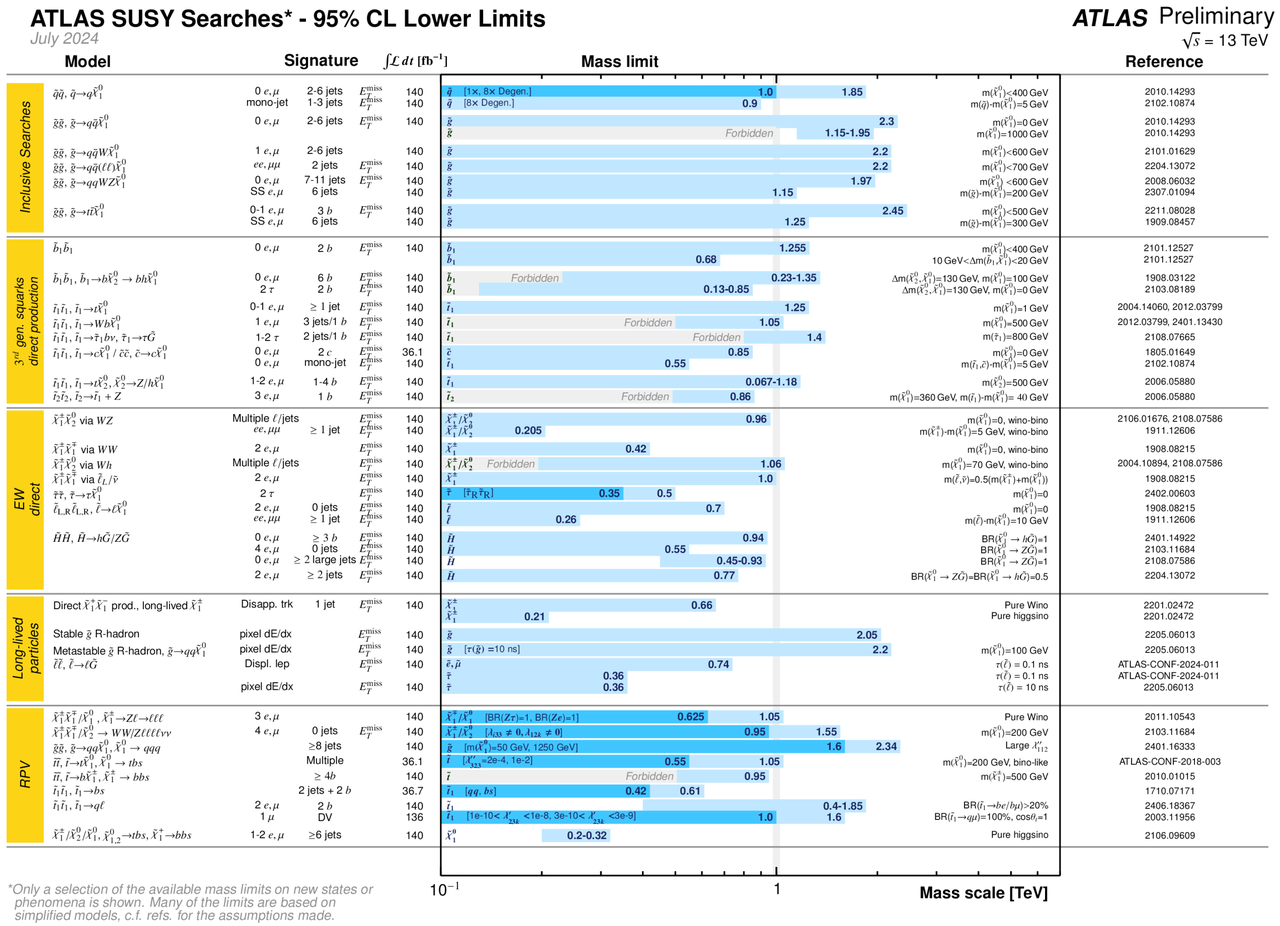
I FEEL SLOVENIA

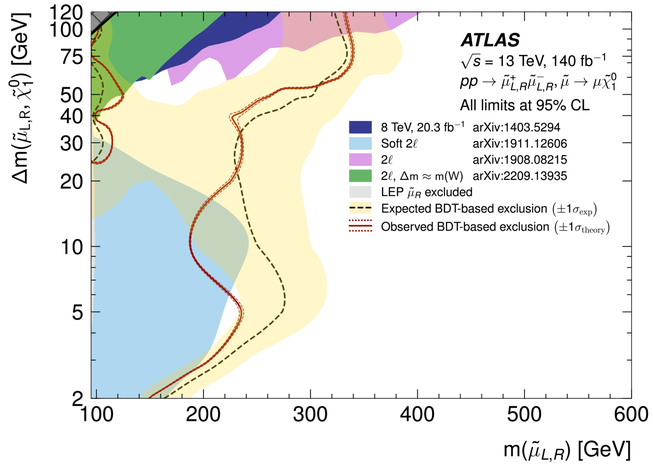
Jožef Stefan Institute

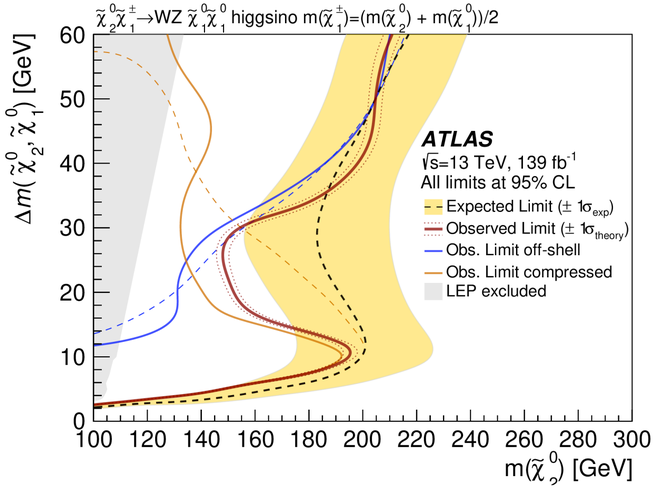
SMASH
machine learning for science and humanities postdoctoral program

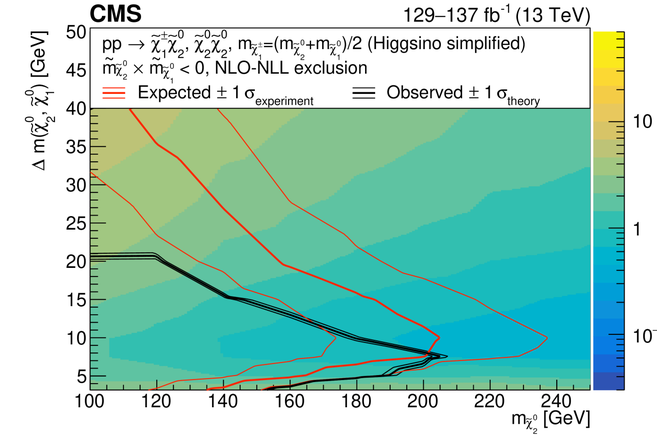
EXCLUSION AND ANOMALIES

ATLAS SUSY Summary Plots









HMBS-2024-64, JHEP (2025)

ATLAS SUSY-2018-16, PRD (2020)

ATLAS SUSY-2019-09, EPJC (2021)

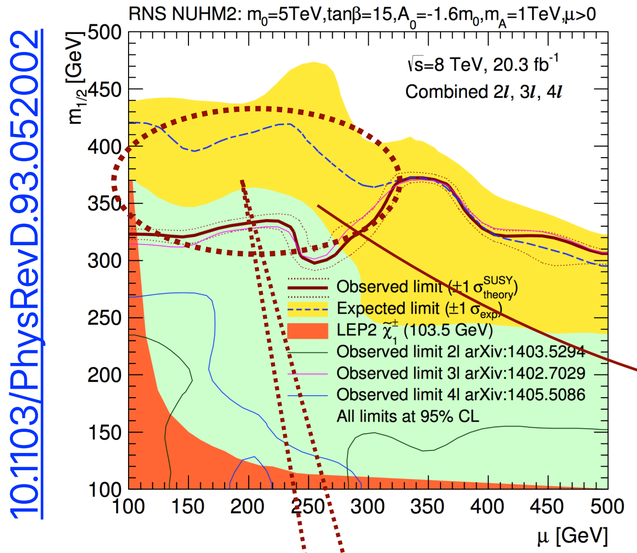
CMS SUS-18-004

- No significant sign of new physics found to date.
- Several analyses observe small excesses.
- ATLAS and CMS observe small excesses at the same model parameter space.

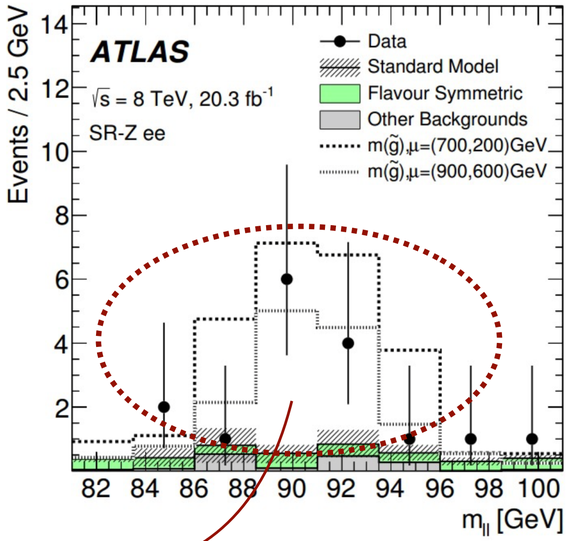
CONNECTION OF SMALL EXCESSES

- Little attention is given to systematic study on connection of small excesses.
- New type of study: Look into models that were expected to be excluded, but were not due to small excess (potential new physics).
- Small Excess analysis criteria: $CL_S^{exp} \leq 0.05$, $CL_S^{obs} > 0.05$, ($Z > 2\sigma$ SD)
- Look for common final states and common pMSSM models. Motivate a new signal region or a statistical combination.

10.1103/PhysRevD.93.052002



Find a connection for final states and models



arXiv:1503.03290

Potential new physics:

Good expected sensitivity, but not excluded due to the small excess

STATISTICAL INTERPRETATION

Model independent

$$P(D \mid B)$$

- How significant is the excess?

- Rule of thumb in SUSY:
  - ~ 3-10 SD: sign of new physics
  - < 3 SD: not significant
  - ~ 2 SD: small excess

Model dependent

$$P(D \mid S+B)$$

$$CL_S = \frac{p_{S+B}}{1-p_B}$$

- Is the model excluded?

- Model excluded at 95% CL for CLs_obs < 0.05 (exclusion).
- Analyses optimized to maximize parameter space with CLs_exp < 0.05 (sensitivity).

- Not all models were tested at 3 sigma level with injection test
- Model independent 2 σ SD excesses should be considered seriously!
- Motivate a new search, (try to) distinguish new physics from statistical fluctuations

arXiv:1105.3166

ANALYTIC SCAN, ARTISTS VIEW RESULTS

- Analytic scan in preparation by the ATLAS collaboration using Run2 data and analyses.
- ATLAS EWK pMSSM study done in Nishant Gaurav master thesis.
- Preliminary study using 2 x 10k pMSSM models and electroweakino production yields ~ 2 x 200 models using random sampling, general and 3G scans in preparation.
- Single out best motivated models for Run3 searches.

Best motivated models:

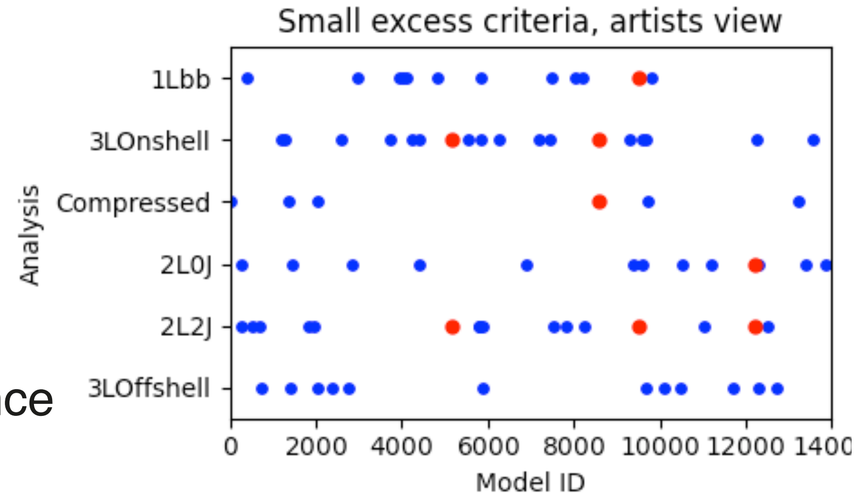
- Found by multiple analyses (orthogonal)
- Not excluded by any ATLAS analysis
- Passes DM constraints
- Passes EW constraints
- Passes Flavor constraints
- High model dependent expected significance

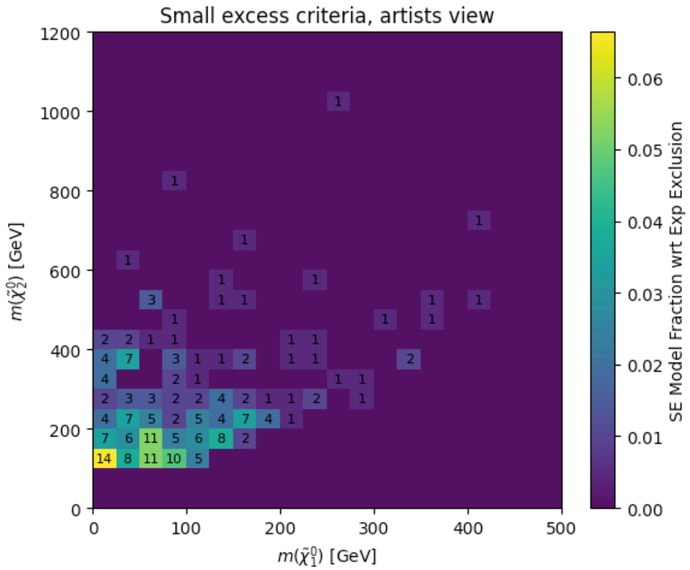
Best motivated parameter space:

- Model parameters
- (Analyses selections)

⚠ Random generation, for illustration only!

- Models found once
- Models found twice



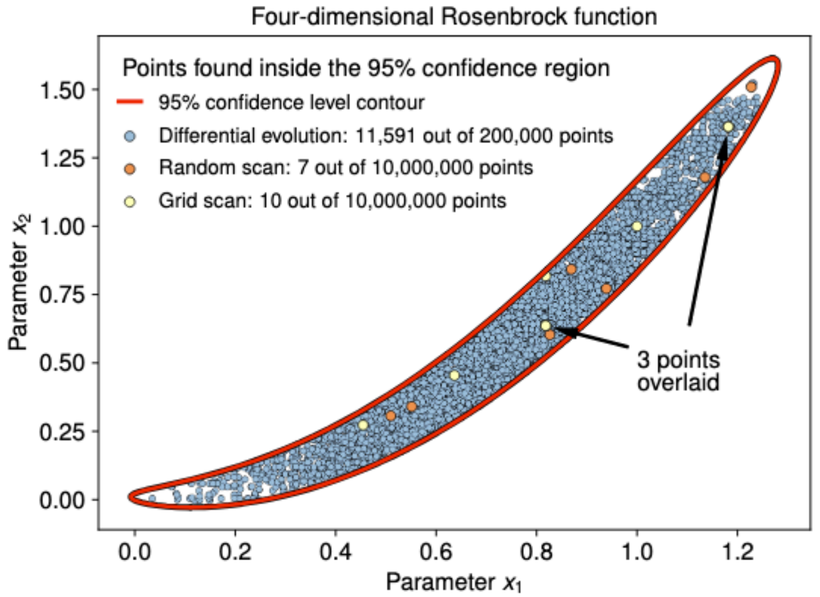


- Single out models surviving additional criteria
- However, do not attempt to make SUSY a theory of everything!

SAMPLING AND CLUSTERING WITH ML

- More information can be extracted using Machine Learning.

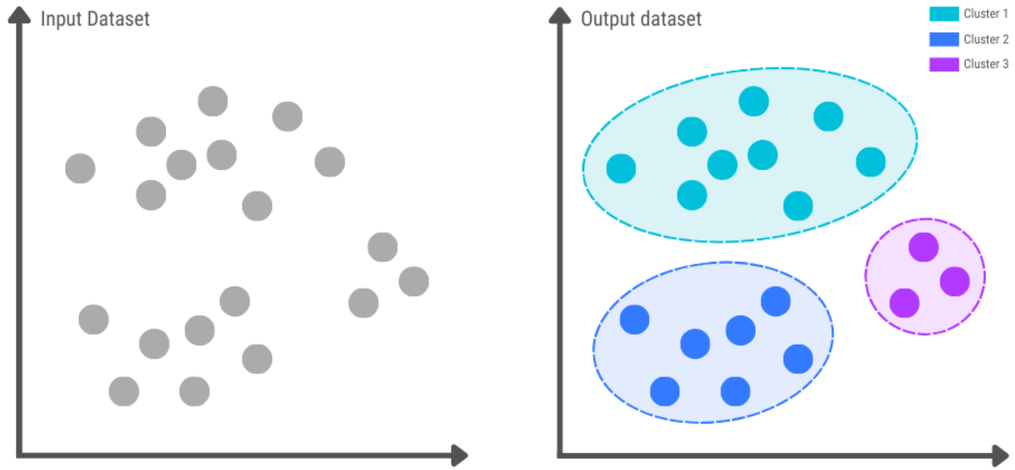
Model oversampling



arXiv:2012.09874

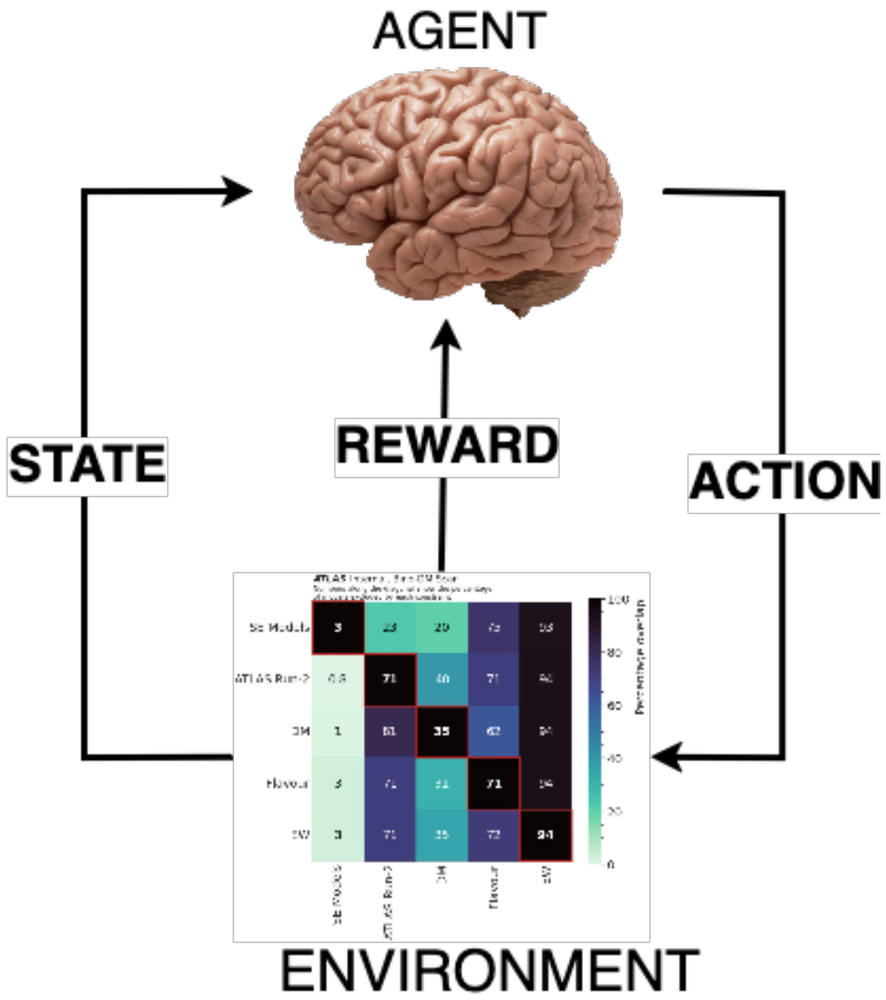
- Oversampling in the interesting region using Small Excesses criteria required to scan better the pMSSM parameter space.

Result: Model and final state clusters



- Clustering of models passing Small Excesses criteria to motivate future searches.
- Improve by considering external constraints

REINFORCEMENT LEARNING



- Performs minimization, very good at finding a global minimum for high dimensional parameter space (state-of-the-art algorithm):
  - STATE: Current step (SE pMSSM models)
  - REWARD: high mass SUSY parameters, EWK scale mass parameters, production cross-section, branching ratios, mixing, and kinematic variable distributions, CL_S, external constraints
  - ACTION: Next step (next SE pMSSM models)
- Agent observes the STATE and makes an ACTION, environment transitions to STATE+1 and gives reward. Agent updates *policy* for STATE-ACTION transition.
- Agent discovers by trial and error what actions lead to good outcomes.
- Oversample in the interesting region.
- Explore interesting high-dimensional parameter space, find better motivated regions.
- Single out models and kinematic parameter space for Run3 searches (clusters to define a simplified model, not single models).

MSCA PROJECT

MATREX: Classical and Quantum **Ma**chine Learning **T**a**r**geting Small **Ex**cesses in ATLAS

https://smash.ung.si/fellows/

- Initially planned for proof-of-concept and ATLAS data (due to access limitations from CMS), but most interesting to exploit ATLAS + CMS data

Small Excesses using ML:

- Models
- Final states

Data events using ML:

- Data events
- Final states

Small Excesses using QC:

- Models
- Final states

ATLAS + CMS

- Warning: First consider cross-validation of ATLAS vs CMS (see if we see the same things independently), then do the ATLAS + CMS combination to exploit all the excesses information

Wish list from CMS:

- Models and analyses statistical interpretation (fast interpretation and RECAST)
- Data events and analyses SR selections (ntuples)
- Long term: Full analyses preservation for SR, VR and CR, exploit also under fluctuations