LHC searches beyond simplified models

Krzysztof Rolbiecki

Institute of Theoretical Physics, University of Warsaw

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NATIONAL SCIENCE CENTRE
POLAND

Outline

1. Introduction
2. Simplified models
3. Tools for reinterpretation of searches
   a) MadAnalysis
   b) SModelS
   c) CheckMATE
4. Examples of reinterpretation studies
5. Summary

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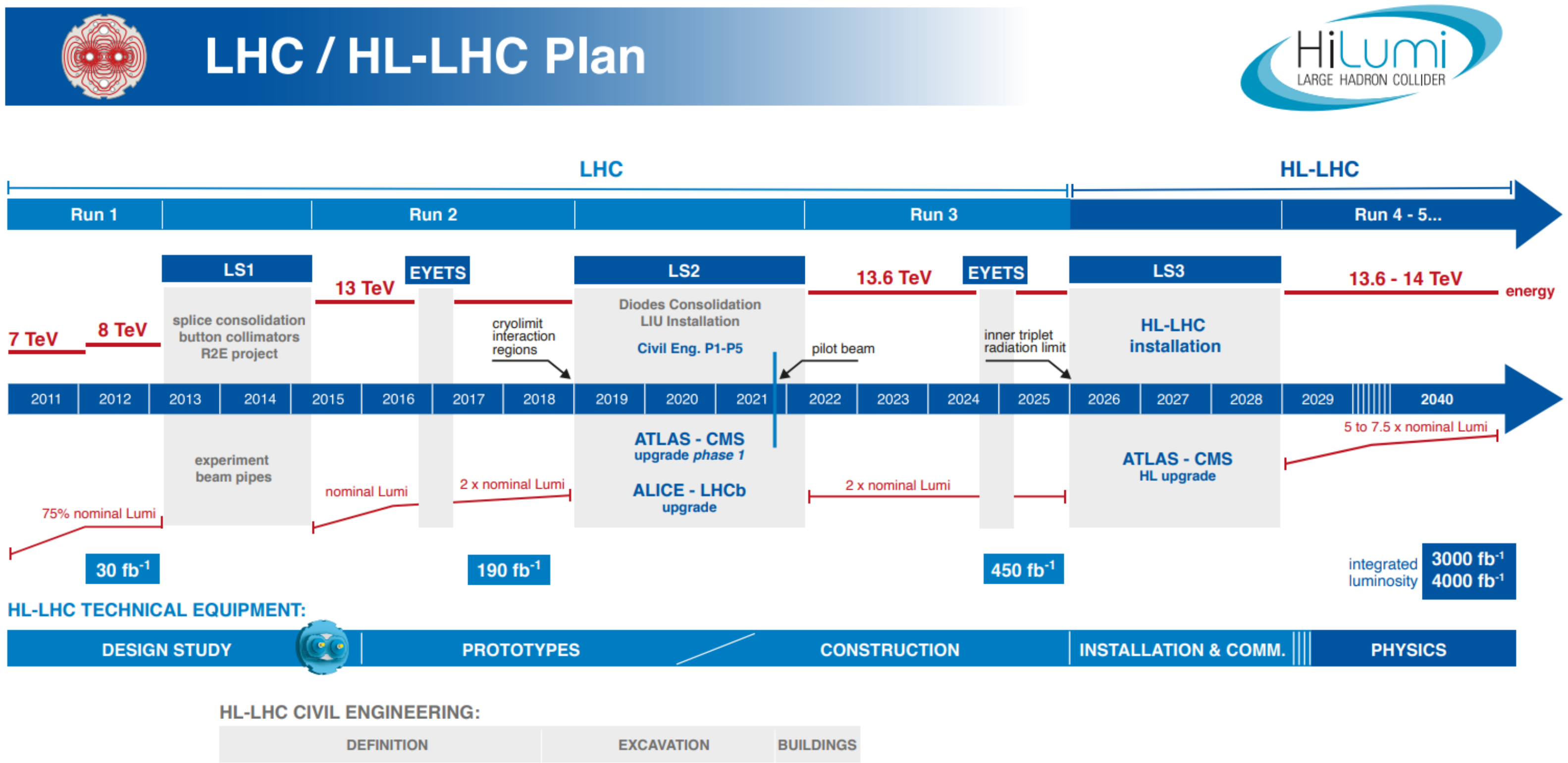
LHC timeline



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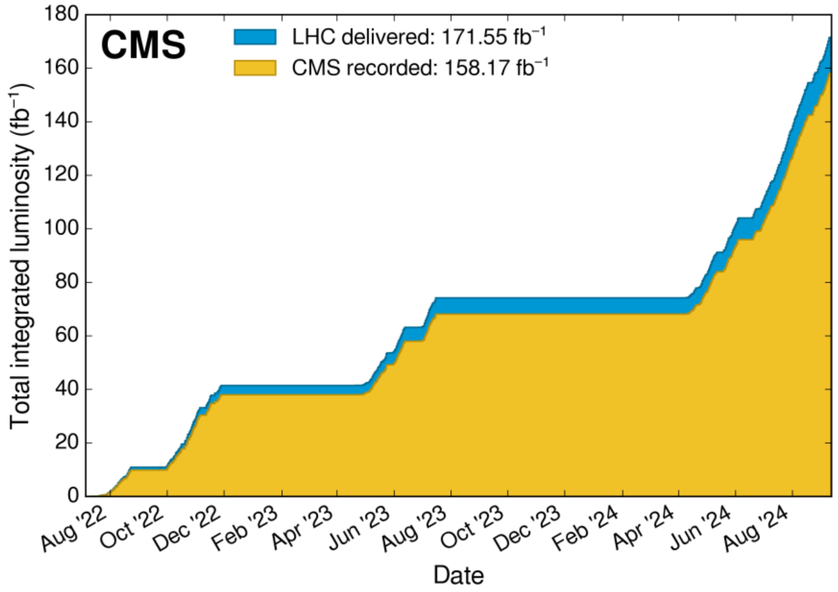
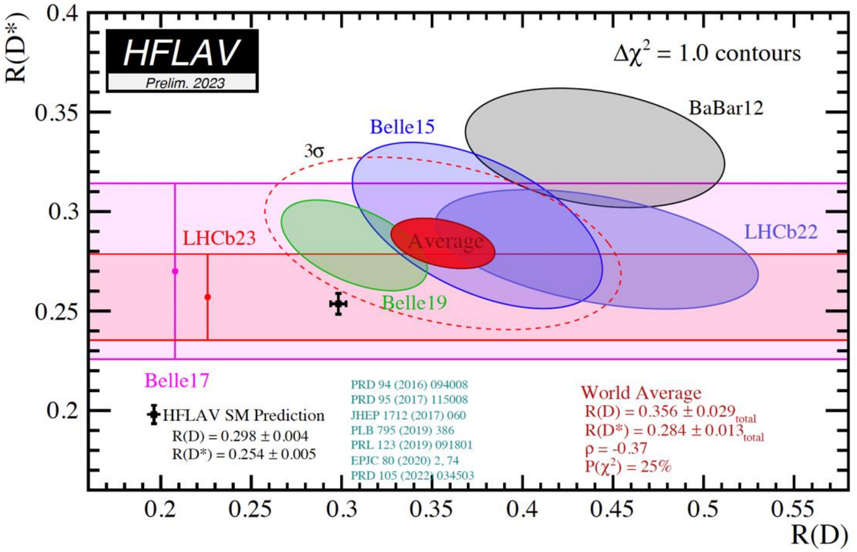
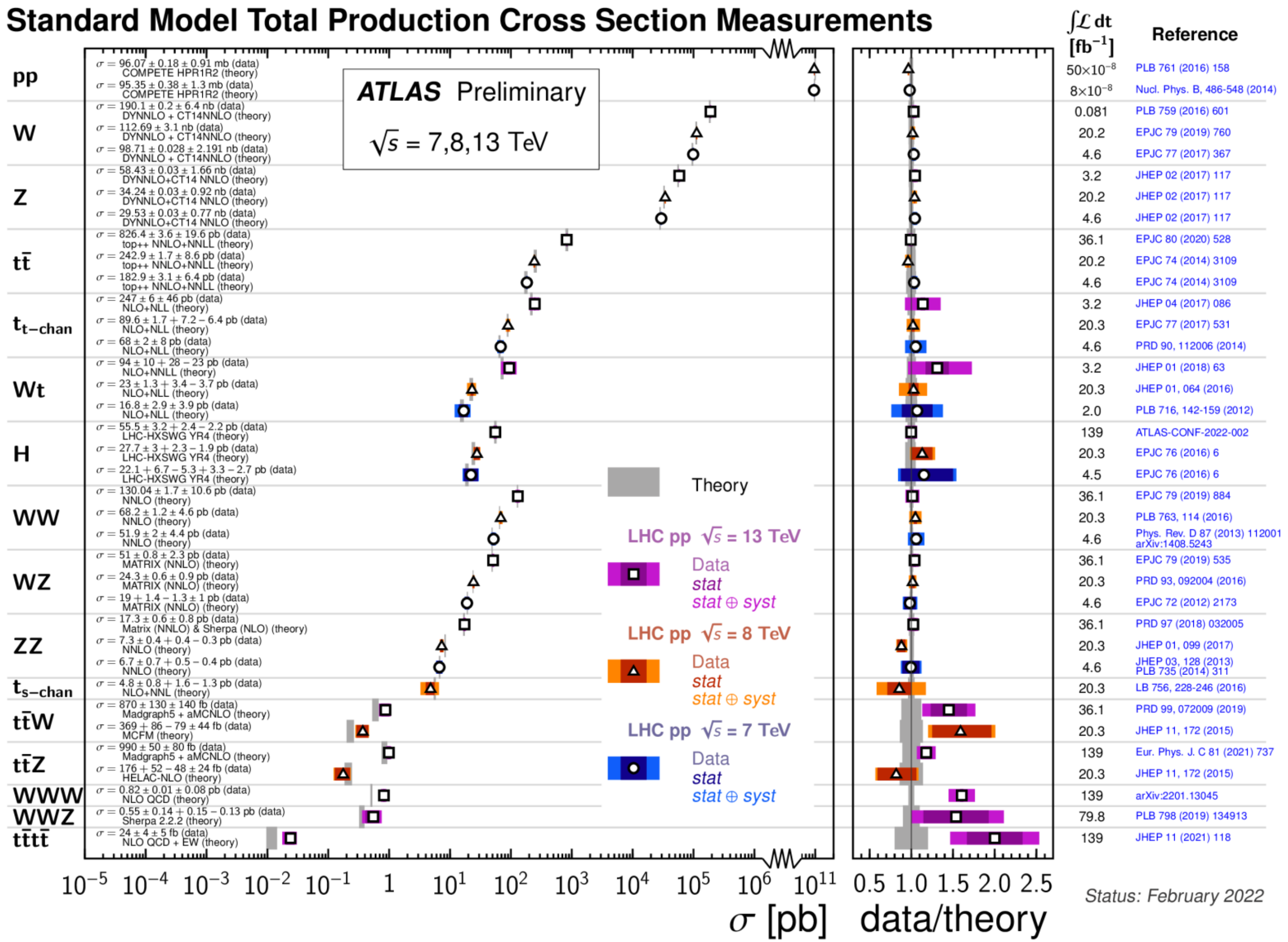


Still a long road ahead!

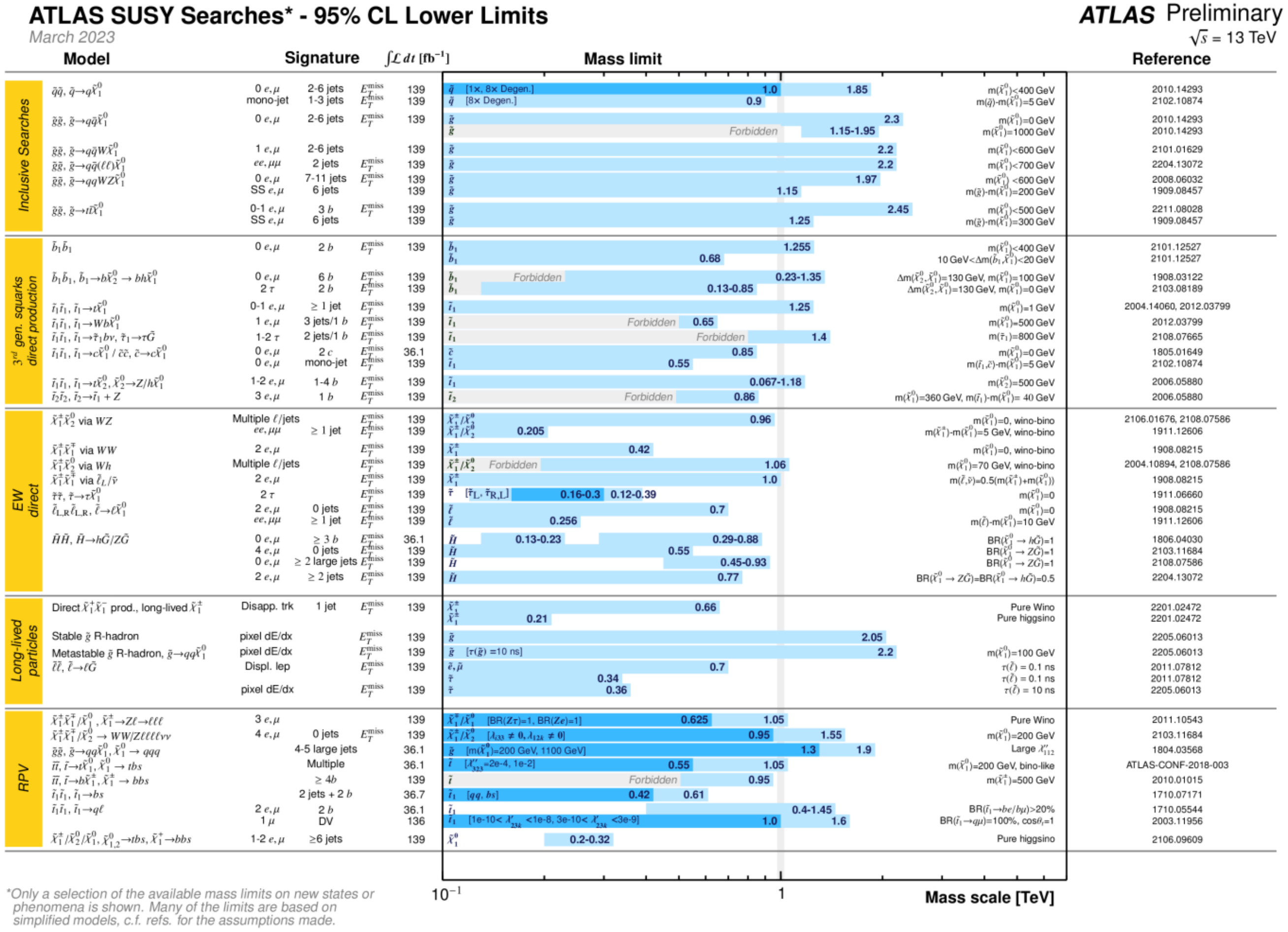
SM in perfect shape

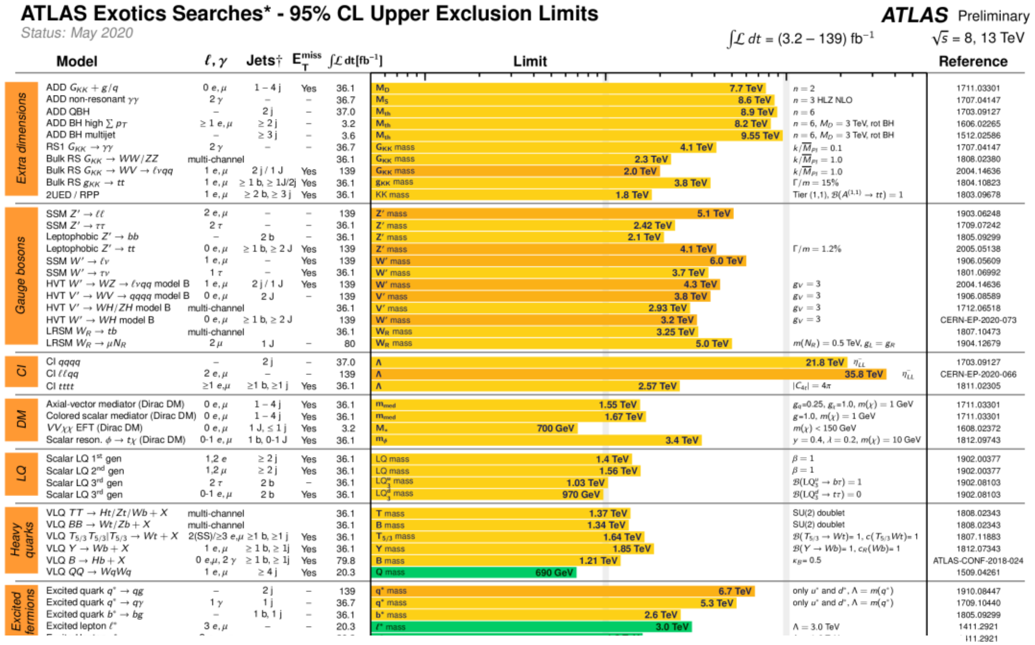
- Hundreds of measurements in excellent agreement with Standard Model predictions
- Several excesses with unclear status

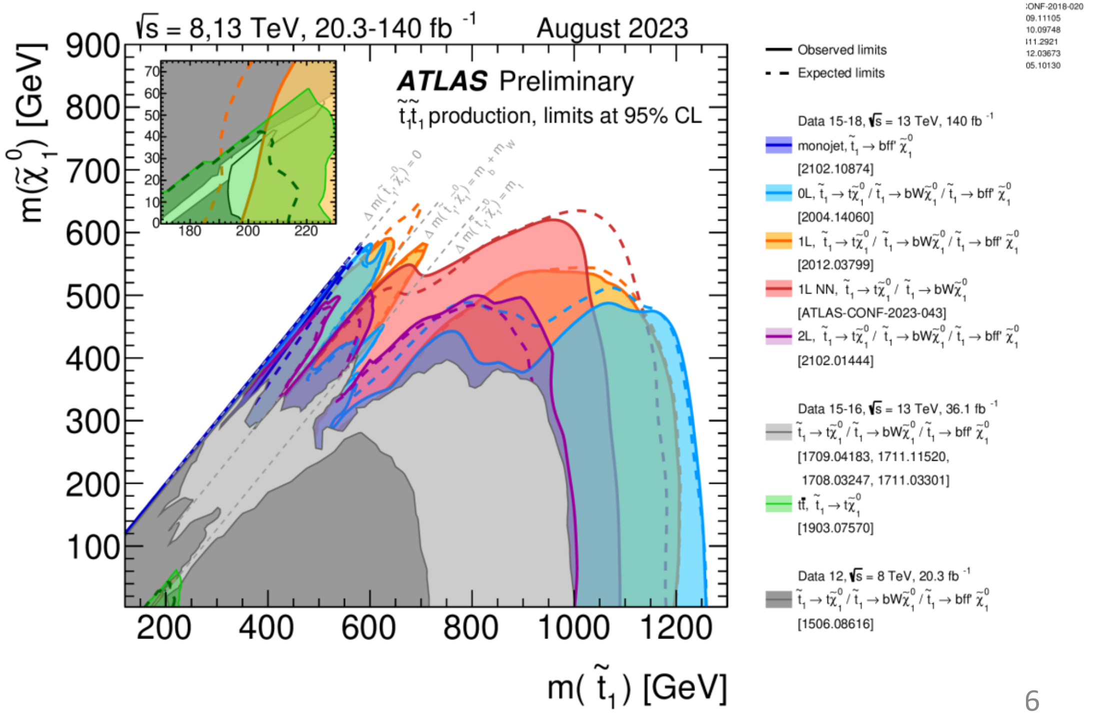




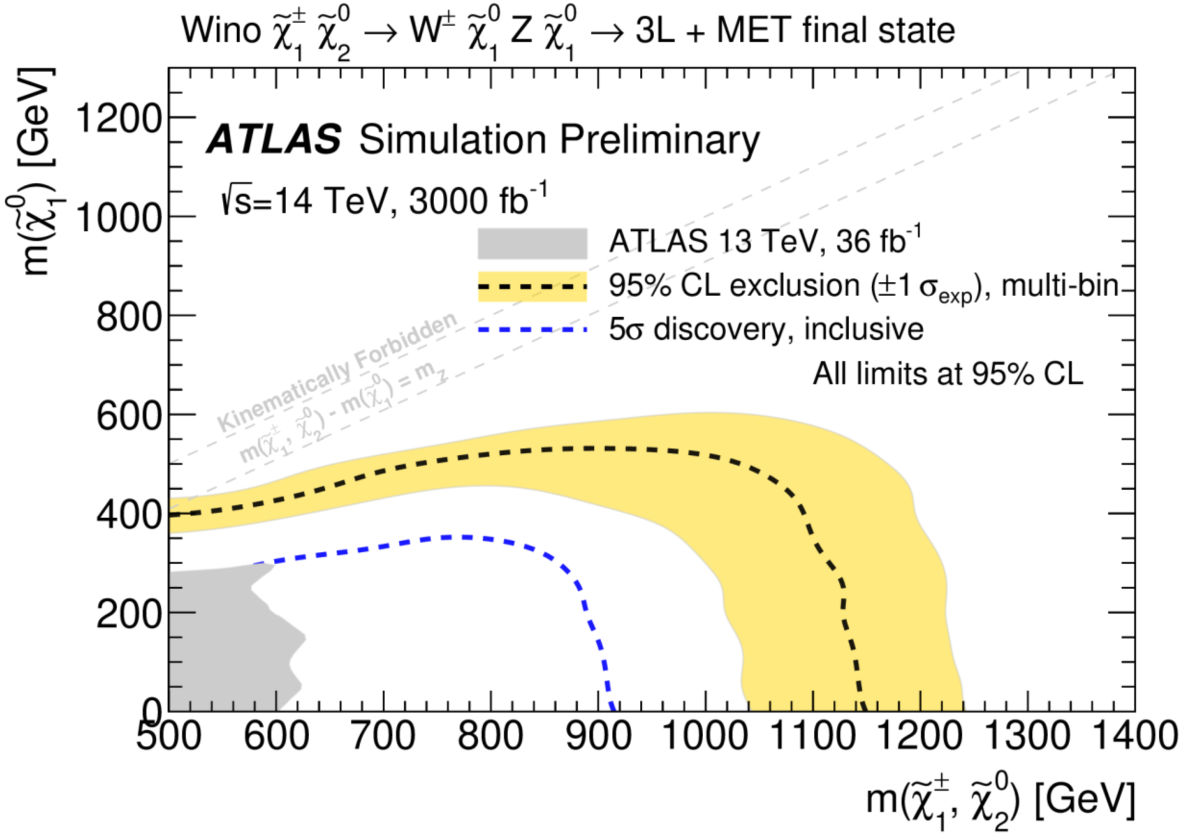
Searches, searches…

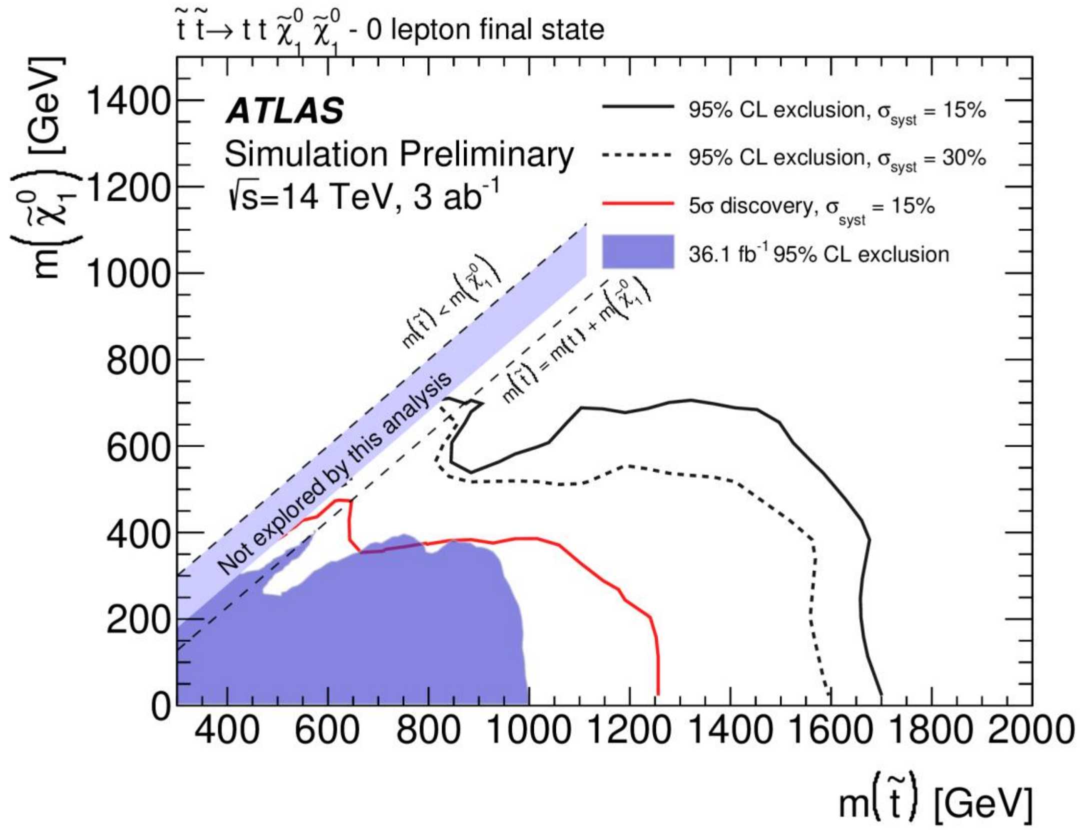






More expected at the High Luminosity LHC





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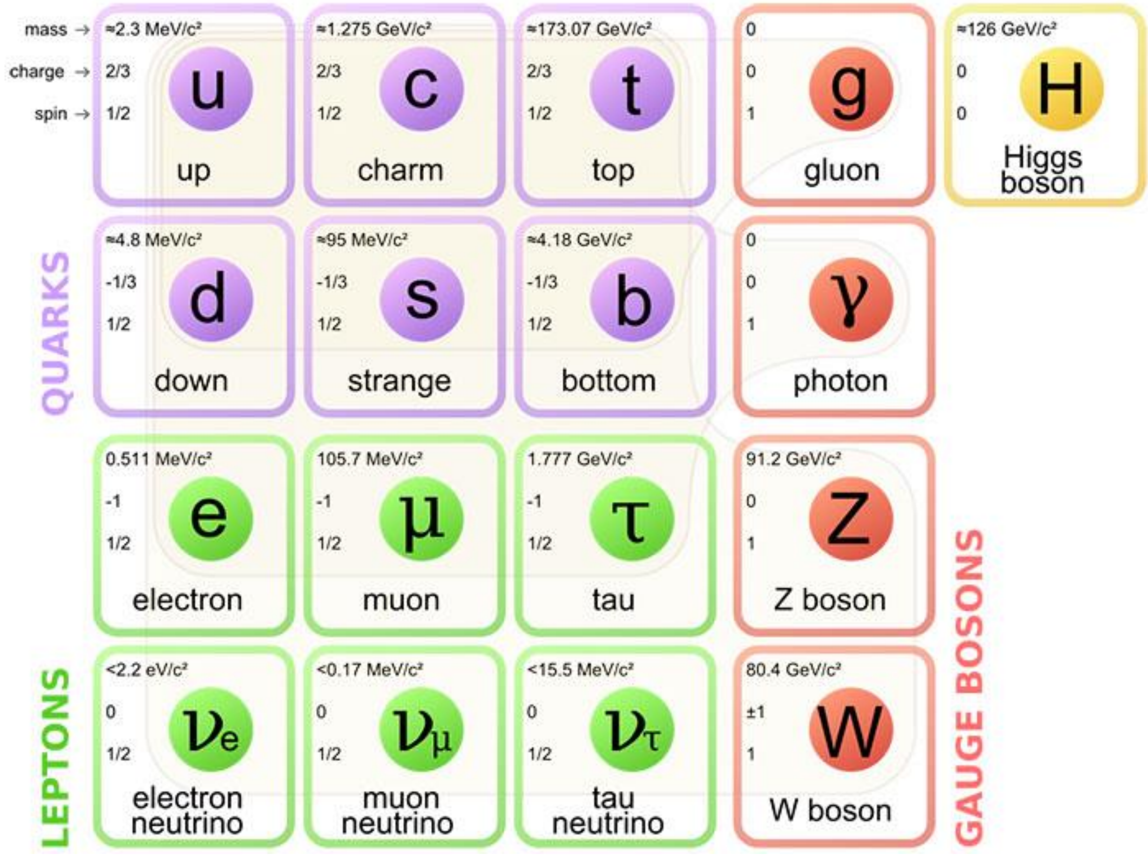
SM and then what?



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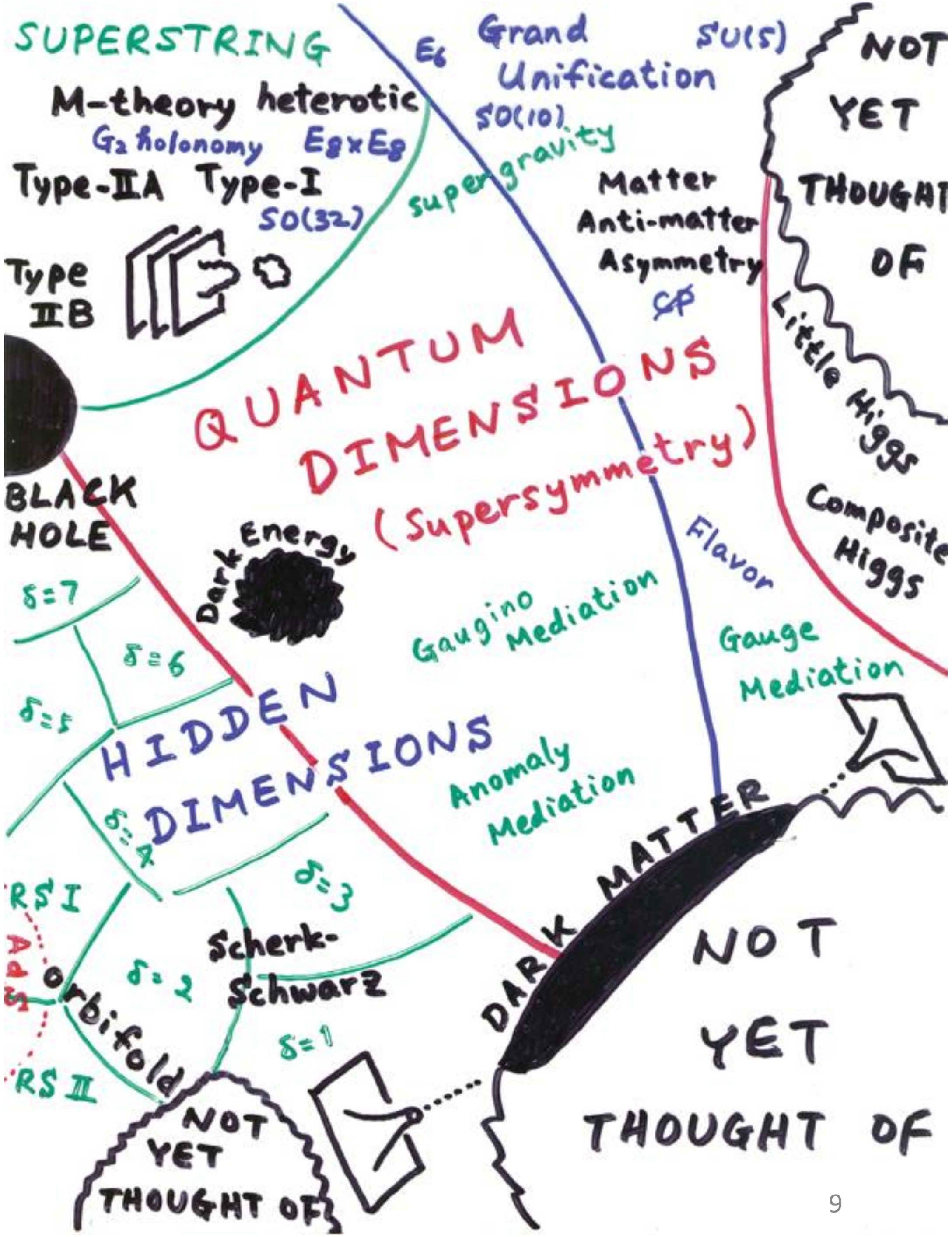
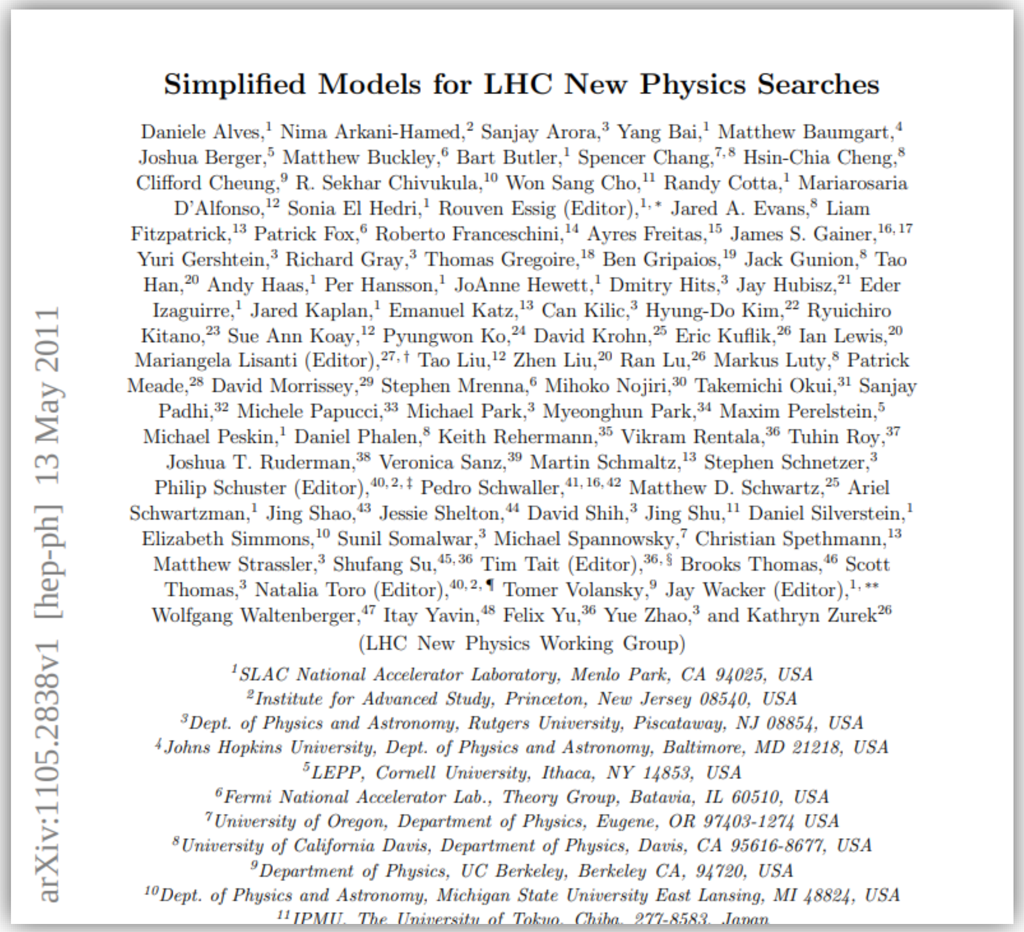


Why simplified models?

- Realistic new physics models tend to involve many new parameters, for example the Minimal Supersymmetric Standard Model ~ 100
- This makes the interpretation and design of searches difficult
- The purpose of simplified models is to reduce the number of parameters: include only a few particles and interactions of a full model with fixed branching fractions


arXiv:1105.2838v1 [hep-ph] 13 May 2011

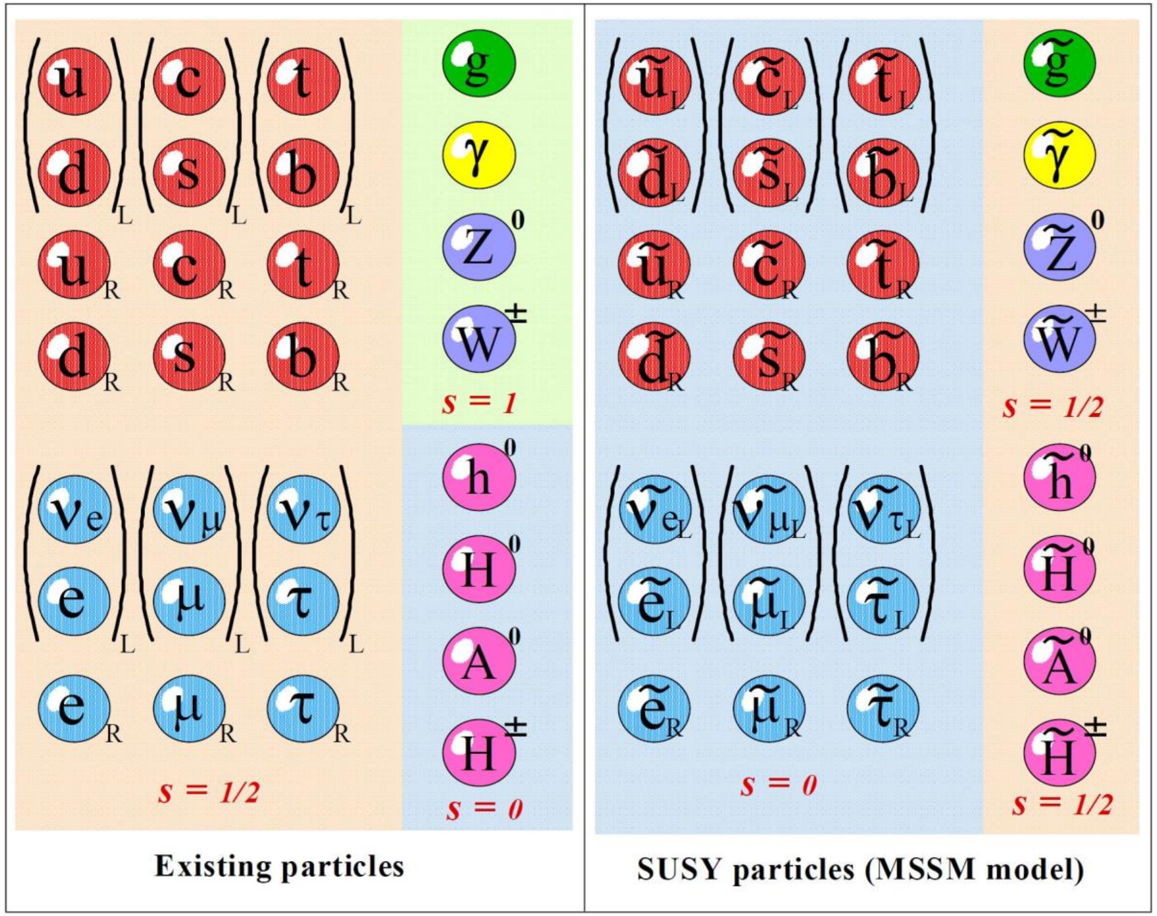
Simplified Models for LHC New Physics Searches

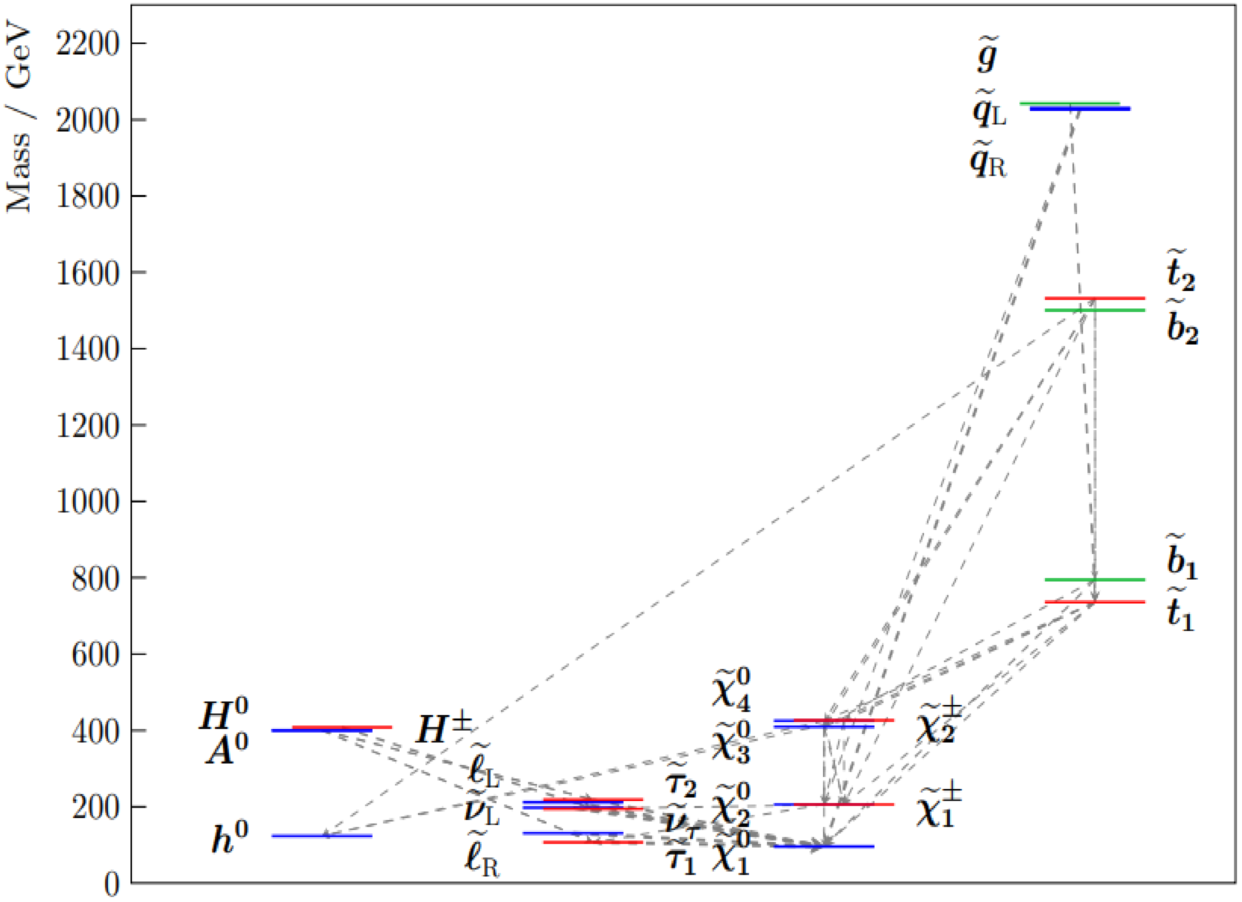
Daniele Alves,[1] Nima Arkani-Hamed,[2] Sanjay Arora,[3] Yang Bai,[1] Matthew Baumgart,[4] Joshua Berger,[5] Matthew Buckley,[6] Bart Butler,[1] Spencer Chang,[7,8] Hsin-Chia Cheng,[8] Clifford Cheung,[9] R. Sekhar Chivukula,[10] Won Sang Cho,[11] Randy Cotta,[1] Mariarosaria D'Alfonso,[12] Sonia El Hedri,[1] Rouven Essig (Editor),[1,*] Jared A. Evans,[8] Liam Fitzpatrick,[13] Patrick Fox,[6] Roberto Franceschini,[14] Ayres Freitas,[15] James S. Gainer,[16,17] Yuri Gershtein,[3] Richard Gray,[3] Thomas Gregoire,[18] Ben Gripaios,[19] Jack Gunion,[8] Tao Han,[20] Andy Haas,[1] Per Hansson,[1] JoAnne Hewett,[1] Dmitry Hits,[3] Jay Hubisz,[21] Eder Izaguirre,[1] Jared Kaplan,[1] Emanuel Katz,[13] Can Kilic,[3] Hyung-Do Kim,[22] Ryuichiro Kitano,[23] Sue Ann Koay,[12] Pyungwon Ko,[24] David Krohn,[25] Eric Kuflik,[26] Ian Lewis,[20] Mariangela Lisanti (Editor),[27,†] Tao Liu,[12] Zhen Liu,[20] Ran Lu,[26] Markus Luty,[8] Patrick Meade,[28] David Morrissey,[29] Stephen Mrenna,[6] Mihoko Nojiri,[30] Takemichi Okui,[31] Sanjay Padhi,[32] Michele Papucci,[33] Michael Park,[3] Myeonghun Park,[34] Maxim Perelstein,[5] Michael Peskin,[1] Daniel Phalen,[8] Keith Rehermann,[35] Vikram Rentala,[36] Tuhin Roy,[37] Joshua T. Ruderman,[38] Veronica Sanz,[39] Martin Schmaltz,[13] Stephen Schnetzer,[3] Philip Schuster (Editor),[40,2,‡] Pedro Schwaller,[41,16,42] Matthew D. Schwartz,[25] Ariel Schwartzman,[1] Jing Shao,[43] Jessie Shelton,[44] David Shih,[3] Jing Shu,[11] Daniel Silverstein,[1] Elizabeth Simmons,[10] Sunil Somalwar,[3] Michael Spannowsky,[7] Christian Spethmann,[13] Matthew Strassler,[3] Shufang Su,[45,36] Tim Tait (Editor),[36,§] Brooks Thomas,[46] Scott Thomas,[3] Natalia Toro (Editor),[40,2,¶] Tomer Volansky,[9] Jay Wacker (Editor),[1,**] Wolfgang Waltenberger,[47] Itay Yavin,[48] Felix Yu,[36] Yue Zhao,[3] and Kathryn Zurek[26]

(LHC New Physics Working Group)

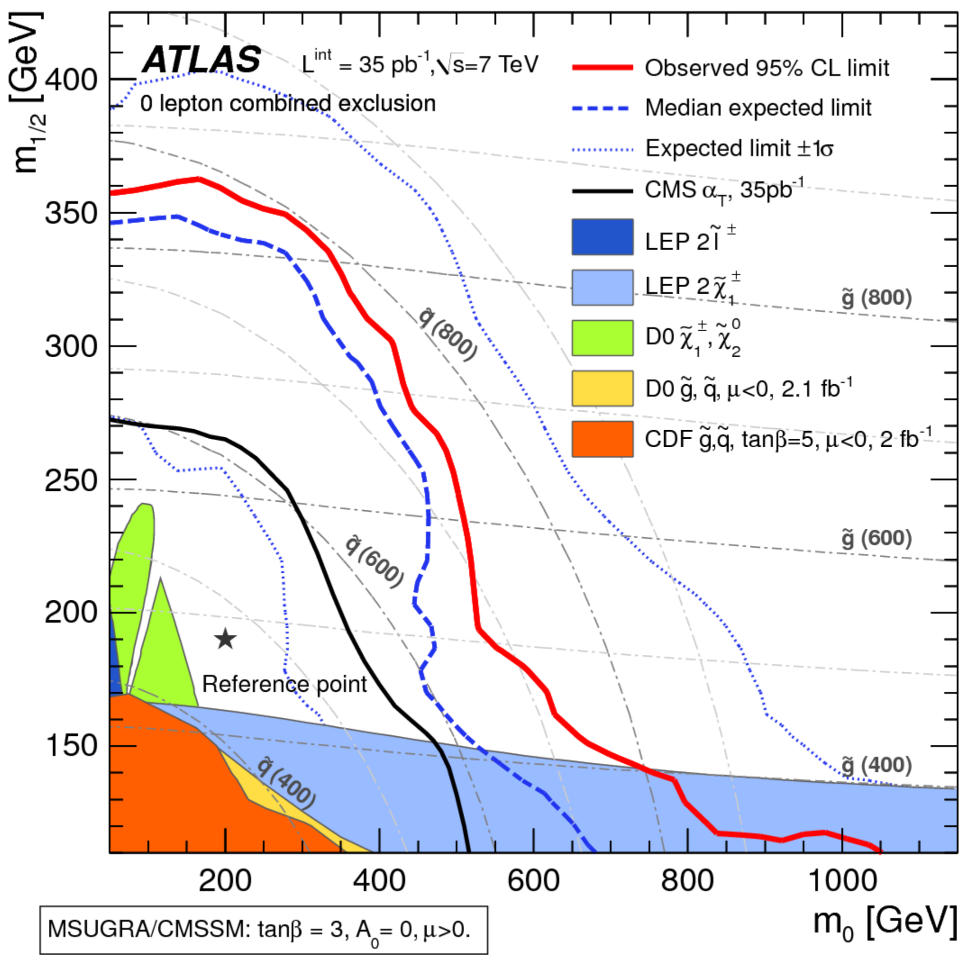
[1] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
[2] *Institute for Advanced Study, Princeton, New Jersey 08540, USA*
[3] *Dept. of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854, USA*
[4] *Johns Hopkins University, Dept. of Physics and Astronomy, Baltimore, MD 21218, USA*
[5] *LEPP, Cornell University, Ithaca, NY 14853, USA*
[6] *Fermi National Accelerator Lab., Theory Group, Batavia, IL 60510, USA*
[7] *University of Oregon, Department of Physics, Eugene, OR 97403-1274 USA*
[8] *University of California Davis, Department of Physics, Davis, CA 95616-8677, USA*
[9] *Department of Physics, UC Berkeley, Berkeley CA, 94720, USA*
[10] *Dept. of Physics and Astronomy, Michigan State University East Lansing, MI 48824, USA*

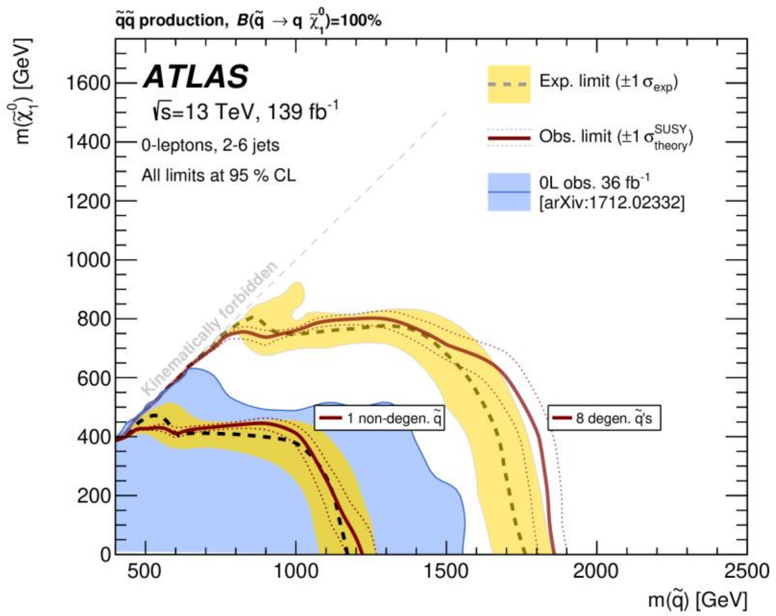
Benchmark MSSM example

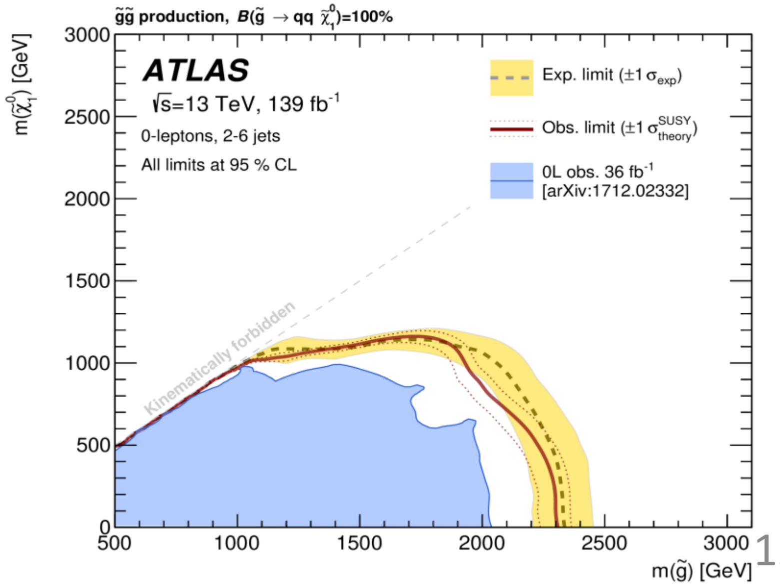




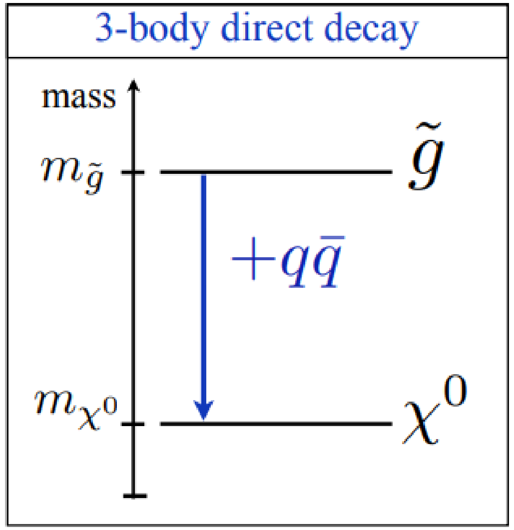
Example: supersymmetry

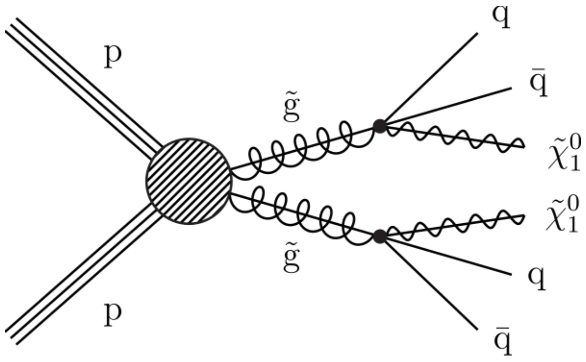


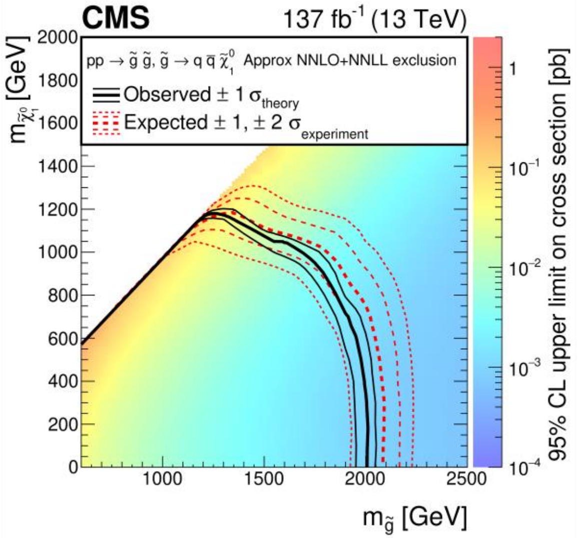


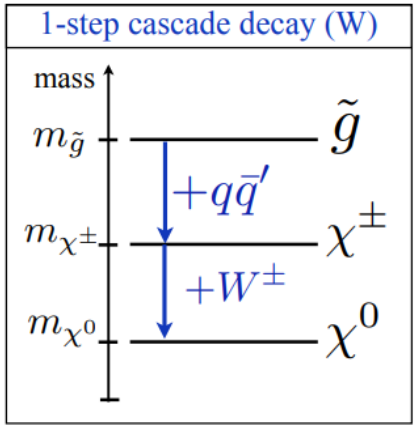


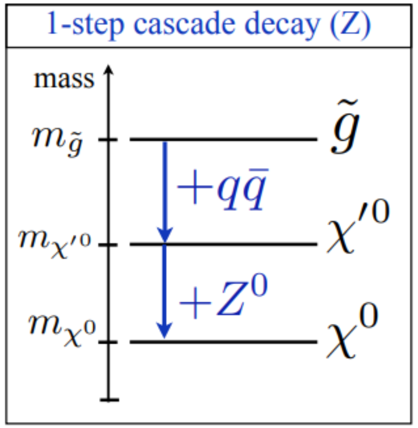
Example: gluino simplified models – jets+MET

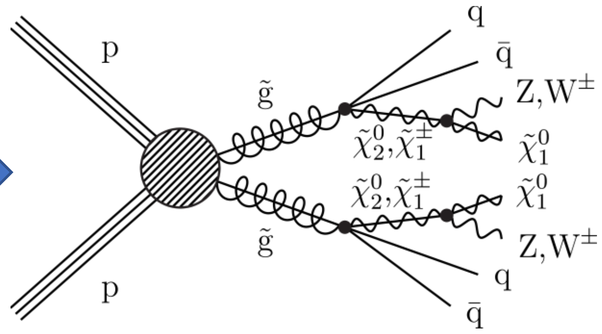


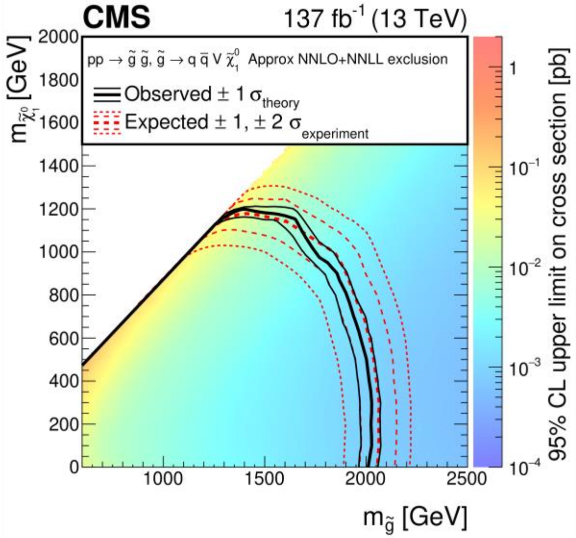




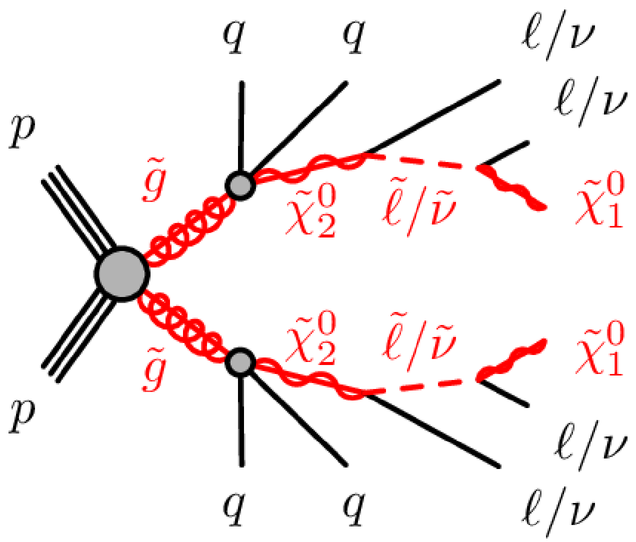


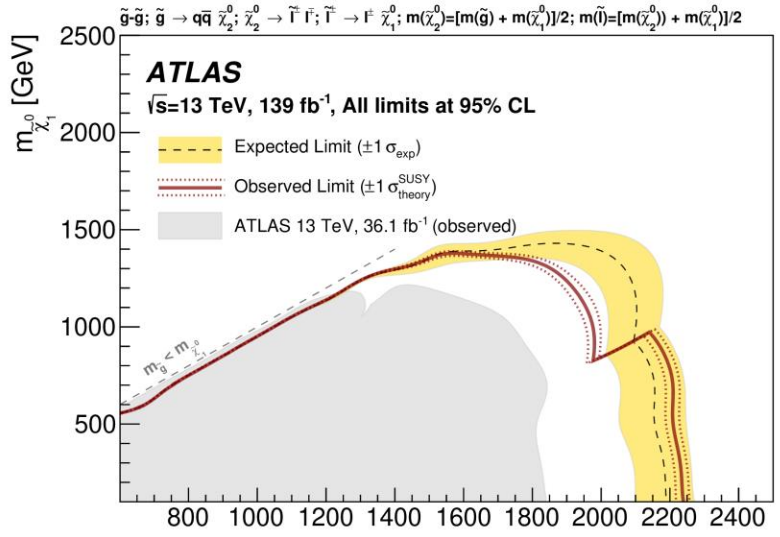


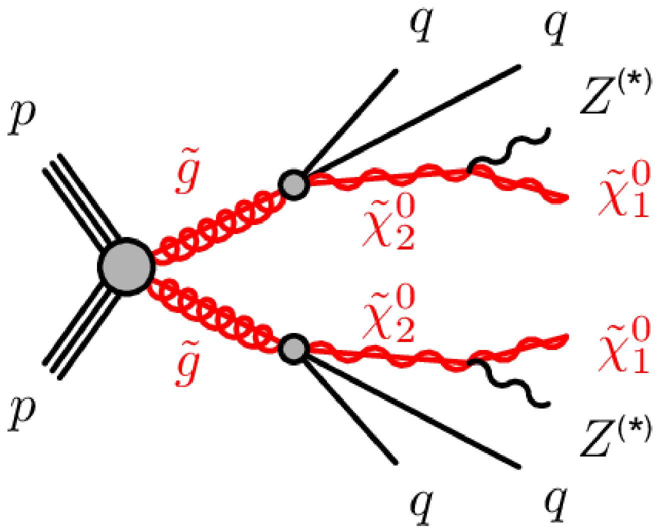


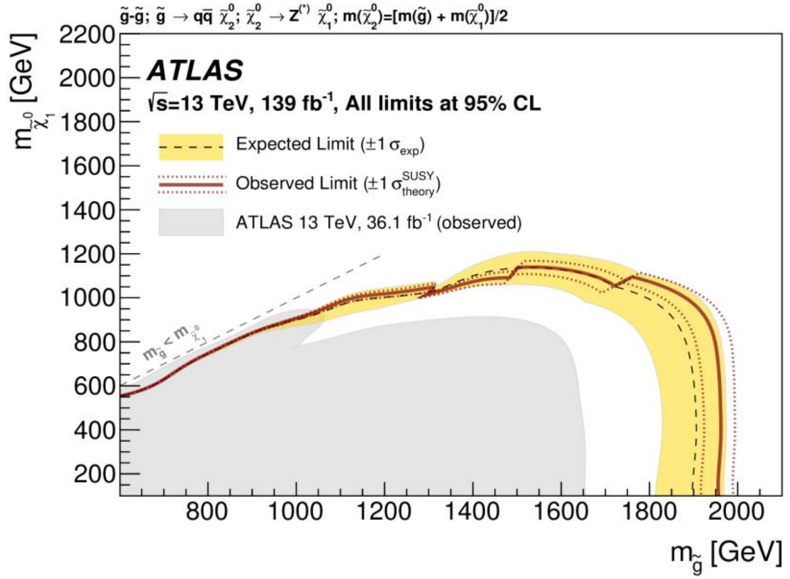


More gluino models – jets+leptons+MET

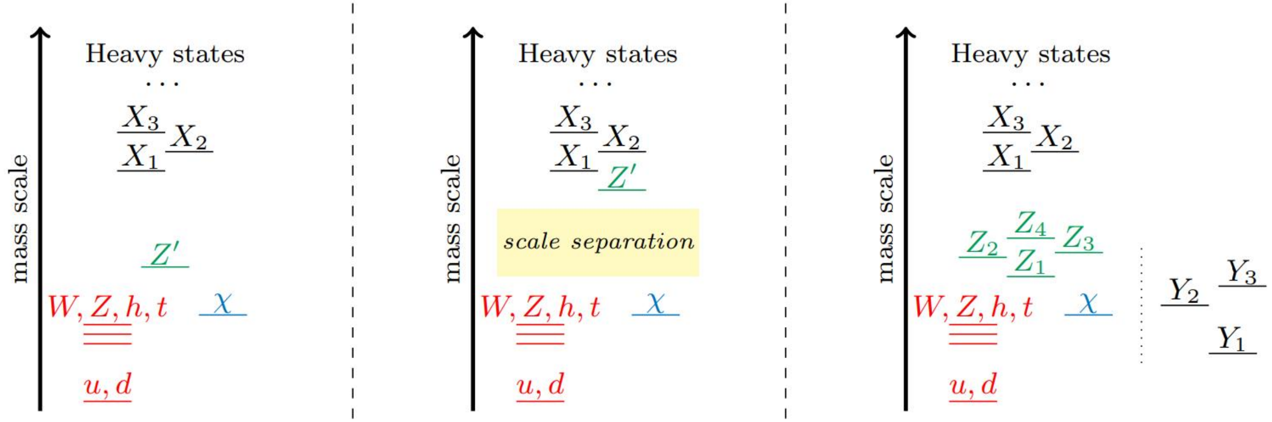


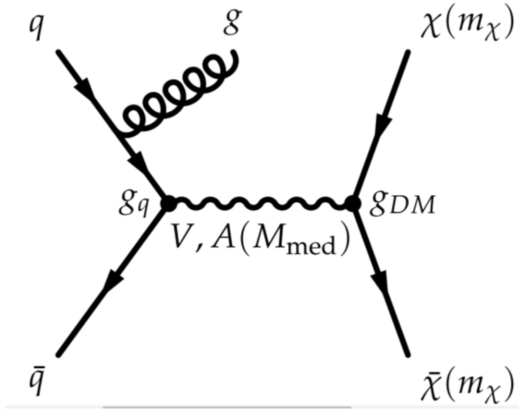


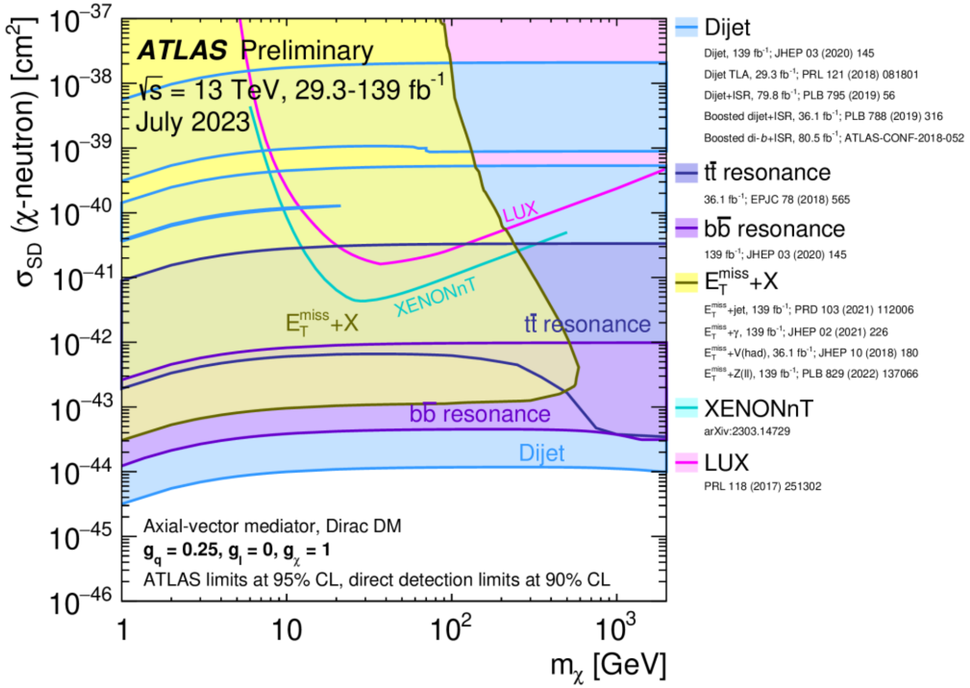


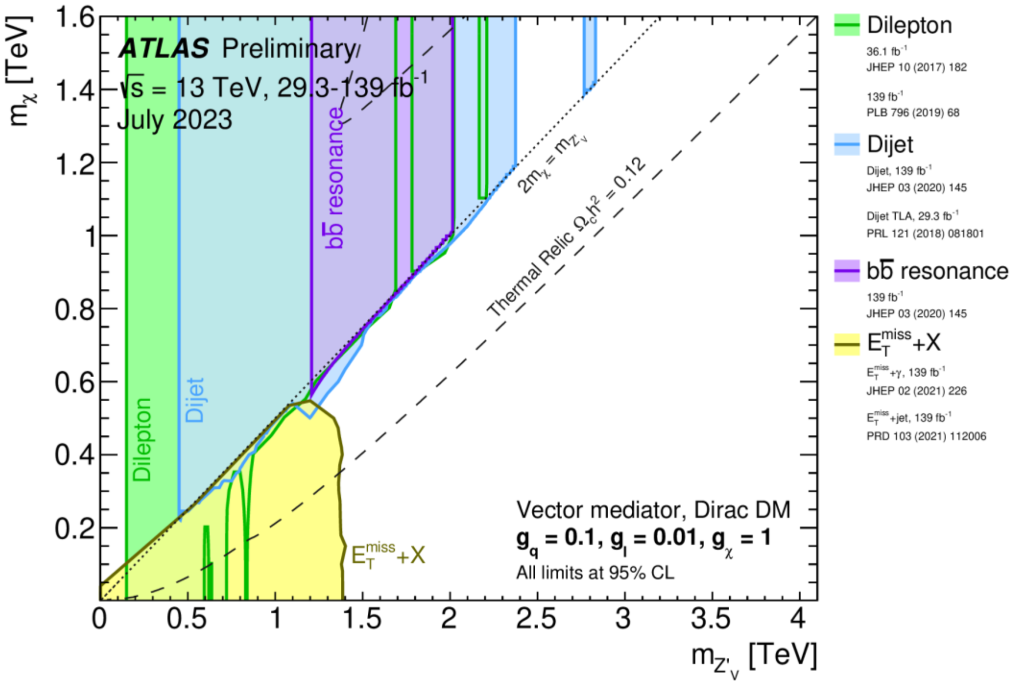


Dark matter searches – colliders vs DD









The purpose of simplified models

A simplified model is specifically designed to involve only a few new particles and interactions. They are limits of more general new physics scenarios, where all but a few particles are integrated out.

- **Identifying the boundaries of search sensitivity:**
  one- and two-dimensional slices within a simplified model can illustrate these boundaries very clearly and help to identify kinematic ranges
- **Characterizing new physics signals:**
  simplified models can be a starting point for identification of observed signal with different realistic models
- **Deriving limits on more general models:**
  the initial assessment within a simplified model should be followed by a dedicated recasting study

Simplified model summary

- Simplified models cover a small and often unrealistic part of the models and parameters landscape
- Simplified models provide an easy parametrization in terms of just a few parameters e.g., 2-3 masses, perhaps a branching fraction (but often 100%)
- Hundreds of searches for supersymmetry but other models used to be less popular (this is changing though)
- Provide a clear link in terms of limits between particular topologies and final states e.g.: jets + MET, jets + lepton + MET, jets + lepton...
- Simplified models were never meant as a final word in searches for TeV-scale physics
- Allows for confrontation with other detection methods
- A quick way of recasting searches optimized for simplified models is essential in the quest for new physics

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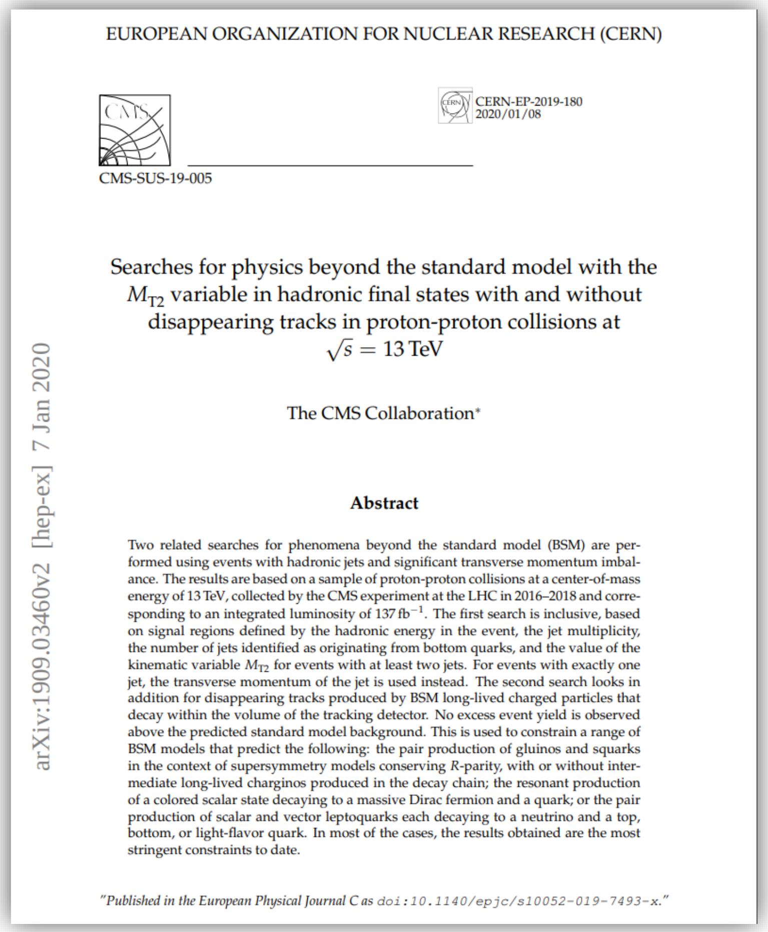
Monte Carlo tools & discoveries at the LHC

Searches for new TeV-scale physics still one of the main goals in the coming years

- Theoretical model building offers a vast number of models with particles in the LHC reach
- Experimental papers cover only a small fraction of existing models
- We need tools to cover the gap and: assess viability of models, guide future searches, looking for blind spots
- Computer tools are essential: Monte Carlo generators, fast detector simulators, cross section calculators
- We need tools to analyze MC output easily and compare it quickly and reliably with existing experimental exclusions

This is the main purpose of recasting tools

Reinterpretation/recasting in a nutshell



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2019-180
2020/01/08

CMS-SUS-19-005

Searches for physics beyond the standard model with the M_{T2} variable in hadronic final states with and without disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV

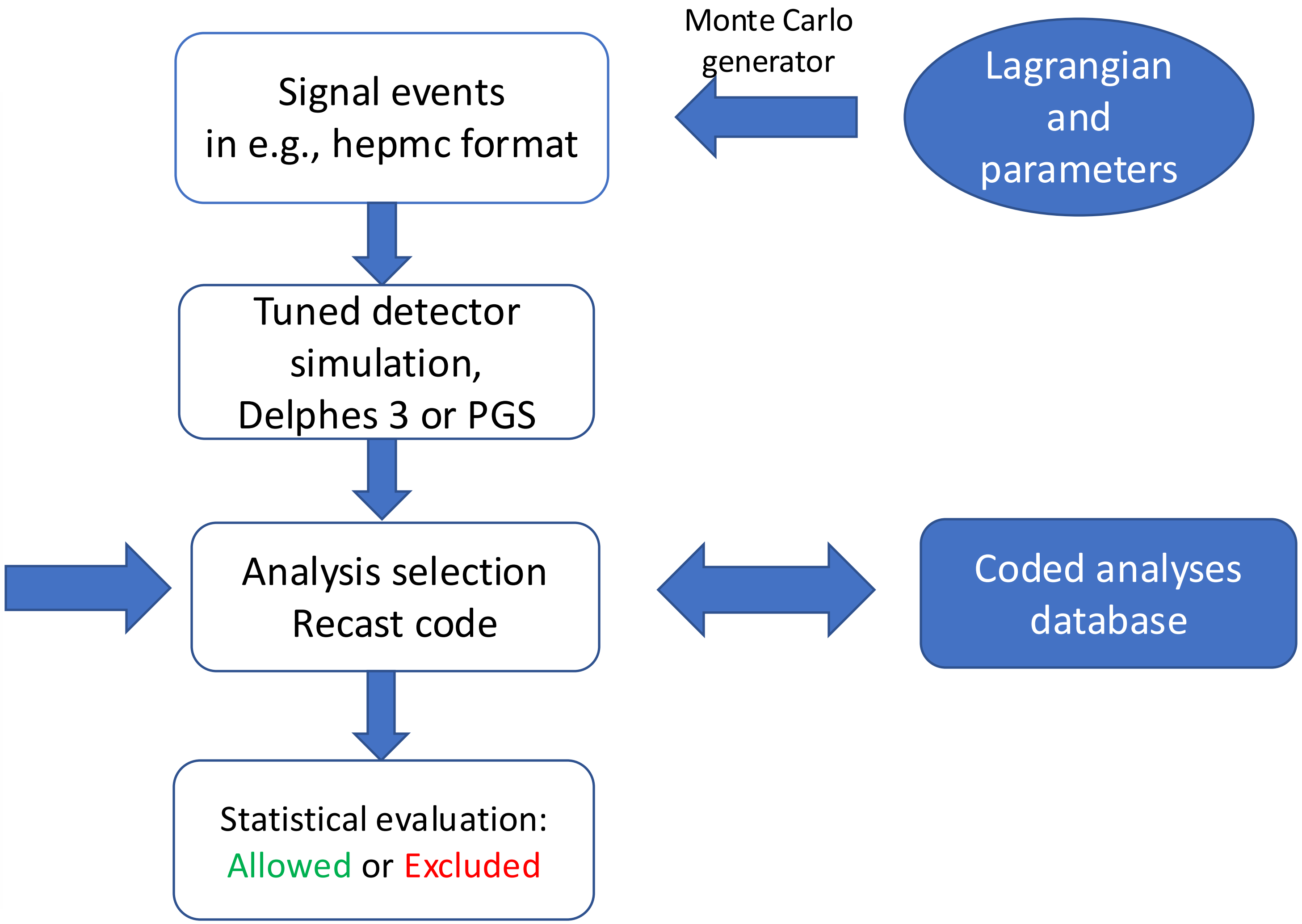
The CMS Collaboration*

Abstract

Two related searches for phenomena beyond the standard model (BSM) are performed using events with hadronic jets and significant transverse momentum imbalance. The results are based on a sample of proton-proton collisions at a center-of-mass energy of 13 TeV, collected by the CMS experiment at the LHC in 2016–2018 and corresponding to an integrated luminosity of 137 fb^{-1}. The first search is inclusive, based on signal regions defined by the hadronic energy in the event, the jet multiplicity, the number of jets identified as originating from bottom quarks, and the value of the kinematic variable M_{T2} for events with at least two jets. For events with exactly one jet, the transverse momentum of the jet is used instead. The second search looks in addition for disappearing tracks produced by BSM long-lived charged particles that decay within the volume of the tracking detector. No excess event yield is observed above the predicted standard model background. This is used to constrain a range of BSM models that predict the following: the pair production of gluinos and squarks in the context of supersymmetry models conserving R-parity, with or without intermediate long-lived charginos produced in the decay chain; the resonant production of a colored scalar state decaying to a massive Dirac fermion and a quark; or the pair production of scalar and vector leptoquarks each decaying to a neutrino and a top, bottom, or light-flavor quark. In most of the cases, the results obtained are the most stringent constraints to date.

"Published in the European Physical Journal C as doi:10.1140/epjc/s10052-019-7493-x."

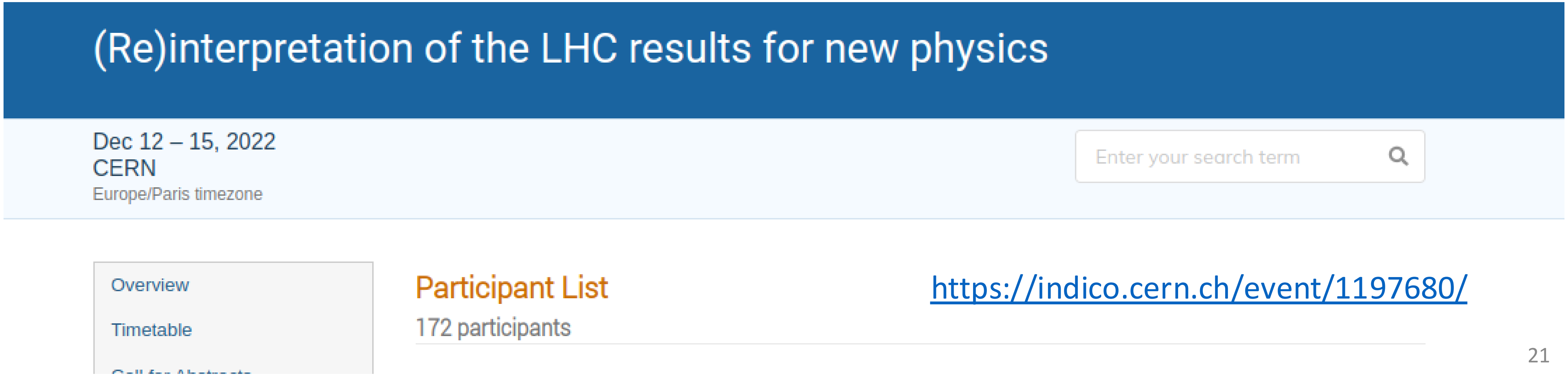
arXiv:1909.03460v2 [hep-ex] 7 Jan 2020



LHC Reinterpretation Forum

The purpose of the RIF is to discuss topics related to the BSM (re)interpretation of LHC data, including the development of the necessary public recasting tools and related infrastructure, and to provide a platform for a continued interaction between theorists and with the experiments. The recent topics:

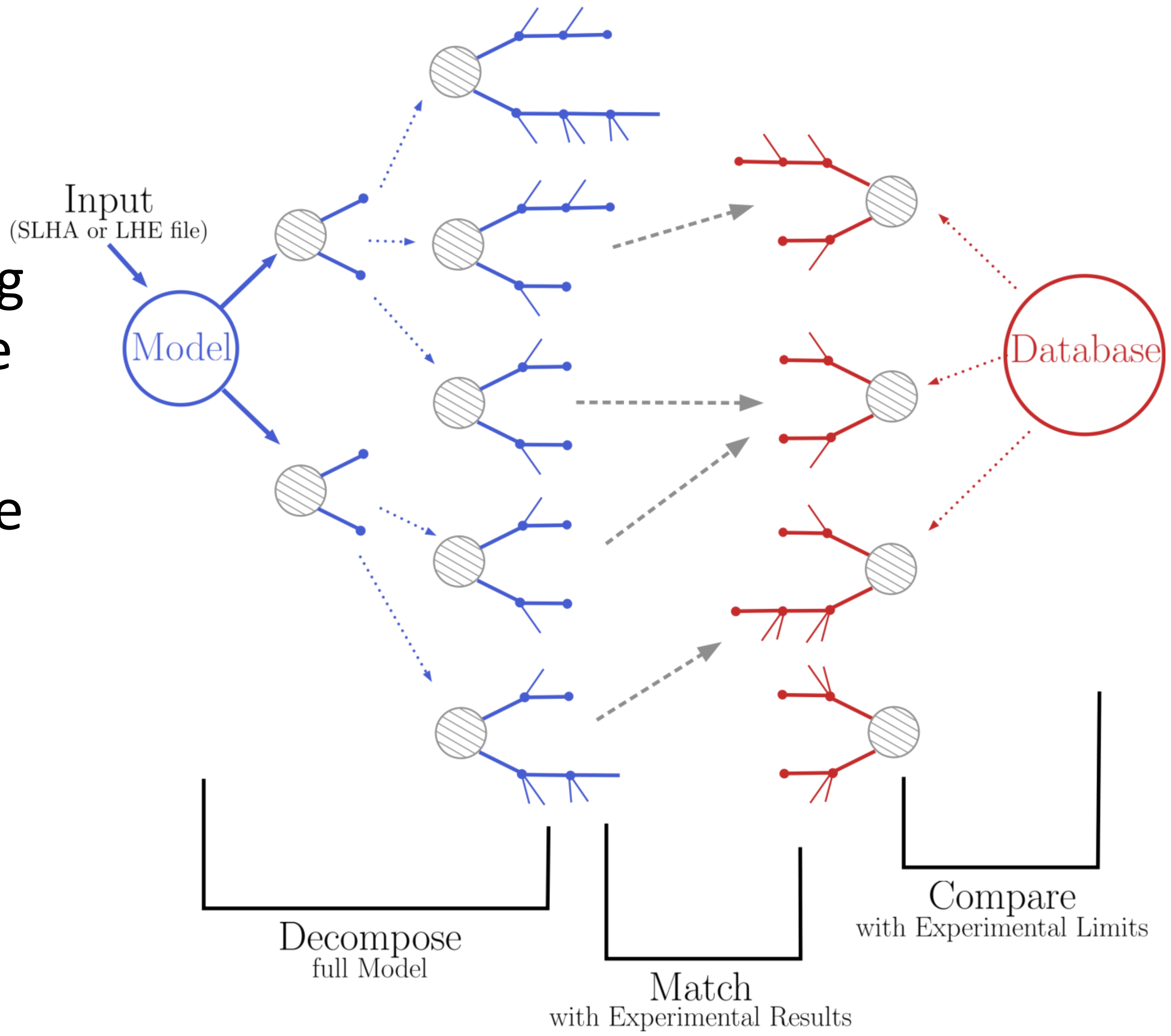
- the publication and reuse of statistical models
- the reinterpretation of analyses that employ machine learning
- global analyses and global fits
- preservation of data and methods for replication/reanalysis in future: for a once in a lifetime experiment we want to make sure all the necessary information is provided and understandable for people outside of a particular analysis



https://indico.cern.ch/event/1197680/

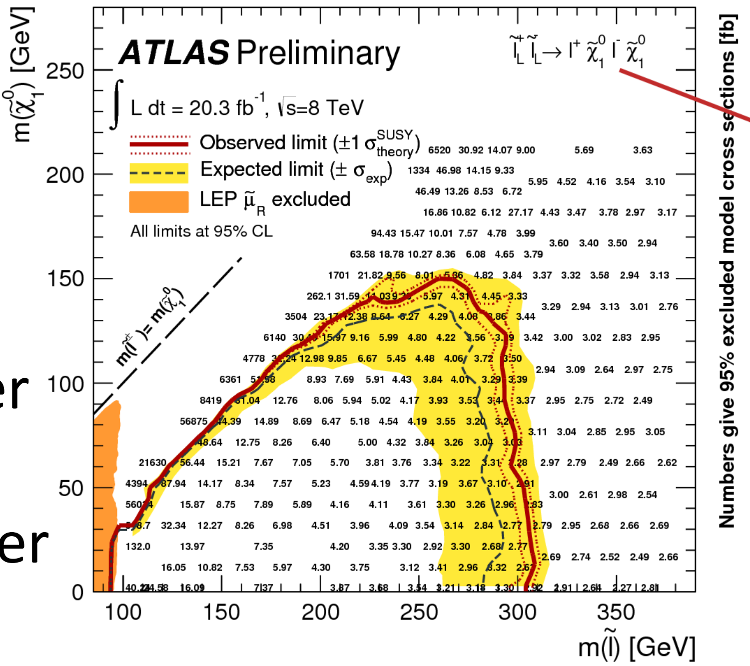
SModelS

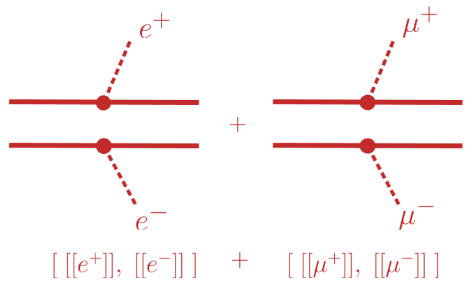
- An automatic tool for interpreting simplified-model results from the LHC
- It is based on a general procedure to decompose Beyond the Standard Model (BSM) collider signatures presenting a Z_2-like symmetry into Simplified Model Spectrum (SMS) topologies
- https://smodels.readthedocs.io/

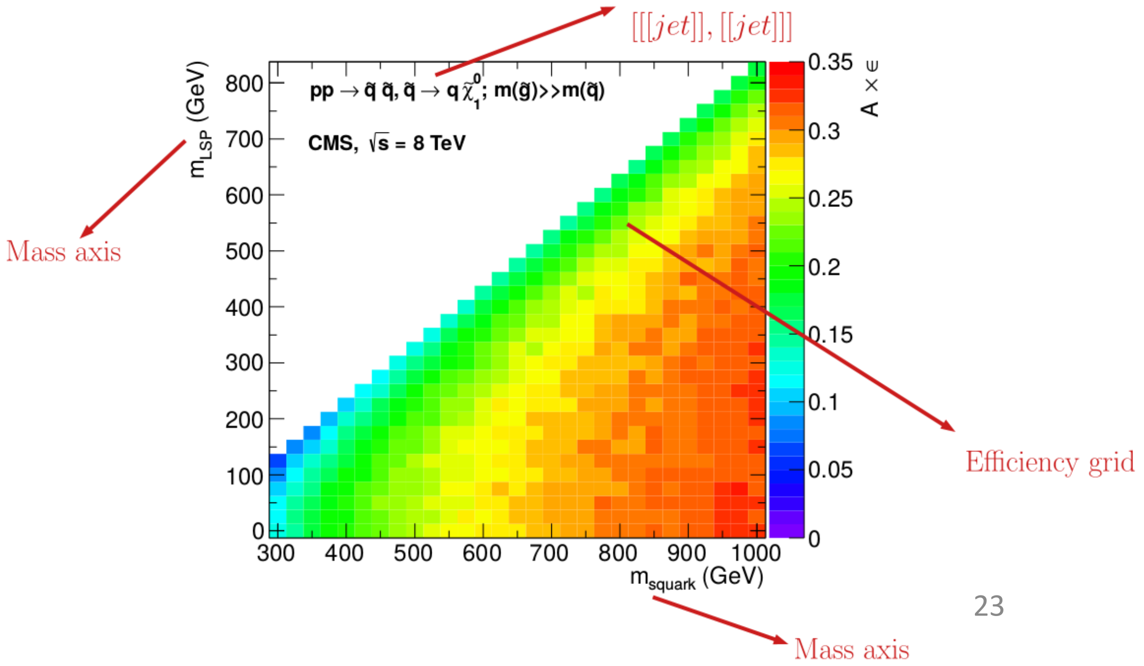


SModelS

- Based on a database of efficiencies either obtained directly from experimental collaboration or recasted (also using other tools like MadAnalysis or CheckMATE)
- Covers models which have SUSY-like topologies
- Less versatile than MadAnalysis or CheckMATE but significantly faster
- Uses efficiency maps or upper limits for specific topologies
- New: combination of searches/experiments







SModelS coverage

Run 2 - 13 TeV:

- In total, we have results from 35 ATLAS and 39 CMS 13 TeV searches.
- ATLAS upper limits: 32 analyses, 80 (of which 4 LLP) results
- ATLAS efficiency maps: 21 analyses, 65 (of which 11 LLP) results, 599 individual maps
- CMS upper limits: 36 analyses, 143 (of which 3 LLP) results
- CMS efficiency maps: 8 analyses, 53 results, 3186 individual maps

Run 1 - 8 TeV:

- In total, we have results from 15 ATLAS and 18 CMS 8 TeV searches.
- ATLAS upper limits: 13 analyses, 34 results
- ATLAS efficiency maps: 10 analyses, 31 results, 269 individual maps
- CMS upper limits: 16 analyses, 56 (of which 3 LLP) results
- CMS efficiency maps: 9 analyses, 47 (of which 9 LLP) results, 980 individual maps

MadAnalysis 5

- High level of integration with Monte Carlo generator MadGraph5
- A Python and C++ based framework for phenomenological analyses
- Any level of sophistication: partonic, hadronic, detector, reconstructed
- Several input format: STDHEP, HEPMC, LHE, LHEO, ROOT (from Delphes)
- Interfaces to other HEP packages (fast detector simulation, jet clustering etc.)
- Two modules
  1) Python command line interface (interactive)
  2) C++ core module, SampleAnalyzer
- https://launchpad.net/madanalysis5

MadAnalysis: Public Analysis Data Base

ATLAS analyses, 13 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Version
ATLAS-SUSY-2015-06	Multijet + missing transverse momentum (3.2 fb-1)	S. Banerjee, B. Fuks, B. Zaldivar	MA5 dataverse	PDF	v1.3/Delphes3
ATLAS-SUSY-2016-07	Multijet + missing transverse momentum (36.1 fb-1)	G. Chalons, H. Reyes-Gonzalez J.Y. Araz	MA5 dataverse MA5 dataverse	PDF Pythia files Sec. 5.2 in 2006.09387	v1.7/Delphes3 v1.8/SFS
ATLAS-SUSY-2017-04	Displaced vertices with opposite-charge lepton pairs (32.8 fb-1)	M. Utsch, M. Goodsell	MA5 dataverse	Sec. 4 in 2112.05163	v1.9/SFS
ATLAS-SUSY-2018-04	Staus in the ditau + met channel (139 fb-1)	J. Lim, C.-T. Lu, J.-H. Park, J. Park	MA5 dataverse	PDF	v1.8/Delphes3
ATLAS-SUSY-2018-06	Electroweakinos with Jigsaw variables (139 fb-1)	J.H. Kim, T.G. Lee, J.W. Kim, H. Jang	MA5 dataverse	PDF	v1.8/Delphes3
ATLAS-SUSY-2018-17	At least 8 jets + met (139 fb-1)	T. Murphy	MA5 dataverse	PDF	v1.9/Delphes3
ATLAS-SUSY-2018-31	Sbottoms in the multibottom (including Higgs decays) + met channel (139 fb-1)	J.Y. Araz, B. Fuks	MA5 dataverse	PDF	v1.9/SFS
ATLAS-SUSY-2018-32	Electroweakinos/sleptons in the 2l + met channel (139 fb-1)	J.Y. Araz, B. Fuks	MA5 dataverse	PDF	v1.8/Delphes3
ATLAS-SUSY-2019-08	H (into b bbar) + 1 lepton + missing transverse momentum (139 fb-1)	M. Goodsell	MA5 dataverse	PDF	v1.8/Delphes3
ATLAS-EXOT-2015-03	Monojet (3.2 fb-1)	D. Sengupta	MA5 dataverse	PDF	v1.3/Delphes3
ATLAS-EXOT-2016-25	Mono-Higgs (36.1 fb-1)	S. Jeon, Y. Kang, G. Lee, C. Yu	MA5 dataverse	PDF	v1.6/Delphes3
ATLAS-EXOT-2016-27	Monojet (36.2 fb-1)	D. Sengupta	MA5 dataverse	PDF	v1.6/Delphes3
ATLAS-EXOT-2016-32	Monophoton (36.1 fb-1)	S. Baek, T.H. Jung	MA5 dataverse	PDF	v1.6/Delphes3
ATLAS-EXOT-2018-05	Di-jet resonance in association with a photon (78.6 fb-1)	H. Bahl	MA5 dataverse	App. A in 2109.10366	v1.9/SFS
ATLAS-EXOT-2018-30	W' into lepton+neutrino (139 fb-1)	K. Park, S. Lee, W. Jun, U. Min	MA5 dataverse	PDF	v1.8/Delphes3
ATLAS-CONF-2016-086	b-pair + missing transverse momentum (13.3 fb-1)	B. Fuks & M. Zumbihl	MA5 dataverse	PDF	v1.6/Delphes3
ATLAS-CONF-2019-040	Jets + missing transverse momentum (139 fb-1)	F. Ambrogi J.Y. Araz	MA5 dataverse MA5 dataverse	PDF TBA	v1.8/Delphes3 v1.8/SFS
ATLAS-CONF-2020-002	At least 8 jets + missing transverse momentum (139 fb-1)	T. Murphy	MA5 dataverse	PDF	v1.9/Delphes3

All detector parametrisations can be obtained from the MA5 dataverse links, together with the corresponding analysis codes.

CMS analyses, 13 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Version
CMS-SUS-16-033	Supersymmetry in the multijet plus missing energy channel (35.9 fb-1)	F. Ambrogi and J. Sonneveld	MA5 dataverse	PDF	v1.7/Delphes3
CMS-SUS-16-039	Electroweakinos in the SS2L, 3L and 4L channels (35.9 fb-1)	B. Fuks and S. Mondal	MA5 dataverse	PDF	v1.7/Delphes3
CMS-SUS-16-048	Compressed electroweakinos with soft leptons (35.9 fb-1)	B. Fuks J.Y. Araz	MA5 dataverse MA5 dataverse	Sec. 19 in 2002.12220 Sec. 5.3 in 2006.09387	v1.8/Delphes3 v1.8/SFS
CMS-SUS-16-052	SUSY in the 1l + jets channel (36 fb-1)	D. Sengupta	MA5 dataverse	PDF	v1.6/Delphes3
CMS-SUS-17-001	Stops in the OS dilepton mode (35.9 fb-1)	S.-M. Choi, S. Jeong, D.-W. Kang *et al.*	MA5 dataverse	PDF	v1.6/Delphes3
CMS-SUS-19-006	SUSY in the HT/missing HT channel (137 fb-1)	M. Mrowietz, S. Bein, J. Sonneveld	MA5 dataverse	PDF	v1.8/Delphes3
CMS-B2G-17-014	Vector-like quarks with charge 5/3 with same-sign dileptons (35.9/fb)	J. Salko, L. Panizzi	MA5 dataverse	App. A in 2107.07426	v1.9/Delphes3
CMS-EXO-16-010	Mono-Z-boson (2.3 fb-1)	B. Fuks	MA5 dataverse	PDF	v1.6/Delphes3
CMS-EXO-16-012	Mono-Higgs (2.3 fb-1)	S. Ahn, J. Park, W. Zhang	MA5 dataverse	PDF	v1.6/Delphes3
CMS-EXO-16-022	Long-lived leptons (2.6 fb-1)	J. Chang M. Ustch, M. Goodsell	MA5 dataverse MA5 dataverse	PDF Sec. 3 in 2112.05163	v1.7/Delphes3 v1.9/SFS
CMS-EXO-17-009	Leptoquark pair production in the electron(s)+jets channel (35.9 fb-1)	T. Murphy	MA5 dataverse	PDF	v1.10/Delphes3
CMS-EXO-17-011	WR and heavy neutrino in the 2l2j mode (35.9 fb-1)	A. Jueid, B. Fuks	MA5 dataverse	TBA	v2.0.4/SFS
CMS-EXO-17-015	Leptoquarks + dark matter in the 1mu+1jet+met channel (77.4 fb-1)	A. Jueid and B. Fuks	MA5 dataverse	PDF	v1.8/Delphes3
CMS-EXO-17-030	Pairs of trijet resonances (35.9 fb-1)	Y. Kang, J. Kim, J. Choi, S. Yun	MA5 dataverse	PDF	v1.8/Delphes3
CMS-EXO-19-002	Type-III seesaw and top-philic scalars with multileptons (137/fb)	E. Conte, R. Ducrocq	MA5 dataverse	PDF	v1.9/Delphes3
CMS-EXO-19-010	CMS disappearing tracks (139/fb)	M. Goodsell	MA5 dataverse	Sec. 5 in 2112.05163	v1.9/SFS
CMS-EXO-20-002	WR and heavy neutrino in the 2l2j mode (138 fb-1)	A. Jueid, B. Fuks	MA5 dataverse	TBA	v2.0.4/SFS
CMS-EXO-20-004	Dark matter in the multi-jet+met channel (137 fb-1)	A. Albert	MA5 dataverse	App. B.5 in 2107.13021	v1.9/Delphes3
CMS-HIG-18-011	Exotic Higgs decay in the 2 muons + 2 b-jet channel via 2 pseudoscalars (35.9 fb-1)	J.B. Lee and J. Lee	MA5 dataverse	PDF	v1.8/Delphes3
CMS-TOP-17-009	SM four-top analysis (35.9 fb-1)	L. Darmé and B. Fuks	MA5 dataverse	PDF	v1.7/Delphes3
CMS-TOP-18-003	SM four-top analysis (137 fb-1)	L. Darmé and B. Fuks	MA5 dataverse	PDF	v1.8/Delphes3

All detector parametrisations can be obtained from the MA5 dataverse links, together with the corresponding analysis codes.

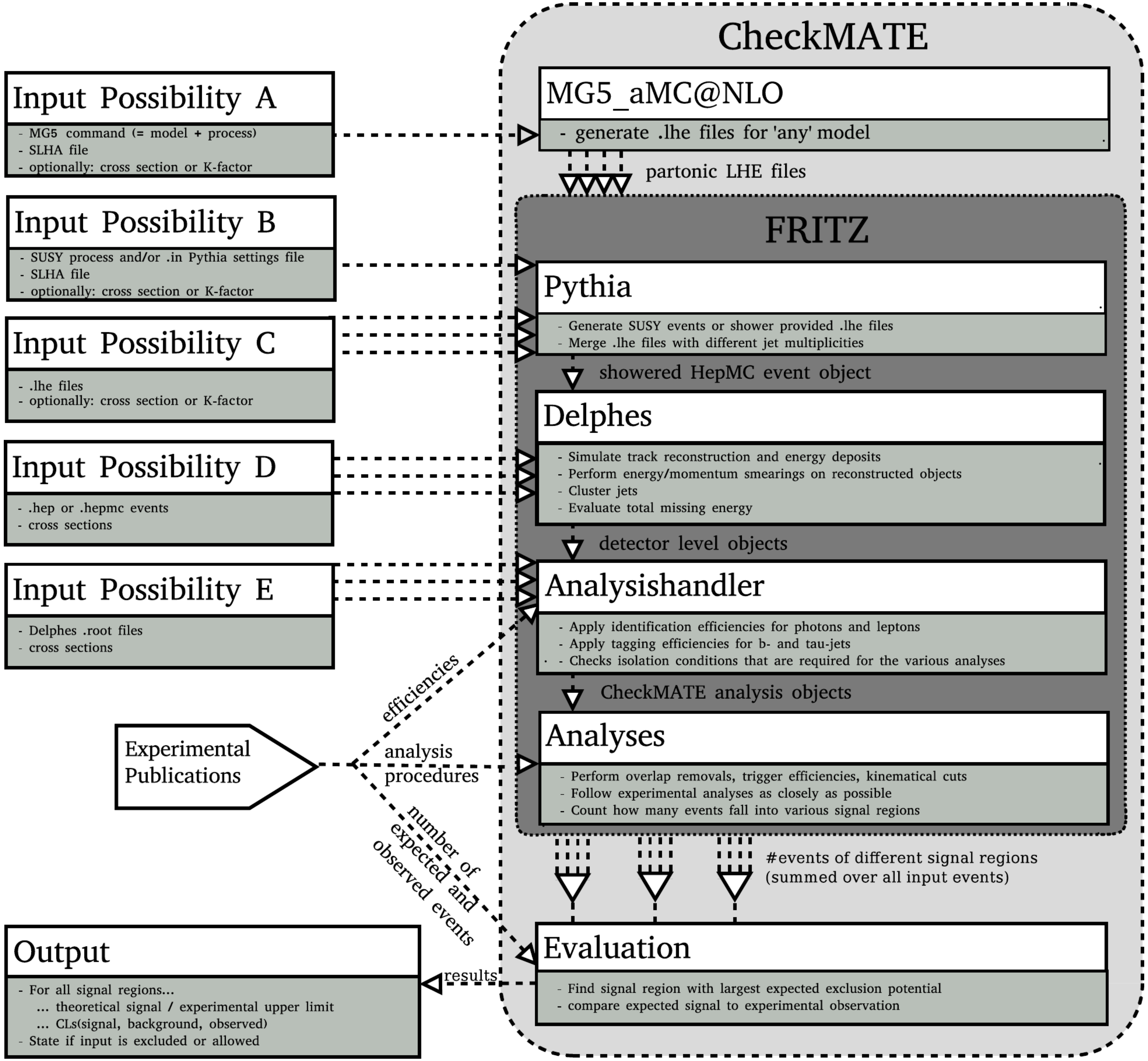
Anyone can contribute

CHECKMATE

Current Members: Manimala Chakraborti, Nishita Desai, Florian Domingo, Jong Soo Kim, Krzysztof Rolbiecki, Roberto Ruiz de Austri, Ipsita Saha, Liangliang Shang, Mangesh Sonawane, Zeren Simon Wang, Yuanfang Yue

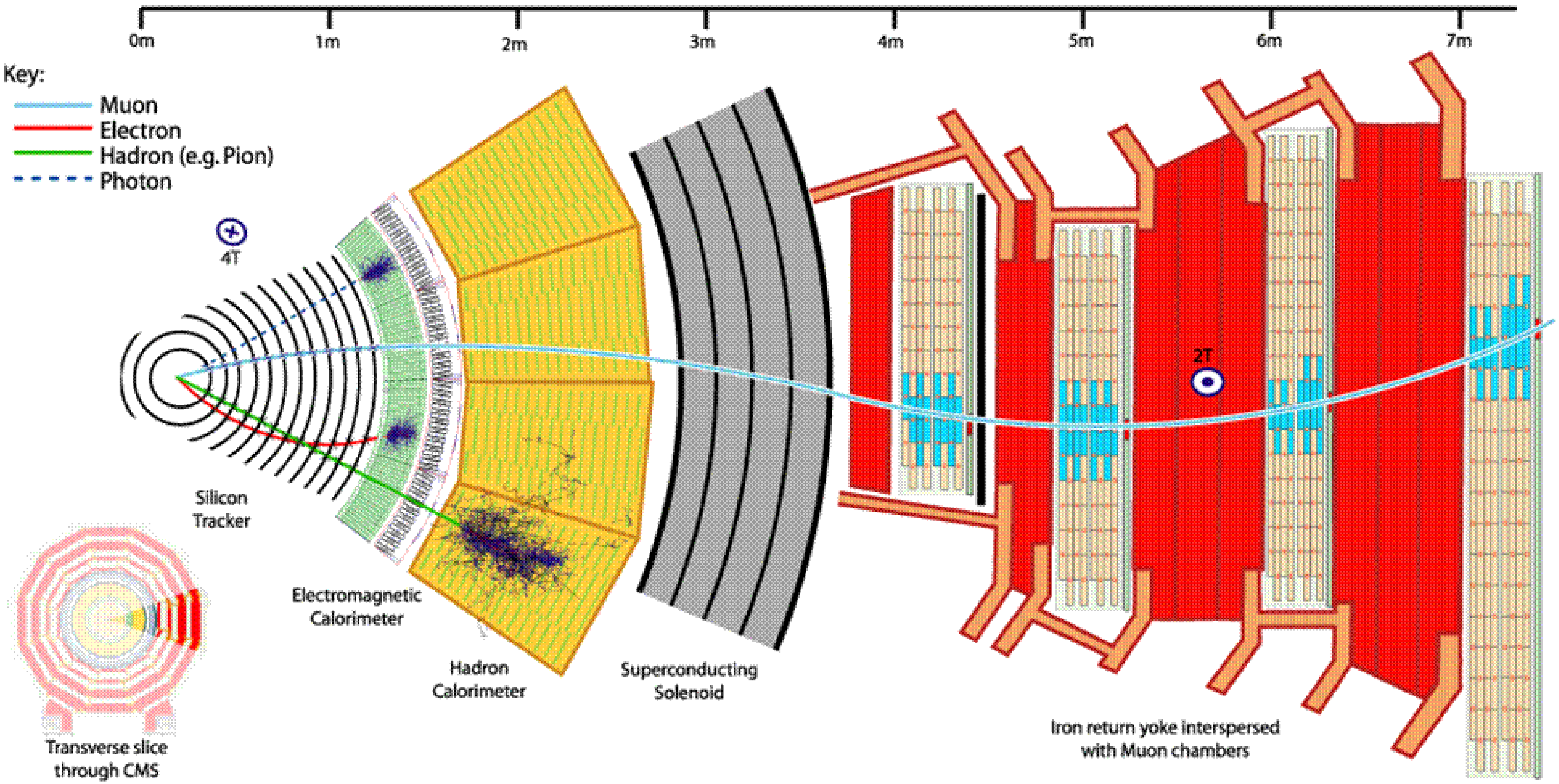
Former Members: Daniel Dercks, Manuel Drees, Herbert Dreiner, Frederic Ponzca, Jamie Tattersall, Thorsten Weber

- CheckMATE is a general tool for recasting arbitrary model
- Accepts events as .hepmc, .lhe; integration with Pythia and MadGraph
- based on Delphes for detector simulation
- using existing LHC searches calculates a limit on a given parameter point
- From SLHA file to the limit in one click
- one can easily constrain models that were not covered in the original ATLAS/CMS search
- currently more than 40 searches at 13 TeV coded, including 14 with full luminosity
- long-lived particles branch
- https://checkmate.hepforge.org/ and https://github.com/CheckMATE2/checkmate2



CheckMATE
MG5_aMC@NLO
- generate .lhe files for 'any' model
partonic LHE files
FRITZ
Pythia
- Generate SUSY events or shower provided .lhe files
- Merge .lhe files with different jet multiplicities
showered HepMC event object
Delphes
- Simulate track reconstruction and energy deposits
- Perform energy/momentum smearings on reconstructed objects
- Cluster jets
- Evaluate total missing energy
detector level objects
Analysishandler
- Apply identification efficiencies for photons and leptons
- Apply tagging efficiencies for b- and tau-jets
- Checks isolation conditions that are required for the various analyses
CheckMATE analysis objects
Analyses
- Perform overlap removals, trigger efficiencies, kinematical cuts
- Follow experimental analyses as closely as possible
- Count how many events fall into various signal regions
#events of different signal regions
(summed over all input events)
Evaluation
- Find signal region with largest expected exclusion potential
- compare expected signal to experimental observation
Input Possibility A
- MG5 command (= model + process)
- SLHA file
- optionally: cross section or K-factor
Input Possibility B
- SUSY process and/or .in Pythia settings file
- SLHA file
- optionally: cross section or K-factor
Input Possibility C
- .lhe files
- optionally: cross section or K-factor
Input Possibility D
- .hep or .hepmc events
- cross sections
Input Possibility E
- Delphes .root files
- cross sections
Experimental Publications
efficiencies
analysis procedures
number of expected and observed events
results
Output
- For all signal regions...
... theoretical signal / experimental upper limit
... CLs(signal, background, observed)
- State if input is excluded or allowed

Particle detector in a nutshell



Detector simulation

Delphes 3.4 / 3.5

- Simulates tracking and energy deposition
- Applies efficiencies for photons and leptons
- Clusters jets
- Performs energy/momentum smearing of all reconstructed objects
- Evaluates total missing energy
- Checks isolation conditions for photons and leptons
- Applies b-/ tau-tag on jets

DELPHES
fast simulation

CheckMATE improvements

- Added identification and isolation flags
- Tuned to reproduce LHC detectors:
  - ATLAS for 13 TeV Run; updates in progress
  - CMS work in progress

CheckMATE: ATLAS analyses

#Name	NSR	Description	Lumi
atlas_1604_01306	1	photon + MET search at 13 TeV	3.2
atlas_1605_09318	8	>= 3 b-jets + 0-1 lepton + Etmiss	3.3
atlas_1609_01599	9	ttV cross section measurement at 13 TeV	3.2
atlas_1704_03848	5	monophoton dark matter search	36.1
atlas_conf_2015_082	1	leptonic Z + jets + Etmiss	3.2
atlas_conf_2016_013	10	4 top quark (1 lepton + jets, vector like quark search)	3.2
atlas_conf_2016_050	5	1-lepton + jets + etmiss (stop)	13.3
atlas_conf_2016_054	10	1-lepton + jets + etmiss (squarks and gluino)	14.8
atlas_conf_2016_076	6	2 leptons + jets + etmiss	13.3
atlas_conf_2016_096	8	2-3 leptons + etmiss (electroweakino)	13.3
atlas_conf_2017_060	20	monojet search	36.1
atlas_conf_2016_066	2	search for photons, jets and met	13.3
atlas_1712_08119	39	electroweakinos search with soft leptons	36.1
atlas_1712_02332	24	squarks and gluinos, 0 lepton, 2-6 jets	36.1
atlas_1709_04183	14	stop pair production, 0 leptons	36.1
atlas_1802_03158	7	search for GMSB with photons	36.1
atlas_1708_07875	2	electroweakino search with taus and MET	36.1
atlas_1706_03731	19	same-sign or 3 leptons RPC and RPV SUSY	36.1
#atlas_conf_2019_018	2	Search for direct stau production in events with two hadronic tau leptons	139
atlas_1908_08215	16	charginos/sleptons, 2 leptons + MET	139
atlas_1909_08457	5	search for squarks and gluinos with same-sign leptons	139
atlas_conf_2019_020	2	Search for chargino-neutralino production with mass splittings near the electroweak scale	139
atlas_1803_02762	20	Search for electroweakino production in final states with two or three leptons	36.1
atlas_2101_01629	32	squarks/gluinos, 1 lepton, jets, MET	139
atlas_conf_2020_048	26	Search for dark matter with monojets	139
atlas_2004_14060	9	stops, leptoquarks, 0 lepton	139
atlas_1908_03122	10	0 leptons, 3 or more b-jets, sbottoms	139
atlas_1911_12606	87	search for sleptons and electroweakinos with soft leptons	139
atlas_1807_07447	633	general search for new phenomena	3.2
atlas_2103_11684	2	Search for SUSY in events with four or more leptons (gravitino SR)	139
atlas_2004_10894	12	EWino search in Higgs (diphoton) and met	139
atlas_2106_09609	21	Search for RPV SUSY in final states with leptons and many jets	139
atlas_1911_06660	2	search for direct stau production	139
atlas_2010_14293	78	search for squarks and gluinos in MET_jet final states	139
atlas_2211_08028	22	search for gluinos decaying via 3rd gen; multi b-jets and MET	139

CheckMATE: CMS analyses

#Name	NSR	Description	Lumi
cms_pas_sus_15_011	47	CMS, 13 TeV, 2 leptons + jets + MET	2.2
cms_sus_16_039	158	electrowekinos in multilepton final state	35.9
cms_sus_16_025	14	electroweakino and stop compressed spectra	12.9
cms_sus_16_048	20	two soft opposite sign leptons	35.9
cms_sus_19_005	303	hadronic final states with MT2	137.0

The list much shorter compared to ATLAS...

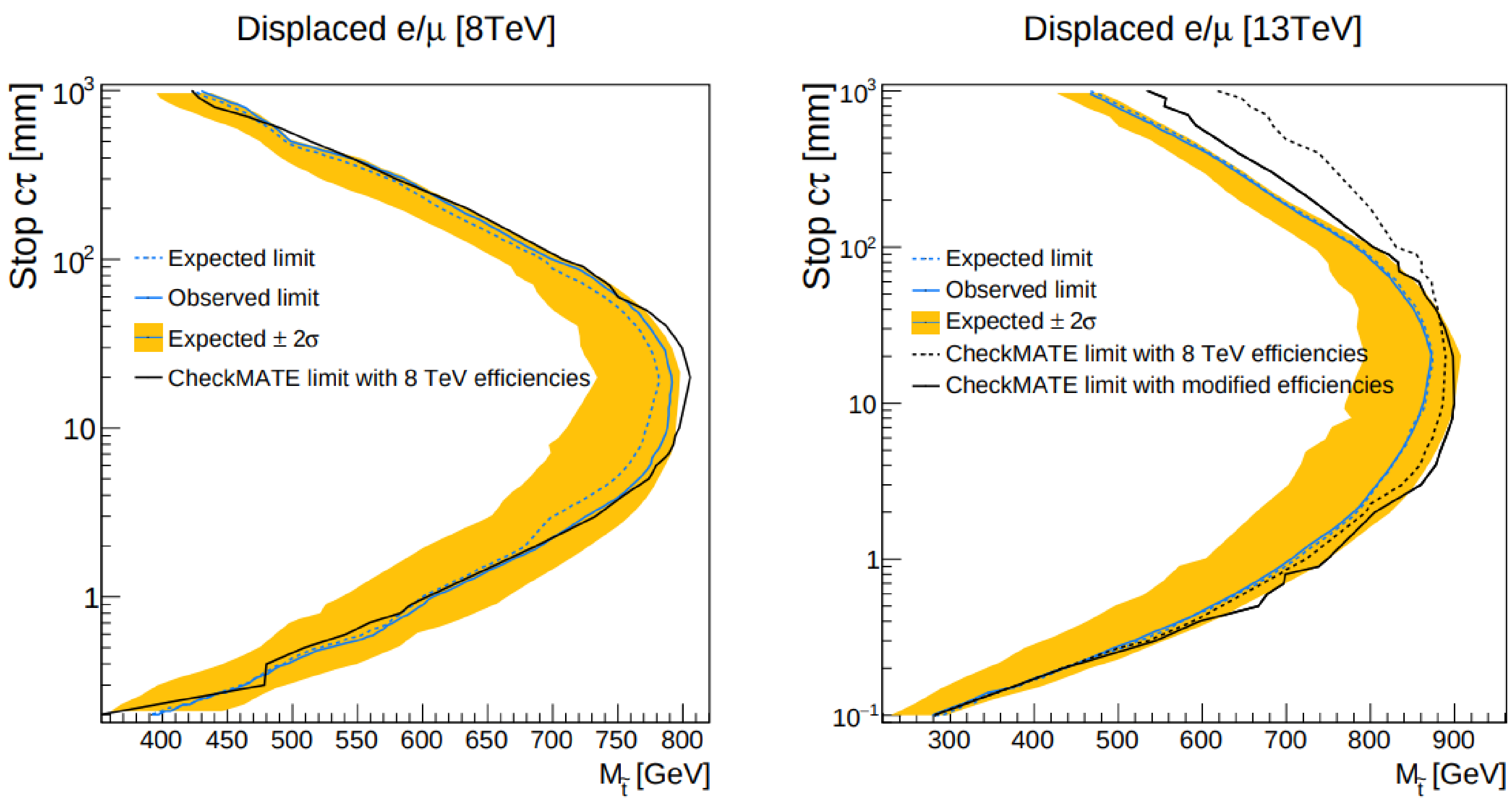
- From start CheckMATE was based on collaboration with ATLAS so the ties are still stronger
- ATLAS is by default releasing reinterpretation material for all SUSY searches: cutflows, simplified analysis code, efficiencies etc., what makes recasting much easier
- Many searches very similar (on the other hand combinations are tempting...)

Note on validation

- How do we check the implementation is correct?
- First assessment: cutflows

	Selection	$m_{\tilde{q}} = 1200$ GeV, $m_{\tilde{\chi}_1^0} = 600$ GeV		$m_{\tilde{q}} = 1400$ GeV, $m_{\tilde{\chi}_1^0} = 600$ GeV		$m_{\tilde{q}} = 1600$ GeV, $m_{\tilde{\chi}_1^0} = 400$ GeV	
		ATLAS	CM	ATLAS	CM	ATLAS	CM
Generated MC events		10000	10000	6000	10000	6000	10000
Common Requirements	Preselection, $E_{\mathrm{T}}^{\mathrm{miss}} > 300$ GeV, $p_T(j_1) > 200$ GeV, $m_{\mathrm{eff}} > 800$ GeV	1763	1780	541	546	174	176
	jet multiplicity ≥ 2	1763	1780	541	546	174	176
	Cleaning cuts	1746	–	535	–	173	–
SR-2j-1600	$\Delta\phi(j_{1,2,(3)}, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.8$	1433	1434	431	433	136	139
	$\Delta\phi(j_{i>3}, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$	1377	1353	411	410	129	130
	$p_T(j_2) > 250$ GeV	853	850	311	310	111	112
	$\lvert\eta(j_{1,2})\rvert < 2.0$	836	832	306	305	109	110
	$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_T} > 16$ GeV$^{1/2}$	568	554	228	227	86.4	87.3
	$m_{\mathrm{eff}}(\mathrm{incl.}) > 1600$ GeV	366	362	202	195	83.5	84.2

Validation: reproducing exclusion contours



(a) 8 TeV

(b) 13 TeV

Figure 1: A Comparison of the exclusion limits on the Displaced Lepton search provided by CMS with those obtained from `CheckMATE` (left: 8 TeV, 19.7 fb^{-1}; right: 13 TeV, 2.6 fb^{-1}).

Validation: reproducing exclusion contours

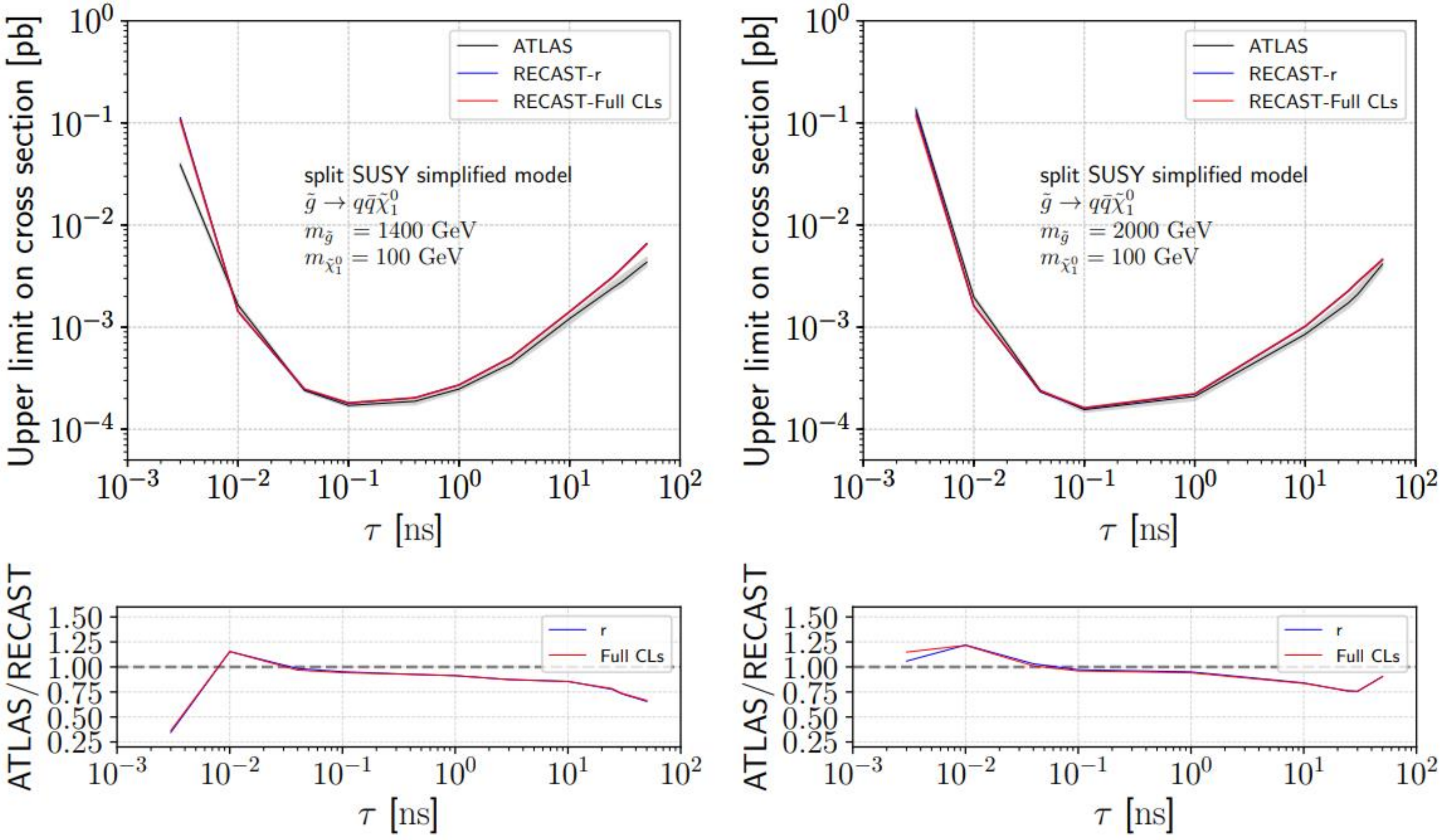
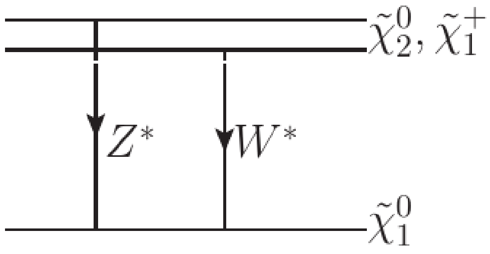


Figure 2: Validation of the DV+MET search in the scenario with large mass-splitting for two different benchmarks (left $m_{\tilde{g}} = 1.4$ TeV, right: $m_{\tilde{g}} = 2$ TeV.). The bottom panel in both cases shows the

Outline

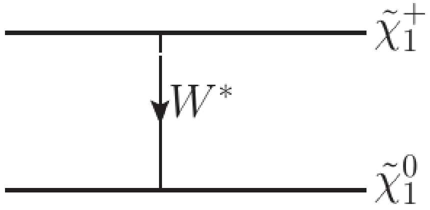
Light SUSY dark matter

- bino-wino: almost mass degenerate winos and bino LSP



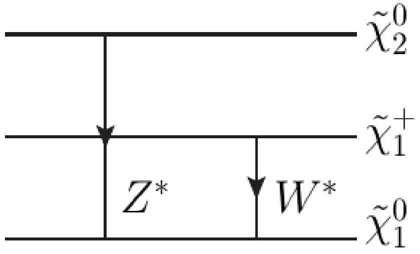
bino-wino

- wino LSP: $M_2 \ll M_1, \mu$, two quasi-degenerate states: χ_1^0, $\chi_1^\pm$



wino

- higgsino LSP, $\mu \ll M_1, M_2$, three quasi-degenerate states: $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$



higgsino

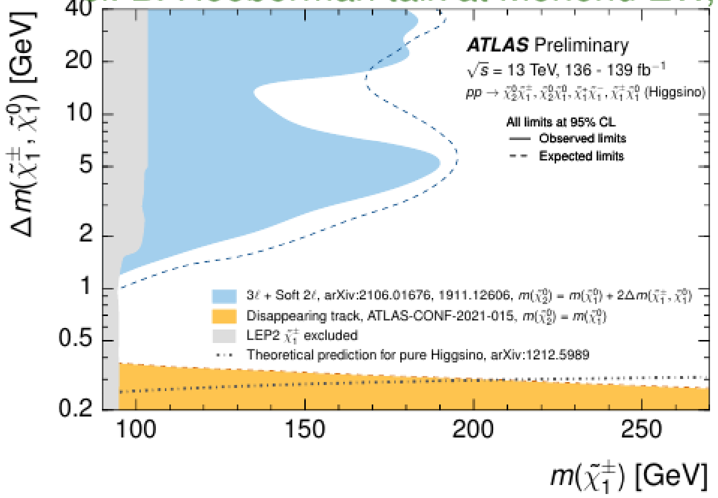
- mass splittings of order 100–1000 MeV

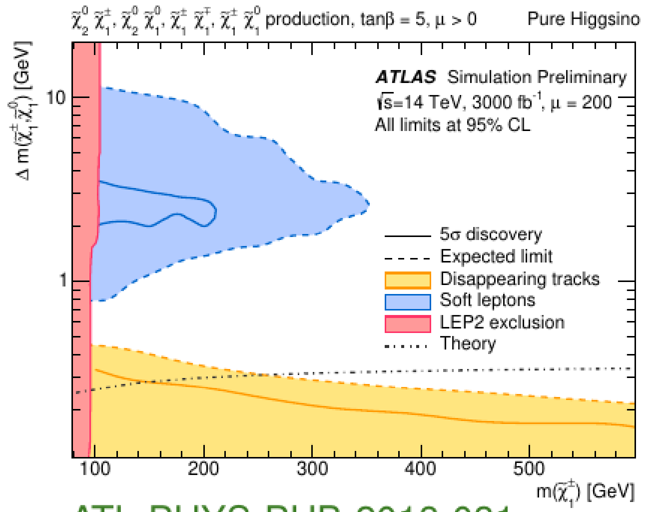
Search strategies

- for sufficiently small mass gap a long-lived massive particle travels macroscopic distance in the detector
- possible signatures: displaced vertex, heavy charged track, displaced jet etc.
- for a larger mass difference (> 1 GeV) look for soft decay products

- at HL the gap remains
- for winos no exclusion in soft ℓ search!

cf. B. Hooberman talk at Moriond EW, 14.03.22



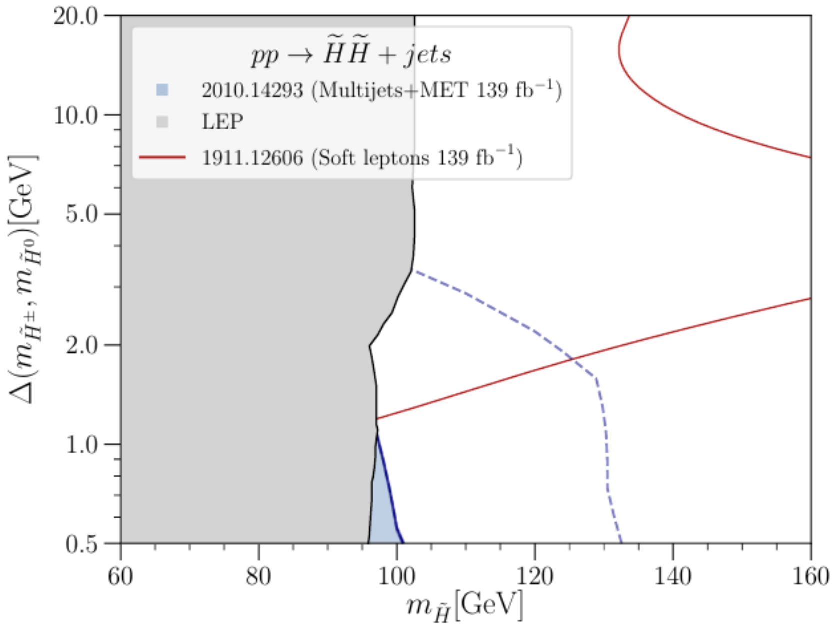


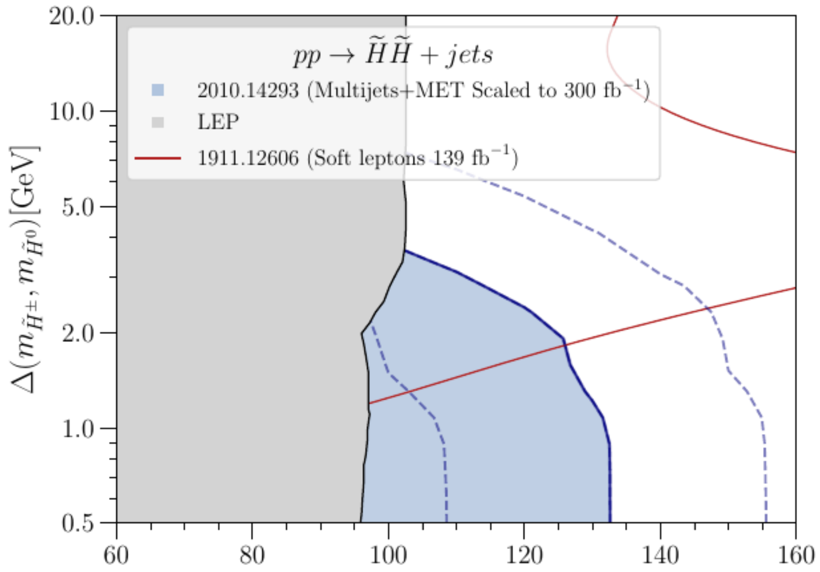
ATL-PHYS-PUB-2018-031

Results: higgsinos

- higgsino model
- $pp \to \widetilde{H}^{\pm}\widetilde{H}^0_{1,2}, \widetilde{H}^+\widetilde{H}^-, \widetilde{H}^0_1\widetilde{H}^0_2$
- $\widetilde{H}^{\pm} \to \widetilde{H}^0_1 W^*, \widetilde{H}^0_2 \to \widetilde{H}^0_1 Z^*$
- currently the limit only slightly above LEP

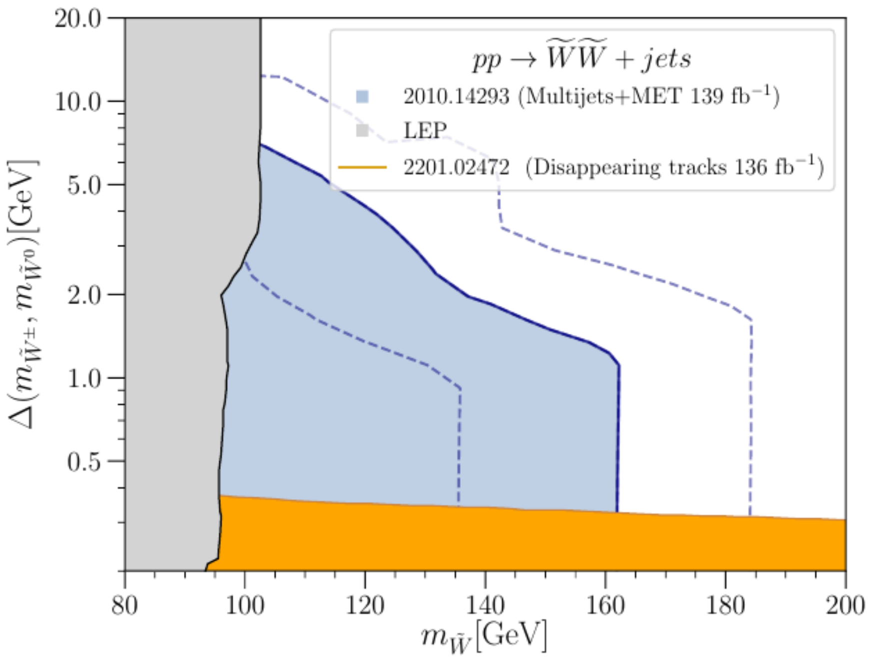
- after Run 3 the expected limit increases to 130 GeV

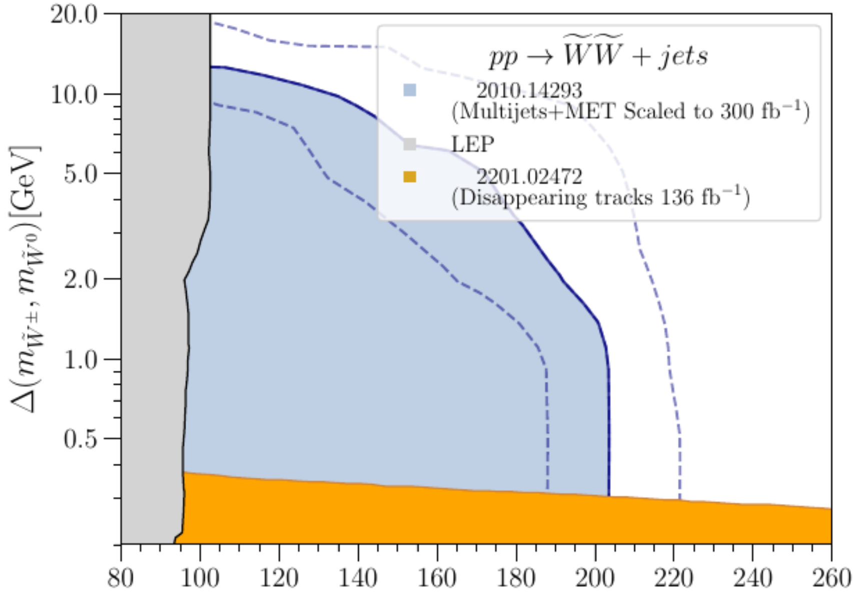




Results: winos

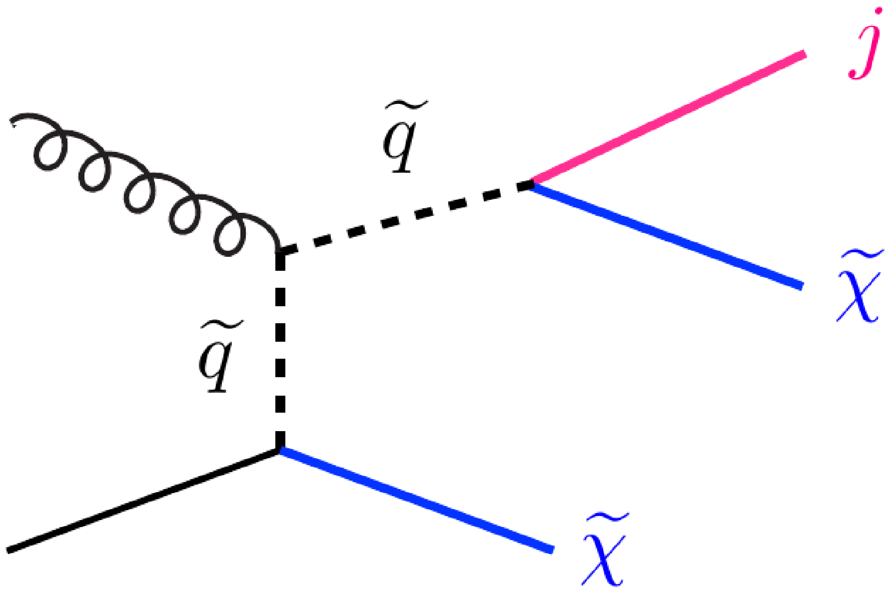
- $\widetilde{W}^{\pm} \to \widetilde{W}^{0} W^{*}$
- $\widetilde{W}^{0}$ stable (DM candidate)
- soft decay products but no same-flavour opposite-charge from Z^{*} and no limits
- the limits from LEP and the search for semi-stable chargino
- the new exclusion on top of LEP and long-lived charged wino limits
- after Run 3 the expected limit increases to 200 GeV





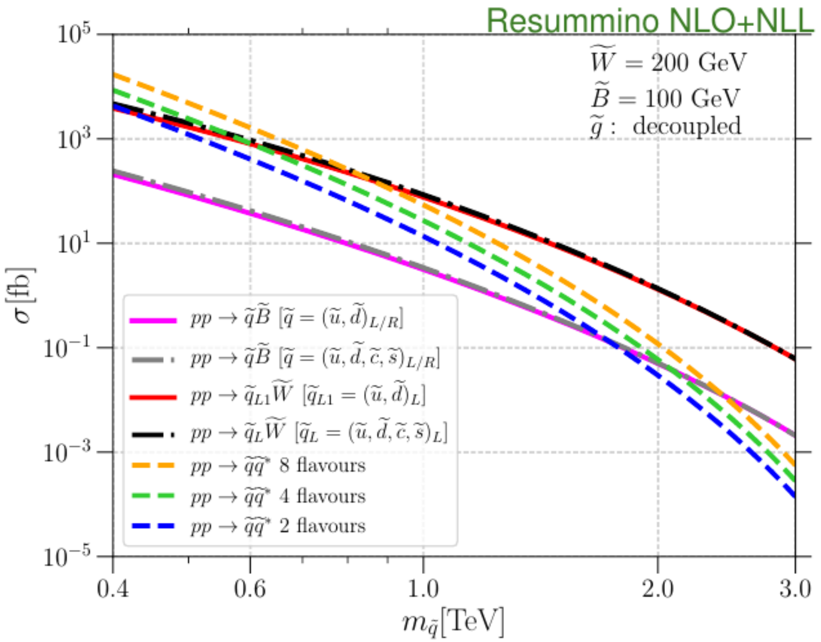
Neglected gaugino-squark production

- light gauginos and squark, rest of the spectrum decoupled
- we consider associated squark-wino production
- $pp \to \widetilde{\chi}\tilde{q},\ \tilde{q} \to \widetilde{\chi} q$
- monojet-type signal
- specifically sensitive to 1st generation doublet
- order $\alpha\alpha_s$ compared to α_s^2 for squark pair production, so maybe can be neglected?



Gaugino-squark production

- three possibilities: $\widetilde{\chi} =$ wino, bino, higgsino
- $pp \to \widetilde{W}\tilde{q},\ \tilde{q} \to \widetilde{W}q$
- at squark mass ~ 1 TeV the cross section competitive with squark pair production ($m_{\widetilde{W}} = 200$ GeV)



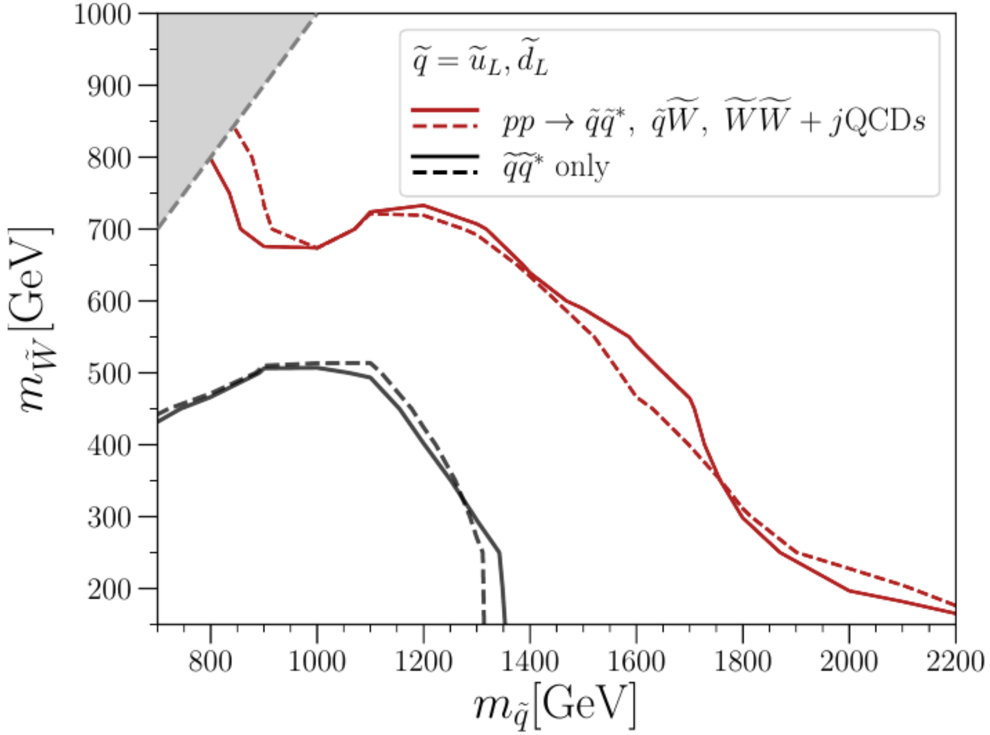
- $pp \to \widetilde{B}\tilde{q},\ \tilde{q} \to \widetilde{B}q$
- at squark mass ~ 2.2 TeV the cross section competitive with squark pair production ($m_{\widetilde{B}} = 100$ GeV)

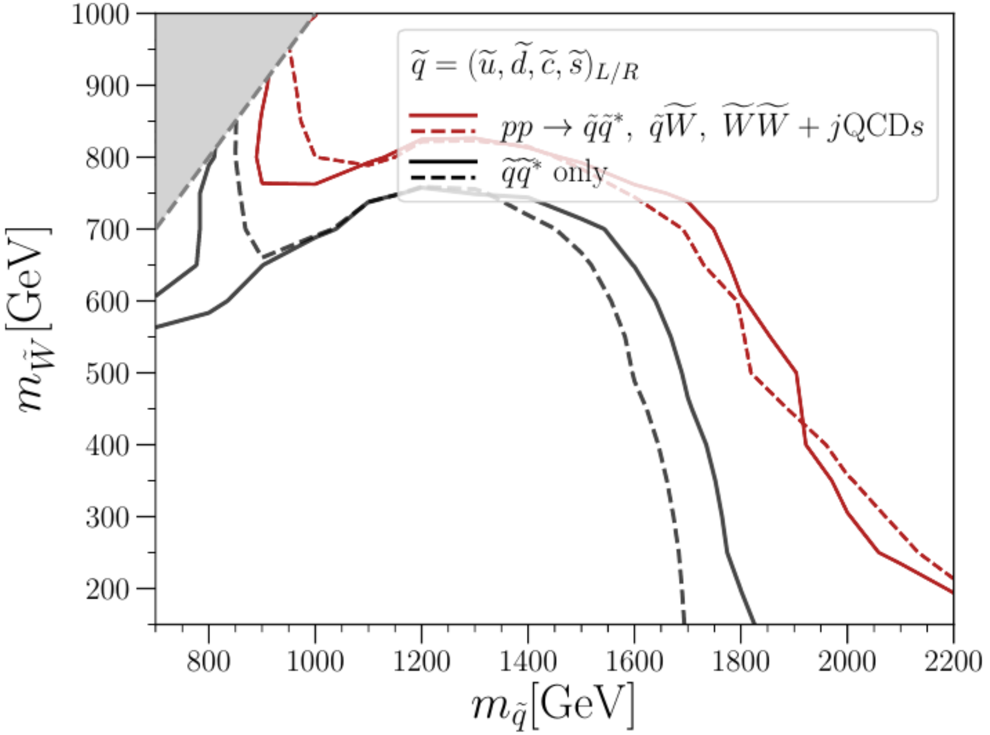
- higgsino production negligible - Yukawa suppressed

Gaugino-squark production

Significant enhancement of exclusion limits!

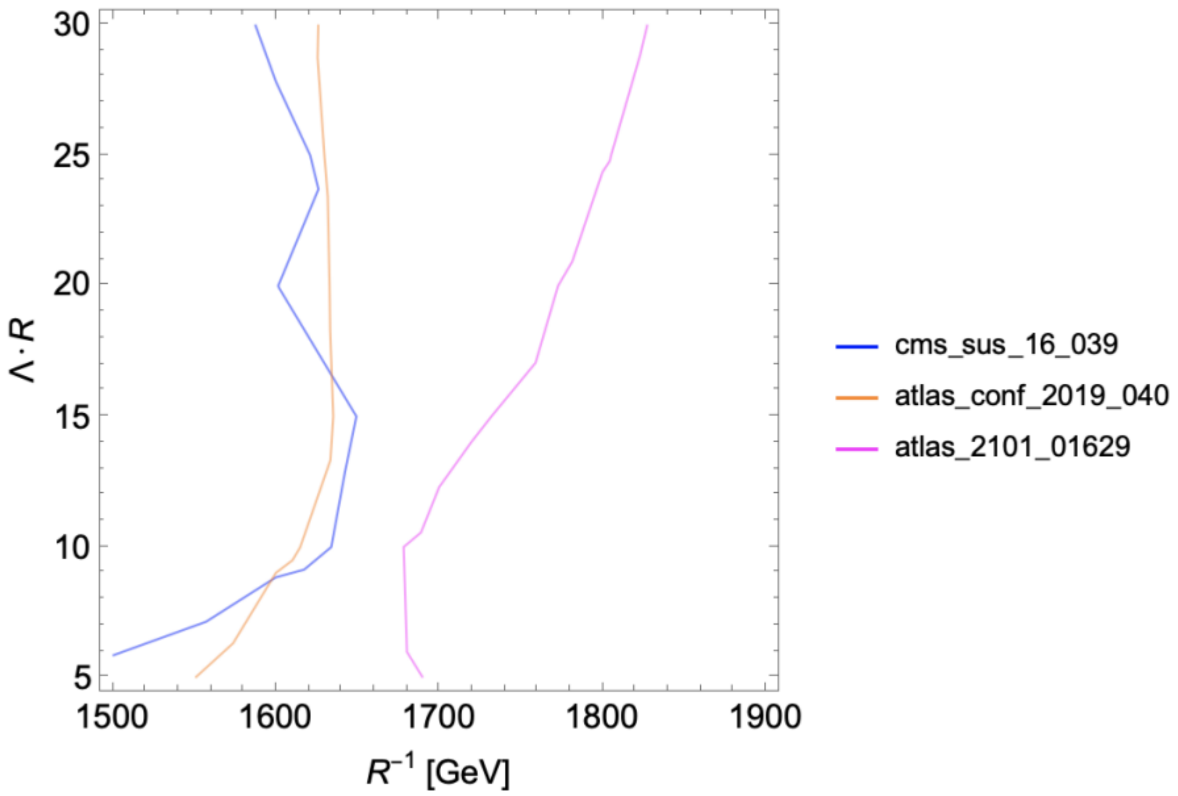
first generation doublet only (2-fold degenerate)	2 generations, left and right (8-fold degenerate)





Minimal Universal Extra Dimensions

- MUED is a viable TeV-scale extension of the SM
- Generally, particle content similar to MSSM but different spins and rather compressed spectrum
- No dedicated searches, but recasting SUSY gives non-trivial constraints
- From this analysis one concludes that in the allowed parameter range DM relic density too high



ArXiv:2110.00500

Outline

1. Introduction
2. Simplified models
3. Tools for reinterpretation of searches
   a) MadAnalysis
   b) SModelS
   c) CheckMATE
4. Examples of reinterpretation studies
5. Summary

Summary

- Simplified models are a useful tool but just a first step in the exploration of TeV-scale physics
- Several codes on the market to facilitate translation of the simplified model limits to realistic physics models:
  - MadAnalysis
  - SModelS
  - Gambit/ColliderBit
  - CheckMATE
- Codes widely used for studies (several hundred citations each), constantly developing with new features and analysis sophistication

Norway grants

NATIONAL SCIENCE CENTRE POLAND

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Understanding the Early Universe:
interplay of theory and collider experiments

Joint research project between the University of Warsaw & University of Bergen

Minimal running example

- Step 1: Decide on a parameter point `benchmark1.slha`
- Step 2: Set up parameters `param.dat`
- Step 3: Run `./CheckMATE`
- Wait.

```
[Parameters]
SLHAFile: /scratch/benchmark1.slha

[squ_asq]
Pythia8Process: p p > sq sq~
MaxEvents: 1000
```

```
Result:  Allowed
Result for r: r_max = 0.74
SR: atlas_conf_2013_047 - ET
```

or

```
Result: Excluded
Result for r: r_max = 1.33
SR: atlas_conf_2013_047 - A
```