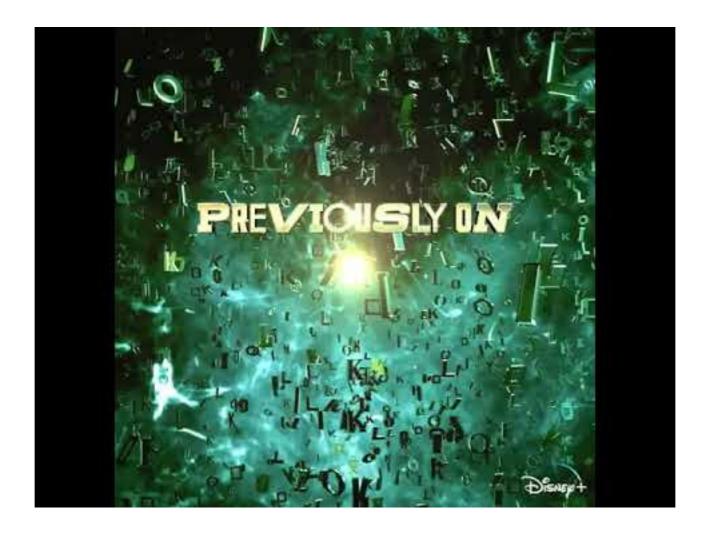


Better Late Than Never

BSM Experimental Searches 4

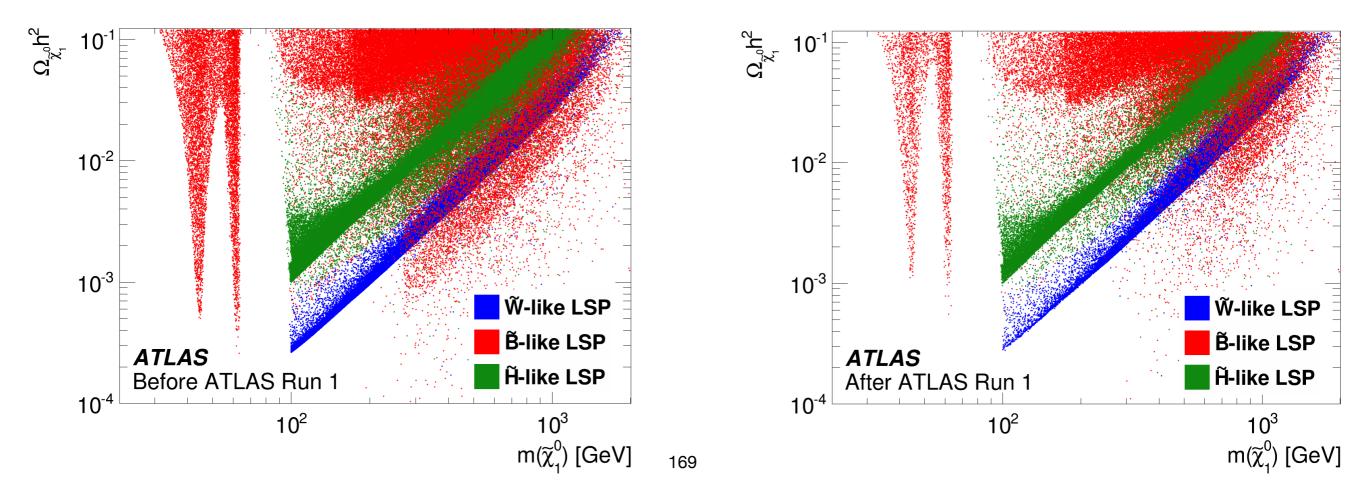
Zach Marshall (LBNL), CERN-Fermilab HCP Summer School, 2 September 2021



- We talked about background estimation and uncertainties
- And then about results
- And started to talk about reinterpretation and big model spaces...

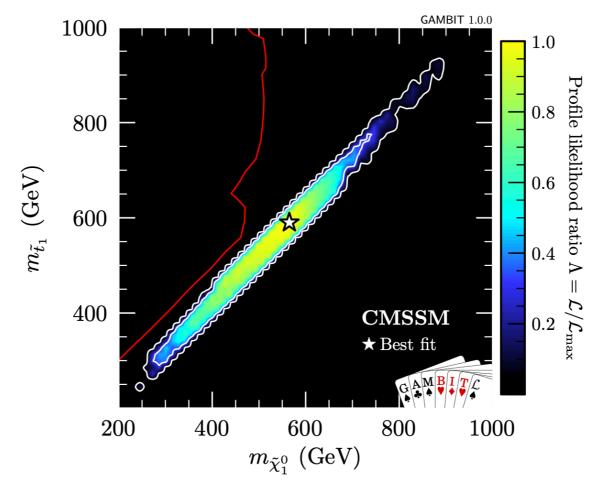
Combinations and Scans

- The experiments (and some <u>other collaborations</u>) take time at the end of runs to do grand combinations and large model-space scans.
- One popular scan is the 19-dimensional pMSSM
- These apply *many* searches to as many model points as we can muster



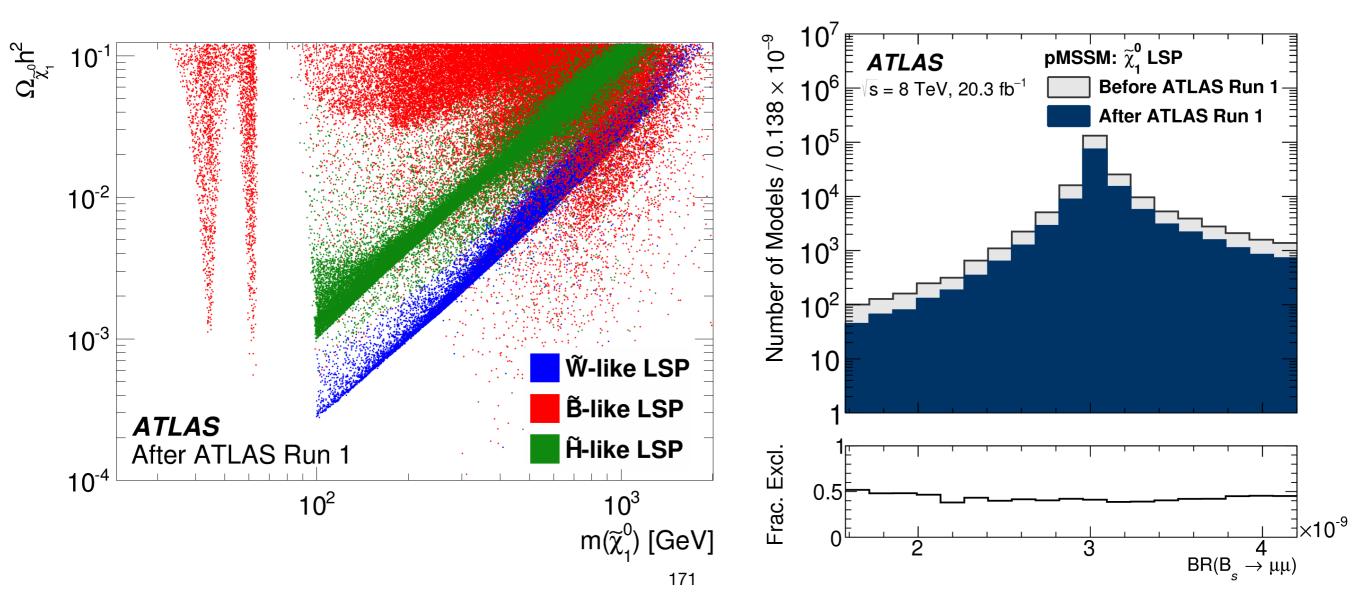
Combinations and Scans

- The experiments (and some <u>other collaborations</u>) take time at the end of runs to do grand combinations and large model-space scans.
- One popular scan is the 19-dimensional pMSSM
- These apply *many* searches to as many model points as we can muster
 - Note that the best fit point will always be just out of reach.



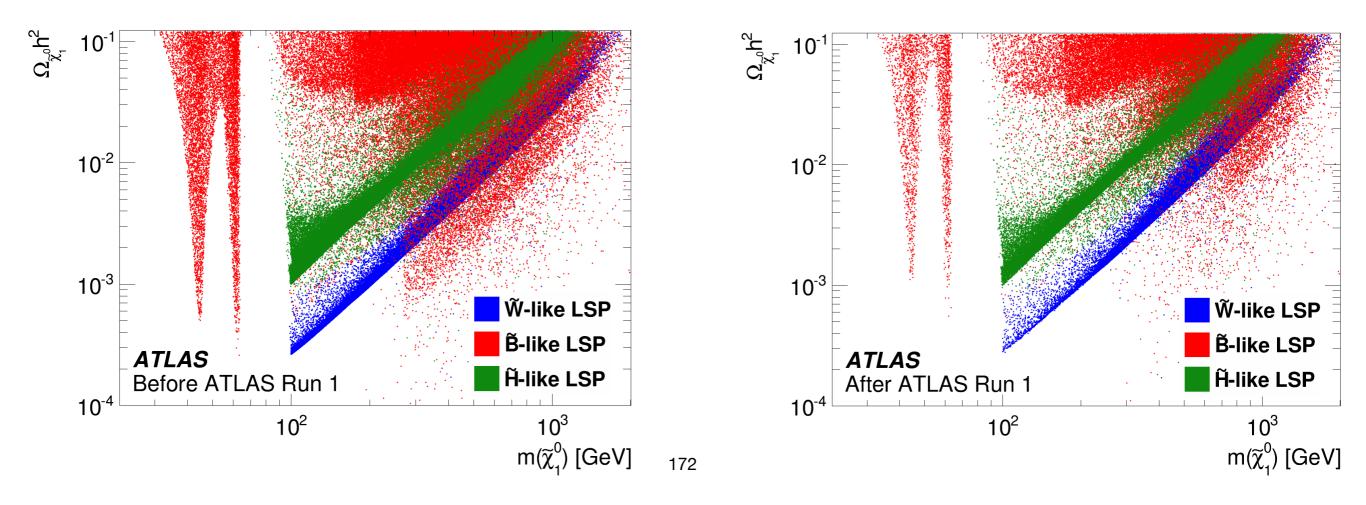
Aside on Limits from Others

- It's very tempting to take very seriously limits from other experiments
- Don't get too fanatical about that
- Remember that there can always be other physics (e.g. high-mass particles) that impact the translation from one field to another (particularly cosmo!)



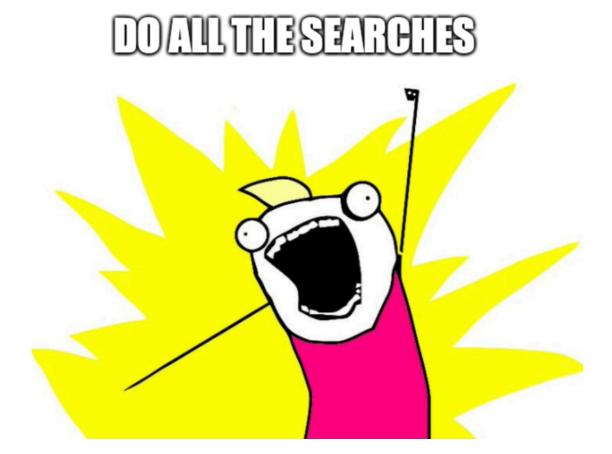
Combinations and Scans

- These always use the *best expected* limit. You could ask: can we do a full statistical combination of all the searches?
- It's extremely hard because of all the *correlation* problems we talked about
- Have to work out those problems across many searches with different methodologies!



Combinations and Scans

• If we can't combine a bunch of independent searches / papers, why not

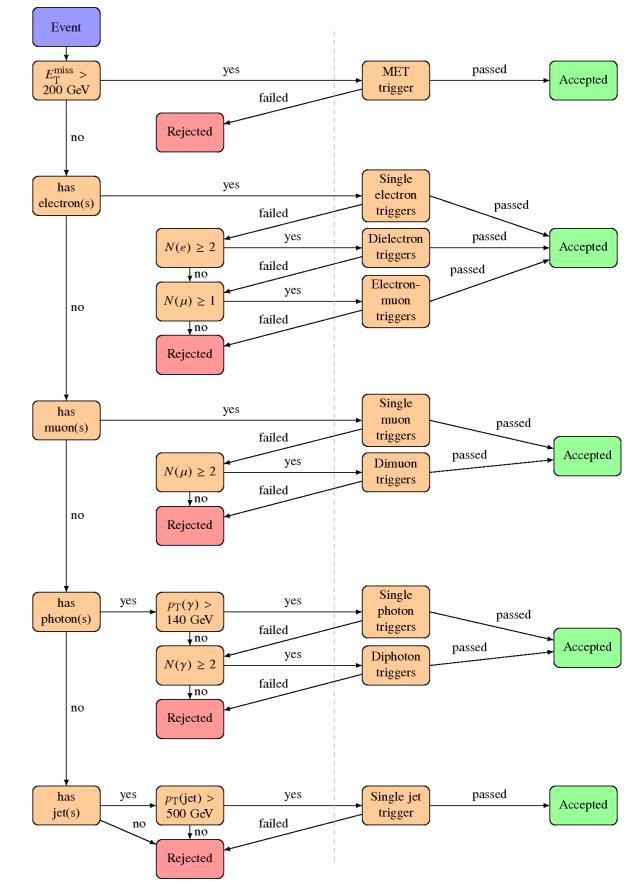


General Searches

- Many groups over the years have tried to do a *general search* by classifying all of the events in categories (and sometimes looking within those categories for bumps, tails, etc)
- This is extremely hard to do well.
- There are some philosophical issues.
 - Do you just unblind everyone's searches?
 - This search is a jack of all trades, master of none

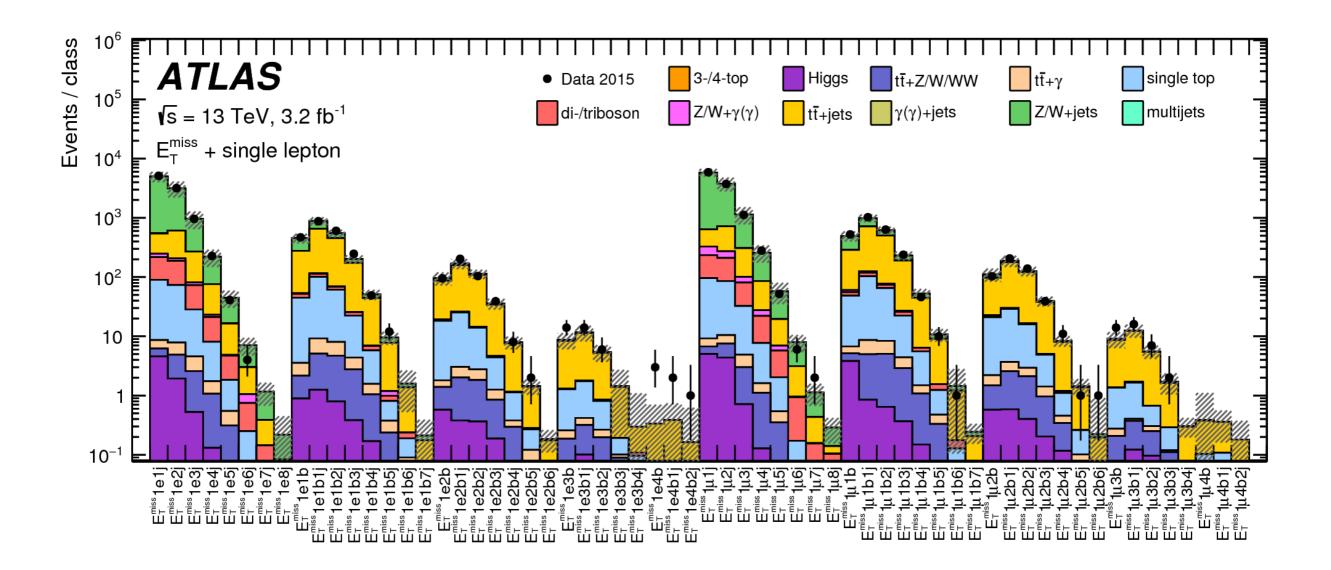
174

- There are also some practical issues
 - How do you do all the backgrounds?
 - Do you have **all** the MC?



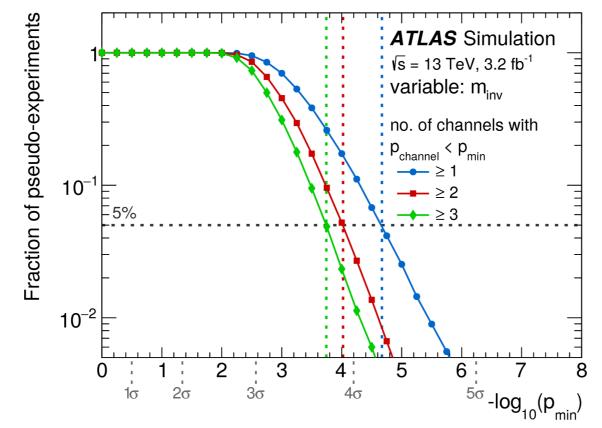
General Searches

• These then produce huge tables and plots with all the events in various categories, which are extremely fun to stare at

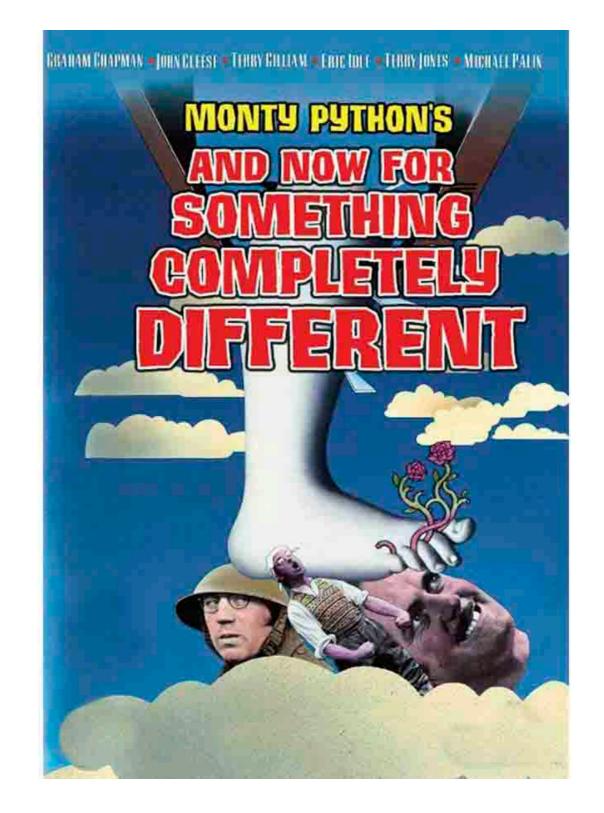


General Searches

- The statistical issue they're fighting is called the <u>look-elsewhere effect</u>.
- Basically: when you have that many distributions, you will have bumps.
- Within searches, we tend to calculate this effect.
 - It's pretty straightforward with a few assumptions and toy MC
- Some folks run **meta-analysis** to see what's happening globally in the search program 1000s of grad students making 100s of plots each!

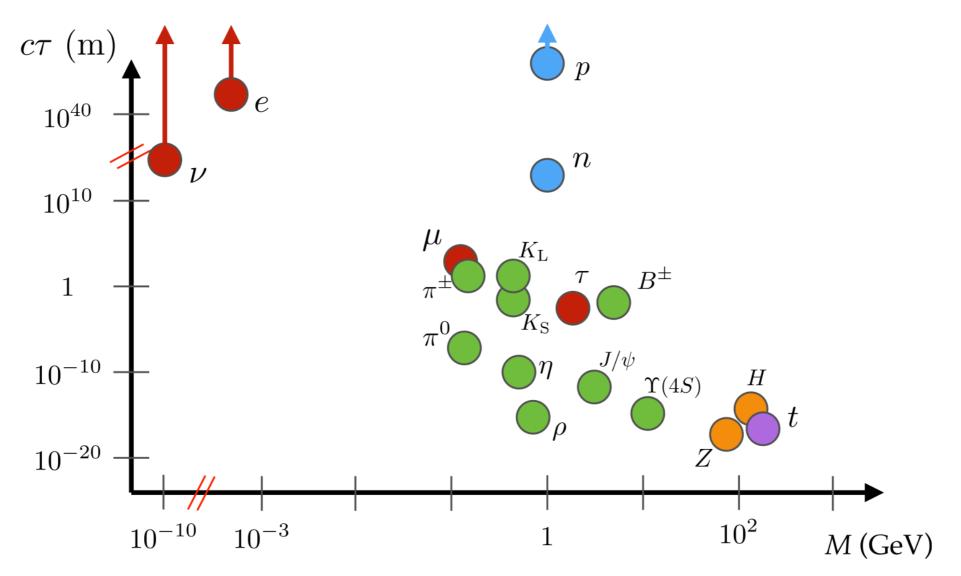


Long lived particles and... Others



Long-lived Particles

- We know of lots of particles in nature with "long" lifetimes
 - "Long" for the LHC usually means $c\tau$ >few mm
- These have gotten a lot more press in recent years

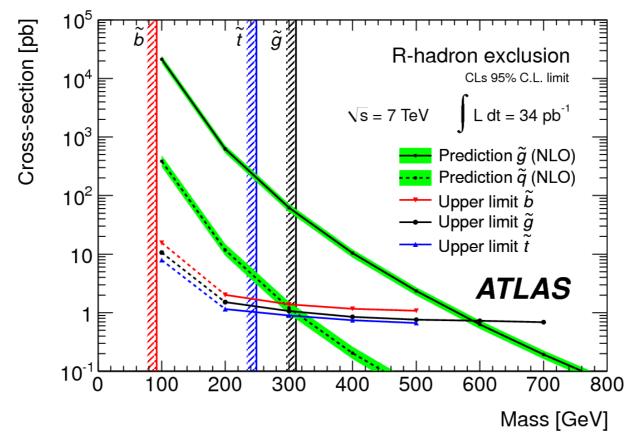


Long-lived Particle Searches

- Don't let anyone tell you that these searches are new!
- Some of the first LHC searches were for long-lived particles.

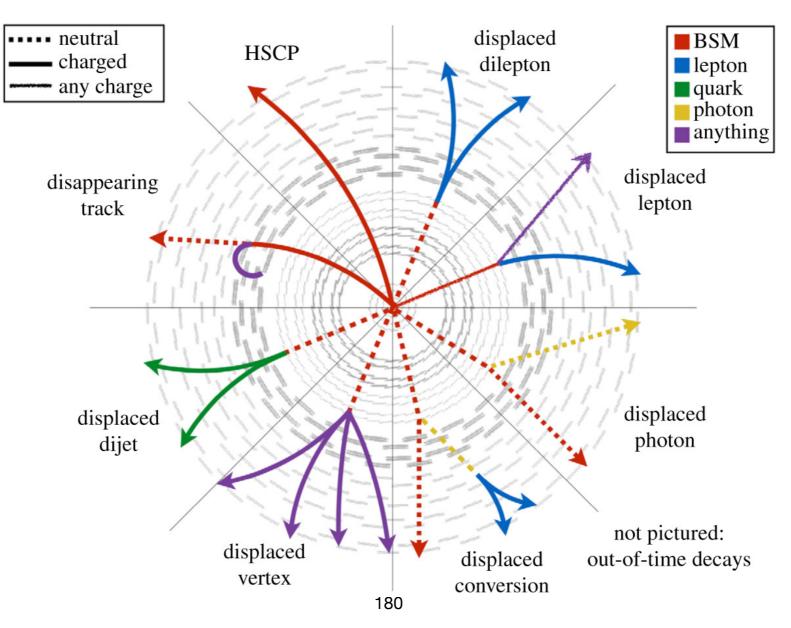
Search for stable hadronising squarks and gluinos with the ATLAS experiment at the LHC

CERN-PH-EP-2011-026



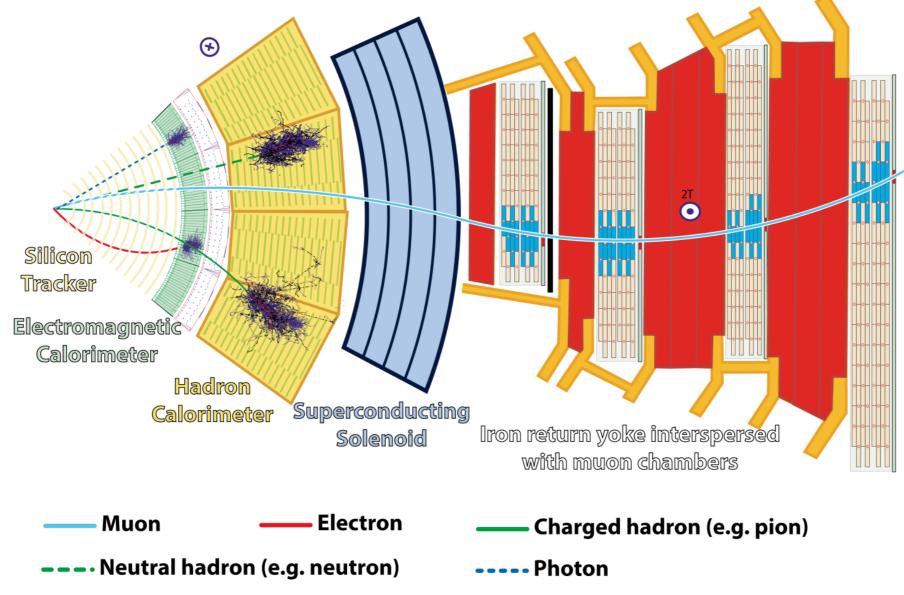
Long-lived Particle Searches

- Searches are as diverse as the phenomenology!
- Very generally they follow the same patterns I've described
- Everything requires a **lot** of care (I'll give you some examples)



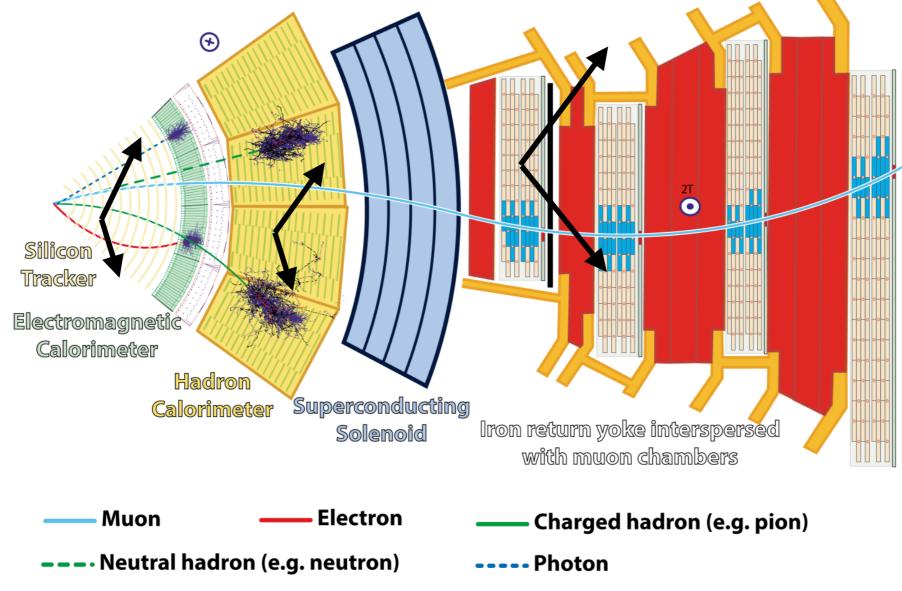
Projectivity

- Our detectors are *projective*. That means they were built at all levels assuming particles come from the origin.
- The triggers also often assume (approximate) projectivity



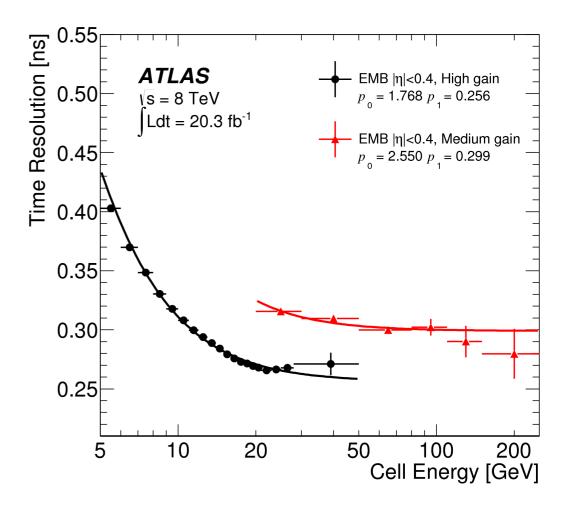
Projectivity

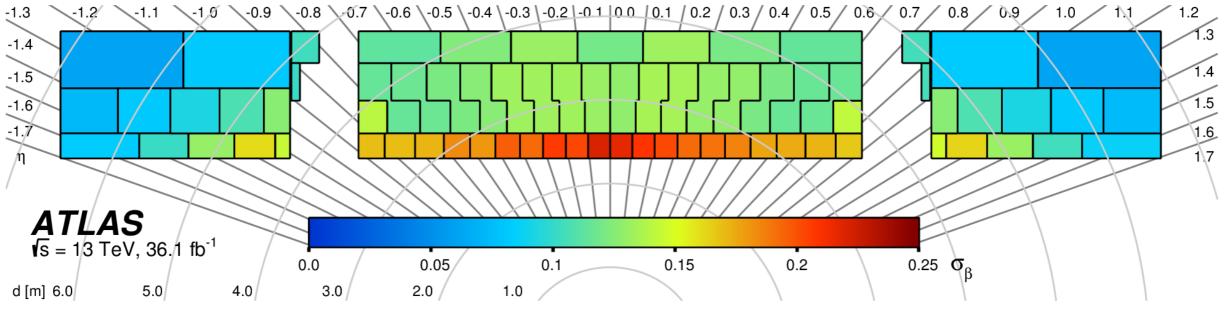
- LLPs can give you SM particles that don't point back to the origin
- Generally speaking, the reconstruction *hates* that
 - You also have to answer some odd questions like "What is p_T ?"



Calibration

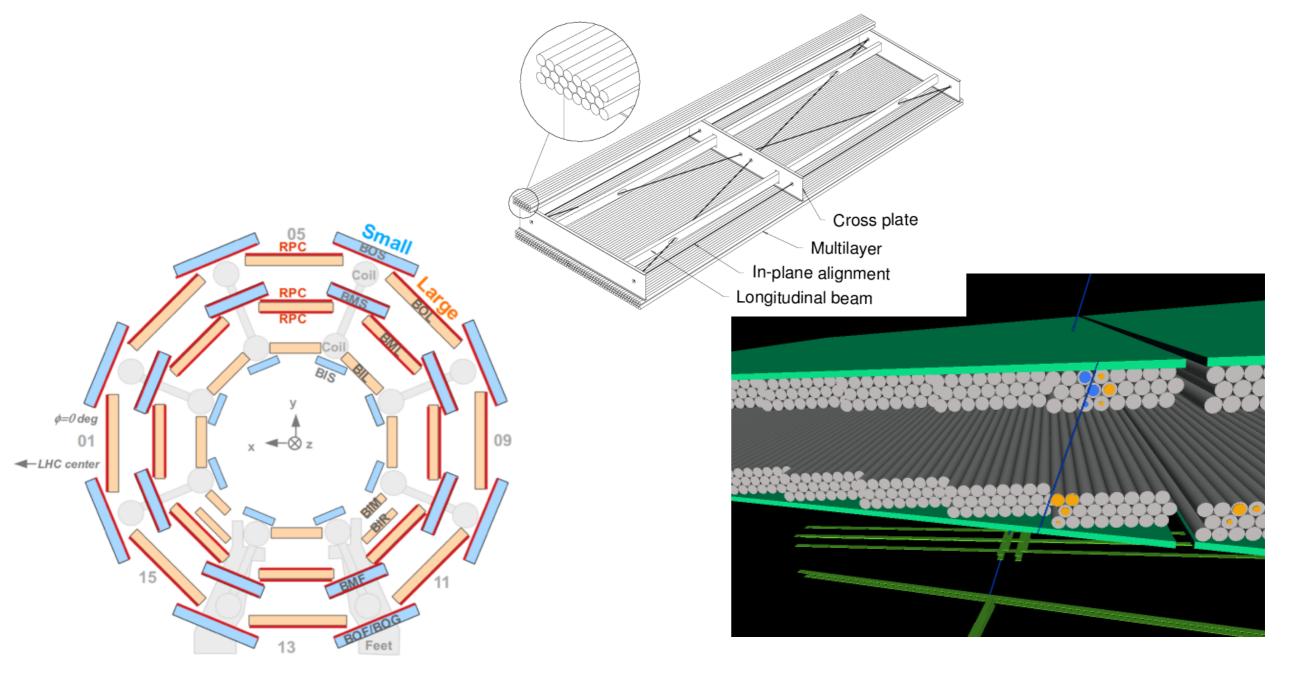
- You may end up having to calibrate something that the rest of the collaboration doesn't care about
- We don't normally need to calibrate *timing* very carefully, for example



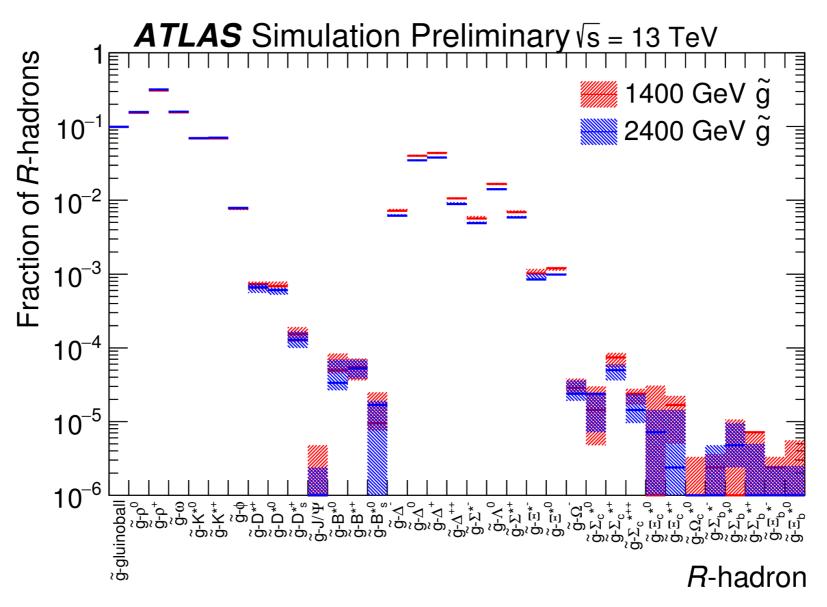


Detector Features

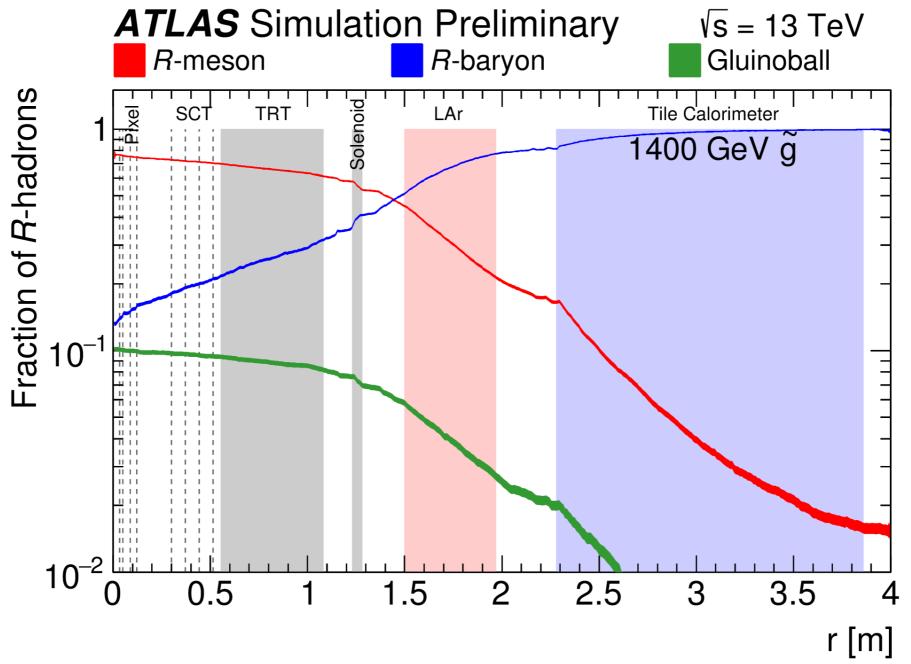
• If you're want to attempt one of these searches, it helps to be very good friends with someone who built part of the detector



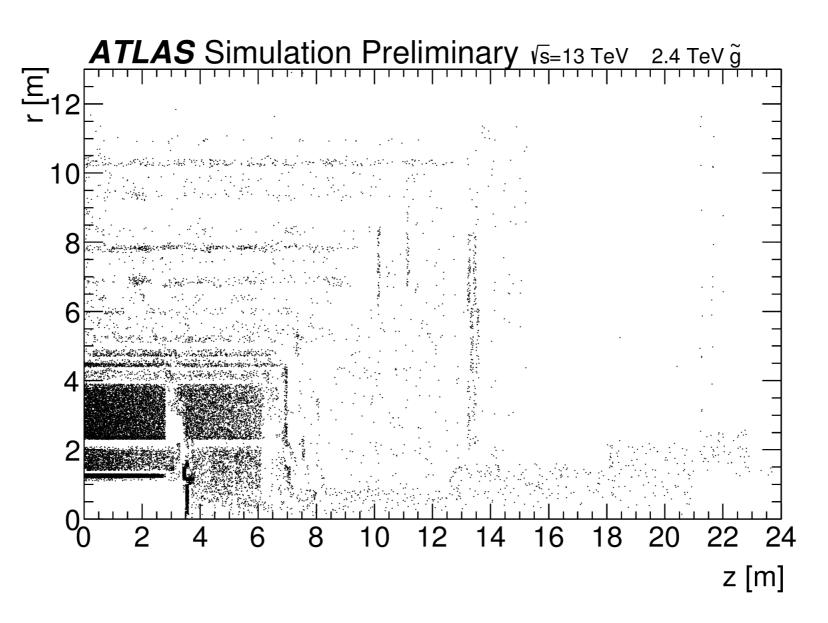
- John mentioned SUSY a few times
- When one of the colored sparticles becomes long lived, it can become an R-hadron



• These interact and change flavors as they move through the detector and re-hadronize!



• They can lose energy as they go along, and even *stop* in heavy parts of the detector!

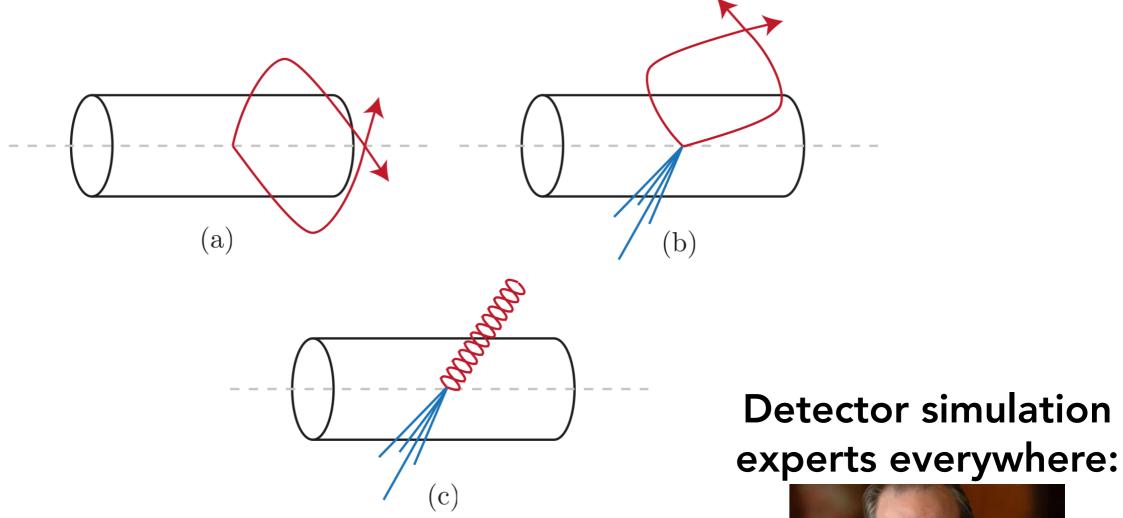




No one has ever modeled this stuff correctly.

It can be worse

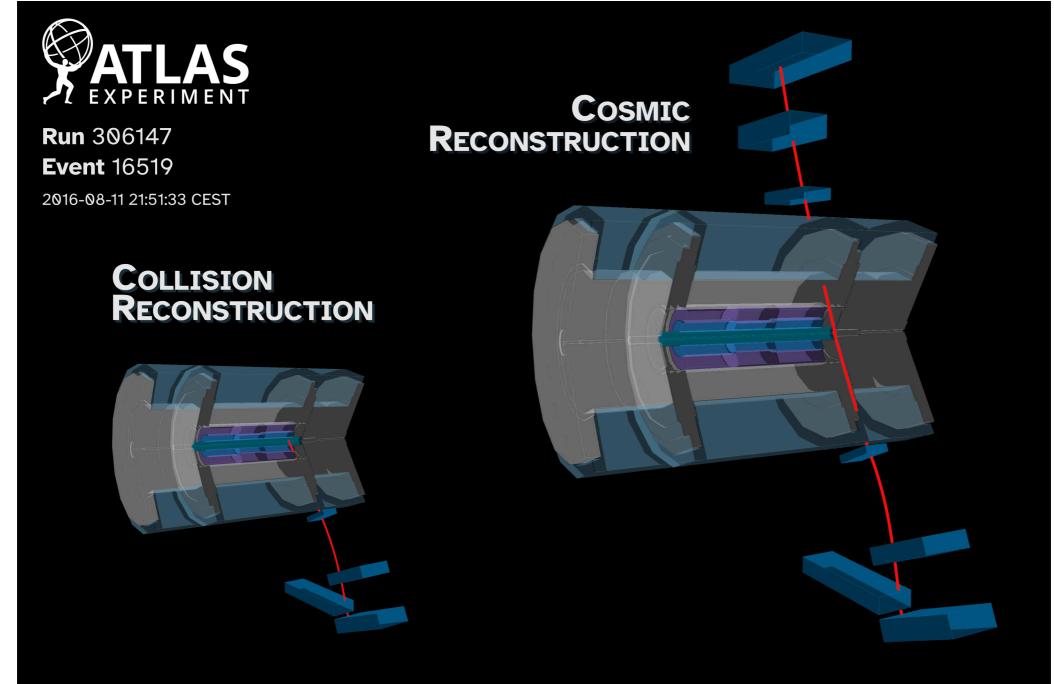
• Particles called "<u>quirks</u>" could form *macroscopic bound states*





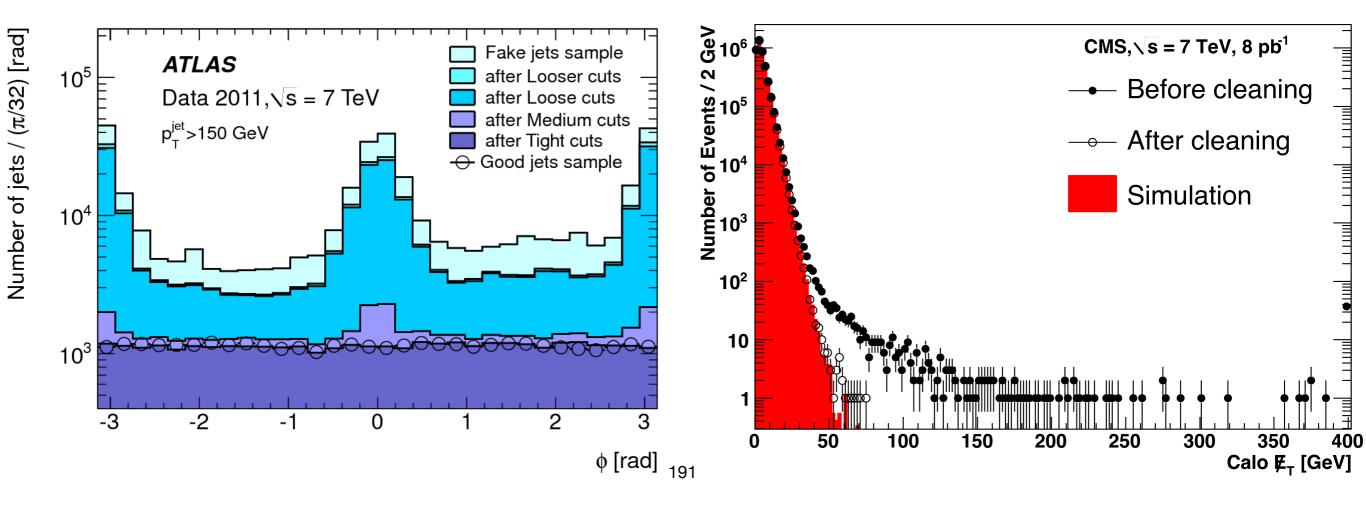
The backgrounds too

• The backgrounds from these searches are often weird and very hard to model and understand.



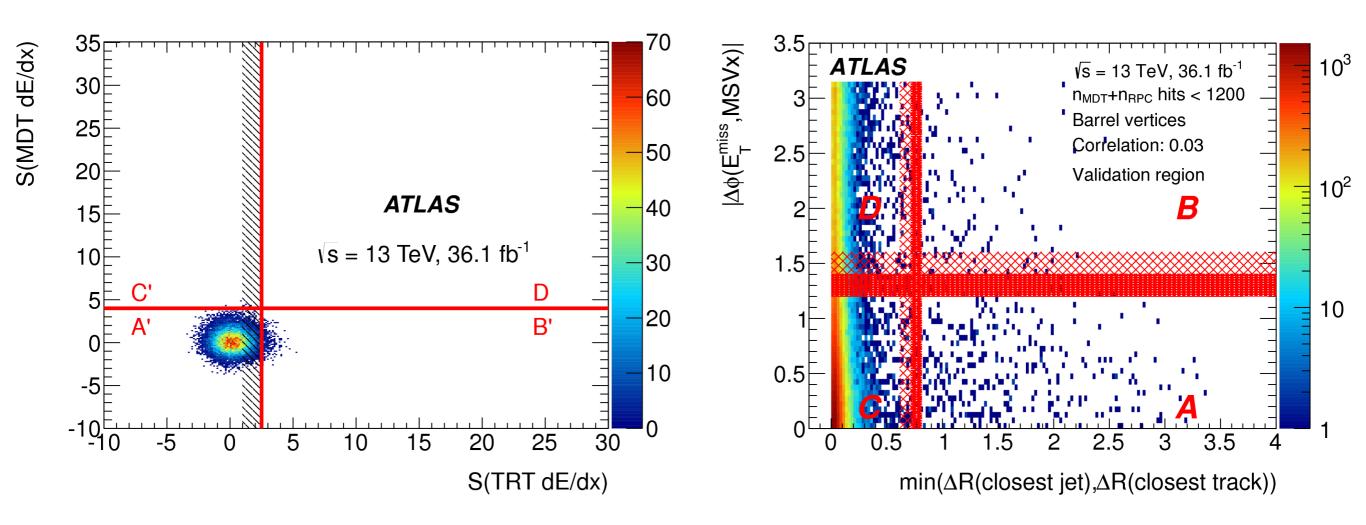
The backgrounds too

- The backgrounds from these searches are often weird and very hard to model and understand.
- Both experiments to significant *cleaning* to get rid of crap
 - We don't tend to document this very well... or model it well.
- This can get very dangerous for LLPs, as we mentioned.



ABCD FTW

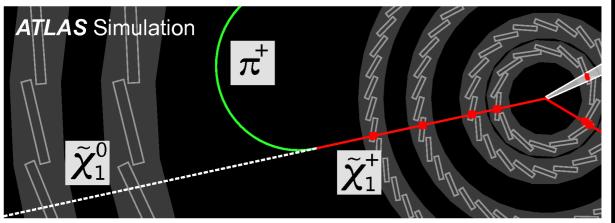
• I promised you ABCD... these searches are rife with it!

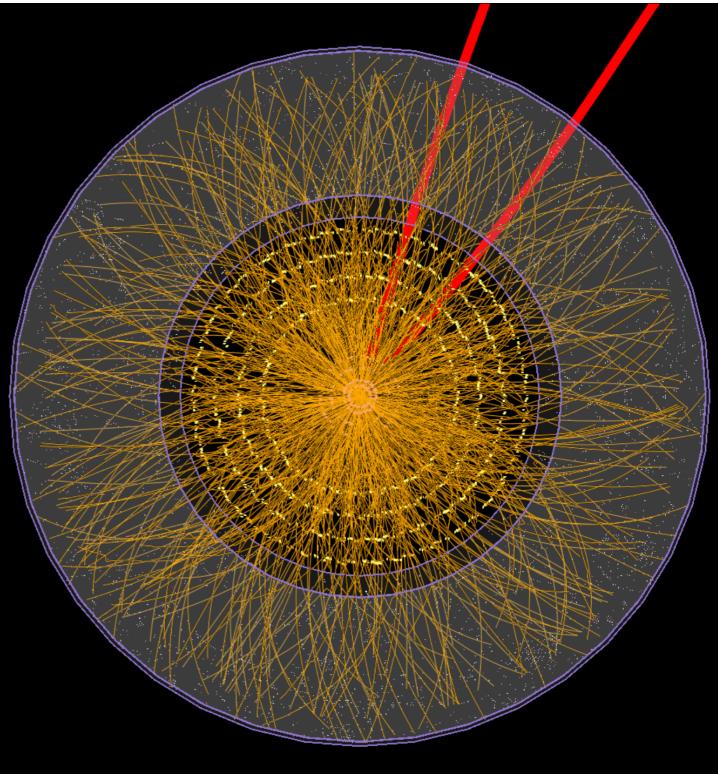


But we're pretty clever

- Just a friendly reminder
- We find disappearing tracks in this kind of event

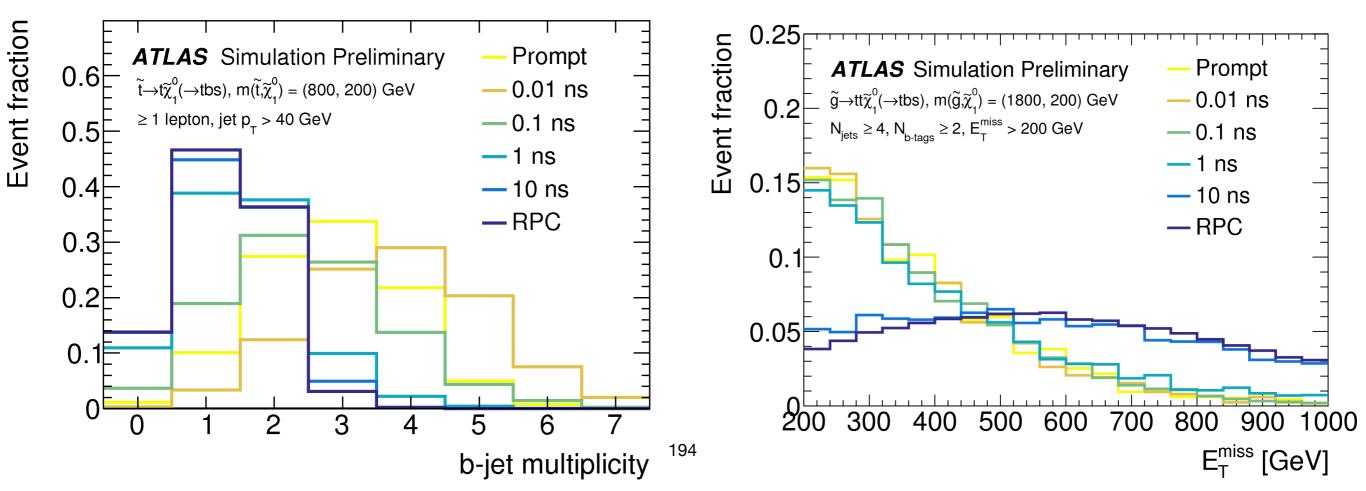




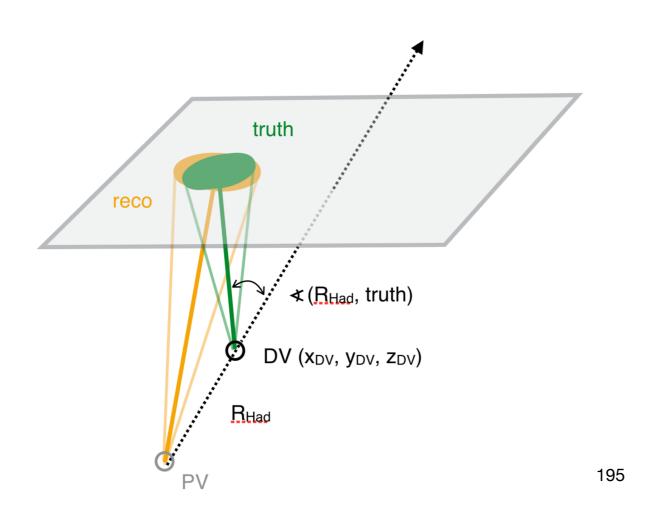


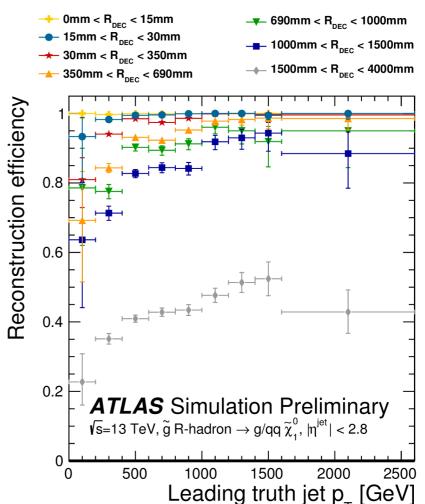
- ATLAS and CMS have gone through the interesting question: "What happens between prompt and LLP signals?"
- The detector sees interesting transitions there!

to the Gqq model considered in this note in the limit of a vanishingly small λ'' coupling. The analysis rejects events from detector noise and non-collision background, if at least one of the two leading jets with $p_T > 100$ GeV fails to satisfy the 'Tight' quality criteria, as described in Ref. [54]. This requirement places a cut on the jet charged particle fraction, defined as the ratio of the scalar sum of the p_T of the tracks associated with the jet to the jet p_T . This requirement introduces a high inefficiency for long-lived signals where displaced jets have no associated tracks, and is modified with respect to the original result. The modified requirement is based on the

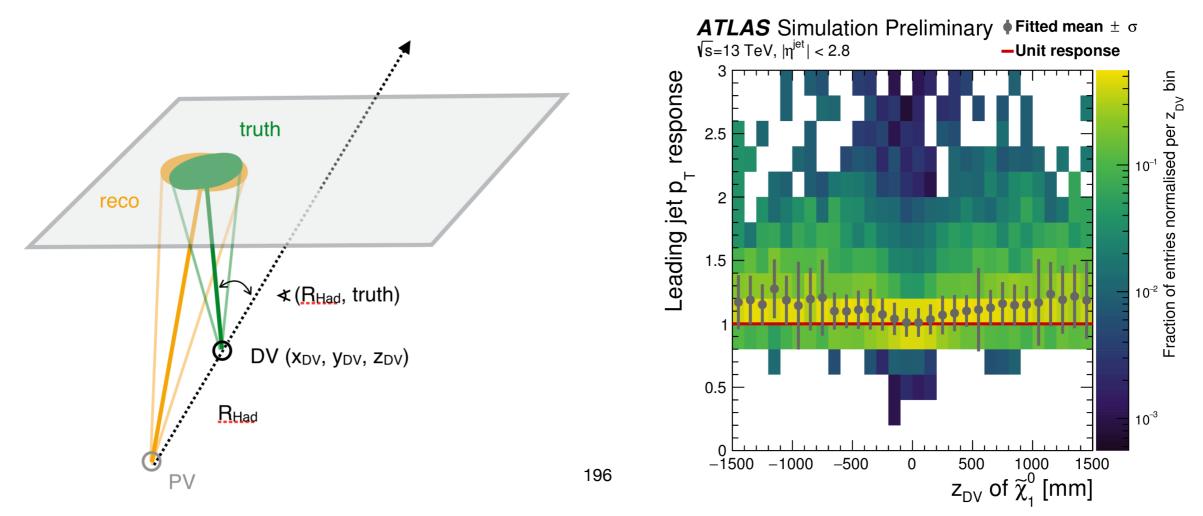


- We also add additional *uncertainties,* because object uncertainties (jet energy scale!) are derived assuming things come from the *origin* of the detector
 - Gotta find some way to characterize our knowledge of particles moving in weird directions in a calorimeter
 - There are no SM particles that do this, so it is very tough.

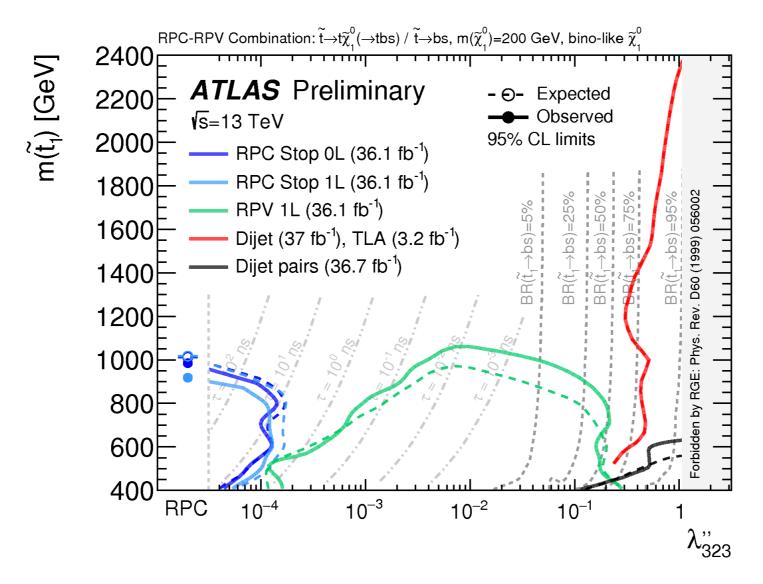




- We also add additional *uncertainties,* because object uncertainties (jet energy scale!) are derived assuming things come from the *origin* of the detector
 - Gotta find some way to characterize our knowledge of particles moving in weird directions in a calorimeter
 - There are no SM particles that do this, so it is very tough.



- These end up showing how these searches all work together
 - "Prompt", "LLP", and "Resonance" as the amount of R-parity violation is increased



Enter the Machine

WIRED STAFF 06.26.12 11:15 AM

Google's Artificial Brain Learns to Find Cat Videos



ImageNet Classification with Deep Convolutional Neural Networks

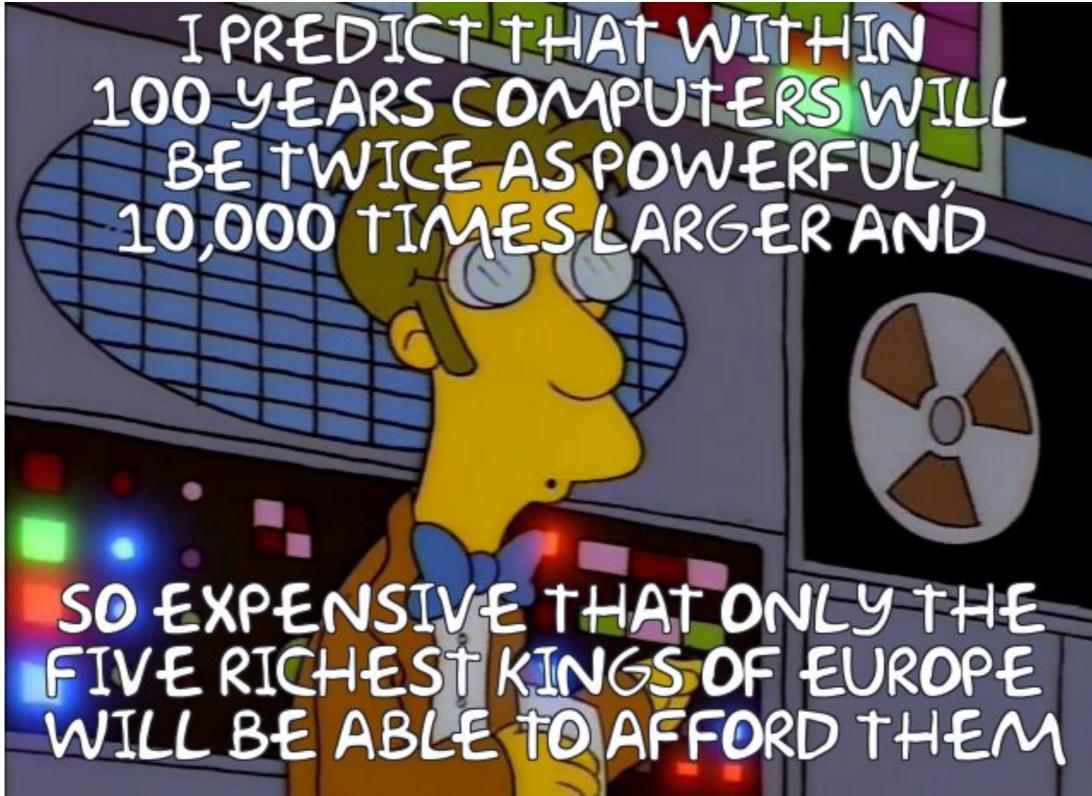
Alex Krizhevsky University of Toronto kriz@cs.utoronto.ca

Ilya Sutskever University of Toronto ilya@cs.utoronto.ca Geoffrey E. Hinton University of Toronto hinton@cs.utoronto.ca

Improving neural networks by preventing co-adaptation of feature detectors

G. E. Hinton*, N. Srivastava, A. Krizhevsky, I. Sutskever and R. R. Salakhutdinov

Enter the Machine



Machine Learning: The Good

• We have a **huge** kinematic space to look through

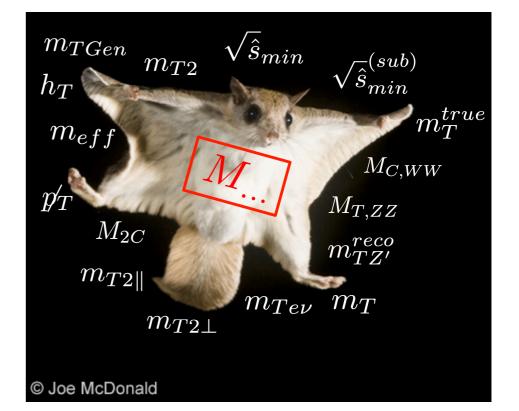
Baseline selection		N_{j}	$N_{\rm b}$	$N_{\rm SV}$	m _T ^b [GeV]	$p_{\mathrm{T}}^{\mathrm{ISR}}$ [GeV]	$p_{\rm T}^{\rm b}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	Bin number
		2–5	0	0		>500	_	[450, 550, 650, 750, ∞]	0–3
Jets	$N_{\rm i} \ge 2 \ (R = 0.4), p_{\rm T} > 30 { m GeV}, \eta < 2.4$	≥ 6	0	0	_	>500	_	[450, 550, 650, 750, ∞]	4–7
H_{T}	$H_{\rm T} > 300 {\rm GeV}$	2–5	0	≥ 1	—	>500	—	$[450, 550, 650, 750, \infty]$	8–11
		≥ 6	0	≥ 1	—	>500	—	$[450, 550, 650, 750, \infty]$	12–15
$p_{\mathrm{T}}^{\mathrm{miss}}$	$p_{\mathrm{T}}^{\mathrm{miss}} > 250\mathrm{GeV}$	≥2	1	0	<175	300-500	20-40	[300, 400, 500, 600, ∞]	16–19
	$\Delta \phi \left(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathbf{j}_{1} \right) > 0.5$	≥ 2	1	0	<175	300-500	40–70	$[300, 400, 500, 600, \infty]$	20–23
	$\Delta \phi \left(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathbf{j}_{2} \right) > 0.15$	≥ 2	1	0	<175	>500	20-40	$[450, 550, 650, 750, \infty]$	24–27
	$\Delta \phi \left(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, j_{3} \right) > 0.15$ (when applicable)	≥ 2	1	0	<175	>500	40–70	$[450, 550, 650, 750, \infty]$	28–31
		≥ 2	1	≥1	<175	>300	20–40	[300, 400, 500, ∞]	32–34
Veto electron	$p_{ m T} > 5 { m GeV}, \eta < 2.5, p_{ m T}^{ m sum} < 0.1 p_{ m T}$	≥2	≥2	—	<175	300-500	40-80	[300, 400, 500, ∞]	35–37
Veto muon	$p_{ m T} > 5{ m GeV}, \eta < 2.4, p_{ m T}^{ m sum} < 0.2p_{ m T}$	≥ 2	≥ 2	—	<175	300-500	80–140	[300, 400, 500, ∞]	38–40
Veto $\tau_{\rm h}$	$p_{\rm T} > 20 { m GeV}, \eta < 2.4, m_{\rm T} < 100 { m GeV}$	≥ 7	≥ 2	—	<175	300-500	>140	[300, 400, 500, ∞]	41–43
Veto track	PF charged candidates, $ \eta < 2.5$, $m_{\rm T} < 100$ GeV	≥ 2	≥ 2	—	<175	>500	40-80	$[450, 550, 650, \infty]$	44-46
		≥ 2	≥ 2	_	<175	>500	80–140	[450, 550, 650, ∞]	47–49
	$p_{ m T} > 5{ m GeV}$, $p_{ m T}^{ m sum} < 0.2p_{ m T}$ for electron and muon tracks		<u>≥</u> 2		<175	>300	>140	[450, 550, 650, ∞]	50–52
	$p_{\mathrm{T}} > 10\mathrm{GeV}$, $p_{\mathrm{T}}^{\mathrm{sum}} < 0.1p_{\mathrm{T}}$ for charged-hadron tracks								

Low Δm baseline selection

$N_{\rm t}, N_{\rm W}, N_{\rm res}$	$N_{ m t}=N_{ m W}=N_{ m res}=0$
$m_{\mathrm{T}}^{\mathrm{b}}$	$m_{\rm T}^{\rm b} < 175 { m GeV}$ (for events with $N_{ m b} \ge 1$)
ISR jet	$N_{\rm j}({ m ISR}) = 1 \ (R = 0.8), \ p_{ m T}^{ m ISR} > 200 \ { m GeV}, \ \eta < 2.4$ $\Delta \phi \ (\vec{p}_{ m T}^{ m miss}, j_{ m ISR}) > 2$
$p_{\mathrm{T}}^{\mathrm{miss}}$	$p_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 10\sqrt{\mathrm{GeV}}$

High Δm baseline selection

Jets	$N_{ m j} \geq 5~(R=0.4), p_{ m T} > 30~{ m GeV}, \eta < 2.4$
b tagging	$N_{\rm b} \ge 1$
$p_{\mathrm{T}}^{\mathrm{miss}}$	$\Delta \phi \left(ec{p}_{ ext{T}}^{ ext{miss}}, ext{j}_{1,2,3,4} ight) > 0.5$



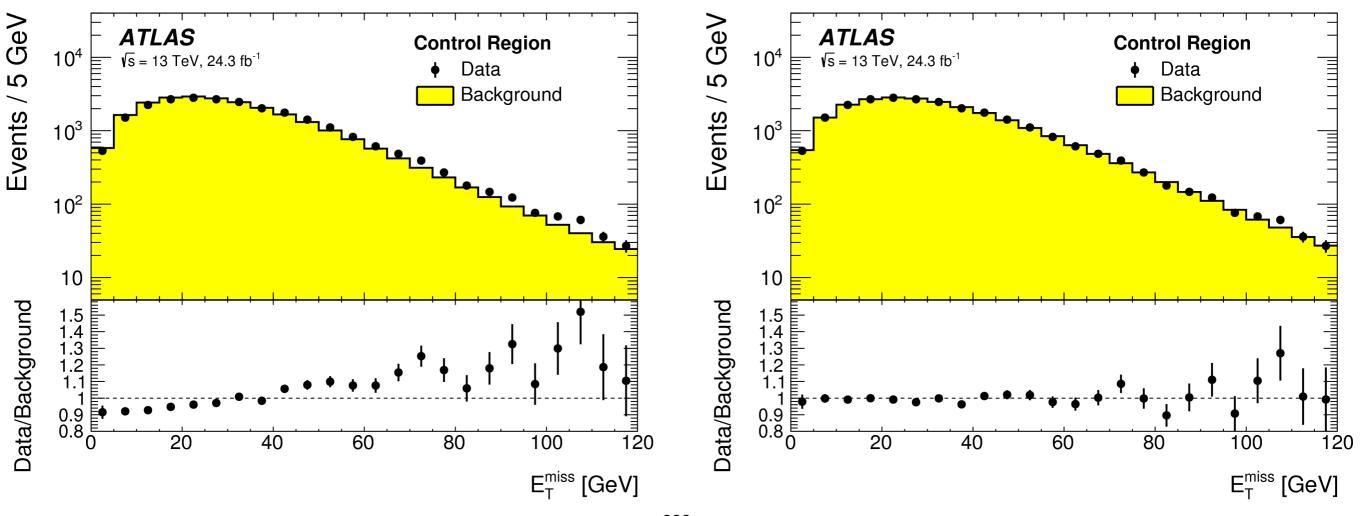
Machine Learning: The Good

• We have a **huge** kinematic space to look through

					_	
Sele	ection		hard-lepton	soft-lepton		
Trigger		$E_{\rm T}^{\rm miss}$ trigger				
Data quality		jet cleaning, primary vertex				
Second-lepton veto		no additional baseline leptons				
Number of leptons, tightness		= 1 'loose' lepton	= 1 'tight' lepton			
Lepton $p_{\rm T}$		[GeV]	> 25	> 4 (4.5) for μ (<i>e</i>)		
Number of jets (jet $p_{\rm T}$)			≥ 4 (> 25 GeV)	$\geq 1 \ (> 200 \text{ GeV}) \text{ or } \geq 2 \ (> 20 \text{ GeV})$)	
$E_{\rm T}^{\rm miss}$		[GeV]	> 230			
$\Delta \phi(j_{1,2}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$		[rad]		> 0.4		
N_{b}	jet		≥ 1	_		
m_{T}		[GeV]	> 30	_		
$m_{ m T2}^{ au}$	2	[GeV]	> 80	-		
-						
	Selection		tN_med	tN_high		
Preselection			hard-lepton preselection			
-	N _{jet} , N _{b-jet}		≥ (4, 1)	≥ (4, 1)		
	Jet p_{T}	[GeV	/] > (100, 90, 70), 50) > (120, 50, 50, 25)		
-	$E_{ m T}^{ m miss}$	[GeV	/] > 230	> 520		
	$E_{\mathrm{T},\perp}^{\mathrm{miss}}$	[GeV	/] > 400	_		
	$H_{\rm T,sig}^{\rm miss}$		> 16	> 25		
	m _T	[GeV	/] > 220	> 380		
	Topness		> 9	> 8		
$m_{top}^{reclustered}$		[GeV	/]	> 150		
_	$\Delta R(b, \ell)$		< 2.8	< 2.6		

Machine Learning: The Good

- Can be used for many-dimensional simultaneous reweighting
 - Deals with correlations better than many / repeated one-dimensional reweighting attempts

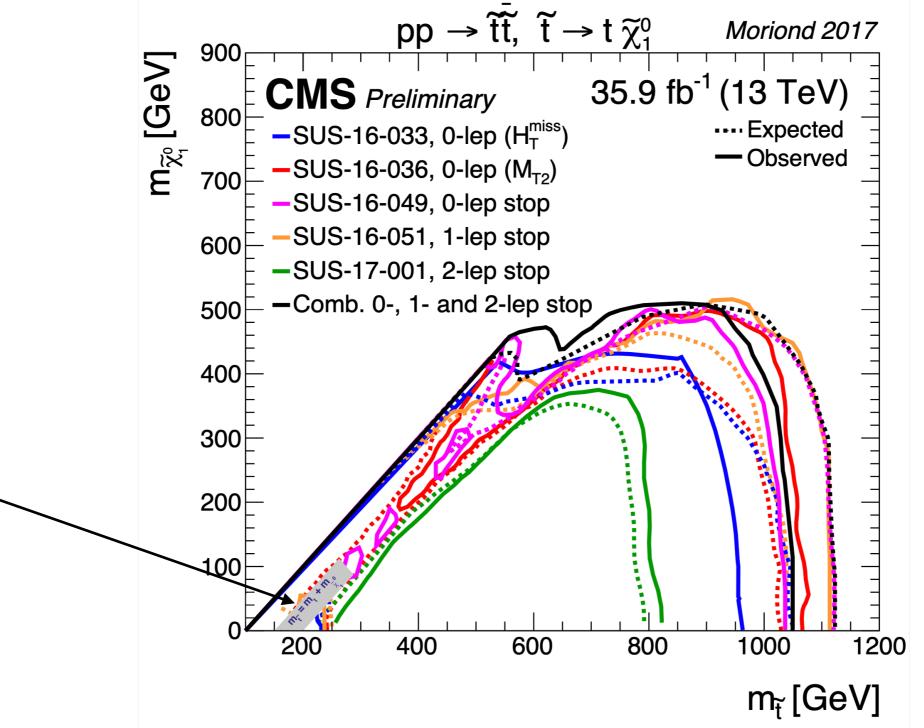


Machine Learning: a Reminder

- Here's a little homework exercise:
- Train a NN to find a circle in two dimensions, giving it x and y as input variables
- Then train a NN to find a circle in two dimensions, giving it r and phi as input variables
- **Eventually** the NN will succeed, but for any practical problem, the basis makes an enormous difference.

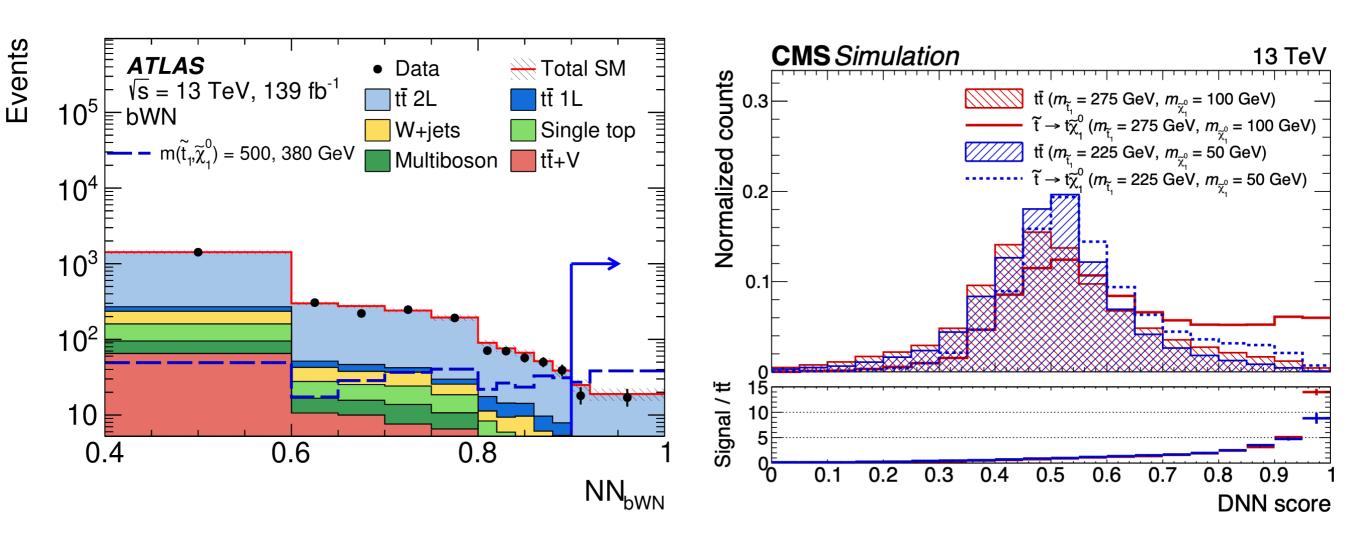
Machine Learning: the Bad

• What exactly am I discriminating from what?



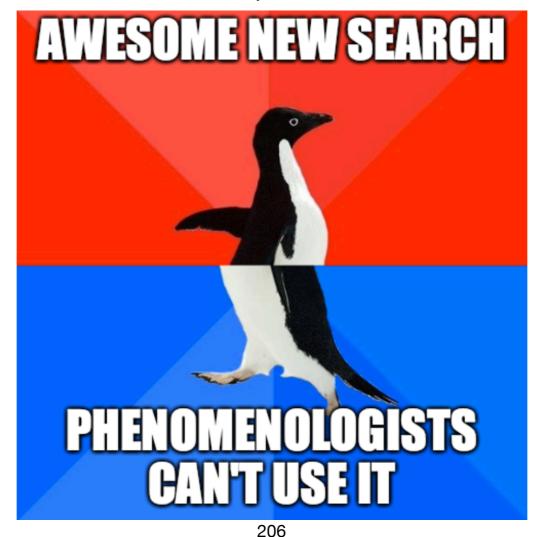
Machine Learning in Real

- We still use it for a lot of things! (Mostly top squarks?)
- It has a lot of good use, just be very careful!



Machine Learning Reinterpretation

- One criticism is to do with reinterpretation.
 - Essentially: "If experimentalists use ML, we can't check our models against their results!"
 - Phenomenologists don't have detailed detector simulation, and many variables dumped into NNs are quite sensitive to detector simulation



Machine Learning Reinterpretation

- Don't worry! We can (and should!) give some guidance
- And the sensitivity to simulation *tends* to be a *background* issue

Auxiliary information for SUSY-2016-16 by the ATLAS Collaboration

A brief instruction for the BDT HEPData material is provided below, in order for those who are not members of the ATLAS Collaboration to reinterpret our results.

Instruction for BDT HEPData materials

BDTs, implemented in the TMVA [1] toolkit, are employed in this analysis. Three BDTs (BDT_low, BDT_med, and BDT_high) are defined targeting three SRs: tN_diag_low, tN_diag_med, and tN_diag_high SR. In the BDT training, the simulated events for signal $(\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0)$ and backgrounds $(t\bar{t}$ and W+jets) are split into two subsets, 'even' and 'odd', based on event numbers. The odd subset is used for the training and the even subset is used for the testing. For validation purposes, a second BDT is built using the 'even' subset for the training and the 'odd' subset for the testing. This results in 6 BDTs ('odd' and 'even' BDTs \otimes 3 SRs) in total.

The output format of the BDT training is an XML file, which contains (1) a list of options used in the training (e.g. NTrees and MaxDepth), (2) a list of discriminating variables used and their scanned range in the training, and (3) trained decision trees including a list of discriminating variables, their cut values, and resulting purity (S/S+B).

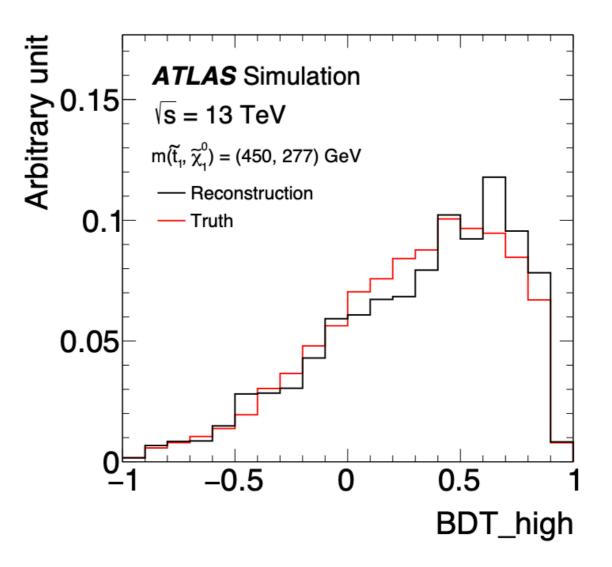
The variables input to BDTs are as follows:

- BDT_low: $E_{\rm T}^{\rm miss}$, $m_{\rm T}$, $\Delta m_{\rm T}^{\alpha}$, $m(t_{\rm had}^{\rm ISR})$, $m(t_{\rm len}^{\alpha})$, $|\Delta\phi(\ell, t\bar{t})|$, and $|\Delta\phi(\ell, \vec{p}_{\rm T}(v^{\alpha}))|$,
- BDT_med: $E_{\rm T}^{\rm miss}$, $H_{\rm T,sig}^{\rm miss}$, $\Delta \phi(\vec{p}_{\rm T}^{\rm miss}, t_{\rm had}^{\chi})$, $\Delta \phi(t_{\rm had}^{\chi}, t_{\rm lep}^{\chi})$, $\Delta R(b, \ell)$, $m_{\rm T}$, $m_{\rm top}^{\chi}$, the number of jets, the third jet $p_{\rm T}$, and the fourth jet $p_{\rm T}$,
- BDT_high: R_{ISR} , $\Delta\phi(\text{ISR}, \text{I})$, $\Delta\phi(t_{\text{had}}^{\chi}, t_{\text{lep}}^{\chi})$, $\Delta R(b, \ell)$, m_{T} , M_{T}^{S} , m_{top}^{χ} the number of jets in the di-stop decay system, the third jet p_{T} , and the fourth jet p_{T} ,

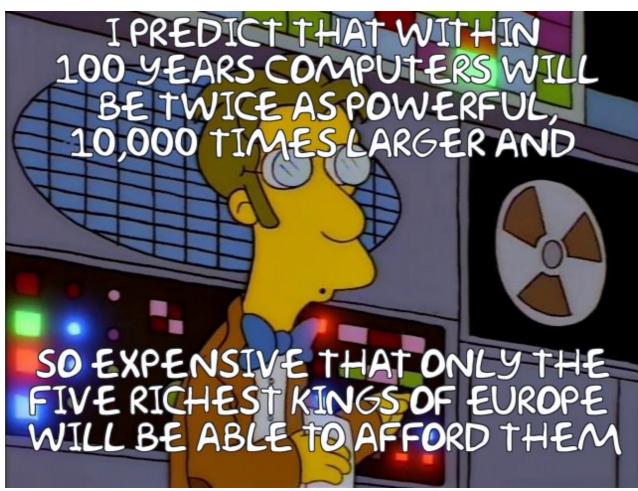
The '200' suffix on the names of the variables in the BDT_low XML implies that α is calculated using a signal point $m(\tilde{t}_1, \tilde{\chi}_1^0) = (200, 27)$ GeV. The unit MeV is commonly used for momenta and energies, besides the dimensionless azimuthal-angle variables. The HEPData record contains the source code file that is used for the calculation of all input variables, and for applying the signal selections at particle-level (or truth-level). The XML files can be read in by the TMVA toolkit. The TMVA toolkit has public member functions called BookMVA for reading XML files and EvaluateMVA for outputing the BDT response (either '0' or '1') given the input signal efficiency.

Figure 1 shows the signal acceptance at truth-level and the truth to full reconstruction (including both detector simulation and reconstruction) efficiency for SRs. These numbers can be used when re-interpreting the BDT analysis with other physics models or when validating other truth codes for the re-interpretation.

Some care is required when applying a BDT to variables computed from truth particles, as the shapes of some kinematic distributions at truth-level are not necessarily similar to the ones with the full reconstruction due to resolution effects. Figure 2 shows the BDT output score distributions for signal benchmark models in the three BDT based selections. Each plot compares the distribution obtained after the full detector simulation (as used in the analysis) with the one obtained using truth particles. The fair agreement demonstrates the usability of the BDTs in the context of reinterpretations, at least for signal models that have similar kinematic features to those used in the analysis.



Future of Machine Learning



- Many people are predicting continued expansion of ML
- Industry are working with very large networks
- Many people have proposed working with the raw data (or similar) as input, *bypassing* much of the reconstruction

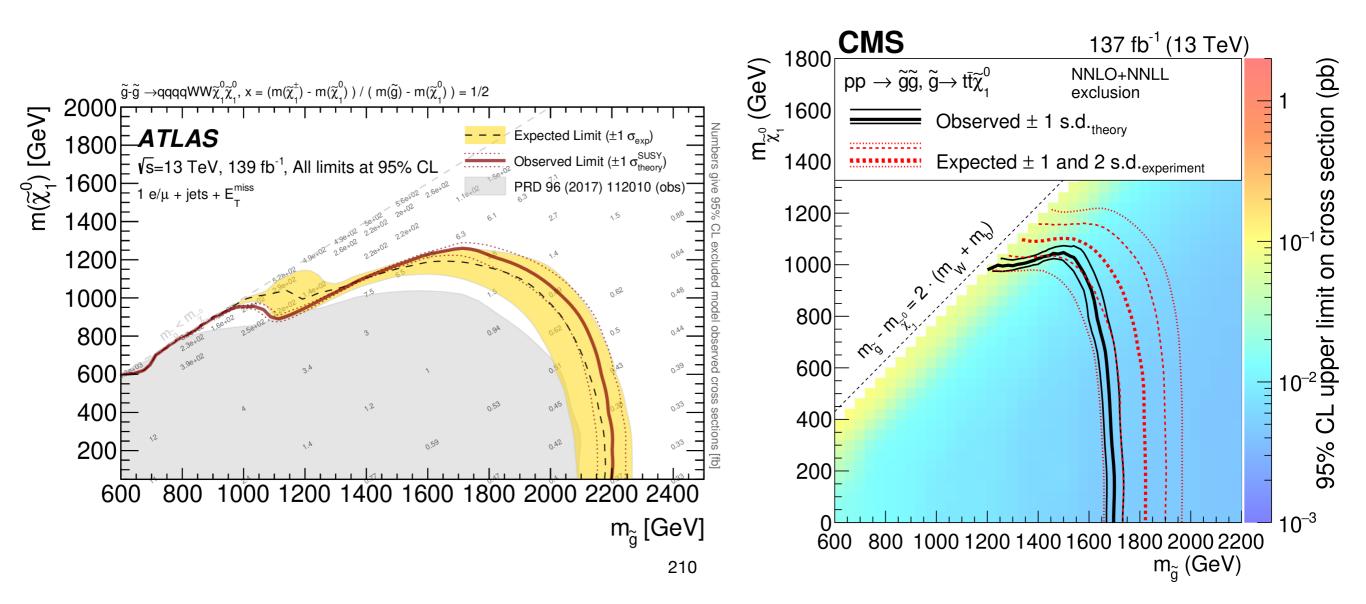
ML Philosophy

- Before you use machine learning, please think: **why and how**?
- The purpose of a search is **not** to exclude a simplified model, but to **find new physics**.
- Think very carefully to avoid a lot of work for little scientific value



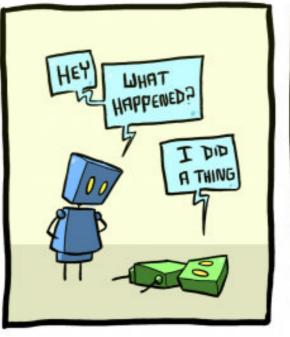
One last note on limits

 Isn't it a little weird how the right one looks like it was drawn with a gradient fill?



Almost there!







• What I told you about really is what ATLAS and CMS are doing!

arXiv	Ref	Short			LLP	Туре	Bac	kgrou	ind					ML	
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2104.12853	3 B2G-19-003	Heavy resonance to top W	1	0)	Multi-bin fit									0
2104.04831	1 B2G-20-005	W' to top bottom	2	2 0)	Multi-bin fit									0
2102.08198	8 B2G-19-006	Heavy resonance to Z Higgs	3	6 ()	Multi-bin fit									0
2008.09835	5 B2G-19-005	Bottom-like VLQ all hadronic	1	0)	Multi-bin fit									0
1909.04721	1 B2G-18-003	Top-like VLQ all hadronic	1	0)	Multi-bin fit									0
2107.13021	1 EXO-20-004	Jets and MET	9) ()	Multi-bin fit									0
2107.04838	8 EXO-20-015	LLPs in the muon endcaps	2	2 ()	Cut and count									0
2106.10509	9 EXO-20-001	W(hadronic) gamma resonances	4	. ()	Bump hunt									0
2105.09178	8 EXO-17-010	SMP in trackless jets	1	0)	Cut and count									1
2104.13474	4 EXO-19-013	LLPs to jets with displaced vertices	2	2 (Multi-bin fit									0
2107.12553	3 SUS-20-003	Charginos and neutralinos to Higgs and W	1	0)	Multi-bin fit									0
2107.10892	2 SUS-20-002	Top squarks combination	2	2 ()	Multi-bin fit									0
2106.14246	6 SUS-19-012	Charginos and neutralinos	6	5 ()	Multi-bin fit									0
2103.0129	9 SUS-19-010	Top squarks all hadronic	g	0 0)	Multi-bin fit									0
2102.06976	6 SUS-19-004	Top squarks to top quarks with jets	2	2 0)	Multi-bin fit									0

arXiv	Ref	Short			LLP	Туре	Bac	kgrou	Ind					ML	(0)
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2108.076	65 SUSY-2019-18	Stop pair; Leptoquarks; taus	3		0	Multi-bin fit									
2108.075	86 SUSY-2018-41	EWK all-had	9		0	Multi-bin fit									
2106.096	09 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5		0	Multi-bin fit									
2106.016	76 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3		0	Multi-bin fit									;
2104.03	05 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1		0	Multi-bin fit									
2103.116	84 SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4		0	Multi-bin fit									
2103.081	89 SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1		0	Multi-bin fit									
2102.014	44 SUSY-2018-08	Search for DM and stops in tt2L + MET final states	4		0	Multi-bin fit									
2101.125	27 SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3		0	Multi-bin fit									
2101.016	29 SUSY-2018-10	Gluino pair, squark pair; 1 lepton	2		0	Multi-bin fit									
2012.037	99 SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton	4		0	Multi-bin fit									
2011.105	43 SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L	2		0	Multi-bin fit									
2011.078	12 SUSY-2018-14	Search for displaced leptons	1		0	Multi-bin fit									
2010.142	93 SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	;	0	Multi-bin fit									
2010.010	15 SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2		0	Multi-bin fit									
2008.060	32 SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3		0	Multi-bin fit									
2006.05	88 SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2		0	Multi-bin fit									
2004.14	06 SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4		0	Multi-bin fit									
2004.108	94 SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2		0	Multi-bin fit									
2102.108	74 EXOT-2018-06	Monojet search	8		1	Multi-bin fit									
2108.075	86 EXOT-2018-09	multi-b-jet resonance	1		0	Bump hunt									
2107.060	92 EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1		0	Cut and count									
2107.004	04 EXOT-2019-36	Multilepton General	0		2	Multi-bin fit									
2105.138	47 EXOT-2018-16	bsll contact interaction	1		0	Cut and count									
2105.124	91 EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1		0	Multi-bin fit									
2101.115	82 EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1		0	Multi-bin fit									
2011.093	08 EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4		0	Multi-bin fit									
2011.052	59 EXOT-2018-63	Photon + MET Search	2		0	Multi-bin fit									
2010.065	48 EXOT-2018-40	Mono-scalar to VV in hadronic channel	1		0	Multi-bin fit									
2010.025	66 EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2		0	Multi-bin fit									
2104.13	24 HIGG-2019-02	Search for H(125)> gamma gamma + Missing-ET	0		3	Multi-bin fit									

arXiv	Ref	Short				LLP	/pe	Bac	kgrou	ind					ML	
				Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2108.076	65 SUSY-2019-18	Stop pair; Leptoquarks; taus	F	3	(0	ulti-bin fit									
2108.075	86 SUSY-2018-41	EWK all-had		9	(0	ulti-bin fit									
2106.096	09 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV		5	(0	fulti-bin fit									
2106.016	76 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and M		3	(0	ulti-bin fit									:
2104.03	05 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings		1	(0	ulti-bin fit									
2103.116	84 SUSY-2018-02	Chargino-neutralino pair; 4 leptons		4	(0	ulti-bin fit									
2103.081	89 SUSY-2018-40	Search for sbottoms		1	(0	ulti-bin fit									
2102.014	44 SUSY-2018-08	Search for DM and state I C · I · C · I		4	(0	ulti-bin fit									
2101.125	27 SUSY-2018-34	Search for DM and str Sbottom pair, WIMP L Loads of simplified		3	(0	ulti-bin fit									
2101.016	29 SUSY-2018-10	Gluino pair squark na		2	(0	ulti-bin fit									
2012.037	99 SUSY-2018-07	Stop pair, WIMP DM models; few		4	(0	ulti-bin fit									
2011.105	43 SUSY-2018-36	Search for chargino a		2	(0	ulti-bin fit									
2011.078	12 SUSY-2018-14	Search for displaced	1	1	(0	ulti-bin fit									
2010.142	93 SUSY-2018-22	Search for displaced Complete models		5	(0	ulti-bin fit									
2010.010	15 SUSY-2018-38	Search for new physic		2	(0	ulti-bin fit									
2008.060	32 SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity		3	(0	ulti-bin fit									
2006.05	88 SUSY-2018-21	Search for stop pair production decaying through Z/h bosons		2	(0	Julti-bin fit									
2004.14	06 SUSY-2018-12	Stop pair; 0 lepton; leptoquarks		4	(0	ulti-bin fit									
2004.108	94 SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	ł	2	(0	ulti-bin fit									
2102.108	74 EXOT-2018-06	Monojet search		8	-	1	ulti-bin fit									
2108.075	86 EXOT-2018-09	multi-b-jet resonance		1	(0	ump hunt									
2107.060	92 EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state		1	(0	ut and count									
2107.004	04 EXOT-2019-36	Multilepton General		0	2	2	ulti-bin fit									
2105.138	47 EXOT-2018-16	bsll contact interaction		1	(0	out and count									
2105.124	91 EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau		1	(0	ulti-bin fit									
2101.115	82 EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepto	Ŧ	1	(0	ulti-bin fit									
2011.093	08 EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state		4	(0	ulti-bin fit									
2011.052	59 EXOT-2018-63	Photon + MET Search		2	(0	ulti-bin fit									
2010.065	48 EXOT-2018-40	Mono-scalar to VV in hadronic channel		1	(0	ulti-bin fit									
2010.025	66 EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau		2	(0	ulti-bin fit									
2104.13	24 HIGG-2019-02		Ş	0	3	3	ulti-bin fit									

rXiv	Ref	Short			LL	Туре	Bac	kgrou	ind					ML	
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2108.076	65 SUSY-2019-18	Stop pair; Leptoquarks; taus	3	. (D	Multi-bin fit									
2108.075	86 SUSY-2018-41	EWK all-had	9) (0	Multi-bin fit									
2106.096	09 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	. (D	Multi-bin fit									
2106.016	76 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	. (D	Multi-bin fit									;
2104.03	05 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	(D	Multi-bin fit									
2103.116	84 SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	. (0	Multi-bin fit									
2103.081	89 SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	(0	Multi-bin fit									
2102.014	44 SUSY-2018-08	Search for DM and stops in tt2L + MET final states	4	. (D	Multi-bin fit									
2101.125	27 SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3	(o k	Multi-bin fit									
2101.016	29 SUSY-2018-10	Gluino pair, squark pair; 1 lepton		0-17 A-191		Multi-bin fit									
2012.037	99 SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton Mostly multi-bin	fi	tc		Multi-bin fit									
2011.105	43 SUSY-2018-36	Search for chargino and neutralino pain		LJ.	• 🕴	Multi-bin fit									
2011.078	12 SUSY-2018-14	Search for displaced leptons				Multi-bin fit									
2010.142	93 SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	6 (D	Multi-bin fit									
2010.010	15 SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	. (D	Multi-bin fit									
2008.060	32 SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	. (D	Multi-bin fit									
2006.05	88 SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	. (D	Multi-bin fit									
2004.14	06 SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	. (D	Multi-bin fit									
2004.108	94 SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	. (D	Multi-bin fit	ŝ								
2102.108	74 EXOT-2018-06	Monojet search	8		1	Multi-bin fit									
2108.075	86 EXOT-2018-09	multi-b-jet resonance	1	(D	Bump hunt									
2107.060	92 EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	(D	Cut and count	t								
2107.004	04 EXOT-2019-36	Multilepton General	0		2	Multi-bin fit									
2105.138	47 EXOT-2018-16	bsll contact interaction	1	(D	Cut and coun	t 🚪								
2105.124	91 EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	(D	Multi-bin fit	1								
2101.115	82 EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	(D	Multi-bin fit									
2011.093	08 EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	. (D	Multi-bin fit									
2011.052	59 EXOT-2018-63	Photon + MET Search	2	. (D	Multi-bin fit									
2010.065	48 EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	(0	Multi-bin fit									
2010.025	66 EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	. (0	Multi-bin fit									
															-

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rXiv	Ref	Short			LLP	Туре	Bac	kgrou	nd				V	1L
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing	Discovery regions
2108.07665	5 SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0)	Multi-bin fit					-	-		
2108.07586	5 SUSY-2018-41	EWK all-had	9	0)	Multi-bin fit								
2106.09609	9 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0)	Multi-bin fit	ļ.							
2106.01676	6 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0)	Multi-bin fit							8	
2104.0305	5 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0		Multi-bin fit							5	
2103.11684	\$USY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit	e la							
2103.08189	9 SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	0)	Multi-bin fit								
2102.01444	\$USY-2018-08	Search for DM and stops in tt2L + MET final states	4	0)	Multi-bin fit								
2101.12527	7 SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3	0		Multi-bin fit	S.							
2101.01629	9 SUSY-2018-10	Gluino pair, squark pair; 1 lepton			~ .									
2012.03799	9 SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton	ots	O^{\dagger}	ŀΝ	/IC!								
2011.10543	3 SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L				10.								
2011.07812	2 SUSY-2018-14	Search for displaced leptons	1	0		Multi-bin fit	2							
2010.14293	3 SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	0		Multi-bin fit								
2010.01015	5 SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	0		Multi-bin fit	2 2							
2008.06032	2 SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit								
2006.0588	3 SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		Multi-bin fit	Č						ě	
2004.1406	6 SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit								
2004.10894	4 SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit								
2102.10874	4 EXOT-2018-06	Monojet search	8	1		Multi-bin fit							5	
2108.07586	6 EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt	\$							
2107.06092	2 EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0		Cut and count								
2107.00404	\$ EXOT-2019-36	Multilepton General	0	2	2	Multi-bin fit								
2105.13847	7 EXOT-2018-16	bsll contact interaction	1	0)	Cut and count								
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit								
2101.11582	2 EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit								
2011.09308	B EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit	N.							
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit								
2010.06548	3 EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit							2	
2010.02566	6 EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit	0							

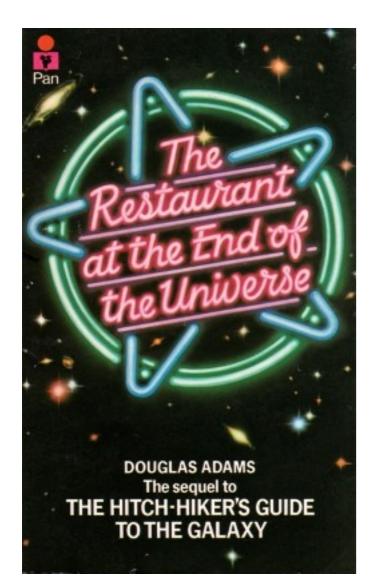
rXiv	Ref	Short			LLP	Туре	Back	kgrou	nd					ML
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	let Smearing	
2108.076	65 SUSY-2019-18	Stop pair; Leptoquarks; taus		3 ()	Multi-bin fit							-	
2108.075	586 SUSY-2018-41	EWK all-had		9 ()	Multi-bin fit								
2106.096	609 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV		5 ()	Multi-bin fit								
2106.016	676 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and ME	т	3 ()	Multi-bin fit								
2104.03	305 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings		1 ()	Multi-bin fit								
2103.116	584 SUSY-2018-02	Chargino-neutralino pair; 4 leptons		4 ()	Multi-bin fit								
2103.081	189 SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus		1 ()	Multi-bin fit								
2102.014	44 SUSY-2018-08	Search for DM and stops in tt2L + MET final states				Multiplie fit			in the second		Section of the			
2101.125	527 SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	~		R /						•			
2101.016	529 SUSY-2018-10	Gluino pair, squark pair; 1 lepton	Son	ne	IV	lachin	е	Le	ee	rn	n	10		
2012.037	799 SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton										3		
2011.105	543 SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L	'hut	- n	$\cap t$	ubiqu	ii+	\frown	IC	·)				
2011.078	312 SUSY-2018-14	Search for displaced leptons	NU			uniqu	ιι			'				
2010.142	293 SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton		5	,	widia-Din nit								
2010.010	015 SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity		2 ()	Multi-bin fit								
2008.060	32 SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity		3 ()	Multi-bin fit							0	
2006.05	588 SUSY-2018-21	Search for stop pair production decaying through Z/h bosons		2 ()	Multi-bin fit								
2004 14		Search for stop pair production decaying through 2/h bosons												
2004.14	406 SUSY-2018-12	Stop pair; 0 lepton; leptoquarks		4 0)	Multi-bin fit								
	406 SUSY-2018-12 394 SUSY-2018-23)								Ļ	
2004.108		Stop pair; 0 lepton; leptoquarks				Multi-bin fit								
2004.108 2102.108	394 SUSY-2018-23	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons		2 (0 8 1		Multi-bin fit Multi-bin fit								
2004.108 2102.108 2108.075	894 SUSY-2018-23 874 EXOT-2018-06	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons Monojet search		2 (8 1 1 ()	Multi-bin fit Multi-bin fit Multi-bin fit								
2004.108 2102.108 2108.075 2107.060	894SUSY-2018-23874EXOT-2018-06586EXOT-2018-09	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons Monojet search multi-b-jet resonance Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state		2 (0 8 1 1 (0 1 (0))	Multi-bin fit Multi-bin fit Multi-bin fit Bump hunt								
2004.108 2102.108 2108.075 2107.060 2107.004	394 SUSY-2018-23 374 EXOT-2018-06 586 EXOT-2018-09 592 EXOT-2018-57	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons Monojet search multi-b-jet resonance Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state		2 0 8 1 1 0 1 0 2		Multi-bin fit Multi-bin fit Multi-bin fit Bump hunt Cut and count								
2004.108 2102.108 2108.075 2107.060 2107.004 2105.138	894SUSY-2018-23874EXOT-2018-06586EXOT-2018-09992EXOT-2018-57404EXOT-2019-36	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons Monojet search multi-b-jet resonance Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state Multilepton General		2 (0 8 1 1 (0 1 (0 2 1 (0) 	Multi-bin fit Multi-bin fit Multi-bin fit Bump hunt Cut and count Multi-bin fit								
2004.108 2102.108 2108.075 2107.060 2107.004 2105.138 2105.124	394 SUSY-2018-23 374 EXOT-2018-06 586 EXOT-2018-09 092 EXOT-2018-57 404 EXOT-2019-36 347 EXOT-2018-16	Stop pair; 0 lepton; leptoquarks Chargino-neutralino pair; Higgs boson in final state, 2 photons Monojet search multi-b-jet resonance Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state Multilepton General bsll contact interaction Lepton Flavor Violating Z Decay with a Leptonic Tau		2 (0 8 1 1 (0 1 (0 2 1 (0 1 (0		Multi-bin fit Multi-bin fit Multi-bin fit Bump hunt Cut and count Multi-bin fit Cut and count								
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2108.075	86 SUSY-2018-41	EWK all-had	9	0)	Multi-bin fit							1	5
2106.096	09 SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0)	Multi-bin fit								
2106.016	76 SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit								6
2104.03	05 SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0		Multi-bin fit								Š.
2103.116	84 SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit								ž.
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2102.014	44 SUSY-2018-08	Search for DM and stops in tt2L + MET final states		+~	~	faliance	· · ·		~ /	5				
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Last Reminders

- When you search, search for new physics, don't simply try to exclude a model
 - And remember that a search for one thing can find or set limits on many other things!
- For most searches, you will have a good time if your uncertainty is statistical in nature rather than systematic.
- For most searches, aim to do one or two difficult things.
 - If you're a phenomenologist: always find that difficult thing they did.
 - If you're watching a talk: ask about that difficult thing they did.
- Always check what other searches did and found
 - We're a community working together to understand nature!





Thanks!