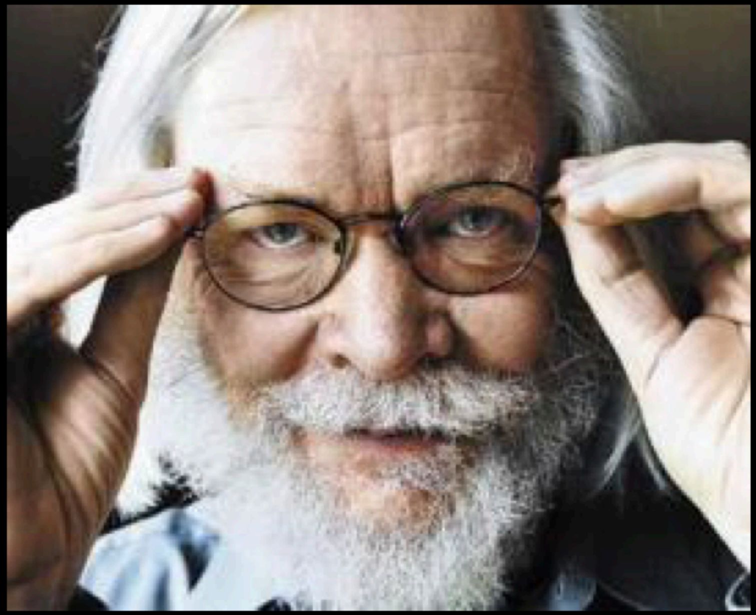


Better Late Than Never

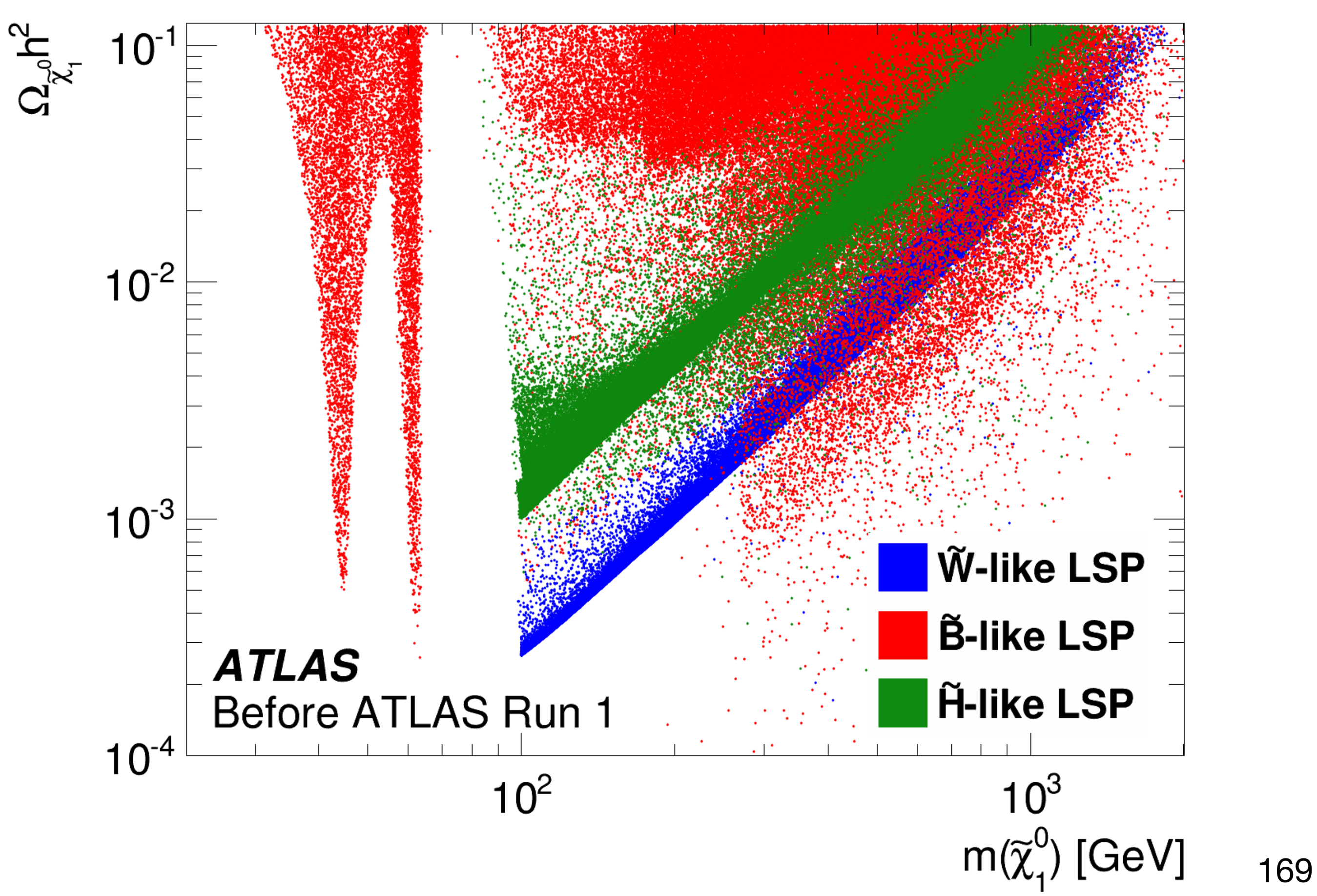
BSM Experimental Searches 4

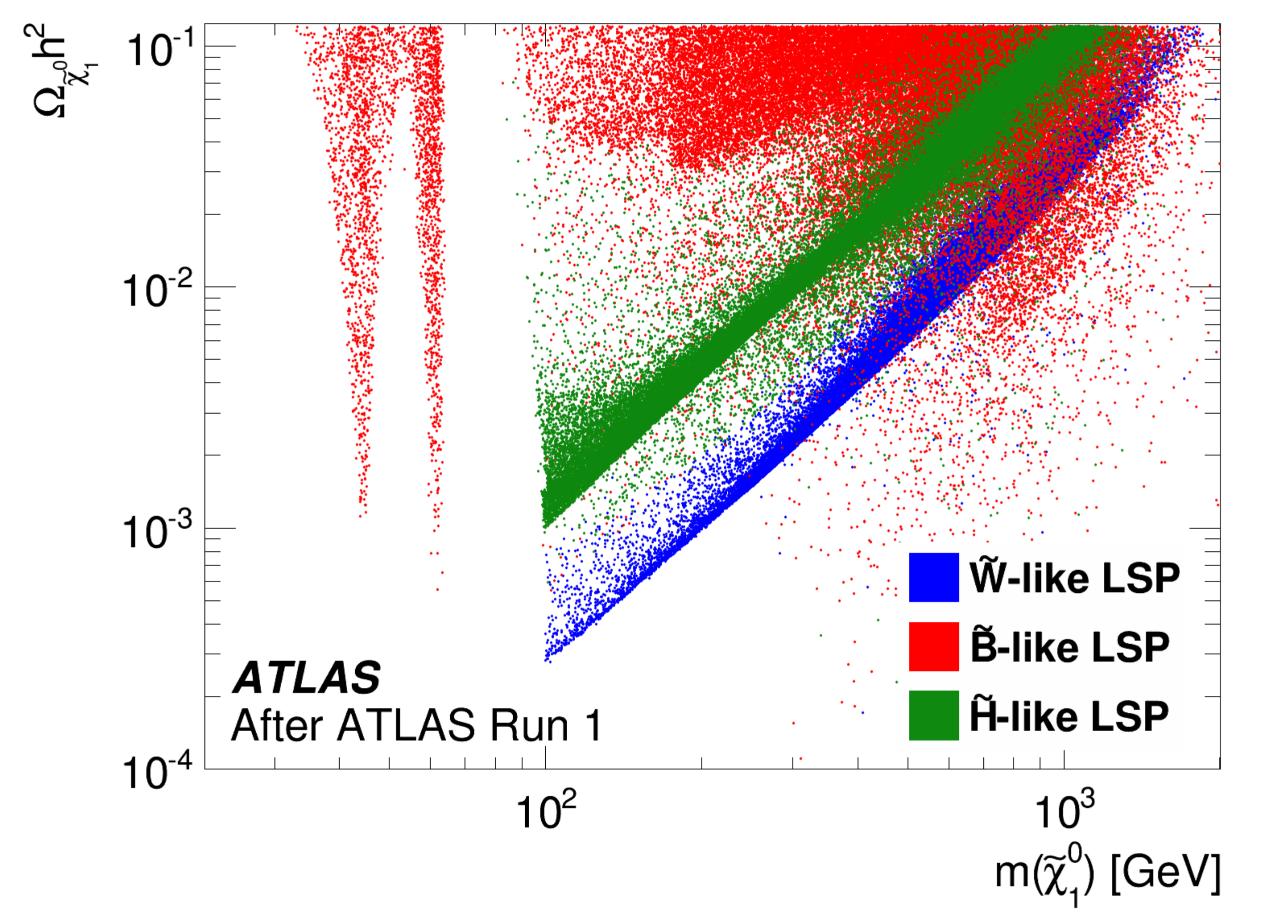
Zach Marshall (LBNL), CERN-Fermilab HCP Summer School, 2 September 2021

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

Combinations and Scans

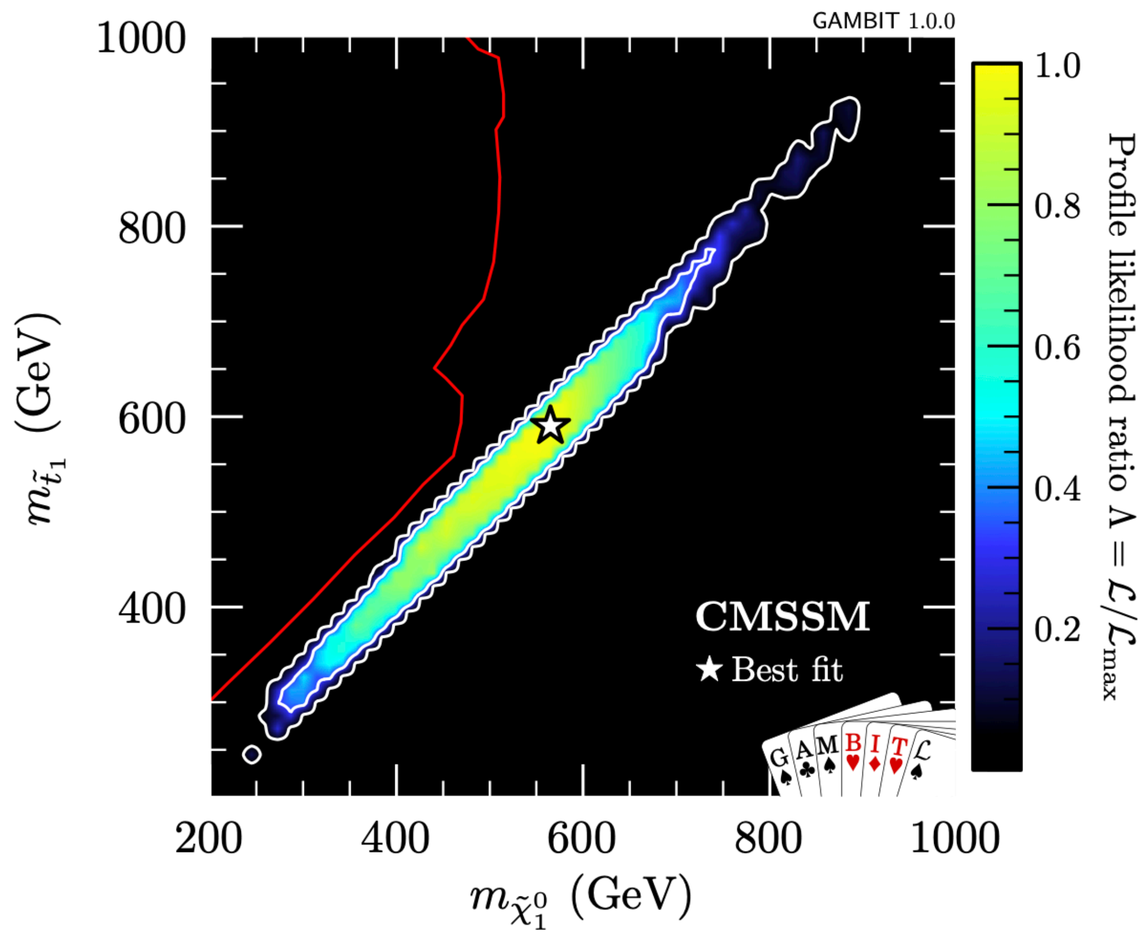
- The experiments (and some other collaborations) take time at the end of runs to do *grand combinations* and *large model-space scans*.
- One popular scan is the 19-dimensional pMSSM
- These apply *many* searches to as many model points as we can muster





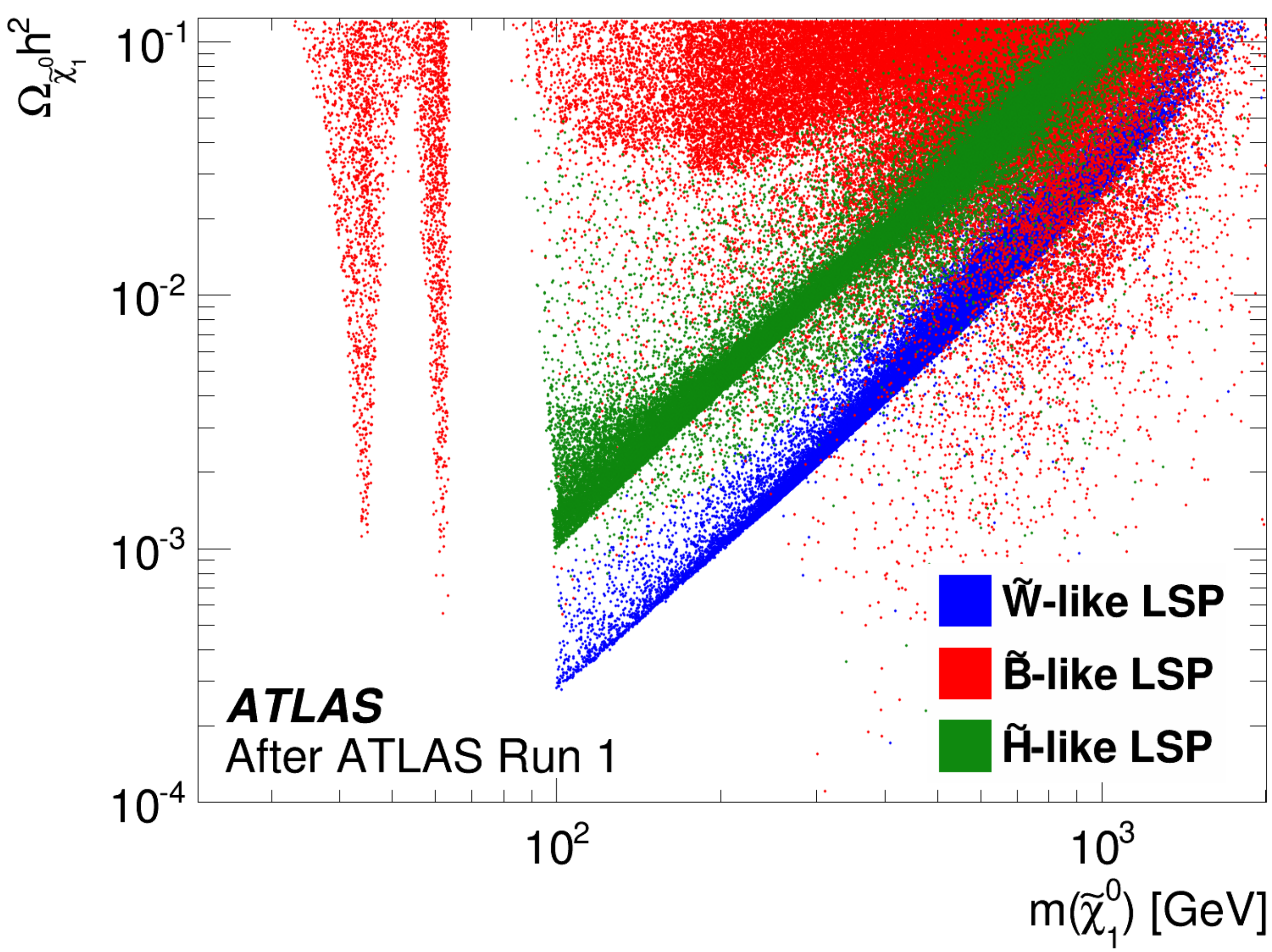
Combinations and Scans

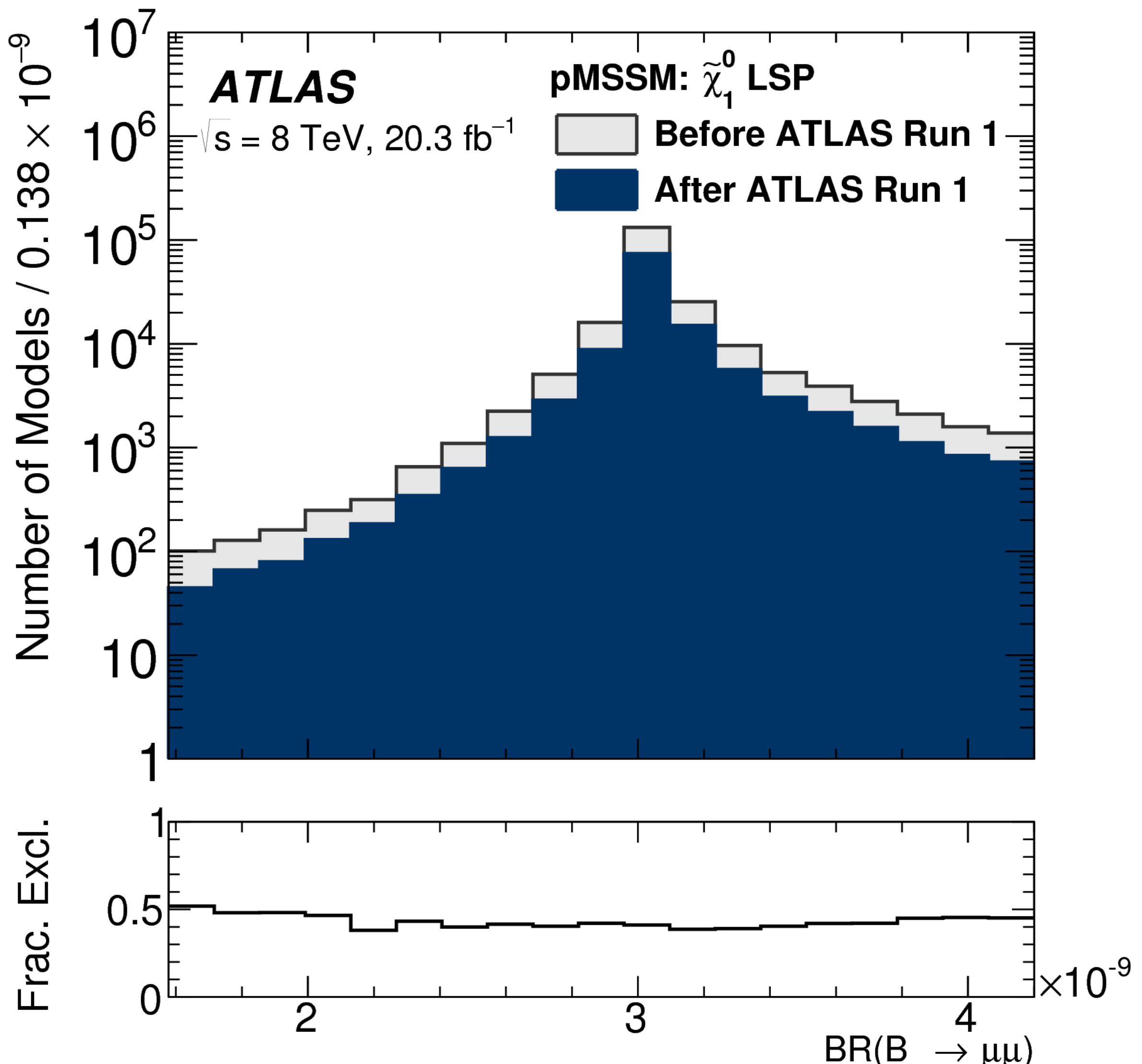
- The experiments (and some other collaborations) take time at the end of runs to do *grand combinations* and *large model-space scans*.
- One popular scan is the 19-dimensional pMSSM
- These apply *many* searches to as many model points as we can muster
    - Note that **the best fit point will always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



Aside on Limits from Others

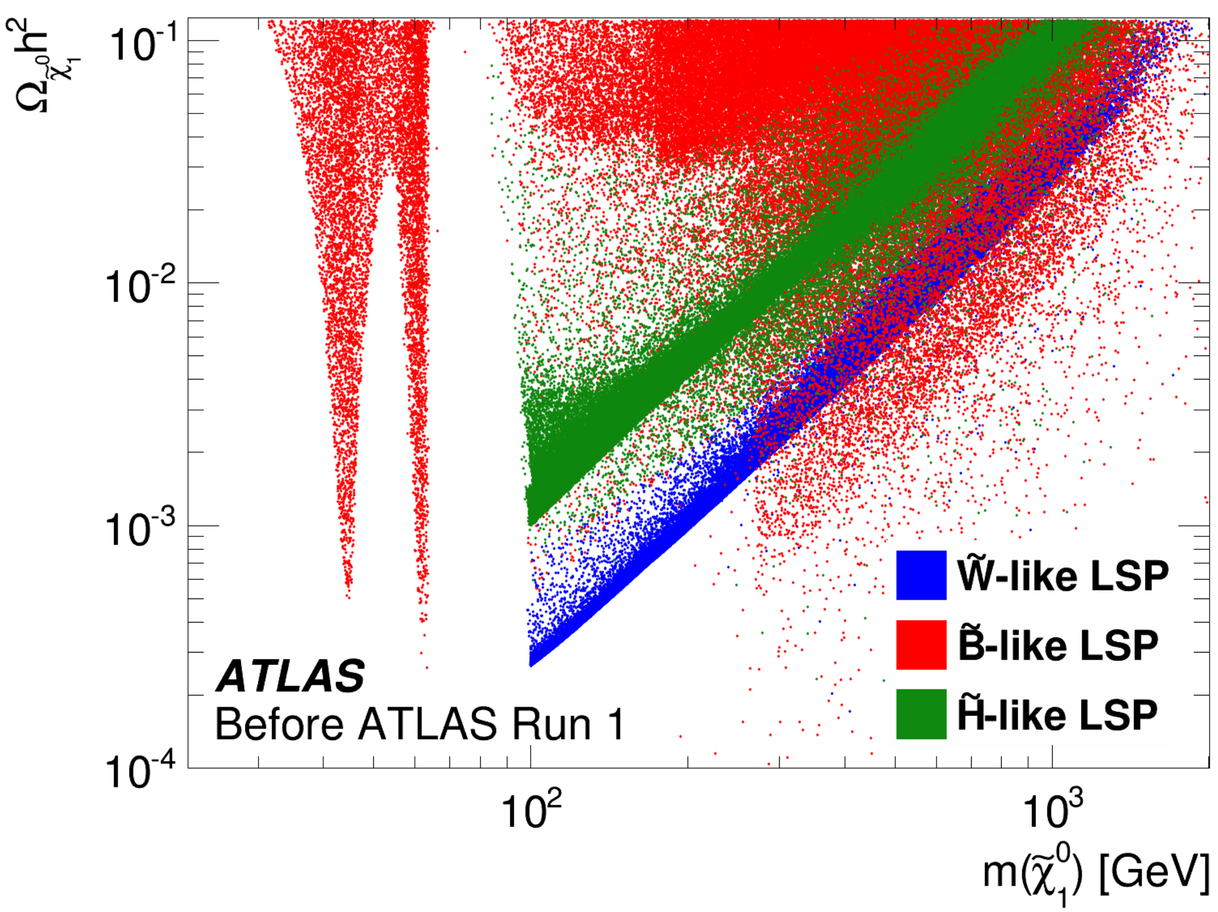
- It's very tempting to take very seriously limits from other experiments
- Don't get too fanatical about that
- Remember that there can always be other physics (e.g. high-mass particles) that impact the translation from one field to another (particularly cosmo!)

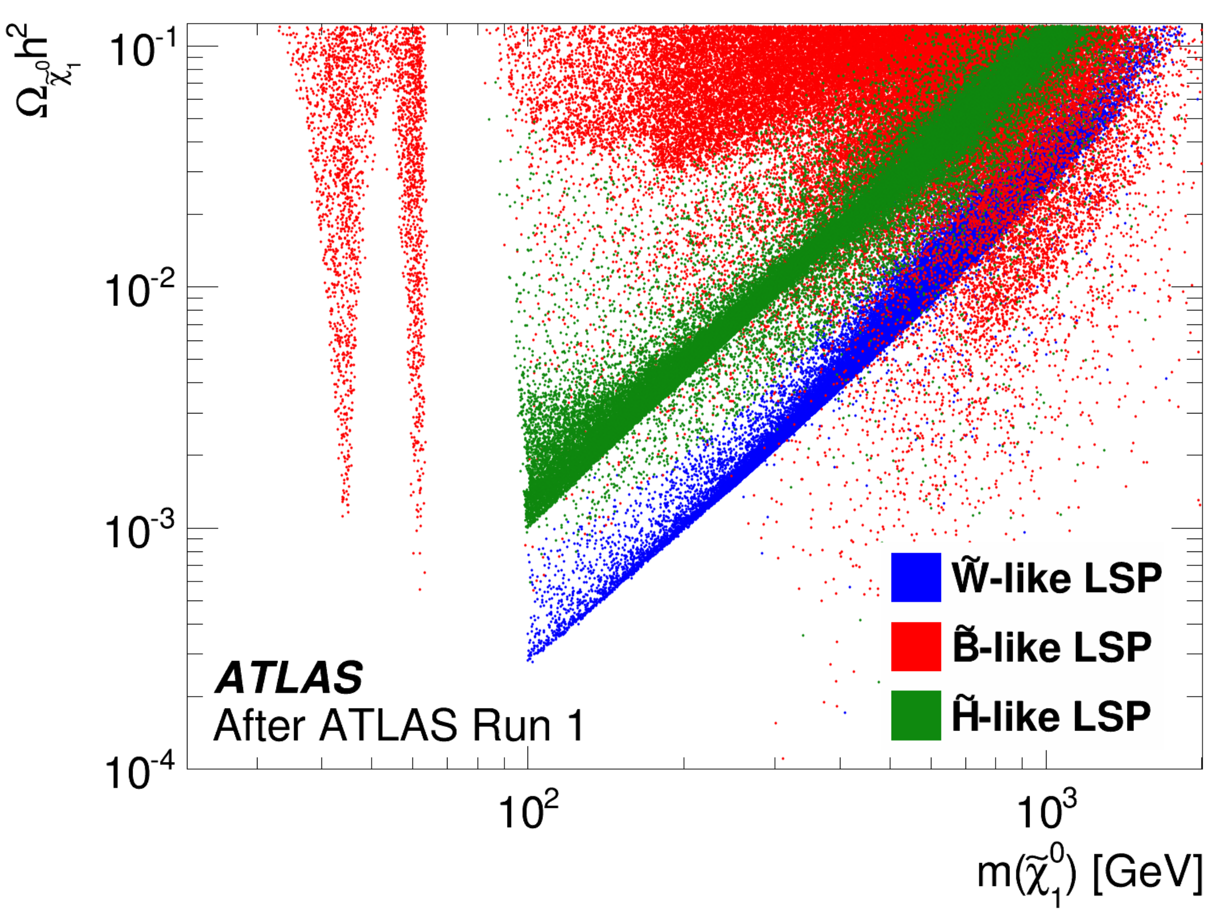




Combinations and Scans

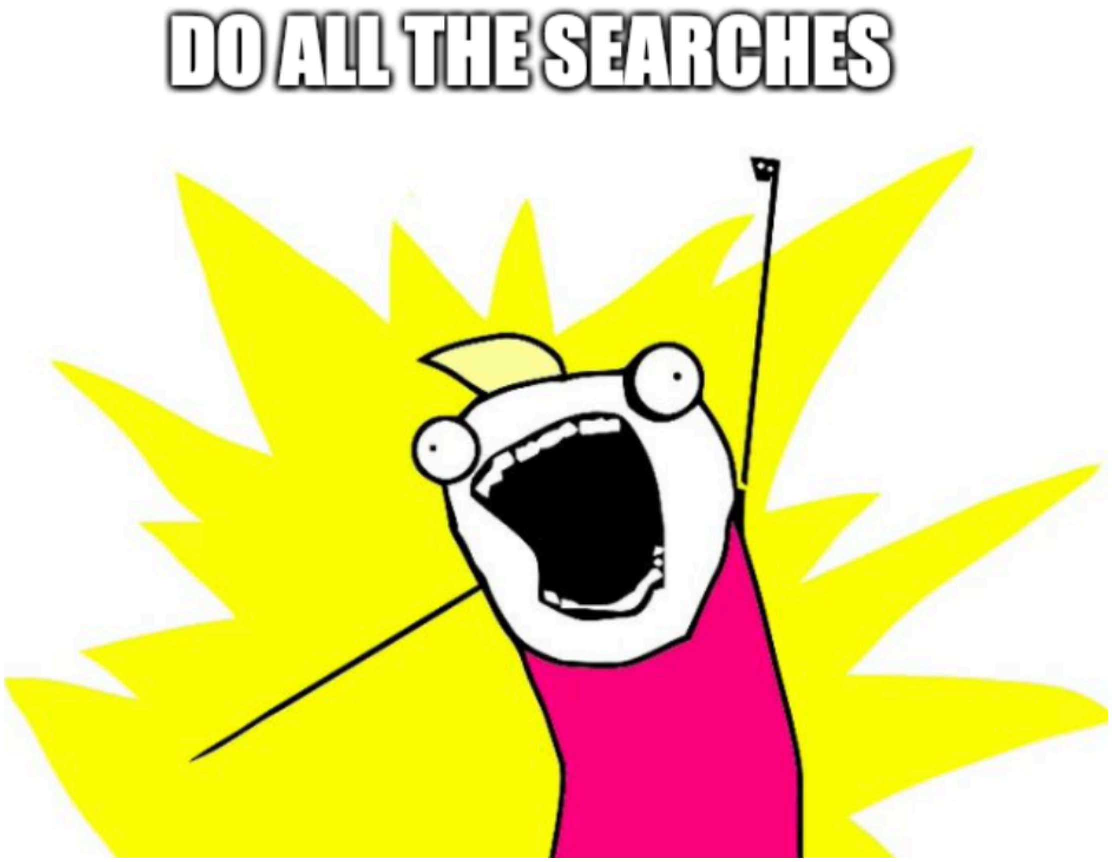
- These always use the *best expected* limit. You could ask: can we do a full statistical combination of all the searches?
- It's extremely hard because of all the *correlation* problems we talked about
- Have to work out those problems across many searches with different methodologies!





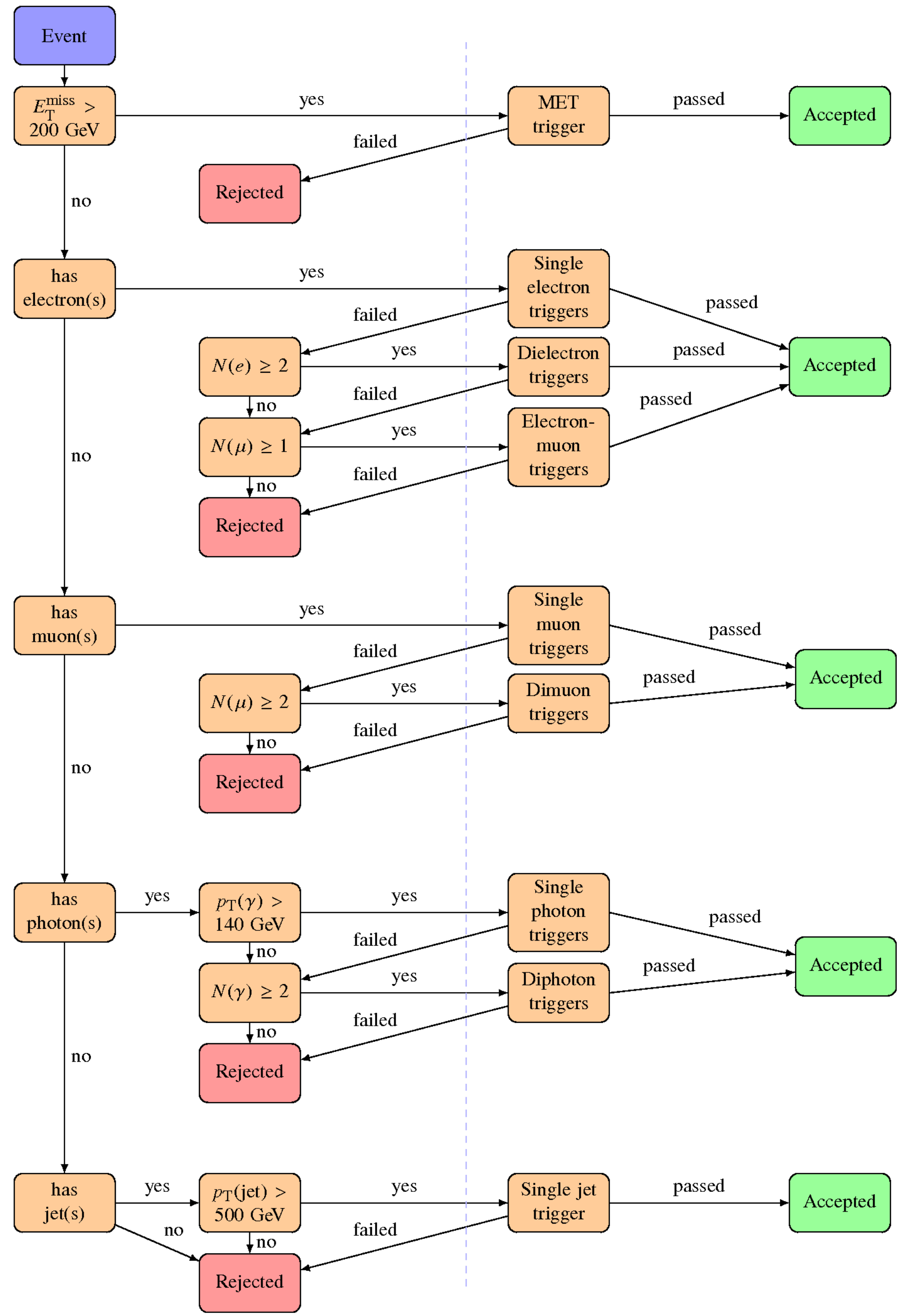
Combinations and Scans

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



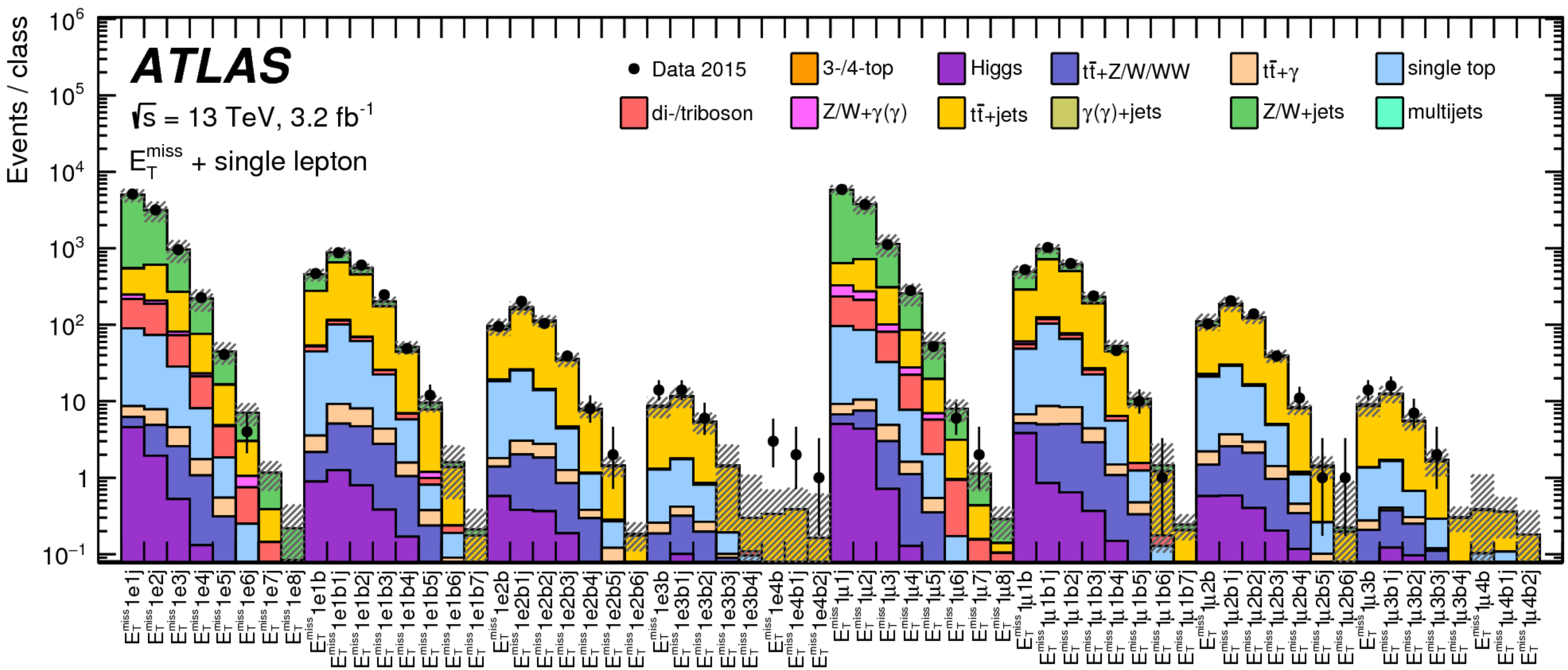
General Searches

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



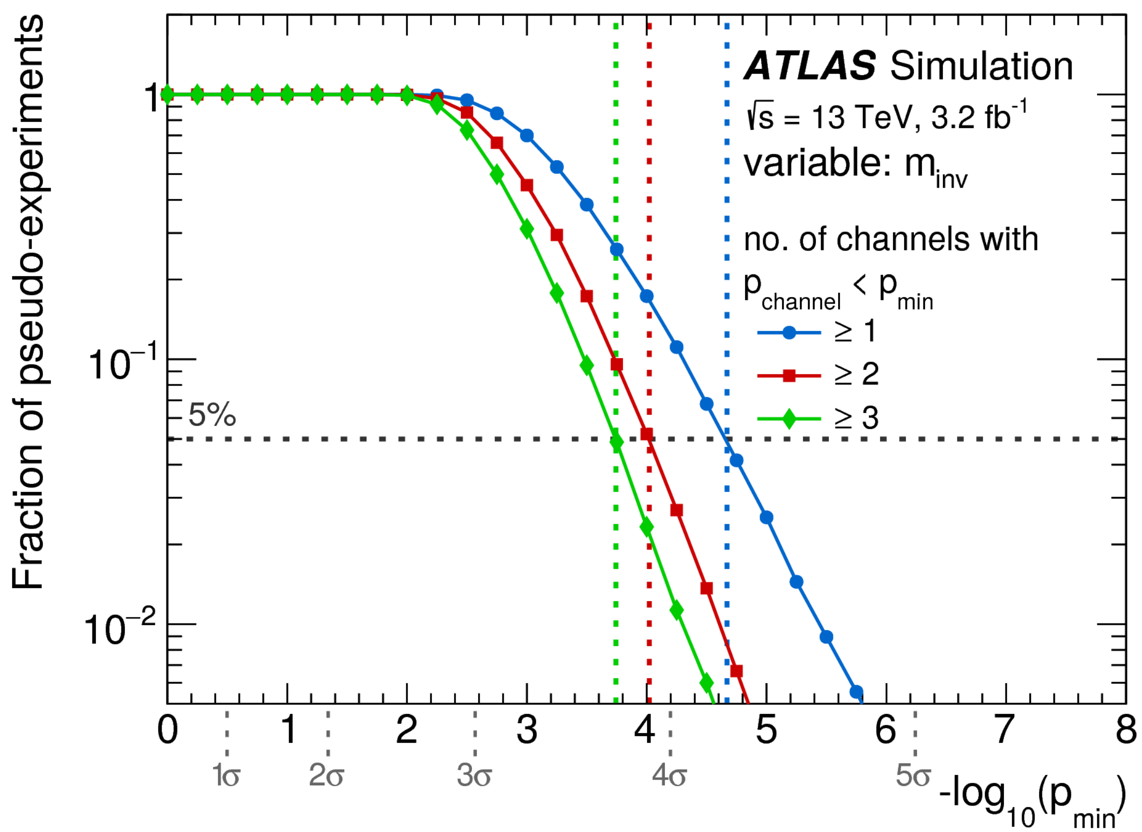
General Searches

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

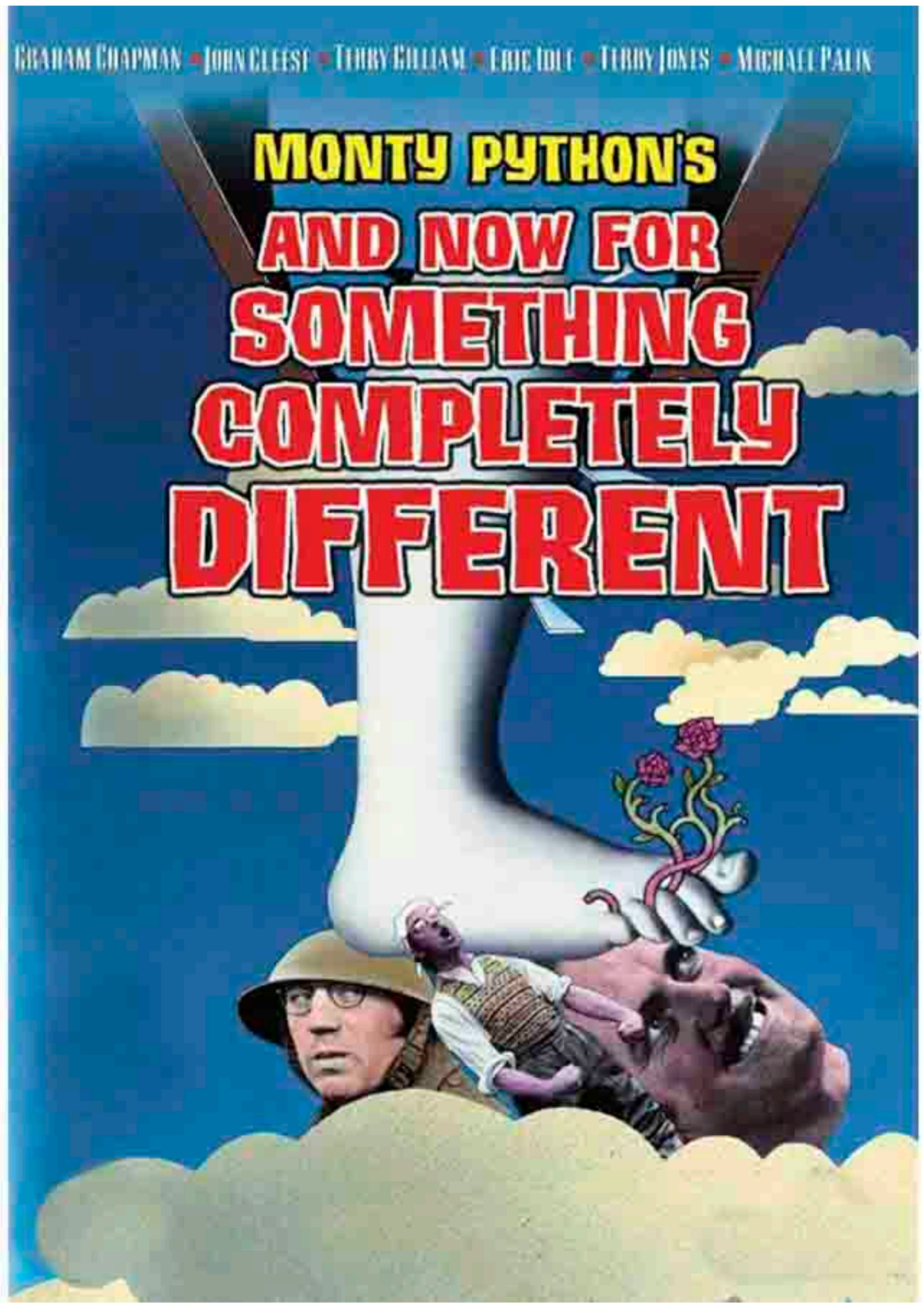


General Searches

- The statistical issue they're fighting is called the look-elsewhere effect.
- 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!

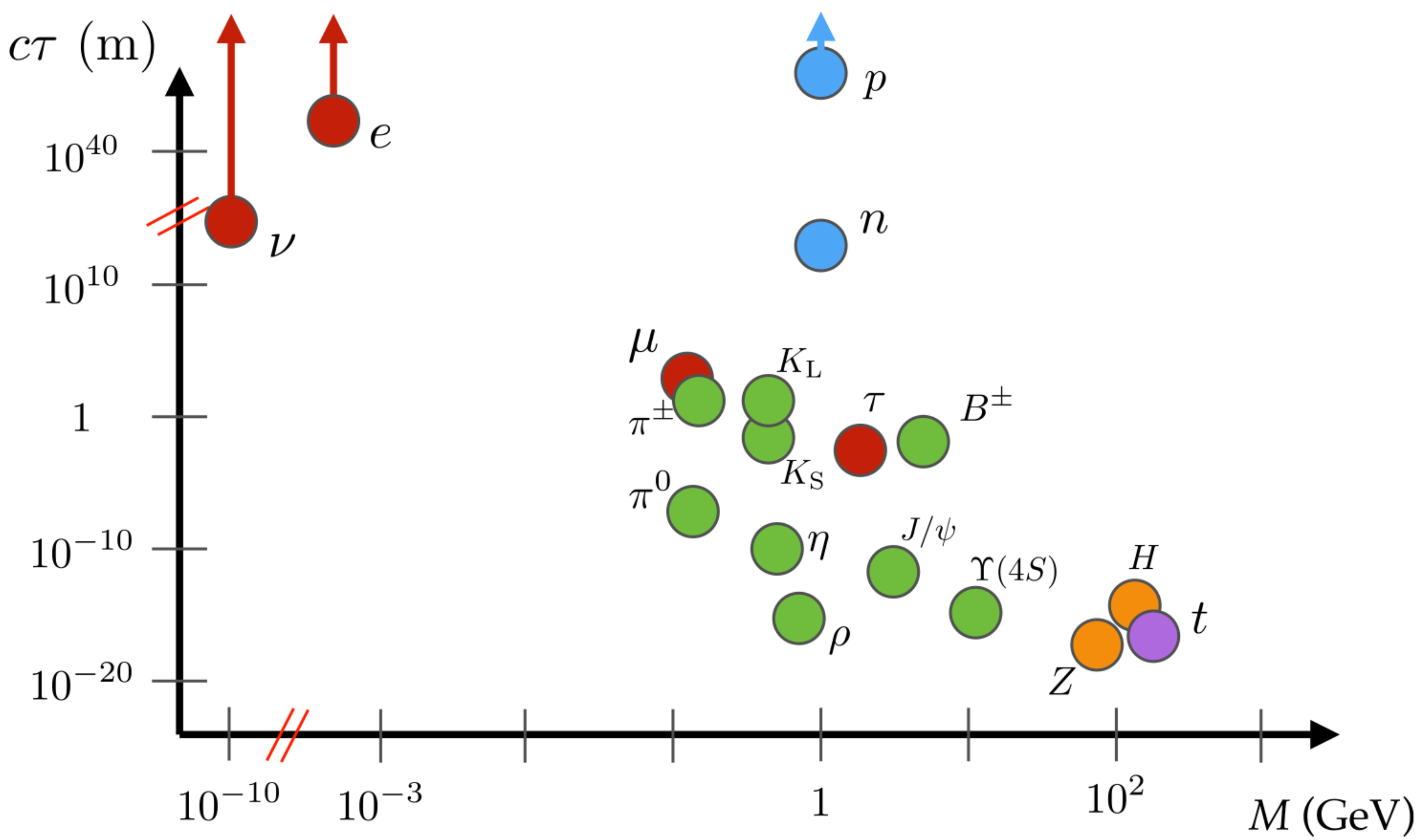


Long lived particles and… Others



Long-lived Particles

- We know of lots of particles in nature with “long” lifetimes
  - “Long” for the LHC usually means cτ>few mm
- These have gotten a lot more press in recent years

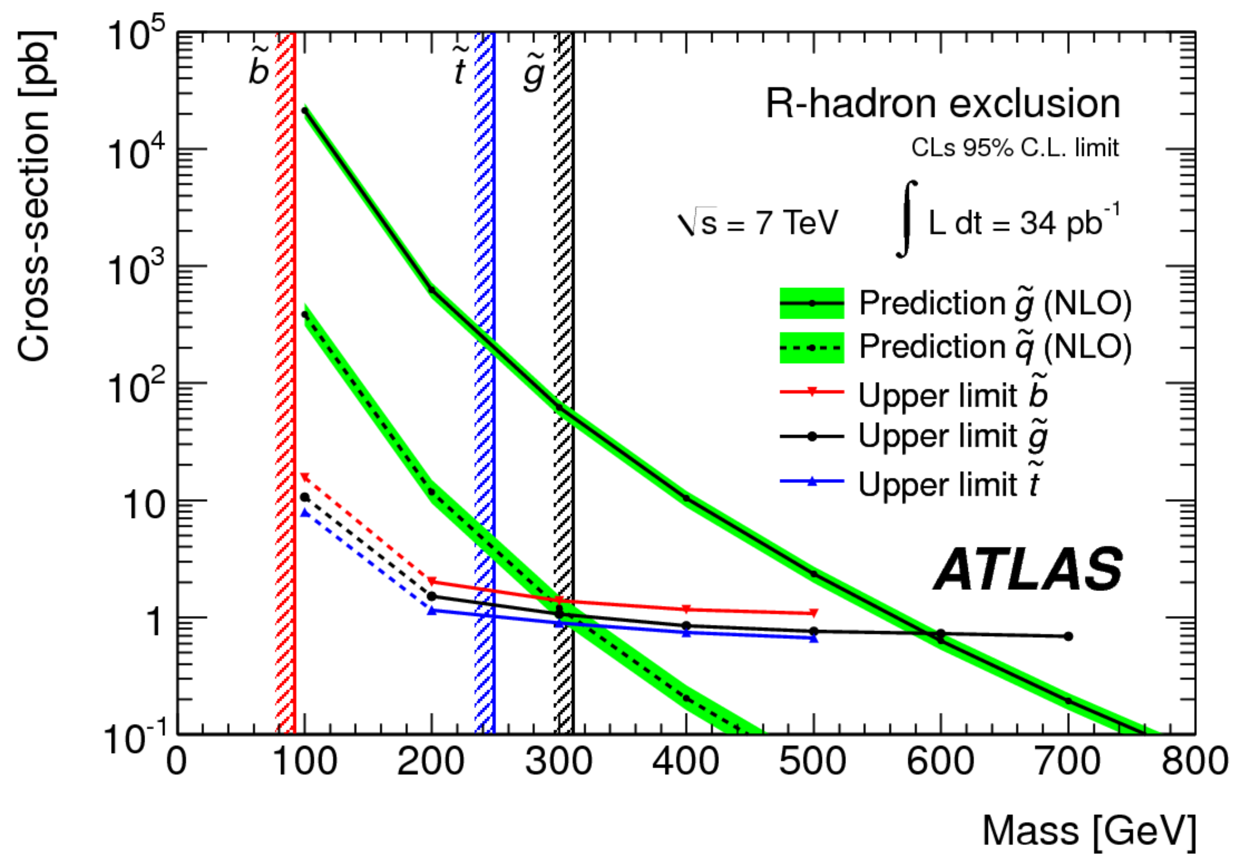


Long-lived Particle Searches

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

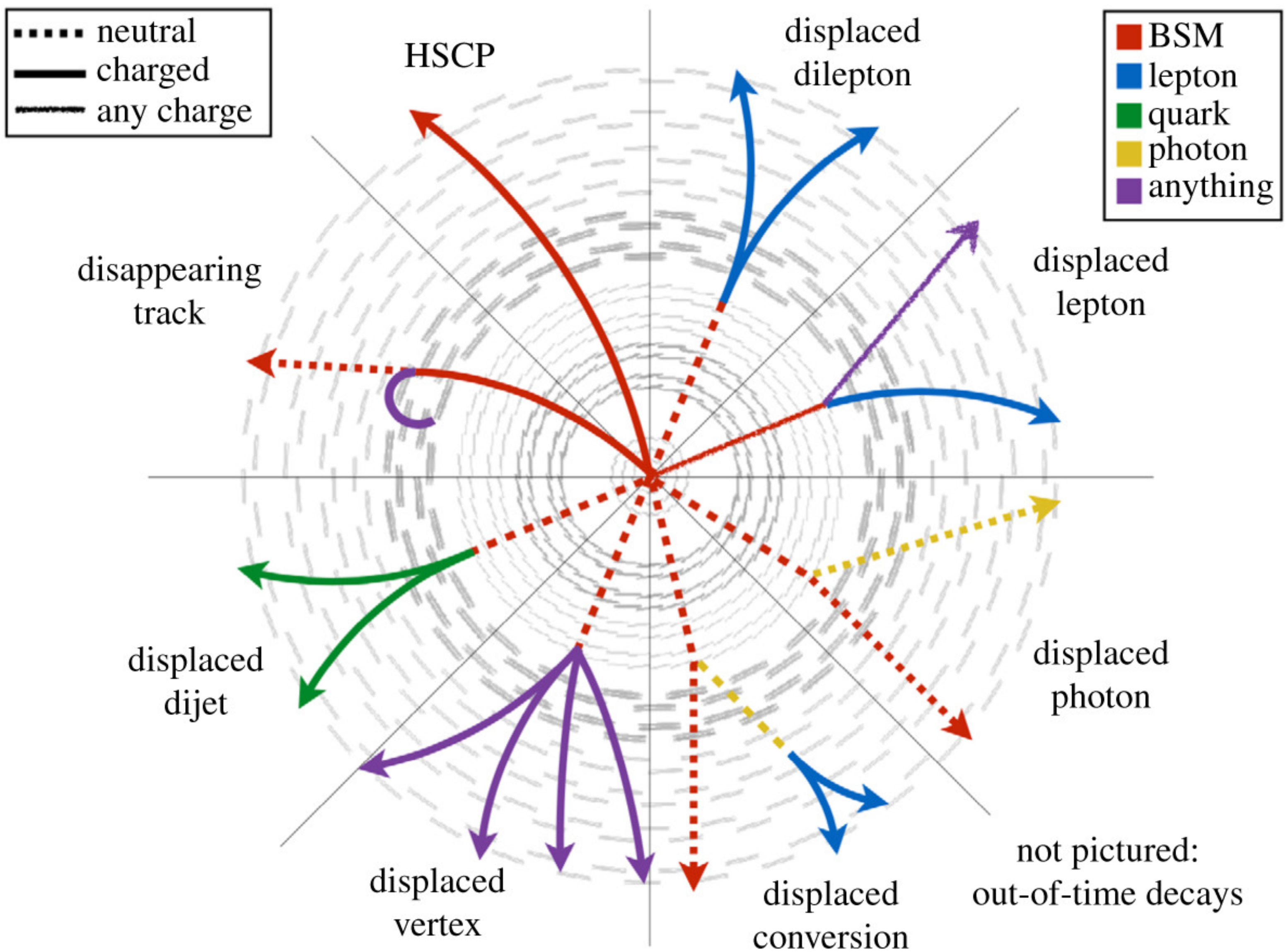
Search for stable hadronising squarks and gluinos with the ATLAS experiment at the LHC

CERN-PH-EP-2011-026



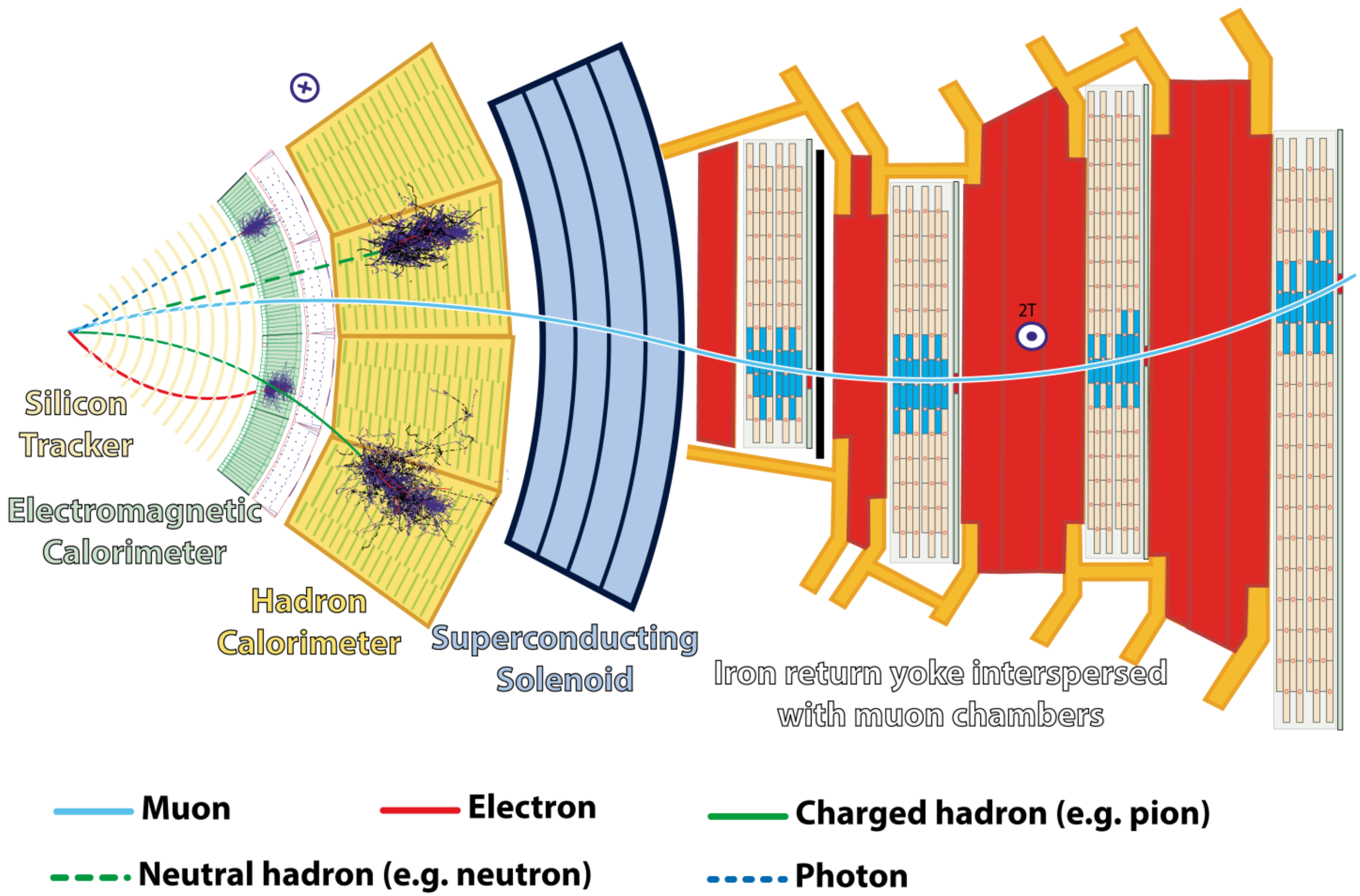
Long-lived Particle Searches

- 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)



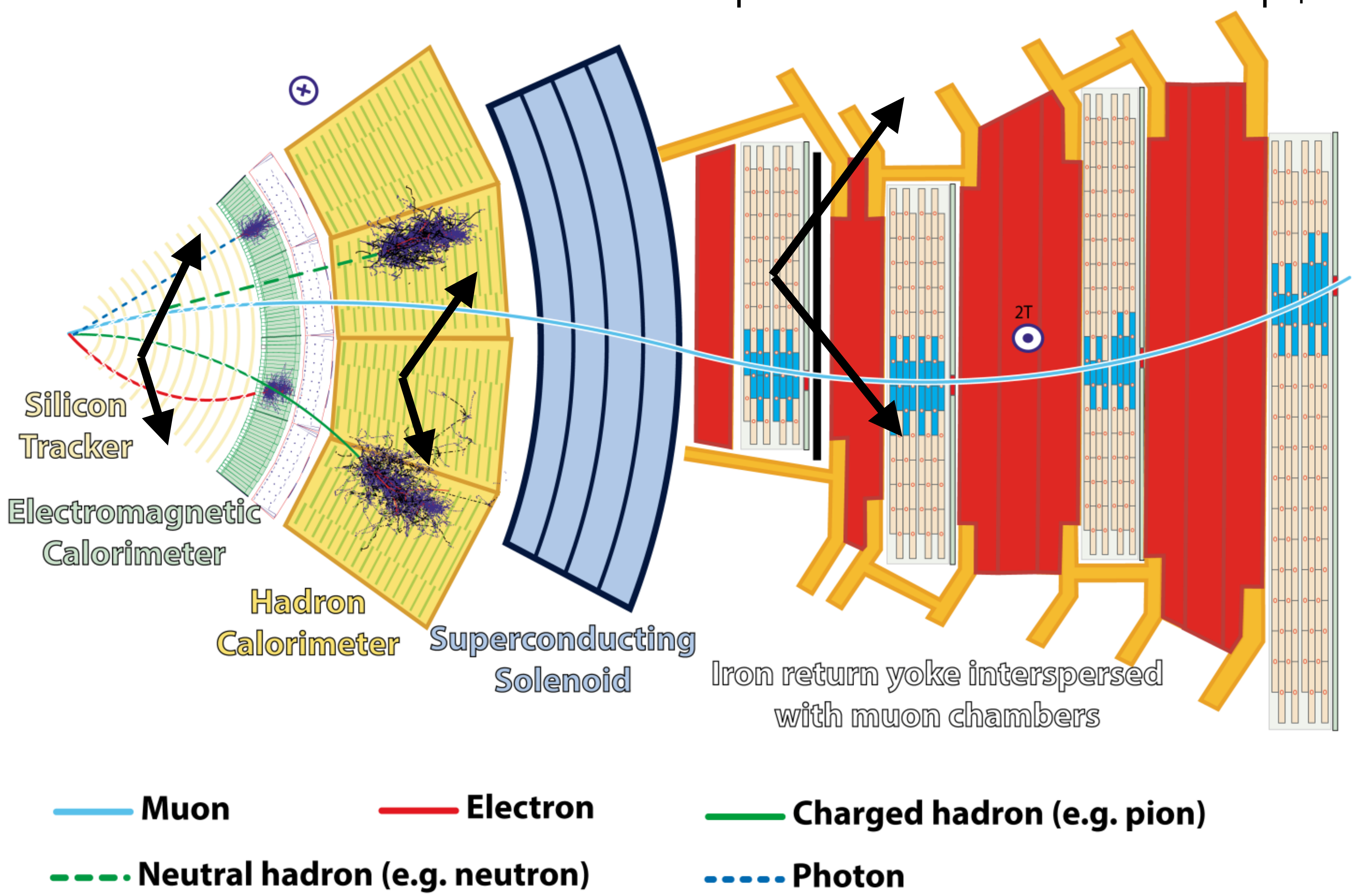
Projectivity

- 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



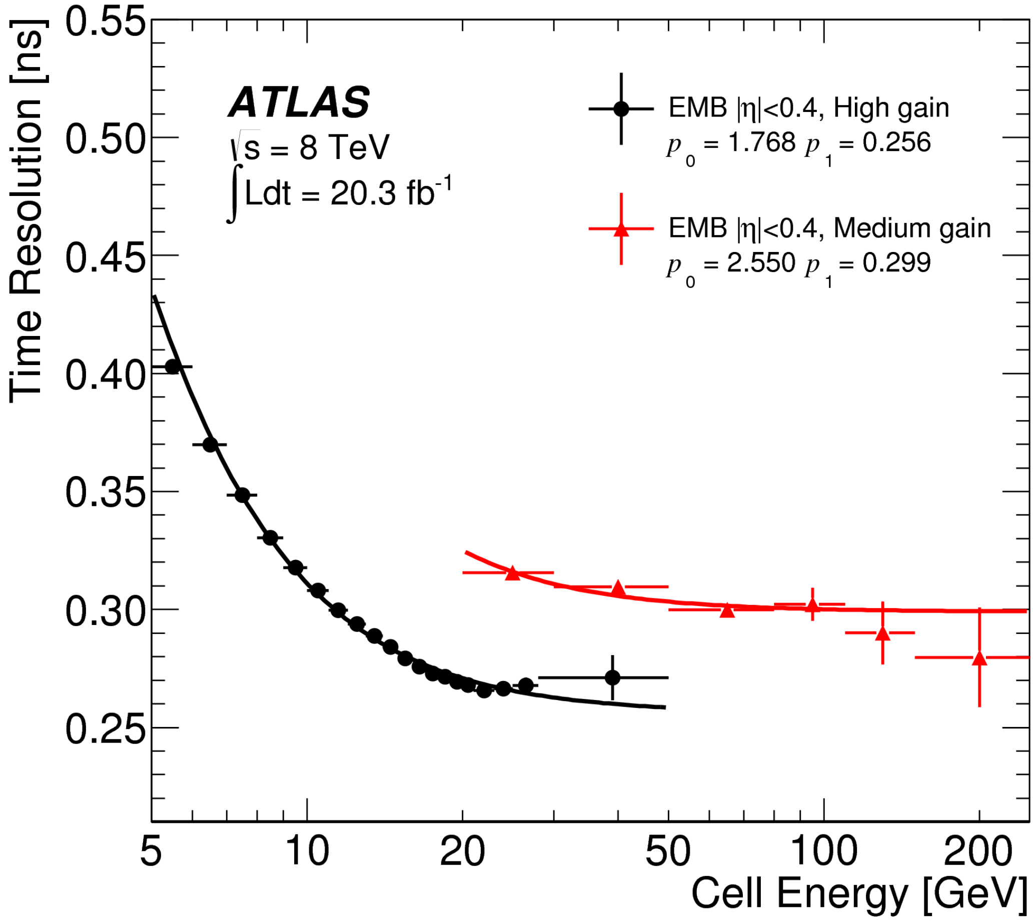
Projectivity

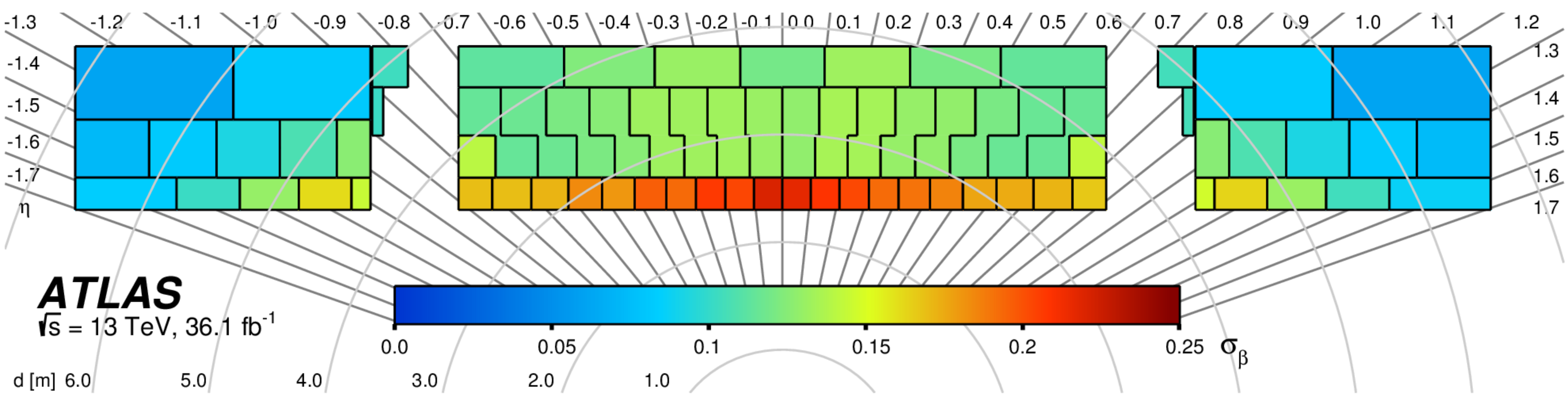
- LLPs can give you SM particles that don't point back to the origin
- Generally speaking, the reconstruction *hates* that
    - You also have to answer some odd questions like "What is p_T?"



Calibration

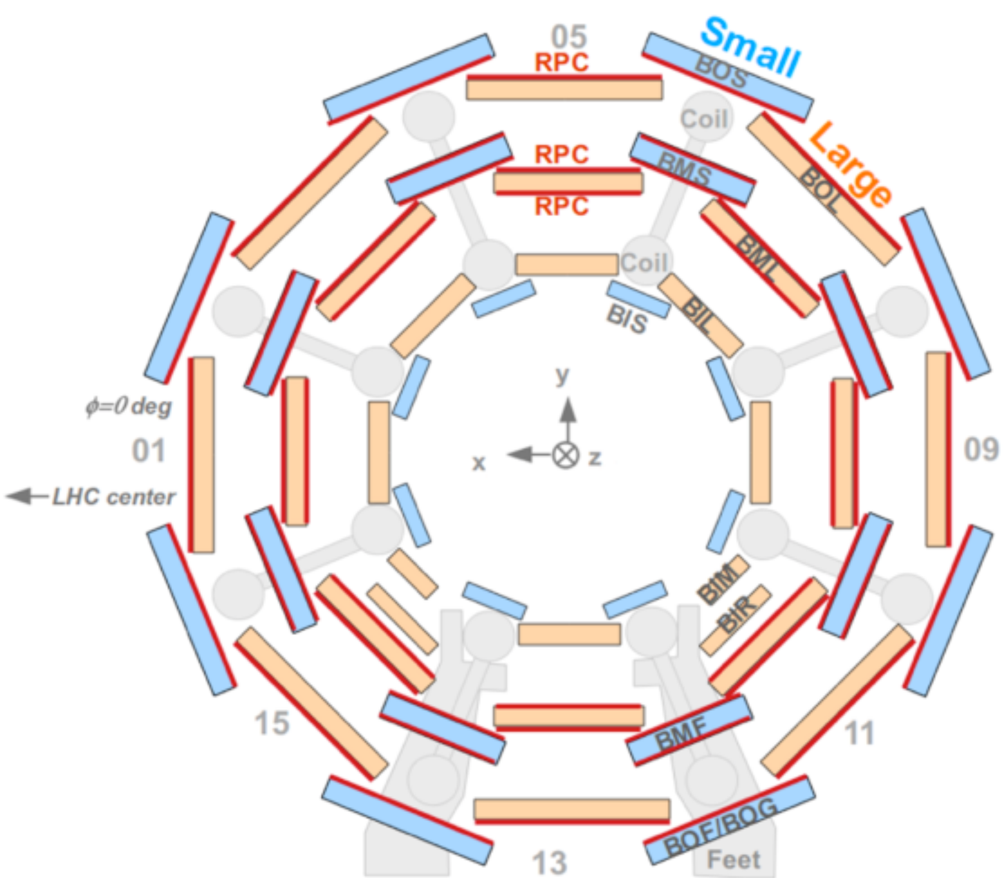
- You may end up having to calibrate something that the rest of the collaboration doesn't care about
- We don't normally need to calibrate *timing* very carefully, for example

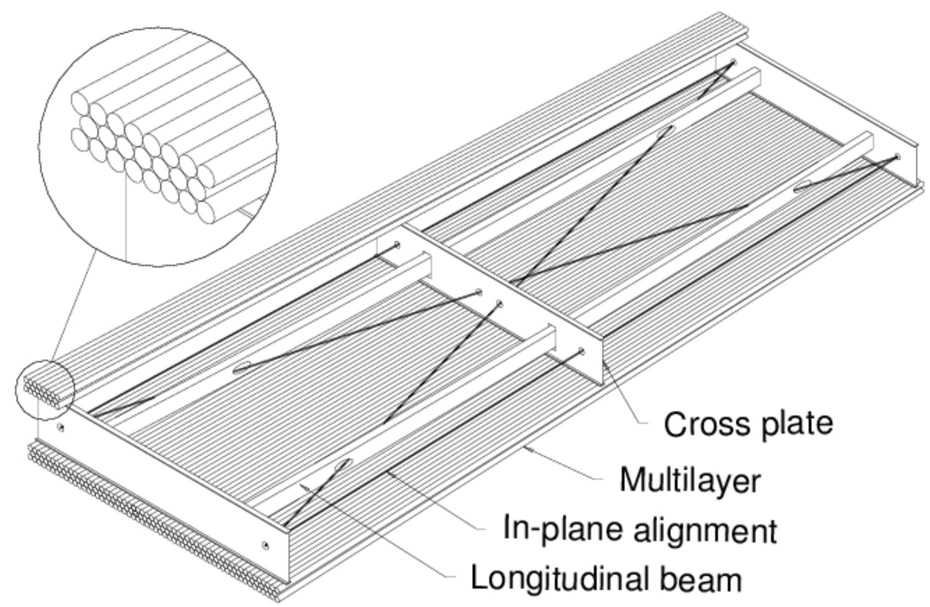


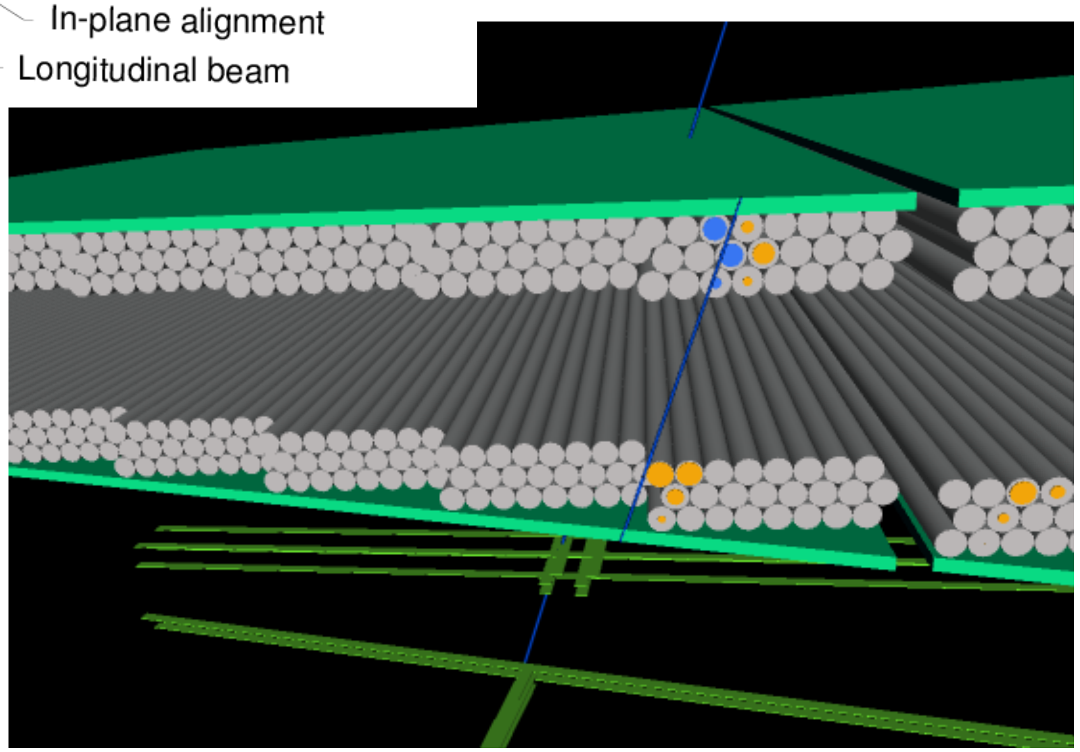


Detector Features

- 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

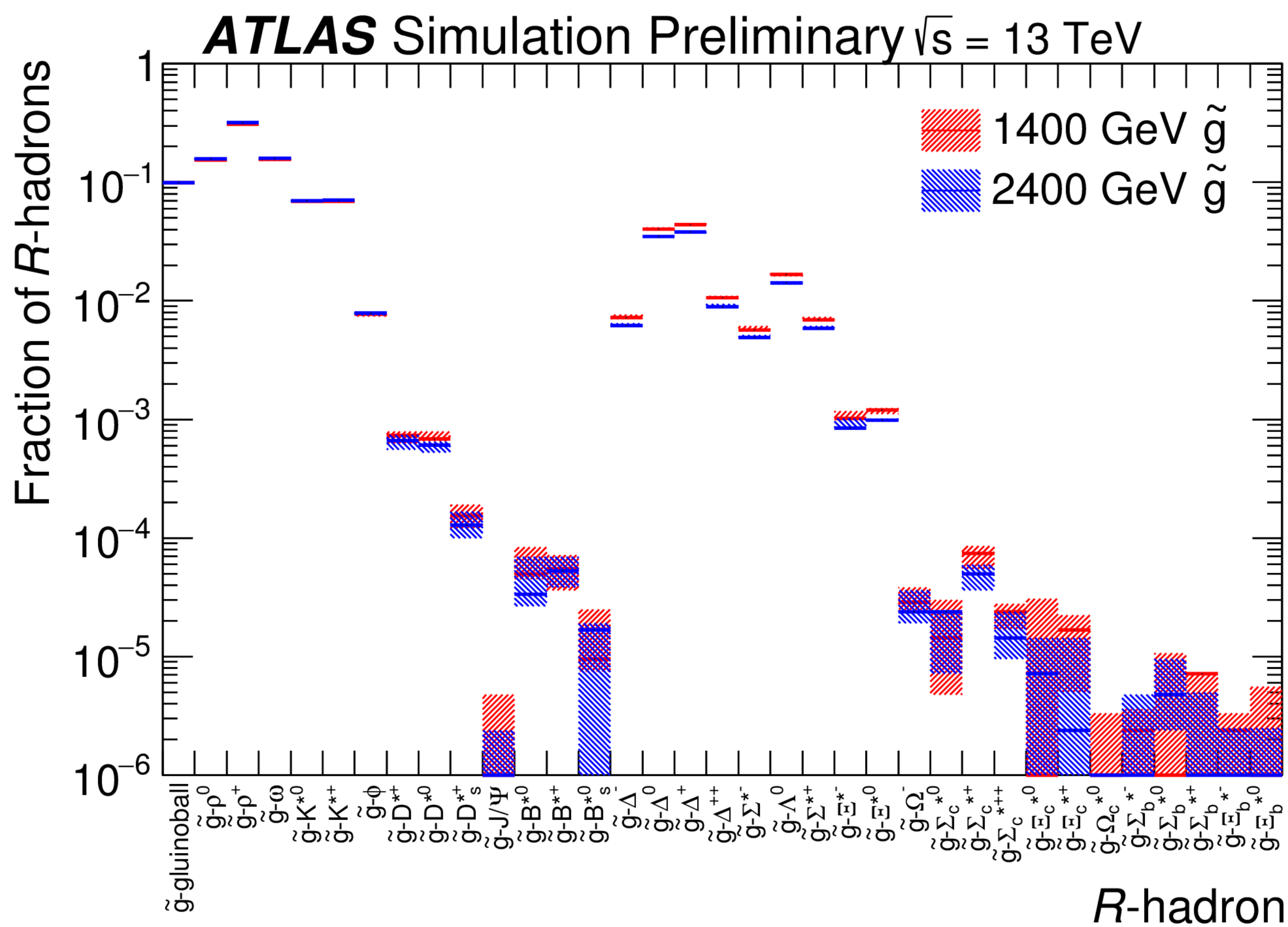






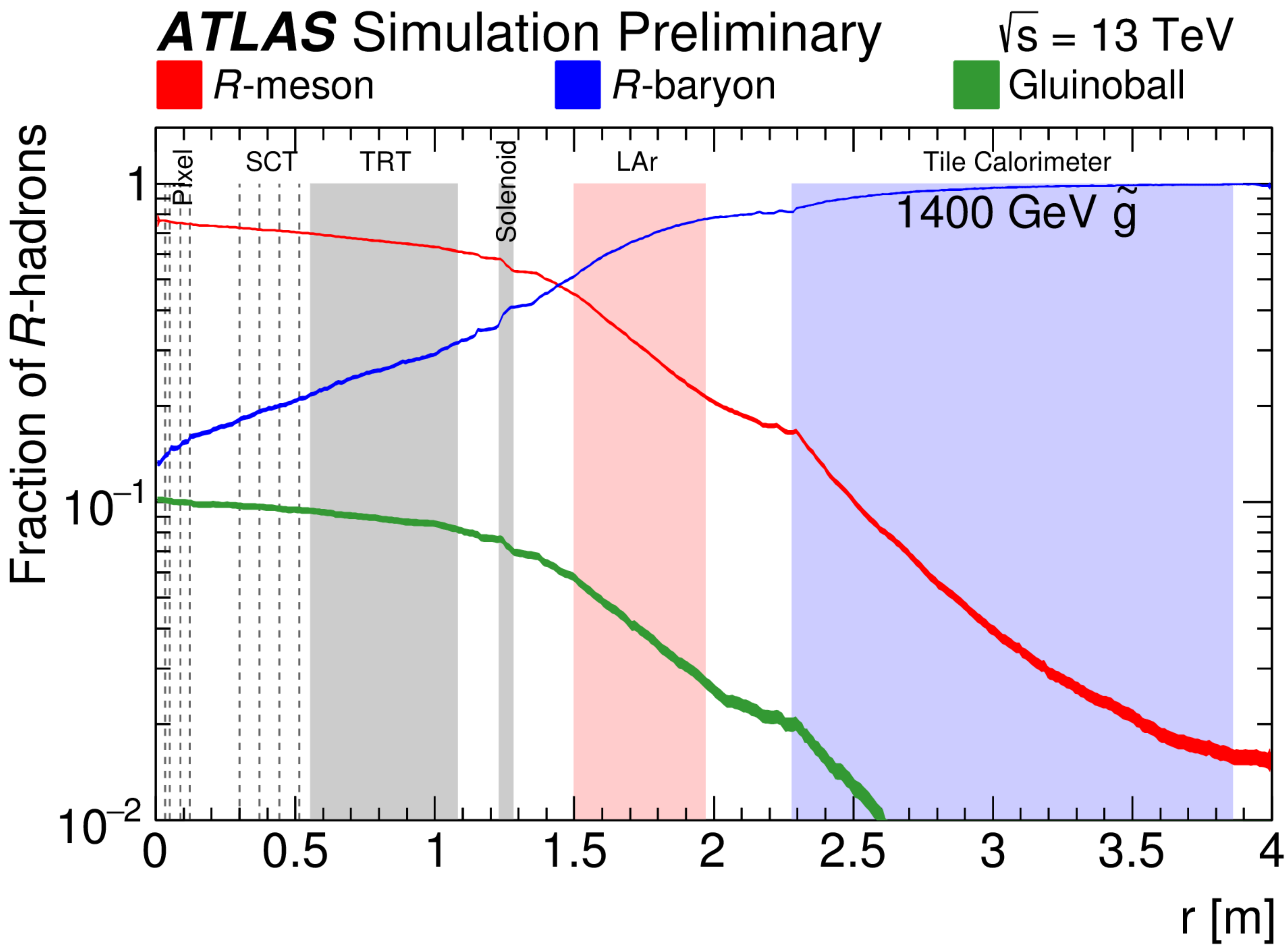
Models Get Tricky

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



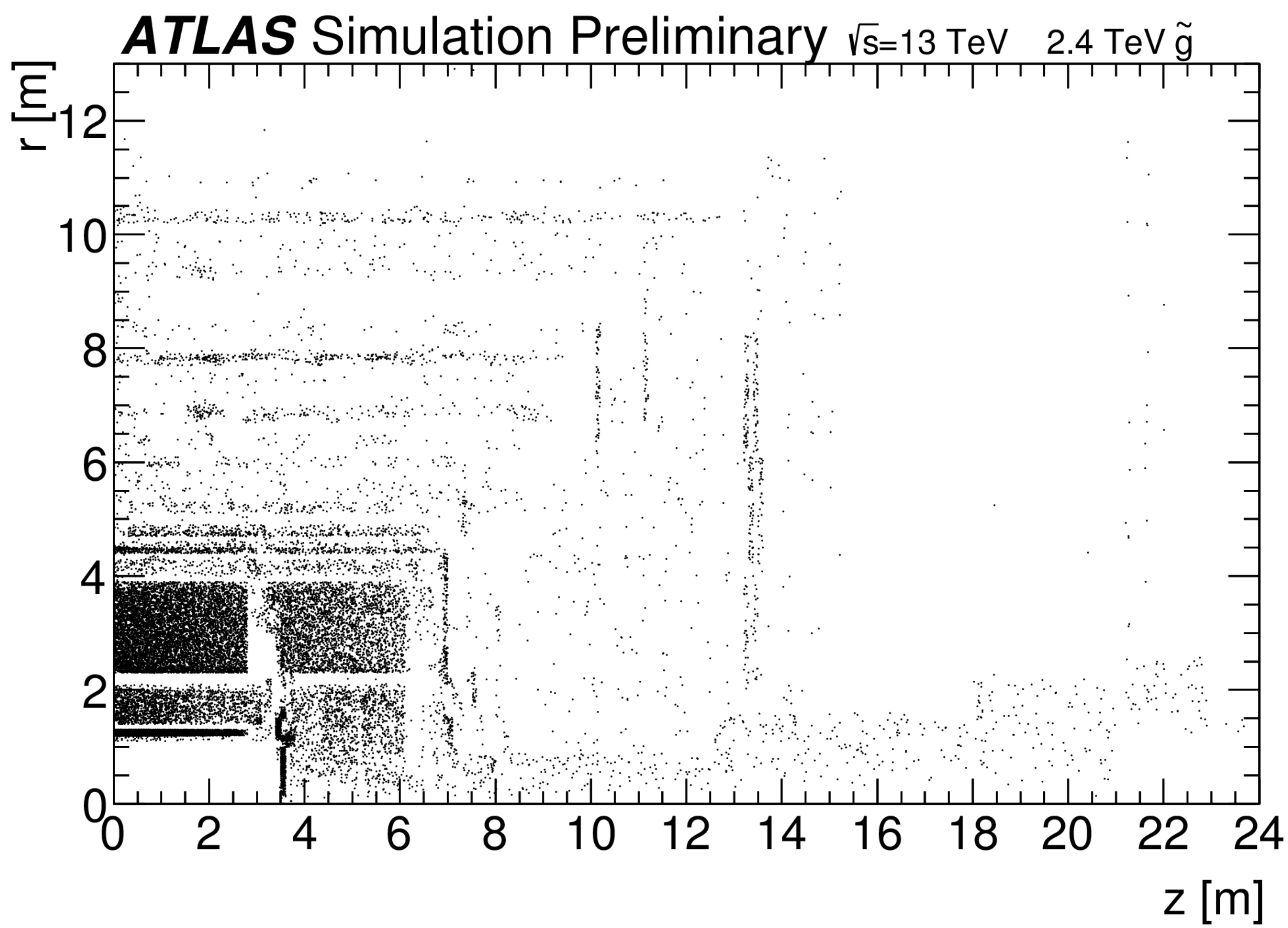
Models Get Tricky

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



Models Get Tricky

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

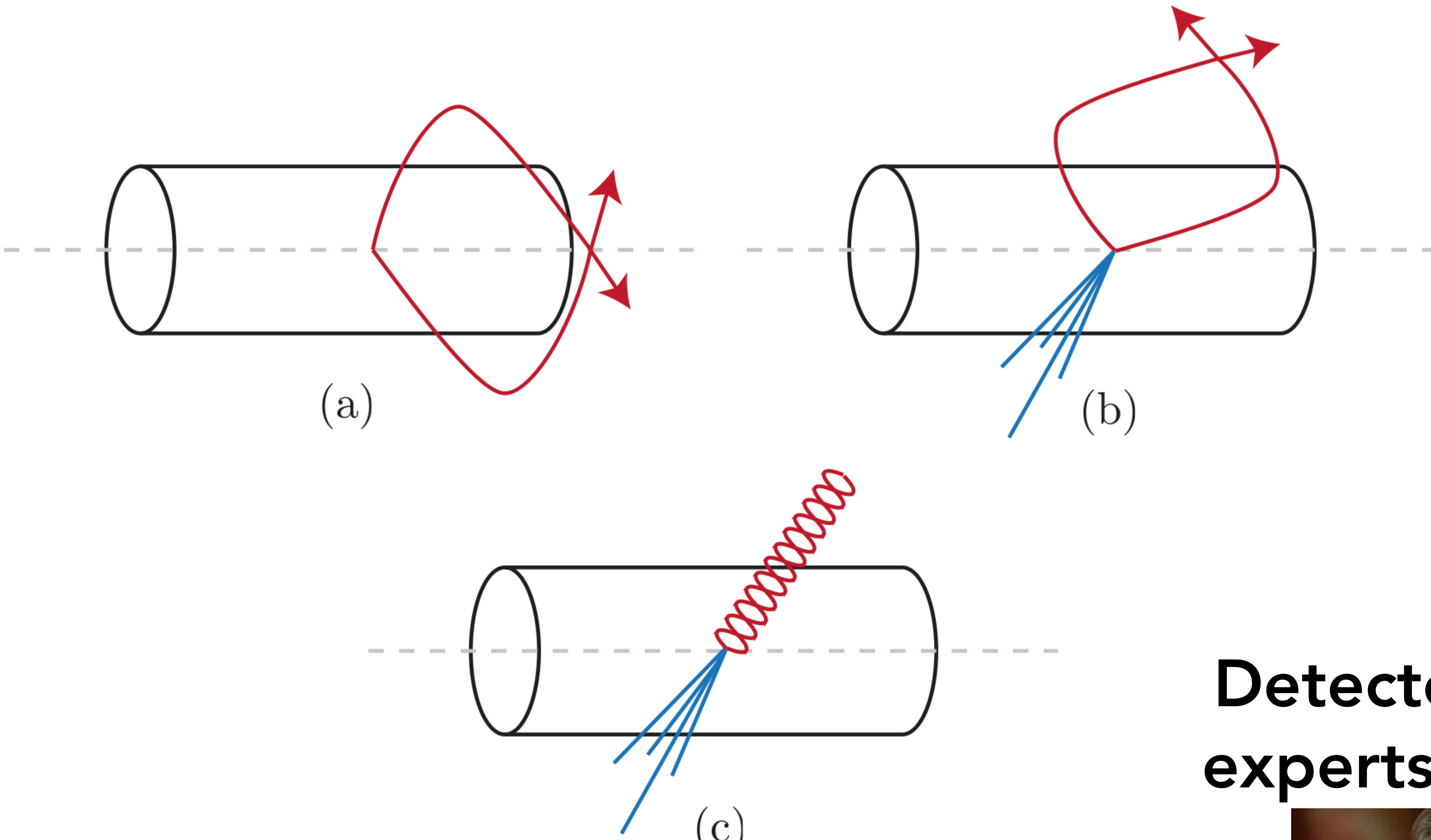


Models Get Tricky

No one has ever modeled this stuff correctly.

It can be worse

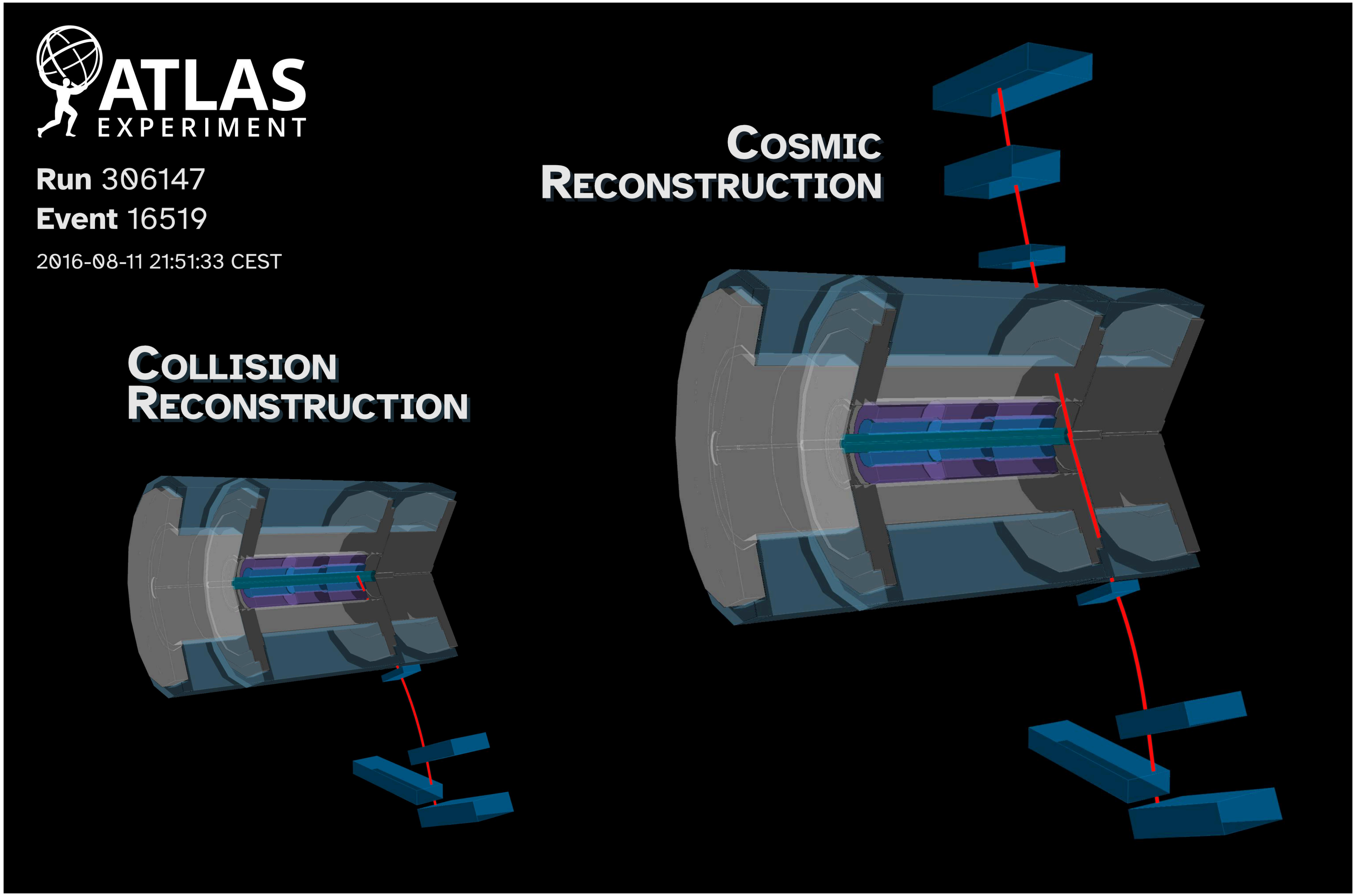
- Particles called "quirks" could form *macroscopic bound states*



Detector simulation experts everywhere:

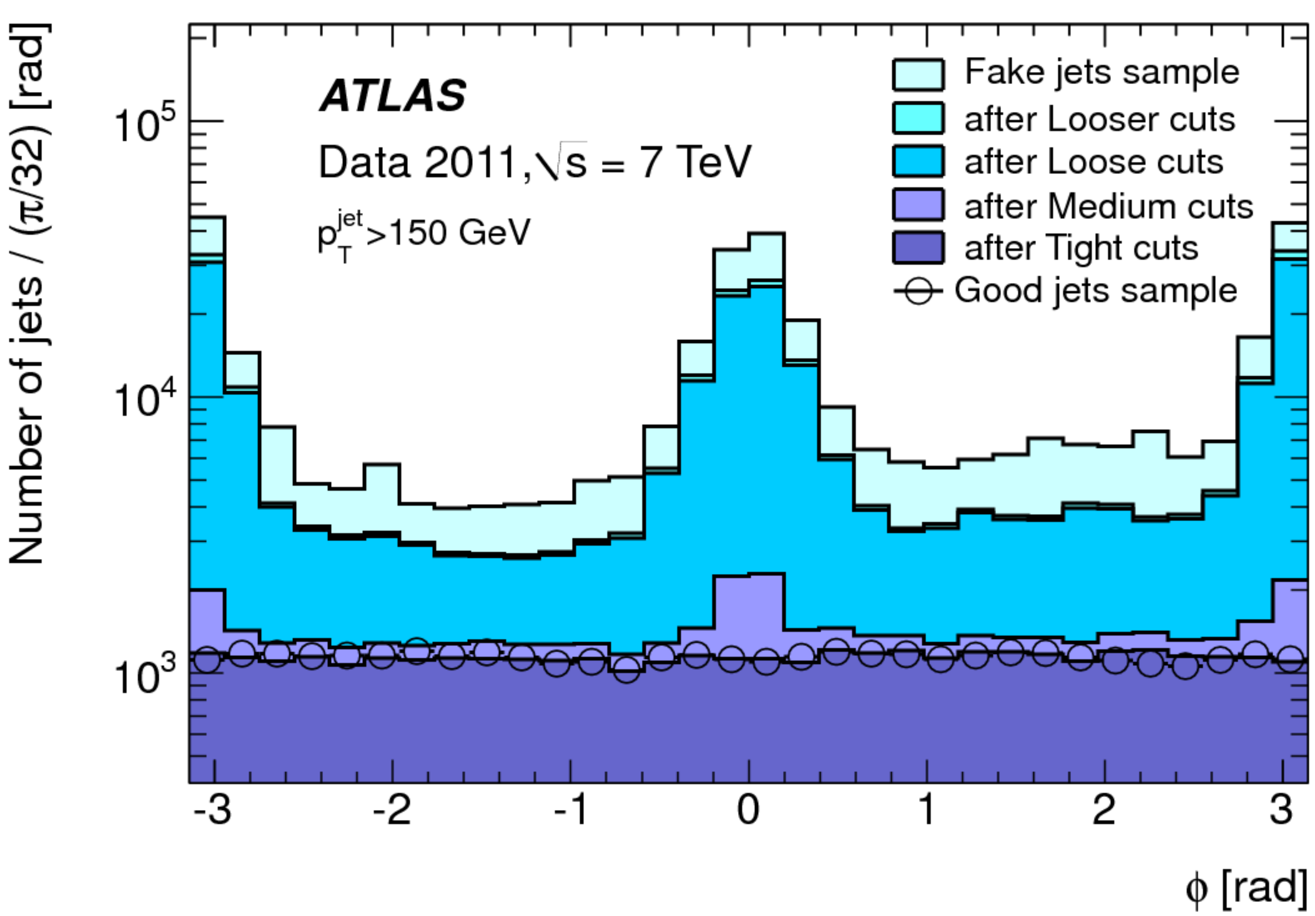
The backgrounds too

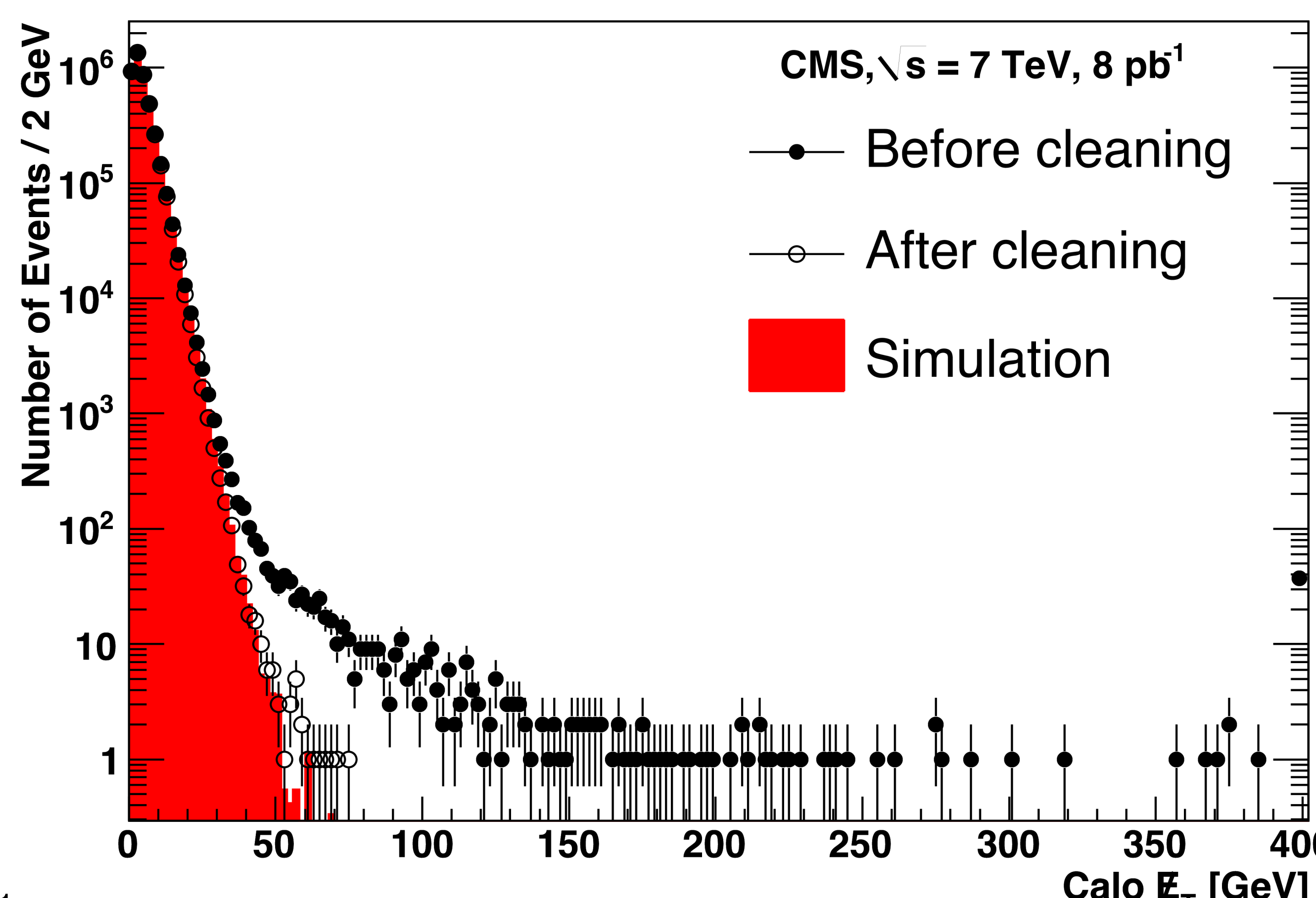
- The backgrounds from these searches are often *weird* and *very hard to model and understand.*



The backgrounds too

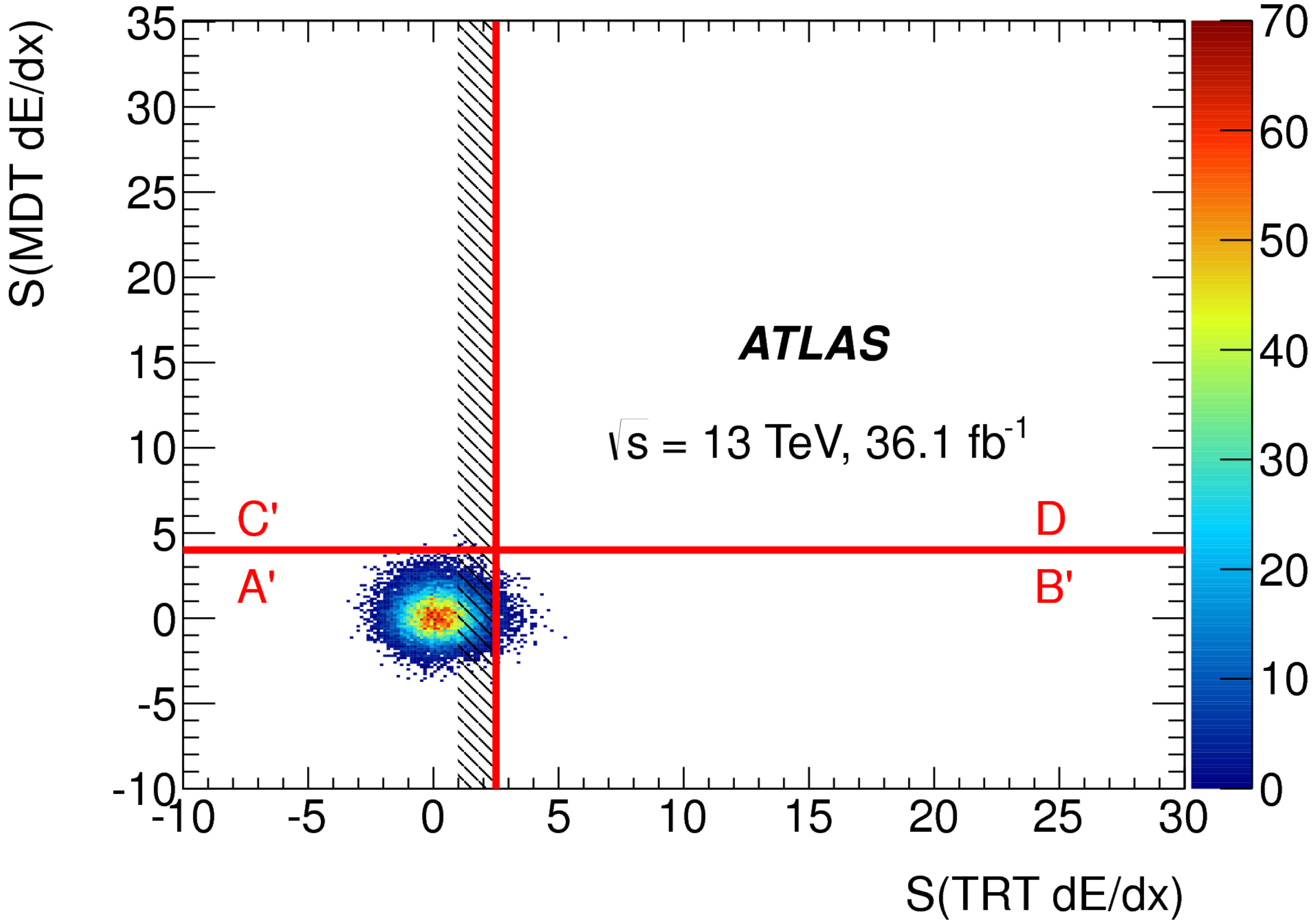
- The backgrounds from these searches are often *weird* and *very hard to model and understand.*
- Both experiments to significant *cleaning* to get rid of crap
  - We don't tend to document this very well… or model it well.
- This can get very dangerous for LLPs, as we mentioned.

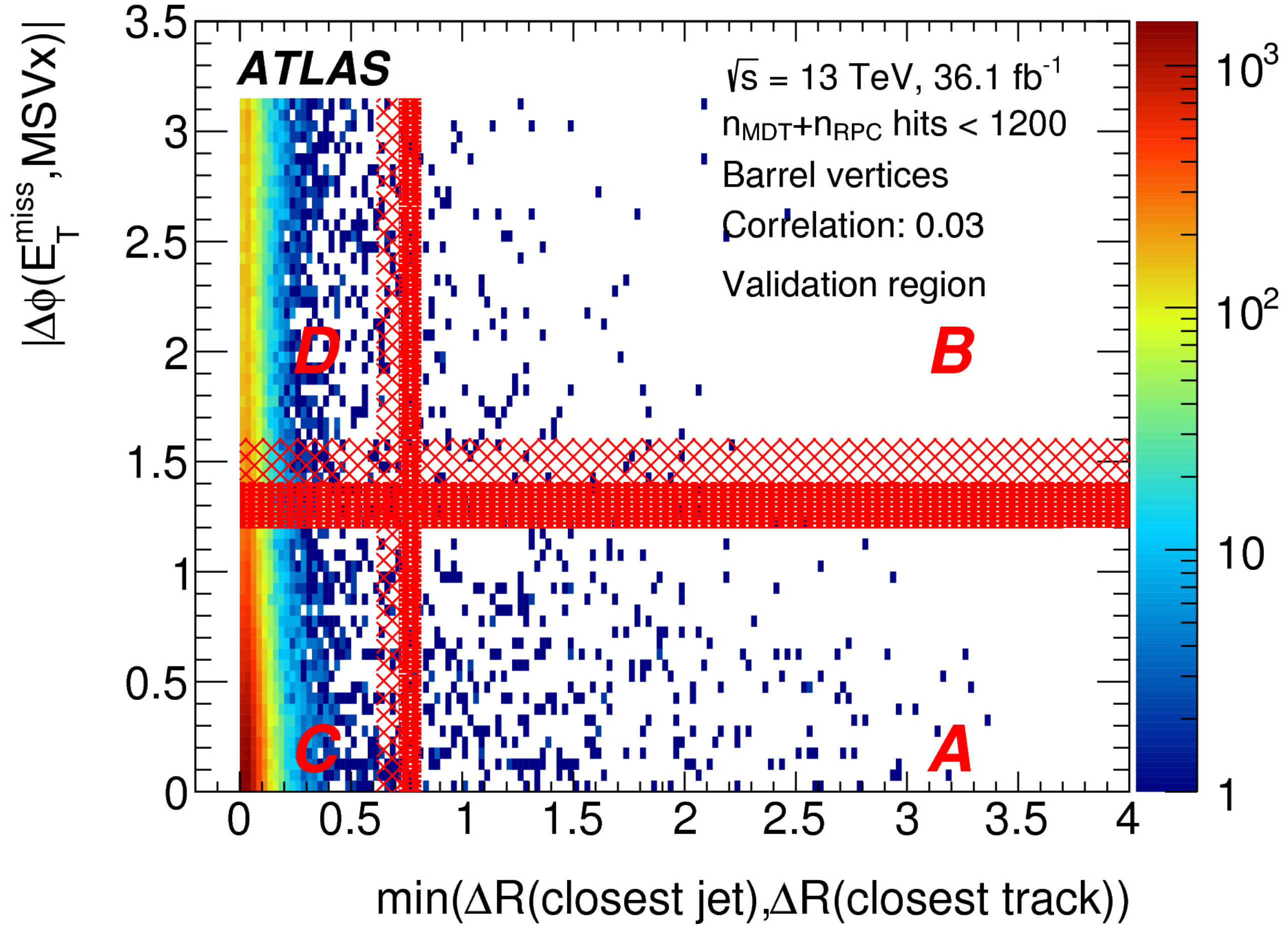




ABCD FTW

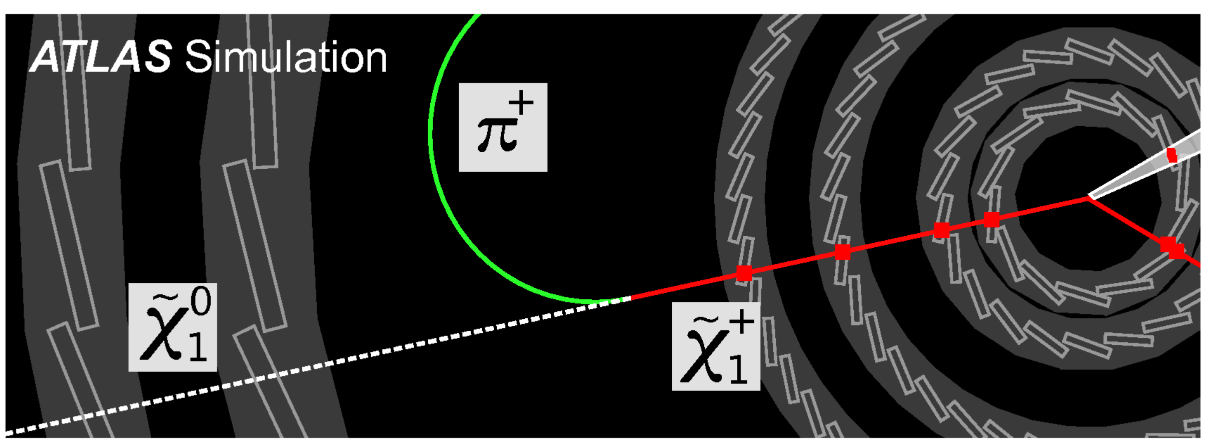
- I promised you ABCD… these searches are rife with it!

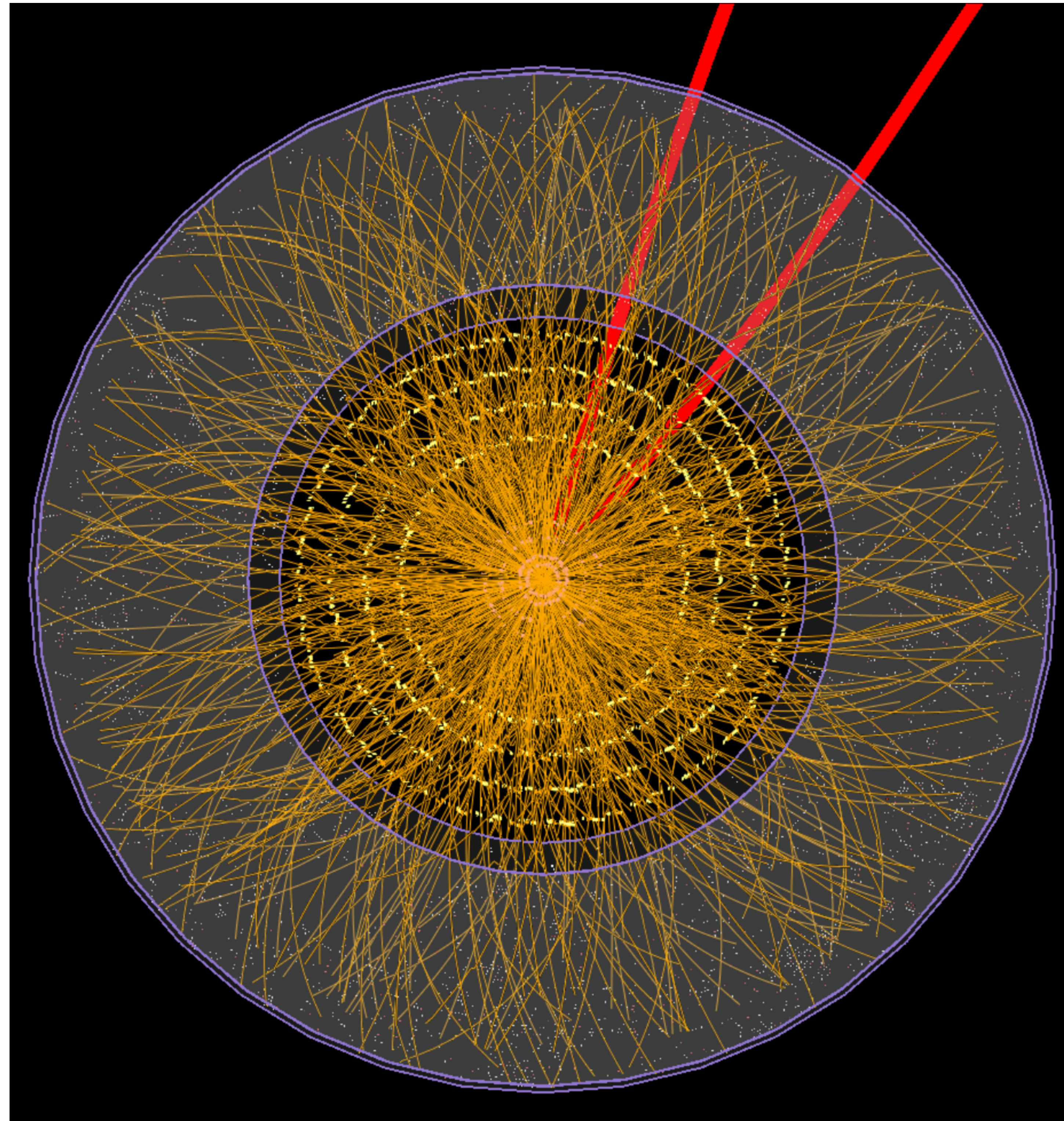




But we're pretty clever

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

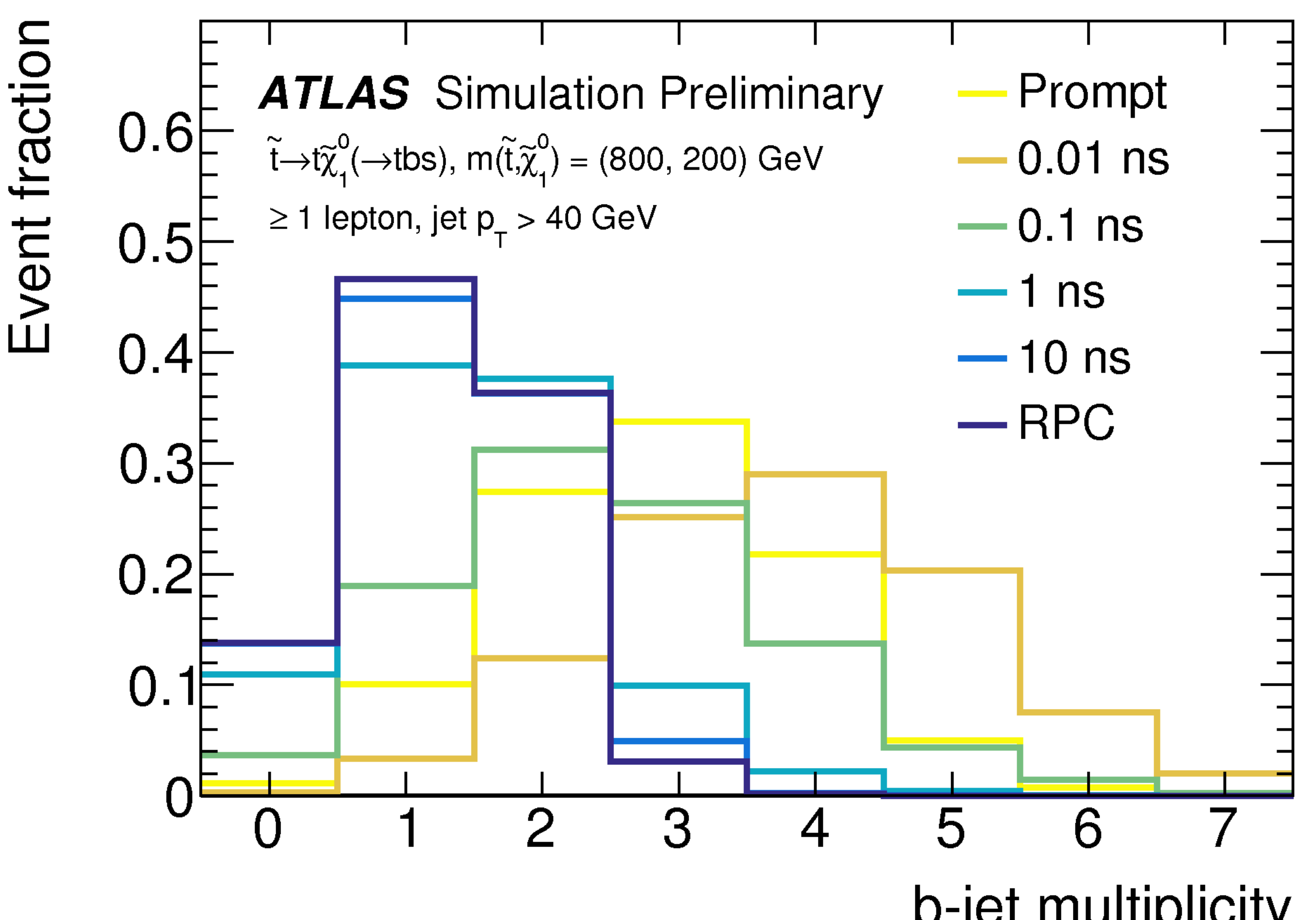


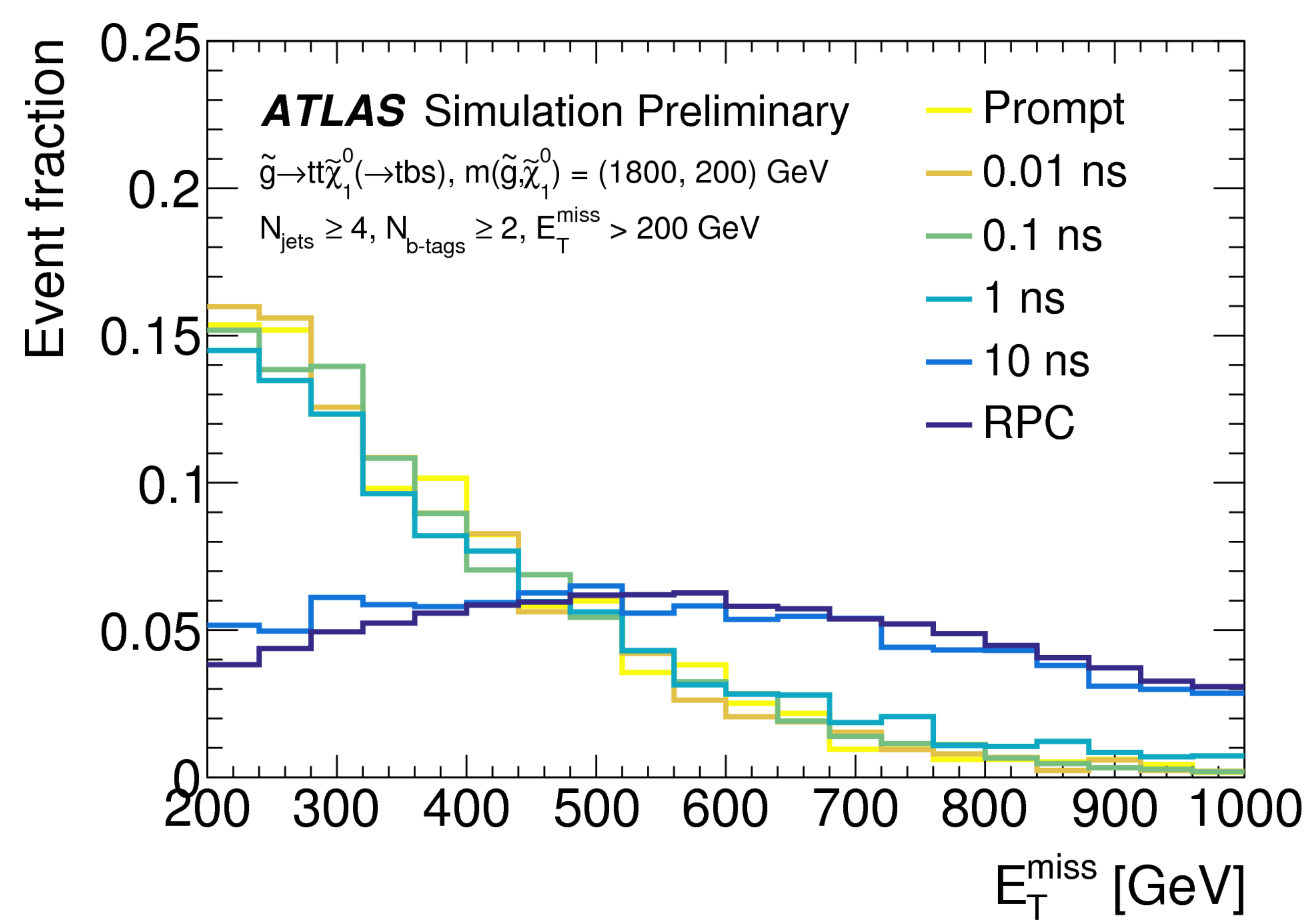


Going from Prompt to Long-Lived

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

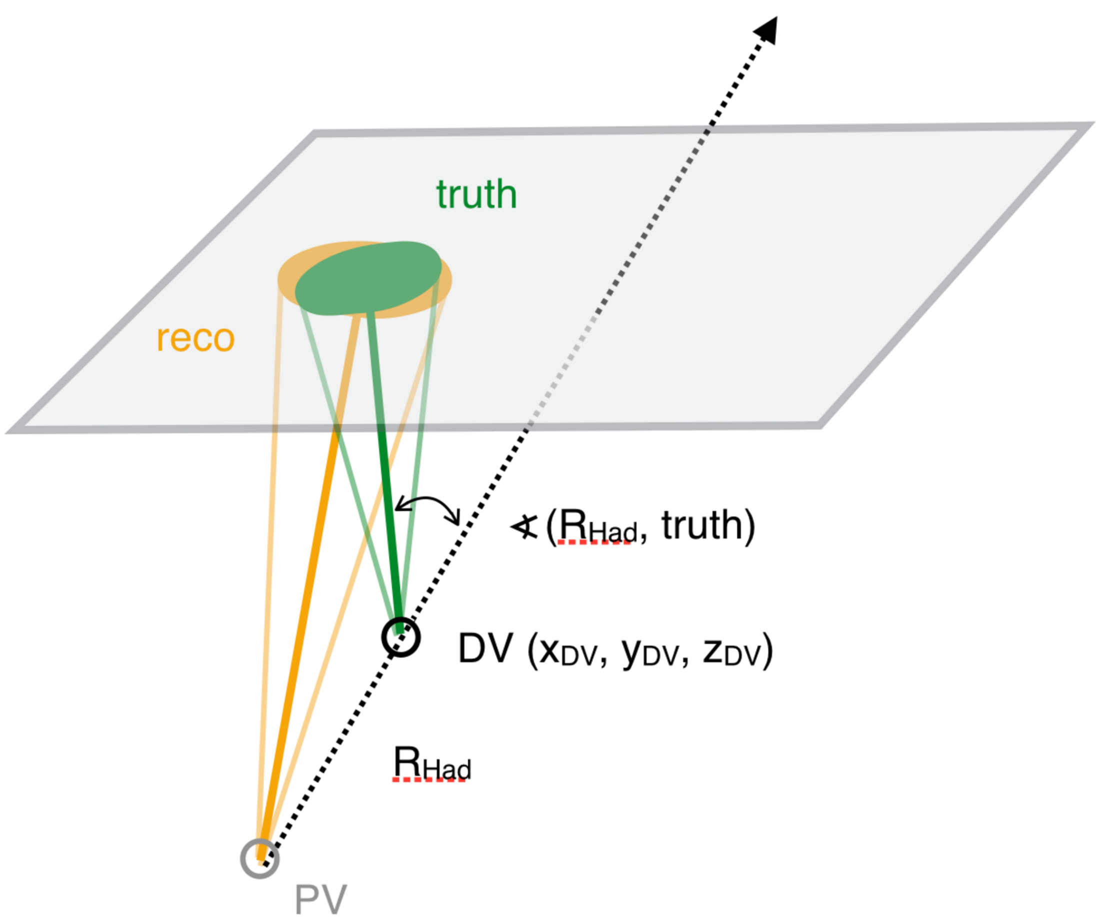
to the Gqq model considered in this note in the limit of a vanishingly small λ'' coupling. The analysis rejects events from detector noise and non-collision background, if at least one of the two leading jets with $p_{\mathrm{T}} > 100$ GeV fails to satisfy the ‘Tight’ quality criteria, as described 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

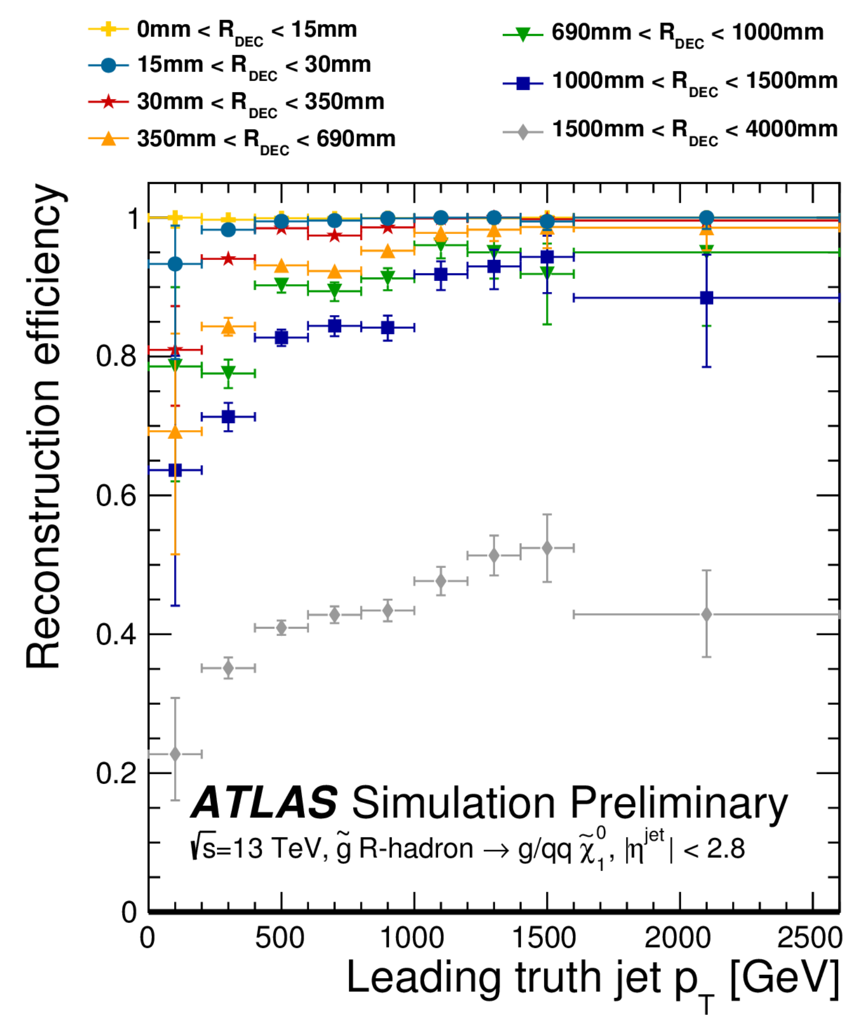




Going from Prompt to Long-Lived

- 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*.





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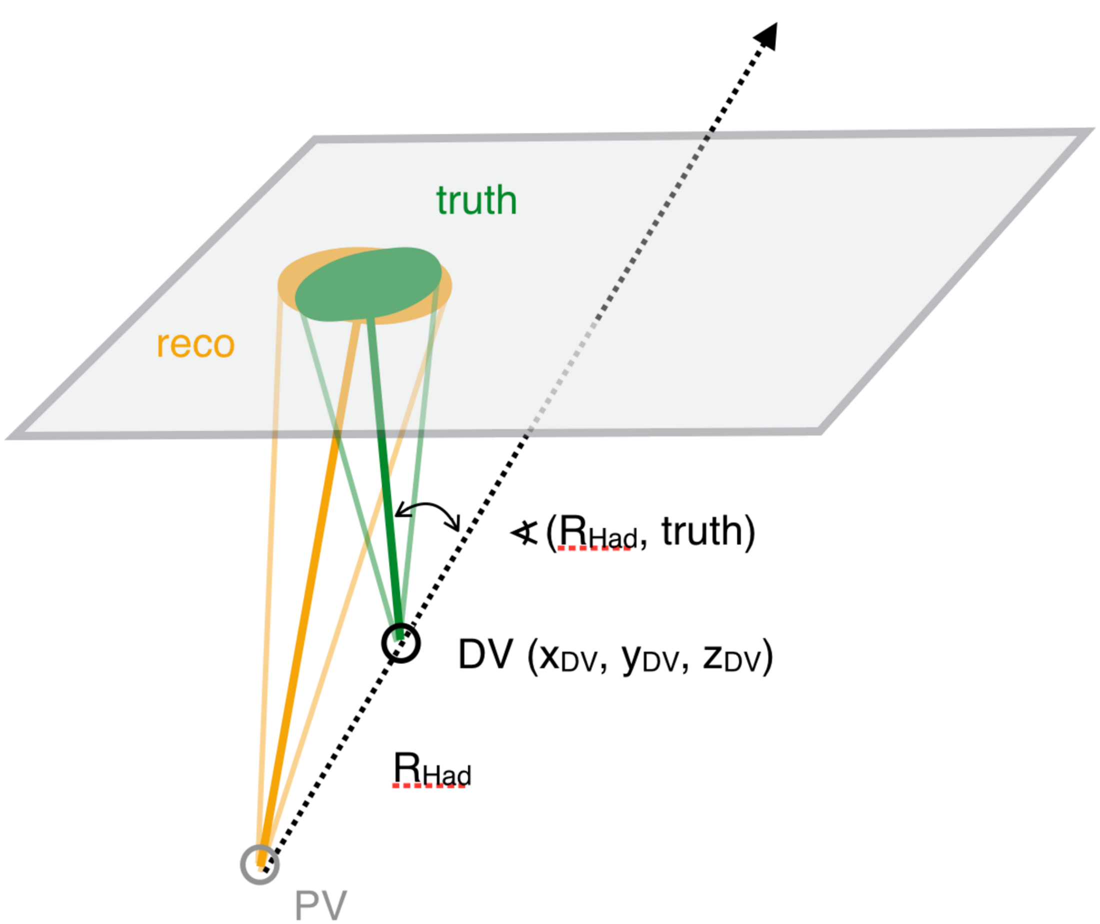
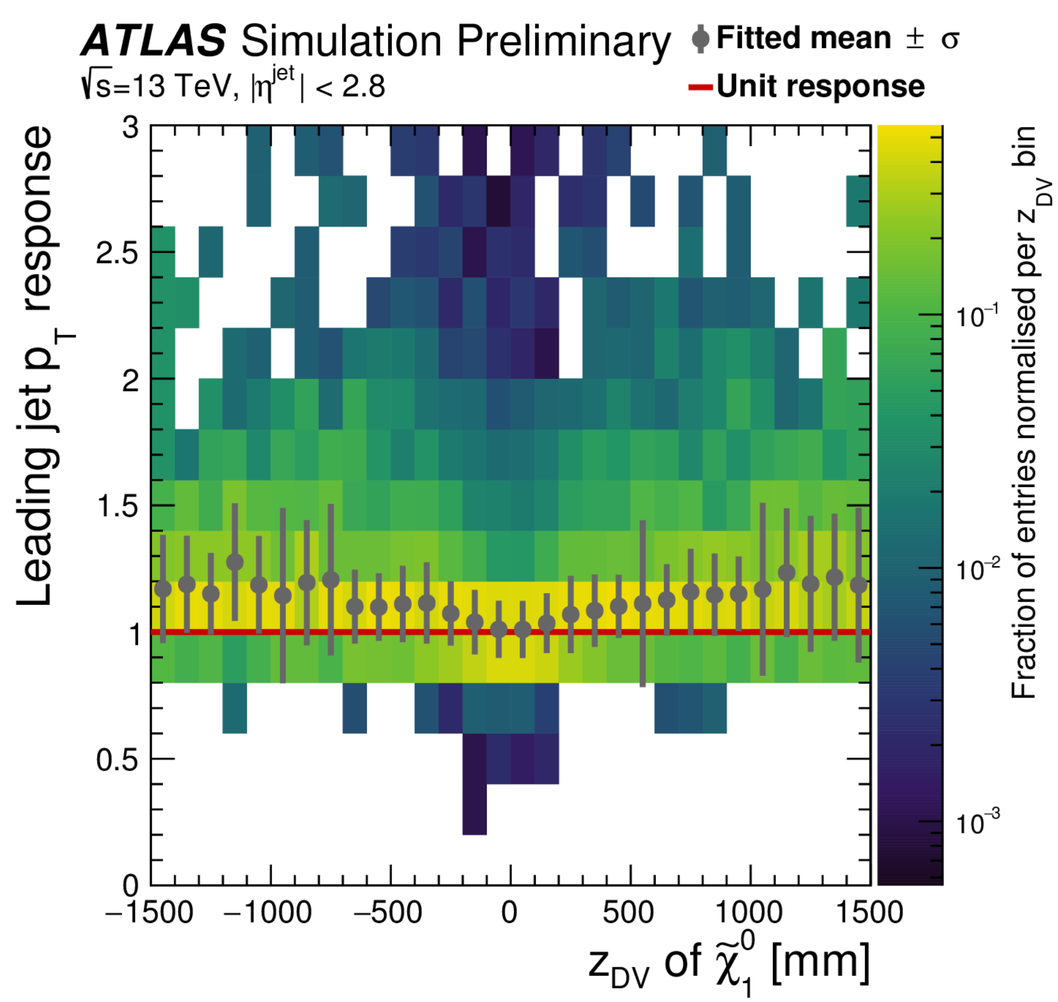
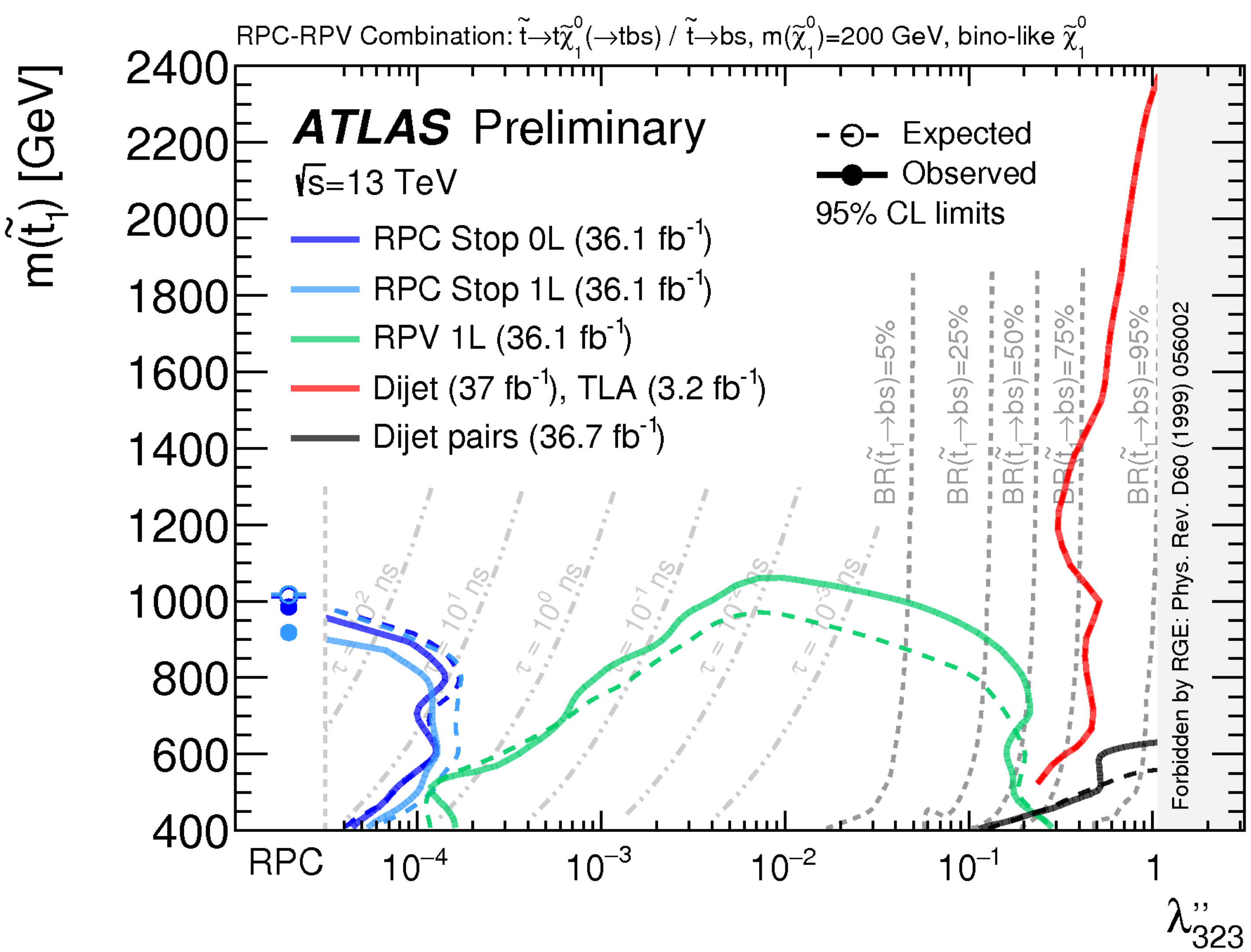




Going from Prompt to Long-Lived

- 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

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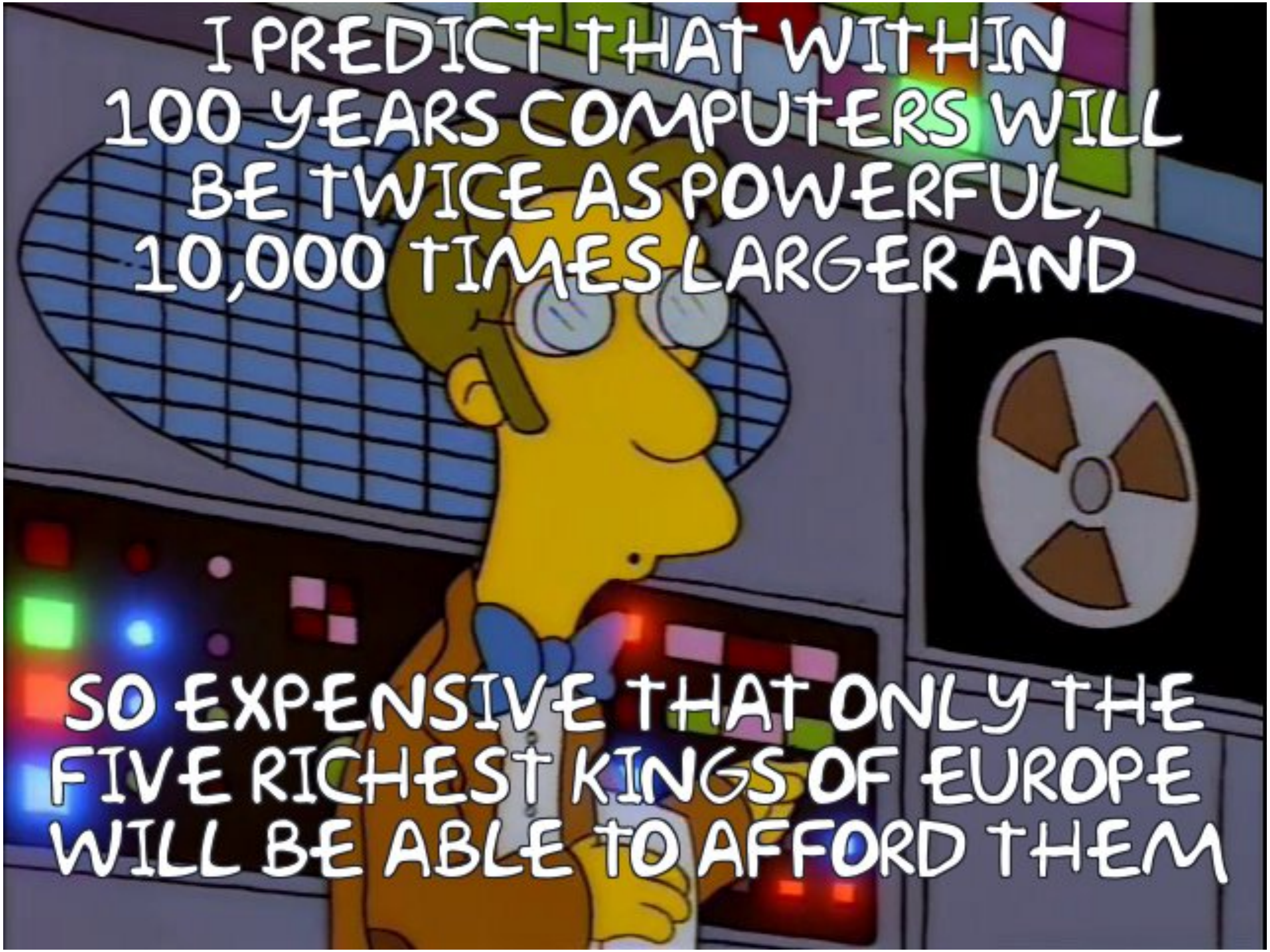
Improving neural networks by preventing co-adaptation of feature detectors

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

Enter the Machine

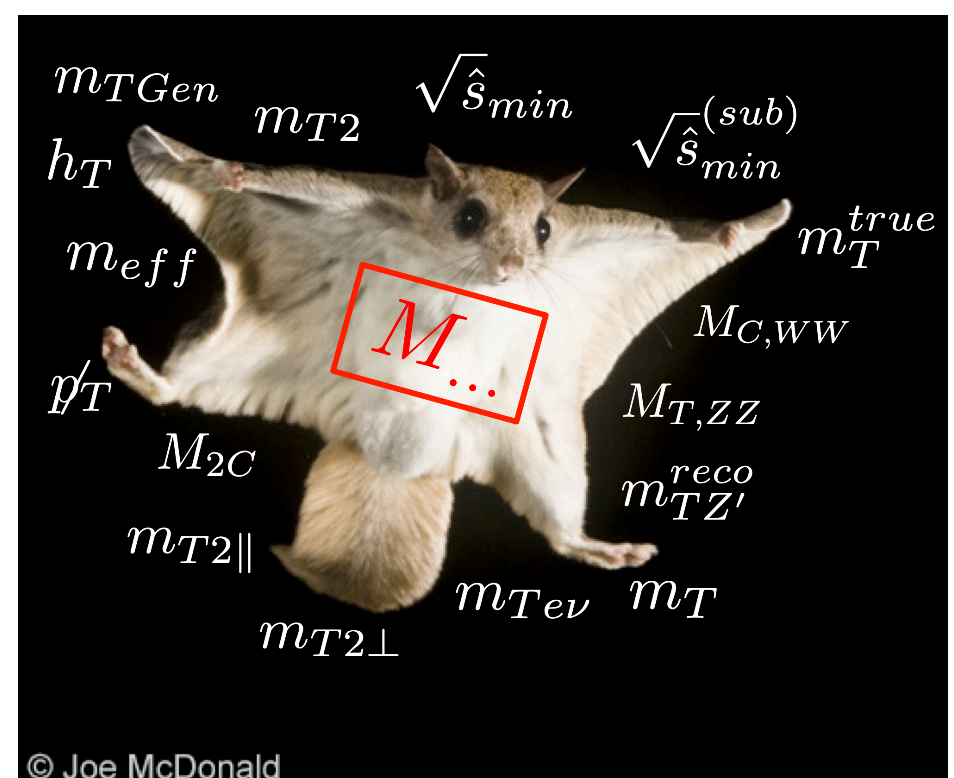


Machine Learning: The Good

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

Baseline selection	
Jets	$N_j \geq 2$ ($R = 0.4$), $p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$
H_T	$H_T > 300$ GeV
p_T^{miss}	$p_T^{miss} > 250$ GeV $\Delta\phi(\vec{p}_T^{miss}, j_1) > 0.5$ $\Delta\phi(\vec{p}_T^{miss}, j_2) > 0.15$ $\Delta\phi(\vec{p}_T^{miss}, j_3) > 0.15$ (when applicable)
Veto electron	$p_T > 5$ GeV, $\lvert\eta\rvert < 2.5$, $p_T^{sum} < 0.1\, p_T$
Veto muon	$p_T > 5$ GeV, $\lvert\eta\rvert < 2.4$, $p_T^{sum} < 0.2\, p_T$
Veto τ_h	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.4$, $m_T < 100$ GeV
Veto track	PF charged candidates, $\lvert\eta\rvert < 2.5$, $m_T < 100$ GeV $p_T > 5$ GeV, $p_T^{sum} < 0.2\, p_T$ for electron and muon tracks $p_T > 10$ GeV, $p_T^{sum} < 0.1\, p_T$ for charged-hadron tracks
Low Δm baseline selection	
N_t, N_W, N_{res}	$N_t = N_W = N_{res} = 0$
m_T^b	$m_T^b < 175$ GeV (for events with $N_b \geq 1$)
ISR jet	$N_j(\text{ISR}) = 1$ ($R = 0.8$), $p_T^{ISR} > 200$ GeV, $\lvert\eta\rvert < 2.4$ $\Delta\phi(\vec{p}_T^{miss}, j_{ISR}) > 2$
p_T^{miss}	$p_T^{miss} / \sqrt{H_T} > 10\,\sqrt{\text{GeV}}$
High Δm baseline selection	
Jets	$N_j \geq 5$ ($R = 0.4$), $p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$
b tagging	$N_b \geq 1$
p_T^{miss}	$\Delta\phi(\vec{p}_T^{miss}, j_{1,2,3,4}) > 0.5$

N_j	N_b	N_{SV}	m_T^b [GeV]	p_T^{ISR} [GeV]	p_T^b [GeV]	p_T^{miss} [GeV]	Bin number
2–5	0	0	—	>500	—	[450, 550, 650, 750, ∞]	0–3
≥6	0	0	—	>500	—	[450, 550, 650, 750, ∞]	4–7
2–5	0	≥1	—	>500	—	[450, 550, 650, 750, ∞]	8–11
≥6	0	≥1	—	>500	—	[450, 550, 650, 750, ∞]	12–15
≥2	1	0	<175	300–500	20–40	[300, 400, 500, 600, ∞]	16–19
≥2	1	0	<175	300–500	40–70	[300, 400, 500, 600, ∞]	20–23
≥2	1	0	<175	>500	20–40	[450, 550, 650, 750, ∞]	24–27
≥2	1	0	<175	>500	40–70	[450, 550, 650, 750, ∞]	28–31
≥2	1	≥1	<175	>300	20–40	[300, 400, 500, ∞]	32–34
≥2	≥2	—	<175	300–500	40–80	[300, 400, 500, ∞]	35–37
≥2	≥2	—	<175	300–500	80–140	[300, 400, 500, ∞]	38–40
≥7	≥2	—	<175	300–500	>140	[300, 400, 500, ∞]	41–43
≥2	≥2	—	<175	>500	40–80	[450, 550, 650, ∞]	44–46
≥2	≥2	—	<175	>500	80–140	[450, 550, 650, ∞]	47–49
≥7	≥2	—	<175	>300	>140	[450, 550, 650, ∞]	50–52



Machine Learning: The Good

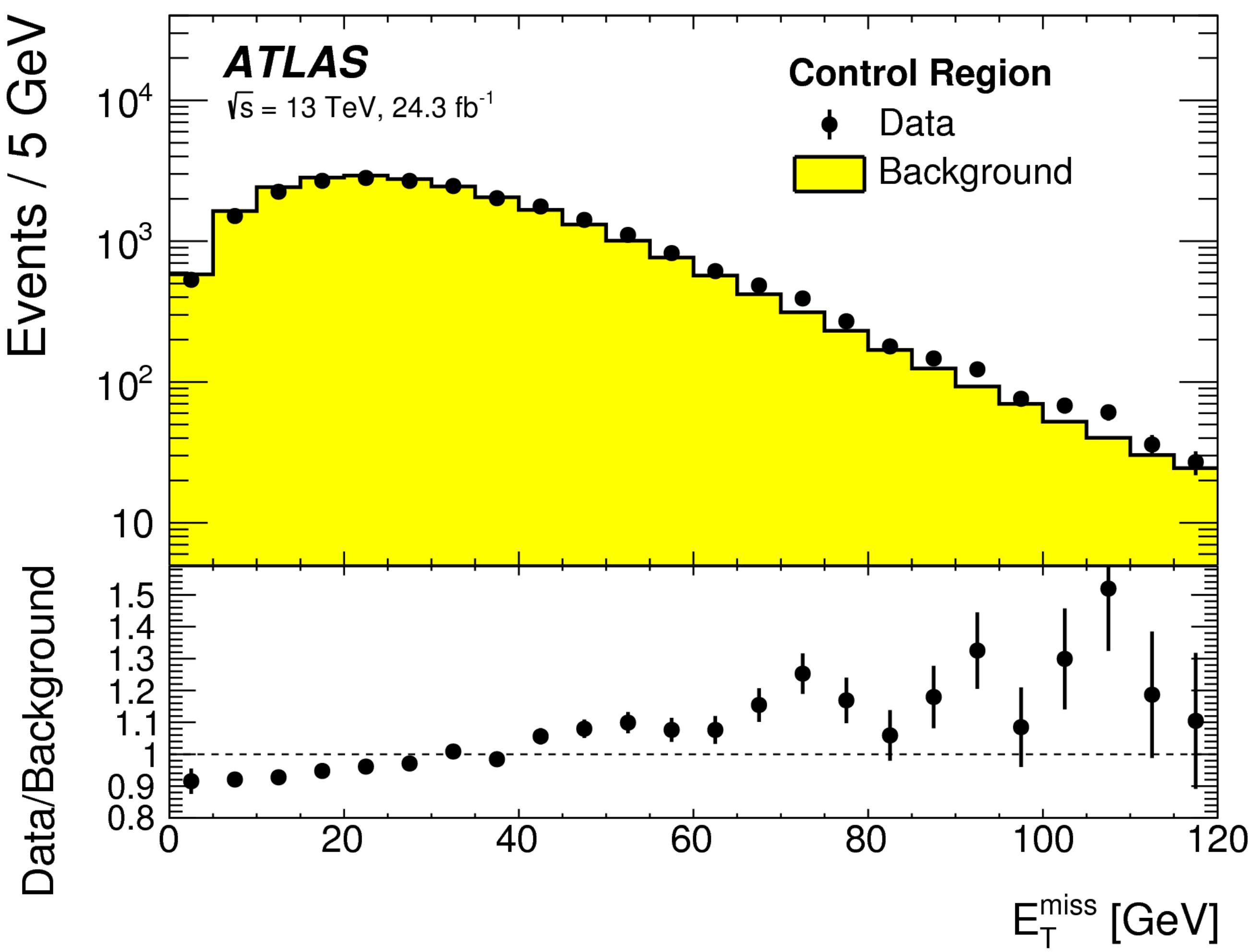
- We have a **huge** kinematic space to look through

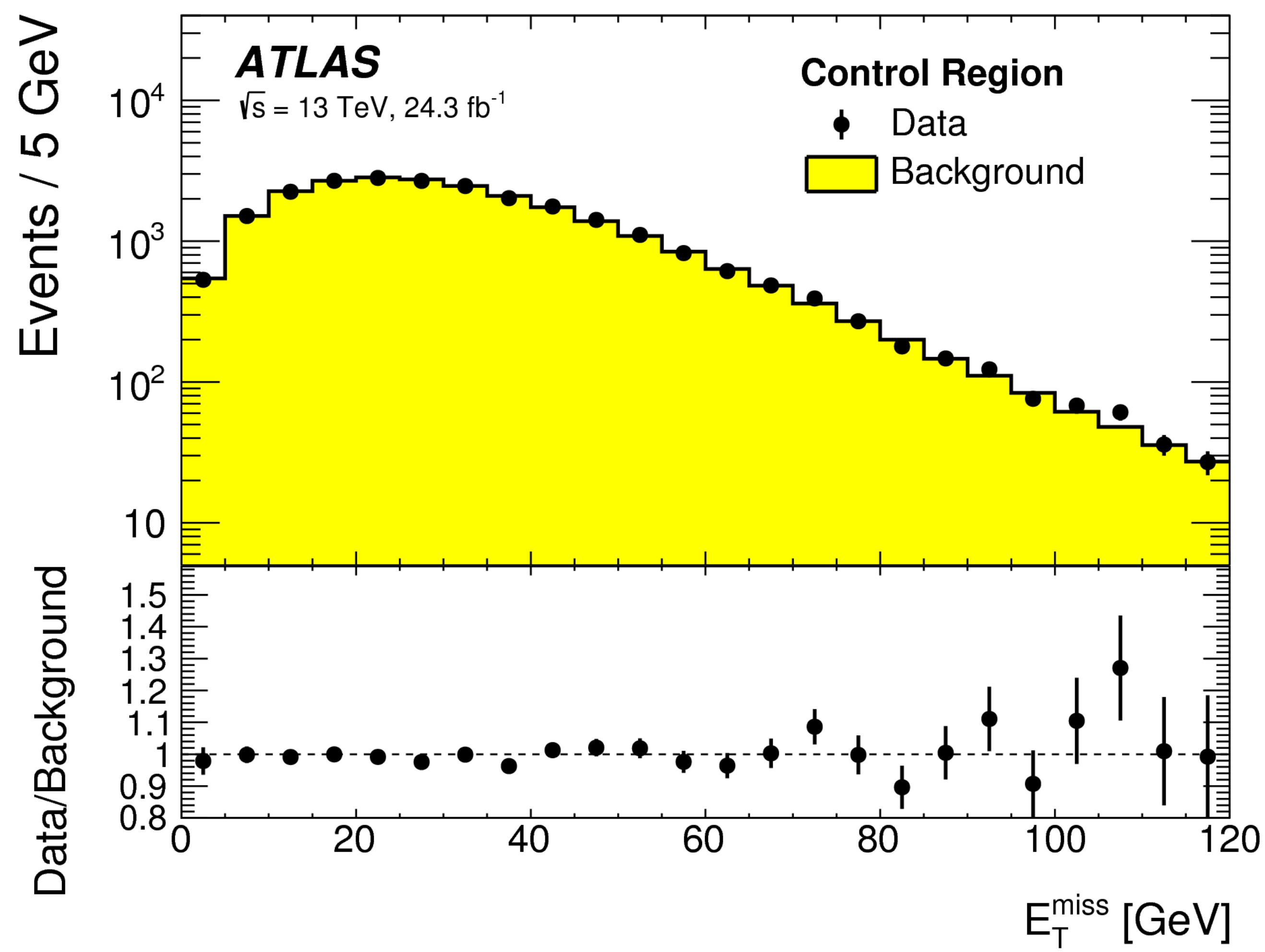
Selection		hard-lepton	soft-lepton
Trigger		E_T^{miss} trigger	
Data quality		jet cleaning, primary vertex	
Second-lepton veto		no additional baseline leptons	
Number of leptons, tightness		= 1 'loose' lepton	= 1 'tight' lepton
Lepton p_T	[GeV]	> 25	> 4 (4.5) for μ (e)
Number of jets (jet p_T)		≥ 4 (> 25 GeV)	≥ 1 (> 200 GeV) or ≥ 2 (> 20 GeV)
E_T^{miss}	[GeV]	> 230	
$\Delta\phi(j_{1,2}, \vec{p}_T^{miss})$	[rad]	> 0.4	
$N_{b\text{-jet}}$		≥ 1	–
m_T	[GeV]	> 30	–
m_{T2}^{τ}	[GeV]	> 80	–

Selection		tN_med	tN_high
Preselection		hard-lepton preselection	
N_{jet}, $N_{b\text{-jet}}$		≥ (4, 1)	≥ (4, 1)
Jet p_T	[GeV]	> (100, 90, 70, 50)	> (120, 50, 50, 25)
E_T^{miss}	[GeV]	> 230	> 520
$E_{T,\perp}^{miss}$	[GeV]	> 400	–
$H_{T,sig}^{miss}$		> 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:

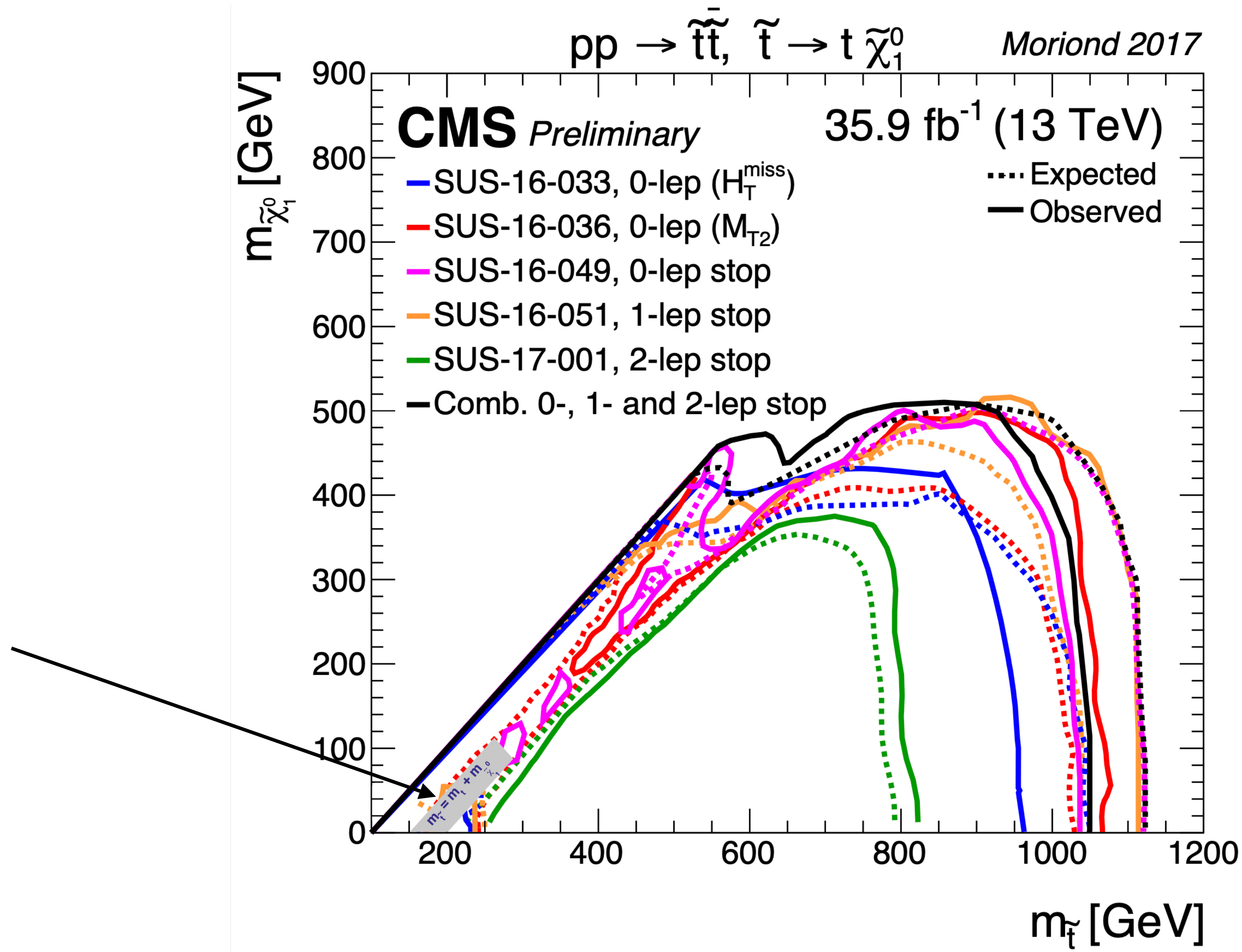
- Train a NN to find a circle in two dimensions, giving it x and y as input variables

- 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*.

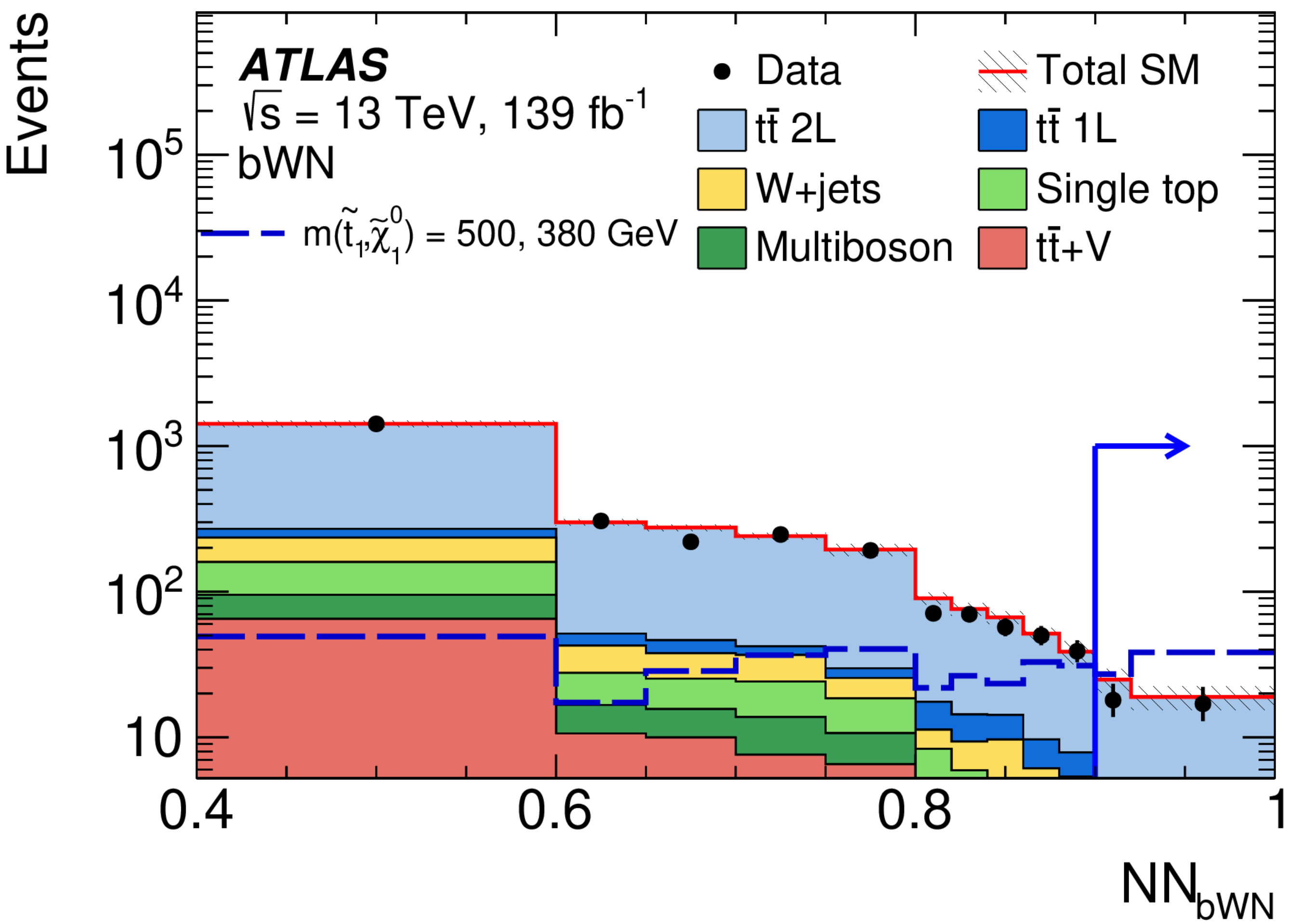
Machine Learning: the Bad

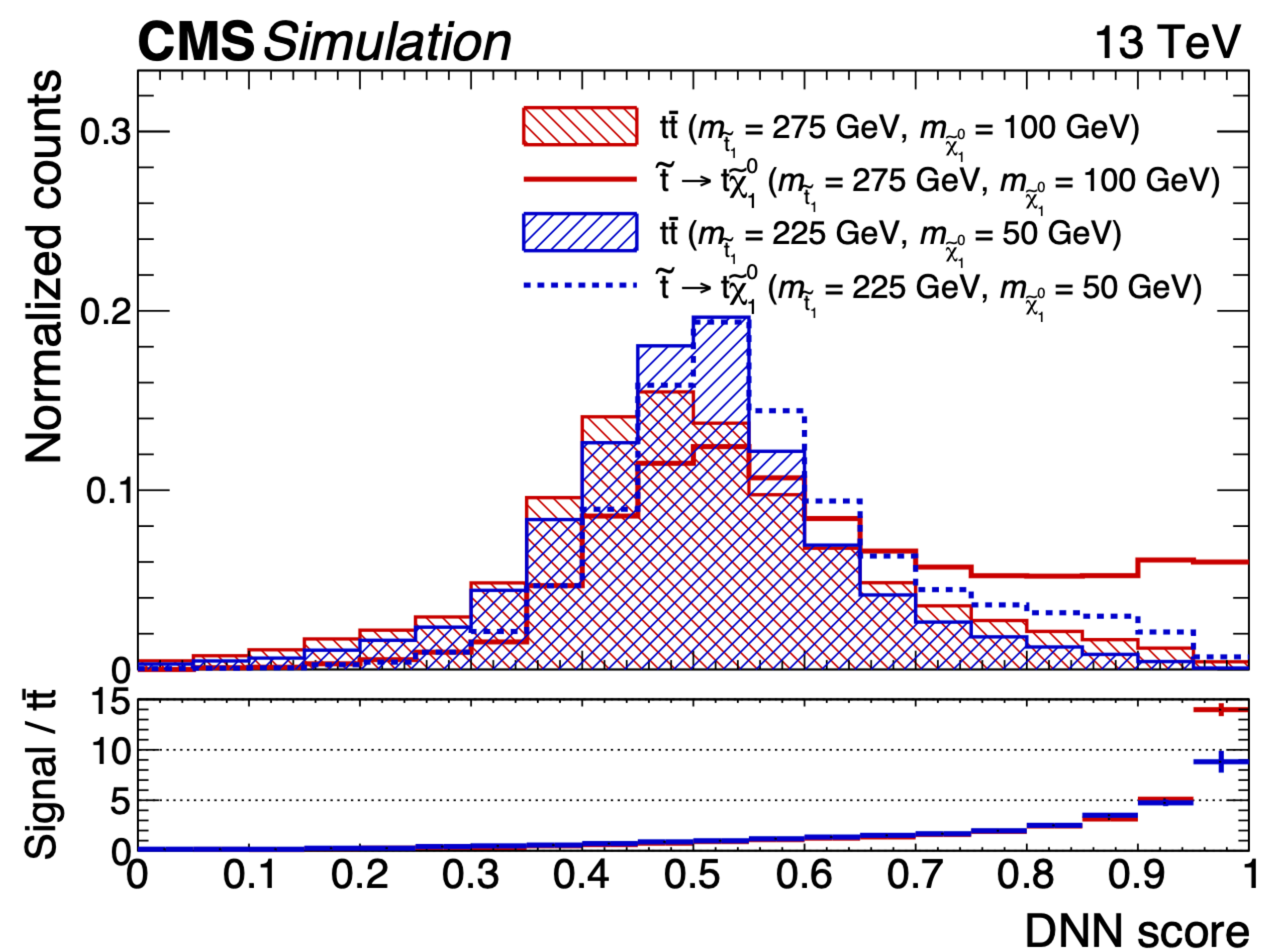
- **What exactly** am I discriminating from **what?**



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 ($\tilde{t}_1 \to t\tilde{\chi}_1^0$) 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).

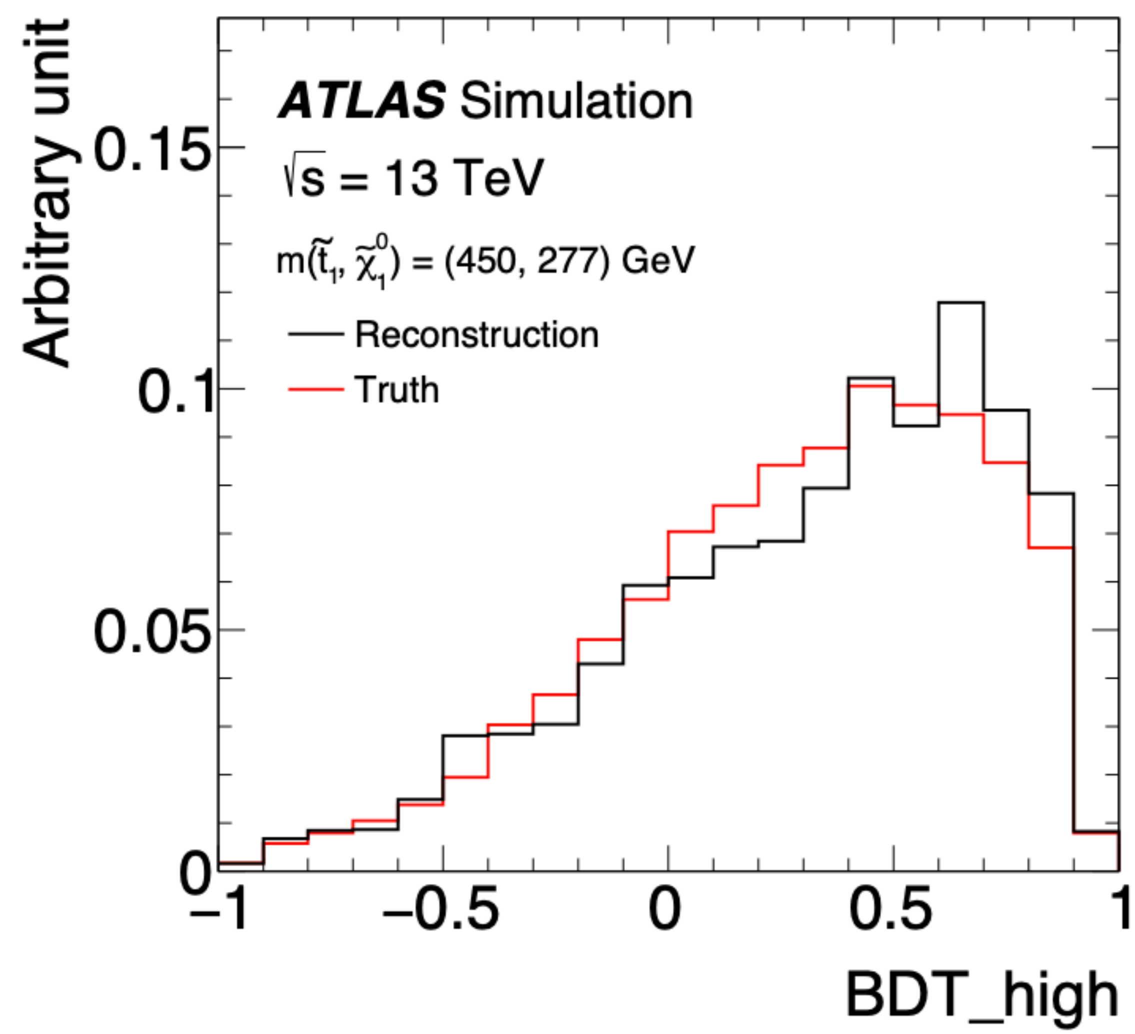
The variables input to BDTs are as follows:

- BDT_low: E_T^{miss}, m_T, Δm_T^{α}, $m(t_{had}^{ISR})$, $m(t_{lep}^{\alpha})$, $|\Delta\phi(\ell, t\bar{t})|$, and $|\Delta\phi(\ell, \vec{p}_T(\nu^{\alpha}))|$,
- BDT_med: E_T^{miss}, $H_{T,sig}^{miss}$, $\Delta\phi(\vec{p}_T^{miss}, t_{had}^{\chi})$, $\Delta\phi(t_{had}^{\chi}, t_{lep}^{\chi})$, $\Delta R(b,\ell)$, m_T, m_{top}^{χ}, the number of jets, the third jet p_T, and the fourth jet p_T,
- BDT_high: R_{ISR}, $\Delta\phi(ISR, I)$, $\Delta\phi(t_{had}^{\chi}, t_{lep}^{\chi})$, $\Delta R(b,\ell)$, 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,

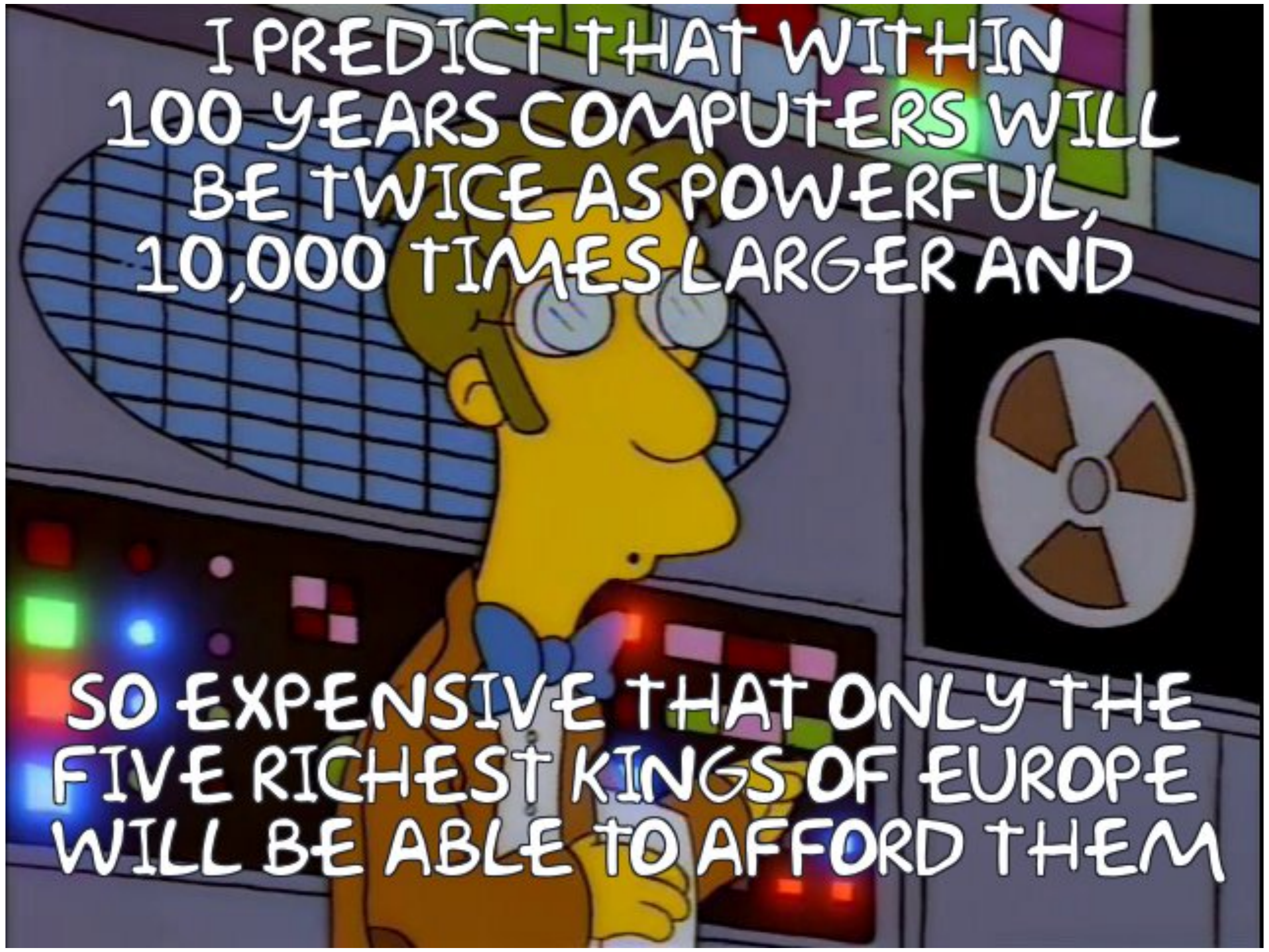
The ‘200’ suffix on the names of the variables in the BDT_low XML implies that α is calculated using a signal point $m(\tilde{t}_1, \tilde{\chi}_1^0) = (200, 27)$ GeV. The unit MeV is commonly used for momenta and energies, besides the dimensionless azimuthal-angle variables. The HEPData record contains 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



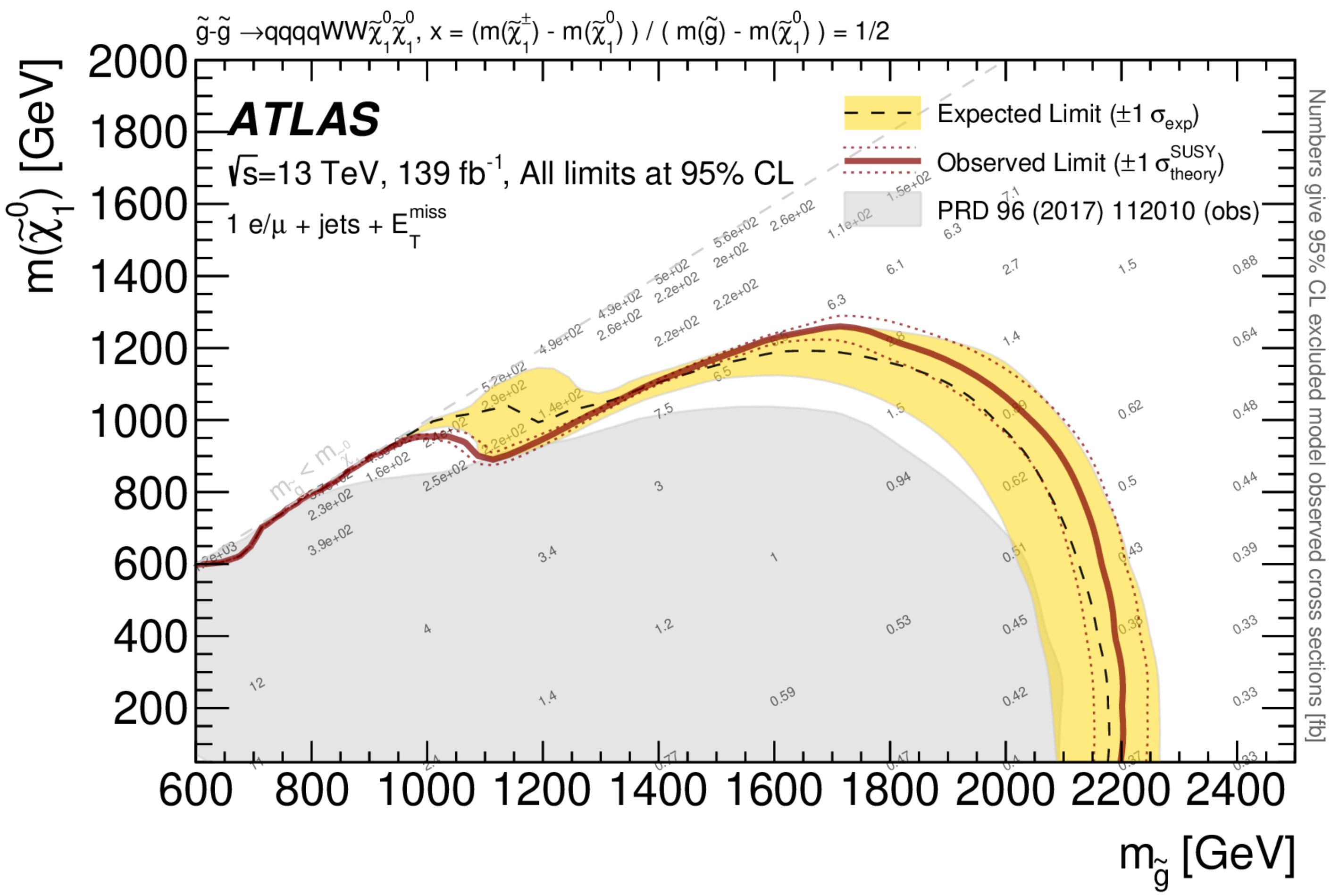
- Many people are predicting continued expansion of ML
- Industry are working with *very large* networks
- Many people have proposed working with the raw data (or similar) as input, *bypassing* much of the reconstruction

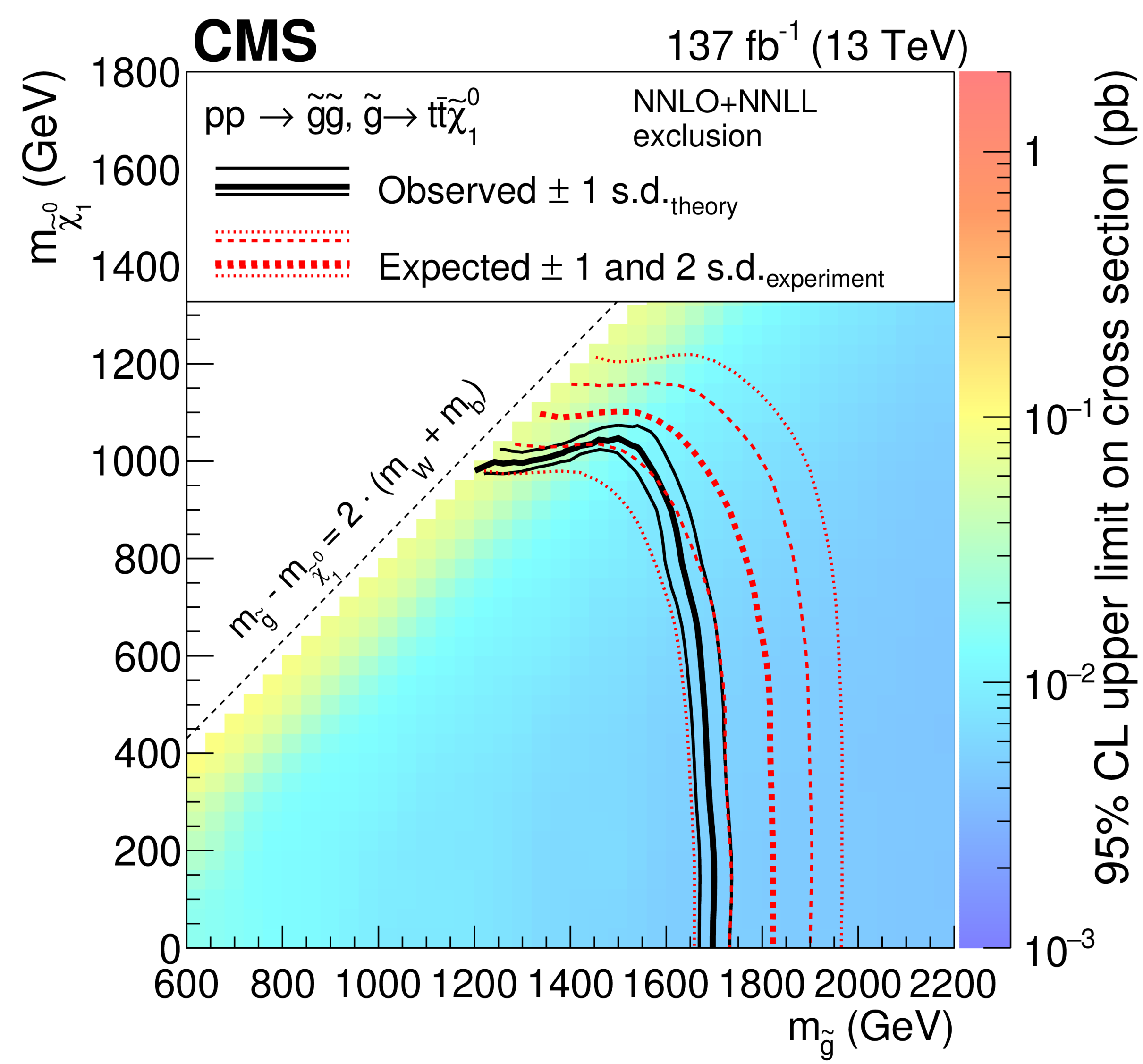
ML Philosophy

- 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

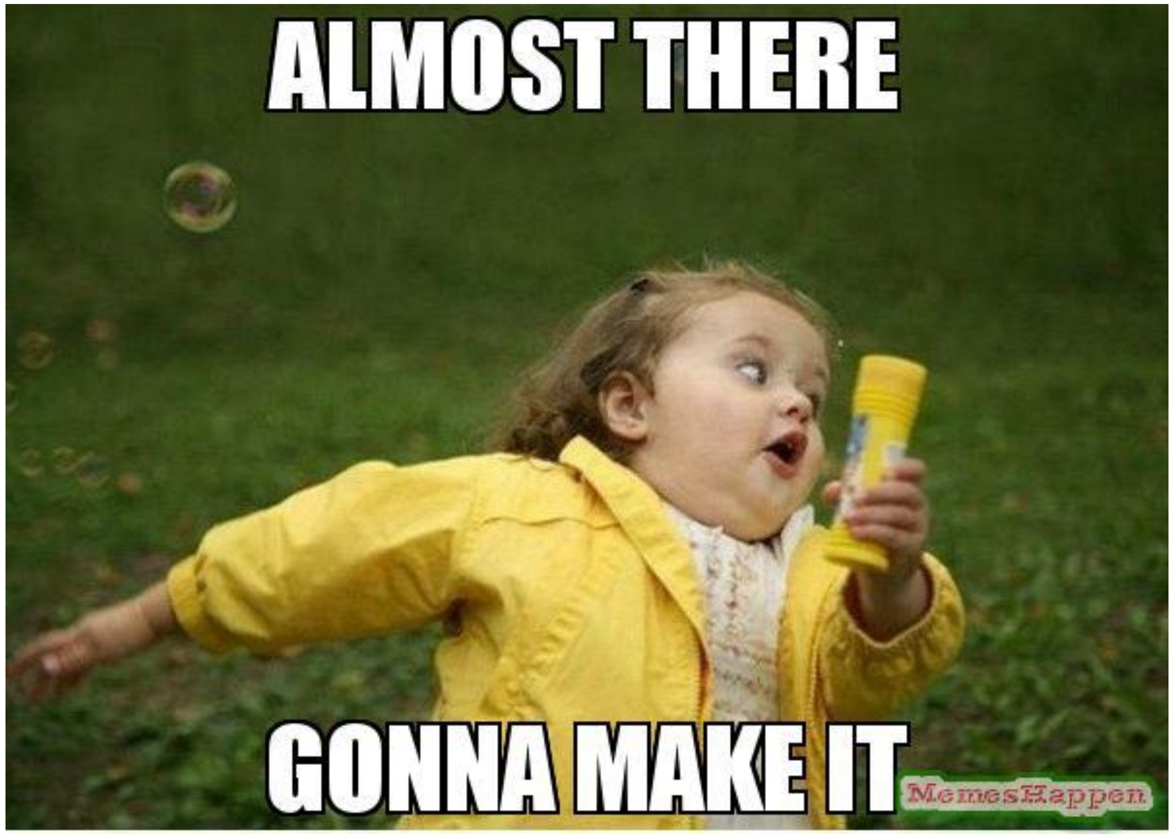
One last note on limits

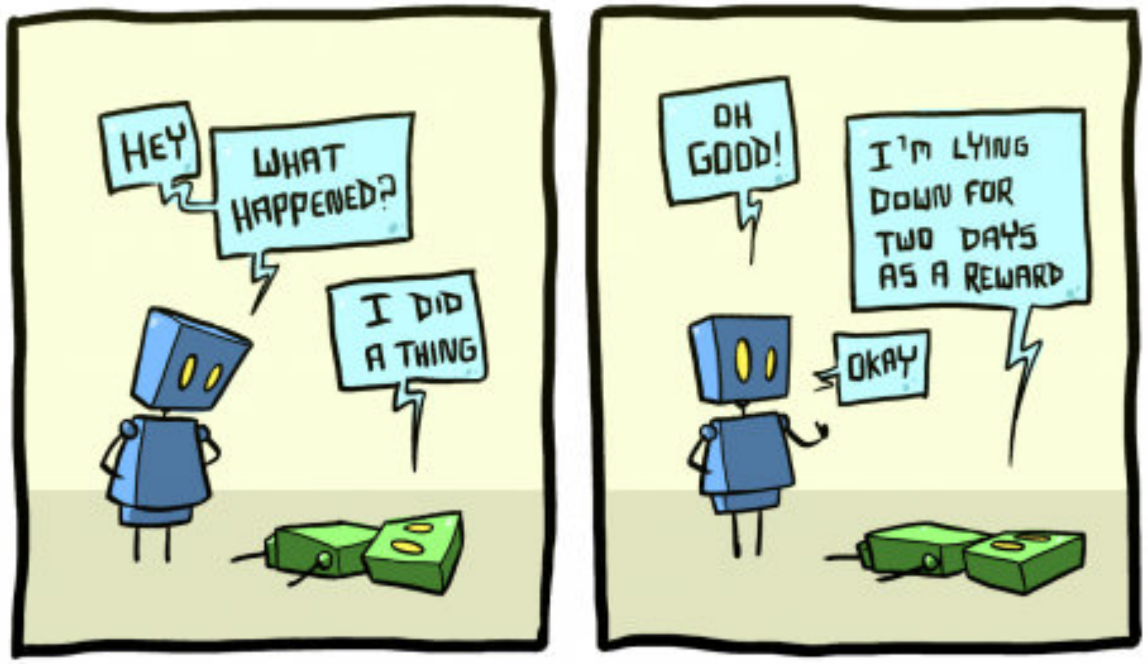
- Isn't it a little weird how the right one looks like it was drawn with a gradient fill?





Almost there!





Summary Table

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

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

Summary Table

arXiv	Ref	Short			LLP	Type	Background							ML	
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		Multi-bin fit	■								2
2108.07586	SUSY-2018-41	EWK all-had	9	0		Multi-bin fit	■	■							2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		Multi-bin fit	■	■			■			■	7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit	■	■							31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0	■	Multi-bin fit		■			■				6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit	■	■							14
2103.08189	SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	0		Multi-bin fit	■	■					■		1
2102.01444	SUSY-2018-08	Search for DM and stops in tt2L + MET final states	4	0		Multi-bin fit	■	■							13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3	0		Multi-bin fit	■								11
2101.01629	SUSY-2018-10	Gluino pair, squark pair; 1 lepton	2	0		Multi-bin fit	■								6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton	4	0		Multi-bin fit	■							■	8
2011.10543	SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L	2	0		Multi-bin fit	■	■							48
2011.07812	SUSY-2018-14	Search for displaced leptons	1	0	■	Multi-bin fit					■				
2010.14293	SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	0		Multi-bin fit	■			■			■	■	18
2010.01015	SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	0		Multi-bin fit	■				■				2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit					■				8
2006.0588	SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		Multi-bin fit	■	■						■	6
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit	■				■		■		16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit	■		■						12
2102.10874	EXOT-2018-06	Monojet search	8	1		Multi-bin fit	■						■		13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt			■						0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0	■	Cut and count					■				0
2107.00404	EXOT-2019-36	Multilepton General	0	2		Multi-bin fit	■	■							22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		Cut and count	■	■	■						4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit	■	■						■	0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit	■	■							0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit	■	■						■	7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit	■	■							7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit	■								0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit	■	■						■	0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		Multi-bin fit	■	■	■					■	0

Summary Table

arXiv	Ref	Short	Simplified Models	Full Models	LLP	ype	Background: MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing	ML	Discovery regions
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		ulti-bin fit	■								2
2108.07586	SUSY-2018-41	EWK all-had	9	0		ulti-bin fit	■	■							2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		ulti-bin fit	■	■			■			■	7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		ulti-bin fit	■	■							31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0	■	ulti-bin fit		■			■				6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		ulti-bin fit	■	■							14
2103.08189	SUSY-2018-40	Search for sbottoms	1	0		ulti-bin fit	■	■					■		1
2102.01444	SUSY-2018-08	Search for DM and st	4	0		ulti-bin fit	■	■							13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP D	3	0		ulti-bin fit	■								11
2101.01629	SUSY-2018-10	Gluino pair, squark pa	2	0		ulti-bin fit	■								6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM	4	0		ulti-bin fit	■							■	8
2011.10543	SUSY-2018-36	Search for chargino a	2	0		ulti-bin fit	■	■							48
2011.07812	SUSY-2018-14	Search for displaced	1	0	■	ulti-bin fit					■				
2010.14293	SUSY-2018-22	Gluino pair; squark pa	5	0		ulti-bin fit	■			■			■	■	18
2010.01015	SUSY-2018-38	Search for new physi	2	0		ulti-bin fit	■				■				2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		ulti-bin fit					■				8
2006.0588	SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		ulti-bin fit	■	■						■	6
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		ulti-bin fit	■				■		■		16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		ulti-bin fit	■		■						12
2102.10874	EXOT-2018-06	Monojet search	8	1		ulti-bin fit	■						■		13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		ump hunt			■						0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0	■	ut and count					■				0
2107.00404	EXOT-2019-36	Multilepton General	0	2		ulti-bin fit	■	■							22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		ut and count	■	■	■						4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		ulti-bin fit	■	■						■	0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepto	1	0		ulti-bin fit	■	■							0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		ulti-bin fit	■	■						■	7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		ulti-bin fit	■	■							7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		ulti-bin fit	■								0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		ulti-bin fit	■	■						■	0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		ulti-bin fit	■	■	■					■	0

Loads of simplified models; few complete models

Summary Table

arXiv	Ref	Short	Simplified Models	Full Models	LLP	Type	Background: MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing	ML	Discovery regions
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		Multi-bin fit	■								2
2108.07586	SUSY-2018-41	EWK all-had	9	0		Multi-bin fit	■	■							2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		Multi-bin fit	■	■			■			■	7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit	■	■							31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0	■	Multi-bin fit		■			■				6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit	■	■							14
2103.08189	SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	0		Multi-bin fit	■	■					■		1
2102.01444	SUSY-2018-08	Search for DM and stops in tt2L + MET final states	4	0		Multi-bin fit	■	■							13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3	0		Multi-bin fit	■								11
2101.01629	SUSY-2018-10	Gluino pair, squark pair; 1 lepton	[illegible]	[illegible]		Multi-bin fit	■								6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton	[illegible]	[illegible]		Multi-bin fit	■							■	8
2011.10543	SUSY-2018-36	Search for chargino and neutralino pai[illegible]	[illegible]	[illegible]		Multi-bin fit	■	■							48
2011.07812	SUSY-2018-14	Search for displaced leptons	1	0	■	Multi-bin fit					■				
2010.14293	SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	0		Multi-bin fit	■			■			■	■	18
2010.01015	SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	0		Multi-bin fit	■				■				2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit					■				8
2006.0588	SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		Multi-bin fit	■	■						■	6
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit	■				■		■		16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit	■		■						12
2102.10874	EXOT-2018-06	Monojet search	8	1		Multi-bin fit	■						■		13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt			■						0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0	■	Cut and count					■				0
2107.00404	EXOT-2019-36	Multilepton General	0	2		Multi-bin fit	■	■							22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		Cut and count	■	■	■						4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit	■	■						■	0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit	■	■							0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit	■	■						■	7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit	■	■							7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit	■								0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit	■	■						■	0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		Multi-bin fit	■	■	■					■	0

Mostly multi-bin fits!

Summary Table

arXiv	Ref	Short	Simplified Models	Full Models	LLP	Type	Background: MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing	ML	Discovery regions
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		Multi-bin fit	■								2
2108.07586	SUSY-2018-41	EWK all-had	9	0		Multi-bin fit	■	■							2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		Multi-bin fit	■	■			■			■	7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit	■	■							31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0	■	Multi-bin fit		■			■				6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit	■	■							14
2103.08189	SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	0		Multi-bin fit	■	■					■		1
2102.01444	SUSY-2018-08	Search for DM and stops in tt2L + MET final states	4	0		Multi-bin fit	■	■							13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	3	0		Multi-bin fit	■								11
2101.01629	SUSY-2018-10	Gluino pair, squark pair; 1 lepton					■								6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton					■							■	8
2011.10543	SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L					■	■							48
2011.07812	SUSY-2018-14	Search for displaced leptons	1	0	■	Multi-bin fit					■				
2010.14293	SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	5	0		Multi-bin fit	■			■			■	■	18
2010.01015	SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	0		Multi-bin fit	■				■				2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit					■				8
2006.0588	SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		Multi-bin fit	■	■						■	6
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit	■				■		■		16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit	■		■						12
2102.10874	EXOT-2018-06	Monojet search	8	1		Multi-bin fit	■						■		13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt			■						0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0	■	Cut and count					■				0
2107.00404	EXOT-2019-36	Multilepton General	0	2		Multi-bin fit	■	■							22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		Cut and count	■	■	■						4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit	■	■						■	0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit	■	■							0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit	■	■						■	7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit	■	■							7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit	■								0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit	■	■						■	0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		Multi-bin fit	■	■	■					■	0

Lots of MC!

Summary Table

arXiv	Ref	Short	Simplified Models	Full Models	LLP	Type	MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing	ML	[illegible]
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		Multi-bin fit									2
2108.07586	SUSY-2018-41	EWK all-had	9	0		Multi-bin fit									2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		Multi-bin fit									7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit									31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0		Multi-bin fit									6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit									14
2103.08189	SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus	1	0		Multi-bin fit									1
2102.01444	SUSY-2018-08	Search for DM and stops in tt2L + MET final states	[illegible]	[illegible]		[illegible]									13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets	[illegible]	[illegible]		[illegible]									11
2101.01629	SUSY-2018-10	Gluino pair, squark pair; 1 lepton	[illegible]	[illegible]		[illegible]									6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton	[illegible]	[illegible]		[illegible]									8
2011.10543	SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L	[illegible]	[illegible]		[illegible]									48
2011.07812	SUSY-2018-14	Search for displaced leptons	[illegible]	[illegible]		[illegible]									
2010.14293	SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton	[illegible]	[illegible]		[illegible]									18
2010.01015	SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity	2	0		Multi-bin fit									2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit									8
2006.0588	SUSY-2018-21	Search for stop pair production decaying through Z/h bosons	2	0		Multi-bin fit									6
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit									16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit									12
2102.10874	EXOT-2018-06	Monojet search	8	1		Multi-bin fit									13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt									0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0		Cut and count									0
2107.00404	EXOT-2019-36	Multilepton General	0	2		Multi-bin fit									22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		Cut and count									4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit									0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit									0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit									7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit									7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit									0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit									0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		Multi-bin fit									0

Some Machine Learning
(but not ubiquitous)

Summary Table

arXiv	Ref	Short			LLP	Type	Background							ML	
			Simplified Models	Full Models			MC	Fakes	Fits	Symmetry	ABCD	Combinatoric	Jet Smearing		Discovery regions
2108.07665	SUSY-2019-18	Stop pair; Leptoquarks; taus	3	0		Multi-bin fit									2
2108.07586	SUSY-2018-41	EWK all-had	9	0		Multi-bin fit									2
2106.09609	SUSY-2019-04	Gluino pair, stop pair; 1 lepton, RPV	5	0		Multi-bin fit									7
2106.01676	SUSY-2019-09	Search for chargino-neutralino pair production in final states with three leptons and MET	3	0		Multi-bin fit									31
2104.0305	SUSY-2018-15	Search for stopped long-lived particles decaying to jets in empty bunch crossings	1	0		Multi-bin fit									6
2103.11684	SUSY-2018-02	Chargino-neutralino pair; 4 leptons	4	0		Multi-bin fit									14
2103.08189	SUSY-2018-40	Search for sbottoms with b-jets and hadronic taus													1
2102.01444	SUSY-2018-08	Search for DM and stops in tt2L + MET final states													13
2101.12527	SUSY-2018-34	Sbottom pair, WIMP DM pair + bb, 0 leptons, b-jets													11
2101.01629	SUSY-2018-10	Gluino pair, squark pair; 1 lepton													6
2012.03799	SUSY-2018-07	Stop pair, WIMP DM pair; 1 lepton													8
2011.10543	SUSY-2018-36	Search for chargino and neutralino pair RPV decays; 3L													48
2011.07812	SUSY-2018-14	Search for displaced leptons													
2010.14293	SUSY-2018-22	Gluino pair; squark pair; gluino-squark; 0-lepton													18
2010.01015	SUSY-2018-38	Search for new physics in final states with large b-jet multiplicity													2
2008.06032	SUSY-2018-17	Gluino pair, 0 lepton, large jet multiplicity	3	0		Multi-bin fit									8
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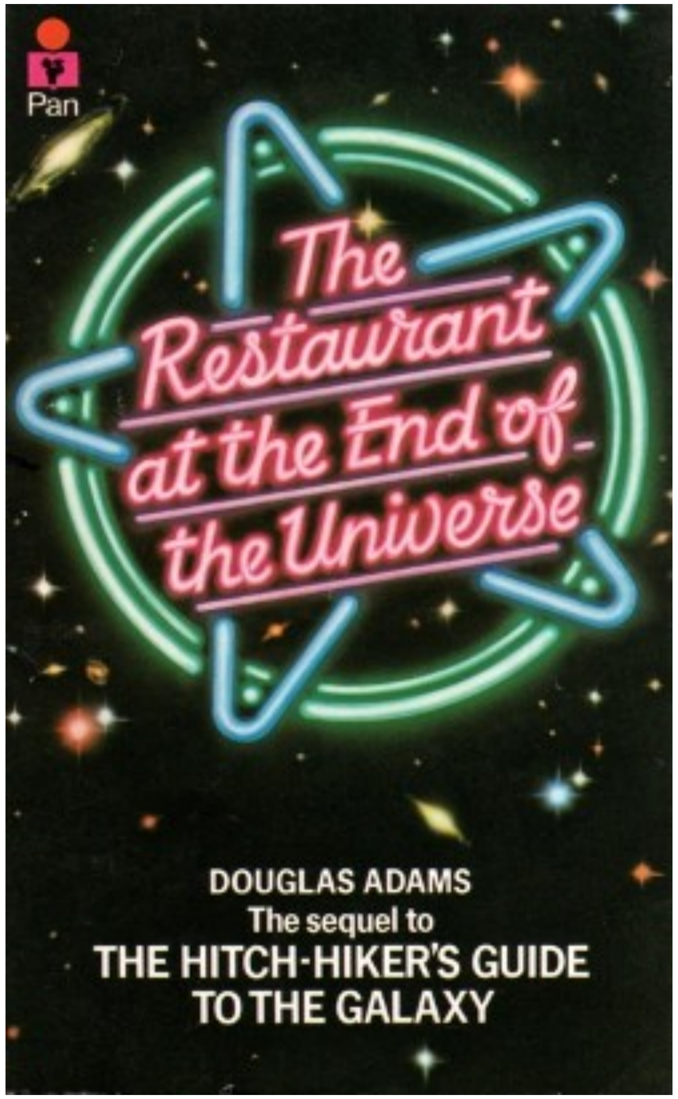
2004.1406	SUSY-2018-12	Stop pair; 0 lepton; leptoquarks	4	0		Multi-bin fit									16
2004.10894	SUSY-2018-23	Chargino-neutralino pair; Higgs boson in final state, 2 photons	2	0		Multi-bin fit									12
2102.10874	EXOT-2018-06	Monojet search	8	1		Multi-bin fit									13
2108.07586	EXOT-2018-09	multi-b-jet resonance	1	0		Bump hunt									0
2107.06092	EXOT-2018-57	Search for Higgs (+V) decaying to hidden sector bosons in displaced 4b final state	1	0		Cut and count									0
2107.00404	EXOT-2019-36	Multilepton General	0	2		Multi-bin fit									22
2105.13847	EXOT-2018-16	bsll contact interaction	1	0		Cut and count									4
2105.12491	EXOT-2020-28	Lepton Flavor Violating Z Decay with a Leptonic Tau	1	0		Multi-bin fit									0
2101.11582	EXOT-2019-15	Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	1	0		Multi-bin fit									0
2011.09308	EXOT-2018-43	Dark Matter Search in the MET + tW or tJ final state	4	0		Multi-bin fit									7
2011.05259	EXOT-2018-63	Photon + MET Search	2	0		Multi-bin fit									7
2010.06548	EXOT-2018-40	Mono-scalar to VV in hadronic channel	1	0		Multi-bin fit									0
2010.02566	EXOT-2018-36	Lepton Flavor Violating Z Decay with a Hadronic Tau	2	0		Multi-bin fit									0
2104.1324	HIGG-2019-02	Search for H(125) --> gamma gamma + Missing-ET	0	3		Multi-bin fit									0

Lots of discovery regions (but it depends a lot on the group!)

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!


Pan
The Restaurant at the End of the Universe
DOUGLAS ADAMS
The sequel to
THE HITCH-HIKER'S GUIDE TO THE GALAXY


ANYWAY, LONG STORY SHORT IS A PHRASE WHOSE ORIGINS ARE COMPLICATED AND RAMBLING.

Thanks!