LHC searches, limits, anomalies, discoveries

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PDG Advisory Committee Meeting

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Outline

- Covering “Miscellaneous searches” section
- Summary Tables, Reviews, Particle Listings
  - Monopoles
  - SUSY
  - Dynamic EWSB
  - Compositeness
  - Extra Dimensions

Is this still a good selection of benchmark BSM theories?

- Disclaimer: a very LHC-centric view, by far not complete
- What's ahead in view of LHC Run-2
  - Prepare in advance for “tough” decisions?

Monopoles

Review:
D. Milstead (Stockholm Univ.), E.J. Weinberg (Columbia Univ.)
Encoders:
D. Milstead (Stockholm Univ.)
Overseers:
D. Milstead (Stockholm Univ.)

- Review update on Aug. 2013
- A lot driven by non-accelerator experiment constraints
- However direct searches can also be important (lower masses)

Monopoles @ LHC

- Listing includes one 7 TeV LHC result

X-SECT (cm^2)	MASS (GeV)	CHG (g)	ENERGY (GeV)	BEAM		DOCUMENT ID		TECN
$<1.6E-38$	200–1200	1	7000	*pp*	1	AAD	12CS	ATLS

- Exploit highly ionizing nature of these hypothetical particles
- Very much threshold-effect → benefit from increased energy in Run-2
  - although hard to have good x-section predictions
- Moedal experiment at LHC(b) results may be expected as well

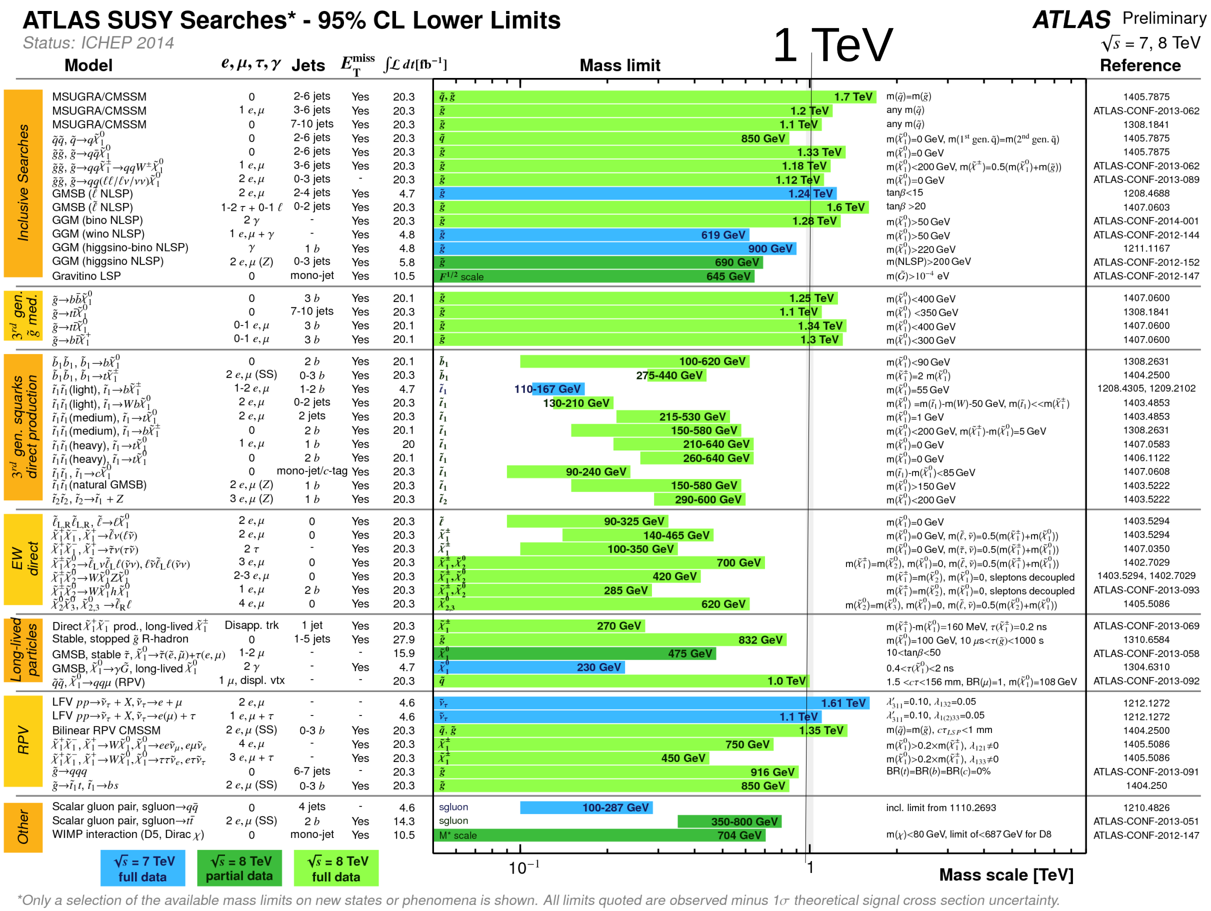
SUSY

Review:
H.E. Haber (UC Santa Cruz) [theory]
O. Buchmueller (Imperial College London),
P. de Jong (Nikhef) [experiment]
Encoders:
A.de Gouvea [theory], K. Olive [astro],
Filip Moortgat (ETH Zurich) [experiment]
Overseers:
H. K. Dreiner (Bonn Univ.)

- Reviews updated Sep/Oct 2013
- 123 papers, 194 measurements
  - 68 papers and 96 measurements in 2012 (roughly)

Susy @ LHC

- Still more papers from LHC Run-1 to come
- Run-2 to produce (at least) a similar amount of papers



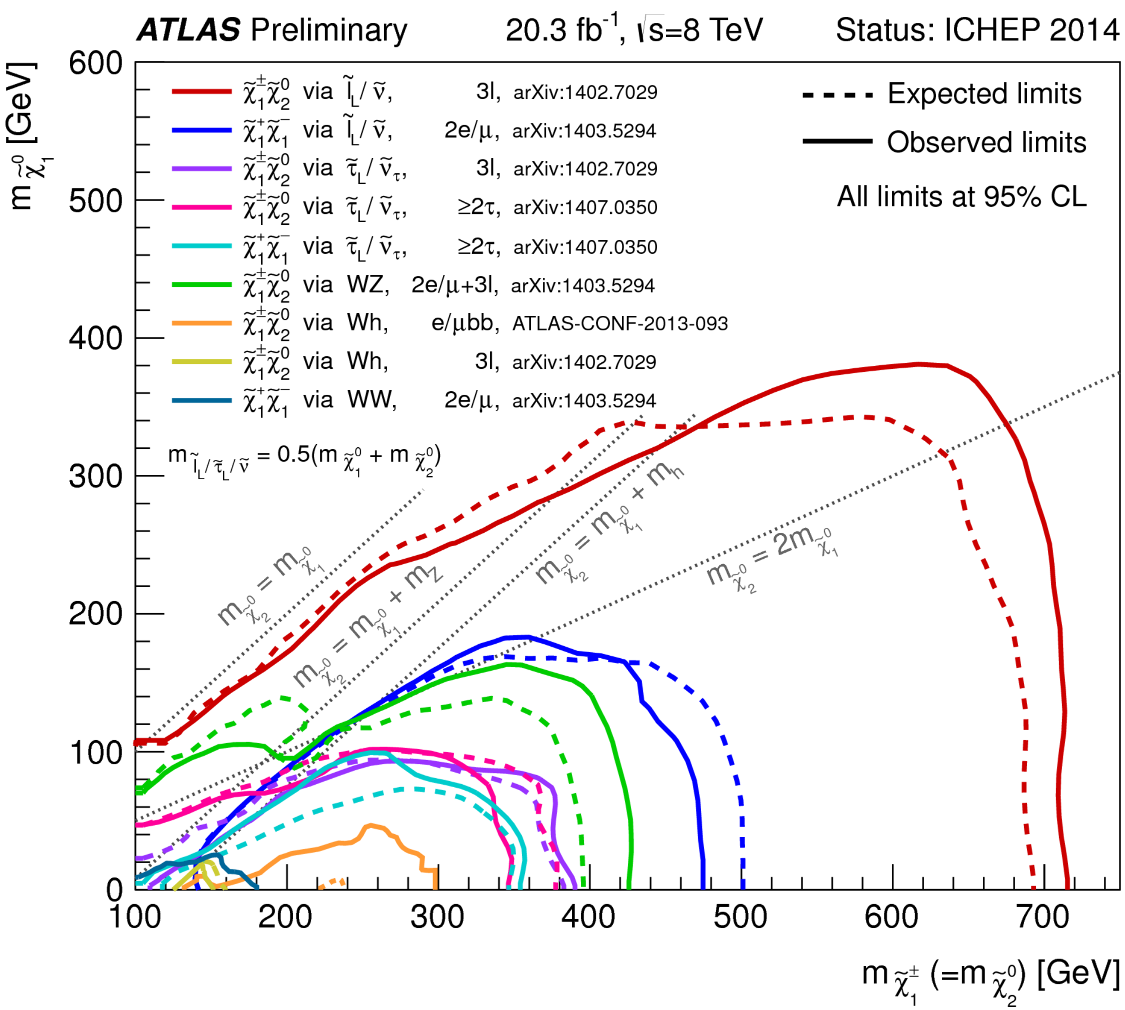
Mass reach of ATLAS searches for Supersymmetry. Only a representative selection of the available results is shown.

SUSY Listing

- G. Weiglein (overseer 2010):
  "The listings (in particular for SUSY) are so diverse that it is not easy to implement common standards for the comments: level of detail, notations, etc."

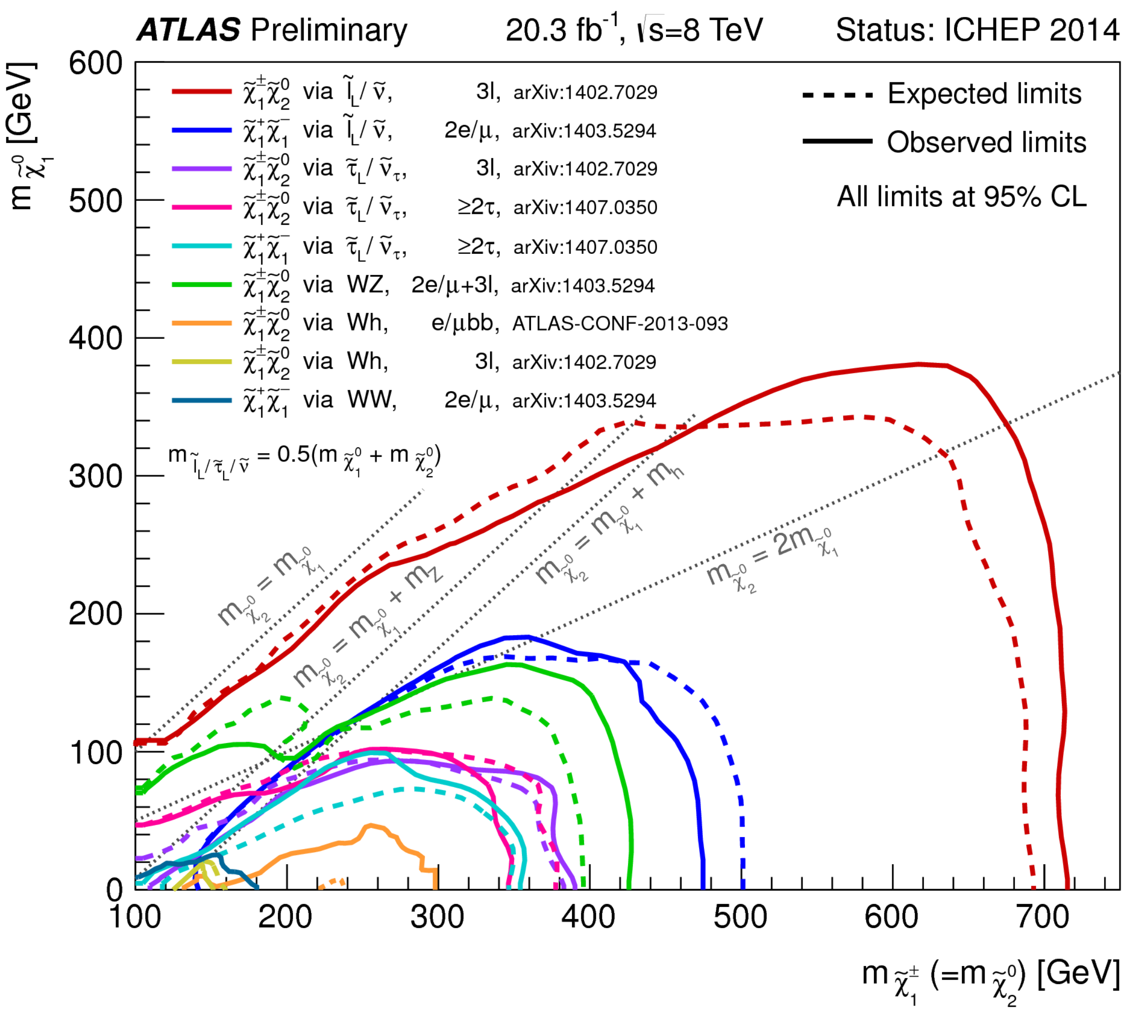
- Some of the encoding challenges:
  - "Digging into the **details of each relevant paper**, in general several times, at the encoding stage and when the verifiers send comments / suggestions,
  - "Trying to **spot mistakes at the encoding stage** and at the stage when Piotr compiles the listings. Since everything is done `by hand', mistakes can happen (and do happen) in every step,
  - "Trying to make the **content of the listing** and the comments appear in a **coherent** way in comparison to the listing of similar measurements in the past. For that it is often necessary to go back to older papers.
  - "**Trying to identify papers that should be moved below the line or removed** from the listing. The latter is rather straightforward for `main stream' Higgs and SUSY searches, but **for less standard topics** (2-Higgs doublet model, various SUSY searches) it is a nightmare to figure out precisely which of the old measurements are superseded by a new one. As a consequence, those sections blow up more and more, since new entries are added while only very rarely old ones are removed."

SUSY combinations



- Combination of results often highly non-trivial
  - different assumptions
  - very diverse final states which makes combination hard if the same model is not used by experiments

SUSY combinations



- E.g. caption:
  - Summary of ATLAS searches for electroweak production of charginos and neutralinos based on 20/fb of pp collision data at sqrt(s) = 8TeV. Exclusion limits at 95% confidence level are shown in the m(C1), m(N1) plane. The dashed and solid lines show the expected and observed limits, respectively, including all uncertainties except the theoretical signal cross section uncertainties. Four decay modes of the charginos and neutralinos are considered separately with 100% branching fraction:
  - C1 → slepton + neutrino / lepton + sneutrino → lepton + neutrino + N1, N2 → slepton + lepton / sneutrino + neutrino → 2 leptons + N1 / 2 neutrinos + N1, resulting in BF(3 leptons)=50% and BF(2 leptons)=100% for C1+N2 and C1+C1 productions, respectively. The decays via sleptons and sneutrinos occur with 50% probability each.
  - C1→ stau + neutrino/tau + sneutrino → tau + neutrino + N1, N2 → stau + tau/sneutrino + neutrino → 2 taus + N1 / 2 neutrinos + N1, resulting in BF(3 taus)=50% and BF(2 taus)=100% for C1+N2 and C1+C1 productions respectively. The decays via staus and tau sneutrinos occur with 50% probability each.
  - C1 → W+N1, N2 → Z+N1;
  - C1→ W+N1, N2→ h+N1, where the Higgs decays with Standard Model branching fractions.
  - In case of C1+N2 production, m(N2)=m(C1) is assumed and the masses of the sleptons, staus and sneutrinos are fixed at the mean of m(N1) and m(C1).
  - Status of figure: July 2014

SUSY Summary Tables

- Need to clearly state the relevant assumptions used in obtaining certain limits:
  - SUSY benchmark scenario (MSSM, CMSSM, NMSSM, . . .
  - Lightest neutralino (stable): gaugino mass unification at the GUT scale, . . .
- **Representative choices**
- Not always easy if relevant searches don't use the needed models

Dynamic EWSB

Review:
R.S. Chivukula (Michigan Univ.), N. Narain (Brown Univ.), J. Womersley (STFC)
Encoders:
M. Tanabashi (Nagoya Univ.), K. Olive [astro]
Overseers:
K. Agashe (Maryland Univ.)

- Very recently updated review (Oct 2013) on dynamical electroweak symmetry breaking and Higgs implications
  - Latest preliminary results also reviewed
- About 6 mass limits from LHC (12 from Tevatron) listed

Summary and Listing

- Summary Table: “The limits for technicolor (and top-color) particles are quite varied depending on assumptions. See the Technicolor section of the full review (the data listing)”
- Many combinations within each experiment
  - often hard to combine intra-experiment
- Overall non-excluded Technicolor models becoming more and more complex
- Most recent results covered in the Review

Dynamic EWSB Review

R Sekhar Chivukula
Meenakshi Narain
John Womersley

Theory summary

H as a composite particle, possibly a:

- σ-meson of technicolor
- a pseudo-dilaton in walking technicolor
- a pseudo-Goldstone Boson, e.g. in a “Little Higgs” model
- a top-Higgs bound via top-color interactions

Experimental summary of searches for particles in these theories:

- W’ and Z’ bosons
- technivector mesons
- vector partners of top and bottom
- +5/3 custodial top partner
- colorons, Z’, and colored scalars

Compositeness

Review:
K. Hagiwara (KEK), K. Hikasa (Tohoku Univ.),
M. Tanabashi (Nagoya Univ.) + 2 new experimentalists
Encoders:
M. Tanabashi (Nagoya Univ.), K. Olive [astro]
Overseers:
J. Terning (UC Davis)

- Review written in 2001
  - Four-fermions interactions and excited fermions
  - Very model-independent approach, no big developments
- Dominated by LEP and LHC searches
- Certainly expect another boost with Run-2 LHC data
  - Likely only “few” papers, quite clearly assigned

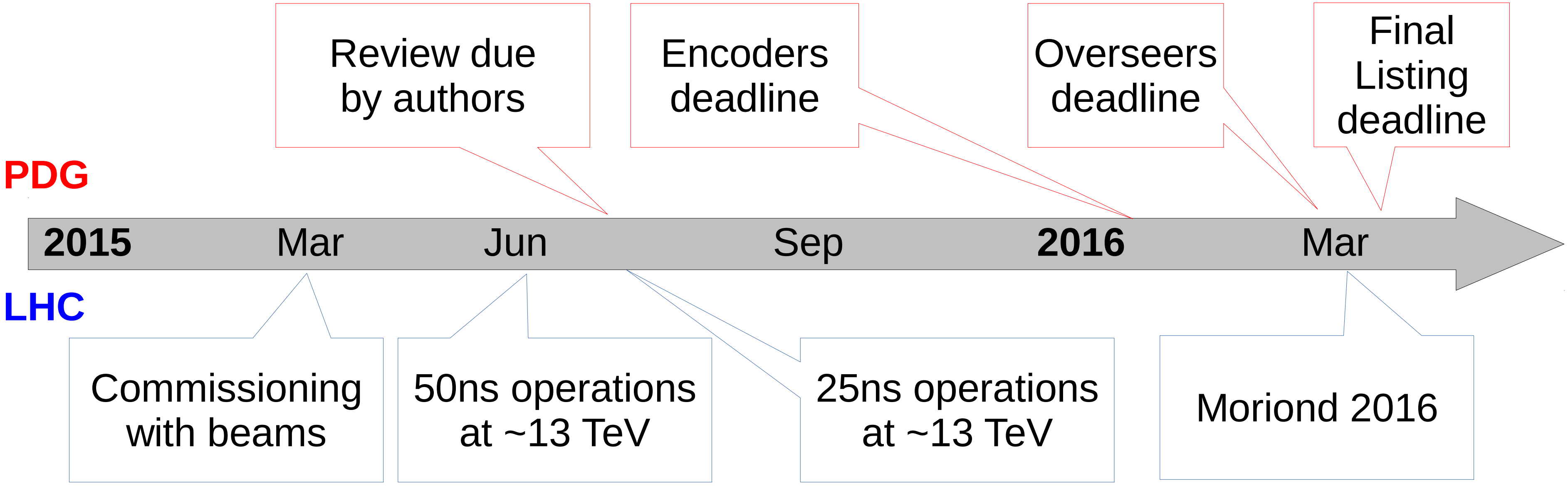
Extra Dimensions

Review:
J. Parsons (Columbia Univ.), A. Pomarol (Barcelona Univ.)
Encoders:
T. Gherghetta (Minnesota Univ.), K. Olive [astro]
Overseers:
D. Dwyer (LBL)

- Review recently updated (Oct 2013)
- Dominated by direct collider searches at LHC
  - Also deviation from gravitational force law (torsion pendulum)
- Expect large boost in reach with run-2 results, but likely just a few papers clearly on the topic
  - Constraints by searches on other final state possible but not easy to combine

What's ahead of us?

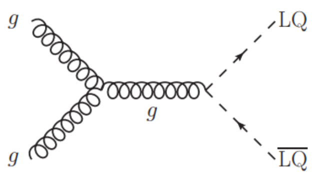
- LHC starting on Run-2 data-taking in 2015
  - Initial results (e.g. compositeness) by late summer?
  - A broad set of searches already by Moriond 2016
  - Most of measurements will take a bit longer



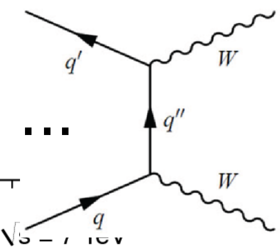
Very rough schedule based on Draft schedule v0.5, Oct 3rd 2014 – beam energy TBA

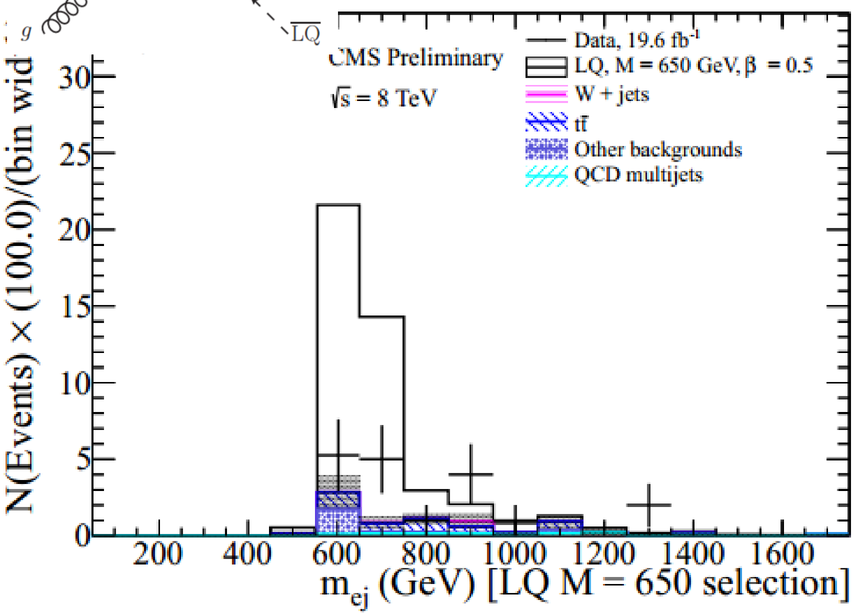
Discoveries? ...

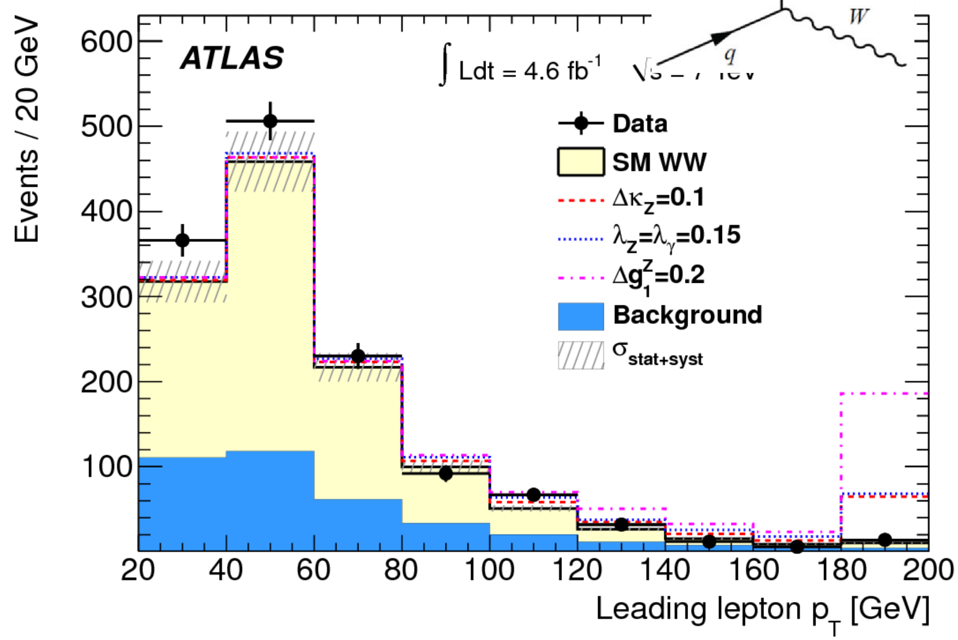
- Intriguing excesses from LHC data analyses are being largely discussed every week on arXiv pre-prints by phenomenologists as “training” for model-building
- Just two (unlikely) examples:



Many SUSY candidates, Extra-dimensions, ...







… or not?

- E.g. Meta-analysis of LHC SUSY searches shows everything within expected statistical fluctuations
  - yes, a **lot** of caveats in such exercises
  - however, often not as easy as analyzing measurements of well-defined particles

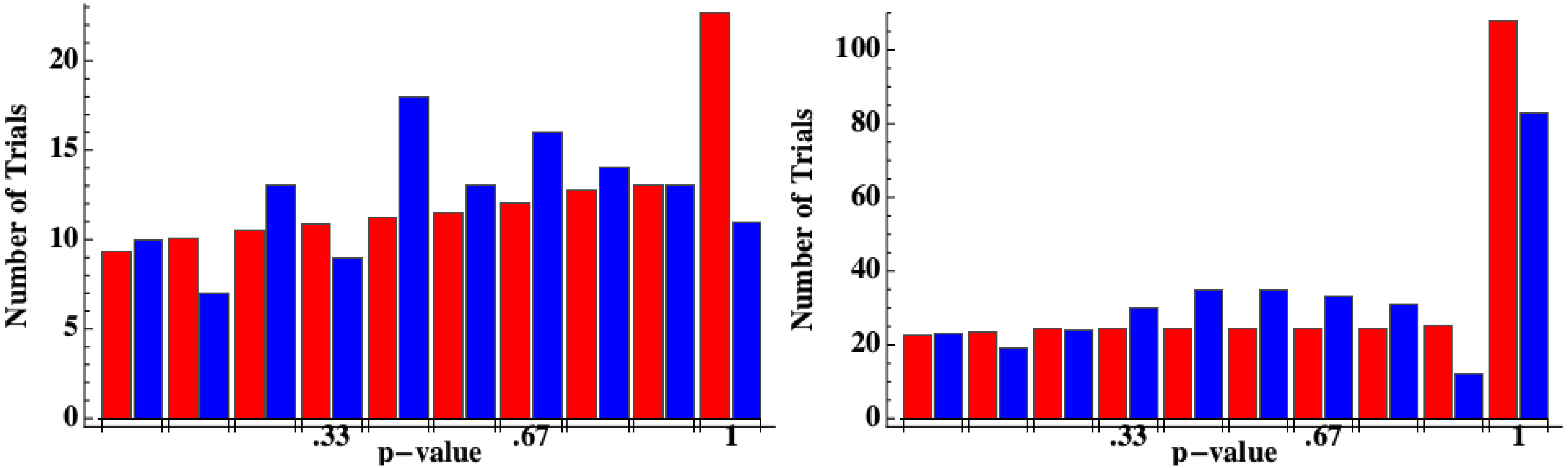


Figure 1. Observed (blue) vs. expected (red) distribution of p-value excesses with a Gaussian error distribution for ATLAS (left) and CMS (right). arXiv:1410.2270v2

Think positive...

- LHC run-2 data may offer us better limits on BSM physics, or lead us to the discovery of new particles
- Let's be optimistic and divide two cases:
  - Z' – like evidence (resonance) → easier to handle in the beginning for PDG, until more detailed studies are performed
  - **One <u>or more</u> significant excess in complex final states**
- Not possible to distinguish if single or multiple particles
- Even less likely to distinguish among many viable models, nor having one which is way more likely
  - i.e. different from the case of Higgs boson discovery
- How to treat those? Special new section(s) + impact on benchmark models?

Conclusions

- Attempt to summarize main results in constraining benchmark models
  - Careful reviews outlining the measurements and their impact / caveats
  - Summary and listing combining the most straightforward ones (complex cases can't always be easily handled)
- Most reviews quite up-to-date
  - Expecting a new large bunch of LHC results in 1-2 years
- Are chosen benchmark models still adequate?
- Are we ready in case of multiple discoveries are made?
  - what/how to update (reviews/models, new listing?)
  - Not easy to distinguish such large variety of possibilities, but a little bit of advanced thought may help?