Reinterpretation and tools

Sabine Kraml
(LPSC Grenoble)

Thanks to Rohini, Aditee and Kunal
for getting me to a doctor yesterday


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Motivation

- ATLAS and CMS are searching for new phenomena **beyond the SM (BSM)** in many different channels. Top priority for Run 2.

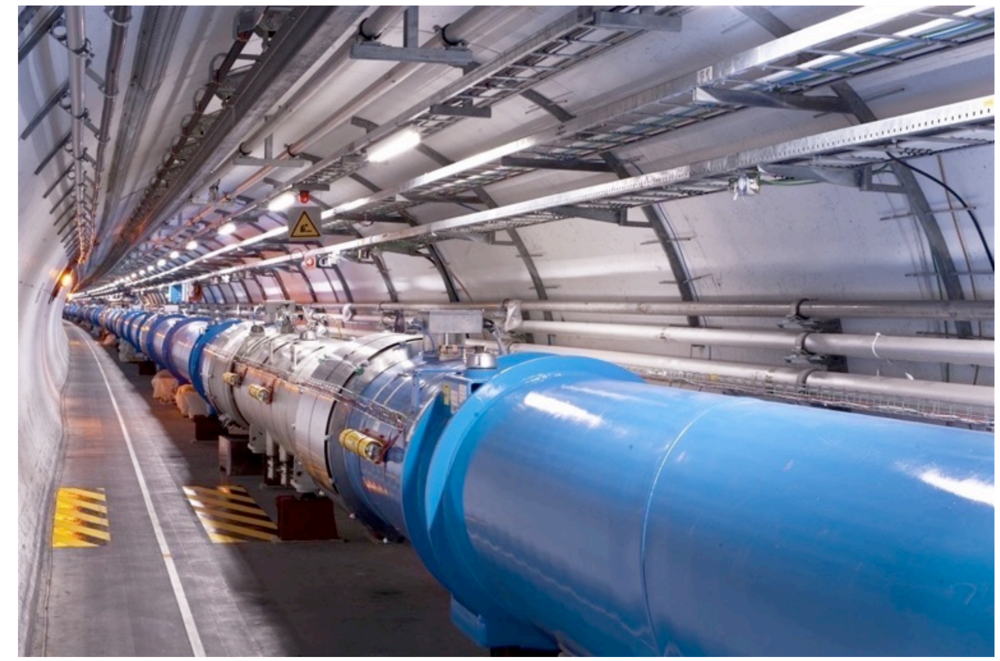
- Results are typically interpreted in the exp. publications in terms of simplified models, within popular ‘phenomenological’ models, EFT fits, …

- We need to be able to test any model or scenario against all LHC results :

  work out the theoretical implications (e.g. naturalness, DM models), give feedback to the experiments about loopholes in the searches, elucidate underlying theory in case of a discovery, etc. etc.

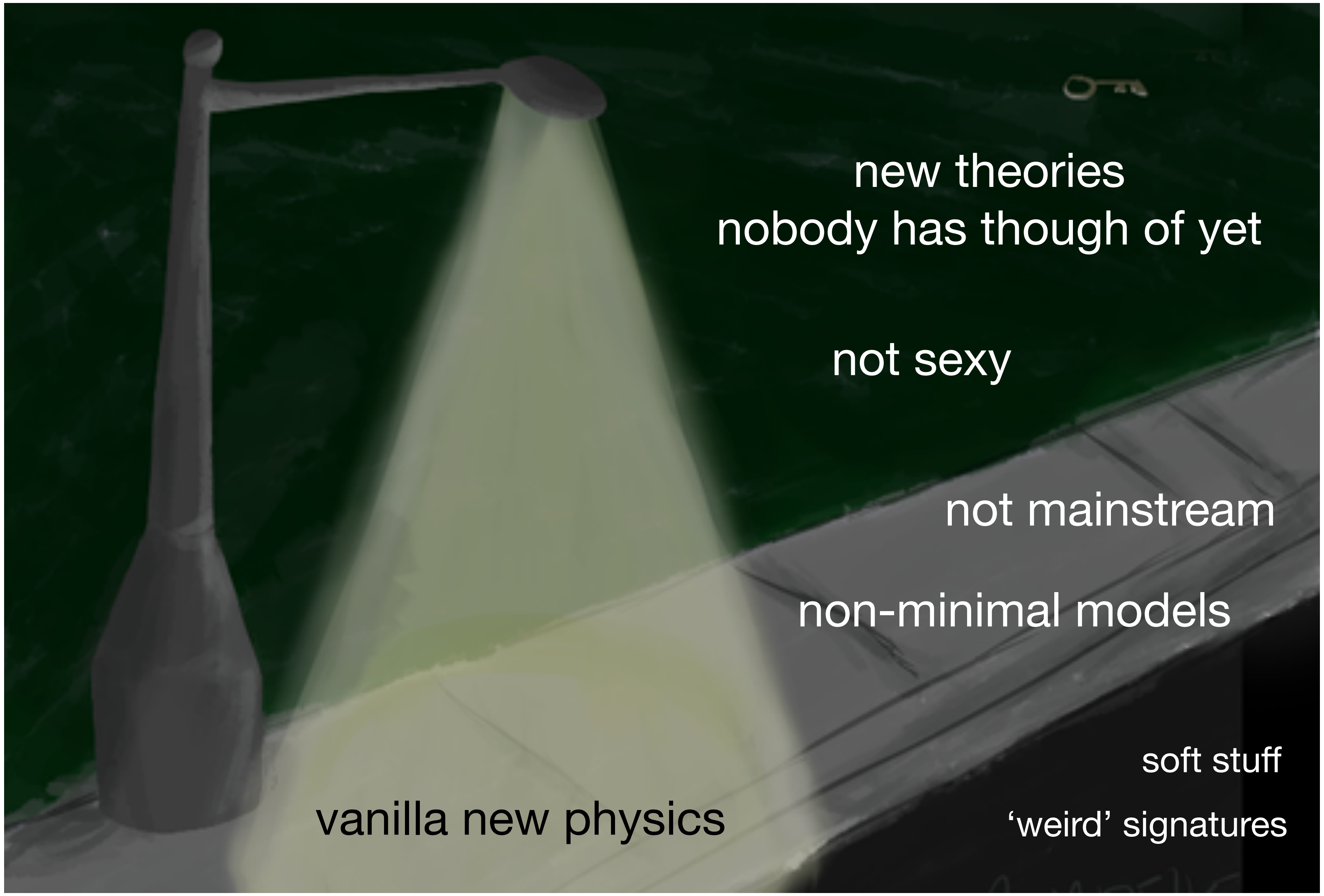
- Close experiment-theory interaction necessary to understand all the implications of the LHC results. (LHC legacy!)

- Public tools for re-interpretation



Why build tools for (re)interpretation?

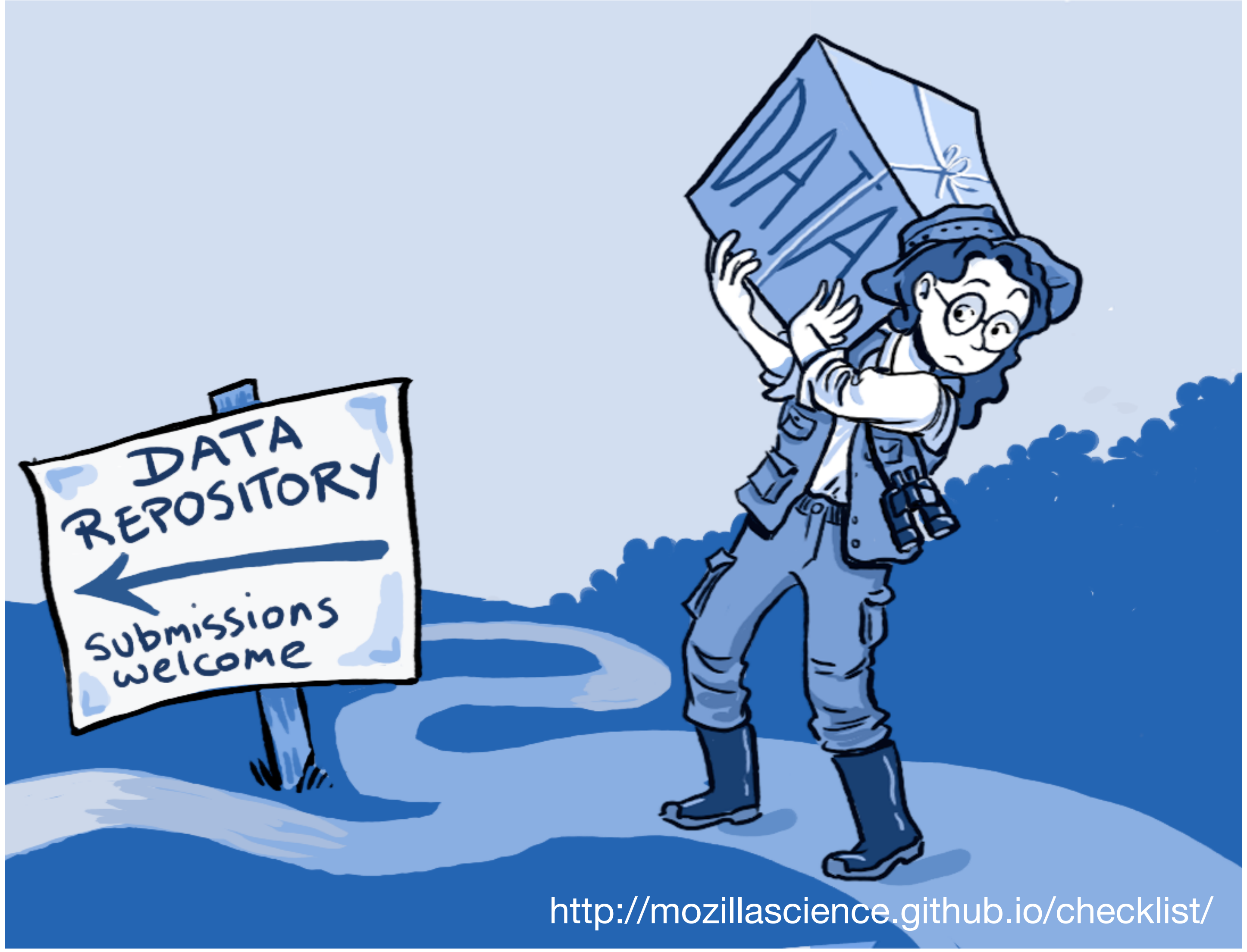
Avoid the streetlight effect



Want to test all possible BSM scenarios, incl. emerging new ones.

Why build tools for (re)interpretation?

Ensure long-term impact of important results, use in global analyses, etc.



GitHub: "This checklist is designed to help you understand what someone outside your research project (or you in 5-10 years) would need to know about your data in order to build on your work."

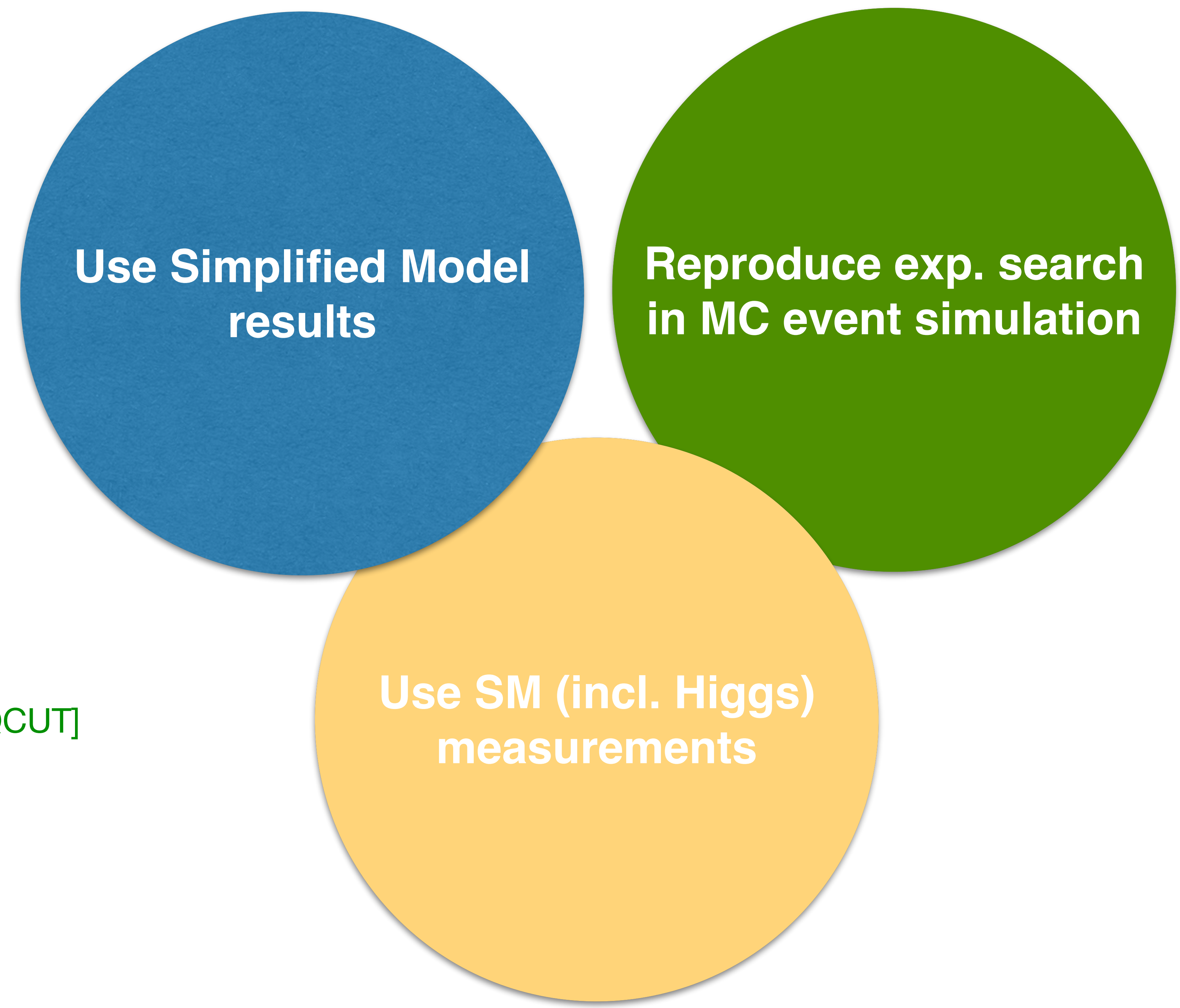
We want to know what all the LHC and other data tell us about the TeV scale and beyond

(Re)interpretation methods

Plus
- Fast, suitable for scans and model surveys
- Easy classification of uncovered signatures

Minus
- Only simple topologies
- Availability of re-usable results (useful format)
- Validity of SMS assumptions

[SModelS, Fastlim, XQCUT]



Plus
- More general, more precise
- Can test prospects of improving an analysis

Minus
- Need detailed information from experiment about each analysis
- Need emulation of detector effects
- Very CPU time consuming
- So far only cut&count analyses

[CheckMATE, MadAnalysis5, Rivet, Gambit]

Unfolded to particle level; important additional constraints
[Rivet, Contur]

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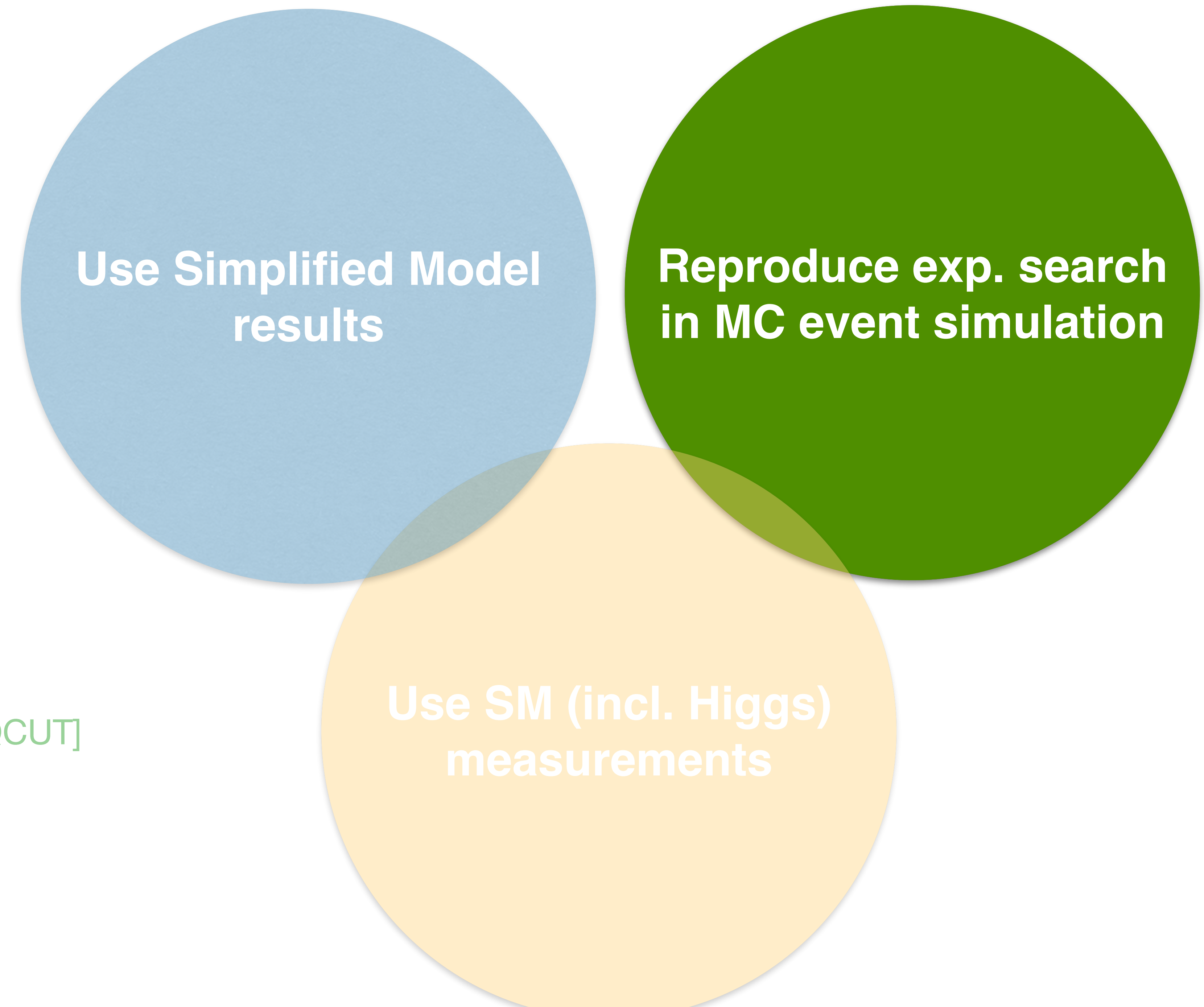

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Recasting based on event simulation

CheckMATE, MadAnalysis, Contur, Rivet, MadGraph, Pythia, Herwig, Delphes…

- Full chain: parton level events, showering, hadronization, emulation of detector effects, signal selection (analysis cuts), statistical interpretation
- **CheckMATE** and **MadAnalysis5** are building databases of ATLAS/CMS BSM (mostly SUSY) analyses (mostly implemented by theorists) plus simple built-in statistics tools;
- Needed from experimental collaboration
  - object definitions, efficiencies, analysis cuts … to properly code the analysis
  - validation material: benchmarks, cutflows, distributions … to check it's done correctly
  - observed and expected numbers of events in each signal region (bin) … to build a likelihood
- Alternative: **Rivet** routines provided by exp. collaboration
  - typically done for SM measurements; unfolded results
  - for searches, Rivet2.5 now foresees to use smearing and efficiencies to emulate detector effects
  - statistical evaluation not taken care of; needs to be done separately by the user (measured data usually available on HepData, but not always the SM expectations)

Difficulty with recasting

Non-collaboration members do not have access to the experimental data, nor the Monte Carlo (MC) event set simulated with an official collaboration detector simulation.

Therefore, the implementation and validation of ATLAS and CMS analyses for re-interpretation of the experimental results in general contexts is a tedious task, even more so as the information given in the experimental papers is often incomplete.

this has improved a lot for cut-based (SUSY) searches,
but MVA, BDT etc still cannot be reproduced outside the exp.collab.

Les Houches Recommendations

"The community should identify, develop and adopt a common platform to store analysis databases, collecting object definitions, cuts, and all other information, including well-encapsulated functions, necessary to reproduce or use the results of the analyses [...]"

"The tools needed to provide extended experimental information will require some dedicated efforts in terms of resources and manpower, to be supported by both the experimental and the theory communities."

Searches for New Physics: Les Houches Recommendations for the Presentation of LHC Results
S. Kraml (LPSC, Grenoble) *et al.*. Mar 2012. 17 pp.
Published in **Eur.Phys.J. C72 (2012) 1976**

[arXiv:1203.2489]

Public analysis database (PAD)

E. Conte, B. Fuks, G. Serret, arXiv:1206.1599; E. Conte, B. Fuks, arXiv:1309.7831
E. Conte, B. Dumont, B. Fuks, C. Wymant, arXiv:1405.3982

B. Dumont, et al, arXiv:1407.3278

Public analysis database (PAD)

- MA5: Public framework for analyzing Monte Carlo events

E. Conte, B. Fuks, G. Serret, arXiv:1206.1599; E. Conte, B. Fuks, arXiv:1309.7831
E. Conte, B. Dumont, B. Fuks, C. Wymant, arXiv:1405.3982

- Validated analysis codes, easy to check and to use for everybody.

B. Dumont, et al, arXiv:1407.3278

- Can serve for the interpretation of the LHC results in a large variety of models.
- Convenient way of documentation; helps long-term preservation of the analyses performed by ATLAS and CMS.
- Modular approach, easy to extend, everybody who implements and validates an existing ATLAS or CMS analysis can publish it within this framework.
- Provides feedback to the experiments about documentation and use of their results.
(The ease with which an experimental analysis can be implemented and validated may actually serve as a useful check for the experimental collaborations for the quality of their documentation.)

Analysis implementation and validation

for MadAnalysis 5 PAD
arXiv:1407.3278

easy

1. Read and understand the experimental paper
2. Write the C++ analyzer code for MadAnalysis 5
3. The difficult part: validation. Often need to get missing information from the experimental collaboration. Needed, but not always publicly available, are:

-essential-

- efficiencies for trigger, electron, muons, b-tagging, event cleaning, … treatment of ISR, jet energy scale } p_T dependence
- exact configuration of MC tools (versions, run card settings)
- benchmark points: SLHA or LHE files
- cut flows for the benchmark points
- expected final number of events in each signal region

4. Digitize the histograms from the experimental paper
   (stupid work; direct numerical form would be highly welcome → HepData, Twiki !)
5. Produce your own cut flows and histograms and compare, iterate until reasonable agreement is achieved

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MadAnalysis 5 Public Analysis Database (PAD) for recasting LHC results

CMS analyses, 8 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Version
CMS-SUS-13-011 (published)	stop search in the single lepton mode	B. Dumont, B. Fuks, C. Wymant	Inspire [1]	PDF (source)	MA5tune
CMS-SUS-13-012 (published)	gluino/squark search in jet multiplicity and missing energy	S. Bein, D. Sengupta	Inspire	PDF (source)	MA5tune
CMS-SUS-13-016 (PAS)	search for gluinos using OS dileptons and b-jets	D. Sengupta, S. Kulkarni	Inspire	PDF (source)	MA5tune
CMS-SUS-14-001 (published)	Third-generation squarks in fully hadronic final states (monojet analysis)	S. Sharma, S. Pandey	Inspire	PDF	MA5tune
CMS-SUS-14-001 (published)	Third-generation squarks in fully hadronic final states (top-tag analysis)	S. Bein, P. Atmasiddha, S. Sharma	Inspire	PDF	MA5tune
CMS-B2G-12-012 (published)	T5/3 top partners in same-sign dilepton channel	D. Barducci, C. Delaunay	Inspire	PDF (source), cards	v1.2/Delphes3
CMS-B2G-12-022 (published)	Monotops	J. Guo, E. Conte, B. Fuks	To appear	To appear	v1.2/Delphes3
CMS-B2G-14-004 (published)	Dark matter with top quark pairs (single lepton)	B. Fuks and A. Martini	Inspire	PDF MadGraph cards	v1.2/Delphes3
CMS-EXO-12-047 (published)	Monophoton	J. Guo, E. Conte, B. Fuks	Inspire	PDF Pythia script	v1.2/Delphes3
CMS-EXO-12-048 (published)	Monojet	J. Guo, E. Conte, B. Fuks	Inspire	PDF MadGraph cards	v1.2/Delphes3

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http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase

Information | **Citations (0)** | **Files**

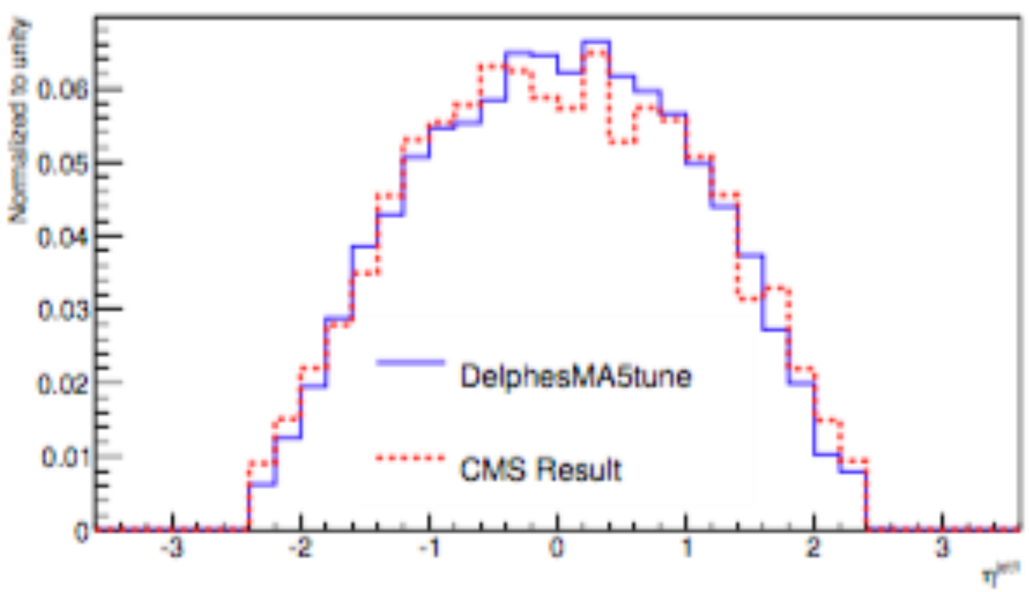
MadAnalysis 5 implementation of CMS-SUS-14-001 (monojet analysis)

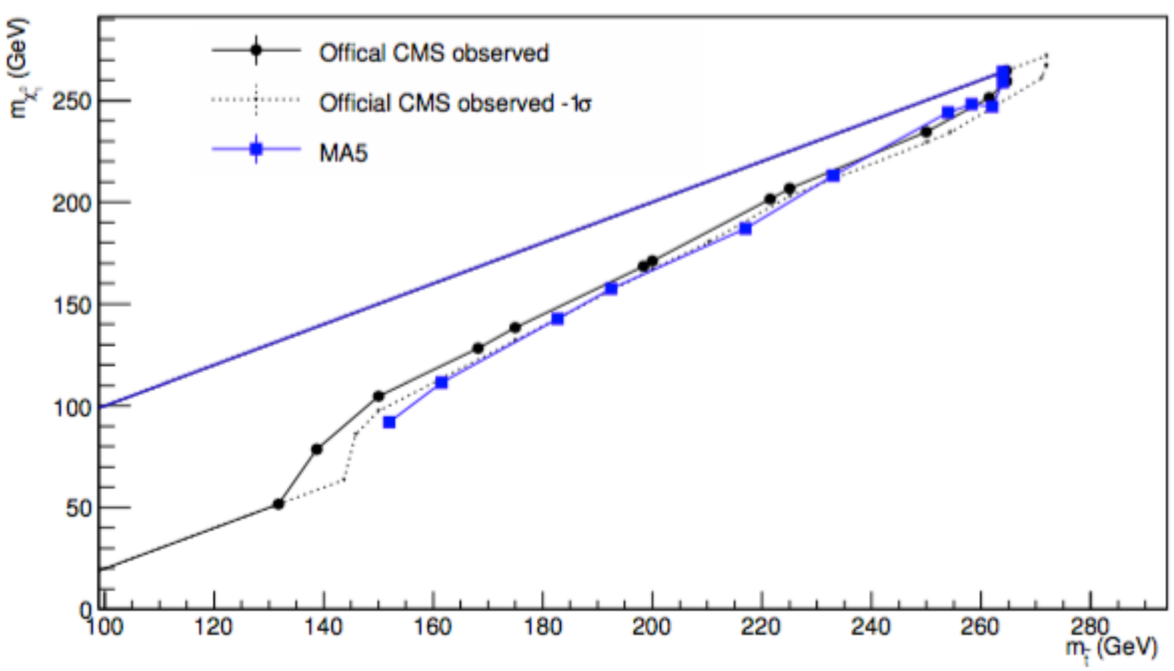
Sharma, Seema; Pandey, Shubham

Description: This is MadAnalysis 5 implementation of the CMS search for production of third-generation squarks (stops or sbottoms) in scenarios of compressed mass specra, that is small mass difference between stop or sbottom and the lightest SUSY particle. The analysis is based on a final state consisting of a high pT jet and large missing transverse momentum, and uses proton proton collision data corresponding to an integrated luminosity of 19.7/fb collected at a centre of mass energy of 8 TeV.

Cite as: Sharma, S., Pandey, S. (2015). MadAnalysis 5 implementation of CMS-SUS-14-001 (monojet analysis). doi: 10.7484/INSPIREHEP.DATA.QGBP.K237

Record added 2015-10-30, last modified 2016-10-19





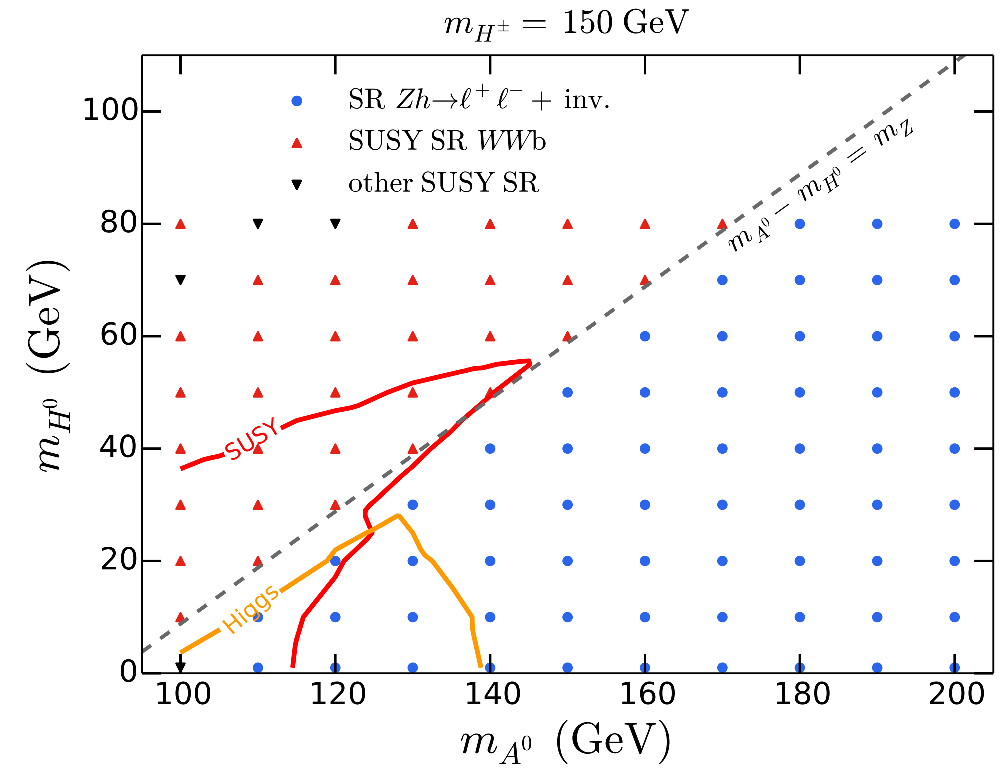
much more in the validation note

Reinterpretation — some examples

Dilepton constraints on the Inert Doublet Model

Belanger et al, 1503.07367

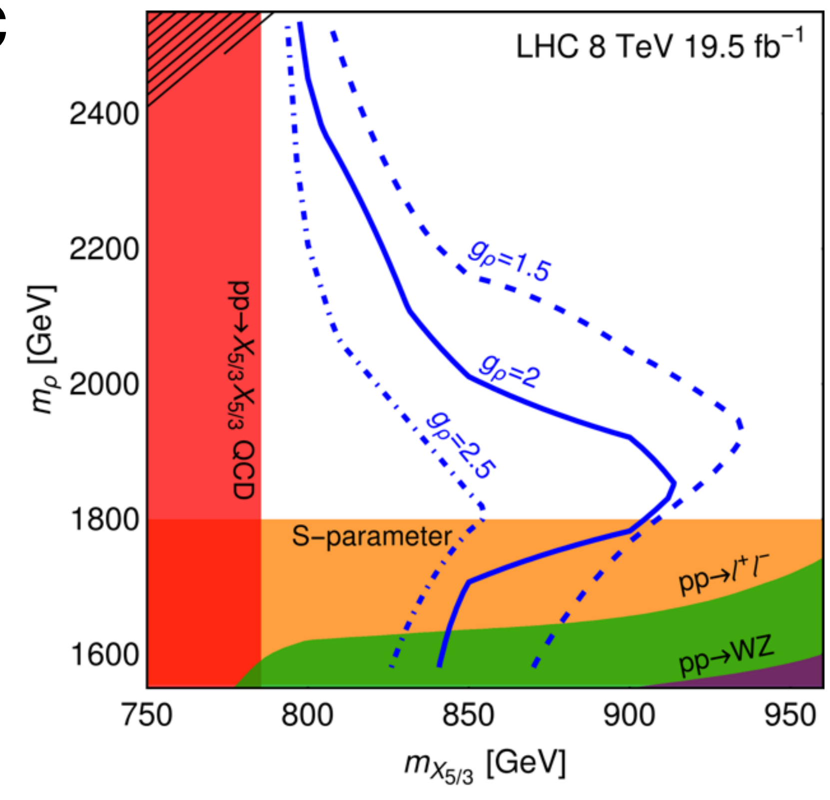
- Most important channel: pp -> AH, A -> $Z^{(*)}$H
- here, H ist the inert scalar, i.e. DM candidate.
- Recasted 2 ATLAS analyses from Run 1: dilepton SUSY search & the ZH, H>inv analysis
- LHC just starts to probe Higgs funnel region at mH~60 GeV, which is most interesting for DM.



Bounding wide composite vector resonances at the LHC

Barducci, Delaunay, 1511.01101

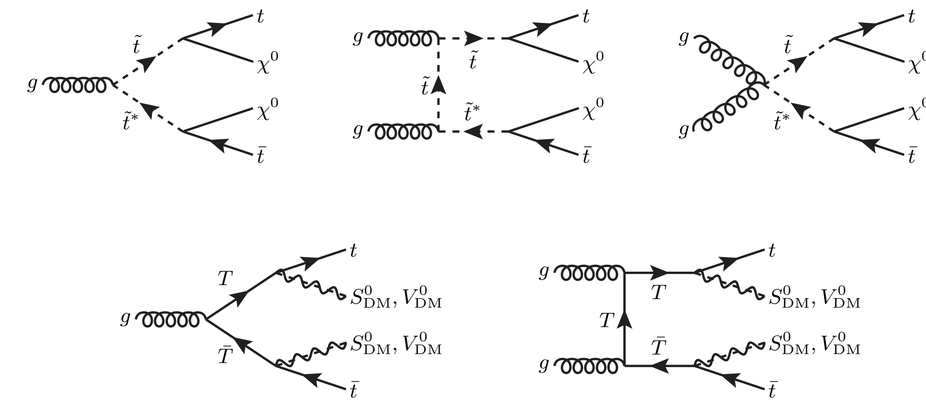
- Minimal composite Higgs model with colourless composite vector resonance, rho, and vector-like top partners, $X_{5/3}$.
- If m(rho) > 2 m($X_{5/3}$), resonance becomes very wide, usual EW spin-1 resonance searches don't apply.
- CMS same-sign dilepton search, originally designed for QCD pair-production of $X_{5/3}$, can be used to constrain pp -> rho -> $X_{5/3}$ $X_{5/3}$; $X_{5/3}$ -> tW^+
  ….. significant extension of reach in parameter space



Scalar versus fermionic top-partner interpretation of ttbar + MET searches

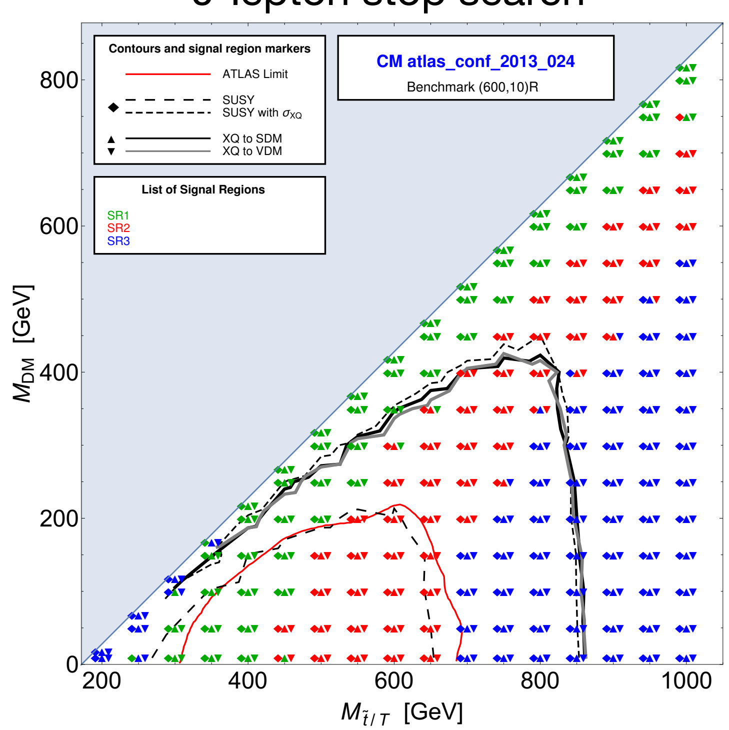
SK, Laa, Panizzi, Prager, 1607.02050

- Used ATLAS and CMS SUSY searches in ttbar+MET final state at Run 1 to constrain scenarios with a fermionic top partner and a dark matter candidate.
- Efficiencies in all-hadronic, 1-lepton and 2-lepton channels are very similar for scalar and fermionic top partners.
- SMS results for stop–neutralino simplified models can also be applied to fermionic top-partner models, provided the narrow width approximation holds in the latter.
- Official eff. maps don’t extend to high enough masses, so we provide our own: http://lpsc.in2p3.fr/projects-th/recasting/susy-vs-vlq/ttbarMET/

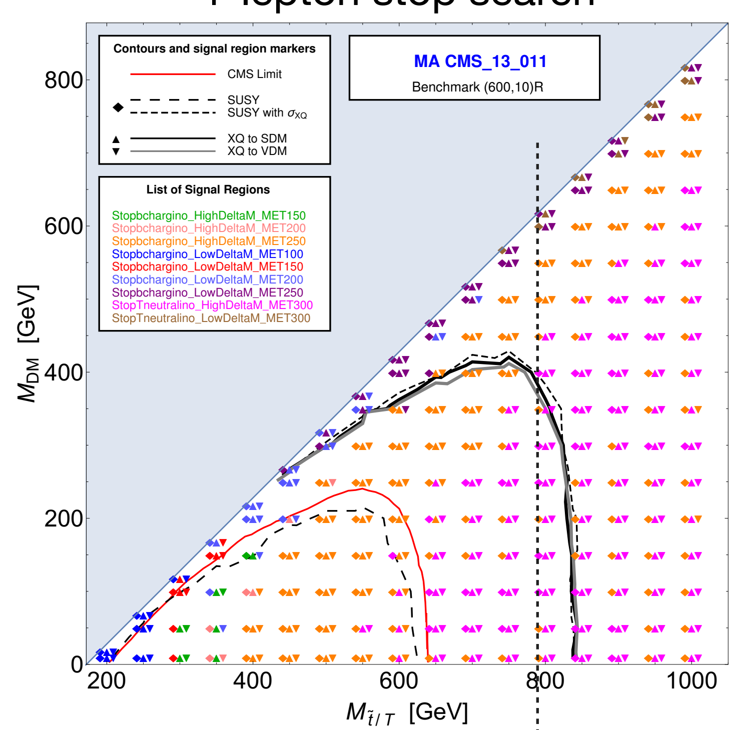


Generic gluino/squark search can also provide a limit on fermionic top partners, due to higher M_{eff} than for stops.

0-lepton stop search

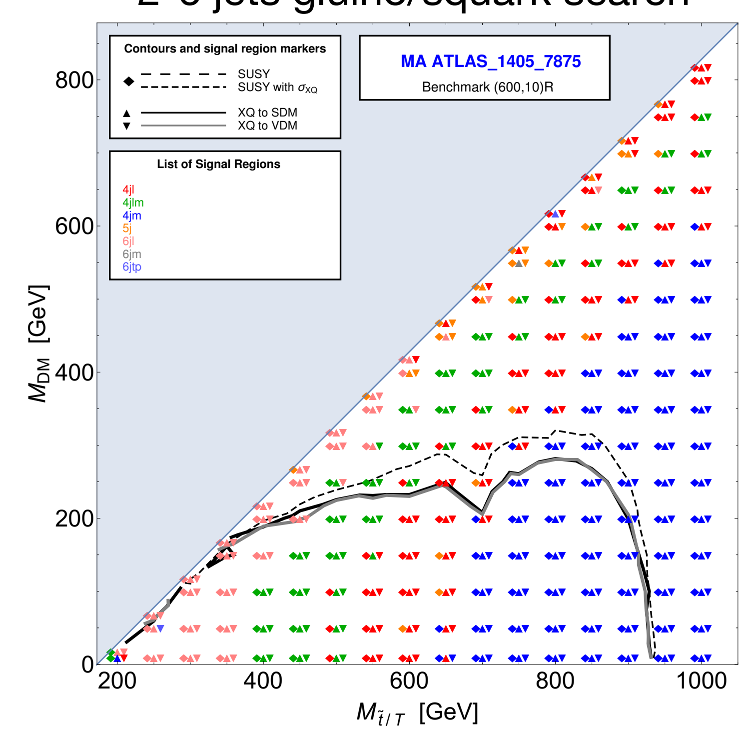


1-lepton stop search



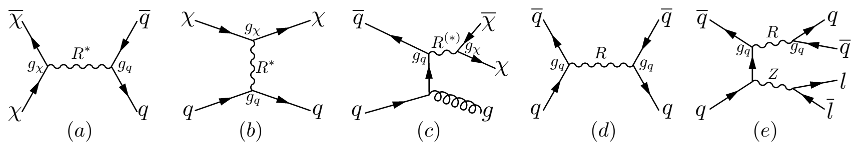
official plots stop here

2-6 jets gluino/squark search

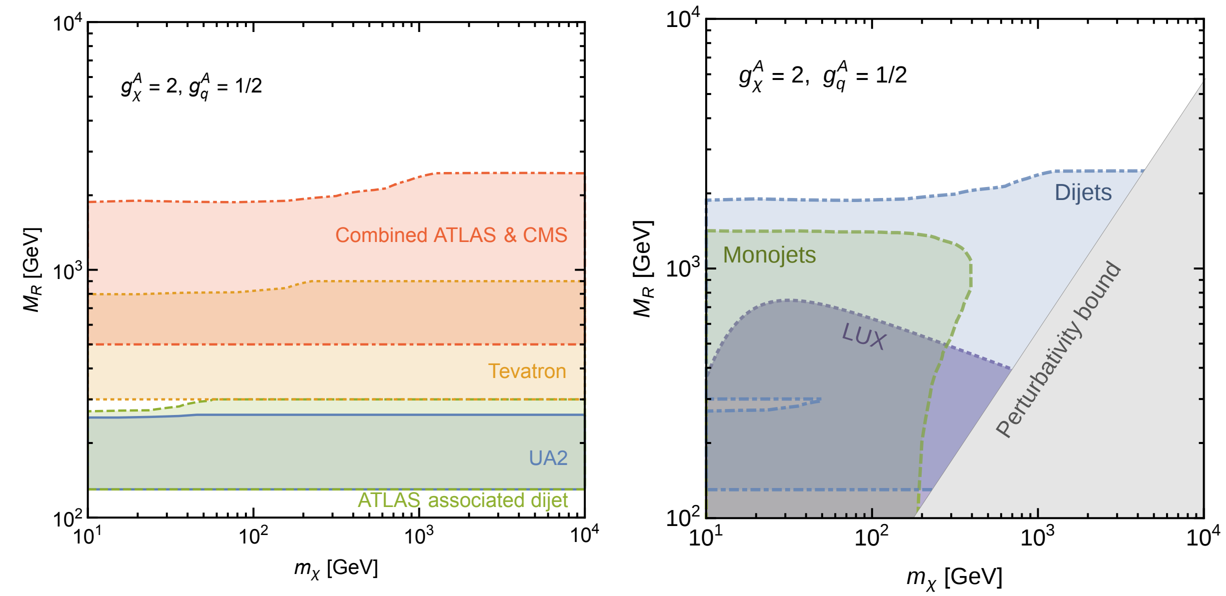


Constraining Dark Sectors with Monojets and Dijets

Chala et al., arXiv:1503.05916



- Consider dark sector particles (DSPs) that obtain sizeable interactions with SM fermions from a new mediator.
- Very rigorous study of searches for DSP production and searches for the mediator itself, in particular bounds on (broad) dijet resonances.
- Important implications for the interpretation of LHC dark matter searches in terms of simplified models.



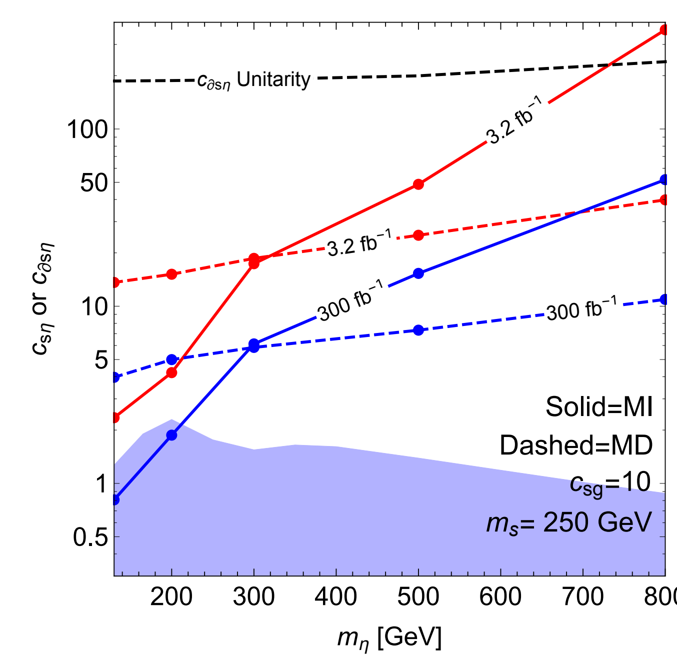
Monojet searches for momentum-dependent dark matter interactions

Barducci et al., 1609.07490

- SM plus a real scalar DM field *η* with derivative pNGB interactions suppressed by powers of the scale f, plus a second singlet scalar mediator field *s.*

$$\mathcal{L}_{\eta,s} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu\eta\partial^\mu\eta - \frac{1}{2}m_\eta^2\eta\eta + \frac{1}{2}\partial_\mu s\partial^\mu s - \frac{1}{2}m_s^2 ss + \frac{c_{s\eta}f}{2}s\eta\eta + \frac{c_{\partial s\eta}}{f}(\partial_\mu s)(\partial^\mu\eta)\eta + \frac{\alpha_s}{16\pi}\frac{c_{sg}}{f}sG^a_{\mu\nu}G^{a\mu\nu}$$

- Recasted ATLAS mono-jet search at 13 TeV (3.2 /fb)

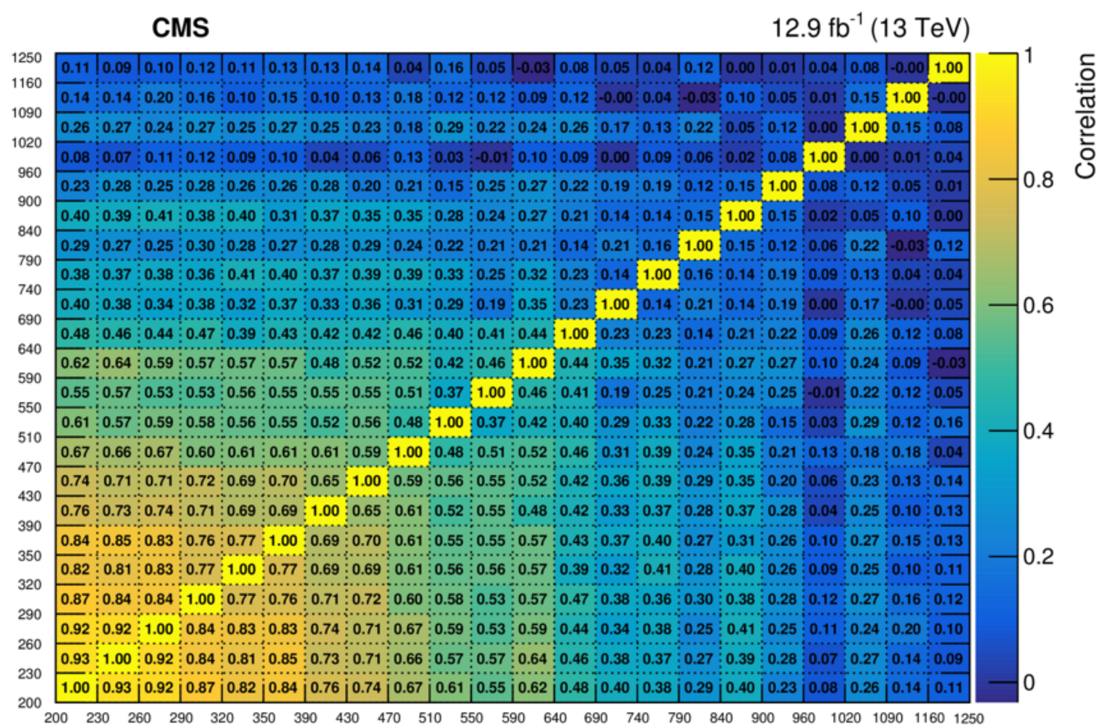


Further developments

Going further: **covariance matrices** for simplified likelihoods now provided by CMS

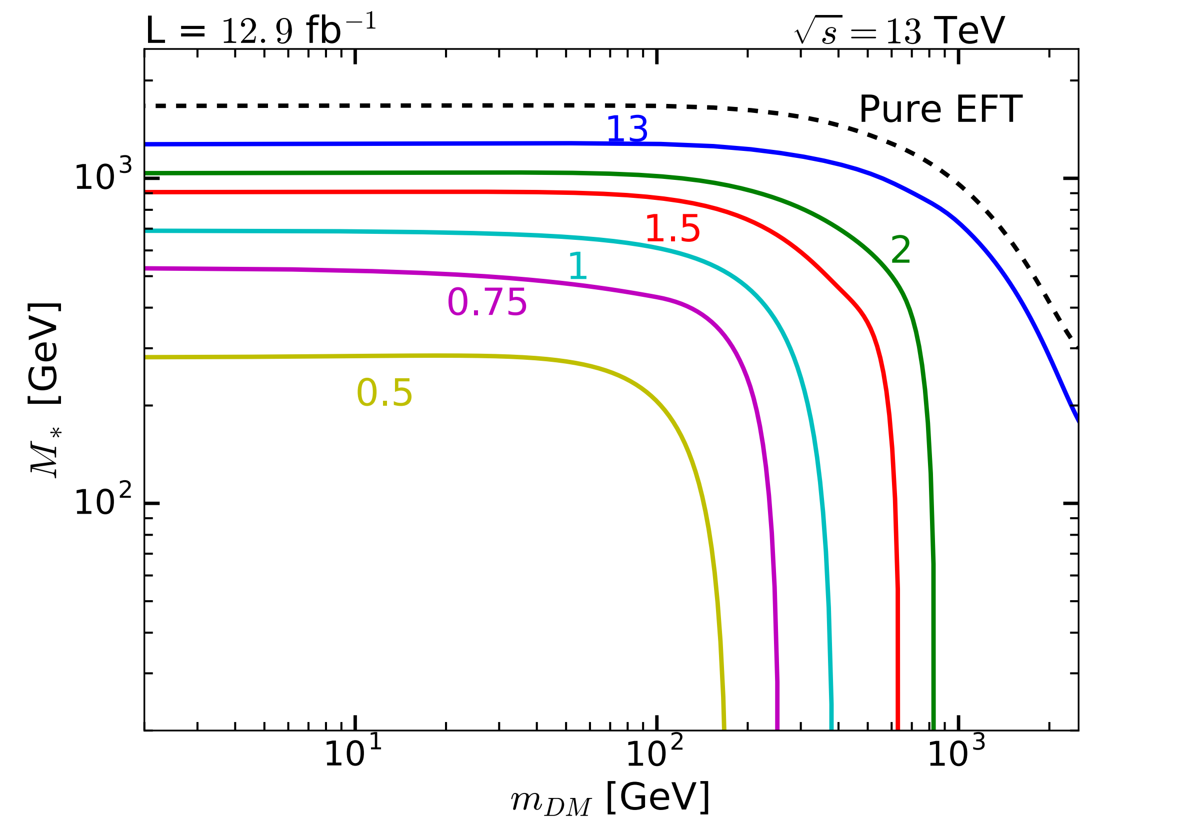
Simplified likelihoods: CMS NOTE-2017-001.

CMS-EXO-16-037, arXiv:1703.01651



Correlations between the uncertainties in the estimated background yields in all the MET bins of the monojet signal region

Pobbe, Wulzer, Zanetti, arXiv:1704.00736



$$\mathcal{L}_{\rm int} = -\frac{1}{M_*^2}(\overline{X}\gamma^\mu\gamma^5 X)(\sum_q \bar{q}\gamma_\mu\gamma^5 q)\,,$$

$$\sigma_{\rm EFT}(M_*, m_{\rm DM}, M_{\rm cut}) = \left[\frac{1\,{\rm TeV}}{M_*}\right]^4 \cdot \overline{\sigma}(m_{\rm DM}) \cdot \epsilon(m_{\rm DM}, M_{\rm cut})$$

Open questions

- Generally, need recast codes for Run2 analyses
- Specifically, recasting of analyses that use machine-learning (ML) techniques.

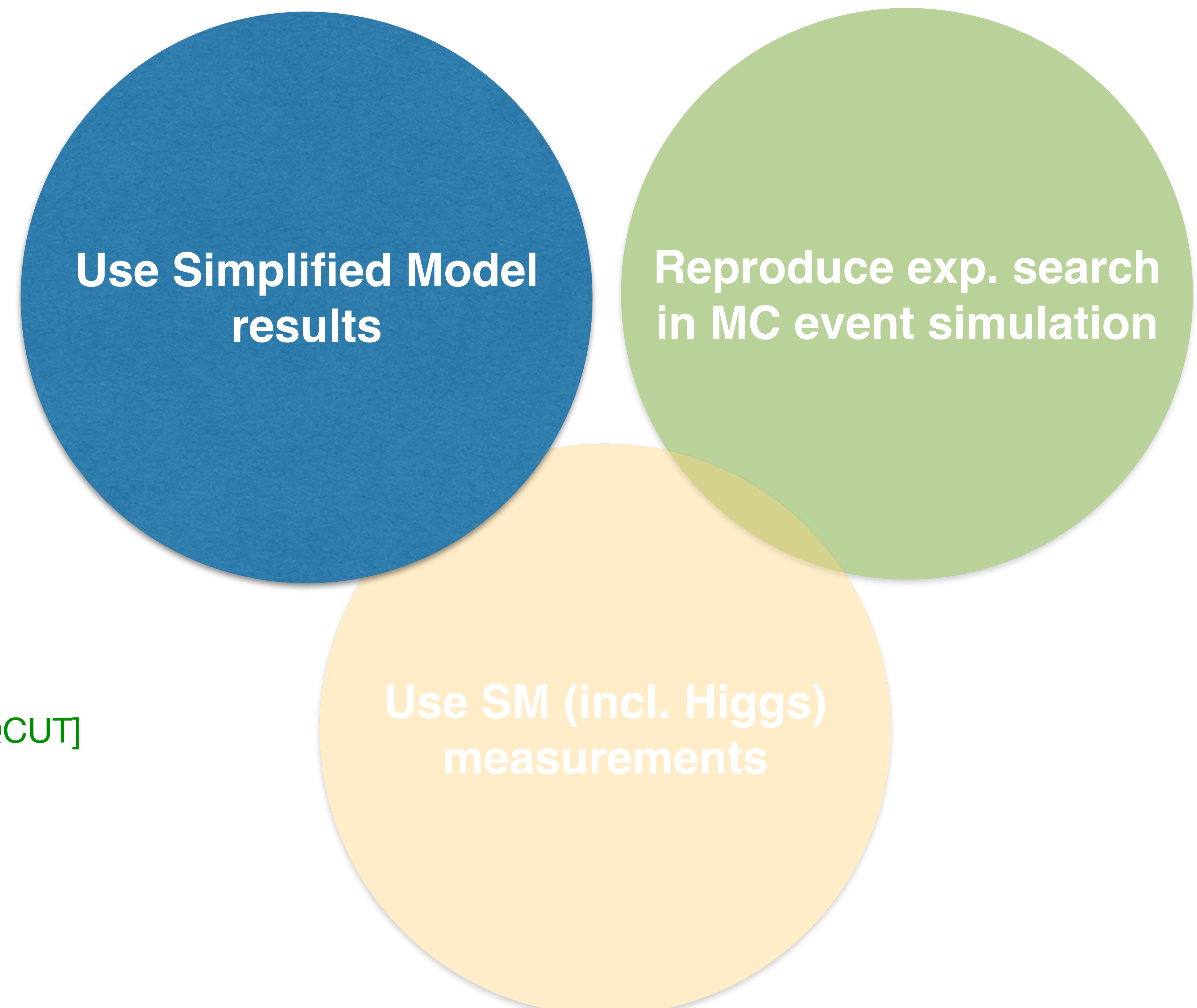
  On principal grounds, as long as the ML uses only physical quantities described by 4-vectors, the final selection can be cast in a form usable in a Monte Carlo simulation. Need a show-case example.

- Recasting of searches for long-lived particles (LLP)

  Some experimental publications on LLP give lots of details, incl. efficiencies, for recasting. So far only private codes. Delphes cannot handle long-lived particles yet (in progress).

- Sensitivity of prompt searches to long-lived particles

(Re)interpretation methods



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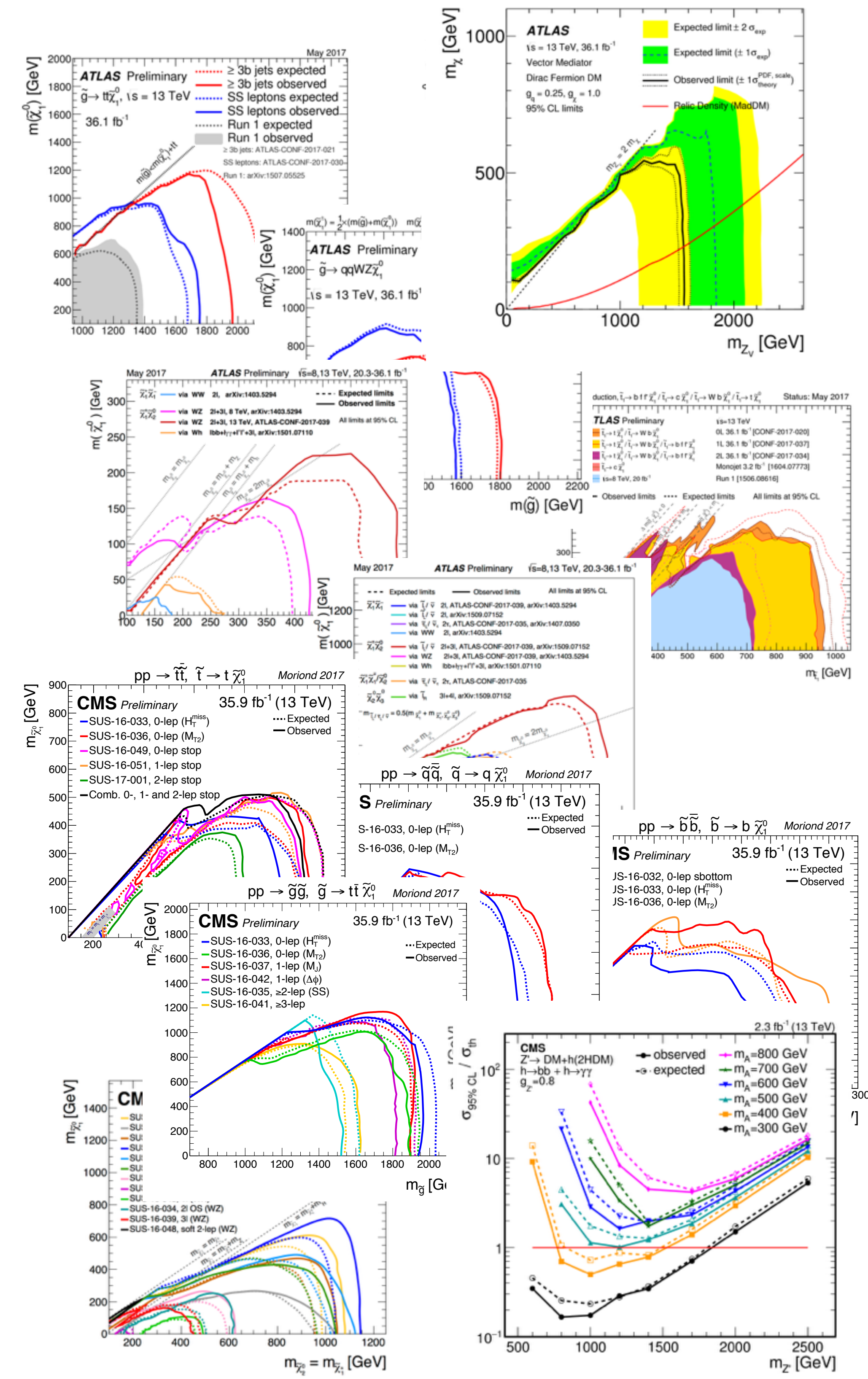
[CheckMATE, MadAnalysis5, Rivet, Gambit]

Unfolded to particle level; important additional constraints

[Rivet, Contur]

Simplified Model results

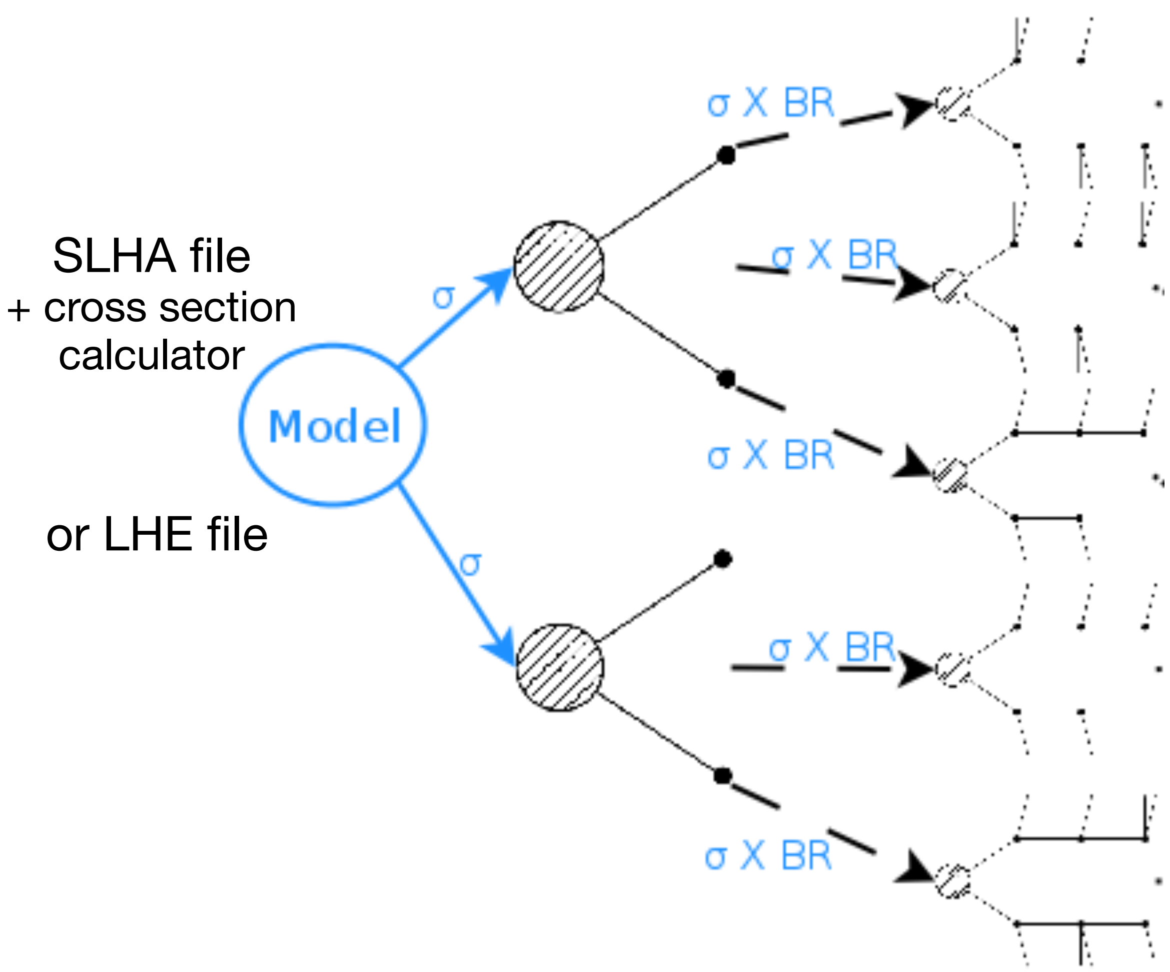
- It has become standard that ATLAS and CMS present the results of their BSM searches in terms of “simplified model” constraints.
- Simplified models (SMS) reduce full models with a plethora of particles and parameters to subsets with just 2-3 new states and a simple decay pattern (often 100% BR for one decay)
- Concept used by SUSY, Exotics, DM searches
- Very convenient for optimising analyses that look for a particular final state, as well as for comparing the reach of different strategies.
- Understanding how SMS results constrain a realistic model with a multitude of parameters, relevant production channels and decay modes is, however, a non-trivial task.

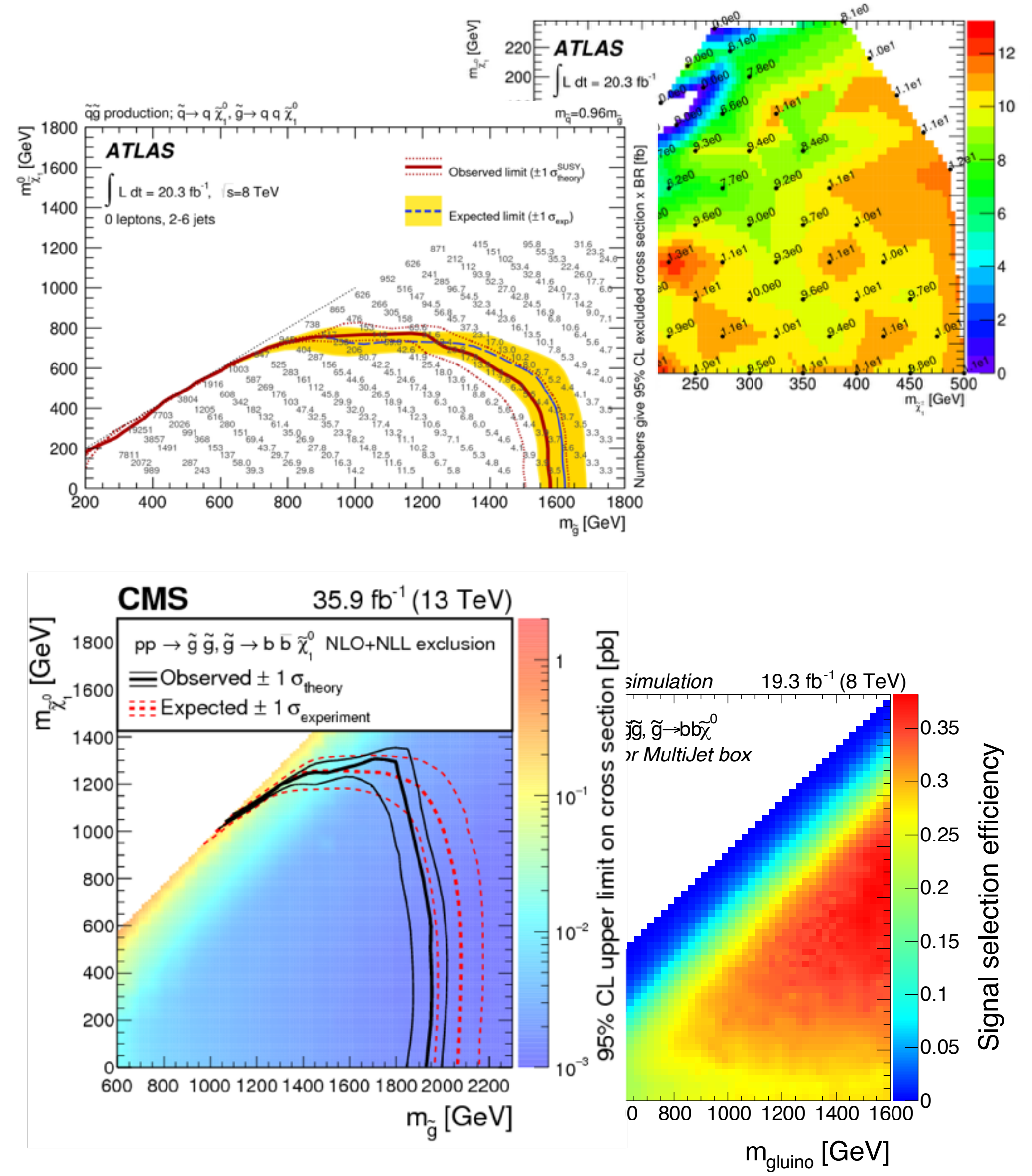


SModelS

arXiv:1312.4175 (v1.0)
arXiv:1701.06586 (v1.1)

Federico Ambrogi, SK, Suchita Kulkarni, Ursula Laa, Andre Lessa, Veronika Magerl, Jory Sonneveld, Michael Traub, **Wolfgang Waltenberger**





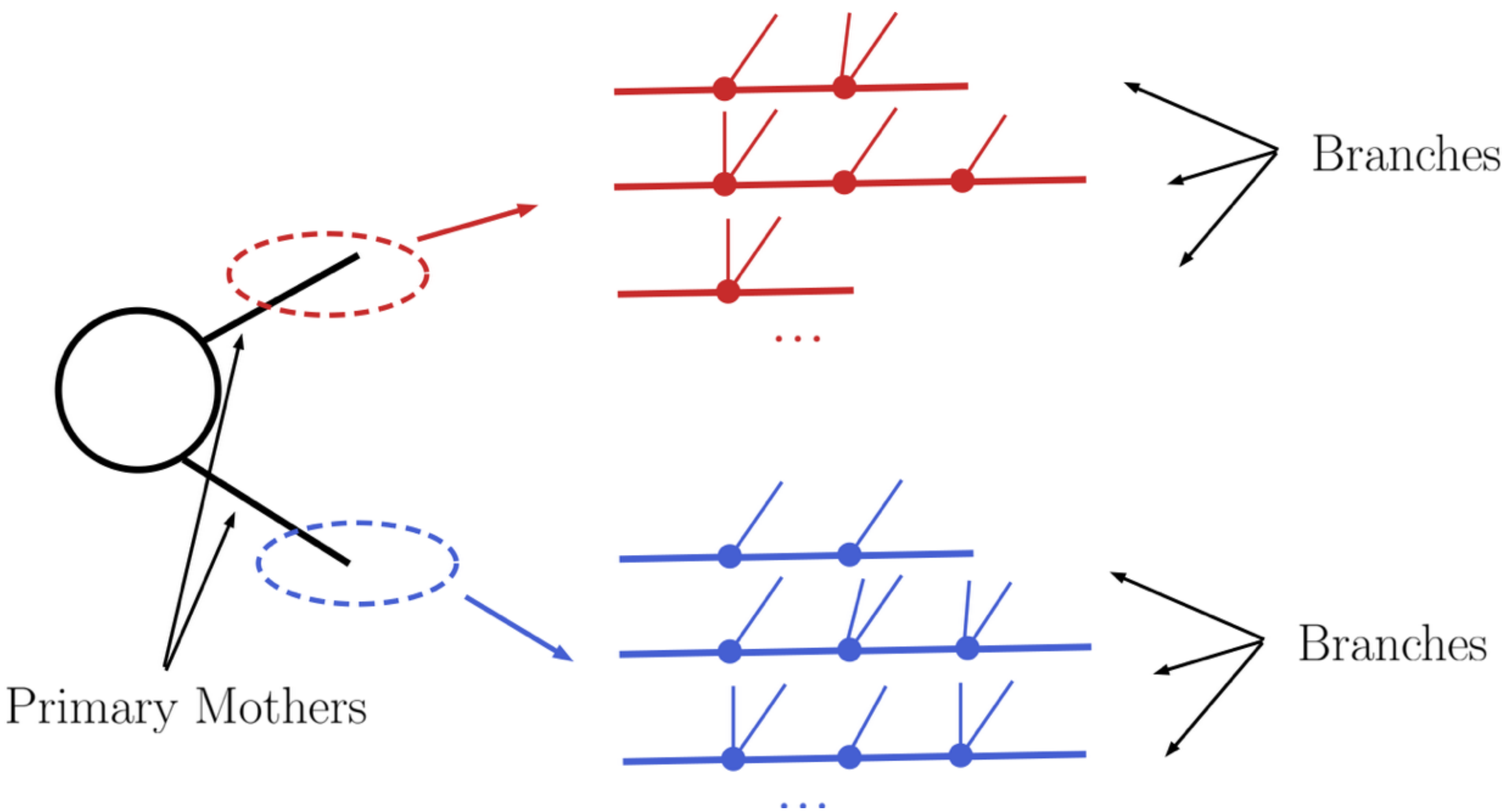
Decompose signatures of full model into SMS elements

Compare with experimental constraints in SModelS database

http://smodels.hephy.at

Decomposition procedure

SModelS takes an SLHA spectrum (with decay table and cross section information) or particle level MC events as input and determines from this all relevant **SMS topologies** ("elements") and their weights (**σ×BR**).



Working assumption: **Z_2 symmetry**; i.e. new particles are produced in pairs (2-branch structure) and cascade-decay promptly to the lightest one, which is stable and leads to missing energy.

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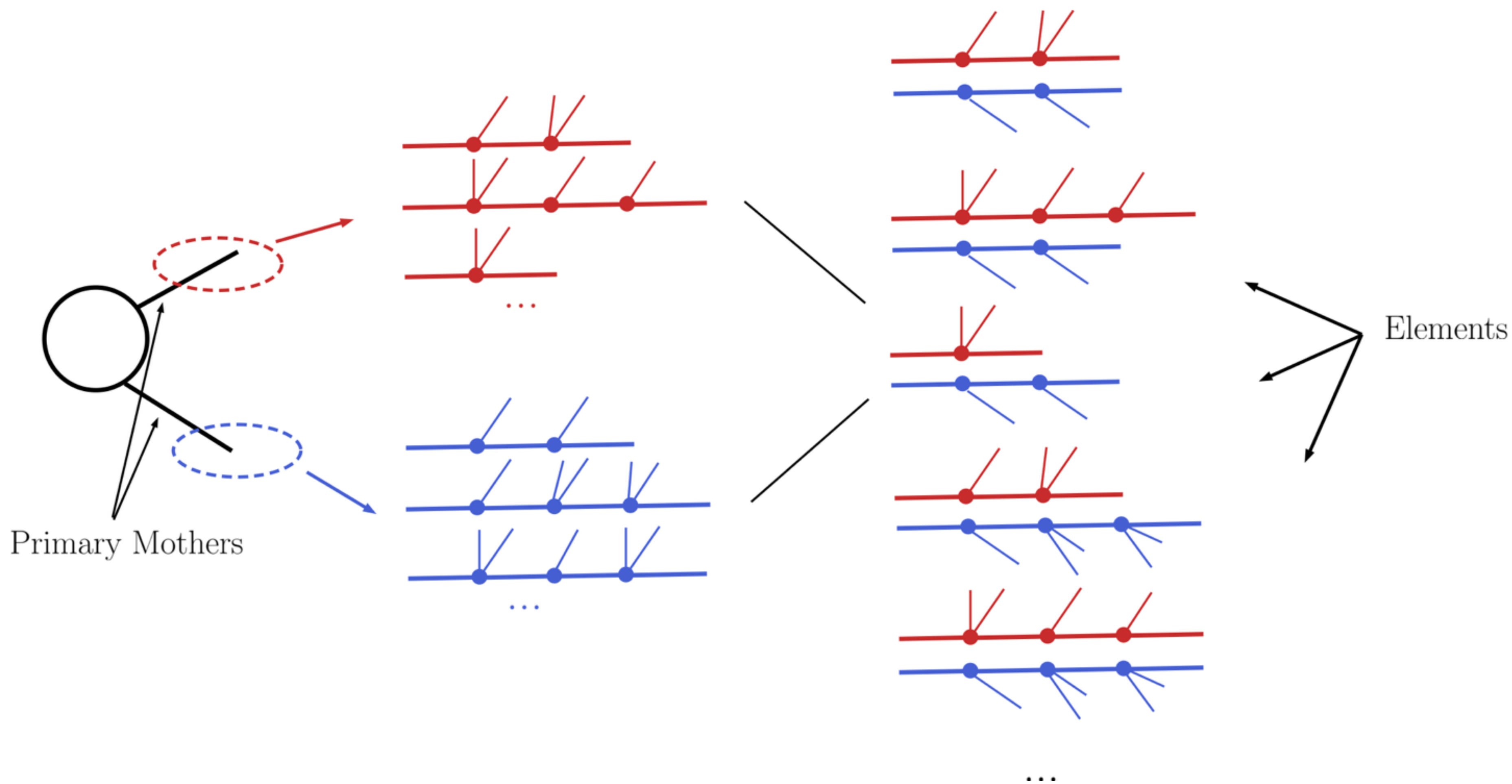

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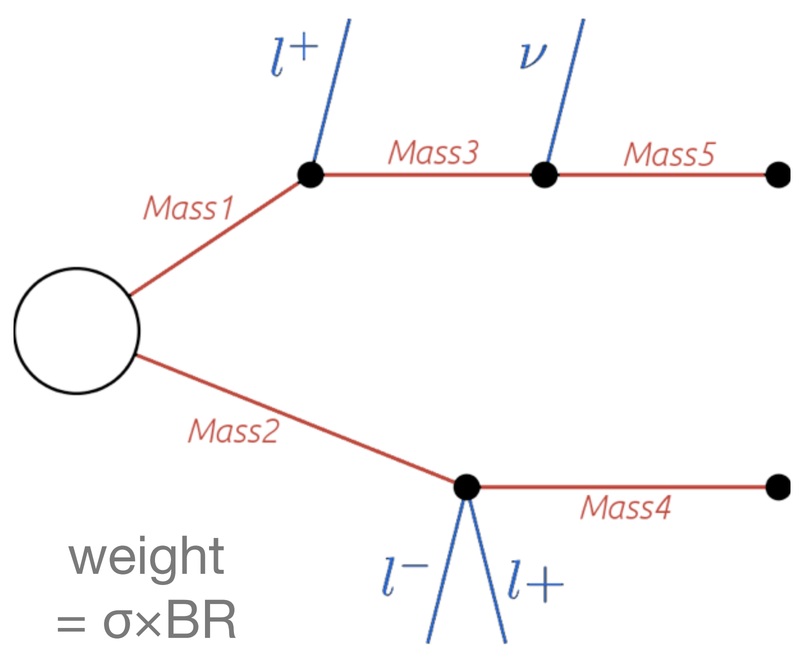
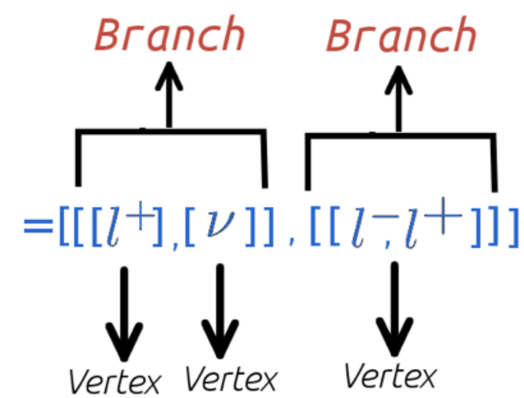
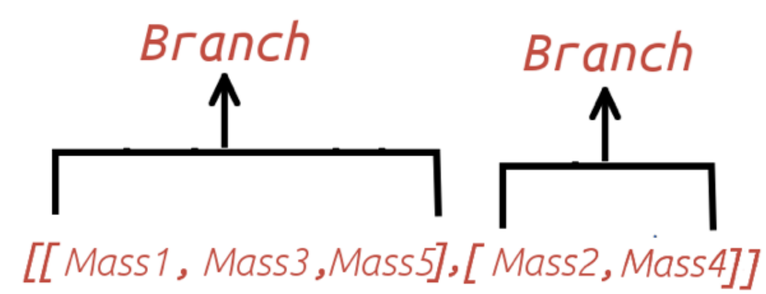
Topology description

An SMS topology is then entirely defined by the **number of vertices in each branch** together with **SM particles originating from each vertex** (final states) and a **mass array** containing the ordered Z_2-odd masses







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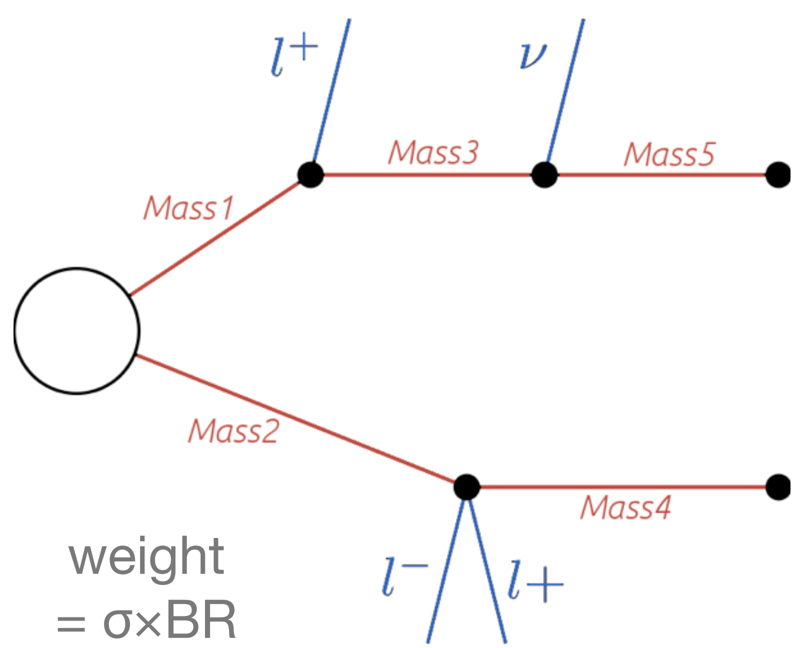
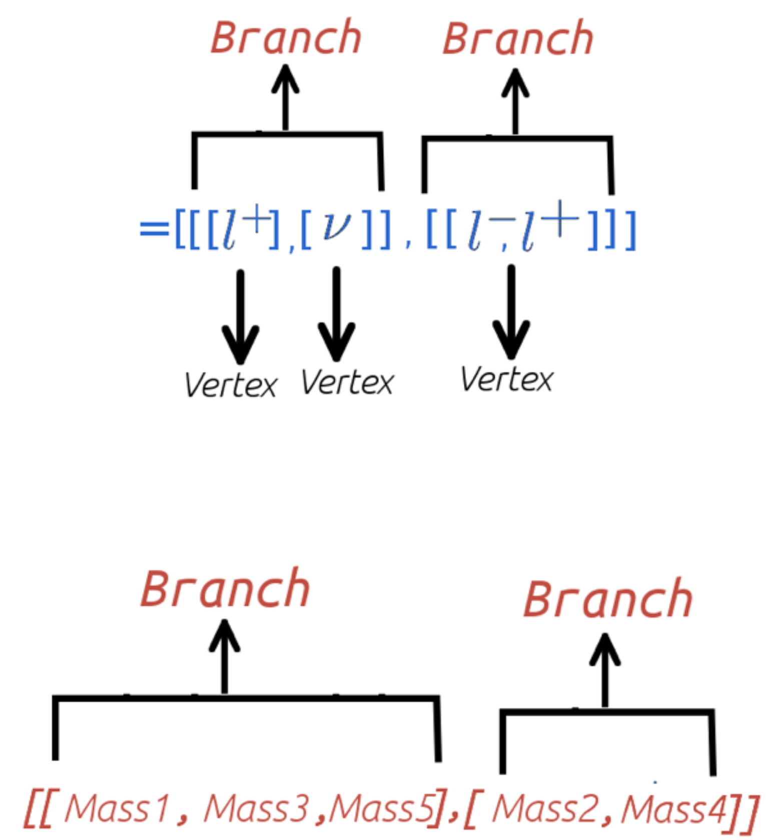


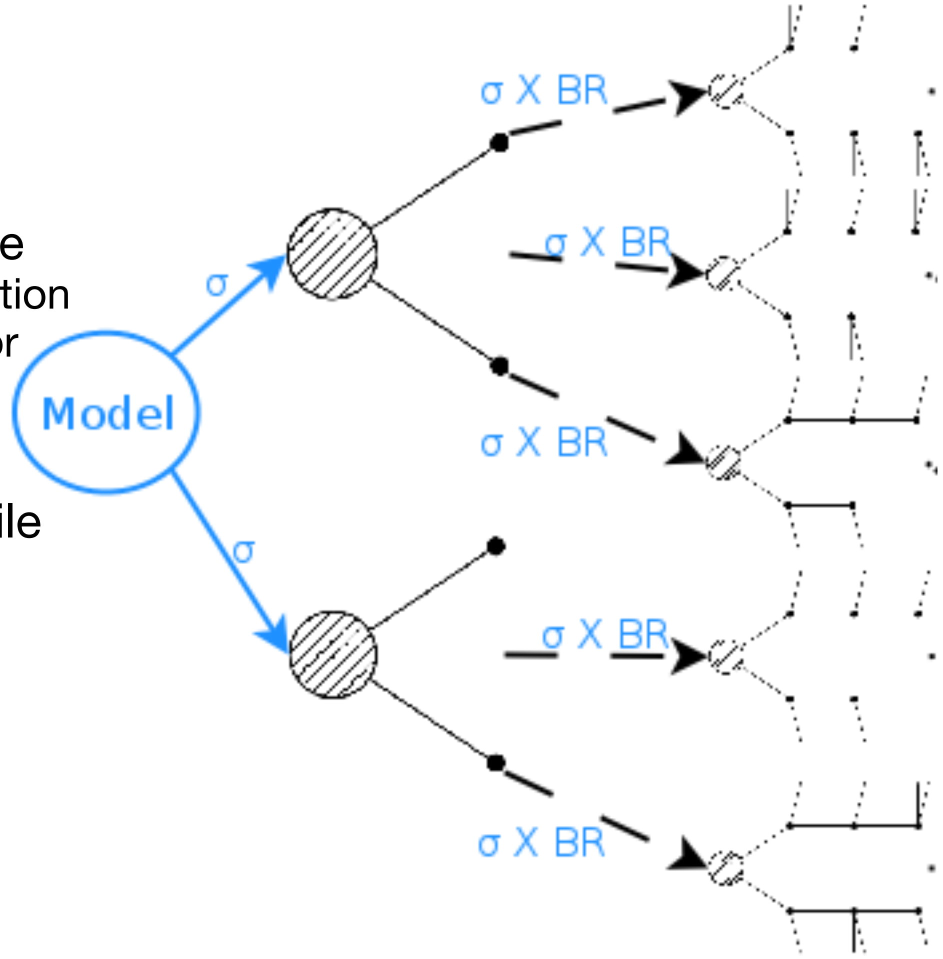
weight
= σ×BR

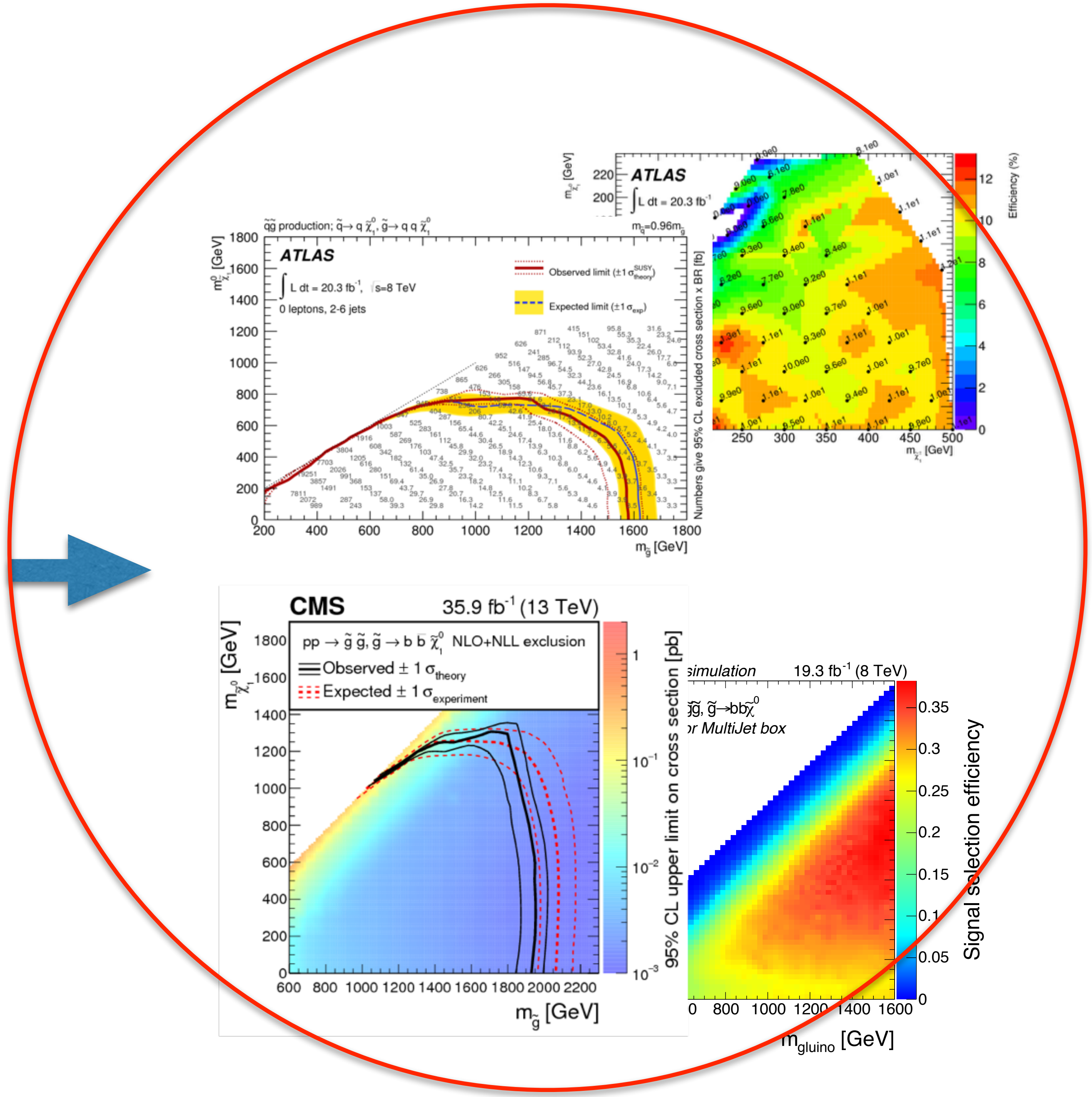


Mass compression: decays of almost degenerate BSM particles into each other are treated as invisible.
Invisible compression: several inv. final-state particles at the end of the decay chain are combined into one.

SLHA file
+ cross section calculator

or LHE file



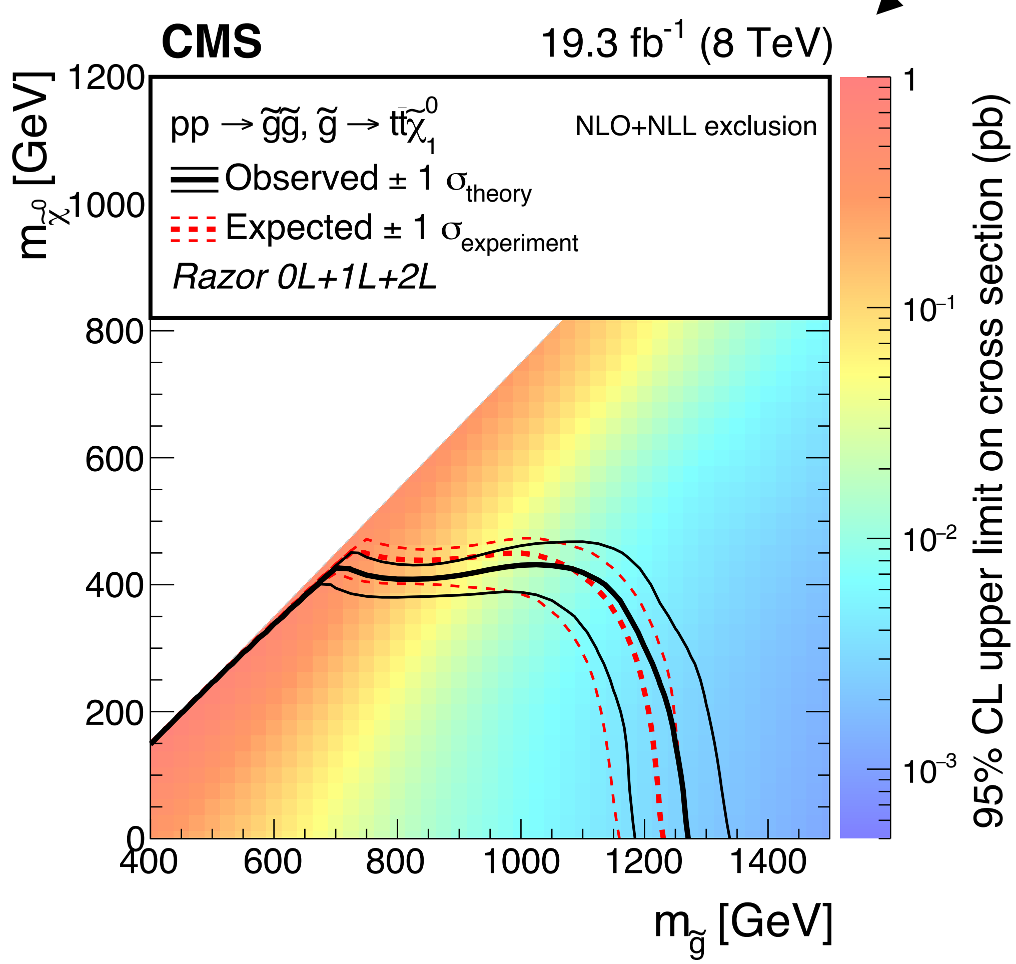


Compare with experimental constraints in SModelS database

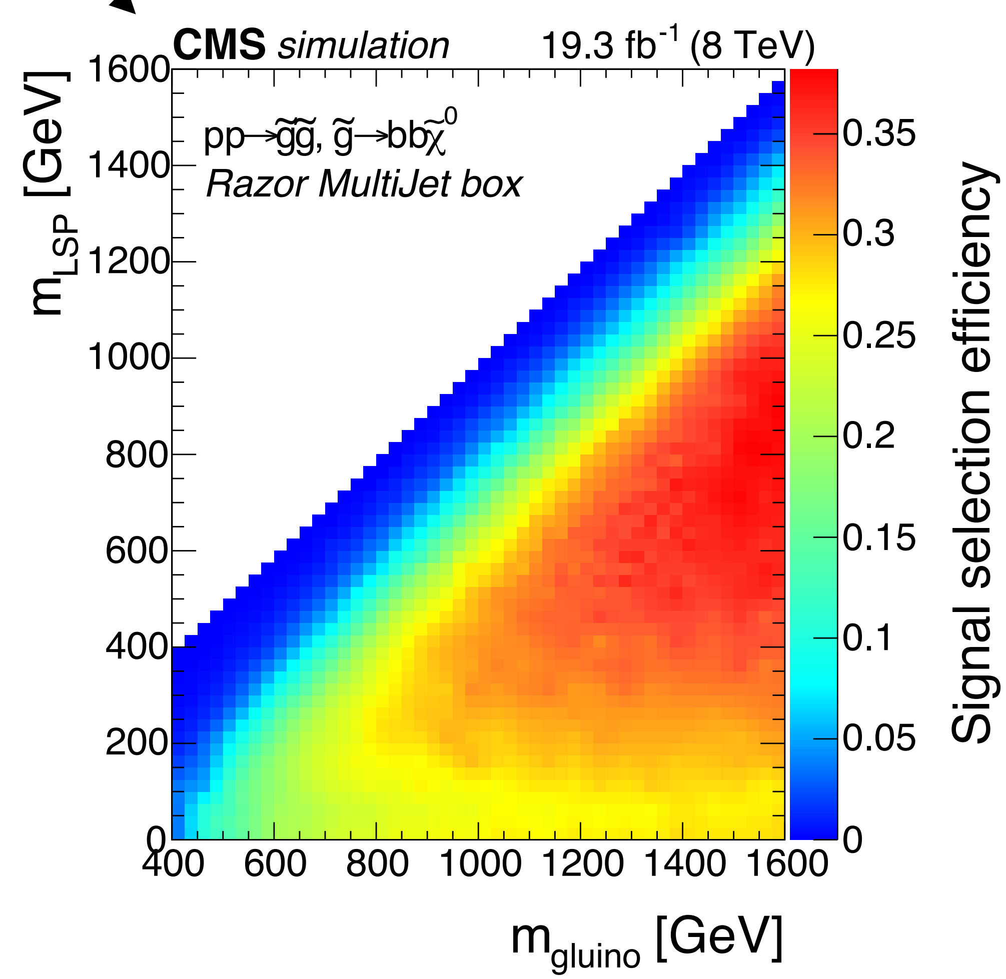
Experimental constraints

need these in numerical form!

Upper Limit (UL) maps



Efficiency maps (EM)



Upper Limit maps give the 95% CL upper limit on cross section x branching ratio for a specific SMS.

The UL values can be based on the best SR (for each point in parameter space), a combination of SRs or more involved limits from other methods.

Efficiency maps correspond to a grid of simulated acceptance x efficiency values for a specific signal region for a specific simplified model.

Together with the observed and expected #events in each SR, this allows to compute a likelihood.

Limit on σ×BR

Limit on Σε×σ×BR

NB: the 95%CL exclusion curve is not used, cannot be re-interpreted

Assumptions

- BSM particles are described only by their masses, production cross sections and branching ratios.

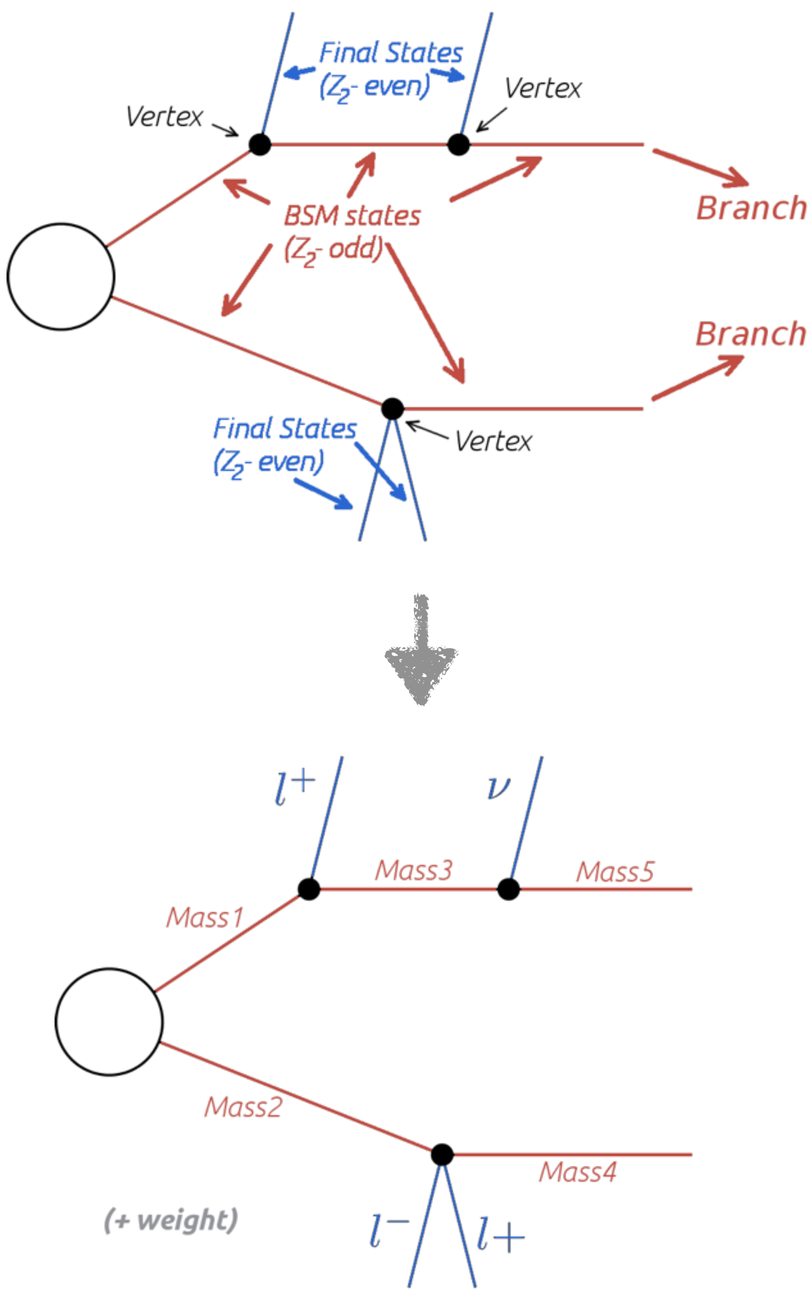
- Underlying assumption is that differences in the event kinematics from, e.g., different production mechanisms or the spins of the BSM particles, do not significantly affect the signal selection efficiencies.

Arkani-Hamed et al., hep-ph/0703088
Alves et al., arXiv:1105.2838

- Procedure applicable to any model with a Z_2 symmetry

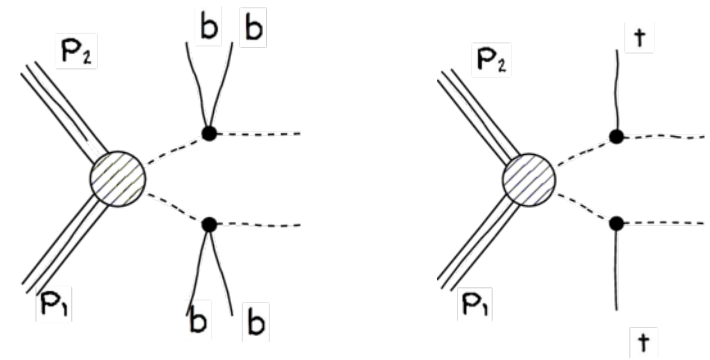
- Tested for and successfully applied to minimal and non-minimal SUSY (NMSSM, UMSSM, sneutrino LSP), as well as extra quark, UED models …

SK et al, 1312.4175; Belanger et al, 1308.3735;
Barducci et al., 1510.00246; Arina et al., 1503.02960;
Edelhauser et al., 1501.03942; Belanger et al, 1506.00665;
SK et al,1607.02050, 1707.09036.

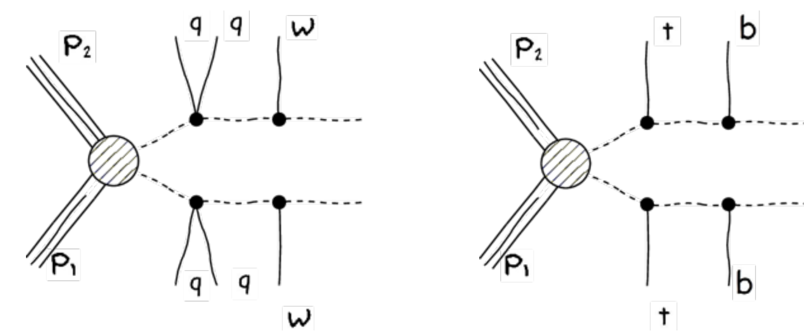


Information used to classify topologies

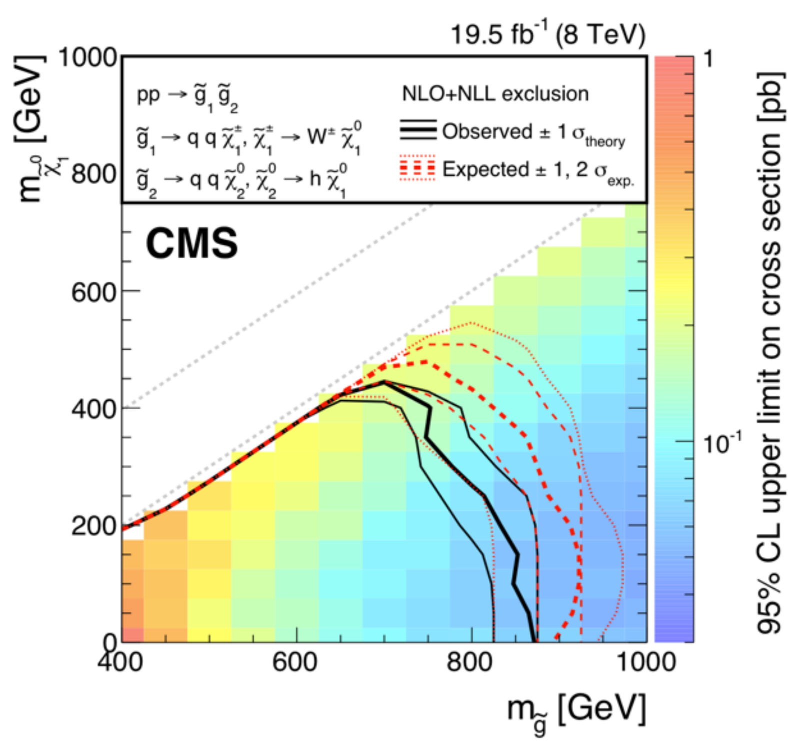
- The simplest SMS have just 2 free parameters, mother and `LSP' mass.
- For more complicated topologies, the results can only be used if an interpolation in all free parameters is possible.
- E.g. if the decay chain proceeds via an intermediate chargino, we need maps (=mass planes) for several different chargino masses.
- If only one plane is given for an SMS with >2 parameters, the result cannot be used.

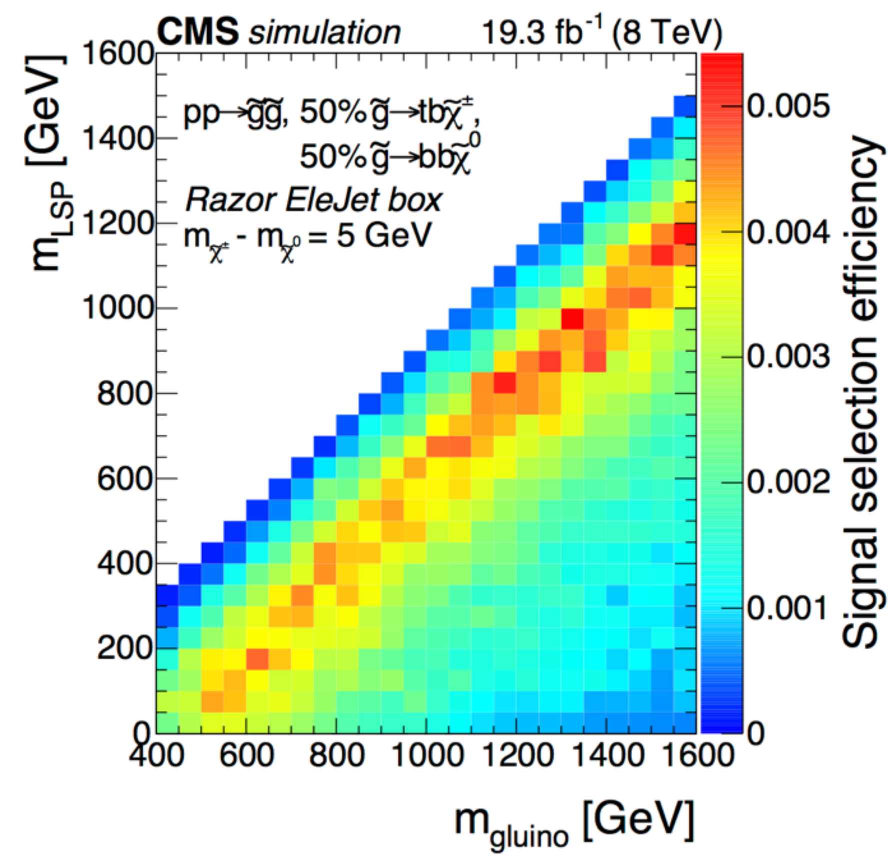


2 parameters



3 parameters





Extension to CMS 36/fb results from Run 2

Summer Conferences 2017 (36 fb^{-1})

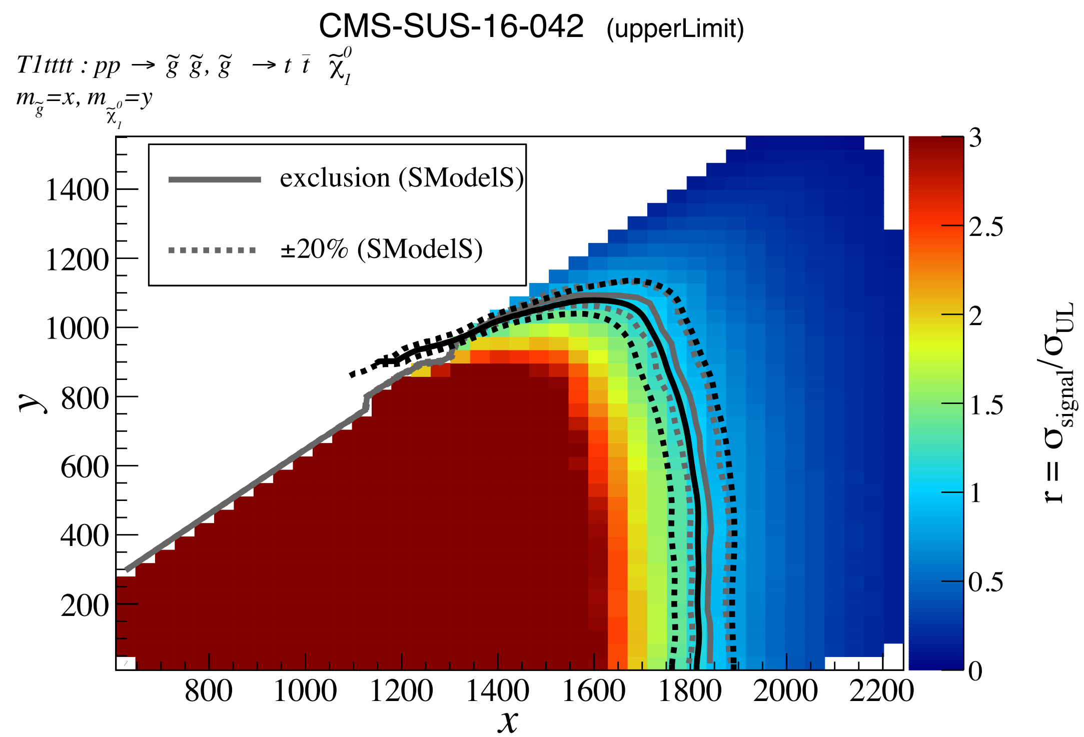
channel	PAS/arXiv	webpage	conference	
0L + top tag	SUS-16-050	link	LHCP	✓
1L compressed stop	SUS-16-052	link	EPS	✓
Hadronic staus	SUS-17-003	link	EPS	✓
Ewkino combination	SUS-17-004	link	EPS	✓
1L RPV	SUS-16-040	link	LP	✗

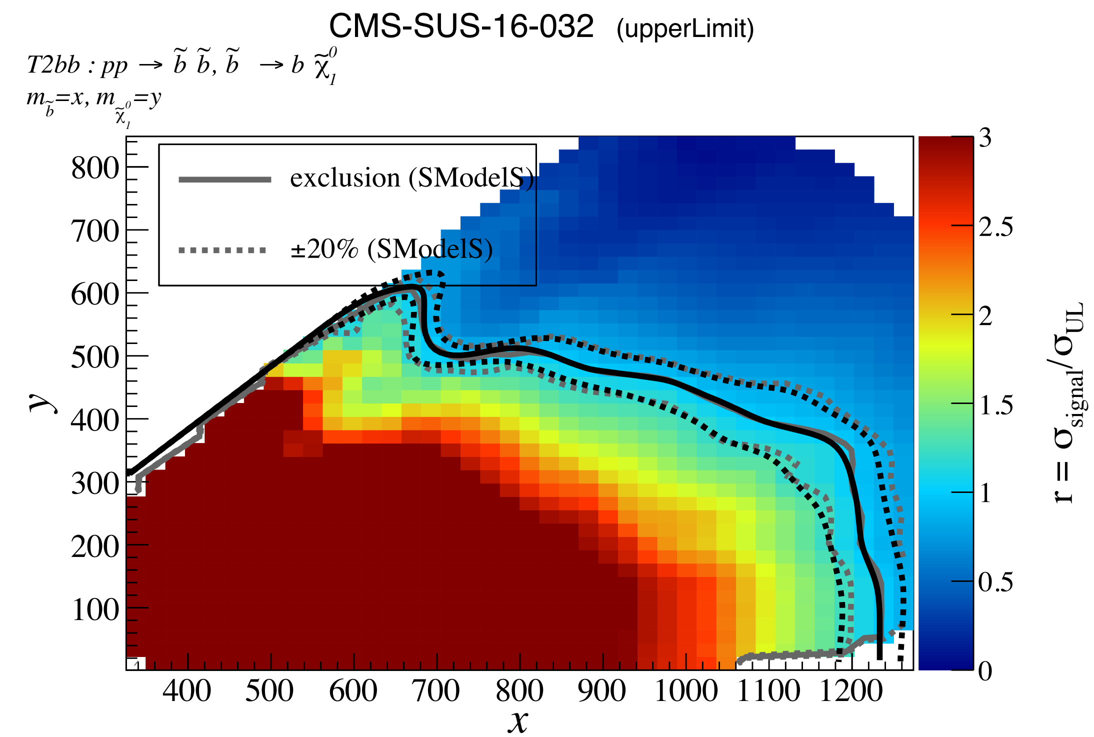
Juhi Dutta, who visited LPSC Grenoble via the IndoFrench network in May 2017, did a great work implementing all the (applicable) SMS results from CMS Run 2 SUSY searches for 36/fb.

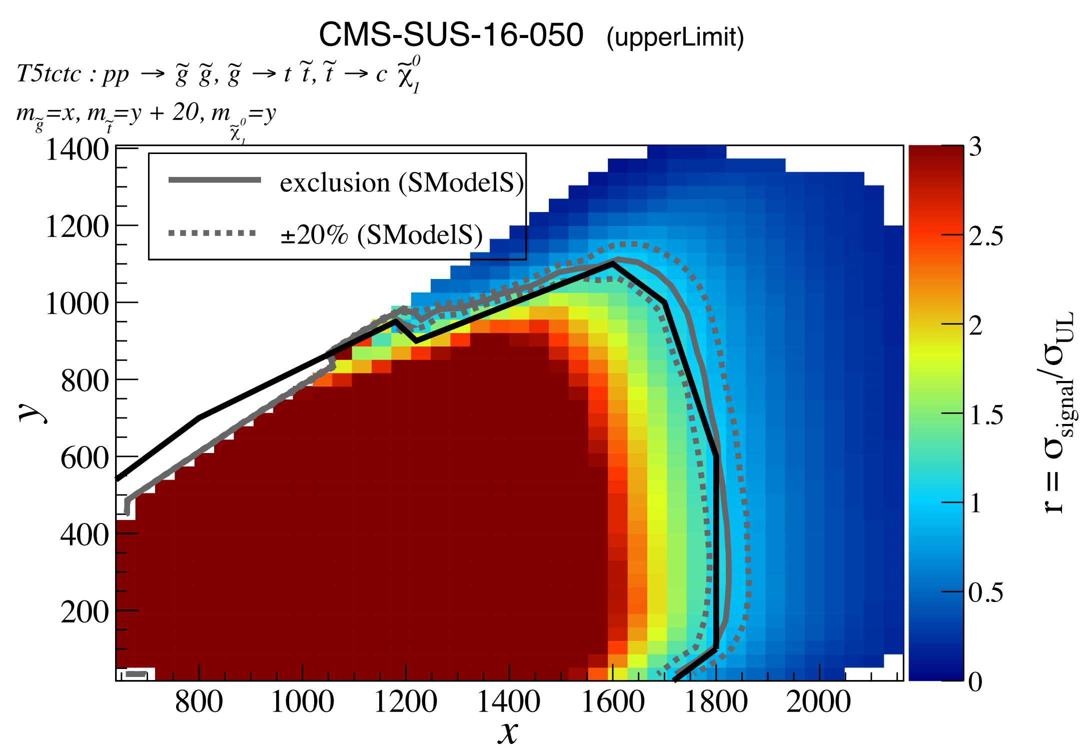
Moriond 2017 (36 fb^{-1})

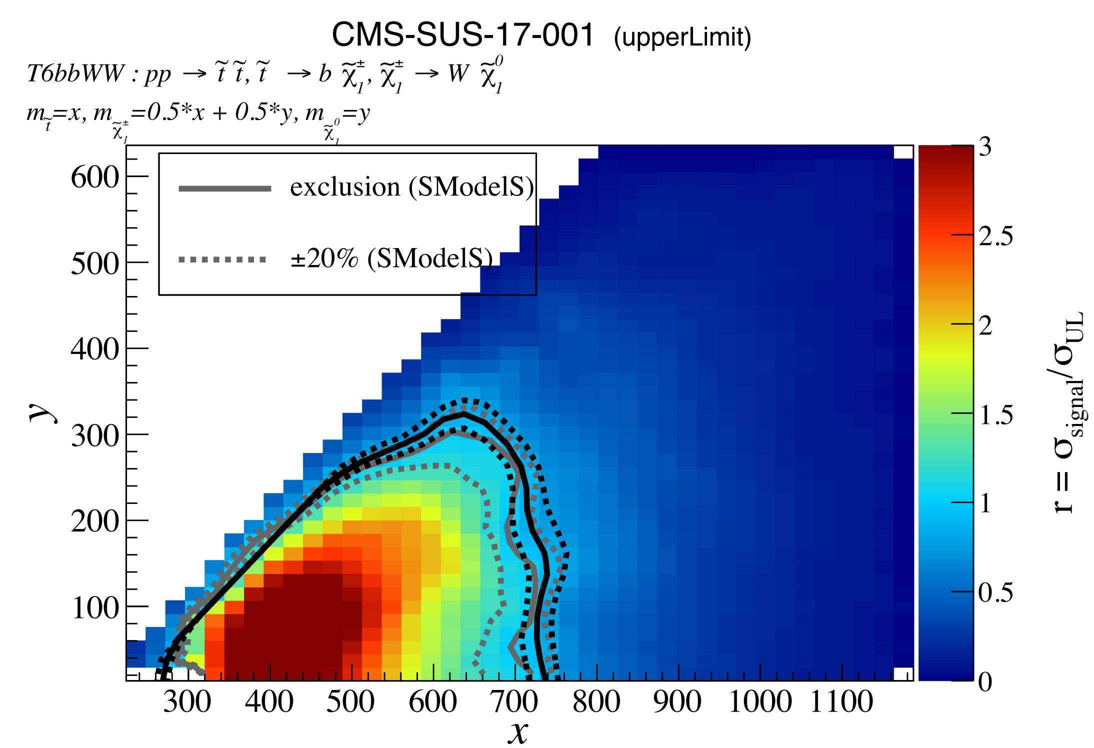
channel	PAS/arXiv	webpage		channel	PAS/arXiv	webpage	
0L + jets with MHT	SUS-16-033	link	✓	Photon + MET	SUS-16-046	link	✓
0L + jets with MT2	SUS-16-036	link	✓	Photon + HT	SUS-16-047	link	✓
1L + jets + MET with MJ	SUS-16-037	link	✓	Stop 0L	SUS-16-049	link	✓
1L + jets + MET with ΔΦ	SUS-16-042	link	✓	Stop 1L	SUS-16-051	link	✓
2SS Leptons	SUS-16-035	link	✓	Stop 2L	SUS-17-001	link	✓
multilepton EWK	SUS-16-039	link	✓	Sbottom and compressed stop	SUS-16-032	link	✓
multileptons + jets	SUS-16-041	link	✓	GMSB Higgsinos in 4b	SUS-16-044	link	✗
2L soft	SUS-16-048	link	✗	2OS leptons	SUS-16-034	link	✓
Razor + Higgs->gg	SUS-16-045	link	✓	EWK WH(bb)	SUS-16-043	link	✓

Validation (examples)

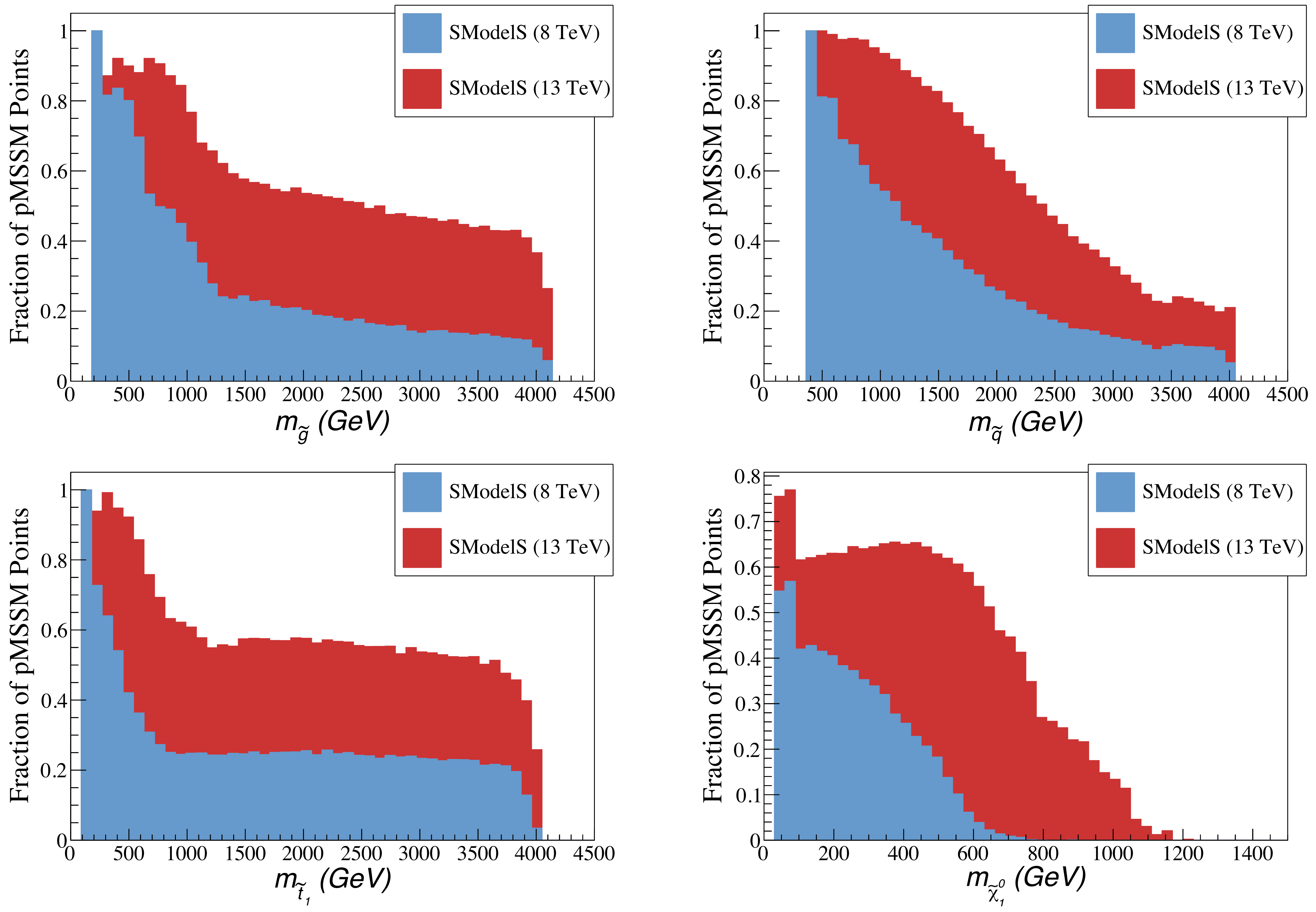








Impact on generic MSSM



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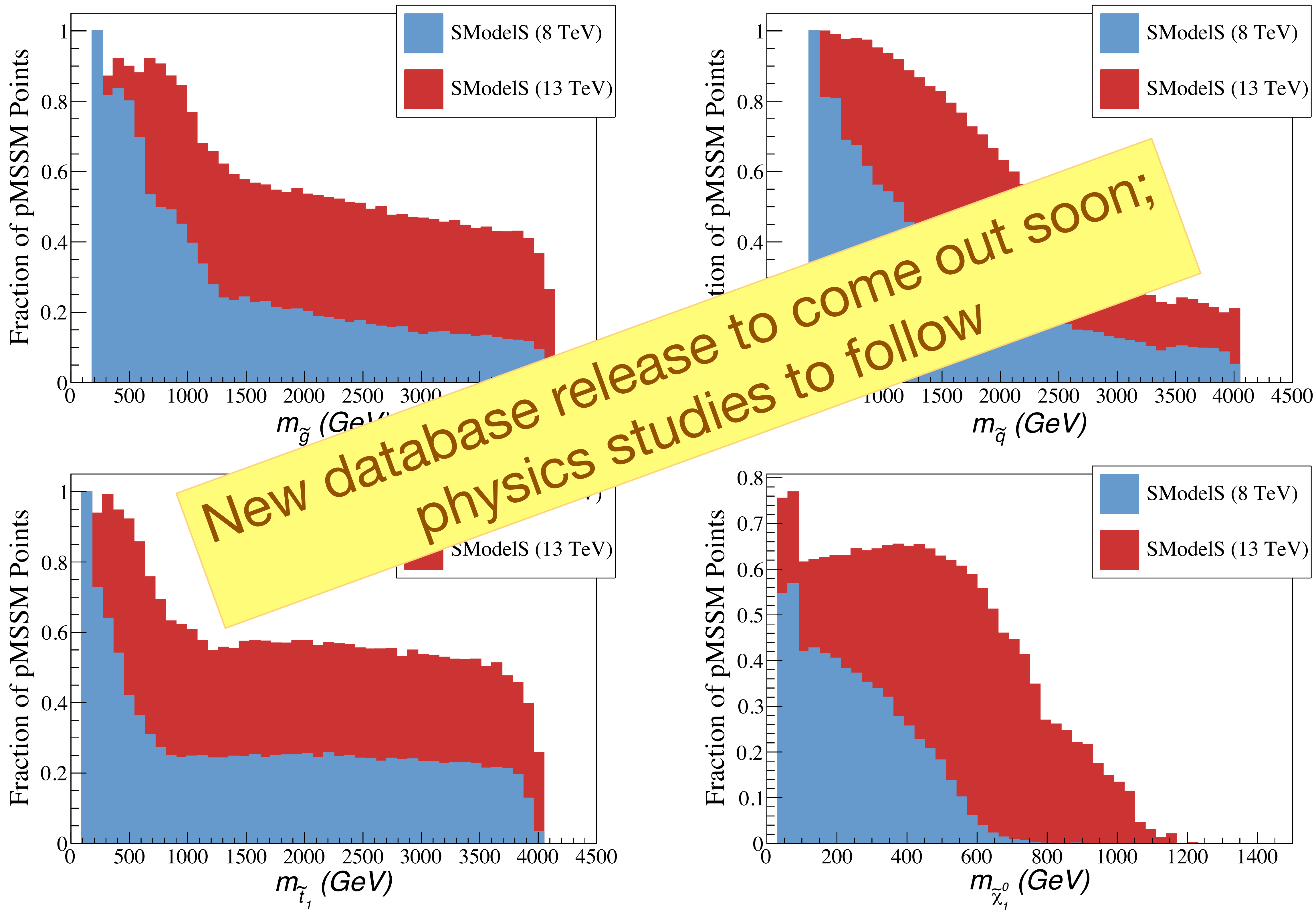

New database release to come out soon; physics studies to follow

International activity

TWiki > LHCPhysics Web > LHCPhysics > InterpretingLHCresults (2018-02-02, SabineKraml) Edit Attach PDF

Forum on the Interpretation of the LHC Results for BSM studies

The quest for new physics beyond the Standard Model is arguably the driving topic for Run 2 of the LHC. Indeed, the LHC collaborations are pursuing searches for new physics in a vast variety of channels. While the collaborations typically provide themselves interpretations of their results, for instance in terms of simplified models, **the full understanding of the implications of these searches requires the interpretation of the experimental results in the context of all kinds of theoretical models.** This is a very active field, with close theory-experiment interaction and with several public tools being developed.

With this forum, we want to provide a platform for continued discussion of topics related to the BSM (re)interpretation of LHC data, including the development of the necessary **public** RecastingTools and related infrastructure.

If you have questions or want to contribute, contact Sabine Kraml, sabine.kraml@gmailNOSPAMPLEASE.com, or any of the topical contacts given below.

Meetings

Meetings of this forum

- **4th workshop**, 14-16 May 2018 at CERN (+ 1-2 days developers' meeting?)
- **3rd workshop**, 16-18 Oct 2017 at Fermilab
- **2nd workshop**, 12-14 Dec 2016 at CERN
  - Agenda | introduction | final discussion | WorkshopSummaryNotes
- **Kick-off workshop:** (Re)interpreting the results of new physics searches at the LHC, 15-17 June 2016 at CERN
  - Agenda | general discussion | KickoffSummaryNotes

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults

(Re)interpreting the results of new physics searches at the LHC

14-16 May 2018
CERN
Europe/Zurich timezone

Search...

- Overview
- Timetable
- Registration
- Call for Abstracts
- Participant List
- Videoconference Rooms
- Programme Commitee

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A Forum on the interpretation of the LHC results for BSM studies was thus initiated to discuss topics related to the BSM (re)interpretation of LHC data, including the development of the necessary public recasting tools and related infrastructure, and to and to provide a platform for a continued interaction between theorists and with the experiments.

This is the **forth workshop** of this Forum. Previous meetings took place

1. workshop: 15-17 June 2016 (kick-off meeting) at CERN
2. workshop: 12-14 Dec 2016 at CERN
3. workshop: 16-18 Oct 2017 at Fermilab