LHC Recasting & Applications

Planck 2018
Bonn
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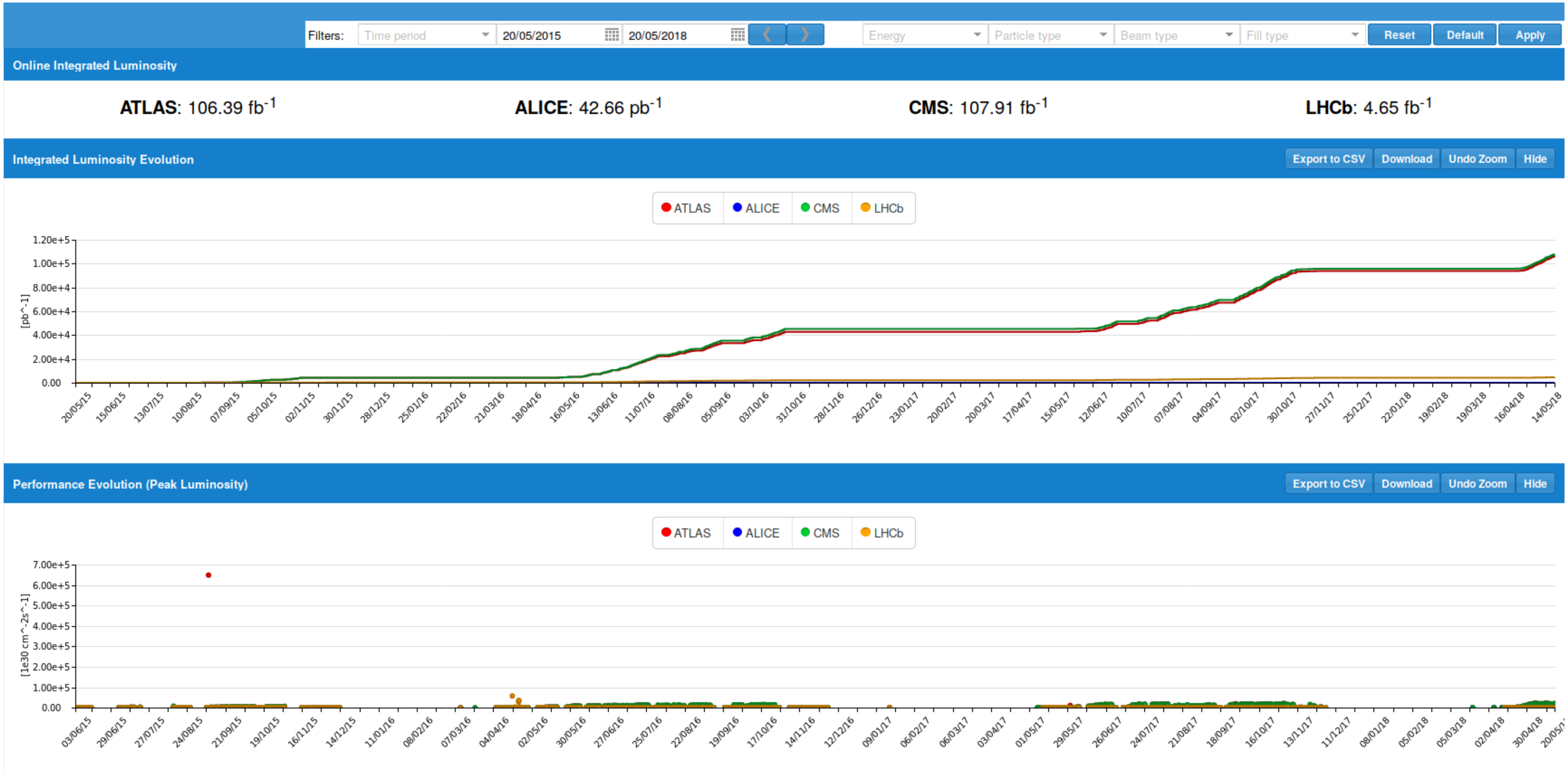
NIThep National Institute for Theoretical Physics

NRF National Research Foundation

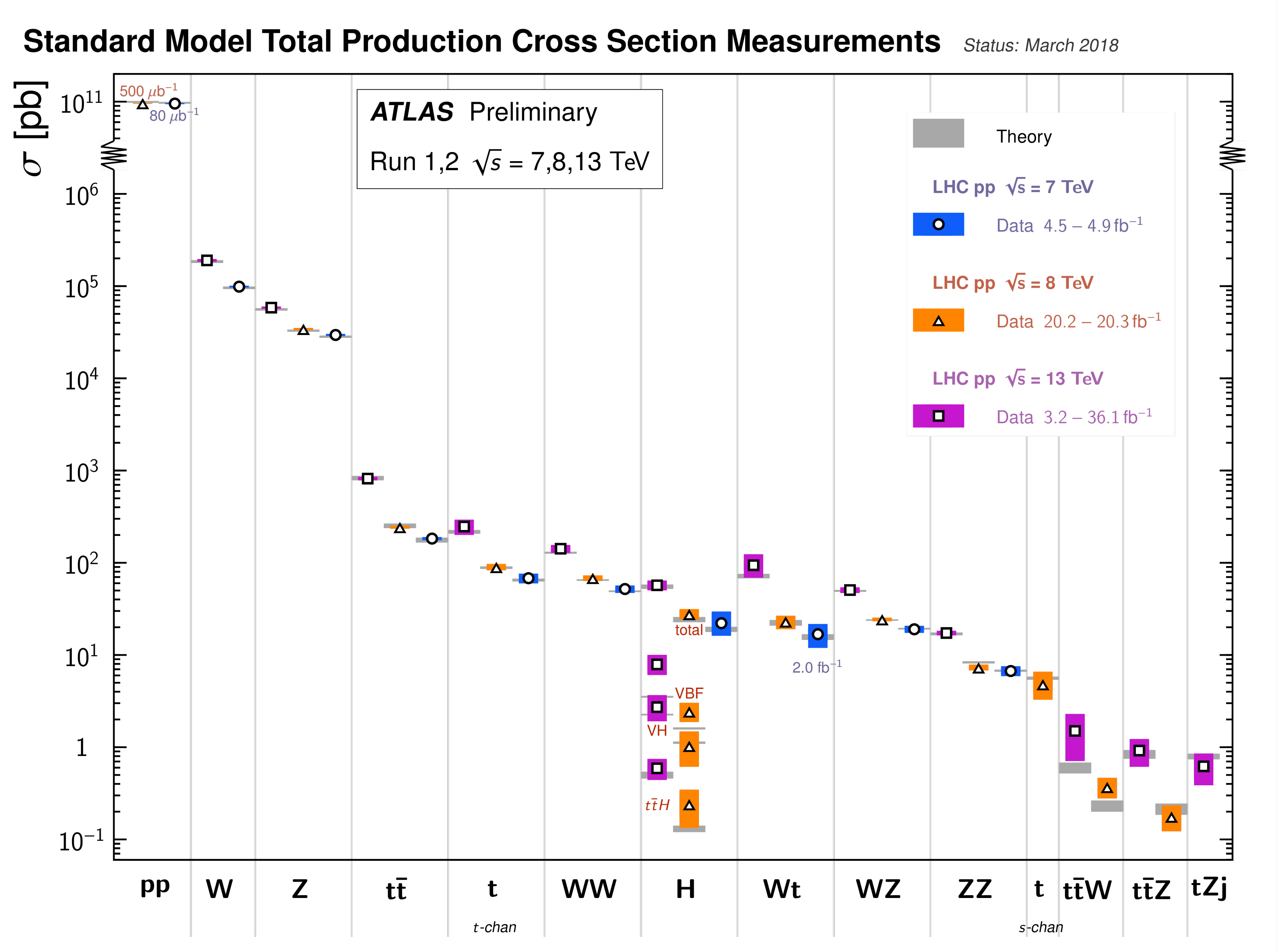
MITP Mandelstam Institute for Theoretical Physics



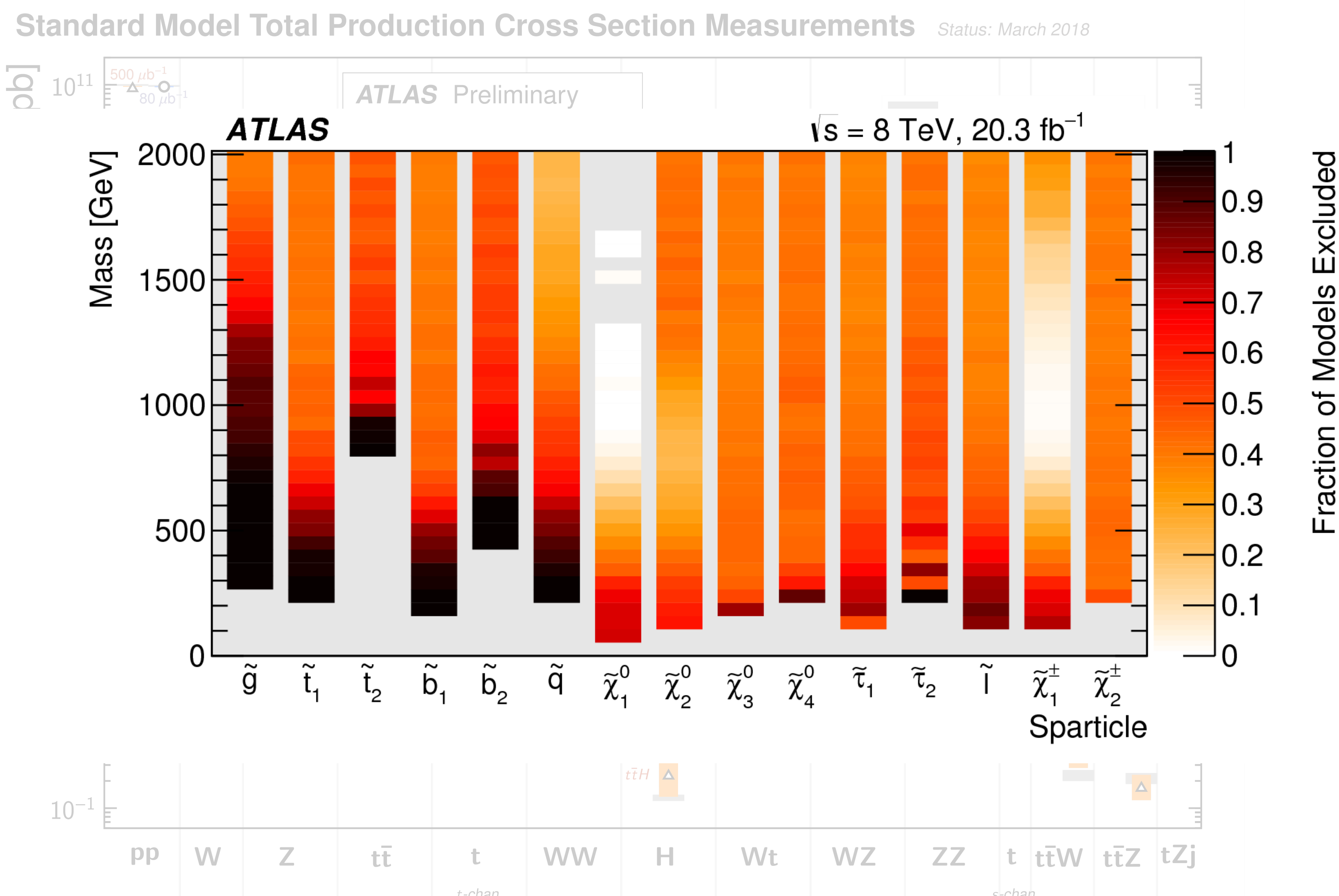
- Run 2 is almost over and both experiments have collected 100 inverse fb so far

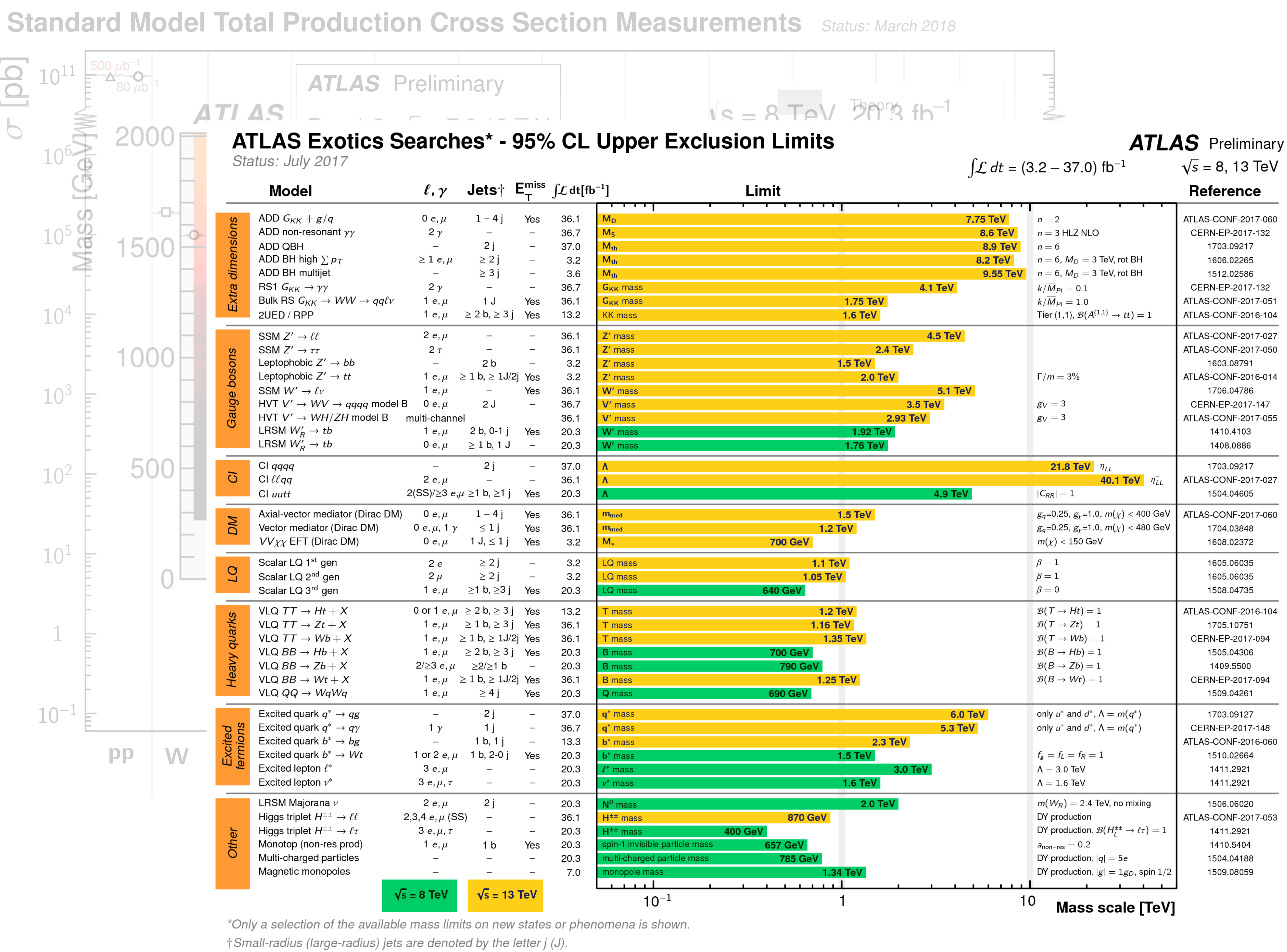
- no signs of new physics

- BSM studies are one of the main tasks at the LHC

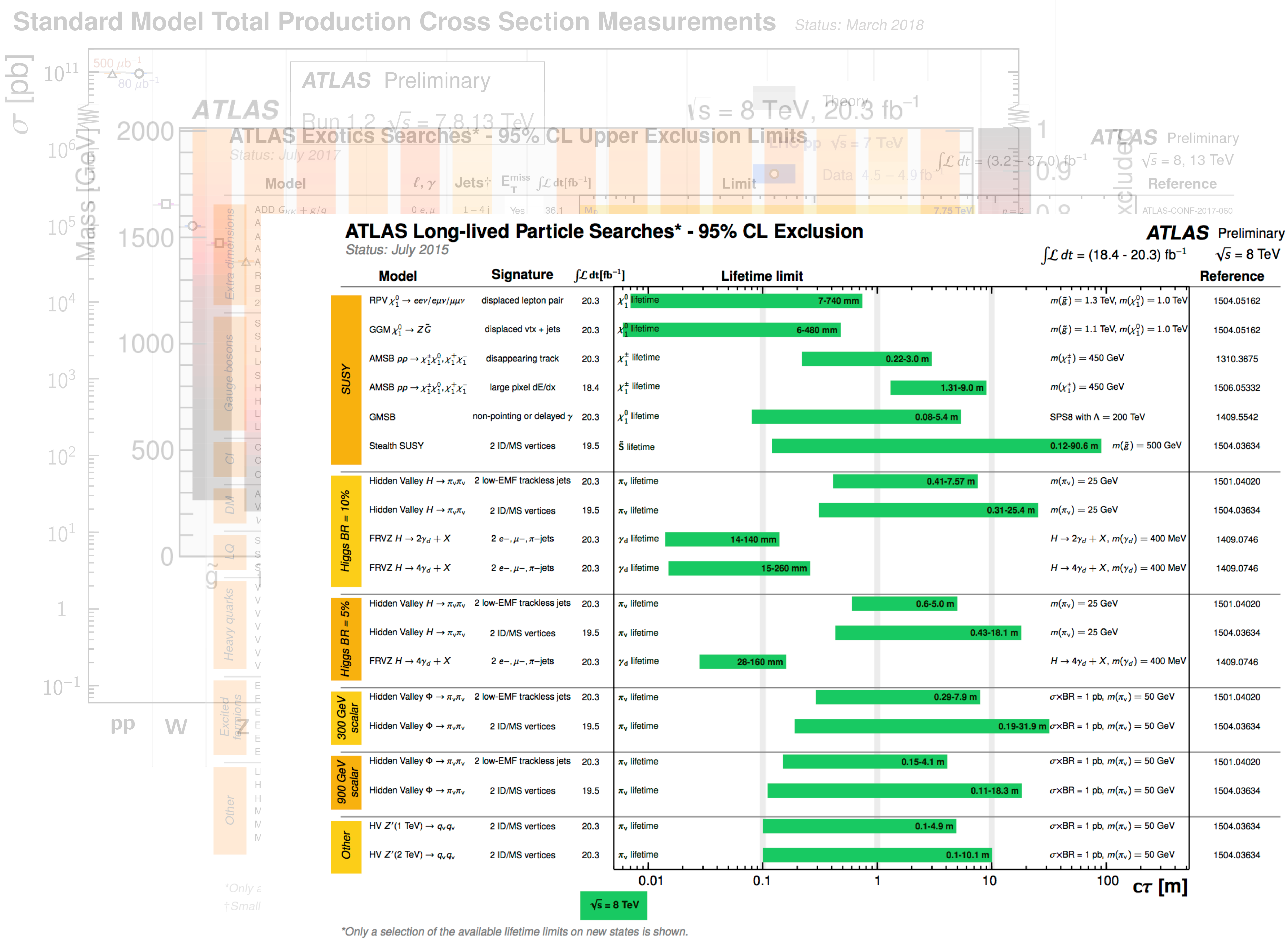


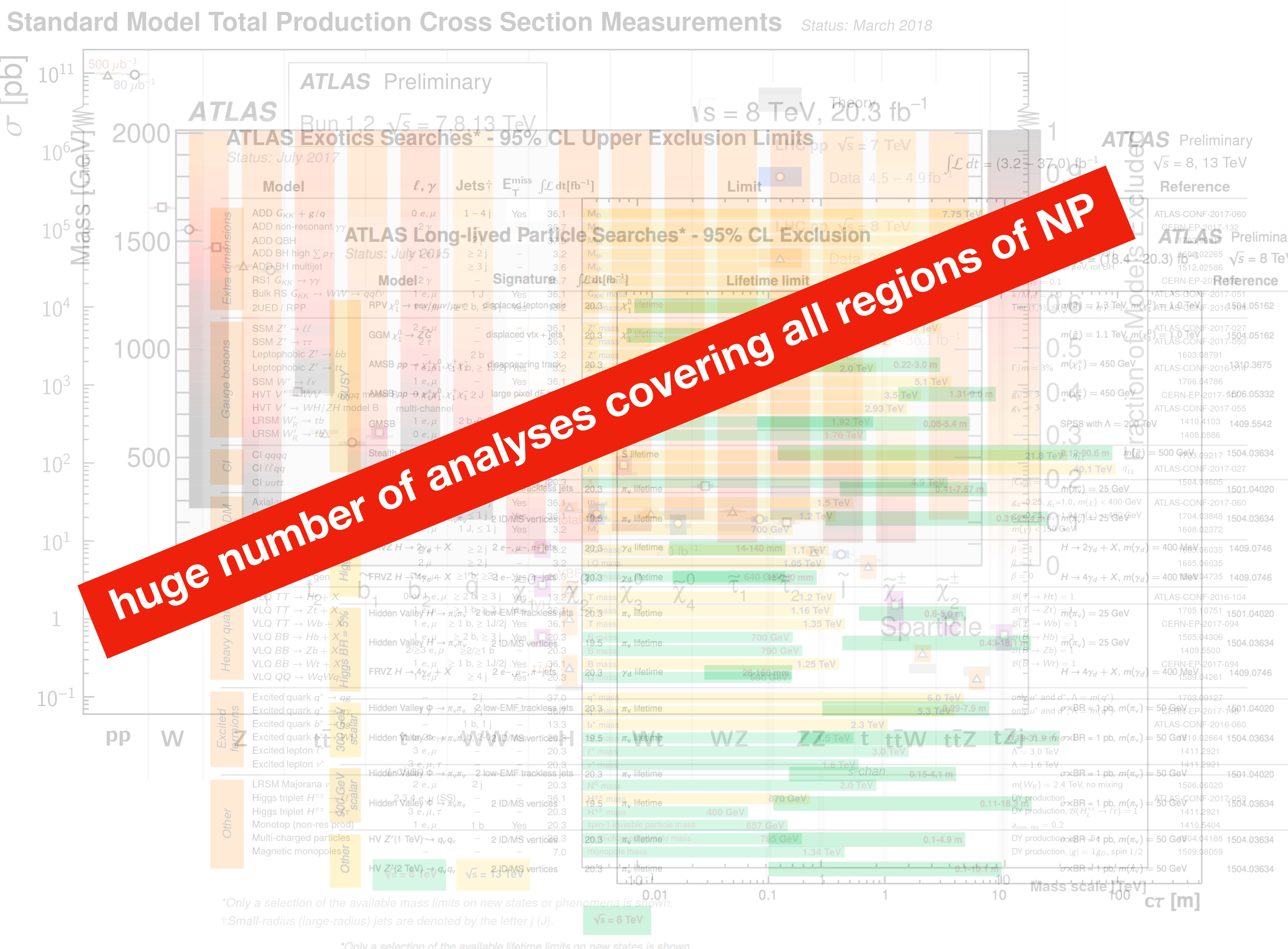
Standard Model Total Production Cross Section Measurements
Status: March 2018
σ [pb]
ATLAS Preliminary
Run 1,2 √s = 7,8,13 TeV
Theory
LHC pp √s = 7 TeV
Data 4.5 – 4.9 fb⁻¹
LHC pp √s = 8 TeV
Data 20.2 – 20.3 fb⁻¹
LHC pp √s = 13 TeV
Data 3.2 – 36.1 fb⁻¹
500 μb⁻¹
80 μb⁻¹
total
VBF
VH
ttH
2.0 fb⁻¹
pp
W
Z
tt̄
t
t-chan
WW
H
Wt
WZ
ZZ
t
s-chan
tt̄W
tt̄Z
tZj


Standard Model Total Production Cross Section Measurements
Status: March 2018
ATLAS Preliminary
ATLAS
$\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}
Mass [GeV]
2000
1500
1000
500
0
$\tilde{g}$ $\tilde{t}_1$ $\tilde{t}_2$ $\tilde{b}_1$ $\tilde{b}_2$ $\tilde{q}$ $\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$ $\tilde{\tau}_1$ $\tilde{\tau}_2$ $\tilde{l}$ $\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$
Sparticle
Fraction of Models Excluded
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
pp W Z $t\bar{t}$ t WW H Wt WZ ZZ t $t\bar{t}W$ $t\bar{t}Z$ tZj
t-chan
s-chan



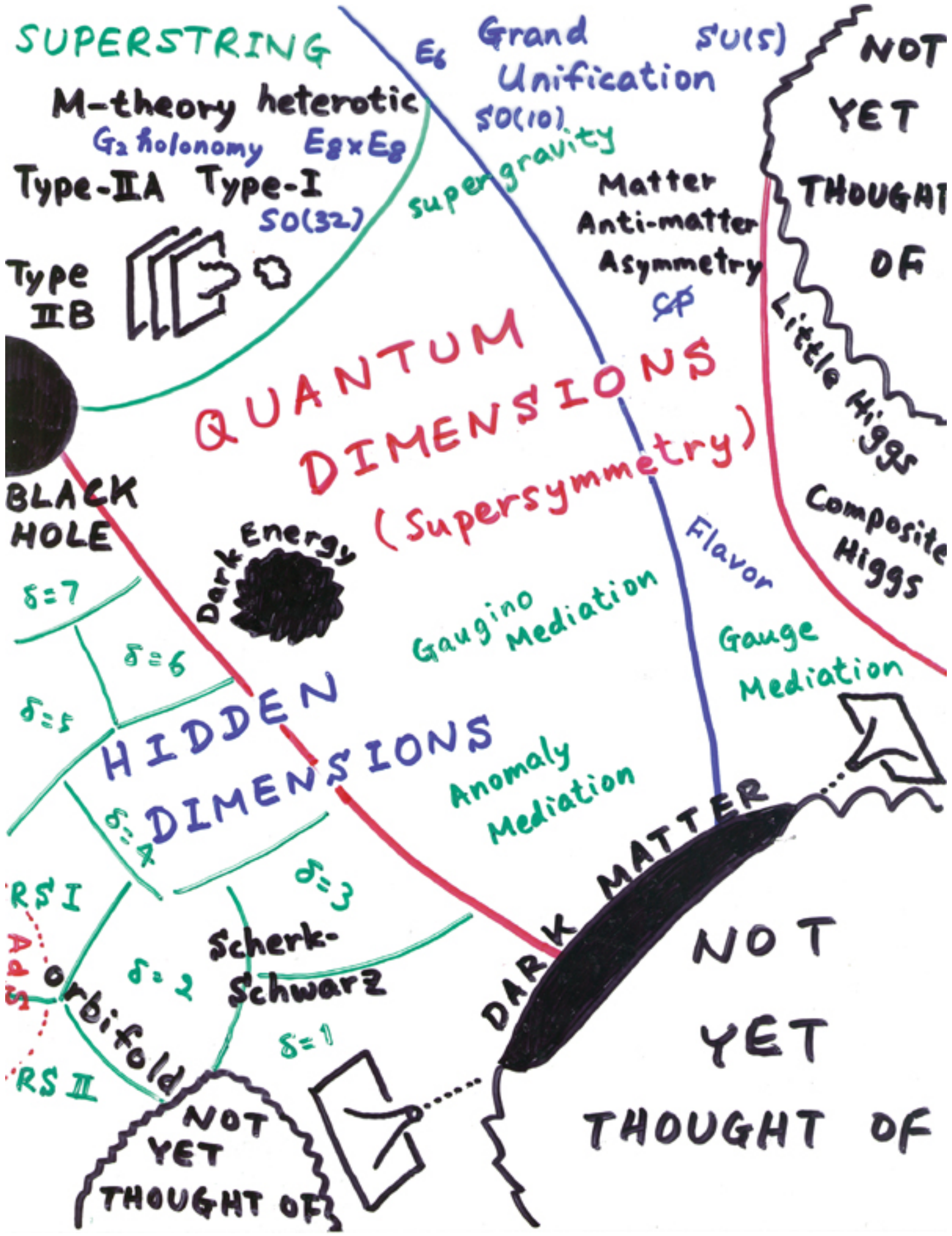
Standard Model Total Production Cross Section Measurements
Status: March 2018
ATLAS Preliminary
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: July 2017
ATLAS Preliminary
$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$
$\sqrt{s}$ = 8, 13 TeV
Model | ℓ, γ | Jets† | E_T^{miss} | $\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$ | Limit | Reference
Extra dimensions
ADD $G_{KK} + g/q$ | 0 e, μ | 1 − 4 j | Yes | 36.1 | M_D 7.75 TeV | n = 2 | ATLAS-CONF-2017-060
ADD non-resonant γγ | 2 γ | – | – | 36.7 | M_S 8.6 TeV | n = 3 HLZ NLO | CERN-EP-2017-132
ADD QBH | – | 2 j | – | 37.0 | M_{th} 8.9 TeV | n = 6 | 1703.09217
ADD BH high $\sum p_T$ | ≥ 1 e, μ | ≥ 2 j | – | 3.2 | M_{th} 8.2 TeV | n = 6, M_D = 3 TeV, rot BH | 1606.02265
ADD BH multijet | – | ≥ 3 j | – | 3.6 | M_{th} 9.55 TeV | n = 6, M_D = 3 TeV, rot BH | 1512.02586
RS1 $G_{KK} \to \gamma\gamma$ | 2 γ | – | – | 36.7 | G_{KK} mass 4.1 TeV | $k/\overline{M}_{Pl}$ = 0.1 | CERN-EP-2017-132
Bulk RS $G_{KK} \to WW \to qq\ell\nu$ | 1 e, μ | 1 J | Yes | 36.1 | G_{KK} mass 1.75 TeV | $k/\overline{M}_{Pl}$ = 1.0 | ATLAS-CONF-2017-051
2UED / RPP | 1 e, μ | ≥ 2 b, ≥ 3 j | Yes | 13.2 | KK mass 1.6 TeV | Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$ | ATLAS-CONF-2016-104
Gauge bosons
SSM $Z' \to \ell\ell$ | 2 e, μ | – | – | 36.1 | Z′ mass 4.5 TeV | | ATLAS-CONF-2017-027
SSM $Z' \to \tau\tau$ | 2 τ | – | – | 36.1 | Z′ mass 2.4 TeV | | ATLAS-CONF-2017-050
Leptophobic $Z' \to bb$ | – | 2 b | – | 3.2 | Z′ mass 1.5 TeV | | 1603.08791
Leptophobic $Z' \to tt$ | 1 e, μ | ≥ 1 b, ≥ 1J/2j | Yes | 3.2 | Z′ mass 2.0 TeV | Γ/m = 3% | ATLAS-CONF-2016-014
SSM $W' \to \ell\nu$ | 1 e, μ | – | Yes | 36.1 | W′ mass 5.1 TeV | | 1706.04786
HVT $V' \to WV \to qqqq$ model B | 0 e, μ | 2 J | – | 36.7 | V′ mass 3.5 TeV | g_V = 3 | CERN-EP-2017-147
HVT $V' \to WH/ZH$ model B | multi-channel | | | 36.1 | V′ mass 2.93 TeV | g_V = 3 | ATLAS-CONF-2017-055
LRSM $W'_R \to tb$ | 1 e, μ | 2 b, 0-1 j | Yes | 20.3 | W′ mass 1.92 TeV | | 1410.4103
LRSM $W'_R \to tb$ | 0 e, μ | ≥ 1 b, 1 J | – | 20.3 | W′ mass 1.76 TeV | | 1408.0886
CI
CI qqqq | – | 2 j | – | 37.0 | Λ 21.8 TeV η_{LL}^- | | 1703.09217
CI ℓℓqq | 2 e, μ | – | – | 36.1 | Λ 40.1 TeV η_{LL}^- | | ATLAS-CONF-2017-027
CI uutt | 2(SS)/≥3 e,μ | ≥1 b, ≥1 j | Yes | 20.3 | Λ 4.9 TeV | $|C_{RR}|$ = 1 | 1504.04605
DM
Axial-vector mediator (Dirac DM) | 0 e, μ | 1 − 4 j | Yes | 36.1 | m_{med} 1.5 TeV | g_q=0.25, g_χ=1.0, $m(\chi)$ < 400 GeV | ATLAS-CONF-2017-060
Vector mediator (Dirac DM) | 0 e, μ, 1 γ | ≤ 1 j | Yes | 36.1 | m_{med} 1.2 TeV | g_q=0.25, g_χ=1.0, $m(\chi)$ < 480 GeV | 1704.03848
$VV\chi\chi$ EFT (Dirac DM) | 0 e, μ | 1 J, ≤ 1 j | Yes | 3.2 | M_* 700 GeV | $m(\chi)$ < 150 GeV | 1608.02372
LQ
Scalar LQ 1st gen | 2 e | ≥ 2 j | – | 3.2 | LQ mass 1.1 TeV | β = 1 | 1605.06035
Scalar LQ 2nd gen | 2 μ | ≥ 2 j | – | 3.2 | LQ mass 1.05 TeV | β = 1 | 1605.06035
Scalar LQ 3rd gen | 1 e, μ | ≥1 b, ≥3 j | Yes | 20.3 | LQ mass 640 GeV | β = 0 | 1508.04735
Heavy quarks
VLQ $TT \to Ht + X$ | 0 or 1 e, μ | ≥ 2 b, ≥ 3 j | Yes | 13.2 | T mass 1.2 TeV | $\mathcal{B}(T \to Ht) = 1$ | ATLAS-CONF-2016-104
VLQ $TT \to Zt + X$ | 1 e, μ | ≥ 1 b, ≥ 3 j | Yes | 36.1 | T mass 1.16 TeV | $\mathcal{B}(T \to Zt) = 1$ | 1705.10751
VLQ $TT \to Wb + X$ | 1 e, μ | ≥ 1 b, ≥ 1J/2j | Yes | 36.1 | T mass 1.35 TeV | $\mathcal{B}(T \to Wb) = 1$ | CERN-EP-2017-094
VLQ $BB \to Hb + X$ | 1 e, μ | ≥ 2 b, ≥ 3 j | Yes | 20.3 | B mass 700 GeV | $\mathcal{B}(B \to Hb) = 1$ | 1505.04306
VLQ $BB \to Zb + X$ | 2/≥3 e, μ | ≥2/≥1 b | – | 20.3 | B mass 790 GeV | $\mathcal{B}(B \to Zb) = 1$ | 1409.5500
VLQ $BB \to Wt + X$ | 1 e, μ | ≥ 1 b, ≥ 1J/2j | Yes | 36.1 | B mass 1.25 TeV | $\mathcal{B}(B \to Wt) = 1$ | CERN-EP-2017-094
VLQ $QQ \to WqWq$ | 1 e, μ | ≥ 4 j | Yes | 20.3 | Q mass 690 GeV | | 1509.04261
Excited fermions
Excited quark $q^* \to qg$ | – | 2 j | – | 37.0 | q* mass 6.0 TeV | only u^* and d^*, $\Lambda = m(q^*)$ | 1703.09127
Excited quark $q^* \to q\gamma$ | 1 γ | 1 j | – | 36.7 | q* mass 5.3 TeV | only u^* and d^*, $\Lambda = m(q^*)$ | CERN-EP-2017-148
Excited quark $b^* \to bg$ | – | 1 b, 1 j | – | 13.3 | b* mass 2.3 TeV | | ATLAS-CONF-2016-060
Excited quark $b^* \to Wt$ | 1 or 2 e, μ | 1 b, 2-0 j | Yes | 20.3 | b* mass 1.5 TeV | $f_g = f_L = f_R = 1$ | 1510.02664
Excited lepton ℓ^* | 3 e, μ | – | – | 20.3 | ℓ* mass 3.0 TeV | Λ = 3.0 TeV | 1411.2921
Excited lepton ν^* | 3 e, μ, τ | – | – | 20.3 | ν* mass 1.6 TeV | Λ = 1.6 TeV | 1411.2921
Other
LRSM Majorana ν | 2 e, μ | 2 j | – | 20.3 | N^0 mass 2.0 TeV | $m(W_R)$ = 2.4 TeV, no mixing | 1506.06020
Higgs triplet $H^{\pm\pm} \to \ell\ell$ | 2,3,4 e, μ (SS) | – | – | 36.1 | $H^{\pm\pm}$ mass 870 GeV | DY production | ATLAS-CONF-2017-053
Higgs triplet $H^{\pm\pm} \to \ell\tau$ | 3 e, μ, τ | – | – | 20.3 | $H^{\pm\pm}$ mass 400 GeV | DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$ | 1411.2921
Monotop (non-res prod) | 1 e, μ | 1 b | Yes | 20.3 | spin-1 invisible particle mass 657 GeV | $a_{non-res}$ = 0.2 | 1410.5404
Multi-charged particles | – | – | – | 20.3 | multi-charged particle mass 785 GeV | DY production, $|q| = 5e$ | 1504.04188
Magnetic monopoles | – | – | – | 7.0 | monopole mass 1.34 TeV | DY production, $|g| = 1g_D$, spin 1/2 | 1509.08059
$\sqrt{s}$ = 8 TeV
$\sqrt{s}$ = 13 TeV
10^{-1}
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter j (J).


Standard Model Total Production Cross Section Measurements
Status: March 2018
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: July 2017
ATLAS Long-lived Particle Searches* - 95% CL Exclusion
Status: July 2015
ATLAS Preliminary
$\int\mathcal{L}dt$ = (18.4 - 20.3) fb^{-1}
$\sqrt{s}$ = 8 TeV
Model
Signature
$\int\mathcal{L}dt[fb^{-1}]$
Lifetime limit
Reference
SUSY
RPV $\chi_1^0 \to ee\nu/e\mu\nu/\mu\mu\nu$ | displaced lepton pair | 20.3 | χ_1^0 lifetime | 7-740 mm | $m(\tilde{g})$ = 1.3 TeV, $m(\chi_1^0)$ = 1.0 TeV | 1504.05162
GGM $\chi_1^0 \to Z\tilde{G}$ | displaced vtx + jets | 20.3 | χ_1^0 lifetime | 6-480 mm | $m(\tilde{g})$ = 1.1 TeV, $m(\chi_1^0)$ = 1.0 TeV | 1504.05162
AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$ | disappearing track | 20.3 | $\chi_1^\pm$ lifetime | 0.22-3.0 m | $m(\chi_1^\pm)$ = 450 GeV | 1310.3675
AMSB $pp \to \chi_1^\pm\chi_1^0, \chi_1^+\chi_1^-$ | large pixel dE/dx | 18.4 | $\chi_1^\pm$ lifetime | 1.31-9.0 m | $m(\chi_1^\pm)$ = 450 GeV | 1506.05332
GMSB | non-pointing or delayed γ | 20.3 | χ_1^0 lifetime | 0.08-5.4 m | SPS8 with Λ = 200 TeV | 1409.5542
Stealth SUSY | 2 ID/MS vertices | 19.5 | $\tilde{S}$ lifetime | 0.12-90.6 m | $m(\tilde{g})$ = 500 GeV | 1504.03634
Higgs BR = 10%
Hidden Valley $H \to \pi_v\pi_v$ | 2 low-EMF trackless jets | 20.3 | π_v lifetime | 0.41-7.57 m | $m(\pi_v)$ = 25 GeV | 1501.04020
Hidden Valley $H \to \pi_v\pi_v$ | 2 ID/MS vertices | 19.5 | π_v lifetime | 0.31-25.4 m | $m(\pi_v)$ = 25 GeV | 1504.03634
FRVZ $H \to 2\gamma_d + X$ | 2 $e-, \mu-, \pi-$jets | 20.3 | γ_d lifetime | 14-140 mm | $H \to 2\gamma_d + X$, $m(\gamma_d)$ = 400 MeV | 1409.0746
FRVZ $H \to 4\gamma_d + X$ | 2 $e-, \mu-, \pi-$jets | 20.3 | γ_d lifetime | 15-260 mm | $H \to 4\gamma_d + X$, $m(\gamma_d)$ = 400 MeV | 1409.0746
Higgs BR = 5%
Hidden Valley $H \to \pi_v\pi_v$ | 2 low-EMF trackless jets | 20.3 | π_v lifetime | 0.6-5.0 m | $m(\pi_v)$ = 25 GeV | 1501.04020
Hidden Valley $H \to \pi_v\pi_v$ | 2 ID/MS vertices | 19.5 | π_v lifetime | 0.43-18.1 m | $m(\pi_v)$ = 25 GeV | 1504.03634
FRVZ $H \to 4\gamma_d + X$ | 2 $e-, \mu-, \pi-$jets | 20.3 | γ_d lifetime | 28-160 mm | $H \to 4\gamma_d + X$, $m(\gamma_d)$ = 400 MeV | 1409.0746
300 GeV scalar
Hidden Valley $\Phi \to \pi_v\pi_v$ | 2 low-EMF trackless jets | 20.3 | π_v lifetime | 0.29-7.9 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1501.04020
Hidden Valley $\Phi \to \pi_v\pi_v$ | 2 ID/MS vertices | 19.5 | π_v lifetime | 0.19-31.9 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1504.03634
900 GeV scalar
Hidden Valley $\Phi \to \pi_v\pi_v$ | 2 low-EMF trackless jets | 20.3 | π_v lifetime | 0.15-4.1 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1501.04020
Hidden Valley $\Phi \to \pi_v\pi_v$ | 2 ID/MS vertices | 19.5 | π_v lifetime | 0.11-18.3 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1504.03634
Other
HV Z'(1 TeV) $\to q_v q_v$ | 2 ID/MS vertices | 20.3 | π_v lifetime | 0.1-4.9 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1504.03634
HV Z'(2 TeV) $\to q_v q_v$ | 2 ID/MS vertices | 20.3 | π_v lifetime | 0.1-10.1 m | $\sigma\times$BR = 1 pb, $m(\pi_v)$ = 50 GeV | 1504.03634
0.01
0.1
1
10
100
$c\tau$ [m]
$\sqrt{s}$ = 8 TeV
*Only a selection of the available lifetime limits on new states is shown.


Standard Model Total Production Cross Section Measurements
Status: March 2018
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: July 2017
ATLAS Long-lived Particle Searches* - 95% CL Exclusion
Status: July 2015
huge number of analyses covering all regions of NP

analysis strategies

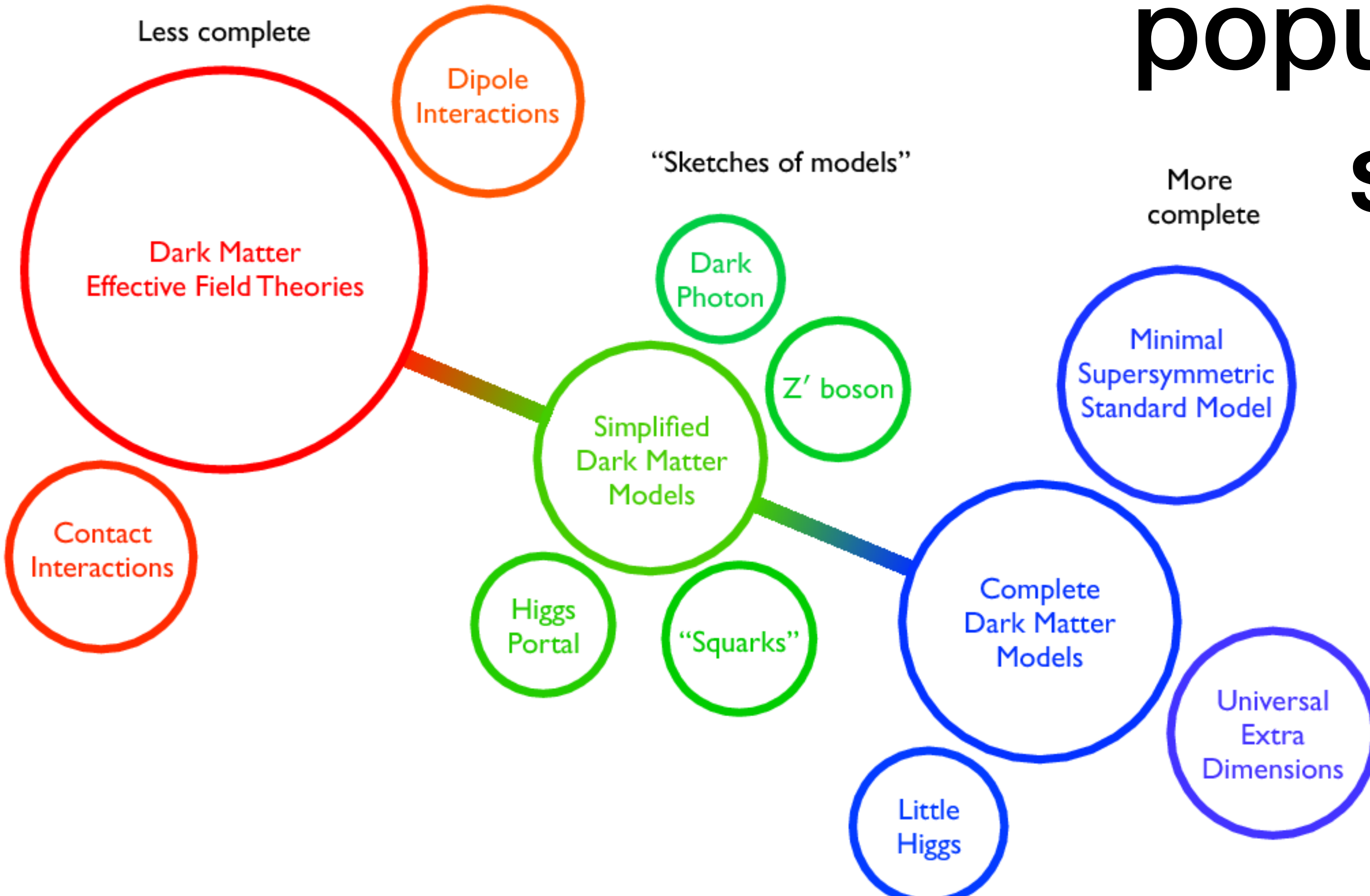
- searches are continuously becoming more complex
- in 2010 simple cut and count searches with a few SR
- now, searches are extremely intricate with very advanced analysis techniques such as mT2 type variables, jet substructures, BDT, NN and so on
- focus on non standard signatures like LLP searches
- hundreds to thousands of complex SR



H. Murayama

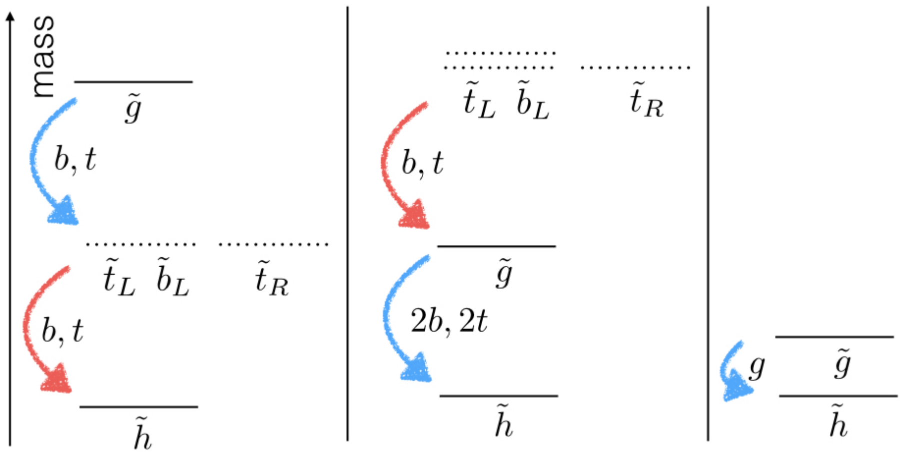
however,
do we really
cover all models?

experimentalists have interpreted results in terms of popular BSM, simplified models and EFT

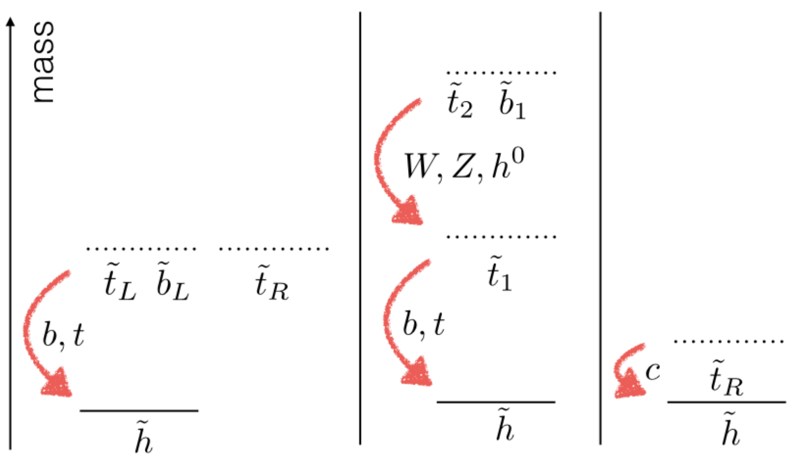


1506.03116

- the limits shown by ATLAS and CMS depend on many assumptions
    - particle content
    - couplings
    - mass hierarchy
- production modes, decay channels and branching ratios can change drastically



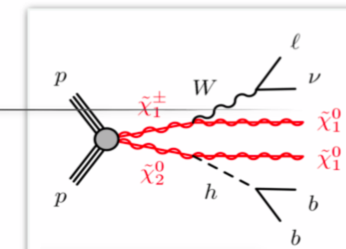
gluino included



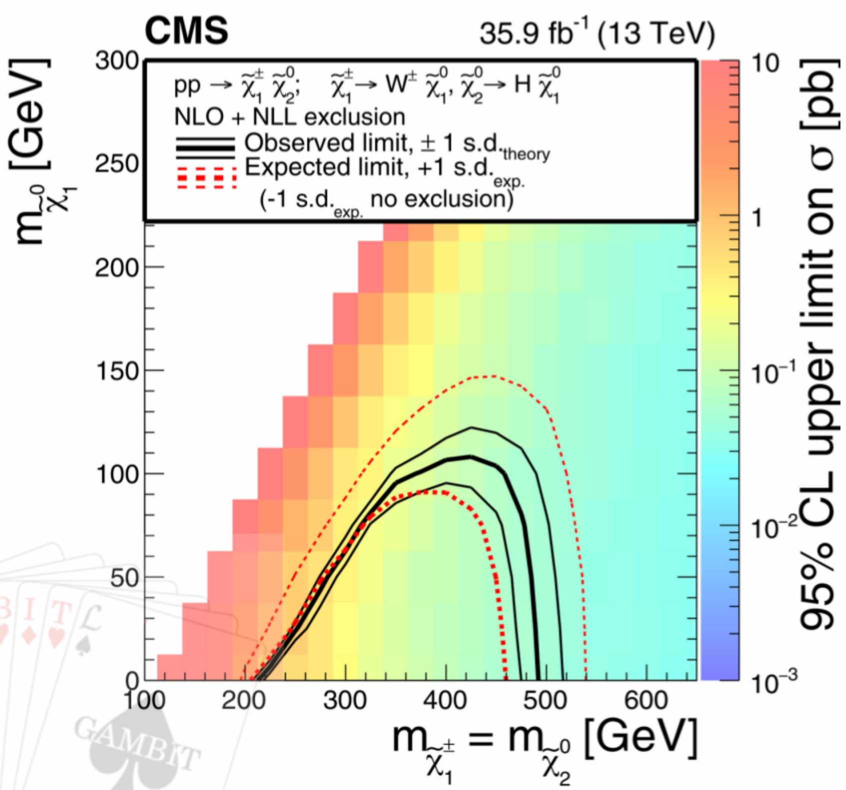
gluino decoupled

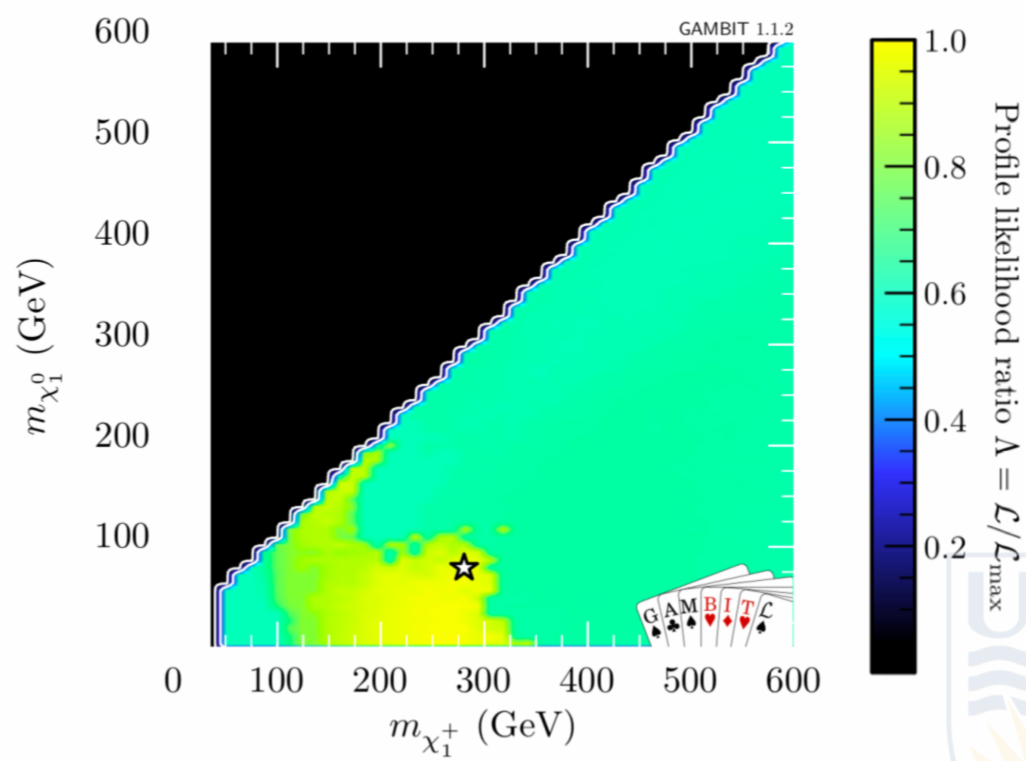
drastic changes of limits...

CMS 1lep(H)bb comparison

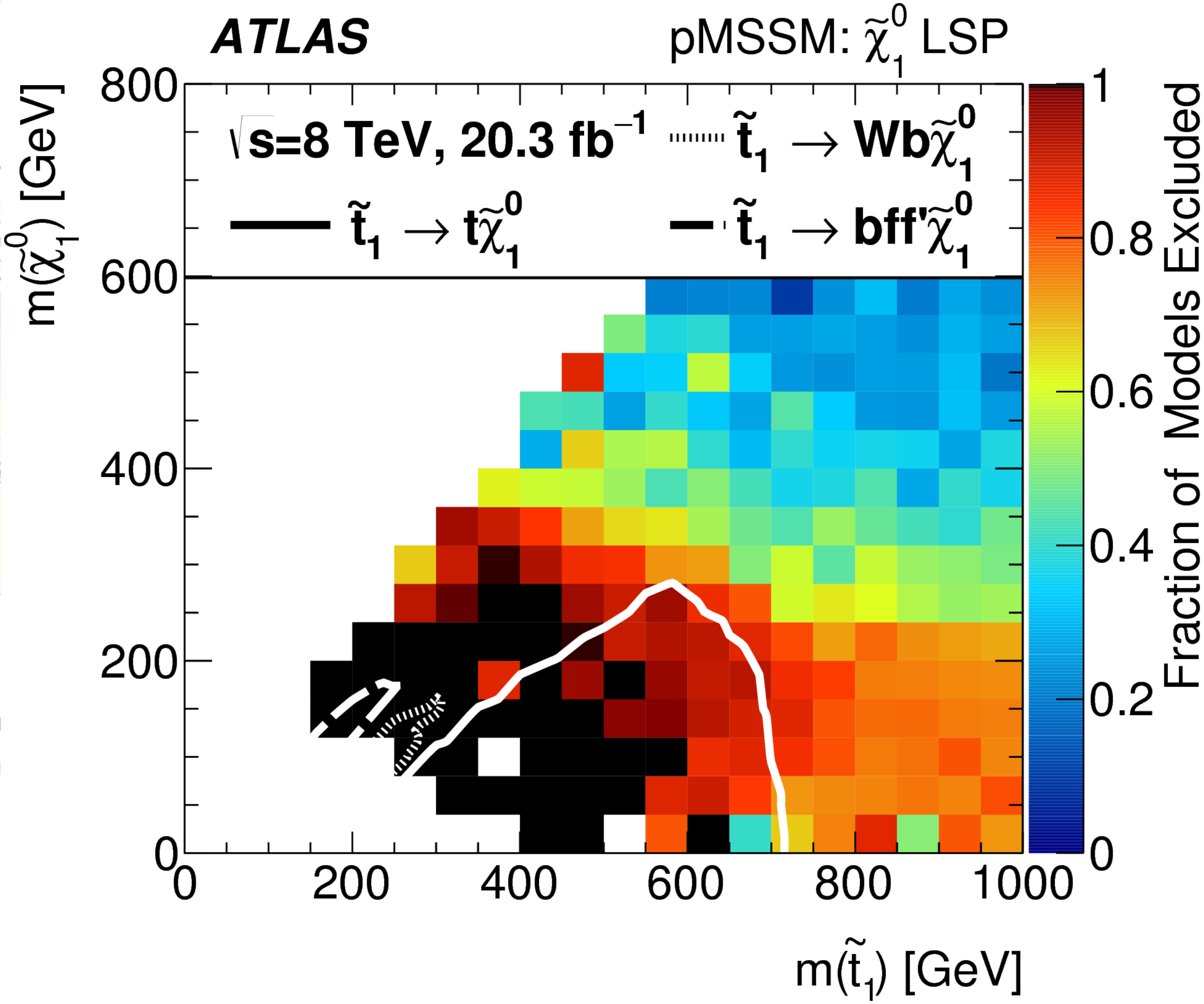


- Almost no models constrained





- Almost no mo



...another example

- simplified model limits are too strong/optimistic
- simplified model signatures cannot cover a complete model.
- we want to test all possible models and their signatures
- but how can phenomenologists (re)interpret experimental results?

we could ask the experimentalists

we could ask the experimentalists

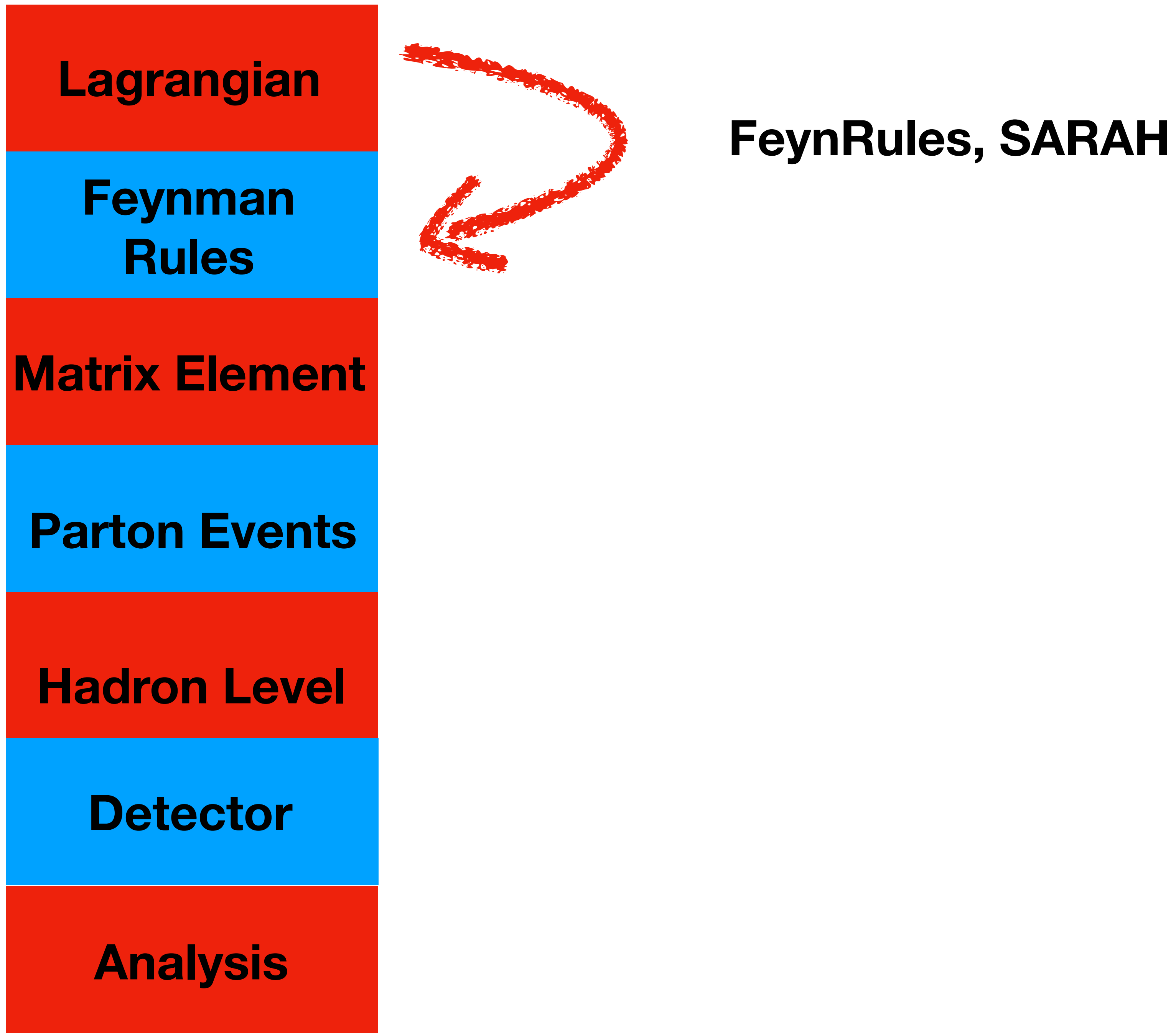
probable answer: no

~~we could ask the experimentalists~~

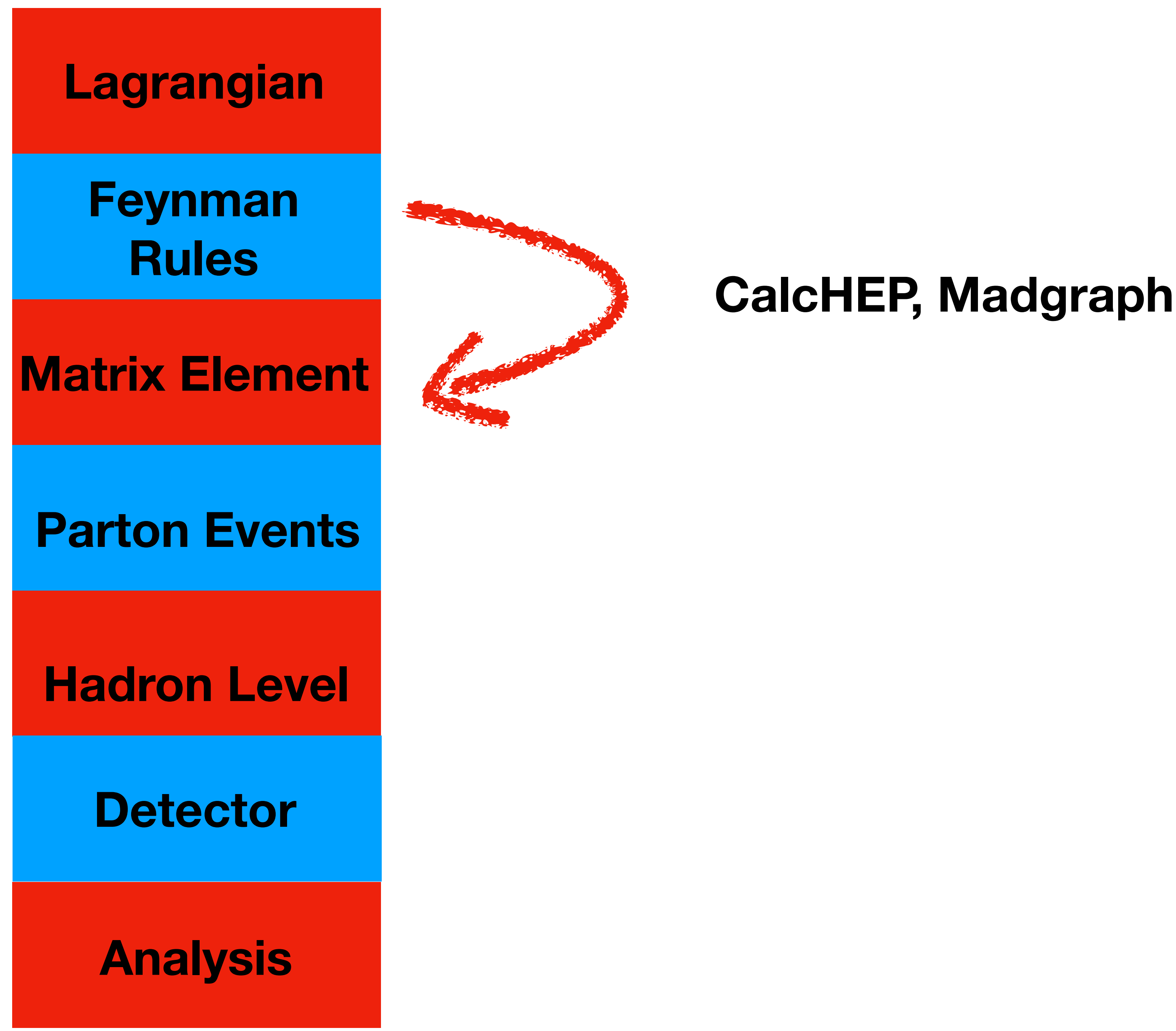
we make our own reinterpretation of the LHC data

Recasting Chain

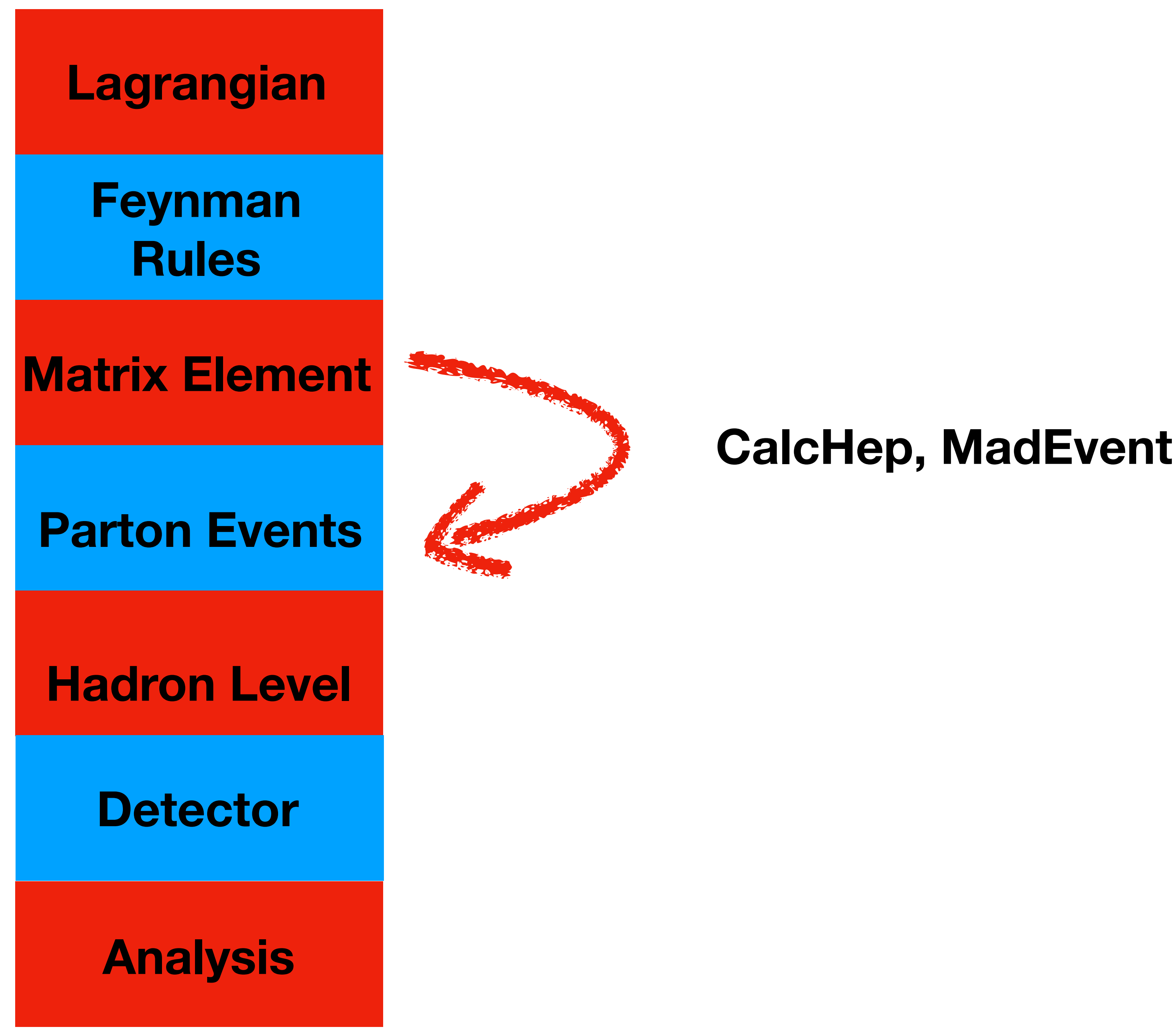
Recasting Chain



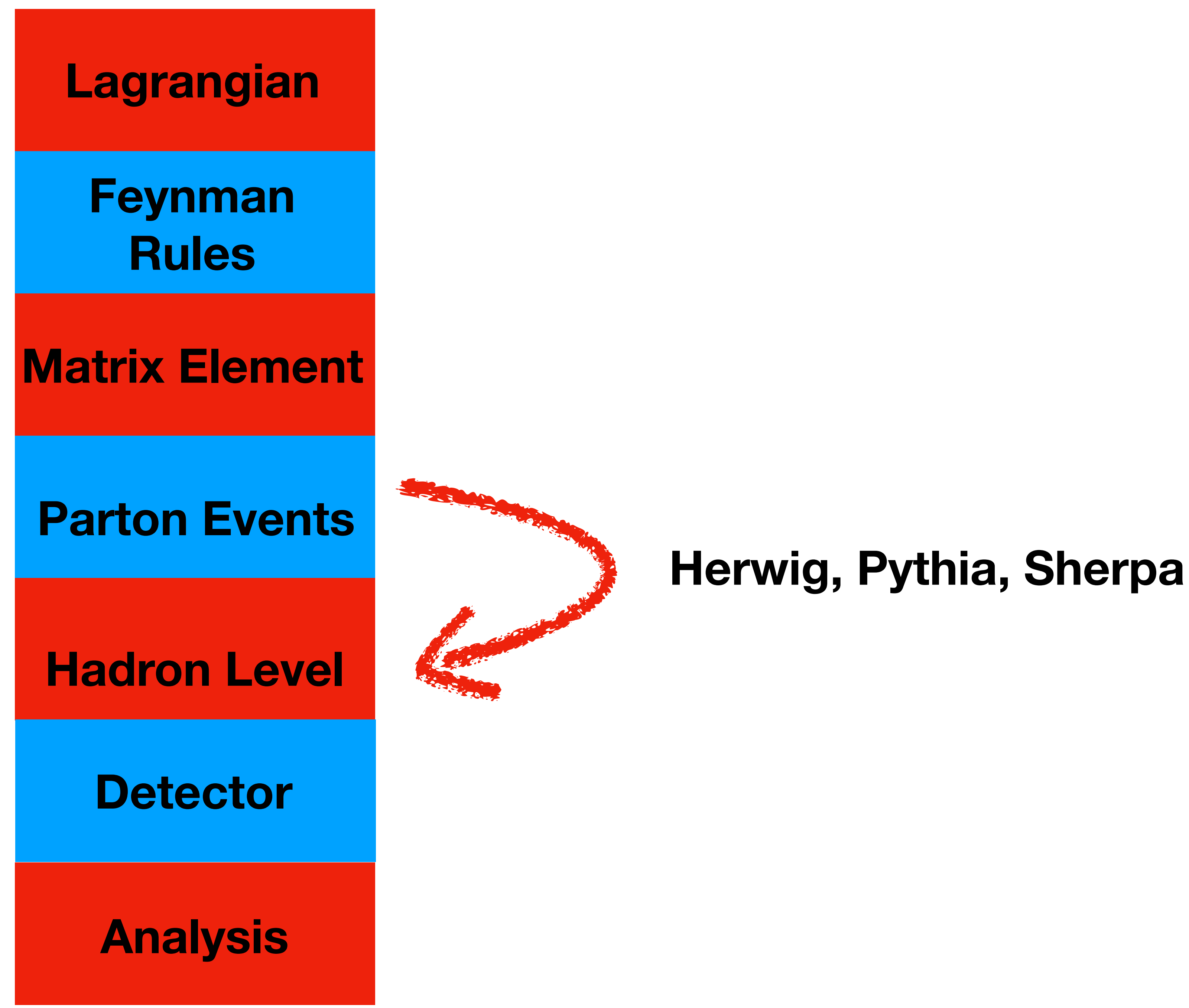
Recasting Chain



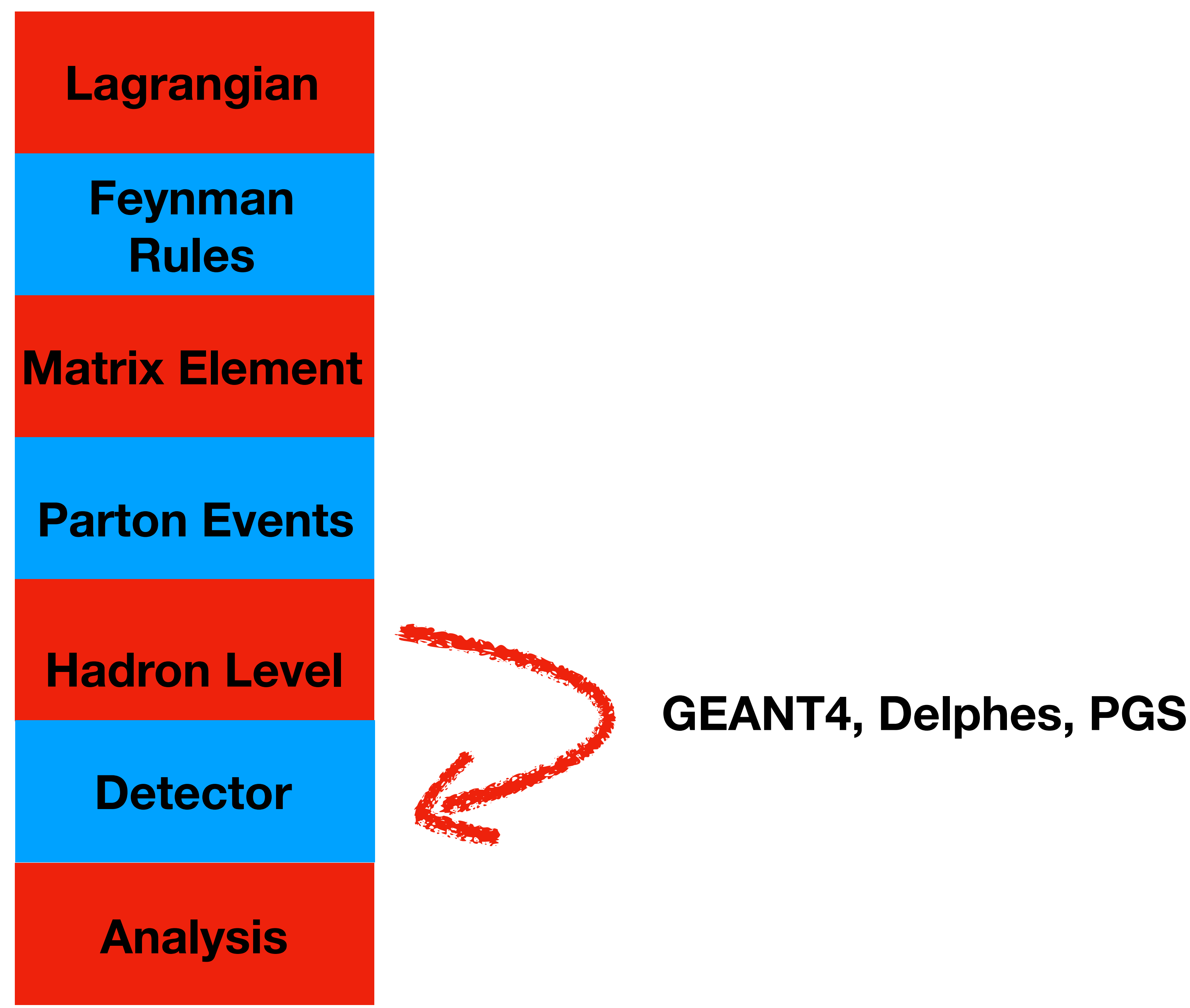
Recasting Chain



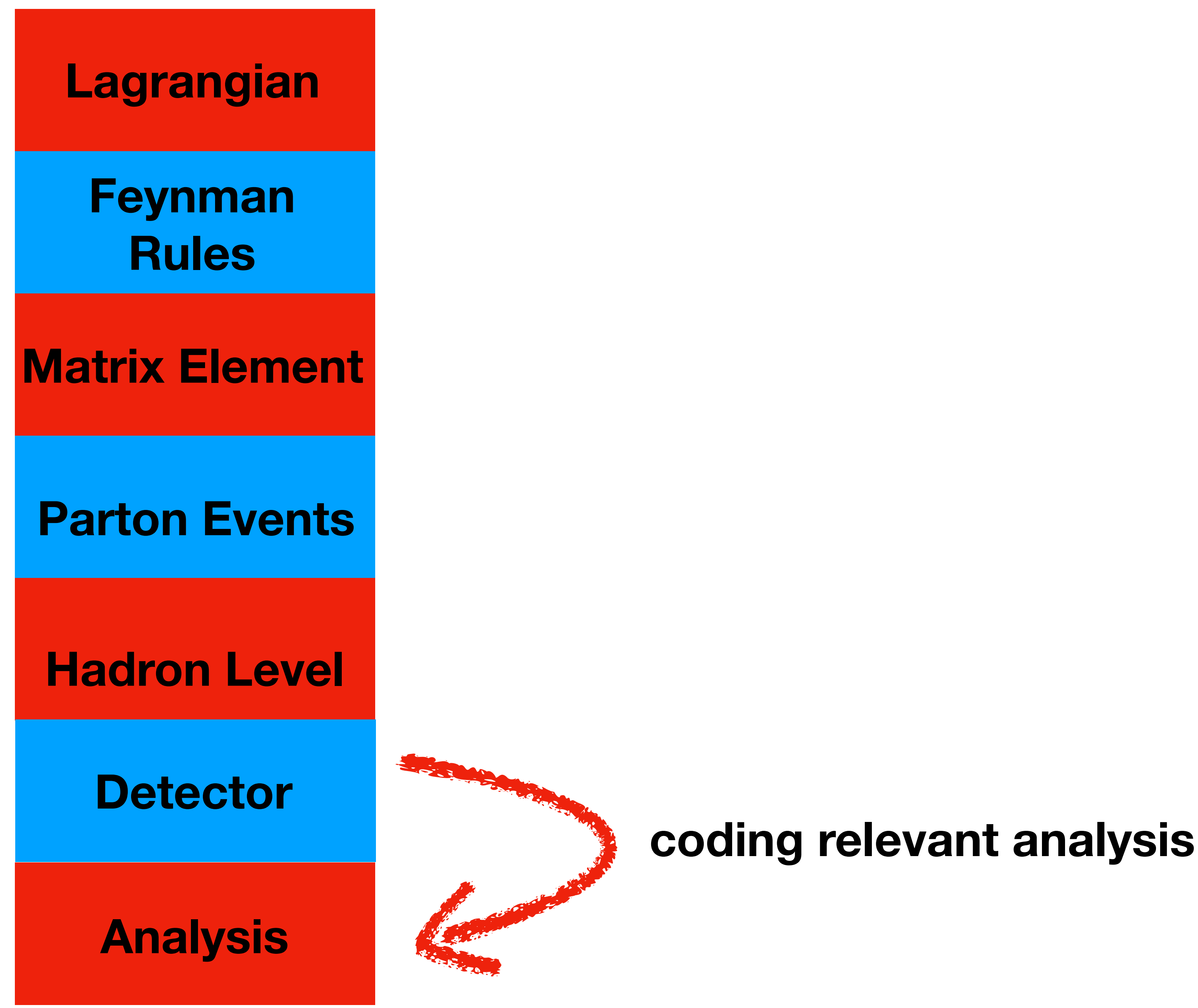
Recasting Chain



Recasting Chain



Recasting Chain



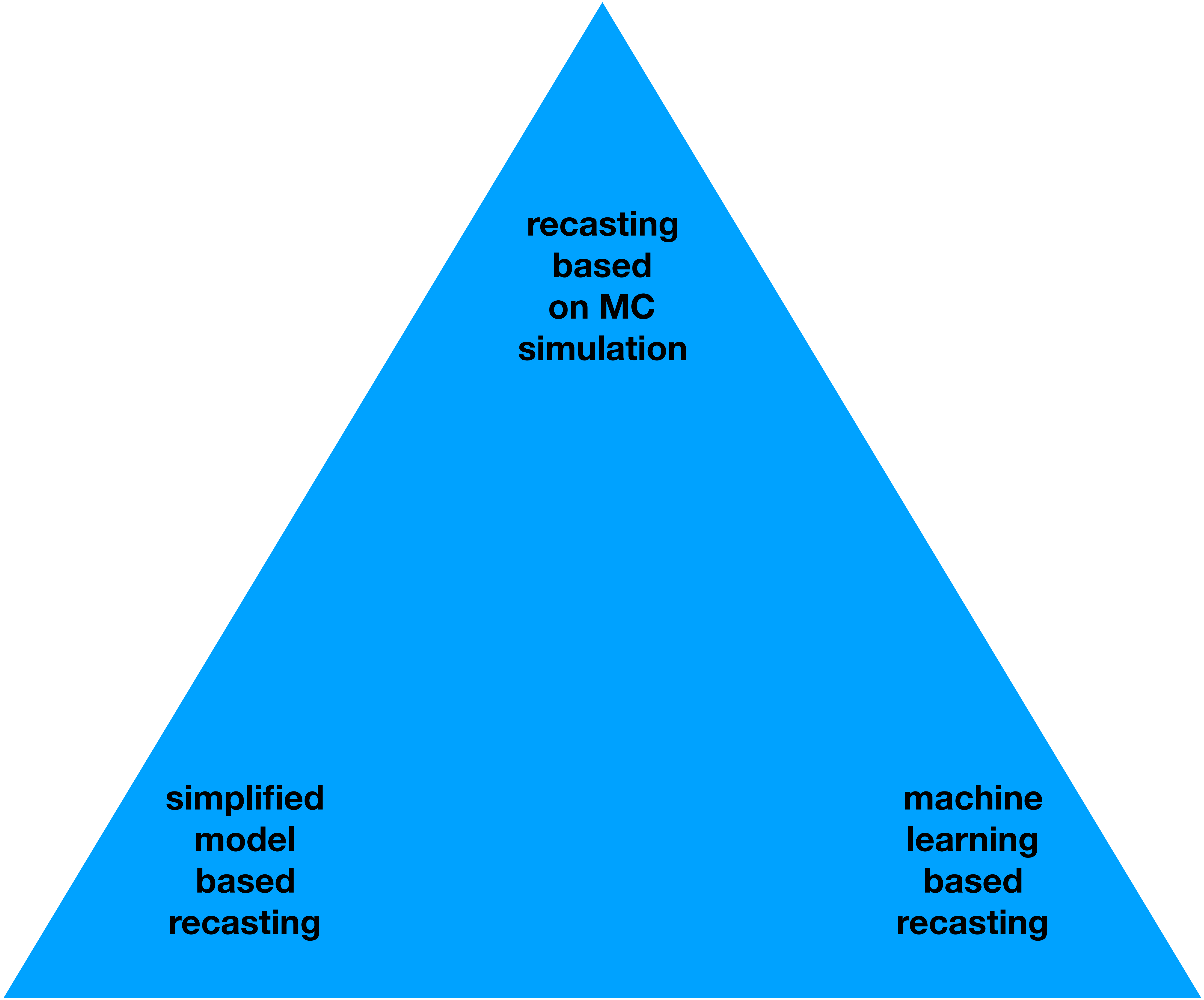
this is already a
formidable
task!

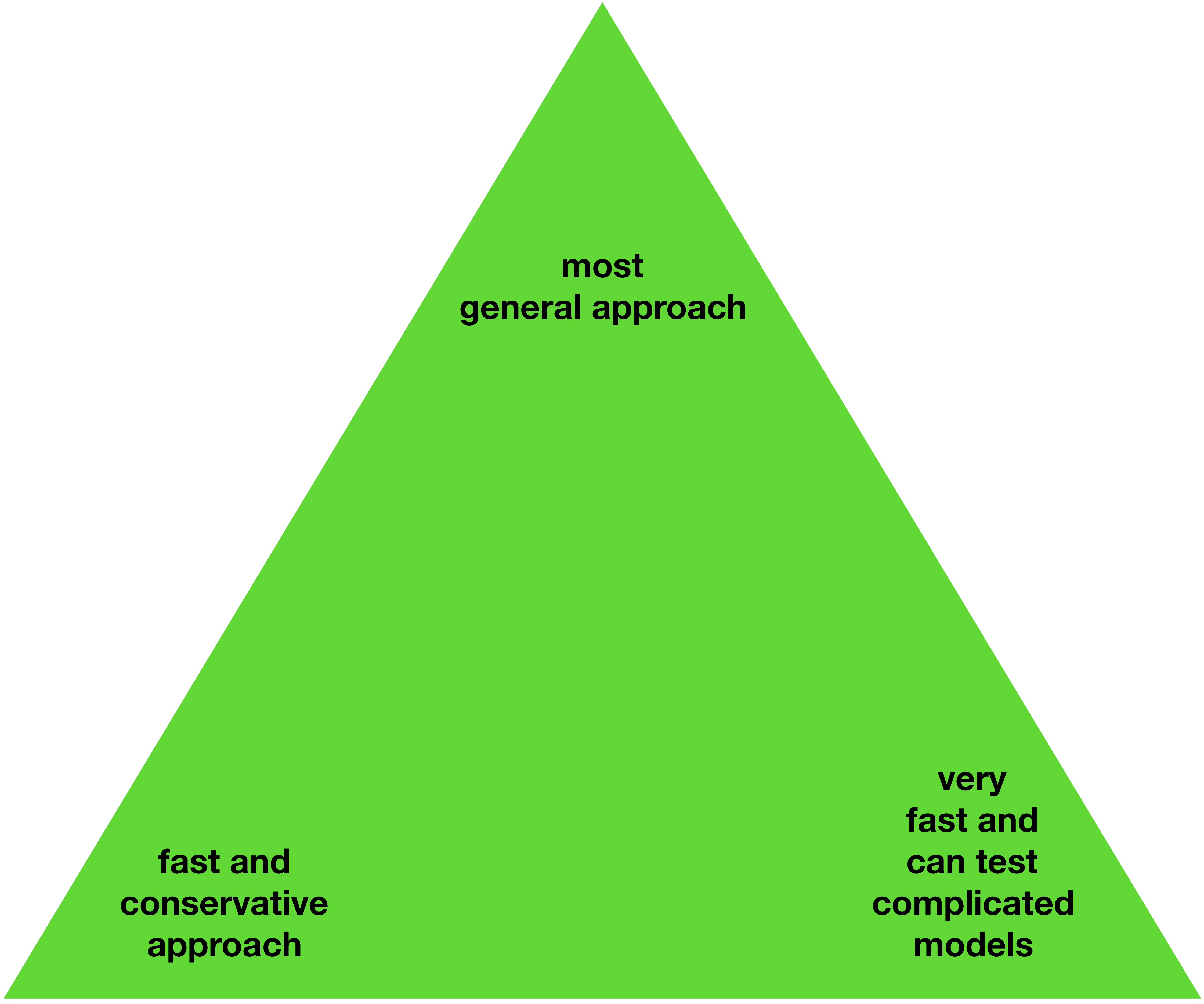
... and super
time consuming
and extremely boring

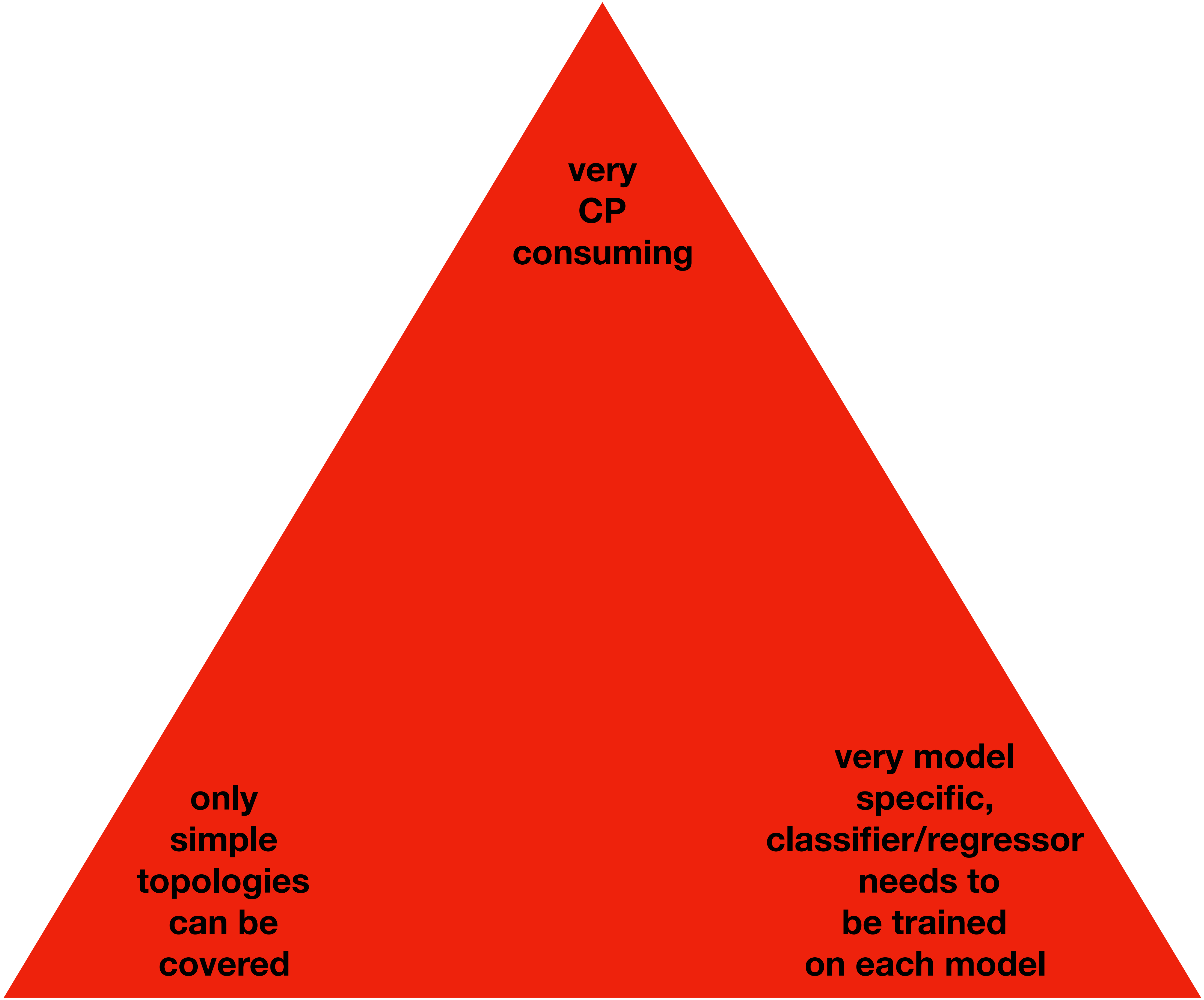
our idea

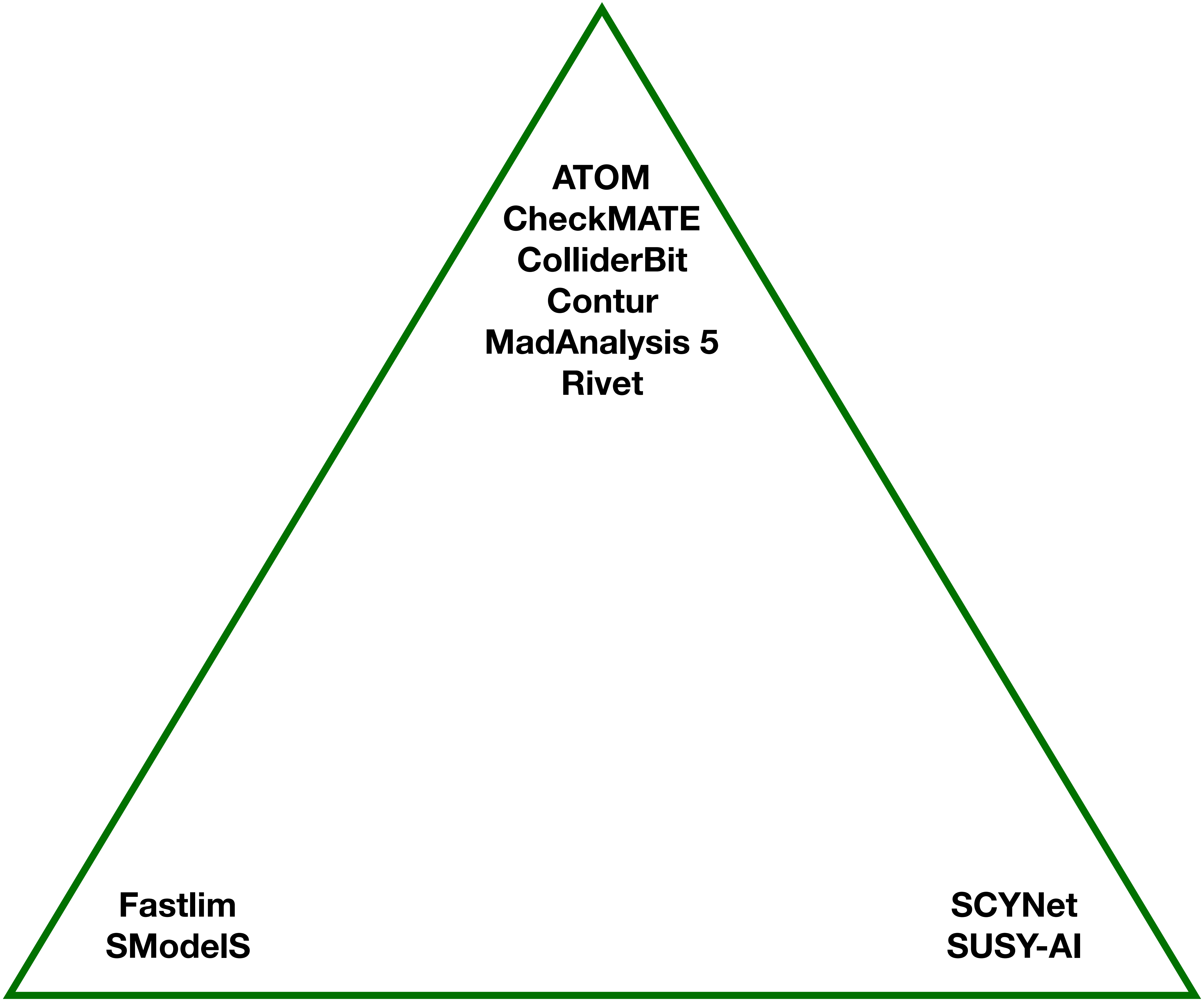
provide your Lagrangian and we
tell you whether your BSM is allowed

how?


recasting based on MC simulation
simplified model based recasting
machine learning based recasting


most
general approach
fast and
conservative
approach
very
fast and
can test
complicated
models


very
CP
consuming
only
simple
topologies
can be
covered
very model
specific,
classifier/regressor
needs to
be trained
on each model


ATOM
CheckMATE
ColliderBit
Contur
MadAnalysis 5
Rivet
Fastlim
SModelS
SCYNet
SUSY-AI

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
- **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

Other workshops, potentially interesting for our forum

- Searches for Long Lived particles 2nd workshop, 17-20 Oct 2017, ICTP Trieste
- The Les Houches PhysTev2017 workshop will have a strong activity on interpreting LHC results; the BSM session in LH is taking place 14-23 June 2017.
- 2nd LHC Long-Lived Particle workshop, CERN, 24-26 April 2017, "to address the status and future of beyond-the-Standard Model LLP searches at the ATLAS, CMS, and LHCb experiments, as well as auxiliary LHC detectors and projects".
- 6th edition of the workshop "Implications of LHCb measurements and future prospects", CERN, 12-14 October 2016. NB participation is restricted to the members of the LHCb Collaboration, and of interested theorists.

Mailing list

- CERN e-group: info-LHC-interpretation@cernNOSPAMPLEASE.ch
- To subscribe, go to https://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=info-lhc-interpretation

Steering group

The steering group comprises a representative of each of the public recasting tools as well as a couple of individual LHC physicists. Current members are:

Jon Butterworth, Andy Buckley, Kyle Cranmer, Daniel Dercks, Matthias Danninger, Matthew Dolan, Benjamin Fuks, Marie-Helene Genest, Ahmed Ismail, Sabine Kraml, Frank Krauss, Michael Krämer, Nazila Mahmoudi, Michelangelo Mangano, Stefano Moretti, Pat Scott, Sezen Sekmen, Wolfgang Waltenberger, Nick Wardle, Andreas Weiler.

Mailing list: : info-LHC-interpretation-organisers@cernNOSPAMPLEASE.ch

CHECKMATE

www.hepforge.checkmate.org

CheckMATE group

Daniel Dercks (Hamburg University)

Nishita Desai (University of Montpellier)

Florian Domingo (IFT-CSIC, Madrid)

Lukas Heinrich (New York University)

Jong Soo Kim (University of the Witwatersrand)

Sung Hak Lim (KEK)

Krzysztof Rolbiecki (University of Warsaw)

Roberto Ruiz de Austri (IFIC, Valencia)

Liangliang Shang (Henan Normal University, Xinxiang)

Torsten Weber (RWTH Aachen)

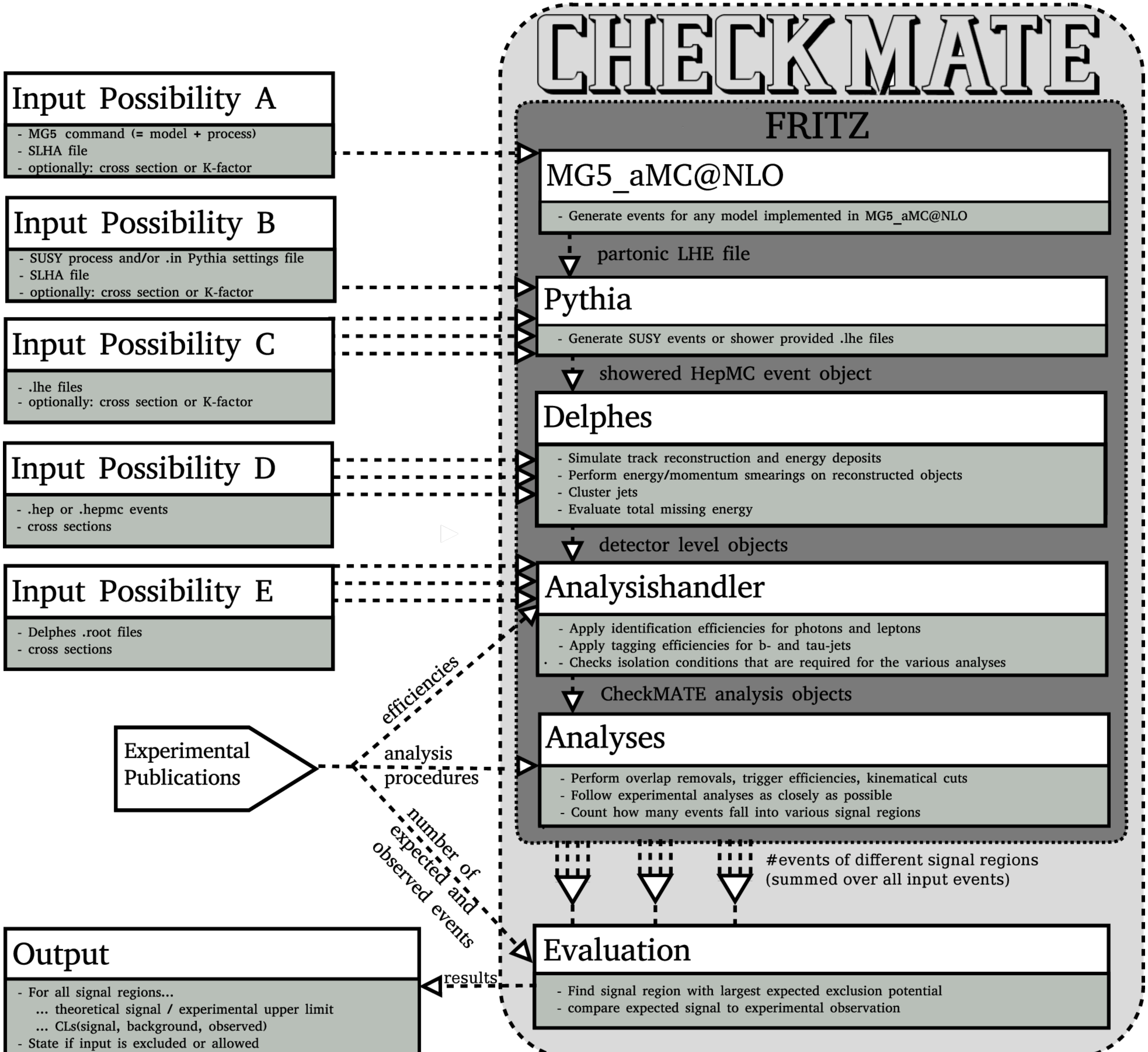
Yuanfang Yue (Henan Normal University, Xinxiang)

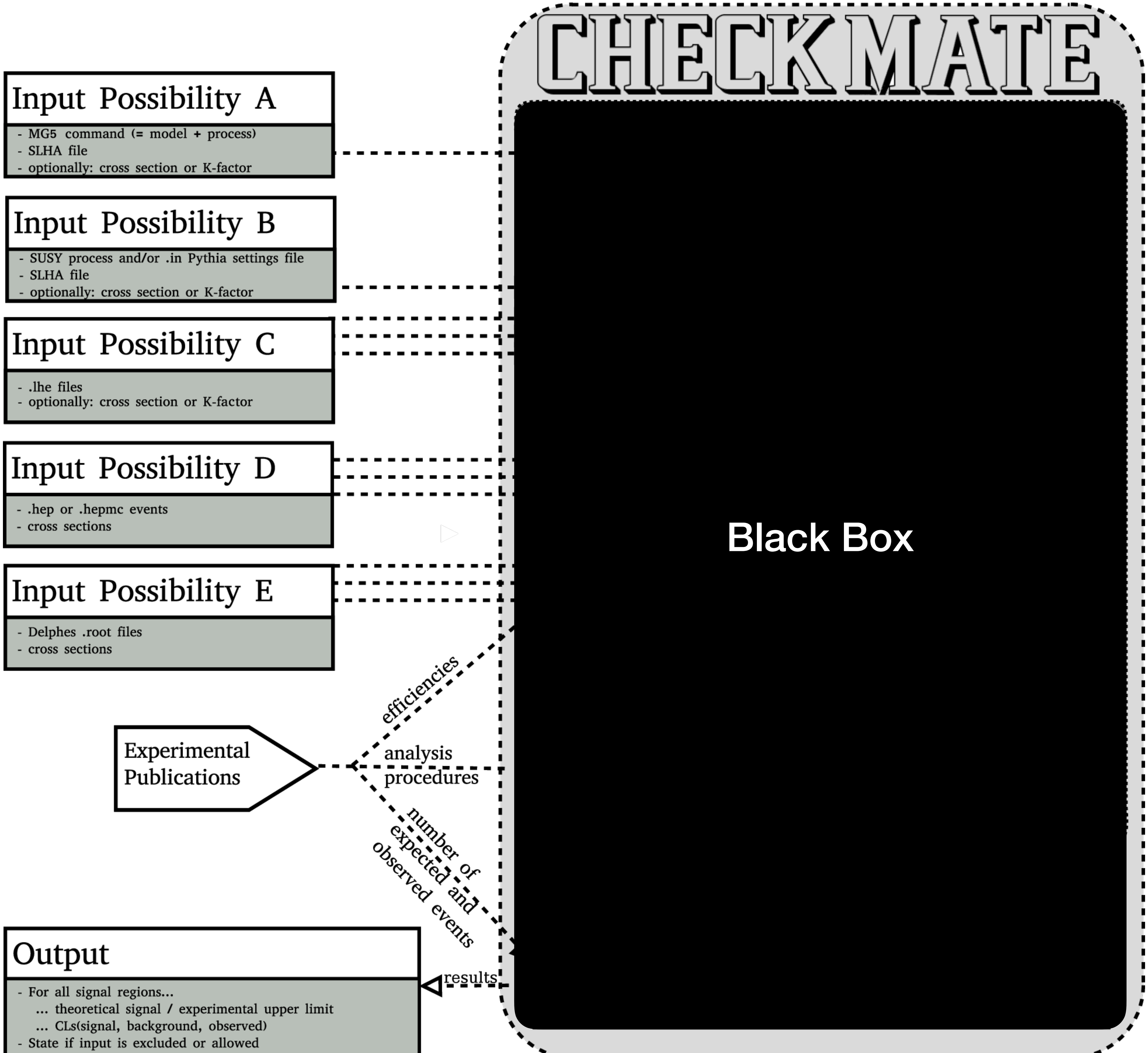
Former Members

Manuel Drees

Herbi Dreiner

Jamie Tattersall


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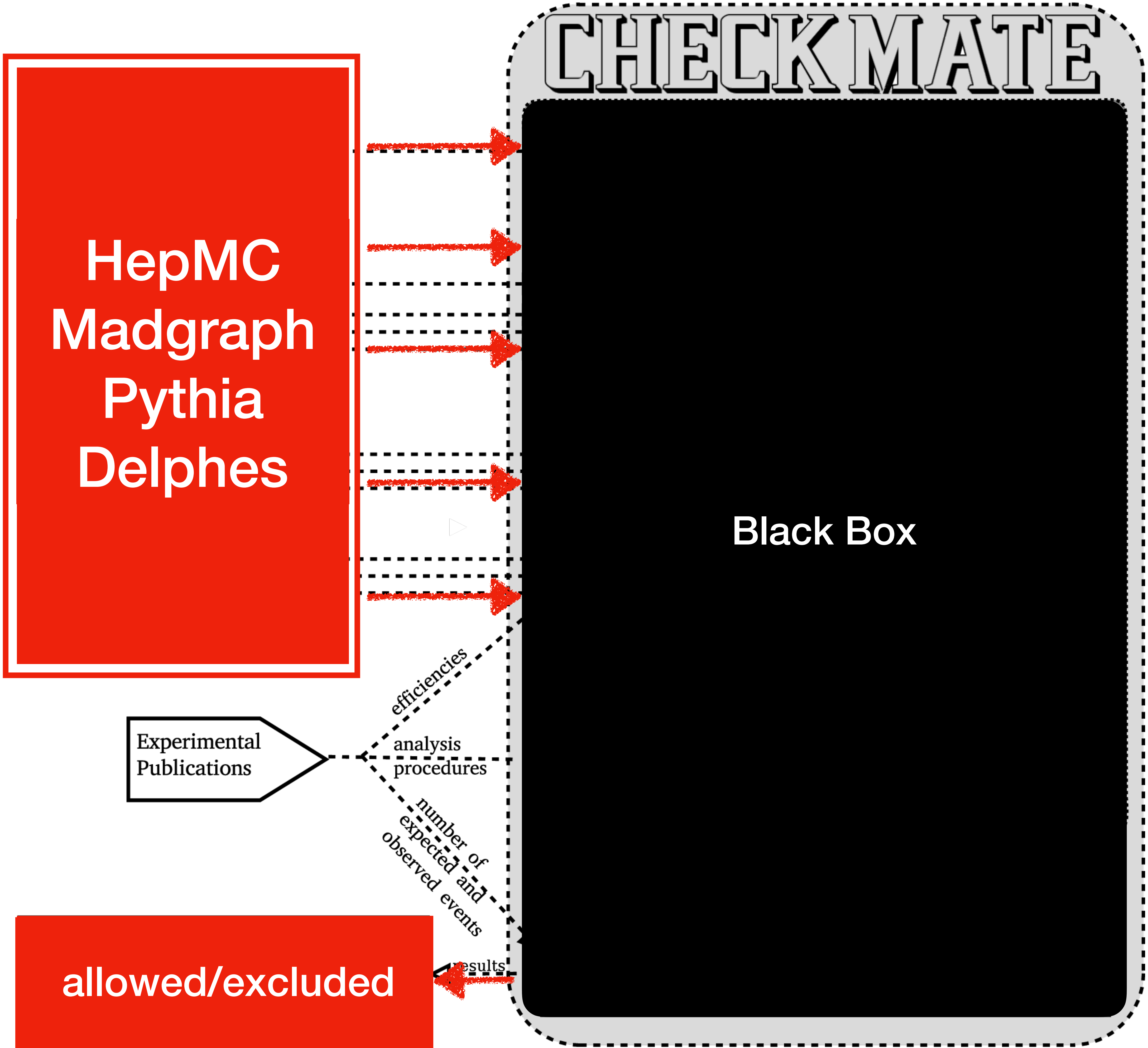
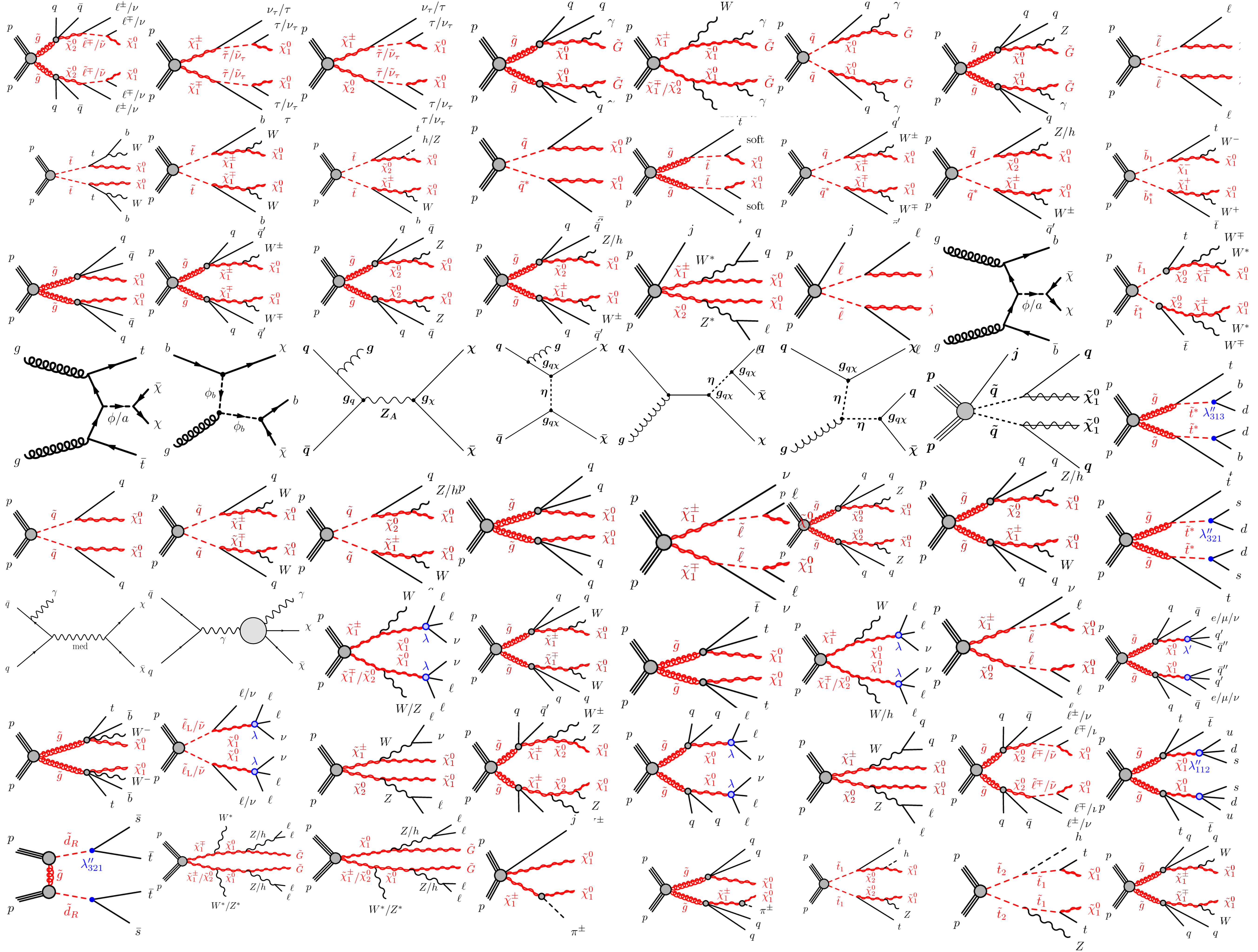


CHECKMATE
HepMC
Madgraph
Pythia
Delphes
Black Box
efficiencies
Experimental
Publications
analysis
procedures
number of
expected and
observed events
allowed/excluded

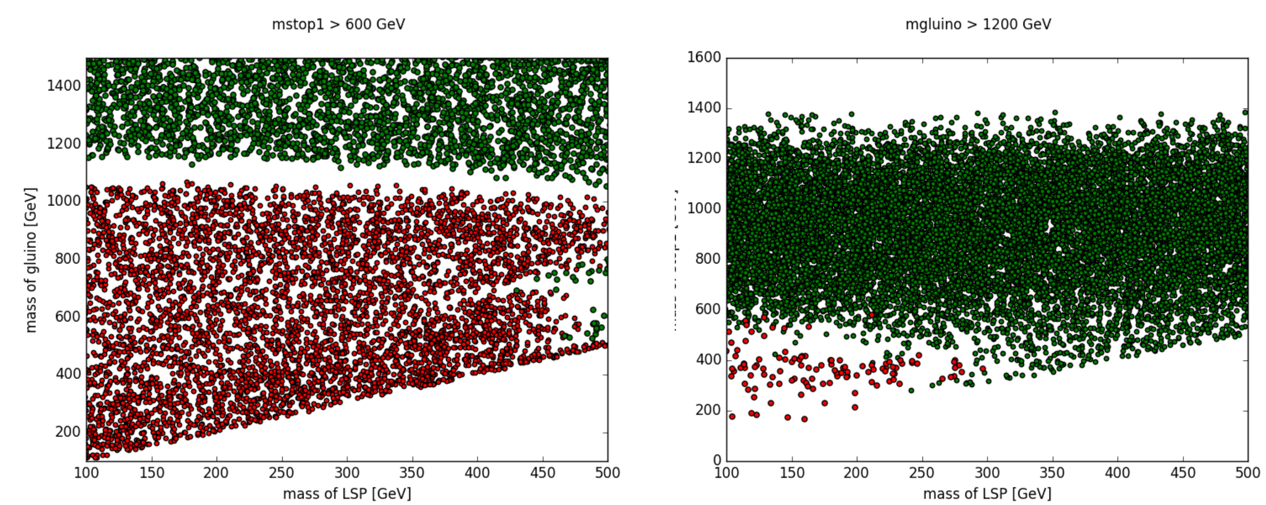
what BSM signatures are covered?



a few examples

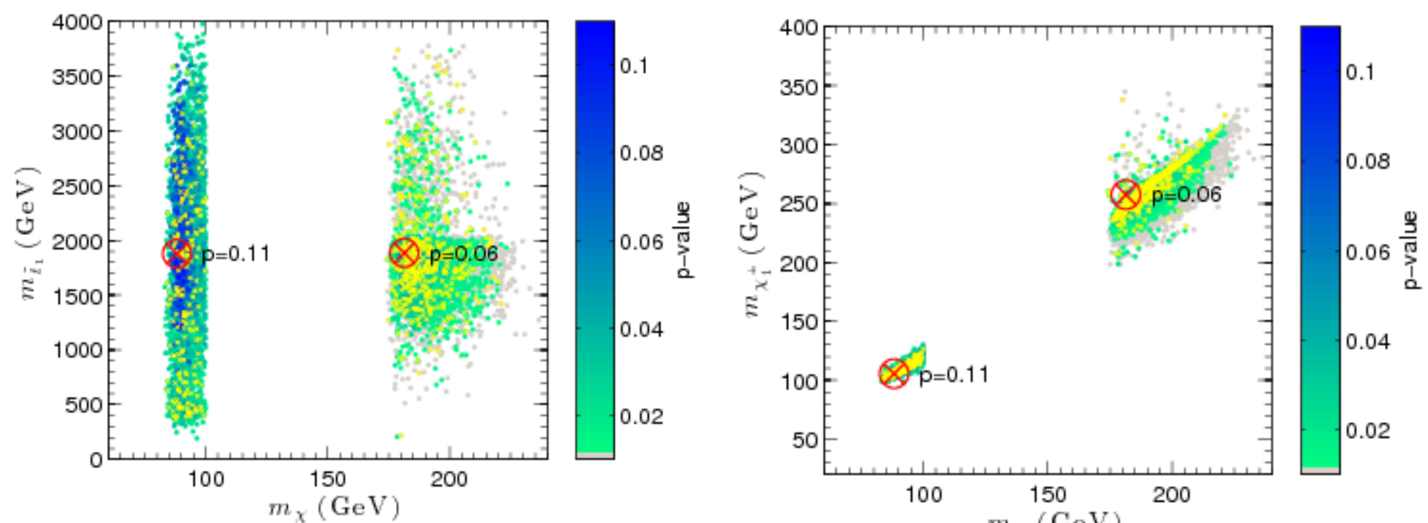
Minimal Natural SUSY after LHC8 (1511.04461)

- 6D natural SUSY random scan
- all relevant 8 TeV searches were included
- derived mass limits for lightest stop and gluino which were not excluded



Global analysis of the pMSSM in light of the Fermi GeV excess: prospects for the LHC Run-II and astroparticle experiments (1507.07008)

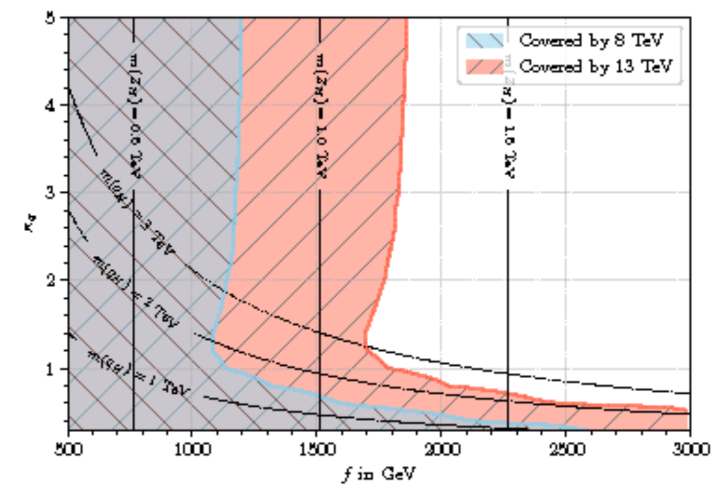
- in this analysis, the Fermi excess was accommodated in the pMSSM19
- global fit taking into account all pheno constraints
- all model points were tested against 8 TeV LHC searches



a few examples

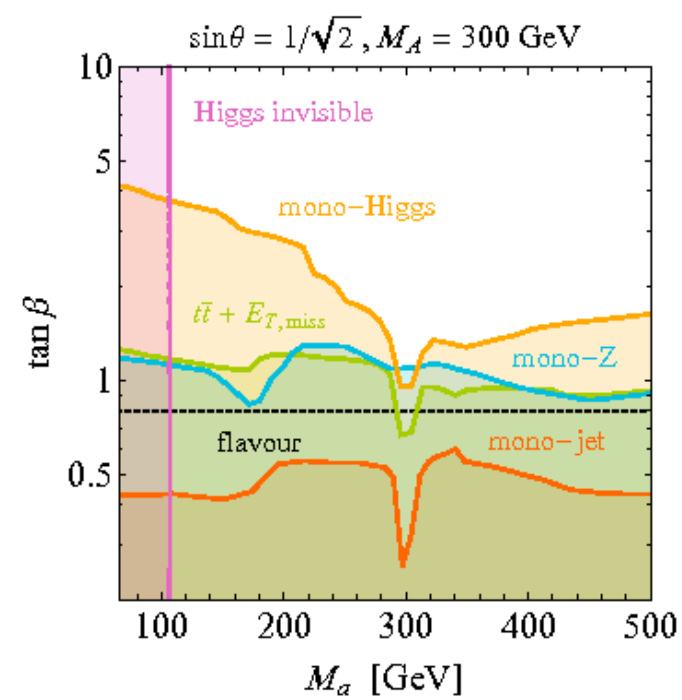
Little Higgs Model with T-Parity under 13 TeV LHC data (1801.06499)

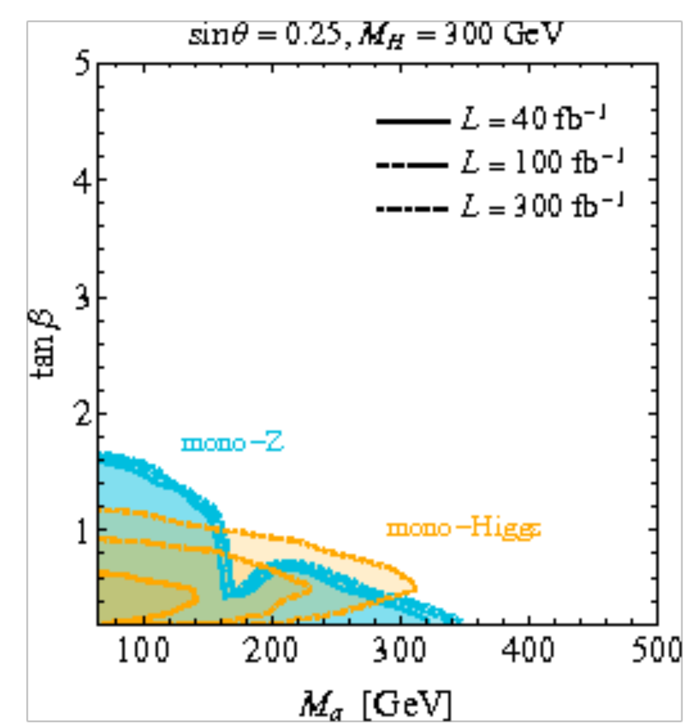
- little Higgs models with T parity have similar final state signatures as SUSY
- the authors tested model points against all available 13 TeV searches in CM
- also discussed the HL-LHC scenario



Simplified dark matter models with two Higgs doublets: I. Pseudoscalar mediators (1701.07427)

- model was tested against future mono Z, mono H and tt + MET searches
- the authors used CM for the whole MC chain
- searches were implemented in CM

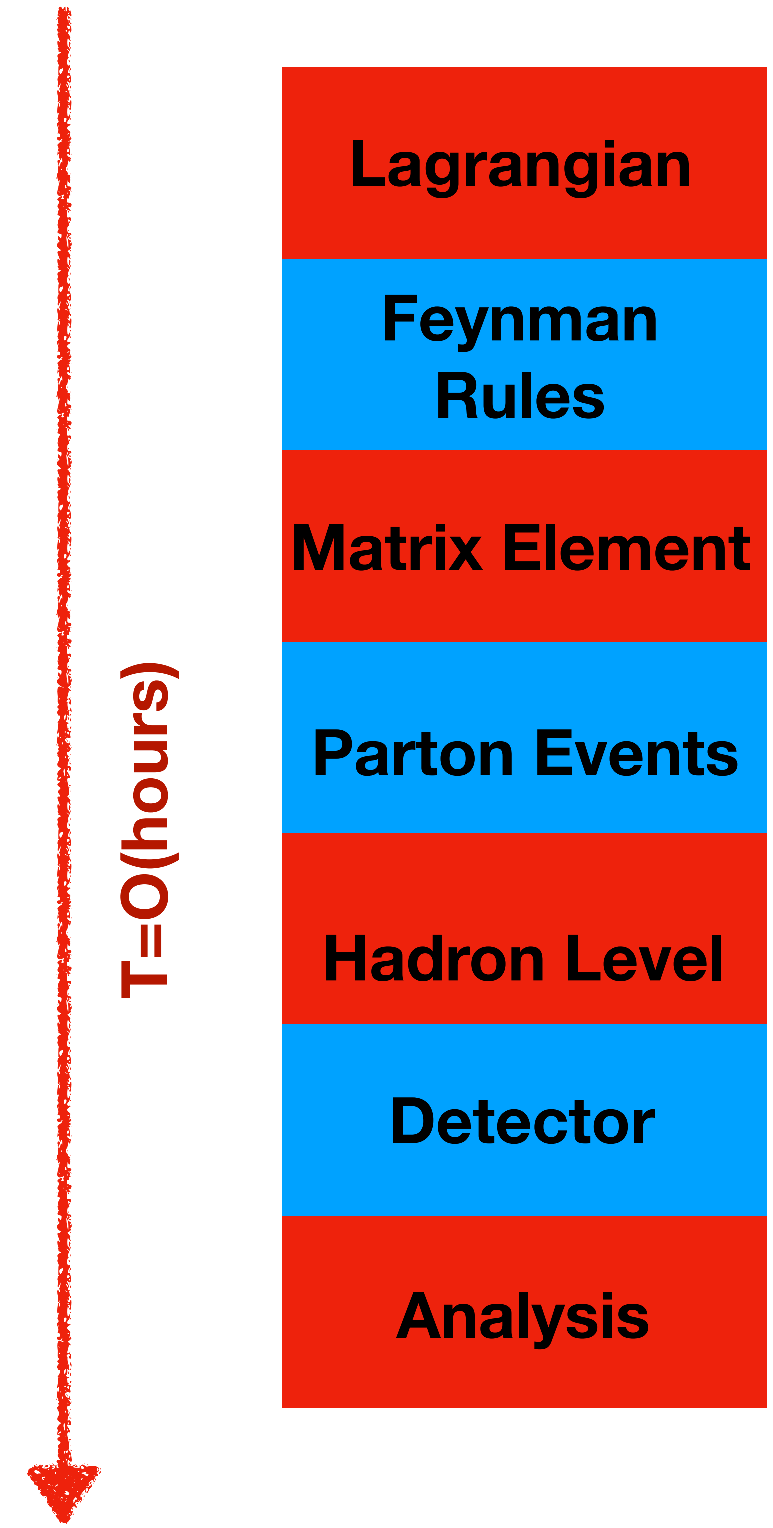




analysis preservation

- the possibility to recycle LHC searches
- ATLAS and CMS have started to study analysis preservation
- we need analysis preservation for phenomenologists
- recasting tools such as CheckMATE, MadAnalaysis and Rivet are very important for analysis preservation

reconsider the recasting chain

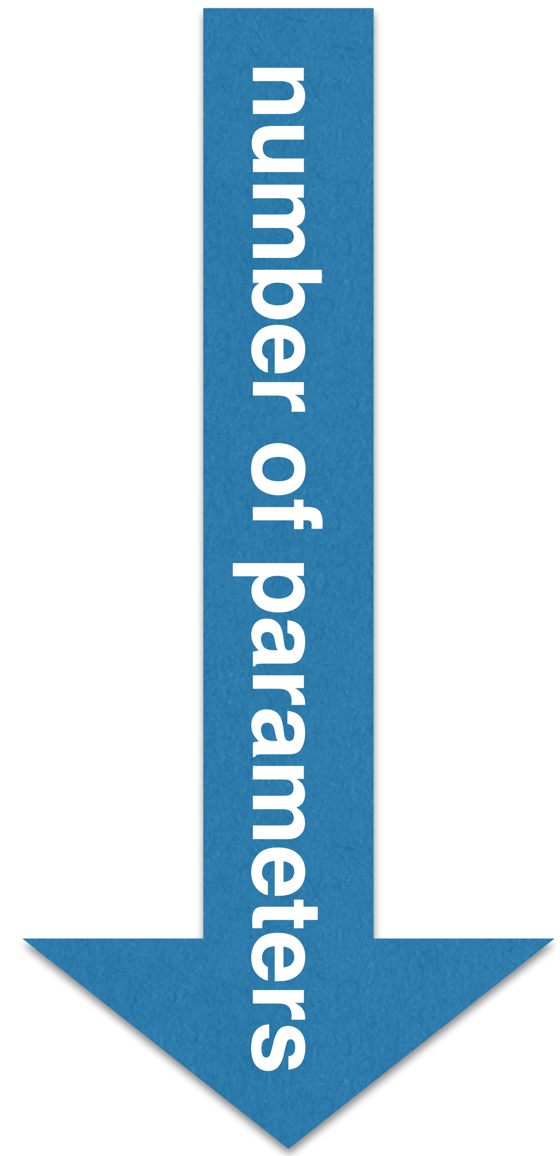


Model complexity

simplified models
(1-3 parameters)

constrained models, e.g. mSUGRA
(4-6 parameters)

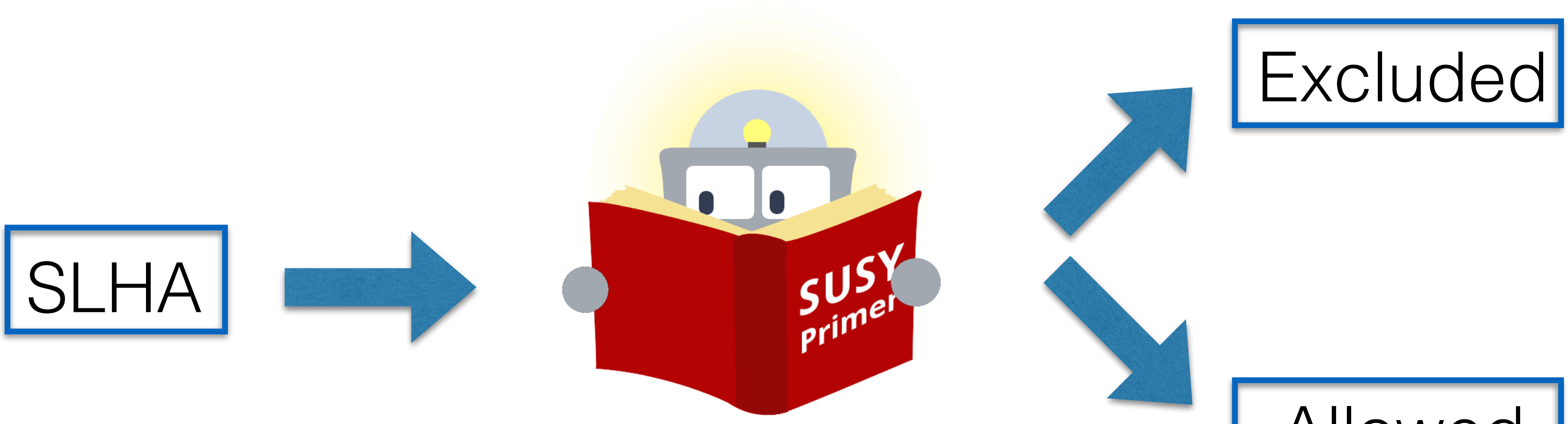
general models, e.g. pMSSM
(7-20 parameters)



with increasing complexity, a general scan of parameter space becomes impractical (curse of dimensionality)

the idea: SUSY-AI

1605.02797



Machine Learning Algorithm

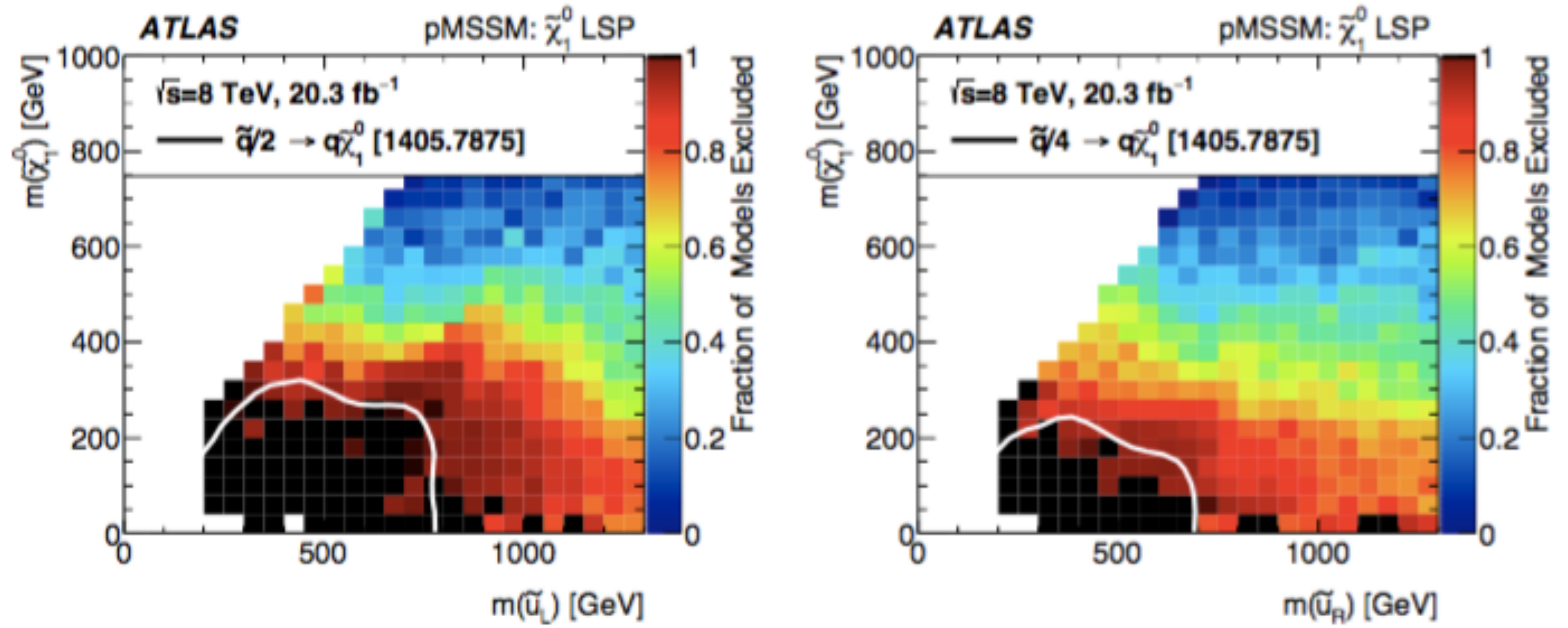
≈ 5000 predictions / CPU second

training data: ATLAS pMSSM-19 study

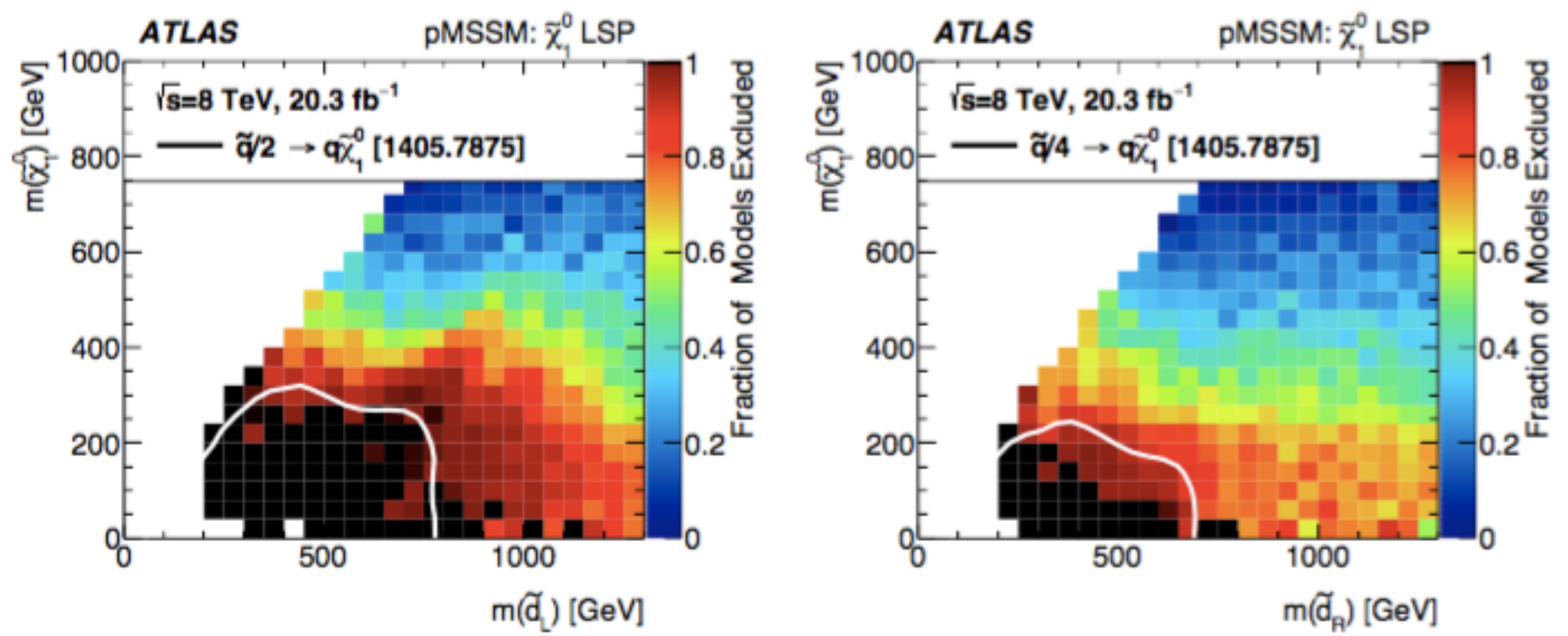
- ATLAS (1508.06608) performed a study on the pMSSM-19
- ATLAS considered 5x10^8 model points based on 1206.4321
- 310,327 model points satisfy all theoretical and experimental constraints

Parameter	Description	Scanned range
$m_{\tilde{L}_1}$	$1^{st}/2^{nd}$ gen. $SU(2)$ doublet soft breaking slepton mass	[90 GeV, 4 TeV]
$m_{\tilde{E}_1}$	$1^{st}/2^{nd}$ gen. $SU(2)$ singlet soft breaking slepton mass	[90 GeV, 4 TeV]
$m_{\tilde{L}_3}$	3^{rd} gen. $SU(2)$ doublet soft breaking slepton mass	[90 GeV, 4 TeV]
$m_{\tilde{E}_3}$	3^{rd} gen. $SU(2)$ singlet soft breaking slepton mass	[90 GeV, 4 TeV]
$m_{\tilde{Q}_1}$	$1^{st}/2^{nd}$ gen. $SU(2)$ doublet soft breaking squark mass	[200 GeV, 4 TeV]
$m_{\tilde{U}_1}$	$1^{st}/2^{nd}$ gen. $SU(2)$ singlet soft breaking squark mass	[200 GeV, 4 TeV]
$m_{\tilde{D}_1}$	$1^{st}/2^{nd}$ gen. $SU(2)$ singlet soft breaking squark mass	[200 GeV, 4 TeV]
$m_{\tilde{Q}_3}$	3^{rd} gen. $SU(2)$ doublet soft breaking squark mass	[100 GeV, 4 TeV]
$m_{\tilde{U}_3}$	3^{rd} gen. $SU(2)$ singlet soft breaking squark mass	[100 GeV, 4 TeV]
$m_{\tilde{D}_3}$	3^{rd} gen. $SU(2)$ singlet soft breaking squark mass	[100 GeV, 4 TeV]
A_t	Stop trilinear coupling	[−8 TeV, 8 TeV]
A_b	Sbottom trilinear coupling	[−4 TeV, 4 TeV]
A_τ	Stau trilinear coupling	[−4 TeV, 4 TeV]
$\lvert\mu\rvert$	Higgsino mass parameter	[80 GeV, 4 TeV]
$\lvert M_1\rvert$	Bino mass parameter	[0 TeV, 4 TeV]
$\lvert M_2\rvert$	Wino mass parameter	[70 GeV, 4 TeV]
M_3	Gluino mass parameter	[200 GeV, 4 TeV]
M_A	Pseudoscalar Higgs mass	[100 GeV, 4 TeV]
$\tan\beta$	Ratio of vacuum expectation values	[1, 60]

pMSSM-19 and ATLAS



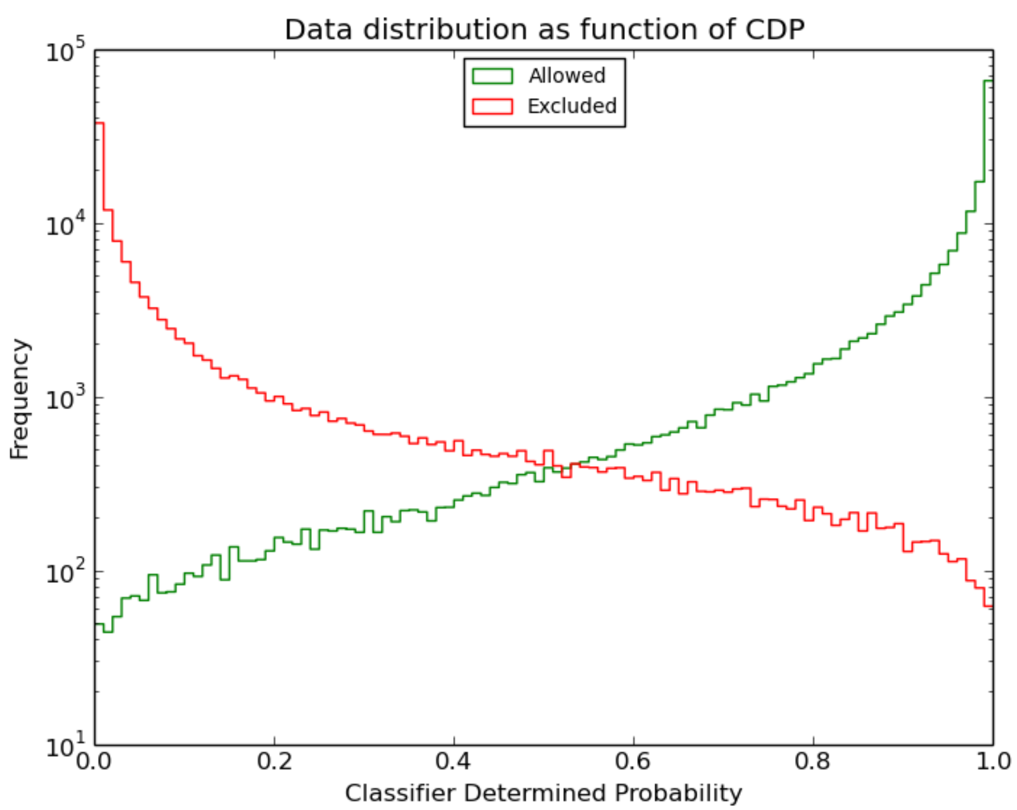
(a) Left up squark (b) Right up squark

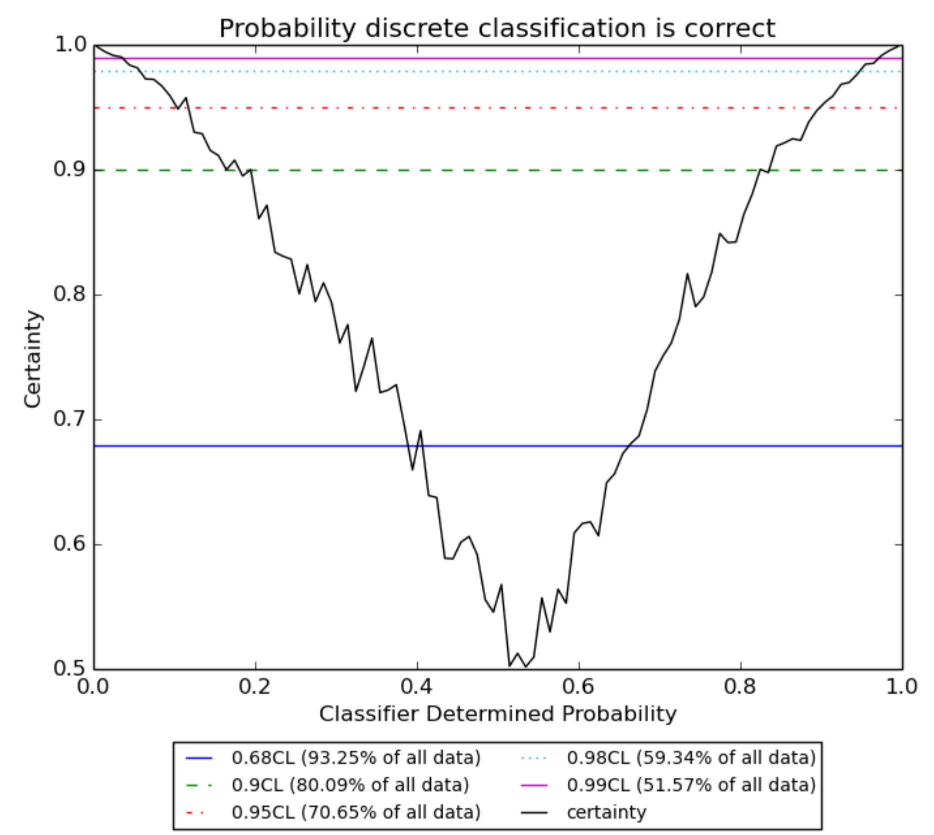


use training data to learn classification

it learns a confidence level of its classification using training data

ratio of majority class per bin





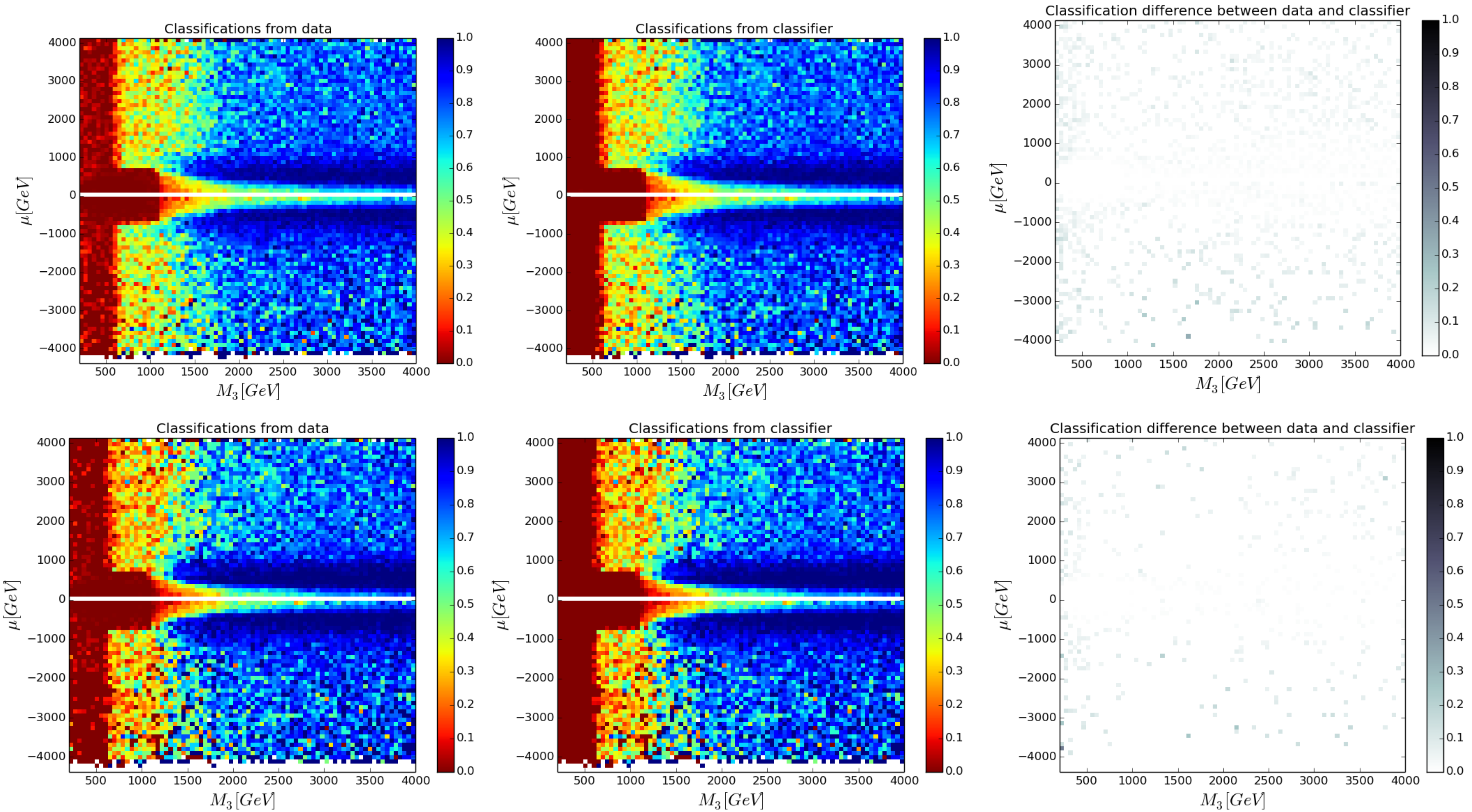
allowed excluded

allowed excluded

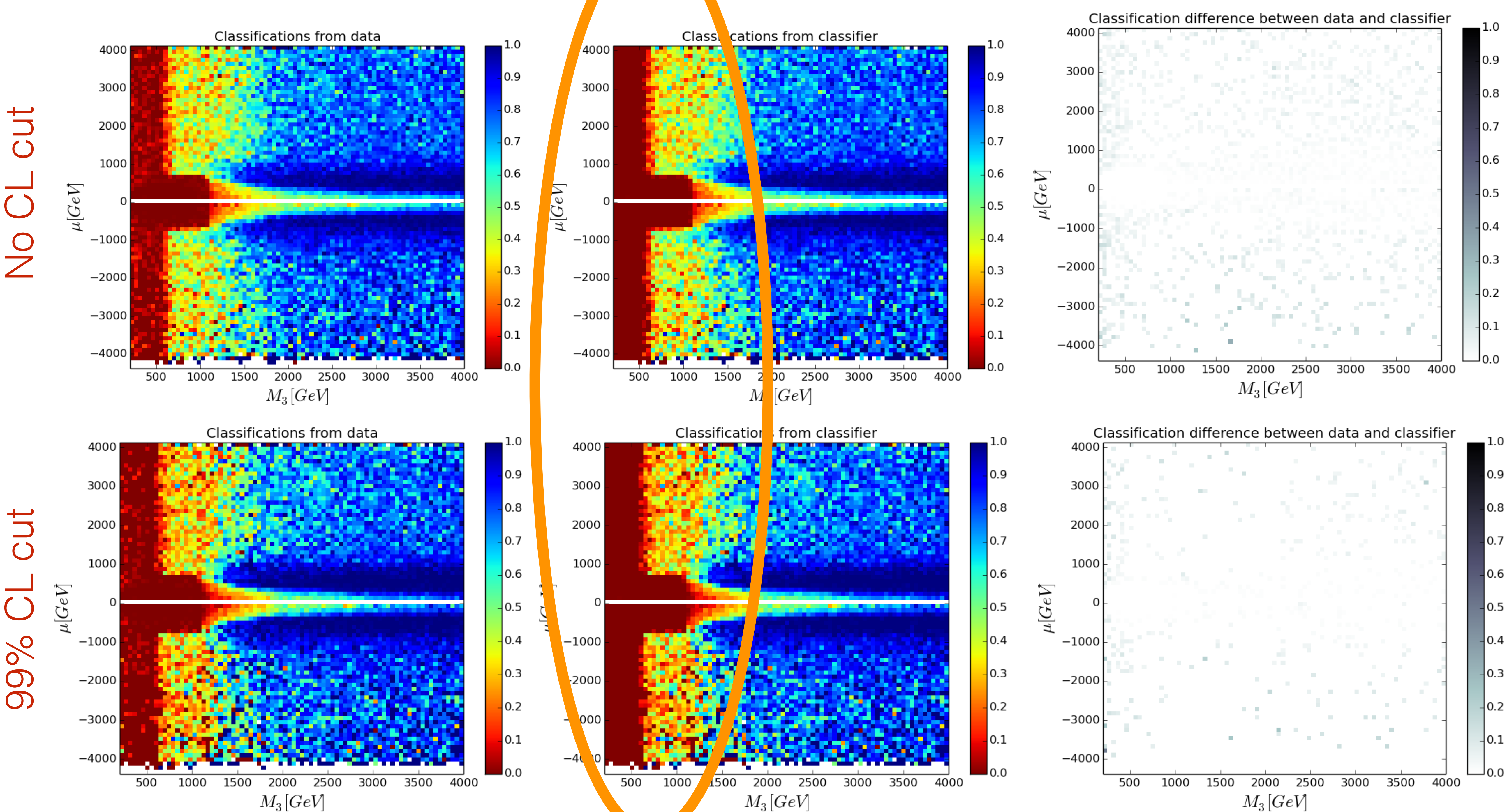
Performance of SUSY-AI

No CL cut

99% CL cut

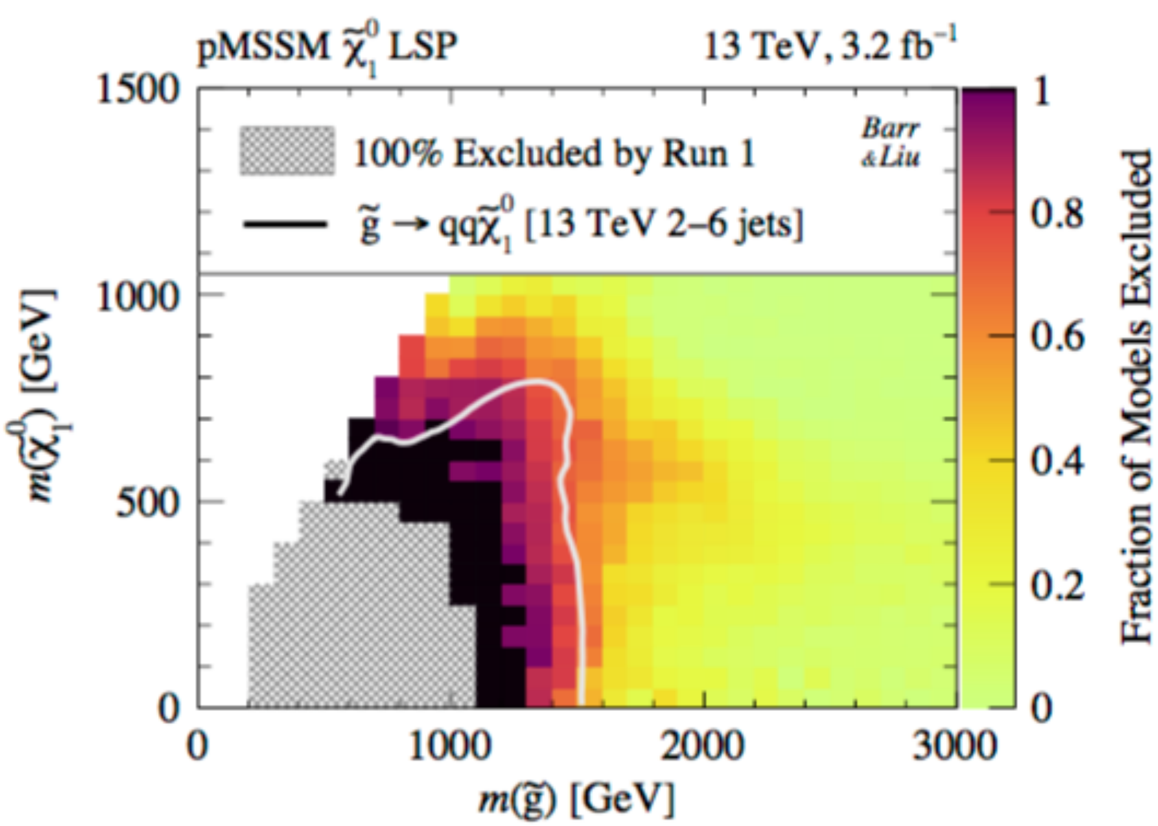


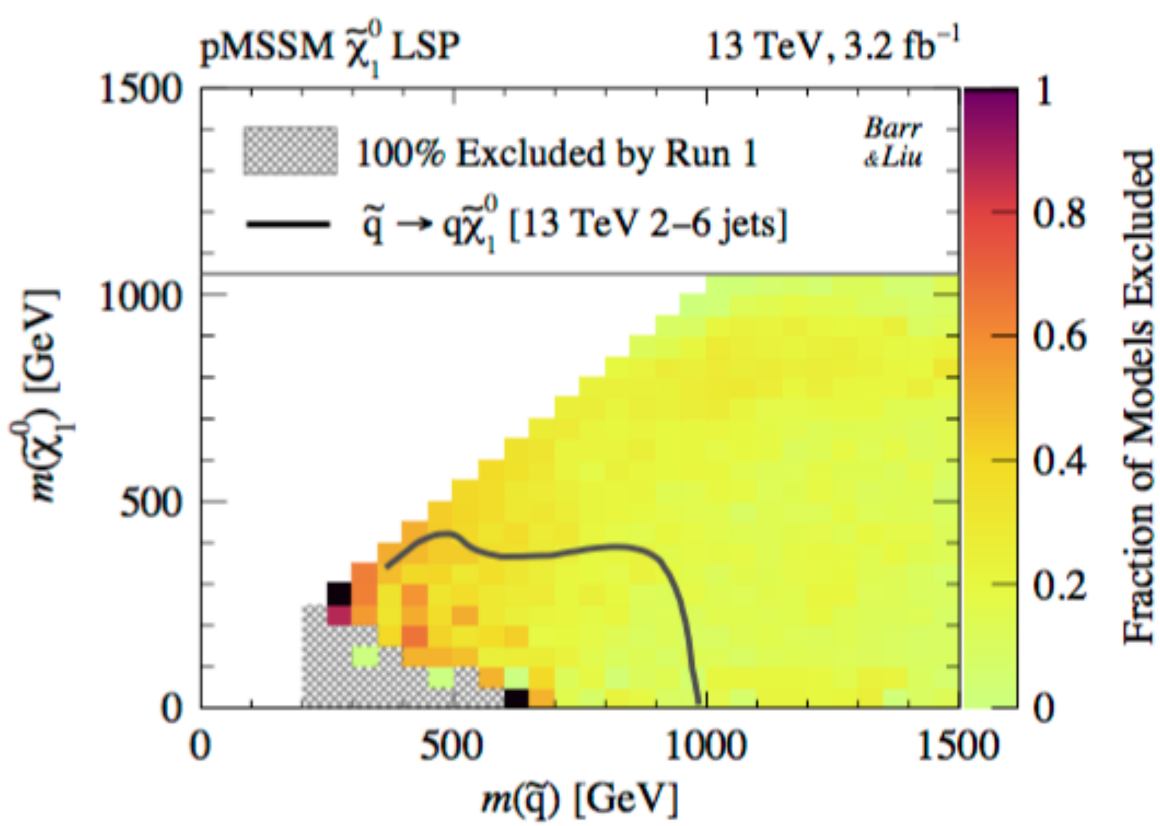
Performance of SUSY-AI



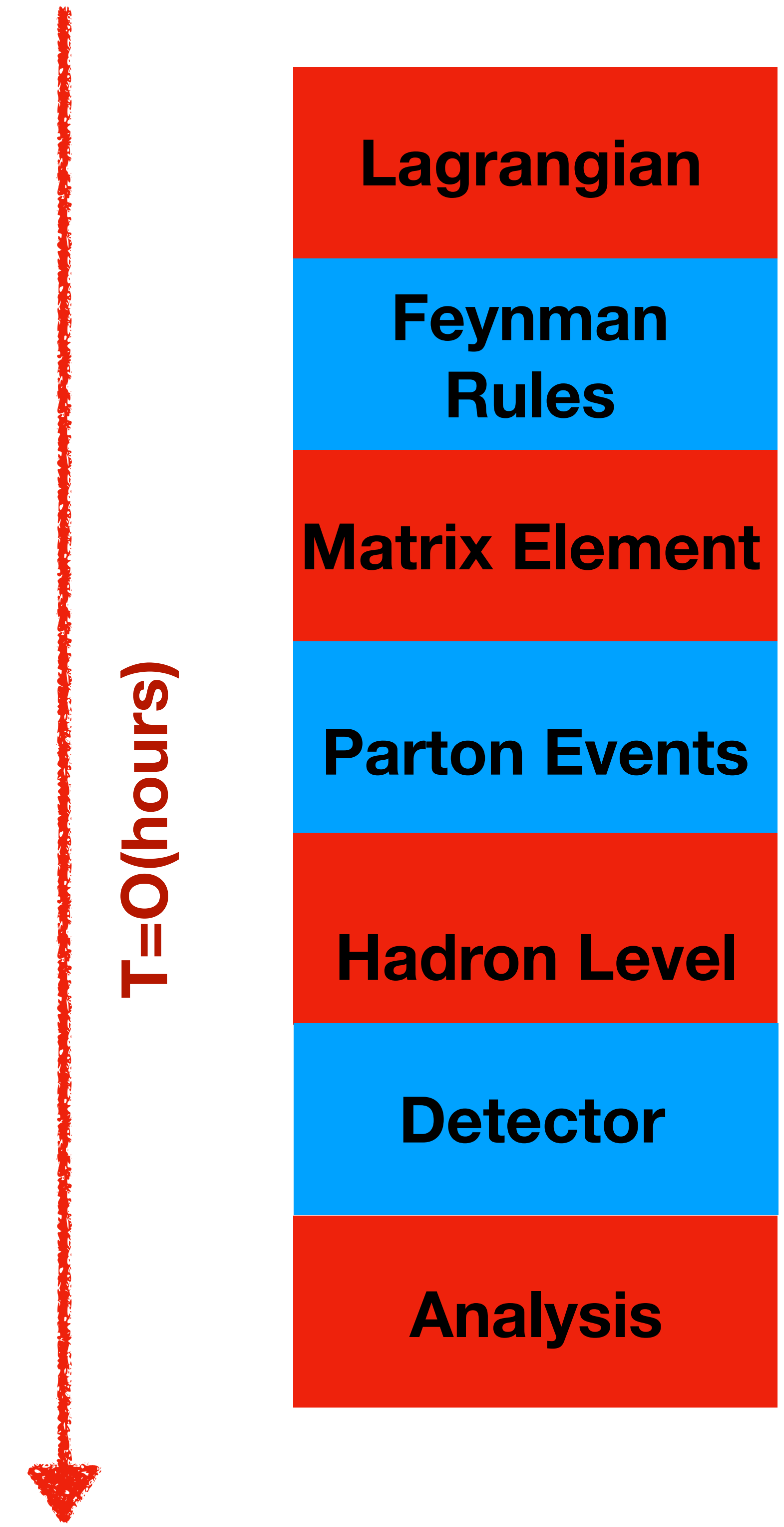
13 TeV constraints

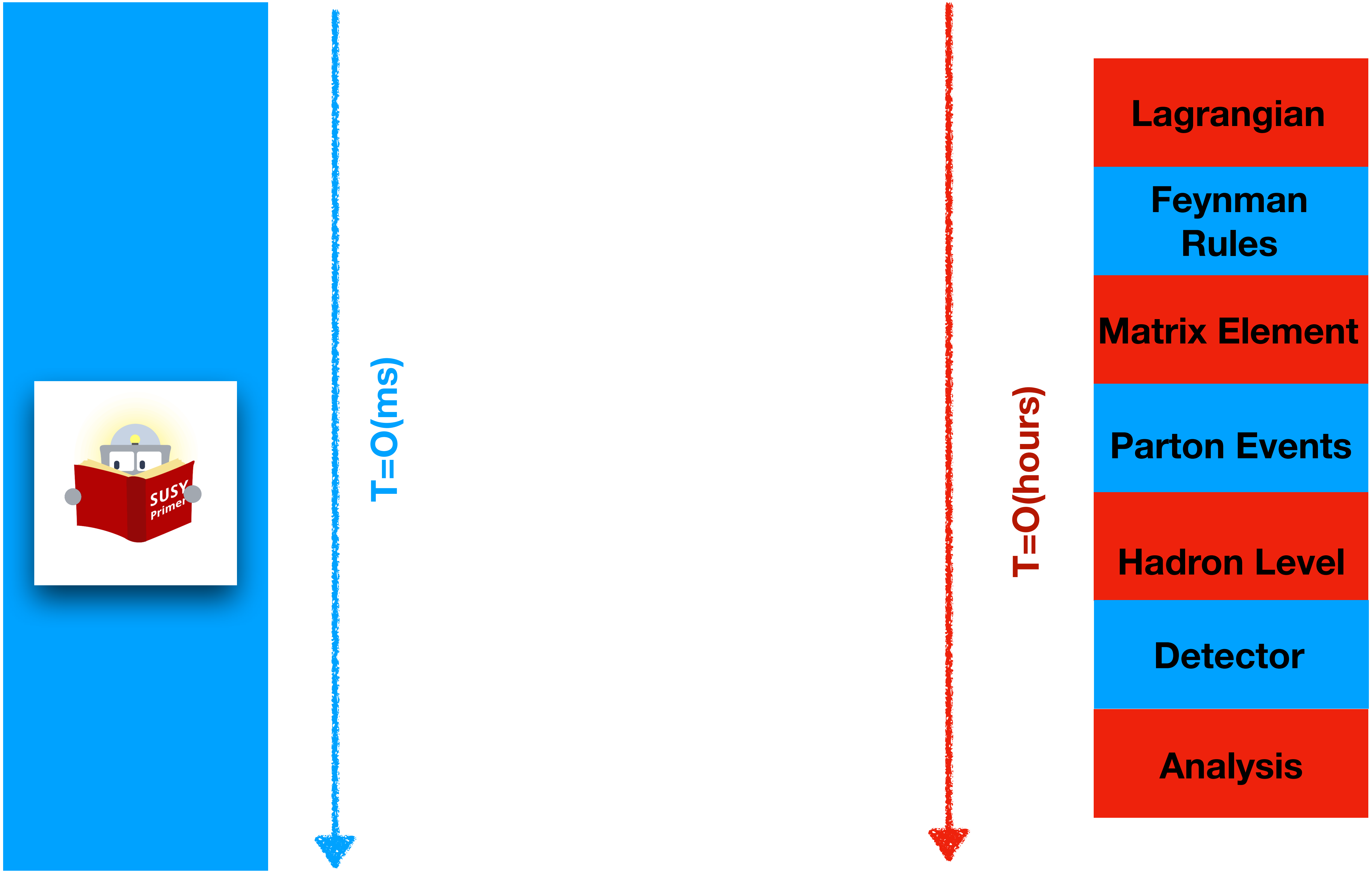
Analysis	All LSPs	Bino	Wino	Higgsino
2–6 jets [1]	12.6%	17.2%	10.8%	10.1%
7–10 jets [2]	0.6%	0.5%	0.5%	0.7%
1-lepton [3]	1.0%	0.8%	1.1%	1.1%
Multi-b [4]	4.2%	3.0%	4.0%	5.2%
SS/3L [5]	0.5%	0.1%	1.6%	0.1%
Monojet [6]	1.3%	3.3%	0.2%	0.2%
All analyses	15.7%	18.8%	14.9%	13.8%



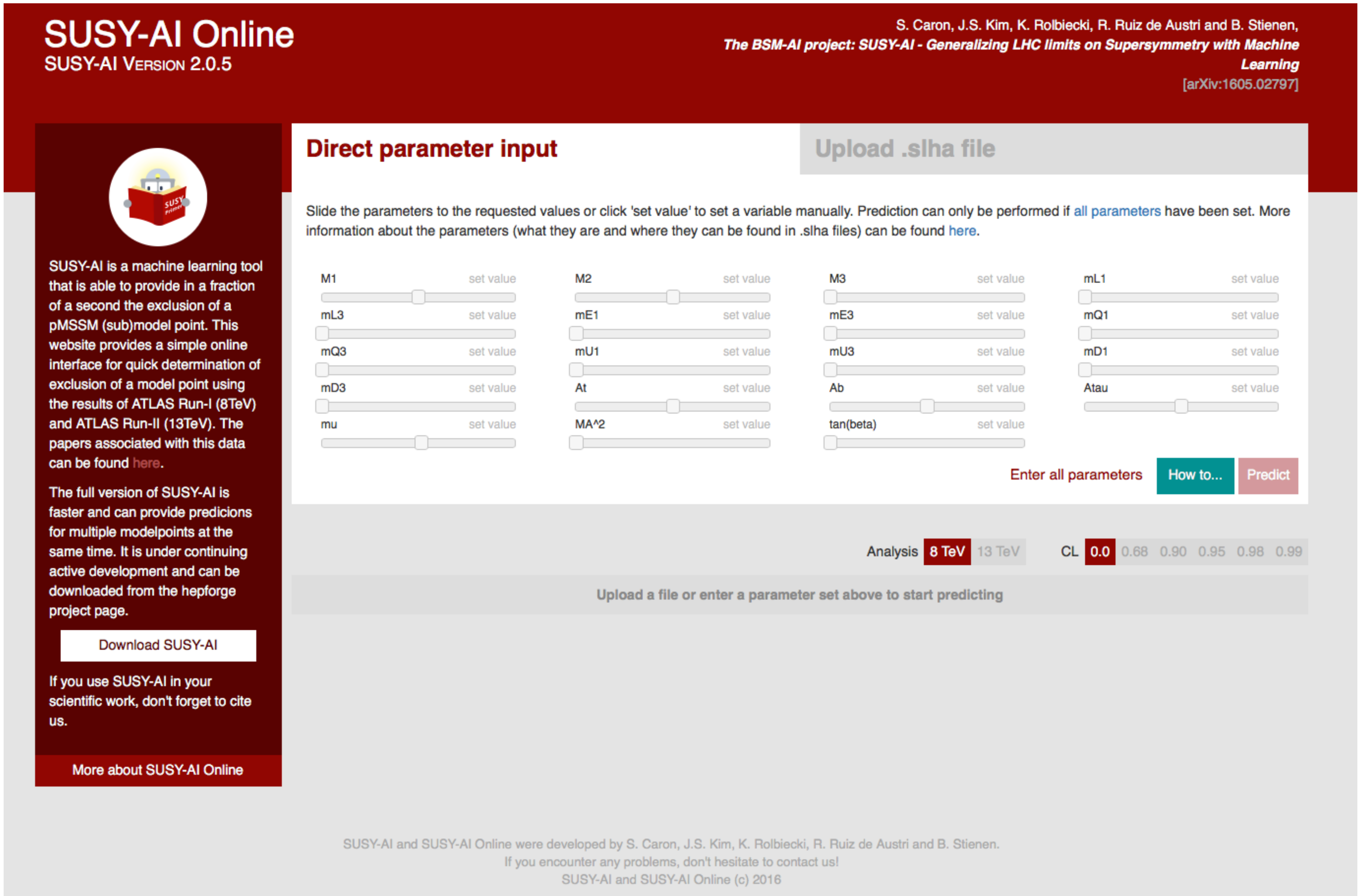


1605.09502


T=O(hours)
Lagrangian
Feynman Rules
Matrix Element
Parton Events
Hadron Level
Detector
Analysis


SUSY
Primer
T=O(ms)
T=O(hours)
Lagrangian
Feynman Rules
Matrix Element
Parton Events
Hadron Level
Detector
Analysis

SUSY-AI Online



www.hepforge.susy-ai.org

www.susy-ai.org

- with ML we go from discrete data to a continuous function
- we can reconstruct the exclusion boundary of the pMSSM19
- however, in some regions SUSY-AI is less certain

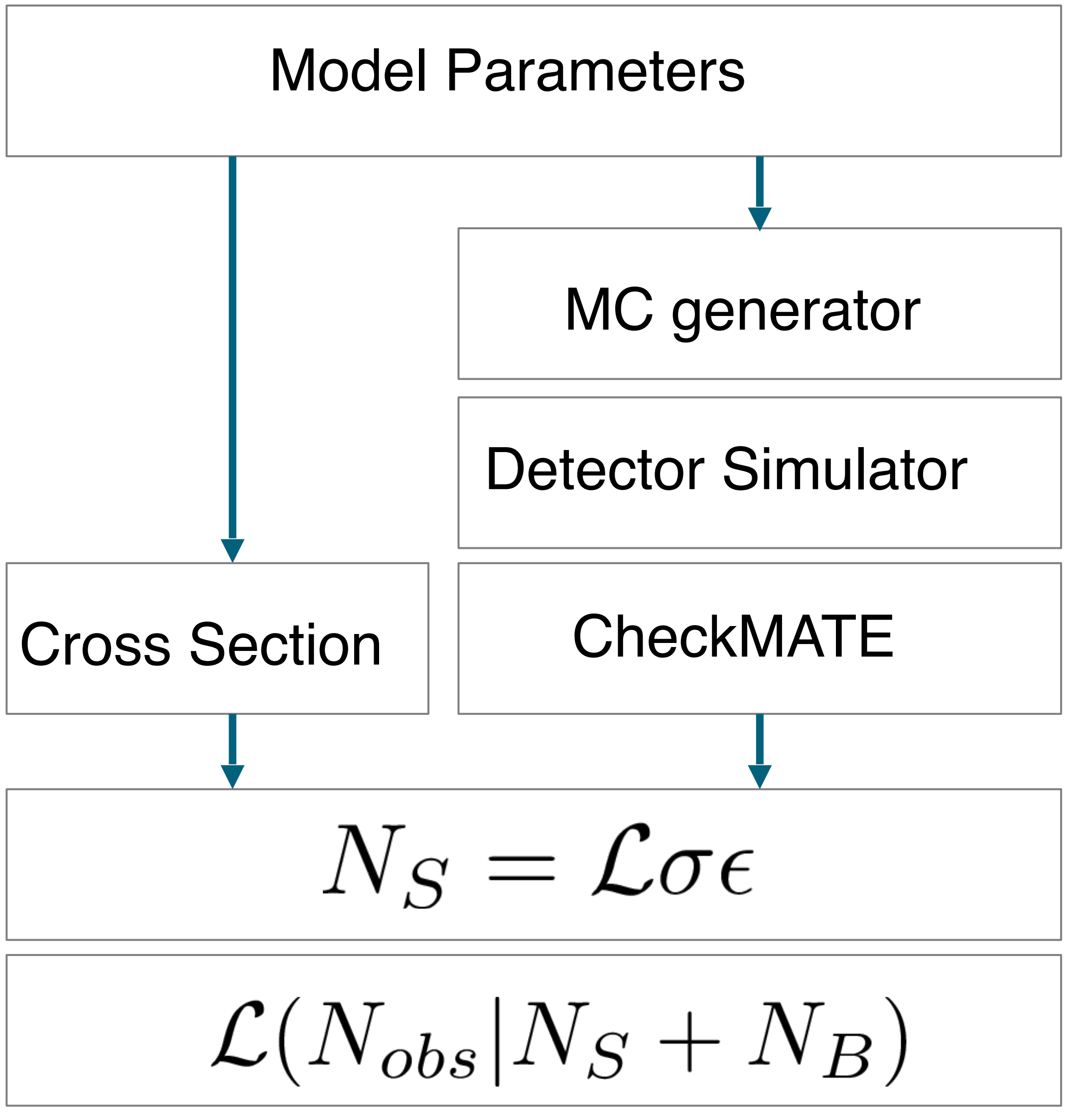
- we want to generate more points in those regions (active learning)
- moreover, we want to sample points which are not excluded with large "certainty"
- currently we are working on other classifiers in the BSM-AI project

we used machine learning
to test models with
classification
methods

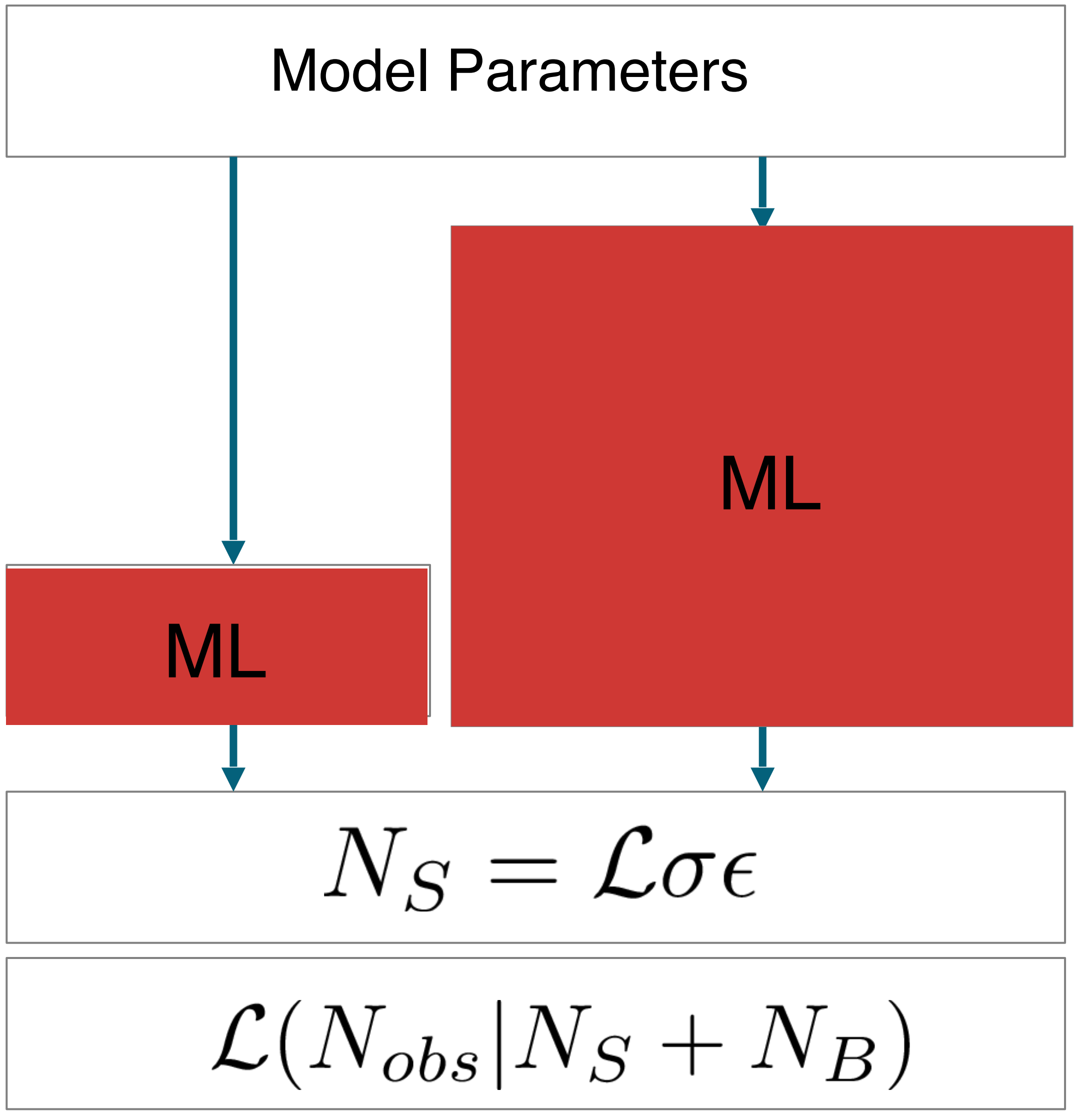
we also want to
predict the likelihood

- LHC constraints cannot easily be included in the likelihood calculation
- LHC computations are prohibitively expensive
- e.g., the ATLAS electroweakino paper had 500 millions benchmark points -> they approximated the likelihood function
- in codes like Mastercode the LHC likelihood calculation is the most time consuming part

- we have to perform the LHC step for each benchmark point
- in particular, the MC event generation takes a lot of time
- is there a way to improve the performance?

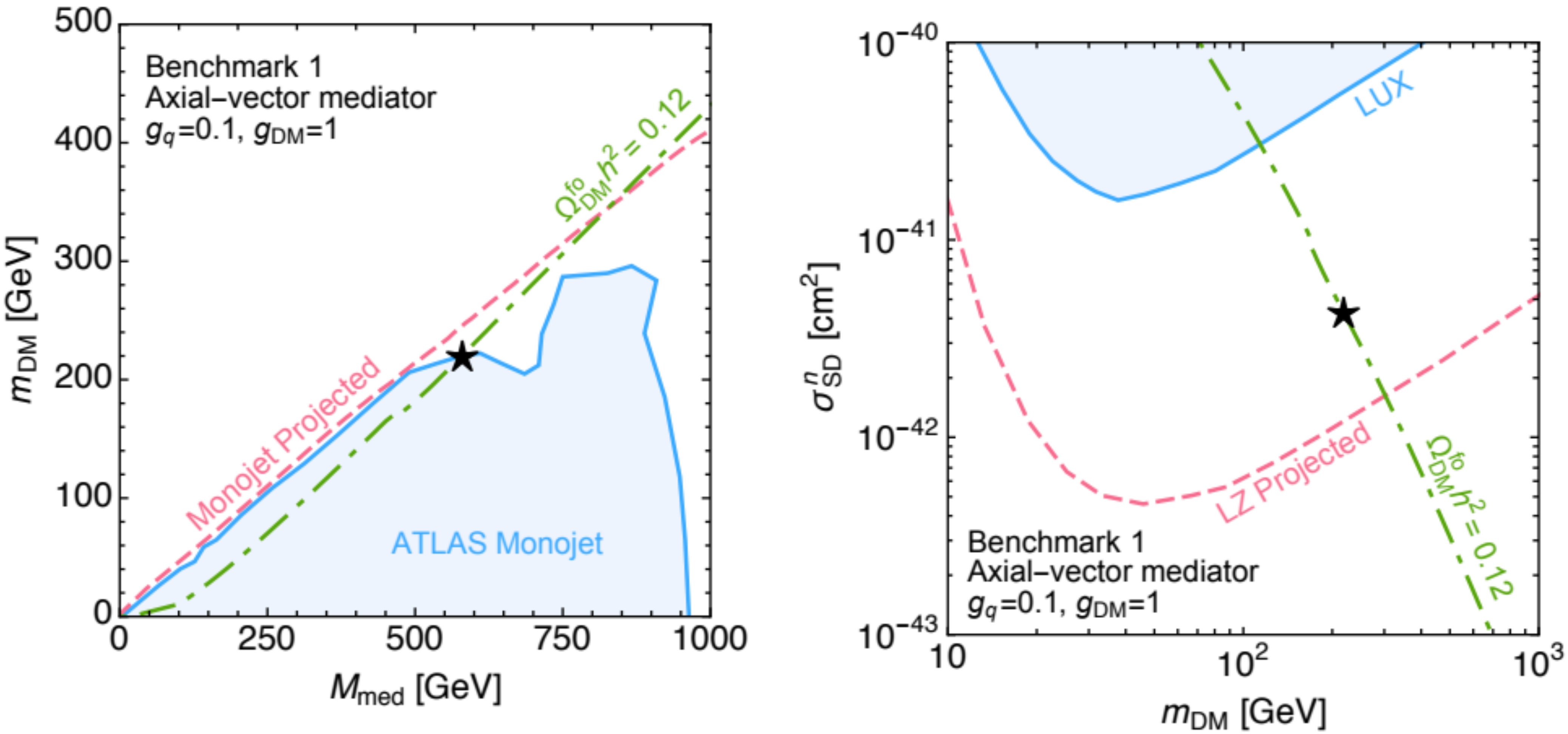


- we replace the expensive computations with ML techniques
- the efficiencies and the production cross sections are predicted in supervised ML



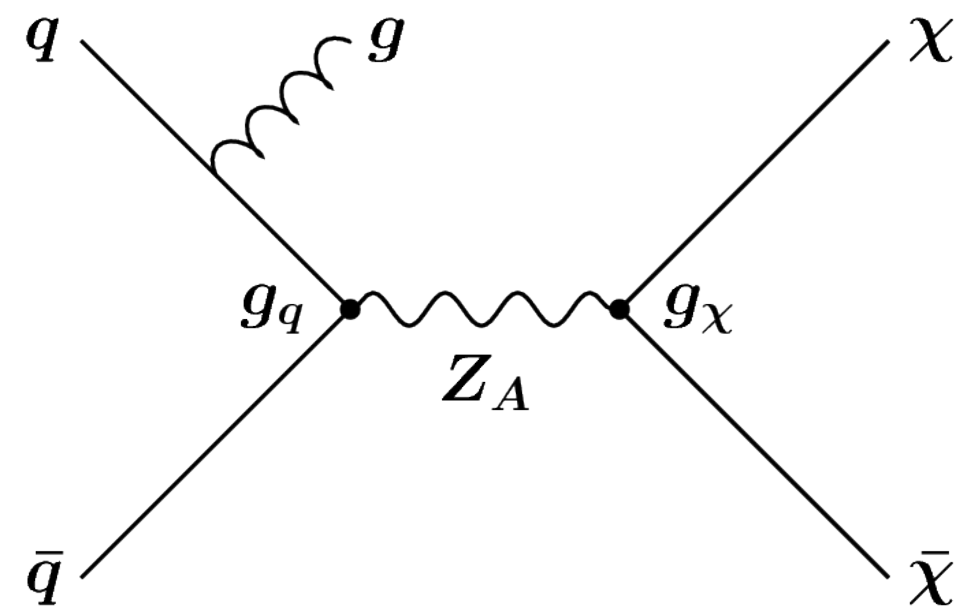
DM study

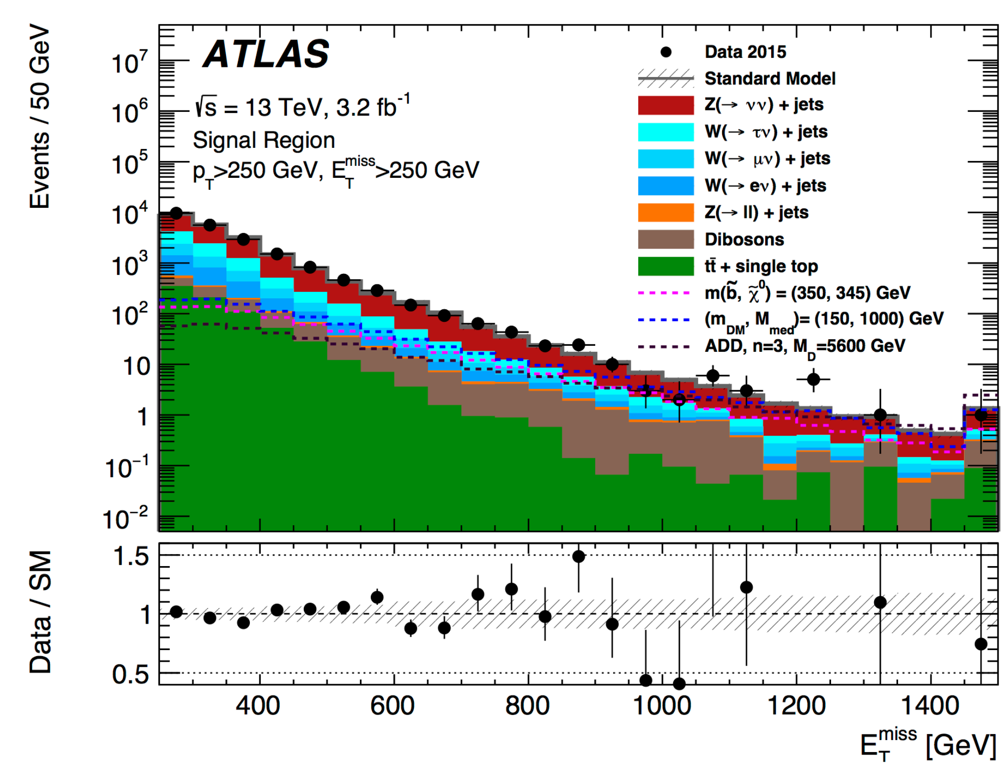
1712.04793



4D simplified AV DM scenario

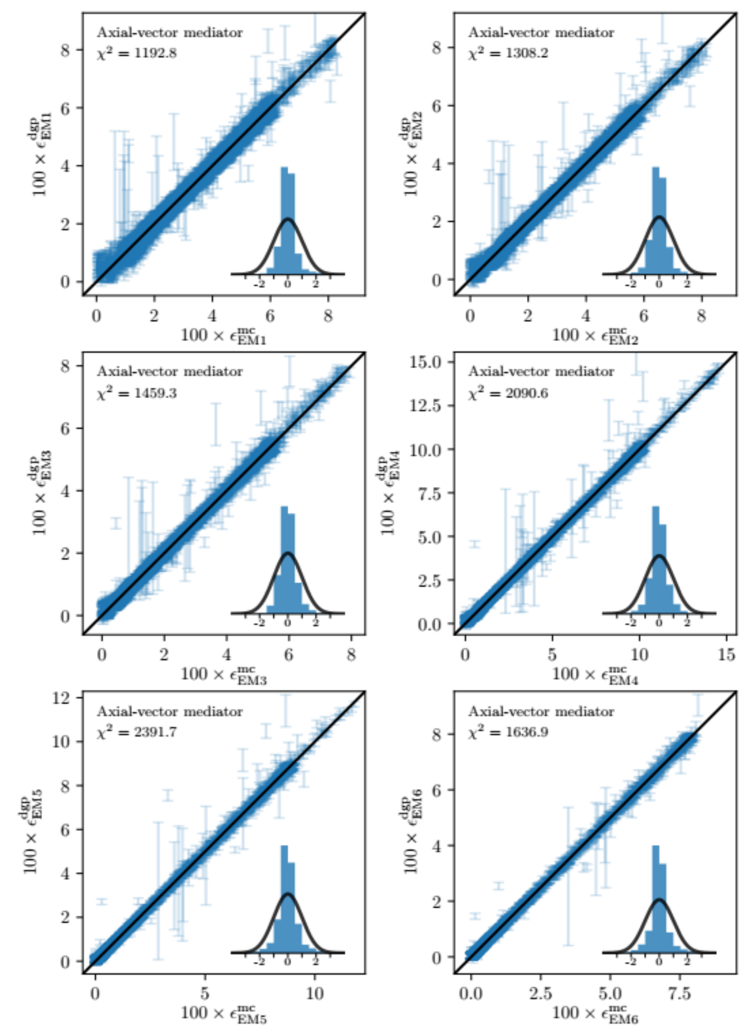
- we assume a future excess with 100 inverse fb of data
- extrapolate current BKG estimates for all SR to the higher luminosity
- projected sensitivity depends on uncertainty of predicted SM rates
- recent ATLAS monojet searches have reduced systematic errors from 5% to 3%
- we consider two scenarios: systematic error ~ 1% & 3%

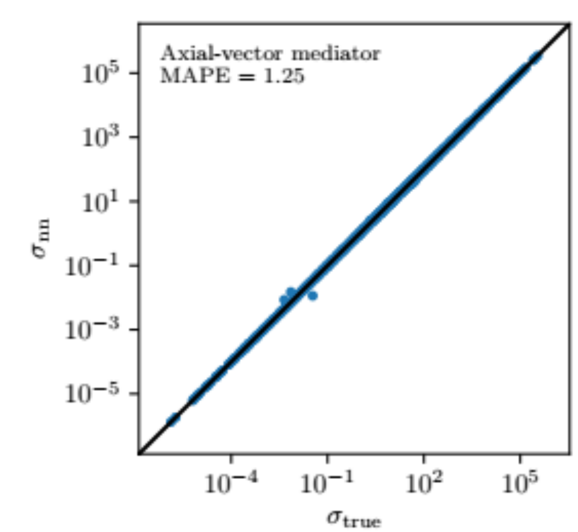




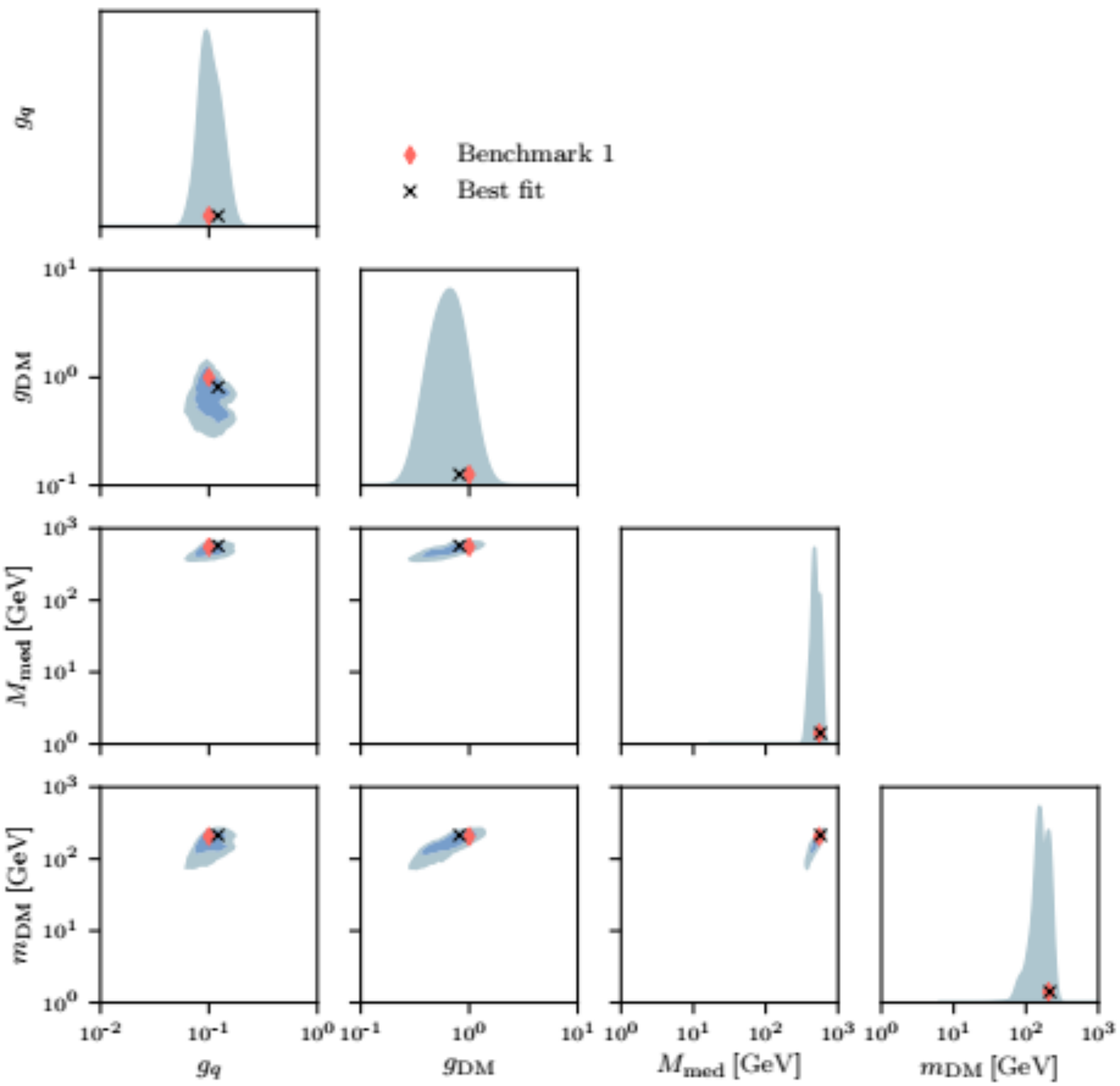
Training

- we generated monojet signals
- we use distributed Gaussian Processes to predict the SR efficiencies
- NN are trained on the NLO XS
- dijet classifier

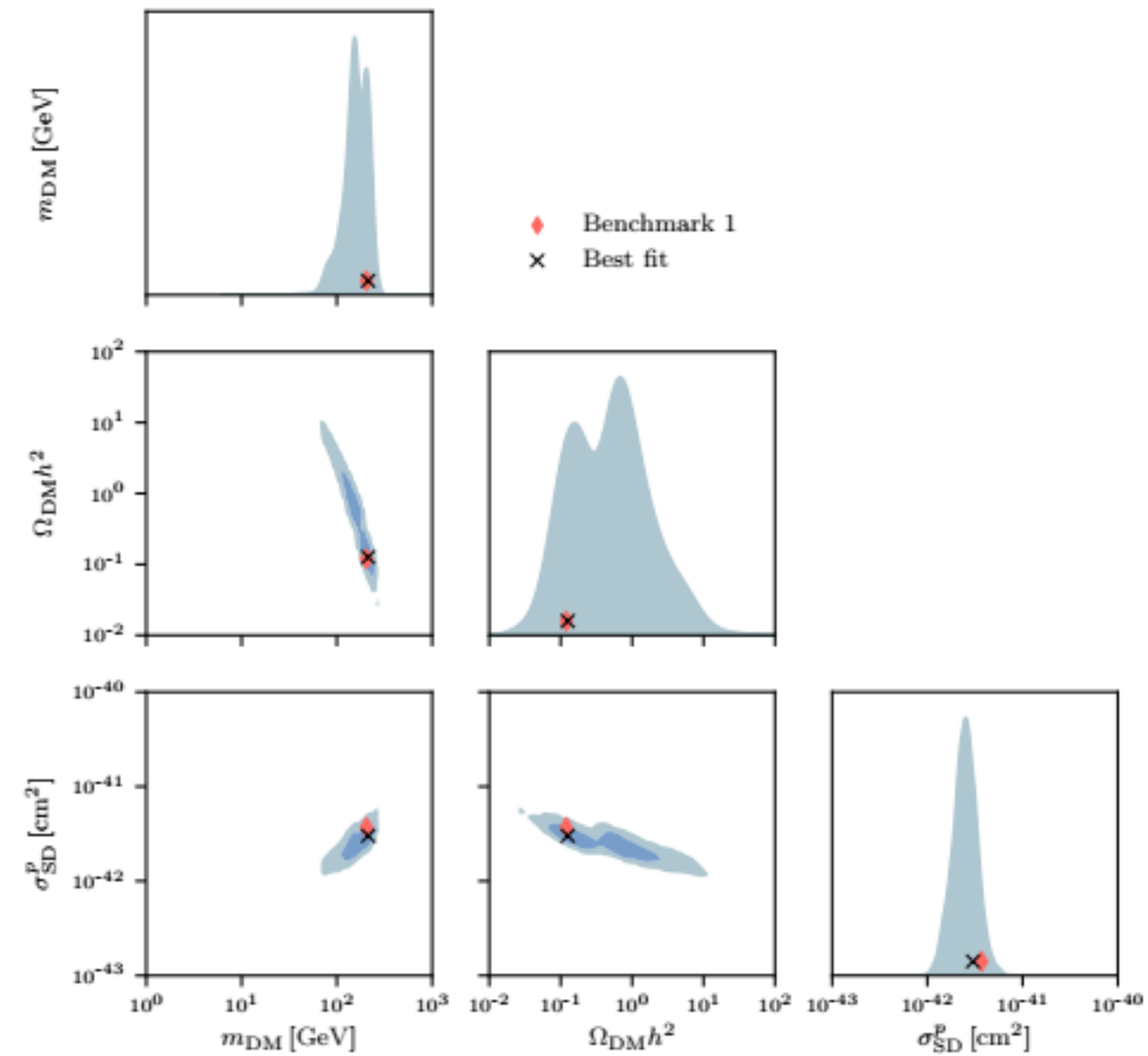




Results



Benchmark 1
Best fit
g_q
g_{DM}
M_{med} [GeV]
m_{DM} [GeV]

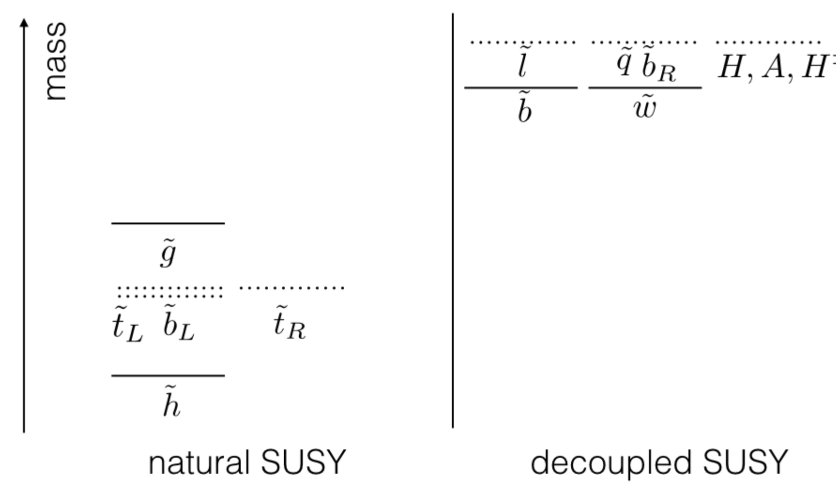


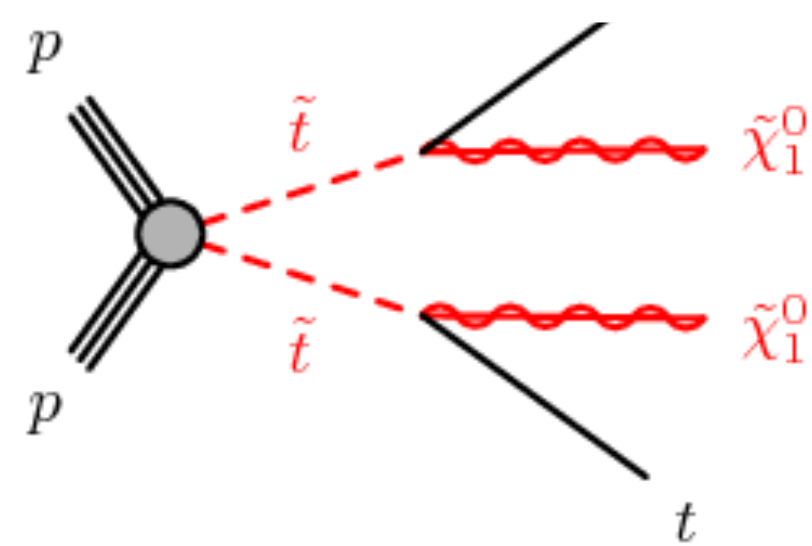
Benchmark 1
Best fit
m_{DM} [GeV]
$\Omega_{DM}h^2$
σ^p_{SD} [cm^2]

Natural SUSY

1611.02704

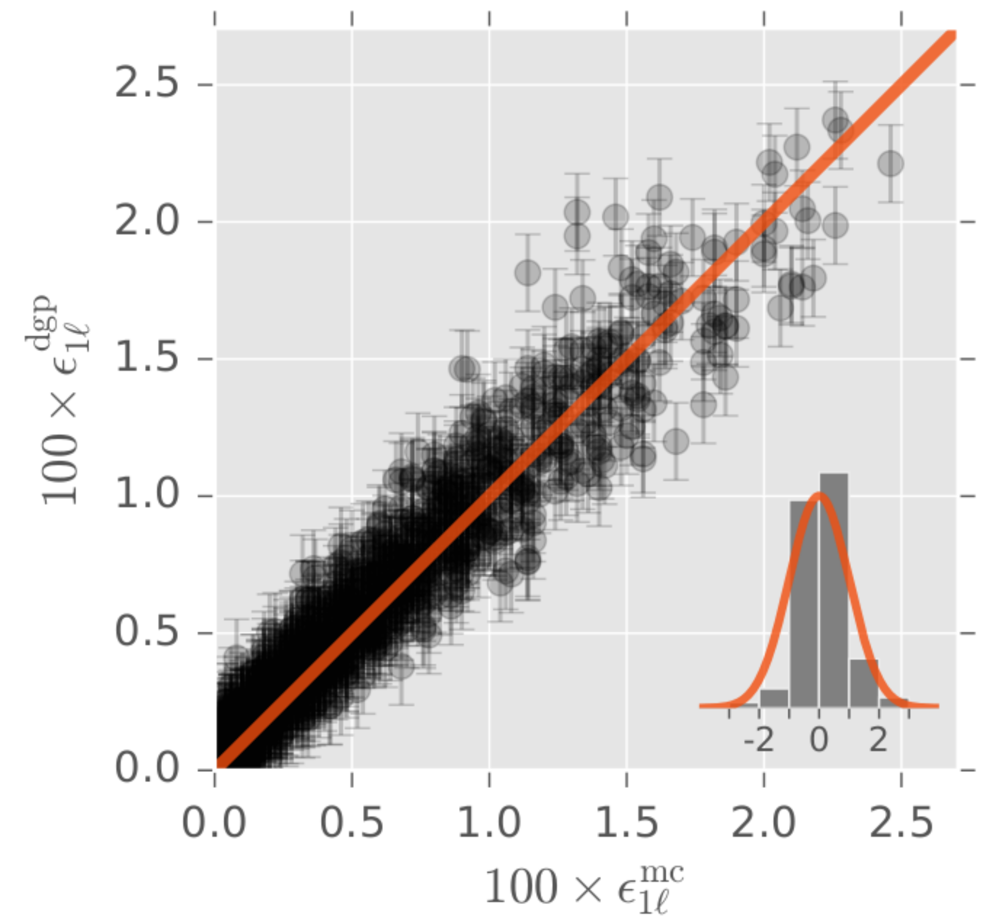
- 6D natural SUSY
- we assumed a excess in the HL-LHC phase
- calculated efficiencies in 0L and 1L stop searches defined in ATLAS-PUB-2013-011
- stops decay to tops, b, W/Z or Higgs and LSP

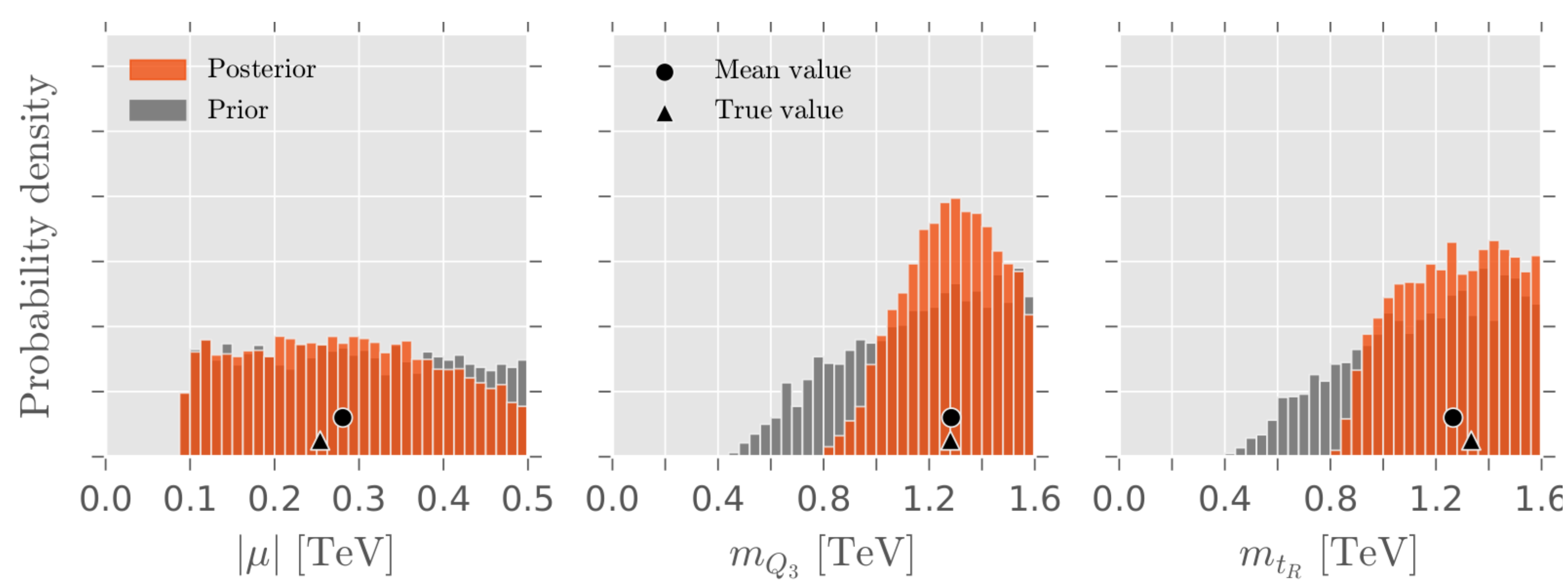




Natural SUSY

- we used Gaussian Processes
- we had 18647 models and used 16k for training
- O(10) min to train per SR
- 0.06 sec/prediction
- 154k likelihood evaluation





Summary

- reinterpretation tools of LHC results are very important to make LHC data more accessible to pheno community
- allows to test any BSM
- analysis preservation
- ATOM, Contur, CheckMATE, ColliderBit, Fastlim, MadAnalysis, Rivet, SModelS
- high dimensional parameter fits are computationally expensive
- ML algorithms allows for fast global fits
- SCYNet, SUSY-AI

Backup

Madgraph+Pythia 8

```
[Parameters]
Name: madgraph
SLHAFile: point.slha
Analyses: 8TeV
RandomSeed: 10

[squ_asq]
MGCommand: import model mssm;
          define sq  = ul ur sl sr dl dr cl cr;
          define sq~ = ul~ ur~ sl~ sr~ dl~ dr~ cl~ cr~;
          generate p p > sq sq~

KFactor: 1.96
MaxEvents: 1000
```

testparam_madgraph.dat

13 TeV analyses

#Name	NSR	Description	Lumi
atlas_1604_01306	1	photon + MET search at 13 TeV	3.2
atlas_1605_09318	8	>= 3 b-jets + 0-1 lepton + Etmiss	3.3
atlas_1609_01599	9	ttV cross section measurement at 13 TeV	3.2
atlas_conf_2015_082	1	leptonic Z + jets + Etmiss	3.2
atlas_conf_2016_013	10	4 top quark (1 lepton + jets, vector like quark search)	3.2
atlas_1606_09150	1	diphotons and met	3.2
atlas_conf_2016_050	5	1-lepton + jets + etmiss (stop)	13.3
atlas_conf_2016_054	10	1-lepton + jets + etmiss (squarks and gluino)	14.8
atlas_conf_2016_076	6	2 leptons + jets + etmiss	13.3
atlas_conf_2016_096	8	2-3 leptons + etmiss (electroweakino)	13.3
atlas_conf_2016_066	2	search for photons, jets and met	13.3
atlas_conf_2017_022	24	squarks and gluinos, 0 lepton, 2-6 jets	36.1
atlas_conf_2017_019	6	search for stops with Higgs or Z	36.1
atlas_conf_2017_060	20	monojet search	36.1
atlas_conf_2017_039	37	ATLAS, 2-3 leptons + etmiss, 13 TeV, 37 invfb	36.1
atlas_conf_2017_040	2	Etmiss + Z, 13 TeV	36.1
atlas_1704_03848	5	monophoton dark matter search	36.1
atlas_1710_11412	1	Search for dark matter produced in association with b or top quarks	36.1
atlas_1712_08119	39	electroweakinos search with soft leptons	36.1
atlas_1712_02332	24	squarks and gluinos, 0 lepton, 2-6 jets	36.1
atlas_1709_04183	14	stop pair production, 0 leptons	36.1
atlas_1802_03158	7	search for GMSB with photons	36.1
atlas_1708_07875	2	electroweakino search with taus and MET	36.1
atlas_1706_03731	19	same-sign or 3 leptons RPC and RPV SUSY	36.1
atlas_1804_03602	6	search for supersymmetry in events with four or more leptons	36.1

13 TeV analyses

- we have a small selection of implemented CMS 13 TeV analyses

#Name	NSR	Description	Lumi
cms_sus_15_011	47	CMS, 13 TeV, 2 leptons + jets + MET	2.2
cms_sus_16_046	4	one photon and missing transverse momentum	35.9
cms_sus_16_039	158	electrowekinos in multilepton final state	35.9
cms_sus_16_025	14	electroweakino and stop compressed spectra	12.9

- for the first time, we have started to consider a search based on jet substructure techniques and a LLP search

#Name	NSR	Description	Lumi
atlas_1801_08769		Search for light resonances decaying to boosted quark pairs and produced in association with a photon or a jet	36.1
atlas_1712_02118	2	Search for long-lived charginos based on a disappearing-track signature	36.1

Gaussian Processes

- a collection of random variables which have a joint Gaussian distribution
- the random variables represent function values f(x)
- f(x)~GP(m(x),k(x, x’))
- we can predict p(f(x’)|x’,y, x) for some given observation y=f(x)+ε
- non parametric: no functional form assumptions
- GP defines prior of functions
- produces posteriors

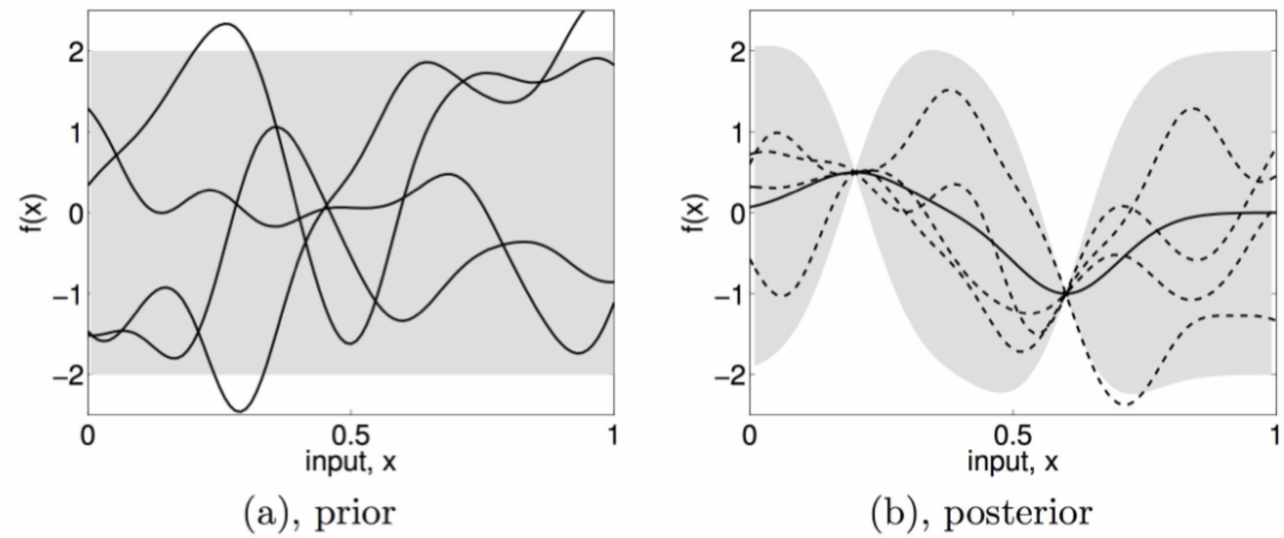
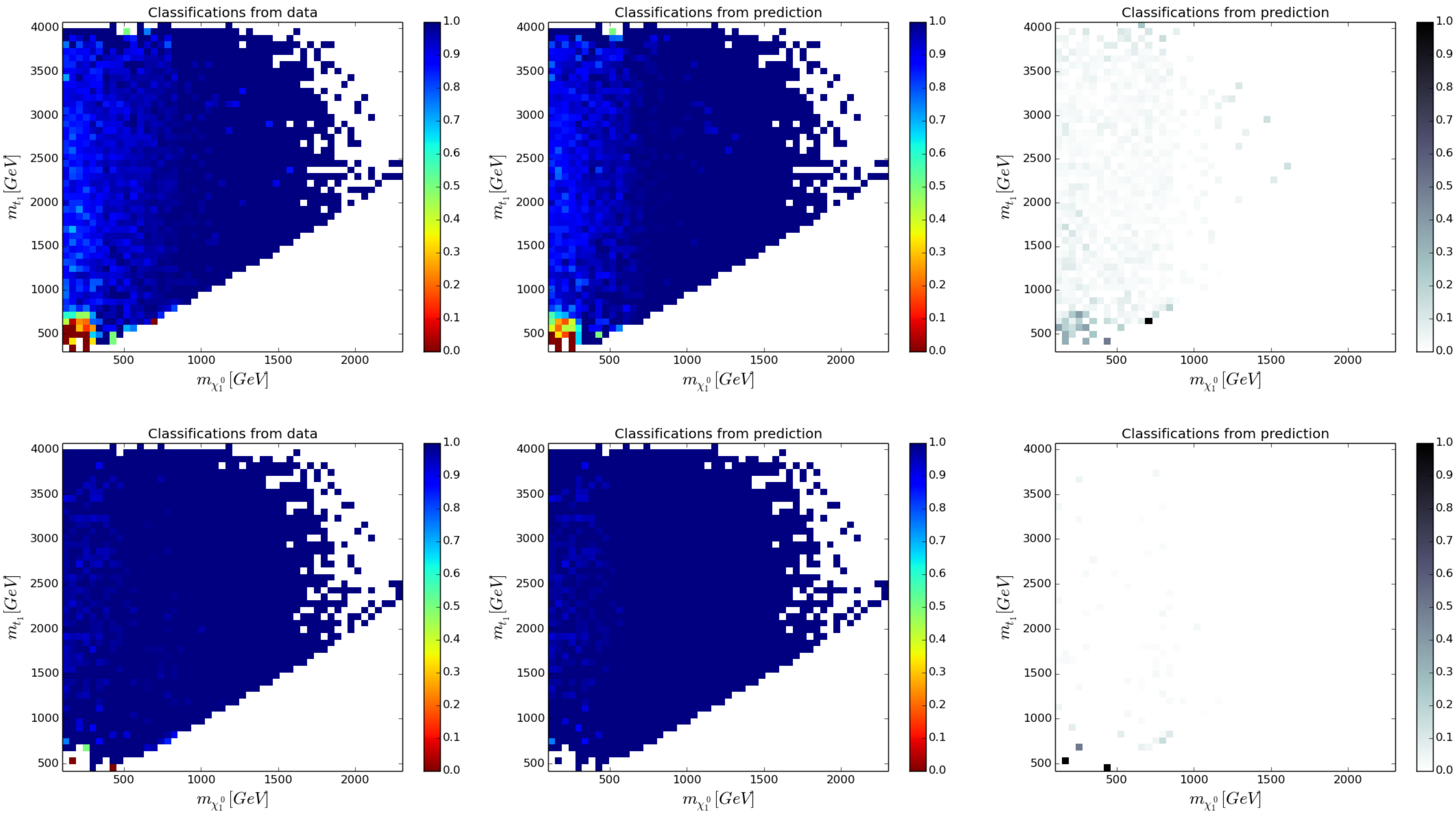


Figure 1.1: Panel (a) shows four samples drawn from the prior distribution. Panel (b) shows the situation after two datapoints have been observed. The mean prediction is shown as the solid line and four samples from the posterior are shown as dashed lines. In both plots the shaded region denotes twice the standard deviation at each input value x.

Limited training data

No CL cut

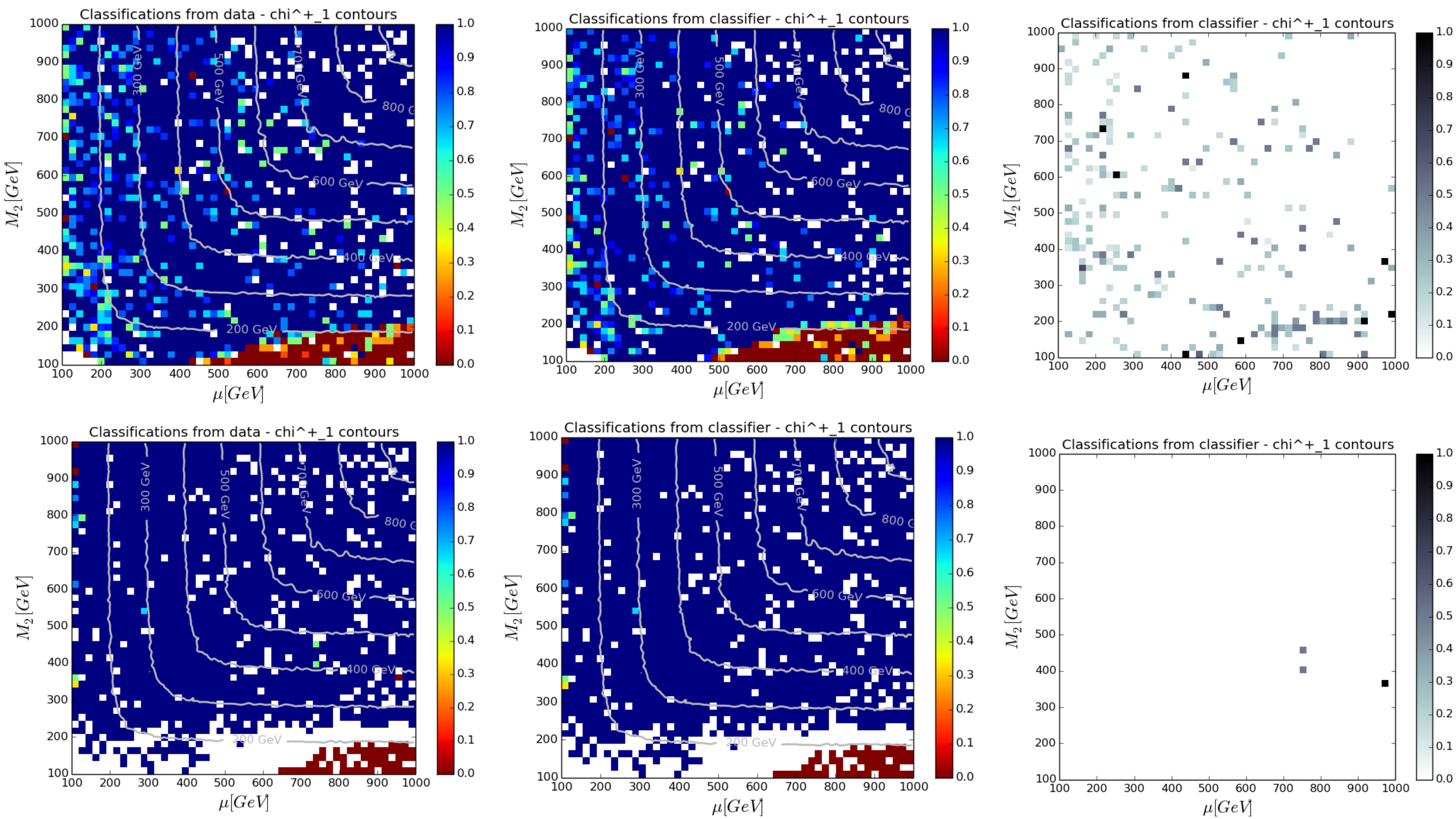
99% CL cut



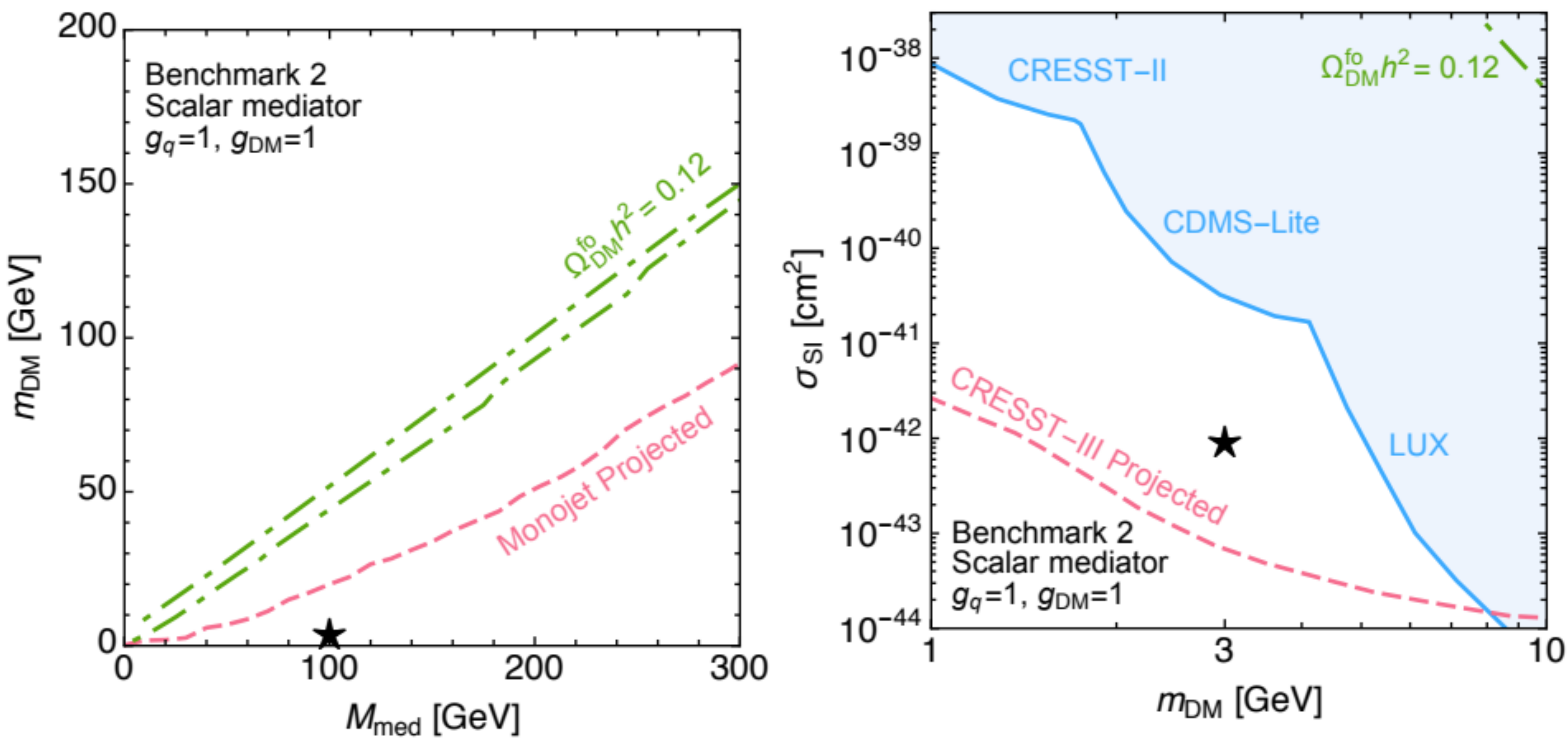
Limited training data

No CL cut

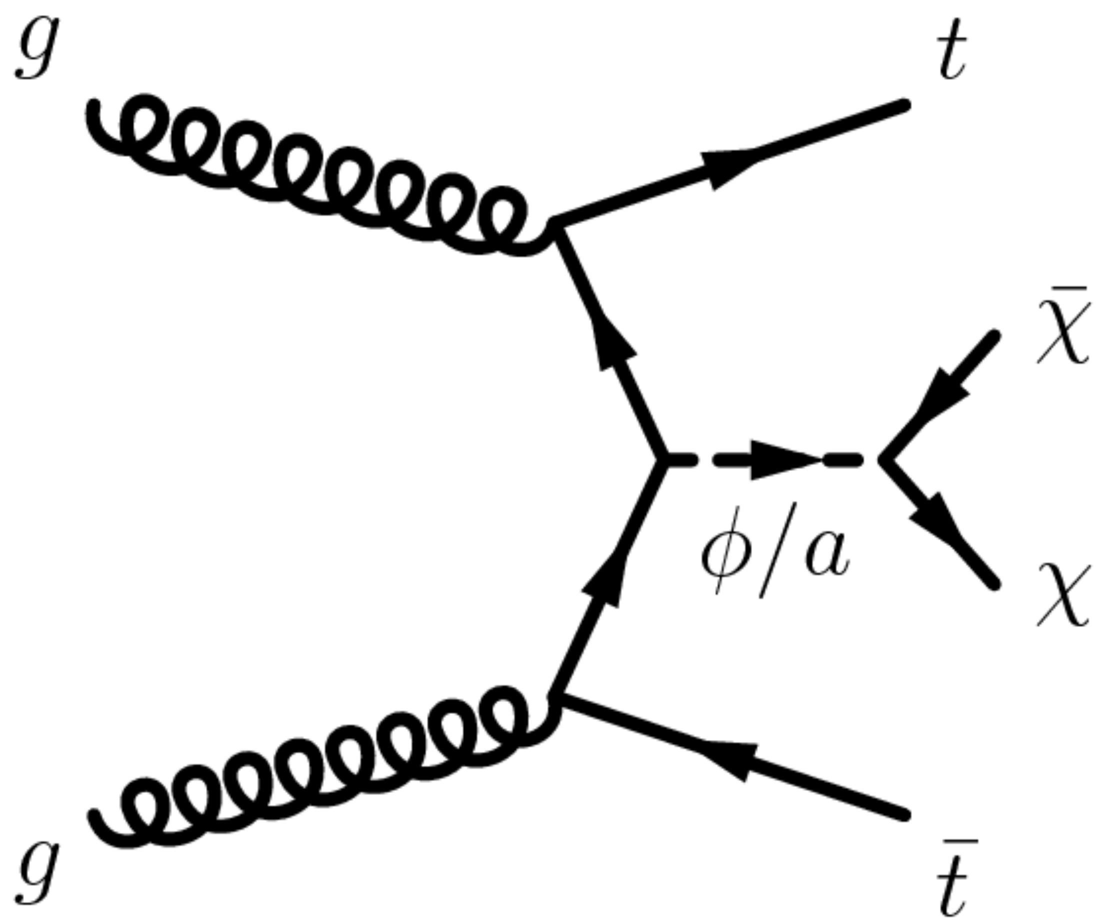
99% CL cut

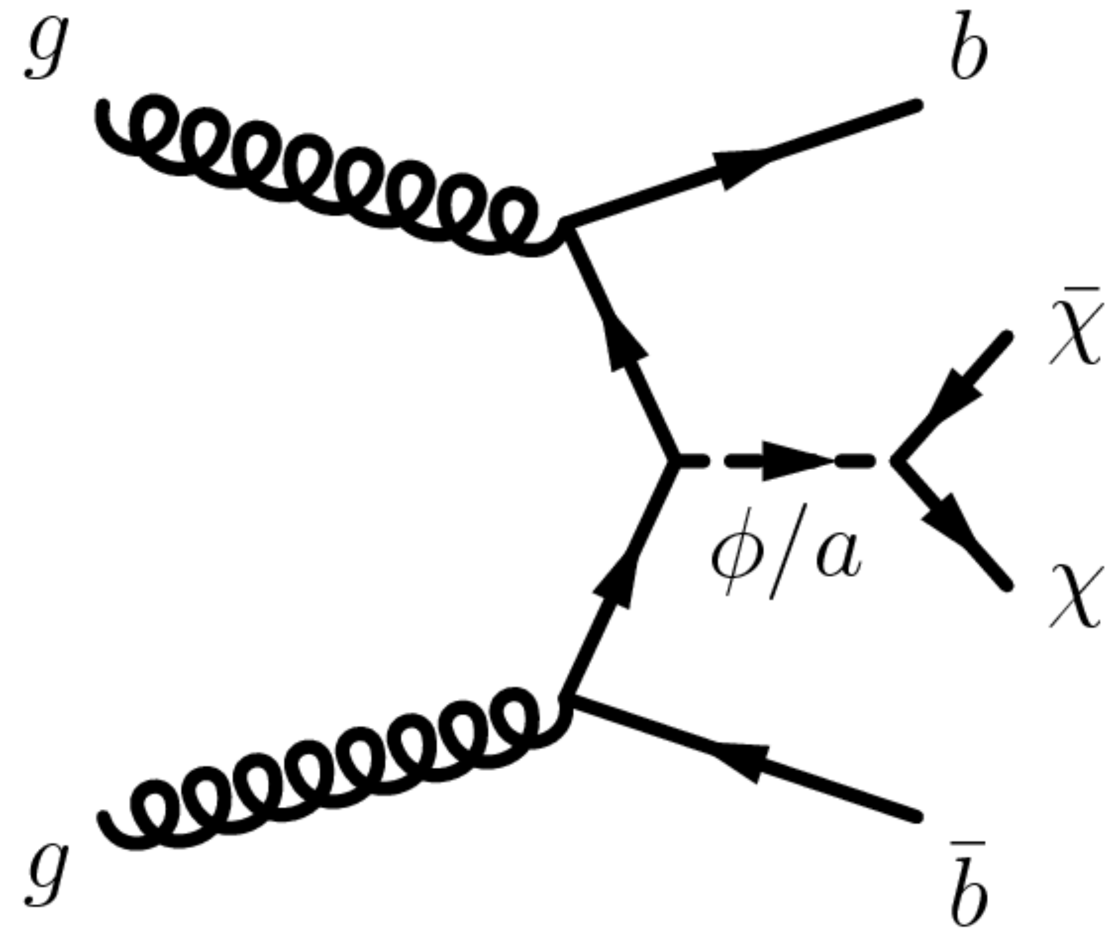


Scalar Benchmark Point

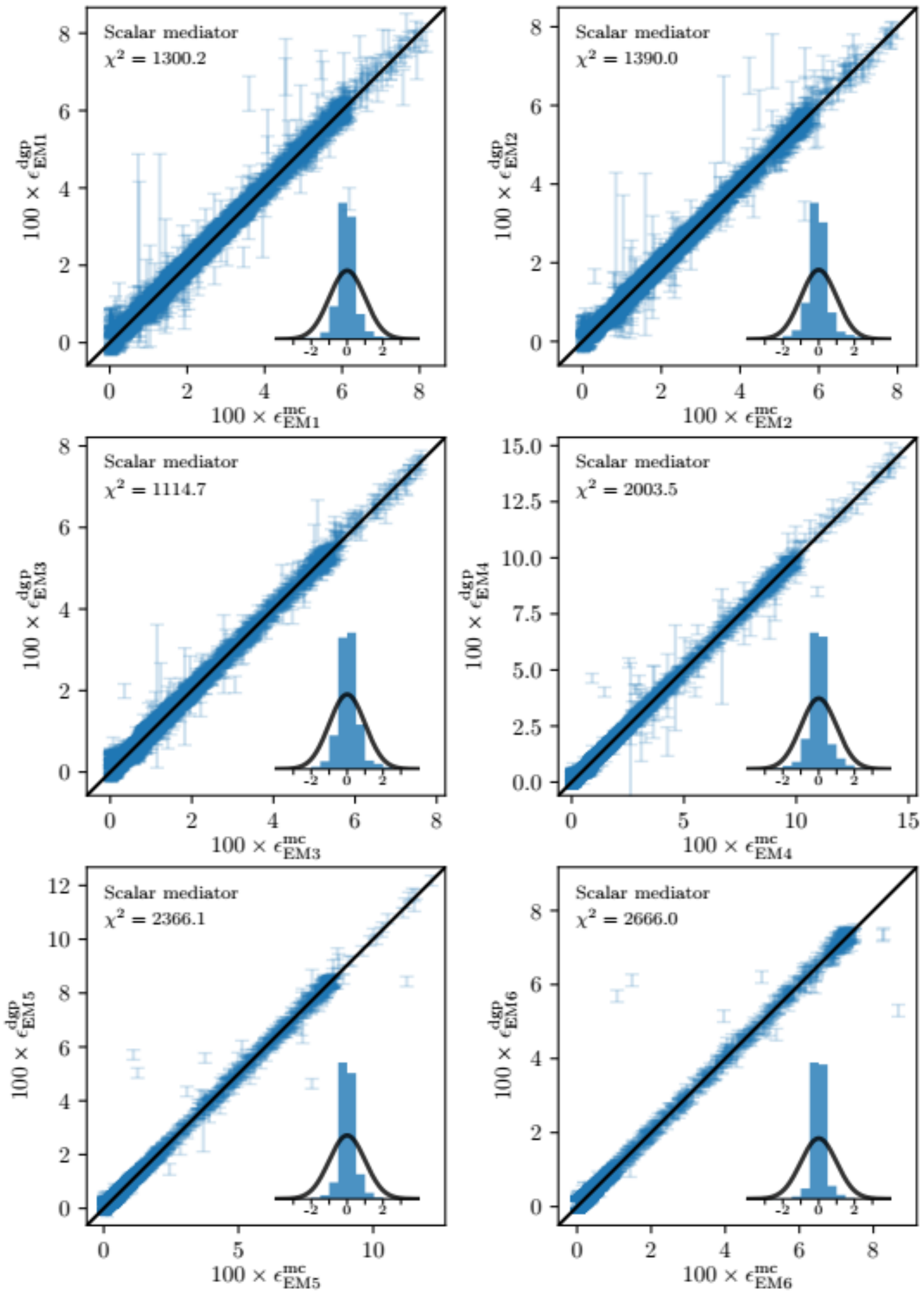


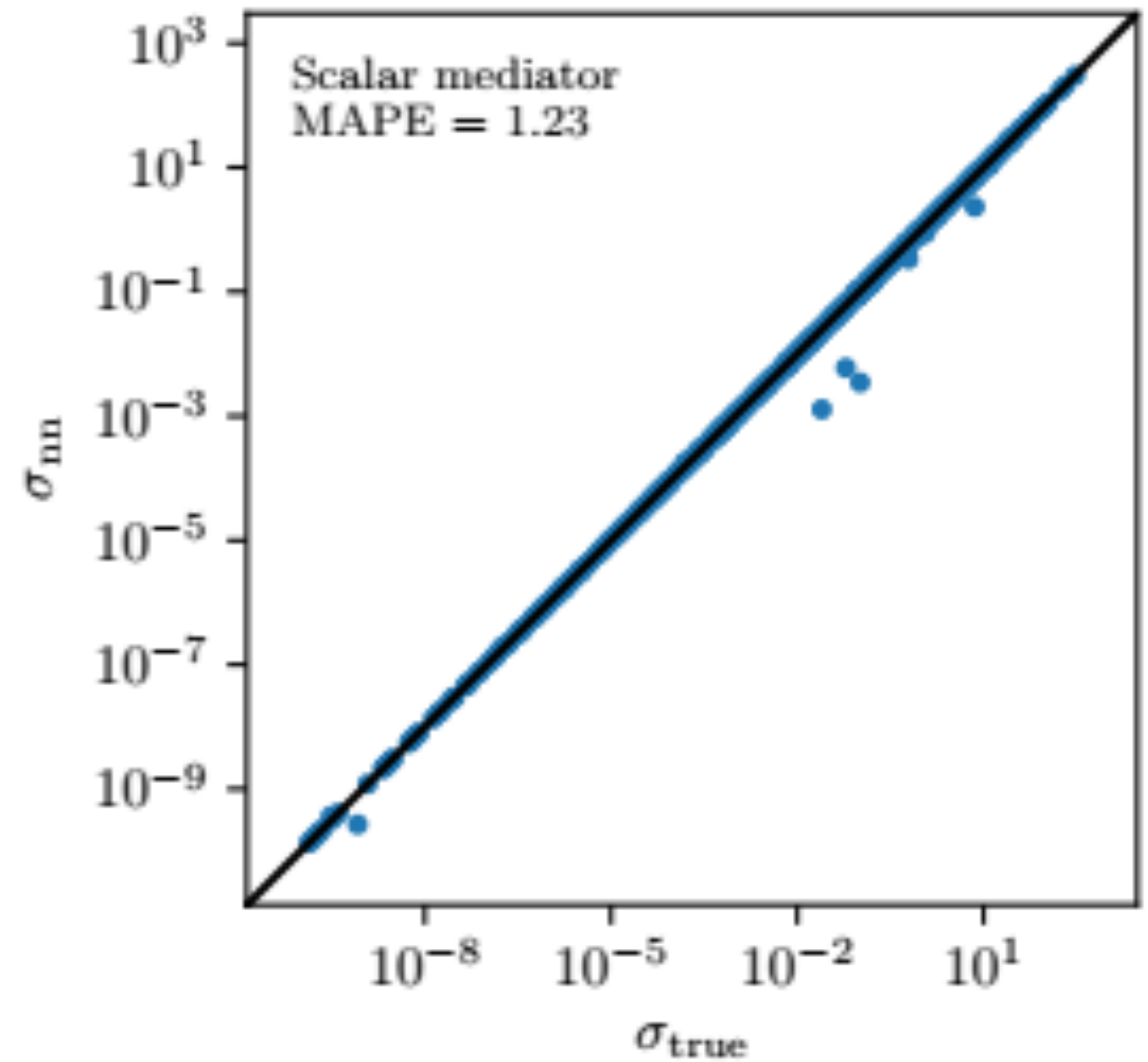
Scalar Benchmark Point





Scalar Benchmark Point





$\sigma_{\rm nn}$

Scalar BP Results