

Pushing the Boundaries 2019 *The Standard Model and Beyond*

INTRODUCTION





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+ Welcome and Thank You

- Our warmest welcome goes to all participants and particularly to all our speakers
 - Thank you for joining us at a busy time of the year

A special thank you goes to IPPP

- For the excellent organization and hospitality
- And for their generous financial contribution to the organization of this workshop through my Senior Experimental Fellowship (2018-19) award
 - https://www.ippp.dur.ac.uk/senior-experimental-fellowships2018-2019

+ Pushing the Boundaries Workshop Series

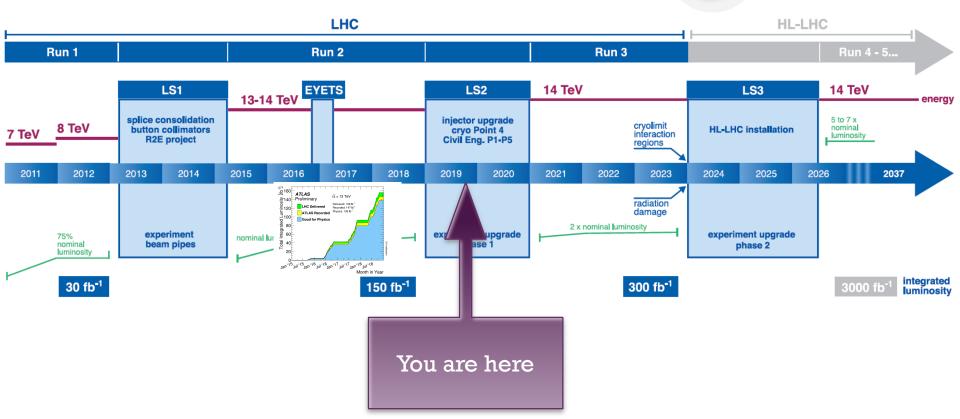
- This is the third of a series of small-scale workshops organized in 2018 & 2019 with support by IPPP and the University of Sussex
 - To facilitate exchanges between theorists and experimentalists, focusing primarily on BSM physics: --
 - IPPP, July 2018
 - BSM searches Status and prospects at the LHC and Beyond
 - Sussex, November 2018
 - BSM searches Taking stocks at the end of the LHC Run2
 - IPPP, September 2019
 - This workshop What now??

+ Rationale for this workshop

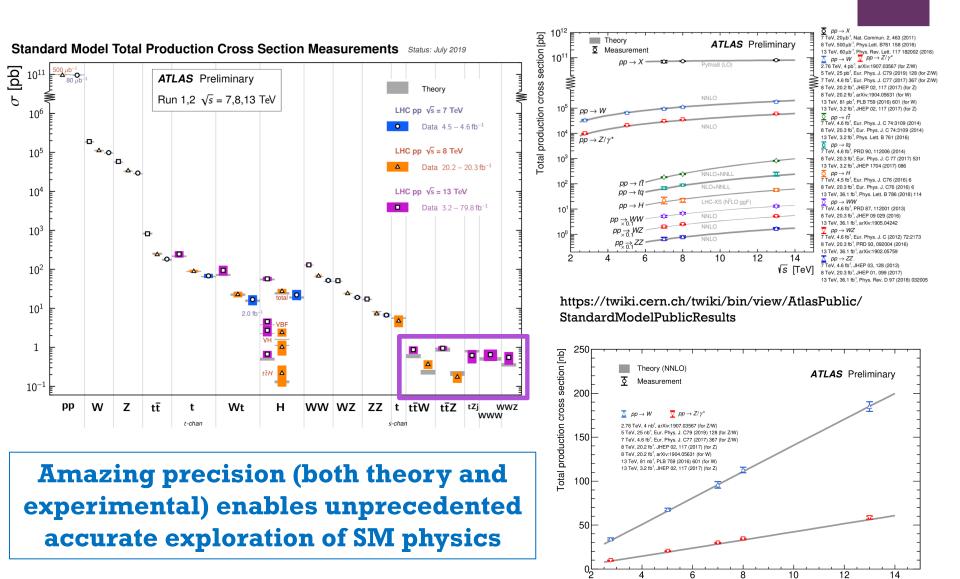






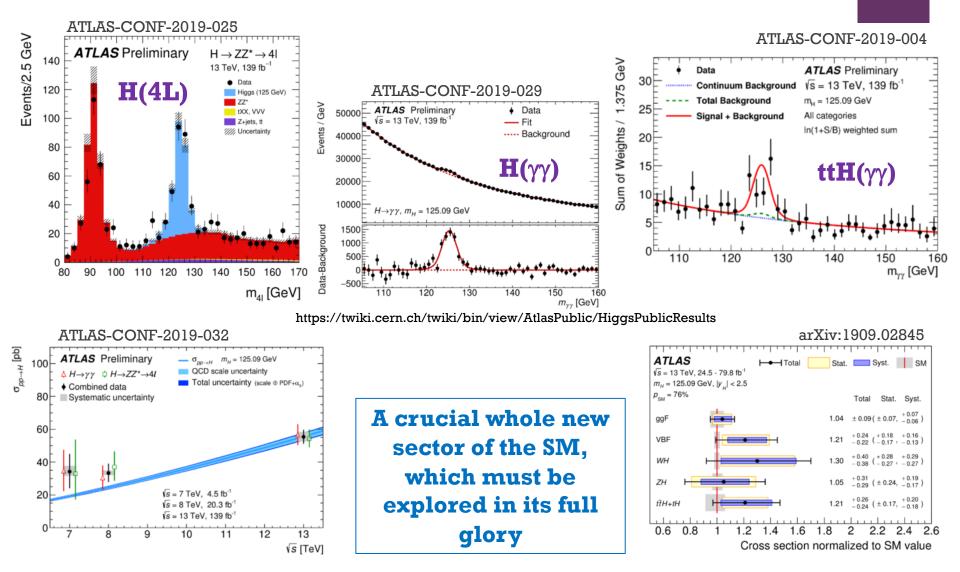


+ The Standard Model is Alive and Well



√s [TeV]

+ Pinning down the SM Higgs Boson



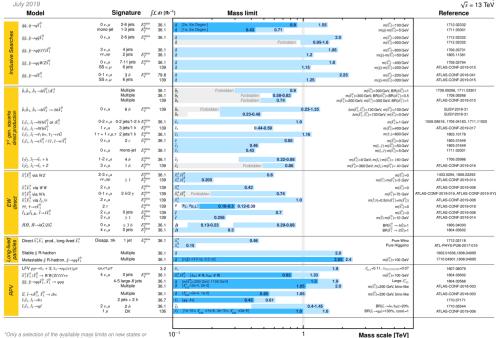
+ Elusive BSM Physics

| Model | ℓ, γ | Jets† | E ^{miss} | ∫£ dt[fb | Limit | | Reference |
|--|------------------|----------------------|-------------------|--------------|--|---|----------------------------------|
| | | | - · | | ···· · · · · · · · · · · · · · · · · · | | 1 |
| ADD $G_{KK} + g/q$ | 0 e, µ | 1 – 4 j | Yes | 36.1 | 7.7 Te | | 1711.03301 |
| ADD non-resonant yy | 2γ | - | - | 36.7 | 8.61 | | 1707.04147 |
| ADD QBH | | 2) | - | 37.0 | 6.9 8.2 Ti | | 1703.09127 |
| ADD BH high ∑ p _T ADD BH multiet | $\geq 1 e, \mu$ | ≥ 2 j | - | 3.2 | | | 1606.02265 |
| | 2 2 | ≥ 3 j | - | 3.6 | | TeV: $n = 6$, $M_D = 3$ TeV, rot BH $k/\overline{M}_{er} = 0.1$ | 1512.02586 |
| RS1 $G_{KK} \rightarrow \gamma\gamma$ Bulk RS $G_{KK} \rightarrow WW/ZZ$ | | | - | 36.7 36.1 | k mass 4.1 TeV | $\frac{k/M_{PT} = 0.1}{k/M_{PT} = 1.0}$ | 1707.04147 |
| Bulk RS $G_{KK} \rightarrow WW/22$ Bulk RS $G_{KK} \rightarrow WW \rightarrow qqqq$ | multi-channe | | | | | $\frac{k/M_{Pf} = 1.0}{k/M_{Pf} = 1.0}$ | |
| Bulk RS $g_{KK} \rightarrow tr tr \rightarrow qqqq$ | 0 е. µ 1 е. µ | 2 J : 1 b, ≥ 1J/ | | 139 36.1 | r mass 1.6 TeV | $k/M_{Pl} = 1.0$ $\Gamma/m = 15\%$ | ATLAS-CONF-2019-00 1804.10823 |
| 2UED / RPP | 1 e.µ | ≥ 2 b, ≥ 3 | | 36.1 | mass 1.8 TeV | $T_{1}(t) = 15\%$ Tier (1,1), $S(A^{(1,1)} \rightarrow tt) = 1$ | 1803.09678 |
| | | 1.1.0,1.0 | 14.9 | | | $\operatorname{rat}(1,1), \mathcal{D}(N^{-1} \to 11) = 1$ | |
| $SSM Z' \rightarrow \ell\ell$ $SSM Z' \rightarrow \tau\tau$ | 2 e, μ 2 τ | - | | 139 36.1 | mass 5.1 TeV mass 2.42 TeV | | 1903.06248 1709.07242 |
| Leptophobic $Z' \rightarrow bb$ | 27 | 25 | | 36.1 | TTADS 2.1 TeV | | 1805.09299 |
| Leptophobic $Z' \rightarrow tt$ | 10.0 | : 1 b. ≥ 1J/ | N Mag | 36.1 | mass 3.0 TeV | $\Gamma/m = 1\%$ | 1804.10823 |
| $SSM W' \rightarrow tr$ | 1 e.u | | Yes | 139 | mass 6.0 TeV | 1/20 - 1/4 | CERN-EP-2019-100 |
| SSM $W' \rightarrow tr$ | 1 7 | | Yes | 36.1 | mass 3.7 TeV | | 1801.06992 |
| HVT $V' \rightarrow WZ \rightarrow gapg model$ | | 2 J | - | 139 | mass 3.6 TeV | $g_{Y} = 3$ | ATLAS-CONF-2019-00 |
| $HVT V' \rightarrow WH/ZH model B$ | multi-channe | | | 36.1 | Tass 2.93 TeV | $g_V = 3$ | 1712.06518 |
| LRSM $W_{e} \rightarrow tb$ | multi-channe | | | 36.1 | mass 3.25 TeV | 11 | 1807.10473 |
| LRSM $W_R \rightarrow \mu N_R$ | 2μ | 1 J | - | 80 | mass 5.0 TeV | $m(N_R) = 0.5 \text{ TeV}, g_L = g_R$ | 1904.12679 |
| Cl gagg | - | 21 | - | 37.0 | | 21.8 TeV 50 | 1703.09127 |
| Cl ((gg | 2 e, µ | | - | 36.1 | | 40.0 TeV 07 | 1707.02424 |
| CI tttt | ≥1 e.µ | ≥1 b, ≥1 j | Yes | 36.1 | 2.57 TeV | $ C_{4z} = 4\pi$ | 1811.02305 |
| Axial-vector mediator (Dirac DM | 0 e.u | 1-4 j | Meg | 36.1 | | g,=0.25, g,=1.0, m(y) = 1 GeV | 1711.03301 |
| Colored scalar mediator (Dirac D | M) 0 c. µ | 1-41 | Meg | 36.1 | | g=1.0, m(y) = 1 GeV | 1711.03301 |
| VV y EFT (Dirac DM) | 0 e. µ | $1J_i \leq 1j$ | Yes | 3.2 | 700 GeV | m(y) < 150 GeV | 1608.02372 |
| Scalar reson. $\phi \rightarrow t_{\chi}$ (Dirac DM | 0-1 e, µ | 1 b, 0-1 J | Yes | 36.1 | 3.4 TeV | $y = 0.4, \lambda = 0.2, m(\chi) = 10 \text{ GeV}$ | 1812.09743 |
| Scalar LQ 1 st gen | 1.2 e | ≥ 2 i | Yes | 36.1 | mass 1.4 TeV | $\beta = 1$ | 1902.00377 |
| Scalar LQ 2nd gen | 1,2 µ | ≥ 2] | Yes | 36.1 | mass 1.56 TeV | $\beta = 1$ | 1902.00377 |
| Scalar LQ 3 rd gen | 2 7 | 2b | - | 36.1 | mass 1.03 TeV | $S(LQ_1^r \rightarrow b\tau) = 1$ | 1902.08103 |
| Scalar LQ 3 rd gen | 0-1 e, µ | 2 b | Yes | 36.1 | mass 970 GeV | $\mathcal{B}(LQ_3^d \rightarrow t\tau) = 0$ | 1902.08103 |
| $VLQ TT \rightarrow Ht/Zt/Wb + X$ | multi-channe | | | 36.1 | 1.37 TeV | SU(2) doublet | 1808.02343 |
| $VLQ BB \rightarrow Wt/Zb + X$ | multi-channel | | | 36.1 | nass 1.34 TeV | SU(2) doublet | 1808.02343 |
| VLQ $T_{5/3}T_{5/3} T_{5/3} \rightarrow Wt + X$ | 2(SS)/23 e. | ≥1 b, ≥1 j | Yes | 36.1 | 1.64 TeV | $S(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3}Wt) = 1$ | 1807.11883 |
| $VLQ Y \rightarrow Wb + X$ | 1 e, µ | ≥ 1 b, ≥ 1 | Yes | 36.1 | nass 1.85 TeV | $S(Y \rightarrow Wb) = 1, c_R(Wb) = 1$ | 1812.07343 |
| $VLQ B \rightarrow Hb + X$ | 0 e.µ, 2 y | | | 79.8 | nass 1.21 TeV | ×8=0.5 | ATLAS-CONF-2018-02 |
| $VLQ QQ \rightarrow WqWq$ | 1 e, µ | ≥4 j | Yes | 20.3 | nass 690 GeV | | 1509.04261 |
| Excited quark $q^* \rightarrow qg$ | - | 2 j | - | 139 | mass 6.7 TeV | only a^* and d^* , $\Lambda = m(q^*)$ | ATLAS-CONF-2019-00 |
| Excited quark $q^* \rightarrow q\gamma$ | 1 γ | 1 j | - | 36.7 | mass 5.3 TeV | only a^* and d^* , $\Lambda = m(q^*)$ | 1709.10440 |
| Excited quark $b^* \rightarrow bg$ | - | 1 b, 1 j | - | 36.1 | mass 2.6 TeV | | 1805.09299 |
| Excited lepton (* | 3 e, µ | - | - | 20.3 | rass 3.0 TeV | A = 3.0 TeV | 1411.2921 |
| Excited lepton v* | 3 e, μ, τ | | | 20.3 | nass 1.6 TeV | A = 1.6 TeV | 1411.2921 |
| Type III Seesaw | 1 e, µ | ≥ 2 j | Yes | 79.8 | mass 560 GeV | | ATLAS-CONF-2018-02 |
| LRSM Majorana v | 2μ | 2) | - | 36.1 | mass 3.2 TeV | $m(W_R) = 4.1$ TeV, $g_L = g_R$ | 1809.11105 |
| | 2,3,4 e, µ (SS | 0 - | - | 36.1 | * mass 870 GeV | DY production | 1710.09748 |
| Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$ | 3 e, µ, r | - | - | 20.3 | 1 mass 400 GeV | DY production, $\mathcal{B}(H_{L}^{ee} \rightarrow \ell \tau) = 1$ | 1411.2921 |
| Multi-charged particles | - | - | - | 36.1 | ti-charged particle mass 1.22 TeV | DY production, q = 5e | 1812.03673 |
| Magnetic monopoles | - | - | - | 34.4 | nopole mass 2.37 TeV | DY production, g = 1g _D , spin 1/2 | 1905.10130 |
| | = 13 TeV | √s = 10 | | | 10-1 1 | 10 | - |
| | rtial data | full d | | | | 10 Mass scale [TeV] | |

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/

ExoticsPublicResults

ATLAS SUSY Searches* - 95% CL Lower Limits



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

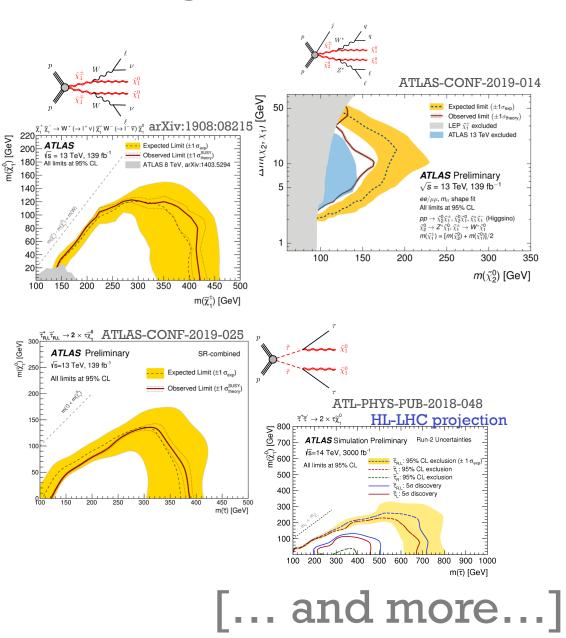


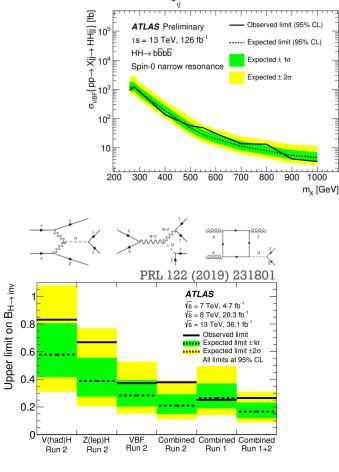
ATLAS Preliminary

+ Shifting Some Boundaries Already

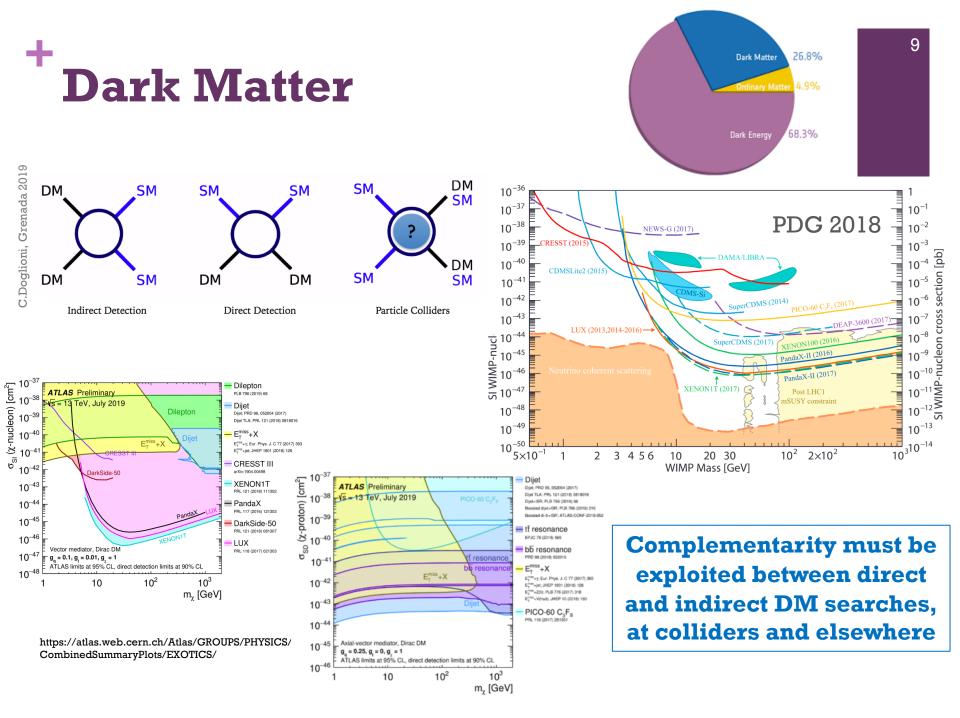
ATLAS-CONF-2019-030

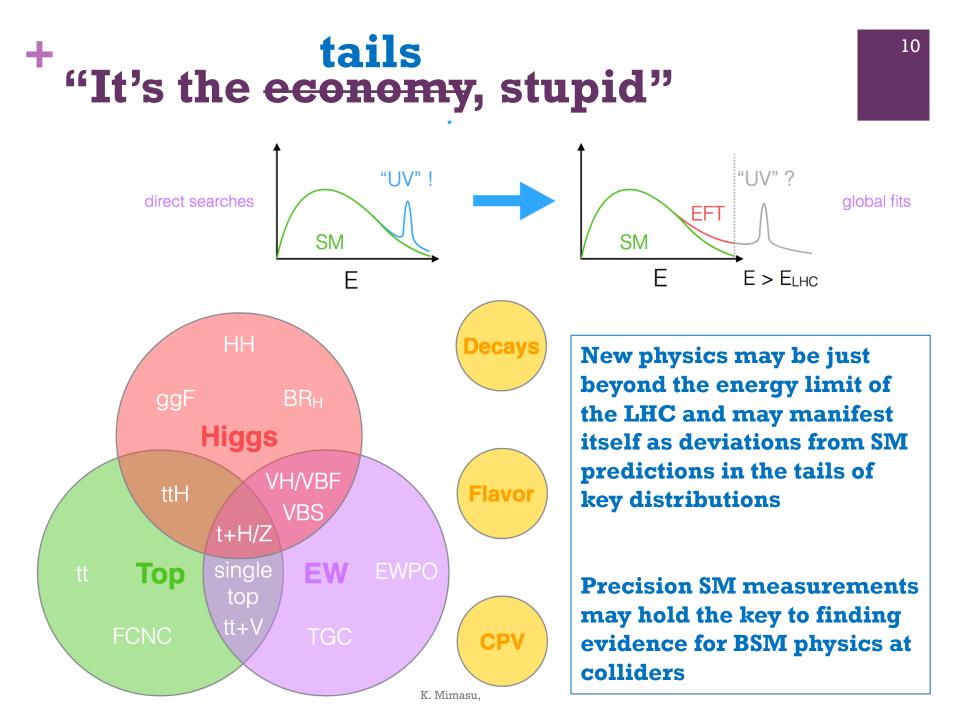
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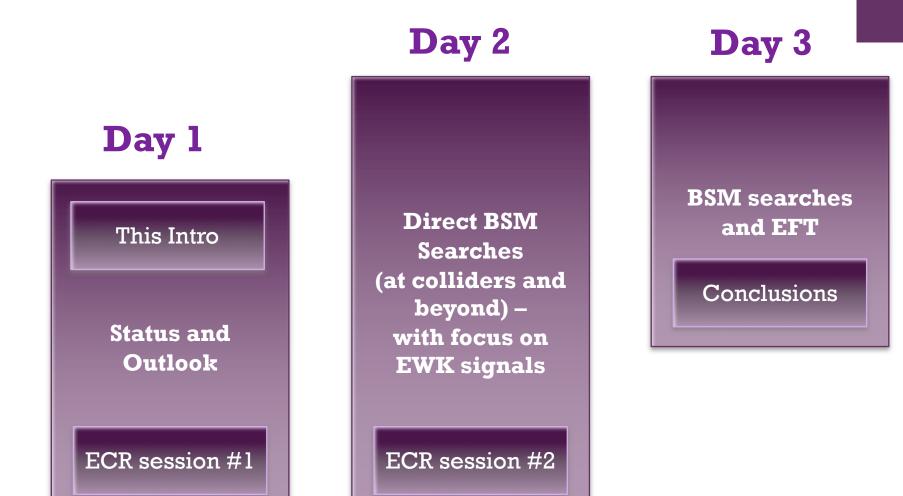


BSM scenarios that had been inaccessible are appearing on the horizon and may be within full reach in the not-so-distant future









+ The Elephant(s) in the Room

- It was a deliberate decision to keep a narrow focus for this workshop, and lots of exciting stuff had to be left out
 - Non-SUSY BSM searches at the LHC (BSM Higgs, exotica)
 - Flavour physics (anomalies, etc)
 - Future colliders
 - Neutrinos and astroparticle physics
 - Other future experiments
 - etc...



• We'll need a bit more Pushing the Boundaries in the future...

+ Thank you and Enjoy!