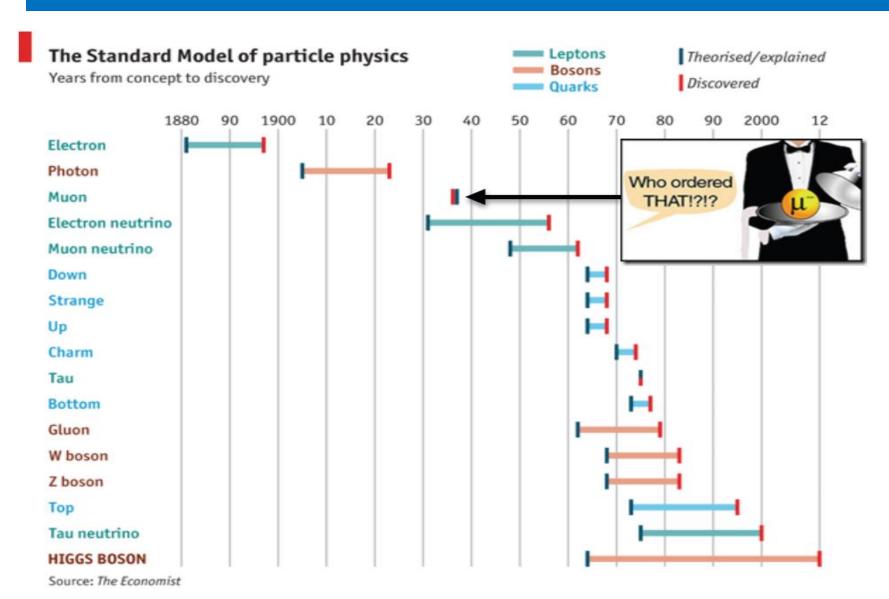
Introduction to particle physics: experimental part

Searches for New Physics Results from Run II

Uncharted discoveries?

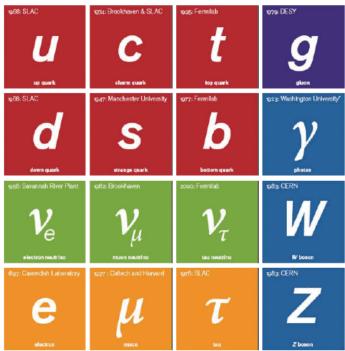


Many unanswered questions....

Why there are 3 families of particles? Are there more? Why is the top quark so heavy?

Why there's more matter then anti-matter?

How do neutrinos get mass?



Are there more forces?

2012: CERN

Miggs bason

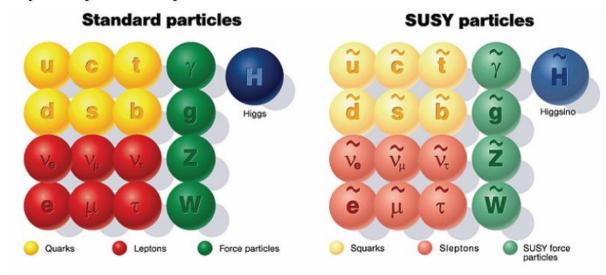
What keeps the Higgs mass so small?

How do we incorporate gravity?

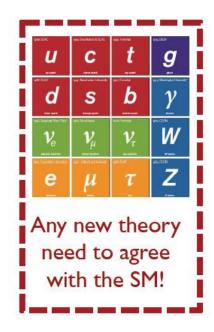
What is Dark Matter?

... as many possible answers to probe!

Super-symmetry?



- Composite quark and/or leptons?
- New Heavy bosons?
- Gravitons?
- Dark Matter particles?
- ...

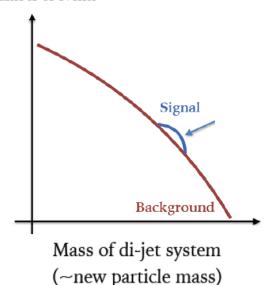


How would new phenomena manifest?

New particles:

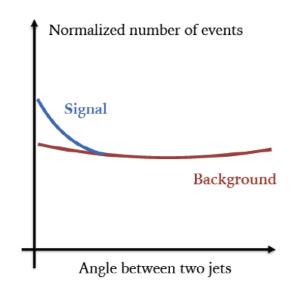
resonant excess (bump) over Standard Model background

Number of events



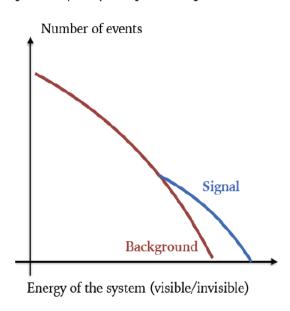
New interactions:

more central production (~Rutherford experiment)

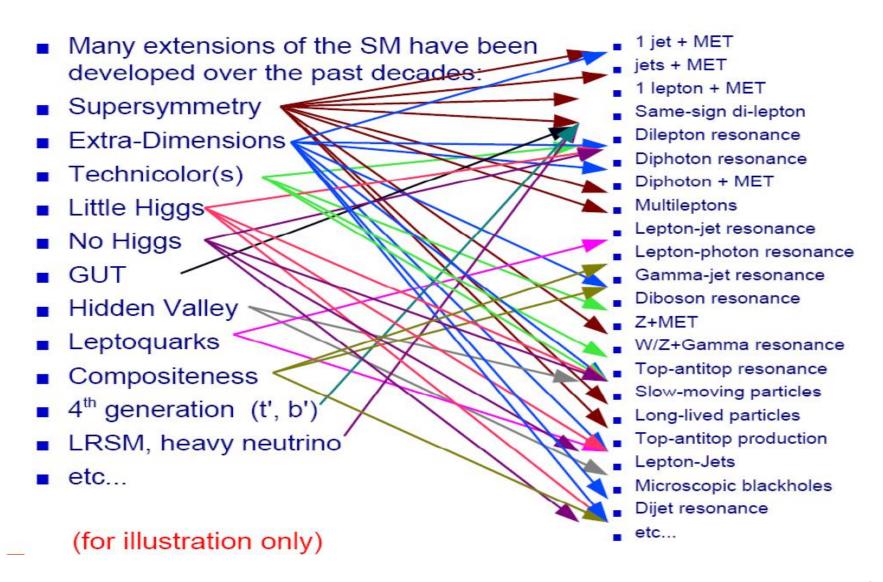


New particles and states:

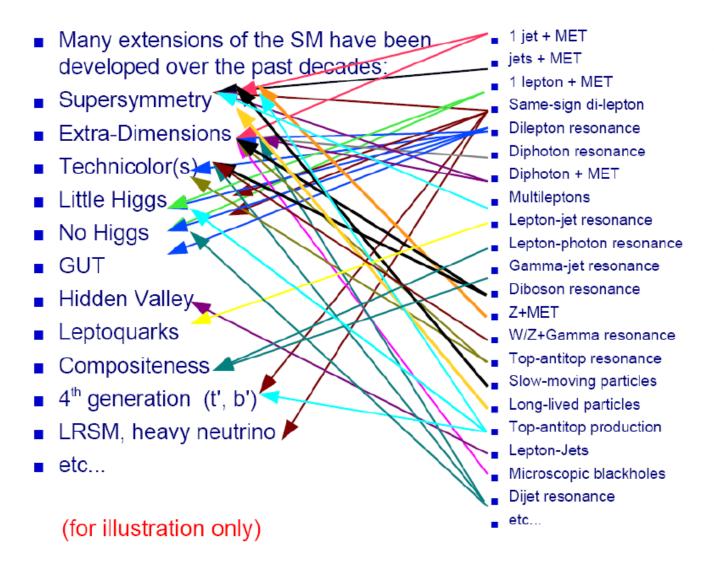
larger multiplicity of objects at high masses



Long list of models and signatures



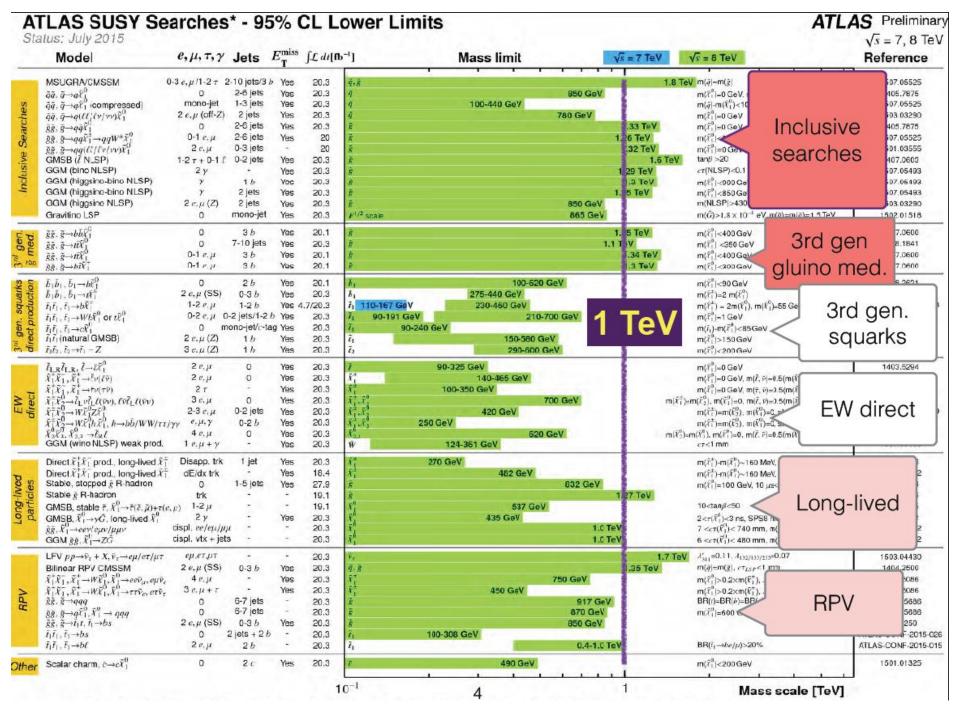
Long list of models and signatures



A complex 2D problem

Experimentally, a signature standpoint makes a lot of sense:

- → Practical
- → Less modeldependent
- → Important to cover every possible signature



ATLAS Exotics Searches* - 95% CL Exclusion ATLAS Prelimina Status: July 2015 $\int \mathcal{L} dt = (4.7 - 20.3) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ Te}'$ $\int \mathcal{L} dt [fb^{-1}]$ 1,7 Limit Model Jets Reference ADD GKK + g/q ≥11 Yes 20.3 5.25 TeV n = 21502.01518 ADD non-resonant & 20, 4 20.3 4.7 TeV n = 3 HLZ1407-2410 ADD QBH → ℓa 1 e. µ 11 20.3 5.2 TeV n = 6ADD QBH 21 5.82 ToV n - 62 µ (SS) ADD BH high North 20.3 4.7 TeV n = 6, $M_O = 3$ TeV, non-rot l Extra ADD BH high $\sum p_T$ ≥ 1 e, µ >21 20.3 5.8 TeV n = 6, Mo = 3 TeV, non-rot 8 ADD BH high multilet ≥2] 20.3 5.8 TeV n=6, $M_{\odot}=3$ TeV, non-rot I2 e. µ RS1 GKK → EE 2.68 TeV 4/Mm = 0.1 20.3 dimensions $k/\overline{M}_{\rm FV} = 0.1$ RS1 GKK → YY 27 20.3 Ger mass 2.55 TeV Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell\ell$ 21/11 G_{KK} mass 740 GeV $k/\overline{M}_{Pl} = 1.0$ 2 e, µ 20.3 Bulk RS GKK → WW → qqlv 1 e, µ 2j/1J 20.3 760 GeV $k/\overline{M}_{Pl} = 1.0$ G_{KK} mass Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ 500-720 GeV $k/\overline{M}_{\rm FF} = 1.0$ 46 19.5 Bulk RS gek → tt 1 e, µ ≥ 1 b, ≥ 1J/2j Yes 20.3 2.2 TeV BR = 0.925 1505.07018 2UED / RPP 2 e, µ (SS) ≥ 1 b, ≥ 1 j 20.3 KK mass 960 GeV 1504.04805 2 e. µ 2.9 TeV SSM $Z' \rightarrow \ell\ell$ 20.3 Z' mass SSM Z' - TT 19.5 2.02 TeV 2 т Z' mass Gauge 3.24 TeV SSM W' -> EV 1 e. u Yes 20.3 W' mass EGM W' → WZ → Ev E'E' 3 c. µ 20.3 W* mass 52 TeV Yes EGM $W' \rightarrow WZ \rightarrow gg\ell\ell$ 21/1J bosons 2 e. µ 20.3 W' mass 59 TeV EGM W' → WZ → gggg 2 J 20.3 W' mass 1.3-5 ToV HVT W' → WH → Evbb 1 e. µ 20.3 W mass 87 TeV $g_V = 1$ 2 b LRSM W' + tb 1 e. µ 2 b. 0-1 | Yos 20.3 1.92 TeV W' mass LRSM WP → tb 0 e. µ > 1 b. 1 J 20.3 W' mass 1.76 TeV Contact CI qqqq 21 17.3 12.0 T V 711 = -1 Cl gglf 2 e. µ 20.3 interaction CI uutt $2e, \mu$ (SS) $\geq 1b, \geq 1$ | Yes 20.3 4.3 TeV Dark Matter EFT D5 operator (Dirac) 0 e. u ≥1; 20.3 974 GeV 1502.01518 EFT D9 operator (Dirac) 0 e, µ 1 J, ≤ 1 j Yes 20.3 2.4 TeV 1309,4017 Scalar LQ 1st gen 2 e 221 20.3 1.05 Te $\beta = 1$ Scalar LQ 2nd gen 6 = 1 2μ ≥2] 20.3 LO mass 1.0 TeV Lepto Scalar LQ 3rd gen 1 c, µ ≥1 b, ≥3 j LQ mass 640 GeV T.B) doublet Quarks $VLQ TT \rightarrow Ht + X$ 1 e.u ≥2b.≥3i Yes T mass 855 GeV Heavy VLQ YY → Wb + X 1 e, µ $\geq 1 \text{ b}, \geq 3 \text{ }$ Y mass 770 GeV (B,Y) doublet VLQ BB → Hb + X Yos nin singlet 1 e. u ≥2b,≥3j 20.3 B mass 735 GeV Quarks $VLQ BB \rightarrow Zb + X$ 2/≥3 e, µ ≥2/≥1 b 20.3 755 GeV (B,Y) doublet Twa - Wt ≥ 1 b, ≥ 5 | Yes 20.3 T_{5/3} max 840 GeV 1 e, µ Excited quark q* -> qy 14 20.3 a" and d" Excited Excited quark q* - qg only o" and d" 20.3 4.09 ToV Excited quark b" → Wt 1 or 2 e, µ 1 b, 2 j or 1 j Yes left-handed co 4.7 b* mass 870 GeV fermions Excited lepton $\ell^* \rightarrow \ell \gamma$ 22 TeV 2 e. µ, 1 y 13.0 A-232 Excited lepton $v^* \rightarrow \ell W, vZ$ 1.6 TeV 3 c. µ. T 20.3 y" mass LSTC at - Wy 960 GeV 1 e. µ. 1 y Yes 20.3 $m(W_R) = 2.4$ TeV, no mixing LRSM Majorana v 2 e. u 2 20.3 N^d mass 1506.06020 2.0 TeV Higgs triplet H** → & DY production, BR(H;** → εε)=1 2 e, µ (55) 20.3 551 GeV 1412,0237 Higgs triplet H** → ET 3 e, µ, τ 400 GeV DY production, $BR(H_{\tau}^{\pm\pm} \rightarrow \ell_{T})=1$ 1411,2921 20.3 Monotop (non-res prod) $s_{\text{non-res}} = 0.2$ 1 e. µ 1 b Yes 20.3 657 GeV 1410.5404 Multi-charged particles 20.3 785 GeV DY production, |a| = 5e 1504.04188 Magnetic monopoles DY production, $|g| = 1_{SD}$, spin 1/2 Preliminary 7.0 √s = 7 TeV √s = 8 TeV 10 1 Mass scale [TeV]

^{*}Only a selection of the available mass limits on new states or phenomena is shown.

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: July 2015

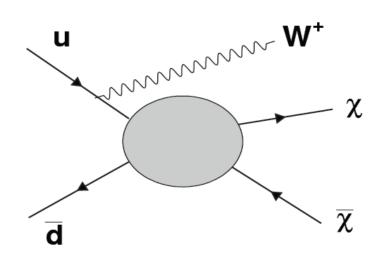
ATLAS Preliminary

 $\int \mathcal{L} dt = (18.4 - 20.3) \text{ fb}^{-1} \qquad \sqrt{s} = 8 \text{ TeV}$

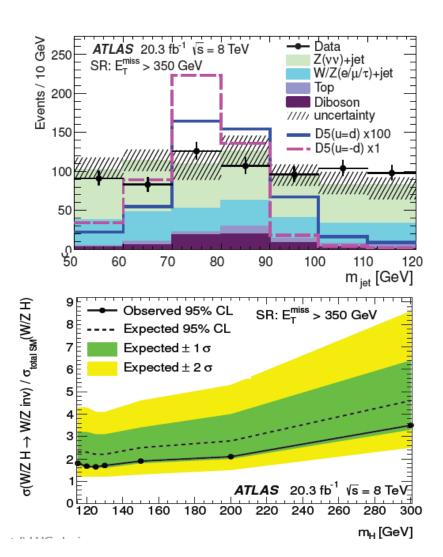
Model Signature $\int \mathcal{L} dt [fb^{-1}]$ Lifetime limit Reference x. lifetime $m(\hat{g}) = 1.3 \text{ TeV}, m(\chi_2^0) = 1.0 \text{ TeV}$ $RPV \chi_1^0 \rightarrow eev/e\mu\nu/\mu\mu\nu$ displaced lepton pair 7-740 mm 1504.05162 GGM XO - ZG 1 lifetime $m(\ddot{g}) = 1.1 \text{ TeV}, m(\chi^0) = 1.0 \text{ TeV}$ displaced vtx + jets 5-480 mm 1504.05162 $m(\chi_1^{\pm}) = 450 \text{ GeV}$ x ! lifetime AMSB $pp \rightarrow \chi_1^4 \chi_1^0, \chi_1^+ \chi_1^$ disappearing track 0.22-3.0 m 20.3 1310,3675 AMSB $pp \rightarrow \chi_1^{\pm} \chi_1^0, \chi_1^{\pm} \chi_1^{-}$ χ[±] lifetime $m(\chi_1^{\pm}) = 450 \text{ GeV}$ 1,31-9.0 m large pixel dE/dx 18.4 1506.05332 non-pointing or delayed y 20.3 χ⁰ lifetime 0.08-5.4 m **GMSB** SPS8 with $\Lambda = 200 \text{ TeV}$ 1409.5542 Stealth SUSY 0.12-90.6 m $m(\tilde{g}) = 500 \text{ GeV}$ 2 ID/MS vertices 19.5 \$ lifetime 1504.03634 0.1 m Hidden Valley $H \rightarrow \pi_v \pi_v$ 2 low-EMF trackless jets 20.3 $m(\pi_{\rm V}) = 25 \,\text{GeV}$ π, lifetime u.+1-7.57 m 1501.04020 Hidden Valley $H \rightarrow \pi_v \pi_v$ 2 ID/MS vertices π_v lifetime (31-25.4 m $m(\pi_{\rm v}) = 25 \, {\rm GeV}$ 19.5 1504.03634 Higgs BR FRVZ $H \rightarrow 2y_d + X$ 7_d lifetime $H \rightarrow 2\gamma_d + X$, $m(\gamma_d) = 400 \text{ MeV}$ 2 e-, μ-, π-jets 14-140 mm 20.3 1409.0746 10 m 7d lifetime 5-260 mm FRVZ $H \rightarrow 4y_d + X$ 2 e-, μ-, π-jets 20.3 1409.0746 Hidden Valley $H \rightarrow \pi_v \pi_v$ 2 low-EMF trackless jets π. lifetime 0.6-5.0 m $m(\pi_{\rm V}) = 25 \, {\rm GeV}$ 1501.04020 Higgs BR = 5% π_v lifetime 0.43-8.1 m Hidden Valley $H \rightarrow \pi_v \pi_v$ 2 ID/MS vertices 19.5 $m(\pi_v) = 25 \text{ GeV}$ 1504.03634 FRVZ $H \rightarrow 4y_d + X$ 7_d lifetime 28-16 mm $H \rightarrow 4\gamma_d + X$, $m(\gamma_d) = 400 \text{ MeV}$ 2 e-, μ-, π-jets 20.3 1409.0746 300 GeV scalar Hidden Valley $\Phi \rightarrow \pi_v \pi_v$ 2 low-EMF trackless jets 0.29-7.9 m $\sigma \times BR = 1 \text{ pb, } m(\pi_v) = 50 \text{ GeV}$ π_v lifetime 1501.04020 0.19-31.9 m $\sigma \times BR = 1$ pb, $m(\pi_e) = 50$ GeV Hidden Valley $\Phi \rightarrow \pi_v \pi_v$ π., lifetime 2 ID/MS vertices 19.5 1504.03634 900 GeV scalar Hidden Valley $\Phi \rightarrow \pi_v \pi_v$ 2 low-EMF trackless jets π_ν lifetime 0.15-4.1 m $\sigma \times BR = 1 \text{ pb, } m(\pi_v) = 50 \text{ GeV}$ 1501.04020 Hidden Valley $\Phi \rightarrow \pi_{\nu}\pi_{\nu}$ 2 ID/MS vertices 19.5 π, lifetime 0.11 8.3 m $\sigma \times BR = 1 \text{ pb. } m(\pi_v) = 50 \text{ GeV}$ 1504.03634 HV Z'(1 TeV) → ququ π, lifetime 0.1-4.9 m $\sigma \times BR = 1 \text{ pb, } m(\pi_V) = 50 \text{ GeV}$ 2 ID/MS vertices 20.3 1504.03634 HV Z'(2 TeV) → a, a, 2 ID/MS vertices 20.3 π, lifetime 0.1-10.1 m $\sigma \times BR = 1 \text{ pb. } m(\pi_v) = 50 \text{ GeV}$ 1504.03634 0.01 0.1 10 Cτ [m] √s = 8 TeV

^{*}Only a selection of the available lifetime limits on new states is shown.

ATLAS dark matter search



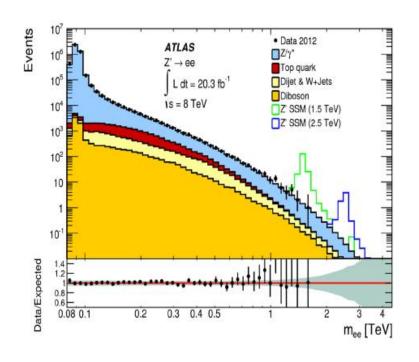
- Pair production of WIMPs plus W or Z bosons decaying and reconstructed as a single massive jet in association with large missing transverse momentum from the undetected WIMPS particles
- The interaction is unknown...
 - ✓ But this doesn't stop the search!



New heavy W and Z like particles

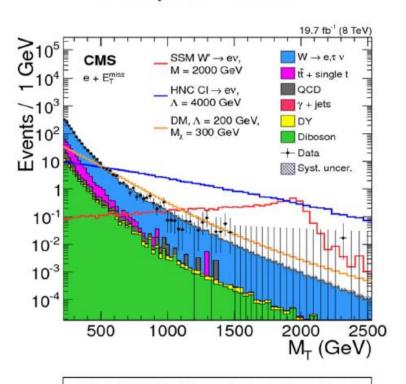
These searches are quite straight-forward, following basically the same analyses as for the familiar W and Z bosons

Z': Di-lepton pairs



Phys. Rev. D 90 (2014) 052005

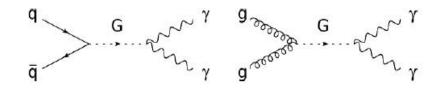
W': Lepton + ETmiss



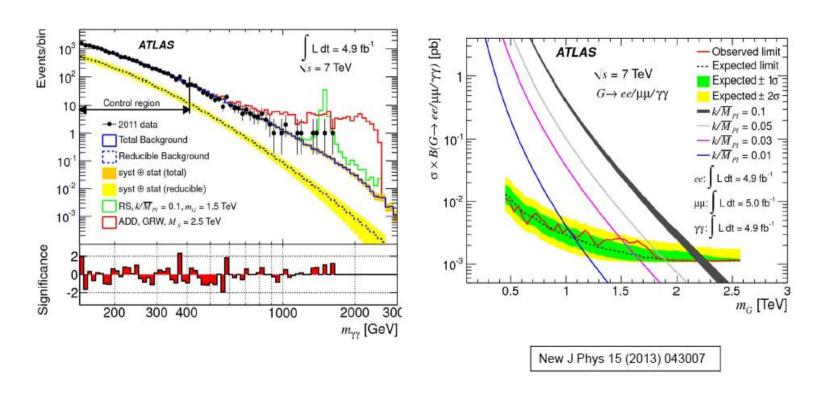
arXiv:1408.2745v1[hep-ex] sub. to Phys. Rev. D

New particles decaying into two photons

Example for a search of extra dimension signals (Kaluza-Klein Graviton in

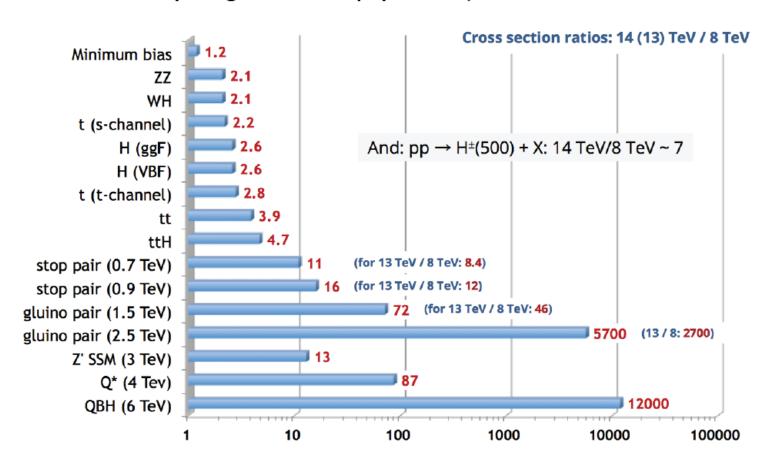


the Randall-Sundrum and Arkani-Hamed, Dimopoulos and Dvali models)



LHC Run 2

Hugely increased potential for discovery of heavy particles at 13 TeV Perfect occasion for young motivated physicists: join the search!



The very successfull 2016

2011: 3.5 TeV

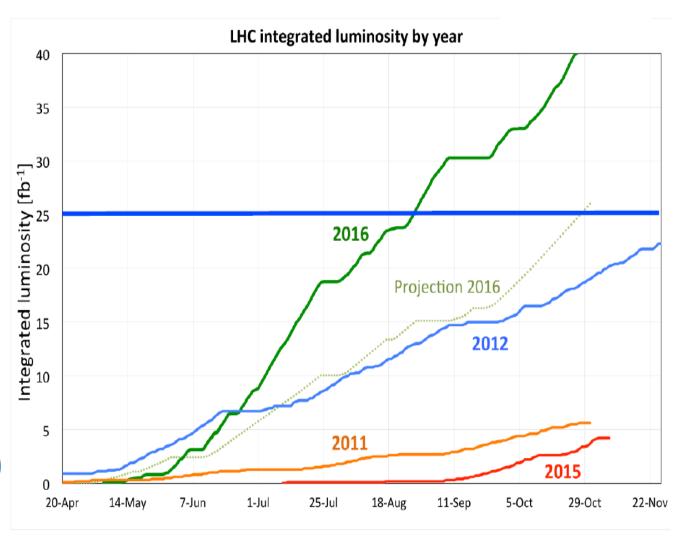
2012: 4 TeV

2015/16: 6.5 TeV

Peak luminosity > 1.35 x 10³⁴ cm⁻²s⁻¹

about 40 fb⁻¹ in both

ATLAS and CMS ©



Availability in 2016

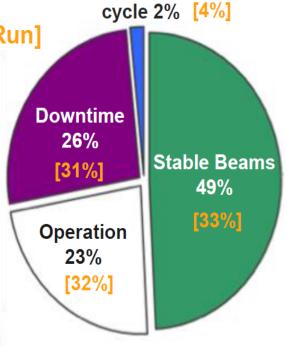
[2015 - 25 ns Run]

Remarkable availability:

- Increased operational efficiency
- Enhanced system availability
- New pre-cycle strategy

Downtime of technical infrastructures

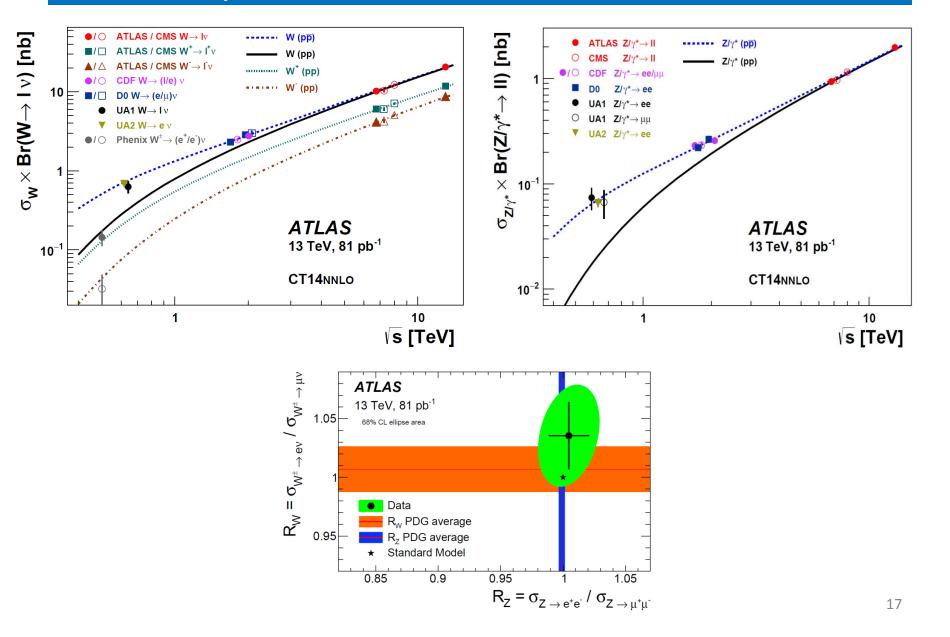




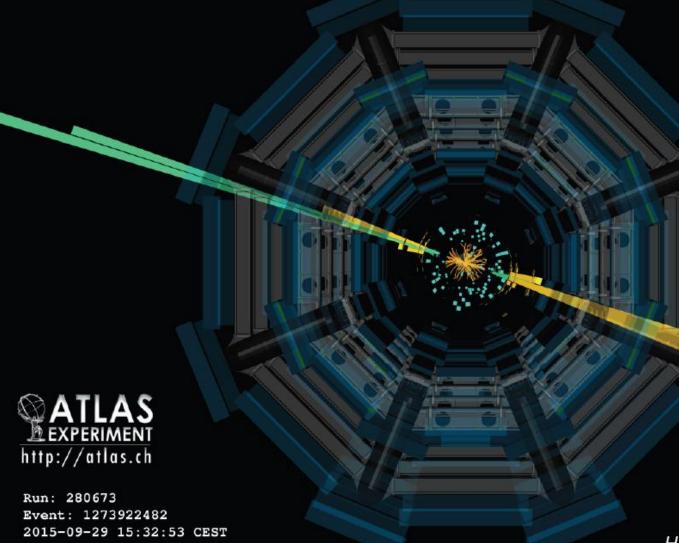
Pre-

Non-availability of beams from the injector complex is the largest source of LHC downtime

W, Z cross-section at 13 TeV







Di-Jet Event

Highest Mass Central Dijet

$$pT_1 = pT_2 = 3.2 \text{ TeV}$$

 $m_{JJ} = 6.9 \text{ TeV}$
 $MET = 46 \text{ GeV}$

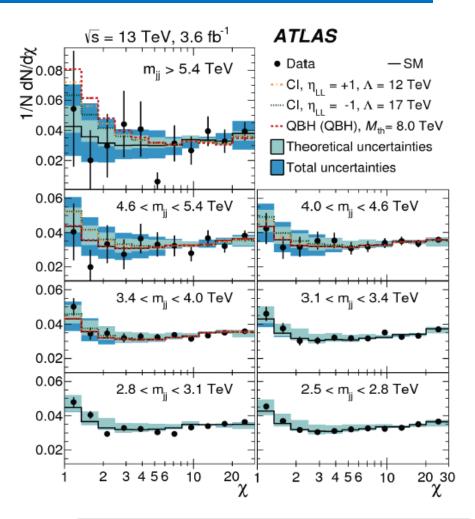
Dijet Angular Searches

Search in dijet mass bins using angular distribution

$$\chi = e^{2|y^*|} \sim \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

1512.01530

Search for distortions of the dijet angular distribution from Contact Interactions of particles at much higher masses $O(\Lambda)$ with color-singlet left-handed chiral couplings (in 4-fermion effective field theory)



No deviations observed, limits set at 12 TeV on Λ (for η_{LL} = 1)

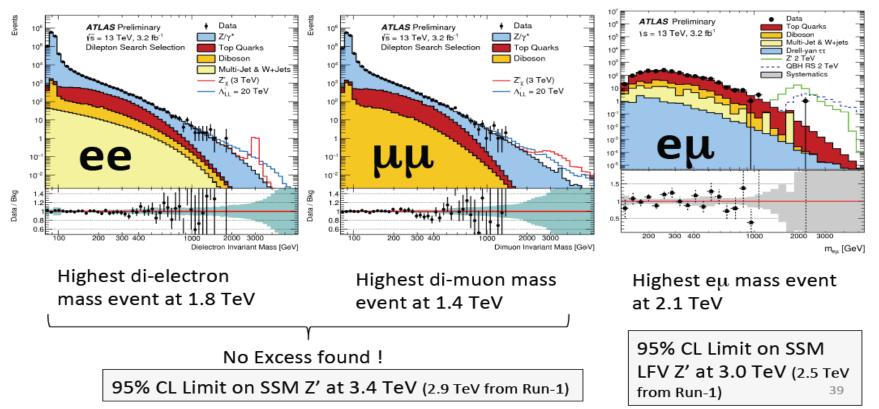
Dilepton Resonances (LFC and LFV)

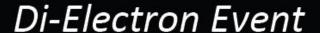
Search for Z' in dilepton (LFC) and (LFV) (in $e\mu$ decays)

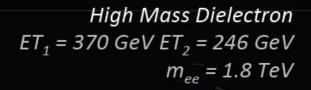
ATLAS-CONF-2015-070

ATLAS-CONF-2015-072

- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)

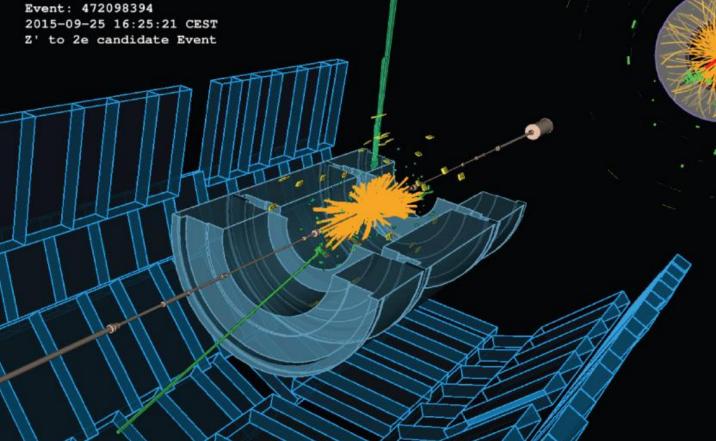








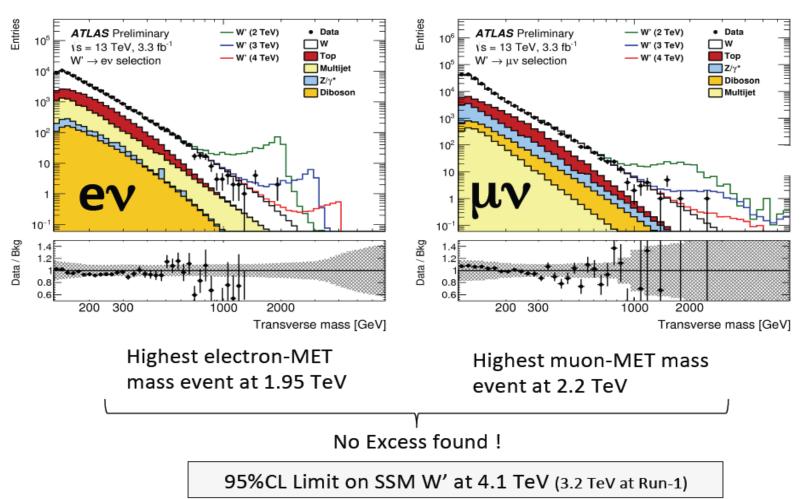
Run: 280319 Event: 472098394



Search for Resonant Lepton-MET

- Search for W' in lepton-MET final states

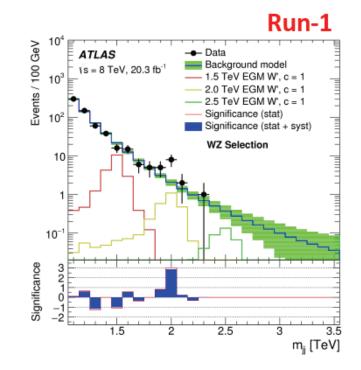
ATLAS-CONF-2015-063

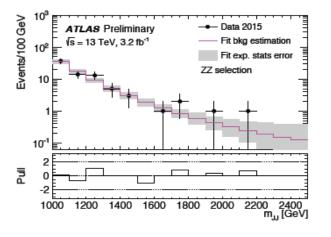


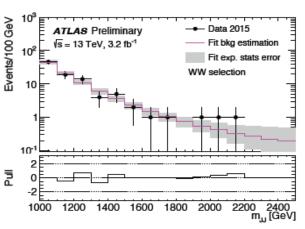
Fully hadronic JJ Diboson Searches

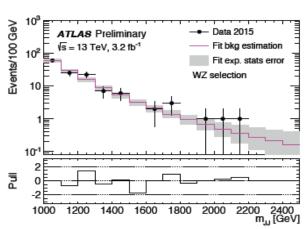
ATLAS-CONF-2015-073

- Modest excess at Run-1: 3.4o local / 2.5o global
- Analysis very similar to Run 1, with functional fit of the background
- No significant excess is observed however sensitivity not high enough for conclusive probe of the Run 1 excess

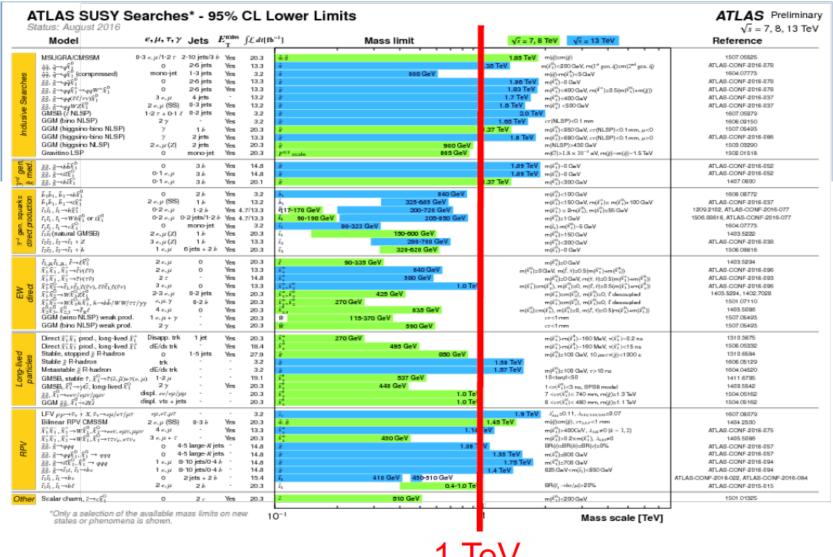






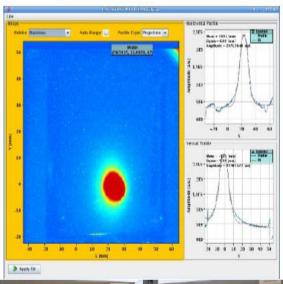


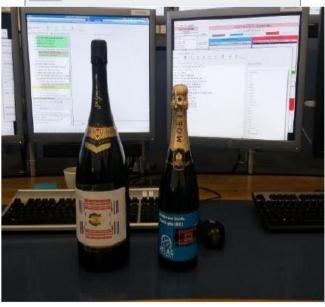
SUSY searches

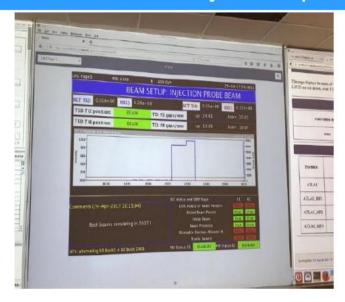


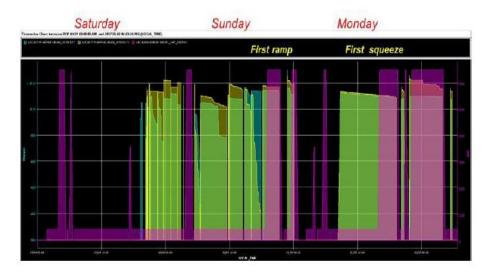


2017: beams are back in LHC from Friday 29th April









2017 scenarios

	Nominal	BCMS	BCMS+
Beta* (1/5) [cm]	40	40	33
Half crossing angle [urad]	185	150	170
No. of colliding bunches	2748	2544	2544
Proton per bunch	1.1e11	1.2e11	1.2e11
Emittance into SB [um]	~3.2	~2.3	~2.3
Bunch length [ns]	1.05	1.05	1.05
Peak luminosity [cm ⁻² s ⁻¹]	~1.1e34	~1.7e34	~1.8e34
Peak pile-up	~28	~48	~52
Luminosity lifetime [h]	~24	~15	~14

2017 plans: 45fb⁻¹

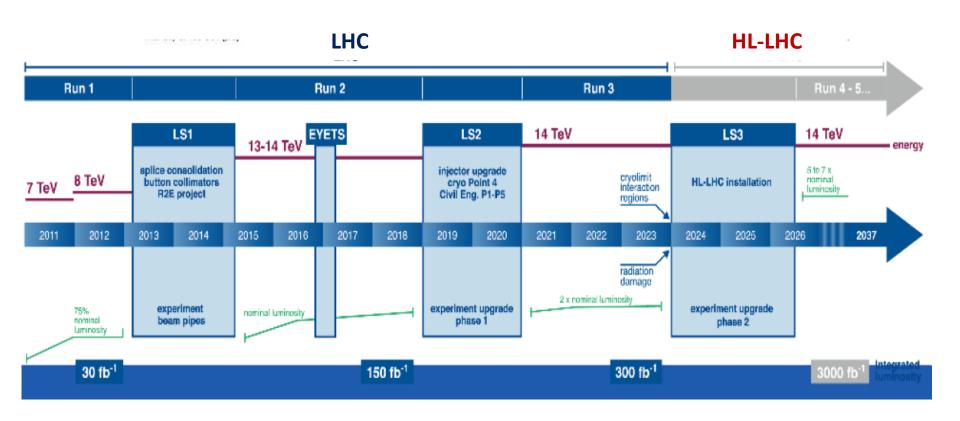
Run 2 @ 13 TeV c.m.

Large Hadron Collider will operate till 2035

More than 1400 papers published 2010-2016 by 4 LHC experiments.

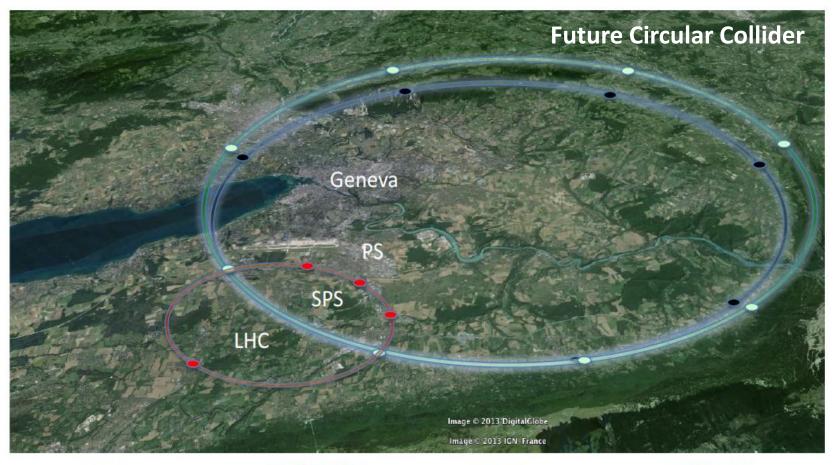
We are on the route to UNKNOWN ...!

Only 2% of complete LHC/HL-LHC has been delivered to date.



ECFA report 2016 (European Committee for Future

Accelerators)



LHC 27 km, 8.33 T 14 TeV (c.o.m.) HE-LHC 27 km, **20 T** 33 TeV (c.o.m.) FCC-hh 80 km, **20 T** 100 TeV (c.o.m.) FCC-hh 100 km, **16 T** 100 TeV (c.o.m.)