

# Elementary Particle Physics: theory and experiments

## **Searches for New Physics**

**Exotic models**

**Dark Matter**

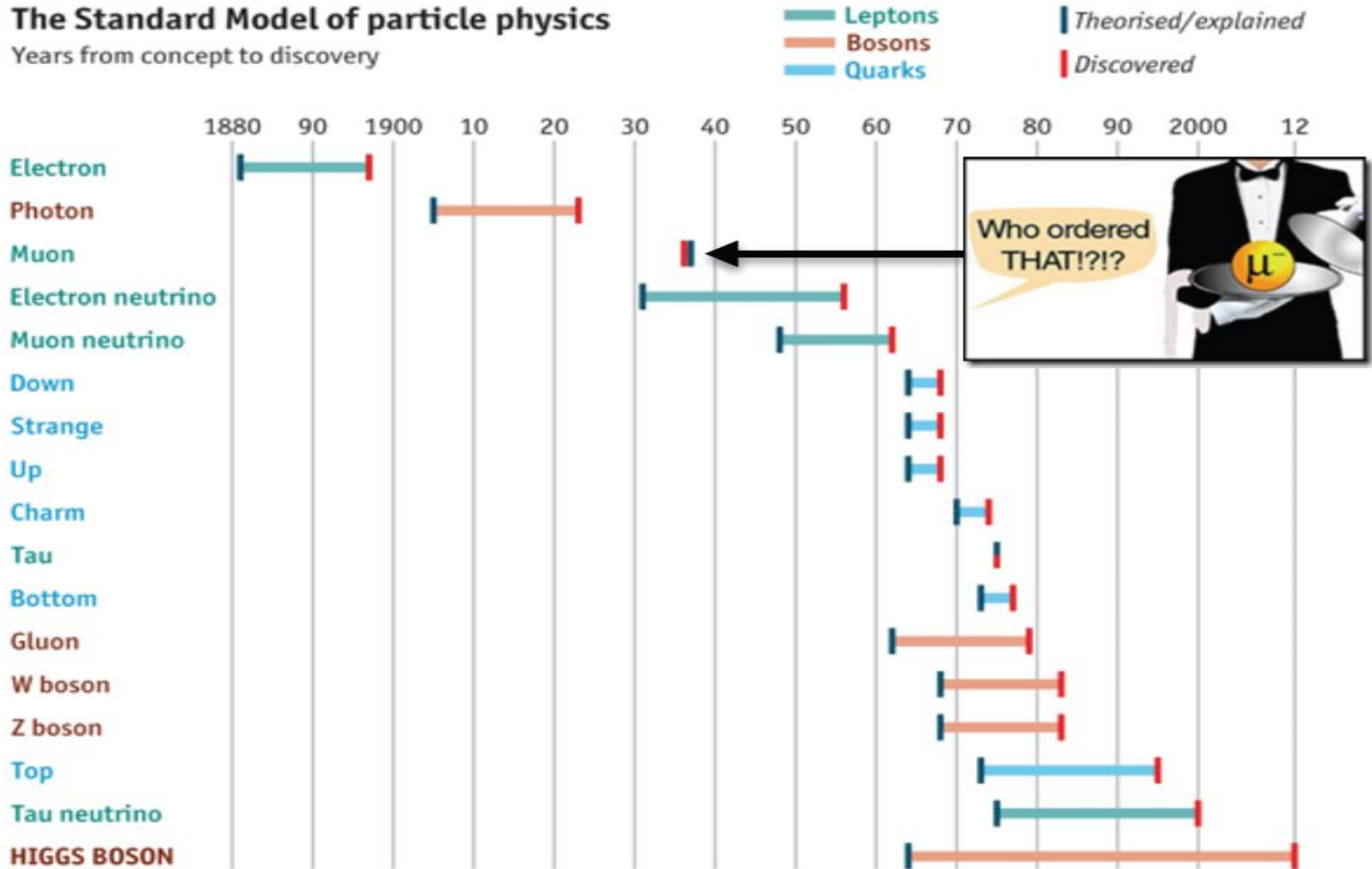
**Sypersymmetry**

## **ATLAS in statistics**

# Uncharted discoveries?

## The Standard Model of particle physics

Years from concept to discovery



Source: *The Economist*

# 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 than anti-matter?

How do neutrinos get mass?

1960: SLAC <b>u</b> up quark	1954: Drottshaven & SLAC <b>c</b> charm quark	1980: Fermilab <b>t</b> top quark	1979: DESY <b>g</b> gluon
1960: SLAC <b>d</b> down quark	1947: Manchester University <b>s</b> strange quark	1977: Fermilab <b>b</b> bottom quark	1923: Washington University <b><math>\gamma</math></b> photon
1926: Savannah River Plant <b><math>\nu_e</math></b> electron neutrino	1962: Drottshaven <b><math>\nu_\mu</math></b> muon neutrino	2000: Fermilab <b><math>\nu_\tau</math></b> tau neutrino	1963: CERN <b>W</b> W boson
1927: Cavendish Laboratory <b>e</b> electron	1937: Coflich and Hewlett <b><math>\mu</math></b> muon	1970: SLAC <b><math>\tau</math></b> tau	1963: CERN <b>Z</b> Z boson
			2012: CERN <b>H</b> Higgs boson

Are there more forces?

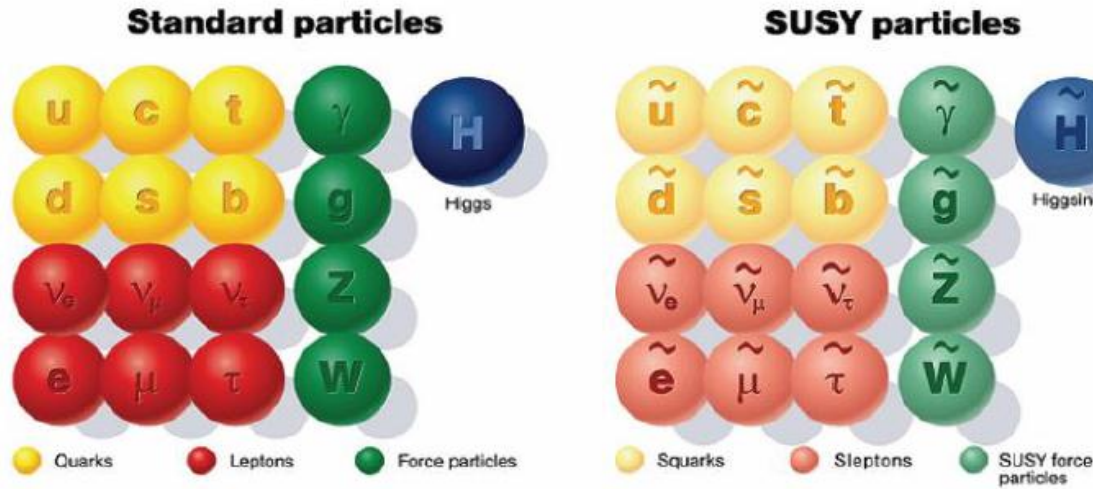
What keeps the Higgs mass so small?

How do we incorporate gravity?

What is Dark Matter?

# ... and as many possible answers to probe!

- Super-symmetry?



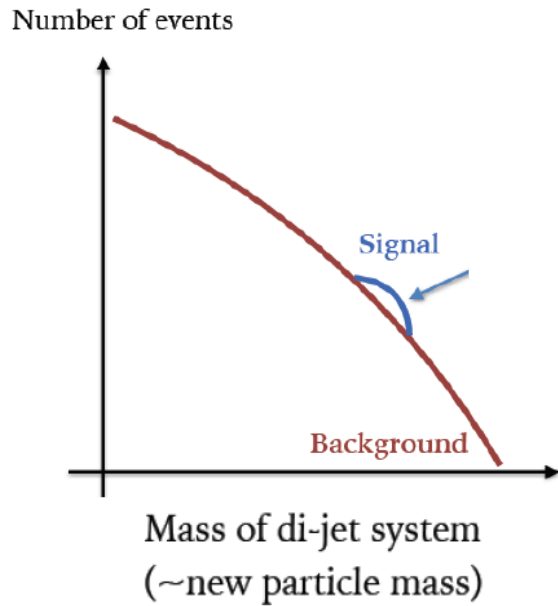
- Composite quark and/or leptons?
- New Heavy bosons?
- Gravitons?
- Dark Matter particles?
- ...



# How would new phenomena manifest?

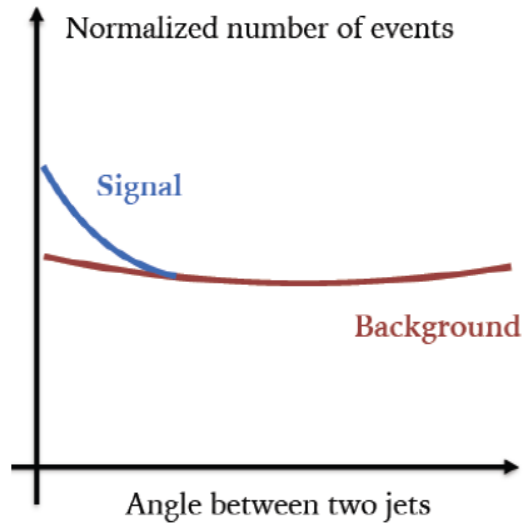
## New particles:

resonant excess (bump) over Standard Model background



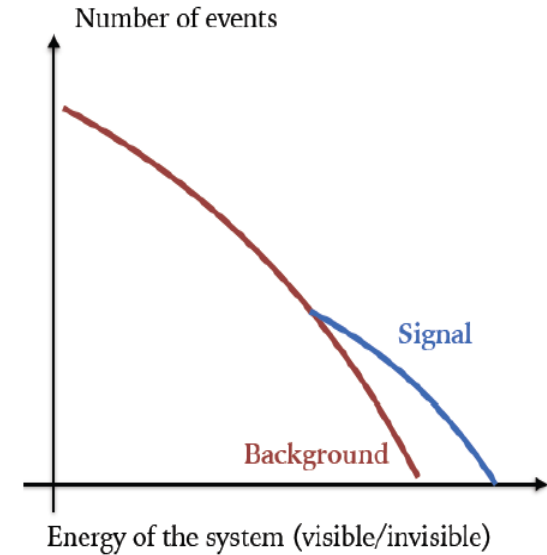
## New interactions:

more central production (~Rutherford experiment)

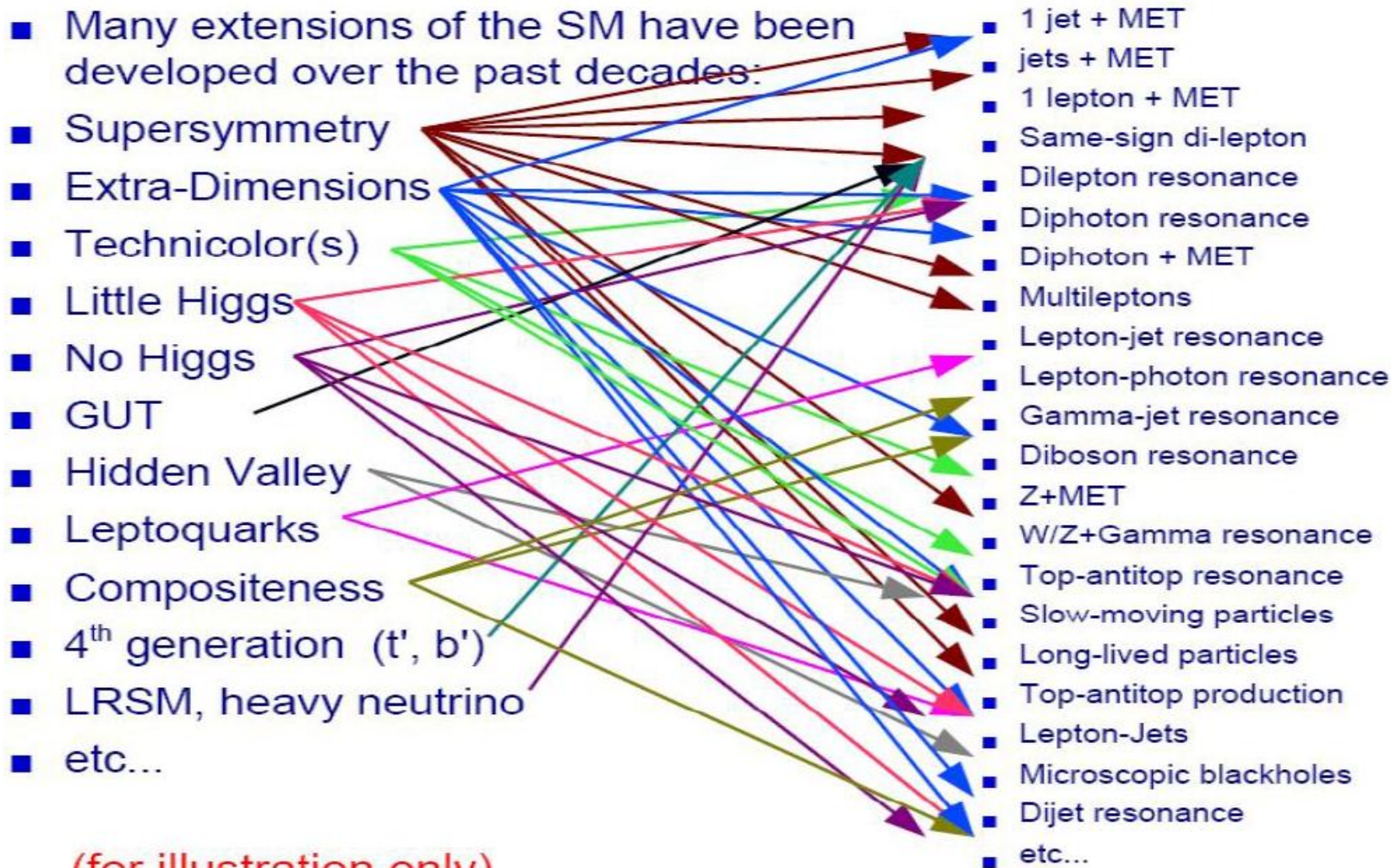


## New particles and states:

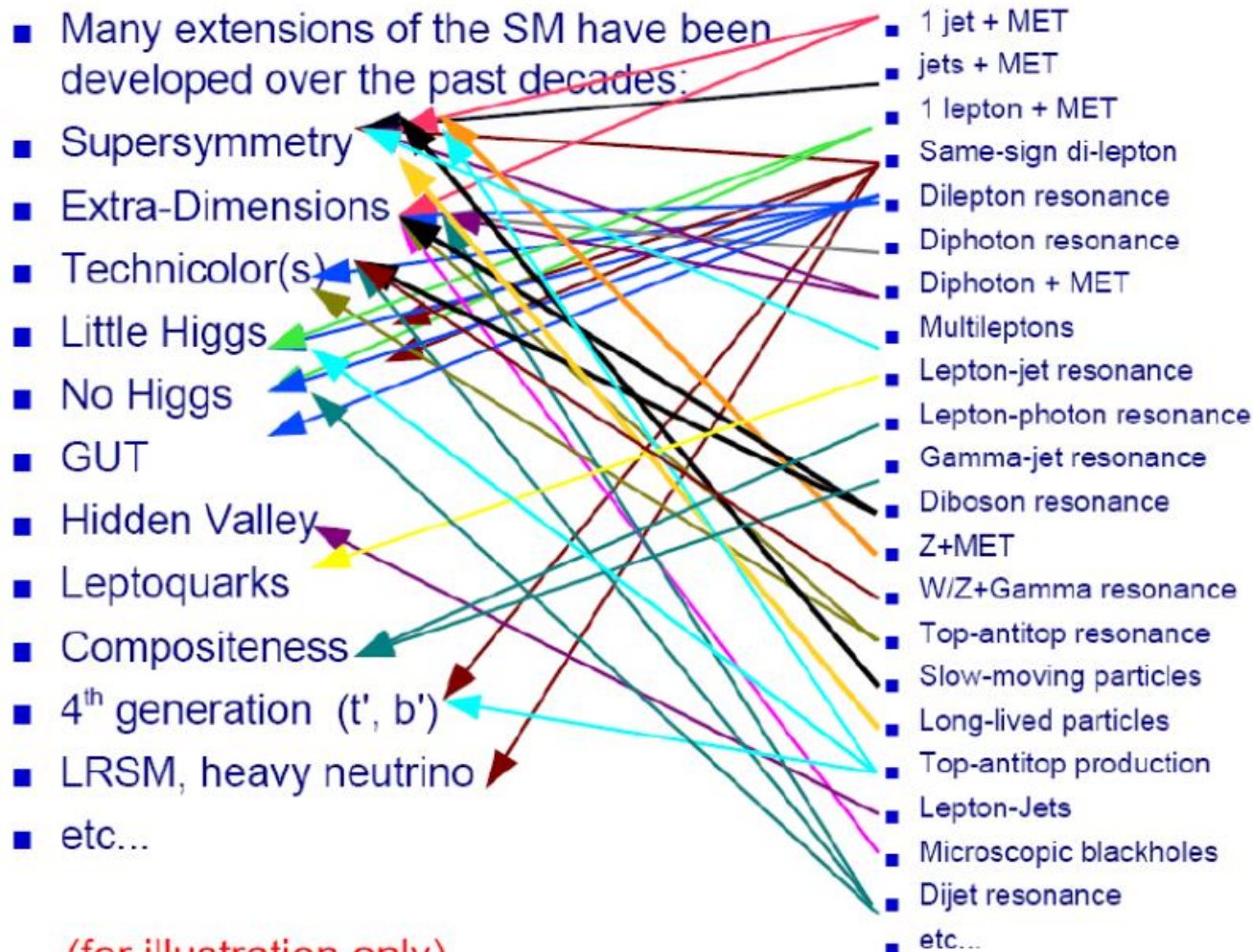
larger multiplicity of objects at high masses



# 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:

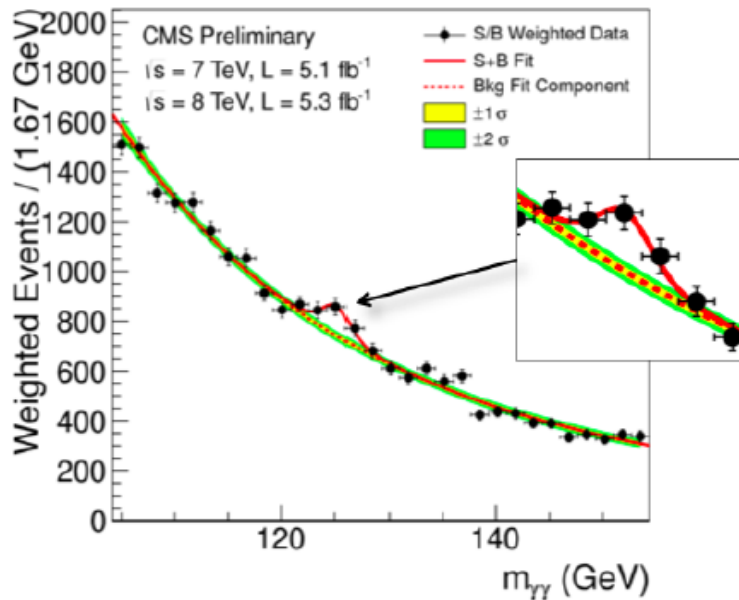
- Practical
- Less model-dependent
- Important to cover every possible signature

(for illustration only)

# What characterizes Exotics Searches

No precise model to guide us

Standard Model:  
Predicted Higgs boson

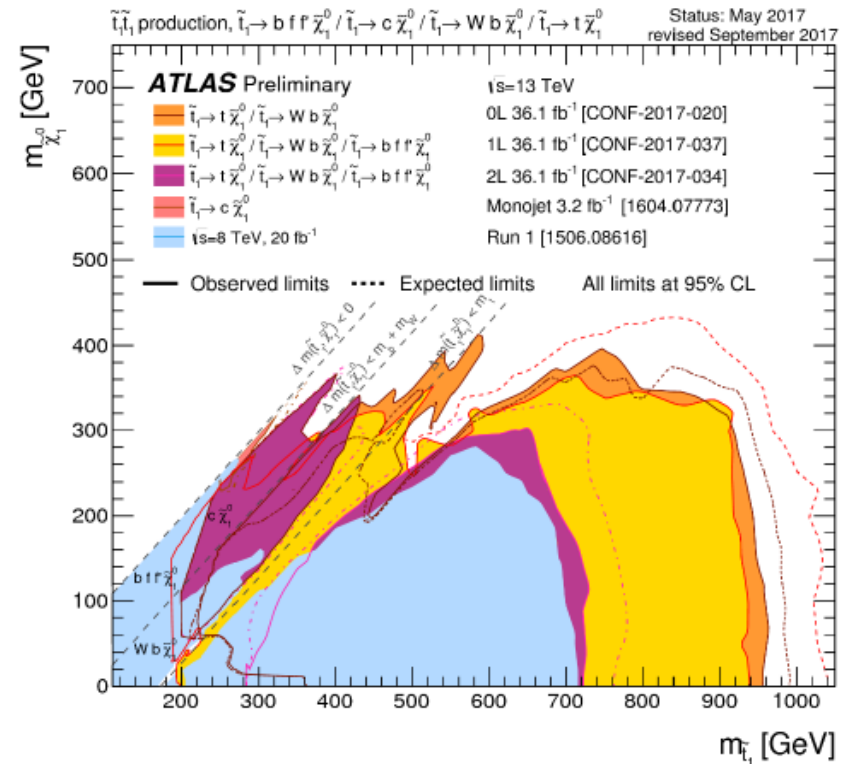


[Phys. Lett. B 716 \(2012\) 1-29](#)

[Phys. Lett. B 716 \(2012\) 30-61](#)

No unified parameter phase space

Supersymmetry Searches:

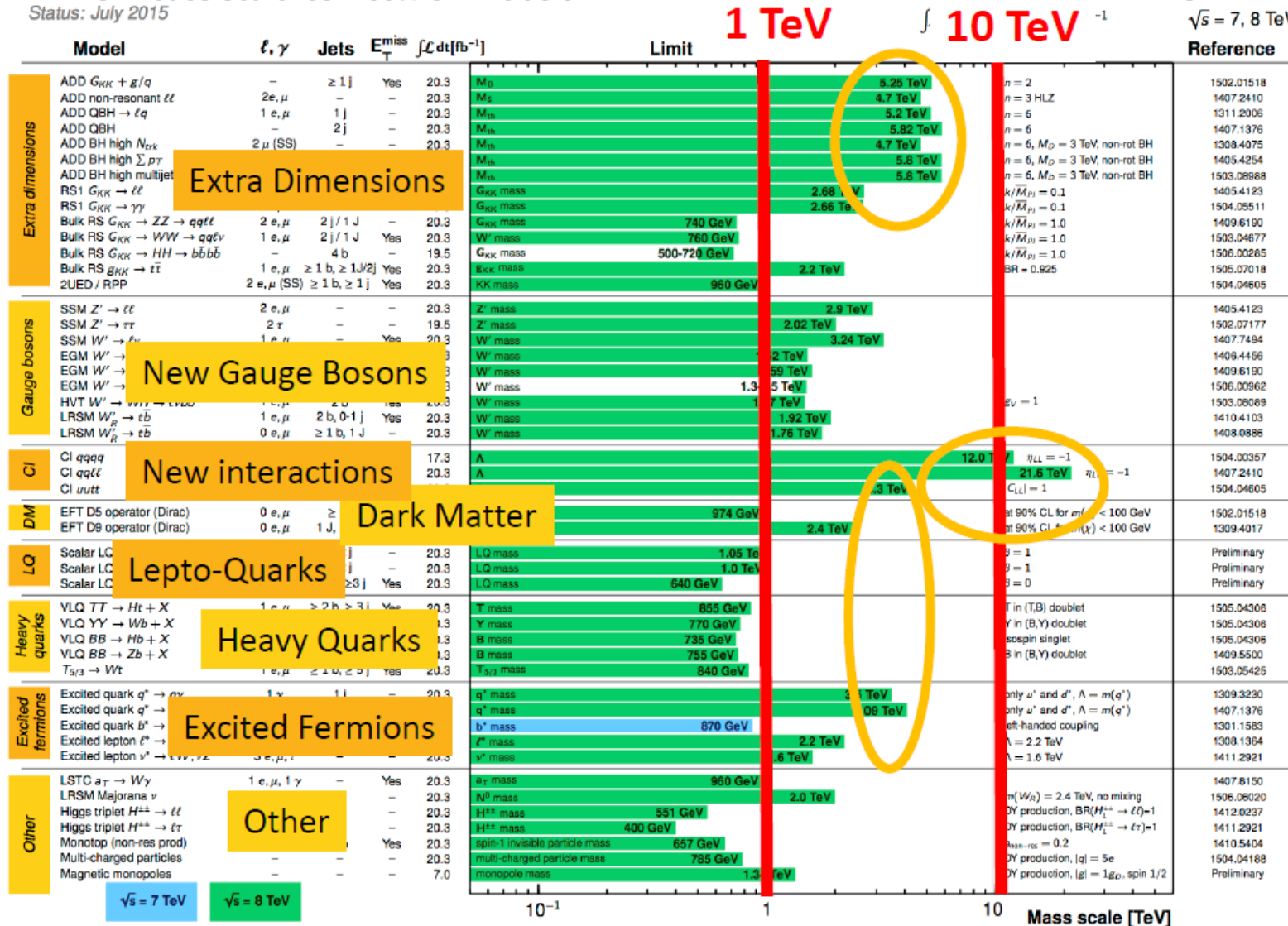




# Exploration range of LHC by mid 2015

ATLAS Exotics Searches\* - 95% CL Exclusion  
 Status: July 2015

ATLAS Preliminary  
 $\sqrt{s} = 7, 8 \text{ TeV}$



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

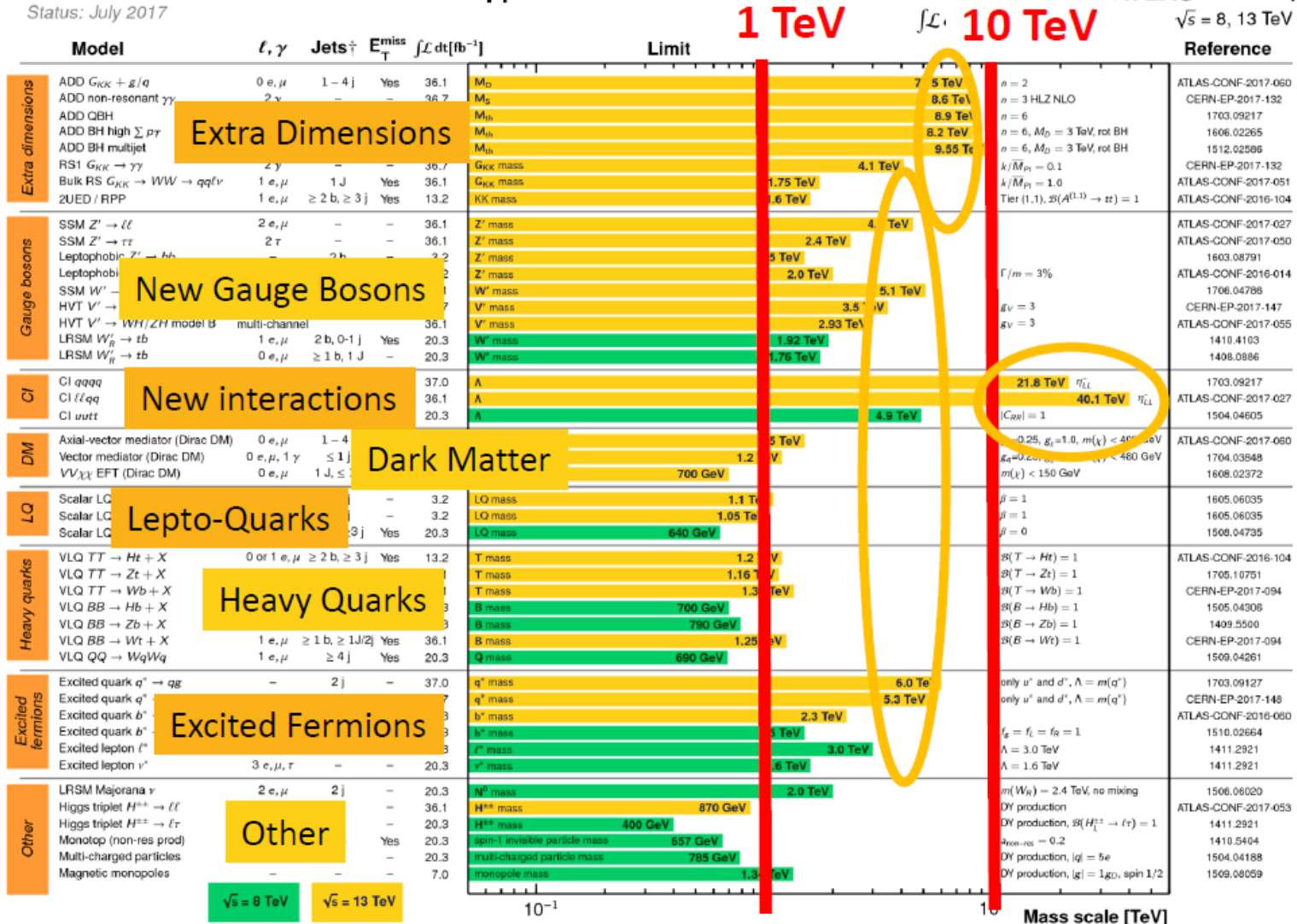
# Exploration range of LHC by mid 2017

## ATLAS Exotics Searches\* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\sqrt{s} = 8, 13 \text{ TeV}$



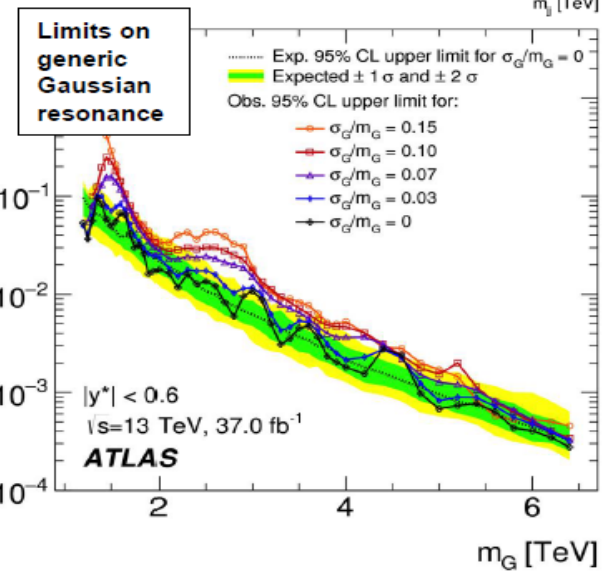
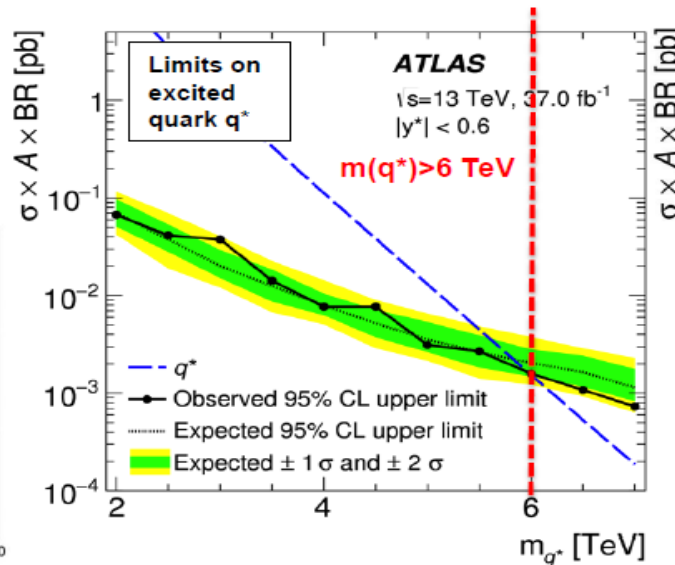
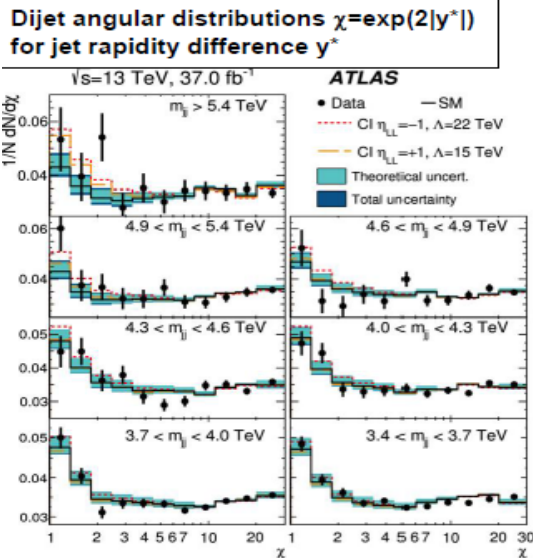
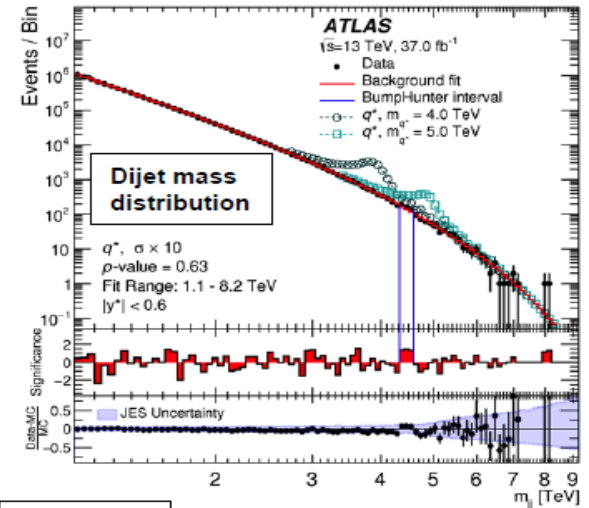
\*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

# Searches with Dijets

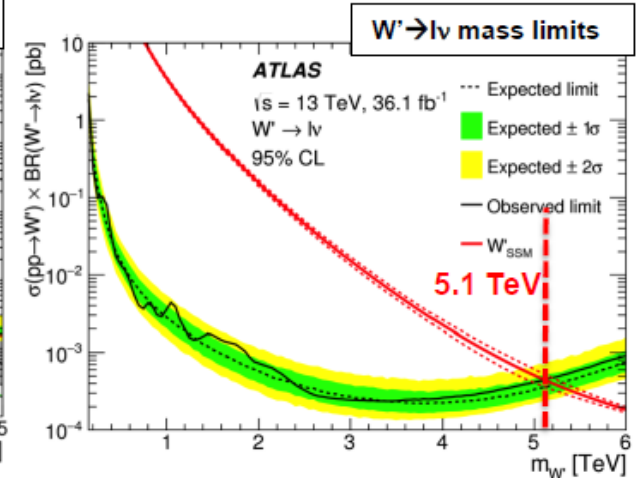
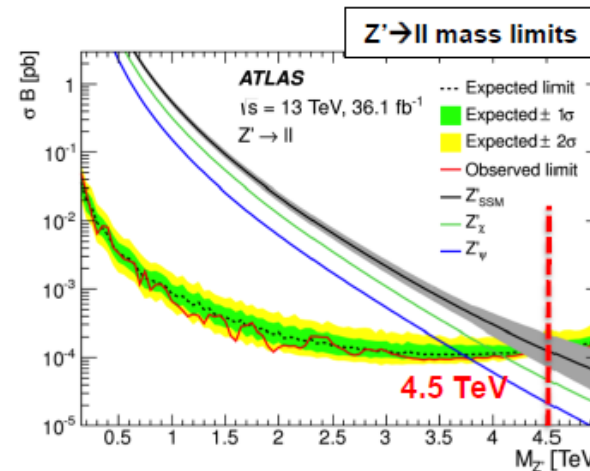
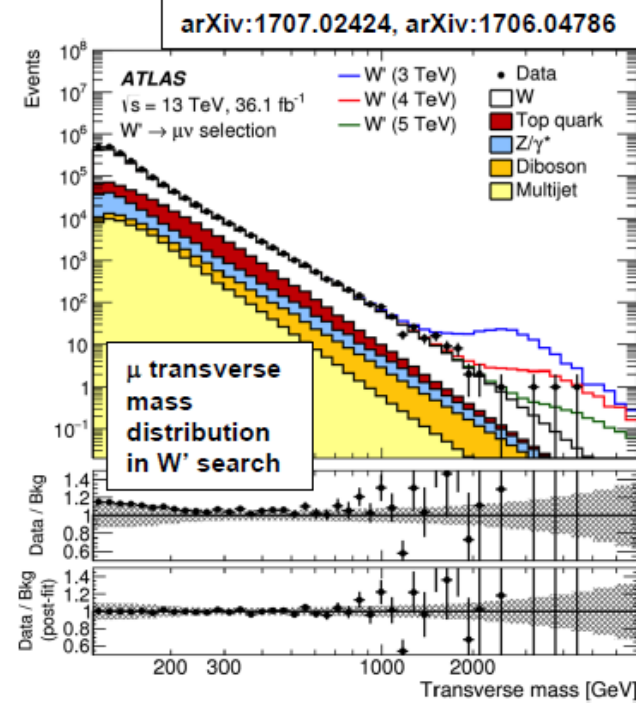
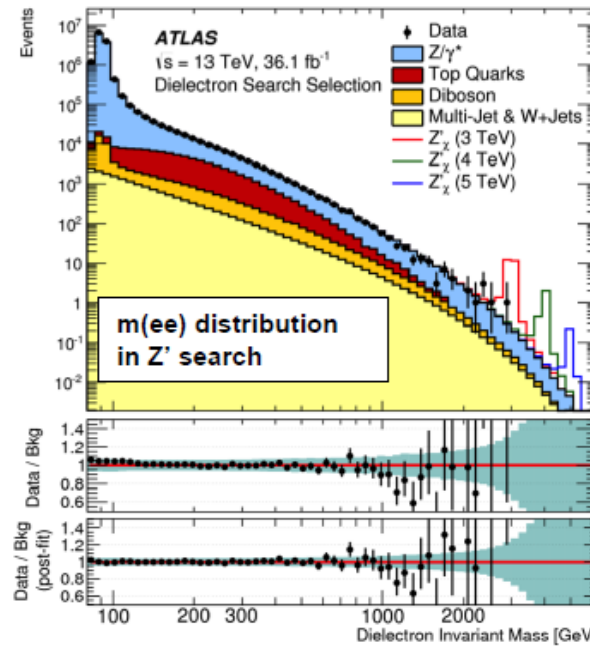
arXiv:1703.09127

- Search for excess in dijet mass and angular distributions
- No significant excesses over SM expectation
- Extends limits significantly beyond 2015 results, on new gauge bosons and contact interactions, e.g.
  - Excited quarks:  $m(q^*) > 6.0$  TeV (5.8 TeV exp.)
  - Add. gauge bosons:  $m(W') > 3.6$  TeV (3.7 TeV exp.)
  - Quantum Black Holes:  $m(\text{BH}) > 8.9$  TeV (8.9 TeV exp.)
  - Contact Interactions:  $\Lambda > 13.1/21.8$  TeV ( $\eta_{LL} = +1/-1$ )
- Limits also set on generic Gaussian resonances



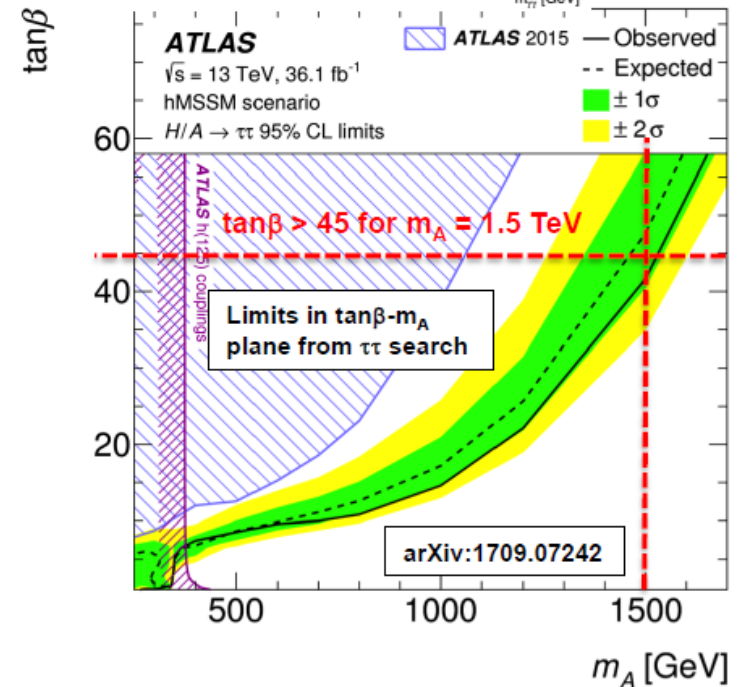
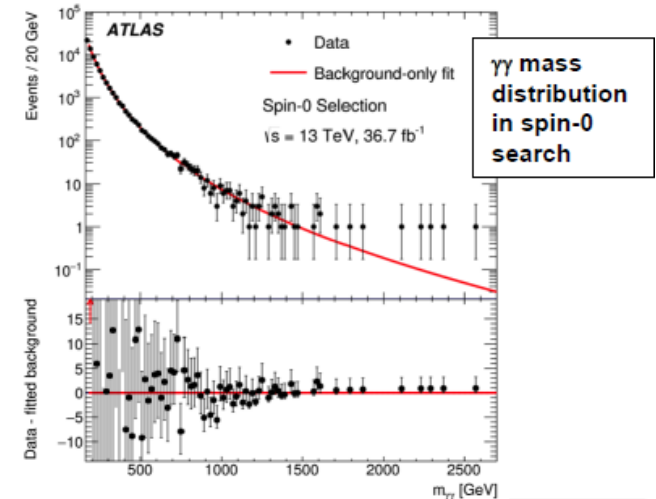
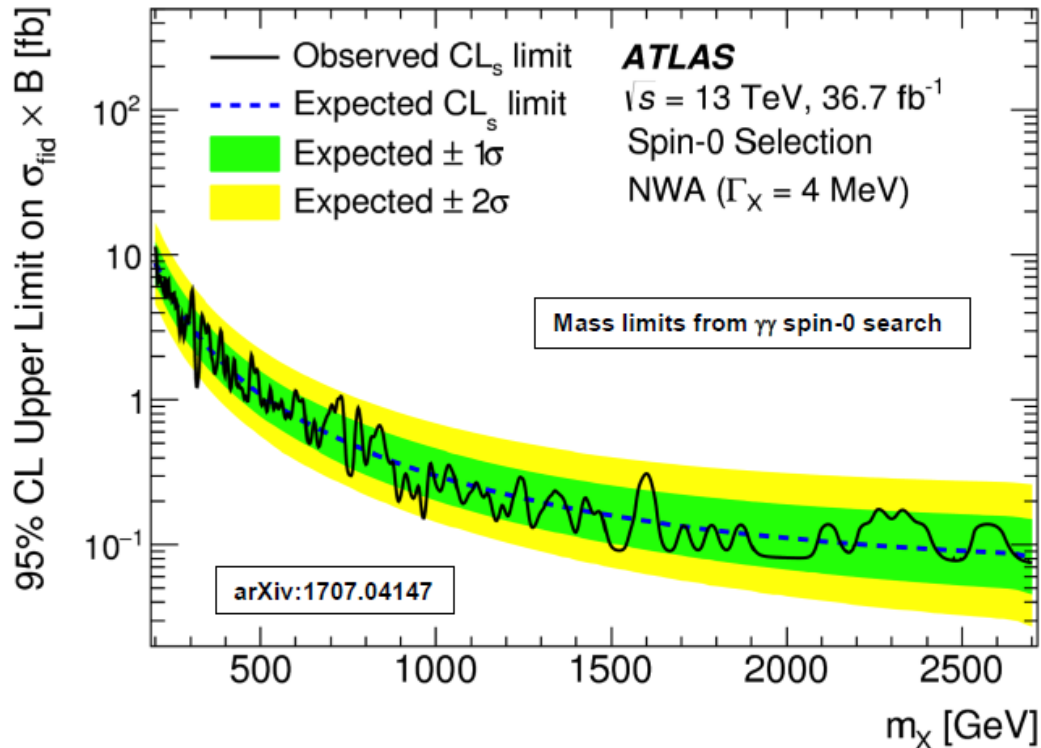
# Resonance Searches (Dilepton, Lepton+ETmiss)

- Searches for new resonances decaying to lepton pairs (e.g.  $Z'$ ) or lepton+ $E_T^{\text{miss}}$  (e.g.  $W'$ )
- Signature is peak in invariant mass distribution (dilepton) or transverse mass distributions (lepton+ $E_T^{\text{miss}}$ )
- No significant excess over SM expectation
- 95% CL exclusion limits extracted in various new physics  $Z'$  and  $W'$  scenarios, e.g. the Sequential Standard Model (SSM)



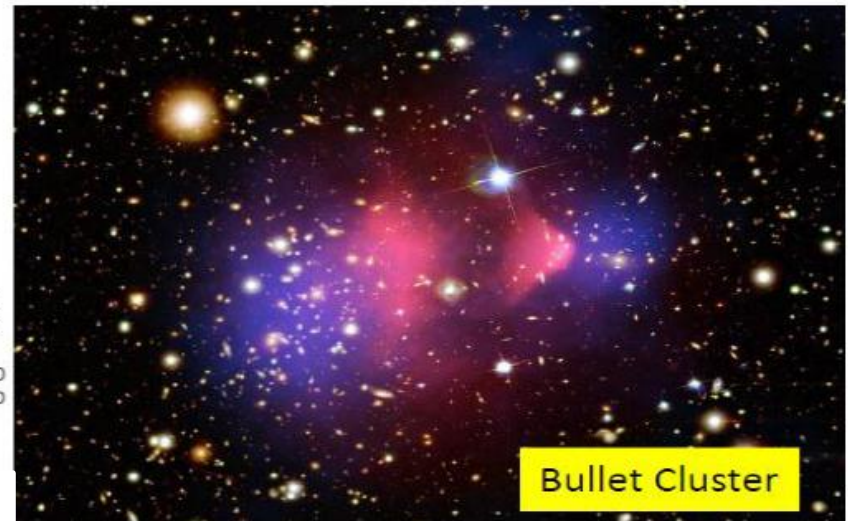
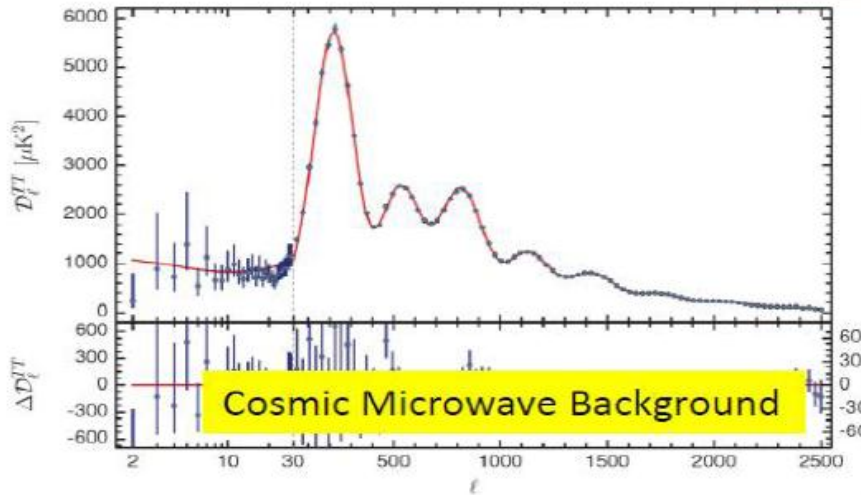
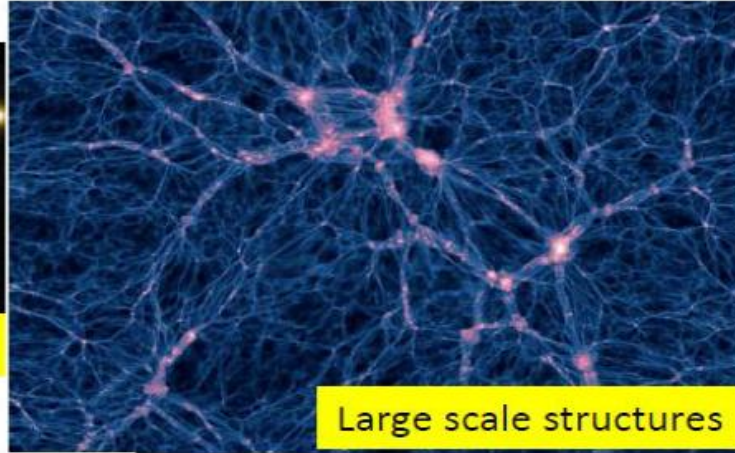
# Resonance Searches ( $\gamma\gamma$ , $\tau\tau$ )

- Diboson resonance searches also sensitive to new heavy scalars, e.g. Higgs bosons.
- Searches also conducted with  $\gamma\gamma$  and  $\tau\tau$  final states
- $\gamma\gamma$  search also targets spin-2 (graviton) production with a dedicated selection
- $\tau\tau$  searches sensitive to SUSY Higgs (H/A) models
- No significant excesses over SM expectation

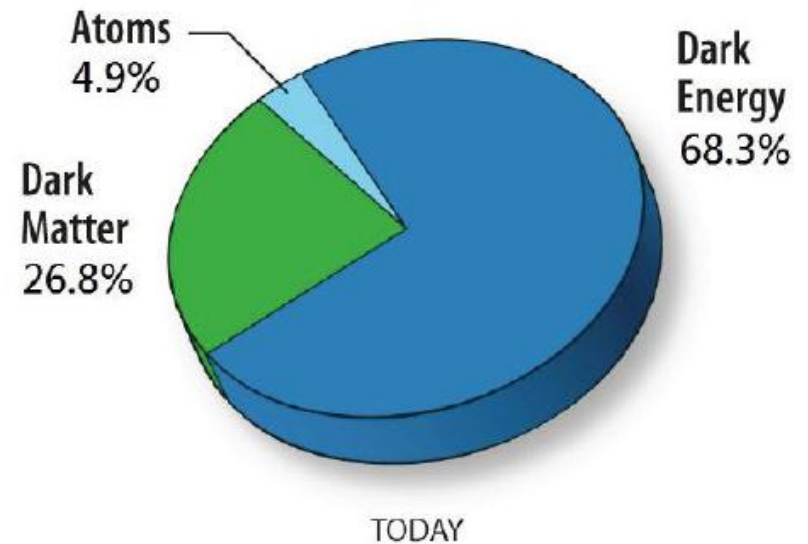
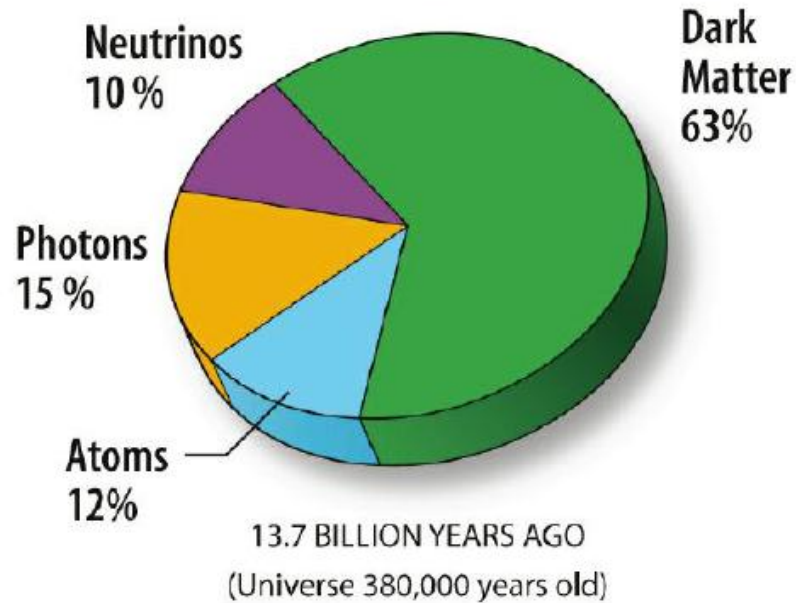


# Why Dark Matter?

## Evidence piling up...



# What do we know about Dark Matter



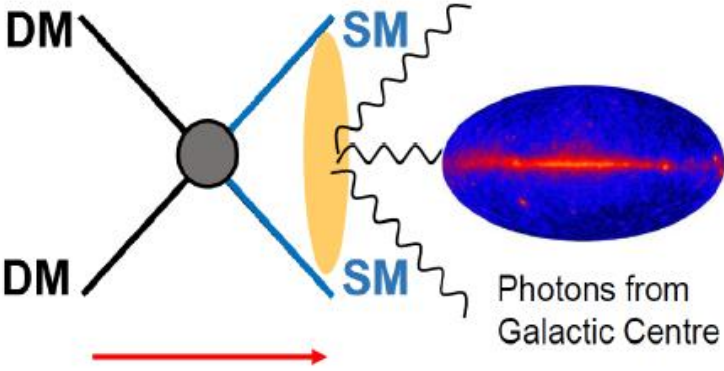
**Strong astrophysical evidence for the existence of dark matter**

# What do we know about Dark Matter

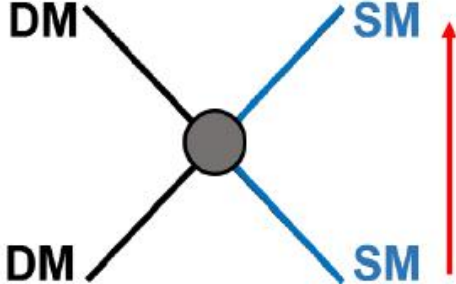
- **Massive**
- **Non-relativistic (slow)**
- **Long lived (old)**
- **No electric or colour charge**
- **Very weakly interacting with ordinary matter**
- **Subject to gravity interactions**



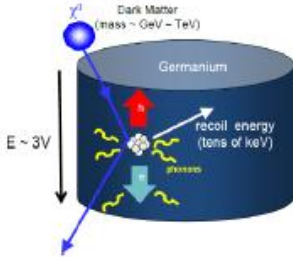
# Experimental detection of Dark Matter



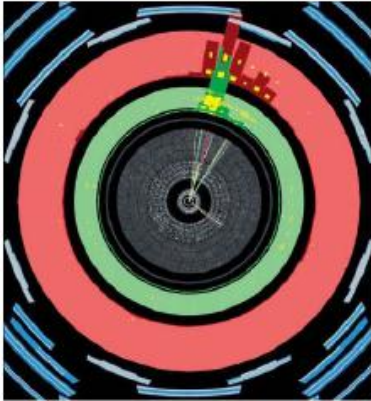
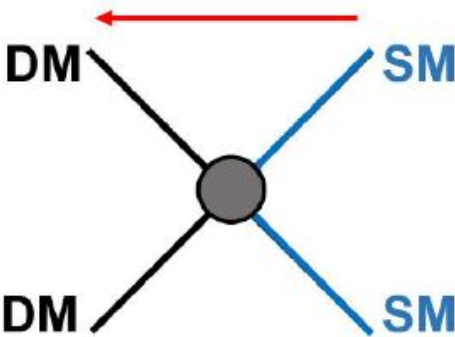
“break it”: indirect detection



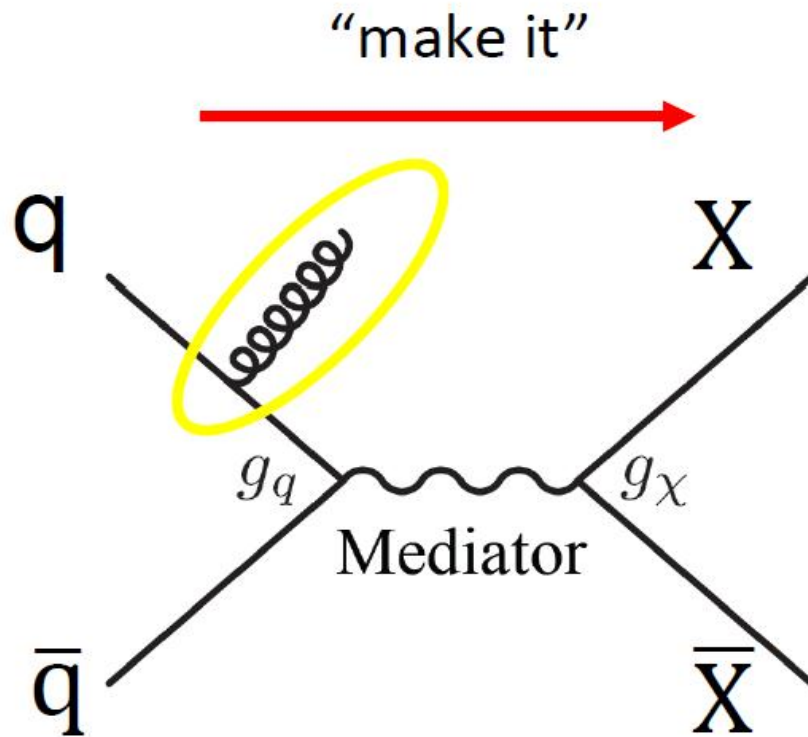
“shake it” direct detection



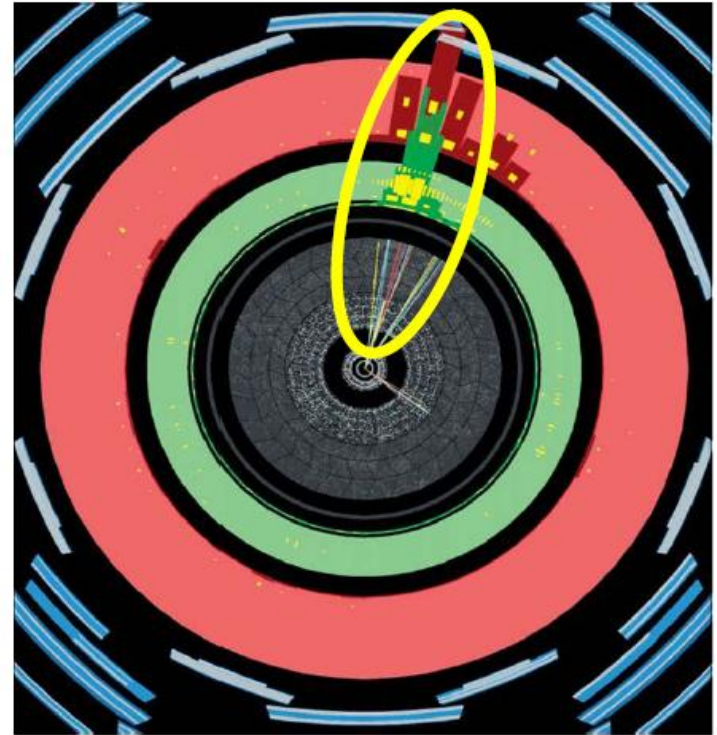
“make it”: Collider Production



# Dark Matter searches at Colliders



$g_q$  and  $g_X$  coupling strengths

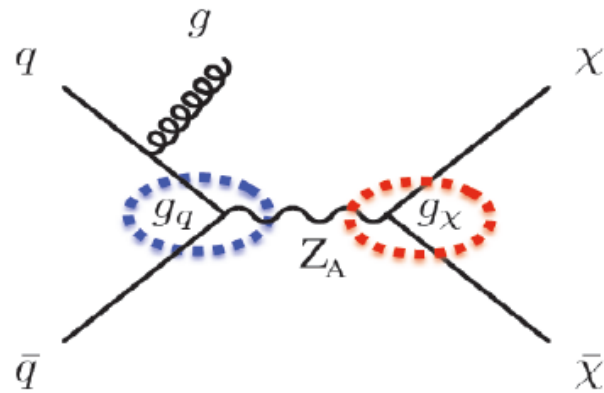


Empty detector + something

# Simplified Model

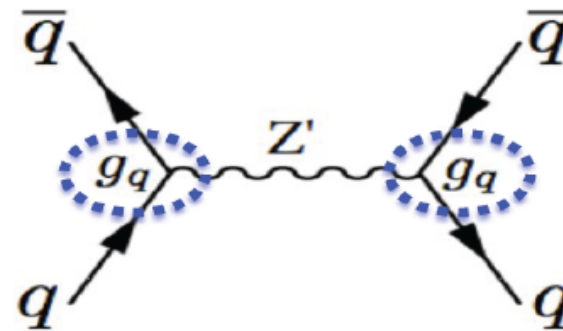
## Simplified Model

$SM \rightarrow \text{mediator} \rightarrow DM$



→ Mono-X signature  
 $E_T^{miss} + \text{jet, W/Z/H, } \gamma, \dots$

$SM \rightarrow \text{mediator} \rightarrow SM$



→ resonant production  
 Dijet, ditop, dilepton.....

**spin 0**

**spin 1**

**Charge**

$Q=0$  for s-channel

**Lorentz structure**

Scalar  $g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$   
 Pseudoscalar  $g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f$

Vector  $g_q \sum_q V_\mu \bar{q} \gamma^\mu q$   
 Axial-vector  $g_q \sum_q A_\mu \bar{q} \gamma^\mu \gamma^5 q$

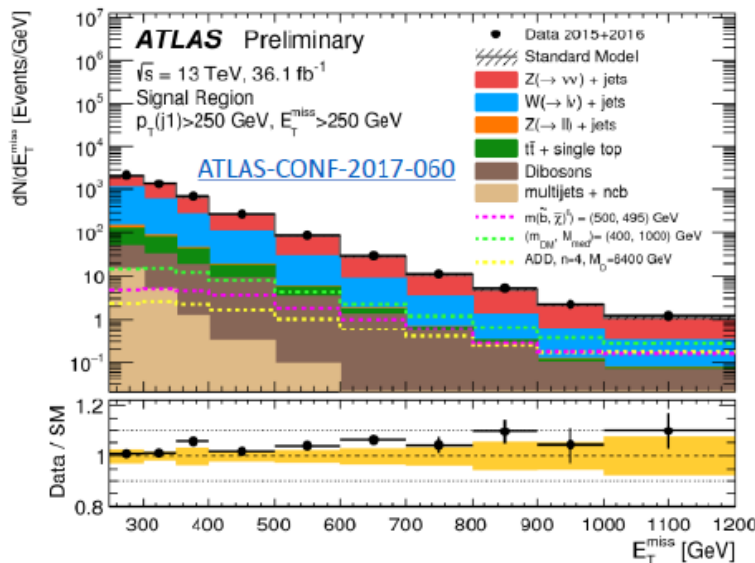
**Coupling**

$\propto$  mass

$\propto$  charge

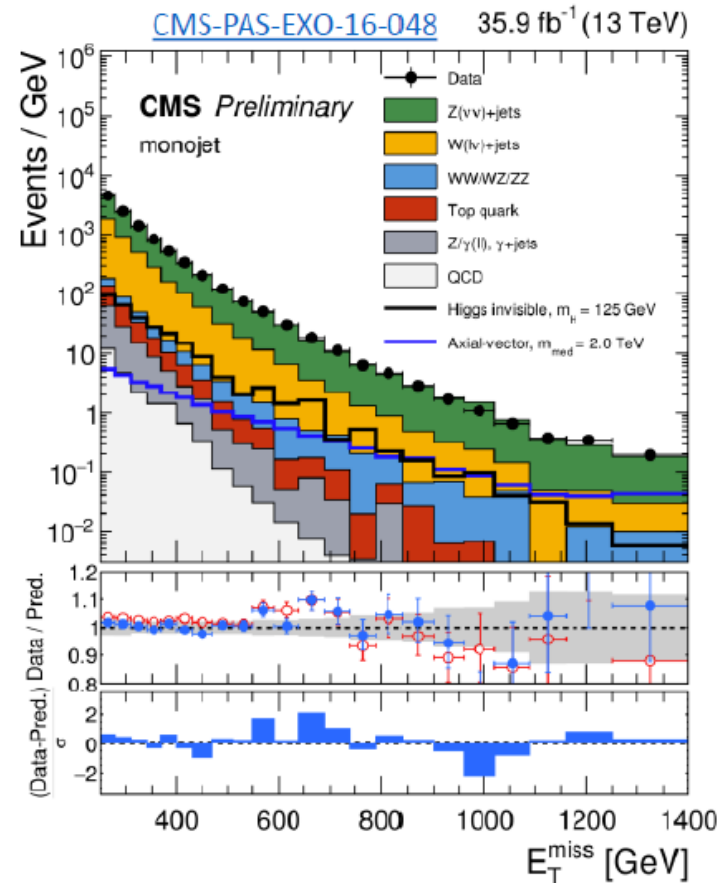
# Mono-X searches

## Mono-jet



### ATLAS

- $E_T^{\text{miss}} > 250 \text{ GeV}, \Delta\phi(\text{jet}, p_T^{\text{miss}}) > 0.4$
- Jet  $p_T > 250 \text{ GeV}, |\eta| < 2.4$
- $N_{\text{jets}} \leq 4$

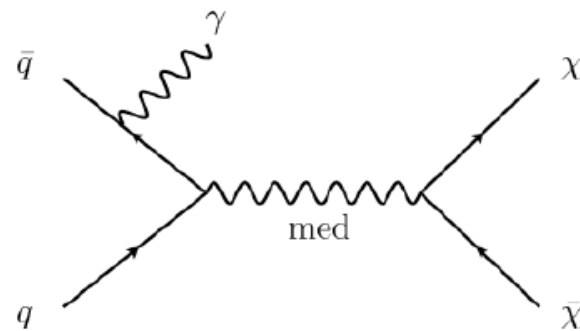
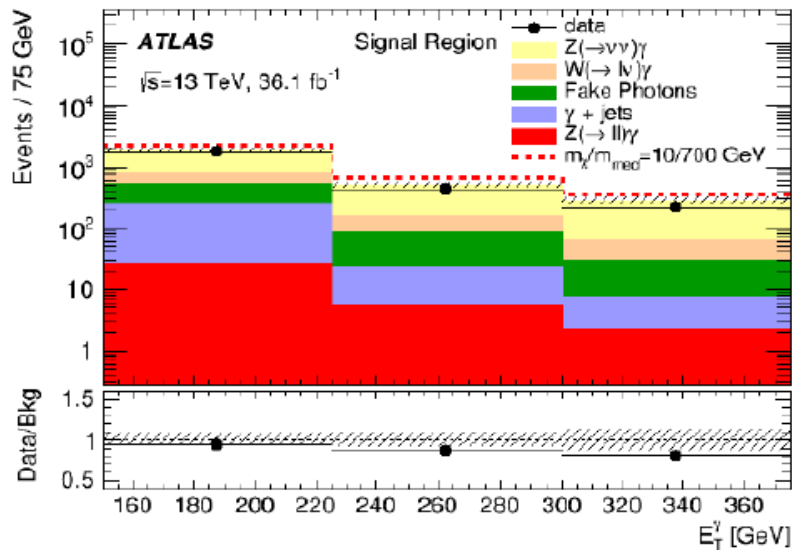


### CMS

- $E_T^{\text{miss}} > 250 \text{ GeV}$
- Jet  $p_T > 100 \text{ GeV}, |\eta| < 2.5$

# Mono-X searches

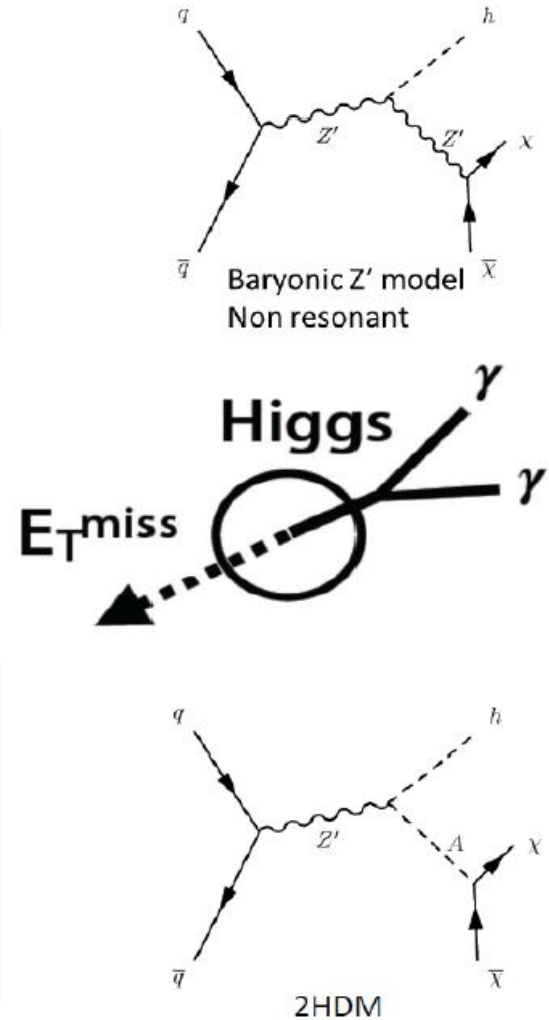
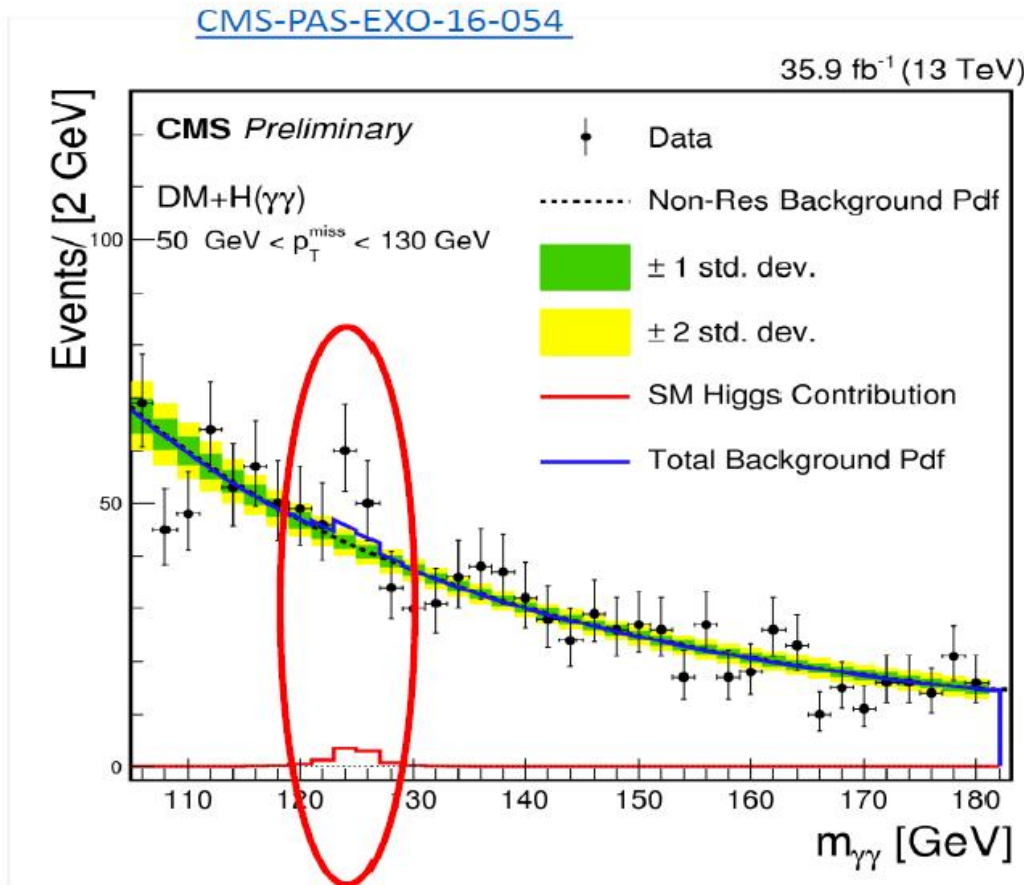
## Mono-photon



- Photon  $E_T > 150 \text{ GeV}, |\eta| < 2.37$
- $E_T^{\text{miss}} / \sqrt{\sum E_T} > 8.5 \text{ GeV}^{1/2}$
- $\Delta\phi(\text{photon}, E_T^{\text{miss}}) > 0.4$
- $N_{\text{jets}}(p_T > 30 \text{ GeV}, |\eta| < 4.5) \leq 1$

# Mono-X searches

## Mono-Higgs



# Mono-Mania!!

- Hundreds of phenomenology papers
- Thousands of citations of collider DM
- “ISR tagging” established technique for all new particle searches (not just DM)





# LHC DM Working Group

Cornell University Library

arXiv.org > hep-ex > arXiv:1507.00966

**arXiv:1507.00966**

High Energy Physics – Experiment

**Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum**

Collection of DM models (simplified models, EFT), Model implementation

arXiv.org > hep-ex > arXiv:1603.04156

**arXiv:1603.04156**

High Energy Physics – Experiment

**Recommendations on presenting LHC searches for missing transverse energy signals using simplified  $S$ -channel models of dark matter**

Guidelines to compare LHC results with DD/ID experiments

arXiv.org > hep-ex > arXiv:1703.05703

**arXiv:1703.05703**

High Energy Physics – Experiment

**Recommendations of the LHC Dark Matter Working Group: Comparing LHC searches for heavy mediators of dark matter production in visible and invisible decay channels**

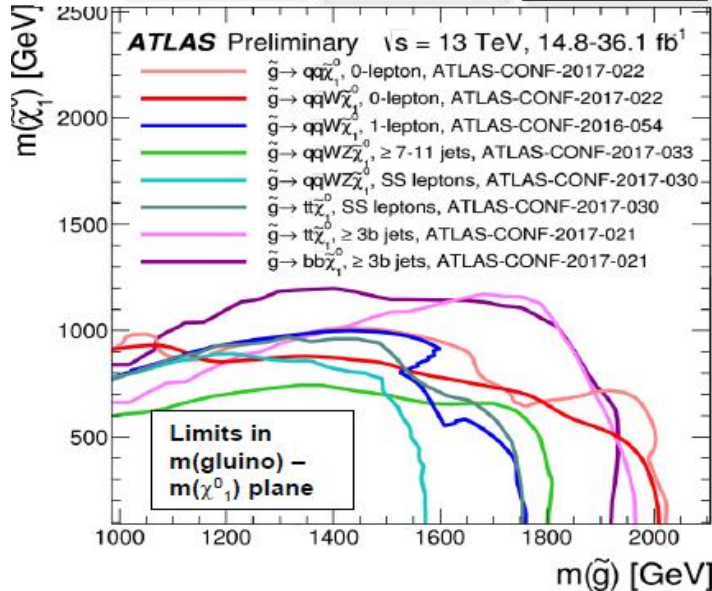
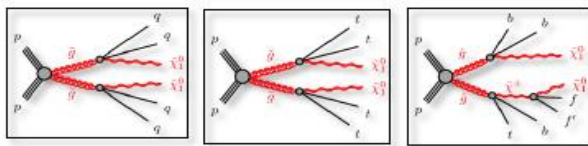
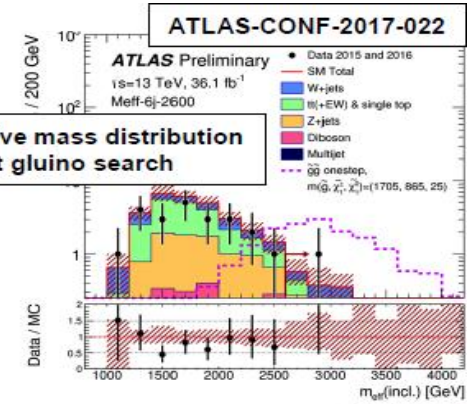
Guidelines to present Mono-X and visible signatures for heavy mediators

# Summary (Exotic Searches)

- Searches for Exotic searches
  - All major search channels reached 1 TeV scales
  - Quite a few at 10 TeV
  - New probe: Higgs boson → emerging field
- Dark Matter Searches are thriving at the LHC
- For vector and axial vector interactions
  - Dark Matter masses up 400 GeV – 700 GeV (mono-jet) excluded
  - Mediator mass up to 1.6 – 1.8 TeV (mono-jet) excluded
  - Mediator mass up to 1.2 TeV (mono-photon) excluded
  - Mediator mass up to 0.7 TeV (mono-Z) excluded
- LHC searches complement DD experiments
  - $m_{\text{DM}} < O(10 \text{ GeV})$

# Searches for Supersymmetry

- Searches for light squarks and gluinos with jets and  $E_T^{\text{miss}}$  : sensitivity beyond 2 TeV for the first time
- Searches extended to stop and sbottom production in cascade decays of gluinos using final states with b-jets.
- No significant excesses over SM expectation
  - Limits extend up to 500 GeV beyond 2015 dataset limits



ATLAS SUSY Searches* - 95% CL Lower Limits										ATLAS Prelim	
May 2017										$\sqrt{s} = 7, 8 \text{ TeV}$	
Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_{\text{miss}}^T$	$\int \mathcal{L} dt (\text{fb}^{-1})$	Mass limit	$\sqrt{s} = 7, 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$	Reference	Reference		
Inclusive Searches	MSUGRA/CMSSM	$0.3 \mu, 1/2, 2$	$2-10 \text{ jets} \geq 3 \text{ b}$	Yes	20.3	6.3	1.85 TeV	$m(\tilde{g}) = m(\tilde{t}_1)$	1587.9525		
	$\tilde{g} \rightarrow q\bar{q}$	0	2-6 jets	Yes	36.1	4	1.37 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-022		
	$\tilde{g} \rightarrow q\bar{q}$ (compressed)	0	mono-jet	Yes	3.2	2	2.00 TeV	$m(\tilde{g}) = m(\tilde{t}_1) = 5 \text{ GeV}$	1654.9773		
	$\tilde{g} \rightarrow q\bar{q} + \text{gluon}$	0	2-6 jets	Yes	36.1	2	2.01 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.5 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-022		
	$\tilde{g} \rightarrow q\bar{q} + \text{gluon} + \text{gluon}$	0	2-6 jets	Yes	36.1	2	1.928 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.5 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-022		
	$\tilde{g} \rightarrow q\bar{q} + \text{gluon} + \text{gluon} + \text{gluon}$	0	7-11 jets	Yes	36.1	2	1.9 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.5 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-022		
	GMSB (if NLSP)	$1-2 \tau + 0-1 \ell$	0-2 jets	Yes	3.2	2	2.0 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}$	1657.5078		
	GGM (bino NLSP)	$2 \gamma$	0	Yes	3.2	2	1.95 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1659.9135		
	GGM (Higgsino-bino NLSP)	$2 \gamma$	1 b	Yes	20.3	2	1.37 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1557.9549		
	GGM (Higgsino NLSP)	$2 \mu, \mu(2)$	2 jets	Yes	13.3	2	1.38 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2016-046		
Gluino LSP	0	mono-jet	Yes	20.3	2	900 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1583.5399			
3rd gen. squark direct production	$\tilde{g} \rightarrow t\bar{t}$	0	3 b	Yes	36.1	2	1.90 TeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-021		
	$\tilde{g} \rightarrow b\bar{b}$	0-1 $\mu, \mu$	3 b	Yes	36.1	2	1.87 TeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-021		
	$\tilde{g} \rightarrow t\bar{t}$	0-1 $\mu, \mu$	3 b	Yes	20.1	2	1.37 TeV	$m(\tilde{g}) = 200 \text{ GeV}$	1407.5800		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon}$	0	2 b	Yes	36.1	2	900 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon}$	$2 \mu, \mu(2)$	1 b	Yes	36.1	2	275-720 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon}$	0-2 $\mu, \mu$	1-2 b	Yes	4.713.3	2	300-720 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1266.2918, ATLAS-CONF-2016-037		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	0-2 $\mu, \mu$	0-2 jets $\geq 1-2 \text{ b}$	Yes	20.336.1	2	90-130 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	1556.2918, ATLAS-CONF-2017-020		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	0	mono-jet	Yes	3.2	2	90-325 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	1654.9773		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu(2)$	1 b	Yes	20.3	2	150-400 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	1403.5232		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$3 \mu, \mu(2)$	1 b	Yes	36.1	2	335-750 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-019		
EW direct	$\tilde{g} \rightarrow t\bar{t} + \text{gluon}$	0	1-2 $\mu, \mu$	Yes	36.1	2	300-400 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-019		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0	Yes	36.1	2	30-440 GeV	$m(\tilde{g}) = 200 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0	Yes	36.1	2	710 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0	Yes	36.1	2	760 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0	Yes	36.1	2	1.74 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0-2 jets	Yes	20.3	2	270 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1581.0719		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$4 \mu, \mu$	0	Yes	20.3	2	635 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1408.5098		
	GGM (bino NLSP) weak prod. $\tilde{g} \rightarrow t\bar{t}$	$1 \mu, \mu + \gamma$	0	Yes	20.3	2	115-370 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1587.9549		
	GGM (bino NLSP) weak prod. $\tilde{g} \rightarrow t\bar{t} + \text{gluon}$	$2 \gamma$	0	Yes	20.3	2	390 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1587.9549		
	Long-lived particles	Direct $\tilde{g} \rightarrow t\bar{t}$ prod. long-lived $\tilde{g}$	Disapp. ink	1 jet	Yes	36.1	2	430 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 160 \text{ MeV}, m(\tilde{b}_1) = 0.2 \text{ GeV}$	ATLAS-CONF-2017-017	
Direct $\tilde{g} \rightarrow t\bar{t}$ prod. long-lived $\tilde{g}$		dE/dx ink	0	Yes	19.4	2	495 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 160 \text{ MeV}, m(\tilde{b}_1) = 0.2 \text{ GeV}$	1594.2038		
Stable, stopped $\tilde{g}$ R-hadron		0	1-5 jets	Yes	37.0	2	850 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1233.8384		
Stable $\tilde{g}$ R-hadron		ink	0	Yes	3.2	2	1.30 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1656.0129		
Metastable $\tilde{g}$ R-hadron		dE/dx ink	0	Yes	3.2	2	1.27 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1654.9420		
GMSB, stable $\tilde{g}, \tilde{g} \rightarrow \text{hadrons}$		0	0	Yes	19.1	2	527 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1411.8795		
GMSB, stable $\tilde{g}, \tilde{g} \rightarrow \text{hadrons}$		$2 \gamma$	0	Yes	20.3	2	440 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1408.5542		
GGM $\tilde{g} \rightarrow t\bar{t} + \text{gluon}$ , long-lived $\tilde{g}$		disapp. ink	0	Yes	20.3	2	1.0 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1584.0143		
GGM $\tilde{g} \rightarrow t\bar{t} + \text{gluon}$ , long-lived $\tilde{g}$		disapp. ink + jets	0	Yes	20.3	2	1.0 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1584.0143		
GGM $\tilde{g} \rightarrow t\bar{t} + \text{gluon}$ , long-lived $\tilde{g}$		disapp. ink	0	Yes	20.3	2	1.0 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1584.0143		
RPV	LFV $\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$3 \mu, \mu + \gamma$	0	Yes	3.2	2	1.8 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1657.2879		
	Bilinear RPV CMSSM	$2 \mu, \mu(2)$	0-2 b	Yes	20.3	2	1.45 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1404.2500		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$4 \mu, \mu$	0	Yes	13.3	2	1.14 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2016-075		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$3 \mu, \mu + \gamma$	0	Yes	20.3	2	450 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1403.5399		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$4 \mu, \mu$	0-5 large $\tau$ jets	Yes	20.3	2	1.26 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-057		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$4 \mu, \mu$	0-5 large $\tau$ jets	Yes	14.8	2	1.38 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2016-097		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$1 \mu, \mu$	0-10 large $\tau$ jets	Yes	36.1	2	1.85 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-015		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$1 \mu, \mu$	0-10 large $\tau$ jets	Yes	36.1	2	1.85 TeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2017-015		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	0-2 jets + 2 b	Yes	15.4	2	610 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	ATLAS-CONF-2016-020, ATLAS-CONF-2017-026		
	$\tilde{g} \rightarrow t\bar{t} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon} + \text{gluon}$	$2 \mu, \mu$	2 b	Yes	36.1	2	370 GeV	$m(\tilde{g}) = 200 \text{ GeV}, m(\tilde{t}_1) = 0.1 \text{ GeV}, m(\tilde{b}_1) = 100 \text{ GeV}$	1581.9125		

\*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.



# ATLAS Statistics

183 Institutions



166 Institutes (single)

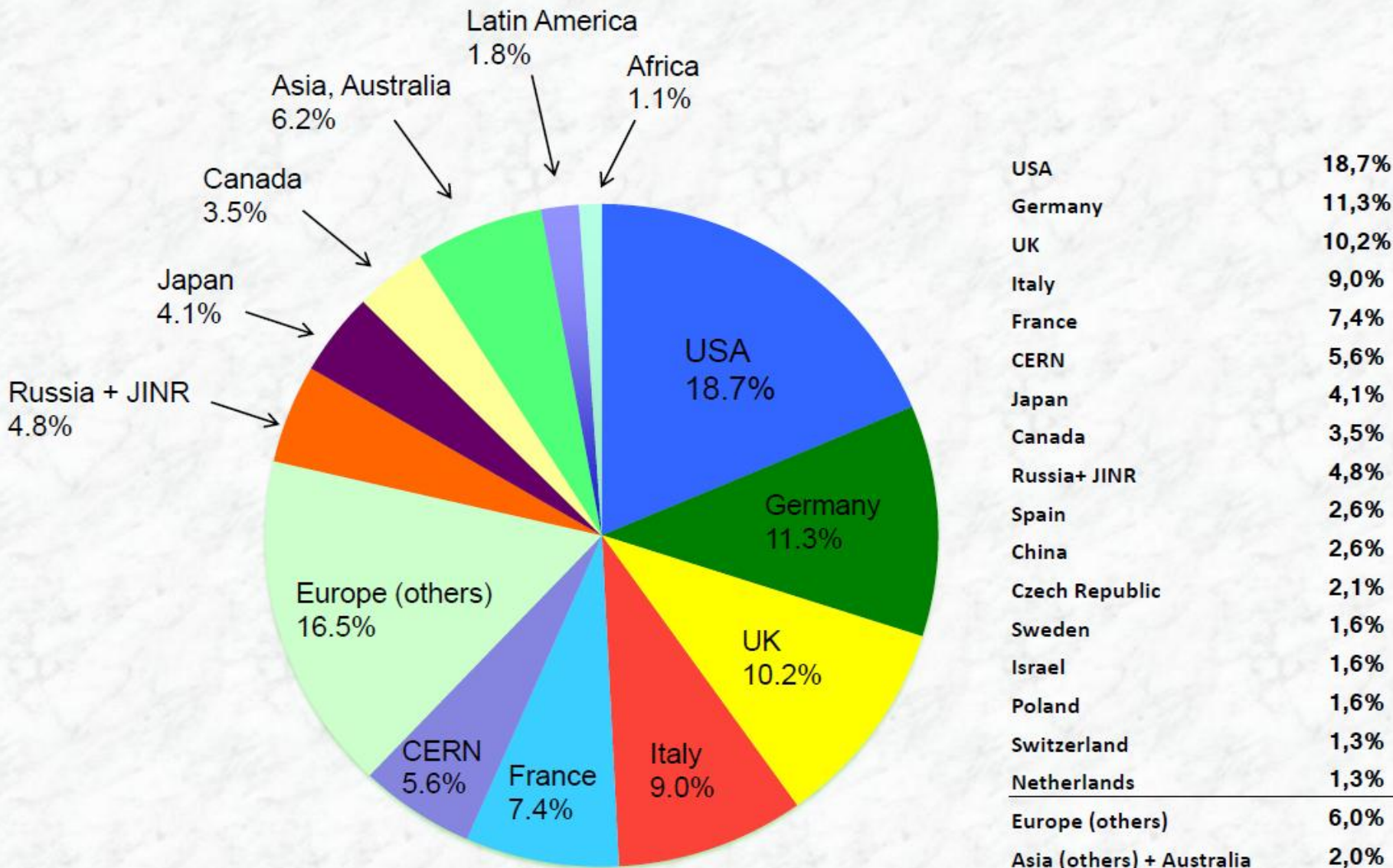
17 clusters (57 institutes in clusters)

14 associated institutes

→ 237 Institutes (preliminary, to be cross-checked)

from 38 Countries

- Active ATLAS members ~5'500  
(Physicists, students, engineers, technicians, ...)
- Scientific authors ~2'900
- with PhD, contributing to M&O share ~1'900
- PhD students ~1'200
- Master / diploma students ~500



Fractions according to PhD physicists  
(M&O share)