Elementary Particle Physics: theory and experiments

Searches for New Physics

Exotic models

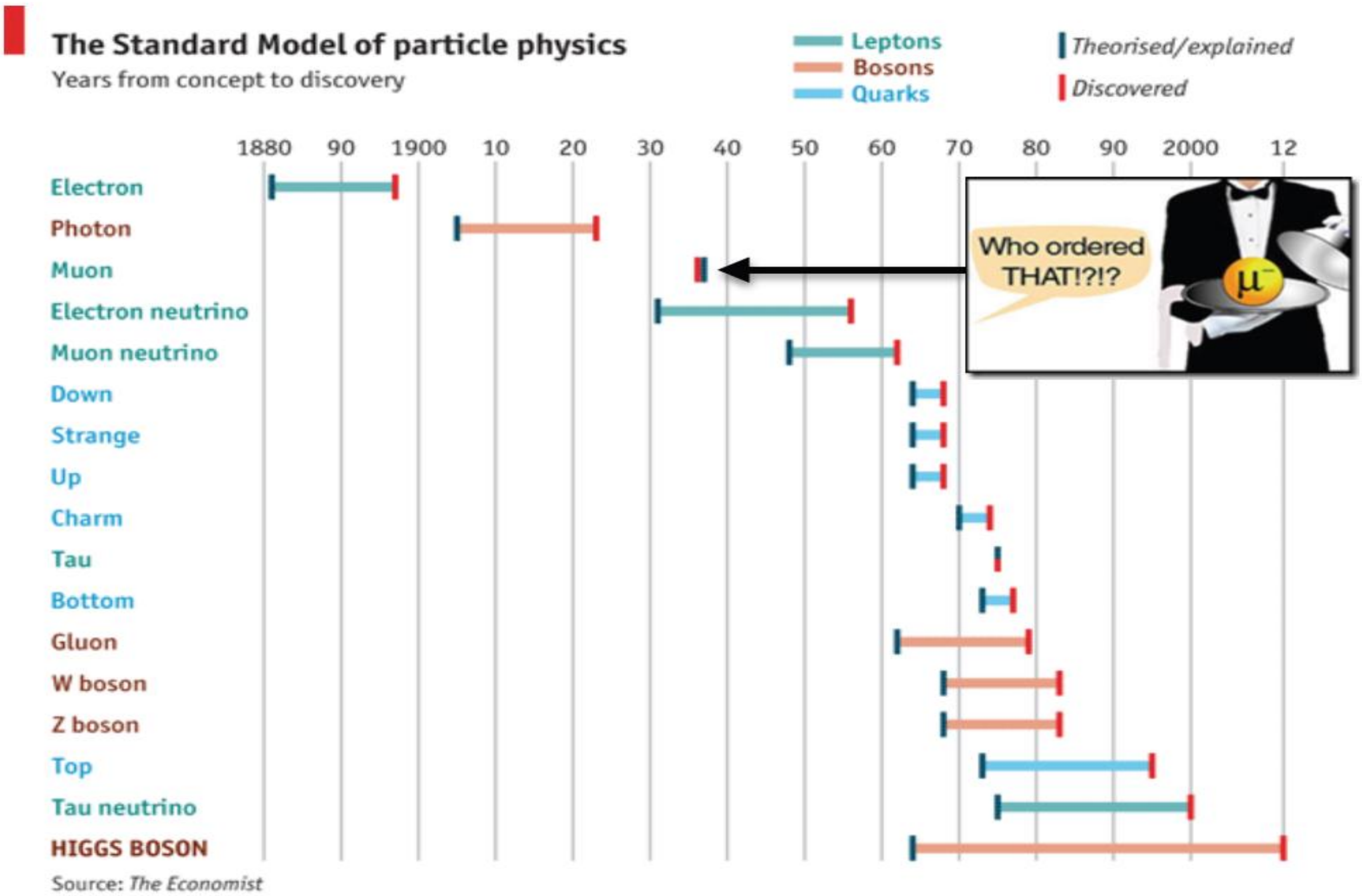
Dark Matter

Sypersymmetry

ATLAS in statistics

Prof. dr hab. Elżbieta Richter-Wąs

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?

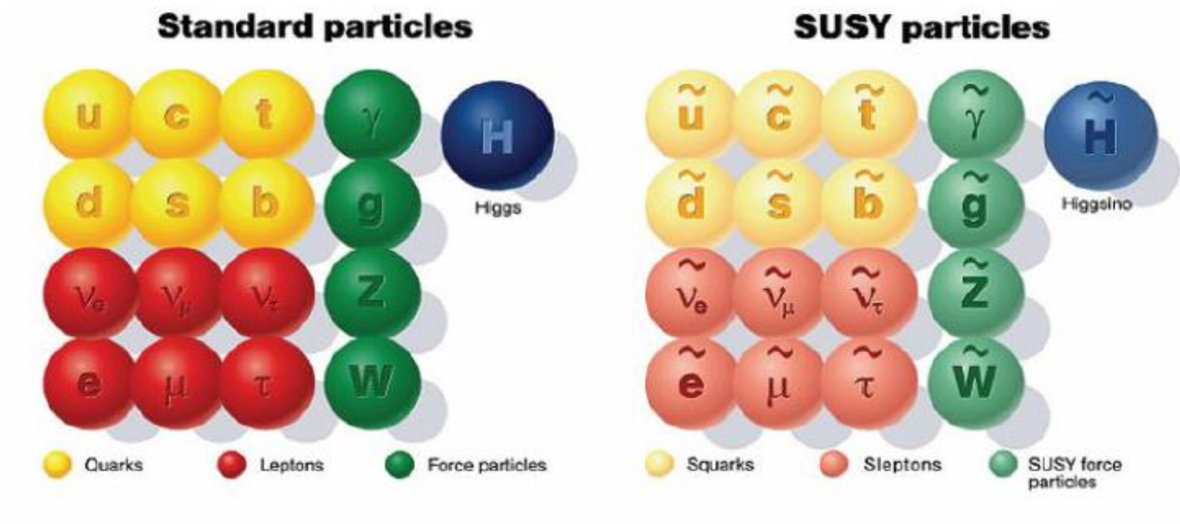
What keeps the Higgs mass so small?

How do we incorporate gravity?

What is Dark Matter?

… and as many possible answers to probe!

- Super-symmetry?



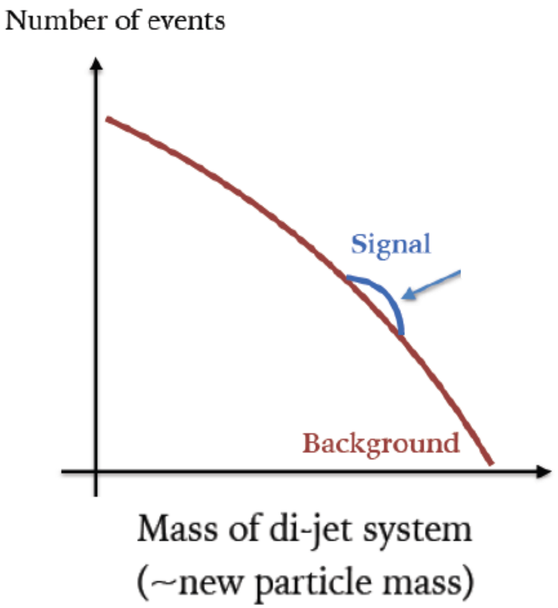
- Composite quark and/or leptons?
- New Heavy bosons?
- Gravitons?
- Dark Matter particles?
- …

Any new theory need to agree with the SM!

How would new phenomena manifest?

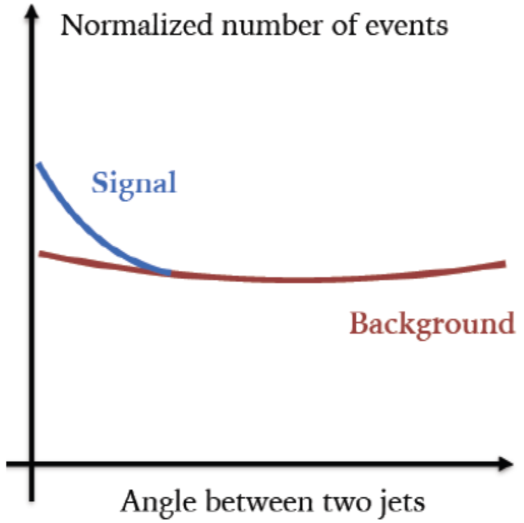
New particles:

resonant excess (bump) over Standard Model background



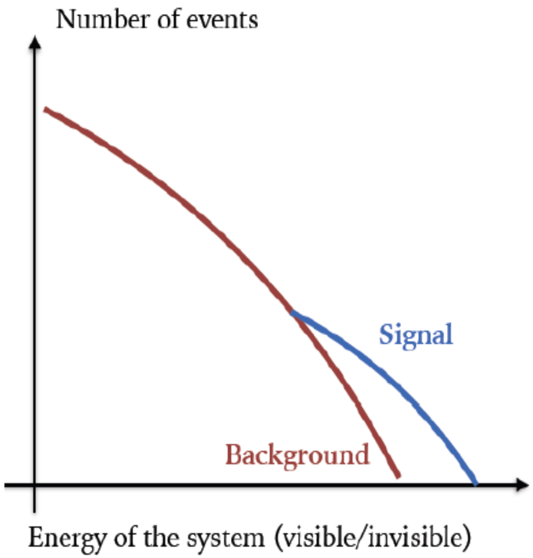
New interactions:

more central production (~Rutherford experiment)

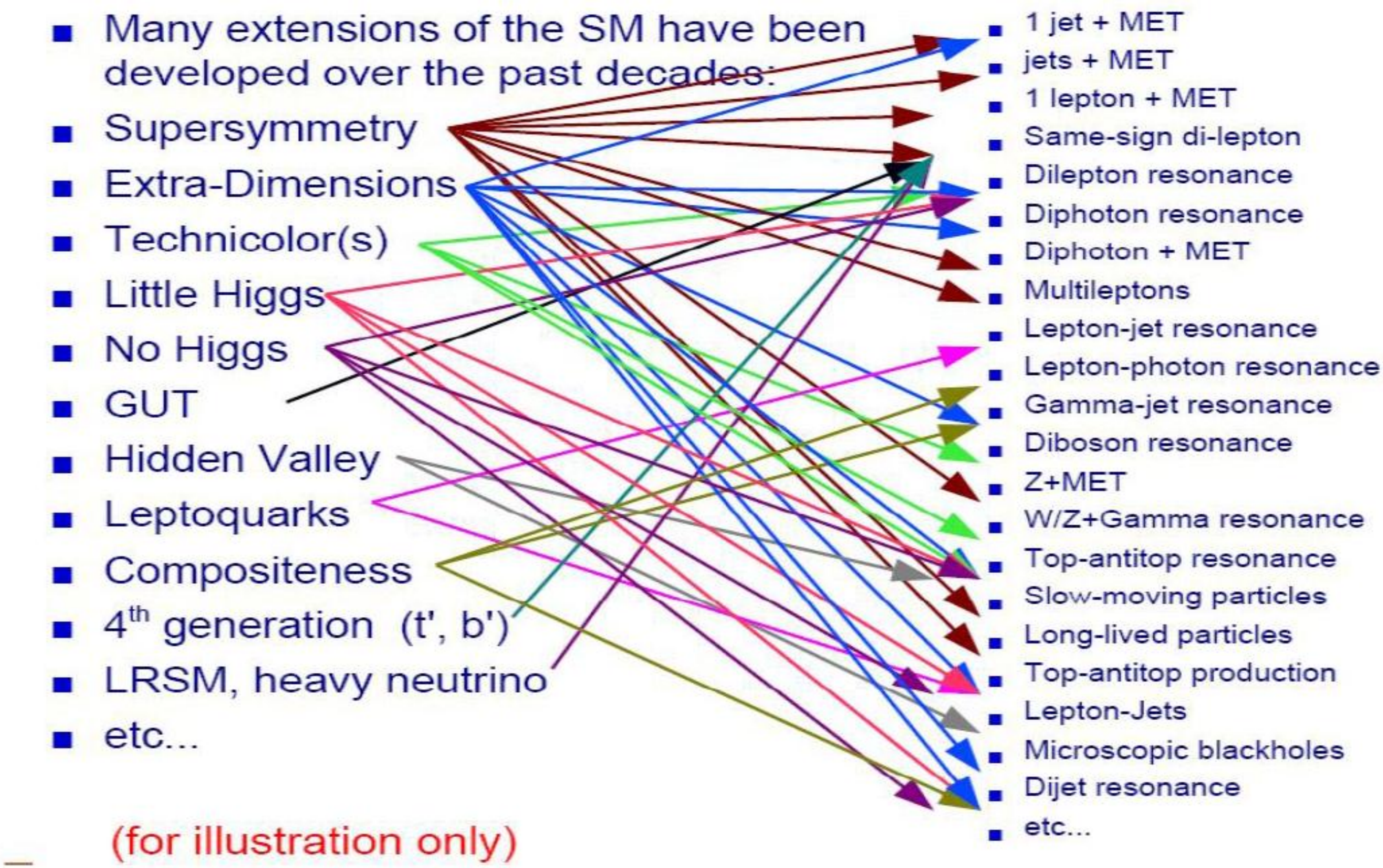


New particles and states:

larger multiplicity of objects at high masses



Long list of models and signatures



Long list of models and signatures

- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4th generation (t', b')
- LRSM, heavy neutrino
- etc...

(for illustration only)

- 1 jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign di-lepton
- Dilepton resonance
- Diphoton resonance
- Diphoton + MET
- Multileptons
- Lepton-jet resonance
- Lepton-photon resonance
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+Gamma resonance
- Top-antitop resonance
- Slow-moving particles
- Long-lived particles
- Top-antitop production
- Lepton-Jets
- Microscopic blackholes
- Dijet resonance
- etc...

A complex 2D problem

Experimentally, a **signature standpoint** makes a lot of sense:

→ Practical

→ Less model-dependent

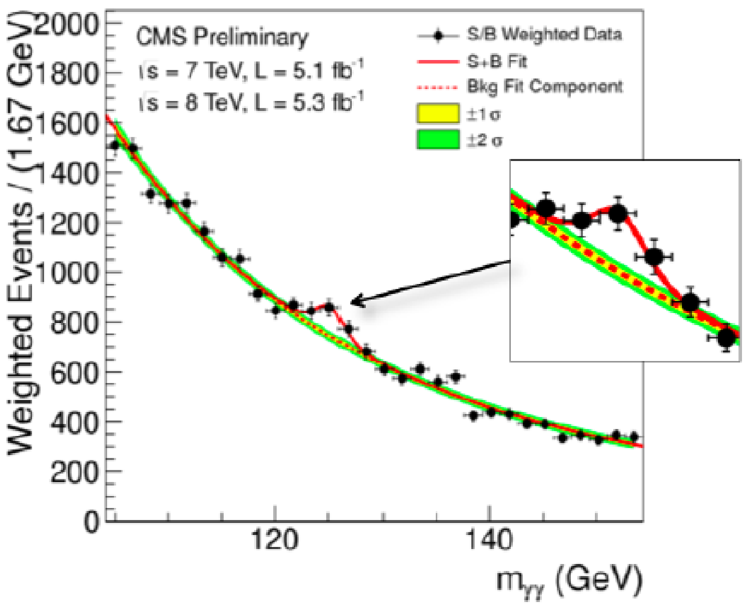
→ Important to cover every possible signature

What characterizes Exotics Searches

No precise model to guide us

Standard Model:

Predicted Higgs boson

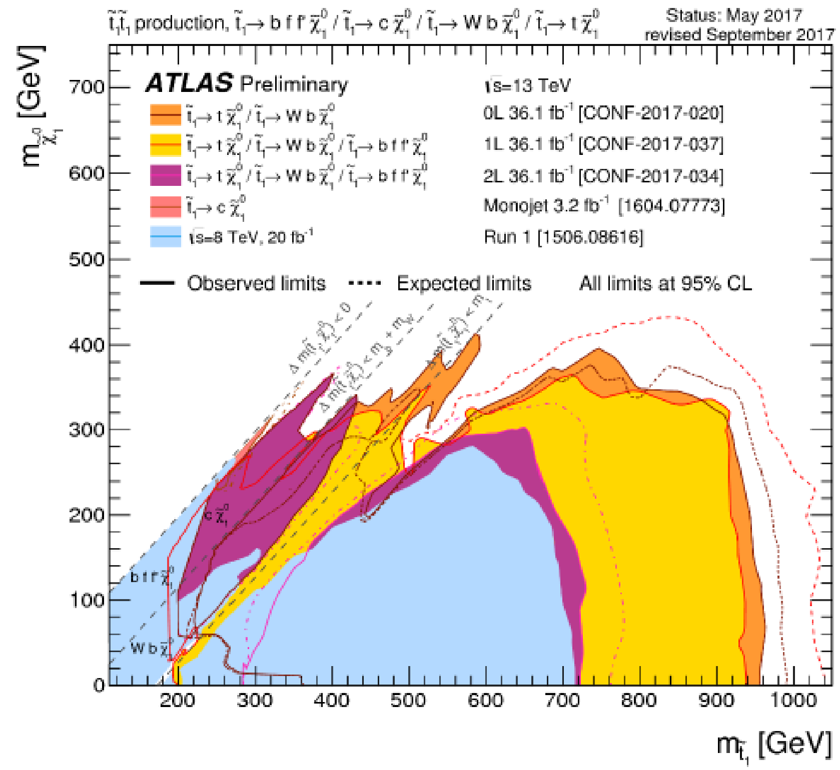


[Phys. Lett. B 716 (2012) 1-29]

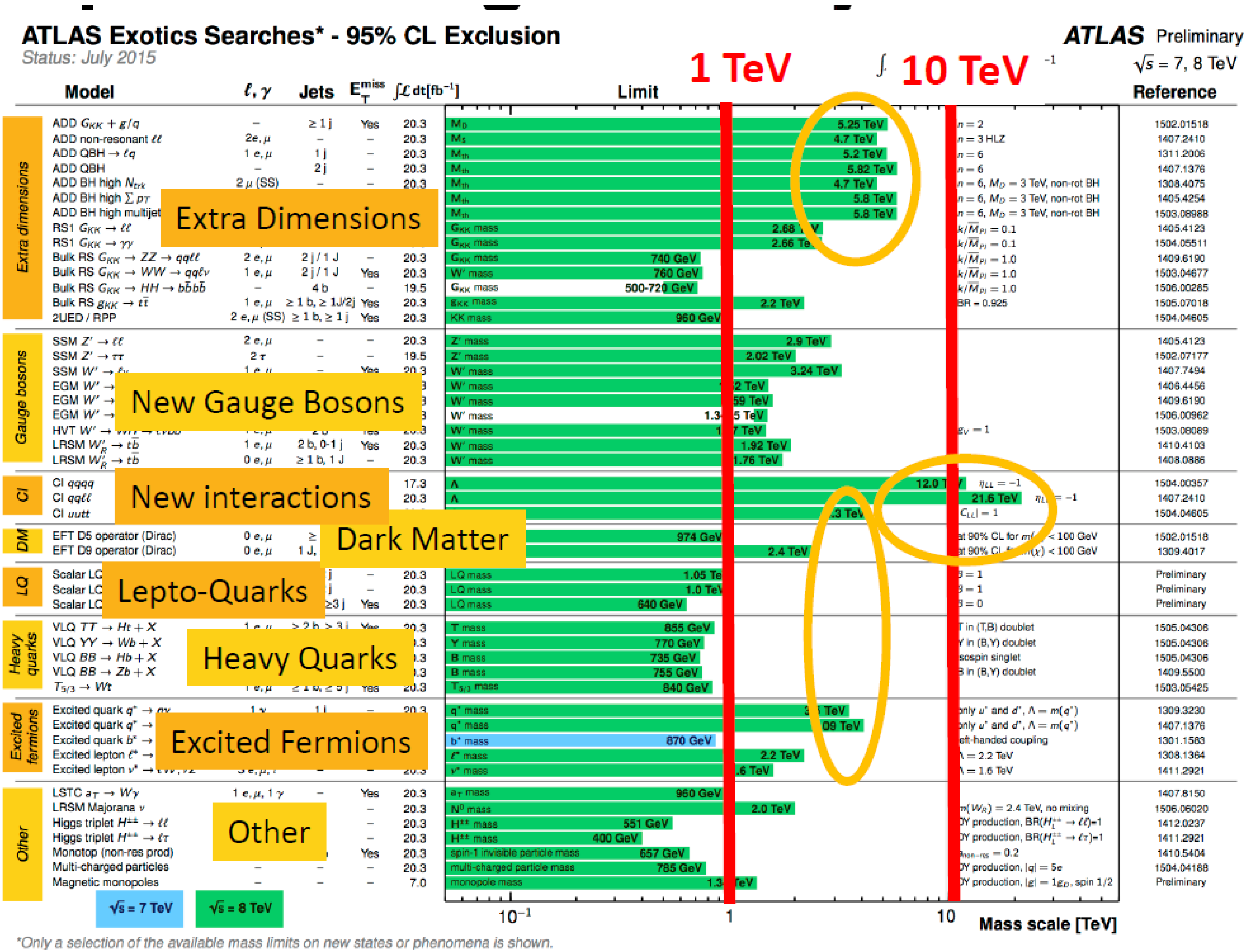
[Phys. Lett. B 716 (2012) 30-61]

No unified parameter phase space

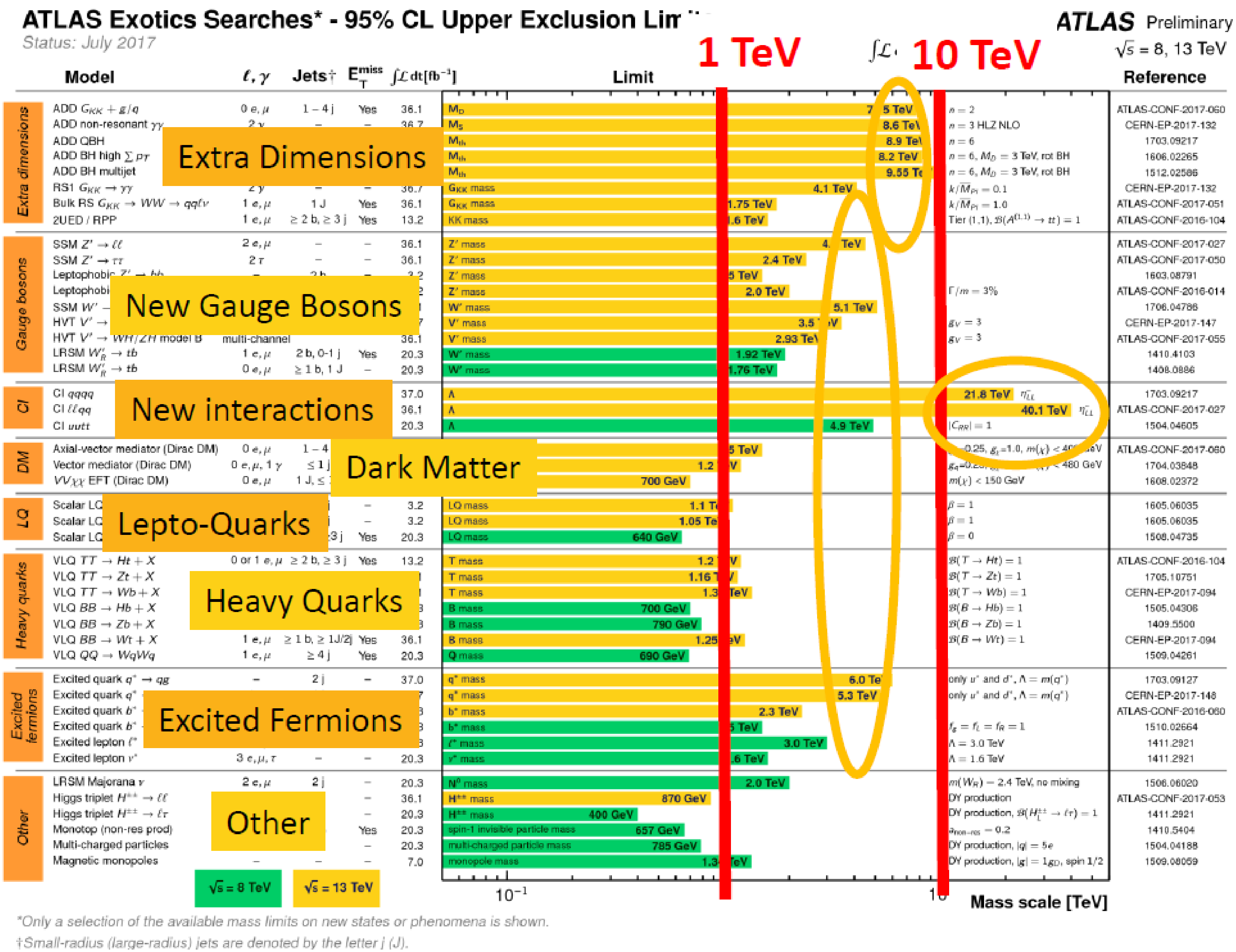
Supersymmetry Searches:



Exploration range of LHC by mid 2015



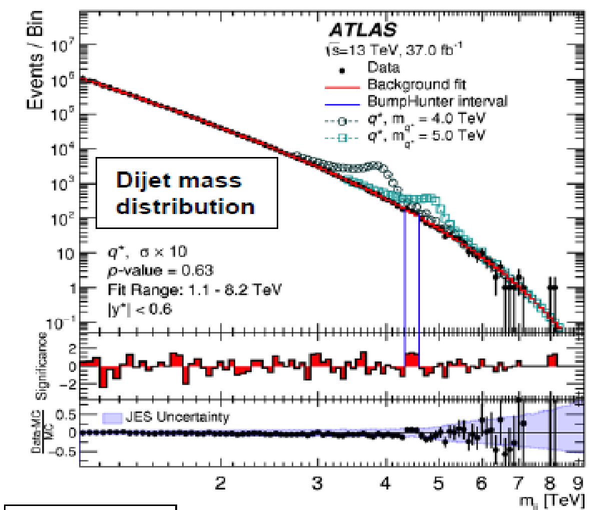
Exploration range of LHC by mid 2017

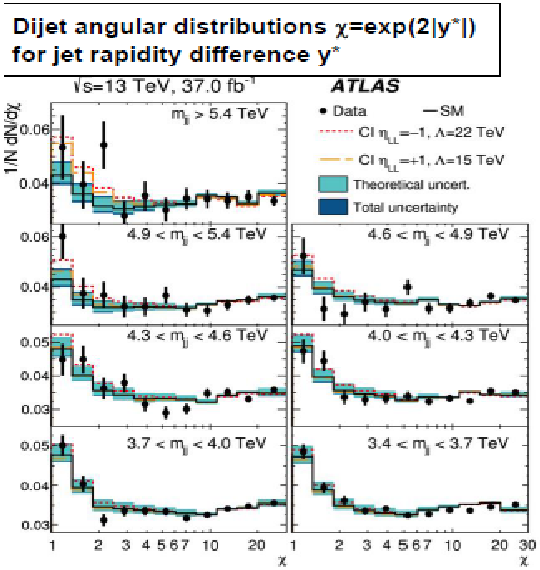


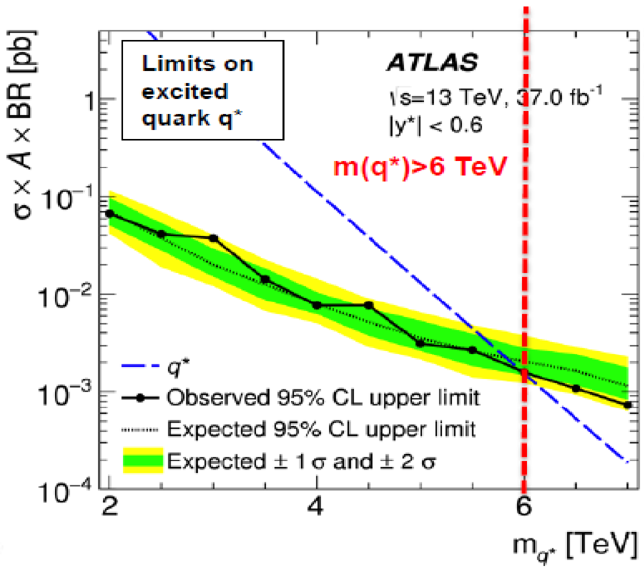
Searches with Dijets

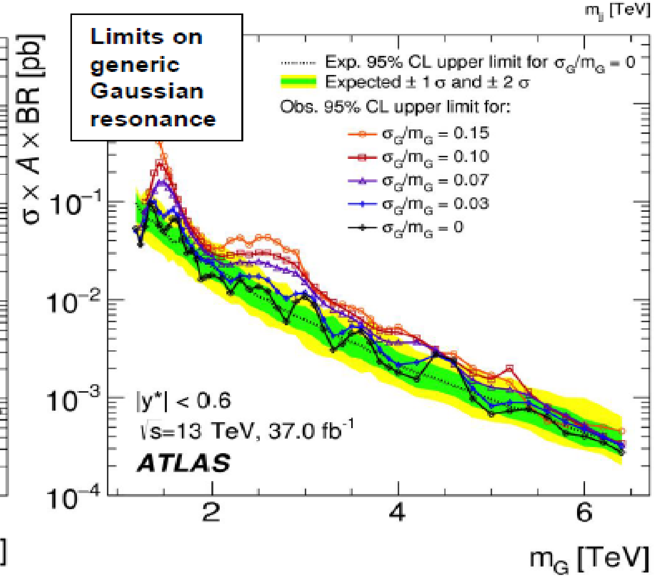
arXiv:1703.09127

- 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(BH) > 8.9 TeV (8.9 TeV exp.)
  - Contact Interactions: Λ > 13.1/21.8 TeV (η_{LL} = +1/-1)
- Limits also set on generic Gaussian resonances





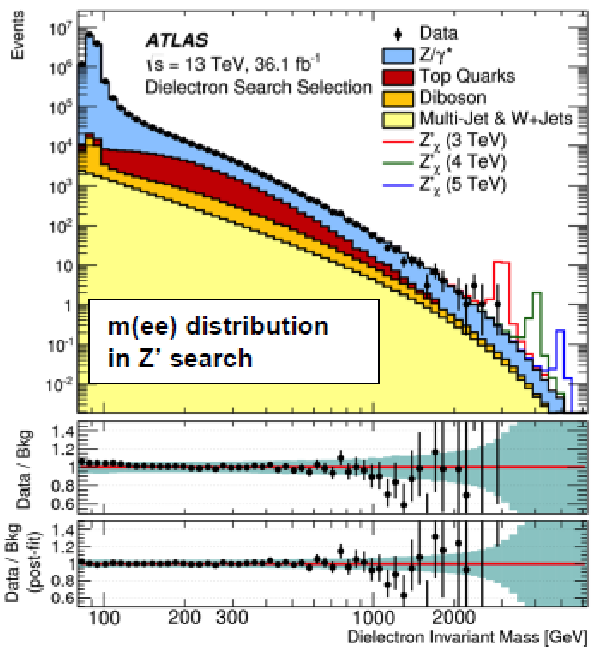


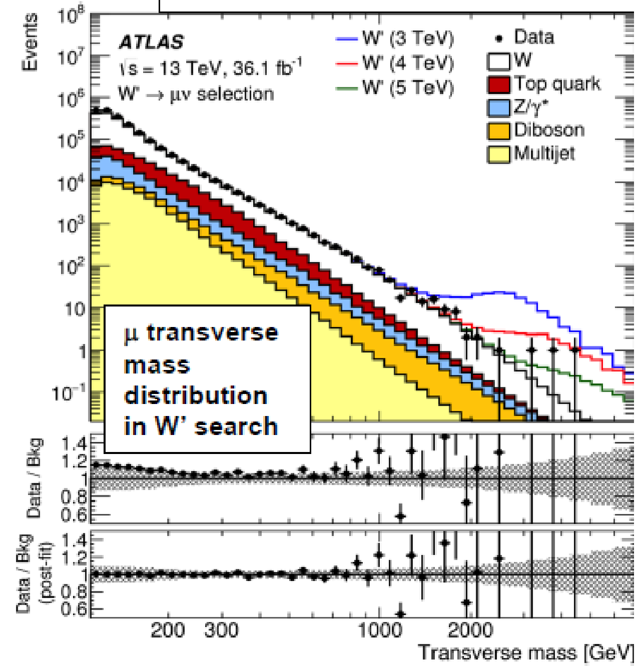


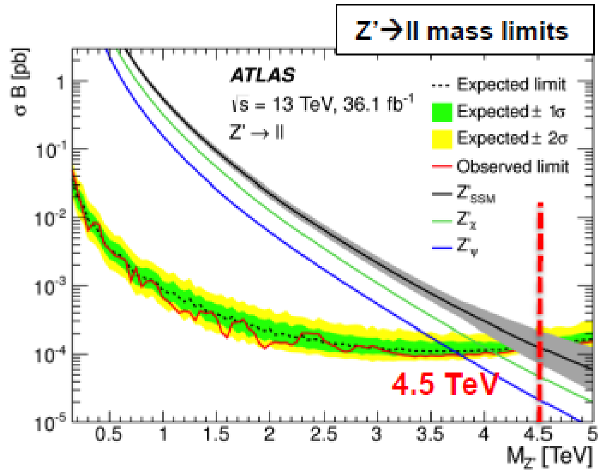
Resonance Searches (Dilepton, Lepton+ETmiss)

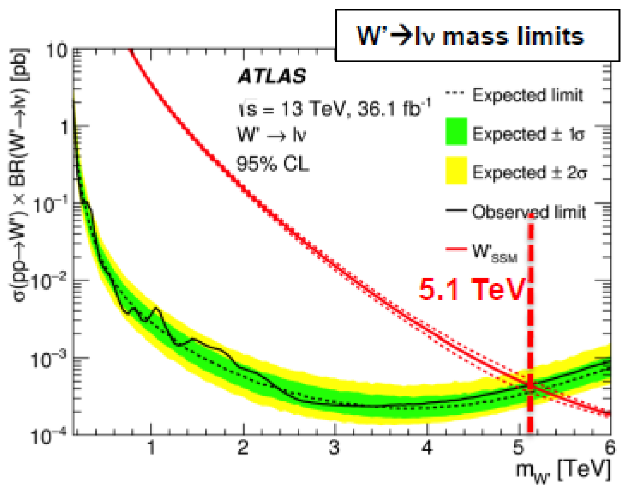
- Searches for new resonances decaying to lepton pairs (e.g. Z') or lepton+E_T^{miss} (e.g. W')
- Signature is peak in invariant mass distribution (dilepton) or tranverse mass distributions (lepton+E_T^{miss})
- No significant excess over SM expectation
- 95% CL exclusion limits extracted in various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

arXiv:1707.02424, arXiv:1706.04786



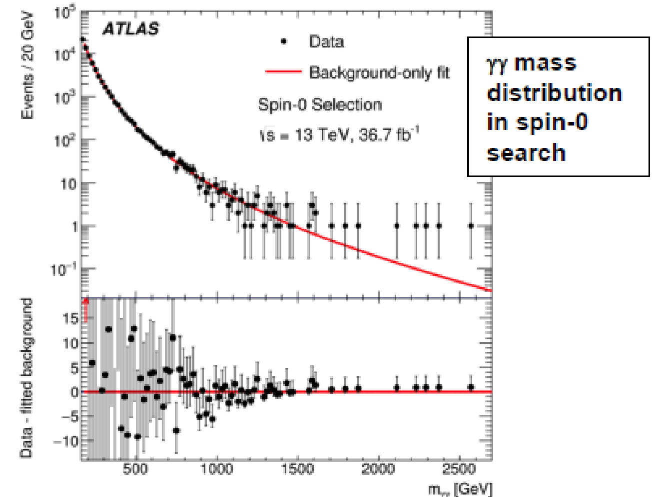


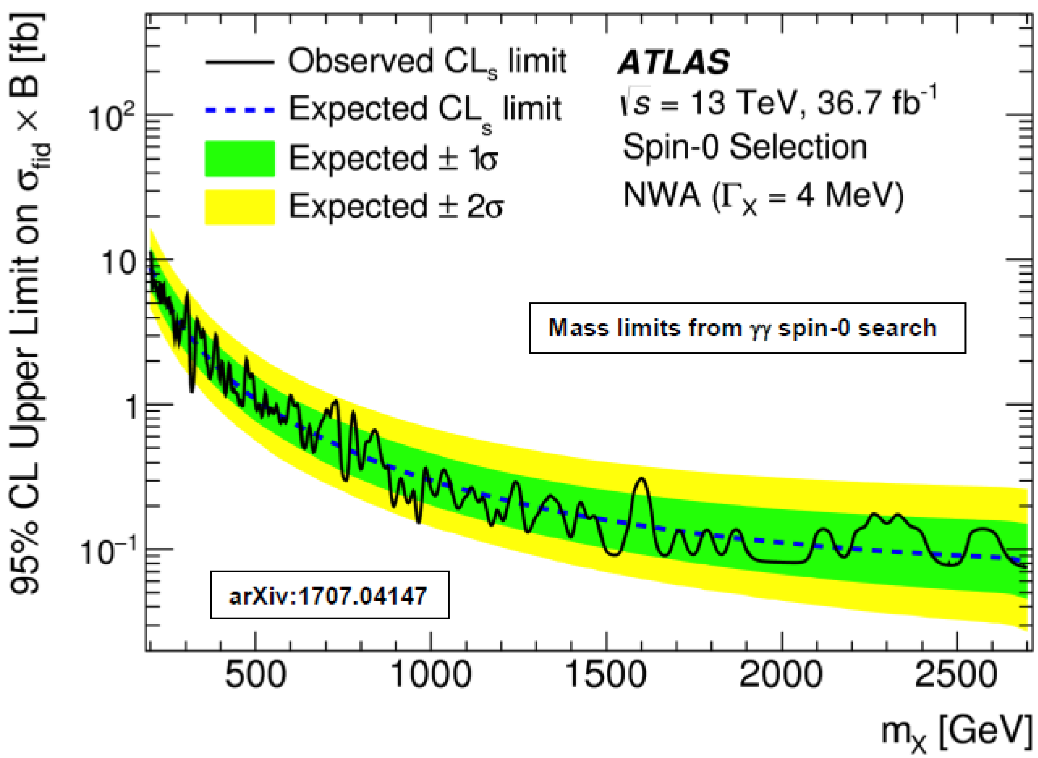


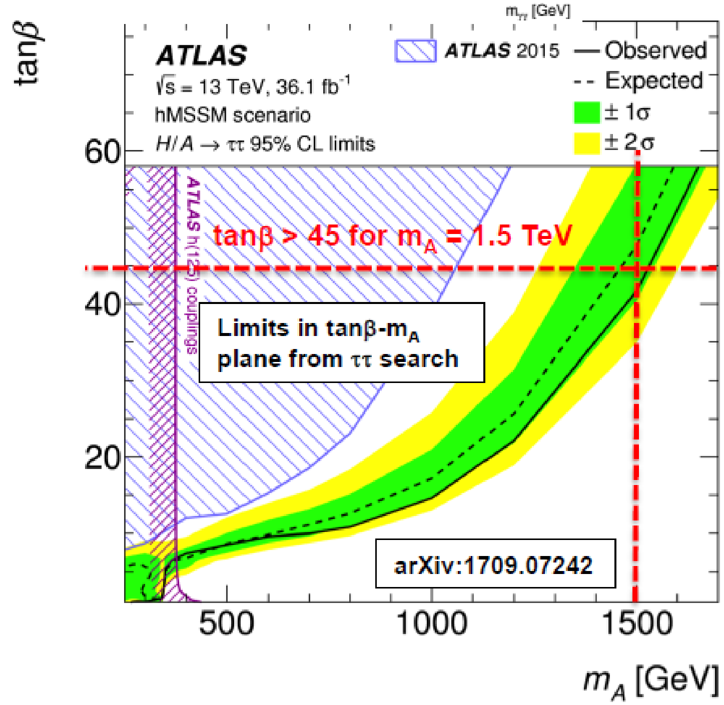


Resonance Searches (γγ, ττ)

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

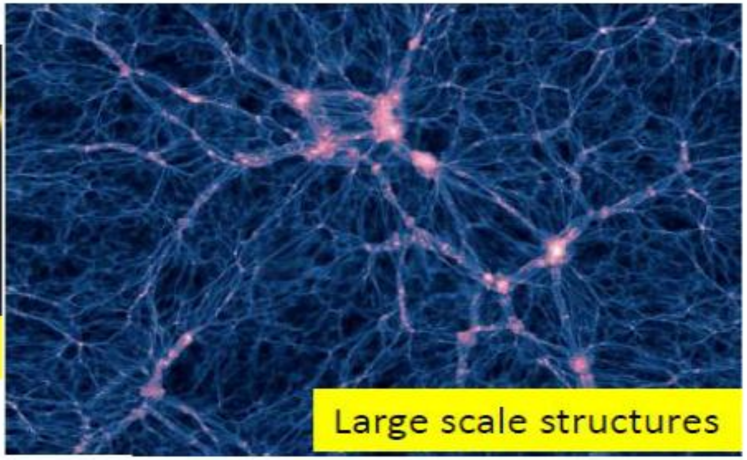


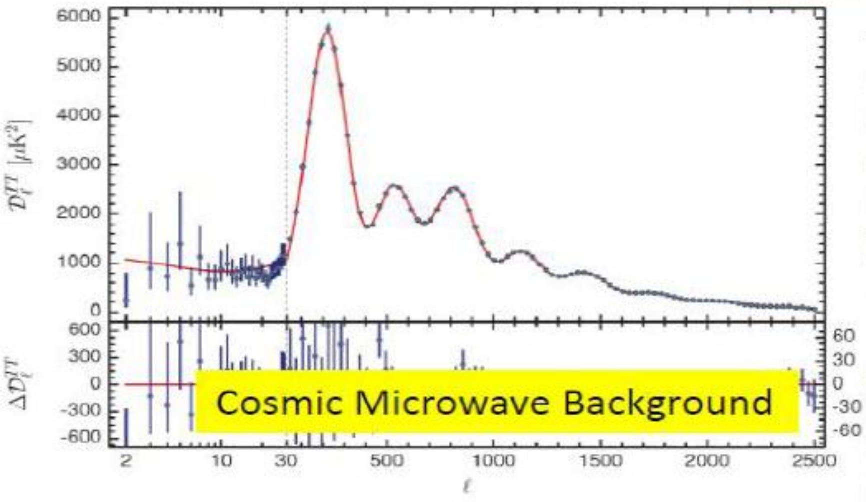




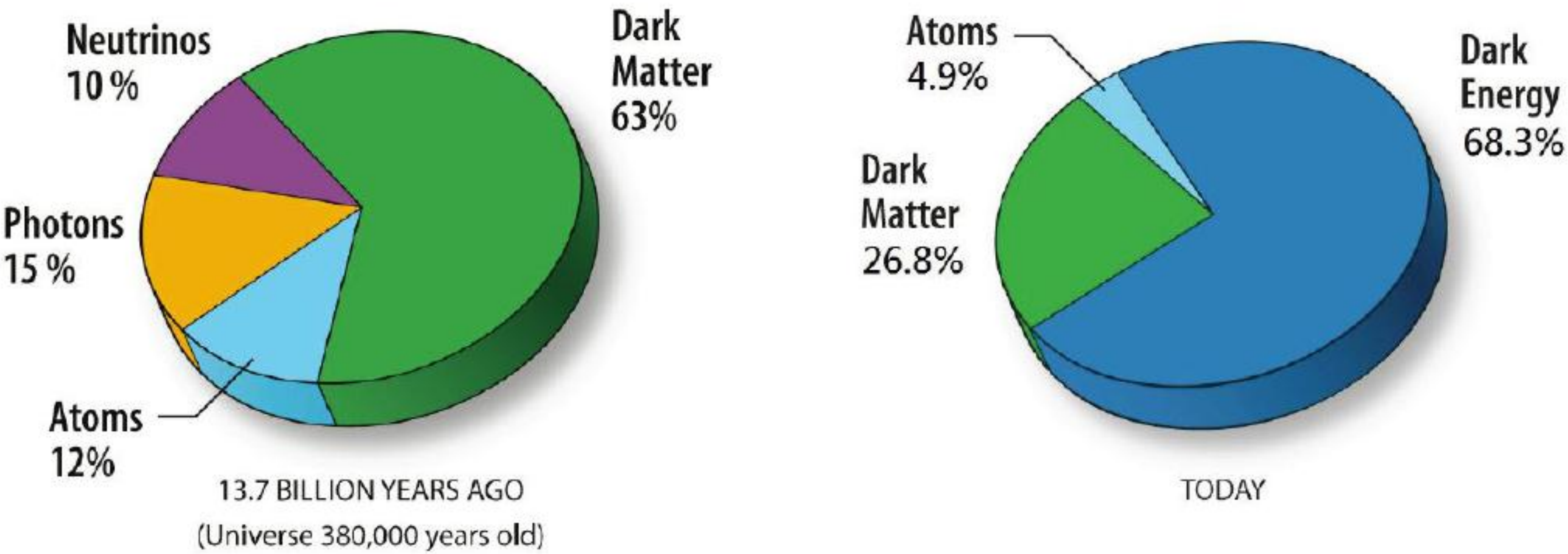
Why Dark Matter?

Evidence piling up...





What do we know about Dark Matter

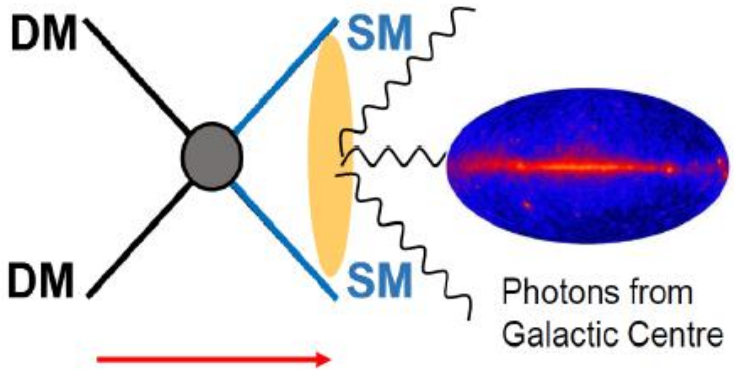


Strong astrophysical evidence for the existence of dark matter

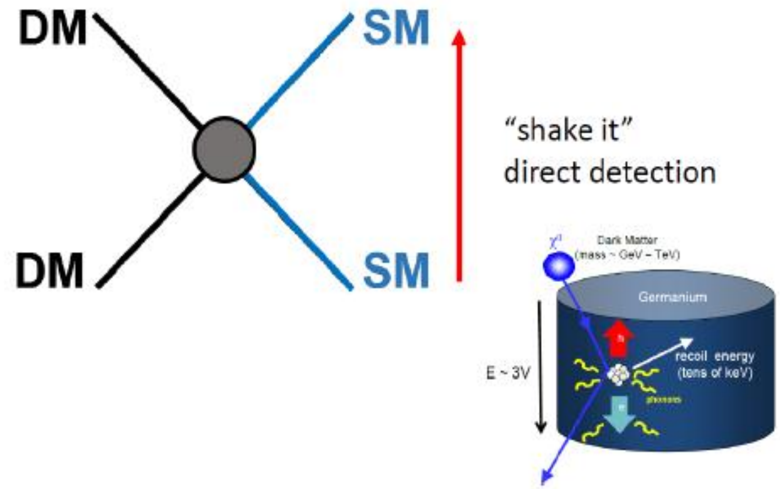
What do we know about Dark Matter

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

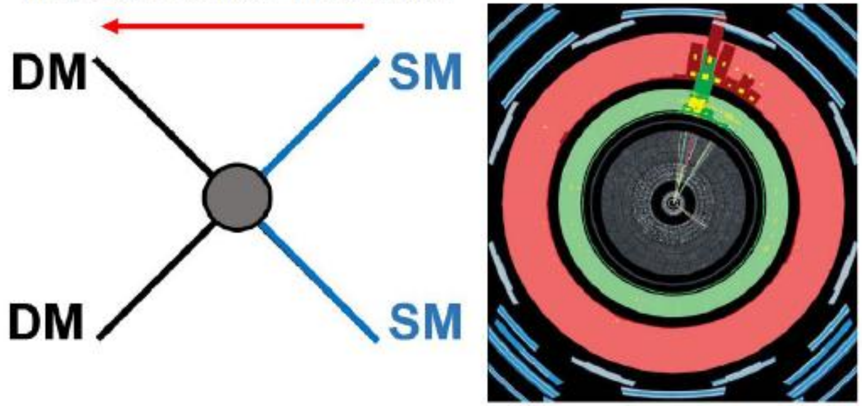
Experimental detection of Dark Matter



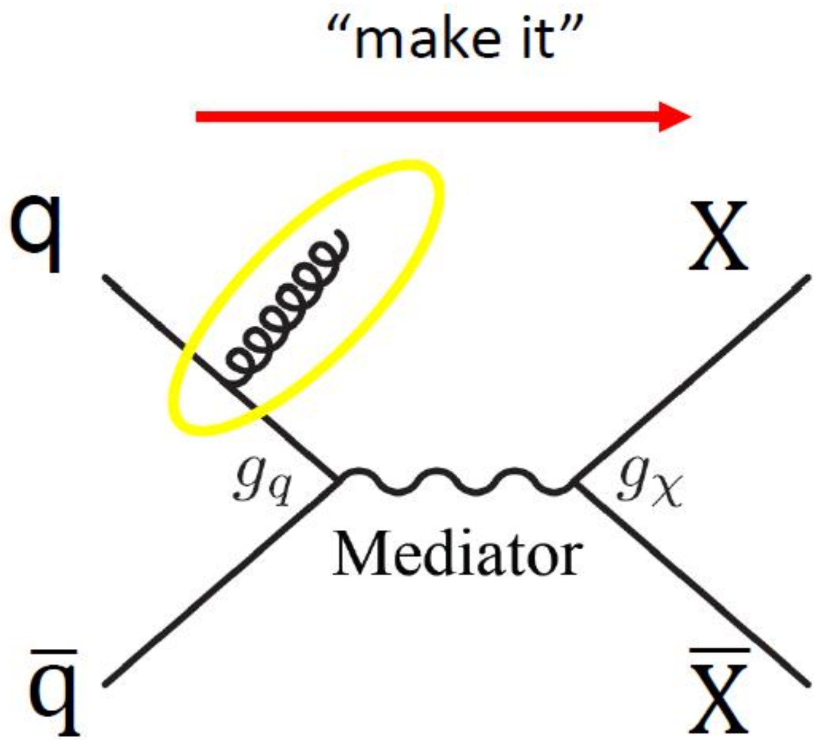
"break it": indirect detection



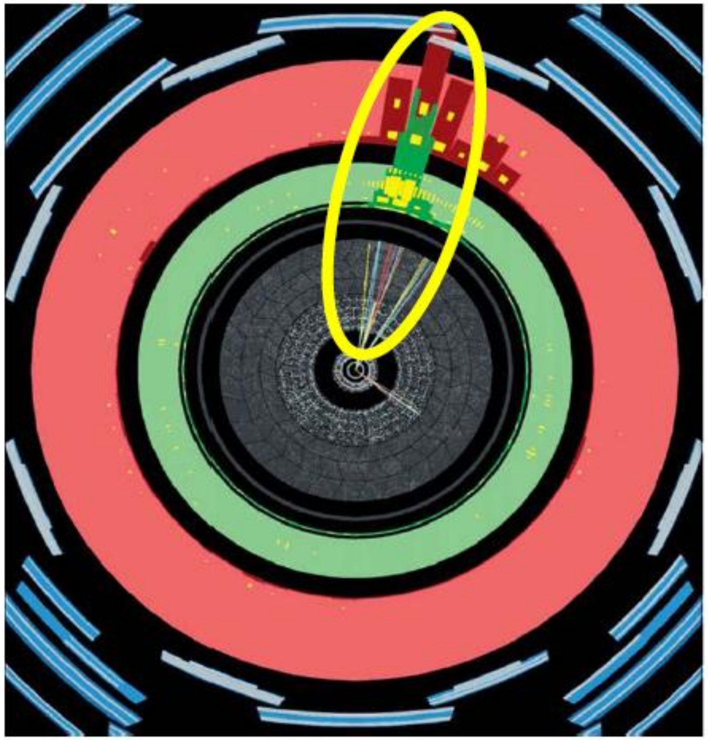
"make it": Collider Production



Dark Matter serches at Colliders



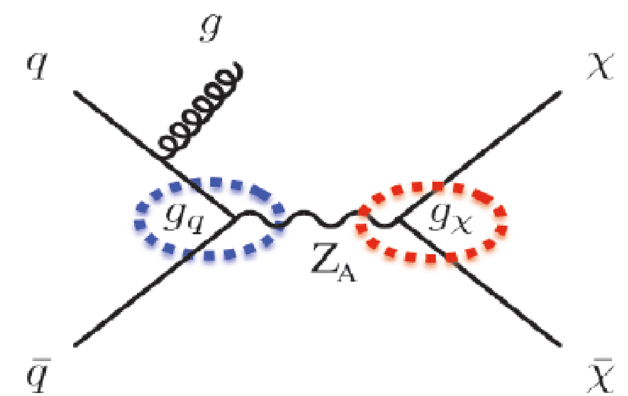
g_q and g_X coupling strengths



Empty detector + something

Simplified Model

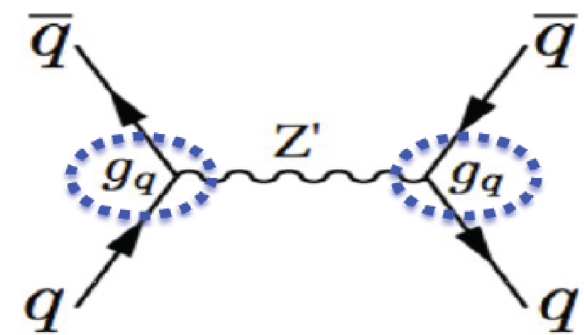
$SM \rightarrow mediator \rightarrow DM$



→Mono-X signature

E_T^{miss} + jet, W/Z/H, γ, ...

$SM \rightarrow mediator \rightarrow SM$



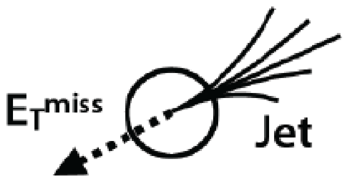
→resonant production

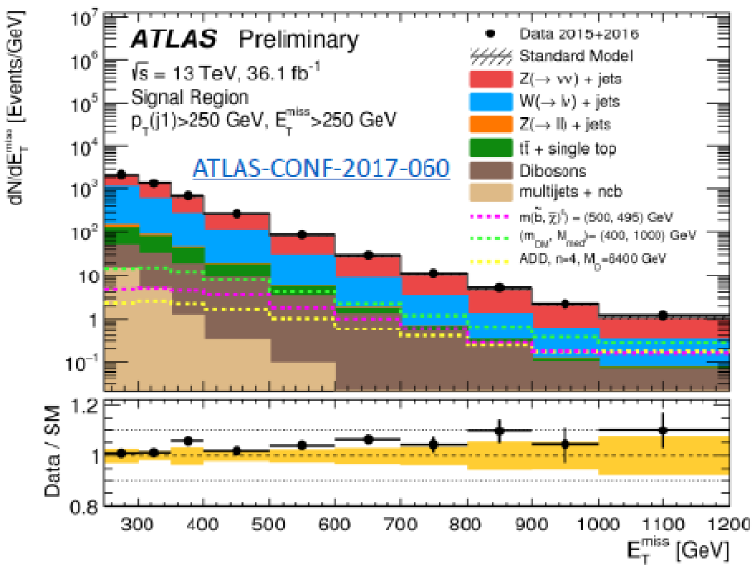
Dijet, ditop, dilepton.....

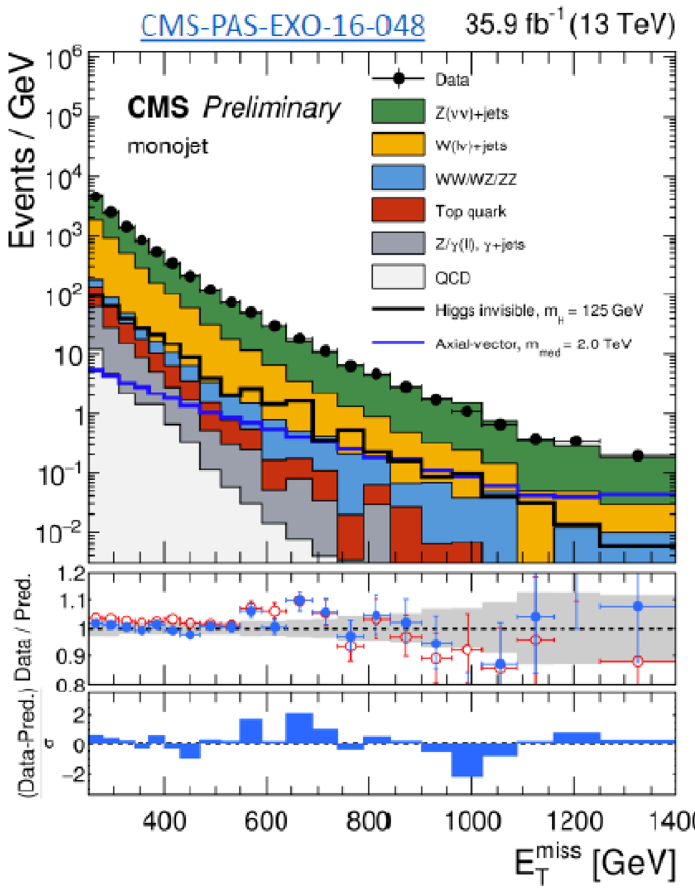
	spin 0	spin 1
Charge	Q=0 for s-channel	
Lorentz structure	Scalar $g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$ Pseudoscalar $g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f$	Vector $g_q \sum_q V_\mu \bar{q} \gamma^\mu q$ Axial-vector $g_q \sum_q A_\mu \bar{q} \gamma^\mu \gamma^5 q$
Coupling	∝ mass	∝ charge

Mono-X searches

Mono-jet







ATLAS

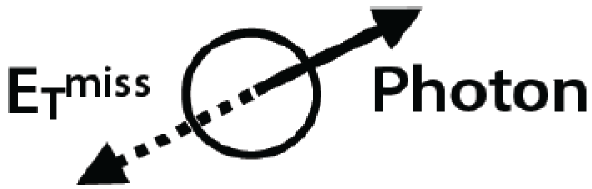
- $E_T^{miss} > 250$ GeV, $\Delta\varphi(\text{jet}, p_T^{miss}) > 0.4$
- Jet $p_T > 250$ GeV, $|\eta| < 2.4$
- $N_{jets} \leq 4$

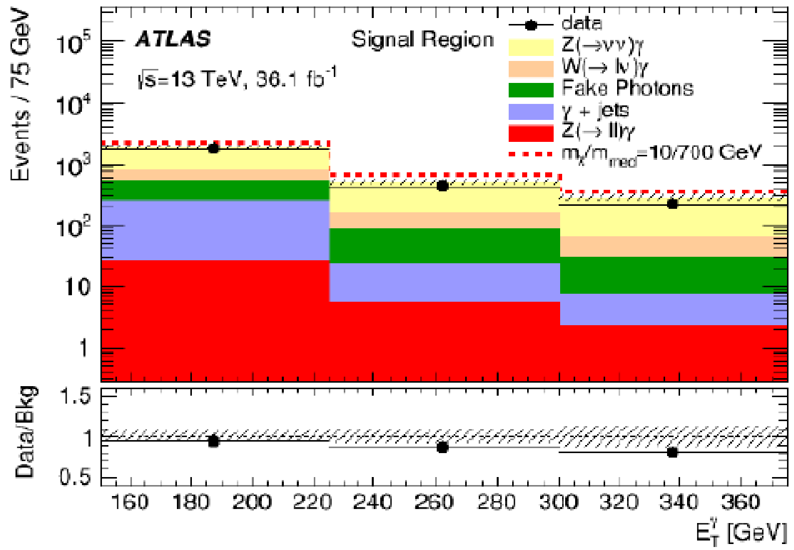
CMS

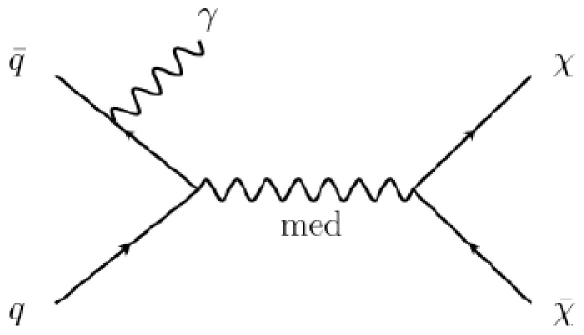
- $E_T^{miss} > 250$ GeV
- Jet $p_T > 100$ GeV, $|\eta| < 2.5$

Mono-X searches

Mono-photon





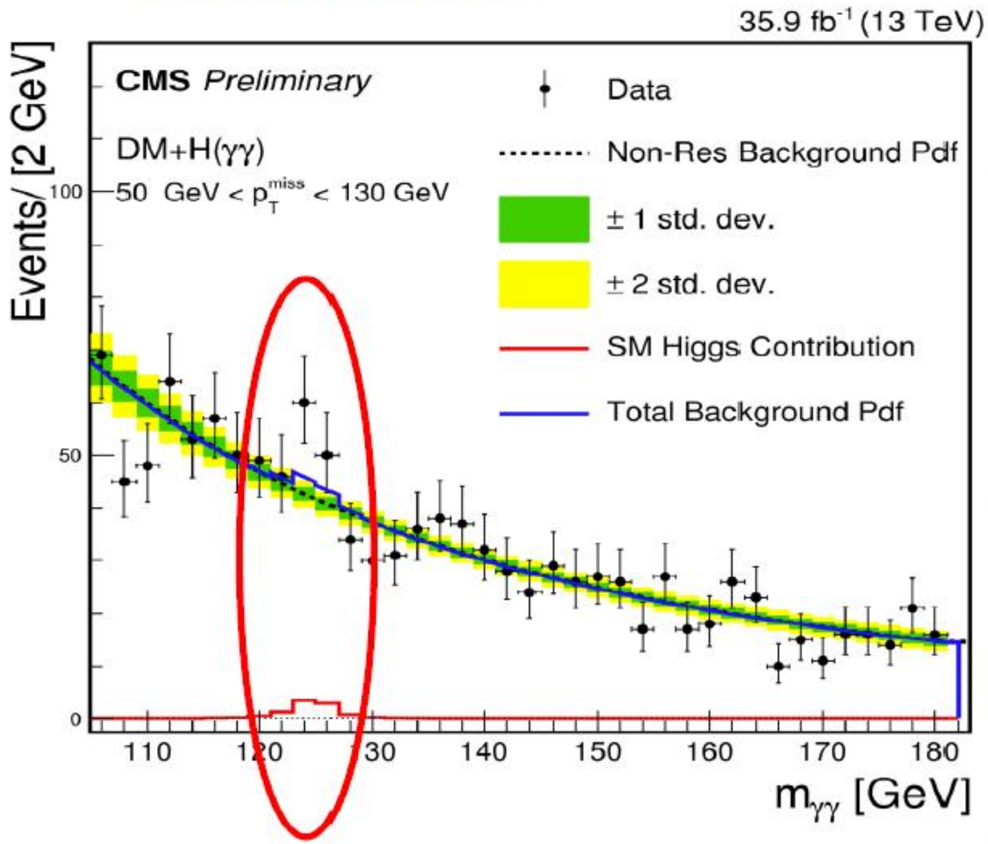


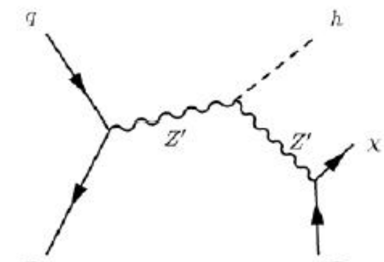
- Photon $E_T > 150$ GeV, $|\eta| < 2.37$
- $E_T^{miss}/\sqrt{\sum E_T} > 8.5\ GeV^{1/2}$
- $\Delta\varphi(\text{photon}, E_T^{miss}) > 0.4$
- $N_{jets}(p_T > 30\ GeV, |\eta| < 4.5) \leq 1$

Mono-X searches

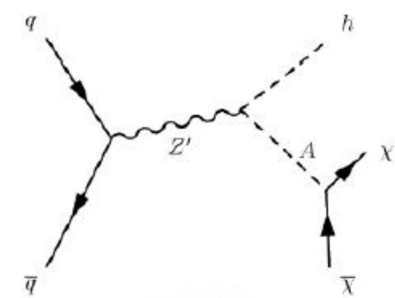
Mono-Higgs

CMS-PAS-EXO-16-054





Baryonic Z′ model
Non resonant

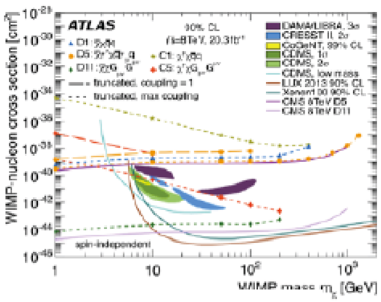


2HDM

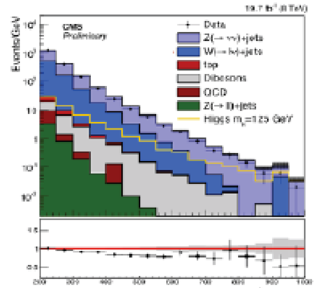
Mono-Mania!!

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

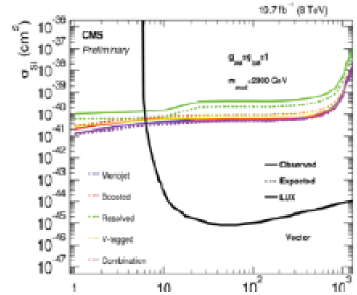
Mono-Mania!!



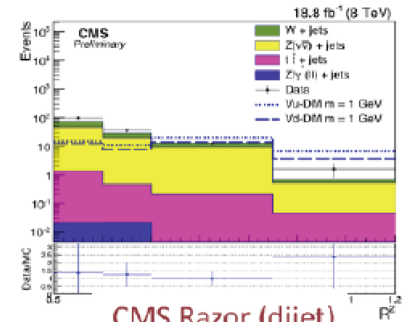
ATLAS Monojet
EPJC (2015) 75:299



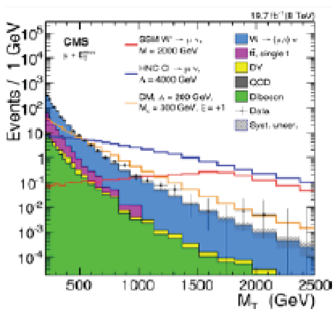
CMS j/V (mono/dijet)
PAS-EXO-12-055



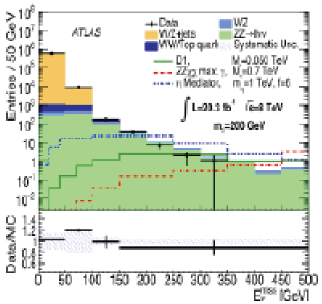
CMS j/V (mono/dijet)
PAS-EXO-12-055



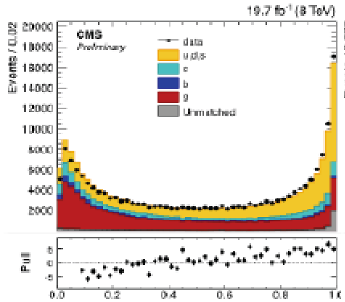
CMS Razor (dijet)
PAS-EXO-14-004



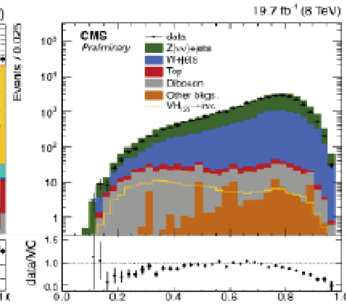
CMS, ATLAS MonoW
PRD 91, 092005, JHEP 09 (2014) 037 (2015)



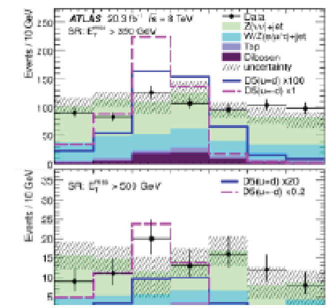
CMS, ATLAS MonoZ
EXO-12-054, PRD 90, 012004 (2014)



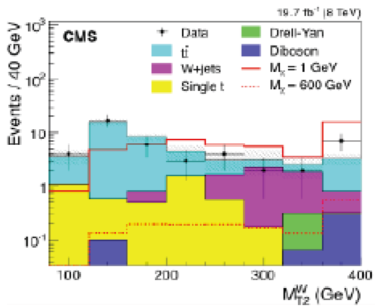
CMS MonoV (resolved)
PAS-EXO-12-005, PAS-JME-14-002



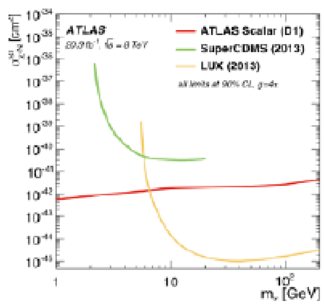
CMS MonoV (boosted)
EXO-12-005/JME-14-002



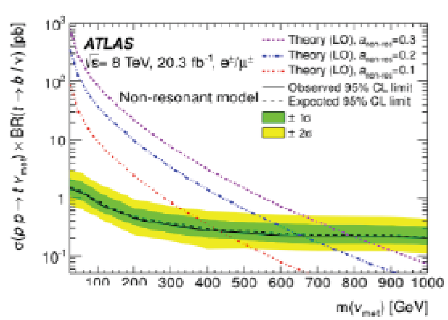
ATLAS MonoV (boosted)
ATLAS, PRL 112, 041802 (2014)



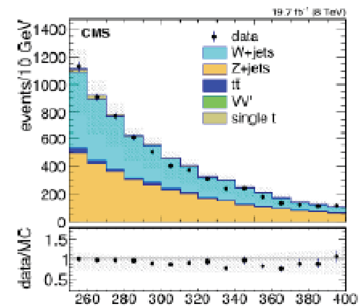
CMS TopPairs
CMS, JHEP 06 (2015) 121



ATLAS TopPairs
ATLAS, EPJC (2015) 75:92

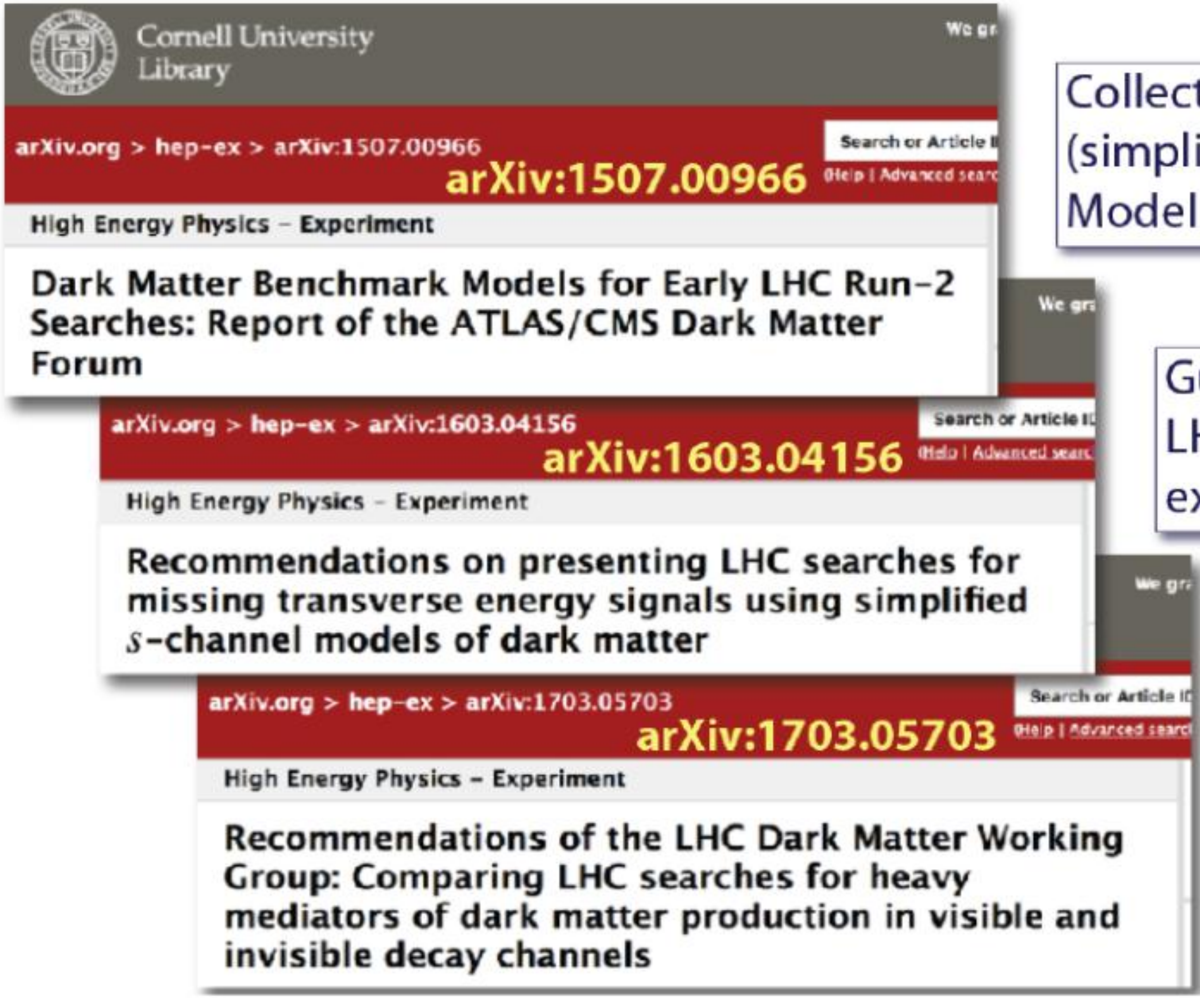


CMS MonoTop
CMS, PRL 114 (2015) 101801



ATLAS MonoTop
ATLAS, JHEP 11 (2014) 118

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

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

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

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

Guidelines to compare LHC results with DD/ID experiments

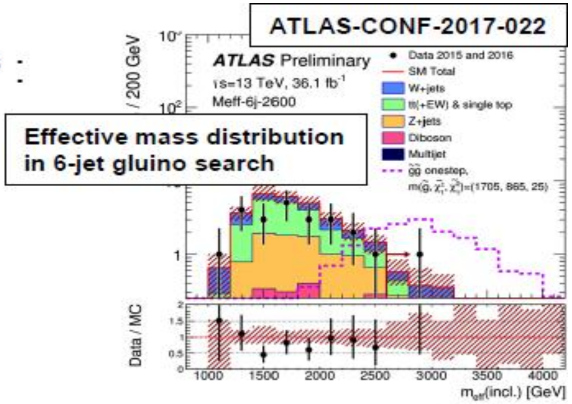
Guidelines to present Mono-X and visible signatures for heavy mediators

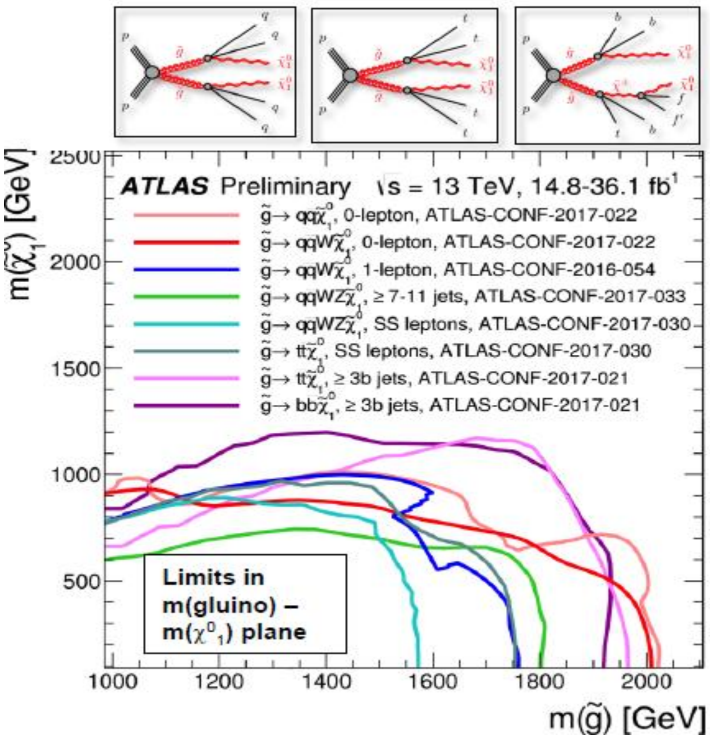
Summary (Exotic Searches)

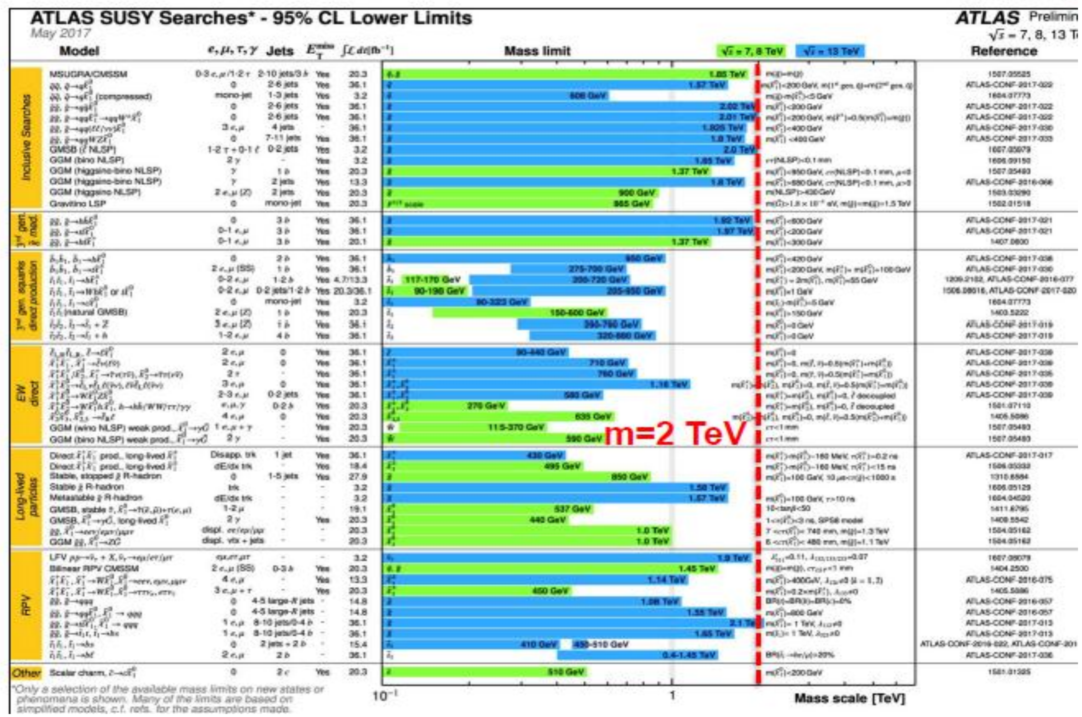
- Searches for Exotic searches
  - All major search channels reached 1 TeV scales
  - Quite a few at 10 TeV
  - New probe: Higgs boson → emerging field
- Dark Matter Searches are thriving at the LHC
- For vector and axial vector interactions
  - Dark Matter masses up 400 GeV – 700 GeV (mono-jet) excluded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

Searches for Supersymmetry

- Searches for light squarks and gluinos with jets and E_T^{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 Statistics

183 Institutions → 166 Institutes (single)
17 clusters (57 institutes in clusters)
14 associated institutes

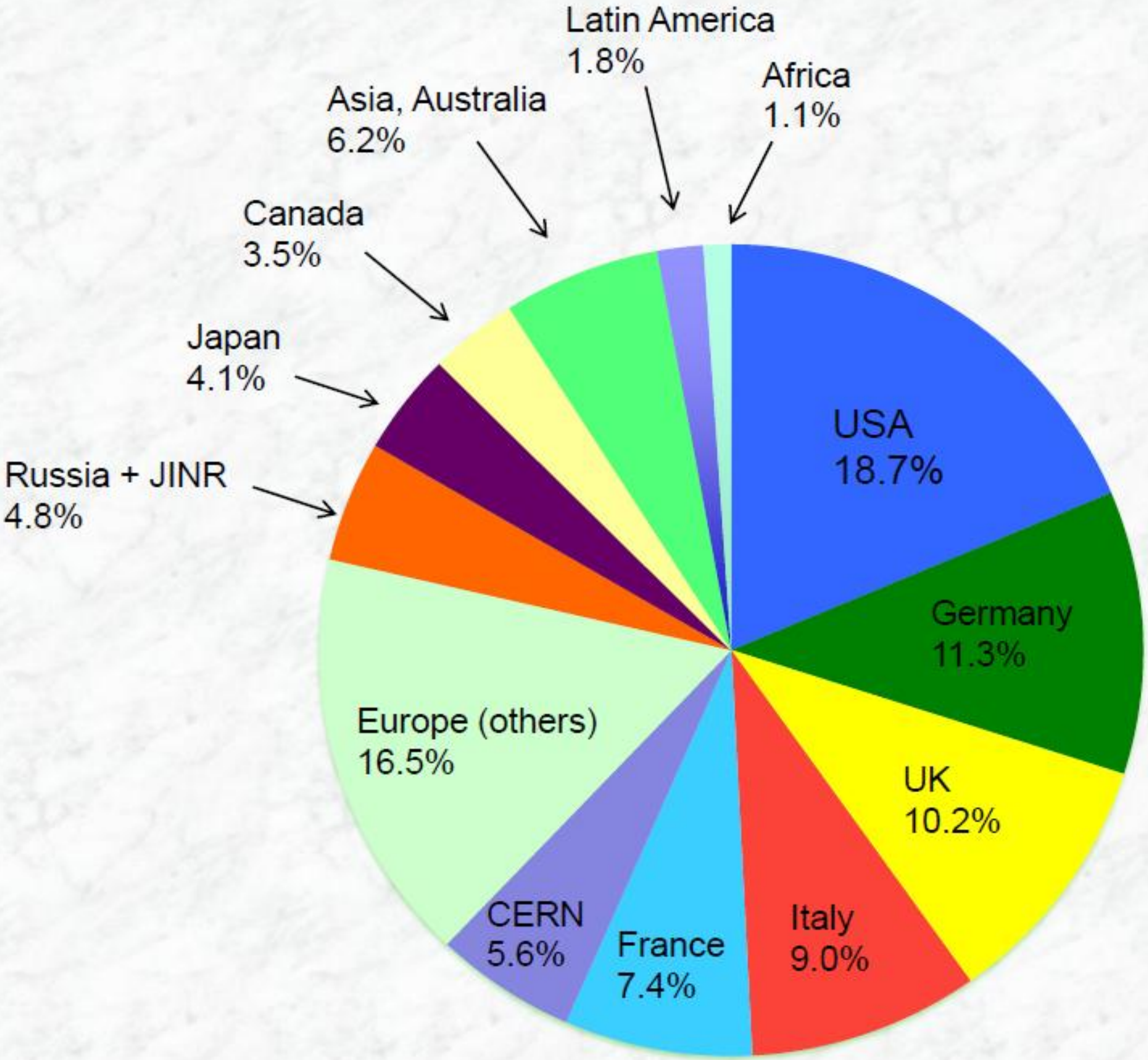
→ 237 Institutes (preliminary, to be cross-checked)

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)

USA	18,7%
Germany	11,3%
UK	10,2%
Italy	9,0%
France	7,4%
CERN	5,6%
Japan	4,1%
Canada	3,5%
Russia+ JINR	4,8%
Spain	2,6%
China	2,6%
Czech Republic	2,1%
Sweden	1,6%
Israel	1,6%
Poland	1,6%
Switzerland	1,3%
Netherlands	1,3%
Europe (others)	6,0%
Asia (others) + Australia	2,0%
Latin America	1,8%
Africa	1,1%