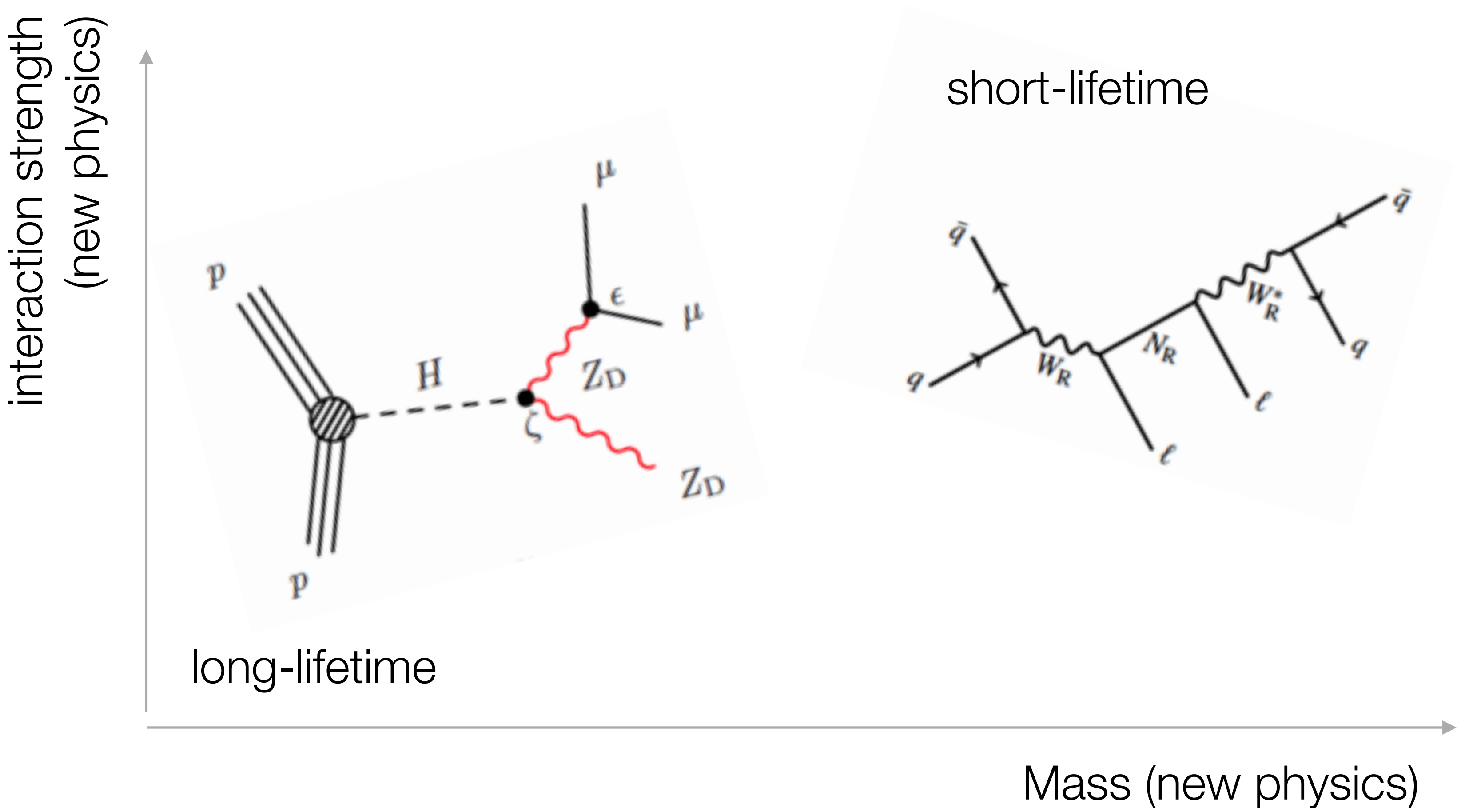
Search for new phenomena with the ATLAS detector

S. Xella (Copenhagen U.) on behalf of the ATLAS collaboration

New phenomena : why ?

- Higgs boson was the last missing piece predicted by the Standard Model : observed in 2012 by ATLAS & CMS
- **But** : Standard Model is NOT the complete theory of Nature
- Dark matter, baryogenesis, neutrino masses and oscillations : we have observed clear signs of Beyond the Standard Model physics.
- New particles or new particle phenomena are most likely behind these extraordinary observations.
- Particle physics enters a new era, where theory is of limited guidance, and as many and as new, unconventional as possible experimental results need to be pursued.

How to find new phenomena @ colliders



We need to expand the set of measurements we do at the LHC and include as many final states as possible

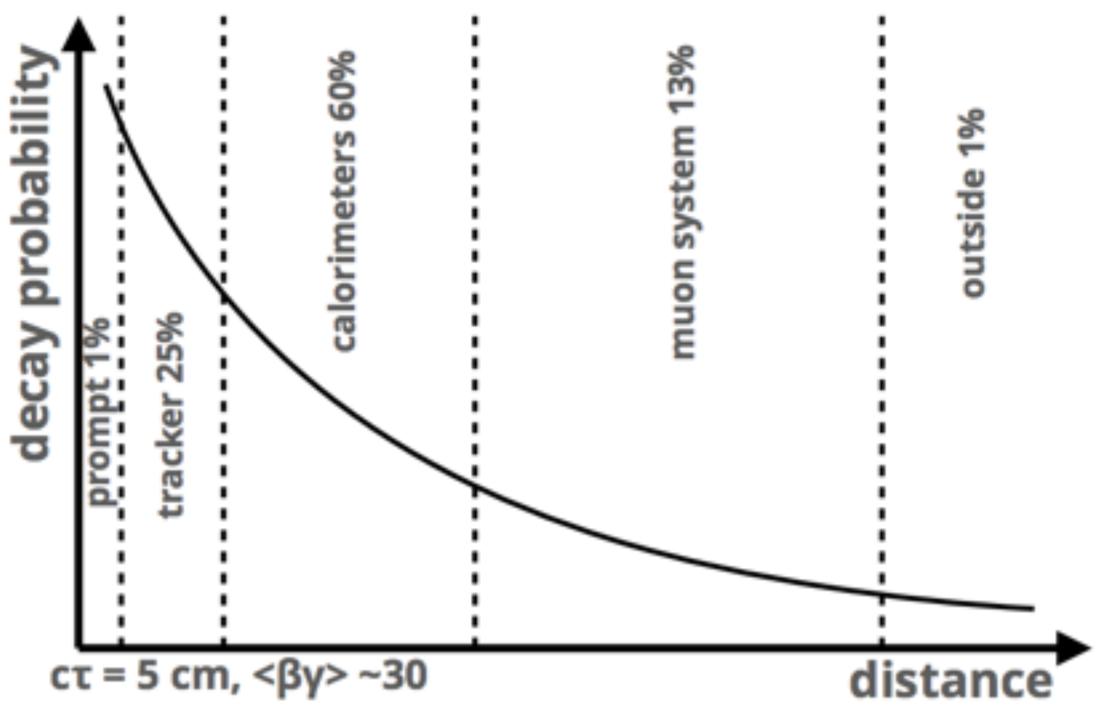
It is possible that so far new physics escaped our detection because our detection or trigger techniques have not been enough wide-reaching

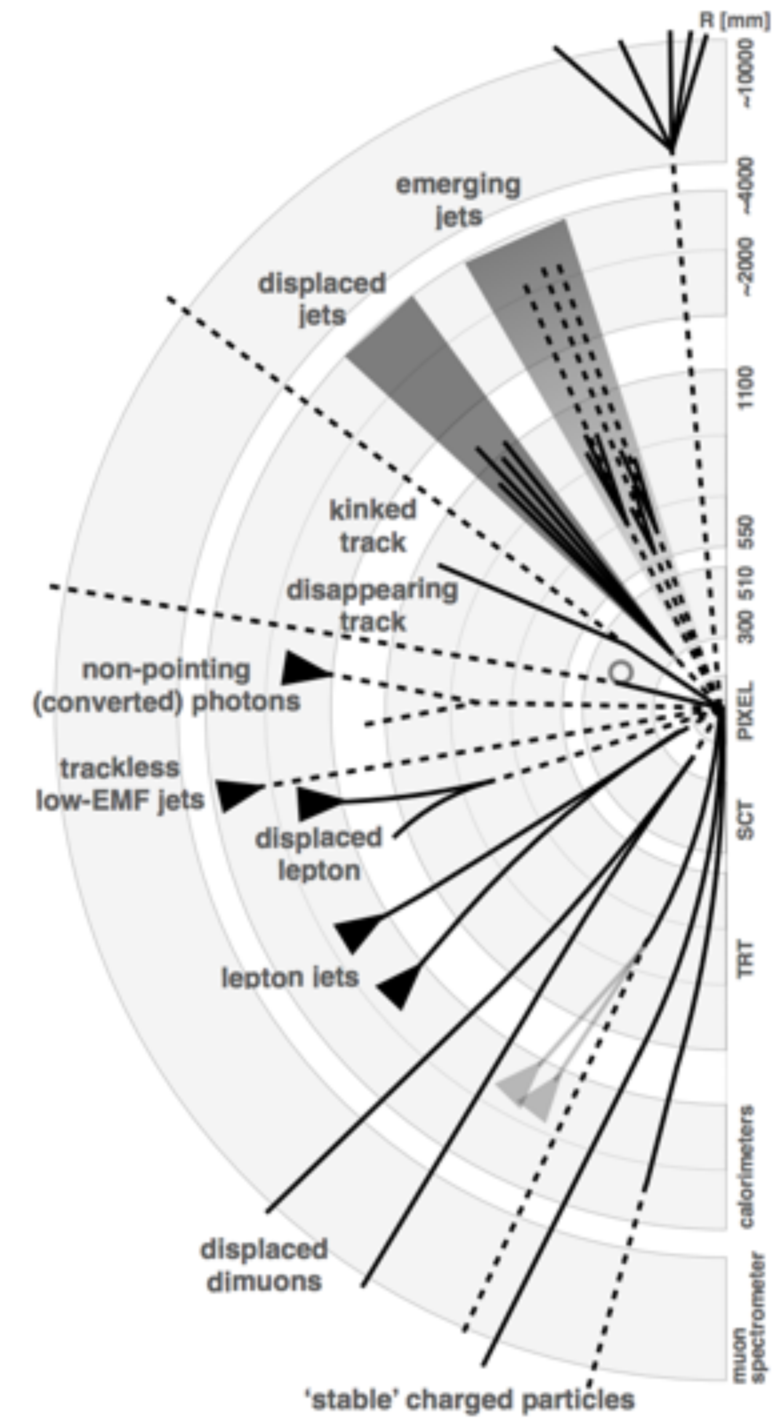
Un-conventional

credit: S. Mehlhase
LLP Workshop - Amsterdam, 2018

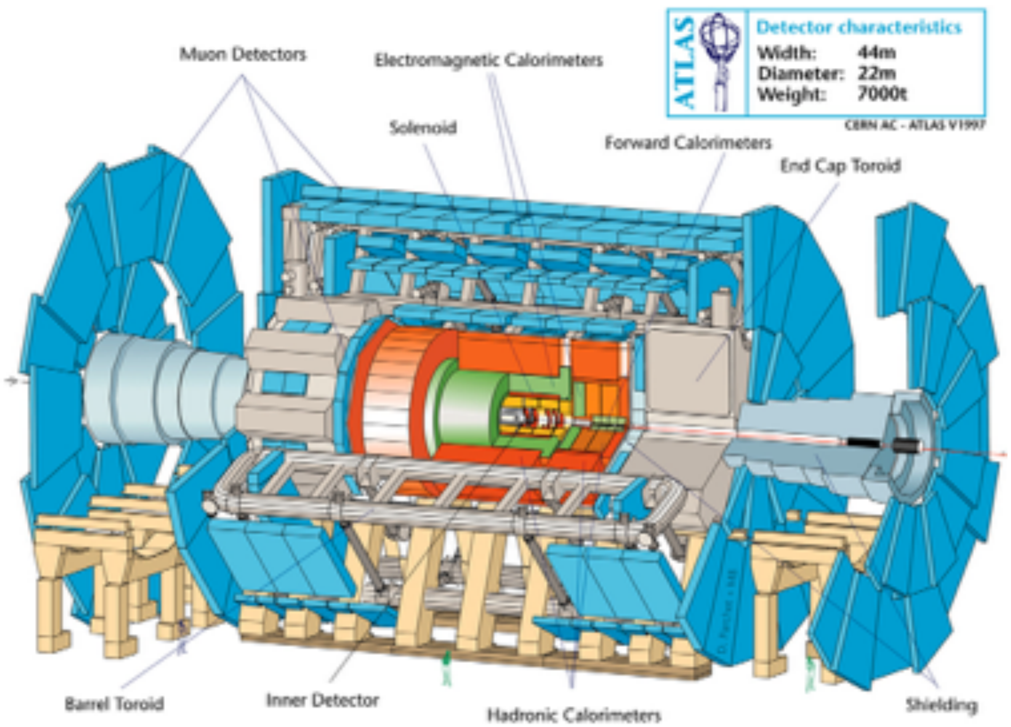
Search for particles that display long lifetime
and still leave some signs within the detector volume

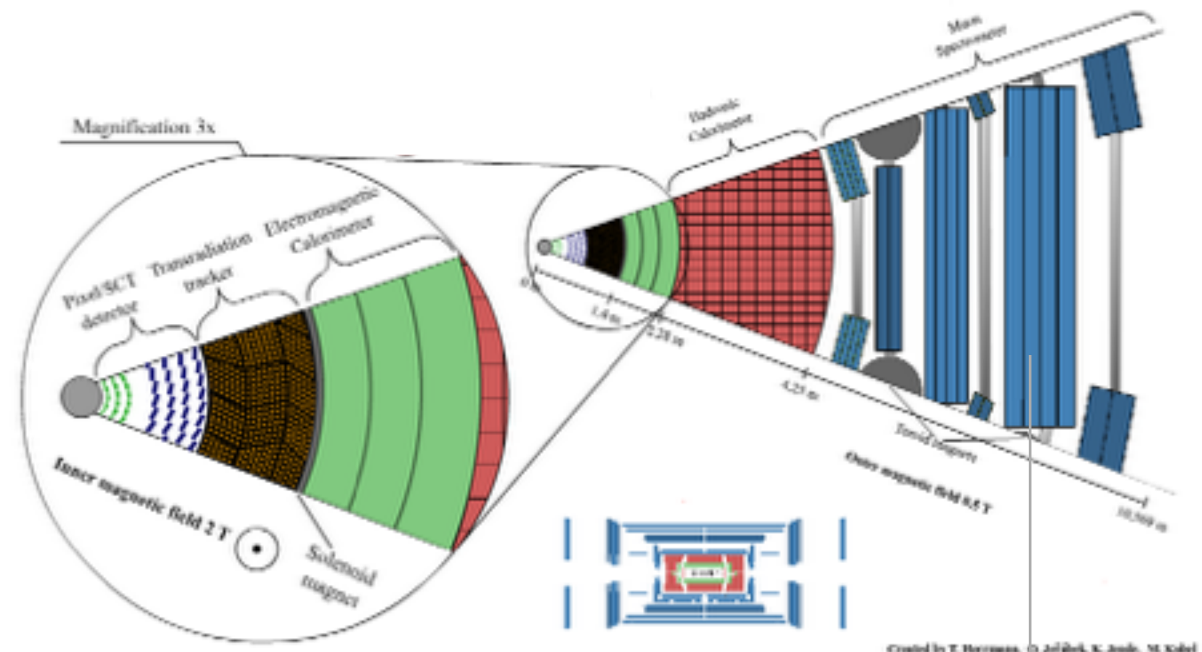
Multiple search strategies can be applied to one physics model, depending on the lifetime
(exp. distribution with constant cτ, proper lifetime).

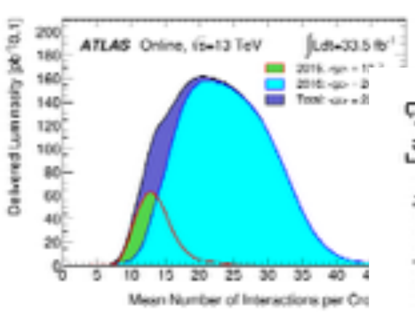


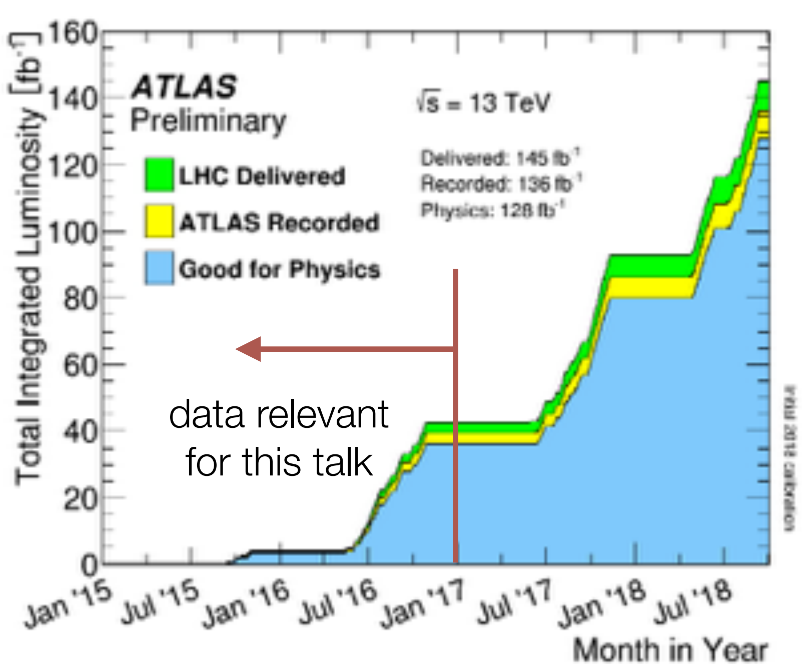


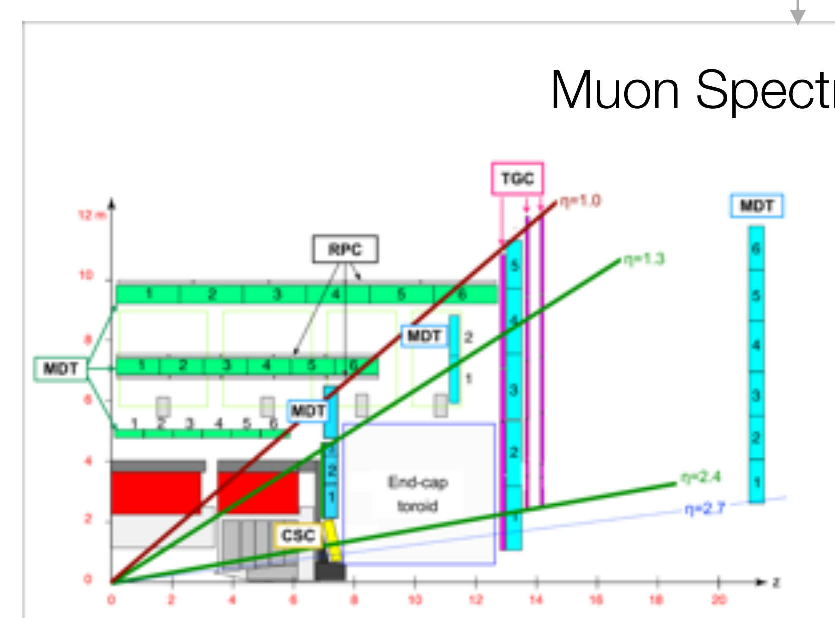
ATLAS detector and data used









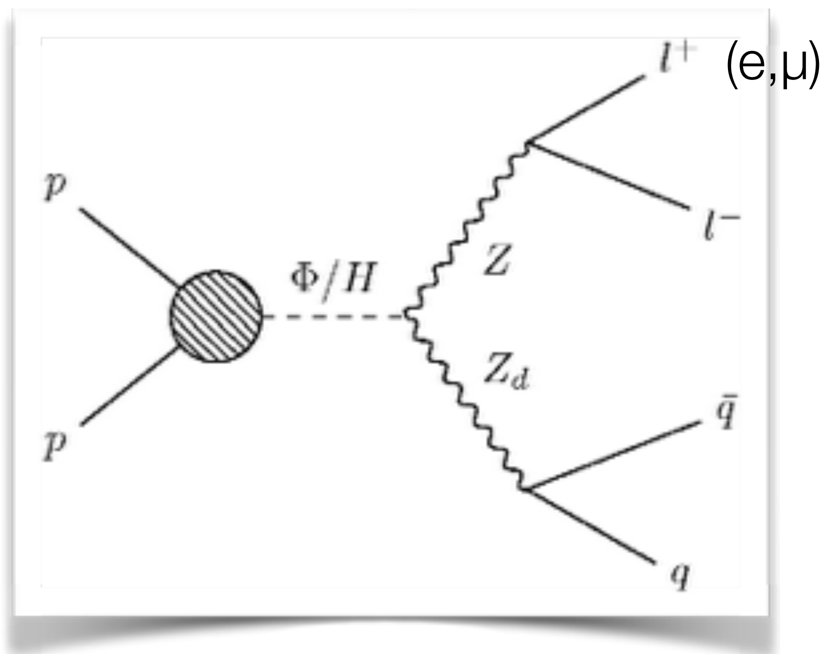


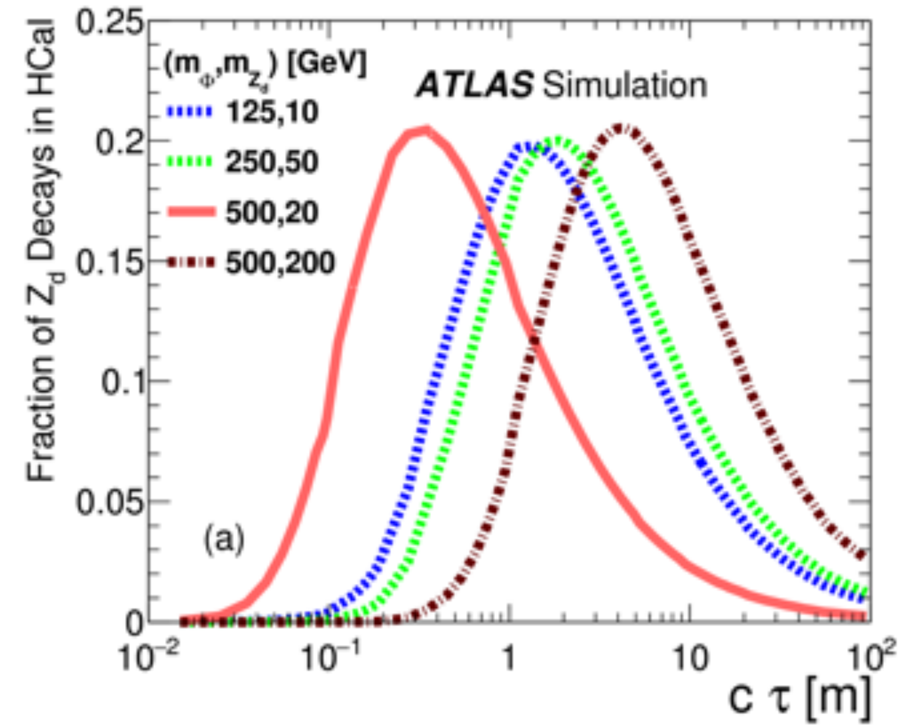
ATLAS analyses presented here

- Search for the production of a long-lived neutral particle decaying within the ATLAS hadronic calorimeter in association with a Z boson
- Search for heavy Majorana or Dirac neutrinos and right-handed W gauge bosons in final states with two charged leptons and two jets
- Search for long-lived particles in final states with displaced dimuon vertices
- Search for long-lived particles that decay to displaced hadronic jets in the ATLAS muon spectrometer

these are all examples of recent new searches that are sensitive to theoretical models providing explanations for the big observations we have in particle physics

Search for the production of a long-lived neutral particle decaying within the ATLAS hadronic calorimeter in association with a Z boson





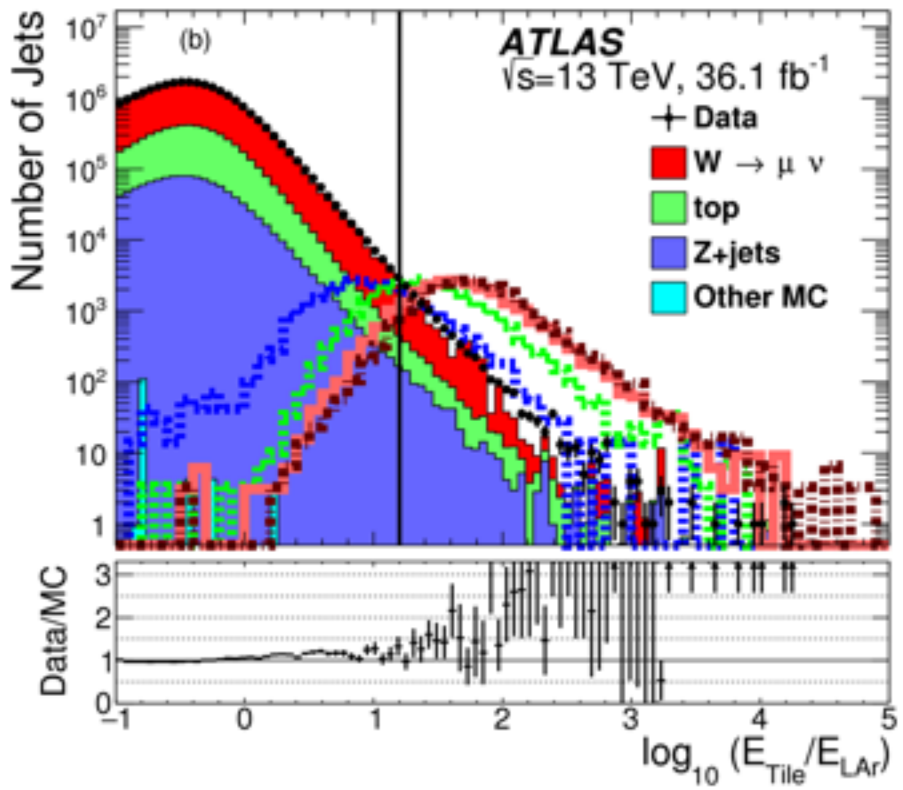
extends previous ATLAS result [1,2]:

- consider an intermediate particle to be general scalar Φ
- consider hadronic final state for dark vector boson Z_d, with long lifetime (lower coupling strength)

Z_d decays in Tile Calorimeter (2m<r<4m), and hence signature is a jet with little deposit in Lar Calorimeter and no tracks in Inner Detector

[1]https://arxiv.org/abs/1505.07645 [2]https://arxiv.org/abs/1802.03388

Selection and backgrounds



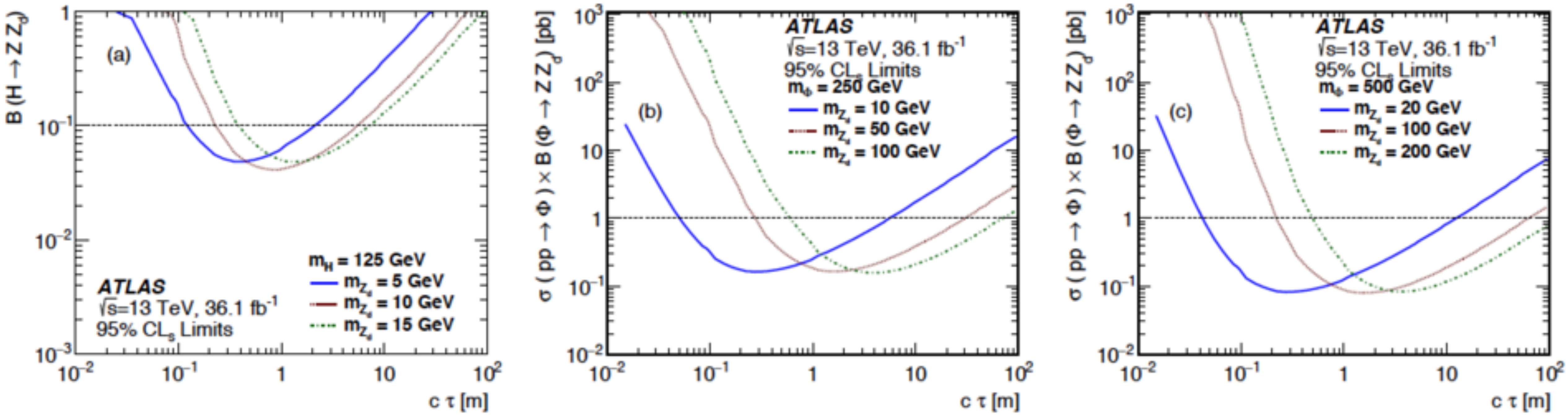
Event selection:

- single lepton trigger + offline p_T e/μ: 25 (27) GeV for 2015 (2016).
- 66 GeV <Mass (ll)<116 GeV
- jet p_T>40GeV, |η|<2.0, calorimeter ratio $\log_{10}(E_{Tile}/E_{Lar})$>1.2, no ghost tracks with p_T>1 GeV. Timing applied to jet to reject out-of-time pile-up and beam induced background.
- Main background : Z+jet (jet mimics the Z_d hadronic decay), data-driven estimated. W+jets and tt less important, MC estimated.

Z+jet background estimation:

- determine the probability for a jet to pass the calorimeter ratio cut , on jets in a W+jets data sample. Apply the probability to the selected sample of Z->ll + njets, calculate the amount of events expected to have 1 jet identified as Z_d hadronic decay.

Results



Minimum jet E_T	40 GeV	60 GeV	80 GeV
Background	175 ±22	33.0 ±4.4	13.2 ±3.5
Data	158	35	16
Expected UL	65	17	10
Observed UL	50	18	13

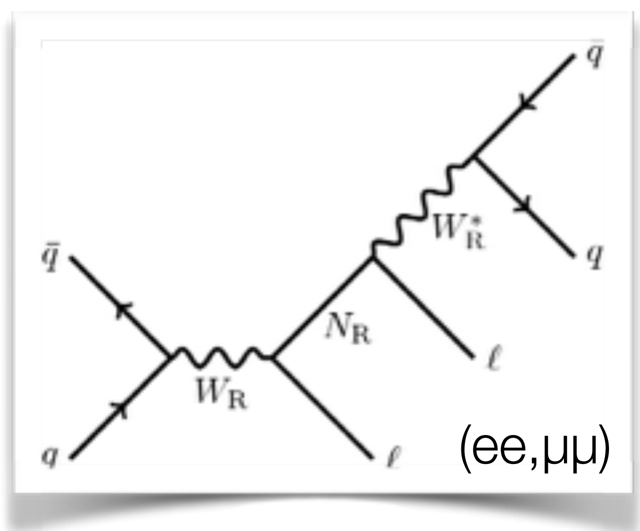
stat and syst error

Main errors:

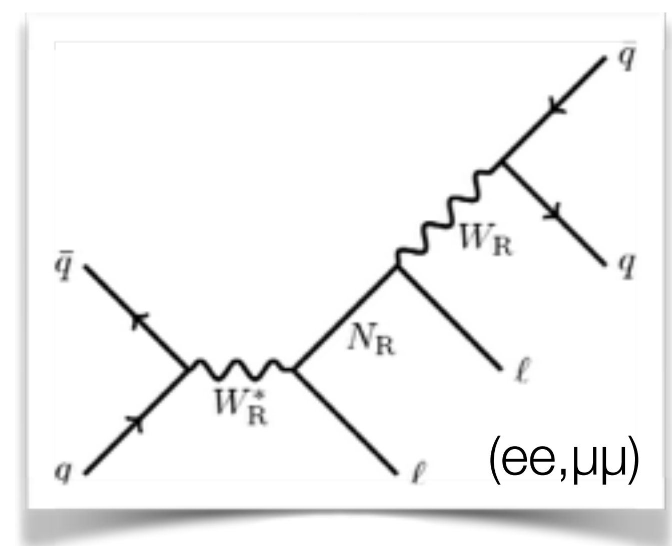
- statistical uncertainty of the W+jets sample 2-8%
- potential quark/gluon difference between the W and Z samples 7-20%
- uncertainty on assumption “jets in W evts = jets in Z evts” 10%

Search for heavy Majorana or Dirac neutrinos and right-handed W gauge bosons in final states with two charged leptons and two jets

Type I see-saw or inverse see-saw mechanism in Left Right Symmetric Models, with new sector parallel to SM, with W bosons with coupling to right-handed particles, and right-handed neutrinos



$M_{WR} > M_{NR}$: llqq invariant mass sensitive to M_{WR}



$M_{WR} < M_{NR}$: qq invariant mass sensitive to M_{WR}

N_R can be Majorana or Dirac particle. Opposite Sign charge channel is sensitive to Majorana and Dirac nature, Same Sign charge channel is sensitive to Majorana only. No flavour mixing is considered in the search.

Selections

Event selection

- single or double lepton trigger + offline pT > 25(30) GeV for Opposite Sign, OS (Same Sign, SS) charge selection of the two leptons. Leptons are isolated.

- two jets pT>100 GeV

Region	Control region			Validation region		Signal region	
Channel	$CR(\ell^\pm\ell^\mp)$	$CR(\ell^\pm\ell'^\mp)$	$CR(\ell^\pm\ell^\pm)$	$VR(\ell^\pm\ell^\mp)$	$VR(\ell^\pm\ell^\pm)$	$SR(\ell^\pm\ell^\mp)$	$SR(\ell^\pm\ell^\pm)$
m_{ee} [GeV]	[60, 110]	—	[110, 300]	[110, 400]	[300, 400]	> 400	> 400
$m_{\mu\mu}$ [GeV]	[60, 110]	—	[60, 300]	[110, 400]	[300, 400]	> 400	> 400
$m_{e\mu}$ [GeV]	—	> 400	—	—	—	—	—
H_T [GeV]	> 400	> 400	—	> 400	—	> 400	> 400
m_{jj} [GeV]	> 110	> 110	—	> 110	—	> 110	> 110
Jet p_T [GeV]	> 100	> 100	> 50	> 100	> 50	> 100	> 100
	OS	OS	SS	OS	SS	OS	SS

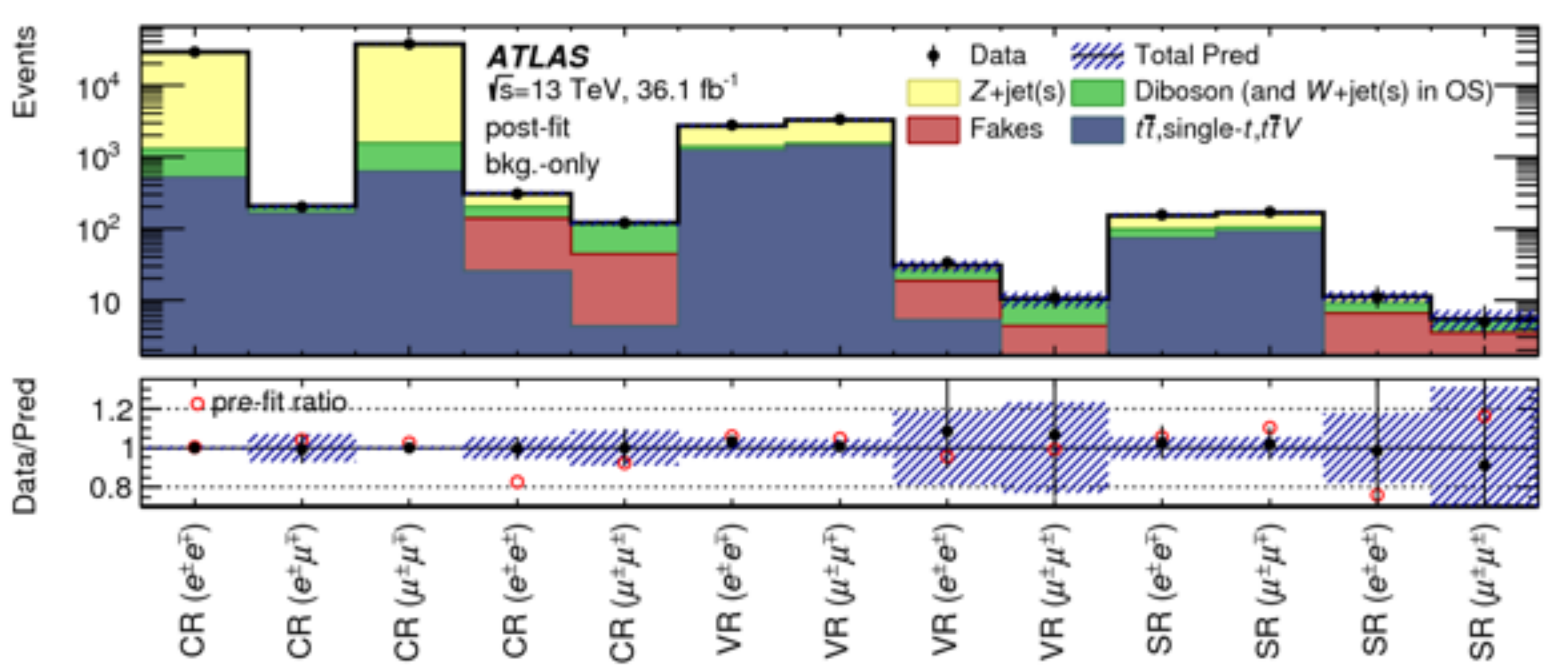
CR: used to scale some of the backgrounds, VR: used to validate the backgrounds, SR: used to set limits

Backgrounds and systematics

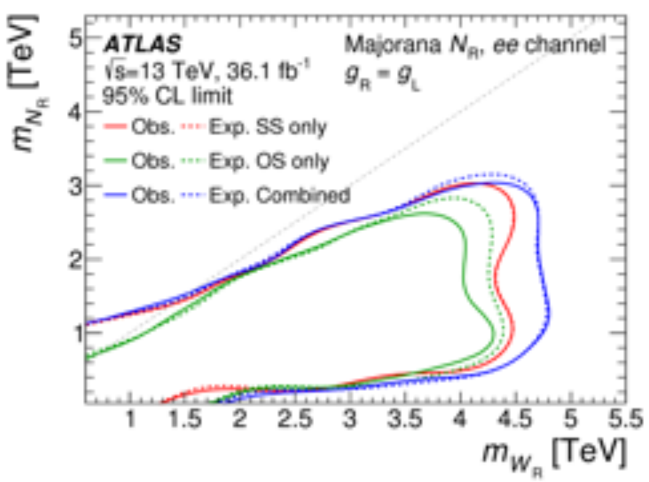
- OS: main backgrounds are Z+jets and tt. MC Z+jets mjj spectrum is reweighted using CR data.

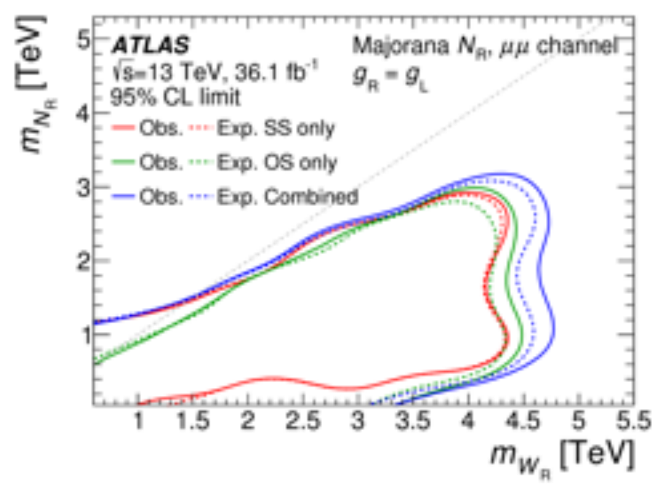
- SS: main backgrounds are Z+jets (misidentified e charge, CR used to scale MC) and diboson in ee, μ μ final state. Additionally, “fakes” from misidentified or non-prompt leptons is a large component.

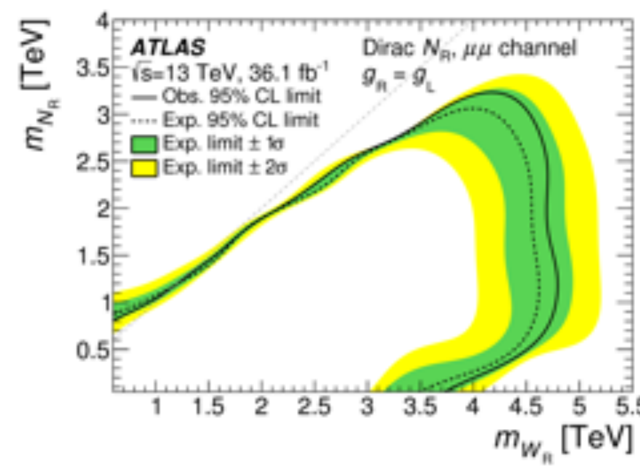
    - Fake factor method where identification or isolation is inverted, and a transfer (“fake”) factor is measured in independent, fake-enriched regions.

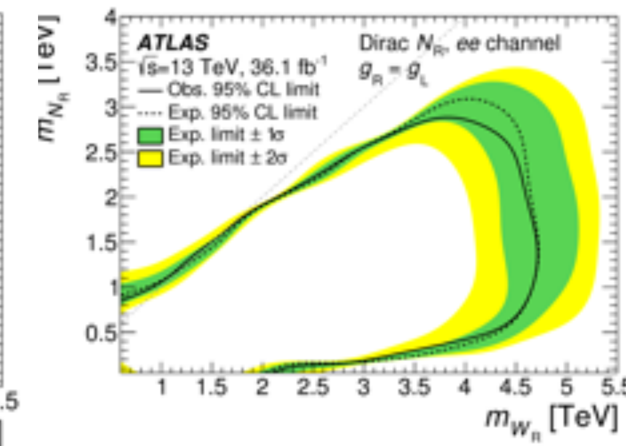


Results

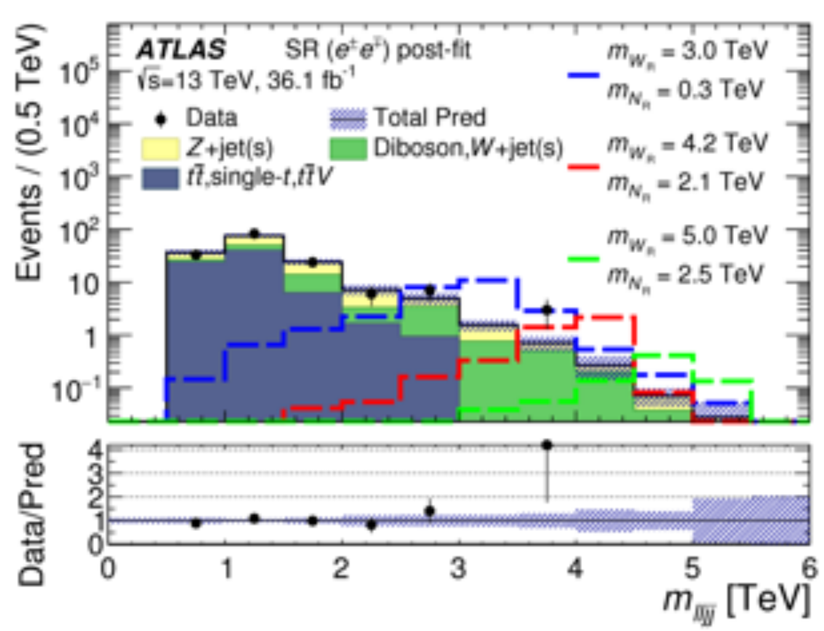




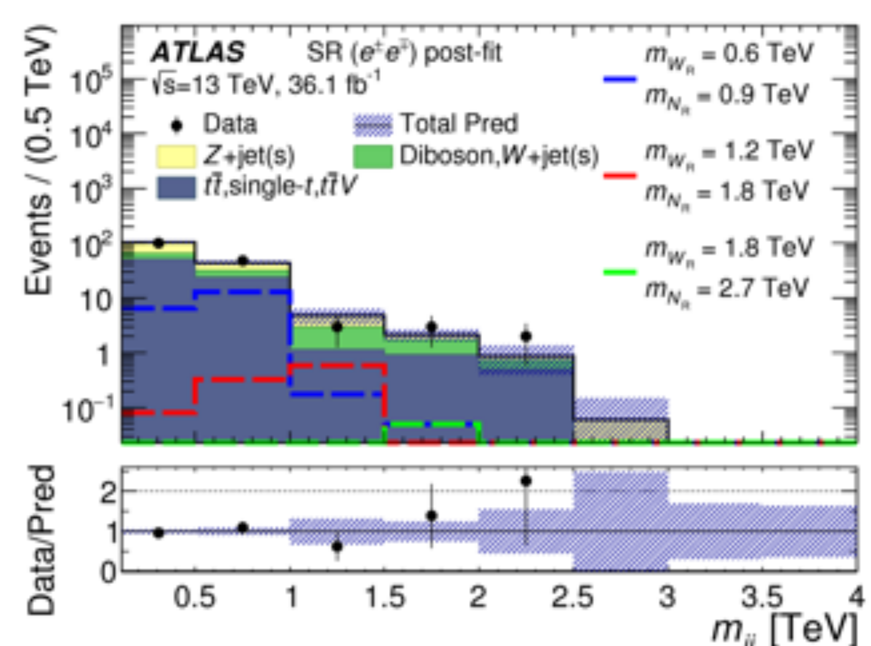




Improves on previous ATLAS results [1], pushing limits on M_{WR} up by 1-2 TeV.
Also, investigates $M_{NR}>M_{WR}$ for first time.



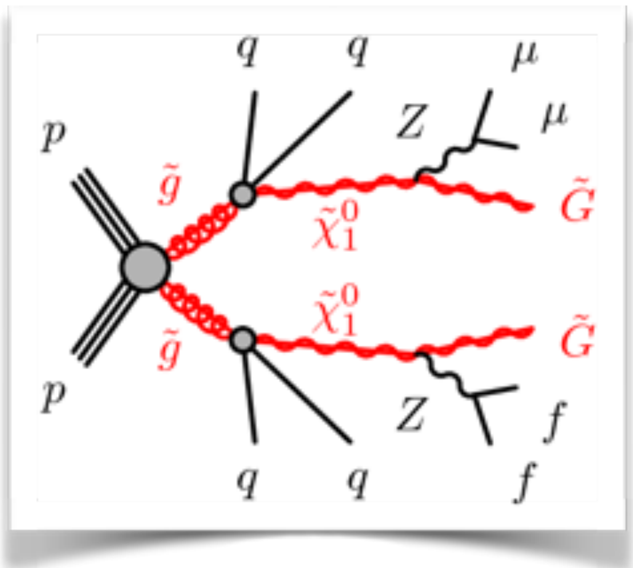
$M_{WR}>M_{NR}$

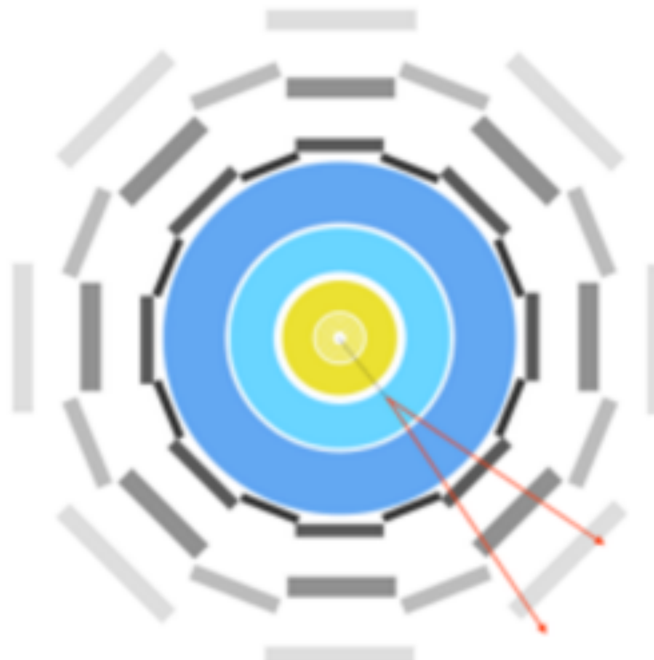


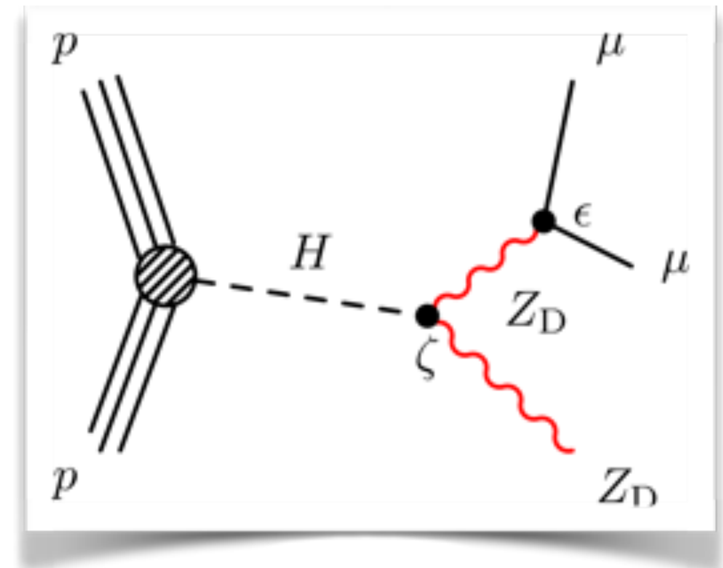
$M_{WR}<M_{NR}$

[1] https://arxiv.org/abs/1506.06020

Search for long-lived particles in final states with displaced dimuon vertices







$c\tau_{\chi} \sim 16\,\pi\, F^2_0/m^5_{\chi}$, F_0: scale new physics
$F_0 \sim 10^6$-10^8 TeV —> long-lived

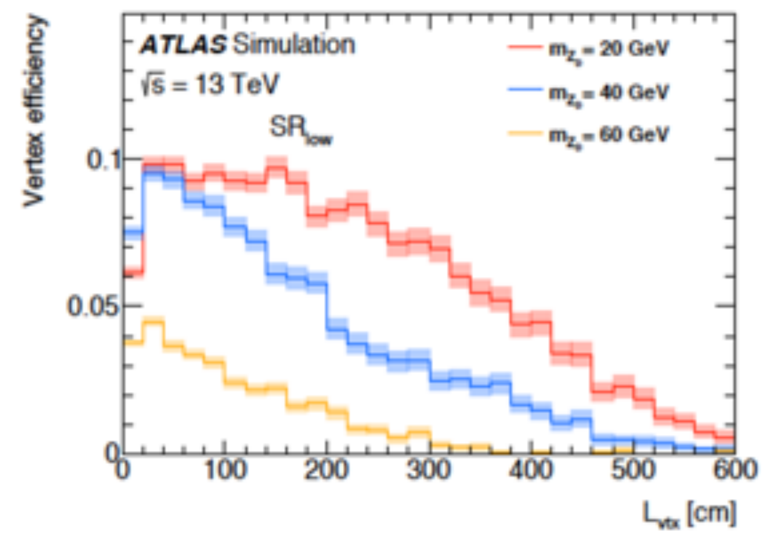
$c\tau_{Z_D} \sim 1/\varepsilon^2$, ε: mixing Z-Z_D
$\varepsilon \sim 10^{-5}$ —> long-lived

Signal type	Trigger	Description	Thresholds
High mass	E_T^{miss}	missing transverse momentum	$E_T^{miss} > 110$ GeV
	single muon	single muon restricted to the barrel region	muon $\|\eta\| < 1.05$ and $p_T > 60$ GeV
Low mass	collimated dimuon	two muons with small angular separation	p_T of muons > 15 and 20 GeV and $\Delta R_{\mu\mu} < 0.5$
	trimuon	three muons	$p_T > 6$ GeV for all three muons

muons exclusively found in the Muons Spectrometer

Selections

Selection	Low mass	High mass
p_T^μ [GeV]	> 10	> 20
$m_{\mu\mu}$ [GeV]	15–60	> 60
Dimuon transverse boost	–	> 2
	SR_{low}	SR_{high}
Muon candidates	both MSonly	both MSonly
Muon candidate charge	opposite charge	opposite charge



background estimate:
solely data driven,
via ABCD method

Region name	Muon candidates in vertex
A	MSonly–MSonly
B	MSonly–MScomb
C	MScomb–MSonly
D	MScomb–MScomb

use SS mainly for non-prompt component (cosmics, beam induced background, fake tracks, π/K decays). R^q= charge ratio

$N_A^{non\text{-}prompt} = N_A^{SS} * R^q$

use OS for prompt component (DY)

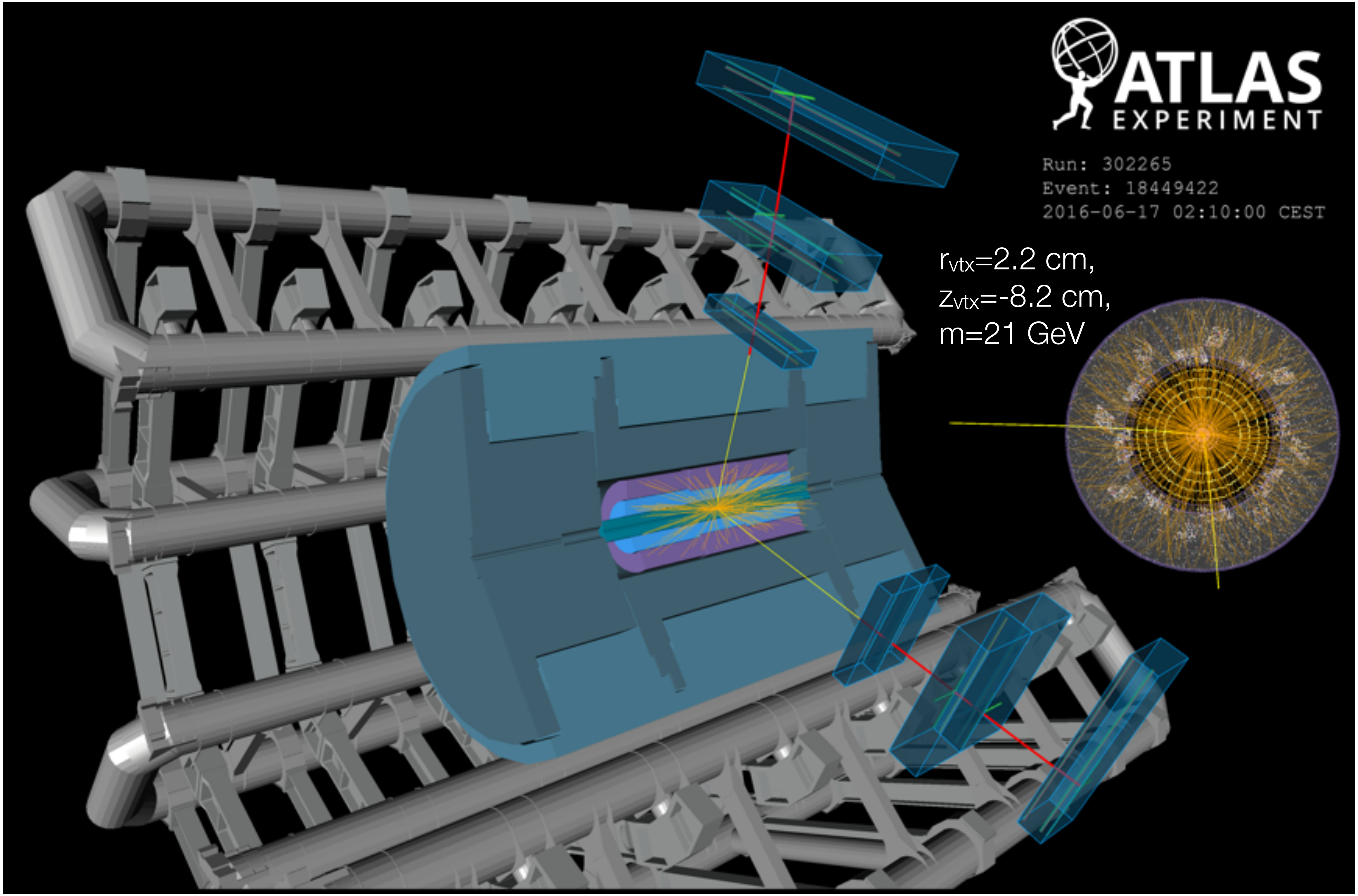
$N_A^{prompt} = [N_B' * N_C' / N_D']^{OS}$

$N_B' = N_B^{OS} - N_B^{SS} * R^q$, and similar for C, D

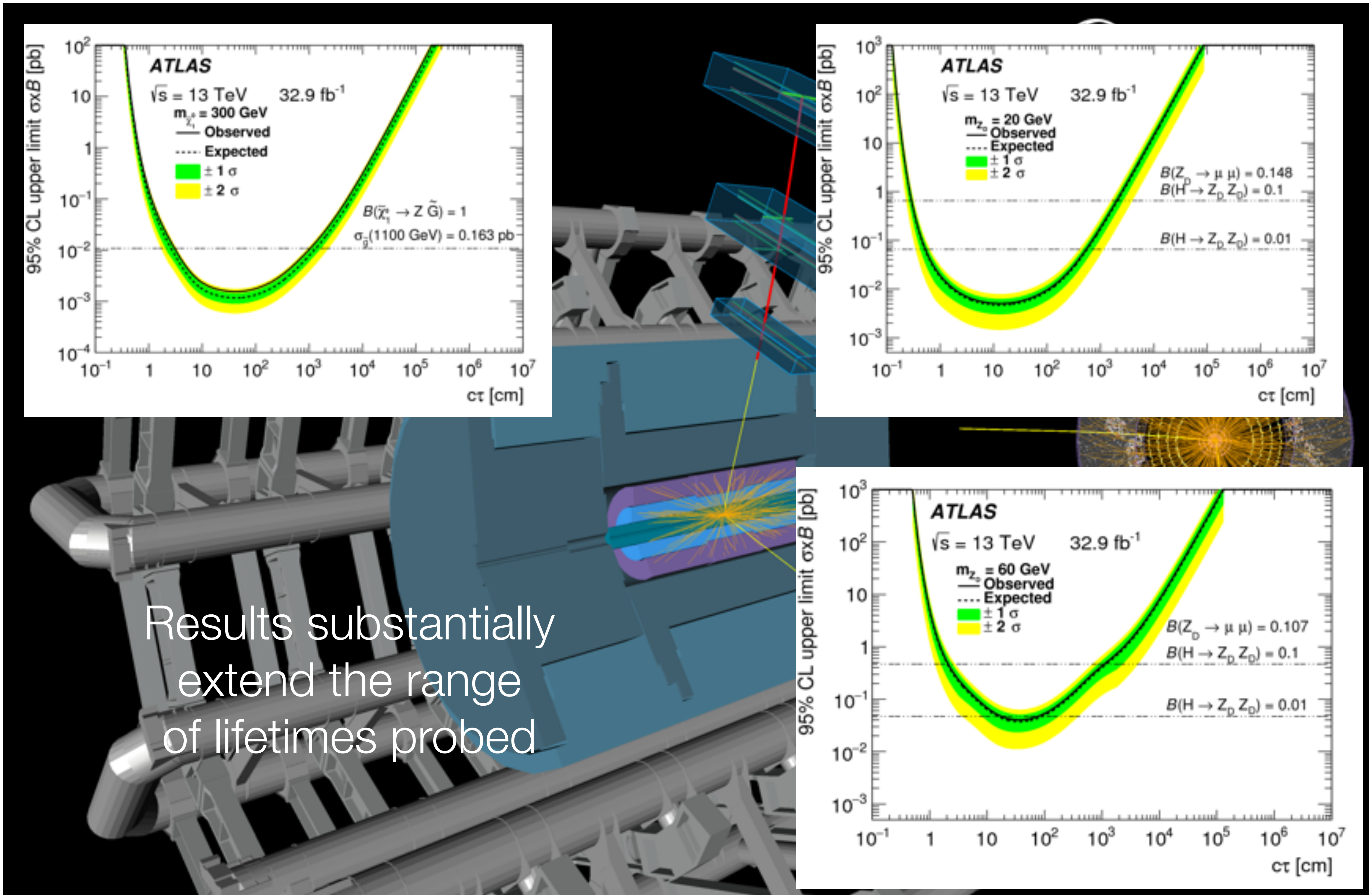
signal region (OS)=
$N_A^{non\text{-}prompt} + N_A^{prompt}$

Yield	SR_{low}	SR_{high}
$N^{non\text{-}prompt}$	13.6 ± 4.9	$0.0\,^{+1.4}_{-0.0}$
N^{prompt}	0.1 ± 0.2	0.50 ± 0.07
N^{bkgd}	13.8 ± 4.9	$0.50\,^{+1.42}_{-0.07}$
N^{obs}	15	2

Results

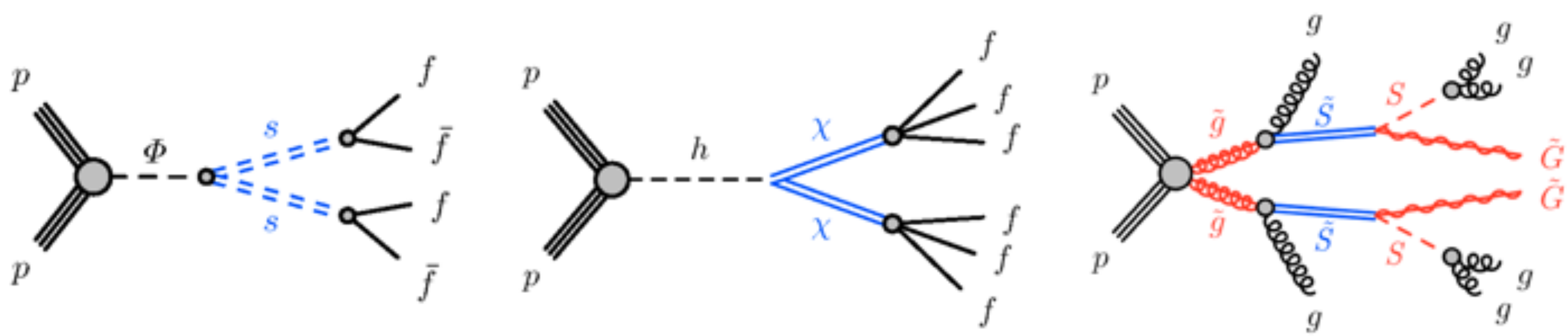

ATLAS
EXPERIMENT
Run: 302265
Event: 18449422
2016-06-17 02:10:00 CEST
r_{vtx}=2.2 cm,
z_{vtx}=-8.2 cm,
m=21 GeV

Results

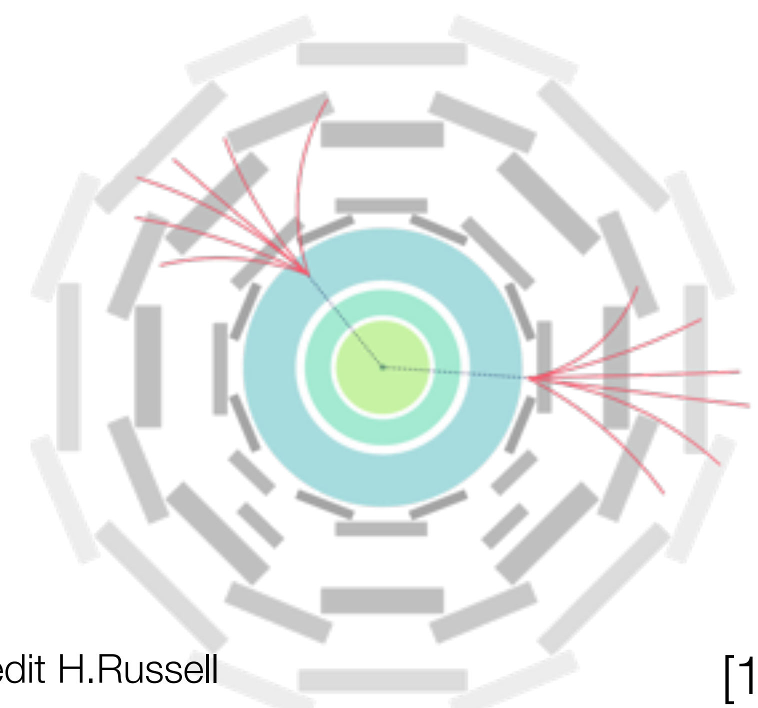

95% CL upper limit σxB [pb]
ATLAS
√s = 13 TeV 32.9 fb-1
Observed
Expected
± 1 σ
± 2 σ
cτ [cm]
B(Z_D → μ μ) = 0.148
B(H → Z_D Z_D) = 0.1
B(H → Z_D Z_D) = 0.01
m_ZD = 20 GeV
m_ZD = 60 GeV
B(Z_D → μ μ) = 0.107
σ(1100 GeV) = 0.163 pb
m = 300 GeV
Results substantially
extend the range
of lifetimes probed

Search for long-lived particles that decay to displaced hadronic jets in the ATLAS muon spectrometer

sensitive to scalar hidden sectors, or stealth susy (no missing energy)



significantly extends the mean proper lifetime (cτ) range of the ATLAS search for a light scalar boson decaying into long-lived neutral particles [1] and extends the range of excluded proper lifetimes [2]. Focuses on Muon Spectrometer (MS) muons

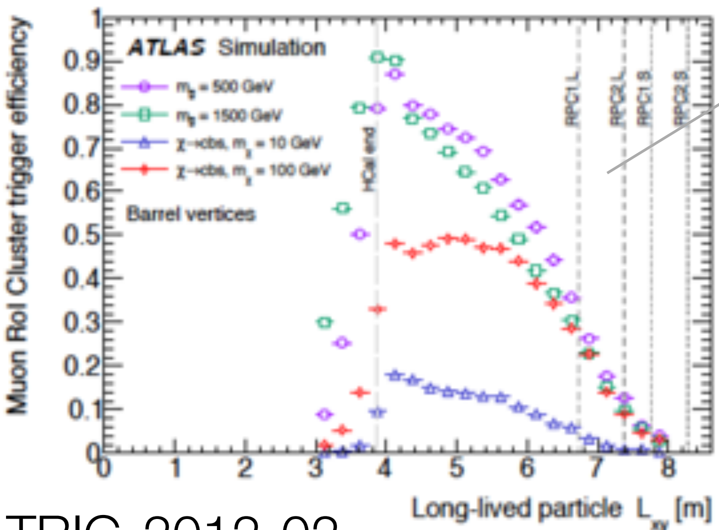


credit H.Russell

Strategy	Basic event selection	Benchmarks
2MSVx	At least 2 MS vertices	Scalar portal, Higgs portal baryogenesis, Stealth SUSY
1MSVx+Jets	Exactly 1 MS vertex At least 2 jets with $E_T > 150$ GeV	Stealth SUSY
1MSVx+E_T^{miss}	Exactly 1 MS vertex $E_T^{miss} > 30$ GeV	Scalar portal with $m_\Phi = 125$ GeV, Higgs portal baryogenesis

[1] https://arxiv.org/abs/1504.03634 [2] https://arxiv.org/abs/1501.04020

Selection and backgrounds



TRIG-2012-02

Event passes Muon RoI Cluster trigger	
Event has a PV with at least two tracks with $p_T > 400$ MeV	
Event has at least one MS vertex	
MS vertex matched to triggering muon RoI cluster (ΔR(vertex, cluster) < 0.4). For 2MSVx strategy: in the case of 2 muon RoI clusters, the second vertex should be matched to the second cluster.	
$300 \leq n_{\text{MDT}} < 3000$	
Barrel	***Endcaps***
MS vertex with $\lvert\eta_{\text{vx}}\rvert < 0.7$ $n_{\text{RPC}} \geq 250$	MS vertex with $1.3 < \lvert\eta_{\text{vx}}\rvert < 2.5$ $n_{\text{TGC}} \geq 250$

2MSVx:
vtx's isolated
from tracks
and jets

1MSVx+jets:
vtx isolated
from tracks
and jets, 2 jets
$p_T > 150$ GeV

1MSVx+MET:
vtx isolated
from tracks
and jets, MET>30 GeV,
$|\Delta\phi(\text{MET,MSVx})| < 1.2$

background determination:

2MSVx

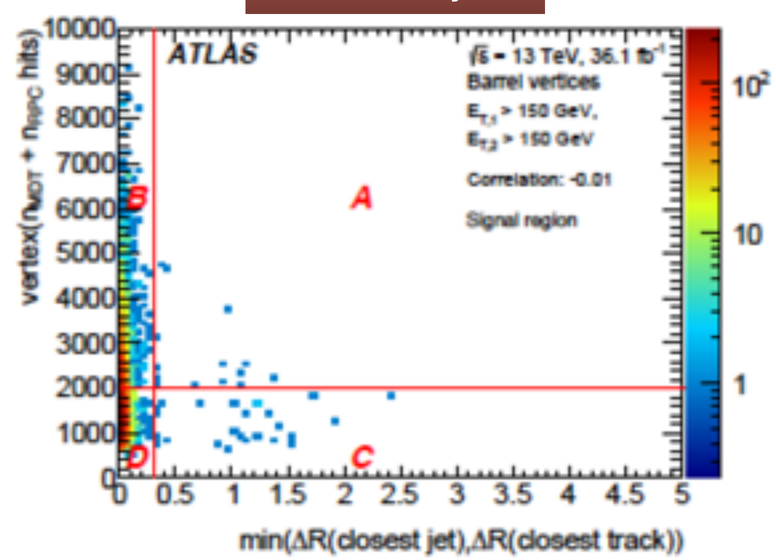
predicted background
with two MSVx

$$N_{2\text{Vx}} = N^{1\text{cl}} \cdot P^{\text{Vx}}_{\text{noMStrig}}$$

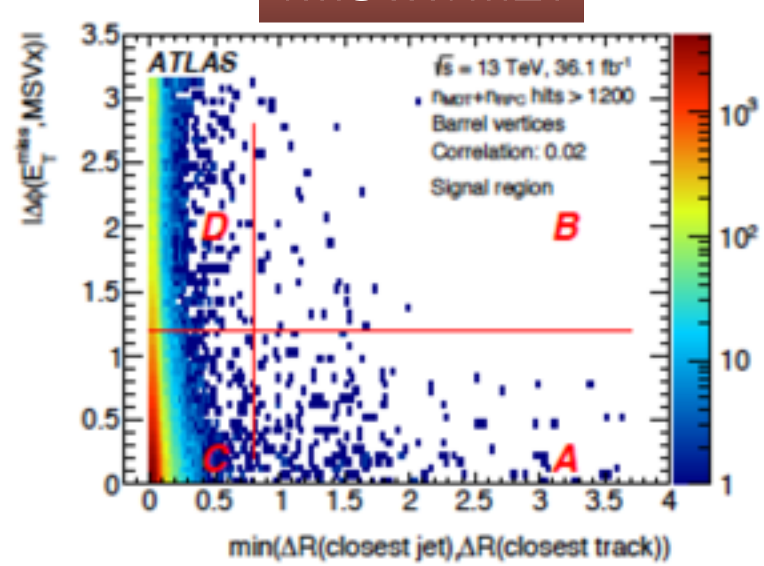
measured
on Muon RoI Cl.
trigger data
with only
one Muon Cl. and
one MSVx

measured
on zero-bias
trigger data
with no Muon Cl. bias
and one MSVx

1MSVx+jets



1MSVx+MET

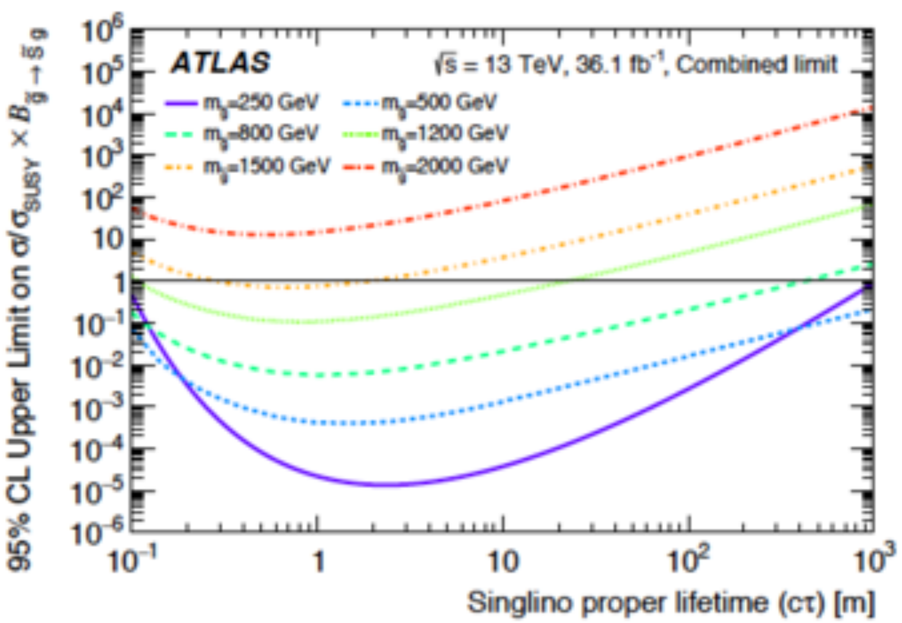


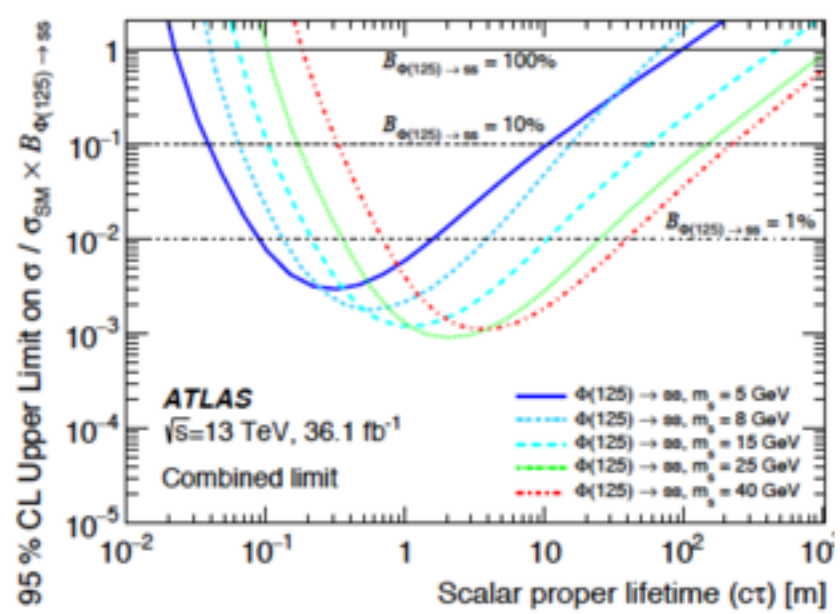
Validation region : SR, invert one jet pT … or invert number MDT+RPC hits

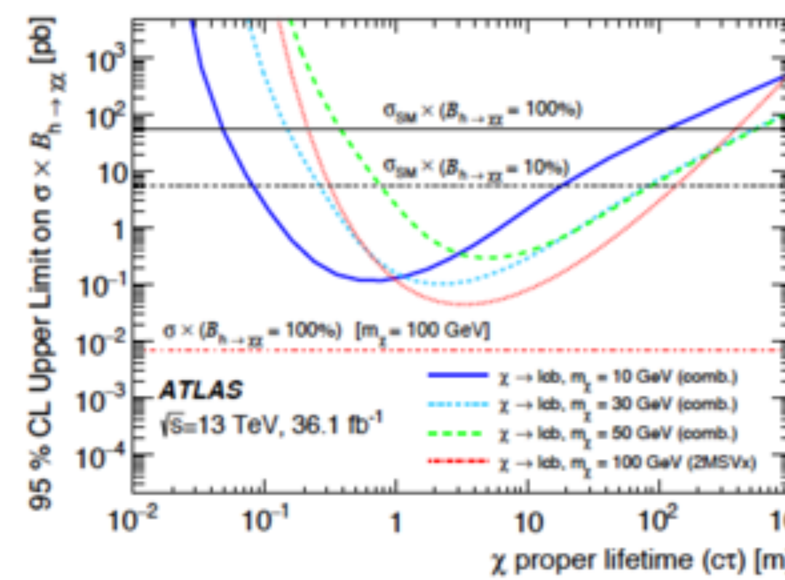
Results

Strategy	Region	A	Expected background	B	C	D
1MSVx+Jets	Barrel	14	15 ± 3 (stat.) ± 3 (syst.)	2, 057	25	3, 414
	Endcaps	4	11 ± 3 (stat.) ± 9 (syst.)	560	15	761
1MSVx+$E_{\mathrm{T}}^{\mathrm{miss}}$	Barrel	224	243 ± 38 (stat.) ± 29 (syst.)	42	132,000	22,800
	Endcaps	489	497 ± 51 (stat.) ± 30 (syst.)	94	165,800	31,390

2MSVx :
0 observed, 0.027±0.011 expected







Improves the cross-section sensitivity for some of the Φ → ss decays by about an order of magnitude compared to the ATLAS Run 1 result.

Extends the sensitivity for the Stealth SUSY model to higher gluino masses that could not be reached with ATLAS Run 1 result.

Conclusions

There are extraordinary beyond Standard Model physics observations : dark matter, baryogenesis, neutrino oscillations. The origin of these phenomena are the big questions in particle physics now.

We are at the start of an era where theory does not provide clear guidelines to the answers, only wide and unconventional experimental searches can. To quote J. Beacham: *The nightmare scenario at the LHC is not no-new-physics; it's : "You didn't keep the right events and didn't do the right searches." We must reduce this chance to as small as possible.*

ATLAS is expanding more and more the range of searches for new physics, starting at the trigger level, focusing on high mass and on low mass and low interaction strength scenarios. New peculiar characteristics, such as long-lived particles, are receiving a renewed focus.

First results on Run-2 partial dataset are presented. They extend results from Run-1 notably in all cases. Three times more Run-2 data are still to be analyzed. They will certainly bring exciting updates!