Searching for Dark Matter and Heavy Neutral Leptons with the ATLAS detector

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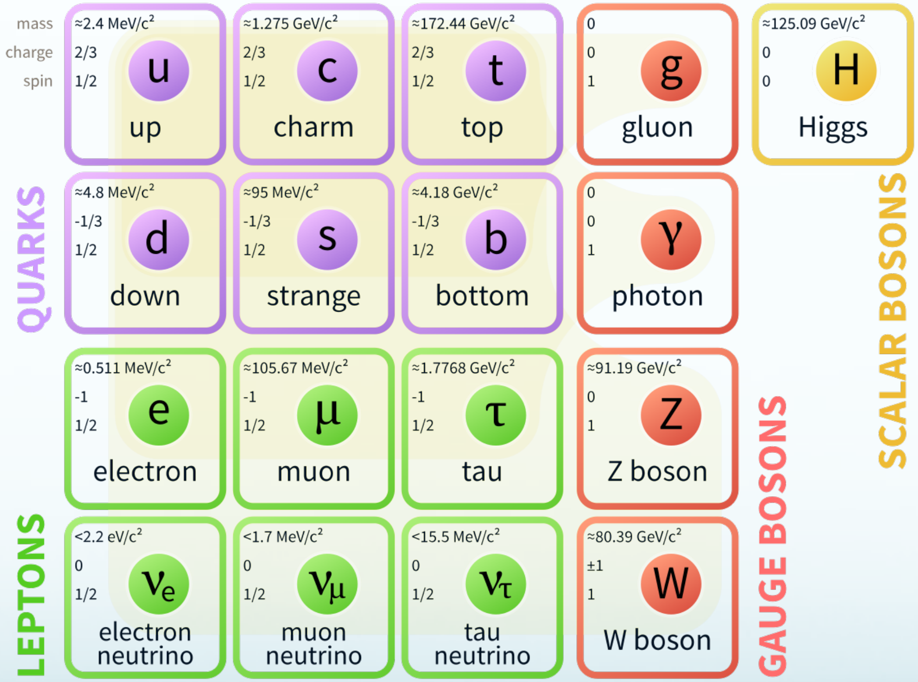
Outline

- ✓ Motivation
- ✓ LHC
- ✓ The ATLAS detector
- ✓ Some Dark matter searches
- ✓ Heavy neutral Lepton searches
- ✓Conclusions

Motivation

While the Standard Model is in excellent agreement with the LHC measurements



	mass charge spin	≈2.4 MeV/c^2 2/3 1/2 u up	≈1.275 GeV/c^2 2/3 1/2 c charm	≈172.44 GeV/c^2 2/3 1/2 t top	0 0 1 g gluon	≈125.09 GeV/c^2 0 0 H Higgs
QUARKS		≈4.8 MeV/c^2 -1/3 1/2 d down	≈95 MeV/c^2 -1/3 1/2 s strange	≈4.18 GeV/c^2 -1/3 1/2 b bottom	0 0 1 γ photon	SCALAR BOSONS
		≈0.511 MeV/c^2 -1 1/2 e electron	≈105.67 MeV/c^2 -1 1/2 μ muon	≈1.7768 GeV/c^2 -1 1/2 τ tau	≈91.19 GeV/c^2 0 1 Z Z boson	
LEPTONS		<2.2 eV/c^2 0 1/2 ν_e electron neutrino	<1.7 MeV/c^2 0 1/2 ν_μ muon neutrino	<15.5 MeV/c^2 0 1/2 ν_τ tau neutrino	≈80.39 GeV/c^2 ±1 1 W W boson	GAUGE BOSONS

Motivation

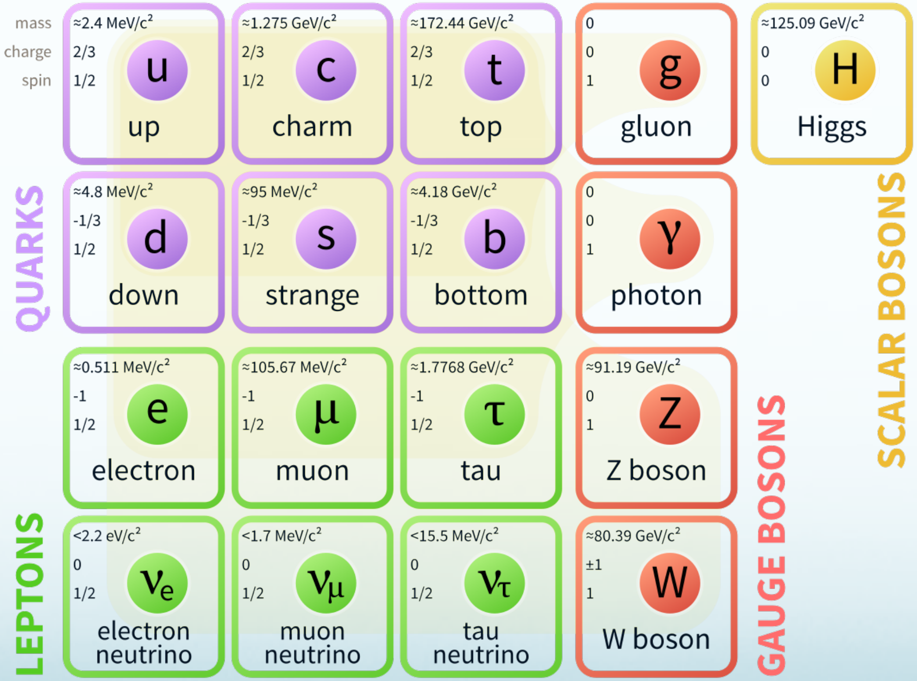
Many questions still unanswered

The solution to the hierarchy problem

Origin of Dark Matter

Neutrino oscillations and neutrino masses

Lepto-quarks
Vector-like quarks
Compositeness

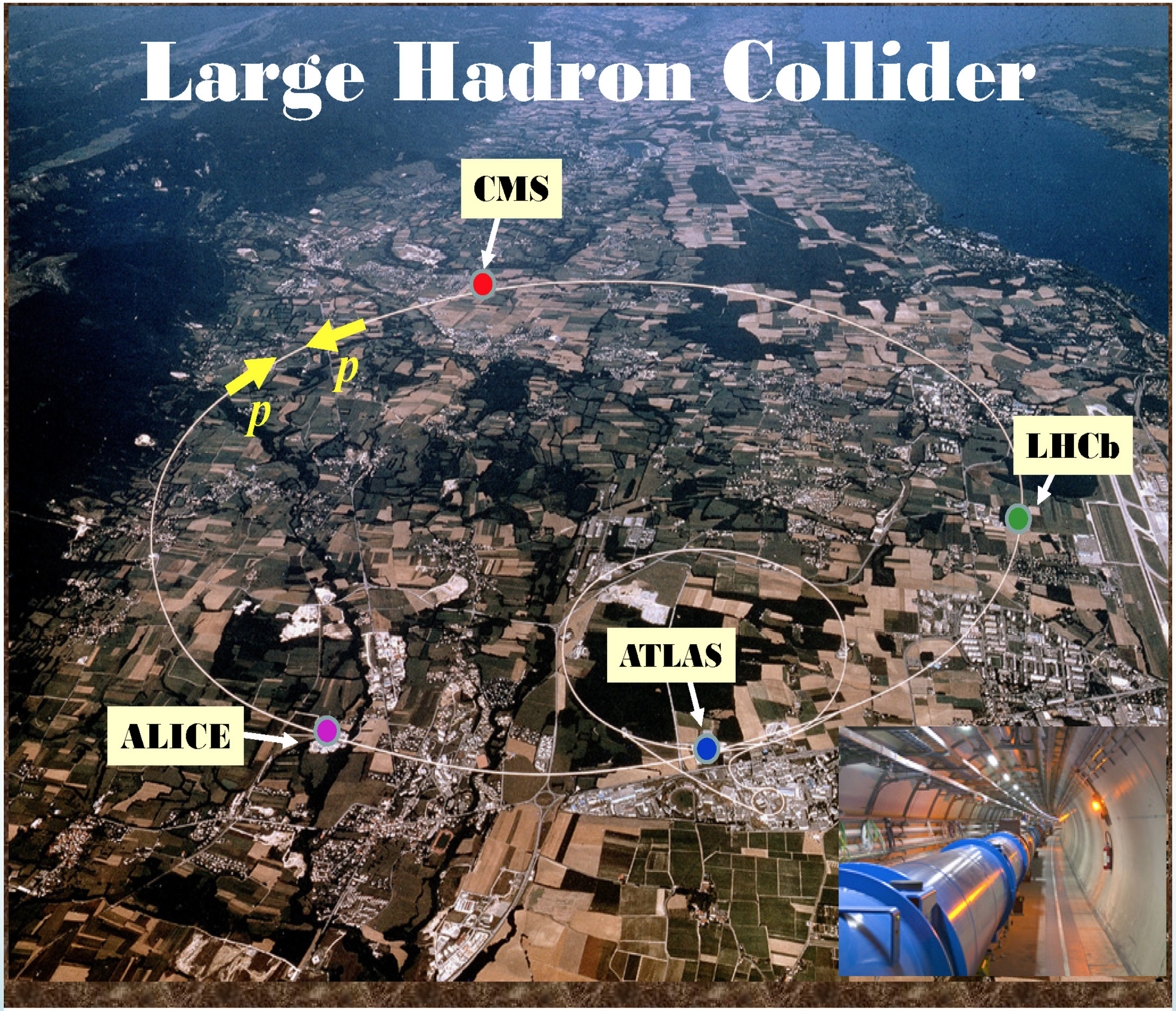


Non minimal Higgs sector

Heavy Neutral Leptons linked to neutrino masses

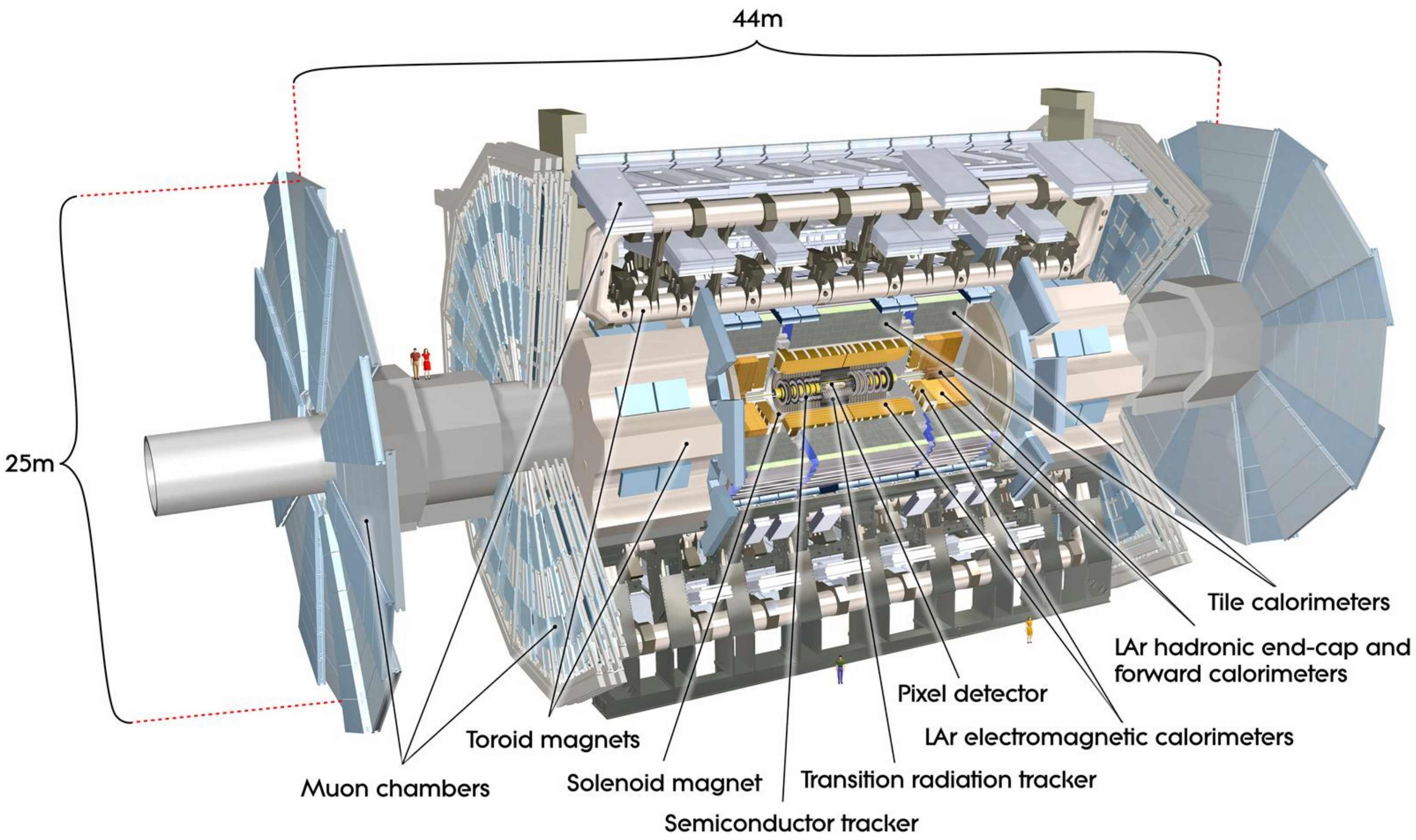
Heavy vector Bosons W′, Z′

The LHC



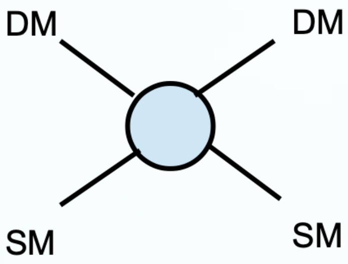
With 13 TeV energy in the c.m. , the LHC offers the best scenario for searching a large variety of signals.

The ATLAS detector



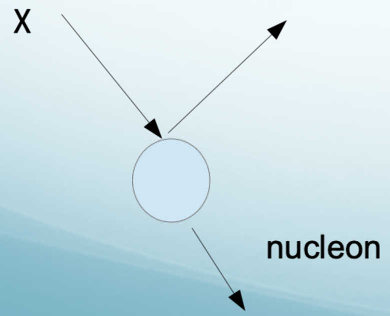
Dark Matter searches

Direct detection

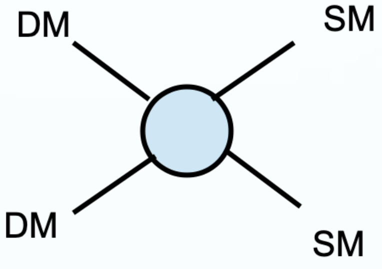


Elastic scattering on detector nuclei
In the lab

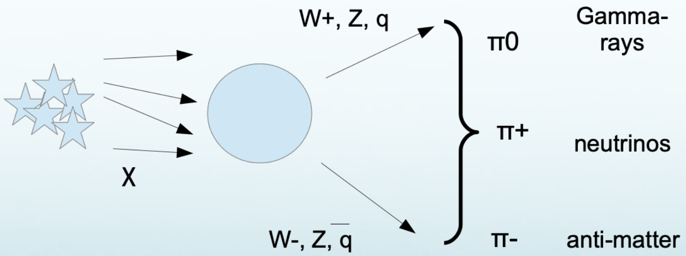
$$\chi + N \rightarrow \chi + N$$



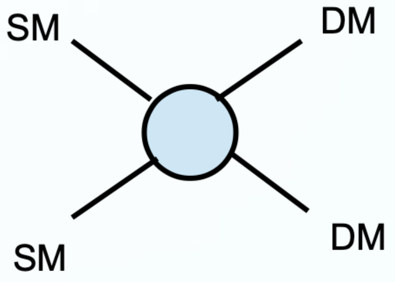
Indirect detection

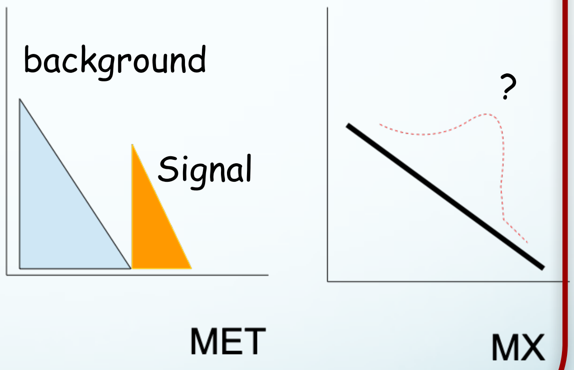


Annhilation products from gamma-rays
and antimatter



Colliders





Dark Matter Models

- ✓ Simplified models: a new particle (or particles) mediates the interaction of DM and SM particles.

X + MET

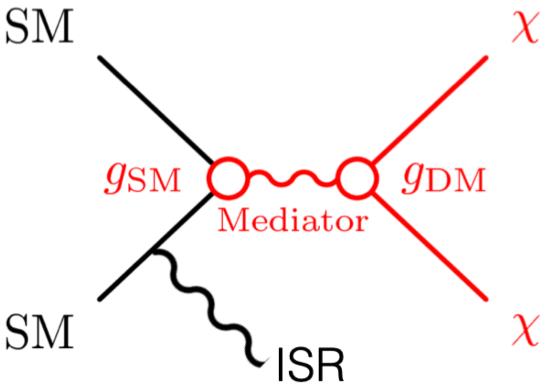
Deviation from SM background

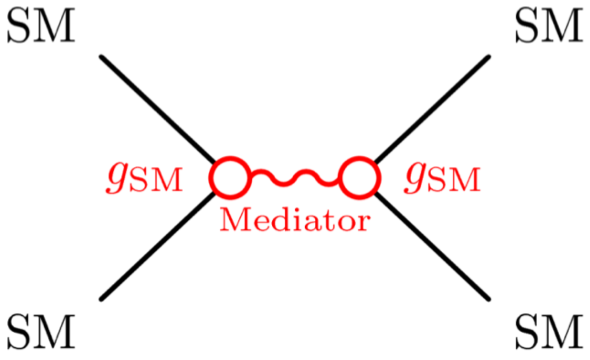
Resonances

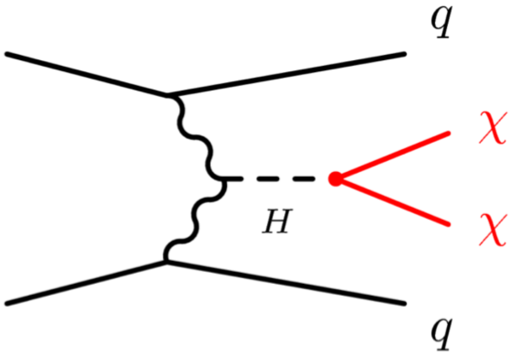
Looking for a bump coming from mediators decaying to fermions

Higgs as mediator

Looking for an enhancement of Higgs to invisible

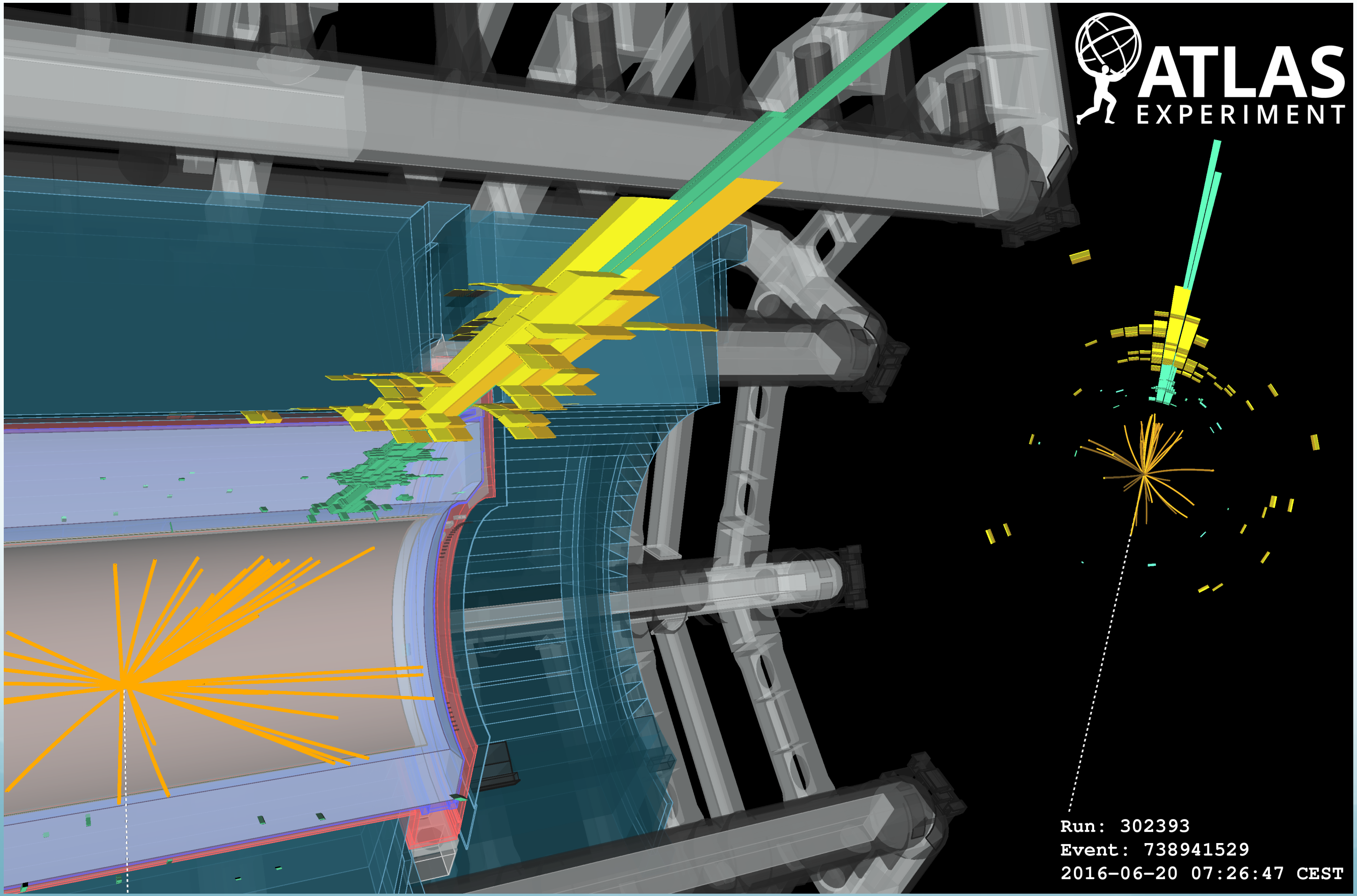






Dark Matter searches: X + MET

- ✓ Invisible final state requires additional particles from ISR or associated production.



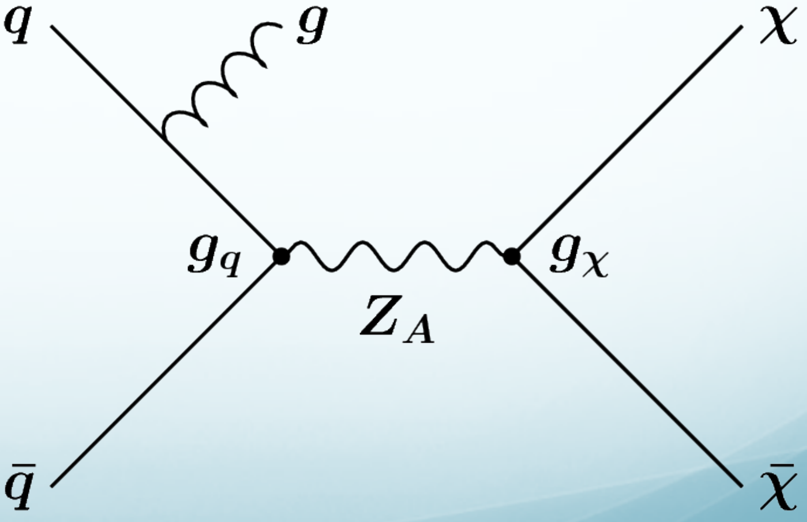
DM becomes visible as ETmiss

Dark Matter searches: Jet + E_T^{Miss}

JHEP 01 (2018) 126

- ✓ Search for events containing an energetic jet and large missing transverse energy.

- ✓ Signal model:
  - Simplified DM models: a new particle mediates the interaction of DM with SM particles.
  - Dirac fermions WIMPs (χ) are pair-produced from quarks via s-channel exchange of:
    - Spin-1 mediator Z_A with axial-vector coupling or
    - Spin-1 mediator Z_V with vector coupling or
    - Spin-0 pseudo scalar Z_P



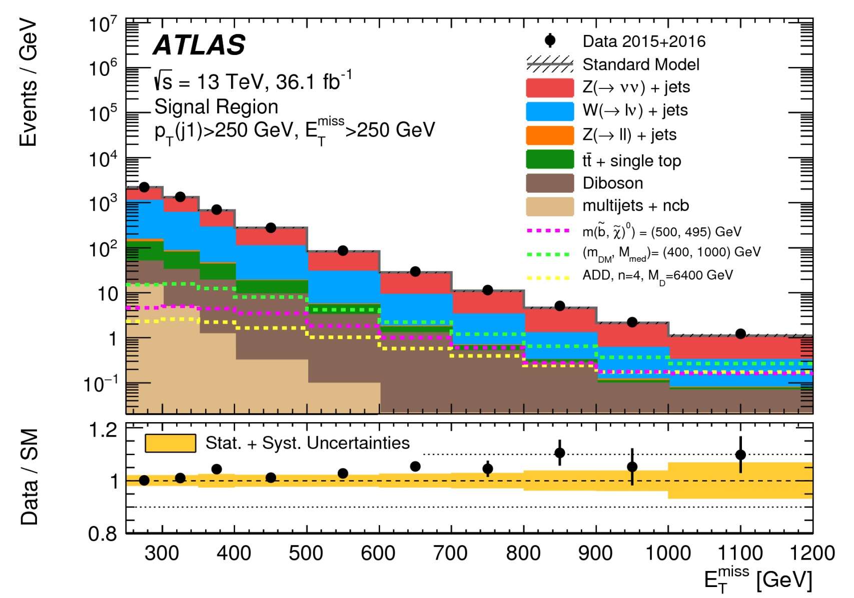
- ✓ Free parameters:

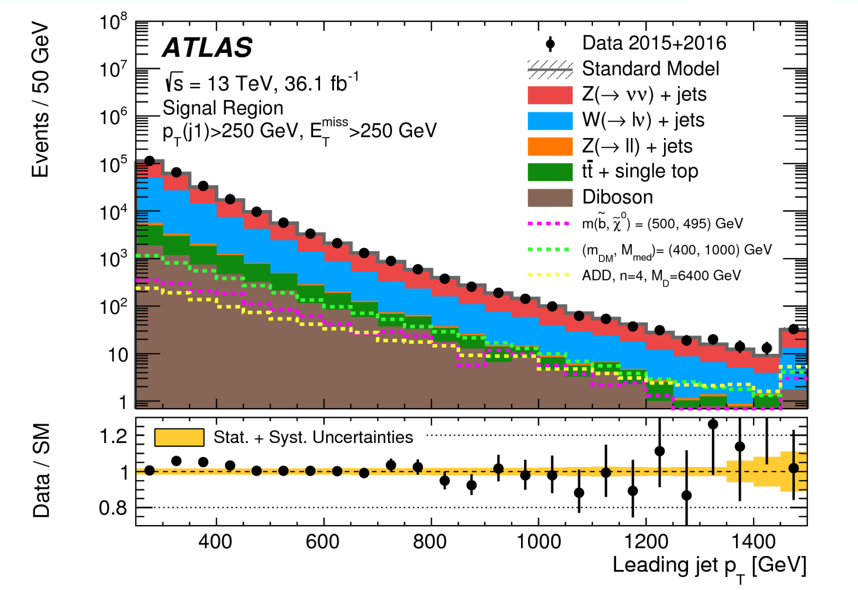
$m_\chi, (m_{Z_A} or m_{Z_V} or m_{Z_P}), g_q, g_\chi$

Dark Matter searches: Jet + E_T^{Miss}

JHEP 01 (2018) 126

- ✓ Dataset: pp collisions recorded during 2015-2016, integrated luminosity of ~ 36 fb^{-1}
- ✓ Event selection:
  - Energetic Jet $p_T > 250$ GeV, $E_T^{Miss} > 250$ GeV, maximum of four jets with $p_T > 30$ GeV and no leptons.
- ✓ Backgrounds:
  - W+jets, Z+jets, top-quark related backgrounds -> estimated with MC samples
  - Diboson (WW/WZ/ZZ) -> estimated from MC samples.
  - Multijets extracted from data.





Dark Matter searches: Jet + E_T^{Miss}

✓ Interpretation in DM production via an axial mediator

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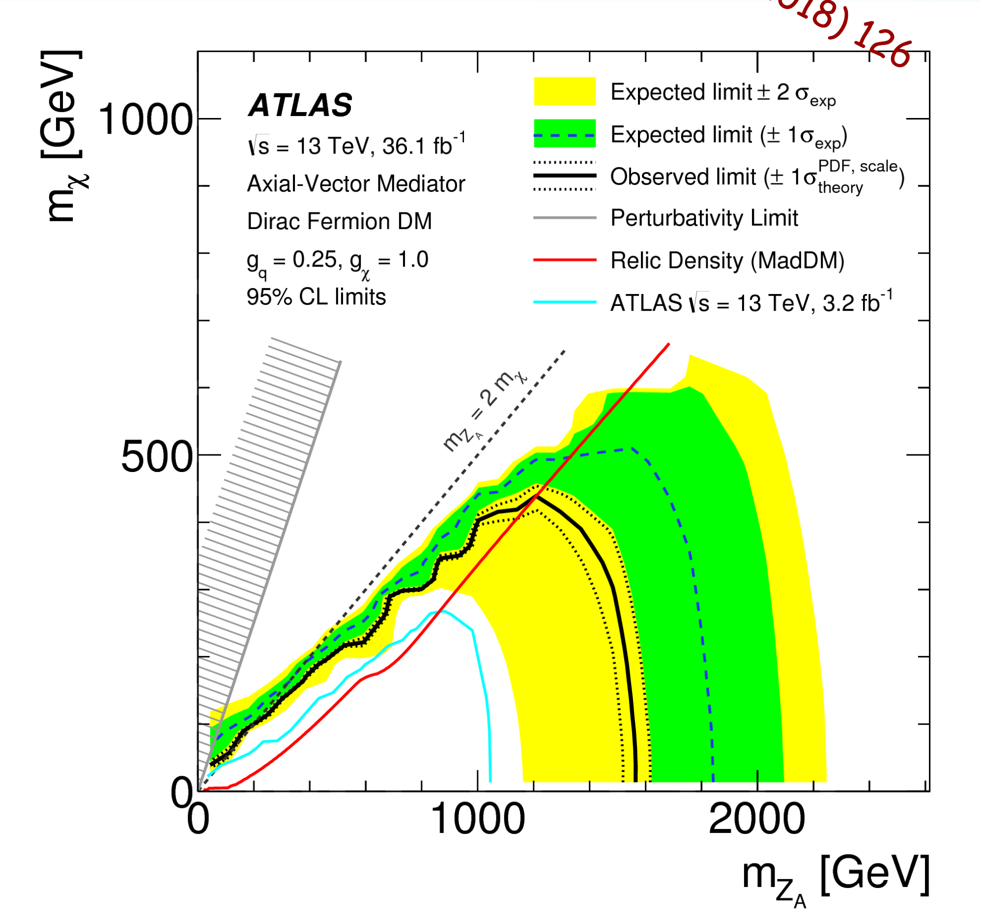


95% CL exclusion contours in the $m_{ZA} - m_{\chi}$ parameter plane for a simplified model with an axial-vector mediator.

In the on-shell regime, models with mediator masses up to 1.55 TeV are excluded for mx = 1 GeV.

Dark Matter searches: h(bb) + MET

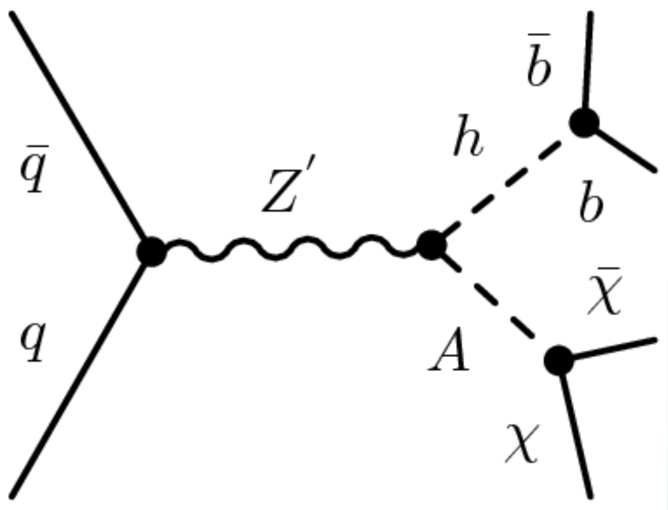
ATLAS-CONF-2018-039

✓ Search for DM produced in association with a Higgs boson h, with h decaying into two b-quarks (most frequent decay, BR of 57%)

✓ Signal model: 2HDM type-II with an additional U(1)$_{Z'}$ gauge symmetry.

✓ Among five physical Higgs boson:

- Light scalar h -> SM Higgs boson
- Pseudo-scalar A, which decays to a pair $\chi\bar{\chi}$



✓ Model parameters:

- m_A, m'_Z, m_χ
- Gauge coupling of Z'
- $tan\beta$: ratio of the vacuum expectation values

of the two Higgs fields coupling to the up- and down-type quarks

Dark Matter searches: h(bb) + MET

✓ Dataset: pp collisions recorded during 2015-2017, integrated luminosity of ~ 80 fb^{-1}.

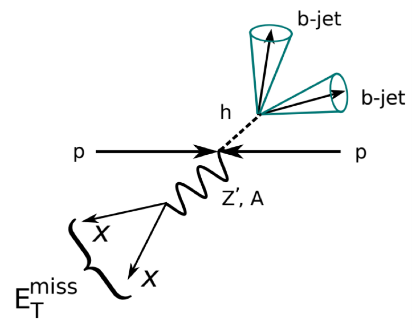
✓ Event selection SR

ATLAS-CONF-2018-039

- $E_T^{Miss} > 150$ GeV, no leptons
- Use Variable Radius track jets (VR) for jet reconstruction
- To suppress multijet background -> azimuthal angle between E_T^{Miss} and any of three highest-pT jets > 20°.

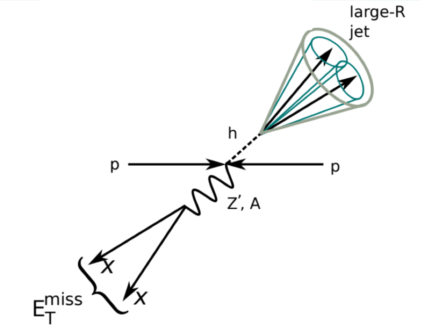
✓ Events are divided into:

- resolved regions with $E_T^{Miss} < 500$ GeV



Exactly two of the jets are required to be b-tagged

- merged region with $E_T^{Miss} > 500$ GeV



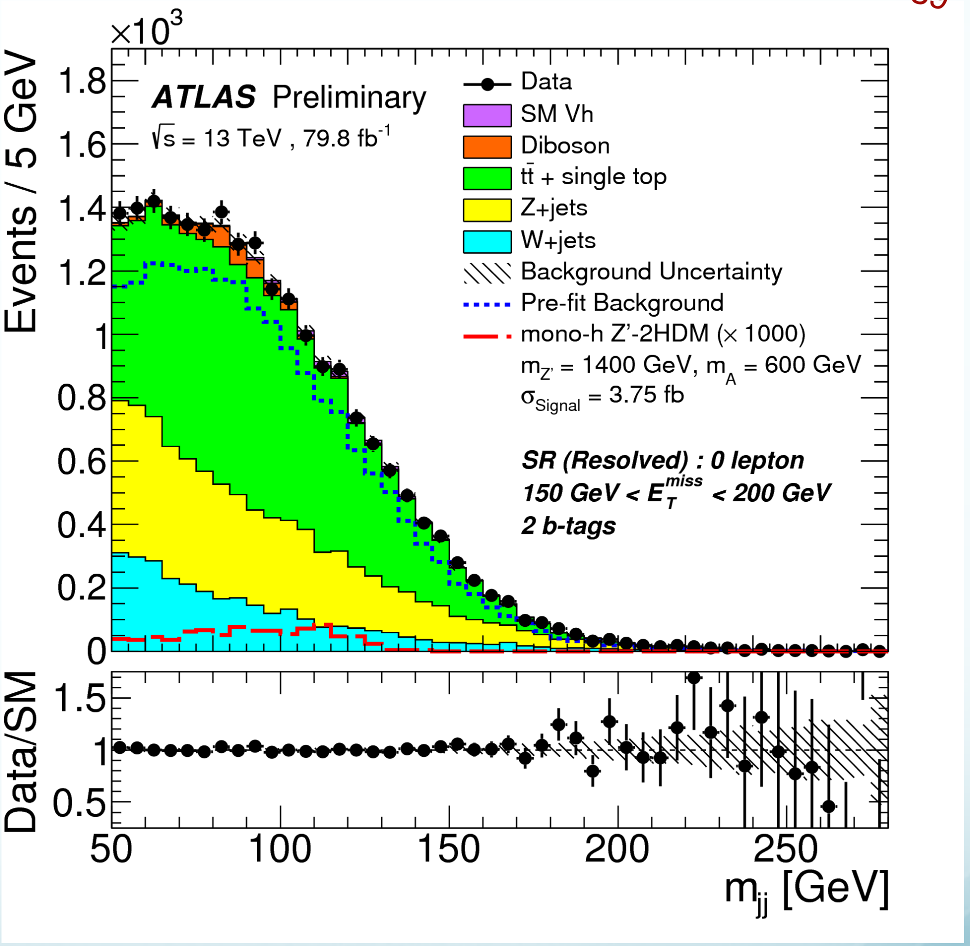
Presence of at least one large-R jet.

Dark Matter searches: h(bb) + MET

ATLAS-CONF-2018-039

✓ Background sources

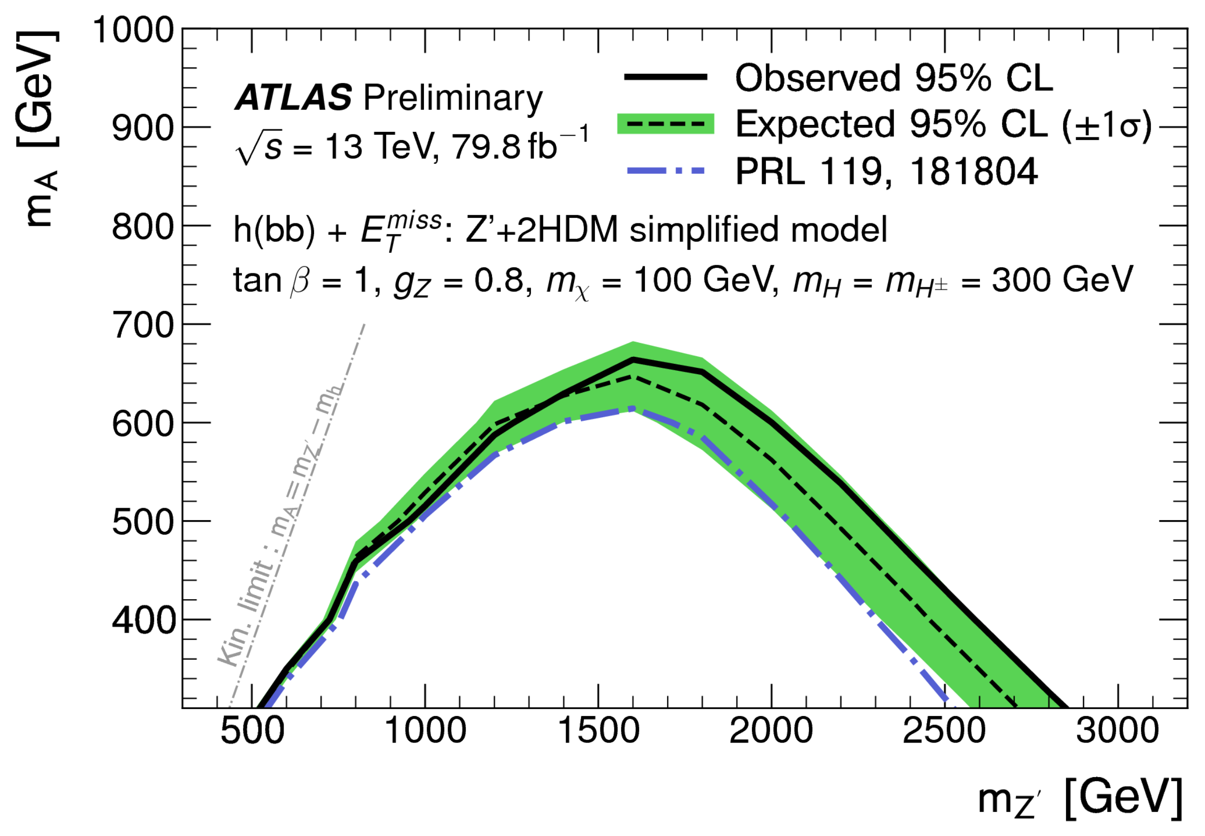
- Main: W+jets, $t\bar{t}$, Z($\nu\nu$) +jets -> estimated through data control samples.
- Subdominant: multijets originated from pure strong interactions in the resolved SR (negligible in the merged SR) -> estimated with data-driven method
- Discriminating variable: mass of the Higgs boson candidate m_h
- Resolved SR: dijet invariant mass m_{jj} of the two leading small-R jets
- merged region : leading large-R jet mass m_J.



Dark Matter searches: h(bb) + MET

ATLAS-CONF-2018-039

- ✓ Exclusion contour in the $(m_{Z'}, m_A)$ space in the Z'-2HDM scenario for
  - $tan\beta = 1$
  - $g_{Z'} = 0.8$
  - $m_\chi = 100$ GeV
  - Observed limits are consistent with the expectation under SM-only hypothesis within uncertainties.

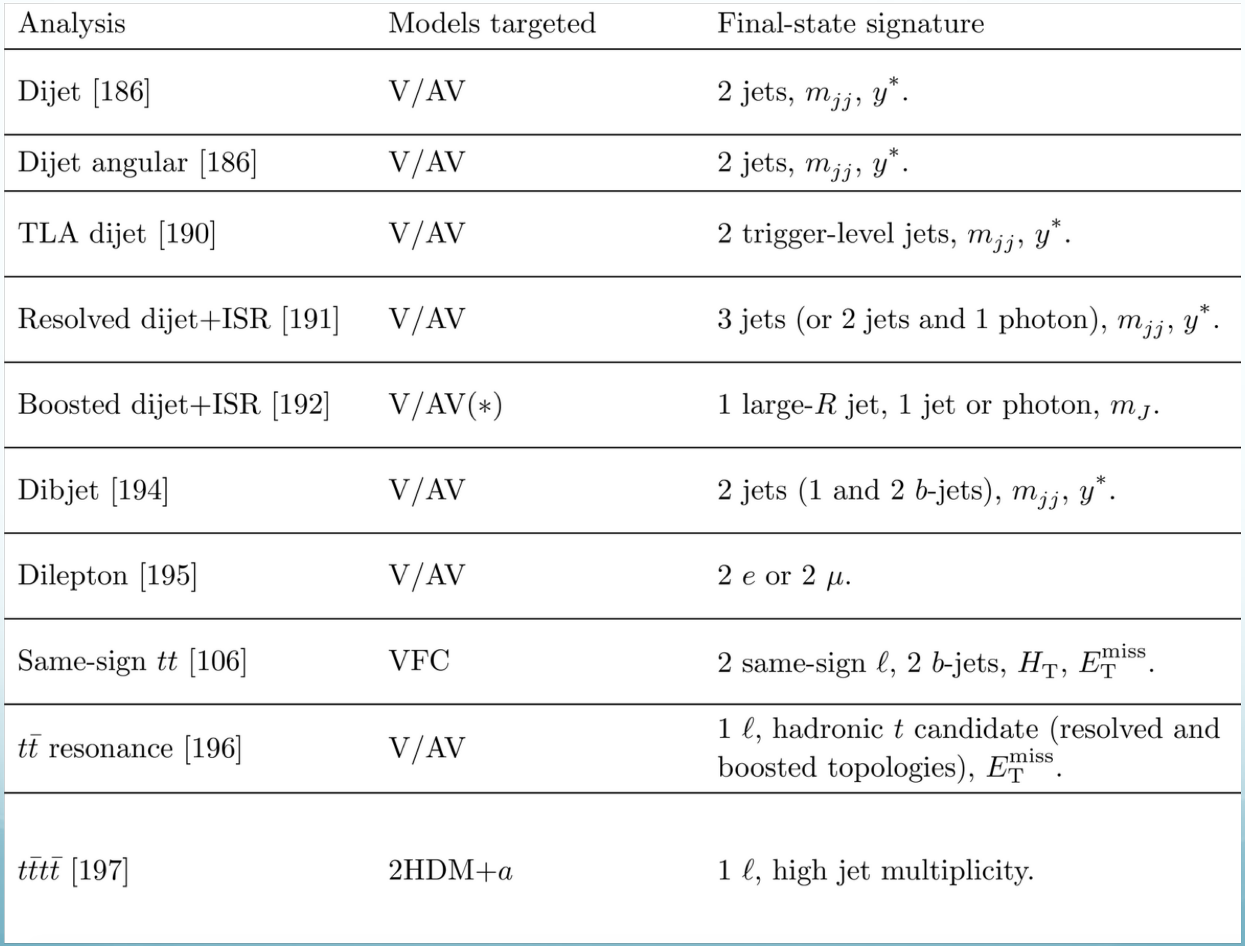


Improvement from using VR track jets

Dark Matter: Resonances

JHEP05 (2019) 142

- ✓ Several searches for narrow resonances are interpreted in terms of DM models
- ✓ Several final-state signatures which select different visible particles.



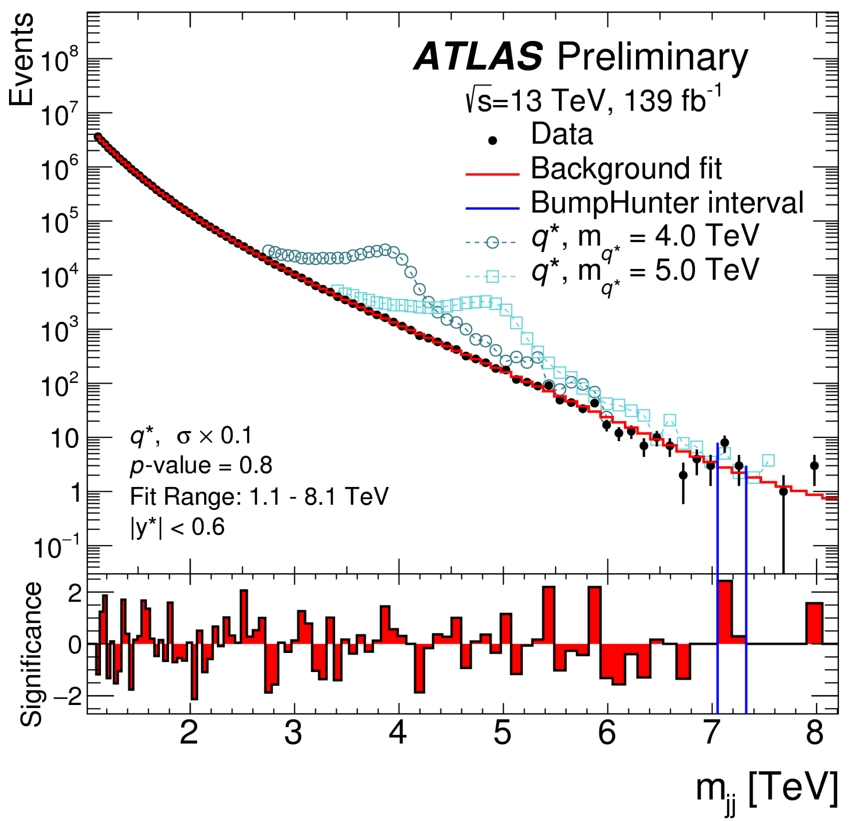
Analysis	Models targeted	Final-state signature
Dijet [186]	V/AV	2 jets, m_{jj}, y^*.
Dijet angular [186]	V/AV	2 jets, m_{jj}, y^*.
TLA dijet [190]	V/AV	2 trigger-level jets, m_{jj}, y^*.
Resolved dijet+ISR [191]	V/AV	3 jets (or 2 jets and 1 photon), m_{jj}, y^*.
Boosted dijet+ISR [192]	V/AV(∗)	1 large-R jet, 1 jet or photon, m_J.
Dibjet [194]	V/AV	2 jets (1 and 2 b-jets), m_{jj}, y^*.
Dilepton [195]	V/AV	2 e or 2 μ.
Same-sign tt [106]	VFC	2 same-sign ℓ, 2 b-jets, H_T, $E_\mathrm{T}^\mathrm{miss}$.
$t\bar{t}$ resonance [196]	V/AV	1 ℓ, hadronic t candidate (resolved and boosted topologies), $E_\mathrm{T}^\mathrm{miss}$.
$t\bar{t}t\bar{t}$ [197]	2HDM+a	1 ℓ, high jet multiplicity.

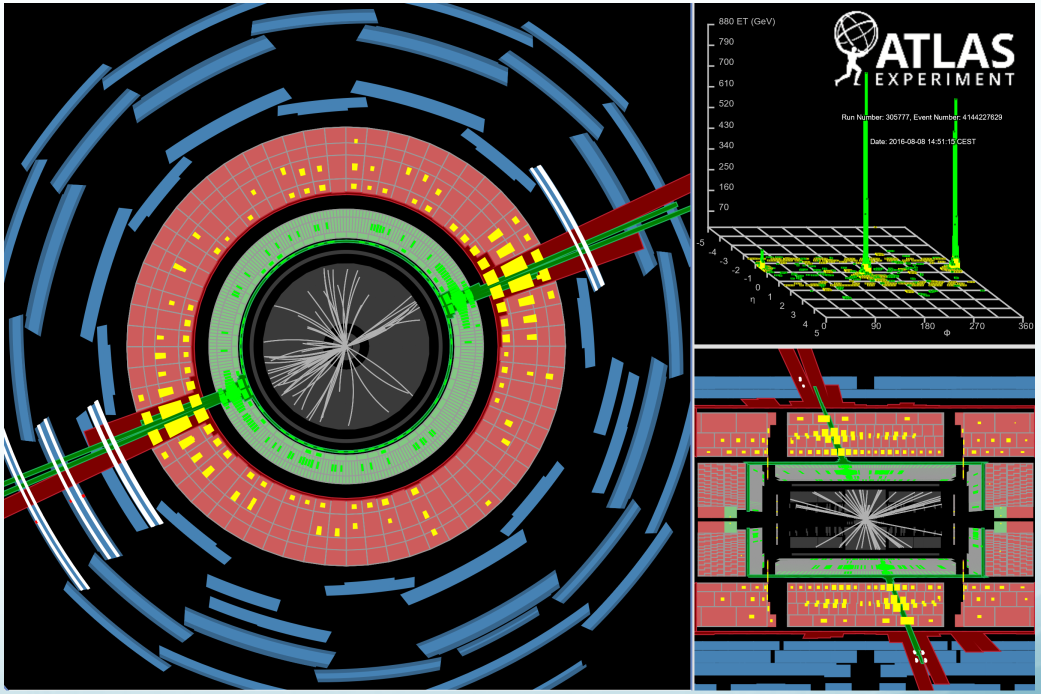
Dark Matter: Dijet

JHEP05 (2019) 142

✓ Search for a new resonant state decaying to two jets :

- Excess in the distribution of the dijet invariant mass m_{jj} localized near the mass of the resonance.





Dark Matter: Dijet

JHEP05 (2019) 142

✓ Dataset: pp collisions recorded during 2015-2016, integrated luminosity of ~ 37 fb^{-1}.

✓ Event Selection:

- Events with at least two small-R jets with $p_T > 440(60)$ GeV for leading (subleading) jets.
- Rapidity difference |y*|< 0.6 (reduces the QCD background)
- Invariant mass of dijet m_{jj} > 1.1 TeV

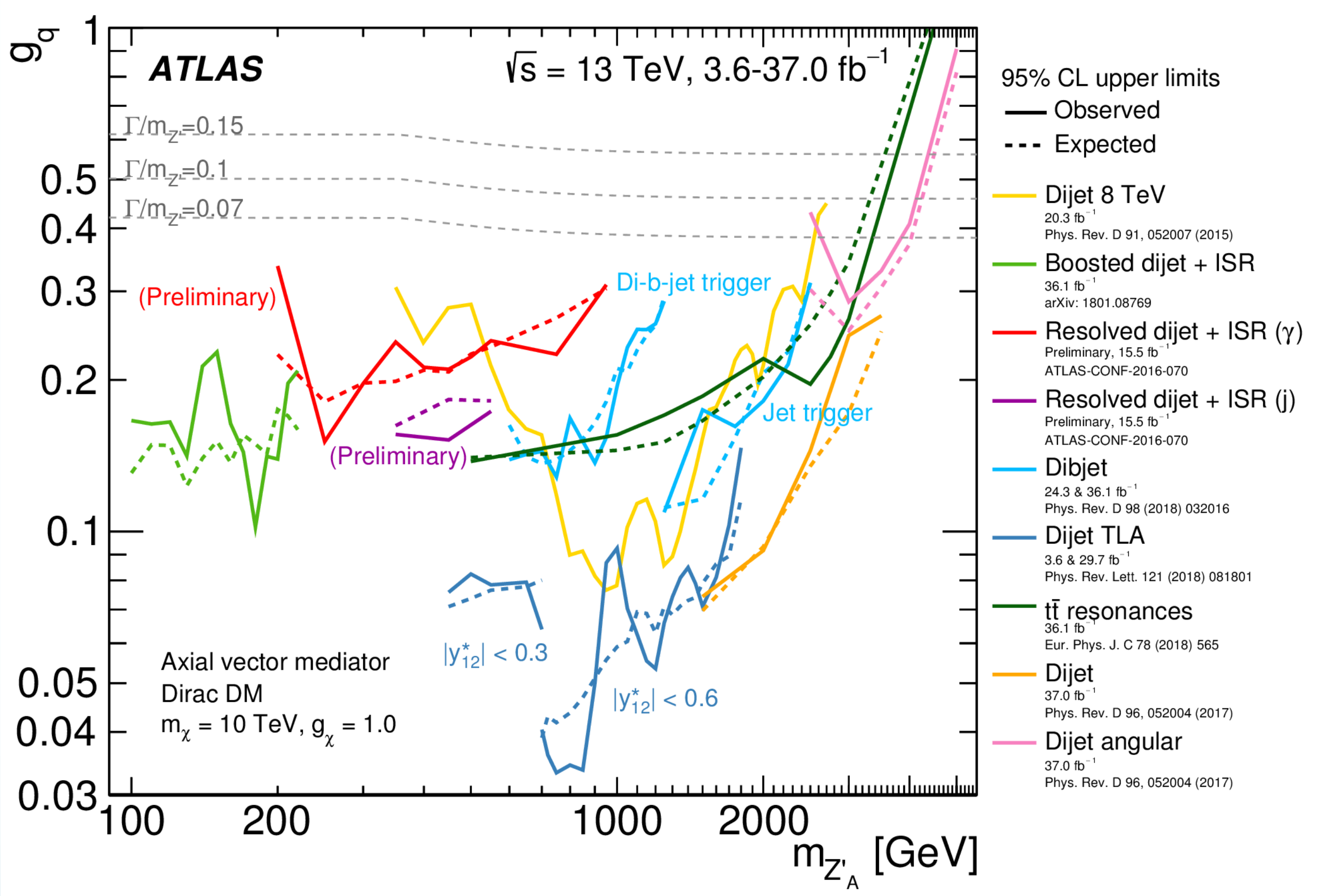
✓ Backgrounds:

- Multijet production described by QCD -> estimated from MC simulations for the angular distributions and from data for the invariant mass distribution.

Dark Matter: Dijet

JHEP05 (2019) 142

- ✓ Dijet search contours for 95% CL upper limits on the coupling g_q as a function of resonance mass $m_{Z'_A}$.
- ✓ Each resonance search analysis is sensitive to complementary regions of mass-coupling parameter space.
- ✓ Couplings above exclusion lines are excluded.



Dark Matter: Higgs to invisible

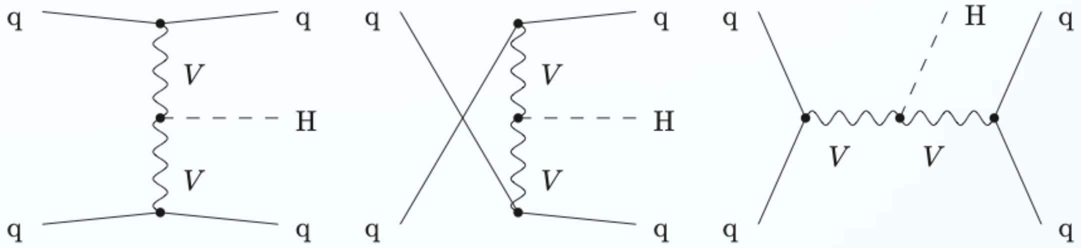
Phys. Rev. Lett. 122 (2019) 231801

✓ 125 GeV Higgs boson H acts as portal between a dark sector and the SM sector

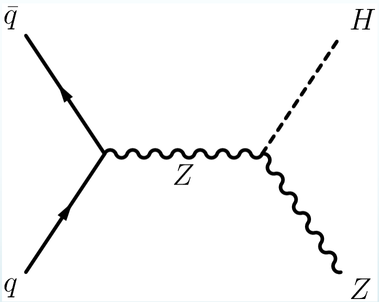
✓ Decays of H to DM particles represent a distinct signature in these models -> indirectly inferred through E_T^{Miss} (invisible).

✓ Different topologies assuming SM production rates:

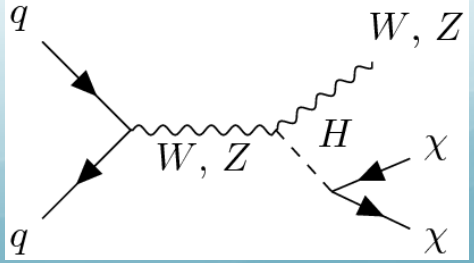
◉ VBF topology



◉ Z(lep)H topology: Z decays to leptons



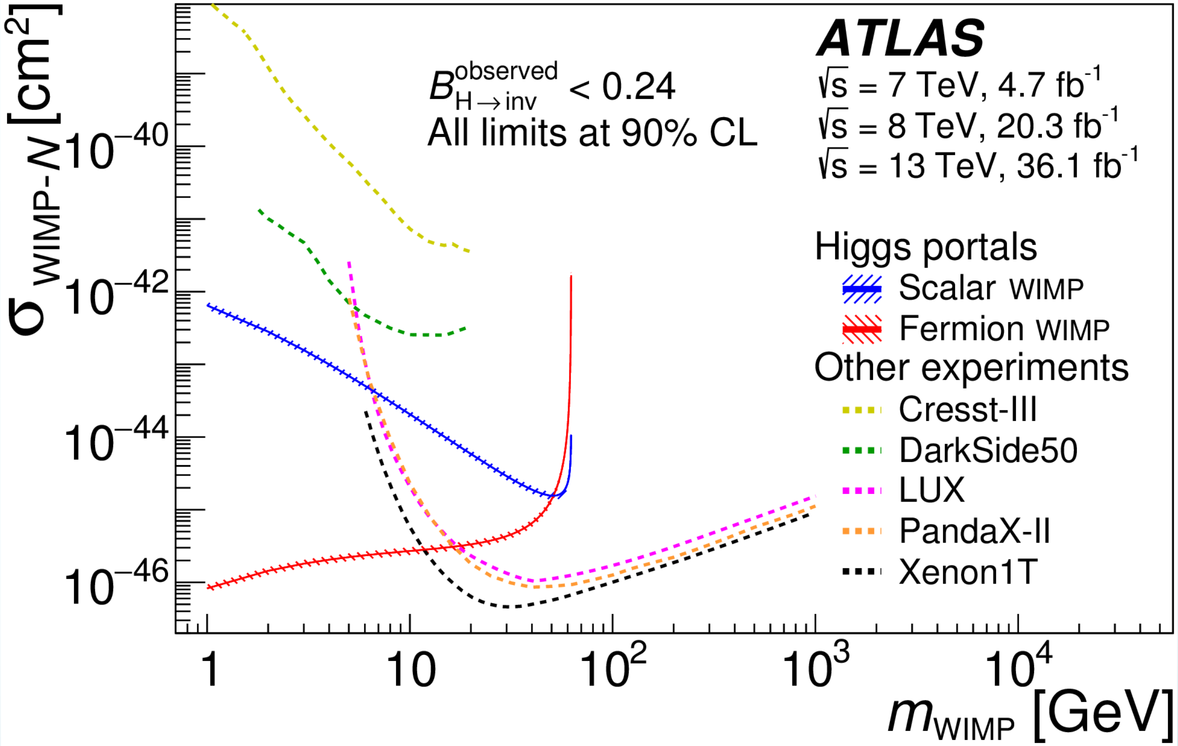
◉ V(had)H topology: W or Z decay hadronically



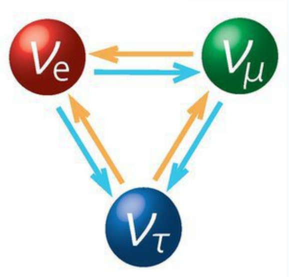
Dark Matter: Higgs to invisible

- ✓ Comparison of the upper limits at 90% CL from direct detection experiments on Wimp-nucleon scattering cross section to this analysis observed exclusion limits.
- ✓ The excluded σ_{WIMP-N} values range down to 2 x 10^{-45}cm^2 in the scalar scenario.
- ✓ In the fermion WIMP case, σ_{WIMP-N} values down 10^{-46} cm^2 are excluded.

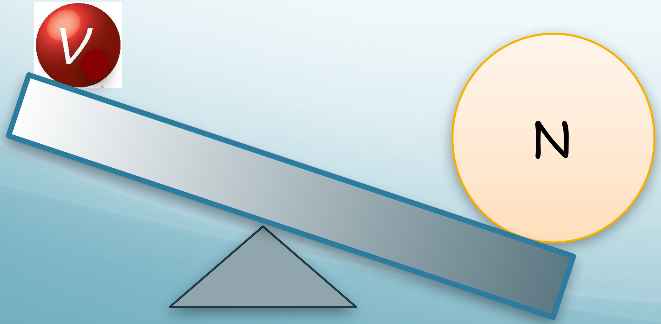
Phys. Rev. Lett. 122 (2019) 231801



Heavy neutrinos



- ✓ Neutrinos in the SM are massless.
- ✓ Neutrino oscillation observations show that they have non-zero masses -> neutrinos are "light" with masses < 1 eV (compared to the other massive fundamental particles).
- ✓ See-saw mechanism can explain the small neutrino masses:
  - Idea: introduce right-handed neutrinos in the Standard Model which have very heavy masses.
  - A left-handed neutrino converses spontaneously in the right-handed for a brief moment, before reverting back to being a left-handed neutrino again.



- This results in the very small observed mass for the left-handed neutrino -> its smallness being associated with the heaviness of the right-handed neutrino

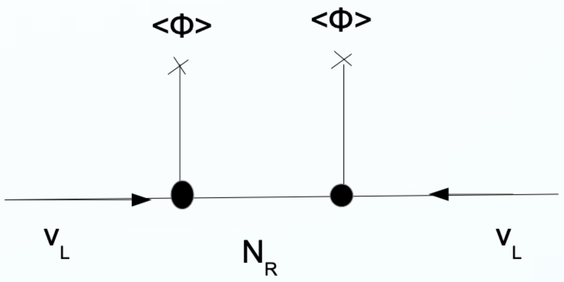
Heavy neutrinos

✓ Type-1 Seesaw mechanism

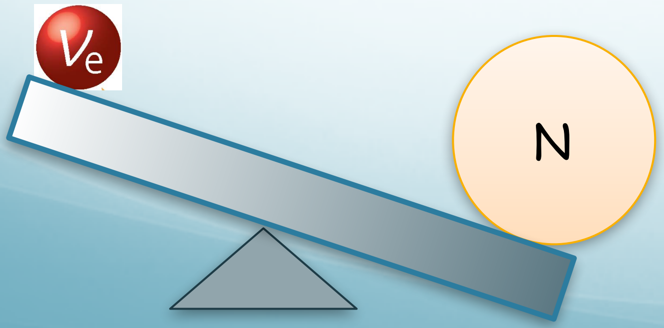
- Introduce right-handed neutrinos (Majorana-type) into the SM with heavy masses.

$$L_Y = H_\nu \overline{L} H N_R + M_R N N$$

$$m_\nu \sim - \frac{h_\nu^2 < \phi >^2}{M_R}$$



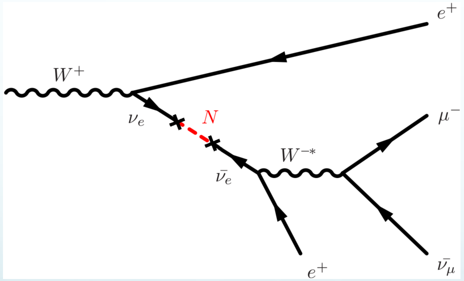
- HNL could generate the observed amount of baryon asymmetry through leptogenesis and would be a valid dark-matter candidate.

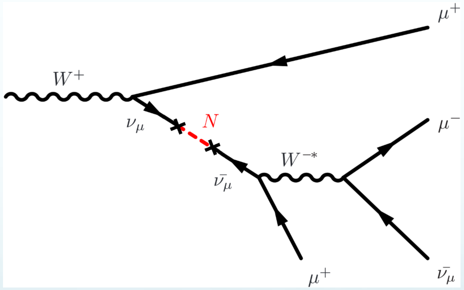


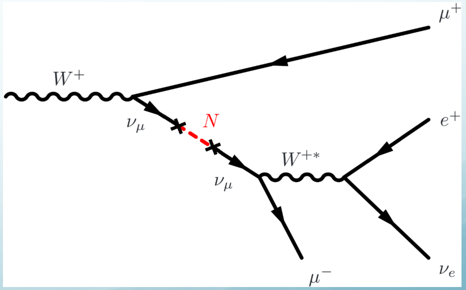
Heavy neutrinos

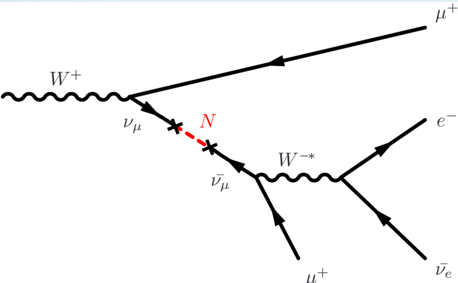
arXiv:1905.09787, Accepted by JHEP

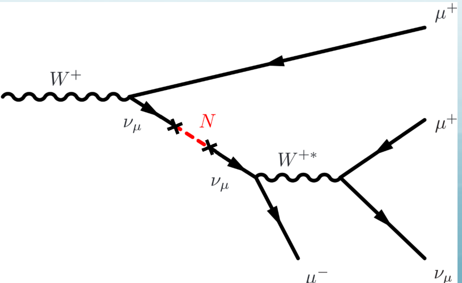
- ✓ HNL masses > 5 GeV can be accessed directly through the decays of W, Z or H bosons.
- ✓ This search: W bosons exclusively decaying into a muon or electron and an HLN
- ✓ Two distinct experimental signatures have been designed to probe both short or long HNL lifetimes:
  - Prompt signature: three leptons originating from the interaction point (IP), two muons and an electron or two electrons and one muon, with same flavor leptons of same charge.
  - Displaced signature: prompt muon accompanied by a vertex significantly displaced from IP, formed by either two muons or a muon and an electron.











Signal Model

arXiv:1905.09787, Accepted by JHEP

- ✓ HNL production

$$\sigma(pp \to W) \cdot B(W \to \ell N) = \sigma(pp \to W)B(W \to \ell\nu) \cdot |U^2|(1 - \frac{m_N^2}{m_W^2})^2(1 + \frac{m_N^2}{m_W^2})$$

- ✓ HNL decay

HNL lifetime τ_N is dependent on the coupling strength $|U^2|$ and the mass m_N

$$\tau_N = \frac{\hbar}{\Gamma} \qquad \Gamma = \Sigma_i \Gamma_i(m_N, |U^2|)$$ total width

- ✓ In this search:

$$4.5GeV < m_N < 50GeV$$

$c\tau$ = 0.001, 0.01, 0.1, 1, 10 or 100 mm

Mean proper decay length

Heavy neutral leptons

Prompt Signature

arXiv:1905.09787,
Accepted by JHEP

- ✓ Search conducted in two channels:

$W^{\pm} \rightarrow \mu^{\pm}\mu^{\pm}e^{\mp}\nu_e$ (muon channel) and $W^{\pm} \rightarrow e^{\pm}e^{\pm}\mu^{\mp}\nu_{\mu}$ (electron channel)

- ✓ Selection:

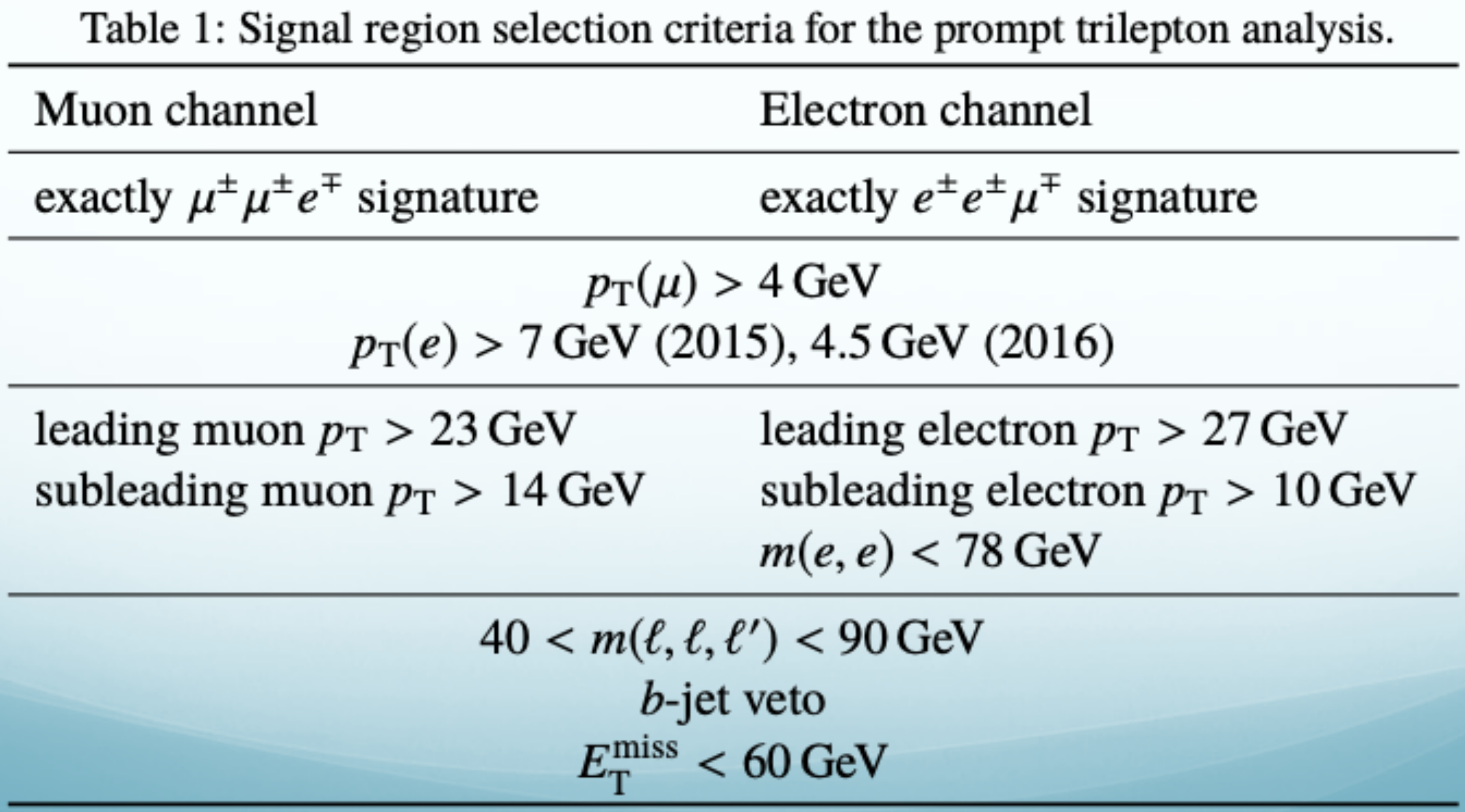


Table 1: Signal region selection criteria for the prompt trilepton analysis.

Muon channel	Electron channel
exactly $\mu^{\pm}\mu^{\pm}e^{\mp}$ signature	exactly $e^{\pm}e^{\pm}\mu^{\mp}$ signature
$p_{\mathrm{T}}(\mu) > 4$ GeV $p_{\mathrm{T}}(e) > 7$ GeV (2015), 4.5 GeV (2016)	
leading muon $p_{\mathrm{T}} > 23$ GeV subleading muon $p_{\mathrm{T}} > 14$ GeV	leading electron $p_{\mathrm{T}} > 27$ GeV subleading electron $p_{\mathrm{T}} > 10$ GeV $m(e, e) < 78$ GeV
$40 < m(\ell, \ell, \ell') < 90$ GeV b-jet veto $E_{\mathrm{T}}^{\mathrm{miss}} < 60$ GeV	

Heavy neutral leptons

Prompt Signature

✓ Backgrounds:

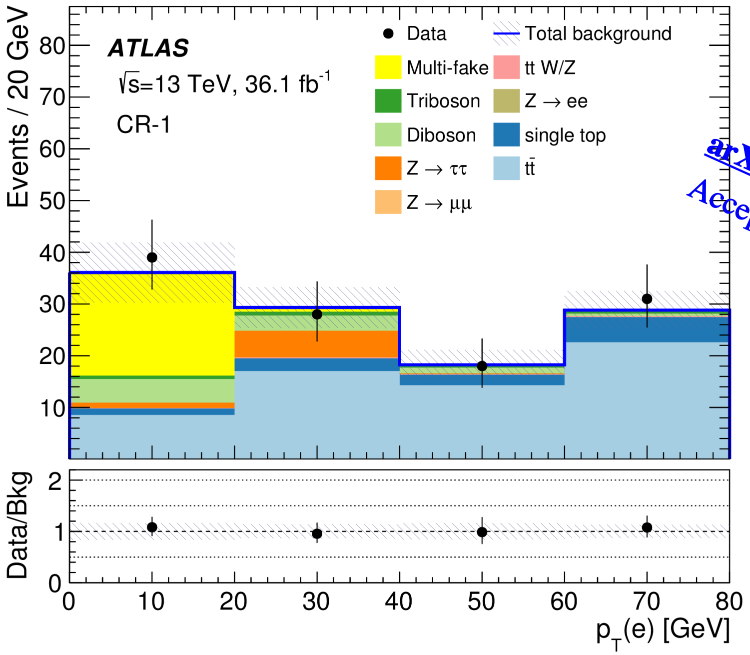
- Irreducible: exactly three leptons (diboson, triboson, $t\bar{t}V$) -> negligible due to small cross sections -> estimated from MC simulations.

- Reducible: events with fake leptons (semi-leptonic decays of b(c)-hadrons, photon conversions …).

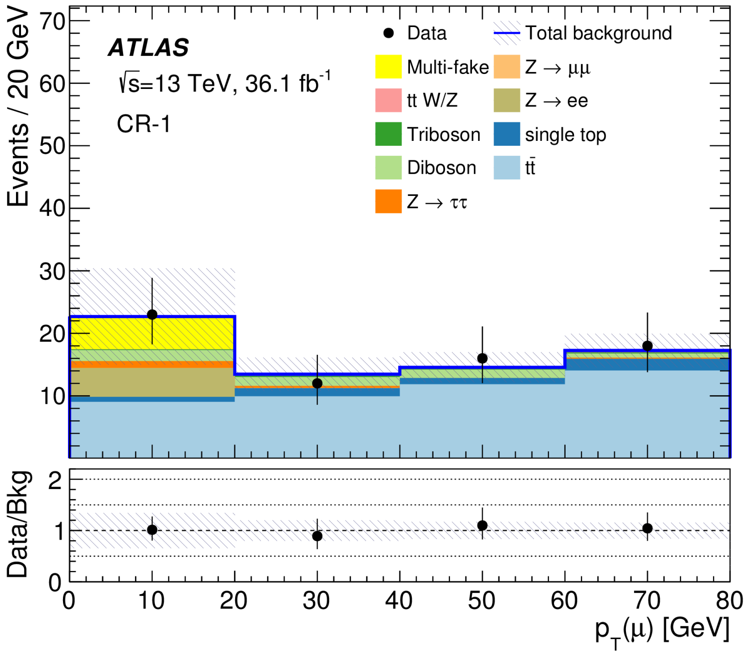
Large fraction comes from W+jets and multijets events (multi-fake) -> estimated from data.

$t\bar{t}$ estimated from data.

Z+jets and single-top-quark estimated from MC simulations.



arXiv:1905.09787, Accepted by JHEP



Heavy neutral leptons

arXiv:1905.09787, Accepted by JHEP

Displaced-vertex Signature

✓ For $m_N \leq 20$ GeV -> HNL lifetime gets longer -> DV is needed to explore these regions.

✓ Search for a prompt isolated muon accompanied by a DV formed by either two muons or a muon and an electron.

✓ DV can be reconstructed at radial distances up to ~ 300 mm due to the application of "large radius tracking (LRT) algorithm"

✓ Selection: first applied a pre-selection and then LRT algorithm.

- Presence of at least two muons.
- The first muon is required to have an ID track matched to an MS track segment, with $p_T > 28GeV$.
- The displaced muon candidate must have:
  - MS track which either has no matched track in the ID or
  - if it has a match track -> $d_0 > 0.1mm$
  - $p_T > 5GeV$

Heavy neutral leptons

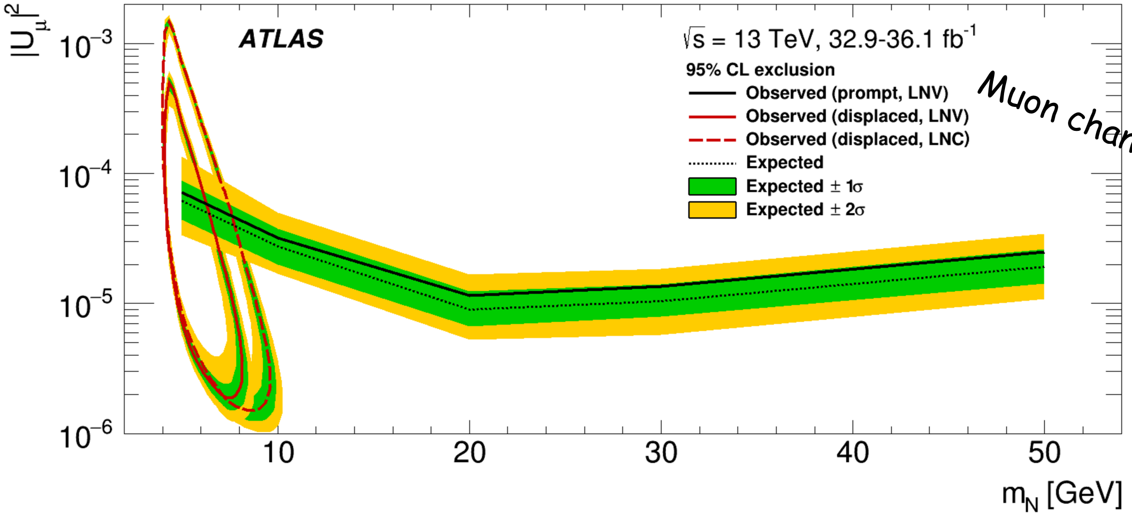
arXiv:1905.09787, Accepted by JHEP

Displaced-vertex Signature

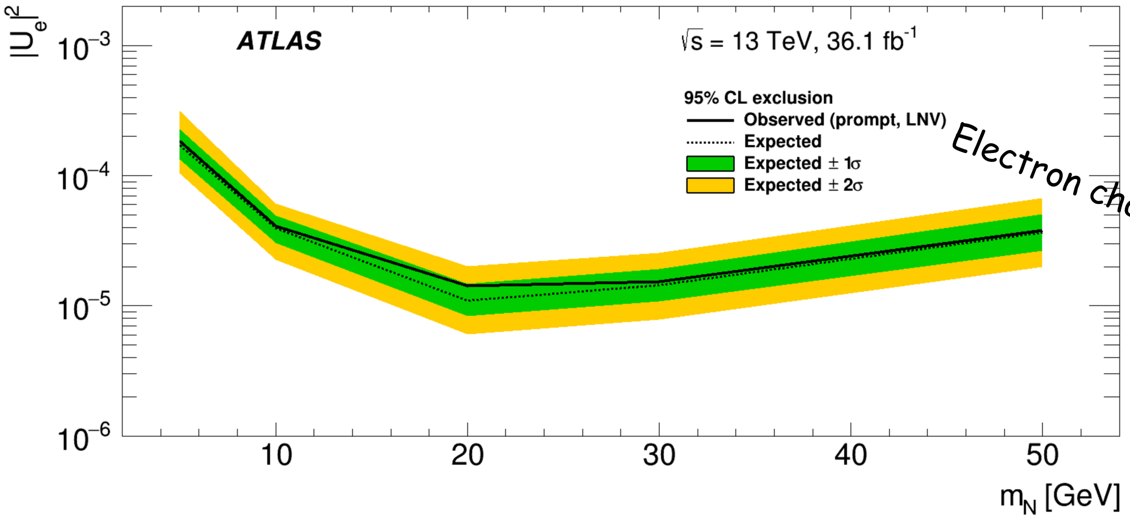
✓ Backgrounds:

- Sources of two-track DVs include:
  - ✳ hadronic interactions in material,
  - ✳ decays of metastable particles (b-hadron, s-hadron), accidental crossings of charged particles,
  - ✳ cosmic-rays muons crossing charged particle or reconstructed as two back-to-back muons.
- Other sources: dijets and W+jets -> estimated with data-driven.

Heavy neutral leptons



Muon channel



Electron channel

Results

arXiv:1905.09787,
Accepted by JHEP

- ✓ Observation in the signal regions are consistent with background expectations in both signatures.
- ✓ Limits from prompt signature cover the mass range 5-50 GeV. For m_N between 20-30 GeV mass -> regions in $|U^2|$ above 1.4 x 10^{-5} excluded.
- ✓ Limits from DV signature cover the mass range 4.5-10 GeV, in which they exclude coupling strengths down to ~ 2 x 10^{-6}

Heavy neutral leptons

Other searches

13 TeV results

- ✓ Search for RH-gauge bosons decaying into heavy neutrinos and a charged lepton -> Left-Right symmetric Models Phys. Lett. B 798 (2019) 134942
- ✓ Search for Heavy Majorana o Dirac neutrinos and RH-gauge bosons with final states with two charged leptons and two jets -> Left-Right Symmetric Models JHEP 01 (2019) 016

8 TeV results

- ✓ Search for type-III heavy leptons in llqq final state Phys. Rev. D 92 (2015) 032001
- ✓ Search for type-III heavy leptons in lll final state. JHEP09(2015)108

Conclusions

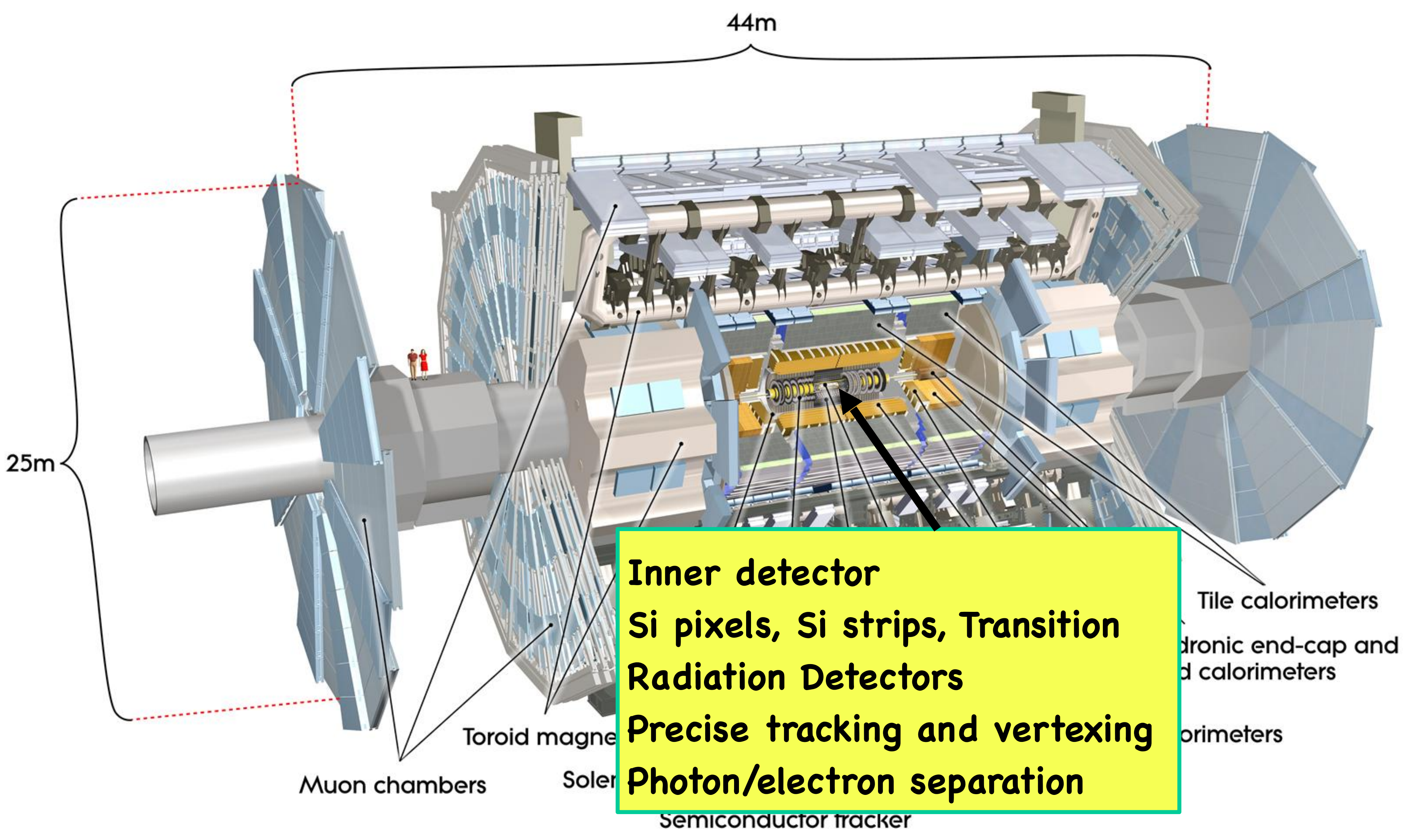
- ✓ The LHC searches are complementary to direct searches, providing improved sensitivity to low DM masses.
- ✓ ATLAS has a diverse program in DM searches:
  - Complementarity in different final states.
  - Wide program of searches in Supersymmetry (not discussed in this talk)
- ✓ None of the DM searches have observed a significant excess over expected backgrounds.
- ✓ ATLAS has performed different searches of Heavy Neutral Leptons, which if stable, could be a valid DM candidate.
- ✓ None of the HNL searches have observed a significant excess over expected backgrounds. Exclusion Limits in $|U^2|$vs m_N have been set and they improve former searches.
- ✓ Many searches in progress for the full Run 2

Stay tuned …

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

Backup Slides

The ATLAS detector



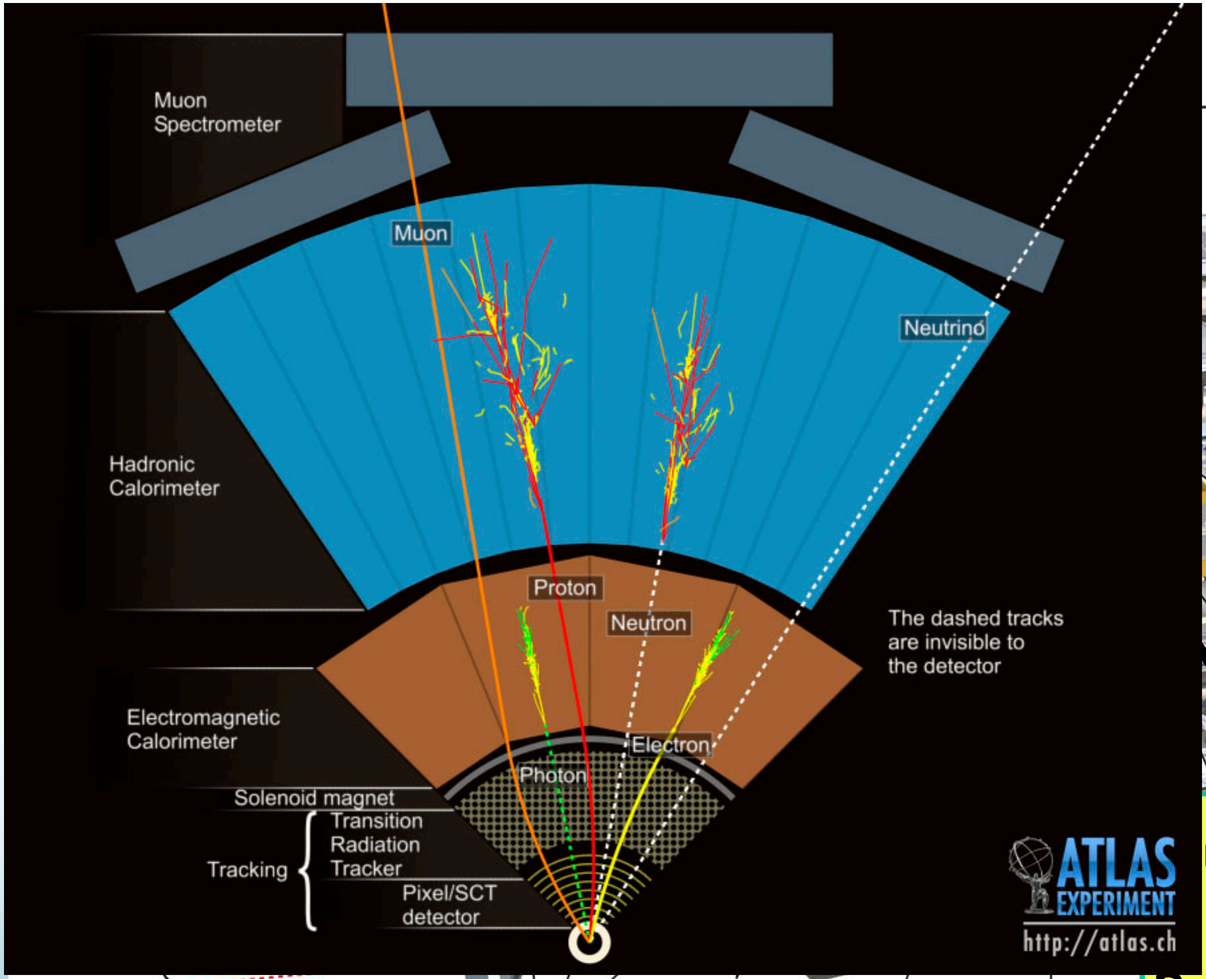
Inner detector

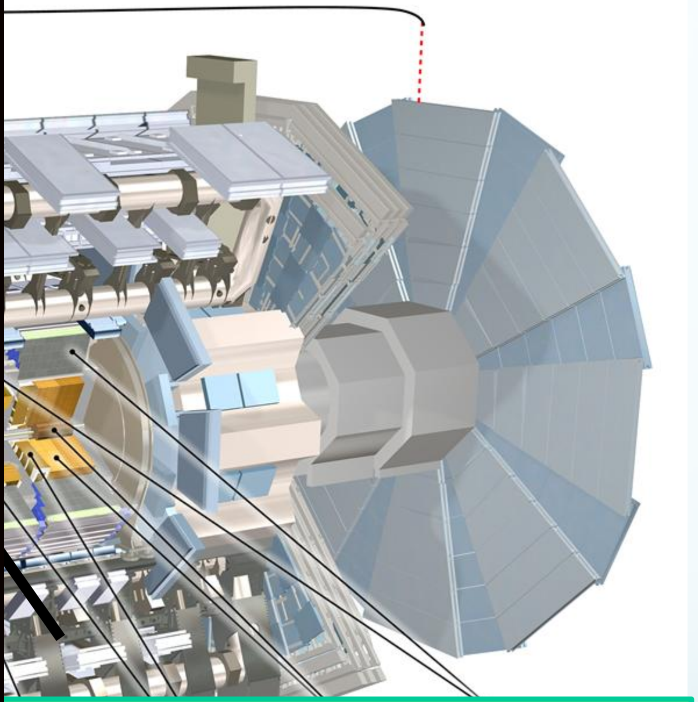
Si pixels, Si strips, Transition Radiation Detectors

Precise tracking and vertexing

Photon/electron separation

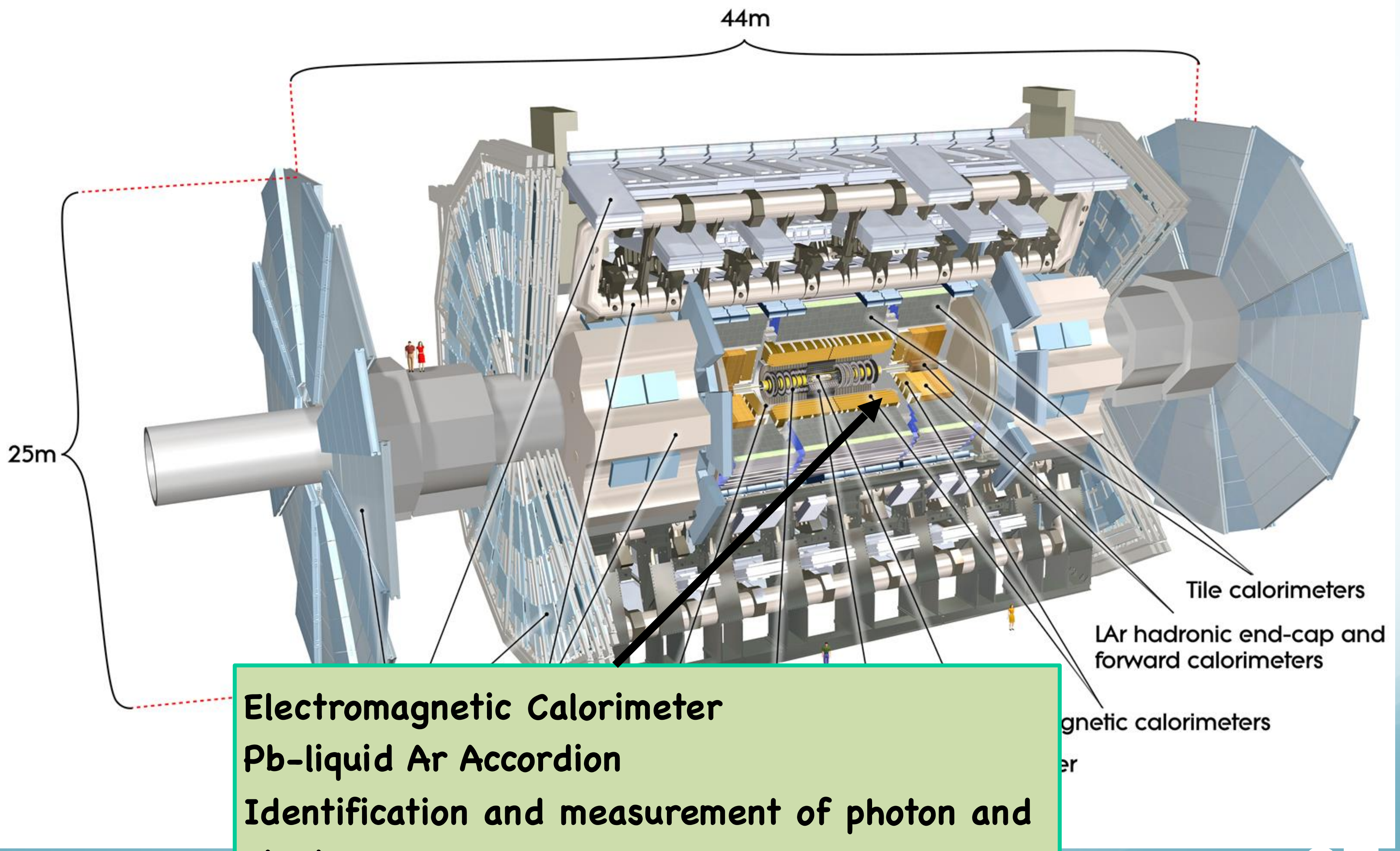
The ATLAS detector





ner detector
pixels, Si strips, Transition Radiation Detectors
Precise tracking and vertexing
Photon/electron separation

El detector ATLAS

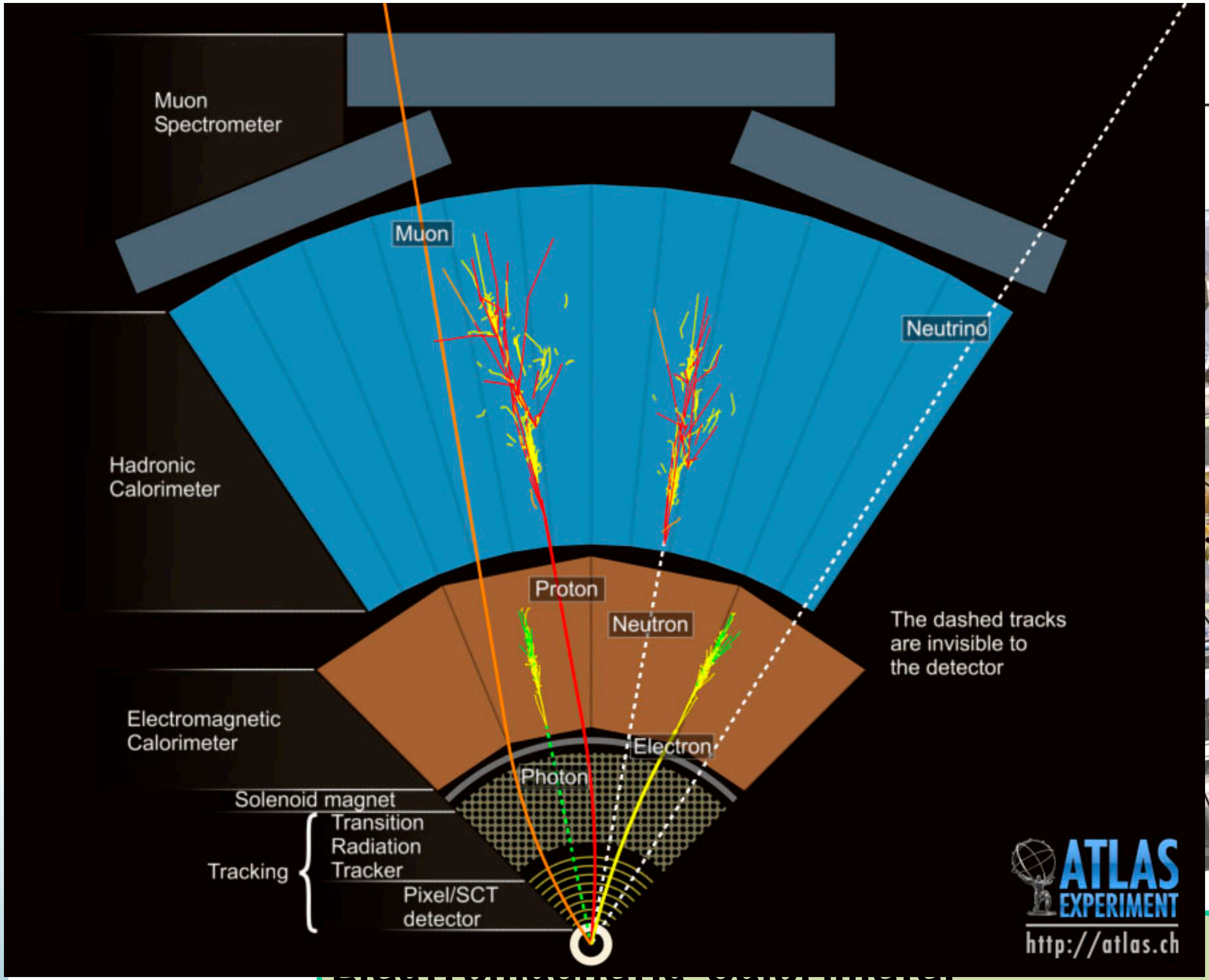


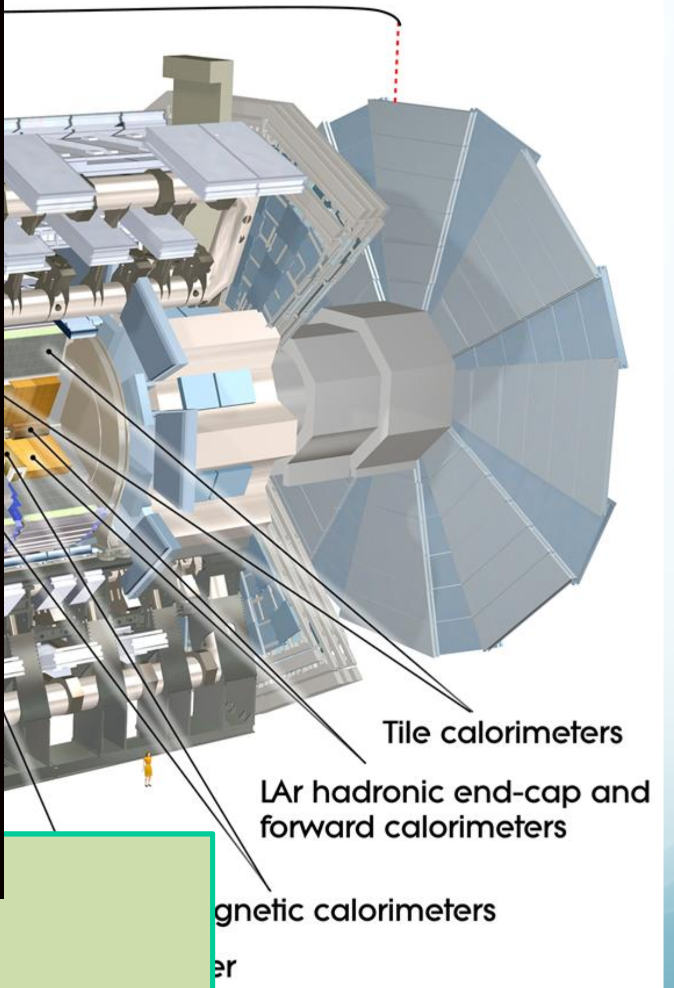
Electromagnetic Calorimeter

Pb-liquid Ar Accordion

Identification and measurement of photon and electrons energy.

The Atlas detector





Electromagnetic Calorimeter

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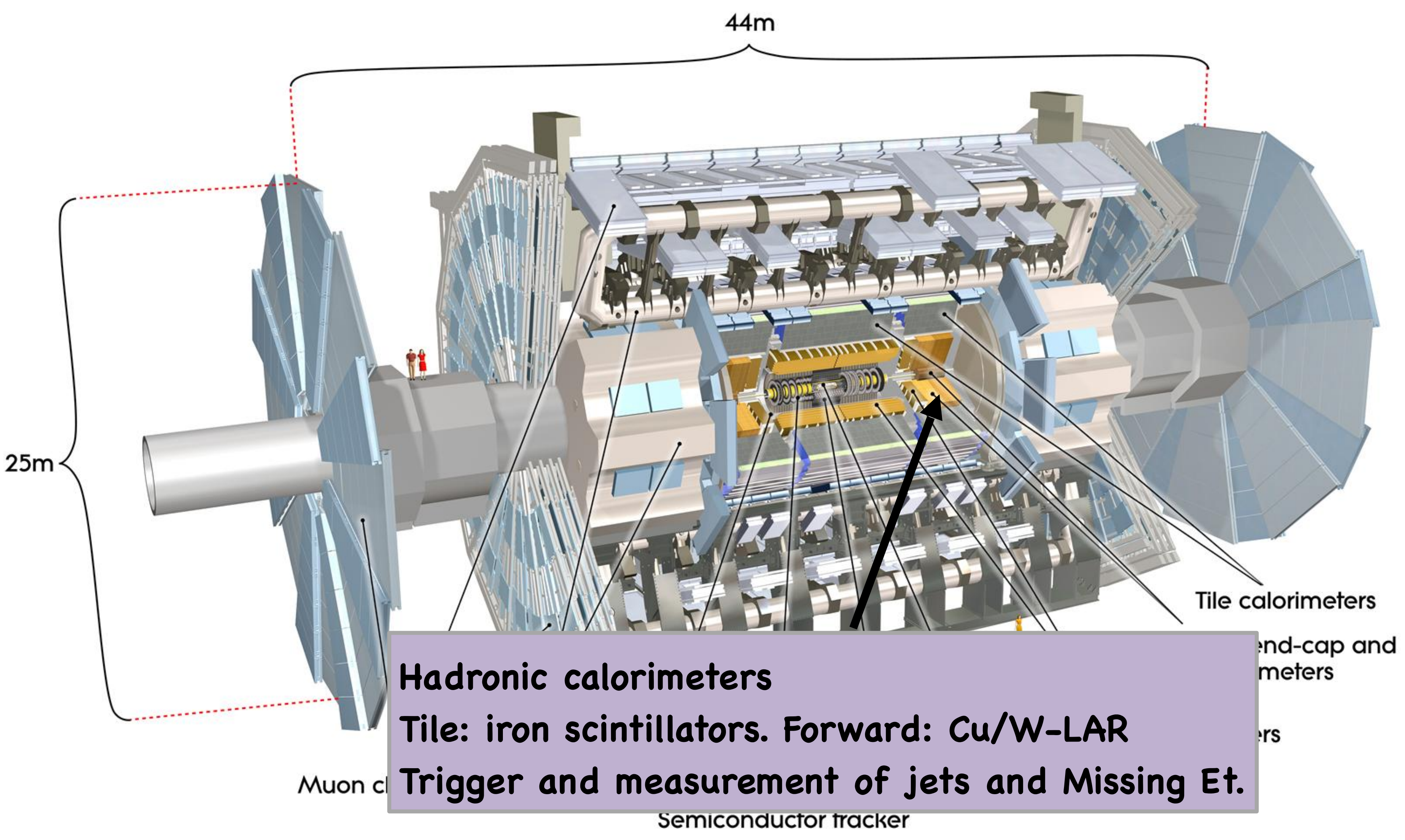
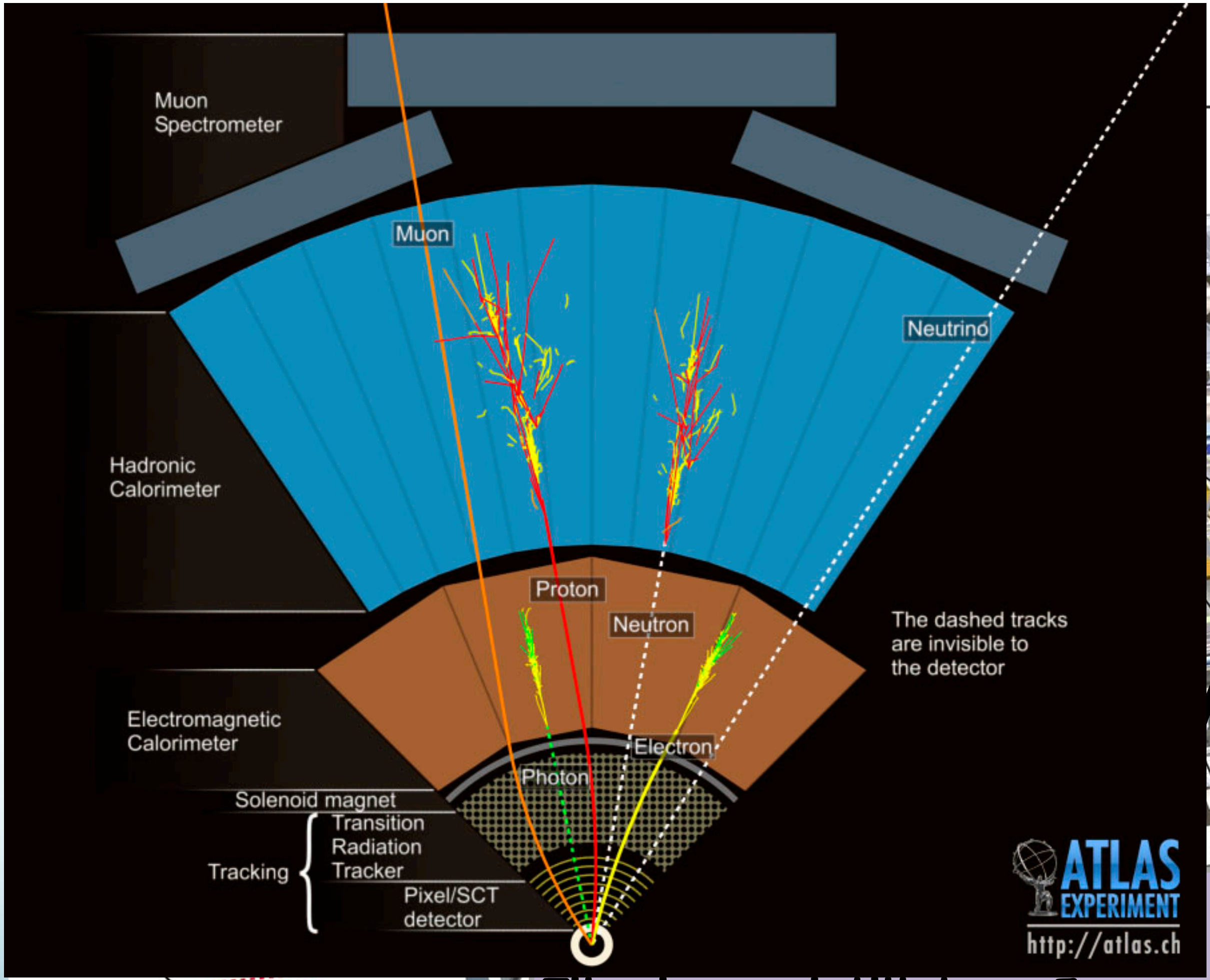


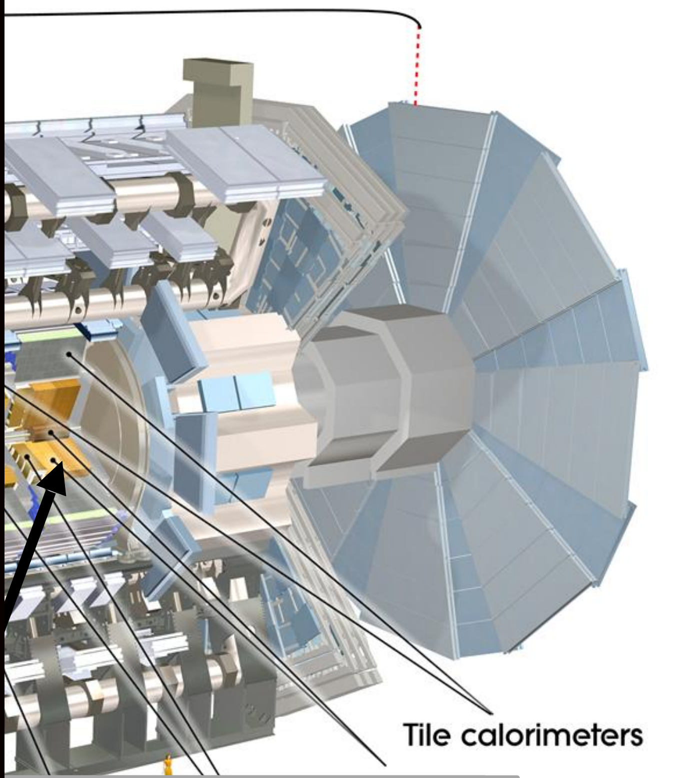
Hadronic calorimeters

Tile: iron scintillators. Forward: Cu/W-LAR

Trigger and measurement of jets and Missing Et.

El detector ATLAS

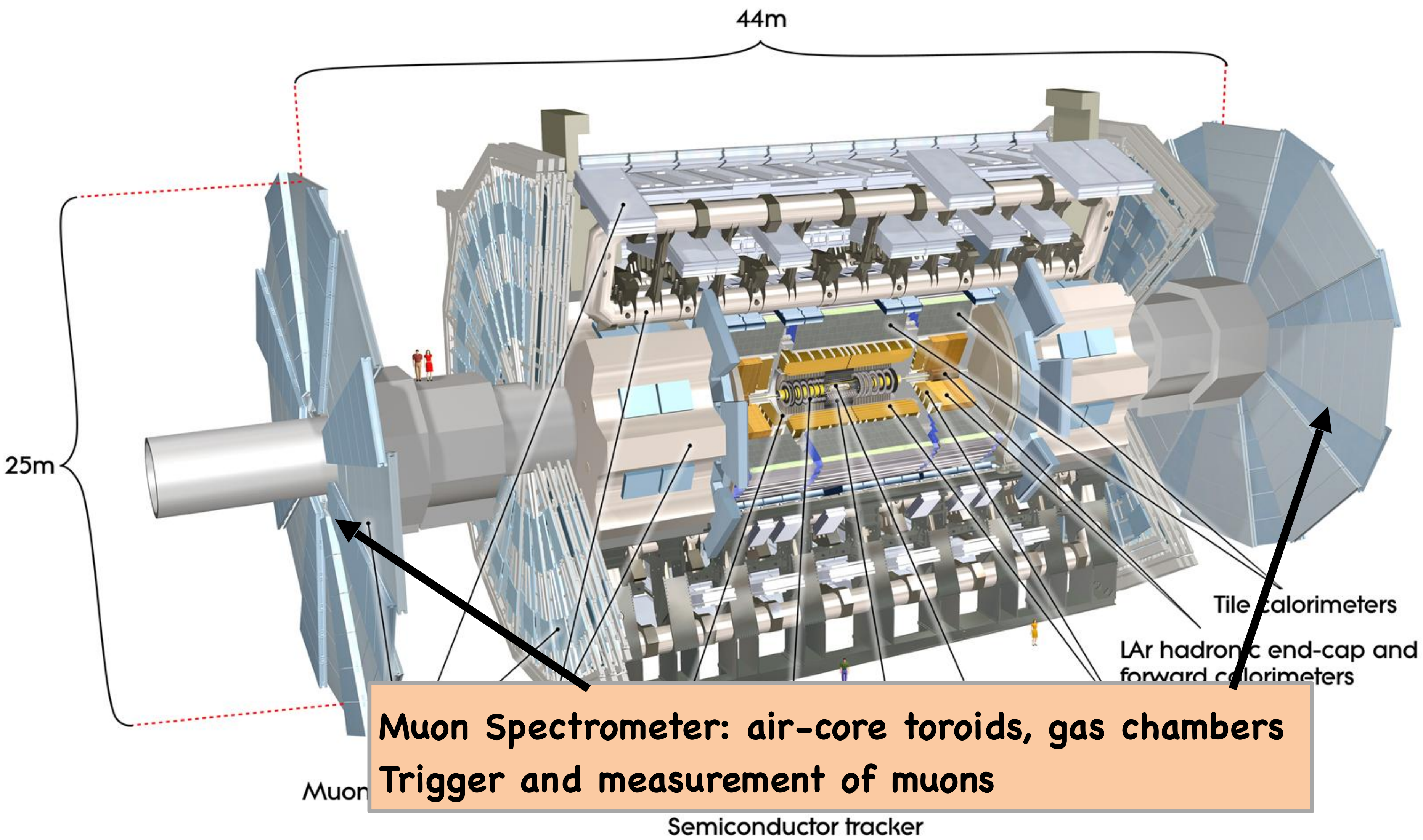




Tile: iron scintillators. Forward: Cu/W-LAR

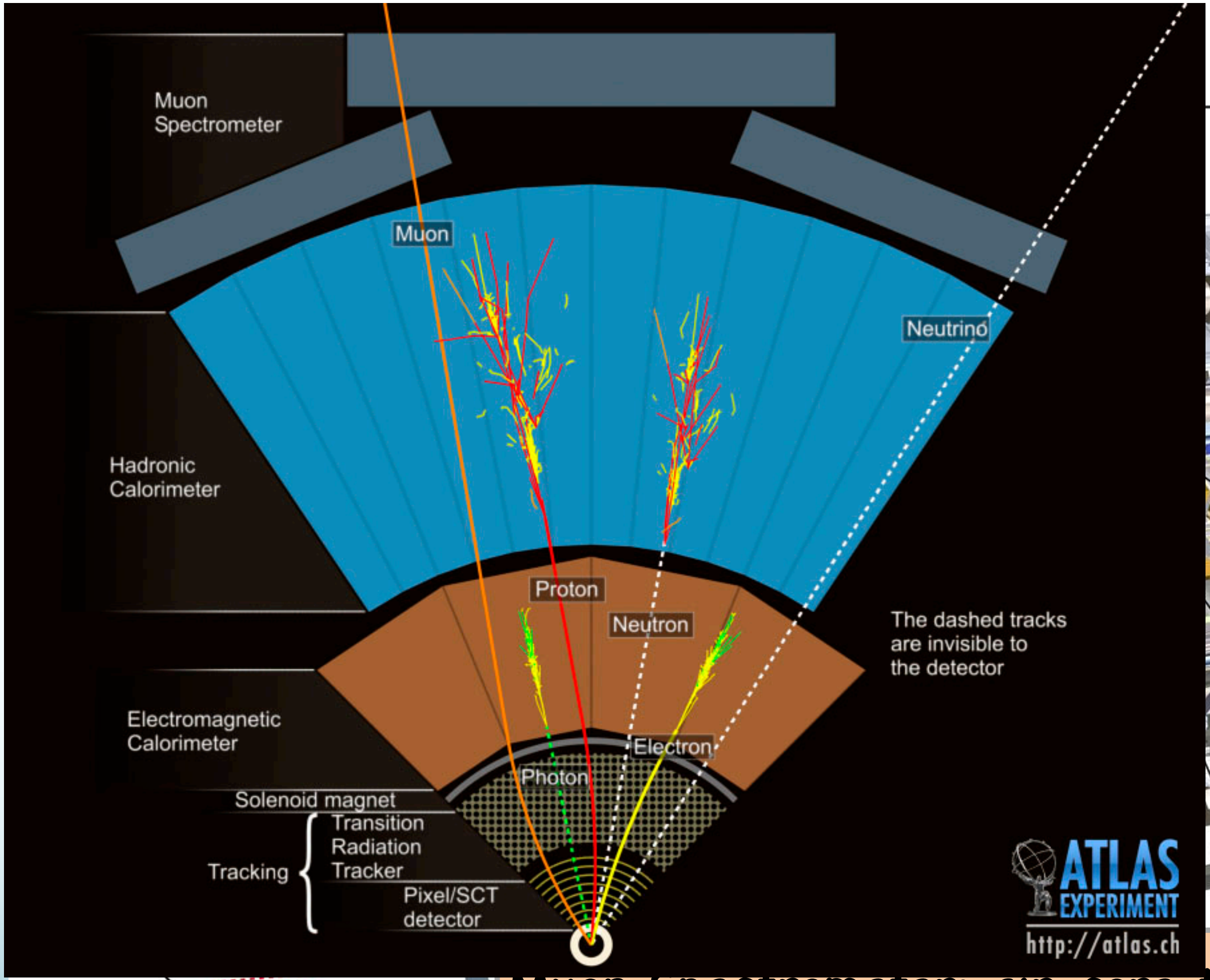
Trigger and measurement of jets and Missing Et.

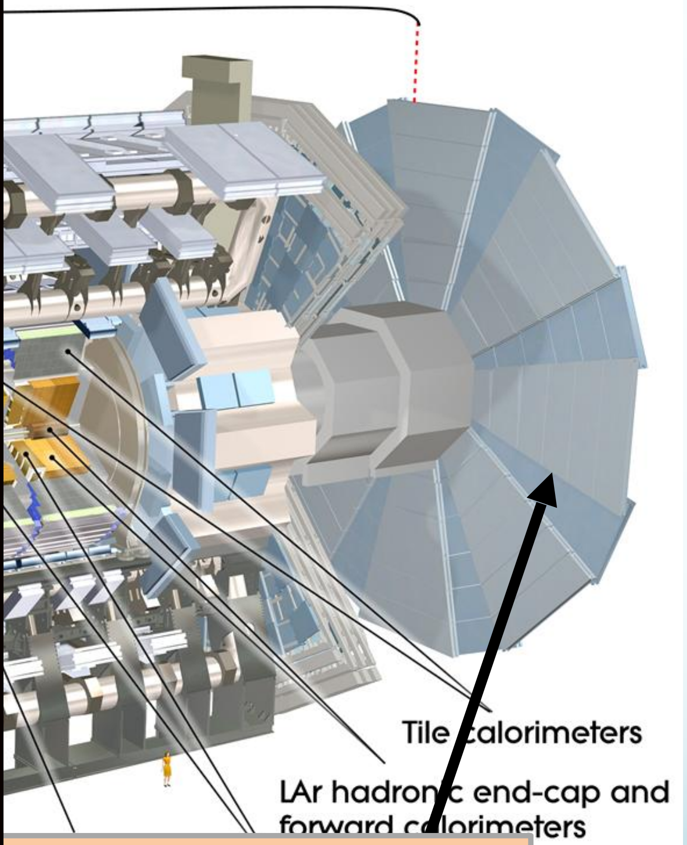
El detector ATLAS



Muon Spectrometer: air-core toroids, gas chambers
Trigger and measurement of muons

El detector ATLAS

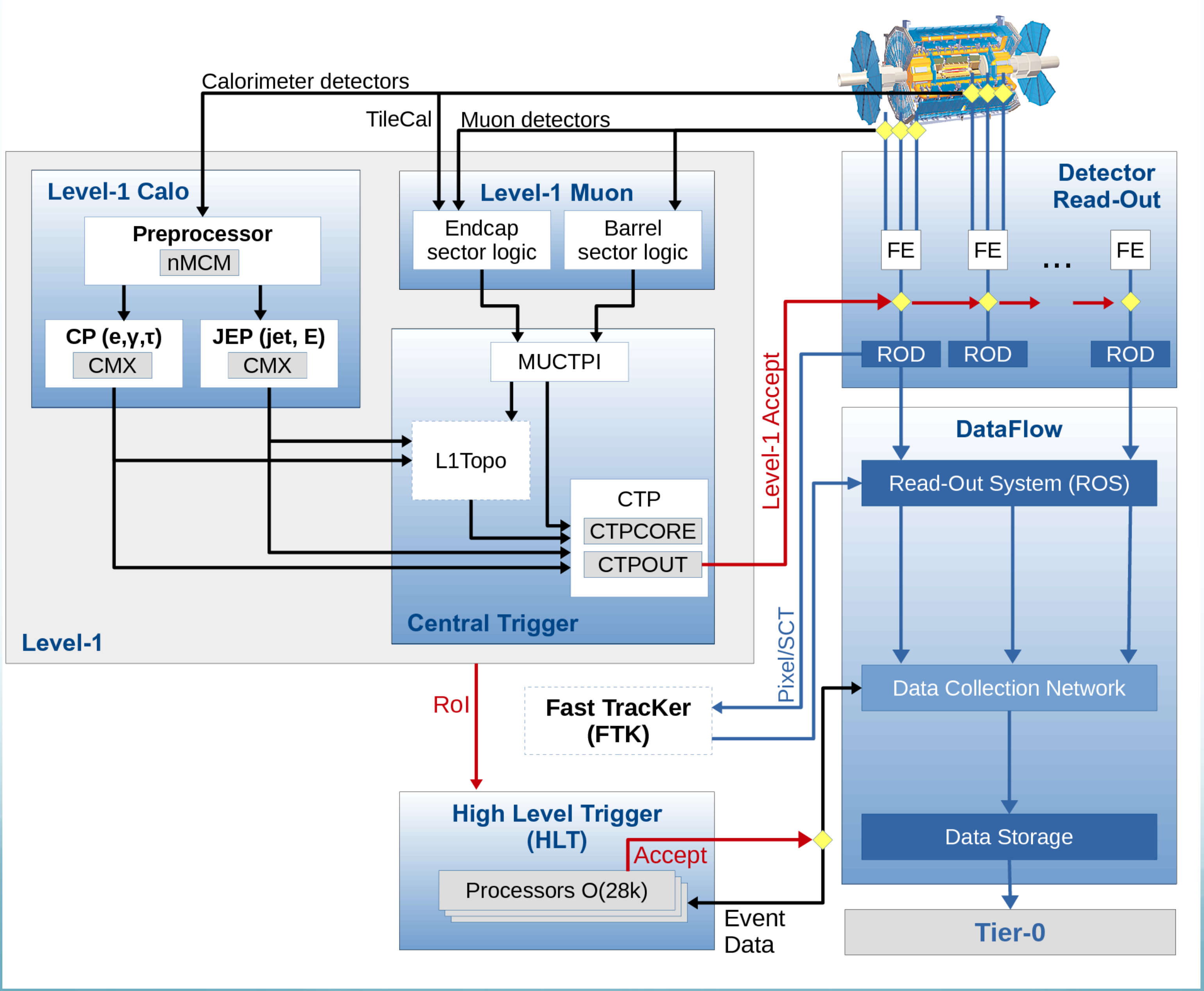




Muon Spectrometer: air-core toroids, gas chambers

Trigger and measurement of muons

The ATLAS detector



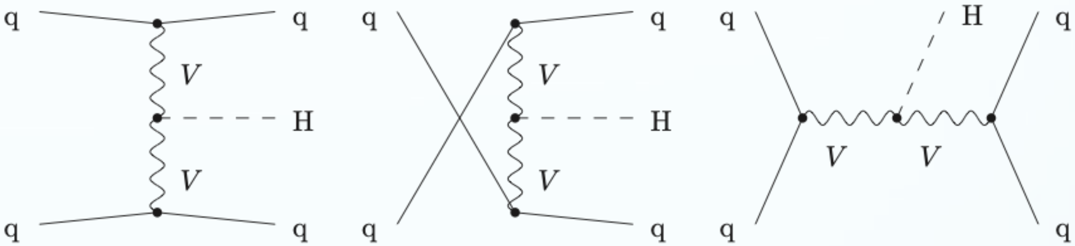
Trigger and Data acquisitio
(TDAQ) system
Of the ATLAS
Detector for
"Run 2"

Dark Matter: Higgs to invisible

- ✓ 125 GeV Higgs boson H acts as portal between a dark sector and the SM sector.

Phys. Rev. Lett. 122 (2019) 231801

- ✓ Decays of H to DM particles represent a distinct signature in these models -> indirectly inferred through E_T^{Miss} (invisible).
- ✓ Different topologies assuming SM production rates:



◉ VBF topology

Event Selection:

- E_T^{Miss} > 180 GeV
- Two jets leading in p_T separated in $|\Delta\eta_{ij}| > 4.8$
- No additional jets with $p_T > 25$ GeV, no isolated electrons or muons with $p_T > 7$ GeV (reduce background from V+ jets.

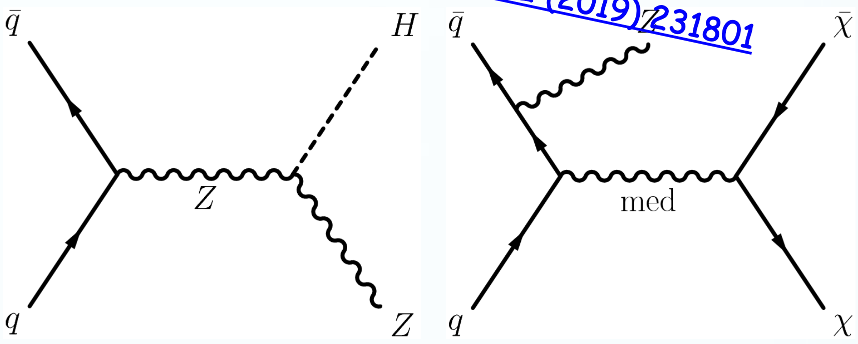
Backgrounds:

- Dominant Z($\nu\nu$)+ jets and W(l ν) + jets (lepton not detected)

Dark Matter: Higgs to invisible

✓ Different topologies assuming SM production rates:

Phys. Rev. Lett. 122 (2019) 231801



◉ Z(lep)H topology: Z decays to leptons

Event Selection:

- E_T^{Miss} > 90 GeV and $E_T^{Miss}/H_T > 0.6$
- Exactly one pair of isolated electrons or muons with an invariant mass that is consistent with Z boson.
- Dilepton system aligned back-to-back to the E_T^{Miss} vector (reduce Z+jets)
- B-jets vetoed to reduce backgrounds from top quark pair production and Wtop.

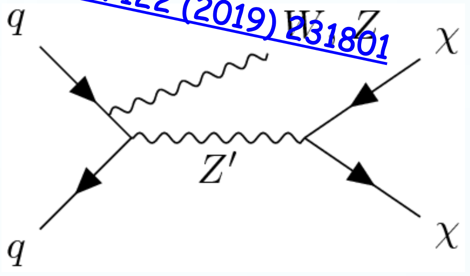
Backgrounds:

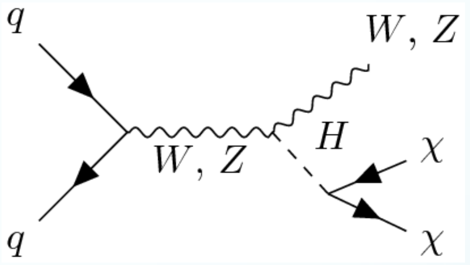
- Irreducible Z($\nu\nu$)Z(ll) estimated from MC simulations.
- W(lν)Z(ll) predicted by MC simulations and Z+jets estimated with data driven method.

Dark Matter: Higgs to invisible

✓ Different topologies assuming SM production rates:

Phys. Rev. Lett. 122 (2019) 231801





◉ V(had)H topology: W or Z decay hadronically

Event Selection:

- E_T^{Miss} trigger and no isolated lepton with $p_T > 7$ GeV
- V is boosted -> jets are collimated -> two different

regions.

- “merged”: E_T^{Miss} > 250 GeV and has at least one large-R jet.
- “resolved”: E_T^{Miss} > 150 GeV and has at least two small-R jets.

Backgrounds:

- Main: V+jets and $t\bar{t}$ -> estimated from MC simulations.

BSM Higgs

✓ Two Higgs Doublet Model(2HDM)

- Addition of a second Higgs complex doublet: ϕ_1 & ϕ_2
- If the potential conserves CP symmetry -> 5 Higgs Bosons:
  - Two scalar fields with CP even h y H
  - One pseudo-scalar field with CP odd A
  - Two charged fields $H^{\pm}$.
- Model parameters
  - m_H, m_h, m_A, $m_{H^{\pm}}$
  - α : rotation angle that diagonalizes the square of the scalar field mass matrix
  - $\tan\beta$: ratio between the vacuum expectation values of the scalar fields.

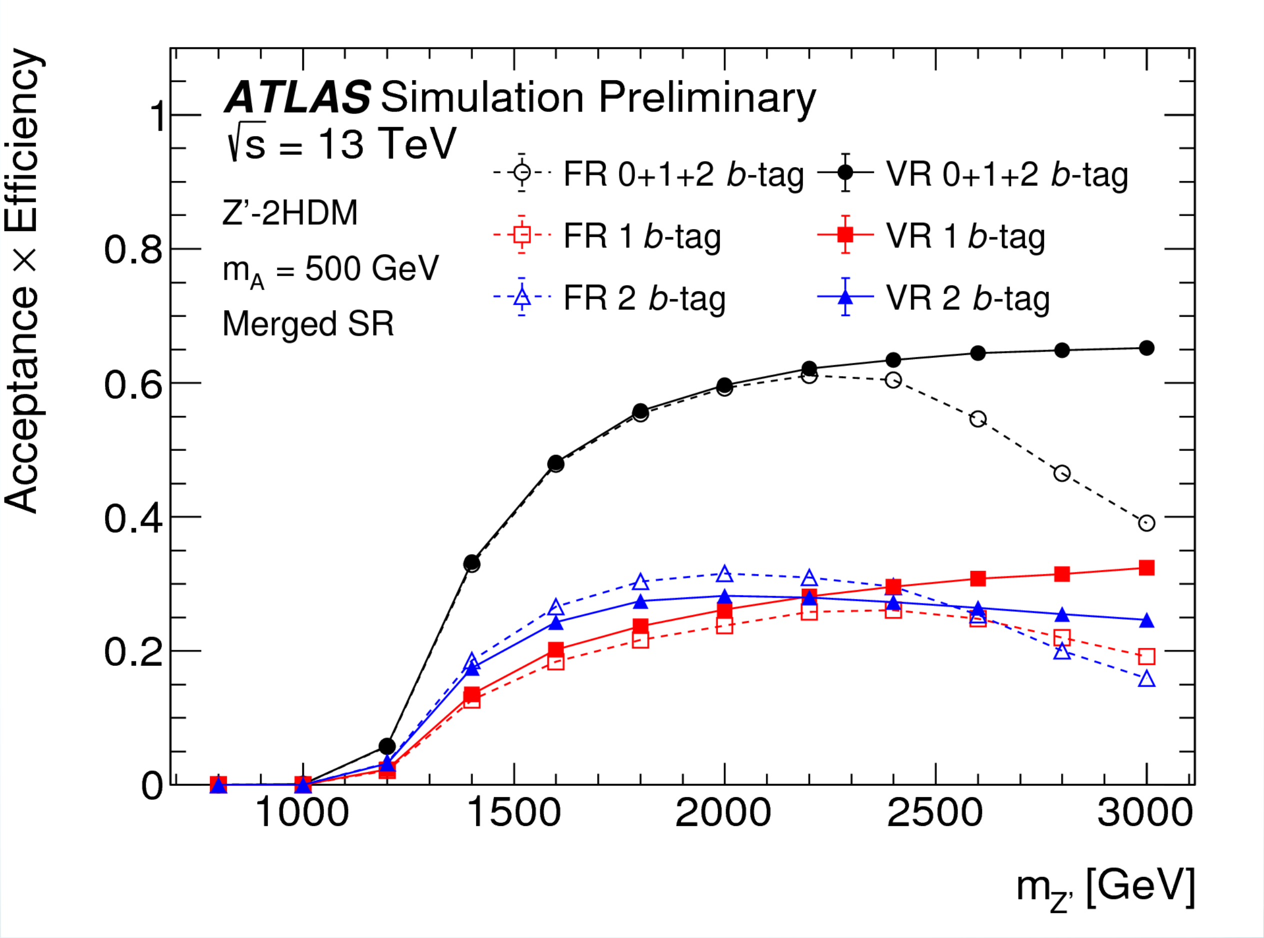
- Types
  - Type-I: all quarks couple with ϕ_2 .
  - Type-II: RH up-quarks couple with ϕ_2 and RH down-quarks couple with ϕ_1 .
  - Lepton-specific: ϕ_1 couples to leptons and ϕ_2 to quarks.
  - Flipped: like type-II but leptons couple to ϕ_2 .

Variable-radius track jets

- ✓ Reconstructed from inner detector using anti-kt algorithm.
- ✓ Main feature: pt dependence of the jet radius:

$$R \rightarrow R_{eff}(p_T) \sim \frac{\rho}{p_t}$$

- ✓ Two other parameters: R_{min} and R_{max} -> lower and uppercut on jet radius.

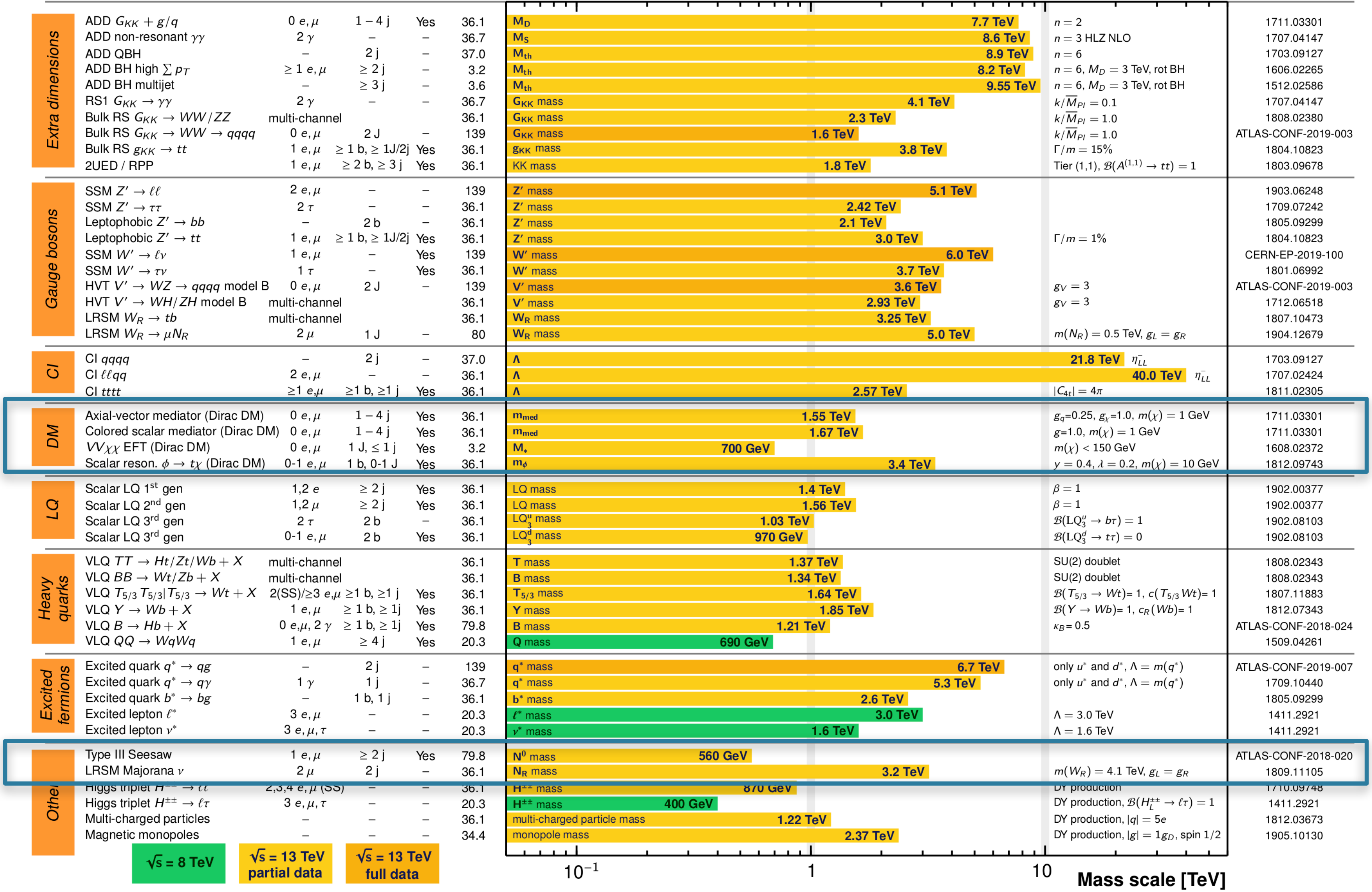


ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 139)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

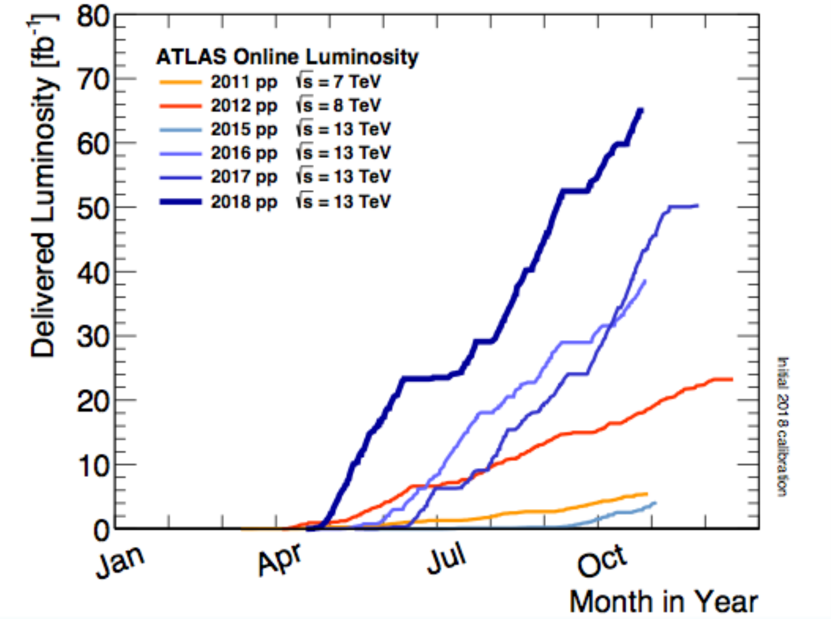


	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WW \to qqqq$	0 e, μ	2 J	–	139	G_{KK} mass 1.6 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2019-003
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	W' mass 6.0 TeV		CERN-EP-2019-100
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WZ \to qqqq$ model B	0 e, μ	2 J	–	139	V' mass 3.6 TeV	$g_V = 3$	ATLAS-CONF-2019-003
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W_R \to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	2 μ	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^{-}	1703.09127
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.0 TeV	η_{LL}^{-}	1707.02424
	CI $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	1811.02305
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4$, $\lambda = 0.2$, $m(\chi) = 10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$	1902.00377
	Scalar LQ 3rd gen	2 τ	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(\text{LQ}_3^u \to b\tau) = 1$	1902.08103
	Scalar LQ 3rd gen	0-1 e, μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(\text{LQ}_3^d \to t\tau) = 0$	1902.08103
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3} Wt)$= 1	1807.11883
	VLQ $Y \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb + X$	0 e,μ, 2 γ	≥ 1 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2019-007
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e, μ	≥ 2 j	Yes	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g\rvert = 1 g_D$, spin 1/2	1905.10130

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

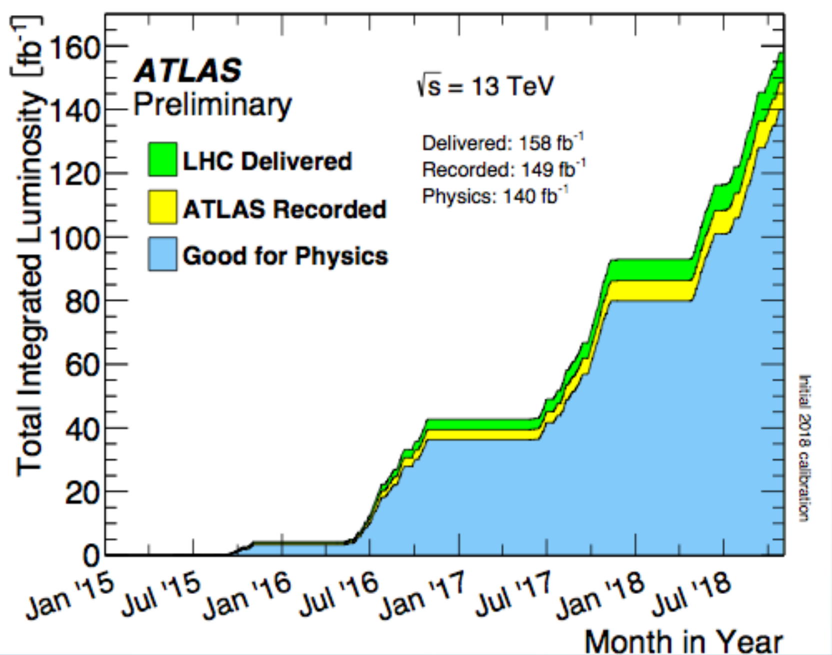
†Small-radius (large-radius) jets are denoted by the letter j (J).

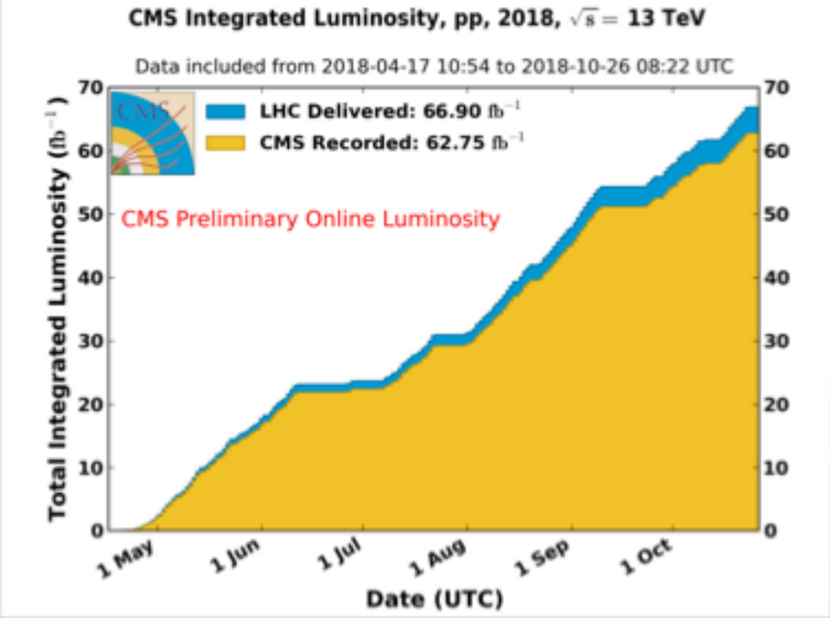
Luminosity



$$N_{exp} = \sigma_{exp} \times \int \mathscr{L}(t)dt$$

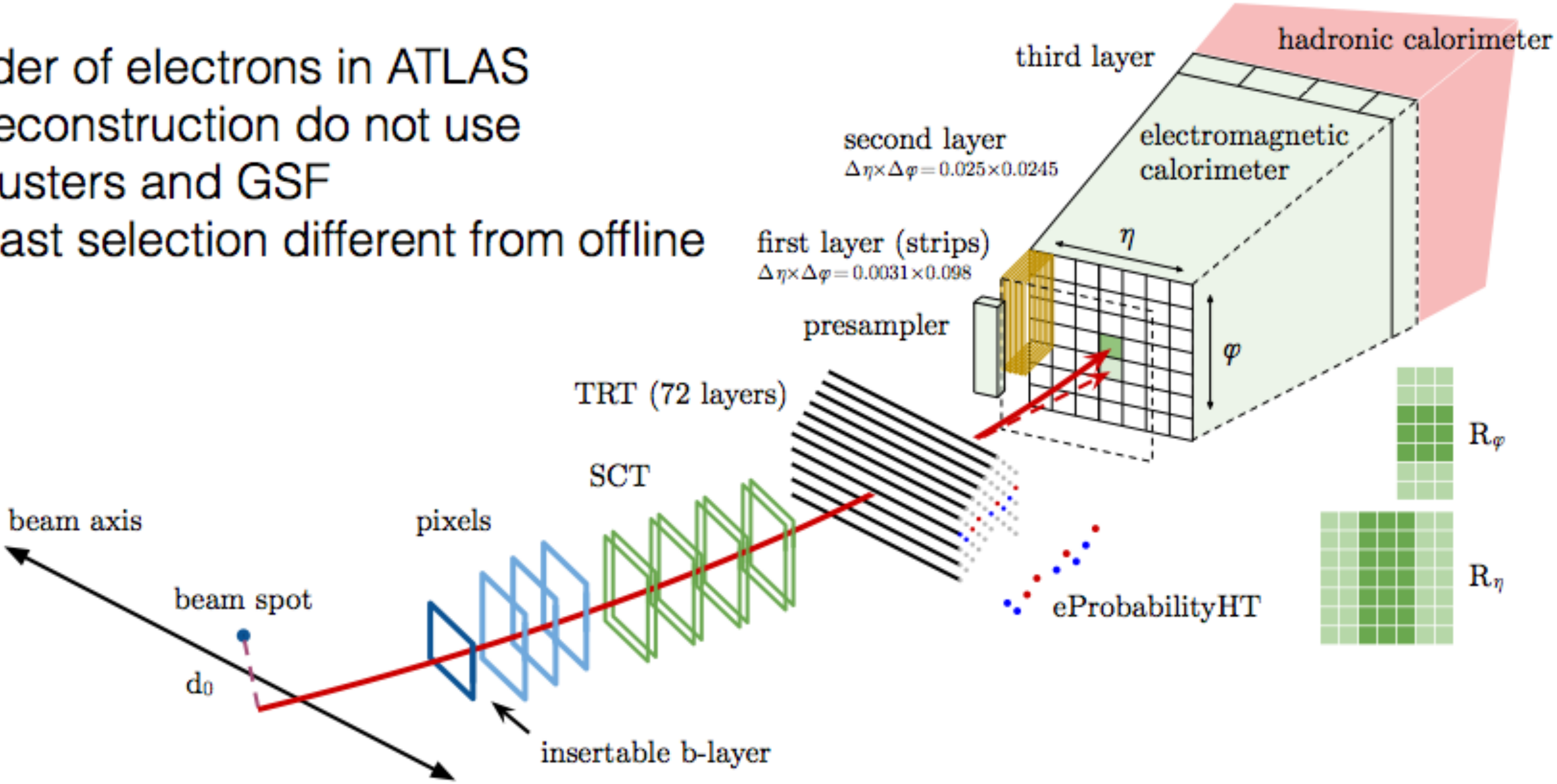
$$\mathscr{L} = f_{coll} \frac{n_1 n_2}{4\pi\sigma_x^* \sigma_y^*}$$





Calorimeter towers

- A reminder of electrons in ATLAS
- Online reconstruction do not use SuperClusters and GSF
- L1 and fast selection different from offline



Upgrade phase 1

Phase 1

- New muon small wheel
  - Has to be replace because of new conditions of Run III
- New trigger Schemes :
  - FTK ->track finding and fitting done at hardware level -> fast (latency less than 100μs for input rates up to 100 kHz).
  - Tracks will be available at the beginning of L2 -> less load on L2.

Phase 2

- New inner detector.
- Calorimeter and trigger upgrades.

Prospects for new colliders

	FCC-ee	CEPC	ILC	CLIC
Species	e^+e^-	e^+e^-	e^+e^-	e^+e^-
Beam energy (GeV)	46, 120, 183	46, 120	125, 250	190, 1500
Circumference / Length (km)	97.75	100	20.5, 31	11, 50
Interaction regions	2	2	1	1
Estimated integrated luminosity per exp. (ab^{-1}/year)	26, 0.9, 0.17	4, 0.4	0.2, 0.2	0.2, 0.6
Peak luminosity (10^{34} cm^{-2} s^{-1})	200, 7, 1.5	32, 3	1.4, 1.8	1.5, 6
Time between collisions (μs)	0.015, 0.75, 8.5	0.025, 0.68	0.55	0.0005
Energy spread (rms, 10^{-3})	1.3, 1.65, 2.0	0.4, 1.0	e^-: 1.9, 1.2 e^+: 1.5, 0.7	3.5
Bunch length (rms, mm)	12.1, 5.3, 3.8	8.5, 3.3	0.3	0.09, 0.044
IP beam size (μm)	H: 6.3, 14, 38 V: 0.03, 0.04, 0.07	H: 5.9, 21 V: 0.04, 0.07	H: 0.52, 0.47 V: 0.008, 0.006	H: 0.15, 0.04 V: 0.003, 0.001
Injection energy (GeV)	on energy (topping off)	on energy (topping off)	5.0 (linac)	9.0 (linac)
Transv. geom. emittance (rms, pm)	H: 270, 630, 1340 V: 1, 1, 3	H: 170, 1210 V: 2, 3	H: 20, 10 V: 0.14, 0.07	H: 2.4, 0.22 V: 0.08, 0.01
β^* at interaction point (cm)	H: 15, 30, 100 V: 0.08, 0.1, 0.16	H: 20, 36 V: 0.1, 0.15	H: 1.3, 2.2 V: 0.041, 0.048	H: 0.8, 0.69 V: 0.01, 6.8×10^{-3}
Full crossing angle (mrad)	30	33	14	20
Crossing scheme	crab waist	crab waist	crab crossing	crab crossing
Piwinski angle $\phi = \sigma_z \theta_c / (2\sigma_x^*)$	28.5, 5.8, 1.5	23.8, 2.6	0	0
Beam-beam parameter ξ_y (10^{-3})	133, 118, 144	72, 109	n/a	n/a
Disruption parameter D_y	0.9, 1.1, 1.9	0.3, 1.0	34, 25	8, 12
Average Upsilon Υ	0.0002, 0.0004, 0.0006	0.0001, 0.0005	0.03, 0.06	0.26, 3.4
RF frequency (MHz)	400, 400, 800	650	1300	11994
Particles per bunch (10^{10})	17, 15, 27	8, 15	2	0.52, 0.37
Bunches per beam	16640, 328, 33	12000, 242	1312 (pulse)	352, 312 (trains at 50 Hz)
Average beam current (mA)	1390, 29, 5.4	19.2	6 (in train)	1660, 1200 (in train)
RF gradient (MV/m)	1.3, 9.8, 19.8	3.6, 19.7	31.5	72, 100
Polarization (%)	≥10, 0, 0	5–10, 0	e^-: 80% e^+: 30%	e^-: 70% at IP
SR power loss (MW)	100	64	n/a	n/a
Beam power/beam (MW)	n/a	n/a	5.3, 10.5	3, 14
Novel technology	—	—	high grad. SC RF	two-beam accel.

Estrategia para el análisis de los datos

Cualquier análisis que pretenda estudiar un fenómeno específico involucra definir:

1) SR: una región donde la señal predice un exceso de eventos sobre el background predicho. Esta región se obtiene aplicando una selección a diferentes variables cinemáticas.

2) CR: una región de control donde los backgrounds pueden ser controlados comparándolos con los datos. Esta región permite estimar los procesos de background que contaminan la SR.

3) VR: regiones de validación del modelo utilizado para predecir los eventos de background en la SR.

Los espacios de fase explorados deben ser amplios, considerando varios observables capaces de discriminar la señal del background.

Las búsquedas actuales poseen gran complejidad, haciendo uso de todos los datos colectados.

Si no se observa señal de nueva física, se establecen límites de exclusión para los valores de los parámetros testeados.