# Search for Dark Matter in Events with a Hadronically Decaying W or Z Boson and Missing Transverse Momentum in pp Collisions at $\sqrt{s} = 8\,TeV$ with the ATLAS Detector.

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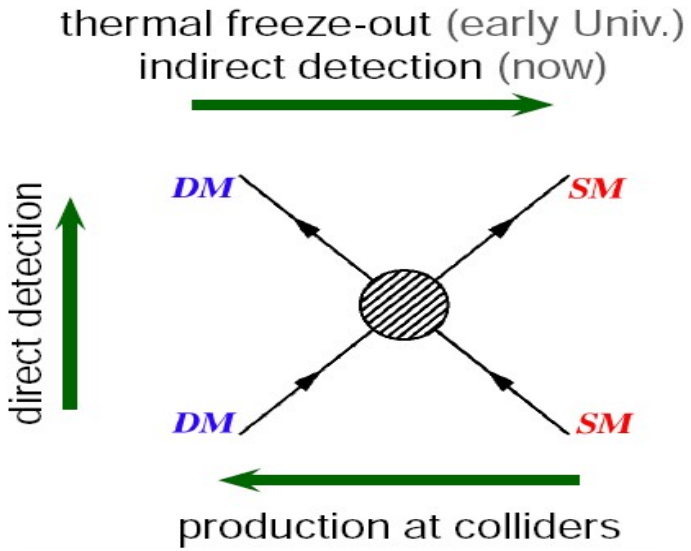
# Introduction

- Cosmology $\Longrightarrow$ 25% of universe = Dark matter
  - Weakly interacting Massive Particles (WIMP) are one possibility

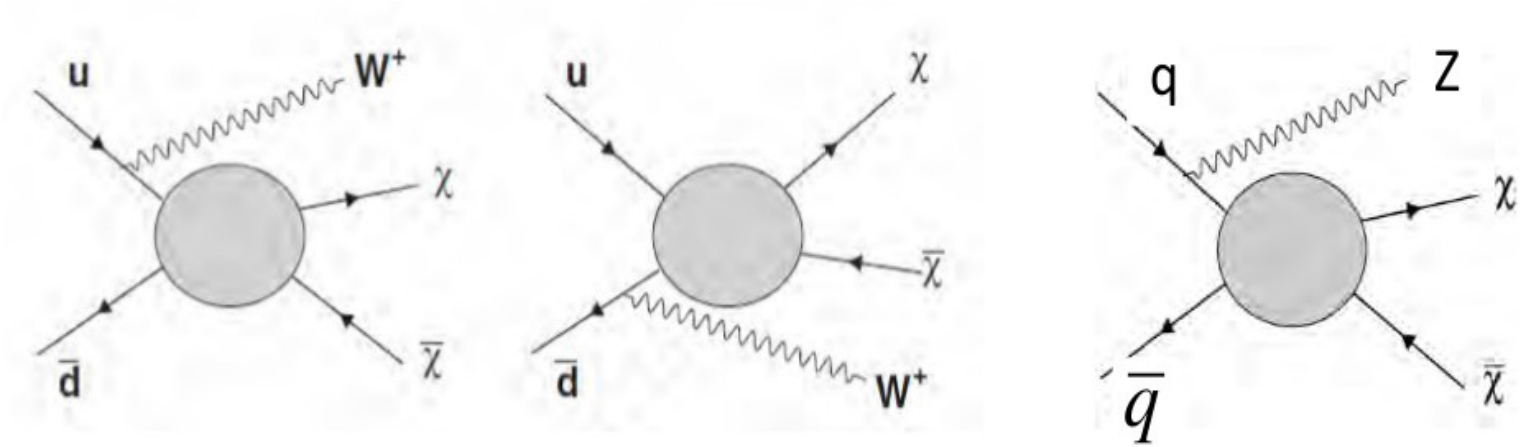
- The main theoretical characteristics of a WIMP are:
  - Interactions only through the weak nuclear force and gravity,
  - Large mass compared to standard particles

- Search for WIMP particles and their interactions with the SM particles:
  - Effective model to describe pair productions of the WIMPs particles
  - Search at the LHC $pp \to \chi\bar{\chi}$
  - $\chi$- nucleon interaction



# Introduction (cont.)

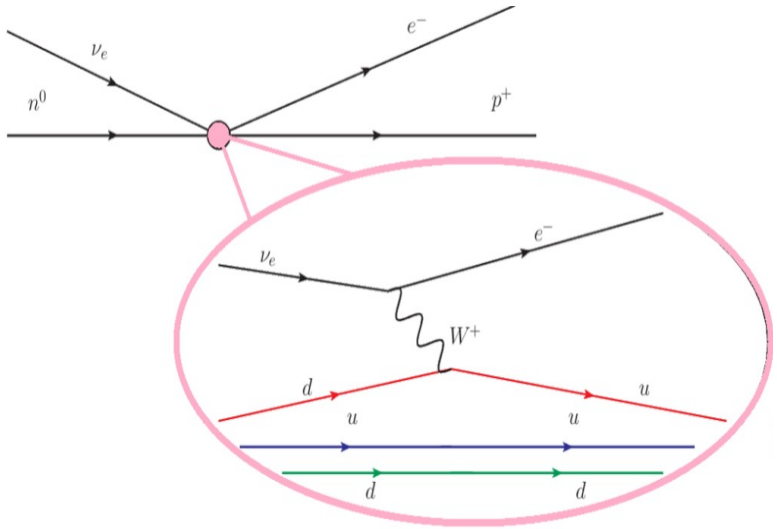
- But the final state $\chi\bar{\chi}$ are invisible to the detector
- Only mono-W/Z-boson events decaying hadronically are considered




- Signature W or Z + MET = two merged jets + $E_T^{miss}$
- W is sensitive to interference for different u/d couplings:
  - $C(u) = C(d)$ destructive interference
  - $C(u) = -C(d)$ constructive interference

# Effective interaction

- Analogy with the Fermi effective theory of Beta decay
- Fermion: Dirac or Majorana
- Scalar: real or complex
- $M_*$ characterize the interaction strength of the interactions



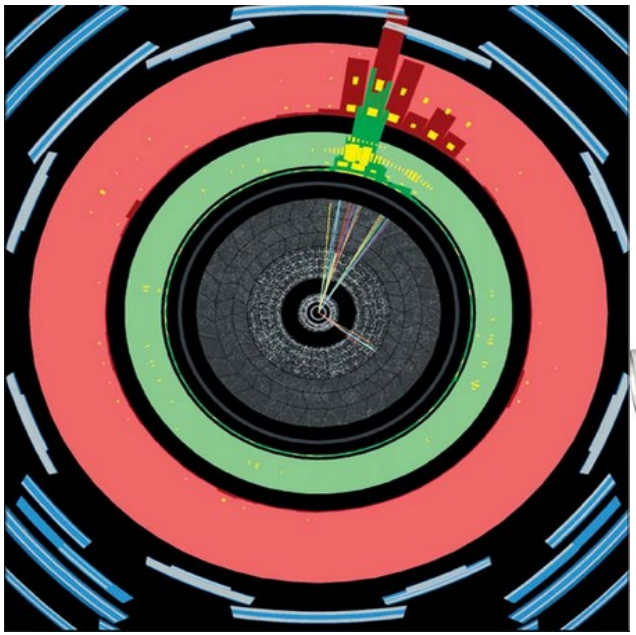

- Most prominent couplings

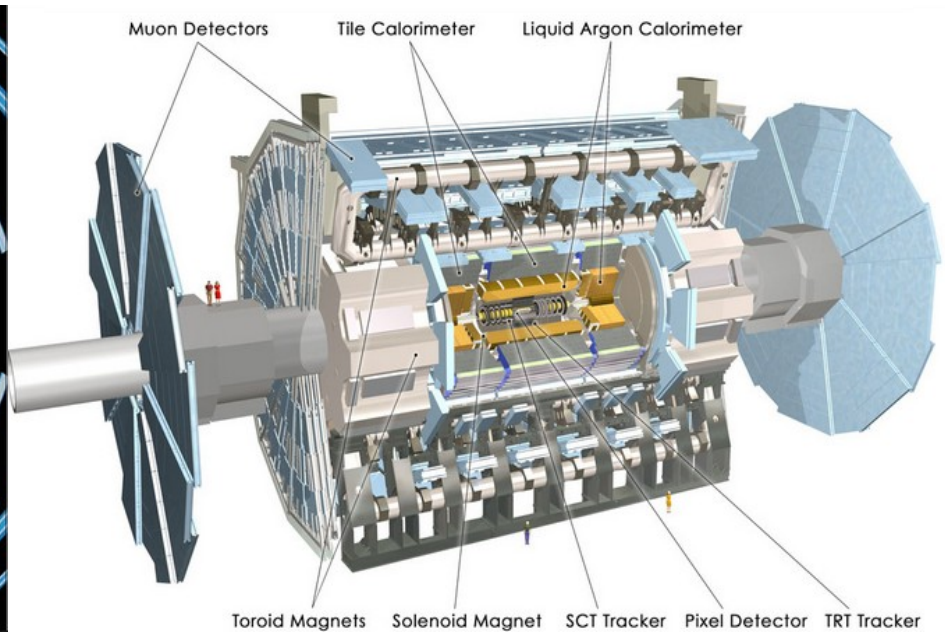
| Name | Type | Operator | Coefficient |
|---|---|---|---|
| D1 | scalar $(qq)$ | $\bar{\chi}\chi\bar{q}q$ | $m_q/M_*^3$ |
| D5 | vector | $\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$ | $1/M_*^2$ |
| D8 | axial-vector | $\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$ | $1/M_*^2$ |
| D9 | tensor | $\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$ | $1/M_*^2$ |
| D11 | scalar $(gg)$ | $\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$ | $\alpha_s/4M_*^3$ |
| C1 | scalar | $\chi^\dagger\chi\bar{q}q$ | $m_q/M_*^2$ |

- MC samples generated for $pp \to W\bar{\chi}\chi$ and $pp \to Z\bar{\chi}\chi$

# Experimental setup

- Data recorded with the ATLAS detector at LHC
- $\sqrt{s} = 8\,TeV$ and $20.3 fb^{-1}$ of integrated luminosity



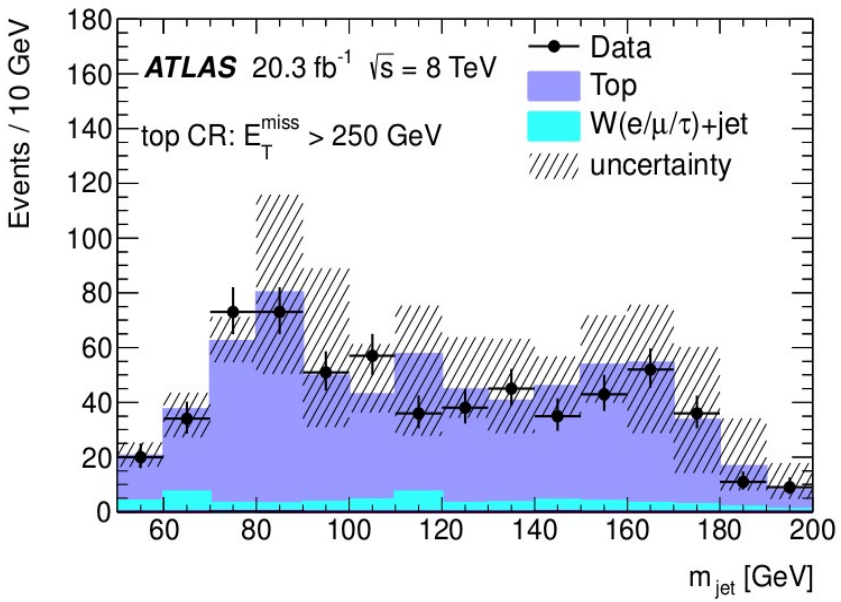


# Hadronically decaying W

- The jet candidates are reconstructed using the Cambridge-Aachen algorithm
  - Internal structure characterized by the momentum balance of the two leading subjets

$$\sqrt{y} = min(p_{T1}, p_{T2})\Delta R/m_{jet} \quad (1)$$

- The reconstruction of hadronic W boson decays with large-radius jets is validated in a $t\bar{t}$-dominated control region with:
  - One muon
  - One large-radius jet ($p_T > 250GeV, |\eta| < 1.2$)
  - Two additional narrow jets ($p_T > 40GeV, |\eta| < 4.5$) separated from the leading jet
  - At least one b miss tag
  - $E_T^{miss} > 250GeV$



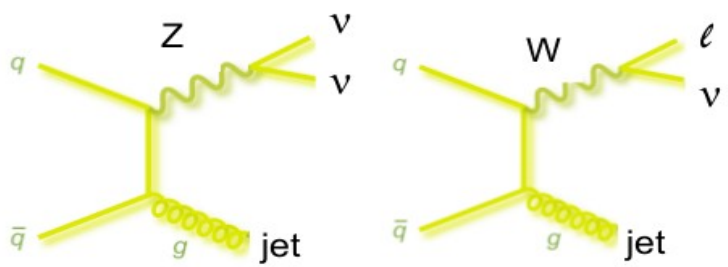
# Signal candidate

- Event selection:
  - Inclusive $E_T^{miss}$ trigger $\Longrightarrow$ 99% efficient for events with $E_T^{miss} > 150 GeV$
  - At least one large-radius jet
  - $p_T > 250 GeV$ (boosted jets)
  - $50 GeV < m_{jet} < 120 GeV$
  - $\sqrt{y} > 0.4$
  - Two signal regions: $E_T^{miss} > 350 GeV$ and $E_T^{miss} > 500 GeV$

- Aditional cuts to suppress background:
  - $\bar{t}t$ and multijet:
    - More than one narrow jet with $p_T > 40 GeV$ and $\mid \eta \mid < 4.5$
    - Not completly overlapping with the large-radious ($\Delta R > 0.9$)
  - $W \rightarrow l\nu$ contribution:
    - electron, photon or muon candidates with $p_T > 10 GeV$
    - Detected in the central region

# Background composition

- The dominant source of bkg: $Z \to \nu\bar{\nu}$ + jets from the initial-state radiation
- W or Z bosons leptonic decays in which the charged leptons fail identification requirements
- Diboson production
- Top quark pair production and single-top production



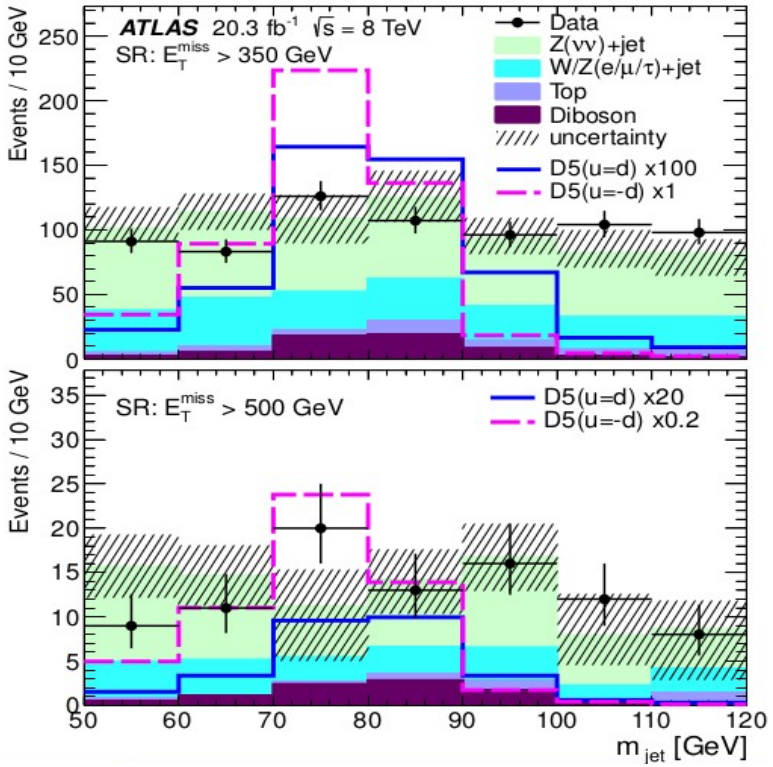

| Process | $E_{\mathrm{T}}^{\mathrm{miss}} > 350$ GeV | $E_{\mathrm{T}}^{\mathrm{miss}} > 500$ GeV |
|---|---|---|
| $Z \to \nu\bar{\nu}$ | $402^{+39}_{-34}$ | $54^{+8}_{-10}$ |
| $W \to \ell^{\pm}\nu$, $Z \to \ell^{\pm}\ell^{\mp}$ | $210^{+20}_{-18}$ | $22^{+4}_{-5}$ |
| $WW, WZ, ZZ$ | $57^{+11}_{-8}$ | $9.1^{+1.3}_{-1.1}$ |
| $t\bar{t}$, single $t$ | $39^{+10}_{-4}$ | $3.7^{+1.7}_{-1.3}$ |
| Total | $707^{+48}_{-38}$ | $89^{+9}_{-12}$ |
| Data | 705 | 89 |

# Search in the $m_{jet}$ distribution

- The Combined mono-W-boson and mono-Z-boson signal distribution with $m_{\chi}$=1GeV and $M_{*}$=1TeV for the D5 destructive and constructive cases

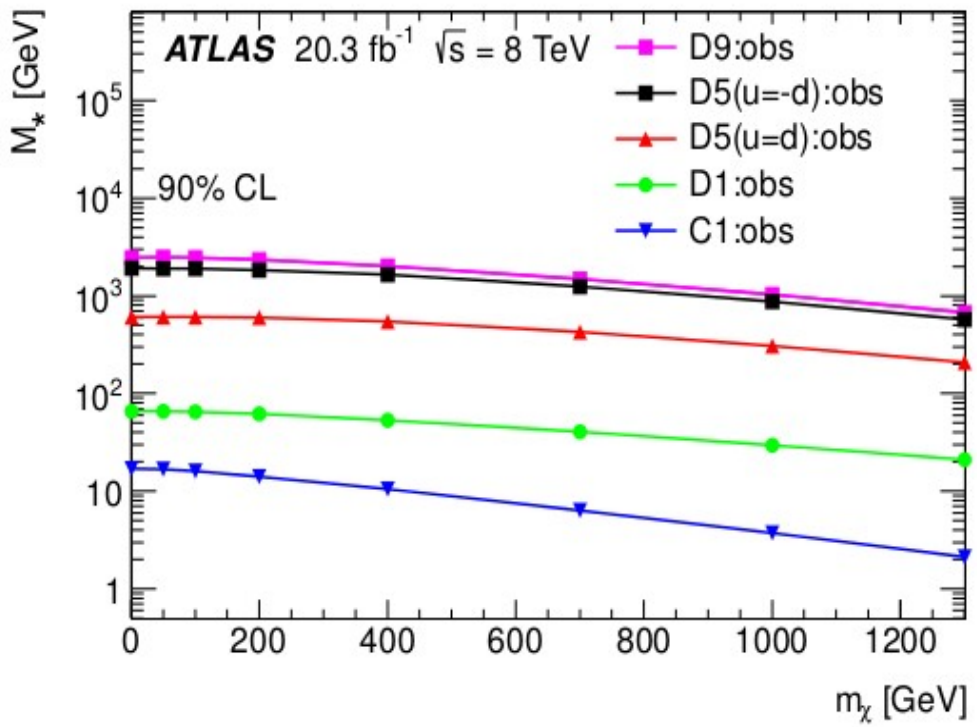
- Data in agreement with the SM expectation

- Dominating syst. uncertainties:
  - Limited statistics in control samples
  - Theoretical uncertanties
  - Jet and $E_T^{miss}$ reconstruction



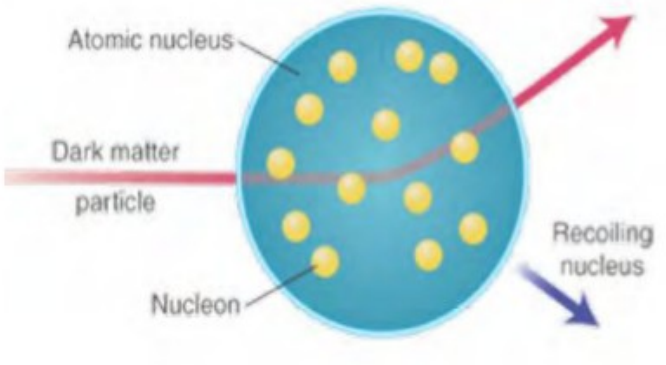
# Mass scale limits

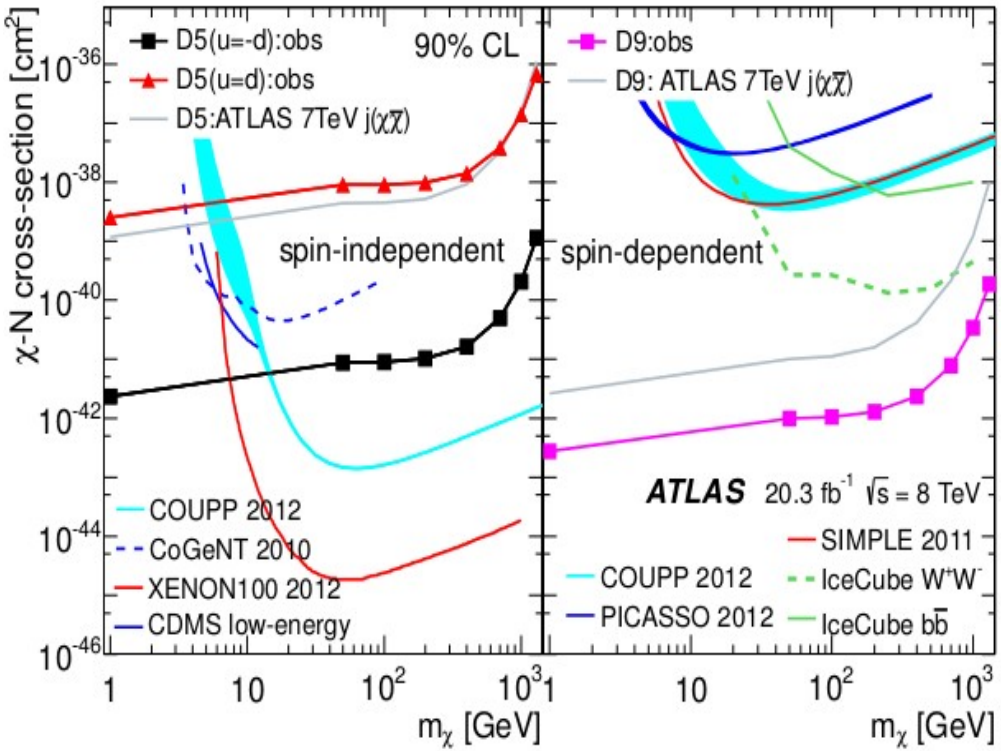
- Mass scale of the effective theory as function of $m_\chi$ at 90% C.L. for various operators
- The values below the corresponding operators are excluded



# Mono-W/Z in the $\chi$-N plane

- Limits on $\chi$-nucleons cross sections as funtion of $m_{jet}$ at 90% C.L.
- Spin-independent limits very strong $10^{-42} cm^2$ for vector coupling when u & d have opposite sign
- Set strong spin-dependent limits $10^{-43} cm^2$ for tensor operator



# Conclusion

- Limits on the dark-matter nucleon scattering cross sections
- The valid region of the theory becomes a poor aproximation if the mass of the intermediate state is below the momentum transfered
- The results are compared with measurements from direct detection experiments
- Dark matter production with mono-W/Z-boson extends the limits on the DM-Nucleon cross section in the low mass region
- Limits are also compared to the limits set by ATLAS in the / TeV mono-jet analysis
- For the spin-independient case with oposite-sign couplings, the limits improve 3 order of magnitud with respect to the constructive

# Thanks for your atttention!