Searches for Dark Matter at the LHC

IMPRS Young Scientist Workshop at Ringberg Castle
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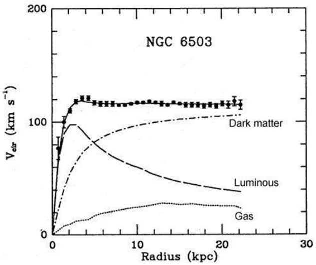
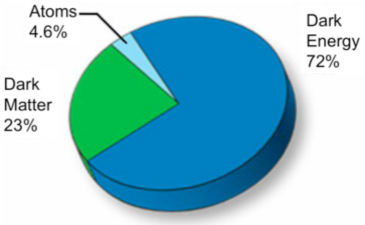
Dark Matter (DM)



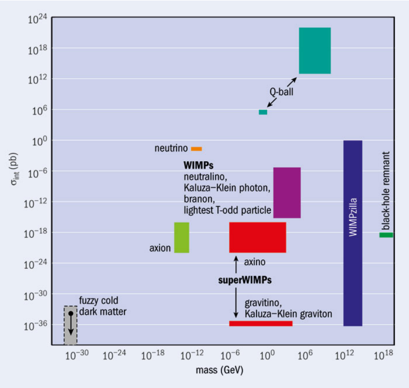
Begeman, Broeils, Sanders (MNRAS, 1991)



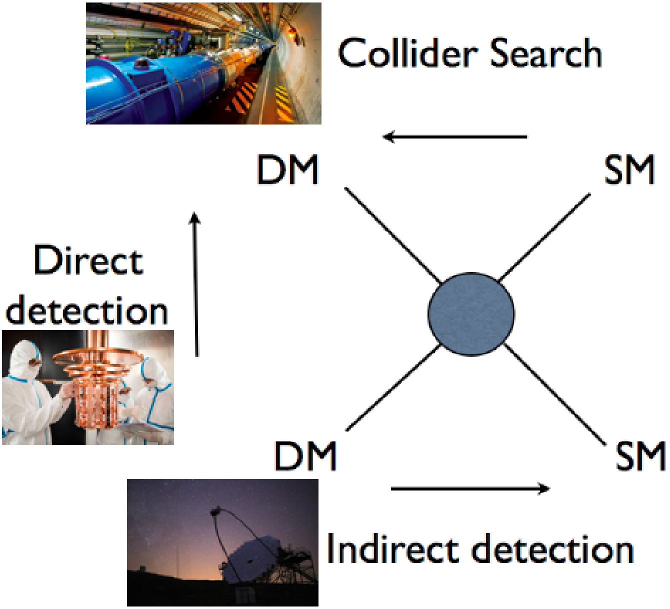
- Much evidence for the presence of DM
  - Galaxy rotation curves, gravitational lensing etc. (But only gravitational interaction)
- 23% of the universe is DM
- Explaining DM is one of the main motivations for physics beyond the standard model
- One candidate for DM is WIMP

Weakly Interacting Massive Particle (WIMP)

- Most favourite DM candidate
- Stable, non-baryonic, electrically neutral
- Mostly WIMP taken as Dirac Fermion
- Expected mass range: 1 GeV-10 TeV

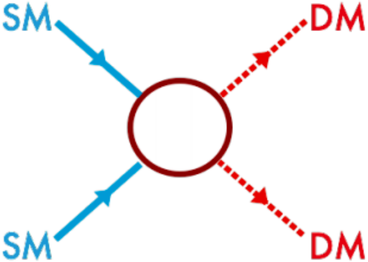


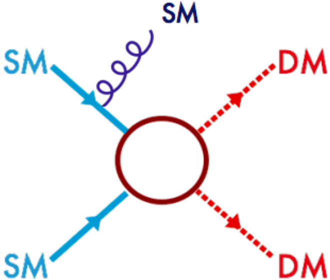
Ways to search for Dark Matter



Mono-X searches

- At colliders: WIMP pair production
- However, without additional particles, WIMPs do not create any signal
- WIMP production in association with visible SM particle(s) X results in signatures with E_T^{miss}
- Search for Mono-X with X $=$ jet, γ, W, Z, H
- Mono-jet is the most powerful search for DM at LHC





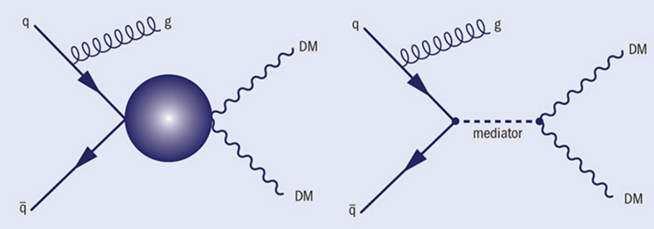
Simulation of WIMP production

EFT

- Effective Field Theory (EFT): 4-point interaction
- Used in LHC Run 1
- But EFT invalid at large momentum transfer

Simplified model

- Used in LHC Run 2
- Expanding the contact interaction of DM with SM particles, including a new massiv mediator
- Spin 1 and 0 mediator
- 4 free parameters (m_χ,m_{med},g_{SM},g_{DM})



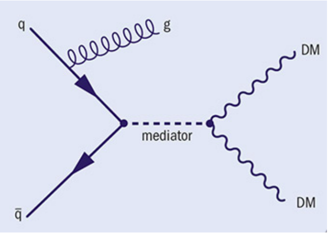
Simulation of WIMP production

Mediator Type	g_{DM}	g_q
Vector	1	0.25
Axial-Vector	1	0.25
Scalar	1	1
Pseudo Scalar	1	1

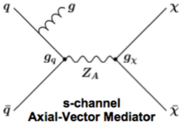
- ATLAS-CMS Dark Matter Forum (arXiv:1507.00966) define benchmark models

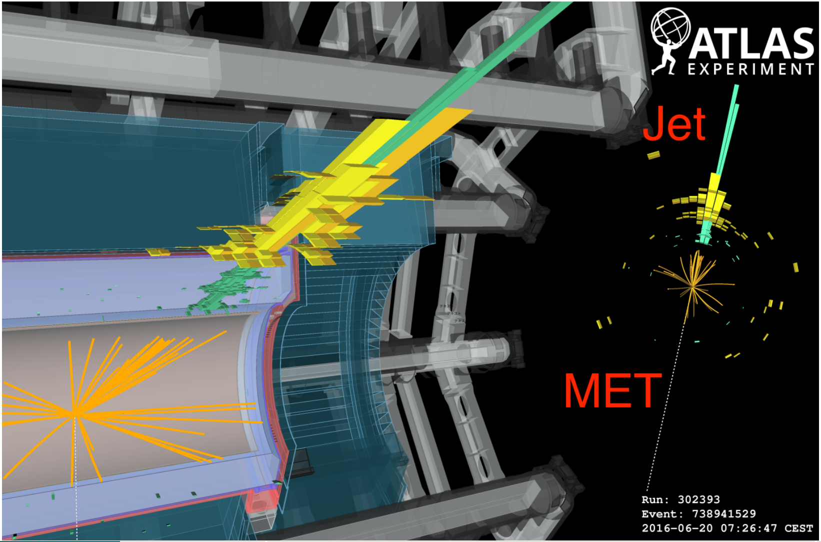
Simplified model

- Used in LHC Run 2
- Expanding the contact interaction of DM with the SM, include a mediator
- Spin 1 and 0 mediator
- 4 free parameters (m_χ,m_{med},g_{SM},g_{DM})



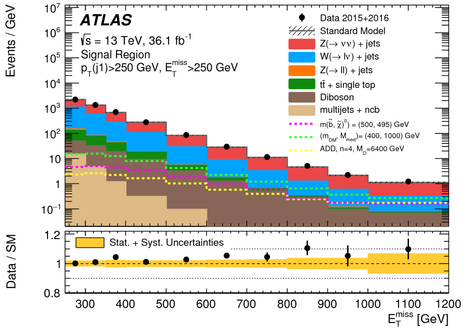
Mono-jet search at ATLAS





Mono-jet search at ATLAS

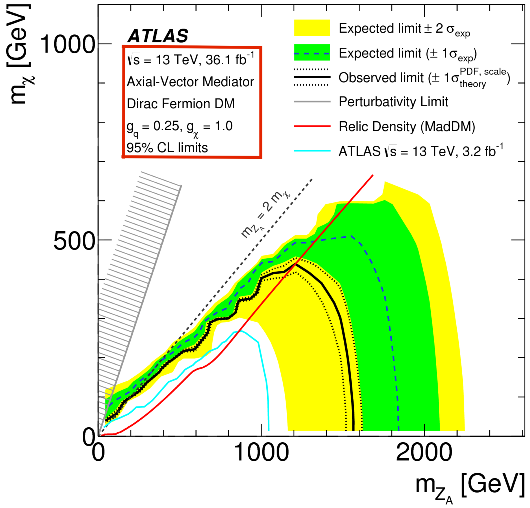
- Signal region:
  - At least 1 jet with $p_T > 250$ GeV
  - $E_T^{miss} > 250$ GeV
  - Lepton veto
  - And up to 3 jets with $p_T > 30$ GeV arrowed
- Dominant backgrounds: Z+jets, W+jets
- Control regions are used to study backgrounds
  - Determine normalization factor and test in signal free validation regions



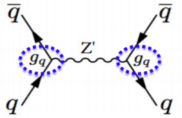
Mono-jet exclusion limits

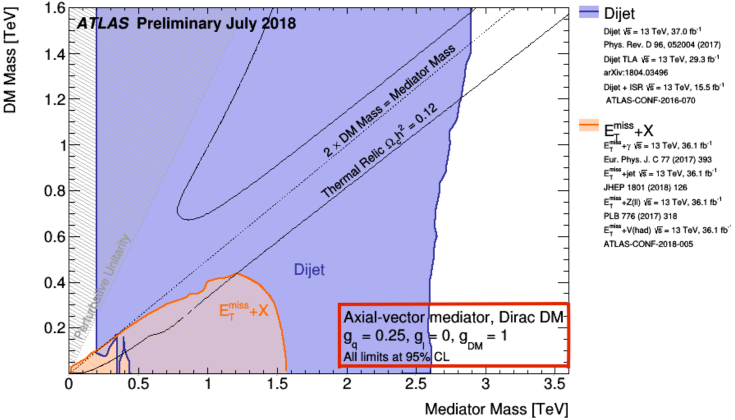
Perturbativity limits: $\frac{m_{DM}^2 g_{DM}^2}{(\pi M_{med}^2)} < \frac{1}{2}$

For $g_{DM}=1$: $m_{DM} < \sqrt{\frac{\pi}{2}} M_{med}$

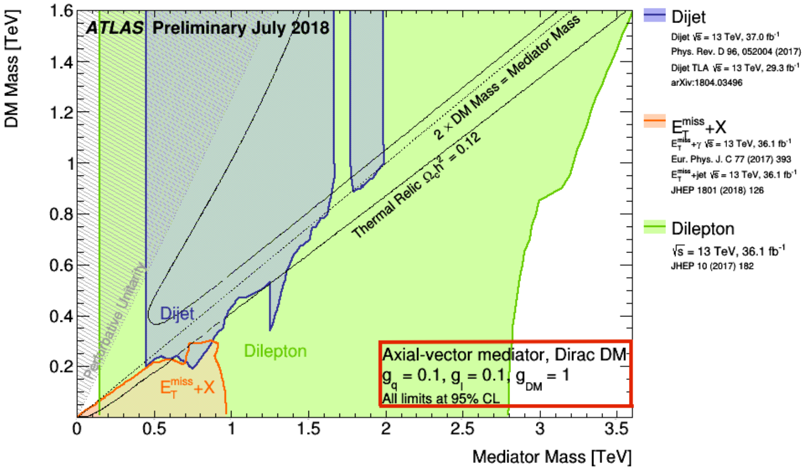


Exclusion limits for all Mono/Di-jet searches



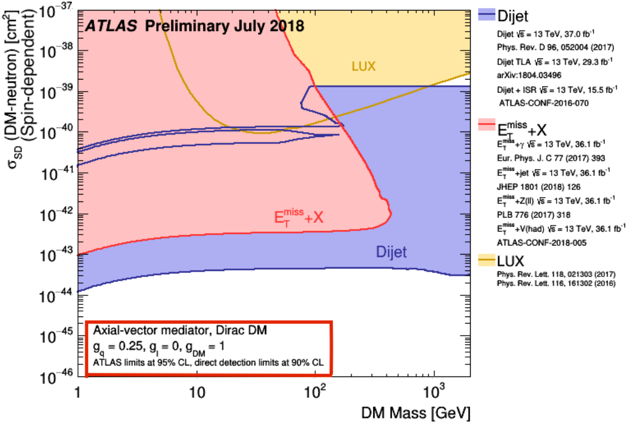


Exclusion limits for all Mono/Di-jet searches



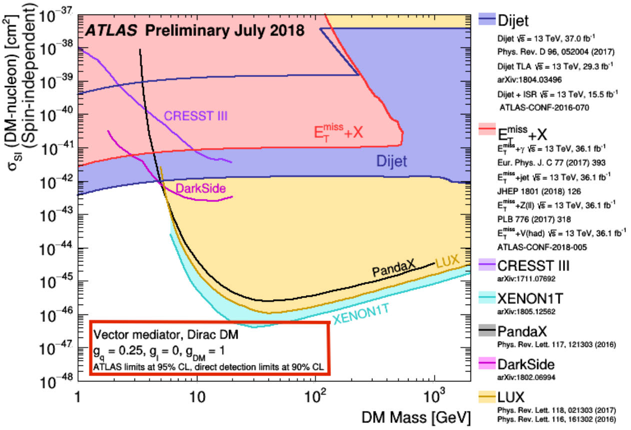
Comparison to direct detection experiments

Axial-vector mediator: $\sigma_{\mathrm{SD}} \propto \frac{g_{\mathrm{DM}}^2 \mu_{n\chi}^2}{M_{\mathrm{med}}^4}$, $\mu_{n\chi} = \frac{m_n m_{\mathrm{DM}}}{(m_n + m_{\mathrm{DM}})}$



Comparison to direct detection experiments

Vector mediator: $\sigma_{\mathrm{SI}} \propto \frac{g_{\mathrm{DM}}^2 \mu_{n\chi}^2}{M_{\mathrm{med}}^4}$, $\mu_{n\chi} = \frac{m_n m_{\mathrm{DM}}}{(m_n + m_{\mathrm{DM}})}$



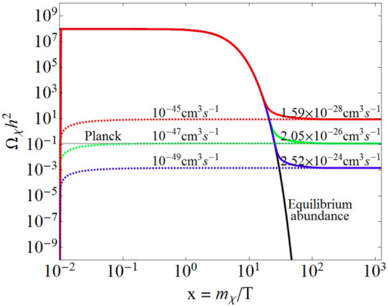
Summary

- Most favoured DM candidate: WIMP
- Searches for DM at colliders
- Example: ATLAS Mono-jet analysis
- LHC searches for DM are complementary to (in)direct DM searches
- Next talk: Dark Matter and the Higgs Boson at ATLAS
  Speaker: Rainer Röhrig

Backup

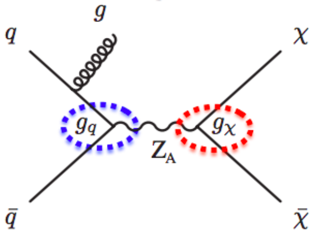
Weakly Interacting Massive Particle (WIMP)

- In early universe WIMPs are present in large number
- They are in theremal equilibrium $\chi\chi \longleftrightarrow ff$
- Universe expanded and cooled
  - Density are reduced through pair annihilation
- Annihilation rate drops below the expansion rate of the Universe and the DM interactions become insufficient to maintain thermal equilibrium (freeze out)

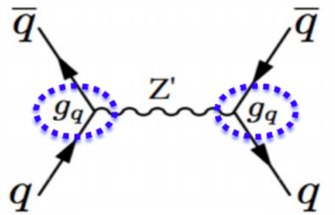


DM models

- invisible DM search (Mono-X)



- DM Mediator search (DI-X)



- spin 1 and 0 mediator, 4 free parameters (m_χ,m_{med},g_{SM},g_{DM})

Fitting Strategy Mono-Jet

- Background only fit
- Fit applied using 10 MET bins for model dependent interpretation
- Fit applied using inclusive MET cuts for model-indipendent interpretation

Exclusive bins (used for interpretation)	Inclusive bins (used for model-independent results)
$250\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 300\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 250\,\text{GeV}$
$300\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 350\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 300\,\text{GeV}$
$350\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 400\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 350\,\text{GeV}$
$400\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 500\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 400\,\text{GeV}$
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$800\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 900\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 800\,\text{GeV}$
$900\,\text{GeV} < p_{\text{T}}^{\text{recoil}} < 1\,000\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 900\,\text{GeV}$
$p_{\text{T}}^{\text{recoil}} > 1\,000\,\text{GeV}$	$p_{\text{T}}^{\text{recoil}} > 1\,000\,\text{GeV}$