Search for dark matter candidates in events with a jet and missing transverse momentum with the ATLAS detector

C. M. Delitzsch, P. Clavier

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Introduction

Our article:

Search for dark matter candidates and large extra dimensions in events with a jet and missing transverse momentum with the ATLAS detector
ATLAS-CONF-2012-084
ATLAS Collaboration
July 3, 2012

A CMS article: arXiv:1204.0821v1

Outline:

1. Introduction
2. Dark matter
3. WIMPs
4. Data set, event selection and background
5. Results
6. Conclusion

Dark matter(1)

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Dark matter= explanation to cosmological observations

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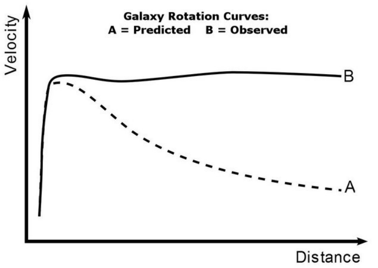
galactic rotation curve:

Look at a galaxy and deduce its weight

$\Rightarrow$ Use GR to have rotation curve



galaxies look heavier than predicted!

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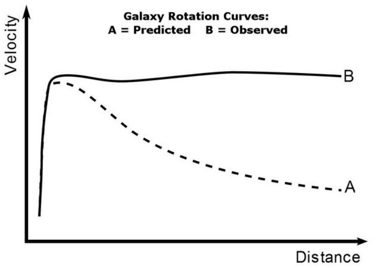

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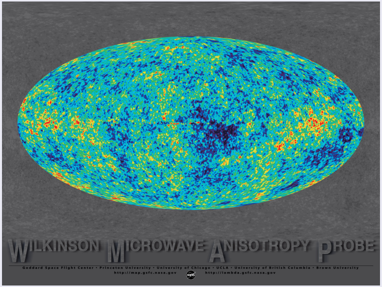
CMB:



Baryonic matter interacts with photons

Dark matter does not

$\Rightarrow$ different spectrum of CMB!

Dark matter(2)

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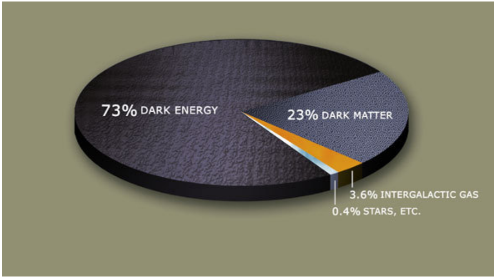
HUGE amount of dark matter!!



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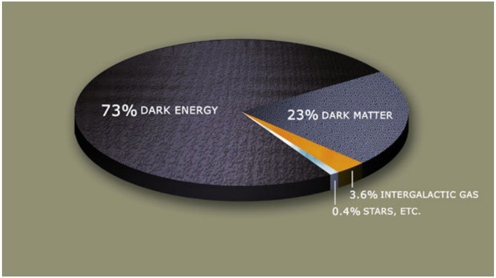

SUSY? Neutrinos? WIMPs?

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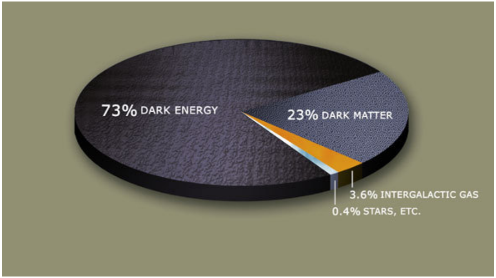

SUSY? Neutrinos? WIMPs? ⇒ BSM physics ⇒ accelerators

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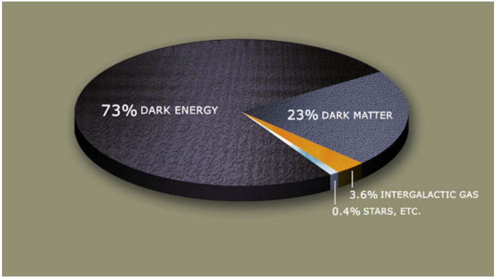

SUSY? Neutrinos? WIMPs? $\Rightarrow$ BSM physics $\Rightarrow$ accelerators

Other theories:

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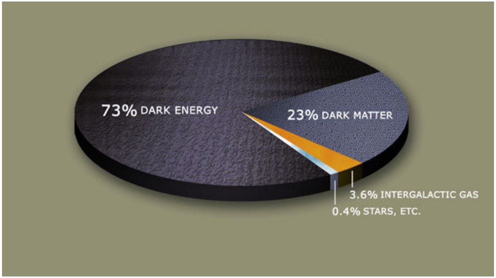

SUSY? Neutrinos? WIMPs? $\Rightarrow$ BSM physics $\Rightarrow$ accelerators

Other theories:

- MOdified Newton Dynamics (MOND)
- Dark Fluid
- Quantum Gravity

WIMPs(1)

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- Interact only via weak force and gravity
- Masses $\sim$ 10 GeV - 10 TeV
- numerous candidates (LSP, Neutralinos...)

Assumptions:

- Masses $\gtrsim$ few GeV $\Rightarrow$ effective theory
- Dirac fermions $\Rightarrow$ bispinors transforming under $(\frac{1}{2},0) \oplus (0,\frac{1}{2})$ rep of SO(3,1).

WIMPS(2)

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Interactions:

WIMPS(2)

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- $q\bar{q} \rightarrow \chi\bar{\chi} \rightsquigarrow$ Scalar, Vector, Axial-Vector, Tensor operators
- $gg \rightarrow \chi\bar{\chi} \rightsquigarrow$ Scalar operator

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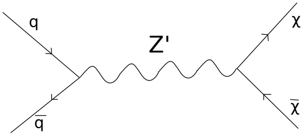
The vector operator:

- $\mathcal{O}_V = \frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
- spin-independent scattering
- s-channel: $q\bar{q} \to Z' \to \chi\bar{\chi}$

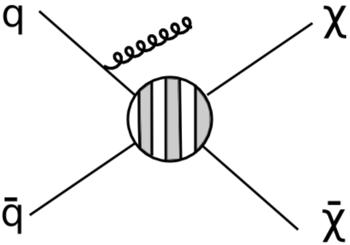
$\mathcal{O}_V$ is the effective coupling derived from the Feynman diagram:



What we're searching for

Signal events in monojet topology

- one high-energetic jet (initial state radiation)
- large missing transverse energy



Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

Data set:

- Full 2011 data set
- $\sqrt{s} = 7$ TeV, $\mathcal{L} = 4.7\ \mathrm{fb}^{-1}$

Event Selection:

1. Quality requirements, e.g. trigger has fired, good primary vertex, ...
2. max. of two jets with $p_T > 30$ GeV, $|\eta| < 4.5$, leading jet: $|\eta| < 2$
3. suppress dijet events: $|\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\mathrm{jet2}})| > 0.5$
4. veto event which have an electron or muon

- define four different signal regions (SR) with different kinematic selections
  $\Longrightarrow$ sensitive to a wide range of BSM models

Signal region	SR1	SR2	SR3	SR4
cut on $p_{\mathrm{T}}^{\mathrm{jet1}}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	120	220	350	500

Background

Dominant background:

- $Z \rightarrow \nu\nu$ + jets — irreducible
- $W \rightarrow l\nu_l$ + jets — $(l = \tau, \mu, e)$
- $Z \rightarrow ll$ + jets

} data driven

- estimated in four different control regions

Further backgrounds:

- single and pair production of top quarks
- di-boson production

} MC simulation

- non-collision background
- QCD multijet background

} data driven

Z/W + jets background estimation I

- define four different control regions (CR) by selecting $e^{\pm}$ or $\mu^{\pm}$
- tighter cuts on electrons, muons than in signal region
- CR dominated by Z and W events, no contamination from BSM
- apply same cuts on $E_{\mathrm{T}}^{\mathrm{miss}}$ and leading jet p_{T} as in SR

SR	$Z \to \nu\bar{\nu}$+jets	$W \to \tau\nu$+jets $W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \tau^+\tau^-$+jets $Z \to \mu^+\mu^-$+jets
CR	$W \to e\nu$+jets $W \to \mu\nu$+jets $Z \to e^+e^-$+jets $Z \to \mu^+\mu^-$+jets	$W \to \mu\nu$+jets	$W \to e\nu$+jets	$Z \to \mu^+\mu^-$+jets

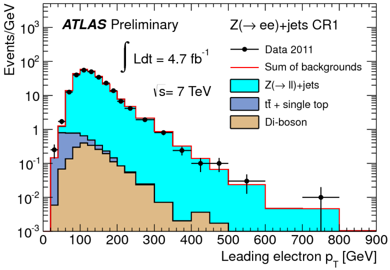
- estimate background shape and normalization in SR from CR by applying corrections
- corrections account for e.g different kinematic selections and trigger
- correction factors calculated using data and MC simulations

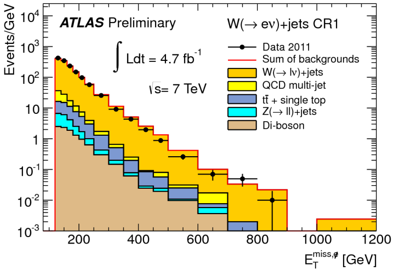
Z/W + jets background estimation II

Background prediction in SR

$$N_{SR}^{\mathrm{predicted}} = (N_{CR}^{\mathrm{data}} - N_{CR}^{\mathrm{bkg}}) \cdot C \cdot \frac{N_{SR}^{MC}}{N_{\mathrm{jet}/E_T^{\mathrm{miss}}}^{MC}}$$

- C : contains acceptances, efficiencies and trigger luminosities
- $\frac{N_{SR}^{MC}}{N_{\mathrm{jet}/E_T^{\mathrm{miss}}}^{MC}}$: translates observed number of events in data in CR to predicted number of events in SR



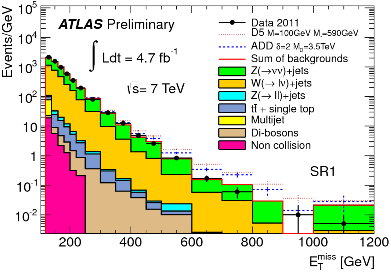


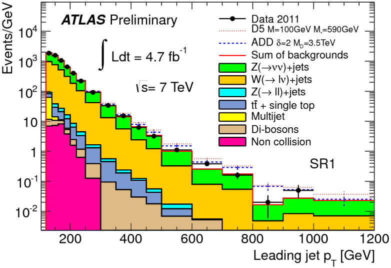
Results

- good data/MC agreement
  $\Longrightarrow$ set limits on visible σ_{vis}

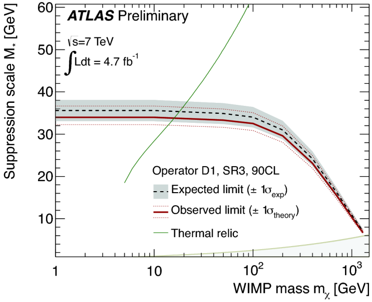
$$\sigma_{\text{vis}} = \sigma \cdot A \cdot \epsilon$$

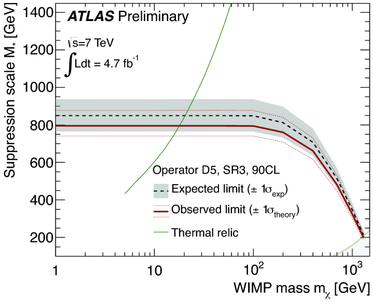
	SR1	SR2	SR3	SR4
$Z \to \nu\bar{\nu}$+jets	63000 ± 2100	5300 ± 280	500 ± 40	58 ± 9
$W \to \tau\nu$+jets	31400 ± 1000	1853 ± 81	133 ± 13	13 ± 3
$W \to e\nu$+jets	14600 ± 500	679 ± 43	40 ± 8	5 ± 2
$W \to \mu\nu$+jets	11100 ± 600	704 ± 60	55 ± 6	6 ± 1
$t\bar{t}$ + single t	1240 ± 250	57 ± 12	4 ± 1	-
Multijets	1100 ± 900	64 ± 64	8^{+9}_{-8}	-
Non-coll. Background	575 ± 83	25 ± 13	-	-
$Z/\gamma^* \to \tau\tau$+jets	421 ± 25	15 ± 2	2 ± 1	-
Di-bosons	302 ± 61	29 ± 5	5 ± 1	1 ± 1
$Z/\gamma^* \to \mu\mu$+jets	204 ± 19	8 ± 4	-	-
Total Background	124000 ± 4000	8800 ± 400	750 ± 60	83 ± 14
Events in Data (4.7 fb^{-1})	124703	8631	785	77
$\sigma_{\text{vis}}^{\text{obs}}$ at 90% [pb]	1.63	0.13	0.026	0.006
$\sigma_{\text{vis}}^{\text{exp}}$ at 90% [pb]	1.54	0.15	0.020	0.006
$\sigma_{\text{vis}}^{\text{obs}}$ at 95% [pb]	1.92	0.16	0.030	0.007
$\sigma_{\text{vis}}^{\text{exp}}$ at 95% [pb]	1.82	0.17	0.024	0.008





Limits on suppression scale M_*





- 90% CL on suppression scale M_* as a function of WIMP mass m_χ
- Limits for different operators
- Systematics taken into account
- Green curve: thermal relic density

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D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
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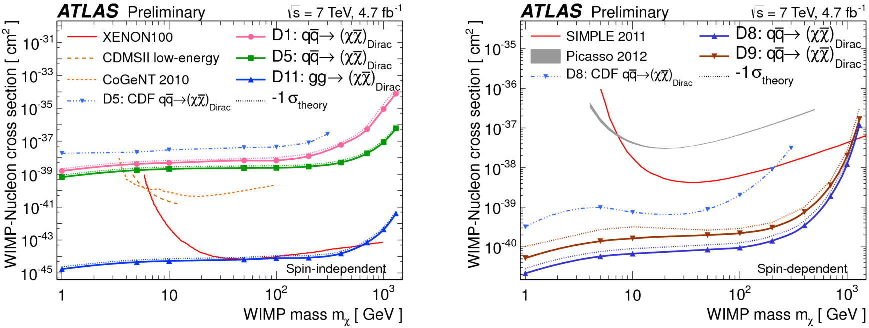
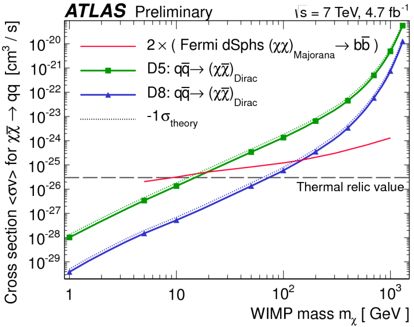
Limits on WIMP-nucleon scattering cross section

- convert limits on suppression scale to WIMP-nucleon scattering
- compare with direct dark matter detection experiments
- spin-dependent and independent interactions



Limits on WIMP annihilation rates

- Limits on M_* can be translated in upper limits on annihilation rate of WIMPs to light quarks (vector and axial-vector interaction)
- Assumption: WIMPs annihilate only into the four light flavor quarks

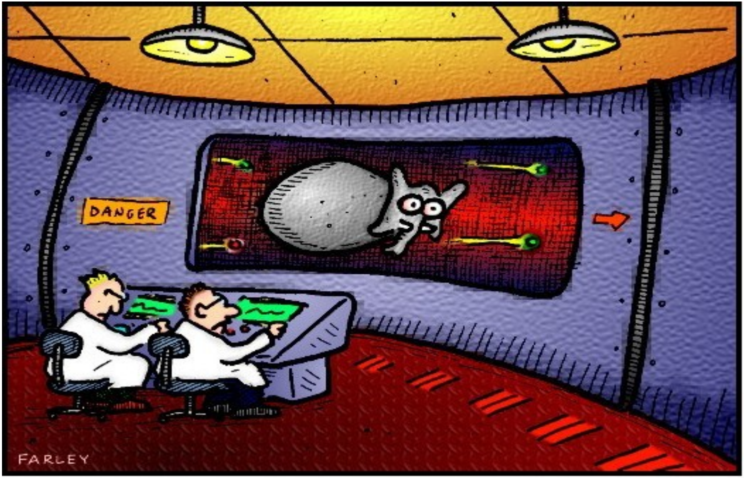


- Red curve: annihilation to $b\bar{b}$ from galactic high-energy gamma ray observations

Conclusion

- Dark matter is needed for astrophysical observations to make sense
- WIMPs are good candidates for dark matter
- Search for events with a high p_{T} jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ in 2011 data set
- Analysis sensitive to a wide range of BSM models (four different signal regions)
- No deviations from Standard Model predictions were found
- Limits on suppression scale M_* are set
- WIMP pair production at LHC is compared to direct dark matter detection experiments

THANK YOU FOR YOUR ATTENTION !



Deep within the atomic supercollider, the search continues for the elusive elephantino.