Search for Prompt Lepton-Jets in pp Collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector.

Physics Letter B 719 (2013) 299-317

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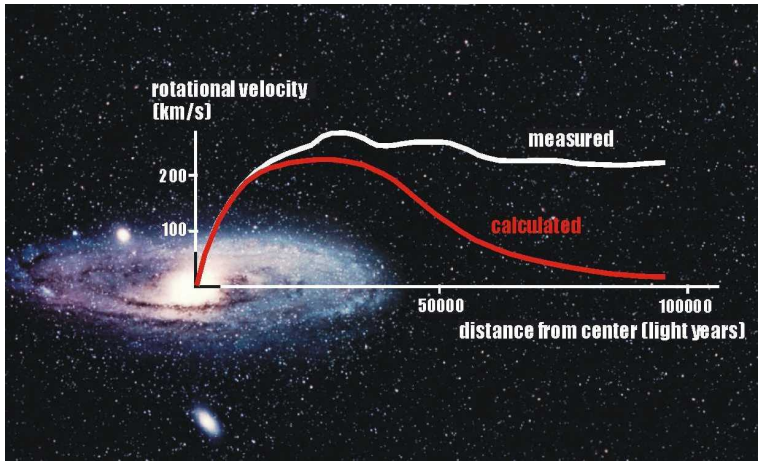
Outline

Introduction

- Dark matter: 85% of all matter.
- Evidence for dark matter's existence.
  - Kinematics of galactic clusters.[1]
  - Galactic rotation curves.[2]
  - Collision of galactic clusters.[4]
  - PAMELA[6], HEAT[3], ATIC[5] $\leftarrow$??
- Hypothesized Dark Sector (DS):
  - Dark particles.
  - Dark forces $\rightarrow$ Dark gauge bosons.
  - Dark higgs.



Credit:
http://cdms.phy.queensu.ca/Public_Docs/DM_Intro.html

1. F. Zwicky, 1937, APJ, 86, 217
2. V. Rubin, *et al.*, The APJ, 238:471-487, 1980
3. HEAT, APJ, 482 (1997) L191
4. D. Clowe *et al.*, 2006 APJ 648 L109
5. ATIC, Nature 456 (2008) 362
6. PAMELA, Nature 458 (2009) 607
7. Fermi LAT Collaboration, Phys. Rev. Lett. 102 (2009) 181101
8. DAMA, Eur. Phys. J. C 67 (2010) 39

Dark Sector & Collider Signature

- Small DS-Standard Model (SM) interaction hypothesized through kinetic mixing of Dark and SM photons.
- Dark sector radiation (α_D).

Search parameter values

m_{γ_D} (MeV)	α_D
150	0
300	0.1
500	0.3

Theory ref.

N. Arkani-Hamed, *et al.*, JHEP 12 (2008) 104
M. Baumgartm *et al.*, JHEP 0904 (2009) 014
D.S. Alves, *et al.*, Phys. Lett. B 692 (2010) 323
G.D. Kribs, *et al.*, Phys. Rev. D 81, 095001 (2010)
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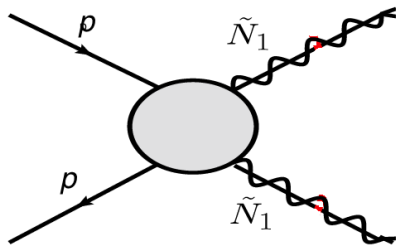
C. Cheung, *et al.*, JHEP 1004 (2010) 116



$m_{\tilde{N}1} = 96$ GeV

$m_h = 2$ GeV

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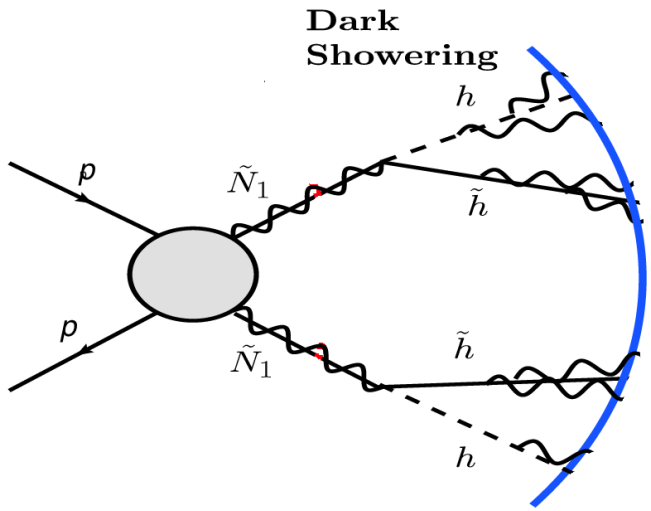

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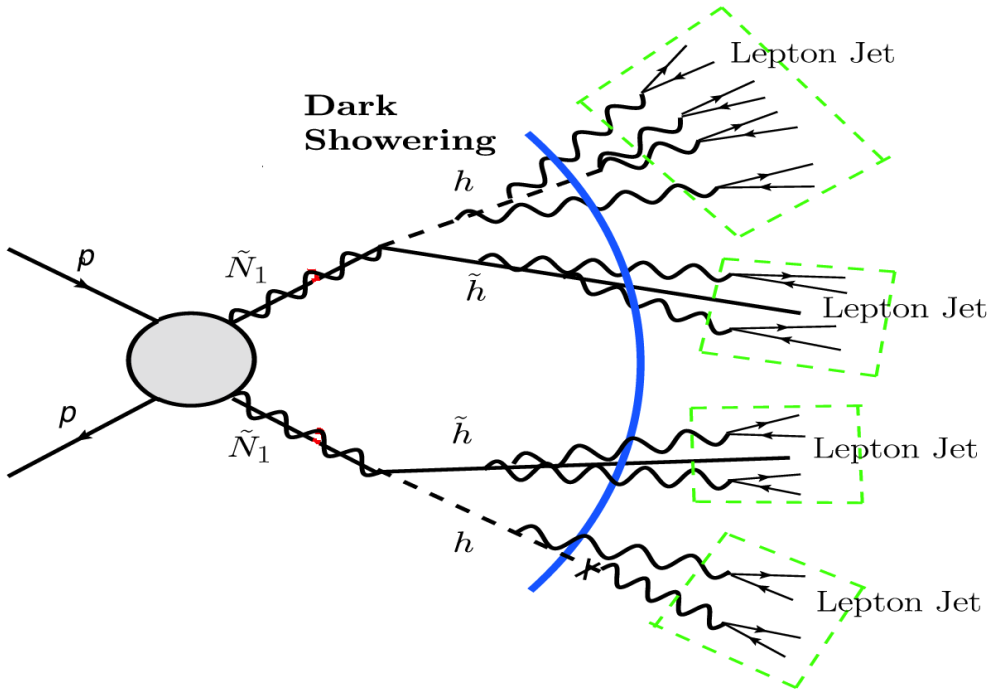

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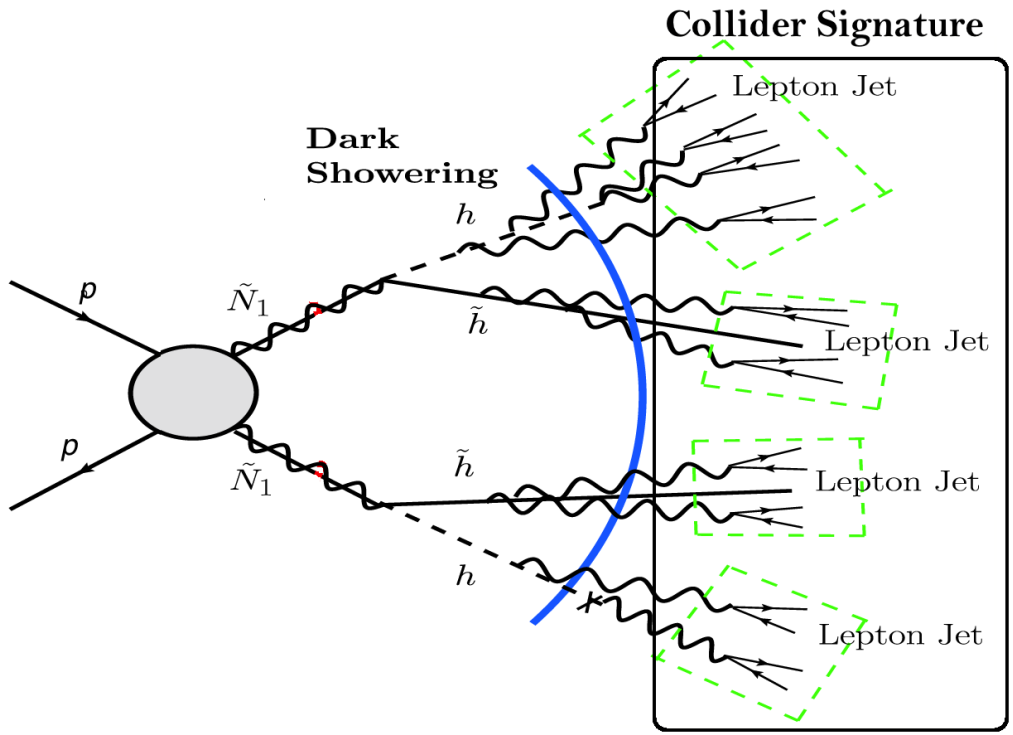
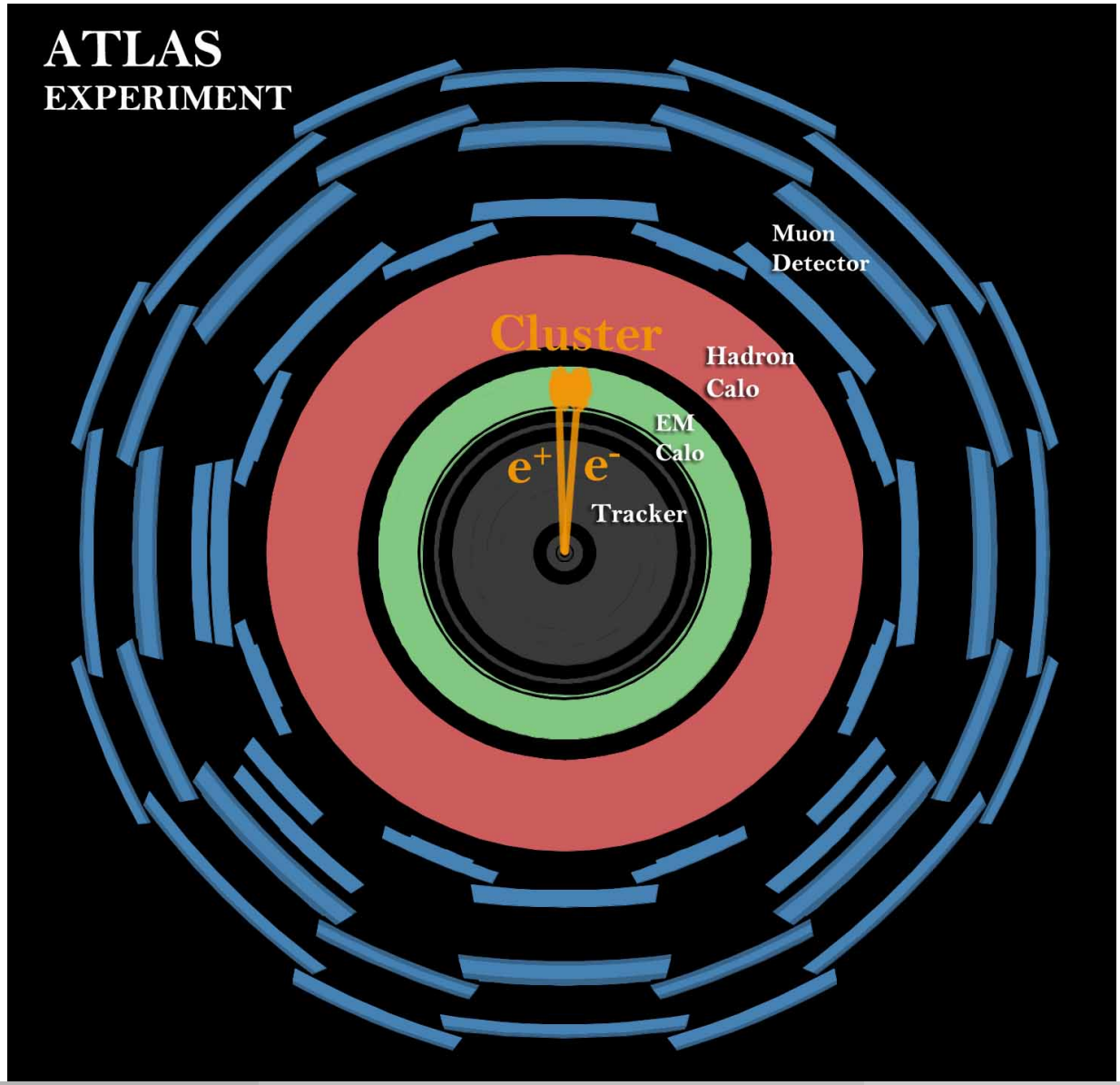
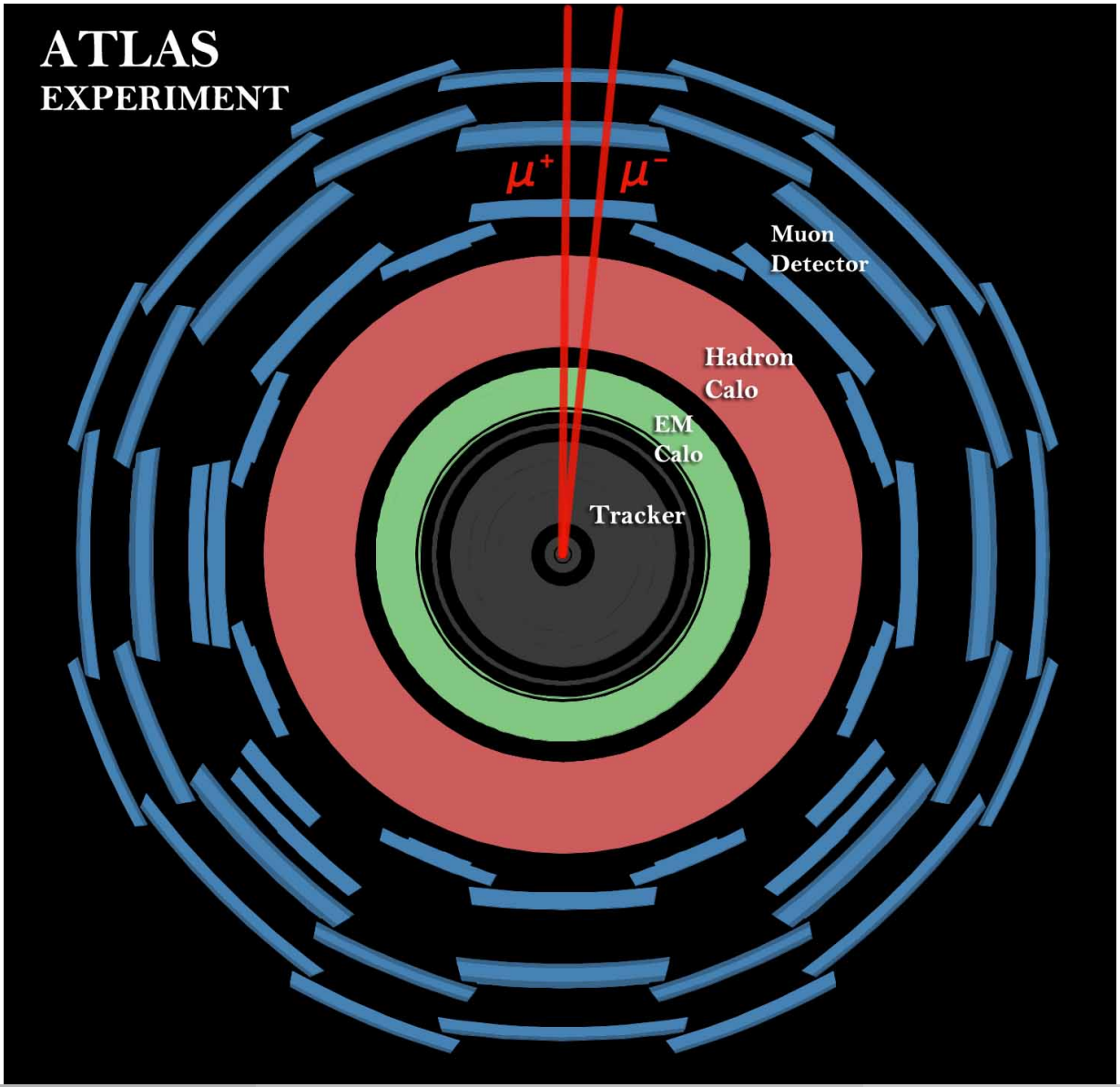


Collider Signature Cartoon: Electron-Jet



Collider Signature Cartoon: Muon-Jet

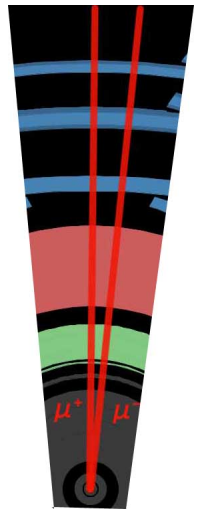


Event and Object Selection

2011 data, CM energy, $\sqrt{s} = 7$ TeV.

Electron-jet preselection

- ElectroMagnetic (EM) cluster, $E_T > 10$ GeV.
- At least two electron-jets per event.
- Electron trigger: $E_T > 20$ GeV.
- Trigger-Reconstructed cluster match: $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.2$.
- Two 10 GeV tracks from the primary vertex point to cluster.
- Invariant mass (highest p_T tracks) < 2 GeV.



Muon-jet preselection

- Combined info from the Inner detector and the Muon detector.
- Muons from the primary vertex.
- Trigger: Single muon-jet - 18 GeV 1-muon trigger.
  Double muon-jet - 18 GeV 1-muon + 6 GeV 3-muon trigger.
- Invariant mass (highest p_T tracks) < 2 GeV.

Signal and Background Samples

- Monte Carlo (MC) simulation: Understanding signal and Background (BG) behavior.
- Discriminating variables.
- Optimizing signal selection and BG rejection.

Signal simulation

		m_{γ_D}[MeV]		
		150	300	500
α_D	0	✔	✔	✔
	0.1	✔	✔	✔
	0.3	✔	✔	✔

BG characterization

MC samples

- γ + jets
- Di-bosons (W^+W^-, $W^\pm Z^0$, Z^0Z^0)
- $t\bar{t}$

Hadronic jets - data driven.

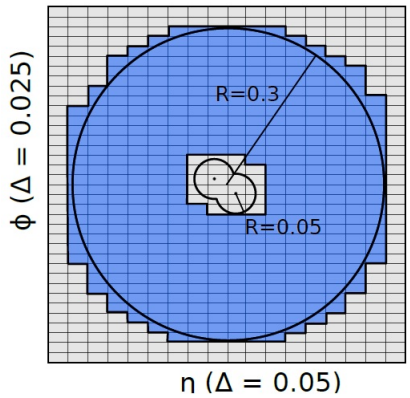
Discriminating Variables

Electron-jet

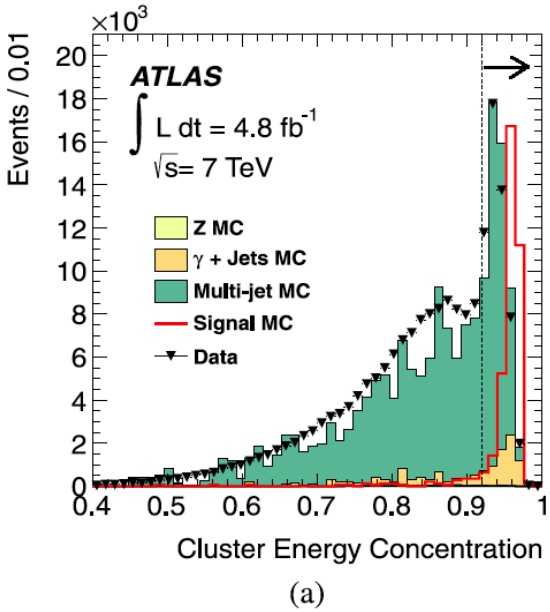
- $R_{\eta 2} = \frac{\textit{Energy deposited in } 3\times7(\eta\times\phi)\textit{cells of EM Calorimeter}}{\textit{Energy deposited in the } 7\times7\textit{cells of EM Calorimeter}} > 0.92$
- $w_{\eta 2} = \sqrt{\frac{\sum_i E_i \times \eta_i^2}{\sum_i E_i} - \left(\frac{\sum_i E_i \times \eta_i}{\sum_i E_i}\right)^2} < 0.0115$
- Scaled isolation $= \frac{\textit{Energy with } 0.1 < \Delta R < 0.4 \textit{ around the cluster}}{Cluster E_T} < 0.3.$
- EM fraction $= \frac{\textit{Energy deposited in EM Calorimeter}}{\textit{Energy deposited in the EM + Had calorimeter}} > 0.98$
- TRT HT Ratio $= \frac{\textit{Number of HT TRT hits}}{\textit{Total No. of TRT hits}} > 0.05$

Muon-jet

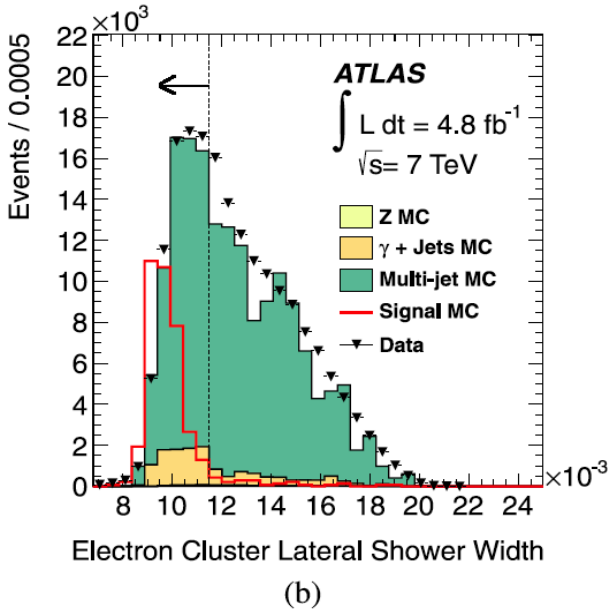
- Scaled isolation $= \frac{\textit{Energy with } 0.05 < \Delta R < 0.3}{muon-jet p_T} < 0.3.$
- p_T of the lowest-p_T muon.



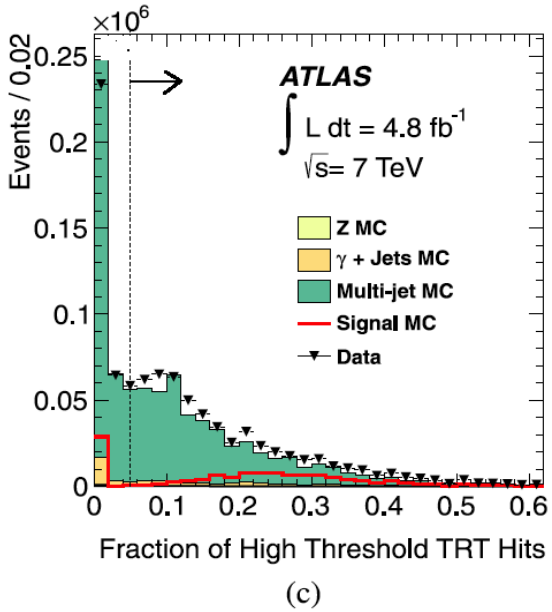
Discriminating Variables for Electron-Jet



(a)



(b)



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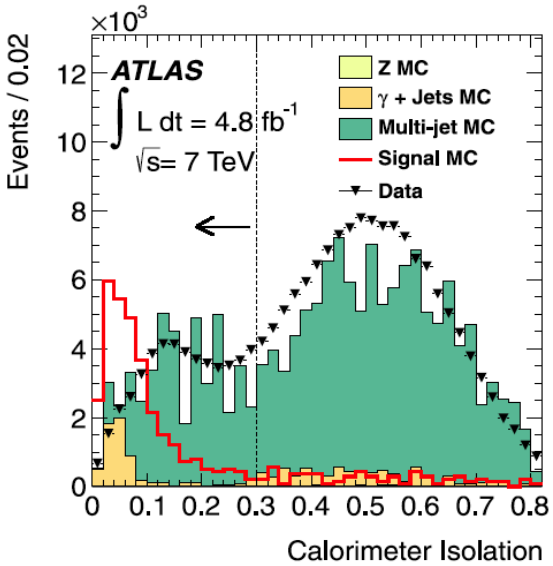

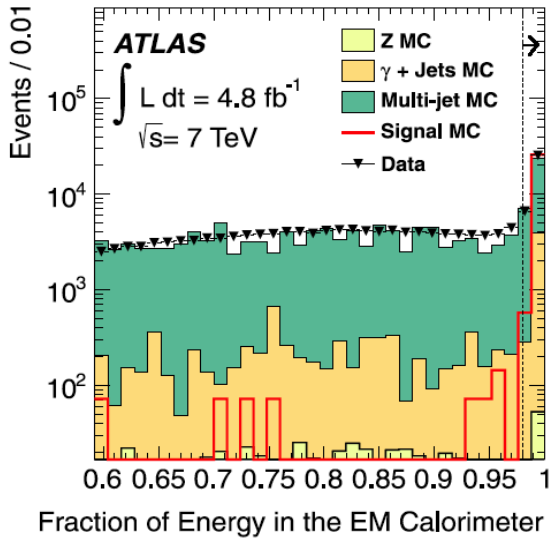

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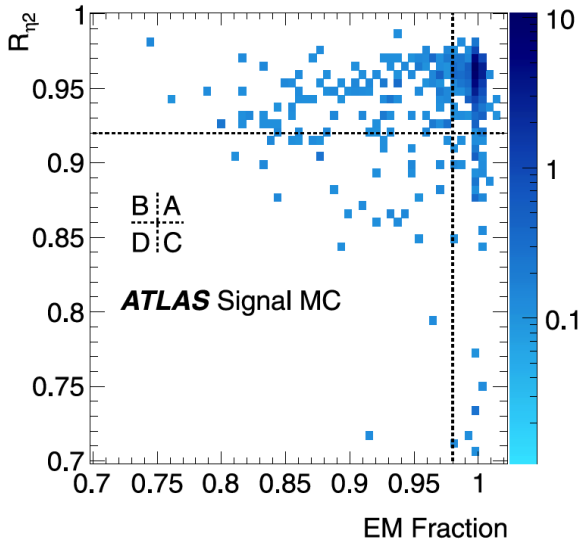
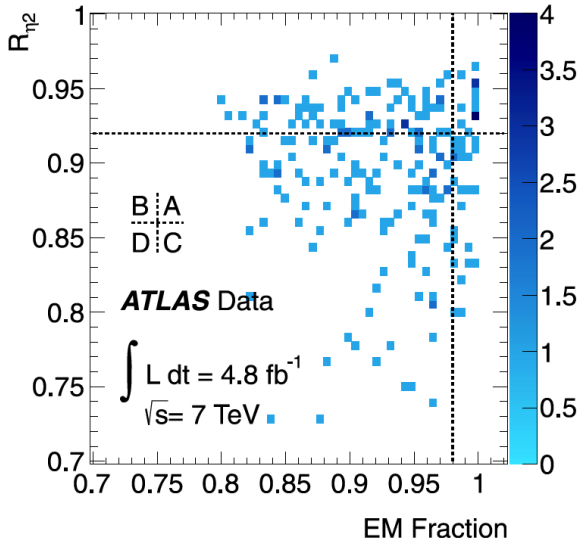
Background Estimation

ABCD method

- Region A- Signal region.
- Region B, C and D - Control regions
- Two uncorrelated variables.
- Data-driven background estimate
  - Use regions B,C,D to predict BG in A.
  - Signal would be excess over BG in A.





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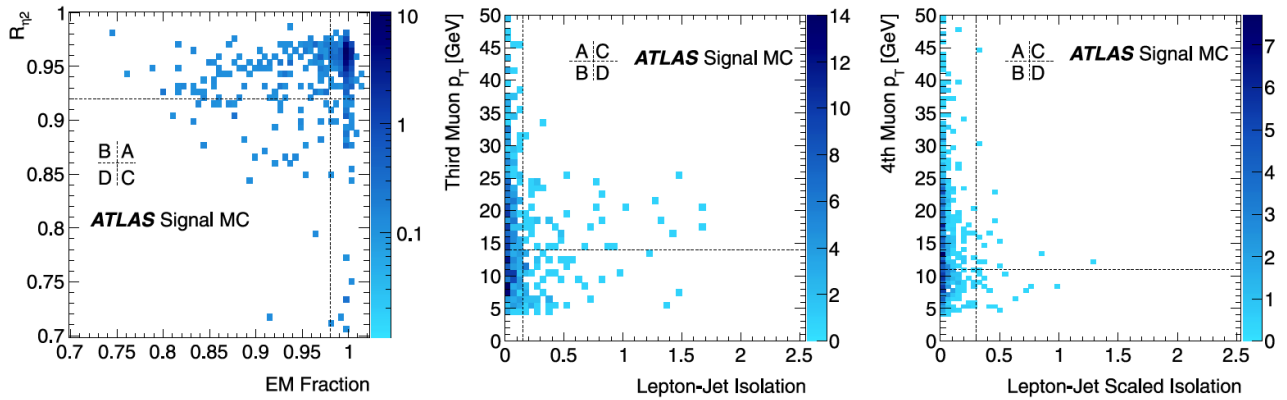
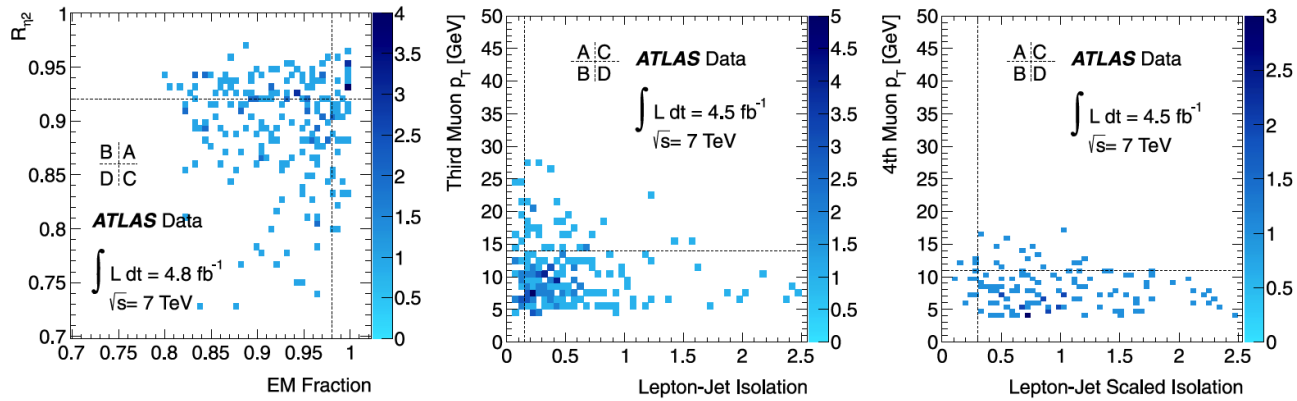
Signal Region Yields

Signal MC



Data



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	Electron LJ	1 Muon LJ	2 Muon LJ
Region A - Observed	15	7	3
Region A - Exp. from BG	15.2 $\pm$ 2.7	3.0 $\pm$ 1.0	0.5 $\pm$ 0.3

Statistical error dominates systematic error.

Upper Limits on Lepton-Jet (LJ) Production

Signal parameters		Electron LJ	1 Muon LJ	2 Muon LJ
m_{γ_D}[MeV]	α_D	Exp. pb	Exp. pb	Exp. pb
150	0	0.082	–	–
150	0.1	0.10	–	–
150	0.3	0.11	–	–
300	0	0.11	0.035	0.011
300	0.1	0.37	0.036	0.011
300	0.3	0.40	0.055	0.012
500	0	0.21	0.090	0.012
500	0.1	0.39	0.035	0.011
500	0.3	1.2	0.043	0.015

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Signal parameters		Electron LJ	1 Muon LJ	2 Muon LJ
m_{γ_D}[MeV]	α_D	Exp.(Obs.) pb	Exp.(Obs.) pb	Exp.(Obs.) pb
150	0	0.082 0.082	–	–
150	0.1	0.10 0.096	–	–
150	0.3	0.11 0.11	–	–
300	0	0.11 0.11	0.035 0.060	0.011 0.017
300	0.1	0.37 0.37	0.036 0.064	0.011 0.018
300	0.3	0.40 0.40	0.055 0.099	0.012 0.020
500	0	0.21 0.20	0.090 0.15	0.012 0.019
500	0.1	0.39 0.39	0.035 0.053	0.011 0.018
500	0.3	1.2 1.2	0.043 0.066	0.015 0.022

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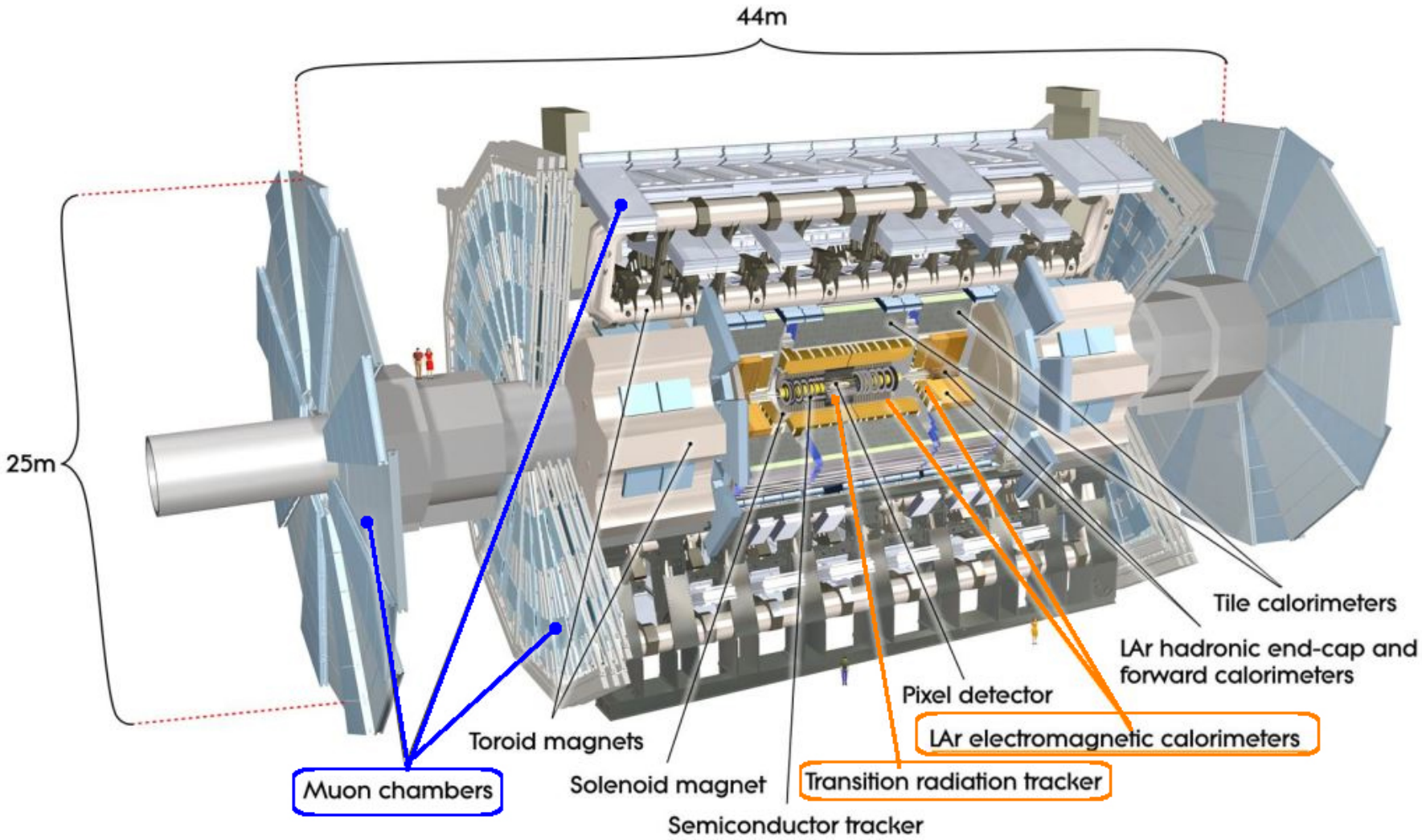
- Electron-jets: The observed limits are consistent with the expected limits.
- Muon-jets: Small excess leads to slightly poorer limits.
  2σ consistency with null hypothesis.

Conclusion

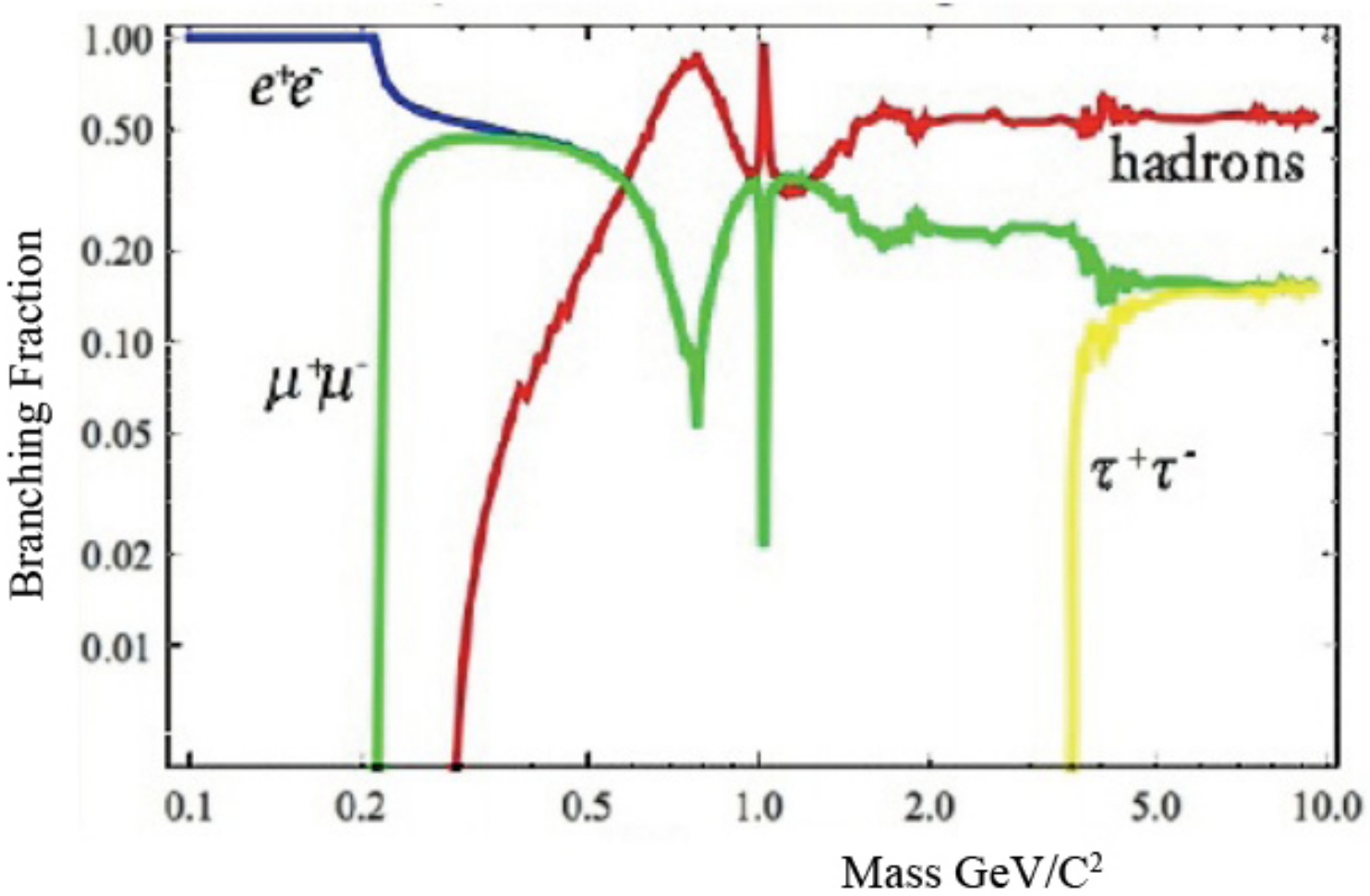
- Lepton jets -
  - Proposed detection method for dark matter.
  - Would be consistent with cosmic ray observations.
- A search for lepton-jets has been performed using
  - 2011, $\sqrt{s} = 7$ TeV ATLAS data.
- No lepton-jet excess observed.

Backup

ATLAS


44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Transition radiation tracker
Muon chambers
Solenoid magnet
Semiconductor tracker

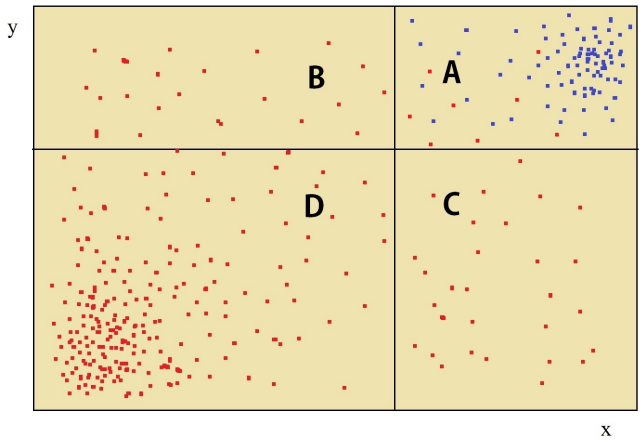
Branching Fraction



Background Estimation

ABCD-Likelihood method

- Region A- Signal region, region B, C and D - Control regions or background regions.
- 'x' and 'y' are uncorrelated variables.
  - $\mu_A = \mu^U + \mu$
  - $\mu_B = \mu^U \tau_B + \mu b$
  - $\mu_C = \mu^U \tau_C + \mu c$
  - $\mu_D = \mu^U \tau_B \tau_C + \mu d$



The parameter values are determined by fitting the likelihood function.

$$L(n_A, n_B, n_C, n_D|\mu, \theta_\mu) = \prod_{i=A,B,C,D} \frac{e^{-\mu_i} \mu_i^{n_i}}{n_i!}$$

Systematic Uncertainty

Table shows the systematic uncertainty on the signal yields for the three different lepton-jet (LJ) channels given as percentages. A "NA" means this source does not apply.

	Electron LJ [%]	1 muon LJ [%]	2 muon LJ [%]
Luminosity	3.9	3.9	3.9
Trigger efficiency	1.5	2.0	3.6
Offline ΔR efficiency	13.0	10.7	10.7
Lepton momentum scale	0.6	1.0	1.0
Isolation	5.2	< 0.1	< 0.1
$R_{\eta 2}$ and $w_{\eta 2}$ efficiency	8.0	NA	NA
f_{HT} efficiency	1.0	NA	NA
f_{EM} efficiency	3.0	NA	NA
Muon momentum resolution	NA	< 1.0	< 1.0