Searches for long-lived massive particles stopping in ATLAS

Paul D. Jackson (SLAC)
on behalf of the ATLAS Collaboration

SUSY 2010 - Bonn, Germany

Outline

- Introduction
  - Long Lived Particles (LLP)
  - The ATLAS Detector
- Search strategy for Stopped Gluinos in ATLAS
- Summary & Outlook

LLPs in SUSY scenarios

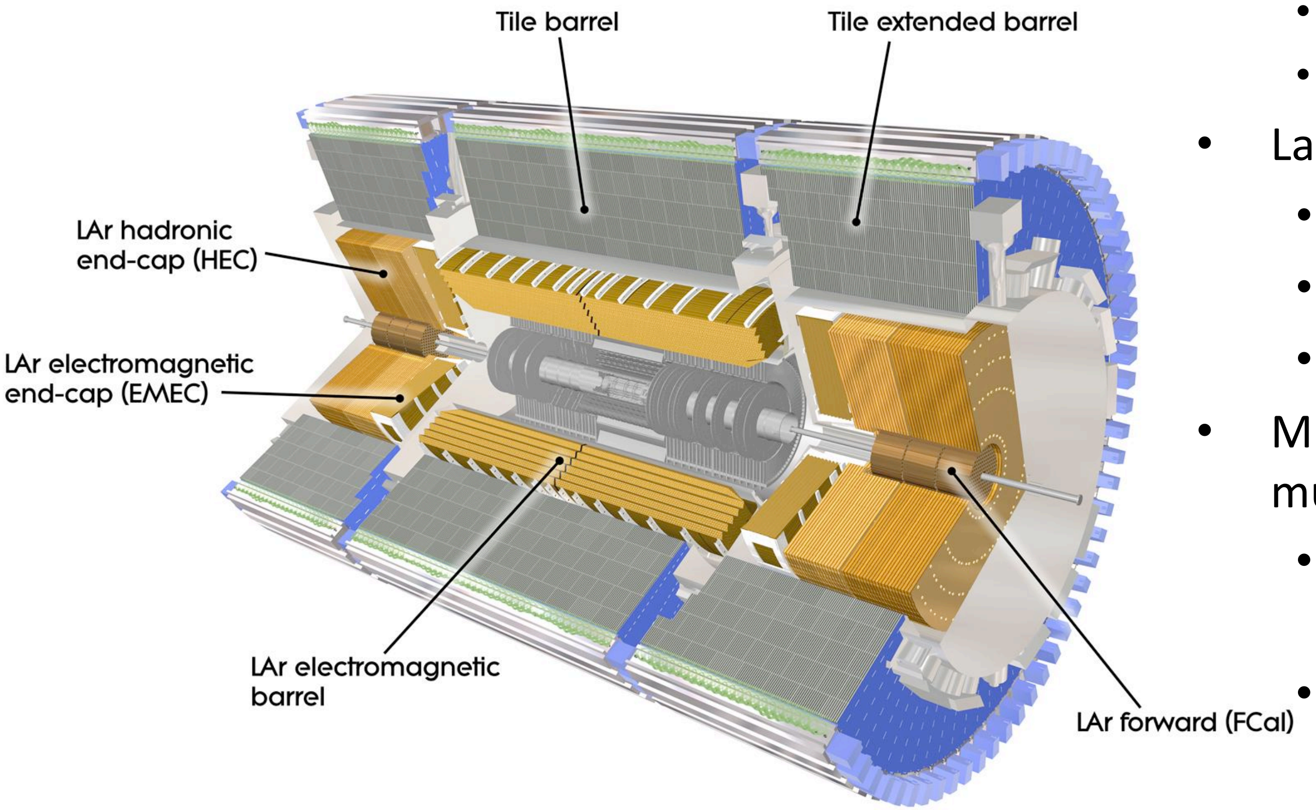
- LLPs are predicted in many SUSY and other BSM scenarios
- Within SUSY, LLPs can have different colour and electric charge
  - $\tilde{q}/\tilde{g}$ (bound states – R-Hadrons)
  - $\tilde{l}$ (or $\tilde{\chi}^{+}$)
- Typically β < 1
  - Use Time-of-Flight for measuring β
  - LLP Candidate mass = p/βγ
- In some case (e.g. gluinos) they might stop in calorimeters and decay later
  - Large isolated energy deposit
  - Decay happens much later than production

SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}, \mu, \tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg |\mu|$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll |\mu|$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{GS} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Table 1
Brief overview of possible SUSY SMP states considered in the literature. Classified by SMP, LSP, scenario, and typical conditions for this case to materialise in the given scenario.

arXiv: hep-ph/0611040v2

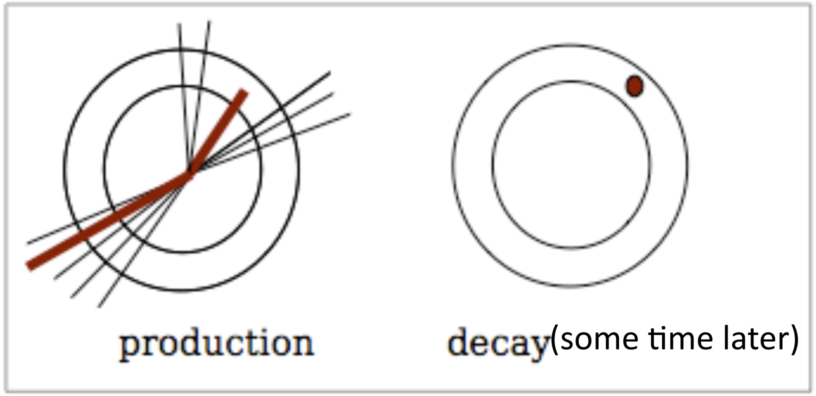
The ATLAS Detector



- TileCal: barrel part of Hadronic Calorimeter, Fe/scintillator Tiles
  - Central Barrel: $|\eta| \leq 1$
  - Extended Barrel: $0.8 \leq |\eta| \leq 1.7$
- Lar Cal: Pb-LAr Accordion,
  - e/γ trigger id
  - Central Barrel: $|\eta| \leq 1.475$
  - End-caps: $1.375 \leq |\eta| \leq 3.2$
- Muon Spectrometer: detect muons in range $|\eta| < 2.7$
  - Precision tracking chambers (MDTs + CSCs)
  - Fast Trigger chambers (RPCs + TGSs) for $|\eta| < 2.4$

Stopped-gluino searches

- In split-SUSY gluinos are long lived
- Some may loose enough momentum and stop in the calorimeters
  - Decay later to gluon+LSP or qq+LSP
- Signature:
  - large isolated energy deposit in calorimeters
  - rest of the event is "empty"
- Main background from cosmic events, beam halo, beam gas etc
- Good understanding of background is essential for this analysis
  - Trigger in empty bunch crossings
  - Compare cosmic ray data to out of time collision data

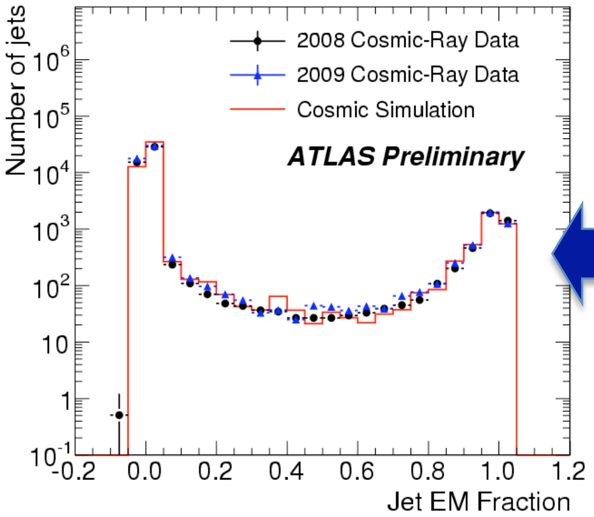


Very generic! Search for any long-lived, heavy, coloured particle...

Early Search Strategy

- Our main background is cosmics, we would like to demonstrate this, and show that we understand it.
- Use cosmics taken in 2009 and compare to the empty bunch triggered 2010 collision data.
- Define some well motivated selection criteria based on reducing cosmic backgrounds while remaining efficient at selecting Stopped Gluino signal MC and apply these to data.
- Plot the cosmic sample and empty bunch triggered collision data.
- Demonstrate this level of agreement with several pertinent distributions and cut flow tables.
- Compare these in the region where we would be sensitive to the stopped Long-lived particle signal.
- Details described in ATLAS-CONF-2010-071

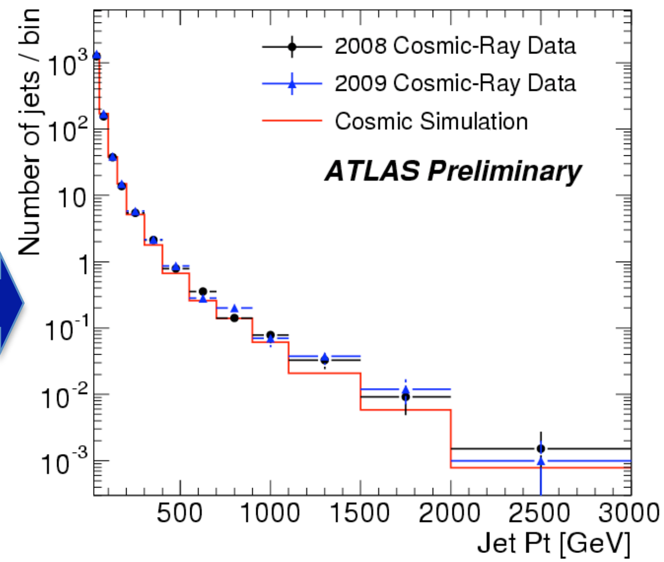
Detector Performance

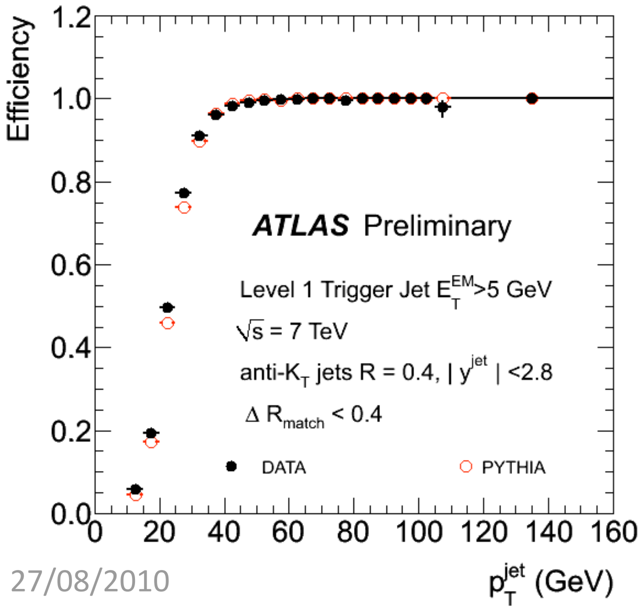


Jet Pt and EMF from the 2008/2009 cosmic-ray data and cosmic-ray simulation.

Anti-Kt4 jets with Pt>20 GeV.

MC does not include air showers and has imperfect modeling of electronic noise





L1_J5 trigger turn-on curve

Fully efficient at ~40GeV

Taken in collision events and compared to pythia

Anti-Kt4 jets used

Good agreement between data and simulation for cosmic samples and trigger

Selection criteria

Jet Quality and cleaning requirements:
- ATLAS 'ready for physics' and calorimeters marked good in data quality
- Noise cuts for calorimeters - removes single cell bursts or partition noise
- Jet/trigger and cleaning requirements

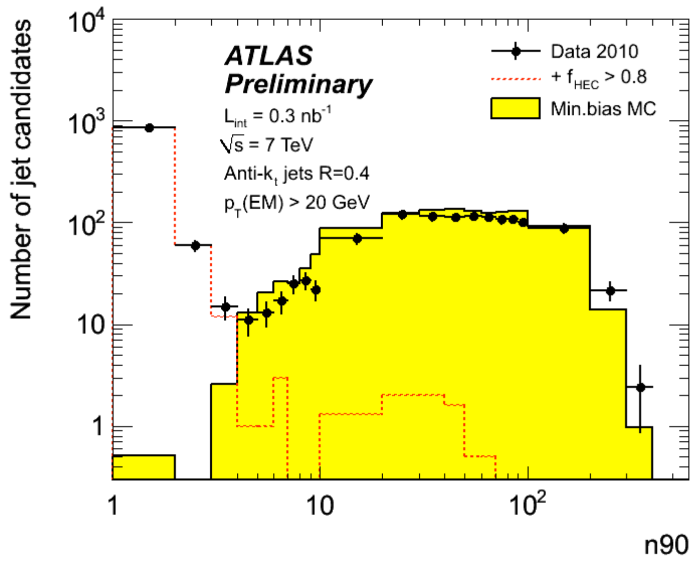
Central Jet and cosmic reduction requirements:
- Jets are built from topological clusters formed from energy deposits in the calorimeter. Use an anti-Kt jet algorithm, size = 0.4
- Leading Jet central in η, small number of Jets
- 90% of energy in more than 3 cells (reduction of noise and cosmic bkgds)

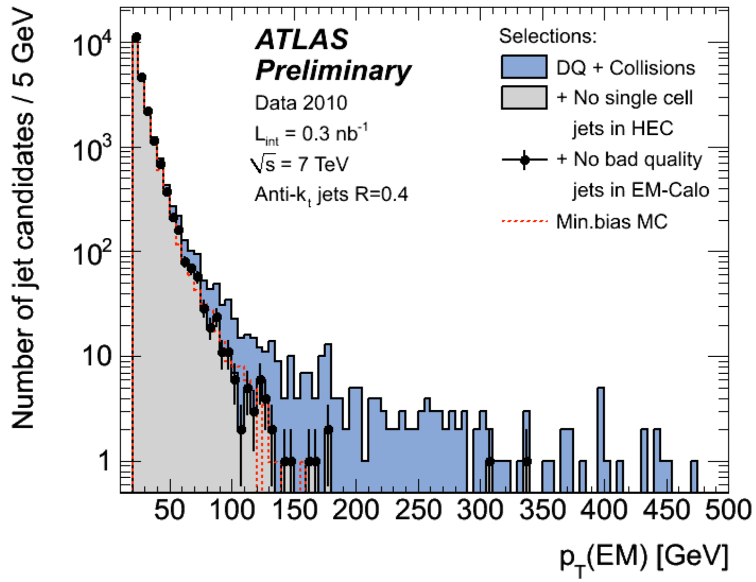
Muon segment veto:
- To reduce cosmics (by 10^3), demand events contain zero muon segments

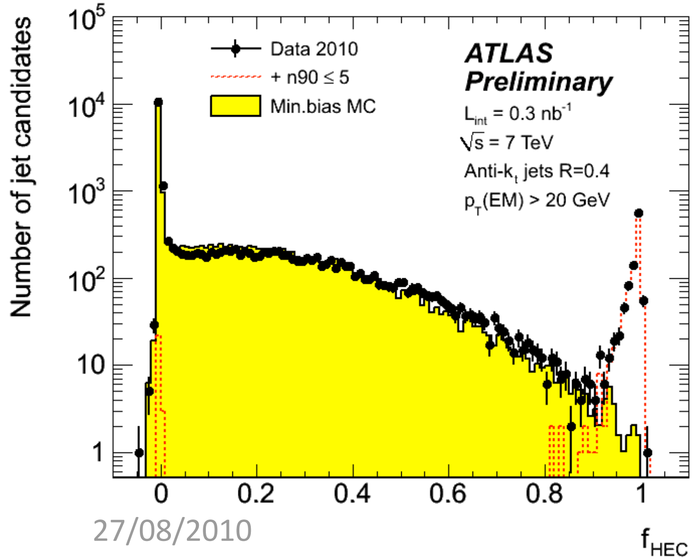
Jet Energy and shape cuts:
- Leading Jet has high energy and shapes such as width and EMF consistent with signal expectation

SLAC NATIONAL ACCELERATOR LABORATORY

Jet cleaning requirements







Cleaning requirements remove noise from the calorimeters

Remove high energy tails in the Energy or pt distributions

Selection criteria

	2009 Cosmic Data		2010 Collision Data
Selection Criteria	Yield of cosmics	Cosmics (scaled)	Yield of data
Good runs and data quality cuts	9.43×10^5	–	1.58×10^6
Leading Jet $\|\eta\|<1.2$	6.26×10^5	1.29×10^6	1.29×10^6
Jet n90>3	3.83×10^5	7.89×10^5	7.90×10^5
number of Jets<4	3.82×10^5	7.87×10^5	7.83×10^5
Muon Segment Veto	530 ± 23.0	1092 ± 47.4	1170
Leading Jet Energy > 50 GeV	39 ± 6.2	80 ± 12.8	75
Leading Jet Width > 0.05	6 ± 2.4	12 ± 4.9	8
Jet n50<6	3 ± 1.7	6 ± 3.5	4
Leading Jet EMF<0.95	2 ± 1.4	4 ± 2.9	4

- 2009 Cosmic data samples
  - $5.4\text{x}10^6$ events with 10 GeV jet at L1-trigger
- 7 TeV data collected between March-June 2010 with trigger running in empty bunches
  - Lumi = 2.7 nb^{-1}
- Normalize samples after cleaning cuts applied to cosmic and collision data

Jet variables

- We plot jet variables to demonstrate our level of understanding of their shape and yield
- All plots correspond to the sample remaining after the leading jet Energy cut from previous tables

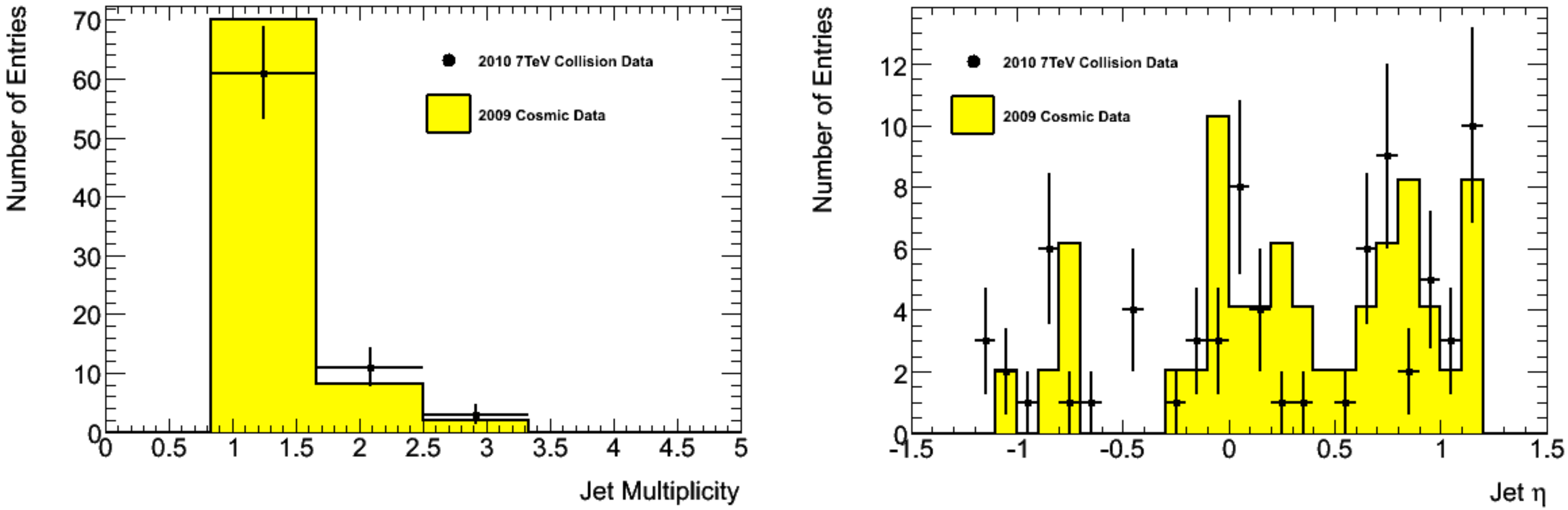


Figure 1: Jet variables plotted for the empty bunch triggers in 7 TeV collision data (black points) compared with 2009 cosmic data (filled histogram). We demand that all cleaning cuts are applied and that n90>3. We further require that there are zero reconstructed muon segments, that there be a leading jet with energy greater than 50 GeV and situated within $|\eta| < 1.2$. The jet multiplicity (left) and leading jet η (right) are plotted.

Jet variables

- Plots using same normalization. Show the electromagnetic fraction and jet width to demonstrate agreement of the shapes of these jets. Jet width is the first moment of the radial jet energy distribution.

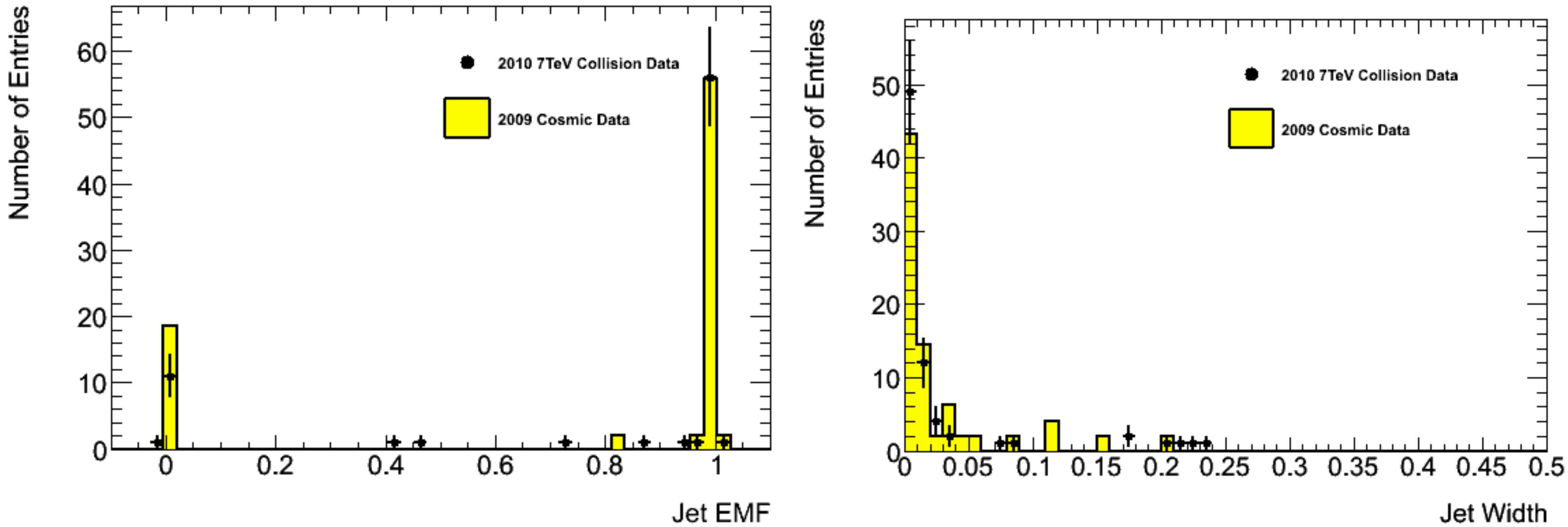


Figure 2: Jet variables plotted for the empty bunch triggers in 7 TeV collision data (black points) compared with 2009 cosmic data (filled histogram). We demand that all cleaning cuts are applied and that n90>3. We further require that there are zero reconstructed muon segments, that there be a leading jet with energy greater than 50 GeV and situated within $|\eta| < 1.2$. The leading jet electromagnetic fraction (left) and leading jet width (right) are plotted.

Jet variables

- Jet Energy is one of the most sensitive variables in which we could observe the signal mode (depending on gluino and χ masses)
- We make a cut that the leading Jet E>50GeV to show signal sensitive region

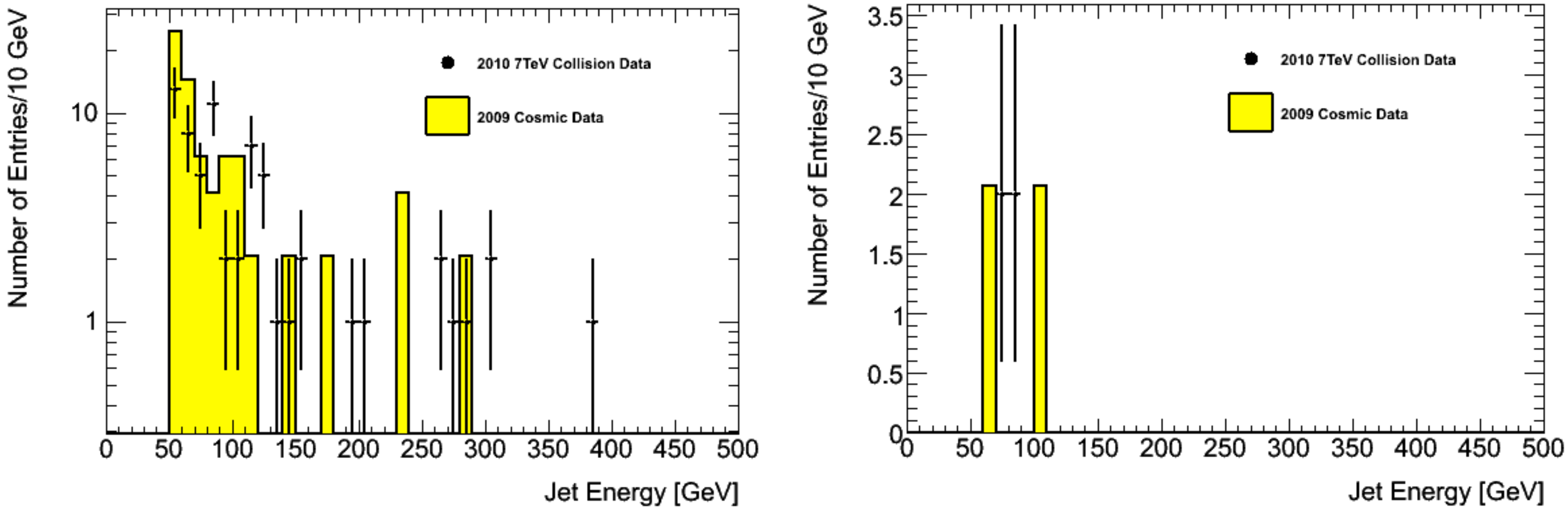


Figure 3: Jet energy plotted for the empty bunch triggers in 7 TeV collision data (black points), compared with 2009 cosmic data (black histogram). We demand there be no muon segments reconstructed in the muon detectors. There must be a leading jet with energy> 50 GeV and situated within $|\eta| < 1.2$. For the Figure on the right we additionally impose that the leading jet width>0.05, n90>3, n50<6 and jet electromagnetic fraction<0.95.

SLAC NATIONAL ACCELERATOR LABORATORY

ATLAS

Summary & Outlook

- New exotic long-lived particles are predicted in most Beyond the Standard Model theories and could be the first signal of new physics at the LHC
- Several studies are under way in ATLAS to look for feasibility of LLP searches using various techniques
- Stopped gluino searches
  - collision data triggered in empty bunches due to cosmic ray events
  - good agreement between cosmic data and collision data for all the jet variables studied so far
  - Positioned to complete analysis with early ATLAS data

Looking forward to exciting results with increasing LHC data !