ATLAS Displaced Jets: Solving the LLP Reinterpretation Challenge using RECAST

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Reinterpretation
What and why?

- Interpreting an existing experimental result in the context of an alternative BSM physics scenario

- Higher cost/effort for dedicated analyses vs reusing old analyses

- Many more theoretical ideas than experimental results
LLP reinterpretation challenge

To unfold or not to unfold?

- LLP searches especially hard to unfold: detector effects important and non-regular; low statistics

- Folded reinterpretations:
  - By pheno community - publish efficiency tables, cutflows, approximate particle-level selections, etc.
  - By original experimentalists - need expertise of small analysis team who might be too busy / have moved on

  - **recast** - new signals run through analysis (semi-) automatically, compared to stored data and background
RECAST framework

For analysis archival and re-execution

- Allow community to suggest reinterpretations
- Collaborations review suggestions and choose which to fulfil
- Reinterpretation is performed using archived analysis - full fidelity, no simplifications or approximations
- Analysers capture signal processing steps and workflow
CalRatio displaced jets
Neutral LLPs decaying in hadronic calorimeter

- CalRatio jets are trackless and narrow, with high $E_H/E_{EM}$
  - CalRatio analysis designed to select these jets
  - Benchmark HS model* studied

*other models may give similar results...

- Backgrounds: QCD, BIB, cosmics
CalRatio triggers

Dedicated triggers

- **High-\(E_T\) trigger:** 33.0 fb\(^{-1}\) dataset
  - used for \(m_\Phi > 200\) GeV
  - \(E_T > 60\) GeV
  - \(\log(\text{CalRatio}) > 1.2\)

- **Low-\(E_T\) trigger:** 10.8 fb\(^{-1}\) dataset
  - used for \(m_\Phi \leq 200\) GeV
  - \(E_T > 30\) GeV
  - \(\log(\text{CalRatio}) > 1.2\)
Many ML steps...

Decay position estimation

- LLP decay position estimated using multi-layer perceptron
Many ML steps...

Per-jet classification

- LLP decay position estimated using multi-layer perceptron
- Per-jet BDT uses decay position and other jet variables to classify jets as signal / QCD / BIB
Many ML steps...

Per-event classification

- LLP decay position estimated using multi-layer perceptron
- Per-jet BDT uses decay position and other jet variables to classify jets as signal / QCD / BIB
- Per-event BDT uses per-jet BDT output and event variables to separate signal from backgrounds
  - Output used to define search region
Background estimation

Modified ABCD method

- Define plane with per-event BDT and track isolation
- Estimate background contribution in search region A using B, C, D
- Simultaneous fit to signal and data
- No excess observed in data in region A

<table>
<thead>
<tr>
<th>Selection</th>
<th>Obs</th>
<th>Exp</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (-E_T)</td>
<td>10</td>
<td>8.5^{+2.3}_{-2.0}</td>
</tr>
<tr>
<td>Low (-E_T)</td>
<td>7</td>
<td>5.3^{+2.1}_{-1.6}</td>
</tr>
</tbody>
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CalRatio results

Lifetime extrapolation & limit setting

- Extrapolate efficiency as function of LLP lifetime
  
  \[ w_{\text{LLP}} = \frac{\tau_{\text{gen}}}{\exp(-t_{\text{LLP}}/\tau_{\text{gen}})} \cdot \frac{\exp(-t_{\text{LLP}}/\tau_{\text{new}})}{\tau_{\text{new}}} \]

- Limits set for HS benchmark model with \( m_\Phi = 125 \text{ GeV} \) – 1000 GeV and \( m_S = 5 \text{ GeV} \) – 400 GeV

- Combination with results from MS displaced jets search
CalRatio RECAST reinterpretations

Analysis preservation

• Software preserved in Docker containers
• Analysis steps and workflow stored as directed acyclic graph

• High-$E_T$ and low-$E_T$ analysis streams preserved
CalRatio RECAST reinterpretations

Models considered

Stealth SUSY

\[ m_{\tilde{g}} = 250 - 2000 \text{ GeV} \]
\[ m_{\tilde{S}} = 100 \text{ GeV} \]

Higgs-portal baryogenesis

\[ m_h = 125 \text{ GeV} \]
\[ m_\chi = 10 - 100 \text{ GeV} \]

\[ \chi \rightarrow c b s \]
\[ \chi \rightarrow \ell c b \]
\[ \chi \rightarrow \nu b \bar{b} \]
\[ \chi \rightarrow \tau \tau \nu \]

Existing limits: MS displaced jets

FRVZ dark photons

\[ m_H = 125, 800 \text{ GeV} \]
\[ m_{\gamma_d} = 400 \text{ MeV} \]

\[ H \rightarrow 2 \gamma_d + X \]
\[ H \rightarrow 4 \gamma_d + X \]

Existing limits: displaced lepton-jets
Stealth SUSY

Selection of results

ATLAS Preliminary $\sqrt{s} = 13$ TeV

- RECAST result, high-$E_T$ selection [33.0 fb$^{-1}$] ± 1σ, 2σ
- MS displaced jets result (Comb) [36.1 fb$^{-1}$] Obs.

95% CL Upper Limit on $\sigma \times B$ [pb]

Stealth SUSY

$m_g = 250$ GeV, $c\tau_{\text{gen}} = 0.96$ m

& more in backup slides
Higgs-portal baryogenesis

Selection of results

ATLAS Preliminary \( \sqrt{s} = 13 \text{ TeV} \)

- RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1}\)]
- Exp. \( \pm 1\sigma, 2\sigma \)
- MS displaced jets result (Comb) [36.1 fb\(^{-1}\)]
- Obs.

\[ \chi \rightarrow l c b \]
\[ m_H, m_{\chi} = [125,10] \text{ GeV}, c\tau_{\text{gen}} = 0.92 \text{ m} \]

\[ \chi \text{ proper decay length (c} \tau\text{) [m]} \]

\& more in backup slides
Dark photons
Selection of results

\[ \text{ATLAS Preliminary } \sqrt{s} = 13 \text{ TeV} \]

- RECAST result, high-\(E_T\) selection [33.0 fb\(^{-1}\)]
- Exp. ± 1σ, 2σ
- Displaced lepton-jets result [36 fb\(^{-1}\)]
- Obs.

\[ \text{Selection of results} \]

\[ H \rightarrow 2\gamma_d + X \]

\[ m_H, m_{\gamma_d} = [800, 0.4] \text{ GeV}, c\tau_{\text{gen}} = 0.01176 \text{ m} \]

\[ \gamma_d \text{ proper decay length (} c\tau \text{)} [\text{m}] \]

\& more in backup slides
Summary

• LLP search reinterpretations often challenging

• ATLAS CalRatio displaced jets search preserved with RECAST and used to set limits on new models quickly and efficiently

• More information:
  • Reinterpretation of the ATLAS search for displaced hadronic jets with the RECAST framework, ATL-PHYS-PUB-2020-007
Backup
Stealth SUSY

All results

ATLAS Preliminary \( \sqrt{s} = 13 \text{ TeV} \)

- **ATLAS** Preliminary \( \sqrt{s} = 13 \text{ TeV} \)
  - RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1} \)]
  - Exp. ± 1\( \sigma \), 2\( \sigma \)
  - MS displaced jets result (2Vx) [36.1 fb\(^{-1} \)]
  - Obs.

95\% CL Upper Limit on \( \sigma \times B \) [pb]

- **ATLAS** Preliminary \( \sqrt{s} = 13 \text{ TeV} \)
  - RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1} \)]
  - Exp. ± 1\( \sigma \), 2\( \sigma \)
  - MS displaced jets result (Comb) [36.1 fb\(^{-1} \)]
  - Obs.

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  - RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1} \)]
  - Exp. ± 1\( \sigma \), 2\( \sigma \)
  - MS displaced jets result (Comb) [36.1 fb\(^{-1} \)]
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  - RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1} \)]
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95\% CL Upper Limit on \( \sigma \times B \) [pb]

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  - RECAST result, high-\( E_T \) selection [33.0 fb\(^{-1} \)]
  - Exp. ± 1\( \sigma \), 2\( \sigma \)
  - MS displaced jets result (Comb) [36.1 fb\(^{-1} \)]
  - Obs.

95\% CL Upper Limit on \( \sigma \times B \) [pb]
Higgs-portal baryogenesis

Results for $\chi \rightarrow c b s$ channel

![Graphs and diagrams showing 95% CL upper limits on $\alpha \times B$ for $\mu \tau$ and $\chi$ proper decay lengths for different mass ranges.]

$\text{ATLAS Preliminary } \sqrt{s} = 13 \text{ TeV}$

- RECAST result, high-$E_T$ selection [33.0 fb$^{-1}$]
- Exp. $\pm \chi$, 2$\chi$
- MS displaced jets result (Comb) [36.1 fb$^{-1}$] — Obs.

**95% CL Upper Limit on $\chi$ proper decay length ($c\tau$) [m]**

- $m_{\mu\tau} = [125,10] \text{ GeV}, c\tau_{\text{gen}} = 0.92 \text{ m}$
- $m_{\mu\tau} = [125,50] \text{ GeV}, c\tau_{\text{gen}} = 5.55 \text{ m}$
- $m_{\mu\tau} = [125,100] \text{ GeV}, c\tau_{\text{gen}} = 3.5 \text{ m}$

- $m_{\mu\tau} = [125,30] \text{ GeV}, c\tau_{\text{gen}} = 2.75 \text{ m}$
Higgs-portal baryogenesis

Results for $\chi \to \ell c b$ channel
Higgs-portal baryogenesis

Results for $\chi \rightarrow \nu b \bar{b}$ channel

**ATLAS Preliminary $\sqrt{s} = 13$ TeV**

- RECAST result, high-$E_T$ selection [33.0 fb$^{-1}$]
- Exp. $\pm 1\sigma, 2\sigma$
- Obs. MS displaced jets result (Comb) [36.1 fb$^{-1}$]
- Obs.

95% CL Upper Limit on $\alpha \times B$ [pb]

- $\chi \rightarrow \nu b \bar{b}$
- $m_{\nu} m_{\chi} = [125,10] \text{ GeV, } c\tau_{\text{gen}} = 0.92 \text{ m}$

- $\chi \rightarrow \nu b \bar{b}$
- $m_{\nu} m_{\chi} = [125,50] \text{ GeV, } c\tau_{\text{gen}} = 5.55 \text{ m}$

- $\chi \rightarrow \nu b \bar{b}$
- $m_{\nu} m_{\chi} = [125,30] \text{ GeV, } c\tau_{\text{gen}} = 2.75 \text{ m}$

- $\chi \rightarrow \nu b \bar{b}$
- $m_{\nu} m_{\chi} = [125,100] \text{ GeV, } c\tau_{\text{gen}} = 3.5 \text{ m}$

$\chi$ proper decay length ($c\tau$) [m]
Higgs-portal baryogenesis

Results for $\chi \rightarrow \tau \tau \nu$ channel

No sensitivity to $m_\chi = 10$ or 30 GeV in this decay channel
Dark photon

Results for $H \rightarrow 2\gamma_d \, + \, X$ channel

Displaced lepton-jets analysis did not set limits on $m_H = 125$ GeV with hadronic-hadronic selection
Dark photon

Results for $H \rightarrow 4\gamma_d + X$ channel

Displaced lepton-jets analysis did not set limits on $m_H = 125$ GeV with hadronic-hadronic selection
ABCD Method

choose 2 ~uncorrelated variables
divide plane into 4 regions

background mostly
in B, C, D

blinded by
ignoring A

signal
mostly
in A

Simultaneous fit can account for any signal contamination