In a nutshell...

Ph.D. student at University of Illinois, Urbana-Champaign

Postdoc at University of Barcelona.

CERN Fellow (TileCal)

Muon Data Quality Coordinator

TileCal Run Coordinator (2015)

TileCal Calibration Coordinator (2016-2019)

Jet+$E_{T}^{miss}$ analysis coordinator

Exotics Jets+DM group convener

DM Summary paper editor/coordinate
Jet + $E_T^{\text{miss}}$ analysis motivation

- **Supersymmetry**
  Jet+$E_T^{\text{miss}}$ becomes interesting in searches of squark decays in compressed scenarios (neutralino in the final state leaving a $E_T^{\text{miss}}$ signature).

- **Dark matter**
  WIMPs do not interact with the detector, thus they leave a signature of missing transverse energy ($E_T^{\text{miss}}$).

To be able to select the event, we look for visible particles produced in association with the DM particles.
Jet + $E_T^{\text{miss}}$ analysis

**Selection**

Signal region:
- veto on muons and electrons.
- Jet $p_T > 250$ GeV
- $|\eta| < 2.4$

**N_{jets} (p_T > 30 GeV) \leq 4**

**$\Delta \phi (E_T^{miss}, \text{jets}) > 0.4$**

**Strategy**

- Dominant bkg: $Z(\nu\nu)+\text{jets}$, followed by $W(\ell\nu)+\text{jets}$.
- $W/Z$ bkg modelled at NLO QCD & EW.
  - Sherpa NLO(LO) for 1,2(3,4) partons + **theory corrections as a function of $p_T(W/Z)$** [arXiv:1705.04664].
  - I initiated and lead the discussions with theorists to obtain such corrections.
- $V+\text{jets}$ and top bkg normalized in dedicated CRs.
- DiBosons from MC. NCB and Multijets data driven.

**Benchmark DM model**

Axial-vector (s-channel) mediator,

$g_{DM} = 1$, $g_q = 0.25$.

Most sensitive Mono-X channel

“jet” has $\alpha_s$ couplings to initial state quarks.

**W/Z +jets** background
e.g. $W(\mu\nu)$ CR used to constrain $Z(\nu\nu)$.

**Muons treated as invisible:**

$E_T^{miss} \sim \text{boson} p_T$

Similarly for $Z(\ell\ell)$ CRs.
Events / GeV

10^6

10^5

10^4

10^3

10^2

10

1

0.1

0.01

0.001

0.0001

0.00001

ATLAS

\( \bar{s} = 13 \ TeV, \ 36.1 \ fb^{-1} \)

\( W(\rightarrow \mu\nu) \) Control Region

\( p_T(j1)>250 \ GeV, \ E_T^{miss}>250 \ GeV \)

Data 2015+2016

Standard Model

Z(\( \rightarrow \nu\nu \)) + jets

W(\( \rightarrow l\nu \)) + jets

Z(\( \rightarrow ll \)) + jets

tf + single top

Diboson

Limits on a vector model are also given.

This channel has sensitivity to several SUSY stop/sbottom compressed decay channels and LED.
Jet + $E_T$ analysis

$\sqrt{s} = 13$ TeV, 36.1-139 fb$^{-1}$

**ATLAS** Preliminary

$\tilde{t}_1 \tilde{t}_1$ production

Limits at 95% CL

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**Run 1**, $\sqrt{s} = 8$ TeV, 20 fb$^{-1}$

[1506.08616]

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**Observed limits**

**Expected limits**

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139.0 fb$^{-1}$

1L, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$

[ATLAS-CONF-2019-17]

36.1 fb$^{-1}$

0L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$

[1709.04183]

1L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow btt\tilde{\chi}_1^0$

[1711.11520]

2L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow btt\tilde{\chi}_1^0$

[1708.03247]

monojet, $\tilde{t}_1 \rightarrow btt\tilde{\chi}_1^0$

[1711.03301]

$\tilde{t}, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$

[1903.07570]

c0L, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

[1805.01649]

monojet, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

[1711.03301]
Jet + $E_T^{\text{miss}}$ analysis

- $E_T^{\text{miss}} + \text{jet}$ provides the largest sensitivity among the searches for invisible.
- Exclusion from dijet resonance searches include multiple analysis techniques to cover a large mediator mass range.
  - I was highly involved in the dijet resonance searches via my role as JDM convener.
- Interplay between $E_T^{\text{miss}} + X$ and resonance searches is highly dependent on choice of couplings.
Searches for dark matter in ATLAS

Results from over 20 analyses were included in the DM summary paper, for which I was editor/coordinator.

Hubs:
- Hubs Interview
- 17.12.2019

Arely Cortes Gonzalez

**Theoretical Framework**
- Supersymmetry
- Long-lived particles sector
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

**Extended Higgs sector DM models**
- 2HDM+a
  - $E_T^{\text{miss}} + H(bb)$
  - $E_T^{\text{miss}} + H(\gamma\gamma)$
  - $E_T^{\text{miss}} + Z(ll)$
  - $E_T^{\text{miss}} + V(had)$
  - $E_T^{\text{miss}} + bb/tt$
  - 4 tops
  - h(inv)

- 2HDM+$Z'_V$
  - $E_T^{\text{miss}} + H(bb)$
  - $E_T^{\text{miss}} + H(\gamma\gamma)$

**Simplified Model: Spin-1 mediator**
- Vector or axial-vector mediator
  - $E_T^{\text{miss}} + \text{jet}$
  - $E_T^{\text{miss}} + \gamma$
  - $E_T^{\text{miss}} + Z(ll)$
  - $E_T^{\text{miss}} + V(had)$
  - Di-jet (low/high mass)
  - Di-b-jet (low/high mass)
  - Di-tops
  - Di-leptons

- Vector-baryon charged mediator
  - $E_T^{\text{miss}} + H(bb)$
  - $E_T^{\text{miss}} + H(\gamma\gamma)$

**Simplified Model: Spin 0-mediator**
- Scalar/Pseudoscalar mediator
  - $E_T^{\text{miss}} + \text{jet}$
  - $E_T^{\text{miss}} + bb$
  - $E_T^{\text{miss}} + tt$

- Scalar colour charged mediator
  - $E_T^{\text{miss}} + \text{jet}$
  - $E_T^{\text{miss}} + b$

**Higgs Portal**
- ATLAS h(inv) combination
- CMS h(inv) combination

**Supersymmetry**
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

**Long-lived particles sector**
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

**Other models?!**
Summary of Dark matter searches

Moving towards a less simplified dark matter model for Run 2 legacy results.

2HDM + a

Extension of type-II 2HDM in the alignment limit.

- Pseudoscalar mediator $a$ couples DM to SM and mixes with heavy pseudoscalar $A$ of 2HDM.
- Rich phenomenology of $E_T^{miss} + X$ signatures (complementary sensitivity).
- Additional sensitivity from resonance searches ($A/H(bb, tt)$).

![Graphical representation of 2HDM + a model with diagrams illustrating various processes involving pseudoscalars and Dirac DM.]

![Graphical representation of ATLAS 2HDM + a limits and $h$ production plots.

<table>
<thead>
<tr>
<th>ATLAS $\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2HDM + a, Dirac DM</td>
</tr>
<tr>
<td>$m_a = 10$ GeV, $g_a = 1$</td>
</tr>
<tr>
<td>$\sin\theta = 0.35$, $\tan\beta = 1$</td>
</tr>
<tr>
<td>$m_a = m_h = m_H$</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>ATLAS $\sqrt{s} = 7,8$ TeV, 4.7, 20.3 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2HDM + a, Dirac DM</td>
</tr>
<tr>
<td>$m_a = 10$ GeV, $g_a = 1$</td>
</tr>
<tr>
<td>$m_a = m_h = m_H = 600$ GeV</td>
</tr>
<tr>
<td>$\sin\theta = 0.35$</td>
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<td>$\tan\beta = 1$</td>
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![Graphical representation of ATLAS $E_T^{miss} + Z(ll)$, $h(\gamma\gamma)$, and $h(\gamma\gamma)$ analysis results with limits and observed/expected plots.]
**$E_T^{\text{miss}} + H(bb)$ search**

Multiple CR and SR defined by the leptons and $N(b$-jets) multiplicity and $E_T^{\text{miss}}$ regions. *Simultaneous $m_J$ and $m_{jj}$ shape fit in all regions.*

In the merged region the reconstruction of these subjets is based on a jet algorithm using tracks as inputs and a radius parameter that decreases as the subjet $p_T$ increases.
Beyond Run 2

$E_T^{\text{miss}} + \text{jet}$

**ATLAS** Simulation Preliminary
\[ \sqrt{s} = 13 \text{ TeV}, 300 \text{ fb}^{-1} \]
- Axial-Vector Mediator
- Dirac Fermion DM
  - $g_q = 0.25, g_\chi = 1$
  - Perturbativity Limit
  - Relic Density (MadDM)

95% CL limits

**ATLAS** $\sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1}$

**Run 3**

**HL-LHC**

Simulation Preliminary
\[ \sqrt{s} = 13 \text{ TeV}, 300 \text{ fb}^{-1} \]
- Axial-Vector Mediator
- Dirac Fermion DM
  - $g_q = 0.25, g_\chi = 1$

Projection from Run-2 data
Improvements using the variable radius jets (as recently introduced in the $E_T^{\text{miss}}+H\,(bb)$ analysis).

**ATLAS Simulation Preliminary**

- $\sqrt{s} = 14$ TeV, 3000 fb$^{-1}$
- Signal region, 3-tag
- 3000 GeV resonance

- Variable-radius jets
- $R = 0.2$ jets

**ATLAS**

- $\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$
- $\sigma(pp \to G_{KK} \to HH \to b\bar{b}b\bar{b})$ [fb]

**ATLAS Preliminary**

- Projection from Run-2 data
- $\sqrt{s} = 14$ TeV, 3000 fb$^{-1}$
- Scaling from dijet simulation

**HL-LHC**
If invited to join the ATLAS group at the Humboldt University of Berlin, I would like to pursue searches including the $H \rightarrow bb$ decay channel. In particular, di-Higgs searches. These searches are now becoming more interesting in view of the increased luminosity and the prospects for future accelerators.

- I believe searches where H-tagging is employed have great potential for continuous improvements given the advancements within the performance groups.
- To be able to take a leadership role, I will contribute significantly in the jet substructure group and thus be able to ensure a good liaison between our physics analysis team and the performance group.

- I believe the jet performance experience within the team will be an excellent platform to accelerate my own contribution. Moreover, I am convinced that my own experience, and past leadership roles, put me in good position to join a new analysis of such interest to the ATLAS community.
Thank you!
- **Low $m_{\text{jj}}$ region** covered by analyses using **trigger-level objects** or **dijet+ISR** (where the ISR object, jet or photon, is used to trigger the event). In the latter case, the dijet system can be **resolved** or **boosted**.

- **Dijet angular** analysis allows to exclude signals with larger widths.
Scanning the mass-mass plane for different operators (V/AV) and different choices of couplings.

Vector

Dilepton \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dijet \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dilepton \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dijet \( E_{\text{miss}} + X \) \[\text{ATLAS} \]

Axial-vector

Dilepton \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dijet \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dilepton \( E_{\text{miss}} + X \) \[\text{ATLAS} \]
Dijet \( E_{\text{miss}} + X \) \[\text{ATLAS} \]

Leptophilic

Vector mediator, Dirac DM \( g_0 = 0.25, g_0 = 0, g_1 = 1 \)
All limits at 95% CL

Leptophilic

Vector mediator, Dirac DM \( g_0 = 0.1, g_0 = 0.01, g_1 = 1 \)
All limits at 95% CL

Arely Cortes Gonzalez

HUB Interview

17.12.2019
Dark matter searches

ATLAS Vector $Z'$
Vector mediator, Dirac DM
\[ g_q = 0.25, \ g_\ell = 0, \ g_\chi = 1 \]
Preliminary ATLAS-CONF-2016-070
JHEP 01 (2018) 126
PLB 776 (2017) 318
JHEP 10 (2018) 180

ATLAS $Z'$ baryonic
$Z'$ baryonic, Dirac DM
\[ \sin \theta = 0.3, \ g_q = 1/3, \ g_\chi = 1 \]

ATLAS Scalar
Scalar mediator, Dirac DM
\[ g_q = 1, \ g_\chi = 1 \]

Details of conversion: arXiv:1603.04156
Relic density predicted by 2HDM+a has a strong dependence on $m_\chi$.

Two a-funnel and A-funnel regions at $m_\chi=125$ GeV and $m_\chi=300$ GeV, respectively (relic density depleted by the resonant enhancement of $\chi\chi\to A/a\to SM$).
Legacy discoveries/measurements?