Search for Exotic Higgs Boson Decay

By Sophie Haight, Ines Ochoa, John Parsons
### Standard Model

- **Fundamental, subatomic particles**
- **Fermions**: bind to make matter
  - Leptons
  - Quarks
    - Color Charge
  - 3 Generations
Standard Model – Gauge Bosons

- Gauge Bosons
  - Photon – EM force
  - W and Z – Weak force
  - Gluons – Strong force
- Gravity - unknown

Four Fundamental Forces

- Weakest
  - Gravitational
- Strongest
  - Weak nuclear
  - Electromagnetic
  - Strong nuclear
Higgs Boson

• Origin of Mass
• Higgs Field
• Brout-Englert-Higgs mechanism (1980s)
• Standard Model
• Detected in 2012 by CERN
• Two Z boson, two photon
Beyond standard model

• Standard Model Questions:
  • Neutrino oscillations
  • Dark Matter
  • GR

• Supersymmetry
  • Unseen ‘super’ particle for every elementary particle
  • More massive
  • Less spin
  • Dark Matter?
  • Ties together inconsistencies
Exotic Higgs Decay

• Associated production of Higgs + Z
• Z → 2 leptons
• Higgs → χ1, χ2 → G, γ
  • Supersymmetric particles
    • Neutralino (NLSP)
    • Gravitino (LSP)
  • Photon (detectable)
• Non-pointing, delayed photon
  • NLSP decay = free parameter
    • β = 0.9
  • Angle of Decay
(more) Exotic Higgs Decay

- Possible Results (post NLSP decay)
  - 2 photons detected
  - 1 photon detected
  - No photons detected

- Occurrence rate
  - < 1% from Higgs + Z
Distinguishing the Exotic Decay

- Data: $Z \rightarrow e^+, e^-, \gamma$
  - Prompt photon
- Differs from delayed photon
- ‘Tail’ between background and signal
- Photon timing accuracy important
  - 100-200 ps
Timing calibration: Data vs. MC

• When samples are simulated in MC, some factors are not accounted for
• Timing uncertainty in data, not in MC yet
Examining Exotic Higgs Decay

✔ Look closely at photon decays from background data compared to simulated signal
✔ Assess timing uncertainty in MC
✔ Calibrate uncertainty in MC with what we see in data
✔ Check that event timing in MC is now ‘correlated’
CERN

- Founded 1954
- Collaboration
  - Over 17,000 scientists across the globe
- Advancing science
  - Particle physics: Higgs, etc.
- Advancing technology
  - World wide web
Large Hadron Collider

- Most powerful particle accelerator in the world
- 4 points of collision
- Successive acceleration by LHC machines
- Bending via magnets
- Goals:
  - Developing and supporting the Standard Model
ATLAS Nevis Team

John Parsons

Ines Ochoa

Daniel Williams

Gustaaf Brooijmans

Julia Gonski

Elena Busch

Juan Varela
ATLAS Experiment

- Detector
  - Inner Detector
  - Calorimeter
  - Muon Spectrometer
  - Magnet System
  - Trigger and Data Acquisition System
  - Computing System
Liquid Argon Calorimeter

- Front End Boards
- Energy and Time deposition
- Resolution
- Calibration
  - 9 corrective steps
  - Machine Related Uncertainty
- Beamspread
Beamspreading

- Beamspreading
  - Proton beams travel in bunches
  - Bunches are finite length
  - Effect on collision time
  - Correlation between position in bunch and collision time
  - Account for beamspreading

Credit: Sergio Bertolucci, CERN
Data Used

• Data with unhelpful preselection
• Signal
  • WH, ZH, ttH samples
  • Various values of mchi1, mchi2, tau

<table>
<thead>
<tr>
<th>Run</th>
<th>Mass $\chi^{20}$</th>
<th>Mass $\chi^{10}$</th>
<th>$\tau$ (ns)</th>
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<td>40</td>
<td>30</td>
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</tr>
<tr>
<td>449739</td>
<td>60</td>
<td>0.5</td>
<td>10</td>
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</table>

ZH Samples
Cuts

- **Electrons**
  - 2 required
  - Di-electron trigger:
    - $\text{Pt} > 20 \text{ GeV}$ for both
  - Single electron trigger
    - Leading $\text{pt} > 27 \text{ GeV}$
    - Sub leading $\text{pt} > 9 \text{ GeV}$

- **Photons**
  - One required
  - $\text{Pt} > 10 \text{ GeV}$

- **Eta (for photons):**
  - Cutoff at 2.47 m
  - Gap between 1.52 m and 1.37 m for detector electronics
Prompt background over ZH decay

![Graph showing number of events (normalized) over time (ns) with different scenarios labeled as ZH, t = 2ns, ZH, t = 10ns, etc., with background and ATLAS internal labels.](image)
Beamspread not Incorporated in MC?

- Calorimeter measures photon time
- Lacking background knowledge about rest of objects in that event

Do we see in MC
- Objects not ‘correlated’
- Evidence: electron timing plots
Electrons in same event uncorrelated
Then sum and difference of leading and sub leading electron times

Times are uncorrelated

Sigma ~ 407 ps

Sigma ~ 420 ps
MC is uncorrelated

- Correlated = move in same direction
  - $t_1$ change yields $t_2$ change
- Timing of objects in the same event appear unrelated
  - Not accounting for beam spread
- Uncertainty of timing same whether you add subleading electron or subtract
  - Adding the other electron event doesn’t affect the uncertainty that beam spread should produce
‘Smearing’ MC with Gaussian

• Apply distribution in a correlated way
• Draw from Gaussian
  • Shape bunch densities along beamline
  • Mean = 0
  • Sigma = 200 ps
  • Random
• Add the SAME draw to ALL objects in each event => correlated at the event level

Electron time plot indicates ~200 ps beamspread for correlated data
Effects on Data

- Timing distribution widened
- Increased sigma
- Objects associated with one and other (and their position in a bunch) at the event level
Photon (delayed), background, and electron (prompt) decays

ATLAS Internal

Pre-Smearing

ATLAS Internal

Post-Smearing
Before and After Smearing for ZH samples

- **Before Smearing**:
  - Tau = 2 ns, $\chi^2_{20} = 40$, $\chi^2_{10} = 30$

- **After Smearing**:
  - Tau = 10 ns, $\chi^2_{20} = 30$, $\chi^2_{10} = 0.5$
  - Tau = 10 ns, $\chi^2_{20} = 30$, $\chi^2_{10} = 2.5$
Tau = 10 ns, $\chi_{20} = 40, \chi_{10} = 0.5$

$\tau = 10 \text{ ns}, \chi = 20 = 50, \chi_{10} = 40$

$\tau = 10 \text{ ns}, \chi = 20 = 60, \chi_{10} = 0.5$
**ATLAS Internal**

- **el_t_addition_smeared**
  - Constant: 46.21
  - Mean: -0.0543
  - Sigma: 0.5683

Sigma ~ 580 ps

- **el_t_difference_smeared**
  - Constant: 63.08
  - Mean: 0.01316
  - Sigma: 0.4214

Sigma ~ 420 ps
Correlation between leading and sub leading electrons

Pre Smearing

Post Smearing
Smearing Successful!

- Uncertainty from beam spread added to MC
- Events are correlated to each other and their position in the bunch
Thank you to everyone who helped make this project possible!

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Questions?
Another important relationship: Mean Energy vs. Time Resolution (sigma) follows trend $1/E$
Data Samples

Background

sample1: 2ns
sample2: 2ns
sample3: 2ns
sample4: 2ns
sample5: 10ns
sample6: 10ns
sample7: 10ns
sample8: 10ns
sample9: 10ns
sample10: 10ns
sample11: 10ns
sample12: 10ns
Selecting Cuts
Electron timing by energy bin

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<table>
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<th>Energy Bin</th>
<th>Entries</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Prob</th>
<th>Constant</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Prob</th>
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</thead>
<tbody>
<tr>
<td>0-50 GeV</td>
<td>426</td>
<td>0.01544</td>
<td>0.5705</td>
<td>0.1478</td>
<td>2.31 ± 30.09</td>
<td>0.02094</td>
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<td>50-100 GeV</td>
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<td>3.75 ± 74.56</td>
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<td>100-200 GeV</td>
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<td>200-1000 GeV</td>
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<td>3.03 ± 35.97</td>
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