New Physics at the LHC: Lepton Reconstruction and Signatures in ATLAS and CMS

Steven Goldfarb
MCTP: LHC New Physics Signatures Workshop
University of Michigan, Ann Arbor - 5 Jan 2008
Nominal Operating Parameters (p-p)

\[ E_{\text{injection}} = 450 \text{ MeV} \]
\[ E_{\text{beam}} = 7 \text{ TeV} \]
\[ L = 10^{34} \text{ cm}^2\text{s}^{-1} \]

Bunch Spacing = 25 ns (40 MHz)

Pile-Up = 2-20 collisions/crossing

Collision Duration \approx 10-24 \text{ h}

Down Time \approx 1.5 \text{ h}

Lifetime (as is) \approx 10 \text{ y}

(when statistical error half-life = 5y)
The LHC: Coming Years

Current Schedule

April 2008 - Machine Closed
May 2008 - Beam Commissioning at 7 TeV
July 2008 - First Collisions at 14 TeV (aim for $10^{32} \text{ cm}^2 \text{s}^{-1}$ by end 2008)
The LHC: Physics

Physics in the First Year

At $L = 10^{22} \text{ cm}^2 \text{s}^{-1}$ and 50% data-taking efficiency (early on)

⇒ few weeks $\approx 100 \text{ pb}^{-1}$
⇒ 6 months $\approx 1 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Example Decay Channel</th>
<th>LEP (all)</th>
<th>Tevatron (all)</th>
<th>LHC (100 pb$^{-1}$)</th>
<th>LHC (1 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow \mu\nu$</td>
<td>$\sim 10^4$</td>
<td>$\sim 10^6$</td>
<td>$\sim 10^6$</td>
<td>$\sim 10^7$</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>$\sim 10^6$</td>
<td>$\sim 10^5$</td>
<td>$\sim 10^5$</td>
<td>$\sim 10^6$</td>
</tr>
<tr>
<td>$tt \rightarrow WbWb \rightarrow \mu\nu + X$</td>
<td></td>
<td>$\sim 10^4$</td>
<td>$\sim 10^4$</td>
<td>$\sim 10^5$</td>
</tr>
<tr>
<td>QCD jets ($p_T &gt; 1 \text{ TeV}$)</td>
<td></td>
<td>$\sim 10^3$</td>
<td>$\sim 10^4$</td>
<td></td>
</tr>
<tr>
<td>$gg (1 \text{ TeV}) \rightarrow q\bar{q}Z\chi\ldots$</td>
<td></td>
<td></td>
<td>$\sim 50$</td>
<td>$\sim 10^3$</td>
</tr>
<tr>
<td>$Z'(1 \text{ TeV}) \rightarrow \mu\mu$</td>
<td></td>
<td>$\sim 20$</td>
<td></td>
<td>$\sim 10^3$</td>
</tr>
<tr>
<td>$H (160 \text{ GeV}) \rightarrow WW^* \rightarrow 4l$</td>
<td></td>
<td></td>
<td>$5\sigma$?</td>
<td></td>
</tr>
</tbody>
</table>

F. Gianotti, D. Froidevaux (a few additions by me)
The LHC: Leptonic Signatures of New Physics

Why Leptons?

§ That’s what you asked me to present.
§ Michigan has a key role in the construction, operation of ATLAS Precision Muon Chambers
§ Lepton signatures are “clean” (easy to trigger, select, low non-physics background)
§ Excellent for benchmarking, calibrating, aligning (Z, W, J/ψ,…)
   
   So we will be tagging and measuring them, anyway…

§ History

Neutral Currents in Gargamelle

J/ψ Decays in E288

Y Decays in E288

Z Decays in UA1 & UA2
The LHC: Leptonic Signatures of New Physics

The LHC Lepton Shopping List

**Standard Model Higgs**
- \( H \rightarrow ZZ \rightarrow lll \)
- \( H \rightarrow WW \rightarrow l\nu\nu \)
- \( qqH \rightarrow qq\tau\tau \) (one or both \( \tau \rightarrow l\nu\nu \))

**MSSM Higgs**
- \( gg \rightarrow bbH(A), H(A) \rightarrow \tau\tau, \mu\mu \)

**Doubly Charged Higgs**
- \( H^{\pm} \rightarrow W^{\pm}W^{\pm} \rightarrow l^\pm\nu^\pm\nu \)

**Massive Vector Bosons (KK, Gravitons, etc.)**
- \( Z', G \rightarrow ll \)
- \( Z', G \rightarrow WW \rightarrow l\nu\nu \)
- \( W' \rightarrow l\nu \) or \( WZ \)

**SUSY**
- \( g \rightarrow qq_l \)
- \( q_l \rightarrow q\chi^0, q\chi^0 \rightarrow ql \)
- \( hh \rightarrow q\chi^0, q\chi^0 \rightarrow ql \)

**GMSB**
- \( \chi^0_1 \rightarrow G \gamma, l_R \rightarrow G l \)
- \( \chi^0_2 \rightarrow ll, l_R \rightarrow ll \chi^0_1 \rightarrow llG \gamma \)

**Right-Handed W**
- \( W_R \rightarrow l + N \rightarrow l + ljj \)

**Excited & Heavy Leptons**
- \( pp \rightarrow l' \rightarrow lZ \rightarrow l + ljj \) (resonances)
- \( gg \rightarrow Z,Z' \rightarrow LL \rightarrow lZ + lZ \rightarrow ljj + ljj \)

**Technicolor**
- \( \rho_{TC} \rightarrow WZ \rightarrow lll\nu \)

**Et Cetera**
- SM precision measurements, e.g.

---

**Allergy Notice:**
The ingredients contain significant traces of hadronic by-products, event pile-up, and cavern background.
ATLAS & CMS: Detector Overview

**Properties**

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>7000 tons</td>
<td>12,500 tons</td>
</tr>
<tr>
<td>Diameter</td>
<td>22m</td>
<td>15m</td>
</tr>
<tr>
<td>Length</td>
<td>46m</td>
<td>22m</td>
</tr>
<tr>
<td>B Field</td>
<td>2T solenoid</td>
<td>4T solenoid</td>
</tr>
<tr>
<td></td>
<td>3.9T (peak) BA toroid</td>
<td>4.1T (peak) EC toroids</td>
</tr>
</tbody>
</table>

**ATLAS Properties**

- Toroid Magnets
- Solenoid Magnet
- SCT Tracker
- Pixel Detector
- Muon Detectors
- Tile Calorimeter
- Liquid Argon Calorimeter

**CMS Properties**

- Muon Chambers
- Inner Tracker
- Crystal Tile
- HO Calorimeter

**LHC**

- LHC Point B
- CERN Point 1
- ALICE Point 2

**CMS**

- CMS Point 5
- LHC - B
Primary Characteristics

**CMS (Compact Muon Solenoid)**
- Large 4T Solenoid
  - Muon Chambers Integrated in Return Yoke
- Muon Spectrometer
  - Precision: Drift Tubes, CSC
  - Trigger: RPC
  - Primary Measurements from Tracker
- Calorimetry
  - PbWO₄ Crystal: Excellent Resolution,
  - Lateral Segmentation
  - FCAL 11.2m from IP
- Inner Tracking
  - Pixels: 100µm (r-φ) x 150µm (z)
  - $\Delta p/p$ (1 GeV) = 0.007, 0.02 ($\eta$≈0.25)
  - $\Delta p/p$ (100 GeV) = 0.015, 0.07
  - Excellent momentum resolution

**ATLAS (A Toidoidal Lhc ApparatuS)**
- “Small” 2T Solenoid for Tracking
- 3 Large Toroids for Muon Spectroscopy
  - High BL² for Standalone Measurements
- Muon Spectrometer
  - Precision: MDT, CSC
  - Trigger: RPC, TGC
  - Excellent acceptance at poles
- Calorimetry
  - Lateral & Longitudinal Segmentation
  - FCAL only 4.9m from IP
- Inner Tracking (Pixel, SCT, TRT)
  - Pixels: 50µm (r-φ) x 400µm (z)
  - $\Delta p/p$ (1 GeV) = 0.013, 0.02 ($\eta$≈0.25)
  - $\Delta p/p$ (100 GeV) = 0.038, 0.11
  - TRT for e/π identification
## ATLAS & CMS: Detector Characteristics

### Tracking Detectors

<table>
<thead>
<tr>
<th>Tracker Parameters</th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solenoid B-Field</td>
<td>2T</td>
<td>4T</td>
</tr>
<tr>
<td>Outer Dimensions (r / z)</td>
<td>115 cm / 700 cm</td>
<td>110 cm / 540 cm</td>
</tr>
<tr>
<td>Coverage (η)</td>
<td>±2.5</td>
<td>±2.5</td>
</tr>
<tr>
<td>Technologies</td>
<td>Si Pixels (140,000,000)</td>
<td>Si Pixels (66,000,000)</td>
</tr>
<tr>
<td></td>
<td>Si Microstrips (6,2000,000)</td>
<td>Si Microstrips (9,600,000)</td>
</tr>
<tr>
<td></td>
<td>Straw Tubes (420,000)</td>
<td></td>
</tr>
<tr>
<td>Elements Crossed by Track</td>
<td>3 pixels, 8 strips, 36 straws</td>
<td>3 pixels, 4 + 6 strips (barrel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 pixels, 3 + 9 strips (endcap)</td>
</tr>
<tr>
<td>Material Crossed by Track</td>
<td>0.35X₀ - 1.35X₀</td>
<td>0.40X₀ - 1.60X₀</td>
</tr>
<tr>
<td>Pixel resolution (r-φ / z)</td>
<td>12 µm / 66 µm (barrel)</td>
<td>10 µm / 20 µm</td>
</tr>
<tr>
<td></td>
<td>12 µm / 77 µm (endcap)</td>
<td></td>
</tr>
</tbody>
</table>
### ATLAS & CMS: Detector Characteristics

#### Electromagnetic & Hadronic Calorimeters

<table>
<thead>
<tr>
<th>Calorimeter Parameters</th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Dimensions (r / z)</td>
<td>2.25m / ±6.65m (ECAL)</td>
<td>1.8m / ±3.8m (ECAL)</td>
</tr>
<tr>
<td></td>
<td>4.25m / ±6.10m (HCAL)</td>
<td>2.9m / ±5.6m (HCAL)</td>
</tr>
<tr>
<td>Coverage (η)</td>
<td>±3.2 (ECAL, HCAL)</td>
<td>±3.0 (ECAL, HCAL)</td>
</tr>
<tr>
<td></td>
<td>±4.9 (FCAL)</td>
<td>±5.0 (FCAL)</td>
</tr>
<tr>
<td>ECAL Technology</td>
<td>Presampler</td>
<td>Preshower (π⁰ rejection)</td>
</tr>
<tr>
<td></td>
<td>Pb / LAr (Liquid Argon) Accordion (190,000)</td>
<td>PbWO₄ Crystals (68,500)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Iron / Quartz Fiber</td>
</tr>
<tr>
<td>HCAL Technology</td>
<td>Fe / Scintillator (10,000)</td>
<td>Brass / Scintillator</td>
</tr>
<tr>
<td></td>
<td>Cu / LAr (HEC)</td>
<td>Scintillator (HO)</td>
</tr>
<tr>
<td></td>
<td>Cu / W / LAr (FCAL)</td>
<td>Steel / Quartz-Fiber (HF)</td>
</tr>
<tr>
<td>Samplings</td>
<td>1 + 3 + 3 (Barrel)</td>
<td>1 + 1 + 1 (Barrel)</td>
</tr>
<tr>
<td></td>
<td>• + 3 + 4 (Endcap)</td>
<td>1 + 1 (Endcap)</td>
</tr>
<tr>
<td></td>
<td>3 + 3 (Forward)</td>
<td>1 + 1 (Forward)</td>
</tr>
<tr>
<td>Material</td>
<td>24 $X_0$ - 26 $X_0$ (ECAL)</td>
<td>25 $X_0$ (ECAL)</td>
</tr>
<tr>
<td></td>
<td>11 $\lambda$ (HCAL)</td>
<td>7-11 $\lambda$ (HCAL)</td>
</tr>
<tr>
<td>Resolution (η / φ)</td>
<td>0.025 / 0.025 mrad (ECAL)</td>
<td>0.017 / 0.017 mrad (ECAL)</td>
</tr>
<tr>
<td></td>
<td>0.100 / 0.100 mrad (HCAL)</td>
<td>0.087 / 0.087 mrad (HCAL)</td>
</tr>
</tbody>
</table>
ATLAS & CMS: Detector Characteristics

Muon Spectrometers

<table>
<thead>
<tr>
<th>Spectrometer Parameters</th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Field</td>
<td>3 Toroids (B = 0.5-2.0T)</td>
<td>Solenoid (B = 2.0T)</td>
</tr>
<tr>
<td>Outer Dimensions (r / z)</td>
<td>11m / ±12.5m (barrel)</td>
<td>7.4m / ±6.4m (barrel)</td>
</tr>
<tr>
<td></td>
<td>11m / ±23m (endcap)</td>
<td>7m / ±11m (endcap)</td>
</tr>
<tr>
<td>Measuring Coverage ((\eta))</td>
<td>±2.7</td>
<td>±2.4</td>
</tr>
<tr>
<td>Trigger Coverage ((\eta))</td>
<td>±2.4</td>
<td>±2.1</td>
</tr>
<tr>
<td>Technologies</td>
<td>Monitored Drift Tubes</td>
<td>Drift Tubes (</td>
</tr>
<tr>
<td></td>
<td>Cathode Strip Chambers</td>
<td>Cathode Strip Chambers</td>
</tr>
<tr>
<td></td>
<td>Resistive Plate Chambers</td>
<td>Resistive Plate Chambers</td>
</tr>
<tr>
<td></td>
<td>Thin Gap Chambers</td>
<td></td>
</tr>
<tr>
<td>Precision Measuring Layers</td>
<td>3 (Barrel)</td>
<td>4 (Barrel)</td>
</tr>
<tr>
<td></td>
<td>4 (Endcap)</td>
<td>3-4 (Endcap)</td>
</tr>
<tr>
<td>Material</td>
<td>non-uniform</td>
<td>~170 (X_0)</td>
</tr>
<tr>
<td>(mainly negligible)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution ((\eta / \phi))</td>
<td>40 (\mu m) ((\eta)) (MDT chamber)</td>
<td>100 (\mu m) ((\phi)) (DT chamber)</td>
</tr>
<tr>
<td></td>
<td>60 (\mu m) ((\eta)) (CSC single wire)</td>
<td>200 (\mu m) ((\phi)) (CSC chamber)</td>
</tr>
</tbody>
</table>
**Electron ID and Reconstruction**

- Build clusters from ECAL cells
- Correct for geometry effects
- Correct for cell saturation
- Match clusters to tracks
- Correct for bremsstrahlung
- Require isolation
- Physics cuts

**Graphs**

- CMS: Energy resolution vs. energy for ECAL, Tracker, and Combined.
- ATLAS: Energy resolution vs. energy for different values of $\eta$.

**Equations**

- $\sigma_{\text{eff}} / E = \sqrt{E^2 + b^2}$

**Legend**

- ECAL
- Tracker
- Combined

**Note**

- The dashed tracks are invisible to the detector.

**ATLAS & CMS: Electron Reconstruction**
**Inside-Out**

- Build segments in stations
- Build tracks from hits or segments
- Correct for $E_{\text{loss}}$ & multiple scattering
- Match to calorimeter, inner tracker
- Combine statistically or re-fit

**Outside-In**

- Start with tracks in inner tracker
- Match with Calorimeter Deposits
- Match with Hits, Segments, Tracks in Spectrometer

---

**ATLAS & CMS: Muon Reconstruction**

**ATLAS**

- Start with segments in stations
- Build tracks from segments
- Correct for $E_{\text{loss}}$ & multiple scattering
- Match to calorimeter, inner tracker
- Combine statistically or re-fit

**CMS**

- Start with tracks in inner tracker
- Match with Calorimeter Depots
- Match with Hits, Segments, Tracks in Spectrometer

---

**Graphs**

- Efficiency vs. $p_T$ for ATLAS and CMS
- Pseudorapidity resolution vs. $p_T$ for ATLAS and CMS

---

- $p_T = 3.5, 4.0, 4.5, 6.0$ GeV

---

**ATLAS**

- Muon Spectrometer
- Inner Detector
- Combined

**CMS**

- $p_T$ = 10 GeV, 50 GeV, 100 GeV, 500 GeV, 1000 GeV
ATLAS & CMS: Tau Reconstruction

**Hadronic Decays**
- Localized energy deposits in calorimeters
- Require hadronic energy
- Match with 1 or 3 tracks in cone
- Remove photon conversion tracks
- Require isolation in calorimeters
- Require small jet mass

**Leptonic Decays**
- Isolated electron or muon, missing $E_T$

---

**CMS**

**ATLAS**

![Graphs showing efficiency]

![ CMS diagram]

![ ATLAS diagram]
### ATLAS & CMS: Detector Performance

#### Tracking

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta \approx 0$</td>
<td>$\eta \approx 2.5$</td>
<td>$\eta \approx 0$</td>
</tr>
<tr>
<td>$\delta p/p$ at $p_T = 1$ GeV</td>
<td>1.3%</td>
<td>2.0%</td>
</tr>
<tr>
<td>$\delta p/p$ at $p_T = 100$ GeV</td>
<td>3.8%</td>
<td>11.0%</td>
</tr>
<tr>
<td>$\varepsilon$ (pions) at $p_T = 1$ GeV</td>
<td>84.0%</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon$ (electrons) at $p_T = 5$ GeV</td>
<td>90.0%</td>
<td></td>
</tr>
</tbody>
</table>

#### Calorimetry

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta E/E$ (100 GeV Photons)</td>
<td>1 - 1.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>$\delta E/E$ (50 GeV Electrons)</td>
<td>1.3 - 2.3%</td>
<td>2.0%</td>
</tr>
<tr>
<td>ECAL+HCAL Stochastic Term</td>
<td>55% / $\sqrt{E}$</td>
<td>70% / $\sqrt{E}$</td>
</tr>
<tr>
<td>ECAL+HCAL Constant Term</td>
<td>2.3%</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

#### Muon Spectrometry

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta p/p$ at $p = 10$ GeV</td>
<td>3.9%</td>
<td>6.4%</td>
</tr>
<tr>
<td>$\delta p/p$ at $p = 100$ GeV</td>
<td>3.1%</td>
<td>3.1%</td>
</tr>
<tr>
<td>$\delta p/p$ at $p = 1000$ GeV</td>
<td>10.5%</td>
<td>4.6%</td>
</tr>
</tbody>
</table>
Cosmic Ray Commissioning Performance Tests

Example: ATLAS Combined Run in 2007

- Integrated runs taking data from all major detector components
- Example here forMuon Spectrometer Performance

ATLAS & CMS: Detector Performance

- ATLAS & CMS: Detector Performance

Graphs showing "Resolution" vs Temperature and "Resolution" vs Pressure (at 21°C)

- "Resolution" vs Temperature: Sector 13 at 20°-22°, RT function referenced to 20°, 3000 mbar
- "Resolution" vs Pressure (at 21°C): Sector 13 pressure estimated range: 2995-3010 mbar, RT function referenced to 20.0, 3000 mbar

MCTP, Ann Arbor - 6 Jan 2008

S. Goldfarb - University of Michigan

LHC Leptons - Slide 16
The LHC: Leptonic Signatures of New Physics

The LHC Lepton Shopping List

Standard Model Higgs
- \( H \rightarrow ZZ \rightarrow llll \)
- \( H \rightarrow WW \rightarrow l\ell\nu\nu \)
- \( qqH \rightarrow qq\tau\tau \text{ (one or both } \tau \rightarrow l\ell\nu) \)

MSSM Higgs
- \( gg \rightarrow bbH(A), H(A) \rightarrow \ell\ell\mu\mu \)

Doubly Charged Higgs
- \( H^{\pm\pm} \rightarrow W^\pm W^\pm \rightarrow l\ell\nu\ell\nu \)

Massive Vector Bosons (KK, Gravitons, etc.)
- \( Z^*, Z', G \rightarrow l\ell \)
- \( Z', G \rightarrow WW \rightarrow l\ell\nu\nu \)
- \( W' \rightarrow l\ell \text{ or } WZ \)

SUSY
- \( g \rightarrow qq_L \)
- \( q_L \rightarrow q\chi_2^0 \rightarrow ql l R \rightarrow qll\chi_1^0 \)

GMSB
- \( \chi_1^0 \rightarrow G \gamma, l_R \rightarrow G l \)
- \( \chi_2^0 \rightarrow l l R \rightarrow ll\chi_1^0 \rightarrow llG \gamma \)

Right-Handed W
- \( W_R \rightarrow l + N \rightarrow l + ljj \)

Excited & Heavy Leptons
- \( pp \rightarrow l l' \rightarrow lZ \rightarrow l + ljj \text{ (resonances)} \)
- \( gg \rightarrow Z, Z' \rightarrow LL \rightarrow lZ + lZ \rightarrow ljj + ljj \)

Technicolor
- \( \rho_{TC} \rightarrow WZ \rightarrow lll\nu \)

Et Cetera
- SM precision measurements, e.g.
SM Higgs Production & Decay at LHC

Hardest place to look: $M_H < 130$ GeV (but, possible with time)

Easiest place to look: $M_H = 160$ GeV (discovery through $WW$, perhaps)
The LHC: Standard Model Higgs

Discovery Potential

ATLAS

Luminosity for 5σ discovery, fb⁻¹
The “Golden” Channel: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu, \mu\mu ee, eee e$  

Not the first, but best for precision measurements  

Effective channel for $120 < M_H < 700$ GeV  

Cuts on lepton quality, isolation
The LHC: Standard Model Higgs

The Discovery Channel?: $H \rightarrow WW \rightarrow l\nu l\nu$

- High rate near $M_H = 160$ GeV
- Spin correlations give small angle between leptons
- Main background from WW production, and $tt$ (also $ZZ \rightarrow l\nu l\nu$)
- Can only measure $m_T$

ATLAS

CMS

MCTP, Ann Arbor - 6 Jan 2008
S. Goldfarb - University of Michigan
LHC Leptons - Slide 21
The LHC: Standard Model Higgs

Vector Boson Fusion: $qqH \rightarrow qq\tau\tau$

Two jets at high rapidity
Tag one $\tau$ with a lepton

![Graph showing CMS data](image_url)

- Signal ($135\text{ GeV}/c^2$)
- EW/QCD $2\tau$+jets
- $t\bar{t}$bar $W$+jets
- Fit to Signal
- Fit to $Z/\gamma^*$ ($\rightarrow 2\tau$)
- Fit to $t\bar{t}$bar $W$+jets
- Sum of fits

![Graph showing CMS, 30 fb$^{-1}$](image_url)

- $H \rightarrow \gamma\gamma$ cuts
- $H \rightarrow \gamma\gamma$ opt
- $H \rightarrow ZZ \rightarrow 4l$
- $H \rightarrow WW \rightarrow 2l2\nu$
- $qqH, H \rightarrow WW \rightarrow lvjj$
- $qqH, H \rightarrow \tau\tau \rightarrow l+jet$
- $qqH, H \rightarrow \gamma\gamma$

MCTP, Ann Arbor - 6 Jan 2008
S. Goldfarb - University of Michigan
LHC Leptons - Slide 22
The LHC: MSSM Higgs

H/A → \tau\tau

*Early H → \tau\tau probably MSSM (SM production too low)*
*At low tan\beta, gg → A → \tau\tau dominates*
*At high tan\beta, bbH and bbA “associated” production boosts signal*
*Need H > 100 GeV to avoid Z → \tau\tau background*
*Tag one \tau with a lepton*
*Tagging b in associated production greatly reduces Z → \tau\tau background*

H/A → \mu\mu

*Lower rates*
  *less background better resolution*

MCTP, Ann Arbor - 6 Jan 2008
S. Goldfarb - University of Michigan
LHC Leptons - Slide 23
$Z' \rightarrow \mu\mu, ee$

Anything massive decaying to oppositely charged leptons of same flavor
- Kaluza-Klein $Z$ excitations, K-K Graviton excitations (Randall-Sundrum), GUT,…

Selected exactly two isolated electrons or muons
- Apply minimal $E_T$ or $p_T$ cuts

A hard photon or two is acceptable
The LHC: SUSY (mSUGRA Example)

\[ g \to q q_L \]

\[ q_L \to q \chi_2^0 \to q l \ell_R \to q l l \chi_1^0 \text{ (assuming } m(g) \geq m(q) \text{ at LM1)} \]

Cascade decay of squarks and gluinos

Look for high \( p_T \) isolated leptons, high \( p_T \) jets and missing \( E_T \)

- Expect triangular shape of di-lepton mass
- Subtract background from different-flavor opposite-sign lepton pairs

Studies typically focus on mSUGRA to determine discoverability

![Graphs showing CMS data](image-url)

- CMS data for different lepton pairs and mass distributions
- Expected triangular shape and different-flavor subtraction
The LHC: Excited W Bosons

$W' \rightarrow ev$

*Resonance appearing high $P_T$ of standard $W$ production*

$W' \rightarrow WZ$

*Main background from continuum of $WZ$ production (or $ZZ$, missing lepton)*

*Look for 3 charged leptons, missing $E_T$*

- Two leptons from $Z$ (same flavor, opposite charge)
- Remove $tt$ background with lepton isolation cuts
The LHC: Technicolor

\[ \rho_{TC} \rightarrow WZ \rightarrow ll\bar{l}l \]

Model: “multiscale technicolor \( SU(N_{TC}), N_{TC}=4 \), 2 isostriplets of \( \pi_{TC} \)”

Same recipe as for \( W' \), but lower mass

Angular distribution sensitive to polarization
Summary

Leptons in the LHC

*LHC Discovery Channels Primarily Leptonic*
- Clean signals, easy to identify, measure

*CMS & ATLAS Optimized to Identify and Measure Leptons*
- Majority of $550M price tags went to Magnets, Spectrometry
- Both detectors provide outstanding performance in resolution, efficiency

Readiness

*The Detectors are both more than 90% installed*
- ATLAS Small Wheel Installation scheduled next week
- CMS in similar situation

*Test Beam, Cosmic Commissioning Successful*
- Detectors working essentially as expected

Steve’s Predictions

*Major Hurdles in 2008-2009*
- Accelerator & Detector Debugging: These are complex devices.
- Computing: These are also complex devices.

*Discoveries in the first 2 years?*
- The only question is “What?”
References & Credit

http://cdsweb.cern.ch/record/922757

http://cdsweb.cern.ch/record/942733

http://cern.ch/Atlas/GROUPS/PHYSICS/TDR/access.html


“The Road to Discovery,” Andy Parker (Cambridge University), Hadron Collider Physics Summer School, FNAL, Jun 2007.

“Search for Extra Dimensions and Leptoquarks in Early LHC Data,” Greg Landsberg (Brown University), ILC/LHC Early Phase Workshop, FNAL, Apr 2007.


“Prospects for Higgs Boson Searches at the LHC,” Karl Jakobs (University of Freiburg), SUSY 07, Karlsruhe.

Coffee and Discussions with Karl Jakobs (University of Freiburg), ATLAS Physics Coordinator.

Correspondence with CMS Physics Conveners: David Futyan, Pascal Vanlaer, Nicola Amapane, Simone Gennai.
Note that, although the speaker is an active member of the ATLAS Collaboration, he has made every effort possible to present both CMS and ATLAS in a fair and non-biased manner.