A Search for Supersymmetry in CMS Photon +Jet + MET Events

Rachel Yohay
University of Virginia
March 29, 2012
Outline

- Detecting photons with the CMS ECAL
  - Distinct challenges of the ECAL endcaps
- SUSY photon + jet + ME$_T$ search
  - Motivation
  - Event selection
  - Background estimation
- Results
  - Interpretation
ECAL operating principles

- Constructed of ~75,000 compact, dense (8.3 g/cm$^3$), relatively radiation hard scintillating lead tungstate (PbWO$_4$) crystals

- Crystal dimensions: ~1 Molière radius (~22 mm) x ~1 Molière radius x ~25 X$_0$ (~9 mm) ⇒ most of an electromagnetic shower is contained within 1 crystal

- Short scintillation time (~80% of scintillation light is emitted in 25 ns, the LHC collision frequency) ⇒ can easily resolve events in different LHC buckets

Energy resolution:

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} + \frac{b}{E} + c^2$$

Goal: 0.05
Distinct challenges of the ECAL endcaps

- ECAL endcaps extend crystal coverage from $\eta = 1.5$ out to $\eta = 3.0$
- Larger acceptance for rare $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$, and $H \rightarrow WW$ processes
- Calorimetry at high $\eta$ (+ particle flow techniques) $\Rightarrow$ better $M_{ET}$ reconstruction $\Rightarrow$ better sensitivity to SUSY processes
- EE faces a much harsher environment than EB
  - Strong magnetic field
  - Higher occupancy
  - More radiation damage
- Significant design difference between EB and EE: choice of vacuum phototriode as photodetector
- Calibrating EE is a considerable challenge
Vacuum phototriodes

Anode, dynode, and cathode HV wires

- Chosen for their radiation hardness and good performance in strong magnetic fields

- Cathode at 0 V, dynode at 600 V, and anode mesh between them at 800 V

Schematic of a CMS VPT

[5]

[6]
VPT testing at UVa

During the spring of 2008, extensive VPT testing was carried out in the UVa 4 T magnet, commissioned during winter 2008-2009.

Certified VPTs were installed on the endcap crystals.

Issues to be understood:

- Response vs. angle with respect to the magnetic field direction: is it smooth and in rough agreement with theoretical calculation?
- How do VPTs with skewed anodes or crinkled anodes compare to nominal?

Response of 9 VPTs vs. angle of VPT with respect to the magnetic field direction.

B field effect in one section of EE.

Apparatus for measuring VPT response vs. angle.
VPT stability

- VPTs first used in the OPAL electromagnetic calorimeter endcaps [8]
- VPT gain varies with frequency/amplitude of incident light [9]
  - Effect strongly suppressed in 4 T magnetic field
  - High→low frequency: gain increases
  - Low→high frequency: gain increases or decreases
- All VPT responses are different
- Provide a constant rate of stability LED pulses to the VPTs to suppress gain changes at LHC on/off transitions

VPT response vs. time for different background pulsing rates

Response of VPTs to SPS spill simulation
Sustained ionizing radiation causes crystal radiation damage, reducing crystal transparency and ultimately the amount of light collected by the photodetectors.

Crystal transparency loss correlated with LHC integrated luminosity, and increases faster for higher instantaneous luminosity.

Continuously pulse crystals from known light source to track and correct for transparency loss from radiation damage.
LED stability and calibration system

- Dual wavelength LED stability and monitoring system designed at UVa
- Blue (450 nm) LED: near the peak of crystal scintillation and VPT photocathode efficiency, so ideal for transmitting the maximum amount of light to VPTs for stability pulsing
- Orange (617 nm): transparent to crystals but still efficient for VPT photocathode, so ideal for disentangling crystal damage from VPT gain changes
- PN diodes for normalization
Hardware setup

- LED amplitudes set via I²C commands communicated to the hardware via Ethernet-to-serial and serial-to-I²C bridges
- Trigger pulse originates in counting room and is regenerated on the LED circuit board on the detector
Use existing LaserSupervisor XDAQ executive as interface to ECAL DAQ

Execute LED on/off commands sent from the LaserSupervisor

Monitoring of electronics every 10 minutes
Control and monitoring software

Wrote this software

Wrote monitoring programs to assess the health of this hardware
LED and VPT performance

- Stable, reliable LED system important for ECAL calibration
- VPT effect currently dwarfed by transparency loss, but system in place to mitigate gain changes in order to achieve best performance
SUSY with photons

- Why search for supersymmetry?
  - Provides a way to control loop corrections to the Higgs mass
  - Provides a stable, feebly interacting particle ⇒ dark matter candidate

- SUSY particles are heavier than their SM counterparts, so SUSY is a broken symmetry
  - In gauge-mediated SUSY breaking (GMSB), ordinary gauge interactions link the SUSY-breaking and visible sectors
  - ~eV-keV gravitino is the lightest SUSY particle ⇒ escapes CMS undetected, leading to large MET
  - Neutralino is the next-to-lightest SUSY particle (NLSP) ⇒ neutralino usually decays to photon + gravitino

[13] Where searching for supersymmetry?

Usually decays to photon + gravitino SUSY particle (NLSP) leading to large ME

[14] Example of Higgs mass regularization via a SUSY loop that cancels its SM counterpart loop.

Particles

Supersymmetric "shadow" particles

 spin changed by half integer
GMSB final states

Bino NLSP: neutralino $\rightarrow \gamma + \text{gravitino}$

$2\gamma + \text{jets} + \mathbf{M}E_T$

Bino NLSP: neutralino $\rightarrow \gamma + \text{gravitino}$ or neutralino $\rightarrow Z(\rightarrow \text{jets}) + \text{gravitino}$

$\gamma + \text{jets} + \mathbf{M}E_T$

Wino NLSP: neutralino $\rightarrow \gamma + \text{gravitino}$ and chargino $\rightarrow W(\rightarrow l\nu) + \text{gravitino}$

$l + \gamma + \text{jets} + \mathbf{M}E_T$

Wino NLSP: neutralino $\rightarrow \gamma + \text{gravitino}$ and chargino $\rightarrow W(\rightarrow \text{jets}) + \text{gravitino}$

$\gamma + \text{jets} + \mathbf{M}E_T$
GMSB final states

2γ+jets+MET

4.7 fb⁻¹

Bino NLSP: neutralino→γ+gravitino

1γ+jets+MET

This talk

Wino NLSP: neutralino→γ+gravitino and chargino→W(→ℓν)+gravitino

γ+jets+MET

Bino NLSP: neutralino→γ+gravitino or neutralino→Z(→jets)+gravitino

γ+jets+MET

Wino NLSP: neutralino→γ+gravitino and chargino→W(→jets)+gravitino
Photon selection

- Single L1-seeded diphoton triggers with 36 and 22 GeV thresholds
- Combined detector isolation cuts in $\Delta R = 0.3$ cone to improve acceptance in jet-rich events
- Shower shape cuts further reduce jet fakes and anomalous energy deposits
- Pileup subtraction from isolation cone using Fastjet [15]
- Minimum $\Delta R$ between the photons to avoid isolation cone overlap
- $\pm 3$ ns timing cut removes cosmics and beam halo
- Pixel veto rejects electrons

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{comb}}$, $\sigma_{\eta\eta}$</td>
<td>$&lt; 6 \text{ GeV } &amp; &amp; &lt; 0.011$</td>
</tr>
<tr>
<td>JSON</td>
<td>Yes</td>
</tr>
<tr>
<td>No. good PVs</td>
<td>$\geq 1$</td>
</tr>
<tr>
<td>$\Delta R_{\text{EM}}$</td>
<td>$&gt; 0.6$</td>
</tr>
<tr>
<td>$\Delta \phi_{\text{EM}}$</td>
<td>$\geq 0.05$</td>
</tr>
</tbody>
</table>
Photon ID efficiency

- Photon ID efficiencies taken from MC and corrected by \((\text{data electron efficiency}) / (\text{MC electron efficiency})\)
- Use \(Z \rightarrow \text{ee}\) events to measure the electron efficiencies
- Photon ID cuts designed to behave similarly for electrons and photons
- Signal MC acceptance \(\times\) efficiency multiplied by 1 factor of \(\varepsilon_{\text{data}} / \varepsilon_{\text{MC}}\) per photon
- Pixel match veto efficiency estimated from MC: \((96.4 \pm 0.5)\%\) (stat. \(\oplus\) syst. due to tracker material budget variation)
- Data/MC efficiency scale factor: \(0.99 \pm 0.04\), with errors due to:
  - \(Z\) signal and background shape variation
  - Signal fit over/underestimation
  - Pileup effects
  - MC electron/photon difference
We investigate the effect of pileup using multijet samples perpendicular components. Pileup, however, will have a considerable effect on the resolution of the parallel and small effect on the scale of the component of the measured component of

Because there is no true high LHC bunch currents and can play an important role in Pileup, namely multiple proton collisions within the same bunch crossing occurs because of 6.5 Effect of multiple interactions

jets to PF calorimetric activity parametrized by Calo indicates that PF above a multiplicities varying from two to four, normalized to the same area. The jets are required to be Figure :- shows the PF the PF Both TC different Figure :- shows the calibrated particle level the particle level We use PF gives the best estimate of the true For in data and in simulation, Figure :- Calibrated particle level

is corrected, on average, to the particle level using a Pythia simulation [sw] m The GeV calibrated PF Figure :- shows calibrated PF Figure :- shows the calibrated electron and PF muon definitions, with references.

Table :- Definition of HBnHE hadronic jets, m

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithm</td>
<td>L1FastL2L3Residual corrected PF</td>
</tr>
<tr>
<td>$p_T$</td>
<td>$&gt; 30 \text{ GeV}$</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>Neutral hadronic energy fraction</td>
<td>$&lt; 0.99$</td>
</tr>
<tr>
<td>Neutral electromagnetic energy fraction</td>
<td>$&lt; 0.99$</td>
</tr>
<tr>
<td>Number of constituents</td>
<td>$&gt; 1$</td>
</tr>
<tr>
<td>Charged hadronic energy</td>
<td>$&gt; 0.0 \text{ GeV if }</td>
</tr>
<tr>
<td>Number of charged hadrons</td>
<td>$&gt; 0$ if $</td>
</tr>
<tr>
<td>Charged electromagnetic energy fraction</td>
<td>$&lt; 0.99$ if $</td>
</tr>
</tbody>
</table>

- $\geq 1$ jet not overlapping any electron, photon, or fake (loosely isolated) photon
Backgrounds

- **Dominant:** QCD with fake $M_{E_T}$
  - Diphoton
  - $\gamma + \text{jet}$: 1 jet misidentified as a photon
  - Multijet: at least 2 jets misidentified as photons

- **Subdominant:** electroweak processes with real $M_{E_T}$
  - $W(\rightarrow e\nu\gamma)$: electron misidentified as a photon
  - $W(\rightarrow e\nu) + \text{jet}$: electron and jet misidentified as photons
Estimating the QCD background

- EM superior to hadronic energy resolution ⇒ fake $M_{E_T}$ due entirely to jet mismeasurement

- Measure QCD background from data—control sample with well-measured EM objects to model the QCD fake $M_{E_T}$ spectrum

- Reweight events in control sample based on di-EM $p_T$ (kinematics) and $N_j$ (hadronic activity)

- Normalize the predicted QCD fake $M_{E_T}$ spectrum to a signal-depleted region with $M_{E_T} < 20$ GeV

Diagram:
- EM objects (well measured kinematics, no fake $M_{E_T}$)
- 2nd most energetic EM object
- Most energetic EM object
- Di-EM $p_T$ (well-measured handle on the kinematics of the jet system)
- Jets (poorly measured kinematics, source of fake $M_{E_T}$)
- $z$ (beam direction)
**Reweighting**

**Step 1:** Find a control sample similar to the $\gamma\gamma$ search sample

![Diagram](https://example.com/diagram1.png)

**Step 2:** $p_T$ of di-EM system different between control and $\gamma\gamma$ samples $\Rightarrow$ different $M_{ET} \Rightarrow$ assign weight to control event based on di-EM $p_T$

![Diagram](https://example.com/diagram2.png)

**Step 3:** Repeat step 2 for events with 0 jets, 1 jet, and $\geq 2$ jets.

![Diagram](https://example.com/diagram3.png)

**Step 4:** Weight each event in control $M_{ET}$ distribution with weights from steps 2-3.

![Diagram](https://example.com/diagram4.png)
QCD control samples

- Z dielectron (ee)
  - $81 \text{ GeV} \leq m_{ee} < 101 \text{ GeV}$
  - Photon with inverted pixel seed veto
    - Similar energy resolution as photons
  - Di-EM $p_T$ reweighting significant because the kinematics of Z and QCD diphoton production are different
  - Subtract $t\bar{t}$ contribution to ee sample using invariant mass sidebands

- Electromagnetic dijets (ff)
  - Photon with inverted isolation or shower shape, below a maximum allowed isolation
  - Tends to have a little bit of HCAL energy, so use PF $E_T$ instead of ECAL $E_T$
  - Similar kinematics to diphoton sample, so reweighting has small effect

<table>
<thead>
<tr>
<th>Pixel seed</th>
<th>ee control region</th>
<th>ff control region</th>
<th>γγ search region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Di-EM $p_T$ spectra

- ee (red) and ff (blue) spectra area-normalized to $\gamma\gamma$ (black) spectrum

- $w_{ij} = (N_{\text{control}}/N_{\gamma\gamma})(N_{\gamma\gamma}^{ij}/N_{\text{control}}^{ij})$
  - i runs over di-EM $p_T$ bins
  - j runs over $N_j$ bins

R. Yohay
March 29, 2012
Estimating the electroweak background

- $W(\rightarrow\text{e}\nu\gamma)$ and $W(\rightarrow\text{e}\nu)$ + jet can fake $\gamma\gamma$ if the electron pixel seed is missed.
- Estimate the electron→photon mis-ID rate $f_{e\rightarrow\gamma}$ by fitting for the Z contribution in the ee and eγ samples.
- $f_{e\rightarrow\gamma} = 0.015 \pm 0.002(\text{stat.}) \pm 0.005(\text{syst.})$
- Systematic error due to small $p_T$ dependence of the mis-ID rate.
- Scale eγ sample by $f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma})$.
• ff sample used for the primary QCD background estimate

• Difference between ee and ff prediction taken as a systematic error

• Use $\slashed{E}_T > 50$ GeV as search region
Upper limit calculation

- CLs 95%
- Limits calculated in multiple MET bins and then combined
  - 50-60 GeV, 60-80 GeV, 80-100 GeV, 100-140 GeV, 140-180 GeV, and ≥180 GeV
- Uncertainties on signal acceptance \( \times \) efficiency, background, and integrated luminosity modeled with log-normal distributions

<table>
<thead>
<tr>
<th>Source</th>
<th>Systematic uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated luminosity</td>
<td>4.5</td>
</tr>
<tr>
<td>Background estimate</td>
<td>-48</td>
</tr>
<tr>
<td>Statistics</td>
<td>-32</td>
</tr>
<tr>
<td>Reweighting</td>
<td>-2.3</td>
</tr>
<tr>
<td>Normalization</td>
<td>-0.23</td>
</tr>
<tr>
<td>Electron→photon mis-ID rate</td>
<td>31</td>
</tr>
<tr>
<td>Difference between ff and ee</td>
<td>-35</td>
</tr>
<tr>
<td>Acceptance ( \times ) efficiency</td>
<td>7-72</td>
</tr>
<tr>
<td>Photon ID efficiency correction</td>
<td>4</td>
</tr>
<tr>
<td>PDF error on cross section</td>
<td>4-66</td>
</tr>
<tr>
<td>PDF error on acceptance</td>
<td>0.1-9</td>
</tr>
<tr>
<td>Renormalization scale</td>
<td>4-28</td>
</tr>
</tbody>
</table>
Modeling the GMSB signal

$M_2$ decoupled,
$m_{\text{neutralino}} = 375$ GeV,
$m_{\text{gluino}} \text{ vs. } m_{\text{squark}}$

Light squarks decoupled, $m_{\text{gluino}} \text{ vs. } m_{\text{neutralino}}$
Model exclusions

- **$M_2$ decoupled**, $m_{\text{neutralino}} = 375$ GeV,
  - $m_{\text{gluino}}$ vs. $m_{\text{squark}}$

- **Light squarks decoupled**, $m_{\text{gluino}}$ vs. $m_{\text{neutralino}}$
Conclusions

- Top performing ECAL is an important instrument in the quest for new physics at CMS
  - Steadily moving toward design calibration precision
  - Utilized in Higgs, SUSY, and Exotica searches
- Searches in the diphoton final state are powerful tools for observing SUSY
  - Clean trigger objects
  - Dominant background estimated from data
- 4.7 fb\(^{-1}\) search has excluded gluinos and light squarks in the GMSB scenario below \(~1\) TeV
  - Best exclusions to date on gauge mediation
  - As energy and luminosity increase, different variants on the diphoton search can be explored to give the best coverage of possible SUSY scenarios
- Looking forward to 2012!
Backup
Effect of intercalibration and transparency corrections on the \(Z \rightarrow \text{ee}\) mass peak position and width

RMS deviation of supercrystal temperature measurements over 2010 running
Comparison of crystal properties

<table>
<thead>
<tr>
<th></th>
<th>NaI(Tl)</th>
<th>BGO</th>
<th>CSI</th>
<th>BaF$_2$</th>
<th>CeF$_3$</th>
<th>PbWO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g/cm$^3$]</td>
<td>3.67</td>
<td>7.13</td>
<td>4.51</td>
<td>4.88</td>
<td>6.16</td>
<td>8.28</td>
</tr>
<tr>
<td>Radiation length [cm]</td>
<td>2.59</td>
<td>1.12</td>
<td>1.85</td>
<td>2.06</td>
<td>1.68</td>
<td>0.89</td>
</tr>
<tr>
<td>Interaction length [cm]</td>
<td>41.4</td>
<td>21.8</td>
<td>37.0</td>
<td>29.9</td>
<td>26.2</td>
<td>22.4</td>
</tr>
<tr>
<td>Molière radius [cm]</td>
<td>4.80</td>
<td>2.33</td>
<td>3.50</td>
<td>3.39</td>
<td>2.63</td>
<td>2.19</td>
</tr>
<tr>
<td>Light decay time [ns]</td>
<td>230</td>
<td>60</td>
<td>16</td>
<td>0.9</td>
<td>8</td>
<td>5 (39%)</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>630</td>
<td>8</td>
<td>25</td>
<td>15 (60%)</td>
<td>100 (1%)</td>
</tr>
<tr>
<td>Refractive index</td>
<td>1.85</td>
<td>2.15</td>
<td>1.80</td>
<td>1.49</td>
<td>1.62</td>
<td>2.30</td>
</tr>
<tr>
<td>Maximum of emission [nm]</td>
<td>410</td>
<td>480</td>
<td>315</td>
<td>210</td>
<td>300</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>310</td>
<td>340</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature coefficient [%/°C]</td>
<td>~0</td>
<td>-1.6</td>
<td>-0.6</td>
<td>-2/0</td>
<td>0.14</td>
<td>-2</td>
</tr>
<tr>
<td>Relative light output</td>
<td>100</td>
<td>18</td>
<td>20</td>
<td>20/4</td>
<td>8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

[2]
Expected radiation dose

Fig. 1.4: The dose and neutron fluence in and around the crystals as a function of pseudorapidity. Numbers in bold italics are doses, in kGy, at shower maximum and at the rear of the crystals. The other numbers are fluences immediately behind the crystals, in the space for endcap electronics surrounded by moderators and in the silicon of the preshower in units of $10^{13}$ cm$^{-2}$. All values correspond to an integrated luminosity of $5 \times 10^{5}$ pb$^{-1}$ appropriate for the first ten years of LHC operation.
Fig. 5. Relative variation of the VPT gain averaged over 20 spills as a function of time for different average VPT anode currents.
LED running modes

- Calibration sequence
  - Few hundred LED pulses read out (readout rate ~100 Hz) for each EE monitoring region
  - Continuous monitoring of the VPTs and crystals, to complement the laser monitoring

- Local run
  - Short sequence of a few hundred LED pulses triggered by ECAL-generated trigger and read out
  - Useful for debugging the system and checking the health of the ECAL

- Soaking
  - Fire the blue LED stability pulses all the time in the abort gaps to dampen VPT gain changes
  - Frequency up to ~11.4 kHz (use only 100 Hz right now)
• SUSY must be a broken symmetry — if not, each SM particle and its superpartner would have the same mass, and the superpartners would have been discovered already

• SUSY-breaking terms in the minimal SUSY Lagrangian generically allow for lepton flavor violating decays:

\[
\begin{bmatrix}
\tilde{e}_R \\
\tilde{\mu}_R \\
\tilde{\tau}_R
\end{bmatrix}
= 
\begin{bmatrix}
c_{ee} & c_{e\mu} & c_{e\tau} \\
c_{\mu e} & c_{\mu\mu} & c_{\mu\tau} \\
c_{\tau e} & c_{\tau\mu} & c_{\tau\tau}
\end{bmatrix}
\begin{bmatrix}
\tilde{e}_R \\
\tilde{\mu}_R \\
\tilde{\tau}_R
\end{bmatrix}
\]

if not proportional to the unit matrix, will lead to, for example, \( \mu \rightarrow e\gamma \)

• The relation \( c_{ee} = c_{\mu\mu} = c_{\tau\tau} = m^2 \) (and similar for the other fermion families) arises naturally in GMSB, because the sparticle masses (i.e. the diagonal terms) only depend on their gauge couplings, which are identical for the three families
GMSB searches with photons

- Minimal GMSB model
- Neutralino pair production
- $m_{\text{neutralino}} > 97$ GeV for short-lived neutralino

**Tevatron Run II (2001-2010)**
- Minimal GMSB model (SPS8) [18]
- Chargino and neutralino pair production
  - $m_{\text{neutralino}} > \sim 170$ GeV ($\Lambda > 124$ TeV)
  - for short-lived neutralino

**LHC7 (2009-2011)**
- Simplified model parametrized in terms of tan $\beta$ and squark, gluino, and wino/bino/higgsino masses
- No assumptions on the number of messengers, the messenger mass, or the SUSY breaking scale
- Squark and gluino production
- Short-lived neutralino
CMS longitudinal cross section

EB edge $|\eta| = 1.479$

ME edge $|\eta| = 2.1$

HE edge $|\eta| = 2.6$

HF edge $|\eta| = 5.0$

beam line

interaction point
Trigger definitions

- IsoVL
  - $I_{ECAL} < 0.012E_T + 6$ GeV
  - $I_{HCAL} < 0.005E_T + 4$ GeV
  - $I_{track} < 0.002E_T + 4$ GeV
- R9Id
  - R9 > 0.85
Photon isolation criteria

- $|E_{\text{ECAL}} - 0.0792\rho + E_{\text{HCAL}} - 0.0252\rho + E_{\text{track}}| < 6\text{ GeV}$
- $\rho = \text{average energy density per unit area in the calorimeters as measured by Fastjet}$

\[
\sigma_{\eta\eta}^2 = \frac{\sum_{i=1}^{25} w_i (\eta_i - \bar{\eta})^2}{\sum_{i=1}^{25} w_i}, \quad < 0.011
\]

where $w_i = \max(0, 4.7 + \ln(E_i / E))$, $E_i$ is the energy of the $i$\textsuperscript{th} crystal in a group of $5 \times 5$ centred on the one with the highest energy, and $\eta_i = \hat{\eta}_i \times \delta\eta$, where $\hat{\eta}_i$ is the $\eta$ index of the $i$\textsuperscript{th} crystal and $\delta\eta = 0.0174$; $E$ is the total energy of the group and $\bar{\eta}$ the average $\eta$ weighted by $w_i$ in the same group [21].
ECAL noise cleaning

- Form $3 \times 3$ matrix of crystals around the photon seed crystal
- Find the 2 highest energy crystals within the matrix
- If the sum of the energies of the 2 highest energy crystals divided by the sum of the energies of all 9 crystals within the matrix exceeds 0.95, reject the photon as ECAL noise

$\frac{E_{\text{1st}} + E_{\text{2nd}}}{E_{3\times3}} > 0.95 \Rightarrow \text{reject}$
Photon ID variables

Figure 7: The commissioning of the photon object at CMS is still in progress. Future results with a large simulation finally we have shown that the number of fakes due to non-collision backgrounds contribution to the "candidate" sample below -99 events at 9-v CL.

Figure 8: Halo events primarily arrive out-of-time with respect to prompt events. The black curve shows the expected track rate as a function of time, while the orange and blue curves represent the observed rates for prompt and halo events, respectively.
Sample definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td>HLT match</td>
<td>IsoVL</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>$H/E$</td>
<td>$&lt; 0.05$</td>
</tr>
<tr>
<td>$R9$</td>
<td>$&lt; 1$</td>
</tr>
<tr>
<td>Pixel seed</td>
<td>No/No</td>
</tr>
<tr>
<td>$I_{\text{comb}}$, $\sigma_{\eta\eta}$</td>
<td>$&lt; 6$ GeV $$$&amp;&amp;$$ $&lt; 0.011$</td>
</tr>
<tr>
<td>JSON</td>
<td>Yes</td>
</tr>
<tr>
<td>No. good PVs</td>
<td>$\geq 1$</td>
</tr>
<tr>
<td>$\Delta R_{\text{EM}}$</td>
<td>$&gt; 0.6$</td>
</tr>
<tr>
<td>$\Delta \phi_{\text{EM}}$</td>
<td>$\geq 0.05$</td>
</tr>
</tbody>
</table>
Effect of reweighting

CMS Work in Progress

CMS 4.7 fb$^{-1}$, no jet requirement

- ee full reweighting
- ee no reweighting

CMS Work in Progress

CMS 4.7 fb$^{-1}$, no jet requirement

- ff full reweighting
- ff no reweighting

CMS Work in Progress

CMS 4.7 fb$^{-1}$, no jet requirement

- $Z|Z|Z$ full reweighting
- $Z|Z|Z$ no reweighting

CMS Work in Progress

- $Z|Z|Z$ full reweighting
- $Z|Z|Z$ no reweighting
PF vs. ECAL $E_T$ (1)

Leading $e$

Leading $f$

Leading $\gamma$

Trailing $e$

Trailing $f$

Trailing $\gamma$
PF vs. ECAL $E_T$ (2)

Profile histograms of previous slide
Removing ttbar from the ee sample

- **ee sample contains a non-negligible high-MET background of ttbar events**

- **71 GeV ≤ m_{ee} < 81 GeV and 101 GeV ≤ m_{ee} < 111 GeV** sidebands used to estimate the non-Z background in the 81 GeV ≤ m_{ee} < 101 GeV ee sample
  
  - Reweight the low and high sidebands independently, using weights derived from events in those sidebands
  
  - Subtract the low and high sideband MET distributions from the Z signal MET distribution
  
  - Proceed with normalization of the sideband-subtracted ee sample
ee sideband weights

CMS Work in Progress

R. Yohay

March 29, 2012
The number of events in the di-electron sample is given by

$$N_{ee} = f_{e\rightarrow e}^2 N_{Z\rightarrow ee}$$

where $f_{e\rightarrow e}$ is the efficiency to correctly identify an electron via pixel match and $N_{Z\rightarrow ee}$ is the true number of $Z\rightarrow ee$ events. The number of events in the $e\gamma$ sample due to misidentification of 1 $Z$ electron as a photon is given by

$$N_{e\gamma}^Z = 2 f_{e\rightarrow e} (1 - f_{e\rightarrow e}) N_{Z\rightarrow ee}$$

Solving for $f_{e\rightarrow e}$,

$$f_{e\rightarrow e} = \frac{1}{1 + \frac{1}{2} \frac{N_{e\gamma}^Z}{N_{ee}}}$$

The number of events in the $e\gamma$ sample due to correctly identifying a W electron is given by

$$N_{e\gamma}^W = f_{e\rightarrow e} N_W$$

where $N_W$ is the number of true $W\rightarrow e\nu$ events. The number of $\gamma\gamma$ events from W electron misidentification is given by

$$N_{\gamma\gamma}^{EW} = (1 - f_{e\rightarrow e}) N_W$$

where we have neglected the contribution from Z electron misidentification since it is small (i.e., $f_{e\rightarrow \gamma}$ is small and the Z contribution involves $f_{e\rightarrow \gamma}^2$, since both electrons have to be misidentified). Since

$$f_{e\rightarrow e} = 1 - f_{e\rightarrow \gamma}$$

solving for $N_{\gamma\gamma}^{EW}$

$$N_{\gamma\gamma}^{EW} = \frac{f_{e\rightarrow \gamma}}{1 - f_{e\rightarrow \gamma}} N_{e\rightarrow \gamma}$$
GMSB MC

- Signal spectrum generation via SuSpect v2.41 [23]
- Signal decays via SDECAY v1.3 [24]
- Event generation, parton showering, hadronization, and decay via Pythia 6 [25]
- CMS detector simulation (GEANT [26]) and reconstruction
- Gravitino LSP
- NLO production cross sections and renormalization and factorization scale uncertainties calculated with Prospino
- PDF uncertainties calculated using PDF4LHC [27] recommendations
- 2 different signal scenarios
  - Bino NLSP (1): $M_1 = 375$ GeV, $M_2 = 3.5$ TeV, $\tan \beta = 2$, squark and gluino masses in [400 GeV, 2000 GeV], sleptons and all gauginos except the lightest neutralino have mass 3.5 TeV, heavy right-handed squarks (GGM sum rules)
  - Bino NLSP (2): $M_1 = 375$ GeV, light squarks $\sim 2.5$ TeV, $M_3$ in [300 GeV, 2000 GeV], $M_2$ in [200 GeV, 1500 GeV]
References

References


