Gunther Roland

CMS Studies of Isolated-Photon+Jet Events in 2.76 TeV PbPb Collisions

Winter Workshop on Nuclear Dynamics

for the CMS Collaboration
CMS PbPb Results

see our webpage at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN
CMS Detector

Inner tracker:
Charged particles
$\sigma(p_T)/p_T < 3@100\text{GeV/c}$

EM and Hadronic calorimeters
Photons, Jets

MinBias Trigger
Centrality

EM and Hadronic calorimeters
Photons, Jets

Muons

detectors

Muon detectors

HCAL

|\eta| < 5.2

ECAL

|\eta| < 3.0

Tracker

|\eta| < 2.5

BSC

(Beam Scintillation Counter)

MinBias Trigger

HF

(Forward Calorimeter)

MinBias Trigger

Centrality
Trigger and Event Selection

- **MinBias Trigger:**
  - Coincidence of BSC or HF signal
  - Trigger efficiency: 97% ± 3%

- **Di-Muon Trigger:**
  - Two tracks in the muon detector

- **Photon Trigger:**
  - Uncorrected photon $E_T > 15$ GeV

- **Jet Trigger:**
  - Corrected jet $E_T > 35, 50$ GeV

- **High $p_T$ track trigger:**
  - Charged particles $p_T > 12$ GeV/c

- **Centrality determination:**
  - Forward calorimeter (HF) energy

![Graph showing CMS ION LUMINOSITY 2011 and 2010](image)

- Dec. 2011: $\approx 150 \mu b^{-1}$
- Dec. 2010: $\approx 7 \mu b^{-1}$
Charged Particle Spectra in pp and PbPb

Spectra measured to 100 GeV/c in PbPb

Uses full high $p_T$ statistics of 2011 run at (150µb$^{-1}$)
Charged particle $R_{AA}$ compared to models

- Final result using full 2011 data set for $p_T > 40$ GeV/c
- Very slow rise of $R_{AA}$ above $p_T \gtrsim 35$ GeV/c

SPS 17.3 GeV (PbPb)
- $\pi^+$ WA98 (0-7%)
- $\pi^0$ WA98 (0-7%)

RHIC 200 GeV (AuAu)
- $\pi^0$ PHENIX (0-10%)
- $h^*$ STAR (0-5%)

LHC 2.76 TeV (PbPb)
- CMS (0-5%)
- ALICE (0-5%)
- PQM: $<\delta> = 30 - 80$ GeV$^2$/fm

arXiv:1202.2554
Summary of CMS $R_{AA}$ results

Color-less probes are unsuppressed

Strong quenching for light hadrons

Non-zero $v_2$ at $p_T \approx 40$ GeV/c

2010 data

arXiv:1201.3093
arXiv:1102.5435

2010+2011 data

arXiv:1202.2554
2011 data

arXiv:1204.1850

b-quarks are quenched (but not as much as light hadrons)

arXiv:1201.5069

2010 data
Photon-Jet Correlations in PbPb
Photon-Jet Observables

- Azimuthal decorrelation: $|\Delta \phi_{J\gamma}|$, and its parametrized width $\sigma(|\Delta \phi_{J\gamma}|)$
- Transverse momentum ratio: $x_{J\gamma} = p_T^{\text{Jet}} / p_T^{\gamma}$, and its mean $\langle x_{J\gamma} \rangle$
- Fraction of photons with associated jets: $R_{J\gamma}$
- $p_T^{\gamma} > 60$ GeV/c (to have sufficient $x_{J\gamma}$ phase space)
- $p_T^{\text{Jet}} > 30$ GeV/c (constrained by efficiency)
Photon-Jet Analysis Flow

Super Clusters
- Spike rejection
- Passing loose photon ID
- H/E < 0.1
- Photon isolation
- Energy correction

Background clusters (Fakes from jet)
- Shower shape
- Background like
- $0.011 < \sigma_{\eta \eta} < 0.017$

Photon Candidates
- Z to ee
- Cross check the energy correction
- Electron rejection
- Remaining contribution 1-3%

Leading Cluster
- Shower shape
- Signal like
- $\sigma_{\eta \eta} < 0.01$

Photon Candidates- AllJet
- Shower shape
- Background like
- $0.011 < \sigma_{\eta \eta} < 0.017$

Selected Jet candidates
- Selected Jet
- Exclude photon candidate
- $|\Delta R| > 0.3$ w/r to leading photon

Electron rejection
- Remaining contribution 1-3%

Purity Determination
- Dijet Background subtraction

Photon Candidates- AllJet
- Signal region
- $|\Delta \phi| > 7\pi/8$

Photon Candidates- AllJet
- Signal region

Photon-Jet correlations in MIXED events

Event Mixing

Photon-Jet Final result

Anti-kT 0.3
- pile-up subtracted
- Jet candidates $|\eta| < 1.6$
Jet Finding in PbPb

- Anti-$k_T$ particle flow jets, $R = 0.3$
- UE estimation/subtraction using $\phi$-rings in $\eta$, excluding jet candidates (two iterations)
- Reconstruction > 90% efficient for $p_T^{\text{Jet}} > 30$ GeV/c in PbPb
• SumIso = uncorrected Track + ECAL + HCAL $E_T$ in $R < 0.4$
• GenIso = generator level particle energy in $R < 0.4$
• Isolated prompt (non-decay) photons with SumIso $< 1$ GeV
• Comparison to MC definition GenIso $< 5$ GeV
• SumIso $\neq$ GenIso due to PbPb underlying event fluctuation
Photon Isolation in PbPb

Background energy subtraction

Before background energy subtraction

Isolated

Non-isolated
Rejection of Decay Photons

- Shower shape
  \[ \sigma_{\eta\eta} = \sum_{i}^{5x5} w_i (\eta_i - \eta_{5x5})^2 / \sum_{i}^{5x5} w_i \]
  \[ w_i = \max(0, c + \ln E_i / E_{5x5}) \]

- Signal photons selected by cutting on \( \sigma_{\eta\eta} < 0.01 \)

- Decay photons contribution determined by fit of (signal + background templates in \( \sigma_{\eta\eta} \))

- Background \( \sigma_{\eta\eta} \) template found using data from photons failing the SumIso cuts
Photon Energy Calibration

- ECAL energy scale in central PbPb requires background correction
- Correction is checked using $Z^0 \rightarrow e^+ e^-$
- Observed mass in central PbPb is $91.6 \pm 6$ GeV
Background Sources for Photon-Jet Analysis

- **Signal photon-jet**
- **Background from dijet**
- **Contribution from uncorrelated multiple interaction/fake**

- Photon
- Jet
- Photon
- Jet
- Photon
- Jet

Remove data-driven using shower shape
Remove by data-driven template from event mixing
Background Subtraction, Part I

Estimated from event mixing using min-bias data

Photon–Jet

Background Photon–Jet

Background Photon–UE Combinatorics

Photon–UE Combinatorics

Δφ

Signal region

Data, cf. Slide 13
30% - 50%

\[ s_{NN} = 2.76 \text{ TeV} \]

\[ \int L \, dt = 150 \mu \text{b}^{-1} \]
Background Subtraction, Part II

**Statistical Subtraction**

- **Δφ**

**Background Photon–Jet**

- **Estimated from shower shape sideband & purity**

**Signal region**
Results
• Distribution is consistent with pp & PYTHIA tune Z2 + Hydjet
• To quantify the centrality dependence, peak region is fit with an empirical formula

\[
\frac{1}{N_{\gamma-jet}} \frac{dN_{\gamma-jet}}{d\Delta \phi_{J\gamma}} = \frac{e^{(\Delta \phi - \pi)/\sigma}}{(1 - e^{-\pi/\sigma})\sigma}
\]
Angular width $\sigma(|\Delta \varphi_{J\gamma}|)$ is consistent, both PbPb to pp and PbPb to PYTHIA tune Z2 + HYDJET

CMS Preliminary

(a) PbPb Data
○ PYTHIA + HYDJET
■ pp Data
□ PYTHIA

$p_T^\gamma > 60\text{GeV}/c$   $|\eta^\gamma| < 1.44$

$p_T^{\text{Jet}} > 30\text{GeV}/c$   $|\eta^{\text{Jet}}| < 1.6$
- Momentum ratio shifts/decreases with centrality
- Unitary normalized distribution, points anticorrelated
- Red/blue boxes try to indicate possible, anticorrelated systematic variation
 Photon-Jet Momentum Balance

(b) $\Delta \phi_{J\gamma} > \frac{7}{8}\pi$

$\sqrt{s_{NN}} = 2.76$ TeV

$\langle x_{J\gamma} \rangle$

CMS Preliminary

Significant deviation of $\langle x_{J\gamma} \rangle$ in PbPb compared to PYTHIA tune Z2 + HYDJET, significance of PbPb vs. pp is weaker.
Significant fraction of associated jets are lost in PbPb (jet $p_T$ shifting below the 30 GeV/c threshold).
Calculation by Vitev
(no detector smearing etc)
Recall: \( \approx 15\% \) shift in \( \langle x_{jg} \rangle \) in data
Summary

• New results on high $p_T$ charged hadron $R_{AA}$
  – $R_{AA}$ measured up to $p_T = 100$ GeV/c
  – $R_{AA}$ approximately flat at 0.5 for $p_T > 35$ GeV/c
  – Combination of $R_{AA}$ and $v_2$ constrains path-length dependence in energy loss models

• Direct observation of jet energy loss vs. initial parton energy
  – No measurable change in $\Delta \varphi_{J\gamma}$
  – Significant fraction of jets are shifted to $p_T < 30$ GeV/c
  – Significant shift of jet–photon $p_T$ ratio with respect to MC
Due to PbPb underlying-event fluctuations, the equivalent GenIso (5GeV) vs SumIso (1GeV) cuts are not at the same value of in-cone energy.

In calculations, an isolation cut (<5GeV in R=0.4) cone at generator (=particle) level for the hard scattering event should be made to compare to data.
Comparison to theory

Combination of $R_{AA}$ and $v_2$ vs centrality and $p_T$ a tough challenge
Comparison to Theory

$p_T > 20\text{GeV}$

Plot by A. Yoon, Wei Li

see also Jia et al, Phys.Rev. C84 (2011) 034904

$p_T$ evolution of $(R_{AA}, v_2)$ for fixed centrality

Combination of $R_{AA}$ and $v_2$ vs centrality and $p_T$ a tough challenge