High Density QCD Physics with Heavy Ions in CMS

Ferenc Siklér for the CMS Collaboration

sikler@rmki.kfki.hu

KFKI Research Institute for Particle and Nuclear Physics
Budapest, Hungary

Moriond QCD, March 23, 2007
Motivation

\[ R_{dAu} \]

\[ p_T \ (GeV/c) \]

\[ \Delta \phi \ (radians) \]

\[ \frac{1}{N_{\text{trigger}}} \frac{dN}{d(\Delta \phi)} \]

RHIC $\Rightarrow$ LHC
The Compact Muon Solenoid (CMS) detector

Big acceptance, hermetic coverage
Heavy ion program: study of QCD matter under extreme conditions

"CMS Physics: Technical Design Report v.2
Addendum on High Density QCD with Heavy Ions"

CERN-LHCC-2007-009
**Detectors**
- Silicon tracker: pixels and strips ($|\eta| < 2.4$)
- Electromagnetic ($|\eta| < 3$) and hadronic ($|\eta| < 5$) calorimeters
- Muon chambers ($|\eta| < 2.4$)
- Extension with forward detectors ($|\eta| < 6.8$)

Can measure leptons ($e, \mu$), hadrons ($\pi, K, p$), charged and neutrals ($n, \gamma$)
The CMS Heavy Ion physics program

- **Soft physics and global event characterisation**
  - Centrality and event selection
  - Charged particle multiplicity
  - Spectra and correlations
  - Azimuthal asymmetry, flow

- **High $p_T$ probes**
  - High $p_T$ particles and studies of jet fragmentation
  - Modification of fragmentation functions
  - Quarkonia and heavy quarks
  - High energy photons, $Z^0$, Jet-$\gamma$, Jet-$Z^0$, multijet events

- **Forward physics**
  - Limiting fragmentation
  - Ultra peripheral collisions
  - Exotica

One single detector combines **global** characterization and **specific** probes
Trigger and charged particle multiplicity

- Minimum bias trigger
  - Symmetric number of hits in the forward calorimeters ($3 < |\eta| < 5$)

- Centrality triggers
  - From correlating barrel (ECAL+HCAL) and forward (ZDC) energies

- Charged particle multiplicity
  - Event-by-event, using hits in the innermost pixel layer with $\sim 2\%$ accuracy, systematics below 10%
Low $p_T$ tracking and particle identification

- **Common beliefs so far**
  - CMS cannot track charged particles, if $p_T < 0.75$ GeV/c
  - CMS does not have particle identification

- **CMS is better than previously thought – pixel triplets**
  - Modified pixel triplet generation using geometrical transformations
  - Low fake track rate thanks to geometrical shape of the hit cluster
  - Particle identification using energy loss in silicon, if $p < 1–2$ GeV/c, analogue readout
Low $p_T$ hadron spectra – charged particles

Acceptances and efficiencies at 80–90%, $p_T$ resolution $\sim$6%
Reduced fake rate: below 10% in central Pb+Pb for $p_T > 0.4$ GeV/c

- **Observables**
  - Identified particle spectra and yields, charged: $\pi^\pm$, $K^\pm$, p, $\bar{p}$
  - Multiplicity distributions, correlations, scaling

Spectra down to $p_T$ of 0.1–0.3 GeV/c

F. Siklér
Low $p_T$ hadron spectra – first measurements

- Soft physics in minimum bias $p+p$
  - $p+p$ @ 900 GeV and @ 14 TeV
- Heavy ions
  - Pb+Pb @ 5.5 A·TeV
Observables

- Identified particle spectra and yields, neutrals: $K^0_S$, $\Lambda$, $\bar{\Lambda}$, $\gamma$
- Multi-strange baryons: $\Xi^-$, $\Omega^-$
- On-vertex resonances: $\rho(770)$, $K^*(892)$, $\phi(1020)$
- Open charm ($D^0$, $D^{*+}$) and open beauty ($B \rightarrow J/\psi + K$)

Access to identified particles
Azimuthal correlations

- Reconstruction of the event plane using calorimetry
- Estimated event plane resolution is about 0.37 rad, if $b = 9$ fm
  $v_2$ can be measured with $\sim 70\%$ accuracy
- Add tracker information, use forward detectors; reaction plane with ZDC

Viscosity, parton number density
Triggering on hard probes

- Level-1 trigger
  - hardware, muons + calorimeters, decision after $\sim 3\ \mu s$
- High level trigger
  - 10k CPU, full event information, runs offline algorithms

**HLT study:** parametrising performance of the algorithms
Simulation of various trigger channels, luminosity scenarios
HLT benefits: $50\times$ more $J/\psi$, $10\times$ more $\Upsilon$, $2\times$ jet $E_T$ reach

M. Ballintijn, C. Loizides, and G. Roland
• Charmonium and bottomonium resonances
  – Dimuon decay channel, precise tracking
  – Acceptances at 25% ($\Upsilon$) and 1.2% ($J/\psi$) with 80% efficiency and 90% purity
  – Mass resolution: 86 MeV/c$^2$ at $\Upsilon$ mass; 35 MeV/c$^2$ at $J/\psi$ mass, full $\eta$
    (best mass resolution at LHC)

Thermodynamical state of the medium via melting
Regeneration or suppression?
For 100 GeV jets the resolutions are $\sigma_\eta \approx 2.8\%$, $\sigma_\phi \approx 3.2\%$, $\sigma_{E_T} \approx 16\%$
With high level trigger
- Untriggered dataset and triggered samples
- $E_T$ thresholds of 50, 75 and 100 GeV
- Triggered data sets are merged with a simple scaling procedure

Measure inclusive jet production up to $E_T \approx 0.5$ TeV
High $p_T$ hadrons

- High $p_T$ tracking
  - Algorithmic tracking efficiency of about 75%
  - Few percent fake rate for $p_T > 1$ GeV/c
  - Excellent momentum resolution

Determine nuclear modification factors $R_{AA}$ and $R_{CP}$

Parton energy loss in the hot and dense medium
High $p_T$ hadrons – triggered

- The $p_T$ reach
  - Spectra and nuclear modification factors
  - Enhanced by using the jet trigger
  - Reach extended from $p_T = 90$ to $300$ GeV/c

Precise differential studies of high $p_T$ suppression
**Ultraperipheral collisions**

- **Diffractive photoproduction of vector mesons**
  - $\rho \rightarrow \pi^+\pi^-$ and $\Upsilon \rightarrow e^+e^-, \mu^+\mu^-$
  - Tagged with forward neutron detection in the ZDCs
  - Combined acceptance and efficiency at 20%
  - Good mass resolution in $e^+e^-$ and in $\mu^+\mu^-$
  - Total yield of 400 $\Upsilon$, detailed studies of $p_T$ and $y$ dependence

Constrain the gluon density at small $x$
YB0 (central barrel wheel) arriving in the UXC55 cavern
High density QCD in CMS – summary

**Central Pb+Pb 5.5 TeV**

125 Hydjet events, |η|<2

π ±
K ±
p ±

**Hard sector**

Trigger for extended reach

**Forward capabilities**

Soft physics