Soft physics capabilities of CMS in p-p at 14 TeV and Pb-Pb at 5.5 TeV

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Quark Matter 2008, Jaipur, India
February 9, 2008
Soft physics

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    * neutral hadrons via decay topology (V0)
  – Azimuthal asymmetry, flow
  – Summary

Proton-proton program: analysis exercise, first measurements
Heavy-ion program: study of QCD matter under extreme conditions

One single detector combines **global** characterization and **specific** probes

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The CMS detector – slice

- **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 (next slide)

  Can measure leptons (e, \(\mu\)), hadrons (\(\pi\), K, p), charged and neutrals (n, \(\gamma\))
The CMS detector – forward

- **CASTOR**
  - tungsten and quartz plates \((5.3 < |\eta| < 6.6)\)
  - covers region where baryon density is expected to be maximal in Pb-Pb
  ⇒ See poster of P. Katsas: “Performance studies of the final prototype for the CASTOR forward calorimeter at the CMS experiment”

- **ZDC**
  - quartz fibers in a tungsten matrix, 140 m away from the IP \((|\eta| > 8.3)\)
  - measures spectator neutrons and forward photons
  ⇒ See poster of E. Garcia: “Zero degree calorimeters for beam monitoring and forward physics measurements at the LHC”

Very wide acceptance
• Pb-Pb minimum bias trigger
  – count hits in the hadronic forward calorimeters (HF, $3 < |\eta| < 5$)
  – there are many particles in that region
  – good efficiencies over all centralities

• p-p random trigger
  – zero bias: trigger on beam crossing if intensity is low

Same scheme should work for both p-p and Pb-Pb
Centrality determination in Pb-Pb

Combine information from various independent measurements
- The very forward region is expected to be nearly free of final-state rescattering
- $E_T$ from both CASTOR and HF
- Forward energy of spectator forward neutrons measured in both ZDCs
- Goal: determine impact parameter with a resolution of few tenths of fm

⇒ See poster of S. Ozturk: “Determination of Pb-Pb event centrality using HF and CASTOR calorimeters in CMS”
Charged particle rapidity density in Pb-Pb

- Total event-by-event multiplicity
  - Counting hits in the innermost pixel layer, as done in PHOBOS
  - Expect systematics below 10%
  - Correction for loopers, secondaries
  - Use ADC information to remove hits at high $\eta$ from non-primary sources

Final Pb-Pb multiplicity – initial number of released gluons

Important cross check for particle spectra
Charged particle tracking

- Pixel detector
  - 3 barrel layers (4, 7 and 10 cm radii) and 2 endcaps on each side
  - 100 × 150 μm² pixels, 2% occupancy even at dN/dη_{ch} = 5000

- Hit triplets
  - Use pixel hit triplets instead of pairs, loss of acceptance but lower fake rate
  - Modified triplet finding, reconstructing down to p_T = 0.075 GeV/c

Tracking optimized for the p-p analysis exercise, 2M events
Charged particle tracking – pixel tracks

p-p @ 14 TeV (Pythia)
Charged particle tracking

- **Strategy**
  - Seed generation: triplets tracks
  - Determination of primary vertex (or vertices)
  - Seed re-generation: constrain triplets with previously found primary vertex
  - Trajectory building by successively including strip hits, final fit

  **Note:** global tracks include both pixel and strip hits

- **Cluster shape filters**

Cluster shape must match trajectory direction

Essential for reducing the fake track rate
Charged particle tracking – acceptance and efficiency

Acceptance

Efficiency

Different for low $p_T$ for particles with different mass
Steps at 1 and 2 GeV/c are due to stricter requirements (points on track)
Close to flat and smooth in the mid-rapidity region

Multiple track counting and fake track rate are around per mille level
The $p_T$ resolution is about 1-2% in the barrel region.

Fake rate is below 10% in central Pb+Pb for $p_T > 0.4$ GeV/c.
Charged particle tracking — spectra, comparisons

Comparison of simulated (histogram) and reconstructed (symbols), $0.4 < |\eta| < 0.6$

Can one identify these particles? $\Rightarrow dE/dx$
Particle identification – energy loss estimator

Truncated mean $dE/dx$ (average of lowest half)
Proper treatment for overflows
Combination of pixel and strip energy deposits

PID expected for pions and kaons ($p < 0.8$ GeV/c) and protons ($p < 1.5$ GeV/c)
Particle identification – energy loss fits

p-p @ 14 TeV (Pythia)

Combined fit using sum of many gaussians, where $\sigma \propto 1/\sqrt{n_{\text{hits}}}$
About 5-7% expected resolution, yields can be extracted

Momentum limit of yield extraction is set to $3\sigma$ separation
Could use $\beta\gamma$ scaling to fix parameters and push up limit
Results – pions, kaons and protons

Empirical (Tsallis) fit: \( E \frac{d^3 N}{d \eta d p^3} = \frac{dN}{dy} \frac{(n-1)(n-2)}{2\pi nT [nT+(n-2)m]} \left[ 1 + \frac{E_T(p_T)}{nT} \right]^{-n} \)

\( \eta \) dependence can be studied
Results – rapidity density

p-p @ 14 TeV (Pythia)

The acceptance of the tracker limits the accessible $\eta/y$ range, total number of produced charged particles cannot be measured

Total cross-section can be obtained using luminosity measurements
Comparison to lower energy measurements: FNAL, ISR, UA1, UA5, E735, CDF

We can verify if $\frac{dN}{d\eta}|_{\eta=0}$ continues its linear increase in $\log \sqrt{s}$

A Strong, non-linear increase of $\langle p_T \rangle$ is expected
Results – multiplicity

\[ \frac{1}{2\pi p_T^2} d^2N/dp_T \] 

\[ p_T \] distribution gets flatter with increasing \( N_{ch} \)

We can measure multiplicity distributions

Interesting physics (multiparton interactions, underlying event)
Particle identification – neutral particles

- Decay topology (V0)
  - Identified particle spectra and yields, neutrals: $K_S^0$, $\Lambda$, $\bar{\Lambda}$, $\gamma$
  - Multi-strange baryons: $\Xi^-$, $\Omega^-$
  - Open charm ($D^0$, $D^{*+}$) and open beauty ($B \rightarrow J/\psi + K$)

Access to neutral and multi-strange identified particles
Elliptic flow in Pb-Pb

- Reconstruction of the event plane using calorimetry
  - Good event plane resolution (about 0.37 rad), at $b = 9$ fm

- Elliptic flow coefficient using tracker
  - Estimated systematic error of $v_2$ is below 3%, at $b = 9$ fm
  - Forward detectors will also be used
  ⇒ See poster of G. Eyyubova: "$v_2$ measurement using the CMS detector"
Summary of first measurements with CMS in p-p mode

- Charged hadron spectra
- Identified charged particles via energy loss ($\pi^\pm$, $K^\pm$, $p/\bar{p}$)
- Identified neutral particles via decay ($K^0_S$, $\Lambda$, also $\Xi^-$, $\Omega^-$ and antiparticles)
- On-vertex resonances ($\rho$, $K^*$, $\phi$)
- Not yet studied in detail
  - use calorimetry data to extend rapidity range of some measurements
  - provide PID capabilities in the momentum range 1–5 GeV/c

Now we prepare for data taking: p+p @ 14 TeV and Pb+Pb @ 5.5 TeV