Recent results on hard and rare probes from CMS

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Rare probes → hard scale processes: produced early in the collision, can be sensitive to the medium evolution

- Electroweak bosons and high energy photons
- Heavy flavour and quarkonia
- Jets and high-$p_T$ hadrons

In this talk

Focusing on jet-related results

- Heavy flavour and quarkonia: see A. Lebedev’s talk on Wednesday, 15:03.
- Initial state and electroweak probes: see talk on Friday, 12:30.
Extracting quark / gluon fractions from jet charge in pp and PbPb

\[ Q^K = \frac{1}{(p_{T,jet})^K} \sum_{i \in \text{jet}} q_i p_{T,i}^K \]

- First jet charge measurement in heavy ion collisions
- Exploiting correlation between parton charge and reconstructed jet charge
- Using PYTHIA templates (good description of data)
No significant modification of jet charge distribution in PbPb compared to pp

- **Consistent fractions** extracted from template fitting in pp and PbPb (different centralities)
- **Similar conclusions** for different jet charge parameters (track $p_T$ cut, $\kappa$)
Jet $R_{AA}$: jet radius scan

Jet $R_{AA}$ as a function of jet $p_T$ and radius

- First measurement up to $R = 1.0$
- Advanced experimental techniques
  - Novel underlying event subtraction technique
  - Unfolding

$\hat{R}$

$\hat{R}$

Pythia

Pythia+Hydjet 0-10%

$|\eta| < 1$

$0.3 < p_T < 3.0$ GeV

Event centrality: 13.5%-14.0%

$< 3.0$ GeV

CMS = 5.02 TeV, PbPb 2015 NNs

Preliminary
Jet $R_{AA}$: jet radius scan

Jet $R_{AA}$ as a function of jet $p_T$ and radius

- First measurement up to $R = 1.0$
- Competing effects for wide jets (suppression vs recovery of quenched energy)
- New constraints on jet quenching models

$\sqrt{s_{NN}} = 5.02$ TeV, PbPb 404 $\mu$b$^{-1}$, pp 27.4 pb$^{-1}$

CMS Preliminary

$R = 0.2$

$R = 0.3$

$R = 0.4$

$R = 0.6$

$R = 0.8$

$R = 1.0$
Using photons and Z bosons as unmodified references

- Z bosons and their decay products do not interact with the QGP
- They can be used as a reference for recoiling charged particles
- Study angular correlations, jet fragmentation, ...
- Example: jet shape in photon-tagged events

\[ \rho_{\text{PbPb}}(r) / \rho_{\text{pp}}(r) \]

**CMS Supplementary**

- Cent. 0 - 10%
- \( \sqrt{s_{\text{NN}} = 5.02 \text{ TeV}} \)
- \( p^+_T > 60 \text{ GeV/c} \)
- PbPb 404 \( \mu b^{-1} \)
- anti-\( k_T \) jet \( R = 0.3 \)
- pp 27.4 \( \mu b^{-1} \)
- \( p^+_T > 30 \text{ GeV/c}, \Delta \phi_{j\gamma} > \frac{7\pi}{8} \)
Z-hadron correlations

- Very small signal! Only a few recoiling tracks
- Significant modifications in azimuthal angle distributions
- Also measured: fragmentation functions, hadron $p_T$ spectra
Radial profile of $D^0$ mesons in jets

- Hint of wider distribution in PbPb than pp at low $p_T$
- Charm quark diffusion with respect to the jet axis
Beauty: b-jet shapes in pp

**CMS Preliminary**

pp 27.4 pb\(^{-1}\) (5.02 TeV)

**b jets/inclusive jets**

- Data
- PYTHIA 6

- anti-\(k_T\) PF jet (\(\Delta R=0.4\))
- \(p_T^{\text{jet}} > 120\) GeV, \(|\eta_{\text{jet}}| < 1.6\)
- \(p_T^{\text{trk}} > 1\) GeV

\[\rho(\Delta r_b)/\rho(\Delta_{\text{incl}})\]

**b-jet shapes in pp:**

- Different shape with respect to inclusive jets
- Imperfectly reproduced in PYTHIA
- Flavour dependence in parton fragmentation
The top quark:

- Top quarks decay well before QGP is formed
- nPDF: probing high-$x$ gluons
- With more data: probing the formation time of the QGP
New probe: top quarks

Focusing on the dilepton channel: clean final state

- **Two opposite-sign leptons**
  - Unaffected by the QGP
  - Most of the sensitivity from $e\mu$ final state (reduced Drell–Yan background)
  - Additional sensitivity from $ee$ and $\mu\mu$ (excluding the Z mass region)

- **Two high-$p_T$ b jets**
  - Analysis repeated with and without b jet information
  - Balance robustness and sensitivity

- **“Blind” analysis**: analysis techniques developed using only 1/3 of the full dataset

Top Pair Branching Fractions

- $\tau + \tau$: 1%
- $\tau + \mu$: 2%
- $\tau + e$: 2%
- $\mu + \mu$: 1%
- $\mu + e$: 2%
- $e + e$: 1%
- $e + \text{jets}$: 15%
- $\mu + \text{jets}$: 15%
- $\tau + \text{jets}$: 15%
- "alljets": 46%
- "lepton+jets"
- "dileptons"
New probe: top quarks

Di-lepton multivariate analysis

4.0 $\sigma$: strong evidence!

Also b-jet counting

CMS Preliminary

$1.7 \text{ nb}^{-1} (\sqrt{s_{NN}} = 5.02 \text{ TeV})$

$e\mu$

Data

$tt$

$VV$

$tW$

Nonprompt

$Z/\gamma^*$

Total unc.

E. Chapon (IHEP-Beijing)

Hard and rare probes

LHCP 2020
New probe: top quarks

Measured cross section consistent with pQCD expectation
Large data samples from LHC Run 2 give access to rarer probes and higher precision

- Jet charge
- Large $R$ jets
- Z-hadron correlations
- Heavy flavour
- Top quarks

⇒ new and better ways to study the QGP properties

More recent CMS results

- Publications: [link](https://cern.zoom.us/j/98761185709)
- Preliminary results: [link](https://cern.zoom.us/j/98761185709)