Highlights from the CMS experiment

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Quark Matter
Physics Highlights CMS

Nuclear matter physics
- Onset of collective effects in small systems
- System size dependence of QGP effects
- Flavor dependence of parton shower modification
- Quark and gluon parton distribution function in lead
- Beyond cold nuclear matter effects in Pb ion
- Quarkonia in hot medium

“New” physics
- Limits on chiral magnetic effect
- Observation of light-by-light scattering

proton-proton  proton-lead  xenon-xenon  lead-lead
XeXe: how does it look?

No conclusive evidence for either flat plateau or Gaussian shape

For fixed and large $N_{\text{part}}$: XeXe$>\text{PbPb}$ → no system size scaling
Collective effects
Flow in XeXe

Difference between PbPb and XeXe might be explained by quadrupole deformation of Xe ion

Talk, Collective dynamics, Tue. 12:10, M. Stojanovic
Strange and charm $v_2$ in pPb

New results of charm ($D^0$, $J/\psi$) and strange flow in pPb

Charm $v_2$ observed in pPb collisions. Weaker than for light quarks

Less collectivity for charm quarks in pPb? CGC/Glasma?

Talk, Collectivity in small systems, Mon. 17:30, W. Li
Collectivity in small systems

Suppressing non-flow contamination in low multiplicity events using subevents

Goal: understand onset of collective behaviour

High multiplicity ($N_{\text{trk}} > 80$): all methods consistent $\rightarrow$ non-flow negligible

Low multiplicity ($N_{\text{trk}} < 80$): non-flow suppressed using subevents $\rightarrow v_2$ and $v_3$ anti-correlated down to $N_{\text{trk}} = 50$ in pPb collisions

Talk, Collectivity in small systems, Tue. 12:30, M. Guilbaud
Higher harmonics

Handle on flow fluctuations

\[ \frac{v_n(4)}{v_n(2)} \] larger for \( v_2 \) than \( v_3 \) \( \rightarrow \) **global geometry dominant for** \( v_2 \)

Talk, Collective dynamics, Tue. 9:40, Q. Wang
Higher harmonics

First $v_3\{4\}$ measurement in pPb collisions

$0.3 < p_T < 3.0 \text{ GeV/c}$
$|\eta| < 2.4$

PbPb: $v_n\{4\}/v_n\{2\}$ larger for $v_2$ than $v_3 \rightarrow$ global geometry dominant for $v_2$

pPb: $v_n\{4\}/v_n\{2\}$ similar for $v_2$ and $v_3 \rightarrow$ initial-state fluctuations dominant

Talk, Collective dynamics, Tue. 9:40, Q. Wang
Hard probes
XeXe: charged hadron $R_{AA}$

$R_{AA}$ vs $N_{\text{part}}$

CMS Preliminary

- 5.44 TeV XeXe $R^*_AA$
- 5.02 TeV PbPb $R_{AA}$

$|\eta| < 1$
$6.4 \leq p_T < 7.2$ GeV

Similar scaling in XeXe and PbPb

Within uncertainties $R_{AA}$ consistent

Talk, Jet modifications, Tue. 9:20, A. Baty
Photon-tagged jet fragmentation

Initial parton energy constrained by photon $p_T$

Quark enriched jet sample: flavor dependence of jet quenching

Depletion of high momentum particles → sensitive to hard parton shower

Enhancement of particles carrying small momentum fraction in central collisions → recoil

Talk, Jet modifications, Tue. 12:50, K. Tatar
Jet shapes
light quarks vs gluons

Inclusive: Quark/Gluon mixture

Photon-jet: Quark dominated

$r \sim 0.1$: No depletion for photon-tagged jets. Due to changing q/g fraction for inclusive?

$r > 0.15$: Redistribution of energy to large angle for light quark and gluon jets

Talk, Jet modifications, Tue. 12:50, K. Tatar
Jet shapes
light vs heavy

Inclusive: Quark/Gluon mixture

- \( p_T^{\ell} > 0.7 \) GeV
- \( p_T^{\mu} > 2 \) GeV
- \( p_T^{\mu} > 4 \) GeV

\( 0-10\% \)
\( \Delta r \)
\( p_T^2 < 2 \) GeV: enhancement
\( p_T^2 > 4 \) GeV: depletion

D-jet: Heavy flavor + gluons

Hint of \( D^0 \) mesons with \( p_T > 4 \) GeV appearing at large angle

What mechanism could cause this?

Talk, Jet modifications, Wed. 11:10, J. Wang
Jet substructure

Groomed jet mass with flat and large angle grooming

Large angle grooming

Jet core hardly affected by medium

Flat grooming

Jet quenching models do not describe large mass data

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Talk, Jet modifications, Wed. 17:10, Y. Chen
Beauty suppression via non-prompt D

First measurement of non-prompt D\(^0\) \(R_{AA}\)

D\(^0\) from b hadrons

For 5<p\(_T\)<15 GeV

Non-prompt D\(^0\) and J/\(\psi\) less suppressed than D\(^0\) and charged hadrons
Strange B mesons

First probe of recombination between beauty and strange quarks

351 μb⁻¹ (PbPb 5.02 TeV)

|y| < 2.4

CMS Preliminary
Supplementary

B₀⁻

Data
Fit
Signal
Combinatorial

Significance = 4.0
χ²/νDOF: 47/45 = 1.1
Yield = 20

Hint for enhancement of Bₛ with respect to B⁺

Effect of recombination due to strangeness enhancement in QGP?

Talk, Open Heavy Flavor, Tue. 16:20, T.-W. Wang
Charmonia

\[ \psi(2S) \text{ RAA} < J/\psi \text{ RAA} \Rightarrow \text{ in PbPb and pPb.} \]

Effects beyond shadowing and energy loss in pPb?

Talk, Quarkonia, Wed. 17:10, G. Oh
Sequential suppression for Upsilons for all centralities
Prompt J/ψ

**PbPb: prompt J/ψ suppression**

- PbPb 368 μb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)
- CMS
- Supplementary

**pp: Prompt J/ψ fragmentation**

- pp 27.39 pb⁻¹ (5.02 TeV)
- CMS
- Preliminary

**J/ψ suppression similar to D⁰ suppression?**

**Jet quenching for charmonia?**

Prompt J/ψ in jet fragmentation function not well described by PYTHIA

Talk, Quarkonia, Wed. 17:10, G. Oh

Poster, B. Diab (J/Psi in jet), QRK-06
Nuclear PDFs with W boson

Nuclear modification of the quark PDF needed to describe the data
Constraints quark + antiquark PDF at $10^{-3} < x < 10^{-1}$

Poster, H. Kim (W boson), ELW-16
Talk, Electromagnetic and weak probes, Wed. 11:30, A. Stahl
First experimental observation of the top quark in nuclear collisions (>5σ)

Poster, G. Krintiras (top quark), INI-12
Talk, Electromagnetic and weak probes, Wed. 11:30, A. Stahl

Nuclear PDFs with top quark

Reconstructed top mass

Top pair cross section

Compatible with nPDF expectation $\sigma$ [nb]
Nuclear PDFs with dijets

Large x (>0.3) in lead ions strongly suppressed wrt unbound nucleons

Inconsistent with DSSZ

→ Evidence of strong gluon EMC effect

Stronger shadowing effect than models

Data more precise than nPDF uncertainties

→ Improve description of gluon nPDF

Talk, Initial state physics, Mon. 17:50, D. Takaki
“New” physics
Possible CME signal (at LHC energies) is less than 7% for PbPb collisions @ 95% CL

Talk, Chirality, vorticity and polarisation effects, Wed. 9:00, K. Tu
Light-by-light scattering

Significance of signal: $4.1\sigma$ ($4.4\sigma$) observed (expected)
Measured fiducial cross section: $\sigma_{\text{fid}} = 122 \pm 46 \text{ (stat)} \pm 29 \text{ (syst)} \pm 4 \text{ (th)} \text{ nb}$
→ Consistent with Standard Model ($\sigma_{\text{fid,SM}} = 138 \pm 14 \text{ nb}$)

Invariant mass

Light-by-light event candidate

Talk, Electromagnetic and weak probes, Wed. 12:30, D. d’Enterria
CMS at QM18

**Collective Dynamics**
- Higher order harmonics, Q. Wang, Tue. 9:40
- XeXe flow, M. Stojanovic, Tue. 12:10

**Collectivity in small systems**
- Charm and strange v2, W. Li, Mon. 17:30
- Subevent cumulants, M. Guilbaud, Tue. 12:30

**Chirality, vorticity and polarisation effects**
- CME effect, Z. Tu, Wed. 9:00

**Quarkonia**
- Bottomonia, S. Tuli, Tue. 11:30
- nPDF with charmonia, G. Oh, Wed. 17:10

**Jet modification and high $p_T$ hadrons**
- XeXe hadron RAA, A. Baty, Tue. 09:20
- D in jet, J. Wang, Tue. 11:10
- Gluon splitting, K. Jung, Tue. 12:30
- Photon-tagged jet FF and shape, K. Tatar, Tue. 12:50
- Jet reconstruction large R, C. McGinn, Wed. 11:50
- Groomed jet mass, Y. Chen, Wed. 17:10

**Open heavy flavor**
- D RAA and v2, Z. Shi, Tue. 14:40
- Strange and non-strange B, T. W. Wang, Tue. 16:20
- LambdaC, R. Xiao, Wed. 9:00

**Electromagnetic and weak probes**
- W boson, A. Stahl, Wed. 11:30
- Light-by-light scattering, D. d'Enterria, Wed. 12:30

**Initial state physics**
- Exclusive Upsilon, R. Chudasama, Mon. 16:30
- nPDF with dijets, D. Takaki, Mon. 17:50
- XeXe multiplicity, R. Bi, Wed. 17:50

**Posters**
- Top Quark, G. Krintiras, INI-12
- W boson, H. Kim, ELW-16
- Charmonium, E. Chapon, QRK-02
- JPsi in jet, B. Diab, QRK-06
- Femtoscopy, C. Bernardes, COR-02
- Non-prompt D, H. Qiu, OHF-34
- Jet reconstruction, M. Peters, JET-XX
Summary

- Redistribution of light and charm quarks within a jet
- Core of jet not modified
- $\Upsilon(3S)$ smallest $R_{AA}$ of all observed hadrons
- Hint for beauty recombination with strange
- XeXe similar to PbPb
- Evidence of guon EMC effect and quark modification in Pb
- First observation of top quark in nuclear collisions
- Collectivity in pPb down to $N_{\text{trk}}=50$
- CME effect not observable at LHC energies
- Observation of light-by-light scattering
Performance updates

Jet reconstruction updates to measure jets up to large $R$

Identification of gluon splitting jets using jet substructure

$\Lambda_c \rightarrow p \pi K$

Clear signal in PbPb collisions!

**CMS Preliminary Simulation**

<table>
<thead>
<tr>
<th>PYTHIA+HYDJET</th>
<th>0-10%</th>
<th>10-30%</th>
<th>30-50%</th>
<th>50-70%</th>
<th>70-100%</th>
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<tbody>
<tr>
<td>$</td>
<td>s_{NN}</td>
<td>=5.02$ TeV</td>
<td>R=0.8 anti-(k_t) jets</td>
<td>1/N d(N/dz)</td>
<td>Gen. Jet $p_T$ (GeV)</td>
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1/N d\(N/dz\)

CMS Simulation Preliminary

- Pythia 8 GSP Jets ($\Delta R > 0.1$)
- Pythia 8 GSP (double-b-tag, $\Delta R > 0.1$)

SoftDrop $\beta=0$, $z_{cut}=0.1$, $\Delta R_{1,2} > 0.1$

160 < $p_T$ < 400 GeV

**CMS Preliminary**

$\Lambda_c^+ + \Lambda_c^-$

10 < $p_T$ < 20 GeV/c\( \gamma < 1.0 \) Cent. 0-30%

Raw yield: 824 ± 194

PbPb 0-30%

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