What To Expect from LHC

- LHC (Large Heavy ion Collider) is expected to provide pA and AA collisions.
- Energy: 7 TeV/charge

<table>
<thead>
<tr>
<th>Ion</th>
<th>$L_{\text{max}}$</th>
<th>$\langle L \rangle$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{208}\text{Pb}^{82}$</td>
<td>$1.0 \times 10^{27}$</td>
<td>$4.2 \times 10^{26}$</td>
</tr>
<tr>
<td>$^{120}\text{Sn}^{50}$</td>
<td>$1.7 \times 10^{28}$</td>
<td>$7.6 \times 10^{27}$</td>
</tr>
<tr>
<td>$^{84}\text{Kr}^{36}$</td>
<td>$6.6 \times 10^{28}$</td>
<td>$3.2 \times 10^{28}$</td>
</tr>
<tr>
<td>$^{40}\text{Ar}^{18}$</td>
<td>$1.0 \times 10^{30}$</td>
<td>$5.2 \times 10^{29}$</td>
</tr>
<tr>
<td>$^{16}\text{O}^{8}$</td>
<td>$3.1 \times 10^{31}$</td>
<td>$1.4 \times 10^{31}$</td>
</tr>
</tbody>
</table>
What to Expect From CMS

A Compact Solenoidal Detector for LHC

Total Weight: 14.500 t.
Overall diameter: 14.60 m
Overall length: 21.60 m
Magnetic field: 4 Tesla

Pablo Yepes, Rice U.

Heavy Ion Physics with CMS, Jan 16, 2001
A minimum bias Pb-Pb event in CMS

Detector designed for pp. However due to flexible design offers unique capabilities for AA
Some CMS Assets

- CMS has excellent muon detection capabilities:
  - $|\eta|<1.3$ for barrel and $|\eta|<2.4$ with endcaps.
  - Good mass resolution: 46 MeV for the Upsilon.
  - Efficient suppression of background from $\pi/K$ decays:
    - Electromagnetic calorimeter at 1.3 m from beam axis.
    - $P_T$ threshold at 3.5 GeV/c for a single muon to reach the $\mu$-chambers.

- Large calorimeter coverage with good jet reconstruction capabilities.
Physics Topics

- Event Characterization
- Quarkonium Production: Upsilon and J/Ψ
- $Z \rightarrow \mu\mu$
- Jet Production:
  - Single/Double jet ratios.
  - $Z$ and $γ$ tagged jets
- Ultra-Peripheral Collisions: $γγ$ and $γ$-Pomeron
In spite of very strong magnetic field (4 Tesla) there is a good correlation between centrality and transverse energy.
A scaling law:

\[ \sigma_{AA} = A^{2\alpha} \sigma_{pp} \]

- \( \sigma_{pp} \) from CDF @ 1.8 TeV extrapolated to 5.5(7) TeV.
- \( \alpha = 0.9(0.95) \) for J/\( \Psi \) (Upsilon).

<table>
<thead>
<tr>
<th></th>
<th>( Pb+Pb )</th>
<th>( Ca+Ca )</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/( \Psi ) (mb)</td>
<td>58.0</td>
<td>3.6</td>
</tr>
<tr>
<td>( \Psi' ) (mb)</td>
<td>1.4</td>
<td>0.09</td>
</tr>
<tr>
<td>( \Upsilon ) (( \mu b ))</td>
<td>410</td>
<td>21</td>
</tr>
<tr>
<td>( \Upsilon' ) (( \mu b ))</td>
<td>120</td>
<td>6.4</td>
</tr>
<tr>
<td>( \Upsilon'' ) (( \mu b ))</td>
<td>41</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Quarkonia Acceptance in $\mu$–Chambers

- $J/\Psi$ with $p_T > 5$ GeV in Barrel
- Upsilon down to low transverse momentum
Quarkonia Reconstruction

- Essential sub-detectors:
  - Tracking devices
  - Muon system

- Pessimistic assumptions for background estimates:
  - $dN^{\text{ch}}/dy=8000$ (most generators $<5500$)
  - $<p_t>^\pi=0.48 \text{ GeV/c}$ (HIJING $0.39 \text{ GeV/c}$)
  - $<p_t>^k=0.67 \text{ GeV/c}$

Special Heavy Ion Tracking Algorithm

Significant Muon background from $\pi$ and $K$ decays
J/ψ Signal

Min bias collisions - 1 month run - barrel only
muons with P > 3.5 GeV/c

Pb-Pb
Ψ/cont. = 1.0

Ca-Ca
Ψ/cont. = 9.7

L = 10^{27} \text{ cm}^2 \text{ s}^{-1}

L = 2.5 \times 10^{29} \text{ cm}^2 \text{ s}^{-1}

1 month running at top Luminosity:
J/ψ’s detected and reconstructed in the Barrel:

<table>
<thead>
<tr>
<th></th>
<th>Ca-Ca</th>
<th>Pb-Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td># J/ψ</td>
<td>2.2 \times 10^5</td>
<td>10^4</td>
</tr>
<tr>
<td>S/B</td>
<td>9.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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Upsilon in Pb-Pb

1 month: 22000 Υ and 7500 Υ'
detected in the barrel

Combinatorial background subtracted after reconstruction

Di-muon Invariant Mass (GeV/c^2)

Opposite-sign di-muon invariant mass (GeV/c^2)

Background contributions

L = 10^{27} cm^{-2} s^{-1}

Upsilon/cont. = 1.6

Total

Decay-b

Decay-c

b-b

c-c

Events/25 MeV/c^2

Events/25 MeV/c^2
Pablo Yepes, Rice U. Heavy Ion Physics with CMS, Jan 16, 2001

Upsilon in Ca-Ca

\[ L = 2.5 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1} \]

Upsilon/cont. = 9.4

- 1 month:
  - 340000 \( \Upsilon \)
  - 115000 \( \Upsilon' \)
- Only barrel used.

\( \Upsilon \) events/25 MeV/c^2

Opposite-sign di-muon invariant mass (GeV/c^2)

- Total
- b-b
- Decay-Decay
- Decay-b
- Decay-c

- 10^5
- 10^4
- 10^3

- 8.5
- 8.75
- 9
- 9.25
- 9.5
- 9.75
- 10
- 10.25
- 10.5
- 10.75
- 11
Quarkonia Reference

- At SPS, J/Ψ is compared to Drell-Yan.
- At LHC Drell-Yan contribution is negligible.
- Z⁰ proposed as reference to Υ production.
  - M_{Z⁰} > M_{Υ}
  - Different production mechanisms:
    - Z⁰: antiquark-quark, quark-gluon and antiquark-gluon.
    - Υ: gluon-gluon.

- Cross check di-muon reconstruction algorithm
Jets are Easy

Jet quenching

- monojet/dijet enhancement
- jet-$Z^0 \rightarrow \mu\mu$ or jet-$\gamma$

Jet Finding
100 GeV $E_T$
- $\epsilon \sim 100\%$
- $\sigma(E_T)/E_T = 11.6\%$

$E_r(\text{jet1}) = 92.6 \text{ GeV}$
$E_r(\text{jet2}) = 86.9 \text{ GeV}$

$dN_{ch}/dy = 8000$

Z+jet event in the Heavy Ion collision
$dN_{ch} / dY = 5000$

Pt(Z) = Et(Jet) = 100 \text{ GeV}$

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Balancing Photons and Jets

- $E_t^{\text{jet}}, \gamma > 120$ GeV in the barrel
- 1 month:
  - 900 events for Pb-Pb
  - $10^4$ events for Ca-Ca

2 weeks at $L=10^{27}$ cm$^{-2}$s$^{-1}$

$E_{T\gamma}/\pi^0 - E_{T\text{Jet}}$ (GeV)

# Events/4 GeV
Ultra-Peripheral Collisions

\[ \sigma_{AA}(M) \text{ (barn)} \]

\[ \text{hadrons} \]

\[ \text{events/sec/GeV} \]

\[ \text{events/year} \]

\[ M \text{ (GeV)} \]

\[ \gamma \text{ or } P \]

\[ \text{Meson or lepton/quark pair} \]

\[ \gamma \text{ or } P \]
Conclusions

- **CMS** is provides unique tools to study Heavy Ion Collisions at LHC.

- **Physics considered:**
  - Event characterization with large rapidity coverage.
  - Quarkonium production: $\Upsilon$ and $J/\Psi$ families.
  - Jet quenching.
  - Ultra-Peripheral collisions.
Addendum: Tracking

- Developed for dN^{ch}/dy=8000 and dN^{0}/dy=4000.
- Track only particles with tracks in $\mu$ detector.
- Use $\mu$-chambers tracks as seeds.
- Use only tracking detector providing 3D space points.

![Graph showing detector pitch and occupancy]

Detector Pitch $\mu$m
- MSGC 200
- MSGC 240
- Silicon 147

Radius of MSGC layer (cm)
LHC Parameters (Addendum)

- Bunches 7.5 cm long every 125 ns.
STAR First Ultra-Peripheral Collisions

Two oppositely charged co-linear tracks

Eventually additional coincident signal in ZDC

Typical Event:

Not as dramatic as central collision