Two-photon and photon-hadron interactions at the LHC

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HERA AND THE LHC
4th workshop on the implications of HERA for LHC physics

26-30 May 2008
CERN
Central vs. Ultra-peripheral Collisions

This talk:

\[ b > \text{or} \gg 2R \implies \]

Electromagnetic interactions
Electromagnetic Field of a Relativistic Charged Particle

Fermi 1924: The effect of the electromagnetic field of a relativistic particle is equivalent to a flux of photons with a continuous energy spectrum. (hep-th/0205086)

Pulse width $b/\gamma c \leftrightarrow$ the spectrum contains photons with $\hbar \omega < \gamma \hbar c/b$

Quantum Mechanical derivation 1935 by Weizsäcker, Williams. ⇒ Weizsäcker-Williams method

We can calculate $n(\omega)$ through a Fourier transform.
Ultra-peripheral collisions

The photons and nuclei can interact in several ways

1. Electromagnetic interaction, two-photon

2. Direct photonuclear interaction, gamma+parton (γ+g→qq, γ+q→jet+jet)

3. Resolved photonuclear interaction (VMD), elastic or inelastic
Electromagnetic Interactions in p+p and A+A vs. in e+p(A) and e+e Collisions

Traditionally, photon-induced interactions have been studied with electron beams:
Two-photon interactions at PEP, Petra, LEP.
Photon-proton interactions at HERA and in fixed target expts w/ electron beams.

Why study them at hadron colliders?
- Higher photon energies than at any existing accelerator (LHC).
- An opportunity to study strong electromagnetic fields (coupling $Z\sqrt{\alpha}$ rather than $\sqrt{\alpha}$ in heavy-ion collisions).
- Interference between the photon-emitter and target.
- An opportunity to search for the Odderon.
The Equivalent Photon Luminosity

The spectrum of photons with energy $E_\gamma = x \cdot E_{\text{beam}}$ and virtuality $Q^2$ is given by

$$x \frac{dn_\gamma}{dx dQ^2} = \frac{\alpha Z^2}{\pi} (1 - x + 1/2x^2) \frac{Q^2 - Q_{\text{min}}^2}{Q^4}$$

$Q_{\text{min}}^2$ is constrained by $x$ and the mass of the projectile. For hadron beams, the maximum of $Q^2$ is given by a form factor. In configuration space, this corresponds to $Q_{\text{max}}^2 = (1/R)^2$.

Integrating over all virtualities gives the following equivalent photon spectrum (energy in the rest frame of the target).
Electromagnetic interactions in heavy-ion interactions vs. in e⁺e⁻ and ep (eA)

• Directional symmetry. Both beams (nuclei) and can act as photon emitter or target.
• Away from y=0, the different photon emitter/target combinations give different contributions.
• Strong fields lead to high probability for emission of multiple photons.
No tagging of the nuclei

The coherence requirement limits the angular deflection to
\[ \theta \sim \frac{0.175}{(\gamma \cdot A^{4/3})} \]

At RHIC
- \( \text{Au} \) A=197 \( \theta \sim 1 \, \mu\text{rad} \)
- \( \text{Si} \) A=28 \( \theta \sim 17 \, \mu\text{rad} \)

At LHC
- \( \text{Pb} \) A=208 \( \theta \sim 0.05 \, \mu\text{rad} \)
- \( \text{Ar} \) A=40 \( \theta \sim 0.3 \, \mu\text{rad} \)

\[ \Rightarrow \text{Not possible to tag the outgoing nuclei. Might be possible with protons.} \]

Experimental method: Rapidity gaps, reconstruct the entire event, signal of coherence from low \( p_T \).
Particle production with Coulomb break-up

• Very high probability for emitting one soft photon, which can excite the target to a Giant Dipole Resonance.
• $P \approx 35-50\%$ in grazing Au+Au/Pb+Pb collisions at RHIC-LHC.
• $\approx 10 – 50\%$ of exclusive events are accompanied by break-up of one or both nuclei.
• Excitation to GDR leads to emission of neutrons which can be detected in ZDC calorimeters. $\Rightarrow$ Useful as trigger

![Diagram a) vs. b)](image-url)
Example I: Production of Heavy Quarks

Consider the production of heavy quarks in a high-energy nucleus-nucleus collision. 3 production modes can be identified:

1. Hadronic production, dominated by $g g \rightarrow Q\bar{Q}$.
2. Photonuclear production, dominated by $\gamma g \rightarrow Q\bar{Q}$.
3. Electromagnetic production, $\gamma\gamma \rightarrow Q\bar{Q}$.

Estimated cross sections for these processes in Pb+Pb interactions at the LHC:

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma(Pb + Pb \rightarrow QQ + X)$</th>
<th>$\sigma(Pb + Pb \rightarrow Pb + QQ + X)$</th>
<th>$\sigma(Pb + Pb \rightarrow Pb + Pb + QQ)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>hadroproduction</td>
<td>252 b*</td>
<td>1.2 b</td>
<td>1.1 mb</td>
</tr>
<tr>
<td>photoproduction</td>
<td>8.1 b*</td>
<td>4.9 mb</td>
<td>0.9 $\mu$b</td>
</tr>
<tr>
<td>two-photon production</td>
<td>~10^{-3}</td>
<td>~10^{-6}</td>
<td></td>
</tr>
</tbody>
</table>

Hadroproduction dominates, but the cross sections for photoproduction and two-photon production are not small in absolute terms.

> $\sigma_{tot}$ because of production of multiple pairs in a single event.
**Example II: Exclusive Production of di-lepton pairs**

\[ A+A \rightarrow A+A + e^+e^- / \mu^+\mu^- \quad \text{or} \]
\[ p+p \rightarrow p+p + e^+e^- / \mu^+\mu^- \]

(\text{the nuclei/protons remain intact}).

A strong contribution from exclusively produced vector mesons (\( \gamma + \text{Pomeran} \)), followed by \( V \rightarrow e^+e^- / \mu^+\mu^- \).

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Colliding system</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma + \gamma )</td>
<td>( e^+e^- / \mu^+\mu^- ) ee, ep, pp/AA</td>
</tr>
<tr>
<td>( \gamma + \text{Pomeran} )</td>
<td>( V \rightarrow e^+e^- / \mu^+\mu^- ) ep, pp/AA</td>
</tr>
<tr>
<td>Odderon+Pomeron</td>
<td>( V \rightarrow e^+e^- / \mu^+\mu^- ) pp/AA</td>
</tr>
</tbody>
</table>

⇒ If the \( \gamma + \gamma \) and \( \gamma + \text{Pomeran} \) contributions are well understood, pp (and AA) interactions can be used to search for the Odderon.

Trigger and Analysis Techniques

Special techniques are required to separate the signal from background.

- Low multiplicity.

- Rapidity gap between photon-emitting nucleus and the produced particles, suppression for a gap $\Delta y$: $\exp(-<dn/dy> \cdot \Delta y)$

  With $<dn/dy> \approx 2.5-3.5$ in pp at the LHC and $\Delta y = 2 \Rightarrow \sim 10^{-2} - 10^{-3}$ reduction.

- Coherence requirement for exclusive production in nucleus-nucleus collisions. If all produced particles are reconstructed, the total (summed) $p_T$ is determined by the nuclear form factor, $p_T < \approx 50$ MeV/c, much smaller than the typical $p_T$ for hadronic events, $\approx 350$ MeV/c.

Background sources: Cosmic rays (triggering), beam-gas, low-multiplicity hadronic events.
Exclusive Vector Meson Production

\[ A + A \rightarrow A + A + V \quad \text{or} \quad p + p \rightarrow p + p + V \]

- No accompanying hadronic interactions.
- Cross section factor \( \approx 100 \) larger than for two-photon production of mesons with similar mass.
- Electromagnetic excitation through exchange of additional photons, e.g. to a Giant Dipole Resonance, possible (in heavy-ion collisions).
The Vector Mesons are produced in a $\gamma$+Pomeron interaction. For the heavy states ($J/\Psi$, $\Psi'$, $\Upsilon$), the cross section, $\sigma(\gamma A \rightarrow VA)$ can be calculated from QCD (2-gluon exchange):

$$\left. \frac{d\sigma}{dt} \right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}^e}{3\alpha M_V^5} 16 \pi^3 [xg(x, \frac{M_V^2}{4})]^2$$

For $V \rightarrow \text{e}^+\text{e}^-$, there is a background from $\gamma\gamma \rightarrow \text{e}^+\text{e}^-$. The cross section is thus a probe of the nucleon and nuclear gluon distribution function. High sensitivity because of $g^2(x, Q^2)$.

$$\left. \frac{d\sigma(\gamma A \rightarrow VA)}{dt} \right|_{t=0} = \left[ \frac{G_A(x, M_V^2 / 4)}{G_N(x, M_V^2 / 4)} \right]^2$$
The A+A or p+p cross section is calculated from a convolution of the photonuclear/photon-proton cross section with the photon spectrum.

\[ \sigma(A + A \rightarrow A + A + V) = 2 \int n(\omega)\sigma_{\gamma p \rightarrow Vp}(\omega)d\omega \]

- Weizsäcker-Williams photon spectrum.
- Scaling of \( \sigma(\gamma p \rightarrow Vp) \) to \( \sigma(\gamma A \rightarrow VA) \) using a Glauber-like model.

<table>
<thead>
<tr>
<th>Meson</th>
<th>Au+Au, RHIC ( \sigma ) [mb]</th>
<th>Pb+Pb, LHC ( \sigma ) [mb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho^0 )</td>
<td>590</td>
<td>5200</td>
</tr>
<tr>
<td>( \omega )</td>
<td>59</td>
<td>490</td>
</tr>
<tr>
<td>( \phi )</td>
<td>39</td>
<td>460</td>
</tr>
<tr>
<td>( J/\Psi )</td>
<td>0.29</td>
<td>32</td>
</tr>
</tbody>
</table>
More calculations have followed, using slightly different approaches, including gluon shadowing, a full Glauber model for the absorption, the color dipole model etc.


\[ \text{Pb+Pb} \rightarrow \text{Pb+Pb+V at the LHC} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>( \rho^0 ) [b]</th>
<th>( J/\Psi ) [mb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>KN</td>
<td>5.2</td>
<td>32</td>
</tr>
<tr>
<td>GM</td>
<td>10.1</td>
<td>41.5</td>
</tr>
<tr>
<td>IKS</td>
<td>4.0, 4.4</td>
<td>26.7, 26.3</td>
</tr>
<tr>
<td>FSZ</td>
<td>9.5</td>
<td>14, 85</td>
</tr>
</tbody>
</table>
Calculations have also been done for $p+p \rightarrow p+p+V$ and $p+\bar{p} \rightarrow p+\bar{p}+V$ (S.R.Klein, J.Nystrand PRL 92(2004)142003).

$$p+p \rightarrow p+p+V$$

<table>
<thead>
<tr>
<th>Energy ($\sqrt{s}$)</th>
<th>$J/\Psi$ [nb]</th>
<th>$\Psi'$ [nb]</th>
<th>$\Upsilon(1S)$ [nb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.96 TeV</td>
<td>19.6</td>
<td>3.2</td>
<td>0.12</td>
</tr>
<tr>
<td>14 TeV</td>
<td>76</td>
<td>12</td>
<td>3.5</td>
</tr>
</tbody>
</table>

See also V.Khoze, A.D.Martin, M.G.Ryskin, EPJ 24(2002)459.
The VM rapidity distribution is given by

$$\frac{d\sigma}{dy} = k_1 \frac{dn_\gamma}{dk_1} \sigma_{\gamma p \rightarrow p} (k_1) + k_2 \frac{dn_\gamma}{dk_2} \sigma_{\gamma p \rightarrow p} (k_2)$$

where

$$k_{1,2} = \frac{1}{2} M V e^{\pm y}$$

Away from $y=0$, there is a two-fold ambiguity in the photon energy ($k$) and consequently in $x$.

Production is centered around mid-rapidity
Probing the nuclear structure functions

For a final state with invariant mass $m_{\text{inv}}$, the equivalent photon-proton center-of-mass energy is

$$W_{\gamma p}^2 = 2 \cdot m_{\text{inv}} \cdot E_p$$

and the corresponding Bjorken $x$ is

$$x = m_{\text{inv}}^2 / W_{\gamma p}^2$$

Examples of $x$-ranges probed at mid-rapidity at the LHC (exclusive vector meson production):

- **$J/\psi$**
  - LHC pp: $x \approx 2 \cdot 10^{-4}$
  - LHC PbPb: $x \approx 6 \cdot 10^{-4}$

- **$\Upsilon$**
  - LHC pp: $x \approx 6 \cdot 10^{-4}$
  - LHC PbPb: $x \approx 2 \cdot 10^{-3}$

For $y \neq 0$, $x = (m_{\text{inv}}^2/W_{\gamma p}^2) \exp(\pm y)$

Energy dependence of $J/\Psi$ production

$Pb+Pb \rightarrow Pb+Pb+J/\Psi$

$J/\psi$  RHIC 0.3 mb  $\rightarrow$  LHC 32mb  factor 100
Experimental Results on Ultra-Peripheral Collisions
The Hadron Colliders RHIC, Tevatron and LHC

RHIC (1st collisions 2000):
Au+Au at $\sqrt{s_{nn}} = 200$ GeV; p+p at $\sqrt{s} = 200$ and 500 GeV.

Tevatron (1st collisions 1987):
p+p at $\sqrt{s} = 1.8$ and 1.96 TeV

LHC (1st collisions expected in 2008):
Pb+Pb at $\sqrt{s_{nn}} = 5.5$ TeV; p+p at $\sqrt{s} = 14$ TeV.
Experimental UPC results from RHIC so far:

1) $\rho^0$-production, $\text{Au}+\text{Au}\rightarrow\text{Au}+\text{Au}+\rho^0$ STAR Collaboration (C. Adler et al. PRL 89(2002)272302; B.I. Abelev et al. arXiv:0712.3320).


3) $J/\Psi$ and high-mass $e^+e^-$-pair production (D. d’Enterria et al. nucl-ex/0601001).
Two UPC trigger classes:
1) Topology trigger: Based on hits in Central Trigger Barrel, with a “topology” cut to remove cosmic rays.
2) Min. Bias trigger: At least one neutron in each ZDC (Coulomb break-up). Low mult. in Central Trigger Barrel.
Ultra-Peripheral Collisions in STAR at RHIC

Exclusive $\rho^0$-production, $\text{Au}+\text{Au} \rightarrow \text{Au}+\text{Au}+\rho^0$


Run 1 $\sqrt{s_{NN}} = 130$ GeV – Identification of coherent $\rho^0$.

Run 4 $\sqrt{s_{NN}} = 200$ GeV – Measurement of coherent and incoherent $\rho^0$.

Signal+background, unlike-sign pairs

background, like-sign pairs
Interference in $\rho^0$ Production

The production amplitudes will interfere (at $y=0$ $|A_1|=|A_2|$),
$|A_1+A_2|^2 = 2 |A_1|^2 [1 - \cos(p\cdot b)]$

The interference is destructive because of the $(-)$ parity of the photon.

Fit the observed $t$ distribution (with $t=p_T^2$) to a function

$$\frac{dN}{dt} = Ae^{-kt} (1 + C[R(t) - 1])$$

$C = 0 \leftrightarrow$ no interference
$C = 1 \leftrightarrow$ interference

Ultra-Peripheral Collisions in PHENIX

The goal was to search for the process $\gamma+\text{Au} \rightarrow J/\Psi+\text{Au}$ in reactions $\text{Au}+\text{Au} \rightarrow \text{Au}+\text{Au}+e^+e^-$. There was also a contribution from $\gamma+\gamma\rightarrow e^+e^-$. The electrons were identified in the central tracking arm ($|\eta| \leq 0.35$, $\Delta\phi = 2\times90^\circ$).
Ultra-Peripheral Collisions in PHENIX

PHENIX (bird’s eye view)

Level 1 Ultra-Peripheral Trigger:
Veto on coincident BBC $|\eta| \sim 3 - 4$, Neutron(s) in at least on ZDC (E $> 30$ GeV), Large Energy (E $> 0.8$ GeV) cluster in EmCal.
Ultra-Peripheral Collisions in PHENIX


\[ \frac{dN}{d\minv} \text{ (backgd subtracted)} \& \text{ with 2 fits of expected } e^+e^- \text{ continuum shape (normalized at } m_{ee} = 1.8 - 2.2 \text{ GeV/c}^2) \]

\[ \frac{dN}{d\minv} \text{ after } e^+e^- \text{ continuum subtraction} \]

\[ N_{J/\psi} = 10 \pm 3 \text{ (stat) \pm 3 (syst)} \]
Preliminary $J/\Psi$ cross section

$$d\sigma_{J/\Psi}/dy\big|_{y=0} = 1/BR \times 1/(\text{Acc}|_{y=0} \cdot \varepsilon) \times 1/\varepsilon_{\text{trig}} \times 1/L_{\text{int}} \times N_{J/\Psi}/\Delta y =$$

$$= 1/(5.9\%) \times 1/(5.7\% \cdot 56.4\%) \times 1/(90\%) \times 1/120 \ \mu b^{-1} \times (10 \pm 3 \pm 3) =$$

$$= 48. \pm 16. \ (\text{stat}) \pm 18. \ (\text{syst}) \ \mu b$$

- Measured $J/\Psi$ yield at $y=0$ consistent w/ theoret. calcs. [1,2]
- Syst. uncertainty: coherent $e^+e^-$ continuum under $J/\Psi$ (work in progress).
- Reduction of stat. errors need larger luminosity.
- Current uncertainties preclude yet detailed study of crucial model ingredients: $G_A(x,Q^2)$, $\sigma(J/\Psi$ absorption).

"Ultra-peripheral" Collisions at the Tevatron

Exclusive production of $e^+e^-$ and $\mu^+\mu^-$ pairs. See yesterday’s talk by James Pinfold.

**Exclusive $\mu^+\mu^-$ Candidates (1)**

*Many candidate events (334) have been found (CDF-II Preliminary)*

*We now have a ~25% increase of the signal due to a more efficient cosmic ray cut. – we await the blessing of the requisite plot.*

*MENU: CDF Motivation $e^+e^-$ $\gamma\gamma$ $\mu^+\mu^-$ $J/\psi,\Psi',\Upsilon$ $\chi_c$ Odderon*
"Ultra-peripheral" Collisions at the Tevatron

Three possible contributions to the process $p+p\rightarrow p+p+\mu^+\mu^-$:

Note: no feed down from $\chi_c$ to $\Psi'$.  
A contribution from Odderon+Pomereron also possible.
”Ultra-peripheral” Collisions at the Tevatron

Calculations for the first two ($\gamma\gamma$ and $\gamma p$):

\[ \sigma(pp\rightarrow pp+J/\Psi(1S)) : \text{19.6 nb} \]
\[ \sigma(pp\rightarrow pp+\Psi' (2S)) : \text{3.2 nb} \]
\[ \sigma(pp\rightarrow pp+\mu\mu) : \text{2.4 nb (m}_{\text{inv}} > 1.5 \text{ GeV/c}^2) \]

Applying cuts on the $\mu^+\mu^-$:
\[ p_T > 0.5 \text{ GeV/c} \]
\[ \text{|}\eta\text{|} < 2.0 \]
\[ \Rightarrow \]

Yield($\Psi'$)/Yield($J/\Psi$) $\approx$ 1:50

"Ultra-peripheral" Collisions at the Tevatron
Uncertainties and limits on the cross sections

\[
\frac{d\sigma}{dy} = k_1 \frac{dn_\gamma}{dk_1} \sigma_{\gamma p \rightarrow Vp}(k_1) + k_2 \frac{dn_\gamma}{dk_2} \sigma_{\gamma p \rightarrow Vp}(k_2)
\]

Two ingredients:
1) The photoproduction cross section, \(\sigma(\gamma p \rightarrow Vp)\)
   \(\Rightarrow\) Has been measured at HERA
   \(\Rightarrow\) A J/\Psi within \(|y| < 0.5\) at the Tevatron corresponds to
   \(60 \leq W_{\gamma p} \leq 100\) GeV.

2) The photon spectrum, \(dn/dk\), has to be calculated.
"Ultra-peripheral" Collisions at the Tevatron
Measurements at HERA and at lower energies

Data well described by
\[ \sigma_0 = 4.1 \pm 0.4 \text{ nb} \]

\[ \sigma(\gamma p \rightarrow J/\psi p) = \left[ 1 - \frac{(m_p + m_{J/\psi})^2}{W_{\gamma p}^2} \right]^2 \cdot \sigma_0 \cdot W^{0.65} \]
"Ultra-peripheral" Collisions at the Tevatron Measurements at HERA and at lower energies

The region $60 \leq W_{\gamma p} \leq 100$ GeV well covered by H1 and ZEUS measurements. Systematic error in $\sigma$: 6 – 9%.

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”Ultra-peripheral” Collisions at the Tevatron

The photon spectrum

The photon spectrum of a single proton – calculable from the Form Factor

\[ \frac{dn}{dk} = \int \frac{dn}{dkdQ^2} |F(Q^2)|^2 dQ^2 \]

In a pp collision, to exclude strong interactions, the calculations can be done in impact parameter space

\[ \frac{dn}{dk} = \int \frac{dn}{dkdb^2} |1 - \Gamma(s, b)|^2 db^2 \]

Where \( \Gamma(s,b) \) is the Fourier transform of the pp elastic scattering Amplitude (Frankfurt, Hyde, Strikman, Weiss, Phys. Rev. D 75 (2007) 054009). This is roughly equivalent to setting a min. impact parameter \( b > 1.4 \) fm.
Ultra-peripheral Collisions at the Tevatron

Uncertainties and limits on the cross sections

Taking into account the error on $\sigma(\gamma p \rightarrow V p)$ (9%), and using the photon spectrum calculated from the Form Factor as a conservative upper limit gives

$J/\Psi$: $\sigma(pp \rightarrow ppJ/\psi) = 19.6^{+4.7}_{-1.8}$ nb

$\frac{d\sigma(y = 0)}{dy} = 2.7^{+0.6}_{-0.2}$ nb

$\Psi'$: $\sigma(pp \rightarrow pp\psi') = 3.2^{+0.8}_{-0.3}$ nb

$\frac{d\sigma(y = 0)}{dy} = 0.46^{+0.11}_{-0.04}$ nb

Eagerly awaiting the final results from CDF on the measured cross sections …
Ultra-peripheral Collisions in ALICE

ALICE (= A Large Ion Collider Experiment) –
The dedicated Heavy-Ion Experiment at the LHC
Located at IP 2 (former L3) and uses the L3 Magnet

See talk by Rainer Schicker on Thursday
Ultra-peripheral Collisions in ALICE

Ideas to study exclusive vector meson production, in particular $J/\Psi$ and $\Upsilon$.

Mid-rapidity $V \rightarrow e^+e^-$. 
Trigger: Level 0 multiplicity from SiPixel, ToF in anti-coincidence w/ t0 and v0 detectors ($\approx 2 < |\eta| < 5$).
Electron Id: Transition Radiation Detector (also in Level 1 Trigger).

Forward region ($2.2 \leq \eta \leq 4.0$) $V \rightarrow \mu^+\mu^-$. 
Trigger: Muon arm trigger in anti-coincidence w/ central arm detectors (SiPixel, ToF).
### Expected rates – Vector Mesons

\( \text{Pb+Pb} \; ; \; <L> = 5 \cdot 10^{26} \text{ cm}^{-2}\text{s}^{-1} \; ; \; \text{ALICE year } 10^6 \text{ s} \)

<table>
<thead>
<tr>
<th>Prod. Rate</th>
<th>Decay</th>
<th>Br.Ratio</th>
<th>Geo Acc.*</th>
<th>Detection Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6\cdot10^9</td>
<td>( \pi\pi )</td>
<td>100%</td>
<td>0.079</td>
<td>2.0\cdot10^8</td>
</tr>
<tr>
<td>1.6\cdot10^7</td>
<td>( e^+e^- )</td>
<td>5.93%</td>
<td>0.101</td>
<td>1\cdot10^5</td>
</tr>
<tr>
<td>\approx 1\cdot10^5</td>
<td>( e^+e^- )</td>
<td>2.38%</td>
<td>0.141</td>
<td>\approx 400</td>
</tr>
</tbody>
</table>

**Geo Acc:** \( |\eta|<0.9, p_T>0.15 \text{ GeV/c} \)

The numbers have been confirmed from aliroot (the ALICE off-line analysis tool) simulations. The exact value of the acceptance will depend on the final track selection and the exact status of the detector when the data were taken.

A bug in the MC was found and that is the reason for the lower J/\( \Psi \) and \( \Upsilon \) acceptances compared with the ALICE Physics Performance Report (J.Phys.G 32(2006)1295).
Ultra-peripheral Collisions in CMS

Exclusive production of $\Upsilon$ in pp and PbPb

From Jonathan Hollar, Presentation at Workshop on High Energy Photon Collisions at the LHC, CERN, 22-25 April, 2008. Also talking here on Thursday.

26 – 30 May 2008 HERA-LHC Workshop, CERN Joakim Nystrand
Two-photon production of Higgs at the LHC

For a standard model Higgs with $M=120$ GeV, calculations give for two-photon production

$$\sigma(pp\rightarrow pp+H) \approx 0.1 \text{ fb} \quad \text{and} \quad \sigma(PbPb\rightarrow PbPb+H) \approx 10 \text{ pb}$$

With integrated luminosities of (1 year $10^7/10^6$ seconds)

$$10^5 \text{ pb}^{-1} \quad \text{and} \quad 1 \text{ nb}^{-1}$$

this gives

$$\approx 10 \text{ events/year} \quad \text{and} \quad \approx 0.01 \text{ events/year}$$

Conclusions and Outlook

- Studying photon-induced interactions at hadron colliders is an opportunity that should not be missed.
- The feasibility has been proven at RHIC and the Tevatron.
- Much focus on Vector Mesons in this talk, but there is a rich variety of topics that can be studied:
  * direct $\gamma+p$ and $\gamma+A$ interactions, e.g.
    $\gamma+p\rightarrow\text{jet+jet+X}$, $\gamma+p\rightarrow Q+\bar{Q}+X$;
  * two-photon interactions, $\gamma\gamma\rightarrow WW$, $\gamma\gamma\rightarrow e^+e^-$ from strong fields in Pb+Pb collisions.
  * etc. etc.