Photon-Photon and Photon-Nucleus Collisions in ALICE at the LHC

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- Overview of ALICE – Differences and Similarities with other LHC Experiments

- Ultra-Peripheral Collision Reaction Channels in ALICE

- Trigger strategies and backgrounds

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

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Central Barrel:

– Main tracking detector: The world's largest Time-Projection Chamber, Radius = 5 m, length = 10 m; $|\eta| \leq 0.9$; B = 0.5 T.

– Inner Tracking System consisting of 6 layers of Si-detectors.

– ToF and Transition Radiation Detector used for PId.

– Partial Calorimetry Coverage (Photon Spectrometer, EmCal).

Muon Barrel:

– Absorber.

– A 3 Tm Dipole Magnet.

– Tracking system consisting of 10 planes of cathode pad chambers.

– 4 Trigger Chambers.

ALICE in comparison with other LHC Experiments

I. Focus on low p_T.

Reconstruct every charged track with $p_T = 0.1 – 100$ GeV/c

ATLAS, CMS $p_T > 1$ GeV/c (Note that $\langle p_T \rangle \sim 0.35$ GeV/c)

II. Handle extremely high multiplicities

Design requirement $dn_{ch}/d\eta = 8000$

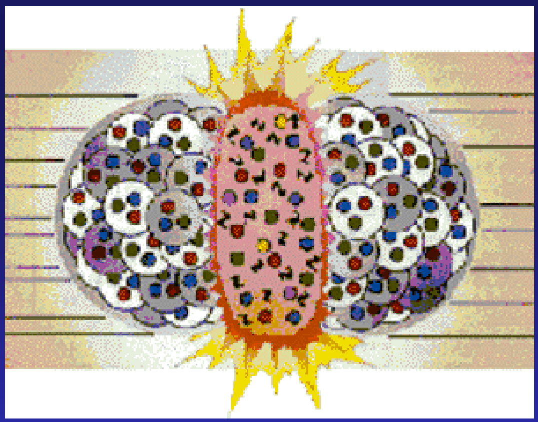
III. Handle very high data rates

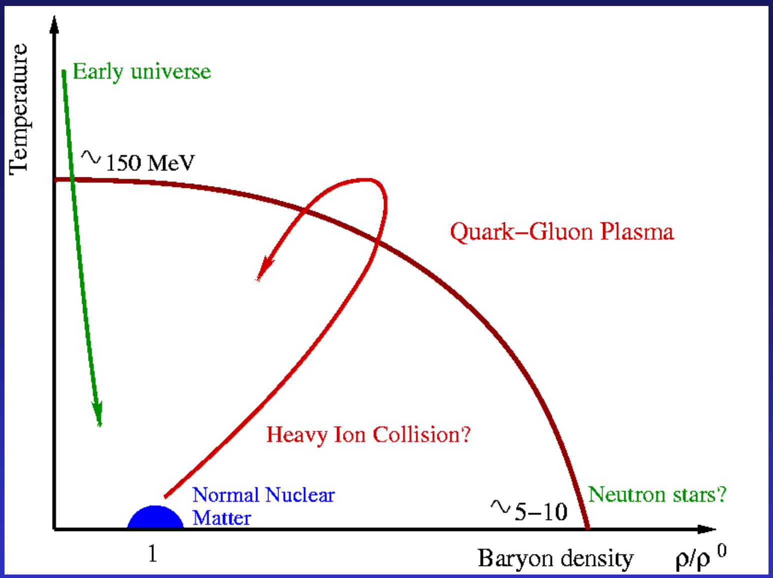
Write 1.25 GByte/sec to tape

ATLAS/CMS ≈ 200 – 300 MByte/sec

These differences in design are driven by the different physics goals of central nucleus-nucleus vs. proton-proton collisions.

Focus on determining the properties of the medium (possibly a new state of matter) produced in the collisions, and probing the phase transition from hadronic → partonic matter.





Ultra-Peripheral Collisions in ALICE

First an overview of what can be done, expected rates etc.

then

A discussion of the main challenge – Triggering on UPCs.

Two classes of UPCs

Exclusive or ”elastic”:

The photon interacts with the entire nucleus coherently.
Both nuclei remain intact.
Pb+Pb→Pb+Pb+V ; γ+Pb→V+Pb; V=ρ, J/ψ, ϒ;
Pb+Pb→Pb+Pb+$\mu^+\mu^-$; γγ→$\mu^+\mu^-$

Inclusive or ”inelastic”:

The photon interacts with a single nucleon or parton.
The ”target” nucleus breaks up.
Pb+Pb→Pb+X+cc; γ+g→cc; Note: σ ≈ 1b, y=0 ↔x=$5\cdot10^{-4}$.
Pb+Pb→Pb+X+2jets.

Ultra-Peripheral Collisions in ALICE

(Ideas for Run 1 and 2)

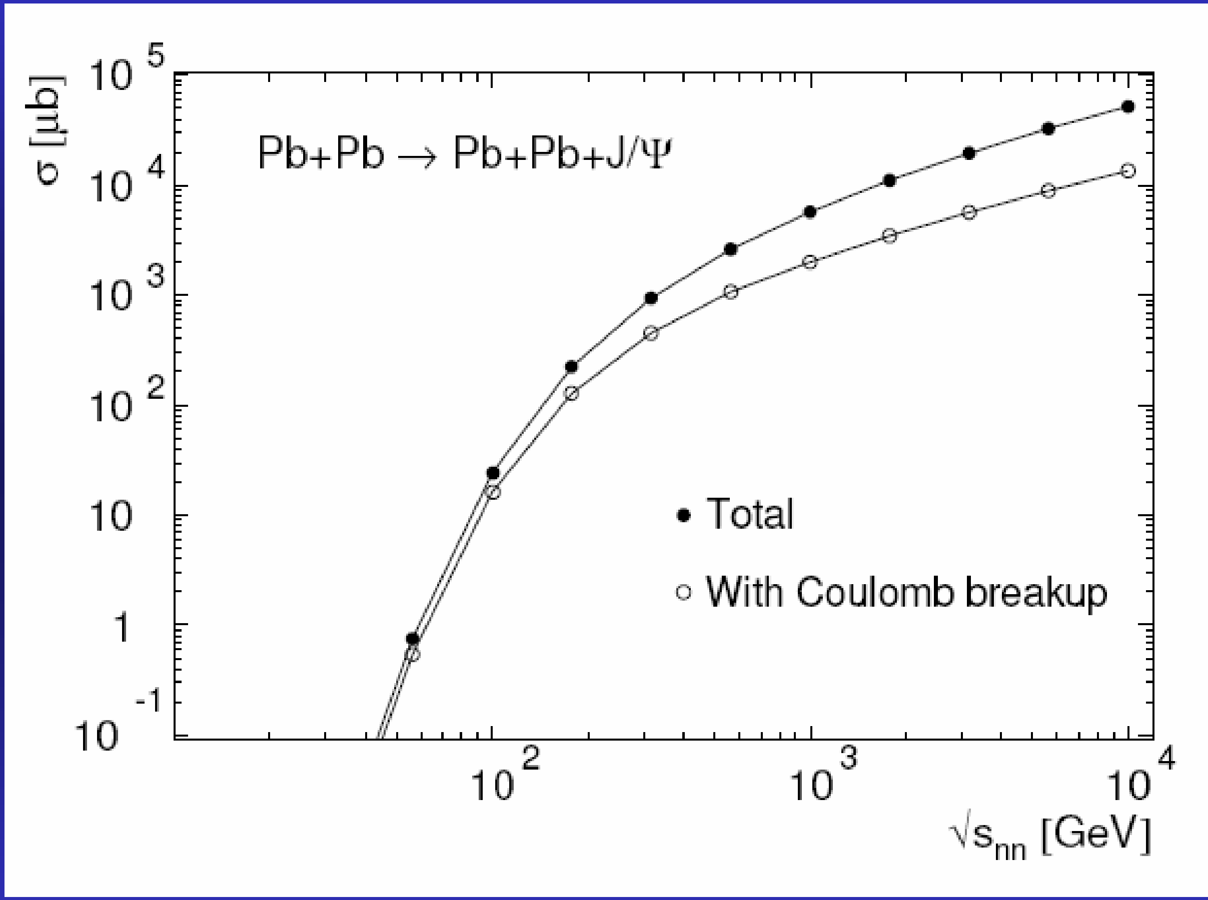
1. Vector Meson production; Unique possibility to measure γ+A$\rightarrow \Upsilon$ +A; sensitive probe of g(x,Q^2)

2. Photonuclear jet production; photon+parton→jet+jet; e.g. γ+g→q+q; R.Vogt hep-ph/0407298, M.Strikman, R.Vogt, S.White PRL 96(2006)082001.

3. Photonuclear production of heavy quarks, γ+g→cc.

4. Meson spectroscopy; e.g. $\gamma\gamma\rightarrow\eta_b$ (rate is too low)

Exclusive Vector Meson Production: Increase in σ(J/Ψ) with energy



ρ: RHIC 590mb → LHC 5200mb factor 9

J/ψ RHIC 0.3 mb → LHC 32mb factor 100

For the heavier VMs ($J/\Psi, \Psi', \Upsilon$), $\sigma(\gamma p \rightarrow Vp)$ calculable from QCD (2-gluon exchange)

$$\frac{d\sigma}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xg(x, \frac{M_V^2}{4})]^2$$ Ryskin 1993

$\Longrightarrow$ Sensitive probe of g(x), $[(g(x))^2]$

Also studied by Frankfurt LL, McDermott MF, Strikman M, *J. High Energy Physics* 02:002 (1999) and
Martin AD, Ryskin MG, Teubner T *Phys.Lett.* B454:339 (1999)

kinematic ranges for photoproduction

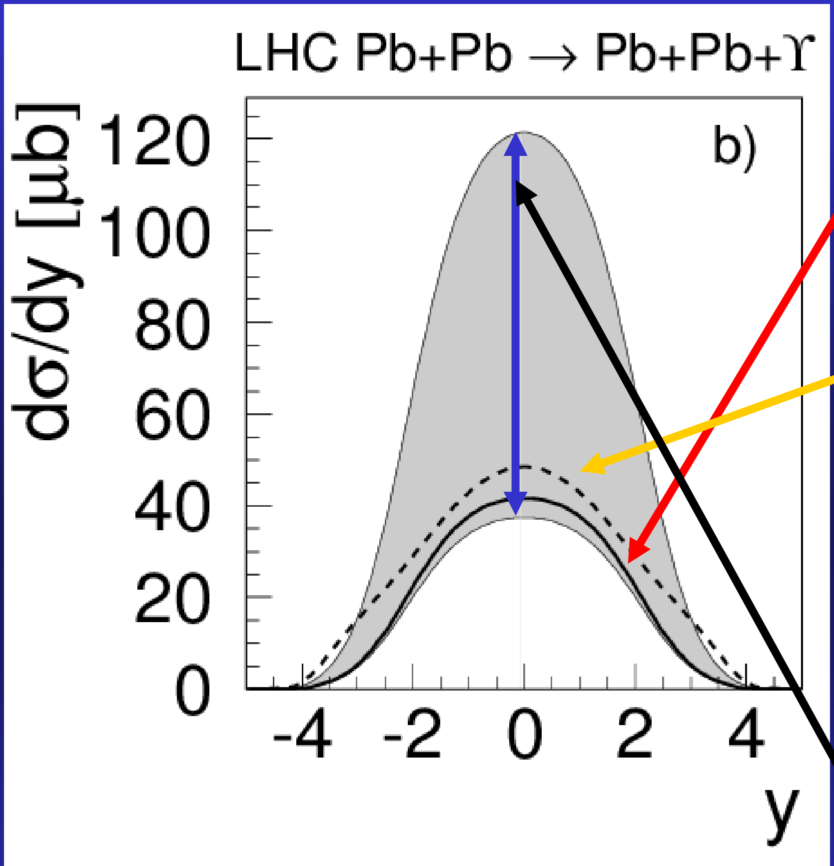
$W_{\gamma p}$ – photon-proton CM energy

x - Bjorken-x of gluon

Q^2 - $M_V{}^2$

y=0	J/ψ	Υ
RHIC	$W_{\gamma p} = 25$ GeV $x \approx 2 \cdot 10^{-2}$	$W_{\gamma p} = 43$ GeV $x \approx 5 \cdot 10^{-2}$
LHC PbPb	$W_{\gamma p} = 130$ GeV $x \approx 6 \cdot 10^{-4}$	$W_{\gamma p} = 230$ GeV $x \approx 2 \cdot 10^{-3}$
LHC pp	$W_{\gamma p} = 210$ GeV $x \approx 2 \cdot 10^{-4}$	$W_{\gamma p} = 350$ GeV $x \approx 6 \cdot 10^{-4}$

Υ rapidity distribution



A^2 scaling of QCD prediction

A^2 scaling of exp. data from HERA.

Uncertainty in measured cross section (mainly poor statistics).

Mid-rapidity y=0 ⇔
γp CM energy $W_{\gamma p}$ = 230 GeV,
$x = 2 \cdot 10^{-3}$

Expected rates – Vector Mesons

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

	Prod. Rate	Decay	Br.Ratio	Geo Acc.*	Detection Rate
ρ	$2.6 \cdot 10^9$	$\pi\pi$	100%	0.079	$2.0 \cdot 10^8$
J/ψ	$1.6 \cdot 10^7$	e^+e^-	5.93%	0.164	$1.5 \cdot 10^5$
Υ	$\sim 1 \cdot 10^5$	e^+e^-	2.38%	0.236	≈ 600

Geo Acc: $|\eta|<0.9$, $p_T>0.15$ GeV/c

Expected rates – e^+e^- continuum

Table 6.104. Cross sections for two-photon production of lepton pairs for different cuts on the invariant mass of the pair, calculated within the equivalent photon approach.

Selection	$\sigma(\mathrm{Pb}+\mathrm{Pb} \rightarrow \mathrm{Pb}+\mathrm{Pb}+l\bar{l})$	
	e^+e^-	$\mu^+\mu^-$
Total	223 kb [1057]	2.0 b
$m_{\mathrm{inv}} > 1.5\,\mathrm{GeV}$	140 mb	45 mb
$m_{\mathrm{inv}} > 6.0\,\mathrm{GeV}$	2.8 mb	1.2 mb

The corresponding event rates, Pb+Pb → Pb+Pb e+e- for one ALICE year:

All:	$7 \cdot 10^7$ events
$\lvert\eta\rvert < 0.9$, $p_T > 0.15$ GeV/c	$7 \cdot 10^5$ events
$\lvert\eta\rvert < 0.9$, $p_T > 3$ GeV/c	14,000 events

Expected rates – $\mu^+\mu^-$ continuum

Table 6.108. Expected yields within the geometrical acceptance of the ALICE muon arm for two-photon production of $\mu^+\mu^-$-pairs.

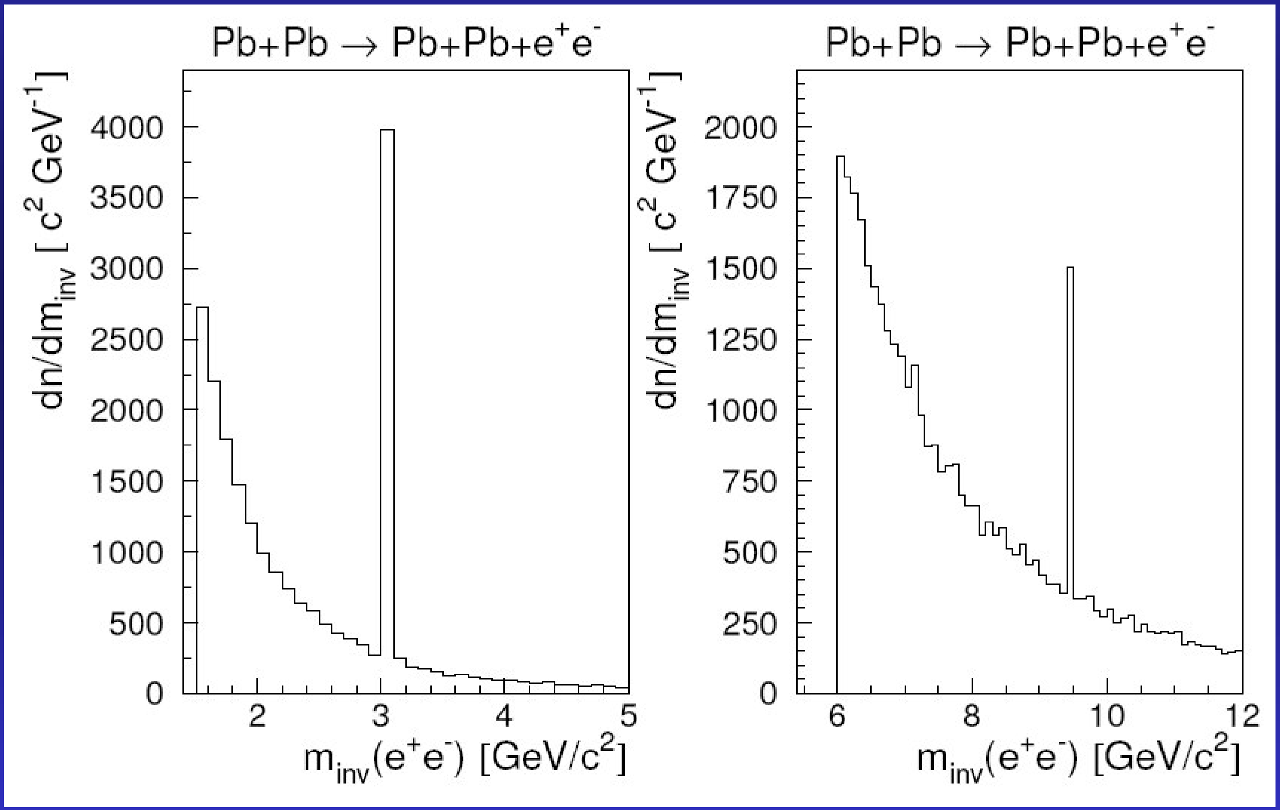
$Pb + Pb \rightarrow Pb + Pb + \mu^+\mu^-$, $m_{inv} > 1.5$ GeV

Selection	Geometrical Acceptance	Rate (per 10^6 s)
All	100%	2.2×10^7
$2.2 \leqslant \eta \leqslant 4.0$, $p_t > 1.0$ GeV	0.26%	60 000

Important background from $\gamma\gamma \rightarrow e^+e^-$

Events in the central barrel ($|\eta|<0.9$)

10^4 s $\qquad$ 10^6 s



Ultra-peripheral production of heavy quarks (with nuclear break-up)

Table 6.105. Cross sections and production rates for $\gamma + g \to q\bar{q}$ in one ALICE year (10^6 s), from [1054, 1062].

Final state	Pb–Pb		Ar–Ar	
	σ	rate (per 10^6 s)	σ	rate (per 10^6 s)
$\gamma + g \to c\bar{c} + X$	1050 mb	5.5×10^8	14 mb	5.6×10^8
$\gamma + g \to b\bar{b} + X$	4.7 mb	2.3×10^6	70 μb	2.8×10^6
$\gamma + g \to t\bar{t} + X$	0.3 nb	–	29 pb	($\sim$1)

Klein S R, Nystrand J and Vogt R 2002 Phys. Rev. C 66 044906

Rate simulations not possible:
No Monte Carlo Event Generator available!!

Detection Principles

1. Vector mesons, γγ:
   Reconstruct 2 tracks (low multiplicity), charge balance, low sum $|\mathbf{p}_T^1 + \mathbf{p}_T^2| < \sim 100$ MeV/c (nuclear form factor) (the two tracks will have higher pT).

2. Photonuclear jets:
   Rapidity gap between photon-emitting nucleus and jet, distinguishes photonuclear jet production from hadronic jet production, suppression for a gap Δy: $\exp(-\langle dn/dy \rangle \cdot \Delta y)$
   $\Rightarrow \Delta y = 2 \leftrightarrow \sim 10^{-2} - 10^{-3}$ reduction.

Trigger Strategies and Backgrounds I

- Trigger in ALICE designed for central, hadronic interactions.
- Main low-level trigger detectors located outside the acceptance of the central barrel, T0 and V0 detectors at $\approx 2 < |\eta| < 5$.
- No problem for central collisions, the produced particles fill the entire rapidity axis (no gaps).

Trigger Strategies and Backgrounds II

- Experience from RHIC $\Rightarrow$ highly advantageous to combine a trigger from the ZDC with a trigger at mid-rapidity.
- Problem in ALICE: Long distance from primary vertex $\rightarrow$ ZDC. The time for the signal to reach the Central Trigger Processor exceeds the allowed maximum (800 nsec) by about 150 nsec.
- The difference is not very big, but the overall L0 time will not be modified before ALICE begins to take data.
- A short, dedicated run with different Level 0 timing is conceivable, but this would lead to a very low integrated luminosity.

Trigger Strategies and Backgrounds III

- A low-level trigger at mid-rapidity in ALICE is, however, not excluded.
- Signals from Si-pixel and ToF-detectors will be included in Level 0 and could be used.
- See talks by Eugenio Scapparone and Rainer Schicker.

Backgrounds

1. Cosmic rays.
2. Peripheral nuclear collisions
3. beam-gas interactions
4. Incoherent photonuclear interactions.

For coherent events (Vector Mesons, $\gamma\gamma$) ➔ Low-p_T cut extremely efficient. Shown in simulations, experience from RHIC.

Rapidity Gaps: Not tried with heavy ions before, should work for gaps with $\Delta y \sim$ 2-3.

Effectiveness of Rapidity Gaps

Production of heavy-quark pairs $\sqrt{s}$ = 5.5 TeV:

R. Vogt [Hard Probe Collaboration], Int. J. Mod. Phys. E 12 (2003) 211.

$\sigma(pp \rightarrow Q\bar{Q} + X)$:	5.8 mb ($c\bar{c}$)	190μb ($b\bar{b}$)
[$A^2 \cdot \sigma(pp \rightarrow Q\bar{Q} + X)$:	252 b ($c\bar{c}$)	8.1 b ($b\bar{b}$)]

Photoproduction $\sqrt{s}$ = 5.5 TeV:

$\sigma(Pb+Pb \rightarrow Pb+ Q\bar{Q} + X)$:	1.2 b ($c\bar{c}$)	4.9 mb ($b\bar{b}$)

Rapidity gap between photon-emitting nucleus and the produced particles, suppression for a gap Δy:
$\exp(-\langle dn/dy\rangle \cdot \Delta y)$
$\Rightarrow$ With $\langle dn/dy\rangle \approx$ 2.5-3.5 and $\Delta y=2 \Rightarrow$
~10^{-2}–10^{-3} reduction.

Conclusions

• Acceptance and efficiency of the ALICE detector $\Rightarrow$ Rates for many interesting UPC channels are high.

• There are ideas for triggering, but these must be implemented and shown to work with acceptable background rates.

• With appropriate triggers, there are analysis techniques to separate a signal from background.