Photon-Induced Physics with Heavy-Ion Beams in ALICE

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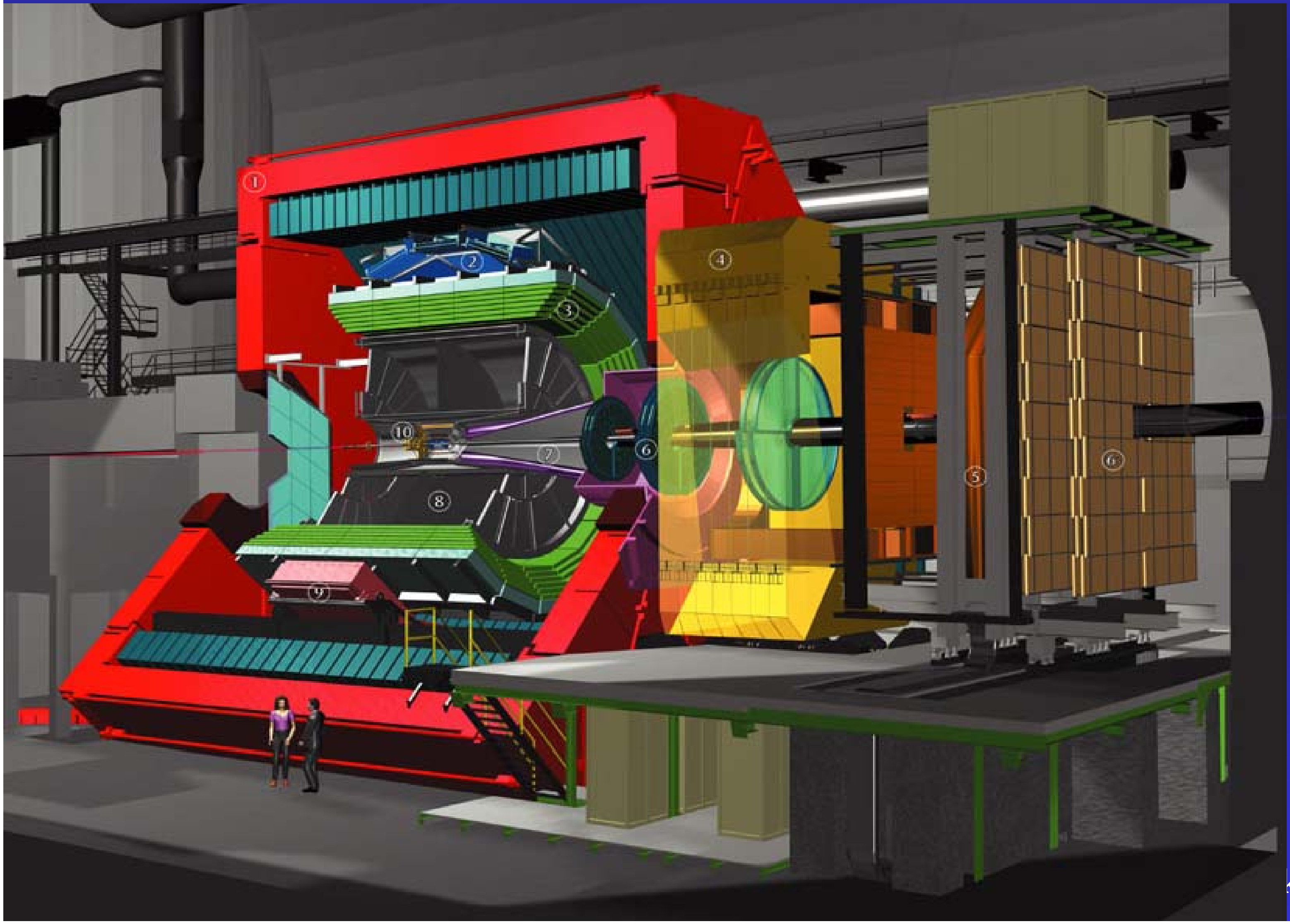
- Overview of ALICE – Differences and Similarities with other LHC Experiments

- 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



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 focus on $p_T > 1$ GeV/c (Note that $\langle p_T \rangle \sim 0.35$ GeV/c)

II. Handle extremely high multiplicities

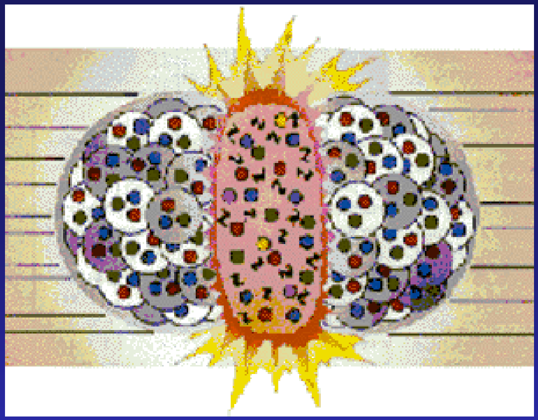
Design requirement $dn_{ch}/d\eta = 8000$

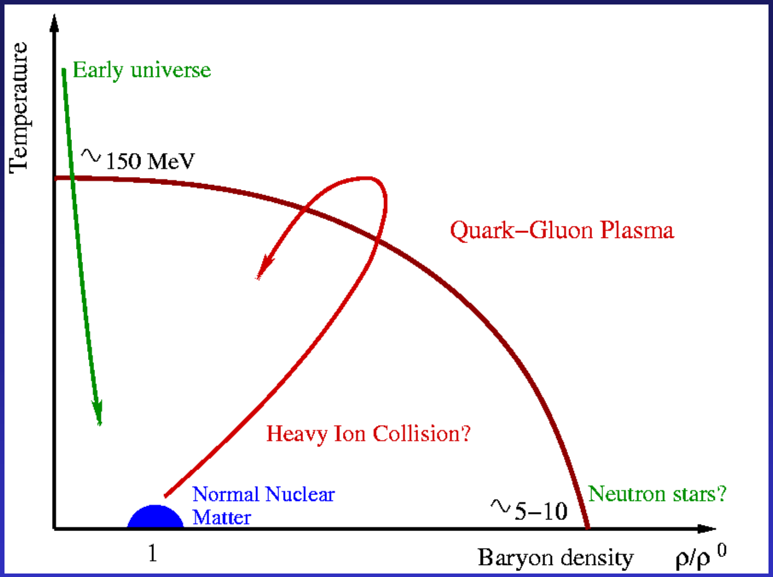
III. Handle very high data rates

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.
$Pb+Pb \rightarrow Pb+Pb+V$; $\gamma+Pb \rightarrow V+Pb$; $V=\rho$, J/ψ, Υ;
$Pb+Pb \rightarrow Pb+Pb+\mu^+\mu^-$; $\gamma\gamma \rightarrow \mu^+\mu^-$

Inclusive or ”inelastic”:

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

Ultra-Peripheral Collisions in ALICE

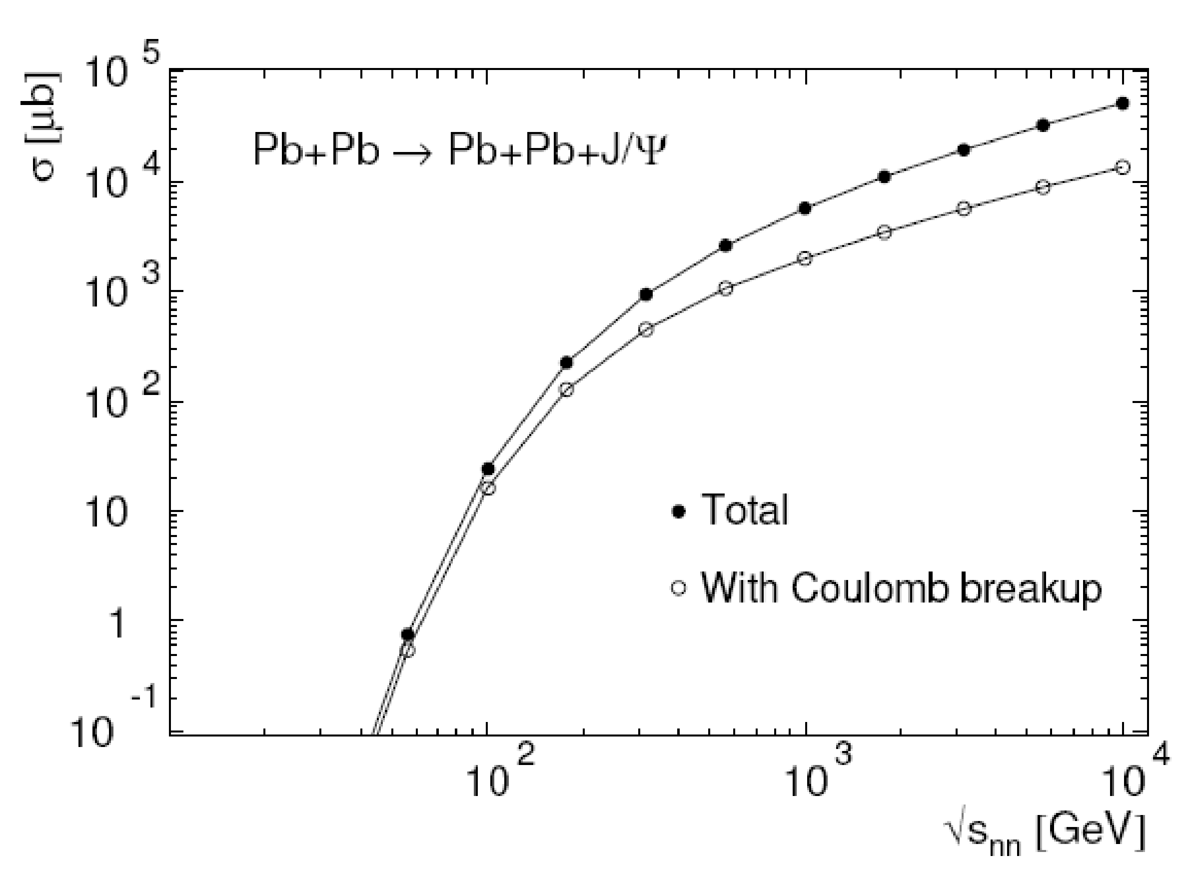
(Ideas for Run 1 and 2)

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

2. Photonuclear jet production; photon+parton$\rightarrow$jet+jet; e.g. γ+g$\rightarrow$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$\rightarrow$cc.

Exclusive Vector Meson Production: Increase in $\sigma(J/\Psi)$ with energy



ρ: RHIC 590mb → LHC 5200mb factor 9

J/ψ RHIC 0.3 mb → LHC 32mb factor 100

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

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

$\Rightarrow$ 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)

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	$2.6 \cdot 10^9$	ππ	100%	0.079	$2.0 \cdot 10^8$
J/ψ	$1.6 \cdot 10^7$	e^+e^-	5.93%	0.101	$1 \cdot 10^5$
ϒ	$\sim 1 \cdot 10^5$	e^+e^-	2.38%	0.141	≈ 400

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

These 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.

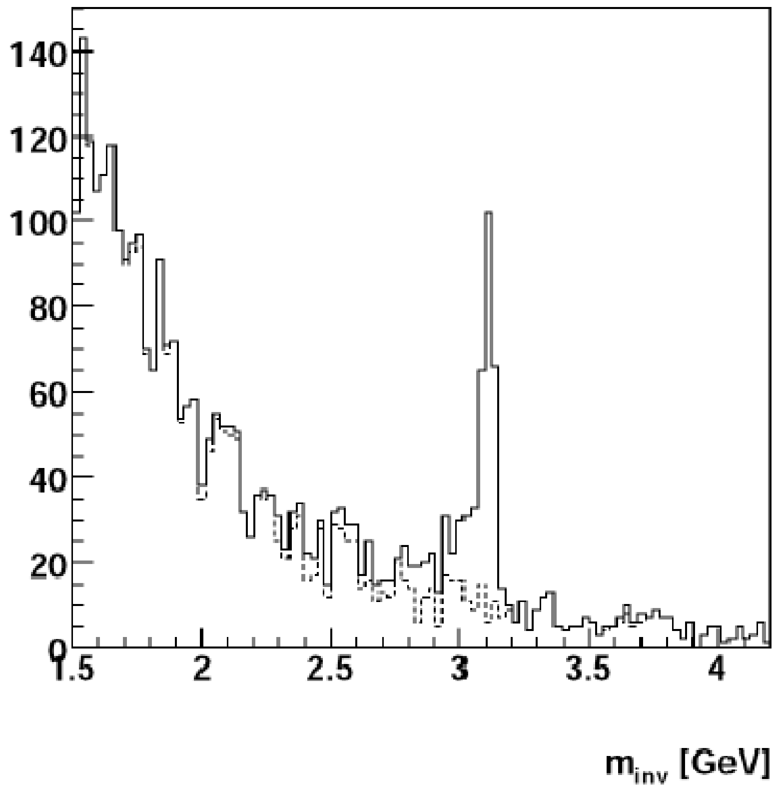
There is in addition a vertex reconstruction efficiency, currently 85% for 2-track events, but this can probably be improved by tuning the parameters for low-multiplicity events.

A bug in the MC was found and that is the reason for the lower J/Ψ and ϒ acceptances compared with the ALICE Physics Performance Report (J.Phys.G 32(2006)1295).

An example analysis, corresponding to 1.5 h at design luminosity (or 15 h at 10% of design luminosity):

Event Generator (StarLight) + Detector response simulation (Geant) + Event reconstruction (aliroot)

375,000	$\gamma\gamma \to e^+e^-$
5,141	$J/\Psi \to e^+e^-$
122	$\Psi' \to e^+e^-$

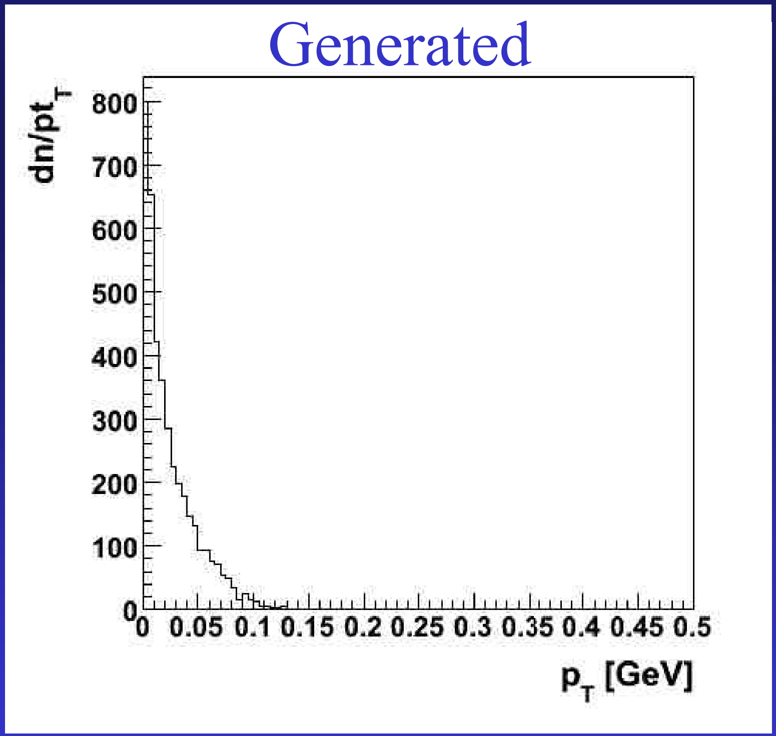


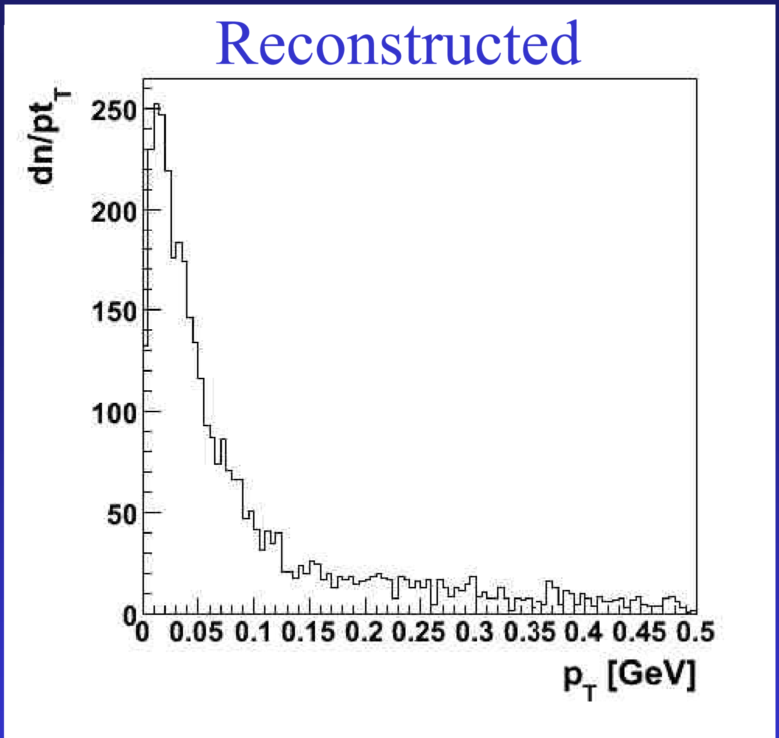
Gives about
3,500 reconstructed $\gamma\gamma \to e^+e^-$
500 reconstructed J/Ψ
10 reconstructed Ψ'

Note: continuum and VM production have very different angular distributions $\Rightarrow$ different acceptance.

Events are identified from the low multiplicity, charge conservation (one + and one -), and the low transverse momentum, p_T.

Note that p_T is the momentum of the J/Ψ. The electrons/positrons have p_T of about 1.5 GeV/c.

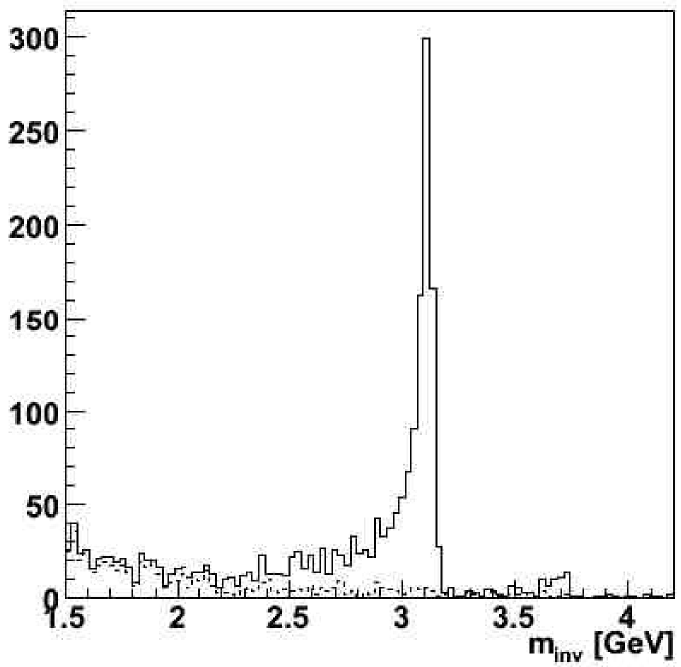




A similar analysis for pp, corresponding to 250 h at ALICE pp luminosity (NOTE: a factor 10^3 lower than the LHC design luminosity):

Event Generator (StarLight) + Detector response simulation (Geant) + Event reconstruction (aliroot)

150,000	$\gamma\gamma \rightarrow e^+e^-$
35,796	$J/\Psi \rightarrow e^+e^-$
729	$\Psi' \rightarrow e^+e^-$

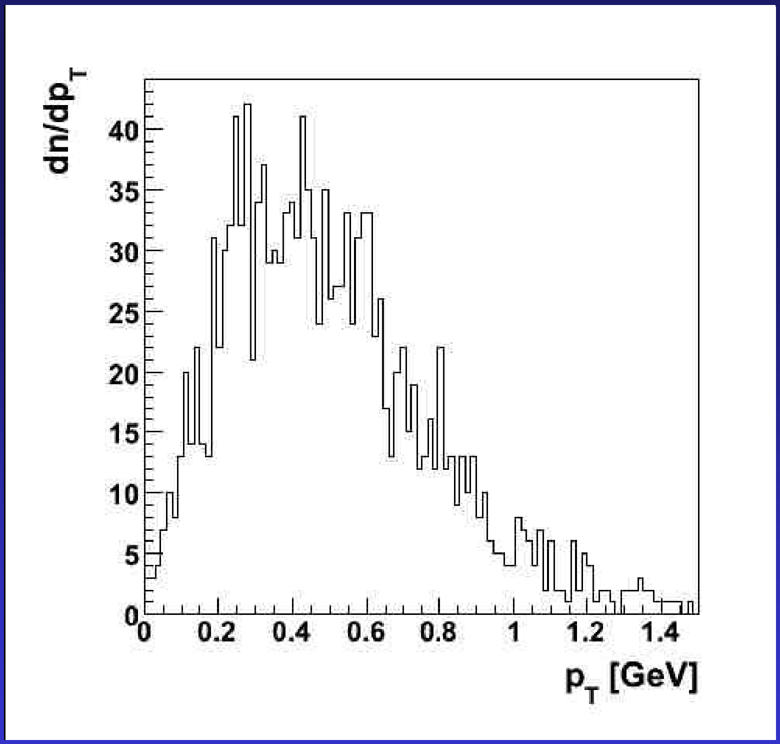


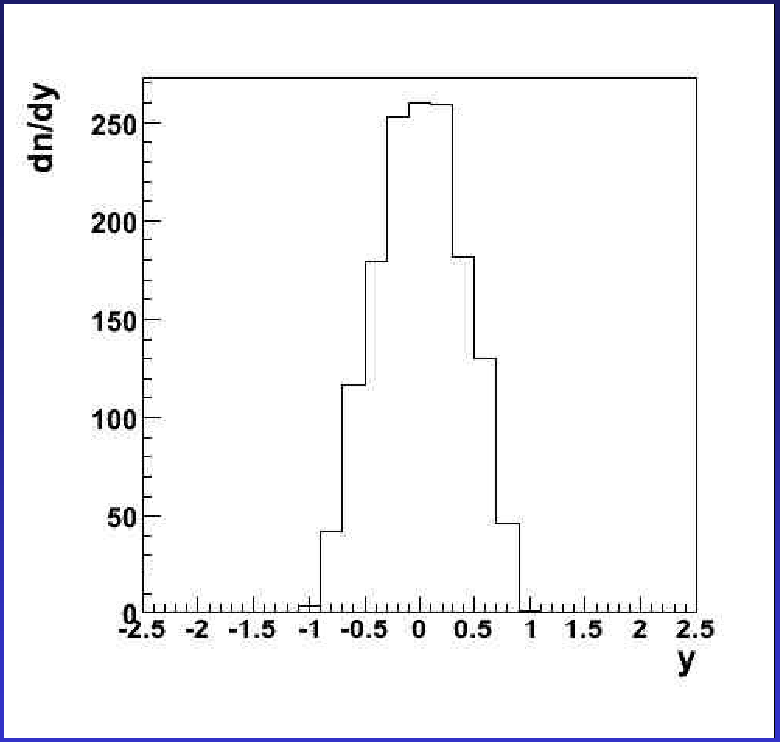
Gives about
700 reconstructed $\gamma\gamma \rightarrow e^+e^-$
1,400 reconstructed J/Ψ
30 reconstructed Ψ'

Much less background from $\gamma\gamma \rightarrow e^+e^-$ than in Pb+Pb.

Transverse momentum and rapidity distributions of recontructed J/Ψs.

The pT distribution is much wider than for Pb+Pb, because of the different form factors. Identification must rely on rapidity gaps.





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

Table 6.105. Cross sections and production rates for $\gamma + g \rightarrow q\bar{q}$ 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)
$\gamma + g \rightarrow c\bar{c} + X$	1050 mb	5.5×10^8	14 mb	5.6×10^8
$\gamma + g \rightarrow b\bar{b} + X$	4.7 mb	2.3×10^6	70 μb	2.8×10^6
$\gamma + g \rightarrow t\bar{t} + X$	0.3 nb	–	29 pb	($\sim$1)

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

Detection Principles

1. Vector mesons, $\gamma\gamma$:
   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.

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: Used by PHENIX at RHIC, should work for gaps with $\Delta y \sim 2\text{-}3$.

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 $\langle dn/dy \rangle \approx 2.5\text{-}3.5$ and $\Delta y=2 \Rightarrow$

$\sim 10^{-2}$–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.