Ultraperipheral Collisions

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Physics at LHC

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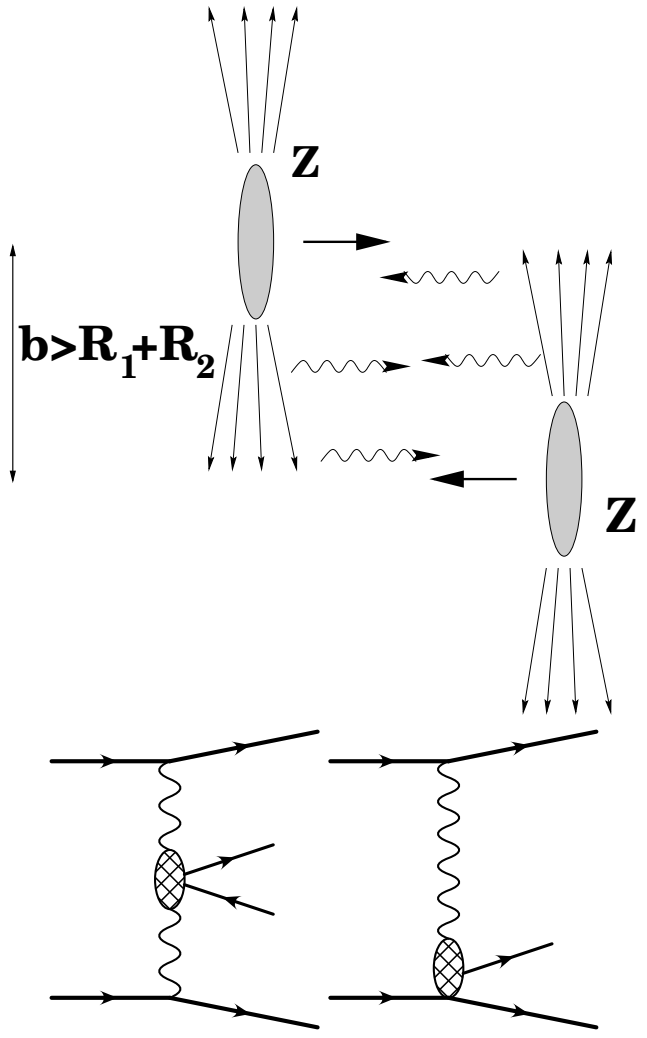
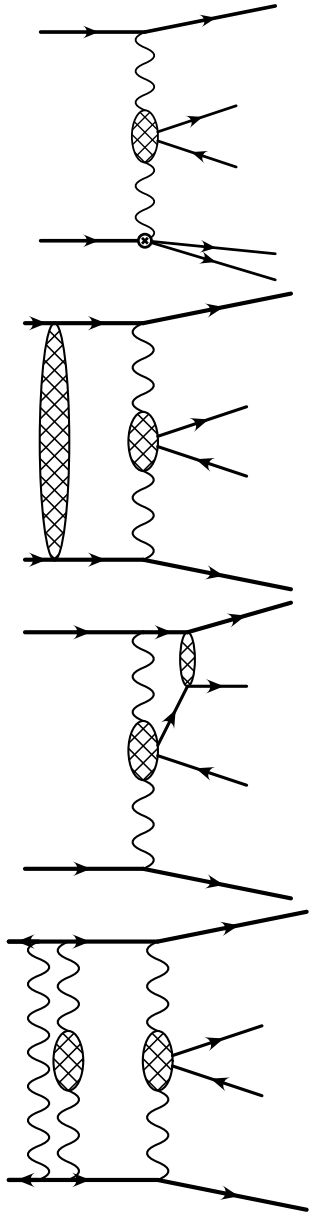
What are Ultra-Peripheral Collisions?

- Idea behind UPC: Use the strong Coulomb field surrounding the ions in Relativistic Heavy Ion Collisions.
- Impact parameter $b > 2R$: Only Coulomb field(s) can interact.
- Coherence of protons leads to an enhancement factor Z^4/Z^2.
- Allows to have photon-photon and photon-nucleus interaction.
- Flux of "equivalent photons" up to the 100 GeV/500 TeV region.
- UPC are "orthogonal" to normal heavy ion collisions.
- Dominant background: Diffractive processes, gracing collisions.
- elmgn. processes $\sim Z^2$,
  diff. processes $\sim A^\delta$, $\delta \approx 1/3 < 1$.
- Triggering on "intact" nuclei essential.

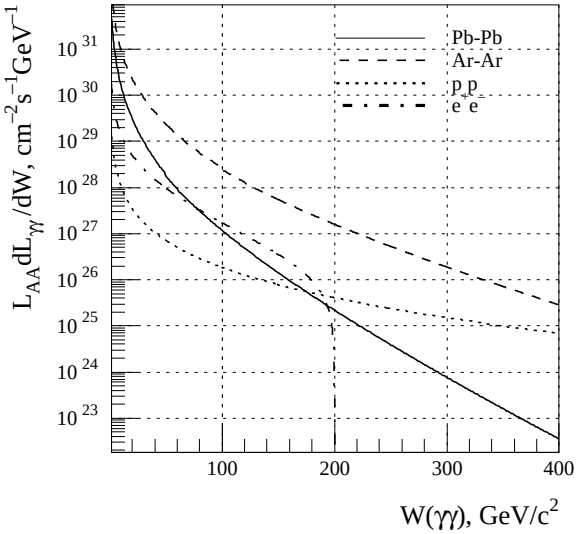


$\gamma\gamma$ and γA collisions: Comparison with ee and ep

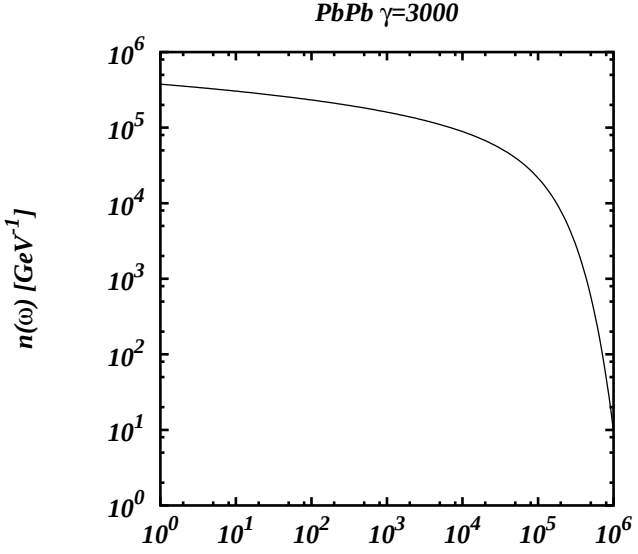
- Photon-photon physics studied with ee at LEP.
- Photon-proton, Photon-Nucleus reactions studied at HERA.
- UPC at LHC allow to extend these to higher energies and higher luminosity.
- Treatment of “equivalent photons” similar to ee, eA.
  Differences:
- Nucleus is not a pointlike object, has finite size: Restriction on
  $k_\perp < 1/R$, $\omega < \gamma/R$.
  Only quasireal photons.
- Hadronic interaction of ions, final state need to be excluded.
- Additional photon exchanges and Photon excitation processes due to strong Coulomb fields
- Semiclassical description useful.



Luminosities



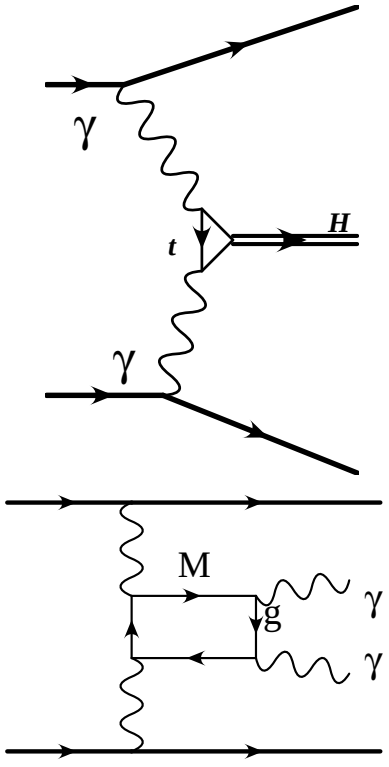
$L_{AA} = 1.4 \times 10^{31}$(p), 5.2×10^{29}(Ar), 4.2×10^{26}(Pb) cm$^{-2}s^{-1}$



- Invariant masses of $\gamma\gamma$ beyond LEP.
- Beam luminosity of lead is smaller than ArAr or pp ($L_{AA} = 10^{34}$).
- Photon spectrum from p is harder: Highest energies can be achieved in pp.
- Heavy ions still useful to reduce background from diffractive processes.
- Distribution centered around $Y = 0$
- Photon-Nuclear processes: In rest frame of the ion photon energies up to 500 TeV.
- In addition collisions with ions as well as with protons.

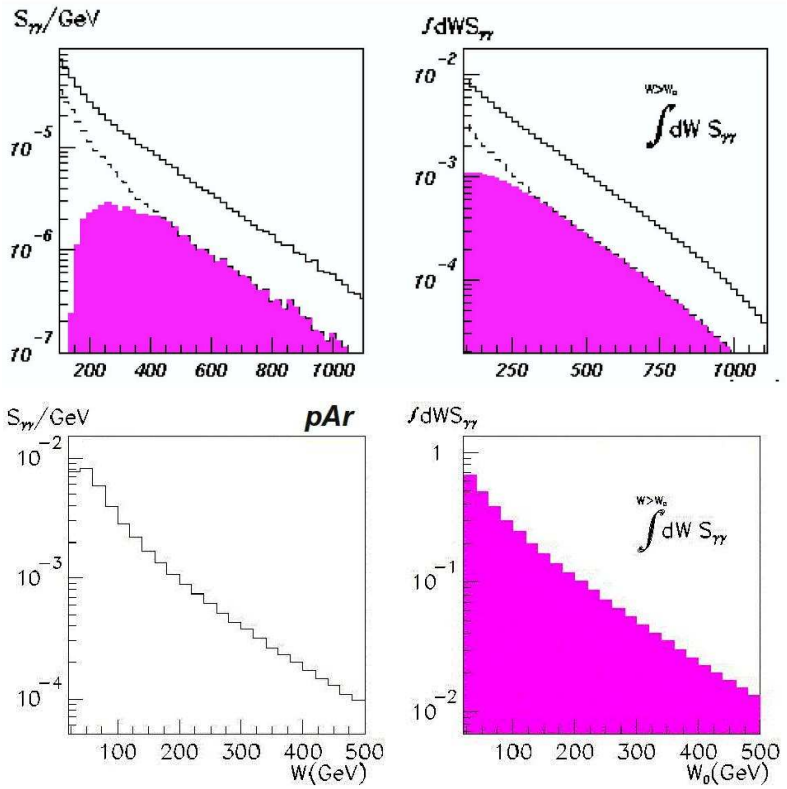
Potential for $\gamma\gamma$ physics

- Production of Higgs boson has been studied extensively.
  Krauss, Greiner, Soff, PPNP39, 503 ('97)
- Electromagnetic production allows for rather clean events.
- Rates for SM, MSSM Higgs are rather small.
- Nonstandard models with light Higgs possible.
  Lietti et al.,PLB497, 243 ('01)
- Other new physics: Supersymmetric particles, magnetic monopoles, $\gamma\gamma \to \gamma\gamma$ studied as well. Ginzburg, Schiller, PRD57, R6599 ('98), Roldao, Natale PRC61 064907 ('00)
- Rates most of the time too low to give reasonable counting rates.



Tagging for final protons

- At CMS/TOTEM one can tag protons having lost more than 1% of their energy.
  (K. Piotrzkowski: PRD63, 071502 ('00), talk at this conference)
- At this state not possible for ions:
  Finite size restricts spectrum to
  $x_{max} = \frac{1}{RM_N A} = \frac{\lambda_C(A)}{R}$
  4×10^{-3} for O, $1.4 \times 10^{-4}$for Pb
- Also possible: Tag on proton in pA collisions.
- Direct measurement of the energy of the emitted photon.
- Harder spectrum of p allows to go to higher masses.
- Study of electroweak processes: elmgn.-coupling of the gauge boson.

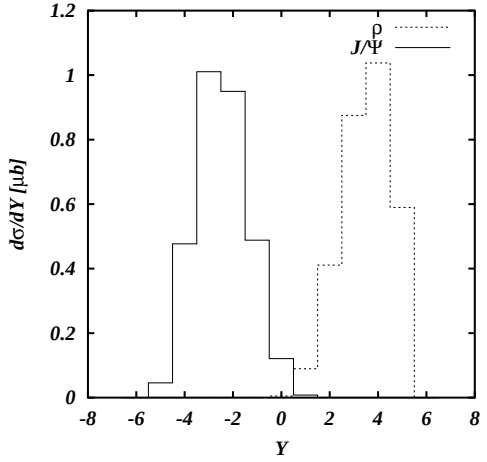


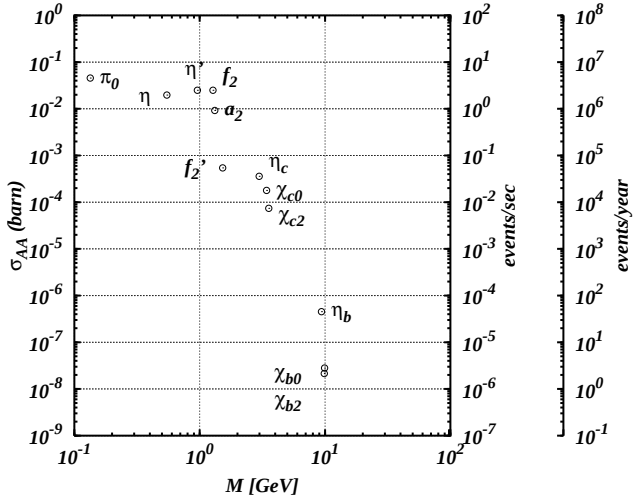
- γp collisions, even γA collisions possible.
- Diffractive processes can be distinguished according to transverse momentum.
- Limitation: overlapping events at high L_{pp}.

$\gamma\gamma$ at lower energies

- At lower invariant masses:
- Double Vector meson production. Studied in connection with FELIX. A. Ageev et al., J. Phys. G28, R117 ('02)
- Test of soft factorization hypothesis.
- Decay of J/Ψ into muons can be used as trigger at ALICE.
- Meson spectroscopy of lighter mesons.
- Of interest: $\gamma\gamma \rightarrow$ hadrons. Deviation from Regge universality found at LEP. Acciari (L3), PLB503 10 ('01)
- Even QED processes: Lepton pair production, bound-free pair production (ECPP), Positronium . . .

$AA \rightarrow AA + \rho + J/\Psi$	3.1 μb
$AA \rightarrow AA + \omega + J/\Psi$	0.36 μb
$AA \rightarrow AA + \phi + J/\Psi$	0.32 μb
$AA \rightarrow AA + J/\Psi + J/\Psi$	1.2 nb



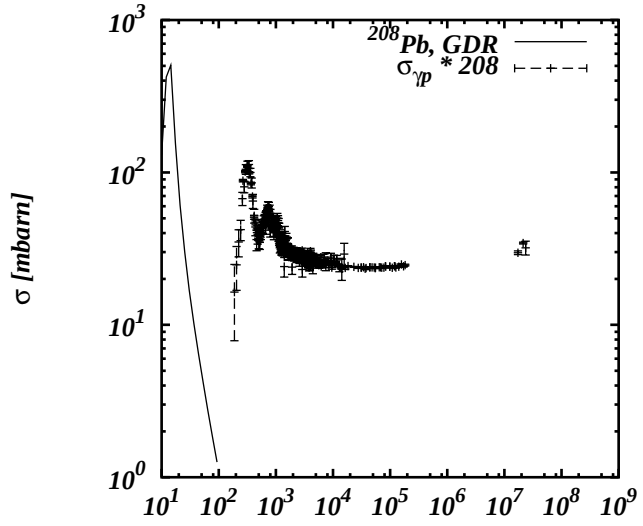


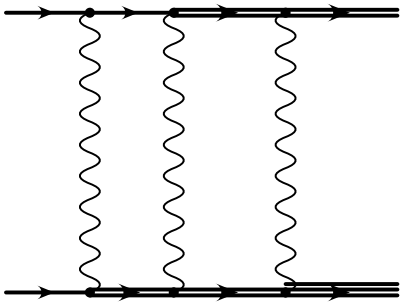
photonuclear reactions

- Photon spectrum ranges from MeV to TeV.
- At low energies: GDR excitation.
- Probability to excite nucleus is 80%.
- One of the dominant loss processes:

$$\sigma \approx 200\text{barn}$$

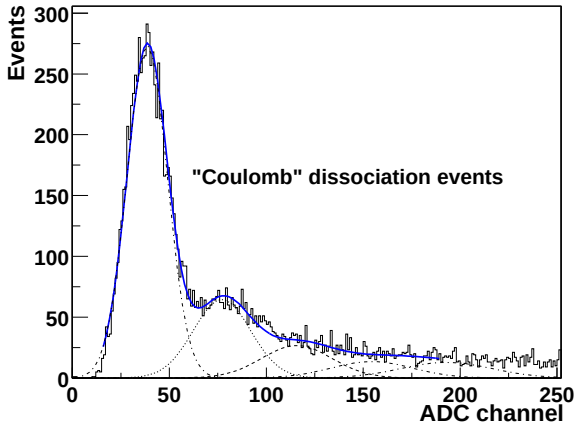
- Together with bound-free pair production.
  Limits the maximum luminosity, lifetime of lead beams.
- Nucleus emits one or few neutrons, which are detected in the ZDC.
- Due to strong field, large probability more than one process can occur in one collision.

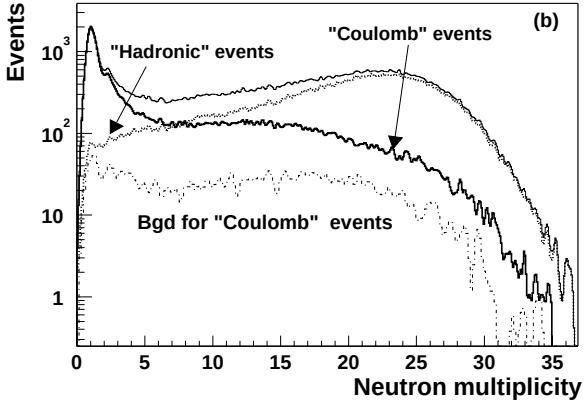


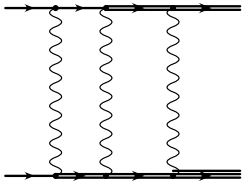


Mutual excitation: Lum. measurement, triggering for UPC

- Used at RHIC as a luminosity measurement tool.
  Baltz, Chasman, White, NIM417 1 ('98), Chiu et al., PRL89 ('02) 012302.
- Compared to prediction from RELDIS.
  I. Pshenichnov et al., PRC57 1920 ('98)
- At LHC: Double and Triple GDR excitation.
- Can also be useful as a trigger for UPC.
- Single neutron detection sign of only an elmgn. interaction.
- In addition limits impact parameter to small range.
- Pioneered at STAR/RHIC.



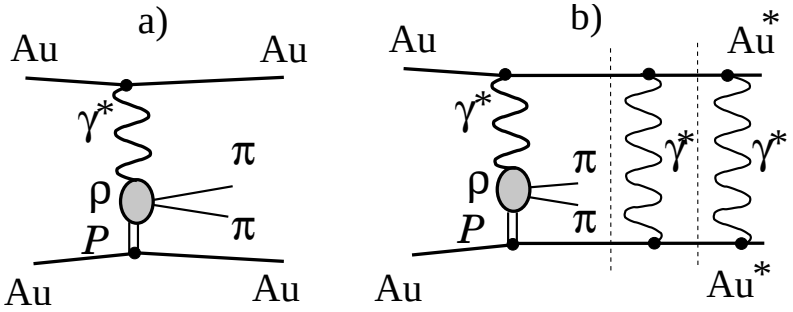


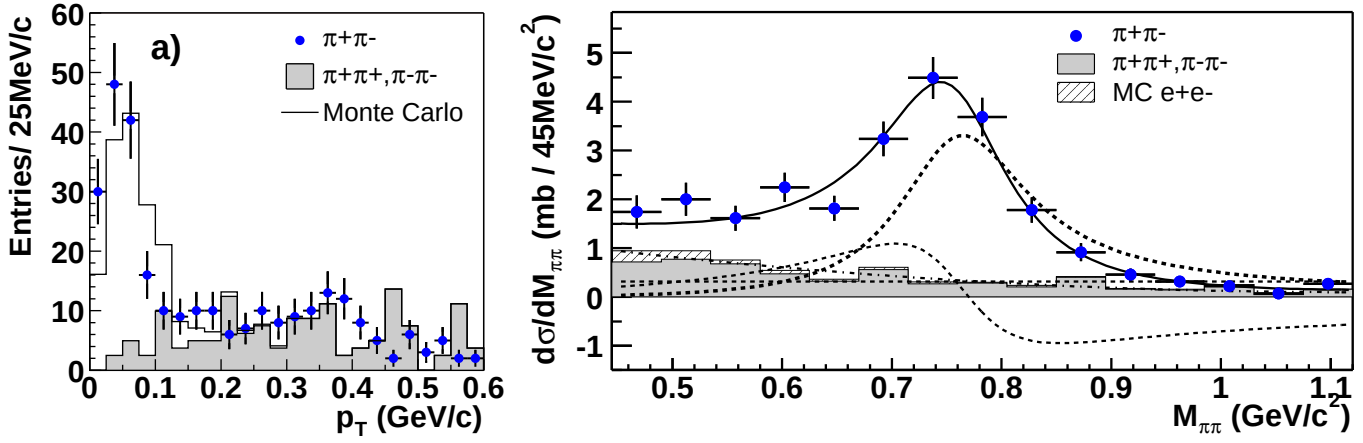


γA at higher energies, measurement at STAR

- At higher energies: Diffractive Vector meson production.
- Experiment pioneered at STAR at RHIC:
  S. Klein, J. Nystrand PRL84, 2330 ('00), PRC60, 014903 ('99), C. Adler et al., PRL89 272302 ('02),J. Nystrand talk at this conference.

- Measurement of coherent ρ photoproduction.
- Measured either with or without "GDR trigger".

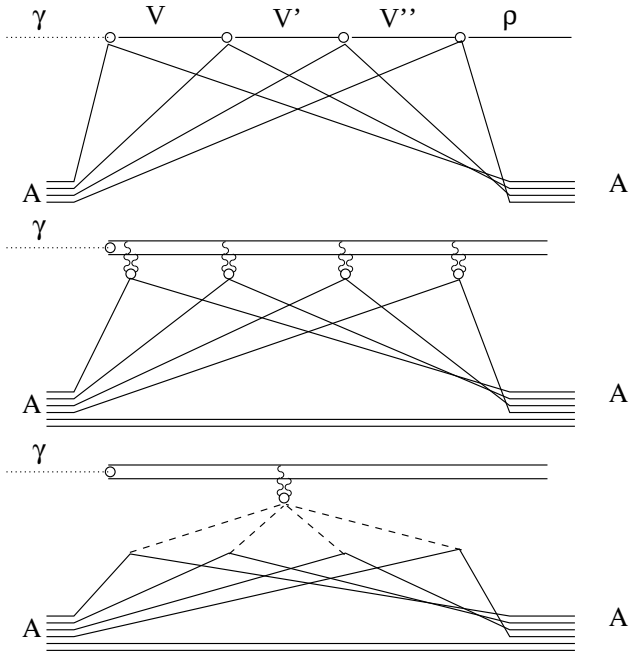


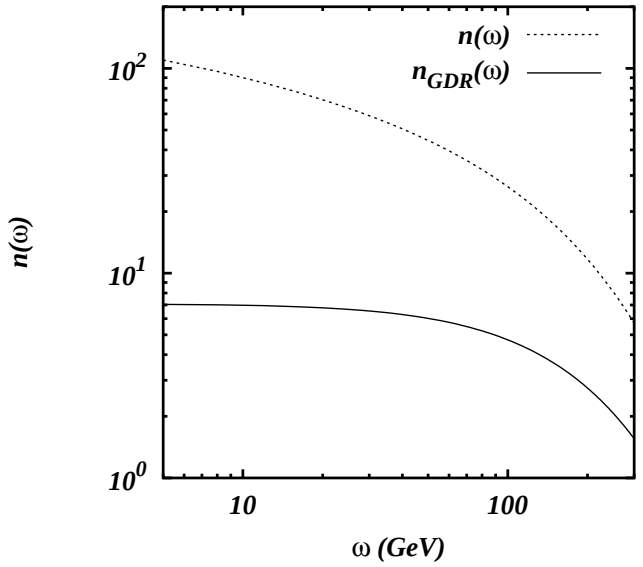


- Coherence clearly seen by enhancement at small P_t.
- ρ-meson clearly seen in invariant mass spectrum.

Measurements of Vector Mesons at LHC

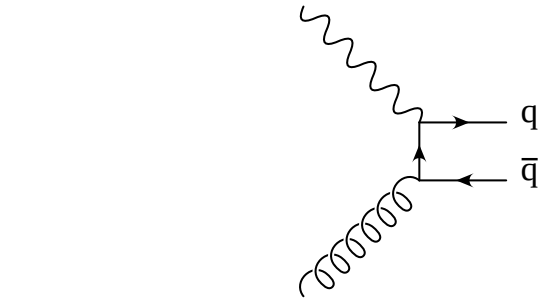
- Possible interference phenomena: Photon can be emitted from both ions.
- At LHC: Studies can be extended to heavier mesons: J/Ψ, even Υ.
  L. Frankfurt, M. Strikman, M. Zhalov, PRC67, 034901 ('03)
- ρ production well described by Glauber calculation.
- J/Ψ and Υ are sensitive to color transparency and nuclear shadowing effects.
- GDR trigger also useful at LHC.
- Can also be used to separate the photon spectra of both ions.

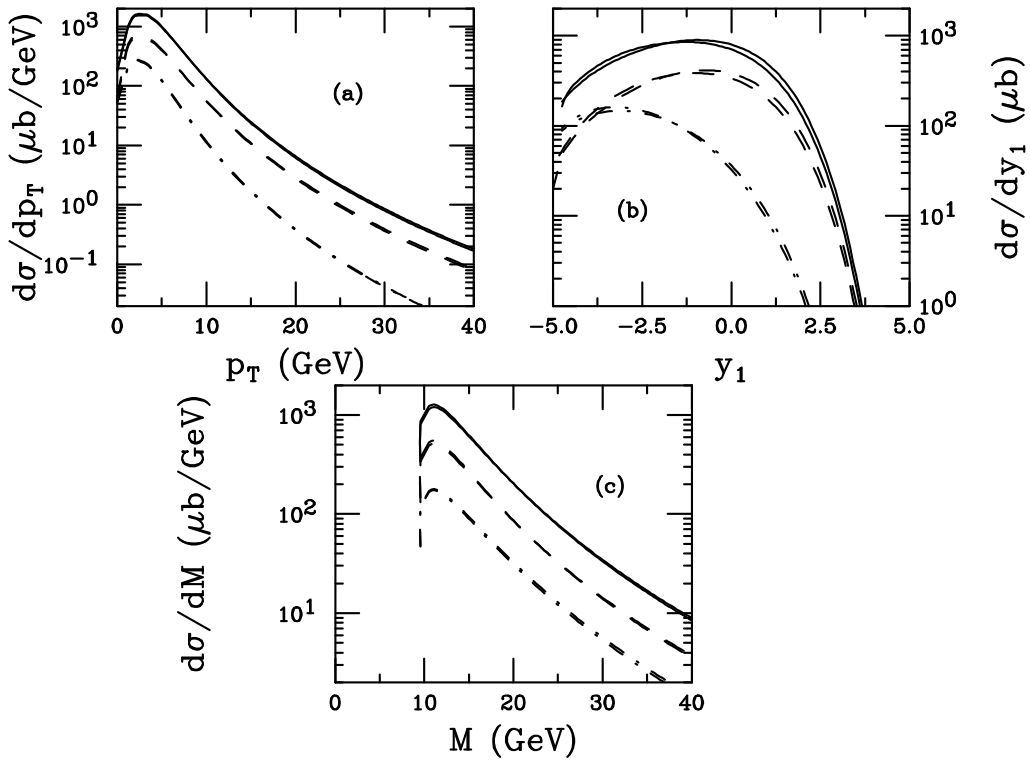




γA: Incoherent processes

- Semicoherent processes: Photon emission elastic, but incoherent interaction with the target.
- Photon-Gluon fusion one possibility to measure gluon pdfs in nuclei.
- Nuclear modifications of these pdfs are of importance also for central heavy ion collisions: Initial state effects.
- Study of medium effect in heavy quark production.
- Not only lowest order diagram, but also resolved contributions.
  R. Vogt PRC64 044901 ('02)

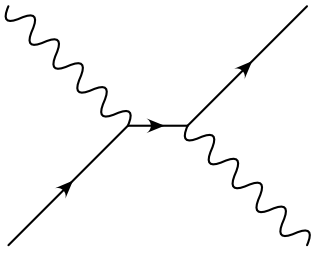


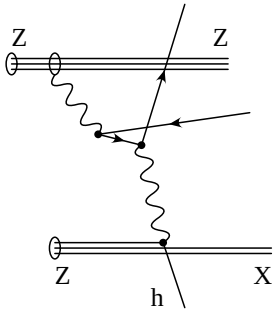


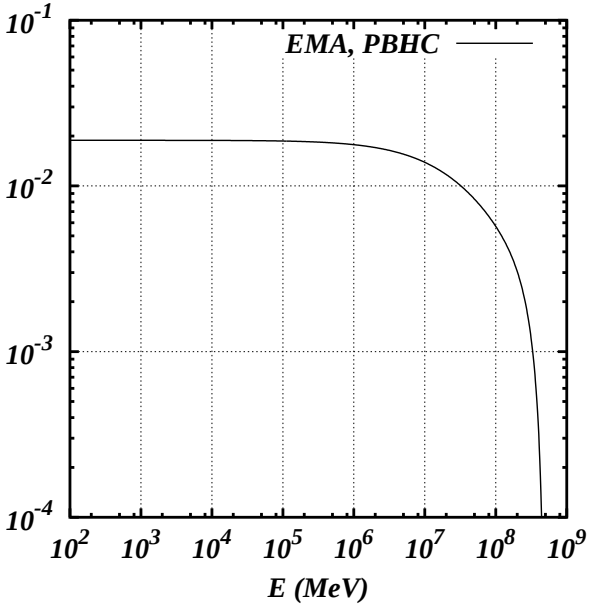
$b\bar{b}$

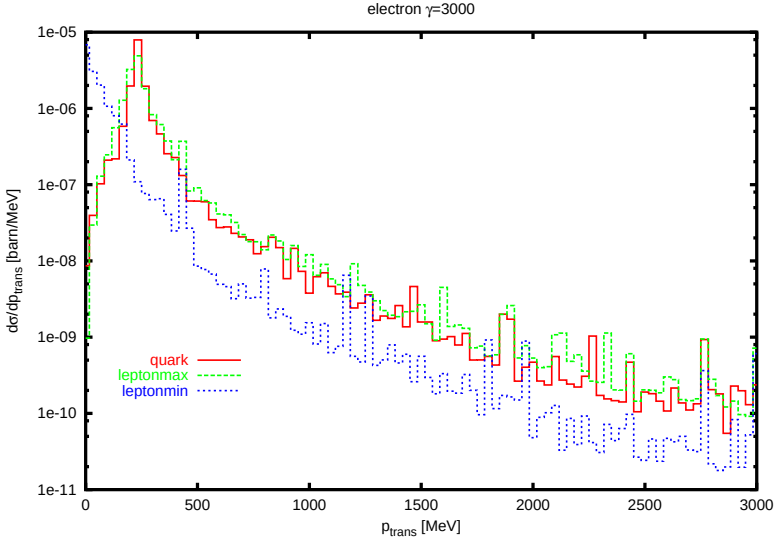
Deep inelastic processes eA collisions

- Quark pdf also acessible, e.g. through $\gamma q \rightarrow \gamma q$.
- Alternativ approach: Inelastic pair production.
- Coulomb field has as one component also equivalent electrons and muons.
- Study electron/muon deep inelastic scattering on ions.









Summary

- Ultraperipheral Collisions at LHC allow to study
  Photon-Photon and Photon-Nucleus Processes
  at high energies and large luminosities.
- Photon-Photon physics: Electroweak processes in tagged pp processes, meson spectroscopy, double vector meson production, new physics(?).
- Photo-Nucleus collisions: Coherent Vector meson production, photon-gluon fusion, gluon-, quark-pdf in nuclei.
- Practical aspects: Mutual GDR excitation, pair production as luminosity measurement. Loss processes from ECPP and electromagnetic excitation.
- Experimental studies are currently under way at ALICE and CMS.
  Part of ALICE PPR, CMS HI LOI.
- Effort to document the physics potential in a Yellow Report under way:
  http://quasar.physik.unibas.ch/UPC/
- General review articles on the subject:
  F. Krauss, M. Greiner, G. Soff, PPNP39, 503 ('97)
  G. Baur, K. Hencken, D. Trautmann, JPG24, 1657 ('98)
  G. Baur et al., Physics Report 364, 359 (2002)
  A. Ageev et al., J. Phys. G28, R117 ('02)
  "The events are there, just don't throw them away"