Ultra-peripheral collisions: a lead-in to an electron-ion collider

- Ultra-peripheral collisions
- A comparison of UPCs and EIC interactions
- Recent UPC results on structure functions
- Future opportunities with diffraction in UPCs
- Conclusions

Spencer Klein, LBNL
Ultra-peripheral collisions

- Nuclear encounters with $b > R_1 + R_2$
  - Usually AA or $p(d)A$
  - More precisely, no hadronic interactions
    - A Glauber calculation determines $P_{\text{hadronic int}}(b)$
- Interaction via photon exchange
  - Photonuclear or two-photon interaction
  - Photon flux $\sim Z^2$
    - Very high UPC rates/cross-sections
      - At the LHC $\sigma(AA->AA\rho^0) \sim \sigma(\text{hadronic})$
- Max. photon energy $= \gamma \hbar c/R$ (lab frame)
  - $\sim 3$ GeV at RHIC
    - $\sqrt{s(\gamma p\text{-in-A})_{\text{max}}} = 35$ GeV
  - $\sim 90$ GeV at the LHC
    - $\sqrt{s(\gamma p\text{-in-A})_{\text{max}}} = 950$ GeV
UPCs

Coherent or incoherent interactions
Photon is quasi-real
$Q^2$ comes from final state
- E. g. $Q^2 \sim M^2 / 2$
- $t = t_{\parallel} + t_T \sim m^2 / 2k + p_T^2$
- $t \sim p_T^2$
High photon flux
- Multiple Interactions possible; allows tagging
- Data available now

EICs

Tag outgoing electron to determine $Q^2$
- Detailed $Q^2$ scans
Reconstruct complete kinematics
Kinematics: $x$ and $Q^2$ in UPCs

- The Bjorken-$x$ value is determined (mostly) by the final state mass and rapidity.

- For vector mesons:
  - $k = M_v/2 \exp(\pm y)$
  - $x = M_v/2 \exp(\mp y)/m_p$
  - There is a 2-fold ambiguity regarding which nucleus emitted the photon.

- Since $Q^2$ is determined by the final state, different reactions probe different $Q^2$ values:
  - For vector mesons, $Q^2 = (M_v/2)^2$

- For coherent production, kinematics is ~ fully constrained.
x, $Q^2$ coverage

Not listed: open charm, bottom

$\rho^0$ photoproduction - STAR

- Au+Au @ 200 GeV
- Coherent $d\sigma/dy$ in good agreement with simple theoretical extrapolations:
  - HERA data on $\gamma p \rightarrow \rho p$
  - Glauber calculation to get nuclear cross-section
    - Accounts for (soft) multiple interactions/shadowing
  - Weizsacker-Williams photon flux
- $\sim 500,000 \rho^0$ present in STAR 2010 data
$\rho^0 p_T$ spectrum

- Coherent & incoherent production
- Diffraction dips visible
- Compared with STARlight and Sartre
  - STARlight peak positions are off, likely because it uses a classical Glauber calculation
  - The depths of the Sartre dips are too large, because it neglects the photon $p_T$
- Fourier transform gives density distribution

R. Debbe (STAR), arXiv:1310.7044
J. Seger (STAR), CERN UPC workshop, June, 2014
T. Ullrich talk, this workshop
ALICE $\rho^0$

- $\text{Pb} + \text{Pb} @ 2.76 \text{ TeV/nucleon}$
- Coherent & Incoherent production seen
- In good agreement with STARlight predictions

C. Mayer (ALICE), CERN UPC workshop, June, 2014
STAR & ALICE $\rho^{*0}$

- 2 (or 1) particles with mass $\sim 1.5$ GeV, decaying largely to $\pi^+\pi^-\pi^+\pi^-$
- STAR observes coherent $\pi^+\pi^-\pi^+\pi^-$
- mass peak at $1540 \pm 40$ MeV/c$^2$
  - ALICE is similar
- $\sigma*$branching ratio $\sim 13\%$ of the $\rho^0$
- No $2\pi$ mass peak seen
  - $\sigma(2\pi)/\sigma(4\pi) < 0.025$ @90\% CL

STAR Collaboration, PRC 81, 044901 (2010)
C. Mayer (ALICE), CERN UPC workshop, June, 2014
J/ψ photoproduction

- Seen by PHENIX, STAR, ALICE, CMS, LHC-b
- Seen in AA and pA collisions
- Probe of gluon distributions

J. Seger (STAR), CERN UPC workshop, June, 2014

M. Chiu (PHENIX), CERN UPC workshop, June, 2014
ALICE pPb -> J/ψ

- μ⁺μ⁻ in forward μ arm
  - Looked at pA and Ap to get forward and backward rapidity
- In pA with cut b>R_A + R_p, photon almost always comes from A, so hadronic reaction is γp-J/ψ p
  - Removes 2-fold ambiguity, allows direct access to photon energy
- σ(γp-J/ψ p) is consistent with power law seen at HERA, but extending to higher energies.
  - Similar results from LHC-b in pp
    - LHC-b assumed a power-law form to account for 2-fold ambiguity

J. Adam (ALICE), CERN UPC workshop, June, 2014
LHC PbPb -> PbPb J/ψ

- ALICE, LHC-b central, ALICE forward
- CMS proof of principle
- 4 components
  - Coherent J/ψ
  - Incoherent J/ψ
  - γγ → l⁺l⁻
  - Hadronic background
- ALICE Cross-section shows moderate nuclear suppression

C. Mayer (ALICE), CERN UPC workshop, June, 2014

AB-MSTW08 – no nuclear effects
Glauber – STARlight, GM, CSS
Partonic – RSZ-LTA, AB-EPS0x, AB-HKN07


ALICE PbPb $\rightarrow \psi(2S)$

- $\Psi' \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow l^+l^-$
- $\sim 14 \mu^+\mu^-$, 10 $e^+e^-$ events
- Models with strong shadowing disfavored

C. Mayer (ALICE), CERN UPC workshop, June, 2014
LHC-b forward $J/\psi$ – in pp

Events passing 2011 Low Multiplicity Dimuon Trigger

Distributions not background-subtracted. 55985 $J/\psi$ and 1565 $\psi(2s)$

P. Collins (LHC-b), CERN UPC workshop, June, 2014
LHC-b cross-sections

- Compatible with none or moderate nuclear shadowing.
LHC-b & saturation effects

$J/\psi$ and $\psi'$ data is compared with the prediction of saturation models.

Data is compatible with saturation models, but uncertainty is large (for now).
Extracting gluon pdfs

- LO and NLO calculations exist
- MNRT (NLO) fit upgraded with recent LHC-b pp -> J/ψ pp data
- Fit data to a power law
  - Because of 2-fold ambiguity
  - The fit is good
- Scale uncertainty remains
- “J/ψ data diminish the huge uncertainty on global gluons at low scale and small-x”
- At x~10^-2, fit is below previous fits
- LHC-b data will go down to x~10^-6

S. Jones, CERN UPC workshop, June, 2014
LHC - $\chi_c$

- Produced by double-Pomeron interactions
- Final state is $J/\psi +$ photon
e\textsuperscript{+}e\textsuperscript{-} pair production

- \( \gamma\gamma \rightarrow e^+e^- \)
  - Easily calculated in lowest order QED
- Cross-section is huge
  - 200,000 barns with PbPb at the LHC
- \( Z_a \approx 0.6 \), so higher order (Coulomb) corrections should be important
  - \( \sim 10\% \) reduction in total cross-section for \( \gamma \) (real) Pb \( \rightarrow \) e\textsuperscript{+}e\textsuperscript{-} Pb
- STAR data for \( 140 < M_{ee} < 265 \) MeV is consistent with lowest order QED
  - Equivalent photon approximation works well except at very low pair \( p_T \)
  - Coulomb correction variable for restricted kinematic ranges

Experimental issues with UPCs

- Low-multiplicity exclusive final states
  - Reconstruction is easy
- Heavy ion detectors have limited acceptance, with gaps in coverage
- Requiring rapidity gaps and/or $p_T$ balance eliminates most backgrounds
  - $p_T<\sim150$ MeV/c efficiently selects coherent production
- ATLAS & CMS are weak on soft particles
- Trigger capabilities limit what we can do
- Reconstruction & efficiency determination are often not easy, because we are using software chains optimized for high multiplicity events.
  - E.g. determining trigger and vertexing efficiency
- Still, there is a lot (more) that we could do
A few open topics

- Photoproduction of open charm & dijets
  - Structure function measurements
  - Photon + gluon & photon + Pomeron
- Photoproduction in polarized pp collisions
  - Probe spin structure of Pomeron
  - $pp \rightarrow pp \ J/\psi$ gives unique access to GPD $E$
- Polarized pA may have similar benefits for nuclear distributions
- Photoproduction of charged mesons (the $a_2^{\pm} (1320)$) separately probe the proton and neutron form factors in heavy nuclei
  - The $a_2^{-} (1320)$ couples to neutrons
  - The $a_2^{+} (1320)$ couples to protons
- Excited vector mesons like the $\rho^{*0}$
  - 6-prongs, KK$\pi\pi$, etc.
- Correlated production, like double $\rho^{0}$ photoproduction

E. Aschenauer
Conclusions

- Ultra-peripheral (photon-mediated) nuclear collisions can be used to explore many areas of physics, including several that overlap with the science goals of an electron-ion collider.
- Data from RHIC and the LHC has been used to explore vector meson photoproduction.
  - Gluon distributions have been extracted from UPC pp photoproduction data
  - The heavy-ion J/ψ data supports models that predict moderate nuclear shadowing.
- There is much more that can be done; many of these studies are good preparation for diffractive EIC physics.