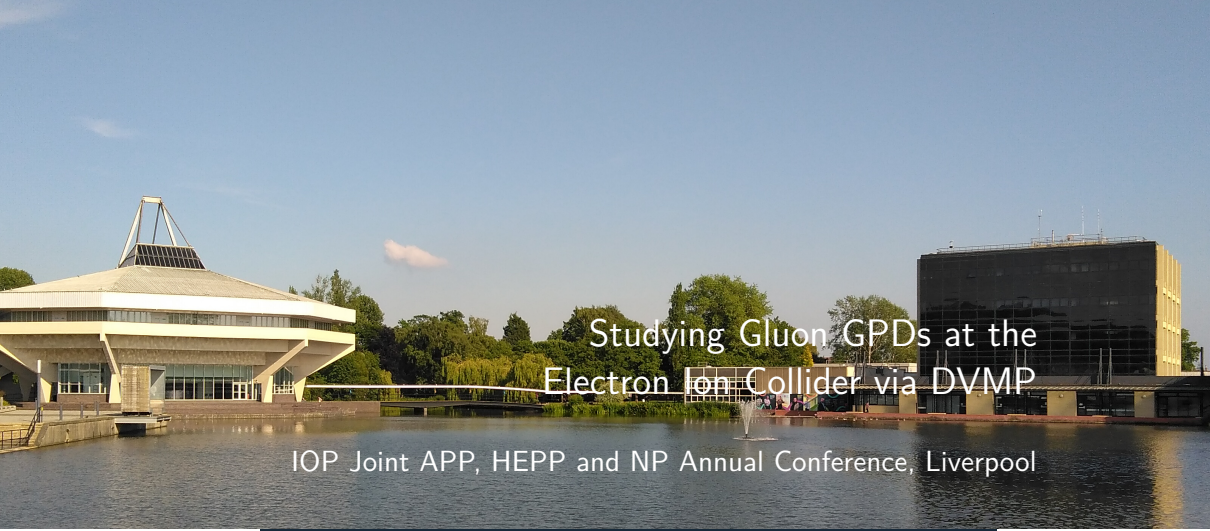


Studying Gluon GPDs at the Electron Ion Collider via DVMP

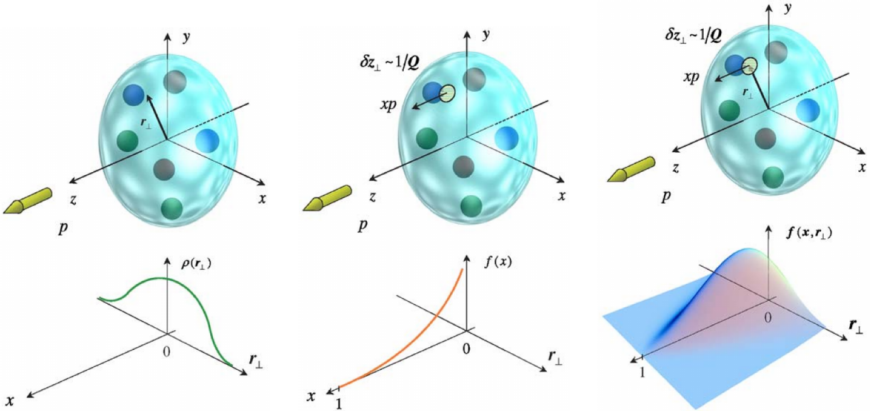
IOP Joint APP, HEPP and NP Annual Conference, Liverpool

Stuart Fegan

University of York

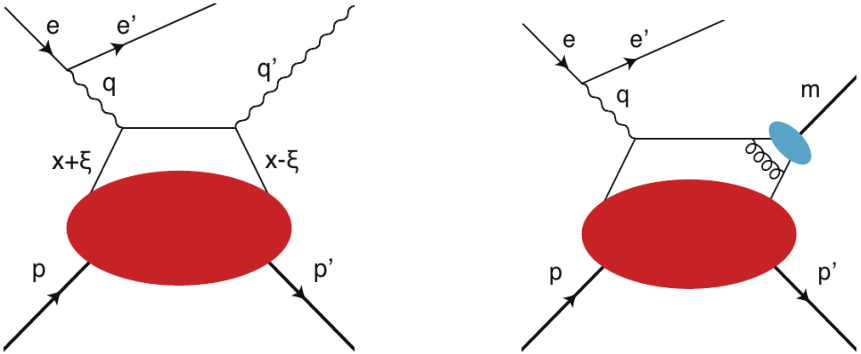
April 10th, 2024

Motivation



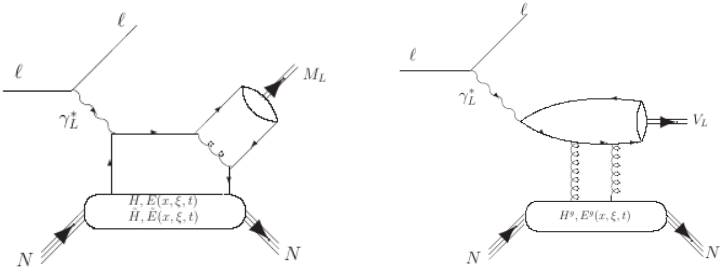
Uncovering Hadron Structure With Generalised Parton Distributions, A.V. Belitsky and A.V. Radyushkin

Accessing GPDs



- GPDs are experimentally accessed via DVCS (left) and DVMP (right)
- DVMP, Deeply Virtual Meson Production, is an analogous process to DVCS, where a meson is produced in the final state instead of a photon.

DVMP

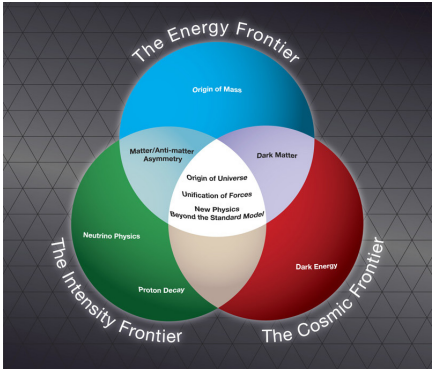


arXiv:1511.04535

- Heavy vector mesons, such as J/Ψ and Υ, can probe gluon GPDs
- This can provide information about saturation by measuring the change in the spatial gluon distribution from low to high x_B
- However, this lies beyond kinematics of current facilities, e.g. Jefferson Lab

The Electron Ion Collider

- The Electron Ion Collider, has been designated by the US Department of Energy as the next machine to address fundamental questions in QCD and hadron structure
- EIC will operate at the intensity frontier, reaching well into gluon dominated kinematics
- A range of experimental probes will explore QCD at a single facility



US DOE Office of Science

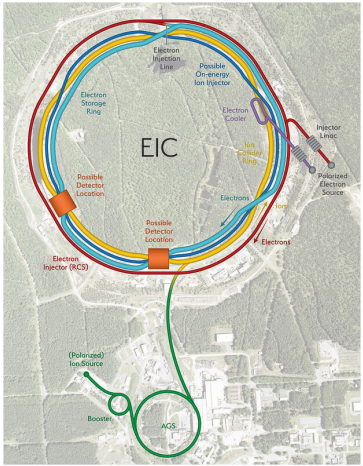
Open Questions

- Precision of the electromagnetic interaction will be combined with the determinative properties of polarised nucleon beams
- Heavy ion beams for in-depth studies of nuclear matter
- Addressing burning questions in nuclear physics
  - What is the internal arrangement of quarks and gluons in nucleons and nuclei?
  - What role do quarks and gluons play in overall nucleon properties, such as spin?
  - How does the nuclear environment affect quarks and gluons in nuclei?
- To do this, we need
  - High energy
  - High luminosity
  - The ability to exploit polarisation in beams and targets
- We need the EIC!

The EIC at Brookhaven

In early 2020, Brookhaven was announced as the host lab for the EIC

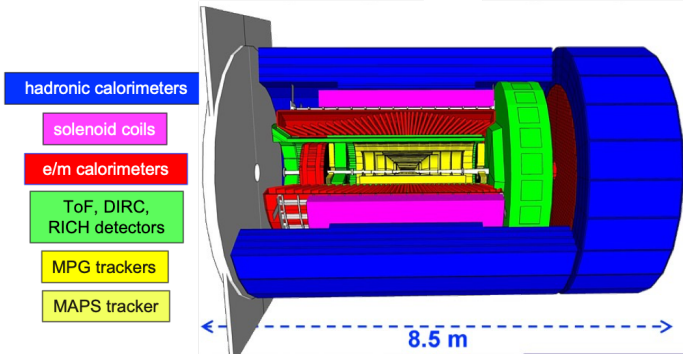
- Existing RHIC beamline will be upgraded, with an electron accelerator installed in the same tunnel
- The first detector, ePIC, will be located at one of the interaction regions (IP6)
- The ePIC design has been informed by two complimentary detector concepts; ECCE and ATHENA



ePIC - electron Proton/Ion Collider Experiment

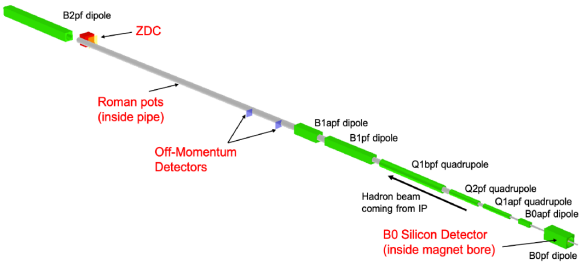
ePIC consists of three major components:

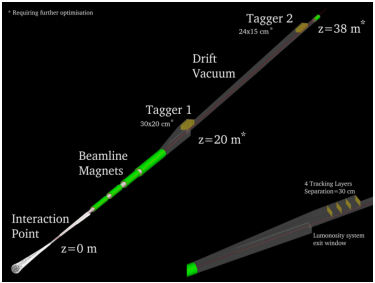
- Central Detector
- Far Forward Systems
- Far Backward Systems



- Forward detector in the hadron/nuclear beam direction, backward detectors in the electron beam direction

ePIC - electron Proton/Ion Collider Experiment

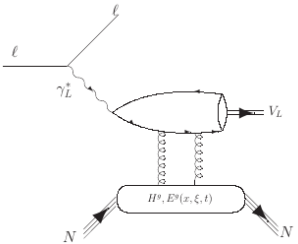




- Forward detector in the hadron/nuclear beam direction, backward detectors in the electron beam direction

DVMP with Vector Mesons

Studies for the ATHENA and ECCE concepts have provided useful benchmark publications for our continuing work in ePIC



arXiv:1511.04535

- Exclusive vector meson channel J/Ψ, studied in ECCE
- Use heavy vector mesons to access gluon GPDs
- Study focussed on J/Ψ, but evaluated potential to expand to lower (ϕ) and higher mass vector mesons ($\psi(2s)$, Υ)
- Overall goal of evaluating ECCE performance against VM event generators and show feasibility of measurement

DVMP Generators

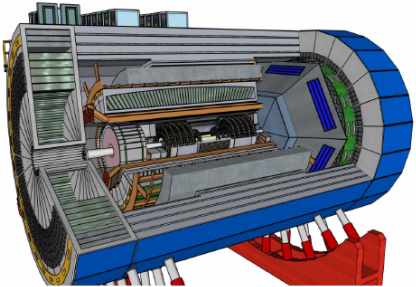
lAger - Argonne generic l/A-event generator (S. Joosten)

- The lAger generator was used to produce event samples for the ECCE studies presented
- Modular accept-reject generator, capable of simulating both fixed target and collider kinematics
- Significant recent developmental effort in support of DVMP studies, with a focus on J/Ψ and Υ

The ECCE Study

See NIM A 1052, 168238 (2023)

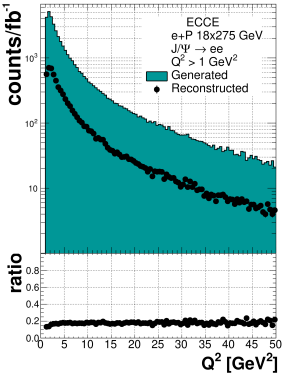
- Plots produced by N. Santiesteban (UNH)

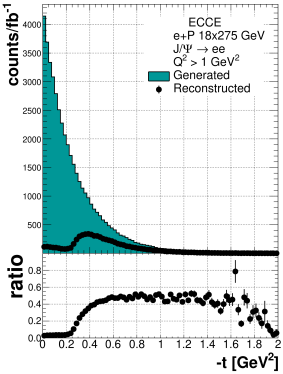


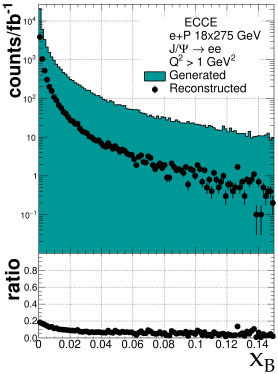
- 10 fb^{-1} of $J/\Psi \rightarrow e^+e^-$ events from eP collisions, generated in lAger at 18×275 GeV
- Smeared and passed through ECCE detector geometry
- Evaluating feasibility of reconstructing J/Ψ DVMP

Kinematics and Resolutions

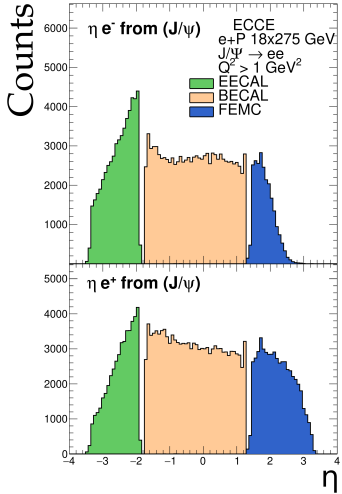
$J/\Psi \rightarrow e^+e^-$ event samples on eP collisions, 10 fb^{-1} at 18×275 GeV



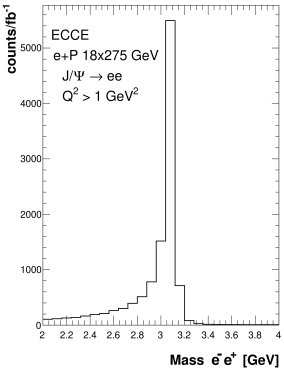




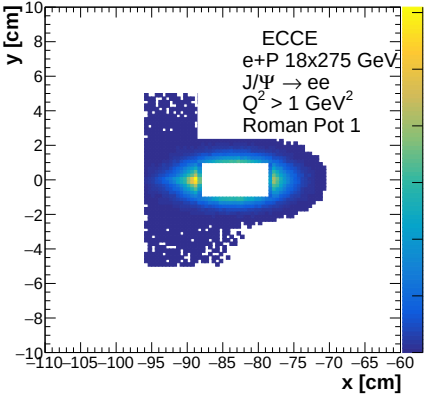
J/Ψ Detection

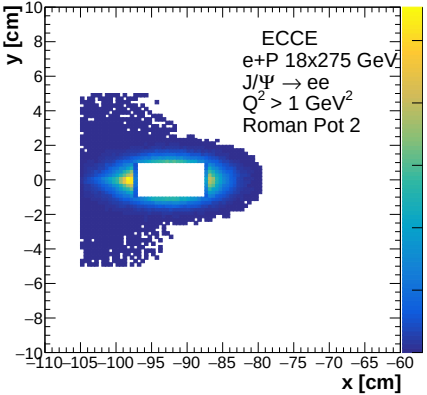


- J/Psi decay products (Top: electron, Bottom: positron)



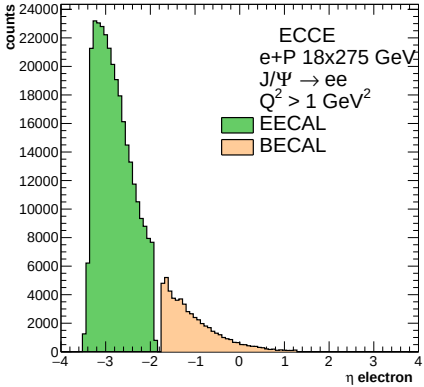
Scattered Proton Detection





Scattered proton detection in Roman Pots. B0 outside acceptance of kinematics studied

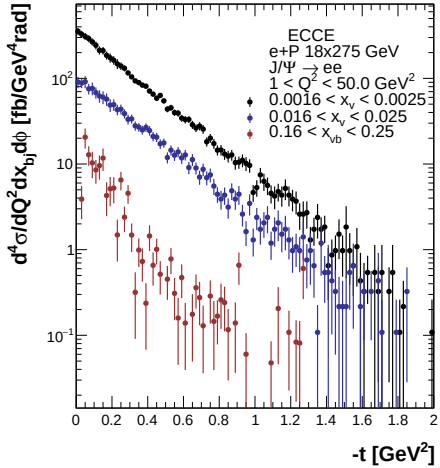
Scattered Electron Detection



- Scattered electron distribution
- Some J/Ψ decay electrons will be seen at negative η
- MC truth was used for this study
- Keenly aware of the need to be able to separate these experimentally

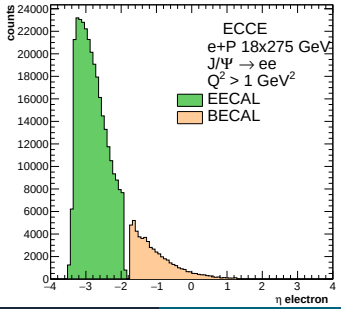
J/Ψ Cross Sections

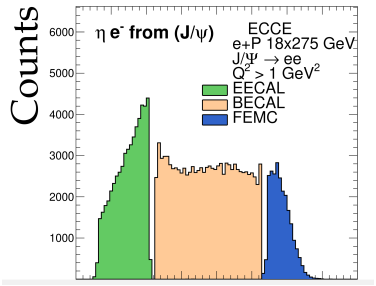
- J/Ψ Differential cross section
- Physics interest will come from the evolution over $-t$
- Q^2 dependence will be useful for multi-dimensional binning



Next Steps for J/Ψ

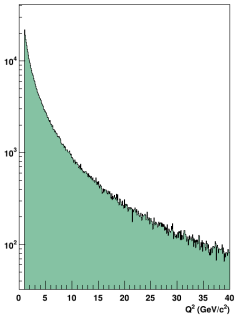
- Studies shown from the ECCE detector model
- The ePIC design uses this as a starting point, but generated events have been processed through the latest geometry
- Investigations motivated by lessons learned so far (e.g. can we adequately separate scattered electron from J/Ψ decay electron in the real world?)

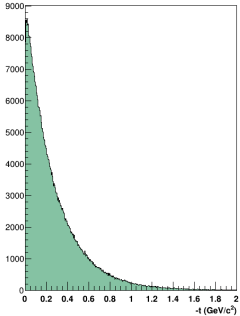


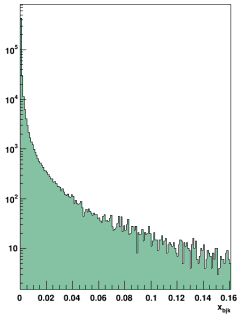


Next Steps for J/Ψ

- Parallel study of $J/\Psi \to \mu^+\mu^-$ will allow assessment of muon detection in ePIC
- Also avoids separating the scattered electron from a J/Ψ decay electron
- Equivalent sample for this channel generated in lAger to match the $10 fb^{-1}$ of $J/\Psi \to e^+e^-$ (18 on 275 GeV eP)

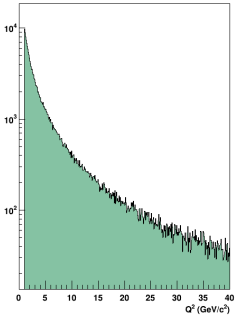


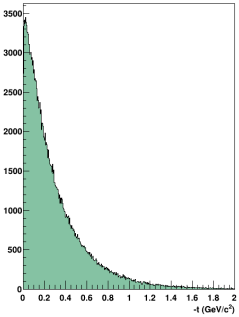


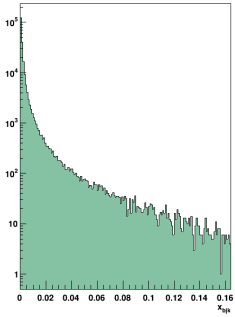


Next Steps for J/Ψ

- $10 fb^{-1}$ of $J/\Psi \rightarrow \mu^+\mu^-$ at 10 on 100 GeV eP collisions





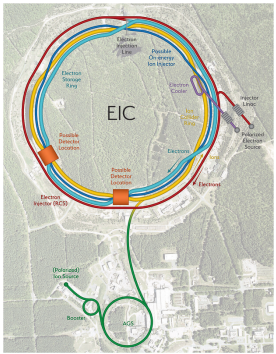


Next Steps for Other Vector Mesons

- Could also generate and repeat studies for other Vector Mesons of interest
- A limited event sample was produced for Υ, but was dropped from ECCE study
- ϕ is also of potential interest, although no suitable generator currently identified for a DVMP study in ePIC
- Heavier charmonium states, e.g. $\psi(2S)$?

Summary and Outlook

The EIC is coming...



- DVMP with Vector Mesons is feasible in an EIC detector design
- Moving from our preliminary ECCE study to one grounded in ePIC
- Current focus on complimentary J/Ψ leptonic decay channels
- New collaborators have joined this effort and plan to pick up other channels

Summary and Outlook

- This work is part of the Exclusive, Diffractive and Tagging working group, one of many physics working groups in the ePIC collaboration
- The ECCE simulation studies are from an earlier iteration of this group, published as NIM A1052, 168238 (2023)
- Thanks to all my collaborators, particularly Nathaly Santiesteban (UNH), whose analysis was at the heart of the J/Ψ studies in ECCE
- Additional thanks to the relevant software groups who provide the tools to realise this work, process events through the evolving detector concepts, and put up with a barrage of "How do I...?" questions

UK Investment

Major research and innovation infrastructure investment announced

27 March 2024

UK-US collaboration

Another project will receive £58.8 million from UKRI in a partnership with the US Department of Energy (DOE), to develop new detector and accelerator infrastructure to address fundamental questions on the nature of matter.

The technology will be built by:

- two STFC national laboratories, Daresbury Laboratory in Cheshire and the Rutherford Appleton Laboratory in Oxfordshire
- the universities of Birmingham, Brunel, Glasgow, Lancaster, Liverpool, Oxford and York
- the Cockcroft Institute for Accelerator Science and Technology in Cheshire

It will be installed at the Electron-Ion Collider (EIC), a major new particle accelerator facility at the Brookhaven National Laboratory in New York in the US.