EICUG Early Career Workshop

Probing the exclusive vector meson production at the EIC

24 July 2023

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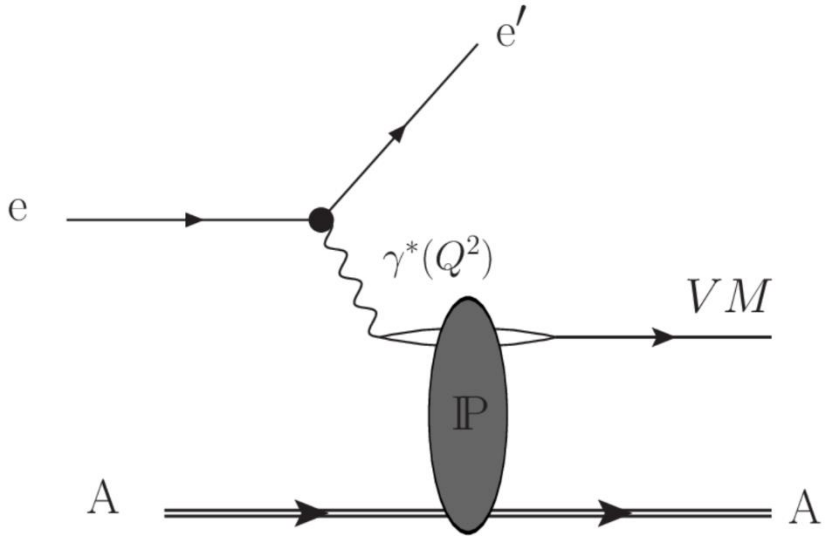
Introduction

Goals

- Probing the low-X structure of the nucleus
- Probing spatial parton structure of nuclei



Methodology

- Measuring coherent vector meson (VM) production
- Differential cross-section $(d\sigma/dt)$ as a function of momentum transfer → spatial distributions of gluons

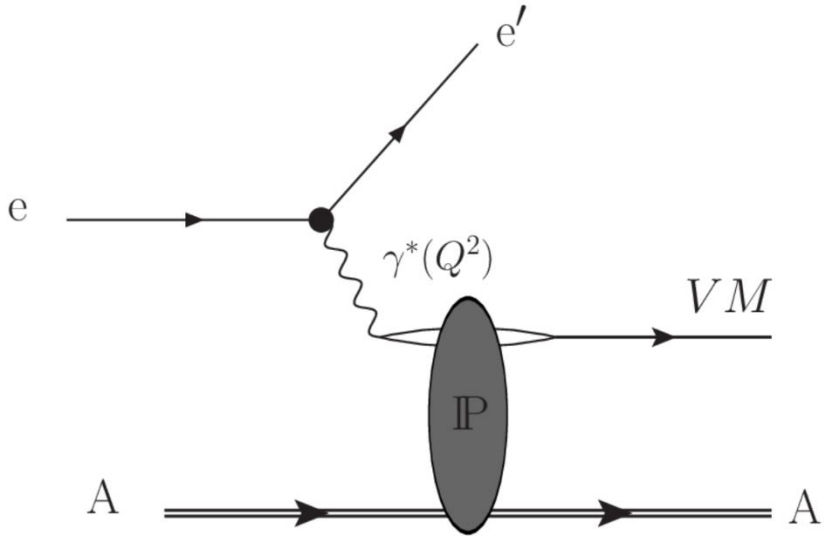
Event Kinematics

Reconstruction of parameters of insterest:

e – incoming electron (**determined by beam parameters**)

e’ – outgoing electron (**measured**)

VM – vector meson (**measured**)



- Energy scale $Q2 = -(e - e').M2()$
- Momentum transfer $-t = (VM - (e - e')).M2()$
- Meson transverse momentum $VM\_PT = VM.Pt()$

Coherent and incoherent production

Event Kinematics

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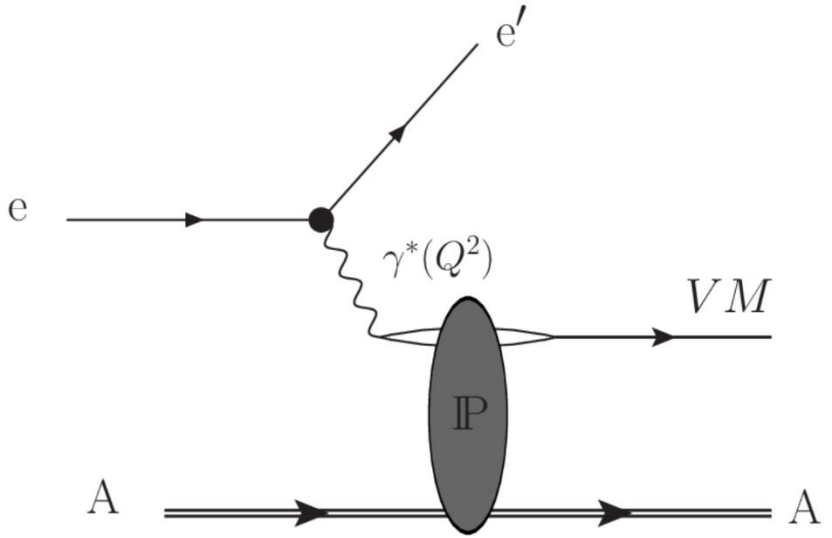
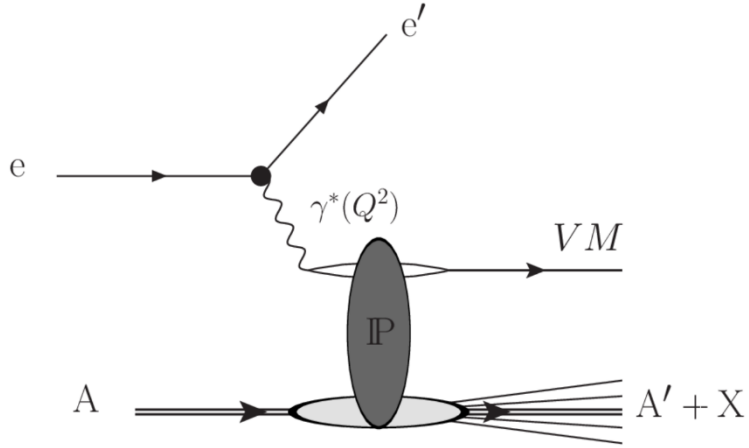
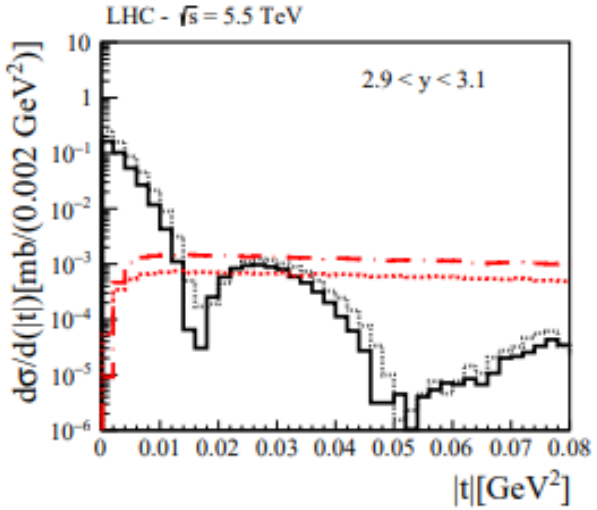


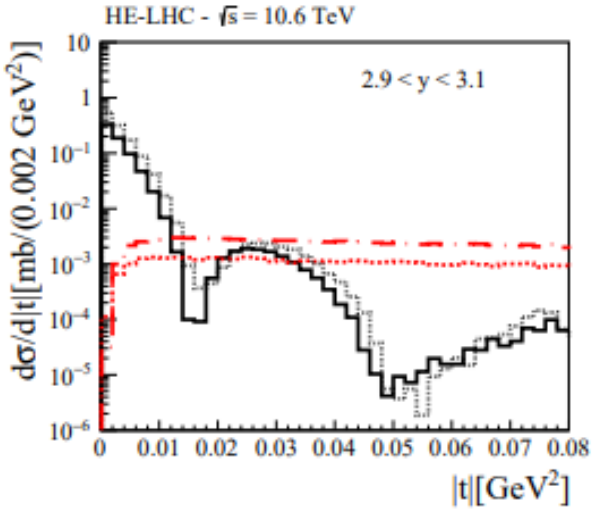


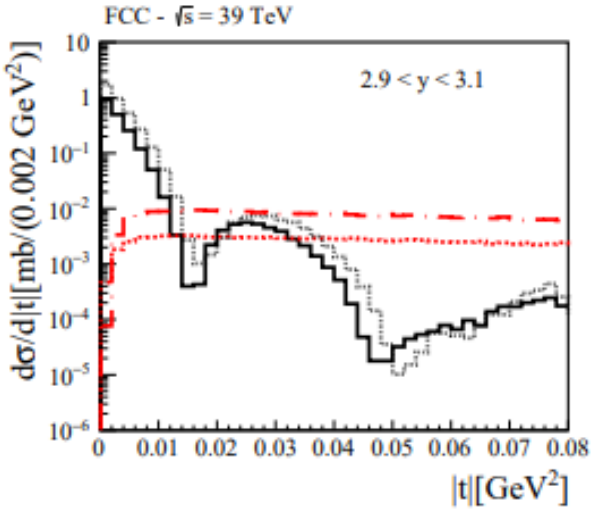
- The main background is e + A → e’ + A’ + VM + X, with A≠A’
- For e + A → e’ + A + VM + X see talk by Eden M. later today

Selected (past) studies

- Coherent and incoherent J/ψ photoproduction in PbPb collisions at the LHC, HE-LHC and FCC (2007.13625):



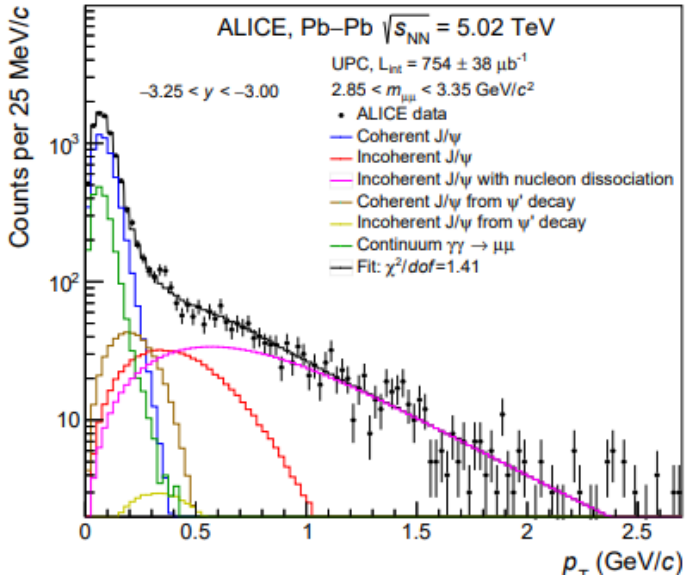


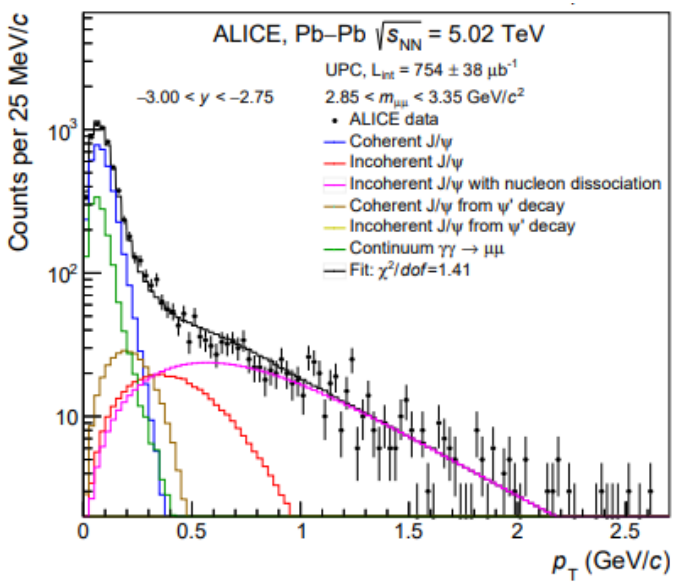


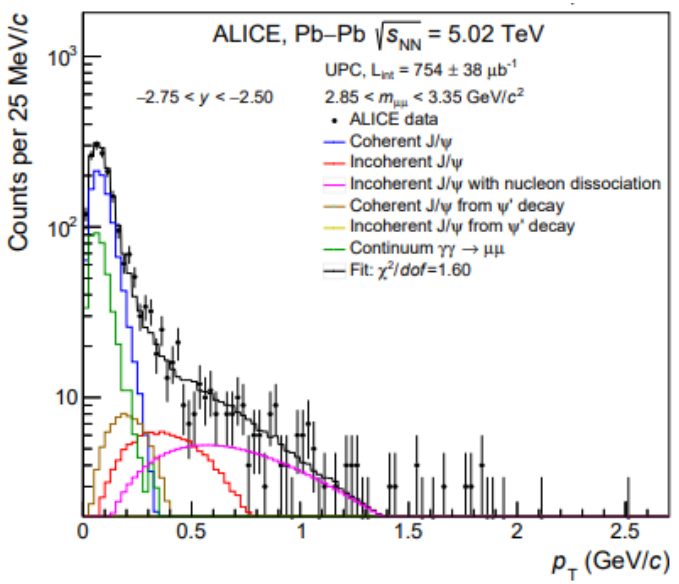
- **Expected large rates**
- **Tagging of coherent events is a subject of ongoing studies**

Selected (past) studies

- Coherent J/ψ photoproduction at forward rapidity in PbPb UPC (1904.06272)





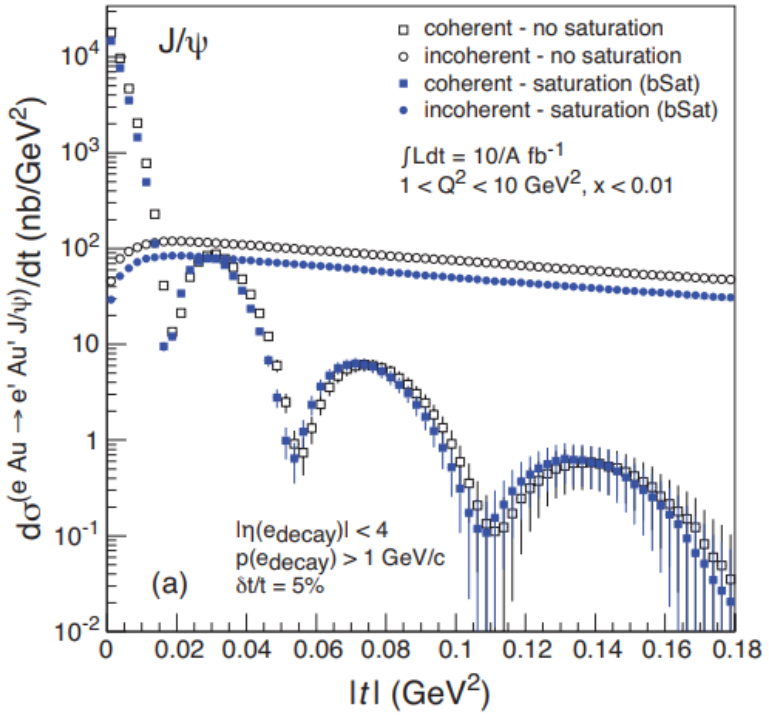


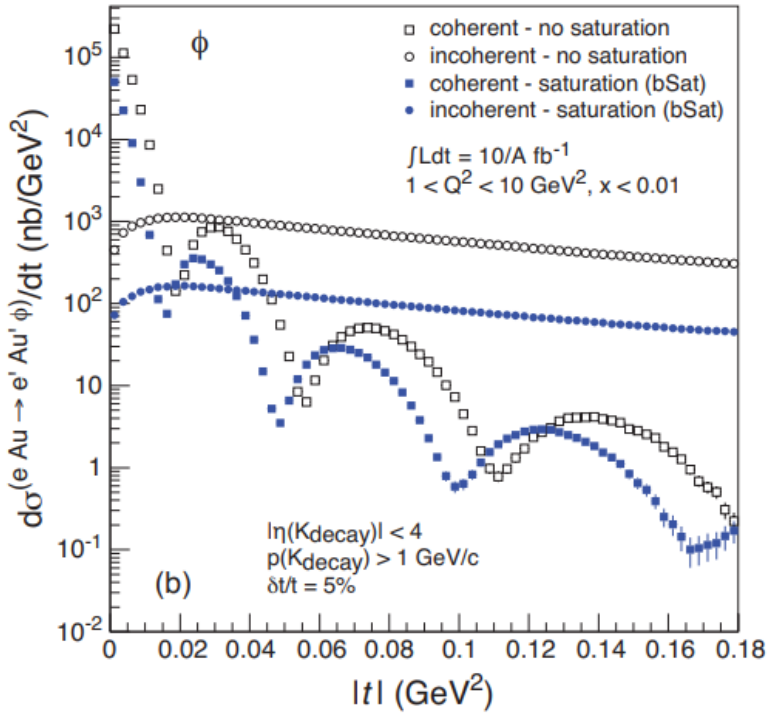
- **Expected large rates**
- **Observing the dips in coherent events is a subject of ongoing studies**

Selected (past) studies

- Exclusive diffractive processes in electron-ion collisions (1211.3048):

Target $Q^2>1$ GeV^2 – backward electron reconstruction





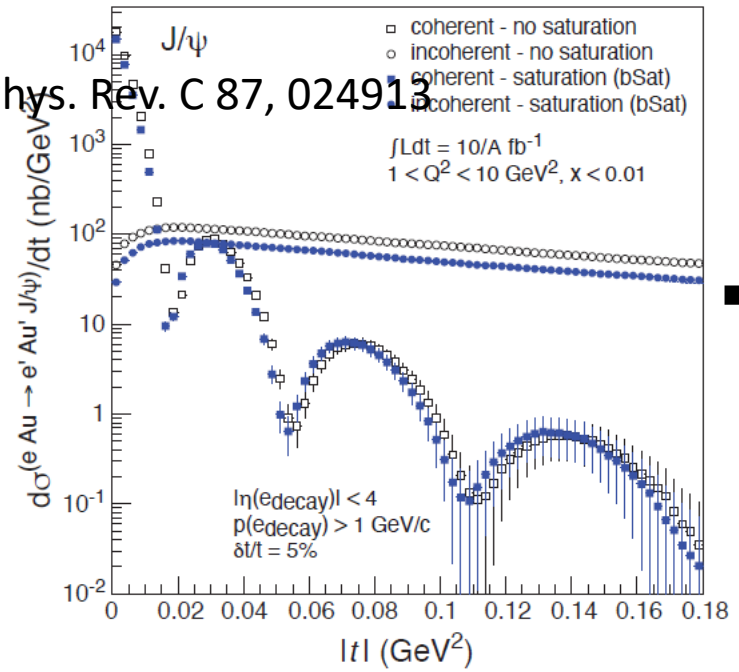
J/ψ less sensitive to saturation

Introduction

Selected (past) studies

- Investigation of the background in coherent J/ψ production at the EIC (2108.01694):

Phys. Rev. C 87, 024913



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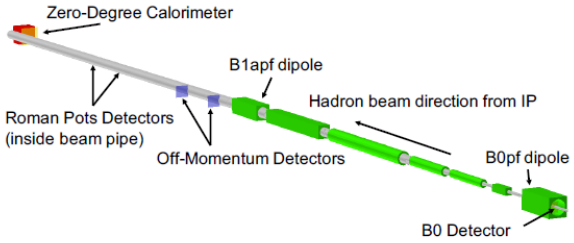

- Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV/c) ;
- Veto.2: Veto.1 and no neutron in ZDC;
- Veto.3: Veto.2 and no proton in RP;
- Veto.4: Veto.3 and no proton in OMDs;
- Veto.5: Veto.4 and no proton in B0;
- Veto.6: Veto.5 and no photon in B0;
- Veto.7: Veto.6 and no photon with $E > 50$ MeV in ZDC.

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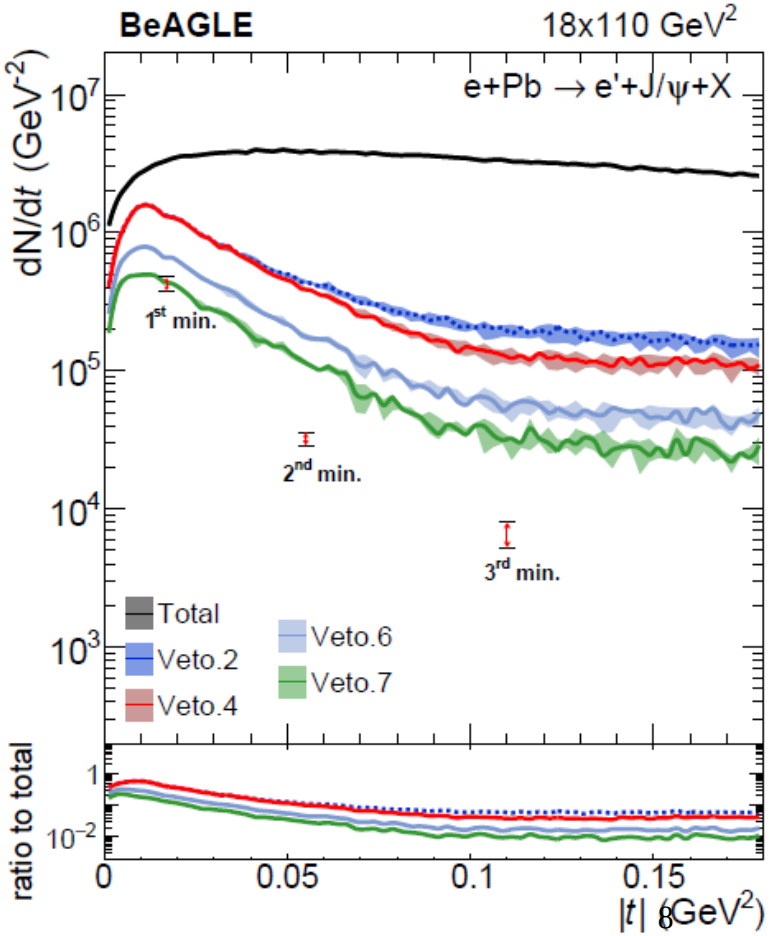


Strong background rejection with FFD at the EIC

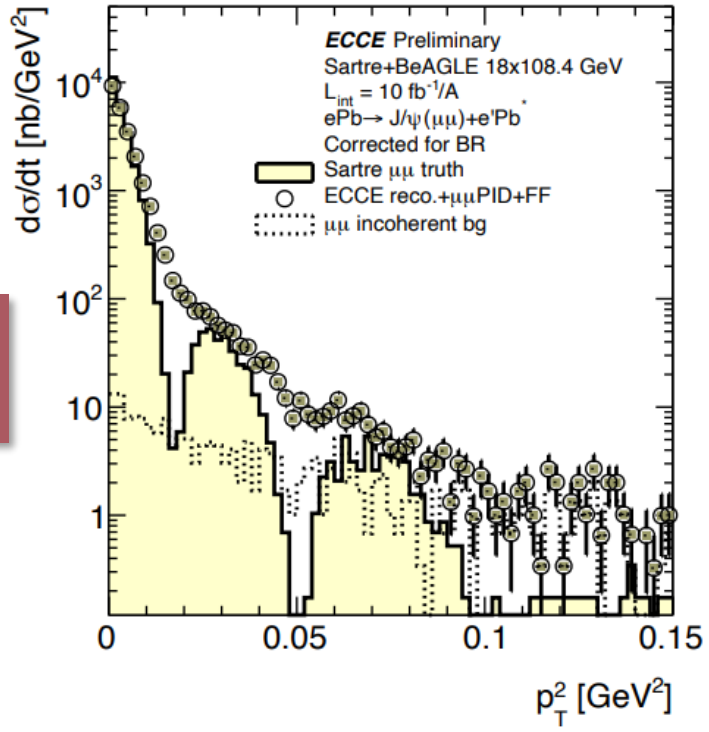
Selected (past) studies

Peter Steinberg talk @ EICUG Theory WG meeting

- Challenges in measurements of exclusive J/ψ at the EIC

PT used as a proxy for t

Main challenge is reconstructing the dips



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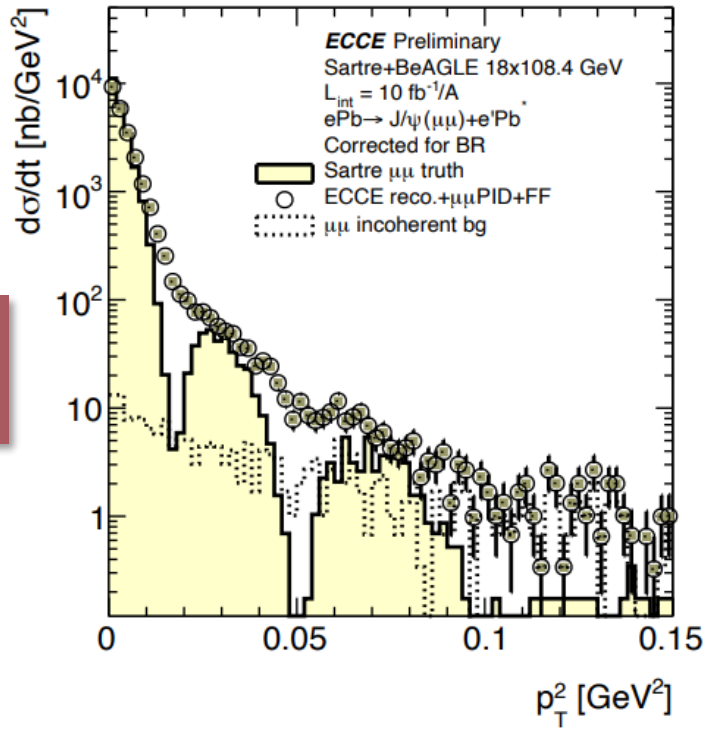
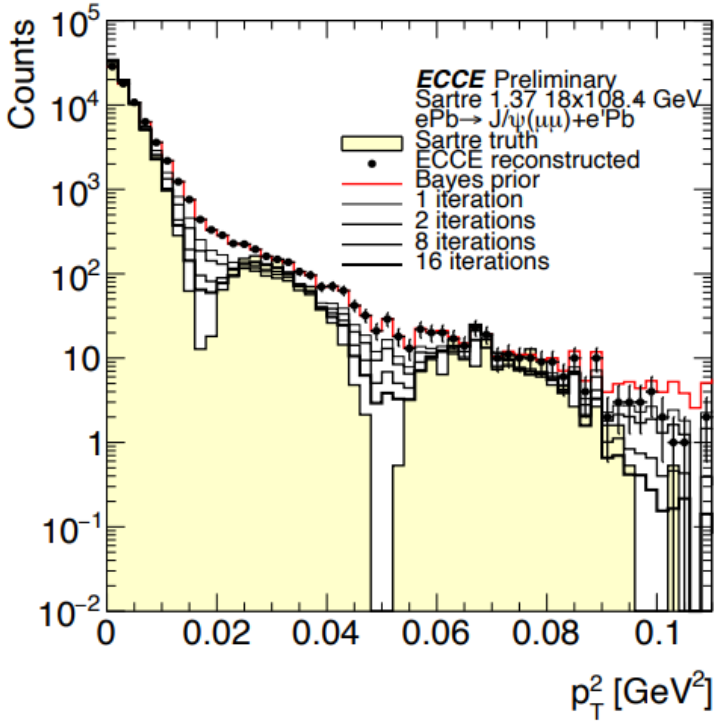


Unfolding



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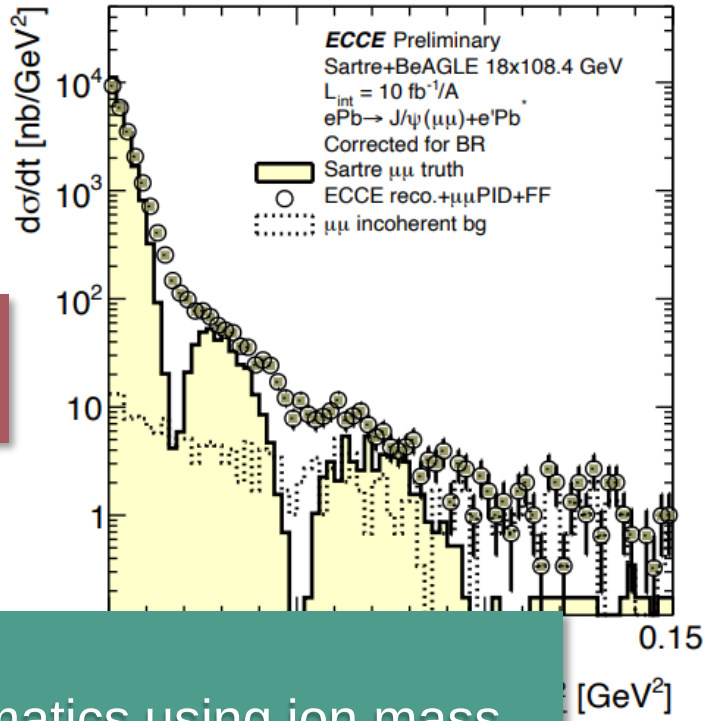

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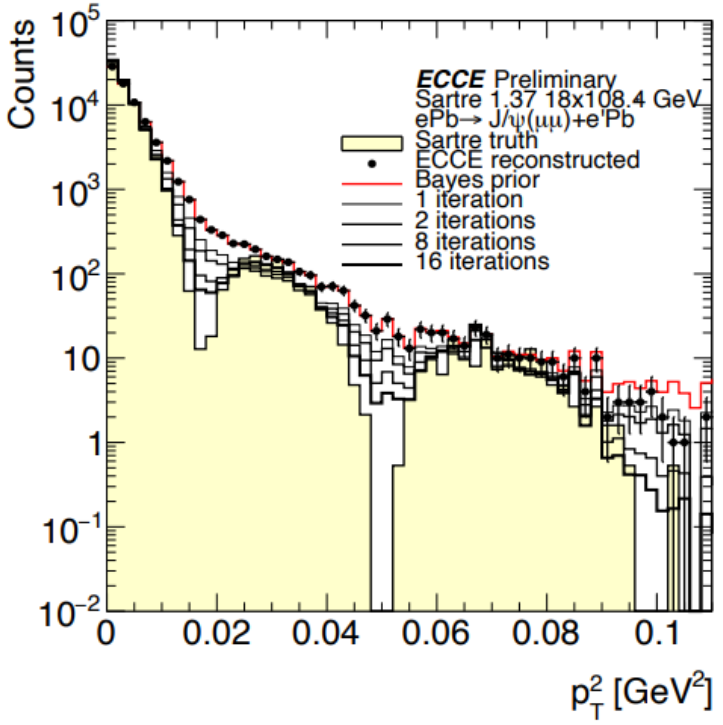


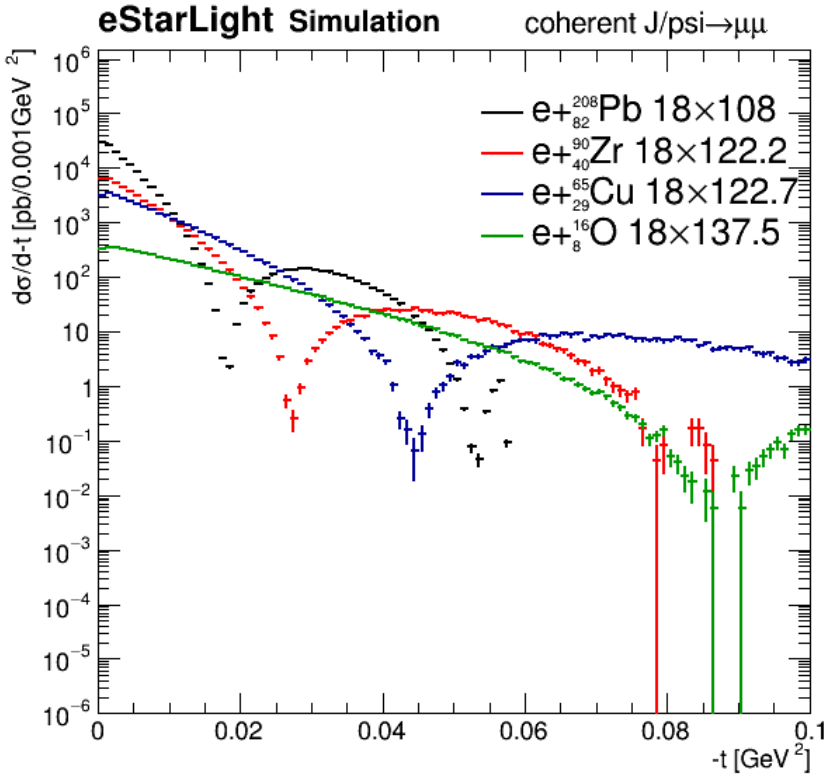
Other options:
- Constrain electron kinematics using ion mass
- Low Q2 region (next slides)

Simulation setup

Event generation

- Simulation with eStarlight[1]: ***e + A →VM + e' + A'***
- Ions: ^{16}O, ^{63}Cu, ^{90}Zr and ^{208}Pb
- Vector mesons: rho, omega, J/psi, Phi, Upsilon
- Consider different energies: 5x100 GeV^2 and 18x275 GeV^2

  (energies of the accelerated electron and proton beam respectively)



Event Reconstruction

- Using ePIC@EIC detector simulation and event reconstruction

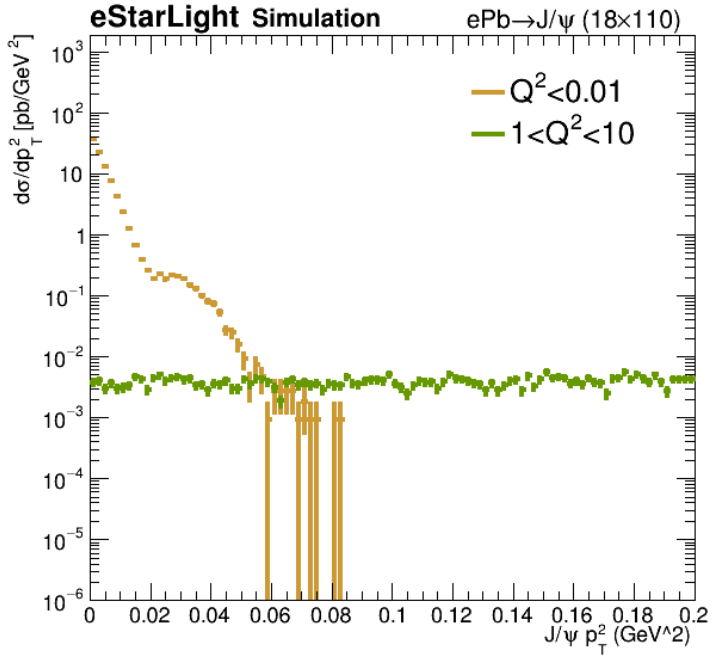
Highlights from the study will be shown in the following slides

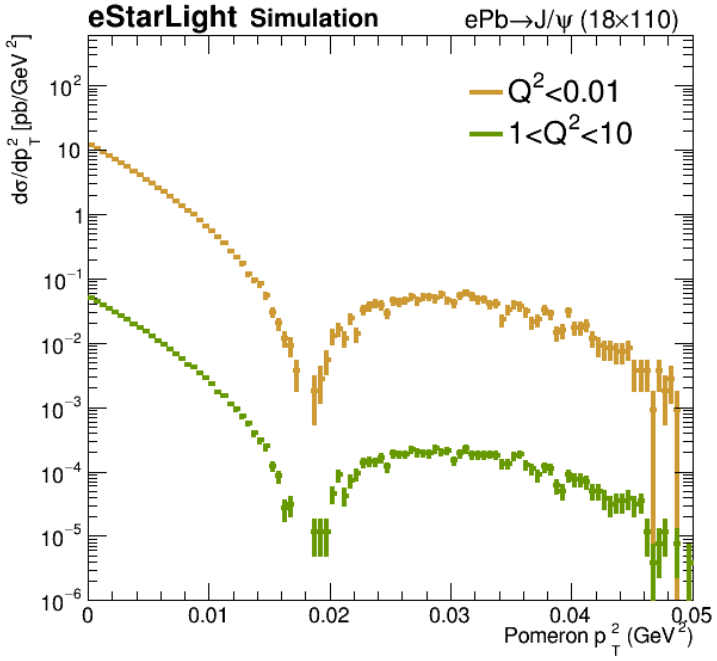
[1] https://github.com/eic/estarlight

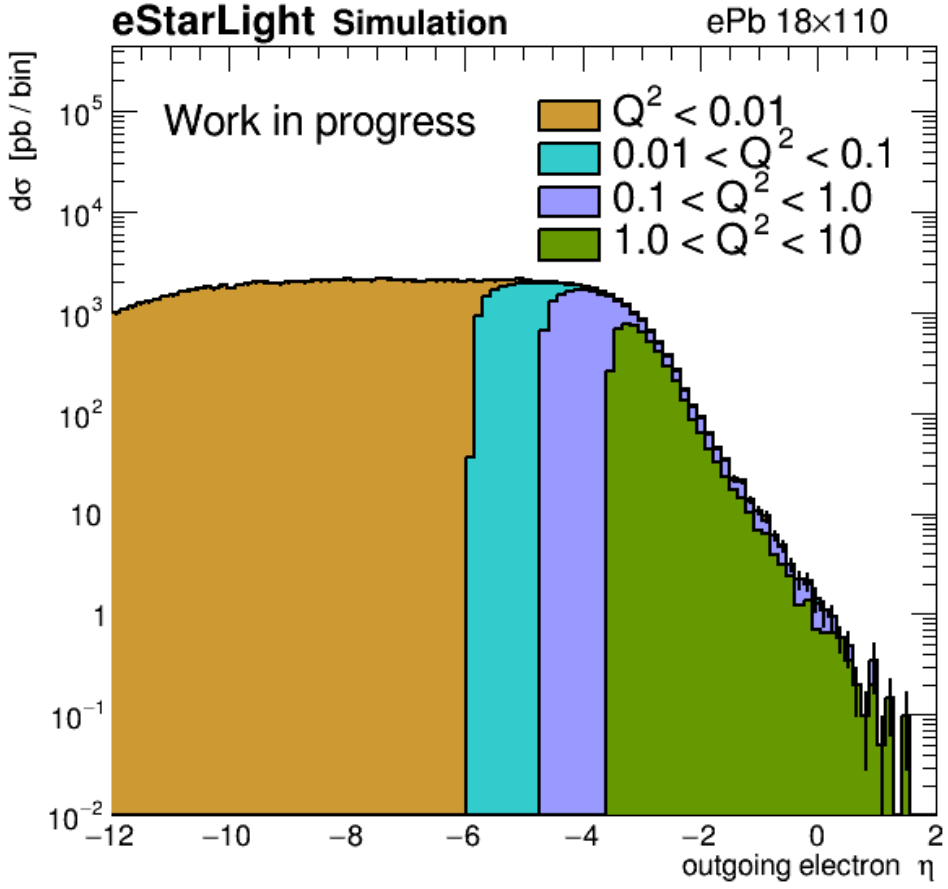
Momentum transfer and Q2

Q2 dependence

- Q^2 is correlated with outgoing electron rapidity.
- Only for low Q, VM pT is correlated with the *t*
- Can we veto backward electron to reach a low Q?

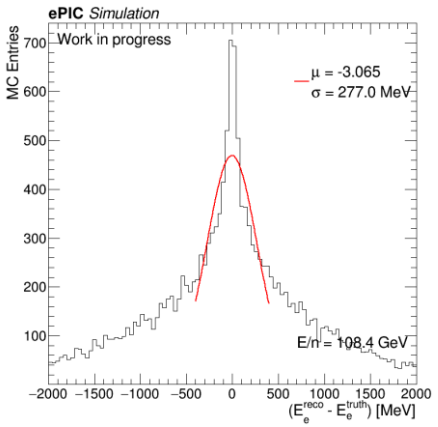




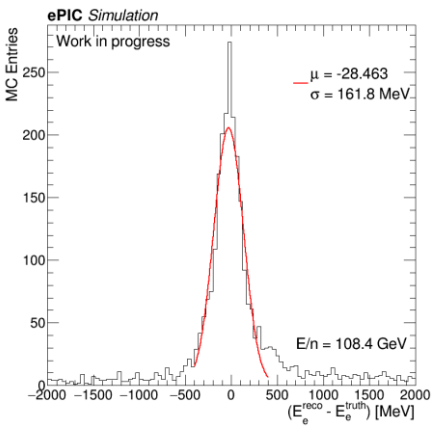


Event categorization

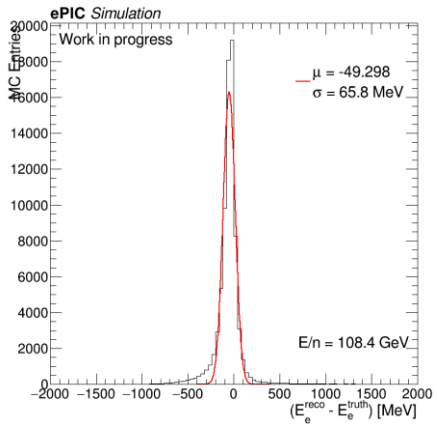
- Depends on the electron reconstructed eta
  - Central detector: ~10%
  - Low-Q2 taggers: ~40%
- Energy resolution – larger in the central region



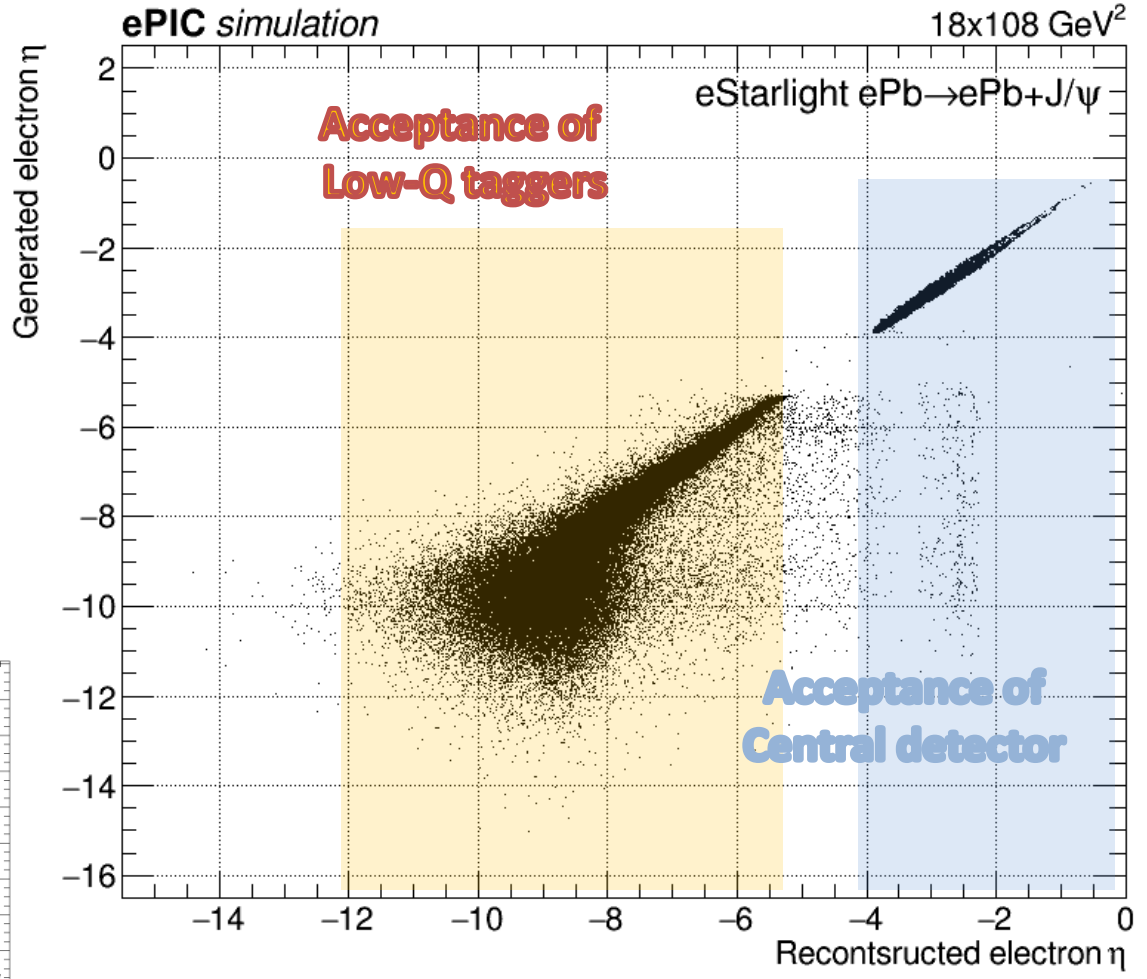
$-4 < \eta < 0$



$-6 < \eta < -4$



$\eta < -6$



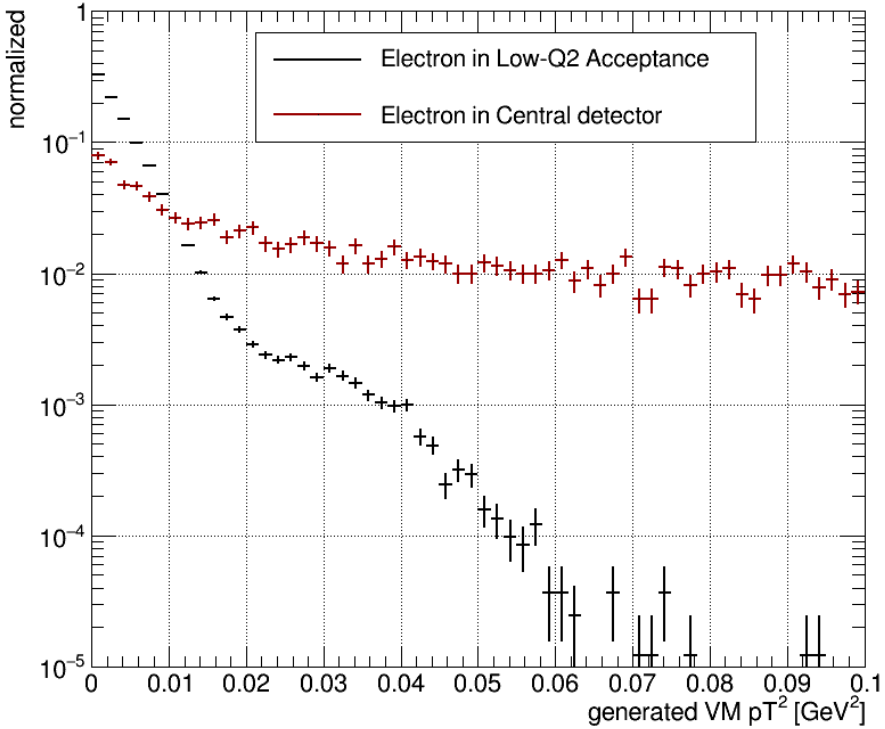
Adding low-Q2 category increases signal acceptance by x5

Analysis (work in progress)

Run EICRecon with `lowq2:electron_energy = 18*dd4hep::GeV`

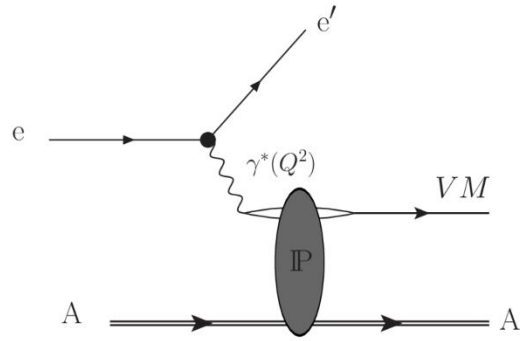
Event reconstruction

- Reconstruction of Momentum transfer:
  - Using VM PT only as a proxy to t – already shows the presence of the first minima



Work in progress

- Improving t reconstruction
  - ➢ Adding the electron reconstruction information
  - ➢ Ion mass constrain



Summary and discussion

Summary

- Coherent vector meson production is a promising channel for studying gluon structure functions of nuclei and is sensitive to gluon saturation effects
- Measurement benefits from the extensive Far-Forward detectors array to suppress the incoherent backgrounds
- The Far-Backward detectors open the door to tag coherent processes at very low Q
  - ✓ **Better t reconstruction**
  - ✓ **Higher cross-section**

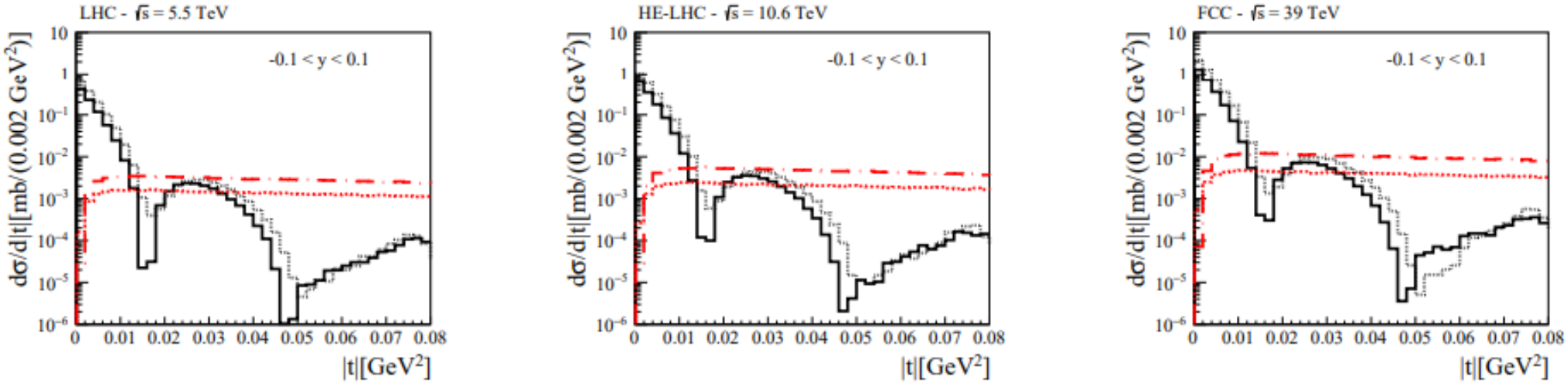
Work in progress

- The study is ongoing, the next step is background estimation for very low-Q2

Backup

Selected (past) studies

- Coherent and incoherent J/ψ photoproduction in PbPb collisions at the LHC, HE-LHC and FCC (2007.13625):



- **Expected large rates**
- **Observing the dips in coherent events is a subject of ongoing studies**

eStarlight setup

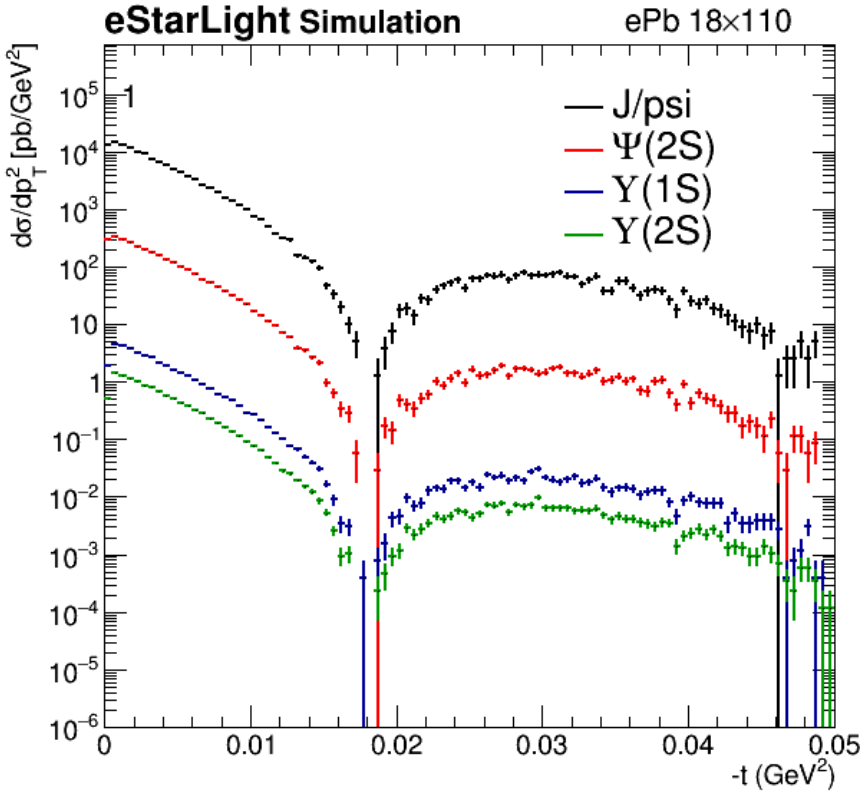
```
TARGET_BEAM_Z = 82   #Z of target
TARGET_BEAM_A = 208   #A of target
ELECTRON_BEAM_GAMMA = 35295 #18 GeV electrons from eRHIC
TARGET_BEAM_GAMMA = 115.8 #275*82/208 GeV/n Pb from eRHIC
W_MAX = -1   #Max value of w from HERA
W_MIN = -1    #Min value of w from HERA
W_N_BINS = 50    #Bins i w
EGA_N_BINS = 400
CUT_PT = 0 #Cut in pT? 0 = (no, 1 = yes)
PROD_MODE = 12     # coherent vector meson (narrow)
PROD_PID = 443013  # J/psi production
RND_SEED = 1 #Random number seed, change when producing multiple output files
BREAKUP_MODE = 5     #Controls the nuclear breakup; a 5 here makes no requirement on the breakup of the ions
PYTHIA_FULL_EVENTRECORD = 1 # Write full pythia information to output (vertex, parents, daughter etc).
MIN_GAMMA_Q2 = Q2MIN  #change this parameter
MAX_GAMMA_Q2 = Q2MAX #change this parameter
QUANTUM_GLAUBER = 1 # Do a quantum Glauber calculation instead of a classical one
SELECT_IMPULSE_VM = 0   # Impulse VM parameter
OUTPUT_FORMAT = 0  # 0 – Standard,  1 - Pythia,  2 - HEPMC
```

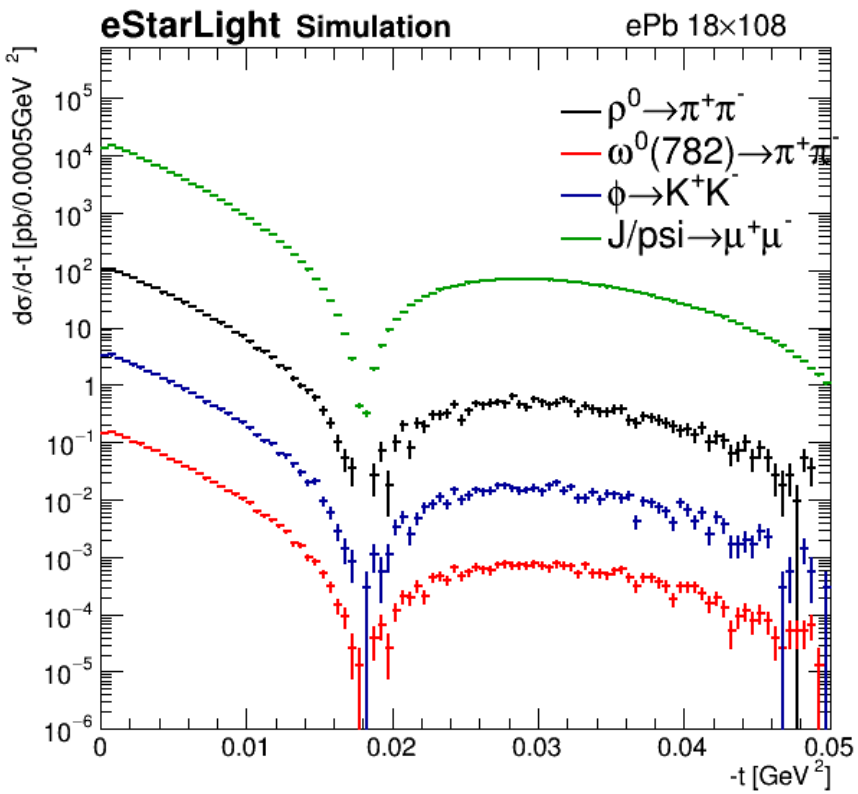
Modified parameters

Cross-sections

Different mesons

- All vector meson production processes show the same t spectra, J/psi has the highest cross-section.

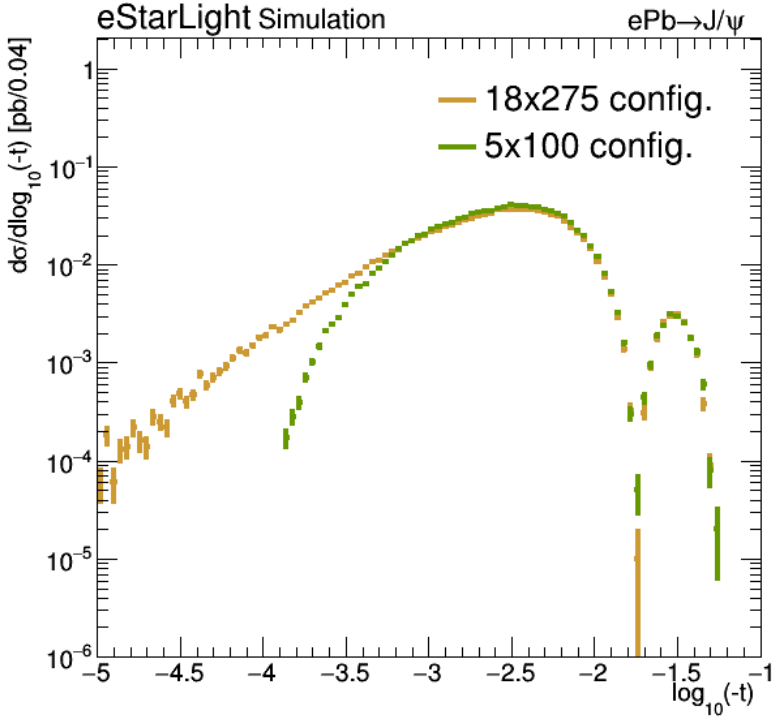


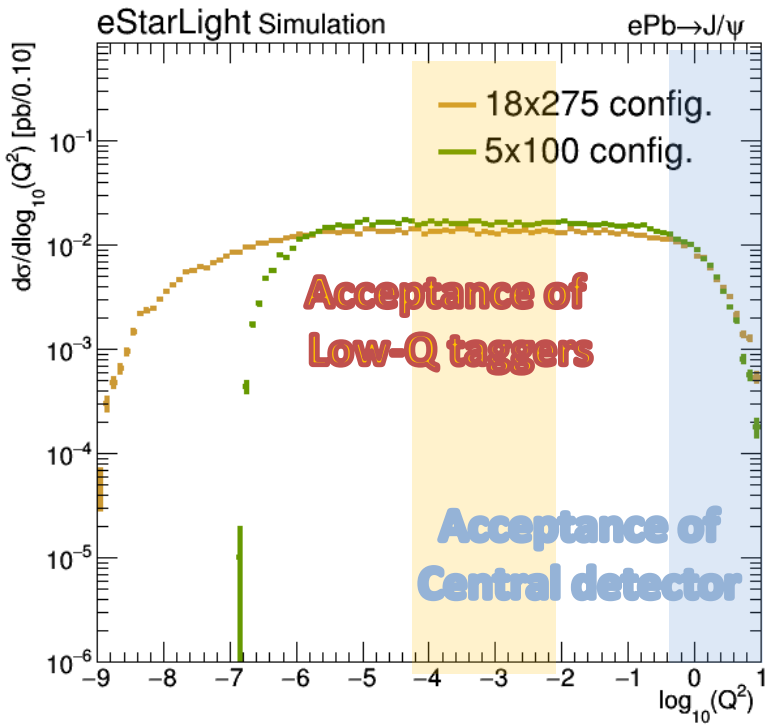


Decay	BR
$\rho^0 \to \pi^+\pi^-$	99.9%
$\omega^0 \to \pi^+\pi^-$	1.53%
$\phi \to K^+K^-$	50%
$J/\psi \to \mu^+\mu^-$	6%

Different beam energies

- Similar cross-section for high t
- High energy configuration more sensitive to Q2~0

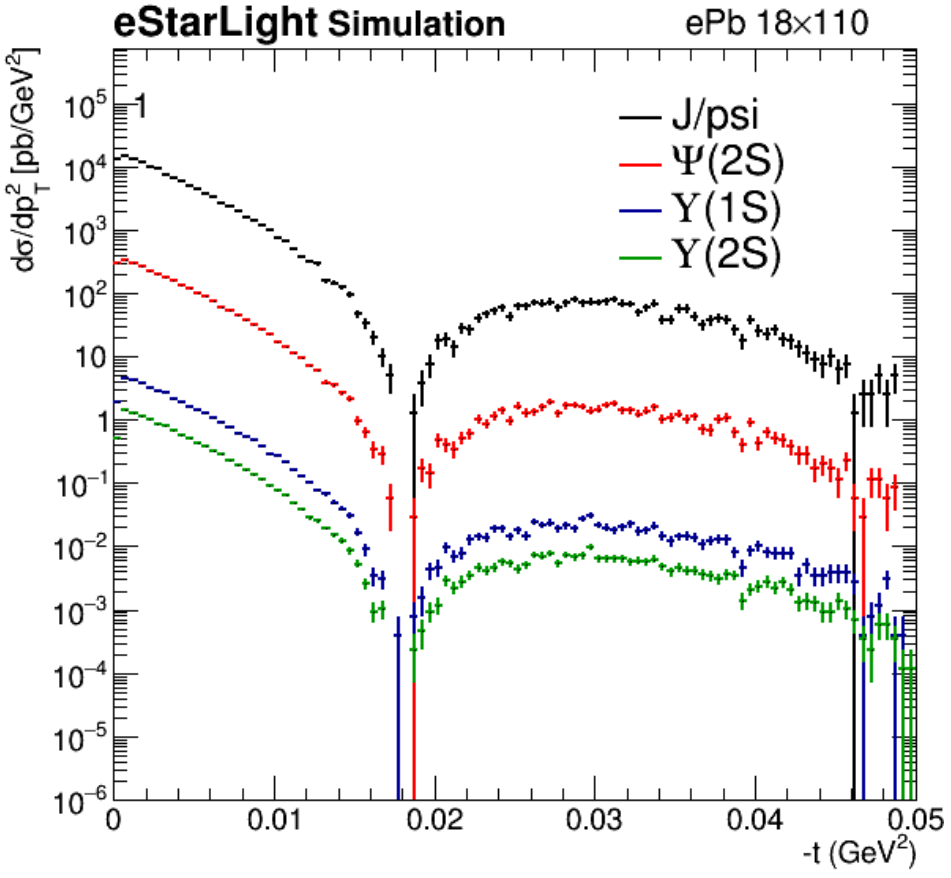


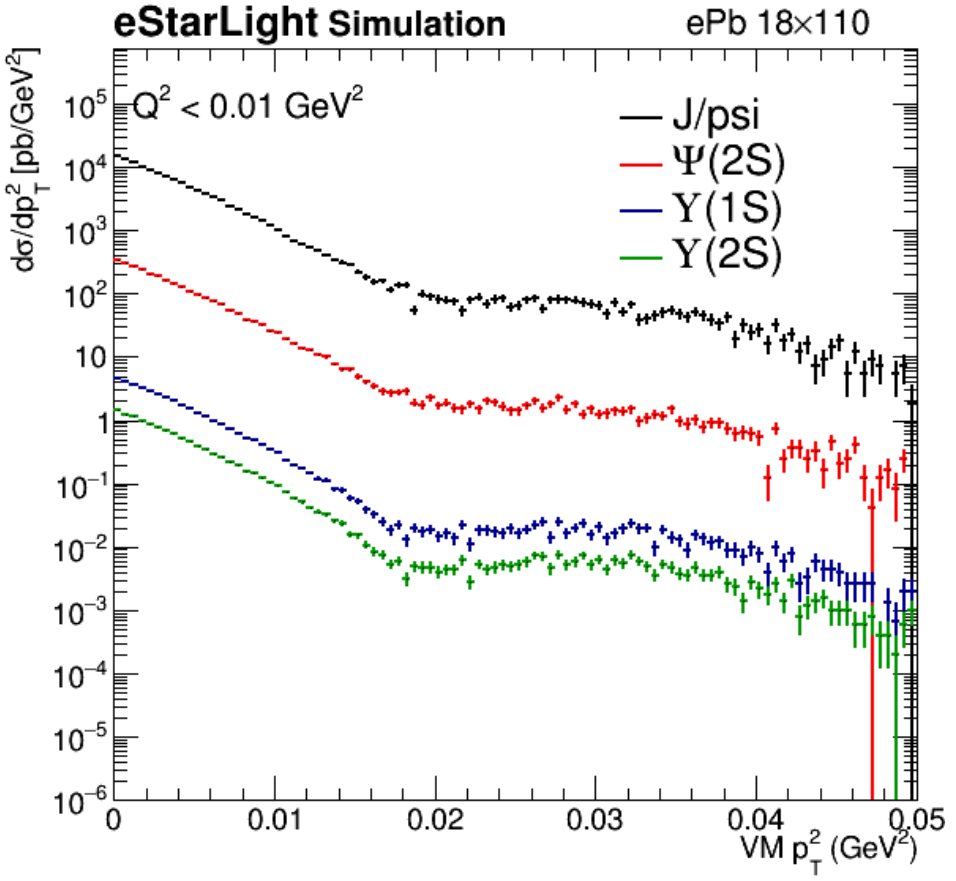


Momentum transfer

Different mesons at low Q2

- Similar spectra for different VM





Event categorization

- Reconstruction of Q2