Coherent VM production

18 September 2023

Study is ongoing within the eA Study group (Kong Tu et al.)

Zvi Citron[1], Eden Mautner[1], Michael Pitt[1,2]

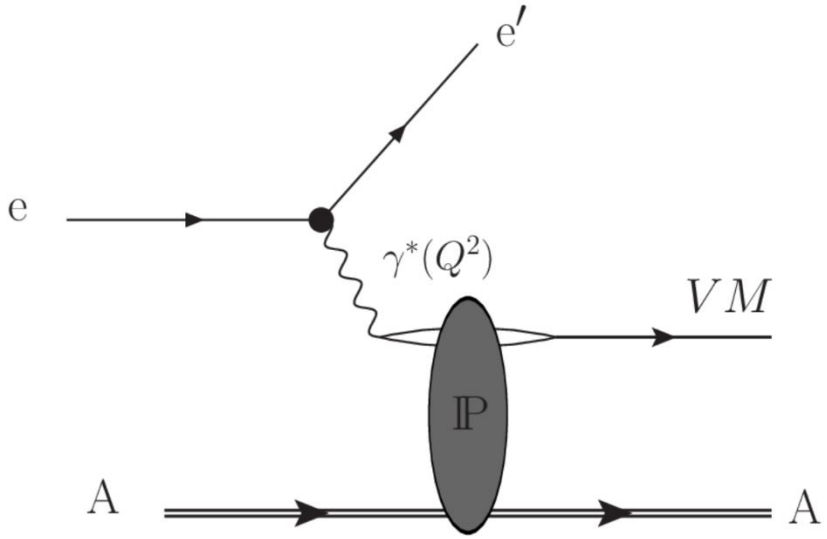
[1]*Ben Gurion University of the Negev (Israel)*

[2]*The University of Kansas (USA)*

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

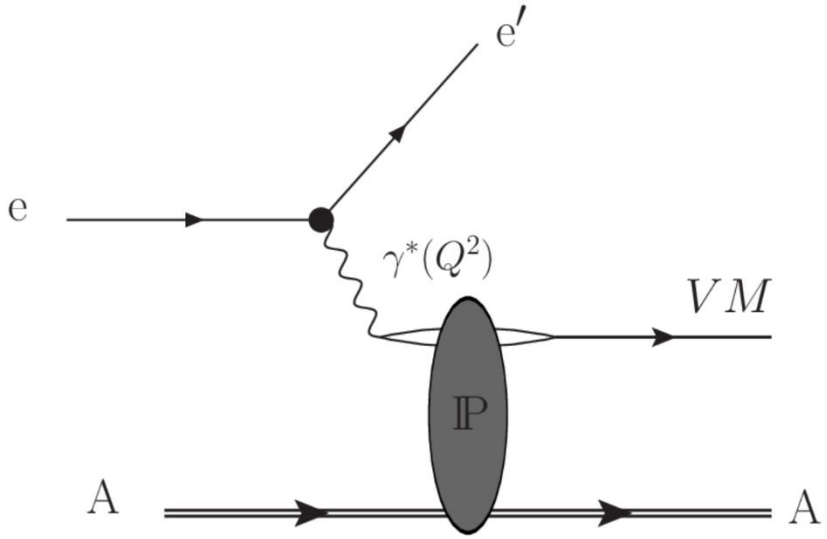
Event Kinematics

Reconstruction of parameters of interest:

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

Reconstruction of parameters of interest:

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

e’ – outgoing electron (**measured**)

VM – vector meson (**measured**)

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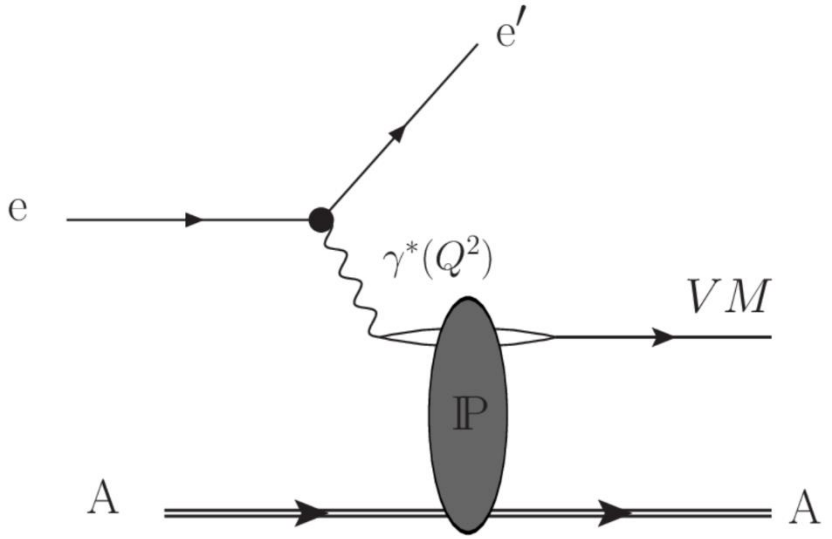
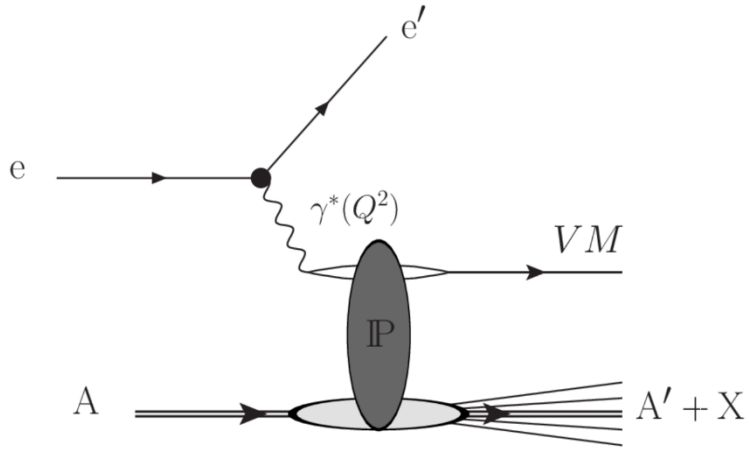
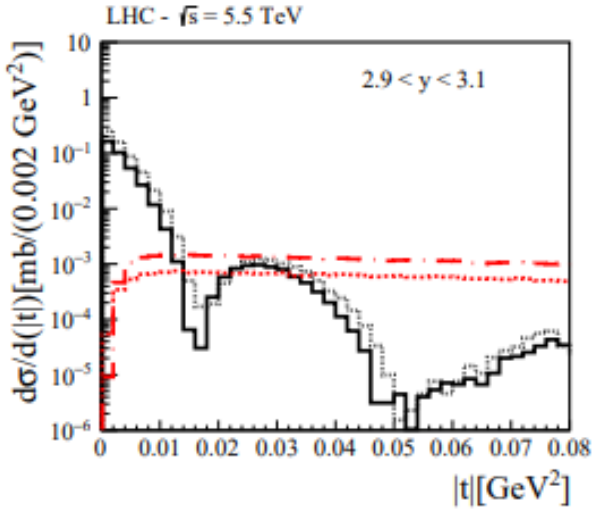


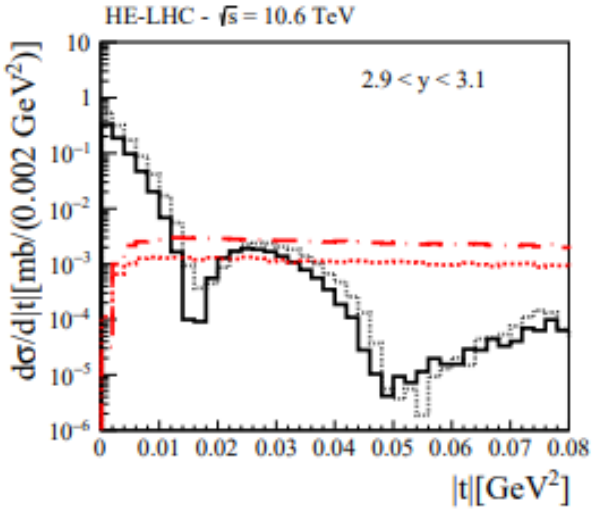


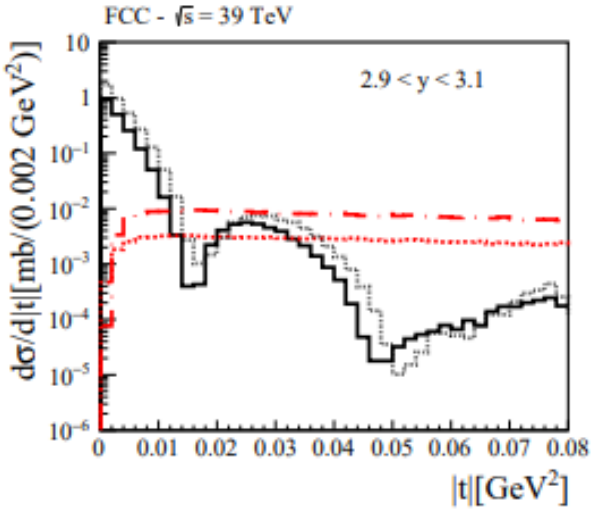
The main background is e + A → e’ + A’ + VM + X, with A≠A’

Selected (past) studies

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



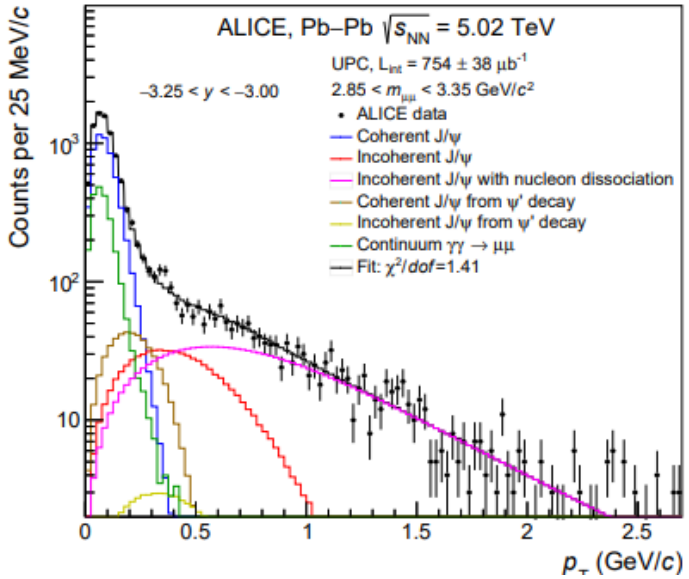


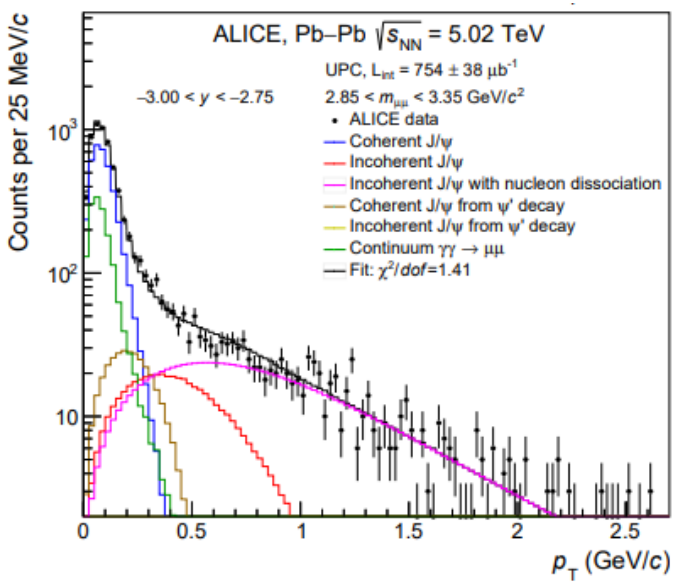


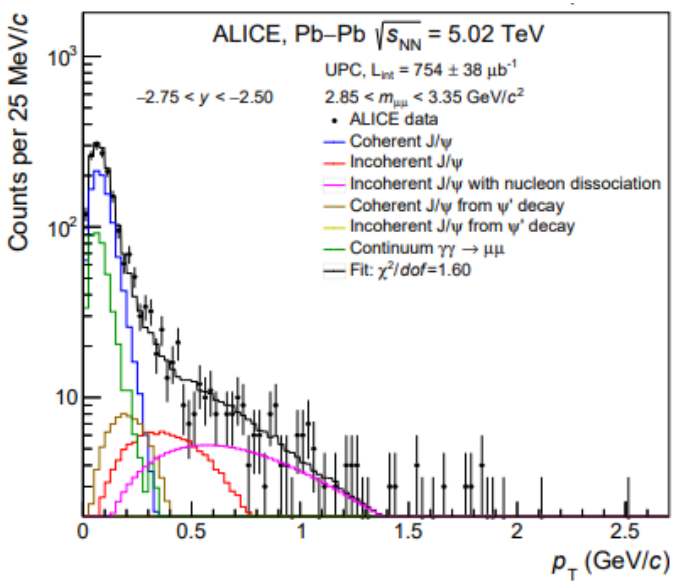
- **Expected large rates**
- **Tagging of coherent events is a subject of ongoing studies (M.Pitt@LowX2023)**

Selected (past) studies

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







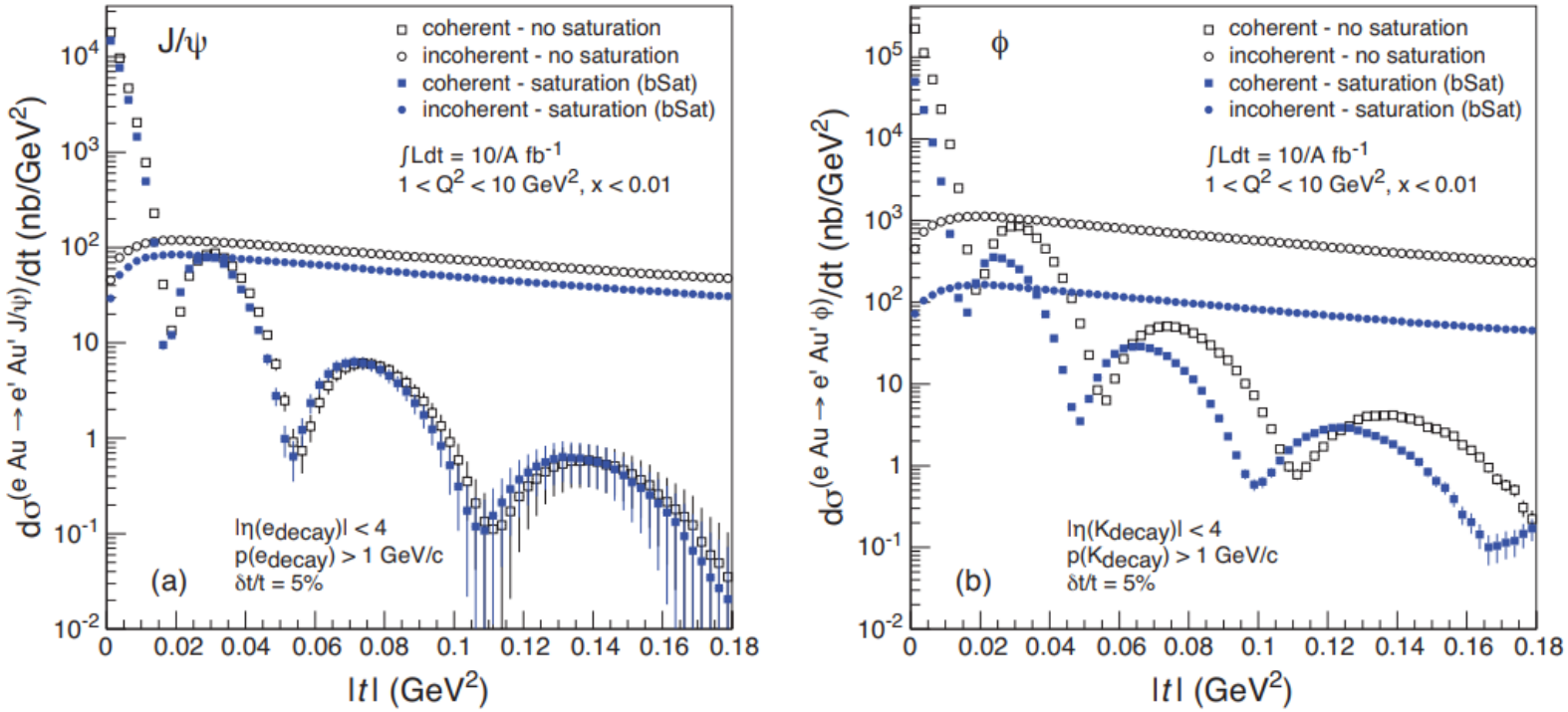
- **Expected large rates**
- **Observing the dips requires suppression of incoherent process**

Introduction

Selected (past) studies

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

Target Q^2>1 GeV² – backward electron reconstruction

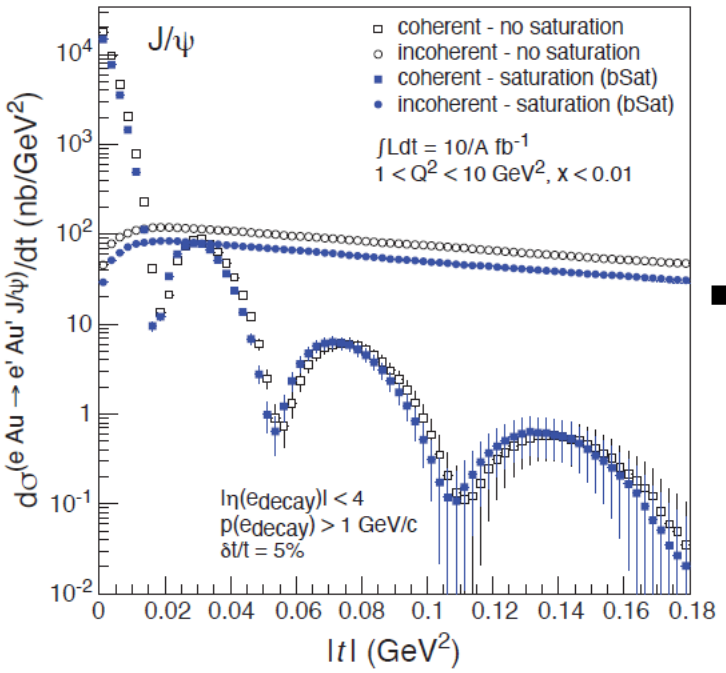


J/ψ less sensitive to saturation

Introduction

Selected (past) studies

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



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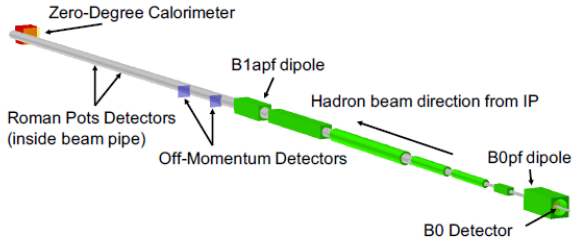

- Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV/c) ;
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- Veto.7: Veto.6 and no photon with $E > 50$ MeV in ZDC.

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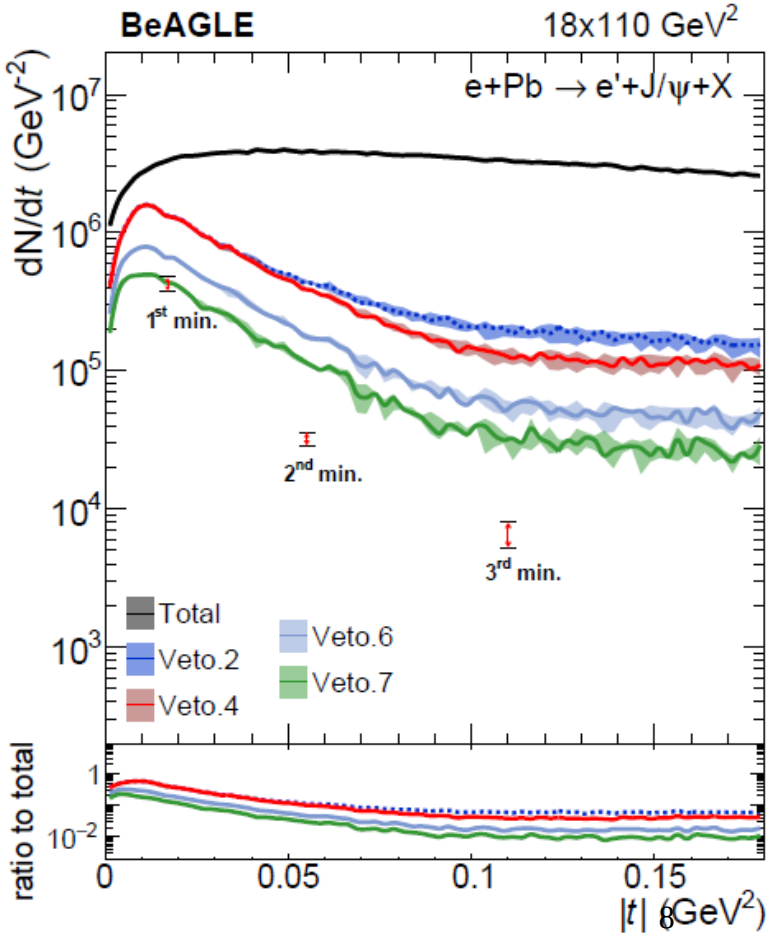


Strong background rejection with FFD at the EIC

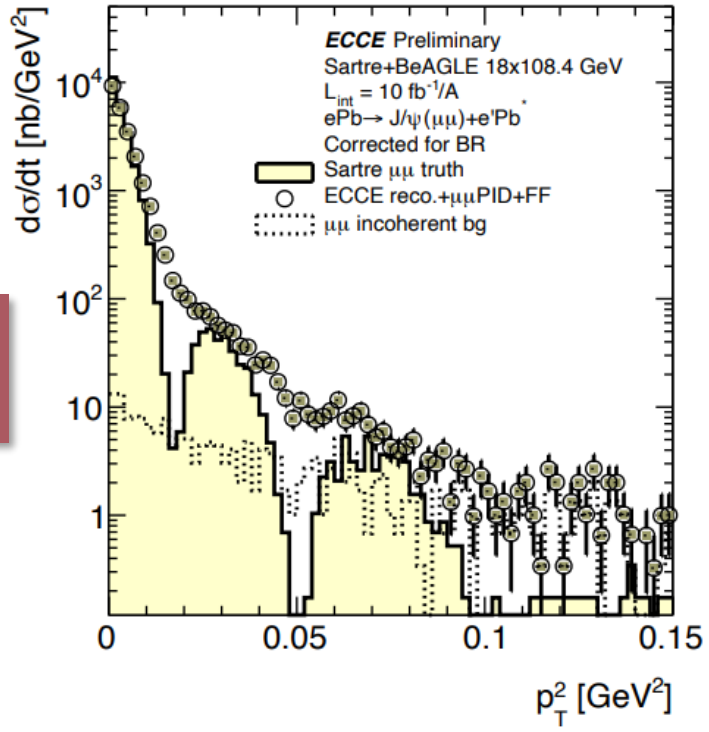
Selected (past) studies

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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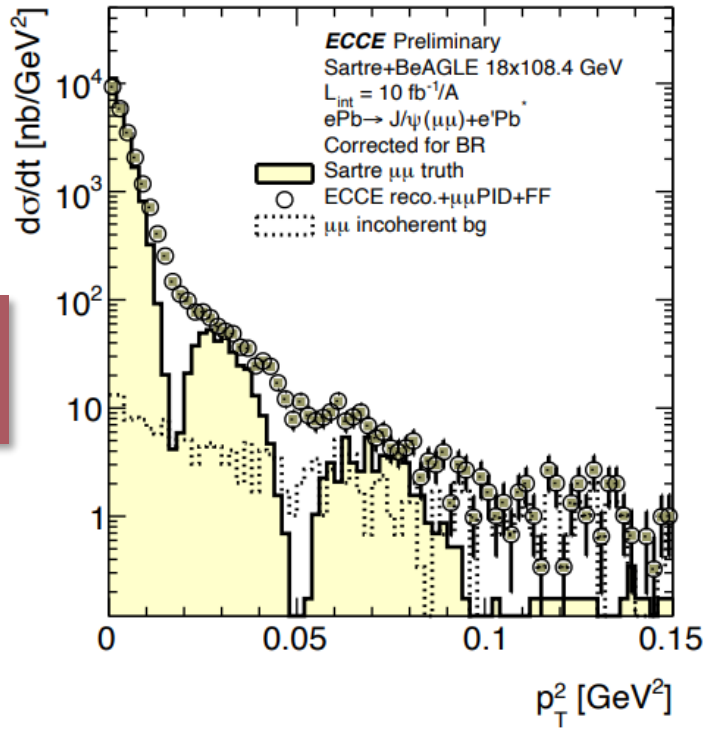
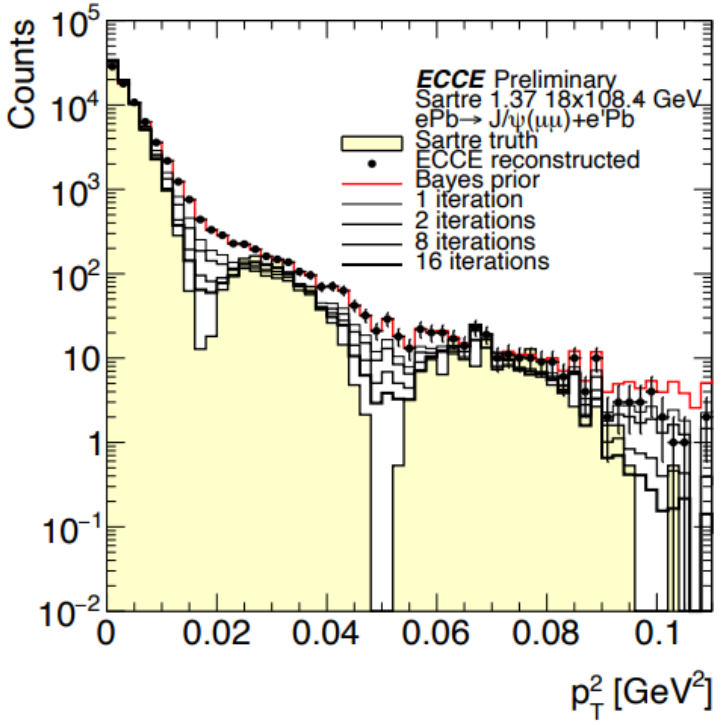


Unfolding



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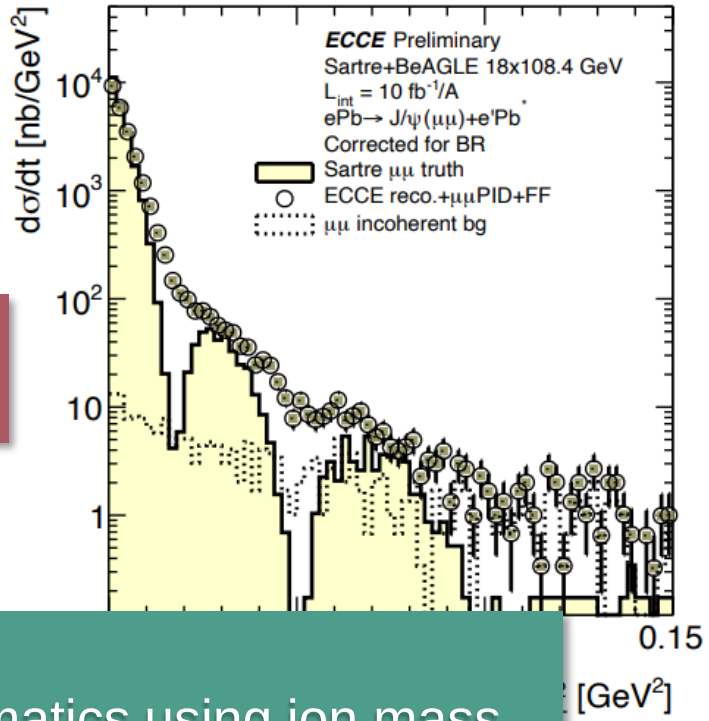

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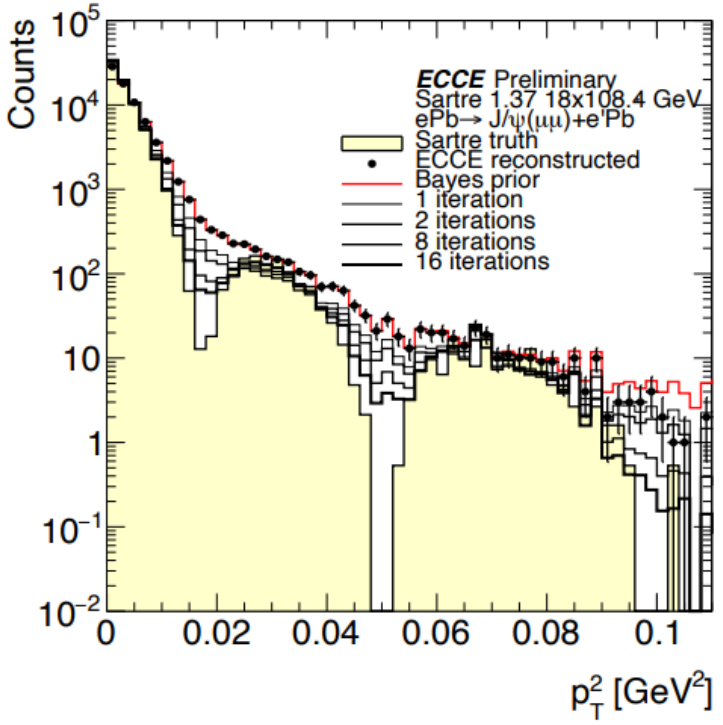


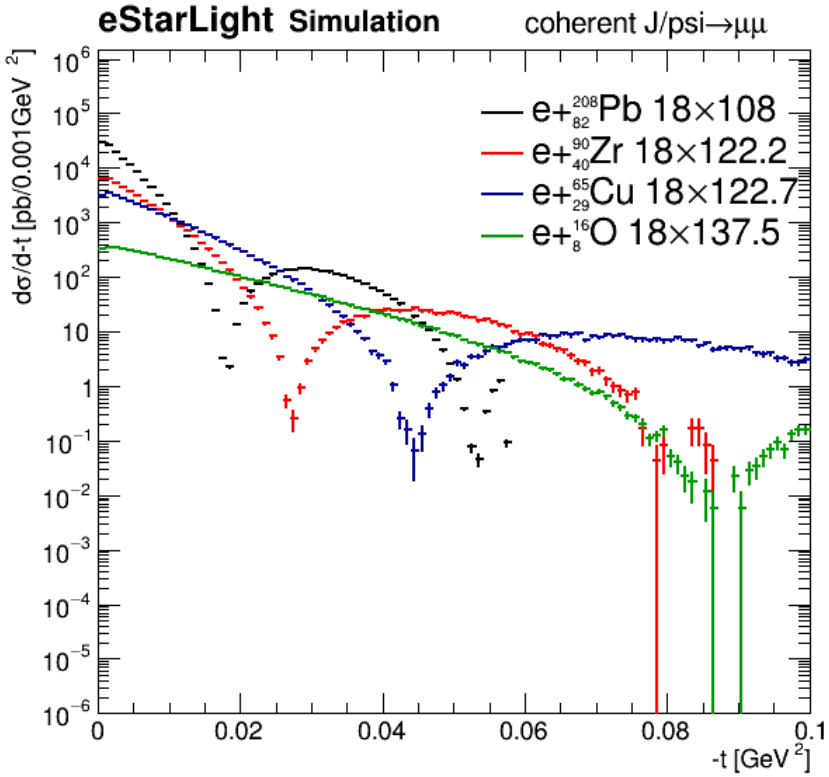
Other options:
- Constrain electron kinematics using ion mass
- Low Q2 region (next slides)

Simulation setup

Event generation

- Simulation with eStarlight[1]: $e + A \rightarrow VM + e' + A'$
- 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

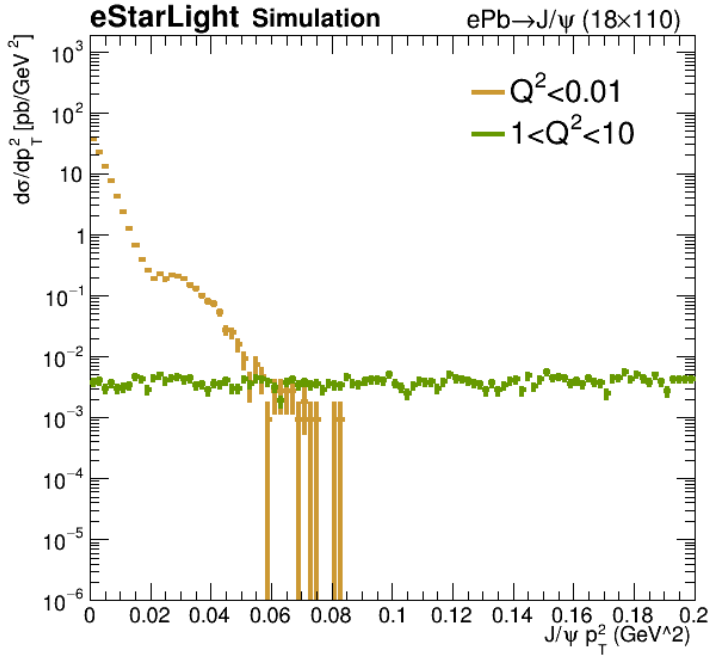
- Using *npsim* detector simulation with World material = Vacuum **(RESOLVED??? IN VALIDATION)**
- Using *eicrecon* with [266-integrate-lowq2-tagger-reconstruction]() (thanks to Simone Gardner)

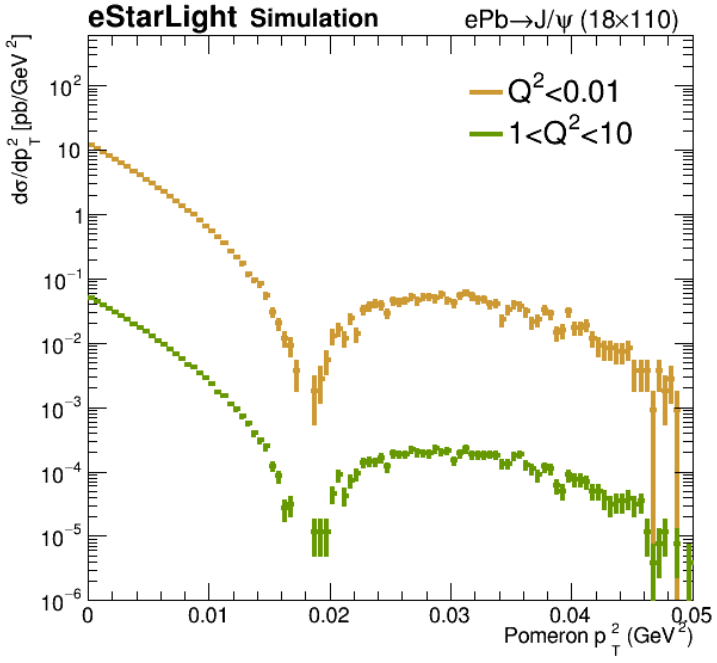
[1] https://github.com/eic/estarlight

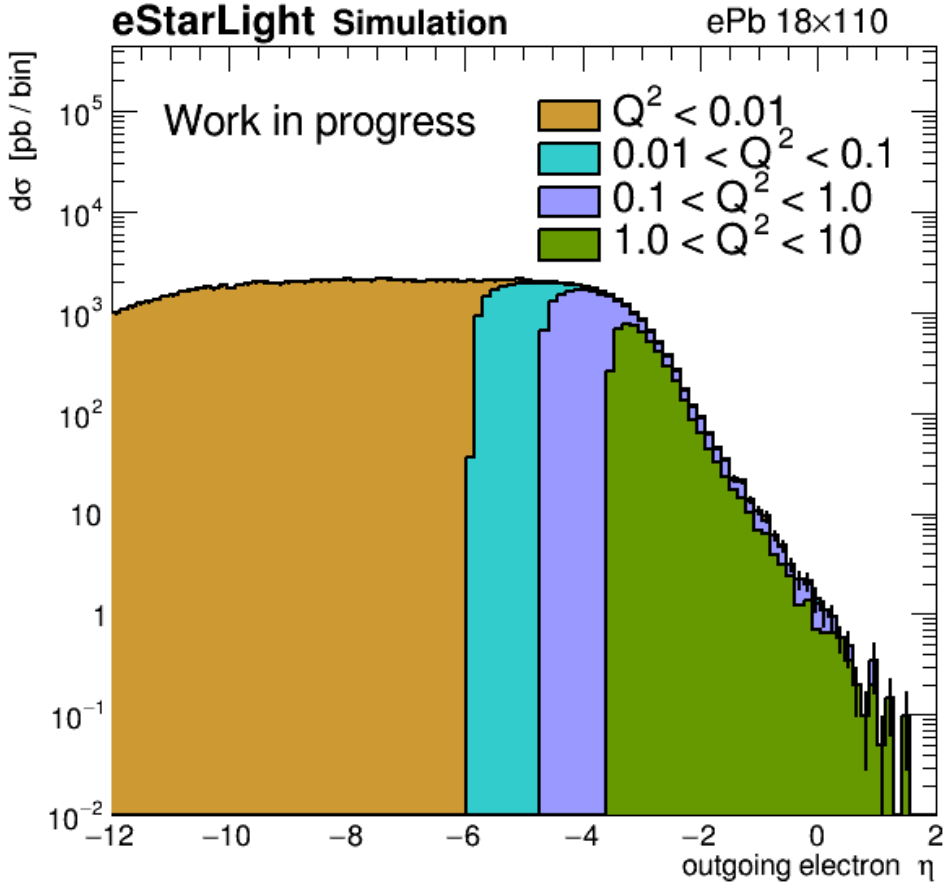
Momentum transfer and Q2

Q2 dependence

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





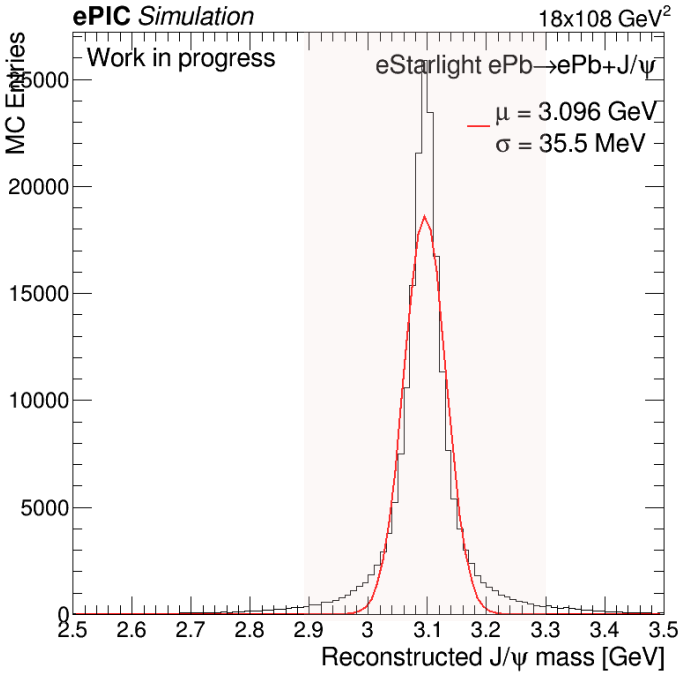


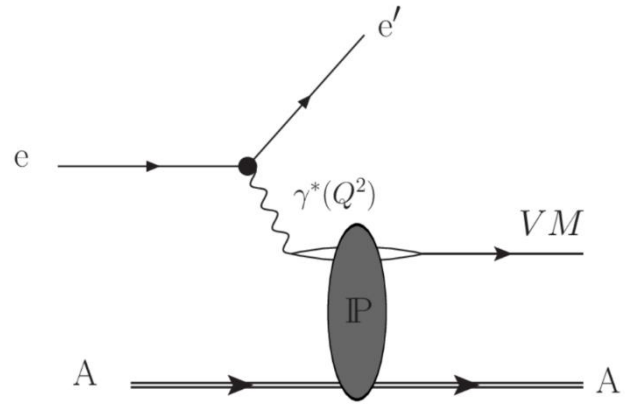
Event Selection

- 3 track events (with 2 tracks in |η|<4)
- VM mass window of 0.4 GeV
- Veto activity in forward region (reco/hits):

B0 tracks, B0 clusters, OMD tracks, RP tracks,

ZDC WSi, Sci, PbSi, Hcal, Ecal hits





Signal efficiency for different Q^2 regions:

Cut	1GeV <Q^2<10 GeV	Q^2<10 GeV	Q^2 < 0.01 GeV
3 tracks	0.975253	0.483794	0.54398
VM mass cut	0.927652	0.463216	0.523327
Veto FFD / ZDC	0.927399	0.463152	0.523256
Veto FFD	0.892045	0.445142	0.50276

Cut	Q^2<10 GeV
3 tracks with |η|<4	0.088701
2 tracks with |η|<4	0.394873

Analysis

Event categorization

- Depends on the electron reconstructed eta
  - Central detector: ~10% of all Q^2<10 GeV
  - Low-Q2 taggers: ~40% of all Q^2<10 GeV

Event Kinematics

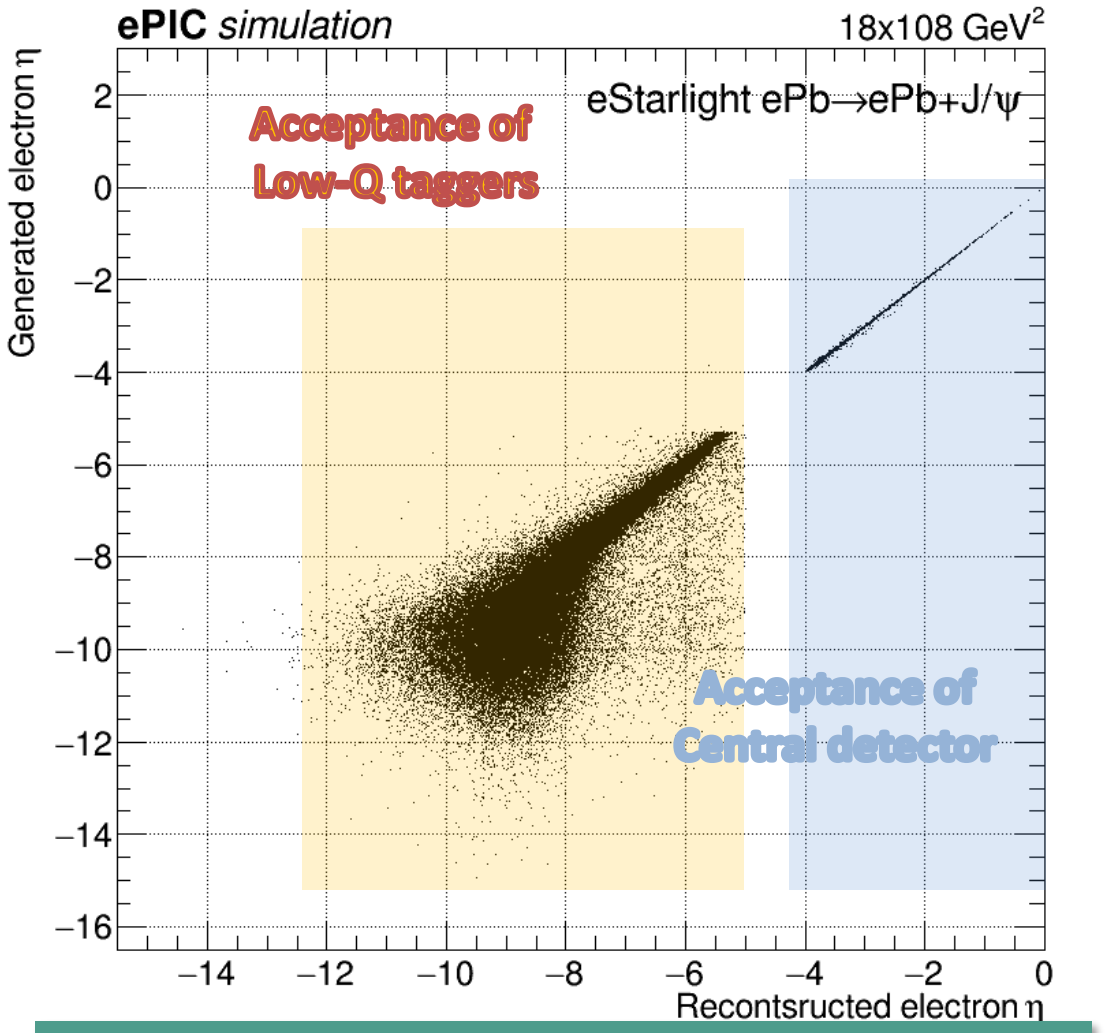
Reconstruction of parameters of interest:

e – incoming electron (**fixed**)

e’ – outgoing electron (**measured**)

VM – vector meson (**measured**)

- Momentum transfer –t =(VM −(e−e')).M2()



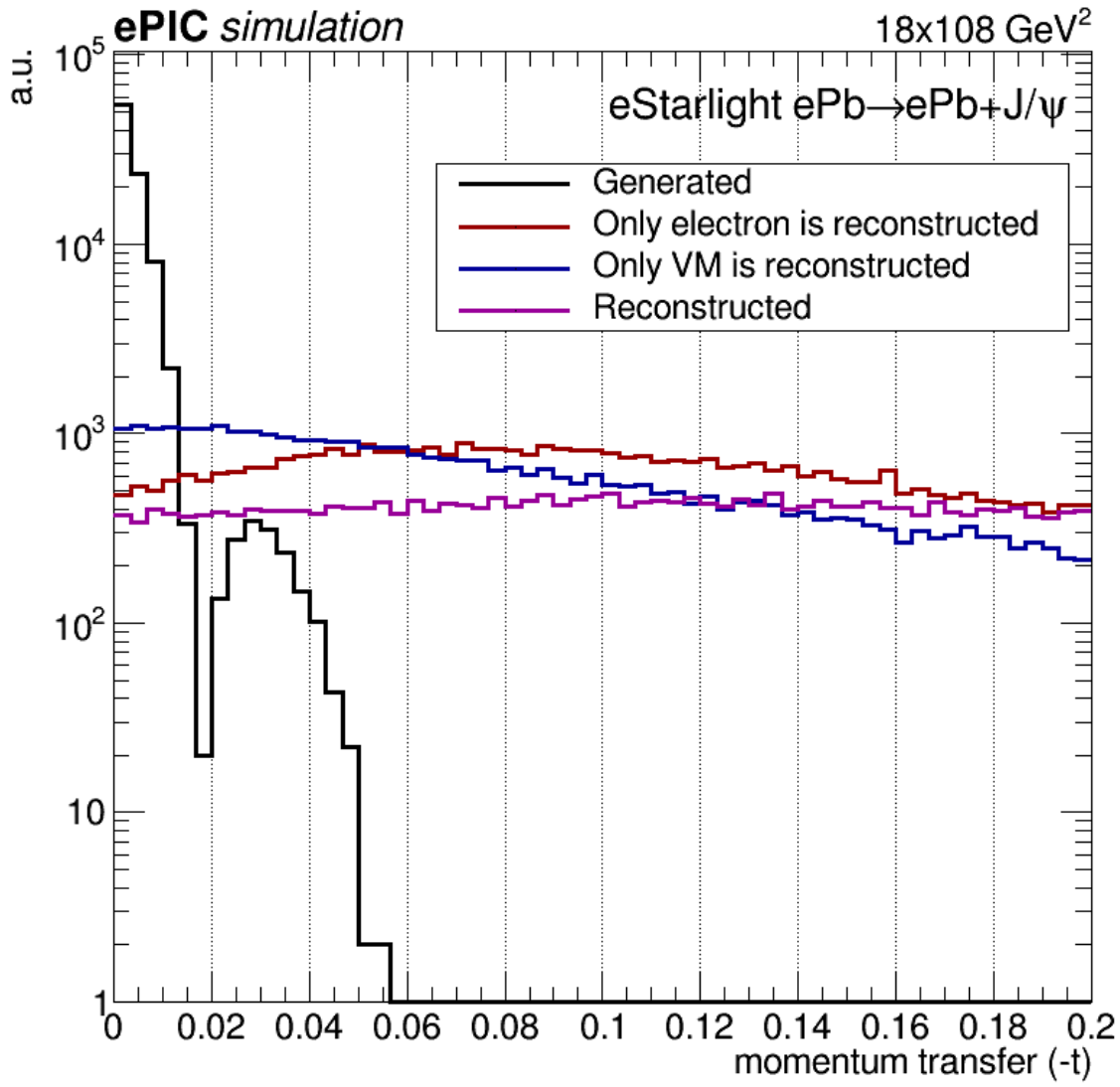
Adding low-Q2 category increases signal acceptance by x5

t reconstruction

- Momentum transfer **–t =(VM −(e−e')).M2()**
- **Reconstruct electron + VM (from tracks)**
  - Impact from electron reconstruction
  - Impact from VM reconstruction

➢ **Large experimental resolution**

  - Observed in both categories (low/high Q2)



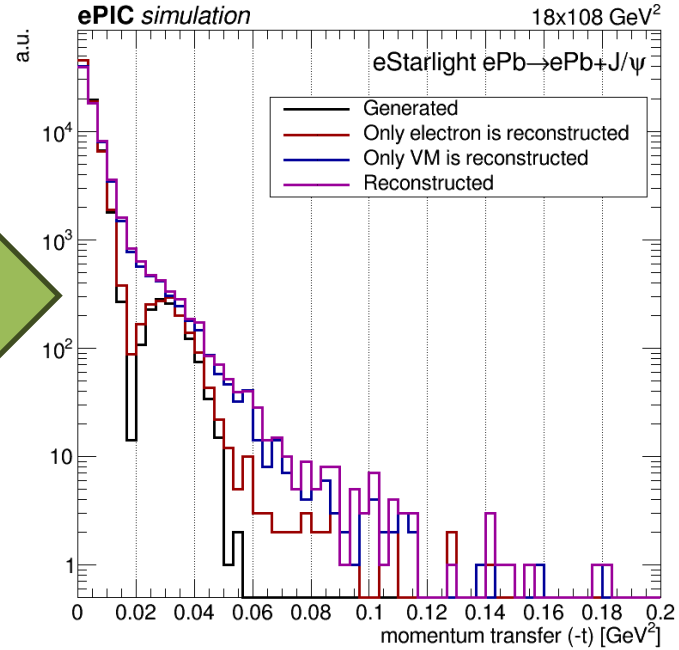
t reconstruction

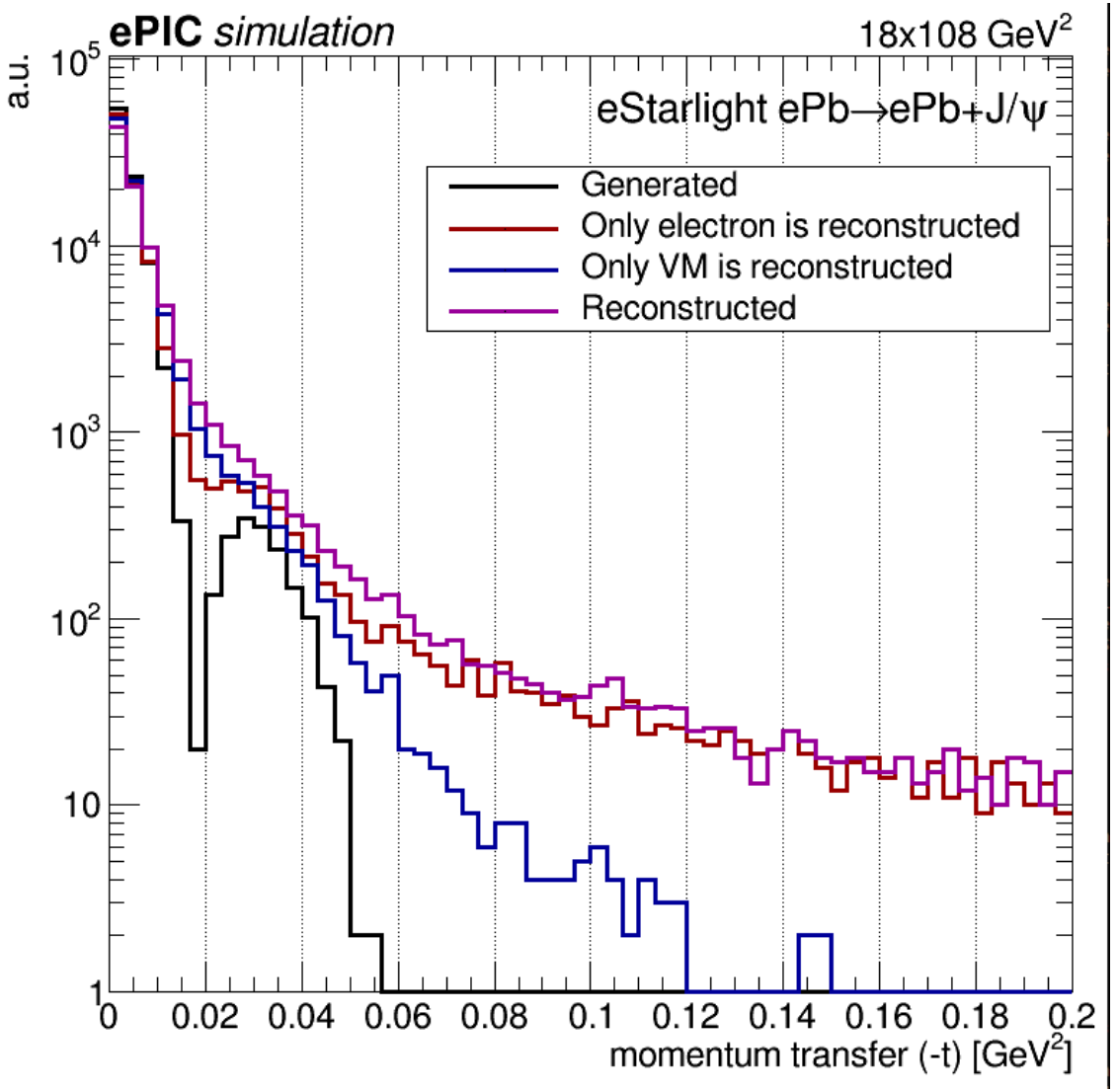
- Add Pb mass constrain (from Kong link):
  - **Better modeling of the t variable**

Larger effect from VM reconstruction

  - At low Q electron do not have impact

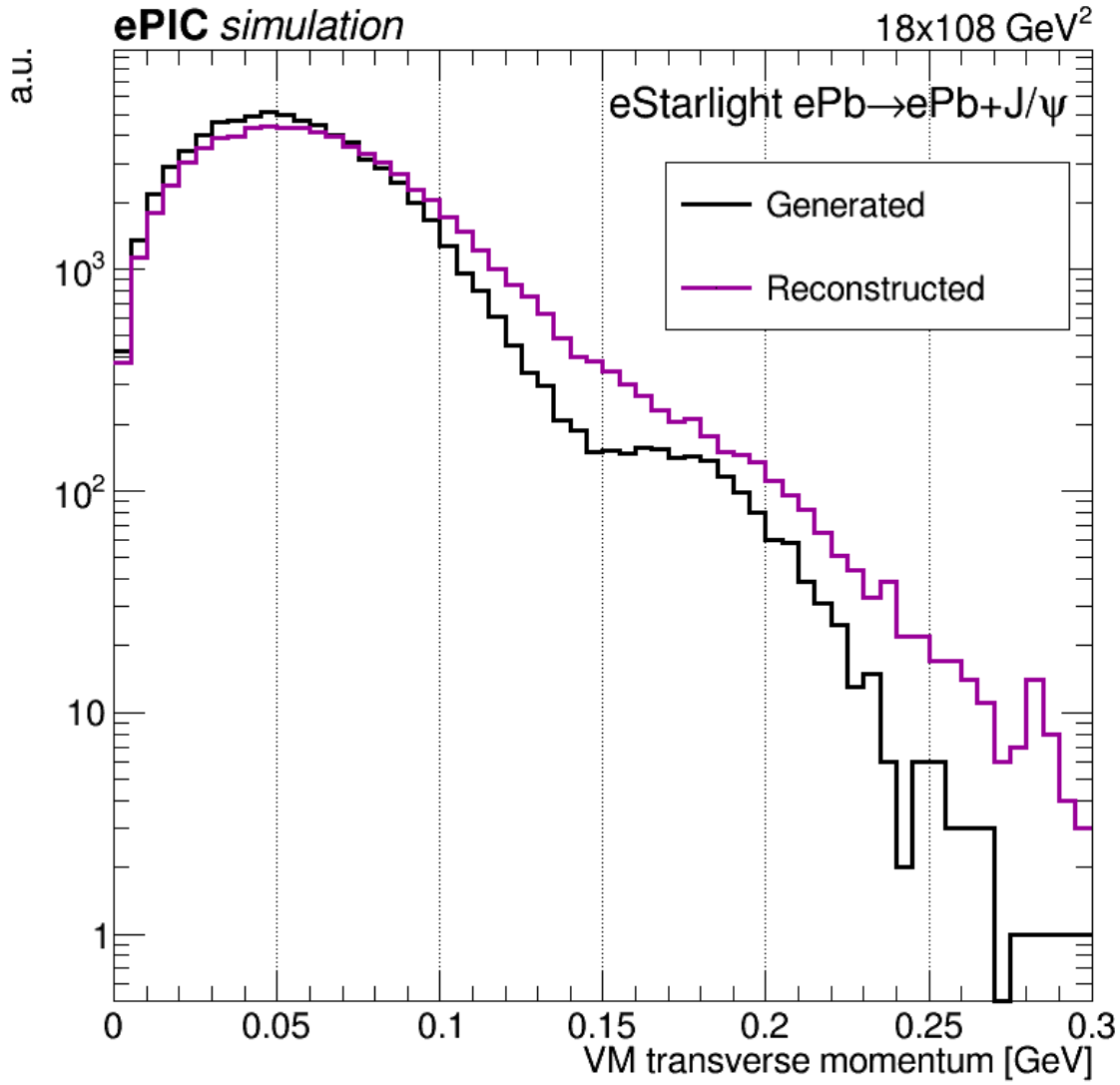
low Q category





VM PT reconstruction

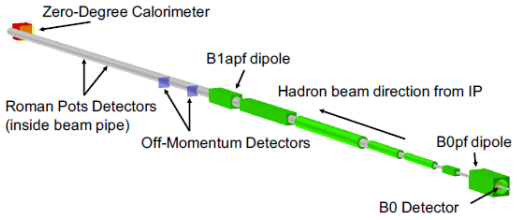
- At low Q, t can be approximated as VM PT
  - Impact from electron reconstruction
  - Impact from VM reconstruction
- ➢ **The dip seen at the generated level**
  - Only low Q2 category can be used
  - Work ongoing – VM pT resolution

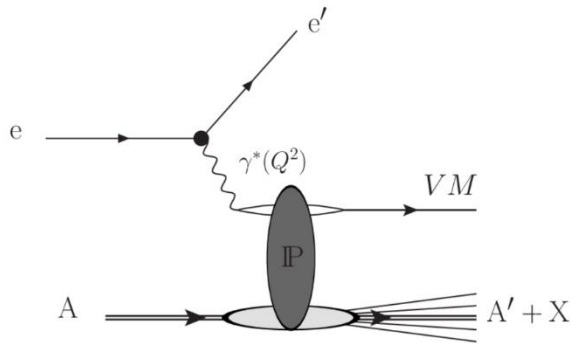


Background rejection

Backgrounds

- The main background is incoherent VM production
- Modify the strategy (from object rejection to signal rejection)
- Work by Eden Mautner (in progress)





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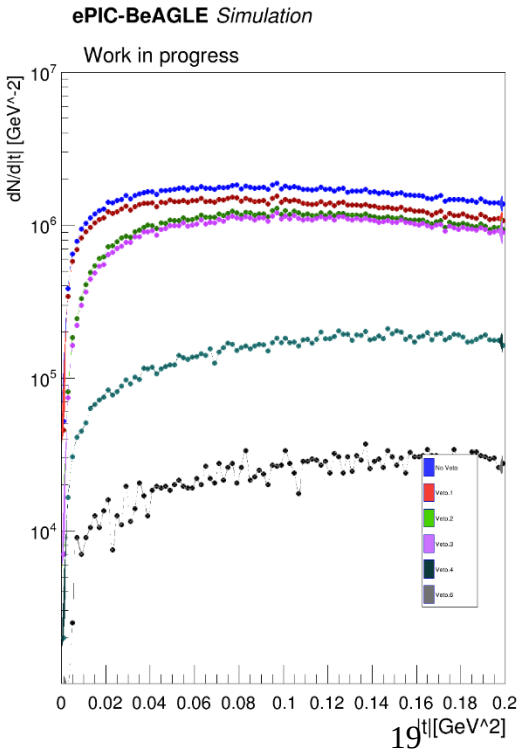
Background efficiency based on ePIC FFD simulation

Cut	1GeV<Q²<10 GeV
3 tracks	0.876579
VM mass cut	0.843891
Veto B0	0.488994
Veto RP/OMD	0.0953154
Veto ZDC	0.0255769



Summary and discussion

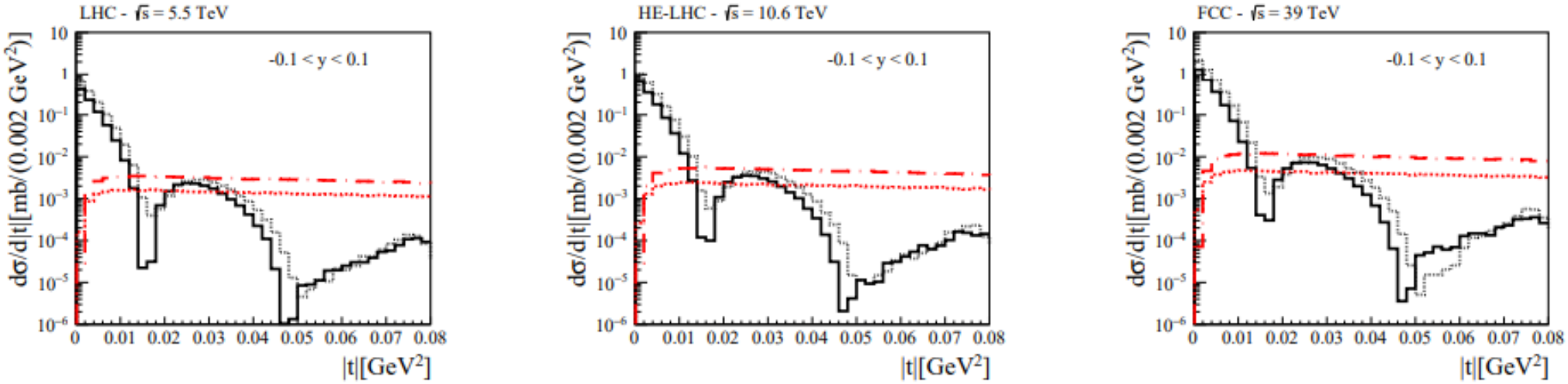
Summary

- 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/Far-Backward detectors
- What is new:
  - ✓ **Low Q taggers – better t reconstruction, higher statistics (x4)**
  - ✓ **Background suppression studied based on most resent detector simulation**
- Work in progress:
  - t reconstruction / background studies

Backup

Selected (past) studies

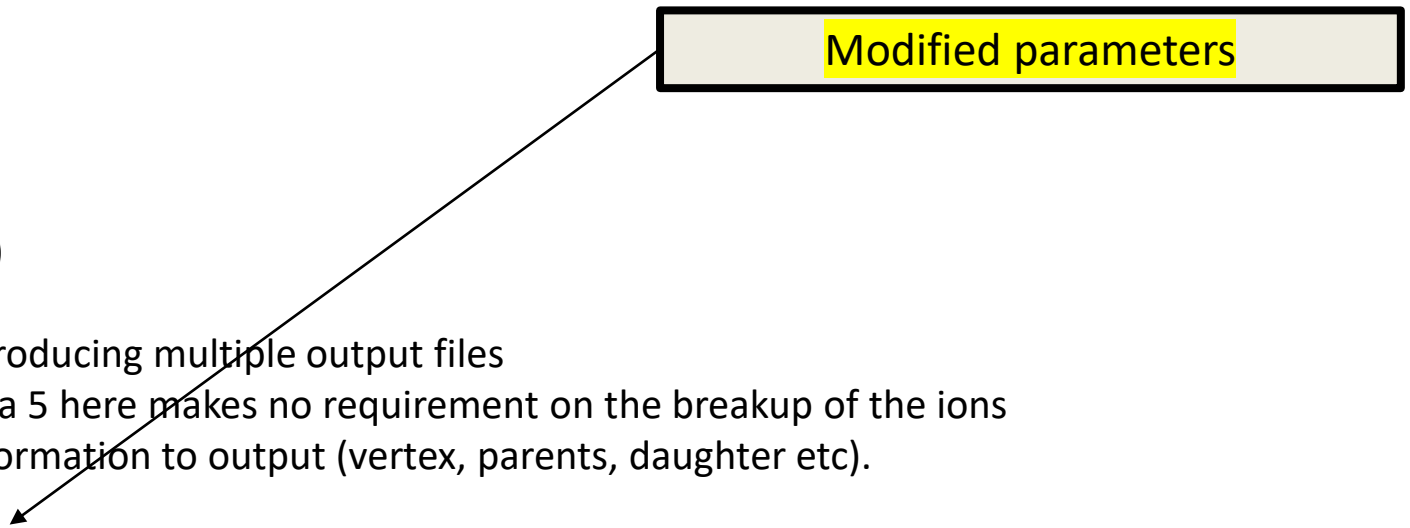
- Coherent and incoherent J/ψ photoproduction in PbPb collisions at the LHC, HE-LHC and FCC (2007.13625):



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

eStarlight setup

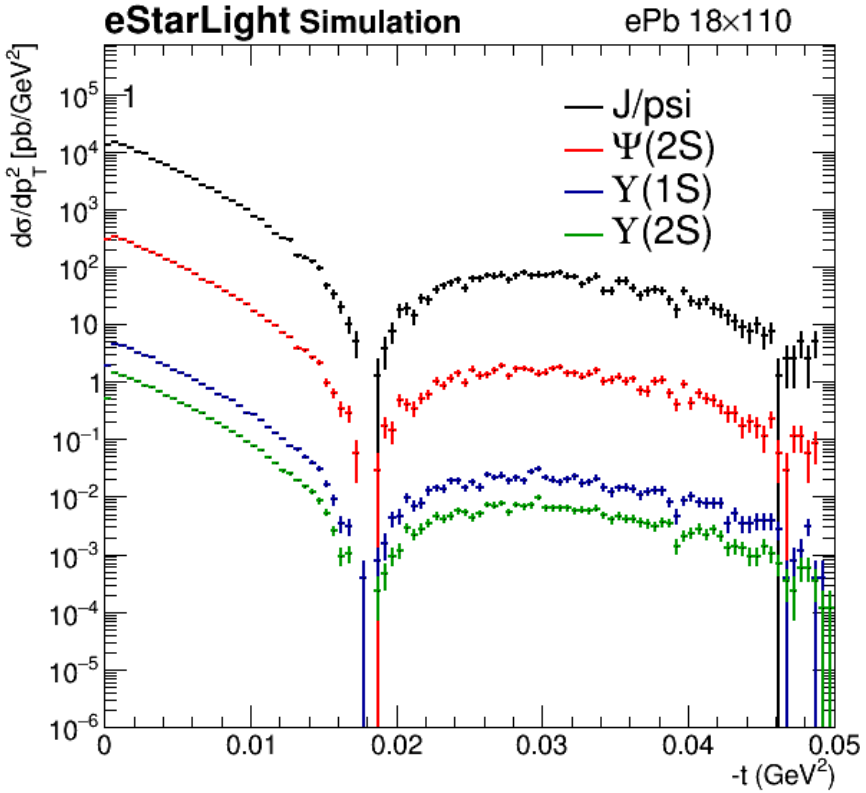
```
TARGET_BEAM_Z = 82   #Z of target
TARGET_BEAM_A = 208   #A of target
ELECTRON_BEAM_GAMMA = 35295 #18 GeV electrons from eRHIC
TARGET_BEAM_GAMMA = 115.8 #275*82/208 GeV/n Pb from eRHIC
W_MAX = -1   #Max value of w from HERA
W_MIN = -1    #Min value of w from HERA
W_N_BINS = 50    #Bins i w
EGA_N_BINS = 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
```

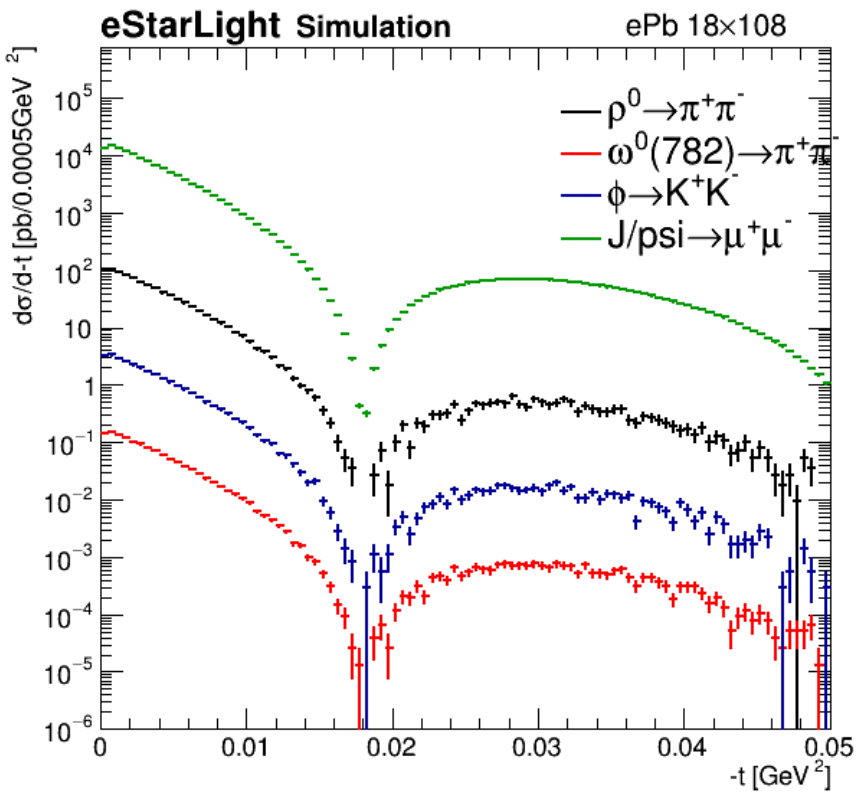


Cross-sections

Different mesons

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

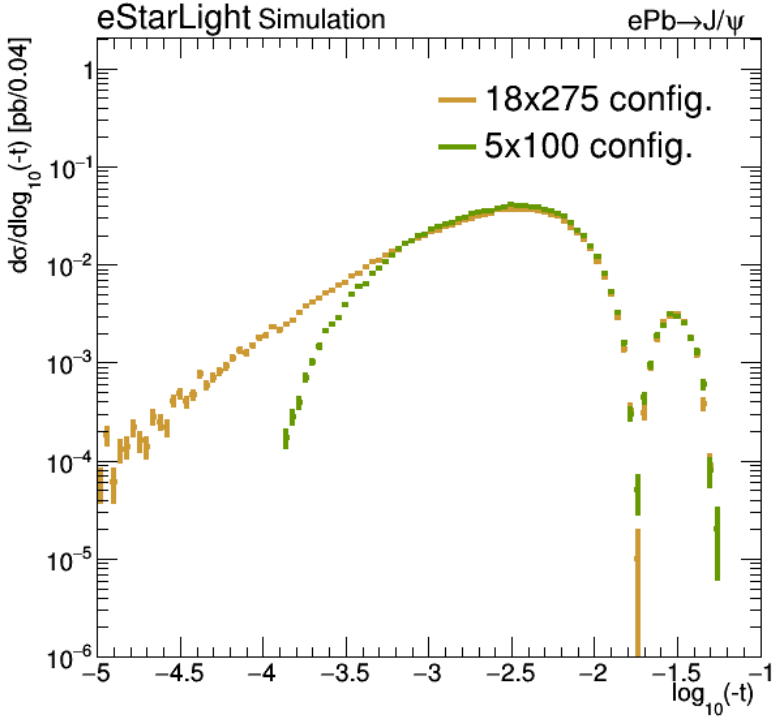


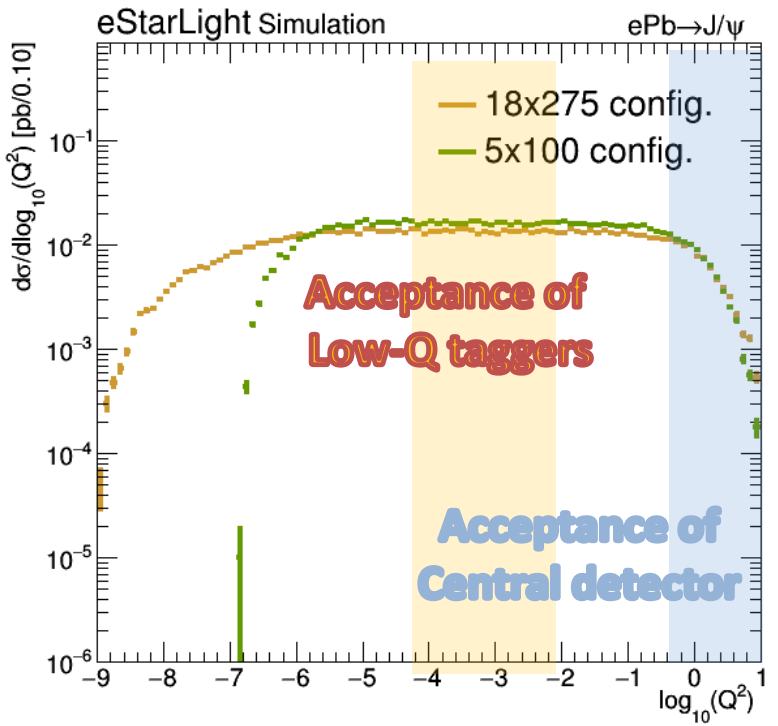


Decay	BR
$\rho^0 \to \pi^+\pi^-$	99.9%
$\omega^0 \to \pi^+\pi^-$	1.53%
$\phi \to K^+K^-$	50%
$J/\psi \to \mu^+\mu^-$	6%

Different beam energies

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

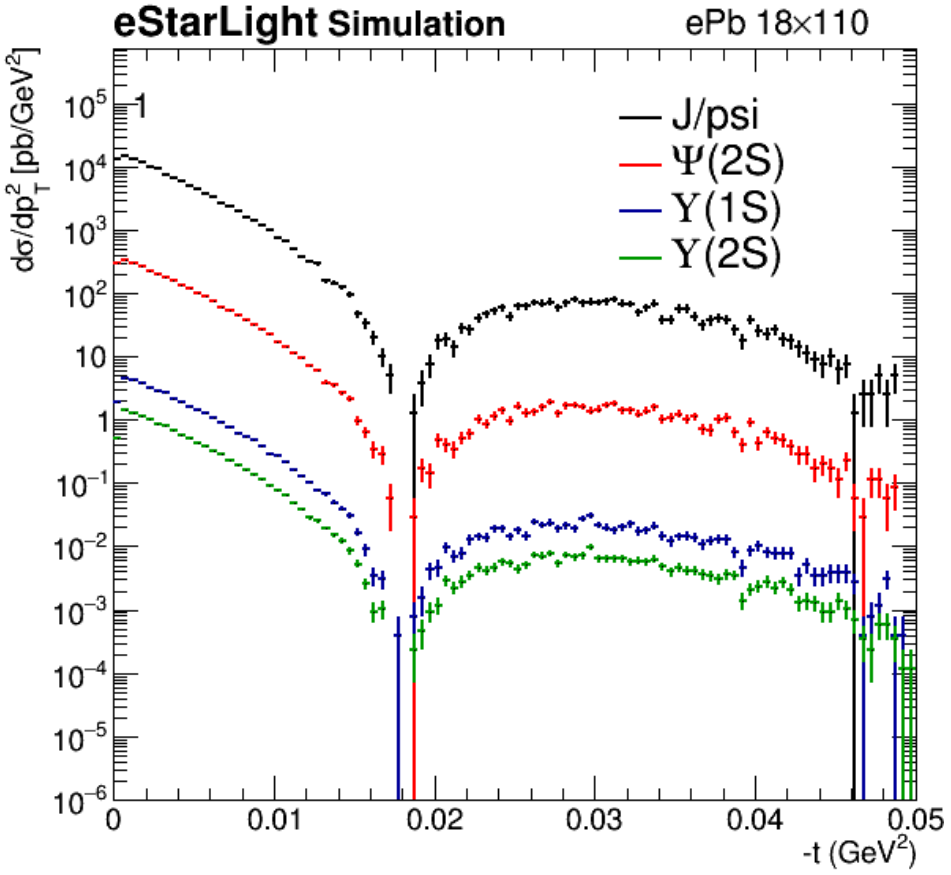


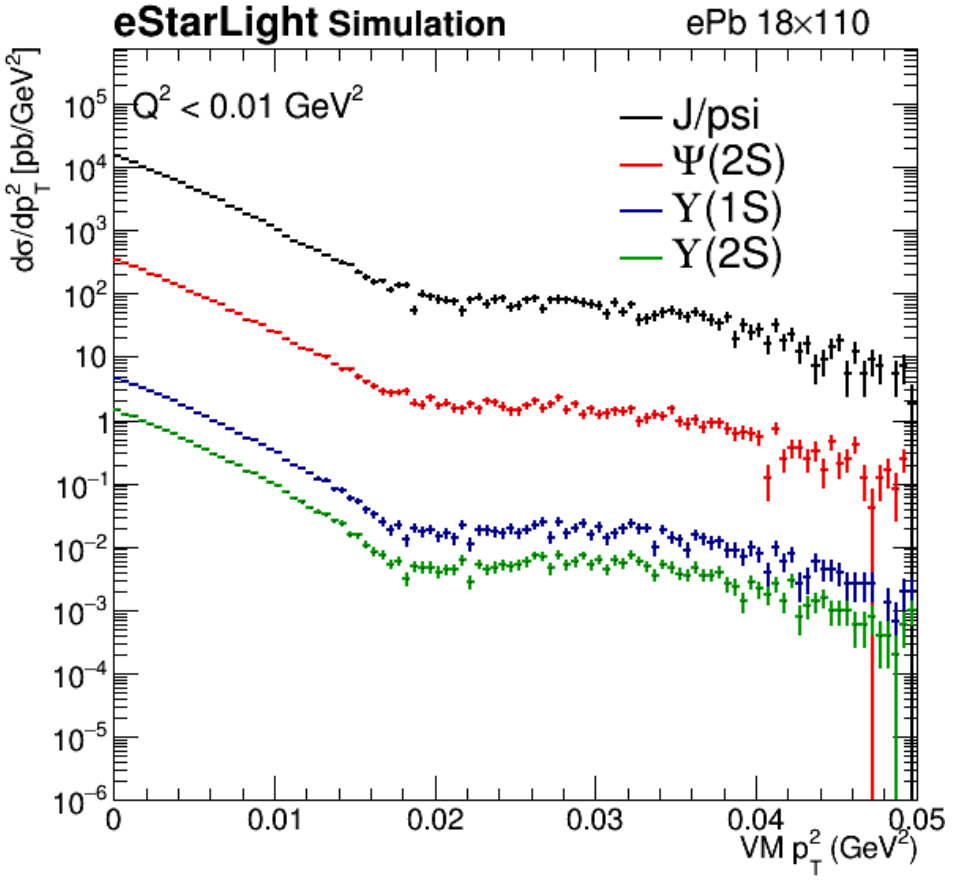


Momentum transfer

Different mesons at low Q2

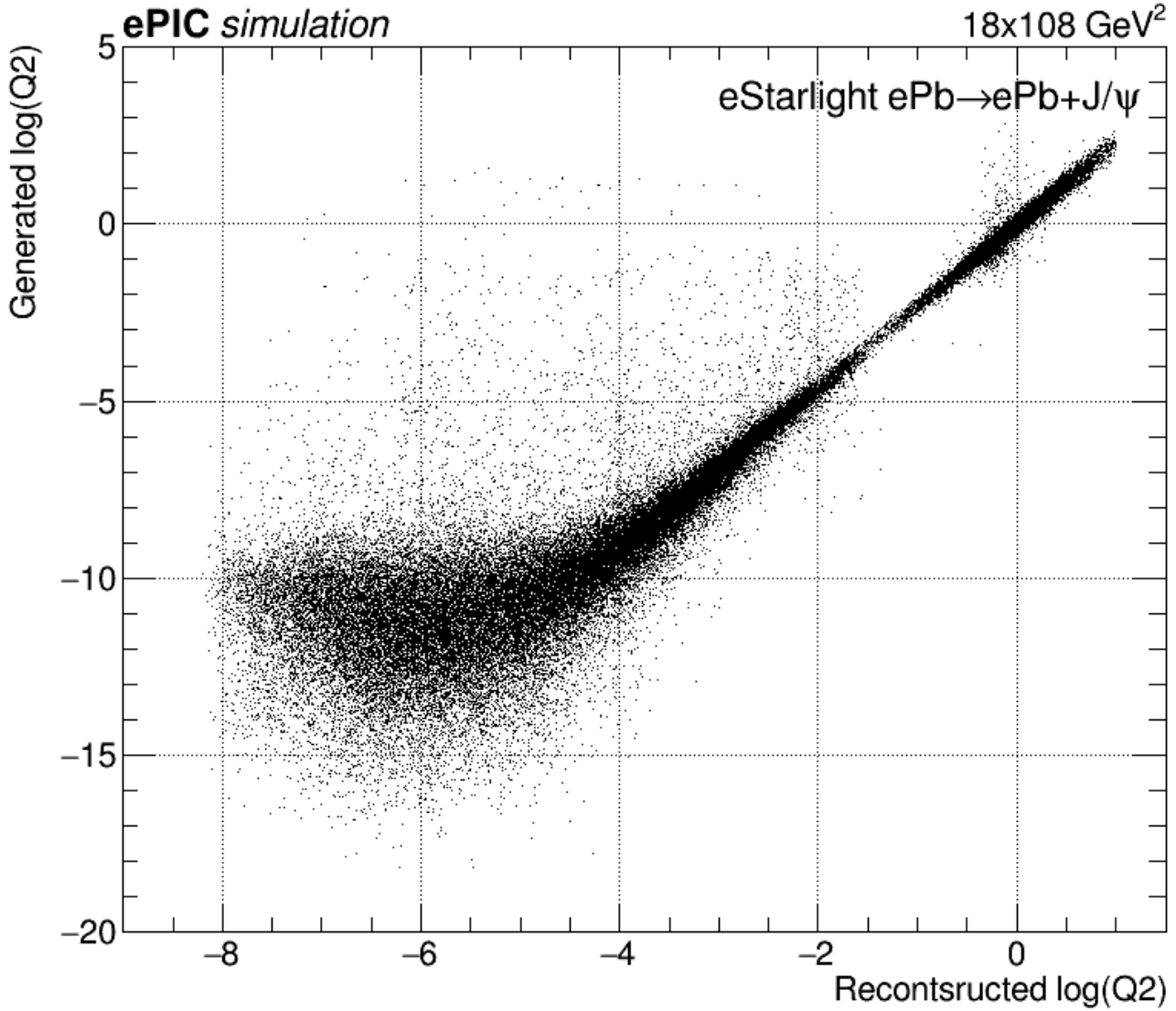
- Similar spectra for different VM





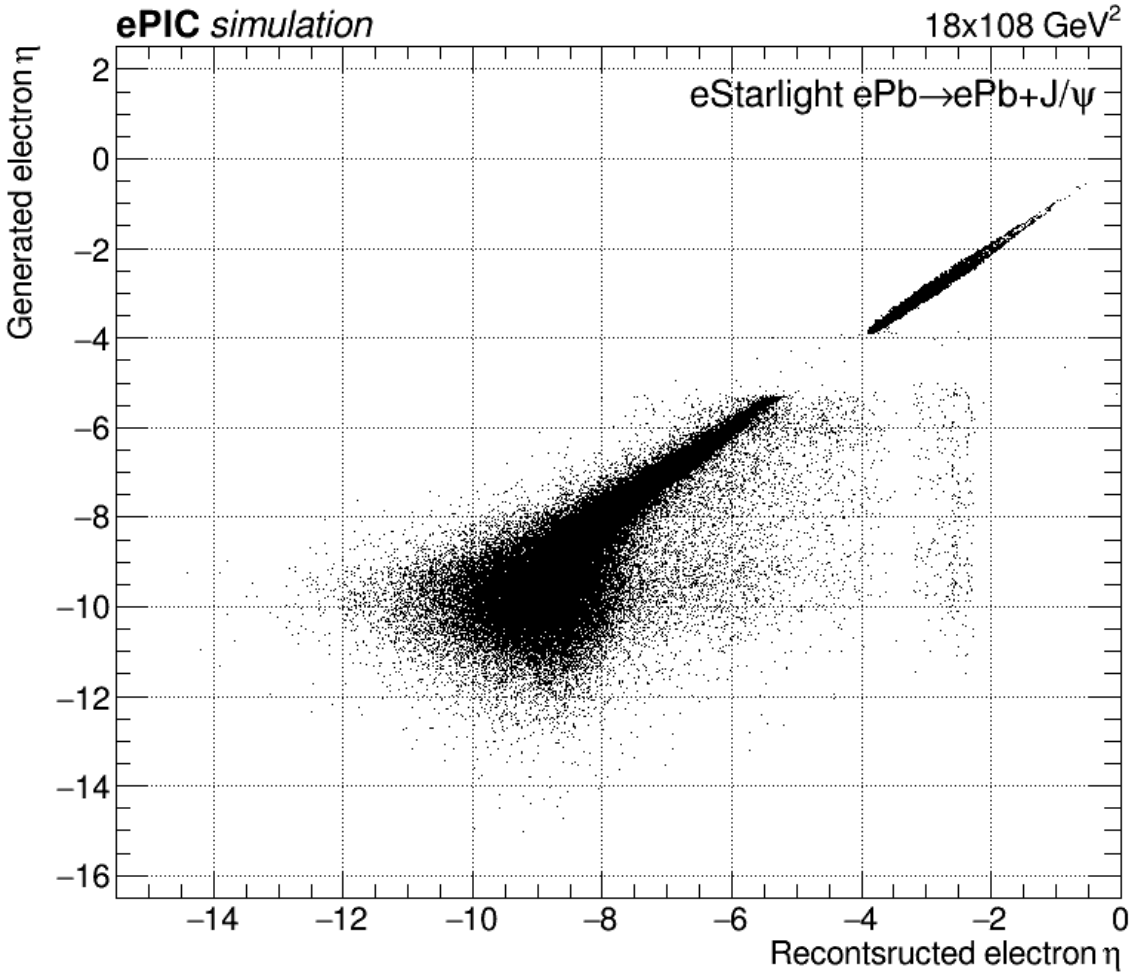
Event categorization

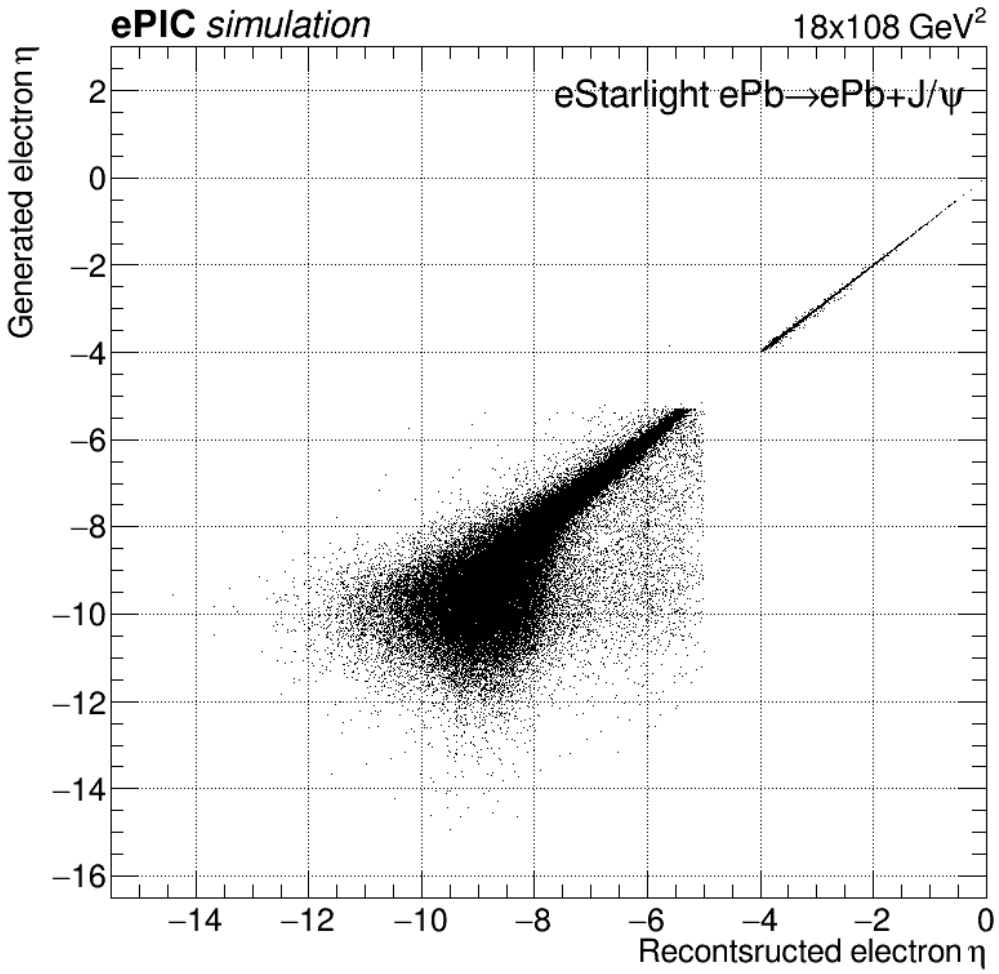
- Reconstruction of Q2



Electron reconstruction

- Coherent J/ψ photoproduction in ePb collisions, Simulation with *npsim*, reconstruction with *eicrecon*
- Left: Old (two month ago), using Air as world material; Right: New (two days ago), using Vacuum





Electron reconstruction

- Coherent J/ψ photoproduction in ePb collisions, Simulation with *npsim*, reconstruction with *eicrecon*
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