Luminosity requirements for Incoh. Diff. J/psi production in eD collisions at the EIC

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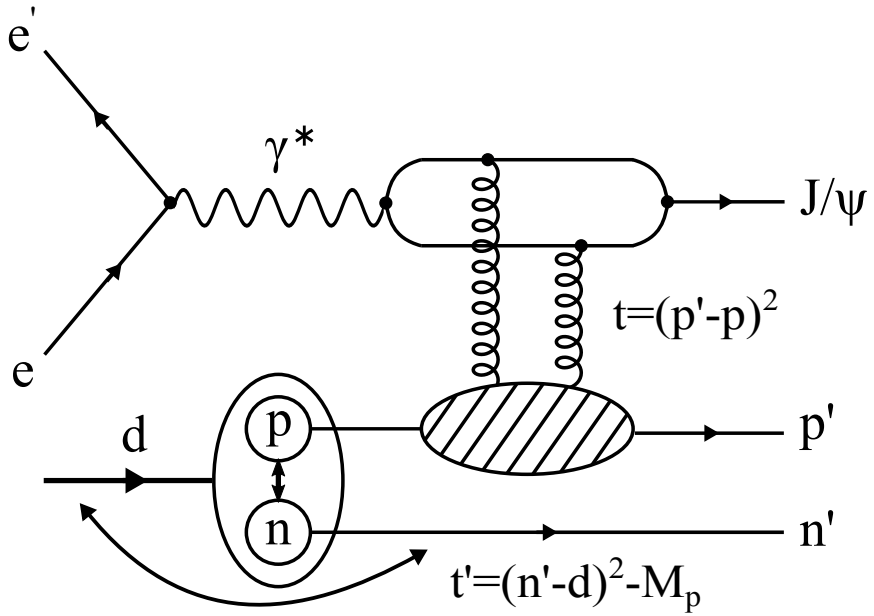
Process of interest



- ***Incoherent*** diffractive J/psi meson production in electron-deuteron collisions - γN interaction
- Spectator tagging controls the deuteron wave function and ***pn*** configurations
- What is the role of gluons in SRCs?

Status:

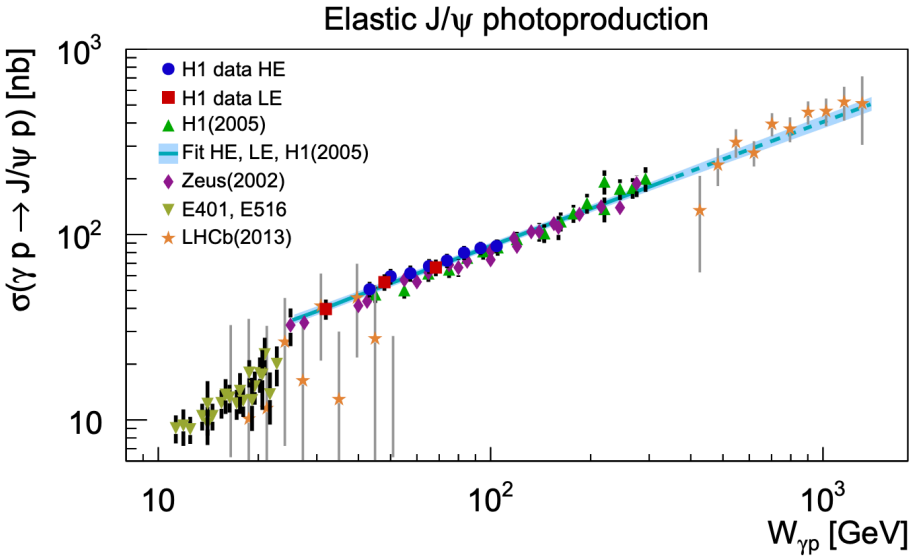
- Detector requirements and simulations are almost finalized, mostly shown at Temple (online) meeting.
- This study will be submitted as a paper, paper draft is ready and under fine-tuning. Will be public soon.

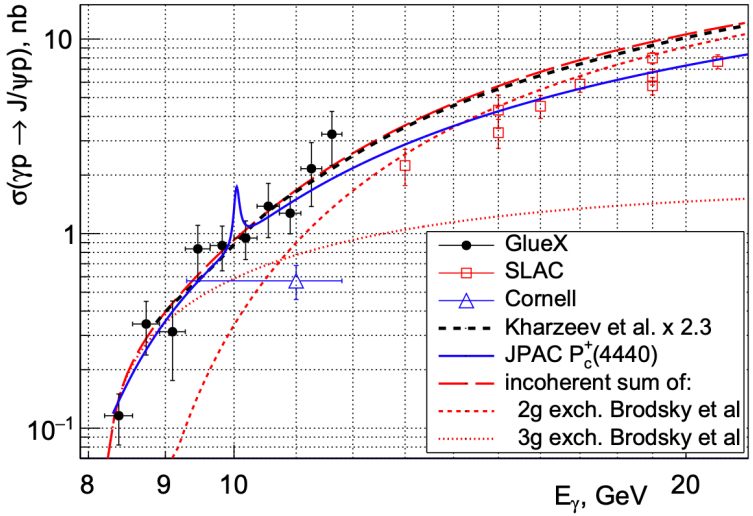
This talk:

- Mostly focus on this process with raw J/psi yield estimations and corresponding luminosity requirements.

J/psi photoproduction ($W_{\gamma p}$)

- High energy elastic J/psi was measured at HERA (H1, ZEUS) and LHC.
- Low energy elastic J/psi was measured by SLAC, Cornell, and GlueX recently.





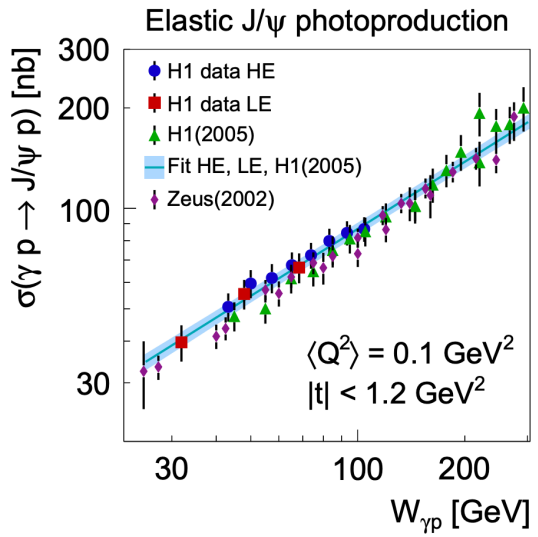
What we understand:

- Photoproduction ($Q^2 \sim 0$)
- Cross section as a function of $W_{\gamma p}$
- ***t***-slope for elastic and proton dissociative

What can EIC provide ?

Kinematics

Eur.Phys.J. C73 (2013) no.6, 2466



W dependence

H1:

W range:

1) @ HE: [40,110] GeV, E_p = 920 GeV
2) @ LE: [25,80] GeV , E_p = 460 GeV

Acceptance:

a) Daughters (leptons,ee+mumu):
-1.75< pseudorapidity < 2.0
(20<theta<165 degrees)

b) J/psi: -0.75 < Rapidity(J/psi) < 1.27
(decay products within ~ 1 unit of rapidity of mother)

Kinematics:

$W^2=2E_pM^*\exp(-rap)$

EIC for deuteron/proton:

Acceptance:

a) Daughters (leptons, ee+mumu)
-4< pseudorapidity < 4

b) Jpsi: -3 < Rapidity(J/psi) < 3

W range acceptance:

I. @HE ep: [14,129] GeV, E_N=275 GeV
II. @HE eD (incoh): [9,82] GeV, E_N=110 GeV

+constraint on y between 0.01 < y < 0.85

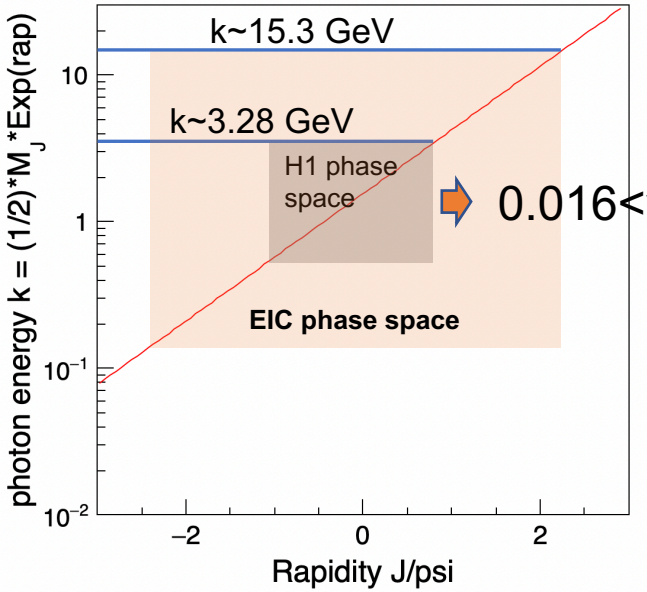
Kinematics

Photon energy k = 1/2 M_J *Exp(-rap), with y cut on the scattered electron, the selection defines the J/psi rapidity range:

At the EIC with 18 GeV electron, using a cut of **(0.01 < y < 0.85),**

W range acceptance:

I. @HE ep: [14,129] GeV, E_N=275 GeV
II. @HE eD (incoh): [9,82] GeV, E_N=110 GeV



Well within EIC acceptance

-2.3 < rapidity of J/psi < 2.2

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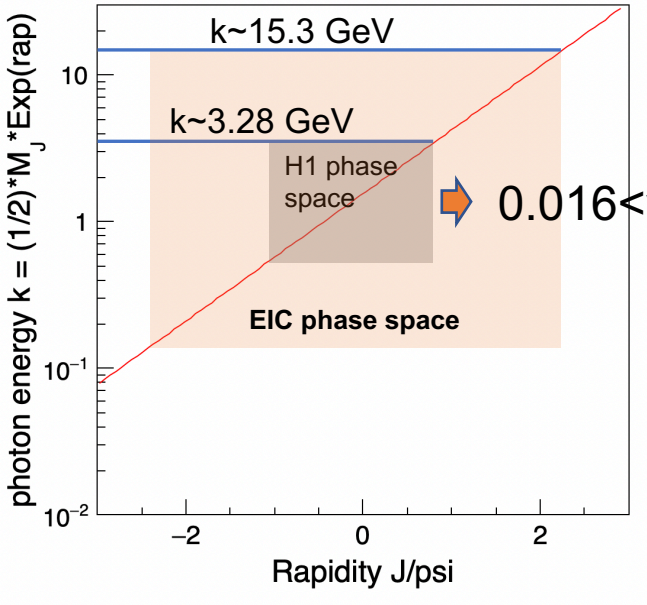

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➡ Well within EIC acceptance

-2.3 < rapidity of J/psi < 2.2

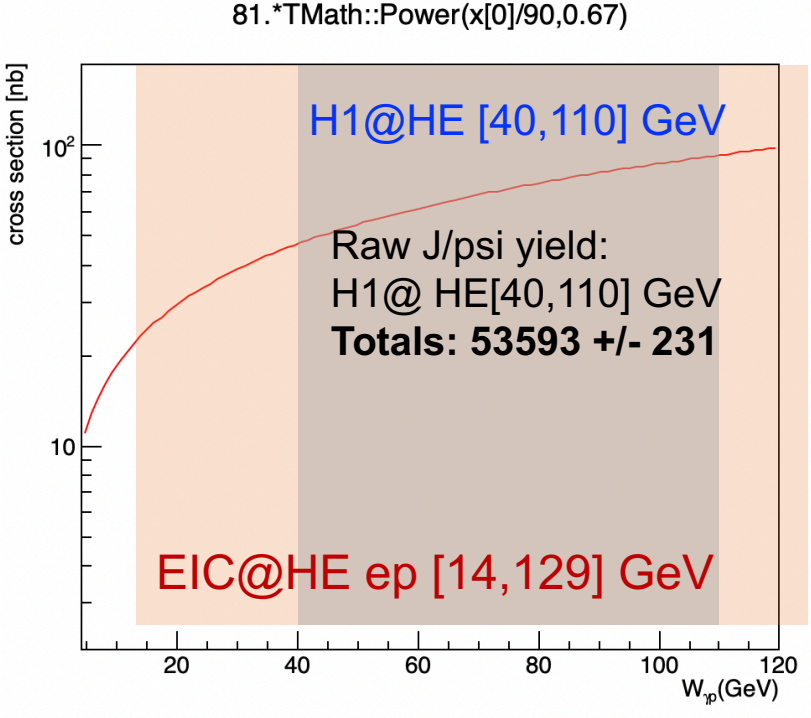
Short take away:

1. At H1/ZEUS, the rapidity selection limits the photon energy, so as the W range. The inelasticity y range used in the measured W range at H1 is only (0.016<y<0.12)

2. At the EIC, the wider acceptance results in a wider W range, if compared for proton.

EIC coverage

Cross section in gamma-proton



*Cross section extrapolation to low energy might not be correct, but overall smaller cross section

(Luminosity @ H1 ~ 130 pb^{-1})

Ratio of W-integrated cross section:

1. H1@HE[40,110] / EIC@HE ep[14,129] = 64%
2. H1@HE[40,110] / EIC@HE eD[9,82] = 1.36

$$\frac{N_{Jpsi,H1}}{N_{Jpsi,EIC}} = \frac{\sigma_{H1}}{\sigma_{EIC}} \cdot \frac{\Phi_{H1}}{\Phi_{EIC}}$$

where σ is W-integrated cross section, and ϕ is y-integrated transverse photon flux.

(JR Smith, BD Burow, 93)

Transverse photon flux for photoproduction

$$\frac{dL_T}{dy} \approx \frac{\alpha}{2\pi}\left([1+(1-y)^2]\log\frac{(1-y)Q^2_{max}}{m_e^2y^2} - 2(1-y) + \frac{2m_e^2y^2}{Q^2_{max}}\right)$$

Integrate over y range at H1 and EIC

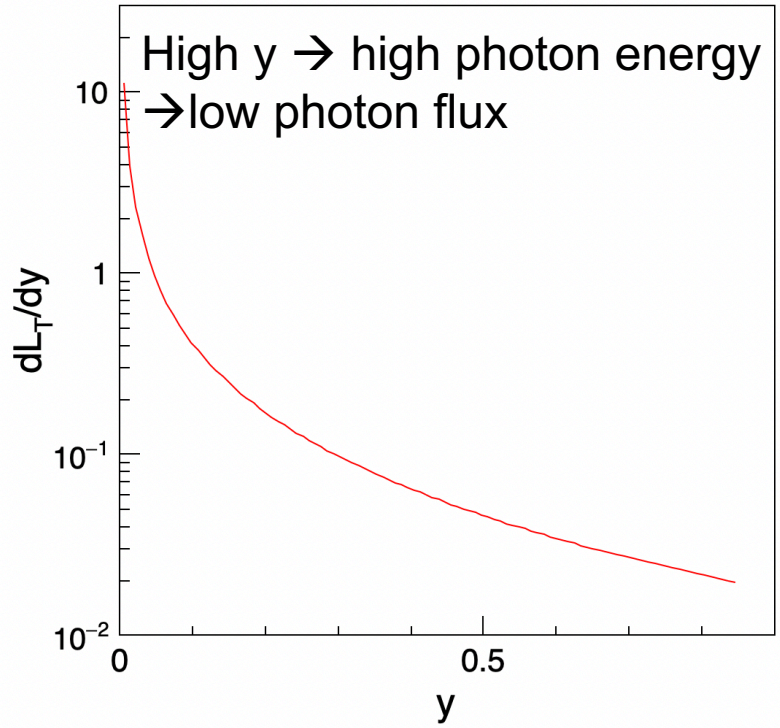
$$\frac{\Phi_{H1}}{\Phi_{EIC}} = 53\%$$

Photoproduction J/psi for ep at EIC with 0.13 fb^{-1}:

EIC@ HE ep, W[14,129] ~ 155k +/- 400 J/psi
EIC@ HE eD(incoh), W[9,82] ~ **74k +/- 270** J/psi

Photon flux @ small Q2

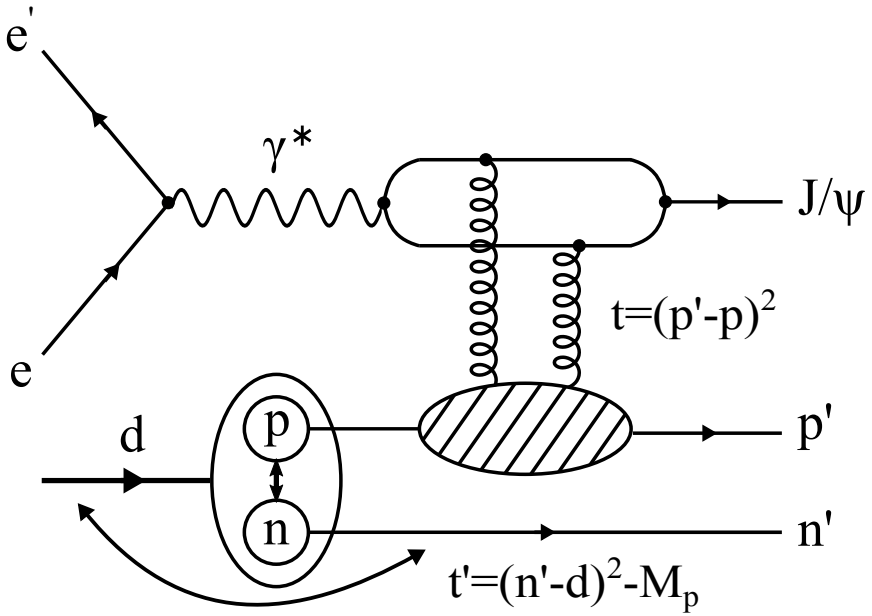
$$\frac{dL_T}{dy} \approx \frac{\alpha}{2\pi}\left([1+(1-y)^2]\log\frac{(1-y)Q^2_{max}}{m_e^2y^2} - 2(1-y) + \frac{2m_e^2y^2}{Q^2_{max}}\right)$$



- For small Q2 limit, e.g., photoproduction limit, the energy difference of the electron (18 GeV vs 27 GeV) does not make a difference!
- For very small electron beam energy, when Q2 is not small compared to beam energy, this approximation breaks down. For the EIC energy, this approximation works well.

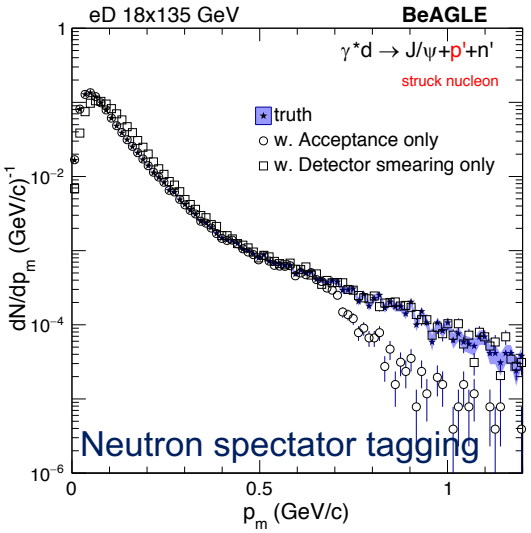
Photon flux determines the J/psi yield in the experiment, so as statistical precisions!

SRC in Deuteron - photoproduction



Caveat: no additional effect

$$\sigma(\gamma + d \to VM + p' + n')\Big|_{spectator\ tagging} = \sigma(\gamma + p \to VM + p') \otimes \sigma(p_m)$$



Total number of events ~ **300k J/psi** per case simulated in BeAGLE

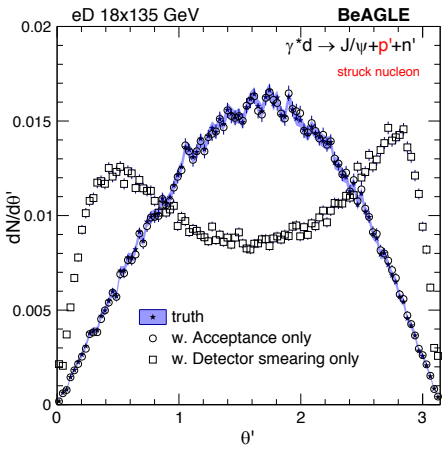
P$_m$ (GeV)	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Neutron tagging	20966	3288	1022	103
Proton tagging	20014	3069	930	105

This is differential in P$_m$ only

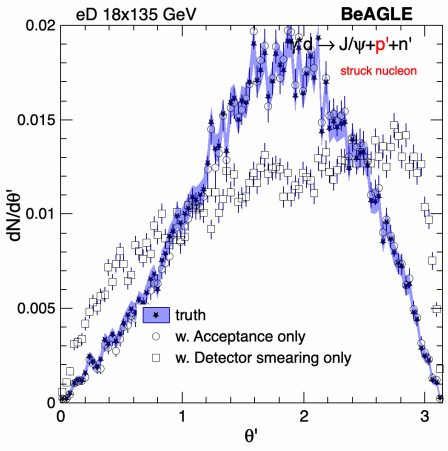
Scattering angle θ_{nq}

Reminder of angle between photon and spectator

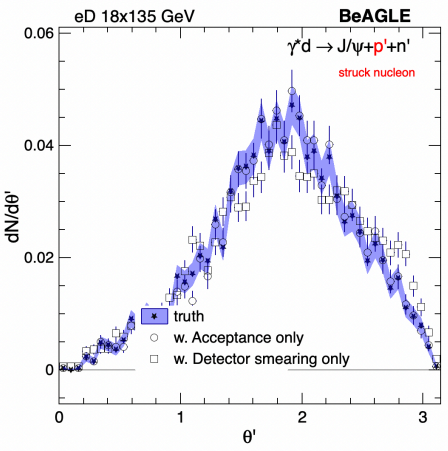
Pm~0-0.2



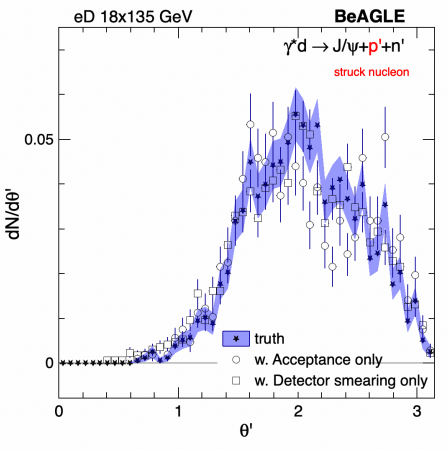
Pm~0.2-0.4



Pm~0.4-0.6



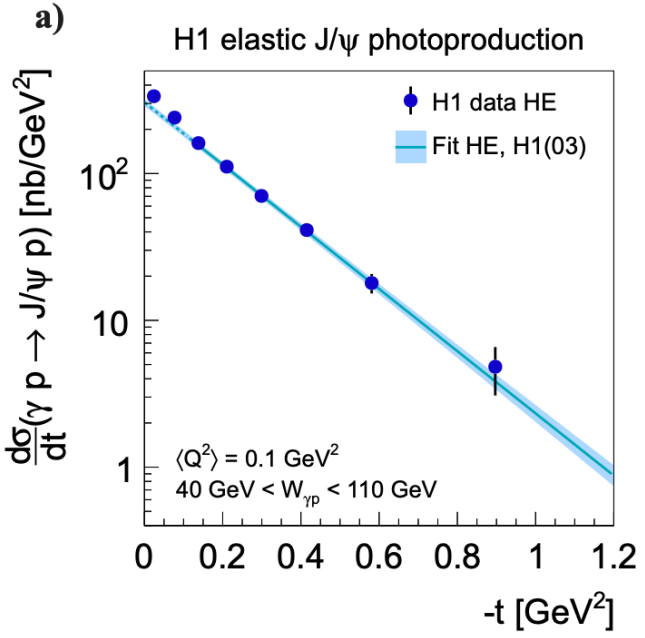
Pm~0.6-0.8



P_m(GeV)

Angle	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Theta(0,1)	2887	234	7	0
Theta(1,2)	11412	1756	444	13
Theta(2,3)	7691	1297	486	94

Luminosity requirements



$\lvert t\rvert$ range [GeV^2]	$\langle \lvert t\rvert^{bc} \rangle$ [GeV^2]	$\frac{d\sigma}{d\lvert t\rvert}(\langle \lvert t\rvert^{bc} \rangle)$ [nb/GeV^2]	Δ_{tot} [nb/GeV^2]	Δ_{comb} [nb/GeV^2]
High energy data period for elastic J/ψ production				
0.00 - 0.05	0.02	336	18	11
0.05 - 0.11	0.08	240.5	12.9	7.2
0.11 - 0.17	0.14	161.2	9.3	5.5
0.17 - 0.25	0.21	111.4	7.0	4.1
0.25 - 0.35	0.30	70.4	5.1	3.2
0.35 - 0.49	0.41	41.2	3.7	2.2
0.49 - 0.69	0.58	18.0	2.7	1.4
0.69 - 1.20	0.90	4.83	1.75	0.67

Last t bin is ~ 13% statistical uncertainty

H1 measurement :

- J/psi elastic production
- [40,110] in W range
- Q2~0 photoproduction

Totals: 53593 +/- 231

In order to achieve the same statistical precision at EIC with:

- eD→J/psi+p+n
- [14,129] GeV in W range
- Q2 ~ 0 photoproduction
- Double differential in Pm and theta

Matched 53k J/psi in this bin to attain the same t distribution

Luminosity requirements

For every bin to achieve the same statistical precision as H1

Luminosity in fb^{-1}

	Pm(0.2-0.4)	Pm(0.4-0.6)	Pm(0.6-0.8)	Pm(0.8-1.0)
Theta(0,1)	10	119	>3000	>>2700
Theta(1,2)	3	16	62	2700
Theta(2,3)	4	21	57	281
Total	1	8	27	280

Quick conclusion:

- 100 fb^{-1} per year would allow us to reach 0.6-0.8 GeV internal nucleon momentum at the highest center-of-mass energy at EIC after the first year (best scenario)

Theoretical uncertainty:

- J/psi cross section as a function of P_m stays constant?
- Gluon shadowing effect or off-shell nucleon cross section
- FSI …
- … or something we don't know

Electroproduction of J/psi

- Diffractive J/psi electroproduction in γp had been measured at HERA as well, and together with other VMs.
- Higher W range was attempted up to 160 GeV in electroproduction, and 305 GeV in photoproduction

(a different, and earlier publication from H1)

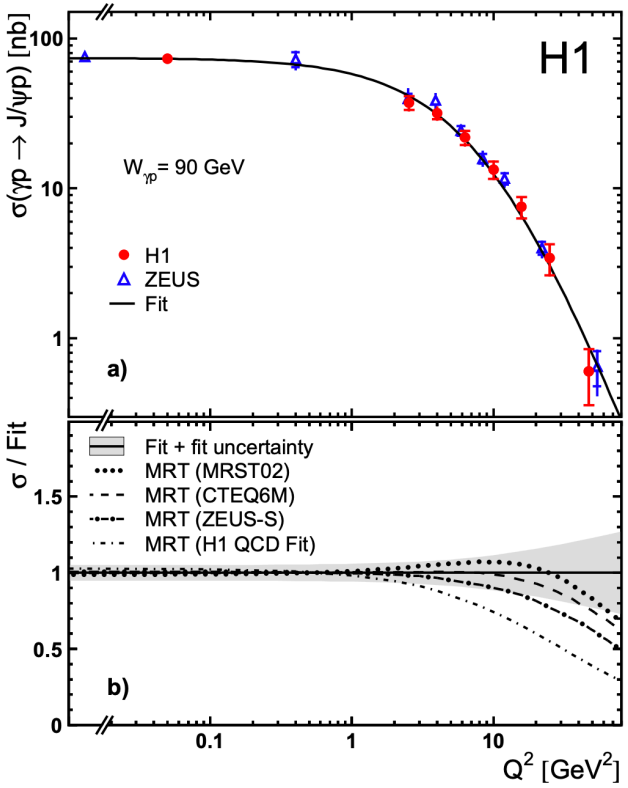
Data set	I	II	III	IV
Kinematic region	Electroproduction	Photoproduction		
Q^2 range $[\mathrm{GeV}^2]$	$2-80$	<1		
$\langle Q^2 \rangle$ $[\mathrm{GeV}^2]$	8.9	0.05		
$W_{\gamma p}$ [GeV]	$40-160$		$135-235$	$205-305$
$\lvert t \rvert$ $[\mathrm{GeV}^2]$	<1.2			
Decay channel	$J/\psi \to \mu^+\mu^-$		$J/\psi \to e^+e^-$	
Lepton signature	Track-Track		Track-Cluster	Cluster-Cluster
Lepton polar angle region [°]	$20-160$		$\theta_1 : 80-155$ $\theta_2 : 160-177$	$\theta_1 : 160-174$ $\theta_2 : 160-175.5$
Lepton energy [GeV]	$p_t > 0.8$		$p_{t,1} > 0.7, p_1 > 0.8$ $E_2 > 4.2$	$E_{1,2} > 4.2$ $\max(E_1, E_2) > 6$
Elastic selection	No signal in forward detectors			
$\int L\,dt$ $[\mathrm{pb}^{-1}]$	54.79		30.26	26.90

Table 1: Summary of the most important event selection criteria for the four different data sets together with the corresponding integrated luminosities.

H1 measurement

Electroproduction of J/psi

- Two major factors are needed for estimating luminosity requirements for J/psi electroproduction in eD or ep collisions at the EIC.
  - Q^2 dependence of cross section
  - Total photon flux including both components



$$\sigma_{\gamma p} = \sigma_{\gamma p}^{T} + \varepsilon \sigma_{\gamma p}^{L}$$

Total photon flux including transverse and longitudinal depends on both y and Q2

Polarization parameter ϵ is close to 1 at HERA kinematics.

Electroproduction of J/psi

When Q^2/W^2 is small, one can derive [Bon73, Bud75, Sch98]

$$f^{\mathrm{T}}_{\gamma/l}(y,Q^2) = \frac{\alpha_{\mathrm{em}}}{2\pi}\left(\frac{(1+(1-y)^2}{y}\frac{1}{Q^2} - \frac{2m_l^2 y}{Q^4}\right)$$

$$f^{\mathrm{L}}_{\gamma/l}(y,Q^2) = \frac{\alpha_{\mathrm{em}}}{2\pi}\frac{2(1-y)}{y}\frac{1}{Q^2},$$

- For the W range EIC can have for eD incoherent J/psi production, W is [9,82] GeV, with <W> ~ 35 GeV. So Q2/W2 is << 1 for bins like, **Q^2 (8,12.7) GeV^2**
- **Total photon flux is ~** 0.047, it's about 26% of flux comparing to photoproduction for the same W range.
- Cross section ratio between Q^2(8,12.7)/Q^2 (0,1) is about 20%.
- **Total reduction factor is 20.**

Luminosity requirements for electroproduction

To achieve the same precision as in photoproduction

Luminosity in fb^{-1}

	Pm(0.2-0.4)	Pm(0.4-0.6)	Pm(0.6-0.8)	Pm(0.8-1.0)
Theta(0,1)	10x20	119x20	>3000x20	>>2700x20
Theta(1,2)	3x20	16x20	62x20	2700x20
Theta(2,3)	4x20	21x20	57x20	281x20
Total	1x20	8x20	27x20	280x20

Conclusion:

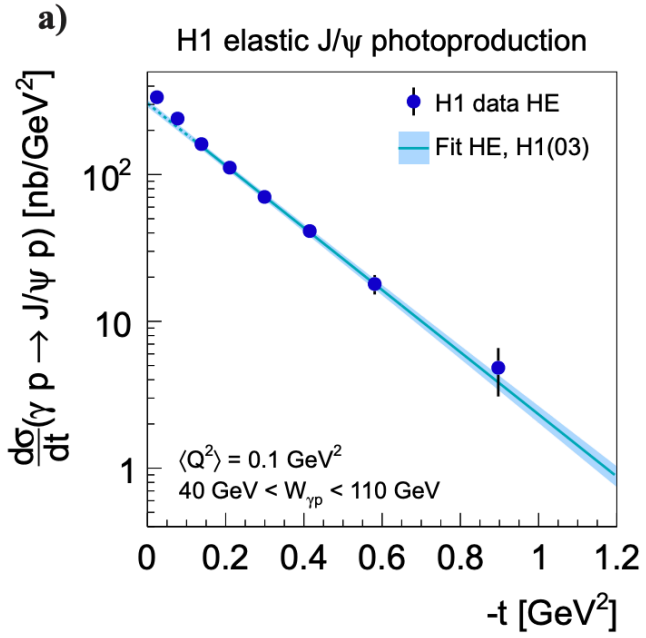
- W [9,82] GeV
- Q^2 [8,12.7] GeV^2
- eD incoherent J/psi electroproduction
- Spectator Pm (0.6,0.8)

500 fb^{-1}

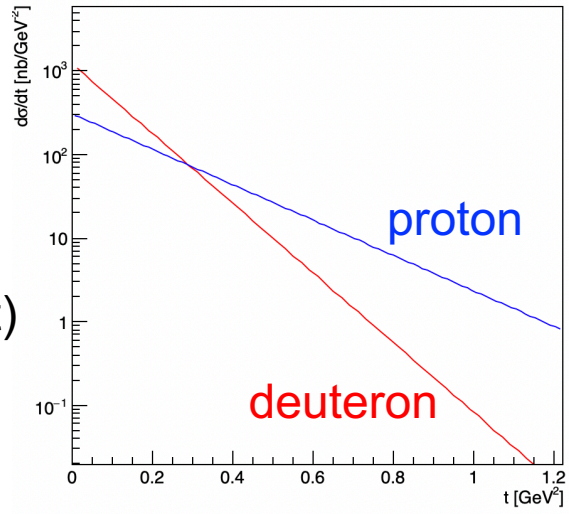
If lower requirement or precision that last ***t*** bin (0.69,1.2) GeV^2 has 30% uncertainty instead of 13%,

100 fb^{-1}

Digression – coherent J/psi off deuteron



(Fair) assumptions:
dσ/dt @t=0 is ~ A^2
Slope ~ 1/(size of target)



<$W_{\gamma p}$> ~ 78 GeV, integral over [0,1.2] in ***t***:
~ 62 nb for proton
~ 125 nb for deuteron (coherent)

The question is, what is the <$W_{\gamma d}$> in order to have this relation between the cross section?

$W_{\gamma p}$=78 GeV@ H1 → 1.65 GeV in photon energy
$W_{\gamma N}$=78 GeV@ EIC → 13.82 GeV in photon energy
(110 GeV per nucleon energy for deuteron beam)

If k = 13.82 GeV photon,
$W_{\gamma d}$ = sqrt($4E_d k$) ~ 110 GeV

Coherent cross section should be a factor of ~ 2 more

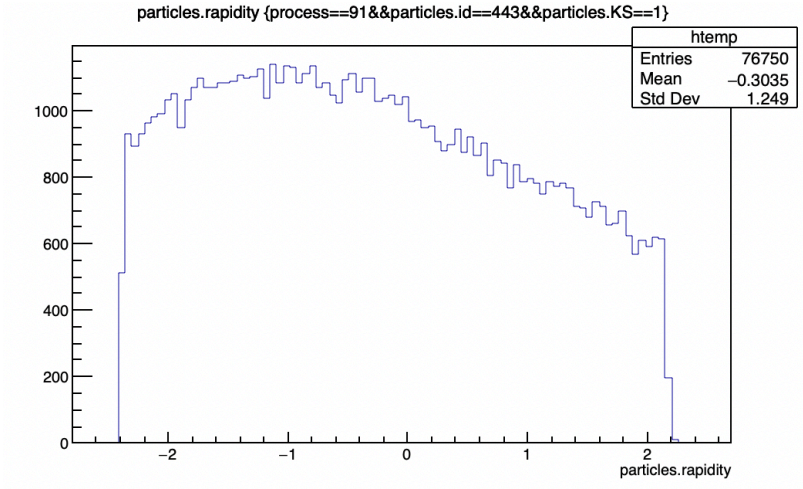
Summary

- First estimate of luminosity requirements for eD exclusive J/psi production at the EIC
  - Photoproduction
  - Electroproduction
- The cross sections are based on photon-proton system for elastic J/psi production
- Statistical precisions are based on H1 published results
- Photon flux are considered for number of events, both transversely and longitudinal polarized photons.
- All estimations assume same or better detector efficiency for J/psi decay

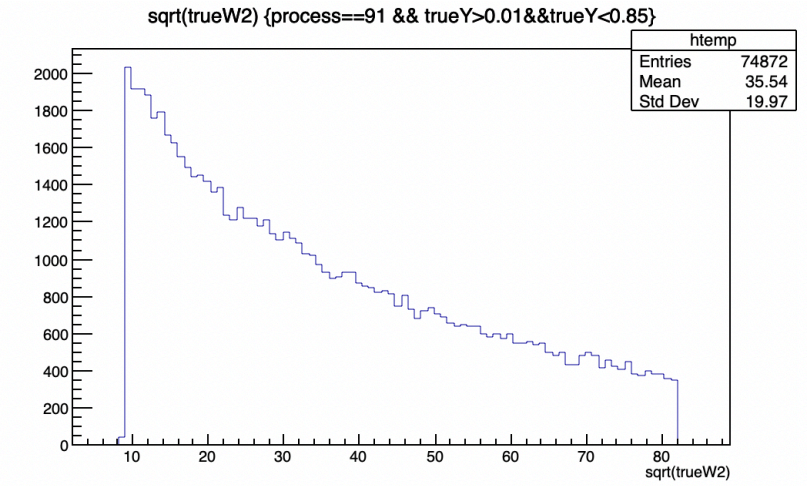
- For non-SRC type of physics, the luminosity requirement will be much lower and should not be a problem.

Backup

BeAGLE ep MODE 18x110 GeV



rapidity



W