EIC-Smear Simulations of XYZ production

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Exclusive Photoproduction (Quasi-real)

Observation of XYZ states in photoproduction
- independent confirmation

Different production mechanism, different kinematics

Measurement of polarisation observables and photocouplings
- insights into production mechanisms and internal structure

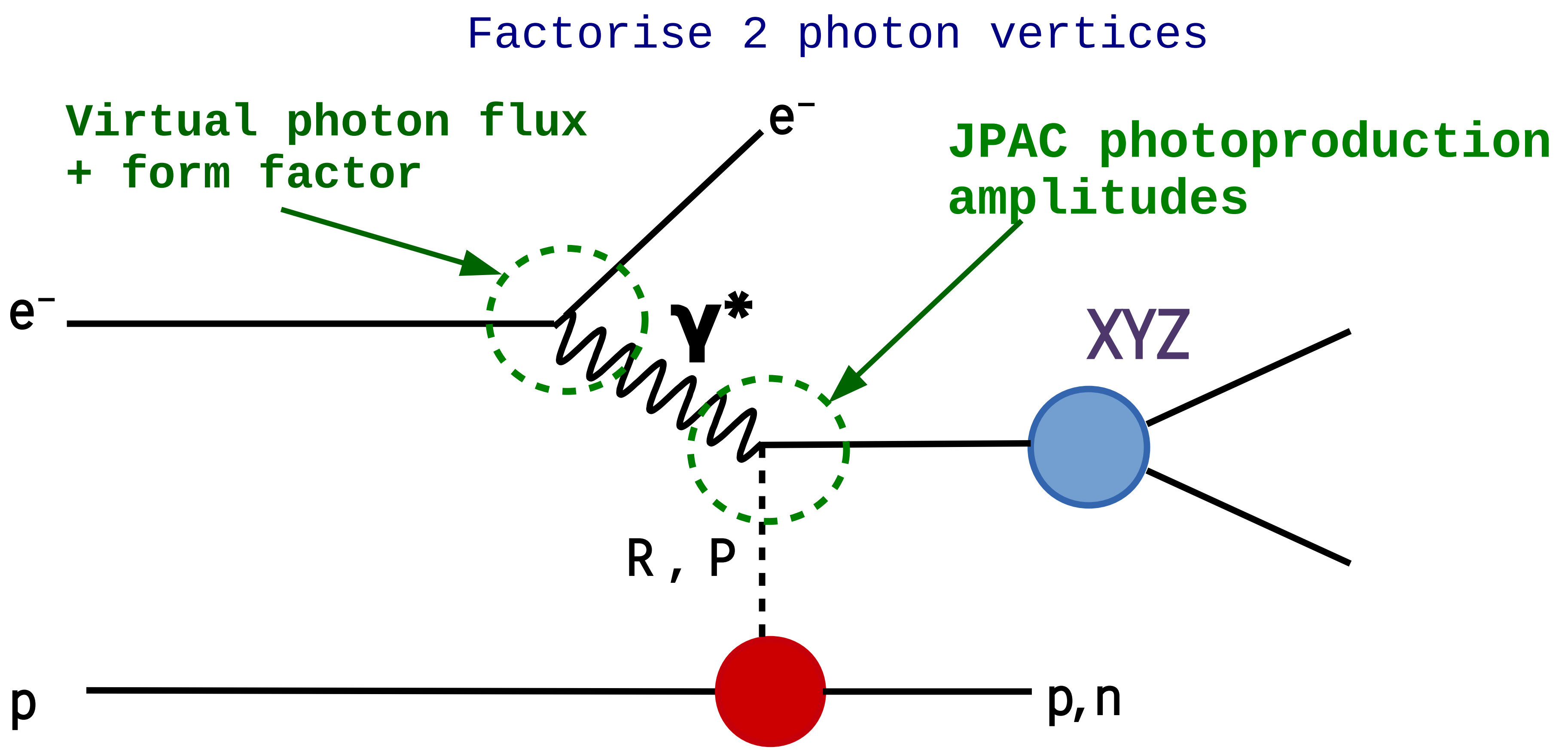
XYZ spectroscopy at electron-hadron facilities: Exclusive processes

M. Albaladejo, A. N. Hiller Blin, A. Pilloni, D. Winney, C. Fernández-Ramírez, V. Mathieu, and A. Szczepaniak
(Joint Physics Analysis Center)
Phys. Rev. D **102**, 114010 – Published 7 December 2020

- qualitative behaviour and order of magnitude estimates

See D.Winney
Exotic Spectroscopy
at the EIC

Event Generator (Pictorial)



Event Generator (Formal)

$$\frac{d^4\sigma}{ds\,dQ^2\,d\phi\,dt} = \frac{d^2\sigma_{e,\gamma * e'}}{dsdQ^2}\,\frac{d^2\sigma_{\gamma * + p\to V+p}(s,Q^2)}{d\phi\,dt}$$

→ Integrate for event rate

$$\frac{d^2\sigma_{e,\gamma * e'}}{dsdQ^2} = \frac{\alpha}{2\pi}\cdot\frac{K.L}{E}\cdot\frac{1}{Q^2}\cdot\frac{1}{(s-M^2+Q^2)}$$

$$Q^2 = 2\,E\,M\,x\,y$$

$$W^2 = M^2 + 2\,E\,M\,y - Q^2$$

$$L = \frac{1+(1-y)^2}{y} - \frac{2m_e^2\,y}{Q^2}$$

$$K = \frac{W^2-M^2}{2\,M} = \nu(1-x) = Ey(1-x) = \nu - \frac{Q^2}{2\,M}$$

$$\frac{d^2\sigma_{\gamma * + p}}{d\phi\,dt} = \frac{d\sigma^T(Q^2,s)}{d\phi\,dt} + (\epsilon+\delta)\frac{d\sigma^L(Q^2,s)}{d\phi\,dt}$$

$$\frac{d^2\sigma^T(Q^2,s)}{d\phi\,dt} = \frac{d^2\sigma_{\gamma+p\to V+p}}{d\phi\,dt}\,F(Q^2)$$

$$\frac{d^2\sigma^L(Q^2,s)}{d\phi\,dt} = 0$$

$$\frac{d^2\sigma_{\gamma+p\to V+p}}{d\phi\,dt} = \frac{1}{128\,\pi^2\,s}\,\frac{1}{|\mathbf{p}_{\gamma * cm}|^2}\,|M(s,t)|^2$$

→ $|M(s,t)|^2$ JPAC Photoproduction Amplitudes

Z(3900)

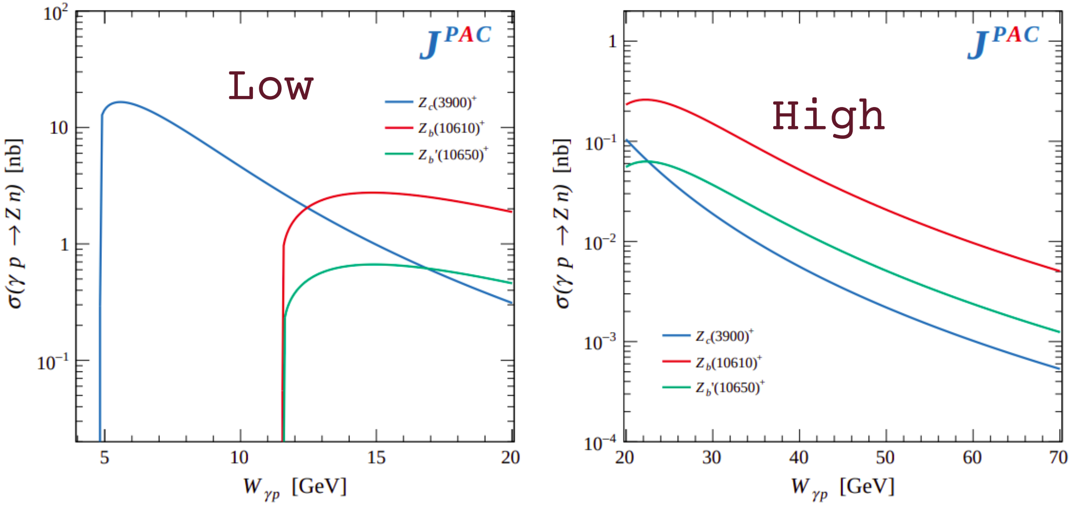
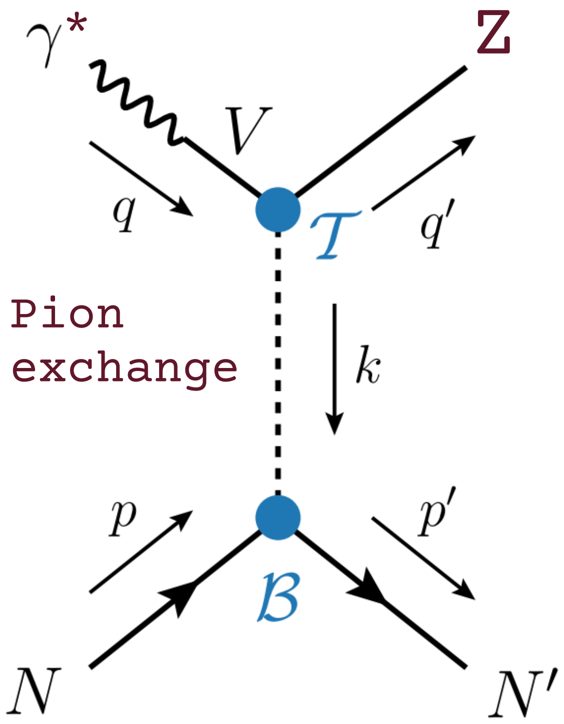


FIG. 2. Integrated cross sections for the three Z states considered. Left panel: predictions for fixed-spin exchange, which we expect to be valid up to approximately 10 GeV above each threshold. Right panel: predictions for Regge exchange, valid at high energies.



Larger at Low W,
Small at High W

Z(3900)

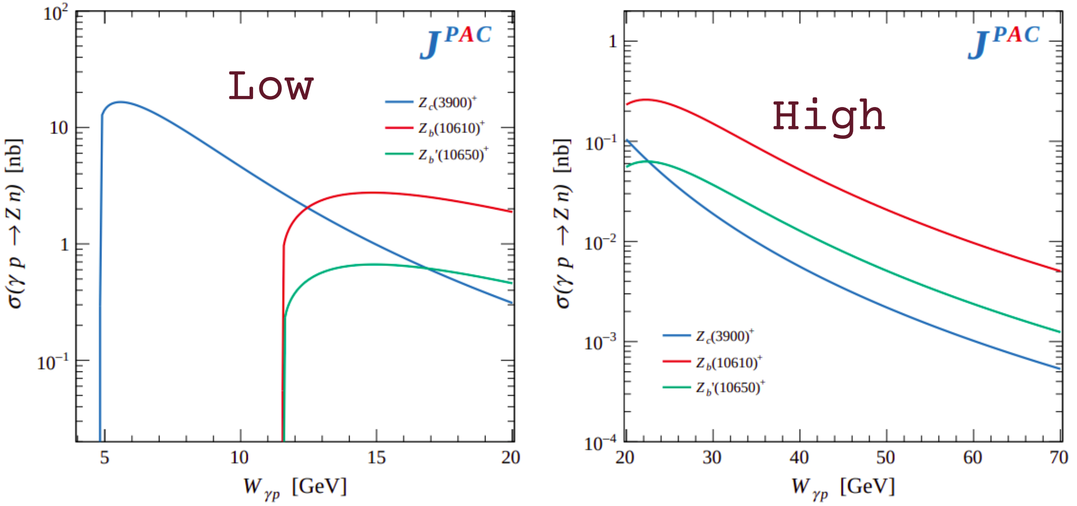


FIG. 2. Integrated cross sections for the three Z states considered. Left panel: predictions for fixed-spin exchange, which we expect to be valid up to approximately 10 GeV above each threshold. Right panel: predictions for Regge exchange, valid at high energies.

$e^- + p \to e^{-'} + Z(3900) + n$
$Z \to J/\psi\, \pi^+$ (10%)
$J/\psi \to e^+e^-$ (6%)

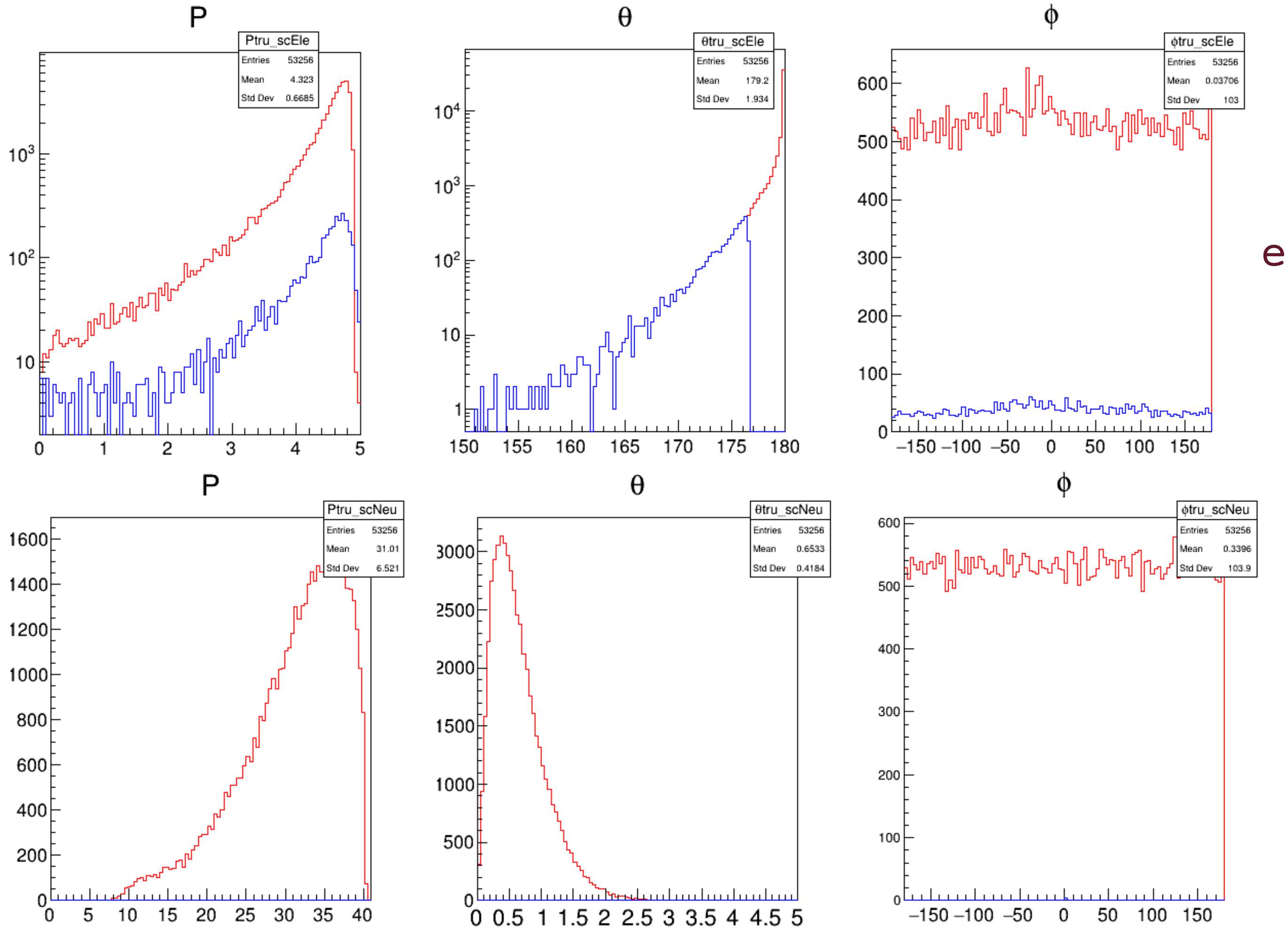
For 1 fb^{-1} ~11 days @ 10^{33}cm-2s-1

Use eic-smear with
MATRIXDETECTOR_0_2_B1_5T

Ngen → number generated
NZ → number detected
NZ e- → NZ with detected scattered electron

	Ngen low	NZ low	Nze- low	Ngenhigh	NZ high	NZe-high	Wmax
5-41	5.3k	4.8k	340	730	700	50	29
5-100	6.0k	4.0k	260	850	730	50	45
10-100	6.3k	4.3k	70	900	750	10	64
18-275	5.2k	2.2k	10	780	350	2	100

Z 5-41 low MATRIXDETECTOR_0_2_B1_5T

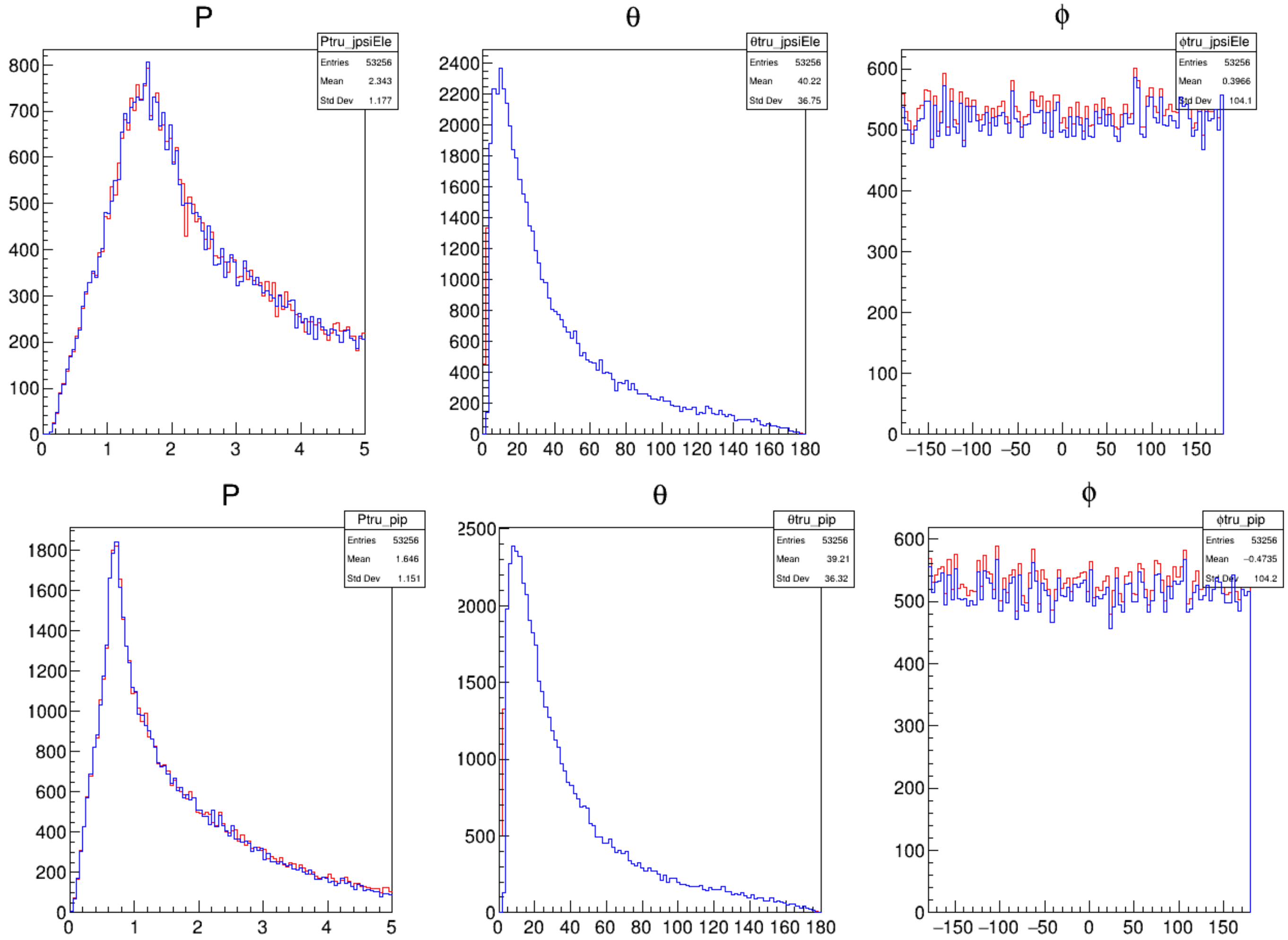


Generated
EIC-Smeared

e-'

n

Z 5-41 low MATRIXDETECTOR_0_2_B1_5T

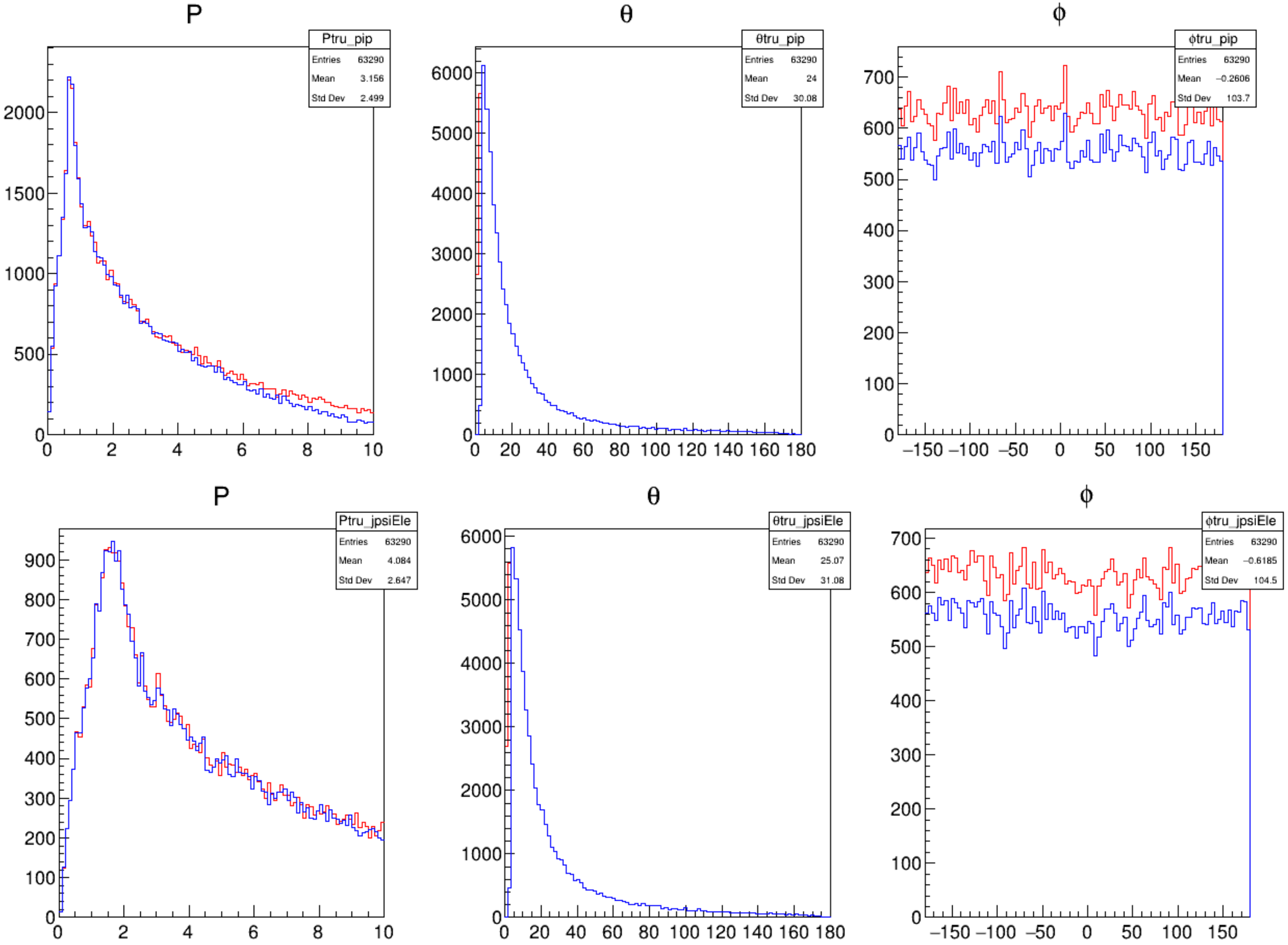


Generated
EIC-Smeared

π+

e- from J/ψ

Z 10-100 low MATRIXDETECTOR_0_2_B1_5T



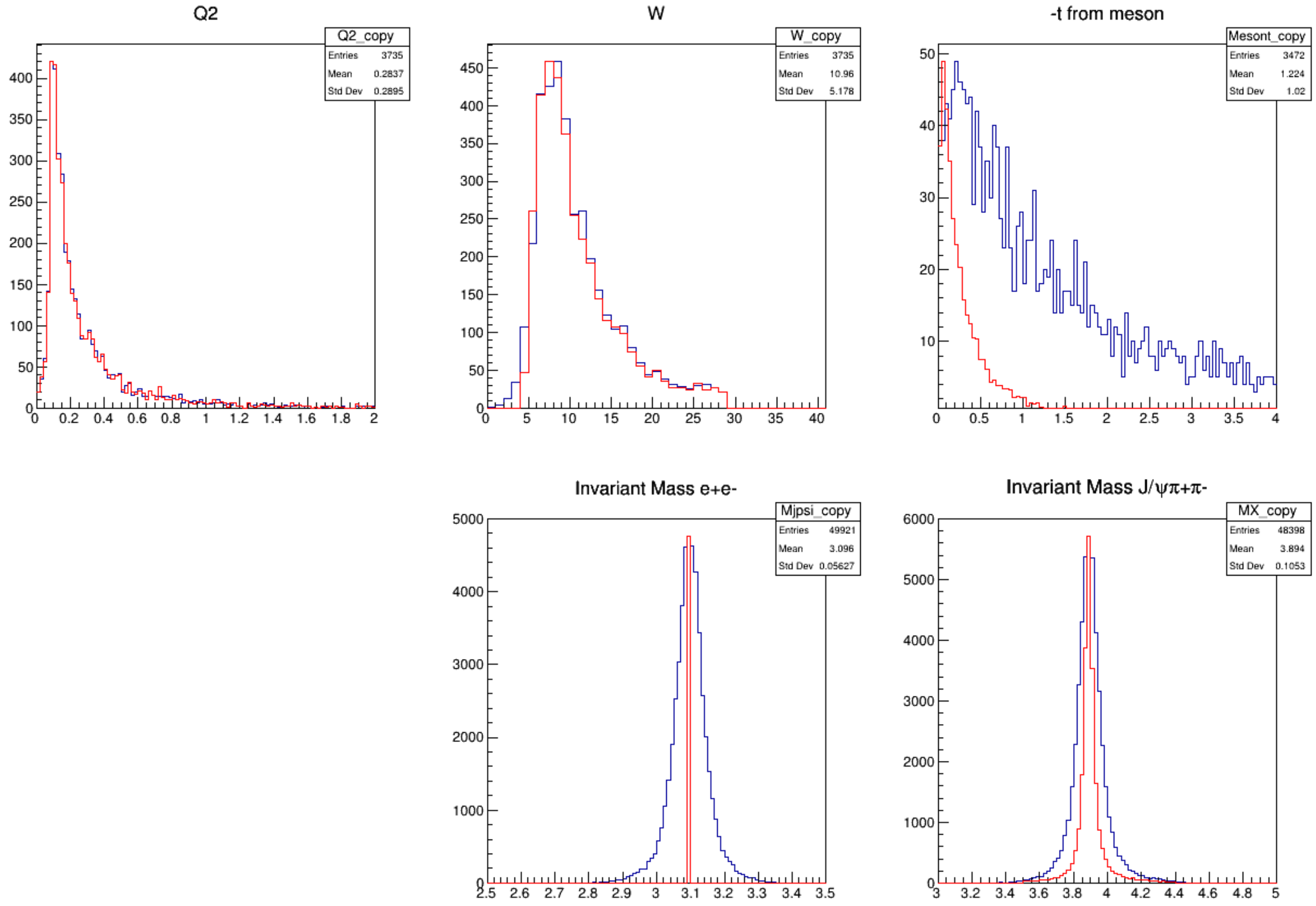
Generated
EIC-Smeared

π+

Lose some particles at forward angle

e- from J/ψ

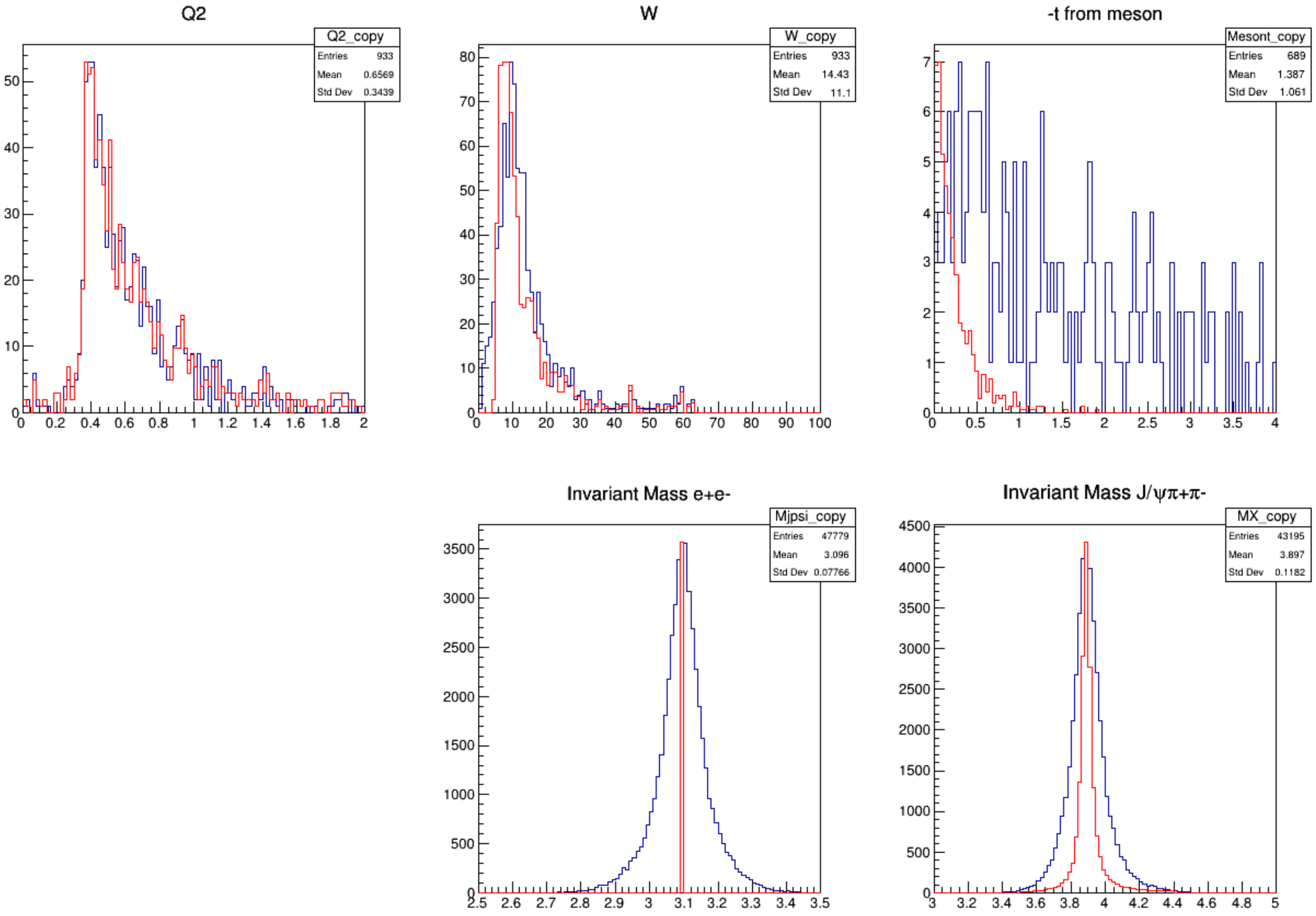
Z 5-41 low MATRIXDETECTOR_0_2_B1_5T



Generated
EIC-Smeared

Normalised to
Same max value

Z 10-100 low MATRIXDETECTOR_0_2_B1_5T



Generated
EIC-Smeared

Normalised to
Same max value

Y(4260)

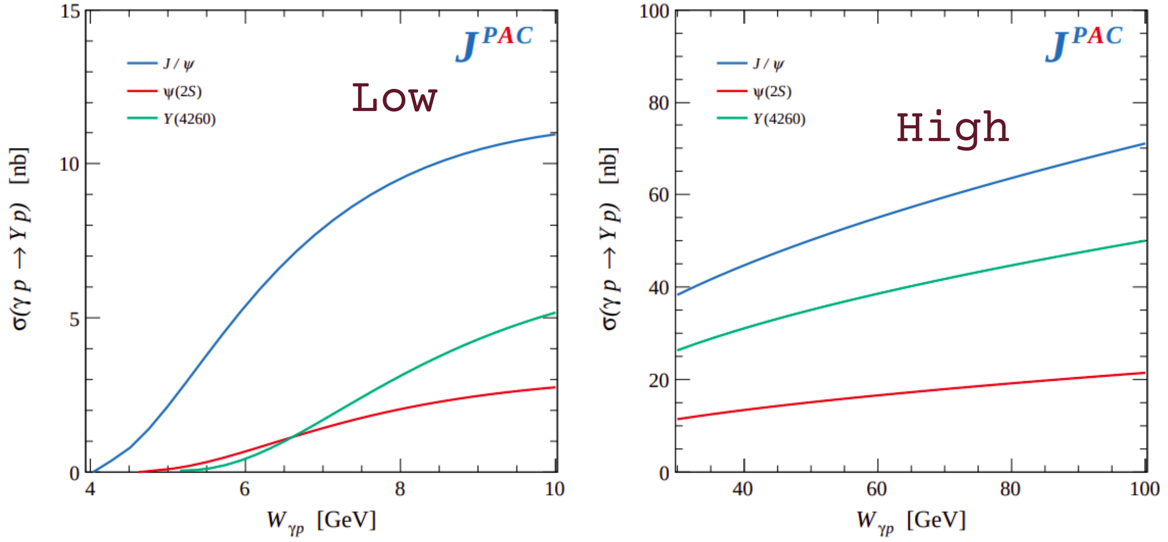
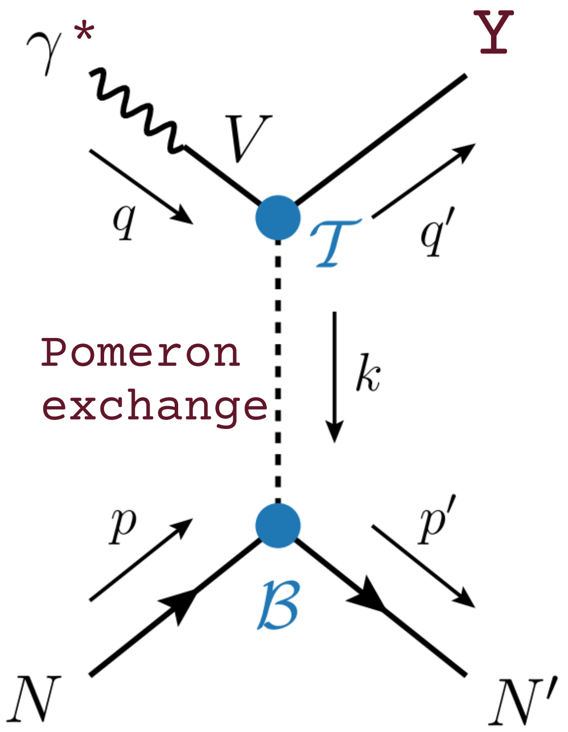


FIG. 7. Cross sections for $Y(4260)$ photoproduction compared to the J/ψ and $\psi(2S)$ at low (left) and high (right) energies.

Increases with W



Y(4260)

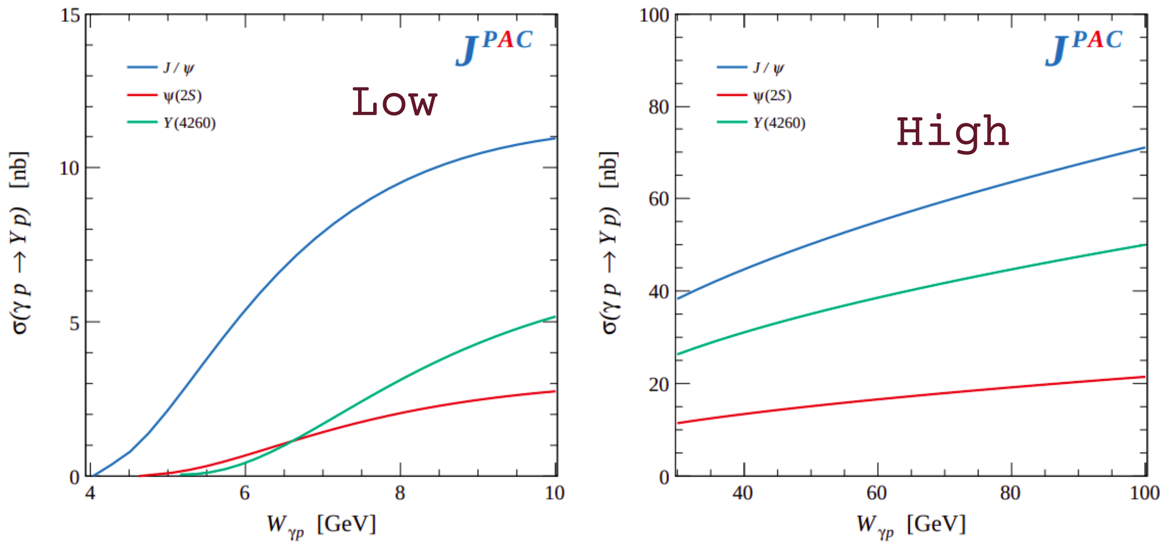


FIG. 7. Cross sections for $Y(4260)$ photoproduction compared to the J/ψ and $\psi(2S)$ at low (left) and high (right) energies.

$e^- + p \rightarrow e^{-'} + Y(4260) + p$

$Y \rightarrow J/\psi\ \pi^+\pi^+$ (1%)

$J/\psi \rightarrow e^+e^-$ (6%)

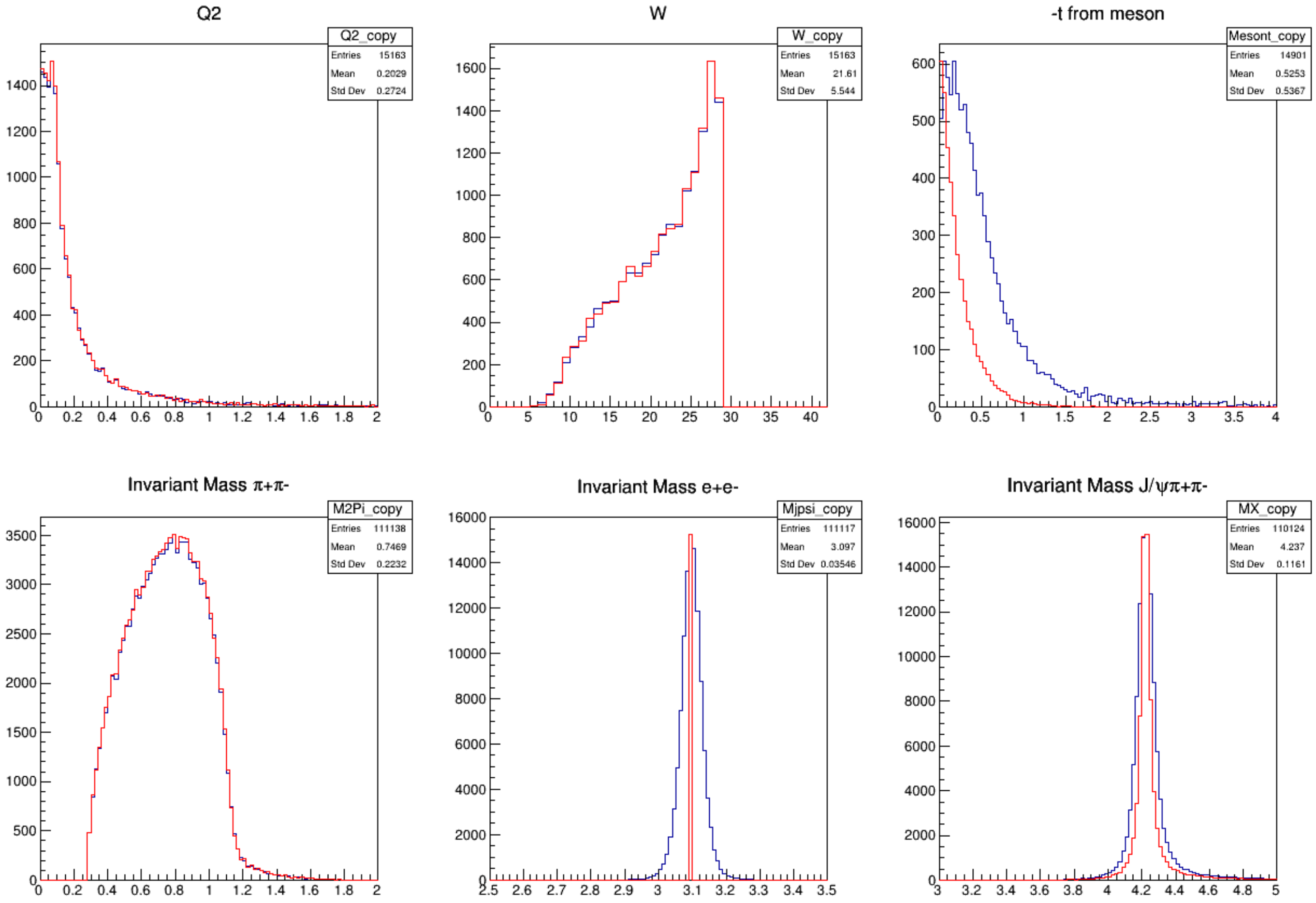
For 1 fb^{-1} ~11 days @ 10^{33}cm-2s-1

Use eic-smear with MATRIXDETECTOR_0_2_B1_5T

Ngen → number generated
NZ → number detected
NZ e- → NZ with detected scattered electron

	Ngen low	NY low	NYe- low	Ngenhigh	NY high	NYe-high	Wmax
5-41	1.12k	1.10k	140	2.55k	2.51k	390	29
5-100	1.24k	1.20k	150	3.76k	3.68k	540	45
10-100	2.27k	2.18k	110	4.44k	4.30k	280	64
18-275	1.84k	1.71k	28	5.22k	4.81k	110	100

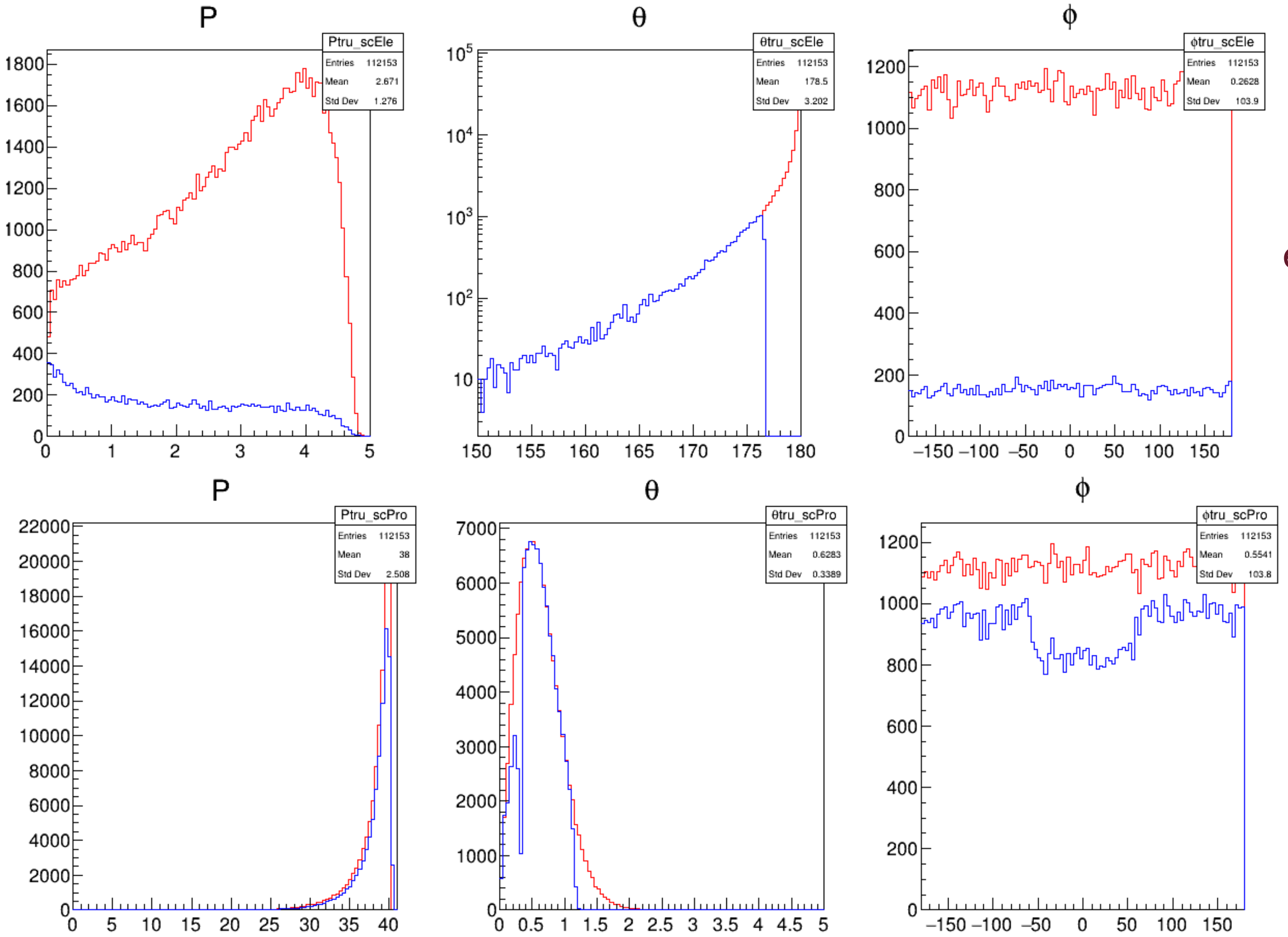
Y 5-41 low MATRIXDETECTOR_0_2_B1_5T



Generated
EIC-Smeared

Normalised to
Same max value

Y 5-41 low MATRIXDETECTOR_0_1_FF



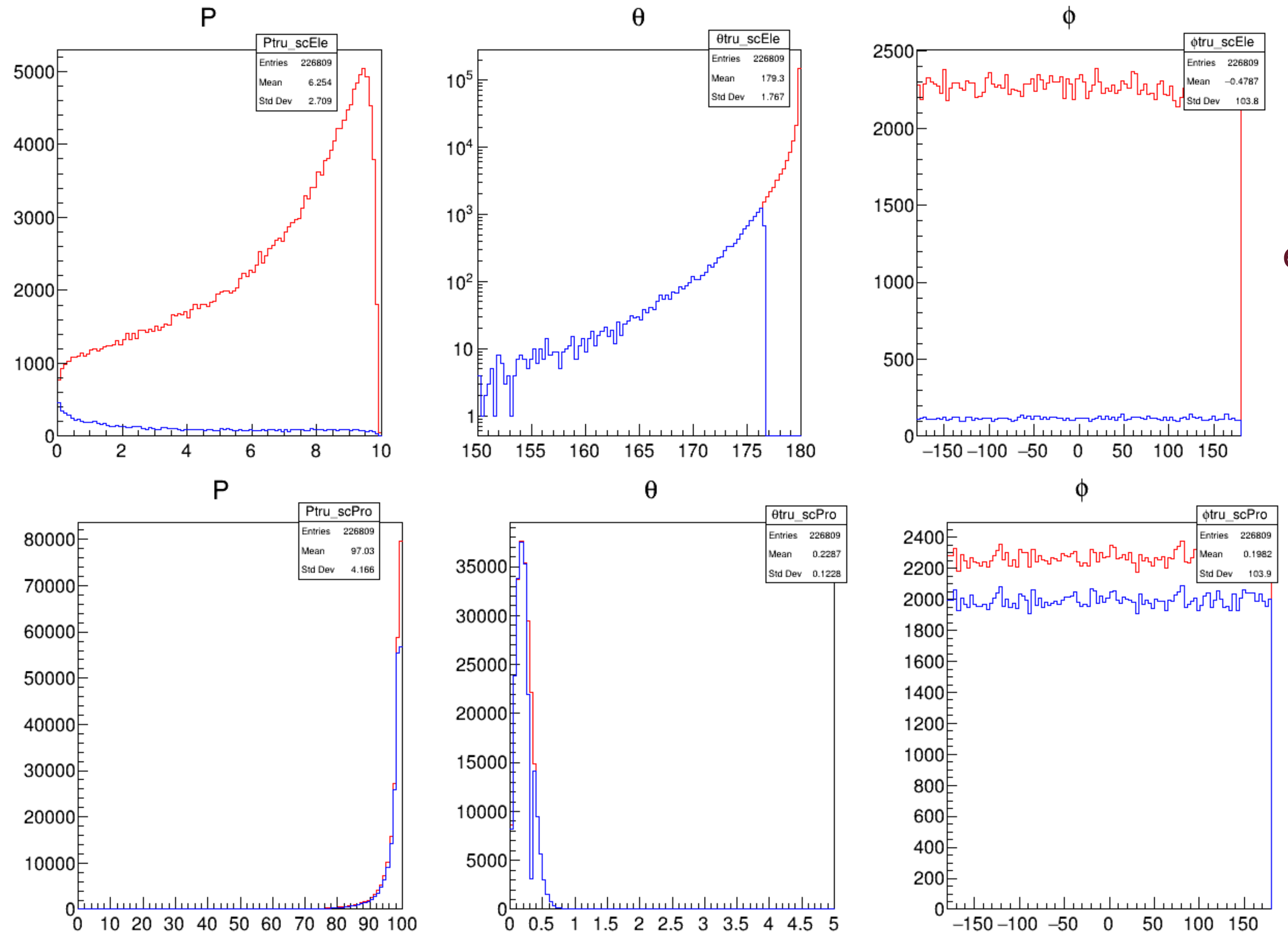
Generated
EIC-Smeared

e-’

Includes ion
Far Forward detectors

p

Y 10-100 low MATRIXDETECTOR_0_1_FF



Generated
EIC-Smeared

e-'

Includes ion
Far Forward detectors

p

X(3872)

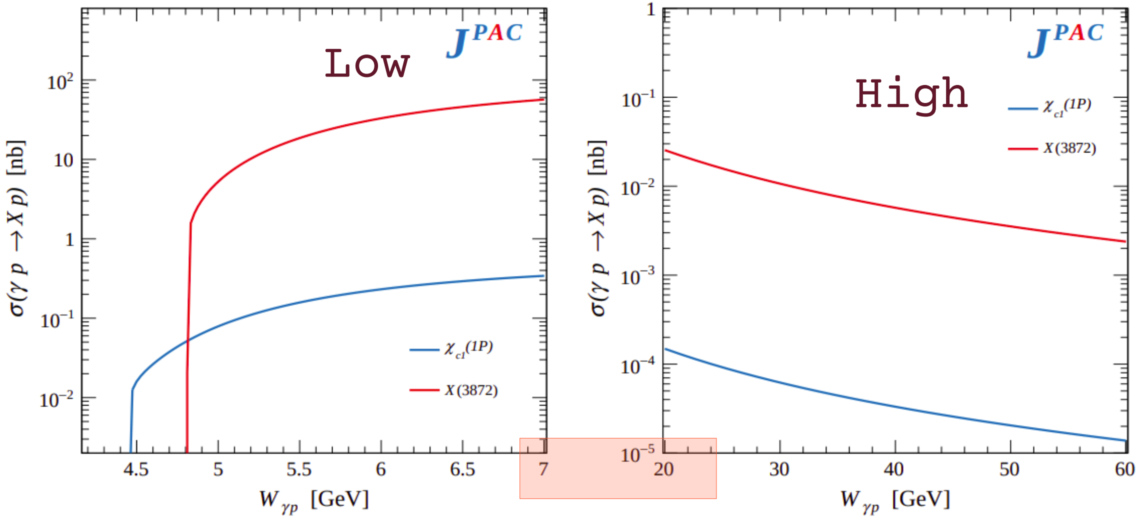
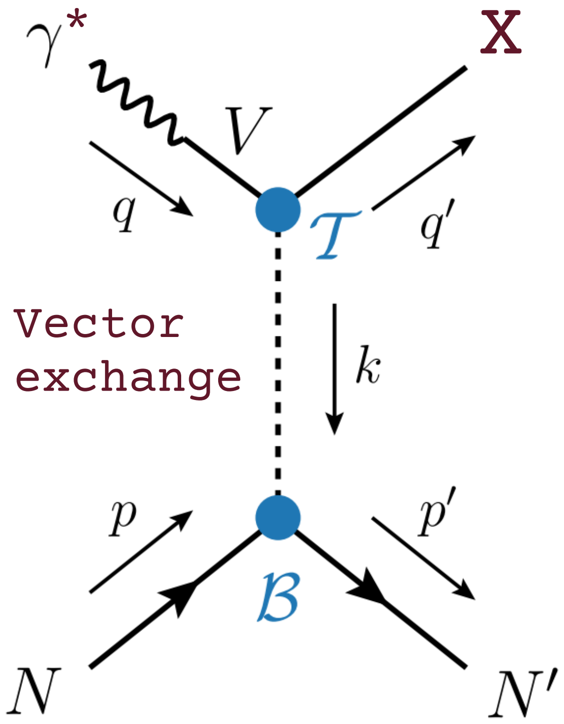


FIG. 3. Integrated cross sections for the axial $\chi_{c1}(1P)$ and $X(3872)$. Left panel: predictions for fixed-spin exchange, valid at low energies. Right panel: predictions for Regge exchange, valid at high energies.



Larger model uncertainty

X(3872)

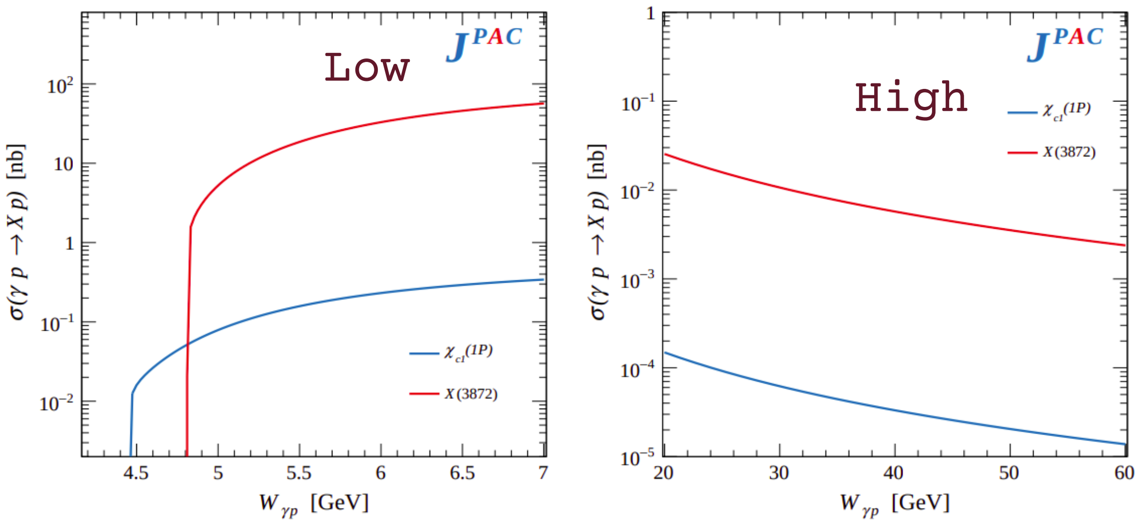


FIG. 3. Integrated cross sections for the axial $\chi_{c1}(1P)$ and $X(3872)$. Left panel: predictions for fixed-spin exchange, valid at low energies. Right panel: predictions for Regge exchange, valid at high energies.

$e^- + p \to e^{-'} + X(3872) + p$

$X \to J/\psi\, \pi^+\pi^+$ (5%)

$J/\psi \to e^+e^-$ (6%)

For 1 fb^{-1} ~11 days @ 10^{33}cm-2s-1

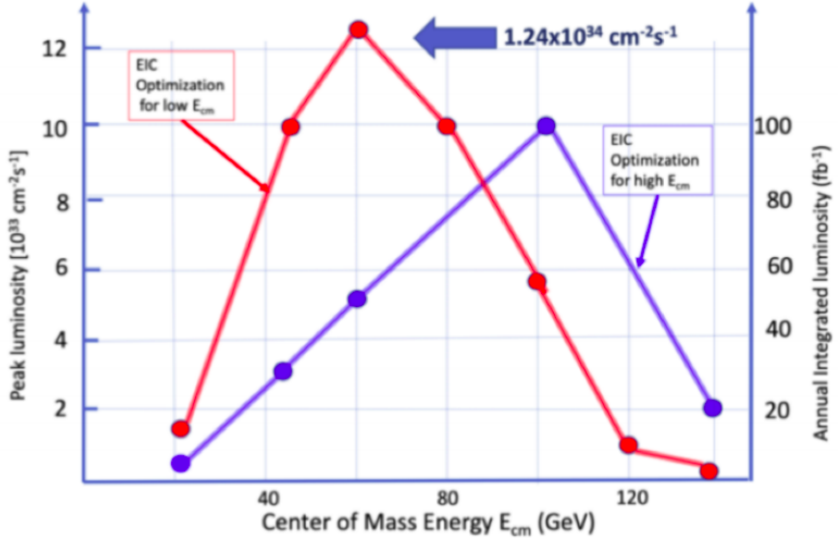
Use eic-smear with
MATRIXDETECTOR_0_2_B1_5T

Ngen → number generated
NZ → number detected
NZ e- → NZ with detected scattered electron

	Ngen low	NX low	NXe- low	Ngenhigh	NX high	NXe-high	Wmax
5-41	25k	24k	3.3k	16	16	1	29
5-100	28k	27k	3.5k	19	17	1	45
10-100	31k	30k	1.6k	21	19	0	64
18-275	31k	29k	0.5k	19	14	0	100

Luminosity

Luminosity The EIC is being designed to achieve peak luminosities between $10^{33}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ and $10^{34}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. To put these numbers into context, note that a luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with strong hadron cooling ($L_{\mathrm{peak}} = L_{\mathrm{avg}}$) yields an integrated luminosity of 1.5 fb^{-1} per month. Here we assume a 60% operation efficiency for the collider complex as routinely achieved by RHIC. Without strong hadron cooling for the same operation's parameters, one would get a 30% reduction, as the average luminosity L_{avg} per fill is reduced to 70% of the peak luminosity L_{peak}. Most of the key physics topics discussed in the EIC White Paper [2] are achievable with an integrated luminosity of 10 fb^{-1} corresponding to 30 weeks of operations. One notable exception is studying the spatial distributions of quarks and gluons in the proton with polarized beams. These measurements require an integrated luminosity of up to 100 fb^{-1} and would therefore benefit from an increased luminosity of $10^{34}\mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$. It should be noted that many measurements can be performed simultaneously by judiciously choosing beam species and their spin orientation appropriately.



Species	p	e	p	e	p	e	p	e	p	e
Beam energy [GeV]	275	18	275	10	100	10	100	5	41	5
$\sqrt{s}$ [GeV]	140.7		104.9		63.2		44.7		28.6	
No. of bunches	290		1160		1160		1160		1160	
	High divergence configuration									
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Luminosity [$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	1.54		10.00		4.48		3.68		0.44	
	High acceptance configuration									
RMS $\Delta\theta$, h/v [μrad]	65/65	89/82	65/65	116/84	180/180	118/86	180/180	140/140	220/380	101/129
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Luminosity [$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	0.32		3.14		3.14		2.92		0.44	

Table 10.1: Beam parameters for e+p collisions for the available center-of-mass energies $\sqrt{s}$ with strong hadron cooling. Luminosities and beam effects depend on the configuration. Values for high divergence and high acceptance configurations are shown.

Summary Table

Take 1 month @ $10^{33}cm^{-2}s^{-1}$ → 1.5 fb^{-1}
6 months → 9 fb^{-1} i.e. scale previous numbers by 9

Take mean of "high" and "low" JPAC estimates

Take Luminosity(W) for low (estimates from plot) and high W optimisation

	L ($10^{33}cm^{-2}s^{-1}$)	N Z	N Z + e-	N Y	N Y + e-	N X *	N X +e- *
5-41	0.44 (1.2)	11k (30k)	770 (2k)	7.1k (19k)	1k (2.9k)	47k (129k)	6.5k (17k)
5-100	3.68 (10)	78k (213k)	5.1k (14k)	81k (220k)	11k (31k)	0.4M (1.1M)	57k (157k)
10-100	4.48 (12)	101k (272k)	1.6k (4.3k)	130k (350k)	8k (21k)	0.5M (1.6M)	26k (86k)
18-275	1.54	17k	83	45k	1k	194k	3.5k

* Numbers for X probably too high

Next steps

Simulate with crossing angle

Simulations with deuteron (e.g. Z^-) and nuclear (Primakoff) targets

Further studies with backgrounds, electron/pion separation for Jpsi

Extraction of spin observables

Excited states?

...

Summary

Implemented JPAC photoproduction amplitudes for XYZ

Produced events for 5-41 , 5-100, 10-100, 18-275
beam momentum distributions

Used Eic-smear of variety of detector configurations including
Yellow Report Matrix_0_2_1_5T

Detection of XYZ decay products very good in all configurations

Lower e- beam momentum results in larger fraction of detected e'-
and better resolution in invariant masses
- Probably gives more measurable polarisation observables

Higher beam energies can give larger production yields

An IR2 low W optimised, 5-100 beam configuration looks promising for XYZ

Cross section integration

$$\frac{d^4\sigma}{ds\,dQ^2\,d\Phi\,dt} = \frac{d^2\sigma_{e,\gamma*e'}}{dsdQ^2}\frac{d^2\sigma_{\gamma*+p\to V+p}(s,Q^2)}{d\Phi\,dt}$$

∫dΦ → factor 2π

Need 3 dimensional numeric integration over s, Q2 and t
Actually transform to use x, y and cosθ

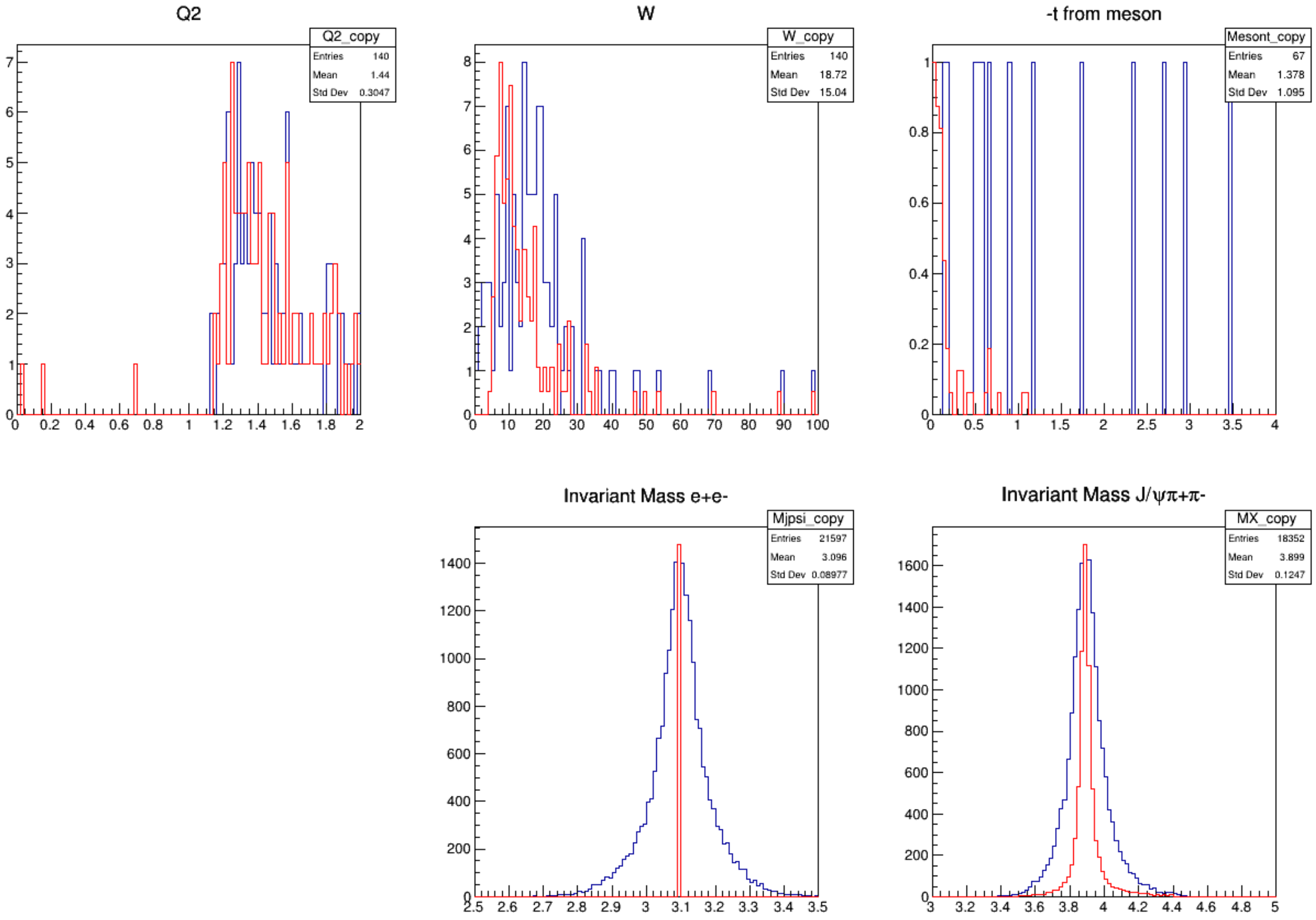
$$\int \frac{d^4\sigma}{ds\,dQ^2\,d\Phi\,dt}\,ds\,dQ^2\,d\Phi\,dt = 2\pi\int\frac{d^3\sigma}{dx\,dy\,d\cos(\theta)}\,dx\,dy\,d\cos(\theta)$$

where

$$\frac{d^3\sigma}{dx\,dy\,d\cos(\theta)} = \frac{d^2\sigma_{e,\gamma*e'}}{dxdy}\frac{d^2\sigma_{\gamma*+p\to V+p}(s(x,y),Q^2(x,y))}{dt}\frac{dt}{d\cos(\theta)}$$

jpacPhoto part

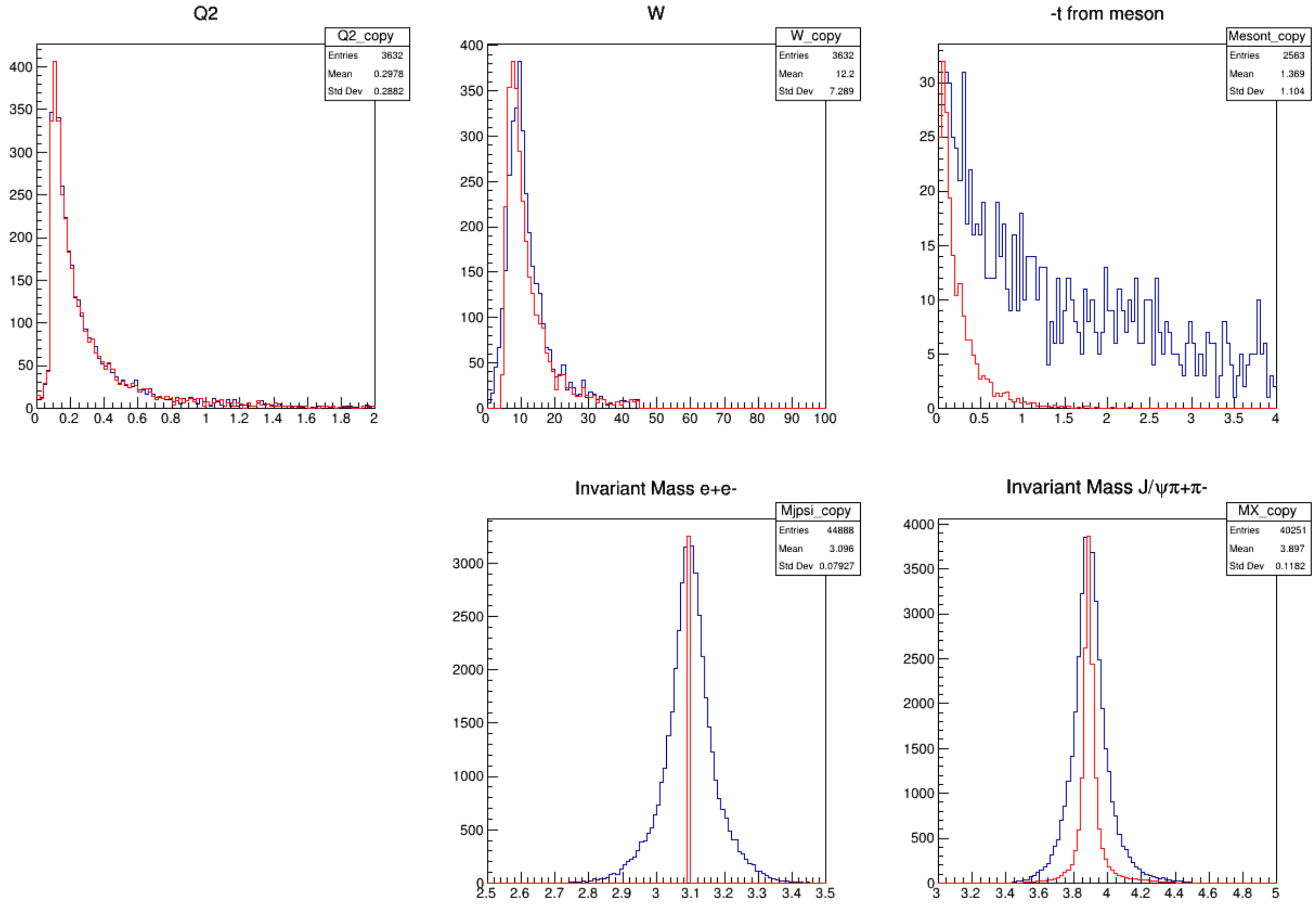
Z 18-275 low MATRIXDETECTOR_0_2_B1_5T



Generated
EIC-Smeared

Normalised to
Same max value

Z 5-100 low MATRIXDETECTOR_0_2_B1_5T



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