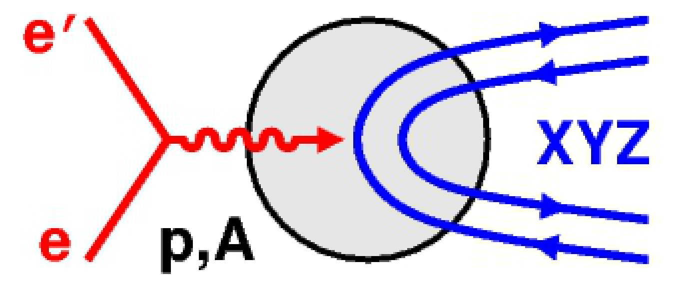
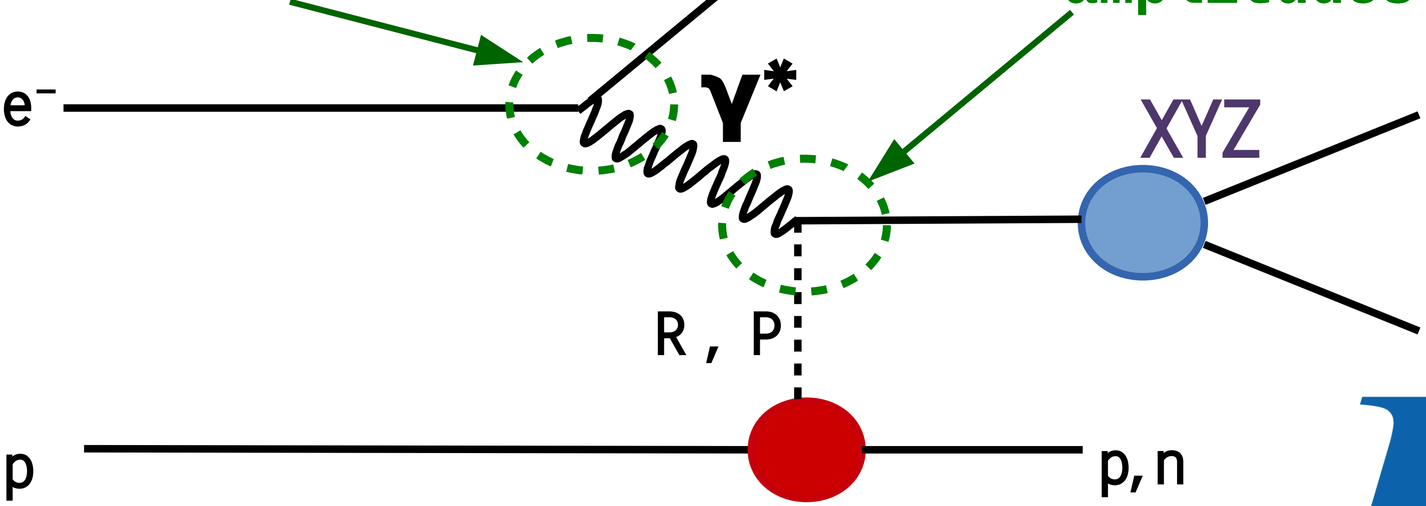
EIC XYZ production simulations

Workshop : Exotic Meson spectroscopy
and structure with EIC

Derek Glazier
University of Glasgow
08/18/2022



Event Generator (Pictorial)



Factorise 2 photon vertices

Virtual photon flux + form factor

JPAC photoproduction amplitudes

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

https://github.com/dwinney/jpacPhoto

Event Generator (Formal)

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

→ Integrate for event rate

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

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

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

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

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

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

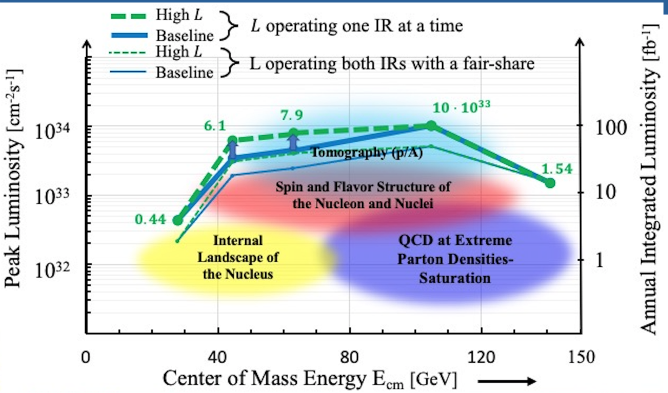
$$\frac{d^2\sigma^T(Q^2,s)}{d\phi\,dt}=\frac{d^2\sigma_{\gamma+p\rightarrow V+p}}{d\phi\,dt}\,F(Q^2)$$

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

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

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

Production estimates for various Exotic candidates



X,Z production benefit from low CM energies
Luminosity too low at 28 GeV
Here focus on 41 GeV configuration
Luminosity assumed 6.1 x 10^{33} cm^{-2}s^{-1}

TABLE II. Summary of results for production of some states of interest at the EIC electron and proton beam momentum $5 \times 100(GeV/c)$ (for electron x proton). Columns show : the meson name; our estimate of the total cross section; production rate per day, assuming a luminosity of 6.1×10^{33} cm^{-2}s^{-1}; the decay branch to a particular measurable final state; its ratio; the rate per day of the meson decaying to the given final state.

Meson	Cross Section (nb)	Production rate (per day)	Decay Branch	Branch Ratio (%)	Events (per day)
$\chi_{c1}(3872)$	2.3	2.0 M	$J/\Psi\ \pi^+\pi^-$	5	6.1 k
$Y(4260)$	2.3	2.0 M	$J/\Psi\ \pi^+\pi^-$	1	1.2 k
$Z_c(3900)$	0.3	0.26 M	$J/\Psi\ \pi^+$	10	1.6 k
$X(6900)$	0.015	0.013 M	$J/\Psi\ J/\Psi$	100	46
$Z_{cs}(4000)$	0.23	0.20 M	$J/\Psi\ K^+$	10	1.2 k
$Z_b(10610)$	0.04	0.034 M	$\Upsilon(2S)\ \pi^+$	3.6	24

* Branching ration J/ψ → e+e- = 0.06 ;
ϒ(2S) → e+e- = 0.0198

** Taken from “Precision Studies of QCD in the Low Energy Domain of the EIC”
(In preparation)

* May be some tension with COMPASS Muoproduction results
* Compared to FKG (Tuesday)
~ x10 lower χ
~ x10 higher Zc, similar Zcs

Simulations for ECCE

Produce X,Y,ψ(2S) based on jpacPhoto & elSpectro

Produce events for 10 fb^{-1}

Here focus on 5 Gev e- and 100 GeV proton beams

Approximately 300k events

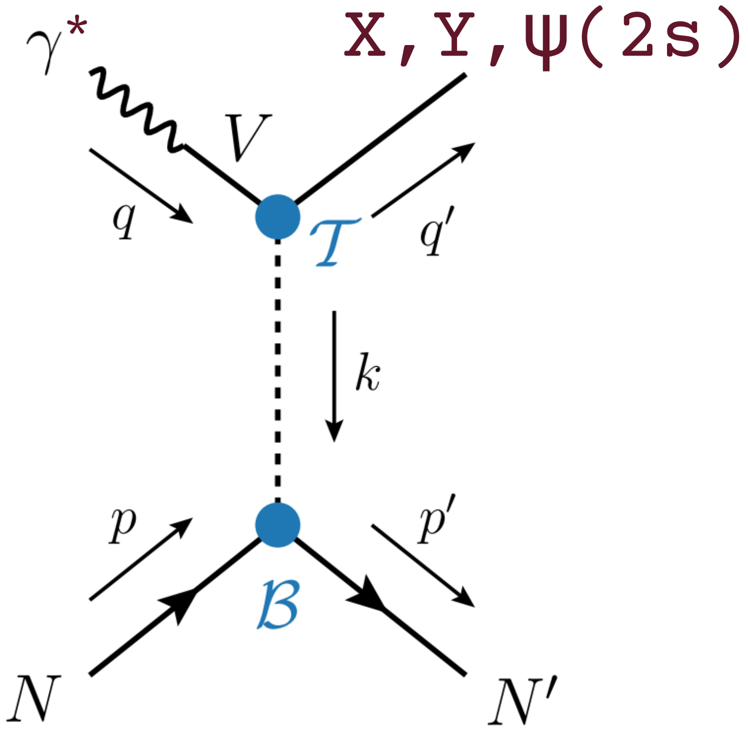
Passed through ECCE detector simulation/reconstruction
After-burner rotates for crossing angle etc.

Simple Analysis results :

- Just using track momentum
- Take PID from truth (100% efficient)
- Calculate Energy from momentum

ECCE Spectroscopy Simulations

Meson → $J/\psi\ (e^+e^-)\ \pi^+\pi^-$



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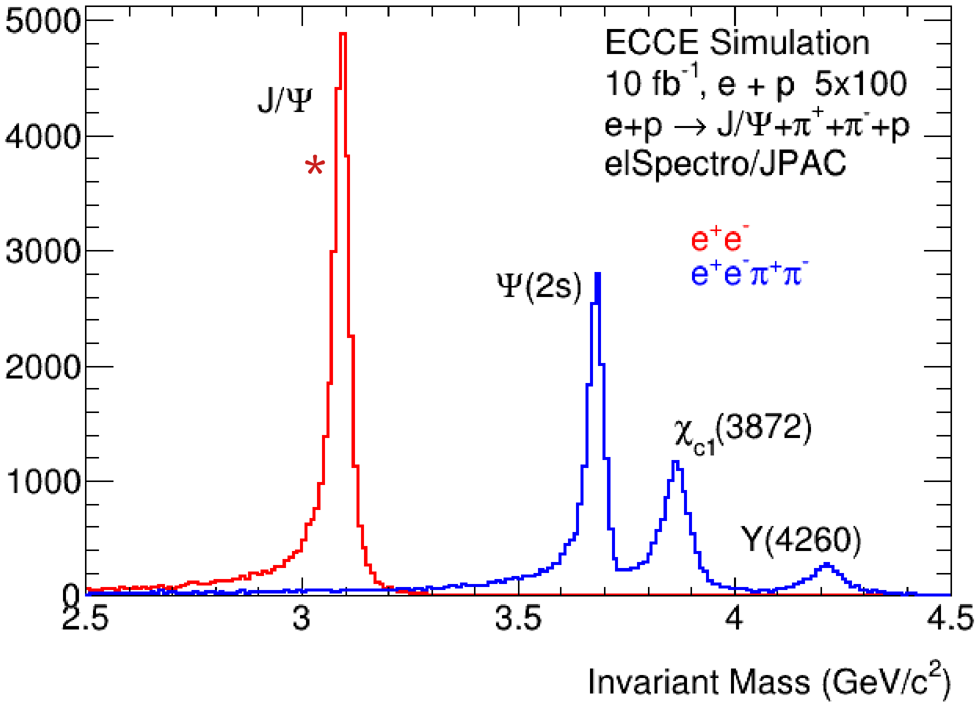
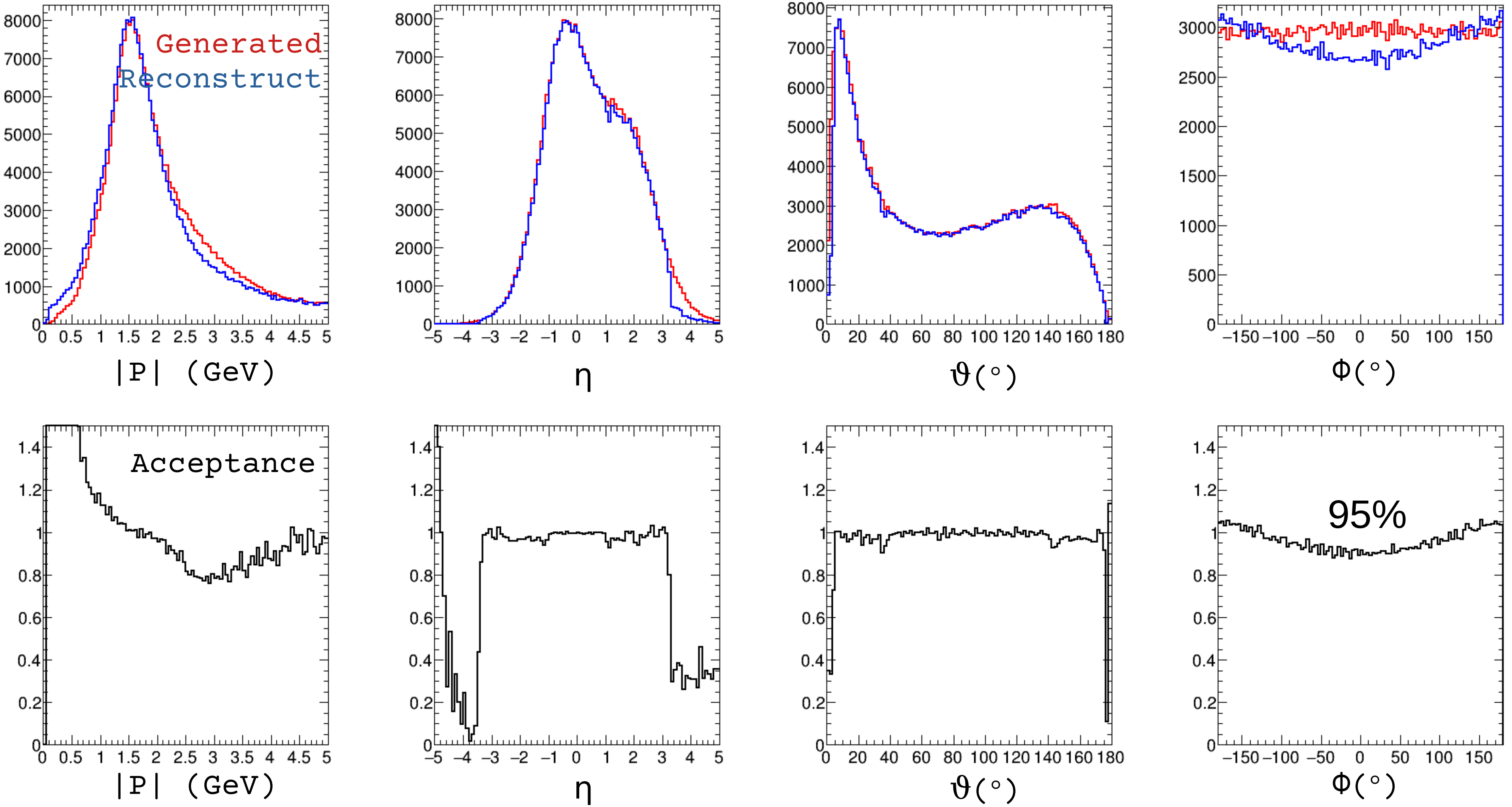


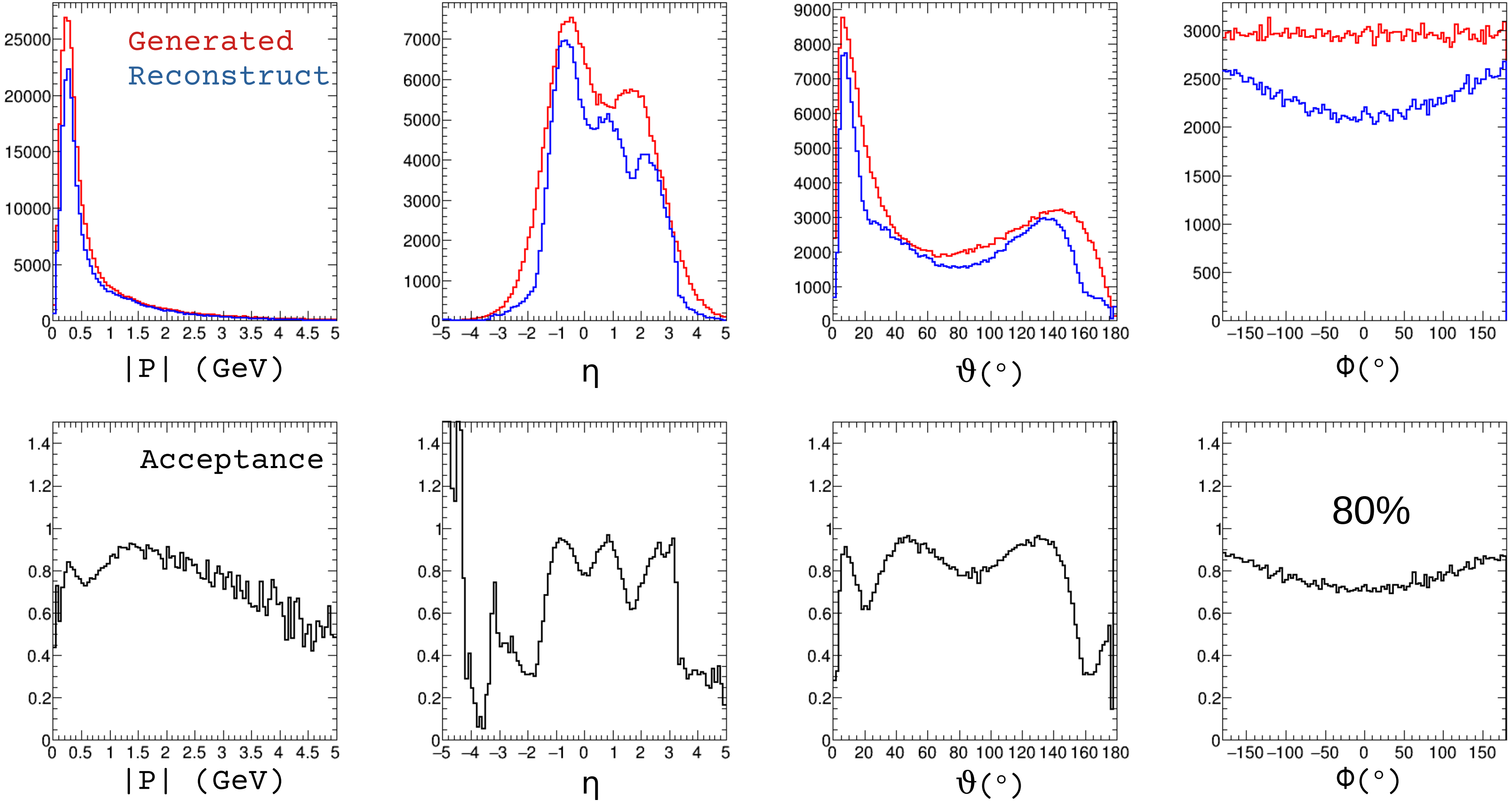
Low Q^2 => Far *ward very important
Low t e-′ and nucleon detection

* only J/ψ from Meson decays

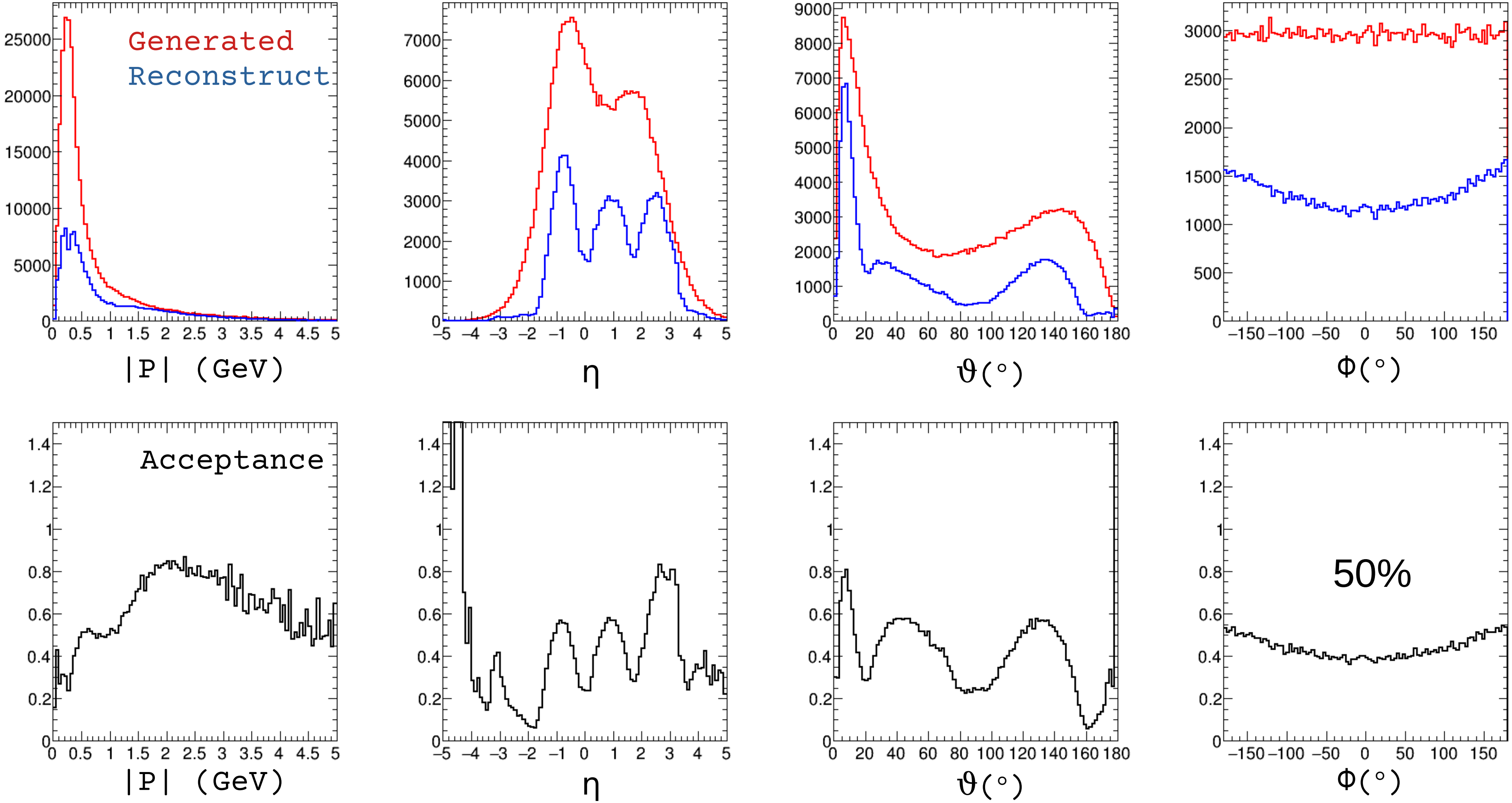
J/ψ decay e+ acceptances at 1.5T



π+ acceptances at 1.5T

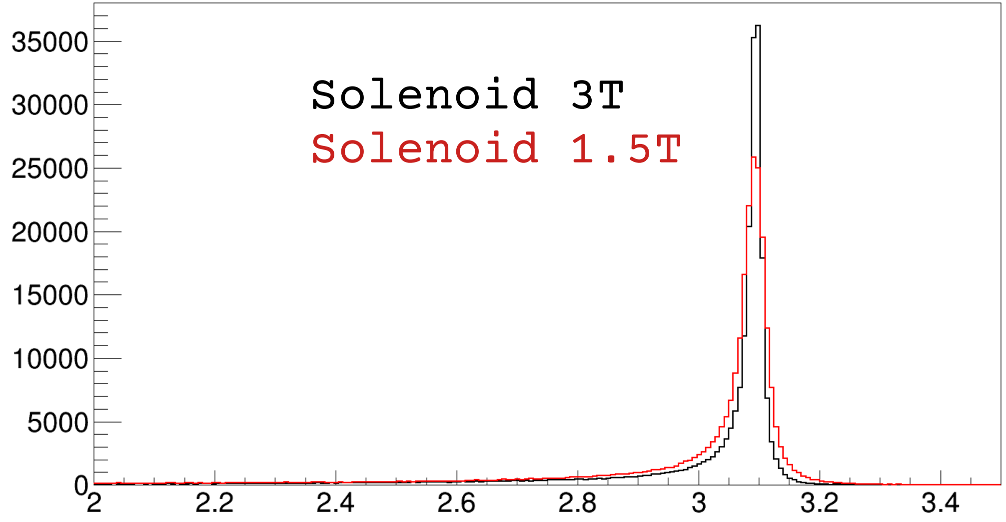


π+ acceptances at 3T

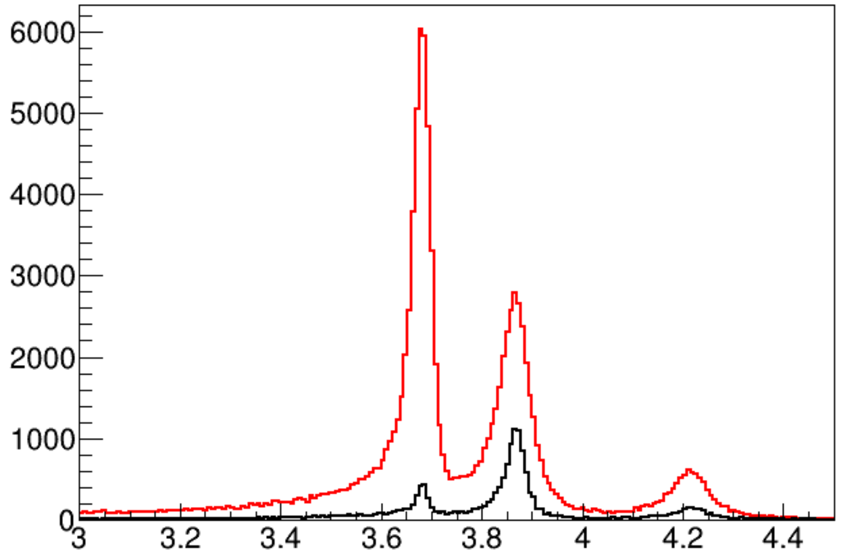


Invariant masses with ECCE

Invariant mass e+e-



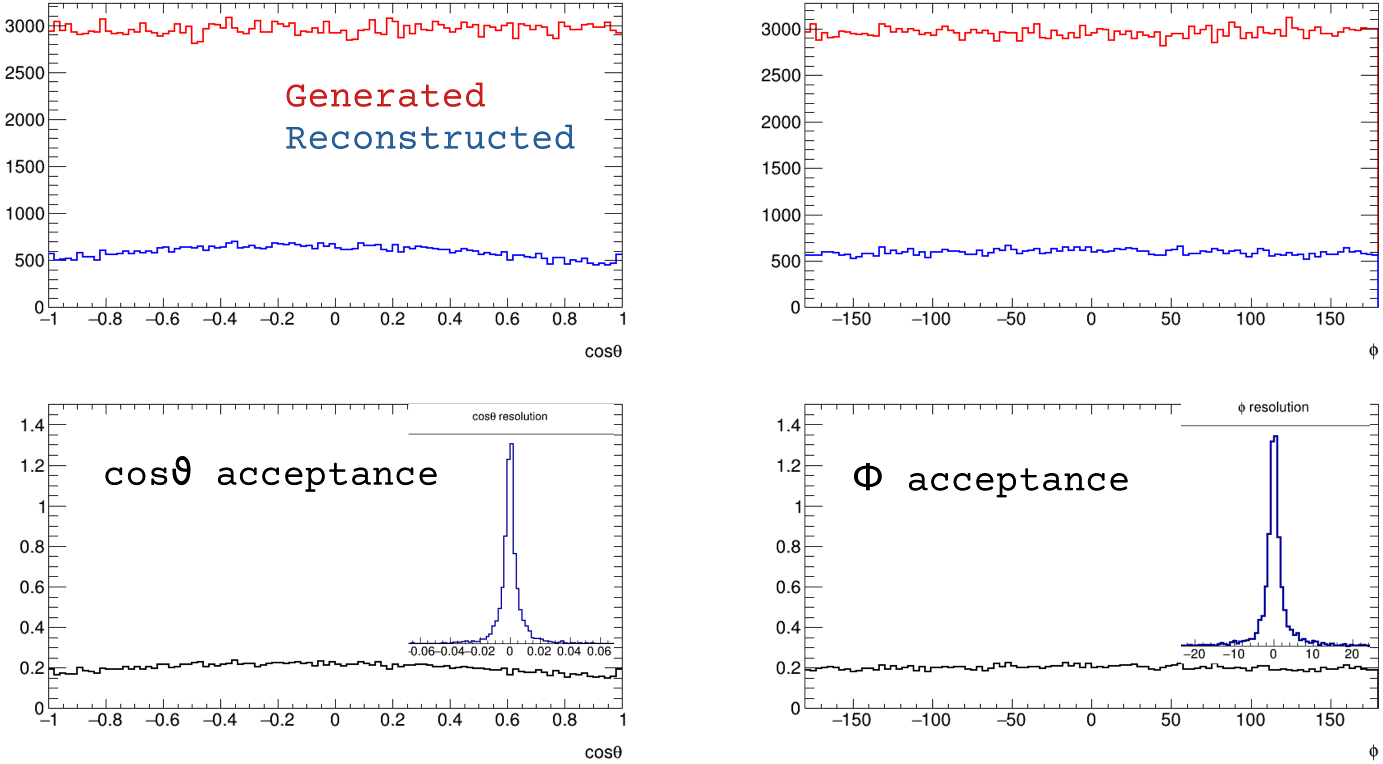
Invariant mass π+π-e+e-



Acceptances for full final state much lower at 3T Solenoid

- low energy pions

Meson Decay angles

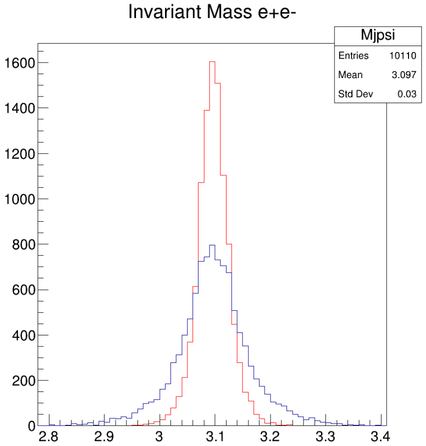


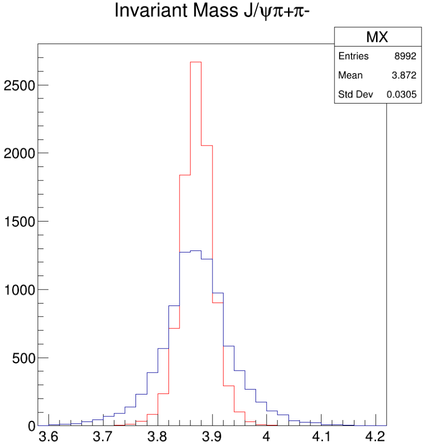
Decay angles of J/ψ in X rest frame

- * Flat acceptances
- * “Good” resolutions
  - 0.01 cosϑ
  - 5° Φ

*Looks good for SDME and quantum numbers

Detector effects on Invariant Masses


Invariant Mass e+e-


Invariant Mass J/ψπ+π-

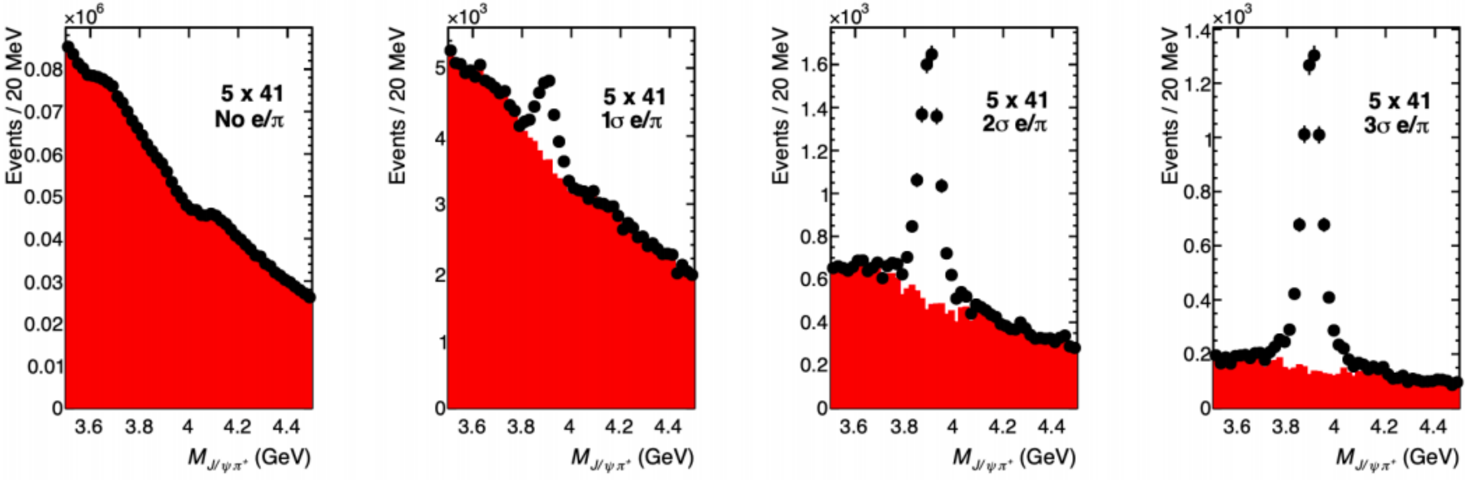
EIC smear for different field strengths

1.5T (65MeV)

3.0T (30MeV)

Typically 2x better Resolution with 3T

e/π seperation also significantly improves signal/background

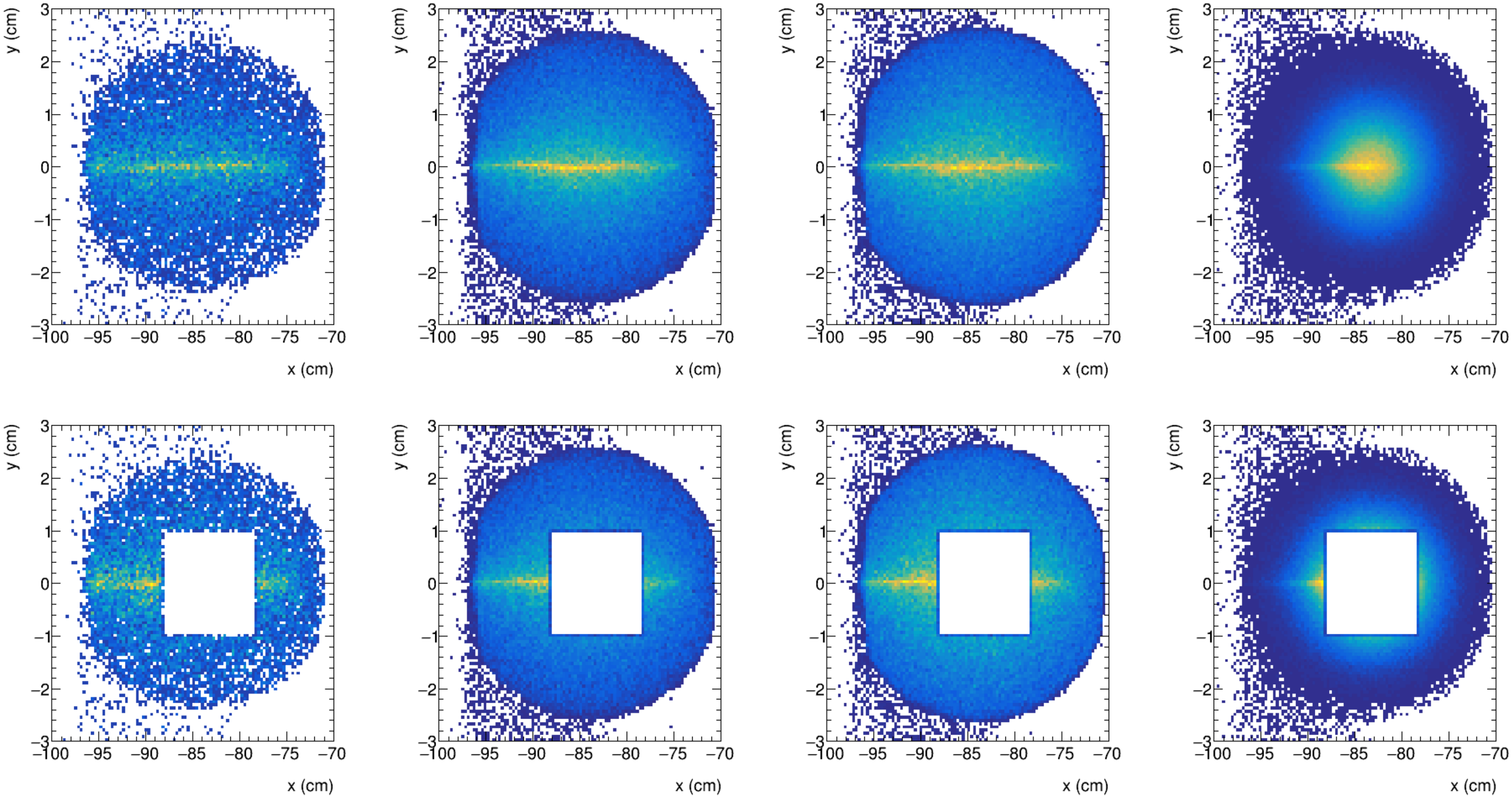


Pythia

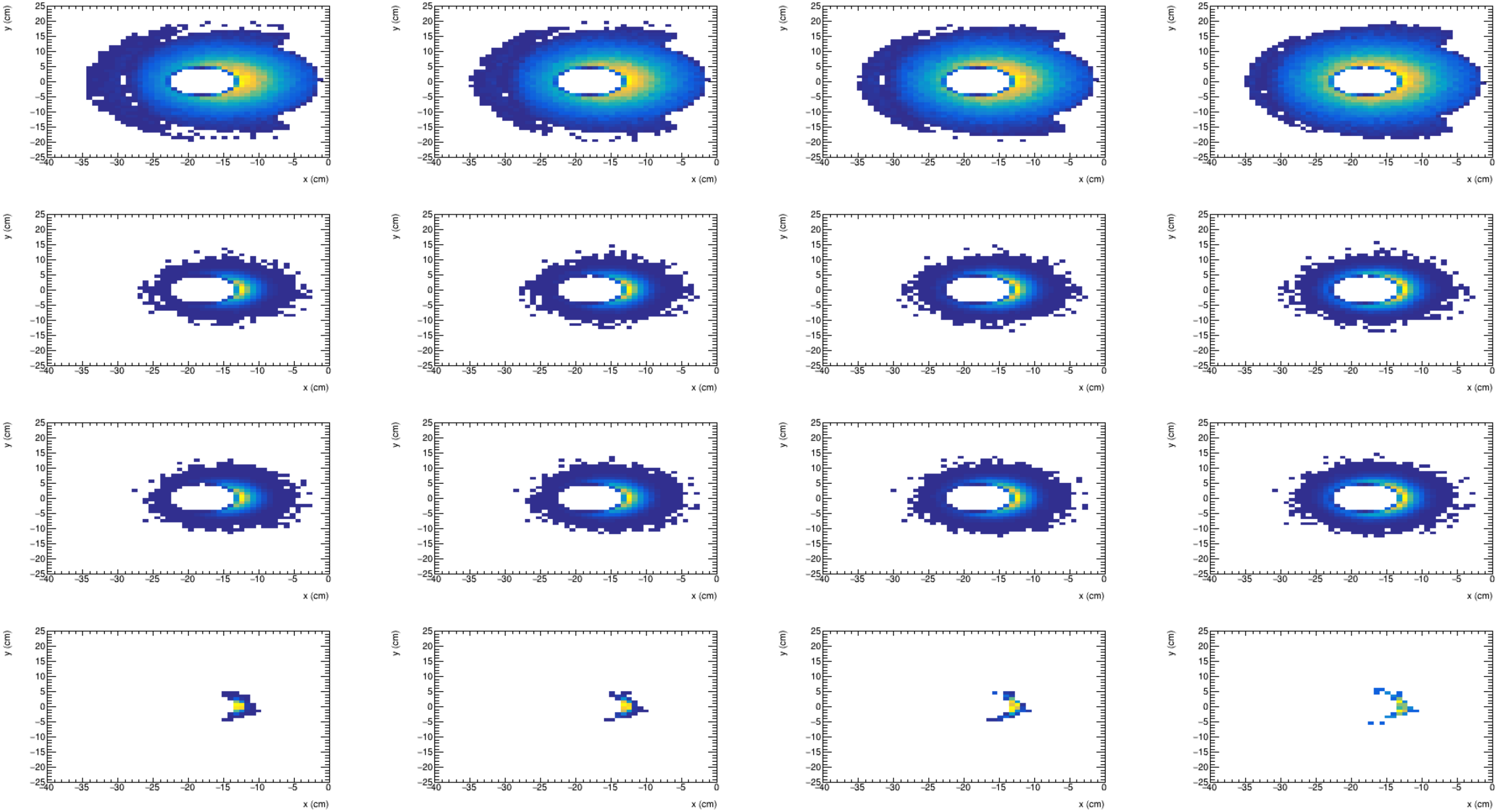
$Z_c \rightarrow J/\psi\pi^+$

J.Stevens
from yellow report

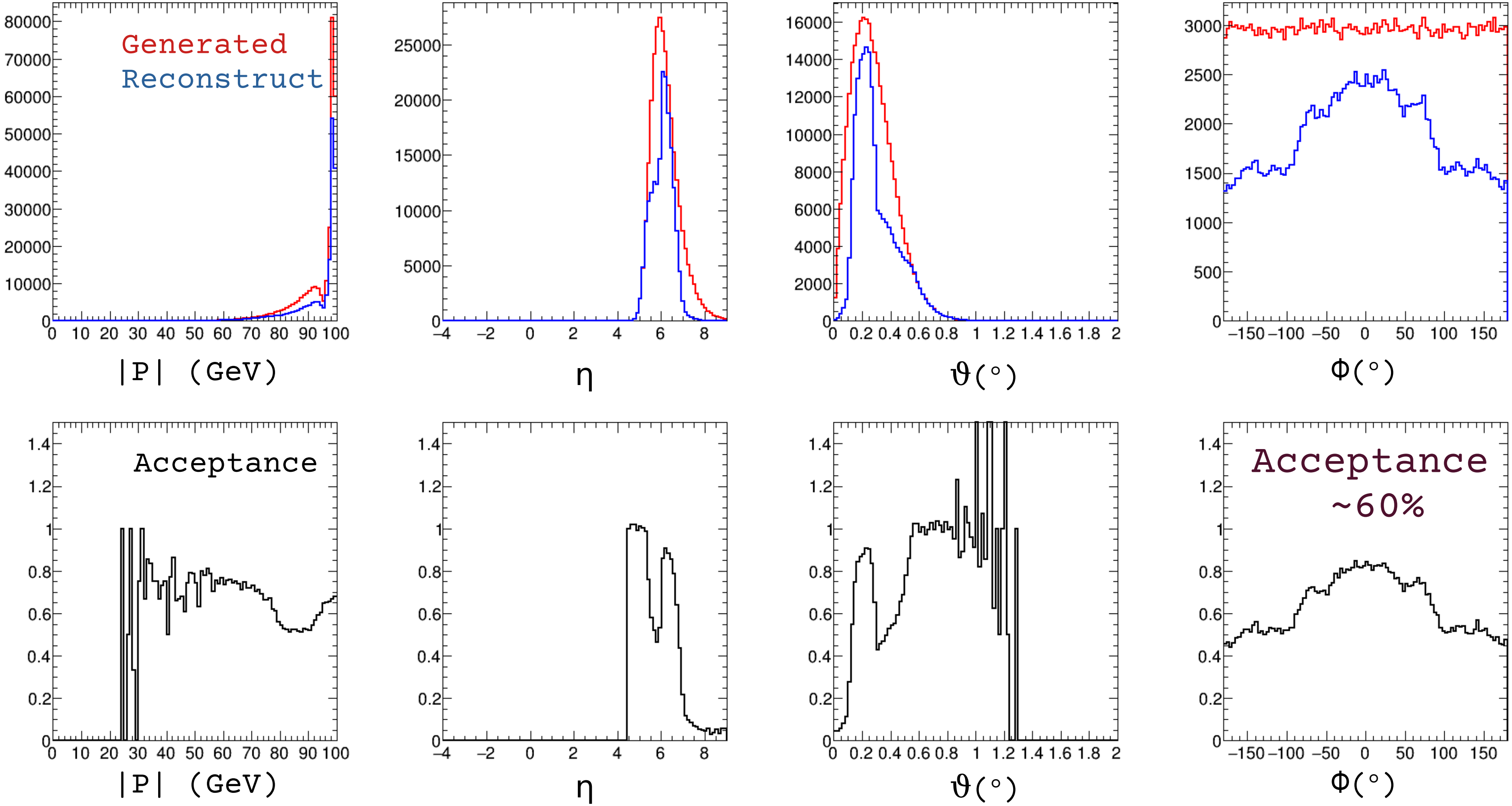
Far Forward Roman Pot Acceptance



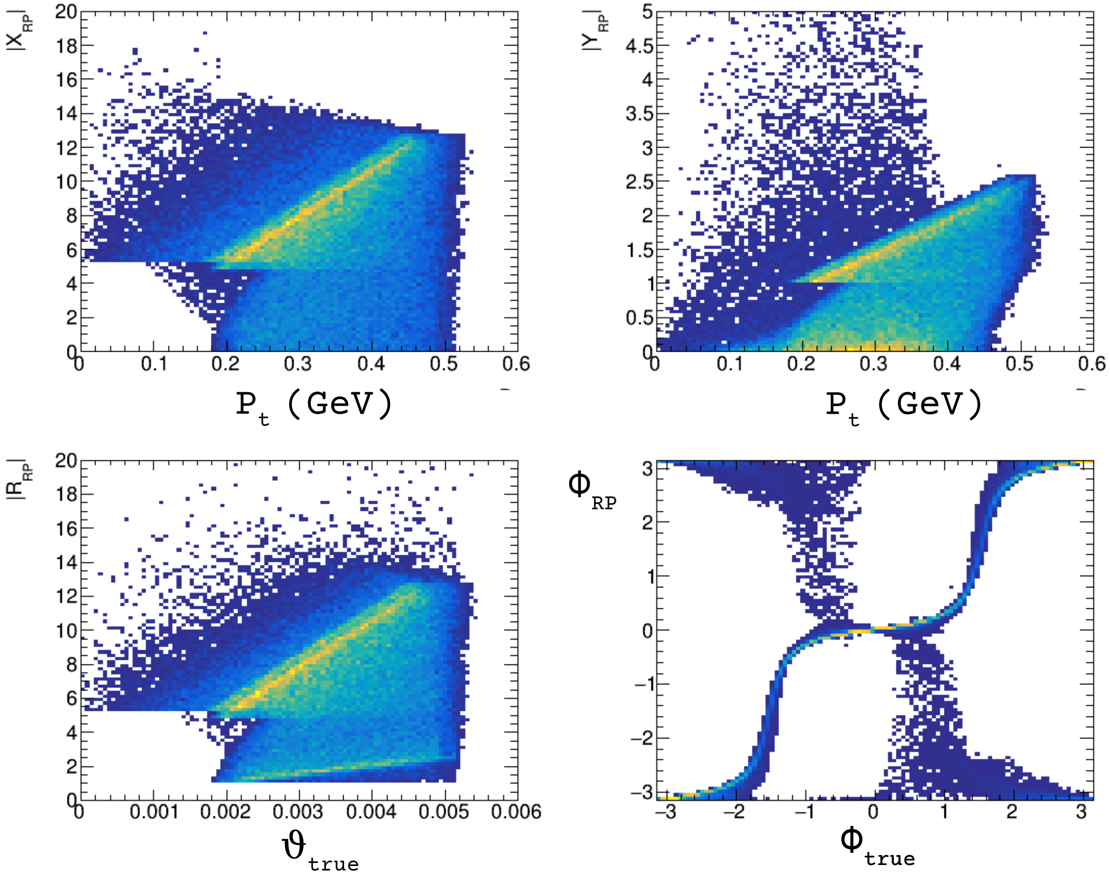
Far Forward B0 Acceptance



Proton Detection B0 and RP



Roman Pot position and momentum



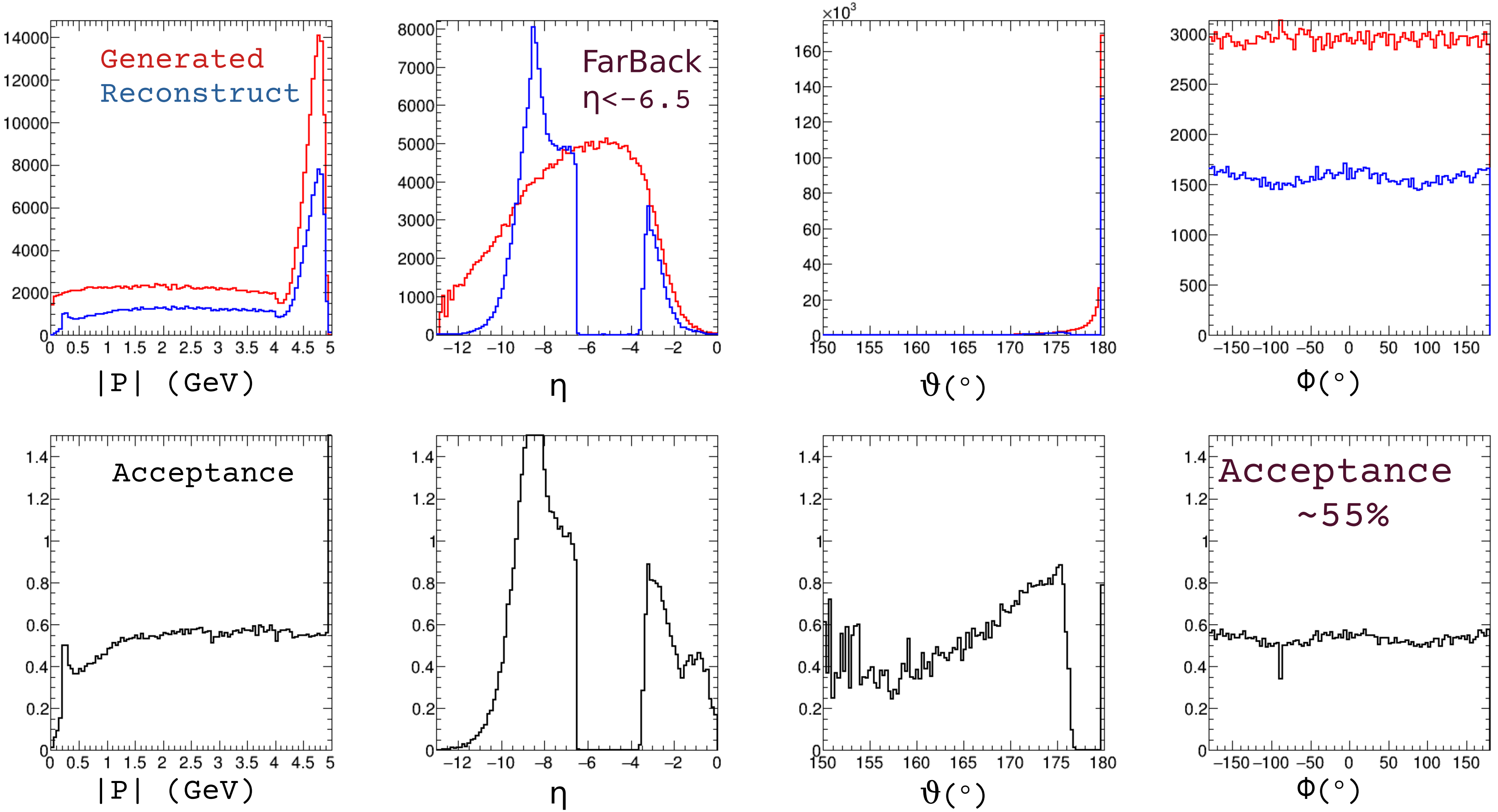
Correlation between position and $P_{t,}$ but dependent on Φ_{RP}

Proton Φ_{true} correlated with Φ_{RP}
=>Assume it can be reconstructed

For these studies, if proton detected in RP 6% P_t resolution,
B0 3% P_t resolution

Assume (unrealistic) perfect Φ reconstruction

Electron Detection



Useful Exclusivity variables

γ= (e^{-} beam) – (e'$^{-}$ scattered) Here we take e-' in Low Q2 Tagger

ΔP_t difference : Here we take proton in Far Forward

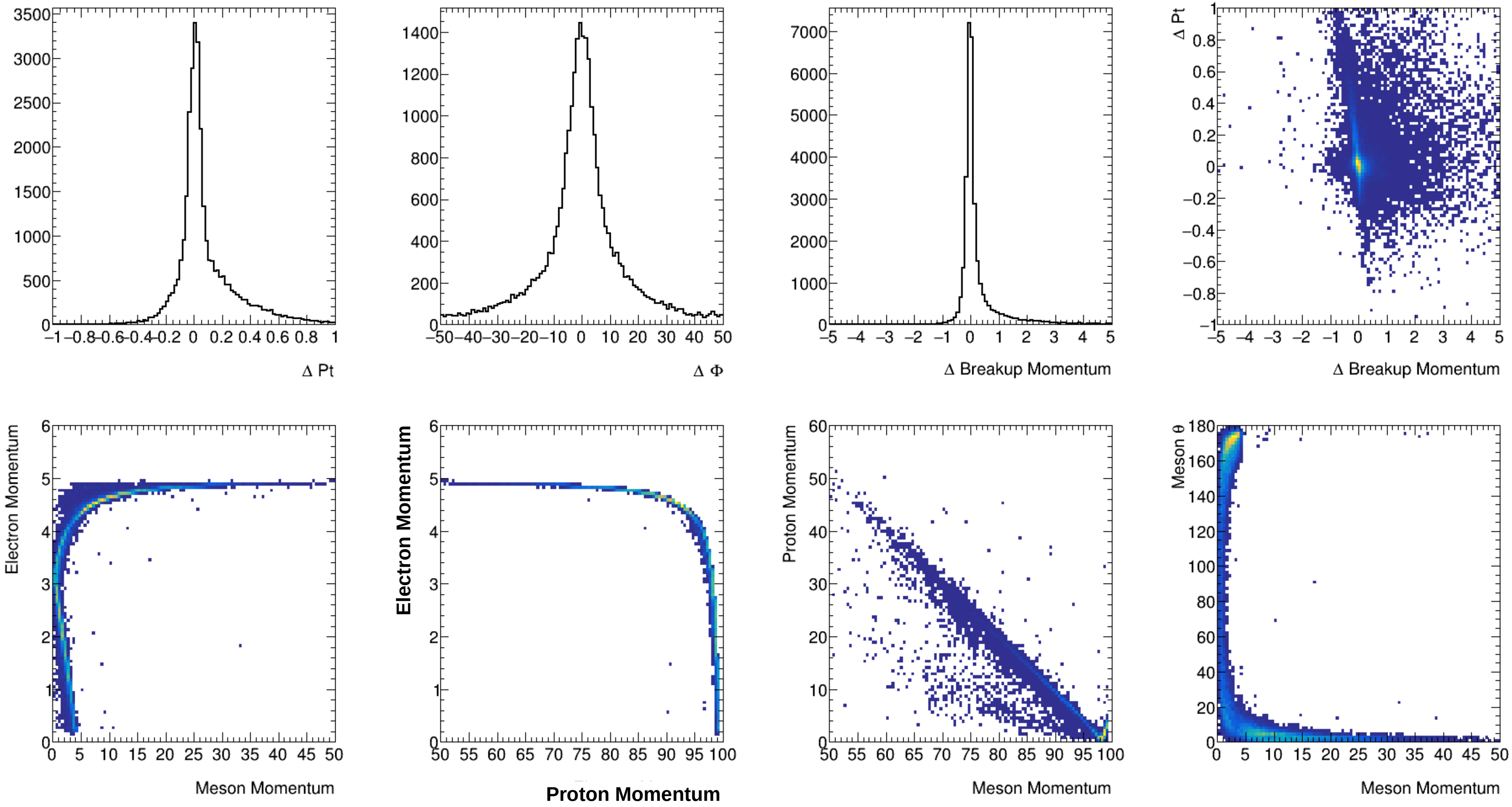
= P_t {calculated proton – measured proton}

$\Delta\Phi$, Production Plane difference : $\Phi_{meson} - \Phi_{proton}$

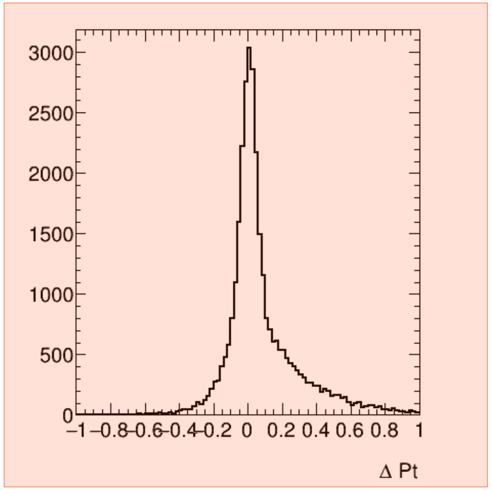
Centre of Momentum frame Δ Breakup Momentum, P_{break} :

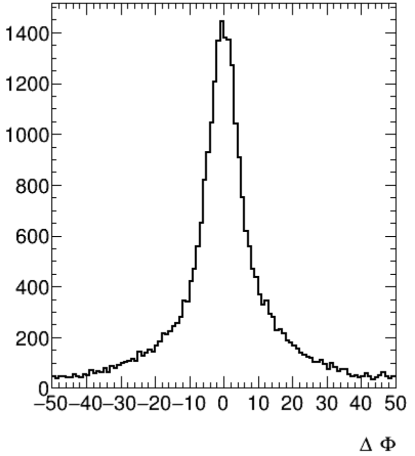
$P_{break}(E_\gamma, M_p, M_{meson}) - P_{break}(E_\gamma, \mathrm{meson})$ second term boosts meson into CM

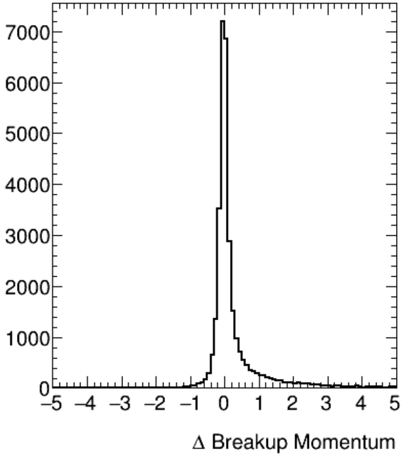
True Electron, True Proton, Realistic Meson

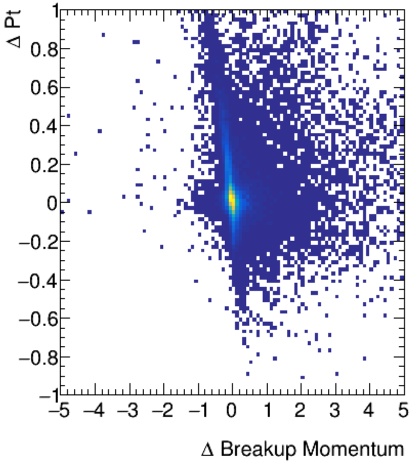


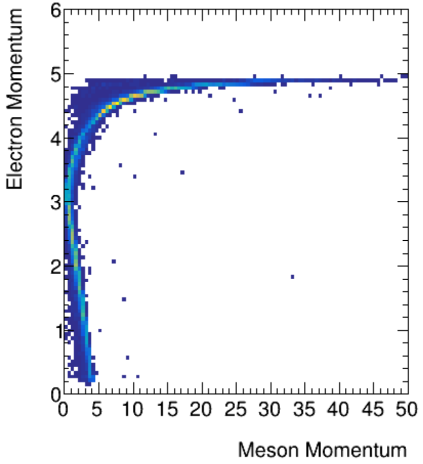
True Electron, “Realistic” Proton

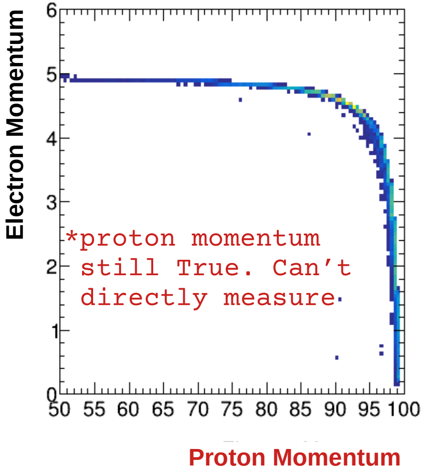




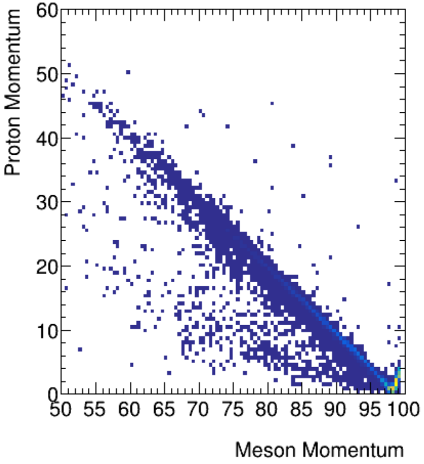


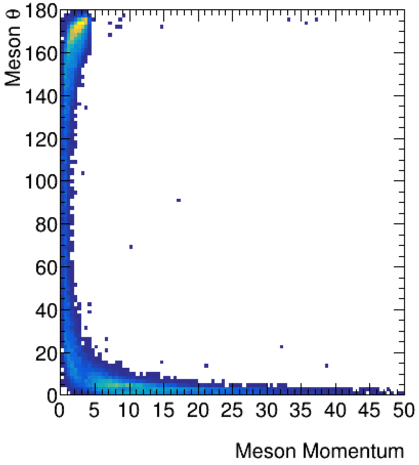




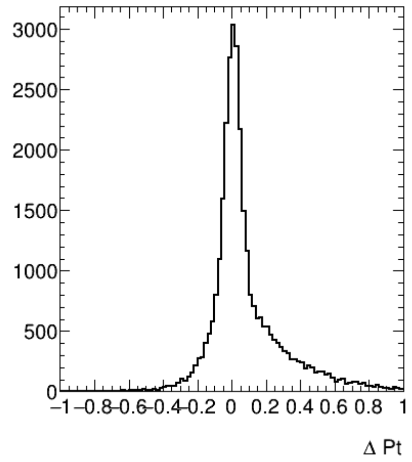


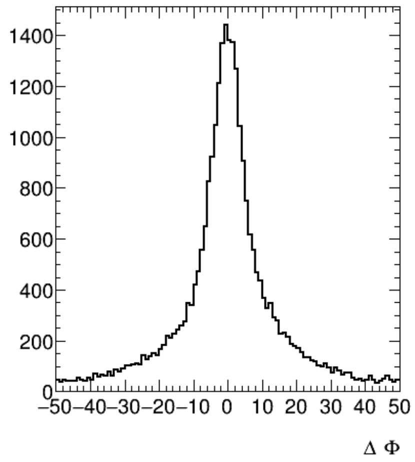
*proton momentum still True. Can’t directly measure

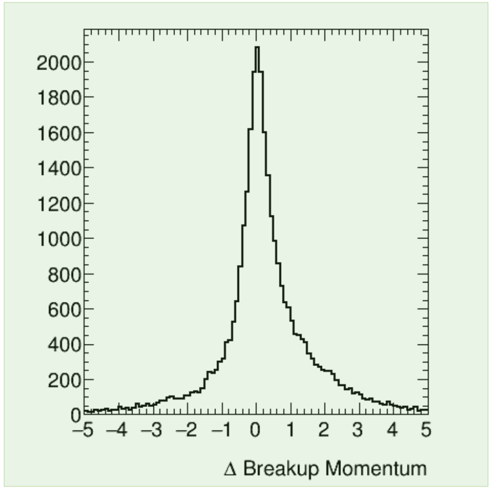


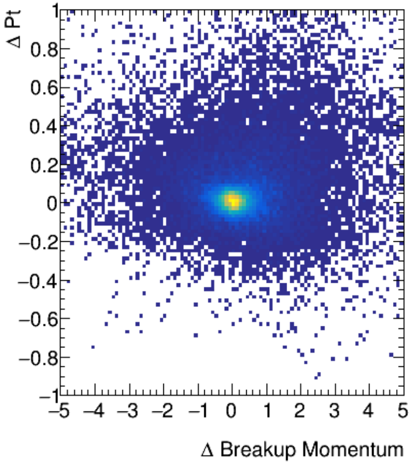


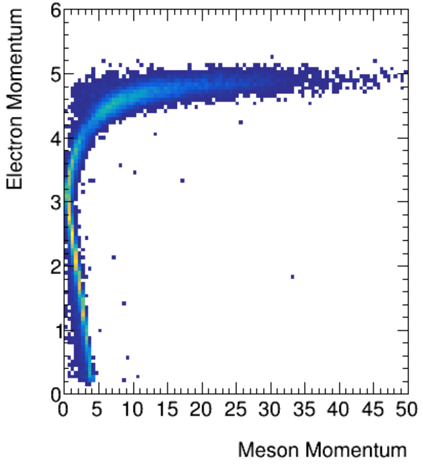
+ Electron 2% energy resolution

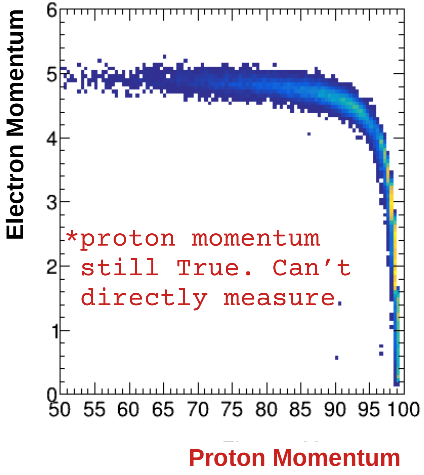












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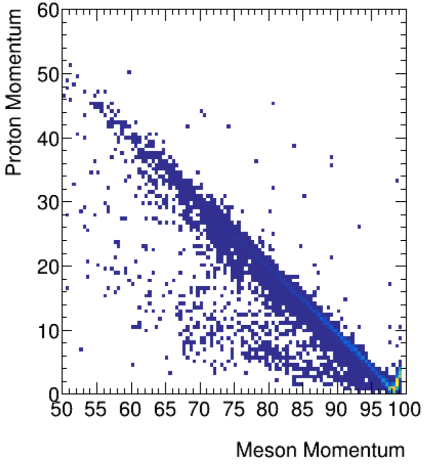
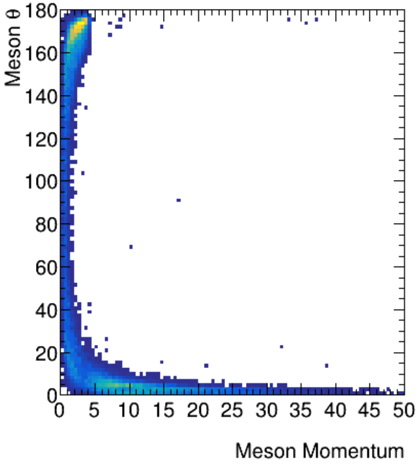
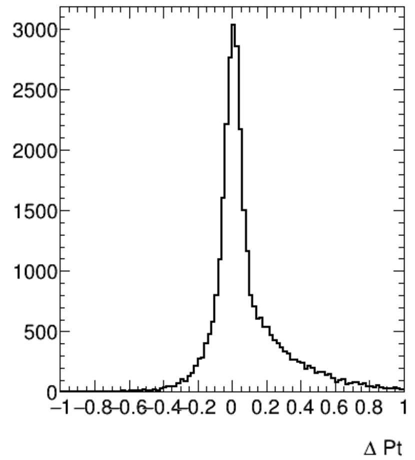
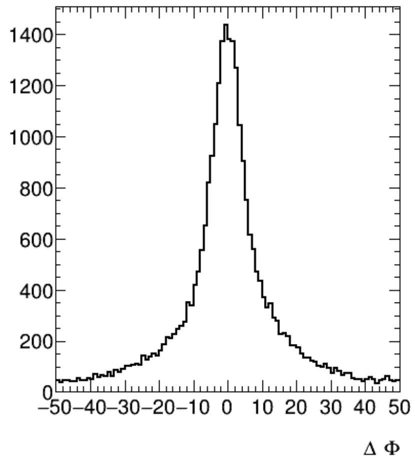
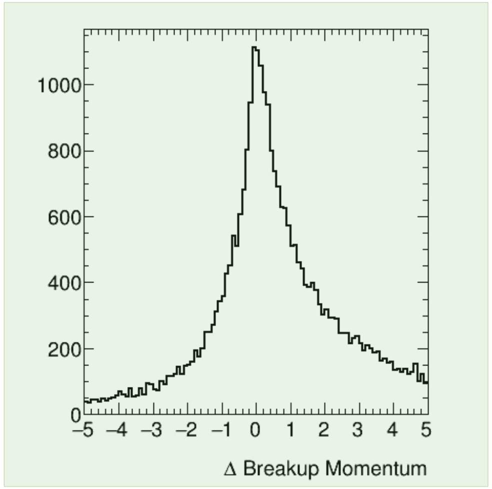


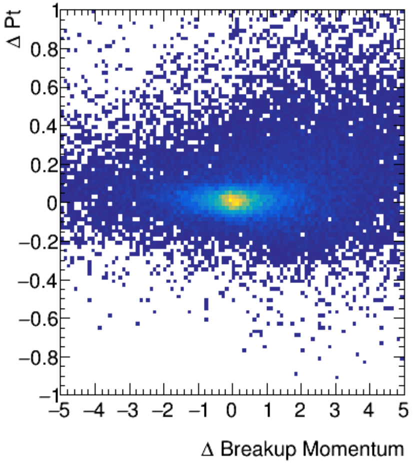


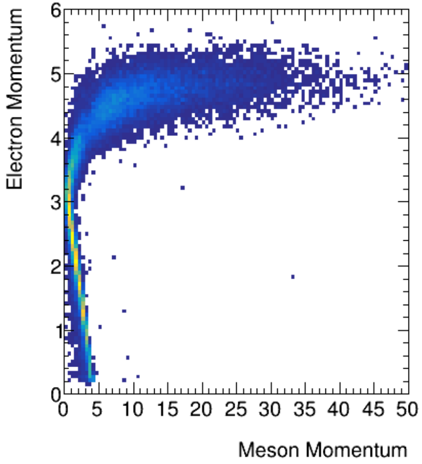
+ Electron 5% energy resolution

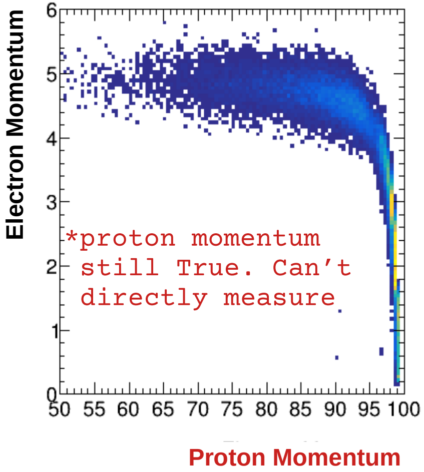












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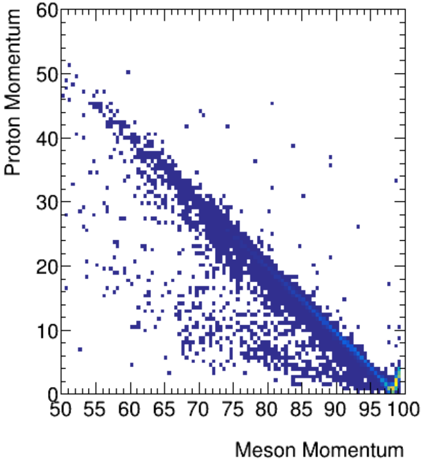
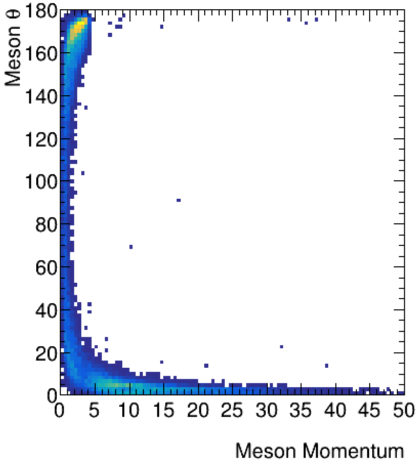
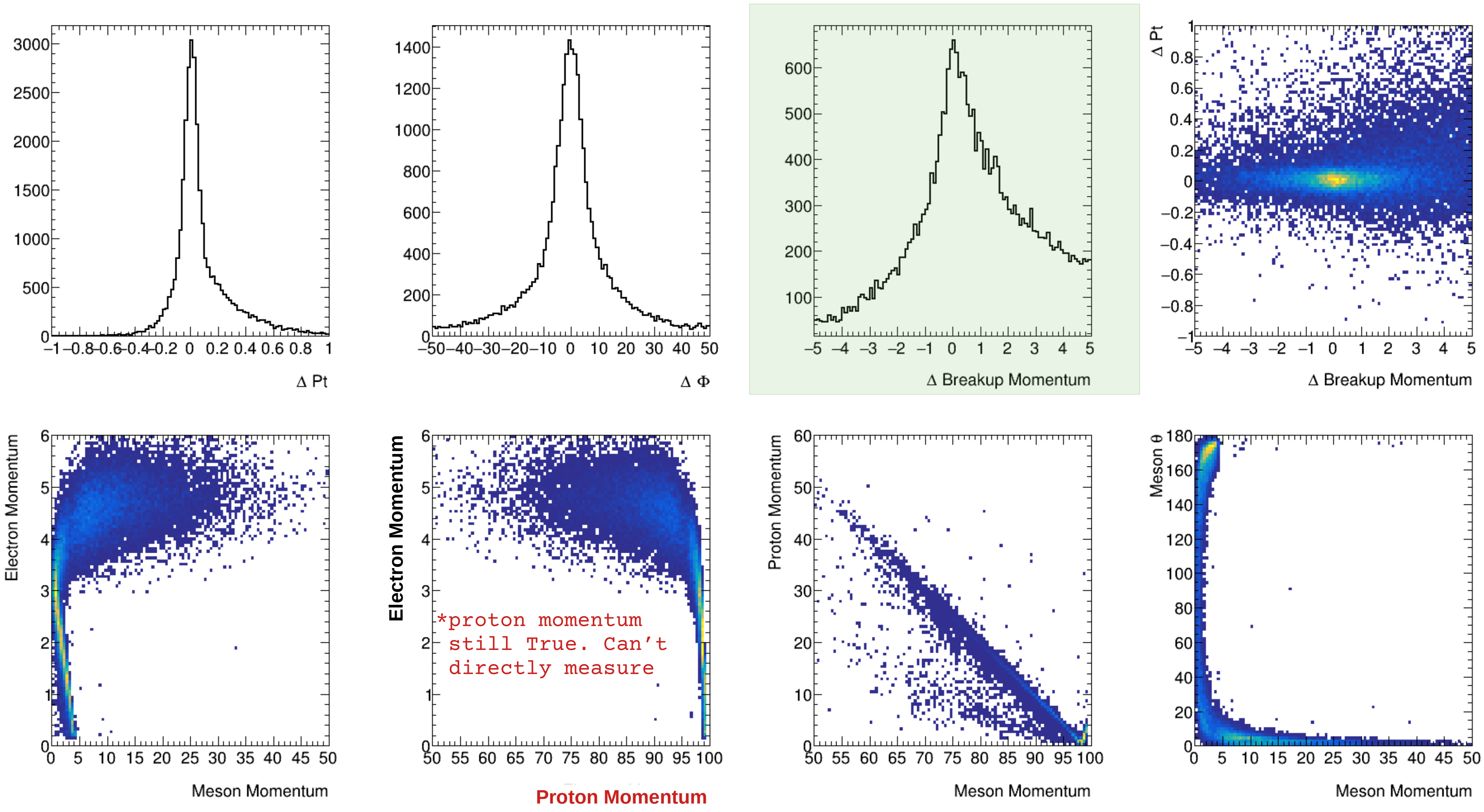


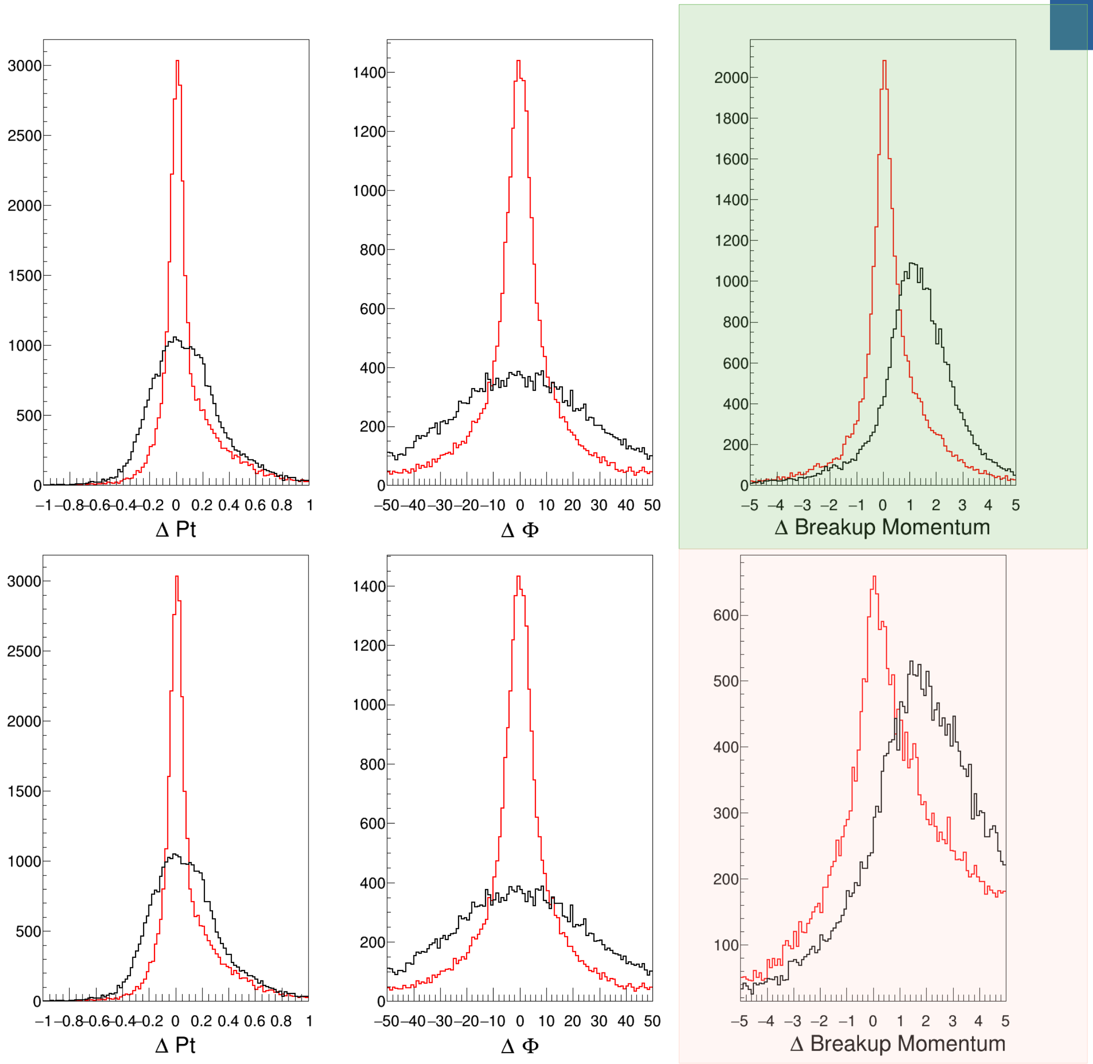


+ Electron 10% energy resolution



*proton momentum still True. Can't directly measure

Missing Pion Background



No simulations of background Channels

Instead create exclusivity variables with missing pion

Top 2% electron resolution
Bottom 10% electron resolution

Fully Exclusive
Missing Pion

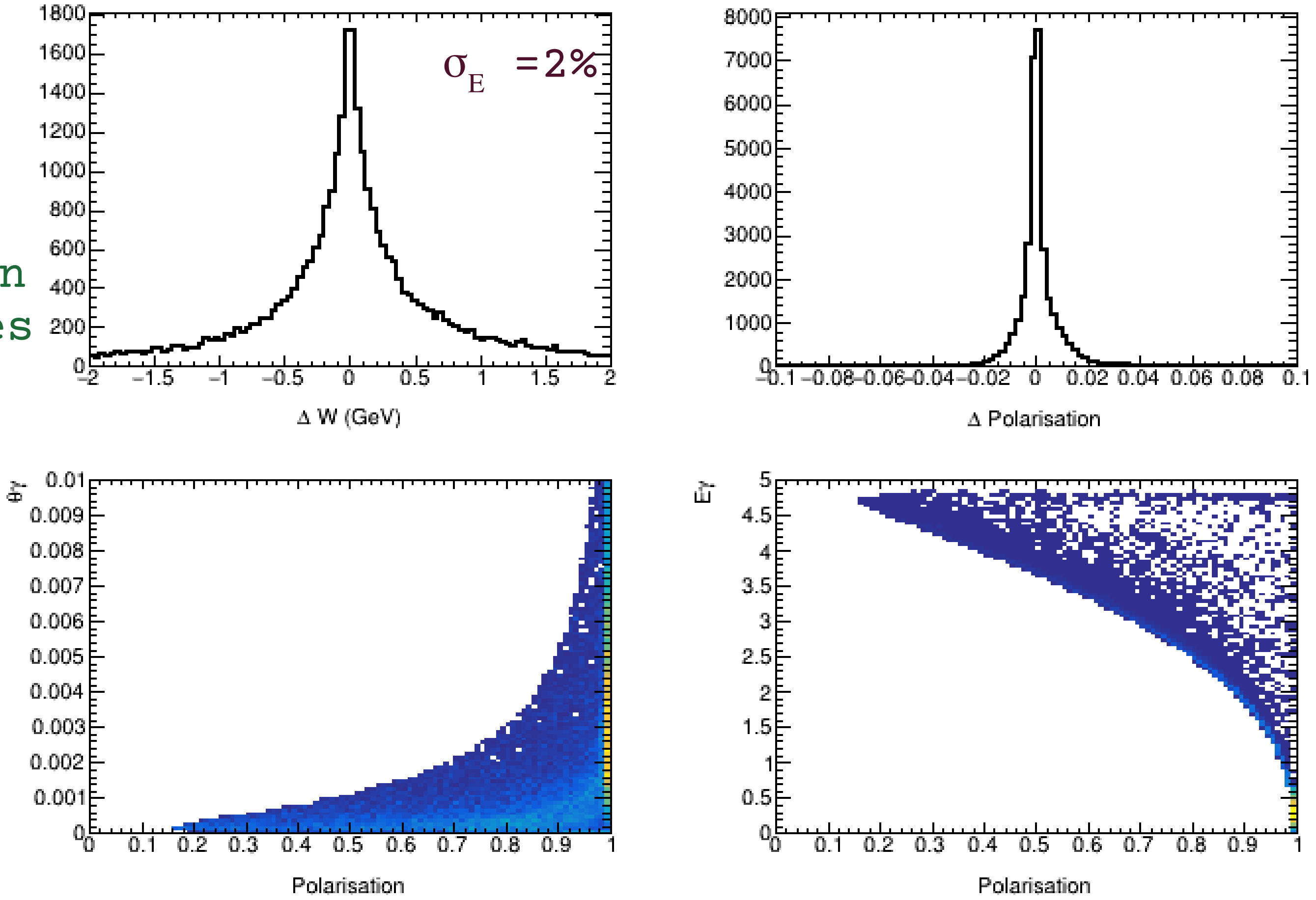
Other Useful Kinematics

Low Q^2 Tagger can also provide :

Reaction W

Electron scatter plane

Transverse Polarisation
=> extra observables
(photon asymmetries,
polarised SDMEs)



Conclusions

Realistic simulations show Spectroscopy measurements benefit from :

- Low beam energies
- Low solenoidal field strength
- Good exclusivity variables from fully reconstructed events
  - Require Far forward and backward acceptance and resolution
- Determination of W and t
- Transverse photon polarisation (~ Linear Polarisation)

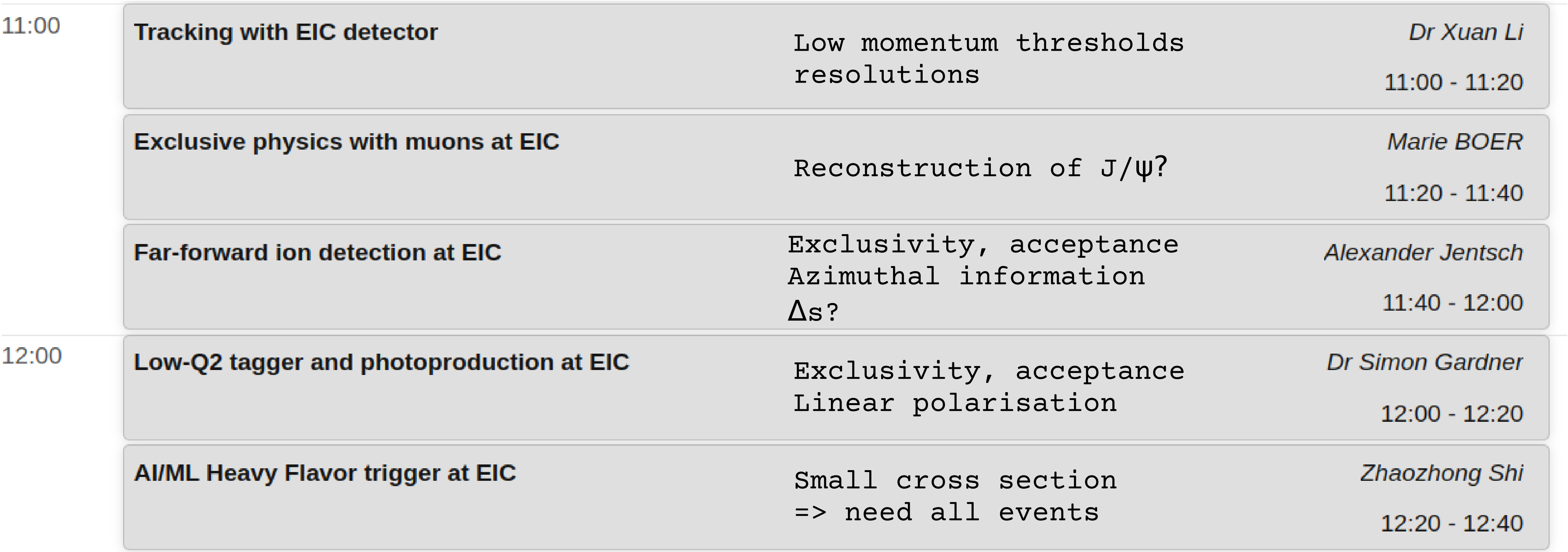
We should expect to reconstruct around 10% fully exclusive events
(most events lost in far forward/backward regions)

Low (and uncertain) cross sections and small branching ratios
are main issue

Given sufficient statistics polarised SDMEs should be measurable

Many possible mesons and final states to simulate...

Detector Talks



11:00	**Tracking with EIC detector**	Low momentum thresholds resolutions	*Dr Xuan Li*	11:00 - 11:20
	Exclusive physics with muons at EIC	Reconstruction of J/ψ?	*Marie BOER*	11:20 - 11:40
	Far-forward ion detection at EIC	Exclusivity, acceptance Azimuthal information Δs?	*Alexander Jentsch*	11:40 - 12:00
12:00	**Low-Q2 tagger and photoproduction at EIC**	Exclusivity, acceptance Linear polarisation	*Dr Simon Gardner*	12:00 - 12:20
	AI/ML Heavy Flavor trigger at EIC	Small cross section => need all events	*Zhaozhong Shi*	12:20 - 12:40

Photoproduction of exotic mesons

1) Identify photoproduction of the narrow XYZ states. Typically these have only been seen in 1 production mechanism and photoproduction offers a clean mechanism whereby any resonance should be able to be photoproduced and therefore we would validate if these are real poles.

2) As photoproduction can produce any state we may see states that haven't been produced in other mechanisms. For example no "exotic" tensor mesons have been identified yet.

3) Photoproduction offers a means to determine quantum numbers of produces states, in particular we may search for broader overlapping states. Polarised beams give us a greater handle on this.

4) The nature of the observed states is a matter of great discussion. How these states behave in different production mechanism can help us understand the underlying dynamics (tetraquark, molecules, hybrids). Things like photocouplings or even Q2 dependences can be helpful here.

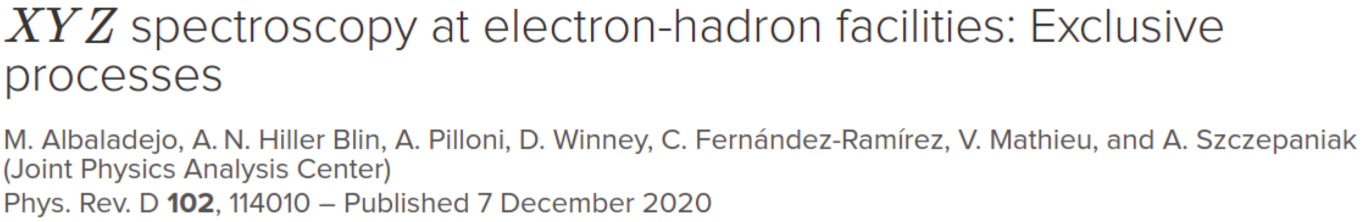
5) We can look for many varieties of decay products $J/\psi + \pi$ or K or vector or ... which are not well established at other experiments.

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

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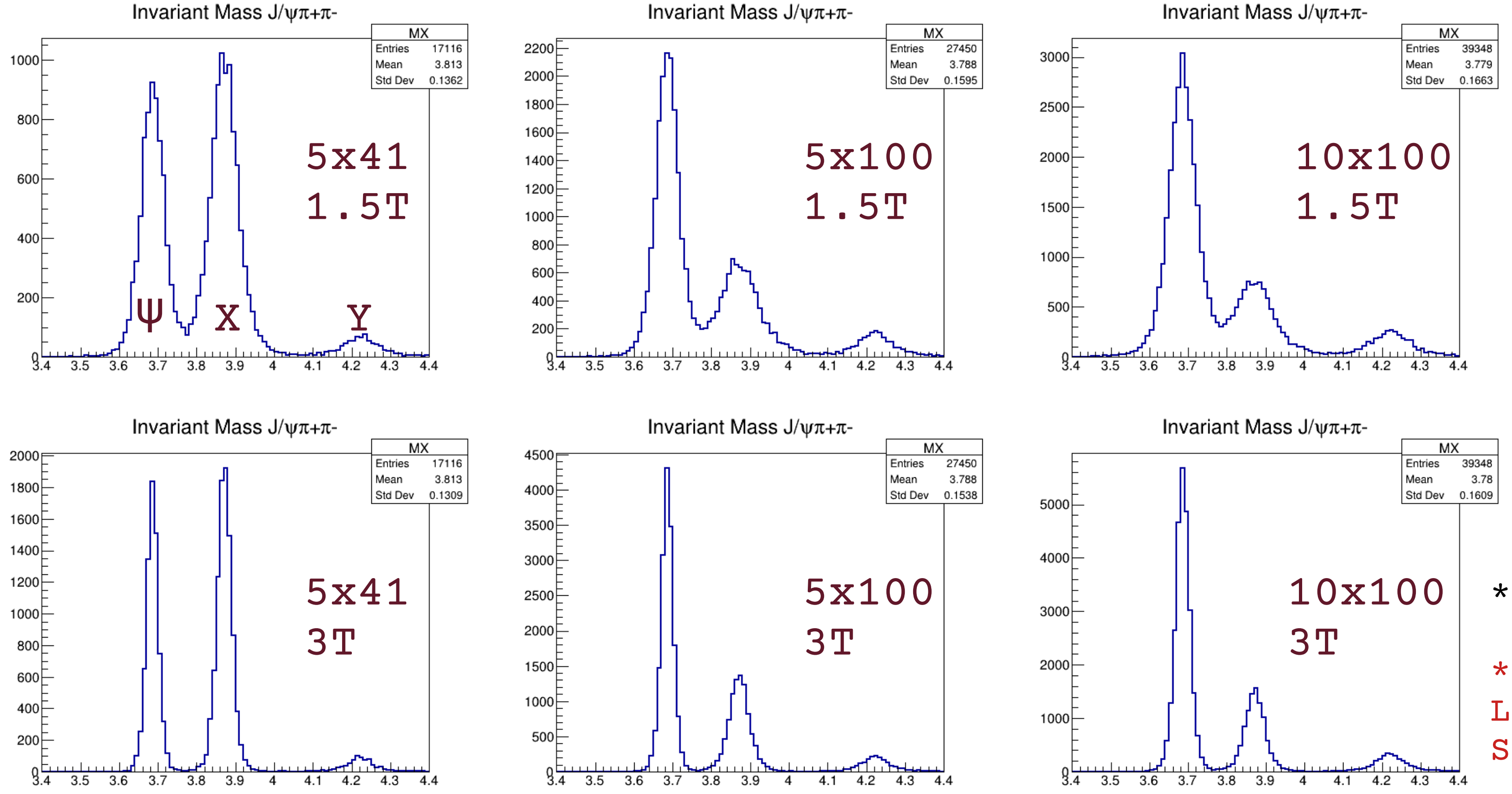
(Joint Physics Analysis Center)
Phys. Rev. D **102**, 114010 – Published 7 December 2020

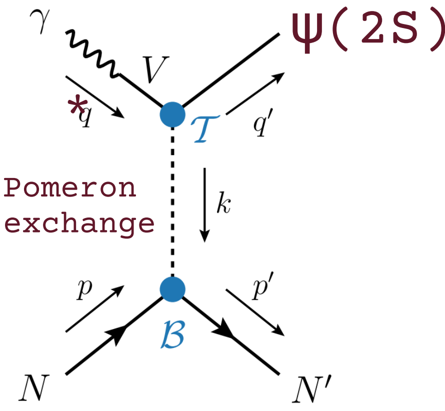
See D.Winney
Exotic Spectroscopy
at the EIC

- qualitative behaviour and order of magnitude estimates

X & Y & ψ(2S)

Invariant mass distributions for different beam/ magnetic fields



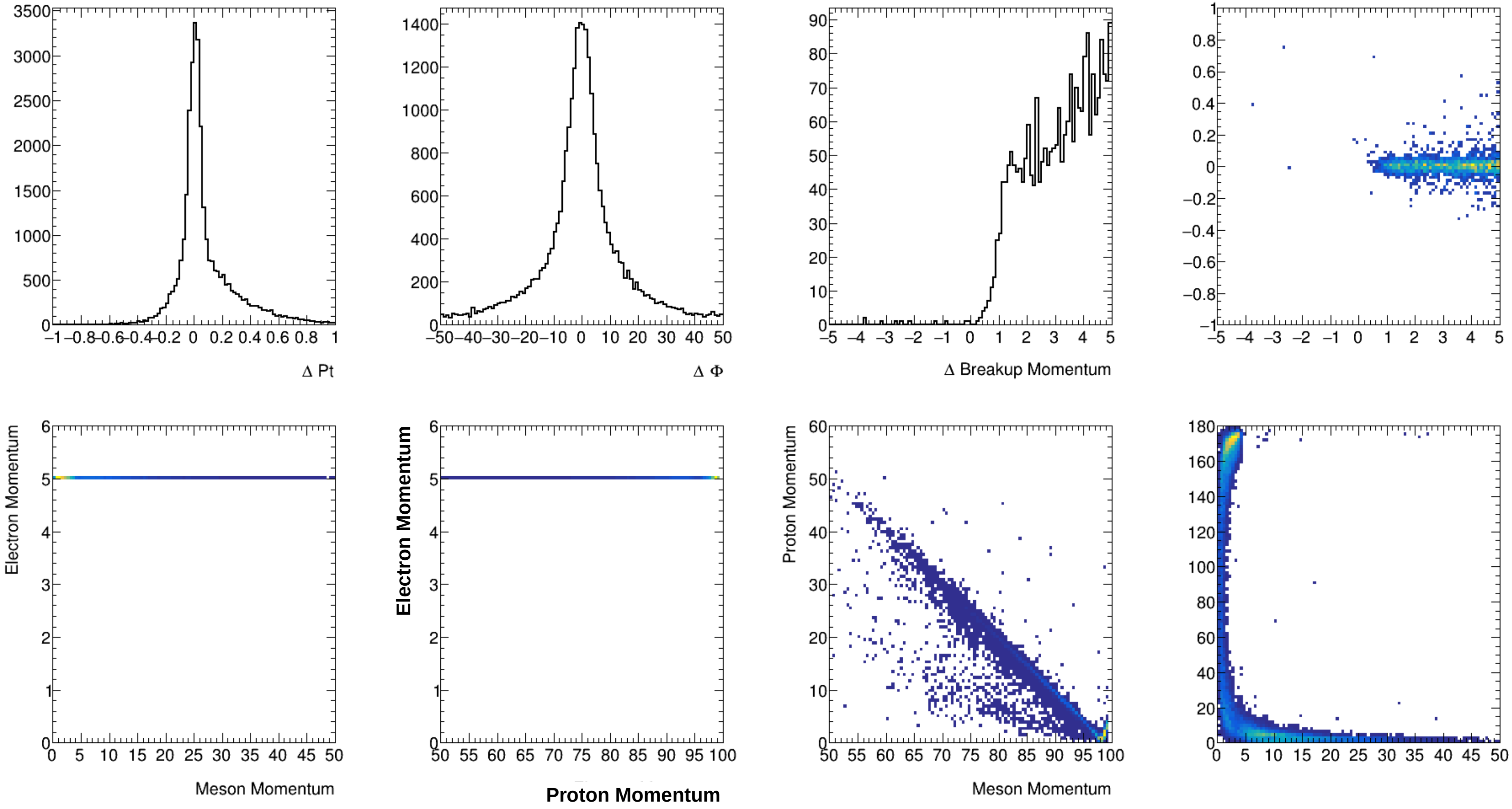


* With EIC-smear
Not ECCE

** Assumes same Luminosity
See slide 4

X better at low proton Energy, Y,ψ better at high proton Energy

No Electron, True Proton, Realistic Meson



X(3872)

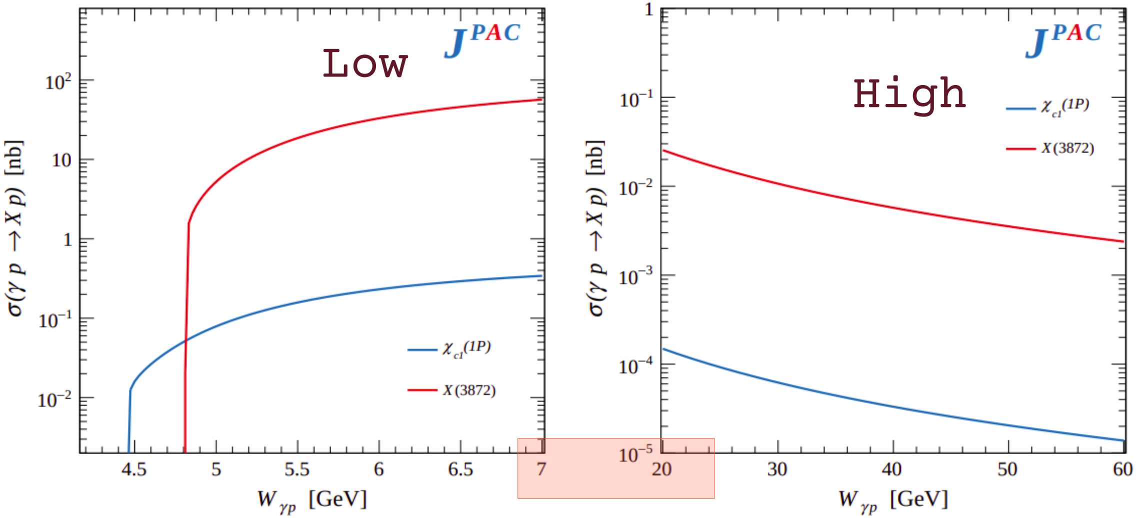
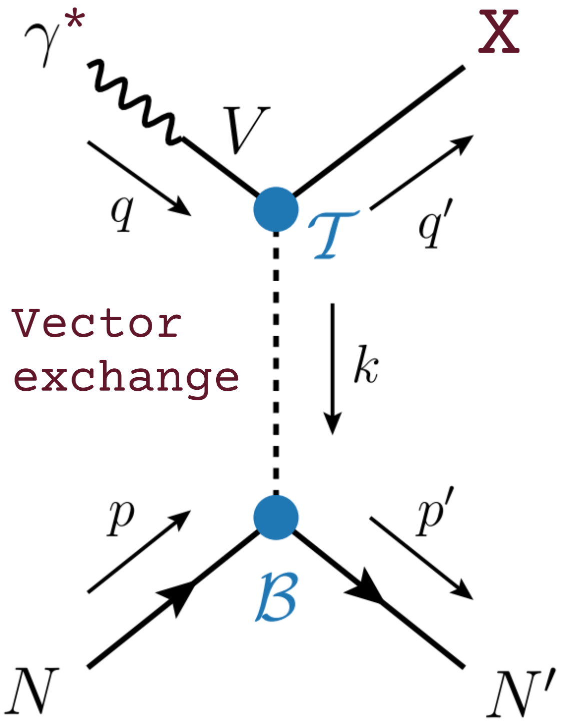


FIG. 3. Integrated cross sections for the axial $\chi_{c1}(1P)$ and $X(3872)$. Left panel: predictions for fixed-spin exchange, valid at low energies. Right panel: predictions for Regge exchange, valid at high energies.



Vector exchange

Larger model uncertainty